Flavour Physics @ Belle II

(~10.58 GeV)

Phillip Urquijo, The University of Melbourne

Flavour Physics @ 100 TeV

IHEP, Beijing, March 2015

Belle II (experiment) at SuperKEKB (collider)

- Successor to Belle@KEKB (1 ab^{-1} of e^+e^- data)
  - Extremely successful in understanding the nature of heavy quarks and leptons, but…
- "Super Flavour Factory" (B, D & τ) with 50 ab^{-1} (~50 billion of each) needed to identify new physics (synergy with direct searches at LHC)
  - Belle II due for first physics in 2017–2018
- **Any NP found by Belle II will have profound implications for new accelerator facilities.**

The case for new physics manifesting in Belle II

Issues (addressable at a Flavour factory)

→ NP beyond the direct reach of the LHC

- Baryon asymmetry in cosmology
  → New sources of CPV in quarks and charged leptons
- Quark and Lepton flavour & mass hierarchy
  → higher symmetry, massive new particles, extended gauge sector
- 19 free parameters
  → Extensions of SM relate some, (GUTs)

$$\mathcal{L}_{\mathrm{Yukawa}} = g_u^{ij}\,\bar{u}_R^i\,H^T\,\epsilon\,Q_L^j - g_d^{ij}\,\bar{d}_R^i\,H^\dagger\,Q_L^j - g_e^{ij}\,\bar{e}_R^i\,H^\dagger\,L_L^j \quad + \mathrm{h.c.}\,,$$

$$\mathcal{L}_{W^\pm\ \mathrm{quark\ int.}} = \frac{g_2}{\sqrt{2}}\,W_\mu^+\,\bar{u}'_L\,\gamma^\mu\,V_{\mathrm{CKM}}\,d'_L + \mathrm{h.c.}\,,$$

- No (WIMP) candidates for Dark Matter
  → Hidden dark sector
- Finite neutrino masses
  → Tau LFV.
- + Puzzling nature of exotic “new” QCD states.

B factories

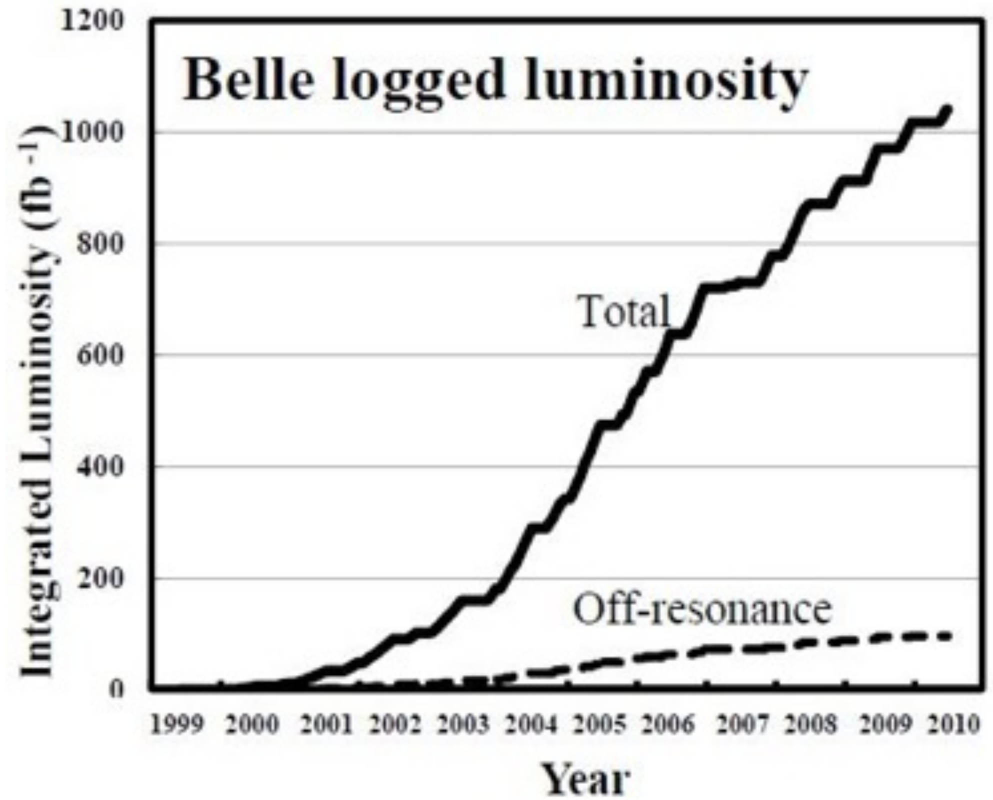
"The Physics of B Factories" Book
European Physics Journal C,
74:3026 (arXiv:1406.6311)

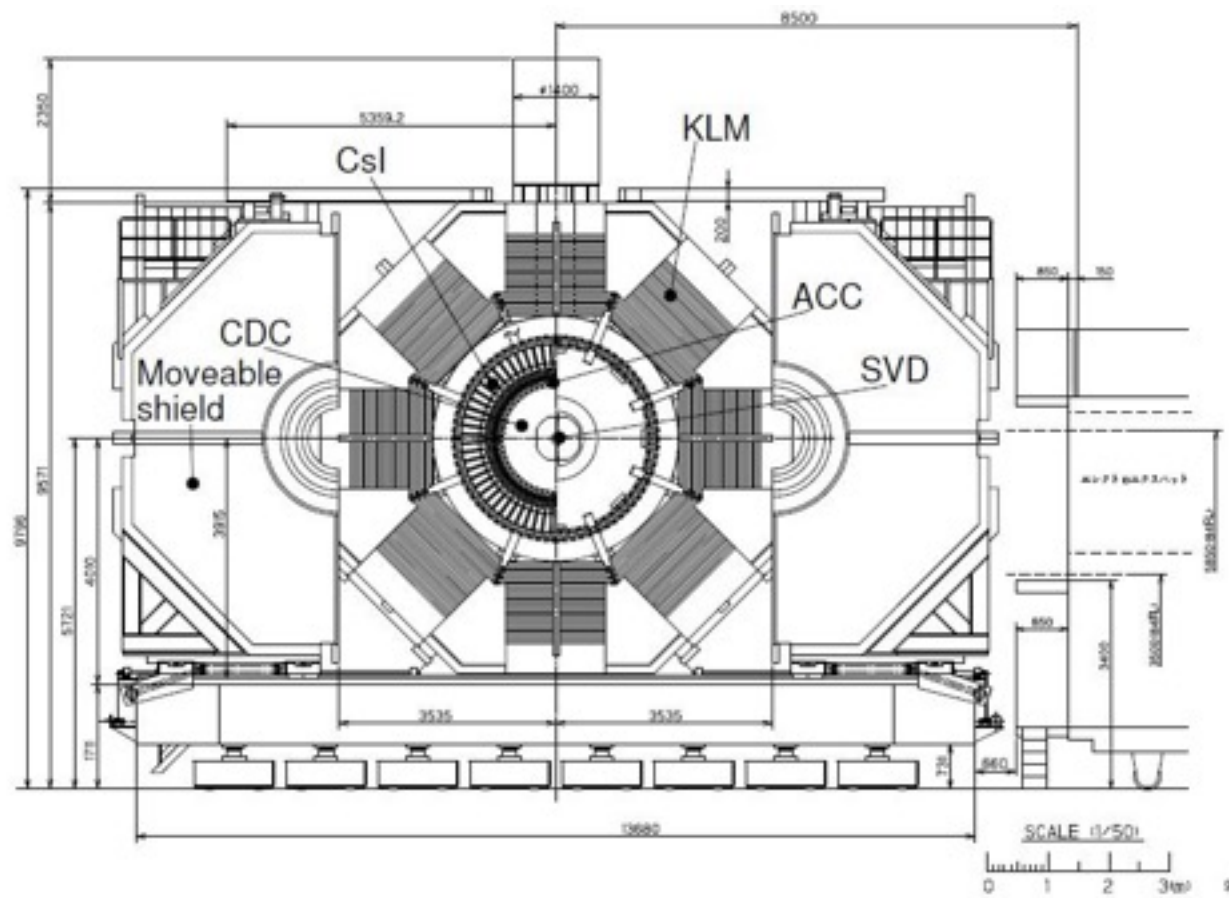
Belle: 1999-2010 analyses still ongoing

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow BB$

$\int L^{\Upsilon(4S)} dt \sim 710\ \text{fb}^{-1}$

2008 Nobel Prize





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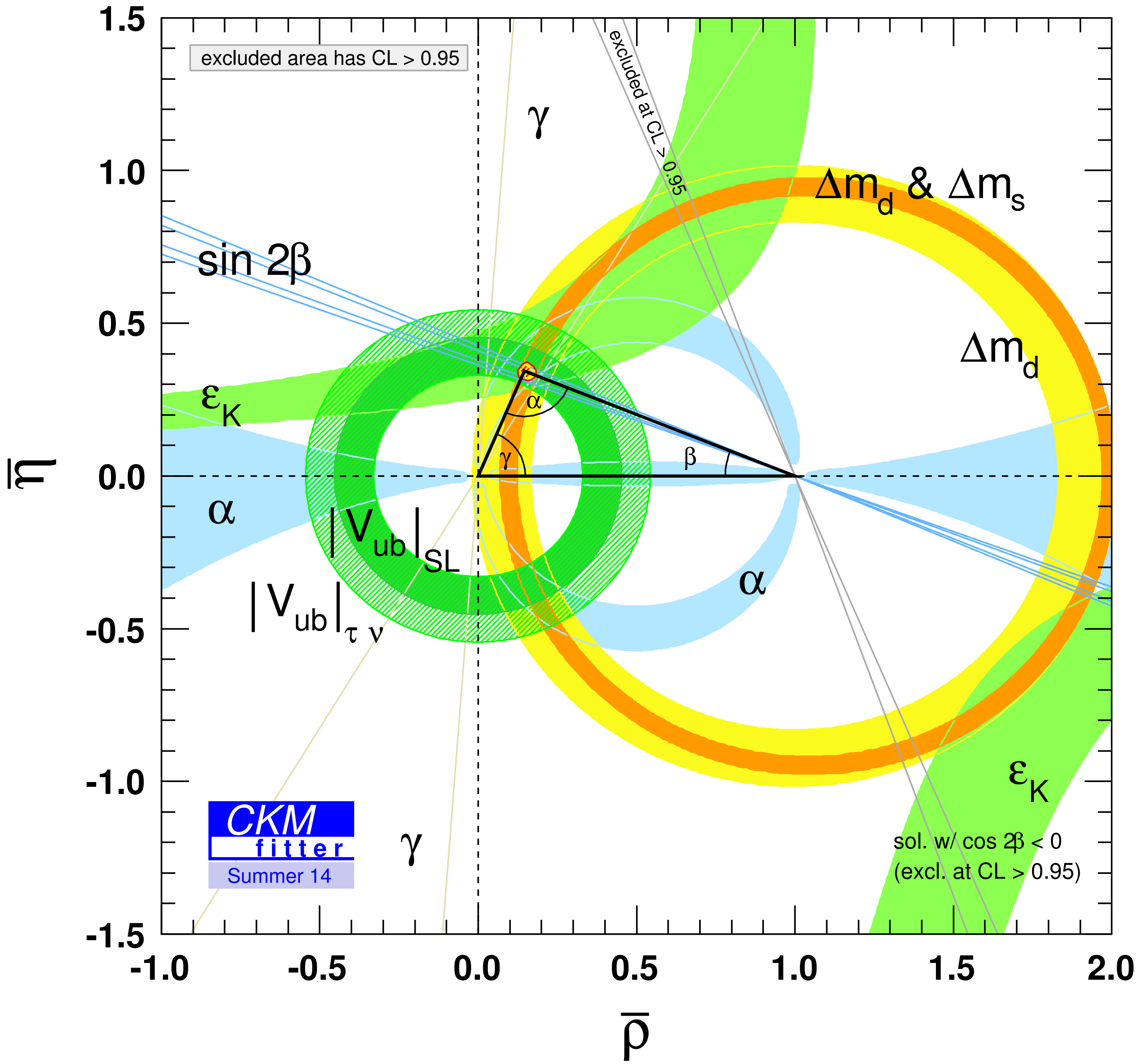
BaBar (**PEPII@SLAC**) and Belle (**KEKB@KEK**)

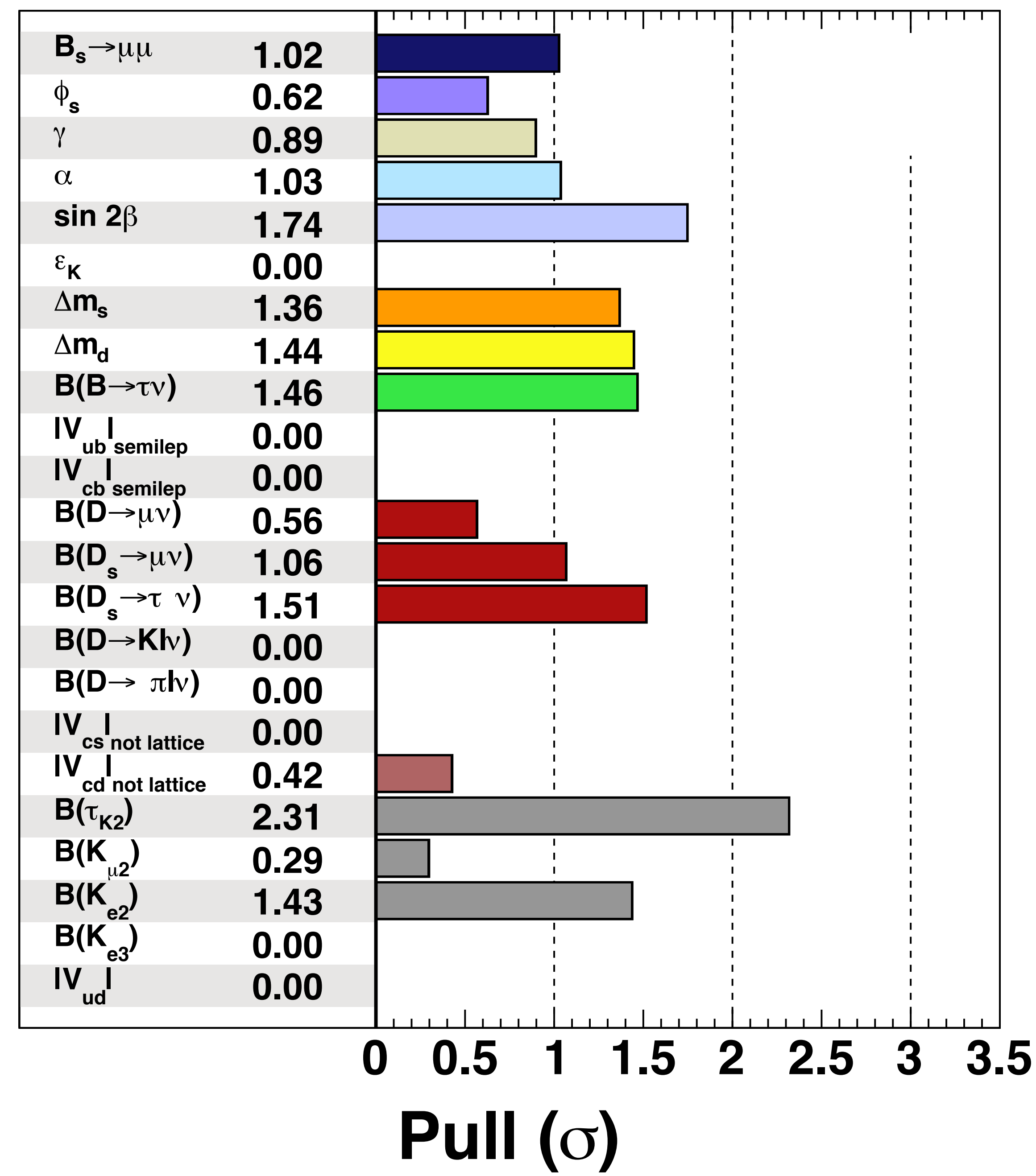
Together recorded over 10^9 $e^+e^- \rightarrow \Upsilon(4S) \rightarrow BB$ *events.*

- Discovery of CPV in *B*
- Measurements of UT sides and angles
- Rare *B* decays
- Mixing in charm
- Searches for rare τ decays
- New hadrons

CKM Fits

CKMFitter (http://ckmfitter.in2p3.fr)





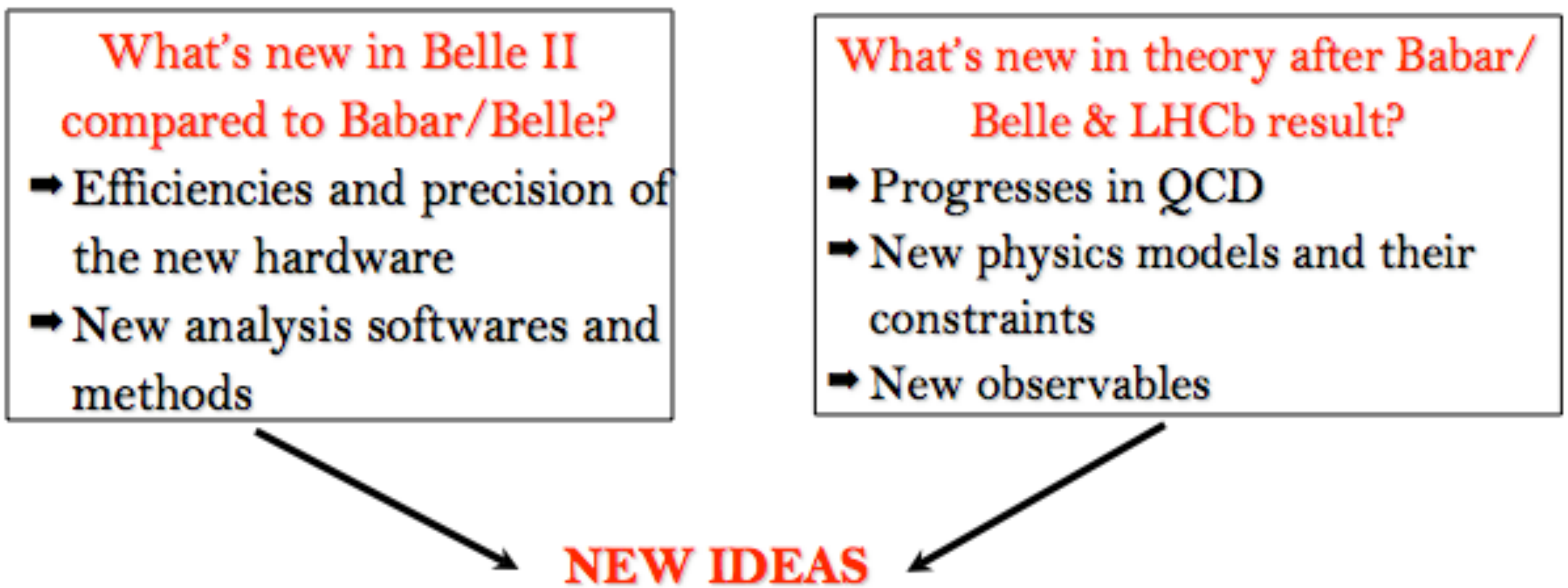
B-factories + LHCb indicate excellent agreement with the SM, but potential NP requires a different search paradigm.

Belle II Theory Interface Platform

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

Joint theory-experiment effort to study the potential impacts of the Belle II program, and complementarity with LHCb.

2 workshops a year, starting in June 2014. **Received very well by theory and Belle II.**



Deliverable: "KEK yellow report" by the end of 2016

Next OPEN B2TiP Workshop: 27-29 April 2015 @ Krakow
http://kds.kek.jp/conferenceDisplay.py?confId=17654

B2TIP Working Groups

I. Inclusive semi-leptonic (Vub, Vcb, mb) & Exclusive semi-leptonic and pure leptonic (Vub, Vcb, new physics)

II. Electroweak penguins (inclusive, exclusive, semi-inclusive b->s l+l-, angular analysis, very rare) & Radiative penguins (inclusive, exclusive b-> s/d gamma, CP violation, polarisation, very rare)

III. Hadronic decays (charmless decays, direct CP violation)

IV. Phi_1 (tree, penguins, new physics) & Phi_2 (penguin/tree interference)

V. Phi_3 (time dependent/independent)

VI. Charm (CPV, hadronic, leptonic, semi-leptonic decays, spectroscopy)

VII. Tau (LFV, CPV, alphas) & Low multiplicity & EW

VIII. Upsilon (nS) (dark matter, mb measurements etc, energy scan)&Charmonium (conventional, exotics XYZ)

➡Belle II & New Physics

Coordinators: Theory, Lattice, Belle II,

+ LHCb invitees

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TABLE XXIII: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY models from Ref. [416]. ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

	AC	RVV2	AKM	δLL	FBMSSM
$D^0 - \bar{D}^0$	★★★	★	★	★	★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★

Strengths of e^+e^- @ Y(4S)

Full reconstruction of B

- modes w/ multiple ν's
- inclusive modes

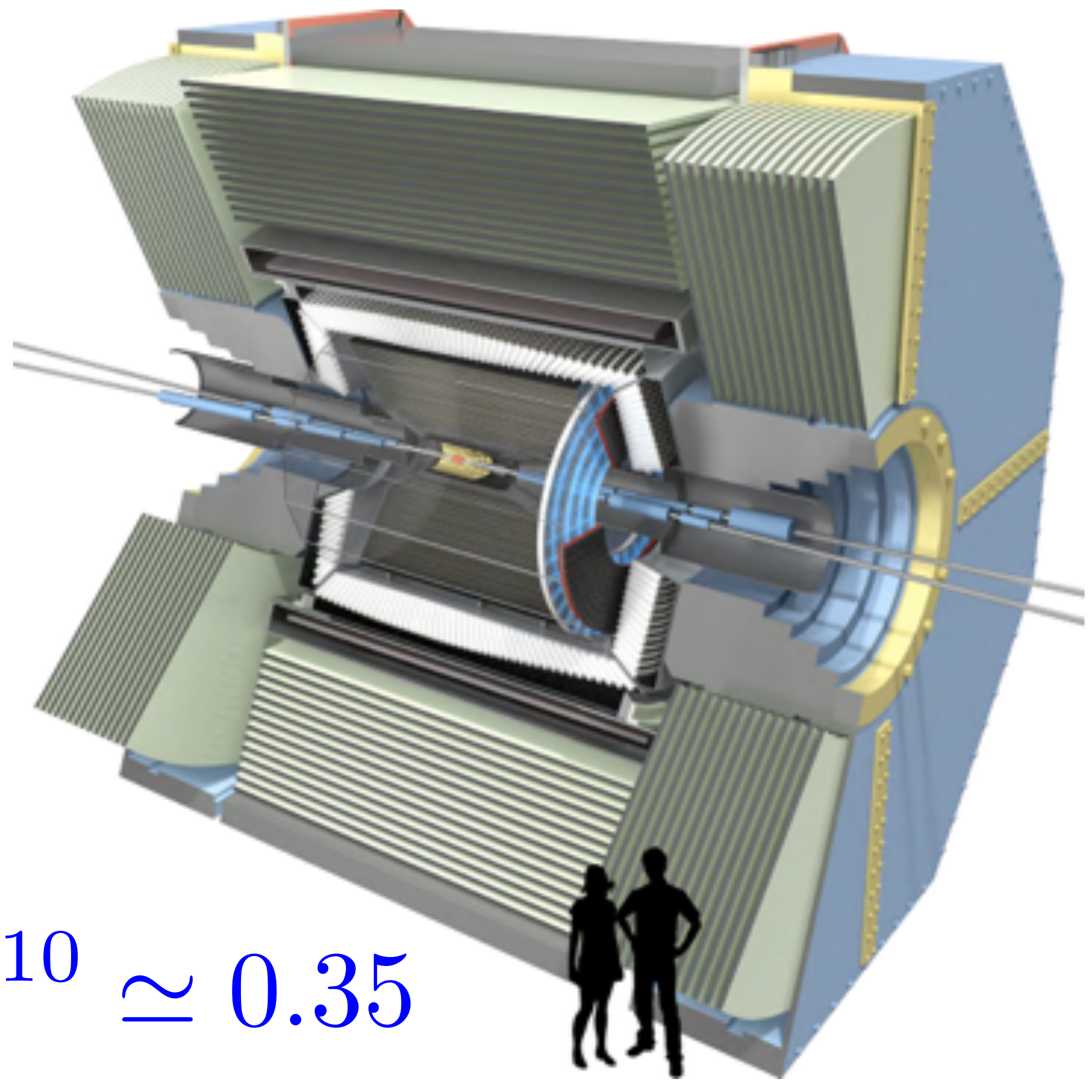
Hermeticity

- 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

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



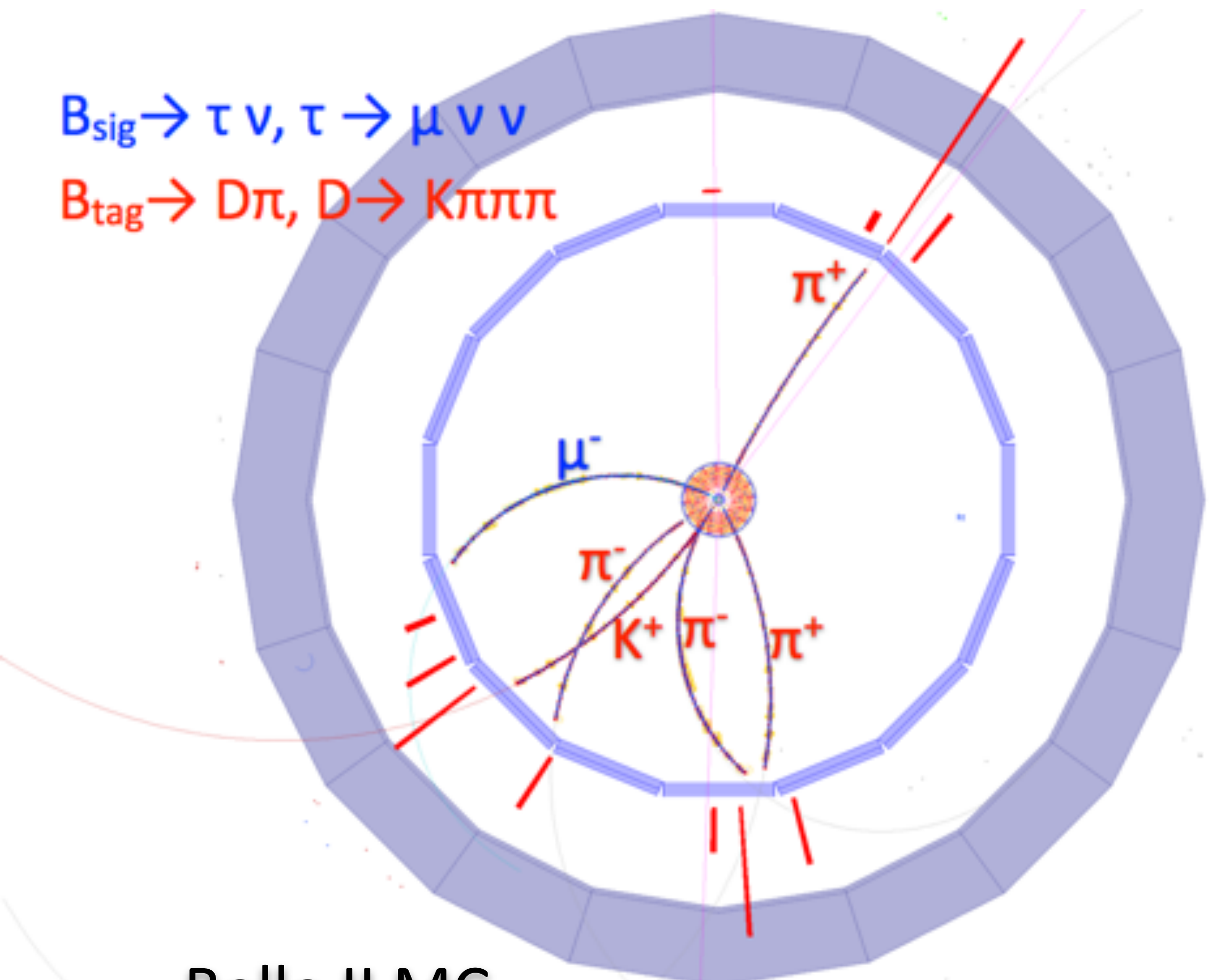
$$0.9^{10} \simeq 0.35$$

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

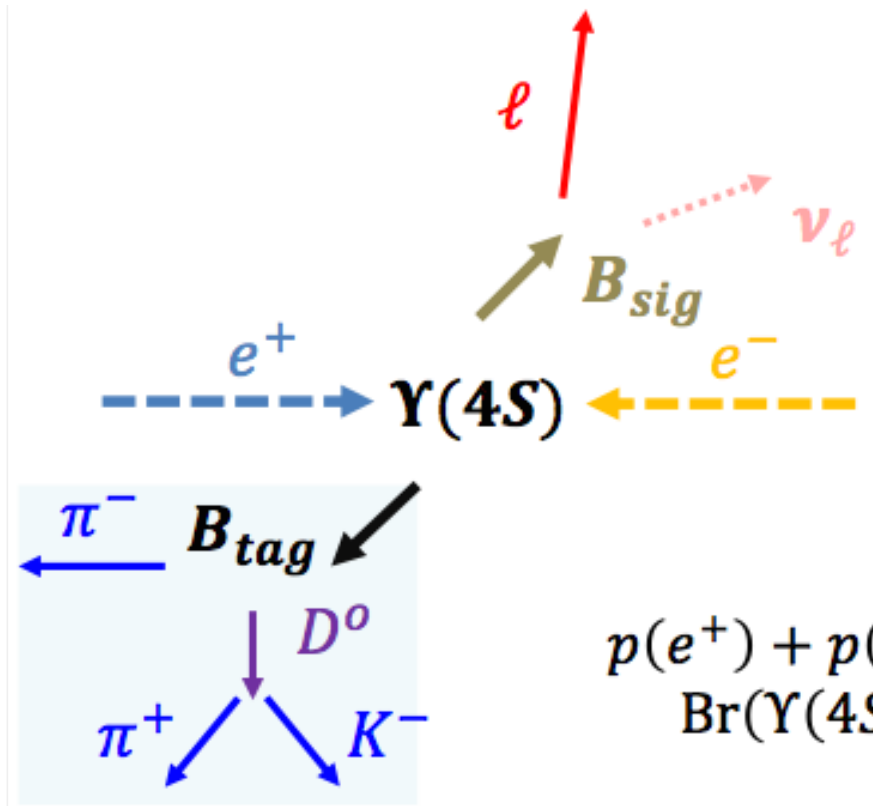
1. B full reconstruction (Neutrinos & Inclusive)

Exploit $\Upsilon(4S) \rightarrow B_{tag} B_{sig}$
Reconstruct $B_{tag} \rightarrow$ (E,p), Q, flavour of B_{sig}
Had: $\varepsilon(B_{tag})$ = 0.20 - 0.25% @ Purity(B_{tag}) = 20%

→ Btag efficiency in Belle II expected to be >2x more efficient!



Belle II MC

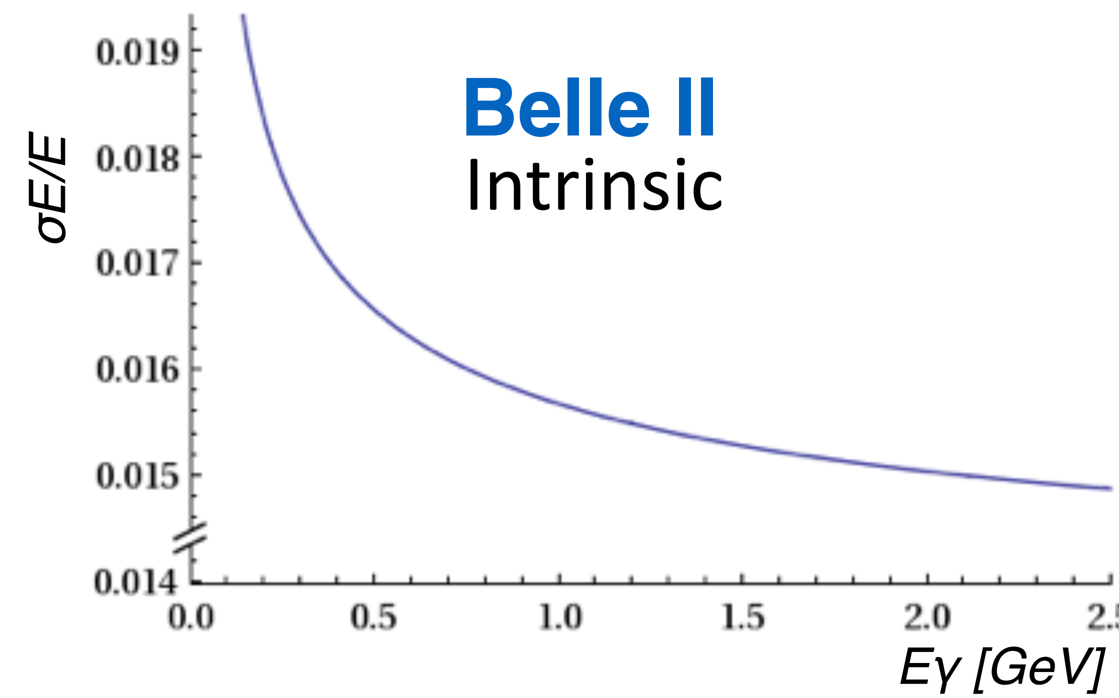


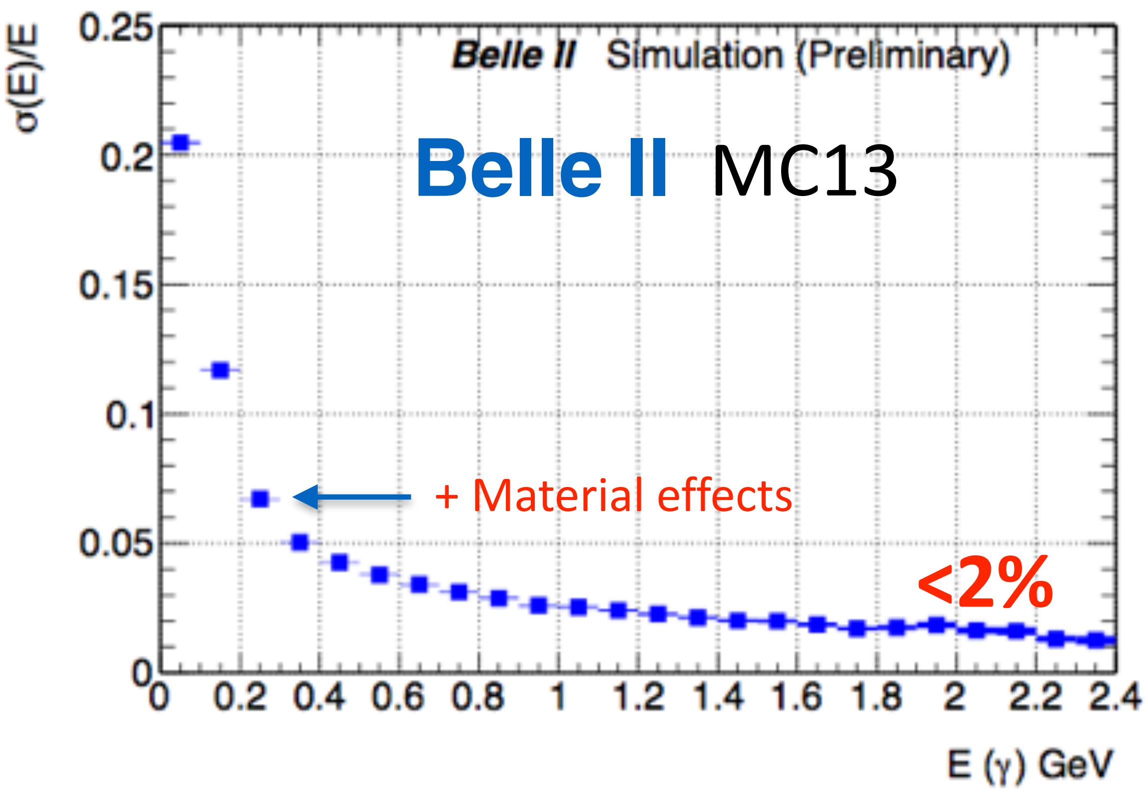
$$p(e^+) + p(e^-) = p(B) + p(\bar{B})$$
$$\mathrm{Br}(\Upsilon(4S) \rightarrow B\bar{B}) > 96\%$$

