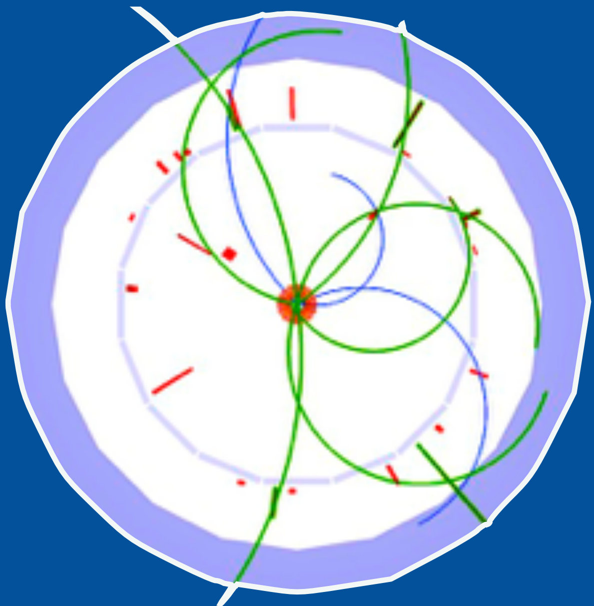


CP Violation in B-Physics: SM & Beyond

Key results from 2014-2016
+ Belle II and LHCb upgrade prospects

https://www.facebook.com/belle2collab
https://twitter.com/belle2collab

Phillip Urquijo
The Uni. of Melbourne

MIAPP Workshop
June 2016

BELLE

Belle II

THE UNIVERSITY OF MELBOURNE

HFAG
Prel. Winter 2016

CKM fitter
EPS 15

Australian Government
Australian Research Council

CKM

CKM theory is highly predictive

large range of phenomena (particularly in B-physics), predicted by only 4 independent parameters relating the 9 CKM elements + G_F + m_q +QCD

CKM matrix is hierarchical

flavour sector of SM not necessarily replicated in any extended theories

CKM mechanism introduces CP violation

Only source of CPV in SM (m_ν=0)

$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

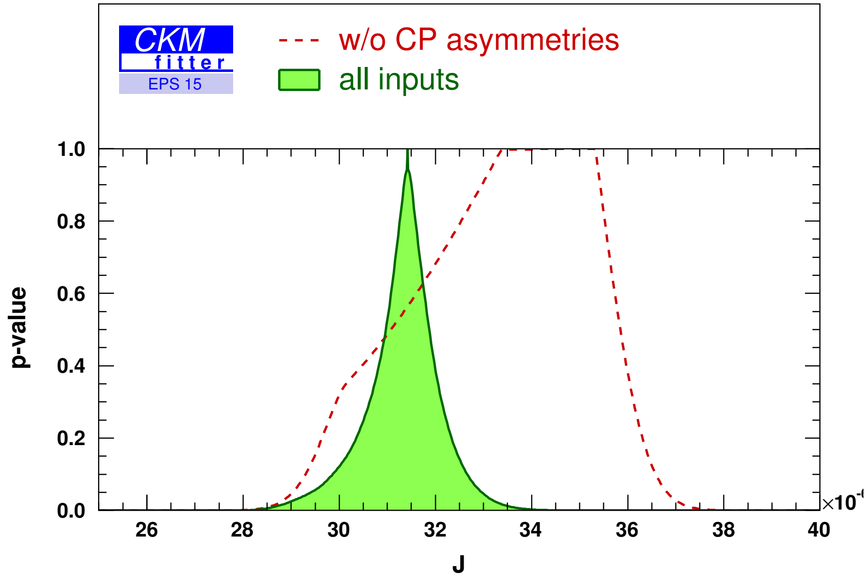
Jarlskog Invariant

- In the SM, CP violation expressed as the Jarlskog invariant (Δ~2%)

$$
\begin{aligned}
F_u F_d J &\neq 0 \\
F_u &= (m_u^2 - m_c^2)(m_c^2 - m_t^2)(m_t^2 - m_u^2) \\
F_d &= (m_d^2 - m_s^2)(m_s^2 - m_b^2)(m_b^2 - m_d^2) \\
\mathrm{Im}(V_{ij} V_{kl} V_{il}^* V_{kj}^*) &= J \sum_{m,n=1}^{3} \varepsilon_{ikm} \varepsilon_{jln} \\
J &= c_{12} c_{23} c_{13}^2 s_{12} s_{23} s_{13} \sin\delta
\end{aligned}
$$

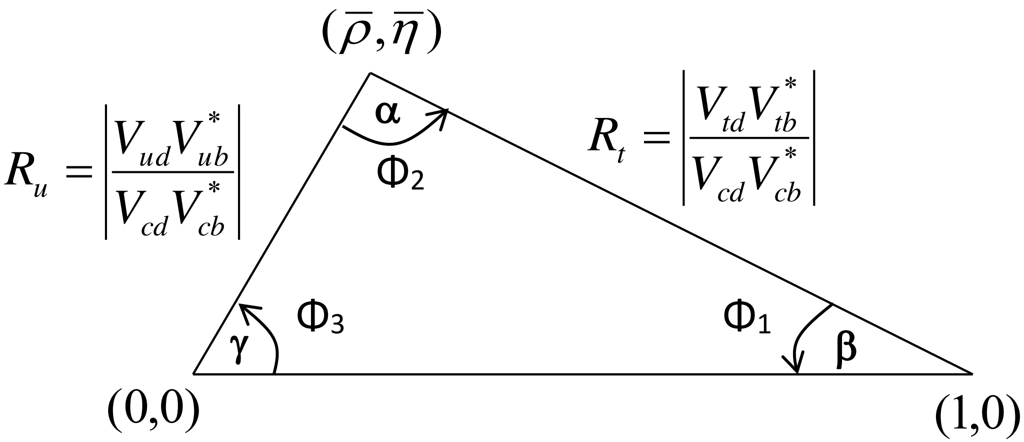
- 3 gen. mixing and CPV phase (δ) necessary for CP violation.

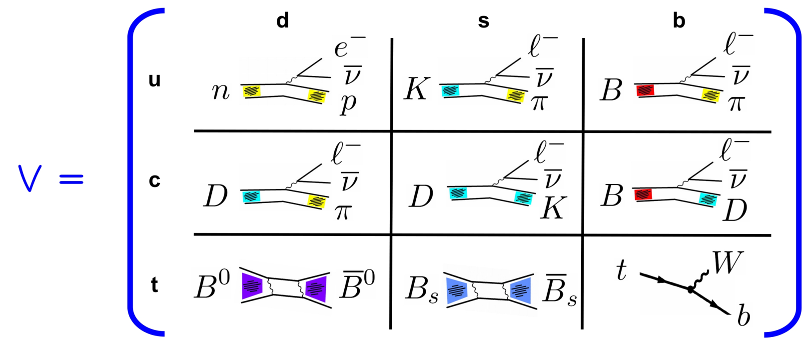
- Feature of SM: J can be predicted from CP conserving quantities



Unitarity Triangle Test

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





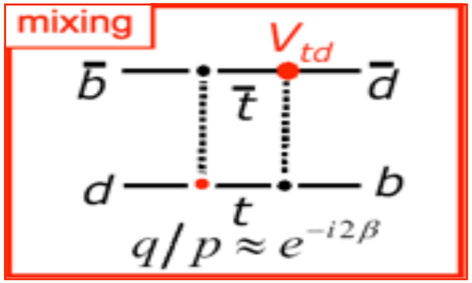
$B \to \pi\pi, \rho\rho$	α/Φ_2	$B \to D\, l\, \nu$ / $b \to c\, l\, \nu$	$\lvert V_{cb}\rvert$ via Form factor / OPE
$B \to D^{(*)} K^{(*)}$	γ/Φ_3	$B \to \pi\, l\, \nu$ / $b \to u\, l\, \nu$	$\lvert V_{ub}\rvert$ via Form factor / OPE
$B \to J/\psi\, K_s$	β/Φ_1	$M \to l\, \nu\, (\gamma)$	$\lvert V_{UD}\rvert$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

Classification of CP-violating Effects

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle, \quad |B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

- Condition for CP conservation

$$|\langle f_{\rm CP}|H|P^0(t)\rangle|^2 = |\langle f_{\rm CP}|H|\bar{P}^0(t)\rangle|^2$$



1. CP violation in the decay **(direct CP violation)**

$$\Gamma(P \to f) \neq \Gamma(\bar{P} \to \bar{f}) \Leftrightarrow \left|\frac{\bar{A}_{\bar{f}}}{A_f}\right| \neq 1$$

2. CP violation in mixing **(indirect CP violation)**

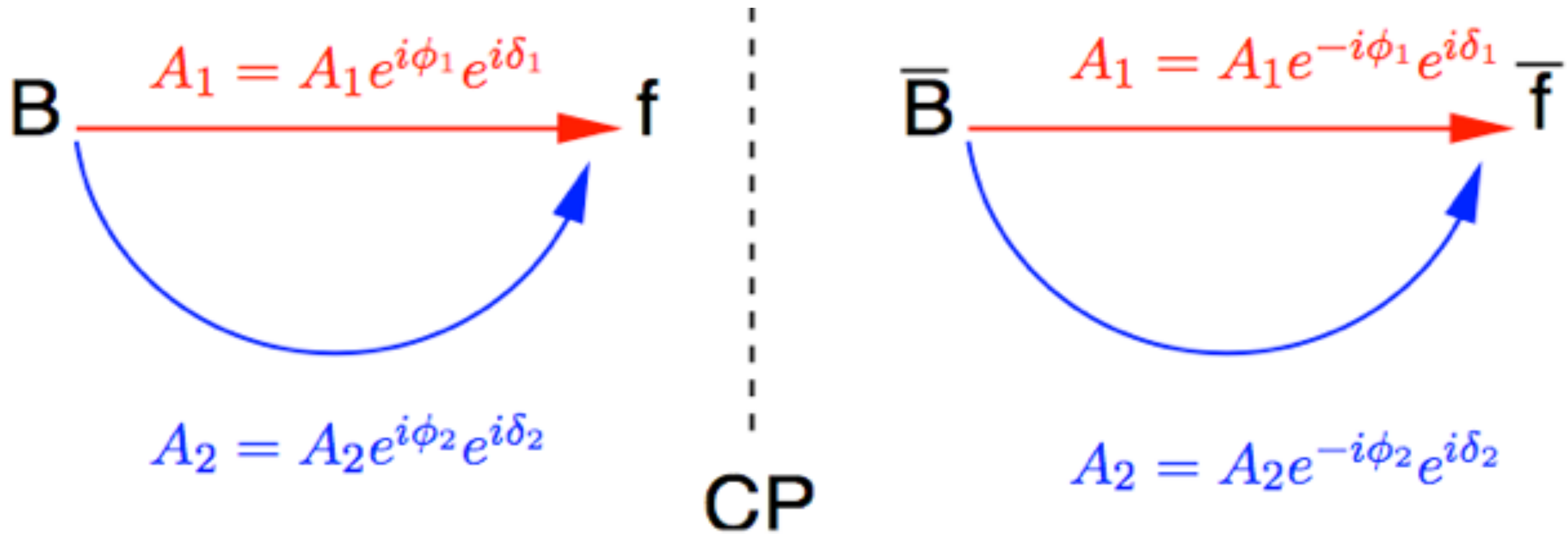
$$\Gamma(P^0 \to \bar{P}^0) \neq \Gamma(\bar{P}^0 \to P^0) \Leftrightarrow \left|\frac{q}{p}\right| \neq 1$$

