Paricle Physics Summary of PPC 2012

November 9, 2012

Particle Physics and Cosmology 2012

Nov/5-9, 2012 at Korea Institute for Advanced Studies

Kaoru Hagiwara (KEK/Sokendai, KIAS)

Higgs

3	ATLAS (M. Kuna)
8	CMS (J.C. Maestro)

15 S.Y. Choi … J, PC

21 J.S. Lee … MSSM

23 E.J. Chun … triplet (type II seasaw)

24 S.K. Kang … 2HDM

26 T.C. Yuan … more models

34 H. Cai … vector-quark

Dark Matter

37	IceCube (C. Rott) … ν
49	Fermi-LAT (C. Sgro) … γ

54 C. Weniger … 130 GeV γ ×

55 H.M. Lee … axion-$\gamma\gamma$

58 J.C. Park … 130 GeV γ

62 X. Huang … 130 GeV γ

64 S. Park … KK DM

65 T. Flacke … KK DM @LHC

67 S. Baek … Higgs portal DM

73	XENON (E. Duchovni)
79	LUX (A. Lindote)
83	CDMS (J. Sander)
88	KIMS (J. Lee) ×

89	ATLAS (M. Baak)
94	CMS (S. Jain)

107 B. Dutta … computing Ω_{DM} from LHC

Neutrino

114	Dayabay (Q. Wu)
116	Reno (S.H. Seo)
119	DChooz (J. Maricic)
121	T2K (P. Litchfield)

124 X.G. He … θ_{13} review

129 C. Giunti … 3ν status + α

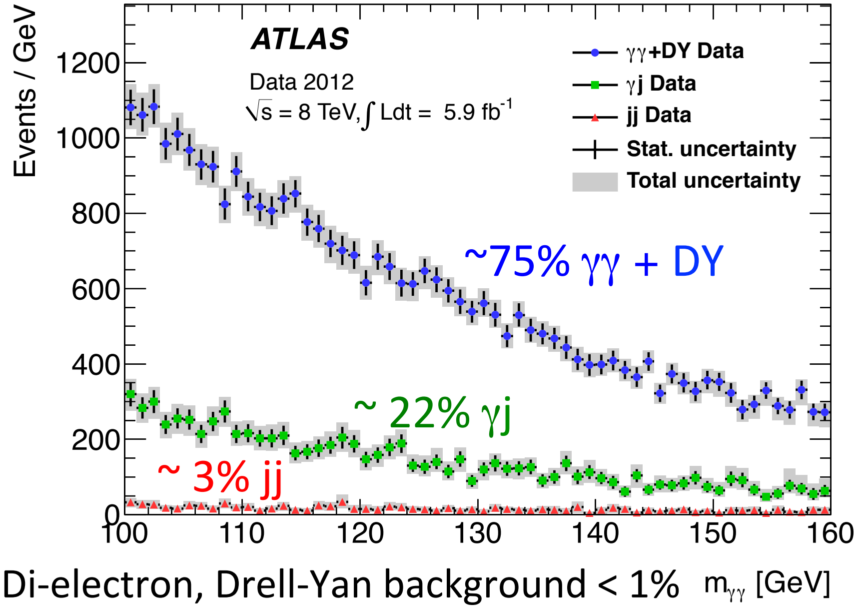
139 S. Kumar … SO(10)

143 Y. Takaesu … reactor $\bar{\nu}$ @ 50km

Neutrino AstroPhys. / Cosm.

146 T. Kajino

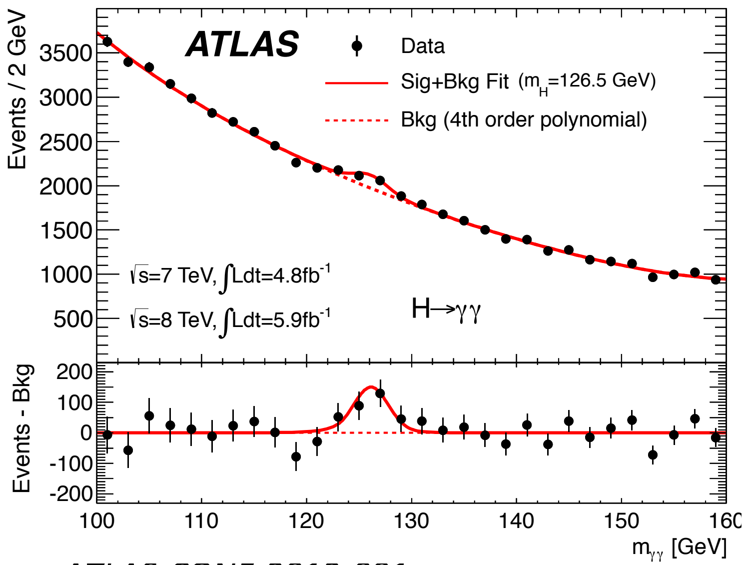
H→γγ: Background



Di-electron, Drell-Yan background < 1%

- Data-driven background estimation
- Background model choice:
  - Perform a S+B fit to bkg only high statistics MC → number of signal fitted is a bias
  - Among models with sufficiently low bias choose the one to optimise significance
  - Largest bias over 100-150 GeV taken as signal yield systematics

Category	Parametrization	Uncertainty [N_{evt}] $\sqrt{s}$ = 7 TeV	Uncertainty [N_{evt}] $\sqrt{s}$ = 8 TeV
Inclusive	4th order pol.	7.3	10.6
Unconverted central, low p_{Tt}	Exp. of 2nd order pol.	2.1	3.0
Unconverted central, high p_{Tt}	Exponential	0.2	0.3
Unconverted rest, low p_{Tt}	4th order pol.	2.2	3.3
Unconverted rest, high p_{Tt}	Exponential	0.5	0.8
Converted central, low p_{Tt}	Exp. of 2nd order pol.	1.6	2.3
Converted central, high p_{Tt}	Exponential	0.3	0.4
Converted rest, low p_{Tt}	4th order pol.	4.6	6.8
Converted rest, high p_{Tt}	Exponential	0.5	0.7
Converted transition	Exp. of 2nd order pol.	3.2	4.6
2-jets	Exponential	0.4	0.6

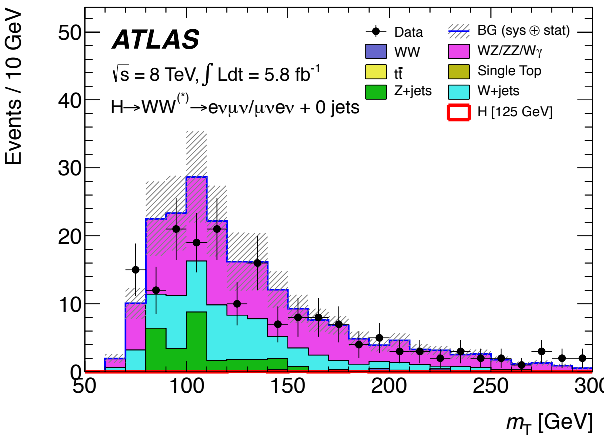


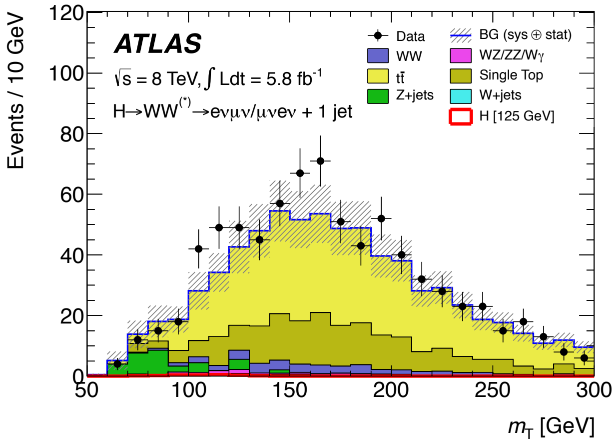
ATLAS-CONF-2012-091

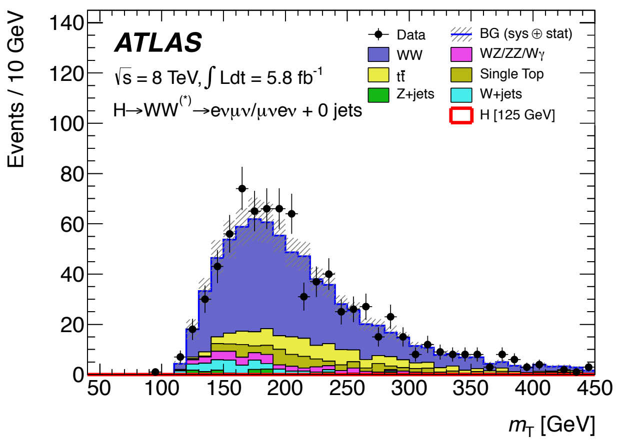
H→WW: Control Regions

- *WW* and top estimated using partially data-driven techniques, normalising the MC predictions to the data in control regions
- The *W*+jets background fully estimated from data for all jet multiplicities.
- Drell-Yan, diboson processes other than *WW*, and the *WW* background for the *H*+ 2-jet analysis estimated using simulation. VBF signal in the 2-jet bin is expected to be very low.

- W+jet control sample: one of the leptons fails tight ID/isolation criteria but pass relaxed ones ("anti-identified"), validated in the same-sign region where the OS requirement is inverted:
- Top control sample: Normalise 1-jet, 2-jet top background from b-tagged control region
- *WW* control sample (*H* + 0-jet and *H* + 1-jet) summed over lepton flavours, Δϕll cut removed and *m*ll relaxed < 80 GeV.



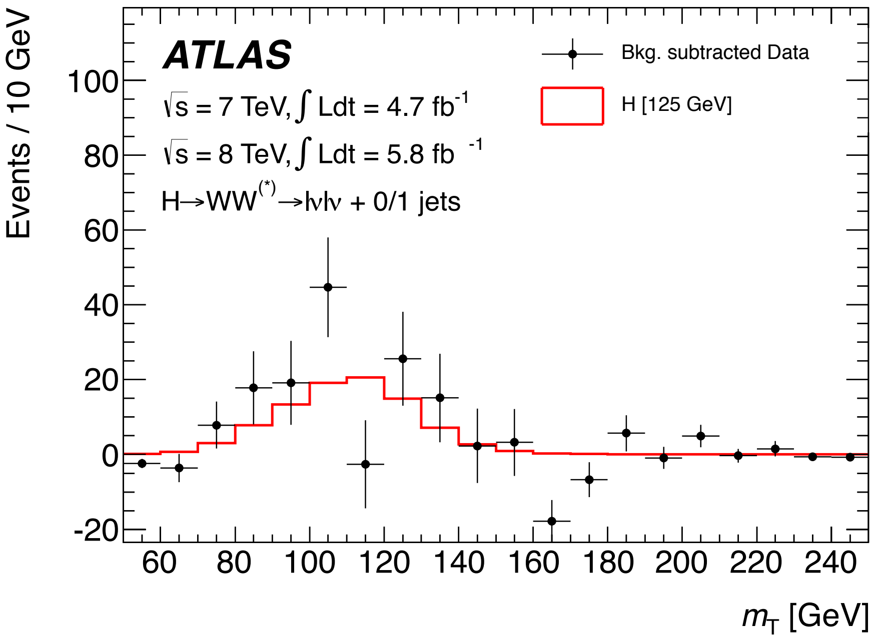




ATLAS-CONF-2012-098

H→WW: Yield

- Transverse mass distributions in data after all selection criteria have been applied, with the total estimated background subtracted



Signal region yield for $e\mu$ and μe channels separately				
	0-jet $e\mu$	0-jet μe	1-jet $e\mu$	1-jet μe
Total bkg.	177 ± 4	162 ± 4	43 ± 2	40 ± 3
Signal	18.7 ± 0.3	14.9 ± 0.2	4.3 ± 0.1	4.2 ± 0.1
Observed	213	194	54	52

→ In the *H* + 2-jet channel only two events in the data pass all of the selection

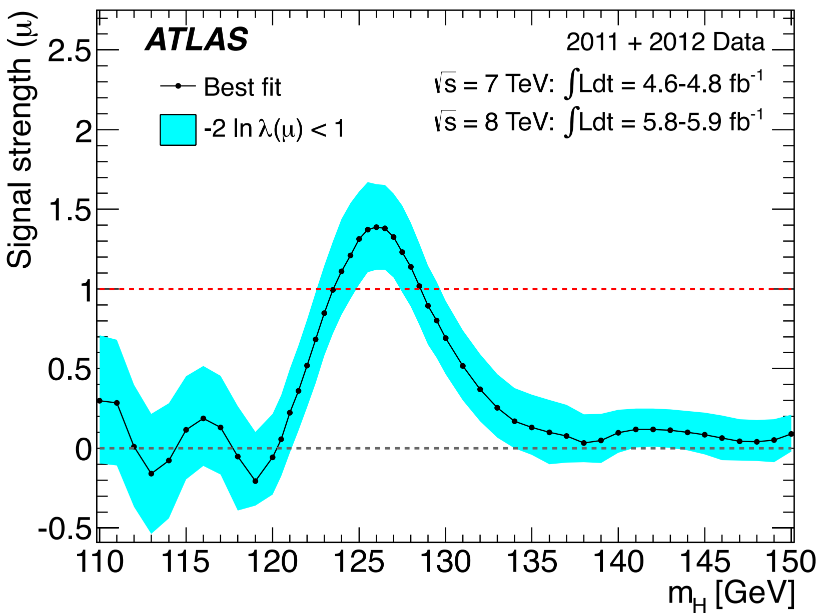
- The statistical analysis of the data employs a binned likelihood function L(μ, θ)

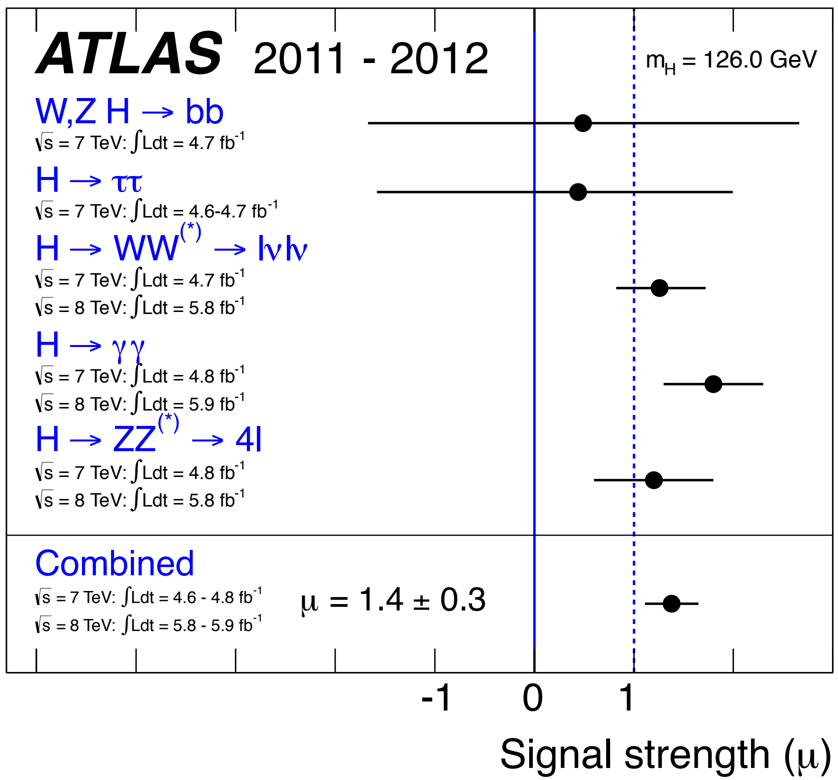
→ product of Poisson probability terms (low stat.) in each lepton flavour channel.

ATLAS-CONF-2012-098

Combined Results: Signal Strength

- Estimate for the mass of the observed particle is 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV
- Measurements of the signal strength parameter μ = 1.4 ± 0.3 for M_H = 126 GeV, which is consistent with the SM Higgs boson hypothesis μ = 1





arXiv:1207.7214

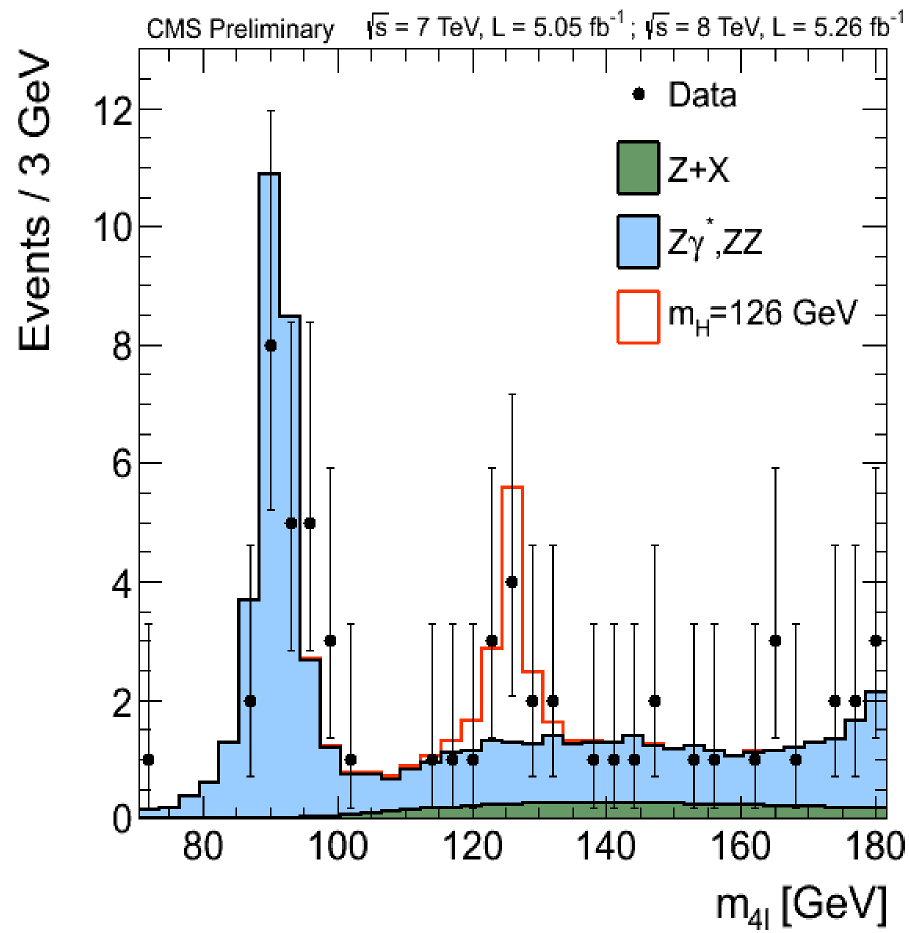
Summary of Channels

Higgs Boson Decay	Subsequent Decay	Sub-Channels	m_H Range [GeV]	$\int L\,dt$ [fb^{-1}]
2011 $\sqrt{s}$ =7 TeV				
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	110–600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low, high pile-up}	200–280–600	4.7
	$\ell\ell q\bar{q}$	{b-tagged, untagged}	200–300–600	4.7
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes$ conversion$\} \oplus$ {2-jet}	110–150	4.8
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu/\mu e, \mu\mu\} \otimes$ {0-jet, 1-jet, 2-jet} $\otimes$ {low, high pile-up}	110–200–300–600	4.7
	$\ell\nu qq'$	$\{e, \mu\} \otimes$ {0-jet, 1-jet, 2-jet}	300–600	4.7
$H \to \tau\tau$	$\tau_{lep}\tau_{lep}$	$\{e\mu\} \otimes$ {0-jet} $\oplus \{\ell\ell\} \otimes$ {1-jet, 2-jet, VH}	110–150	4.7
	$\tau_{lep}\tau_{had}$	$\{e, \mu\} \otimes$ {0-jet} $\otimes \{E_T^{miss} < 20$ GeV, $E_T^{miss} \geq 20$ GeV$\}$ $\oplus \{e, \mu\} \otimes$ {1-jet} $\oplus \{\ell\} \otimes$ {2-jet}	110–150	4.7
	$\tau_{had}\tau_{had}$	{1-jet}	110–150	4.7
$VH \to Vbb$	$Z \to \nu\nu$	$E_T^{miss} \in \{120-160, 160-200, \geq 200$ GeV$\}$	110–130	4.6
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110–130	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110–130	4.7
2012 $\sqrt{s}$ =8 TeV				
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	110–600	5.8
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes$ conversion$\} \oplus$ {2-jet}	110–150	5.9
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes$ {0-jet, 1-jet, 2-jet}	110–200	5.8

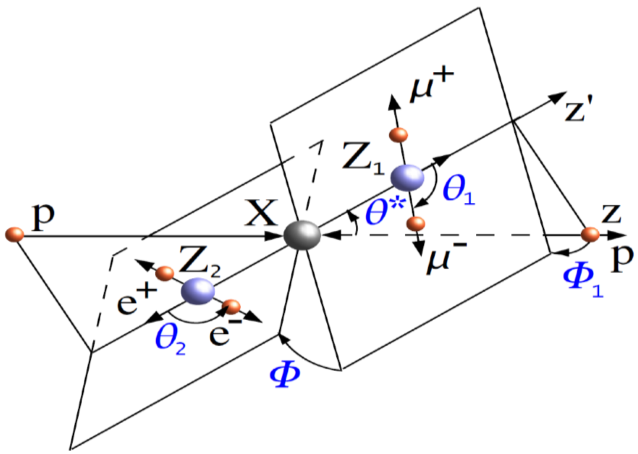
$H \rightarrow ZZ \rightarrow 4l$

Improvements in 2012:

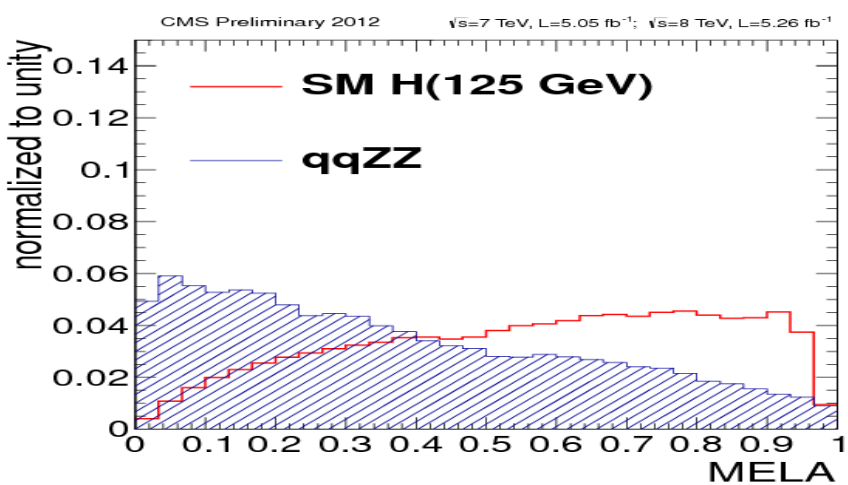
- New lepton selection
- Recovery of photons from final state radiation
- Exploit angular information to discriminate signal from irreducible ZZ background
- ~20% gain in sensitivity with respect to the 2011 analysis
- Optimization done without looking at the data in the signal region.



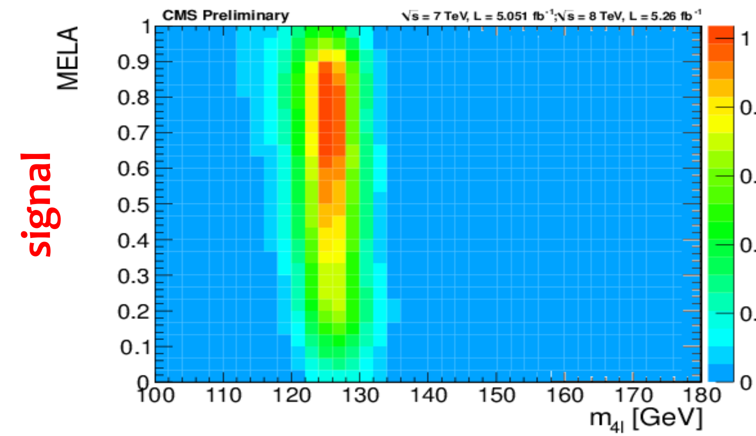
Matrix Element Likelihood Analysis

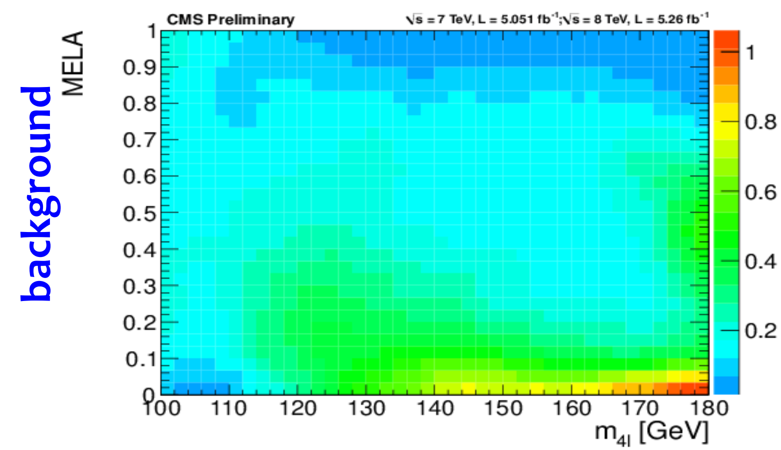


$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$



2D analysis using m_{4l} and MELA

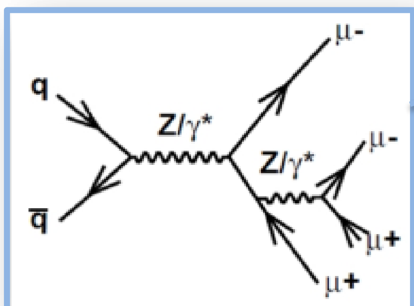


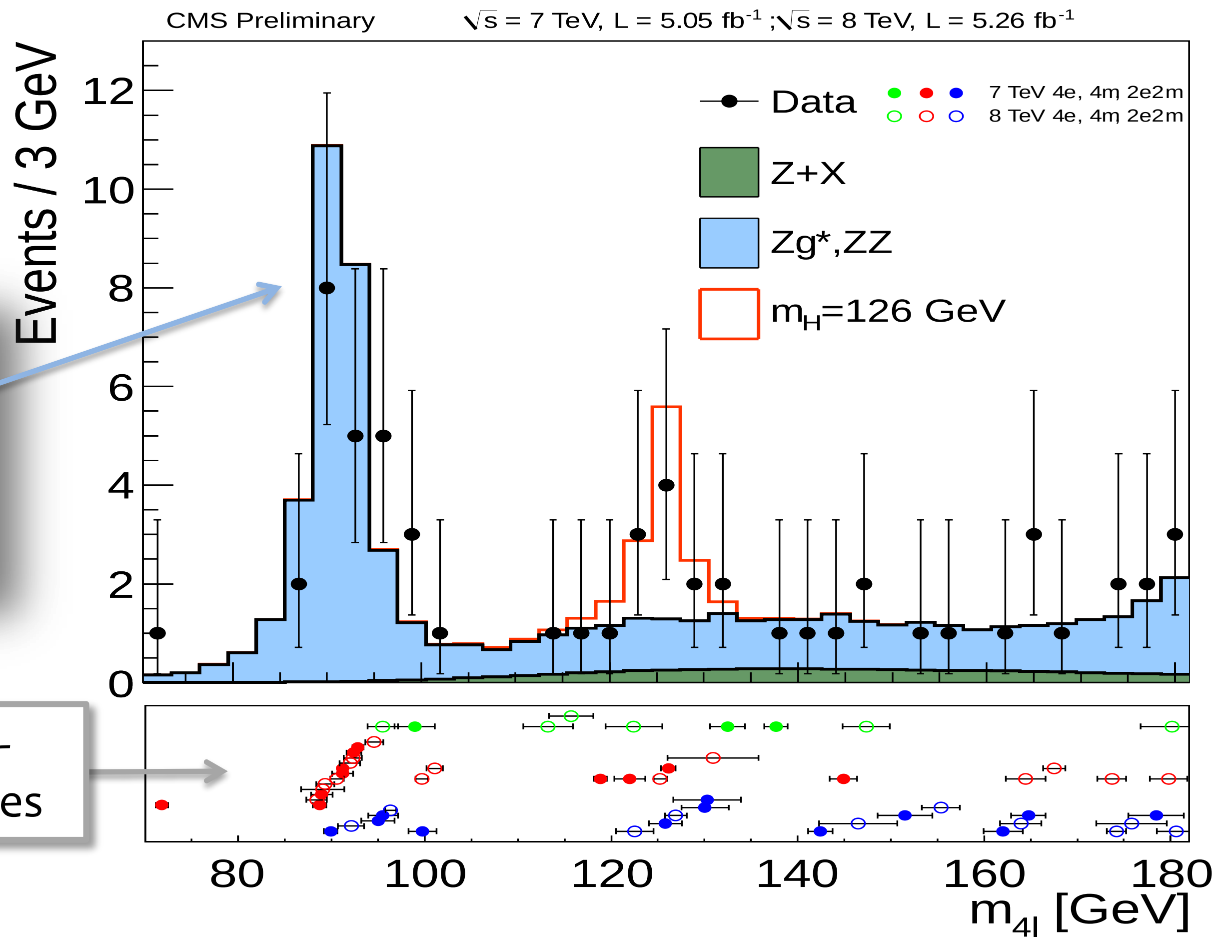


PRD81,075022(2010),arXiv:1001.5300

H → ZZ → 4l results

- Localized excess of events observed around 126 GeV

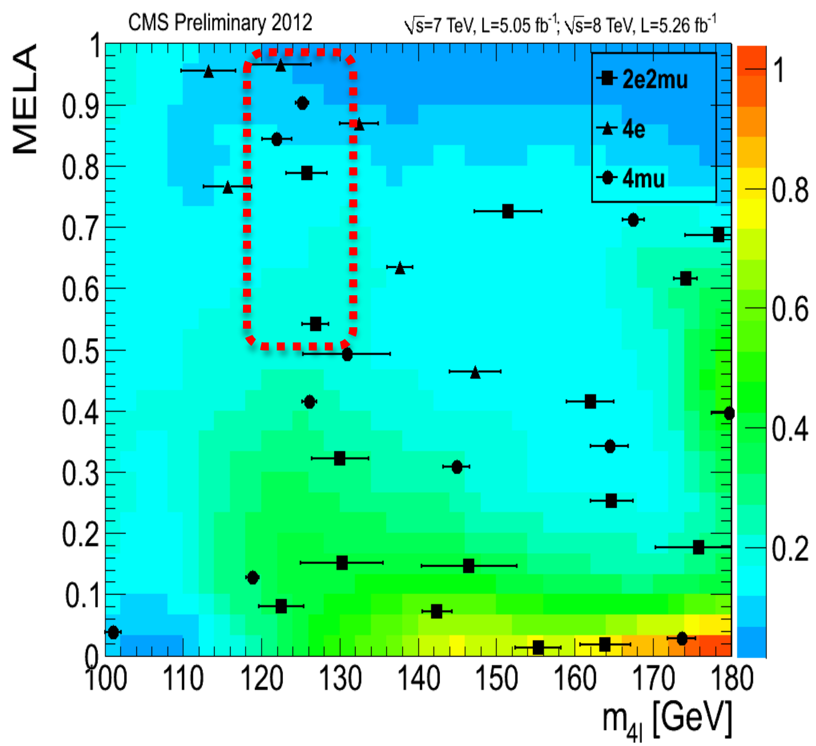


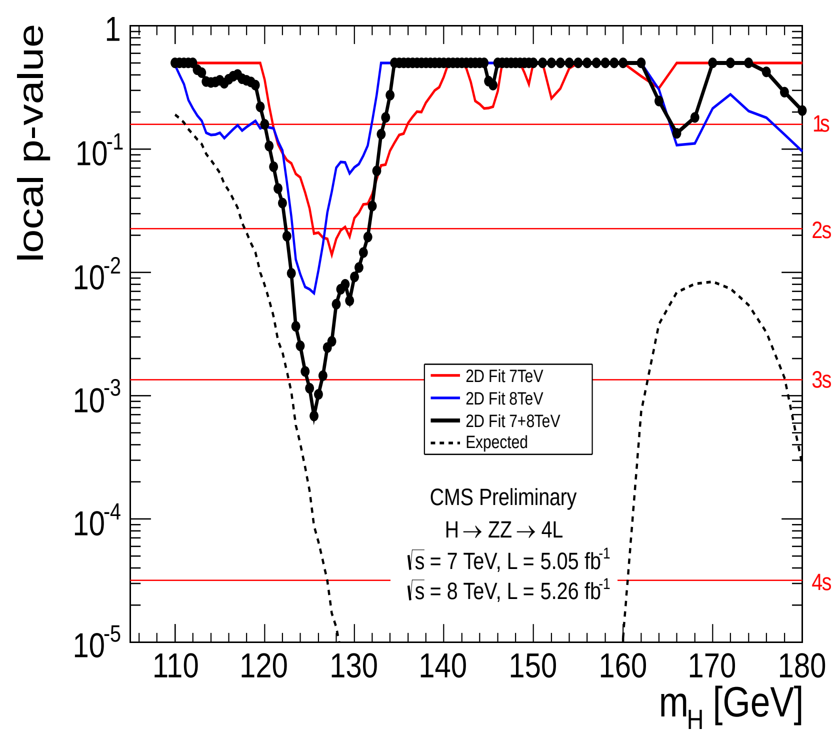


ZZ candidates with per-event mass uncertainties

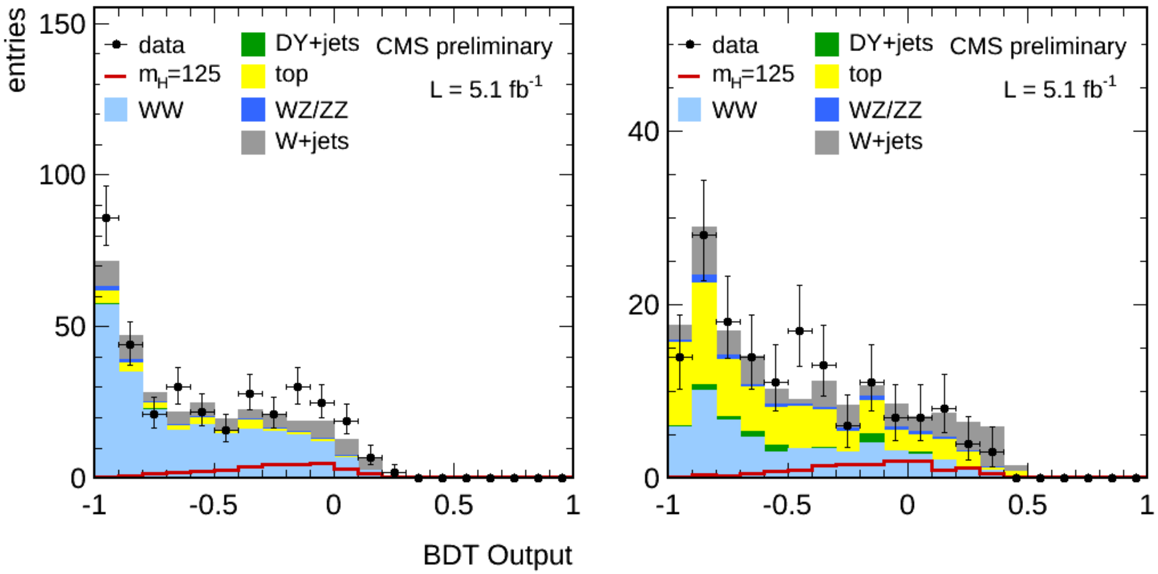
H → ZZ → 4l results

- **Localized excess of events observed around 126 GeV and at signal-like values of the angular discriminator**
- Local significance **3.2σ** (expected from SM H: **3.8σ**)





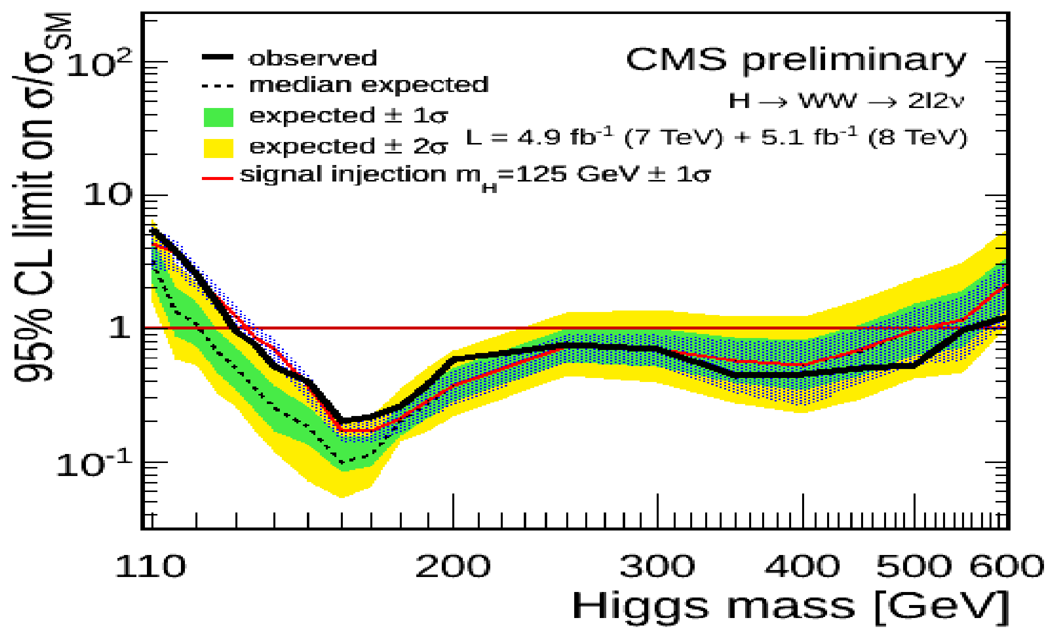
$H \rightarrow WW \rightarrow 2l\ 2\nu$: post-ICHEP results



MultiVariate shape analysis in the eμ final state in the 0 and 1 jet categories: Cut-based variables + ΔR_{ll}, $m_T^{(1,2)}$, $\Delta\phi(ll, MET)$, $\Delta\phi(ll, jet1)$

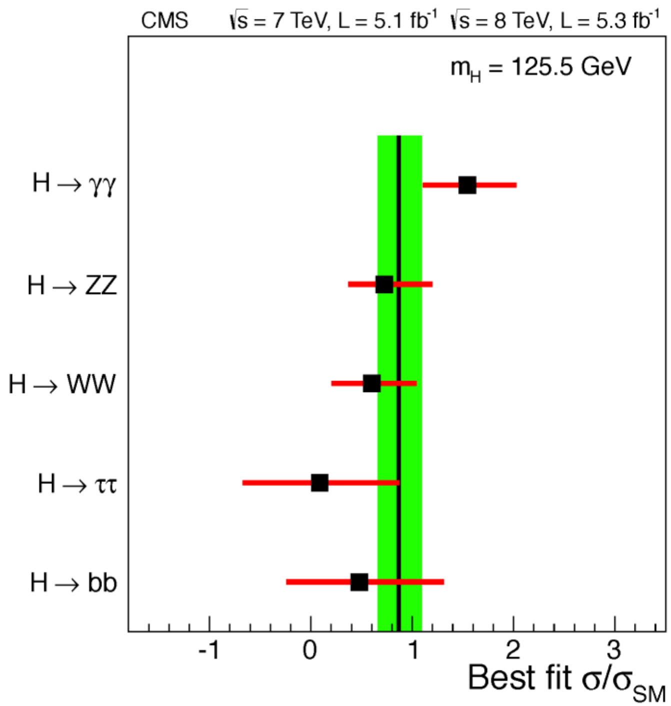
@ mH = 125 GeV
Exp. significance 2.5 σ
Obs. significance 2.2 σ

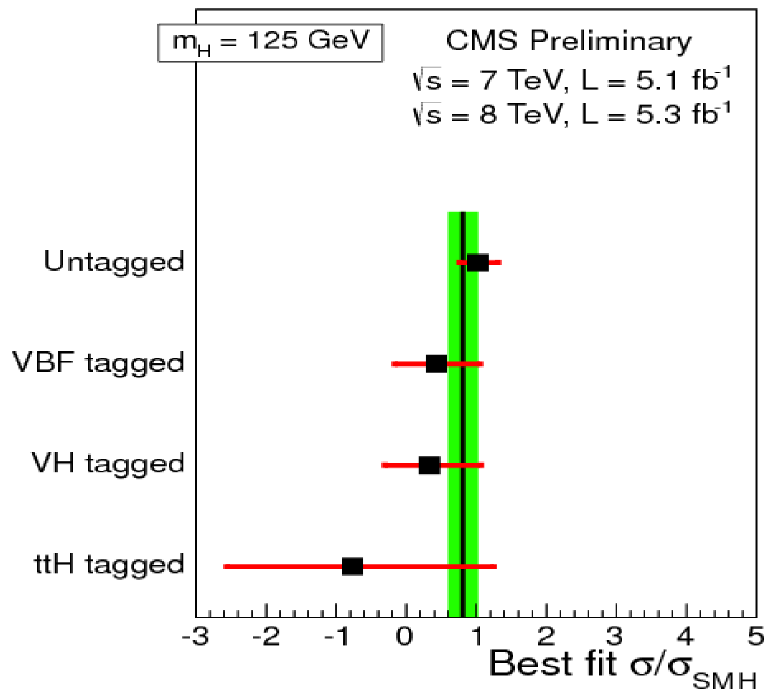
Signal strength: 0.82 ± 0.38



Is it a SM Higgs boson?

- Slightly better sensitivity when combining channels by decay mode or production topology.
- Compatible with SM Higgs within uncertainties

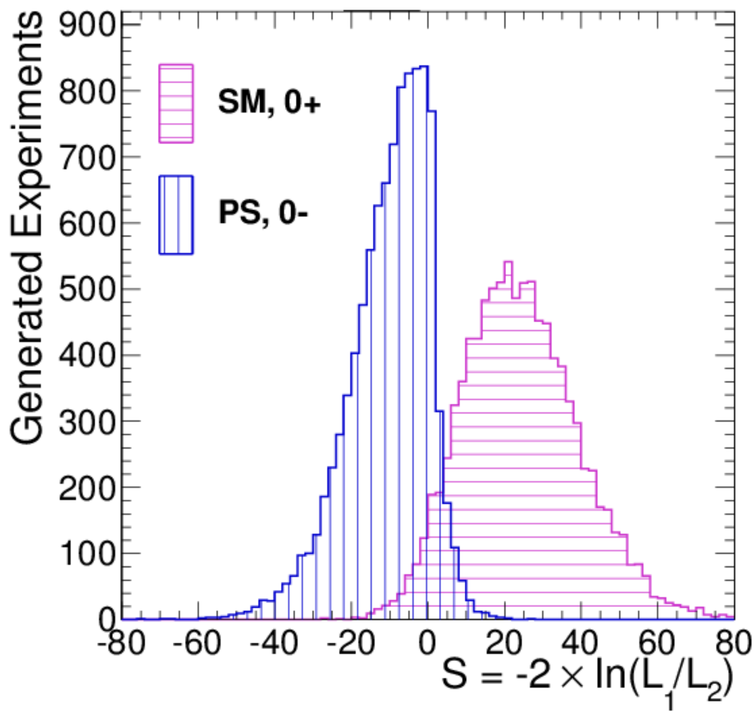




Projections for J^{PC} measurements

$H \to ZZ \to 4l$

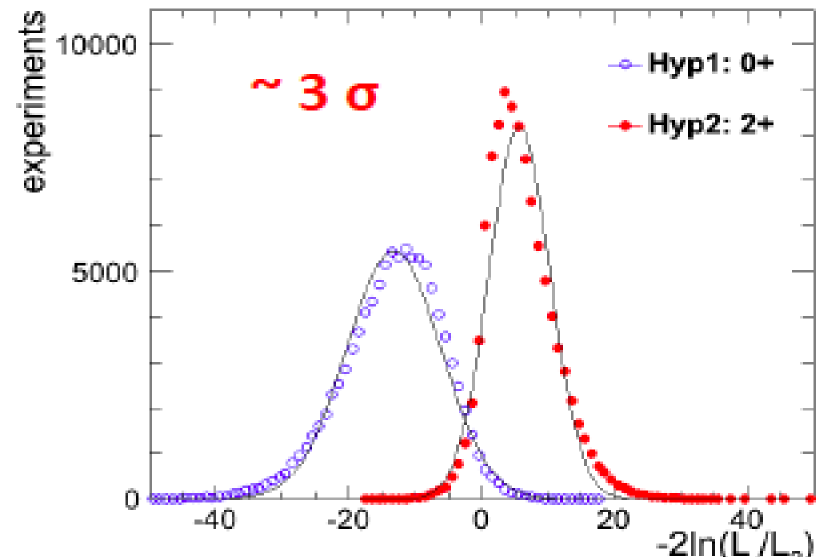
CMS Simulation L = 30 fb^{-1}, $\sqrt{s}$ = 8 TeV



Expect ~3σ separation between scalar and pseudoscalar in 2012

$H \to WW \to 2l2\nu$

JHU Generator level L = 10 fb^{-1}, $\sqrt{s}$ = 8 TeV

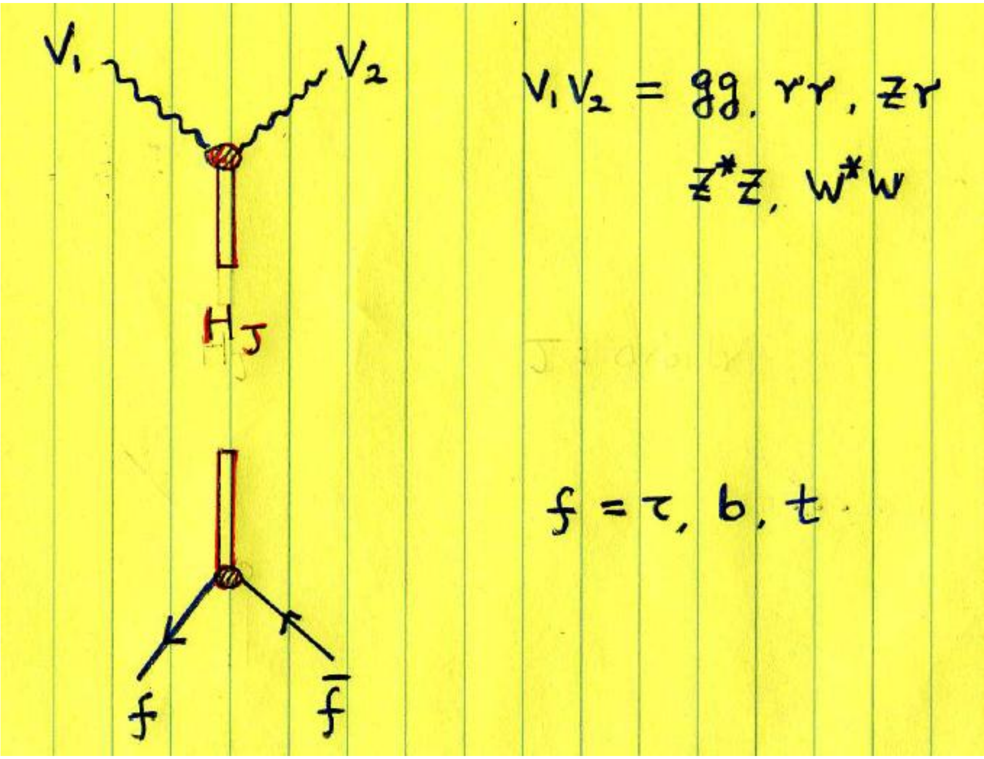


Expect ~3σ separation between spin 0, 2 with 10 fb^{-1} but assuming no systematics and WW as only background

http://indico.cern.ch/contributionDisplay.py?contribId=473&sessionId=53&confId=181298

Model-independent analysis

General vertex structure

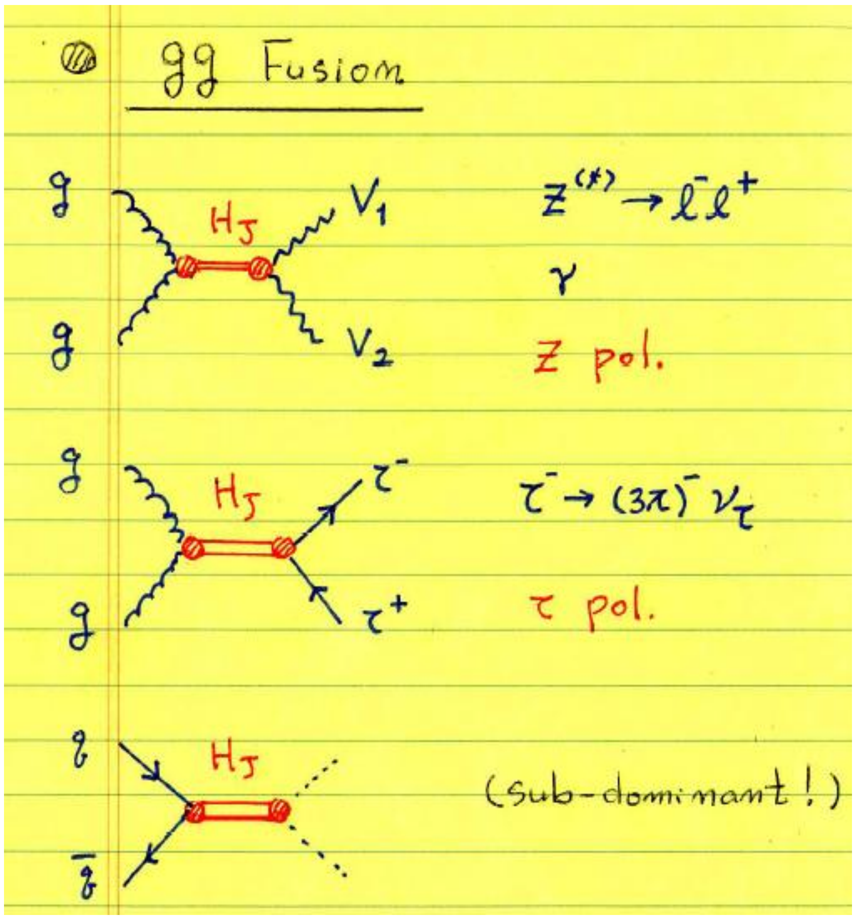


Arbitrary integer spin J
Even(+) vs. odd(-) parity

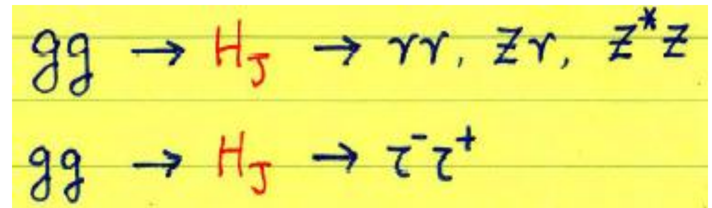
Angular correlations
Invariant mass distribution
Polarization

Complementary processes

LHC = Large Hadron Collider (pp)
LC = Linear Collider (e^+e^-)
PLC = Photon Linear Collider ($\gamma\gamma$)



LHC



Production angle
Z momentum
Z polarization
Z* invariant mass

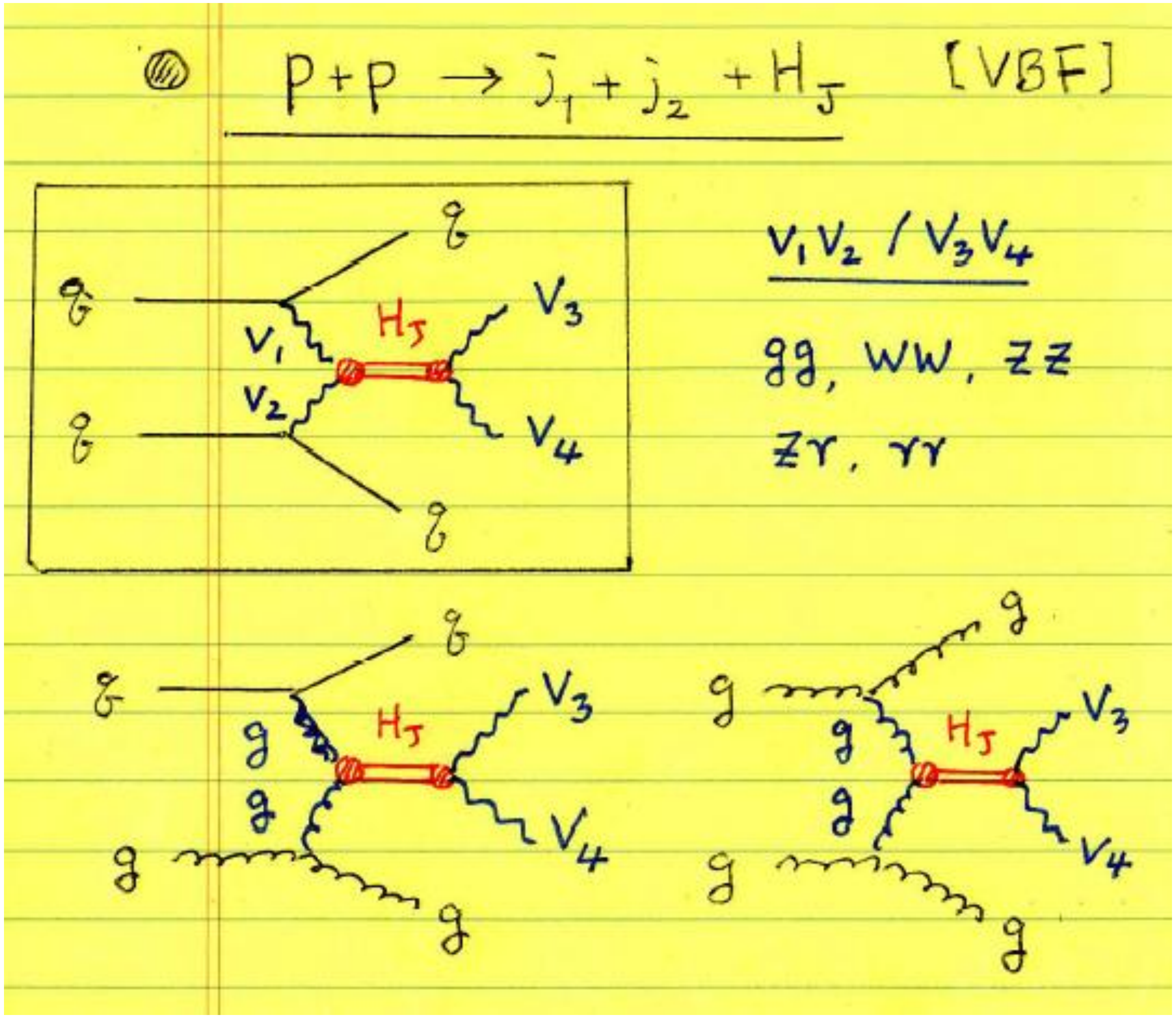
Gao ea, + De Rujula ea 2010

Partial spin (0, 1, 2) + parity

τ direction
τ polarization

Parity only

Berge, Bernreuther, Ziethe, 2008



LHC

Various angular correlations

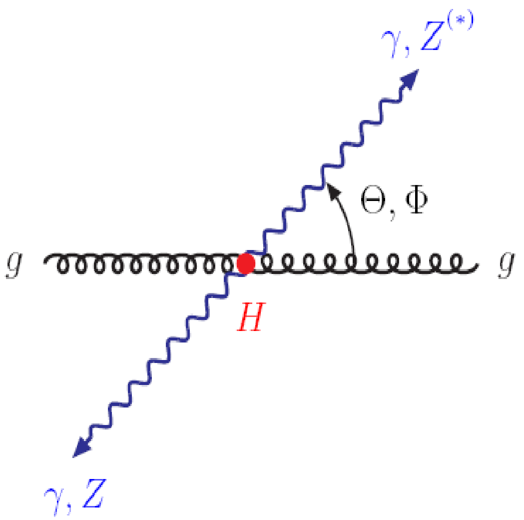
Partial spin (0 and 2) + parity analysis

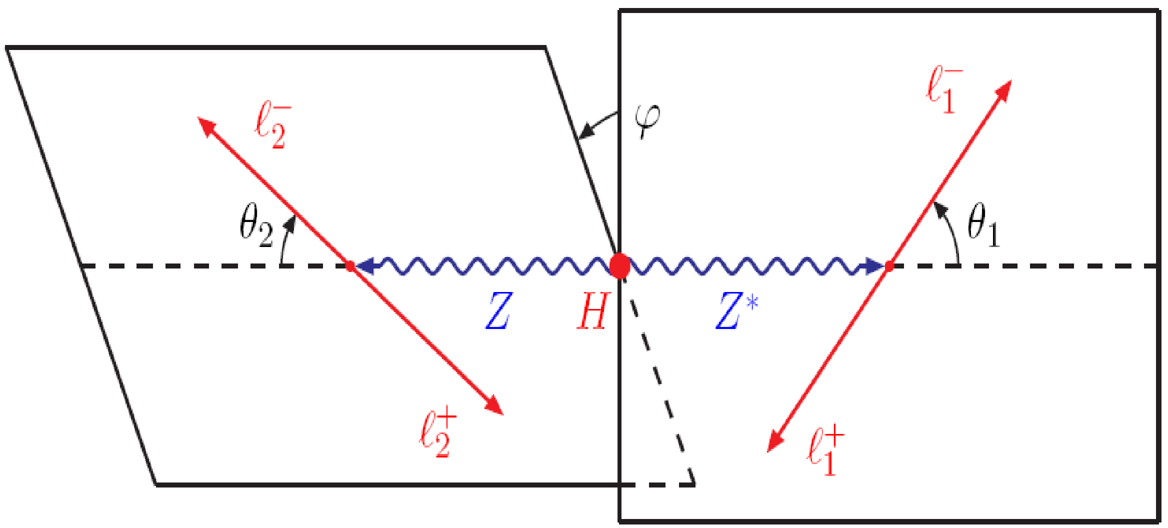
Hagiwara, Li, Mawatari, 2009

Most powerful channels for spin/parity determination

$$gg \rightarrow H \rightarrow \gamma\gamma \oplus Z^*Z$$

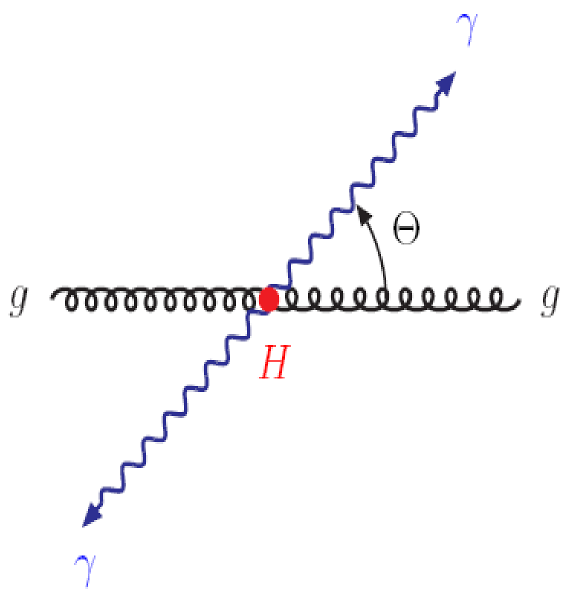
Clean & precise
Fully reconstructed





$\ell = e, \mu$

P-invariant polar-angle distribution for arbitrary spin



$m\ (\lambda) = g\ (\gamma)$ helicity difference

$$\mathcal{D}^J_{m\lambda} = \frac{1}{4}\{[d^J_{m,\lambda}]^2 + [d^J_{m,-\lambda}]^2 + [d^J_{-m,\lambda}]^2 + [d^J_{-m,-\lambda}]^2\}$$

$$\mathcal{X}^J_0 + \mathcal{X}^J_2 = 1 \quad \text{and} \quad \mathcal{Y}^J_0 + \mathcal{Y}^J_2 = 1$$

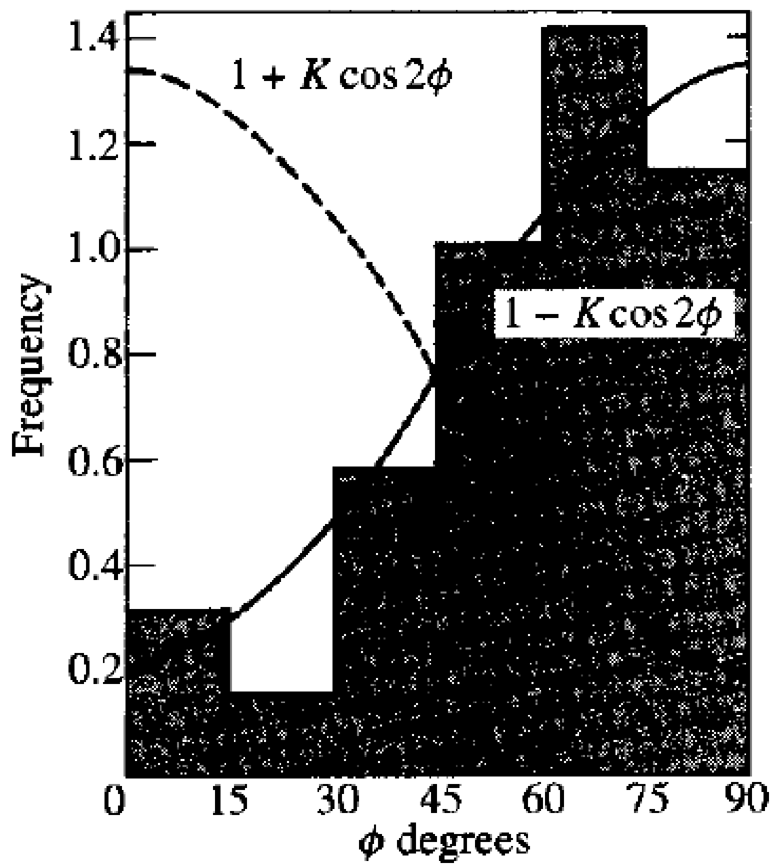
Scalar-type ⟺ Tensor-type

$$\frac{1}{\sigma}\frac{d\sigma[gg \to H \to \gamma\gamma]}{d\cos\Theta} = (2J+1)\ [\mathcal{X}^J_0 \mathcal{Y}^J_0\, \mathcal{D}^J_{00} + \mathcal{X}^J_0 \mathcal{Y}^J_2 \mathcal{D}^J_{02} + \mathcal{X}^J_2 \mathcal{Y}^J_0 \mathcal{D}^J_{20} + \mathcal{X}^J_2 \mathcal{Y}^J_2\, \mathcal{D}^J_{22}]$$

J extracted!

