Physics at the Belle II Experiment and Lattice QCD

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Lattice2015 @ Kobe

NAGOYA UNIVERSITY

Kobayashi-Maskawa Institute for the Origin of Particles and the Universe

Belle II

My Cards

exactly match to my research history

Master thesis
A-dependence of
$K^- + `p' \rightarrow K^+$ 'Ξ'
at KEK-E176

Doctor thesis
H-dibaryon search
at BNL-E813/836

Present research
b-quark
physics at Belle/
Belle II

Talk Outline

B Physics (Heavy Flavor Physics)

Belle II, LHCb, …

Value of b-quark card is high !

Lattice QCD

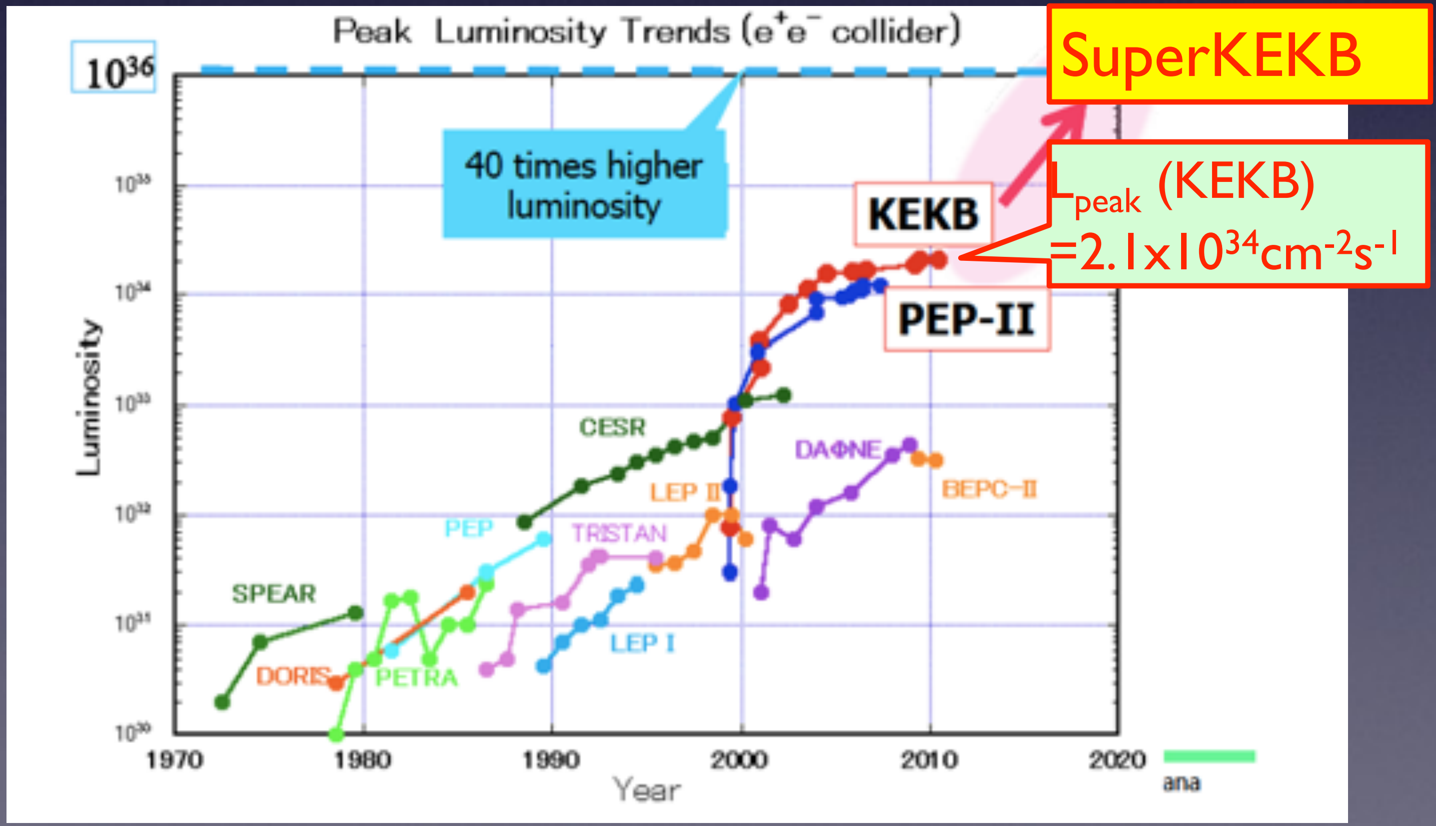
+

Status of SuperKEKB/Belle II

SuperKEKB/Belle II

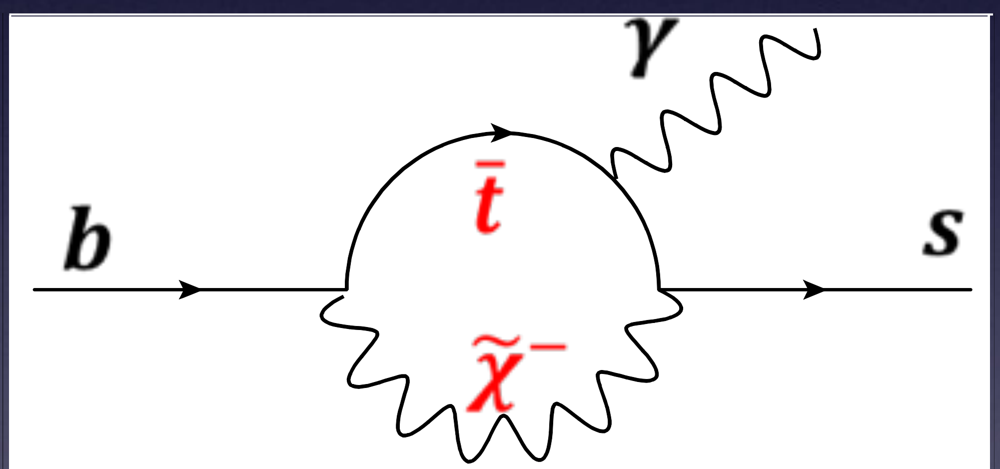
- New intensity frontier facility
- Target luminosity ; $L_{peak} = 8 \times 10^{35} cm^{-2}s^{-1}$
  $L_{int} > 50\ ab^{-1}$ by early 2020's.

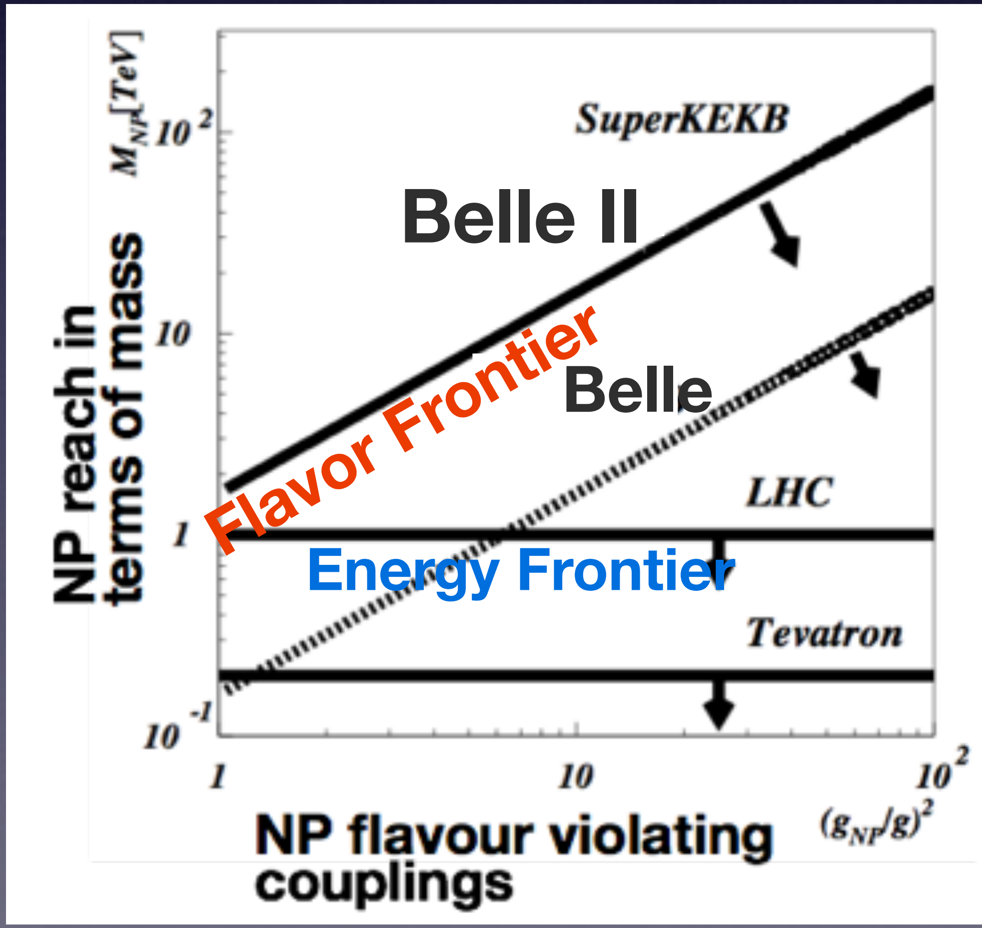
$\Rightarrow \sim 10^{10}$ $B\bar{B}$, $\tau^+\tau^-$ and charms per year !



Motivation of Belle II

- Search for New Physics through processes sensitive to presence of virtual heavy particles.
- Complementary to direct search in LHC high P_T programs.





Tasting New Physics

Variety of observables w/ different sensitivity to New Physics models.

Elucidation of New Physics scenario.

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0-\bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\rm CP}(B\to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B\to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B\to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B\to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s\to\mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+\to\pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L\to\pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu\to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau\to\mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu+N\to e+N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

Table 8: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

W. Altmannshofer, A. J. Buras, S. Gori, P. Paradisi, D. M. Straub, Nucl. Phys. B830, 17-94, 2010.

Unresolved issues
Indication of New Physics ?

- Anomalies in $b \to s\, l\, l$ data
- Enhanced $Br(B \to D^{(*)}\, \tau\, \nu)$ rate
- $B_s \to \mu\, \mu$ and $B_d \to \mu\, \mu$
- Tension between excl. – incl. $|V_{xb}|$
- Large CPV in charm decays
- LFV in Higgs decay $H \to \mu\tau$ (CMS)
- $(g\text{-}2)_\mu$ (BNL-E821)   etc.

Lattice QCD

- $f_{B \to D}$
- $f_{B \to \pi, K}$
- f_B
- $f_{D \to \pi, K}$
- f_D

The most recent results were summarized in FPCP2015 @ Nagoya (May 25-29)

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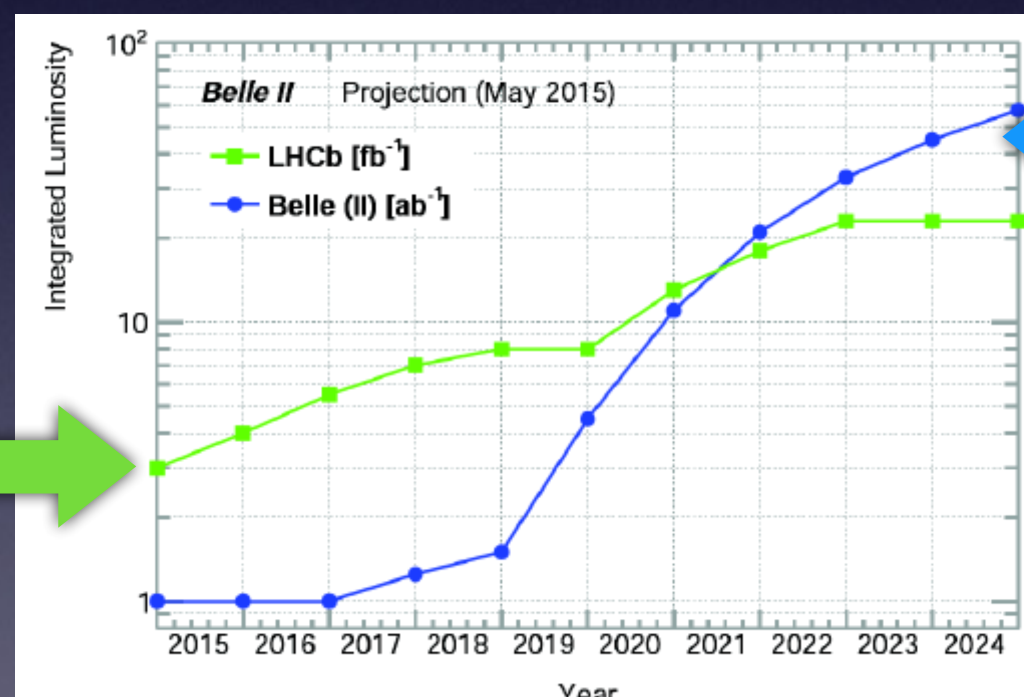
Belle II & LHCb

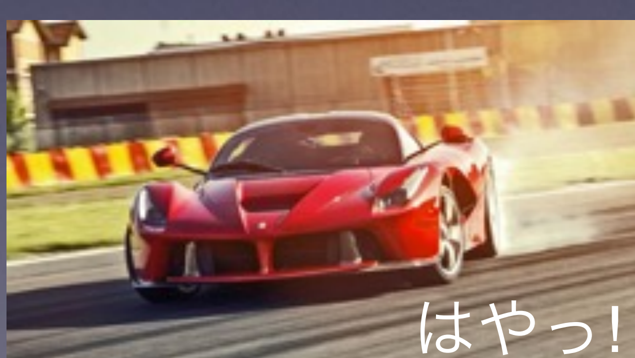
Heavy Flavor data ($B/D/\tau$) with ultimate precision become available !

pp collision
large production rate

Note: two lines are not in the same units



e^+e^- collision
low background



Ferrari

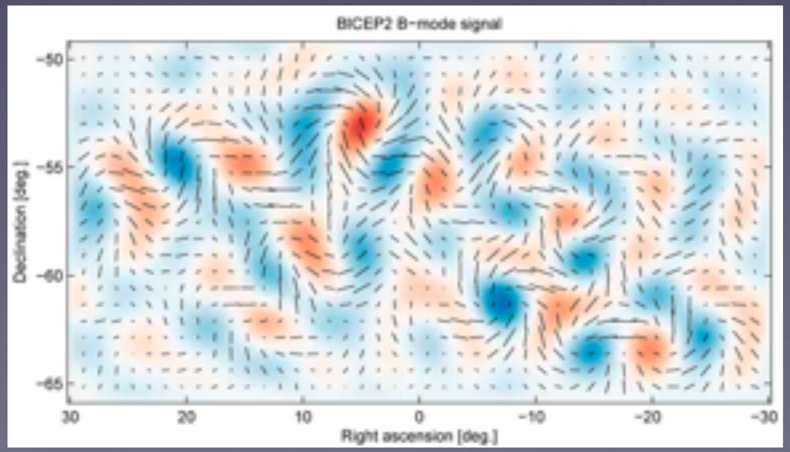
Powerful !

Clean !

TOYOTA FCV
COMING SOON !

Flavor Physics & Lattice

- If LHC (ATLAS/CMS) finds NP, their effects will emerge also in flavor physics observables, and they provide useful information for elucidation of NP.
- If LHC finds no NP, precision flavor measurements provide unique ways to find NP.
- In either case, lattice QCD inputs are of crucial importance to study or find NP in flavor physics measurements !



… Cosmic inflation can be indirectly detected by B-mode polarization of CMB. It requires very good understanding of foreground backgrounds !

Key Measurements @ Belle II

arXiv:1002.5012

- CPV in b→s penguin decays
- FCNC
- Tauonic decays
- LFV τ decays

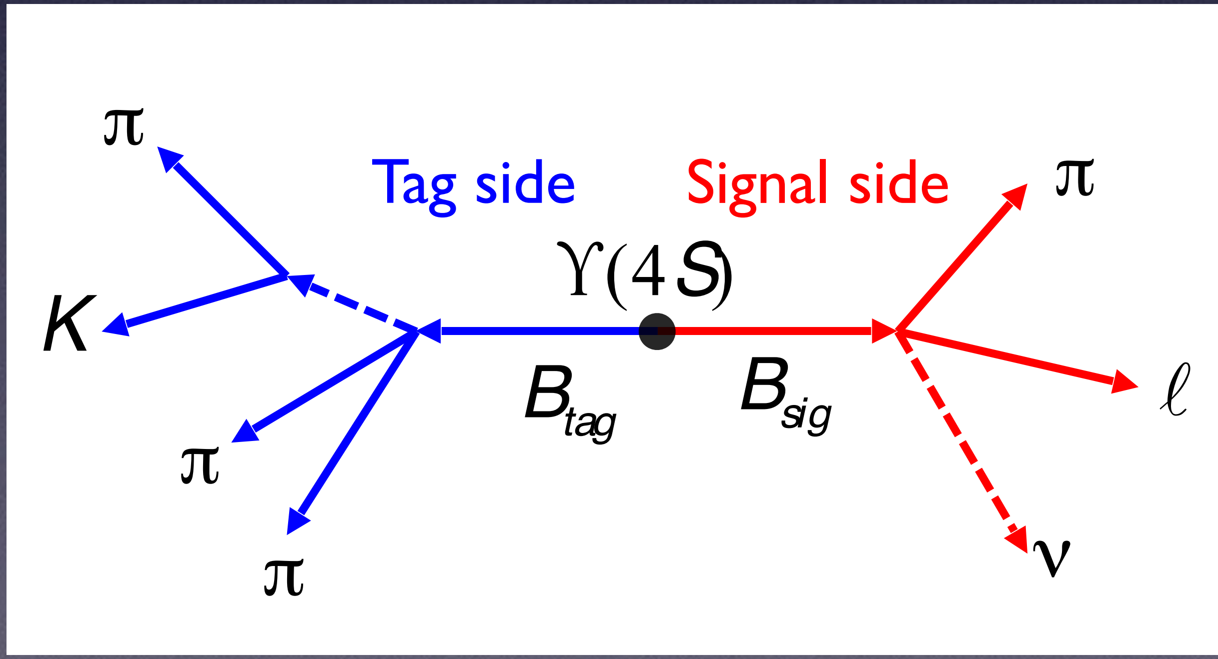
Observable	Belle 2006 ($\sim$0.5 ab^{-1})	SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})
Hadronic $b \to s$ transitions			
$\Delta S_{\phi K^0}$	0.22	0.073	0.029
$\Delta S_{\eta' K^0}$	0.11	0.038	0.020
$\Delta S_{K^0_S K^0_S K^0_S}$	0.33	0.105	0.037
$\Delta A_{\pi^0 K^0_S}$	0.15	0.072	0.042
$A_{\phi\phi K^+}$	0.17	0.05	0.014
$\phi_1^{eff}(\phi K_S)$ Dalitz		3.3°	1.5°
Radiative/electroweak $b \to s$ transitions			
$S_{K^0_S \pi^0 \gamma}$	0.32	0.10	0.03
$\mathcal{B}(B \to X_s \gamma)$	13%	7%	6%
$A_{CP}(B \to X_s \gamma)$	0.058	0.01	0.005
C_9 from $\overline{A}_{\rm FB}(B \to K^* \ell^+ \ell^-)$	-	11%	4%
C_{10} from $\overline{A}_{\rm FB}(B \to K^* \ell^+ \ell^-)$	-	13%	4%
C_7/C_9 from $\overline{A}_{\rm FB}(B \to K^* \ell^+ \ell^-)$	-		5%
R_K		0.07	0.02
$\mathcal{B}(B^+ \to K^+ \nu\nu)$	$^{\dagger\dagger} < 3\ \mathcal{B}_{\rm SM}$		30%
$\mathcal{B}(B^0 \to K^{*0} \nu\bar{\nu})$	$^{\dagger\dagger} < 40\ \mathcal{B}_{\rm SM}$		35%
Radiative/electroweak $b \to d$ transitions			
$S_{\rho\gamma}$	-	0.3	0.15
$\mathcal{B}(B \to X_d \gamma)$	-	24% (syst.)	
Leptonic/semileptonic B decays			
$\mathcal{B}(B^+ \to \tau^+ \nu)$	3.5σ	10%	3%
$\mathcal{B}(B^+ \to \mu^+ \nu)$	$^{\dagger\dagger} < 2.4 \mathcal{B}_{\rm SM}$	4.3 ab^{-1} for 5σ discovery	
$\mathcal{B}(B^+ \to D \tau \nu)$	-	8%	3%
$\mathcal{B}(B^0 \to D \tau \nu)$	-	30%	10%
LFV in τ decays (U.L. at 90% C.L.)			
$\mathcal{B}(\tau \to \mu\gamma)$ [10^{-9}]	45	10	5
$\mathcal{B}(\tau \to \mu\eta)$ [10^{-9}]	65	5	2
$\mathcal{B}(\tau \to \mu\mu\mu)$ [10^{-9}]	21	3	1

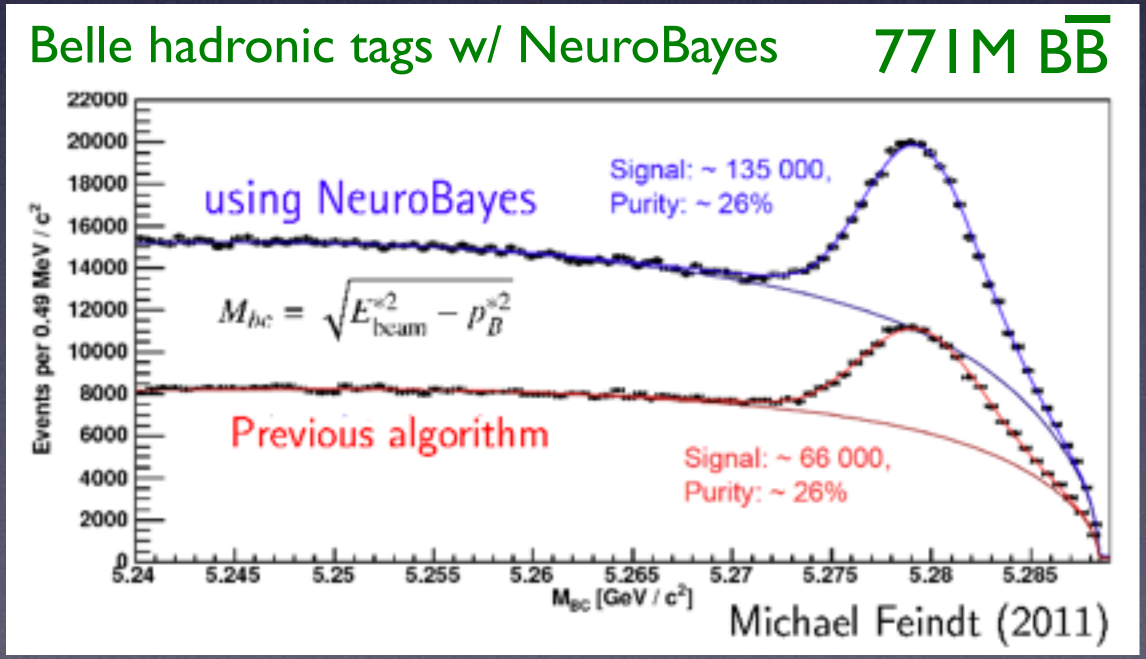
Ultimate measurements down to theory error !

