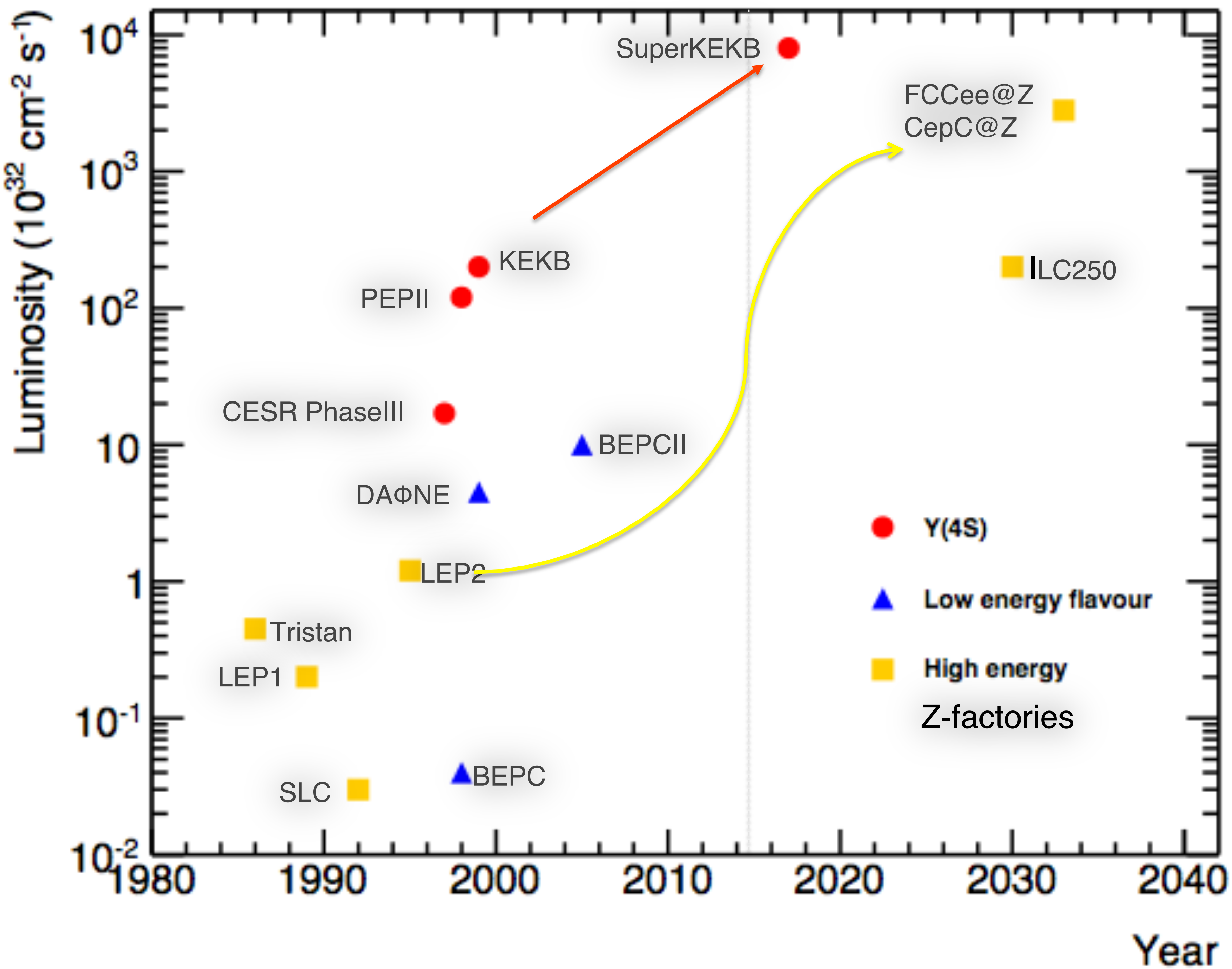
Present and future CKM studies from B-physics at e^+e^- machines

CKM Workshop
Vienna, September 2014

Phillip Urquijo
The University of Melbourne

Past, future & proposed e^+e^- colliders



SuperKEKB construction to be completed in JFY2014

$L_{peak} = 8 \times 10^{35}$ cm^{-2}s^{-1}

[40 x KEKB, ~80 x KEKB design]

50 ab^{-1} by early 2020s

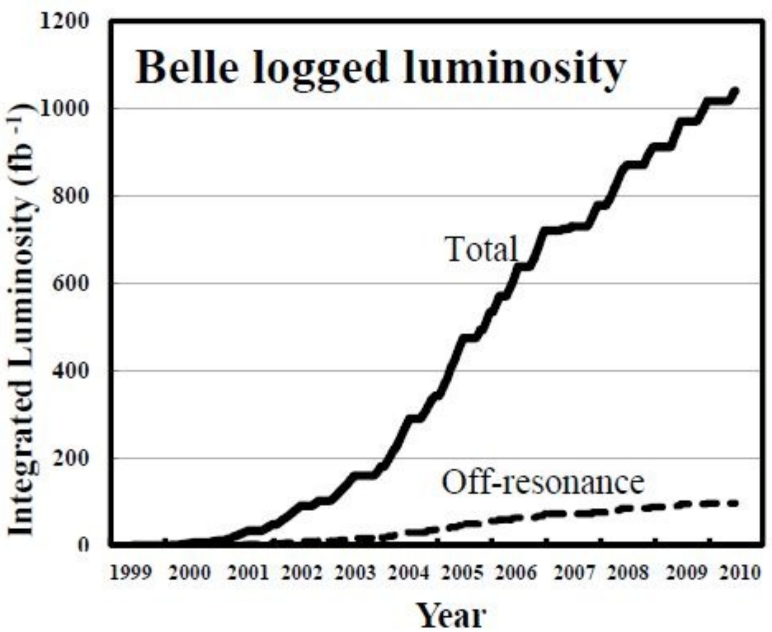
[50 x Belle, *i.e.* faster ramp up]

H/Z-factory on the horizon – up to 10^{13} Zs

B-factories

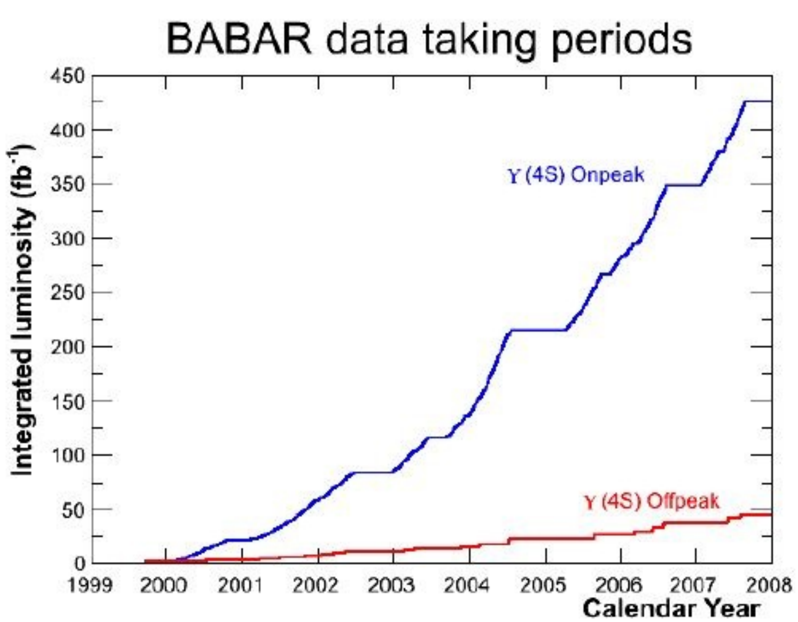
B factories

datataking:
Belle: 1999-2010, BaBar: 1999-2008
analyses still ongoing



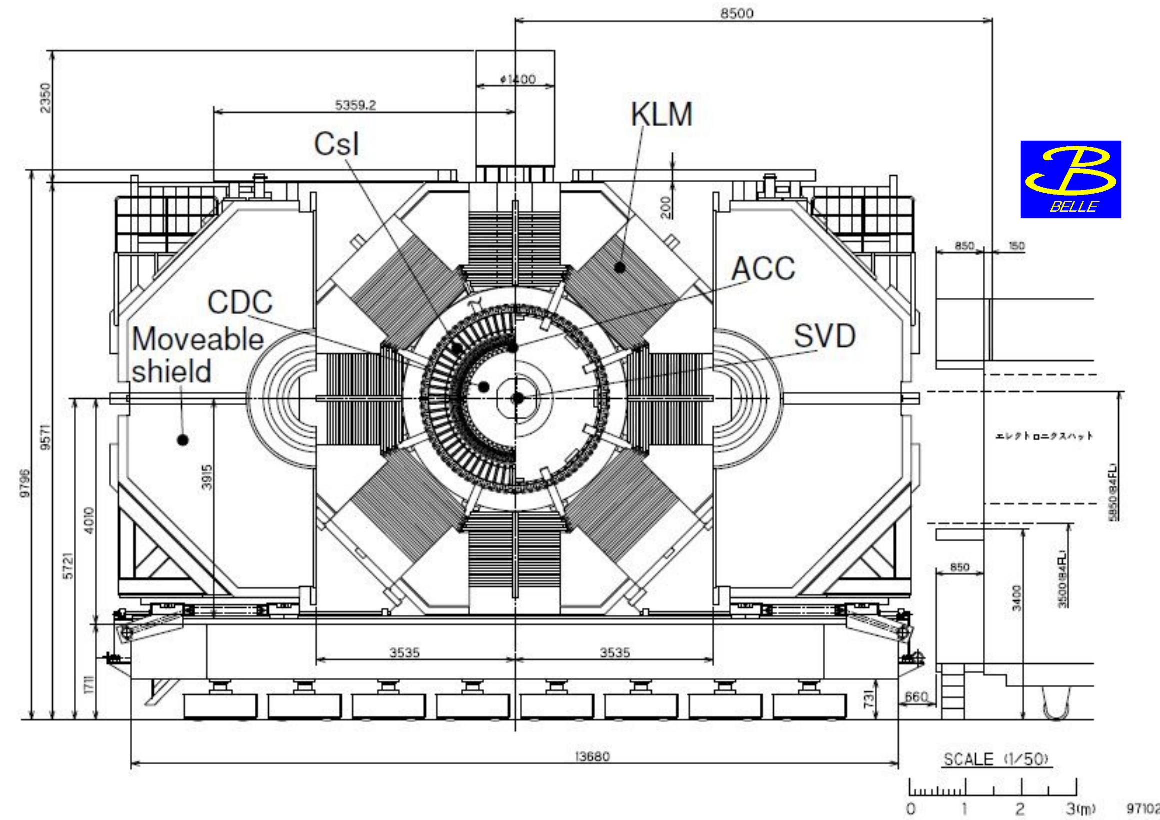
$\int L^{\Upsilon(4S)} dt$ ~710 fb^{-1}
$e^+e^- \to \Upsilon(4S) \to BB$

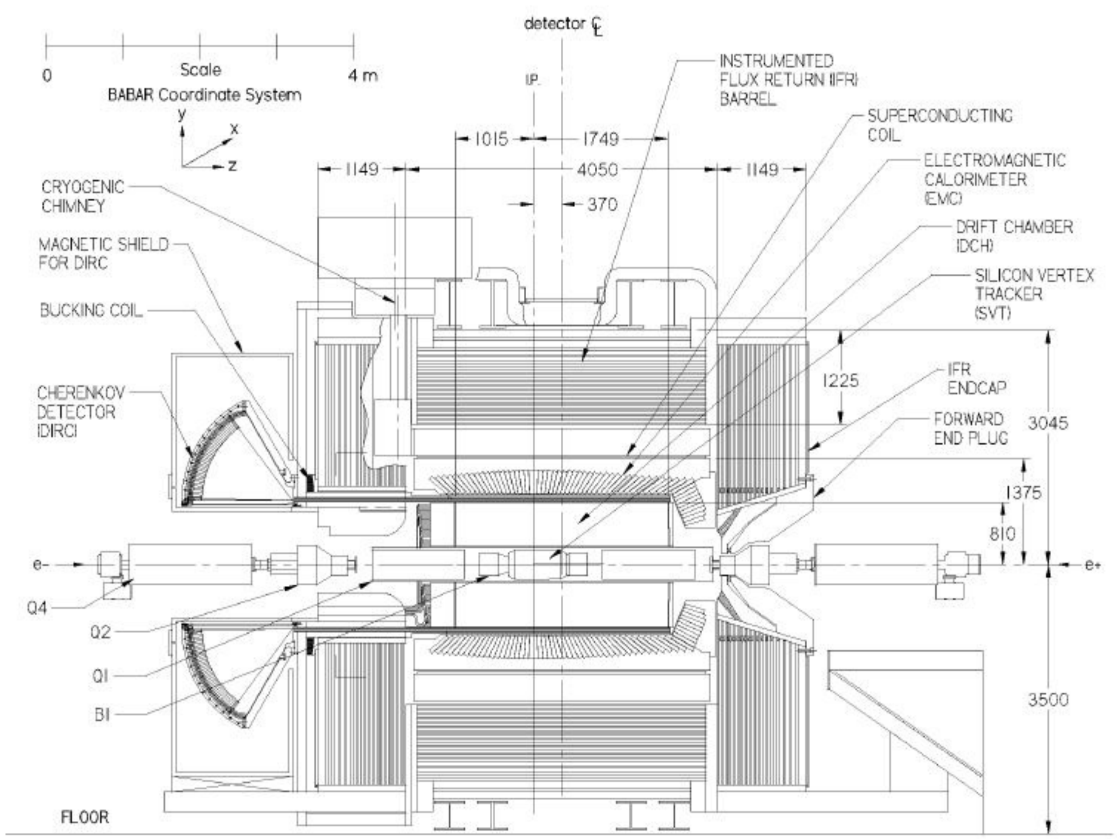
$\int L^{off} dt$ ~ 90 fb^{-1}
$e^+e^- \to \gamma* \to qq$



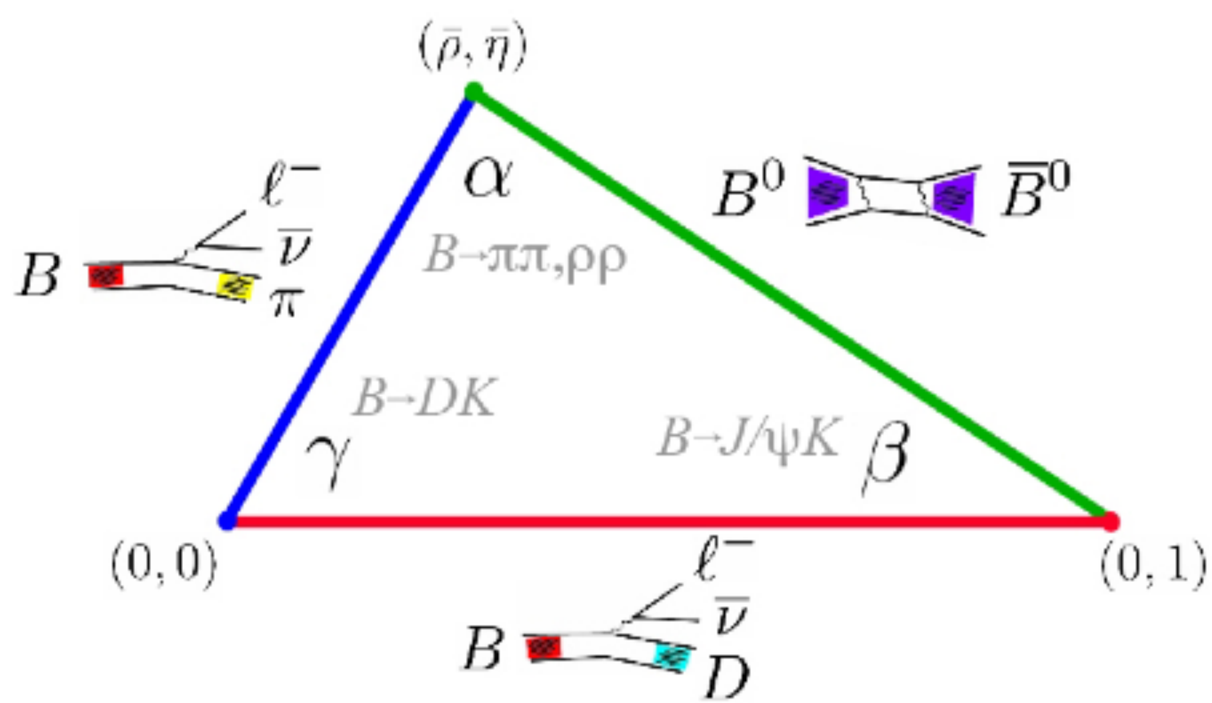
$\int L^{\Upsilon(4S)} dt$ ~420 fb^{-1}

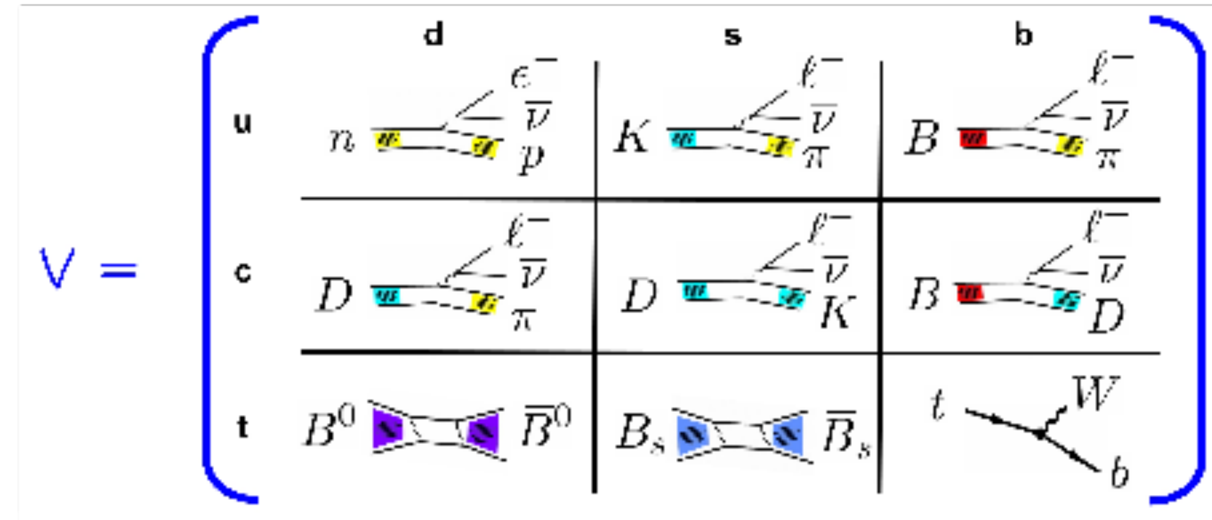
$\int L^{off} dt$ ~ 40 fb^{-1}





Role of e^+e^- B data in SM CKM Metrology



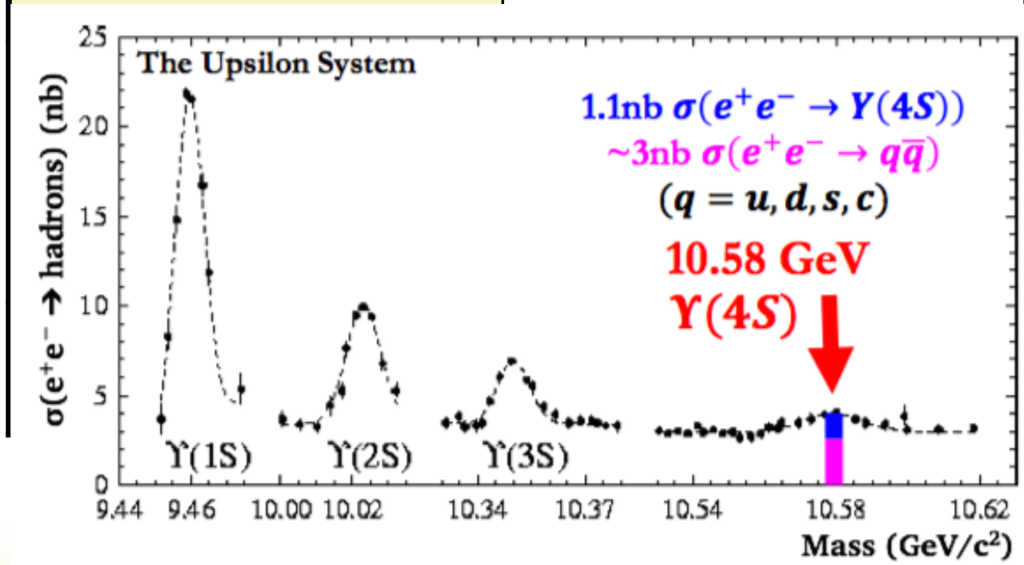


$B \to \pi\pi, \rho\rho$	α/Φ_2	$B \to D\, l\, \nu$ / $b \to c\, l\, \nu$	$\lvert V_{cb} \rvert$ via Form factor / OPE
$B \to D^{(*)} K^{(*)}$	γ/Φ_3	$B \to \pi\, l\, \nu$ / $b \to u\, l\, \nu$	$\lvert V_{ub} \rvert$ via Form factor / OPE
$B \to J/\psi\, K_s$	β/Φ_1	$M \to l\, \nu\, (\gamma)$	$\lvert V_{UD} \rvert$ via Decay constant f_M
$B_s \to J/\psi\, \Phi$	β_s	ε_K	(ρ, η) via B_K
$K \to \pi\, \nu$ anti-ν	ρ, η	Δm_d, Δm_s	$\lvert V_{tb}\, V_{t\{d,s\}} \rvert$ via Bag factor B_B
		$B_{(s)} \to \mu+\, \mu-$	$\lvert V_{t\{d,s\}} \rvert$ via Decay constant f_B

+ ongoing search to find new sources of CPV and other NP in 3rd generation.

B Production

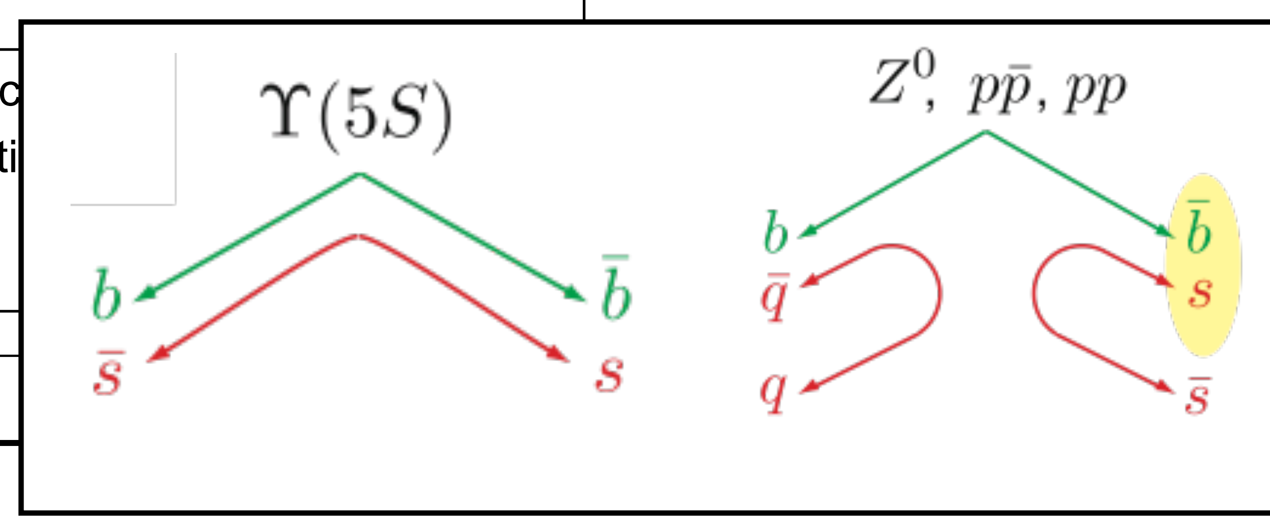
	e+e- (PEPII, KEKB)	e+e- (Super KEKB)	pp→b anti-bX ($\sqrt{s}$=14TeV) LHC	e+e- → Z→b anti-bX ($\sqrt{s}$=91 GeV) FCCee, CepC
Prod. σ_{bb}	1 nb		~500μb	σ(45nb) x BF(0.15) = 7nb
Total yield	10^9	$5\ 10^{10}$	10^{13}	10^{11}-10^{12}
typ. bb rate	10 Hz	400Hz	~500kHz	~1kHz
purity	~25%		~0.6%	~10%
pile-up	0		0.5→25	0
B content	B^+(50%),B^0(50%)		B^+(40%),B^0(40%),B_s(10%),B_c(<1%),b-baryon(10%)	
B boost	small, βγ~0.5		large, decay vertices are displaced	large, βγ~7 (average)



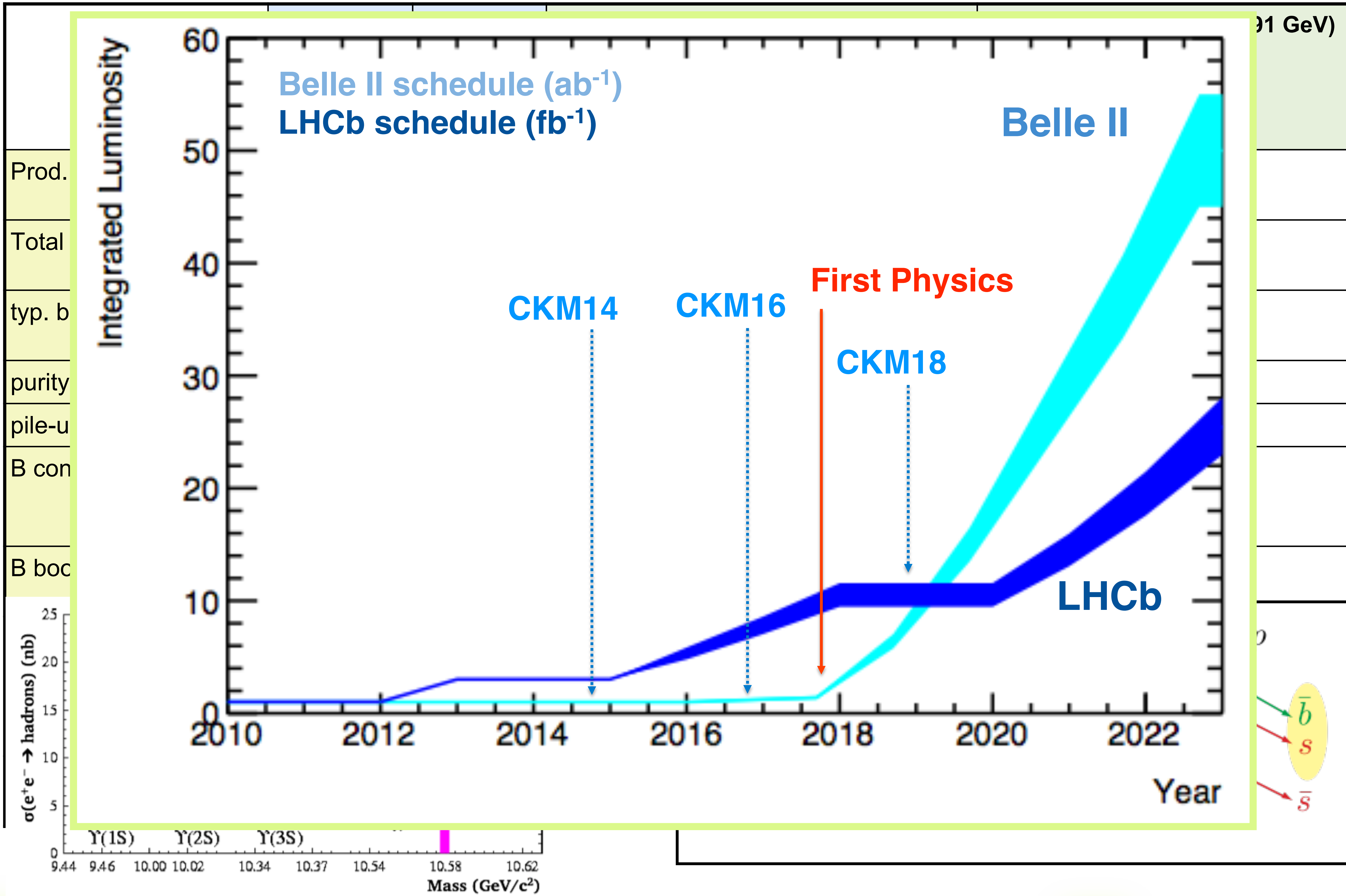
Many partic

Low hermiti

ncoherent



B Production



Summary of CKM

	Belle & Babar	*Global Fit (CKMfitter*	*LHCb Run-2*	*Belle II 50 ab^{-1}*	*LHCb Upgrade 50 fb^{-1}*	*Theory*
φ_1: ccs	*1.4°*	*1.5°*	*1.6°*	*0.4°*	*0.6°*	
φ_2: uud	*4°*	*2.1°*		*1°*		*~1-2°*
φ_3: DK	*11°*	*3.8°*	*4°*	*1.5°*	*1°*	
$\lvert V_{cb}\rvert$ *inclusive*	*1.7%*	*2.4%*		*1.2%*		
$\lvert V_{cb}\rvert$ *exclusive*	*2.2%*			*1.4%*		
$\lvert V_{ub}\rvert$ *inclusive*	*7%*	*4.5%*		*3.0%*		
$\lvert V_{ub}\rvert$ *exclusive*	*8%*			*2.4%*		
$\lvert V_{ub}\rvert$ *leptonic*	*11%*			*3.0%*		

Experiment

- **No result**
- **Moderate precision**
- **Precise**
- **Very Precise**

Theory

- **Moderate precision**
- **Clean / LQCD**
- **Clean**

Strengths of e^+e^- @ Υ(4S)

Full reconstruction of B

- modes w/ multiple ν's
- inclusive measurements

Hermeticity

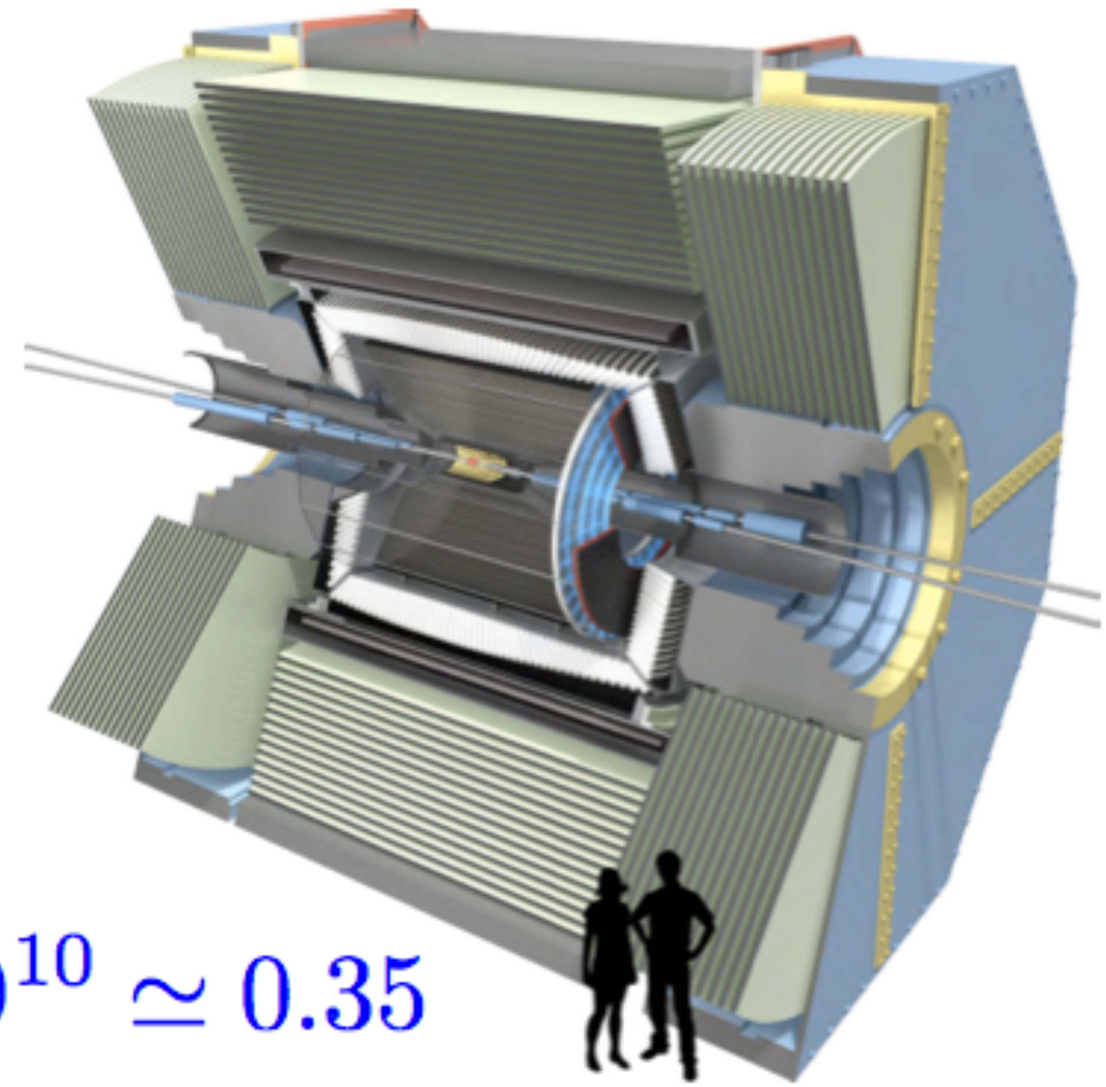
- minimal trigger for, e.g. Dalitz analysis
- precision τ measurements

Neutral particles π^0, K_S^0, K_L^0

and for η, η`, ρ^+, etc.

other notable features

- good PID for both $\mu^\pm$ and $e^\pm$
- high flavour-tagging efficiency



$$0.9^{10} \simeq 0.35$$

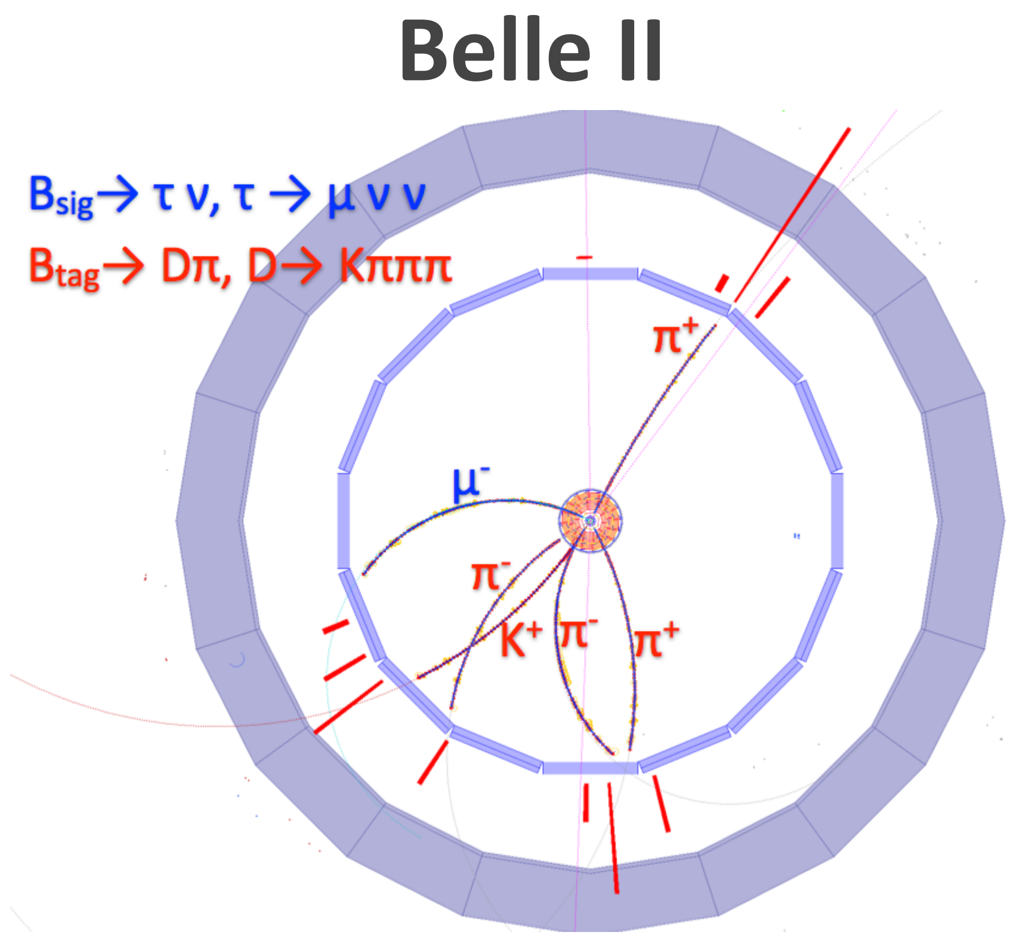
Belle II covering ≳90% of 4π,
and ⟨N(track)⟩ ~ 10 per event

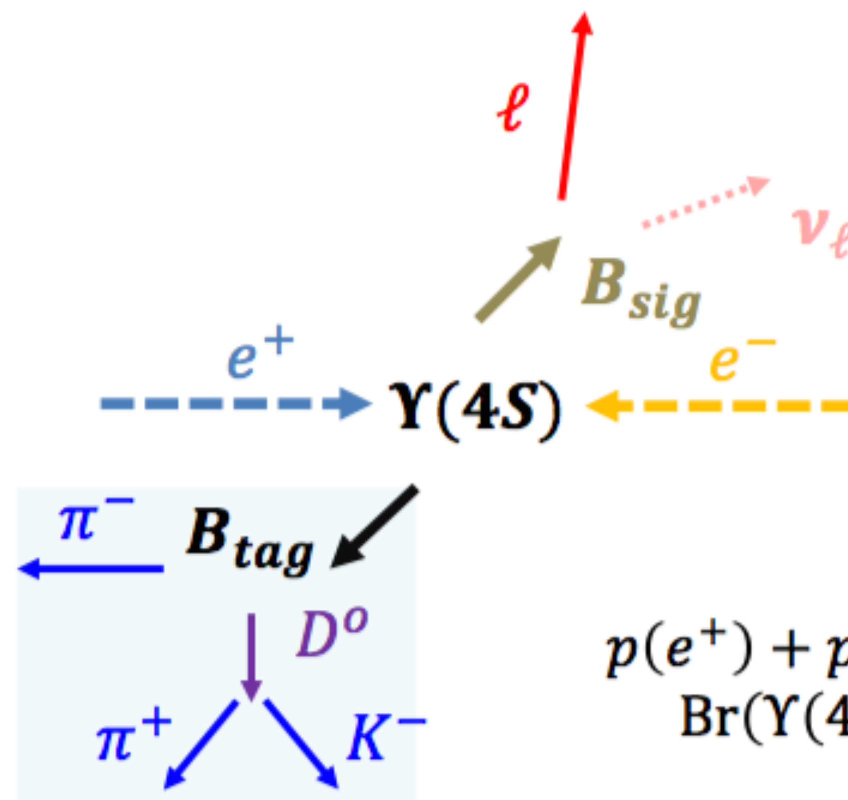
1. B full reconstruction (Neutrinos & Inclusive)

Exploit $\Upsilon(4S) \rightarrow B_{tag}\, B_{sig}$

Reconstruct B_{tag} chain - constrain (E,p), charge, flavour of Bsig

Had: $\varepsilon(B_{tag})$ = 0.20 - 0.25% @ Purity(B_{tag}) = 20%





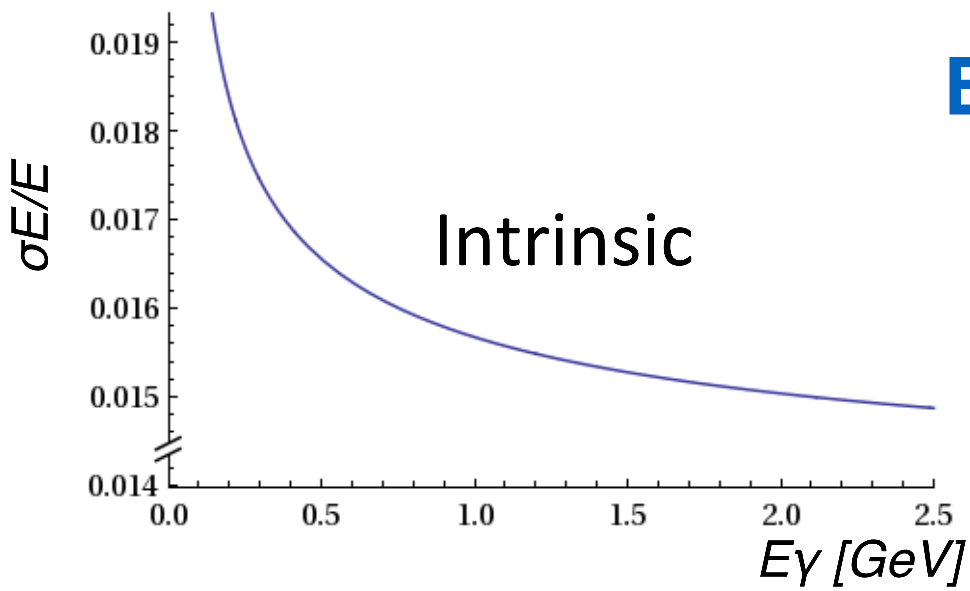
$$p(e^+) + p(e^-) = p(B) + p(\bar{B})$$
$$\mathrm{Br}(\Upsilon(4S) \rightarrow B\bar{B}) > 96\%$$

b→u	b→c	b→s	b→d
$\pi l\nu$, $\rho l\nu$	$D^{(*)}\tau\nu$	$K^{(*)}\nu\nu$	$\pi\nu\nu$
$X_u l\nu$	$D^{(*)}l\nu$	$X_s\gamma$	$\nu\nu$
$\tau\nu$	$X\nu\, l/\tau$	$X_s ll$	$B_{(s)}^0 \rightarrow \tau\tau$
$\mu\nu$			

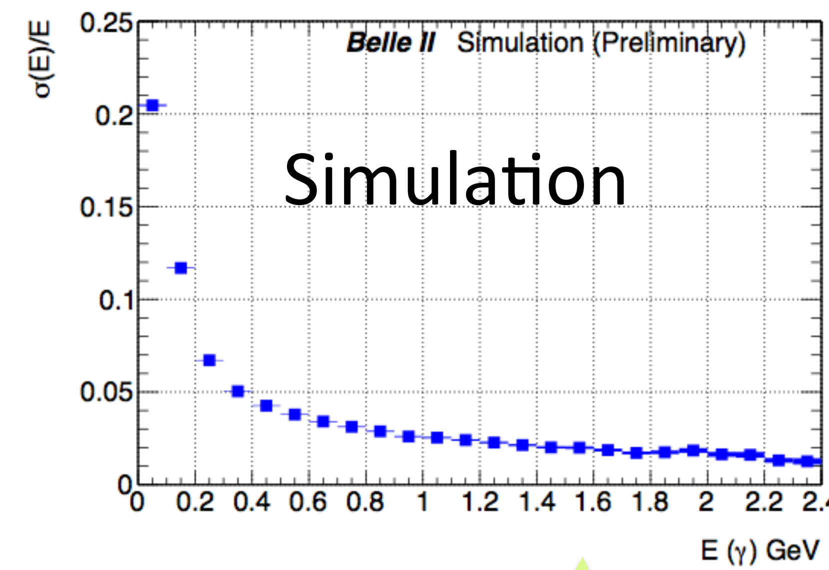
2. EM Calorimetry: Neutrals & Electrons

1. *Far fewer background photons than LHC*
2. ***Higher performance calorimeter***
3. ***Much less material in front (good for electrons)***

Belle II



+ Material effects (& not optimised for waveform sampling)

