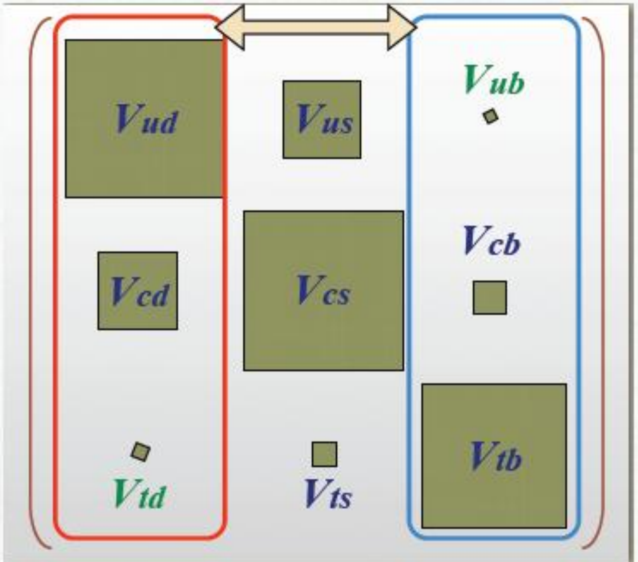
March 11, 2011
BSM mini-workshop
KIAS, Korea

한국과학기술정보연구원 Korea Institute of Science and Technology Information KiSTi www.kisti.re.kr

Belle II vs. LHCb

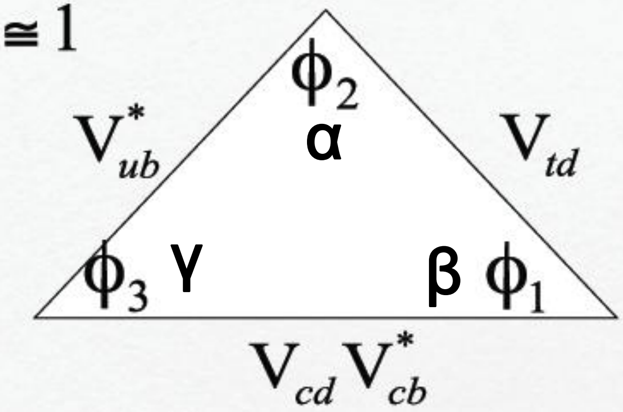
Kihyeon Cho
High Energy Physics Team
KISTI (Korea Institute of Science and Technology Information)

CKM Matrix



$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$

$$V_{ud} \cong V_{tb} \cong 1$$



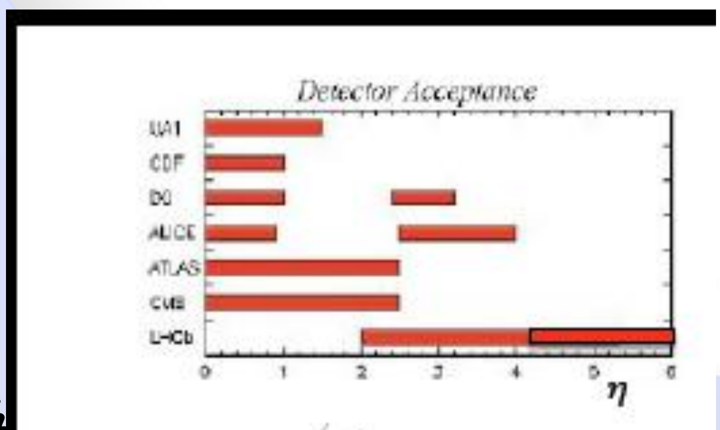
αβγ
αβγ

Unitarity triangle angles			
BABAR:	β	α	γ
BELLE:	ϕ_1	ϕ_2	ϕ_3
This talk:	易	難	魔

Z. Ligeti, from plenary talk @ ICHEP 2004

Heavy Flavor Experiments (2011.02)

	Belle/Belle II	CDF	LHCb
Year	1998–2010 (Belle) 2014 – (Belle II)	2001–	2009–
Place	KEK, Japan	Fermilab, USA	CERN, Europe
Collaboration	13/47/~300(Belle II) (Nat./Ins./member)	15/63/620	15/54/730
σ	1 nb (10GeV)	150 μb (2TeV)	300~500 μb (7~14TeV)
Current Luminosity	1 ab^{-1}	9 fb^{-1}	10 pb^{-1}



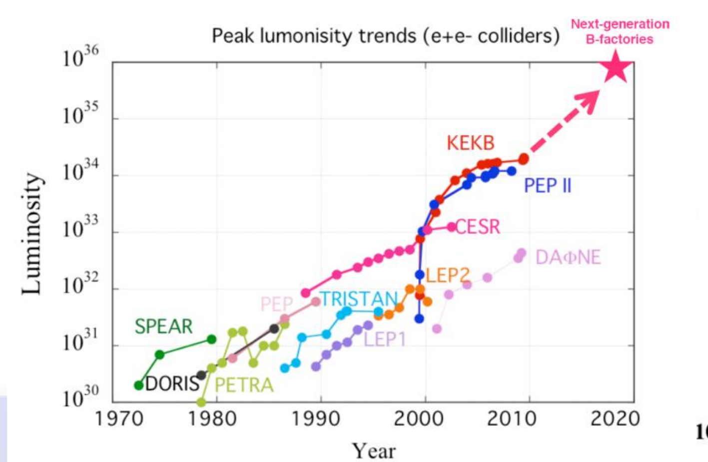


Table I. Some interesting observables. In the "present status" column, upper bounds are 90% CL. The expected experimental sensitivities are current estimates and may change in the future. In several processes the most interesting information will come from more detailed measurements that cannot be captured simply by a single number.

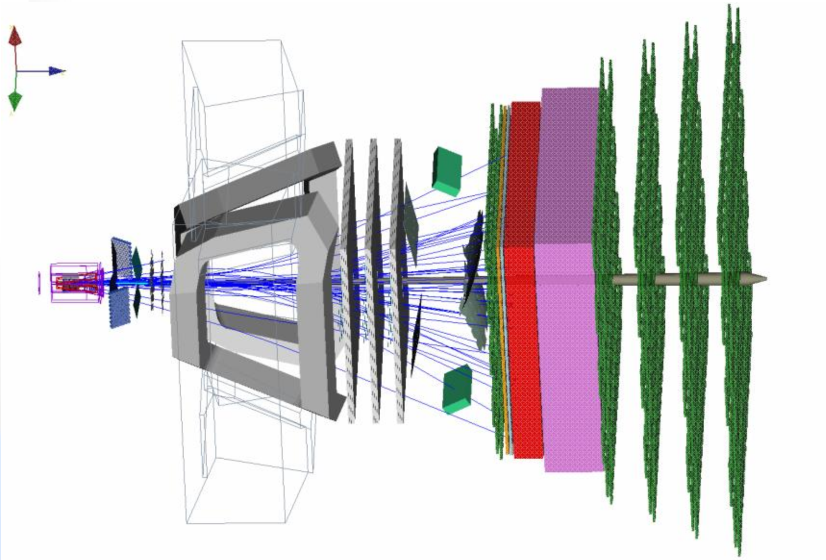
Observable	Approximate SM prediction	Present status	Uncertainty / number of events Super-B ($50\,\mathrm{ab}^{-1}$)	LHCb ($10\,\mathrm{fb}^{-1}$)
$S_{\psi K}$	input	0.671 ± 0.024	0.005	0.01
$S_{\phi K}$	$S_{\psi K}$	0.44 ± 0.18	0.03	0.1
$S_{\eta' K}$	$S_{\psi K}$	0.59 ± 0.07	0.02	not studied
$\alpha(\pi\pi, \rho\rho, \rho\pi)$	α	$(89 \pm 4)^\circ$	2°	4°
$\gamma(DK)$	γ	$(70^{+27}_{-30})^\circ$	2°	3°
$S_{K^*\gamma}$	few $\times$ 0.01	-0.16 ± 0.22	0.03	—
$S_{B_s \to \phi\gamma}$	few $\times$ 0.01	—	—	0.05
$\beta_s(B_s \to \psi\phi)$	1°	$(22^{+10}_{-8})^\circ$	—	0.3°
$\beta_s(B_s \to \phi\phi)$	1°	—	—	1.5°
A^d_{SL}	-5×10^{-4}	$-(5.8 \pm 3.4) \times 10^{-3}$	10^{-3}	10^{-3}
A^s_{SL}	2×10^{-5}	$(1.6 \pm 8.5) \times 10^{-3}$	$\Upsilon(5S)$ run?	10^{-3}
$A_{CP}(b \to s\gamma)$	< 0.01	-0.012 ± 0.028	0.005	—
$\lvert V_{cb}\rvert$	input	$(41.2 \pm 1.1) \times 10^{-3}$	1%	—
$\lvert V_{ub}\rvert$	input	$(3.93 \pm 0.36) \times 10^{-3}$	4%	—
$B \to X_s\gamma$	3.2×10^{-4}	$(3.52 \pm 0.25) \times 10^{-4}$	4%	—
$B \to \tau\nu$	1×10^{-4}	$(1.73 \pm 0.35) \times 10^{-4}$	5%	—
$B \to X_s\nu\bar\nu$	3×10^{-5}	$< 6.4 \times 10^{-4}$	only $K\nu\bar\nu$?	—
$B \to X_s\ell^+\ell^-$	6×10^{-6}	$(4.5 \pm 1.0) \times 10^{-6}$	6%	not studied
$B_s \to \tau^+\tau^-$	1×10^{-6}	$<$ few %	$\Upsilon(5S)$ run?	—
$B \to X_s\tau^+\tau^-$	5×10^{-7}	$<$ few %	not studied	—
$B \to \mu\nu$	4×10^{-7}	$< 1.3 \times 10^{-6}$	6%	—
$B \to \tau^+\tau^-$	5×10^{-8}	$< 4.1 \times 10^{-3}$	$\mathcal{O}(10^{-4})$	—
$B_s \to \mu^+\mu^-$	3×10^{-9}	$< 5 \times 10^{-8}$	—	$> 5\sigma$ in SM
$B \to \mu^+\mu^-$	1×10^{-10}	$< 1.5 \times 10^{-8}$	$< 7 \times 10^{-9}$	not studied
$B \to K^*\ell^+\ell^-$	1×10^{-6}	$(1 \pm 0.1) \times 10^{-6}$	15k	36k
$B \to K\nu\bar\nu$	4×10^{-6}	$< 1.4 \times 10^{-5}$	20%	—

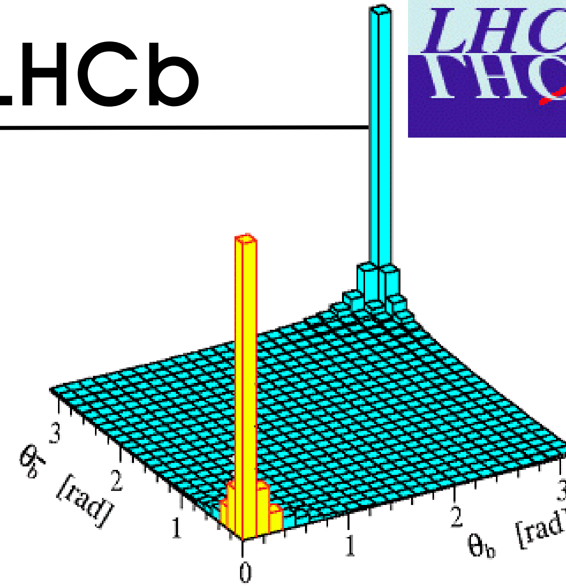
Not so near future!!

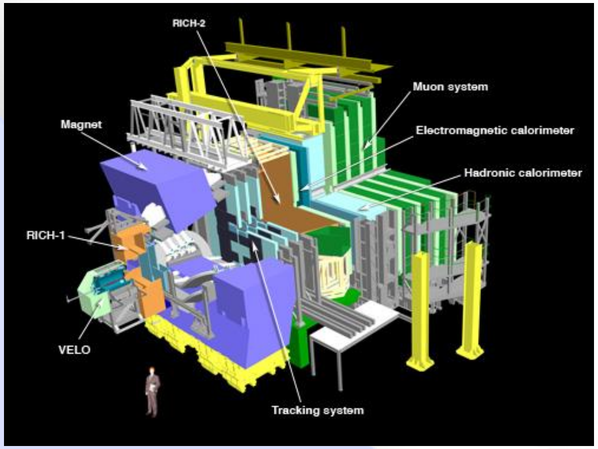
Grossman, Ligeti, Nir (May 2009)

