Search for Dark matter with Xenon100

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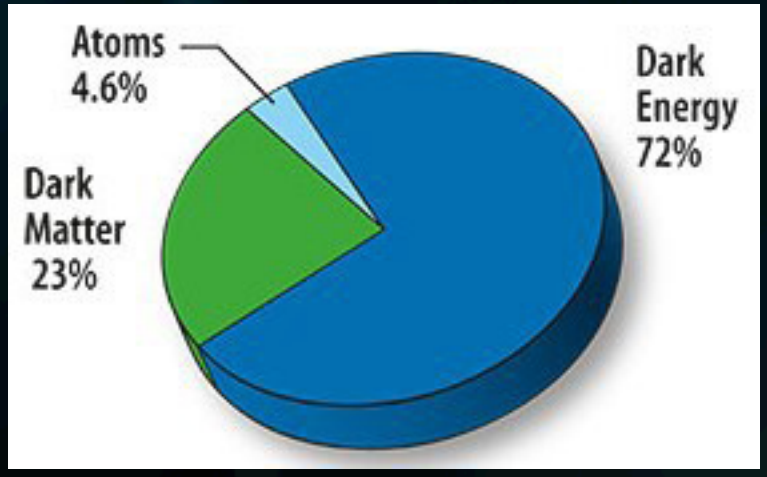
On behalf of the XENON100 collaboration

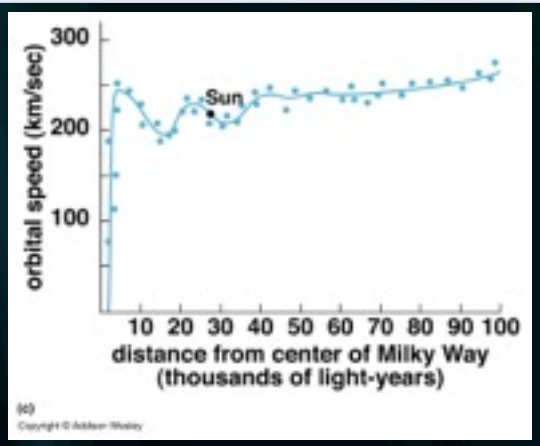
Outline

DM in the universe,
DM detection with passive experiments,
    Liquid Xenon (LXe) as a detecting substance
    LXe Dual-Phase TPC The Xenon detector
The 225 days run
    Data taking & improvements
    Results
Prospects



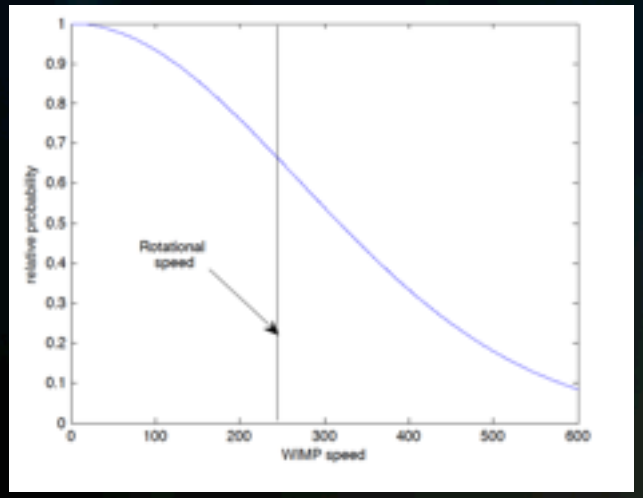
Reminder: Direct DM Detection

From rotational curve(s), the local DM density in the solar system orbit (27,200±1100 ly) is 0.30±0.05 GeV⋅fm^{-3}.



The local velocity is ~220km/s leading (with some assumption and uncertainties) to DM velocity distribution of:.

$$f(\vec{V}) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{|V|^2}{2\sigma^2}}$$

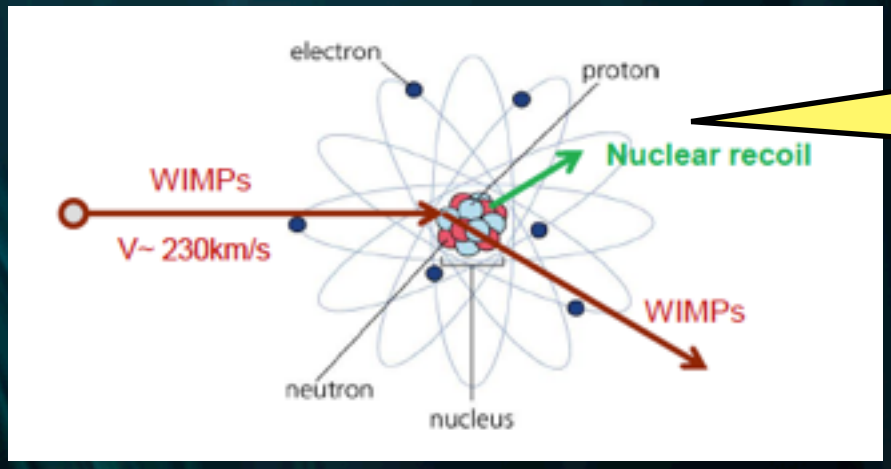


Where σ=220Km/s

WIMP's Kinetic energy O(10KeV)

The Principle

Elastic scattering of a wWIMP off a target nuclei

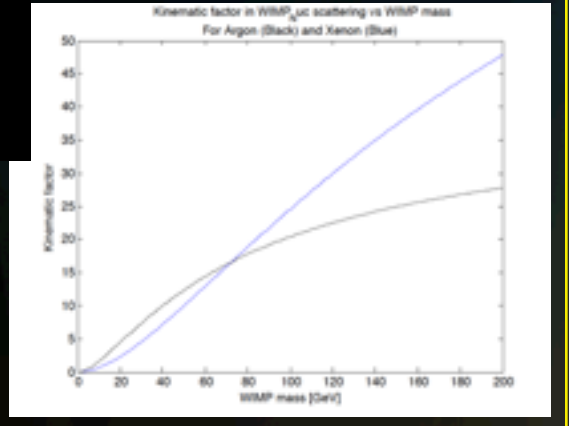


Nuclear recoil leaves detectable signal

Detect the remnants of the recoil energy which is given by:

$$E_r = \frac{|q|^2}{2m_N} = \frac{\mu^2 v^2}{m_N}(1-\cos\theta) = \frac{2\mu^2}{m_N m_\chi} E_{kin}^{\chi}(1-\cos\theta)$$

Order 10 KeV



Event Rate

The expected event rate is:

Physics

$$\frac{dR}{dE_{NR}} \propto N\sigma_{\chi N}\frac{\rho_\chi}{2m_\chi\mu^2}|F^2(E_{NR})|\int_{v_{min}}^{v_{esc}}\frac{f(\vec{v})}{v}d^3v$$

When N is the number of target nuclei;
$\sigma_{\chi N}$ is the cross-section of WIMP on target nuclei
ϱ_χ is the local density of DM (0.3GeV/fm^{-3})
μ is the WIMP-Target reduced mass
F is nuclear form factor
f(v) is the WIMP velocity distribution
v_{esc} is the escape velocity from the galaxy (~600km/s)
v_{min} is the minimal observable energy

$$v_{min} = \sqrt{\frac{m_N E_{NR}}{2\mu^2}}$$

Note that for Spin Independent (SI) interactions $\sigma_{\chi N}$ scales like A^2!

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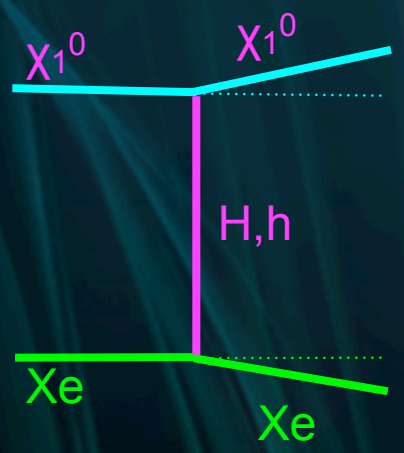
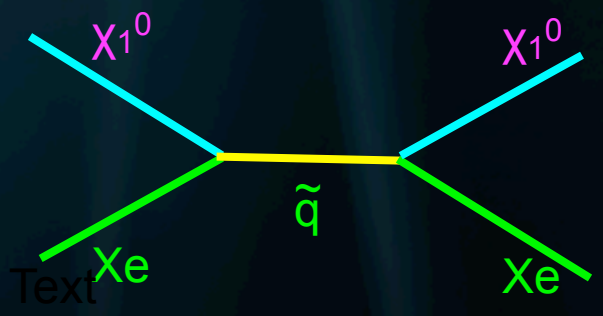
Spin Independent

$\sigma_{\chi N}$





$\mathcal{L}_S \sim \bar{\chi}\chi\bar{q}q$

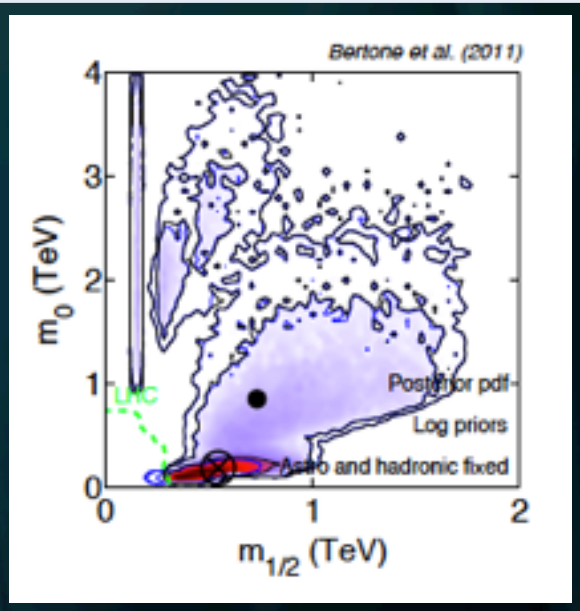
$\mathcal{L}_V \sim \bar{\chi}\gamma_\mu\chi\bar{q}\gamma^\mu q$

The De Broglie wavelength of a WIMP $\lambda = h/p$ is of the order of the nucleus size.

$$\sigma_{\chi N} \propto |\mathcal{A}_{\chi N}|^2 \simeq |\sum |\mathcal{A}_{\chi n}|^2 \simeq A^2 |\mathcal{A}_{\chi n}|^2 \propto A^2$$

What Does SUSY predict?

LHC SUSY expert use the ($m_{1/2}$,m_0) plane for expressing SUSY results (or, tanβ,m_A)...



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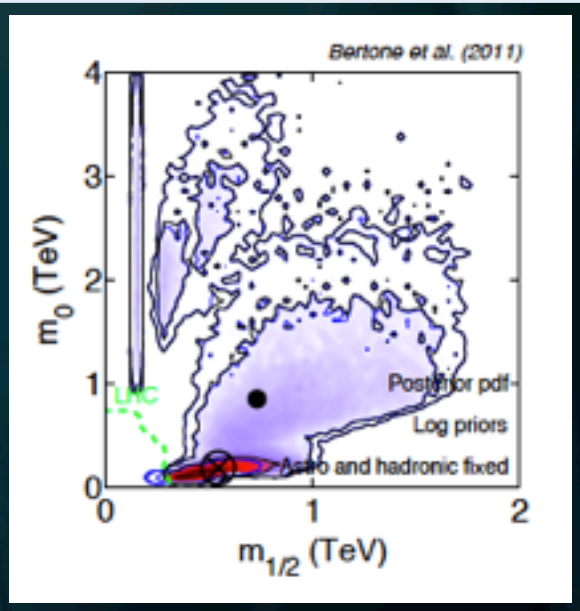
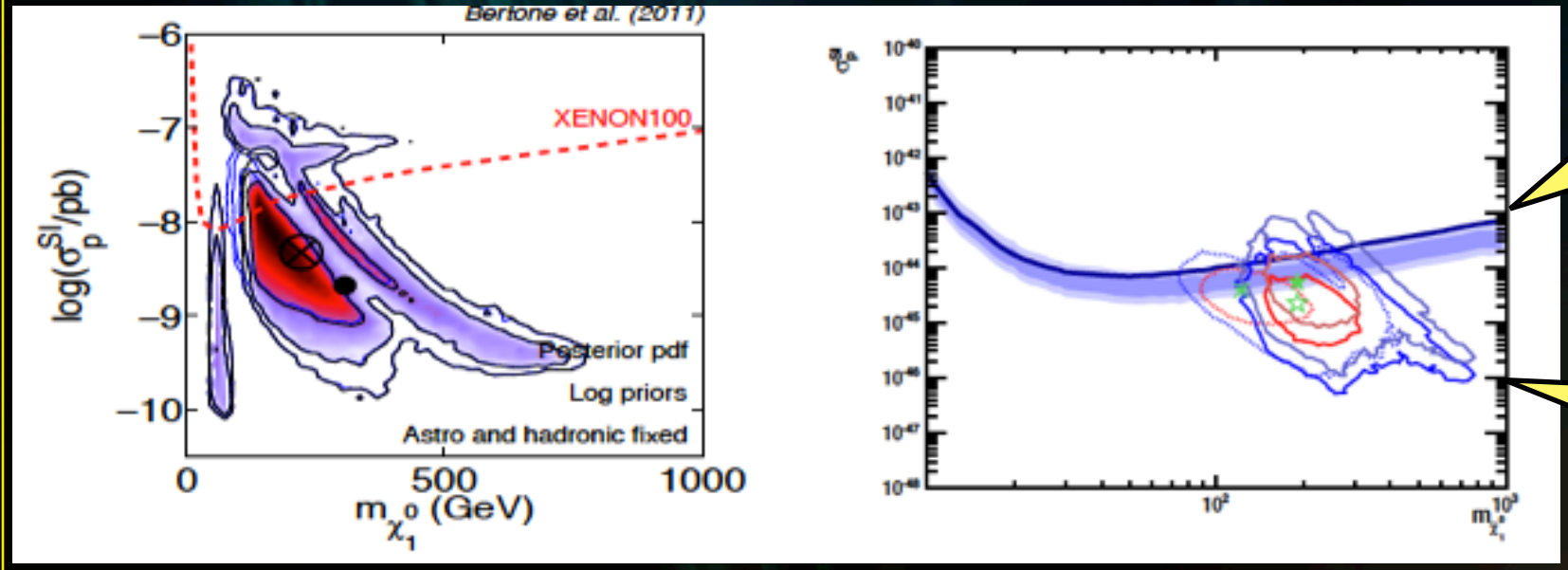
But this can be translated to





one event per Kg per year

one event per ton per year

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

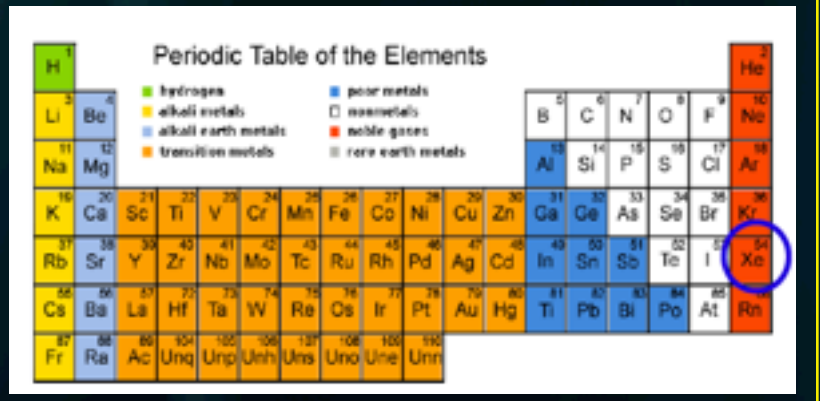
Fast scintillator

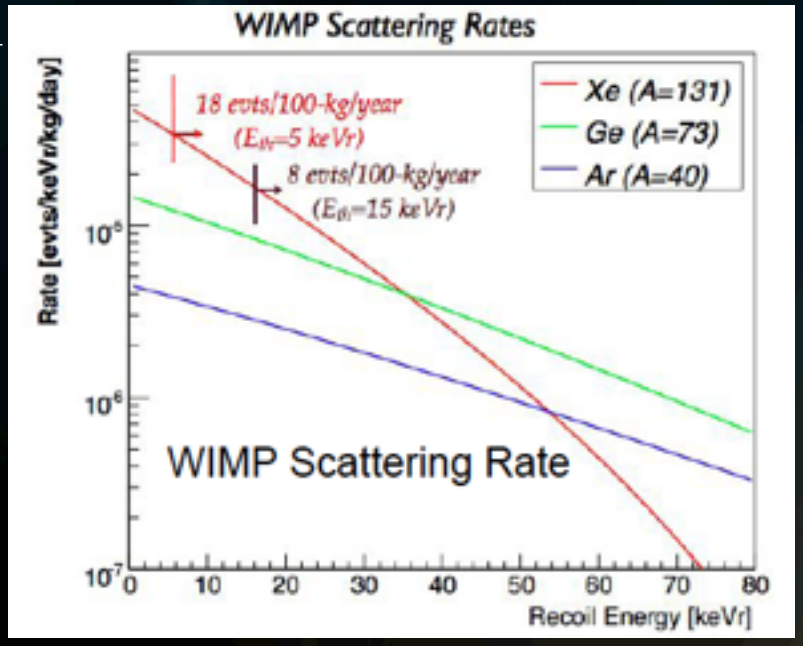
Intrinsically pure

Scalable

Highest yield of charge & light

Good b.g. discrimination in TPC





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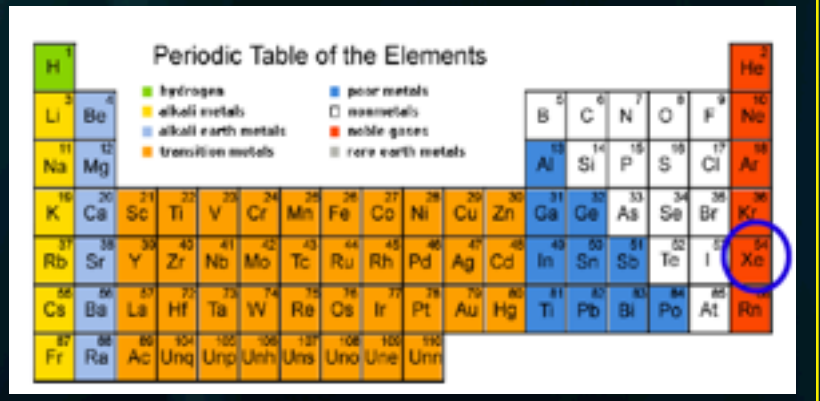
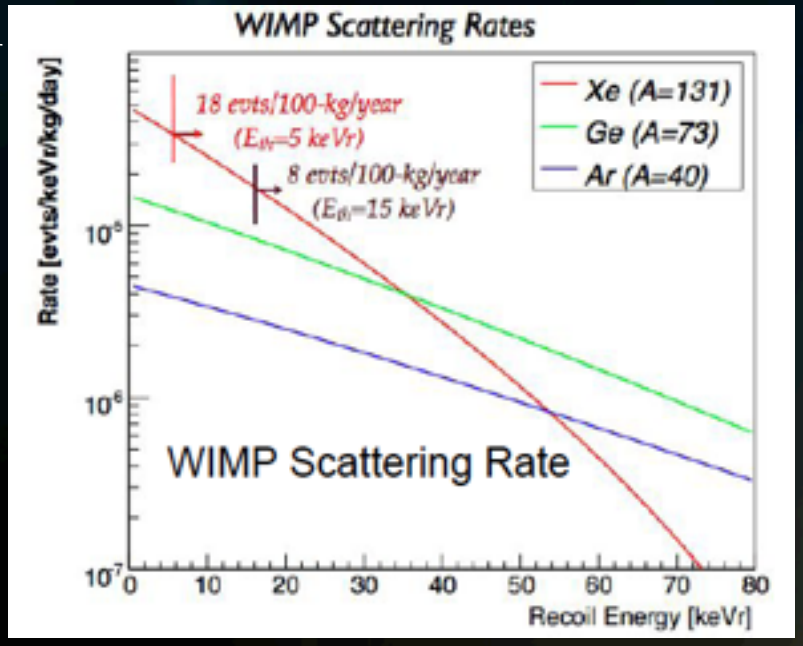
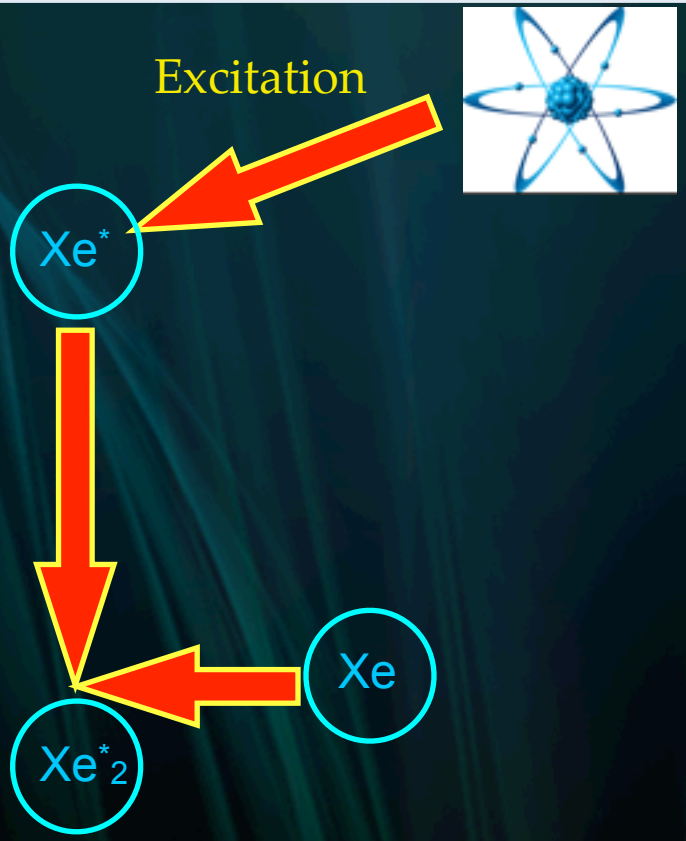
Ok, So I had 9. Its within errors....