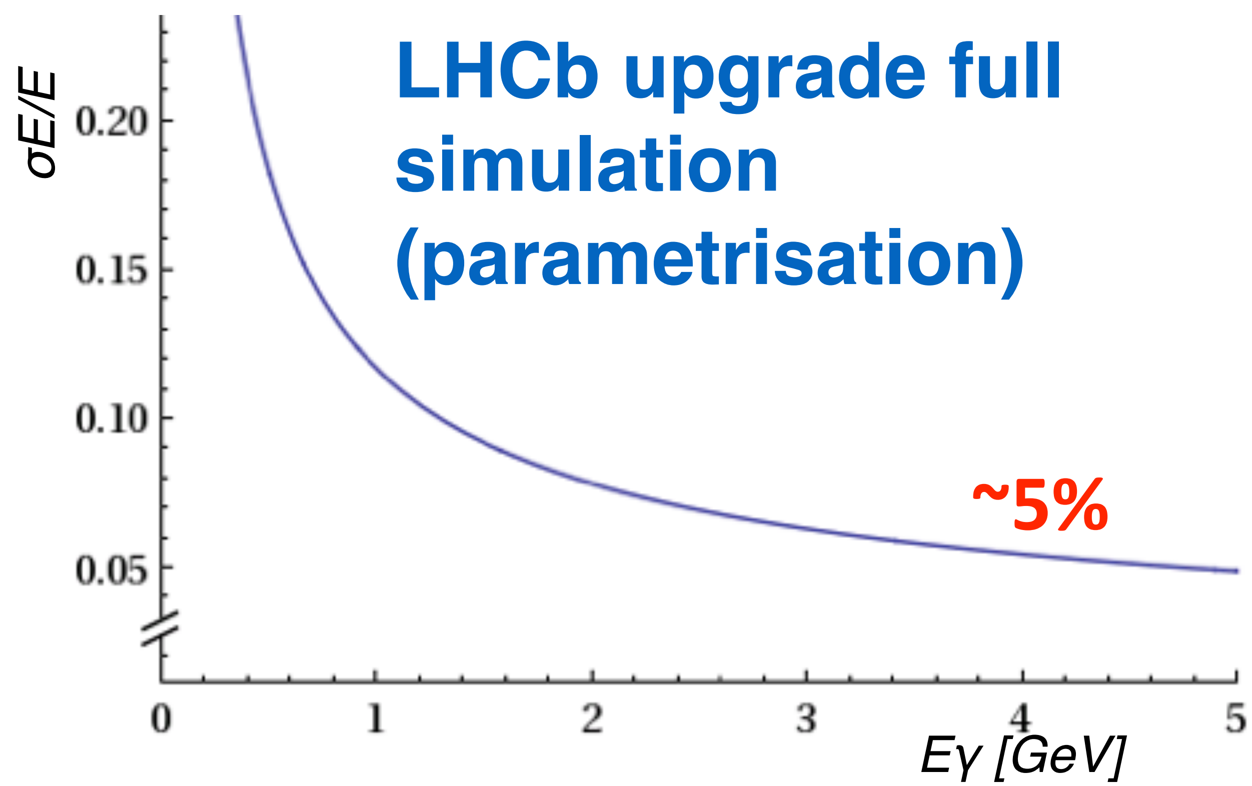
$b \rightarrow u$	$b \rightarrow c$	$b \rightarrow s$	$b \rightarrow d$
$\pi l\nu$, $\rho l\nu$	$D^{(*)}\tau\nu$	$K^{(*)}\nu\nu$	$\pi\nu\nu$
$X_u l\nu$	$D^{(*)}l\nu$	$X_s\gamma$	$\nu\nu$
$\tau\nu$	$X\nu\, l/\tau$	$X_s ll$	$B_{(s)}^0 \rightarrow \tau\tau$
$\mu\nu$			

2. EM Calorimetry: Neutrals & Electrons

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





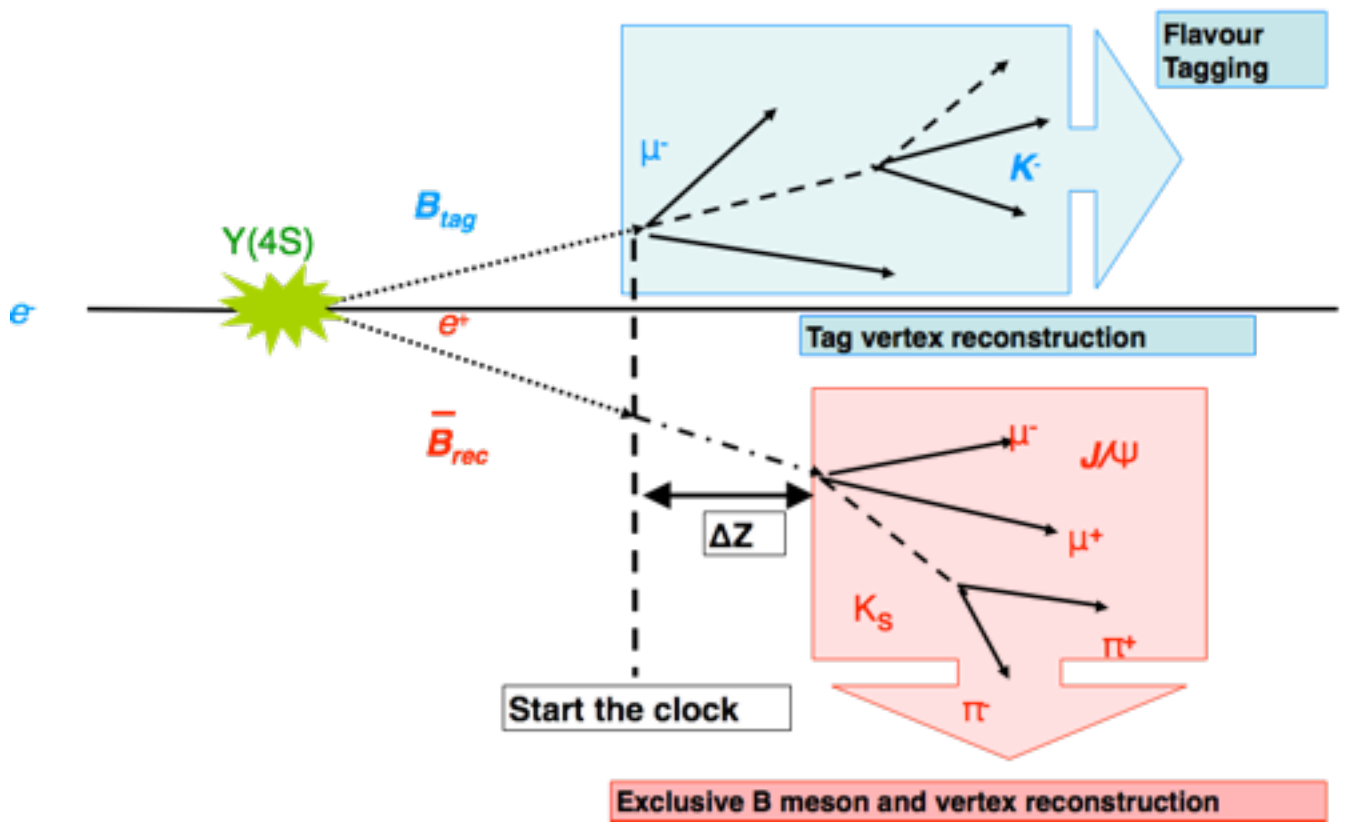


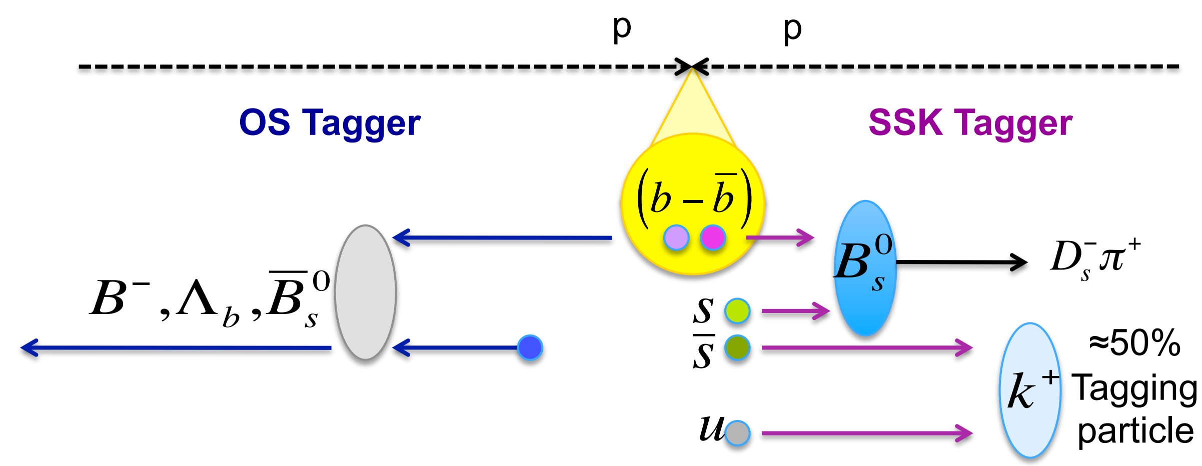
3. Flavour-tagging & Neutral Kaons

Tagging power

~30% for a B-factory

~2.0±0.3% for LHCb (http://arxiv.org/pdf/1202.4979.pdf)





In $B_d \rightarrow ssq$ CP eigenstate usually detected via K_S

(> 10 X more efficient in Belle II than LHCb)

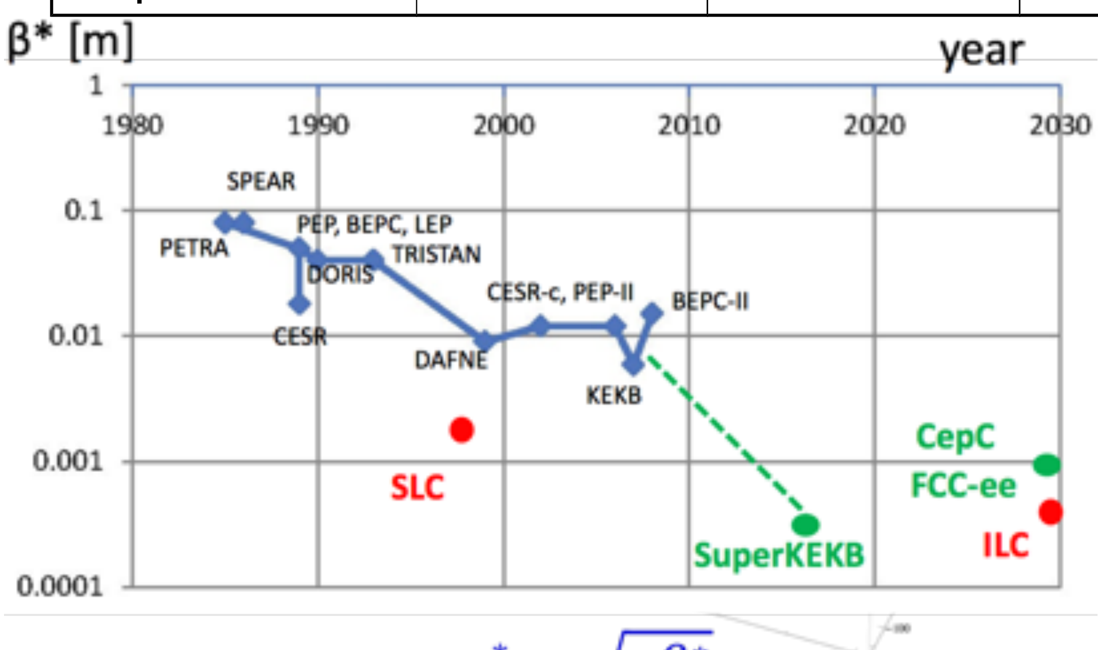
K_L detection much improved (Impossible @ LHCb)

How to make a Super Flavour Factory

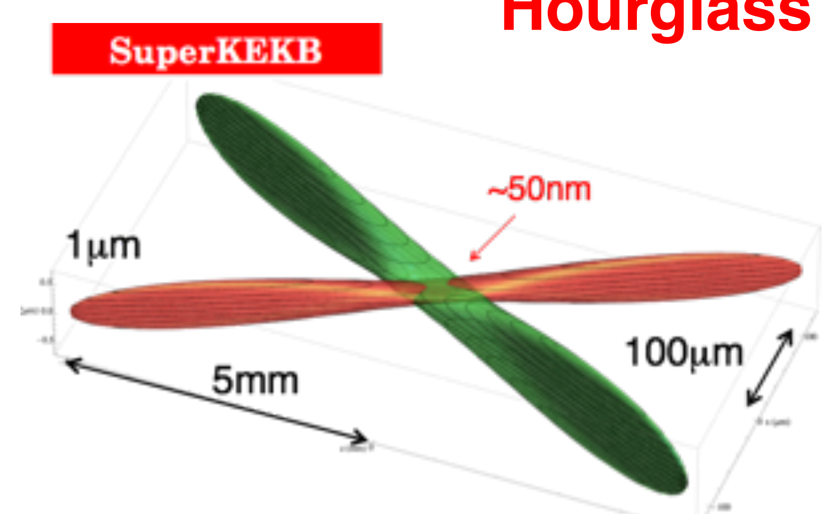
$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

- 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

	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}



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

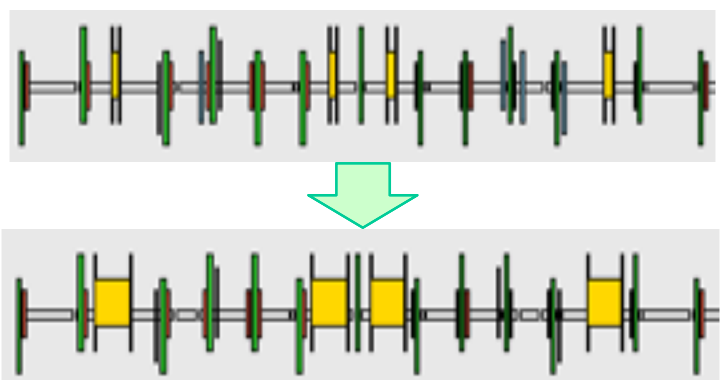


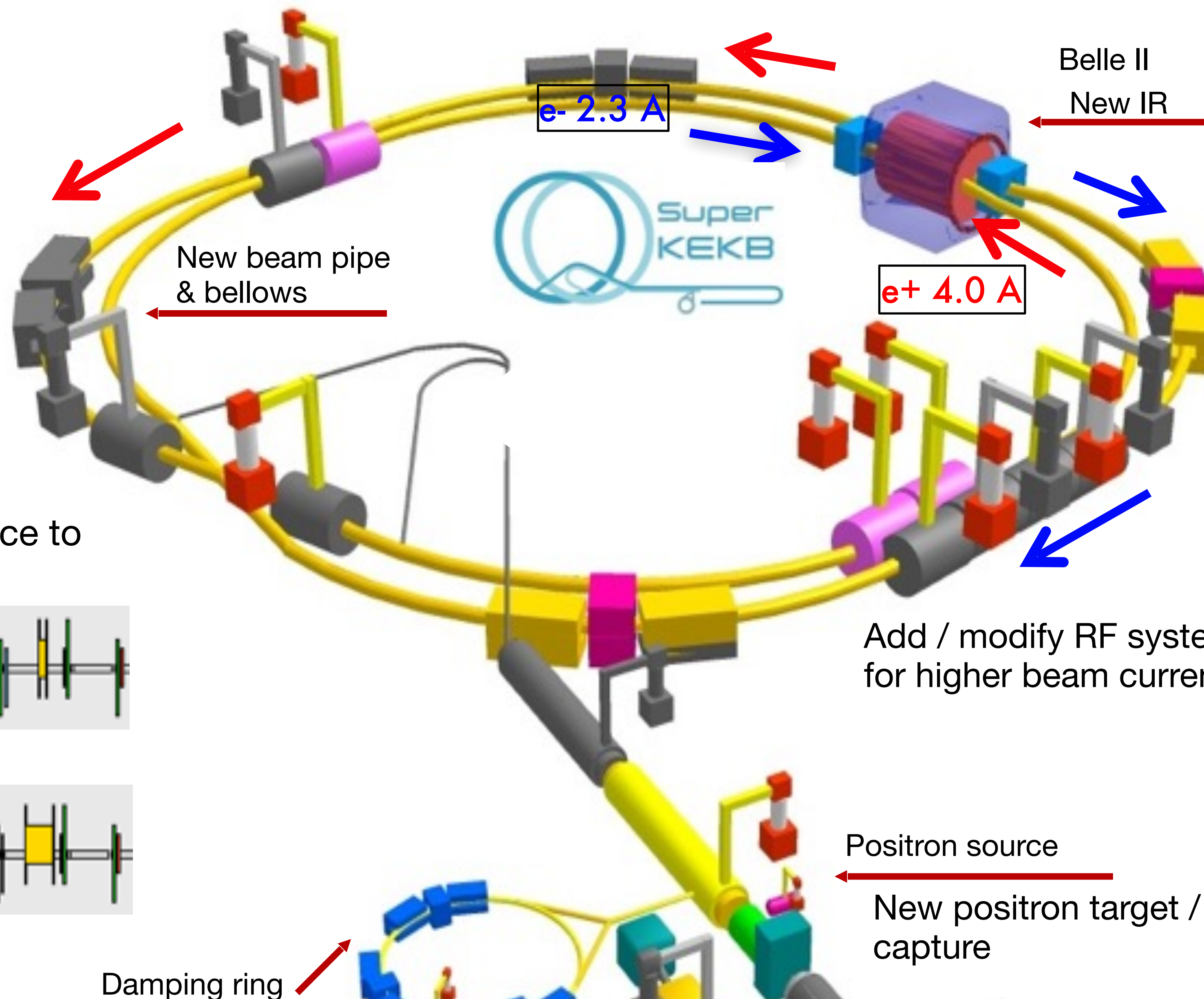
Hourglass condition:

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

KEKB to SuperKEKB...Built! (grey=recycled, colour=new)

Redesign the magnetic lattice to reduce the emittance



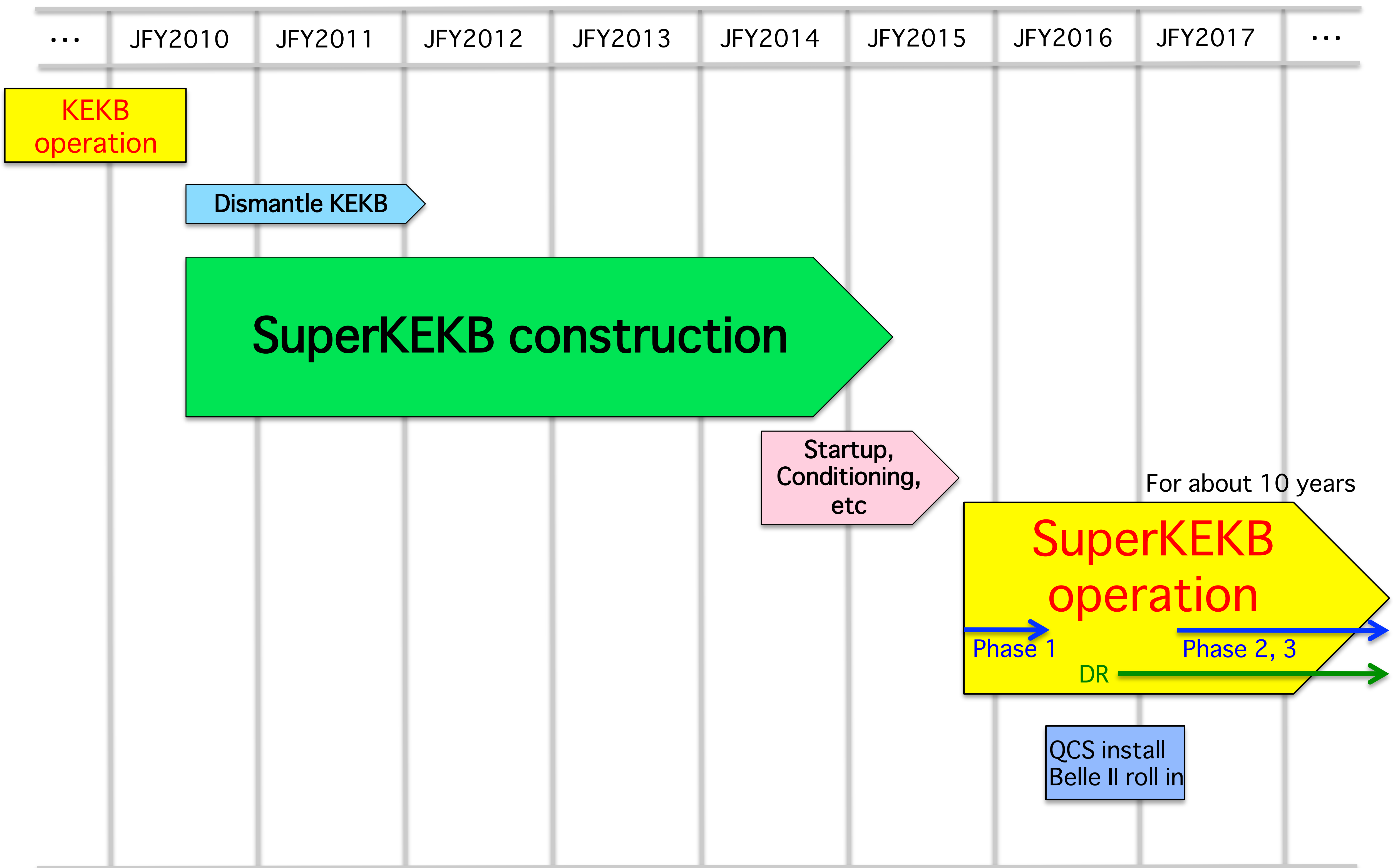


New superconducting / final focusing quads

Low emittance

L=8·10^{35} s^{-1}cm^{-2}

SuperKEKB Master Schedule (Feb 2015)



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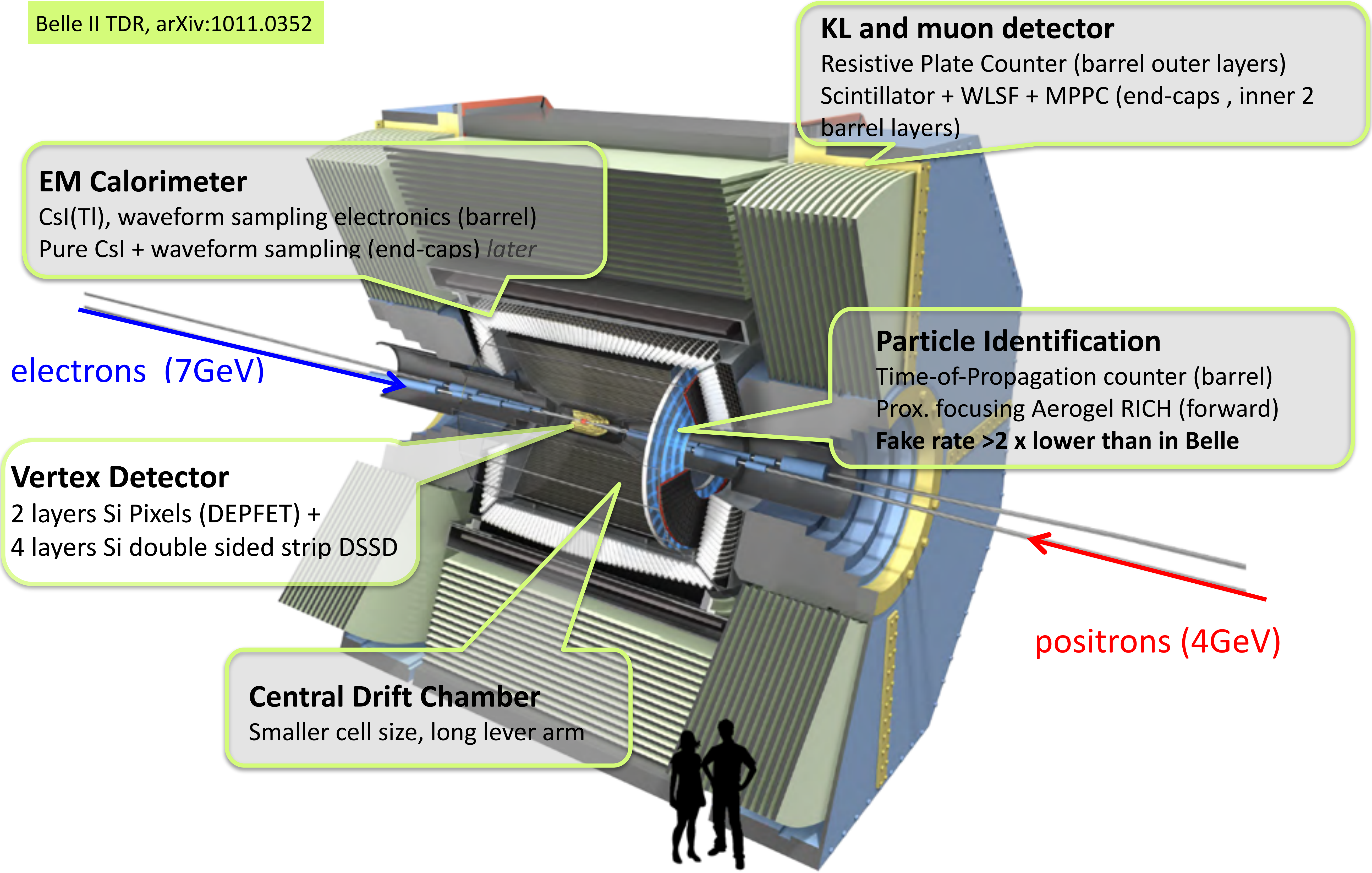
Belle II Detector

[600+ collaborators, 99 institutes, 23 nations]

Belle II TDR, arXiv:1011.0352



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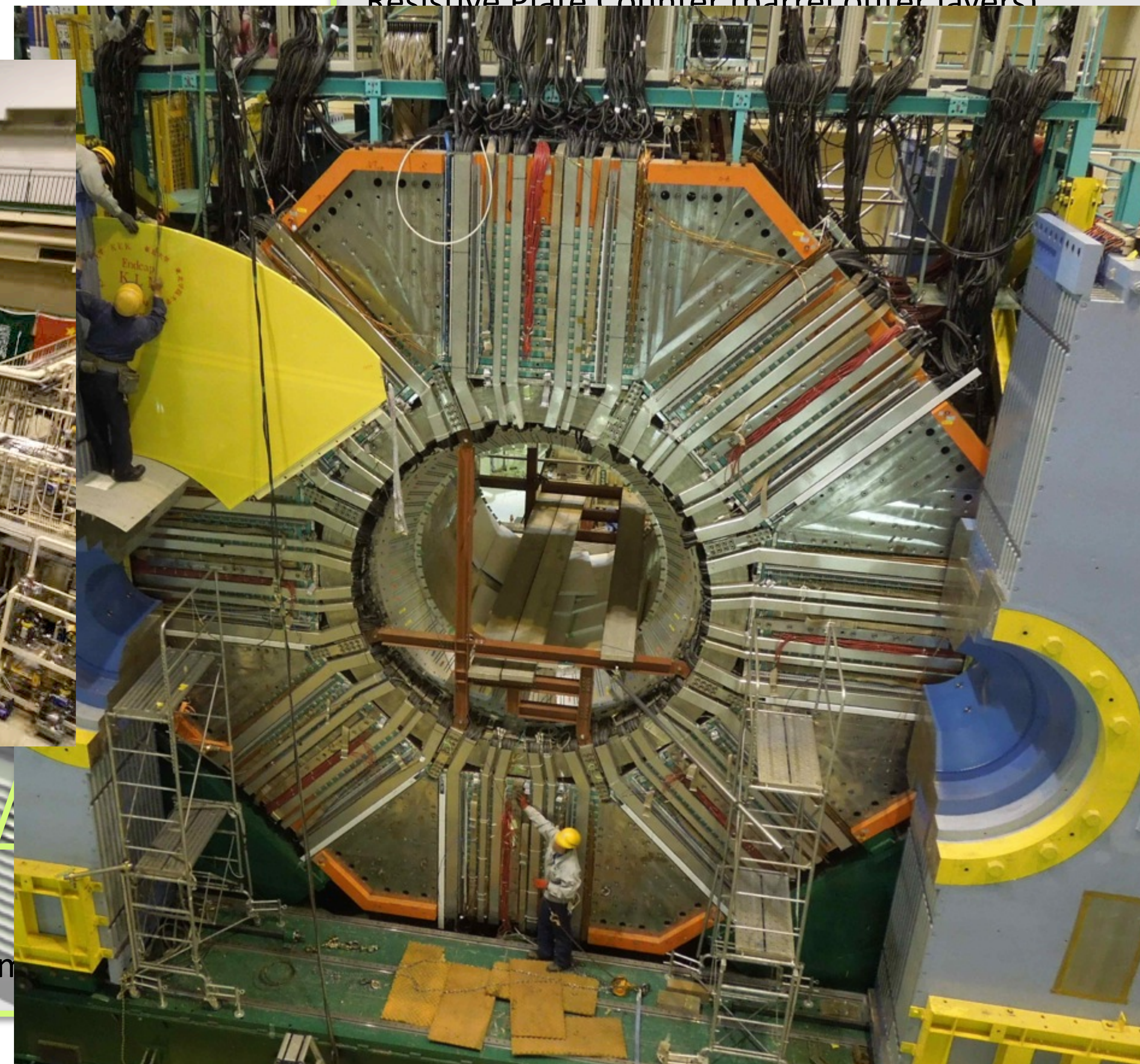
KL and muon detector

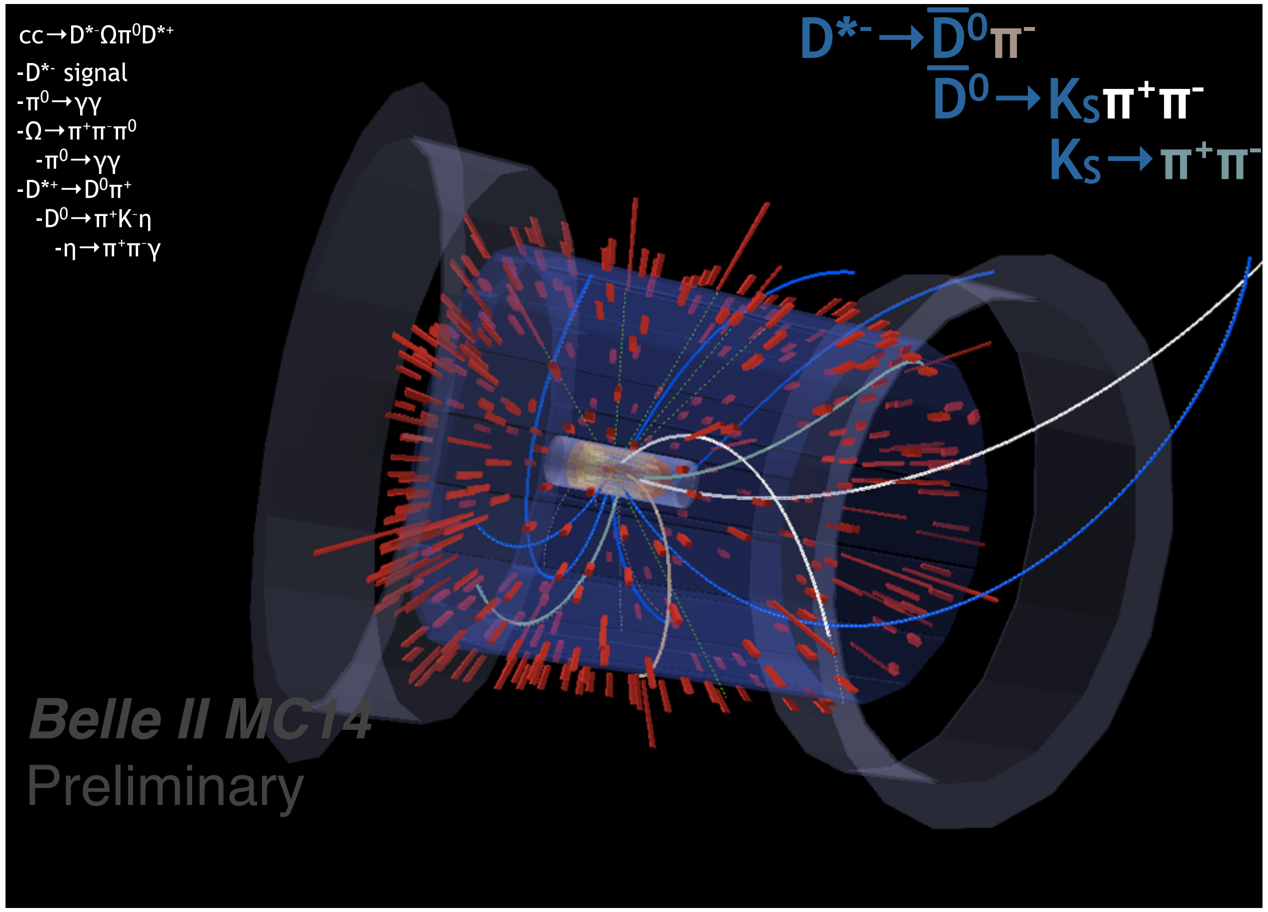
Resistive Plate Counter (barrel outer layers)

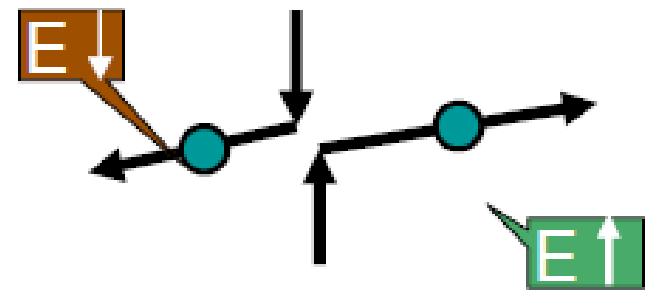


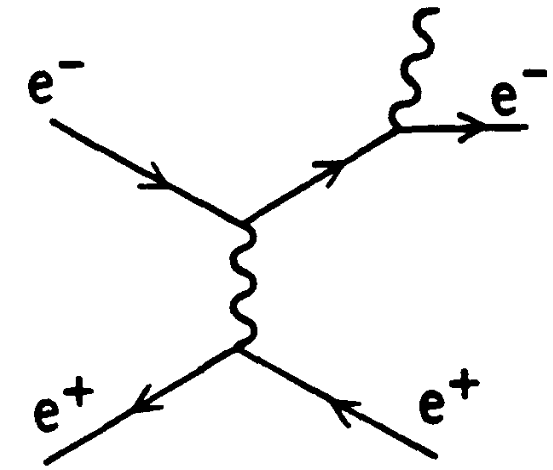
Central Drift Chamber

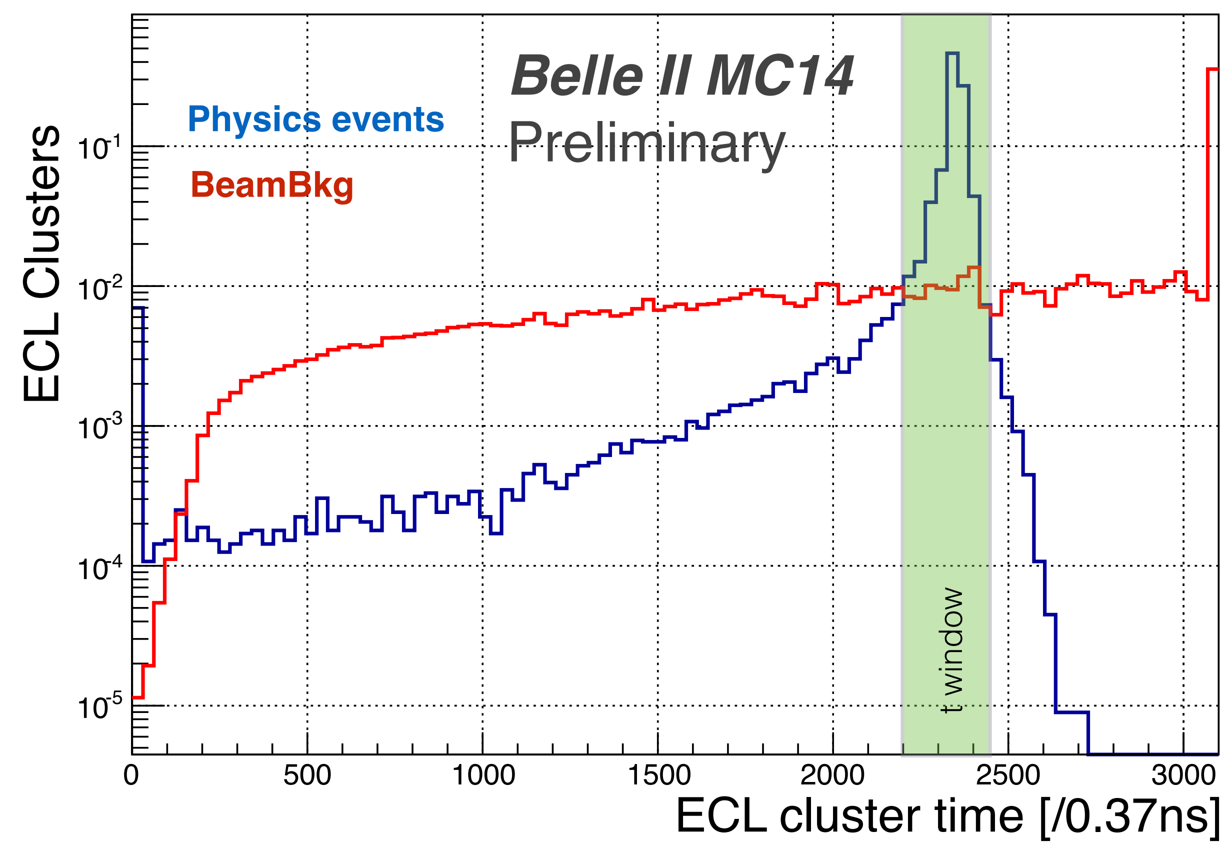
Smaller cell size, long lever arm

Beam-Background, Electromagnetic Calorimeter (ECL)