3. CP violation in mixing/decay **interference**

$$\Gamma(P^0(\rightsquigarrow \bar{P}^0) \to f)(t) \neq \Gamma(\bar{P}^0(\rightsquigarrow P^0) \to f)(t)$$

Observing CPV

Basic idea: two interfering amplitudes that involve the CKM parameter η.



$$|A|^2 = A_1^2 + A_2^2 + 2A_1A_2\cos(\Delta\phi + \Delta\delta)$$

$$|A|^2 = A_1^2 + A_2^2 + 2A_1A_2\cos(-\Delta\phi + \Delta\delta)$$

For CPV A_1 and A_2 need to have **different weak phases Φ** and different **CP invariant (e.g. strong) phases δ**

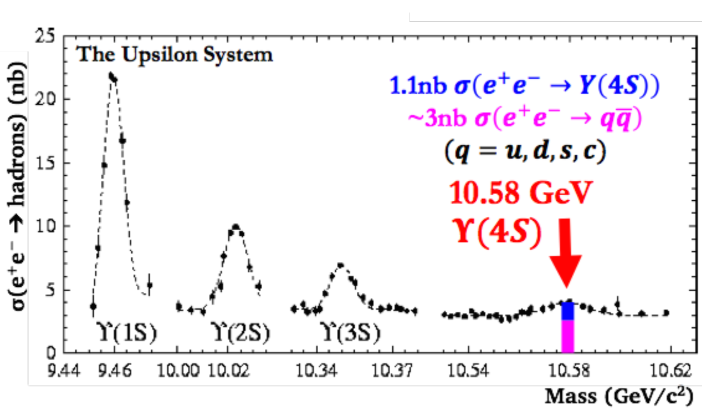
Testing models through CP violation

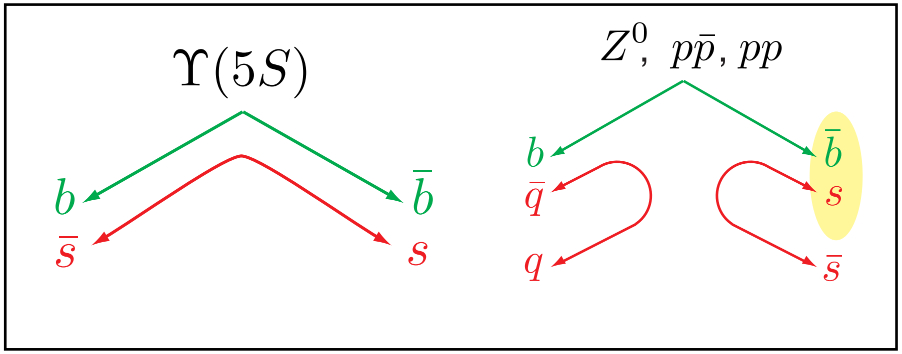
- Accuracy of ***predictions*** of CP asymmetries in the quark sector depend on the possibility to get rid of hadronic effects, or to compute them.

***	Φ_3	exact at LO of weak int.
***	$A^{SL}(d,s)$, $A(b \to s+d\ \gamma)$	SM vanishingly small
**	Φ_1, Φ_s	Penguins contribute
*	ε_K, B direct CP, Φ_2	Non-trivial had input
*/?	ε'/ε, rare B, D system	Requires more progress

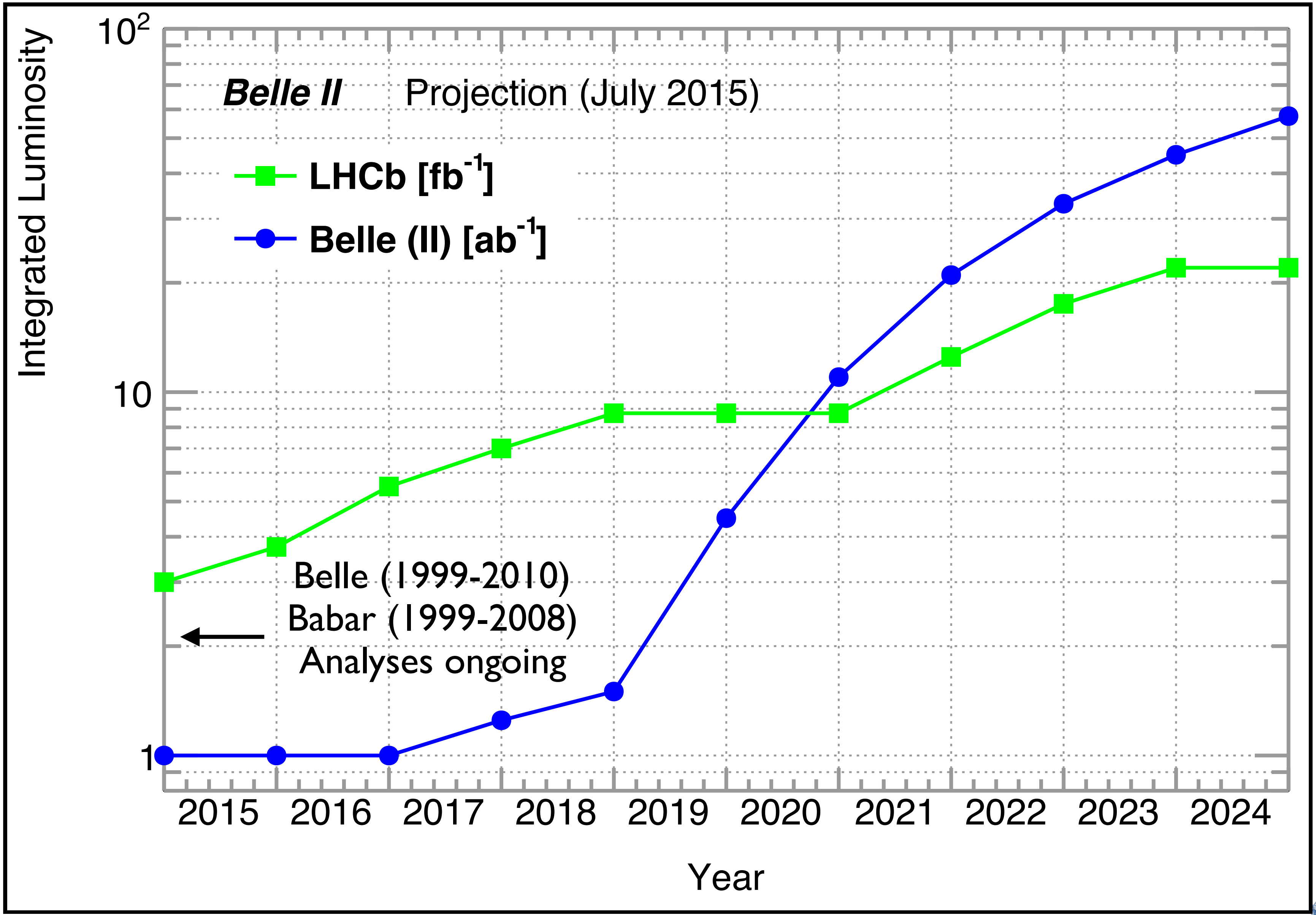
B Production (See C. Kiesling's talk on Belle II)

	e+e- (PEPII, KEKB)	e+e- (Super KEKB)	pp→b anti-bX ($\sqrt{s}$=13TeV) LHC
Prod. σbb	1 nb		~500μb
typ. bb rate	10 Hz	400Hz	~500kHz
Total yield of B anti-B pairs	**450 10^6 Babar** **770 10^6 Belle**	**50 10^9 Belle II**	10^{13} (3 fb^{-1} @ LHCb)
purity	~25%		~0.6%
pile-up	0		0.5→25
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
event structure	BB pair alone, hermetic detector		Many particles not associated to b, non hermetic detector
B^0 anti-B^0 mixing	coherent		incoherent→flavour tagging dilution