Photon Emission in Xenon



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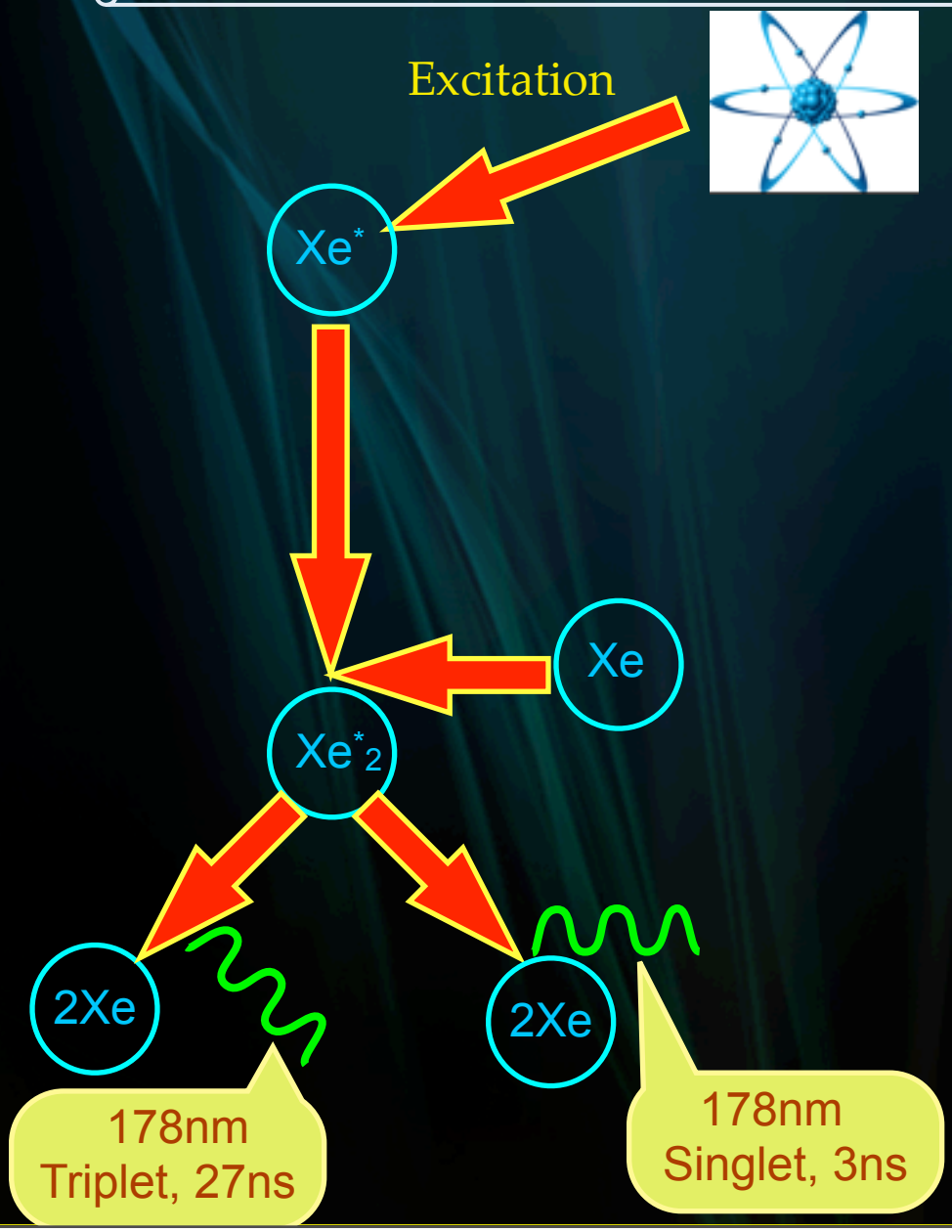

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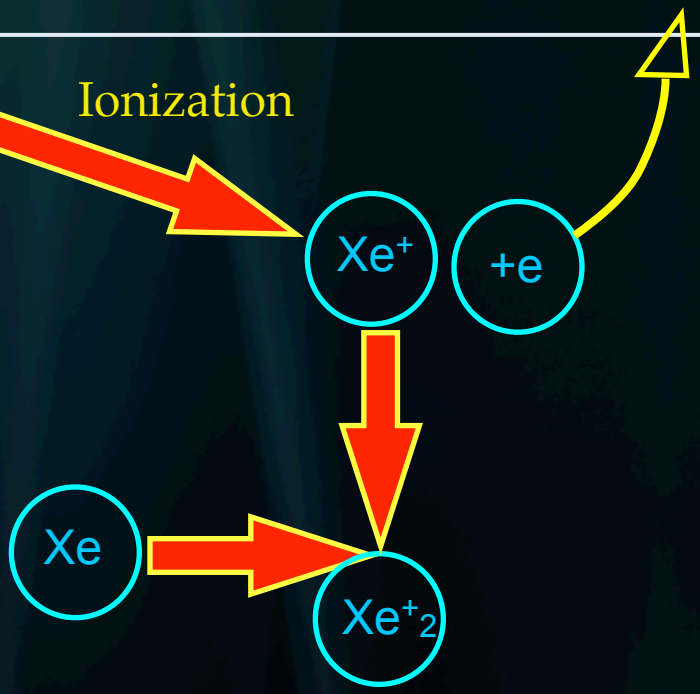

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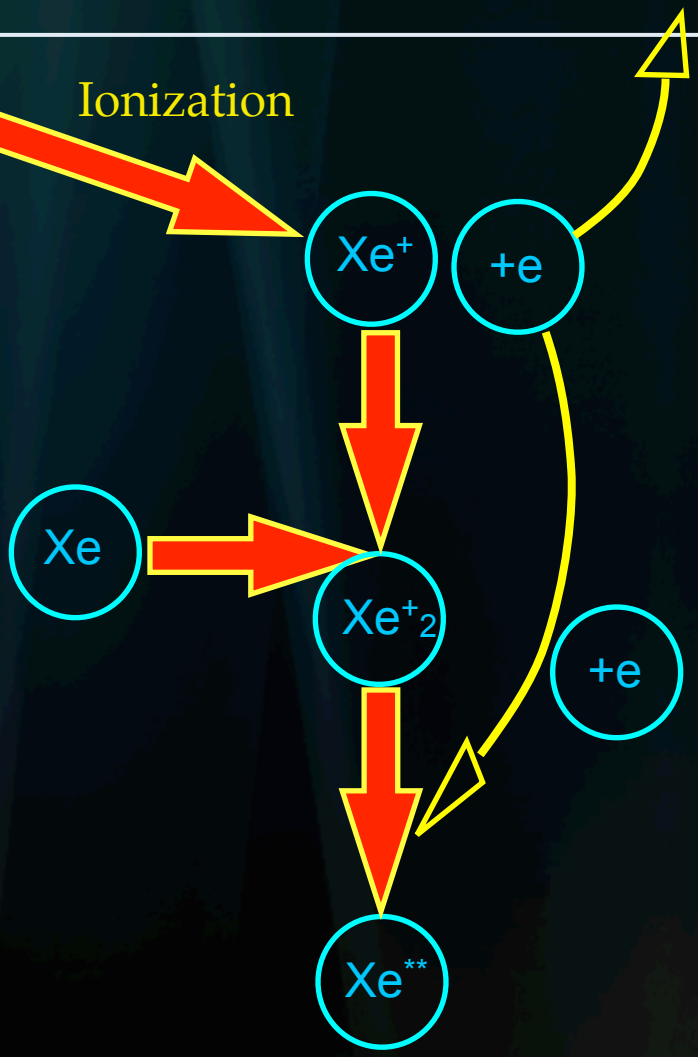


Photon Emission in Xenon

Excitation

Ionization

Xe^*

Xe^+

$+e$

Xe

Xe^+_2

$+e$

Xe

Xe^*_2

Xe^{**}

2Xe

2Xe

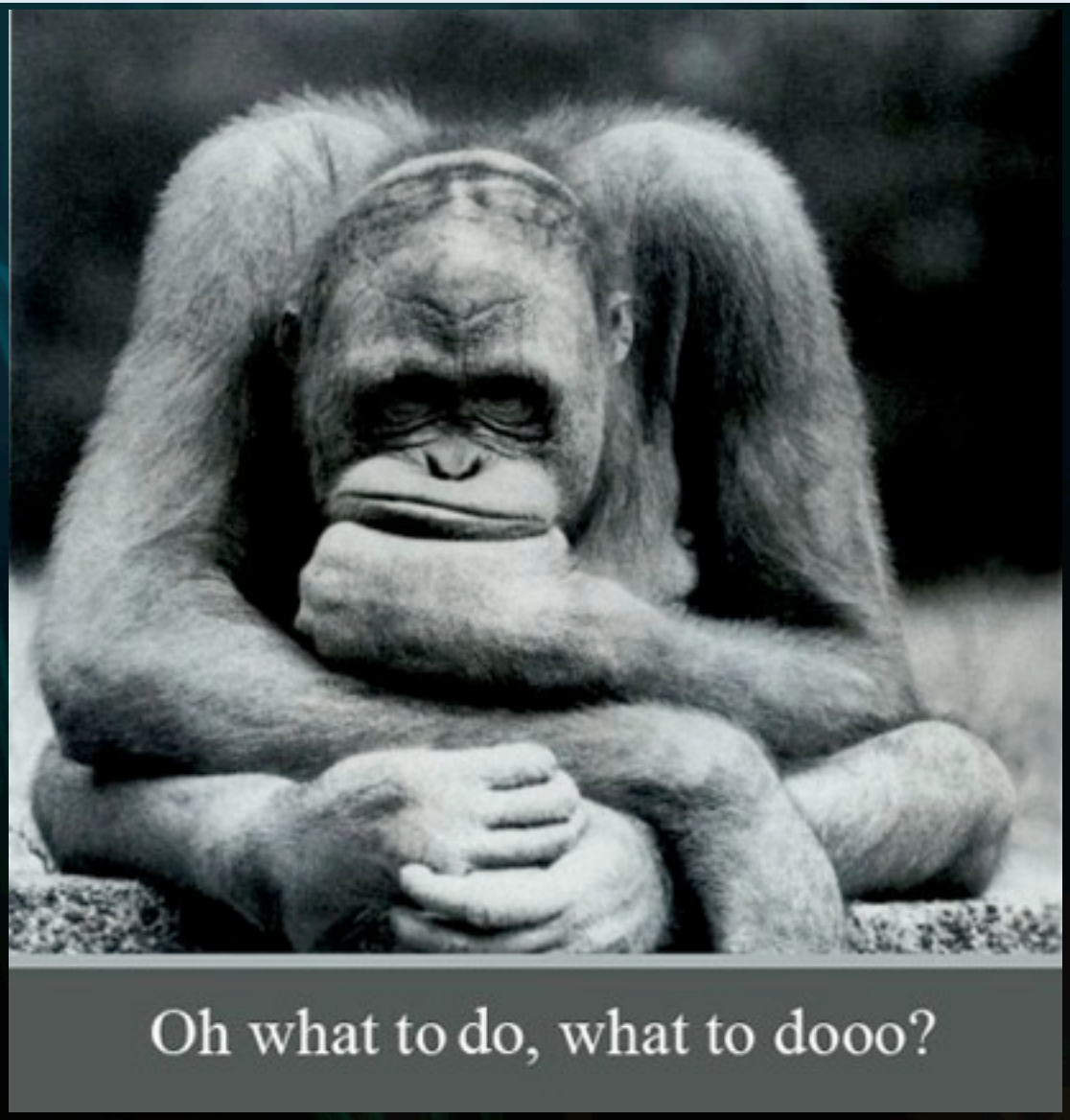
Xe

178nm
Triplet, 27ns

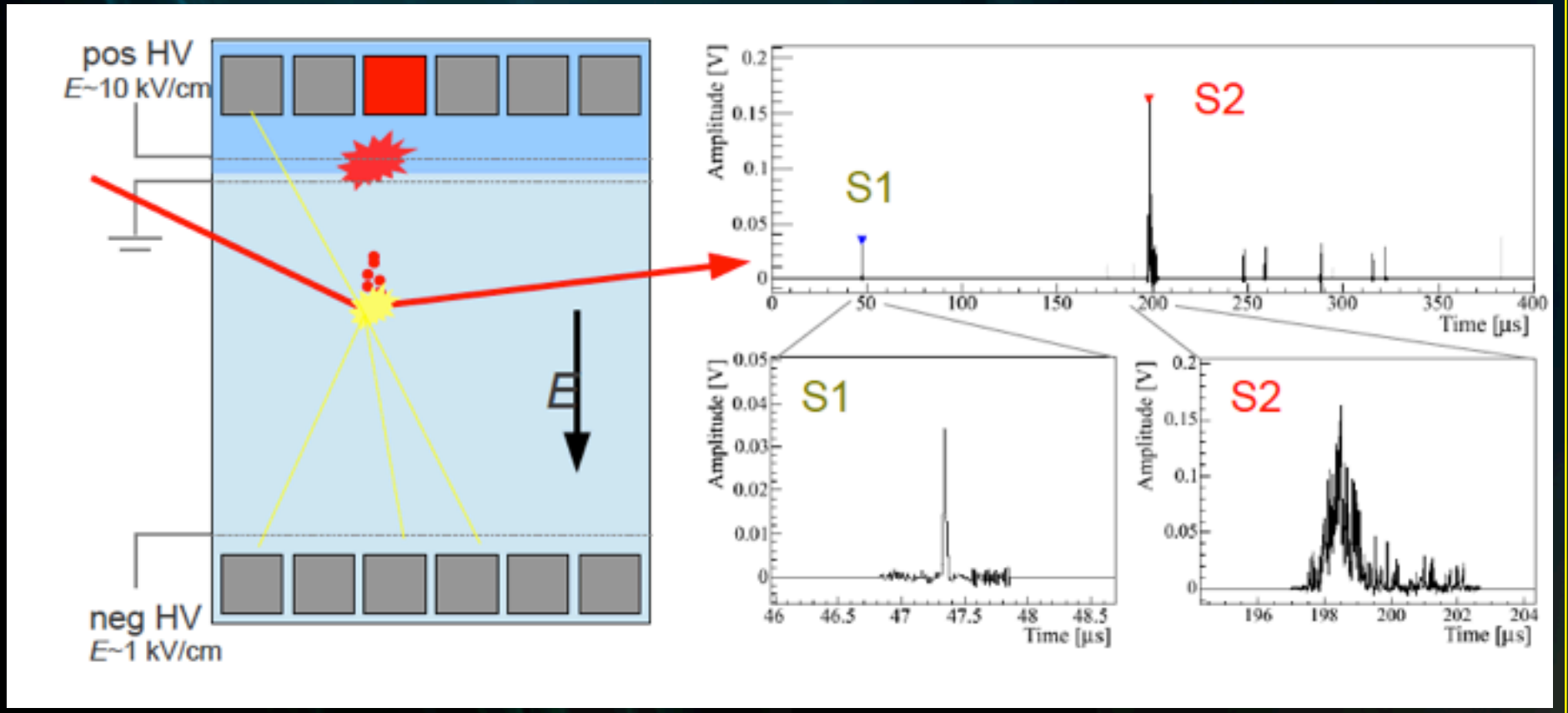
178nm
Singlet, 3ns

Confused?

a



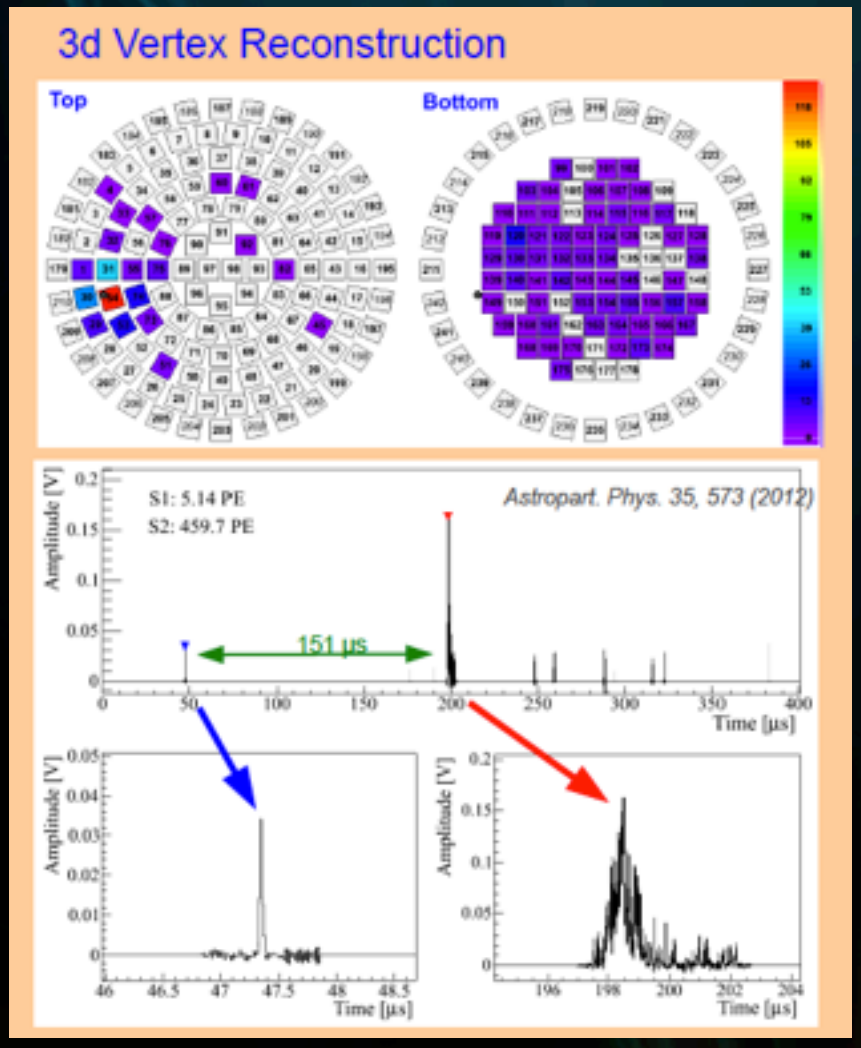
The Principle of Operation

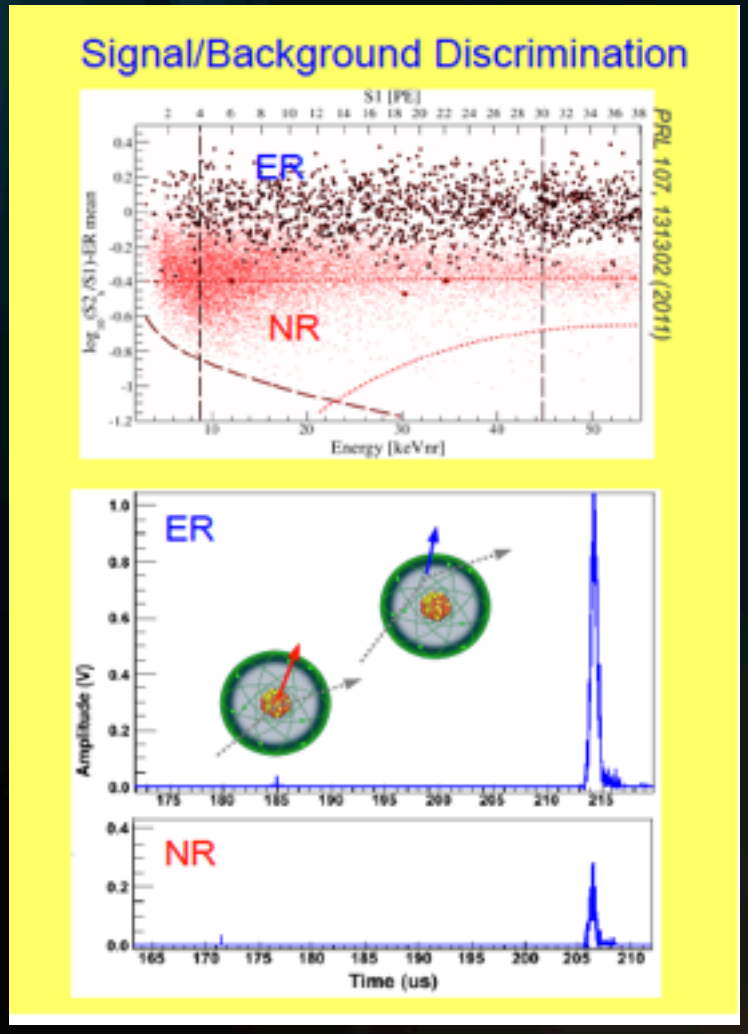


An "event" consists of a S1 and S2 spikes

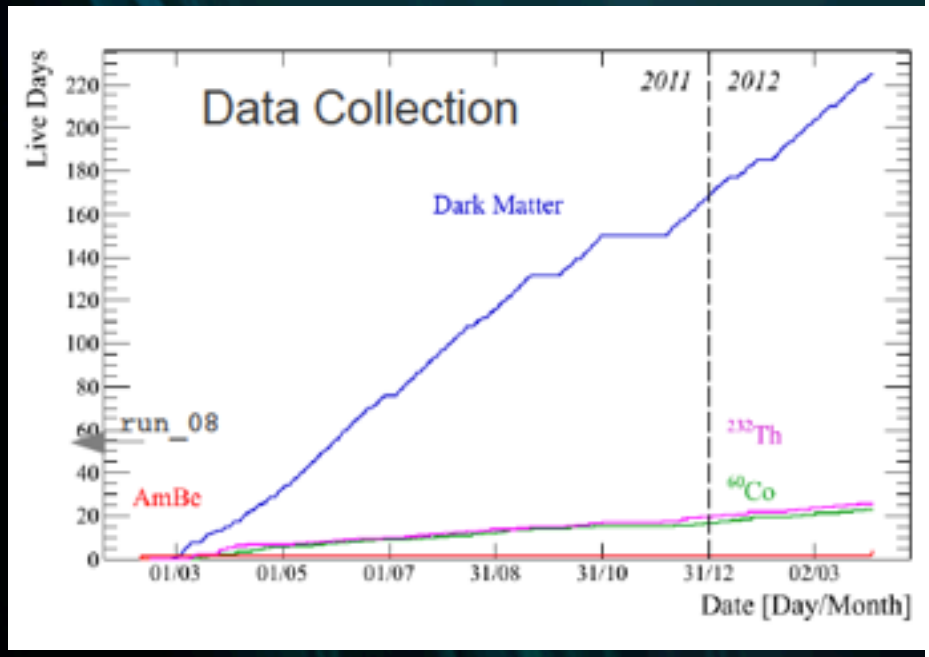
Detector Response

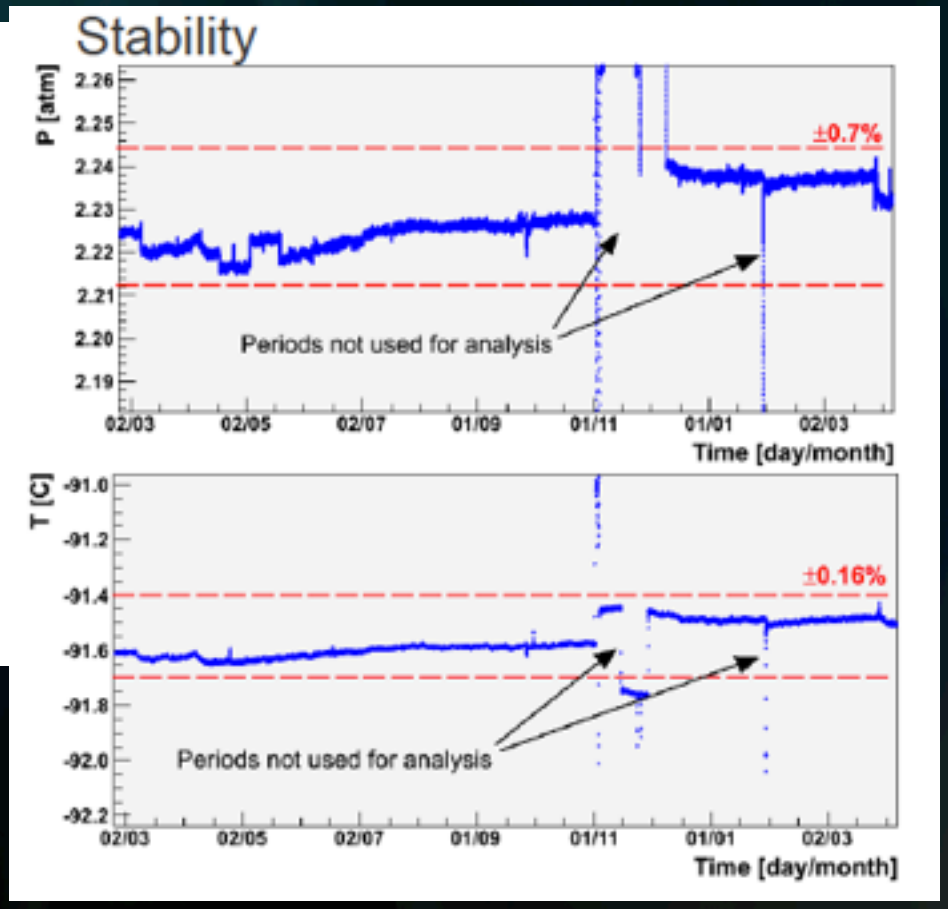
The upper and lower PMT arrays record the signals