Uniqueness of Belle II

- Fully reconstructed tags to produce "offline B meson beam".
  - Strong tool for modes with neutrinos

    $B \to X l\nu$, $X \tau\nu$, $\tau\nu$, $K^{(*)}\nu\bar{\nu}$…
- Excellent γ& π^0 detection capability
  - $S(K_S^0\pi^0\gamma)$, $Br(X_S\gamma)$, $A_{CP}(X_S\gamma)$



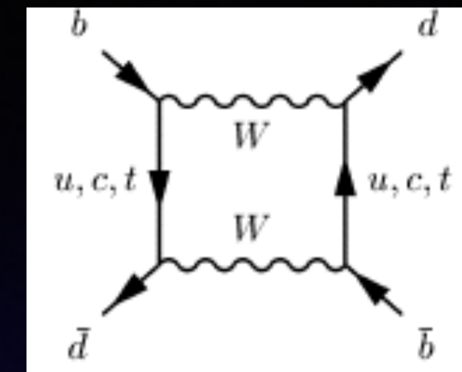


NIM A654, 432 (2011)

Precision CKM Measurements

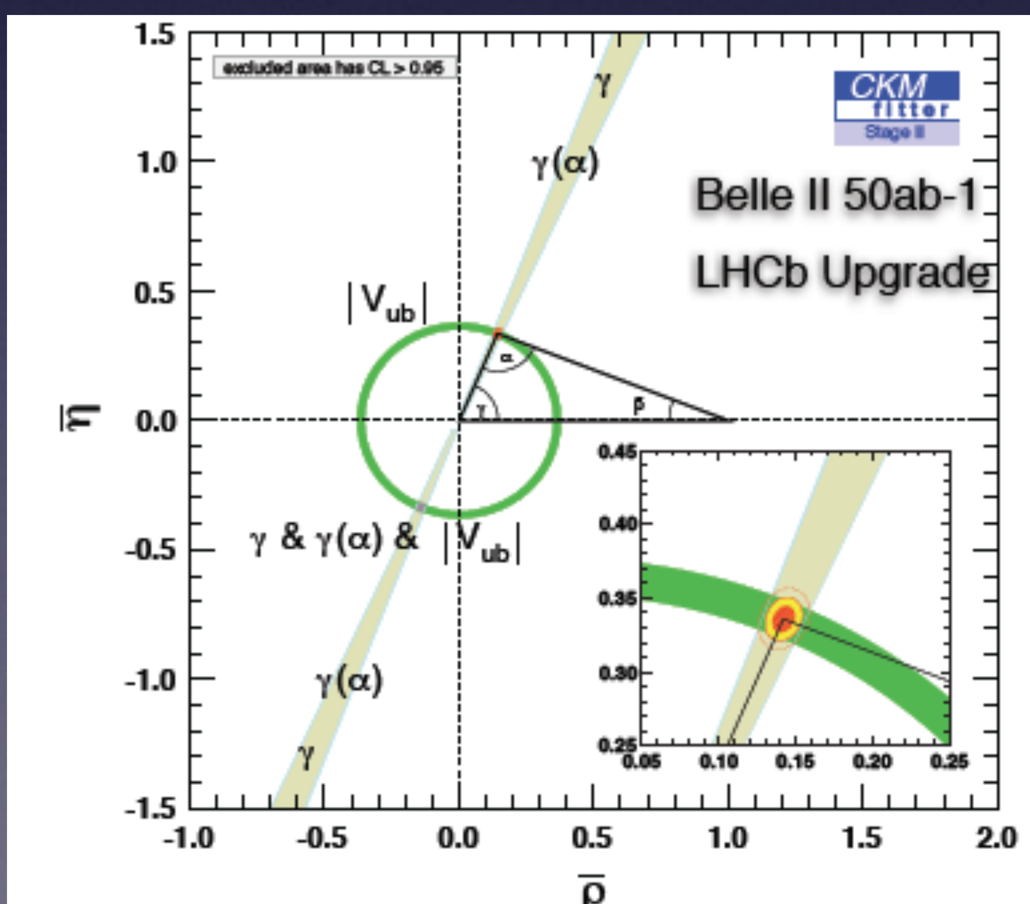
- Comparison between
  - tree-based ; $|V_{ub}| + \varphi_3$
  - loop-based ; φ_1, φ_2, $|V_{td}|$

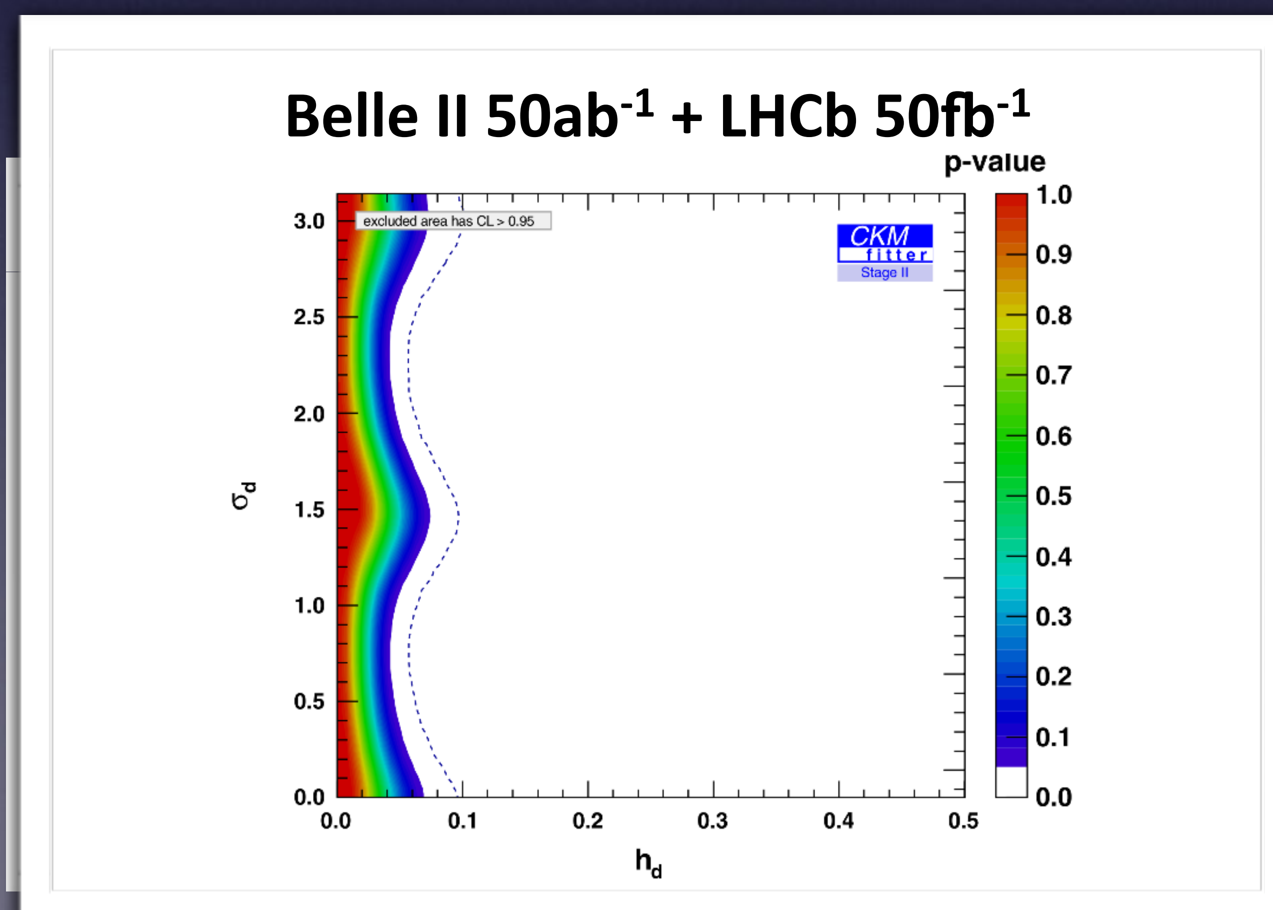
  → NP in loop
- Belle II is unique for $|V_{cb}|$ and $|V_{ub}|$



$$M_{12}^{d,s} = (M_{12}^{d,s})_{SM} \times (1 + h_{d,s} e^{2i\sigma_{d,s}})$$

Relative amplitude   phase





Lattice QCD and Belle II

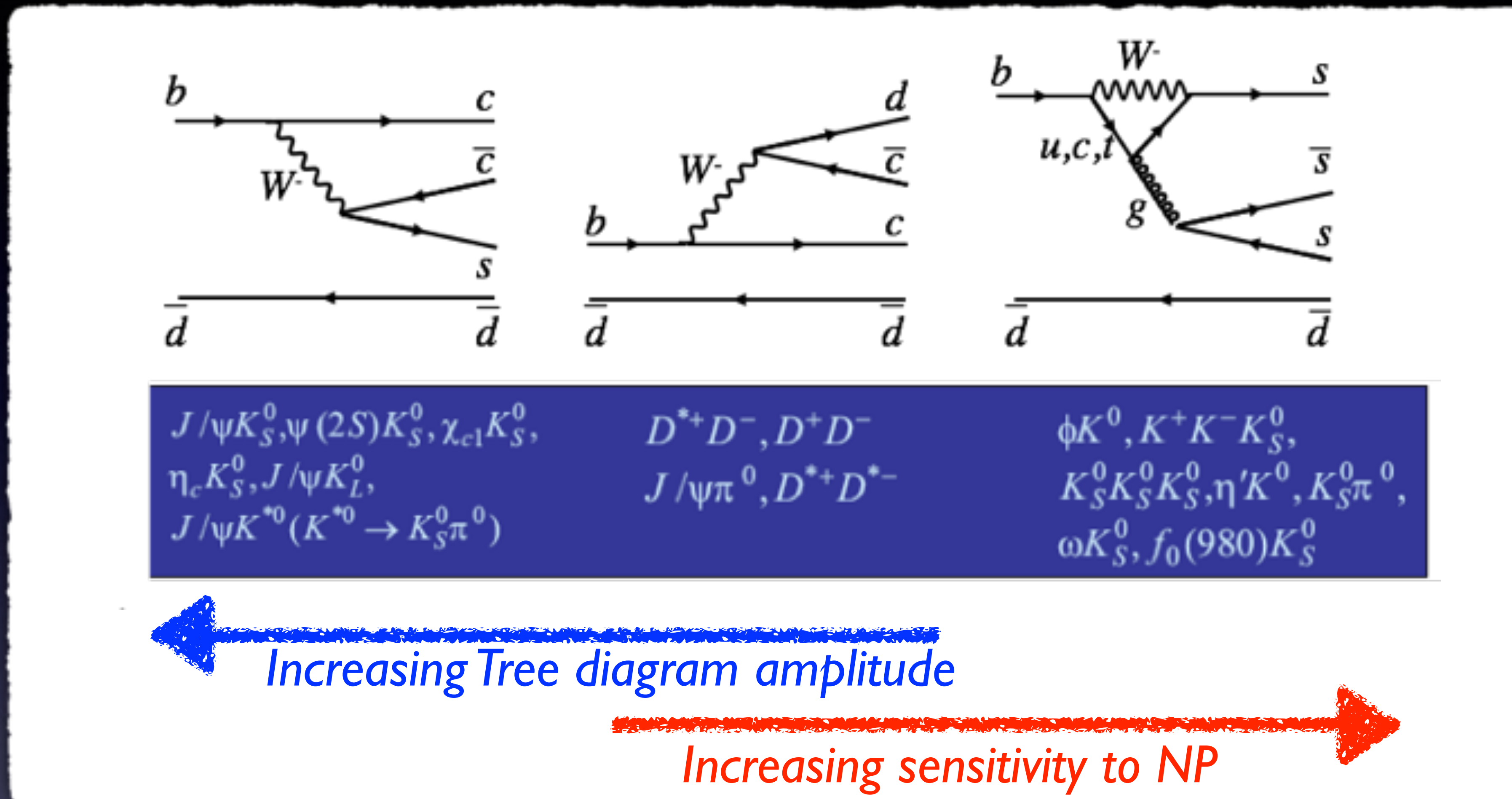
- Lattice QCD is important for CKM physics.

USQCD "Lattice QCD at the Intensity Frontier"
http://www.usqcd.org/documents/13flavor.pdf

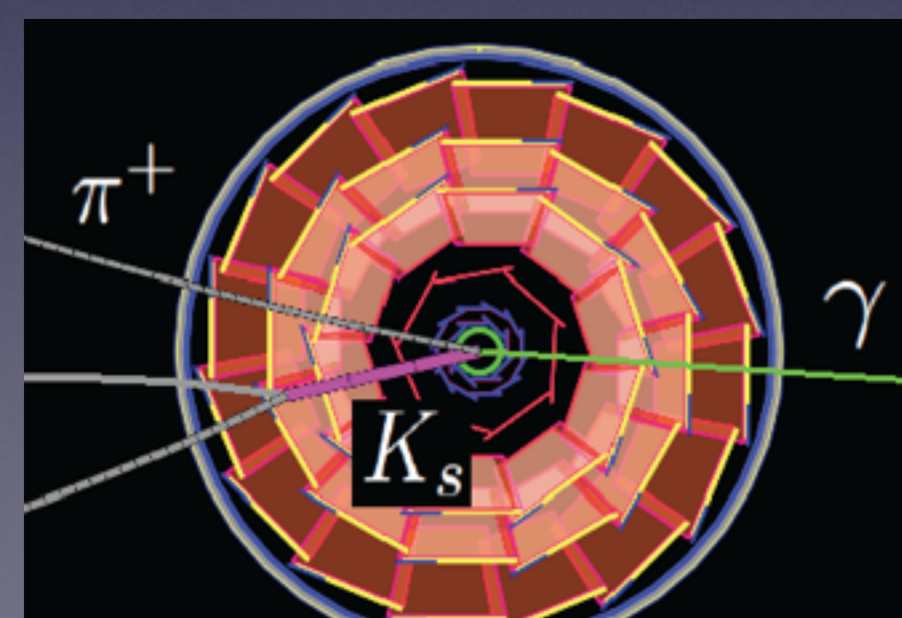
Quantity	CKM element	Present expt. error	2007 forecast lattice error	Present lattice error	2018 lattice error
f_K/f_π	$\|V_{us}\|$	0.2%	0.5%	0.5%	0.15%
$f_+^{K\pi}(0)$	$\|V_{us}\|$	0.2%	–	0.5%	0.2%
f_D	$\|V_{cd}\|$	4.3%	5%	2%	< 1%
f_{D_s}	$\|V_{cs}\|$	2.1%	5%	2%	< 1%
$D \to \pi \ell \nu$	$\|V_{cd}\|$	2.6%	–	4.4%	2%
$D \to K \ell \nu$	$\|V_{cs}\|$	1.1%	–	2.5%	1%
$B \to D^* \ell \nu$	$\|V_{cb}\|$	1.3%	–	1.8%	< 1%
$B \to \pi \ell \nu$	$\|V_{ub}\|$	4.1%	–	8.7%	2%
f_B	$\|V_{ub}\|$	9%	–	2.5%	< 1%
ξ	$\|V_{ts}/V_{td}\|$	0.4%	2-4%	4%	< 1%
ΔM_s	$\|V_{ts}V_{tb}\|^2$	0.24%	7–12%	11%	5%
B_K	$\mathrm{Im}(V_{td}^2)$	0.5%	3.5–6%	1.3%	< 1%

- Also for rare decay processes: e.g.: $B \to K^{(*)} l^+ l^-$, $B \to K^* \gamma$

Time-dependent CPV

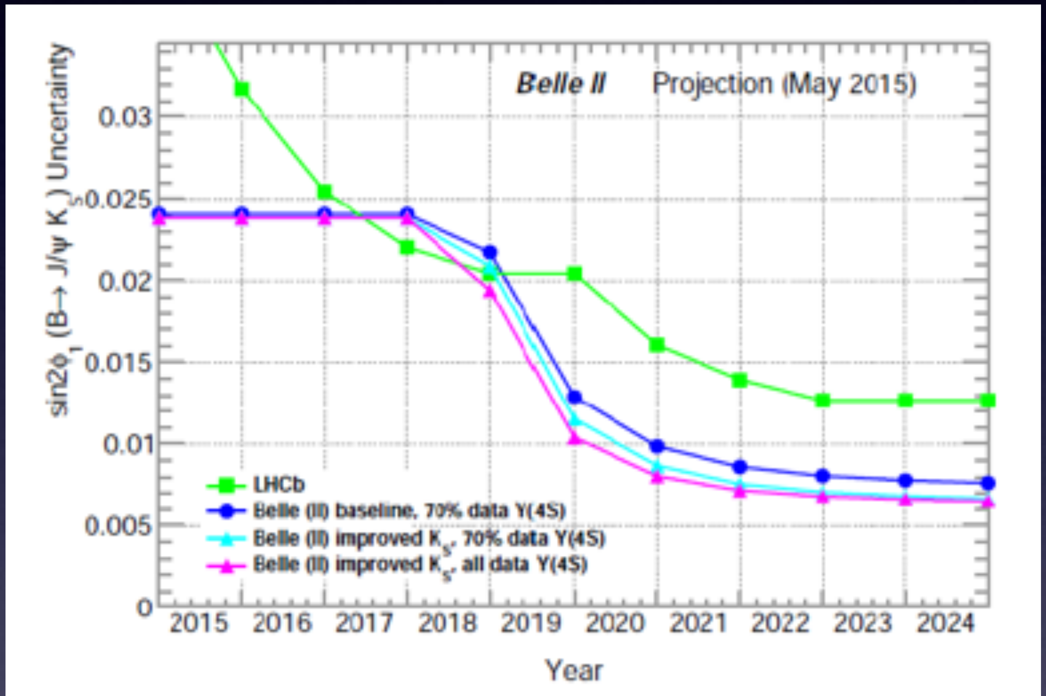


- Larger acceptance for Ks decay vertex +30%
- Improved vertex resolution
  $\sigma(Z)$~18μm @ Belle II ↔ ~61μm @ Belle
  → less systematic error



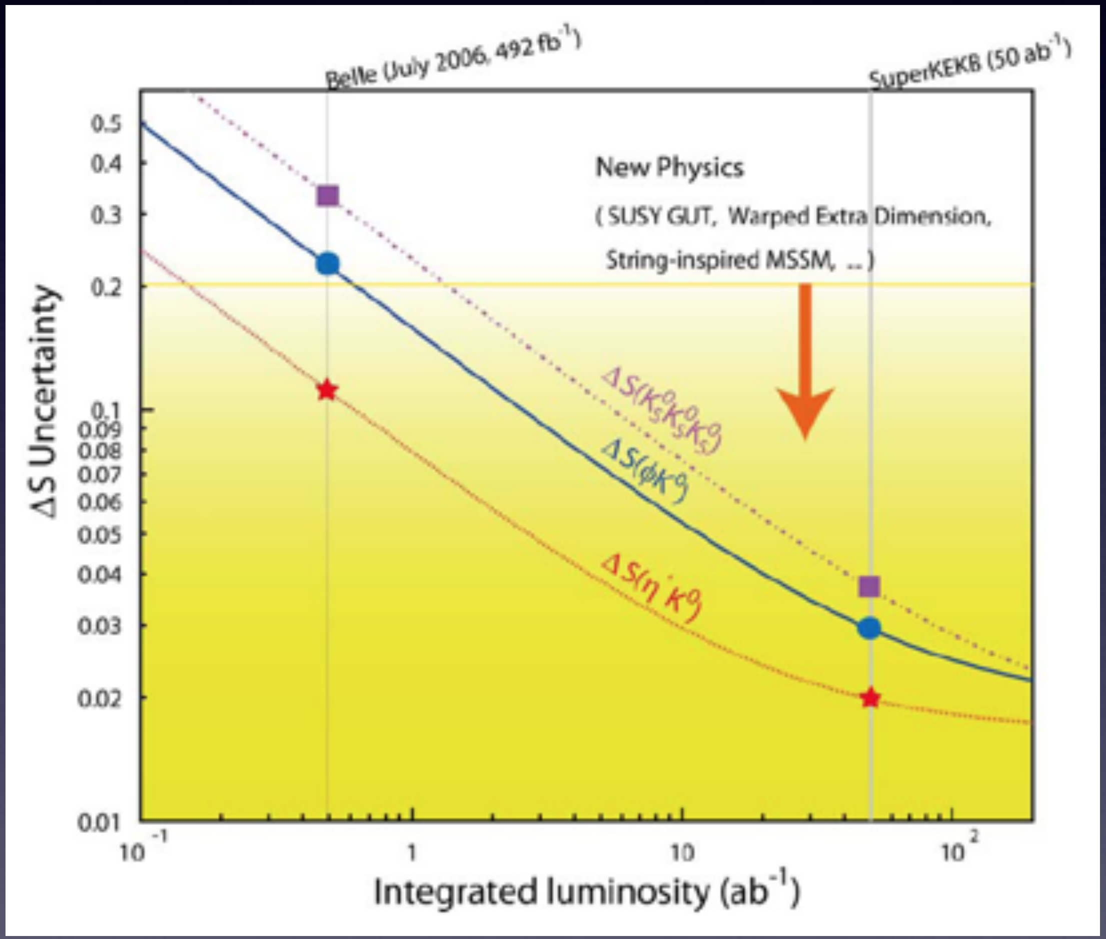
Φ_1 ($\equiv\beta$) Projection

Belle II projection for $\sin 2\varphi_1$ from $B \to J/\psi K_S$

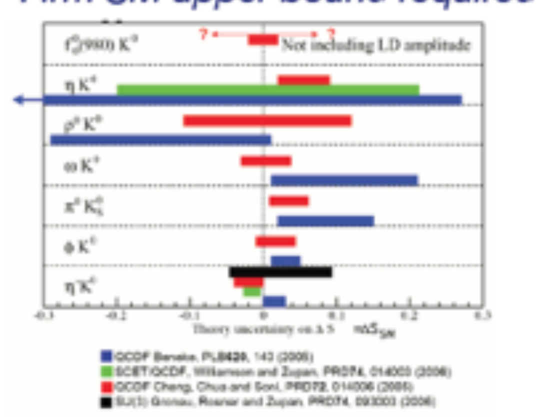


BELLE2-NOTE-PH-2015-02:
LHCb projections taken from:
HL-LHC ECFA Workshop 2014
LHCb-PUB-2014-040,
LHCb EPJC 73, 2373.