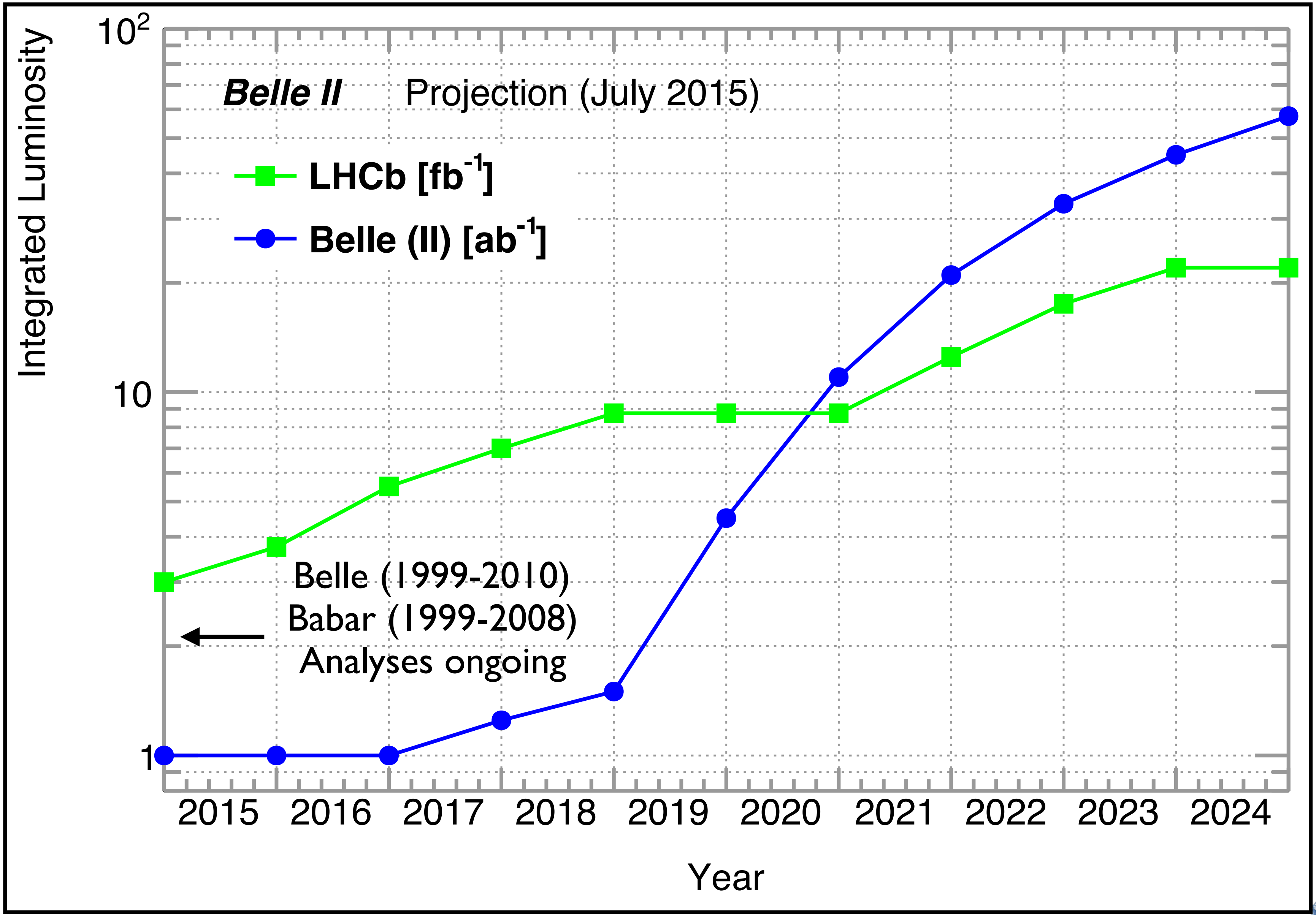




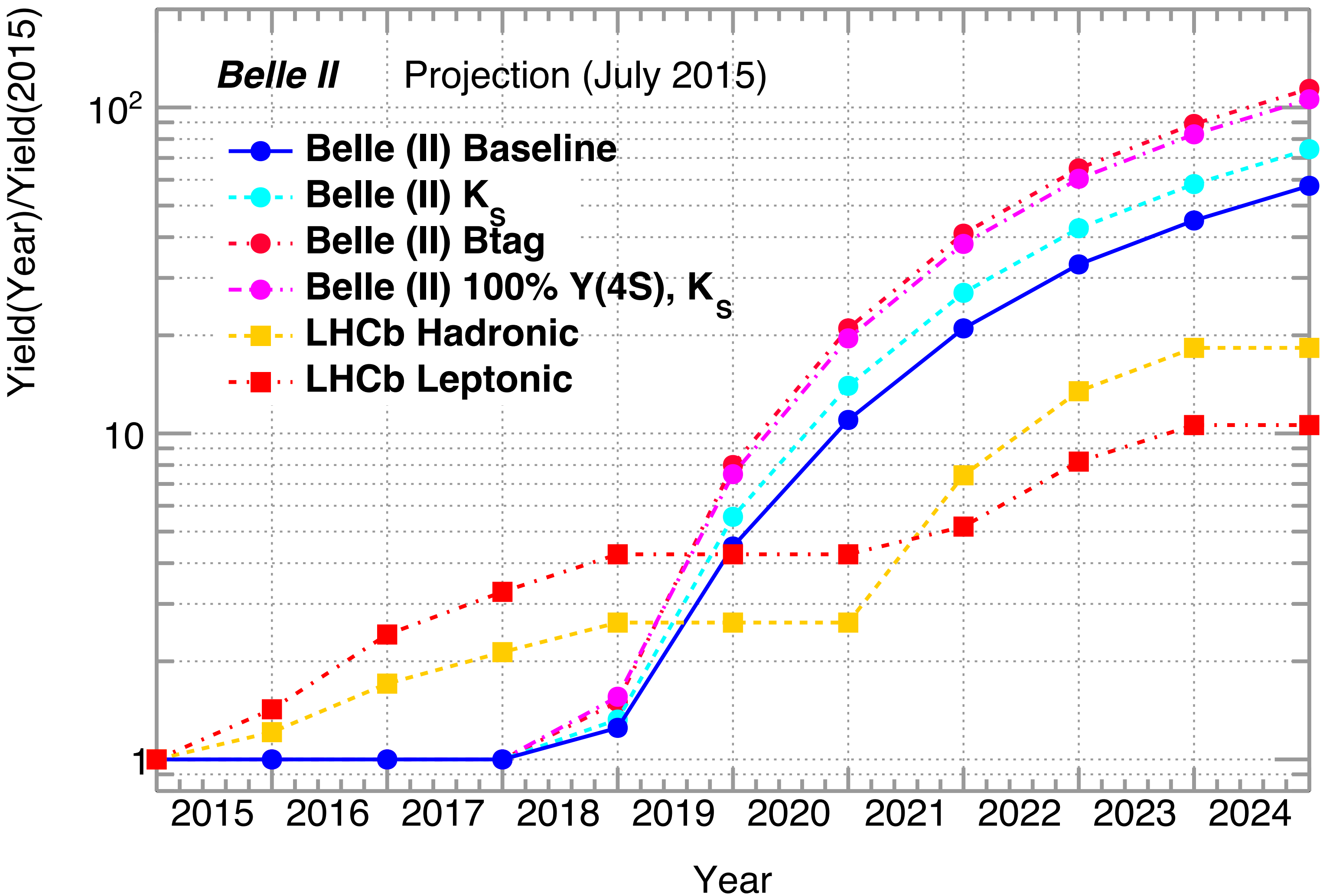
LHCb Vs Belle II



LHCb Vs Belle II



LHCb Vs Belle II



Topics

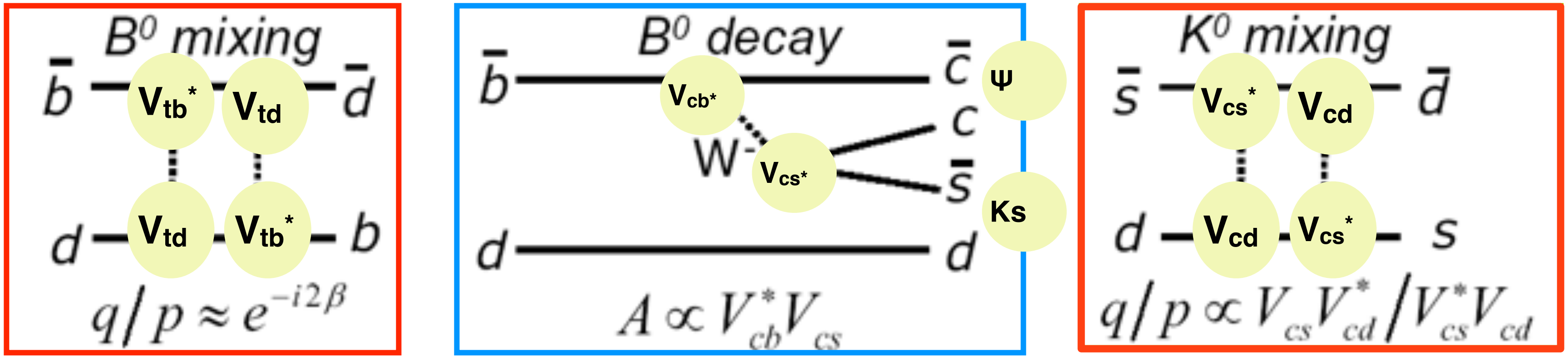
- Time Dependent CP Violation
- Direct CP Violation
- CP Violation in mixing
- UT Precision Tests
- Areas to watch

Time Dependent CP Violation

Measurement of angle Φ_1 using CP eigenstates

CP violation in interference between **decay** w/ and w/o **mixing**

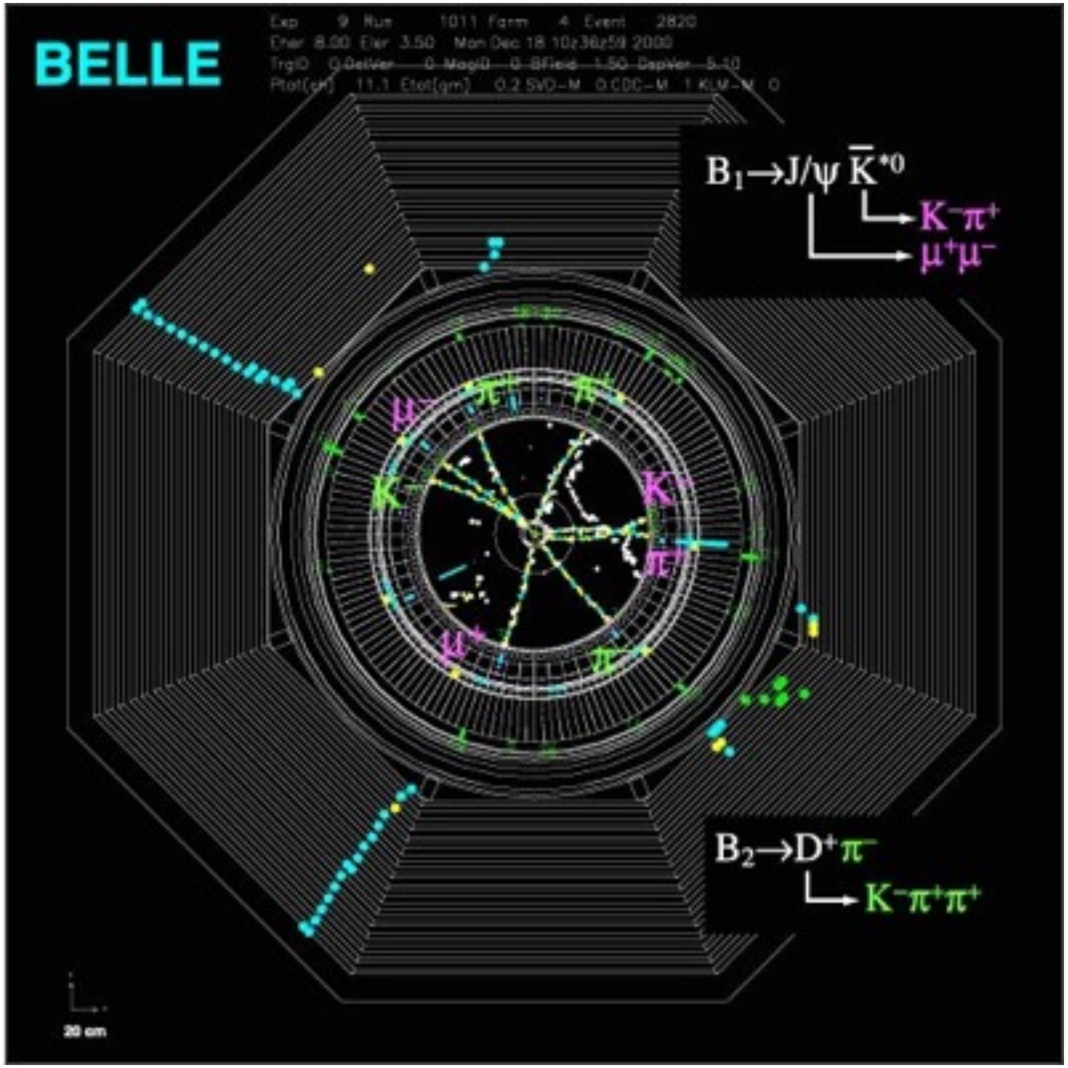
The "Golden Decay": $B^0 \rightarrow J/\Psi\, K^0$