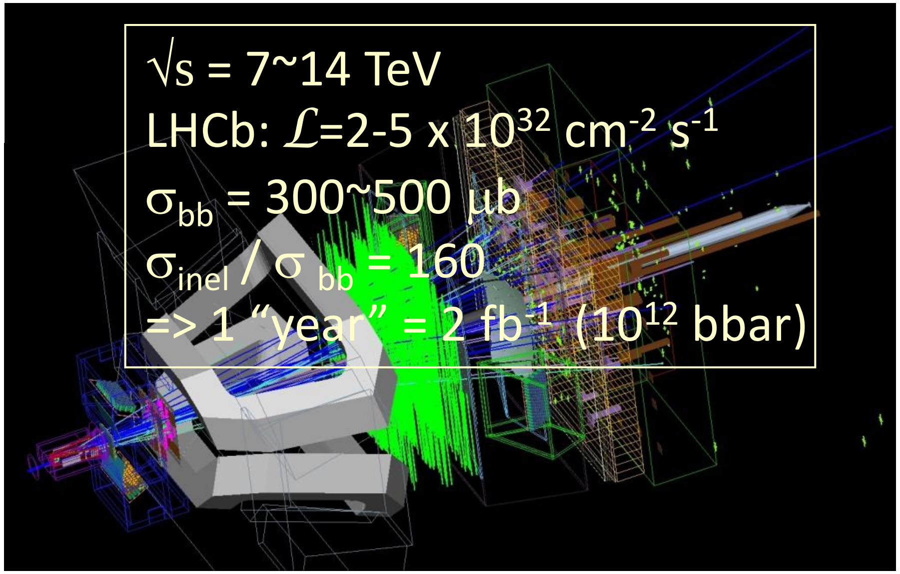
LHCb

Heavy Flavor Physics by LHCb







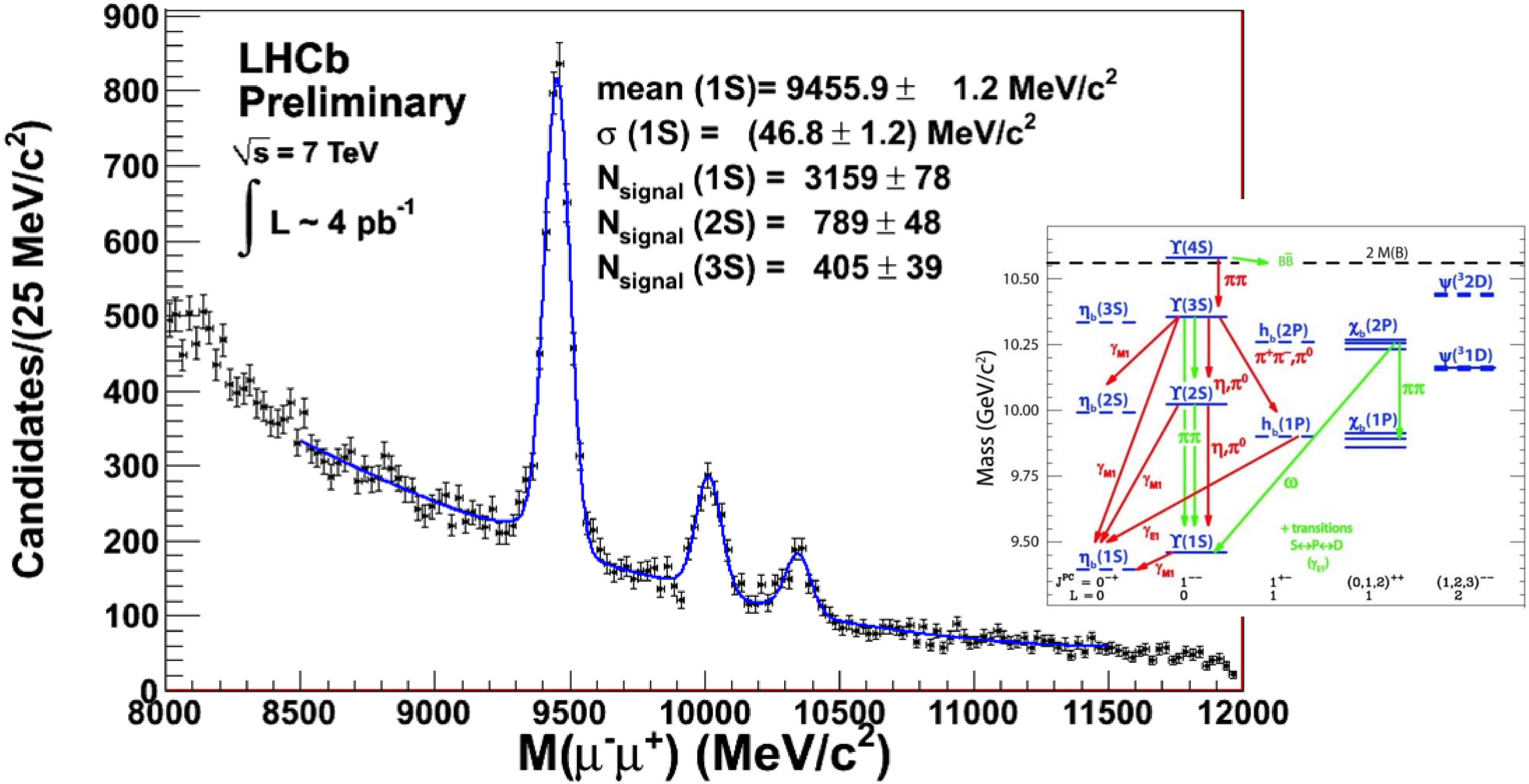


$\sqrt{s}$ = 7~14 TeV
LHCb: $\mathcal{L}$=2-5 x 10^{32} cm^{-2} s^{-1}
σ_{bb} = 300~500 μb
σ_{inel} / σ_{bb} = 160
=> 1 "year" = 2 fb^{-1} (10^{12} bbar)

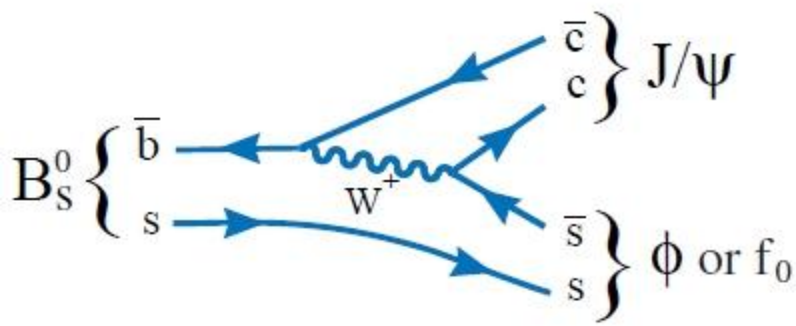
LHCb is a heavy flavour precision experiment searching for New Physics in **CP Violation** and **Rare Decays.**

http://www.cern.ch

B physics @ LHCb

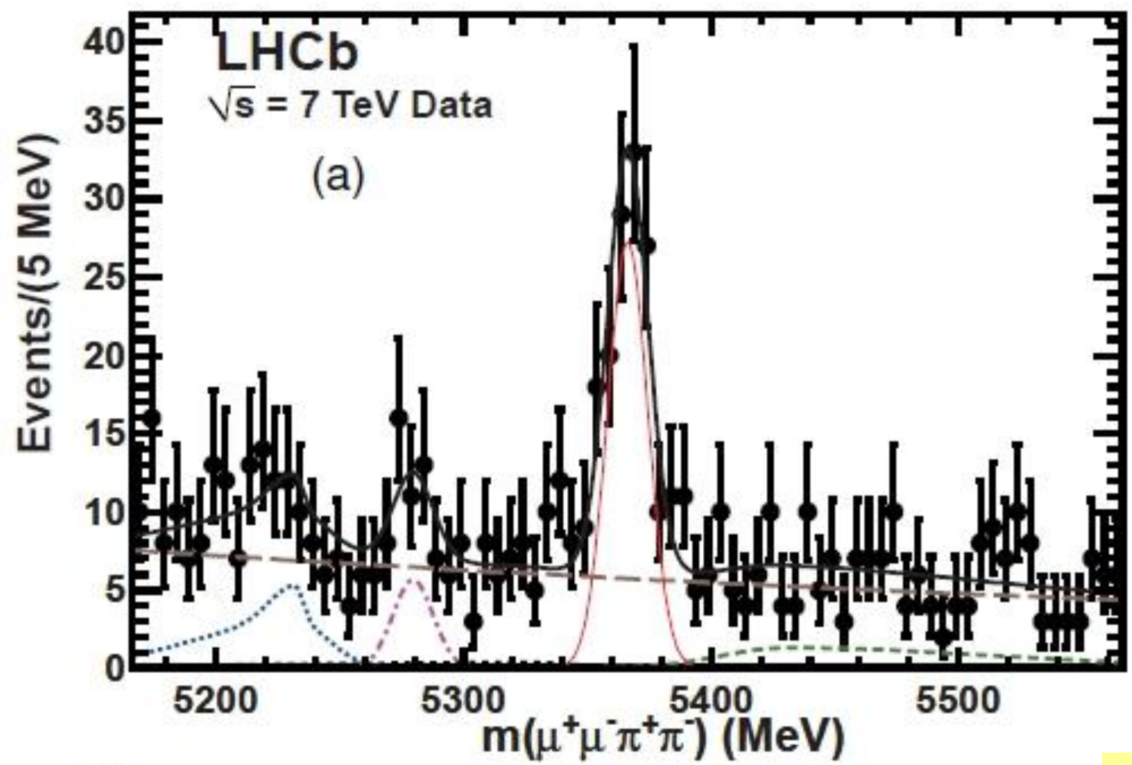


Bs->J/psi f0(980)



Bs -> J/psi $f_0(980)$

$f_0(980) \to \pi^+\pi^-$

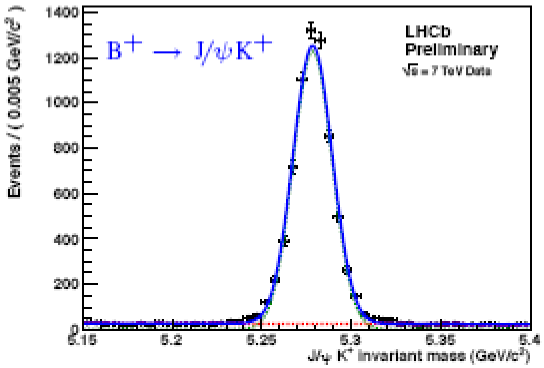


Selections

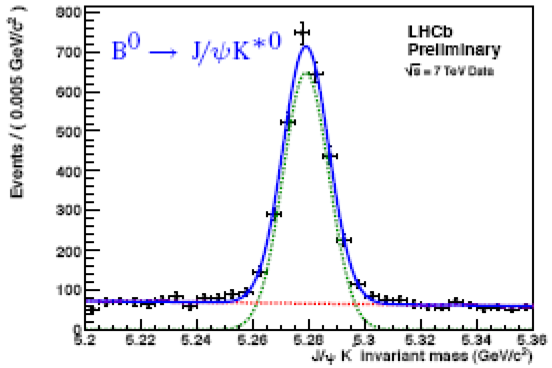
[LHCb-CONF-2011-001]

- Similar selection for all channels $B_s^0 \to J/\psi\phi$, $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$, $B^0 \to J/\psi K_S^0$ and $\Lambda_b \to J/\psi\Lambda$ $\longrightarrow$ cross-check and systematics
- Reconstruct $J/\psi \to \mu^+\mu^-$, then simple and small number of cuts
- No lifetime biasing cuts (IP, decay length, ...) $\longrightarrow$ significant prompt background at small proper time
  Plots with $t > 0.3\,\mathrm{ps}$, J/ψ mass constrained:

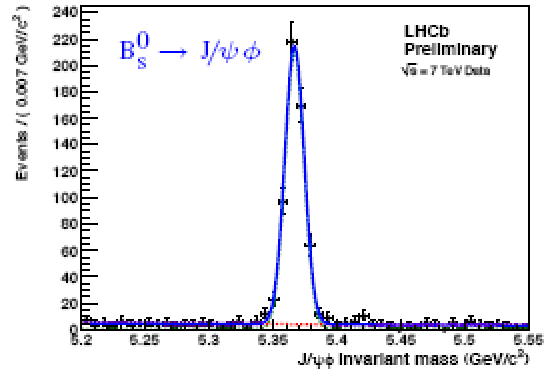
$\sigma_m = 10.7\,\mathrm{MeV}/c^2$



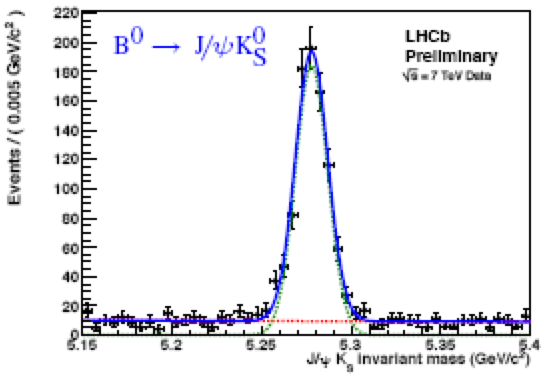
$\sigma_m = 8\,\mathrm{MeV}/c^2$



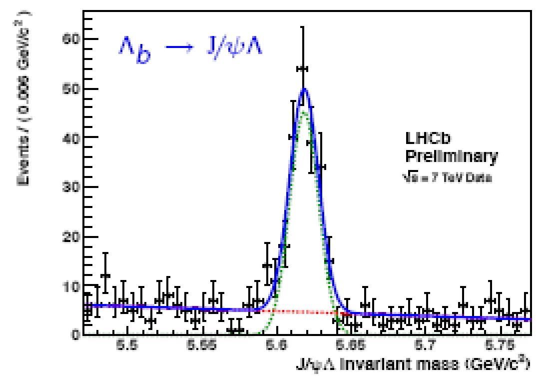
$\sigma_m = 7\,\mathrm{MeV}/c^2$



$\sigma_m = 8.8\,\mathrm{MeV}/c^2$



$\sigma_m = 9\,\mathrm{MeV}/c^2$

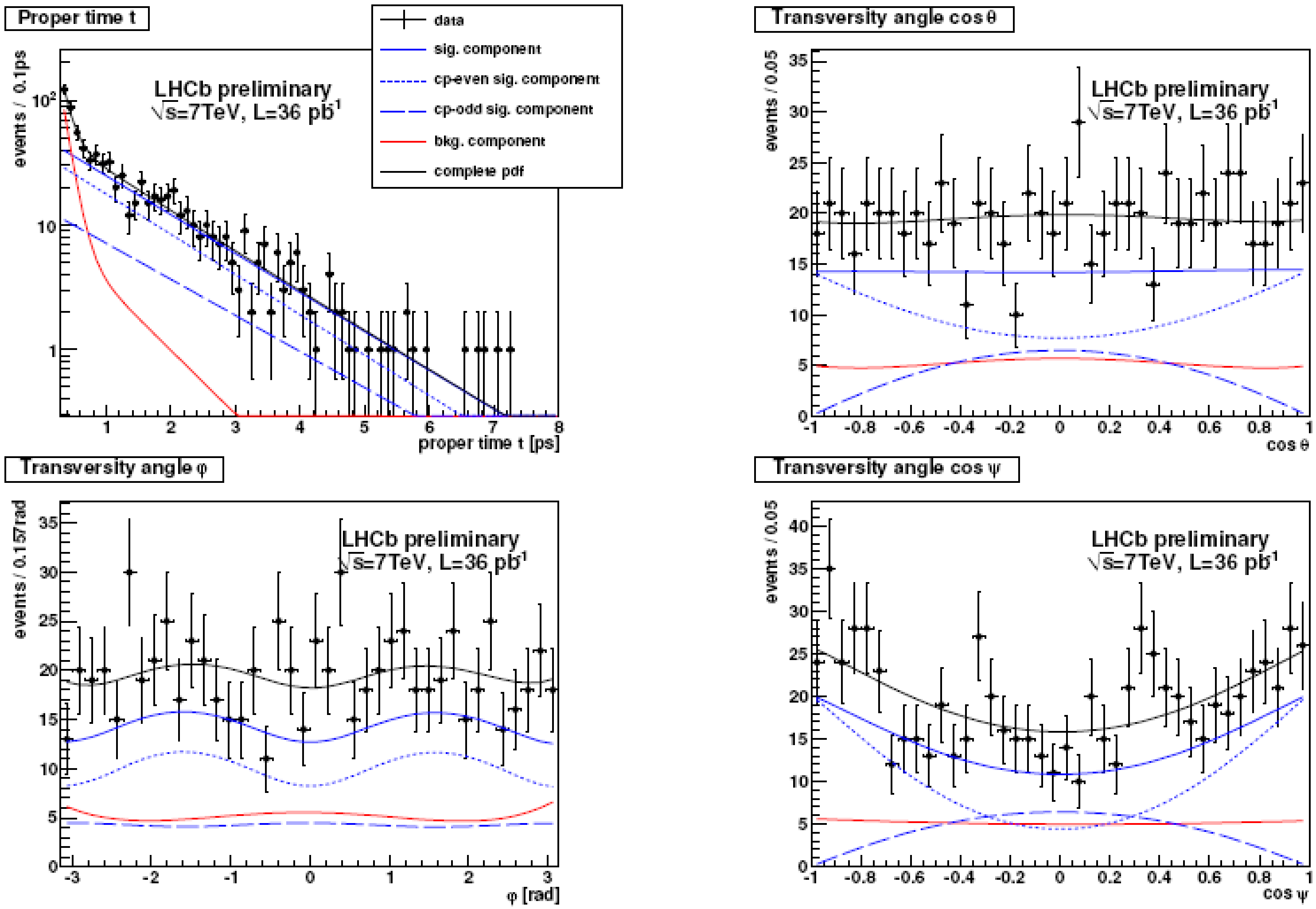


- Excellent mass resolution, very low background

Untagged angular analysis of $B_s^0 \to J/\psi\phi$ (ϕ_s fixed to 0) [LHCb-CONF-2011-002]