Data Taking (225 days=Run 10)

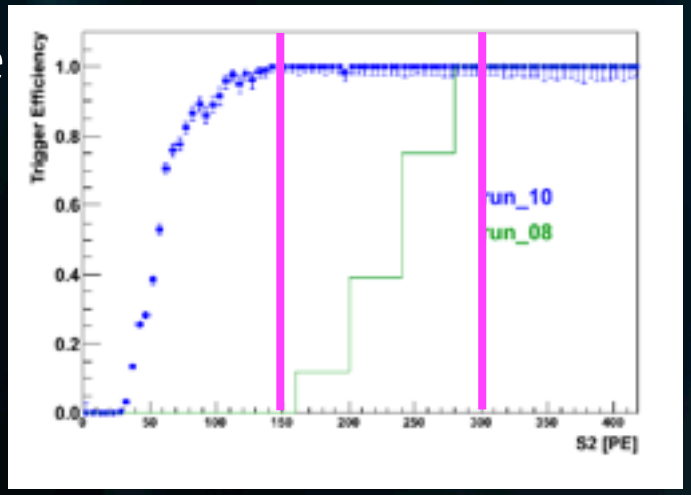


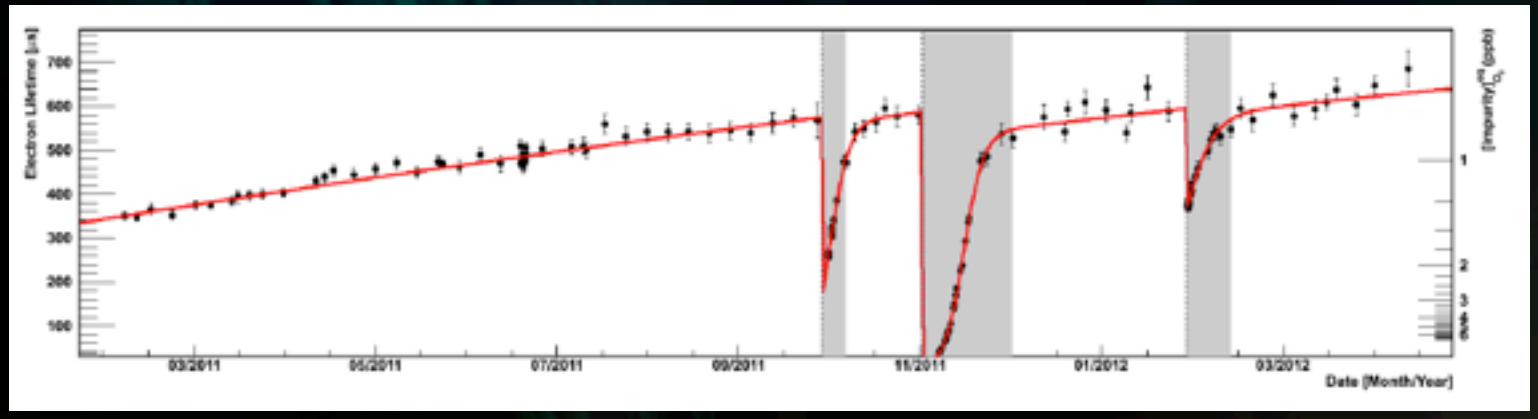


Collect data for almost a year. 224.56 days declared as stable and suitable for DM search

Improvements

- Improve trigger system & lower trigger cutoff
- More than double the exposure time
- Cleaner LXe ⇨ Lower background
- Smaller corrections
- Calibrated more frequently



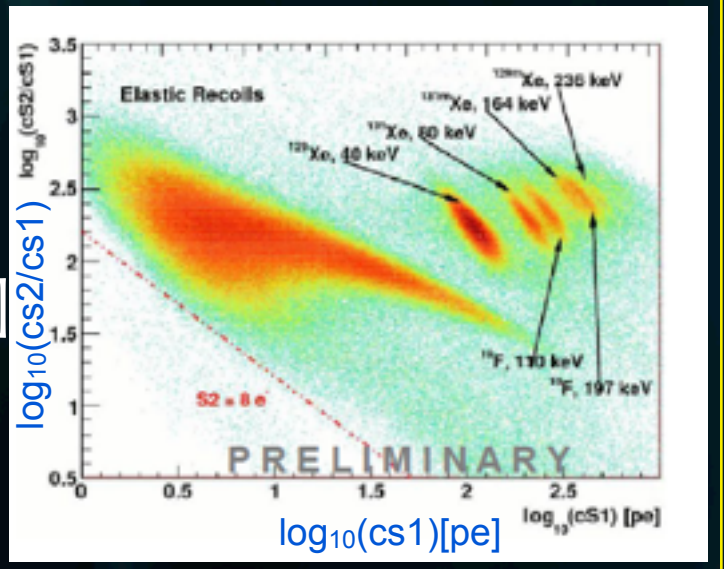


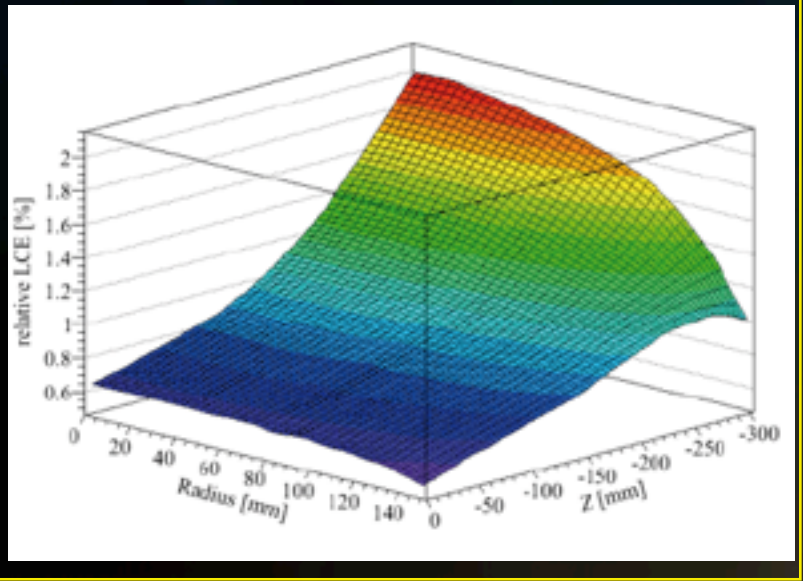
A Bit Technical

Light collection calibration done with "standard Candle"

Electron life time with Cs137. τ=[375-610]
<τ>=514μs

Position dependent Corrections:
Cs137, AmBe inelastic (40 keV), Xe* (164KeV)
Agreement better than 3%





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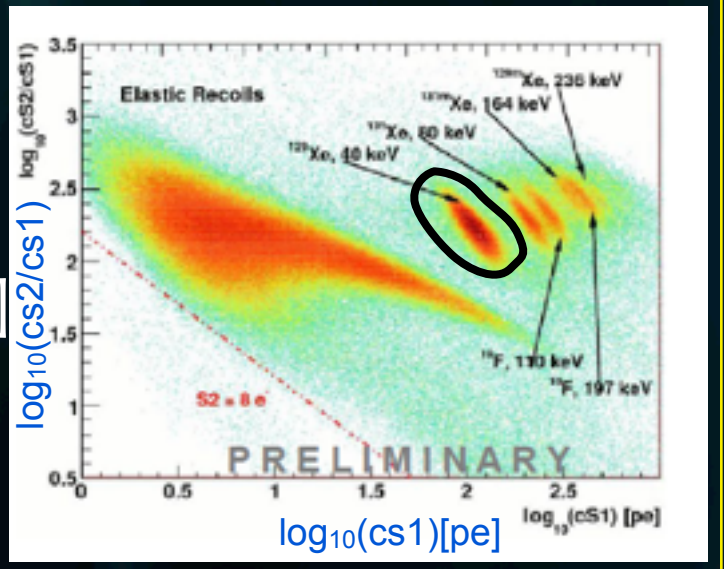
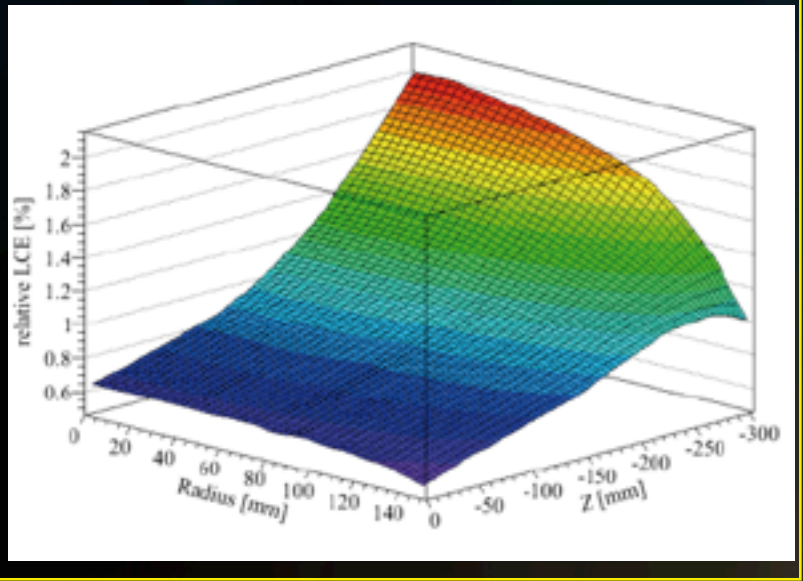
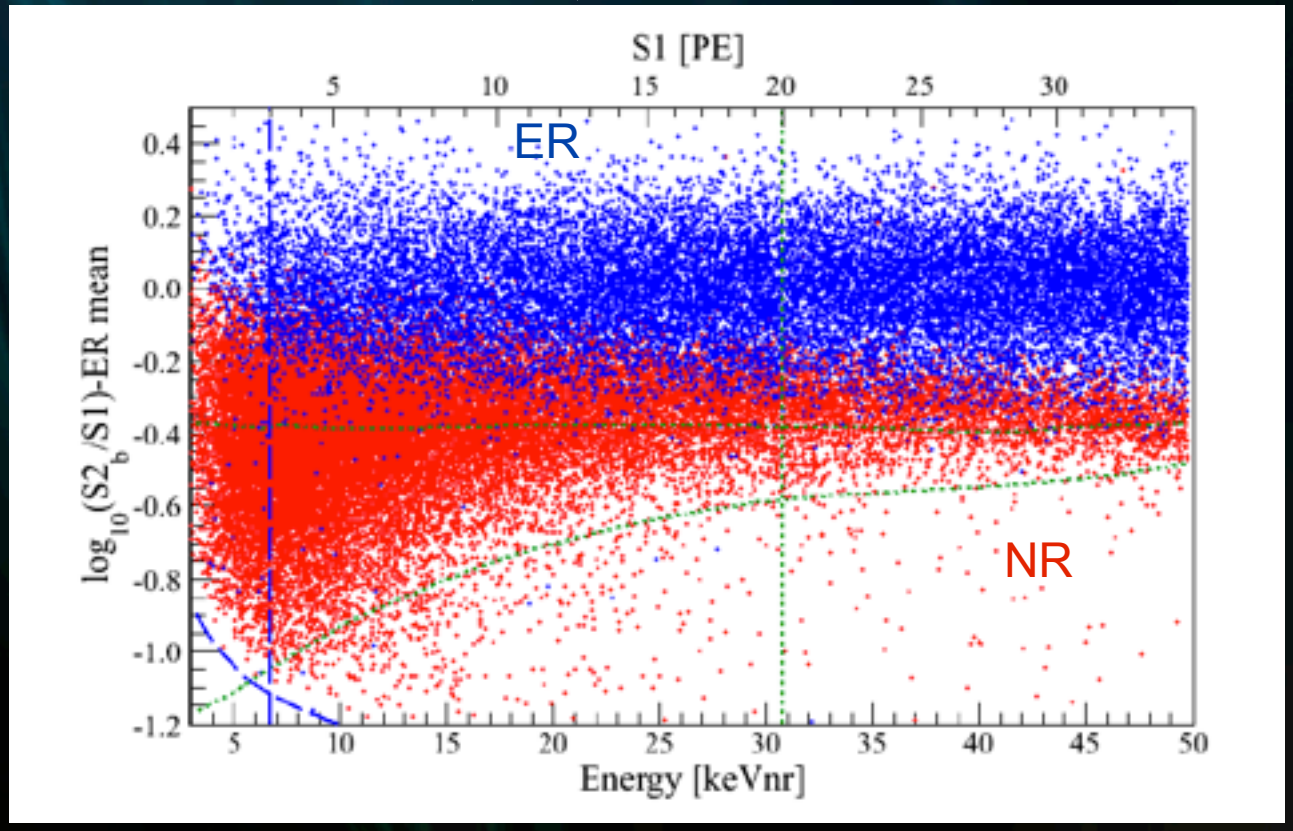




Signal Region

In order to determine the "Signal Region" (SR) use Co60 & Th232 to simulate the Electron Recoil band (ER)

For Nuclear Recoil band (NR) use neutrons from AmBe source.

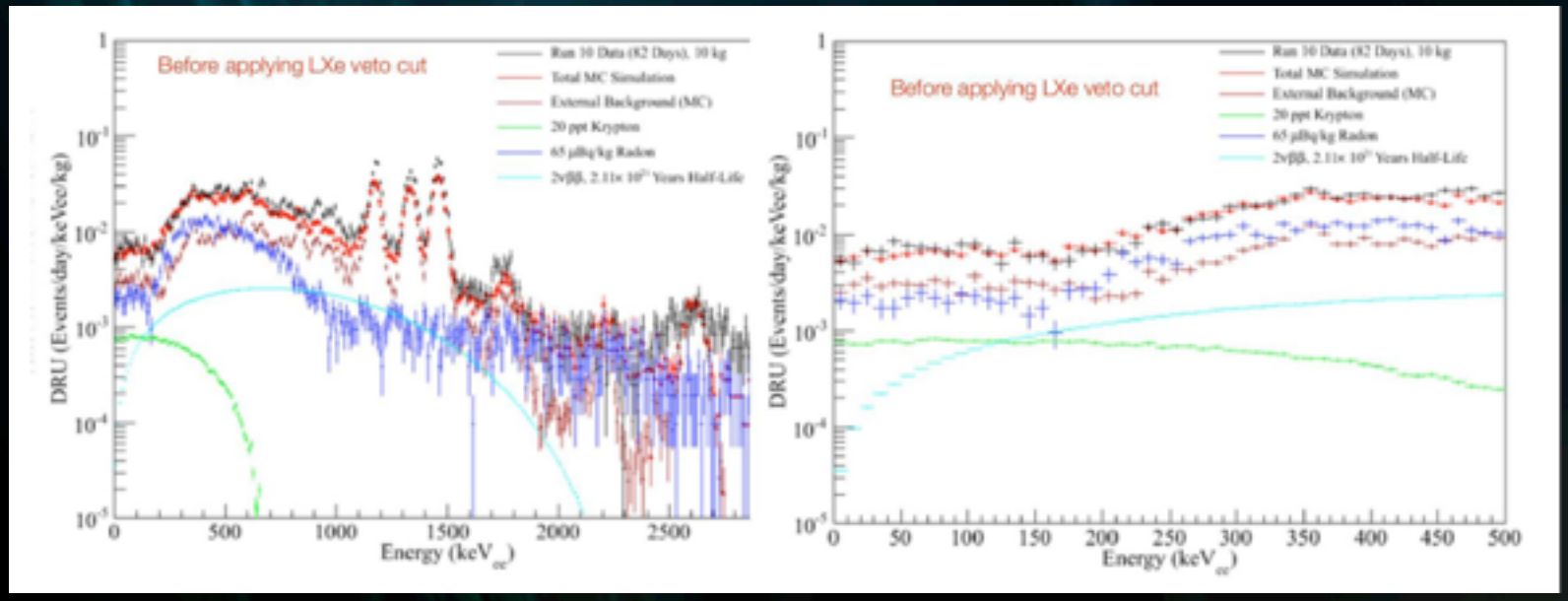


Choose ε(NR)=50% & ε(ER)=0.5%

Background

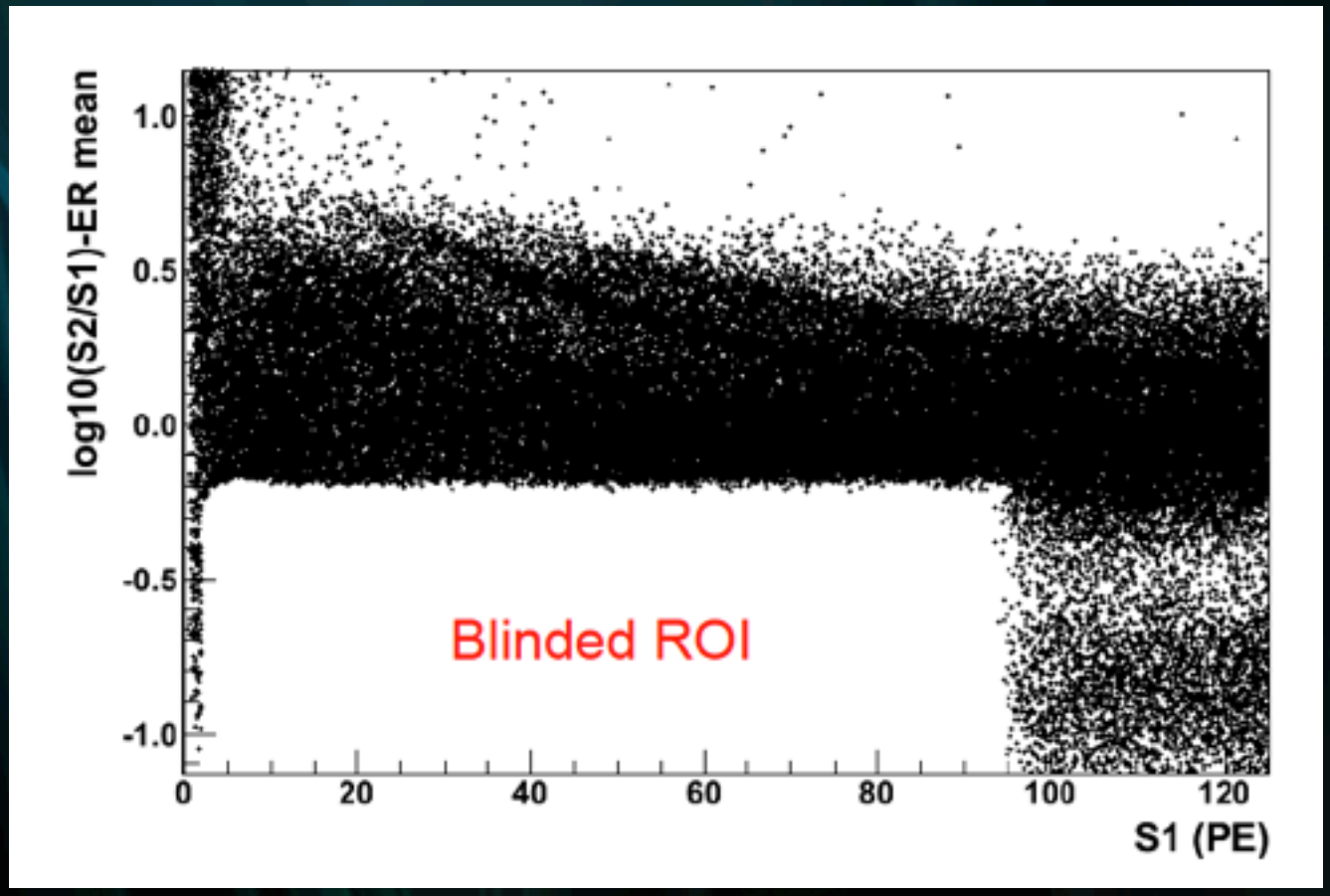
$$^{238}U \xrightarrow[\alpha]{} {}^{234}Th \xrightarrow[\beta]{} {}^{234m}Pa \xrightarrow[\beta]{} {}^{234}U \xrightarrow[\alpha]{} {}^{230}Th \xrightarrow[\alpha]{} {}^{226}Ra \xrightarrow[\alpha]{} {}^{222}Rn \xrightarrow[\alpha]{} {}^{218}Po \ldots$$

$$^{232}Th \xrightarrow[\alpha]{} {}^{228}Ra \xrightarrow[\beta]{} {}^{228m}Ac \xrightarrow[\beta]{} {}^{228}Th \xrightarrow[\alpha]{} {}^{224}Ra \xrightarrow[\alpha]{} {}^{220}Rn \xrightarrow[\alpha]{} {}^{216}Po \ldots$$



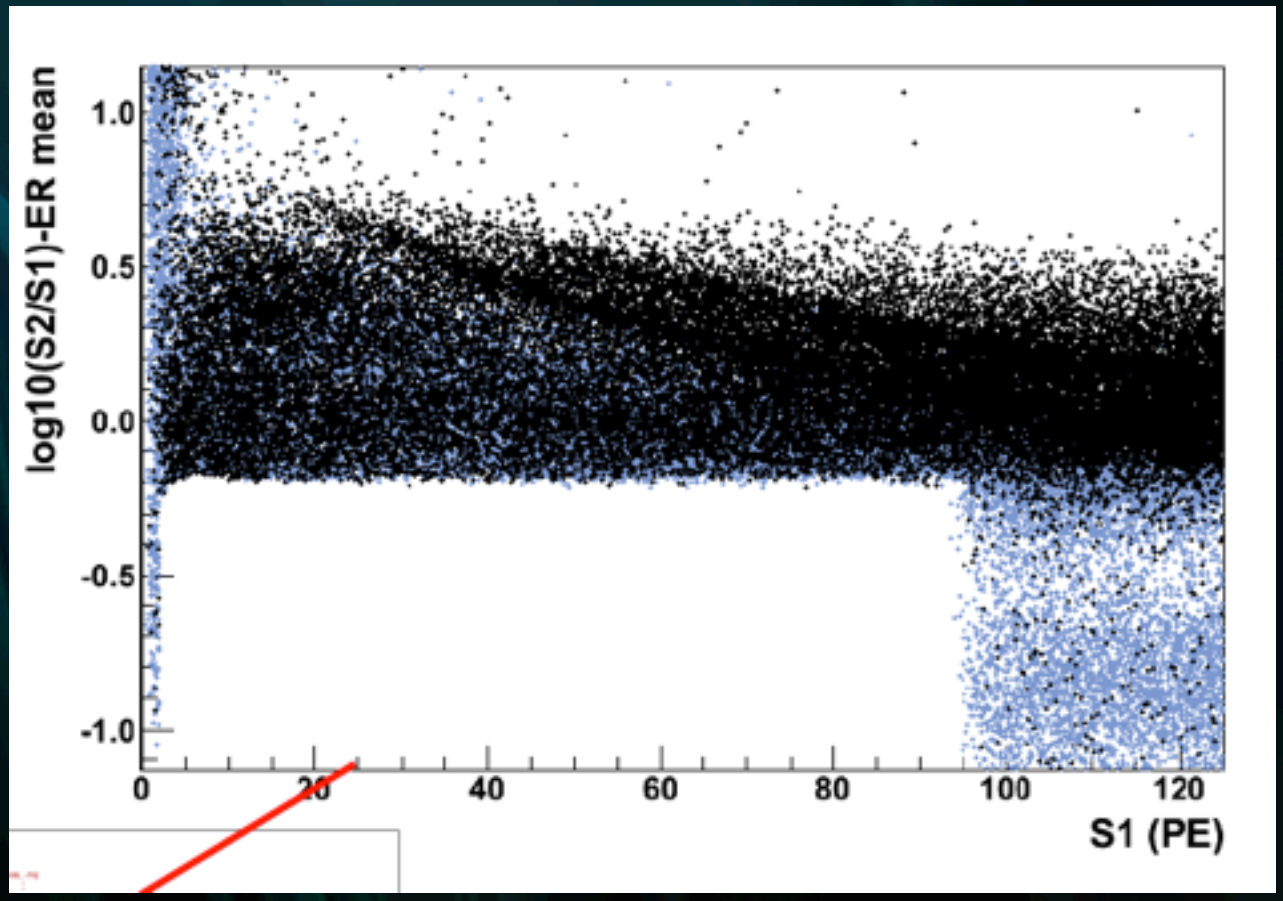
- Understand the background (Simulation describes data well)
- B.g level before s2/s1 discrimination is 0.0053 events/kg/day/KeV

Blinding the Data



No cuts at all

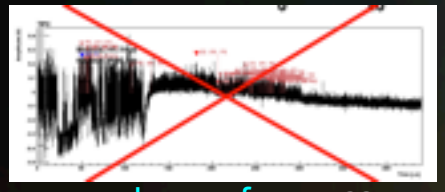
Apply Quality Cuts



S1 coincidence: require a twofold PMT coincidence[1].