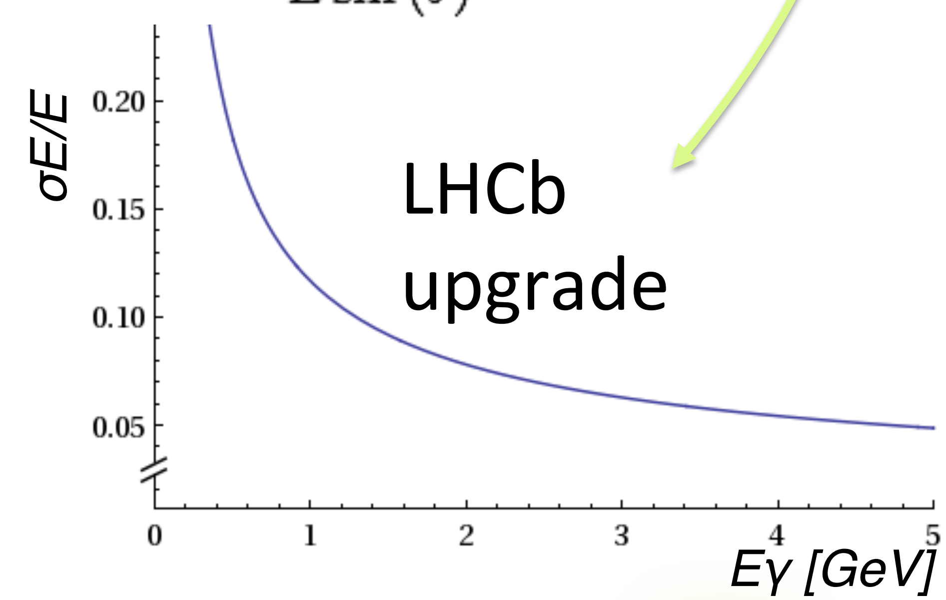


LHCb

$$\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E(\mathrm{GeV})}} \oplus 1.5\% \oplus \frac{0.0025 \times \mathrm{RMS}}{E\sin(\theta)}(\mathrm{Pile-up}) \oplus \frac{0.01}{\mathrm{E}\sin(\theta)}(\mathrm{Noise})$$

Noise+Pileup

$\mathcal{L}(cm^{-2}.s^{-1})$	2×10^{32}		10^{33}	
Resolution	Total	Pile-up	Total	Pile-up
$B \to D^*(D\gamma)K$	7.4%	4.7%	14.3%	13.1%
$B \to \phi\gamma$	2.3%	0.5%	2.7%	1.5%

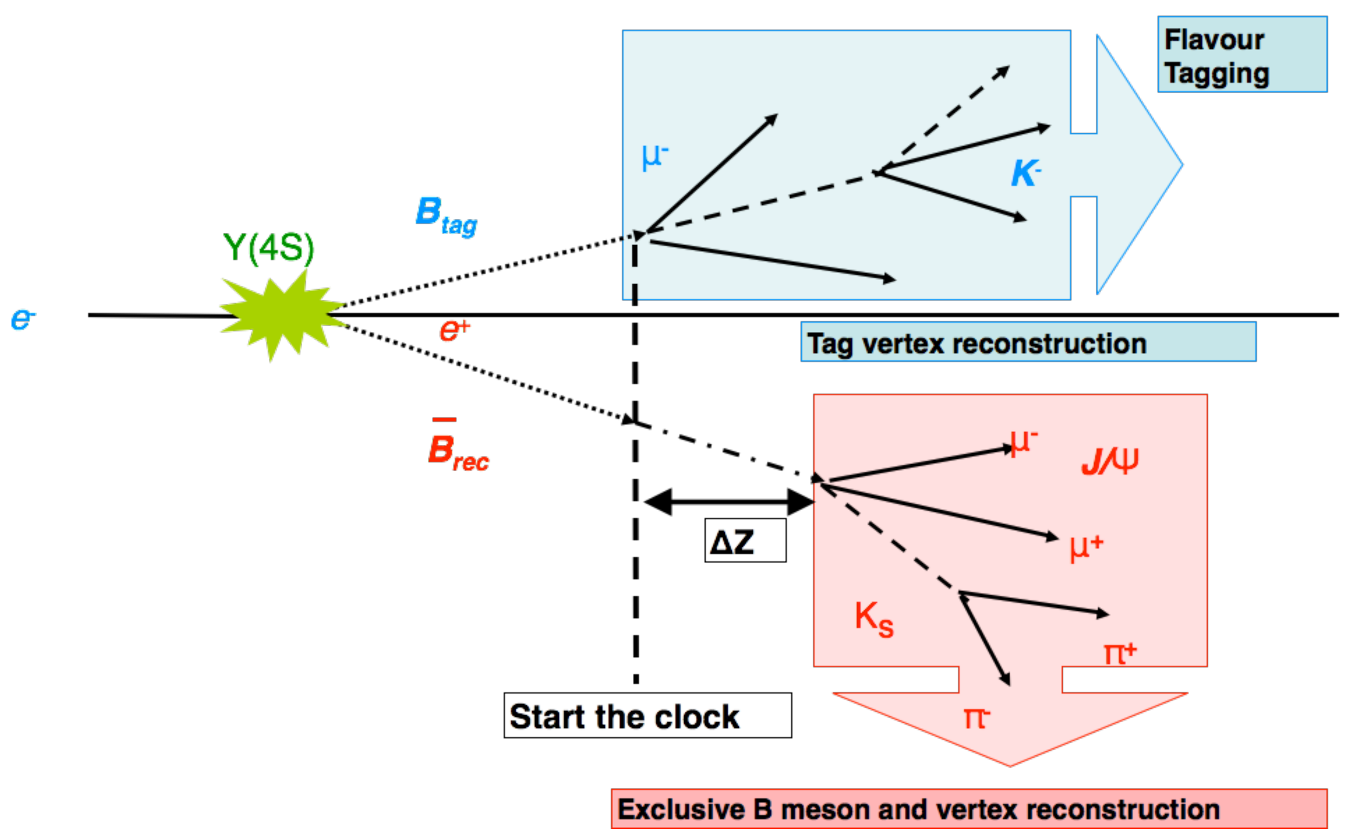


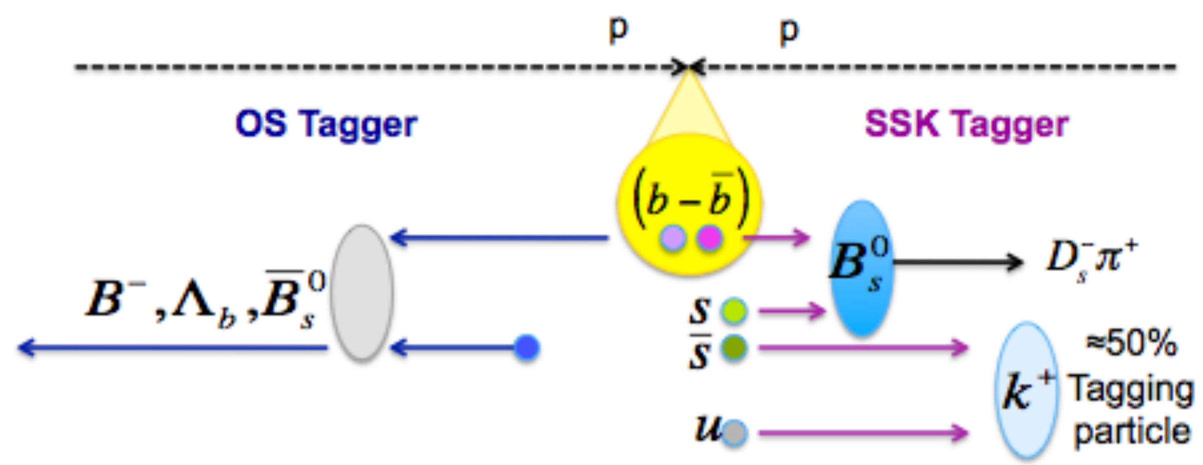
3. Flavour-tagging & Neutral Kaons

$Q = \varepsilon_{tag}(1 - 2\omega)^2$,

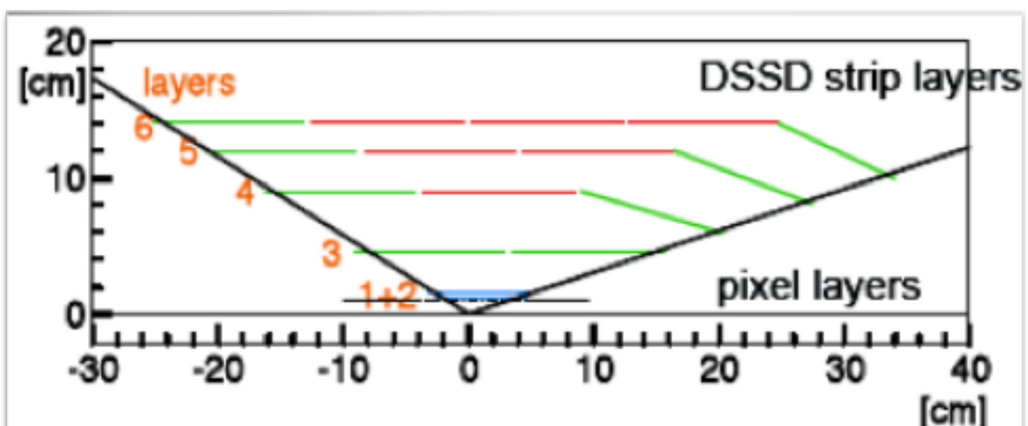
~30% for a B-factory

~2.0±0.3% for LHCb (arXiv:1202.4979)



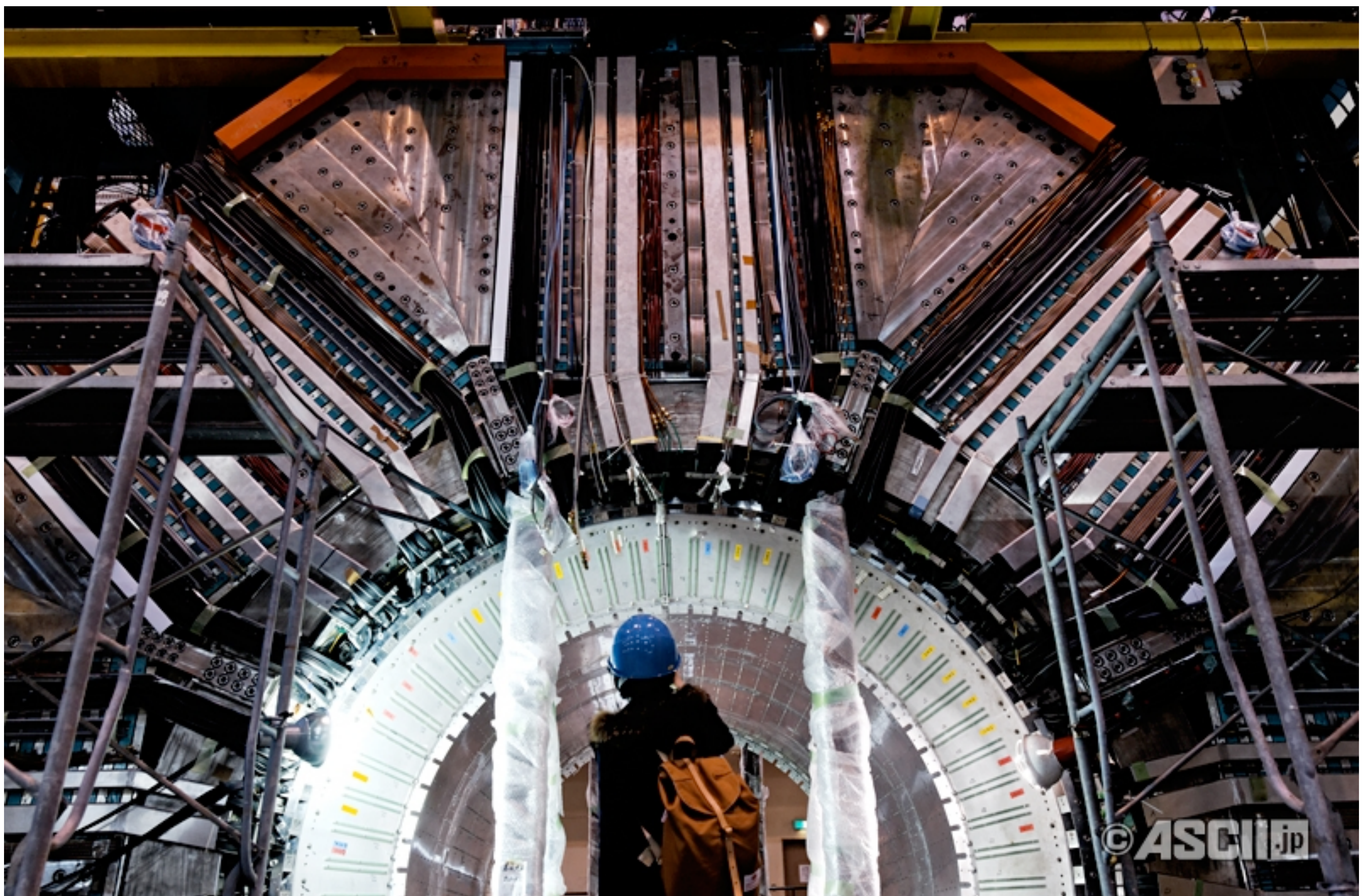


$B_d \to ss q$ CP eigenstate often detected via K_S
(> 10 X more efficient in Belle II than LHCb)



K_L detection much improved (Impossible @ LHCb)

SuperKEKB & Belle II



KEKB to SuperKEKB (Completion in CY2015)

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lorentz factor

Beam current

Beam-beam parameter

Classical electron radius

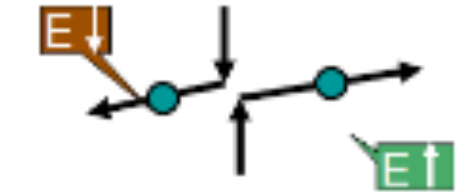
Beam size ratio@IP
1 ~ 2 % (flat beam)

Vertical beta function@IP

Lumi. reduction factor (crossing angle)&
Tune shift reduction factor (hour glass effect)
0.8 ~ 1
(short bunch)

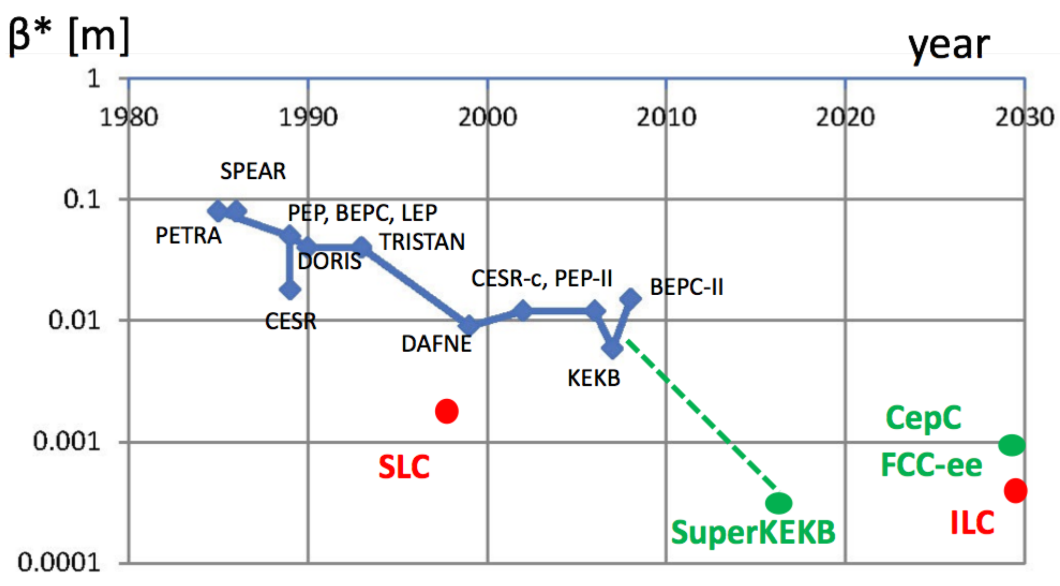
Beam-related backgrounds 10-20 x KEKB.

- Touschek scattering

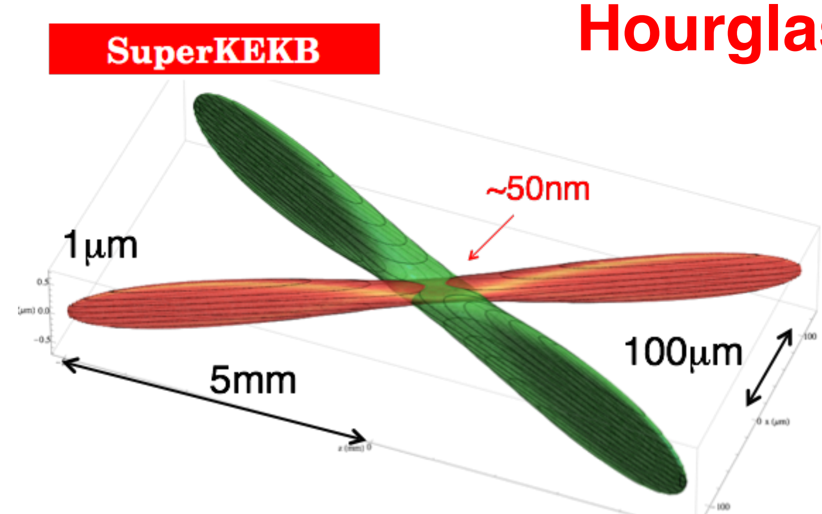


- Radiative Bhabha
- 2-γ

	E (GeV) LER/HER	β*y (mm) LER/HER	β*x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L (cm^{-2}s^{-1})
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}



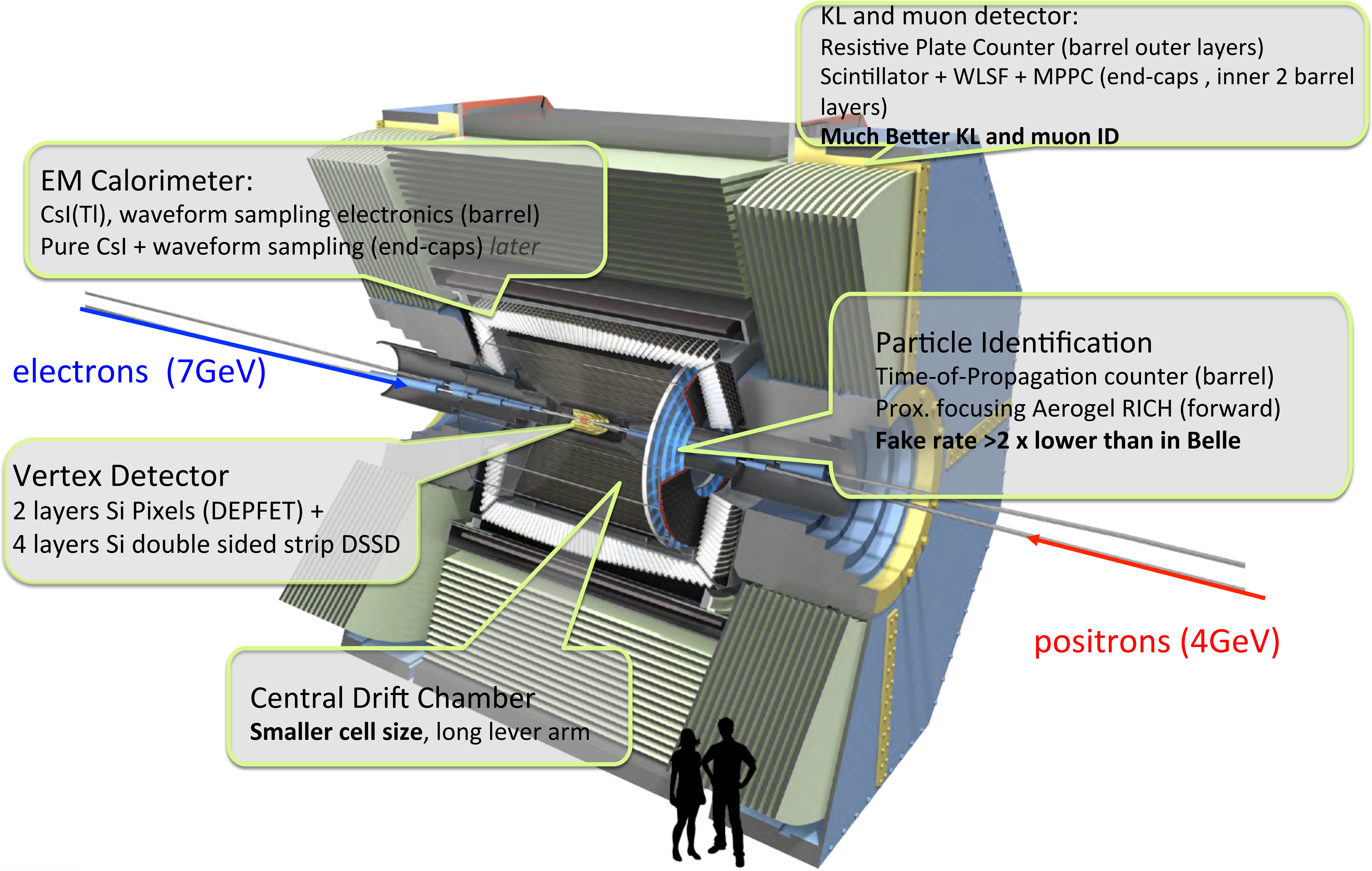
$\sigma^* = \sqrt{\varepsilon\beta^*}$



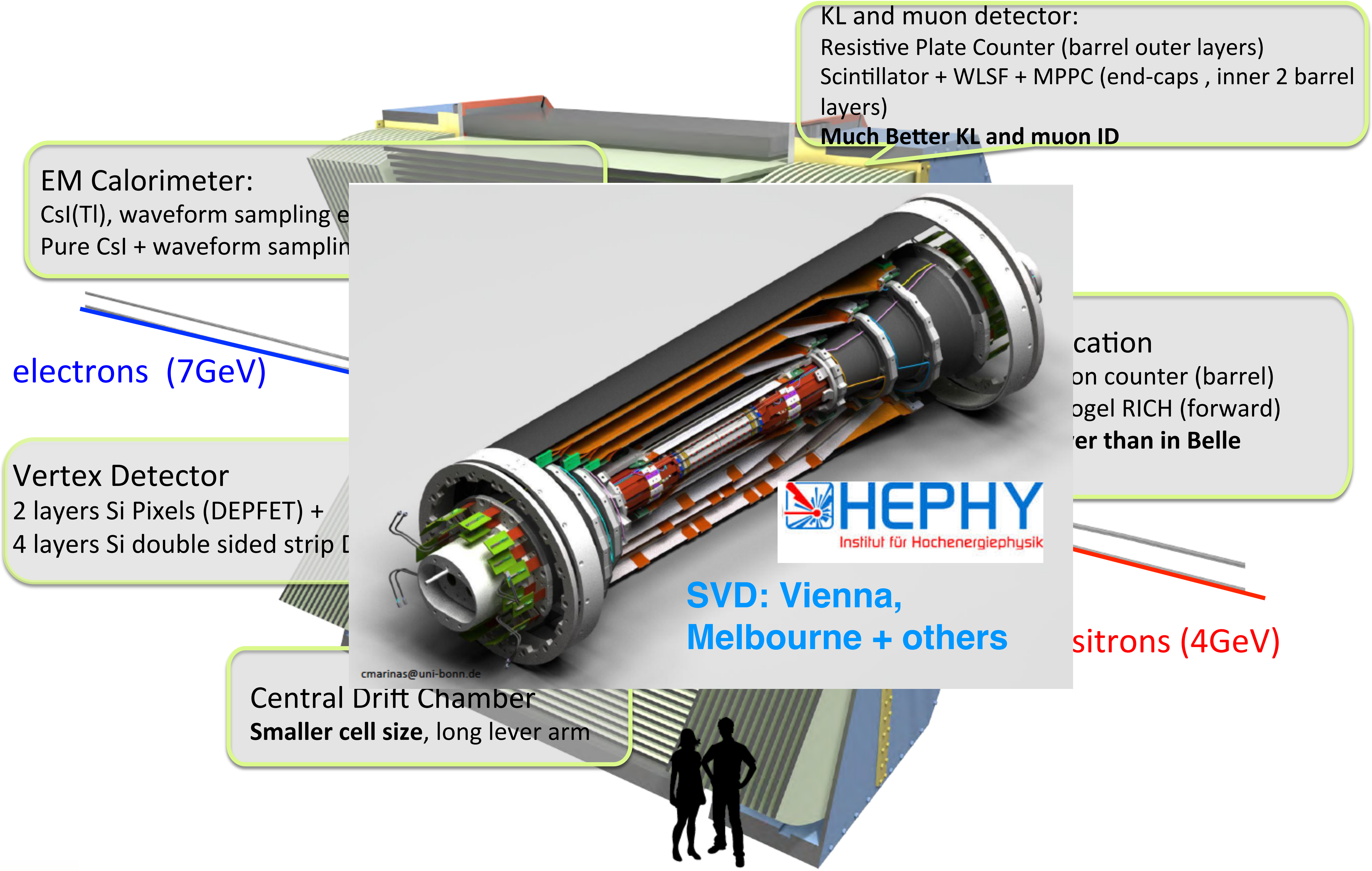
Hourglass condition:

$\beta_y^* >\sim L = \sigma_x/\phi$

Belle II Detector

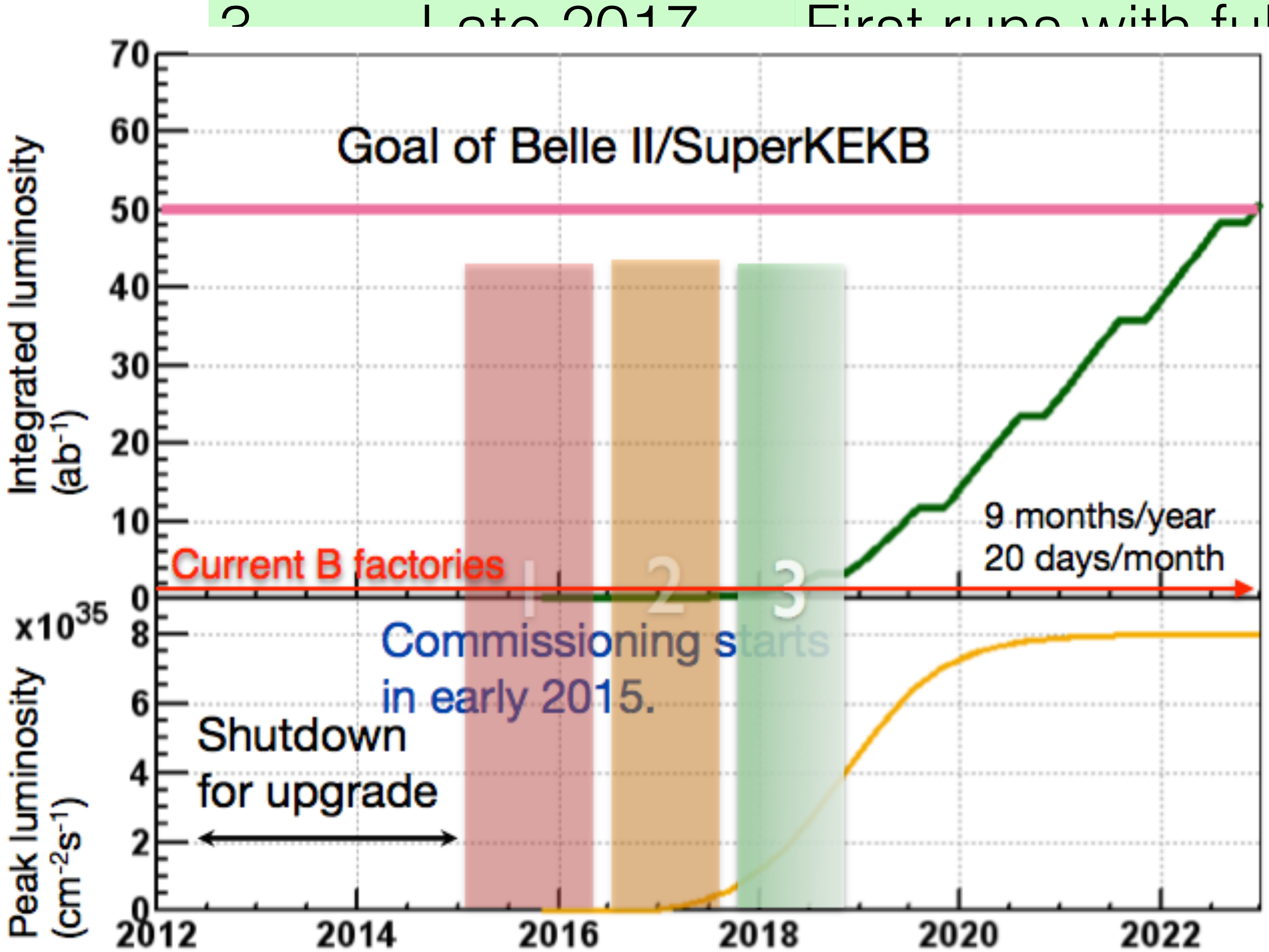


Belle II Detector



Belle II Data collection timeline

1	2015	Accelerator commissioning
2	2016-2017	Belle II "Beast" and partial detector commissioning
3	Late 2017	First runs with full detector



Channel	Belle	BaBar	Belle II (per year)
$B\bar{B}$	7.7×10^8	4.8×10^8	1.1×10^{10}
$B_s^{(*)}\bar{B}_s^{(*)}$	7.0×10^6	–	6.0×10^8
$\Upsilon(1S)$	1.0×10^8		1.8×10^{11}
$\Upsilon(2S)$	1.7×10^8	0.9×10^7	7.0×10^{10}
$\Upsilon(3S)$	1.0×10^7	1.0×10^8	3.7×10^{10}
$\Upsilon(5S)$	3.6×10^7	–	3.0×10^9
$\tau\tau$	1.0×10^9	0.6×10^9	1.0×10^{10}

assuming 100% running at each energy

May not have full PID immediately.

→*alternatives to Y(4S) for early physics, **O**(3-500 fb^{-1}).*

Y(2,3S): Dark sector, light Higgs, bottomonia

Scan near Y(5S) to Y(6S): bottomonia & m_b mass

Semi(Leptonic) Sides of the UT

	Observables	Belle or LHCb (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
UT Sides	$\lvert V_{cb}\rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 2.4\%)$	1.2%			
	$\lvert V_{cb}\rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\text{ex.}} \pm 2.7\%_{\text{th.}})$	1.8%	1.4%		
	$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\text{ex.}} \pm 2.5\%_{\text{th.}})$	3.4%	3.0%		
	$\lvert V_{ub}\rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 9.5\%)$	4.4%	2.3%		
Leptonic and Semi-tauonic	$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$96(1 \pm 26\%)$	10%	5%		
	$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%		
	$R(B \to D\tau\nu)$ [Had. tag]	$0.440(1 \pm 16.5\%)^{\dagger}$	5.6%	3.4%		
	$R(B \to D^{*}\tau\nu)^{\dagger}$ [Had. tag]	$0.332(1 \pm 9.0\%)^{\dagger}$	3.2%	2.1%	?	

Driving questions:

Extended Higgs & Gauge Sectors?
Charged Right Handed Currents?
CKM metrology.

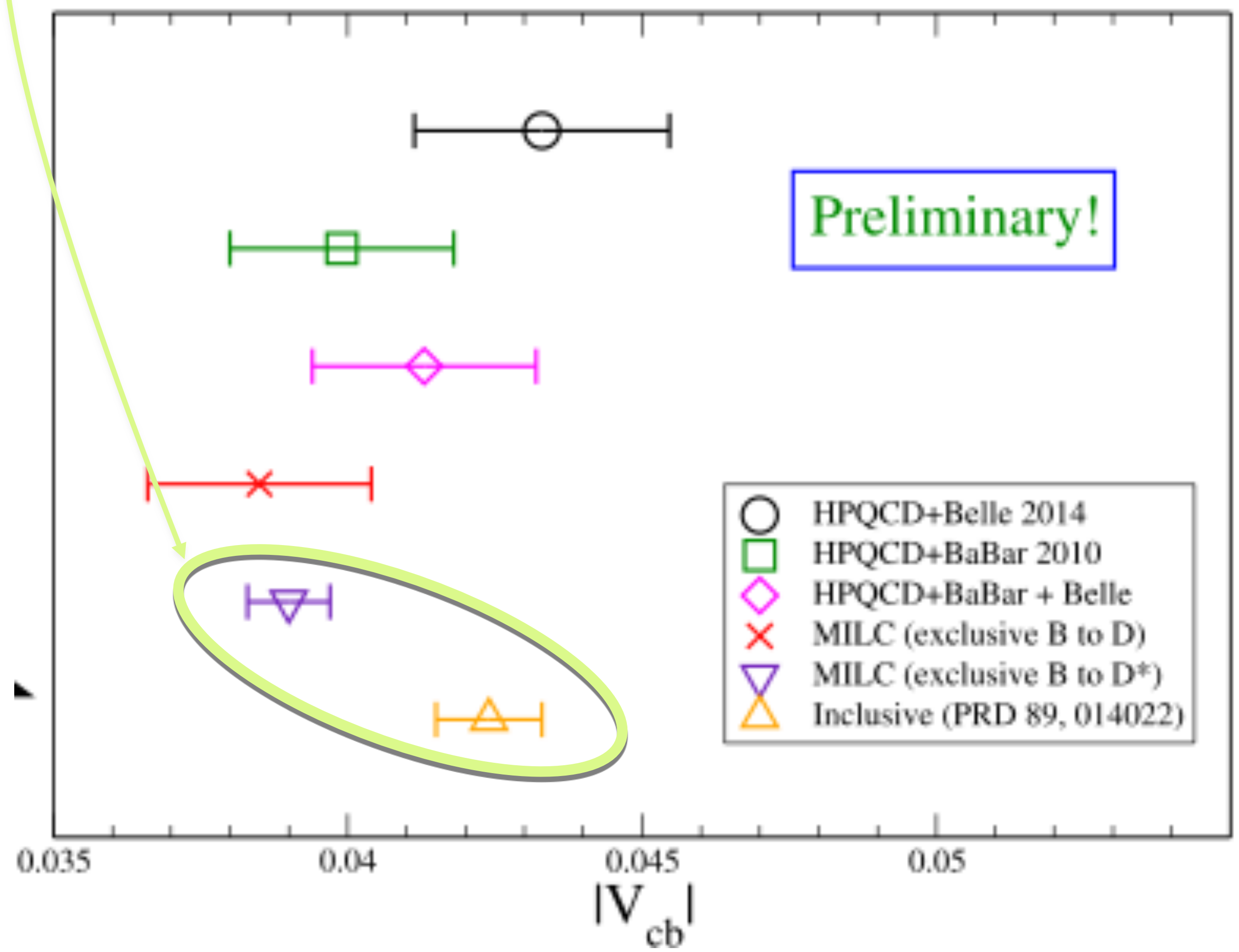
‡Note: Summary table shows only 1 B-factory to demonstrate the power of a single device

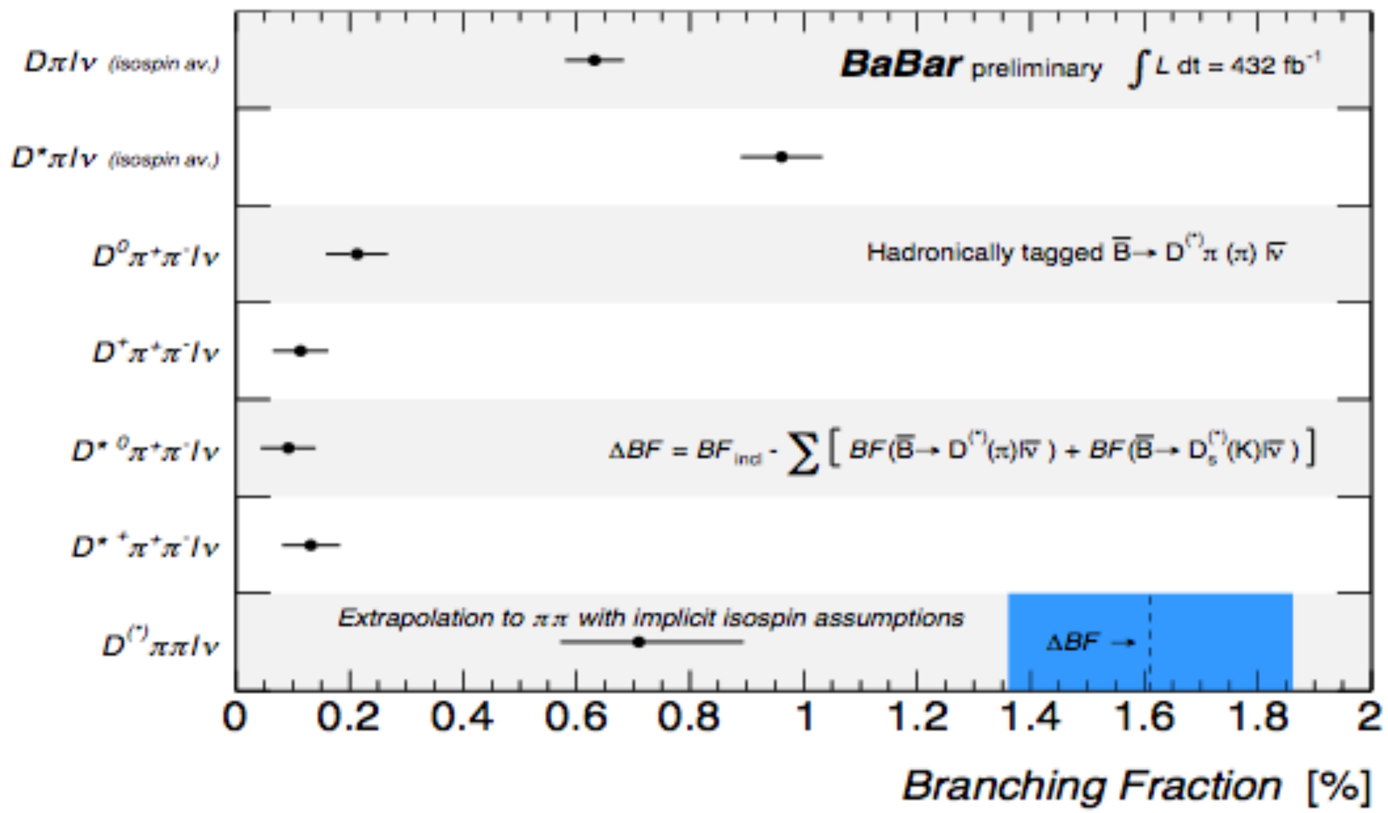
$|V_{cb}|$ Inclusive and Exclusive

$|V_{cb}|$, Inc.-Exc. disagree by up to 3σ

- Inclusive: $b \to c\, l\, \nu$ + OPE / Heavy quark symmetry
- Exclusive: $B \to D^* l\, \nu$ + Form factors (LQCD)

Belle, B→ D l ν G(1)|Vcb|, Preliminary (2014)
Babar, B→ D(*) π π l ν, Preliminary (2014 ICHEP)





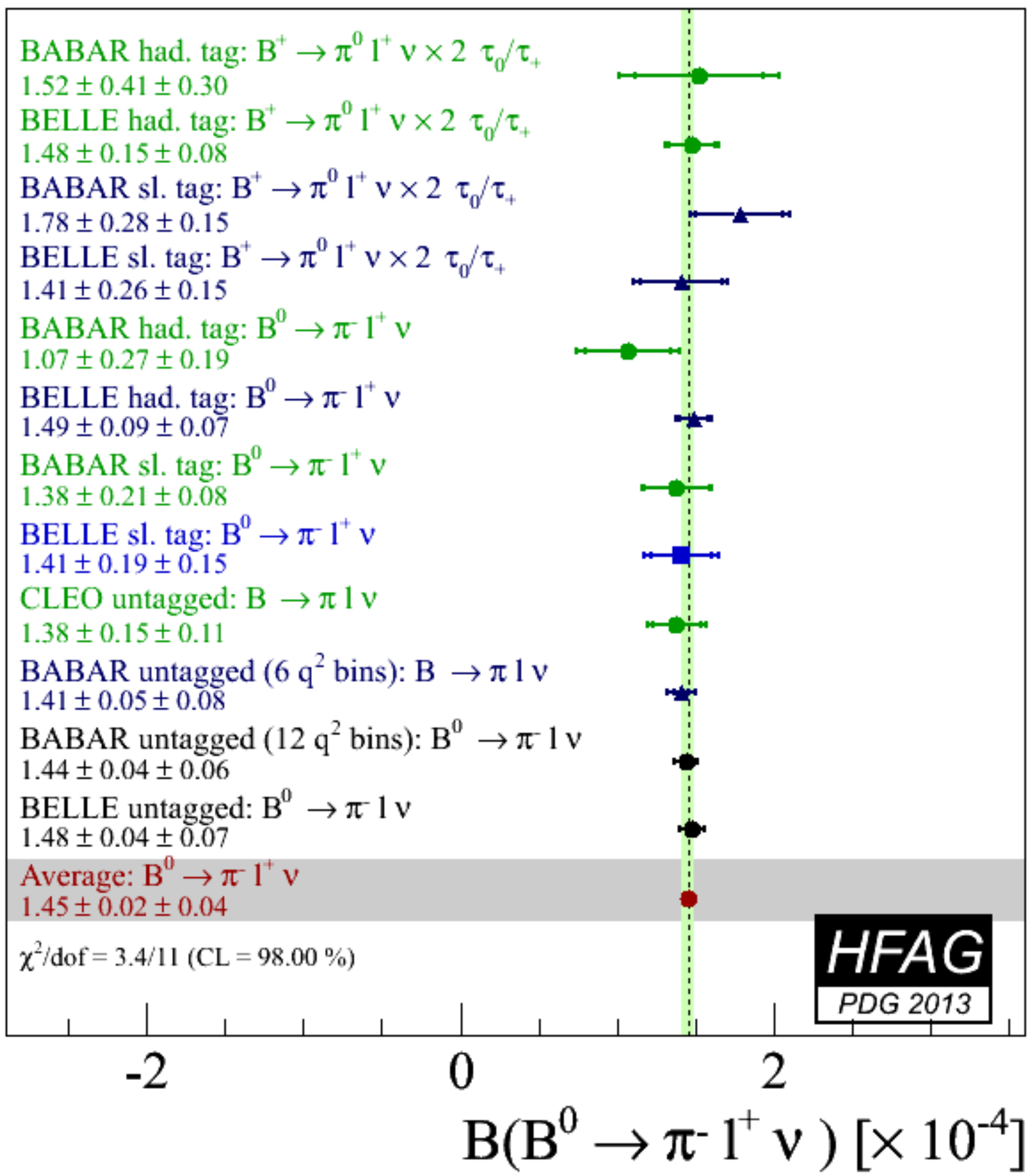
Clear issues in consistency for $|V_{qb}|$ methods
$B \to D\, l\, \nu$ improves with cleaner tagging @Belle II