5D unbinned likelihood fit ($m, t, \cos\theta, \varphi, \cos\psi$)

Projection on proper time and transversity angles:



Untagged angular analysis of $B_s^0 \to J/\psi\phi$ (ϕ_s fixed to 0) [LHCb-CONF-2011-002]

$$
\begin{aligned}
\Gamma_s\ (\mathrm{ps}^{-1}) &= 0.679 \pm 0.036(\mathrm{stat}) \pm 0.027(\mathrm{sys}) \\
\Delta\Gamma_s\ (\mathrm{ps}^{-1}) &= 0.077 \pm 0.119(\mathrm{stat}) \pm 0.021(\mathrm{sys}) \\
|A_0|^2 &= 0.528 \pm 0.040(\mathrm{stat}) \pm 0.028(\mathrm{sys}) \\
|A_\perp|^2 &= 0.263 \pm 0.056(\mathrm{stat}) \pm 0.014(\mathrm{sys}) \\
\delta_\parallel\ (\mathrm{rad}) &= 3.14 \pm 0.52(\mathrm{stat}) \pm 0.13(\mathrm{sys})
\end{aligned}
$$

CDF note 10206:

$$
\begin{aligned}
\Gamma_s\ (\mathrm{ps}^{-1}) &= 0.653 \pm 0.011(\mathrm{stat}) \pm 0.005(\mathrm{syst}) \\
\Delta\Gamma_s\ (\mathrm{ps}^{-1}) &= 0.075 \pm 0.035(\mathrm{stat}) \pm 0.010(\mathrm{syst}) \\
|A_0|^2 &= 0.524 \pm 0.013(\mathrm{stat}) \pm 0.015(\mathrm{syst})
\end{aligned}
$$

- Compatible with world best measurements
- Systematic uncertainties $<$ statistical ones
- Will be competitive in 2011

CPV in $B_s \to J/\psi\phi$

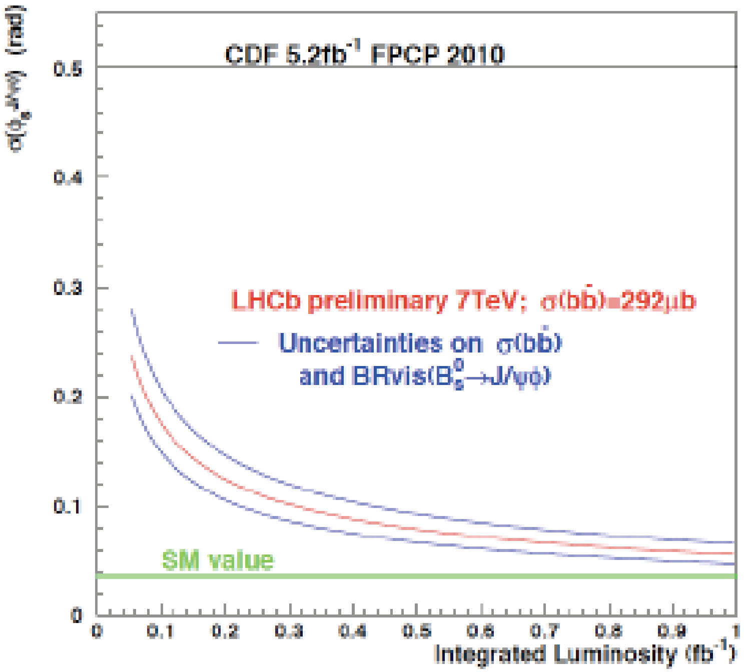
Expected sensitivity:

MC performance:

- 50k events / fb^{-1} consistent with number of $B_s \to J/\psi\phi$ candidates seen in data

- $<\sigma_t> = 0.038$ ps. Present resolution in data is ~ 1.6 worse but sufficient for $\Delta m_s \sim 17.7$/ps (adds 30% dilution to the sensitivity)

- Tagging performance $\varepsilon D^2 = 6.2\%$ will be tested with more data



ICHEP, Paris 2010

40

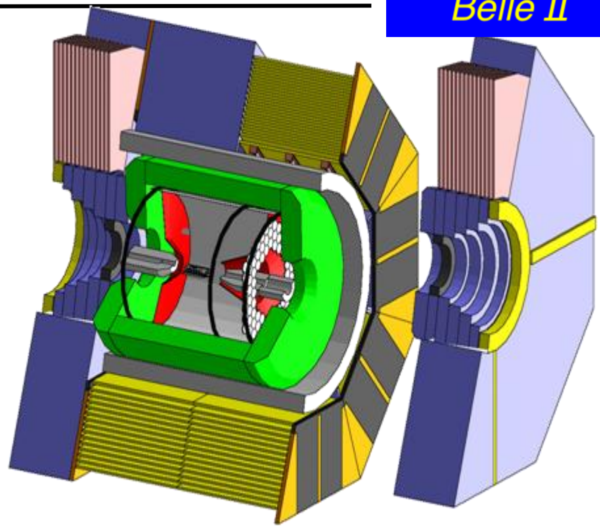
A. Golutvin

한국과학기술정보연구원
Korea Institute of Science and Technology Information
www.kisti.re.kr

Belle II

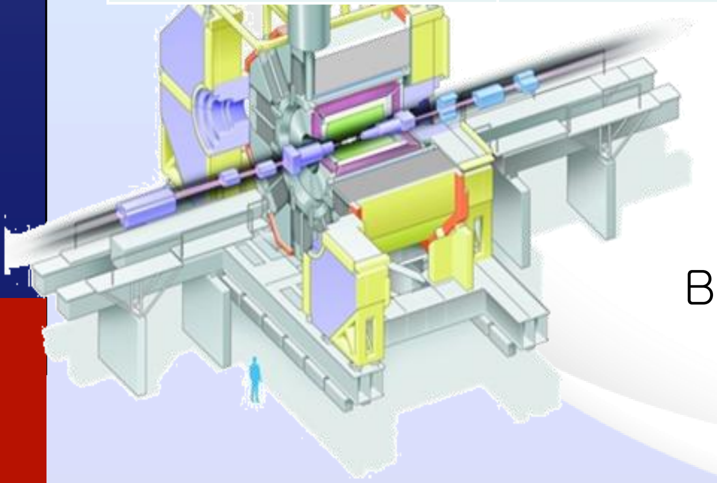
Belle vs. Belle II

Belle	Content	Belle II
1998~2010	Time Schedule	2014~
8 X 3.5 GeV	Energy	7 X 4 GeV
1 ab^{-1}	Luminosity	50 ab^{-1}
1 Billion	BBbar events	50 Billion
CP measurement	Goal	New Physics



Belle II

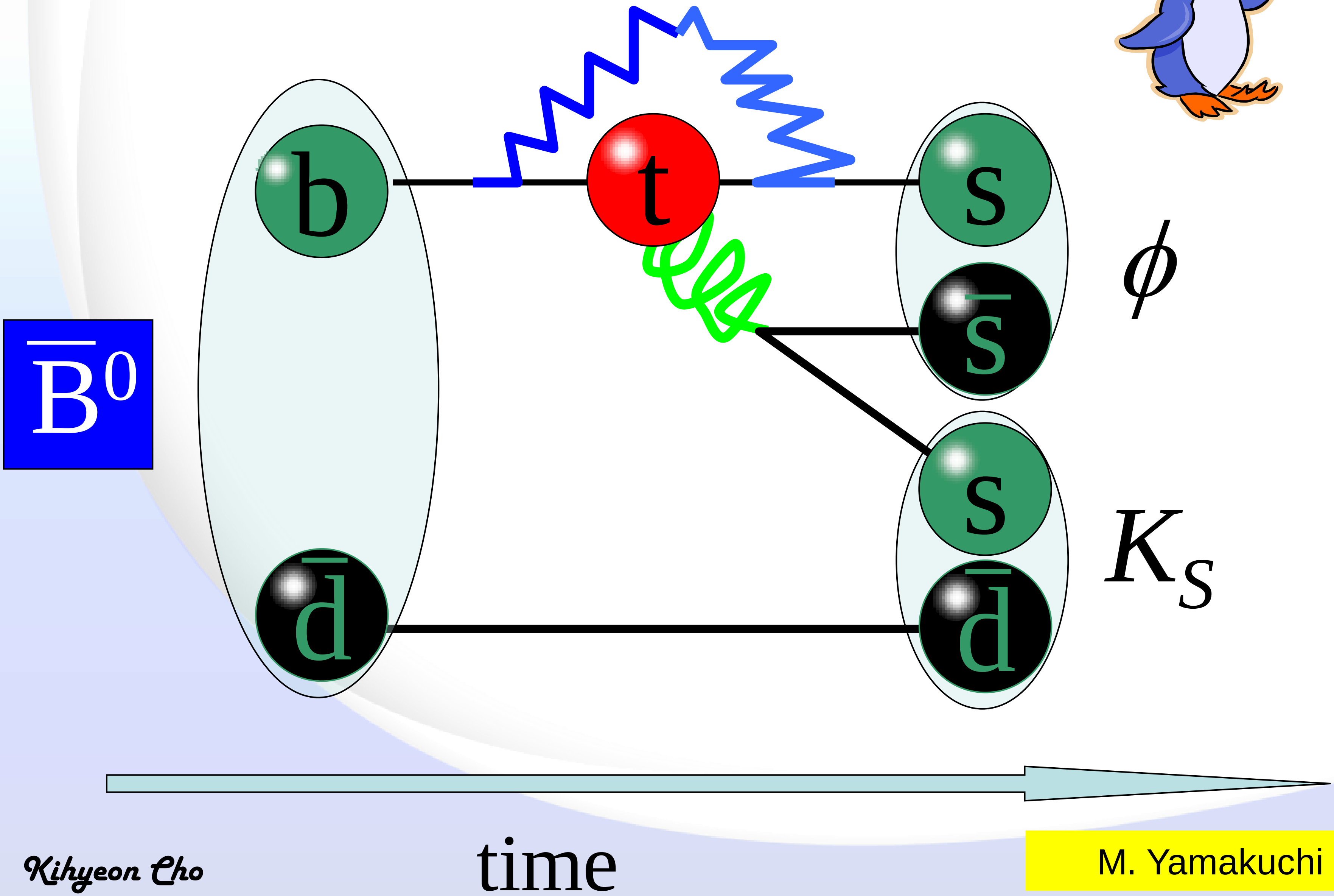
To handle 50 times more data and grid farms
=> New Data Handling System



Belle

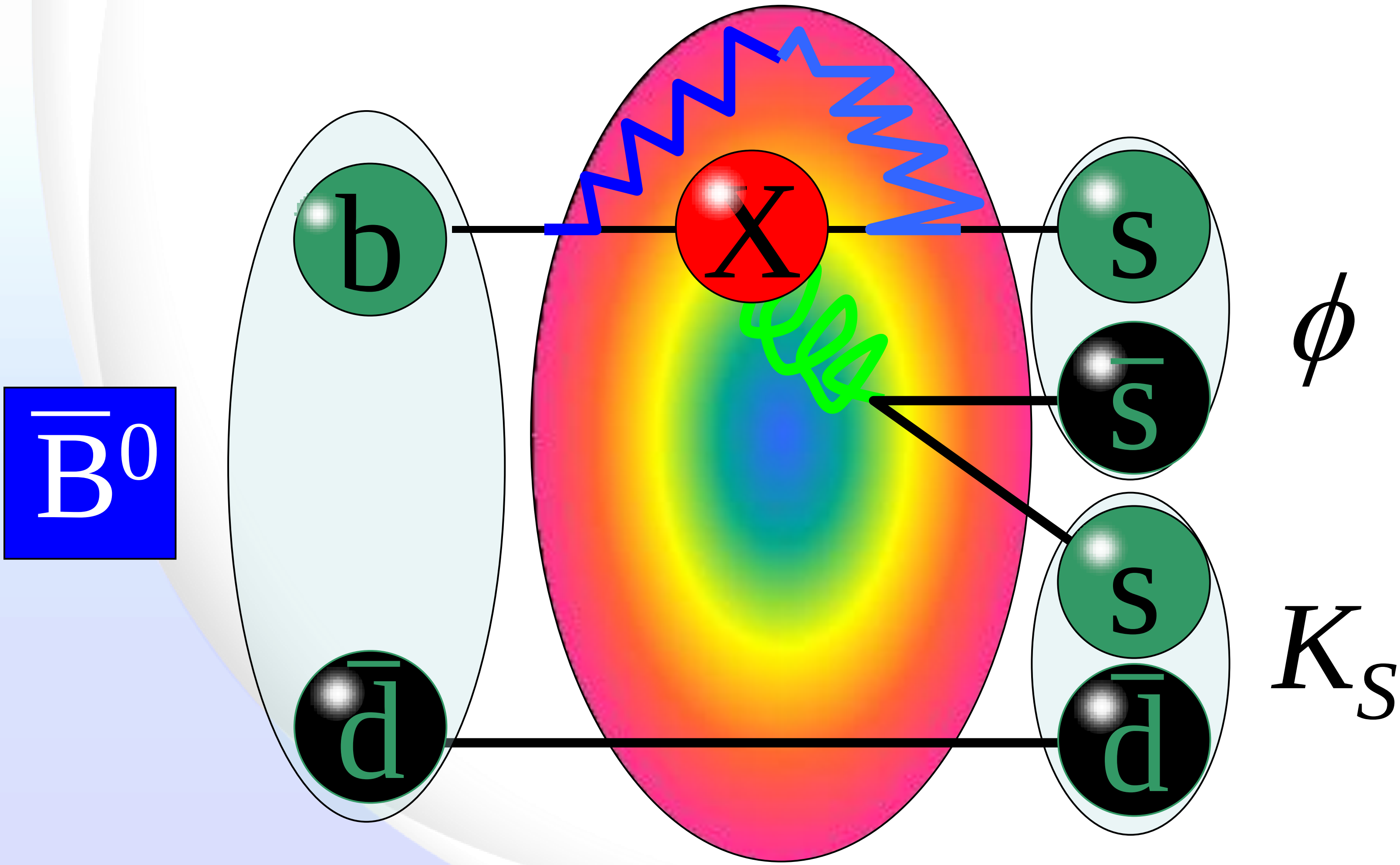
Kihyeon Cho

Penguin diagram



M. Yamakuchi

If a new particle X exists…



This measurement is sensitive to new physics such as SUSY.