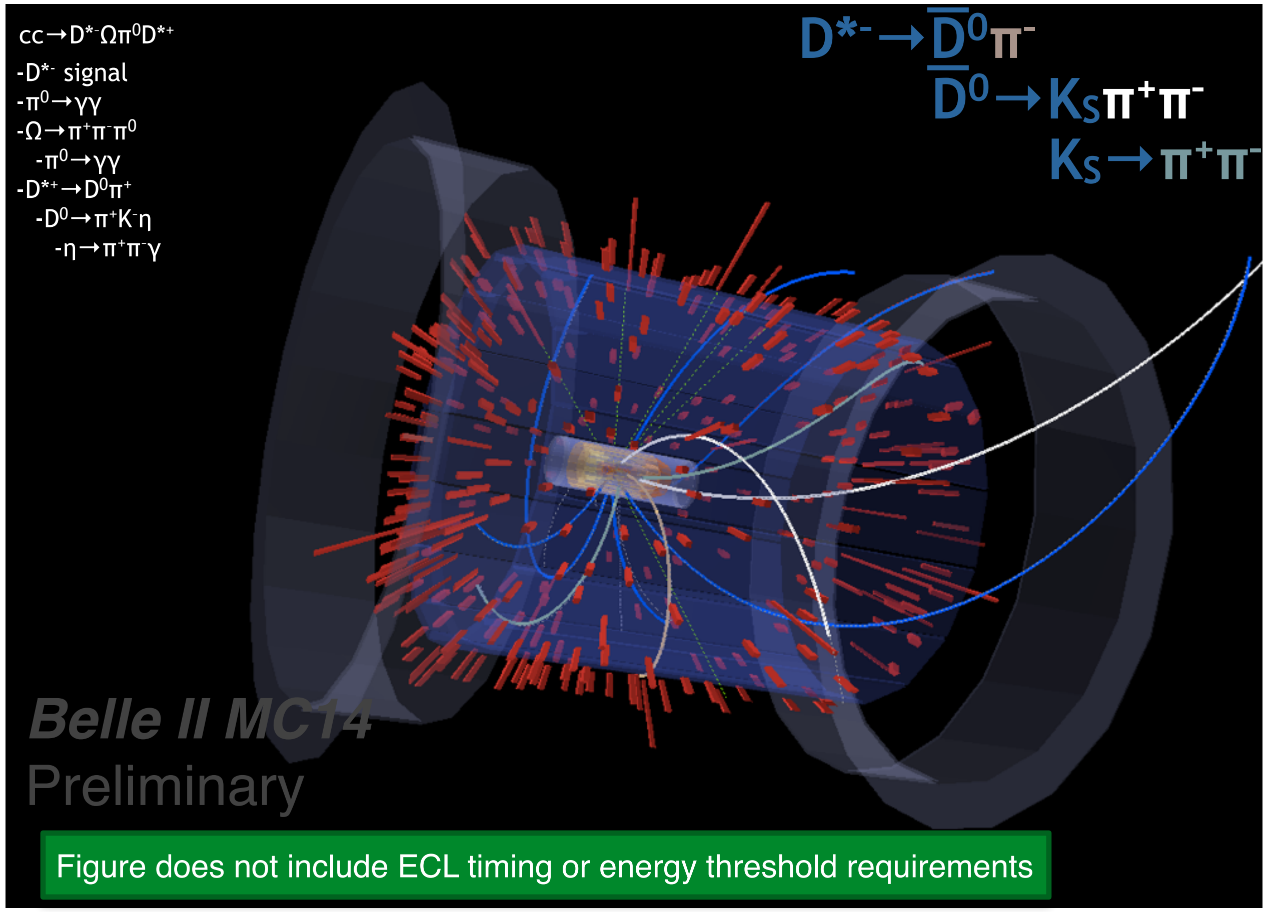
<u>Beam-related backgrounds are much larger than KEKB.</u>

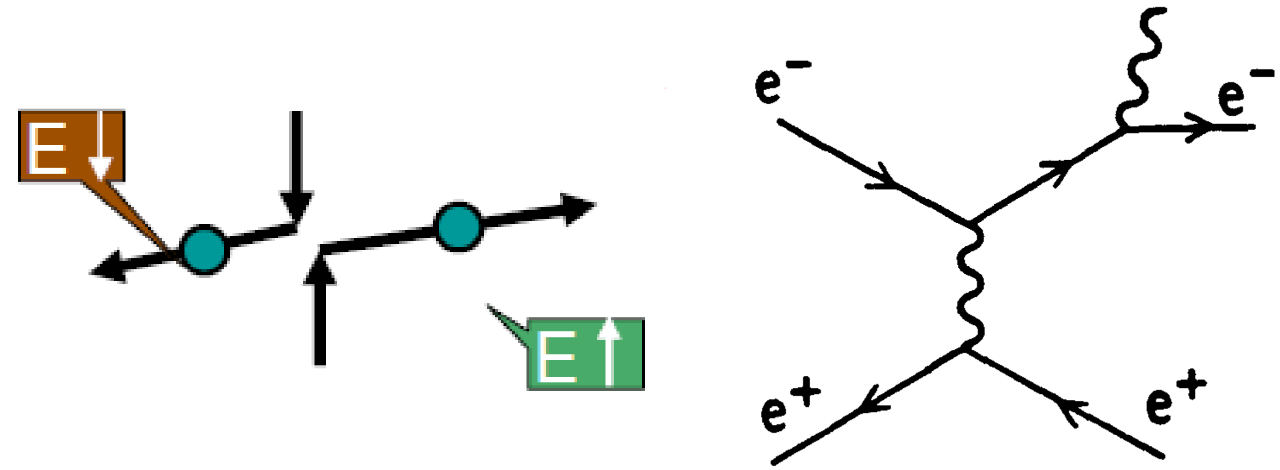
- Touschek scattering
- Radiative Bhabha, 2-γ

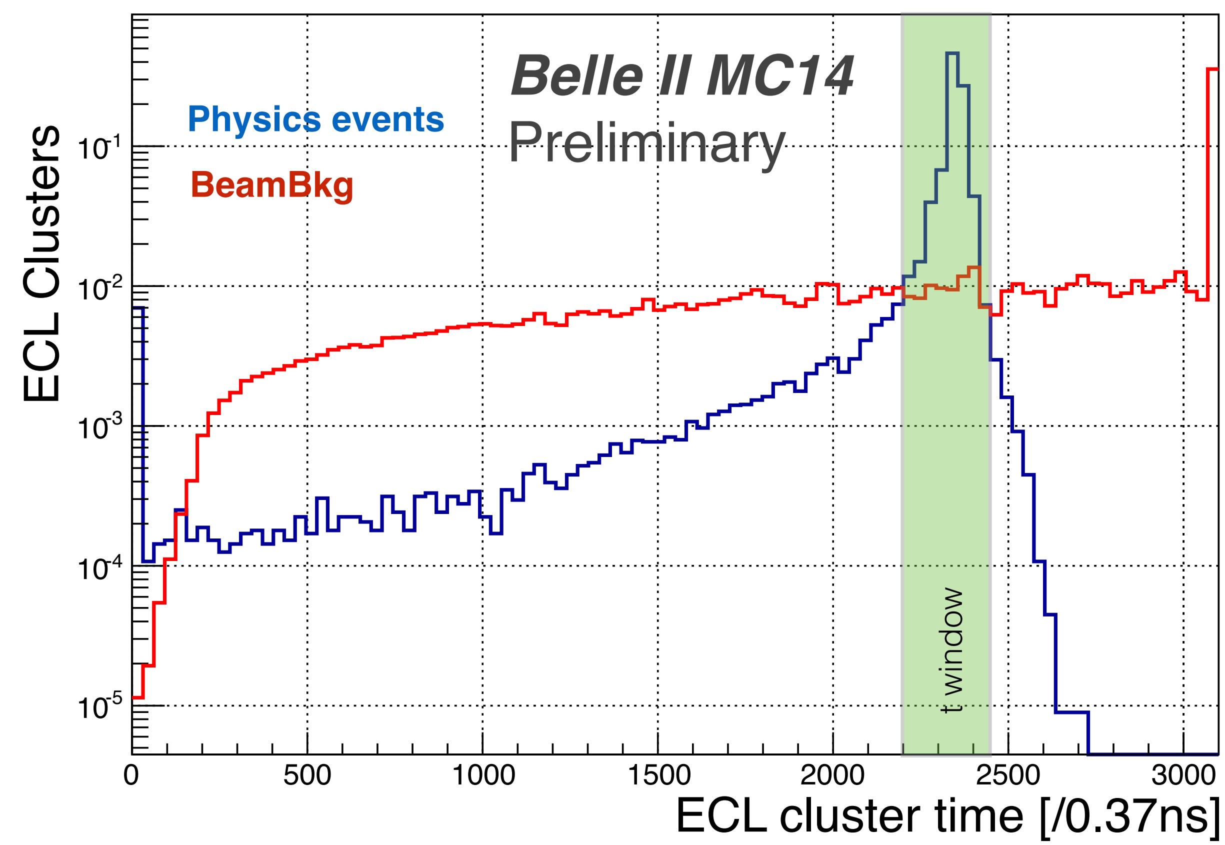
Fake hits, pile up photons, radiation damage

<u>Suppression: </u>based on high speed, waveform sampling electronics

Beam-Background, Electromagnetic Calorimeter (ECL)







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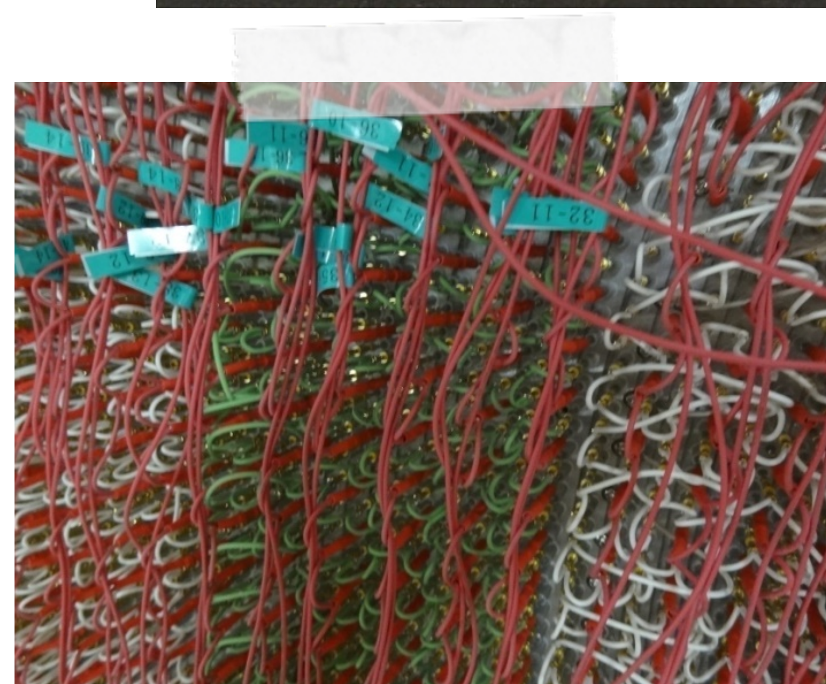
CDC

Hardware work almost complete
- Wire stringing done in 2014
- Gas leak checks, tension measurements, cabling

Moved to main experimental hall in Jan 2015
DAQ tests ongoing.

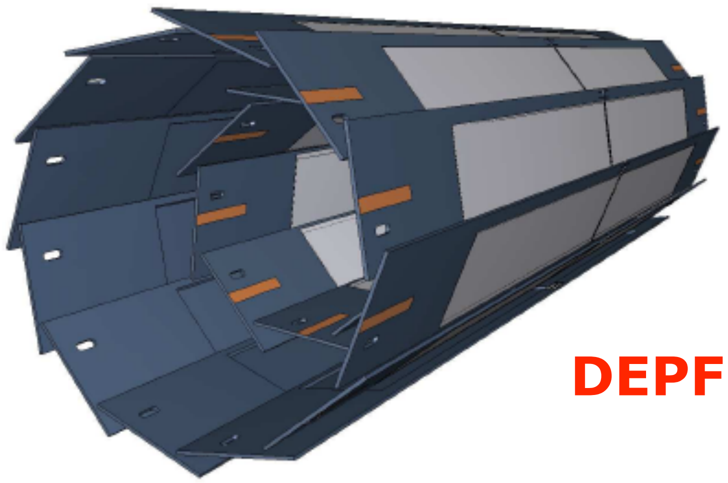


$\sigma_p/p \sim 0.3\% + 0.1\% \times p(\mathrm{GeV})$ in $B = 1.5\mathrm{T}$
$\sigma(\mathrm{d}E/\mathrm{d}x) \sim 6\%$

Pixel detector

PXD: excellent spatial granularity (resolution ~15 μm)

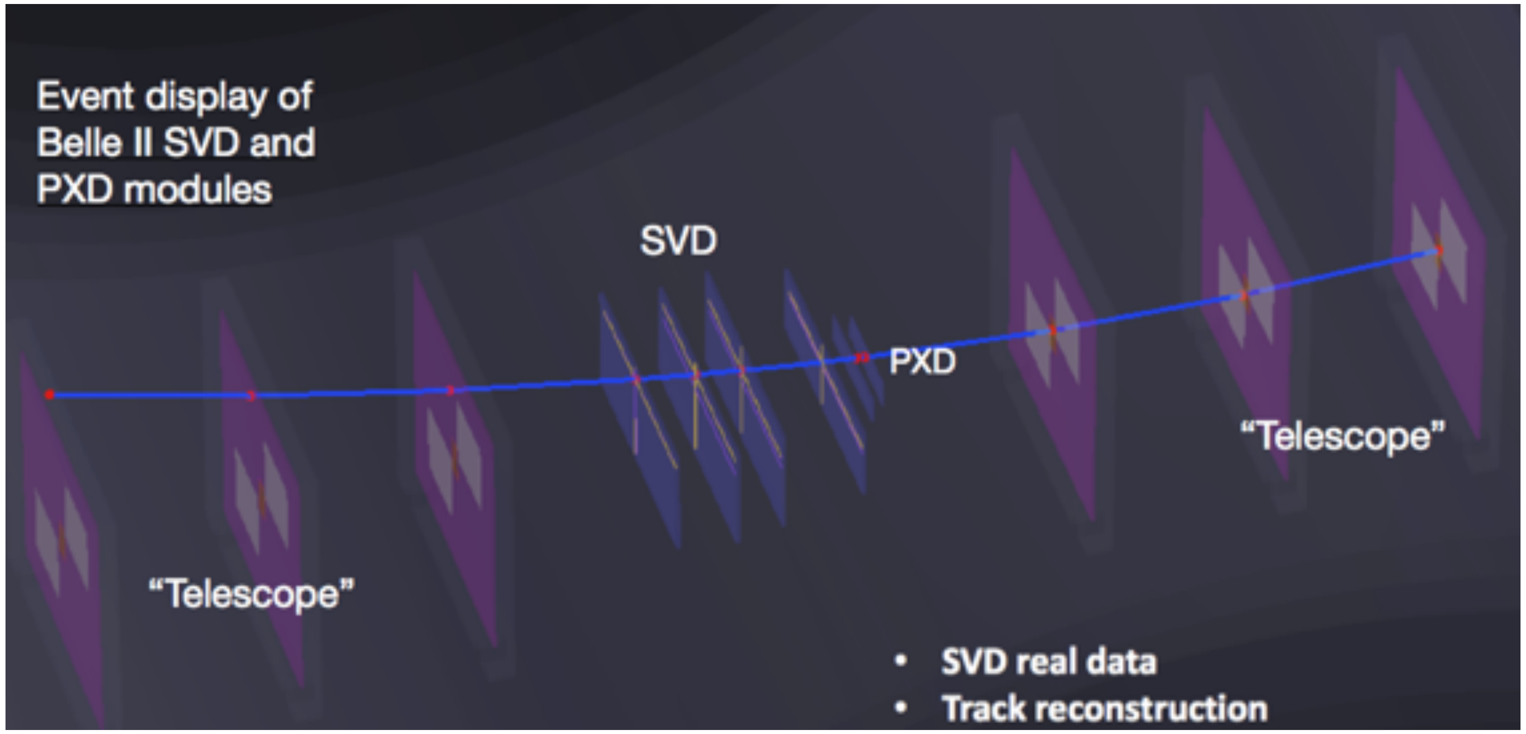
low material (0.16%X_0 for layer 1), huge data rate.



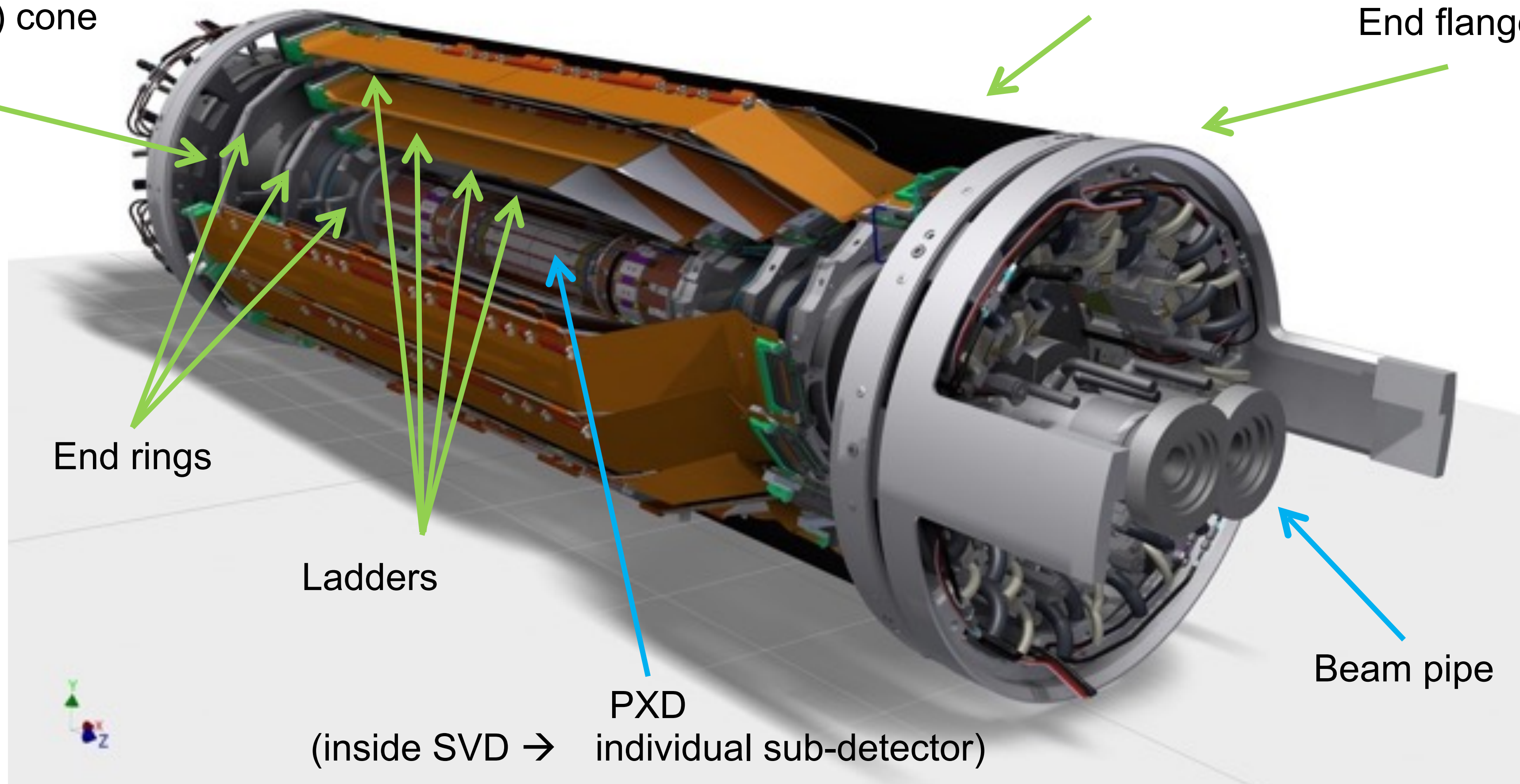
2 DEPFET layers located at the innermost position at R=14mm (cf. 18mm at Belle)

DEPFET sensor production going smoothly.

(Successful test beam in 2014 with PXD and SVD Prototypes) : To reduce 20 Gbit/s data from PXD, read out ***Regions Of Interest*** *from projected SVD tracks*



Silicon Vertex Detector



- 4 Layers double sided silicon strip detectors
- 2,3,4 or 5 sensors per ladder
- Preparing to start SVD ladder production by mid-2015

Greater outer radius ~100→140 mm enhances acceptance for long-lived particles.

type	Q	$c\tau$
$K^0_S(497) \to \pi^-\pi^+$	206 MeV/c	2.68 cm
$\Lambda(1115) \to p\pi^-$	101 MeV/c	7.89 cm
$\bar{\Lambda}(1115) \to \bar{p}\pi^+$	101 MeV/c	7.89 cm
$\gamma \to e^-e^+$	0	(in any material)

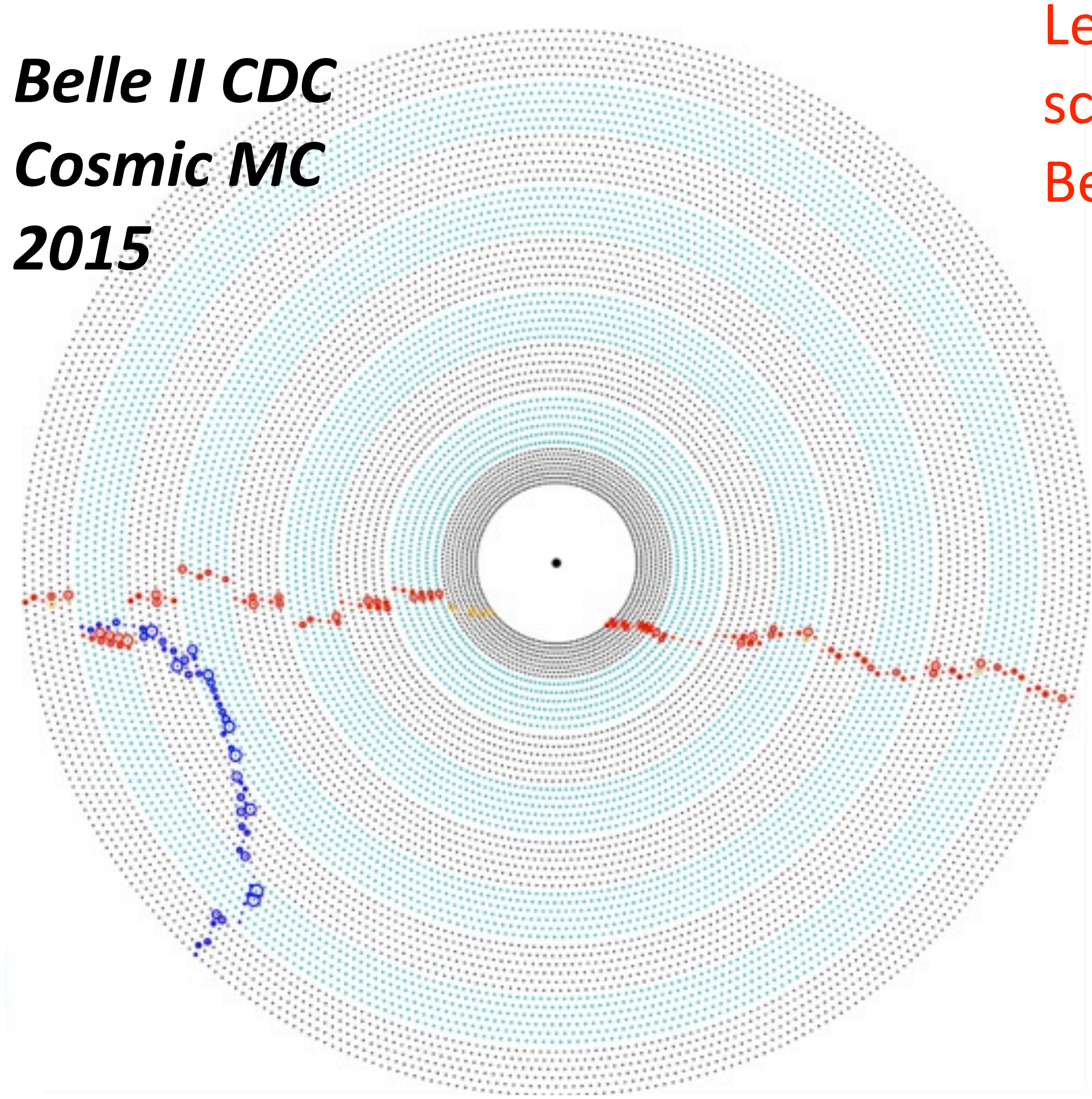
Tracking Performance

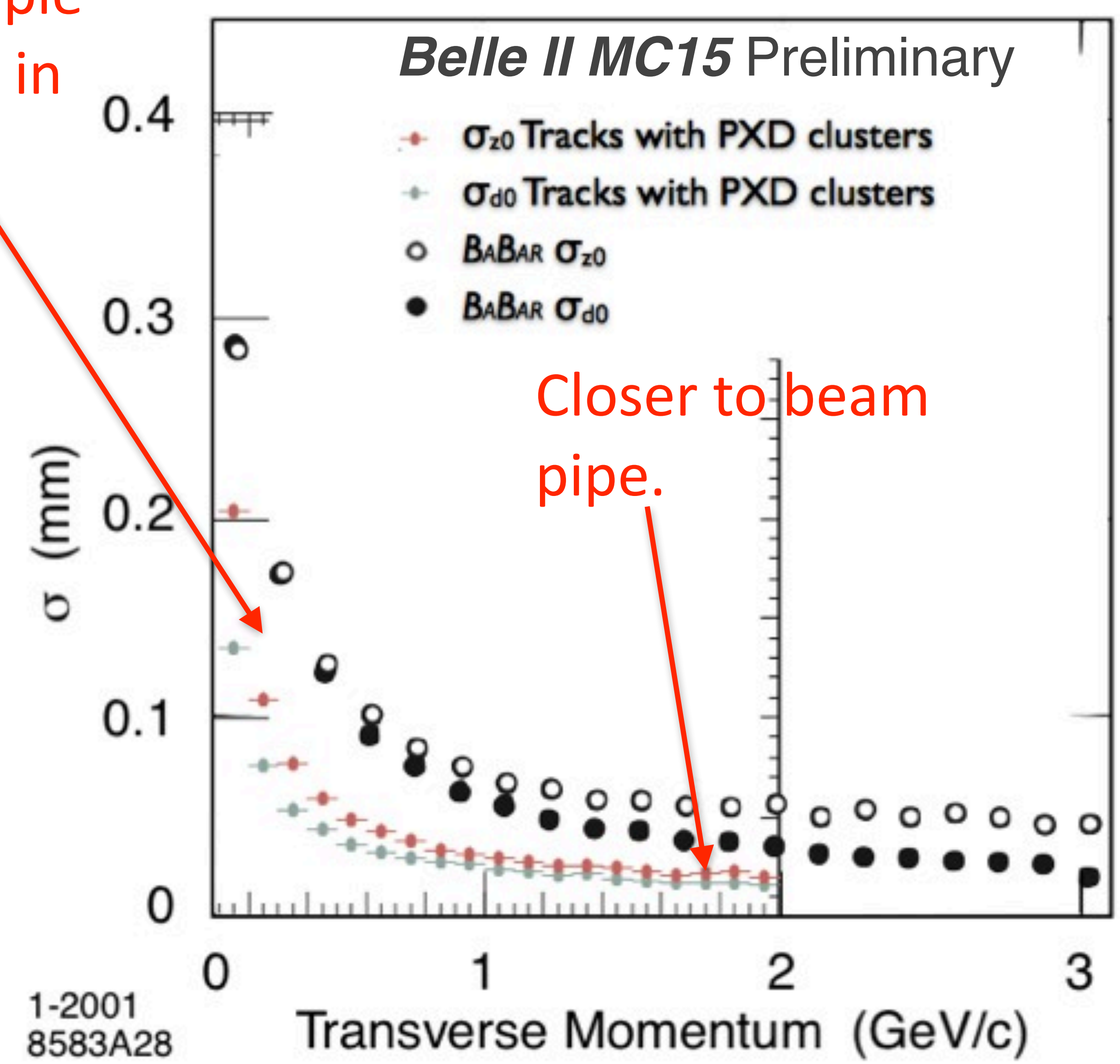
Cosmic ray interacting with CDC back endplate. 2-tracks identified.

VXD + CDC Tracking

Resolution much better than Belle&Babar

Belle II CDC Cosmic MC 2015





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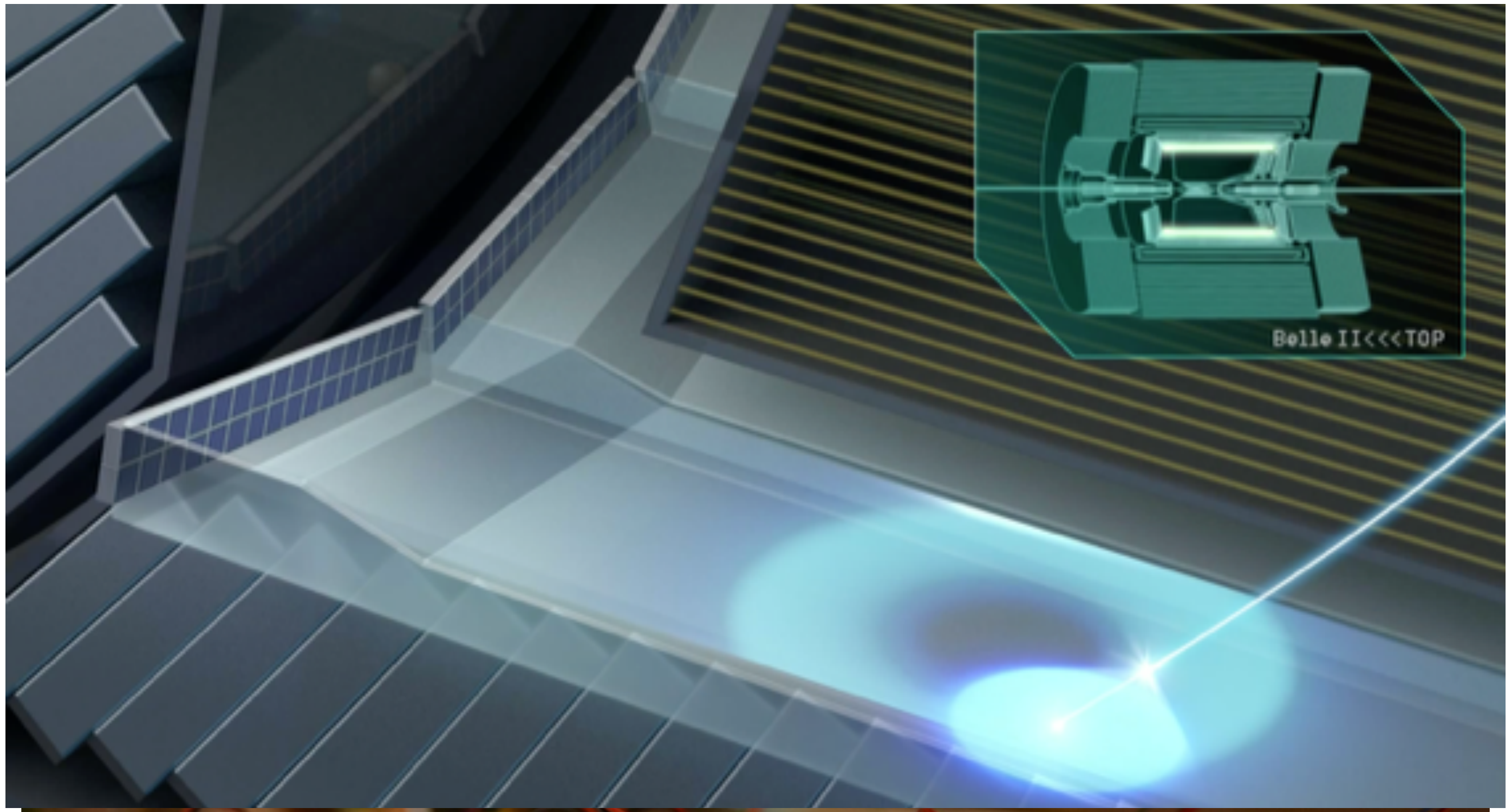
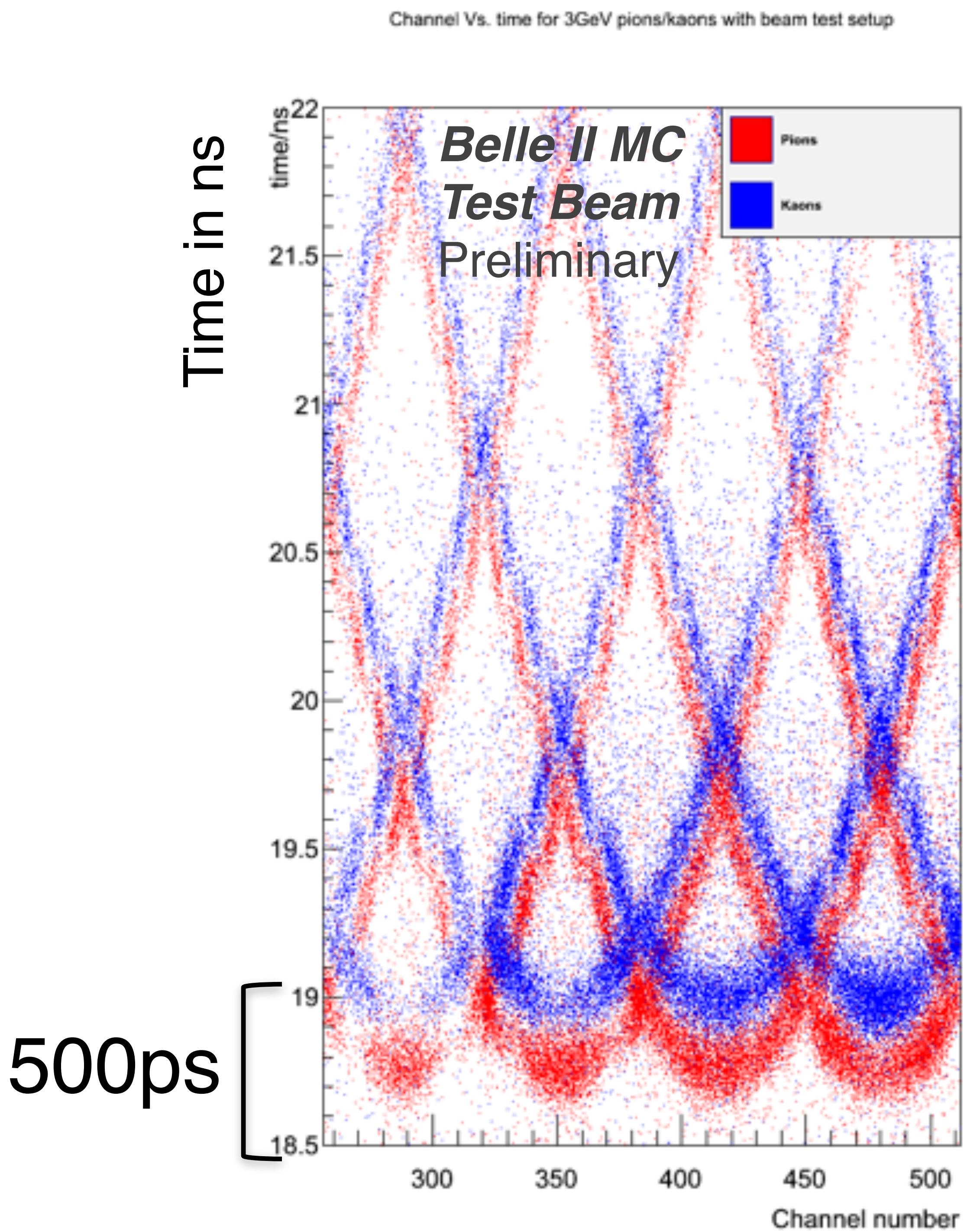
Time-of-Propagation(TOP) Detector



Critical path for Belle II

1st module produced.