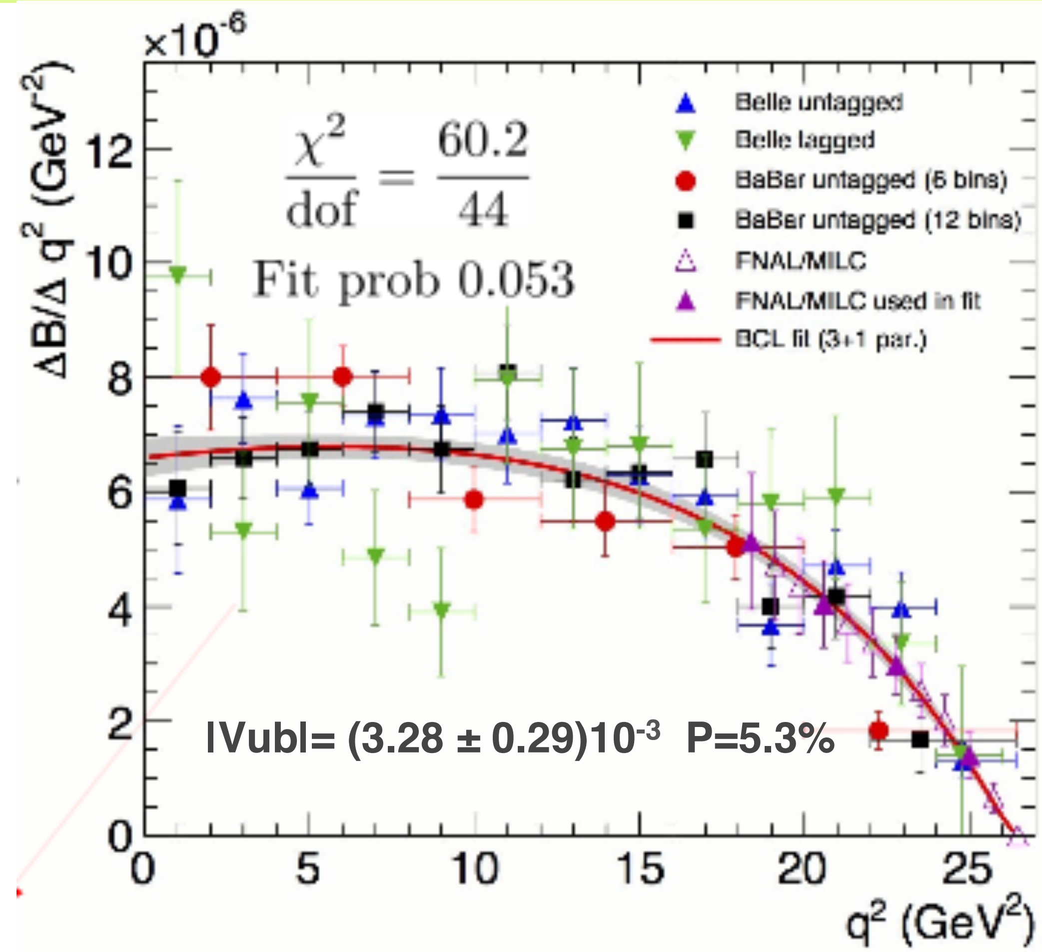
Indirect

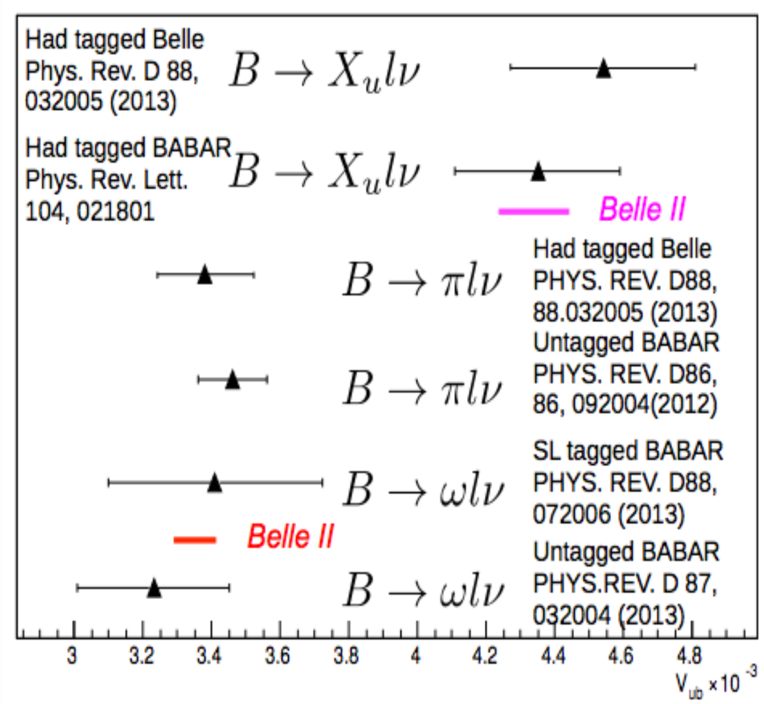
$|V_{cb}| = (41.4^{+2.4}_{-1.4})10^{-3}$ (4.6%)

|V_{ub}| Exclusive

Belle, Exclusive B→ π/ρ/ω l ν (Had), PRD88 032005 (2013)
Babar, Exclusive B→ π/ω/η(') l ν (Un), PRD86 092004 (2012)
Babar, Exclusive B→ ω l ν (SL), PRD 88, 072006 (2013)





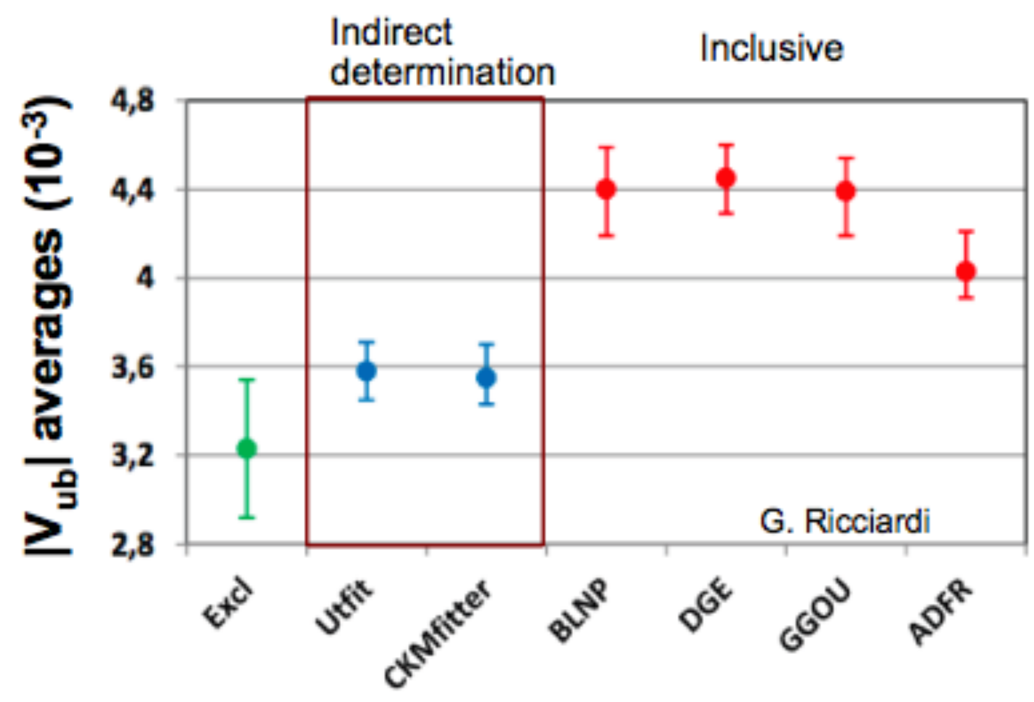


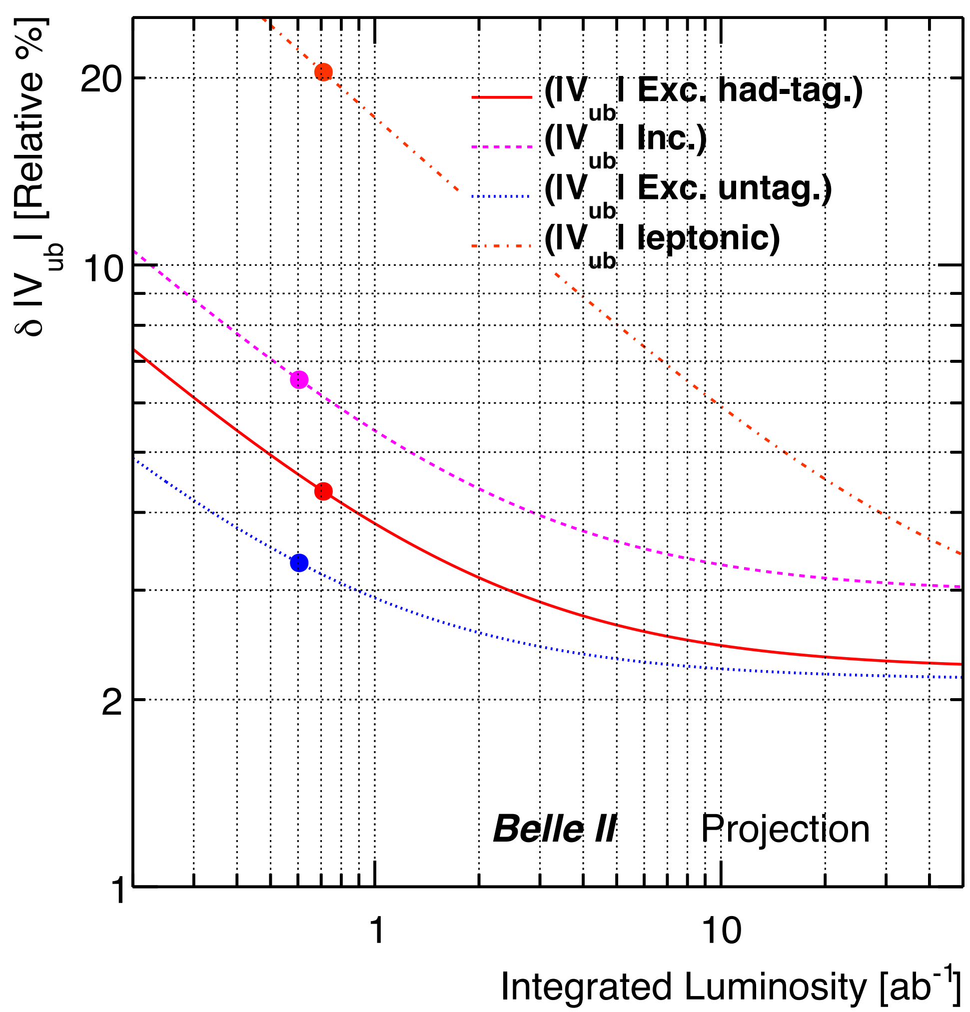
$|V_{ub}|$ (& $|V_{cb}|$): Future

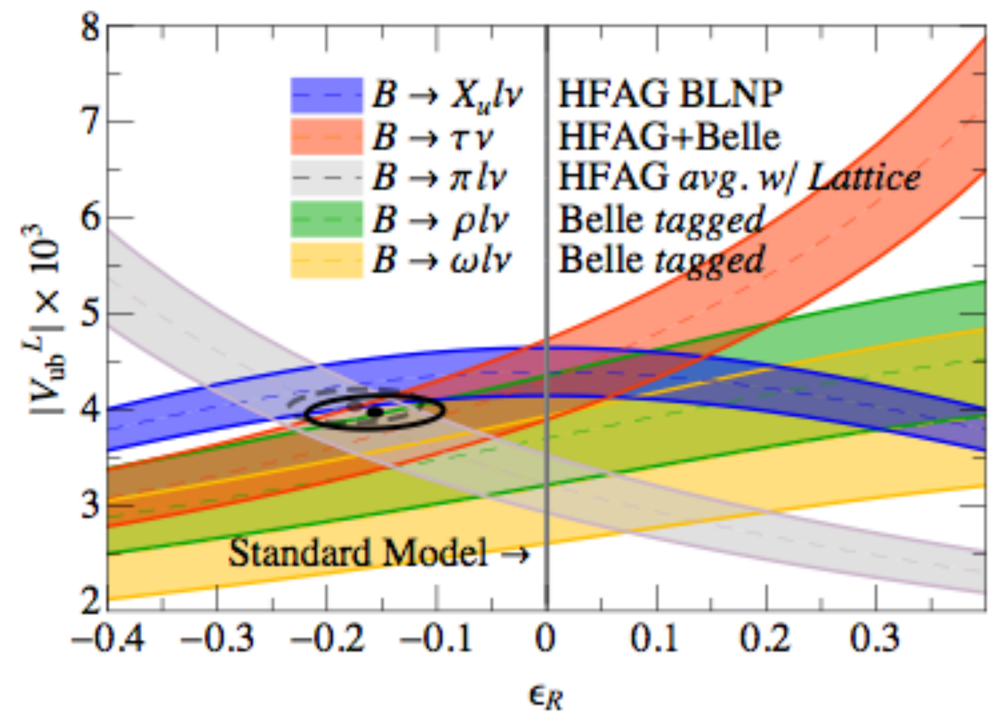
- Only Belle II can resolve $|V_{ub/cb}|$ exclusive/ inclusive puzzles (or → NP).

→ Decay differentials & hadronisation in inclusive.

$|V_{ub}|$ @ 2-3% precision for all approaches!







[F. Bernlochner, ST, CKM2012],
see also [Buras. et. al., arXiv:1007.1993]

H^+ Search: $B^+ \to \tau\upsilon, \mu\upsilon$

Babar, B→ τ ν (SL) PRD88 031102 (2013)
Belle, B→ τ ν (Had) PRL110 131801 (2013)
Belle, B→ τ ν (SL) Preliminary (2014 CKM)

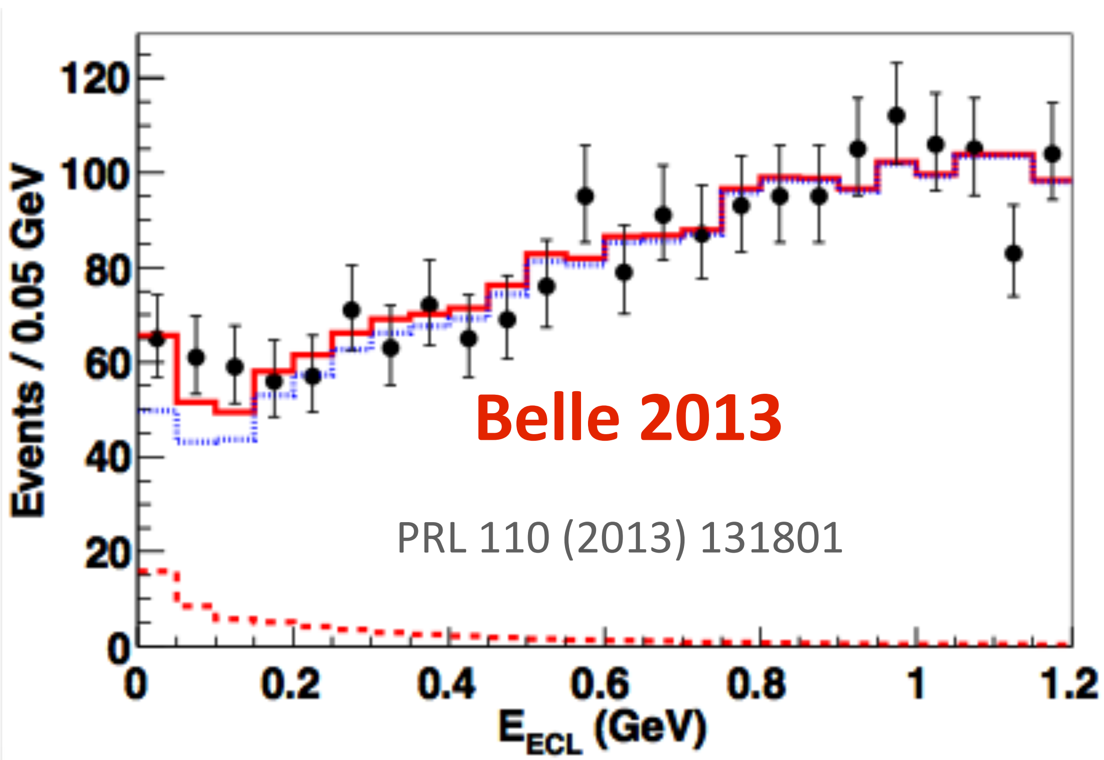
$$\mathrm{BR}(B_u \to \tau\nu_\tau) = \frac{G_F^2 f_B^2 |V_{ub}|^2}{8\pi} \tau_B m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left[1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \lambda_{bb}\lambda_{\tau\tau}\right]^2$$

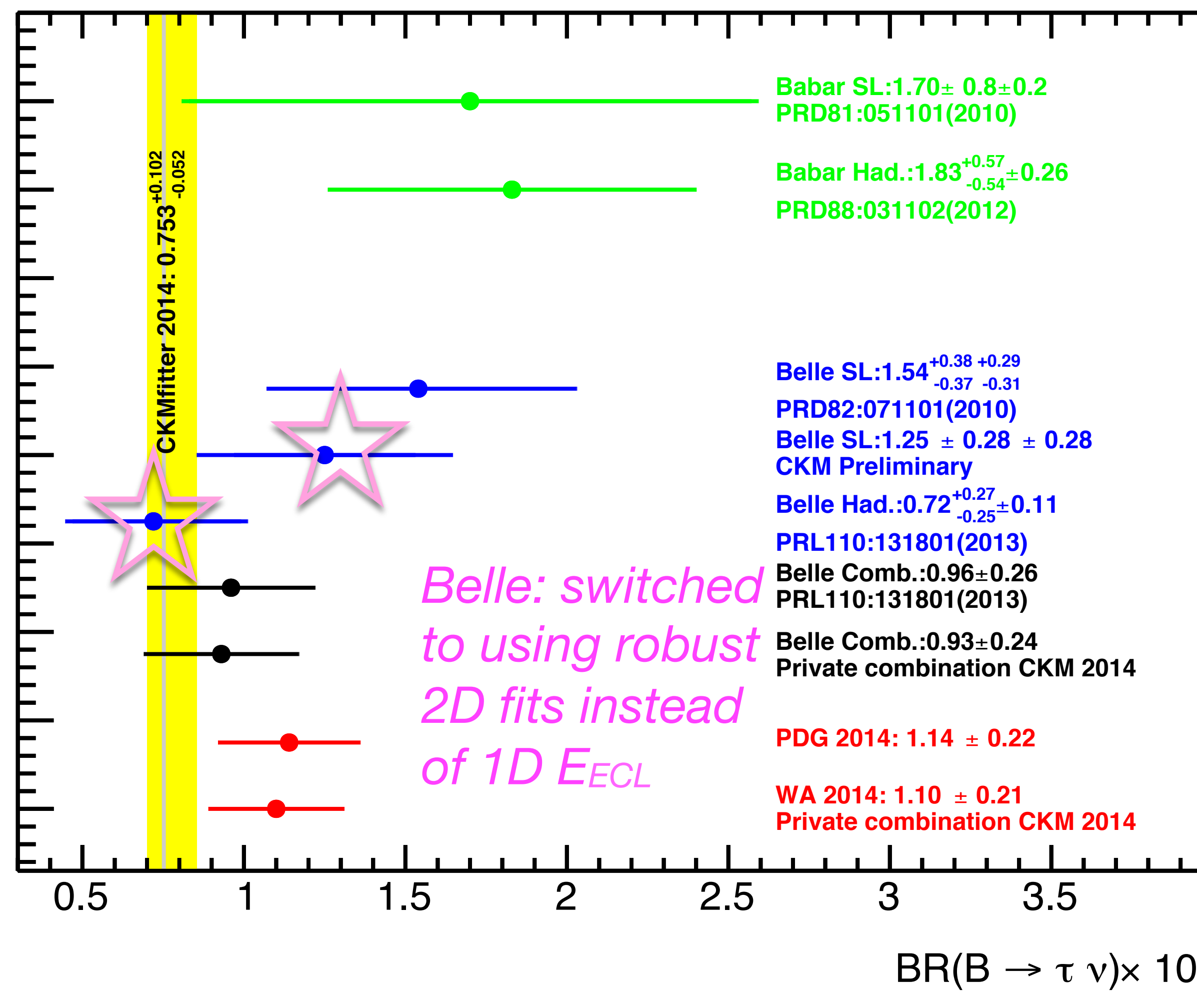
BF_{SM}

r_H

2HDM scenarios

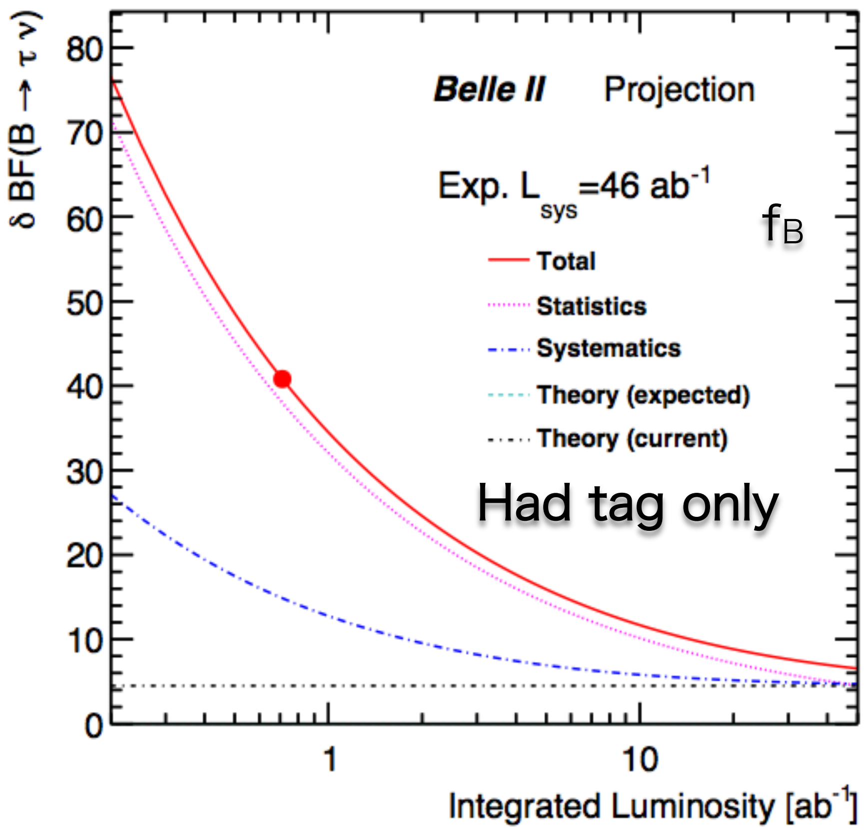
Type	λ_{UU}	λ_{DD}	λ_{LL}
I	$\cot\beta$	$\cot\beta$	$\cot\beta$
II	$\cot\beta$	$-\tan\beta$	$-\tan\beta$
III	$\cot\beta$	$-\tan\beta$	$\cot\beta$
IV	$\cot\beta$	$\cot\beta$	$-\tan\beta$



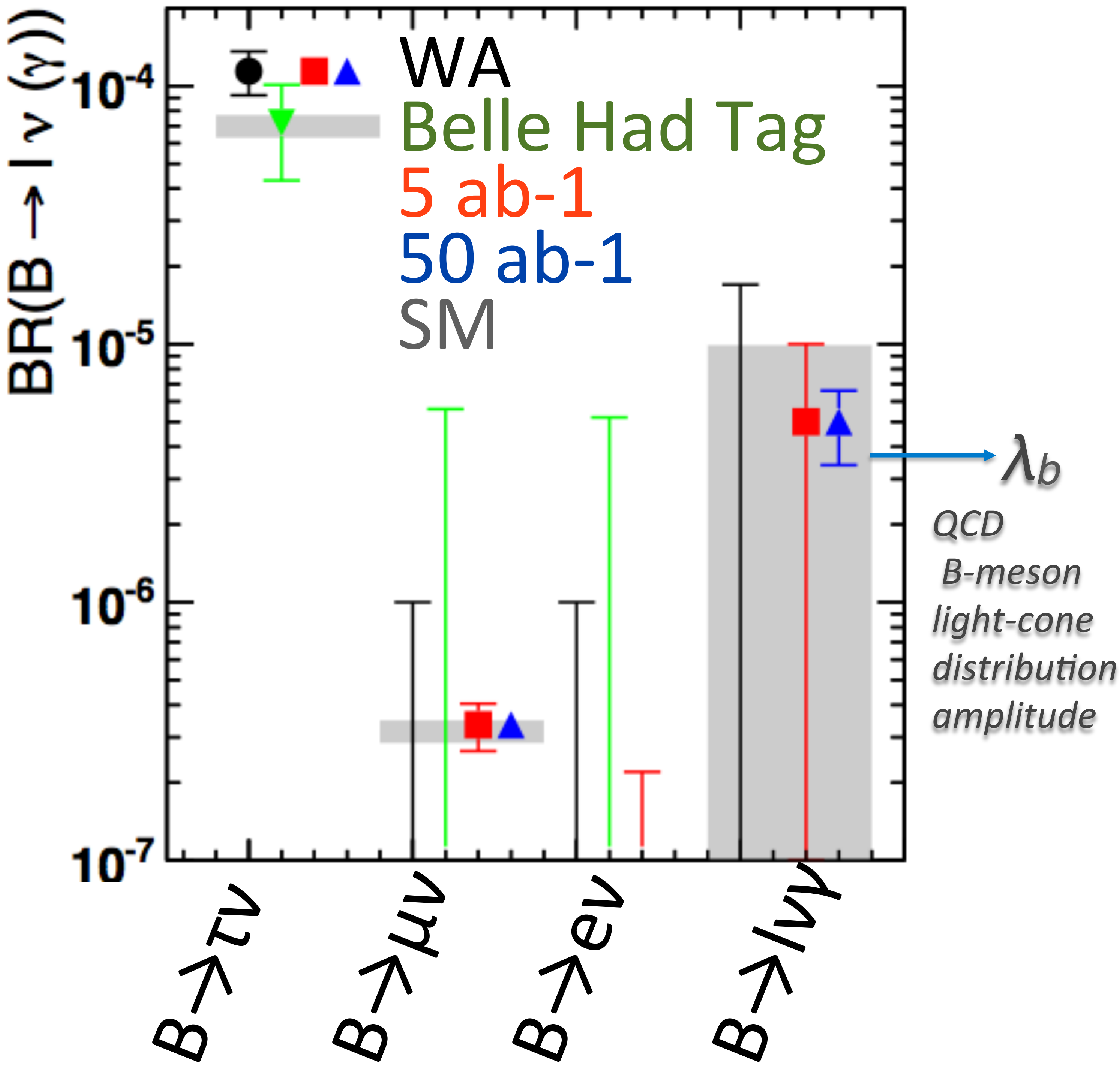


B→τ/e/μν(γ) Projections

Belle, B→ μ ν , e ν (Had) arXiv:1406.6356

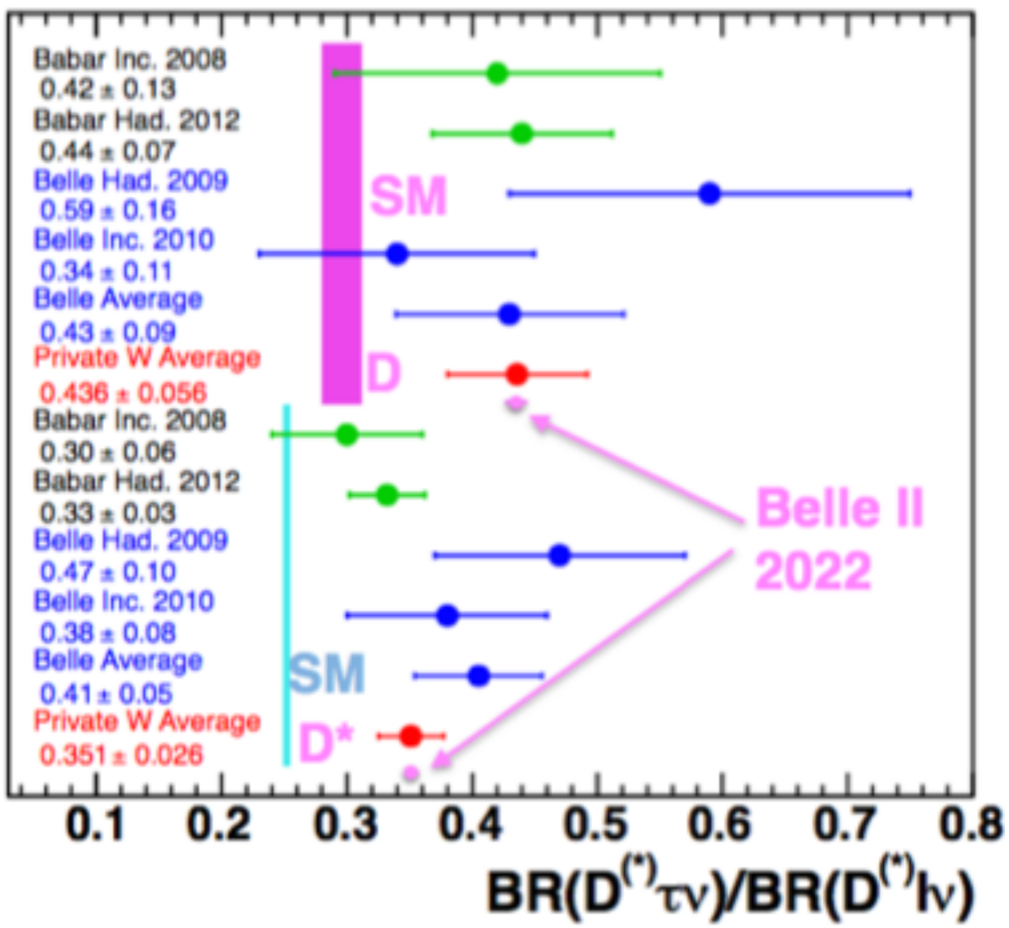


K_L momentum measured by layer timing coincidence – not available at Belle.



$B \rightarrow D^{(*)}\tau\nu$ (& $D^{(*)}\pi\pi l\nu$)

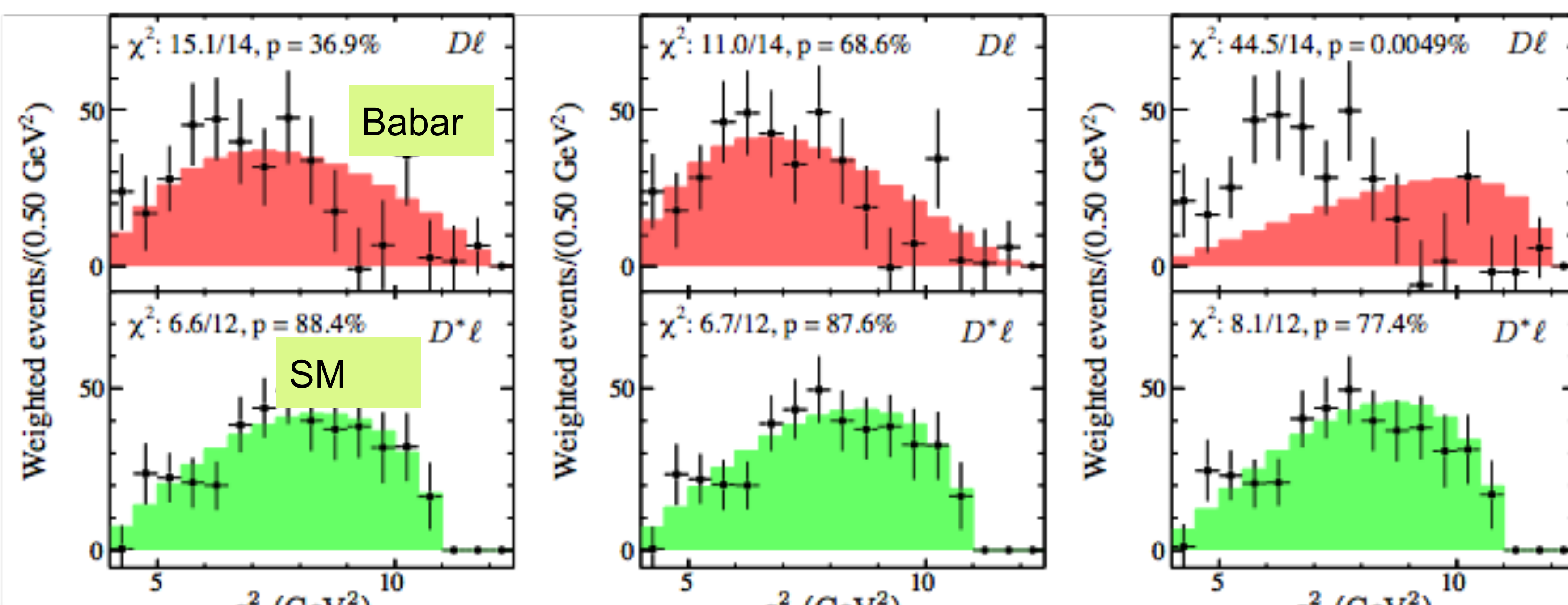
Babar, $B \rightarrow D(*)\ \tau\ \nu$, PRD88 072012 (2013)



- $B \rightarrow D^{(*)}\ \tau\nu$: WA is ~5 σ from the SM!
  - *Differentials and NP observables (A_{FB}).*
- *Belle (still) working hard on Had-tag result.*

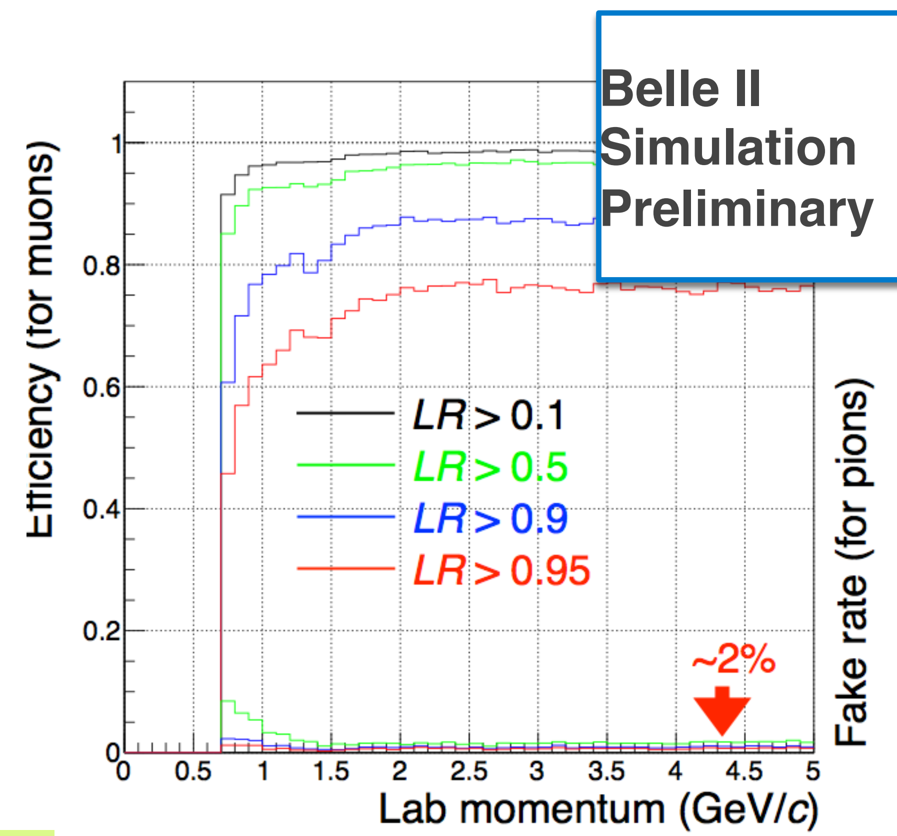
Large background ($D^{*(**)}l\nu$, D^*X)

Belle II → better low p_T tracking (Eff. ~2x @ p_T<150 MeV), & low p PID.



tanβ/m_H=0.3 GeV^{-1}

tanβ/m_H=0.45 GeV^{-1}

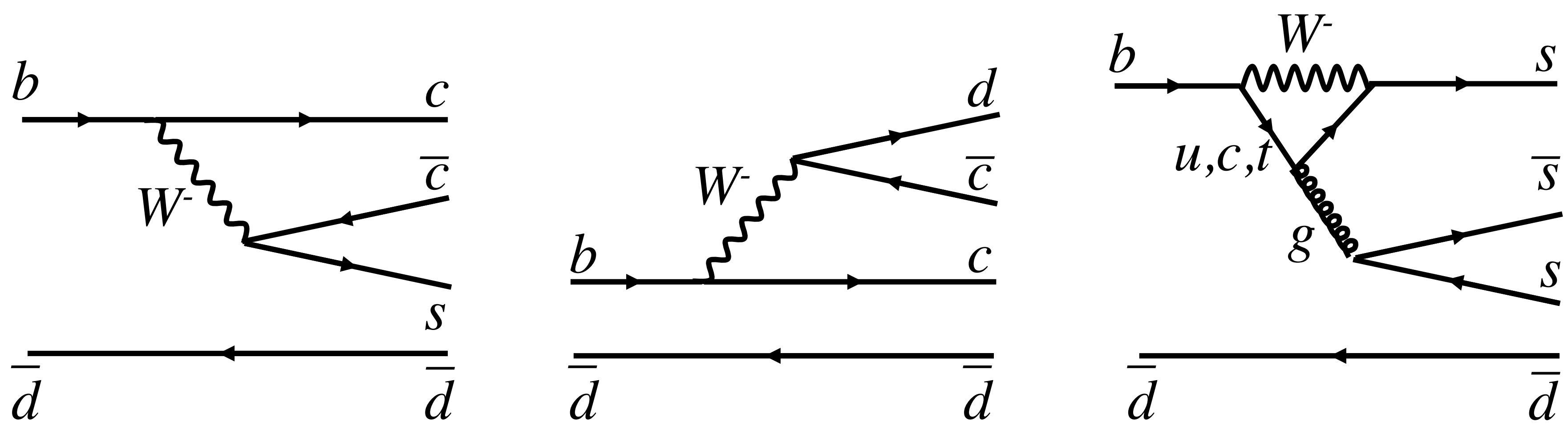


CP Violation in B Decays

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (1.4^\circ)$	0.7°	0.4°	1.6°	0.6°
	α [°]	85 ± 4 (Belle+BaBar)	2	1		
	γ [°] $(B \to D^{(*)} K^{(*)})$	68 ± 14	6	1.5	4	1
	$\phi_s (B_s \to J/\psi \phi)$	0.05^*			0.025	0.009
Gluonic Penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K_S^0 K_S^0 K_S^0)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{\text{eff}} (B_s \to \phi \phi)$ [rad]	$\pm 0.18^*$			0.12	0.03
	$\beta_s^{\text{eff}} (B_s \to K^{*0} \bar{K}^{*0})$ [rad]	$\pm 0.19^*$			0.13	0.03
Direct CP in hadronic Decays	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04		

Driving questions: *New sources of CPV?*

Time dependent CPV



$J/\psi K_S^0, \psi(2S)K_S^0, \chi_{c1}K_S^0,$ $\eta_c K_S^0, J/\psi K_L^0,$ $J/\psi K^{*0}(K^{*0} \to K_S^0\pi^0)$	$D^{*+}D^-, D^+D^-$ $J/\psi\pi^0, D^{*+}D^{*-}$	$\phi K^0, K^+K^-K_S^0,$ $K_S^0K_S^0K_S^0, \eta' K^0, K_S^0\pi^0,$ $\omega K_S^0, f_0(980)K_S^0$

← Increasing Tree diagram amplitude

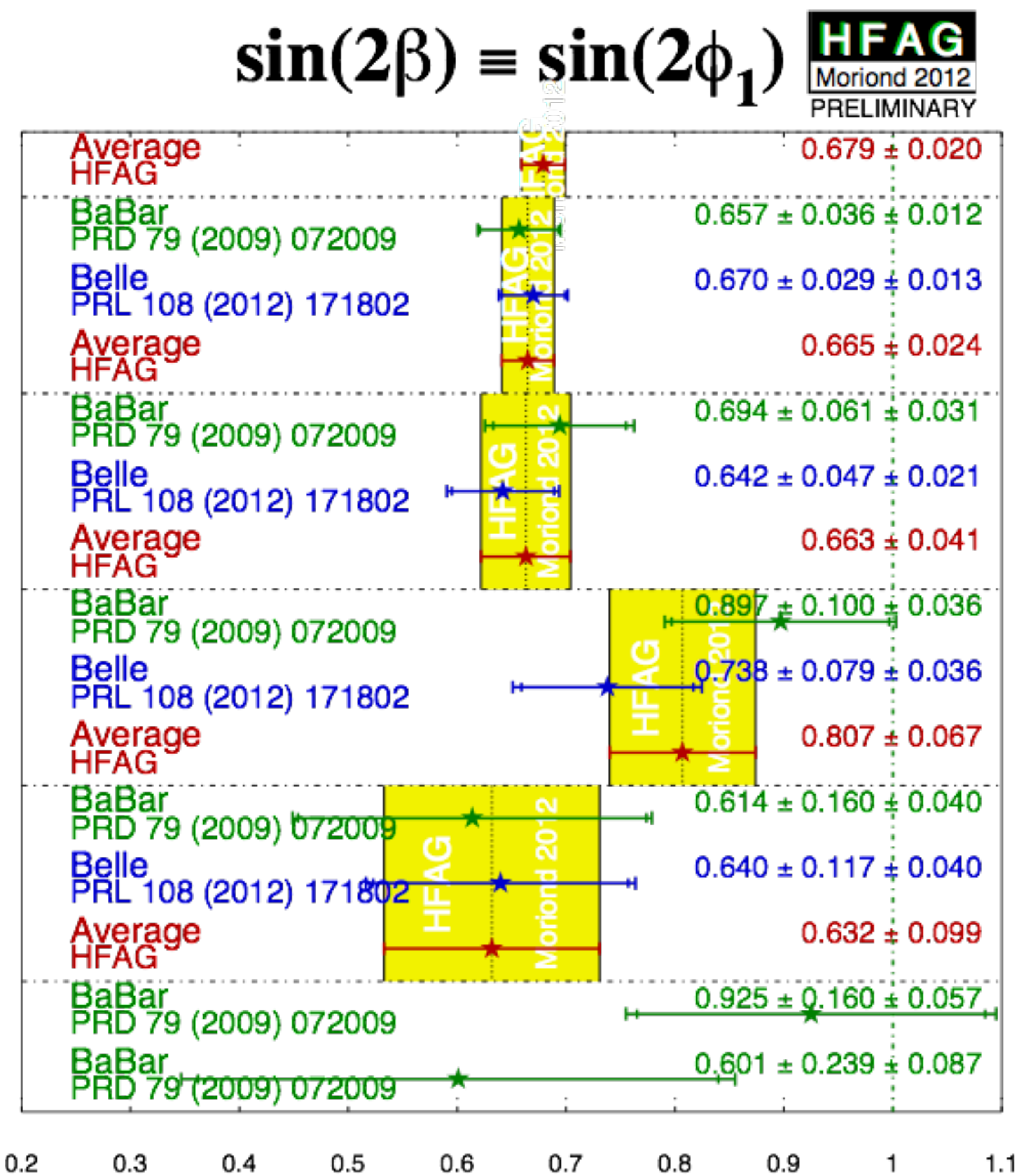
Increasing NP sensitivity →

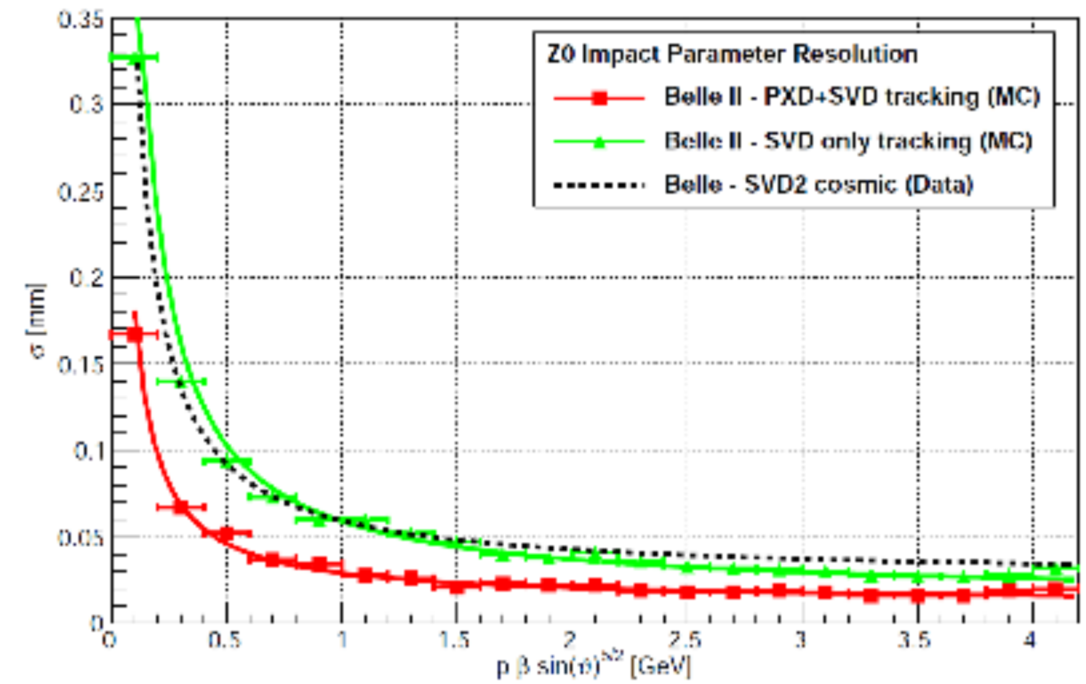
SM: b→s Penguin phase = $(c\bar{c})\ K^0$

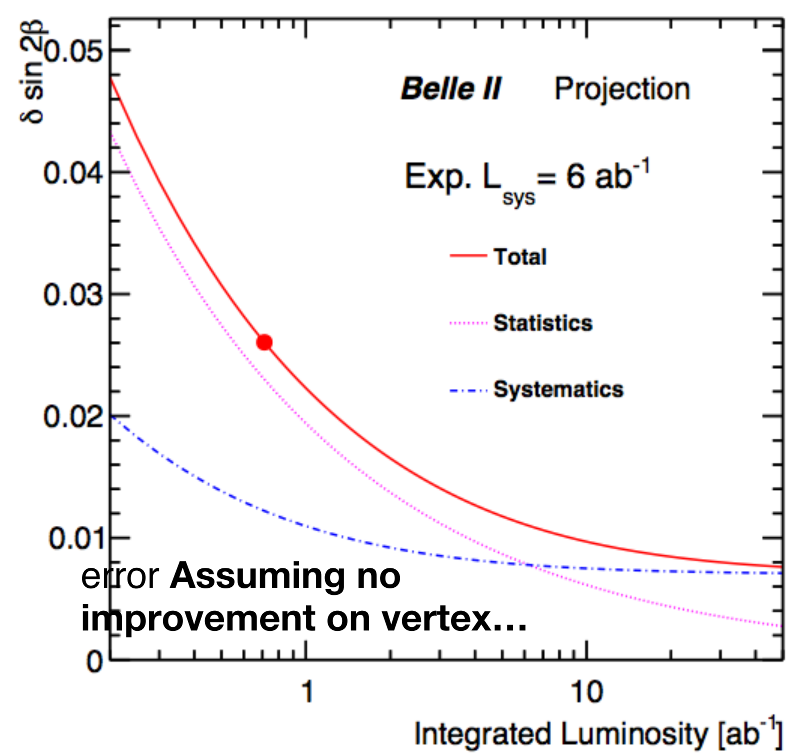
+ New Physics with New Phase

β, b → c c s & b → c c d

- Many ways to measure β, and all agree within uncertainties





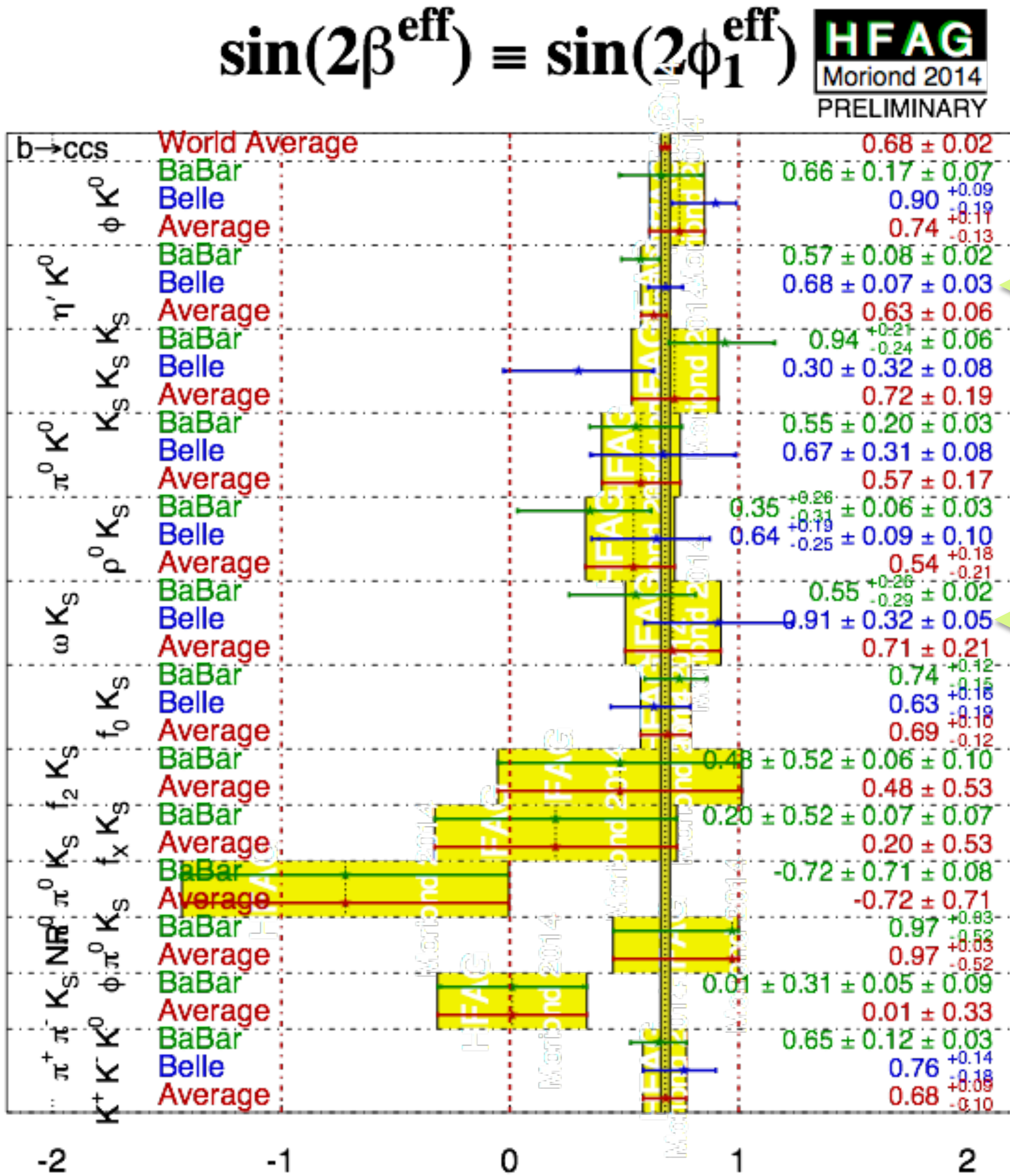


sys. dominated by **vertex** resol^{n}.