Non-negative $\mathcal{X}$'s and $\mathcal{Y}$'s $\Rightarrow\ ^{\exists}\cos^{2J}\Theta$ terms

$$\pi^0 \rightarrow \gamma^*\gamma^* \rightarrow (e^-e^+)(e^-e^+)$$

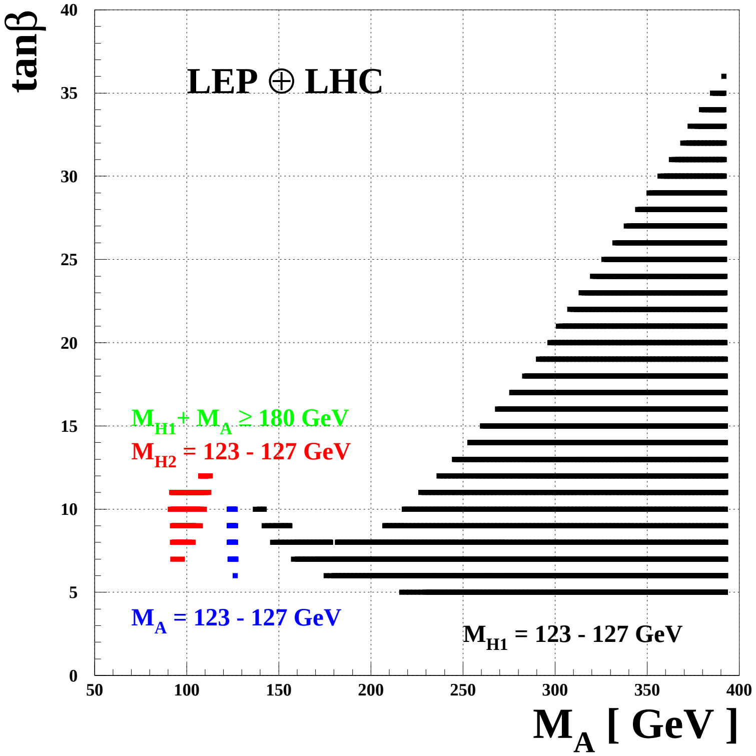


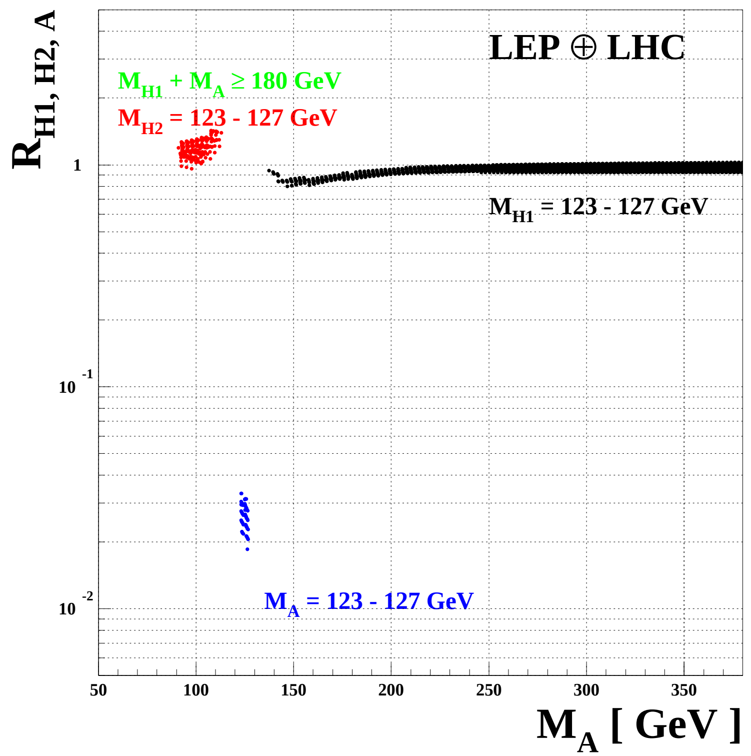
Parity : Odd!

Plano, Prodell, Samios, Schwartz, Steinberger, 1959
Abouzaid ea, 2008 with much more improvement

♠ *Some Results*

- MHmax scenario $\oplus$ varying A_t:





– Remind: The MHmax scenario

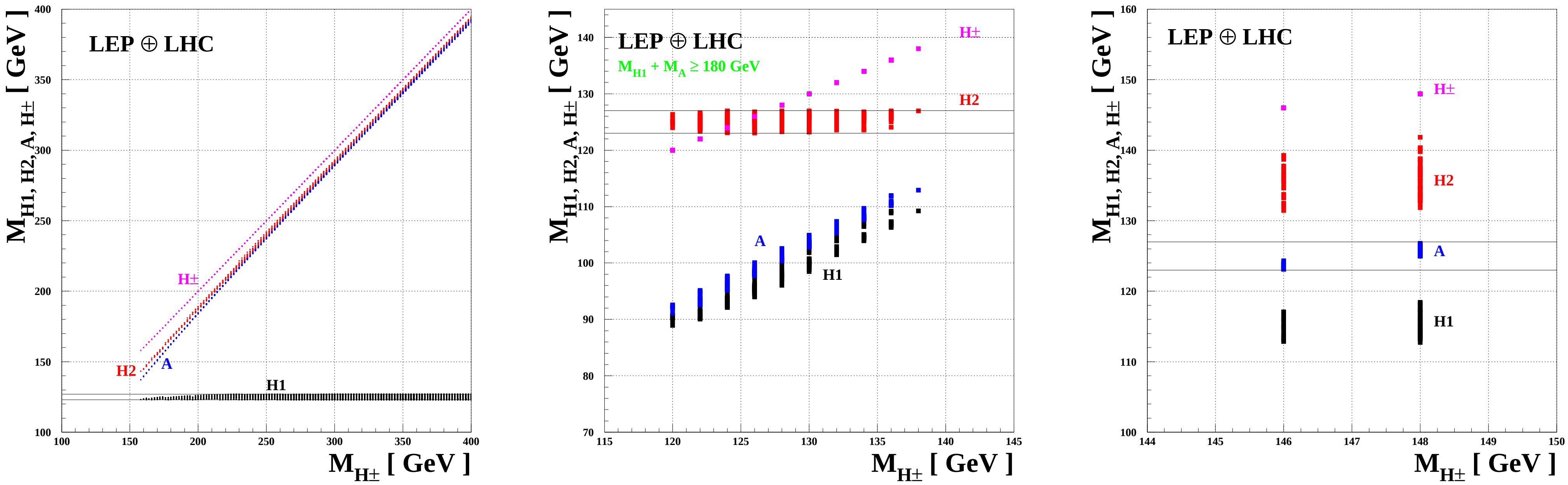
$$m_{\tilde{Q}_3} = m_{\tilde{U}_3} = m_{\tilde{D}_3} = m_{\tilde{L}_3} = m_{\tilde{E}_3} = M_{\rm SUSY} = 1 \text{ TeV} ;$$

$$\mu = 200 \text{ GeV} , M_1 = 100 \text{ GeV} , M_2 = 200 \text{ GeV} , M_3 = 800 \text{ GeV} ;$$

$$A_t = \sqrt{6}\, M_{\rm SUSY} + \mu / \tan\beta , A_b = A_\tau = A_t$$

♠ *Some Results*

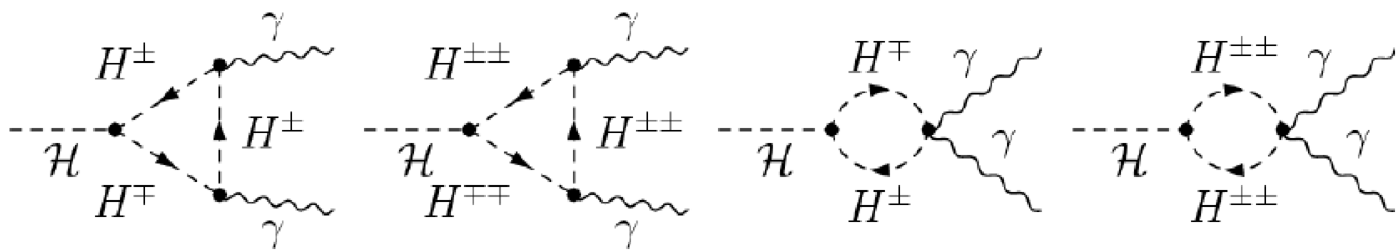
- MHmax scenario $\oplus$ varying A_t:



  - The H_1 scenario: the decoupling limit with $M_A \gtrsim 135$ GeV ... boring ?
  - The H_2 scenario: $M_{H_1} \sim M_A = 90 - 110$ GeV with $M_A - M_{H_1} \leq 5$ GeV and $g^2_{H_1AZ} = g^2_{H_2VV} \gtrsim 0.75$; $M_{H_2} \sim M_{H\pm} = 120 - 140$ GeV ... interesting ?
  - The A scenario: squeezed spectrum but too small $R_A \sim 2.5 \times 10^{-2}$ ... excluded?

Higgs-to-diphoton

- H^{++} & H^{+} contribution:



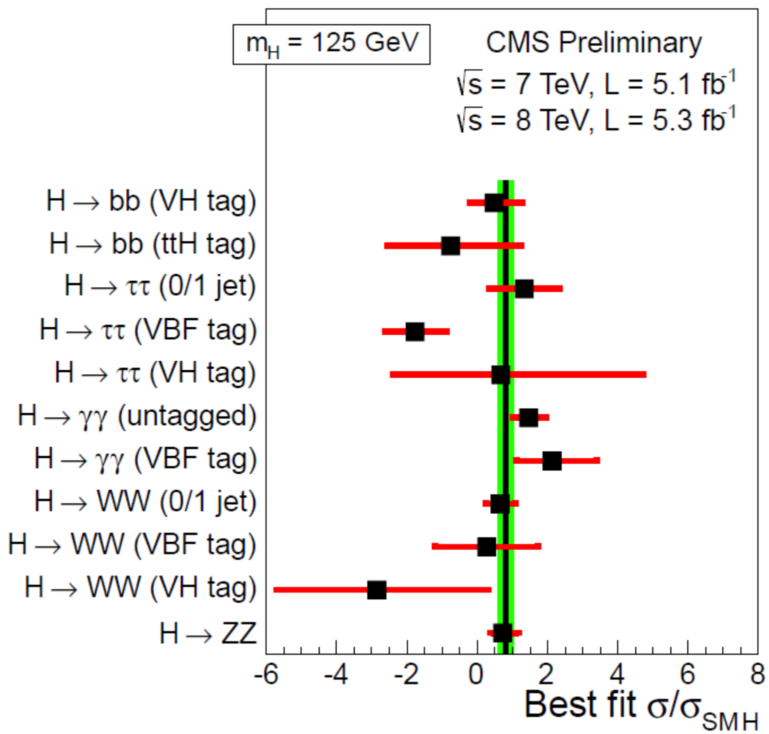
$$\Gamma(h \to \gamma\gamma) = \frac{G_F \alpha^2 m_h^3}{128\sqrt{2}\pi^3} \Big| \sum_f N_c Q_f^2 \, g_{ff}^h A_{1/2}^h(x_f) + g_{WW}^h A_1^h(x_W)$$
$$+ g_{H^+H^-}^h A_0^h(x_{H^+}) + 4 g_{H^{++}H^{--}}^h A_0^h(x_{H^{++}}) \Big|^2$$

- $g_{H^+H^+}^h = \frac{\lambda_4}{2} \frac{v_0^2}{M_{H^+}^2}$,
- $g_{H^{++}H^{++}}^h = \frac{\lambda_4 - \lambda_5}{2} \frac{v_0^2}{M_{H^{++}}^2}$,

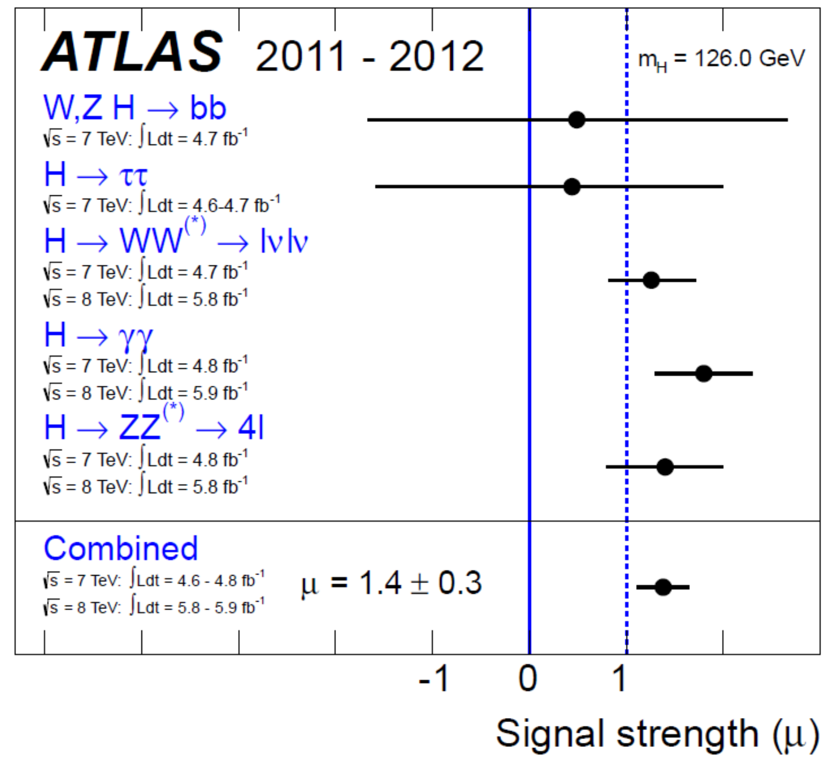
Arhrib, et.al., 1112.5453
Kanemura, Yagyu, 1201.6287
Akeryod, Moretti, 1206.0535

Summary of measured channels

CMS data



ATLAS data



Summary of the LHC Higgs Signals

	ATLAS and CMS	CMS
7 TeV	$\widetilde{R}^{ggF}_{\gamma\gamma} = 1.66 \pm 0.50$, $\widetilde{R}^{ggF}_{WW} = 0.58 \pm 0.41$ $\widetilde{R}^{ggF}_{WW} = 0.58 \pm 0.41$, $\widetilde{R}^{ggF}_{ZZ} = 0.79 \pm 0.41$ $\widetilde{R}^{ggF}_{\tau\tau} = 0.75 \pm 1.02$, $\widetilde{R}^{Vh}_{bb} = 0.62 \pm 1.09$	$\widetilde{R}^{ggF}_{\gamma\gamma} = 1.66 \pm 0.50$, $\widetilde{R}^{Vh}_{WW} = 2.75 \pm 2.96$ $\widetilde{R}^{VBF}_{\tau\tau} = -1.61 \pm 1.25$, $\widetilde{R}^{Vh}_{\tau\tau} = 0.659 \pm 3.07$
8 TeV	$\widetilde{R}^{ggF}_{\gamma\gamma} = 1.69 \pm 0.44$, $\widetilde{R}^{VBF}_{\gamma\gamma} = 1.34 \pm 0.94$ $\widetilde{R}^{ggF}_{WW} = 1.38 \pm 0.49$, $\widetilde{R}^{ggF}_{ZZ} = 0.85 \pm 0.40$	$\widetilde{R}^{VBF}_{WW} = 1.34 \pm 1.82$, $\widetilde{R}^{ggF}_{\tau\tau} = 2.14 \pm 1.48$ $\widetilde{R}^{VBF}_{\tau\tau} = -1.73 \pm 1.25$, $\widetilde{R}^{Vh}_{b\bar{b}} = 0.43 \pm 0.80$

- A new particle around $125-126$ GeV is found, consistent with the SM Higgs boson. The fermionic modes ($\tau^-\tau^+$, $b\bar{b}$) need more data. The $WW^{(*)}, ZZ^{(*)}$ modes are consistent with SM. The $\gamma\gamma$ mode is outstanding with $1.1-2$ times that of the SM.
- The excesses are accumulated at $125-126$ GeV.
- Spin 1 is impossible by Landau-Yang theorem. $0^{\pm}$ and $2^{\pm}$ are next possibilities. Spin 0 consistent with data.
- J^P Determination: [S. Y. Choi's Talk]
  (1) the angular distributions in the 4-fermion modes from $\gamma\gamma$, $WW^{(*)}$, and $ZZ^{(*)}$. (Note: For pseudoscalar, no tree level AVV couplings.
  (2) invariant mass distribution in Higgs-strahlung.

- Within uncertainties, most obvious and natural one is SM Higgs. 2 photon excess due to QCD uncertainties [Baglio, Djouadi, Godbole 1207.1451].
- MSSM – SUSY predicts a light CP-even Higgs boson. But such a light 125 GeV Higgs puts a tight constraint on the stop mass sector, and not easy to enhance the $\gamma\gamma$ rate. [Jae Sik Lee's Talk]
- NMSSM: easier to obtain a 125 GeV Higgs boson, and not difficult to achieve enhanced $\gamma\gamma$ rate.
- Other extended MSSM.
- 2HDM and its variants. [S. K. Kang's Talk]
- Inert Higgs doublet model (IHDM).
- RS Radion/Dilaton: the anomaly couplings to gg and $\gamma\gamma$ easily enhance the diphoton rate.
- Fermiophobic Higgs boson. No free parameter. Yukawas are induced by renormalization.

- Higgs mass requires a large radiative correction from the top-stop sector:

$$m_h^2 \approx m_Z^2 \cos^2 2\beta + \frac{3m_t^2}{4\pi^2 v^2}\left[\frac{1}{2}X_t + t + \frac{1}{16\pi^2}\left(\frac{3m_t^2}{2v^2} - 32\pi\alpha_s\right)(X_t t + t^2)\right]$$

  where

$$X_t = \frac{2(A_t - \mu\cot\beta)^2}{M_{\rm SUSY}^2}\left(1 - \frac{(A_t - \mu\cot\beta)^2}{12M_{\rm SUSY}^2}\right)$$

  A large A_t is needed. Following Carena et al. 1205.5842, we use $m_{Q_3} = m_{U_3} = 850$ GeV, $A_t = 1.4$ TeV, $m_A = 1$ TeV, and $\tan\beta = 60$.

- To enhance the diphoton rate one also needs to push one of the staus ($\tilde{\tau}$s) to be light enough, just above the LEP limit. Following Carena et al. 1205.5842, we scan

$$m_{L_3} = m_{E_3} = 200 - 450 \text{ GeV} \qquad \text{and} \qquad \mu = 200 - 1000 \text{ GeV},$$

  for diphoton rate > 1.

NMSSM

Gunion, Jiang, Kraml 1201.0982; 1207.1545; Ellwanger 1112.3548; King, Muhlleitner, Nevzorov 1201.2671; Ellwanger and Hugonie 1203.5048; Cao, Heng, Yang, Zhang, Zhu 1202.5821; Cao, Heng, Yang, Zhu 1207.3698; Vasquez et al. 1203.3446

- NMSSM:
$$W_{\rm NMSSM} = \lambda S H_u H_d + \frac{\kappa}{3} S^3 + W_{\rm MSSM}$$
with $\mu_{\rm eff} = \lambda v_s/\sqrt{2}$. 3 CP-even Higgs bosons and the SM-like could be the lightest or the second lightest.
- It was found that the second Higgs H_2 can be in the mass range $124 - 127$ GeV and with an enhanced $\gamma\gamma$ branching ratio.
- This is made possible because of the reduction into $b\bar{b}$ width, by a large singlet-doublet mixing.
- So $R_2^{\gamma\gamma} \equiv \sigma^{\gamma\gamma}(H_2)/\sigma^{\gamma\gamma}(h_{\rm SM})$ is enhanced, and potentially R_2^{VV} too, but the $R_2^{\tau\tau}$ is reduced.

Other extended MSSM

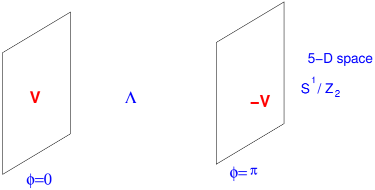
UMSSM – Chang, Cheung, Tseng, Yuan 1202.0054
$U(1)_{B-L} \times U(1)_R$ – Hirsch, Porod, Reichert, Staub 1206.3516
$U(1)_{\rm PQ}$ MSSM – An, Liu, Wang 1207.2473
pMSSM – Cahill-Rowley, Hewett, Ismail, Rizzo 1206.5800
Exceptional MSSM – Athron et al. 1206.5028
PQ-NMSSM – Jeong, Shoji, Yamaguchi 1205.2386
BMSSM – Boudjema, La Rochelle 1203.3141
BLMSSM – Perez 1201.1501

... ...

Radion

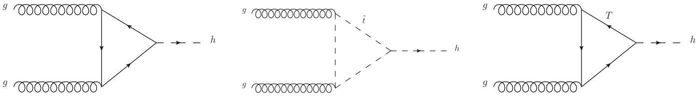
Cheung and Yuan 1112.4146
Barger, Ishida, Keung 1111.4473; 1111.2580
Grzadkowski, Gunion, Toharia 1202.5017
Tang 1204.6145
Matsuzaki and Yamawaki 1201.4722

de Sandes and Rosenfeld 1111.2006

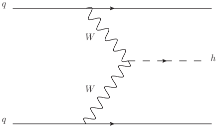


RS I

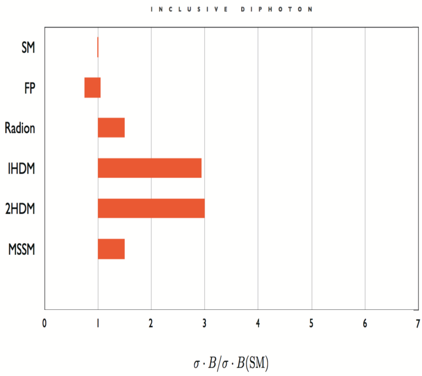
- For most models, except for the FP Higgs, gluon fusion is the dominant production mechanism ($\sigma_{gg \to h_{\rm SM}} \approx 20$ pb for 125 GeV Higgs at LHC8). But the gluon fusion can involve other exotic colored particles:

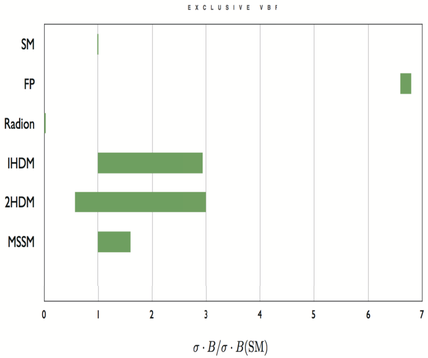


- VBF is the cleanest channel to probe the EWSB sector via the hWW/hZZ couplings:



- VBF additionally gives two energetic forward jets, which experimentally can be identified.
- Before kinematical cuts, VBF cross section is $\approx 8\%$ of gluon fusion for 125 GeV Higgs at LHC8, while Higgs-strahlung is $\approx 5\%$.


INCLUSIVE DIPHOTON
SM
FP
Radion
IHDM
2HDM
MSSM
0
1
2
3
4
5
6
7
σ · B/σ · B(SM)


EXCLUSIVE VBF
SM
FP
Radion
IHDM
2HDM
MSSM
0
1
2
3
4
5
6
7
σ · B/σ · B(SM)

Mono Vector-Quark Production at the LHC

Haiying Cai

Department of Physics, Peking University

arxiv: 1210.5200

Particle Physics and Cosmology
KIAS, November 5-9, 2012

Introduction

Vector-like quark exists in many models of new physics beyond the Standard Model: Little Higgs model, Composite Higgs model and strong dynamic models, etc. The chiral top quarks need one pair of vector like partners to stablize the EW scale or for EW symmetry breaking.

collider phenomenology of heavy quarks has been studied:

- pair production of heavy quarks via gluon fusions

$$gg \to X_{5/3}\bar{X}_{5/3}, B\bar{B}$$

  analysis is conducted in same-sign dilepton final states

  R.Contino and G.Servant, 2008

- associate production with one light quark mediated by W, Z

$$qq' \to jT, jB, jX_{5/3}, jY_{-4/3}$$

  Atre, Azuelos, Carena *et al.* **2011**

Conclusion

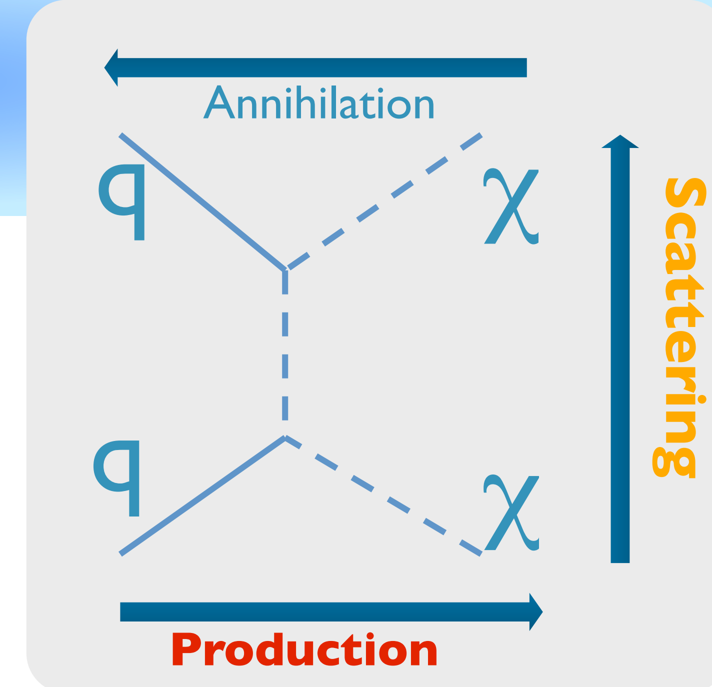
- Electroweak precision measurements impose strong bounds on the model parameters of vector-quark models.

- The leptonic angular distribution is a favored analyzing power for identifying the chiral property of couplings, therefore distinguish varieties of vector-quark models.

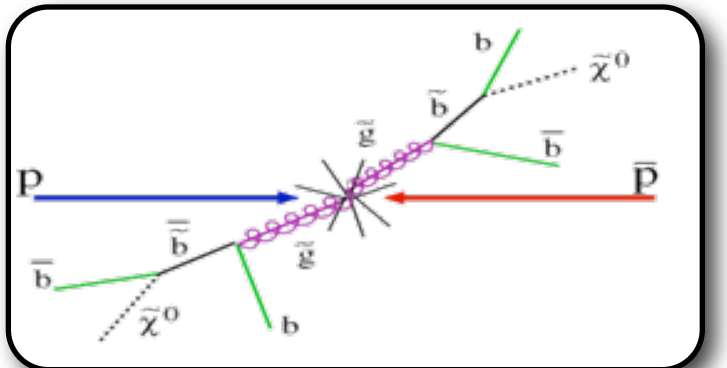
- It is promising to explore the existence of vector-quarks in mono production channel, depending on specific assumptions.

  model independent approach $\Rightarrow$ pair production

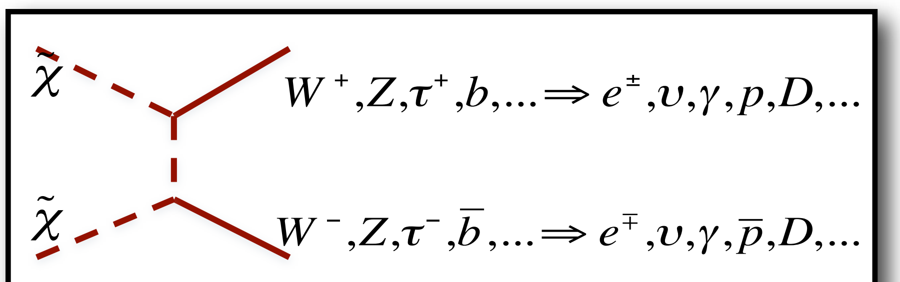
Strategies for WIMP Detection

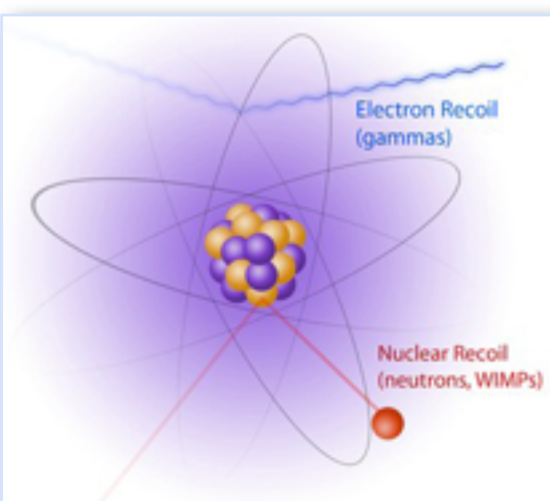


WIMP - Weakly Interacting Massive Particle



- **Production**
  - Colliders
- **Indirect Searches**
  - Annihilation of Dark Matter in Galactic Halo, ...
    - Gamma-rays, electrons, neutrinos, anti-matter, ...
  - Annihilation signals from WIMPs captured in the Sun (or Earth)
    - Neutrinos
- **Direct Searches**
  - WIMP scattering of nucleons → Nuclear recoils





WIMP Self-annihilation cross section

WIMP-Nucleon Scattering cross section

The IceCube Neutrino Telescope

Gigaton Neutrino Detector at the Geographic South Pole

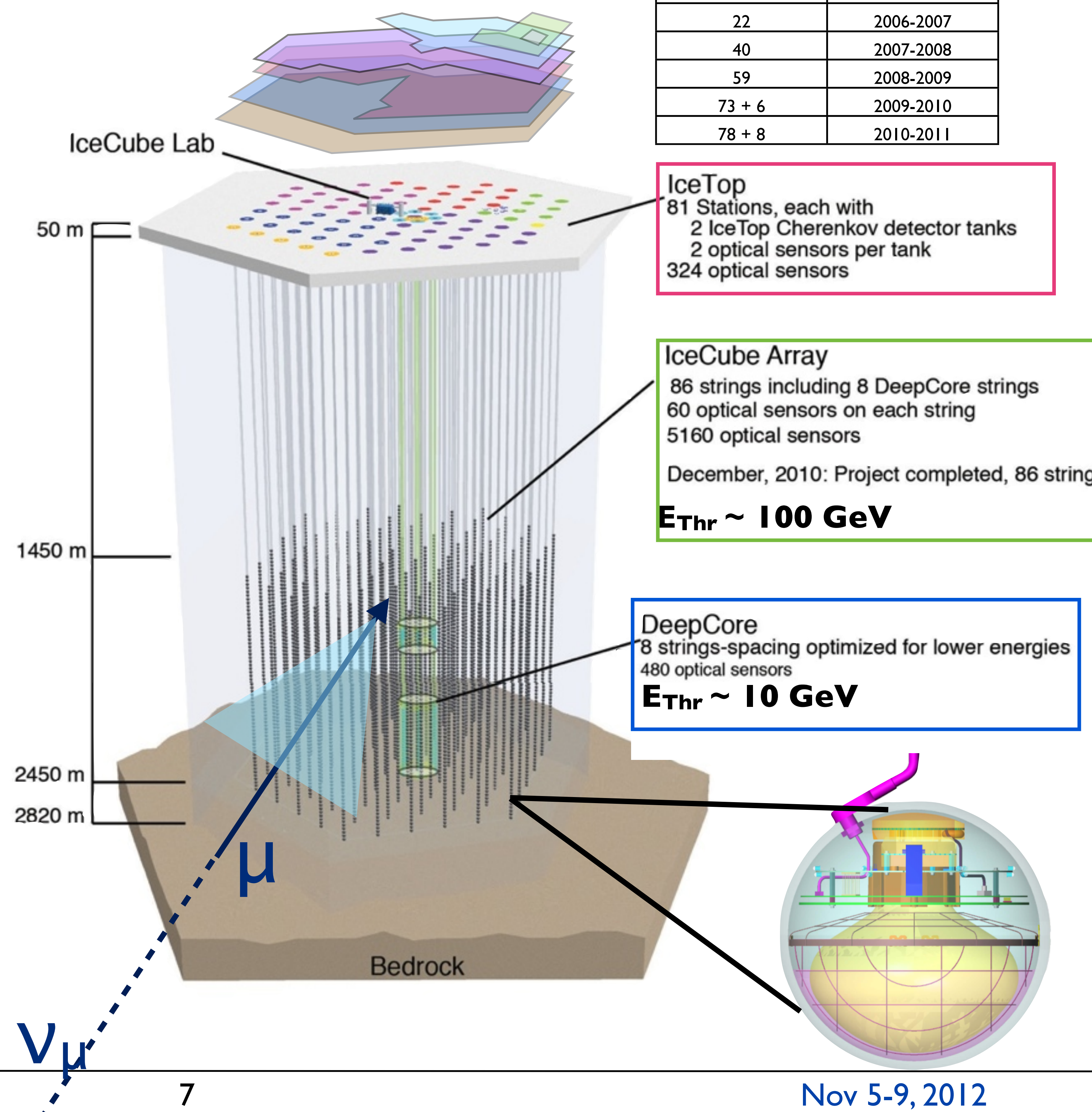
5160 Digital optical modules distributed over 86 strings

Completed in December 2010, start of data taking with full detector May 2011

Data acquired during the construction phase has been analyzed

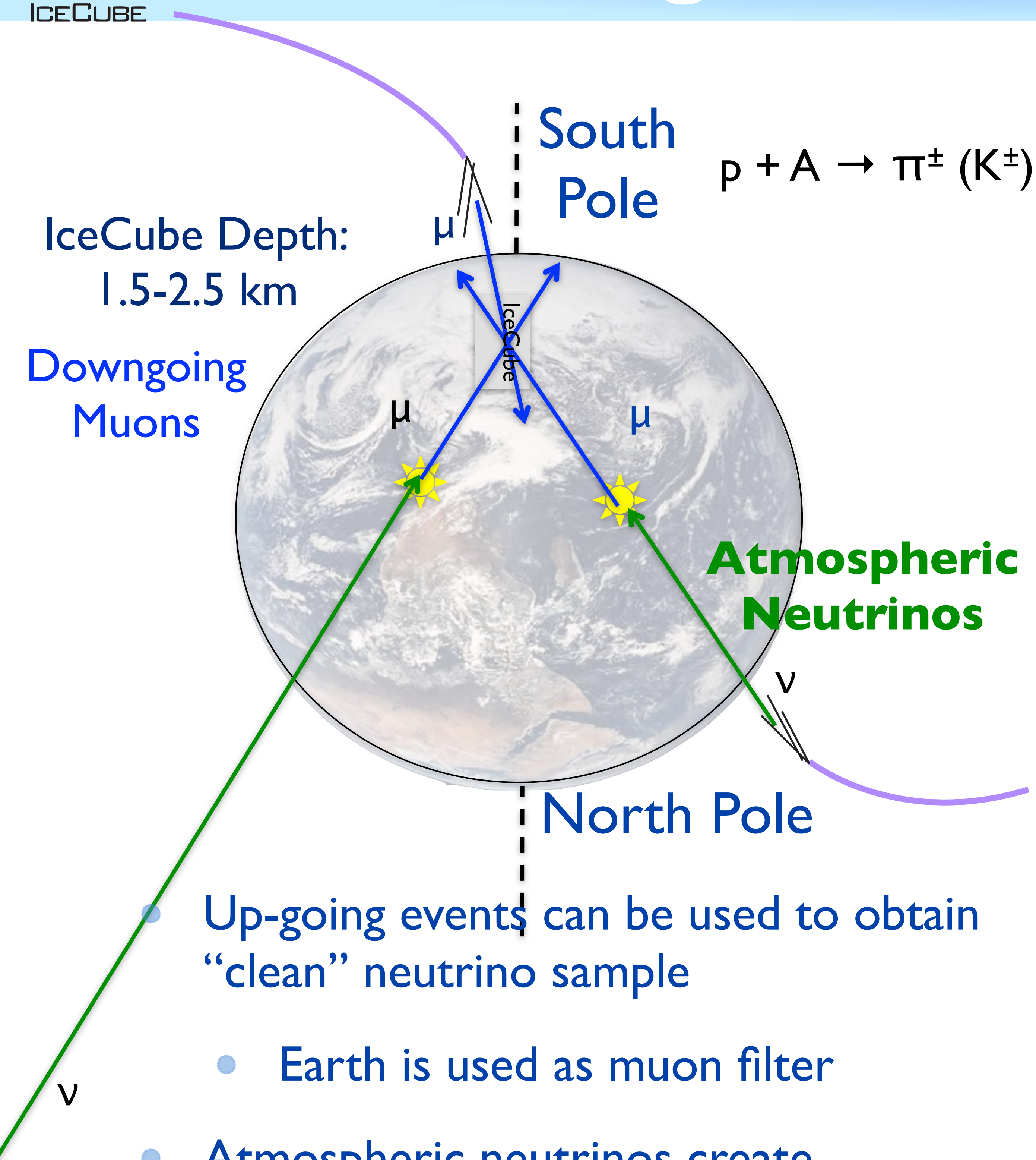
Neutrinos are identified through Cherenkov light emission from secondary particles produced in the neutrino interaction with the ice

Strings	Dataset
1	2004-2005
9	2005-2006
22	2006-2007
40	2007-2008
59	2008-2009
73 + 6	2009-2010
78 + 8	2010-2011

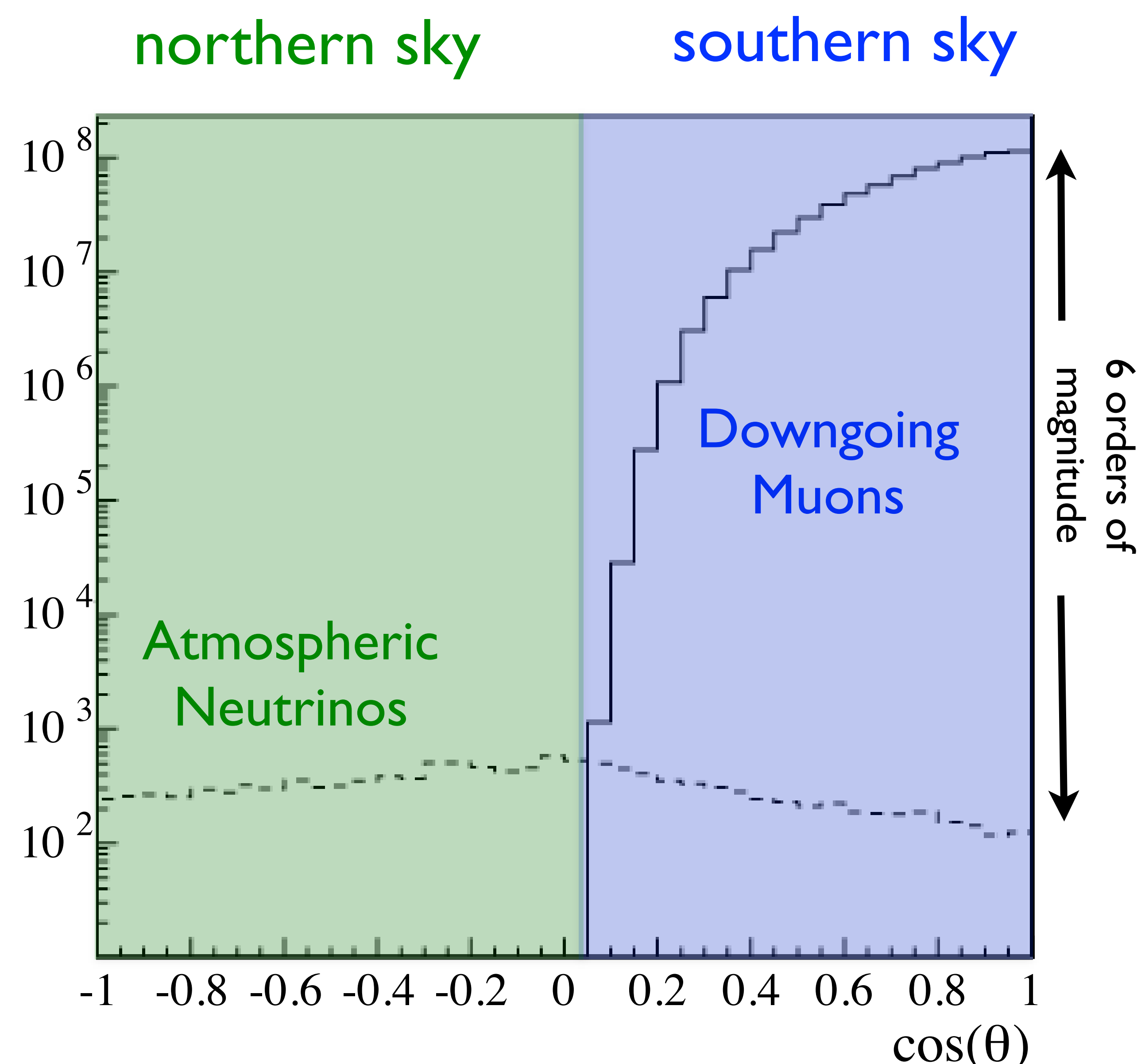


Signals in IceCube

p + A → $\pi^{\pm}$ ($K^{\pm}$) + other hadrons ... $\pi^{+} \rightarrow \mu^{+}\nu_{\mu} \rightarrow e^{+}\nu_{e}\nu_{\mu}\nu_{\mu}$

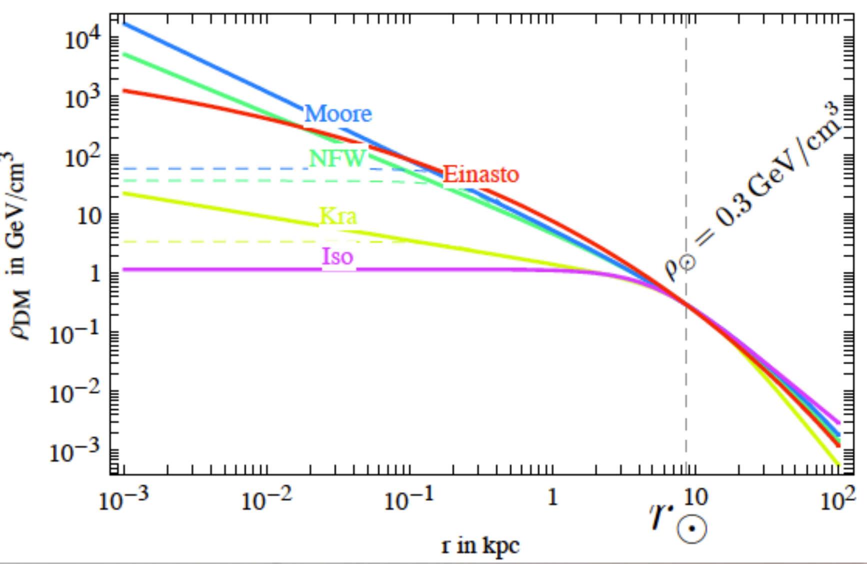


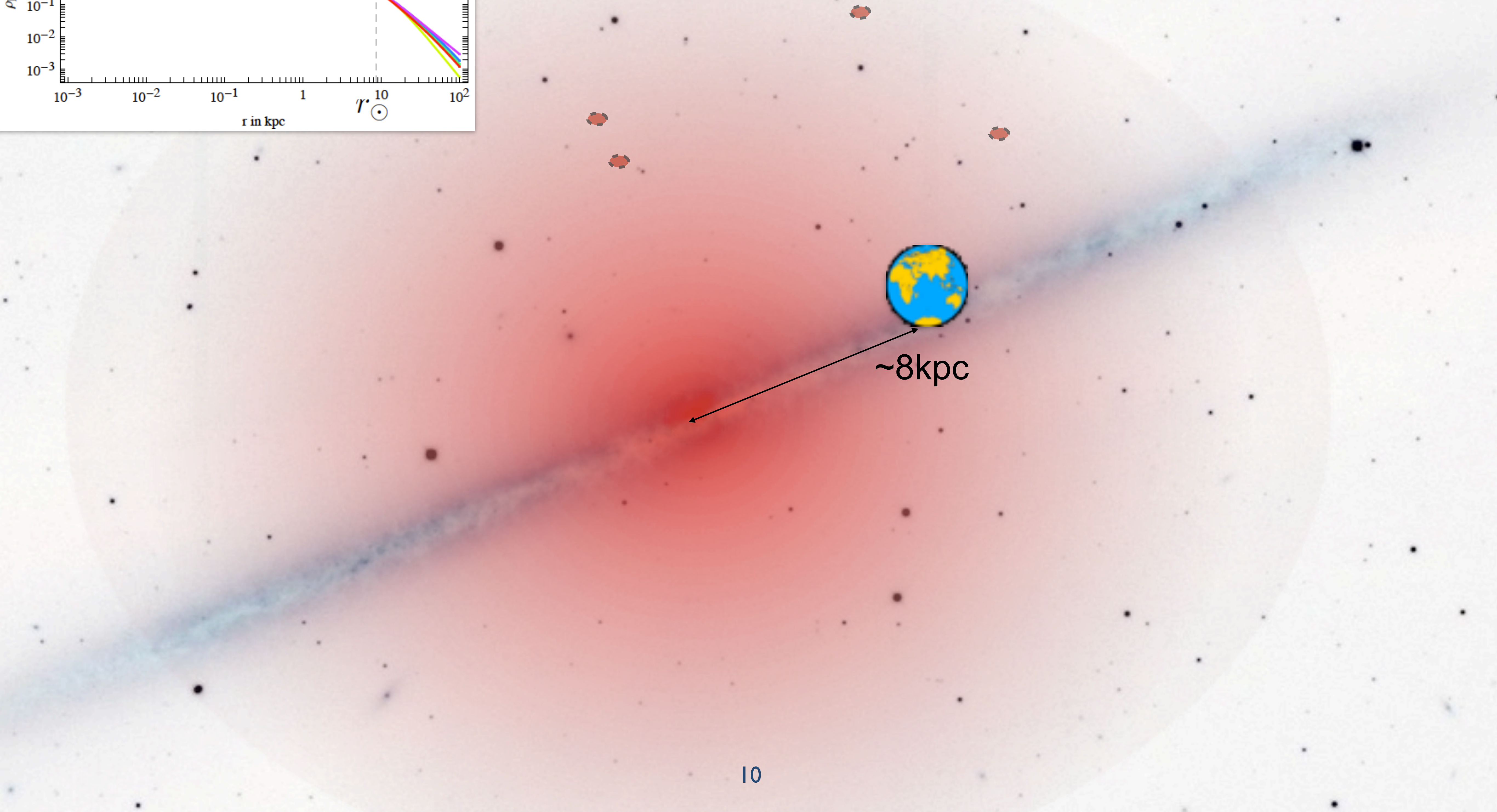
- Up-going events can be used to obtain "clean" neutrino sample
  - Earth is used as muon filter
- Atmospheric neutrinos create irreducible neutrino background to extra terrestrial neutrino fluxes



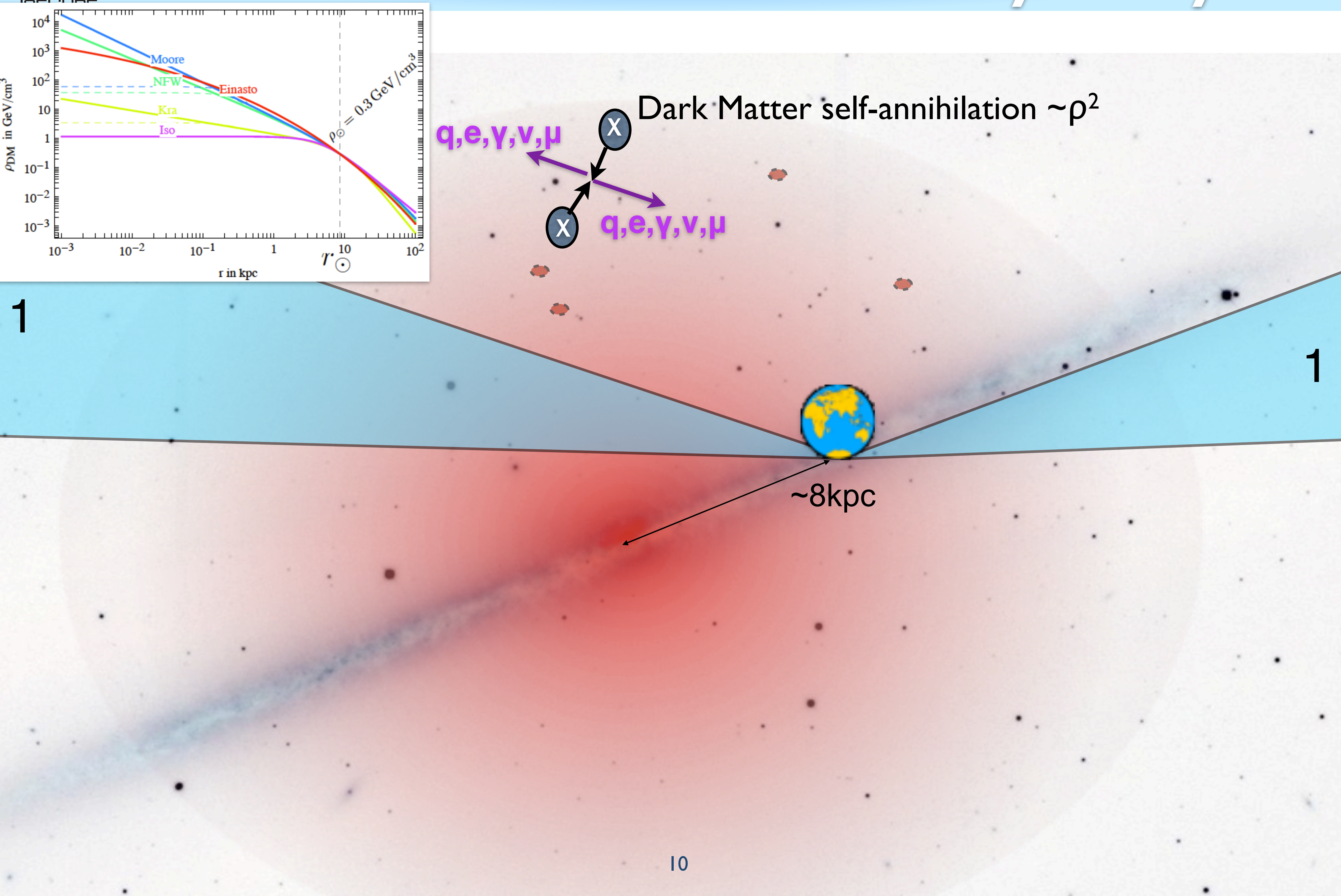
Atmospheric backgrounds for extra-terrestrial neutrino searches at the depth of IceCube

Dark Matter in the Milky Way

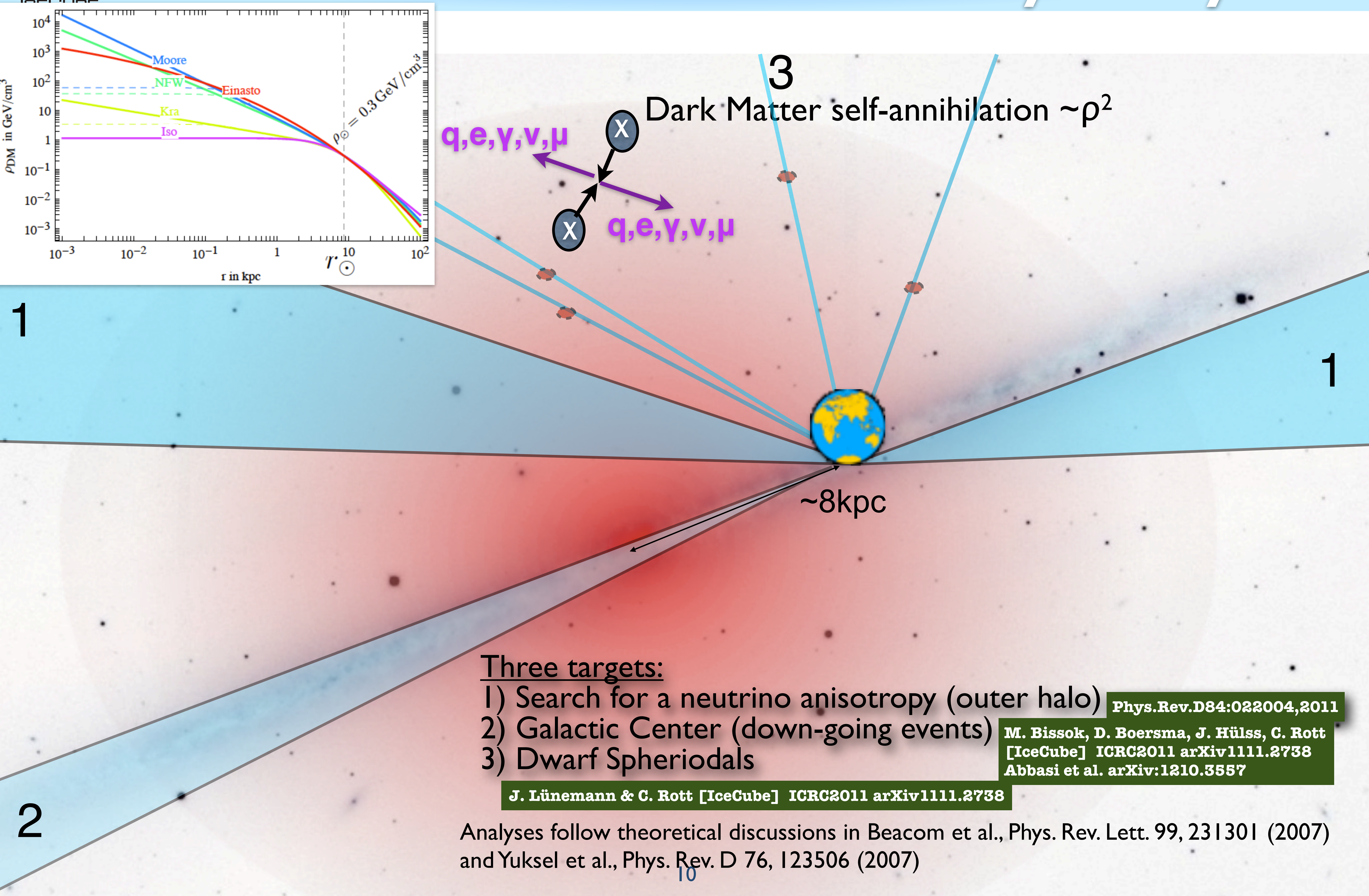




Dark Matter in the Milky Way



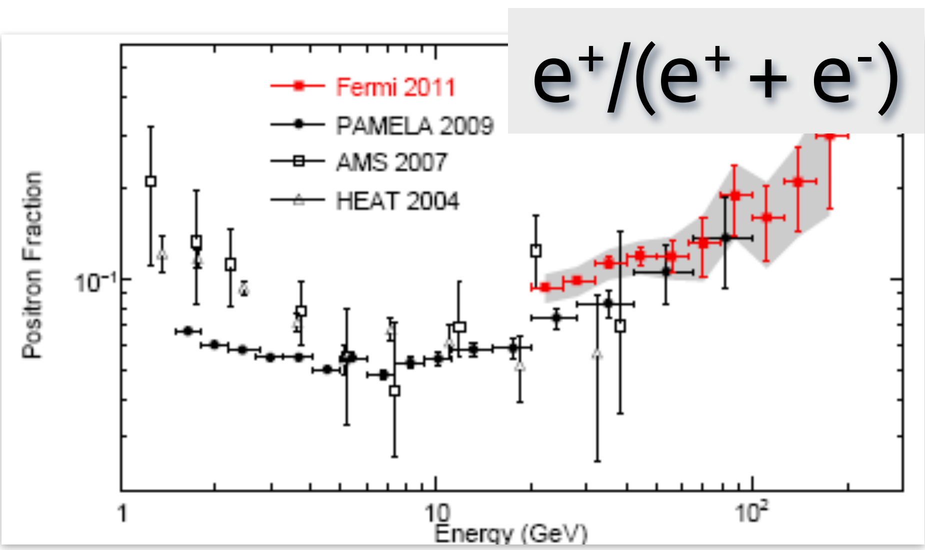
Dark Matter in the Milky Way

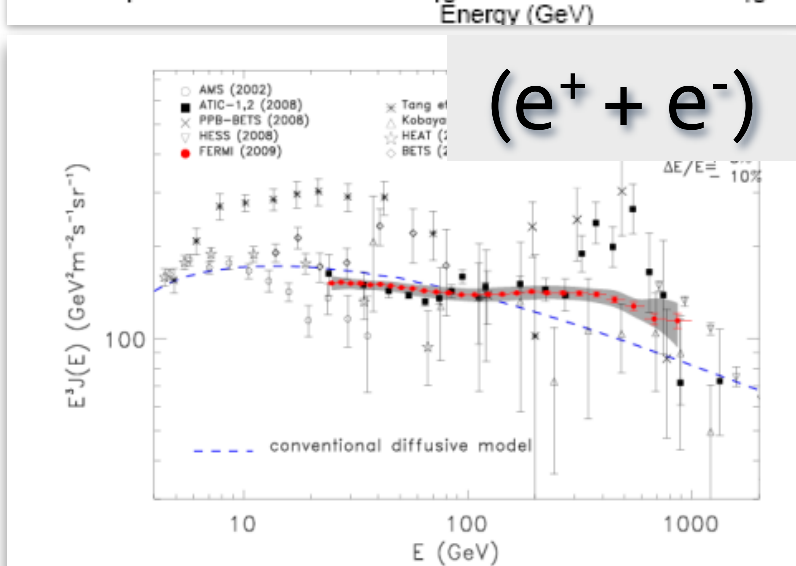


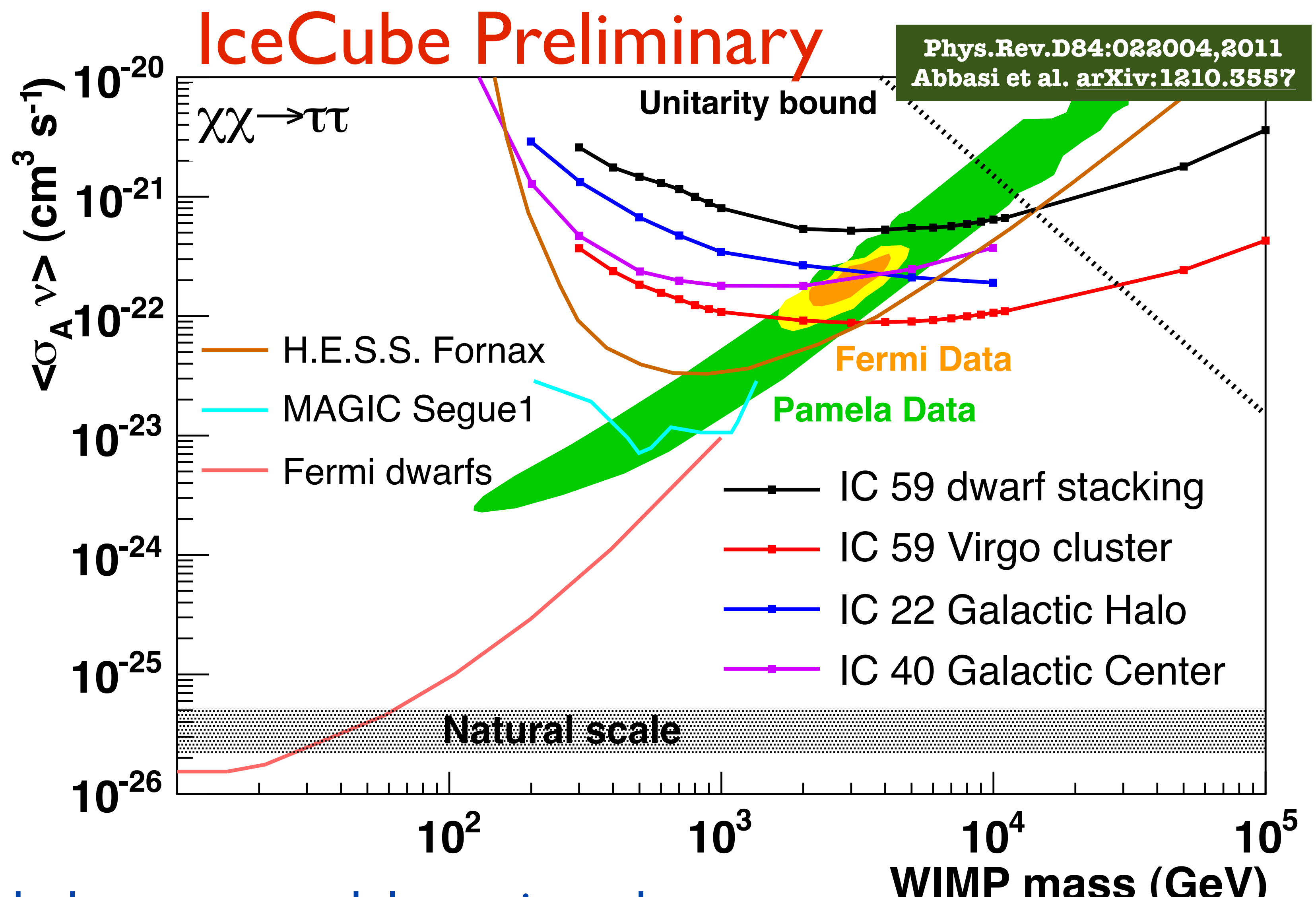
Three targets:
1) Search for a neutrino anisotropy (outer halo) **Phys.Rev.D84:022004,2011**
2) Galactic Center (down-going events) **M. Bissok, D. Boersma, J. Hülss, C. Rott [IceCube] ICRC2011 arXiv1111.2738 Abbasi et al. arXiv:1210.3557**
3) Dwarf Spheriodals **J. Lünemann & C. Rott [IceCube] ICRC2011 arXiv1111.2738**