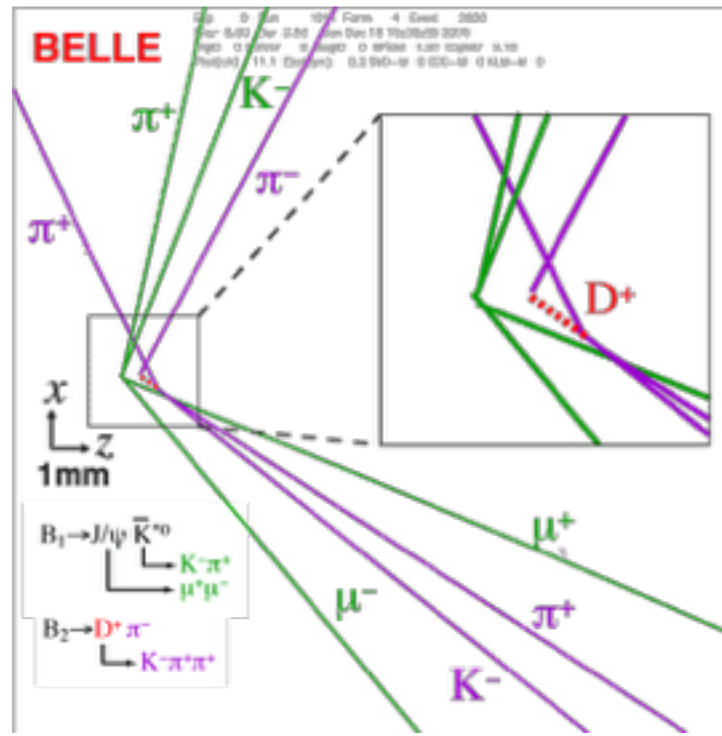


decay **decay + mixing**

$$\arg(V_{cs}V_{cb}^*) - \arg(V_{td}^2 V_{tb}^2 V_{cb} V_{cs}^* V_{cs}^2 V_{cd}^{*2}) = -2\Phi_1$$

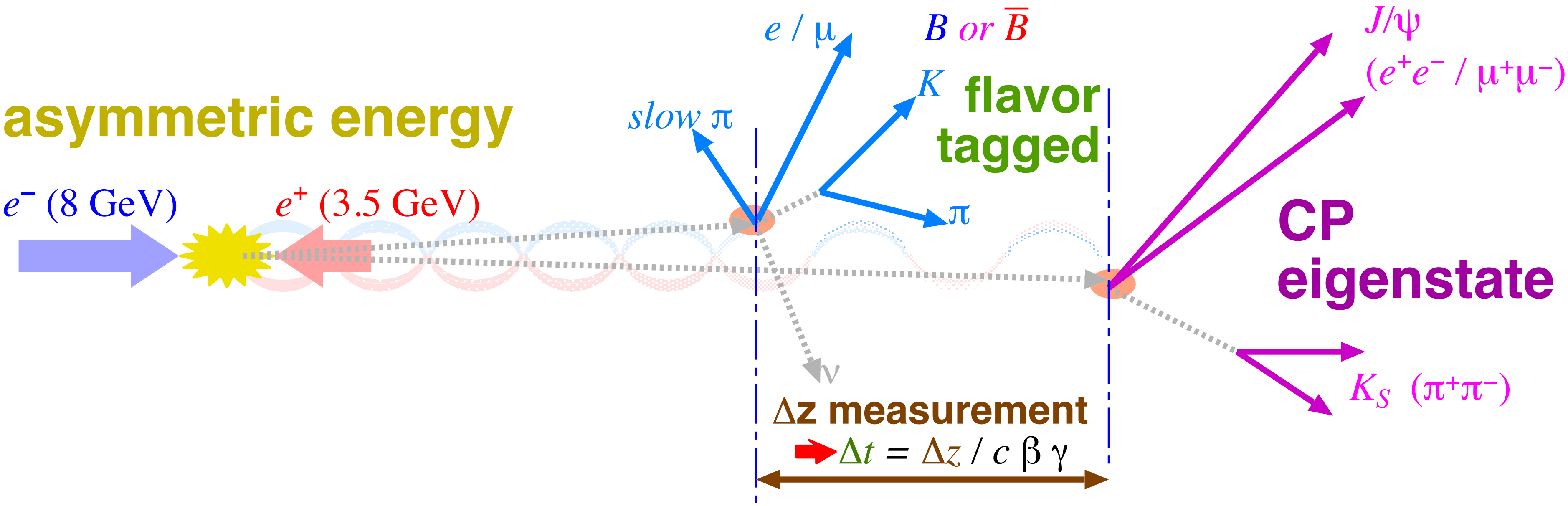
Example of a Fully-reconstructed Event



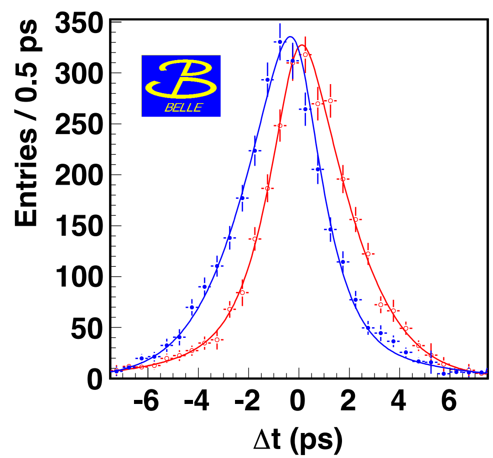


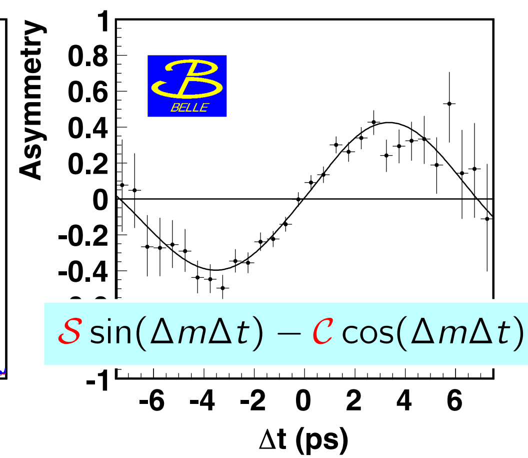
Belle (II) / Babar TDCPV

Belle PRL 108, 171802 (2012)
Babar PRD 79, 072009 (2009)

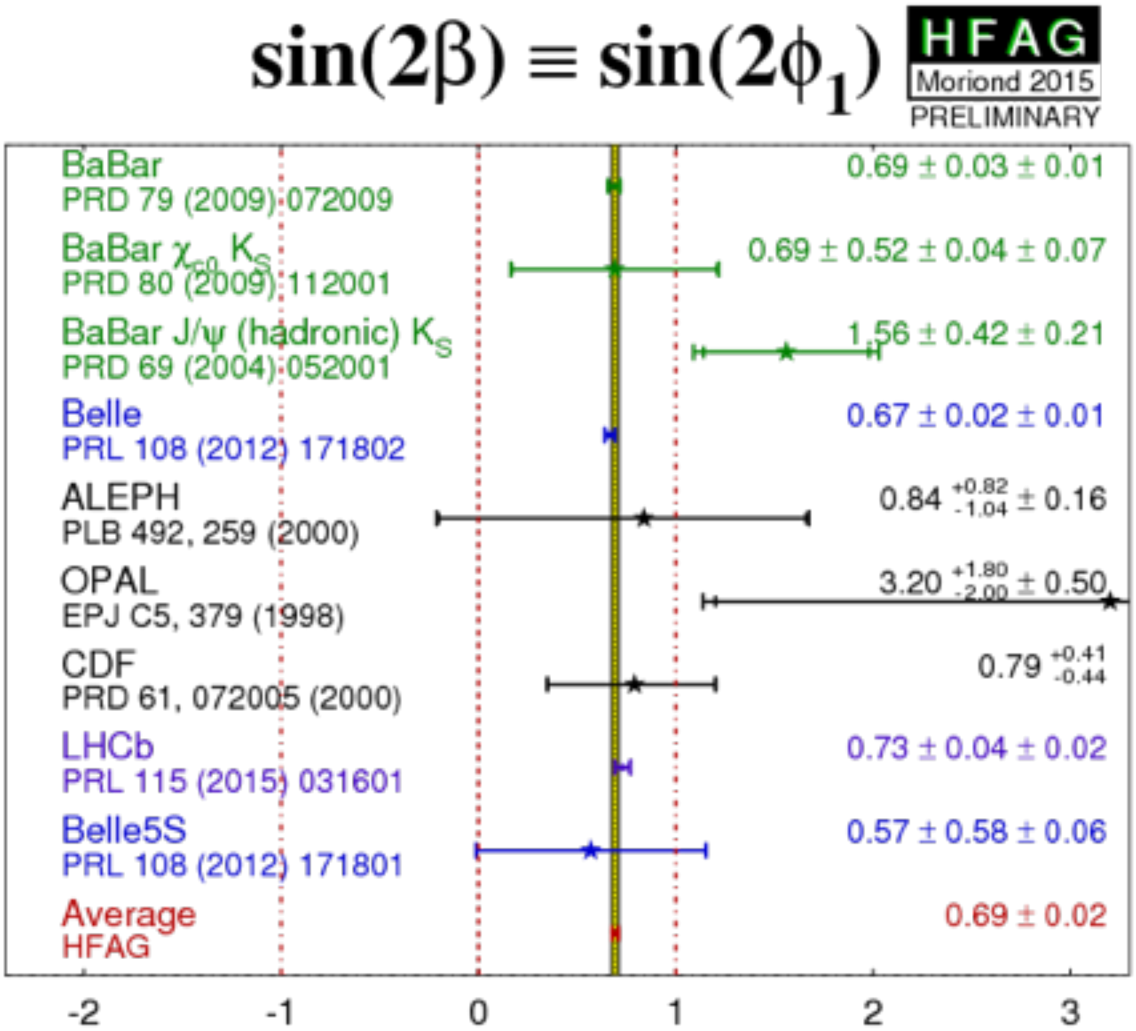


- $B^0 \rightarrow J/\psi\ K_S$
- flavour tag ε~30%
- σ(Δz)~100μm in Belle
- σ(Δz)~60μm in Belle II