Belle II projection for $\sin 2\varphi_1^{eff}$ from $b \to s\bar{s}s$ *processes*

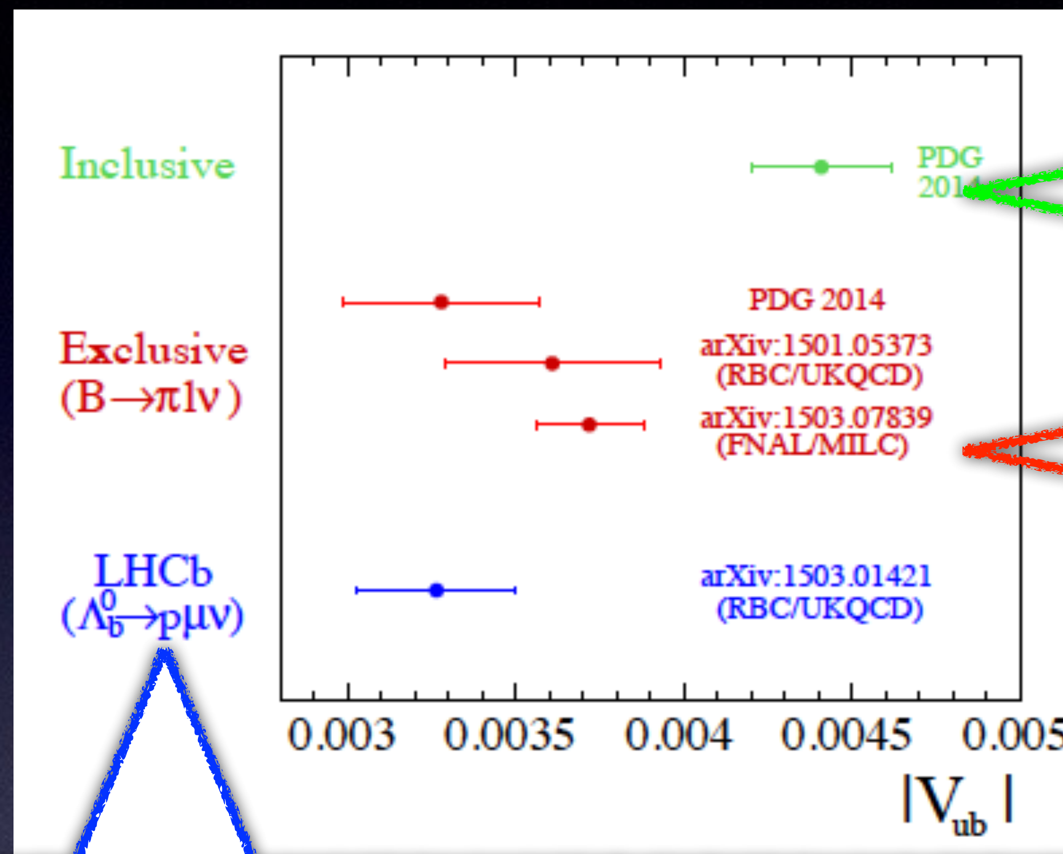


Firm SM upper bound required



$|V_{ub}|$ at present

Persistence tension between inclusive and exclusive $|V_{ub}|$



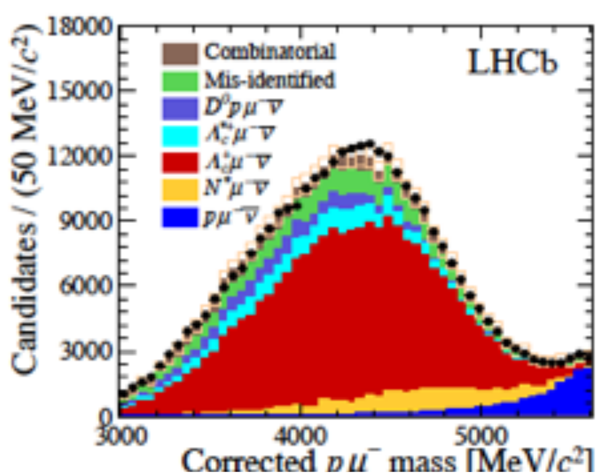
Inclusive result in PDG2014
$|V_{ub}| = (4.41 \pm 0.22) \times 10^{-3}$

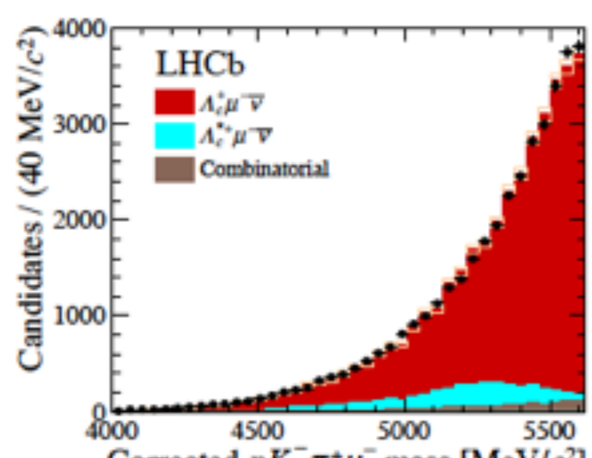
$B \to \pi l \nu$ result from FNAL-MILC
$|V_{ub}| = (3.72 \pm 0.16) \times 10^{-3}$

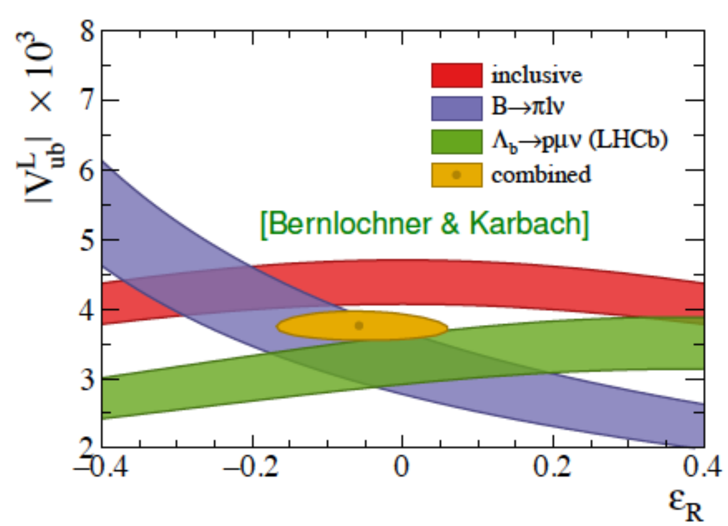
LHCb

arXiv: 1504.01568

New @ FPCP2015







$$|V_{ub}| = (3.27 \pm 0.15 \pm 0.17 \pm 0.06) \times 10^{-3}$$

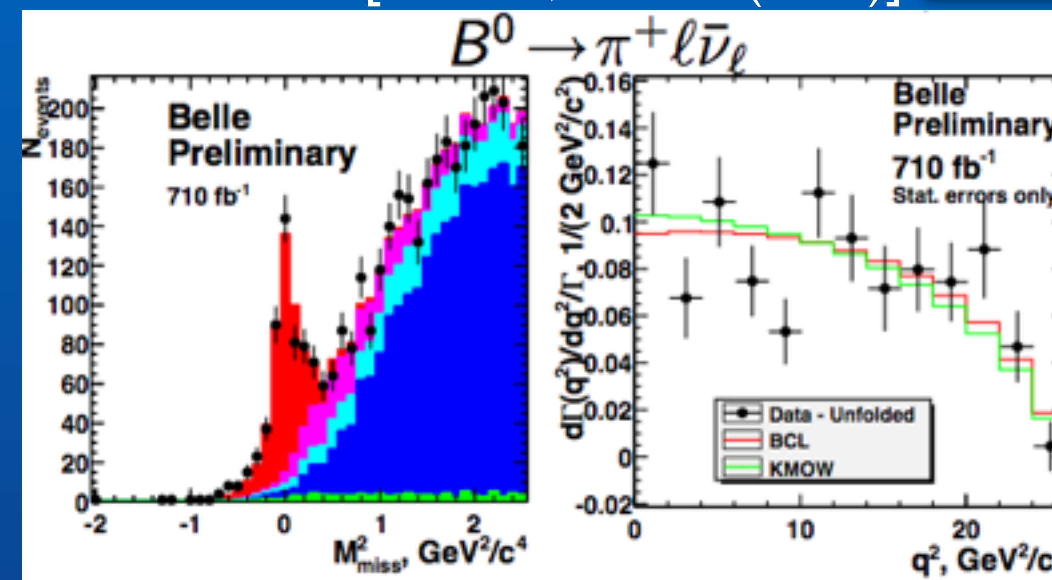
Exp. LQCD Norm.

Right-handed current ?

$|V_{ub}|$ Prospect at Belle II

- Belle II should resolve the "$|V_{ub}|$ problem".
- Precision of the tagged $B \to \pi l \nu$ will be similar to the untagged one.

[PRD 88, 032005 (2013)]



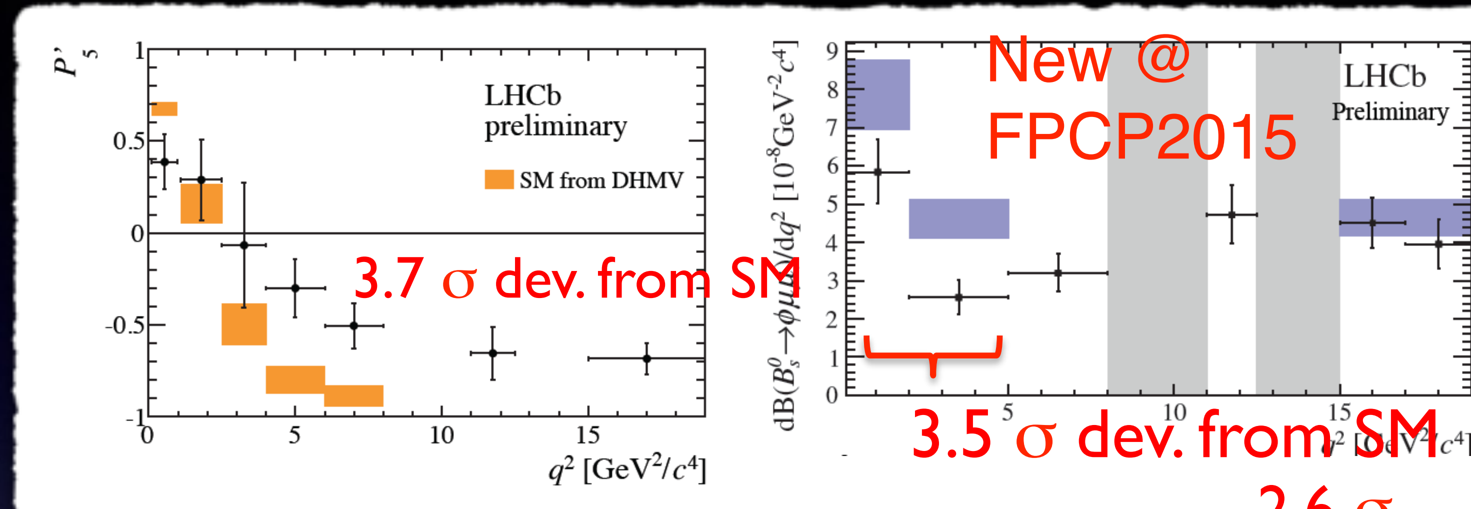
	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ exclusive (had. tagged)					
711 fb^{-1}	5.8	(2.3, 1.0)	6.3	8.7 (2.0)	10.8 (6.6)
5 ab^{-1}	2.2	(0.9, 1.0)	2.6	4.0 (2.0)	4.7 (3.3)
50 ab^{-1}	0.7	(0.3, 1.0)	1.3	2.0	2.4
$\lvert V_{ub}\rvert$ exclusive (untagged)					
605 fb^{-1}	2.7	(2.1, 0.8)	3.5	8.7 (2.0)	9.4 (4.0)
5 ab^{-1}	1.0	(0.8, 0.8)	1.5	4.0 (2.0)	4.2 (2.5)
50 ab^{-1}	0.3	(0.3, 0.8)	0.9	2.0	2.2
$\lvert V_{ub}\rvert$ inclusive					
605 fb^{-1} (old B tag)	4.5	(3.4, 2.3)	6.0	2.5	6.5
5 ab^{-1}	1.1	(1.2, 2.3)	2.8	2.5	3.8
50 ab^{-1}	0.4	(0.4, 2.3)	2.4	2.5	3.4

Belle II Internal Note #0021

Theory error for Inclusive $|V_{ub}|$ uncertainty (2.5% in GGOU 4.5% in BLNP approach)

EW / Radiative Penguin

- Anomalies in b → s l l have been seen by LHCb
  - ✓ P_5' in $B \to K^* \mu\mu$
  - ✓ $Br(B_s \to \varphi \mu\mu)$
  - ✓ Lepton non-universality



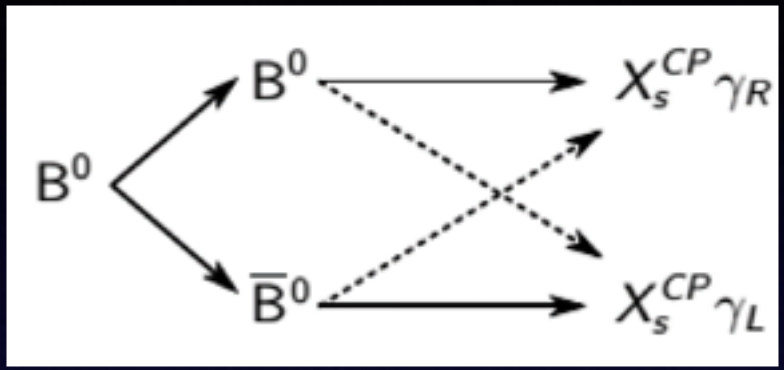
$$R_K \equiv \frac{\Gamma(B^+ \to K^+\mu^+\mu^-)}{\Gamma(B^+ \to K^+e^+e^-)} = 0.745^{+0.090}_{-0.074}(\mathrm{stat}) \pm 0.036(\mathrm{syst})$$

- Belle II can measure inclusive B→Xsll, and also Kνν

	Observables	Belle or LHCb (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
Radiative	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d}\gamma)$ [10^{-2}]	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K_S^0\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035		
	$\phi_s^{\mathrm{eff}}(B_s \to \phi\gamma)$	± 0.20			0.13	0.03
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07		
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7	0.3	–		
Electroweak penguins	$\mathcal{B}(B \to K^{*+}\nu\overline{\nu})$ [10^{-6}]	< 40	< 15	30%		
	$\mathcal{B}(B \to K^{+}\nu\overline{\nu})$ [10^{-6}]	< 55	< 21	30%		
	C_7/C_9 $(B \to X_s\ell\ell)$	∼20%	10%	5%		
	$q_0^2 A_{\mathrm{FB}}(B \to K^*\mu\mu)$	10%	30%	10%	5%	2%
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2	–		
	$\mathcal{B}(B_s \to \mu\mu)$ [10^{-9}]	± 1.0			0.5	0.2

Time-dep. CPV in $b\to s,d+\gamma$

- In SM, photon from $b\to s,d+\gamma$ is almost left-handed.
- Right-handed photon causes interference, and large CPV.



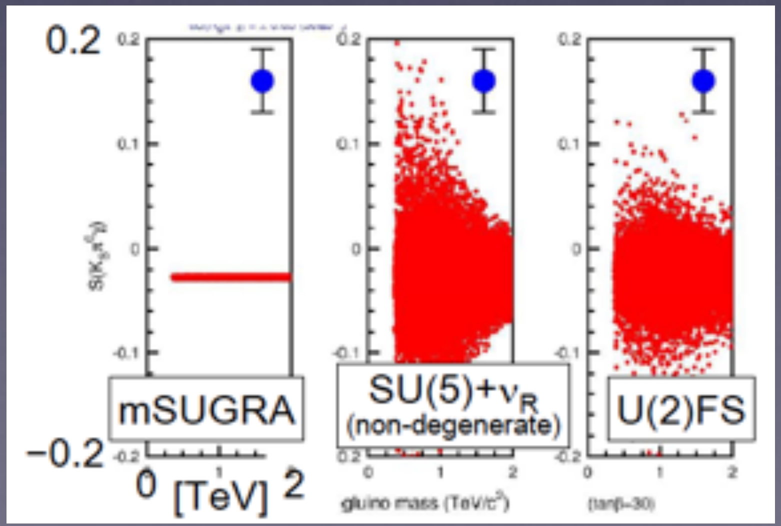
SM prediction

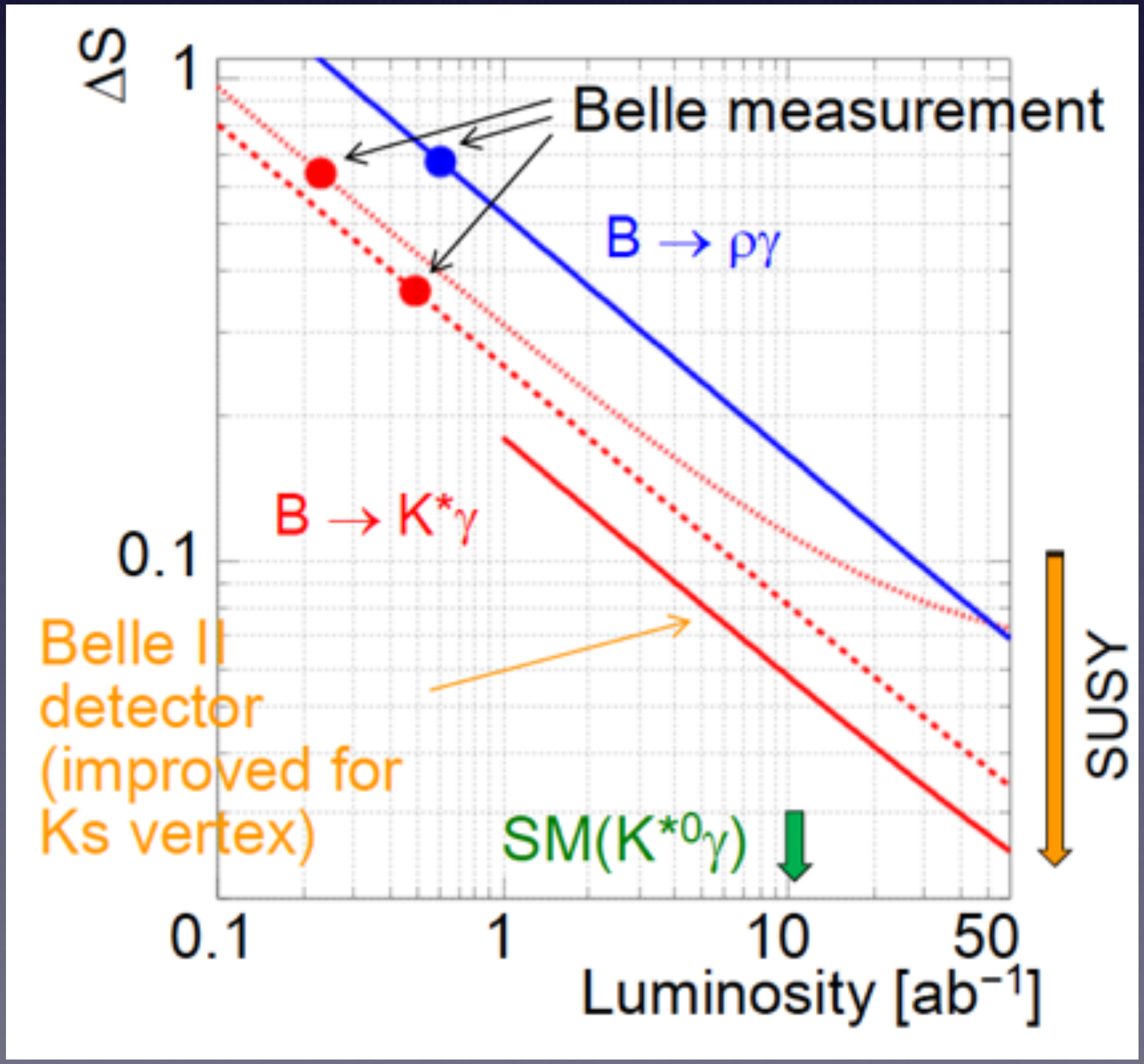
$$S(B\to V\gamma)\simeq -\frac{2m_s}{m_b}\sin 2\phi_1$$

$$|S(B\to K^*\gamma)|\le 0.02$$

$$|S(B\to\rho\gamma)|\sim 0$$

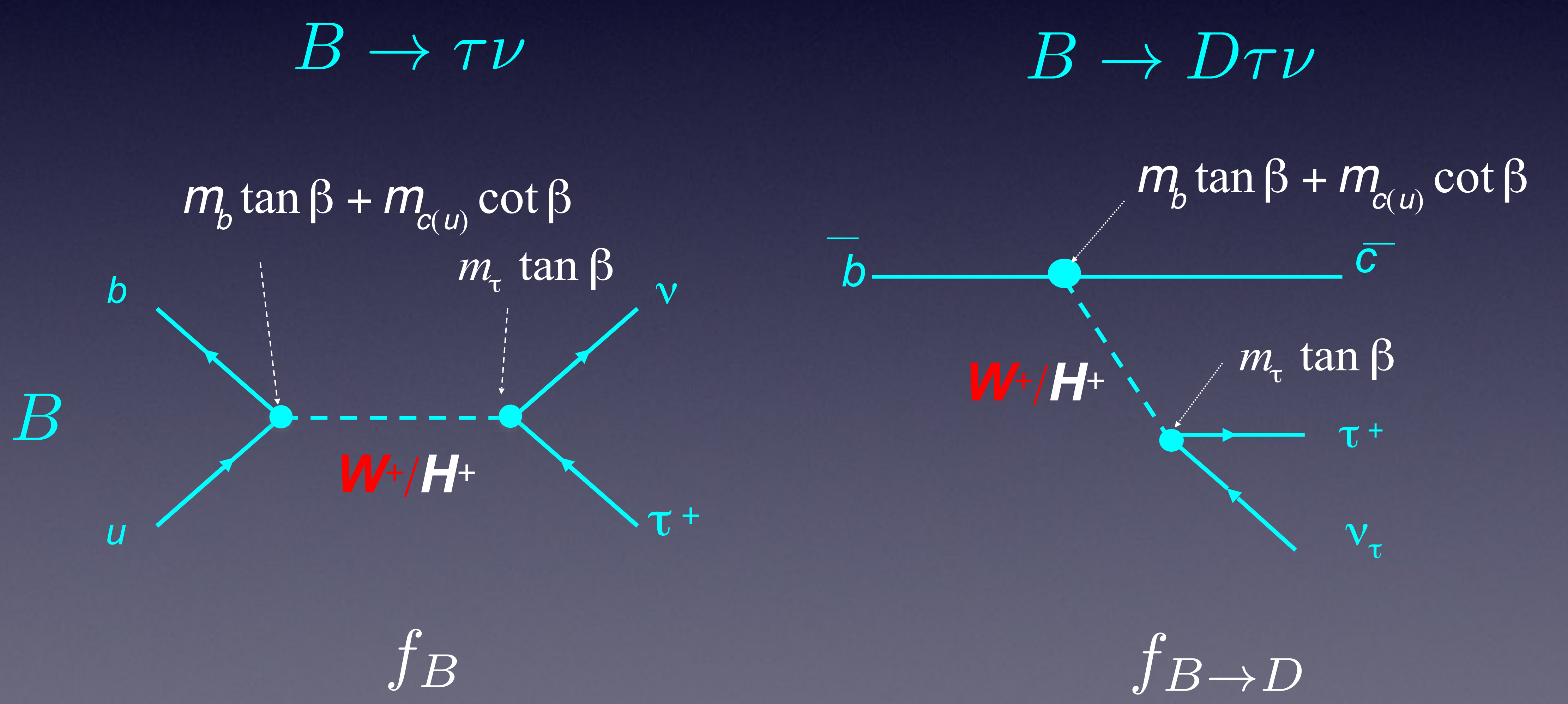
SUSY models





Charged Higgs in B decays

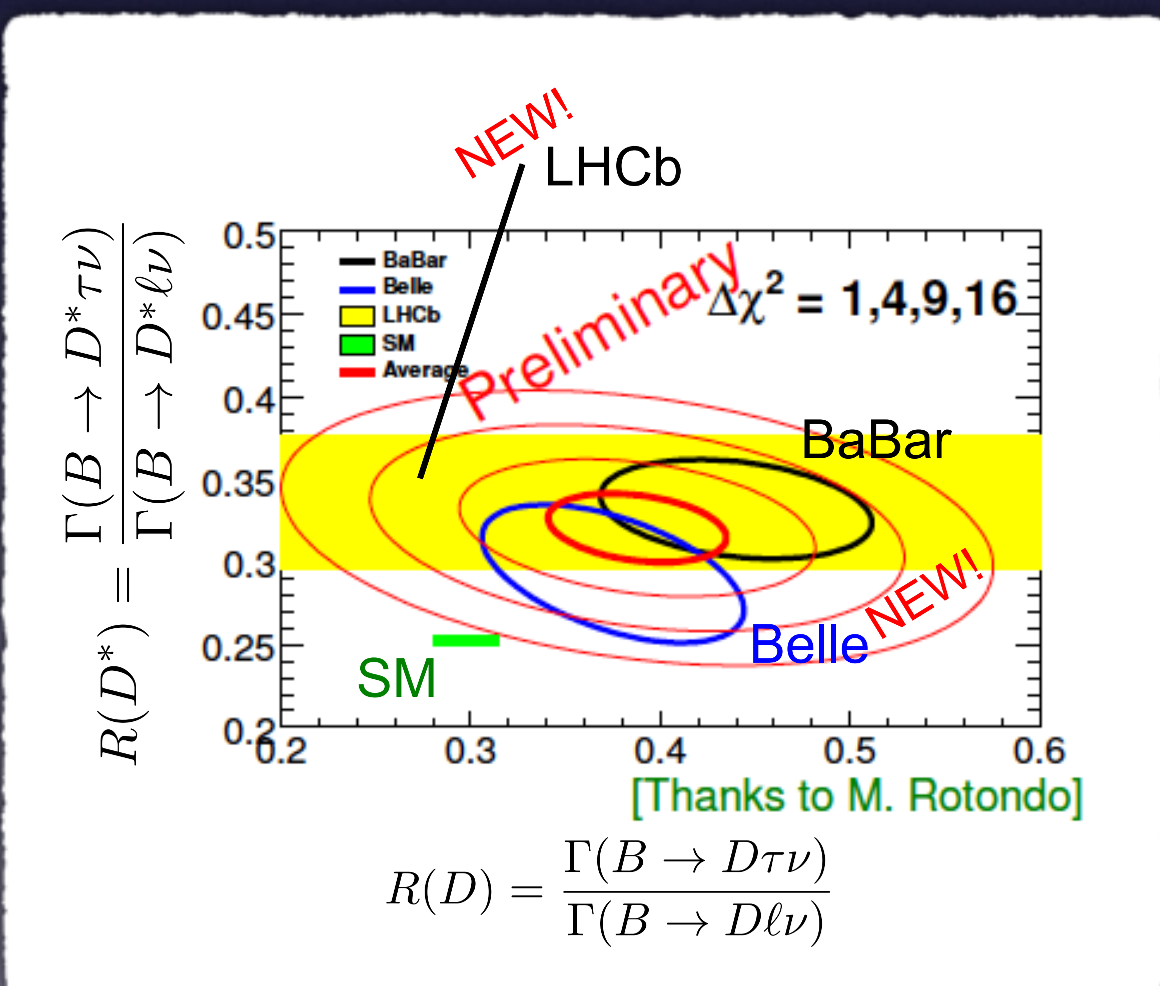
- Charged Higgs exchange may modify (semi-) leptonic B decays to the τ lepton final state.