At 3 GeV *Timing σ(100 ps) required to separate π & K*

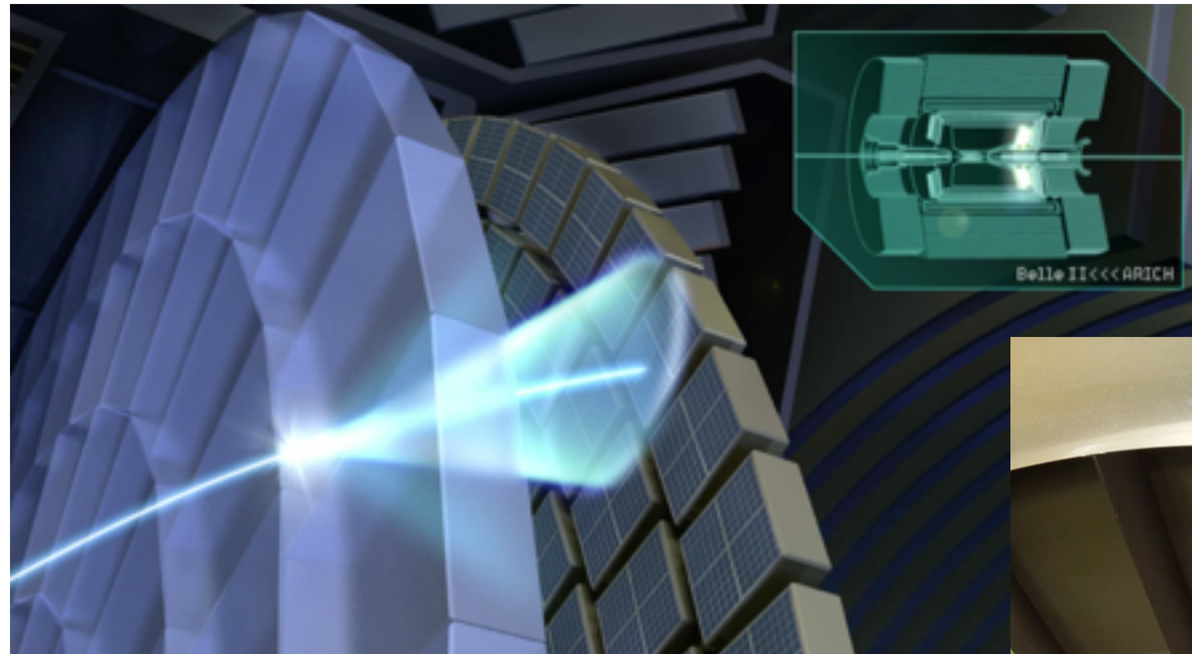


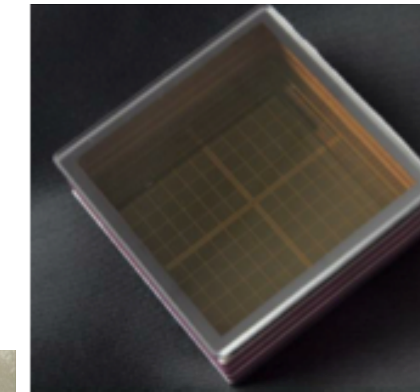
Aerogel RICH: Endcap PID

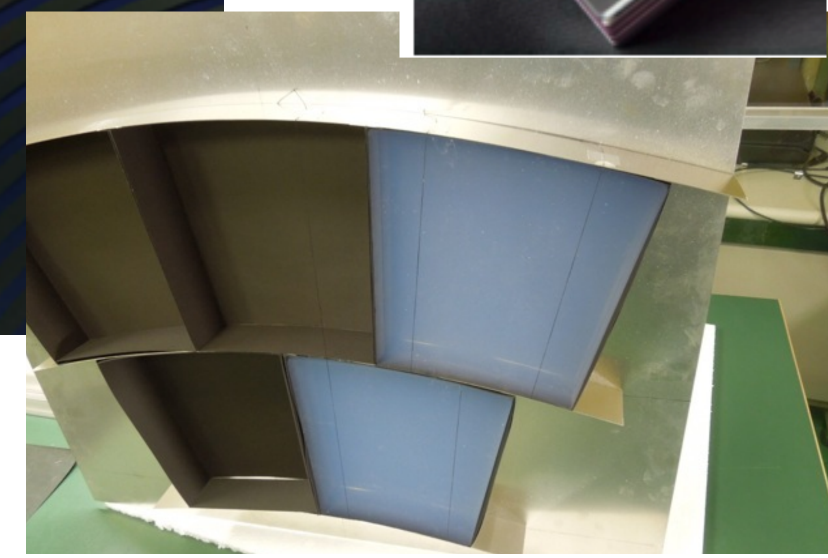
PID in the forward endcap

2-layer aerogel radiator

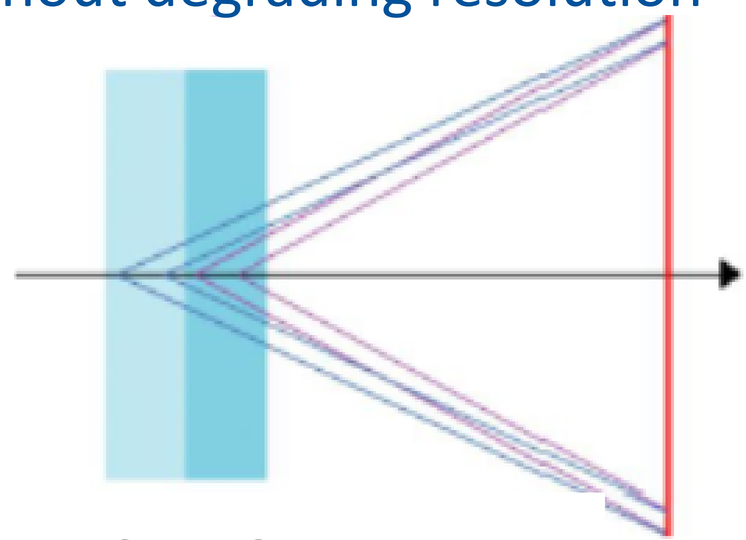
420 Hybrid-Avalanche Photo-detectors (HAPD)







Increases the number of photons without degrading resolution

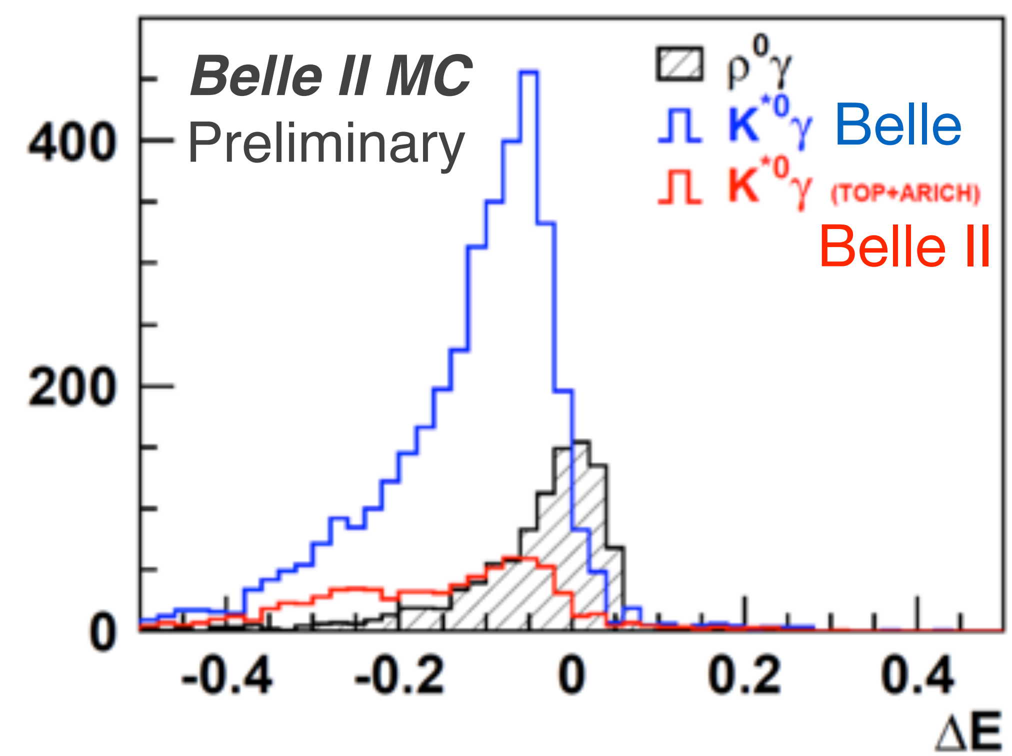


n_1 n_2

$(n_1 < n_2)$

NIM A548 (2005) 383

TOP + ARICH PID



Trigger & Data Flow Challenge

Belle II TDR, arXiv:1011.0352

2 stage trigger: **Hardware** (L1) then **Software**.

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
$e^+e^- \to$ continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\rm lab} \geq 17°$)	44	350 [a]
$\gamma\gamma$ ($\theta_{\rm lab} \geq 17°$)	2.4	19 [a]
2γ processes [b]	~ 80	~ 15000
Total	~ 130	~ 20000

[a] The rate is pre-scaled by a factor of 1/100.
[b] $\theta_{\rm lab} \geq 17°$, $p_t \geq 0.1{\rm GeV}/c$

- **30 kHz L1 trigger rate, 2ns bunch spacing**
  40 x Belle,
  >99% efficiency for bb

	Hardware Trigger rate	Physics output rate	event size
Belle	500 Hz	90 Hz	40 kB
Belle II	30 kHz	3-10kHz	200kB (max)
ATLAS		0.2kHz	1.6MB

Grid Computing

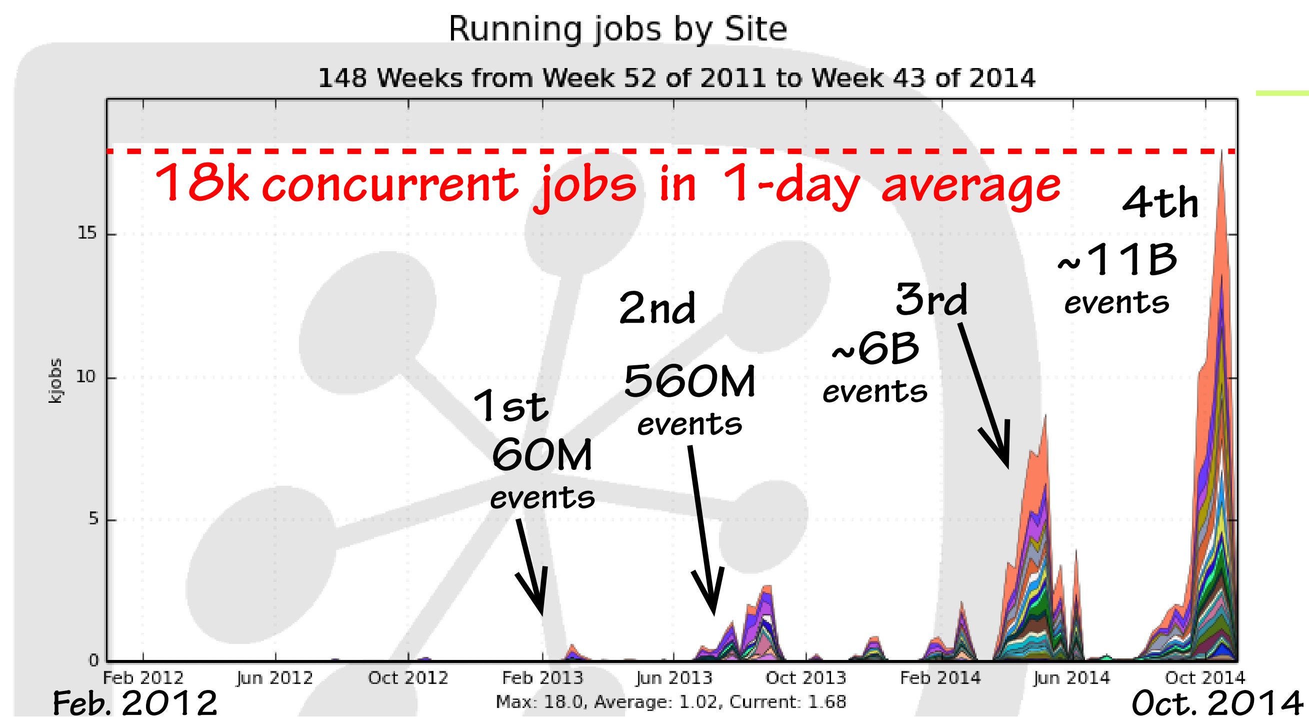
Ramping up Grid Computing

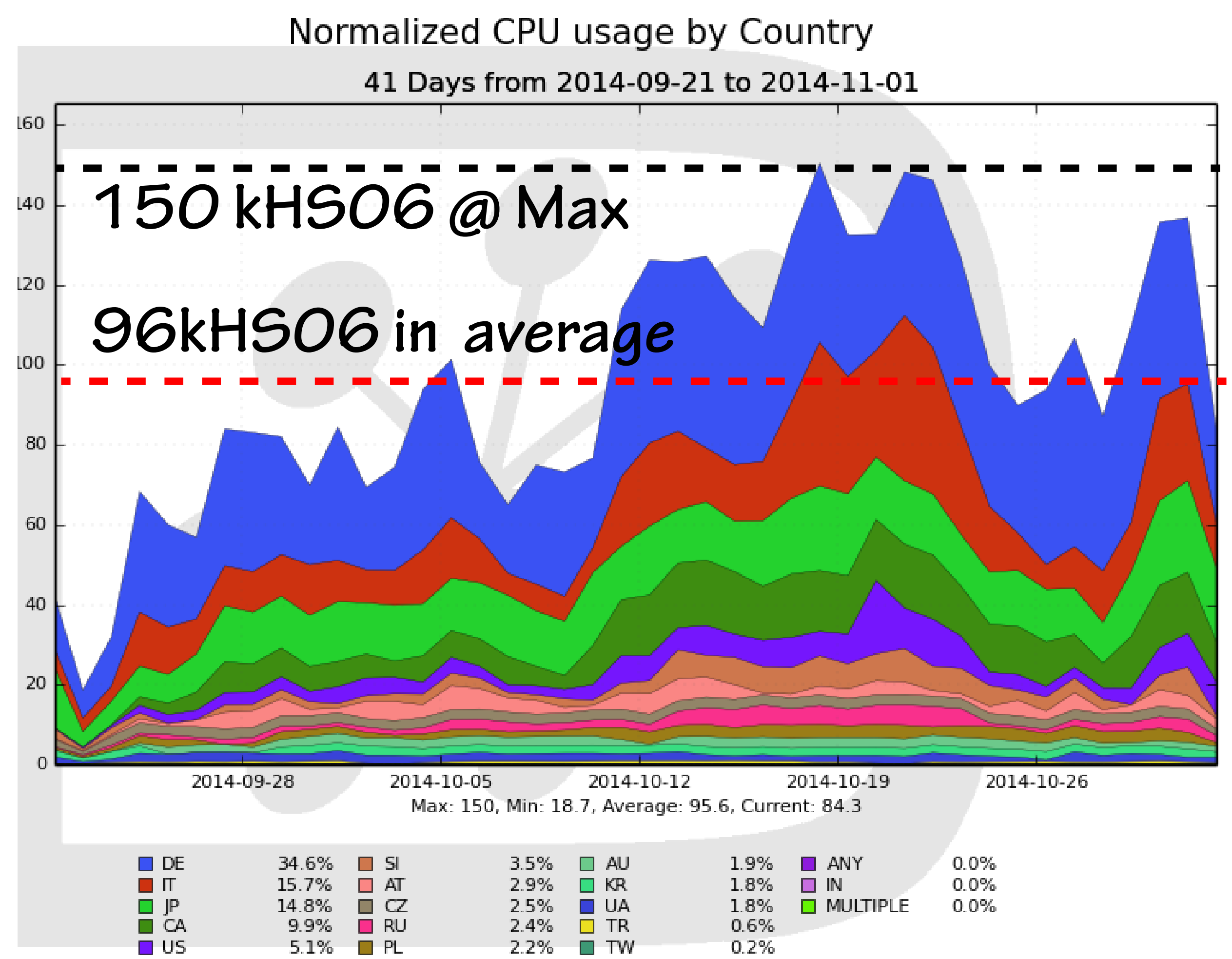
Up to concurrent 18k jobs 2014,

Only 10% @ nominal luminosity

= Similar to ATLAS Run-1!

→ Critical.



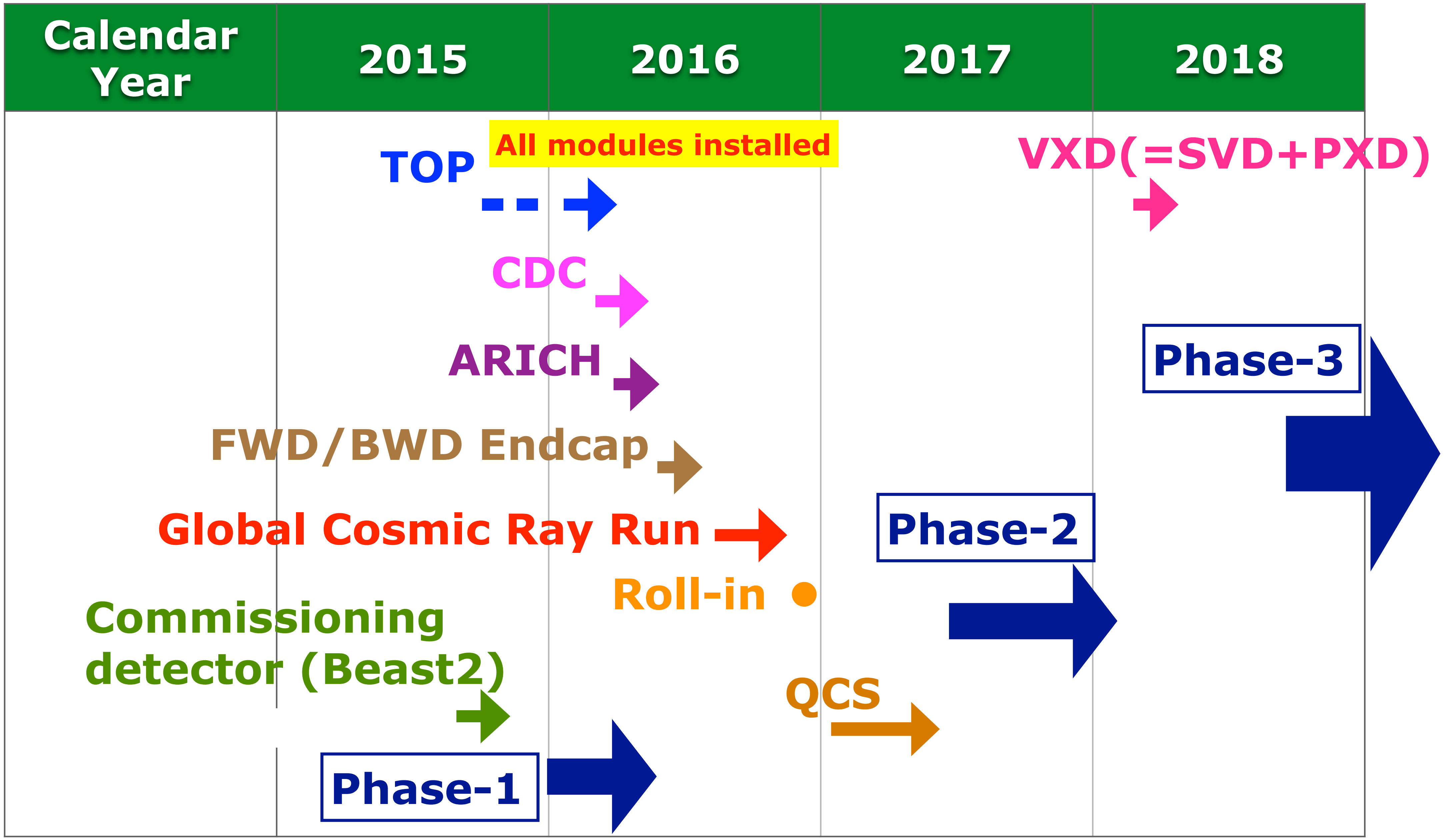


31 sites

GRID, Cloud, local cluster is available

more than $3ab^{-1}$ in total

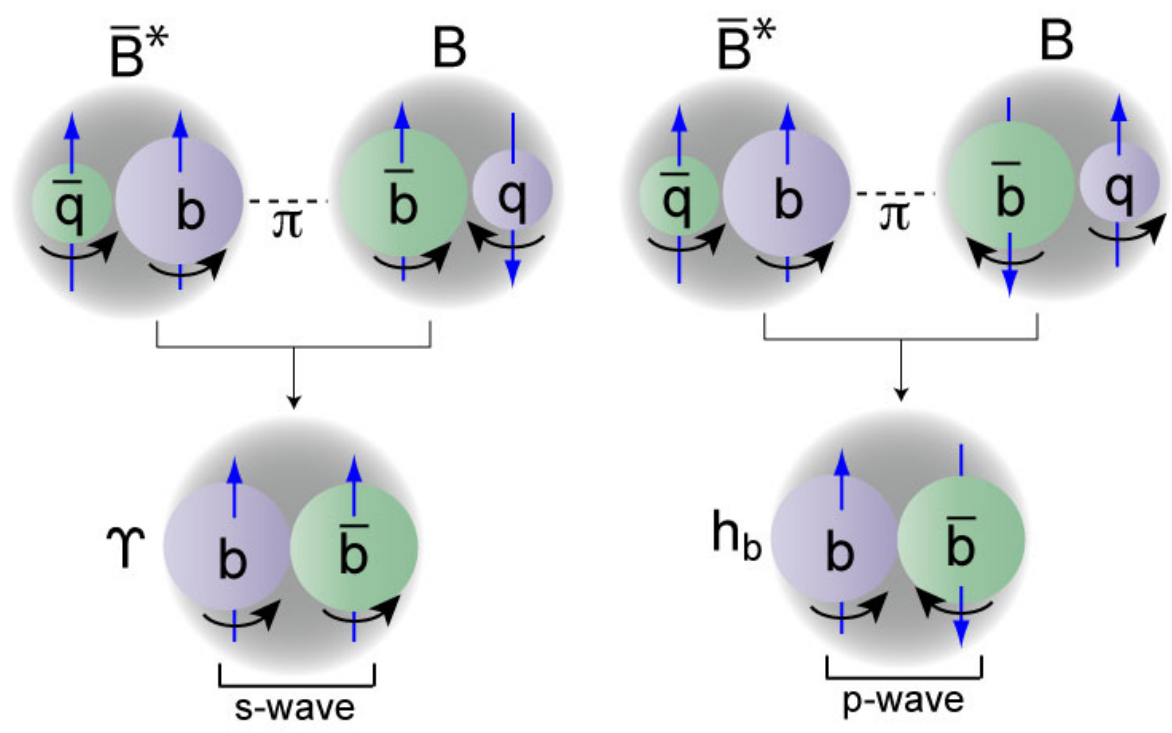
Installation and Commissioning



The first 2-years, "Phases 2 & 3"

Phase 1	**2016**	"BEAST"/SuperKEKB & cosmics
Phase 2	**Mid 2017- Early 2018**	Partial Belle II, commissioning data up to ~O(200fb^{-1})
Full physics	**Oct 2018-**	Full detector

Maximise early scientific output: diverse program of unique data sets.

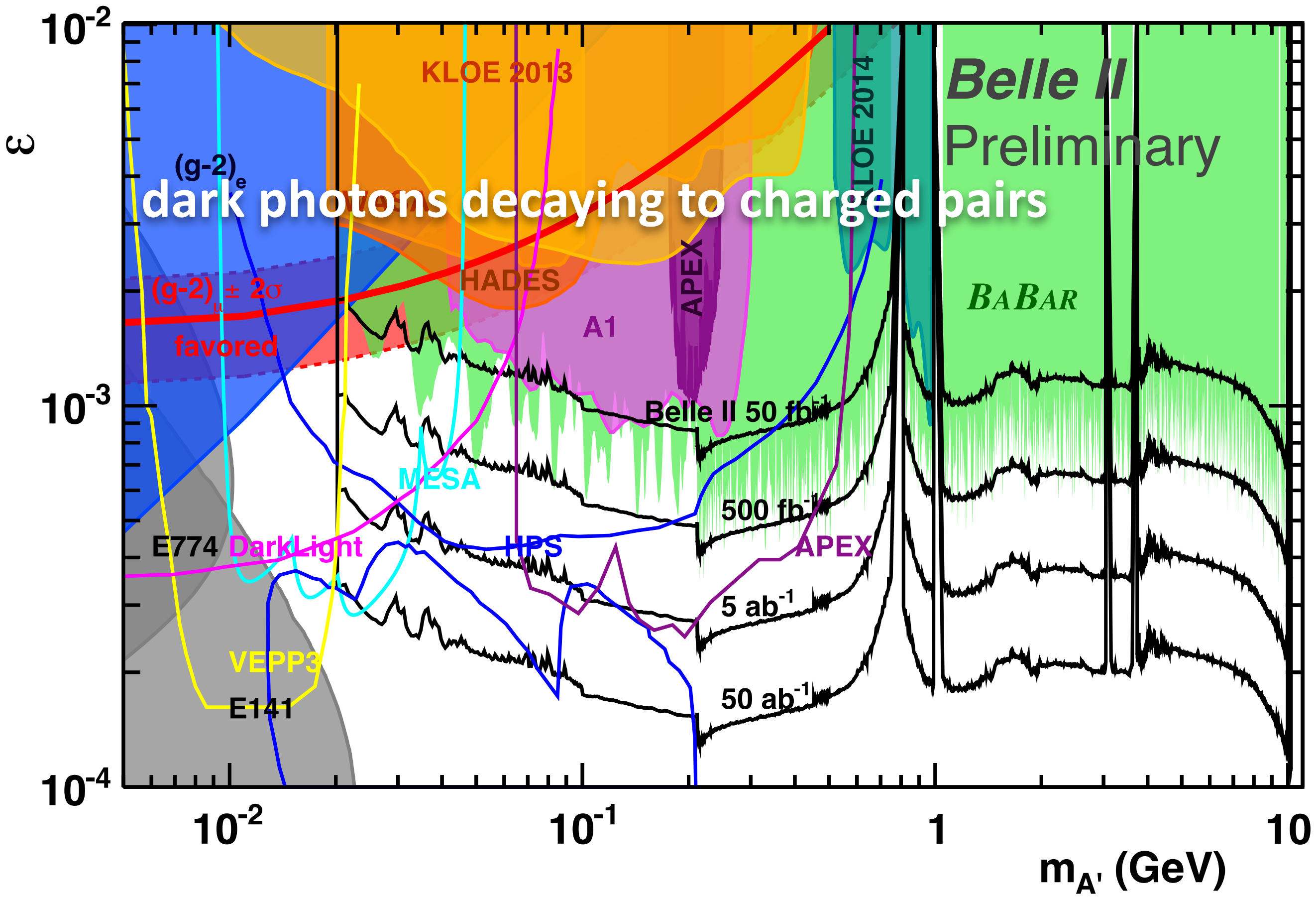


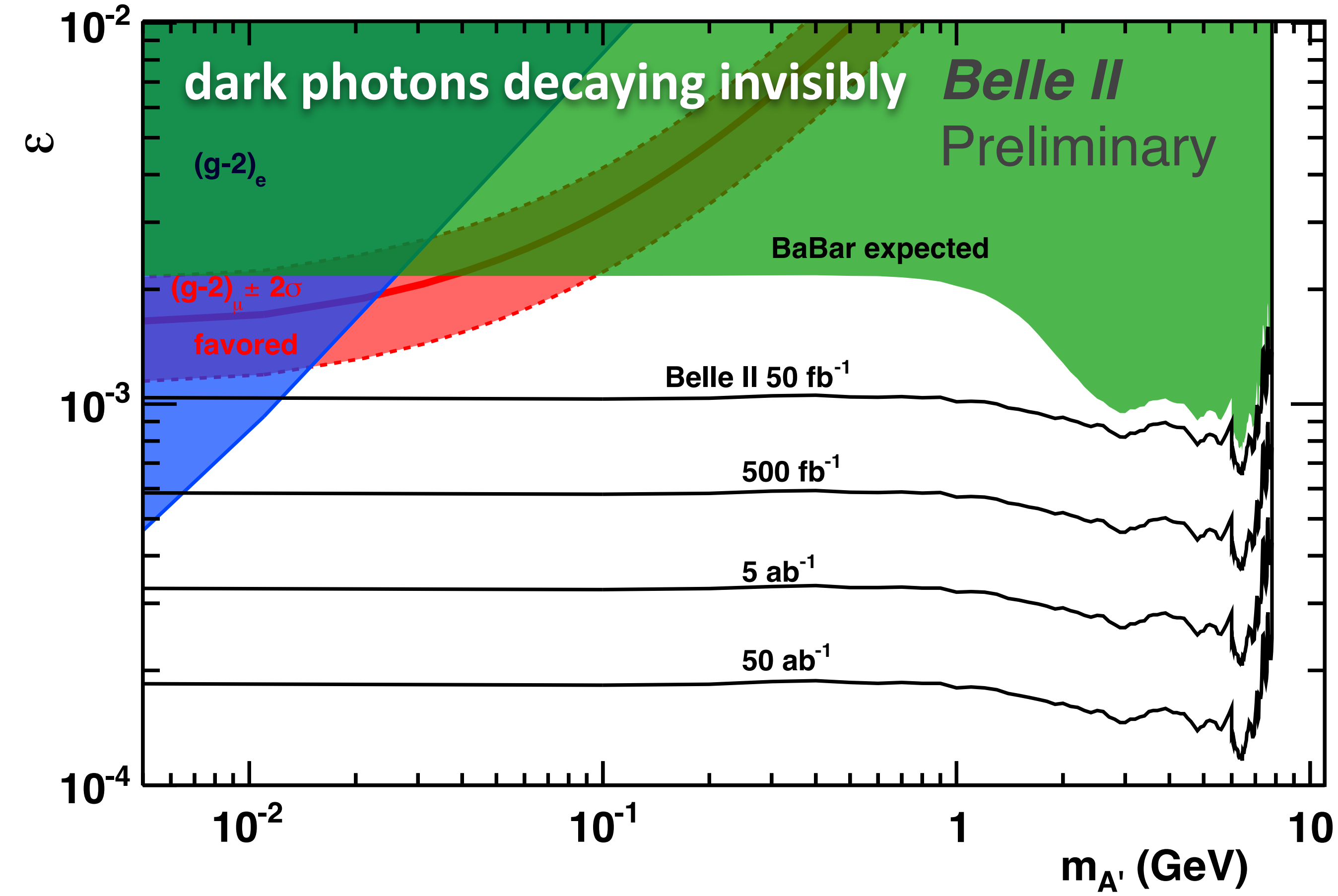
Dark forces & light Higgs [new triggers]

Bottomonium - exotics [Y(3S), Y(5S)→Y(6S)]

Experiment	Scans/Off. Res.	$\Upsilon(5S)$ 10876 MeV		$\Upsilon(4S)$ 10580 MeV		$\Upsilon(3S)$ 10355 MeV		$\Upsilon(2S)$ 10023 MeV		$\Upsilon(1S)$ 9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102

The first 2-years, Dark Sector



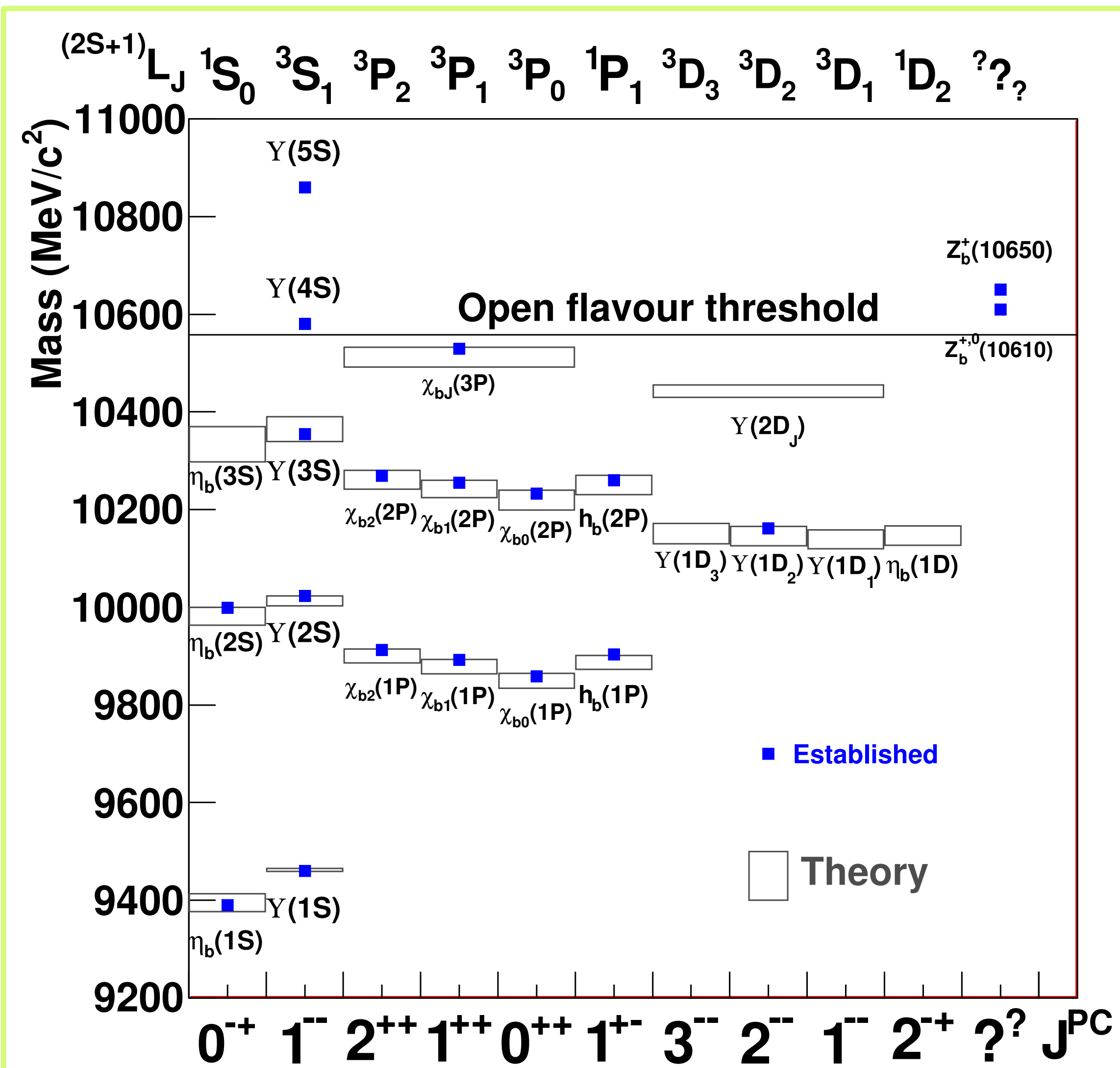


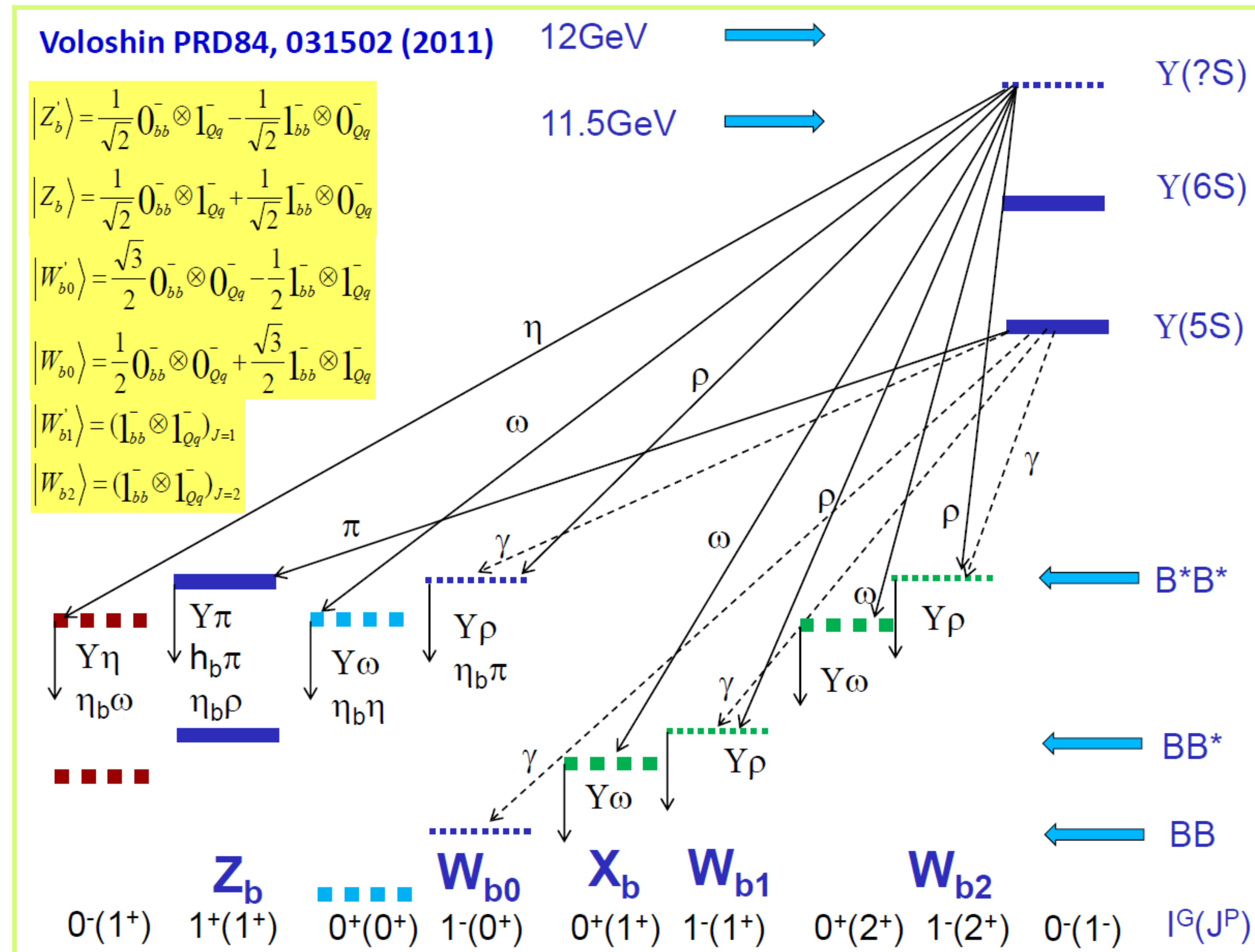
Dark γ to Leptons	Radiative production of A' via ee→γA'
Dark Light Higgs	Y(2S,3S)→A^0 γ, A^0→ invisible, single γ trigger.
Dark Matter	Non-resonant production in ee→A' γ, A^0→*invisible*
Dark Higgs-strahlung	ee → A'h', h'→ A'A'(*), l+l- or hadrons.