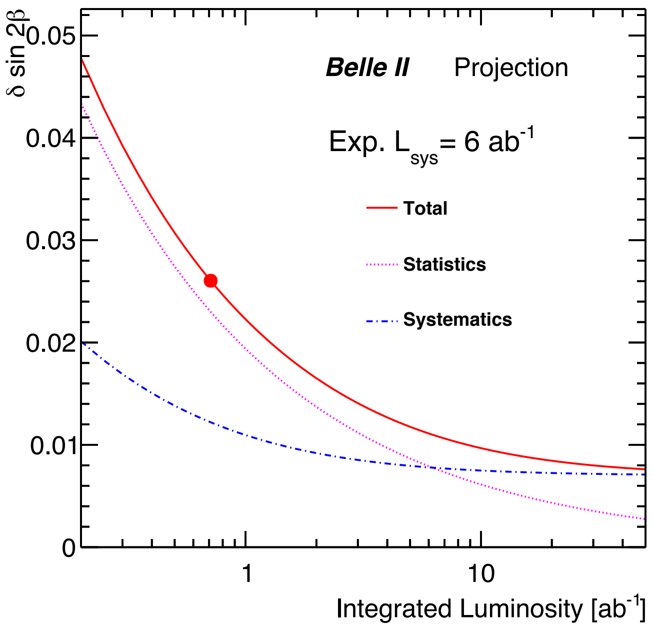




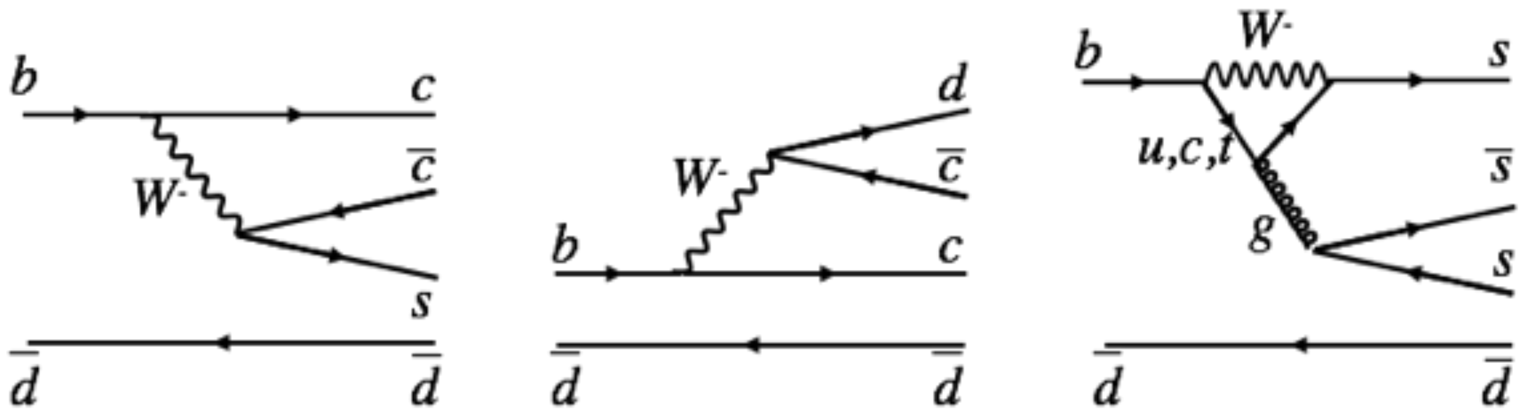
sin $2\Phi_1$



- Penguin contamination enters at ~1% - can be controlled with data.



Looking for new physics in Time Dep. CPV



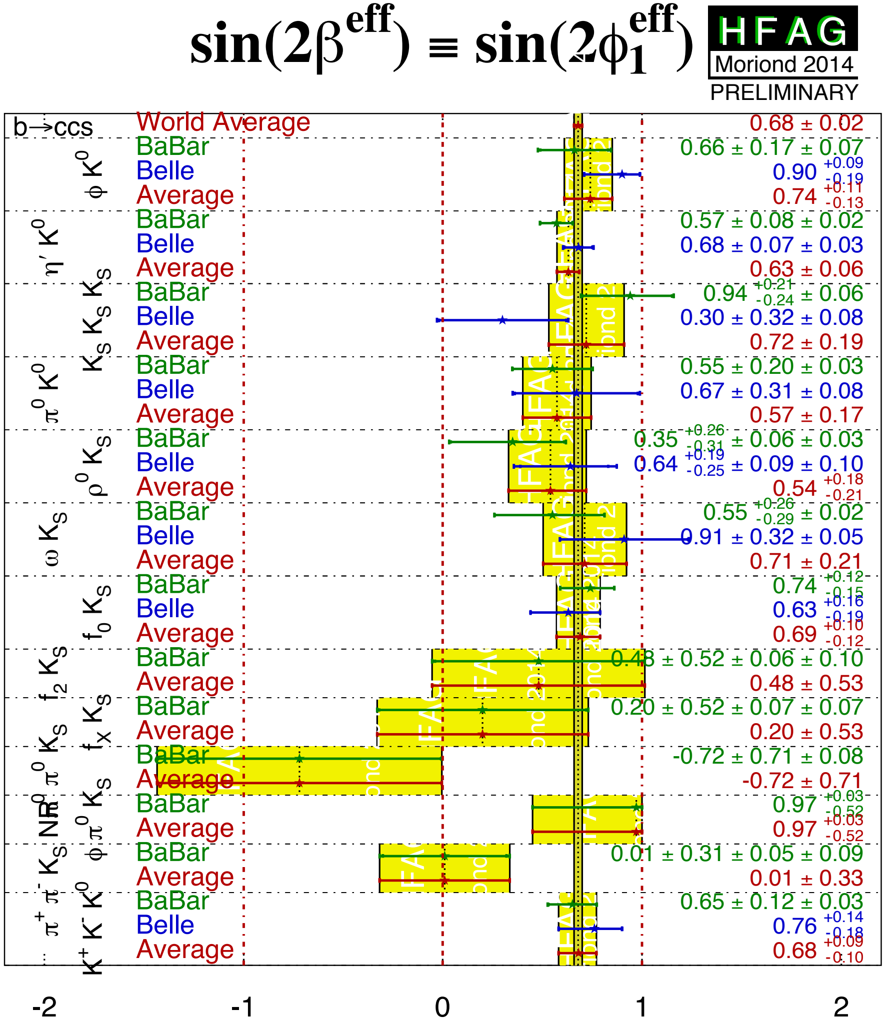
$J/\psi K^0_S, \psi(2S)K^0_S, \chi_{c1}K^0_S,$ $\eta_c K^0_S, J/\psi K^0_L,$ $J/\psi K^{*0}(K^{*0} \to K^0_S\pi^0)$	$D^{*+}D^-, D^+D^-$ $J/\psi\pi^0, D^{*+}D^{*-}$	$\phi K^0, K^+K^-K^0_S,$ $K^0_S K^0_S K^0_S, \eta' K^0, K^0_S\pi^0,$ $\omega K^0_S, f_0(980)K^0_S$

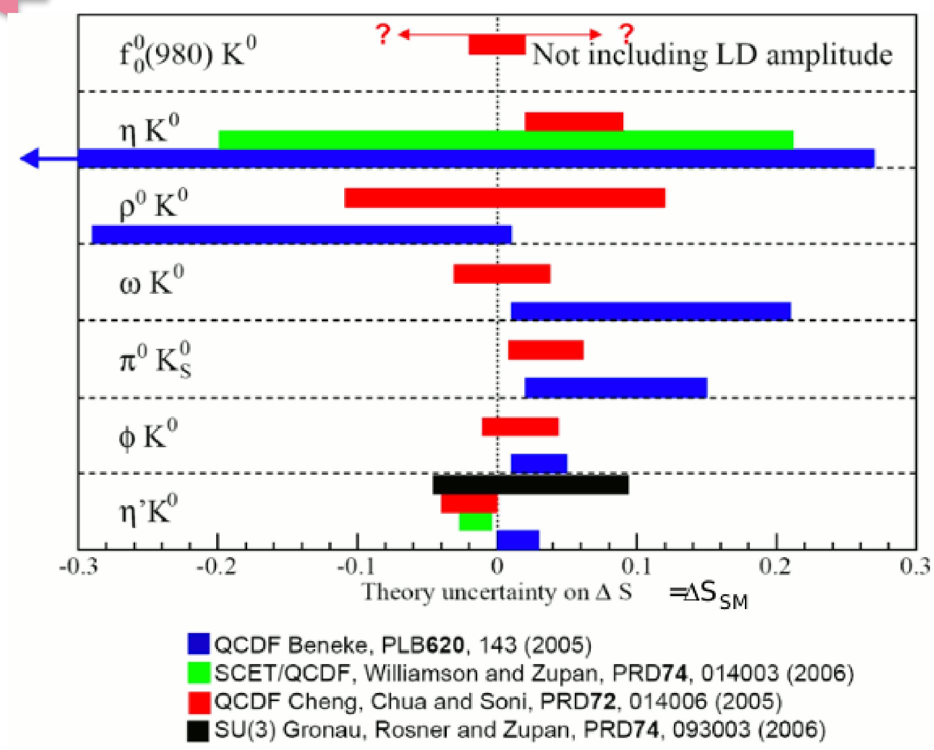
← Increasing Tree diagram amplitude

Increasing NP sensitivity →

Penguin sin 2Φ1

Belle, B → η' K0, JHEP 10 (2014) 165
Belle, B → ω Ks0, PRD 90 012002 (2014)