Analyses follow theoretical discussions in Beacom et al., Phys. Rev. Lett. 99, 231301 (2007) and Yuksel et al., Phys. Rev. D 76, 123506 (2007)

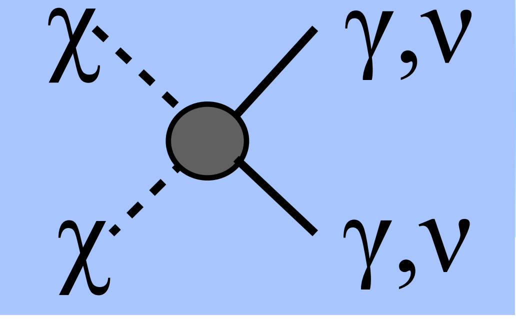
Results







Indirect searches / IceCube can test dark matter models motivated by PAMELA and Fermi-LAT electron data (e.g. Meade et al. 2008)



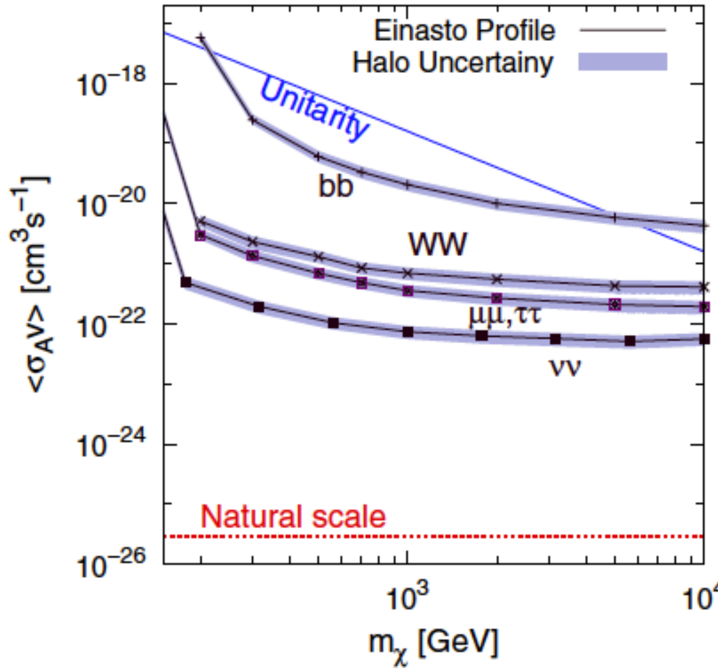
Neutrino Line Search

- Neutrinos set conservative upper limit on the total self-annihilation cross section using the line channel $\chi\chi \rightarrow \nu\nu$

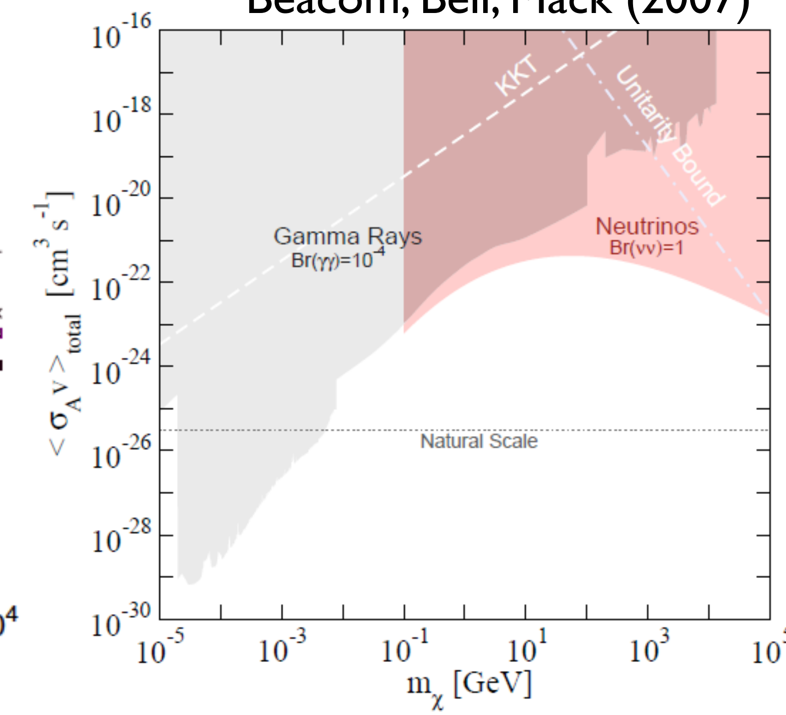
  Beacom, Bell, Mack (2007)

- IceCube has published limits for line channel for large WIMP masses m_χ
- $m_\chi \approx$100GeV match well contained events in DeepCore

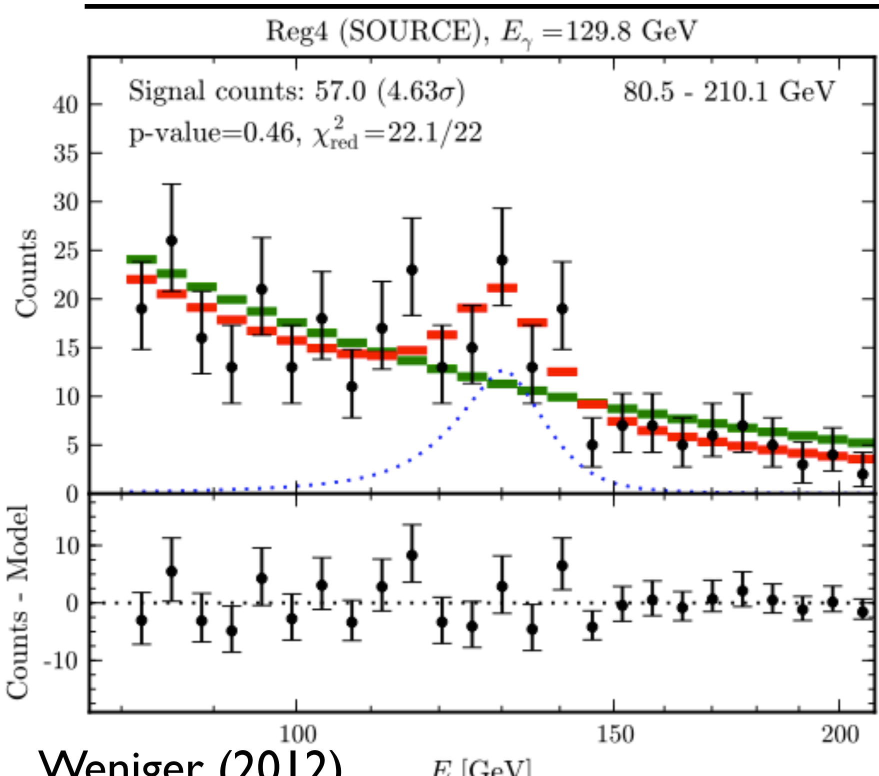
Phys.Rev.D84:022004,2011



Beacom, Bell, Mack (2007)

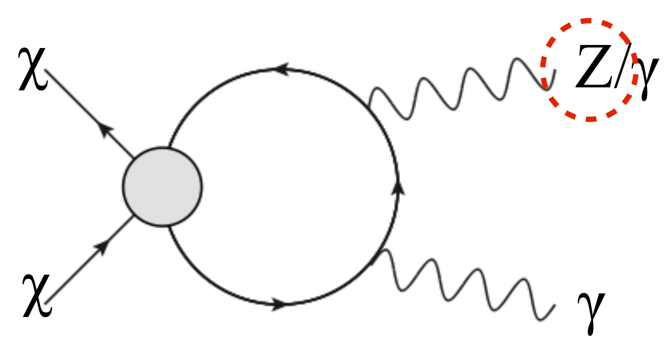


Neutrinos can also check predictions from gamma-ray lines:



Weniger (2012)

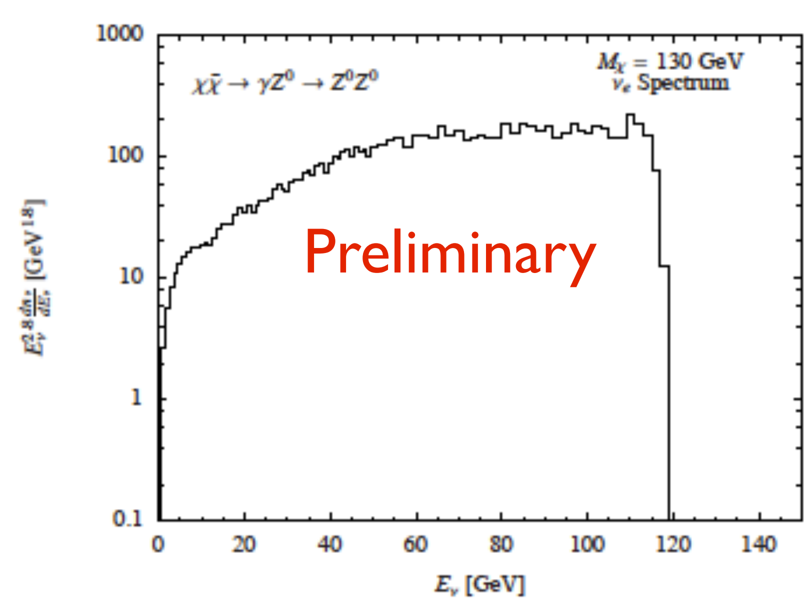
$$\langle\sigma v\rangle_{\gamma\gamma} \sim 10^{-27}\ \mathrm{cm}^3/\mathrm{s}$$



Cohen et al. arXiv:1207.0800v3

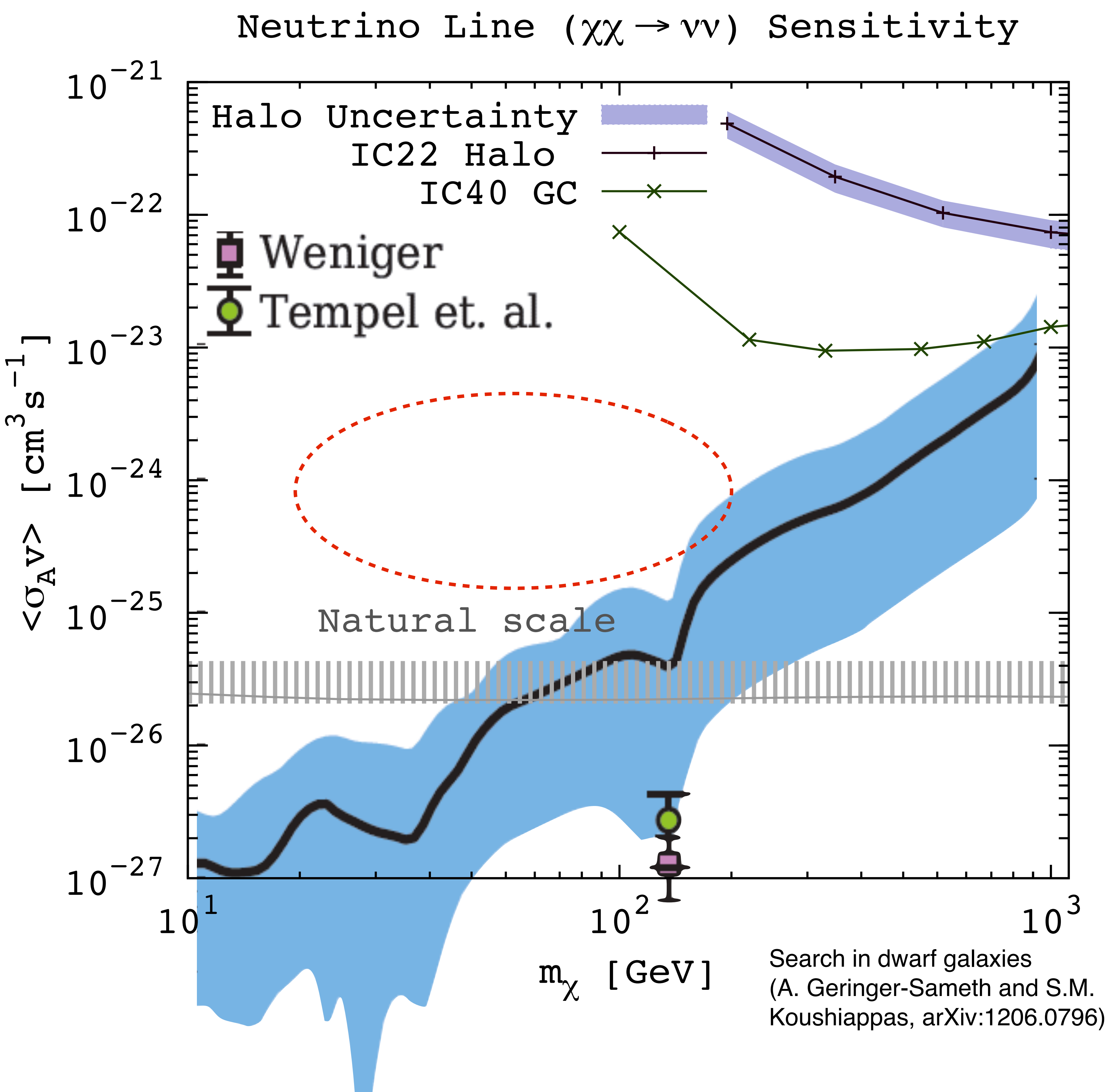
Dedicated analysis focuses on Neutrino lines in the energy range 20-200GeV

A. Z^0Z^0 Channel



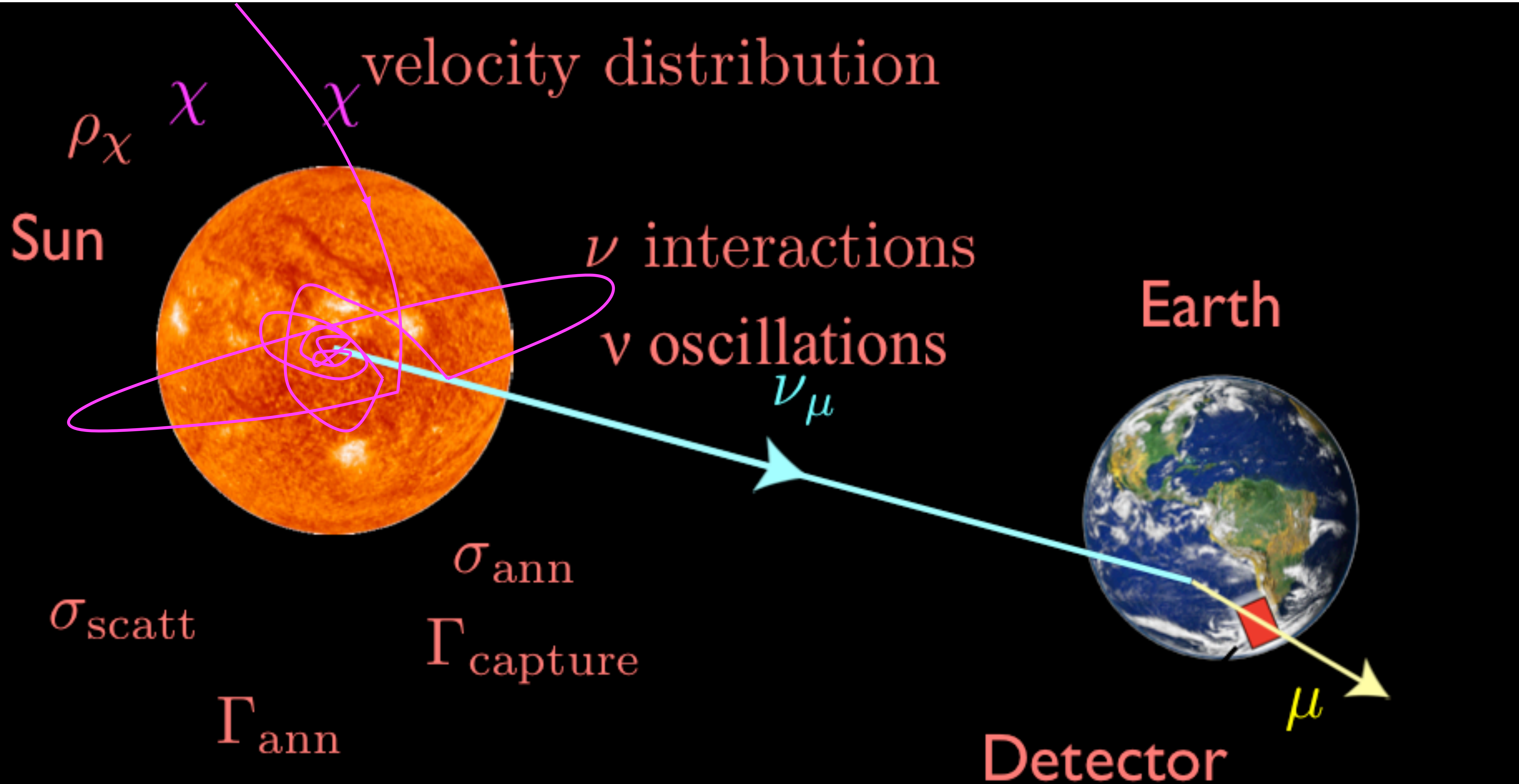
see talk by C.Weniger (this session)

Neutrino lines



Search in dwarf galaxies (A. Geringer-Sameth and S.M. Koushiappas, arXiv:1206.0796)

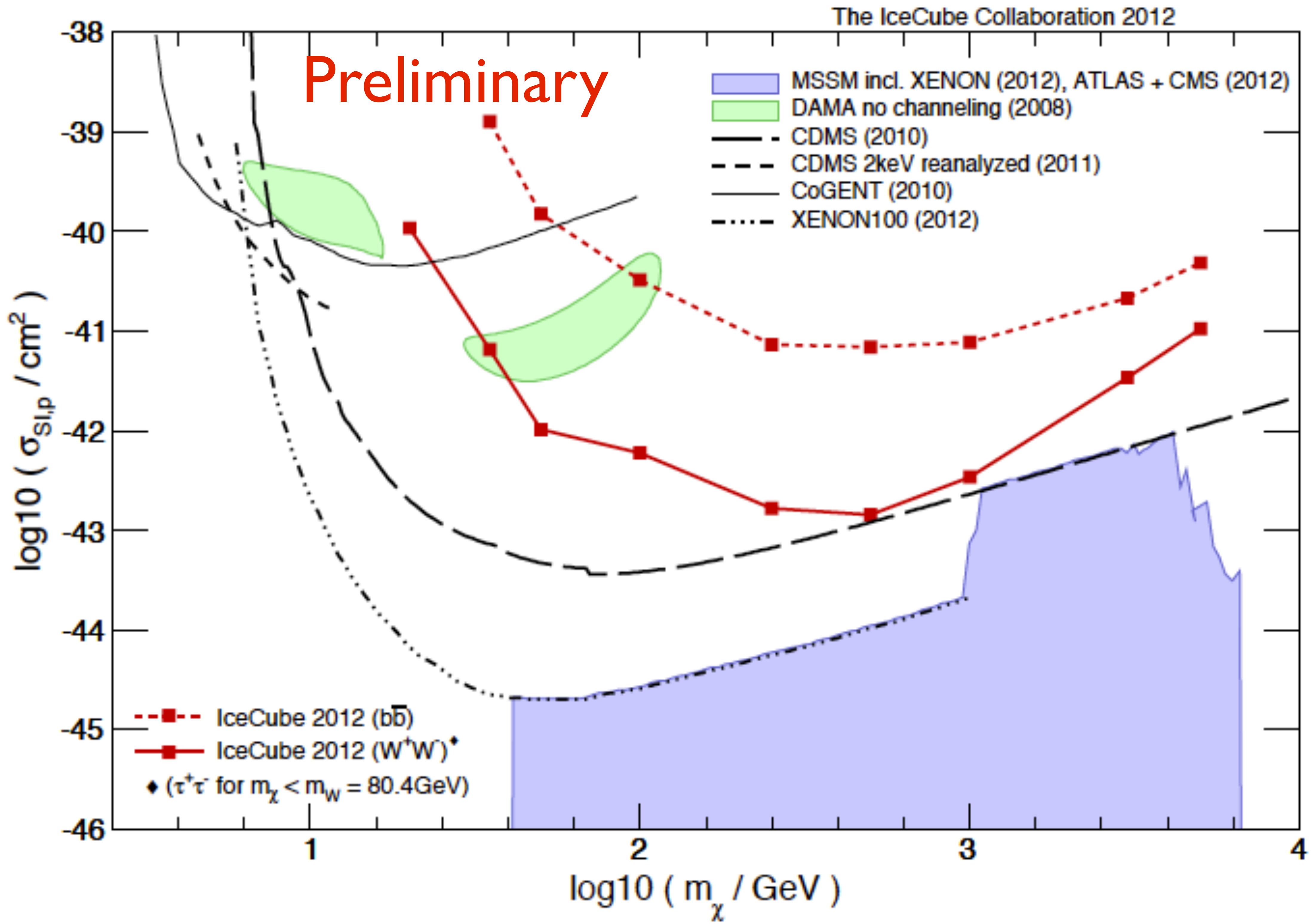
Solar WIMP Signal



Freese '86
Krauss, Srednicki & Wilczek '86
Gaisser, Steigman & Tilav '86

Silk, Olive and Srednicki '85
Gaisser, Steigman & Tilav '86

SI Limit Solar WIMPs



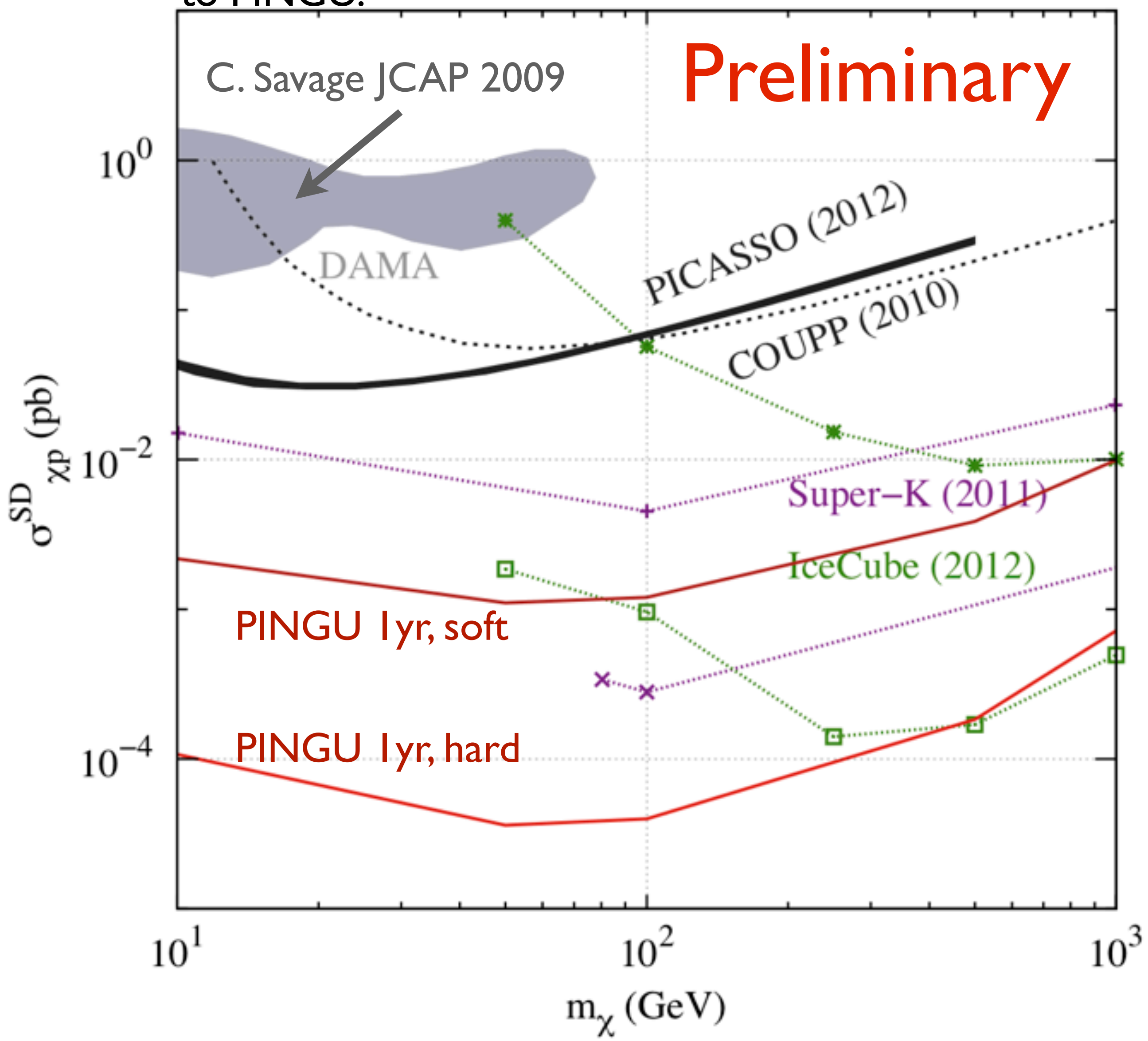
PRL in preparation

PINGU and Solar WIMPs

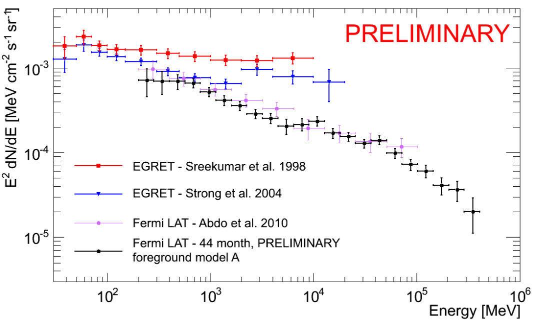
- Preliminary solar WIMP sensitivity based PINGUs effective volume
- Assume that atmospheric muon backgrounds can be effectively rejected (not included in the sensitivity)

Adapted **Rott, Tanaka, Itow JCAP09(2011)029** to PINGU.

- Low-mass WIMP scenarios well testable
- Next steps:
  - Detailed study with full PINGU simulation
  - More sophisticated event reconstruction
  - Check atmospheric muon background

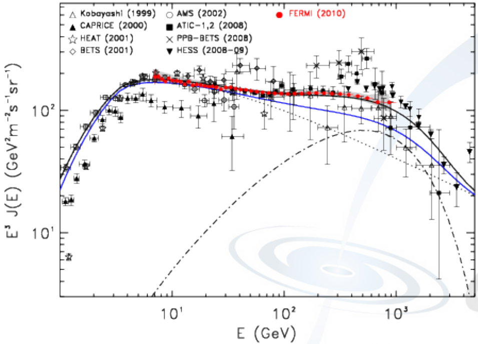


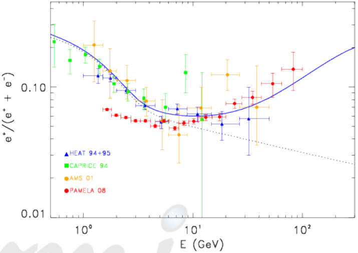
Isotropic Gamma-Ray Background
M. Ackermann at Fermi Symposium 2012



- Fermi-LAT is measuring isotropic γ-ray spectrum to $>$ 400 GeV
  - Published up to 100 GeV in Abdo A. A. et al. 2010, PRL, 104, 101101
  - New, preliminary, analysis on 44 months of LAT data up to 410 GeV
- Can compare measurements to expected unresolved contributions from sources
- Sub-degree scale (high-multipole) anisotropies sensitive to unresolved sources as well as DM sub-structures
- Work ongoing in extending the spectrum to $\sim$ 1 TeV (arXiv:1210.2558)

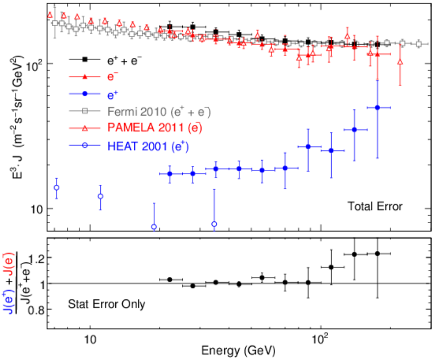
Not only γ-rays: Cosmic Ray Electrons
Abdo, A. A. et al. 2009 PRL 102, 181101 – Ackermann, M. et al. 2010 PRD 82, 092004

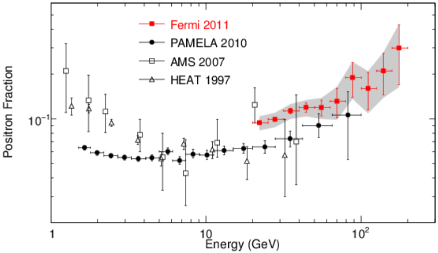




From D.Grasso et al. Astropart. Phys. 32, 140-151 (2009)

- Systematics limited spectrum from 7 GeV to 1 TeV
- Spectrum is harder than in pre-Fermi GALPROP model
  - Compatible with a single power-law → diffusive model
- Adding an extra component nicely fits the Fermi spectrum
  - Together with PAMELA positron fraction
- Several possibilities for an additional source of e^+/e^-
  - Either astrophysical or exotic (or both)

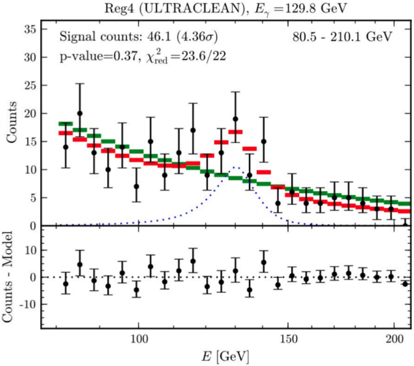


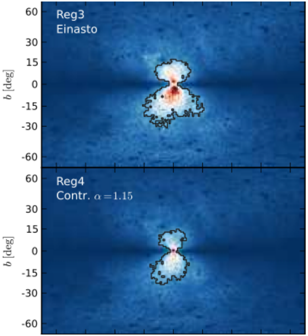


- First measurement of separate electron and positron spectra in this energy range
  - Using the Earths magnetic field as charge discriminator
  - Limited by statistics at high-energy, as we need special data-taking runs (*looking down* for this analysis)
- Positron fraction increasing with energy (consistent with PAMELA)
- The complete explanation has probably to wait for future measurements with greater sensitivity and energy reach

A Gamma-Ray Line at 130 GeV ?

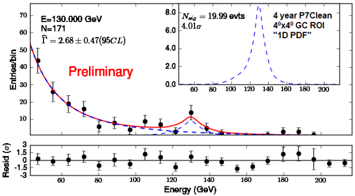
- Recent claim of a narrow spectral feature at $\sim$ 130 GeV near the Galactic center (GC)
- Triggered a huge interest in the community
- Comprehensive Fermi LAT team analysis on line searches based on 4 years of data ongoing (see, e.g. A. Alberts, E. Bloom, E. Charles at Fermi Symposium 2012)
  - Line significance decreases with reprocessed data
  - Line-like feature observed in Earth Limb



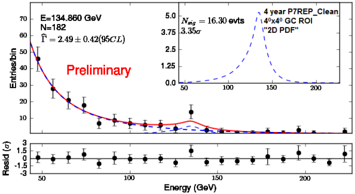


Bringmann+ [arXiv:1203.1312], Weniger [arXiv:1204.2797]

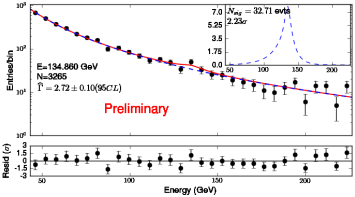
- 4.01σ (local) 1D fit at 130 GeV with 4 year unreprocessed data
  - Look in $4^\circ \times 4^\circ$ GC ROI
  - Use 1D PDF (no use of P_E)



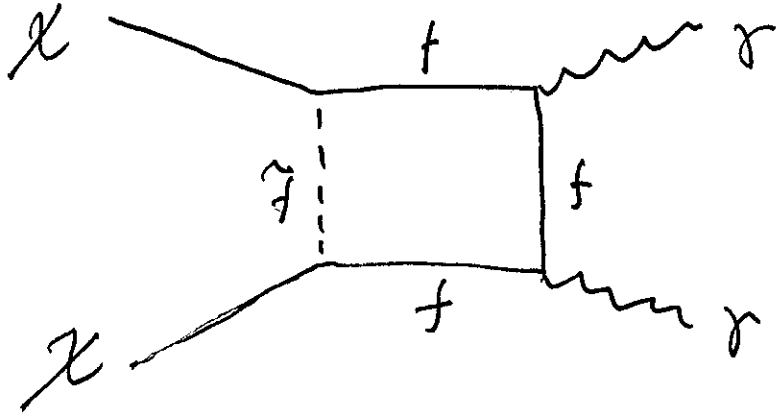
- 3.35σ (local) 2D fit at 135 GeV with 4 year reprocessed data
  - Look in $4^\circ \times 4^\circ$ GC ROI
  - Use 2D PDF



- Line-like feature in the limb at 135 GeV
  - Appears when LAT is pointing at the Limb
    - $|RockAngle| > 52^\circ$
  - Surprising since limb should be smooth
  - Orbit profile changed to increase our Limb dataset



Christoph Weniger on 130 GeV γ line in Fermi-LAT data



Data analysis

$\Rightarrow$ Local significance 4.6σ

Global significance 3.2σ

$\Rightarrow$ 1.4σ hint of an excess at ~ 114 GeV consistent with $\chi\chi \to \gamma Z$

BUT

Data along the Earth Limb gives the 130 GeV γ signal.

$\Downarrow$

Red flag ?

Fermion DM + axion

[HML, Park, Park (2012)]

- Consider the effective axion interactions to a Dirac fermion DM and EW gauge bosons,

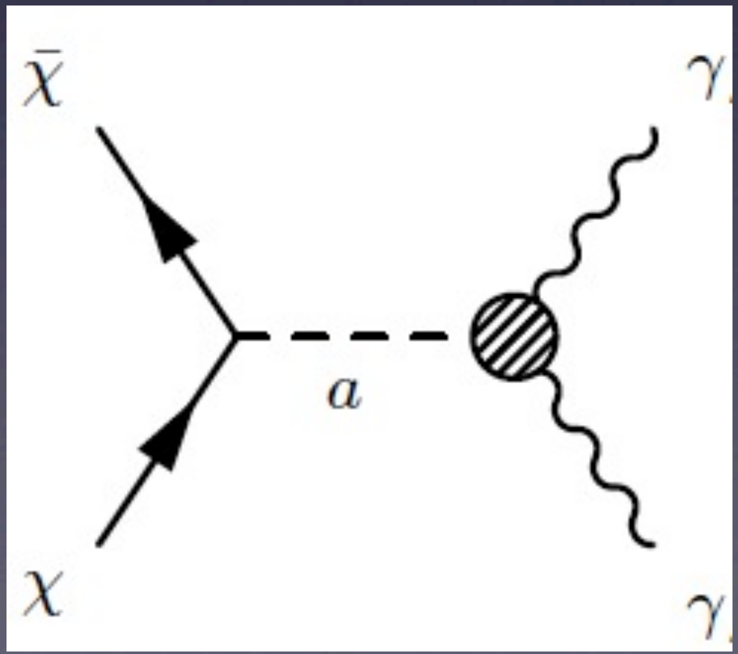
$$\mathcal{L}_{\rm int} = -\frac{\lambda_\chi}{\sqrt{2}} a\,\bar{\chi}\gamma^5\chi + \sum_{i=1,2}\frac{c_i\alpha_i}{8\pi f_a}\,a\,F^i_{\mu\nu}\tilde{F}^{i\mu\nu}.$$

- DM annihilation cross section into a photon pair:

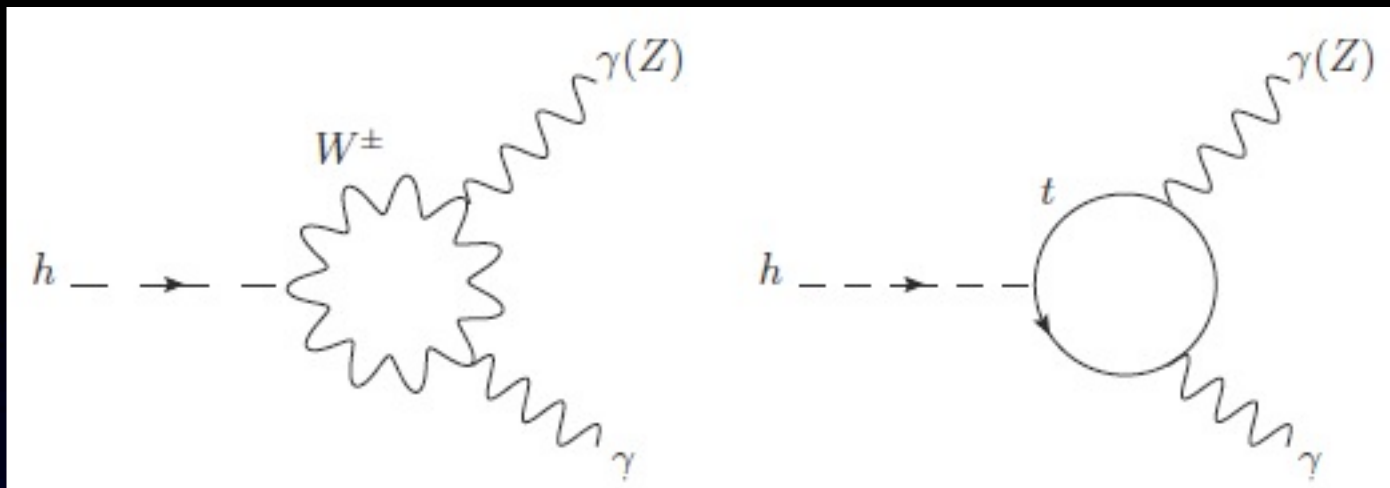
$$\langle\sigma v\rangle_{\gamma\gamma} = \frac{1}{16\pi}|\lambda_\chi|^2|c_{\gamma\gamma}|^2\frac{16M_\chi^4}{(4M_\chi^2-m_a^2)^2+m_a^2\Gamma_a^2},$$

$$c_{\gamma\gamma} = \frac{(c_1+c_2)\alpha}{16\pi f_a}$$

Resonance effect near $m_a \sim 2M_\chi$ enhances the cross section.



Higgs diphoton rate

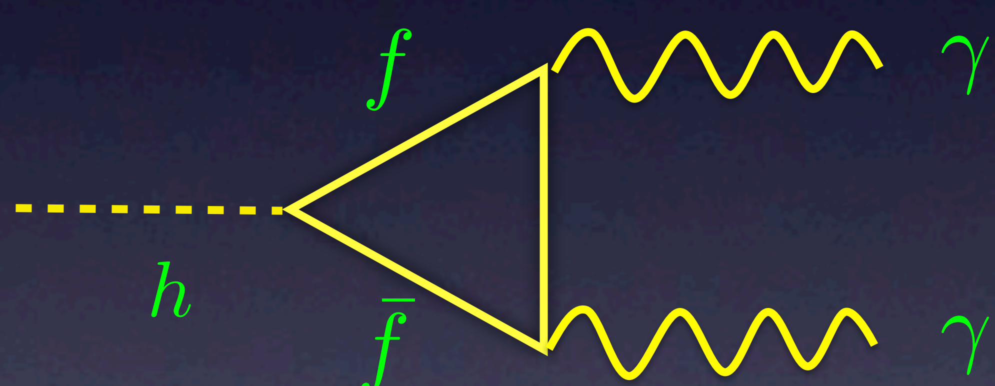


SM: $\mathcal{L}_{\gamma\gamma} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}\sum_i \frac{b_i e^2}{16\pi^2}\log\frac{\Lambda^2}{m_i^2}$

$$\mathcal{L}_{\gamma\gamma} = \frac{\alpha}{8\pi}\Big(-7+\frac{4}{3}N_c Q_t^2\Big)\frac{h}{v}F_{\mu\nu}F^{\mu\nu}$$

"destructive interference"

- New charged fermion can enhance diphoton rate:



$$\mathcal{L}_{\rm eff} = -\frac{c_f}{M}|H|^2\bar{f}f$$

[Carena, Low, Wagner (2012)]

- Higgs diphoton rate:

$$\Gamma_{h\to\gamma\gamma} = \frac{G_F\alpha^2 m_h^3}{128\sqrt{2}\pi^3}\Big|A_1(\tau_W)+N_cQ_t^2A_{1/2}(\tau_t)+\frac{c_f v^2}{Mm_f}A_{1/2}(\tau_f)\Big|^2$$

-8.32 1.84 new fermion

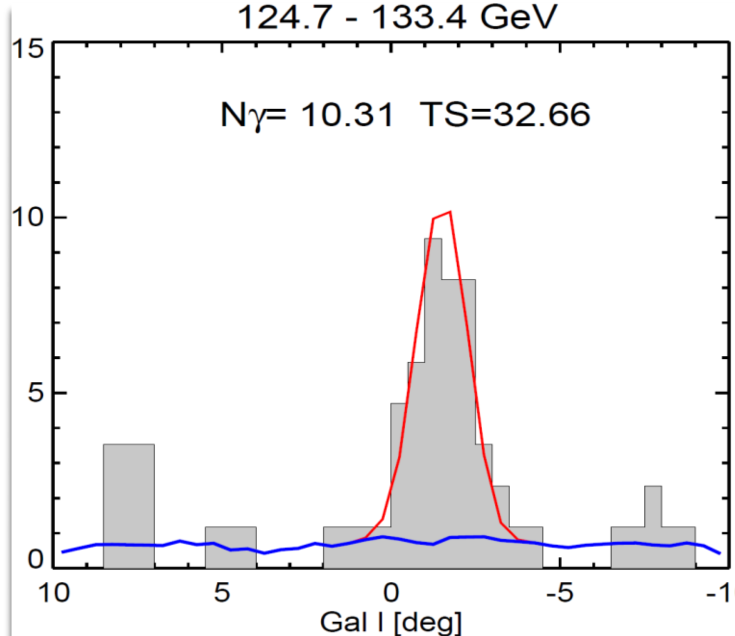
For $\mu_{\gamma\gamma}\simeq 1.7,\quad M=v,\ m_f=100\,\text{GeV}$: $c_f \simeq -3.27$

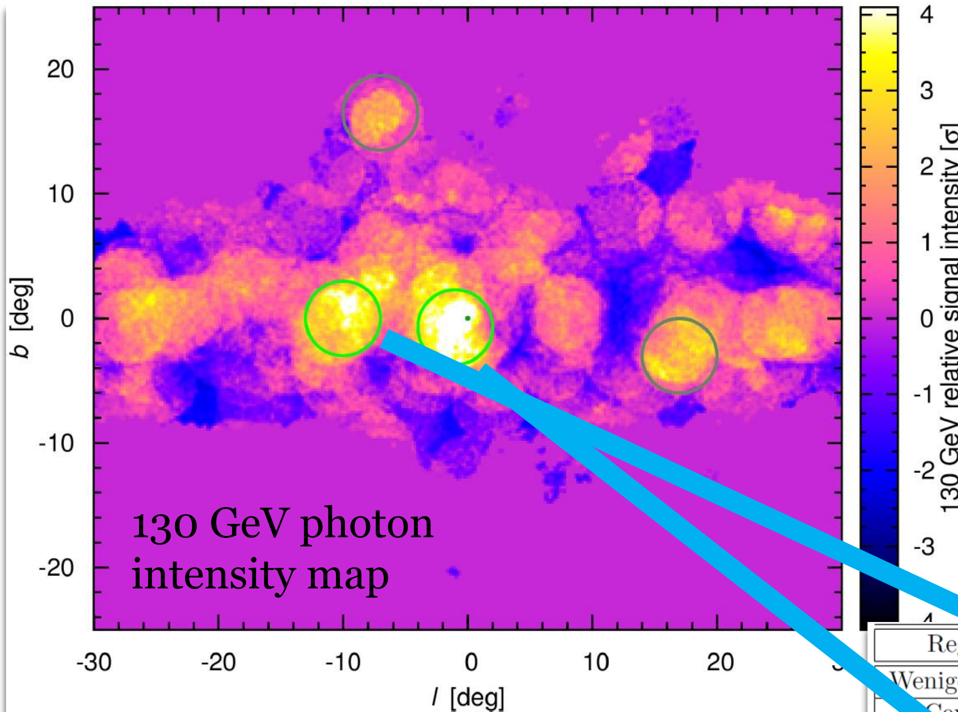
Conclusions

- In the singlet fermion dark matter model with axion mediator, electroweak anomalies lead to the photon line consistent with Fermi LAT data.
- Models of extra leptons determine the branching fraction of Fermi photons and also enhance the Higgs diphoton rate.
- Suppression of tree-level DM ann. channel constrains the Higgs diphoton rate.
- Decaying charged lepton could be probed at the LHC.

More evidence

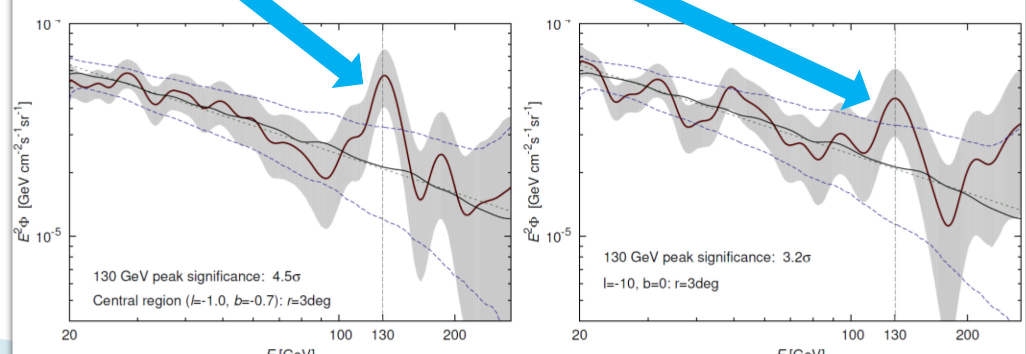
Su & Finkbeiner, arXiv:1206.1616





Tempel et al., arXiv:1205.1045

Region	l (deg)	b (deg)	N_γ (20–300) GeV	N_γ (120–140 GeV)	significance
Weniger Reg3		–	3298	65	3.6σ
Central	-1	-0.7	818	27	4.5σ
West	-10	0	726	21	3.2σ
East	17	-3	481	14	2.7σ
North	-7	16.5	[illegible]	4	1.6σ



DM annihilation

B. Kyae & JCP, arXiv: 1205.4151

- DM is EM neutral

  ⇒ $<\sigma v>_{\gamma\gamma/\gamma X}$: one-loop suppressed (not too heavy charged particles)

- $<\sigma v>_{\gamma\gamma} \sim 2 \cdot 10^{-27}\ cm^3/s$

  ⇒ large enough new couplings or resonance

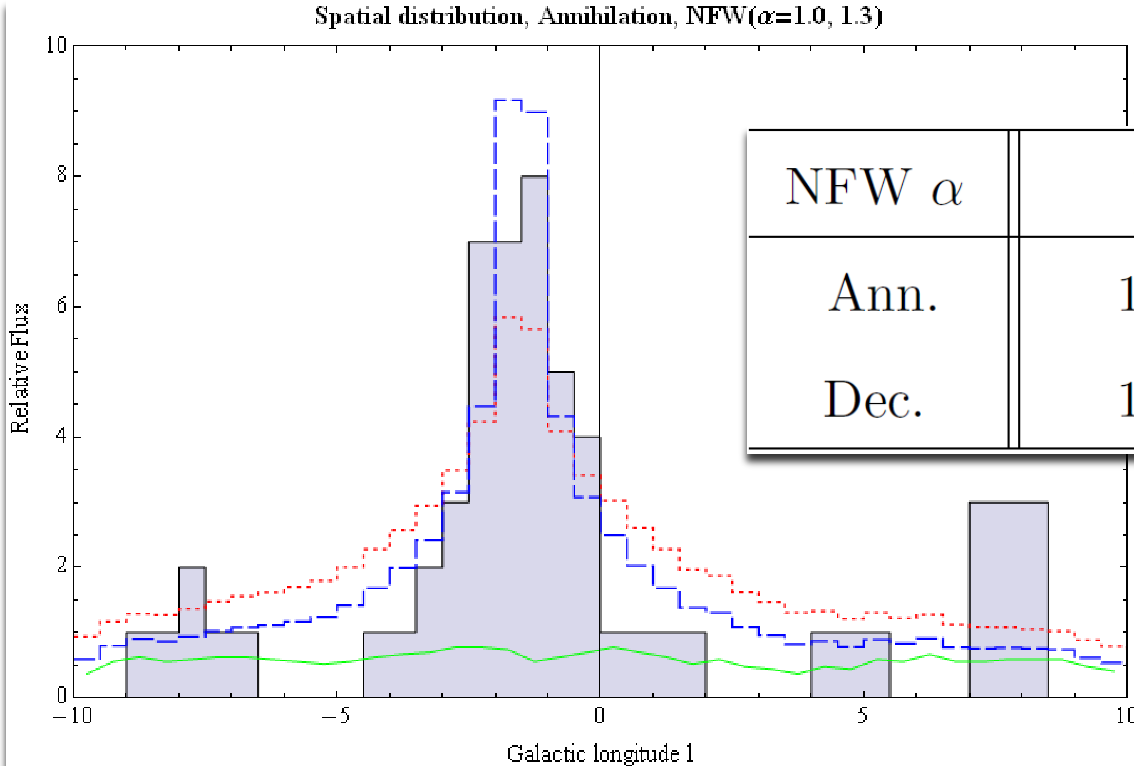
- $<\sigma v>_{thermal} \sim 3 \cdot 10^{-26}\ cm^3/s$

  ⇒ two different interactions to separate $<\sigma v>_{\gamma\gamma}$ from $<\sigma v>_{thermal}$

How about DM decay?

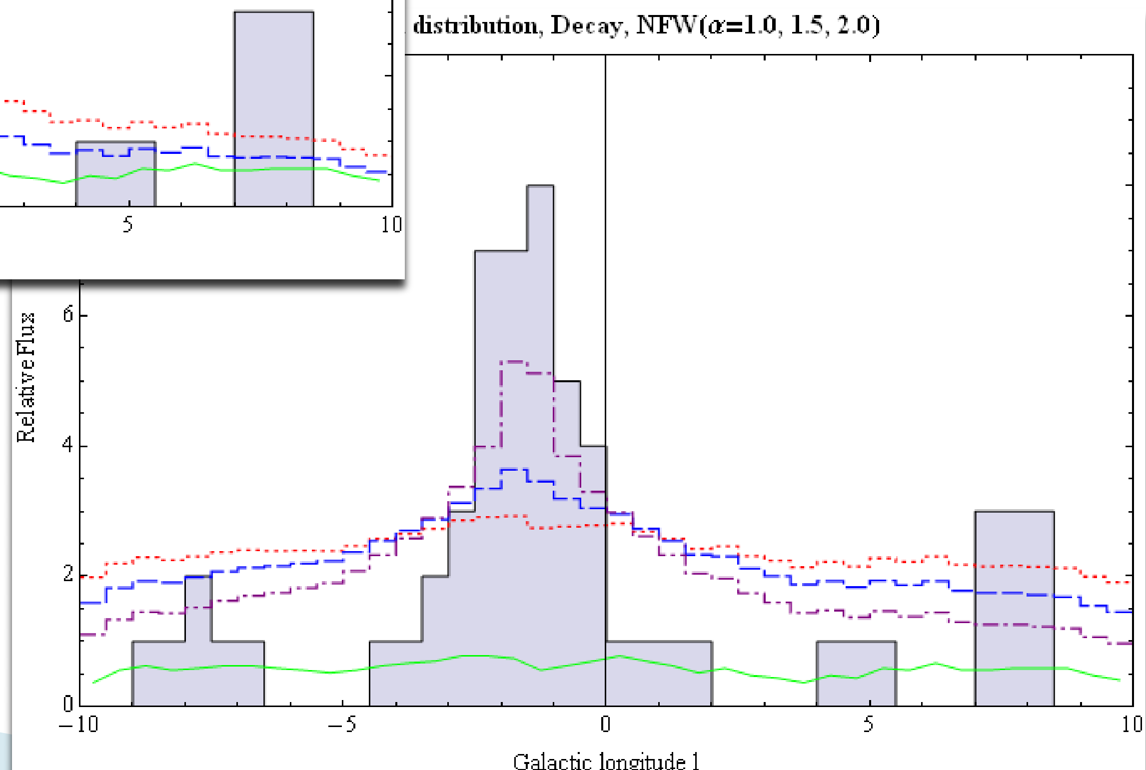
Annihilation vs Decay

JCP & S.C.Park,
arXiv: 1207.4981



χ²/d.o.f.

NFW α	1.0	1.3	1.5	1.7
Ann.	1.05	1.03	1.17	1.40
Dec.	1.80	1.60	1.44	1.28



Conclusion

- 130 GeV peak (3~4 σ) from the Fermi-LAT data?
- $<\sigma v>_{\gamma\gamma} \sim 2\cdot10^{-27}\ cm^3/s$ with $m_{DM}=130$ GeV

  cf. $<\sigma v>_{thermal} \sim 3\cdot10^{-26}\ cm^3/s$
- Decay models are acceptable for DM profiles enhanced

  around the GC.
- DM decay? -> $\Gamma^{-1}_{DM} \sim 10^{28\text{-}29}$ s with $m_{DM} \sim 260$ GeV

  Two sols. -> D6 Op. or D5 Op. W/ additional suppressions.

Thank you

Testing 130 GeV gamma-ray line with Fermi-LAT data

Xiaoyuan Huang

NAOC

Based on arXiv 1208.0267 and work in progress
with Qiang Yuan, Pengfei Yin, Xiaojun Bi and Xuelei Chen

Conclusion

- The constraints on the annihilation cross section of continuous γ-ray emission from the Galactic center are as stringent as the "natural" scale assuming thermal freeze-out of DM, and this is "unnatural" compared with the best fit cross section for gamma-gamma.
- The present constraints from the Milky Way halo observations of the line-like emission are marginally consistent with that from the inner Galaxy if explaining it with DM annihilation.
- Possible concentration of photons in $120 - 140$ GeV from nearby clusters is revealed.
- Constraints from galaxy cluster (with substructures) are marginally consistent with the DM annihilation scenario to explain the ~ 130 GeV emission, and the constraints from dwarf galaxies are weaker.
- The probability to observe dark matter annihilation photons from substructures in our Milky Way is low.

SUMMARY

1398

- In symmetric extra dimension, the LKP is a good DM candidate thanks to KK-parity.
- UED, an effective description of more generic geometry, e.g. RS, provides a useful framework to study KKDM.
- 1/R~TeV, M's (and r's) provide rich phenomenology
- DM+LHC7&LHC8+EWPT already started to probe a part of parameter space in mUED and its generalization.
- LHC 14 and future DM searches(Direct/Indirect) will give us more definite answers for KKDM.

Phenomenological Implications of general UED

Thomas Flacke

KAIST

TF, C. Pasold, PRD85 (2012) 126007

TF, A. Menon, Z. Sullivan, arXiv:1207.4472

TF, KC Kong, SC Park, arXiv:1211.xxxx

PPC 2012 – KIAS, Seoul

Conclusions and Outlook

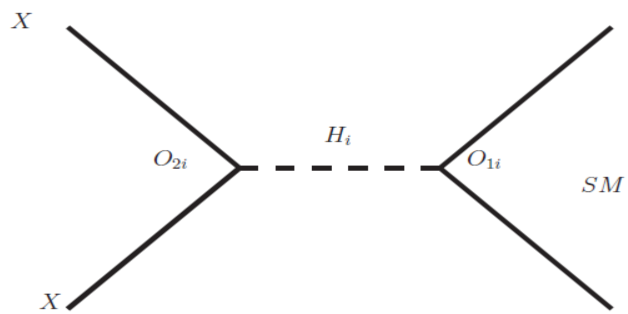
Conclusions:

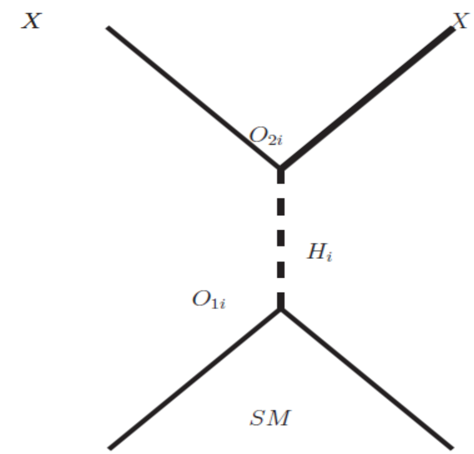
- Modifications of the KK mass spectrum can occur due to boundary localized kinetic terms or fermion bulk mass terms.
- In both cases, the KK wave functions are altered, which implies interactions of Standard Model fermions with all even KK modes of the gauge bosons.
- Combination of DM, electroweak, and $W', Z', \gamma', g', \ldots$ LHC constraints put substantial bounds on bulk masses while still allowing for large boundary kinetic terms.
- The presented results are only a first step.
  There is lots of work to do in terms of precision
  and more systematic studies of the general parameter space.