The first 2-years, below & above Y(4S)

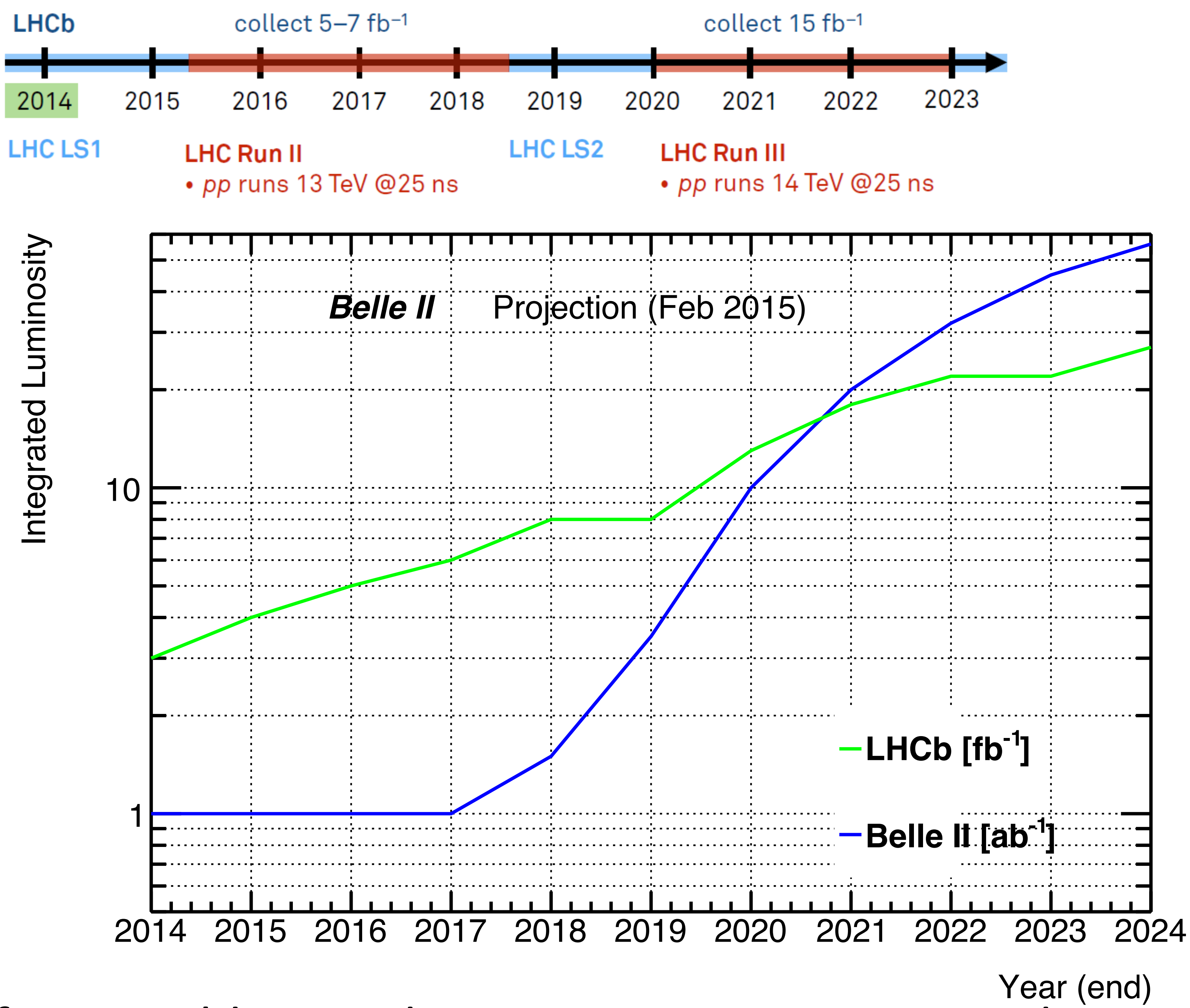
Y(3S): Bottomonium dynamics (hyperfine splitting, compact states).

Above Y(4S): Exotic 4-quark states and precision m_b





Data taking profile & “the competition”



- We have different golden modes: e.g. Missing energy modes at Belle II *(well-known)*; —powerful constraints on the charged Higgs.
  - But there are some areas of fierce competition…

Summary of CKM Metrology

	Belle	BaBar	Global Fit CKMfitter	LHCb Run-2	Belle II 50 ab^{-1}	LHCb Upgrade 50 fb^{-1}	Theory
φ_1: ccs	0.9^o		0.9^o	0.6^o	0.3^o	0.3^o	v. small.
φ_2: uud	4^o (WA)		2.1^o		1^o		~1-2^o
φ_3: DK	14^o		3.8^o	4^o	1.5^o	1^o	negl.
$\|V_{cb}\|$ inclusive	1.7%		2.4%		1.2%		
$\|V_{cb}\|$ exclusive	2.2%				1.4%		
$\|V_{ub}\|$ inclusive	7%		4.5%		3.0%		
$\|V_{ub}\|$ exclusive	8%				2.4%		
$\|V_{ub}\|$ leptonic	14%				3.0%		

Experiment

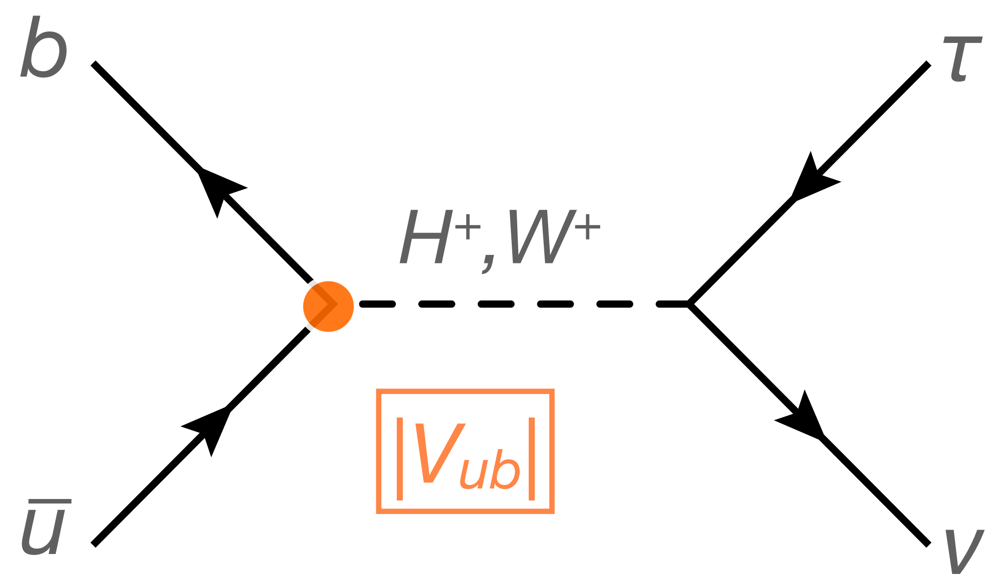
- No result
- Moderate precision
- Precise
- Very Precise

Theory

- Moderate precision
- Clean / LQCD
- Clean

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

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



Helicity suppressed - very small in SM.

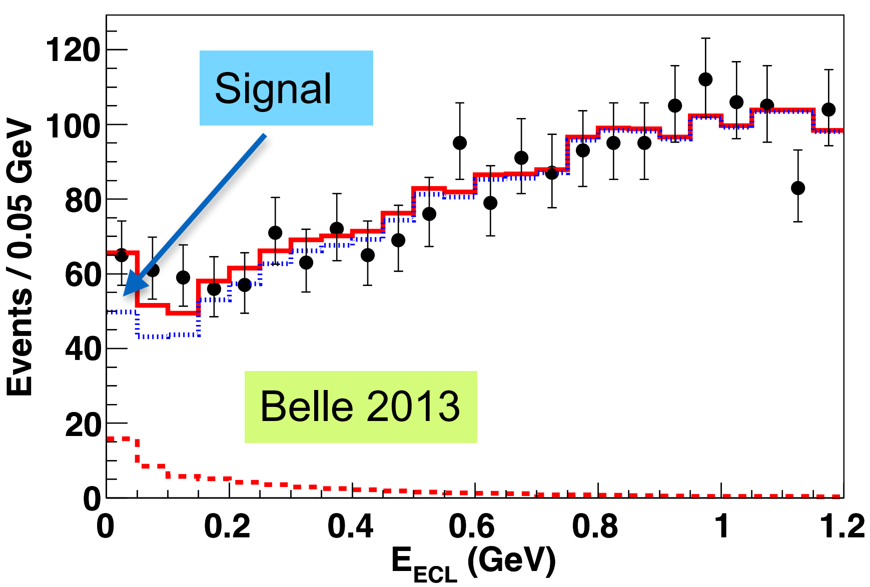
NP could interfere *e.g.* **charged Higgs.**

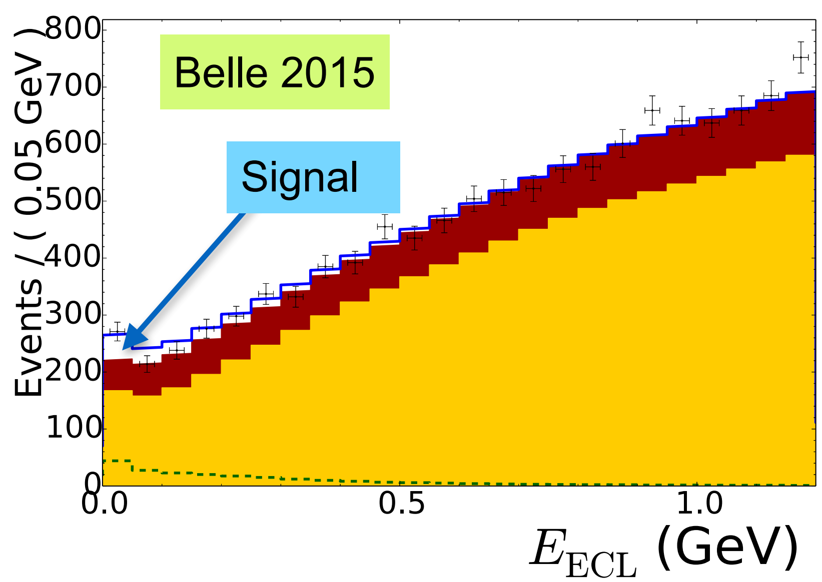
$$\mathrm{BR}(B_u \to \tau\nu_\tau) = \frac{G_F^2 f_B^2 |V_{ub}|^2}{8\pi} \tau_B m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left[1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \lambda_{bb}\lambda_{\tau\tau}\right]^2$$

$\mathbf{BF_{SM}}$

$\mathbf{r_H}$

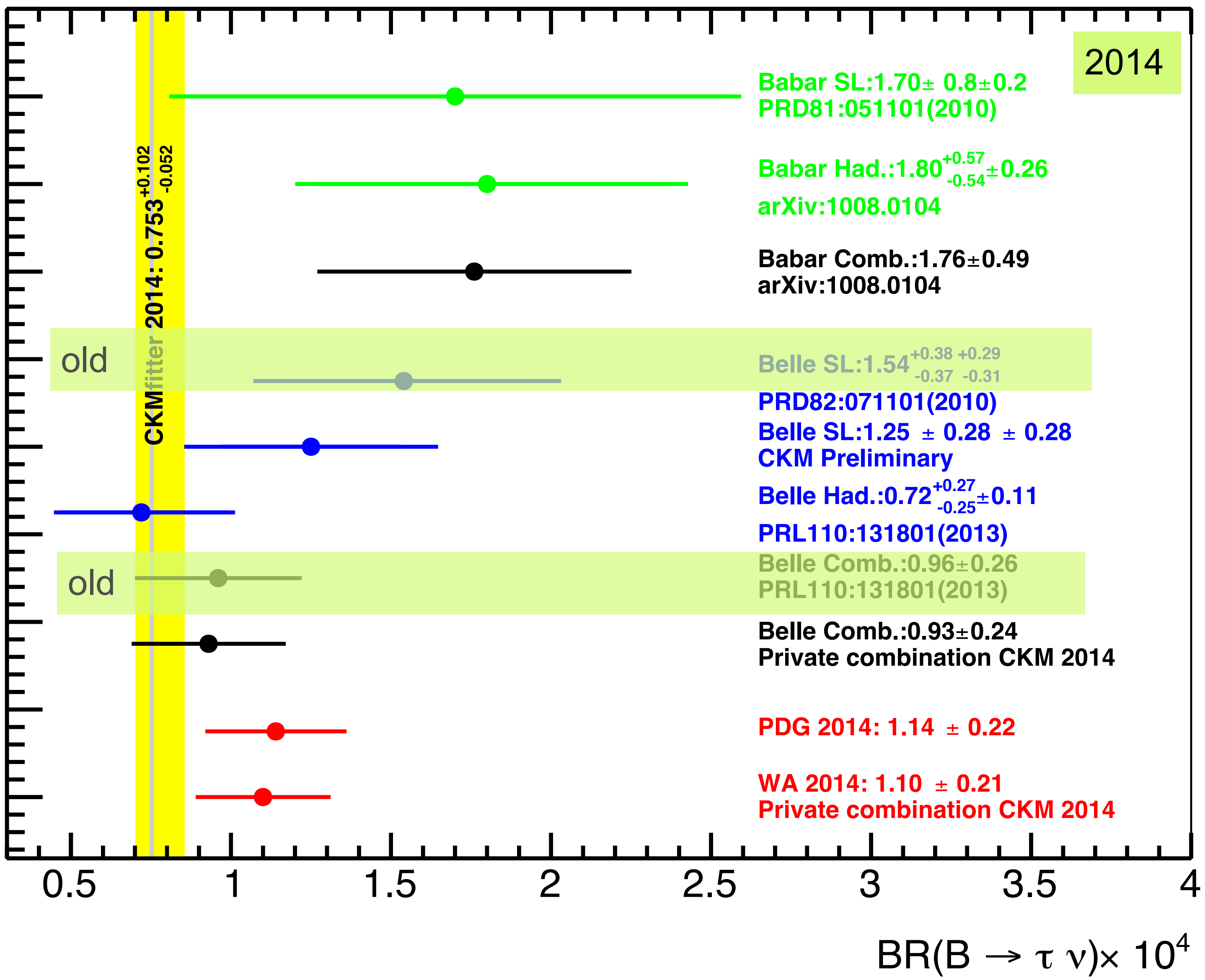
Type	λ_{DD}	λ_{LL}
I	$\cot\beta$	$\cot\beta$
II	$-\tan\beta$	$-\tan\beta$
III	$-\tan\beta$	$\cot\beta$
IV	$\cot\beta$	$-\tan\beta$

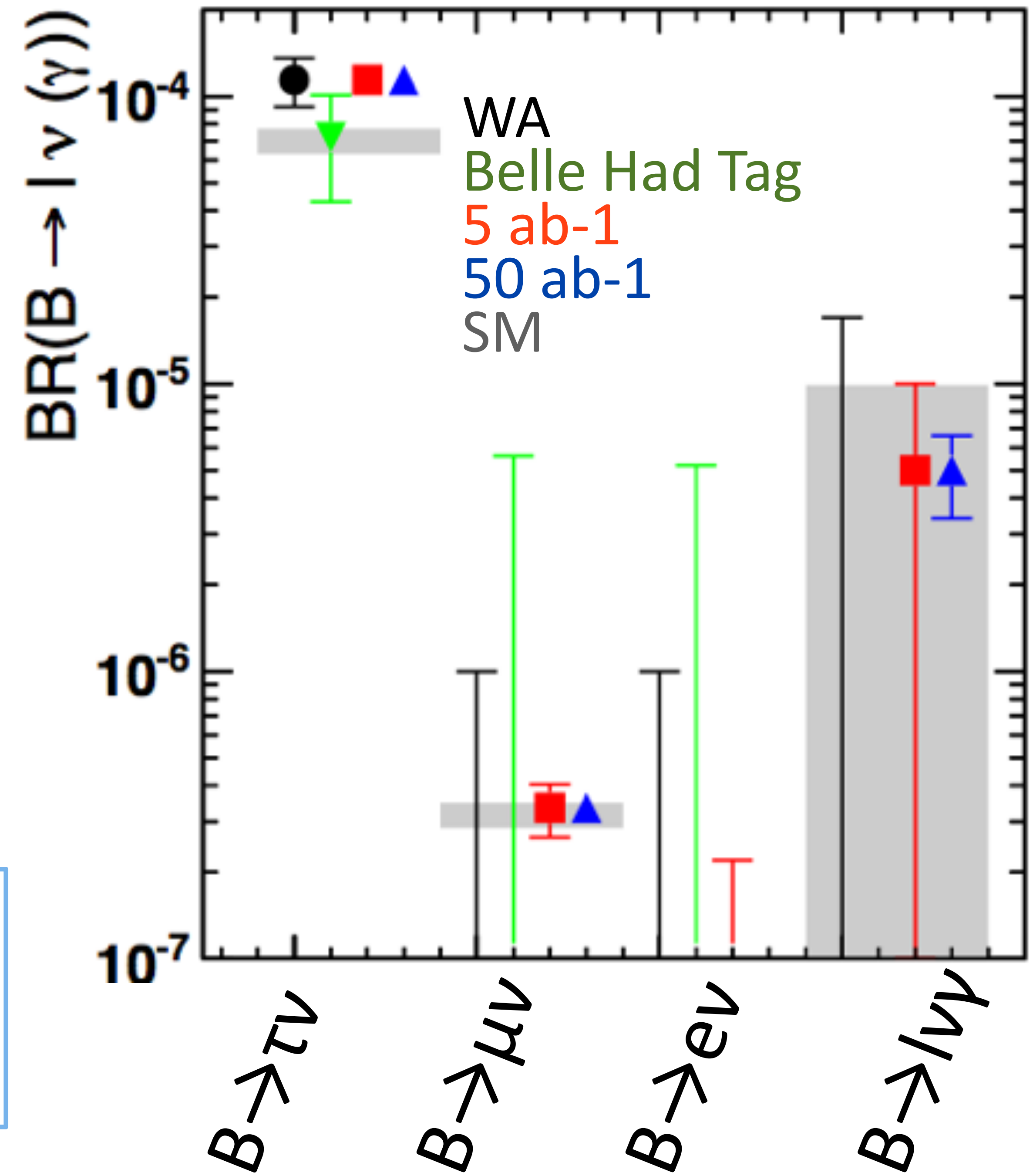




B→τ/e/μν(γ) Projections

Belle, B→ μ ν , e ν (Had) arXiv:1406.6356
Belle, B→ l ν gamma Preliminary (2014 B2TiP)

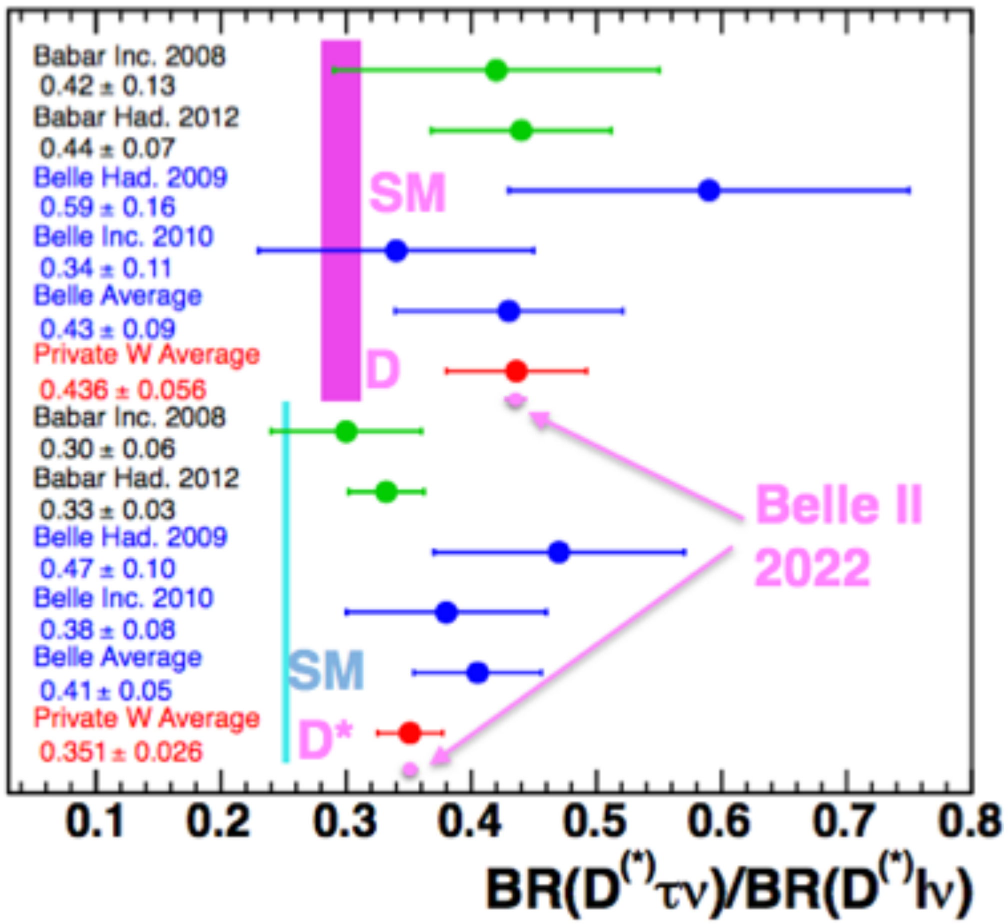




No "Discovery" in a single measurement yet
30% → <5% Precision on B→ τ ν at Belle II
<10% Precision on B→ μ ν & e ν γ

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

New Belle & LHCb results anticipated in 2015

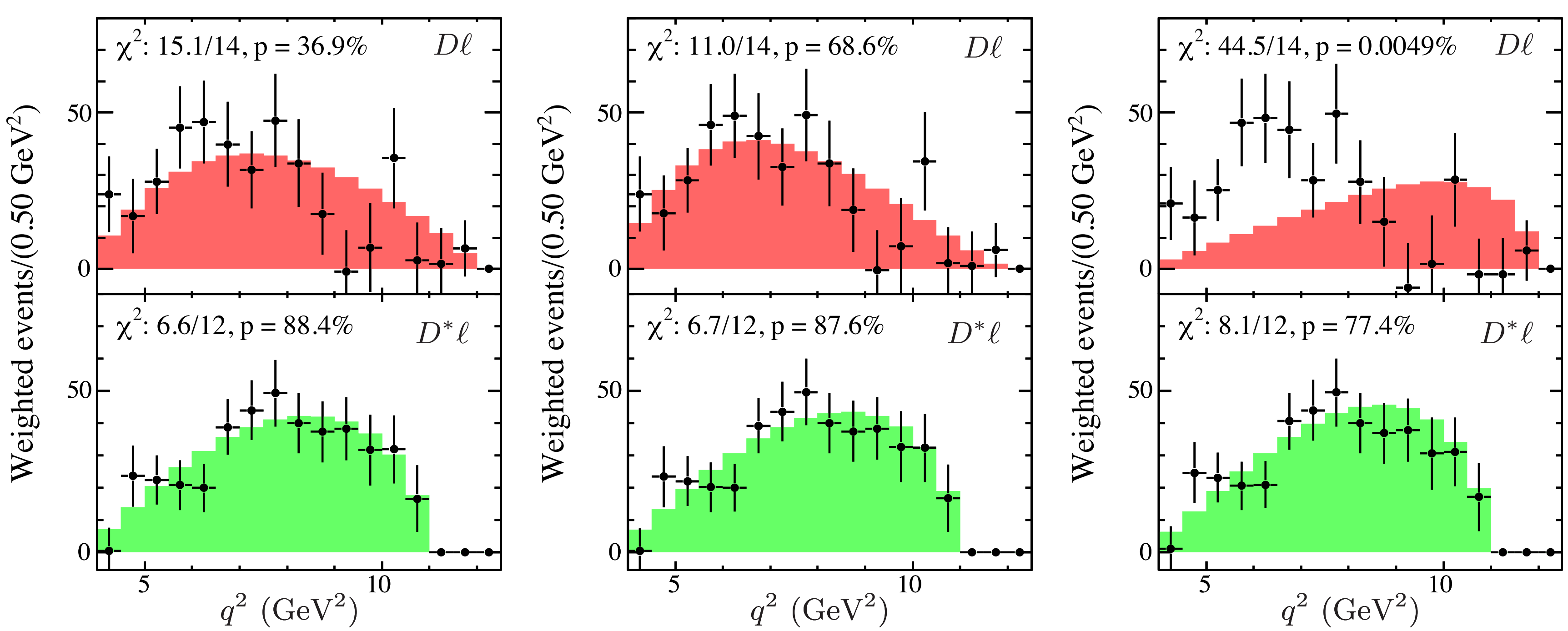


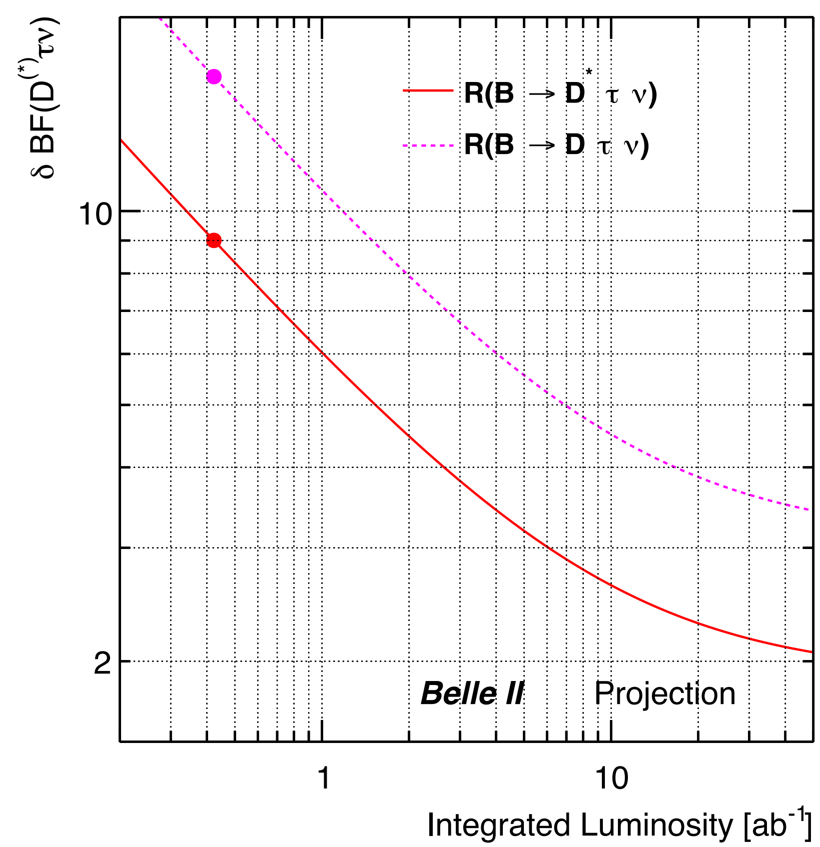
➢ ≥ 2 ν (Missing E)

- $B \rightarrow D^{(*)}\tau\nu$: WA is ~5 sigma from the SM!
- *Need differentials and more NP observables.*

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

Belle II → better low pT tracking, & low p PID.





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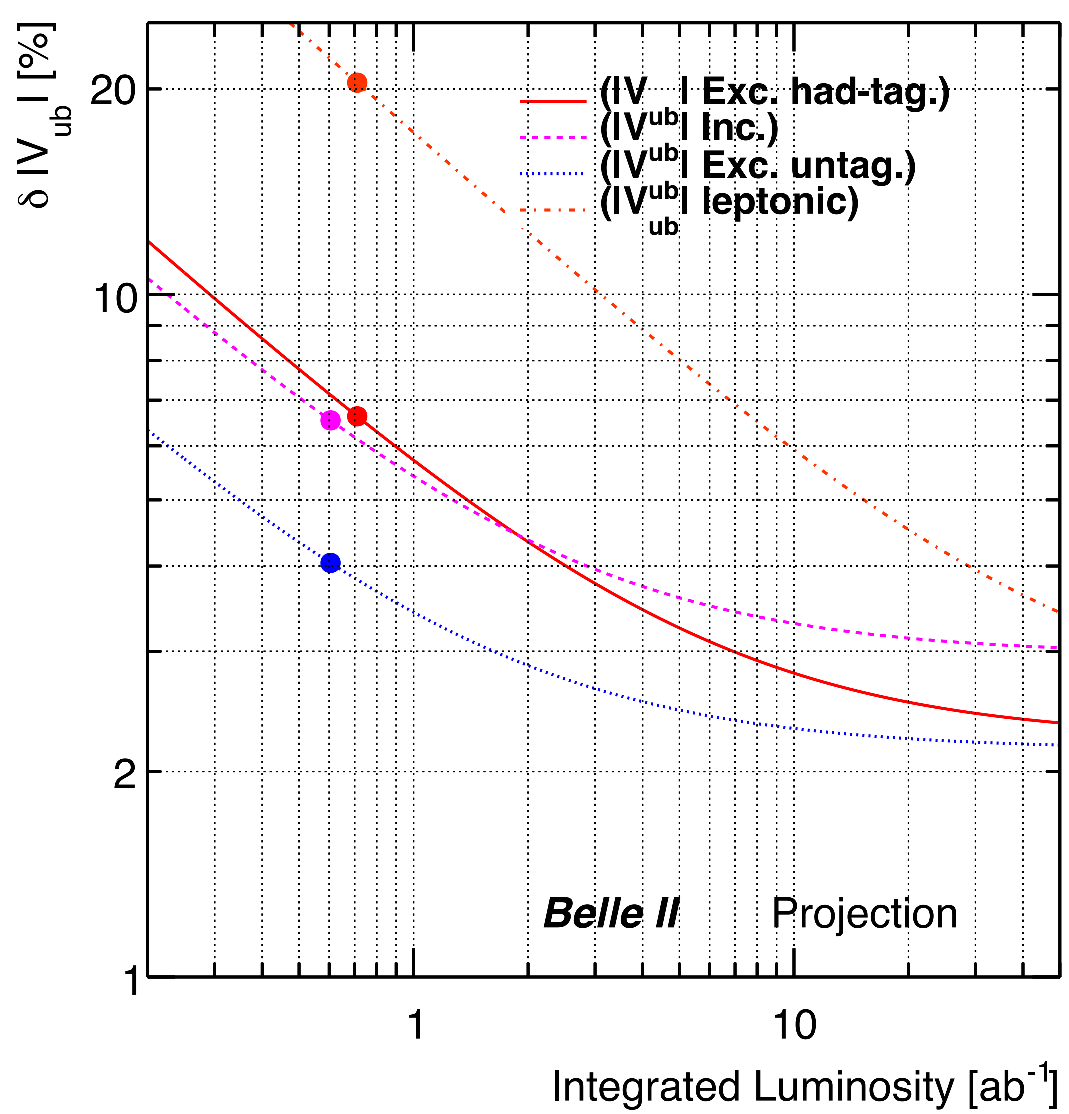
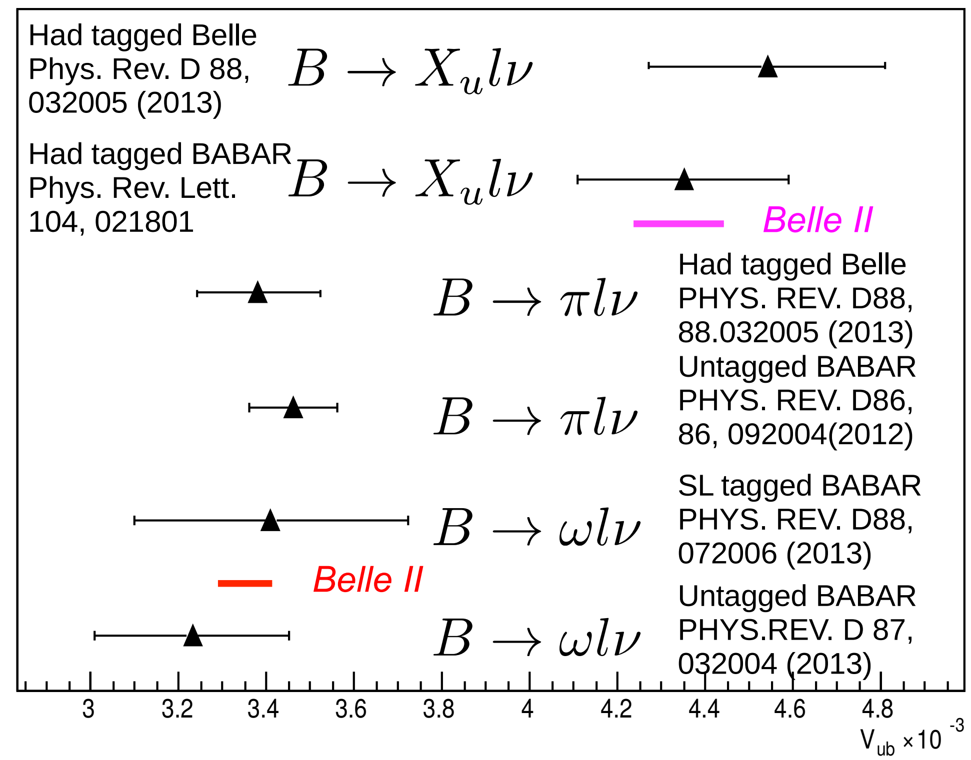
$|V_{ub}|$ (& $|V_{cb}|$): Future

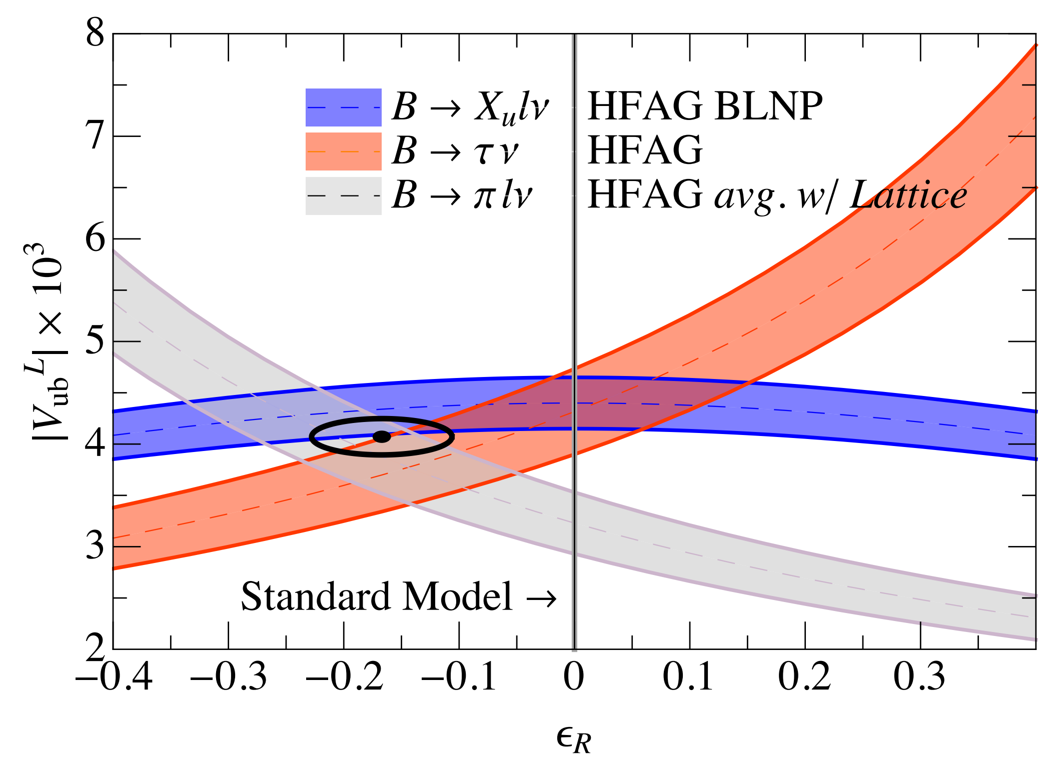
Belle, Exclusive B→ π/ρ/ω l ν (Had), PRD88 032005 (2013)

- Only Belle II can resolve $|V_{ub/cb}|$ exclusive/inclusive puzzles (or → NP). **Both 3 σ!**