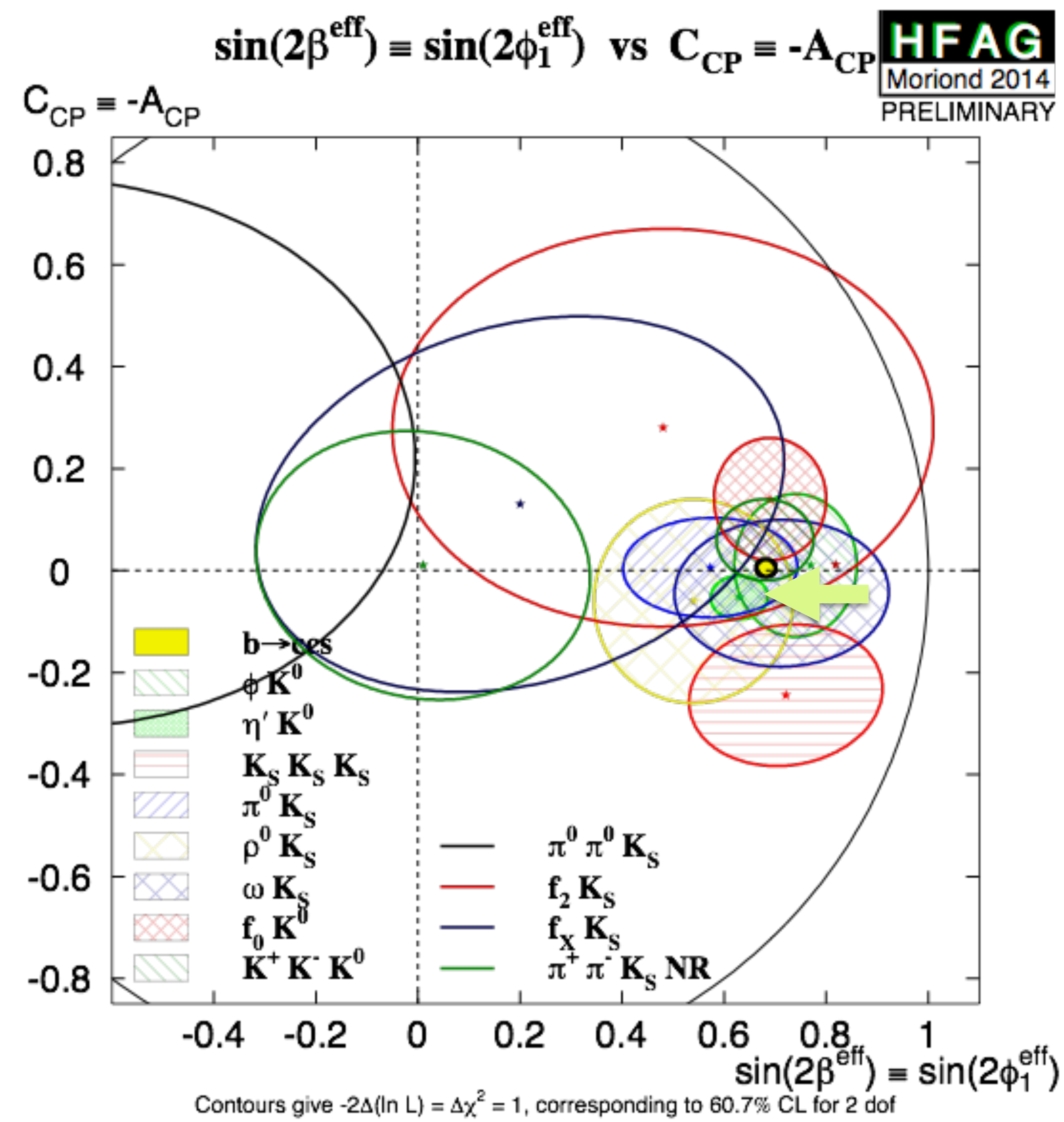
*σ(z) on Vertex: Belle~**61μm** ⇣ Belle II~**18μm***

+ better stats allow for only best quality vertices to be used.

β, b → s s s



Belle, B → η' K0, arXiv:1408.5991 (2014)
Belle, B → ω Ks0, PRD 90 012002 (2014)

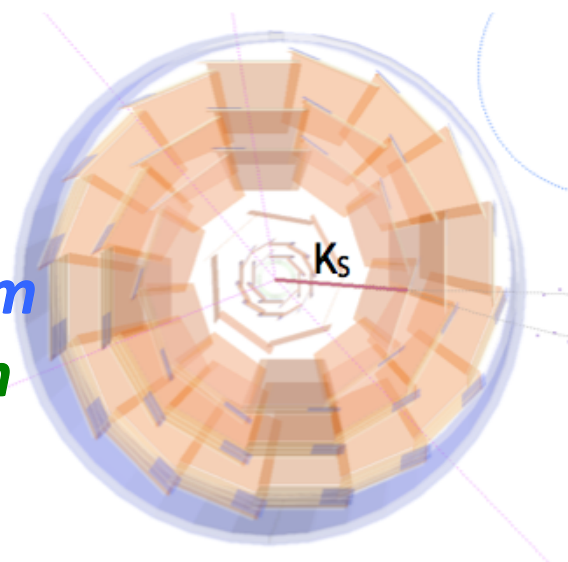


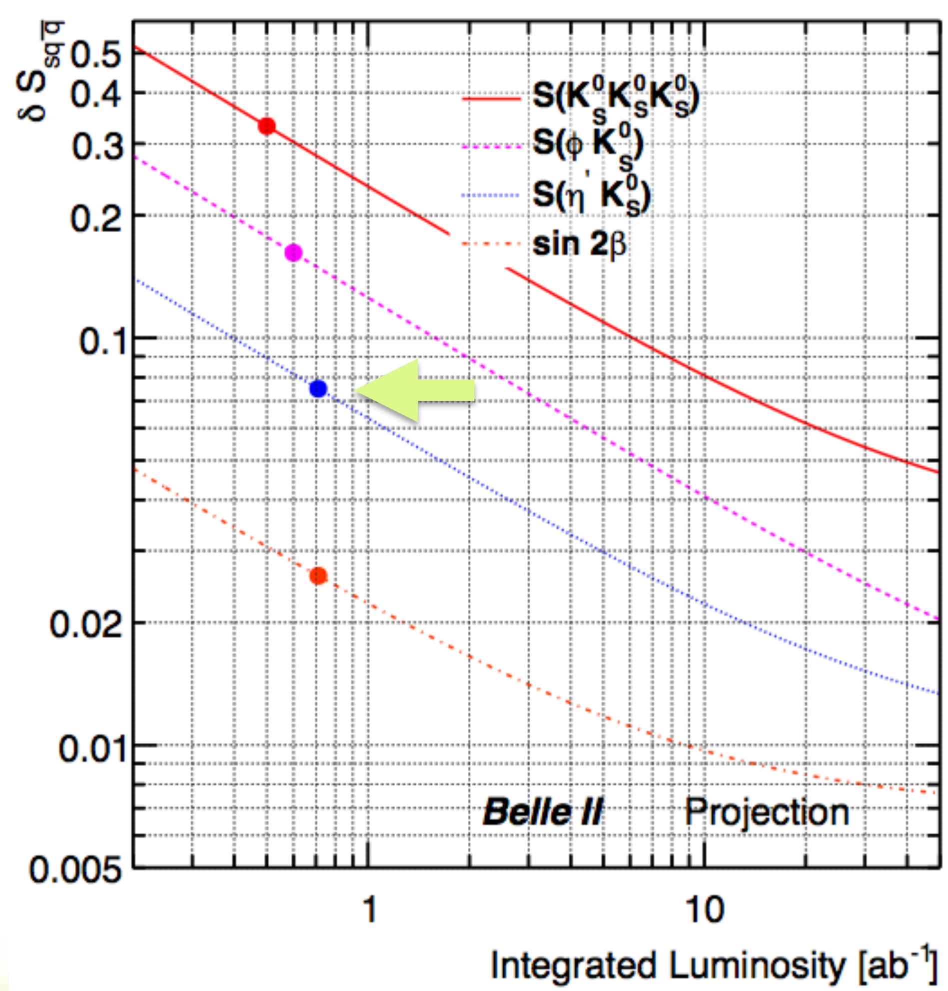
Penguin β: Future

VXD Larger acceptance (by 30%) for detection of π from K_S **improves S(b→s)**

4→ 6 layers, R_{outer}=9→14cm

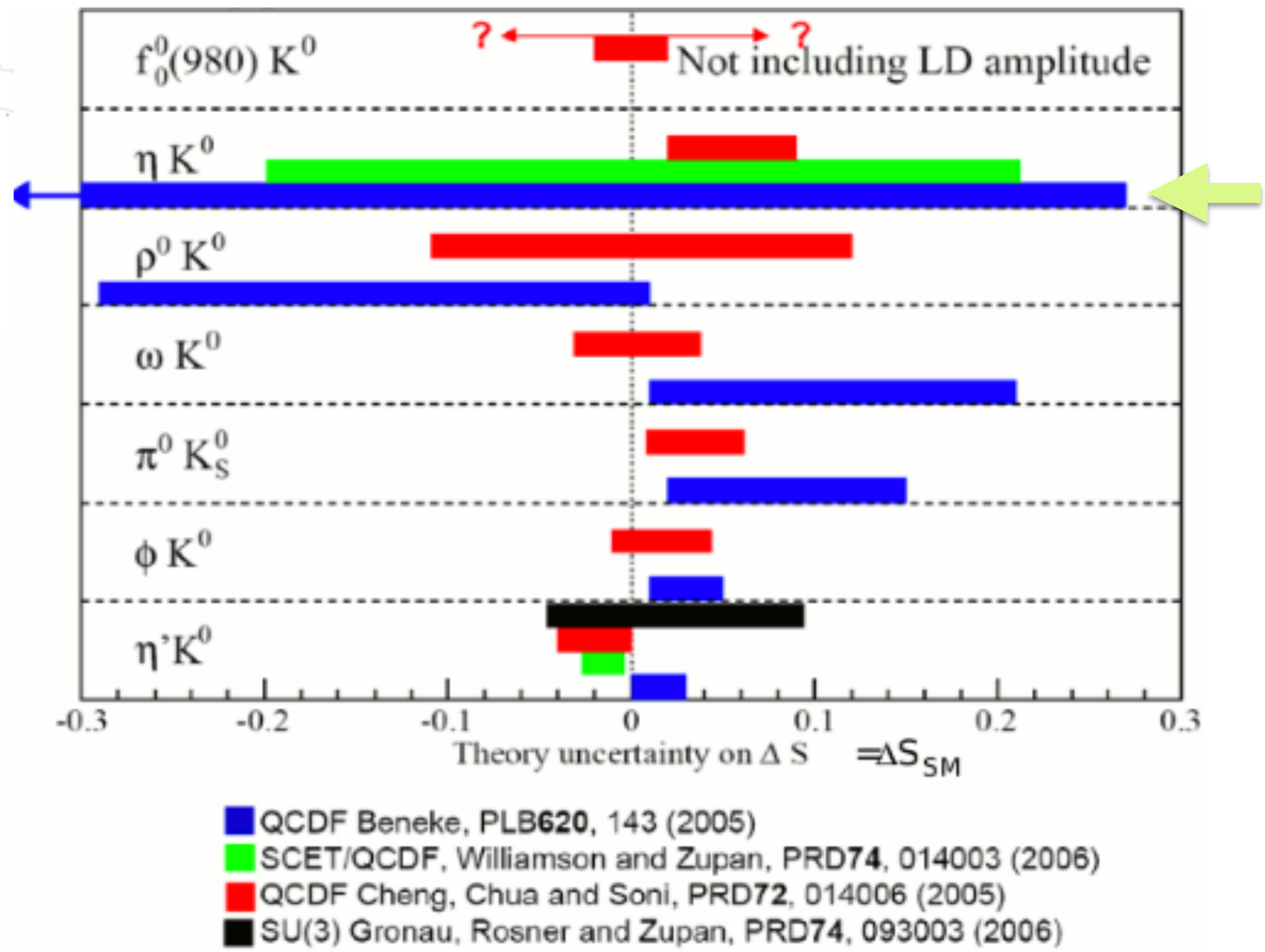
CDC small cells R_{outer}=20cm





Prospect: δS(b→ s)~ 0.012 @ 50 ab^{-1}

But, firm SM upper bound required!



From b → s penguin dominated modes!

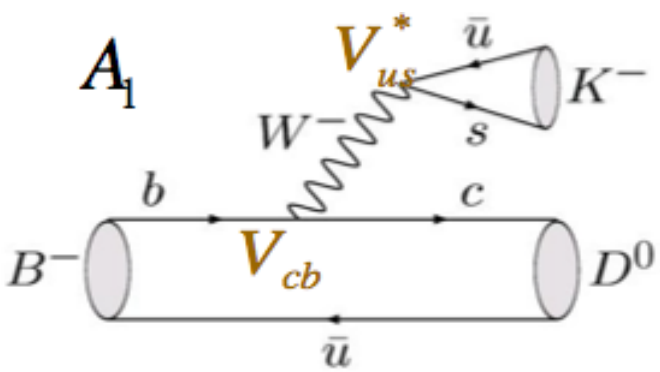
- *how large is the tree pollution in the SM?*
- *how large can the effects be given LHC constraints?*
- *new physics tests using sum rules?*

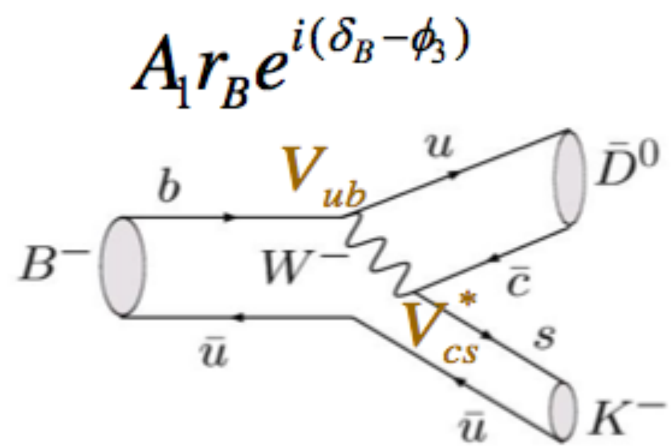
$\phi_3 = \gamma$: Now

Belle, B- → DK-, D → K+π-π0, PRD89 072008 (2013)
Babar, B- → D(*)K(*), PRD87 052015 (2013)
Belle, B± → DK±, D→ Ks⁰π+π-, PRD 85, 112014 (2012)

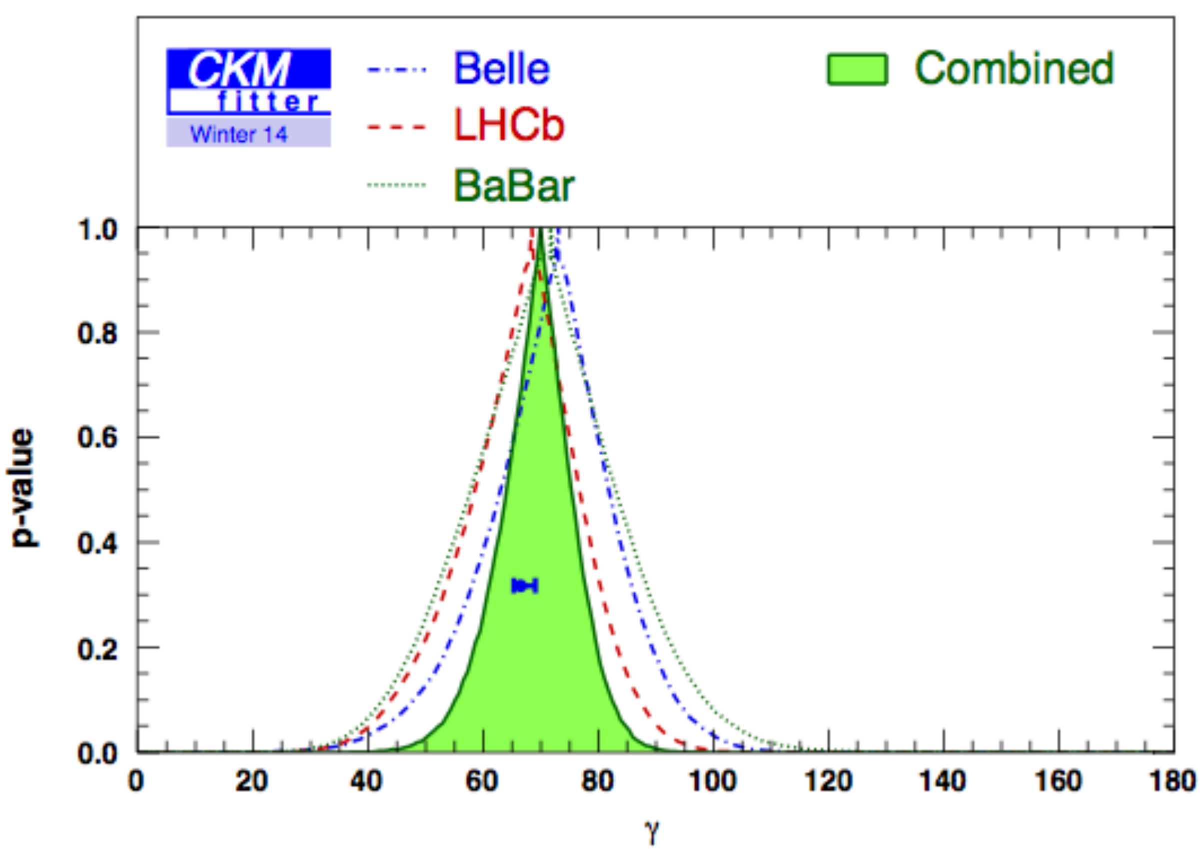
Based on Tree-Level $B \rightarrow D^{(*)}K^{(*)}$ methods.

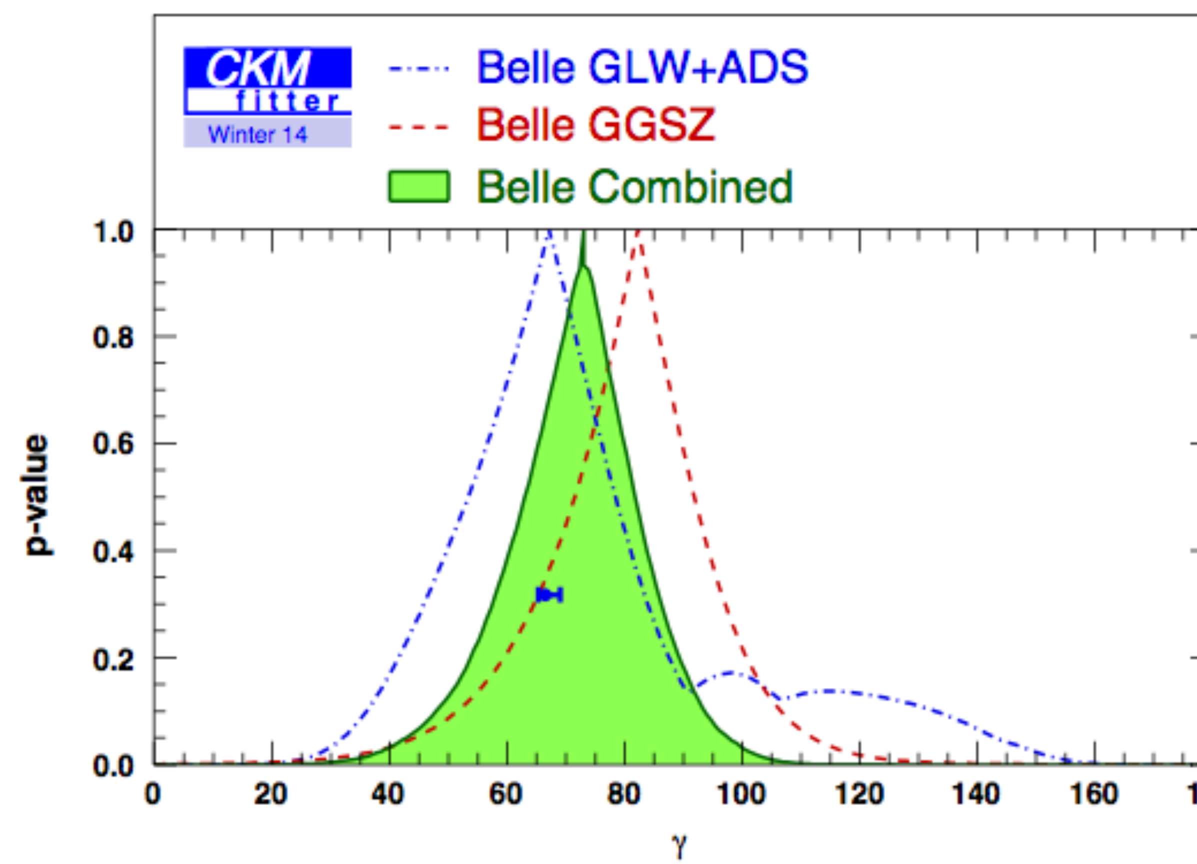
e.g. GLW+ADS, DK, D^*K, DK^*





γ[BaBar] = (72 ± 18)°
γ[Belle] = (73 ± 14)°
γ[combined] = $(70.0^{+7.7}_{-9.0})$°



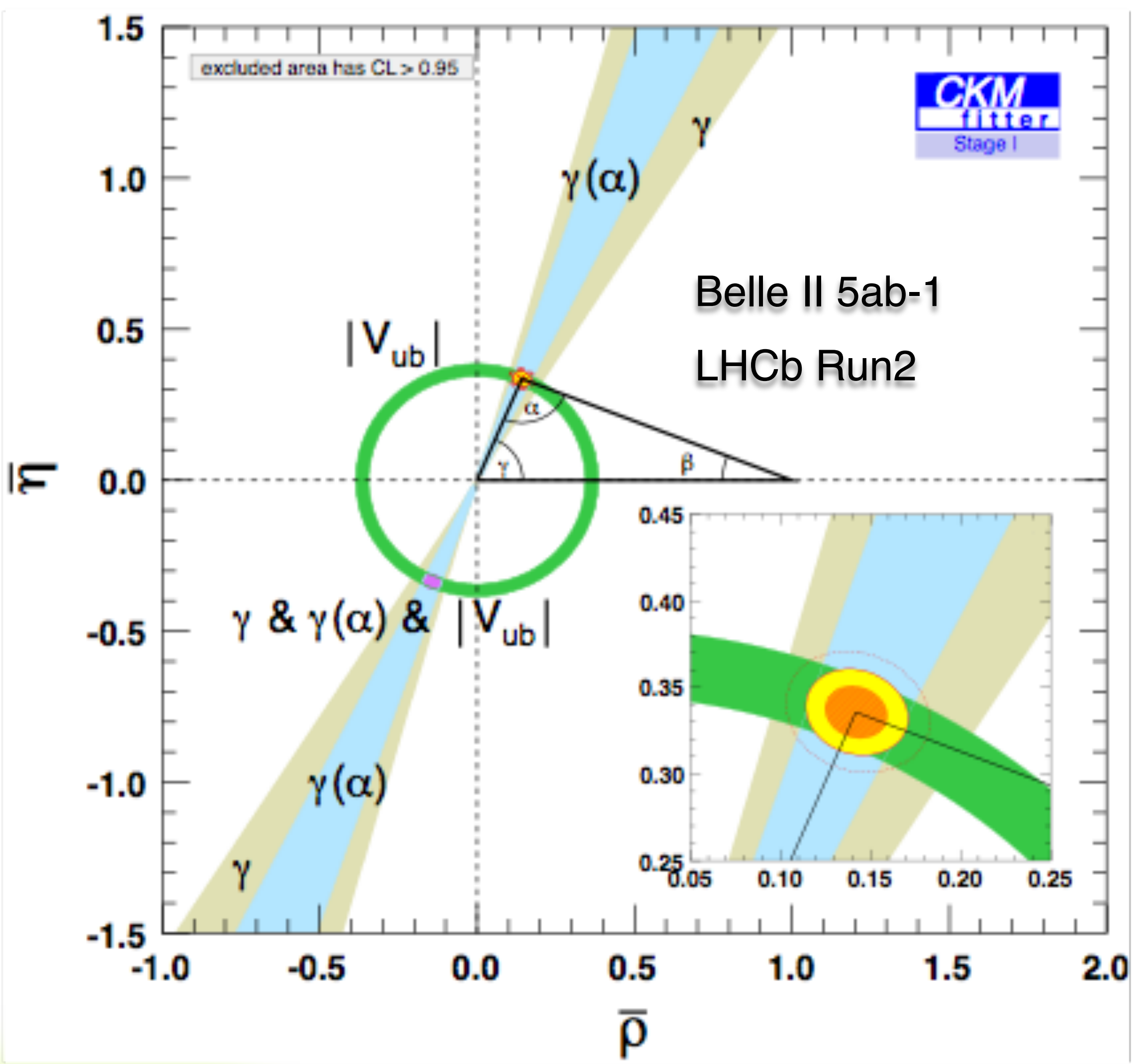


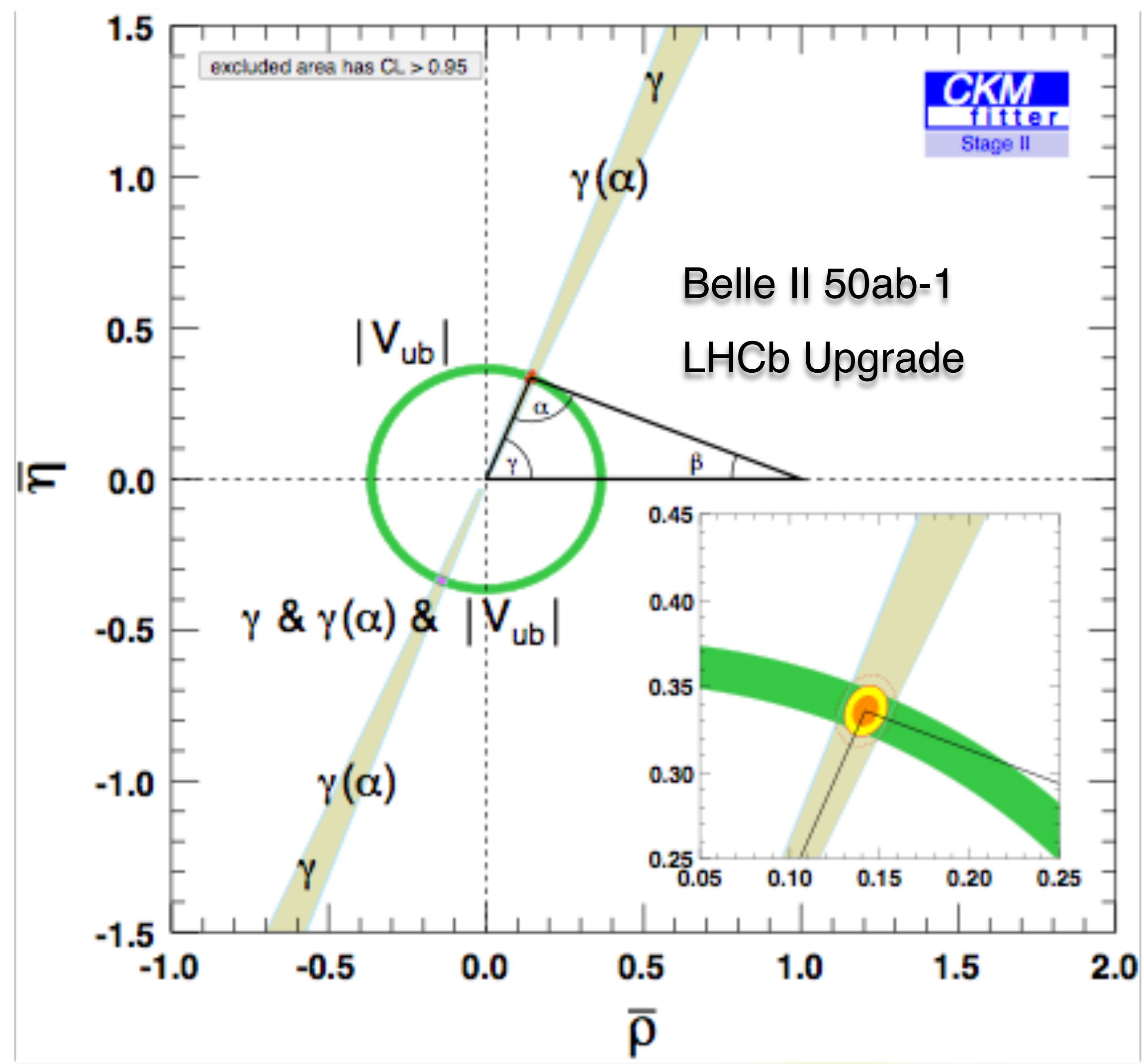
UT angle $\Phi_3=\gamma$: Future

Experiment.
Naive scaling to 50 ab^{-1} gives Δ~1.5-2°
… and still statistics limited!!
(based on $D \to K_S\pi\pi$ only).

Many more D modes to explore.

Theory *Errors?*
Charm mixing, CPV in charm decay
Kaon mixing, Higher order EW
All < 1°: Golden
But what about NP scenarios?

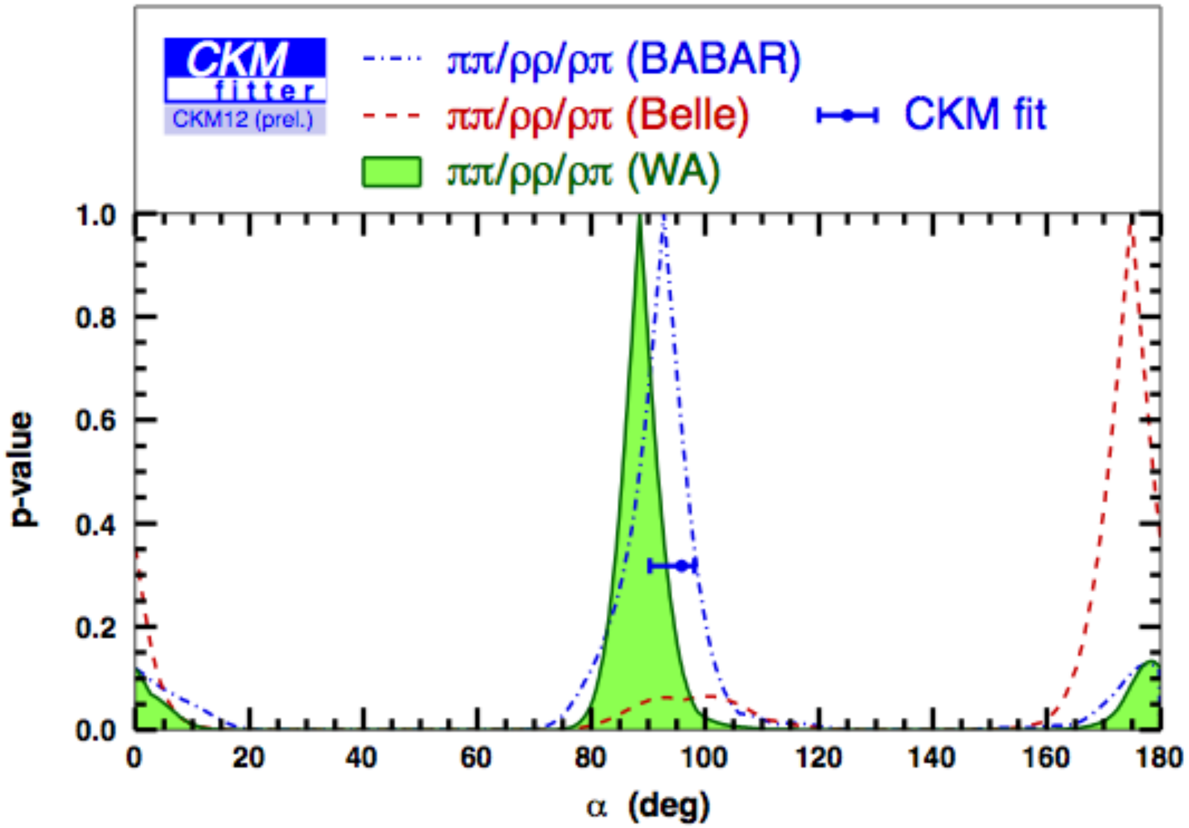




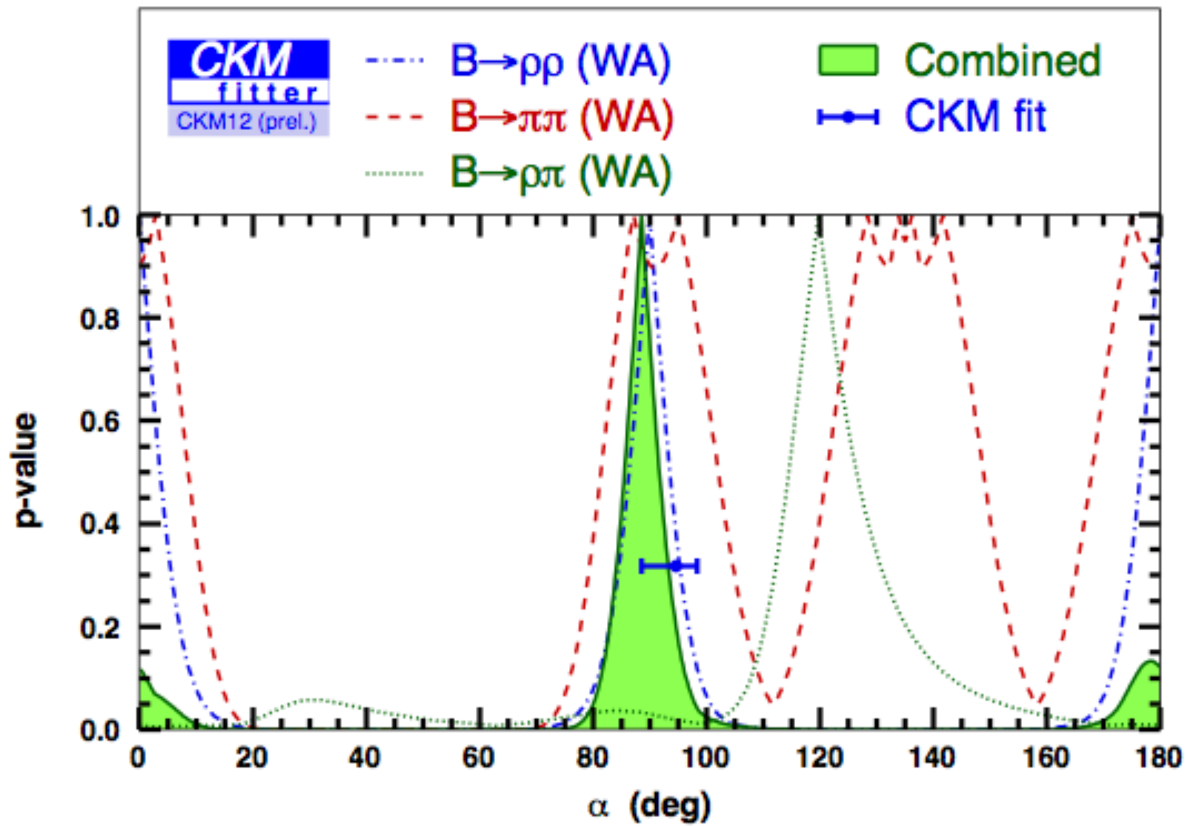
$\alpha = \Phi_2$

Constraints from $B \to \pi\pi$, $\rho\pi$, $\rho\rho$, $a_1\pi$.
Dominated by $B \to \rho^+\rho^0$.
Large tension between modes and experiments.

Belle, $B \to \pi0\ \pi0$ (Preliminary, ICHEP14)
Belle, $B \to \pi+\ \pi-$ PRD 88, 092003 (2013)
Belle, $B \to \rho^0 \rho^0$ PRD 89, 072008 (2014)
Babar, $B \to \rho^0 \pi^0$ PRD 88, 012003 (2013)



2012 CKM



2014 Winter

2012 CKM		2014 Winter
88.8 [+4.5 -4.3]	*Direct*	85.4 [+4.0 -3.9]
95.9 [+2.2 -5.6]	*CKMFitter*	93.6 [+3.2 -2.9]

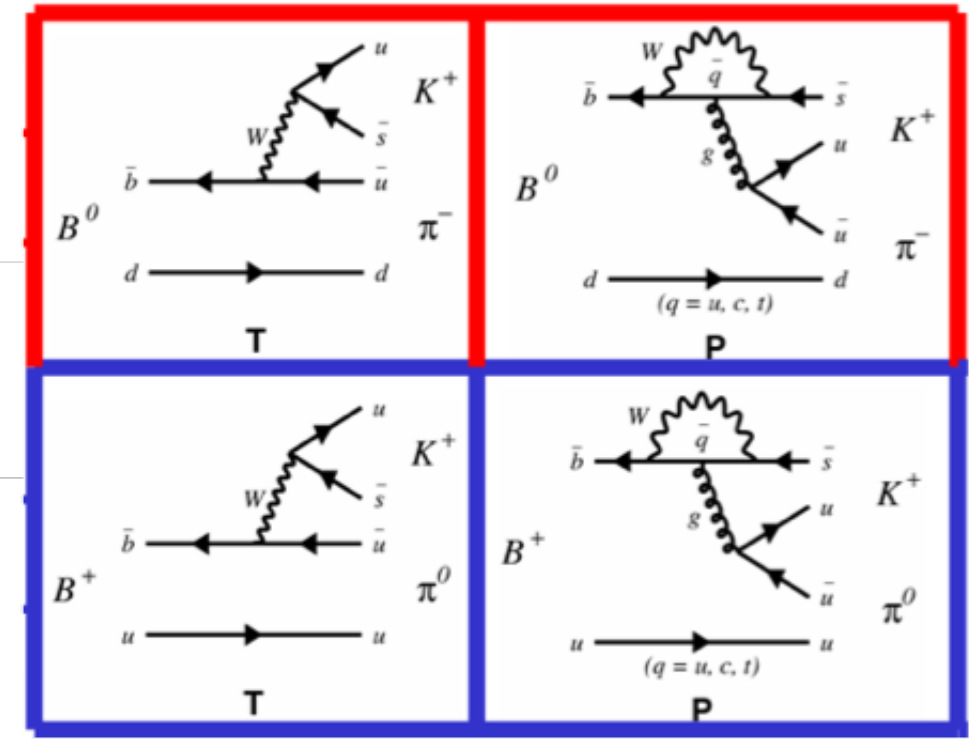
Direct CPV in B→Kπ & K*π : Now

- A_{CP} in hadronic modes cannot be understood w/out full isospin analysis.

  ➡ Need neutral modes.
- Large effects or signs depend on V or P.