DM physics

- GIM-type cancellation occurs in the DM annihilation and scattering cross section

$$\begin{pmatrix} h \\ \varphi \end{pmatrix} = \begin{pmatrix} c_\alpha & s_\alpha \\ -s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} H_1 \\ H_2 \end{pmatrix} \equiv O \begin{pmatrix} H_1 \\ H_2 \end{pmatrix}$$



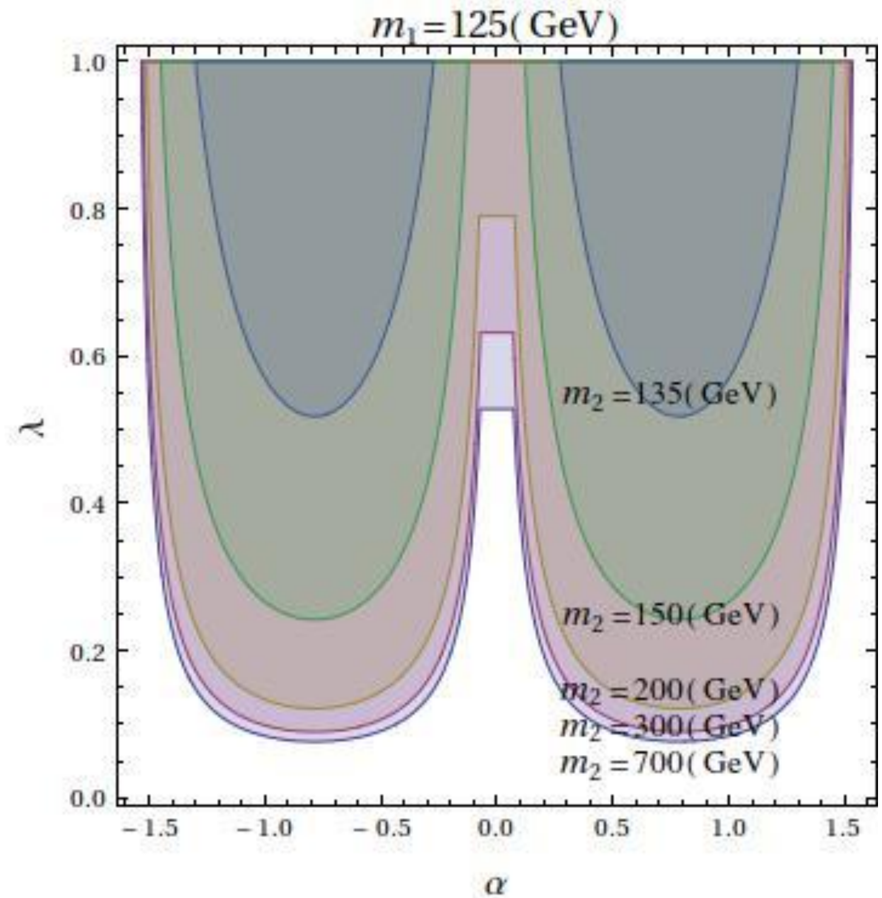


$$\sigma_{\text{ann,el}} \propto \left| \sum_i \frac{O_{1i} O_{2i}}{q^2 - m_i^2} \right|^2$$

➔0 for degenerate Higgs

Direct detection

- Exclusion plot by XENON100
- λ: DM-S coupling
- Cancellation is quite effective
- SB, P. Ko, W.I. Park(2011)



Higgs Phenomenology

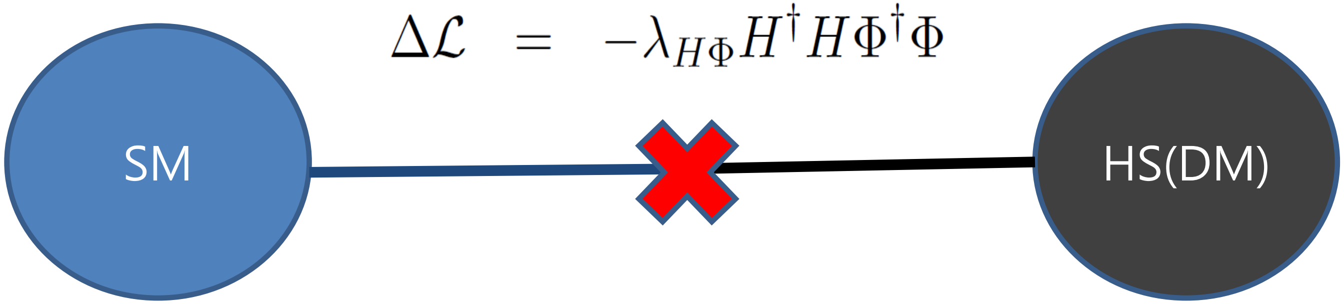
- Higgs sector is extended➔Higgs phenomenology is different from the SM one

$$\Delta\mathcal{L}_{\rm Higgs} = -\frac{\lambda_H}{4}\left(H^\dagger H - \frac{v_H^2}{2}\right)^2 - \frac{\lambda_\Phi}{4}\left(\Phi^\dagger\Phi - \frac{v_\Phi^2}{2}\right)^2 - \lambda_{H\Phi}\left(H^\dagger H - \frac{v_H^2}{2}\right)\left(\Phi^\dagger\Phi - \frac{v_\Phi^2}{2}\right)$$

$$M^2_{\rm Higgs} = \left(\begin{array}{cc} \lambda_H v_H^2 & \lambda_{H\Phi} v_H v_\Phi \\ \lambda_{H\Phi} v_H v_\Phi & \lambda_\Phi v_\Phi^2 \end{array}\right)$$

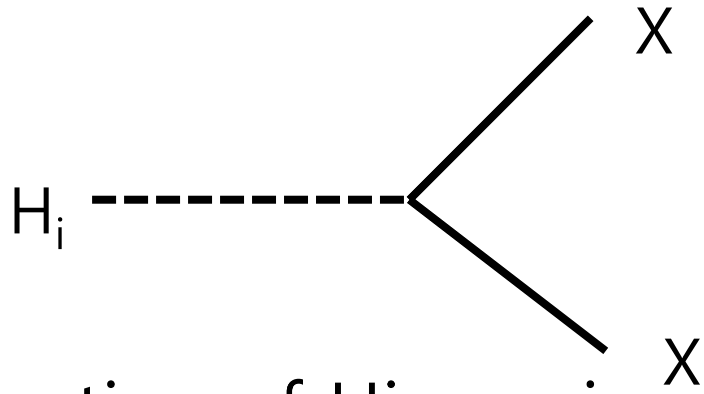
$$\left(\begin{array}{c} h \\ \varphi \end{array}\right) = \left(\begin{array}{cc} c_\alpha & s_\alpha \\ -s_\alpha & c_\alpha \end{array}\right)\left(\begin{array}{c} H_1 \\ H_2 \end{array}\right) \equiv O \left(\begin{array}{c} H_1 \\ H_2 \end{array}\right)$$

$$\Delta\mathcal{L} = -\lambda_{H\Phi} H^\dagger H \Phi^\dagger \Phi$$

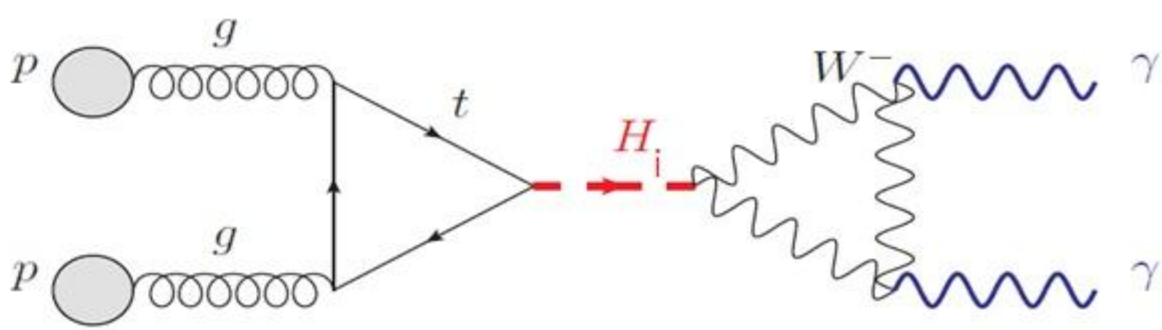


Higgs Phenomenology

- Invisible decay of Higgs at tree is allowed



- Reduction of Higgs signal strength



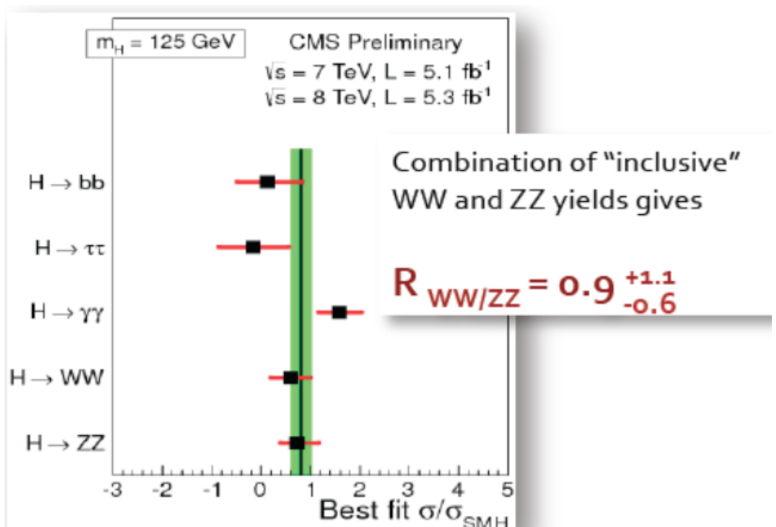
Higgs Phenomenology

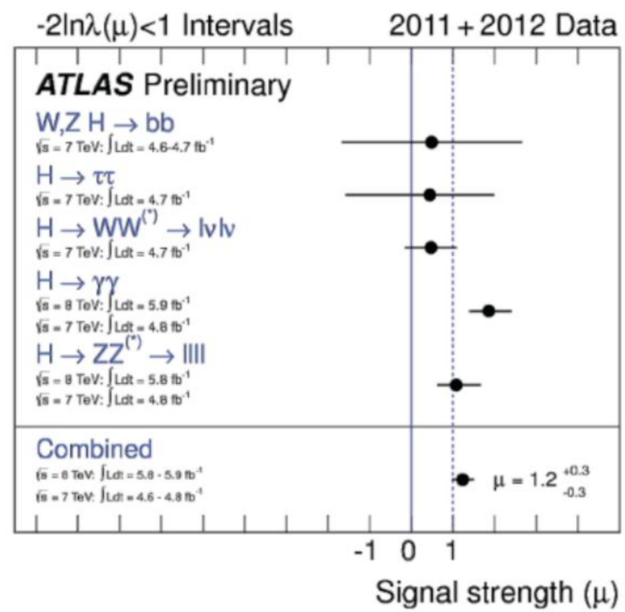
- Signal strength (reduction factor)

$$r_i \equiv \frac{\sigma_{H_i} B_{H_i \to X_{\rm SM}}}{\sigma^{\rm SM}_{H_i} B^{\rm SM}_{H_i \to X_{\rm SM}}} \quad (i = 1, 2) \qquad r_1 = \frac{c_\alpha^4 \Gamma^{\rm SM}_{H_1}}{c_\alpha^2 \Gamma^{\rm SM}_{H_1} + s_\alpha^2 \Gamma^{\rm hid}_{H_1}},$$

$$r_2 = \frac{s_\alpha^4 \Gamma^{\rm SM}_{H_2}}{s_\alpha^2 \Gamma^{\rm SM}_{H_2} + c_\alpha^2 \Gamma^{\rm hid}_{H_2} + \Gamma_{H_2 \to H_1 H_1}},$$

- ri<1. If some ri>1, our scenario is excluded





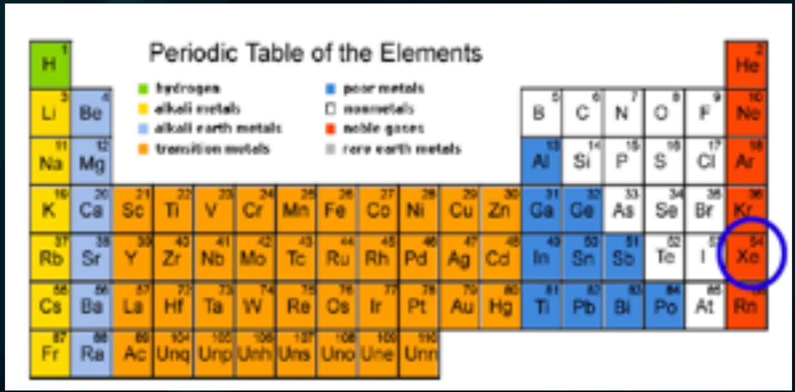
Conclusions

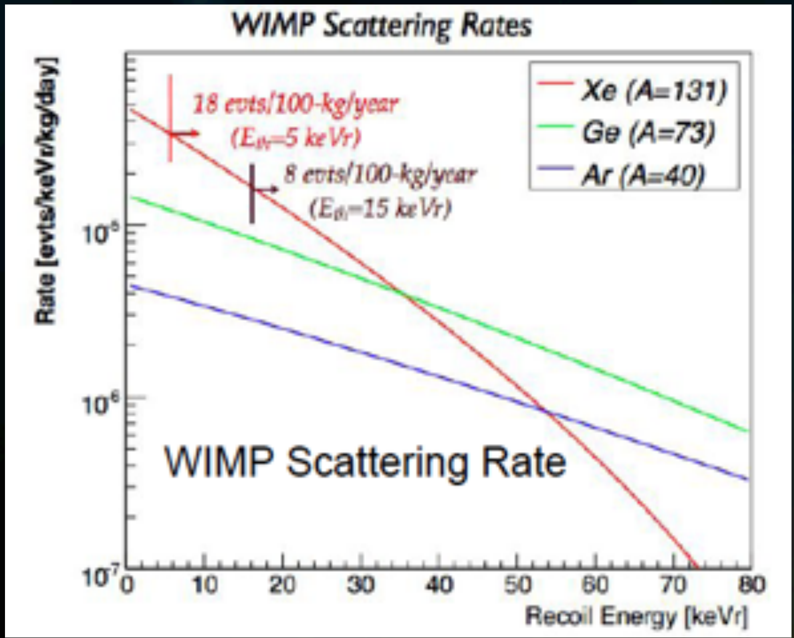
- DM with Higgs portal
  - provides cancellation to reduce the direct search bound
  - improves the stability of Higgs potential
  - changes the Higgs search at colliders
  - is constrained by EWPT and the discovery of SM-Higgs boson
- It will be difficult to produce the 2^{nd} Higgs.

Will be back after the promotions

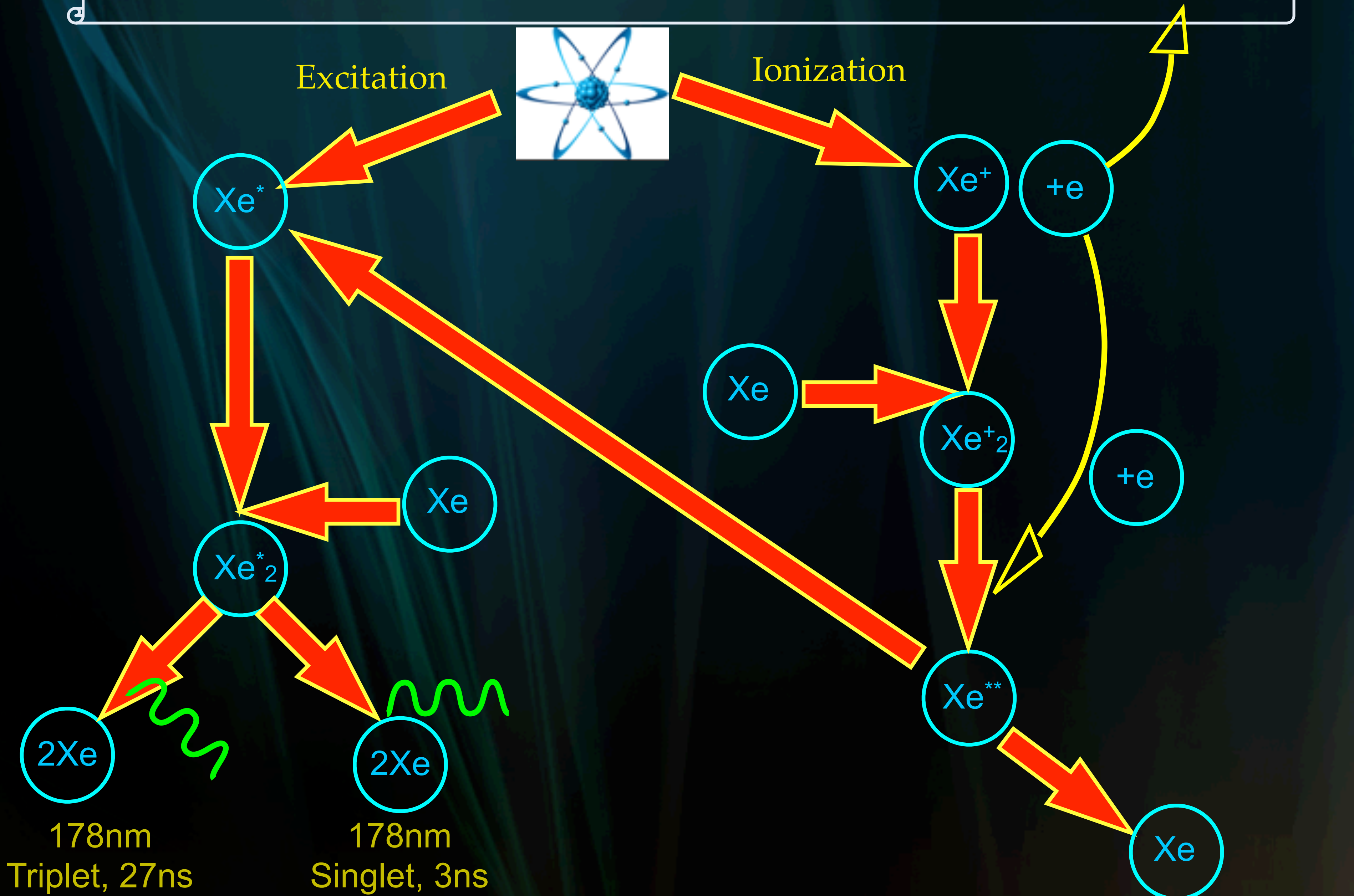
10 reasons why one should use Xenon

- A~131; High rates for SI (A^2)
- ~50% odd-Isotopes; good for S.D.
- Z=54; excellent e.m. self-shielding
- Condense @~-100C^0; Easy to cool down
- Fast scintillator
- Intrinsically pure
- Scalable
- Highest yield of charge & light
- Good b.g. discrimination in TPC
- Ok, So I had 9. Its within errors....

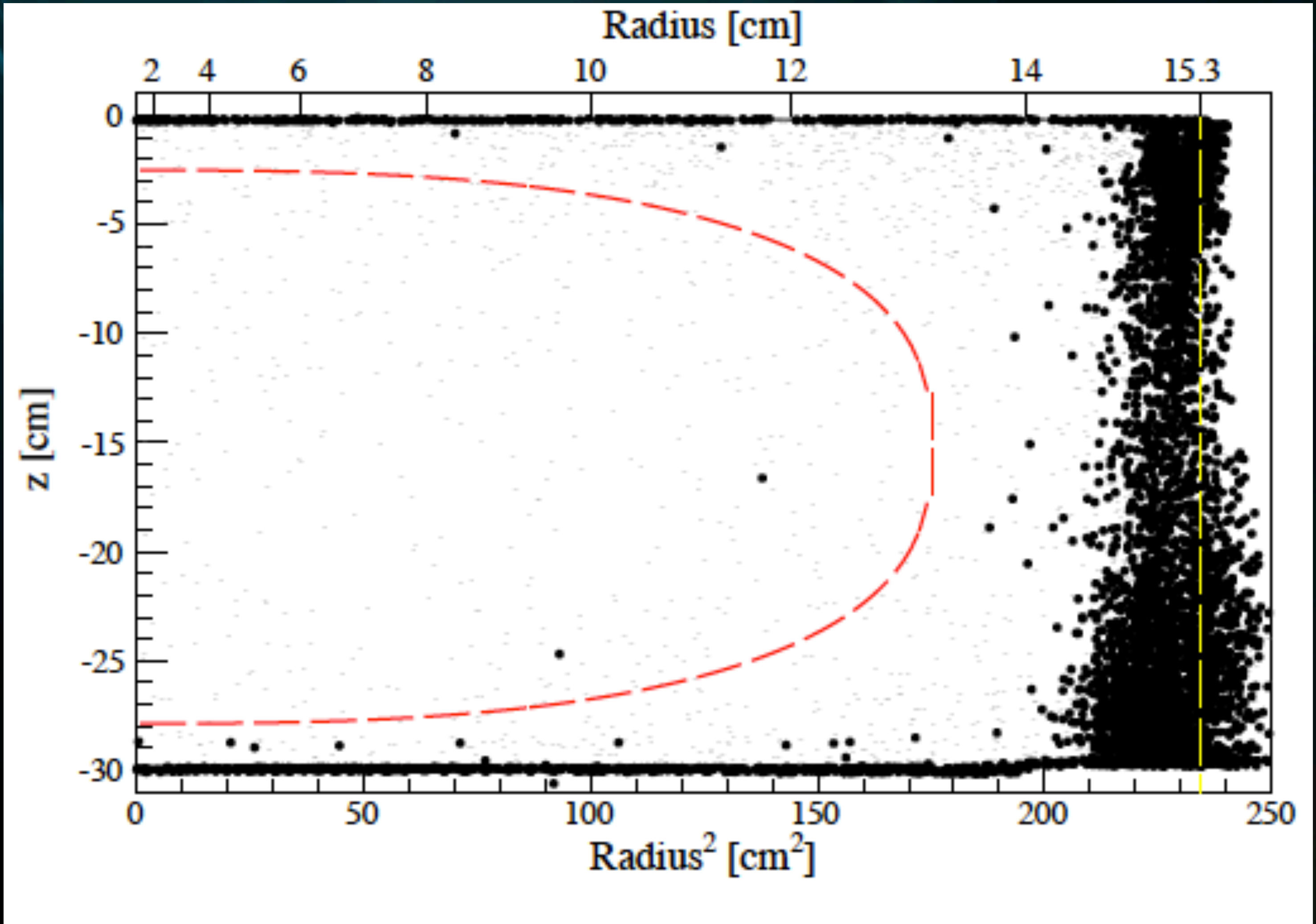




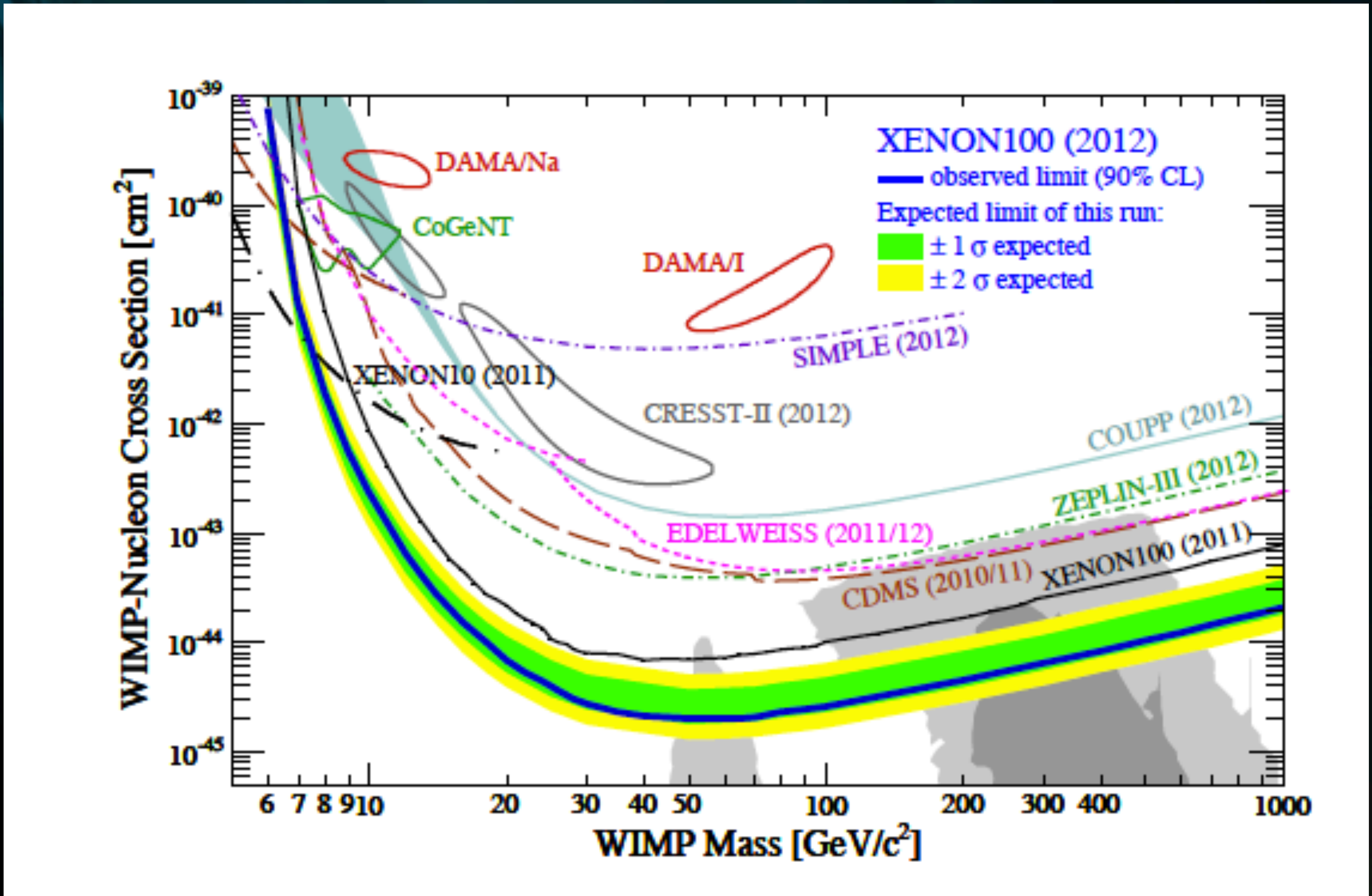
Photon Emission in Xenon



Where are the Two Candidates?



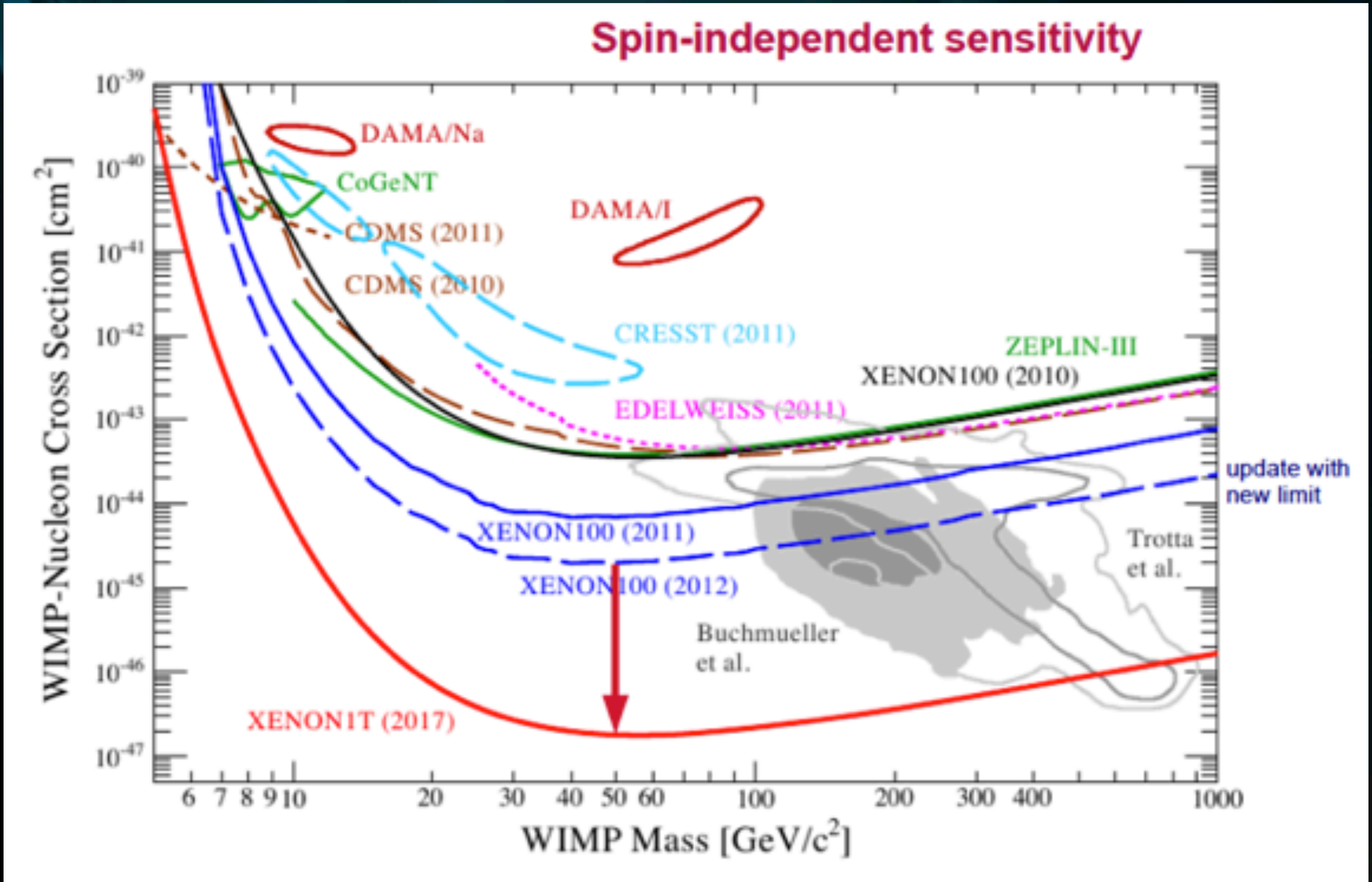
Xenon New Limit



Upper Limit (90% C.L.) is 2 x 10^{-45} cm^2 for 55 GeV/c^2 WIMP

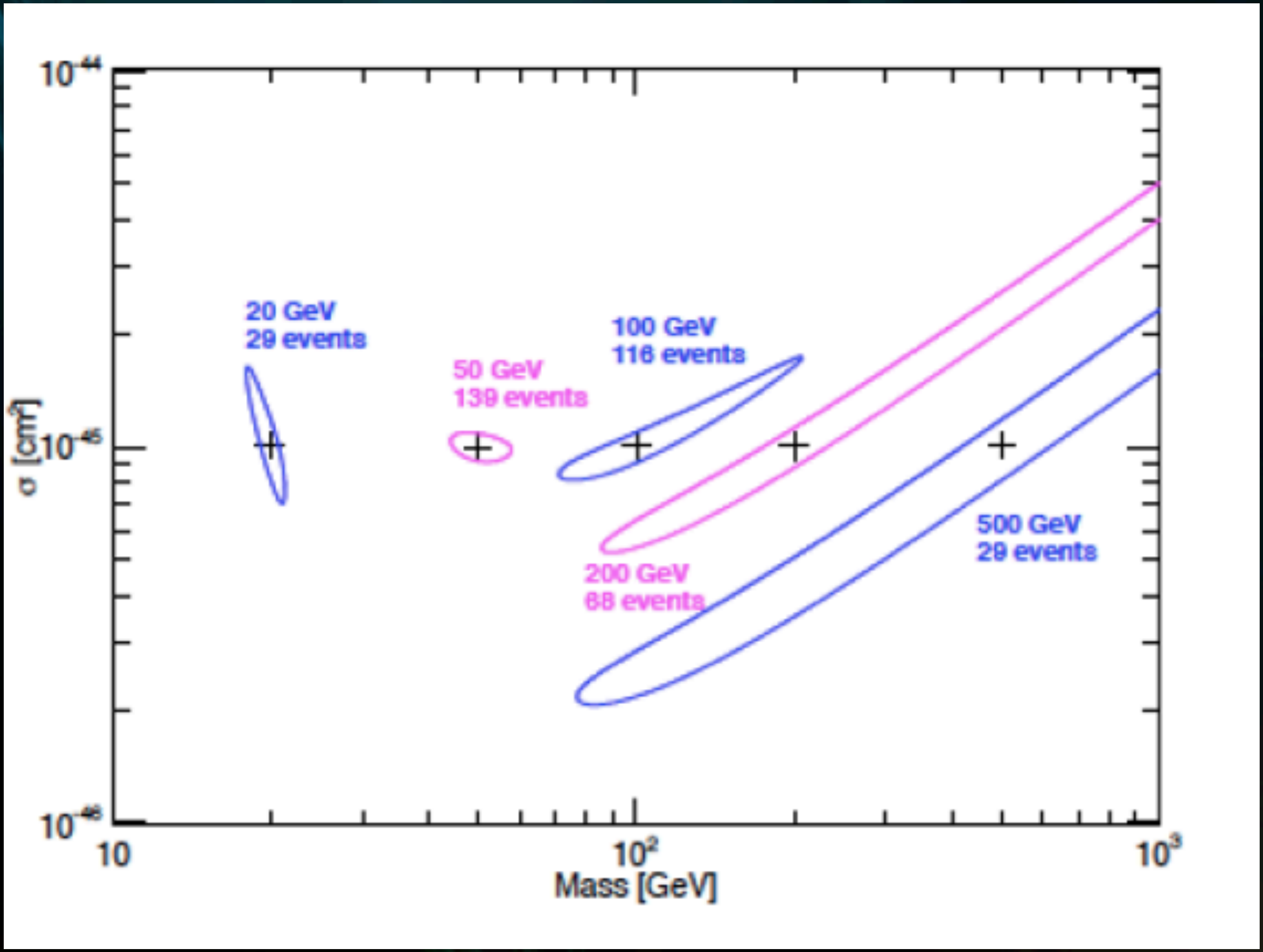
Use profile liklihood technique

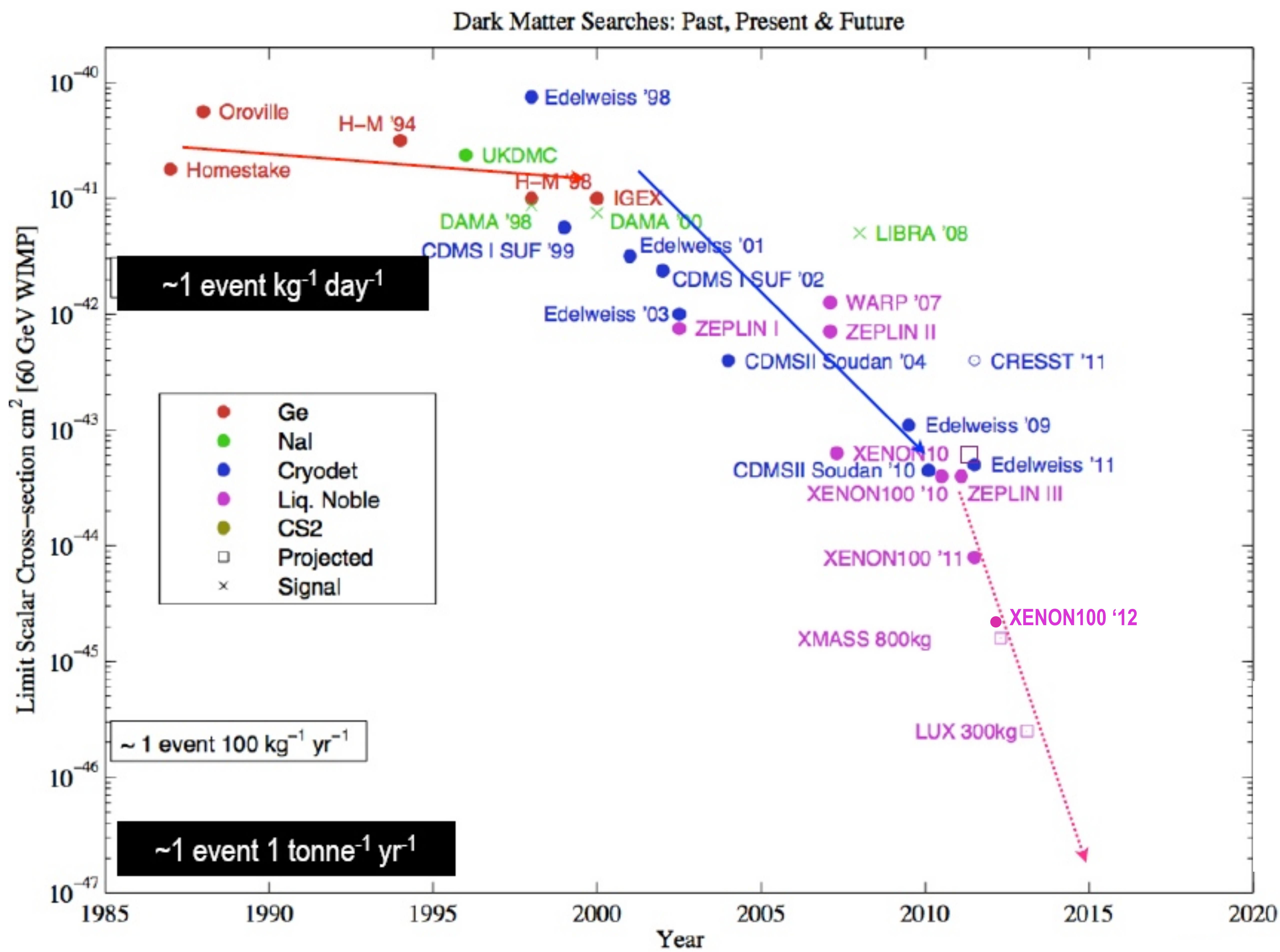
Expected Sensitivity of Xenon1t



Cover most of CMSSM range

Had Enough of Limits, Seek Discovery....




Dark Matter Searches: Past, Present & Future
Limit Scalar Cross−section cm2 [60 GeV WIMP]
Year
Oroville
H−M '94
Homestake
UKDMC
H−M '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '98
Edelweiss '01
CDMS I SUF '02
LIBRA '08
WARP '07
ZEPLIN II
Edelweiss '03
ZEPLIN I
CDMSII Soudan '04
CRESST '11
Edelweiss '09
XENON10
CDMSII Soudan '10
Edelweiss '11
XENON100 '10
ZEPLIN III
XENON100 '11
XENON100 '12
XMASS 800kg
LUX 300kg
~1 event kg-1 day-1
~ 1 event 100 kg−1 yr−1
~1 event 1 tonne-1 yr-1
Ge
NaI
Cryodet
Liq. Noble
CS2
Projected
Signal

LUX schedule (I)

✓ February 2012: End of operations at the surface lab

✓ June 2012: Beneficial occupancy of the Davis lab

- ✓ move subsystems UG: gas system, gas storage, electronics, etc.
- ✓ move detector and breakout cart
- ✓ fill water tank and start water circulation system
- ✓ in parallel: process xenon through Kr removal system

➡ September 2012: LUX detector installed underground

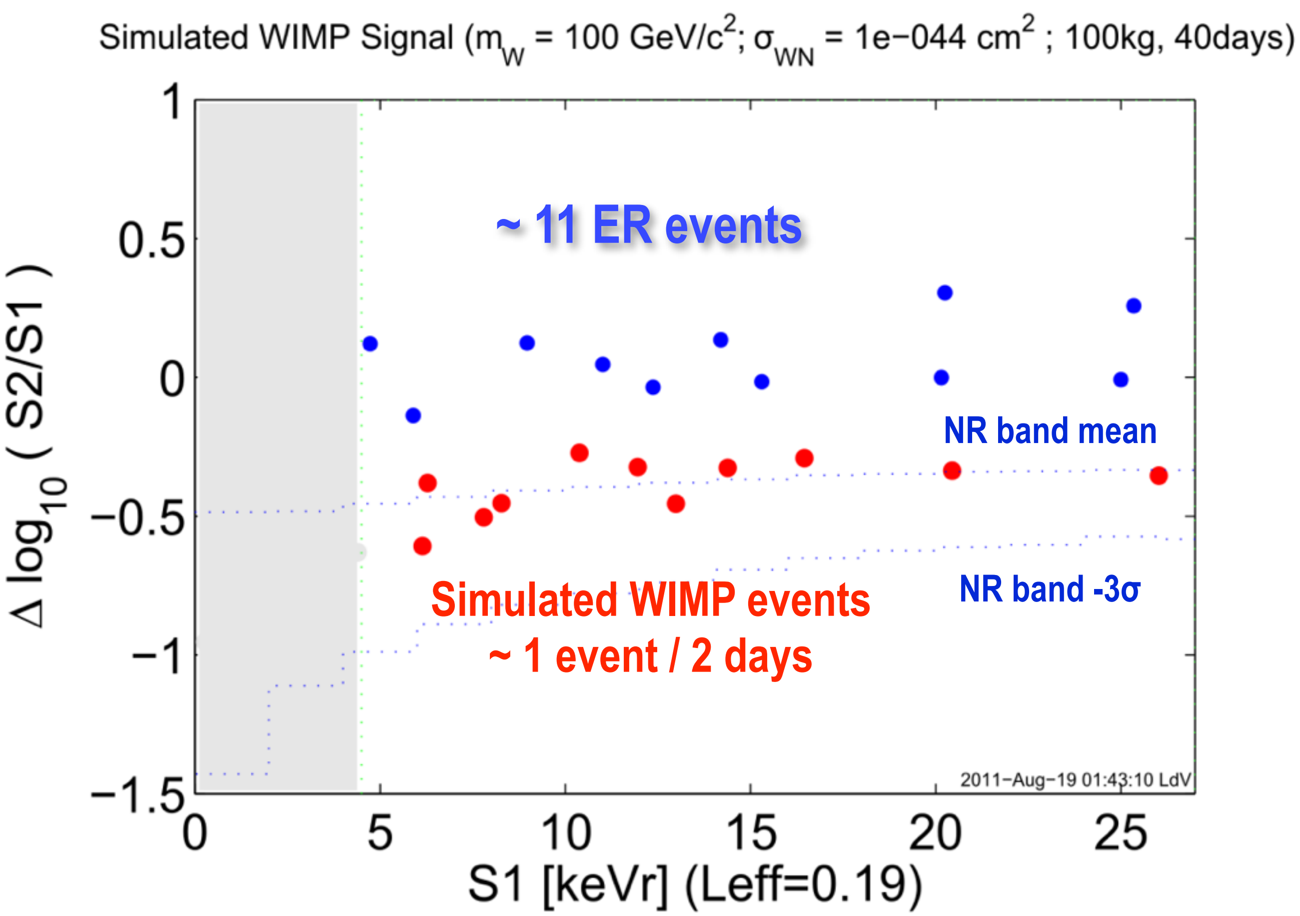
- ~6 weeks for subsystem checkouts
- ~5 weeks for cool down and condensing xenon; start circulation
- ~3 weeks to reach acceptable xenon purity and stable conditions

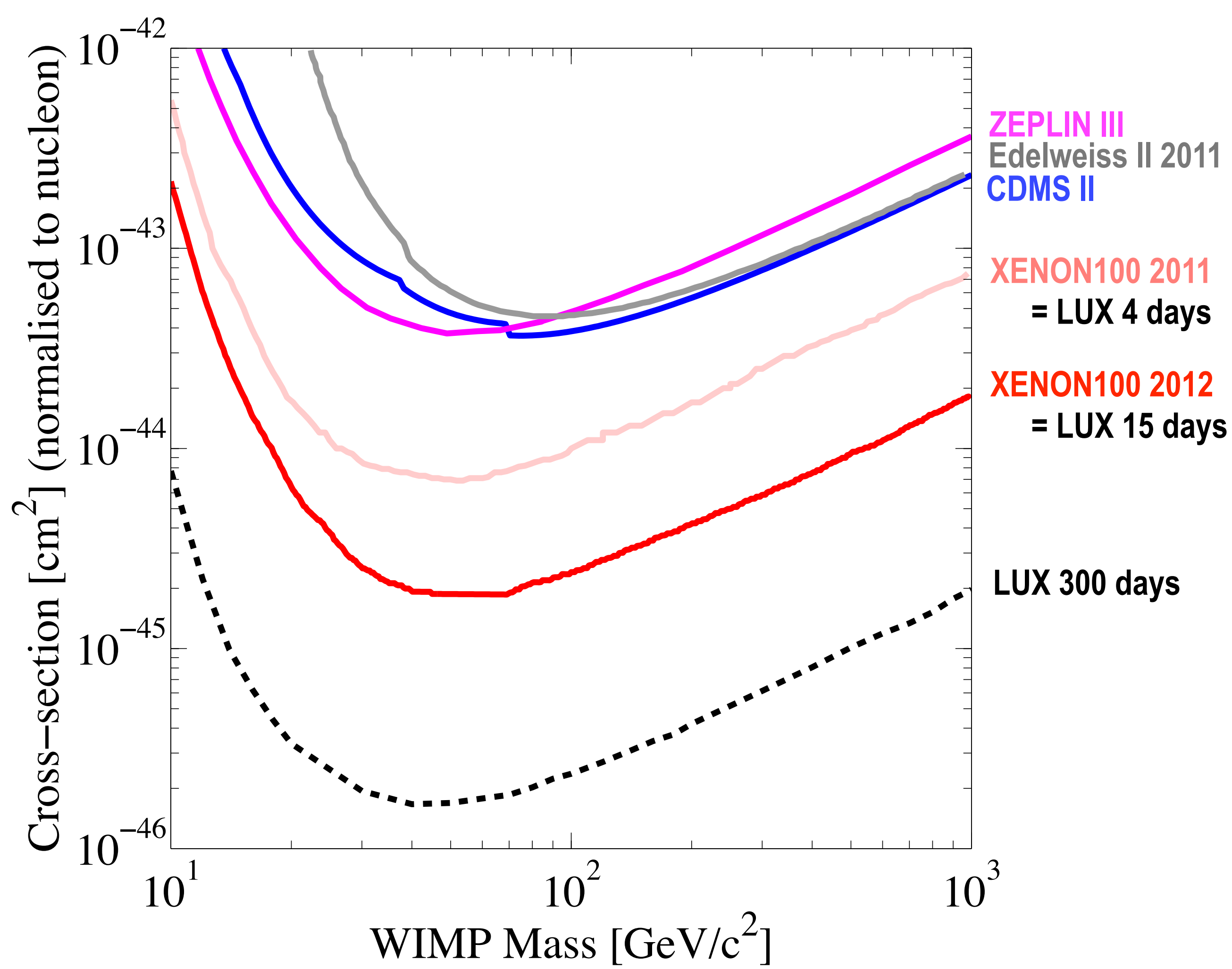
LUX schedule (II)

- Beginning of 2013: Start of the science run
  - one month to first data release
    can match current best WIMP sensitivity in weeks
  - intermediary result after 60 live days
    improve current best limit by 2x or 3x (depending on the background)
  - science goal: 300 live days
    plus a few weeks of calibration data
- February 2014: Earliest possible date for end of science run
- Continue data taking until LZ is ready to be installed UG

WIMP sensitivity

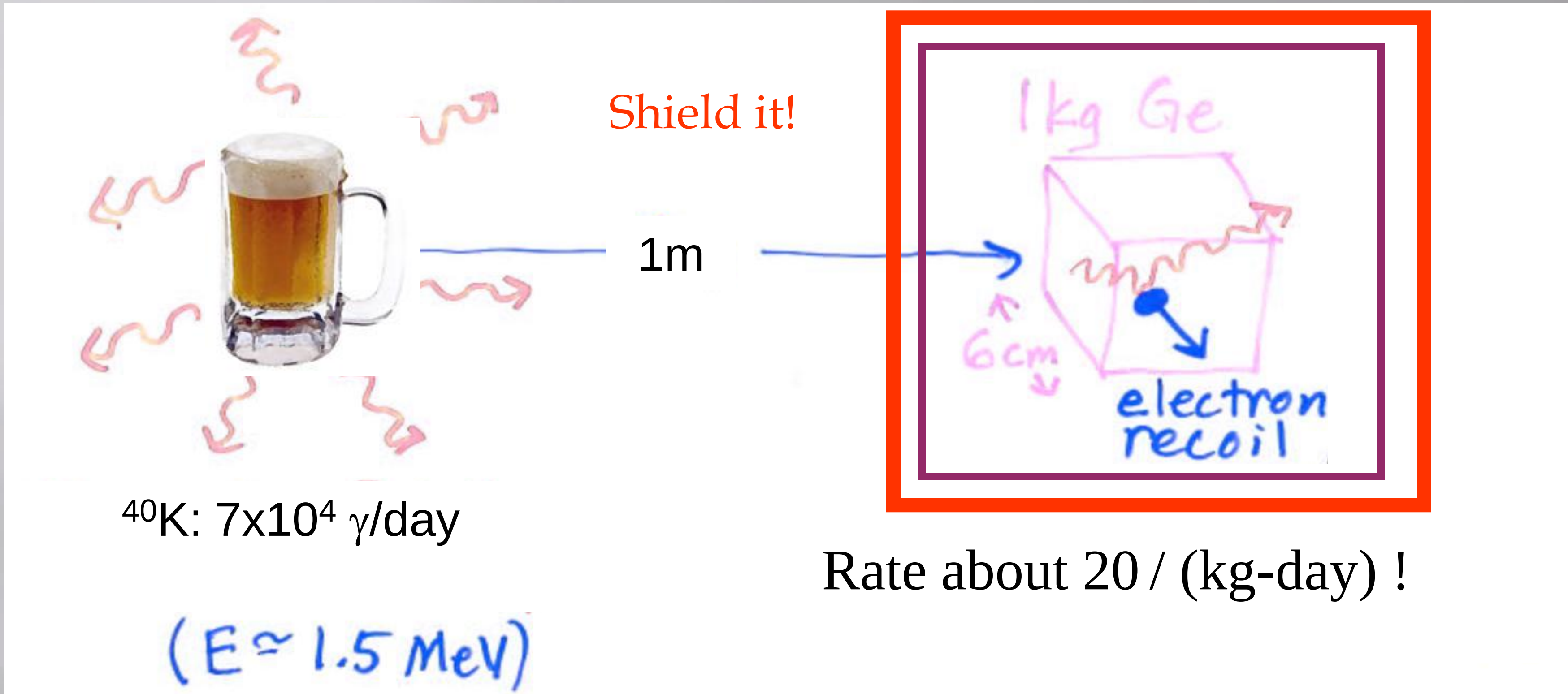
- LUX is designed for very low ER background
  - ➡ Strong emphasis on WIMP discovery





The Challenge in WIMP Detection

Expected WIMP interaction rate < 0.01 event/1kg-day



Strategies: shield Cosmogenic and Radioactive backgrounds, and reject remaining background through detector technology

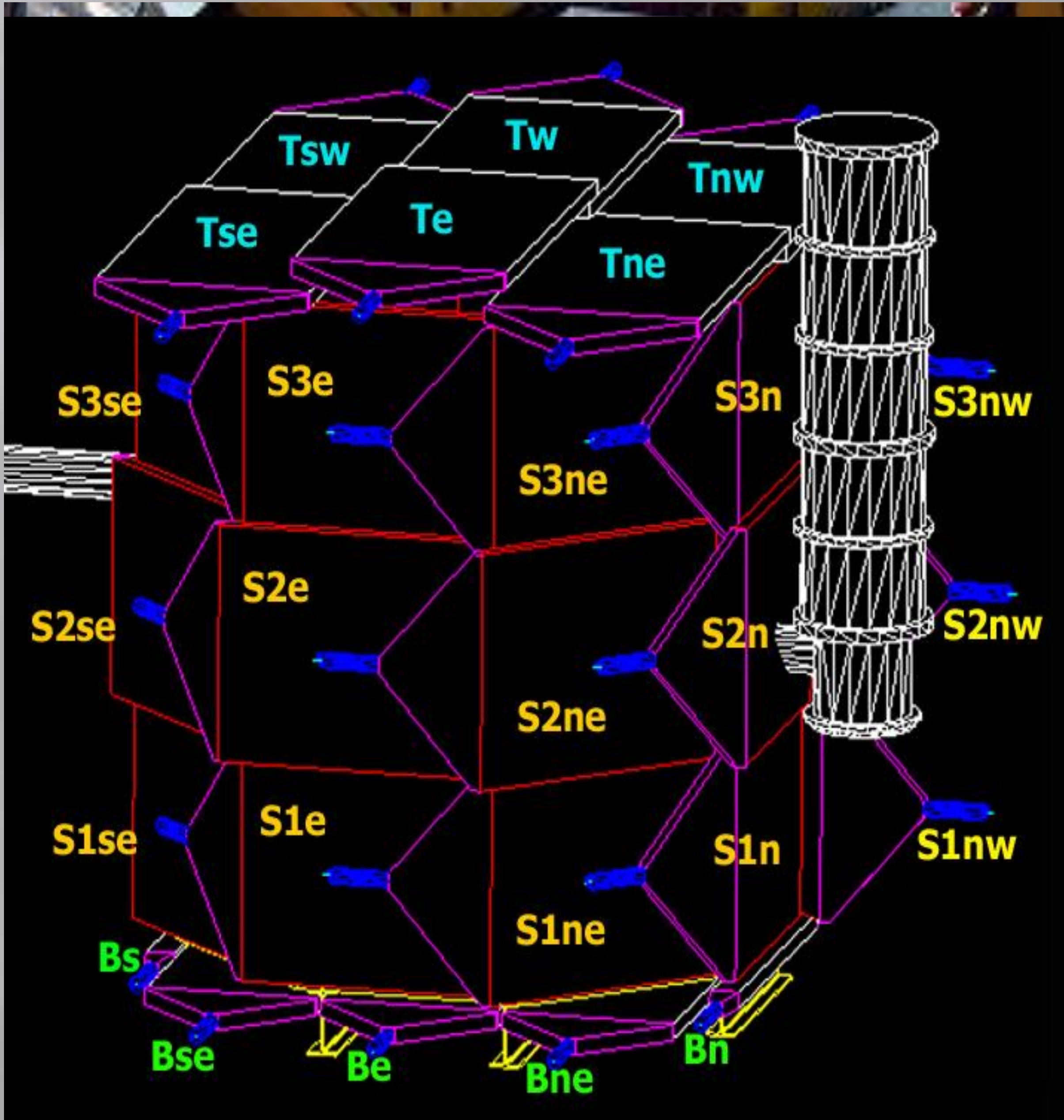
CDMS Shielding & Veto

Surround detectors with active muon veto

Use passive shielding to reduce γ/Neutrons

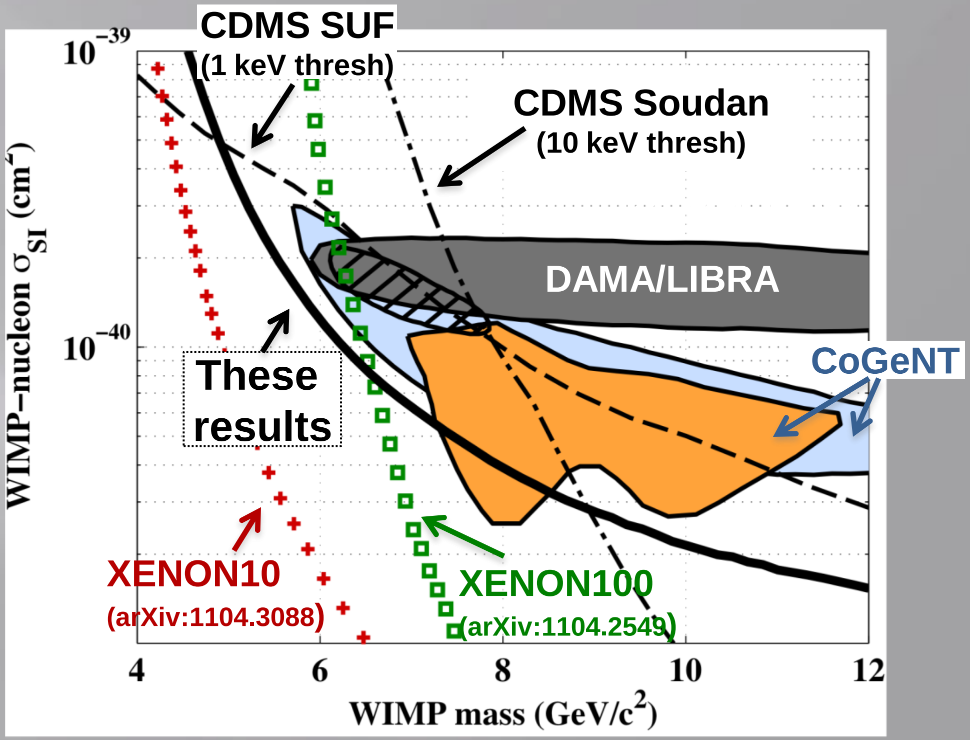
- Lead and Copper for photon
- Polyethylene for low-energy neutron

Typical for any dark matter experiment



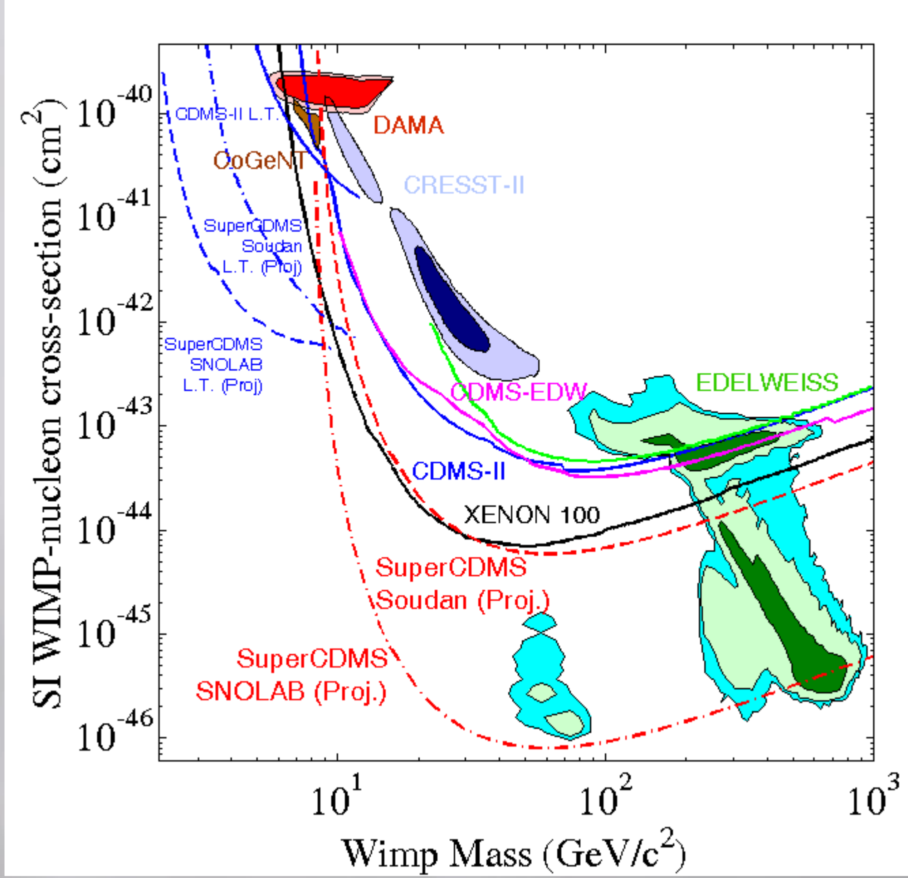
Low Threshold Result

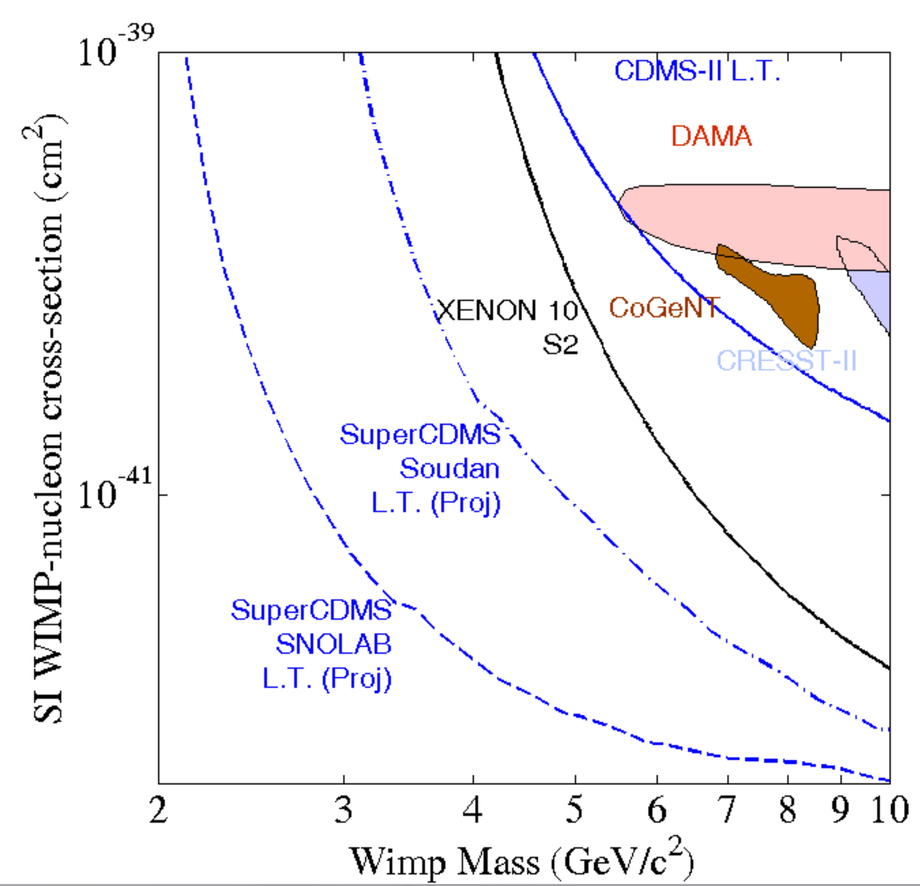
- No background subtraction, ie assume all events could be WIMPs
- For spin-independent, elastic scattering, 90% CL limits incompatible with DAMA/LIBRA and entire CoGeNT excess



- Some parameter space for CoGeNT remains if majority of excess events not due to WIMPs

Projected Sensitivity





Improved threshold for low WIMP-mass analysis: < 1keV

Lightly Ionizing Particles (LIPs)

- Particles with fractional charge?
  - Quarks, but confined in hadrons.
- ***Anything not explicitly forbidden is required.* – Murray Gell-Mann**
- Large Number of searches
- Unique opportunity for us!
  - Cross section and hence # of interactions scales with f^2
  - Also depends on track length and detector type (Si or Ge)
  - Low, 2.5 keV threshold; > 10^3 times lower than typical muon
  - Sensitive of fractional charges of order 1/100!
  - Expected background (< 0.1 events)

“Tower” of 6 Detectors

Assuming LIPs are minimum ionizing.