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

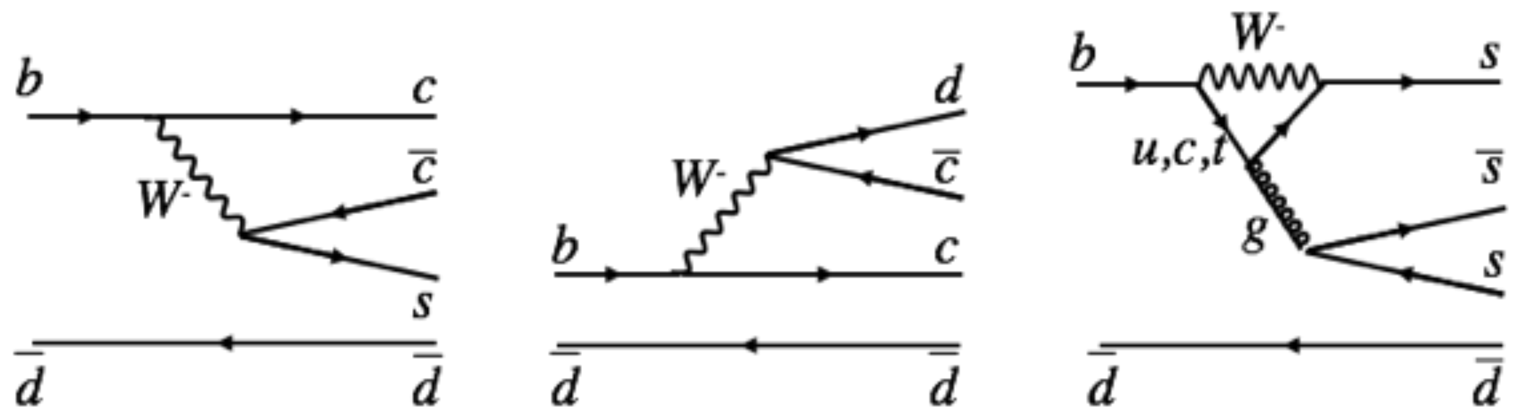






Bernlochner, Ligeti, Turczyk, PRD 90 094003 (2014)

New sources of CPV: Time Dep. CP Violation



Belle II should dominate penguin CPV

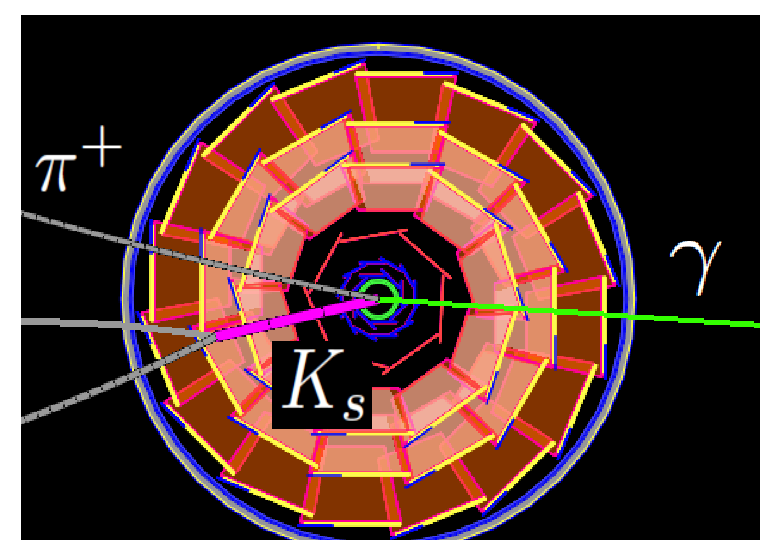
$J/\psi K_S^0, \psi(2S)K_S^0, \chi_{c1}K_S^0,$ $\eta_c K_S^0, J/\psi K_L^0,$ $J/\psi K^{*0}(K^{*0} \to K_S^0\pi^0)$	$D^{*+}D^-, D^+D^-$ $J/\psi\pi^0, D^{*+}D^{*-}$	$\phi K^0, K^+K^-K_S^0,$ $K_S^0K_S^0K_S^0, \eta' K^0, K_S^0\pi^0,$ $\omega K_S^0, f_0(980)K_S^0$

Increasing Tree diagram amplitude

Increasing NP sensitivity

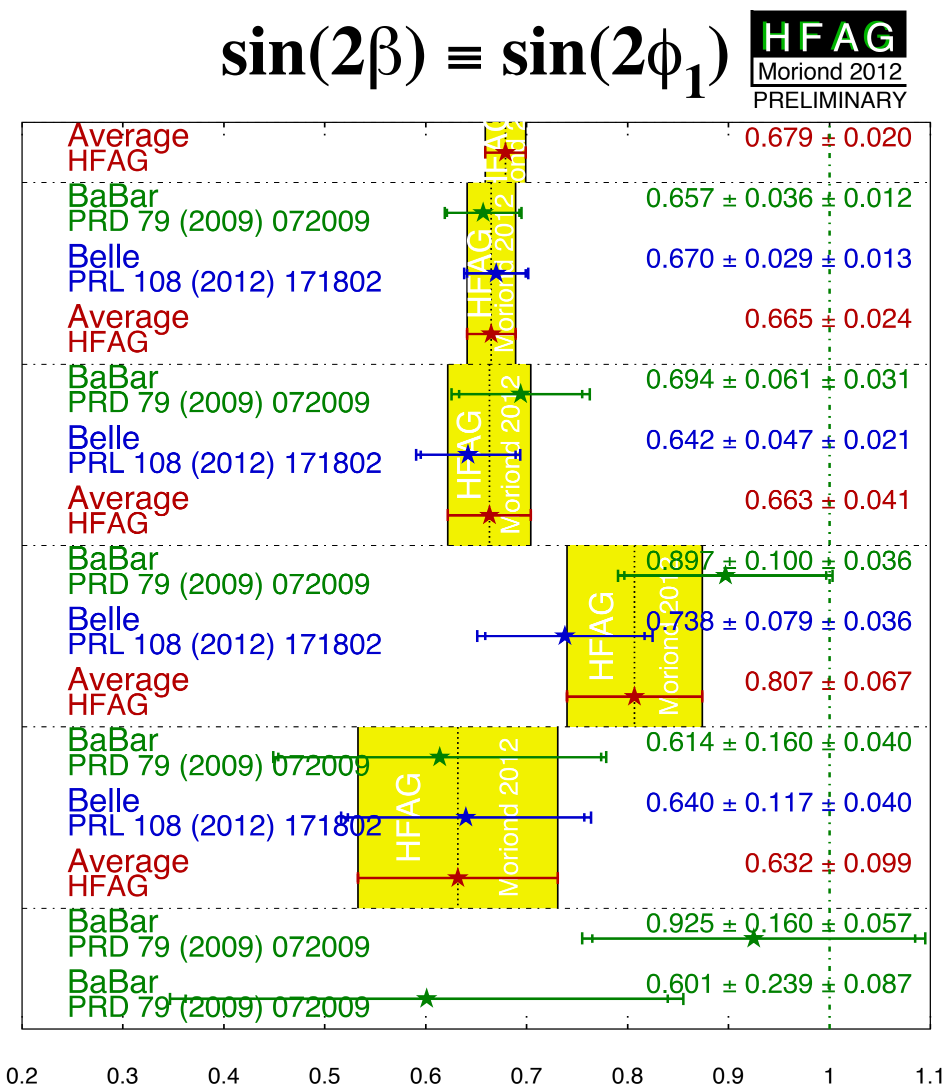
- K-shorts in most signatures: VXD Larger acceptance (+30%) for π from K_S

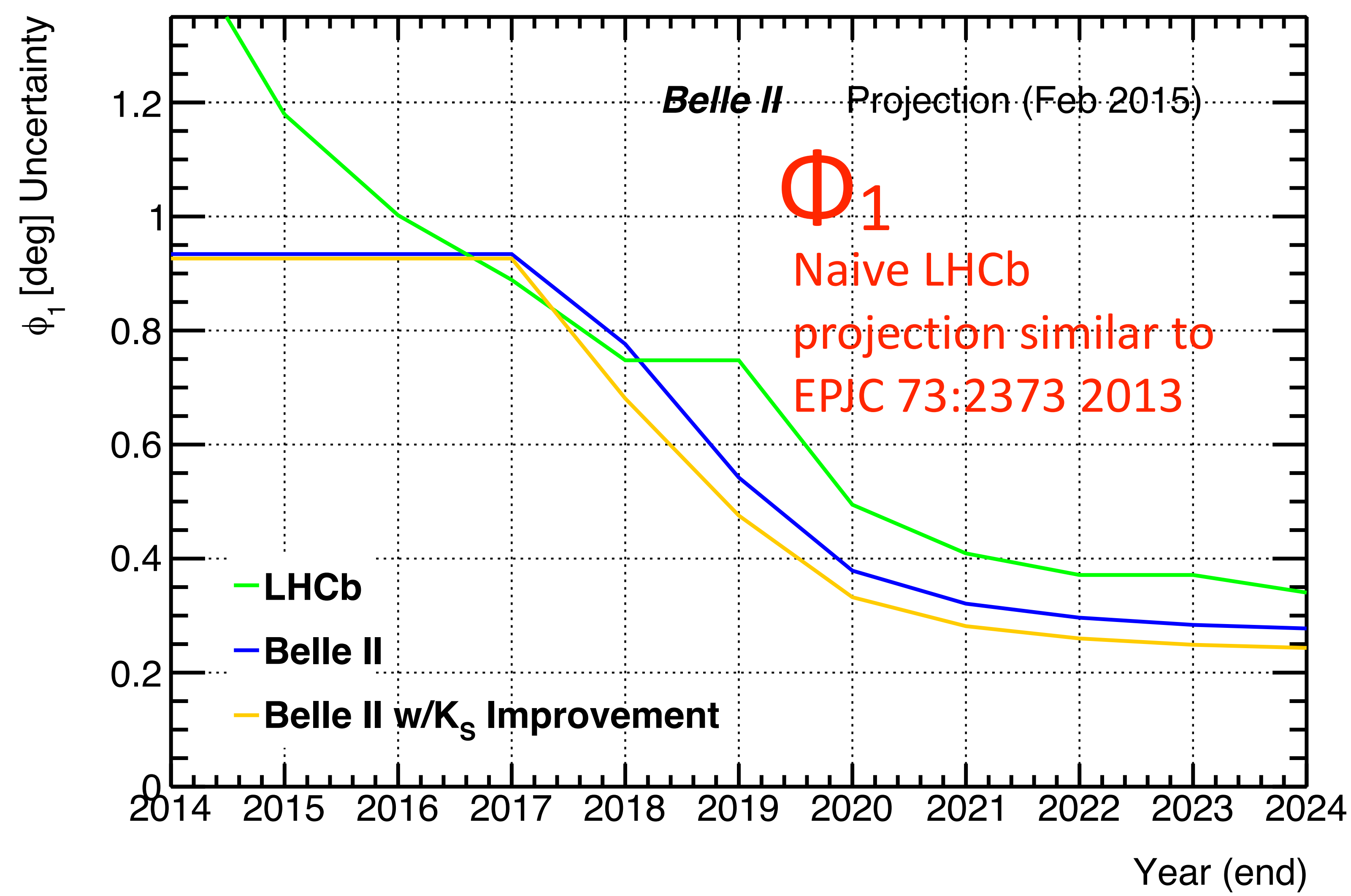
Systematics dominated by vertex resolution:
σ(z) on Vertex: Belle~61μm ⇣ Belle II~18μm



Φ_1, b → c c s

New LHCb result March 2015





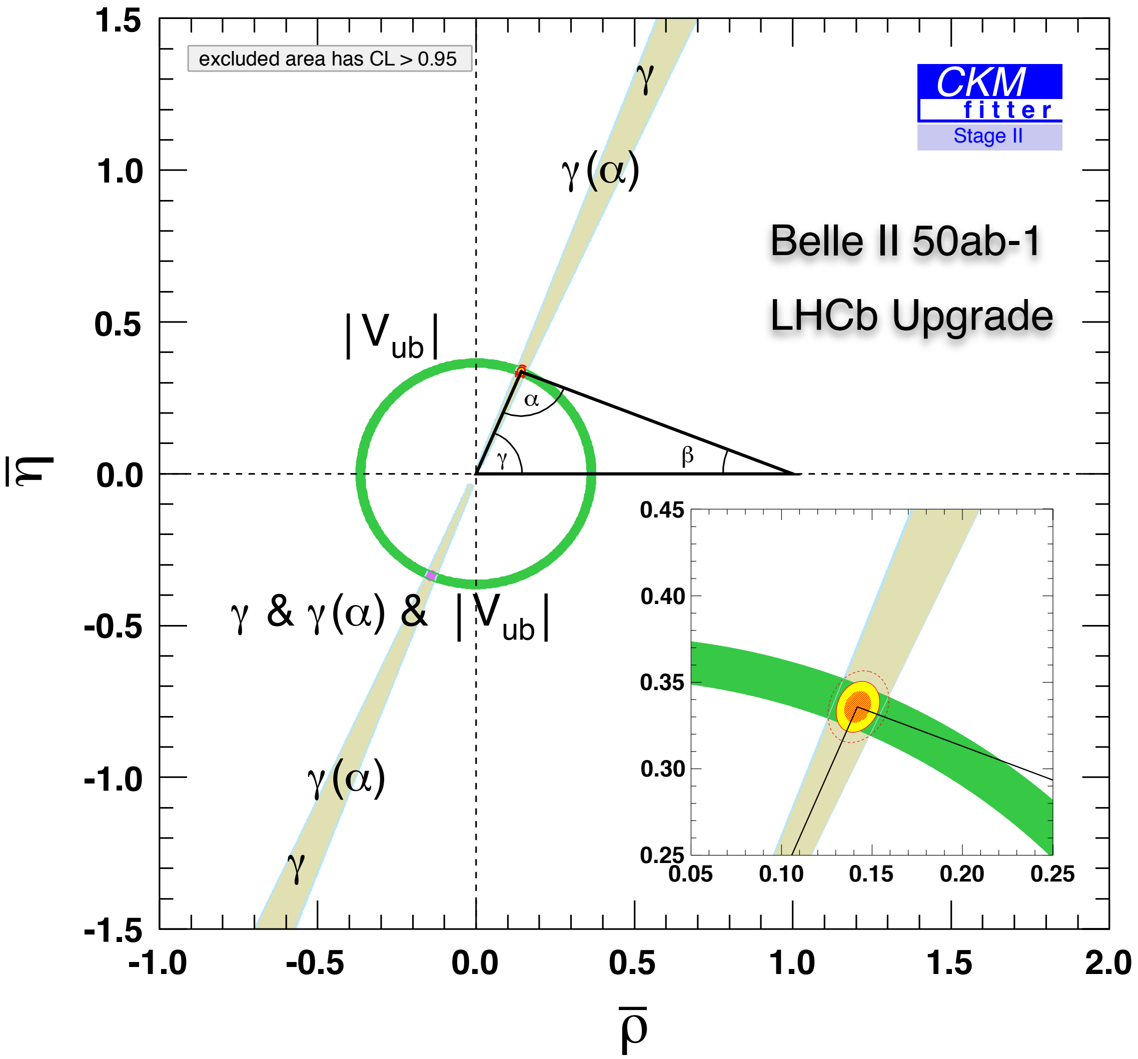
	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012 (0.9^\circ)$	0.4°	0.3°	0.6°	0.3°
	α [°]	85 ± 4 (Belle+BaBar)	2	1		
	γ [°] $(B \to D^{(*)}K^{(*)})$	68 ± 14	6	1.5	4	1
	$2\beta_s (B_s \to J/\psi\phi)$ [rad]	$0.07 \pm 0.09 \pm 0.01^*$			0.025	0.009

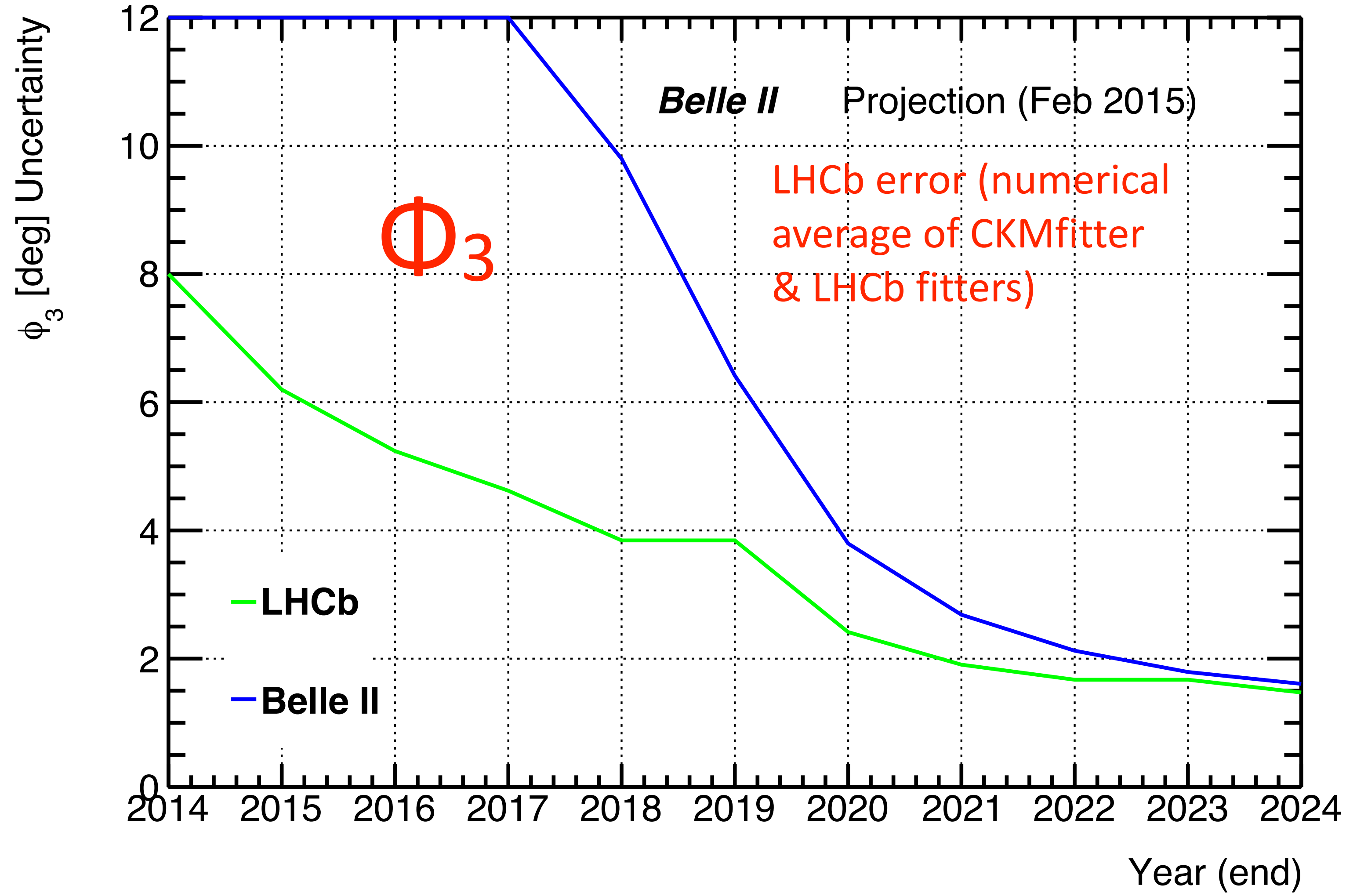
UT angle Φ_3=γ: Future

Experiment: statistics limited!!
Belle II naive scaling: gives Δ~1.5-2°
(based on $D \to K_S\pi\pi$ only).

Many more D modes to explore.

Theory *Errors?*
D mixing, K mixing
CPV in D decay
Higher order EW effects
All < 1°: Golden
Sensitive to NP scenarios.





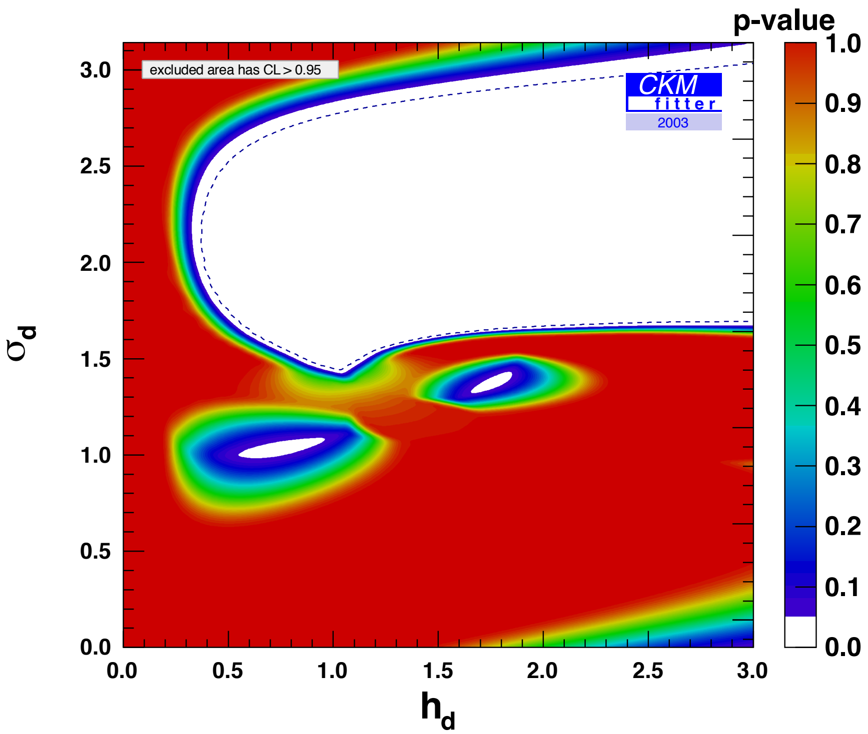
NP in B_d mixing: Φ_1, Φ_2, Δm_d, a_{CP}^{SL}

CKMFitter, PRD 89, 033016 (2014)

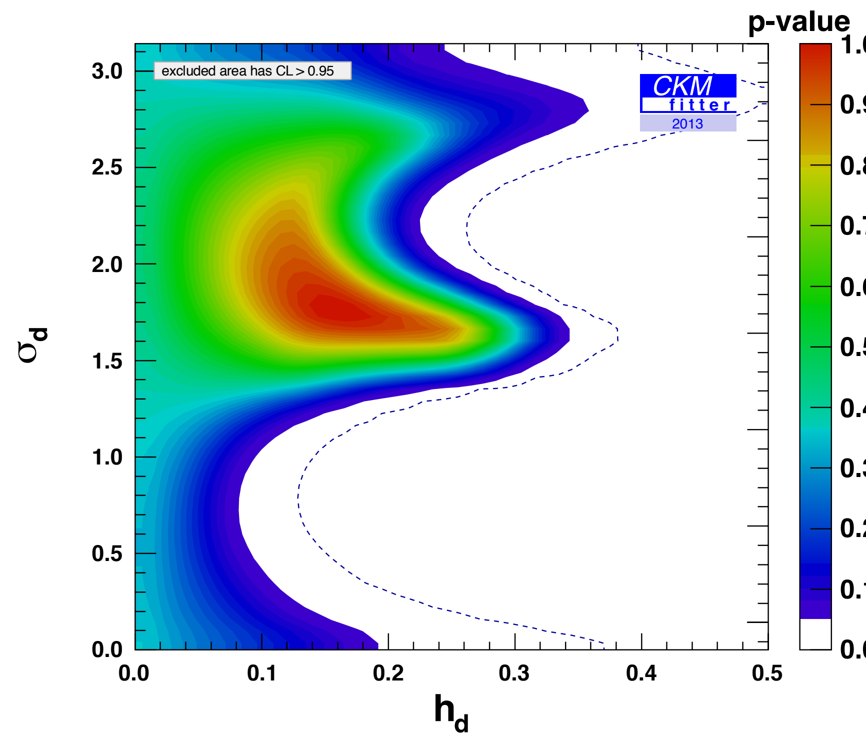
- Assume NP from Trees ($|V_{ud}|$, $|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$, Φ_3) negligible, test for NP in loops only (only enters M_{12}, real part of mixing Hamiltonian.)

$$M_{12} = M_{12}^{SM} \times \left(1 + h e^{2i\sigma}\right)$$

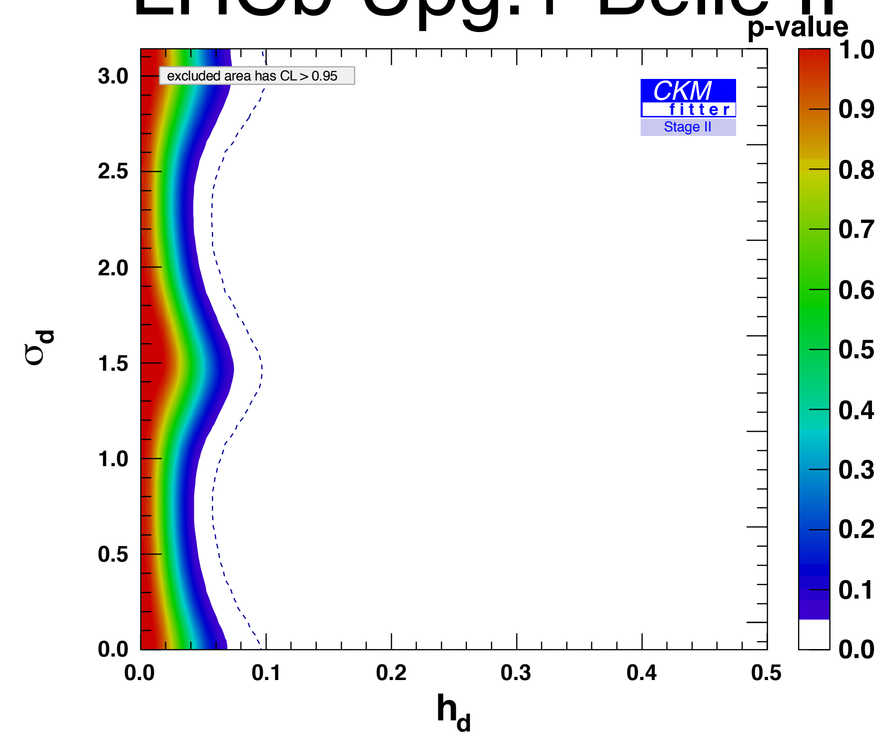
2003



2013



LHCb Upg.+ Belle II



- at 95% NP≲(many × SM) ⟹ NP≲(0.3 × SM) ⟹ NP≲(0.05 × SM)

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2} \frac{(4\pi)^2}{G_F \Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2} \left(\frac{4.5\ \text{TeV}}{\Lambda}\right)^2$$

$$\sigma = \arg(C_{ij} \lambda_{ij}^{t*})$$

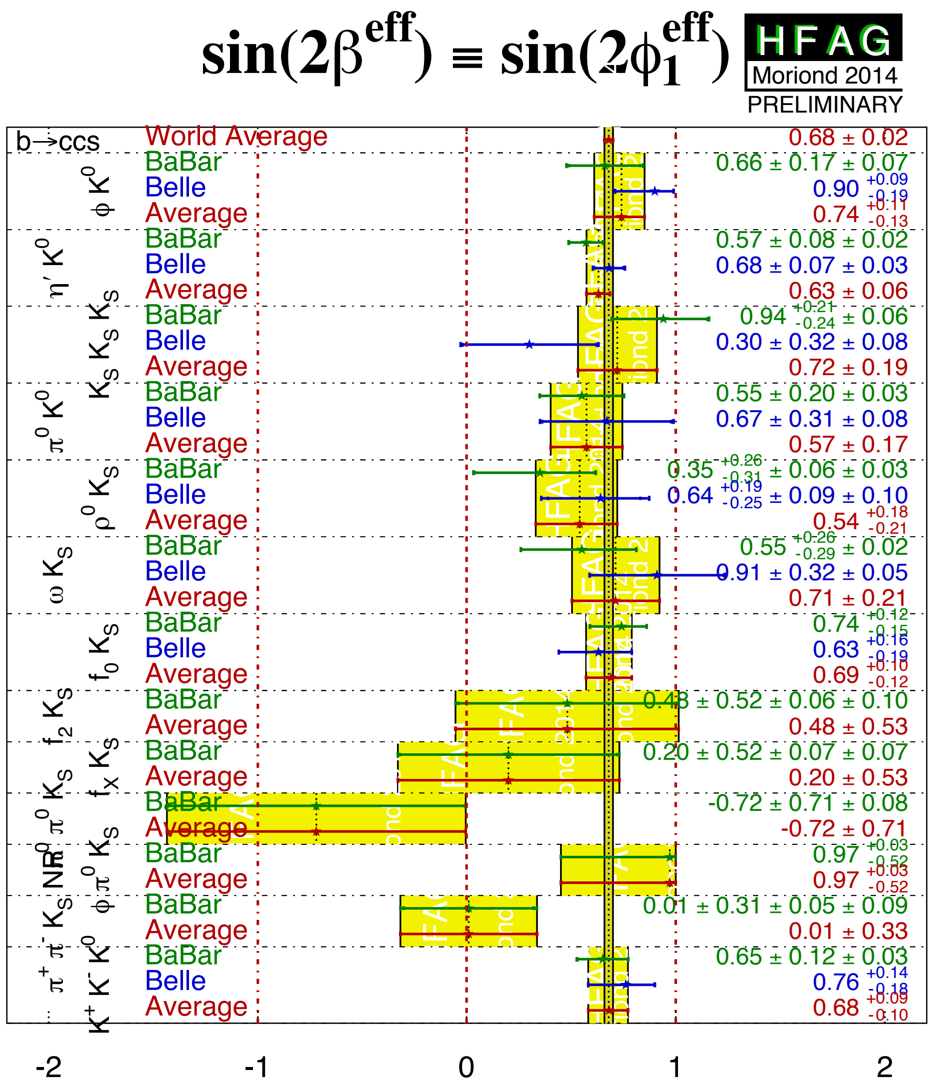
By Stage II,

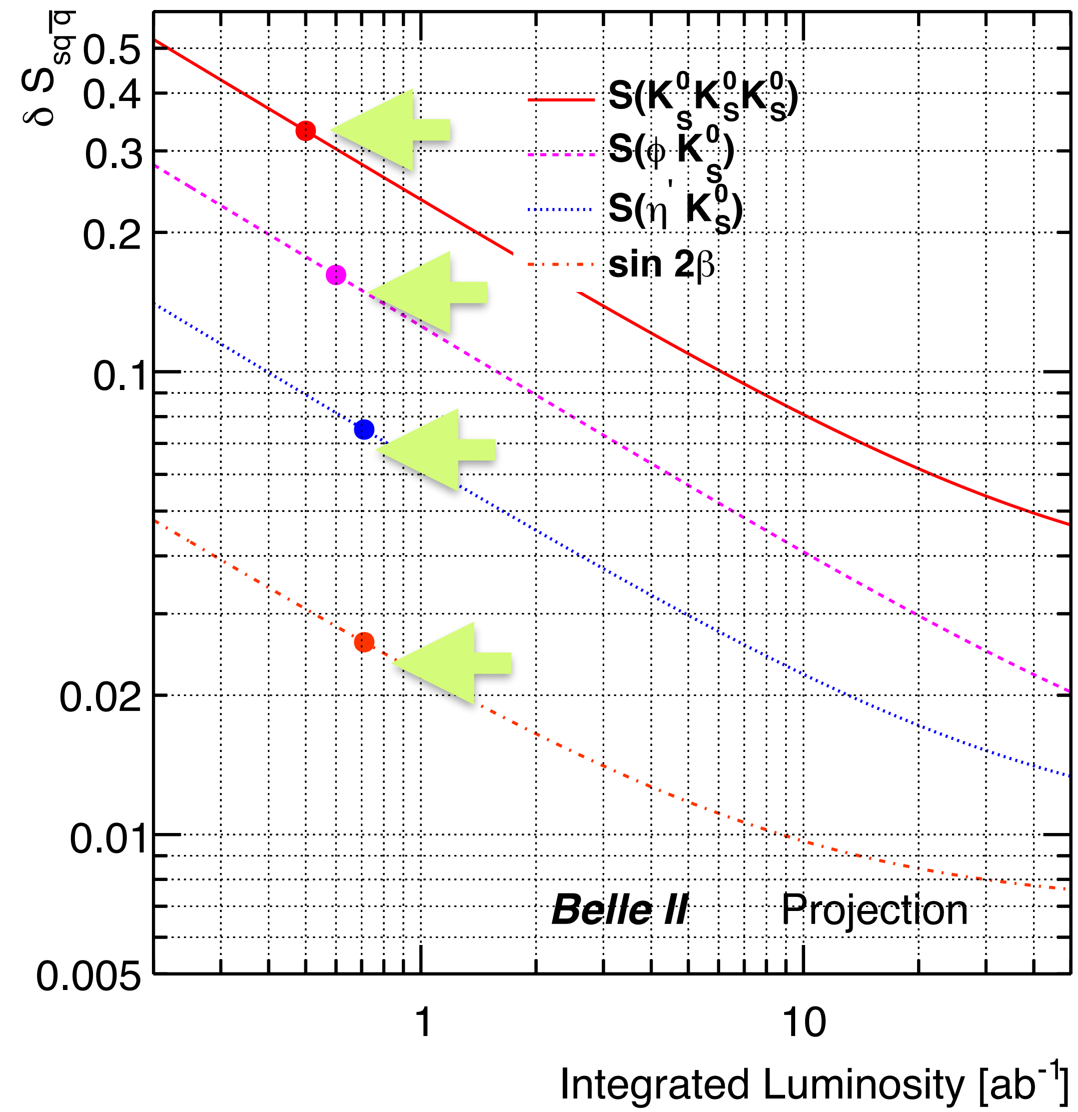
Λ ~ 20 TeV (**tree**)

Λ ~ 2 TeV (**loop**)

b→s Penguin ϕ_1

Belle, B → η‘ K0, JHEP 1410, 165 (2014)
Belle, B → ω Ks0, PRD 90 012002 (2014)

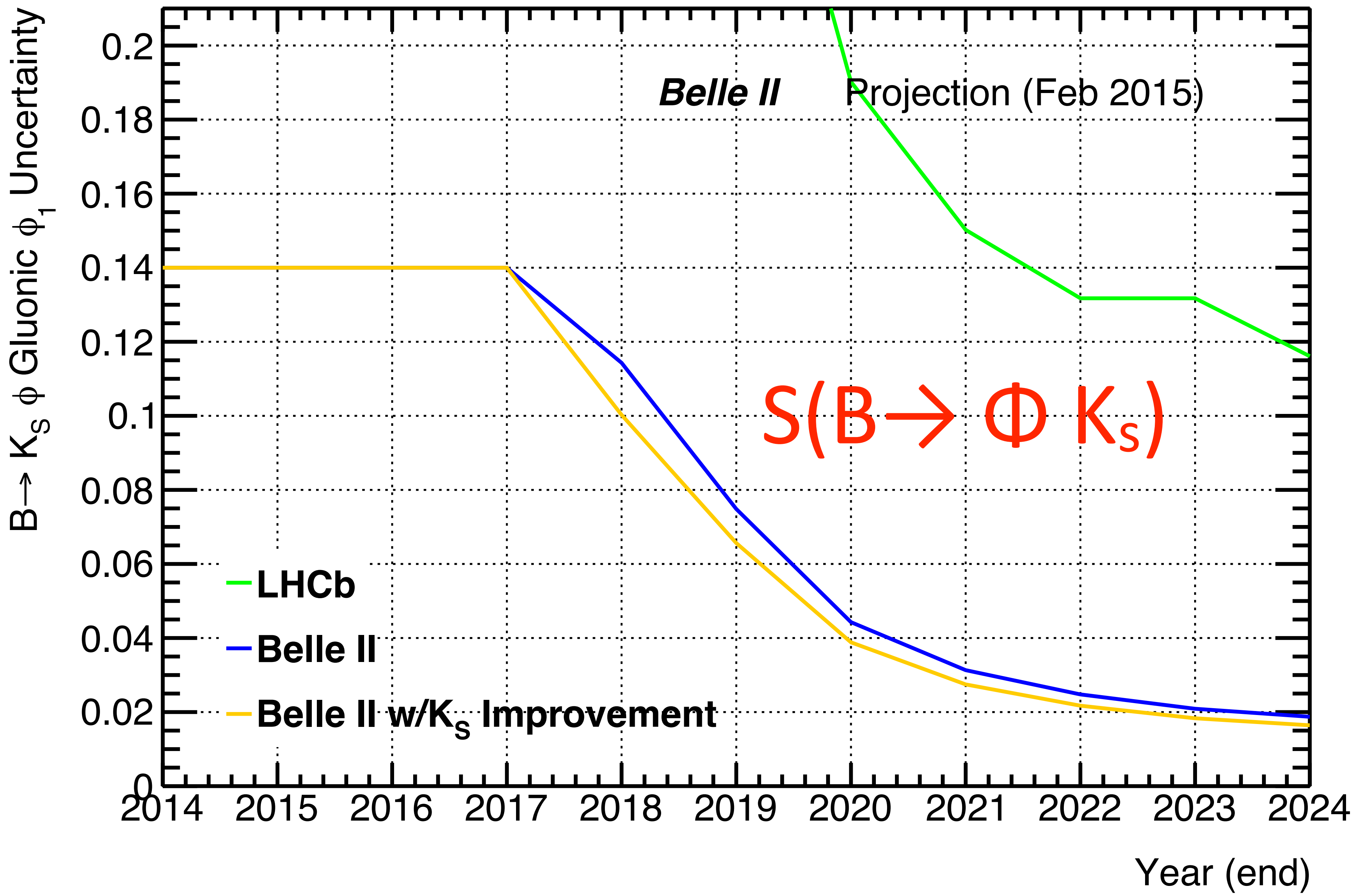




	Observables	Belle or LHCb (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{eff}(B_s \to \phi\phi)$ [rad]	± 0.18			0.12	0.03
	$\beta_s^{eff}(B_s \to K^{*0}\bar{K}^{*0})$ [rad]	± 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		

b→s Penguin ϕ_1: 10 yr Timeline

- Belle II but not LHCb does modes with K_S mesons big fraction of b→s penguin modes *(surprise)* !