$B^0 \to K^+\pi^-$

$B^+ \to K^+\pi^0$



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

$A(K^0\pi^0)$ = 0.006 ± 0.06
$A(K^0\pi^+)$ = -0.015 ± 0.019
$A(K^+\pi^0)$ = 0.040 ± 0.021
$A(K^+\pi^-)$ = -0.082 ± 0.006

Belle, PRD87, 031103(R)(2013)

$A_{CP}(K^{*+}(K_S^0\pi^+)\pi^0)$ = -0.52 ± 0.14 ± 0.04 ± 0.04
$A_{CP}(K^{*+}(K^+\pi^0)\pi^0)$ = -0.06 ± 0.24
$A_{CP}(K^{*+}\pi^0)$ = -0.39 ± 0.13 (priv. average)
$A_{CP}(K^{*+}\pi^-)$ = -0.23 ± 0.06

BaBar, FPCP'14, 470 M BB (Preliminary)

Direct CPV in B→Kπ: Future

Q. New sources of CPV?

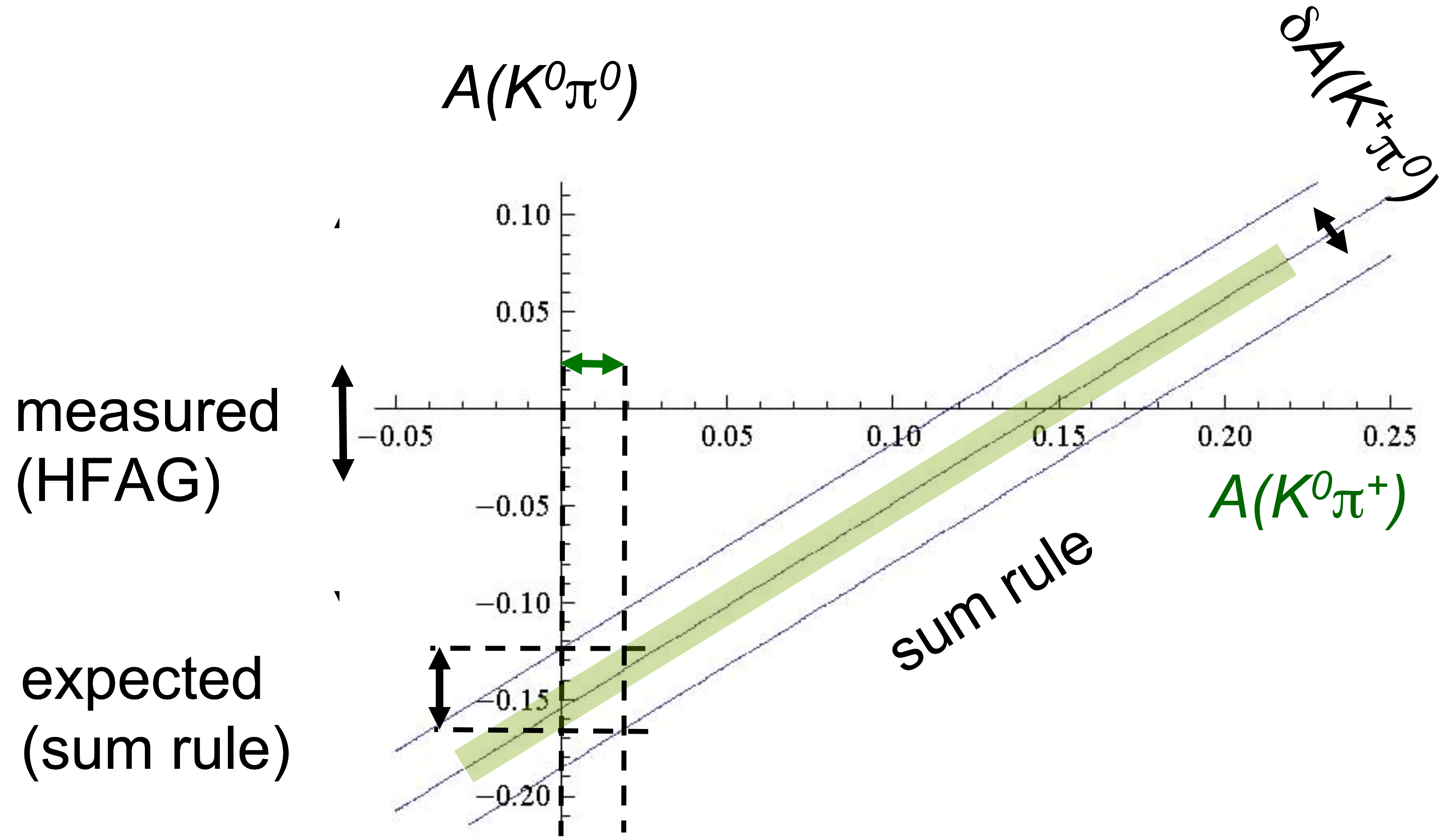
Discrepancy in isospin sum rule may be significant with 10ab-1.

HFAG, Summer'11

Belle II 50 ab^{-1}

Main $K^0 \pi^0$ systematics (tag-side interference) is reducible.

Theory: **Accuracy for T, C, P and P_{EW}?**



Explore this for πK^*, ρK, ρK^*!

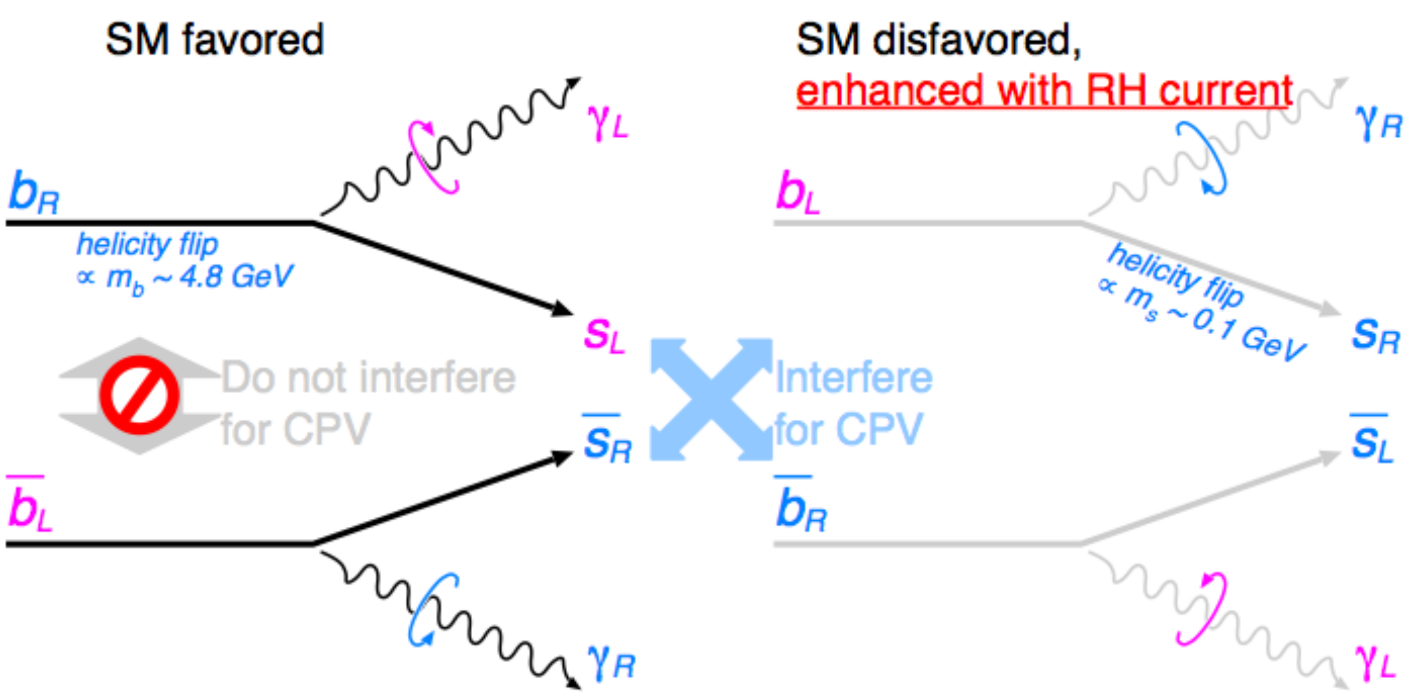
EWP, Radiative FCNC modes

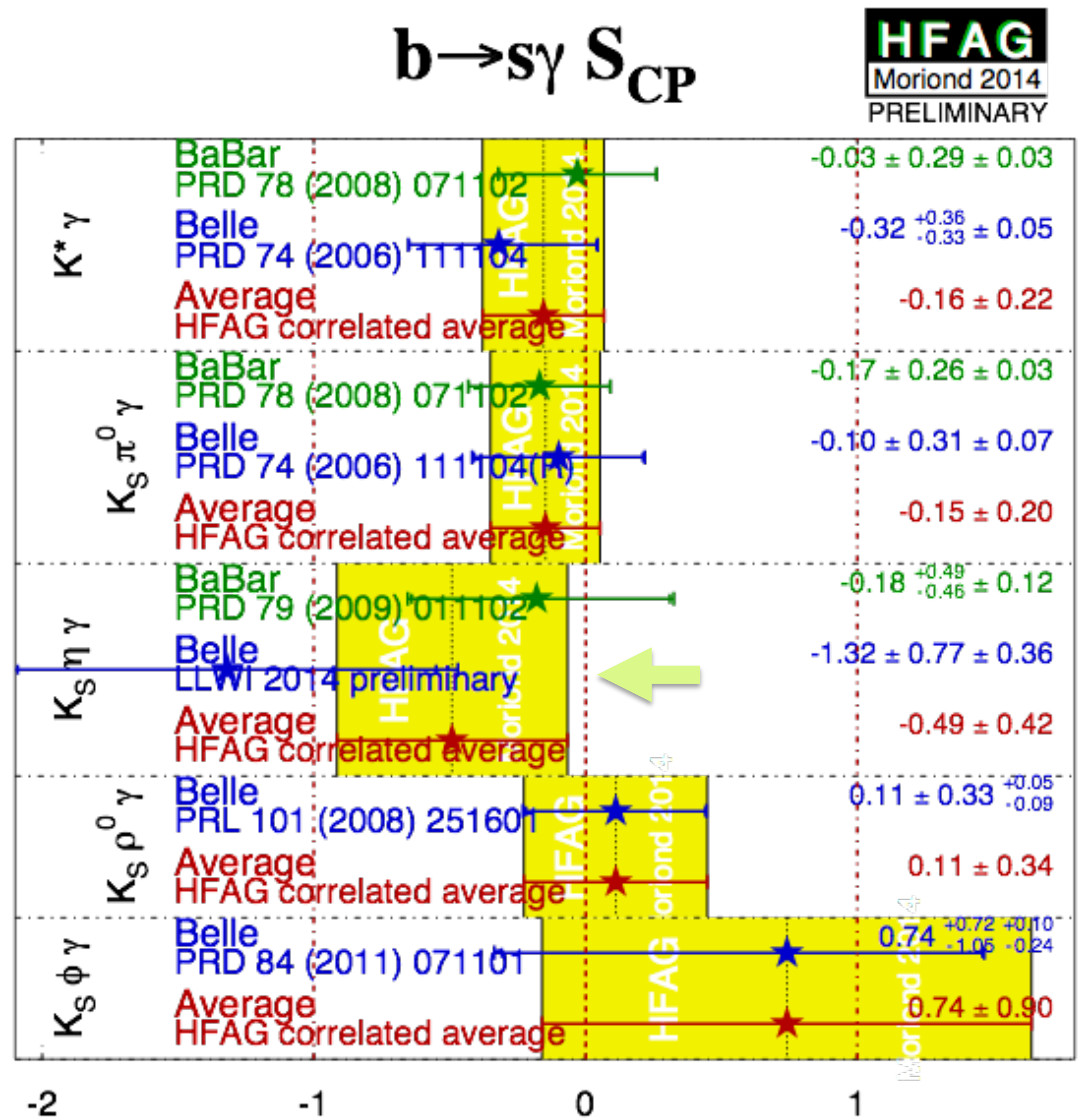
	Observables	Belle or LHCb (2014)	Belle II $5\ \mathrm{ab}^{-1}$	Belle II $50\ \mathrm{ab}^{-1}$	LHCb $8\ \mathrm{fb}^{-1}(2018)$	LHCb $50\ \mathrm{fb}^{-1}$
Radiative	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K_S^0\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035		
	$\phi_s^{\rm eff}(B_s \to \phi\gamma)$	± 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 $(B \to X_s\ell\ell)$	$\sim$20%	10%	5%		
	$q_0^2 A_{\rm FB}(B \to K^*\mu\mu)$	10%	TBC		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

Driving questions: *Right handed currents?*
Quark FCNCs beyond SM?

Mixing induced CPV in Radiative Penguins

Belle, B→ Ks η' γ Preliminary (2014)



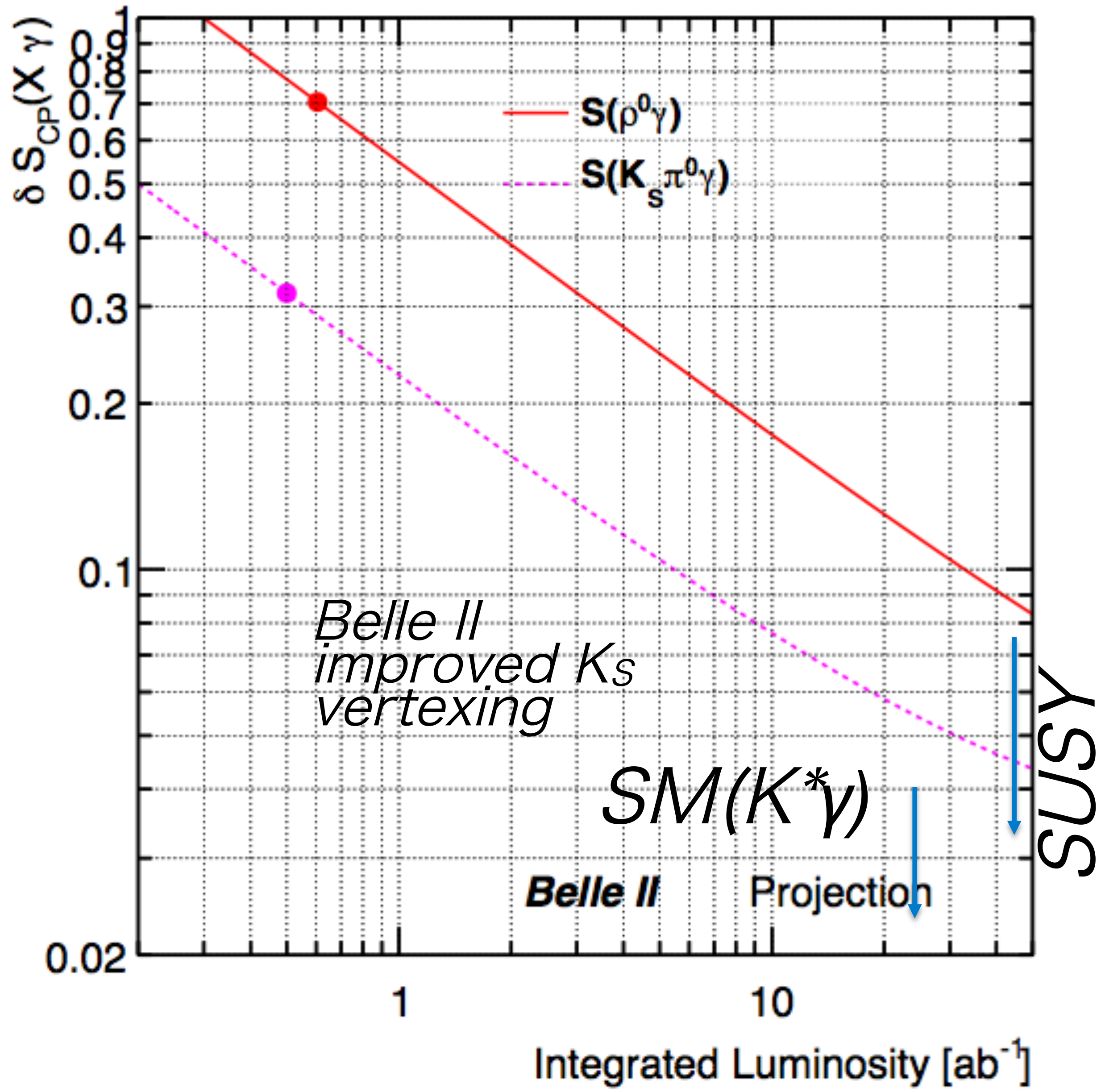


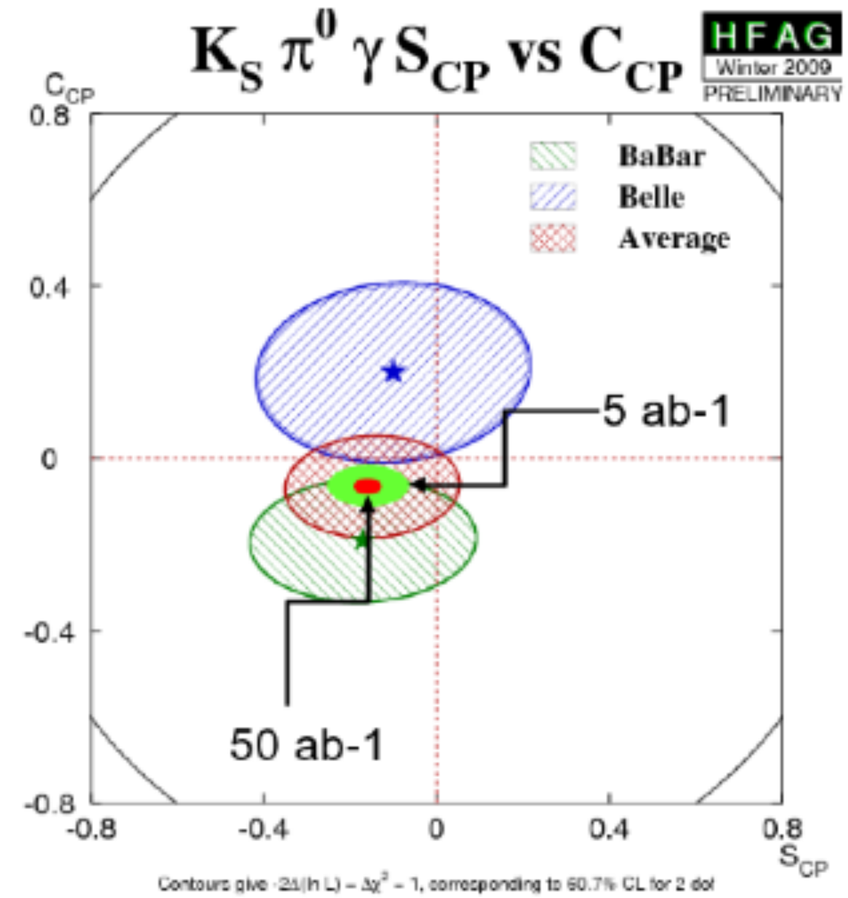
R-handed current is a signature of NP

$S = -2(m_s/m_b)\sin(2\phi_1) \sim \mathbf{-0.03}$

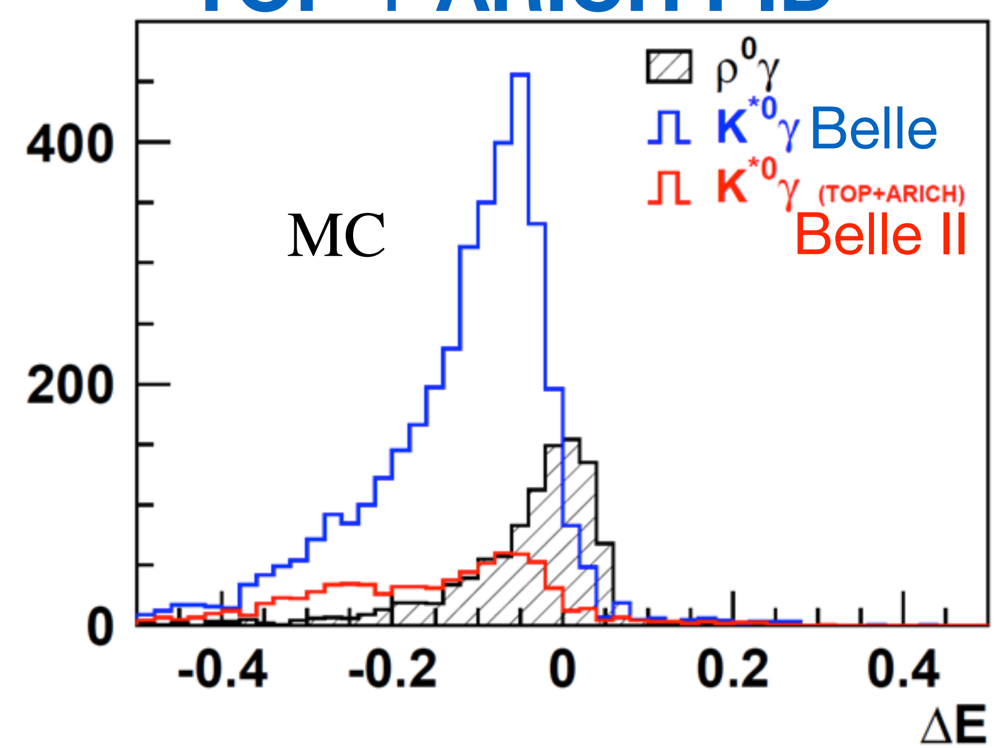
c.f. S=0.5 in **L-R** symmetric **NP** model

Mixing induced CPV in Radiative Penguins





TOP + ARICH PID

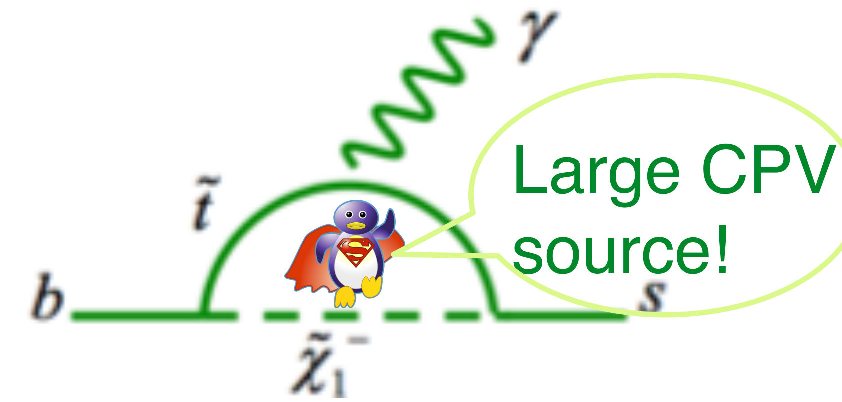


$$\Delta A_{CP}(\rho^0\gamma) \simeq A_{CP}(\rho^+\gamma) \simeq -(11 \pm 3|_{had}\,(?) \pm \Delta_{CKM})\%$$

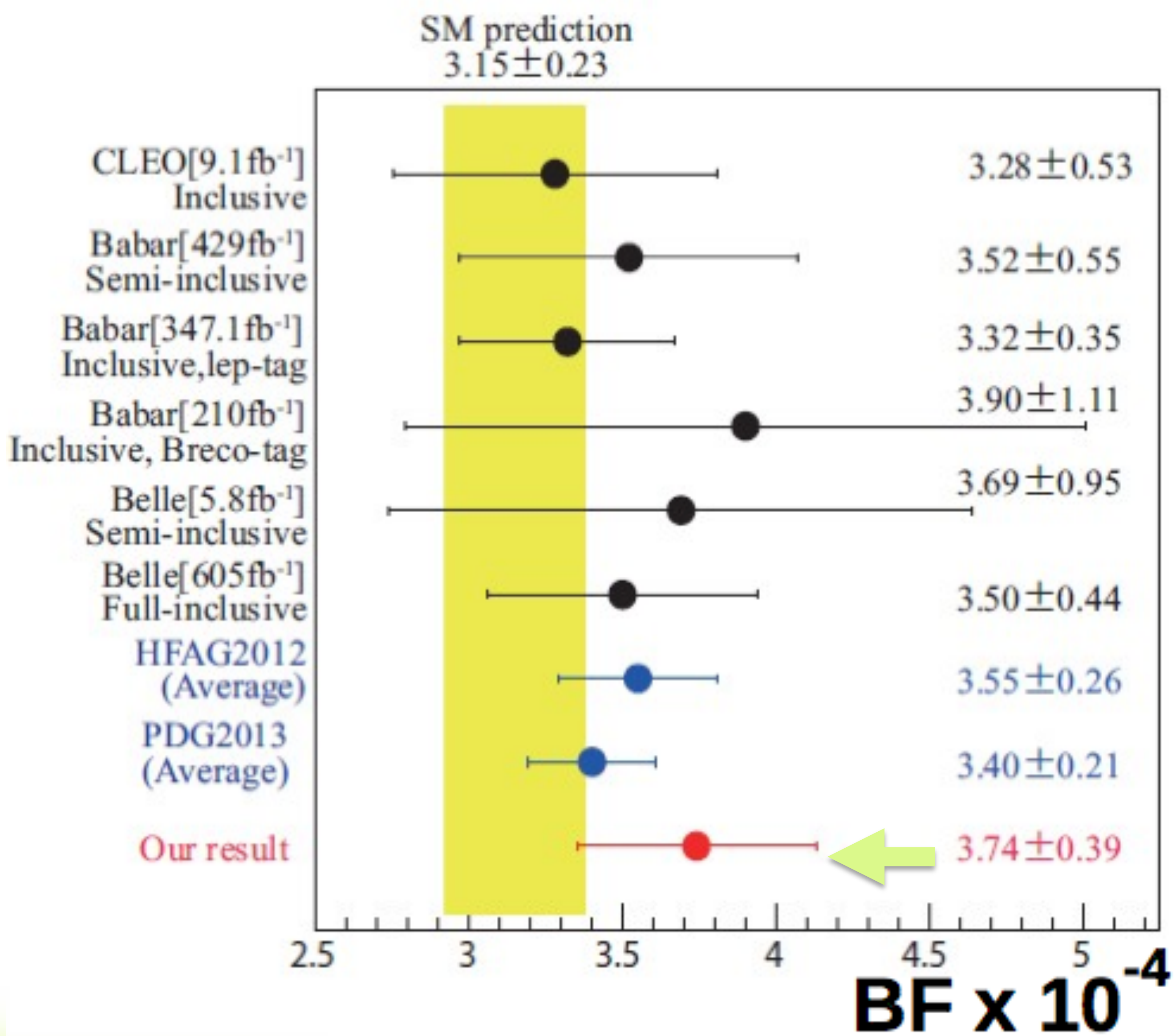
$S(K^*\gamma) = -0.022 \pm 0.015$ [Ball/Zwicky, hep-ph/0609037]

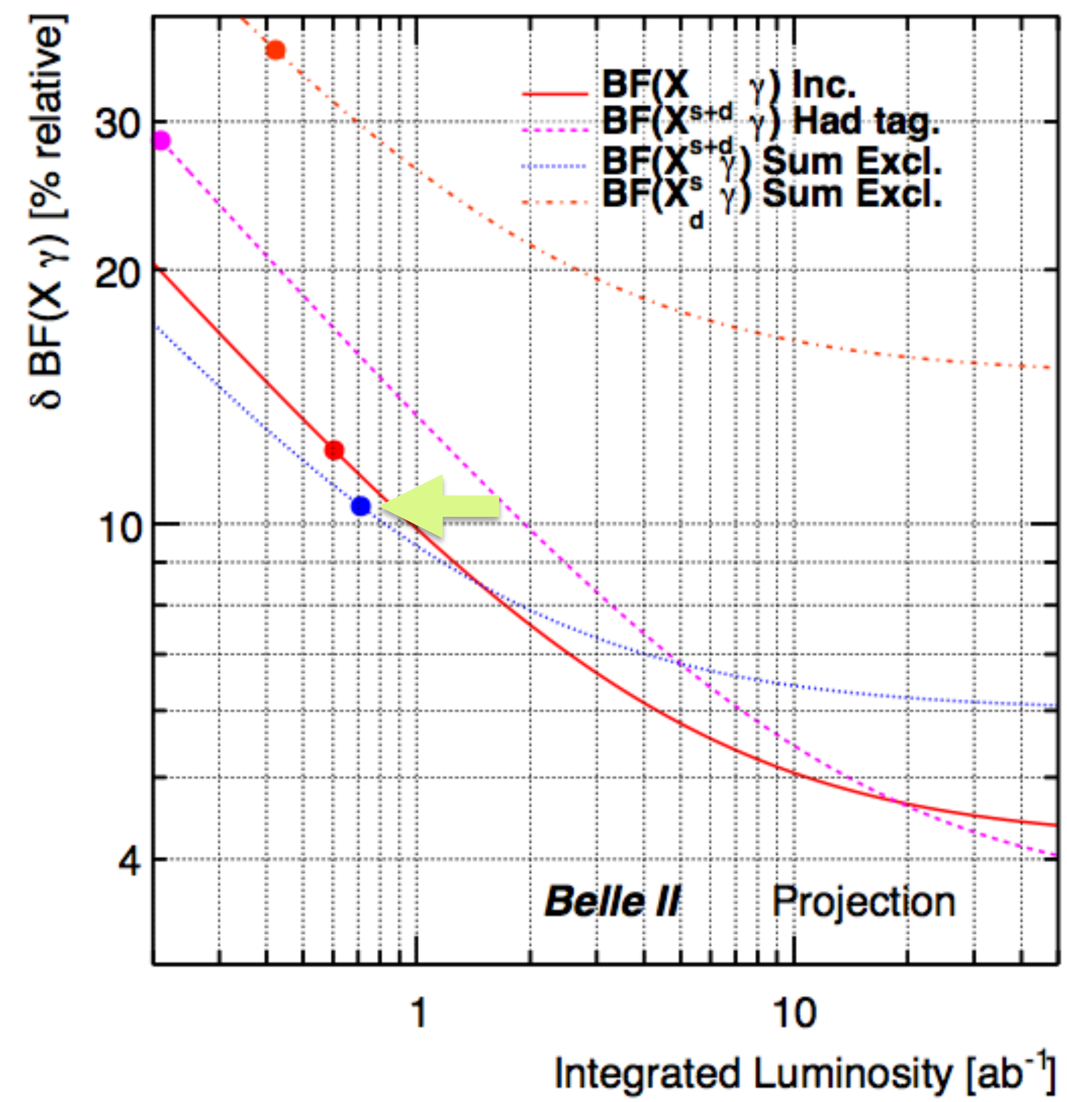
Inclusive Radiative B decays (BF)

Theory: *precision near experimental in b→s (7%),*
Expt.*: Σ exclusive ~ 38 modes. Shows nominal Pythia fragmentation incorrect for inclusive B decays*



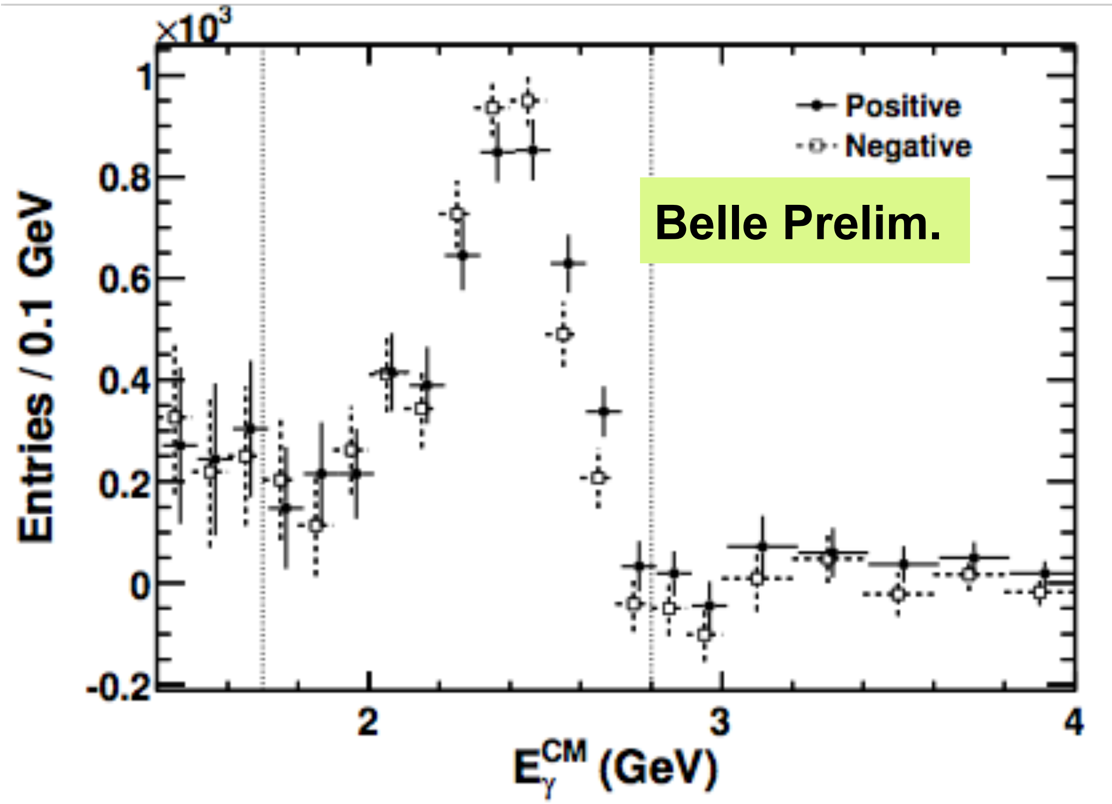
Belle, B→ s γ Sum Excl, Preliminary (DIS 2014)

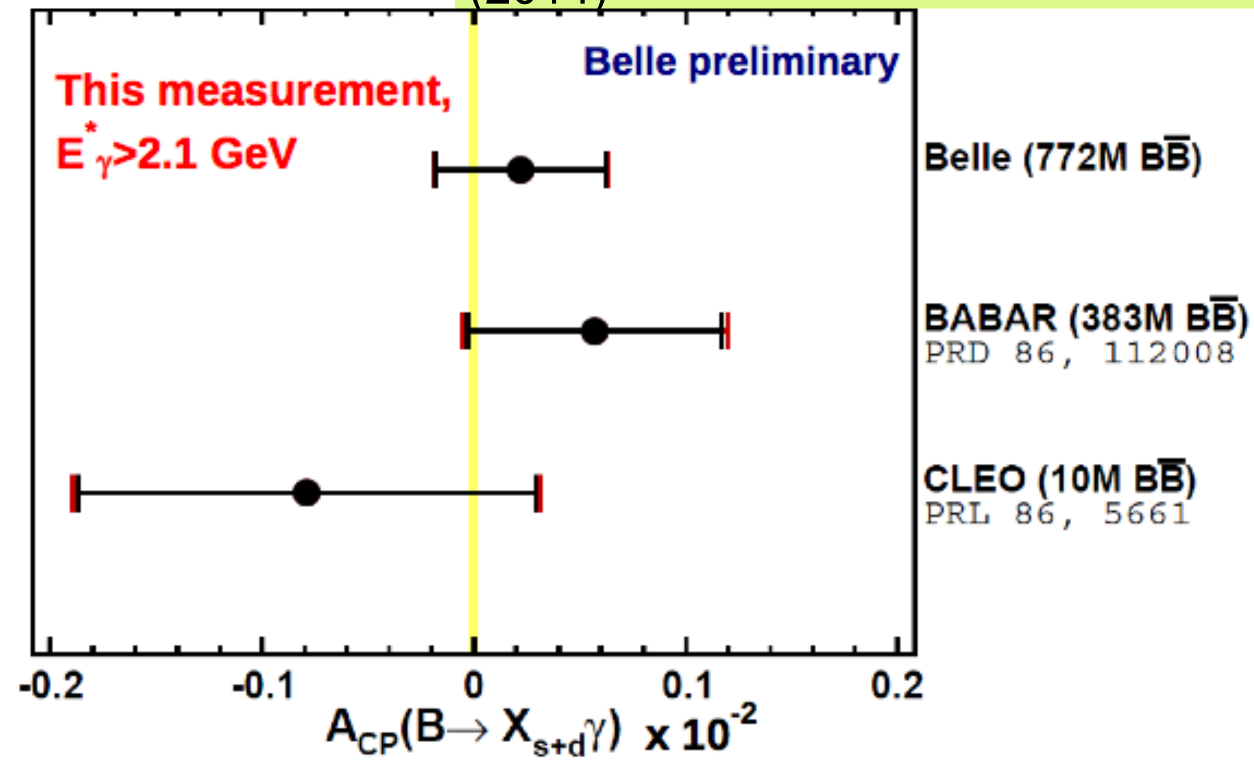




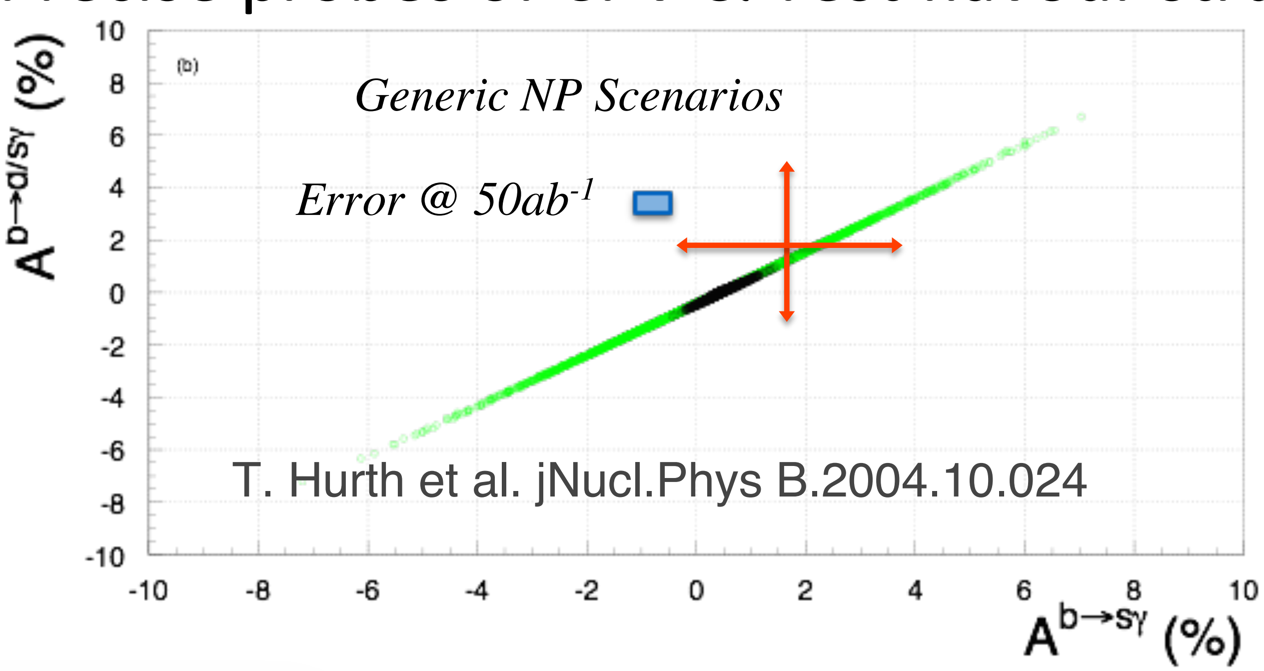
Direct CPV in Radiative B decays

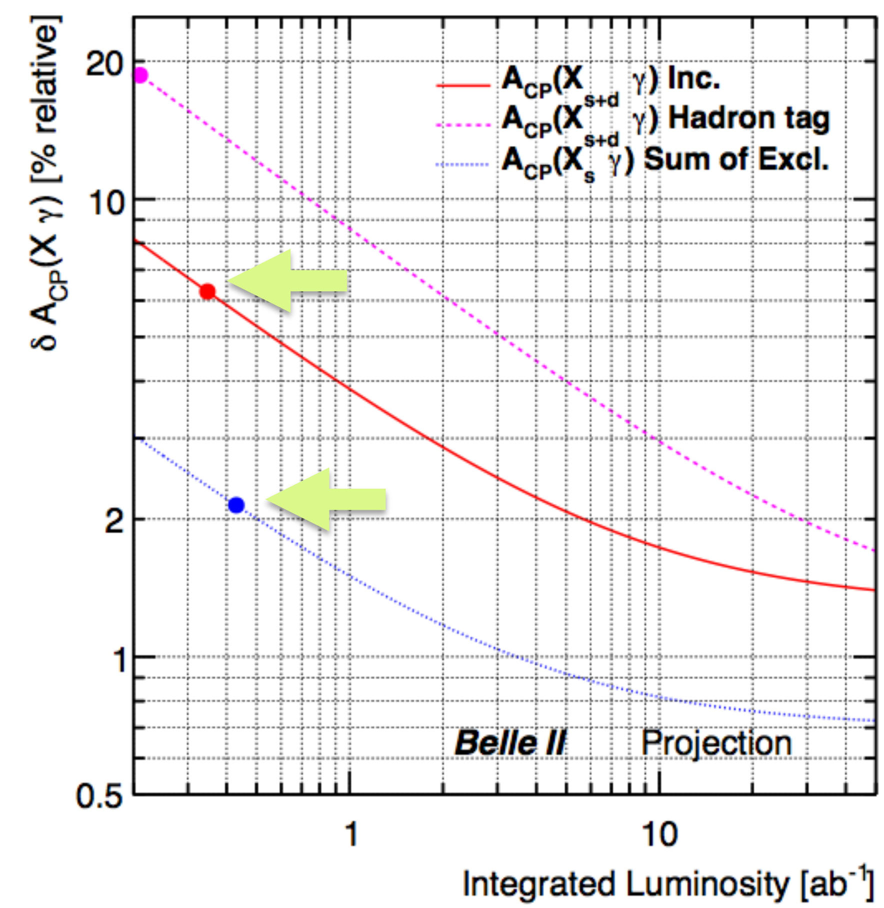
Belle, $A_{CP}(b\to s+d\,\gamma)$ (DIS 2014)
Babar, $A_{CP}(b\to s\,\gamma)$, arXiv:1406.0534 (2014)





Precise probes of CPV & Test flavour structure!