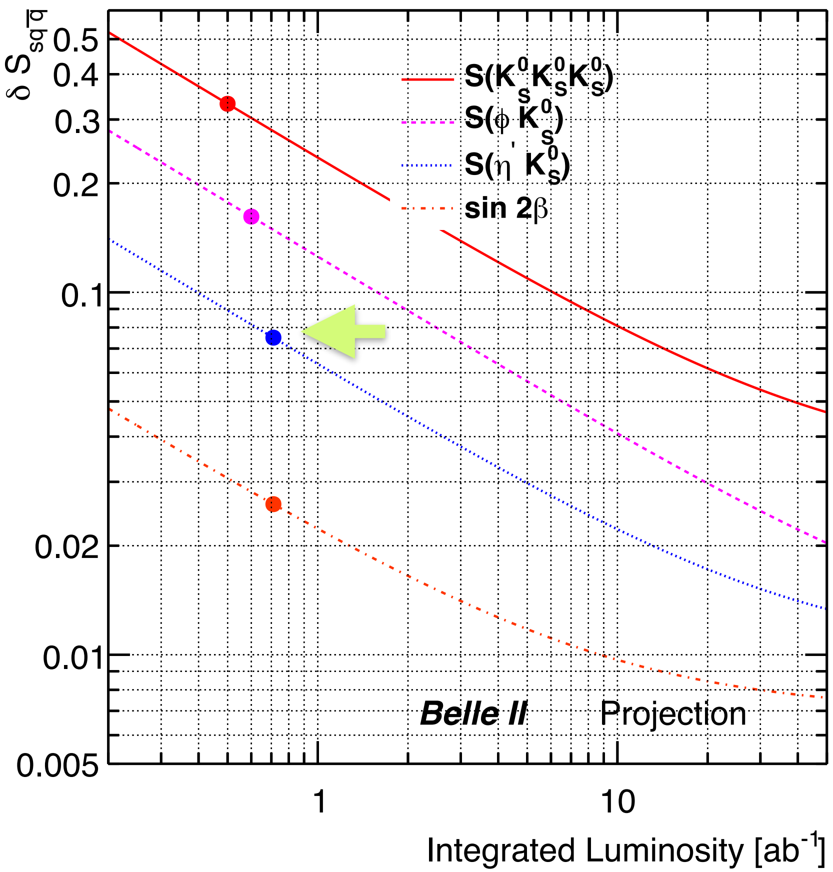


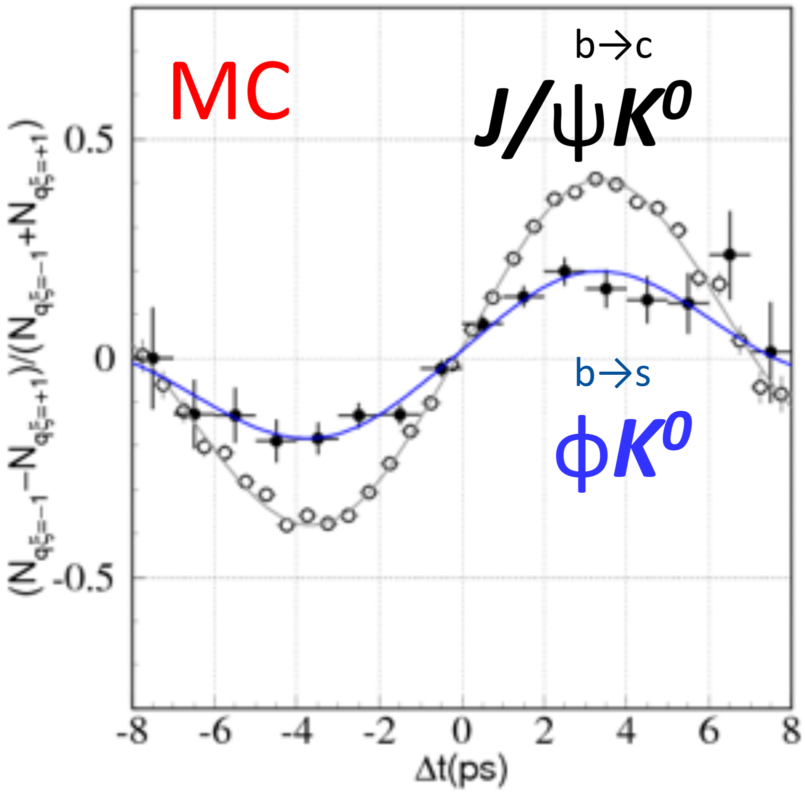


Penguin Φ_1 : Future

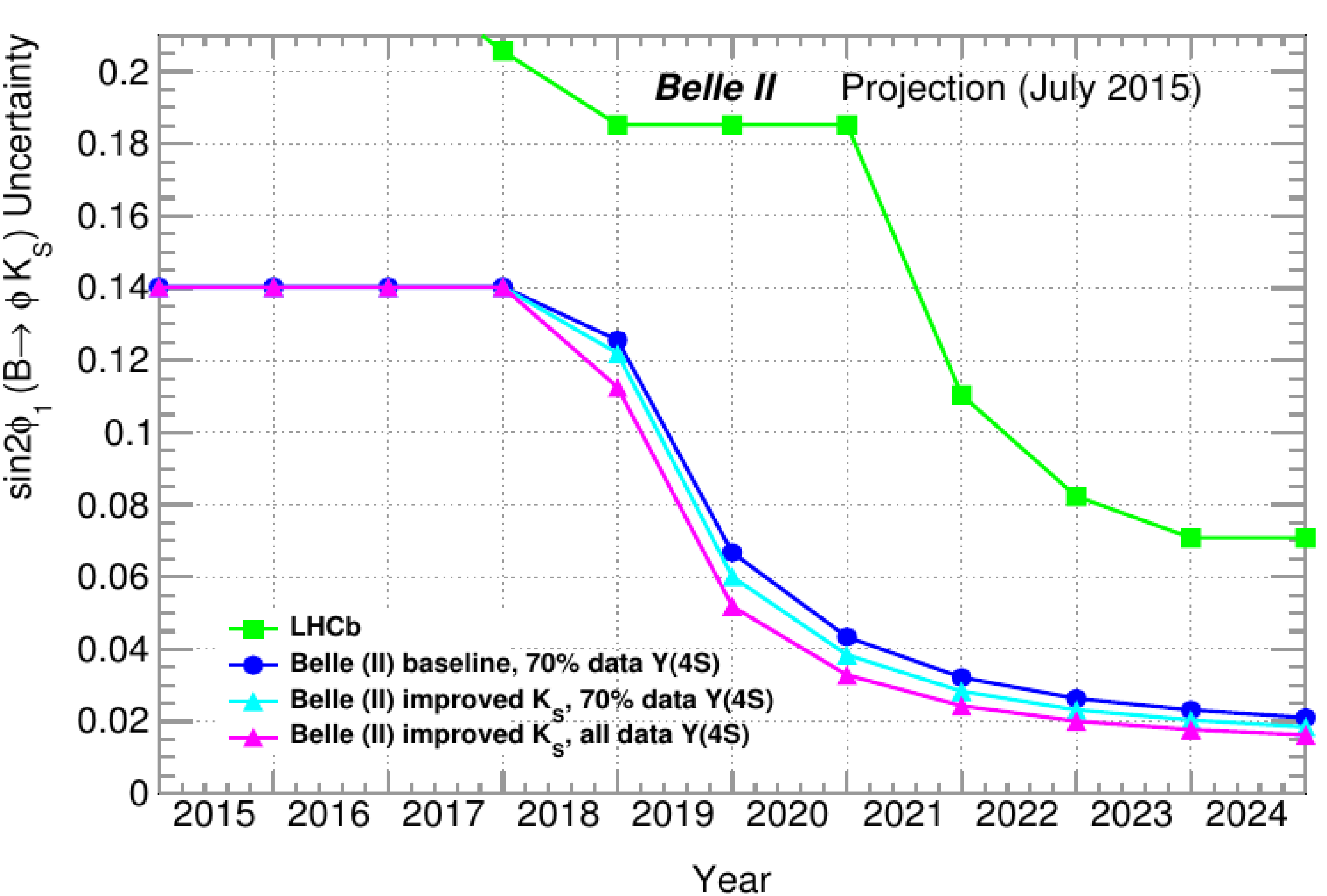
Belle II should do better on penguin Φ_1.
Systematics dominated by vertex resolution:
σ(z) on Vertex: Belle~61μm ⇣ Belle II~18μm