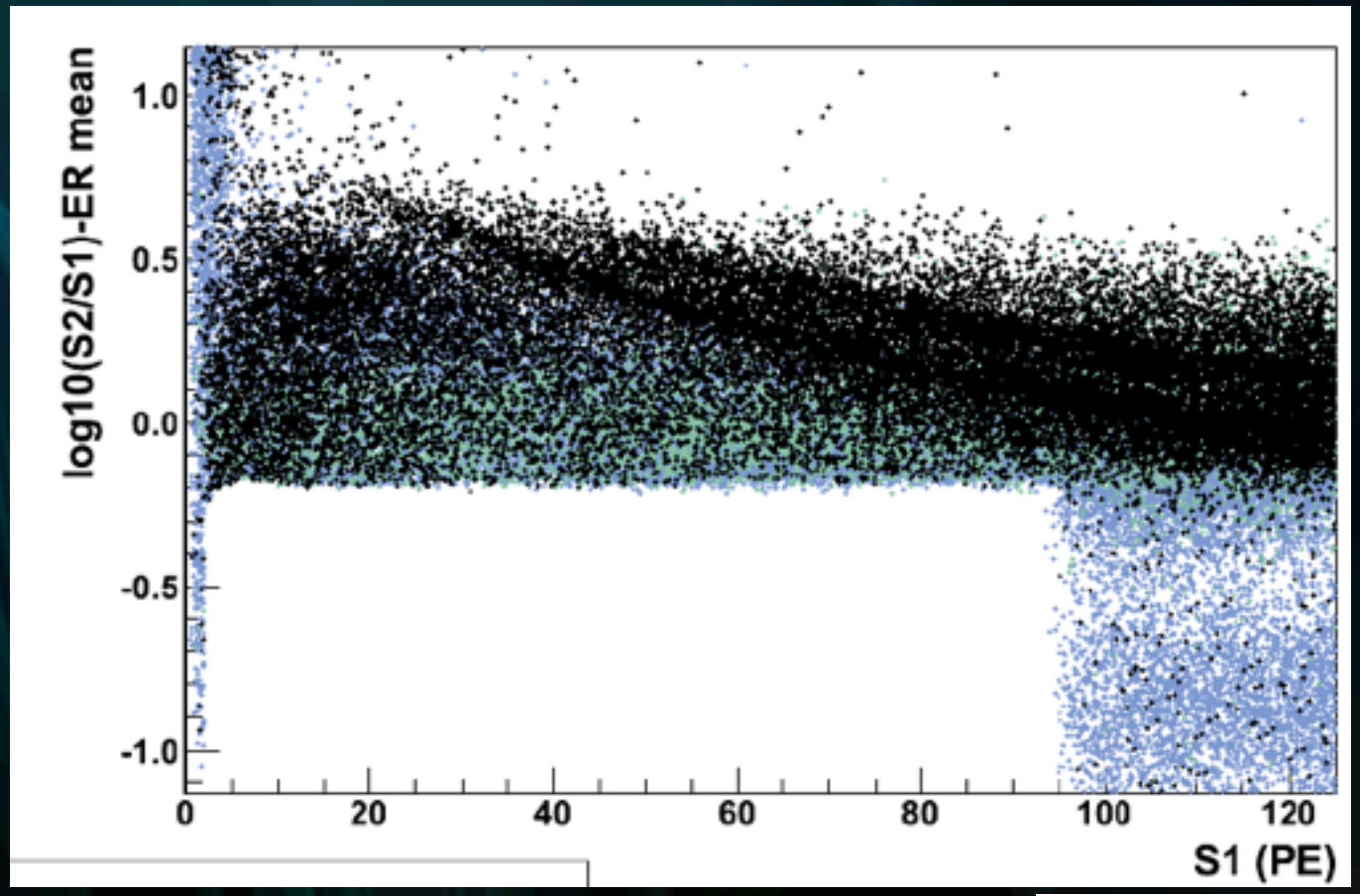
S2 >150 (300) (~8 (15) ionization electrons)

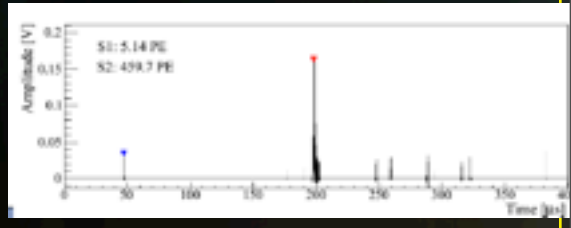
S/N: $\sum E_{\text{outside the detected S1 and S2 signals}} < \alpha \int E_{\text{waveform}}$



1) PMT signal > 0.35 pe & must appear <20 ns away from the S1 peak found in the summed waveform.

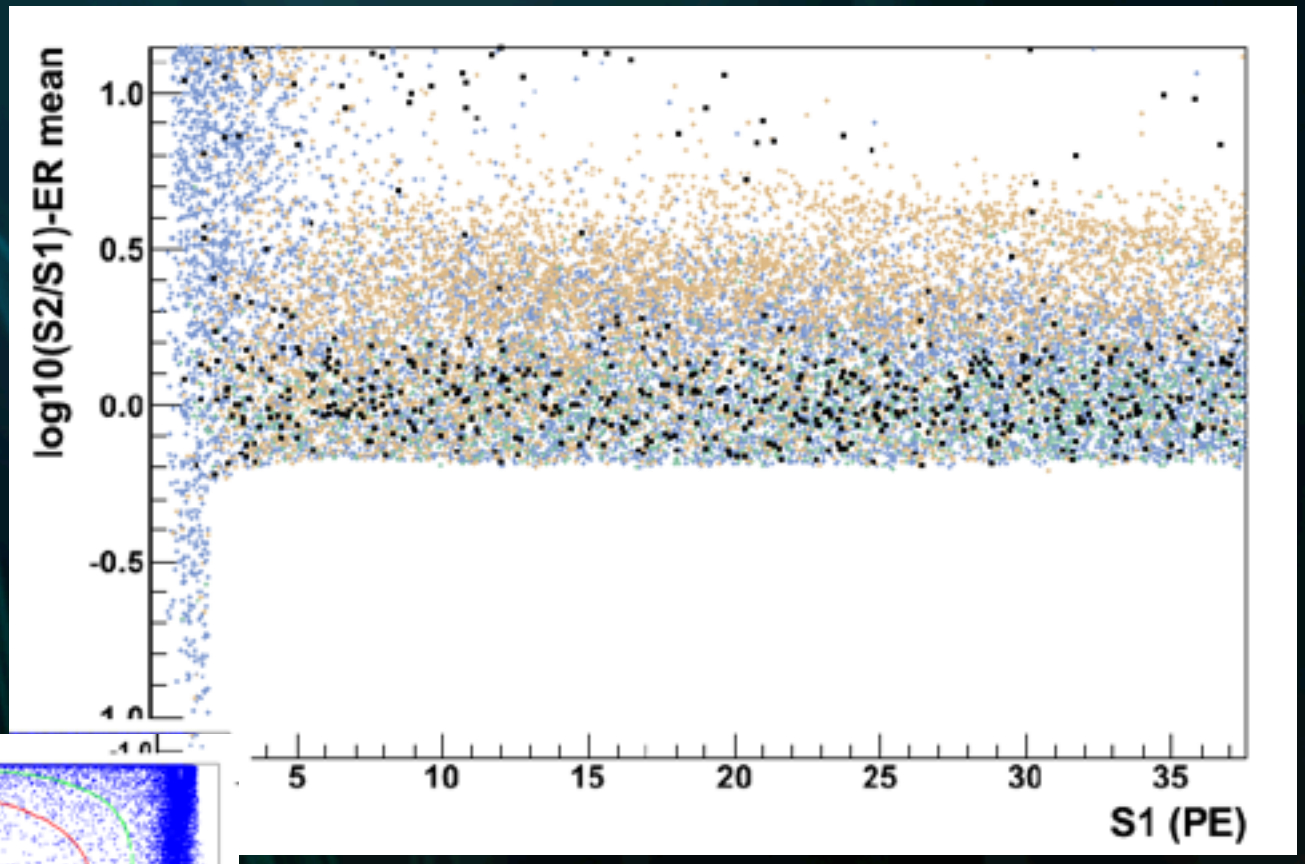
Apply Single Scatter Cuts

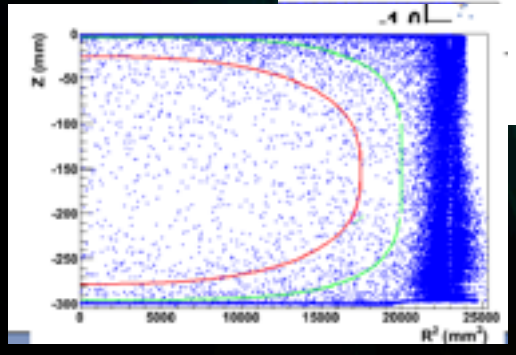




A Single S1-like peak
A single S2 peak above the 300 pe
no energy deposit in the veto in coincidence with the S1

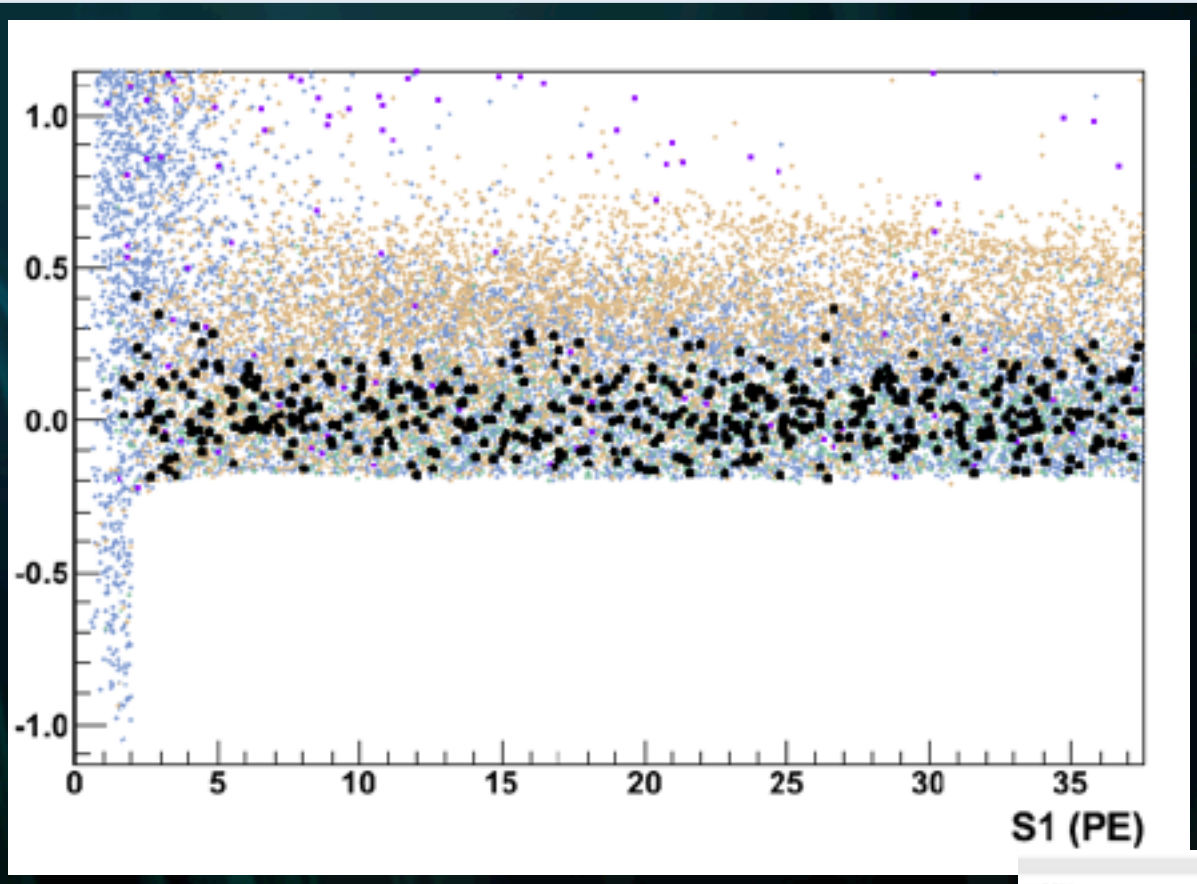
Fiducial Volume

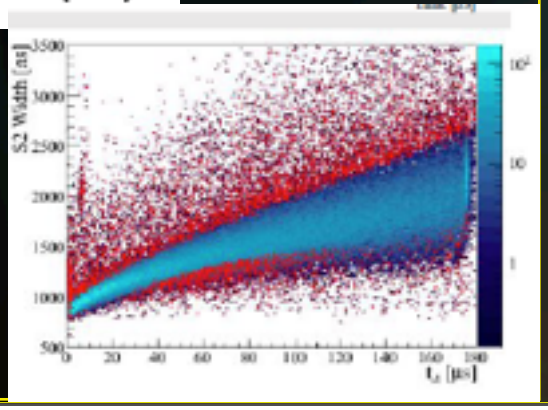




Fiducial volume is optimized for highest sensitivity==>34Kg

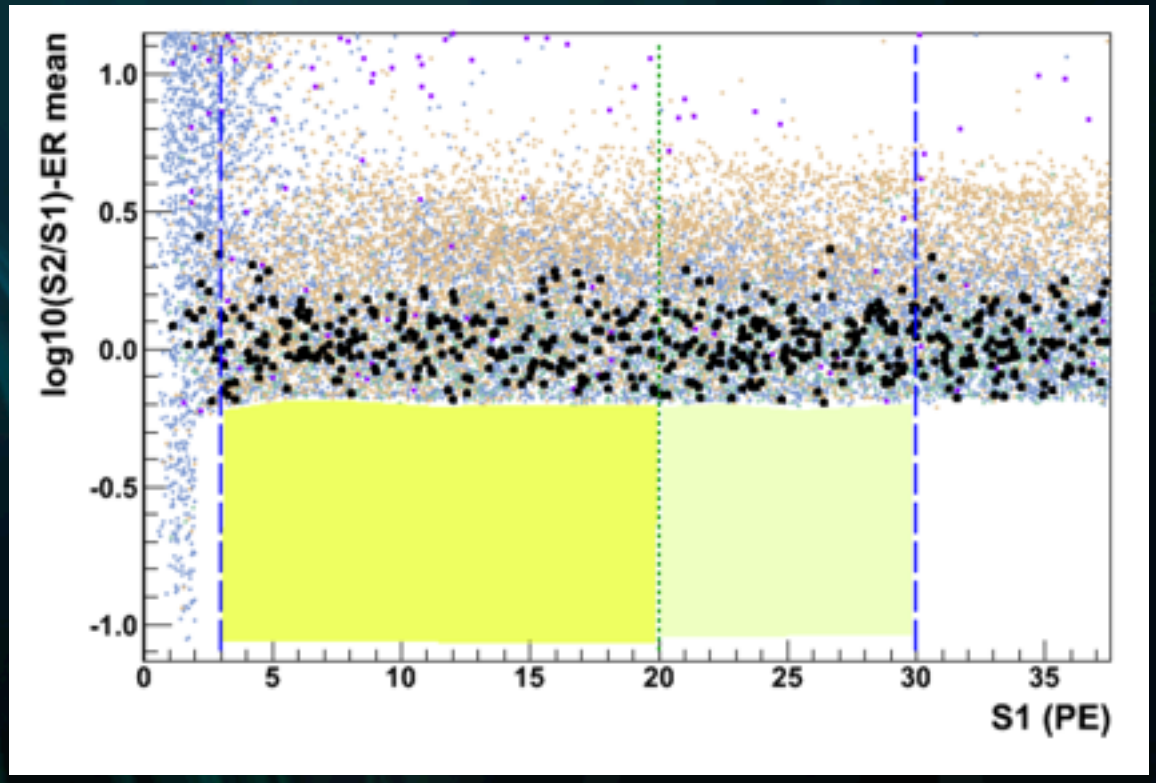
Signal Consistency





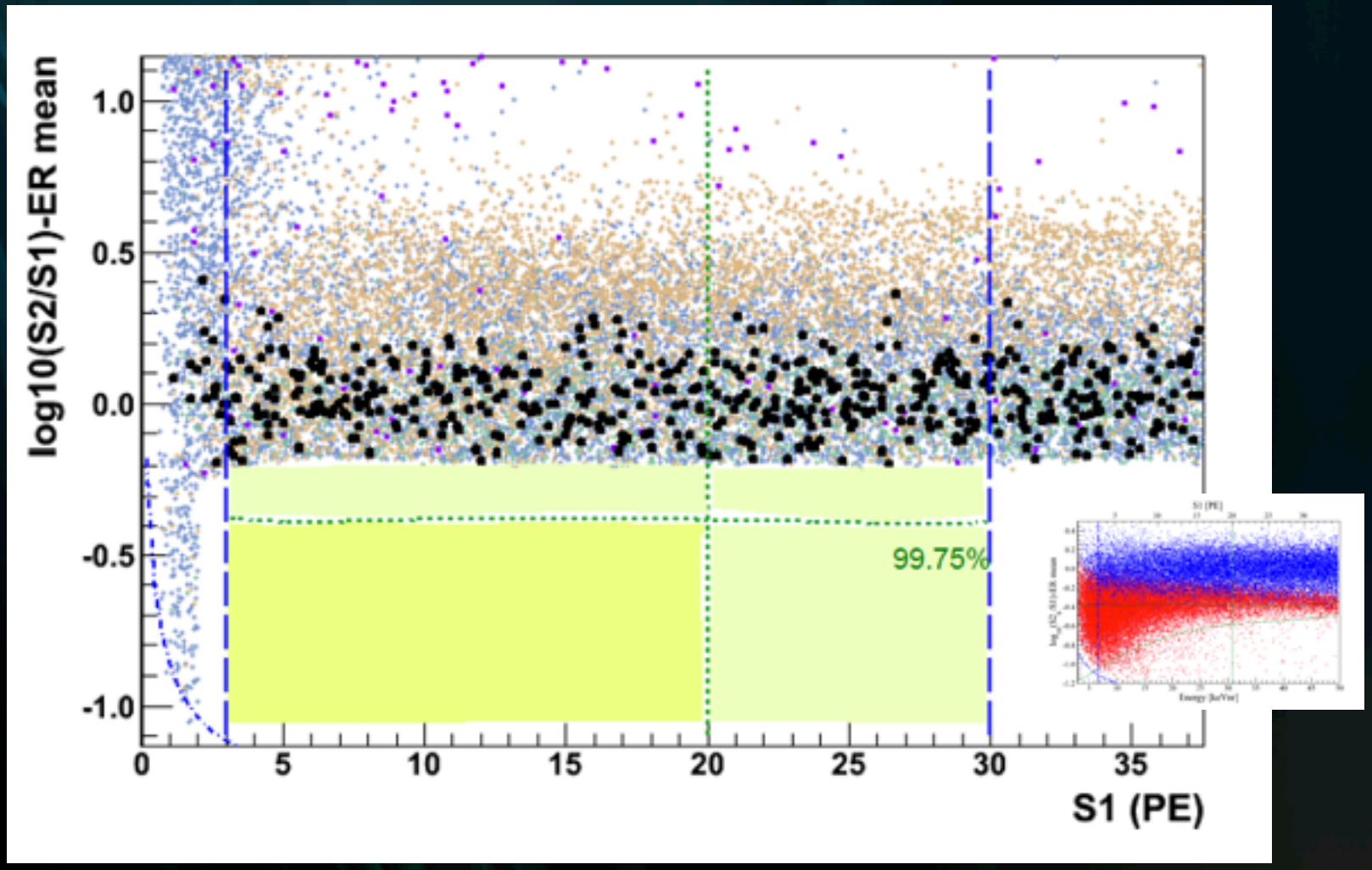
S2 width should be consistent with measured z