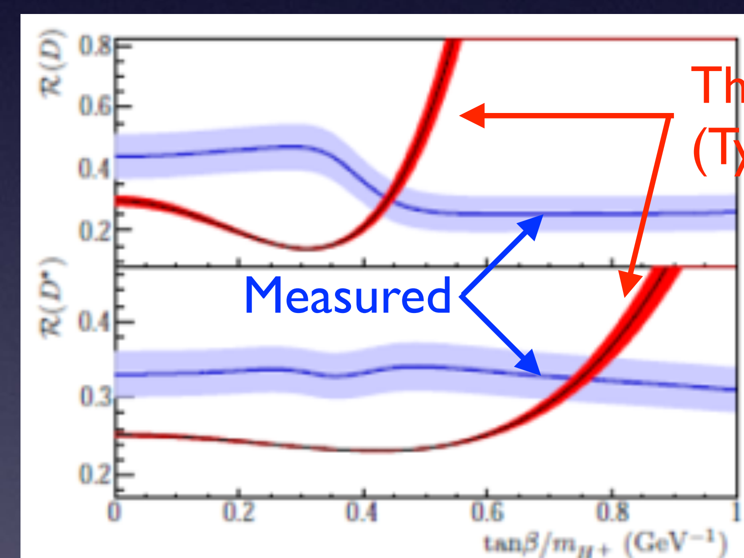


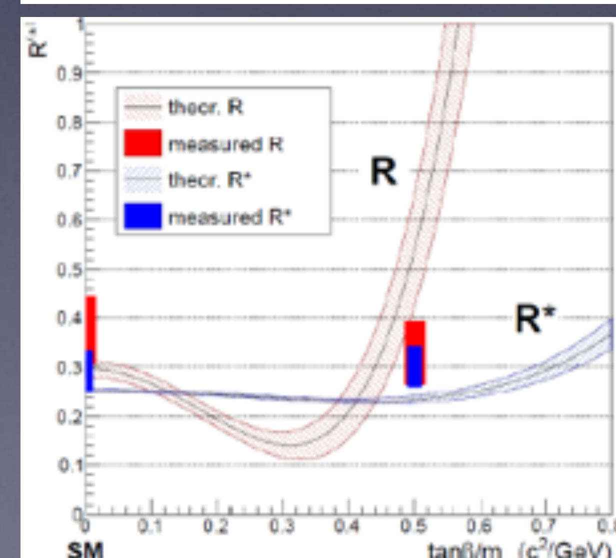
Different theoretical systematics

$B \to D^{(*)}\tau\nu$

- BaBar observes 3.4 σ excess over the SM expectation.
  - It excludes Type-II HDM.
- New results from Belle and LHCb reported at FPCP2015.
  - LHCb result is consistent with SM
  - Belle result is consistent with SM and also with BaBar. It does not exclude Type-II HDM.







- Analysis repeated for 2HDM of type II with $\tan\beta/m_{H+}$ = 0.5 c²/GeV:

$R = 0.329 \pm 0.060 \pm 0.022$
$R^* = 0.301 \pm 0.039 \pm 0.015$

$R_{2HDM} = 0.590 \pm 0.125$
$R^*_{2HDM} = 0.241 \pm 0.007$

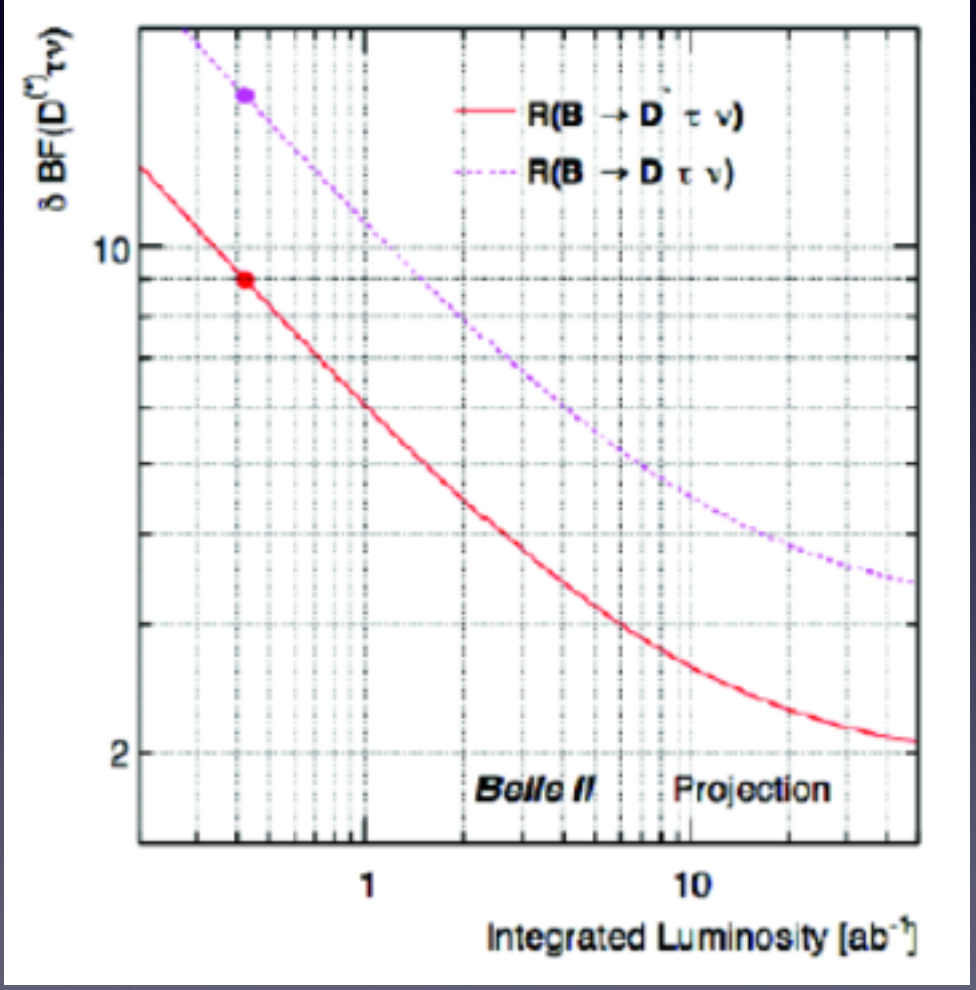
T. Kuhr

$B \to D^{(*)} \tau \nu$ at Belle II

- Better low-momentum and SVD only tracking
  → better D* reconstruction
  → Better tagging efficiency than Belle

[Belle II]

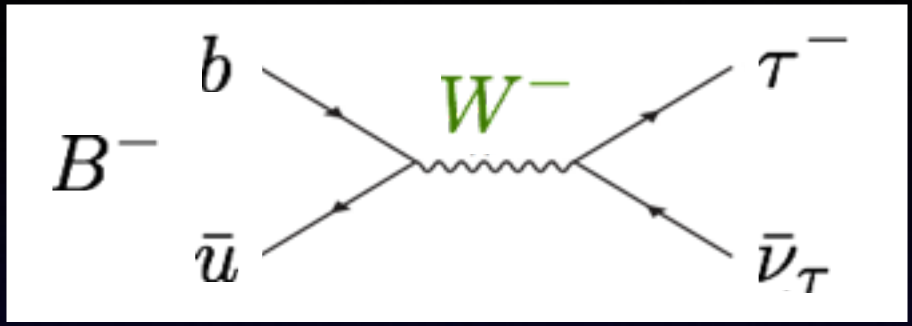
[%]	Statistical	Systematic (reducible, irreducible)	Total Exp
$R(D)$			
5 ab^{-1}	3.8	(2.6, 3.1)	5.6
50 ab^{-1}	1.2	(0.8, 3.1)	3.4
$R(D^*)$			
5 ab^{-1}	2.1	(1.5, 1.9)	3.2
50 ab^{-1}	0.7	(0.5, 1.9)	2.1



- Polarization of τ also can be measured at Belle II

Leptonic decay: B → τ ν

- Branching fraction in SM



$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

  - Global CKM fit predicts $\mathcal{B}(B \to \tau\nu)_{SM} = (0.753^{+0.102}_{-0.052}) \times 10^{-4}$

- In New Physics

$$\mathcal{B}(B \to \tau\nu) = r_H \cdot \mathcal{B}(B \to \tau\nu)_{SM}$$

$$r_H = \left(1 - \frac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)^2$$

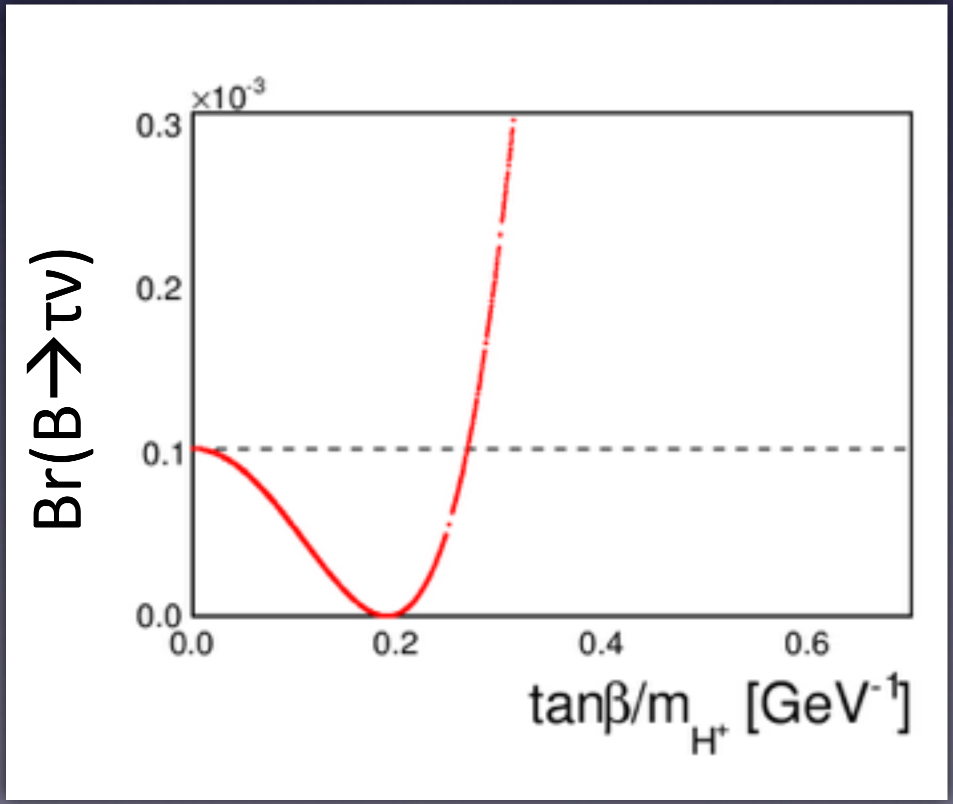
Type-II 2HDM

W.S. Hou, PRD 48, 2342 (1993)

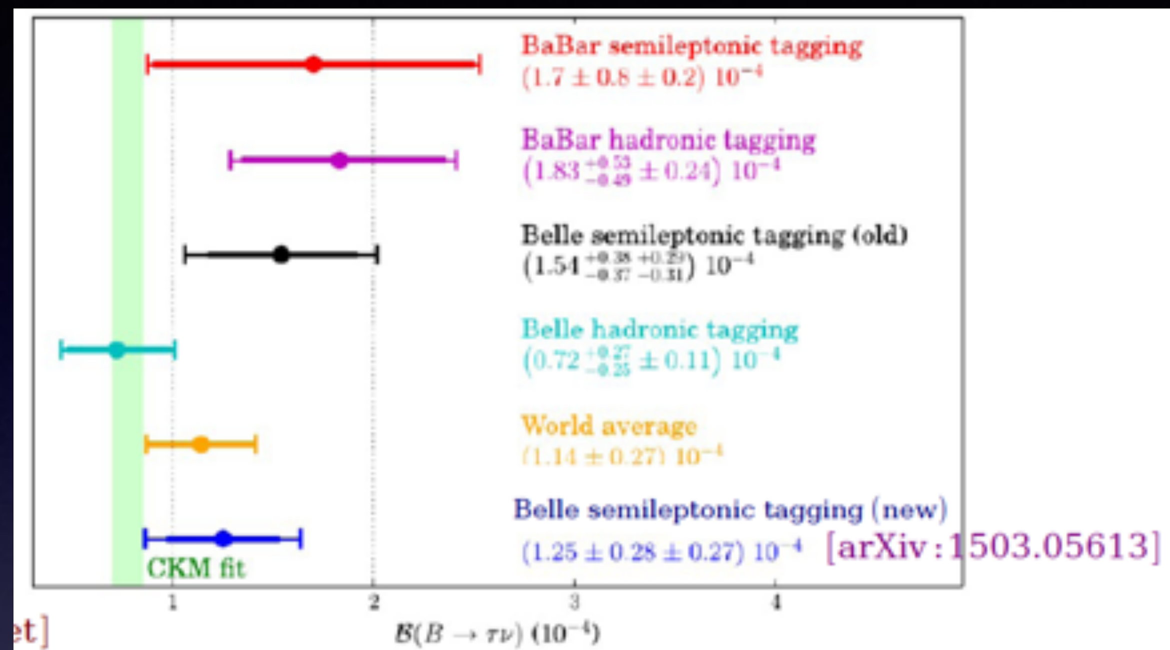
$$r_H = \left(1 - \frac{m_B^2}{m_{H^+}^2}\frac{\tan^2\beta}{1+\tilde{\epsilon}_0 \tan\beta}\right)^2$$

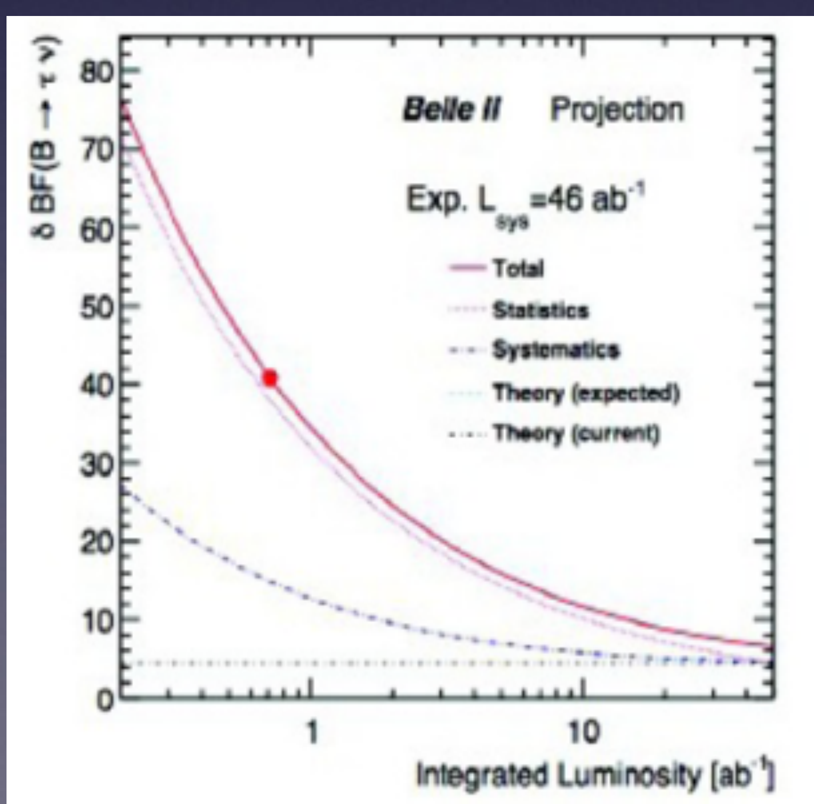
SUSY

A.G. Akeroyd, S.Recksiegel, J. Phys. G29, 2311 (2003)



$B \to \tau\nu$ at Belle II

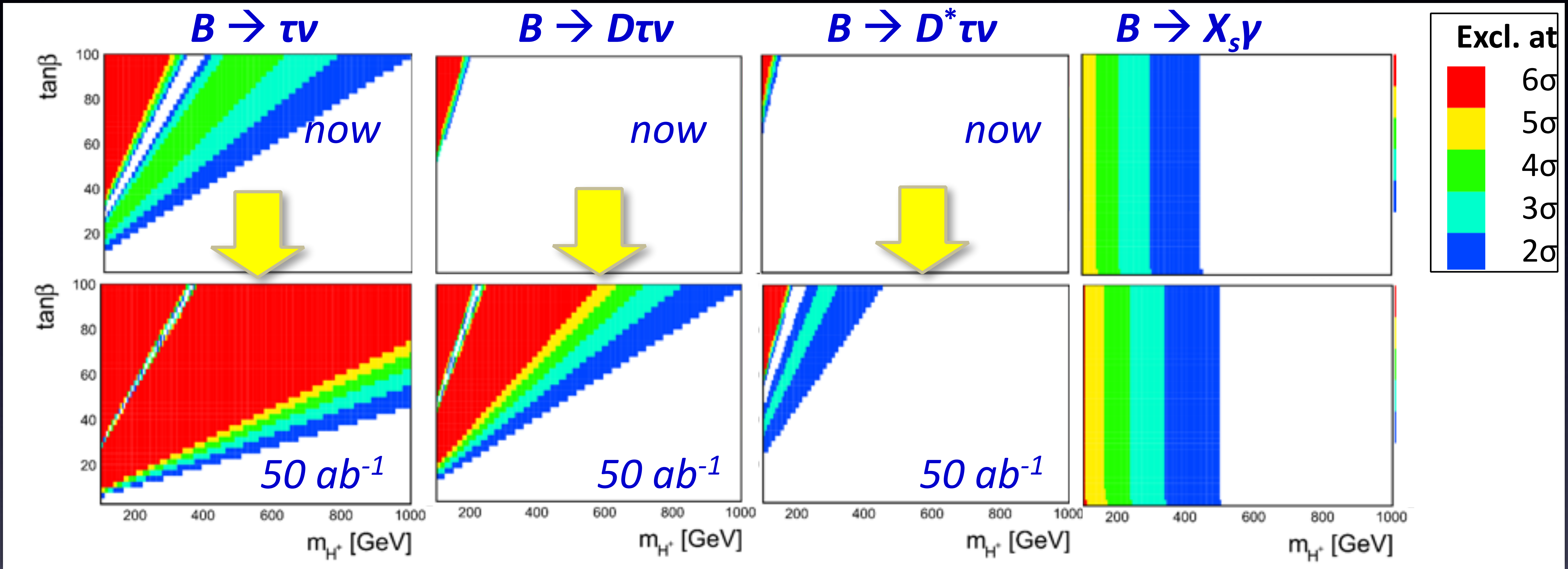




Belle II	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (had. tagged)					
711 fb^{-1}	19.0	(7.1, 2.2)	20.4	2.5	20.5
5 ab^{-1}	7.2	(2.7, 2.2)	7.9	1.5	8.1
50 ab^{-1}	2.3	(0.8, 2.2)	3.2	1.0	3.4
$\lvert V_{ub}\rvert$ $B \to \tau\nu$ (SL tagged)					
605 fb^{-1}	12.4	$(9.0, {}^{+3.0}_{-4.8})$	${}^{+15.6}_{-16.1}$	2.5	${}^{+15.8}_{-16.2}$
5 ab^{-1}	4.3	$(3.1, {}^{+3.0}_{-4.8})$	${}^{+6.1}_{-7.2}$	1.5	${}^{+6.3}_{-7.3}$
50 ab^{-1}	1.4	$(1.0, {}^{+3.0}_{-4.8})$	${}^{+3.4}_{-5.1}$	1.0	${}^{+3.6}_{-5.2}$