Prospect: $\delta S(b \to s) \sim 0.012$ @ 50 ab^{-1}





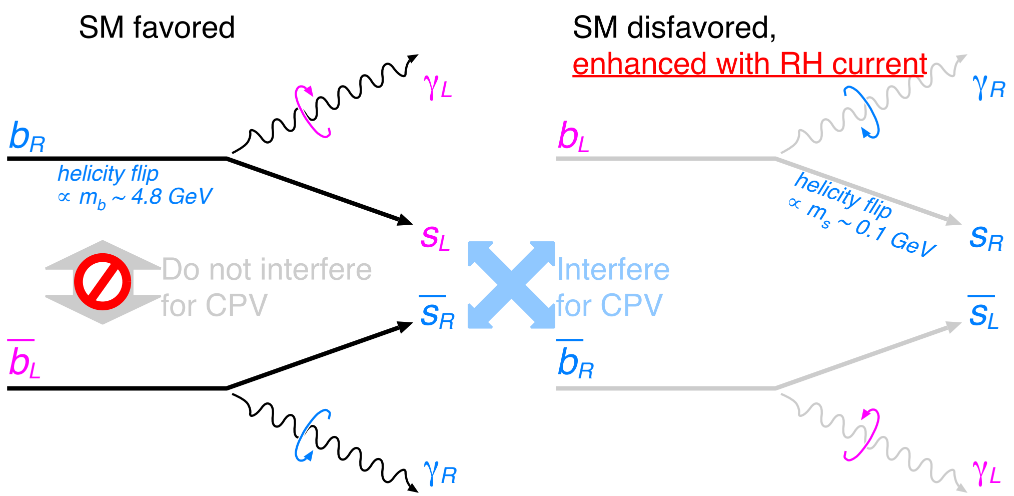
Penguin Φ_1 : Future



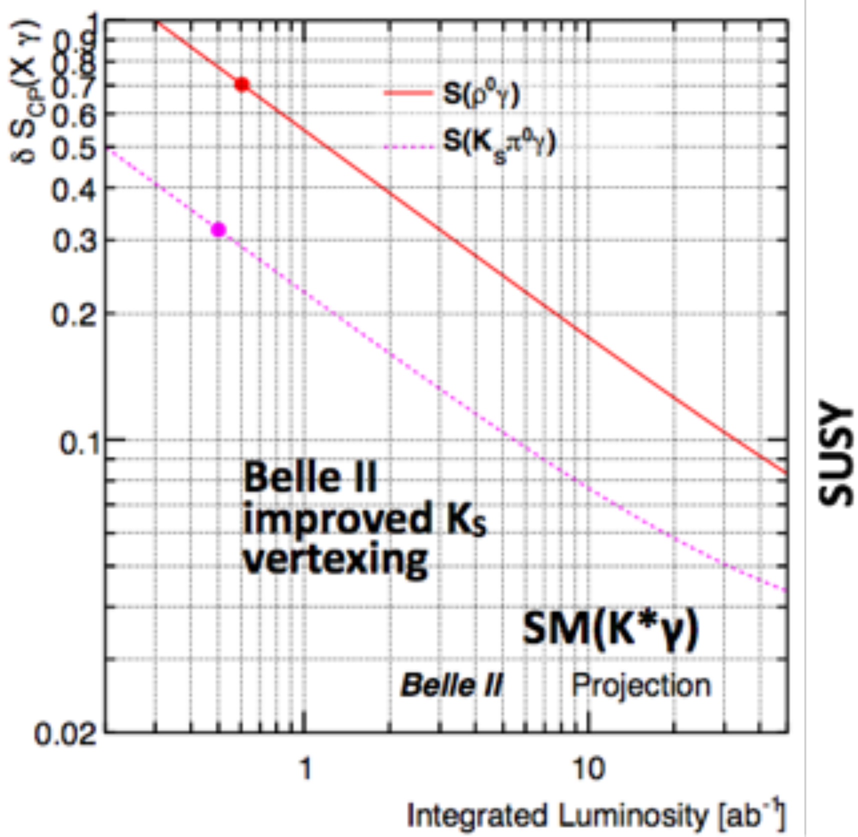
Φ_1 from Radiative Penguin Modes

- SM EW purely L-handed.
- Right-handed current is a signature of NP

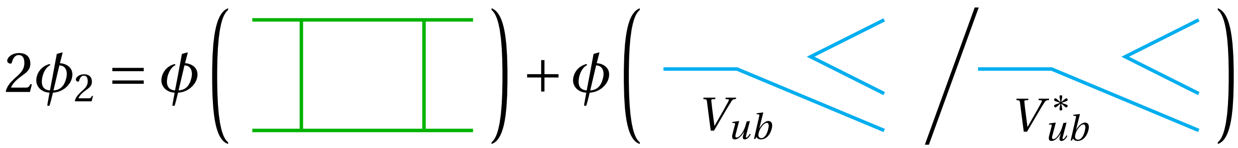
$$S = -2(m_s/m_b)\sin(2\phi_1) \sim -0.03$$



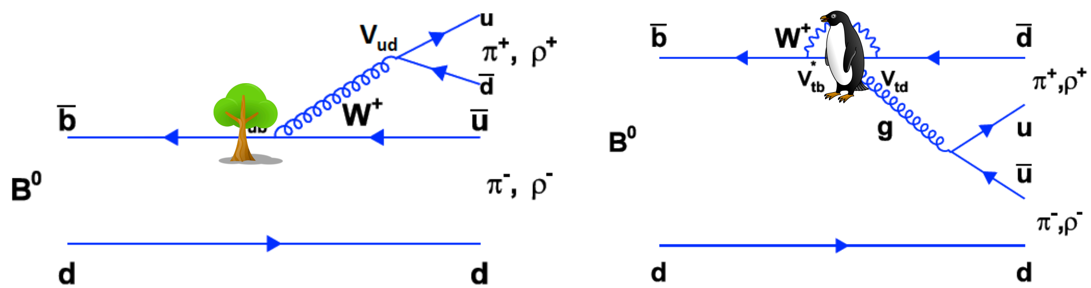
Precision tested at Belle II



Φ_2 & Isospin analysis (also applies to direct CPV)

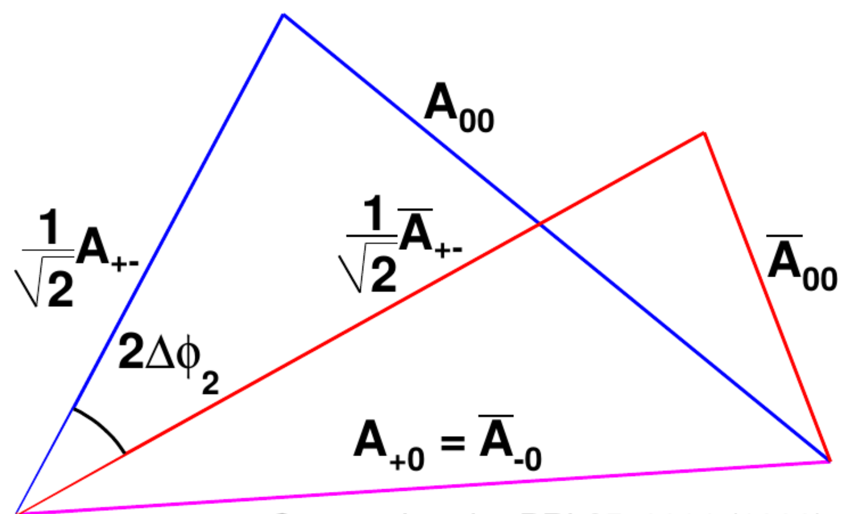


- b → u anti-u d in strict isospin limit, penguin contractions transform differently



- In B → ππ and B → ρρ, a triangle construction allows a clean extraction of Φ_2 , up to an 8-fold discrete ambiguity

A_{+-}: $B^0 \to h^+h^-$
$\overline{A}_{+-}$: $\overline{B}^0 \to h^+h^-$
A_{00}: $B^0 \to h^0h^0$
$\overline{A}_{00}$: $\overline{B}^0 \to h^0h^0$
A_{+0}: $B^+ \to h^+h^0$
$(h = \pi,\ \rho)$

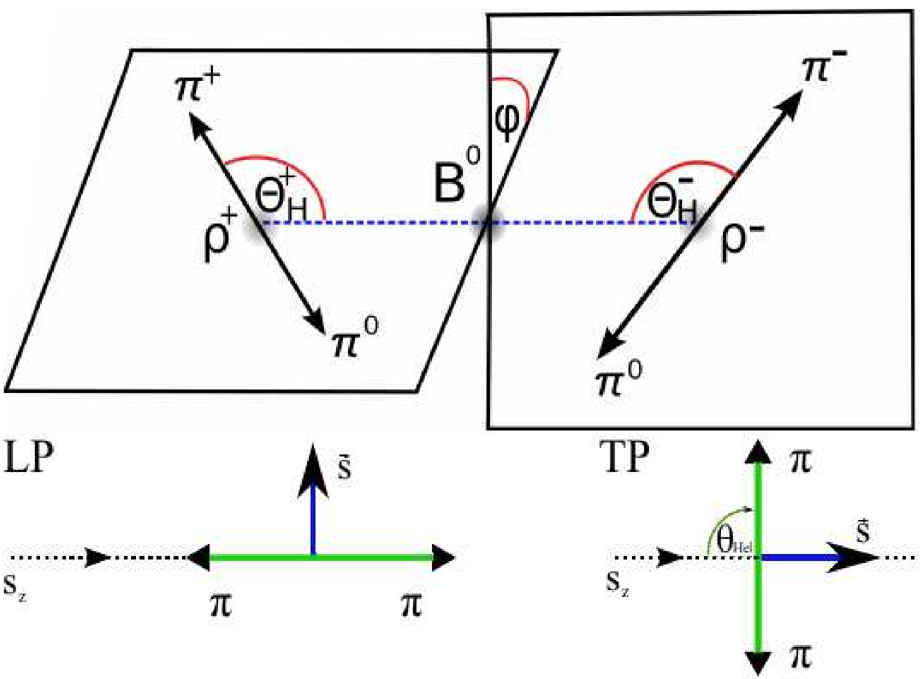


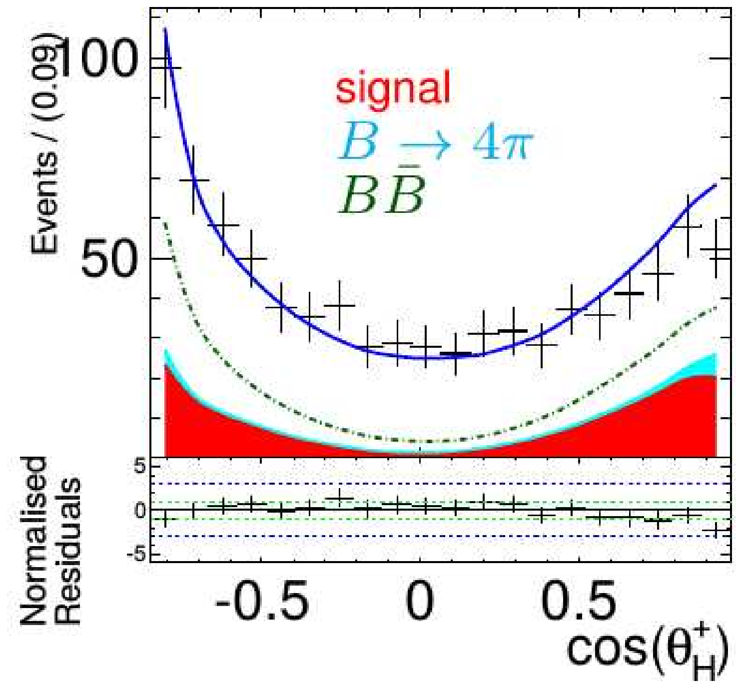
Gronau, London PRL**65**, 3381 (1990)

$B^0 \to \rho^+ \rho^-$ analysis

Belle PRD 93, 032010 (2016)
Belle PRD89, 072009 (2014)