Select Energy Range



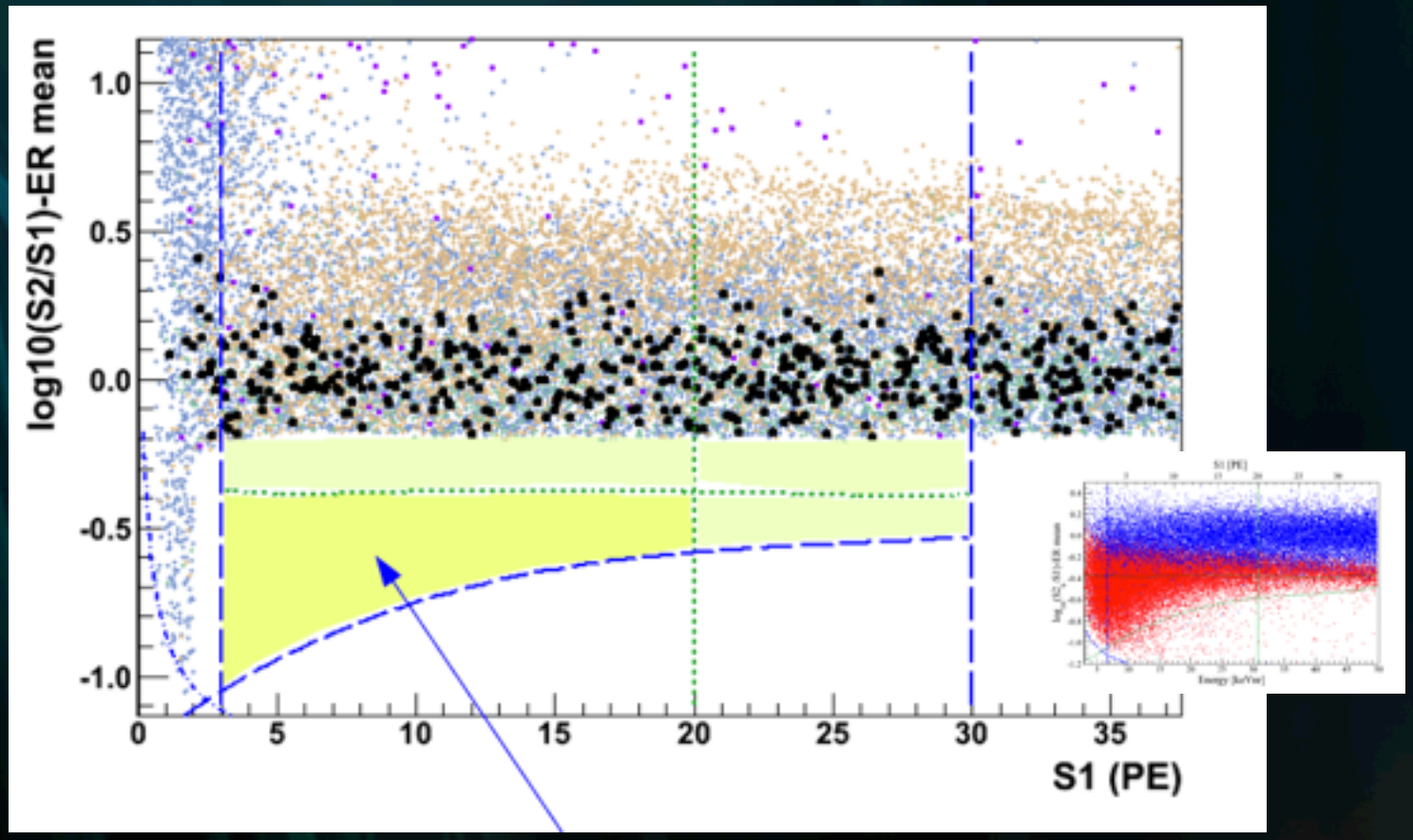
Due to the low velocity, WIMP leaves low energy

ER Rejection



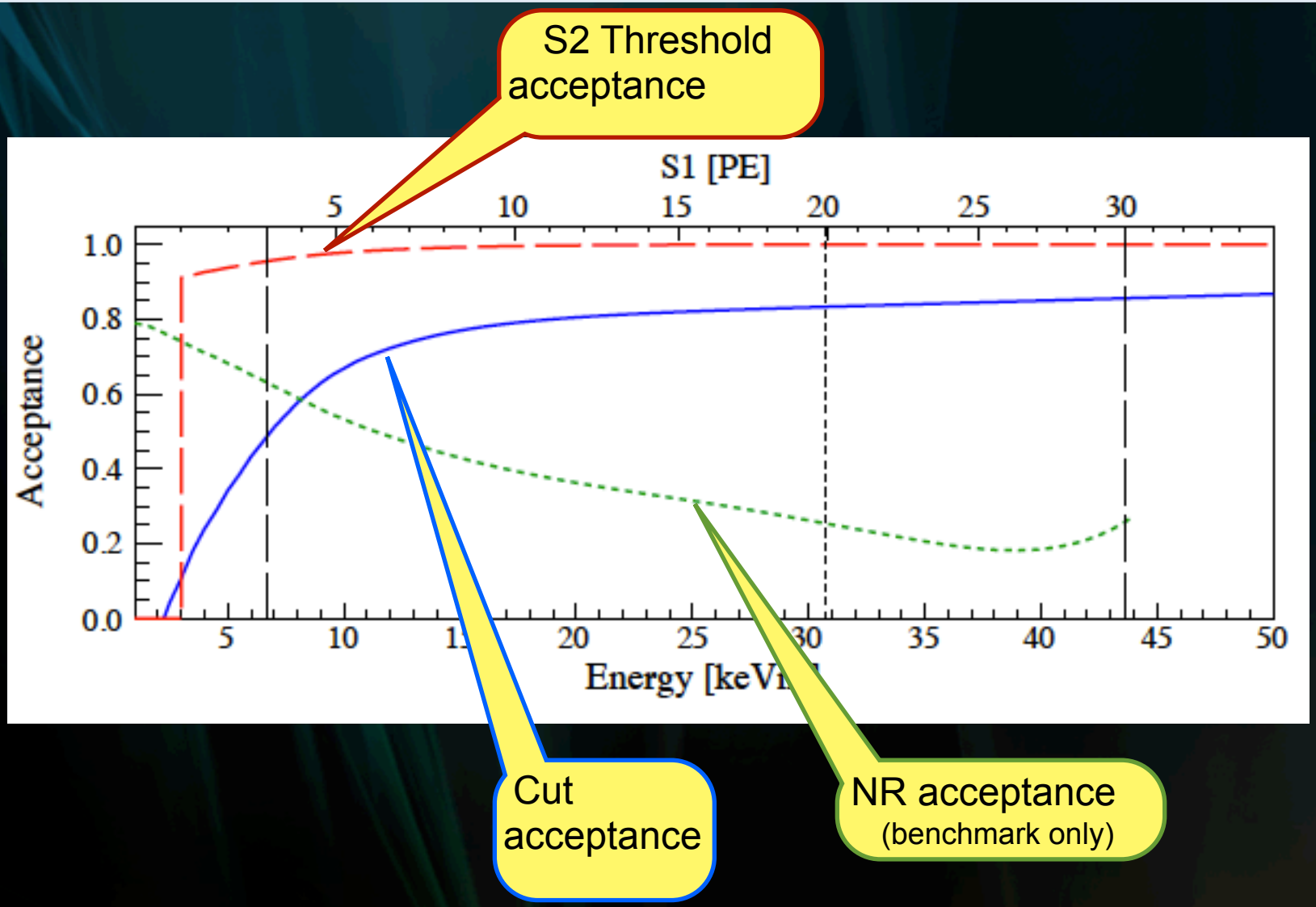
Set an upper bound on s2/s1 such that only 1/400 em events will be below it

WIMP are Neutron-Like



Restrict the signal region also from below

Cut Acceptance

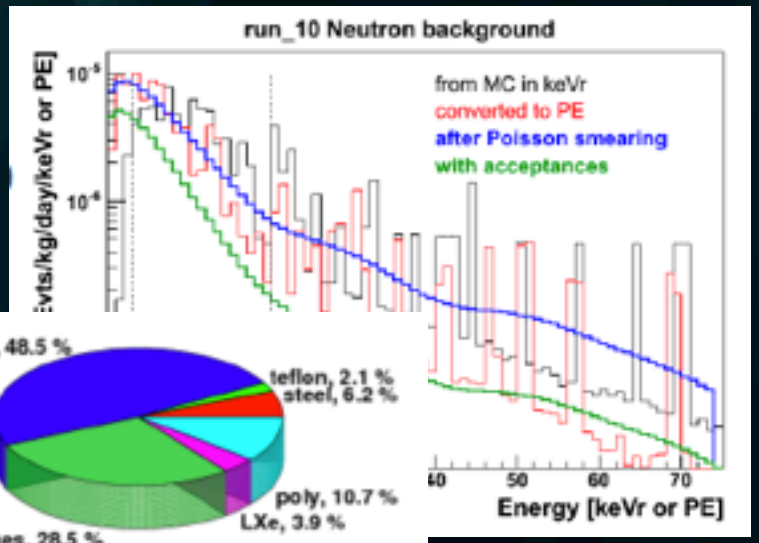


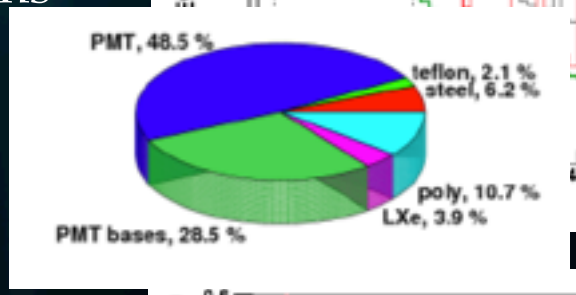
Background Prediction

Neutron background:

- (α,n)+sf and muon induced neutrons
- MC simulation using the exact XENON100 geometry and measured contaminations

Expect: $(0.17\ ^{+0.12}\ _{-0.07})$ events





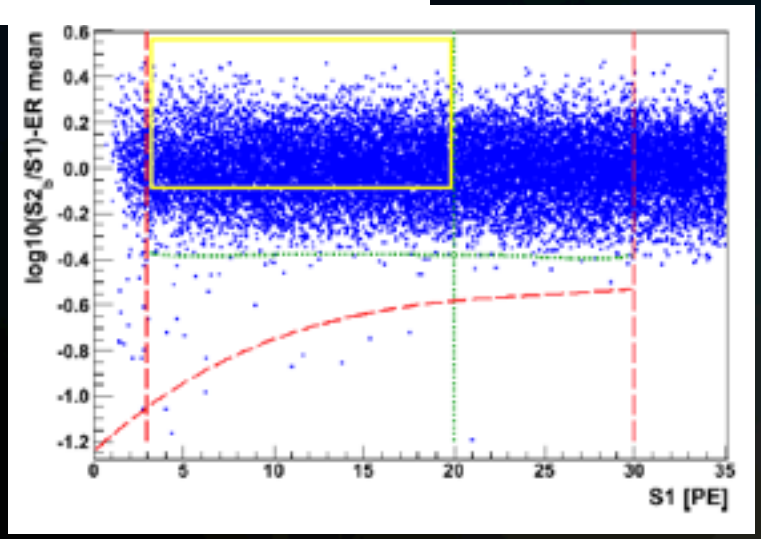
ER background:

- γ activity of the detector and shield
- intrinsic radioactivity in the LXe

(→ considerably lowered this run)

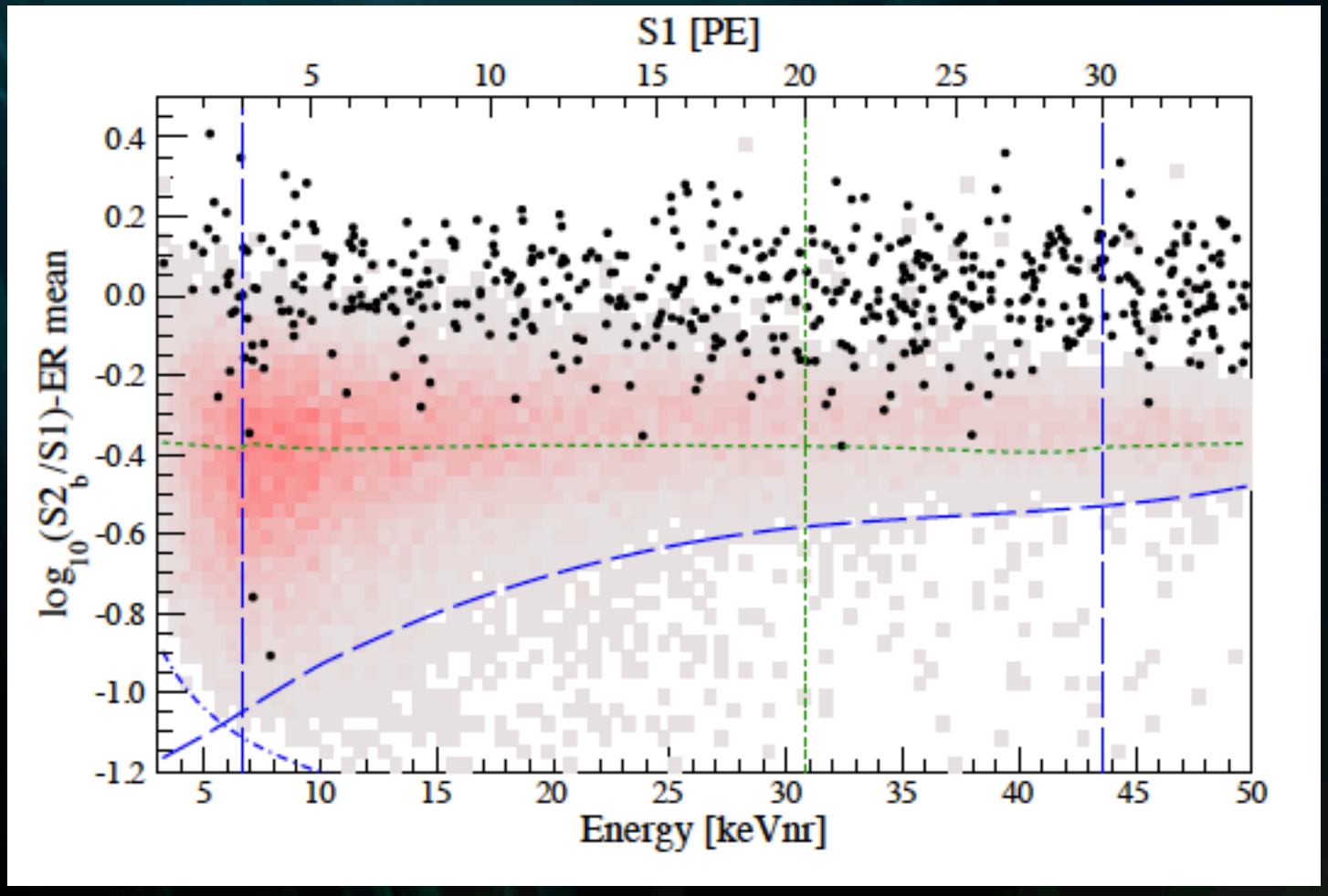
- use ER calibration to model background by scaling it to the observable DM data

Expect: (0.79 +-0.16) events



Total expected b.g. 1.0±0.2 events

Unblinding

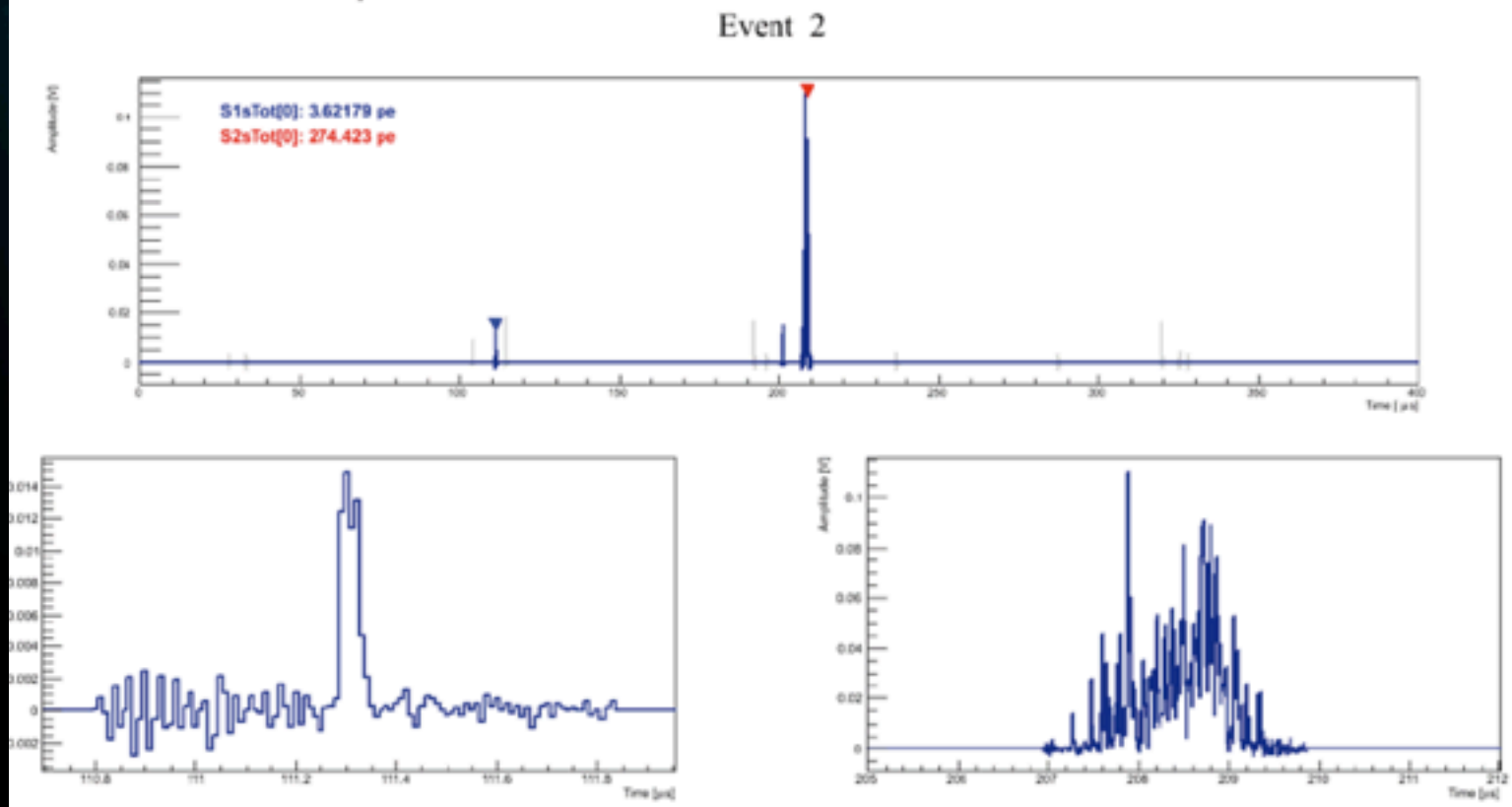


1.0 events are expected, 2 are seen ➪ no evidence for a signal.
Now is the time to set up limits :-{

Candidate “1”

Event #1 (Xe100_120111_1920)

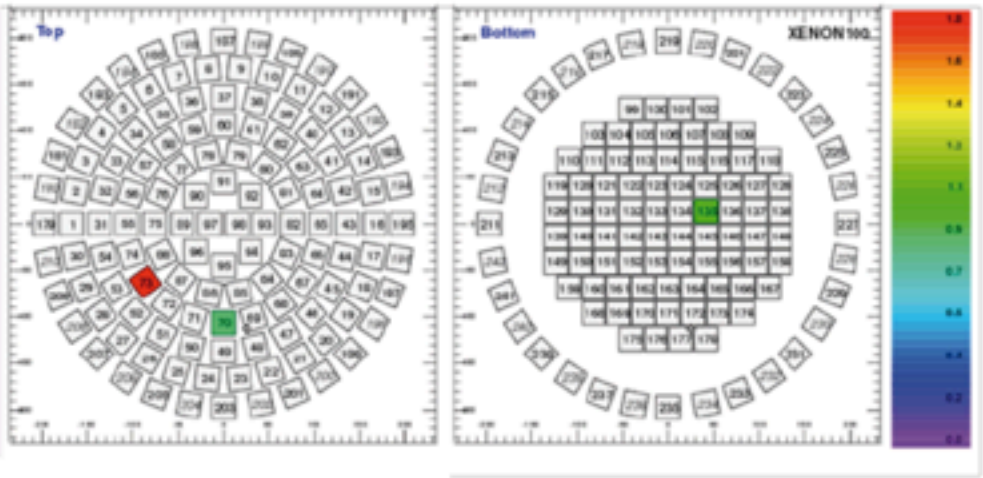
- S2=274 PE ~14 electrons
- S1=3.6 PE ~70 photons

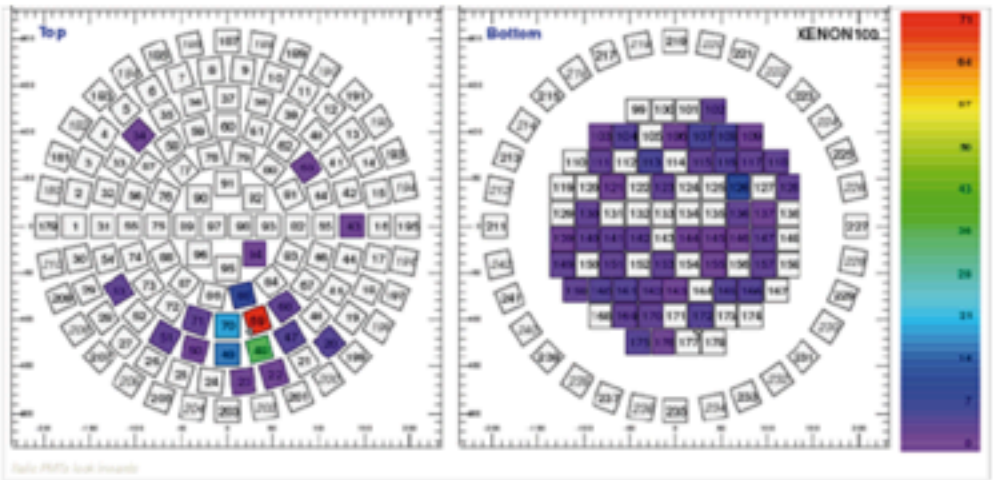


Candidate “1”