M. Yamakuchi

Physics at Belle II

New source of CP violation

New source of flavor mixing

LFV τ decays

Precision test of KM scheme

SUSY breaking mechanism

Charm physics

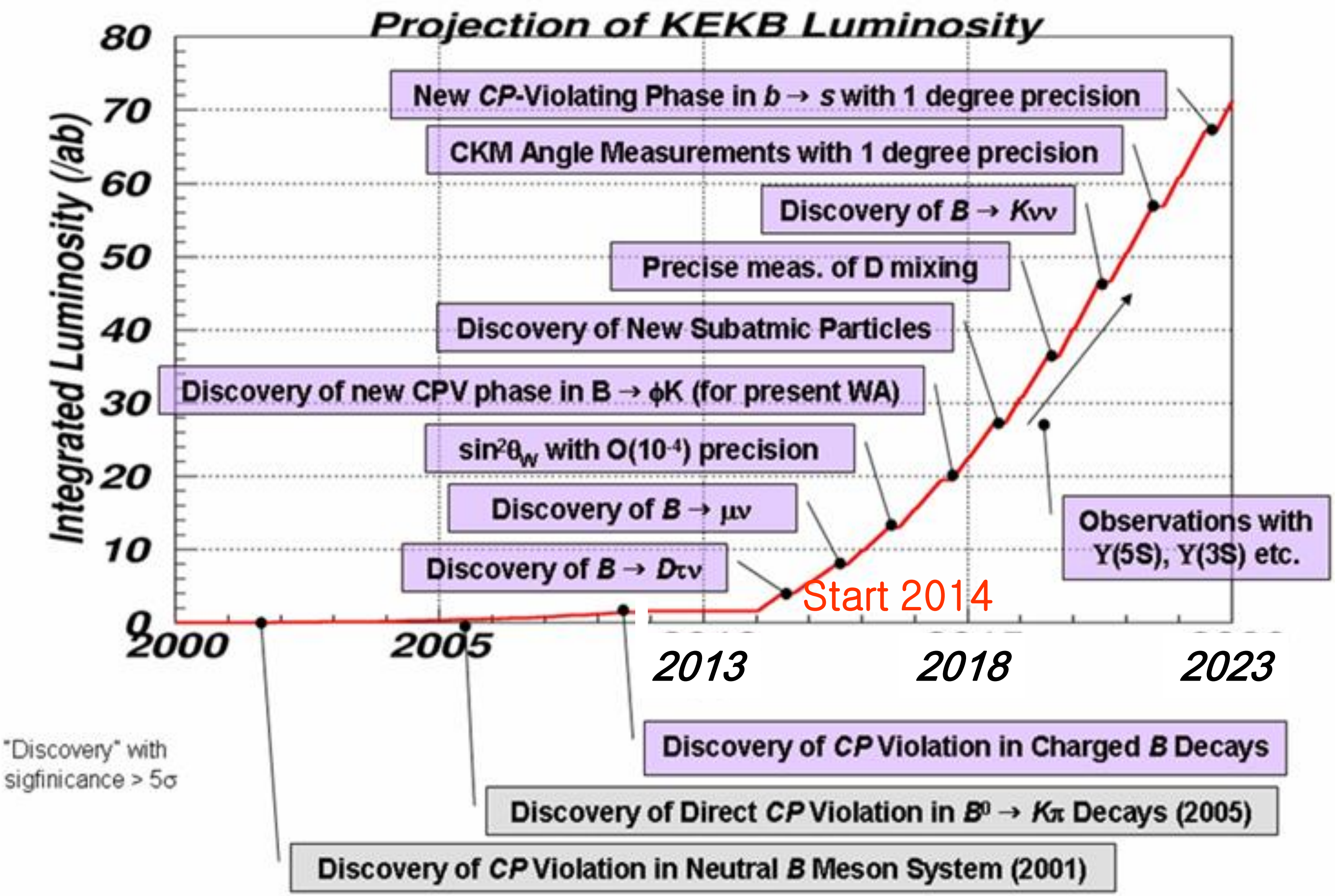
New resonances, $D^0\overline{D}^0$ mixing…

Super-high statistics measurements:

α_S, $\sin^2\theta_W$, etc.

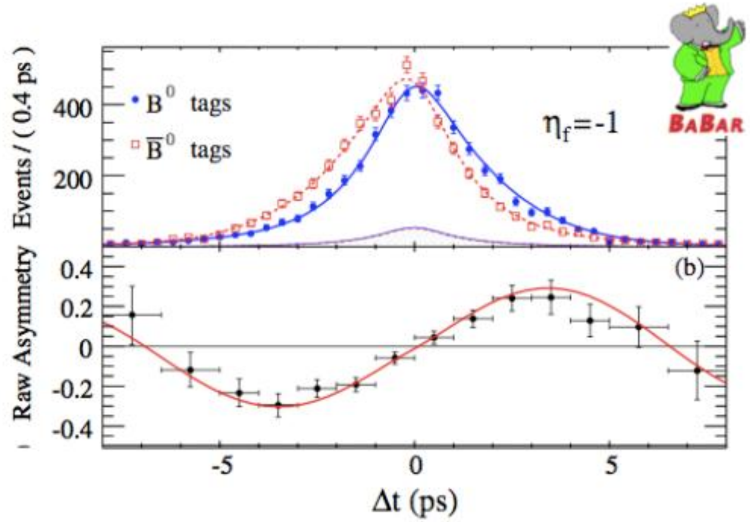
M. Yamakuchi

Luminosity vs. Physics

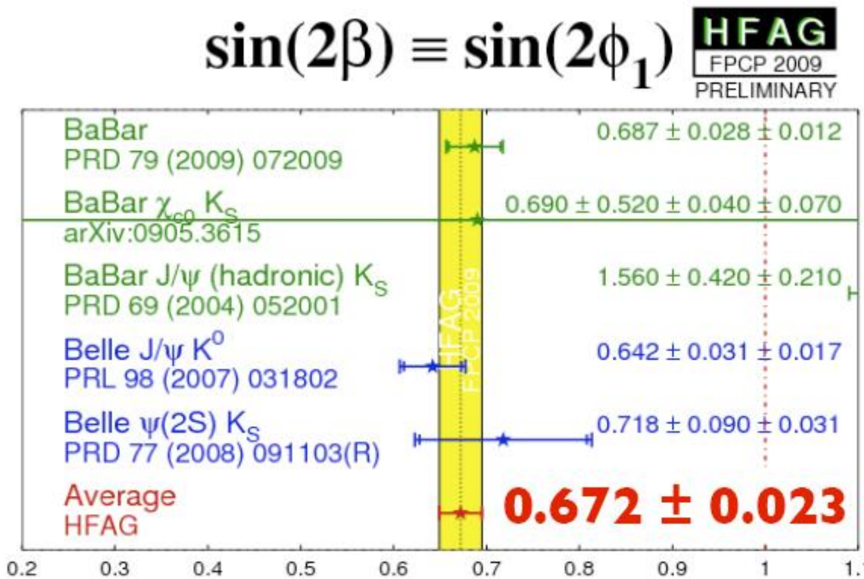


Kihyeon Cho

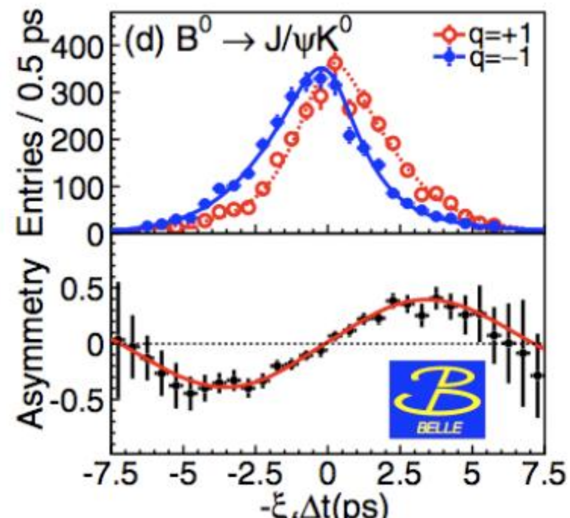
$\sin 2\phi_1$



Raw Asymmetry Events / (0.4 ps)
400
200
0.4
0.2
0
-0.2
-0.4
B0 tags
B̄0 tags
η_f=-1
BABAR
(b)
-5
0
5
Δt (ps)



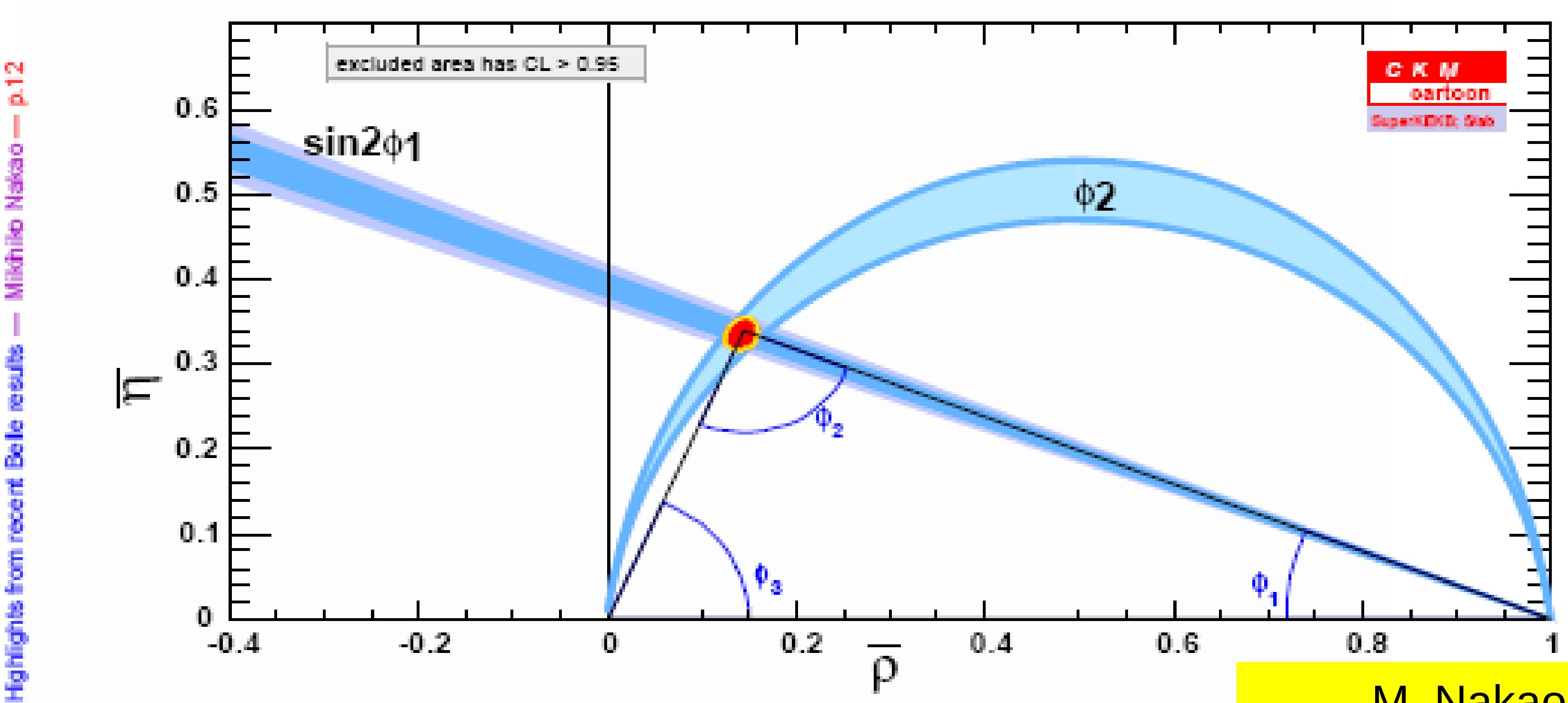
sin(2β) ≡ sin(2φ1)
HFAG
FPCP 2009
PRELIMINARY
BaBar
PRD 79 (2009) 072009
0.687 ± 0.028 ± 0.012
BaBar χc0 KS
arXiv:0905.3615
0.690 ± 0.520 ± 0.040 ± 0.070
BaBar J/ψ (hadronic) KS
PRD 69 (2004) 052001
1.560 ± 0.420 ± 0.210
Belle J/ψ K0
PRL 98 (2007) 031802
0.642 ± 0.031 ± 0.017
Belle ψ(2S) KS
PRD 77 (2008) 091103(R)
0.718 ± 0.090 ± 0.031
Average
HFAG
0.672 ± 0.023
HFAG
FPCP 2009
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1



(d) B0 → J/ψK0
q=+1
q=−1
Asymmetry Entries / 0.5 ps
400
300
200
100
0
0.5
0
-0.5
BELLE
-7.5
-5
-2.5
0
2.5
5
7.5
-ξfΔt(ps)