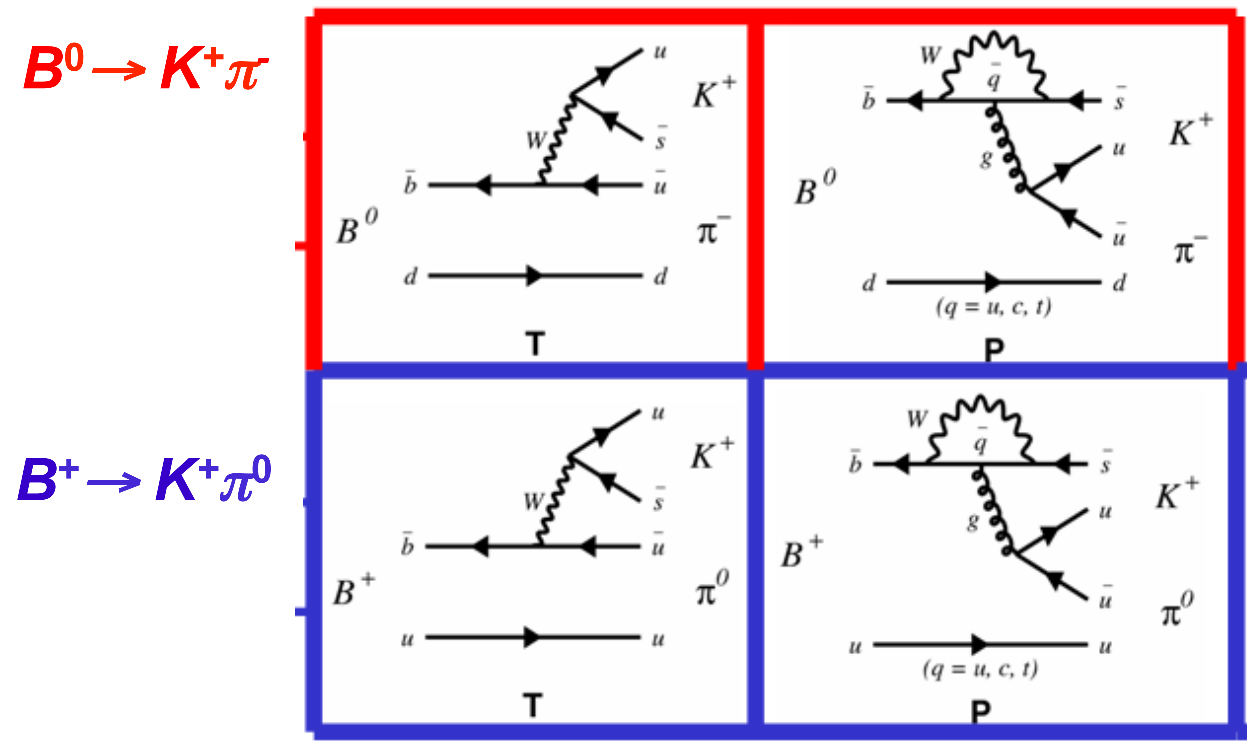


- NB: Belle II projection based on naive extrapolations

Direct CPV in B→Kπ: Future

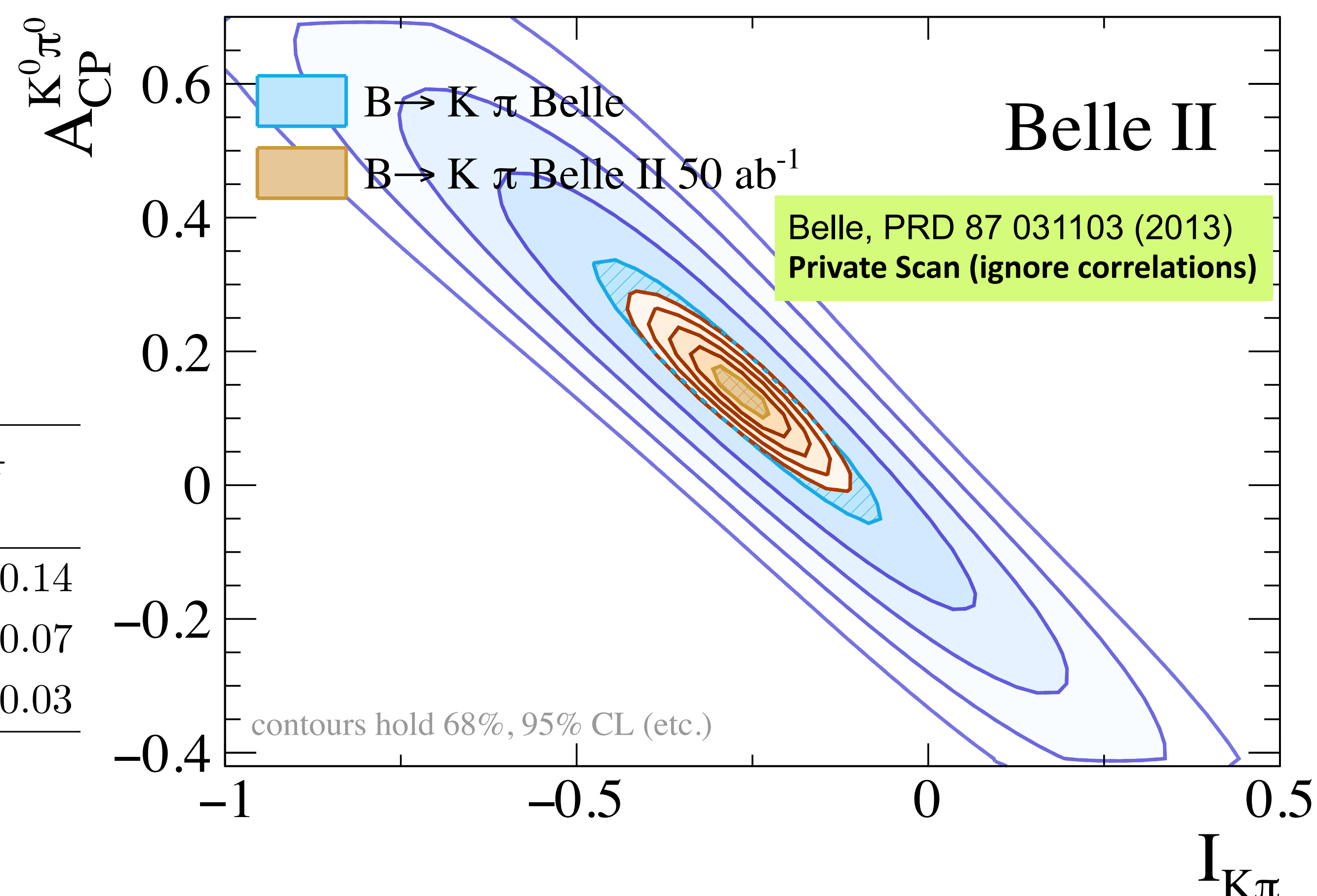
- A_{CP} in hadronic modes cannot be understood w/out full isospin analysis.

  ➡ Need neutral modes.



$$
\begin{aligned}
& I_{K\pi} \cdot \mathcal{B}(B^0 \to K^+\pi^-) \\
= \; & A_{CP}^{K^+\pi^-} \cdot \mathcal{B}(B^0 \to K^+\pi^-) + A_{CP}^{K^0\pi^-} \cdot \mathcal{B}(B^+ \to K^0\pi^-)\frac{\tau_{B^0}}{\tau_{B^+}} \\
- \; & 2A_{CP}^{K^0\pi^0} \cdot \mathcal{B}(B^0 \to K^0\pi^0) + 2A_{CP}^{K^+\pi^0} \cdot \mathcal{B}(B^+ \to K^+\pi^0)\frac{\tau_{B^0}}{\tau_{B^+}}
\end{aligned}
$$

Scenario	$A^{K^0\pi^0}$			$I_{K\pi}$
	Value	Stat.	(Red., Irred.)	
Belle	0.14	0.13	(0.06, 0.02)	0.27 ± 0.14
Belle + $B \to K^0\pi^0$ at Belle II 5 ab^{-1}		0.05	(0.02, 0.02)	0.27 ± 0.07
Belle II 50 ab^{-1}		0.01	(0.01, 0.02)	0.27 ± 0.03

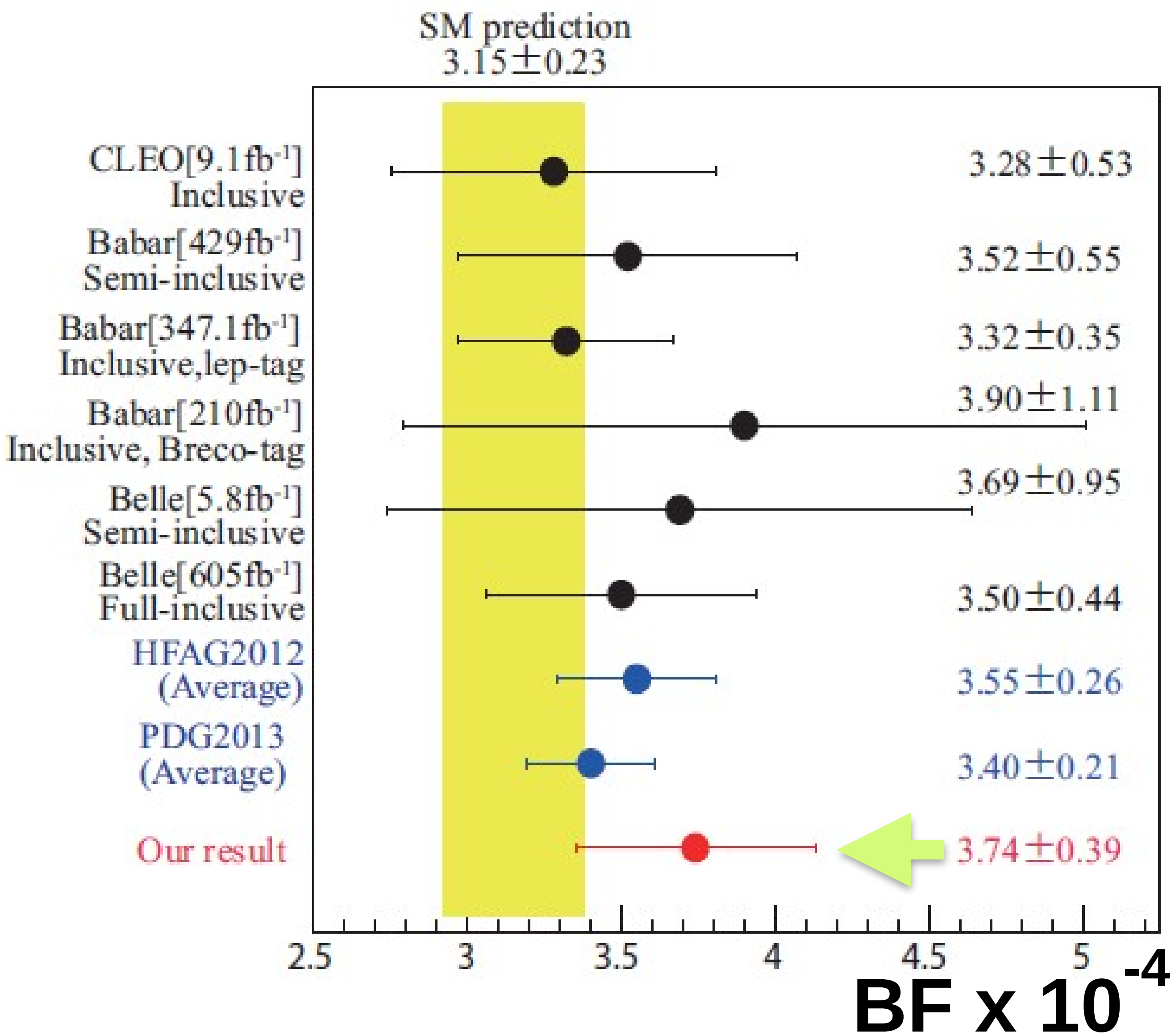


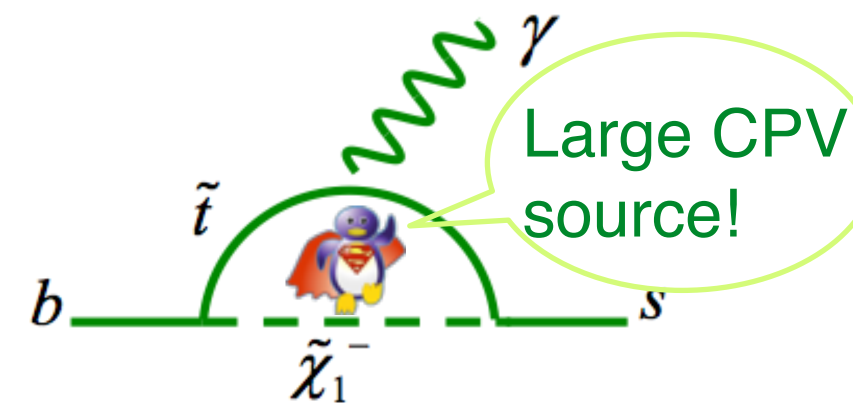
Explore this for πK^*, ρK, ρK^*!

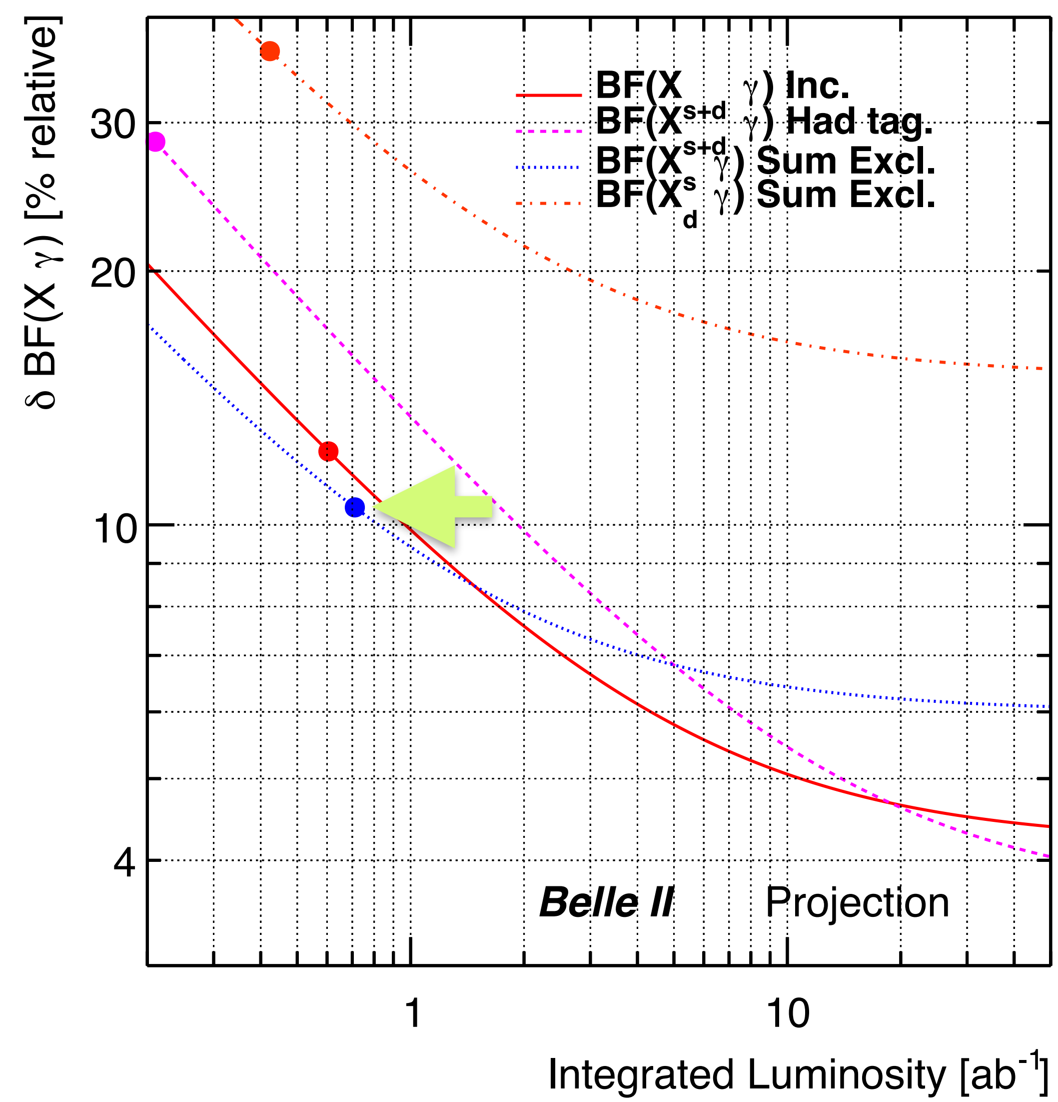
Inclusive Radiative B decays (BF)

*Theory precision near experimental in **b→s***
***b→d** can only be done well at Belle II.*

Belle, B→ sγ Sum Excl, (Submitted to PRD) 1411.7198







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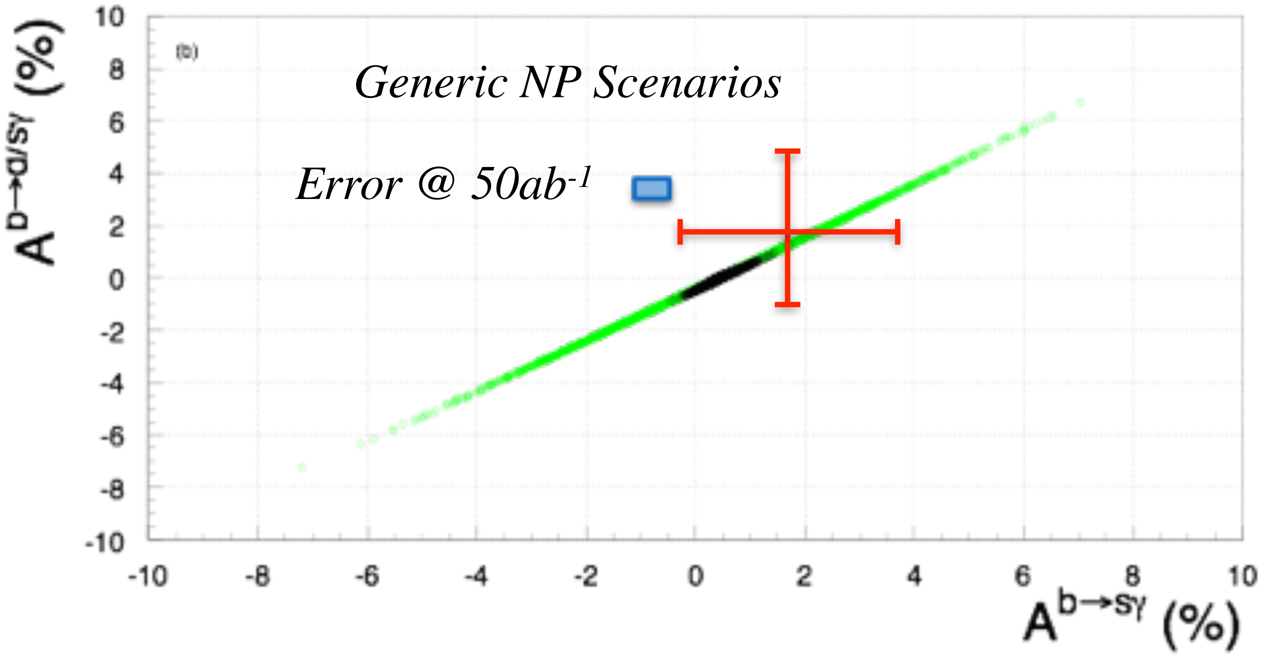
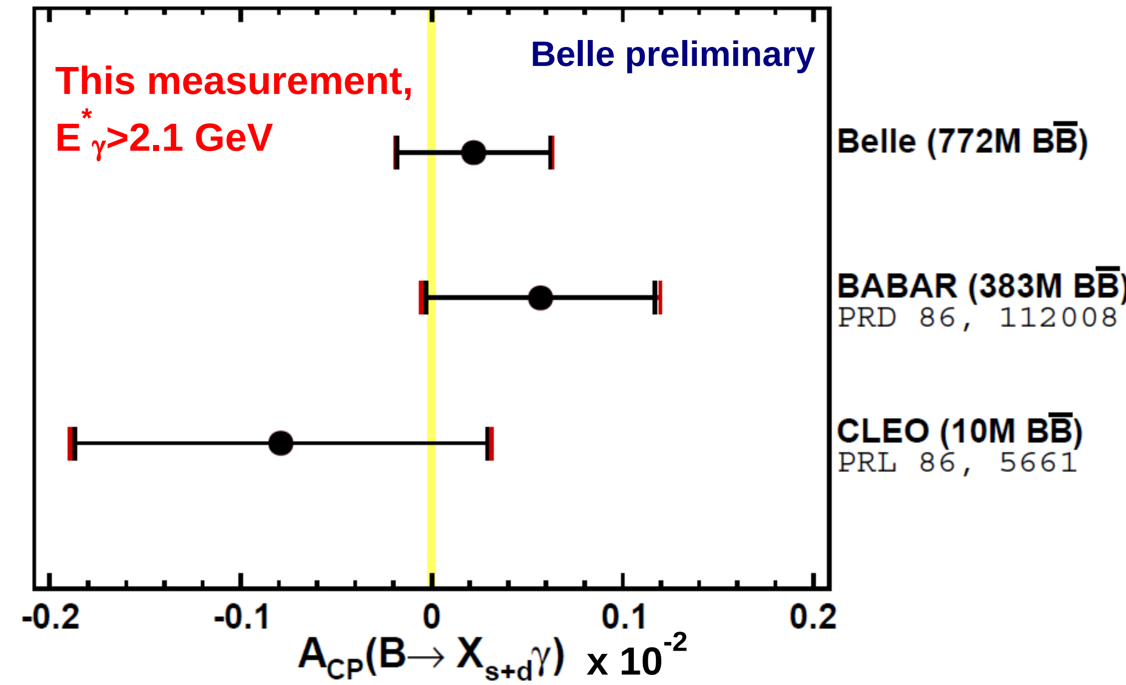
Direct CPV in Inclusive decays

Belle, $A_{CP}(b \to s+d\ \gamma)$ arXiv:1501.01702
Babar, $A_{CP}(b \to s\ \gamma)$, PRD 90 092001 (2014)

Precise probes of CPV & flavour structure!

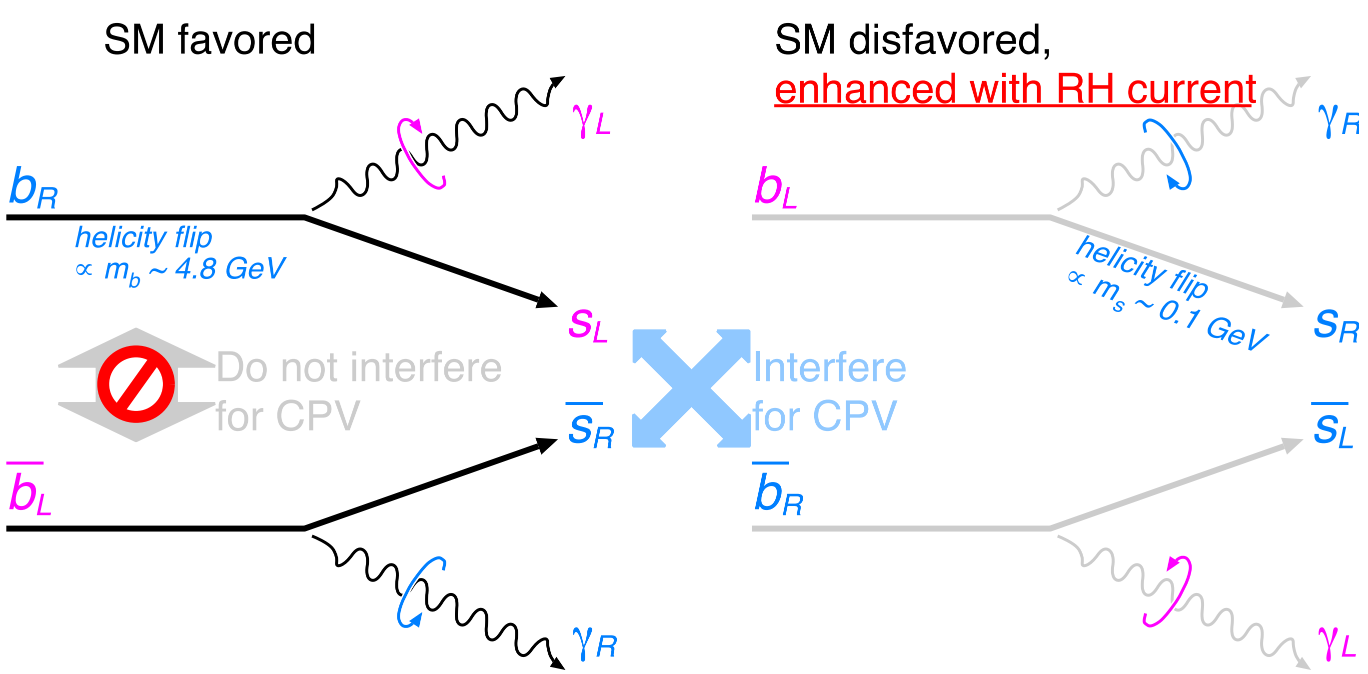




	Observables	Belle or LHCb (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
Radiative	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K_S^0\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	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

b→s{d} Radiative Penguins ϕ_1 *(Null test!)*

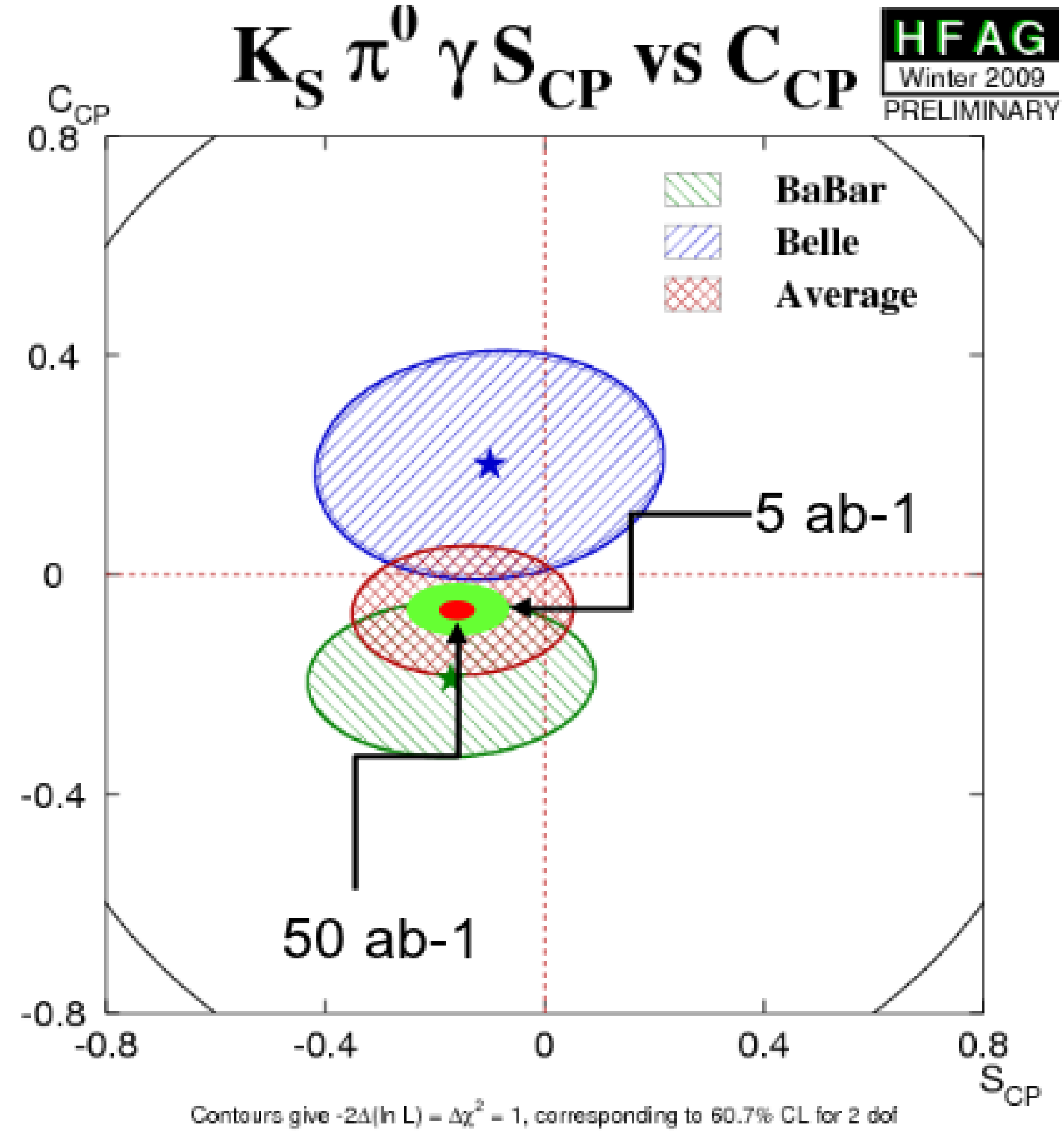
$S = -2(m_s/m_b)\sin(2\phi_1) \sim -0.03$



R-handed current is a signature of NP

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

Belle, B→ Ks η' γ Preliminary (2014)



Belle II will also precisely study b→d penguins

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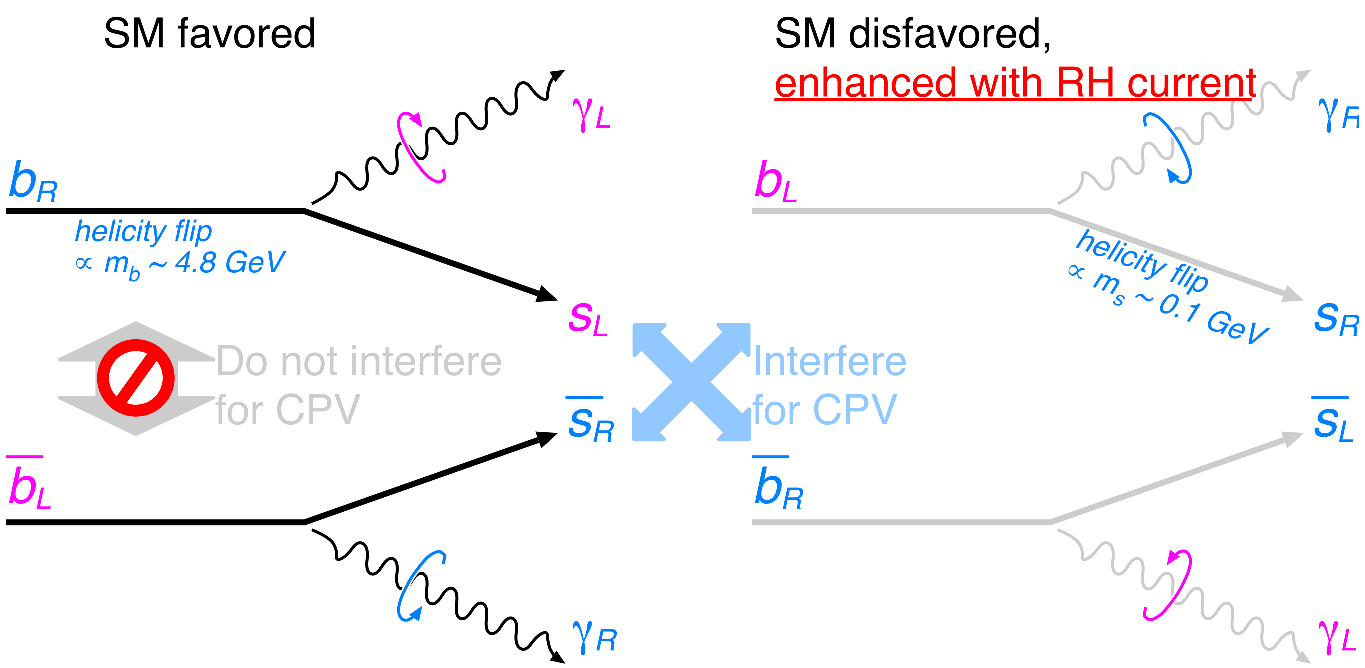
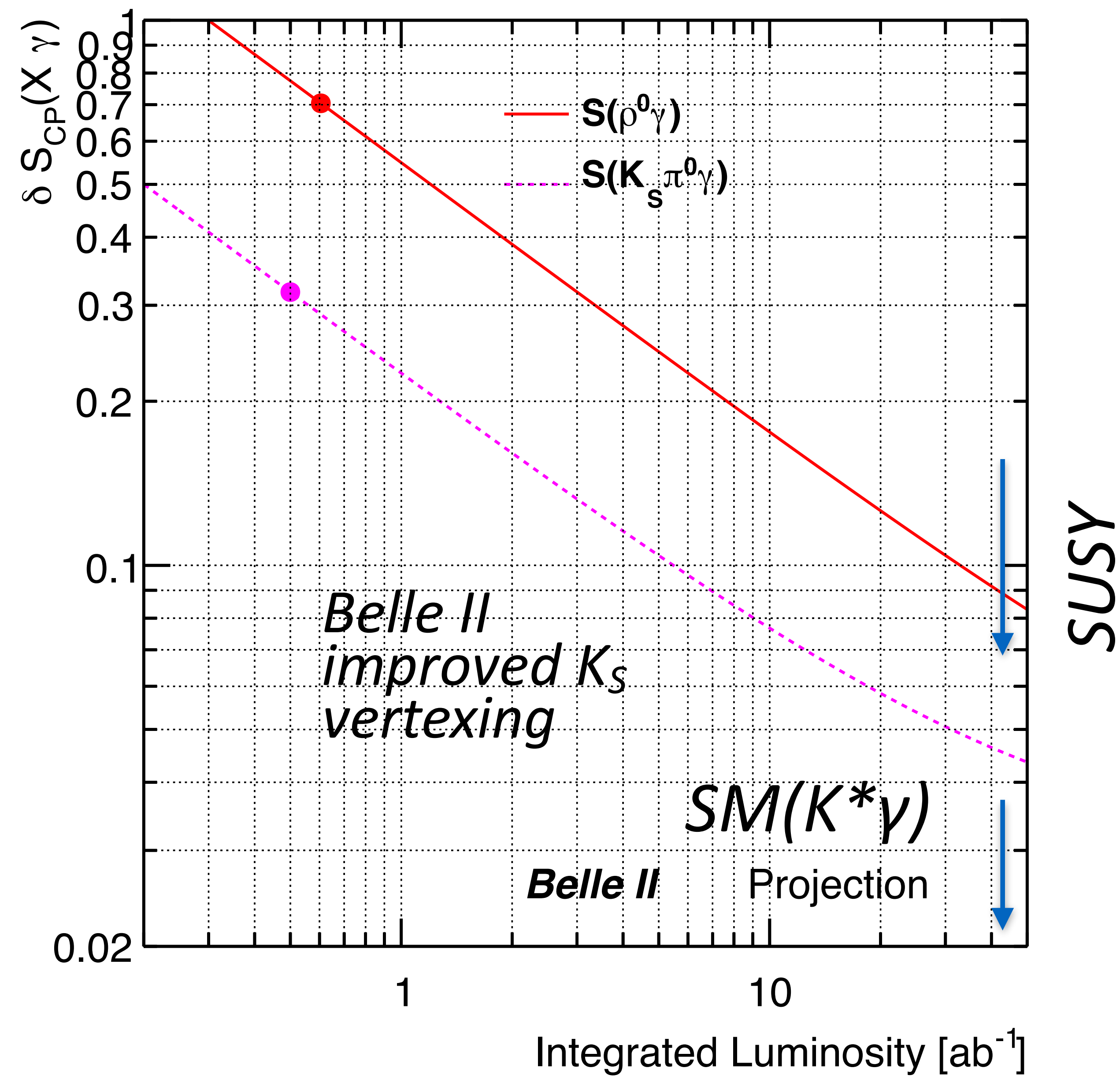
b→s{d} Radiative Penguins ϕ_1 *(Null test!)*

Belle, B→ Ks η' γ Preliminary (2014)