Event #1

S1 Pattern

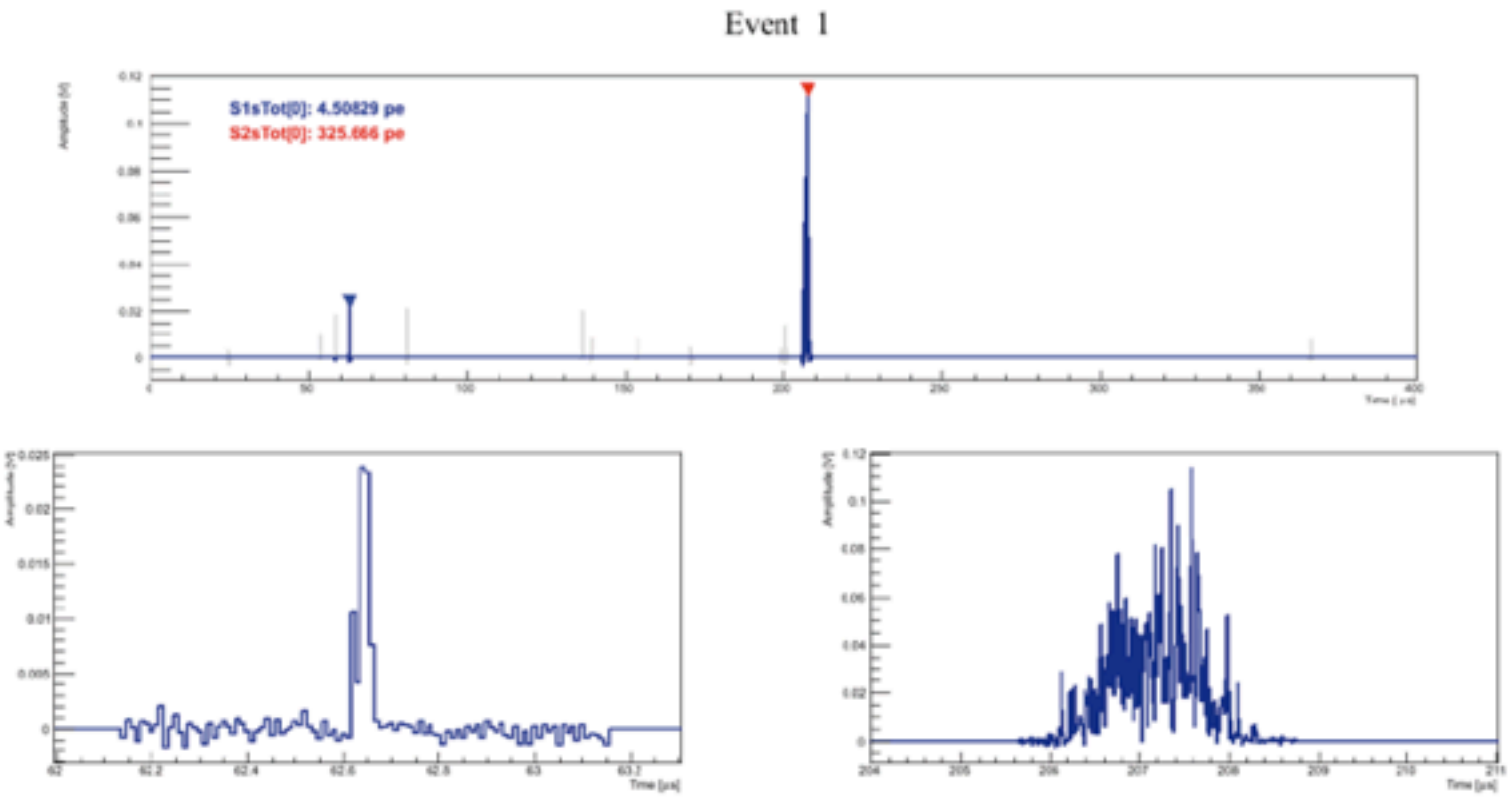




S2 Pattern

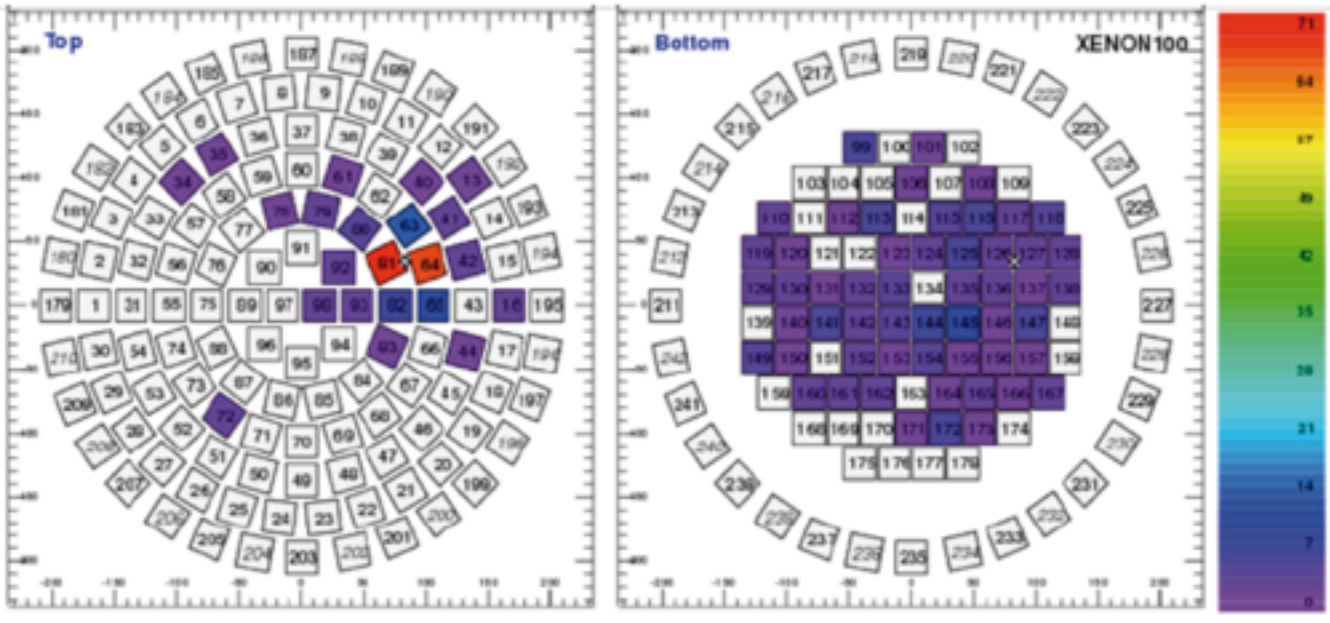
Candidate “2”

Event #2 (Xe100_111023_1101)

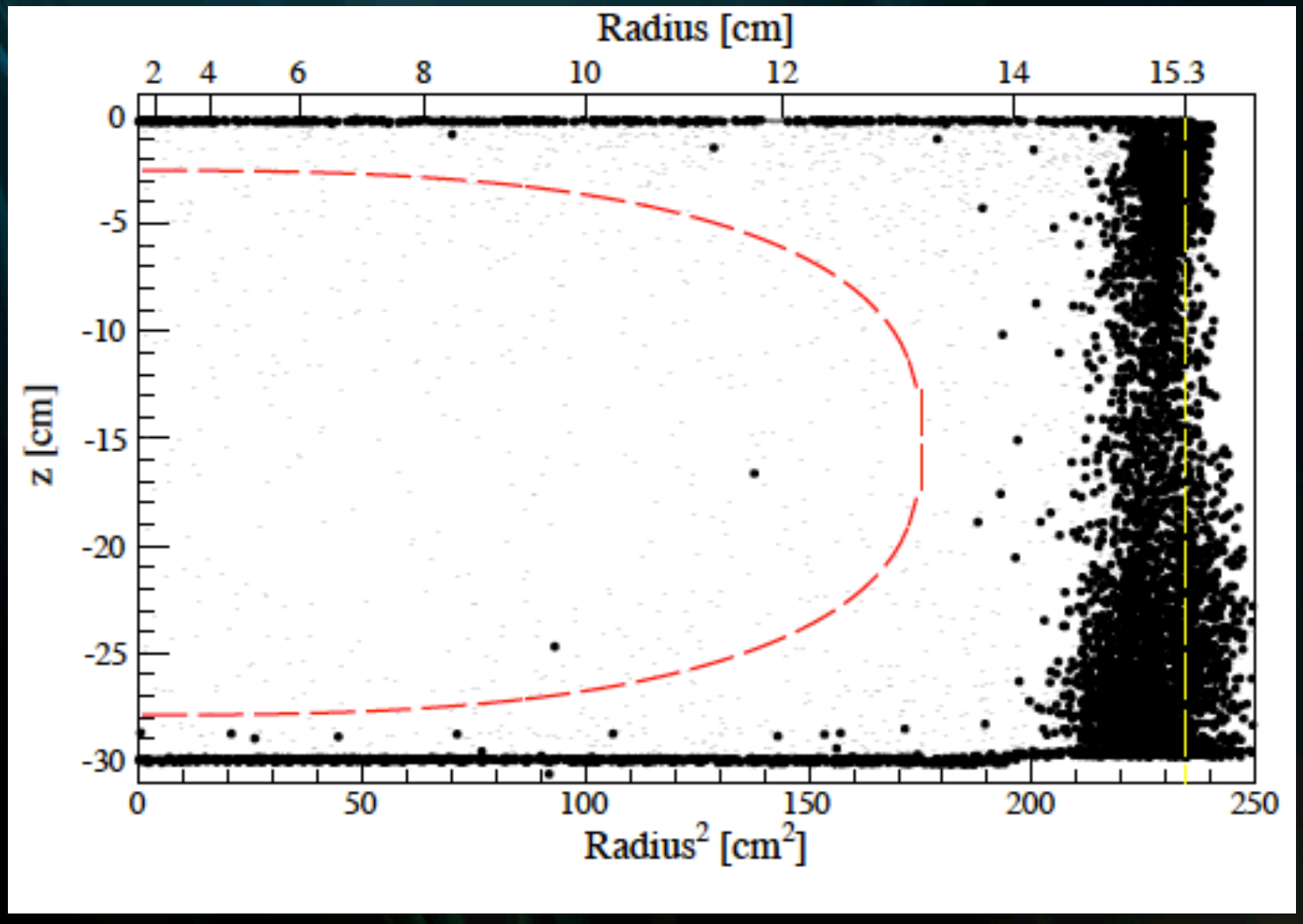


Candidate “2”

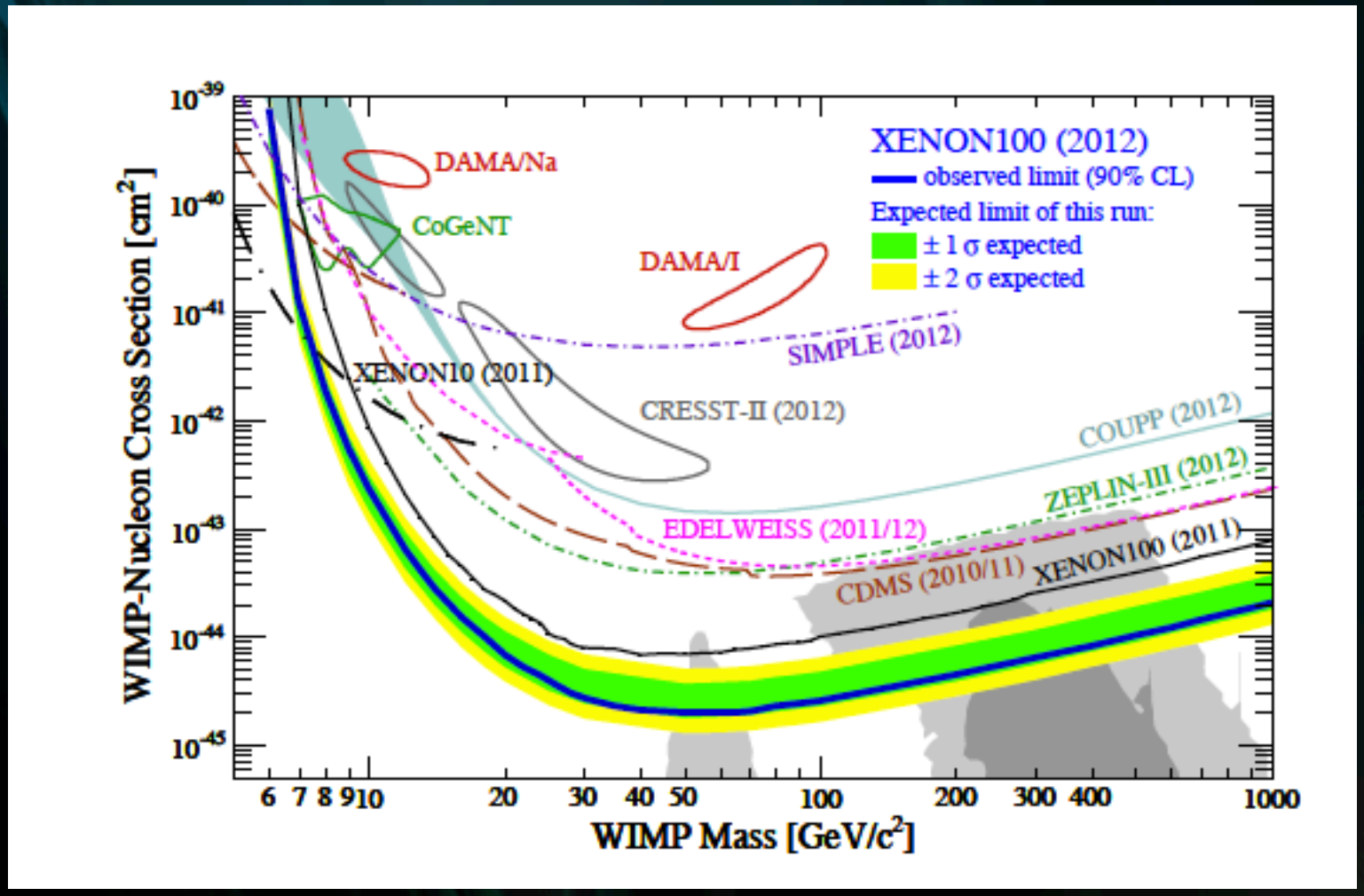
Event #2



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

But We are not Done Yet!!!

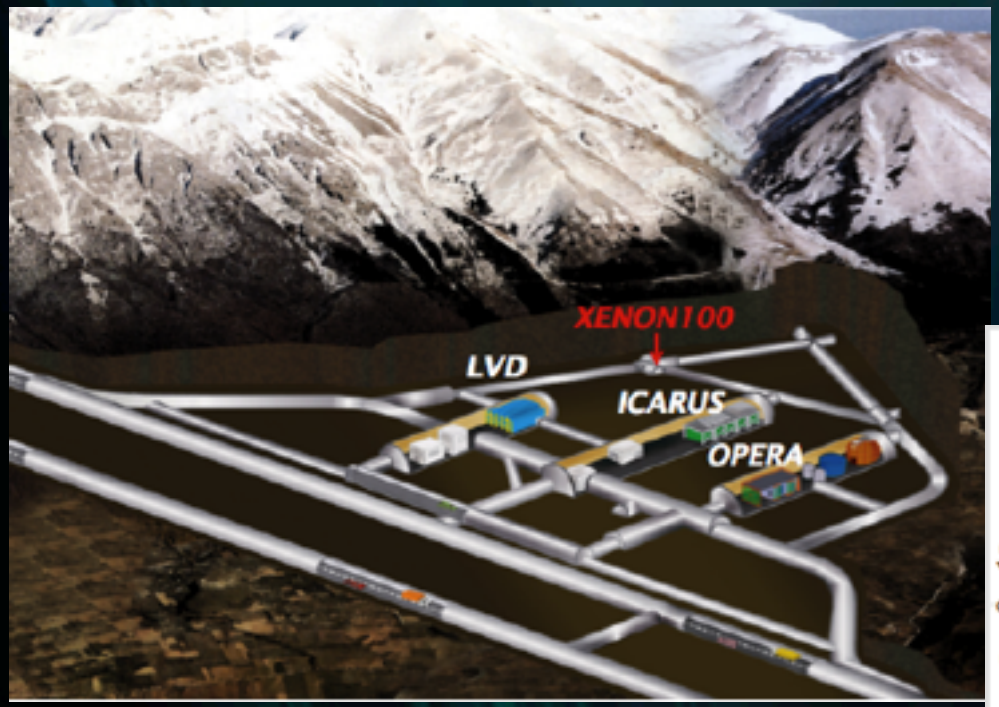
Build a More Sensitive Device

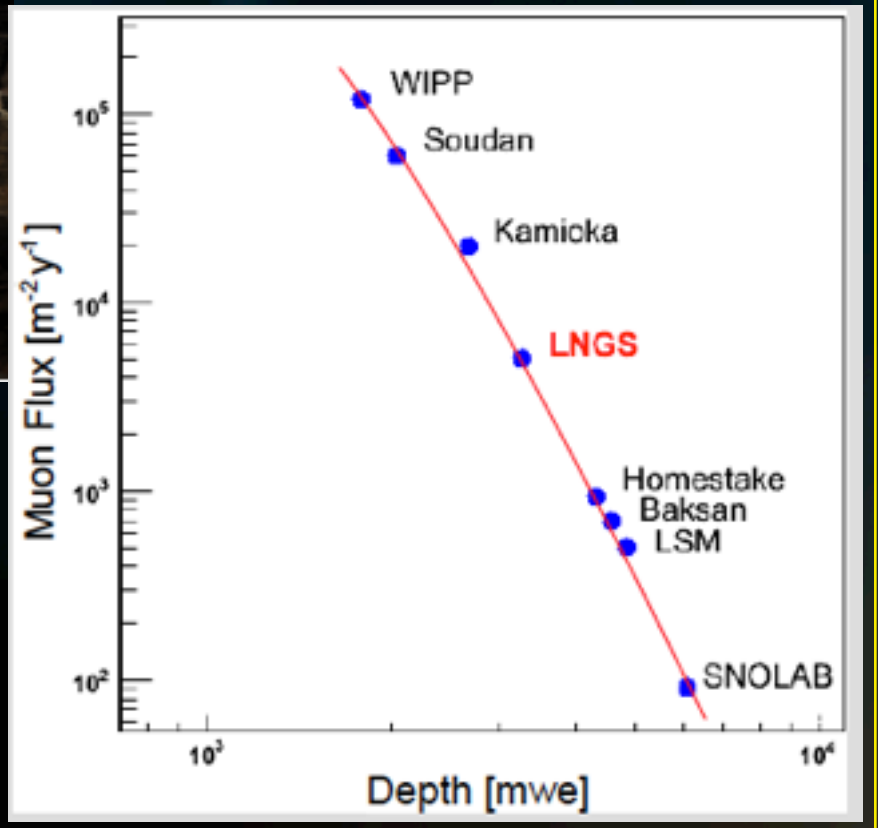
Aim at one-ton detector with sensitivity to $2*10^{-47}$ cm^2

Need

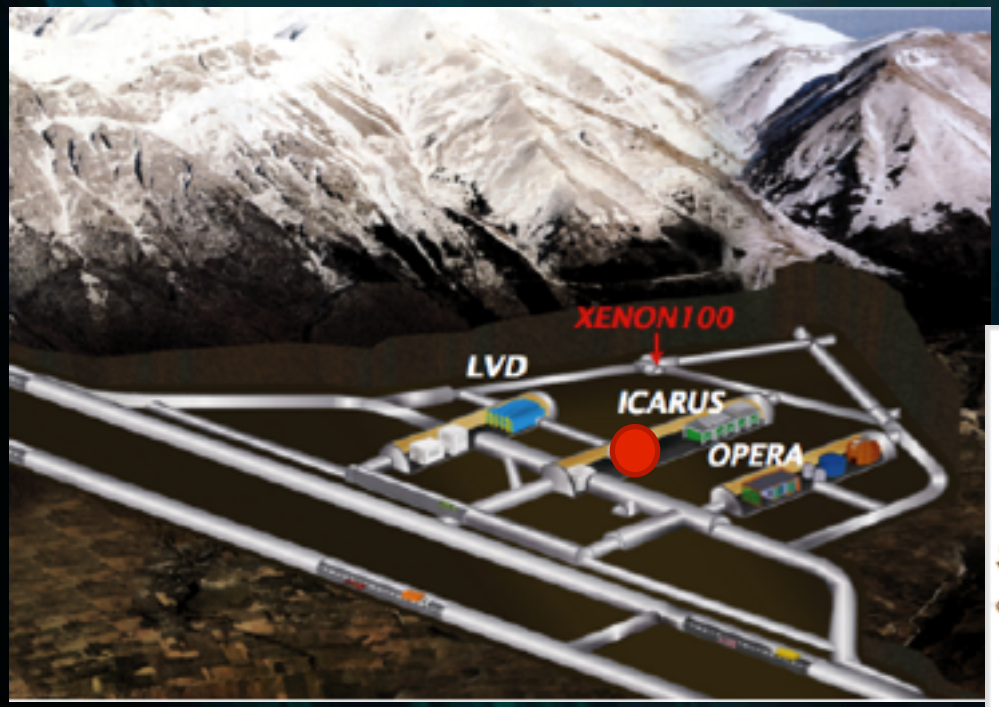
- a cubic meter of LXe
- Ultra-pure construction materials and LXe
- Large active water-Cherenkov muon veto