Prospects on ϕ_1

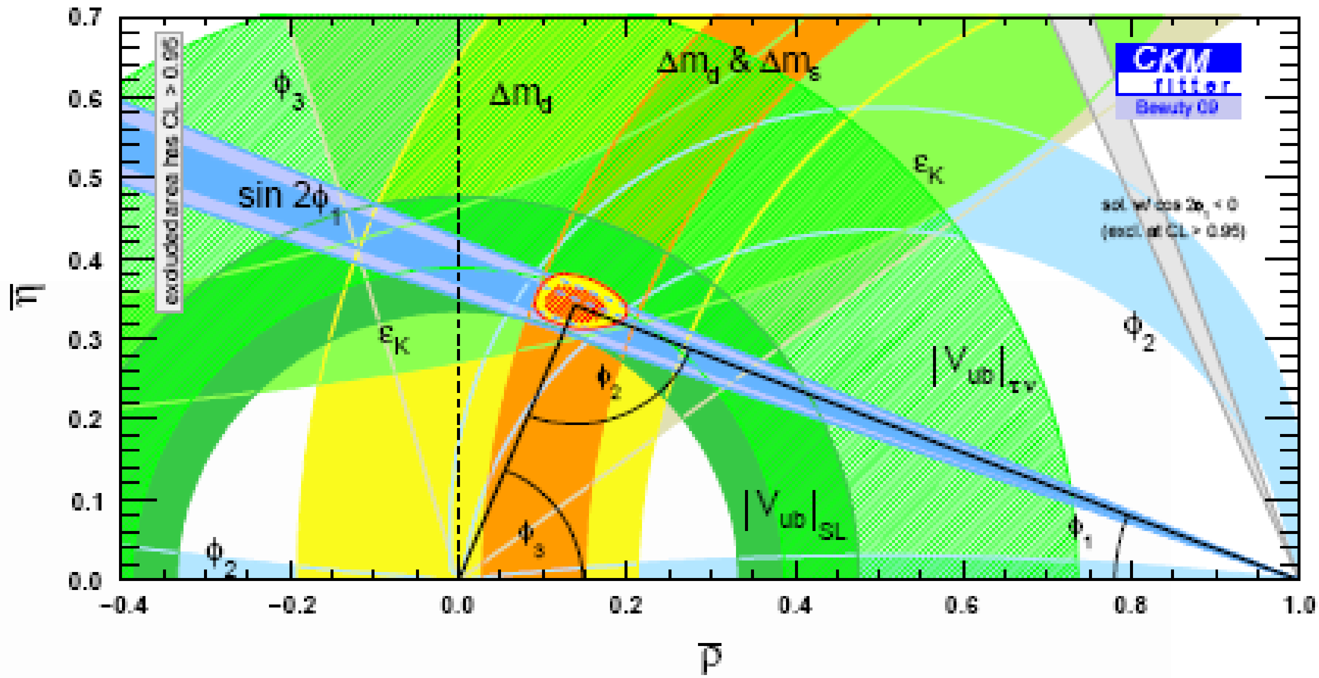
(10 ab^{-1})	(5 ab^{-1})
$\delta \sin 2\phi_1 \sim \pm 0.007 \pm 0.012$	$\delta\phi_2 \sim 2°$
(~theory error limit)	(~theory error limit)



M. Nakao

$|V_{ub}|$

$|V_{ub}|$ determination



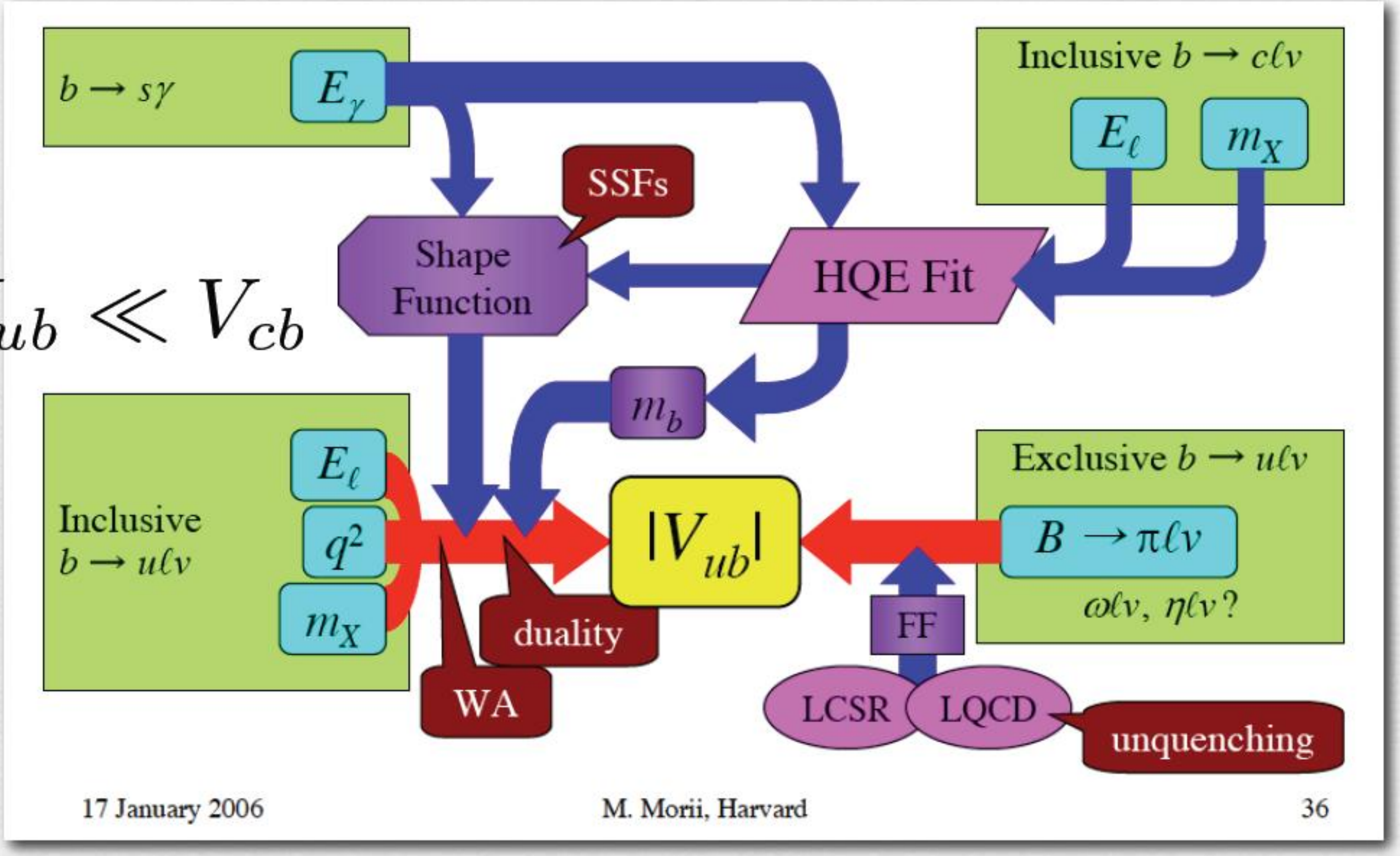
- Tree amplitude dominates — SM contribution only
  - *reliable reference in searches for non-SM effects*
- Theory machinery needed to compute $N_{\text{signal}} \Rightarrow \mathcal{B} \Rightarrow |V_{ub}|$ (very active interaction between theory and experiment communities)

Highlights from recent Belle results — Mikihiko Nakao — p.14

M. Nakao

Roadmap for V_{ub} - *"Morri's chart"*

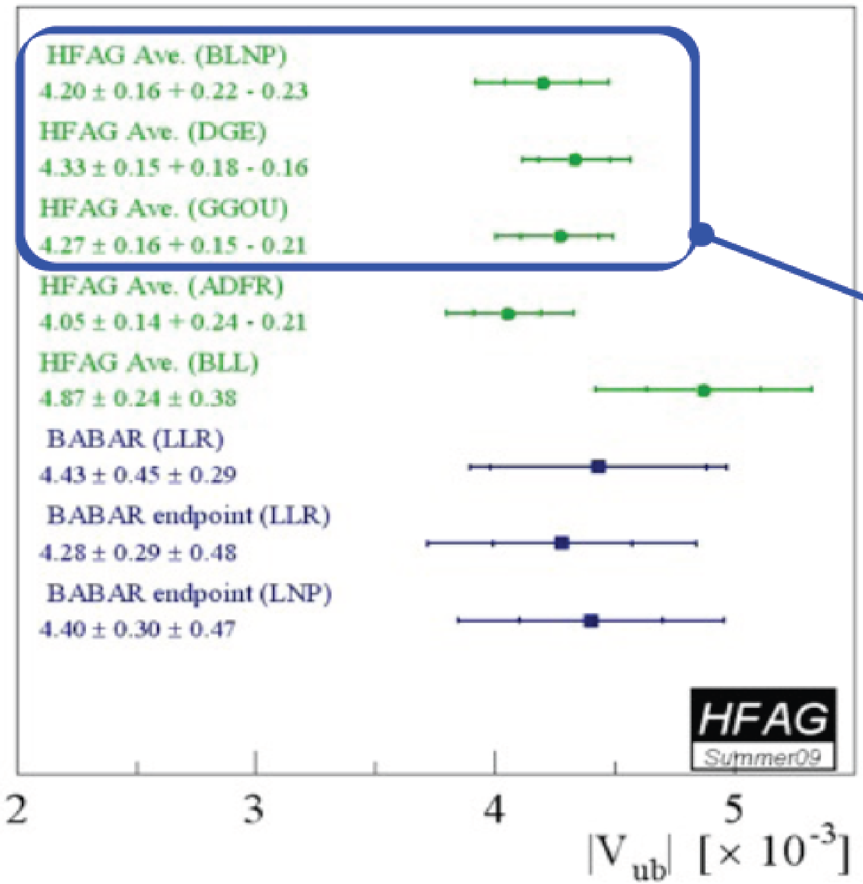
$$V_{ub} \ll V_{cb}$$

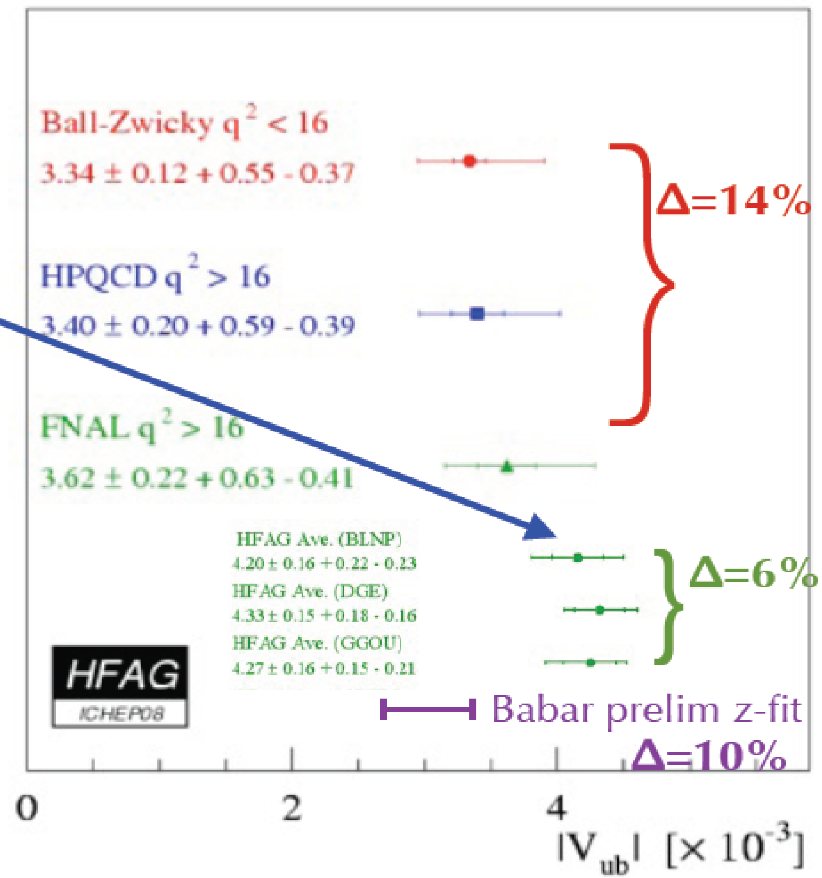


$|V_{ub}|$ summary Inclusive vs. Exclusive

Inclusive

Exclusive

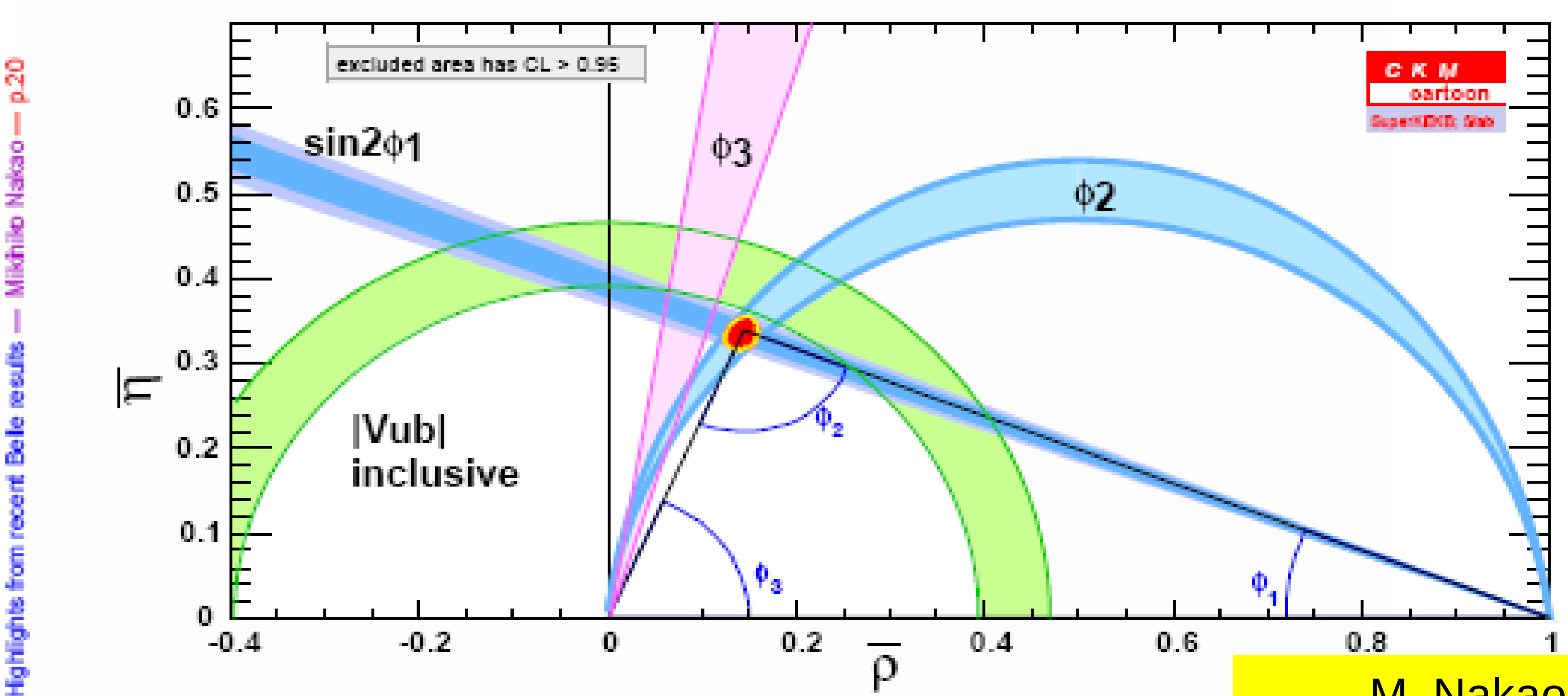




Exclusive < Inclusive ~1-2σ, Greater discrepancy with *z*-fit.