KIMS ~~from~~ by Juhee Lee

CsI (Tl) crystal detector

8.7kg × 12 ~ 100 kg

1 year run with pulse shape discrimination (PSD)

⇒ null signal incompatible with DAMA

⇒ stringent bound on $\sigma_{S.D.}$

2.5 year data without PSD

⇒ show no annual modulation ⇒ incompatible with DAMA.

Selections and Backgrounds

Similar selections for both channels:

- E_T^{miss} trigger (>70 GeV)
- Large E_T^{miss}>120 (150) GeV
- 1 jet (photon) p_T>150 (120) GeV
- At most one extra jets with p_T>30 GeV, $|\eta|$<4.5
- Photon and (possible) subleading jet far away from E_T^{miss} direction
- Veto events with leptons (el p_T<20 GeV, μ p_T<10 GeV)
- Quality criteria to suppress fake calorimeter signals (noise), beam related background, cosmic rays.

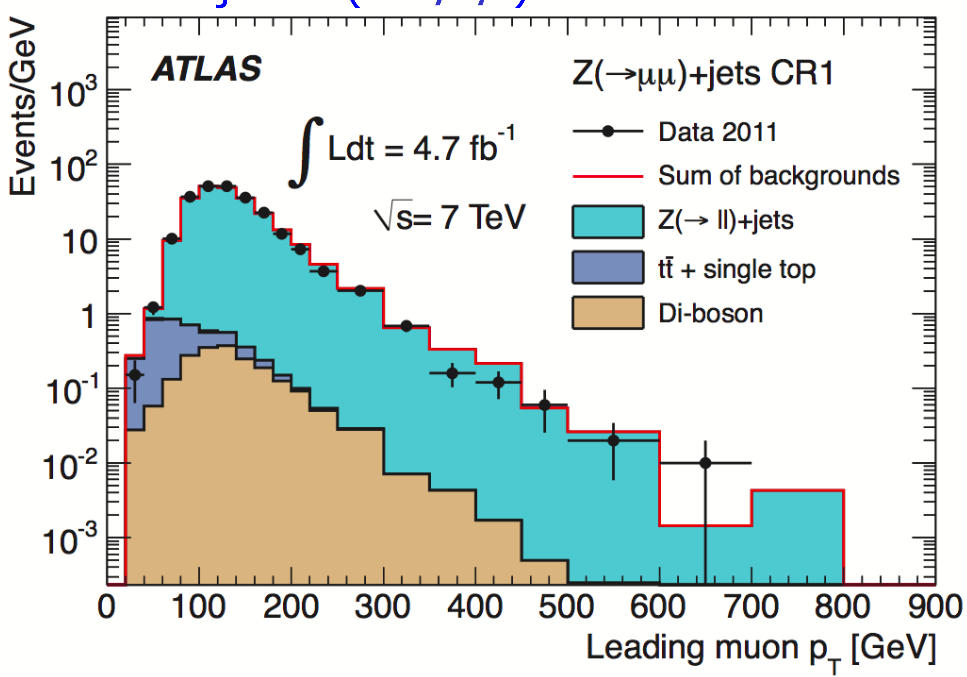
Dominant backgrounds (ordered):

- Z(→νν) + jets / γ ← dominant, irreducible background
- W(→τν) + jets / γ
- W(→μν) + jets / γ
- W(→eν) + jets / γ

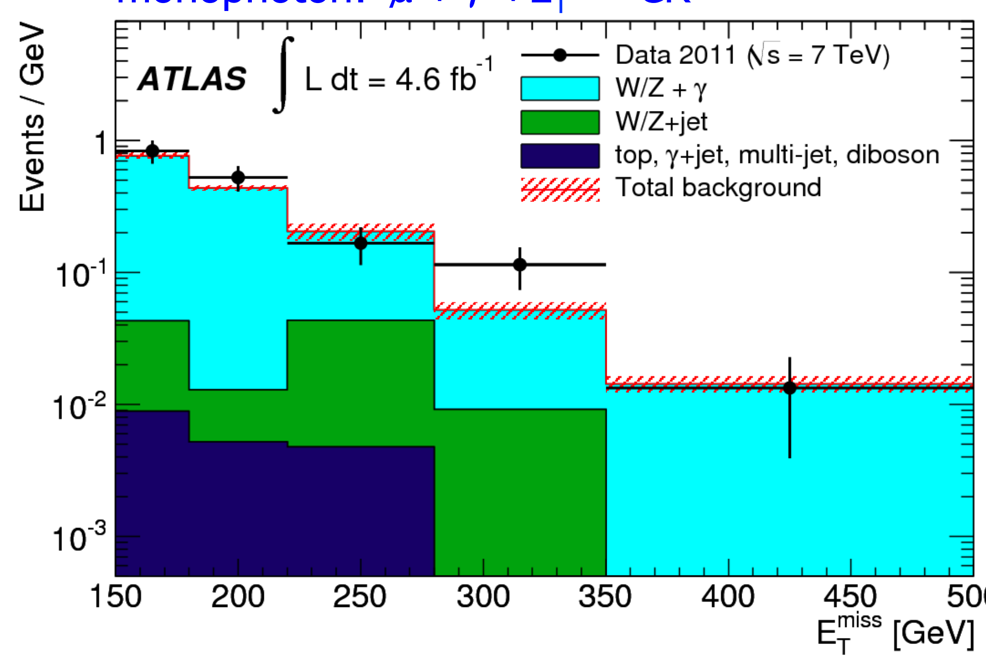
  ← Hadronic τ decay, non-reconstructed e/ μ
- 1γ: W/Z(→ll) + jets ← fake photon from jet, non-reconstructed e/ μ

- *Dominant backgrounds isolated with dedicated control samples in data (CRs).*
- *Use CRs to obtain correct background norm / shape. Extrapolate to SR these MC simulation.*

monojet CR (Z→ μ μ)



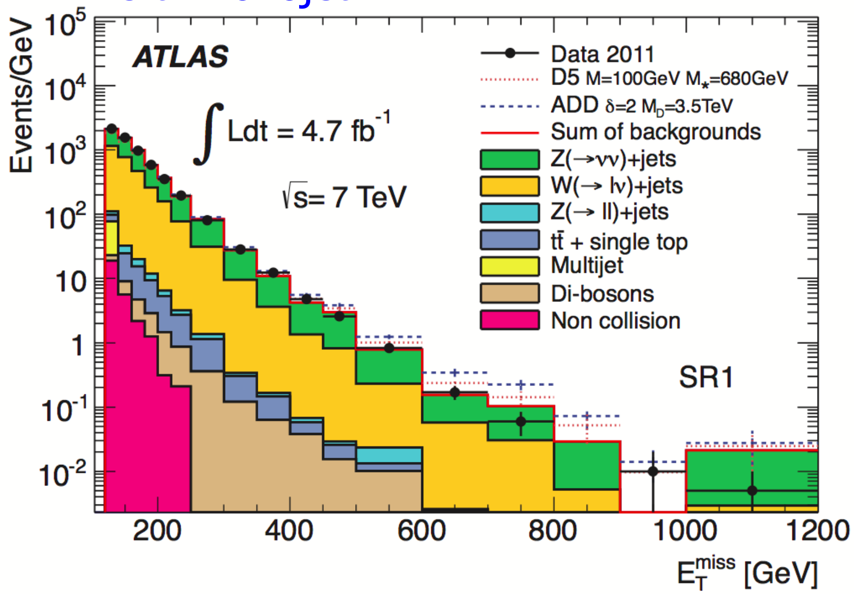
monophoton: $\mu + \gamma + E_T^{miss}$ CR

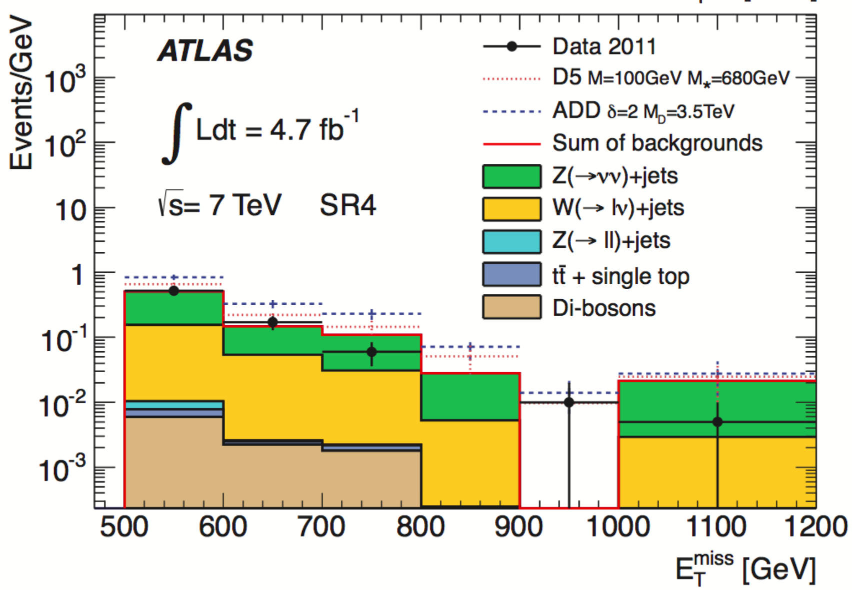


eoul

Results in Signal Regions

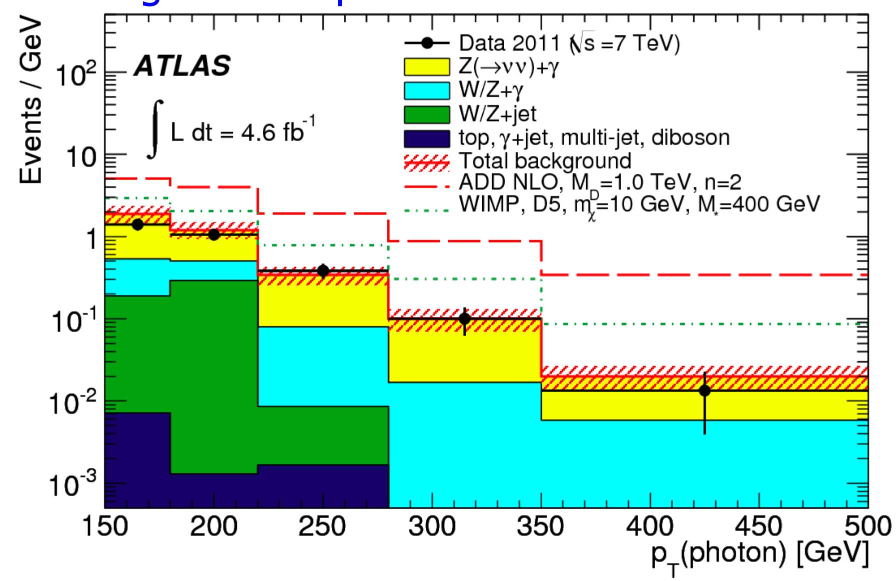
Left: monojet

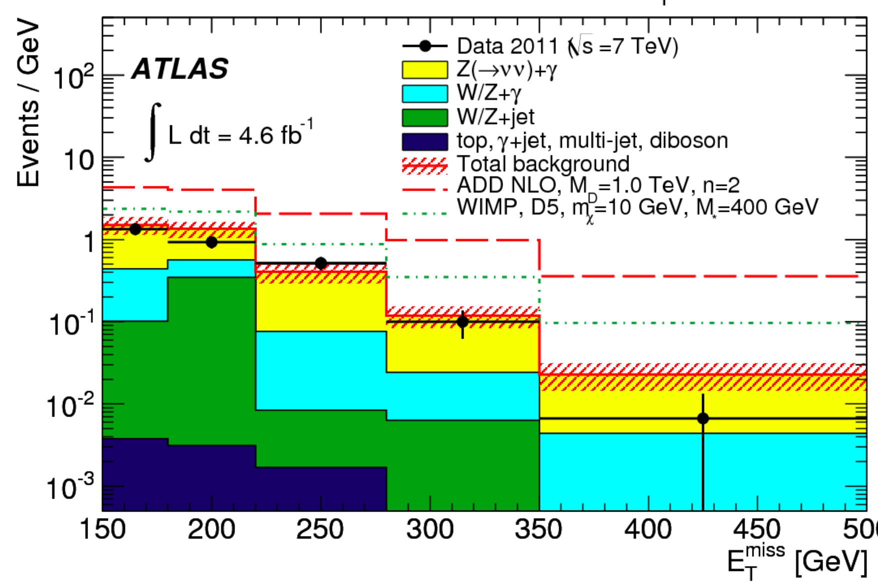




For all analyses: details in backup!

Right: monophoton





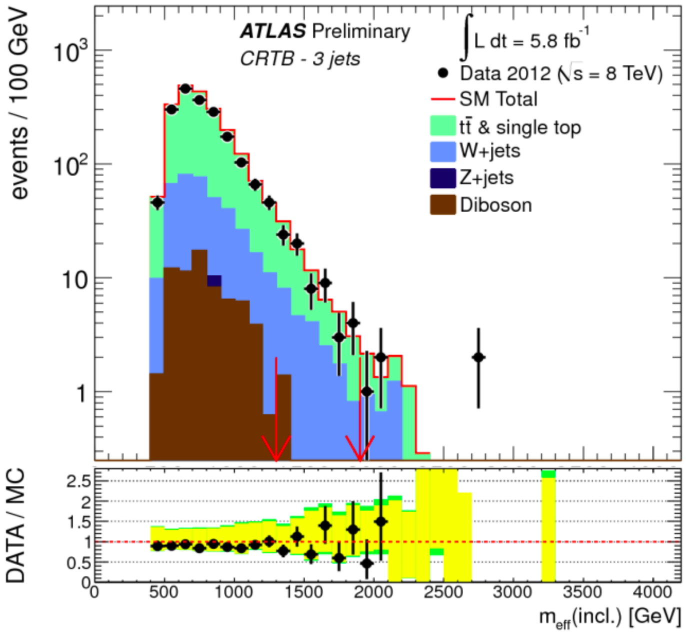
Signal regions	SR1	SR2	SR3	SR4
Common requirements	Data quality + trigger + vertex + jet quality + $\lvert\eta^{\mathrm{jet1}}\rvert < 2.0$ + $\lvert\Delta\phi(\mathrm{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{p}_{\mathrm{T}}^{\mathrm{jet2}})\rvert > 0.5$ + $N_{\mathrm{jets}} \leq 2$ + lepton veto			
$E_{\mathrm{T}}^{\mathrm{miss}}, p_{\mathrm{T}}^{\mathrm{jet1}} >$	120 GeV	220 GeV	350 GeV	500 GeV

← Best limits

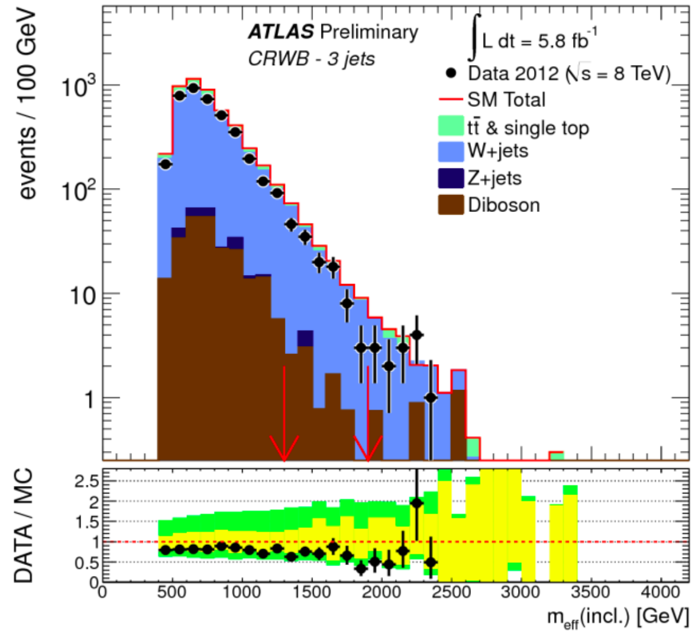
- No evidence for excess over expected background in data.
- For both channels, present limits on DM production x-section.

SM Backgrounds

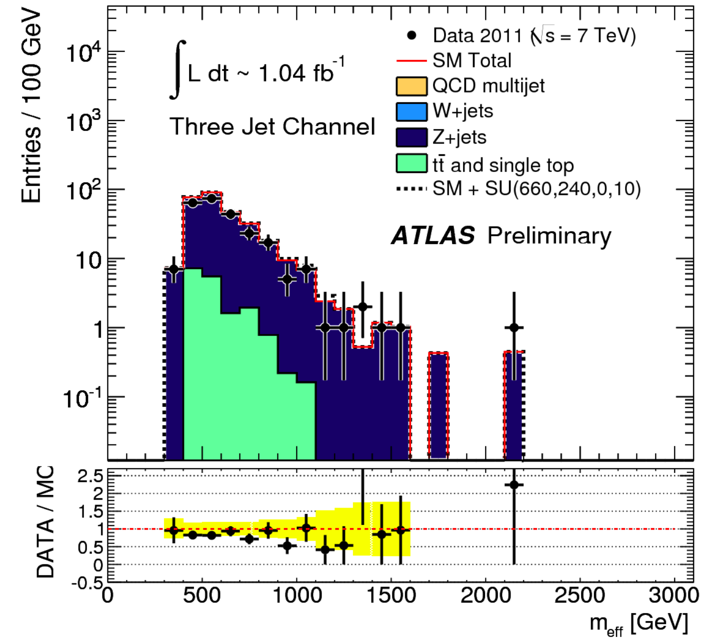
ttbar + multi-jets



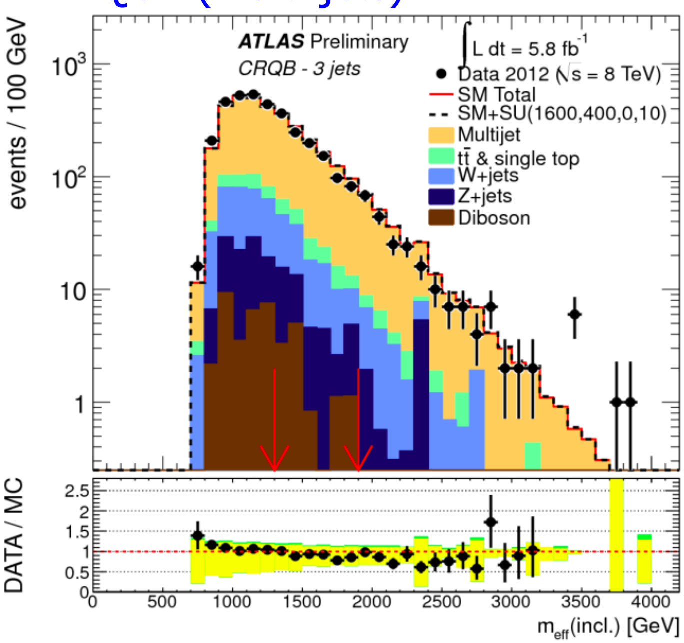
W + multi-jets



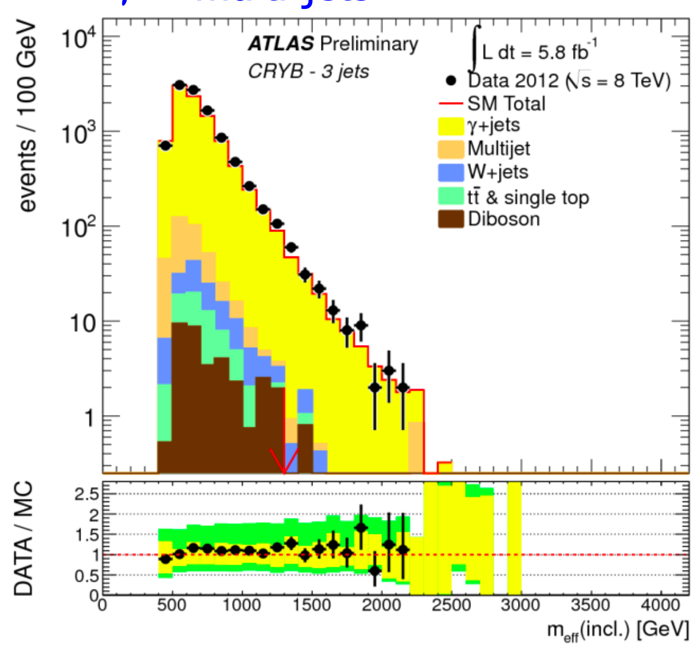
Z + multi-jets (validation)



QCD (multi-jets)



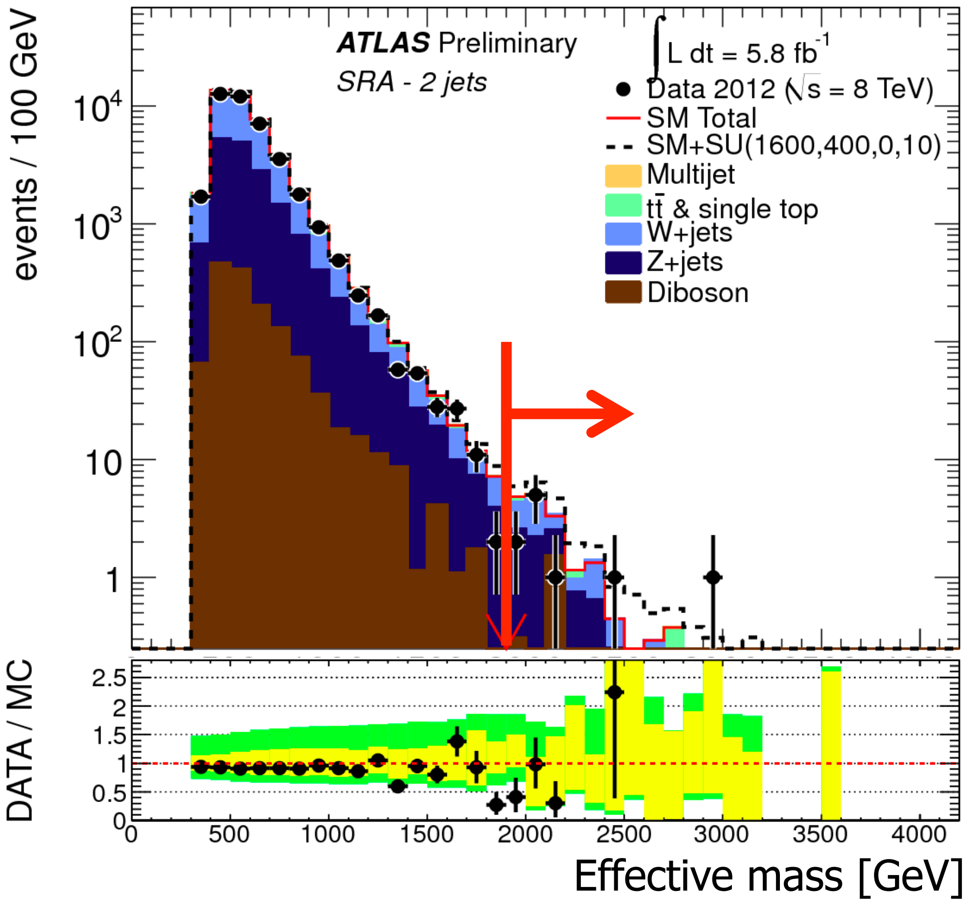
γ + multi-jets



- Understand main BGs with dedicated control regions
  - SR-like selection
  - As pure as possible
  - Signal depleted
- Simultaneous fit
  - Data-driven background normalization
  - Extrapolate to signal region using MC shape.
  - Validate extrapolation with validation regions.

Results in Signal Regions

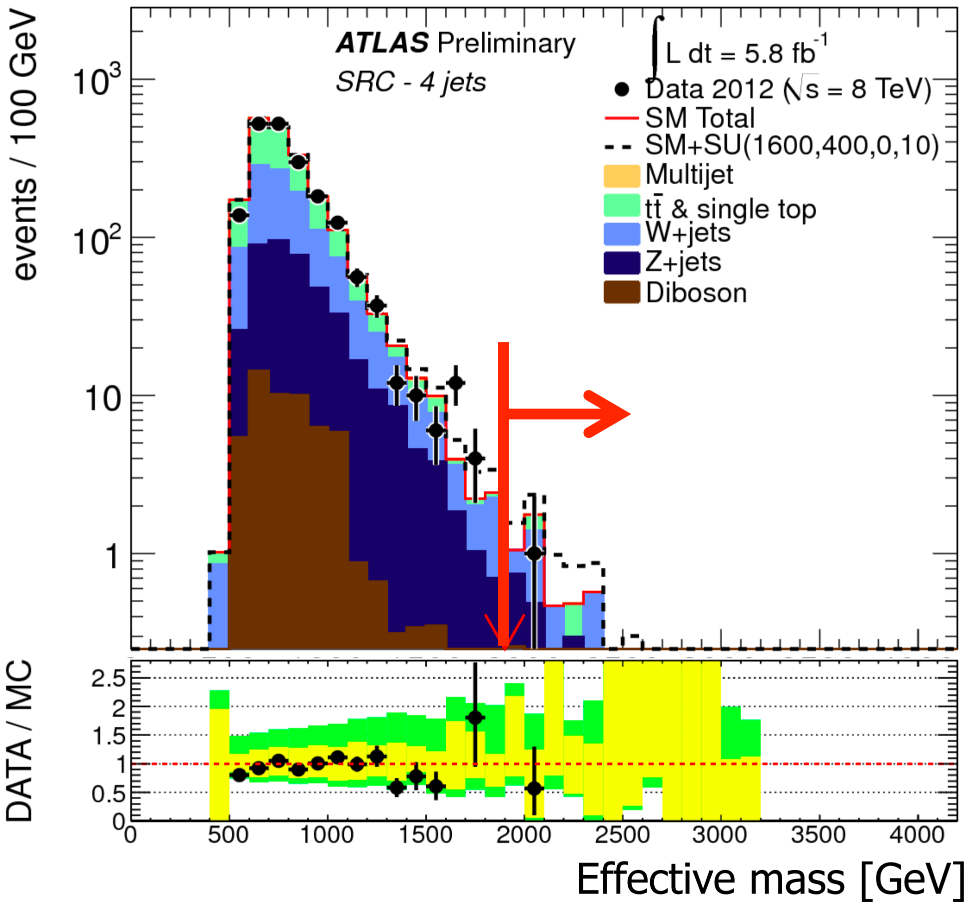
0 lepton + ≧2 jets + E_T^{miss}



Meff: > 1900 GeV
Data: 10 events
MC: 14 ± 5 events
(W:3,Z:7,tt:1,Di:3)

- No evidence for excess over expected background in data.

0 lepton + ≧4 jets + E_T^{miss}



Meff: > 1900 GeV
Data: 1 events
MC: 2.8 ± 1.2 events
(W:0.3,Z:2.0,tt:0.6,Di:-)

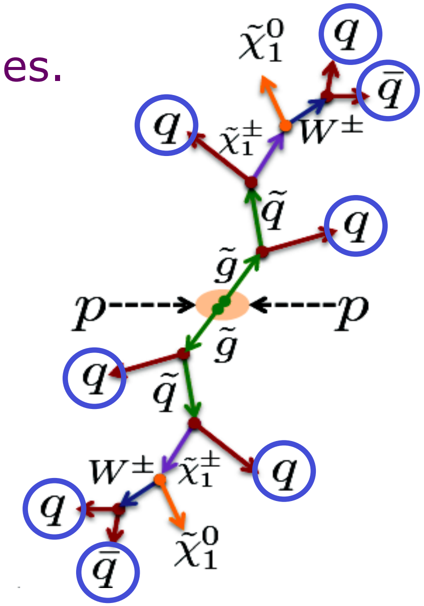
- Proceed to set exclusion limits.

Large jet multiplicities

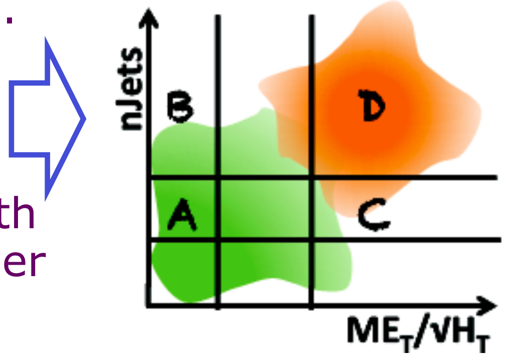
ATLAS-CONF-2012-103

0 lepton + ≧6-9 jets + E_T^{miss}

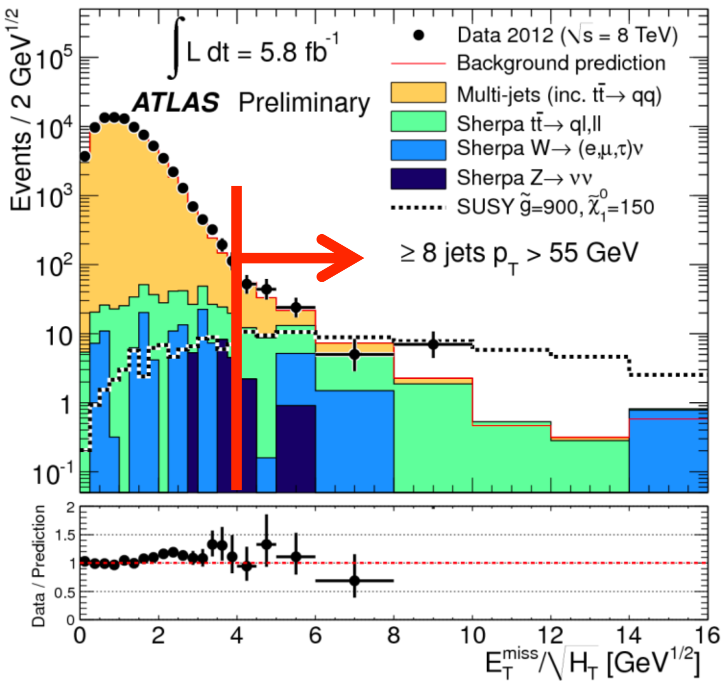
- SUSY cascades can be long: large jet-multiplicities with similar energies.
- Target for gluino-pair production (especially involving stop)



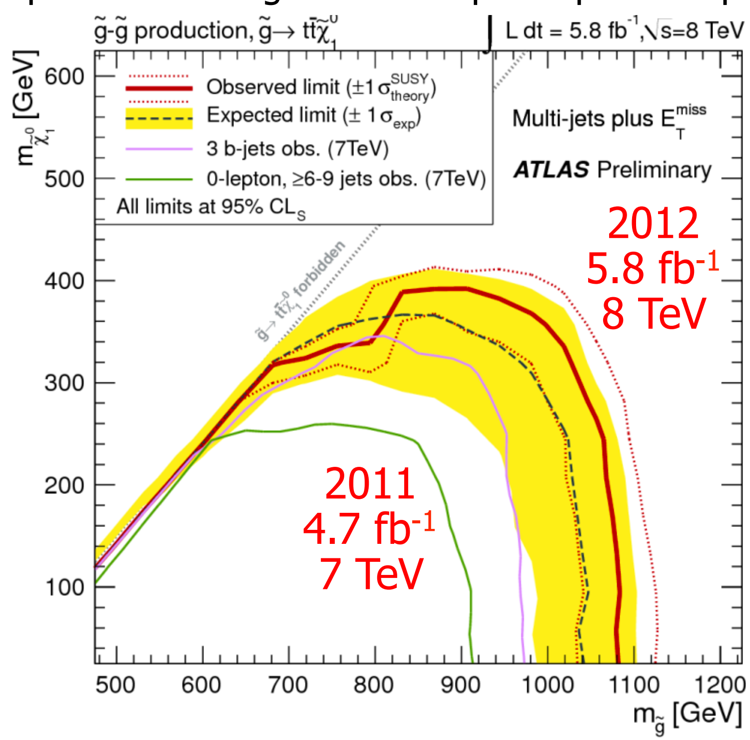
- Main background is multi-jet production.
  - Key variable: $E_T^{miss}/\mathrm{sqrt}(H_T)$ invariant under jet multiplicities
  - Obtain with data-driven technique
- Leptonic BGs subdominant, obtained with MC from dedicated lepton CRs, with lower jet multiplicities. Extrapolated to SR.



- Exclude: m(gluino)~1000 GeV, for m(X^0)<300 GeV



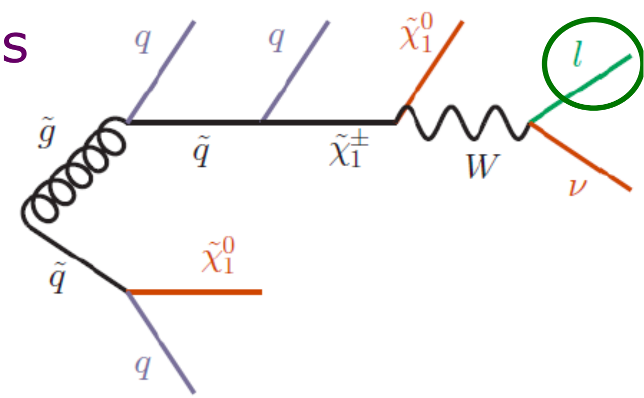
Simplified model: gluino → stop + top → 2 top + LSP

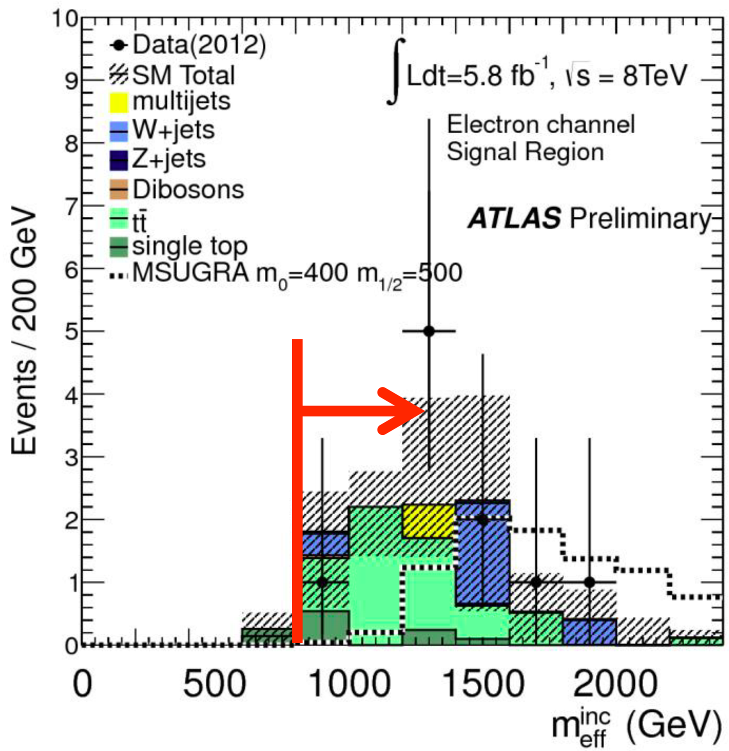


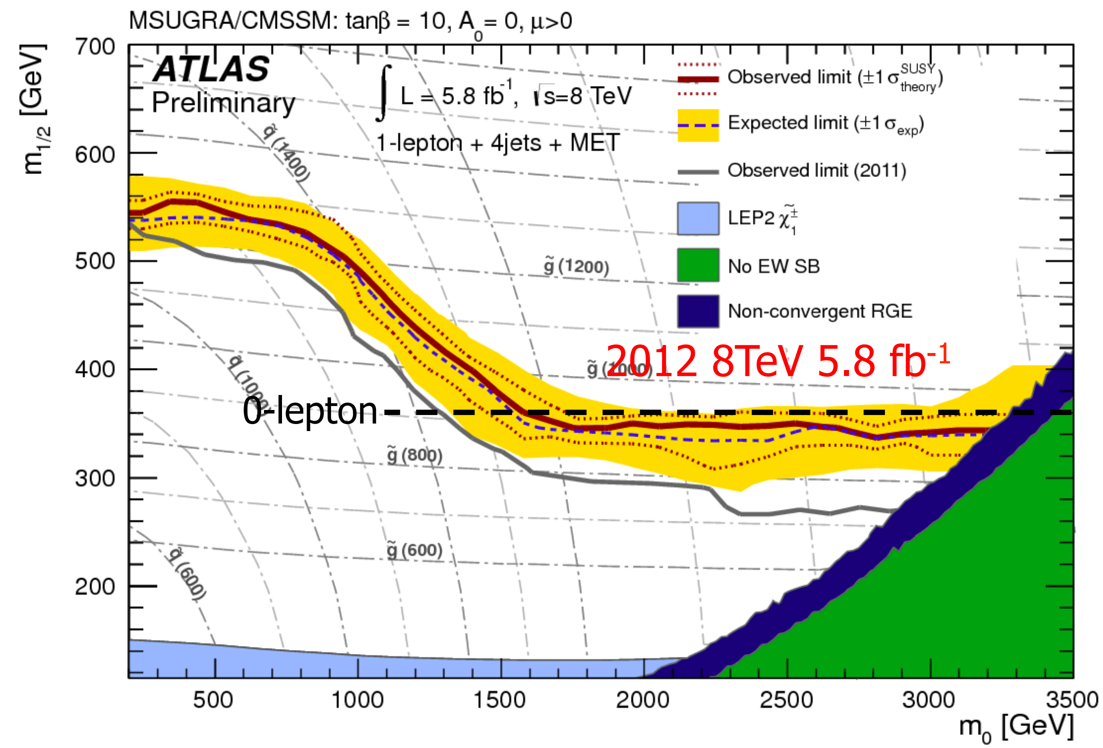
1-lepton + ≧4 jets + E_T^{miss}

ATLAS-CONF-2012-104

- *1 lepton (>25 GeV) + ≧4 jets (>80 GeV) + E_T^{miss}*
- Focus on (single) leptonic gaugino / slepton decays
- Good channel to control backgrounds
  - Eliminates QCD, Z→νν.
  - Reject W+jets and semi-leptonic ttbar backgrounds with transverse mass cut.
- Exclude masses upto:
  - mSUGRA: ~1.24 TeV, for m(squark)=m(gluino)
  - Competitive with 0-lepton at high m_0 (gluino production)



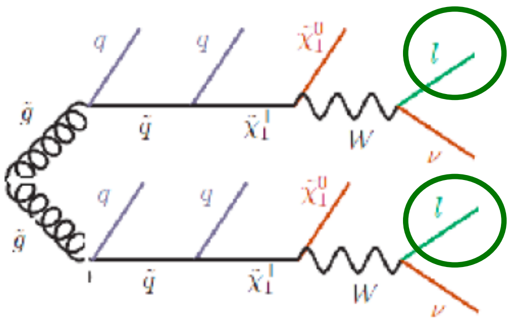




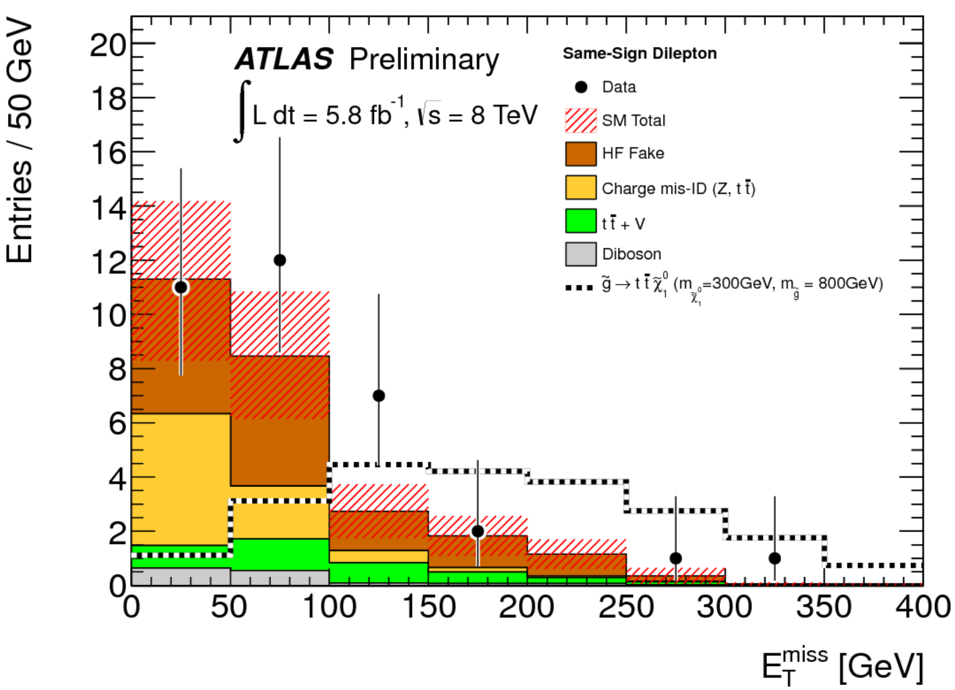
Same-sign 2-lepton search

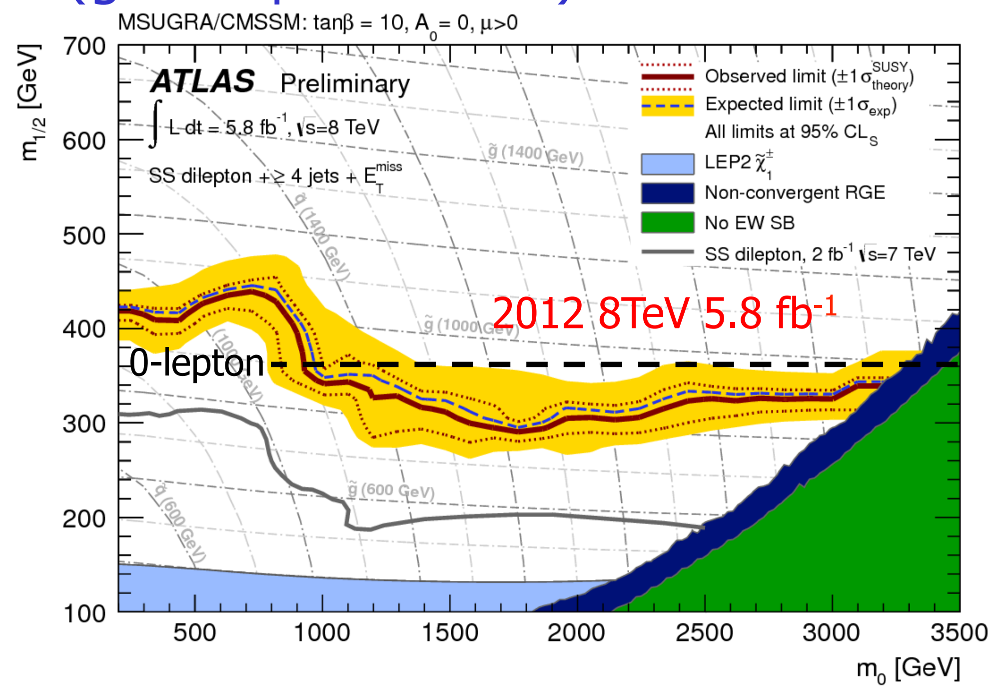
ATLAS-CONF-2012-105

- Focus on two leptonic gaugino / slepton decays
  - ½ of SUSY decays with di-leptons are same sign.
- 2 leptons (same sign, >20 GeV) + 4 jets (50 GeV) + E_T^{miss}
- Statistics limited, but high rejection of SM BG
  - Reject opposite sign SM background (mostly ttbar)
    - ➢ HF Fake: 2 leptons from W-boson and b-jet.
  - Fully data-driven background estimation



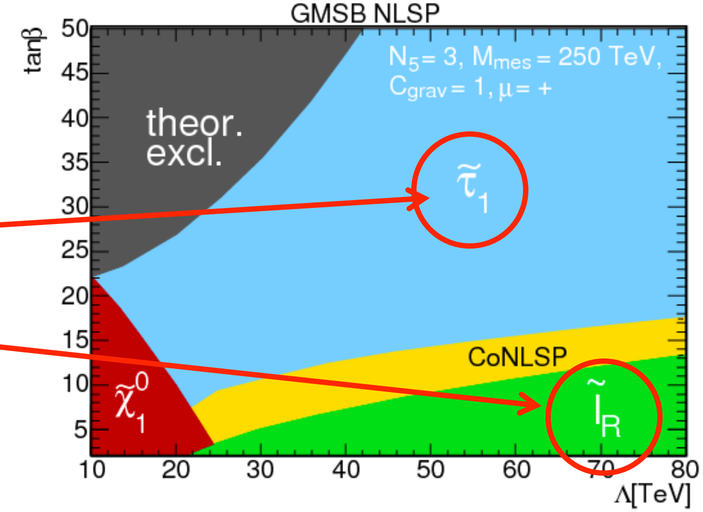
- Competitive at high m_0 in mSUGRA (gluino production)





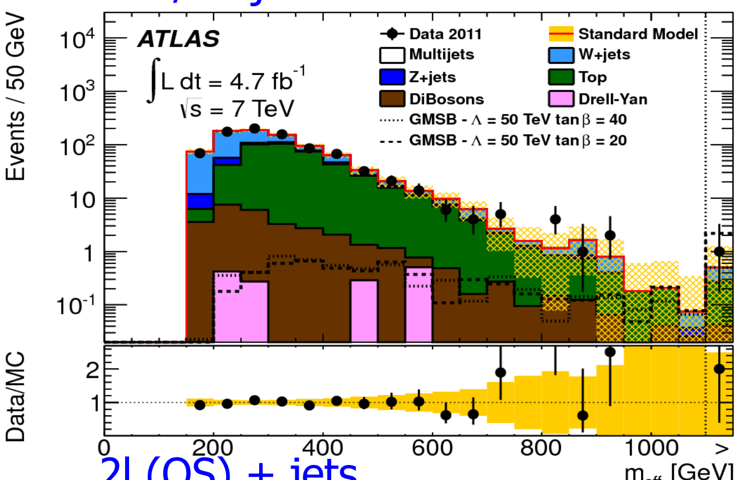
2 taus / 2 leptons (OS) – GMSB

- In GMSB model: gravitino = LSP
- Topology depends on Next-to-LSP (NLSP)
  - stau / slepton NLSP enhances tau / lepton
- ≥1 tau + jets + E_T^{miss}
- 2 opposite-sign leptons + jets + E_T^{miss}

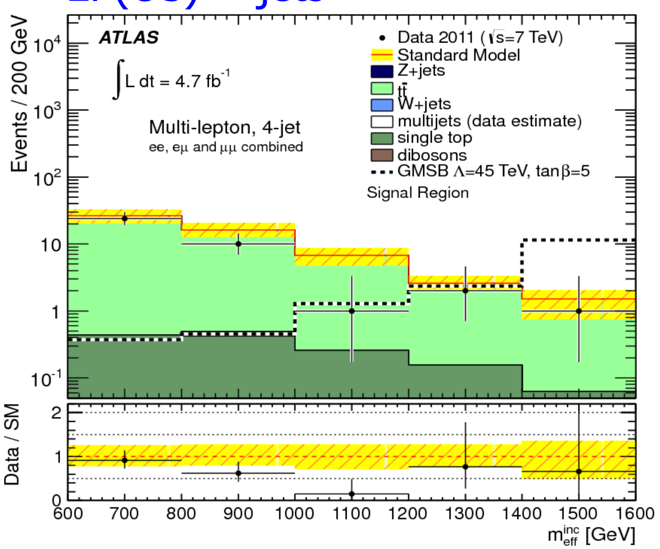


arXiv:1208.4688, accepted by PRD
arXiv:1210.1314, accepted by EPJC

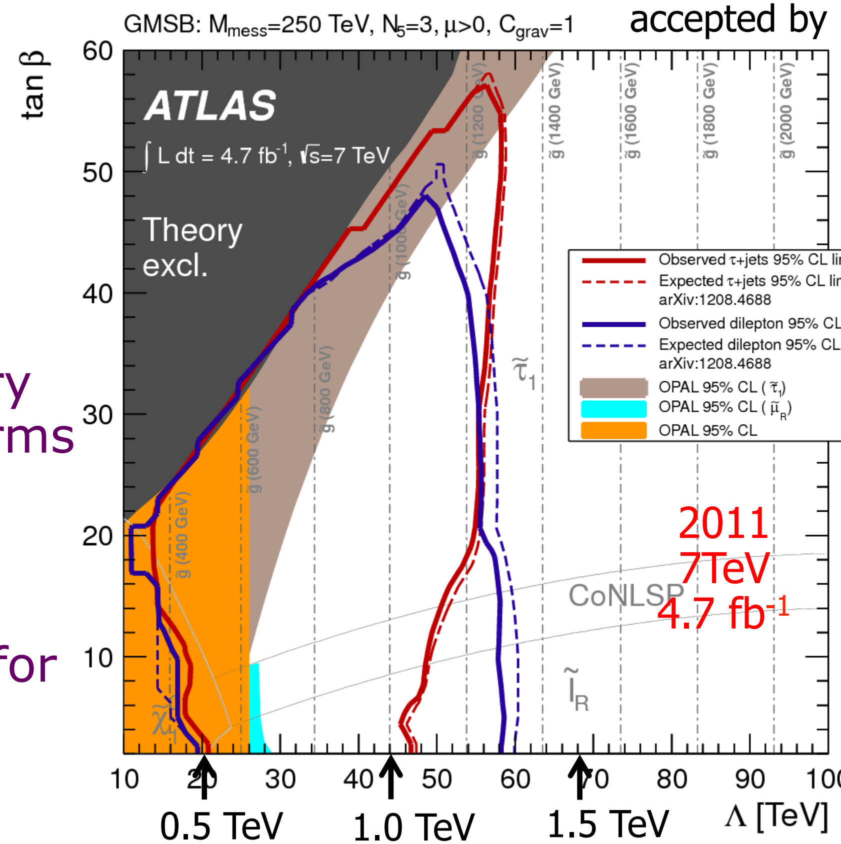
$\tau + \mu$ + jets



2l (OS) + jets



- Complementary analyses in terms of reach.
- Exclude gluino masses up to 1.3 TeV for tanβ<60.



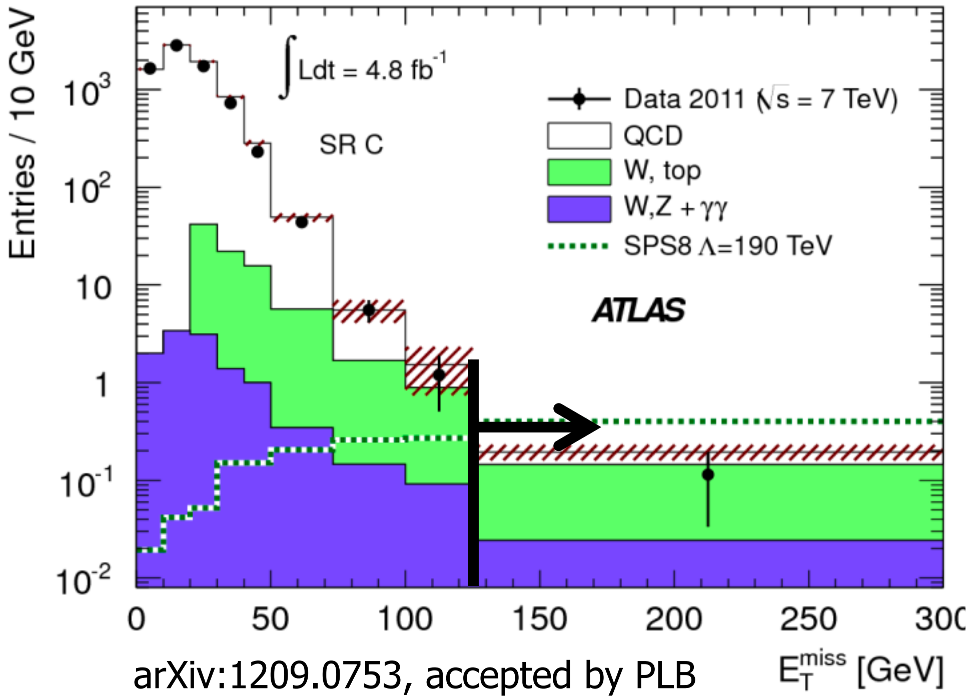
2 photons – GMSB

- *Neutralino (bino) NLSP case – in GMSB*
  - NLSP → gravitino + photon
- ≥2 photons (>50 GeV) + H_T + E_T^{miss}

- Exclude, at 95% CL:
  - gluino masses upto 1.07 TeV
  - squark masses upto 0.87 TeV

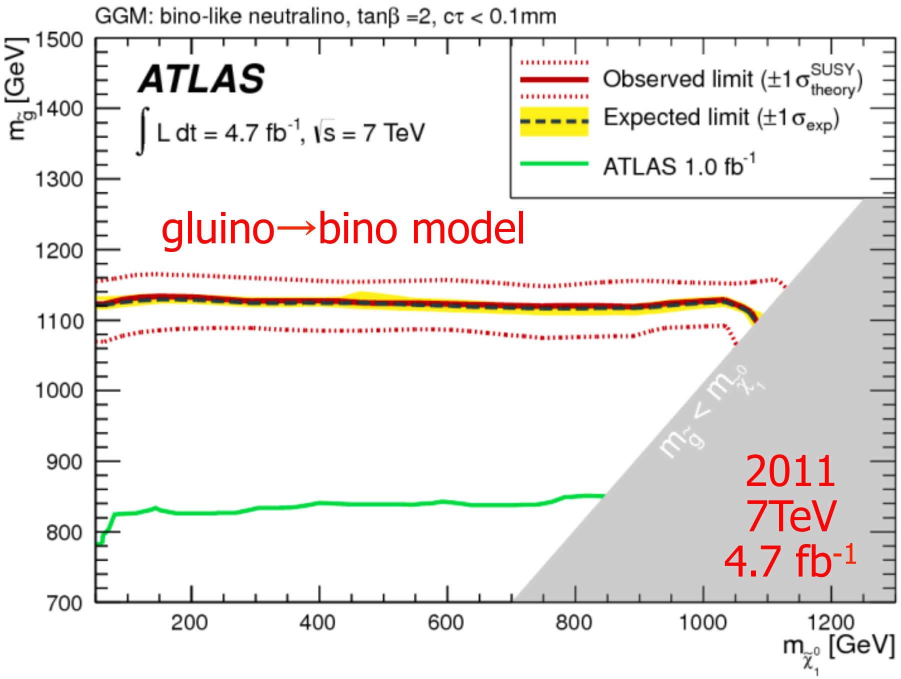
  for wide range of bino masses.

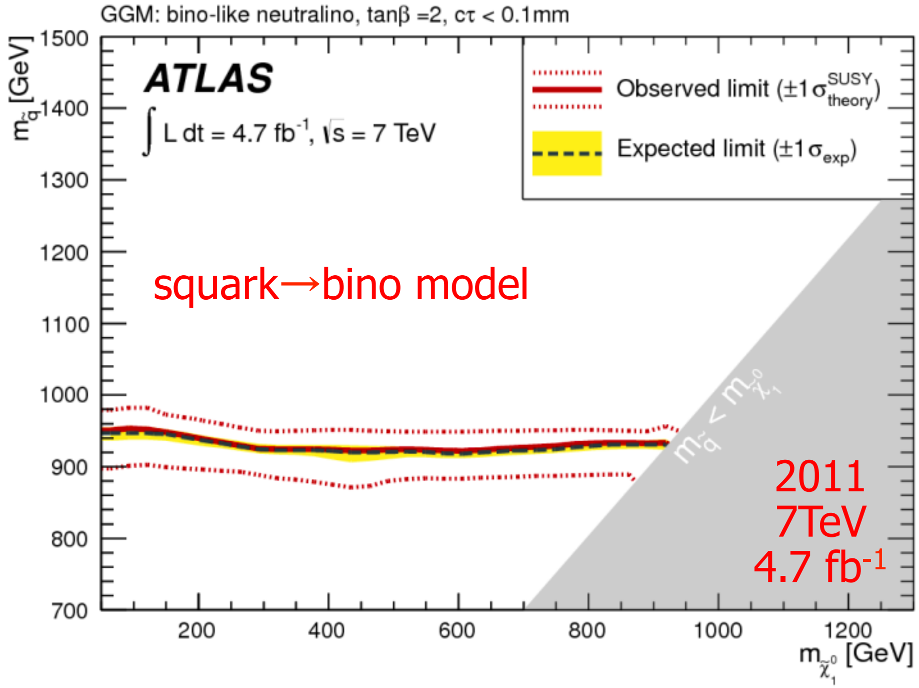
≥2 gamma (>50 GeV) + E_T^{miss} (>125 GeV)



arXiv:1209.0753, accepted by PLB

Simplified GMSB model





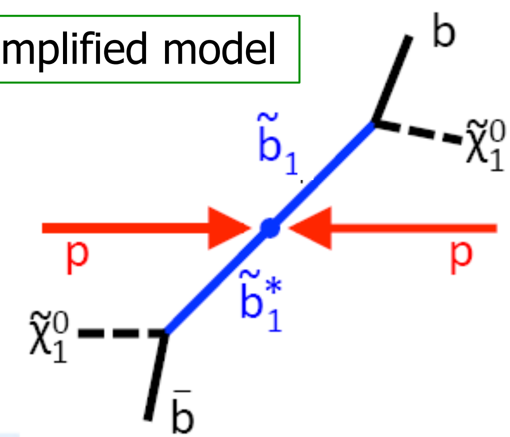
Direct sbottom production

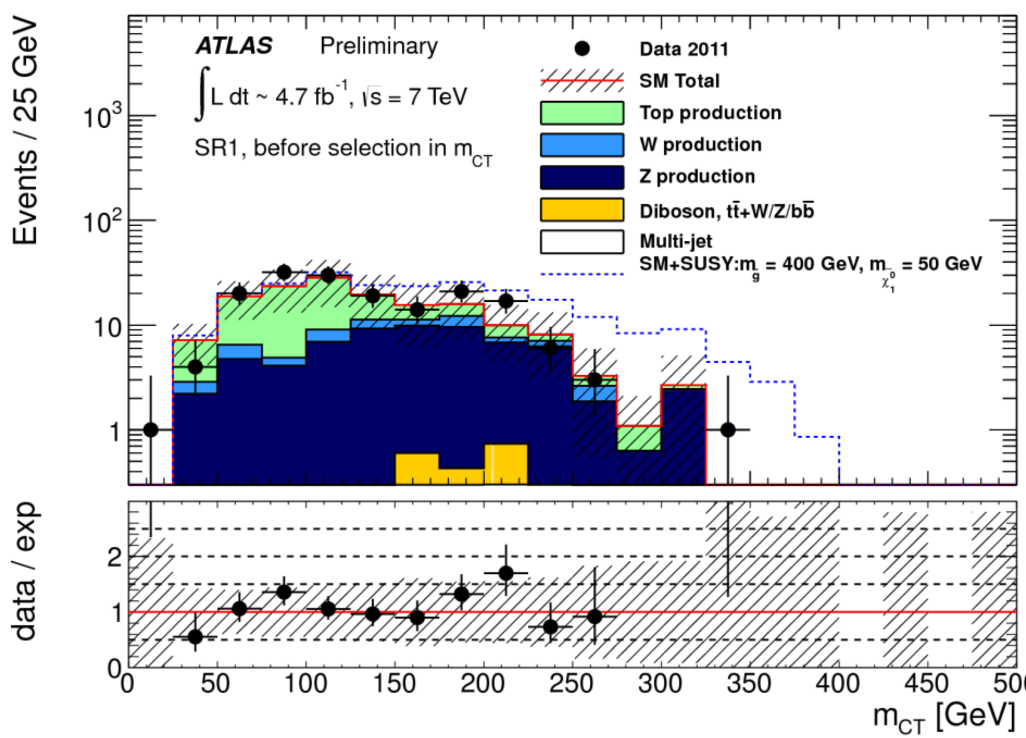
ATLAS-CONF-2012-106

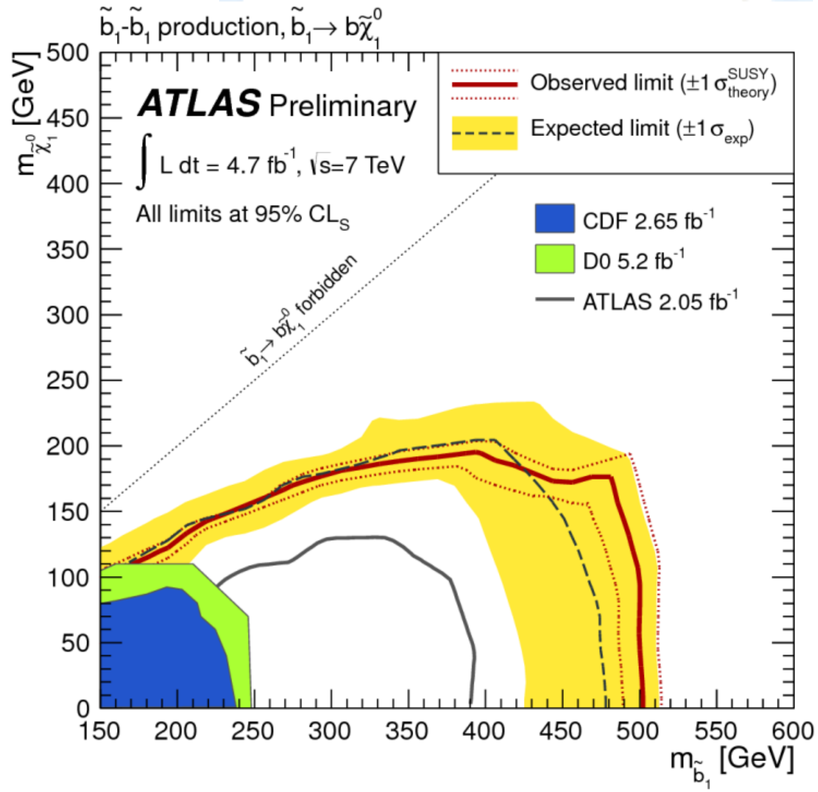
Direct sbottom production

- sbottom → b + LSP (simple 2-body decay)
- Search for: 2 b-jets + E_T^{miss} (+ ISR-jet)
- Selection: cut on M_{CT}
  - Useful for 2-body decays
  - Endpoint distribution related to M_{SUSY}

Simplified model





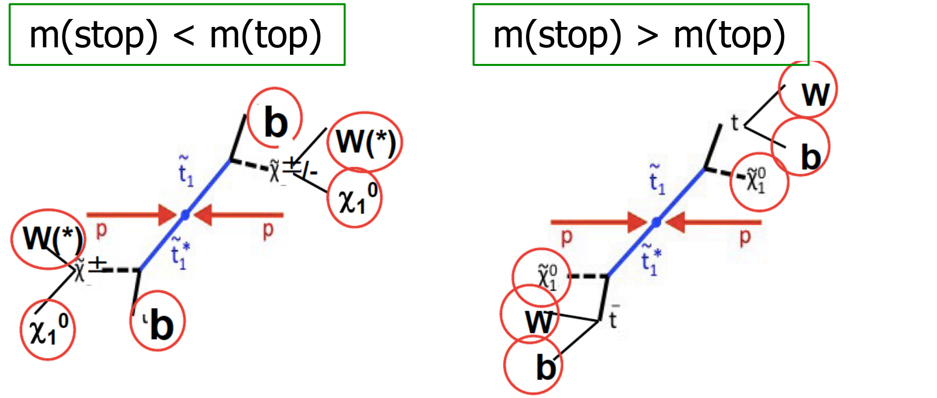


- Exclude m(sbottom) upto 490 GeV, for m(χ)=0 GeV.
- m(χ)>180 GeV, for m(sbottom)~400 GeV.