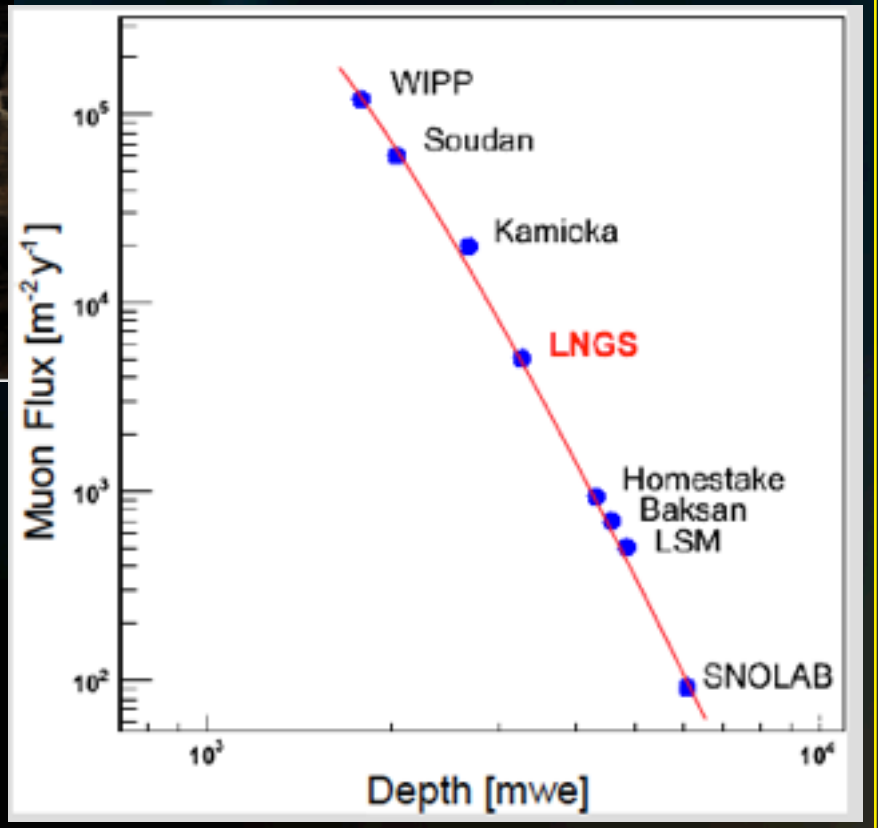
New Location in LNGS





New Location in LNGS

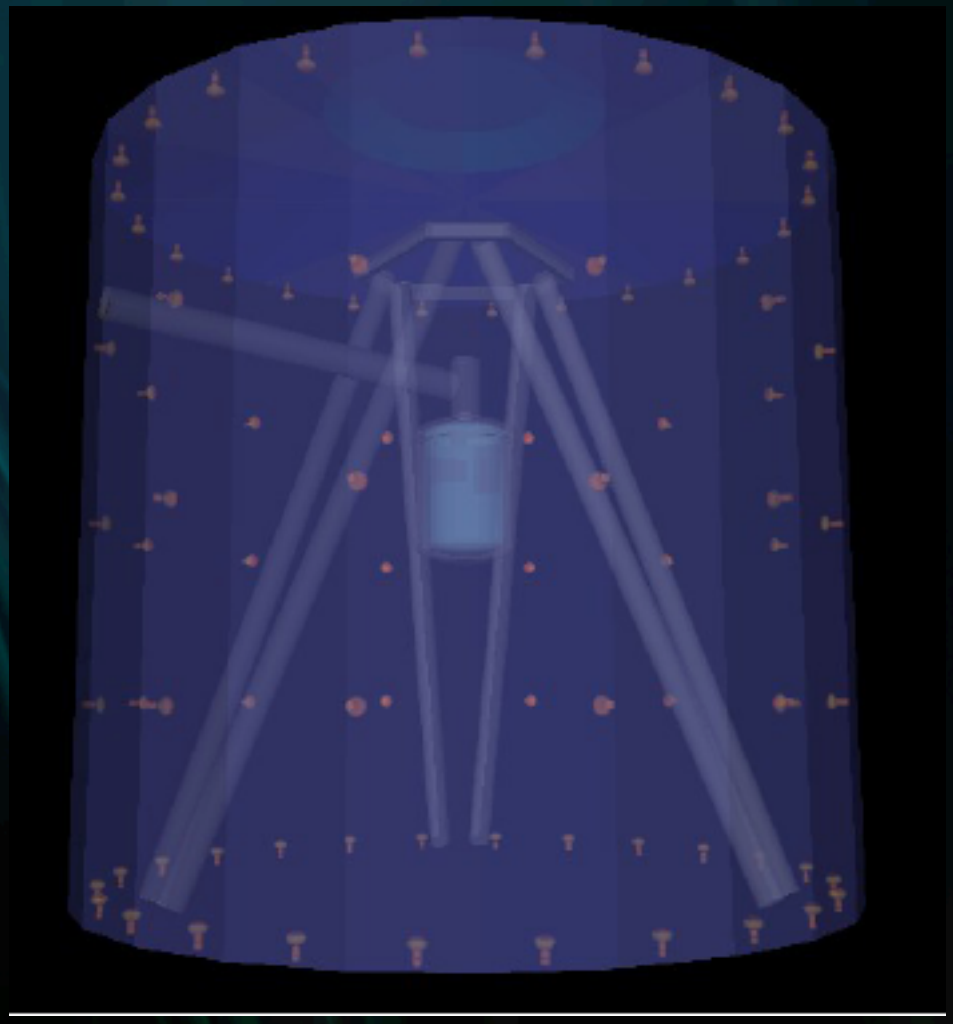




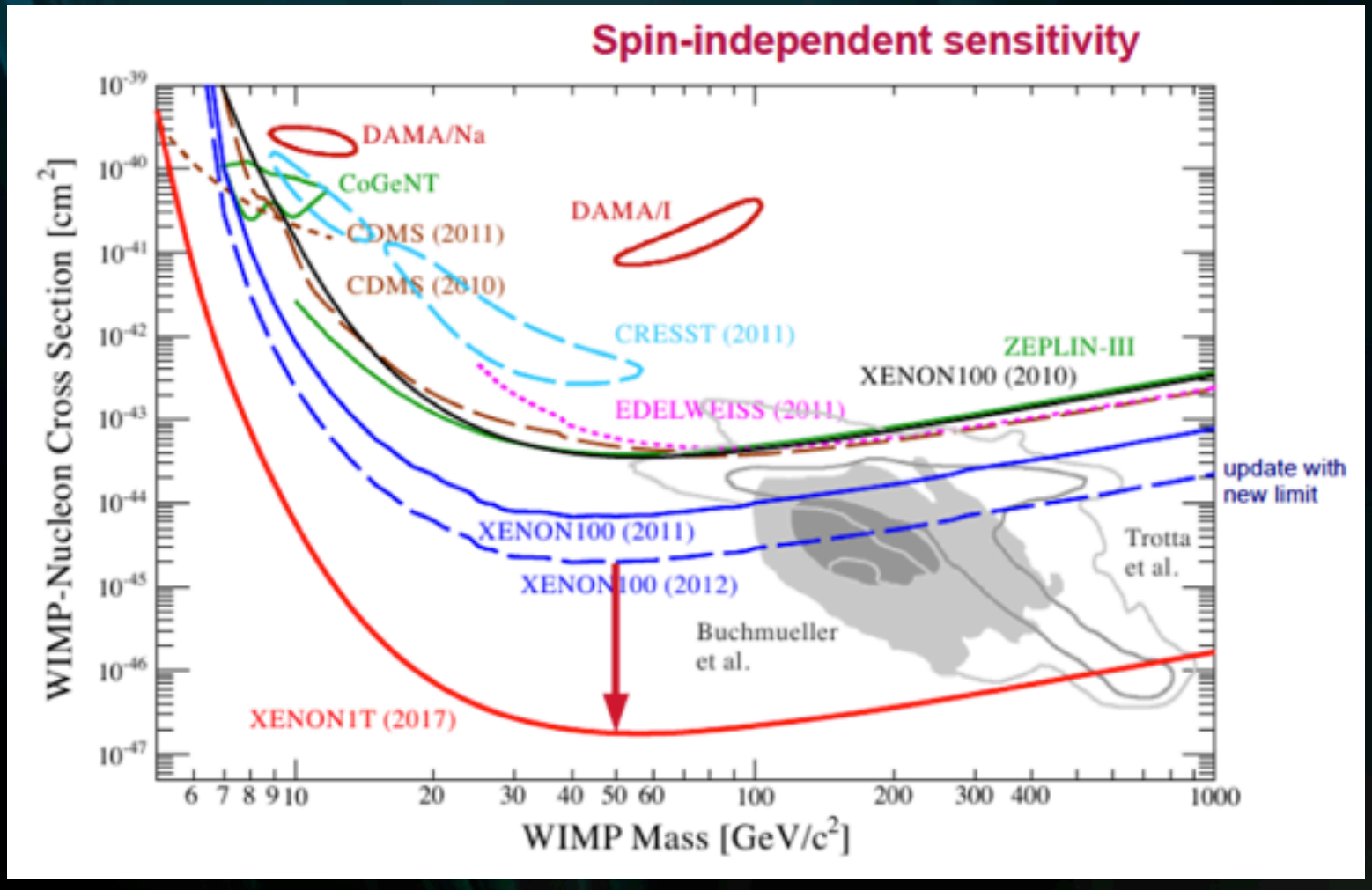
Move to One of the Main Halls

Outline of the New Device

Muon Veto & Cryostat

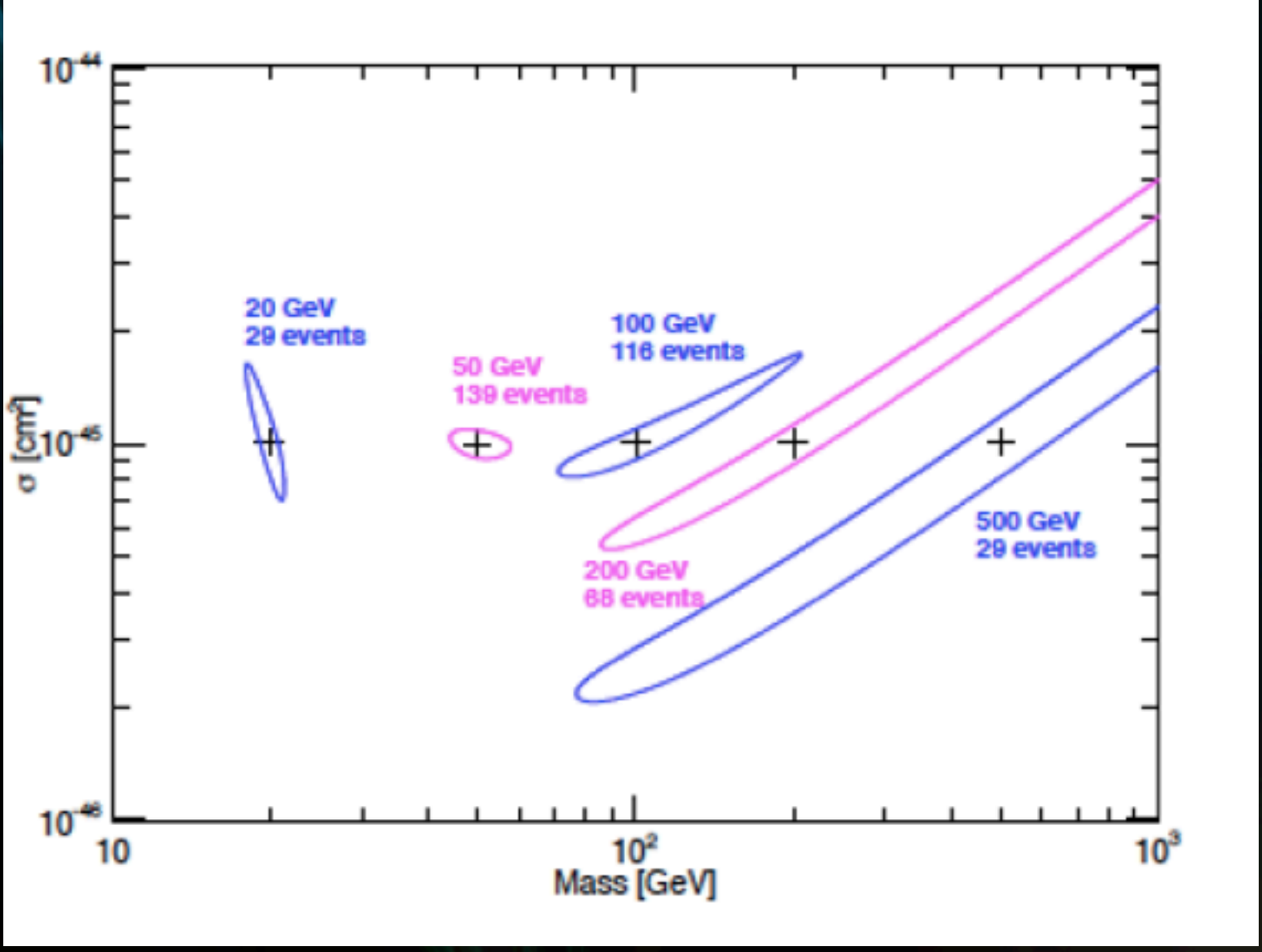


Expected Sensitivity of Xenon1t



Cover most of CMSSM range

Had Enough of Limits, Seek Discovery....



Conclusion

The Xenon100 detector just ended the longest ever run of direct-search search for DM

One b.g. event was expected and tw data events were seen

Using Profile Likelihood we set the world's best upper bound on WIMP c.s. with matter

While Xenon100 continues to run, a new detector, Xenon1t starts now to be built

By increasing the target mass, improving its purity and adding an active water shield we hope to improve the sensitivity by two orders of magnitude.

the new device will cover most of the region predicted by CMSSM

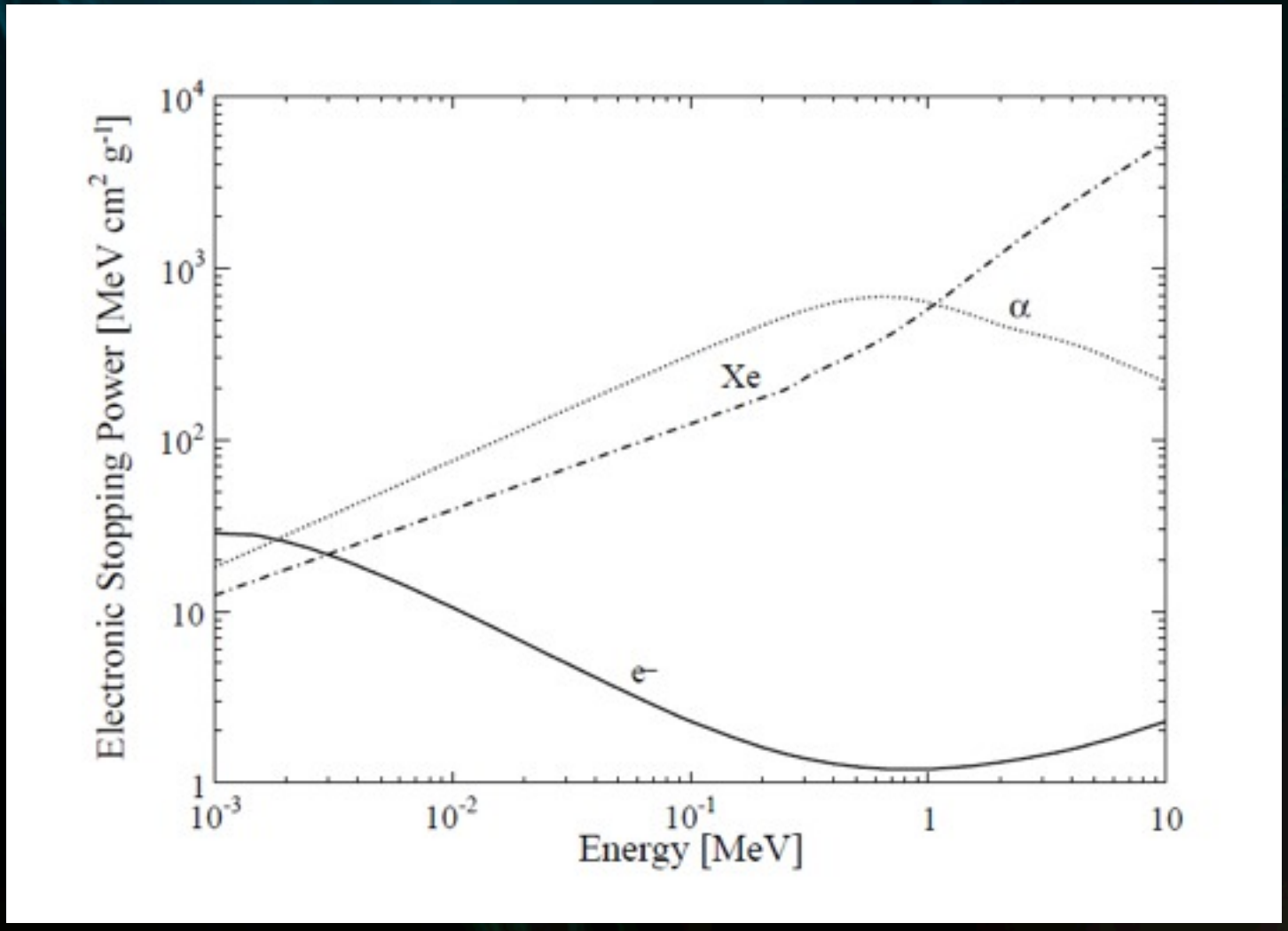
So, next time we get it!

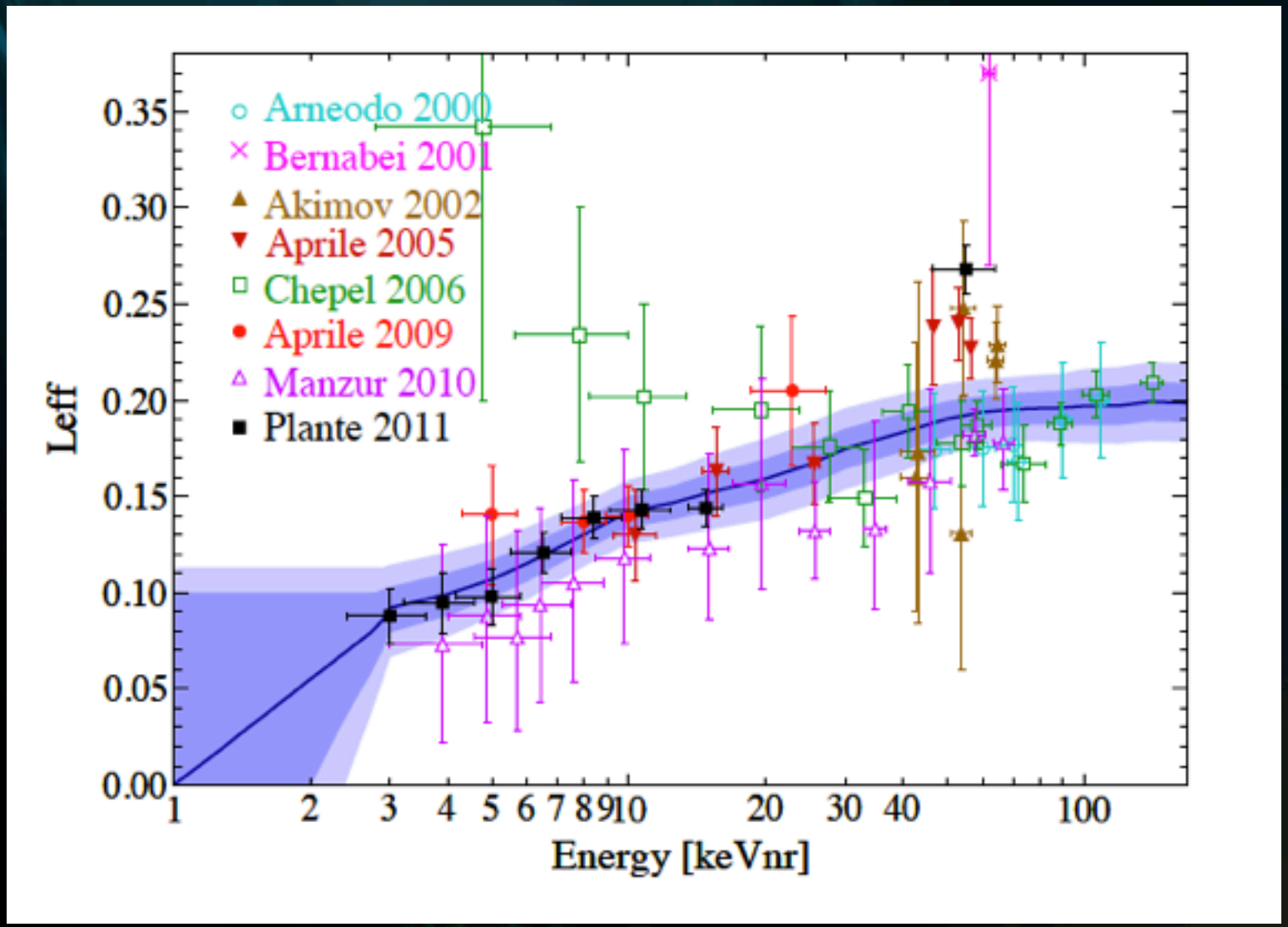
Acceptance

Backup

Stopping power – Self Shieldong

Should get one for Ar




Arneodo 2000
Bernabei 2001
Akimov 2002
Aprile 2005
Chepel 2006
Aprile 2009
Manzur 2010
Plante 2011
Leff
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1
2
3
4
5
6
7
8
9
10
20
30
40
100
Energy [keVnr]

Attenuation Length

Again, shield

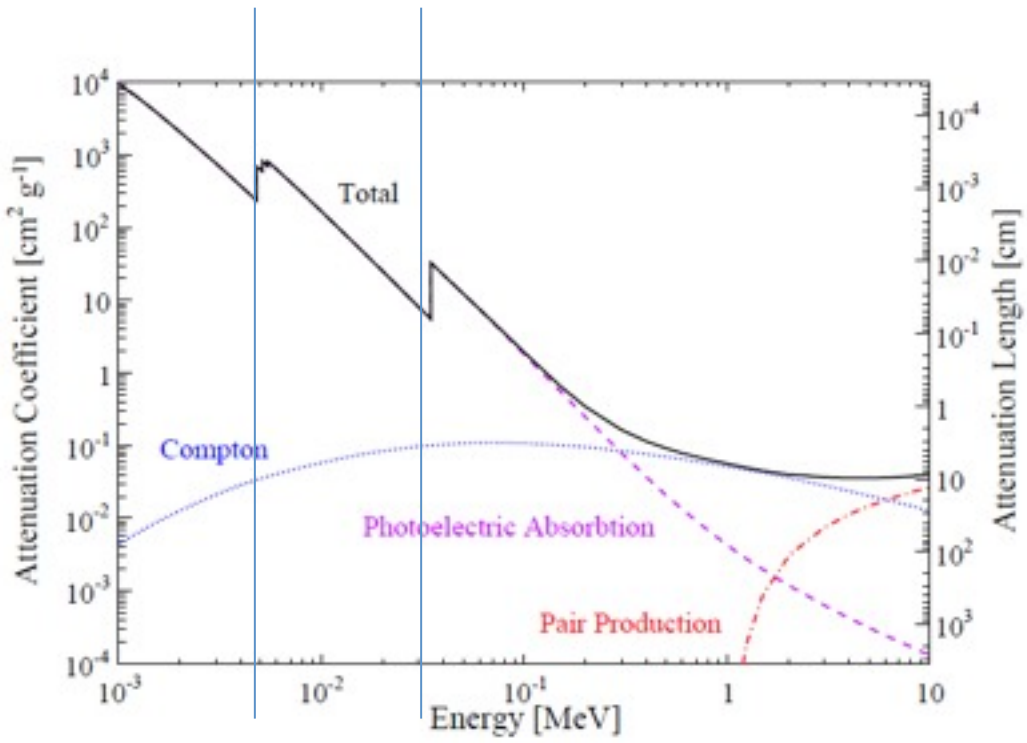
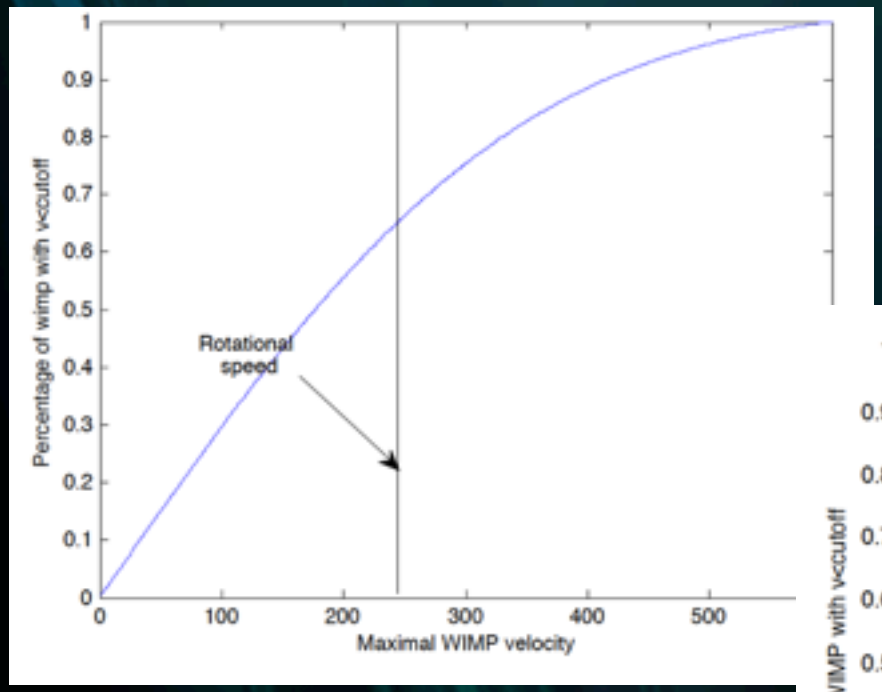
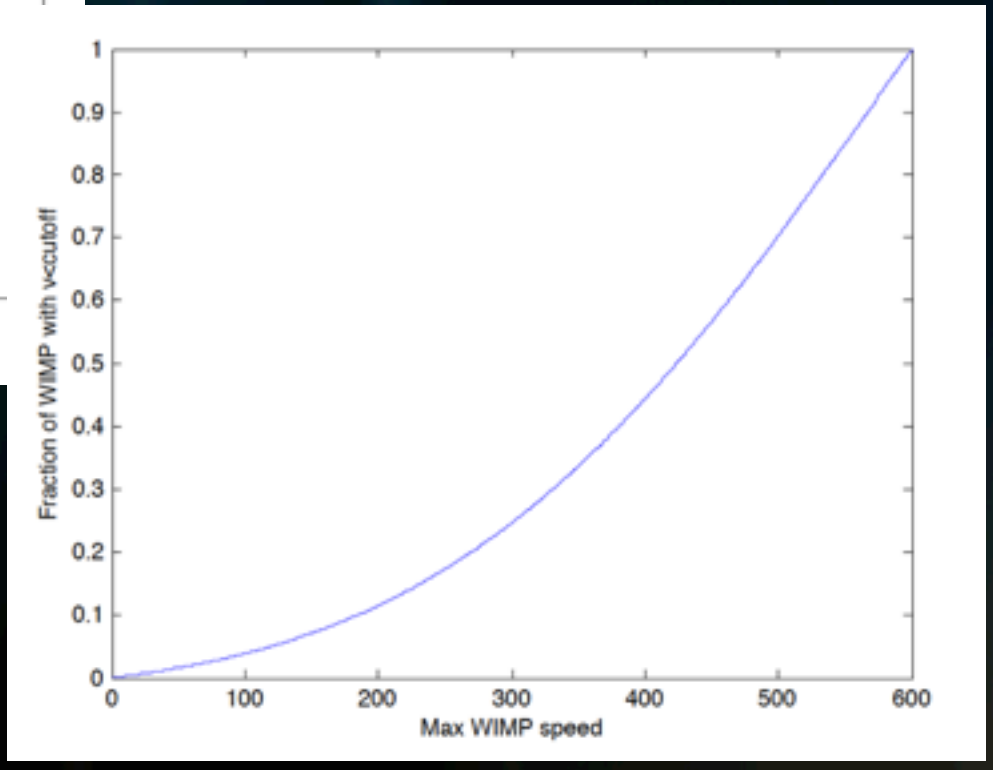


Figure 2.2: Total (solid black), photoelectric absorption (dashed violet), Compton scattering (dotted blue), and pair production (dash-dotted red) γ ray mass attenuation coefficients in Xe, as a function of energy. The right axis indicates the attenuation length in LXe, using a density of $2.86\,\mathrm{g\,cm^{-3}}$. Data from the XCOM database (Berger *et al.*, 2010).