Prospects on $|V_{ub}|$

(50 ab^{-1}) $\delta|V_{ub}| \sim \pm 2\%$ (~theory error limit)	(50 ab^{-1}) $\delta\phi_3 \sim 2°$ (~theory error limit)



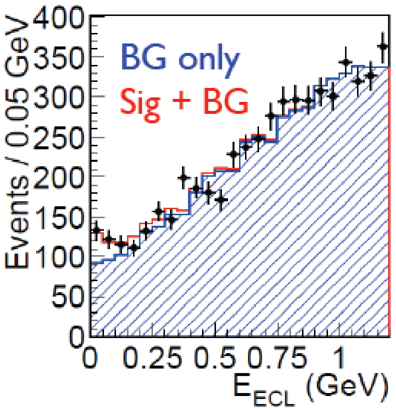
M. Nakao

B→τν

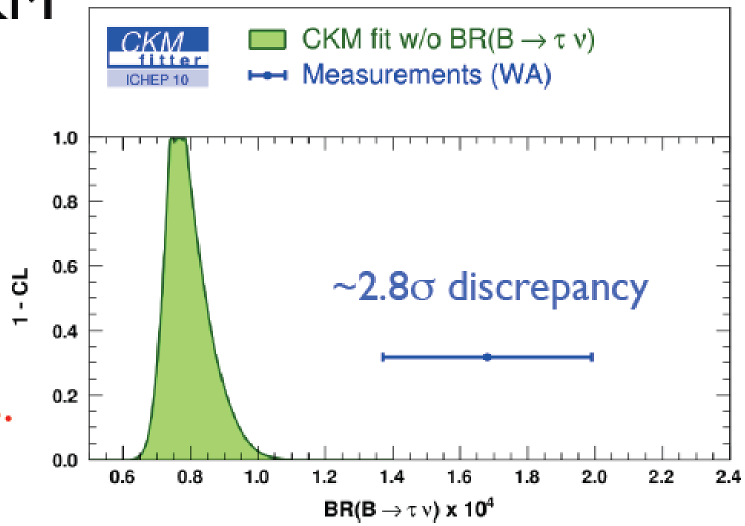
- **Evidence** obtained at the B factories.

Example w/ semileptonic tag, 657M BB
PR**D82**:071101 (2010)

$$\mathcal{B}(B^- \to \tau^- \overline{\nu}_\tau) = (1.54^{+0.38}_{-0.37}(\text{stat})^{+0.29}_{-0.31}(\text{syst})) \times 10^{-4}$$



- **Tension** between the global CKM fit and direct measurement.

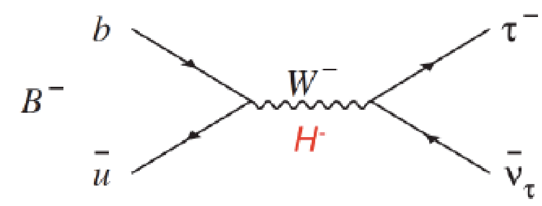


Better measurement of B→τν may reveal source of the tension.
Tag-side information is vital for ≥ 2ν's.

Y. Hori

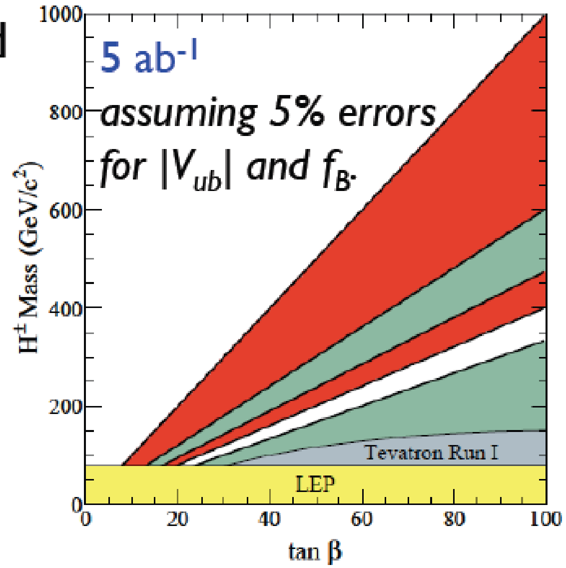
B→τν at Belle II

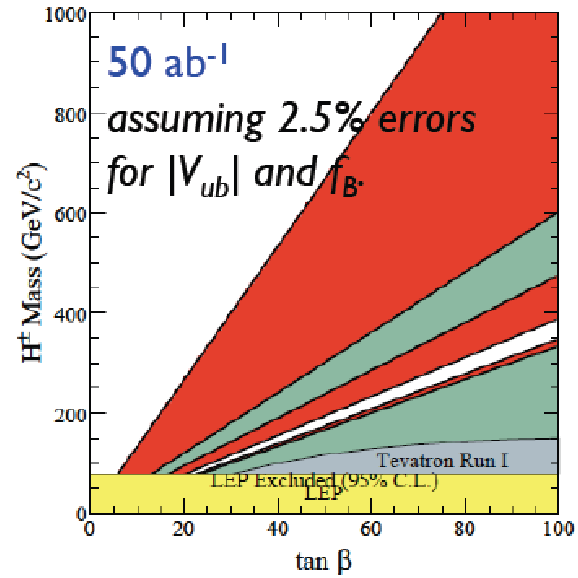
- In Two-Higgs Doublet Model (THDM) Type II, the branching ratio of B→τν can be modified.



$$\mathcal{B}(B^- \to \tau^- \nu) = \mathcal{B}_{\mathrm{SM}}(B^- \to \tau^- \nu) \left[1 - \frac{m_B^2}{m_{H^\pm}^2} \tan\beta^2\right]^2$$

Constrains on H± mass and tanβ can be obtained.



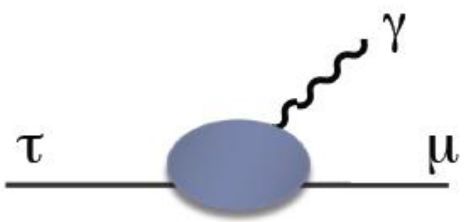


5 σ discovery region
current 95% exclusion

Decays of τ

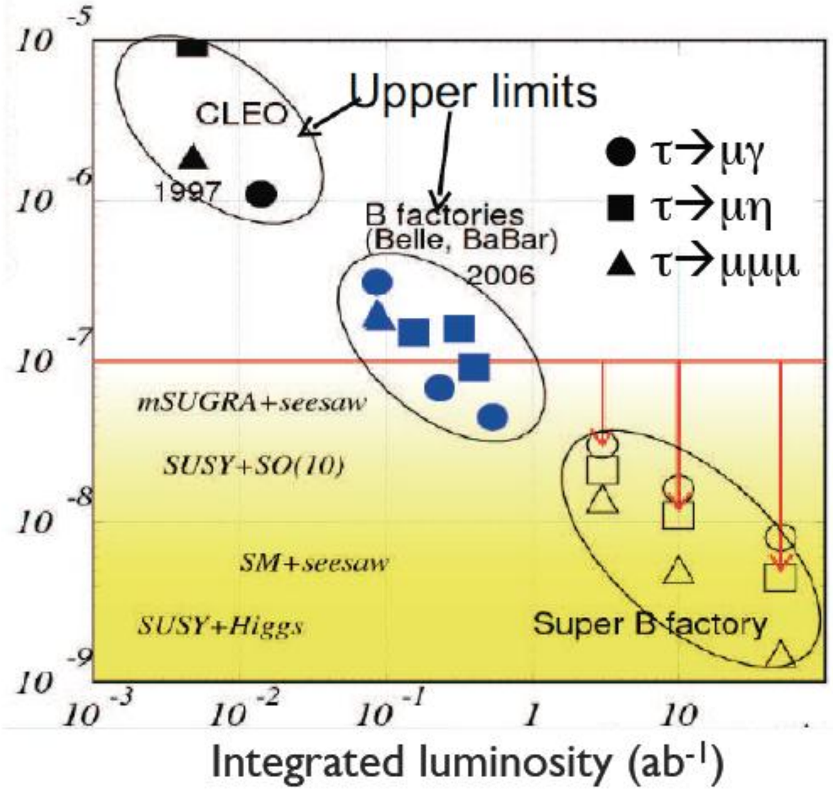
Example: τ → μγ

- Can be enhanced by the effects of new physics in the loop diagram.



model	Br(τ→μγ)
mSUGRA+seesaw	10^{-7}
SUSY+SO(10)	10^{-8}
SM+seesaw	10^{-9}
Non-Universal Z′	10^{-9}
SUSY+Higgs	10^{-10}

Belle II provides good sensitivities on the τ decays.

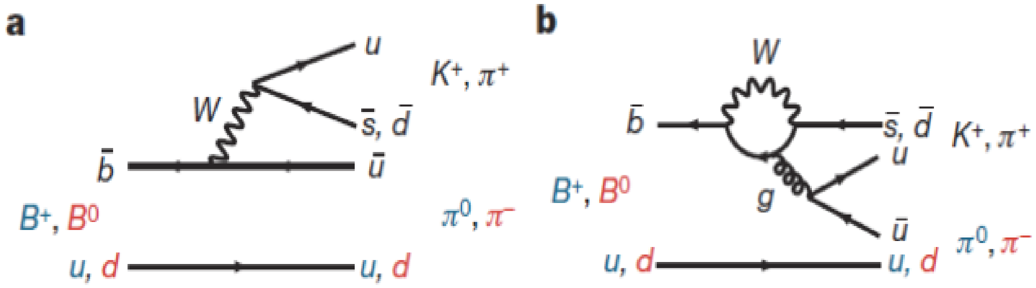


Kihyeon Cho

Y. Hori

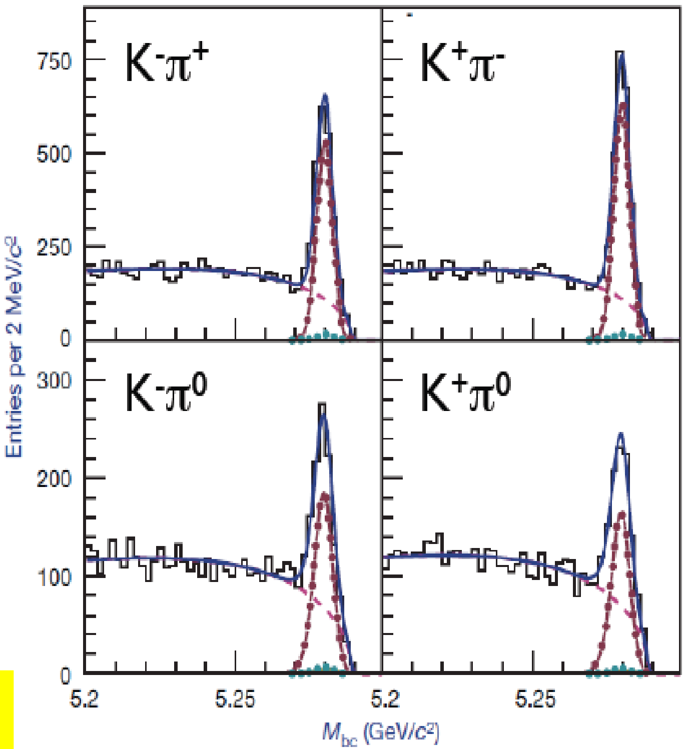
B→Kπ

If the only diagrams are **a** and **b**, we expect $\Delta\mathcal{A} \equiv \mathcal{A}_{K^{\pm}\pi^{0}} - \mathcal{A}_{K^{\pm}\pi^{\mp}} = 0$



However, significant difference is obtained.

$$\Delta\mathcal{A} = +0.164 \pm 0.037$$

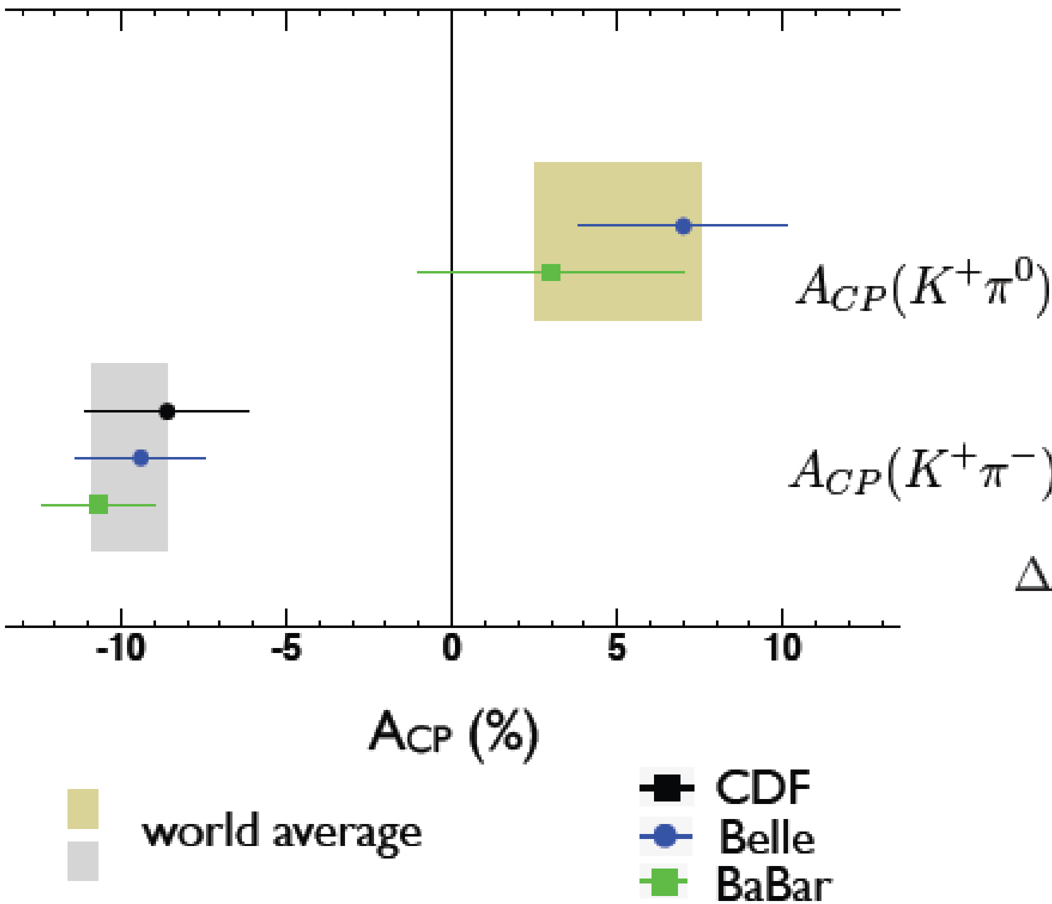


B → K π w/ 535M BB
Nature **452**, 332 (2008).