Charged Higgs at Belle II

Y. Sato (Nagoya)

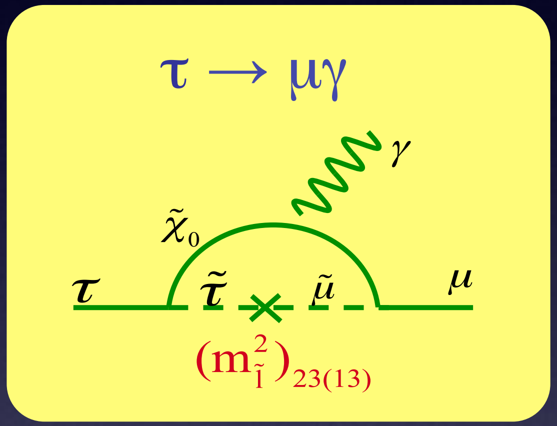


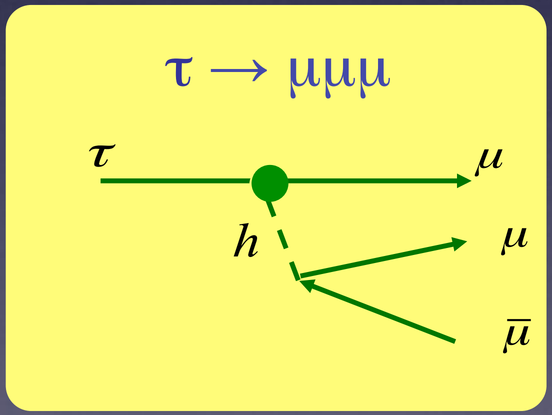
	Exp.			Th.
	Now	*5 ab⁻¹*	*50 ab⁻¹*	*Now*
B → τν	*25%*	*10%*	*3%*	*-7+14%*
B → Dτν	*30%*	*11%*	*4%*	*4%*
*B → D*τν*	*19%*	*7%*	*2%*	*2%*
B → X_sγ	*7%*	*5%*	*4%*	*7%*

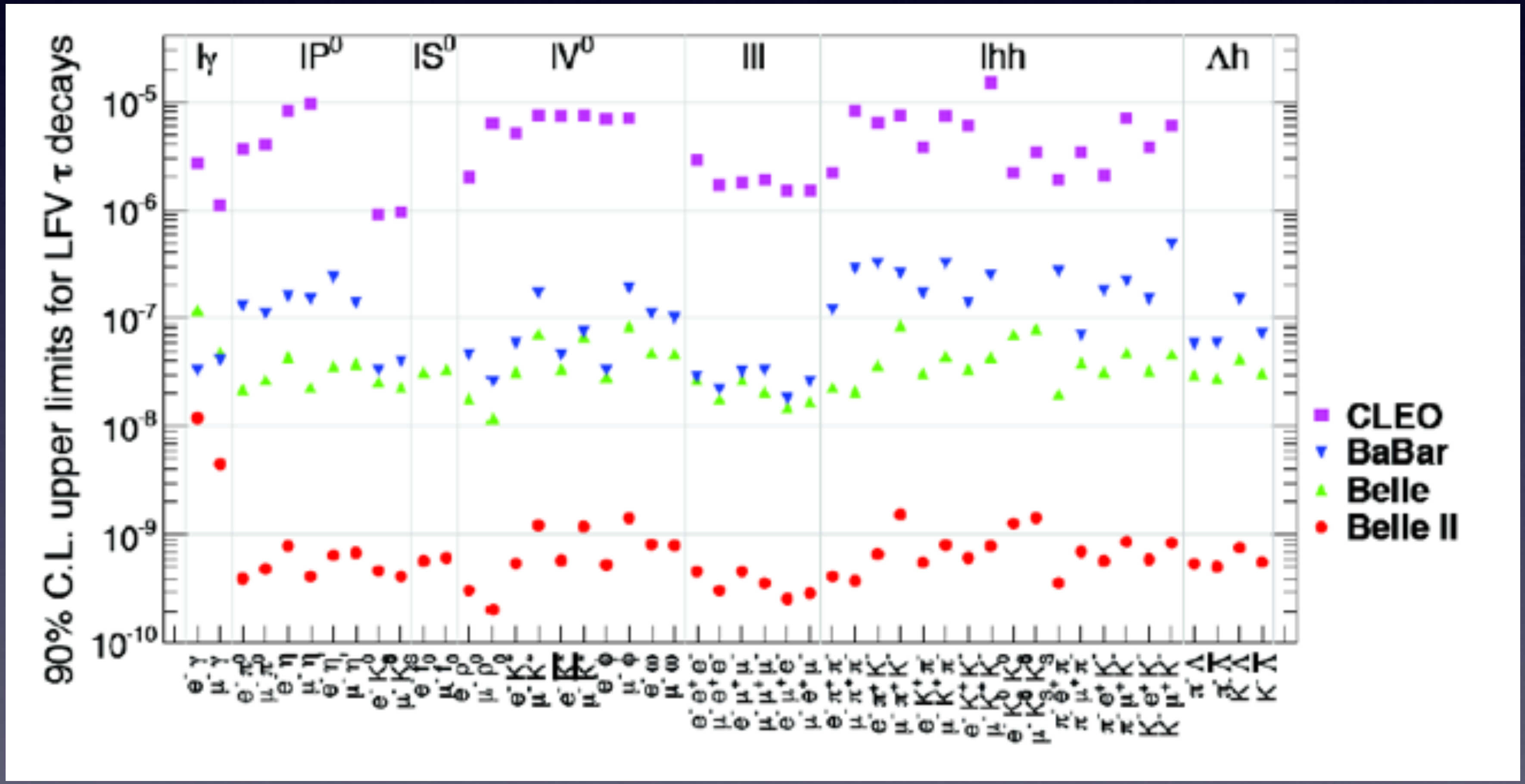
- All experimental inputs are assumed to be SM values.
- Experimental uncertainties are estimated based on Belle II TDR.
- Improvement of theory side is not included except for B → τν.

LFV τ Decays

- SuperKEKB provides also large sample of τ decays ($N_\tau \sim N_B$)
- Lepton-Flavor-Violating decay is an unambiguous NP signal !





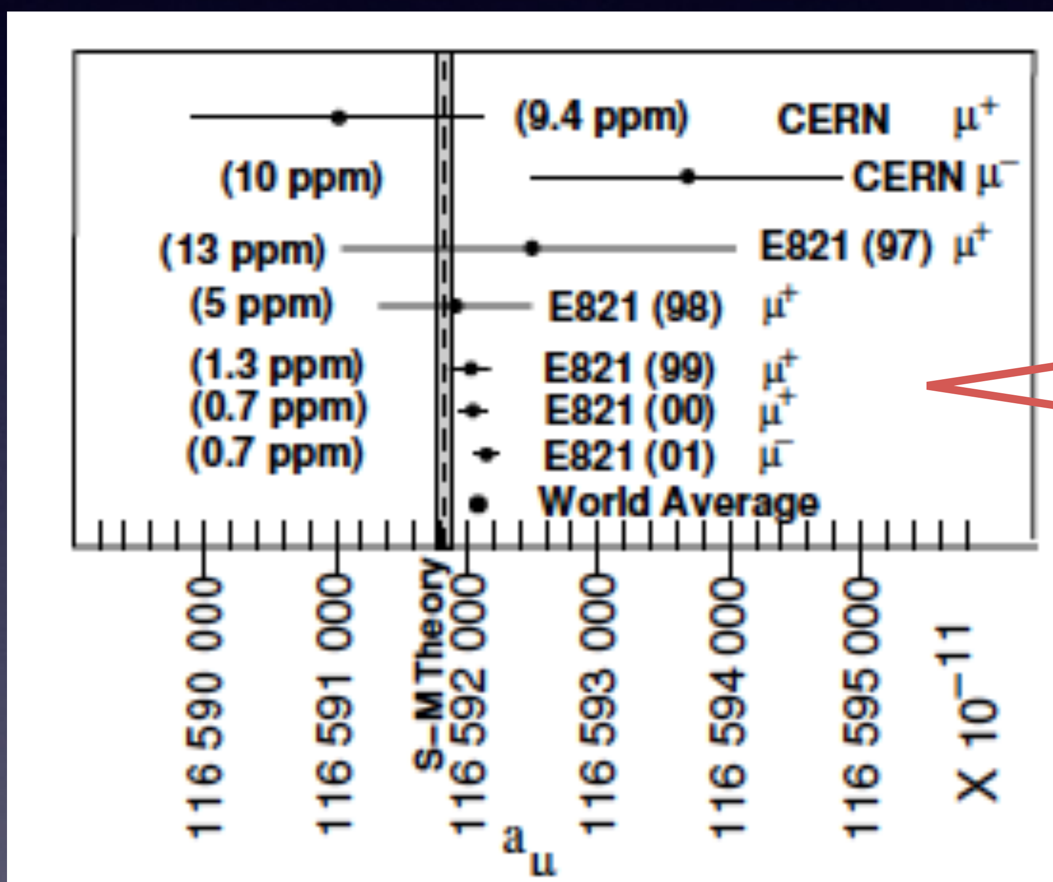


- 48 tau LFV modes have been searched for at B-factories.
- Note: need theorists' help to relate them (other than lγ,lll) to NP

Belle II and $(g-2)_\mu$

- BNL-E821

$$a_\mu^{exp} = 116\ 592\ 089\,(63) \times 10^{-11}$$ 0.54 ppm



3.4 σ diff. from SM pred. ?

T. Blum et al. (1311.2198)

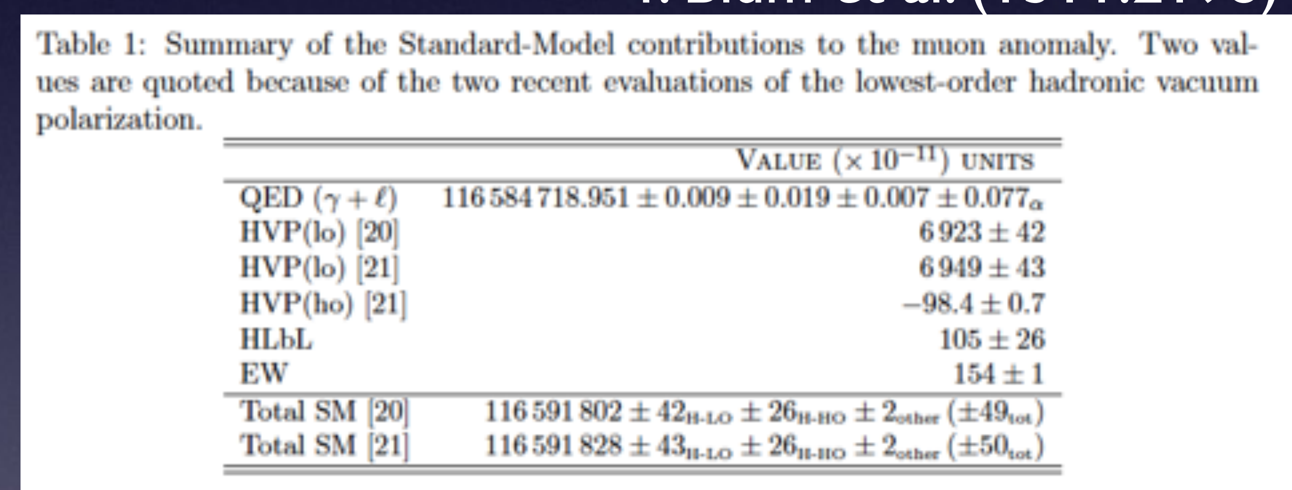


Table 1: Summary of the Standard-Model contributions to the muon anomaly. Two values are quoted because of the two recent evaluations of the lowest-order hadronic vacuum polarization.

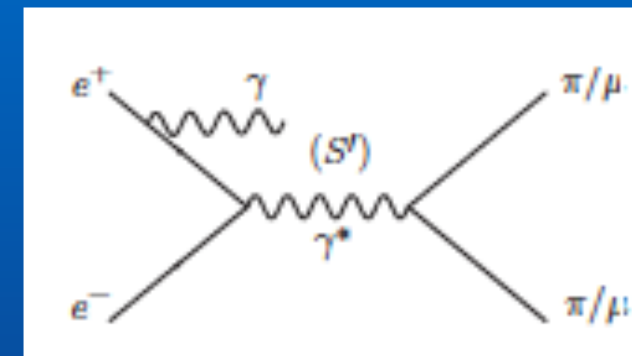
	VALUE ($\times 10^{-11}$) UNITS
QED ($\gamma + \ell$)	$116\,584\,718.951 \pm 0.009 \pm 0.019 \pm 0.007 \pm 0.077_\alpha$
HVP(lo) [20]	$6\,923 \pm 42$
HVP(lo) [21]	$6\,949 \pm 43$
HVP(ho) [21]	-98.4 ± 0.7
HLbL	105 ± 26
EW	154 ± 1
Total SM [20]	$116\,591\,802 \pm 42_{\text{H-LO}} \pm 26_{\text{H-HO}} \pm 2_{\text{other}}\ (\pm 49_{\text{tot}})$
Total SM [21]	$116\,591\,828 \pm 43_{\text{H-LO}} \pm 26_{\text{H-HO}} \pm 2_{\text{other}}\ (\pm 50_{\text{tot}})$

[20] Davier et al. (2011)
[21] Hagiwara et al. (2011)

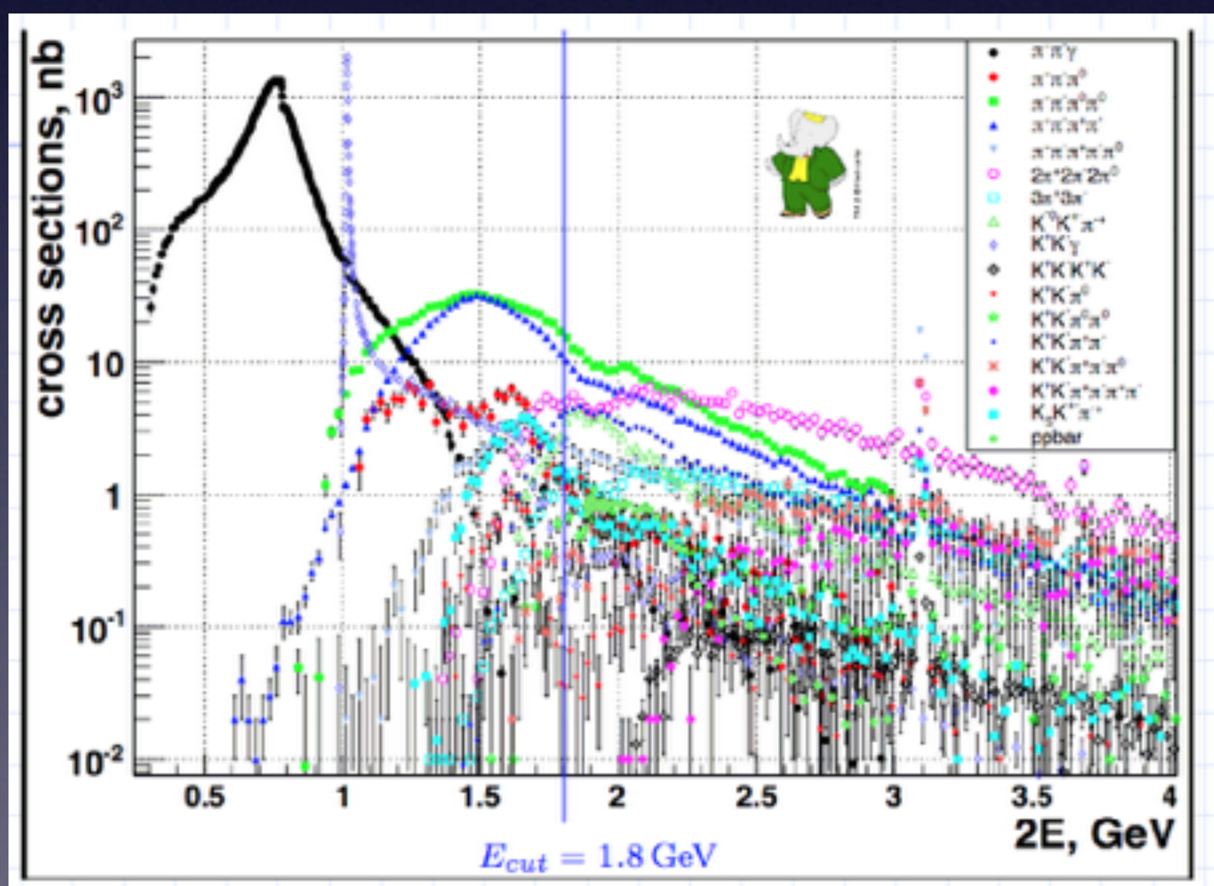
New experiments at J-PARC and Fermilab is aiming at 0.1ppm precision, → requires reducing also the error for hadronic vacuum polarization effects.

Measurement w/ ISR

- BaBar, Frascati (KLOE/KLOE-2), BES III
  - ✓ Pros : Better control of systematic errors (within a single experiment)
  - ✓ Cons : Reduced statistics (1/α reduction)
  - ✓ Overcome by large luminosity at Belle II.



$$s' = s(1 - 2E^*_\gamma/\sqrt{s}\,)$$



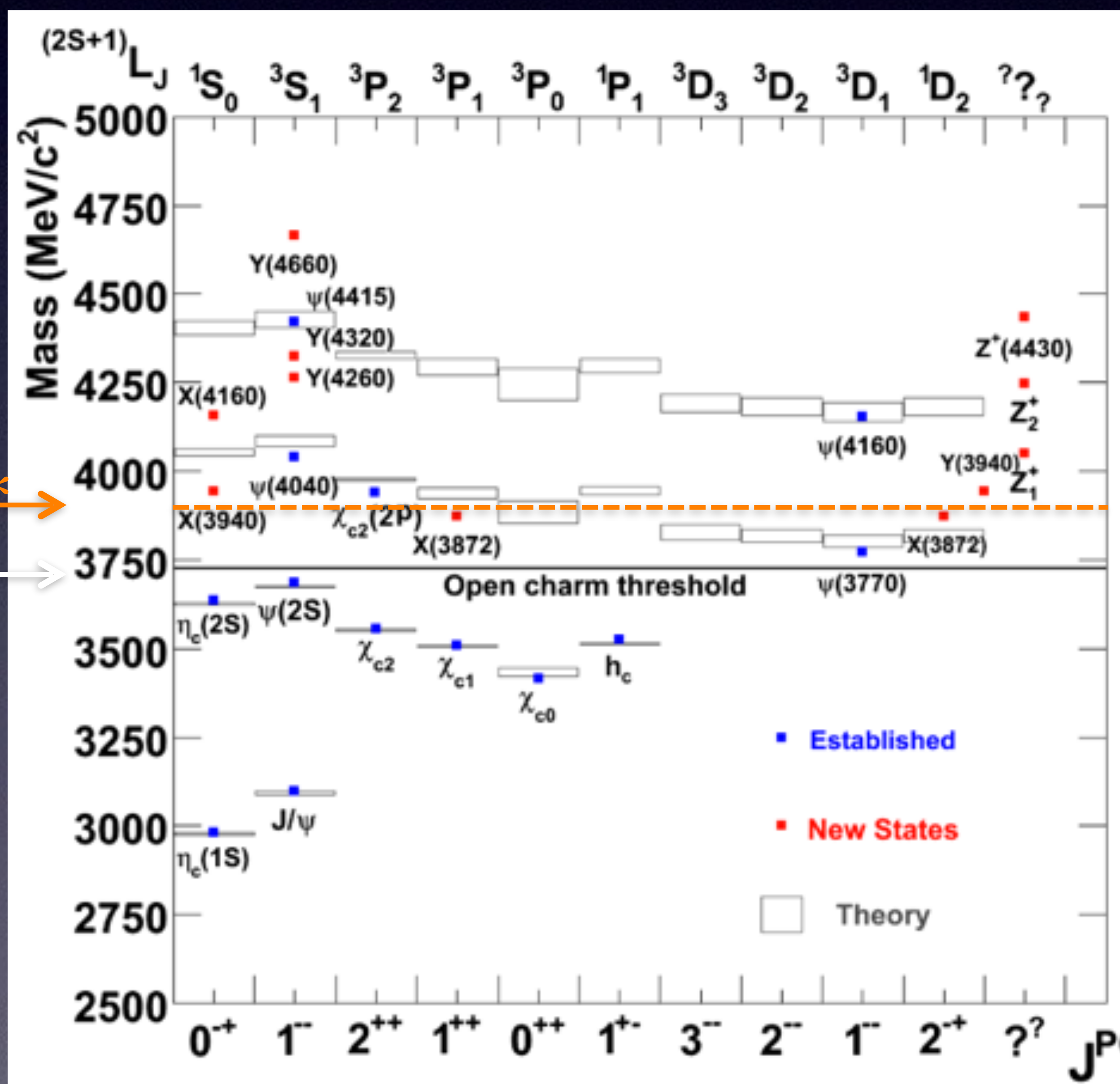
- Belle could not measure $\pi^+\pi^-$ due to trigger problems unfortunately.
- Result for $\pi^+\pi^-\pi^0$ available.

Belle II provides useful inputs to $(g\text{-}2)_\mu$ prediction

Hadron Spectroscopy

- Many charmonium-like and also bottomonium-like hadrons are observed.
- Many of them do not fit to the mass spectra predicted by the quark model.

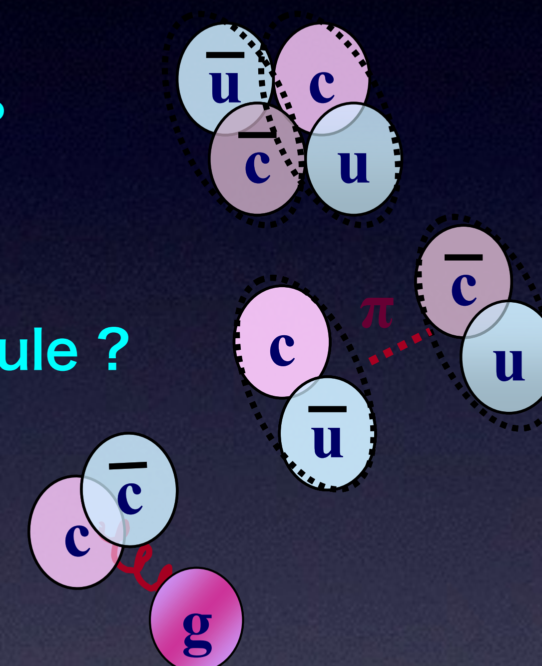
$D\bar{D}^*$ →
$D\bar{D}$ →



Tetraquark ?

$D^{(*)}D^{(*)}$ Molecule ?

Hybrid ?