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





R-handed current is a signature of NP

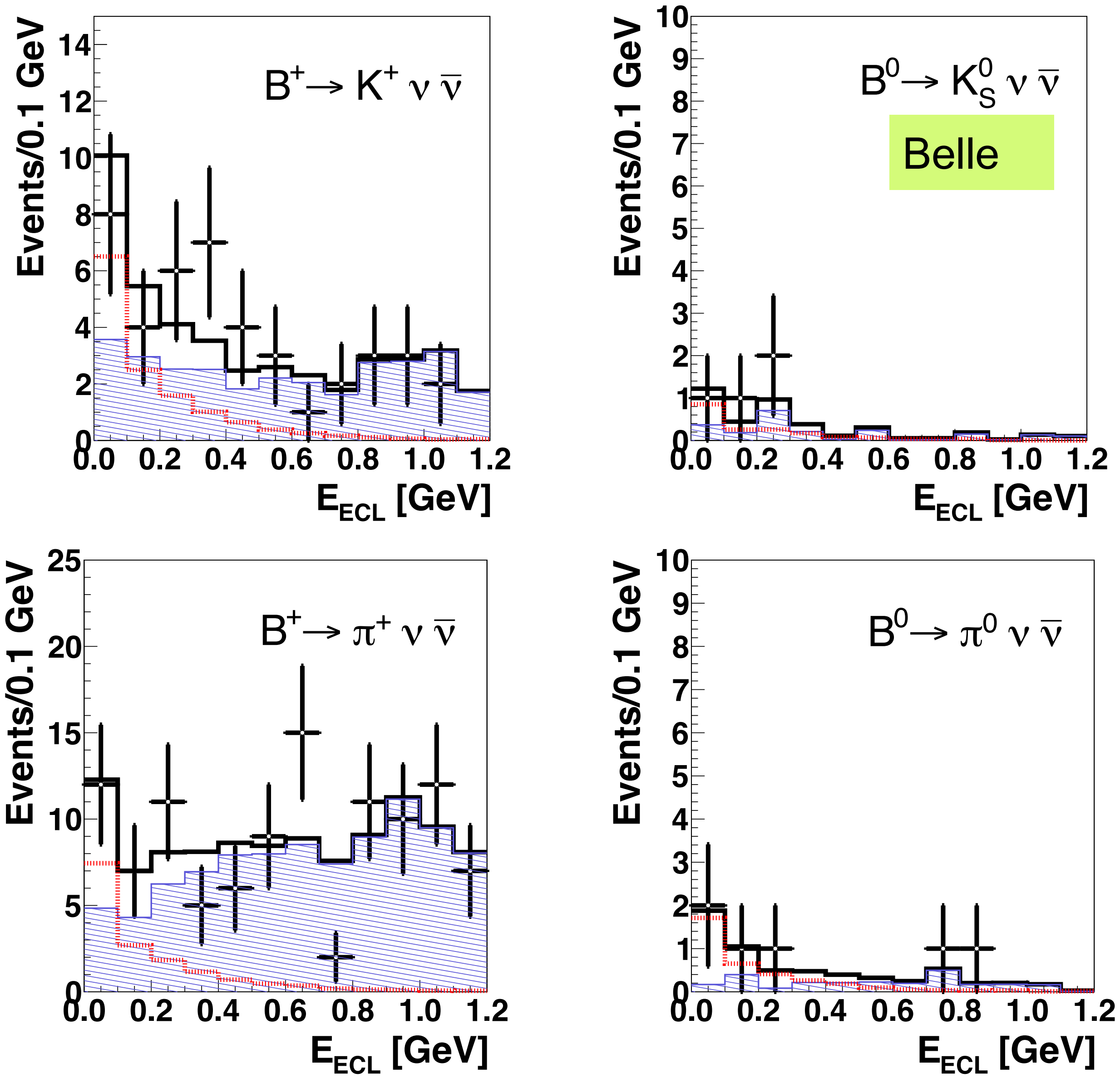
c.f. S=0.5 in **L-R** symmetric **NP** model

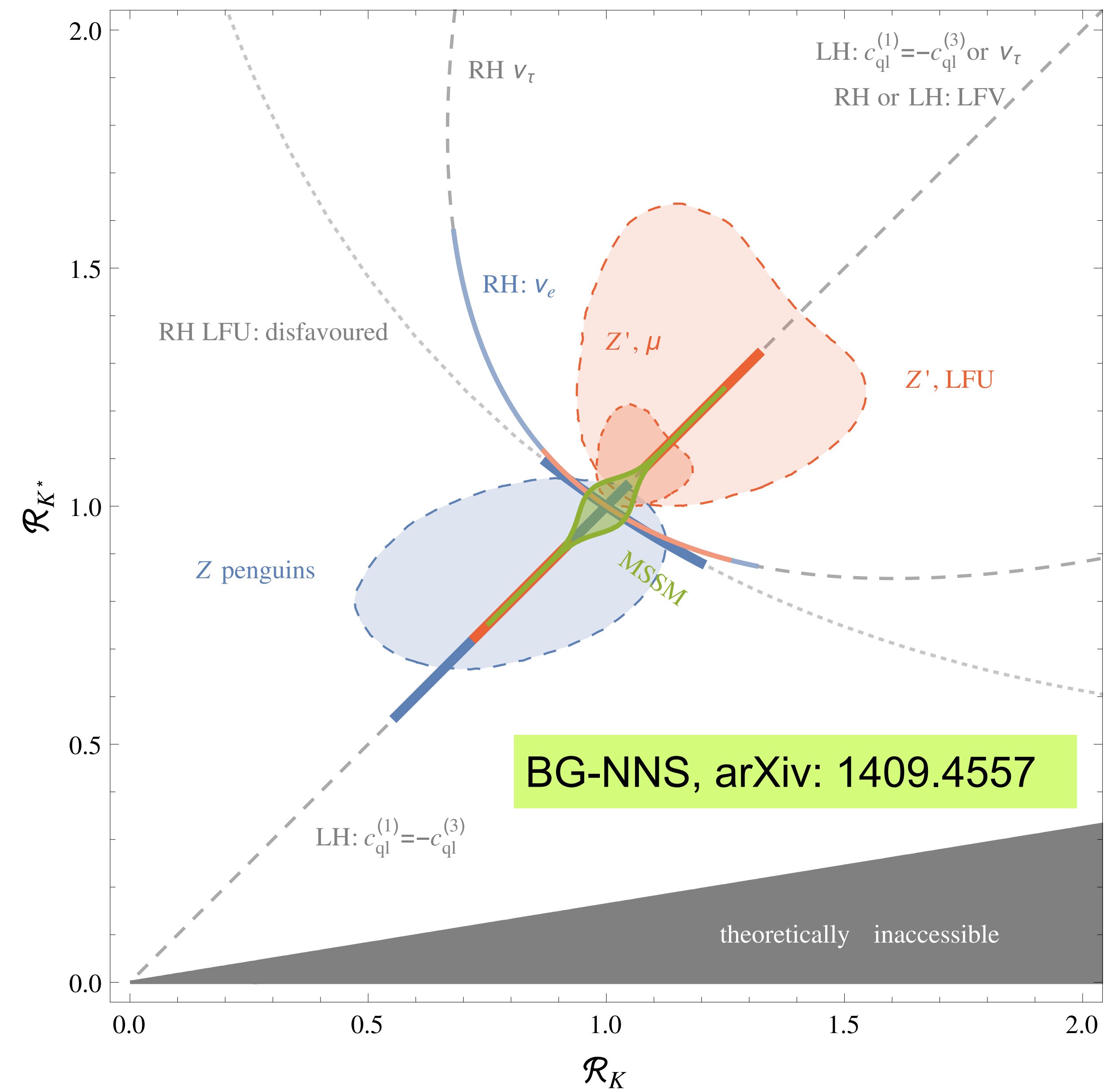
Belle II will also precisely study b→d penguins

Neutrino EWP decays

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

$$\mathcal{B}(B \to K^{*+} \nu\bar{\nu})_{\rm SM} = (9.2 \pm 1.0) \times 10^{-6}$$
$$\mathcal{B}(B \to K^{+} \nu\bar{\nu})_{\rm SM} = (4.0 \pm 0.5) \times 10^{-6}$$

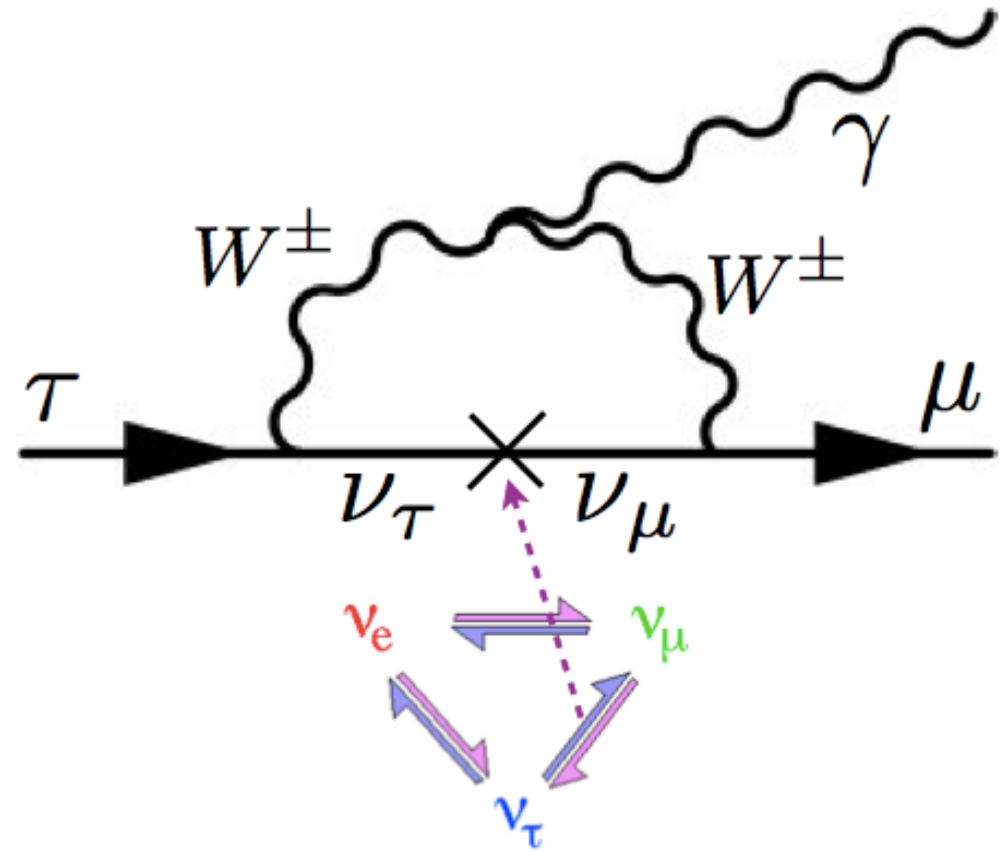




- **Ultimate test of Belle II.**
  B-Tag efficiency, beam-background, better K_L ID.
- **We aim for 5σ on B→ $K^{(*)}$ ν ν!**

τ Lepton Flavour Violation: m→m$_{GUT}$

- LFV is a **theoretically clean** null test of the SM: BF~10^{-25}
- τ decays uniquely studied at **B-factories.**
- NP may induce LFV at one-loop:

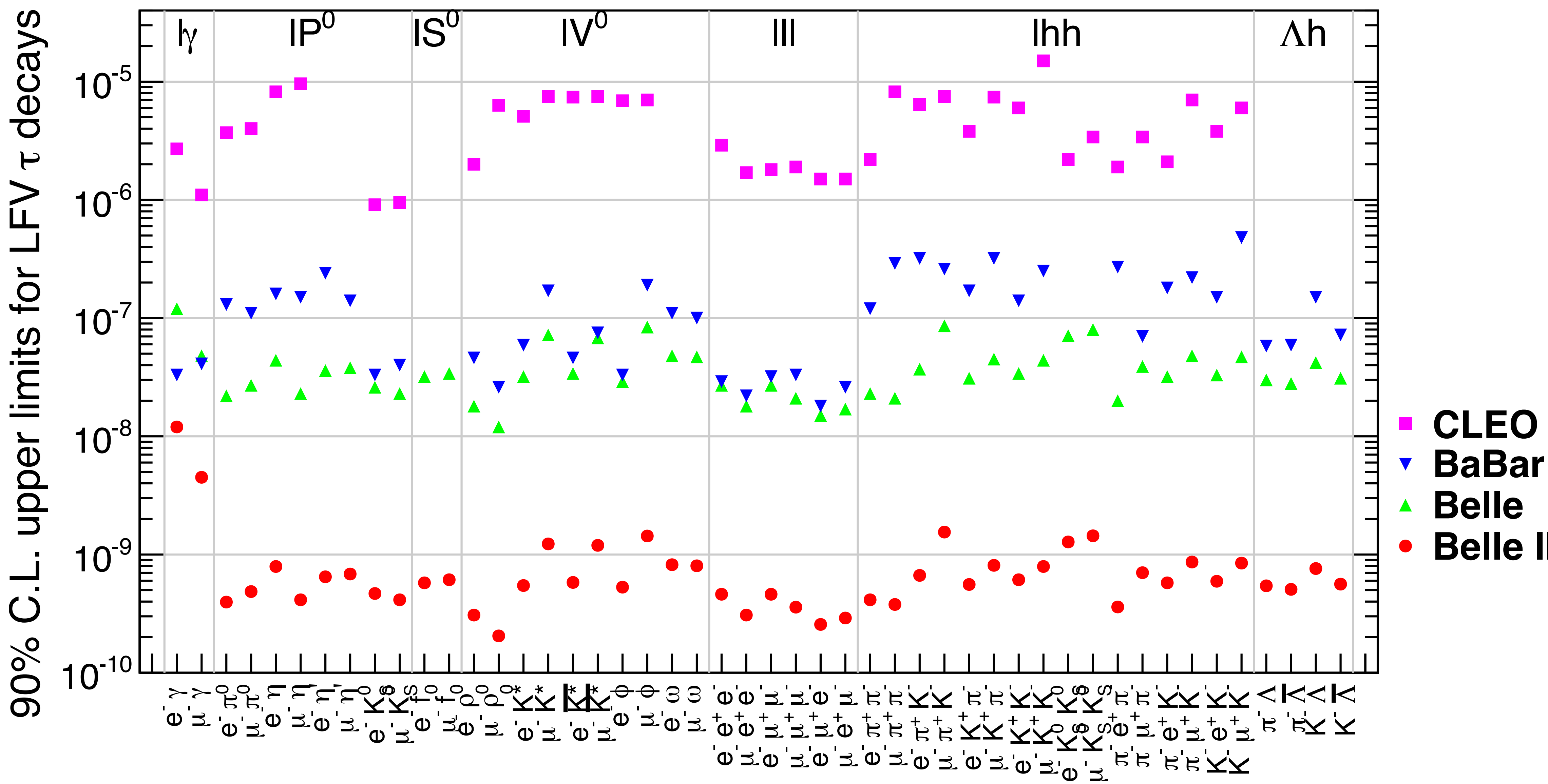


	reference	τ→μγ	τ→μμμ
SM + heavy Maj ν_R	PRD 66(2002)034008	10^{-9}	10^{-10}
Non-universal Z'	PLB 547(2002)252	10^{-9}	10^{-8}
SUSY SO(10)	PRD 68(2003)033012	10^{-8}	10^{-10}
mSUGRA+seesaw	PRD 66(2002)115013	10^{-7}	10^{-9}
SUSY Higgs	PLB 566(2003)217	10^{-10}	10^{-7}

Lepton Flavour Violation

Belle II Flavour Prospects (B2TiP 2014)

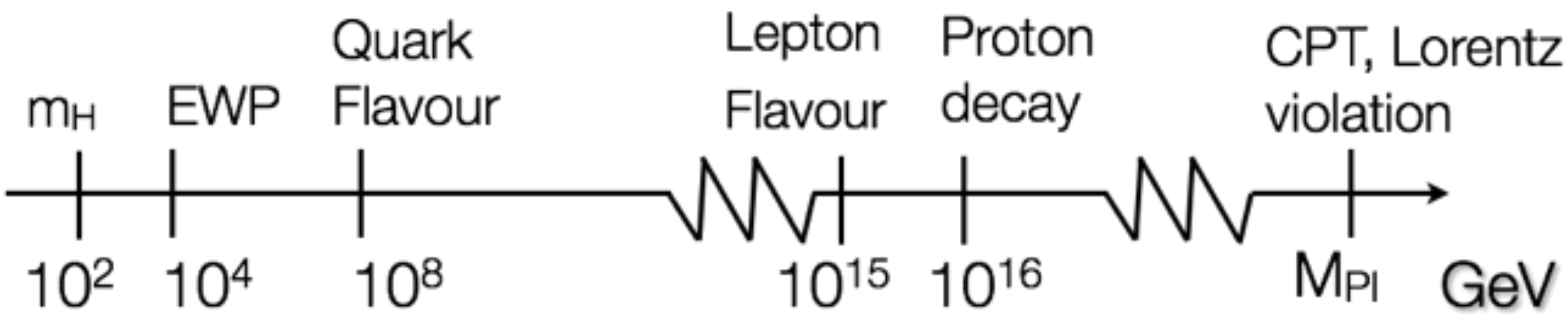
- 2 orders of magnitude improvement.
- Hadron machines not competitive- trigger and track p_T limiting (even μμμ).



- Big program of τ physics in preparation!

Summary

- 50 × integrated luminosity @ Belle II will probe significantly into > 1 TeV mass scale

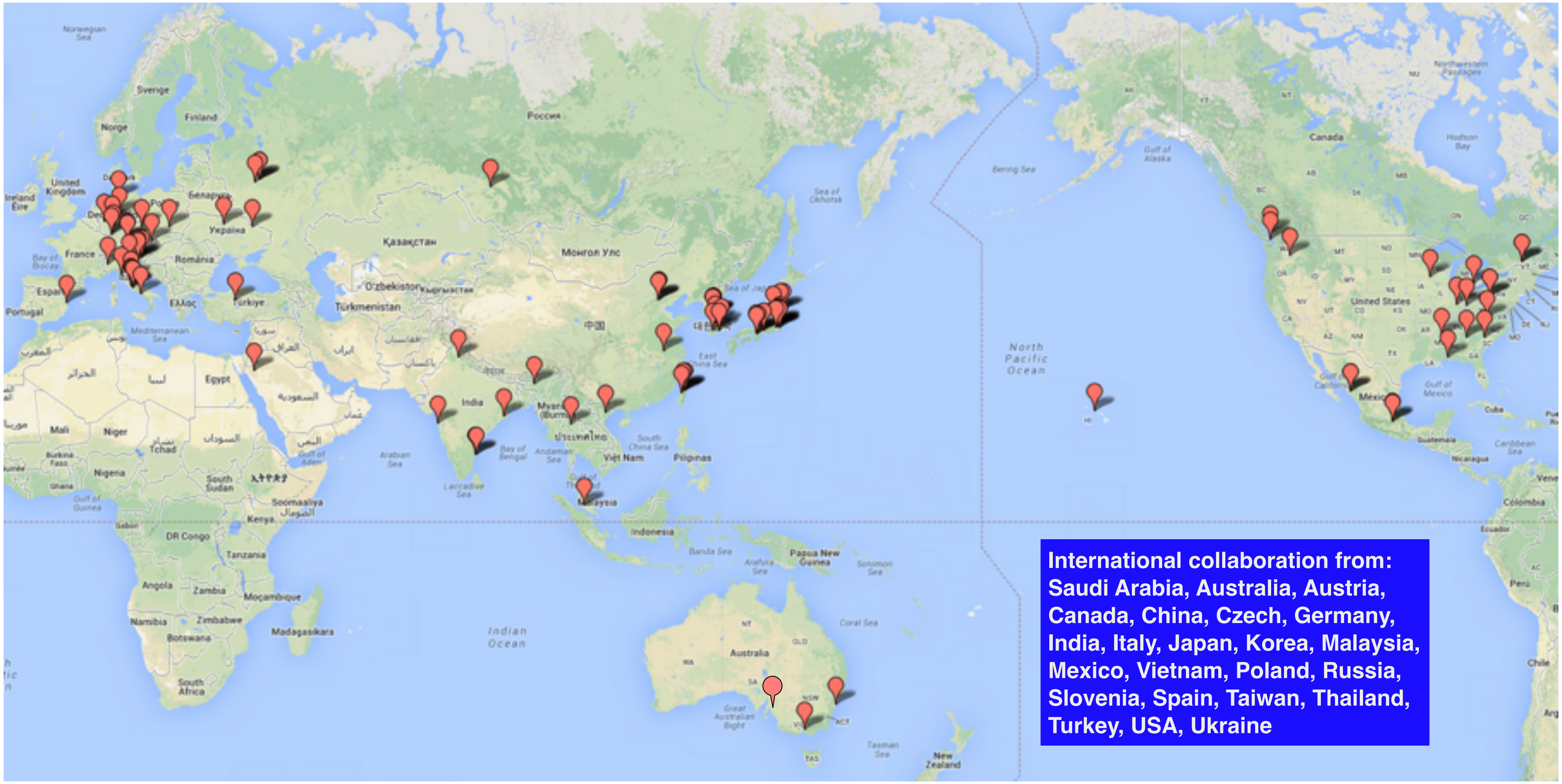


- Rich physics program at SuperKEKB/BelleII in preparation
  - Precision CKM
  - New sources of CPV
  - Lepton Flavour Violation
  - Dark Sectors
  - QCD exotics

- SuperKEKB commissioning starts 2016
- Belle II sub-detectors partially built, and DAQ integrated.
- Belle II first physics in 2017 (Phase2)—2018(Phase3)!

Backup

The Belle II Collaboration



International collaboration from:
Saudi Arabia, Australia, Austria, Canada, China, Czech, Germany, India, Italy, Japan, Korea, Malaysia, Mexico, Vietnam, Poland, Russia, Slovenia, Spain, Taiwan, Thailand, Turkey, USA, Ukraine

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

- **Belle II** experiment**@SuperKEKB** **(online in 2016)**
  [~650 collaborators, 99 institutions, 23 nations/regions]

Golden modes: B physics

SuperKEKB TDR (2014)

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012$ [64]	0.012	0.008
	α [°]	85 ± 4 (Belle+BaBar) [24]	2	1
	γ [°]	68 ± 14 [13]	6	1.5
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$ [19]	0.053	0.018
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$ [65]	0.028	0.011
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$ [17]	0.100	0.033
	$\mathcal{A}(B \to K^0 \pi^0)$	$-0.05 \pm 0.14 \pm 0.05$ [66]	0.07	0.04
UT sides	$\lvert V_{cb}\rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8]	1.2%	
	$\lvert V_{cb}\rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\rm ex.} \pm 2.7\%_{\rm th.})$ [10]	1.8%	1.4%
	$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$ [5]	3.4%	3.0%
	$\lvert V_{ub}\rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 8.2\%)$ [7]	4.7%	2.4%
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ [10^{-6}]	$96(1 \pm 27\%)$ [26]	10%	5%
	$\mathcal{B}(B \to \mu\nu)$ [10^{-6}]	< 1.7 [67]	20%	7%
	$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$ [29]†	5.6%	3.4%
	$R(B \to D^*\tau\nu)^\dagger$	$0.332(1 \pm 9.0\%)$ [29]†	3.2%	2.1%
	$\mathcal{B}(B \to K^{*+}\nu\overline{\nu})$ [10^{-6}]	< 40 [30]	< 15	30%
	$\mathcal{B}(B \to K^{+}\nu\overline{\nu})$ [10^{-6}]	< 55 [30]	< 21	30%
Rad. & EW penguins	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%
	$A_{CP}(B \to X_{s,d}\gamma)$ [10^{-2}]	$2.2 \pm 4.0 \pm 0.8$ [68]	1	0.5
	$S(B \to K^0_S \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$ [20]	0.11	0.035
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$ [21]	0.23	0.07
	C_7/C_9 ($B \to X_s\ell\ell$)	~20% [36]	10%	5%
	$\mathcal{B}(B_s \to \gamma\gamma)$ [10^{-6}]	< 8.7 [42]	0.3	–
	$\mathcal{B}(B_s \to \tau\tau)$ [10^{-3}]	–	< 2 [44]‡	–

Golden modes: D and Tau physics

SuperKEKB TDR (2014)

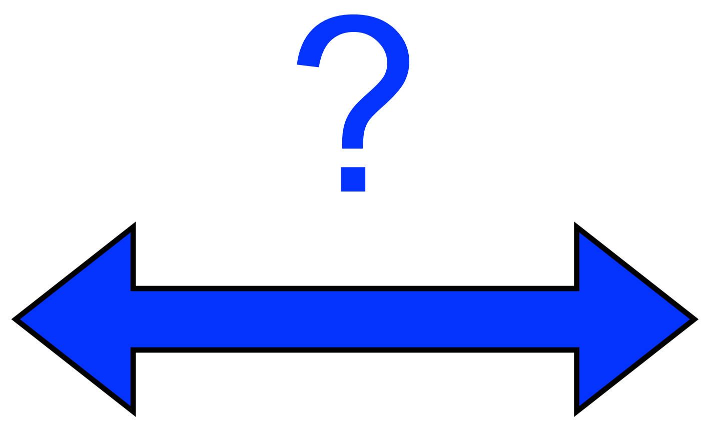
	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$ [46]	2.9%	0.9%
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$ [46]	3.5%	2.3%
	$\mathcal{B}(D^0 \to \gamma\gamma)$ [10^{-6}]	< 1.5 [49]	30%	25%
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ [10^{-2}]	$-0.32 \pm 0.21 \pm 0.09$ [69]	0.11	0.06
	$A_{CP}(D^0 \to \pi^0\pi^0)$ [10^{-2}]	$-0.03 \pm 0.64 \pm 0.10$ [70]	0.29	0.09
	$A_{CP}(D^0 \to K_S^0\pi^0)$ [10^{-2}]	$-0.21 \pm 0.16 \pm 0.09$ [70]	0.08	0.03
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$ [52]	0.14	0.11
	$y(D^0 \to K_S^0\pi^+\pi^-)$ [10^{-2}]	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$ [52]	0.08	0.05
	$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$ [52]	0.10	0.07
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ [°]	$-6 \pm 11 \pm {}^{4}_{5}$ [52]	6	4
Tau	$\tau \to \mu\gamma$ [10^{-9}]	< 45 [71]	< 14.7	< 4.7
	$\tau \to e\gamma$ [10^{-9}]	< 120 [71]	< 39	< 12
	$\tau \to \mu\mu\mu$ [10^{-9}]	< 21.0 [72]	< 3.0	< 0.3

Dark Sector

Dark matter suggests the presence of a dark sector, neutral under all Standard Model forces (i.e. non-WIMP)

Standard Model

$g \quad W^{\pm}, Z \quad \gamma$



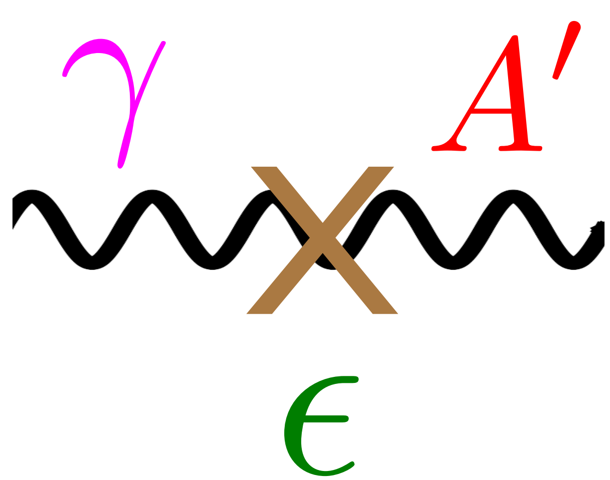
Dark Sector

forces + particles
dark matter?

Known Forces

strong, weak, EM

One way: Dark Photons.



$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

"Kinetic Mixing"

Holdom
Galison, Manohar

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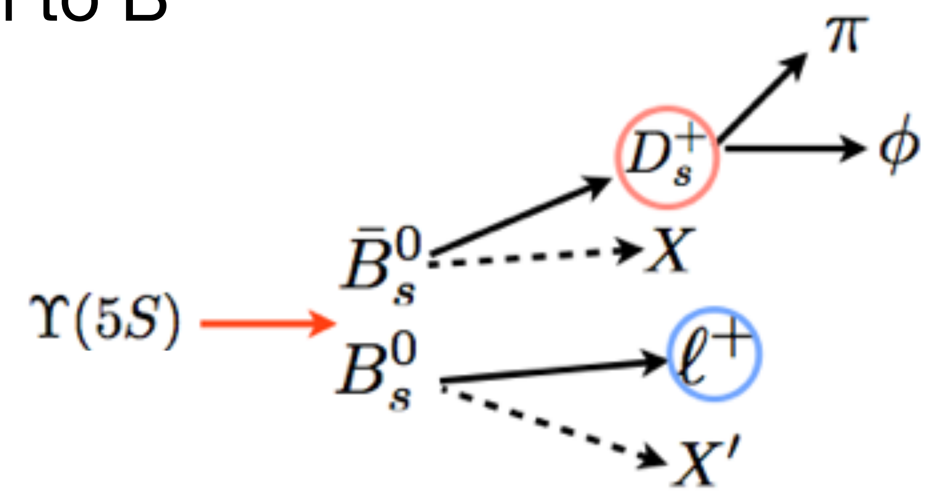
Absolute normalisation: B_s

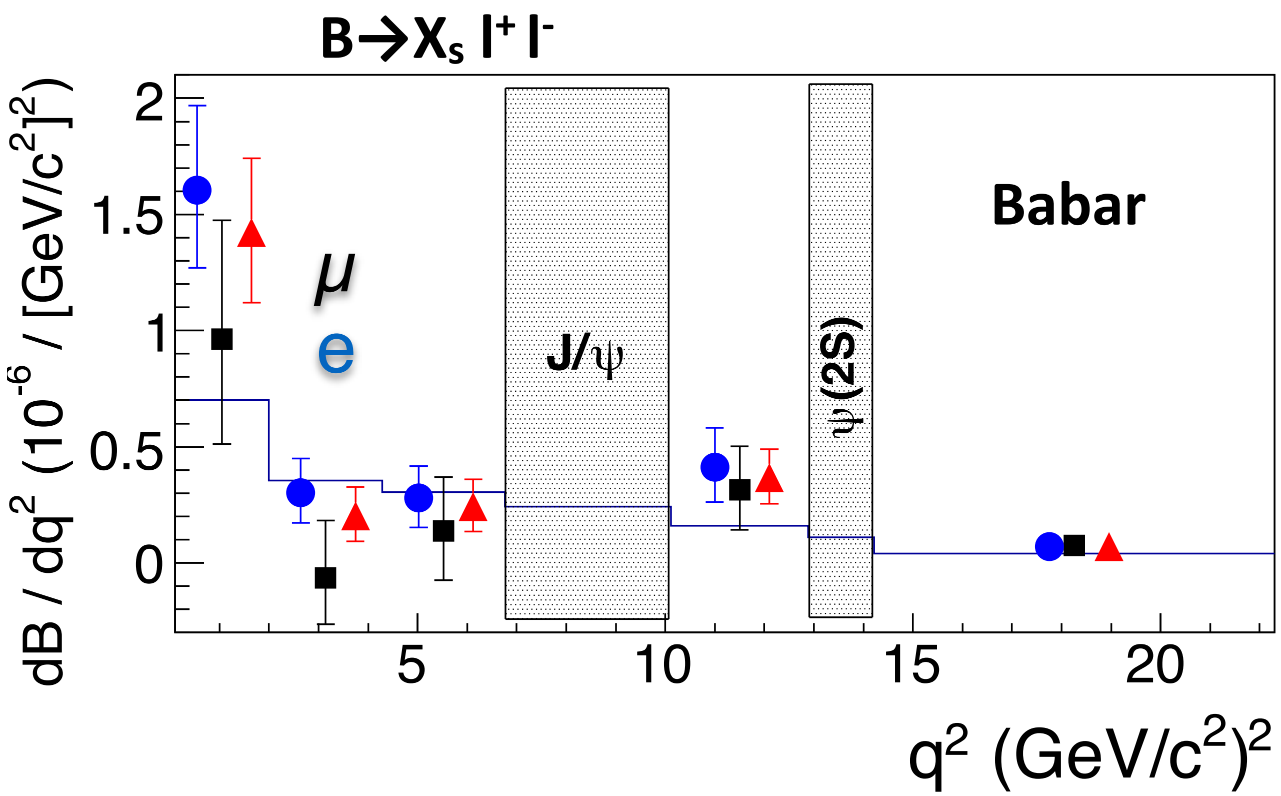
- **5 ab^{-1}** B_s SL or Full recon. @ Υ(5S) similar precision to B^0 studies / **325 fb^{-1}** of Υ(4S)
- f_s will be well measured: WA=**15%** → O(1)**%**
- SU(3) Symmetry heavily relied upon at LHC, e.g. in $B_s \to \mu\mu$ normalisation, needs to be rigorously tested.

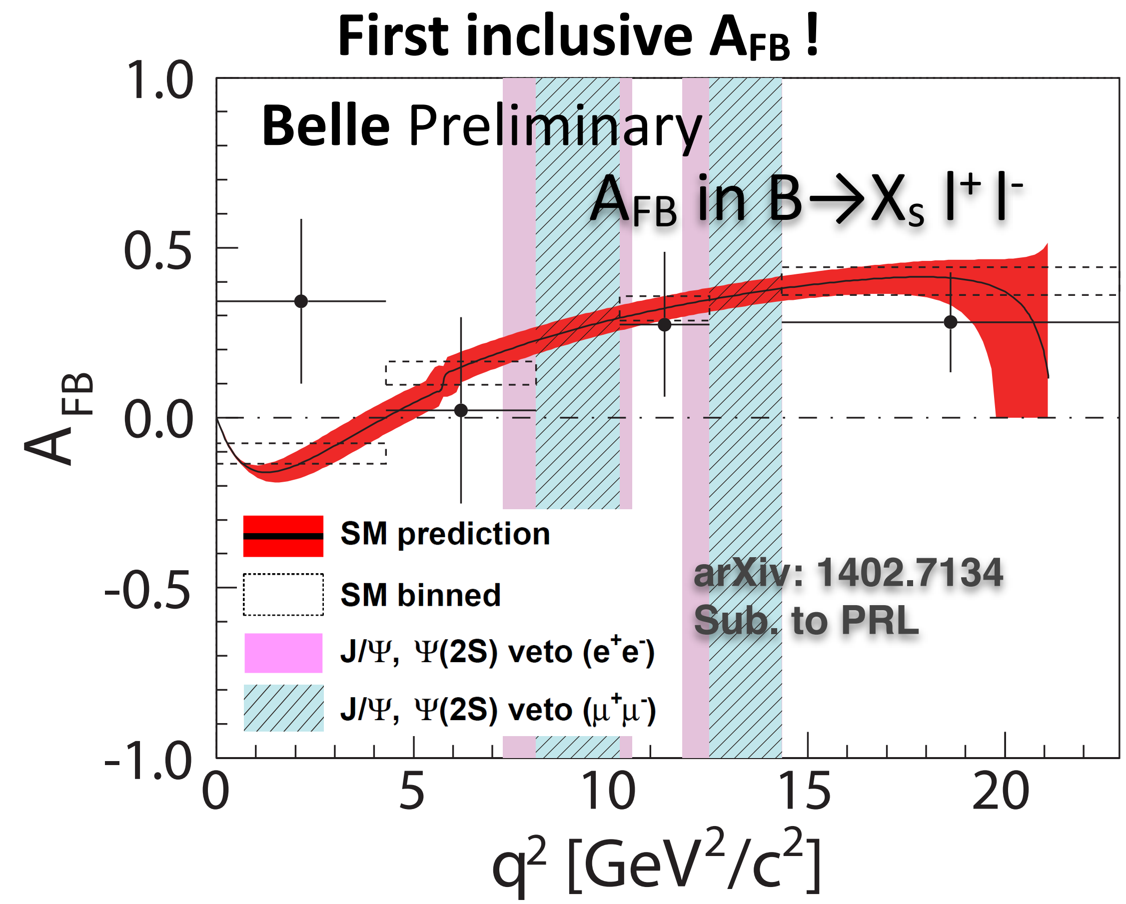


Tag Method	Tag Eff.	NB_s/NB	B_s Yields 121/fb	B_s Yields 5/ab
Untagged	2.000	$f_s/f_{d,u} \simeq 0.25$	1.4E+07	**6.0E+08**
Lepton tag	0.100	$f_s/f_{d,u} \simeq 0.25$	7.0E+05	**3.0E+07**
D_s:Φπ,K_SK,K^*K	0.040	$10 \cdot f_s/f_{d,u}$	2.8E+05	**1.2E+07**
B_s Full Recon.	0.004	$\gg 10$	2.8E+04	**1.2E+06**

Leptonic EWP

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





Inclusive B→X_s {ee,μμ}

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

Exclusive B→{K*,K} {e e, μ μ}

- Lepton Universality.
- Photon Polarisation (low q^2).
- **TDCPV - $B_d \to K^*(K_S\pi^0)l+l-$** arXiv: 1502.05509

→ Third generation

- **B→Kττ** <3×10^{-4} in 50/ab
- **B_s→ττ** <2×10^{-3} in 5/ab @ Υ(5S)