Direct stop production

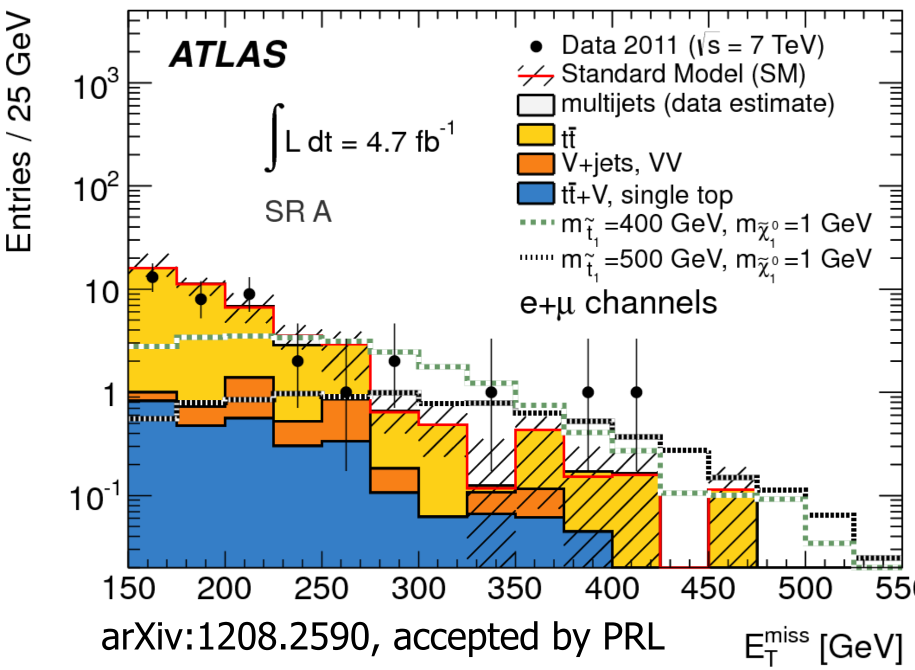
Direct stop production

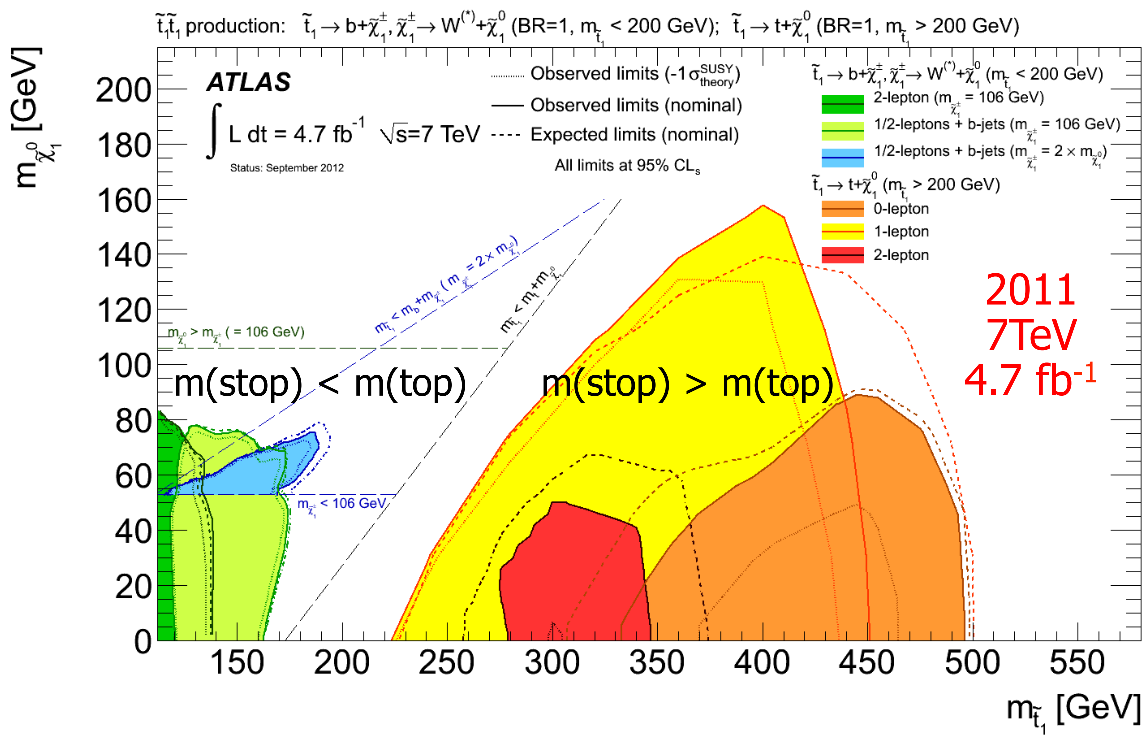
1. m(stop) < m(top) = 173 GeV
   - stop → b + chargino
2. m(stop) > m(top)
   - stop → top + neutralino



- Strategy: exclusive channels for both states
  - Multiple analyses performed (6). Require b-jets. Dominant BG: ttbar.

heavy-stop: 1 lepton channel





arXiv:1208.2590, accepted by PRL

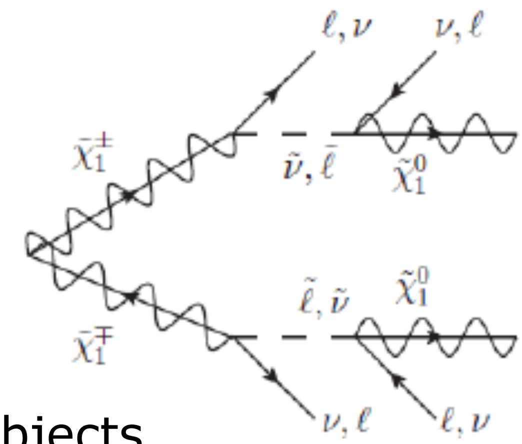
- Sensitivity to m(stop) upto 500 GeV, for m(*X*)=0 GeV.

Direct slepton, chargino production

arXiv:1208.2884, submitted to PLB

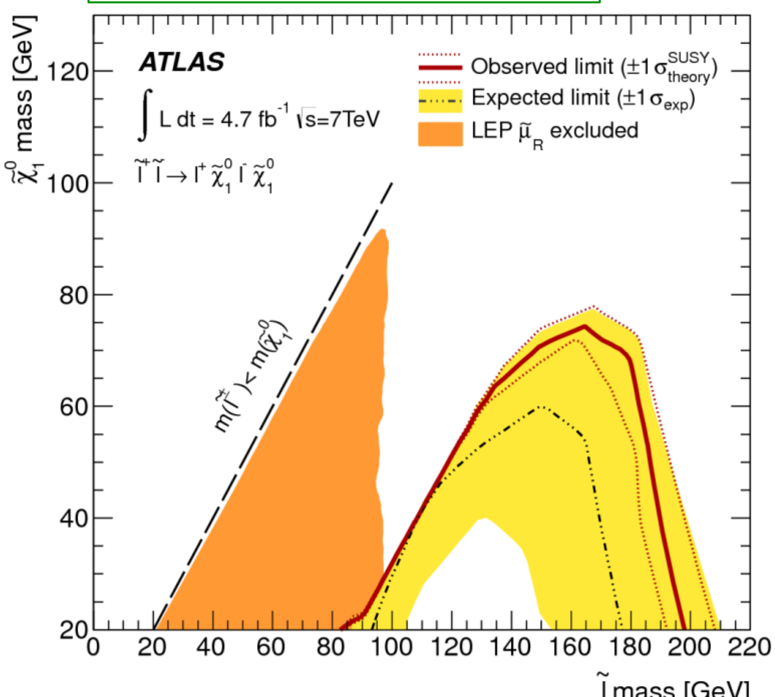
Direct slepton or chargino production

- slepton → lepton + neutralino
- chargino → lepton + ν + neutralino

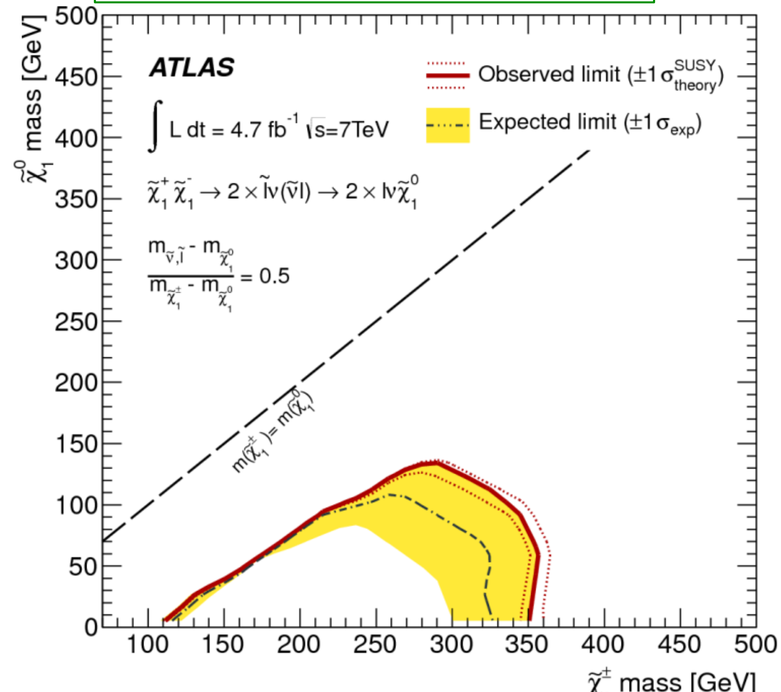


- Search for: 2 lepton[e,μ] + E_T^{miss} + jet-veto
- Dominant BGs: ttbar and WW.
  - Reject with MT2: useful variable for topology of 2 objects

Direct slepton production



Direct chargino production



2011
7TeV
4.7 fb^{-1}

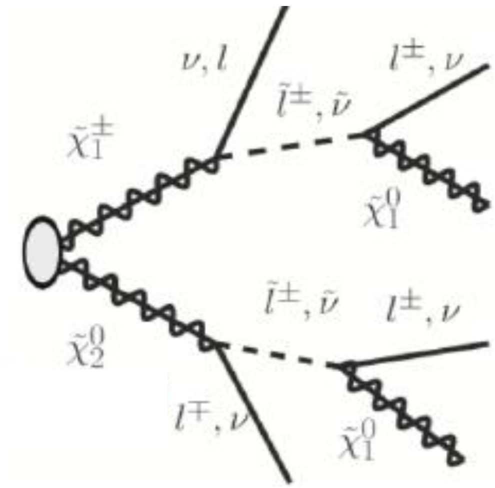
- Exclude: 85<m(sl)<195 GeV, for $m(X^0)$=20GeV ; 110<$m(X^\pm)$<340 GeV for $m(X^0)$=10GeV

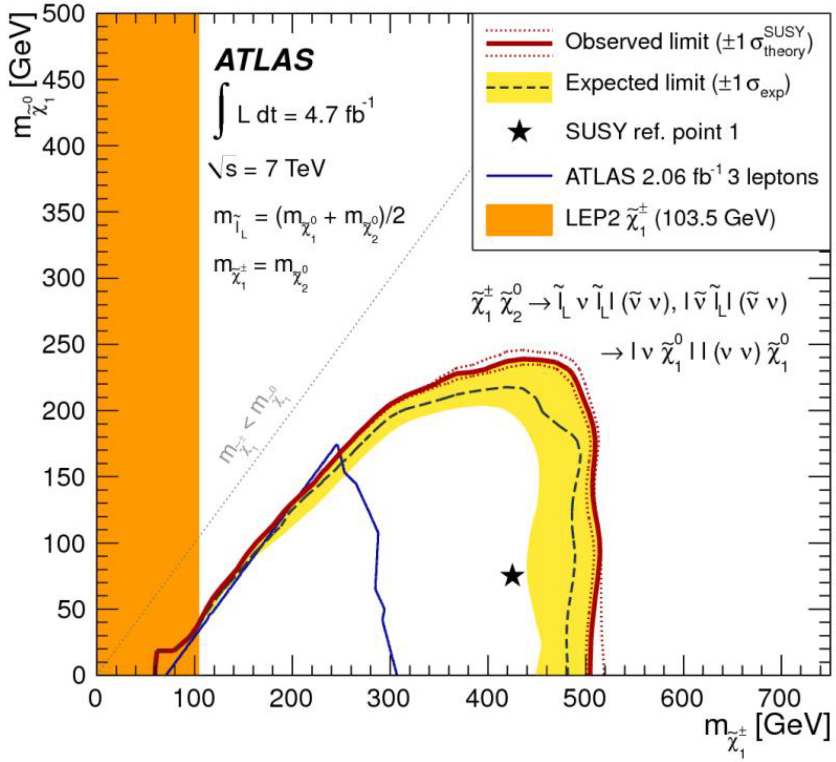
Direct chargino + neutralino(2) production

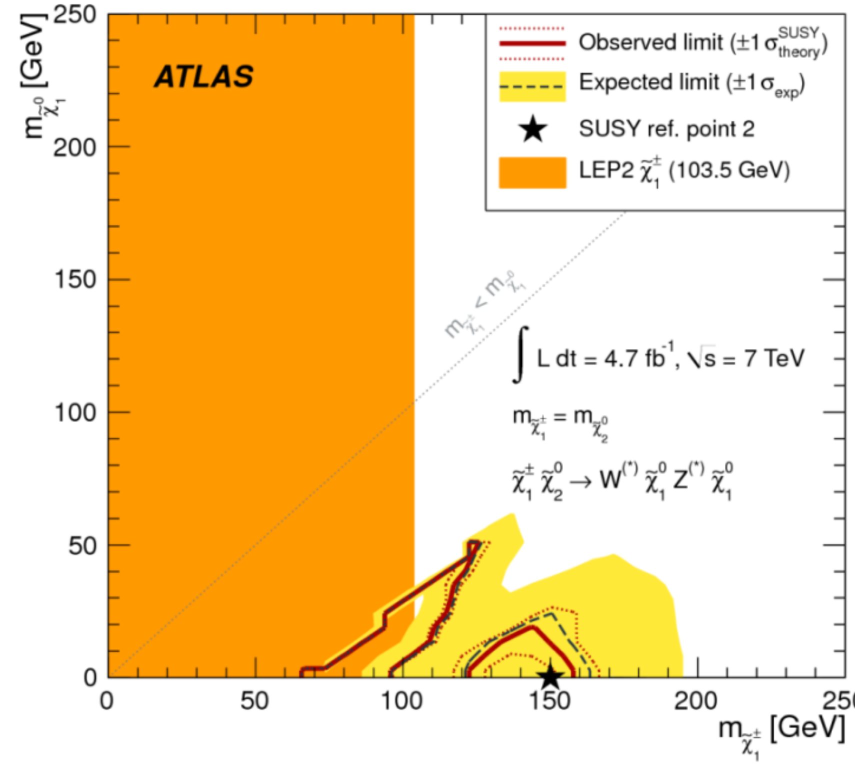
arXiv:1208.3144, submitted to PLB

Direct chargino + neutralino(2) production

- Intermediate slepton or W/Z in decay
- Final state: 3 leptons [e,μ] + E_t^{miss}
  - BG dominated by irreducible WZ background
- Left: 2 sleptons+lepton+3v (→ 3 leptons + E_T^{miss})
- Right: W+Z+2 LSPs (→ 3 leptons + E_t^{miss})







2011
7TeV
4.7 fb^{-1}

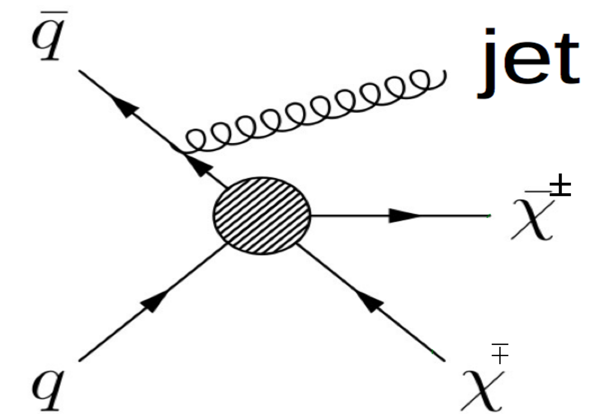
- Left: m(X±) excluded upto 500 GeV, for m(X0)<200 GeV.

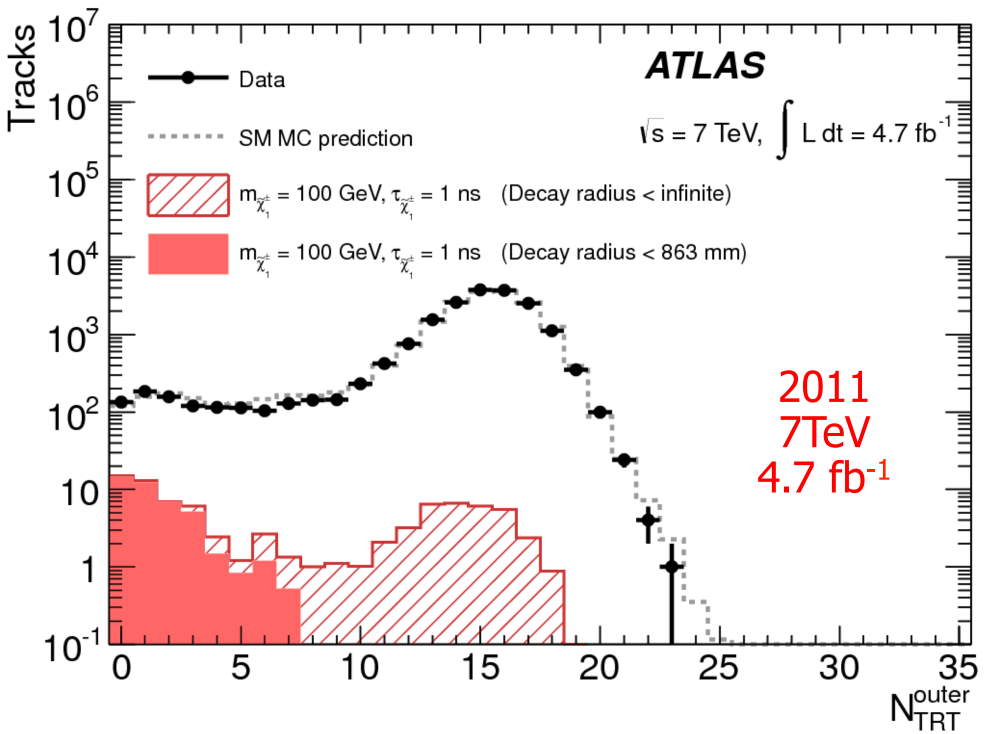
Search for Long-lived Particles (LLP) – AMSB

arXiv:1210.2852, submitted to JHEP

- NLSP particles may have long lifetime
  - Particle can travel few cm or more before decay
  - In particular, can happen when mass difference with LSP is very small
- Here: long-lived charginos (AMSB)
  - AMSB with O(100) GeV wino-LSP: can explain both PAMELA and Fermi-LAT observations.
  - AMSB: lightest chargino / neutralino are nearly degenerate.
    - Production process: direct chargino/ neutralino, plus ISR jet.
    - chargino → neutralino + soft pion
- Search strategy:
  - High-p_T jet + E_T^{miss} from ISR
    - Ala monojet analysis
  - High-p_T disappearing charged track in outer tracker of the Inner Detector (TRT).
    - Fewer than 5 hits in TRT outer module
    - Average for BG tracks: 15 hits.

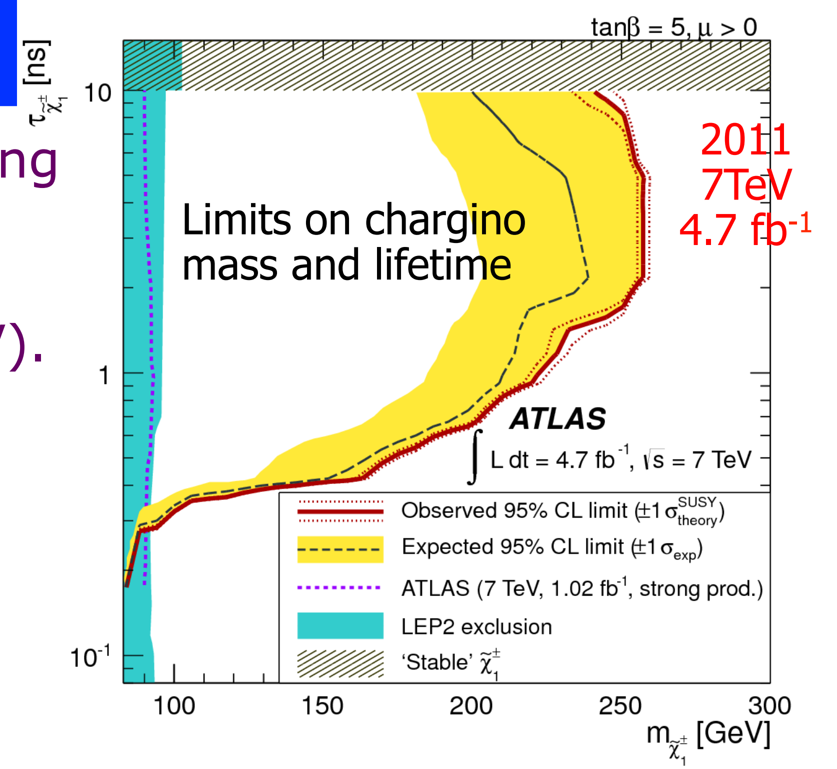
NEW

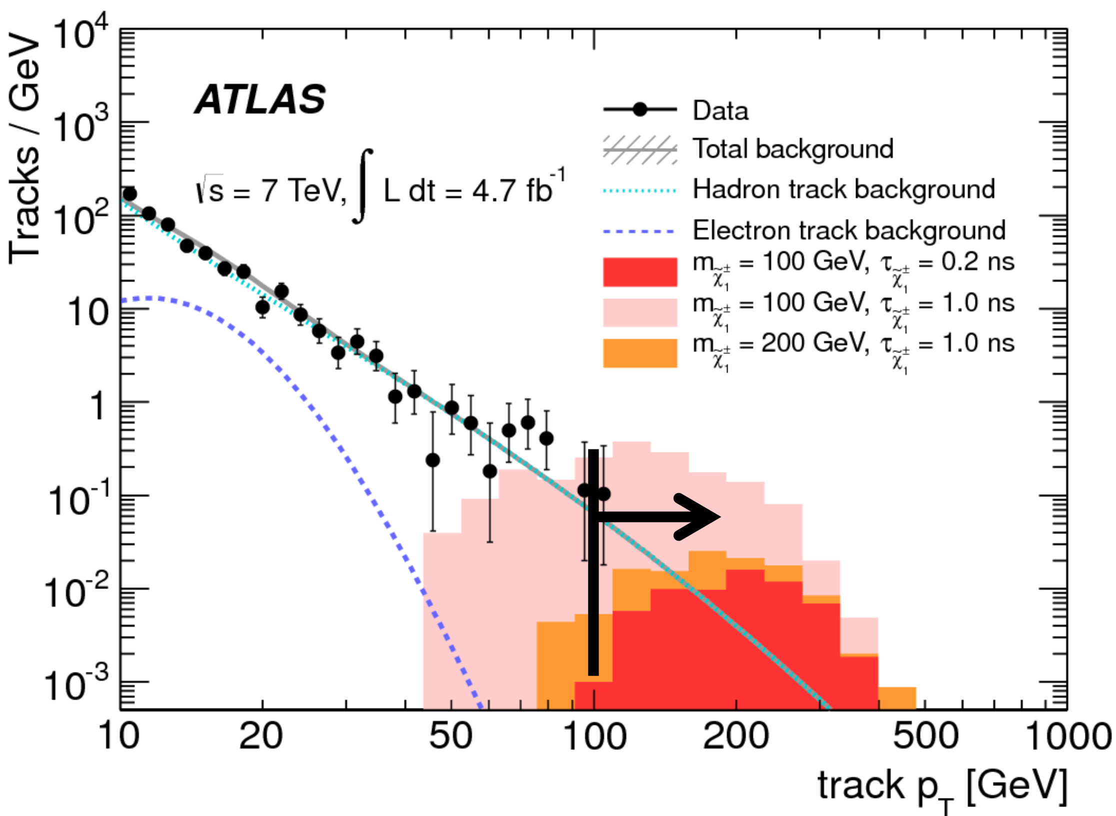


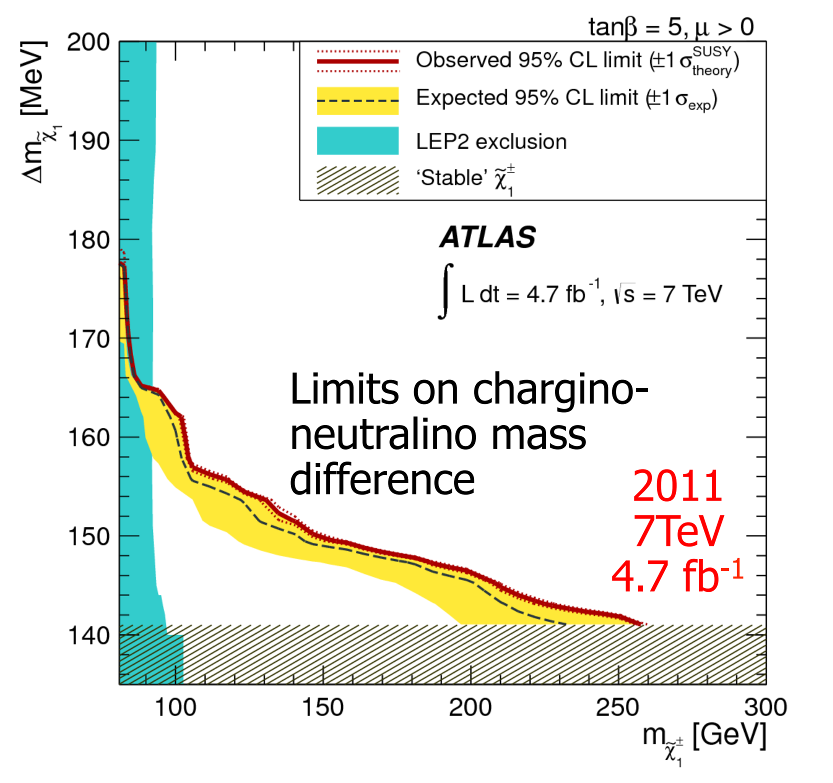


Disappearing-track results

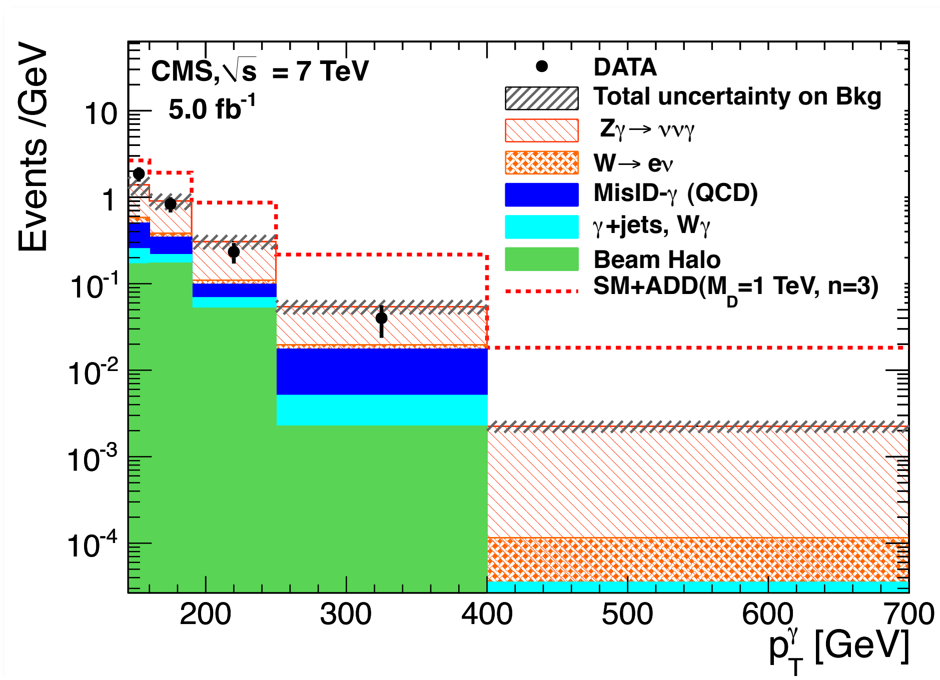
- Dominant BG: high-p_T charged pions interacting with material in TRT tracker.
- Obtain BG estimate from non-interact. tracks (N_{TRT}^{outer}>10). Extrapolate to SR (pT>100GeV).
  - Error dominated by statistical uncertainties in extrapolation technique.
- Data consistent with BG expectation. Set exclusion limits.
- Can exclude upto m(X±) of 260 GeV under certain conditions.

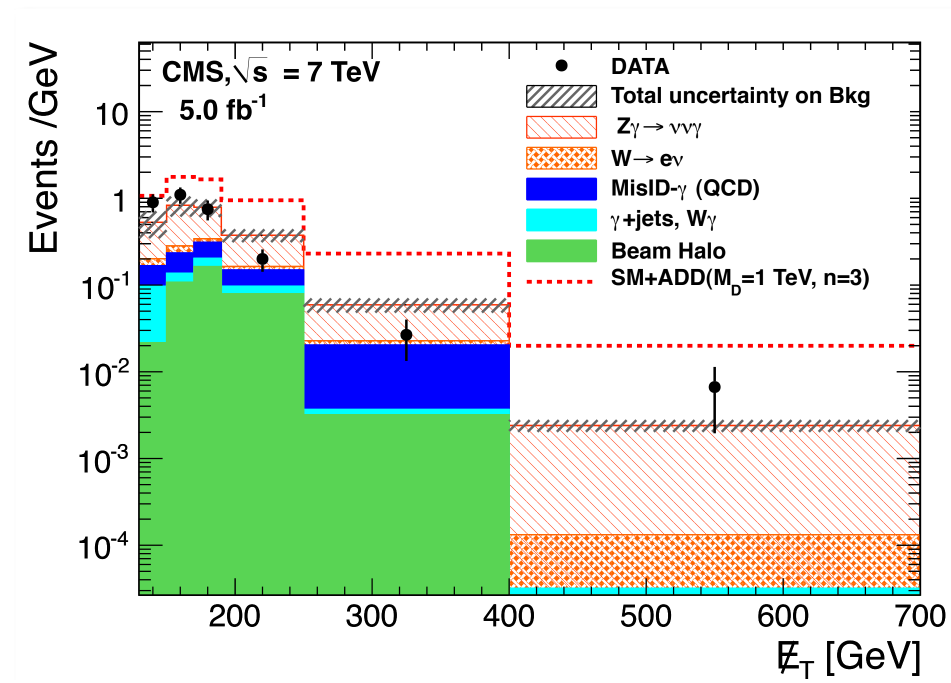






Monophoton Results

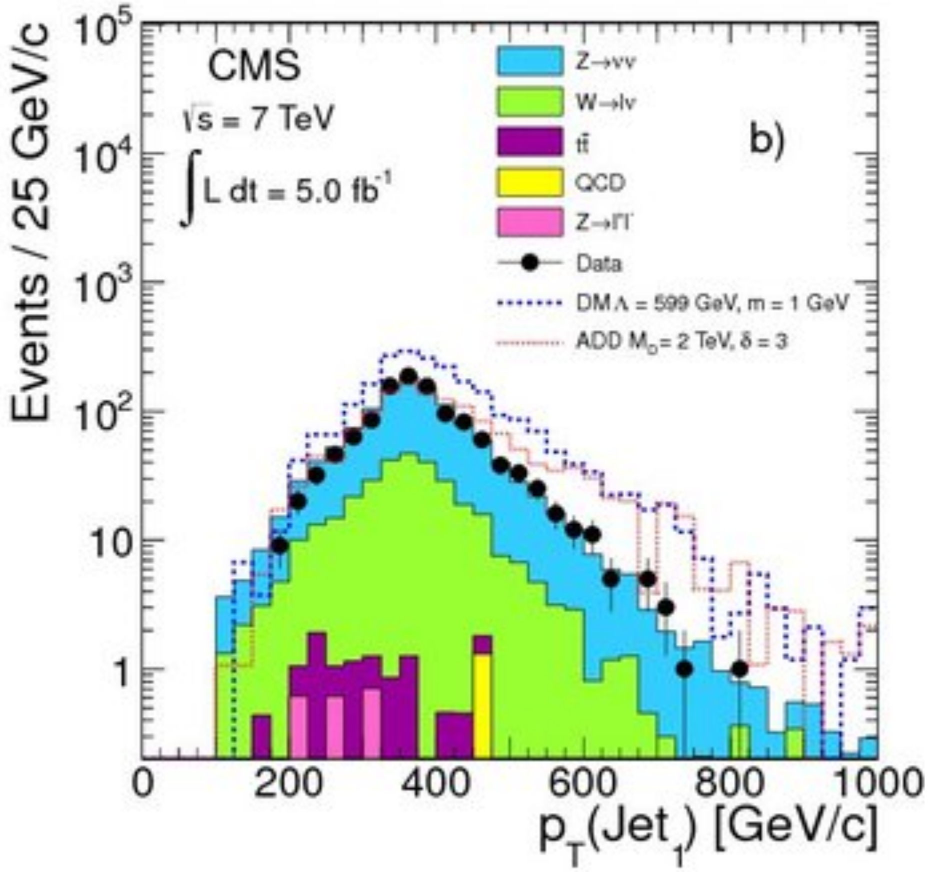


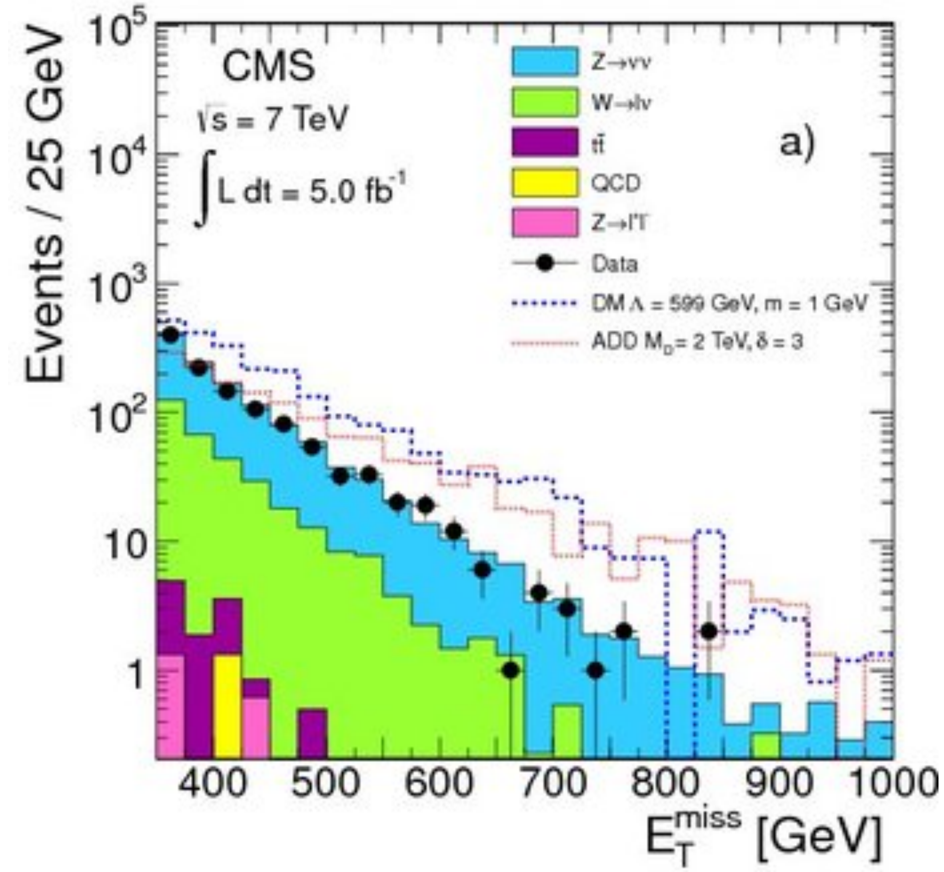


Source	Estimate
Jet Mimics Photon	11.2 ± 2.8
Beam Halo	11.1 ± 5.6
Electron Mimics Photon	3.5 ± 1.5
$W\gamma$	3.0 ± 1.0
γ+jet	0.5 ± 0.2
$\gamma\gamma$	0.6 ± 0.3
$Z(\nu\bar{\nu})\gamma$	45.3 ± 6.9
Total Background	75.1 ± 9.5
Total Observed Candidates	73

No excess observed between data and background expectation

Monojet - Results

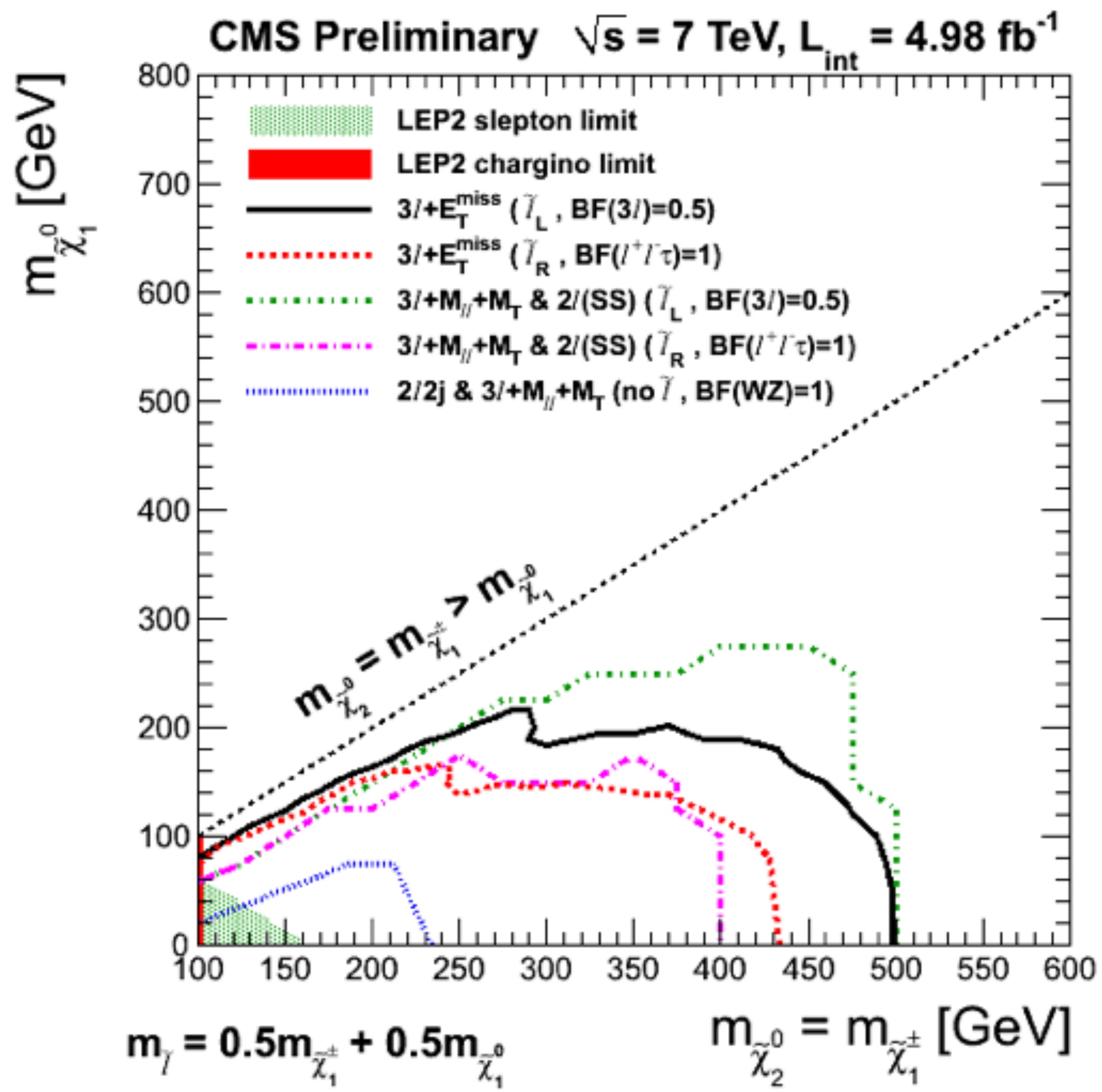




Background process	Events
$Z \to \nu\bar{\nu}$	900 ± 94
W+jets	312 ± 35
$t\bar{t}$	8 ± 8
$Z(\ell\ell)$+jets	2 ± 2
QCD multijet	1 ± 1
Single t	1 ± 1
Total background	1224 ± 101
Observed in data	1142

No excess observed between data and background expectation

Limits - EWK production



- Probe M(χ±, χ0) up to ~ 200-500 GeV, depending on the search mode

DM Relic Density in mSUGRA

$$M_{\tilde{g}} = 831\,\text{GeV}$$
$$M_{\tilde{\chi}_2^0} = 260\,\text{GeV}$$
$$M_{\tilde{\tau}} = 151.3\,\text{GeV}$$
$$M_{\tilde{\chi}_1^0} = 140.7\,\text{GeV}$$

[1] Established the CA region by detecting low energy τ's ($p_T^{vis} > 20$ GeV)

[2] Measured 5 SUSY masses (ΔM, $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{q}$, $\tilde{g}$) from

$$M_{j\tau\tau}^{\text{endpoint}} = X_1(m_{1/2}, m_0)$$
$$M_{\tau\tau}^{\text{endpoint}} = X_2(m_{1/2}, m_0, \tan\beta, A_0)$$
$$M_{\text{eff}}^{\text{peak}} = X_3(m_{1/2}, m_0)$$
$$M_{\text{eff, b}}^{\text{peak}} = X_4(m_{1/2}, m_0, \tan\beta, A_0)$$

$$m_0 =$$
$$m_{1/2} =$$
$$\tan\beta =$$
$$A_0 =$$
$$sgn(\mu) > 0$$

[3] Determine the dark matter relic density by determining m_0, $m_{1/2}$, $\tan\beta$, and A_0

$$\Omega_{\tilde{\chi}_1^0} h^2 = Z(m_0, m_{1/2} \tan\beta, A_0)$$

Determining mSUGRA Parameters

✓Solved by inverting the following functions:

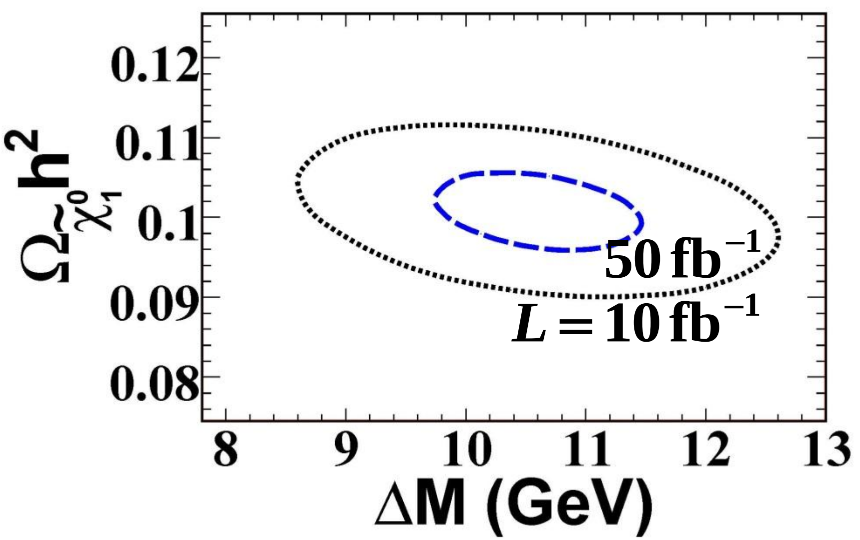
$$M^{\text{peak}}_{j\tau\tau} = X_1(m_{1/2}, m_0)$$
$$M^{\text{peak}}_{\tau\tau} = X_2(m_{1/2}, m_0, \tan\beta, A_0)$$
$$M^{\text{peak}}_{\text{eff}} = X_3(m_{1/2}, m_0)$$
$$M^{(b)\,\text{peak}}_{\text{eff}} = X_4(m_{1/2}, m_0, \tan\beta, A_0)$$

10 fb^{-1} →

$$m_0 = 210 \pm 5$$
$$m_{1/2} = 350 \pm 4$$
$$A_0 = 0 \pm 16$$
$$\tan\beta = 40 \pm 1$$

$$\Omega_{\tilde{\chi}^0_1} h^2 = Z(m_0, m_{1/2}\,\tan\beta, A_0)$$

PRL 100, (2008) , 231802

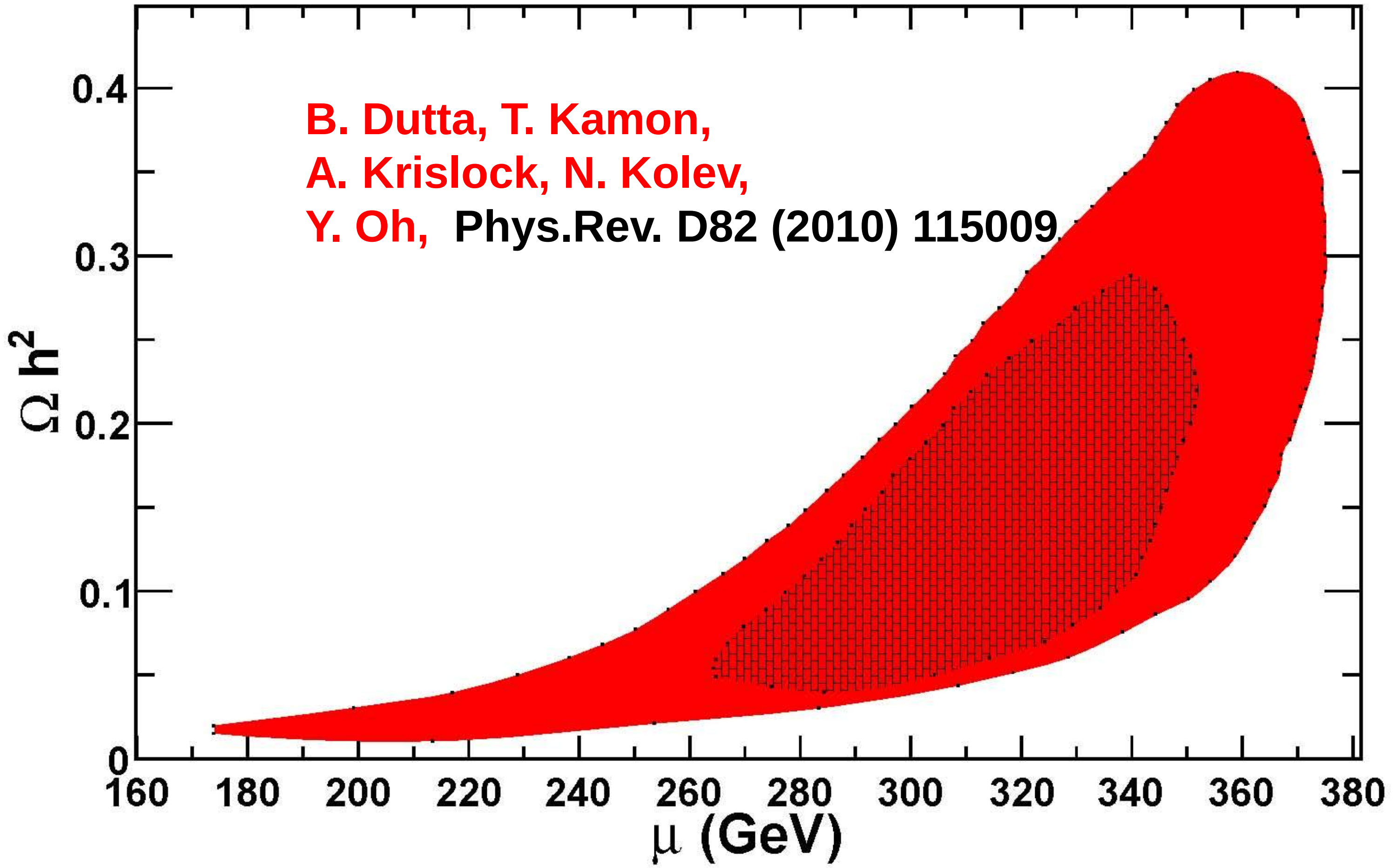


$$\delta\Omega_{\tilde{\chi}^0_1} h^2 / \Omega_{\tilde{\chi}^0_1} h^2 = 6.2\%\ (30\ \text{fb}^{-1})$$
$$= 4.1\%\ (70\ \text{fb}^{-1})$$

$$\delta\sigma_{\tilde{\chi}^0_1 - p} / \sigma_{\tilde{\chi}^0_1 - p} \approx 7\%\ (30\ \text{fb}^{-1})$$

Relic Density

$\mathcal{L}$ (fb^{-1})	$m_{1/2}$ (GeV)	m_H (GeV)	m_0 (GeV)	A_0 (GeV)	$\tan\beta$	μ (GeV)	$\Omega_{\tilde{\chi}_1^0}h^2$
1000	500 ± 3	727 ± 10	366 ± 26	3 ± 34	39.5 ± 3.8	321 ± 25	$0.094^{+0.107}_{-0.038}$
100	500 ± 9	727 ± 13	367 ± 57	0 ± 73	39.5 ± 4.6	331 ± 48	$0.088^{+0.168}_{-0.072}$
Syst.	± 10	± 15	± 56	± 66	± 4.5	± 48	$^{+0.175}_{-0.072}$



Mirage Mediation

Particle	Mass	50 fb^{-1} Stat.	100 fb^{-1} Stat.
$\tilde{g}$	646	$-14,+19$	$-11,+14$
$\tilde{q}_L$	638	$-34,+42$	$-23,+39$
$\tilde{\tau}$	318	$-3,+3$	$-3,+3$
$\tilde{\chi}_2^0$	333	$-7,+11$	$-6,+8$
$\tilde{\chi}_1^0$	276	$-8,+13$	$-7,+10$

Particle	Mass	50 fb^{-1} Stat.	100 fb^{-1} Stat.
$\tilde{b}$	531	$-60, +60$	$-47, +47$
$\tilde{t}$	326	$-5, +8$	$-4, +7$

Parameter	Value	50 fb^{-1} Stat.	100 fb^{-1} Stat.
α	4.58	±0.21	±0.14
$m_{3/2}$	13717	±688	±517
n_m	0.106	±0.015	±0.015
n_H	0.578	±0.095	±0.091
$\tan\beta$	28.76	±1.65	±1.36

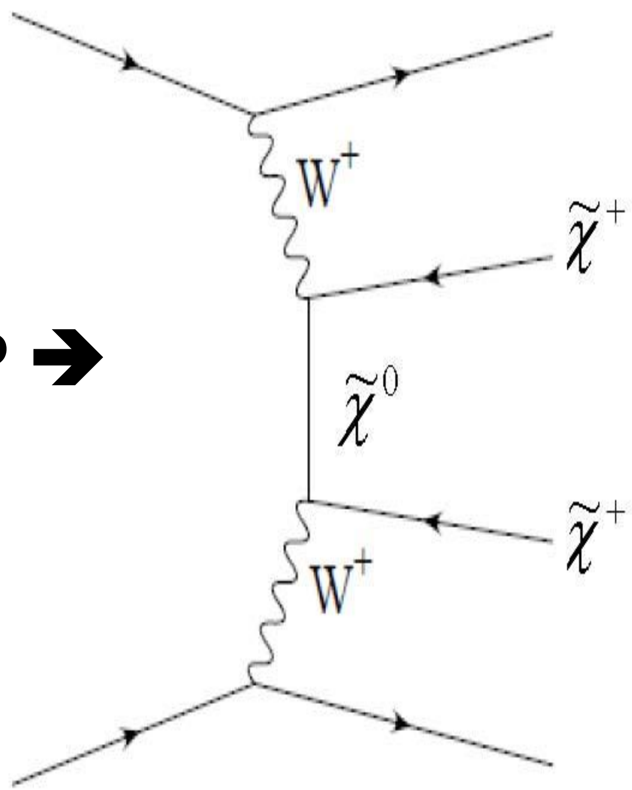
$$\Omega h^2 = 0.096 \pm 0.029$$

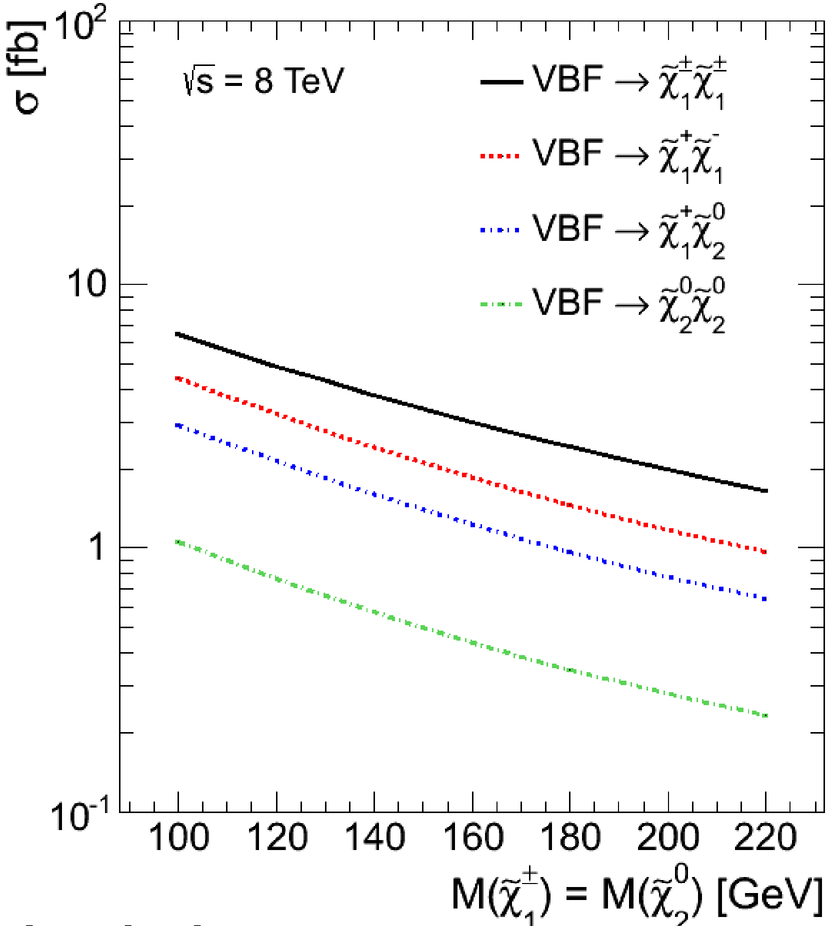
Dutta, Kamon, Krislock, Sinha, Wang, Phys.Rev. D85 (2012) 115007

2. DM at the LHC Via VBF

Direct probes of charginos, neutralinos and sleptons

P + P ➔

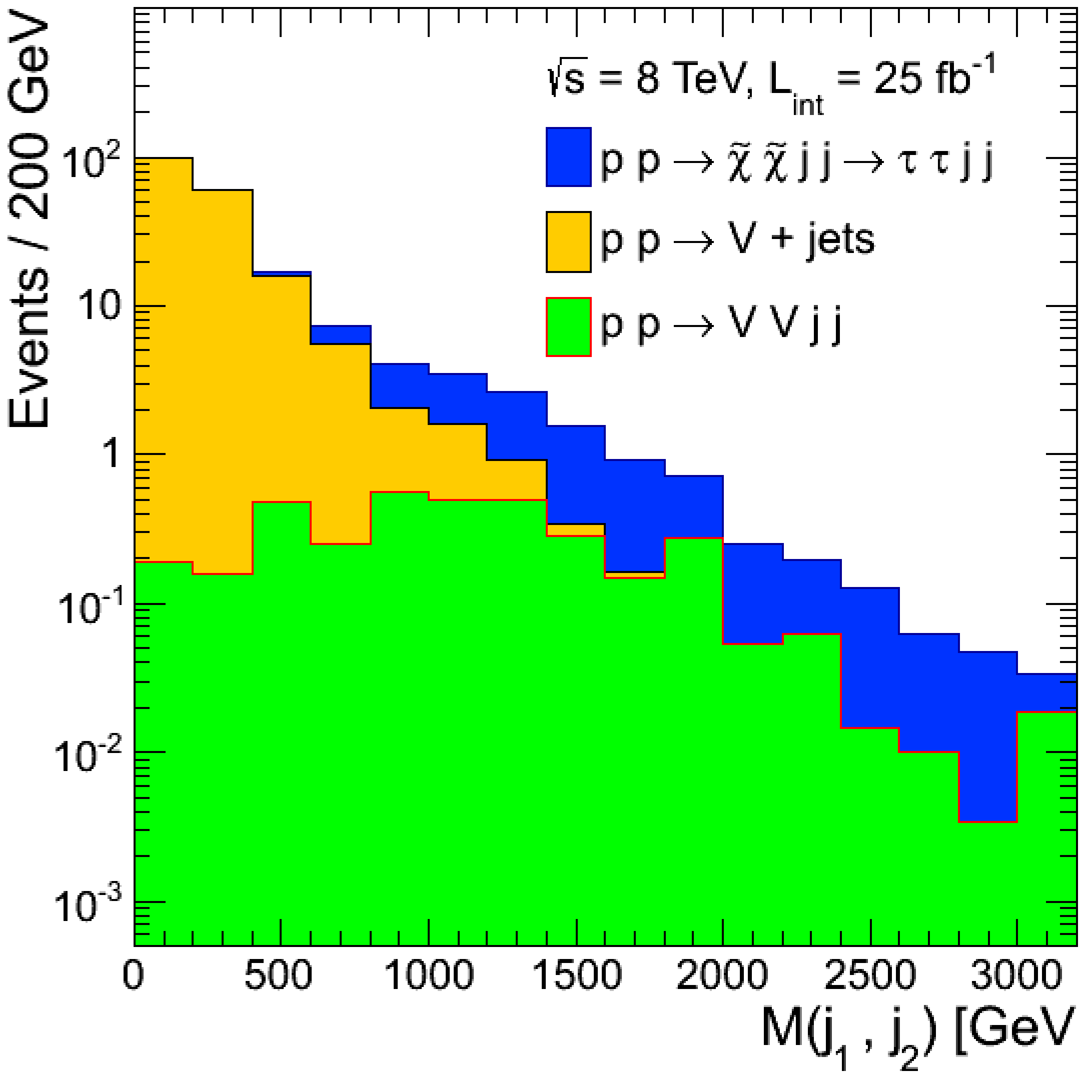




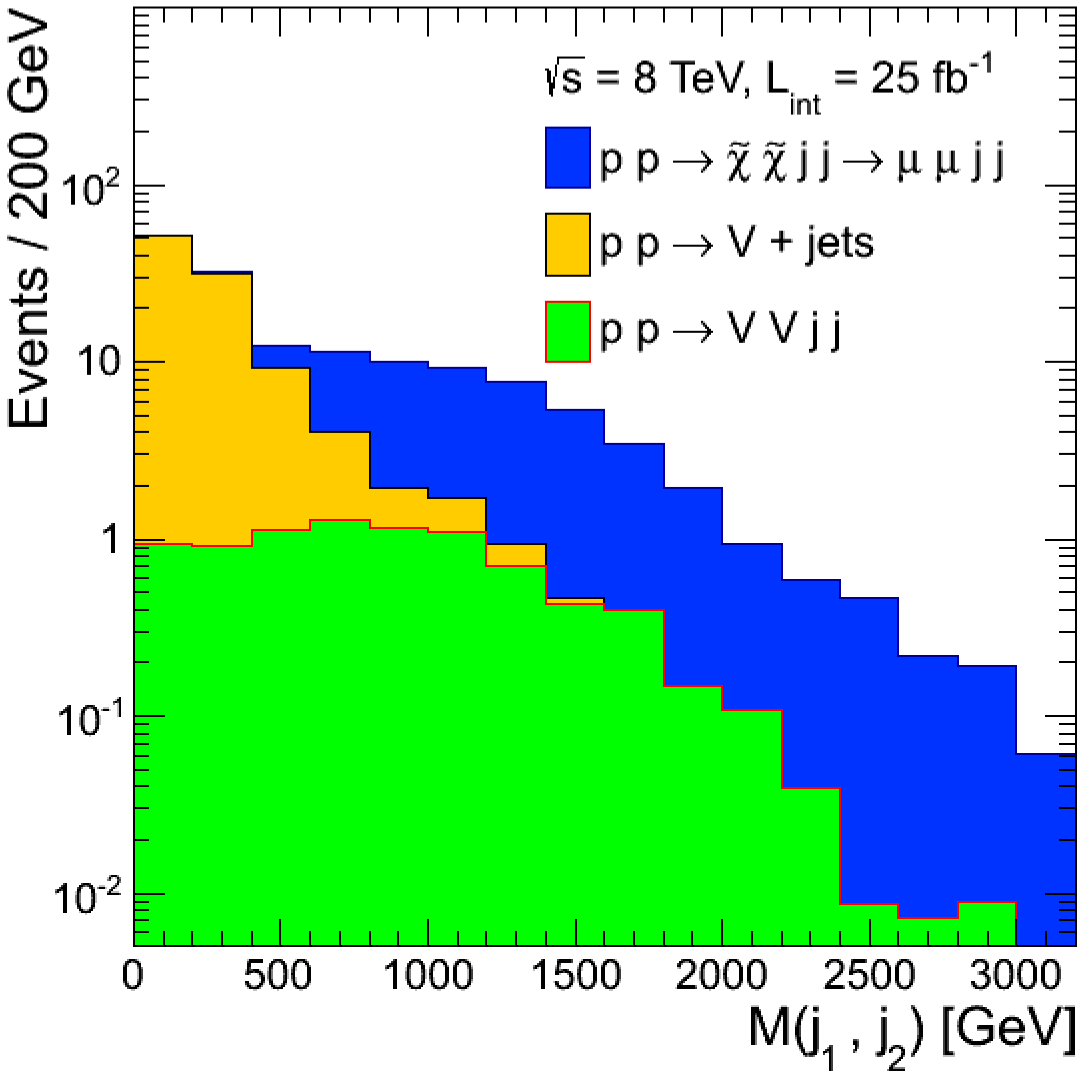
Two high E_T forward jets in opposite hemispheres with large dijet invariant mass

Dutta, Gurrola, John, Kamon, Sheldon, Sinha, arXiv:1210.0964

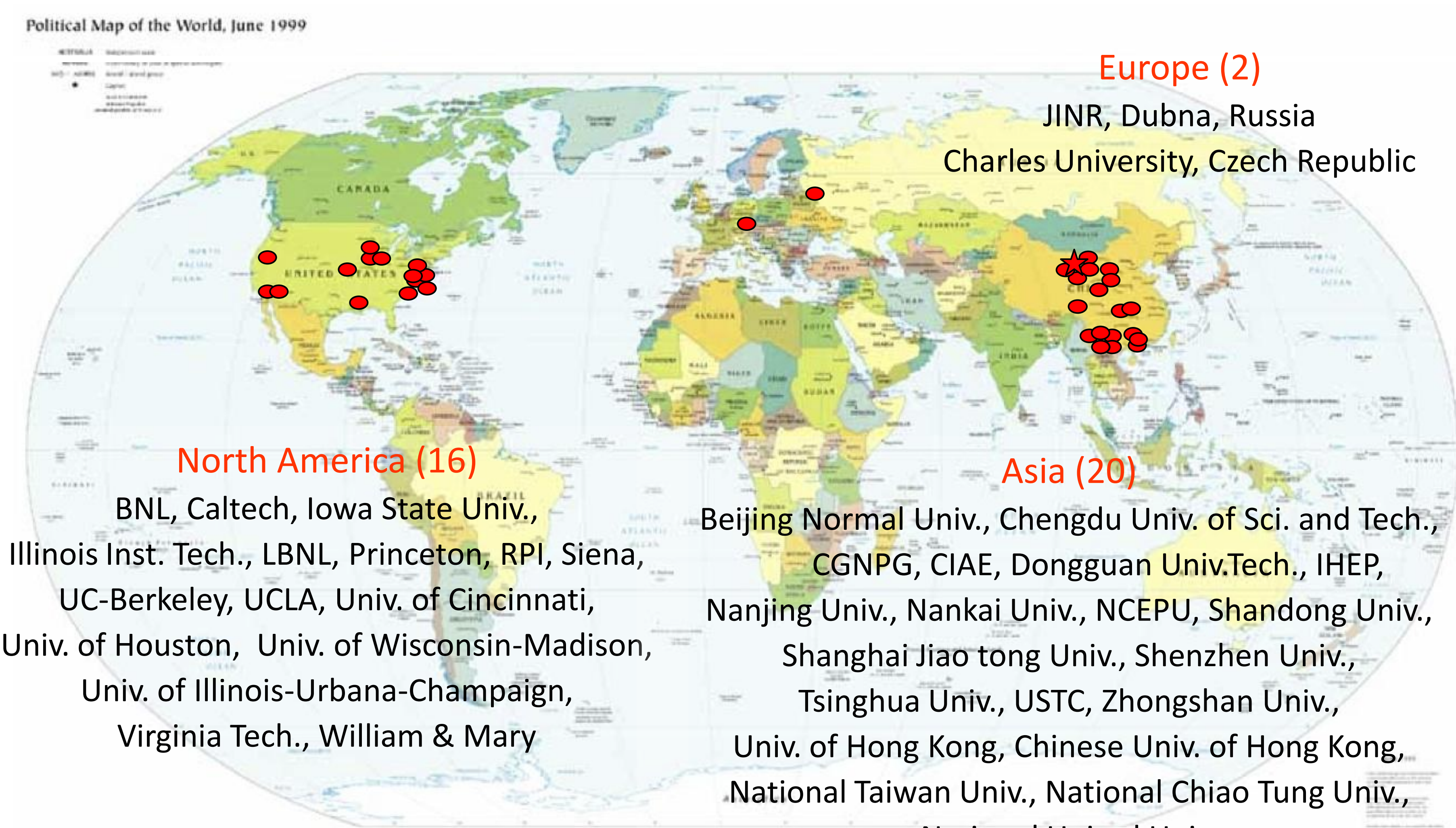
Signal: ≥ 2j+2τ+missing energy



Signal: ≥ 2j+2μ+missing energy



The Daya Bay Collaboration



Europe (2)

JINR, Dubna, Russia
Charles University, Czech Republic

North America (16)

BNL, Caltech, Iowa State Univ., Illinois Inst. Tech., LBNL, Princeton, RPI, Siena, UC-Berkeley, UCLA, Univ. of Cincinnati, Univ. of Houston, Univ. of Wisconsin-Madison, Univ. of Illinois-Urbana-Champaign, Virginia Tech., William & Mary

Asia (20)

Beijing Normal Univ., Chengdu Univ. of Sci. and Tech., CGNPG, CIAE, Dongguan Univ.Tech., IHEP, Nanjing Univ., Nankai Univ., NCEPU, Shandong Univ., Shanghai Jiao tong Univ., Shenzhen Univ., Tsinghua Univ., USTC, Zhongshan Univ., Univ. of Hong Kong, Chinese Univ. of Hong Kong, National Taiwan Univ., National Chiao Tung Univ., National United Univ.