Can lattice QCD explain these states ?

e.g, Sasa Prelovsek, Luka Leskovec
arXiv:1307.5172,
Talk by Sasa Prelovsek @ Lattice2014

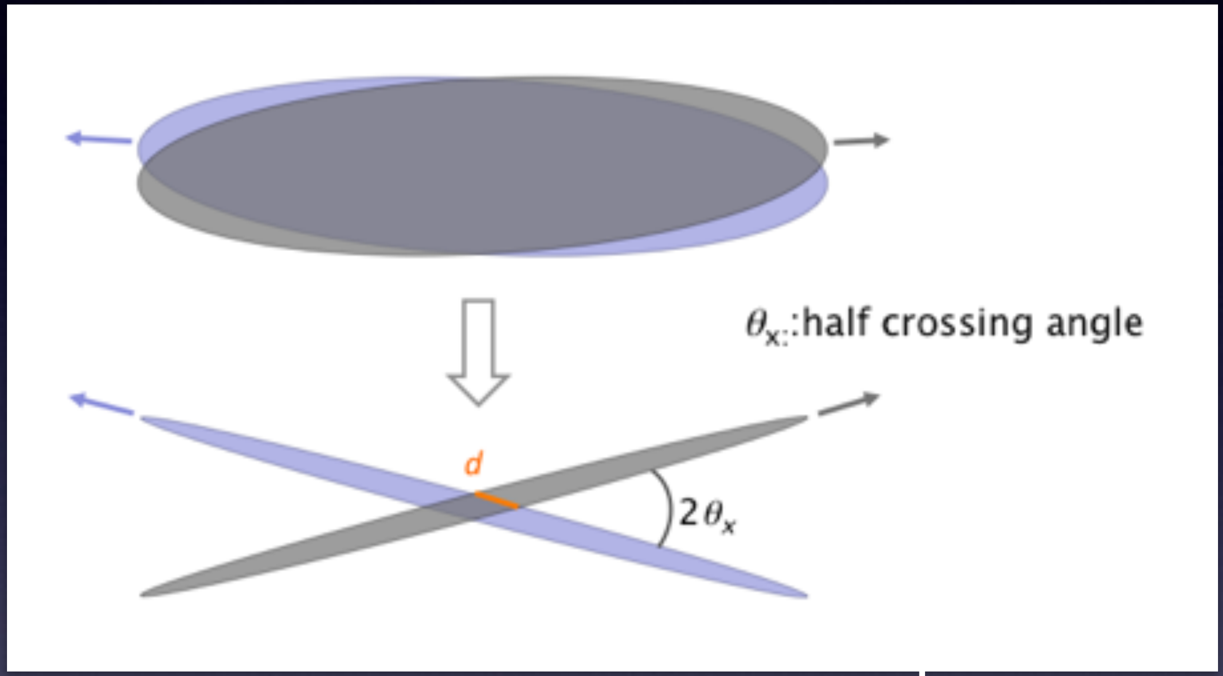
SuperKEKB Accelerator

- **Low emittance ("nano-beam") scheme employed**

proposed by P.Raimondi

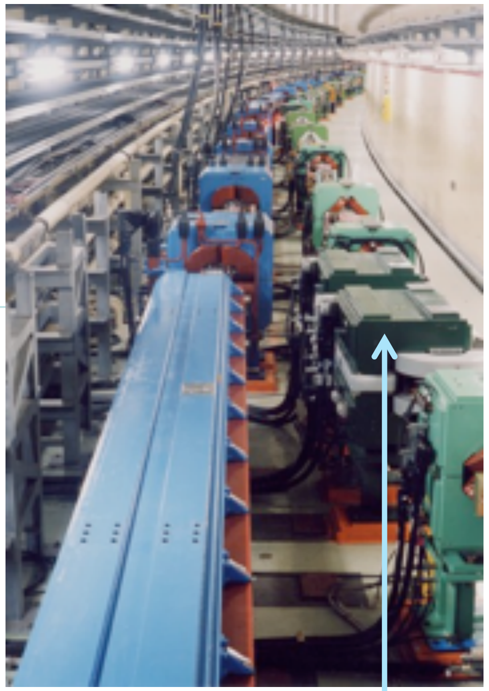
Machine parameters

	SuperKEKB LER/HER	KEKB LER/HER
E(GeV)	4.0/7.0	3.5/8.0
ε_x (nm)	3.2/4.6	18/24
β_y at IP(mm)	0.27/0.30	5.9/5.9
β_x at IP(mm)	32/25	120/120
Half crossing angle(mrad)	41.5	11
I(A)	3.6/2.6	1.6/1.2
Lifetime	~10min	130min/ 200min
L($cm^{-2}s^{-1}$)	80×10^{34}	2.1×10^{34}

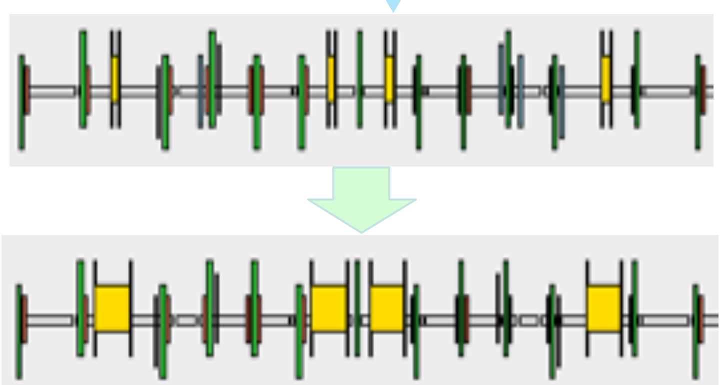


Beam at IP will be squeezed by 1/20.

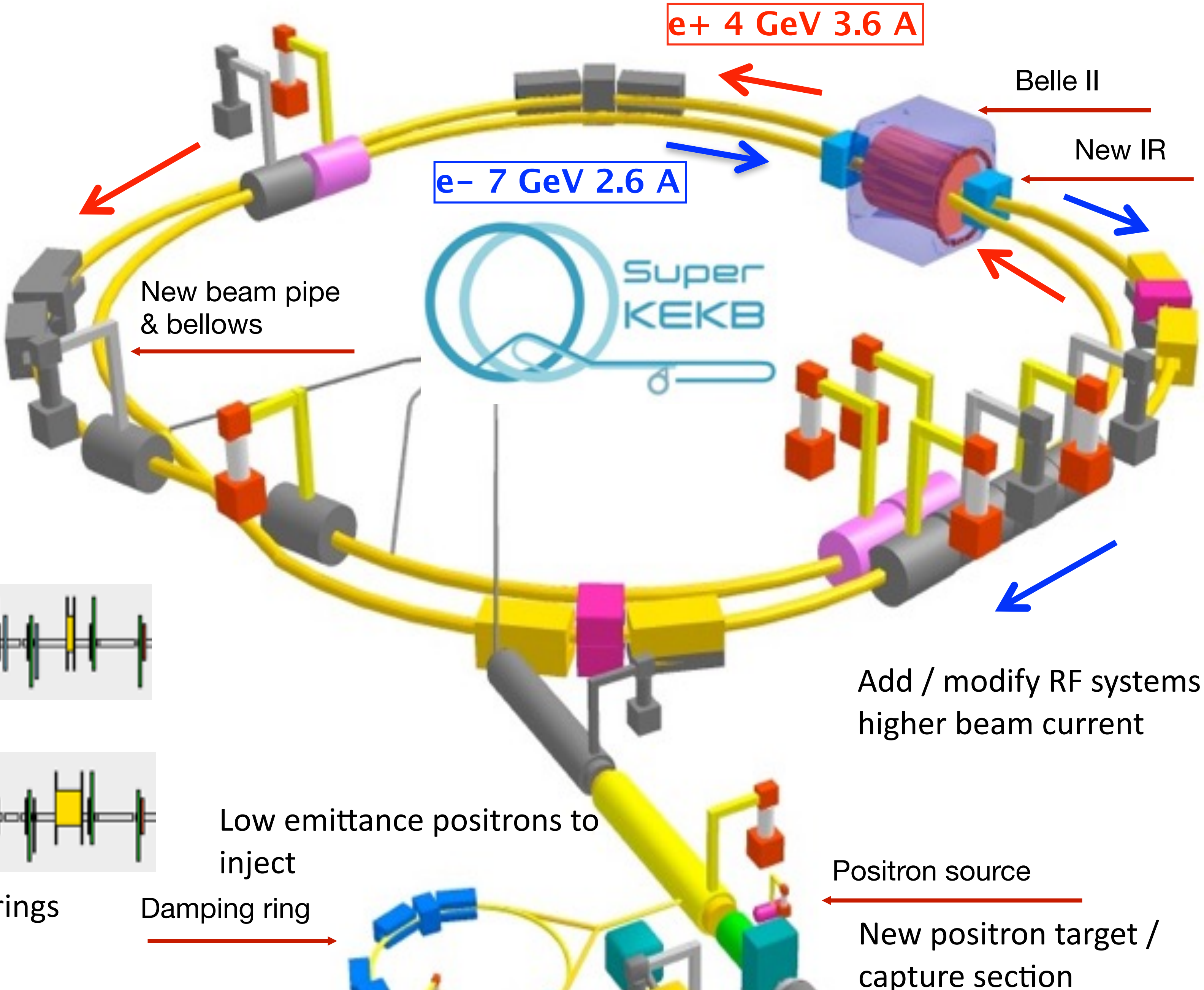
Beam currents will be doubled.

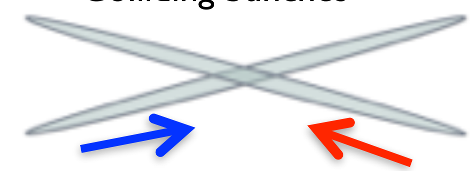


Replace short dipoles with longer ones (LER)

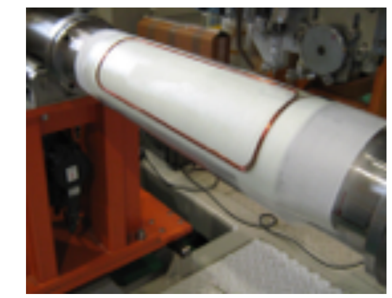


Redesign the lattices of both rings to reduce the emittance





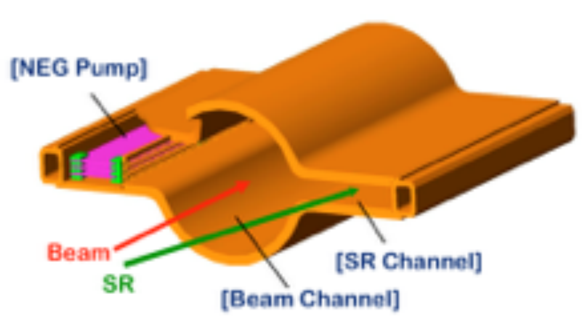
New superconducting final focusing quads near the IP

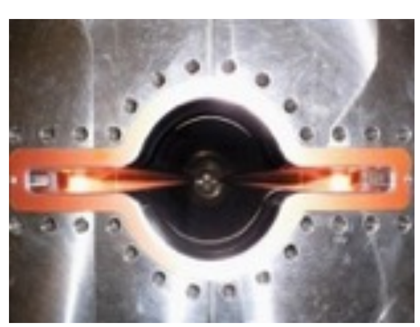


Add / modify RF systems for higher beam current

New positron target / capture section

TiN-coated beam pipe with antechambers in LER



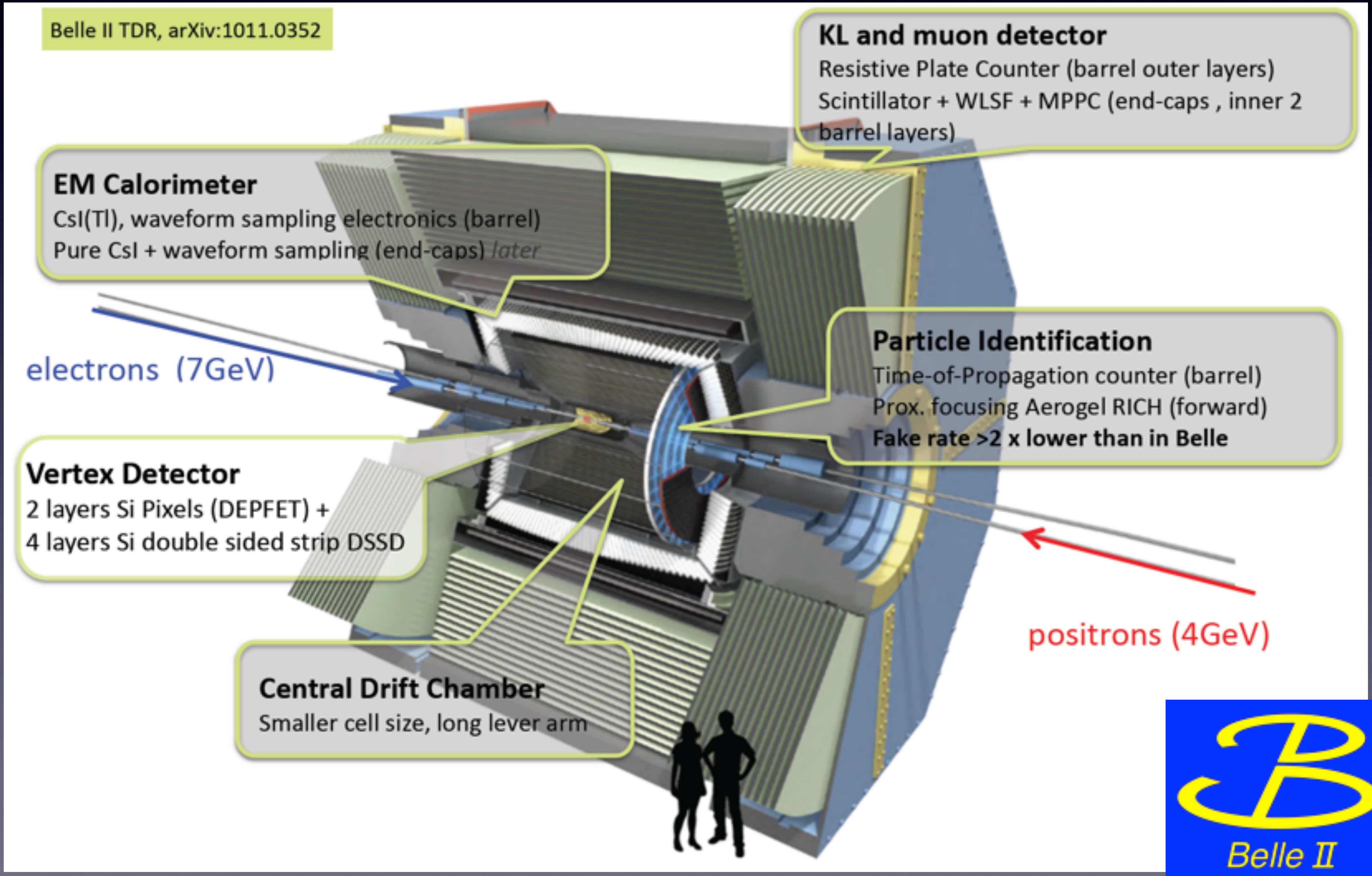


$$L = \frac{\gamma_\pm}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

x 40 Gain in Luminosity

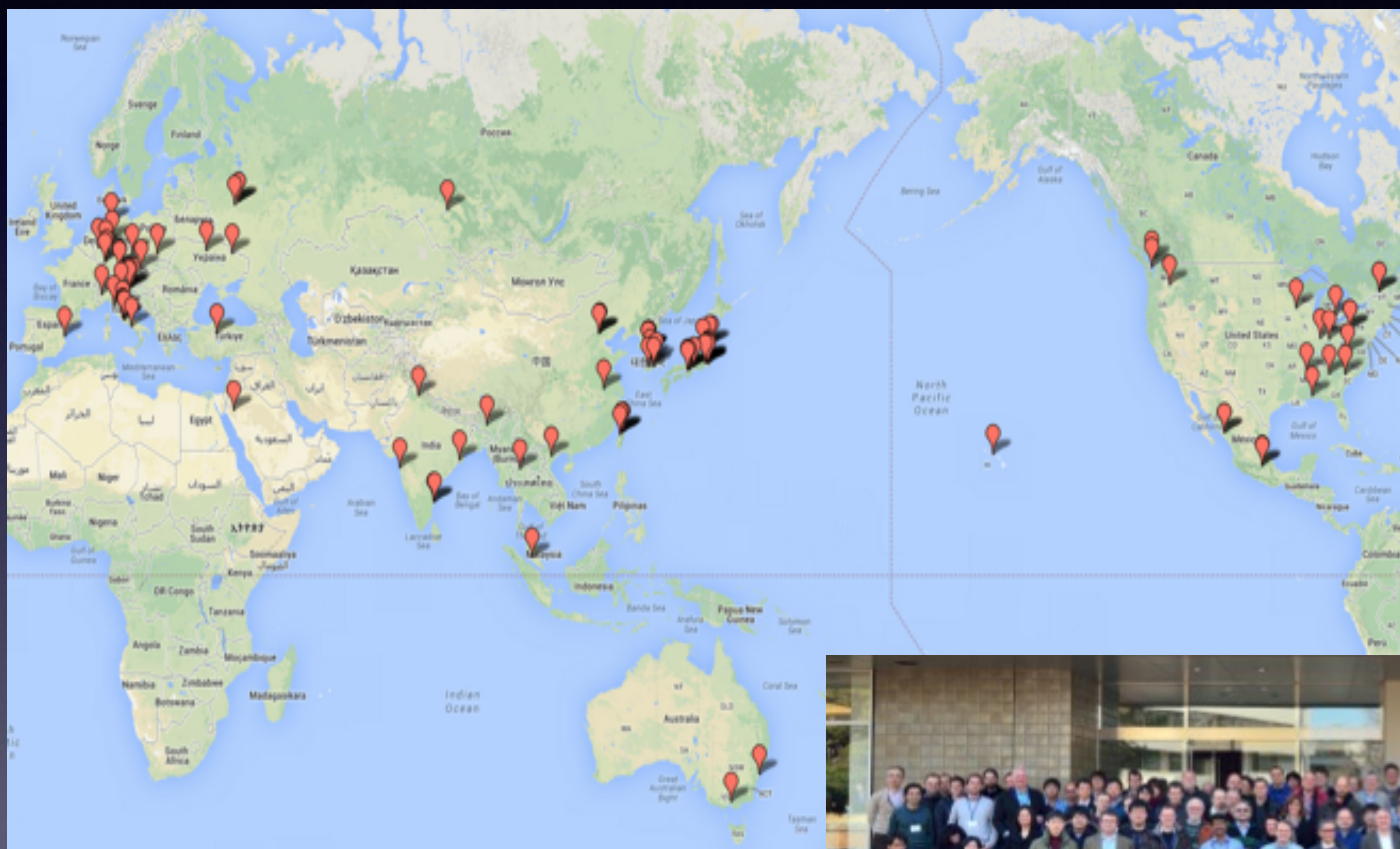
Belle II Detector

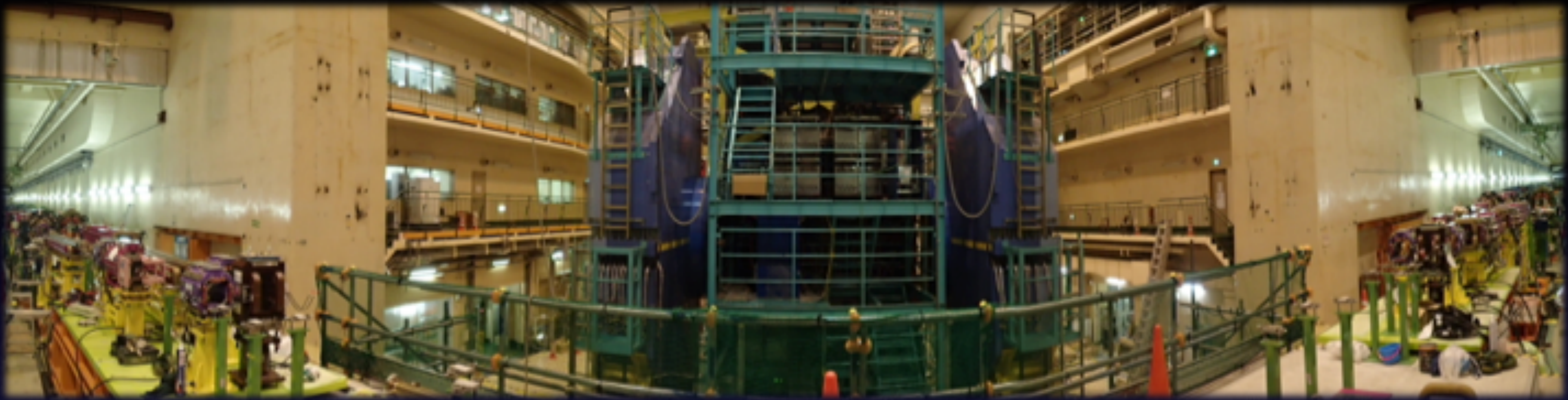
- Deal with higher background (10-20×), radiation damage, higher occupancy, higher event rates (L1 trigg. 0.5→30 kHz)
- Improved performance and hermeticity