Dark Matter in the Galaxy

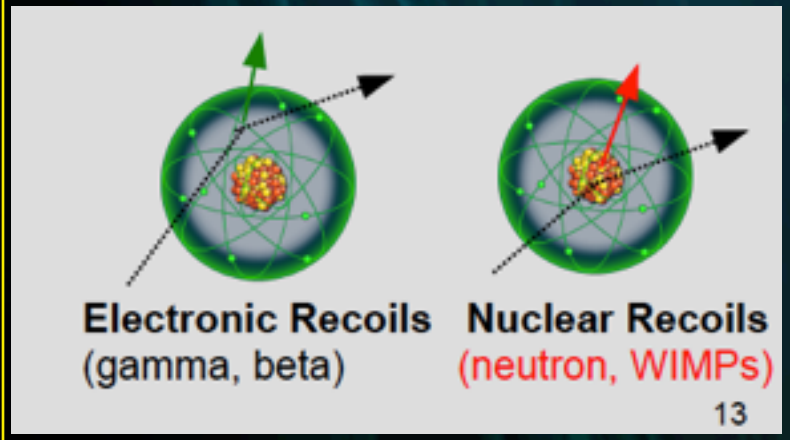




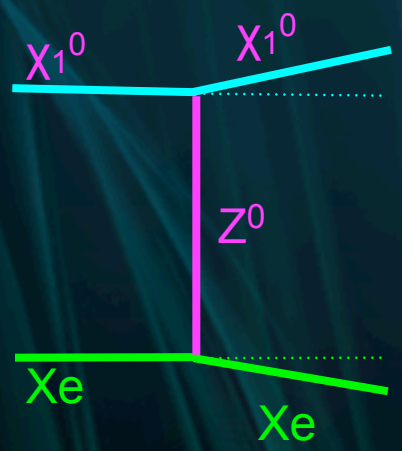
Had Enough of Limits, Seek Discovery....

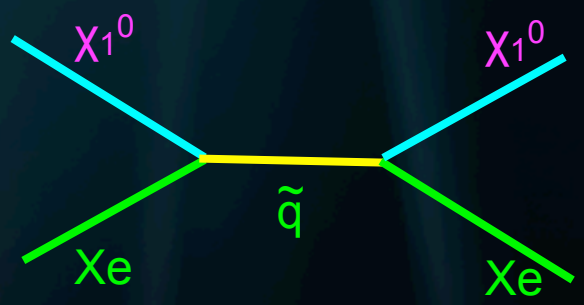
Experimental Sensitivity

without background: $\propto (mt)^{-1}$
with background: $\propto (mt)^{-1/2}$

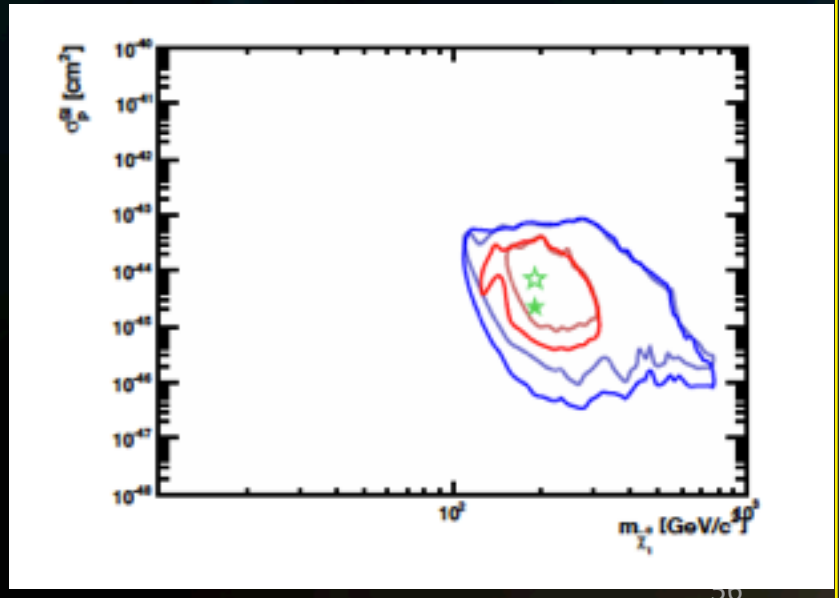


Spin Dependent



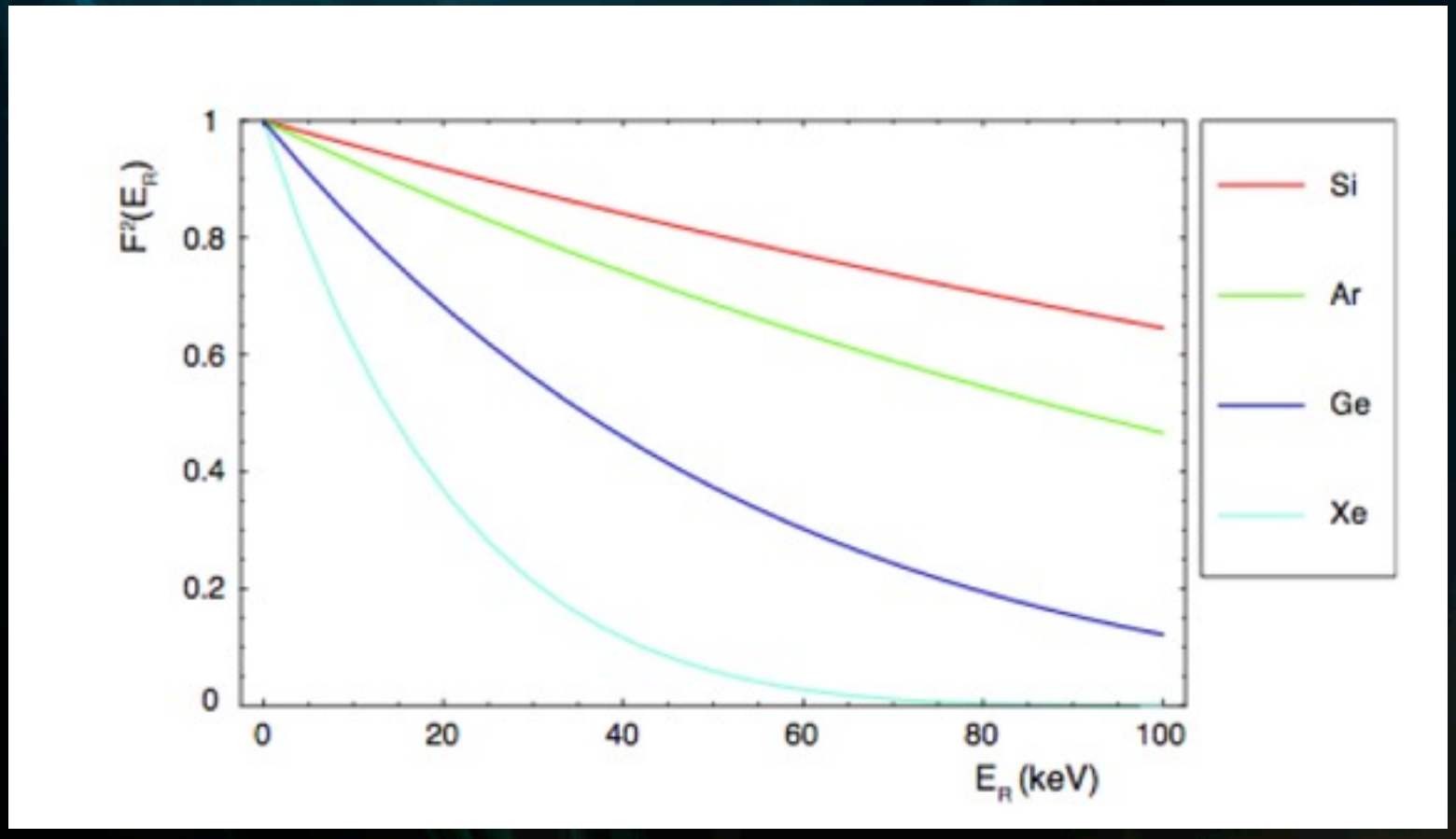


$$\mathcal{L}_A \sim \bar{\chi}\gamma_\mu\gamma_5\chi\bar{q}\gamma^\mu\gamma_5 q$$

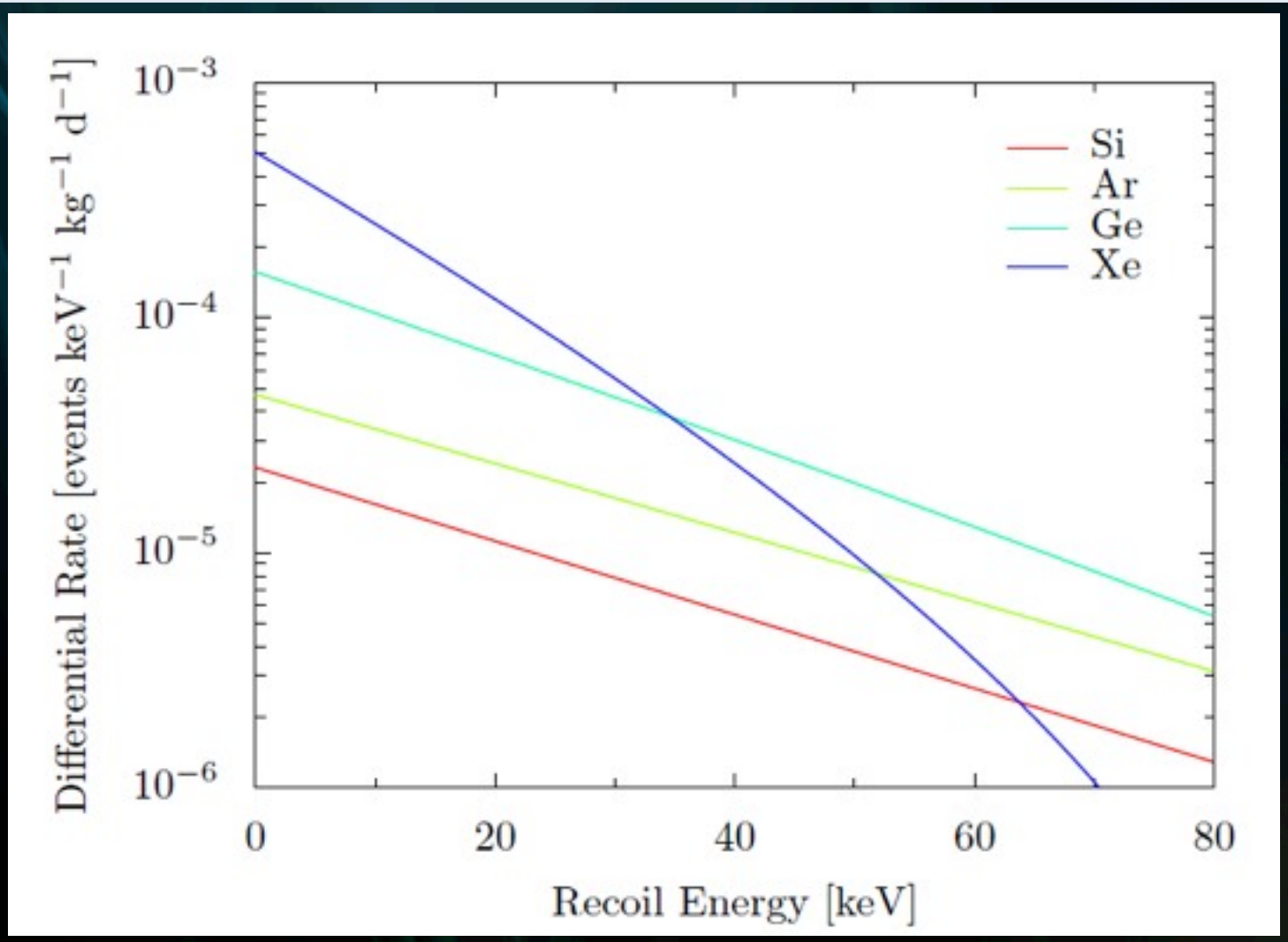


Nuclear Form Factor

A simplified picture

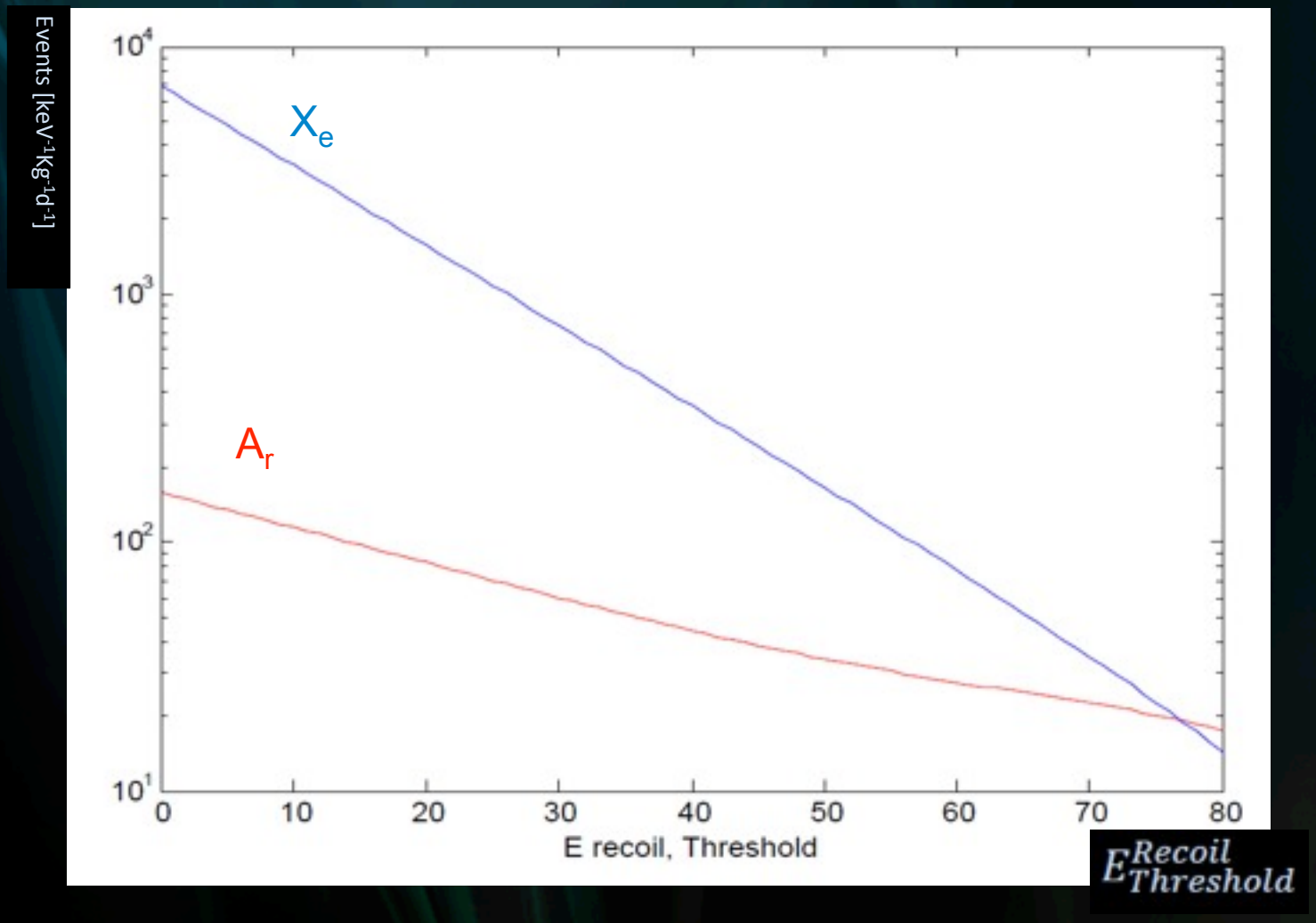


The Differential c.s.



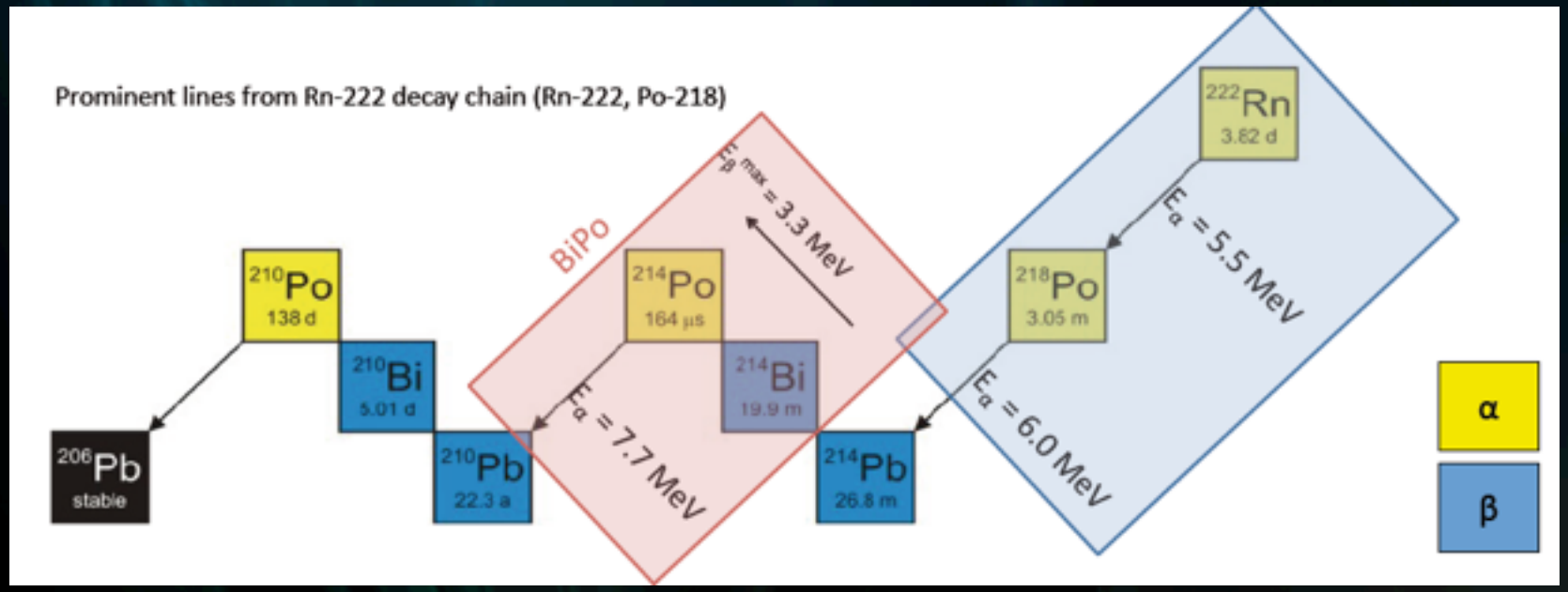
Differential c.s. as a function of the recoil energy for m_{W}=100GeV and σ_{WN}=10^{-44}cm^2 for different materials

Integrated c.s.



Rate of events above a given threshold.

The Two Candidates



Event Rate

The differential event rate per unit target mass is:

$$dR = \frac{N_A}{A}\sigma_{\chi N} v dn$$

Where NA is the Avogadro number, A is the atomic number of the target nuclei v is the WIMP velocity (comes from flux) and $\sigma_{\chi N}$ is the WIMP-Nucleus cross section and is *proportional to* A^2 for spin independent processes

Ignoring the c.s. dependence on velocity and integrating from 0 to infinity one gets that the even rate is:

$$R_0 = \frac{361}{m_\nu m_N}\left(\frac{\sigma_{\chi N}}{1pb}\right)\left(\frac{\rho_D}{0.3GeVc^{-2}cm^{-3}}\right)\left(\frac{v_0}{220kmsec^{-1}}\right)$$

where ρ_D is the local DM density ($0.3GeVf^{-3}$) and v_0 =$220kms^{-1}$ m_N and m_χ in GeV and R_0 in in events/kg/day