~230 Collaborators

Summary

- With 2.5x more data, the Daya Bay reactor neutrino experiment measures a far/near antineutrino deficit at ~2 km:

R = 0.944 ± 0.007 (stat) ± 0.003 (syst)

[Previous value: R = 0.940 ± 0.011 (stat) ± 0.004 (syst)]

- Interpretation of disappearance as neutrino oscillation yields:

$\sin^2 2\theta_{13} = 0.089 \pm 0.010$ (stat) ± 0.005 (syst)

[Previous value: $\sin^2 2\vartheta_{13} = 0.092 \pm 0.016$ (stat) ± 0.005 (syst)]

- Final two ADs are installed during this summer.

RENO Collaboration

12 institutions and 40 physicists

♪

- Chonbuk National University
- Chonnam National University
- Chung-Ang University
- Dongshin University
- Gyeongsang National University
- Kyungpook National University
- Pusan National University
- Sejong University
- Seokyeong University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

- **Total cost : $10M**
- Start of project : **2006**
- The first experiment running with both near & far detectors from **Aug. 2011**

YongGwang

(靈光) :

Future Plan for Precision Measurement of θ_{13}

RENO

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat.) \pm 0.019(syst.)$$

0.113 ± 0.023 (4.9 σ) → ± 0.01 (11 σ)

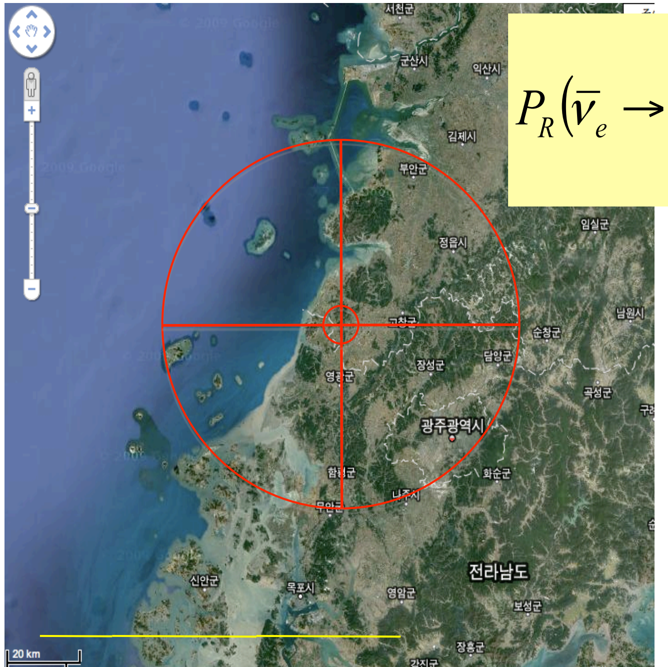
(220 days) (3 years)

- 3 years of data : ±0.01 for the total measurement error
  - **statistical error : ±0.013 (~200 days) → ±0.006**
  - **systematic error : ±0.019 → ±0.014 (background reduction)**
    ±0.010 (reduction of reactor uncertainty + shape analysis)
    ±0.005 (reduction of detection efficiency uncertainty)

- Remove backgrounds
- Spectral shape analysis (with precise energy calibration)
- Reduce uncertainties of reactor neutrino flux & detector efficiency

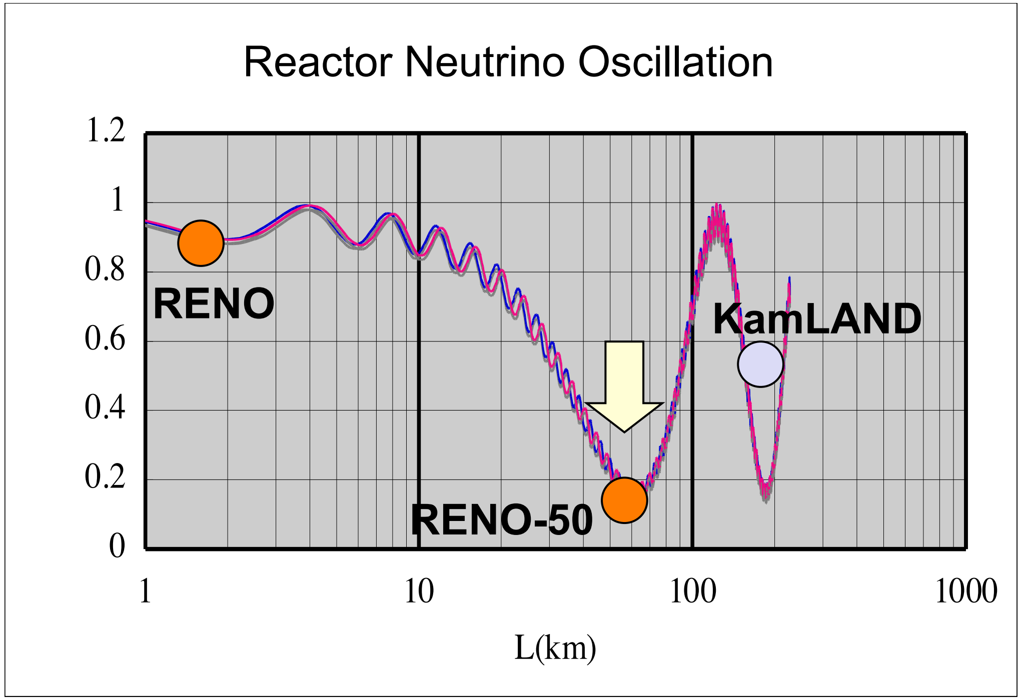
RENO-50

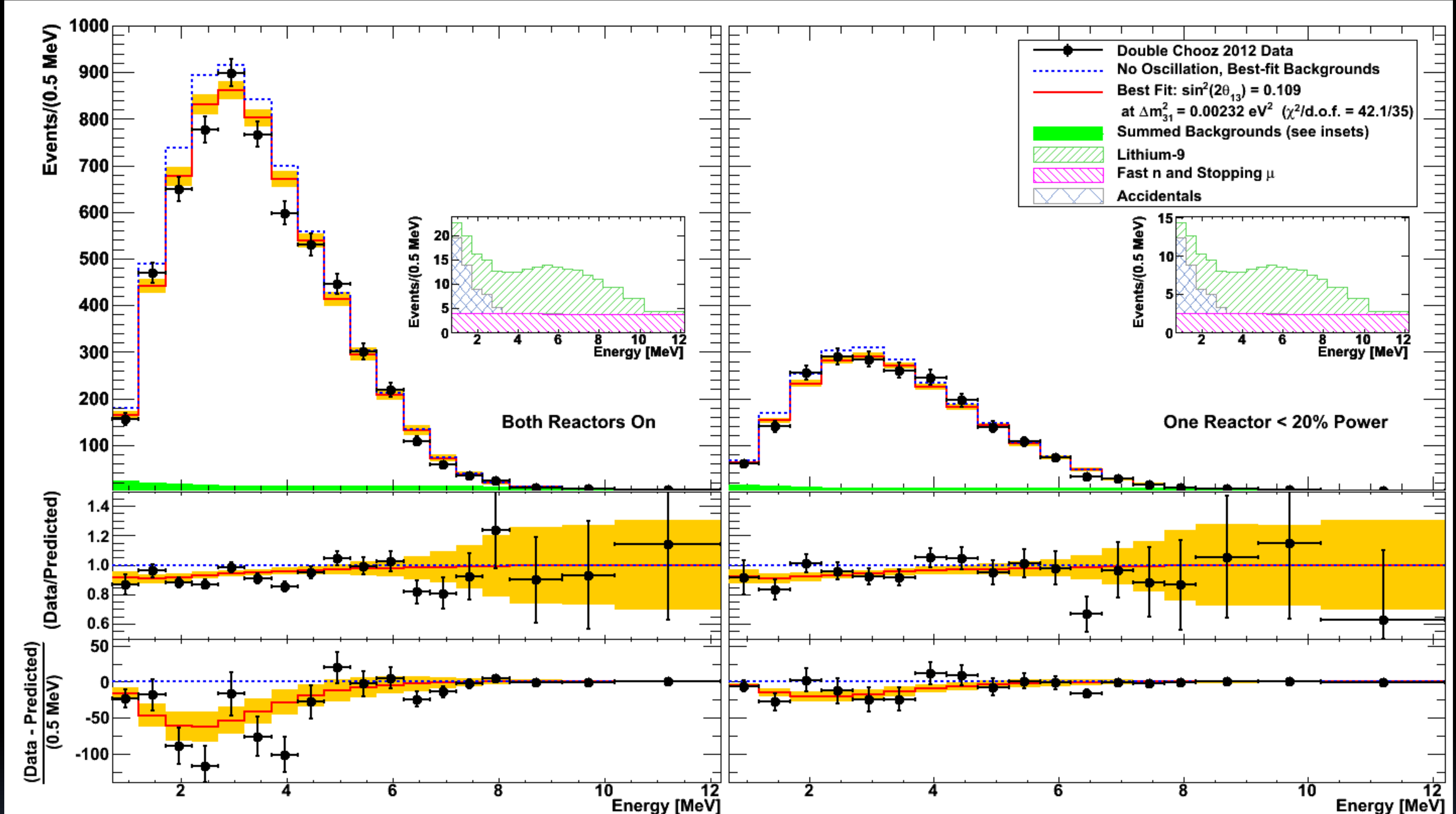
- Large θ_{12} neutrino oscillation effects at 50 km + 5kton liquid scintillator detector
- RENO can be used as near detectors. → Precise reactor neutrino fluxes
- Negligible contribution from other nuclear power plants.



$$P_R(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \left\{ \begin{array}{l} \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21} \\ +\sin^2 2\theta_{13}\sin^2\theta_{12}\left(\cos 2\Delta_{31}\sin^2\Delta_{21} - \tfrac{1}{2}\sin 2\Delta_{31}\sin 2\Delta_{21}\right) \end{array} \right\}$$

L~50km experiment could be a natural extension of current RENO θ_{13} experiment. (2018 ~)





Rate+Shape: $\sin^2 2\theta_{13} = 0.109 \pm 0.030$ (stat.) $\pm$ 0.025 (syst.)

χ^2/d.o.f. = 42.1/35

Rate-only: $\sin^2 2\theta_{13} = 0.170 \pm 0.035$ (stat.) $\pm$ 0.040 (syst.)

Frequentist analysis: $\sin^2 2\theta_{13} = 0$ excluded at 99.8% (2.9σ)

Presented in arXiv:1207.6632, accepted by PRD

Summary and Prospects

- Double Chooz updated measurement of θ_{13}, that includes rate + energy spectrum shape fit:

Rate+Shape: $\sin^2 2\theta_{13} = 0.109 \pm 0.030$ (stat.) ± 0.025 (syst.)

- Results obtained with far detector only: 99.8% exclusion of the zero θ_{13}.
- One full week of data taking with both reactors off : directly cross-check background estimates.
- Two detector phase to commence by the end of 2013.

$\nu_\mu \to \nu_e$ appearance probability

The ν_e appearance probability can be written approximately as a sum of terms quadratic in the small parameters $\alpha = \Delta m^2_{21}/\Delta m^2_{31} \approx 1/32$, and $\sin 2\theta_{13}$:

$$P(\nu_\mu \to \nu_e) \approx T_{\theta\theta} \sin^2 2\theta_{13} \frac{\sin^2([1-A]\Delta)}{[1-A]^2} + T_{\alpha\alpha}\alpha^2 \frac{\sin^2(A\Delta)}{A^2} + T_{\alpha\theta}\alpha \sin 2\theta_{13} \frac{\sin([1-A]\Delta)}{(1-A)} \frac{\sin(A\Delta)}{A} \cos(\delta + \Delta)$$

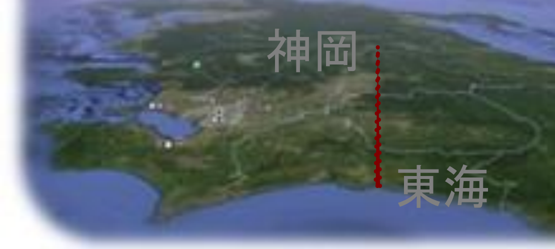
where

$$T_{\theta\theta} = \sin^2\theta_{23}, \qquad T_{\alpha\alpha} = \cos^2\theta_{23} \sin^2 2\theta_{12},$$
$$T_{\alpha\theta} = \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23}$$

and $\Delta = \frac{\Delta m^2_{31} L}{4E} \sim \frac{\pi}{2}$ at 1st osc. maximum.

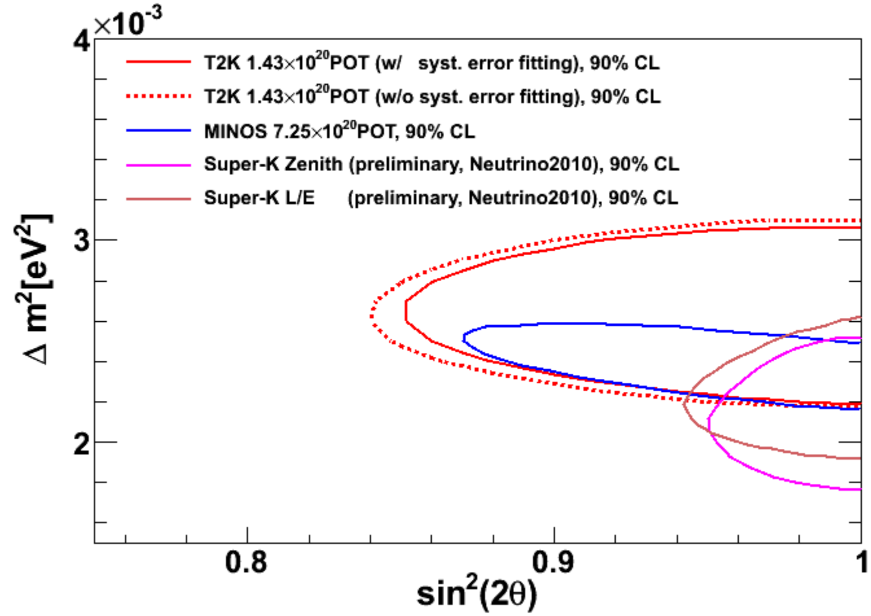
$A(= \pm 2\sqrt{2} G_F n_e E / |\Delta m^2_{31}|)$ is the matter density parameter. For T2K, $|A| \sim 0.07$

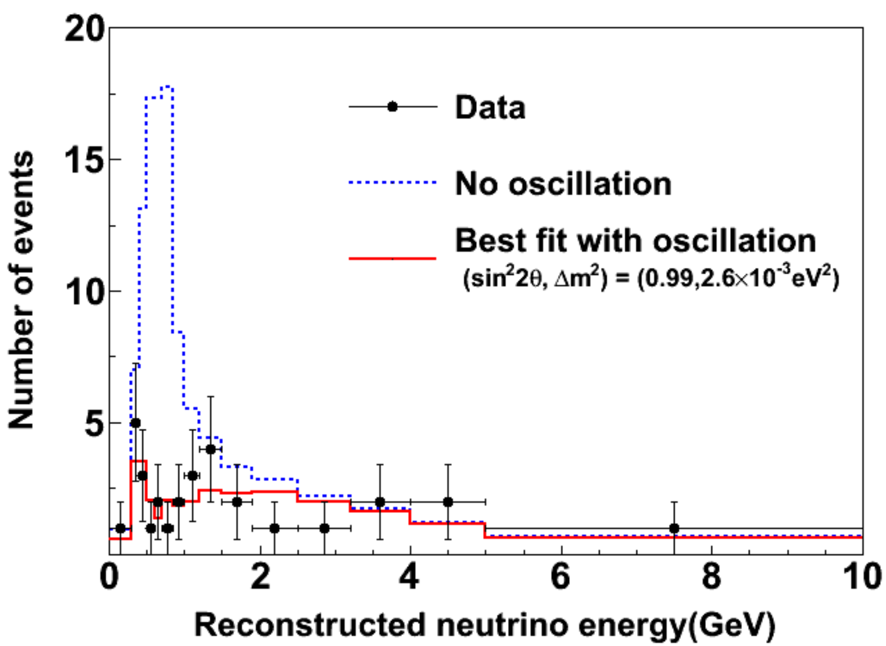
ν_μ disappearance analysis



Use quasi-elastic reaction kinematics to reconstruct neutrino energy.

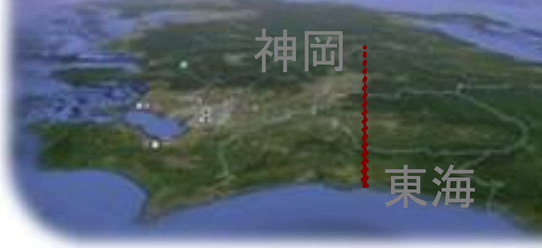
$$E_\nu = \frac{m_N E_\ell - m_\ell^2/2}{m_N - E_\ell + \boldsymbol{p}_\ell \cdot \hat{\boldsymbol{p}}_\nu}$$





Already comparable to MINOS in $\sin^2 2\theta_{23}$.
This is run 1 & 2 only (about half of data taken so far). Goal is to increase by an order of magnitude.

Summary



T2K is progressing well

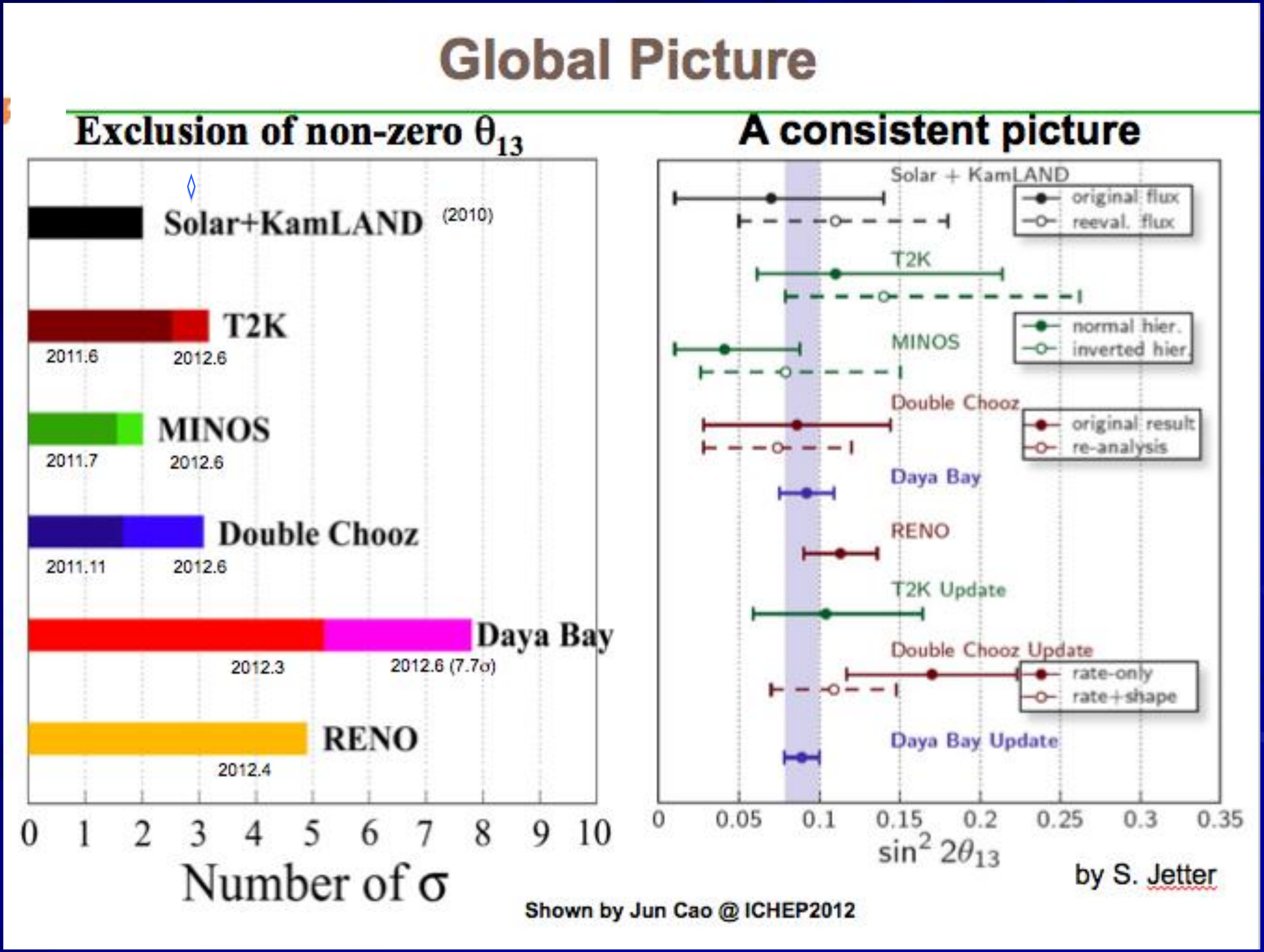
- Earthquake set us back, but still competitive, and now running fine.
  - Data taking in Run 4 (2012~13) started last month.
- Only direct evidence for ν_e appearance at atmospheric scale: **Reject $U_{e3} = 0$ at 3.2σ**
- Will soon have world-leading measurements in disappearance channel ($|\Delta m^2_{\mathrm{atm}}|$, θ_{23})

Future analyses can look into δ_{CP} and $\mathrm{sign}[\Delta m^2_{atm}]$

Many other analyses not covered here:

- Lorentz violation
- Sterile neutrinos and new mass splittings.
- Neutrino-nucleon cross sections

θ_{13} has been measured



SO(10)Grand Unification

SO(10) Yukawa couplings: $16_F(Y_{10}10_H + Y_{\overline{126}}\overline{126}_H + Y_{120}120_H)16_F$

Minimal SO(10) Model without 120

$$\mathcal{L}_{\text{Yukawa}} = Y_{10}\,\mathbf{16}\,\mathbf{16}\,\mathbf{10}_H + Y_{126}\,\mathbf{16}\,\mathbf{16}\,\overline{\mathbf{126}}_H$$

Two Yukawa matrices determine all fermion masses and mixings, including the neutrinos

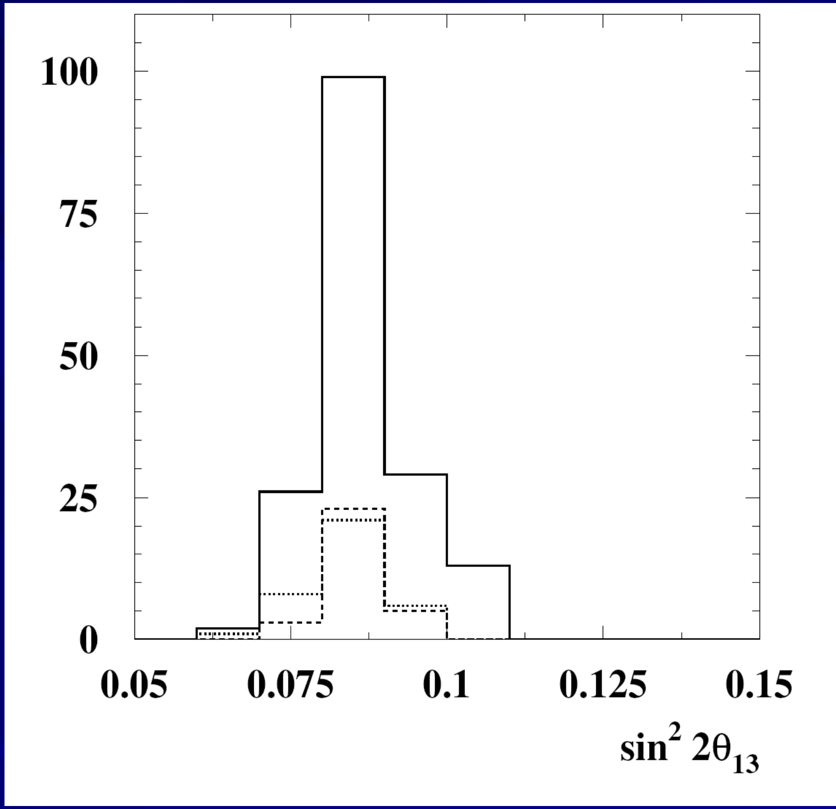
$$\begin{aligned} M_u &= \kappa_u Y_{10} + \kappa'_u Y_{126} \\ M_d &= \kappa_d Y_{10} + \kappa'_d Y_{126} \\ M_\nu^D &= \kappa_u Y_{10} - 3\kappa'_u Y_{126} \\ M_l &= \kappa_d Y_{10} - 3\kappa'_d Y_{126} \end{aligned}$$

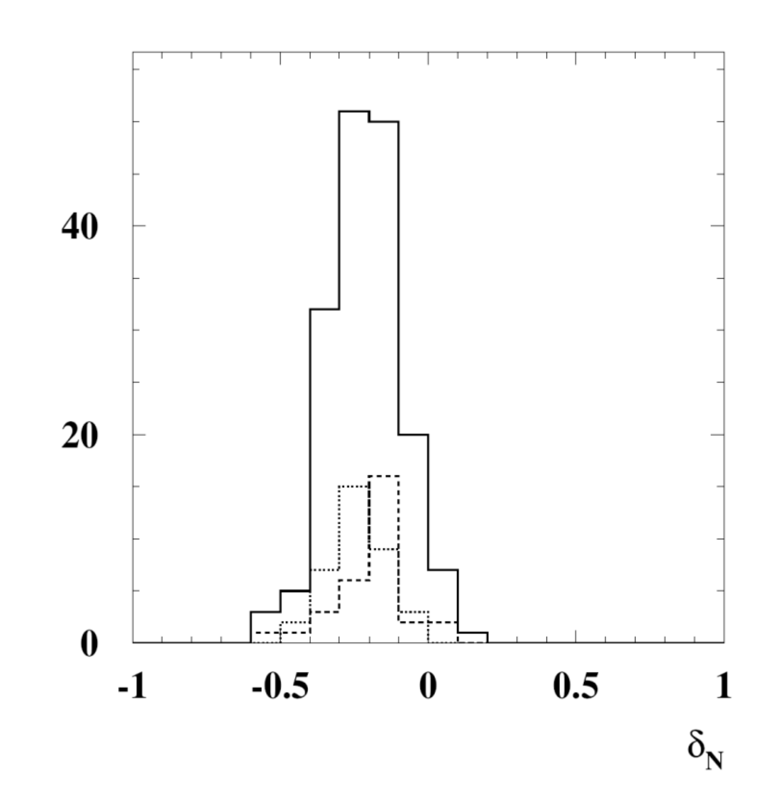
$$\begin{aligned} M_{\nu R} &= \langle \Delta_R \rangle Y_{126} \\ M_{\nu L} &= \langle \Delta_L \rangle Y_{126} \end{aligned}$$

Model has only 11 real parameters plus 7 phases

Babu, Mohapatra (1993)
Fukuyama, Okada (2002)
Bajc, Melfo, Senjanovic, Vissani (2004)
Fukuyama, Ilakovac, Kikuchi, Meljanac, Okada (2004)
Aulakh et al (2004)
Bertolini, Frigerio, Malinsky (2004)
Babu, Macesanu (2005)
Bertolini, Malinsky, Schwetz (2006)
Dutta, Mimura, Mohapatra (2007)
Bajc, Dorsner, Nemevsek

θ_{13} in Minimal SO(10)





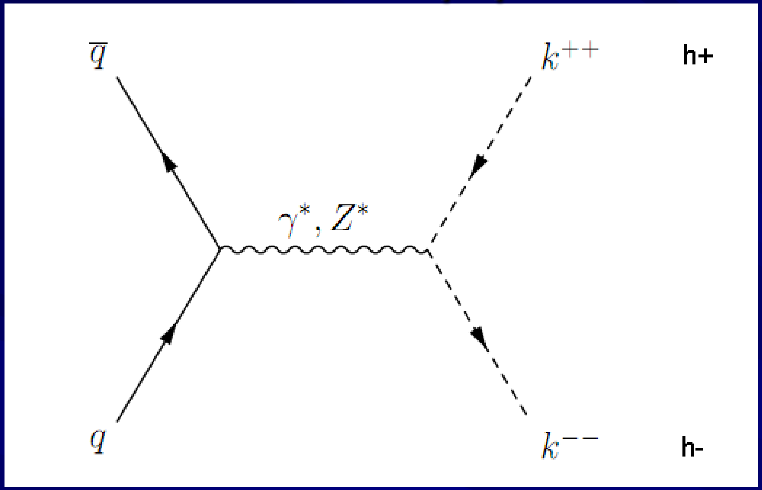
$\sin^2 2\theta_{13}$ and CP violating phase δ_N

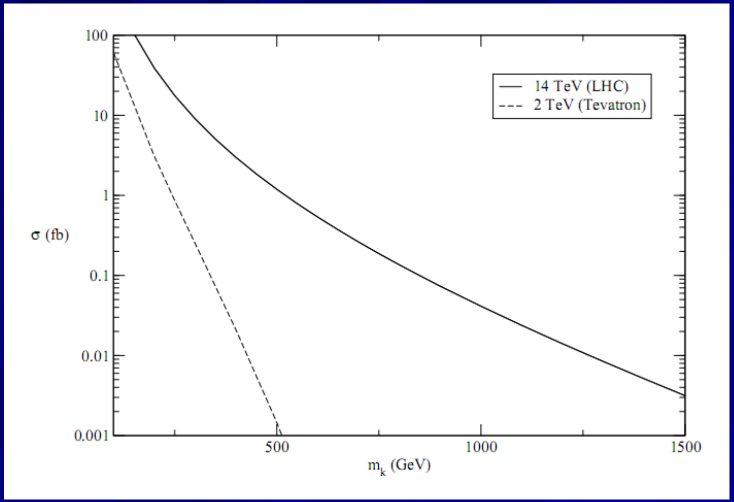
K.S. Babu and C. Macesanu (2005)

Both Zee, Babu-Zee models have q q-bar -> $h^+ h^-$

Zee-Babu new: q q-bar -> $k^{++} k^{--}$

Nebot et al

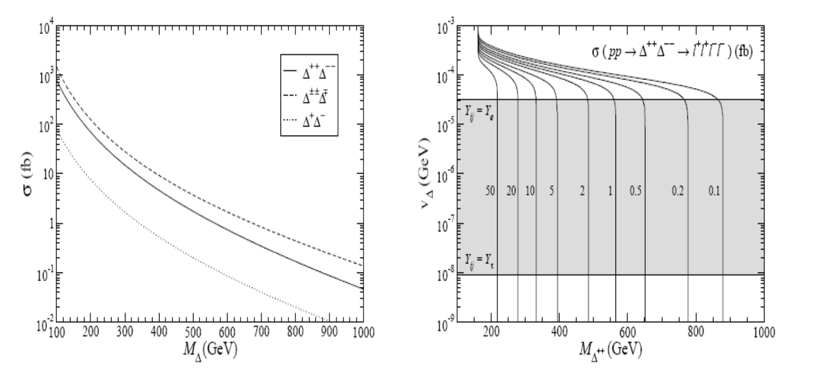




Type II seesaw at the LHC

A new triplet Δ contains:

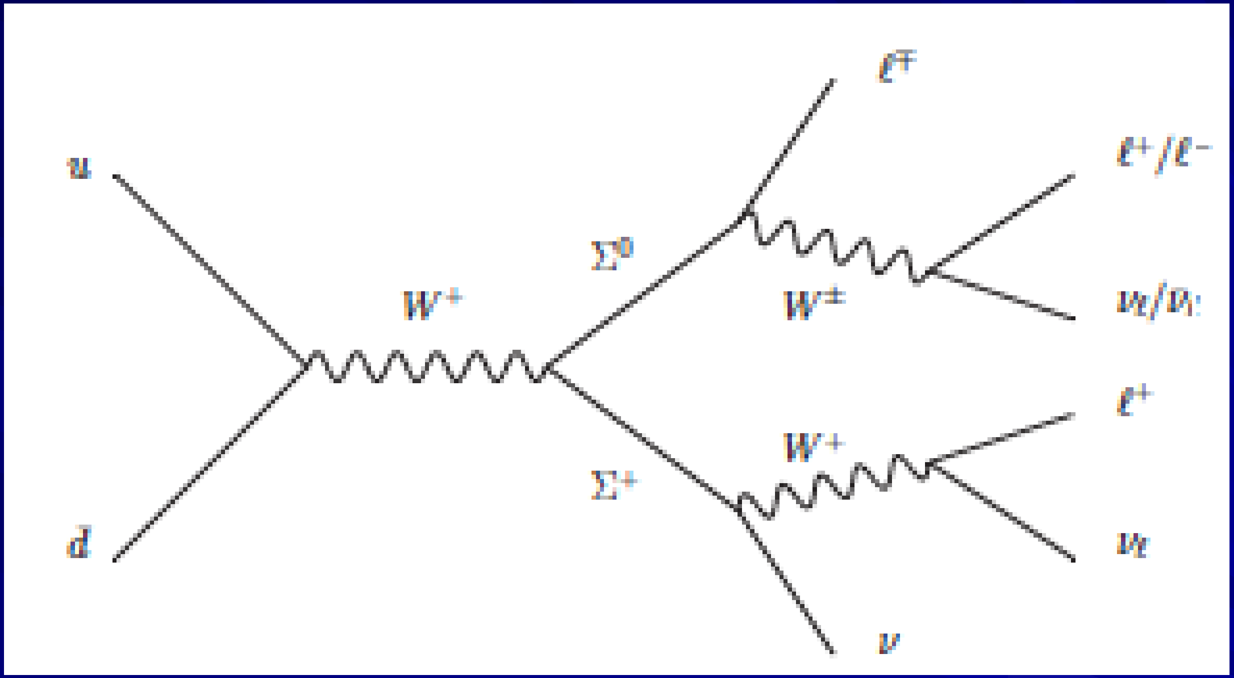
0, +, ++ charged scalars.



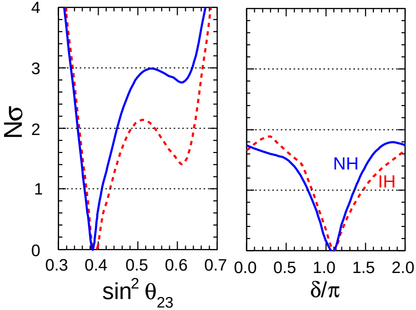
Left: Cross section for production of charged scalar pairs $\Delta^{++}\Delta^{--}$, $\Delta^{\pm\pm}\Delta^{\mp}$ and $\Delta^+\Delta^-$ at LHC. Right: cross section for $\Delta^{++}\Delta^{--}$ decaying into four lepton final states.

Del Aguila and Aguilar-Saavedra

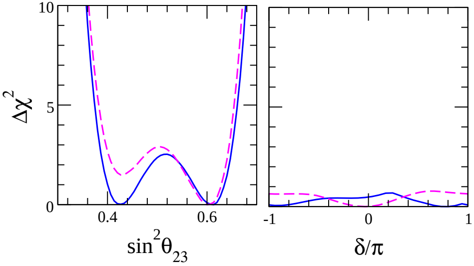
CMS search limit for Type III seesaw particles arXiv:1210.1797



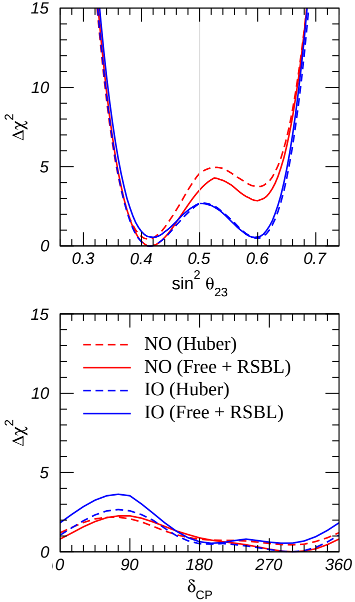
Depending on the considered scenarios, lower limits are obtained on the mass of the heavy partner of the neutrino that range from 180 to 210 GeV.These are the first limits on the production of type III seesaw fermionic triplet states reported by an experiment at the LHC.



[Fogli, Lisi, Marrone, Montanino, Palazzo, Rotunno, PRD 86 (2012) 013012]



[Forero, Tortola, Valle, PRD 86 (2012) 073012]

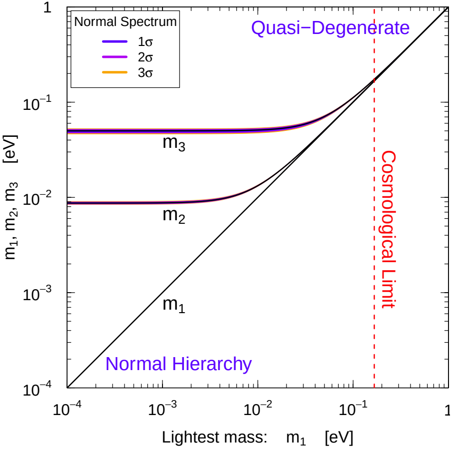


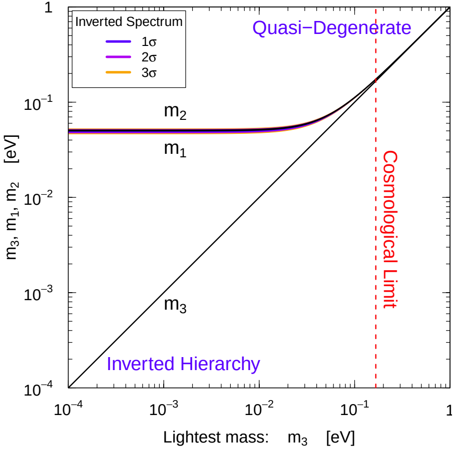
[Gonzalez-Garcia, Maltoni, Salvado, Schwetz, arXiv:1209.3023; http://www.nu-fit.org]

Open Problems

- $\vartheta_{23} < 45^\circ$?
  - Atmospheric Neutrinos, T2K, NOνA, ...
- CP violation ?
  - NOνA, LAGUNA, CERN-GS, HyperK, ...
- Mass Hierarchy ?
  - NOνA, Atmospheric Neutrinos, Day Bay II, Supernova Neutrinos, ...
- Absolute Mass Scale ?
  - β Decay, Neutrinoless Double-β Decay, Cosmology, ...
- Dirac or Majorana ?
  - Neutrinoless Double-β Decay, ...

Absolute Scale of Neutrino Masses



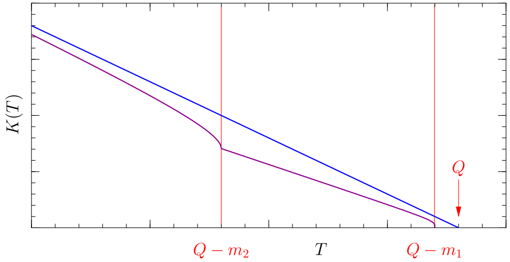


$$m_2^2 = m_1^2 + \Delta m_{21}^2 = m_1^2 + \Delta m_S^2$$
$$m_3^2 = m_1^2 + \Delta m_{31}^2 = m_1^2 + \Delta m_A^2$$

$$m_1^2 = m_3^2 - \Delta m_{31}^2 = m_3^2 + \Delta m_A^2$$
$$m_2^2 = m_1^2 + \Delta m_{21}^2 \simeq m_3^2 + \Delta m_A^2$$

Quasi-Degenerate for $m_1 \simeq m_2 \simeq m_3 \simeq m_\nu \gtrsim \sqrt{\Delta m_A^2} \simeq 5 \times 10^{-2}\,\text{eV}$

Neutrino Mixing $\Longrightarrow K(T) = \left[(Q-T) \sum_k |U_{ek}|^2 \sqrt{(Q-T)^2 - m_k^2} \right]^{1/2}$



analysis of data is different from the no-mixing case: $2N-1$ parameters $\left(\sum_k |U_{ek}|^2 = 1 \right)$

if experiment is not sensitive to masses ($m_k \ll Q - T$)

effective mass: $m_\beta^2 = \sum_k |U_{ek}|^2 m_k^2$

$$K^2 = (Q-T)^2 \sum_k |U_{ek}|^2 \sqrt{1 - \frac{m_k^2}{(Q-T)^2}} \simeq (Q-T)^2 \sum_k |U_{ek}|^2 \left[1 - \frac{1}{2} \frac{m_k^2}{(Q-T)^2} \right]$$

$$= (Q-T)^2 \left[1 - \frac{1}{2} \frac{m_\beta^2}{(Q-T)^2} \right] \simeq (Q-T) \sqrt{(Q-T)^2 - m_\beta^2}$$

Sterile Neutrinos

- Sterile means no standard model interactions (e.g. $\nu_R^c = \nu_{sL}$)
- Oscillation observables:
  - Disappearance of active neutrinos (neutral current deficit)
  - Indirect evidence through combined fit of data (current indication)
- Short-baseline anomalies + 3ν-mixing:

$$
\begin{array}{ccccc}
 & \Delta m^2_{21} \ll & |\Delta m^2_{31}| \ll & |\Delta m^2_{41}| \leq & \ldots \\
\nu_1 & \nu_2 & \nu_3 & \nu_4 & \ldots \\
\nu_e & \nu_\mu & \nu_\tau & \nu_{s_1} & \ldots
\end{array}
$$

- Neutrino number and mass observable:
  - Number of thermalized relativistic particles in early Universe (BBN, CMB, BAO)
  - m_4 effects in cosmology (CMB, LLS), direct β-decay neutrino mass measurements and neutrinoless double-β decay (if Majorana)

Reactor Electron Antineutrino Anomaly

[Mention et al, PRD 83 (2011) 073006]

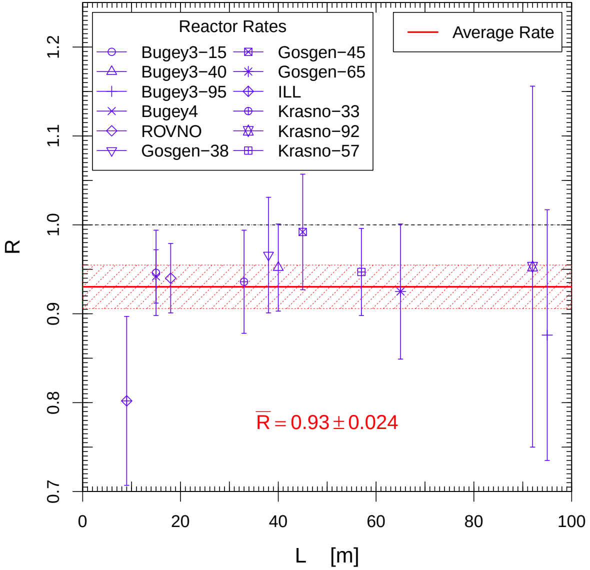
[update in White Paper, arXiv:1204.5379

new reactor $\bar{\nu}_e$ fluxes

[Mueller et al, PRC 83 (2011) 054615]

[Huber, PRC 84 (2011) 024617]

2.8σ anomaly



Gallium Anomaly

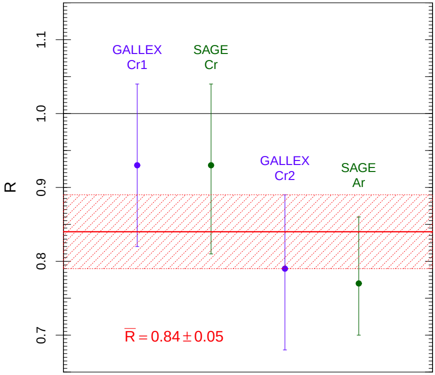
Gallium Radioactive Source Experiments: GALLEX and SAGE

Detection Process: $\nu_e + {}^{71}\text{Ga} \to {}^{71}\text{Ge} + e^-$

ν_e Sources: $e^- + {}^{51}\text{Cr} \to {}^{51}\text{V} + \nu_e$ $e^- + {}^{37}\text{Ar} \to {}^{37}\text{Cl} + \nu_e$

Anomaly supported by new ${}^{71}\text{Ga}({}^{3}\text{He}, {}^{3}\text{H}){}^{71}\text{Ge}$ cross section measurement

[Frekers et al., PLB 706 (2011) 134]



$E \sim 0.7\,\text{MeV}$

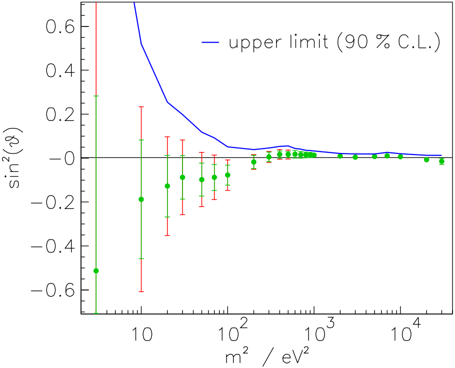
$\langle L \rangle_{\text{GALLEX}} = 1.9\,\text{m}$

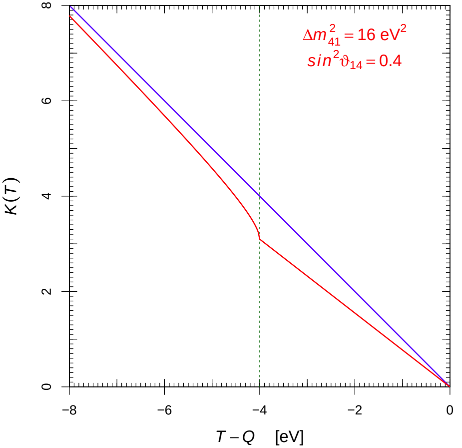
$\langle L \rangle_{\text{SAGE}} = 0.6\,\text{m}$

2.9σ anomaly

Mainz Limit on m_4^2

[Kraus, Singer, Valerius, Weinheimer, arXiv:1210.4194]





$$m_4 \gg m_1, m_2, m_3 \quad \Longrightarrow \quad \Delta m^2_{41} \equiv m_4^2 - m_1^2 \simeq m_4^2$$

Cosmology

- N_s = number of thermalized sterile neutrinos (not necessarily integer)

- CMB and LSS in ΛCDM: $N_s = 1.3 \pm 0.9$ $m_s < 0.66\,\text{eV}$ (95% C.L.)

[Hamann, Hannestad, Raffelt, Tamborra, Wong, PRL 105 (2010) 181301]

$$N_s = 1.61 \pm 0.92 \qquad m_s < 0.70\,\text{eV} \quad (95\%\ \text{C.L.})$$

[Giusarma, Corsi, Archidiacono, de Putter, Melchiorri, Mena, Pandolfi, PRD 83 (2011) 115023]

- BBN: $\begin{cases} N_s \leq 1 \text{ at } 95\%\ \text{C.L.} \\ N_s = 0.0 \pm 0.5 \end{cases}$ [Mangano, Serpico, PLB 701 (2011) 296] [Pettini, Cooke, arXiv:1205.3785]

- CMB+LSS+BBN: $N_s = 0.85^{+0.39}_{-0.56}$ (95% C.L.)

[Hamann, Hannestad, Raffelt, Wong, JCAP 1109 (2011) 034]

- Standard ΛCDM: 3+1 allowed, 3+2 disfavored

Conclusions

- Robust Three-Neutrino Mixing Paradigm. Open problems: $\vartheta_{23} < 45^\circ$?, CP Violation, Mass Hierarchy, Absolute Mass Scale, Dirac or Majorana?
- Short-Baseline ν_e and $\bar{\nu}_e$ 3+1 Disappearance:
  - Reactor $\bar{\nu}_e$ anomaly is alive and exciting
  - Gallium ν_e anomaly strengthened by new cross-section measurements
  - Many promising projects to test short-baseline ν_e and $\bar{\nu}_e$ disappearance in a few years with reactors and radioactive sources
  - Independent tests through effect of m_4 in β-decay and $(\beta\beta)_{0\nu}$-decay
- Short-Baseline $\bar{\nu}_\mu \to \bar{\nu}_e$ LSND Signal:
  - MiniBooNE experiment has been inconclusive
  - Better experiments are needed to check LSND signal
  - If LSND signal is confirmed $m_4 \sim 1\,\text{eV}$, marginally compatible with ΛCDM
- Cosmology:
  - Very powerful probe of neutrino number and masses
  - Model dependent. Thermalization loophole
  - Bright future (Plank, ...)

SO(10): Representations

Under Pati-Salam($SU(4) \times SU(2)_L \times SU(2)_R$):

- Matter Supermultiplets

$$
\begin{aligned}
16 &= (4,2,1) + (\bar{4},1,2) \\
16 \otimes 16 &= 10 \oplus 120 \oplus 126 \Rightarrow 16 \cdot 16 \cdot (10 + 120 + \overline{126})
\end{aligned}
$$

- Higgs Supermultiplets

$$
\begin{aligned}
10_H &= (\mathbf{1},\mathbf{2},\mathbf{2}) + (6,1,1) \\
\overline{126}_H &= (\mathbf{10},\mathbf{1},\mathbf{3}) + (\overline{\mathbf{10}},\mathbf{3},\mathbf{1}) + (\mathbf{15},\mathbf{2},\mathbf{2}) + (6,1,1) \\
120_H &= (10,1,1) + (\overline{10},1,1) + (\mathbf{15},\mathbf{2},\mathbf{2}) + (6,1,3) \\
&\quad +(6,3,1) + (\mathbf{1},\mathbf{2},\mathbf{2}) \\
210_H &= (\mathbf{15},\mathbf{1},\mathbf{1}) + (\mathbf{1},\mathbf{1},\mathbf{1}) + (\mathbf{15},\mathbf{1},\mathbf{3}) + (15,3,1) \\
&\quad +(6,2,2) + (10,2,2) + (\overline{10},2,2)
\end{aligned}
$$

Role Of Different Rep's

Thus a complete viable model can be constructed by choosing different rep's.

- 16 can contain $(Q_L, u_L^c, d_L^c, L_L, e_L \bigoplus \nu_L^c)$
- Charged fermion Masses$(16 \cdot 16 \cdot (10 + \overline{126} + 120))$
  (1,2,2)$\subset$ 10, (15,2,2)$\subset$ $\overline{126}$, (1,2,2),(15,2,2)$\subset$ 120
  Only one not sufficient!!...give bad mass relations!
- $\overline{126}$: Type I + Type II(seesaw masses!!)

$$
\begin{aligned}
M_{\nu_R} &= <(10,1,3)> Y_{\overline{126}}, M_{\nu_L} =< (\overline{10},3,1) > Y_{\overline{126}} \\
M_{\nu} &= -M_{\nu_D} M_{\nu_R}^{-1} M_{\nu_D} + M_{\nu_L}
\end{aligned}
\qquad (1)
$$

- (15,1,1),(1,1,1),(15,1,3) $\subset$ 210
  Completes symmetry breakdown: SO(10)$\rightarrow$ MSSM by 210.