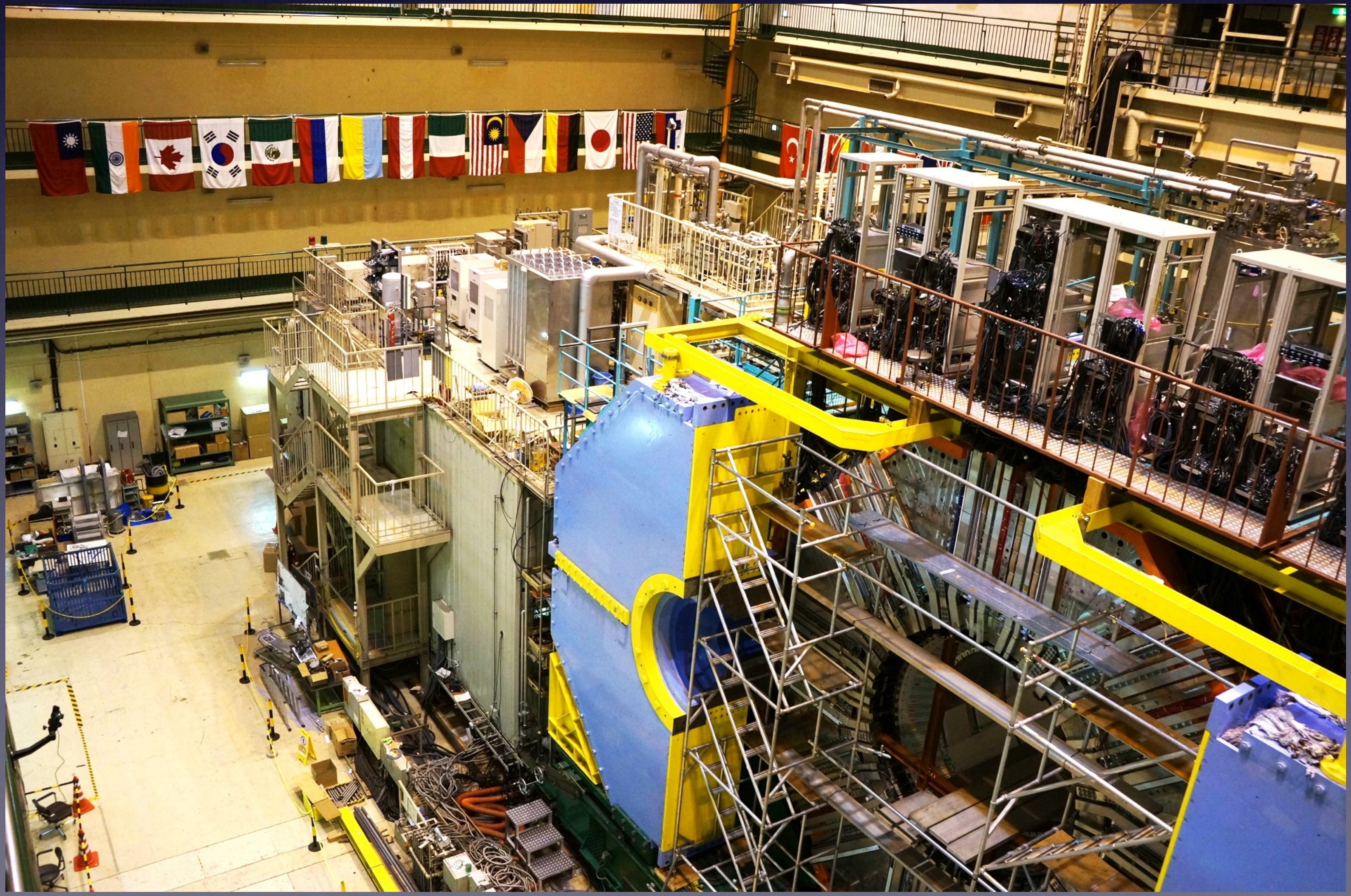


Belle II Collaboration

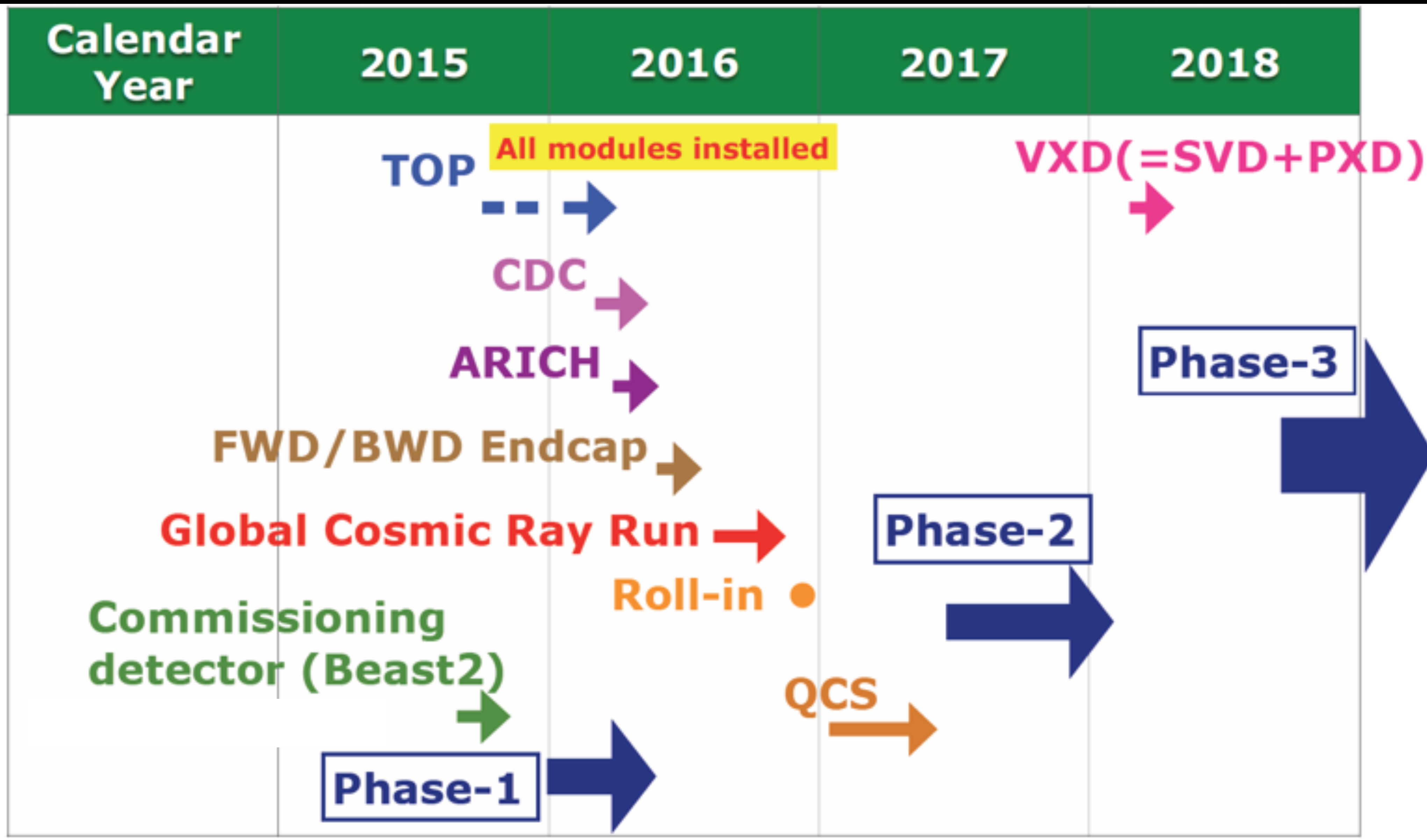
- 23 countries, 99 institutes, 600+ collaborators.







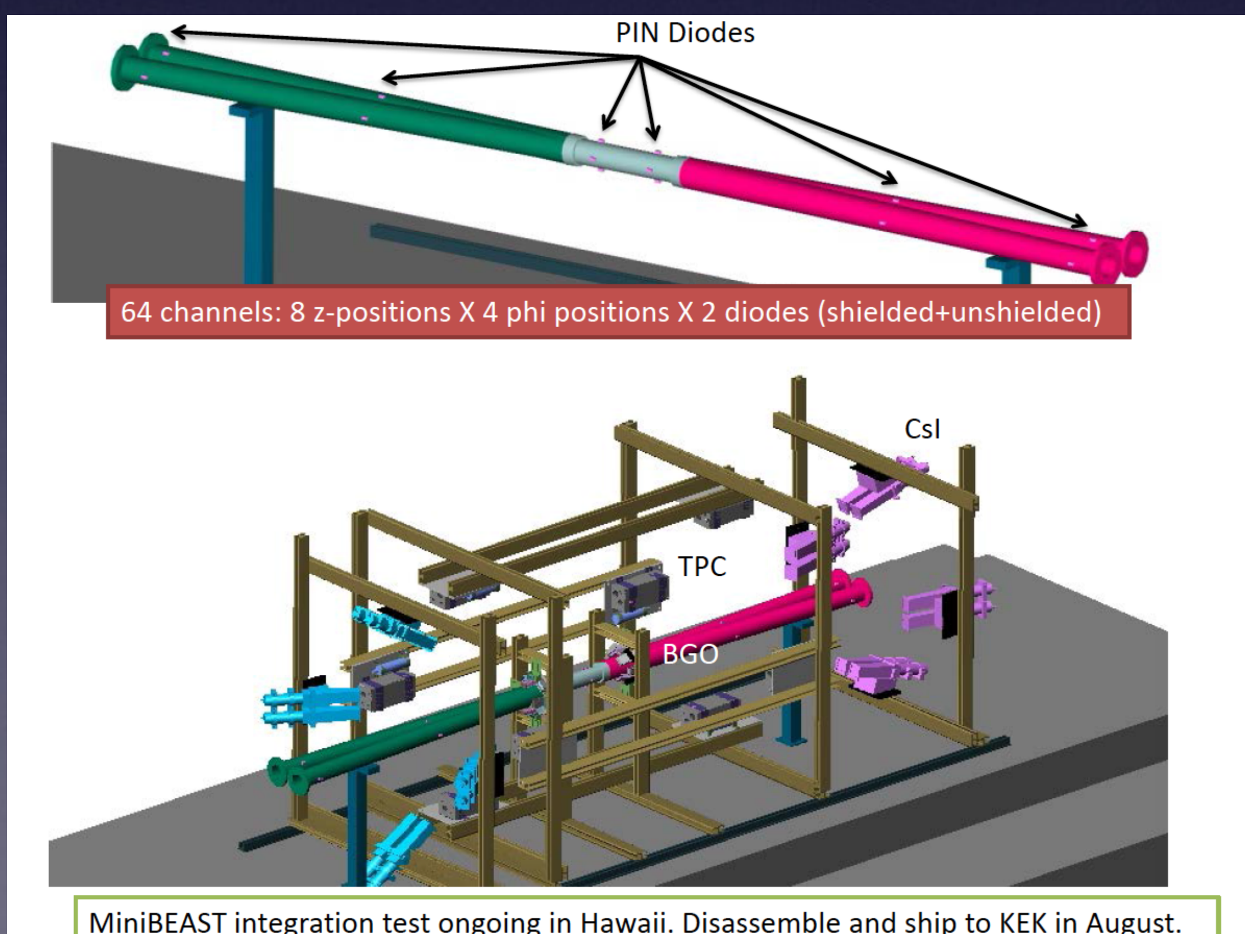
Construction & Commissioning Schedule

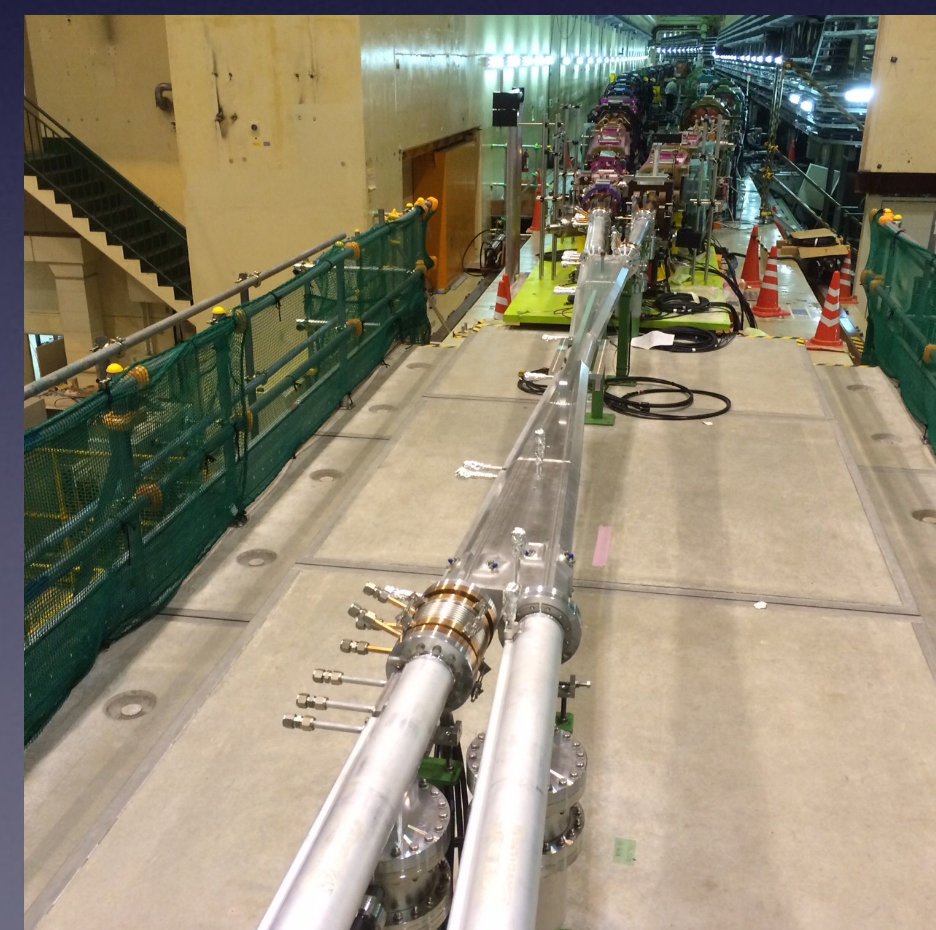


BEAST phase 1	2016	BEAST/SuperKEKB & cosmics
BEAST phase 2	Mid 2017- Early 2018	BEAST with Partial Belle II
Full physics	Oct 2018-	Full detector

BEAST Phase 1

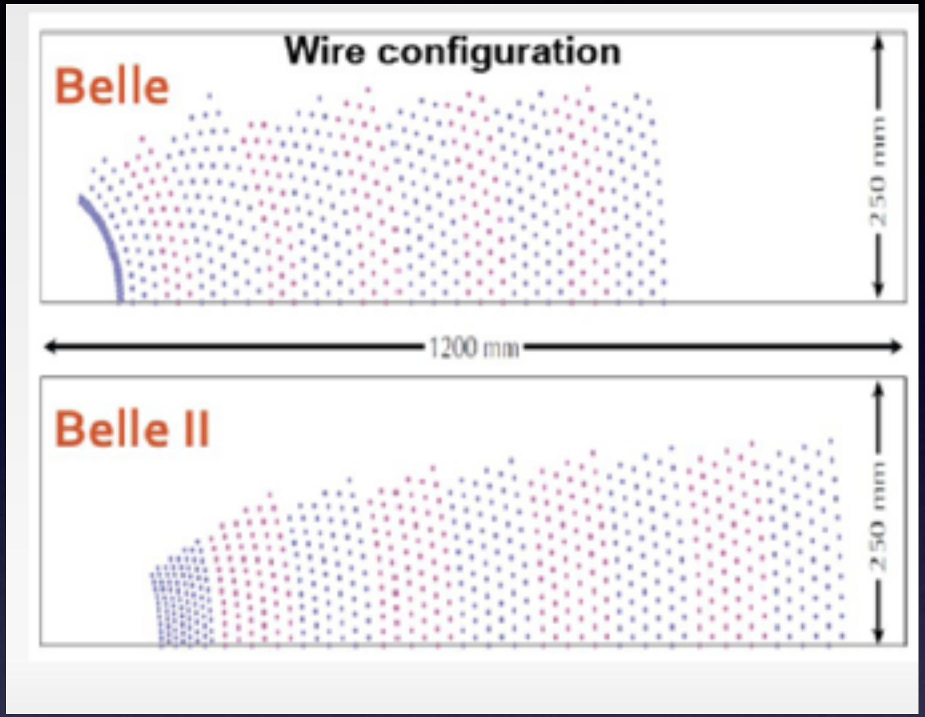
- During Phase 1 and 2 a commissioning detector will be used to measure beam backgrounds.
- BEAST Phase 1 starts in January 2016.
- IR beam pipe has been installed
- BEAST detectors are being installed.



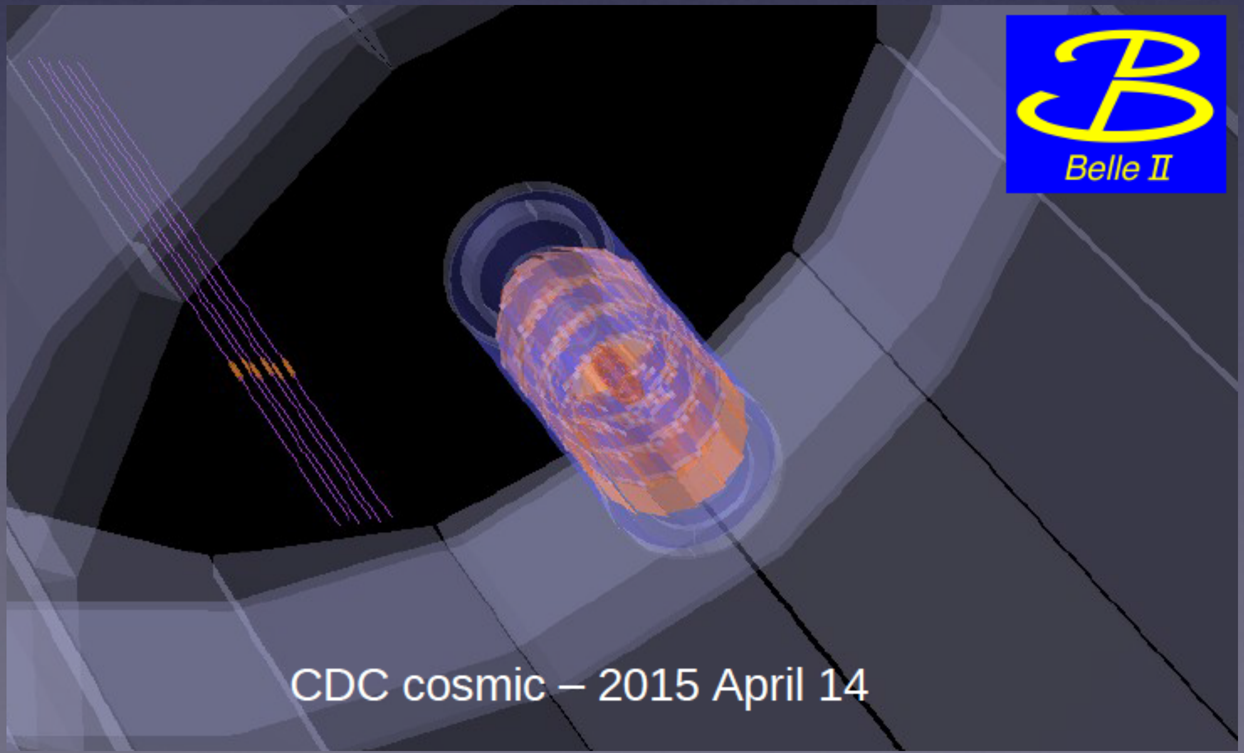


Central Drift Chamber

- Belle II CDC is larger than Belle CDC.
- CDC construction has been done !
- Commissioning with cosmic rays in progress.

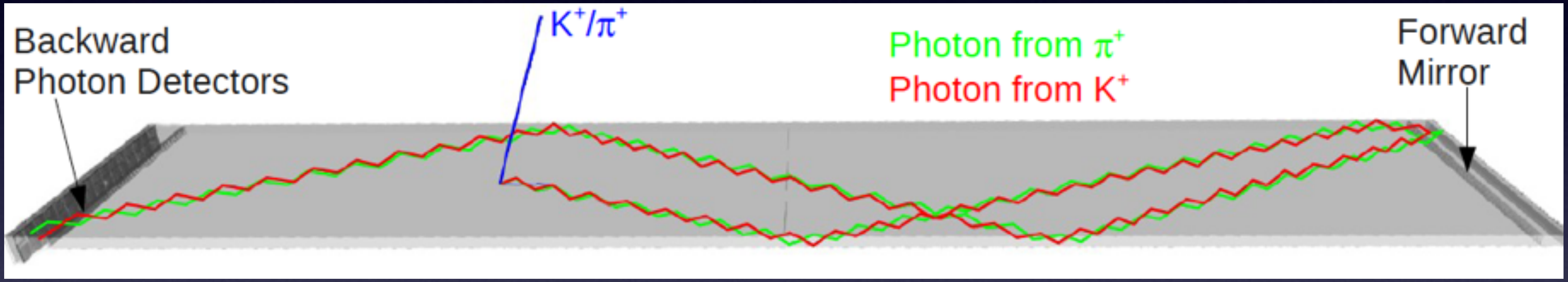


$\sigma_p/p \sim 0.3\% + 0.1\% \times p(\mathrm{GeV})$ in $B = 1.5\mathrm{T}$
$\sigma(\mathrm{d}E/\mathrm{d}x) \sim 6\%$

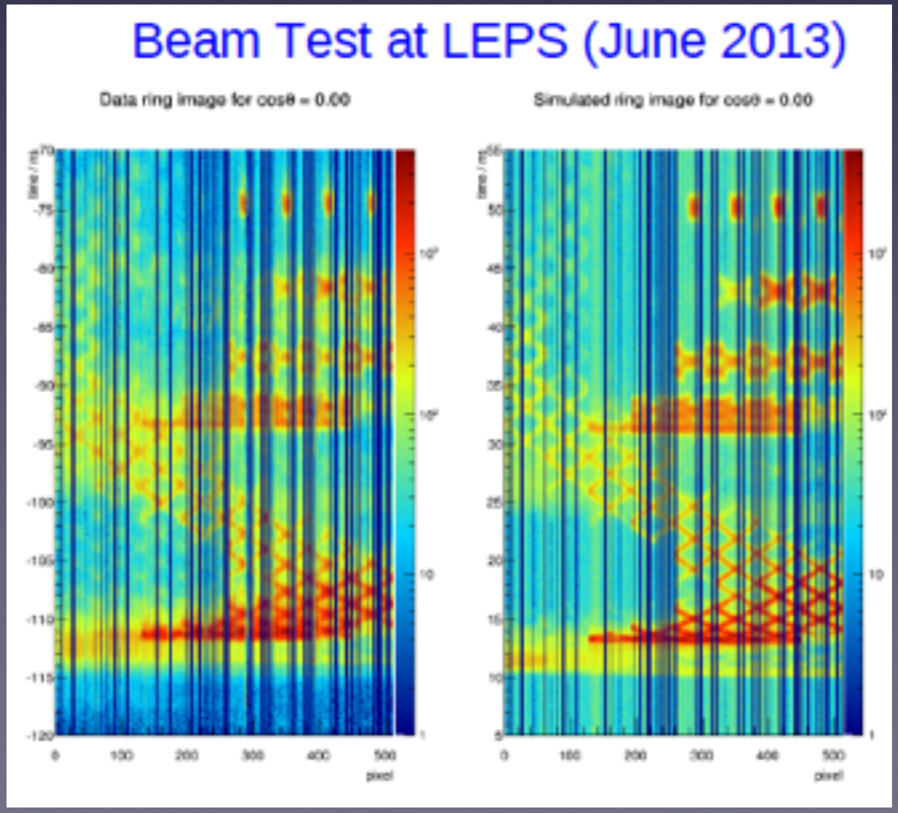


TOP Counter (PID)

- Time-Of-Propagation (TOP) technique: precision timing of internally reflected Cherenkov photons produced in accurately polished quartz radiator (~50ps/photon).

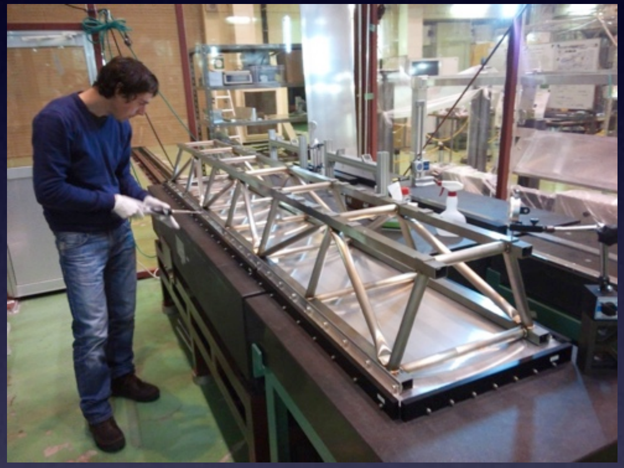


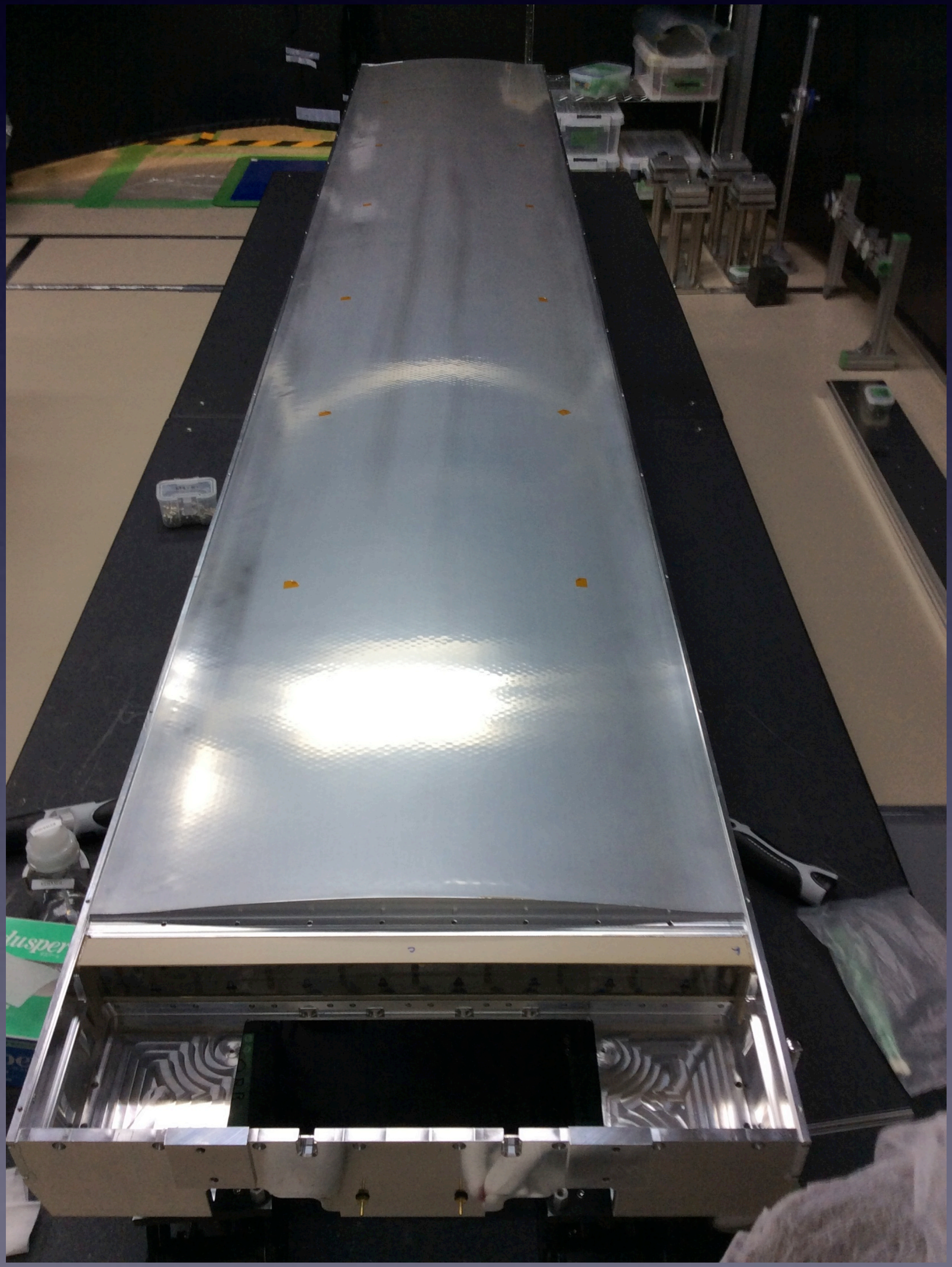
- Key technologies;
  - MCP-PMT and electronics to detect single photon with ~ 50ps resolution.
  - Accurately polished quartz optics, and mechanics.
- Performance has been demonstrated with a beam test at Spring-8.