Missing diagrams?
Large theoretical uncertainty…

Y. Hori

$A_{CP}(K\pi)$ current status



$$\Delta A_{K\pi} \equiv A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0)$$
$$= -0.147 \pm 0.028$$

a 5.3σ effect!

Y. Kwon

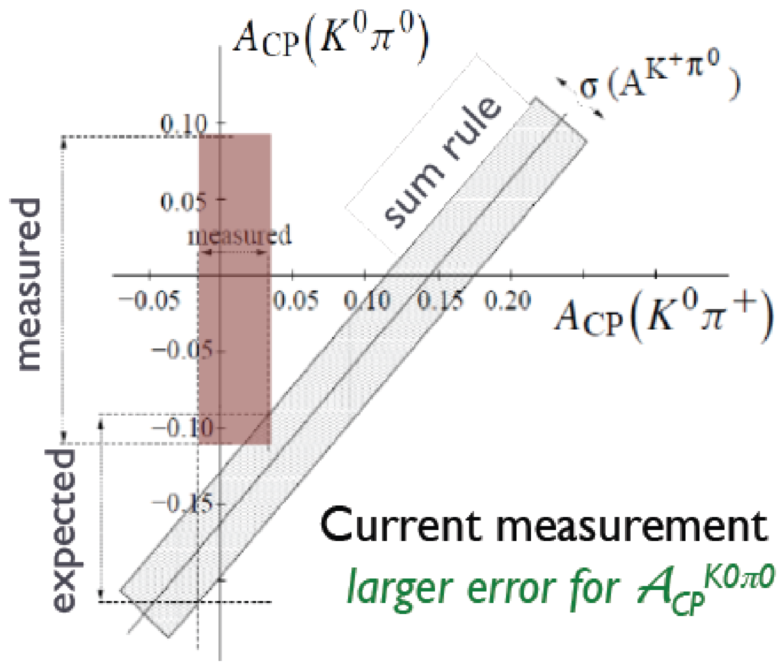
CPV for B→Kπ at Belle II

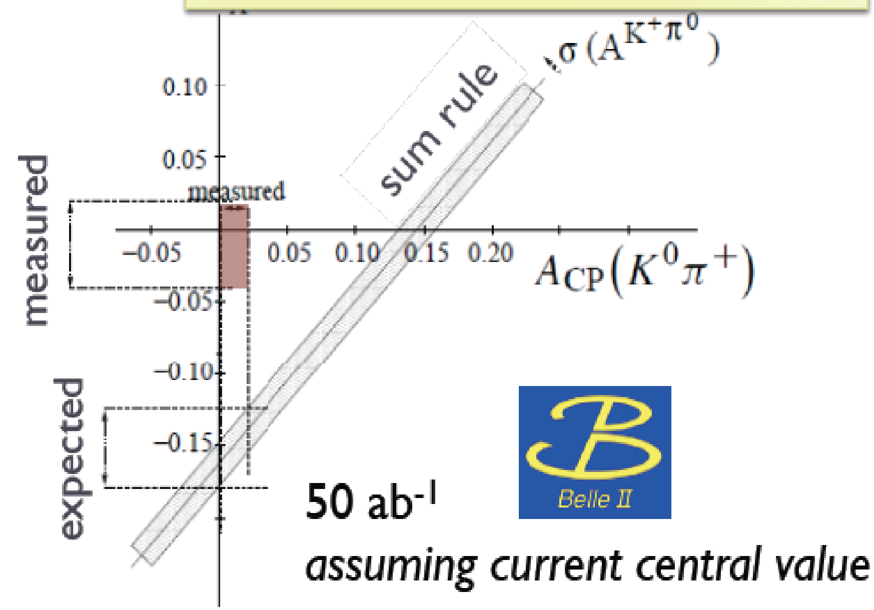
- We can compare to a model-independent sum rule:

$$A_{CP}(K^+\pi^-) + A_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}$$
$$= A_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + A_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

Can be represented as diagonal band (slope precisely known from $\mathcal{B}$ and lifetimes):

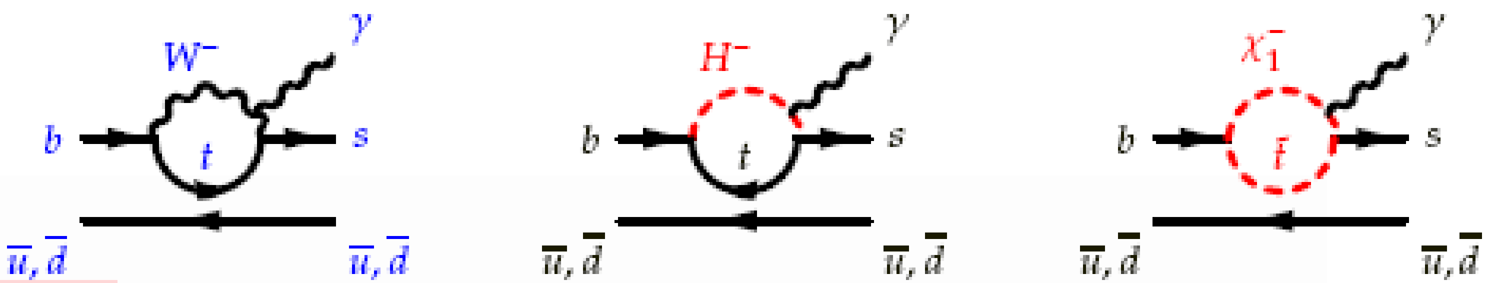
Belle II provides a good environment for the all neutral final state ($K^0\pi^0$).





Radiative and Electroweak Penguin Decays

Sensitive to BSM physics: charged Higgs, SUSY, extra dim., . . .



$b \to s\gamma$

- Inclusive branching fraction
- (Photon spectrum — heavy quark parameters for V_{ub})†
- (Time-dependent CPV — non-SM right handed current)†

$b \to s\ell^+\ell^-$

- Forward backward asymmetry
- Inclusive (differential) branching fraction
- (More observables)†

(† not

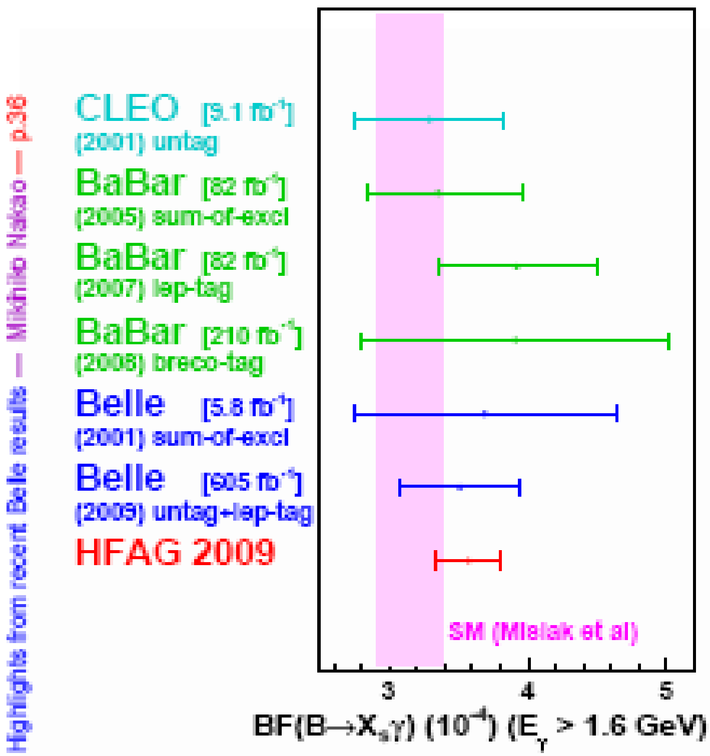
M. Nakao

$\mathcal{B}(B \to X_s\gamma)$

HFAG: $\mathcal{B}(B \to X_s\gamma) = (3.57 \pm 0.24) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)

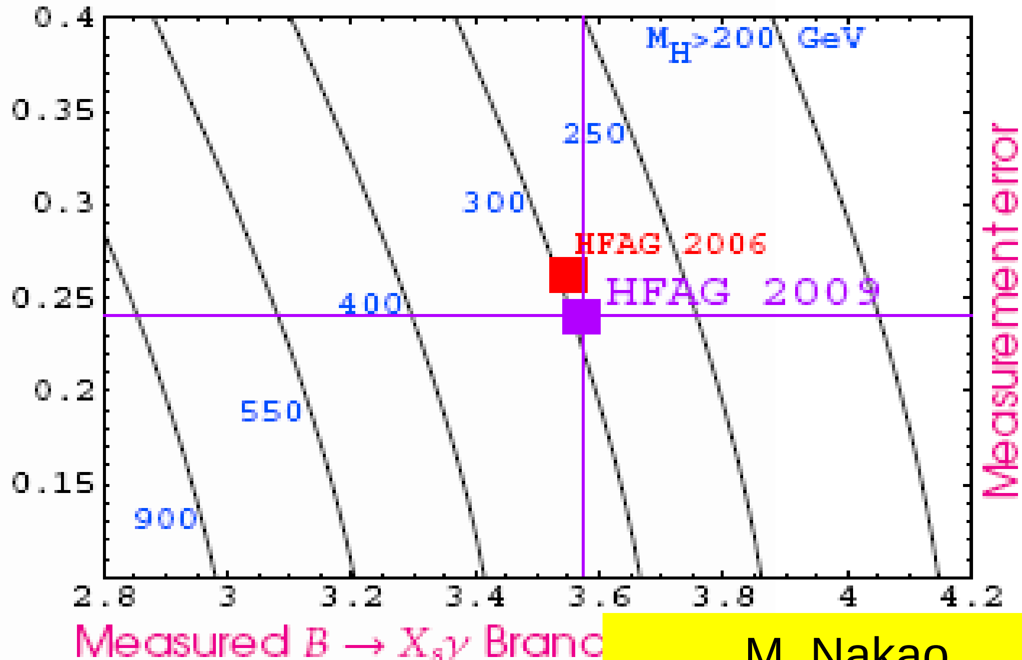
VS

SM: $\mathcal{B}(B \to X_s\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)



Charged Higgs bound (2HDM)

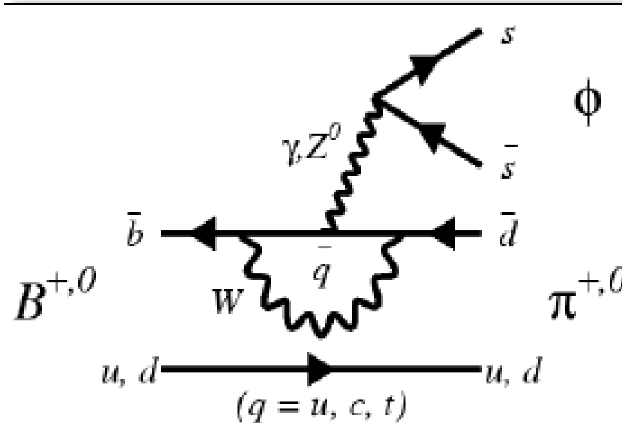
$m_{H^+} > 300$ GeV

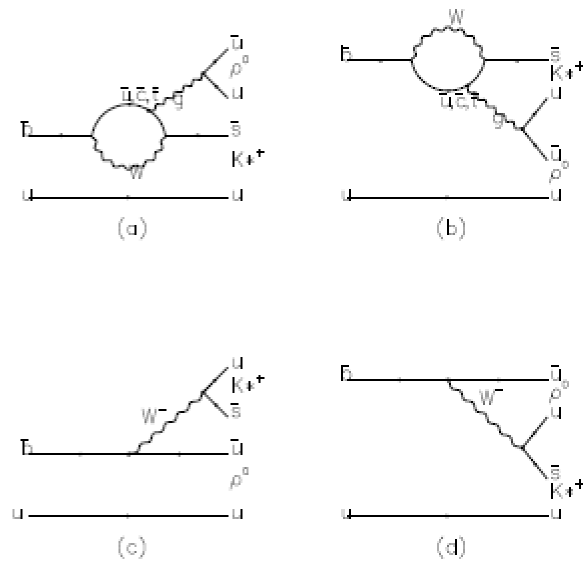


M. Nakao

More penguin modes @ KISTI

- $B \to \Phi\, \pi$
  - Pure EW penguin mode
  - SM Br ~O(10^{-8})
  - Babar with 232M BB:
    - UL($\Phi\, \pi^{+}$) < 2.4*10^{-7} @90%CL
    - UL($\Phi\, \pi^{0}$) < 2.8*10^{-7} @90%CL
  - Draft is almost ready.





- $B^{+} \to \rho^{0} K^{*+}$
  - Penguin dominant status
  - Work on progress

Kihyeon Cho

Junghyun Kim, K. Cho, Nakao, …

Summary

- There are a few interesting results from the heavy flavor physics experiments indicating hints of something unknown…
  - CP Violation and mixing
  - Leptonic B decay
  - Penguin decays

- NP or not-NP, we do not have clear understanding, yet.

What is ahead

- The case for flavor physics in the LHC era is still compelling.
- LHCb is great tool for heavy flavor physics.
- But some aspects, e.g. modes with neutrino will reqiure Super B (Belle II).