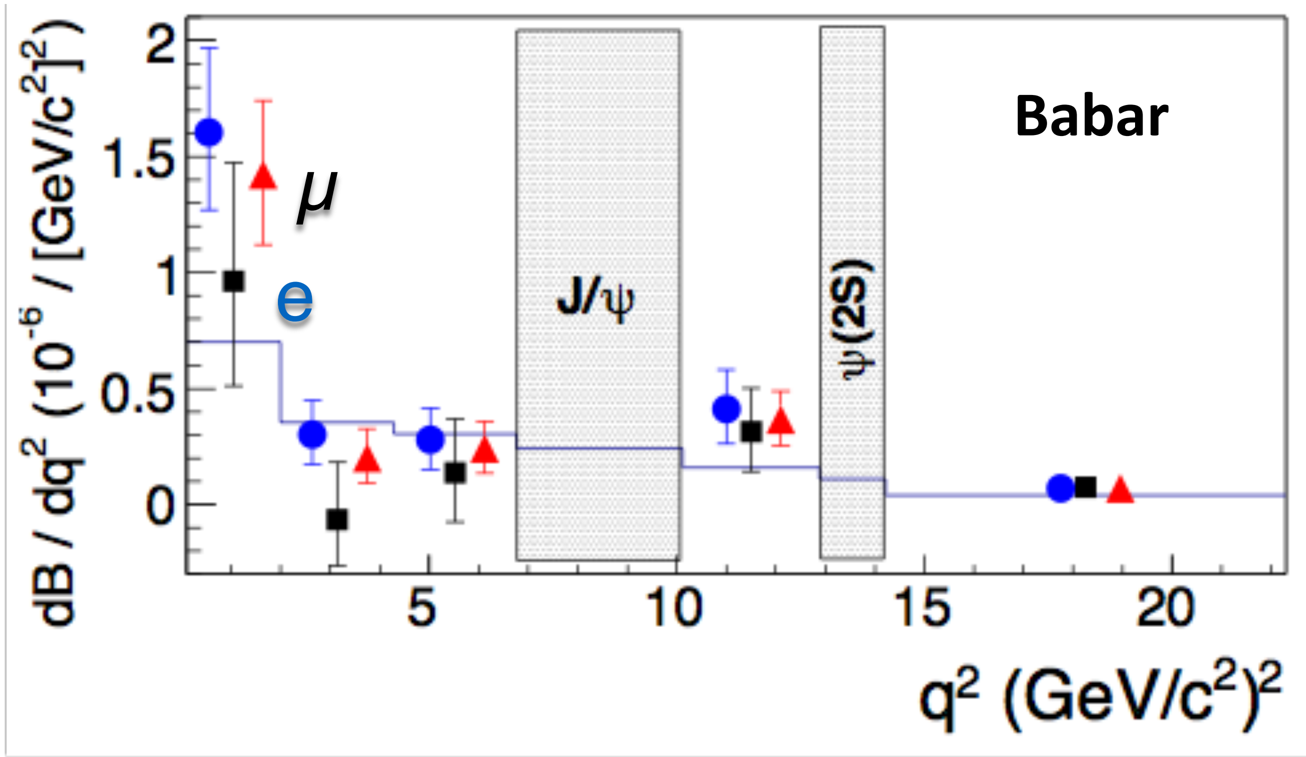


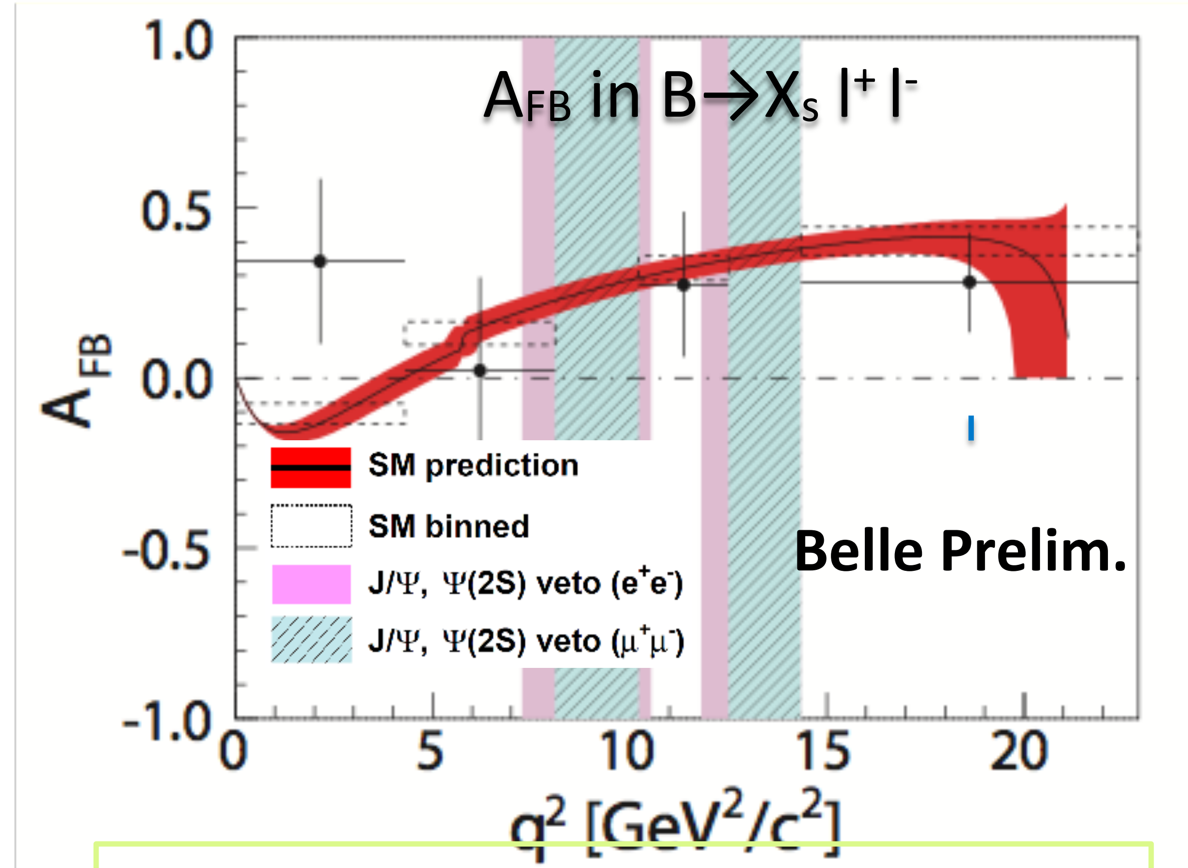


Leptonic EWP

Belle, B→ Xs l l, arXiv:1402.7134 (2014)
Babar, B→ Xs l l, PRL 112, 211802 (2014)

First inclusive A_{FB} !





Inclusive $B \to X_s$ {ee,μμ}

- More precise theory.
- Sum of exclusive hadronic final states
- Lepton "universality".

&@Belle II

B→{K*,K} {e e, μ μ}

- Lepton Universality.
- γ Poln. (low q^2).

→ Third generation

- **B→Kττ** $<3\times10^{-4}$ in 50/ab
- **$B_s \to \tau\tau$** $<2\times10^{-3}$ in 5/ab @ Υ(5S)

B→{π, η} {e e, μ μ}

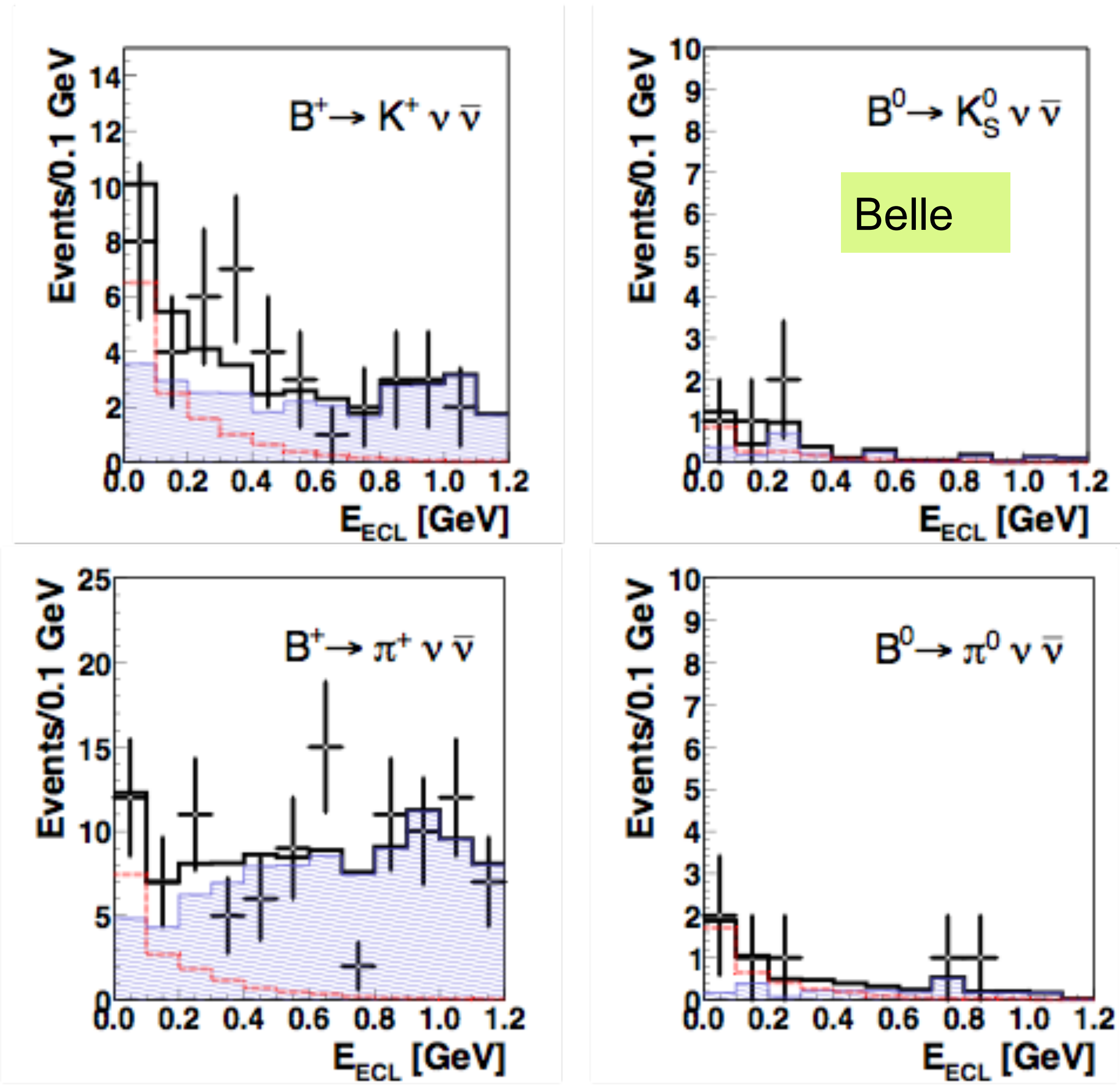
Babar, PRD 88, 032012 (2013)

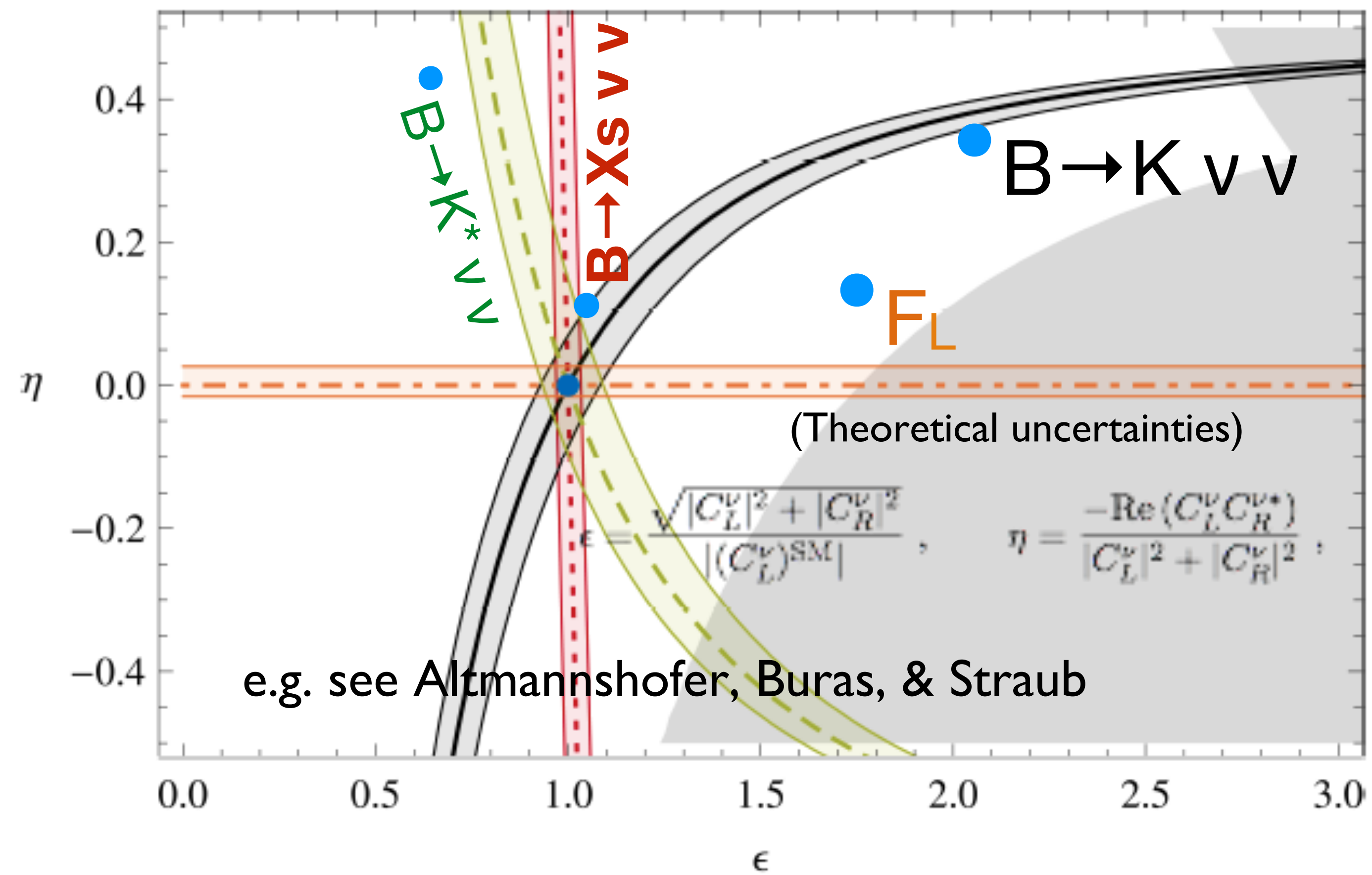
Neutrino EWP decays

Babar, B → K(*) ν ν , PRD 87, 112005 (2013)
Belle, B → K(*)/π/ρ ν ν, PRD 87, 111103(R) (2013)

$BF(B^+ \to K^+ \nu \nu) = (4.4 \pm 0.7) 10^{-6}$
[Buchalla, NPPS 209, 137]

$BF(B^+ \to K^{*+} \nu \nu) = (6.8^{+1.0}_{-1.1}) 10^{-6}$
[Altmannshofer, JHEP 0904, 022]





- **Ultimate test of Belle II.**
  N_{sig} @ Belle II ~ 100±30 based on Belle had tag
- Further improvements: tag efficiency, Calo. timing, better K_L ID.

Summary

- *The (weak decay) B-programs of Belle and Babar are still producing ~15 papers per year each.*
  - $|V_{ub}|$ *and* $D(*)\ \tau\ \nu$ *anomalies persist.*

- Rich physics program at SuperKEKB/BelleII (mostly complementary to LHCb)
  - **B/D**: Extended Higgs sectors, New CPV, CKM metrology
  - **Other**: LFV, Dark Sectors, QCD exotics

- Belle II will performan better even under high beam background.

  Physics to start in 2017!

  Precision 7-100 times better than B-factories!

- **Z-factories (10^{13}) on the horizon – highly boosted clean environment – CepC, FCCee.**

Backup

Belle II Theory Interface Platform

https://belle2.cc.kek.jp/~twiki/bin/view/Public/B2TIP

Inviting Theorist Participation: Kickoff was in June, 1st Workshop in Nov.

Belle II Theory Interface Platform (B2TIP)

Overview

The "Belle II-Theory Interface Platform" is an initiative to coordinate a joint theory-experiment effort to study the potential impacts of the Belle II program.

We plan to organize meetings twice a year gathering theory experts and Belle II members, starting from June 2014 until the end of 2016.

One of the expected outcomes of the project is a "KEK Report", summarizing all the important observables which will be measured at Belle II, their experimentally achievable precision and their impact on our understanding of the theory (Standard Model and New Physics). This report should also include a "milestones table" clarifying the targets for the first 5 to 10 ab-1 of data as well as for the final goal at 50 ab-1.

This project is an official activity of Belle II, approved by the executive board of the Belle II Collaboration, in February 2014.

Workshop Dates

The 2014 meetings will be held at KEK in June and November, as a satellite meeting of the Belle and Belle II General meetings. There is a possibility of holding one workshop in 2015 at an external location. Individual working groups may choose to hold additional meetings. Please register for the meetings on the linked indico pages.

B2TIP Meeting	Meeting Agenda	Belle (II) associated meetings
2014 June 16-17 at KEK	workshop indico	B2GM June 18-21, BGM June 22-23
2014 November/December		B2GM November 3-6, BGM November 7-8
2015 June (External Workshop)		
2015 November (KEK)		
2016 June (External Workshop)		

Committees

Organising Commitee

Toru Goto	KEK
Emi Kou	LAL
Karim Trabelsi	KEK / Lausanne
Phillip Urquijo (B2 Physics Coord.)	Melbourne

Ex Officio

Hiroaki Aihara (B2 EB Chair)	Tokyo
Thomas Browder (B2 Spokesperson)	Hawaii
Marco Ciuchini (KEK FF Advisory)	Rome
Thomas Mannel (KEK FF Advisory)	Siegen

Report Editors

Christoph Schwanda	HEPHY Vienna
Theory TBC	

Advisory Committee

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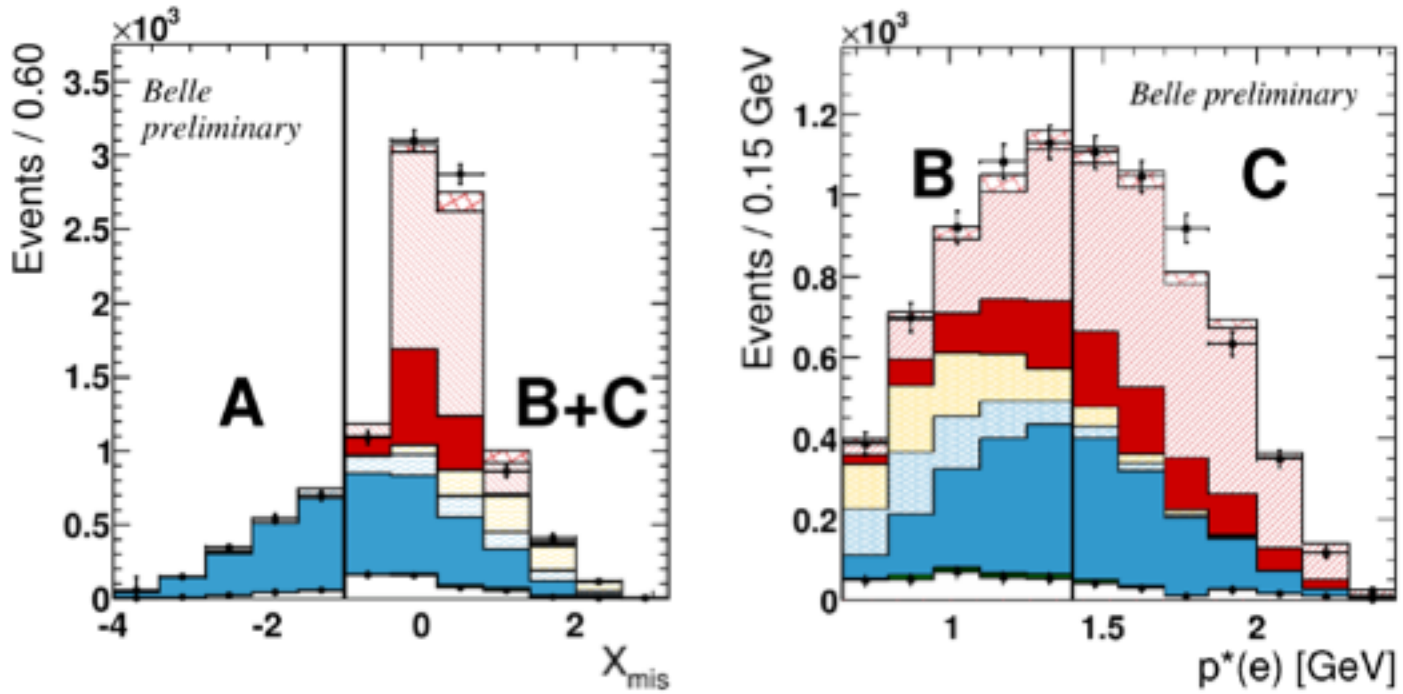
Zoltan Ligeti	LBL
Hitoshi Murayama	IPMU
Matthias Neubert	Mainz
Yoshihide Sakai	KEK
Junko Shigemitsu	Ohio

Towards rare B_s decays

Belle, Bs→ X l ν PRD 87 072008 (2013)
Belle, Bs → Ds(*) X l ν, Preliminary (ICHEP 2014)
Belle, B → Ds(*) K l ν, PRD 86, 072007 (2012)

- **5 ab^{-1}** B_s {Full,SL} tag @ Υ(5S) ≈ **325 fb^{-1}** B_d @ Υ(4S)
- SU(3) Symmetry heavily relied upon at LHC.Needs rigorous testing.



$$\mathcal{B}(B_s \to D_s X \ell \nu) = [8.2 \pm 0.2(\text{stat}) \pm 0.8(\text{syst}) \pm 1.5(\text{N}_{\text{B}_s})]\%$$
$$\mathcal{B}(B_s \to D_s^* X \ell \nu) = [5.4 \pm 0.4(\text{stat}) \pm 0.5(\text{syst}) \pm 1.0(\text{N}_{\text{B}_s})]\%$$

- Belle II goals:
  - $B_s \to \tau\tau$
  - $B \to \gamma\gamma$

			B_s Yields	
Tag Method	**Tag Eff.**	**N_{Bs}/N_B**	**121/fb**	**5/ab**
Untagged	2.000	$f_s/f_{d,u} \simeq 0.25$	1.4E+07	**6.0E+08**
D_s:Φπ,K_SK,K^*K	0.040	$10 \cdot f_s/f_{d,u}$	2.8E+05	**1.2E+07**
B_s Full Recon.	0.004	≫10	2.8E+04	**1.2E+06**

Deciphering NP @ Belle II (Aside)

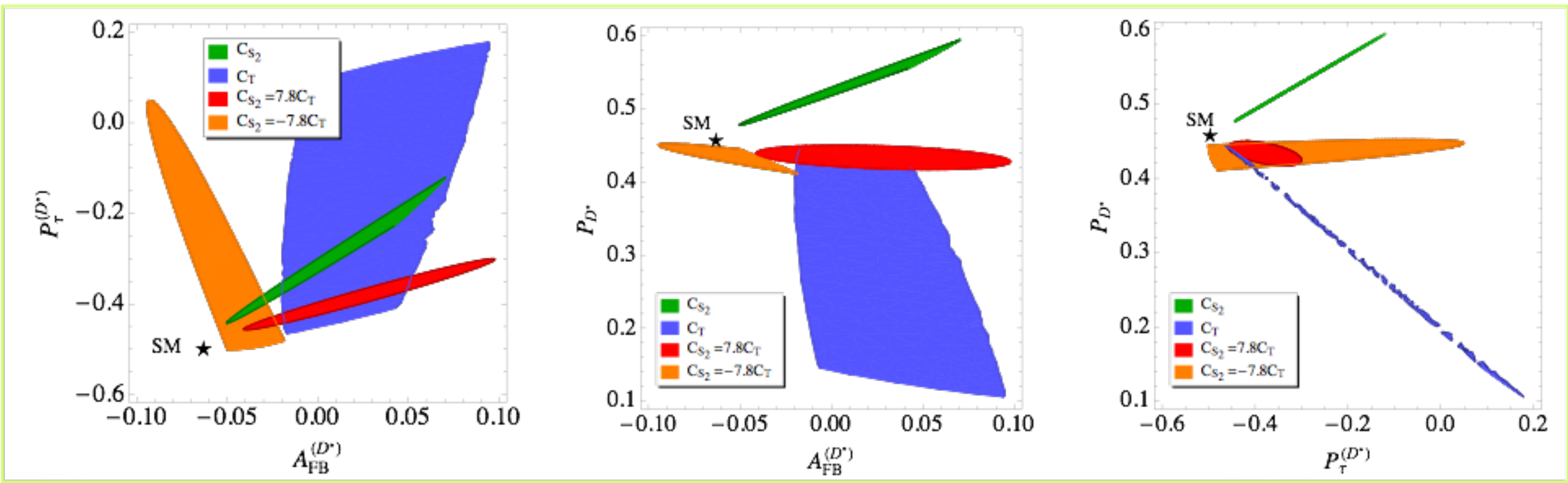
- Only resolved through decay differentials & New observables: **Polarisation, A_{FB}…**

- Explore new Scalar, Vector or Tensors & CPV!
  - "flavour blind" Type II 2HDM ruled out.

- Wilson Coefficients $C_n \sim \Lambda/m^2$

M. Tanaka et al., PRD 88, 094012 (2013)

$\mathcal{O}^l_{V_1} = \bar{c}_L \gamma^\mu b_L \, \bar{\tau}_L \gamma_\mu \nu_{Ll}\,,$	**V-A** SM like
$\mathcal{O}^l_{V_2} = \bar{c}_R \gamma^\mu b_R \, \bar{\tau}_L \gamma_\mu \nu_{Ll}\,,$	**V+A** RH current
$\mathcal{O}^l_{S_1} = \bar{c}_L b_R \, \bar{\tau}_R \nu_{Ll}\,,$	**S+P** Charged Higgs (II)
$\mathcal{O}^l_{S_2} = \bar{c}_R b_L \, \bar{\tau}_R \nu_{Ll}\,,$	**S-P** Charged Higgs
$\mathcal{O}^l_{T} = \bar{c}_R \sigma^{\mu\nu} b_L \, \bar{\tau}_R \sigma_{\mu\nu} \nu_{Ll}\,,$	**Tensor** GUT, LQ



Beyond Belle II → Z-factory

What will LHCb & Belle II miss? A few examples:

1. SM observation of FCNCs with third generation (τ) leptons.
2. Stat limitation:
   a. on rare B_s decays to neutrals, **$\sigma(Y(5S))$ x f_s ~ 0.05,**
   b. SM observation of B→ K ν ν.
   c. Radiative b→d γ.
3. High multiplicity modes with slow pions may be elusive, i.e. full composition of B→ D* τ ν background (B → $D^{(*)}$ π π l ν).

Can be addressed by a LEP-like Z-factory (FCC-ee, CepC) ≈ Belle II ⊗ LHCb

SuperKEKB – *FCC-ee or CepC* demonstrator

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lorentz factor

Beam current

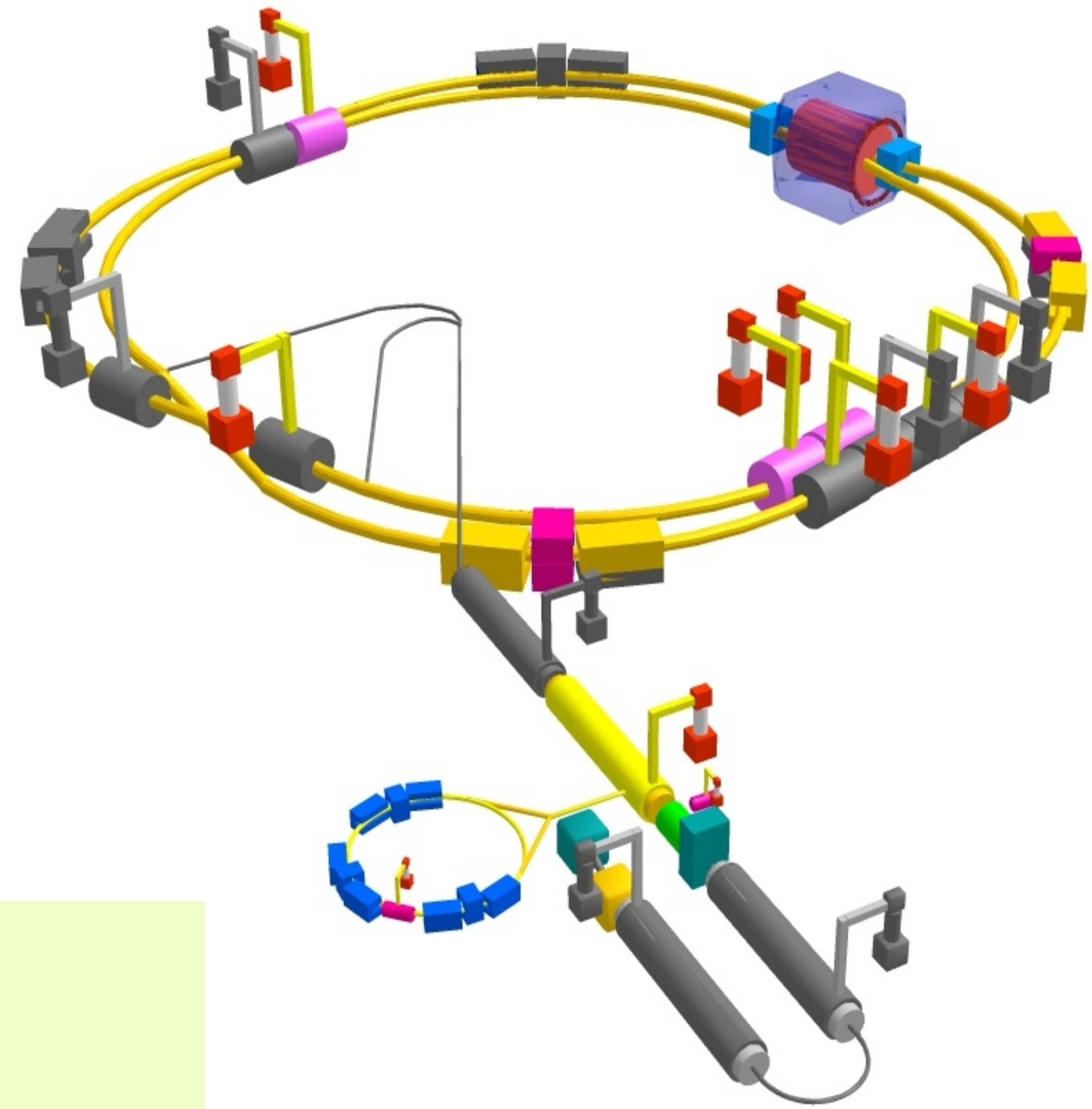
Beam-beam parameter

Lumi. reduction factor (crossing angle)&
Tune shift reduction factor (hour glass effect)
0.8 ~ 1
(short bunch)

Classical electron radius

Beam size ratio@IP
1 ~ 2 % (flat beam)

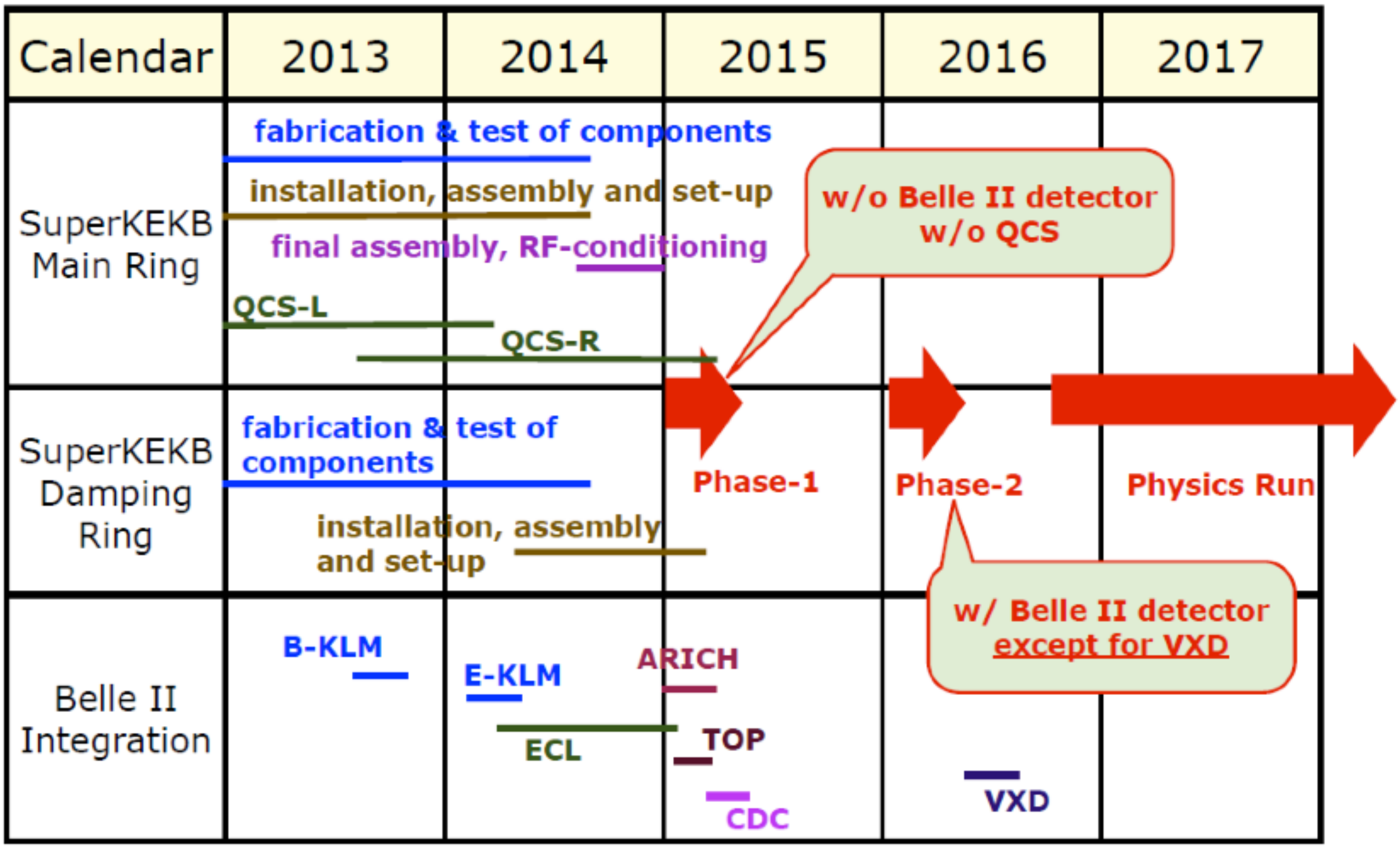
Vertical beta function@IP



- β_y*=300 μm (TLEP: 1 mm)
- lifetime 5 min (TLEP: ~15min)
- $\varepsilon_y/\varepsilon_x$=0.25% ! (TLEP: 0.2%)
- off momentum acceptance (±1.5%, TLEP: ±2%)
- e^+ production rate (2.5x10^{12}/s, TLEP: <1x10^{11}/s)

Construction & Commissioning Schedule

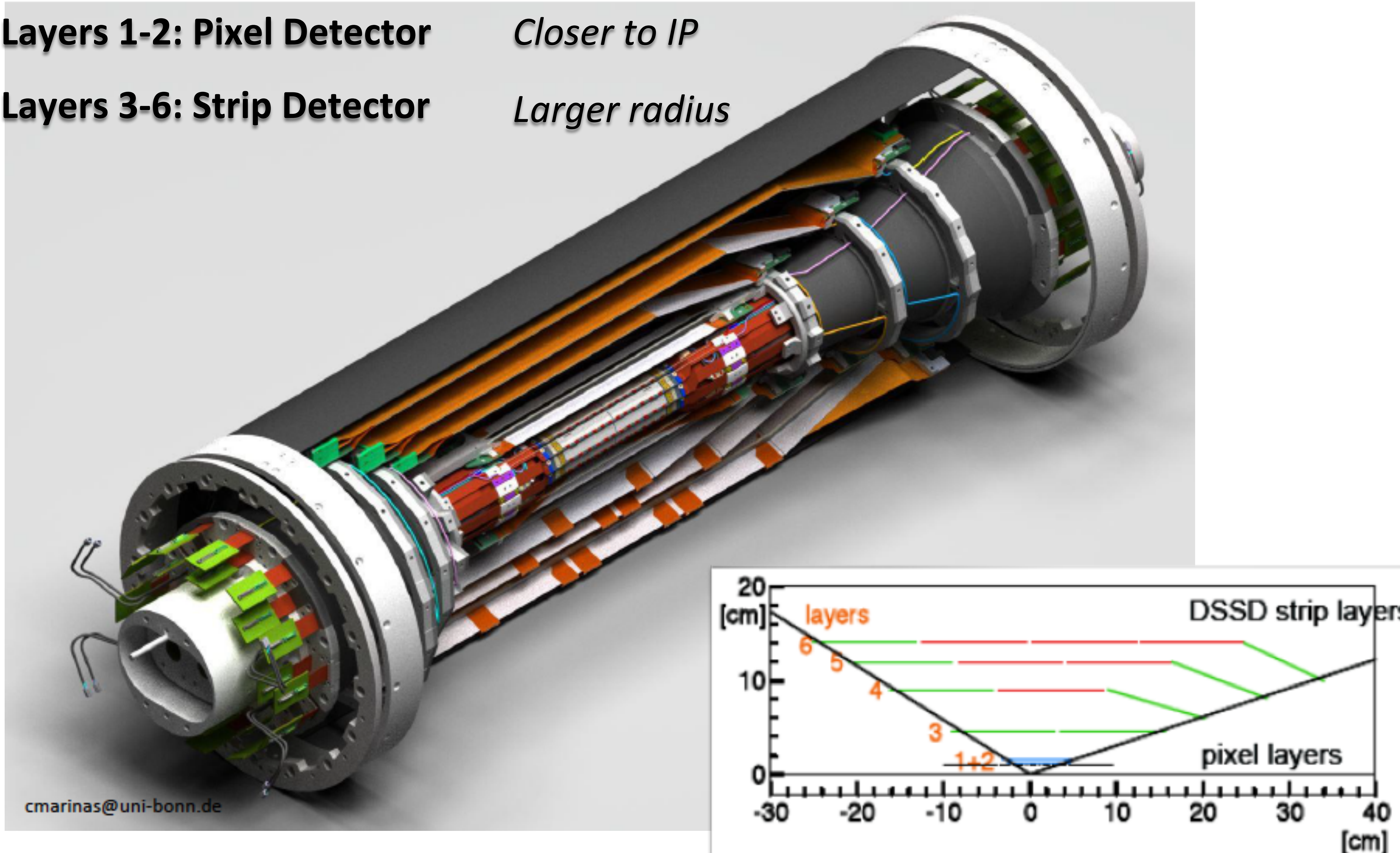
Feb 2014



Vertex Detectors

Layers 1-2: Pixel Detector *Closer to IP*

Layers 3-6: Strip Detector *Larger radius*



Belle II Vertex Detector

PXD: excellent spatial granularity (resolution ~15 μm)

low material (0.16%X_0 for layer 1)

but significant amount of background hits, huge data rate.

~10 million channels!

SVD: precise timing (2–3 ns RMS)

but has **ambiguities in space** due to 1D strip.

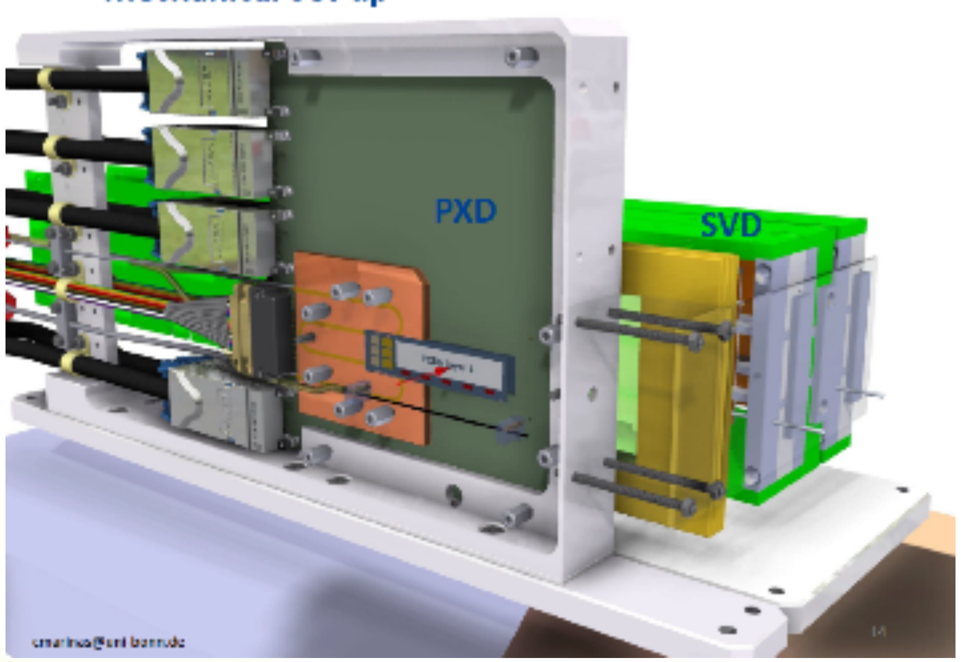
At much larger radius (~100->140 mm)

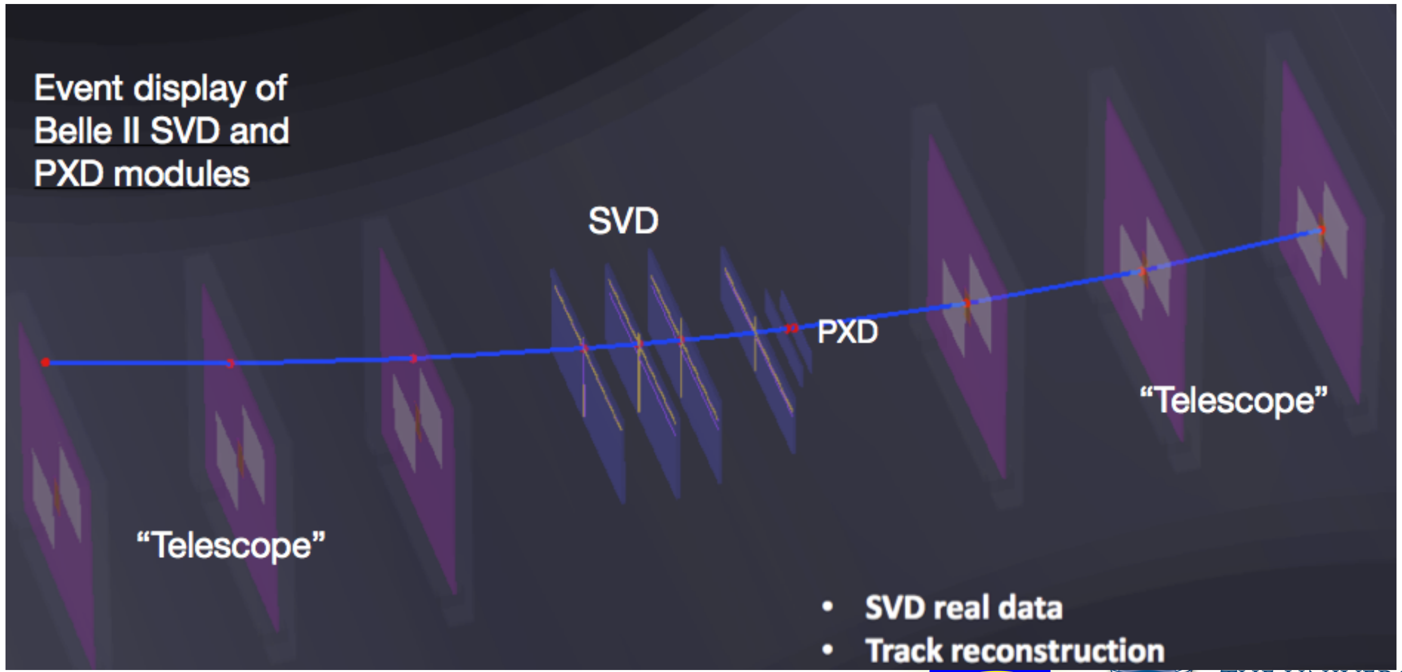
few 100k channels!