Minimal Supersymmetric Grand Unified Theory(MSGUT)

This theory was proposed long ago[1,2] but recently studied in detail

- Superpotential:($\mathbf{10} \oplus \overline{\mathbf{126}} \oplus \mathbf{126} \oplus \mathbf{210}$)

$$\begin{aligned} W_{AM} &= \frac{1}{2} M_H H_i^2 + \frac{m}{4!}\Phi_{ijkl}\Phi_{ijkl} + \frac{\lambda}{4!}\Phi_{ijkl}\Phi_{klmn}\Phi_{mnij} \\ &+ \frac{M}{5!}\Sigma_{ijklm}\overline{\Sigma}_{ijklm} + \frac{\eta}{4!}\Phi_{ijkl}\Sigma_{ijmno}\overline{\Sigma}_{klmno} \\ &+ \frac{1}{4!} H_i \Phi_{jklm}(\gamma\Sigma_{ijklm} + \overline{\gamma}\overline{\Sigma}_{ijklm}) \end{aligned}$$

  and

$$W_{FM} = h_{AB}\psi_A^T C_2^{(5)}\gamma_i\psi_B H_i + \frac{1}{5!} f_{AB}\psi_A^T C_2^{(5)}\gamma_{i_1}...\gamma_{i_5}\psi_B\overline{\Sigma}_{i_1...i_5}$$

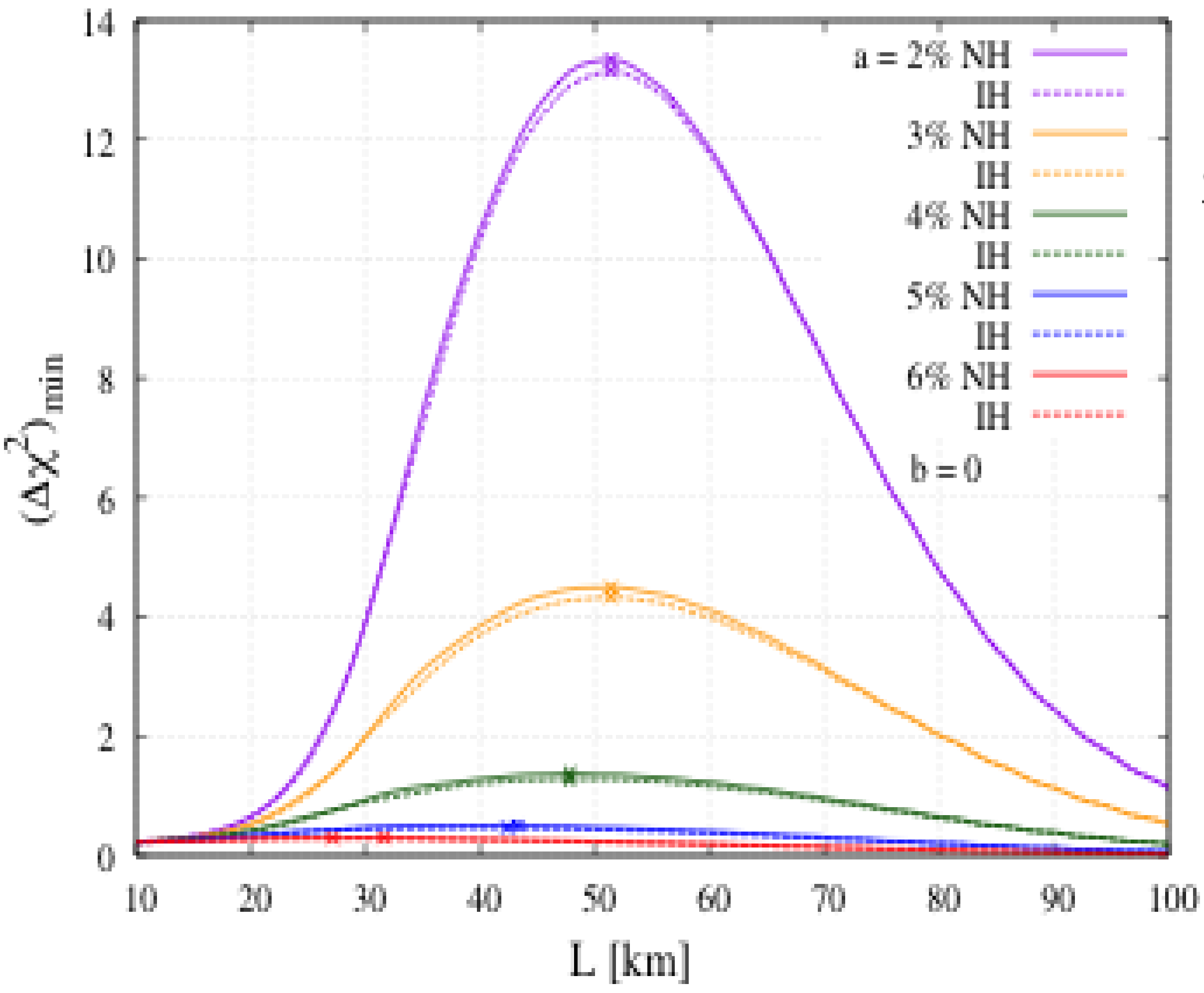
- 26 Hard Parameters(Minimal theory!!..Aulakh etal..hep-ph/0306242)

[1]C.S. Aulakh and R.N. Mohapatra, Phys.Rev.D28,217(1983).
[2]T.E. Clark etal..Phys. lett. **115B**, 26(1982).

NMSGUT:Conclusions

- The model accurately fit the fermion data.
- only 5 GUT scale soft parameters!!
  (correcting mismatch between SM and MSSM yukawa couplings)
- 3rd generation sfermions are heavy then Ist and 2nd generation (a completely distinct signature of model!!)
- However one should test different yukawa fermion fits so that definite conclusions about soft spectra can be made.
- once it is done one can make predictions about proton decay, B physics etc..for this model

Sensitivity for mass hierarchy



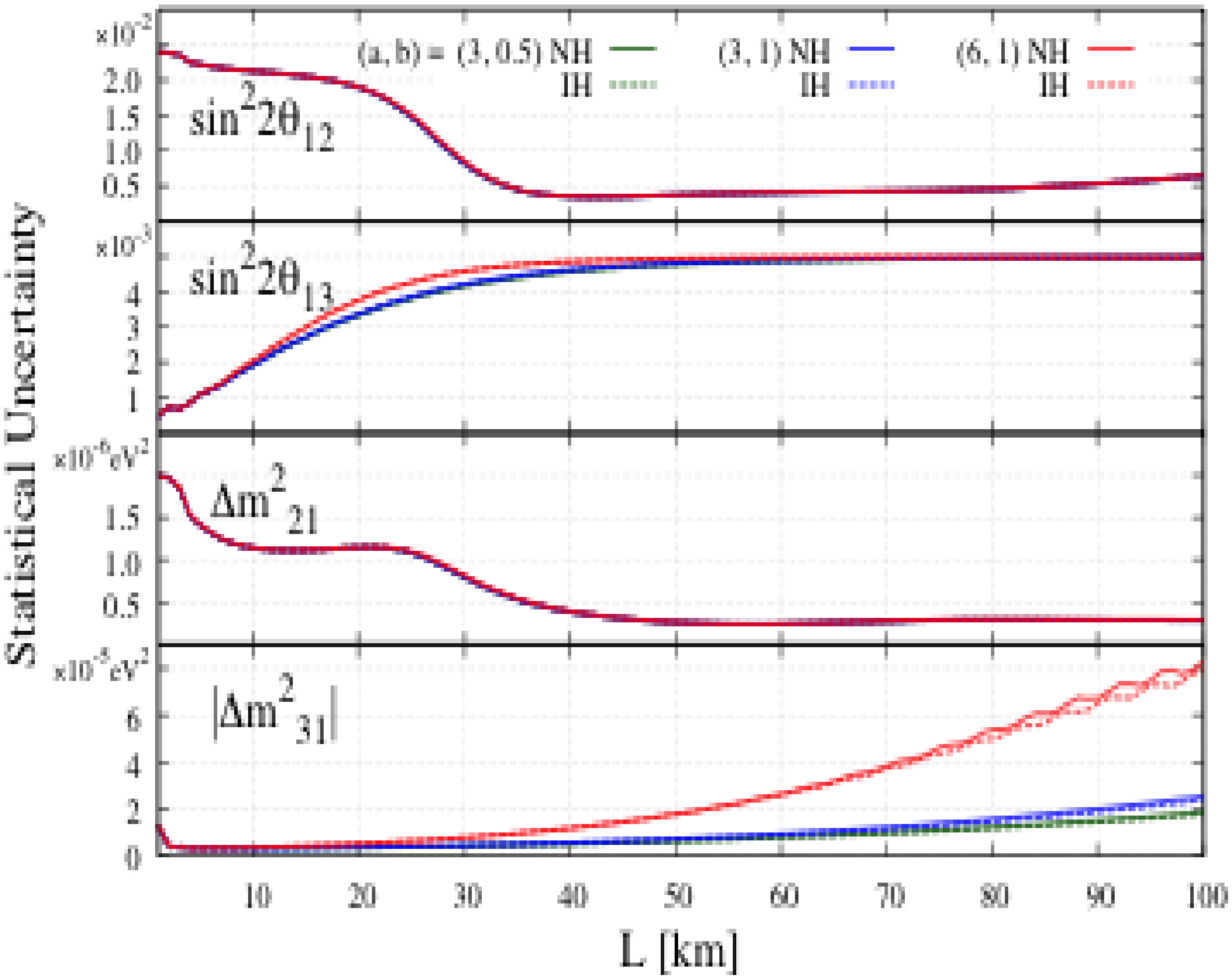
20 GW 5kton 5 years

$$\frac{\delta E}{E} = \sqrt{\left(\frac{a}{\sqrt{E/\mathrm{MeV}}}\right)^2 + b^2}$$

a < 3% for $(\Delta\chi^2)_{min} > 9$

Optimal L ~ 50 km

Uncertainties of Parameters



Parameter measurements are not very sensitive to the Energy resolution

~ 0.5% level of uncertainties can be achieved for

$\sin^2 2\theta_{12}$

Δm^2_{21}

$|\Delta m^2_{31}|$

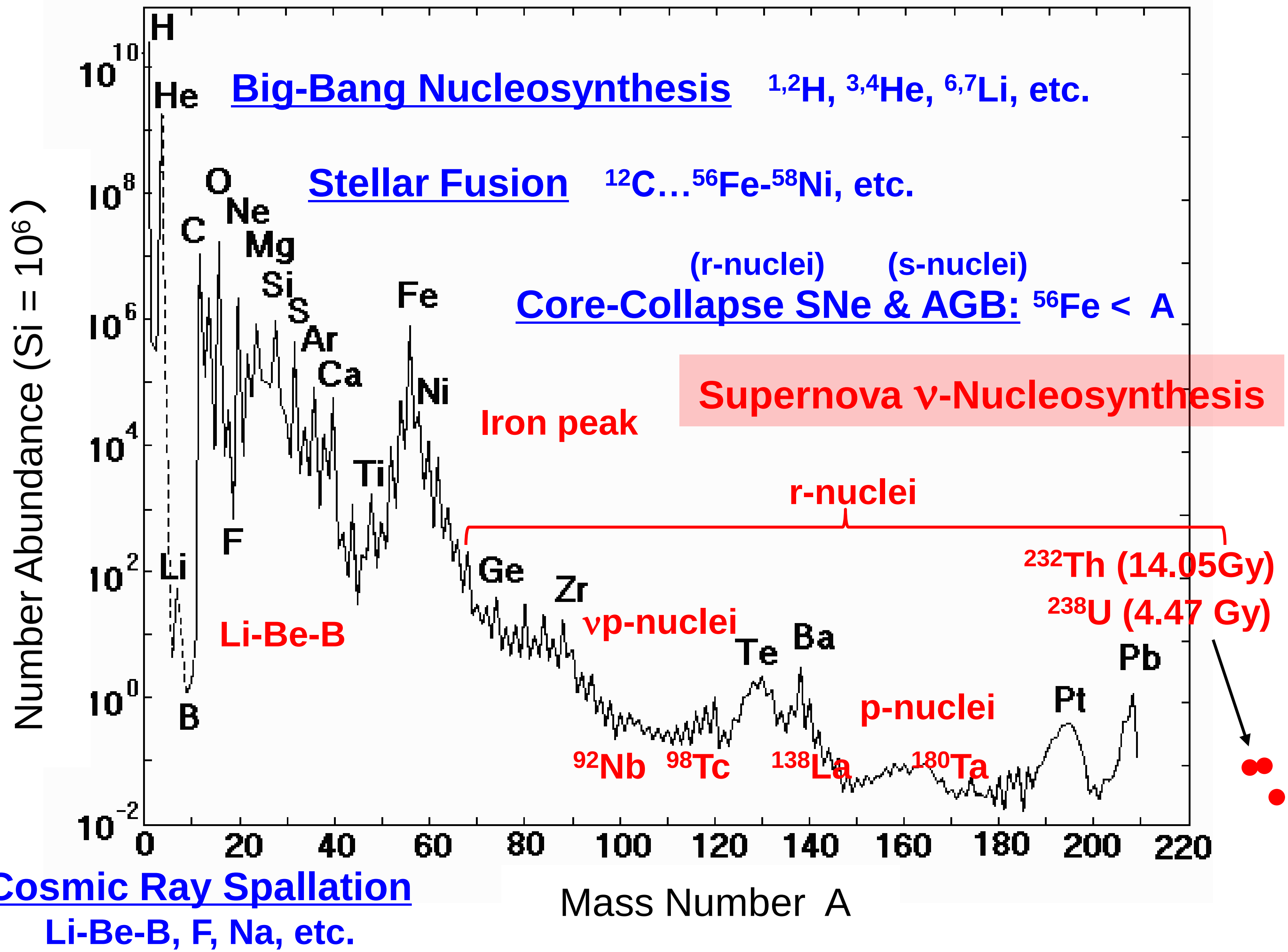
Summary

- We study the sensitivity of a future medium baseline reactor neutrino experiment for MH determination.
- For 20 GW 5kton 5 years exposure,
  - optimal baseline length ~ 50 km
  - < 3% statistical & < 1% systematic errors of Energy Resolution is required
  - 0.5% level of accuracy for Neutrino Parameters

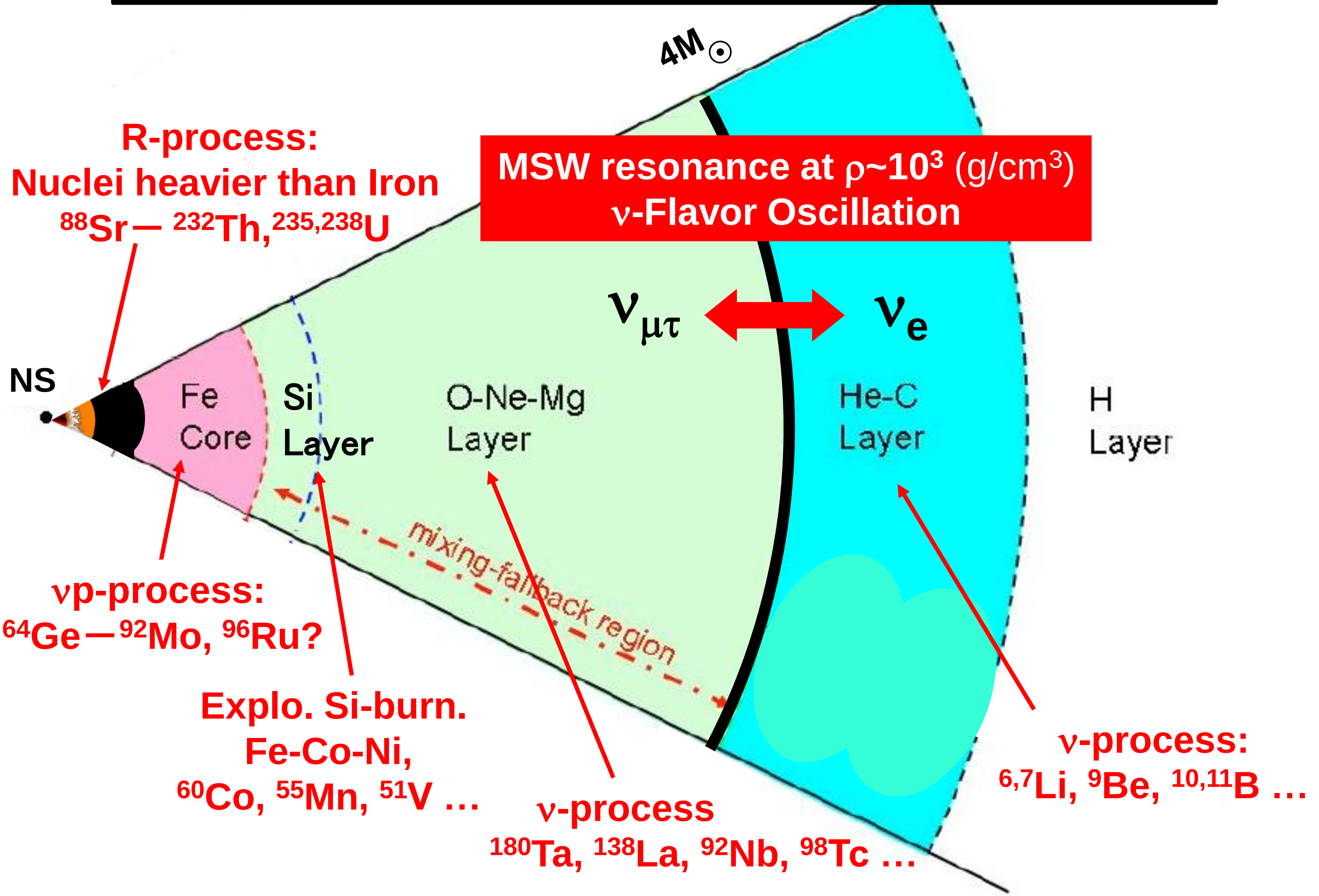
* This study gives the minimum requirement for the energy resolution.

* More realistic study is very sensitive to the environment, such as distribution of reactors within ~100 km from the far detector (J.Evslin et.al, arXiv:1209.2227).

Solar System Abundance



Various roles of ν's in SN-nucleosynthesis



R-process Nucleosynthesis

K. Otsuki, H. Tagoshi, T. Kajino and S. Wanajo, ApJ 533 (2000), 424;
S. Wanajo, T. Kajino, and G. J. Mathews, and K. Otsuki, ApJ J. 554 (2001), 578.

$\nu_e + n \rightarrow p + e^-$

$\overline{\nu}_e + p \rightarrow n + e^+$

$T_{\nu e} = 3.2$ MeV $< T_{\overline{\nu e}} = 4$ MeV

Astrophysical Sites:

- ν-wind SNe
- MHD jets
- NS mergers
- GRBs

\+

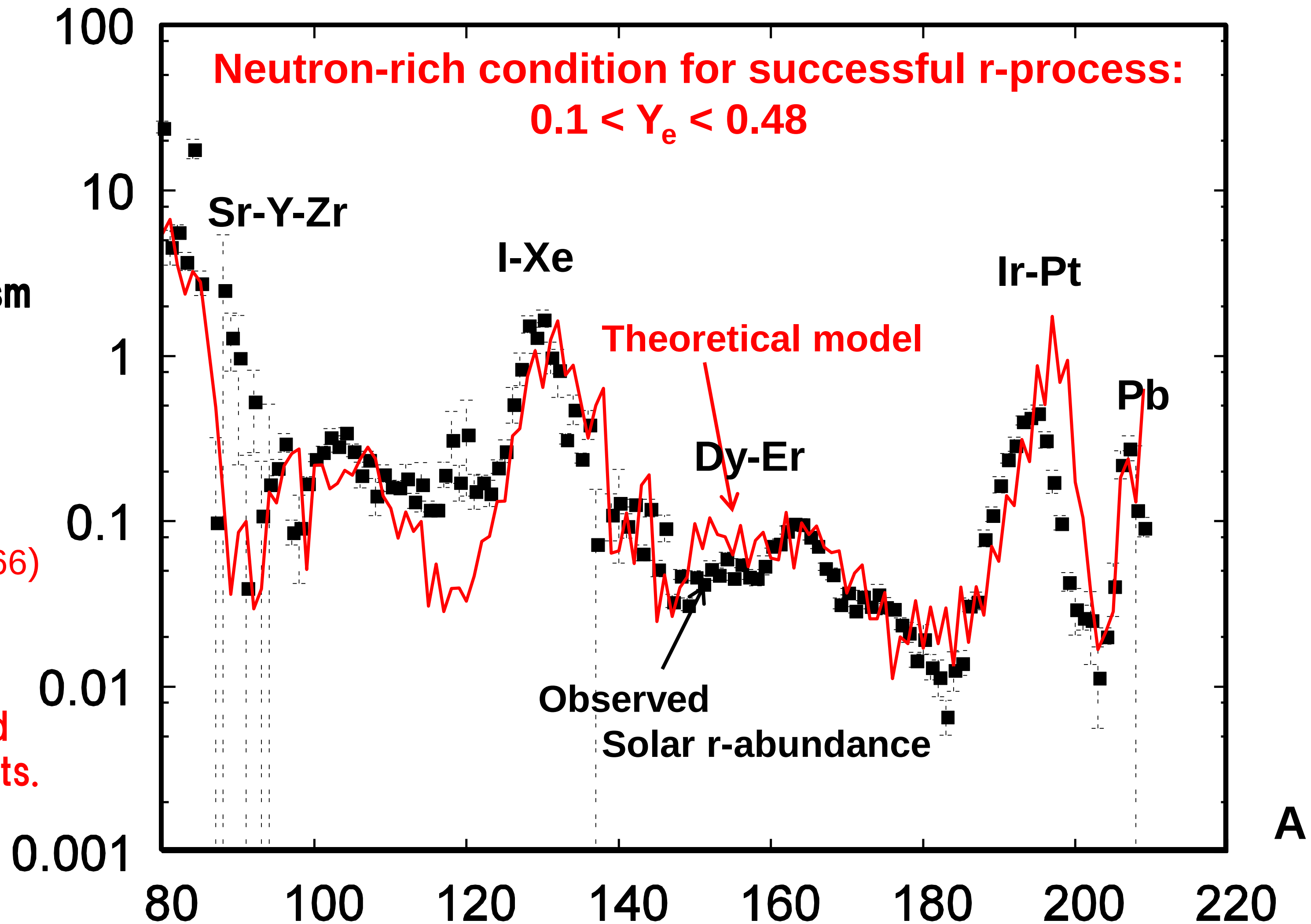
Explosion mechanism

$Y_e > 0.5$?

Roberts, Reddy and Shen (arXiv1205.4066) Confirmed

$Y_e < 0.5$!

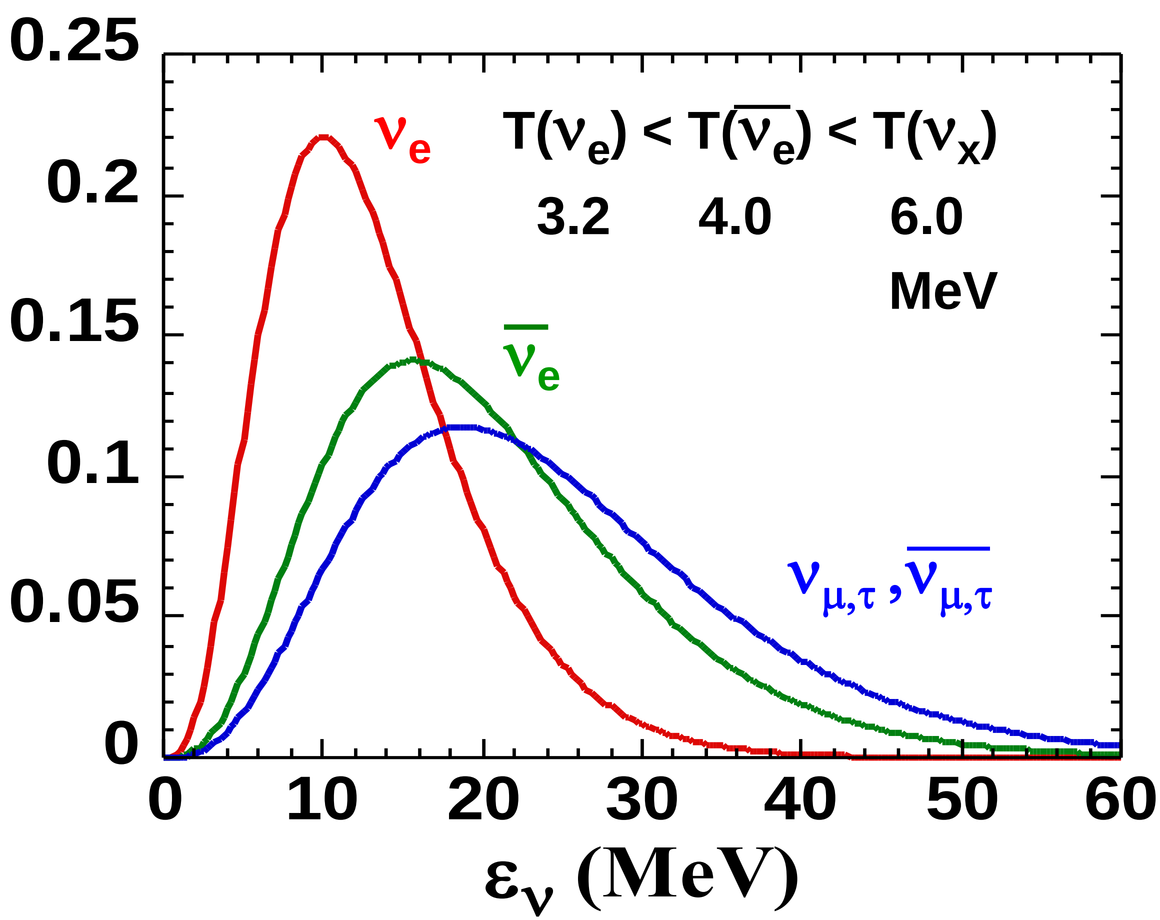
for nucleon pot. and Pauli blocking effects.

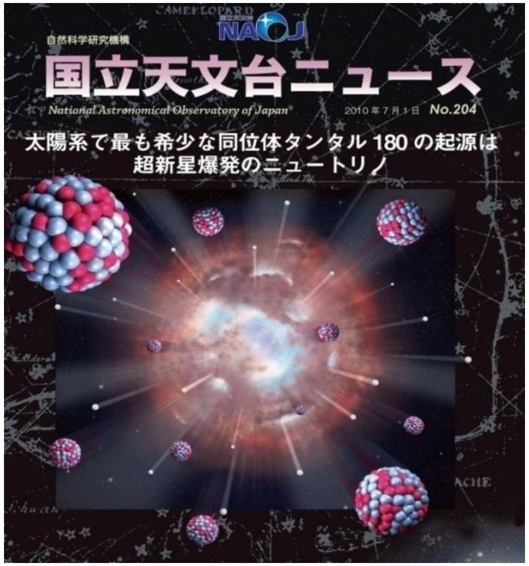


Average ν-temperatures are now known!

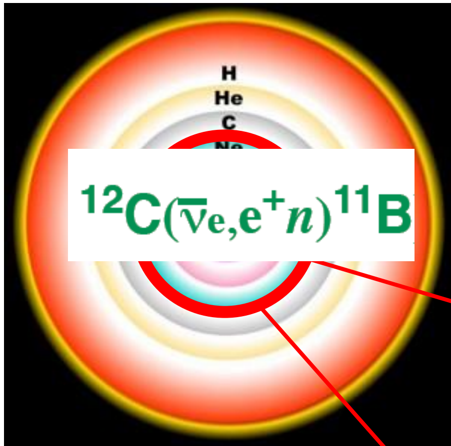
- R-process Elements & $^{180}Ta/^{138}La$ ➡ $T\nu_e = 3.2$ MeV, $T\overline{\nu}_e = 4$ MeV
- Astron. GCE of Light Elements & ^{11}B ➡ $T\nu_{\mu} = T\nu_{\tau} = 6$ MeV

➡ **Study Neutrino Oscillation !**

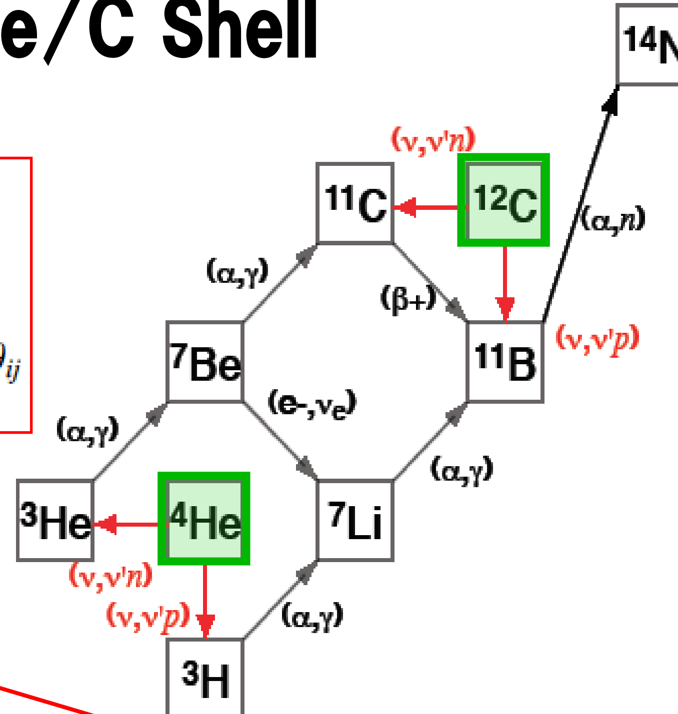




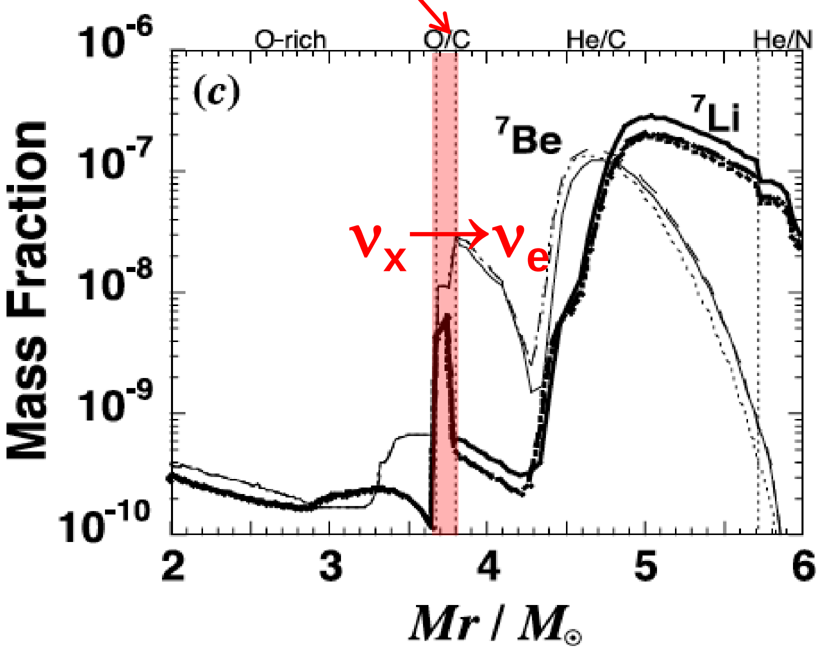
^{7}Li and ^{11}B are produced in the He/C Shell

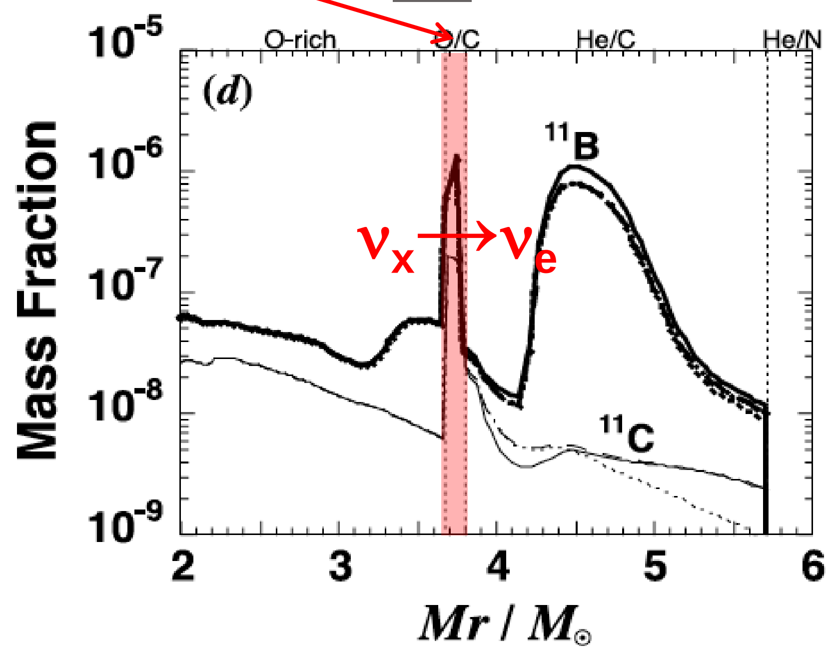


$$\rho_{\rm res} Y_e = \frac{m_u \Delta m_{ji}^2 c^4 \cos 2\theta_{ij}}{2\sqrt{2} G_F (\hbar c)^3 \varepsilon_\nu} \qquad [\,\mathrm{g\ cm^{-3}}\,]$$
$$= 6.55 \times 10^6 \left(\frac{\Delta m_{ji}^2}{1\ \mathrm{eV}^2}\right)\left(\frac{1\ \mathrm{MeV}}{\varepsilon_\nu}\right) \cos 2\theta_{ij}$$

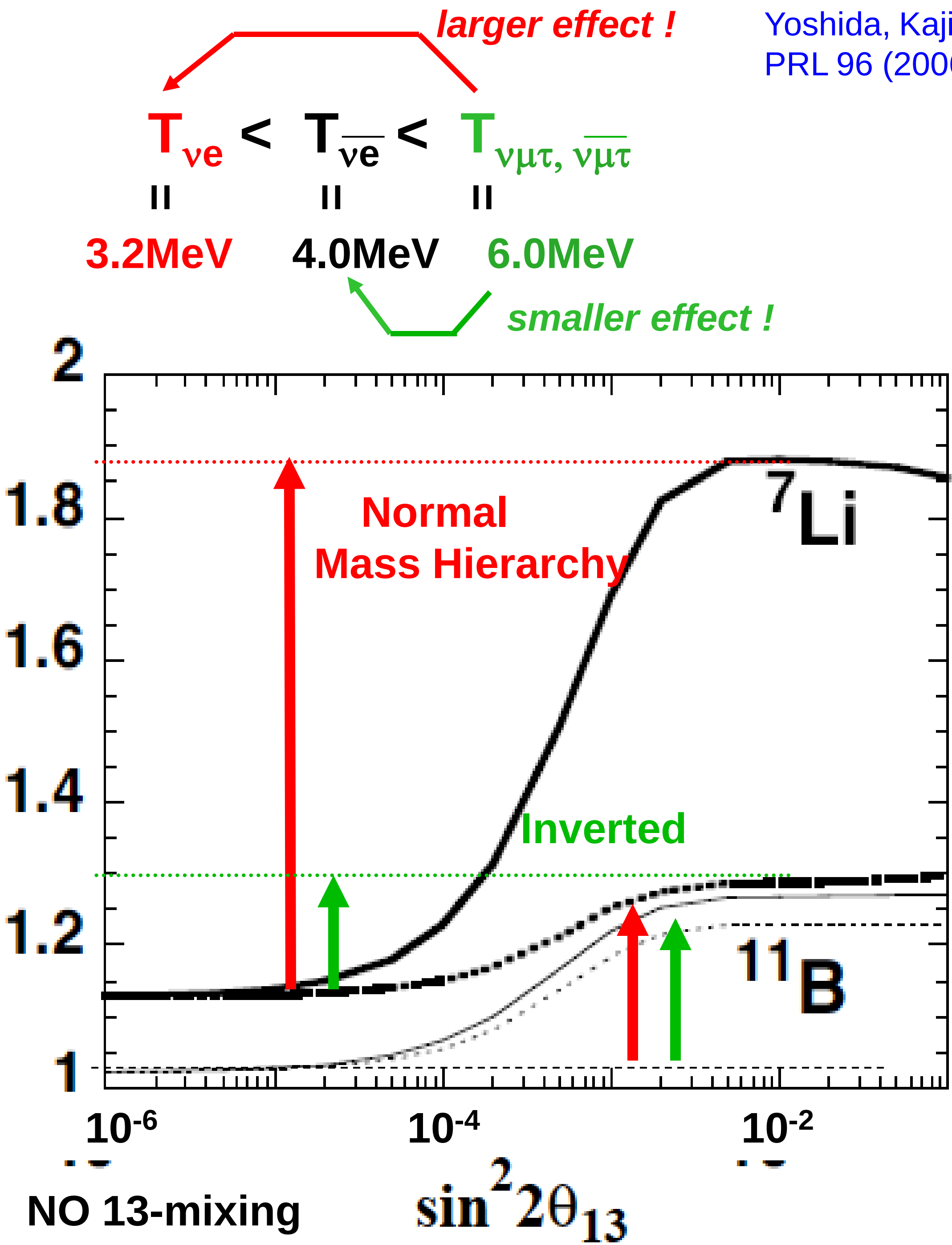


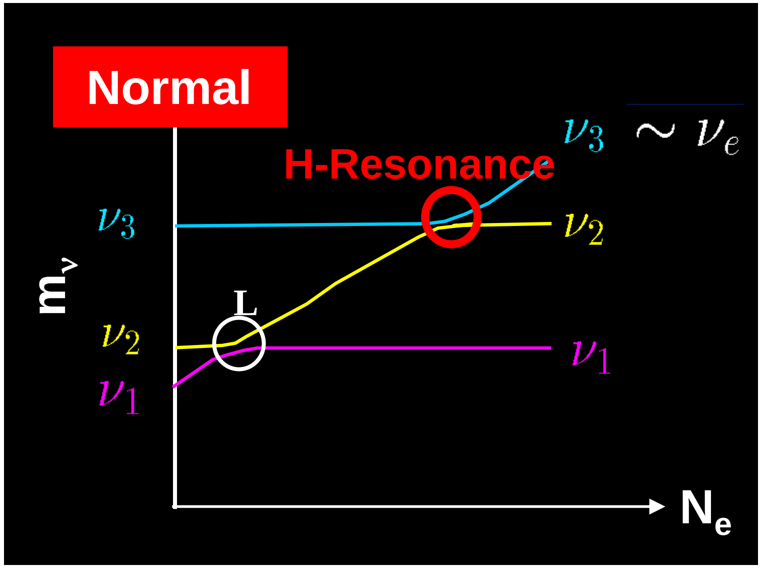
MSW high-density resonance is located at the bottom of C shell.

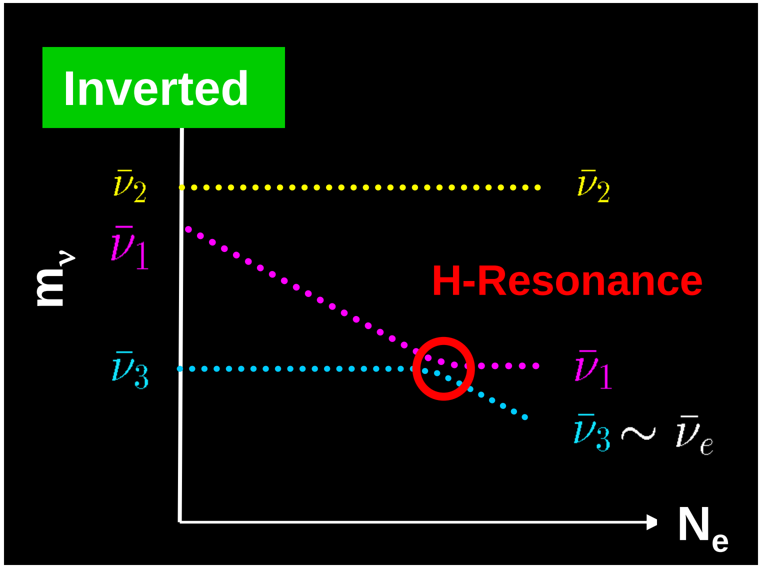




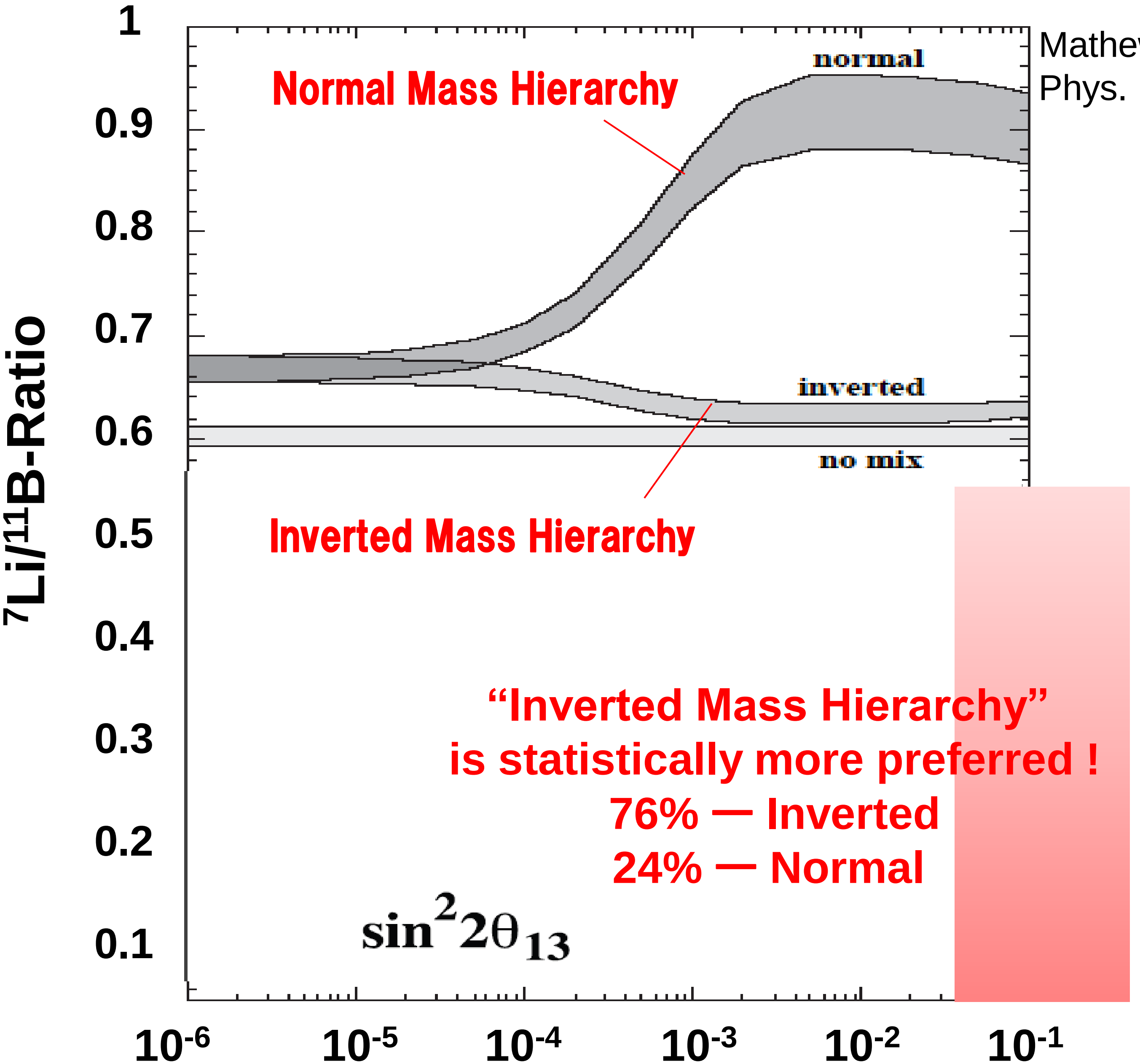
Yoshida, Kajino, Yokomakura, Kimura,Takamura & Hartmann,
PRL 96 (2006) 09110; ApJ 649 (2006), 349.







Supernova X-Grain Coinstraint



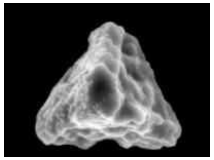
Mathews, Kajino, Aoki & Fujiya, Phys. Rev. D85,105023 (2012).

T2K, MINOS (2011)
Double CHOOZ,
Daya Bay, RENO
(2012)

$\sin^2 2\theta_{13} = 0.1$

+

First Detection of
^{7}Li/^{11}B in SN-grains



W. Fujiya, P. Hoppe, &
U. Ott, ApJ 730, L7 (2011).

Neutrino Physics in Cosmology

● **0νββ in COUORE, NEMO3, EXO, KamLAND Zen:**

$|\sum U^2_{e\beta} m_\beta| < 0.3$ eV: COUORE, NEMO3, EXO, KamLAND Zen (2012)

● **CMB Anisotropies + LSS**

$\sum m_\nu < 0.28$ eV (95% C.L.): WMAP-7yr +SPT (Benson et al. arXiv:1112.5435)

< 0.36 eV (95%C.L.): WMAP-7yr + HST + CMASS (Putter et al. arXiv:1201.1909)

➡ **$\sum m_\nu < 0.2$ eV (2σ, B_λ<2nG):** Yamazaki, Kajino, Mathews & Ichiki, Phys. Rep. 517 (2012), 141; PR D81 (2010), 103519; D77, (2009) 043005.

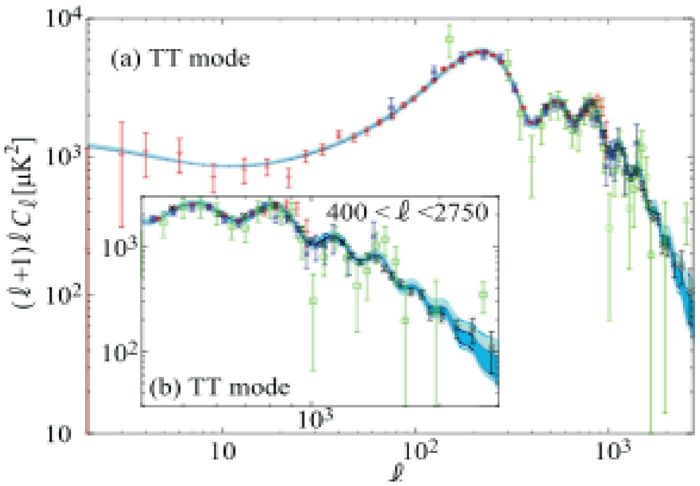
Roles of Neutrino Anisotropic Stress

CMB is affected by:

- integrated Sachs-Wolfe effect
- neutrino free streaming effect

CMB is generated even by :

- compensation mode of neutrino anisotropic stress (π_ν)
- another primordial source of extra anisotropic stress (π_{ext})



Standard cosmology needs tuning initial condition of the inflation-driven (pre-Big-Bang) perturbation !

Neutrino Mass Effect

☆**Analytical solution of massless neutrino anisotropic stress:**

$$\pi_\nu = -\pi_{PMF}\frac{R_\gamma}{R_\nu}\left(1-\frac{c(k\tau)^2}{4R_\nu+15}\right)$$

(Super horizon scale)

☆**Anisotropic stress of massive neutrino:**

$$\pi_h^{(m)} \simeq \pi_\nu^{(m)}\left(1-\frac{1}{2}\frac{5}{7\pi^2}H_0^2\Omega_R m_\nu^2\tau^2\right)$$

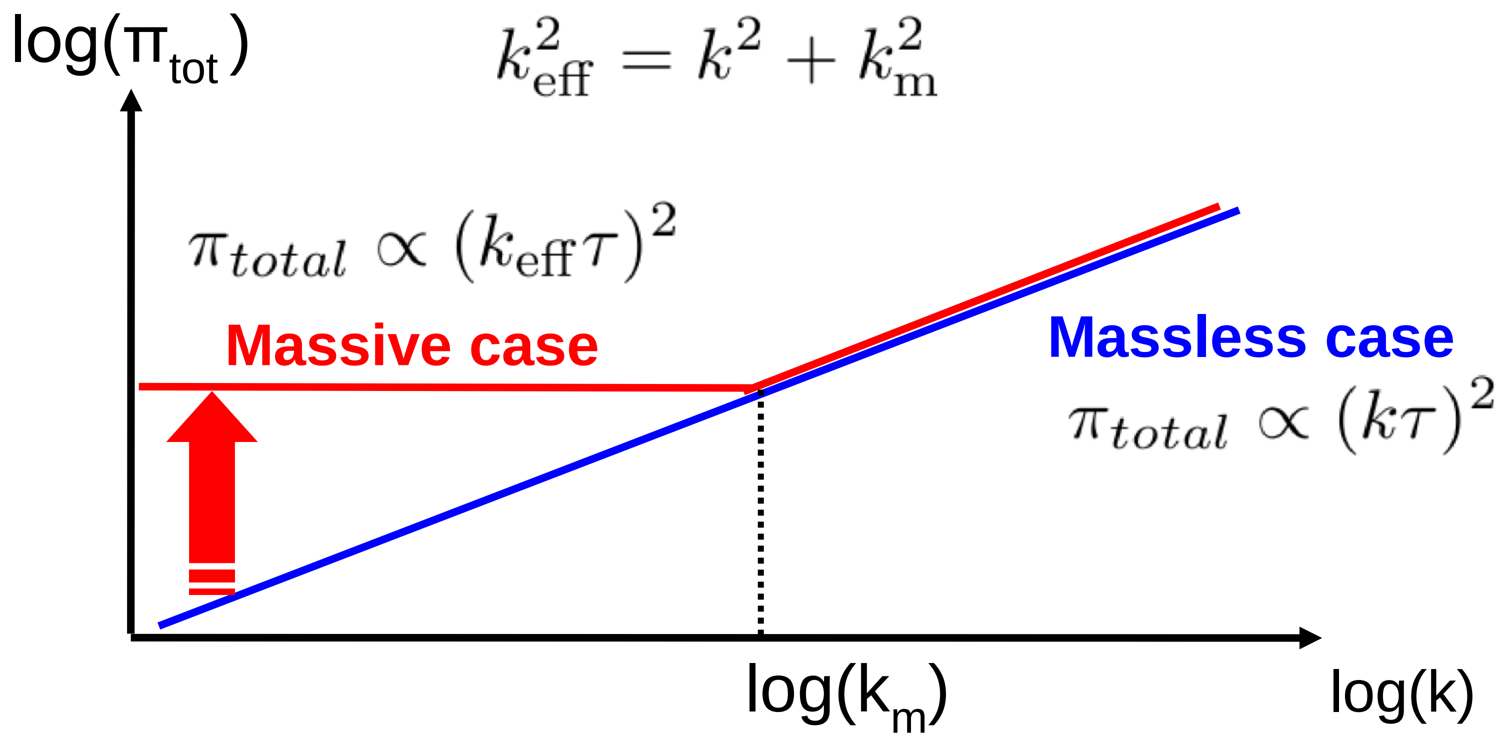
$$\simeq -\pi_{PMF}\frac{R_\gamma}{R_\nu}\left(1-\frac{c(k_{\rm eff}\tau)^2}{4R_\nu+15}\right)$$

Effective wave number

$$k_{\rm eff}^2 = k^2 + k_{\rm m}^2$$

$$k_{\rm m} = \sqrt{\frac{1}{2}\frac{5}{7\pi^2}H_0^2\Omega_R\frac{4R_\nu+15}{c}m_\nu^2}$$

Total anisotropic stress



Vector mode $k_m^{(1)} = 1.9 \times 10^{-3} \times \frac{m_\nu}{\rm eV}\ \ {\rm Mpc}^{-1}$ $\ell_m^{(1)} \sim 27 \times \frac{m_\nu}{\rm eV}$

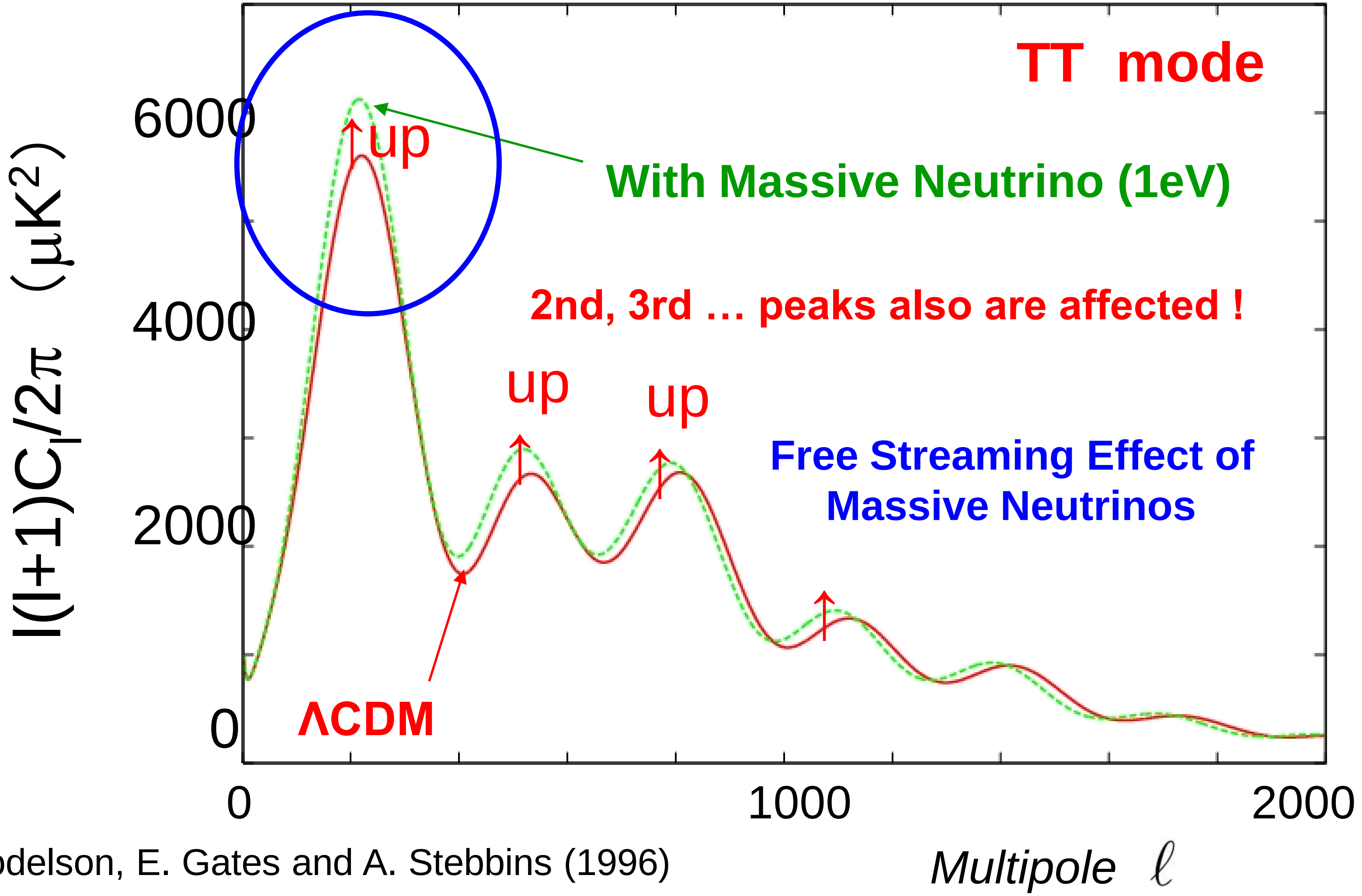
Tensor mode $k_m^{(2)} = 3.3 \times 10^{-3} \times \frac{m_\nu}{\rm eV}\ \ {\rm Mpc}^{-1}$ $\ell_m^{(2)} \sim 46 \times \frac{m_\nu}{\rm eV}$

Effects of Neutrino Mass m_ν

$\vec{B}_{PMF} = \vec{0}$

Integrated Sachs-Wolfe Effect, similarly to CDM

$$\ell_{nr} \simeq \frac{2\pi r_\theta(\eta_{rec})}{\eta_{nr}} \sim 350$$

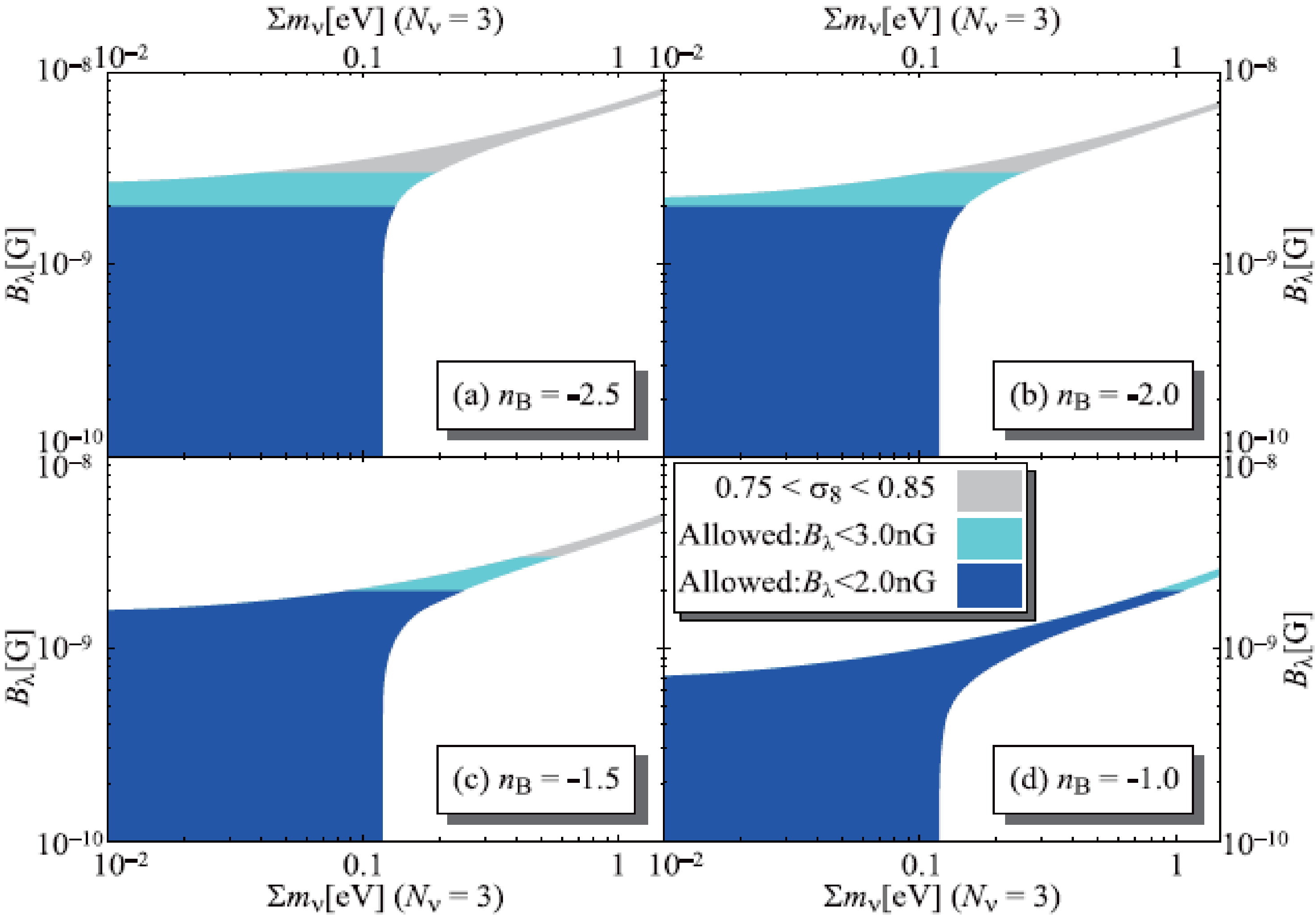


S. Dodelson, E. Gates and A. Stebbins (1996)

Neutrino Mass Constraints

Yamazaki, Ichiki, Kajino, and Mathews, PR D81 (2010), 103519:
D. Yamazaki, T. Kajino, G. J. Mathews, and K. Ichiki, Phys. Rep. 517 (2012) 141.

$\Sigma\, m_\nu < 0.2$ eV



SUMMARY

ν-Mass hierarchy:

- We proposed a new nucleosynthetic method to estimate average ν-spectra from core-collapse supernovae: $T(\nu_e) = 3.2$MeV, $T(\overline{\nu_e}) = 4.0$MeV, $T(\nu_x) = 6.0$MeV.
- $^{7}Li/^{11}B$ isotopic ratios of SiC X-grains (SN-grains) enriched in ν-process materials have the potential to solve the mass hierarchy for finite θ_{13}. Inverted hierarchy is more preferred statistically.

Total ν-mass:

- Curvature perturbation is shown to be generated by the extra anisotropic stress π_{ext} without tuning the initial condition of inflation-driven (pre-Big-Bang) perturbation. This would constrain the generation epoch and the nature of primordial (unknown) π_{ext}.
- Total ν-mass is constrained to be $\Sigma\, m_\nu < 0.2$ eV from the MCMC analysis of CMB temperature and polarization anisotropies including the primordial magnetic field.

Higgs

- 3 ATLAS (M. Kuna)
- 8 CMS (J.C. Maestro)

- 15 S.Y. Choi ··· J, PC
- 21 J.S. Lee ··· MSSM
- 23 E.J. Chun ··· triplet (type II seasaw)
- 24 S.K. Kang ··· 2HDM
- 26 T.C. Yuan ··· more models
- 34 H. Cai ··· vector-quark

Dark Matter

- 37 IceCube (C. Rott) ··· ν
- 49 Fermi-LAT (C. Sgro) ··· γ

- 54 C. Weniger ··· 130 GeV γ ×
- 55 H.M. Lee ··· axion-$\gamma\gamma$
- 58 J.C. Park ··· 130 GeV γ
- 62 X. Huang ··· 130 GeV γ
- 64 S. Park ··· KK DM
- 65 T. Flacke ··· KK DM @LHC
- 67 S. Baek ··· Higgs portal DM

- 73 XENON (E. Duchevni)
- 79 LUX (A. Lindote)
- 83 CDMS (J. Sander)
- 88 KIMS (J. Lee) ×

- 89 ATLAS (M. Baak)
- 94 CMS (S. Jain)

- 107 B. Dutta ··· computing Ω_{DM} from LHC

Neutrino

- 114 Dayabay (Q. Wu)
- 116 Reno (S.H. Seo)
- 119 DChooz (J. Maricic)
- 121 T2K (P. Litchfield)

- 124 X.G. He ··· θ_{13} review
- 129 C. Giunti ··· 3ν status+α
- 139 S. Kumar ··· SO(10)
- 143 Y. Takaesu ··· reactor $\bar{\nu}$ @50km

Neutrino AstroPhys./Cosm.

- 146 T. Kajino