Summary

Epilogue

Flavour Observables Sensitive to New Physics

$\Delta m_K \quad \epsilon_K \quad \epsilon'/\epsilon_K \quad B(K_L \to \pi^0 \nu \bar{\nu}) \quad B(K^+ \to \pi^+ \nu \bar{\nu}) \quad B(K^+ \to l^+ \nu)$

$\Delta m_d \quad A_{SL}(B_d) \quad S(B_d \to J/\psi K_S) \quad S(B_d \to \phi K_S)$

$\alpha(B \to \pi\pi, \rho\pi, \rho\rho) \quad \gamma(B \to DK) \quad \text{CKM fits}$

$\Delta m_s \quad A_{SL}(B_s) \quad S(B_s \to J/\psi \phi) \quad S(B_s \to \phi\phi)$

$B(b \to s\gamma) \quad A_{CP}(b \to s\gamma) \quad S(B^0 \to K_S \pi^0 \gamma) \quad S(B_s \to \phi\gamma)$

$B(b \to d\gamma) \quad A_{CP}(b \to d\gamma) \quad A_{CP}(b \to (d+s)\gamma) \quad S(B^0 \to \rho^0 \gamma)$

$B(b \to s l^+ l^-) \quad B(b \to d l^+ l^-) \quad A_{FB}(b \to s l^+ l^-) \quad B(b \to s \nu \bar{\nu})$

$B(B_s \to l^+ l^-) \quad B(B_d \to l^+ l^-) \quad B(B^+ \to l^+ \nu)$

$B(\mu \to e\gamma) \quad B(\mu \to e^+ e^- e^+) \quad (g-2)_\mu \quad \mu \text{ EDM}$

$B(\tau \to \mu\gamma) \quad B(\tau \to e\gamma) \quad B(\tau^+ \to l^+ l^- l^+) \quad \tau \text{ CPV} \quad \tau \text{ EDM}$

$B(D^+_{(s)} \to l^+ \nu) \quad x_D \;\; y_D \quad \text{charm CPV}$

6

... add your favourite here ...

from Tim Gershon's talk in Coseners Workshop (2007)

81

Epilogue

Will be Studied at Belle-II

Δm_K ϵ_K ϵ'/ϵ_K $B(K_L\to\pi^0\nu\bar{\nu})$ $B(K^+\to\pi^+\nu\bar{\nu})$ $B(K^+\to l^+\nu)$

Δm_d $A_{SL}(B_d)$ $S(B_d\to J/\psi K_S)$ $S(B_d\to\phi K_S)$

$\alpha(B\to\pi\pi,\rho\pi,\rho\rho)$ $\gamma(B\to DK)$ CKM fits

Δm_s $A_{SL}(B_s)$ $S(B_s\to J/\psi\phi)$ $S(B_s\to\phi\phi)$

$B(b\to s\gamma)$ $A_{CP}(b\to s\gamma)$ $S(B^0\to K_S\pi^0\gamma)$ $S(B_s\to\phi\gamma)$

$B(b\to d\gamma)$ $A_{CP}(b\to d\gamma)$ $A_{CP}(b\to(d+s)\gamma)$ $S(B^0\to\rho^0\gamma)$

$B(b\to s l^+l^-)$ $B(b\to d l^+l^-)$ $A_{FB}(b\to s l^+l^-)$ $B(b\to s\nu\bar{\nu})$

$B(B_s\to l^+l^-)$ $B(B_d\to l^+l^-)$ $B(B^+\to l^+\nu)$

$B(\mu\to e\gamma)$ $B(\mu\to e^+e^-e^+)$ $(g-2)_\mu$ μ EDM

$B(\tau\to\mu\gamma)$ $B(\tau\to e\gamma)$ $B(\tau^+\to l^+l^-l^+)$ τ CPV τ EDM

$B(D^+_{(s)}\to l^+\nu)$ x_D y_D charm CPV

8

from Tim Gershon's talk in Coseners Workshop (2007)

82

Kihyeon Cho

Back up

cho@kisti.re.kr

Concluding Remarks

B-Factories have confirmed the large CP violation

in particular, $B \to c\bar{c}K^0$ modes : $\sin 2\phi_1 = 0.672 \pm 0.023$ *high precision !*

Now, the reference for the new physics search

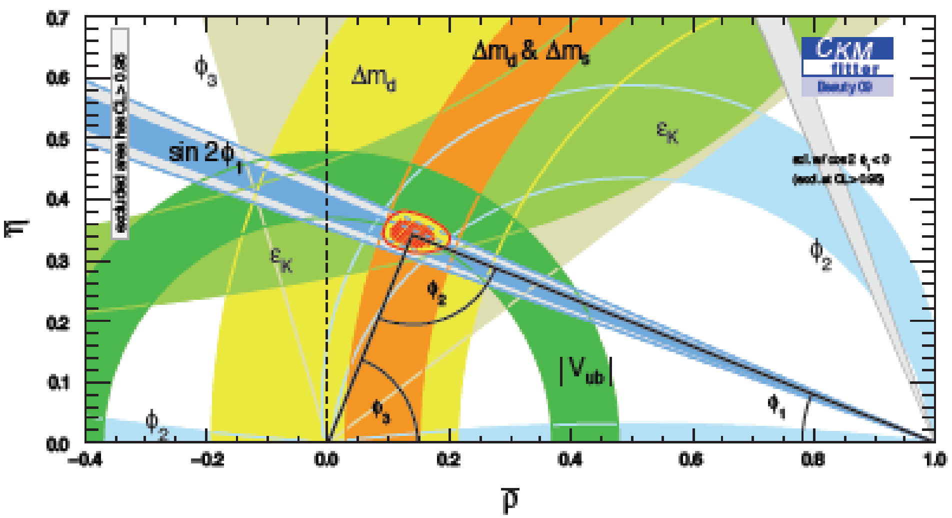
http://ckmfitter.in2p3.fr/

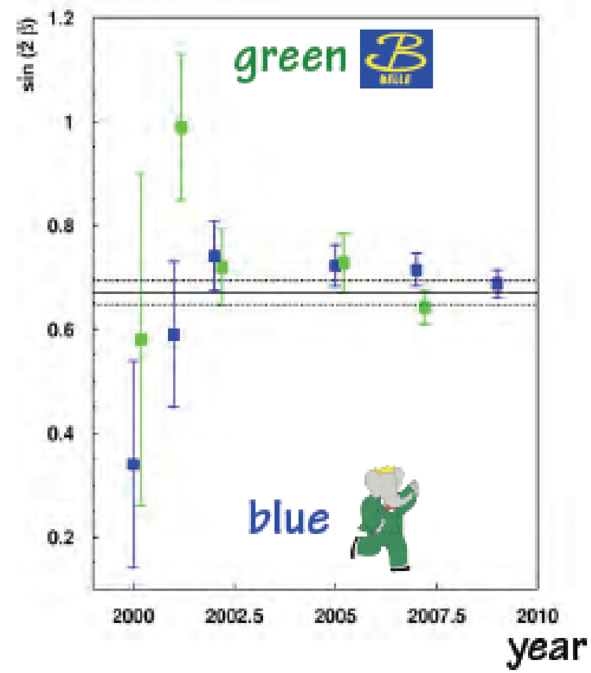
O.Long @ Moriond, EW, 2010

$$\phi_1 = 21.15^{+0.90}_{-0.88}{}^\circ$$

$$\phi_2 = 89.0^{+4.4}_{-4.2}{}^\circ$$

$$\phi_3 = 69^{+19}_{-21}{}^\circ$$





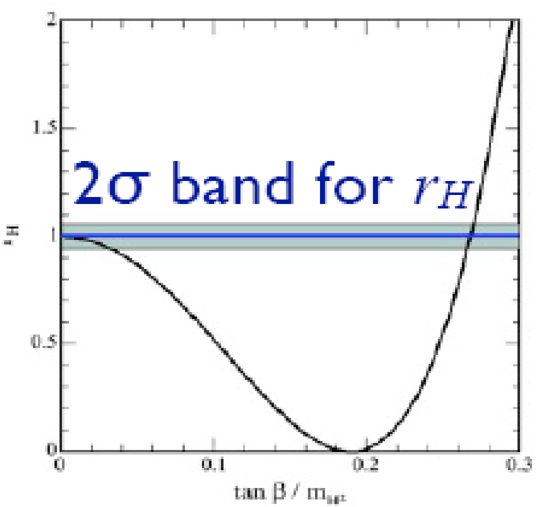
Future prospects

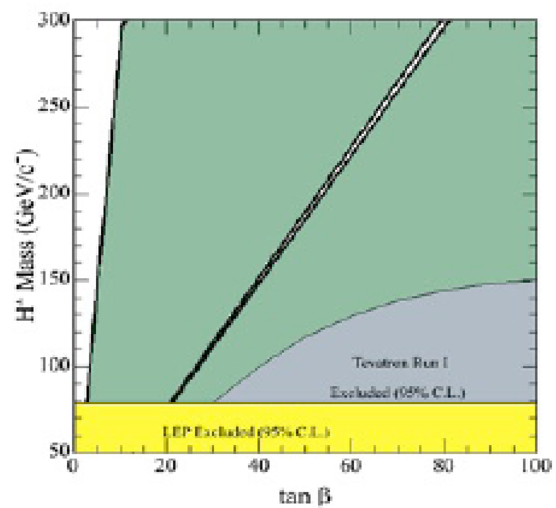
extrapolations

$\int L\,dt$	$\Delta B(B \to \tau\nu)$	$\Delta\,|V_{ub}|$
414 fb^{-1}	36%	7.5%
5 ab^{-1}	10%	5.8%
50 ab^{-1}	3%	4.4%

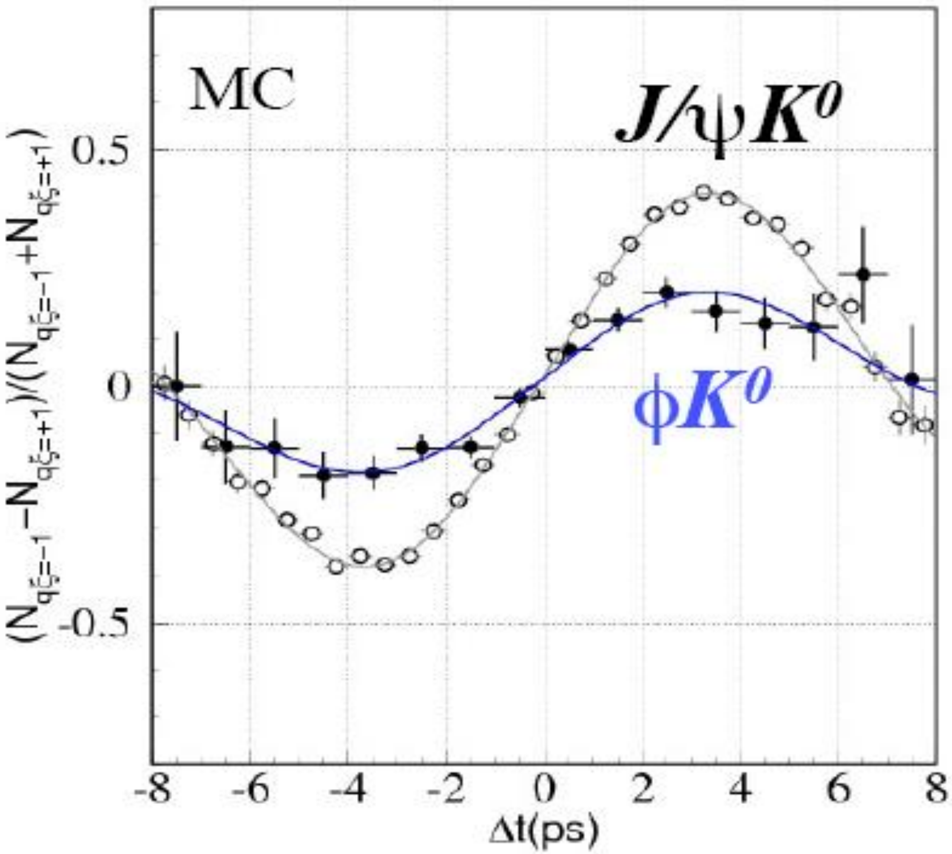
Δf_B(LQCD) = 5% (?)

for 50 ab^{-1}
assuming
$\Delta|V_{ub}| = 0$ & $\Delta f_B = 0$





Extrapolation: $B \rightarrow \phi K^0$ at 50/ab with present WA values

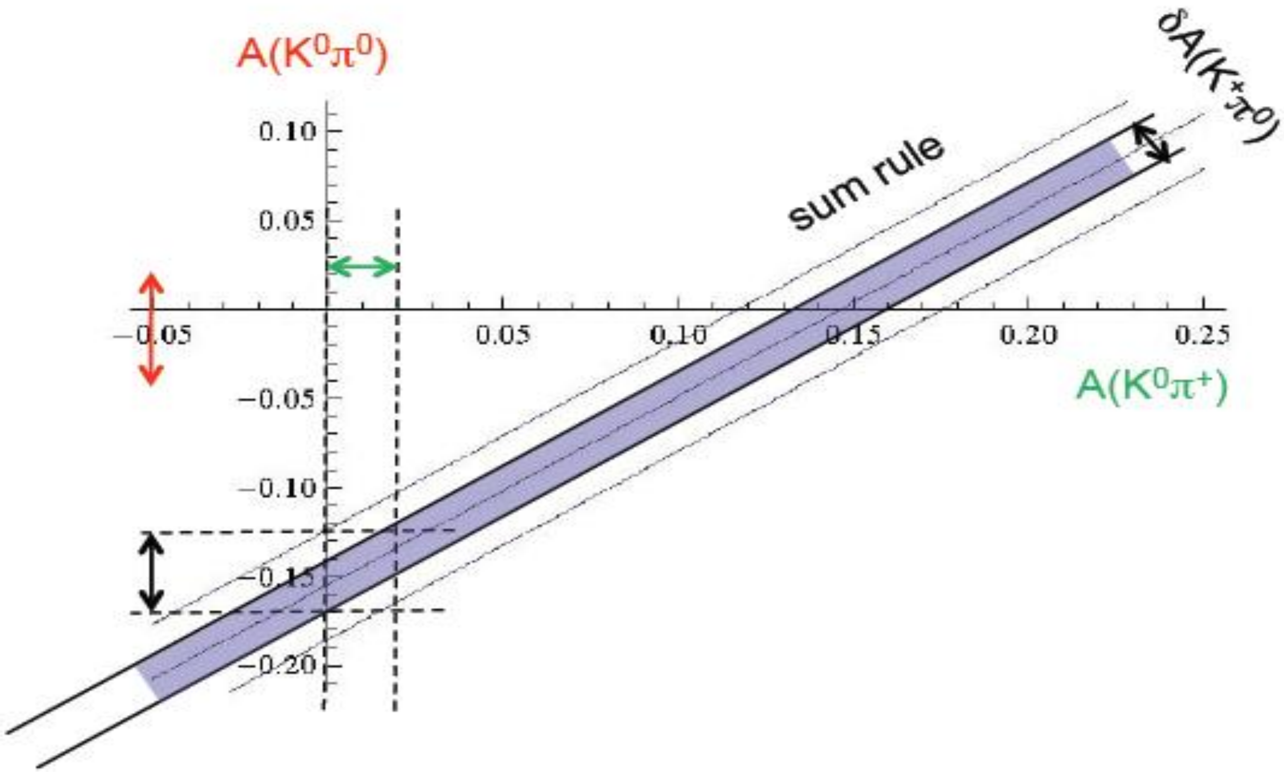


This would establish the existence of a NP phase

Compelling measurement in a clean mode

on $K\pi$ puzzle

e.g. Belle II, 50 ab^{-1}



Thank you.

cho@kisti.re.kr