Combining both yields performance improvements

(Successful test beam January 2014) : To reduce Gbit/s data from PXD, read out only ***Regions Of Interest*** *from projected SVD tracks*

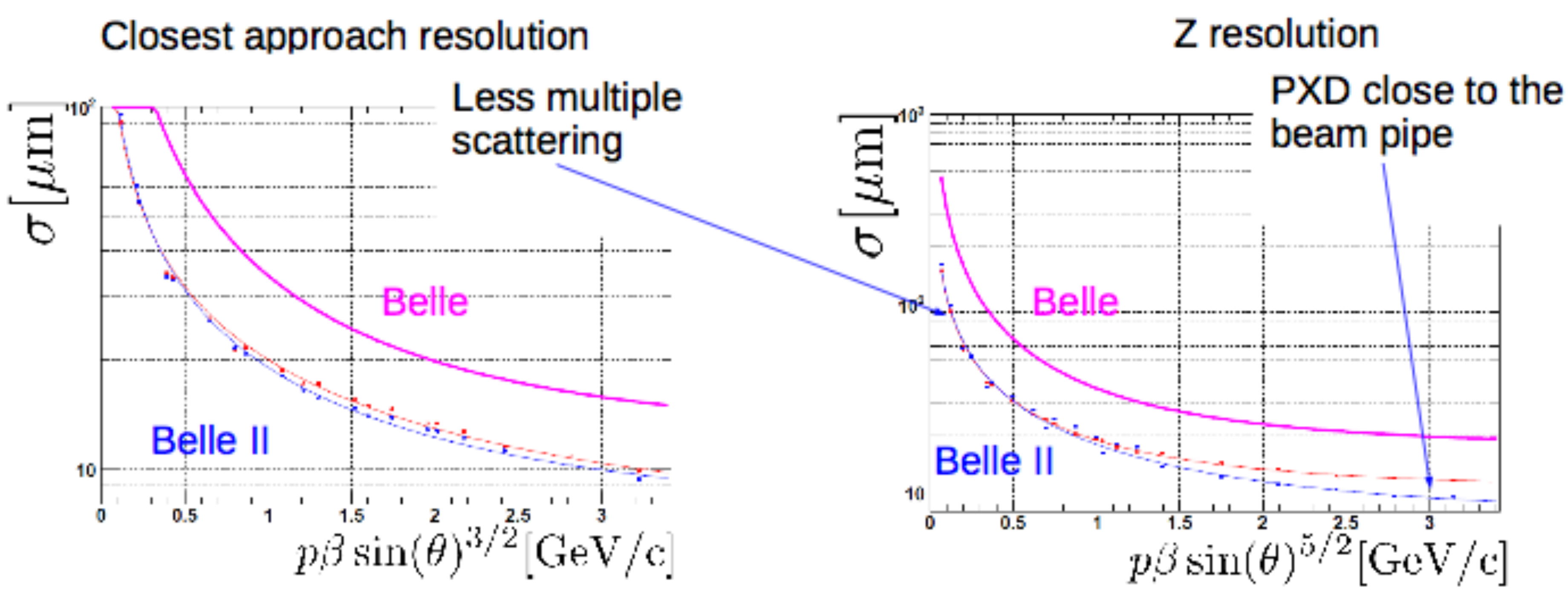
Mechanical Set-up





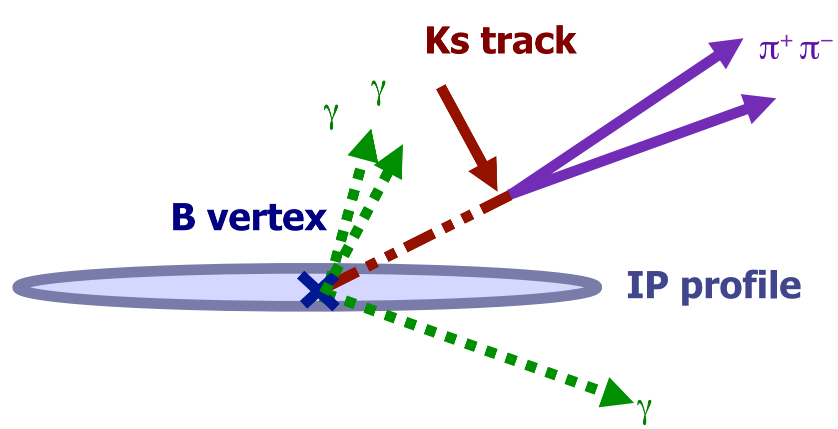
Performance

1)



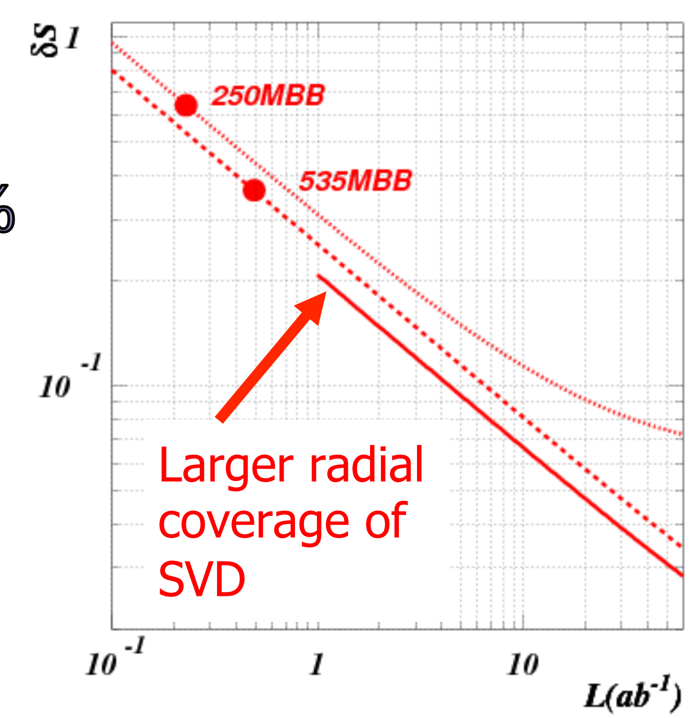
2)

Larger acceptance (by 30%) for detection of pions from K_S decay →
e.g. improves Time Dependent CP Asymmetry $\delta S(K_S\pi^0\gamma)$



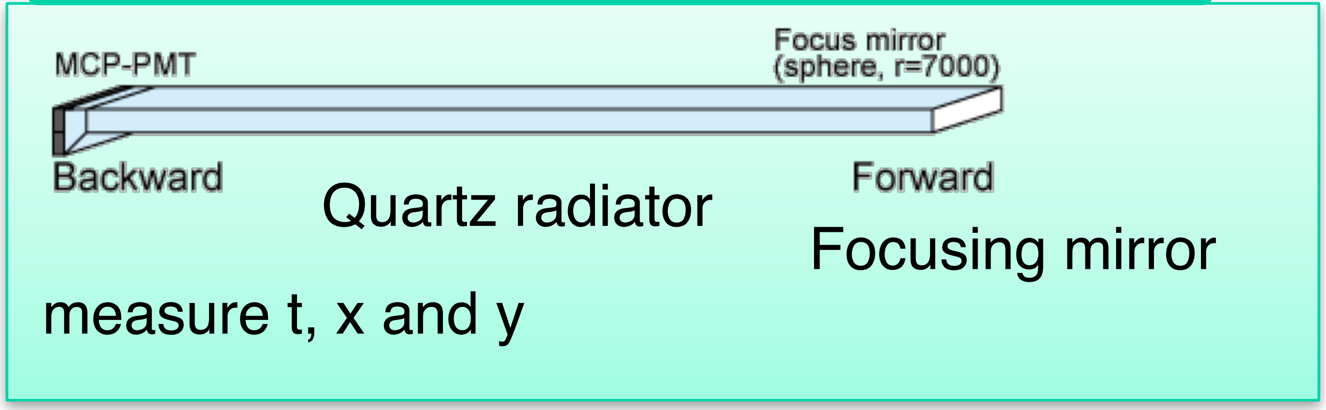
B decay point reconstruction
Using the K_S trajectory

30% -> ~2% precision

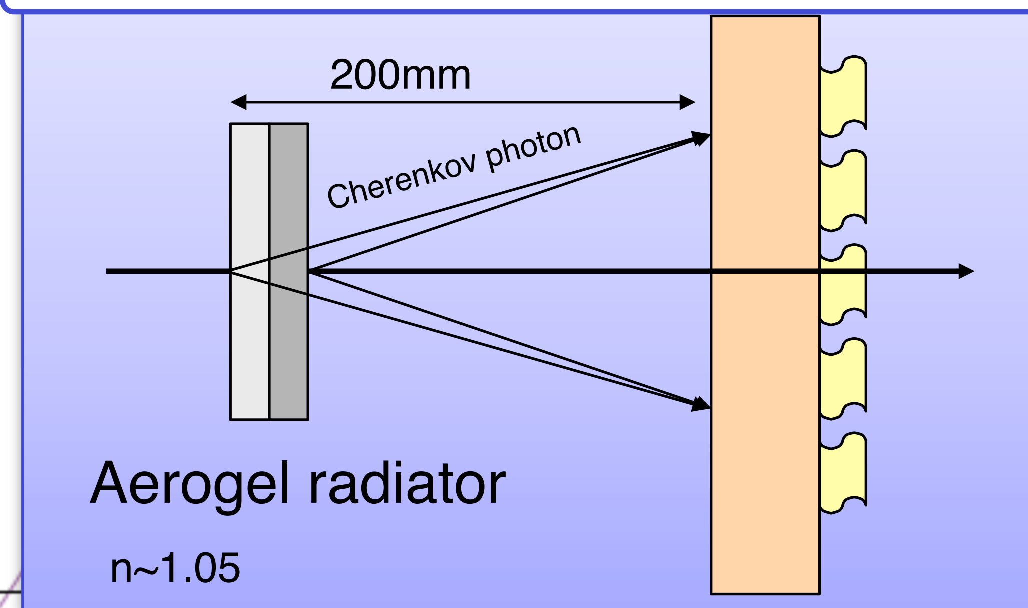


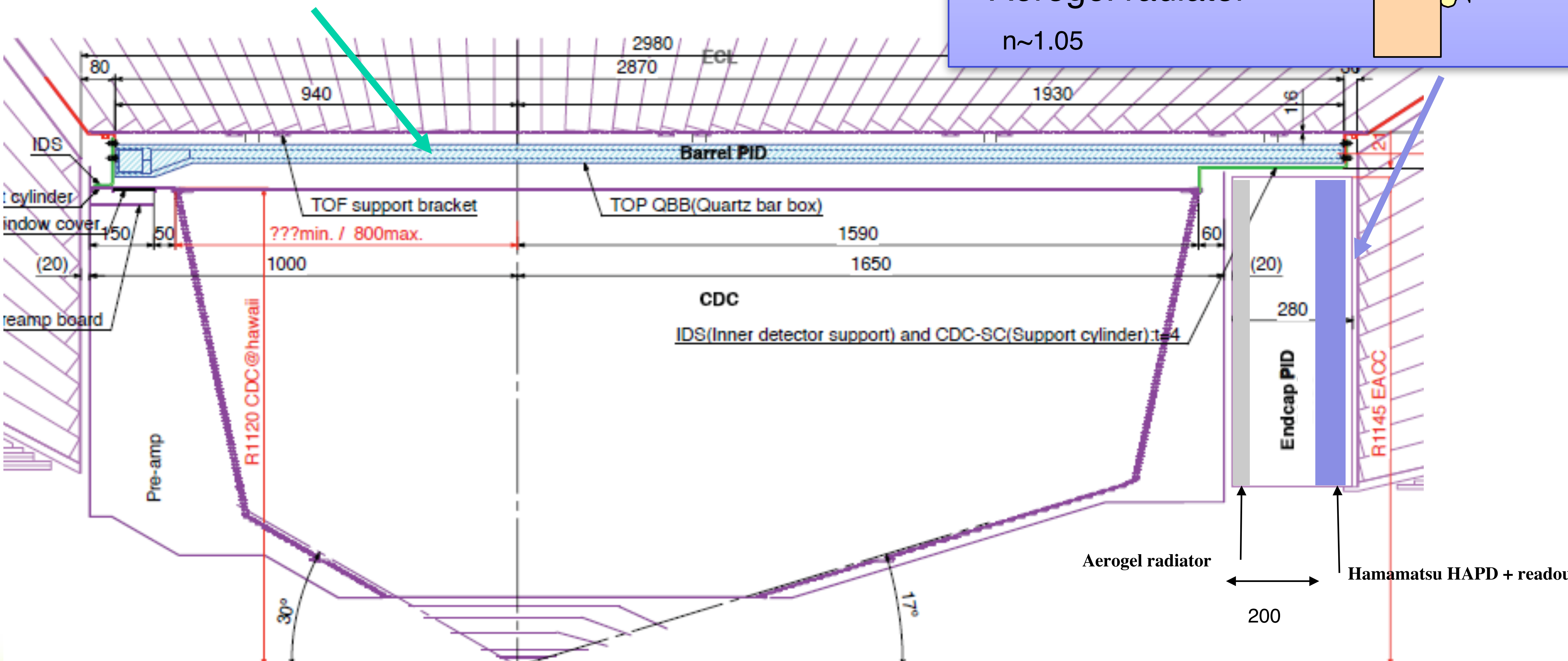
Particle Identification

Barrel PID: Time of Propagation Counter (TOP)



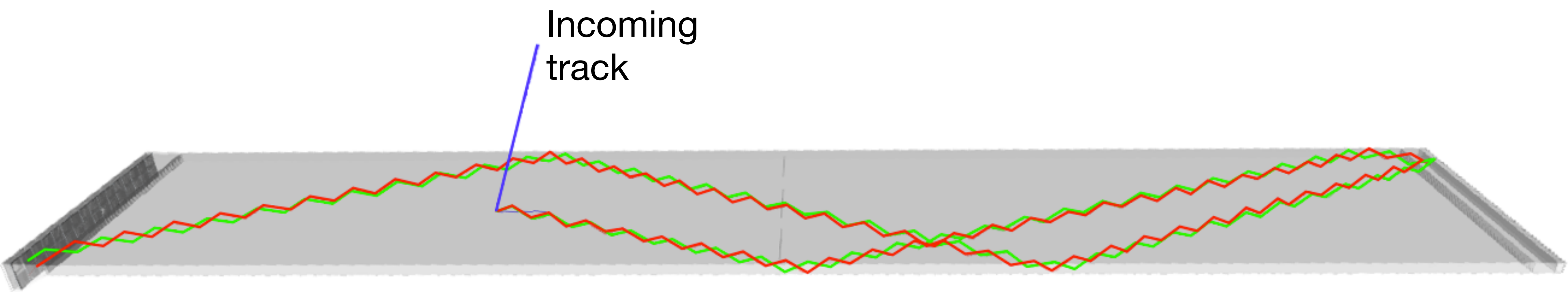
Endcap PID: Aerogel RICH(ARICH)

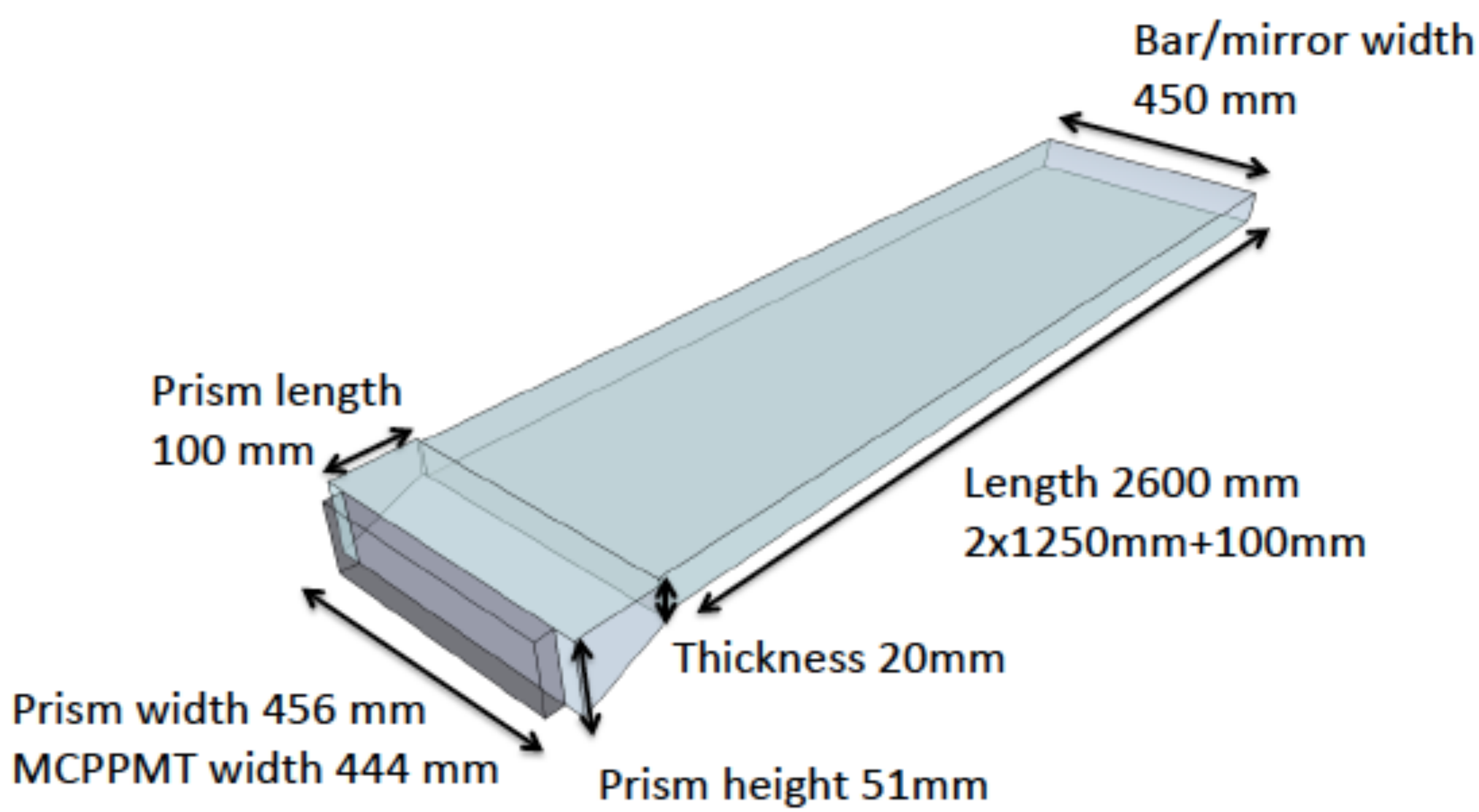


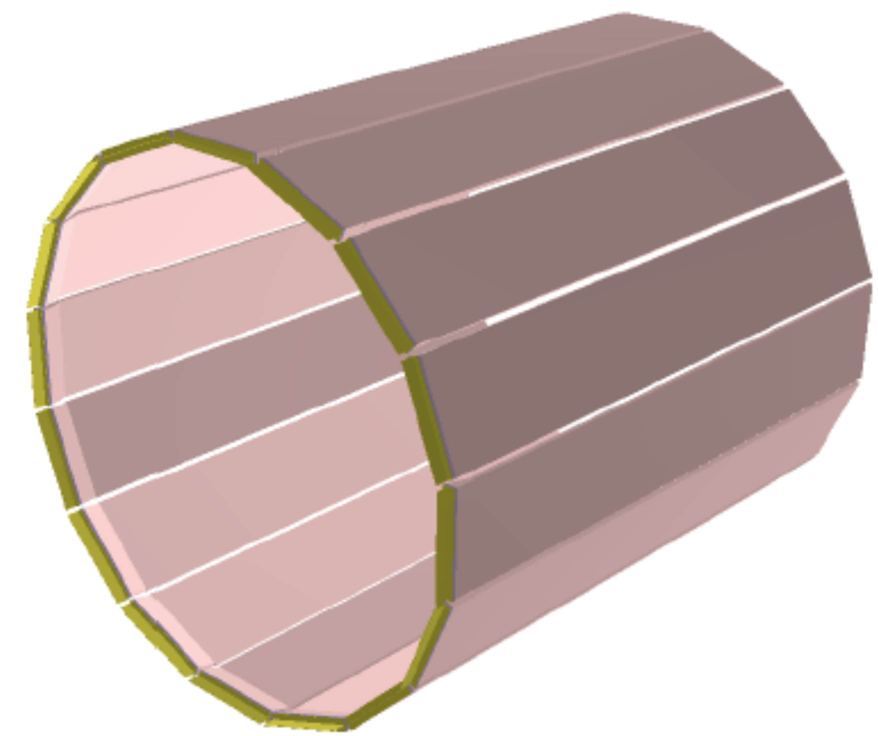


PID: Principle of operation of TOP detector

Simulation of a 2 GeV pion and kaon interacting in a quartz bar.

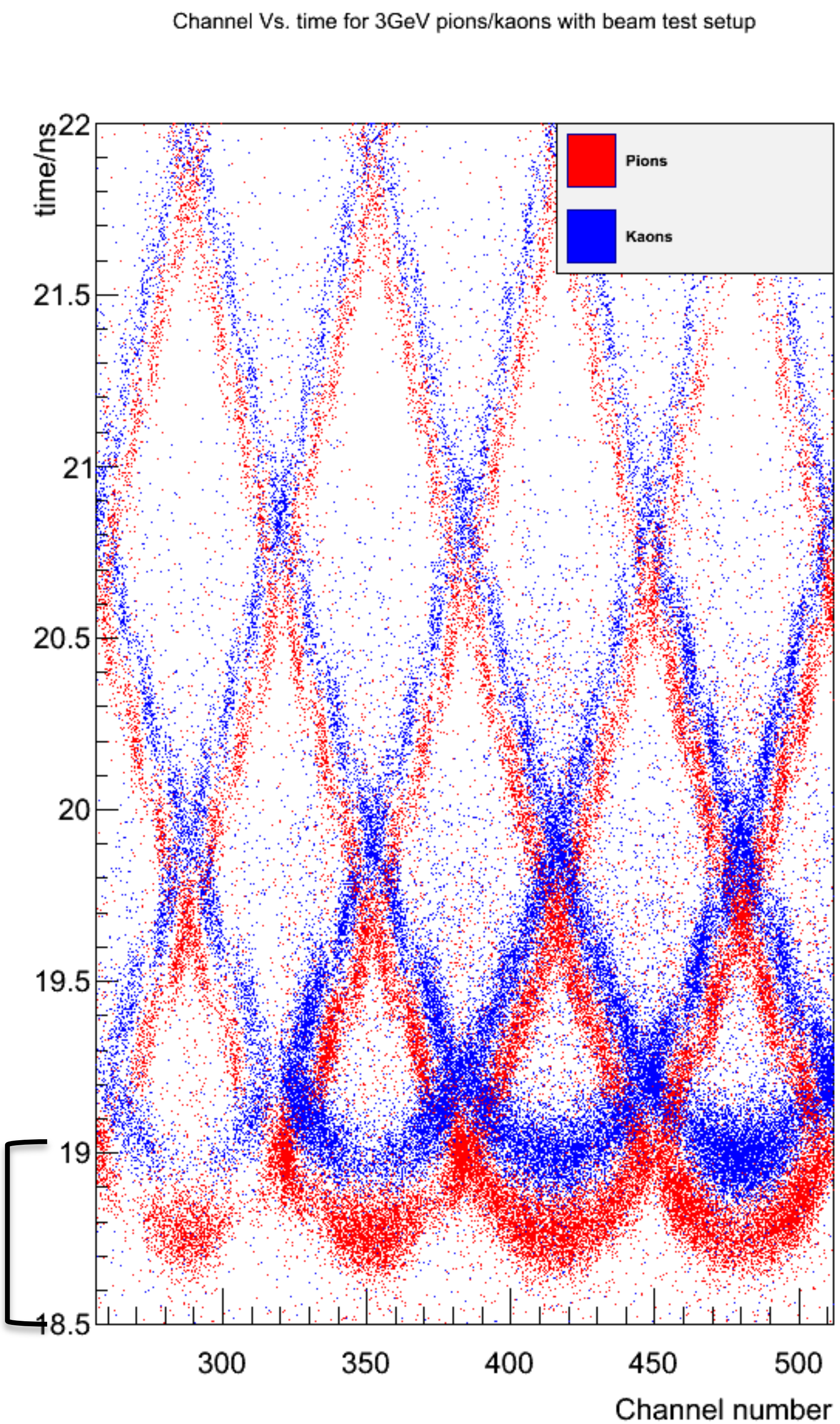






16 bar modules arranged in a "roman arch"

Kaons vs pions: Integrated distributions

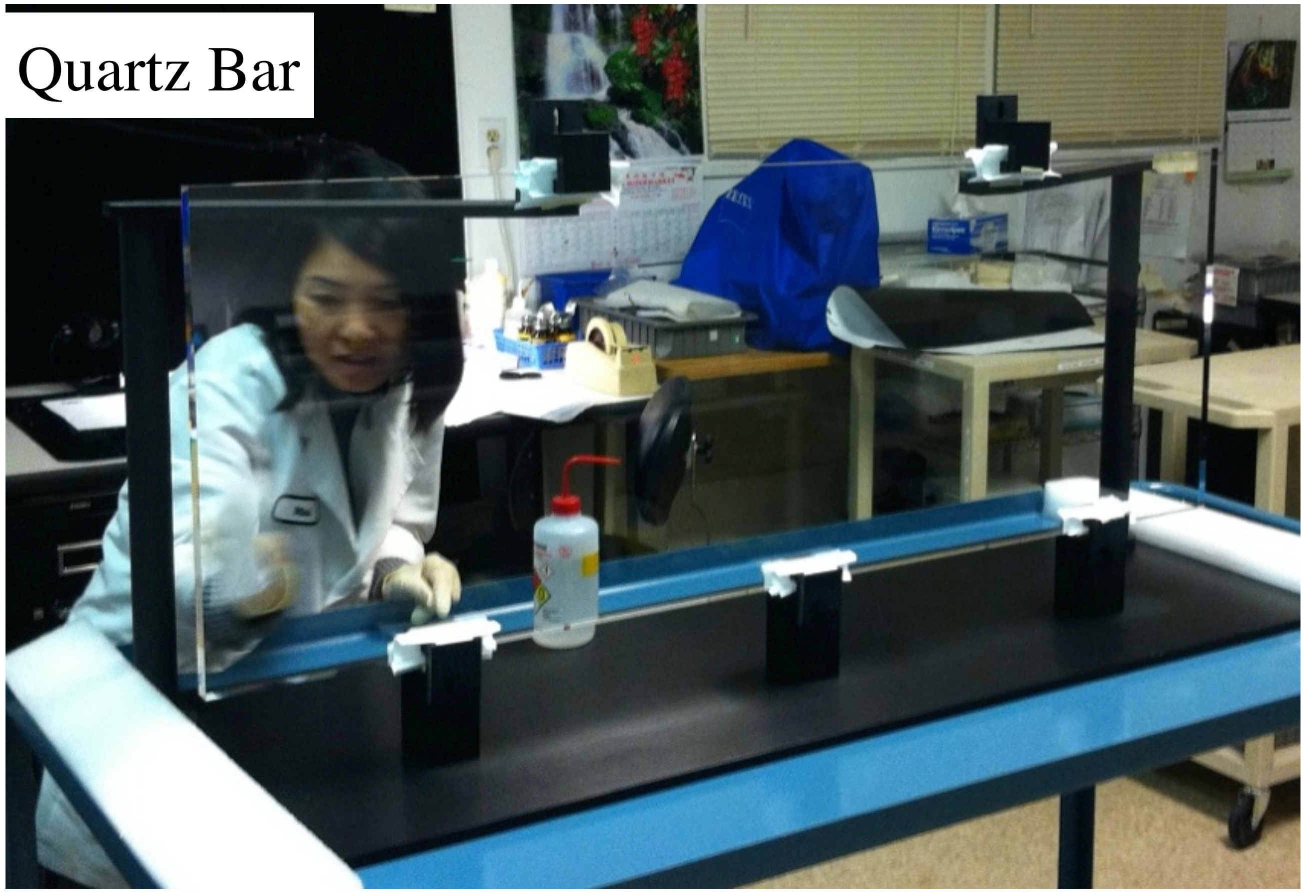


Time in ns

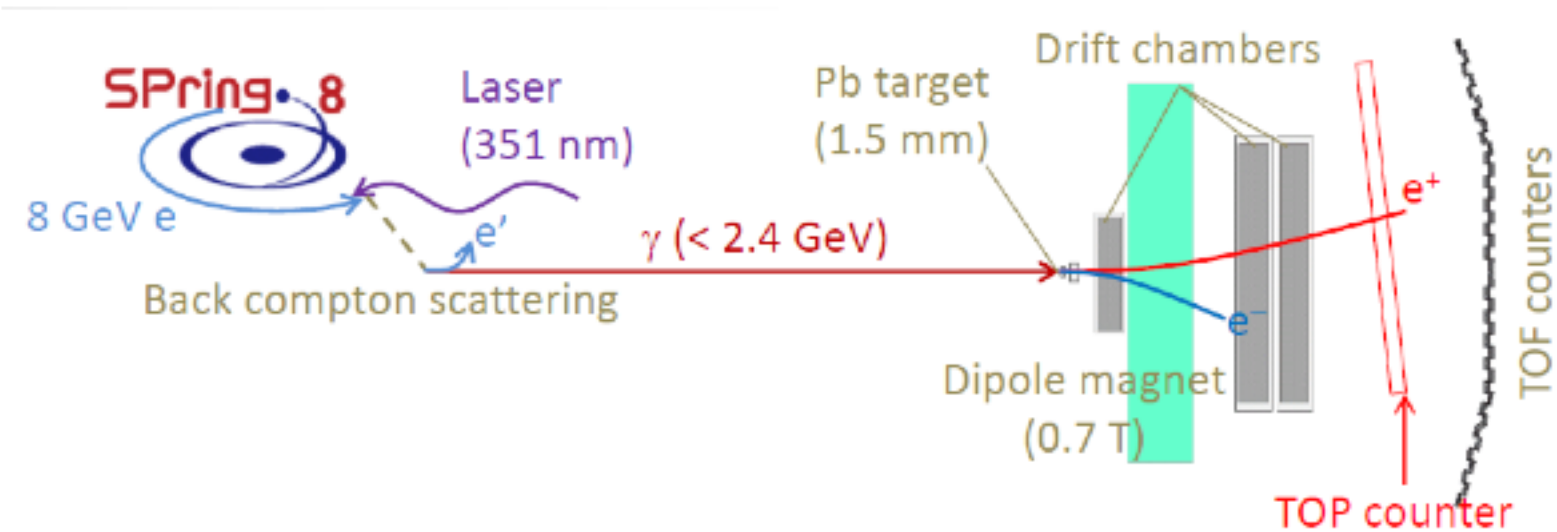
500ps

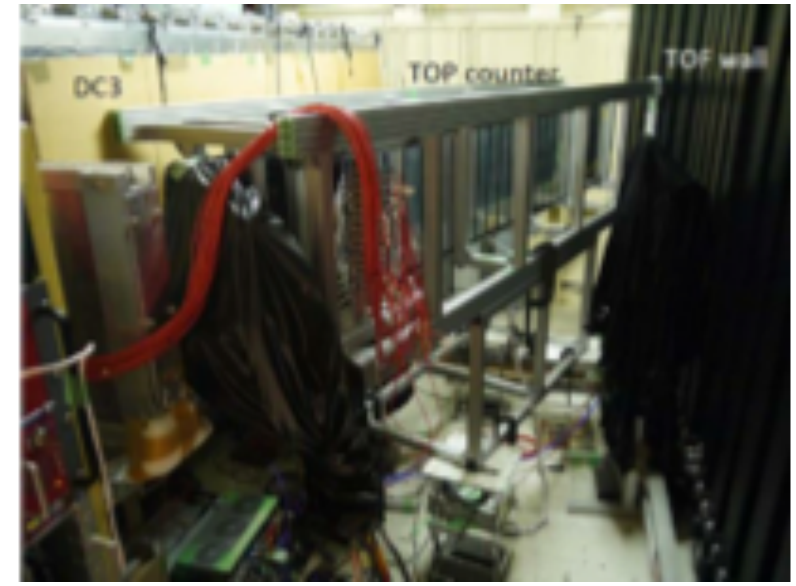
X position

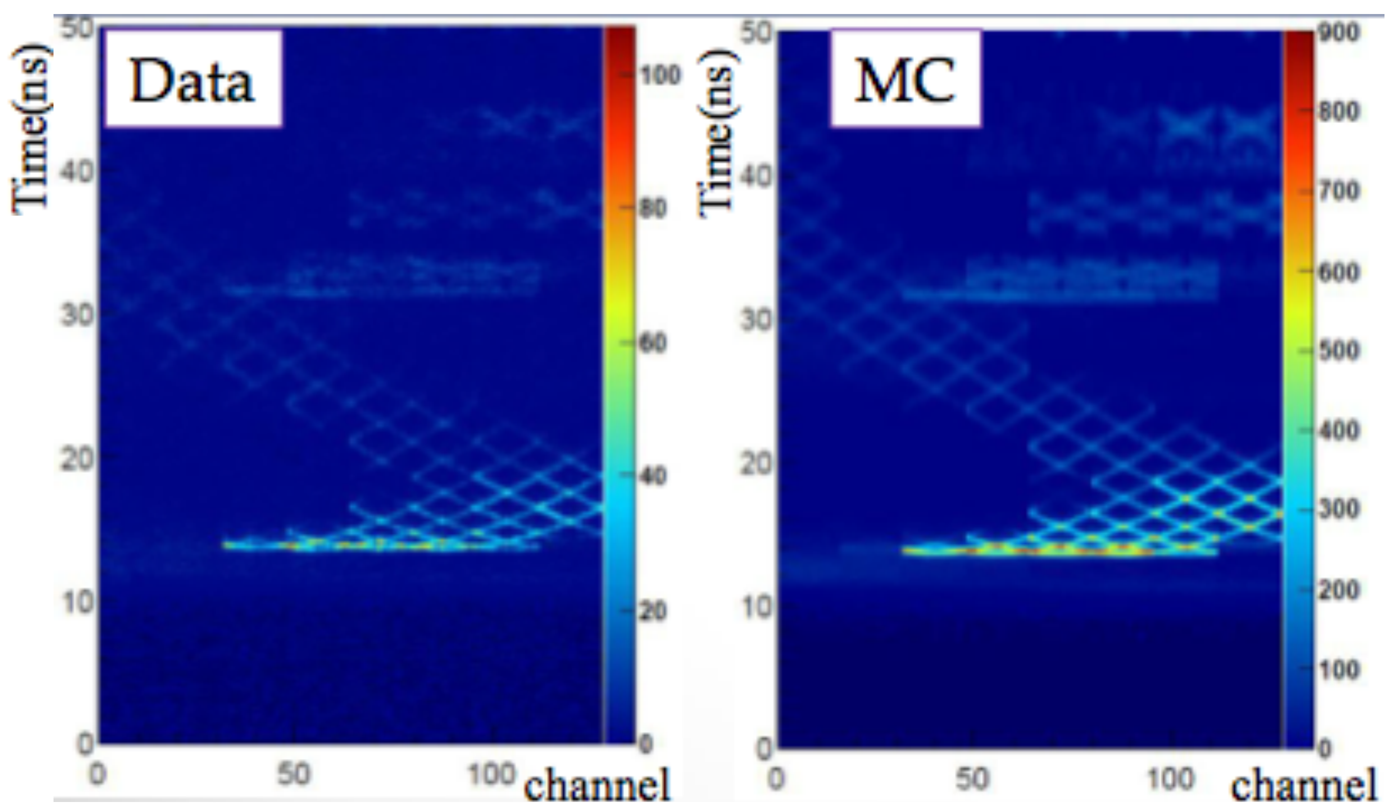
At 3 GeV *Timing at the ~100 ps level is needed to separate pion and Kaon*



TOP Test Beam







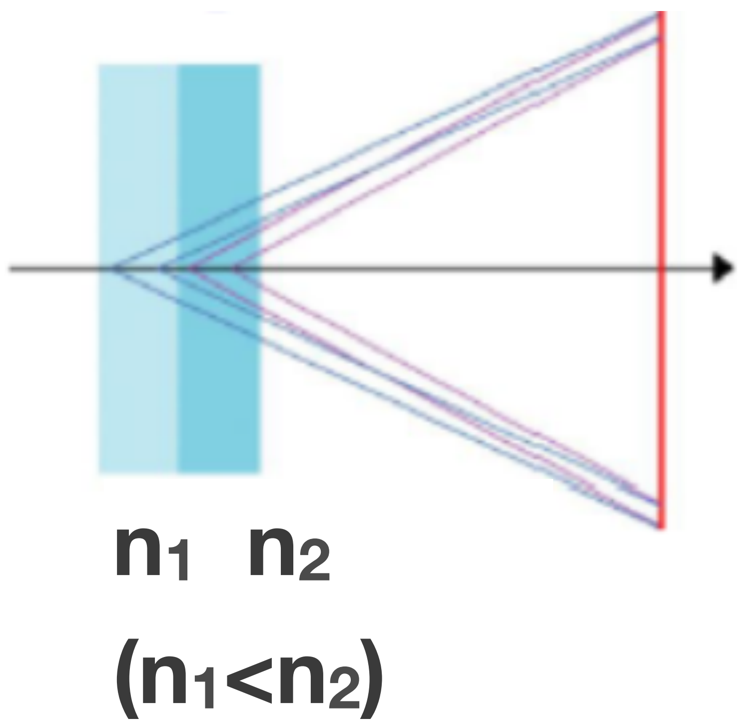
Performance of the 1st full scale prototype Belle II TOP counter was evaluated at SPring-8 LEPS.

- 2GeV/c positron beam
- Precise beam timing: acc. RF
- FEE: “IRS” and backup (CFD)

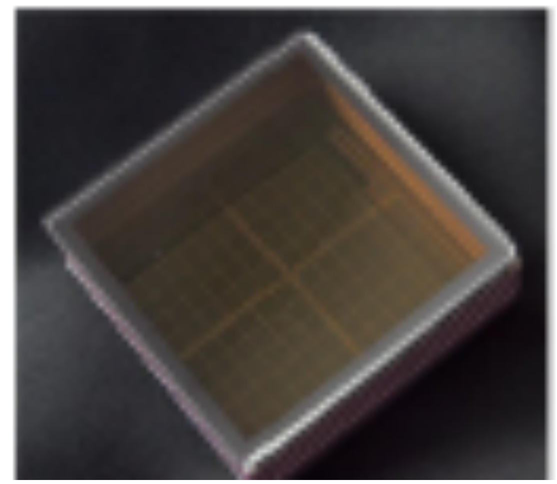
Aerogel RICH: Endcap PID

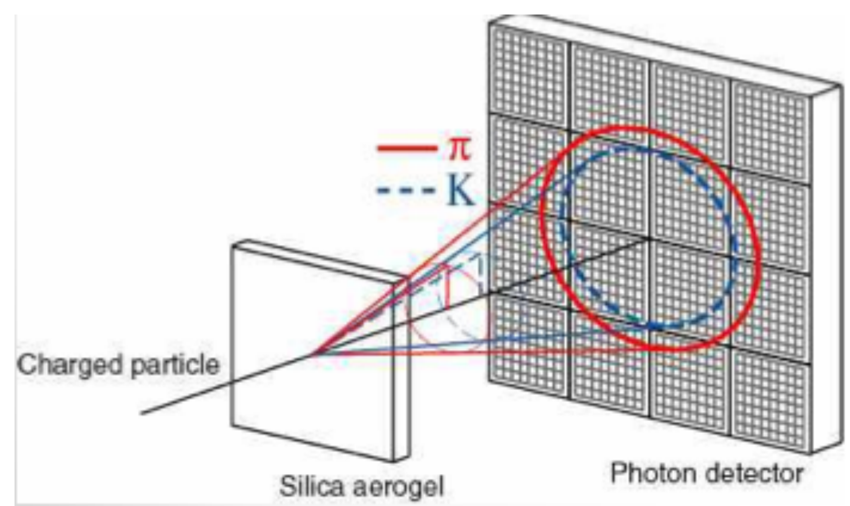
2-layer Aerogel

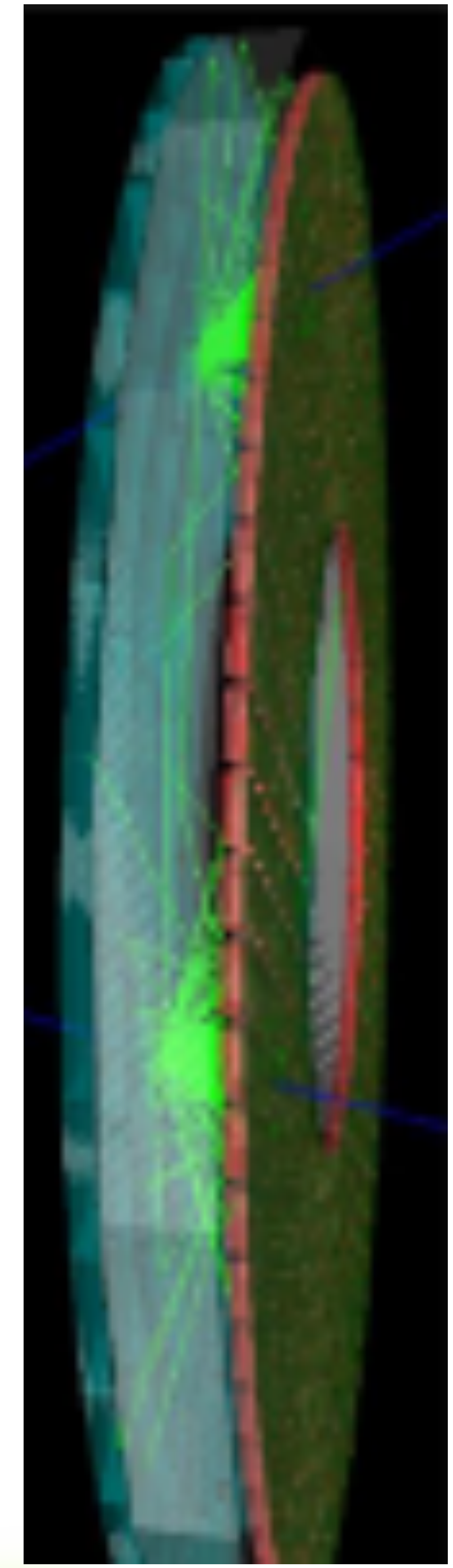
Increases the number of photons without degrading resolution



HAPD Photo-detector







PID in the forward endcap

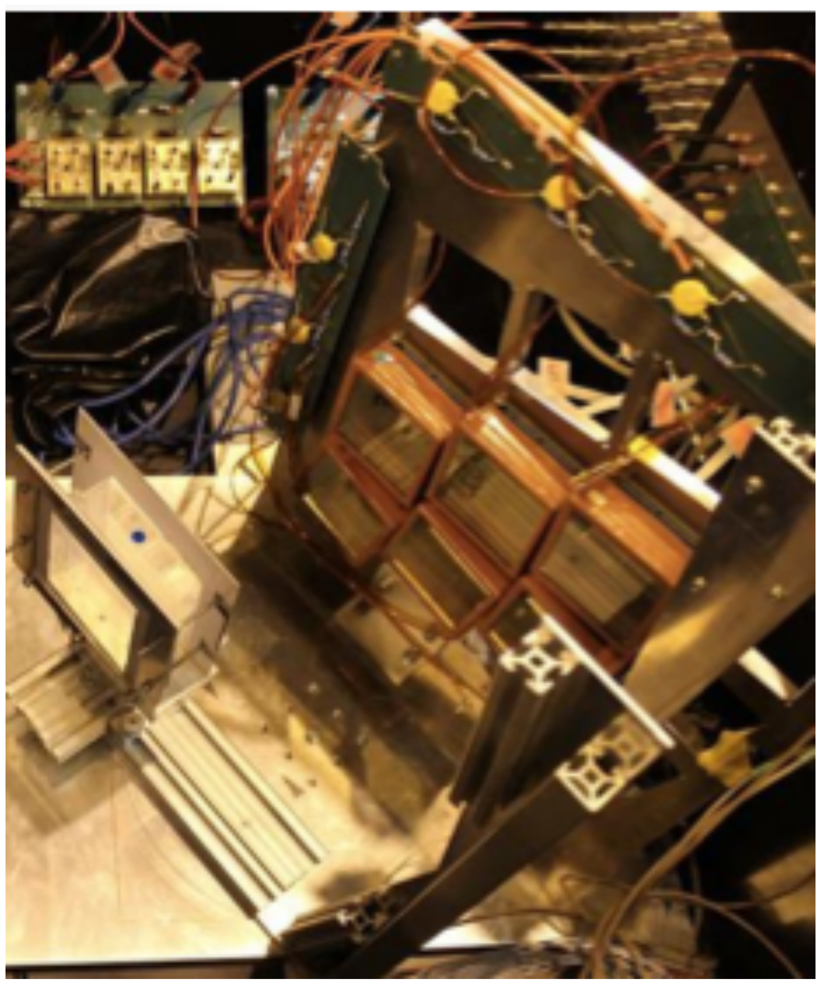
2-layer aerogel radiator

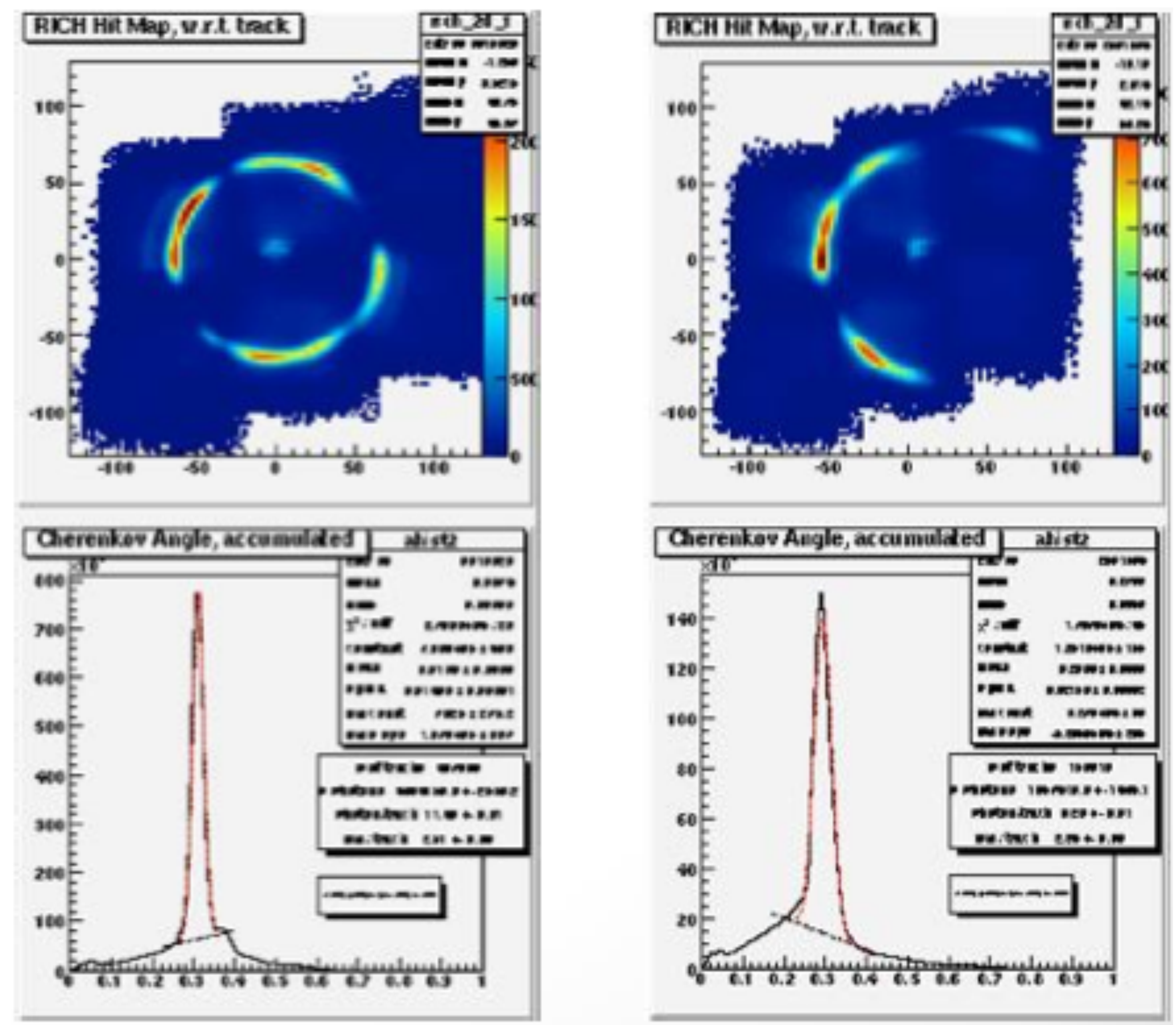
420 × *144*-channel Hybrid-Avalanche Photo-detectors (HAPD)

NIM A548 (2005) 383

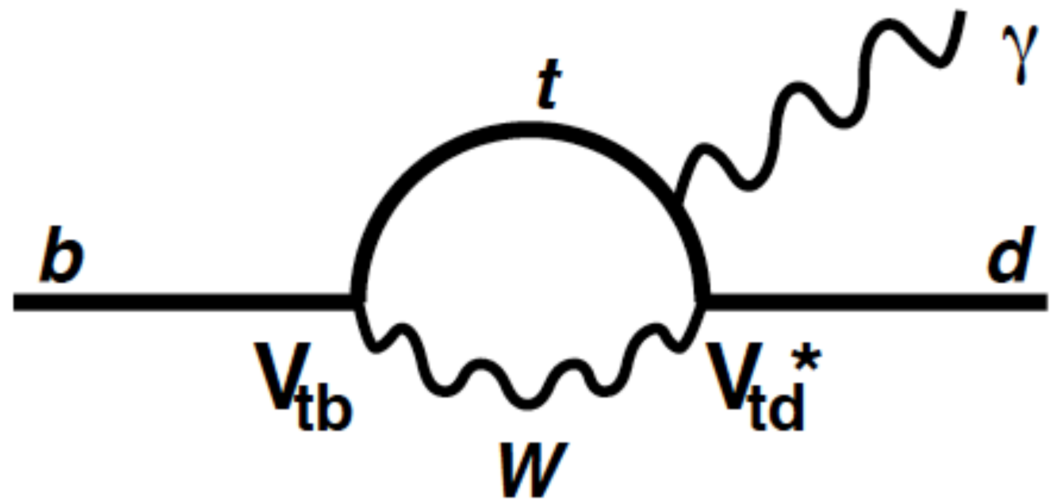
ARICH Beam Test

- Beam tests performed to check performance of prototype ARICH. • Hadron beam @ SPS in CERN and electron beam @ DESY
- Simple performance estimation from cumulative Cherenkov angle distribution. $\Delta\theta c$ = 14.1 mrad, Npe = 11.4
  → K/π separation = 5.5σ (SPS 120 GeV/c hadron beam, incident angle = 0deg case, similar for non-zero incidence.)