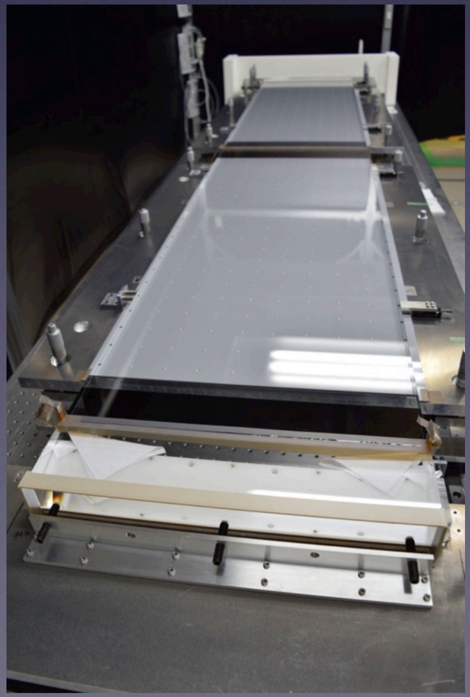


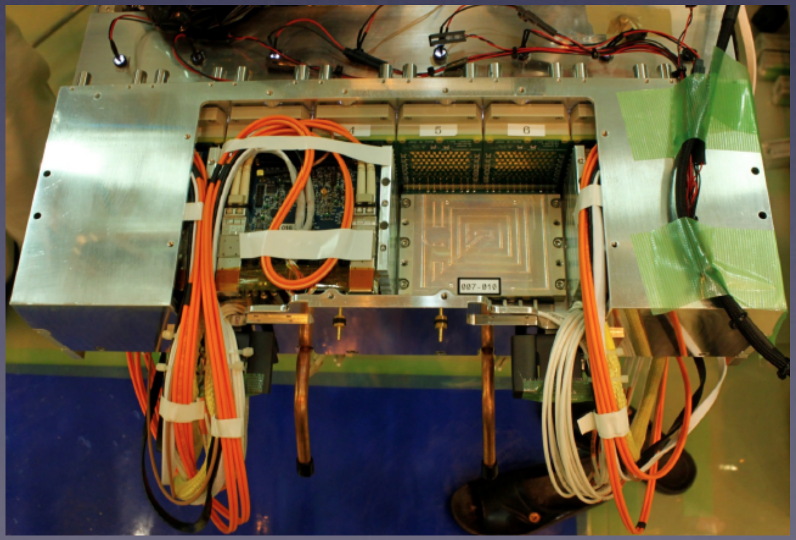
TOP Counter Production

TOP counter module production in progress to complete by April 2016.



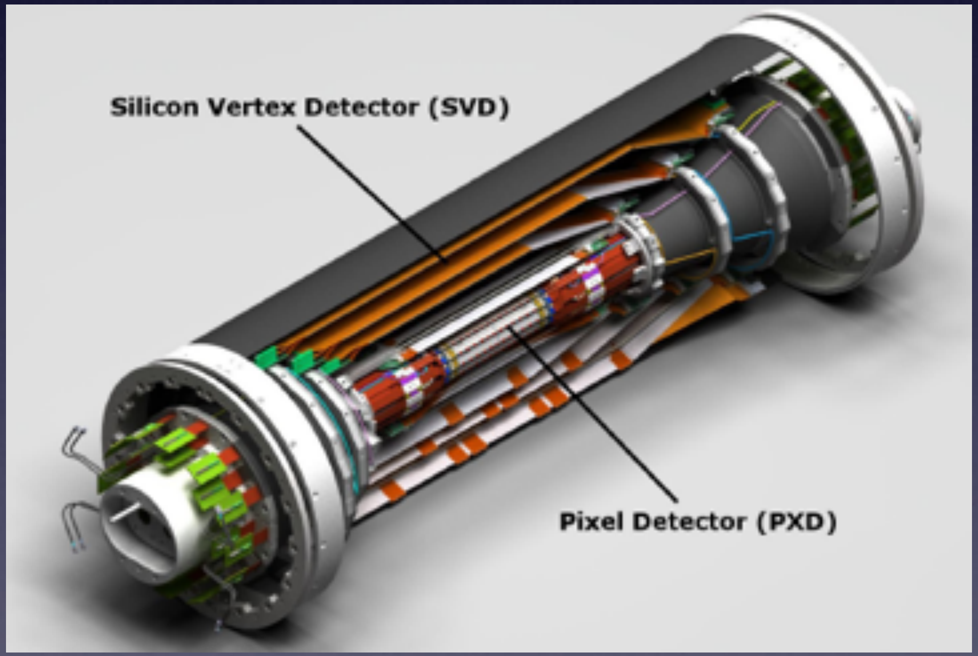


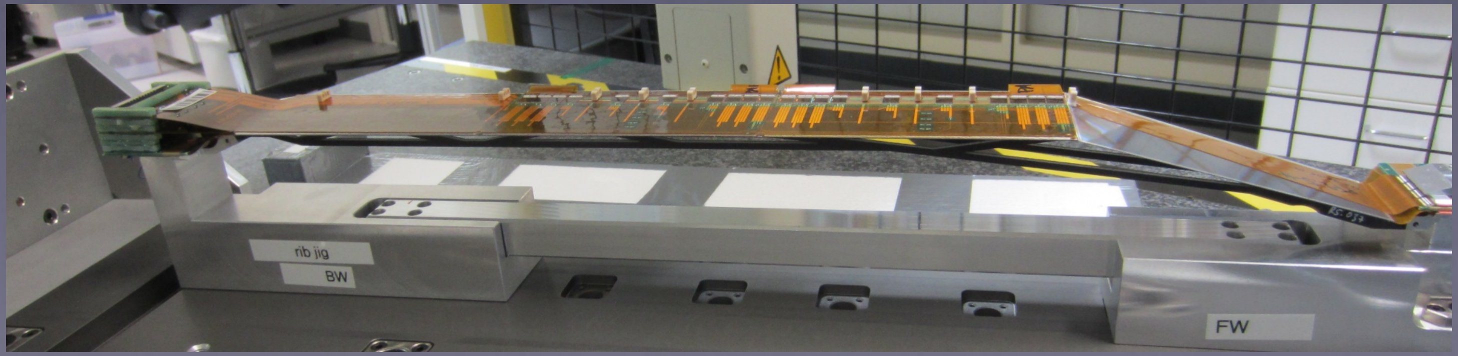




Vertex Detector

- New vertex detectors:
  - ✓ 2-layer pixel detector based on DEPFET (Depleted P-chennel Field Effect Transistor) technology.
  - ✓ 4-layer DSSD (Double Sided Silicon Detector).
- Beam pipe radius reduced to 1cm from 2cm → 1.5cm for Belle





March 23, 2015
First electrically working
DSSD ladder completed

Summary

- The Belle II experiment at SuperKEKB aims to find NP with ultimate precision measurement (a few %, typically) of heavy flavor decays (O(10^{10}) samples / year).
- Lattice QCD provides crucial inputs to extract physics.
  - ✓ Need precise enough calculations timely !
- We will start
  - ✓ Commissioning of SuperKEKB in 2015.
  - ✓ Belle II physics run in 2017 w/o vertex, and in 2018 w/

Let's Keep in Touch !

My Cards

exactly match to my research history

Master thesis
A-dependence of
$K^- + {}^{\backprime}p{}^{\prime} \rightarrow K^+ \; {}^{\backprime}\Xi{}^{\prime}$
at KEK-E176

Doctor thesis
H-dibaryon search
at BNL-E813/836

Present research
b-quark
physics at Belle/
Belle II

Wish values of these cards become higher and higher !

My 4th card

May indicate the subject of my next research
What is it ?

えっ？

Hmm…

My 4th card

May indicate the subject of my next research
What is it ?

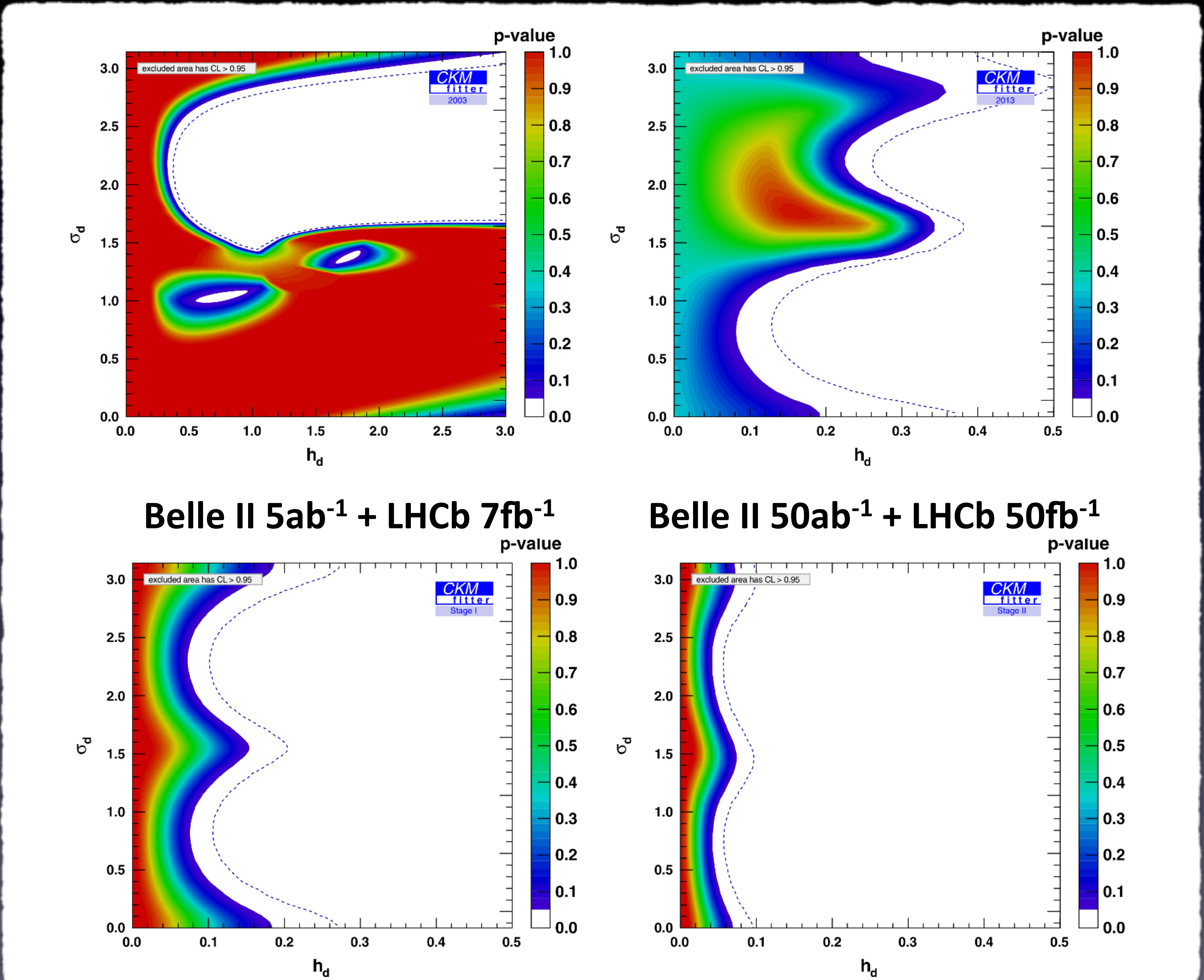
Yeah !

Hopefully, it is something new !

Backup

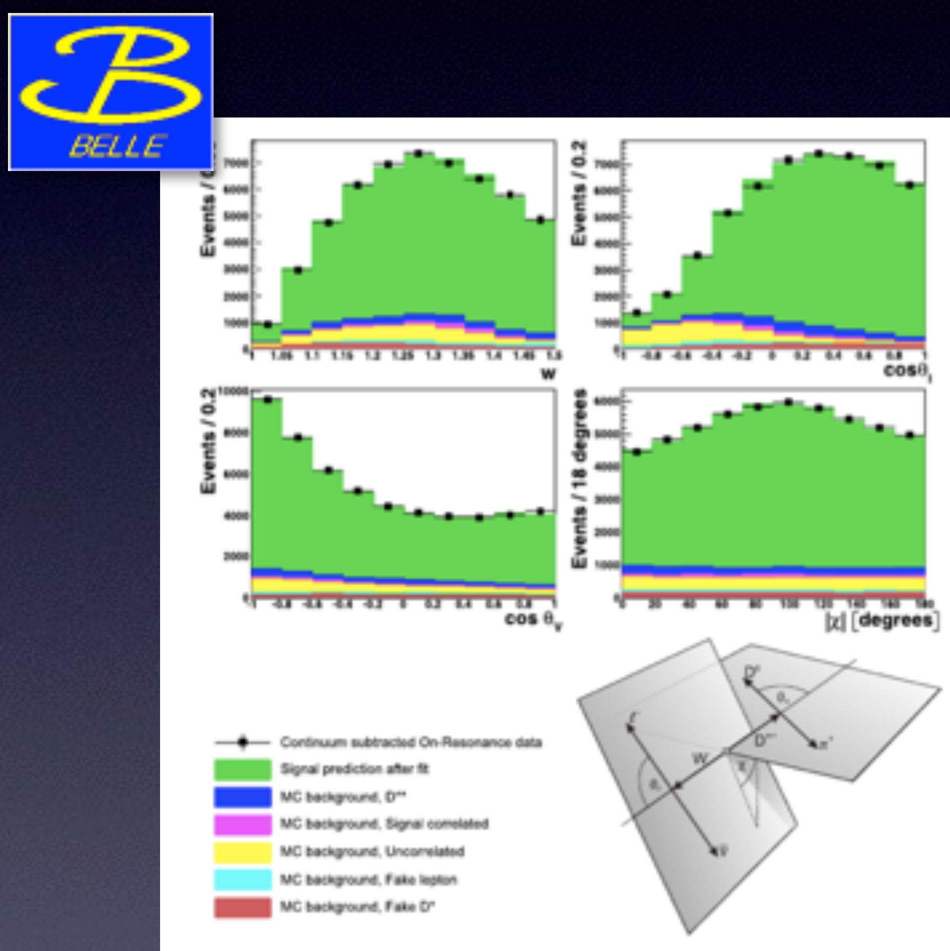
$$M_{12}^{d,s} = (M_{12}^{d,s})_{\mathrm{SM}} \times (1 + h_{d,s} e^{2i\sigma_{d,s}})$$

Relative amplitude phase



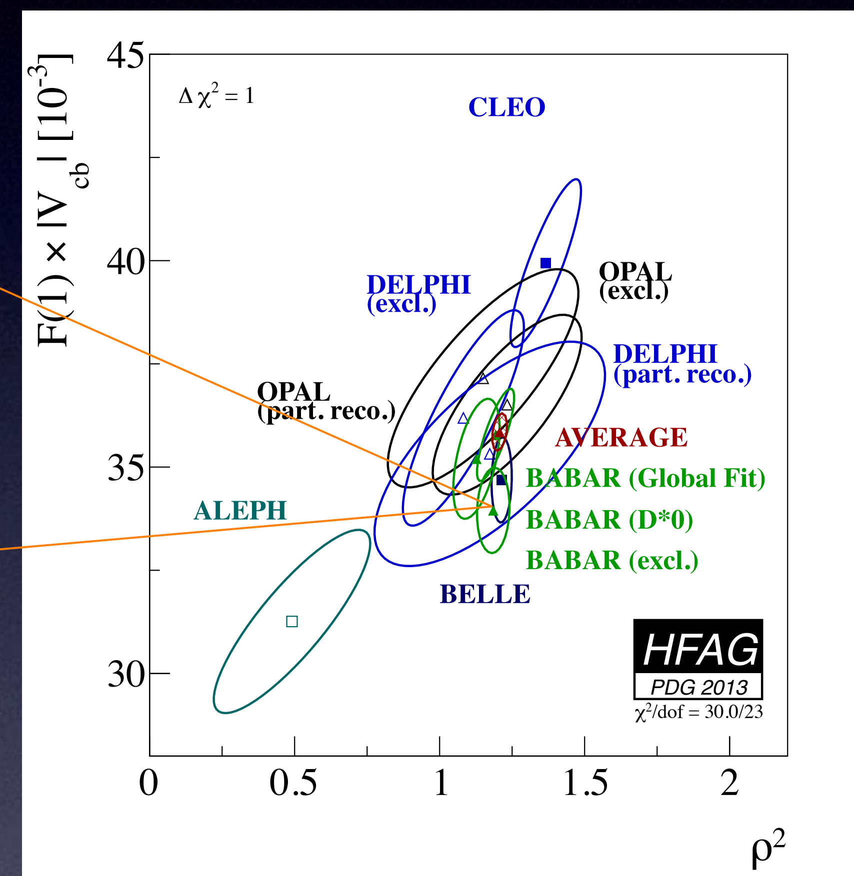
$|V_{cb}|$ at present

- Exclusive $|V_{cb}|$ (relevant to lattice QCD) comes mainly from $B^0 \to D^{*-} l^+ \nu$.
- Precision at the level of ~2%, but slight difference from inclusive (~2σ).



$\mathcal{F}(1)\|V_{cb}\|$	=	$(34.6 \pm 0.2 \pm 1.0) \times 10^{-3}$
ρ^2	=	$1.214 \pm 0.034 \pm 0.009$
$R_1(1)$	=	$1.401 \pm 0.034 \pm 0.018$
$R_2(1)$	=	$0.864 \pm 0.024 \pm 0.008$
χ^2/ndf	=	$138.8/155$

W. Dungel et al. PRD 82, 112007 (2010)



$|V_{cb}|_{excl} = (39.04 +/- 0.49_{exp} +/- 0.53_{QCD} +/- 0.19_{QED}) \times 10^{-3}$

F(1) = 0.906 (4) (12) [arXiv:1403.0635]

$|V_{cb}|_{incl} = (41.88 +/- 0.73) \times 10^{-3}$

arXiv:1207.1158

$|V_{cb}|$ Prospect at Belle II

- Tagged measurement of $B \to D^* l\nu$ and $B \to Dl\nu$ will yield $|V_{cb}|$ with a similar level of precision.

→ Require good prediction for **F(w) and G(w)**

- Improvement in inclusive $|V_{cb}|$ will be far modest.

Expected relative uncertainty in $|V_{cb}|$ from $B \to D^* l\nu$

	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{cb}\rvert$ exclusive					
711 fb^{-1}	0.6	(2.8, 1.1)	3.1	1.8	3.6
5 ab^{-1}	0.2	(1.1, 1.1)	1.5	1.5	2.2
50 ab^{-1}	0.1	(0.3, 1.1)	1.2	1.0	1.5

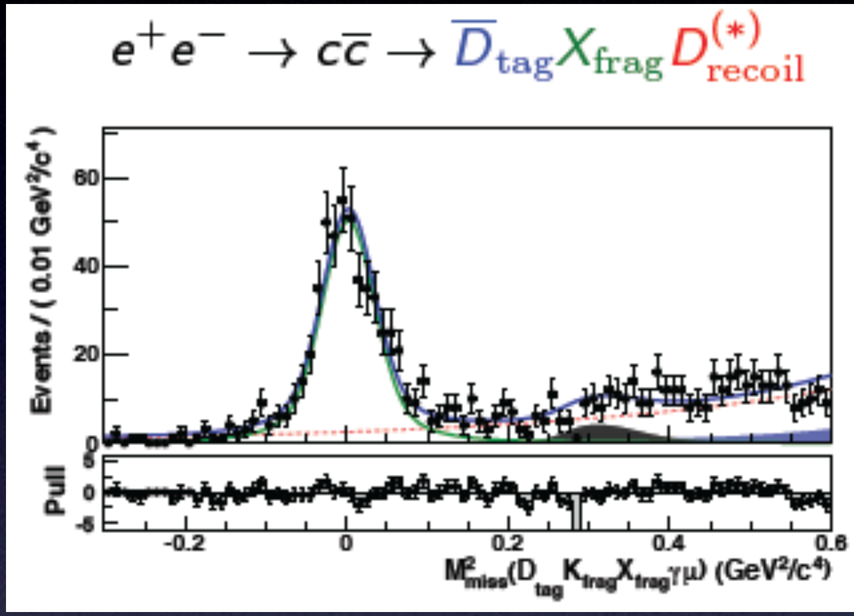
Belle II Internal Note #0021

Tracking eff. (statistics limited)

Normalization: $N(\Upsilon(4S))$, $f_{\pm}/f_0$, B^0 lifetime, $Br(D^* \to D^0\pi)$, $Br(D^0 \to K\pi)$

Prospect for D Leptonic Decays

- Important for both testing the SM and search for NP.
- Belle developed the method to tag D



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	Statistical	Systematic reducible	Systematic irreducible	Total
$\mathcal{B}(D_s \to \mu\nu)$				
913 fb^{-1}	5.3%	0%	3.8%	6.5%
5 ab^{-1}	2.3%	1.6%	0%-0.9%	2.9%
50 ab^{-1}	0.7%	0.5%	0%-0.9%	0.9%-1.3%
$\mathcal{B}(D_s \to \tau\nu)$				
913 fb^{-1}	3.7%	4.4%	3.5%	6.8%
5 ab^{-1}	1.6%	1.9%-2.3%	3.5%-2.2%	3.5%-4.3%
50 ab^{-1}	0.5%	0.6%-0.7%	3.5%-2.2%	2.3%-3.6%

Belle II Internal Note #0021

Irreducible error sources

- $Br(\tau \to X)$, $Br(D_S)$, D^0/D^+ fraction in $c\bar{c}$ fragmentation
- Data-MC difference in E_{ECL} (residual energy recorded in EM calorimeter)