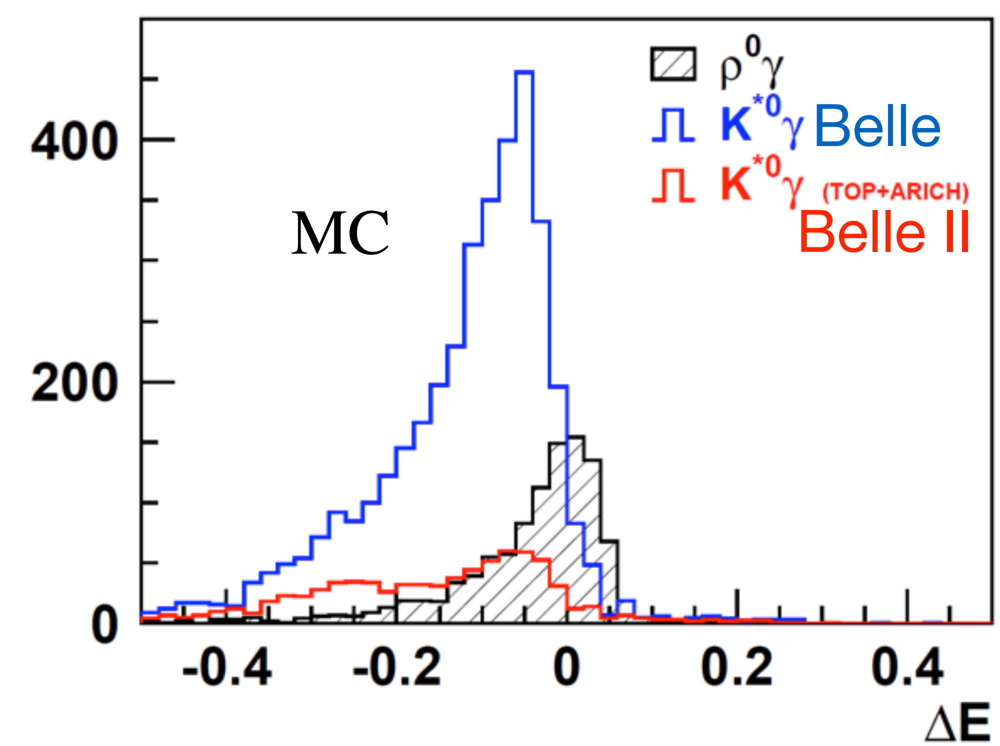




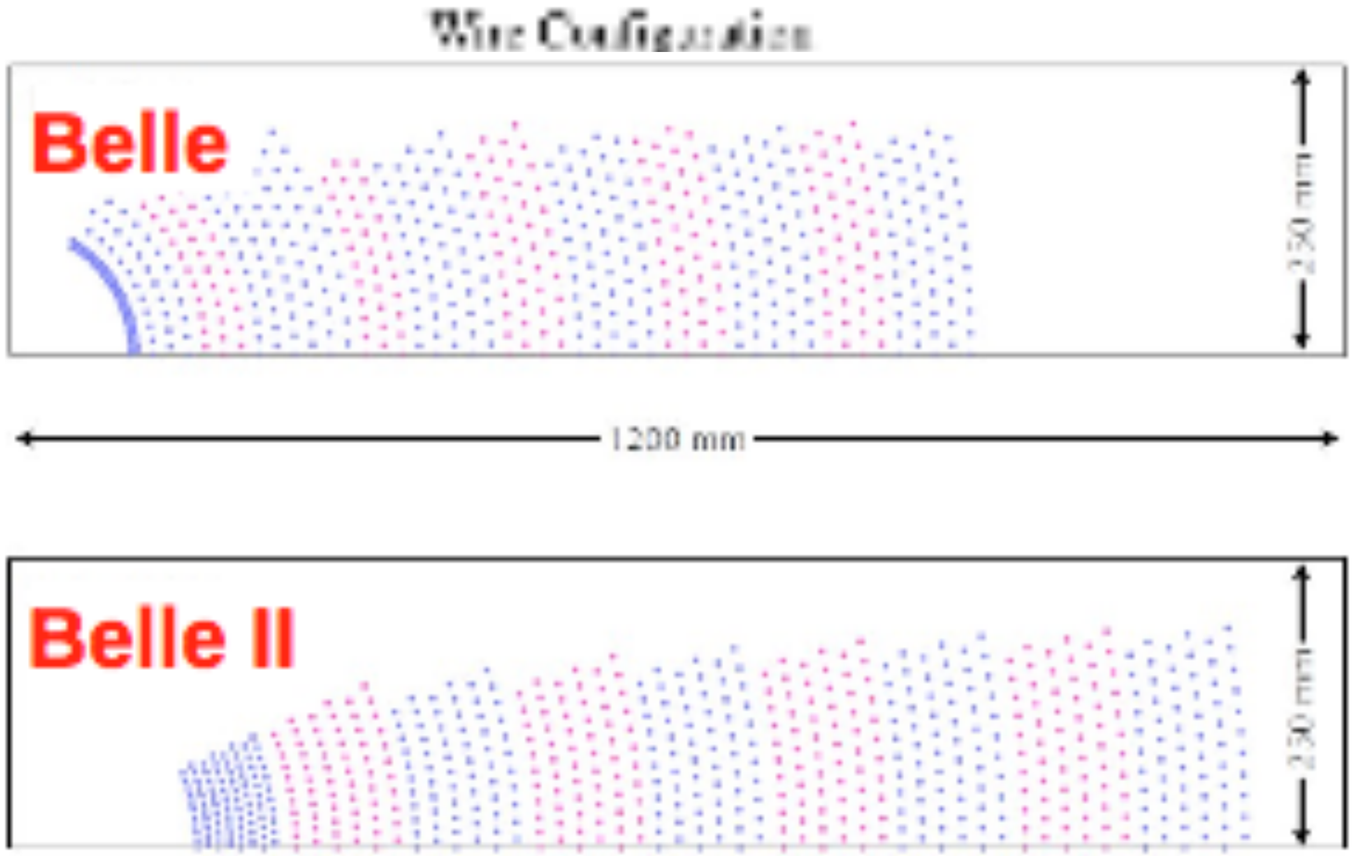
TOP impact on Rare b→d Penguins: B→ργ, K*γ



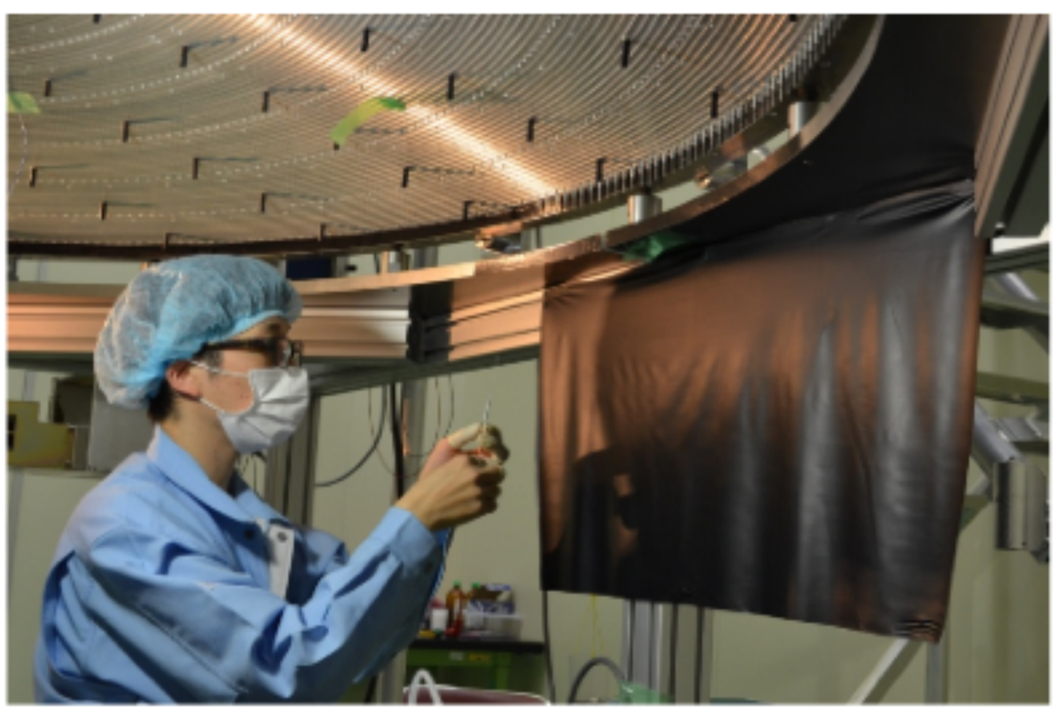
The Background
B→K* γ (Belle / BelleII) ~30X more abundant than the signal **B→ργ.**



Central Drift Chamber



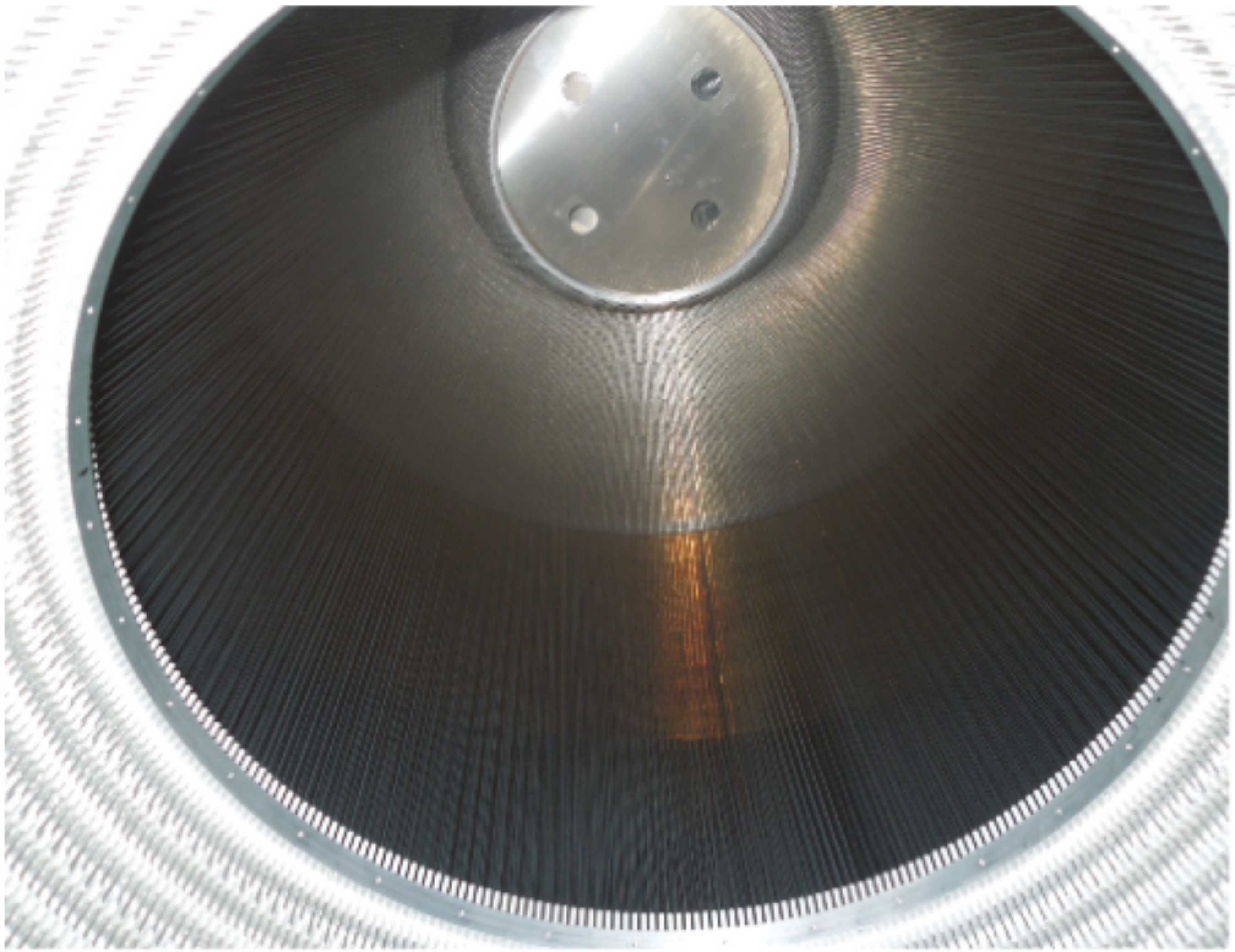
Longer lever arm than in Belle



Wire stringing complete!

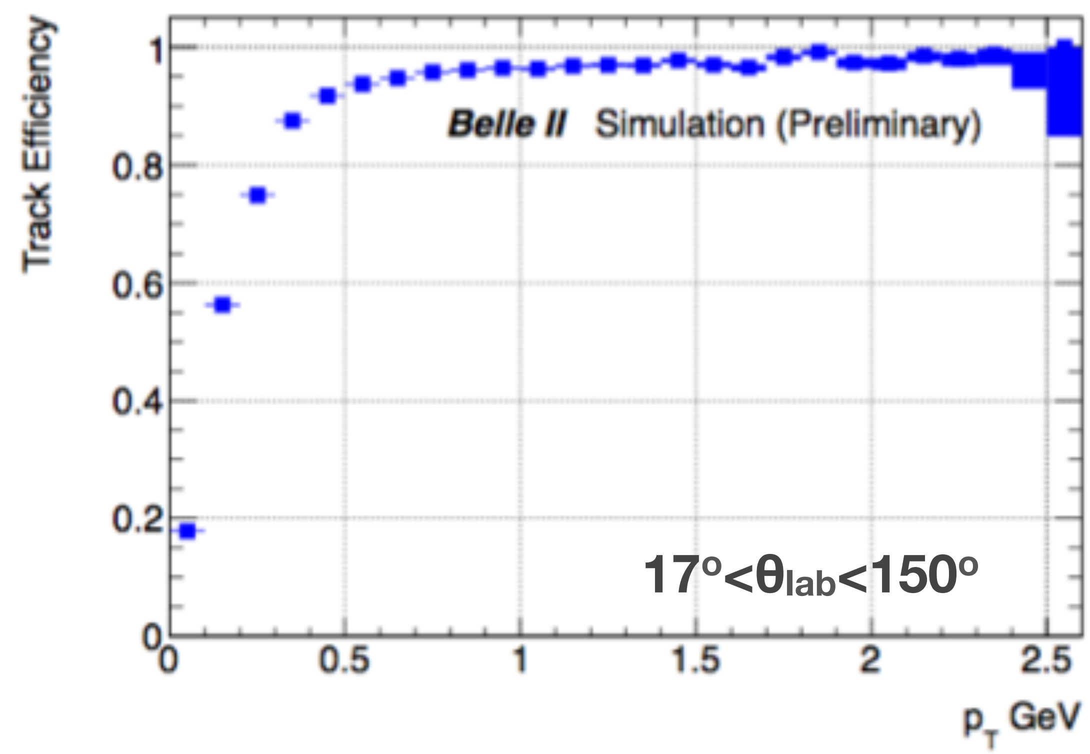
Central Drift Chamber

CDC wire stringing is complete (~51k wires)



CDC viewed from the backward side

Expected performance using a Kalman filter and GEANT4 in CDC-only



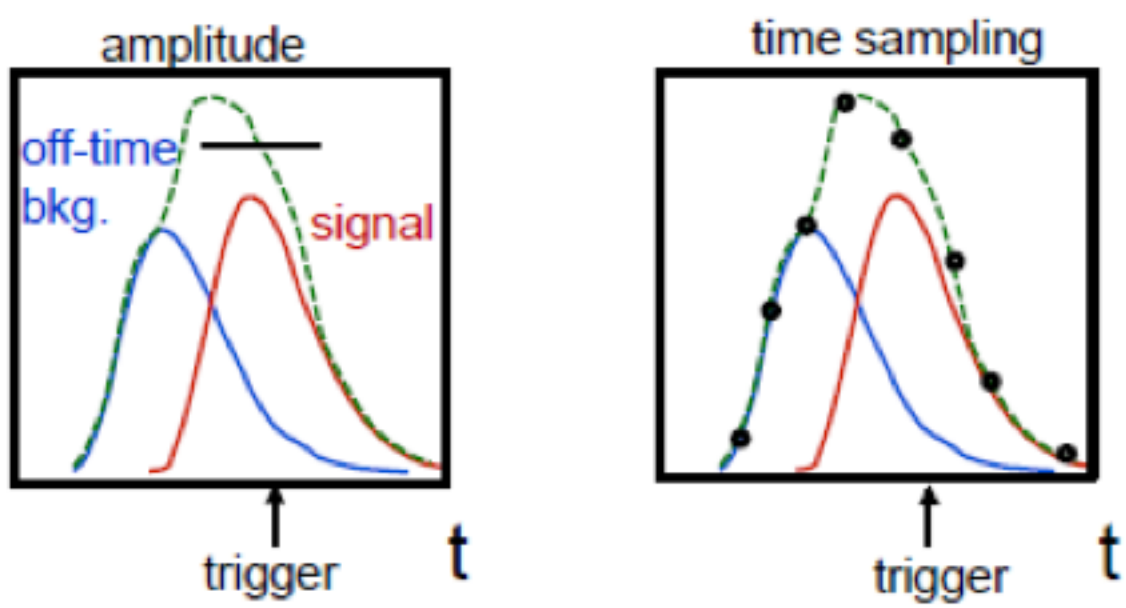
$\sigma_p/p \sim 0.3\% + 0.1\% \times p(\text{GeV})$ in $B = 1.5\text{T}$
$\sigma(\text{d}E/\text{d}x) \sim 6\%$

Calorimeter

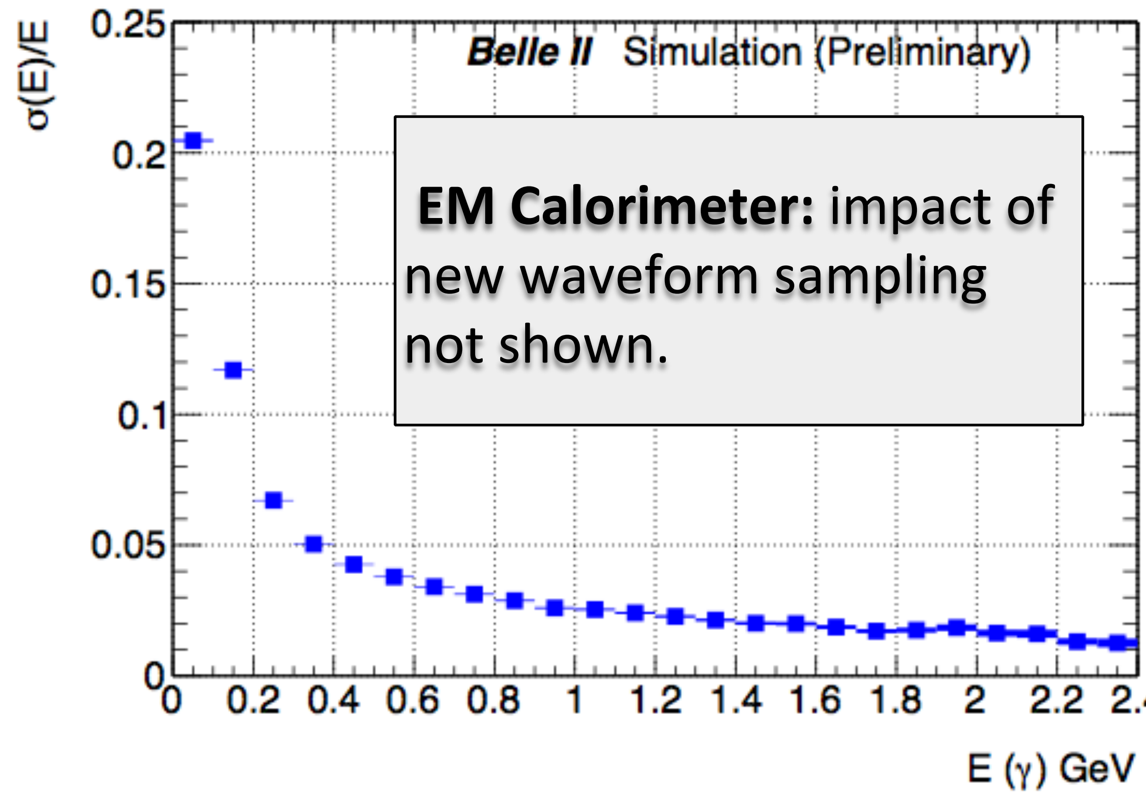
Re-use of Belle's CsI(Tl) crystals, *plus*

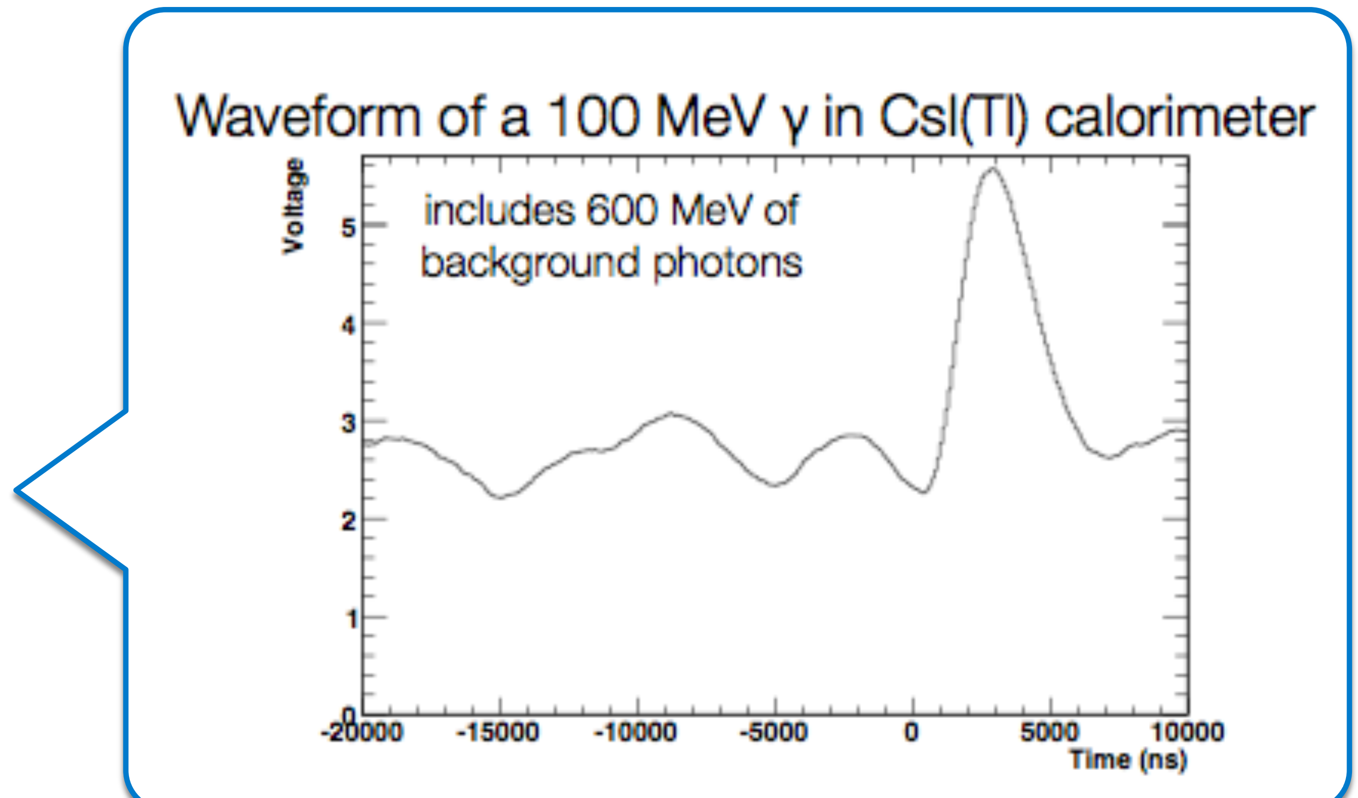
barrel: 2MHz wave form sampling to compensate for larger beam-backgrounds:

2x better resolution at 20x background!



forward endcap: CsI(Tl) ⇒CsI for faster performance and better radiation hardness

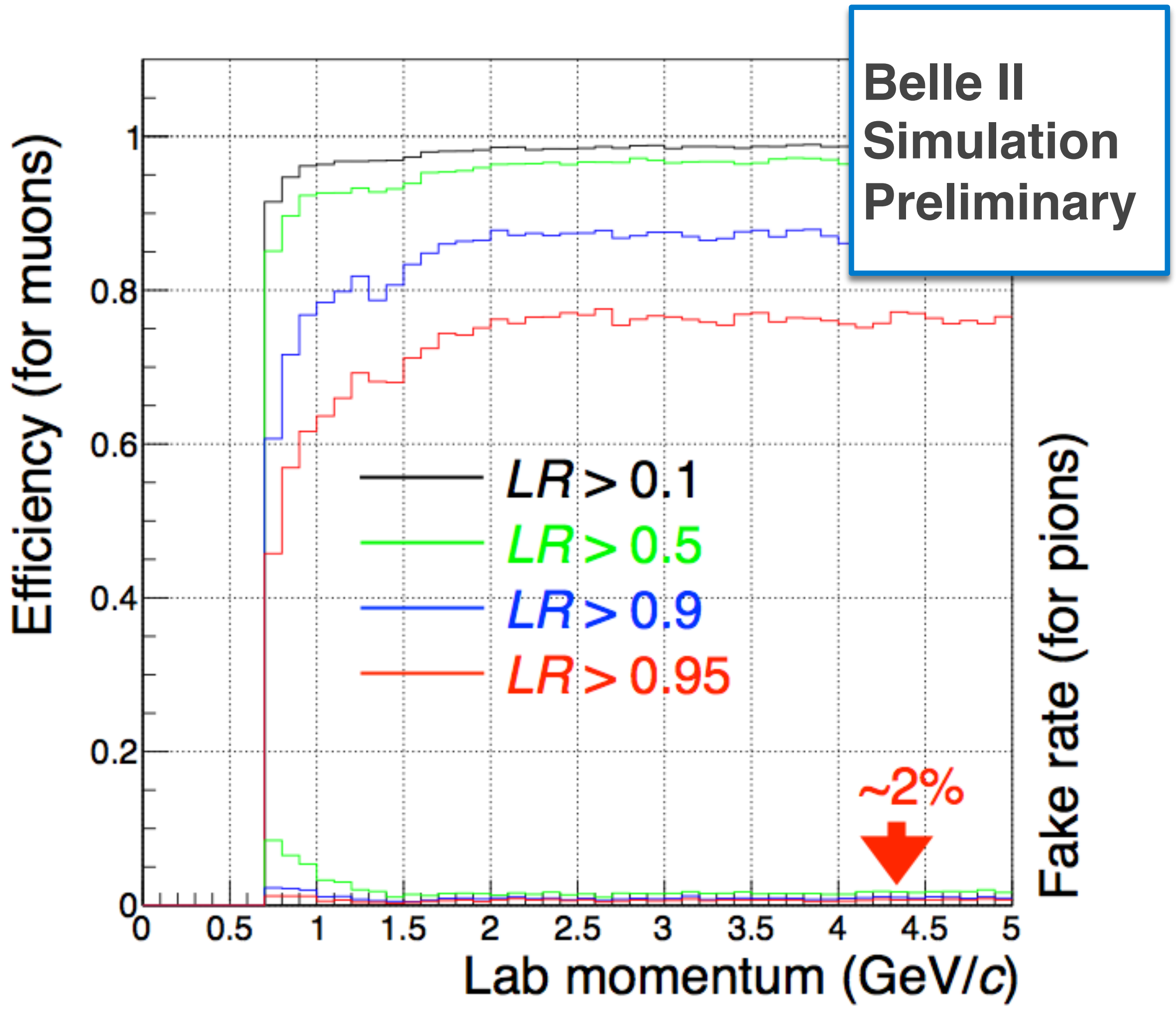




Muon/K_L Detector

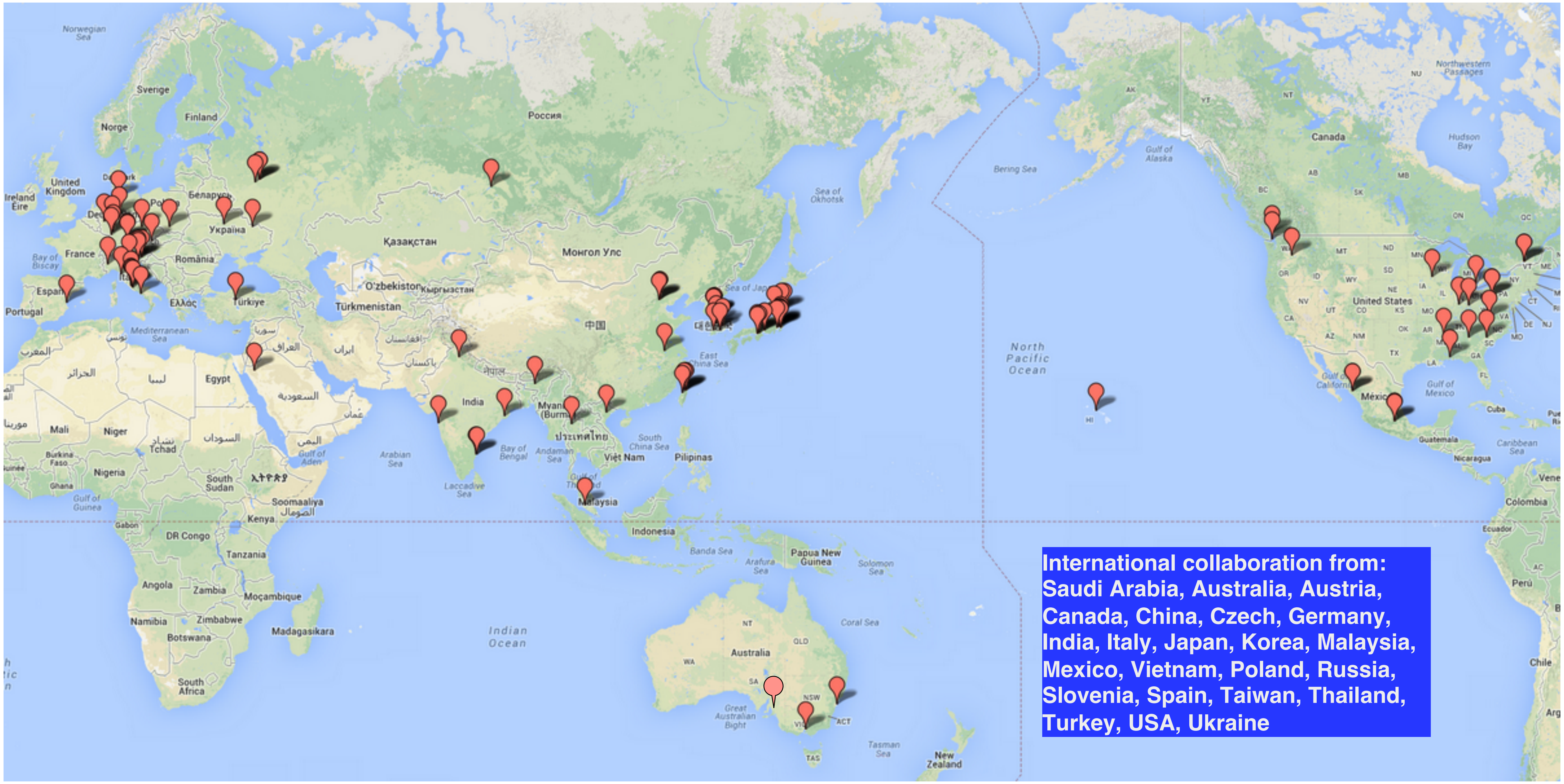
Endcap RPCs and 2 layers of the barrel replaced with scintillators to handle higher backgrounds

***K_L* momentum measured by layer timing coincidence.**



Barrel KLM installation complete - first Belle II sub detector ready!

The Belle II Collaboration



- **Belle** experiment@KEKB **(1999-2010)** [400 collaborators, 15 nations]

  (online in 2016) [~600 collaborators, 96 institutions, 23 nations/regions]

- **Belle II** experiment**@SuperKEKB**

LQCD used in projections

- Lattice QCD promises important improvements in precision.
- 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	$\lvert V_{us}\rvert$	0.2%	0.5%	0.5%	0.15%
$f_+^{K\pi}(0)$	$\lvert V_{us}\rvert$	0.2%	–	0.5%	0.2%
f_D	$\lvert V_{cd}\rvert$	4.3%	5%	2%	$< 1\%$
f_{D_s}	$\lvert V_{cs}\rvert$	2.1%	5%	2%	$< 1\%$
$D \to \pi\ell\nu$	$\lvert V_{cd}\rvert$	2.6%	–	4.4%	2%
$D \to K\ell\nu$	$\lvert V_{cs}\rvert$	1.1%	–	2.5%	1%
$B \to D^*\ell\nu$	$\lvert V_{cb}\rvert$	1.3%	–	1.8%	$< 1\%$
$B \to \pi\ell\nu$	$\lvert V_{ub}\rvert$	4.1%	–	8.7%	2%
f_B	$\lvert V_{ub}\rvert$	9%	–	2.5%	$< 1\%$
ξ	$\lvert V_{ts}/V_{td}\rvert$	0.4%	2-4%	4%	$< 1\%$
ΔM_s	$\lvert V_{ts}V_{tb}\rvert^2$	0.24%	7–12%	11%	5%
B_K	$\text{Im}(V_{td}^2)$	0.5%	3.5–6%	1.3%	$< 1\%$

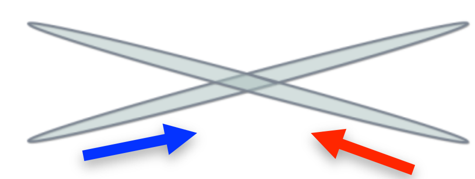
- + other rare processes, e.g. $B \to K^*\gamma$, $B \to K^* l^+ l^-$

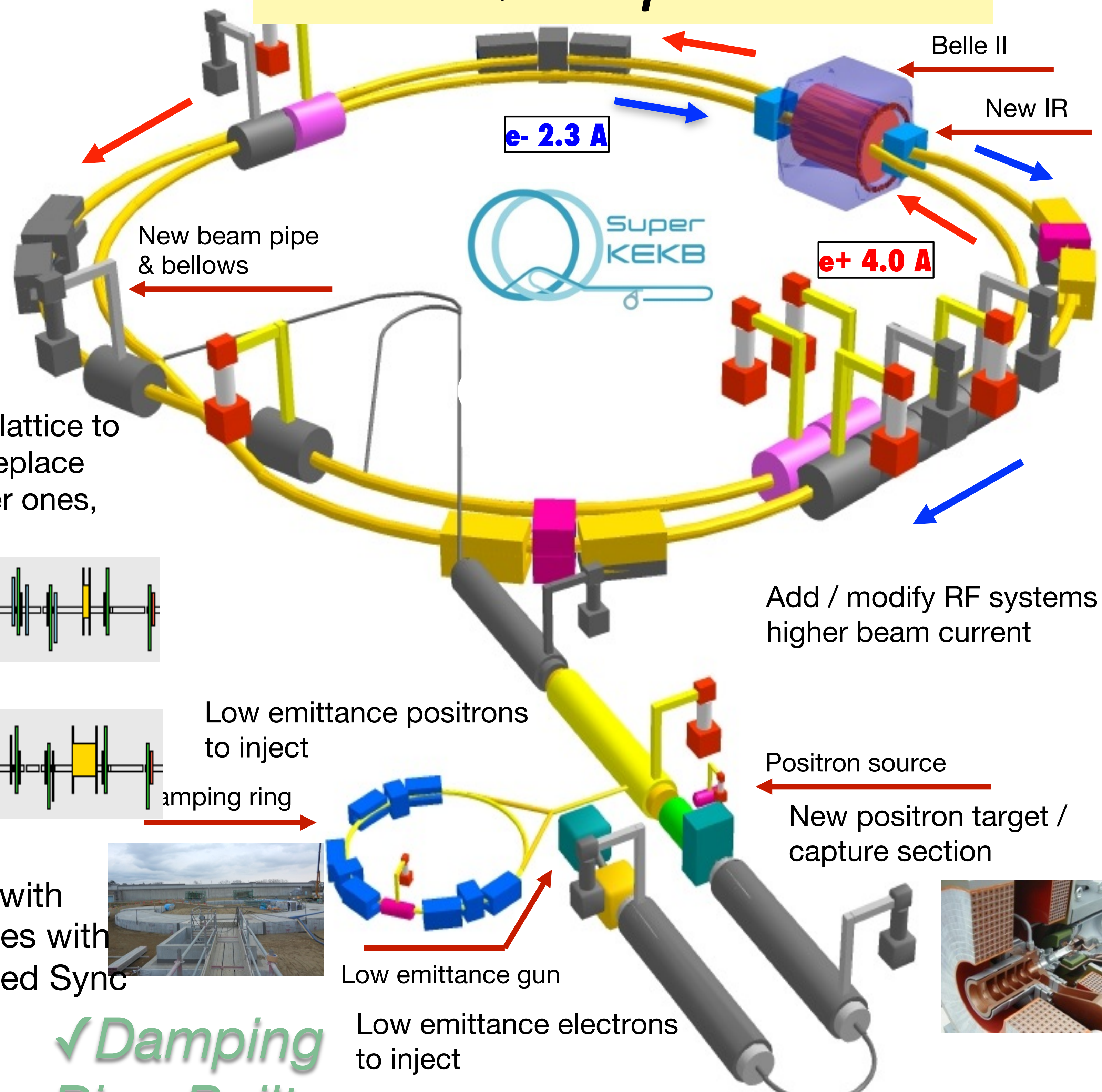
Charm and τ

	Observables	Belle	Belle II		LHCb	
		(2014)	5 ab^{-1}	50 ab^{-1}	2018	50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ $[10^{-6}]$	< 1.5	30%	25%		
Charm *CP*	$A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	3.4			0.5	0.1
	A_Γ $[10^{-2}]$	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0\pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p \rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$	6	4		
Tau	$\tau \to \mu\gamma$ $[10^{-9}]$	< 45	< 14.7	< 4.7		
	$\tau \to e\gamma$ $[10^{-9}]$	< 120	< 39	< 12		
	$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0	< 3.0	< 0.3		

CPV in τ also very promising.

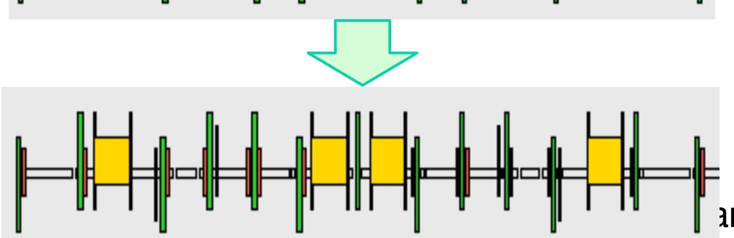
KEKB → SuperKEKB





New superconducting / permanent final focusing quads near the IP

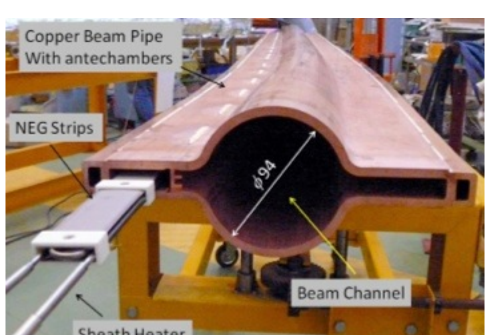
Redesign the magnetic lattice to reduce the emittance (replace short dipoles with longer ones, increase wiggler cycles)



Add / modify RF systems for higher beam current

✓New LER & HER Wiggler cavities installed

Replace beam pipes with TiN-coated beam pipes with antechambers (reduced Sync Rad.)



✓Damping Ring Built

$L = 8 \cdot 10^{35}\ s^{-1}cm^{-2}$

Completion end of 2014

x 40 Gain in Luminosity