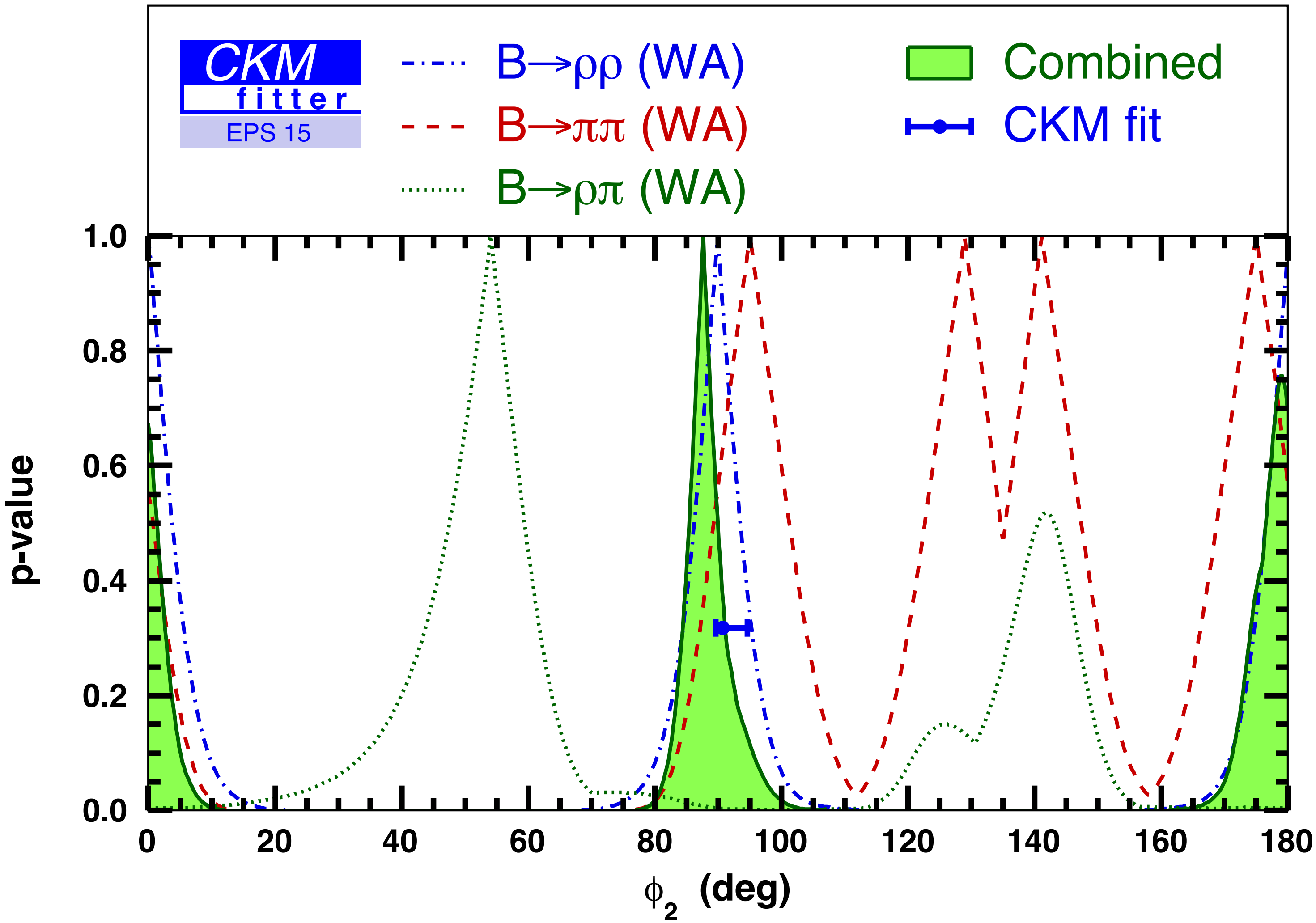
- Vector-vector final state is mixture of CP-even &-odd
- Predicted to be almost fully longitudinally polarized=CP-even
- Time-dependent 9-parameter ML fit





$$\mathcal{B}(B^0 \to \rho^+\rho^-) = (28.3 \pm 1.5 \pm 1.4) \times 10^{-6}$$
$$f_L = 0.988 \pm 0.012 \pm 0.023$$
$$\mathcal{S} = -0.13 \pm 0.15 \pm 0.05,\ \mathcal{A} = 0.00 \pm 0.10 \pm 0.06$$

Φ_2 Grand combination

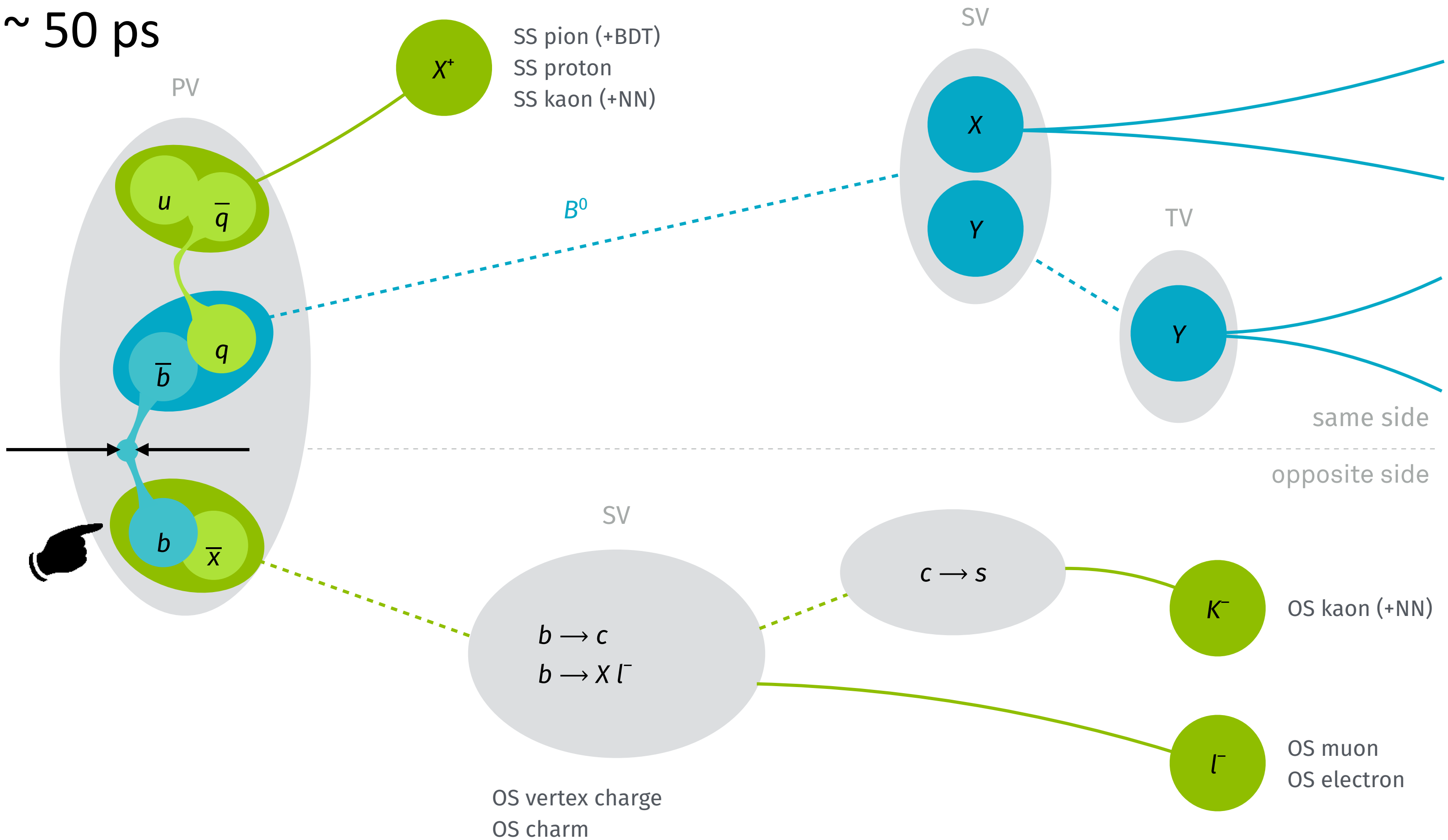


- $\Phi2$ [WA,all]=(87.6+3.5-3.3)°, $\Phi2$[fit]= (90.6+3.9-1.1)°

LHCb time dependent CPV

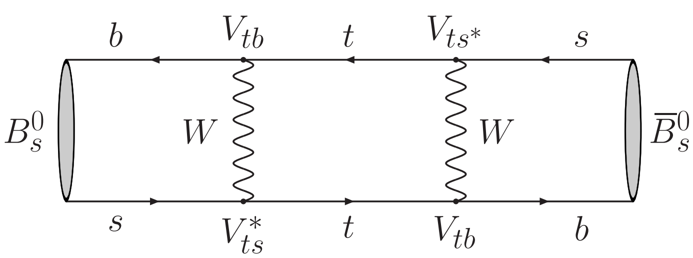
LHCb, JINST 11 (2016) P05010, JINST 10 P10005 (2015)

- $B_s^0 \rightarrow \Phi\ J/\psi$
- flavour tag ε~3%
- σ(Δt) ~ 50 ps

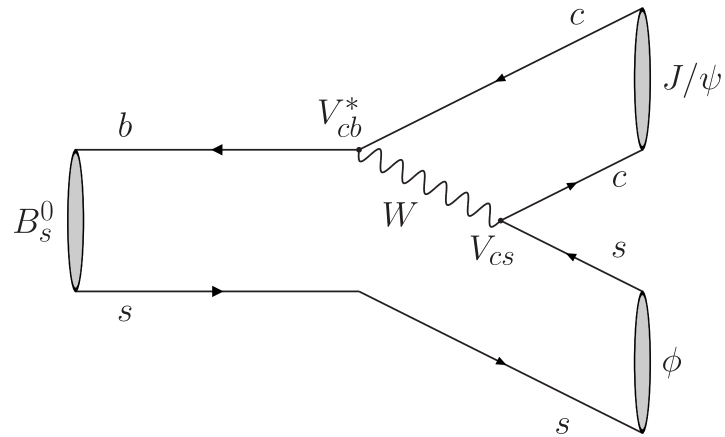


$\Phi_S = \Phi_M - 2\,\Phi_D$

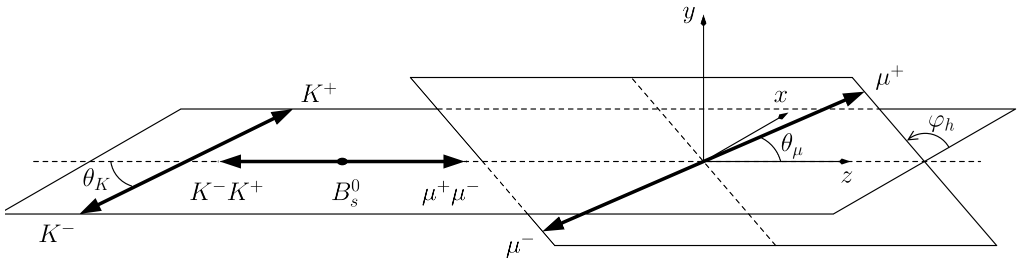
LHCb, PRL 114 (2015) 041801

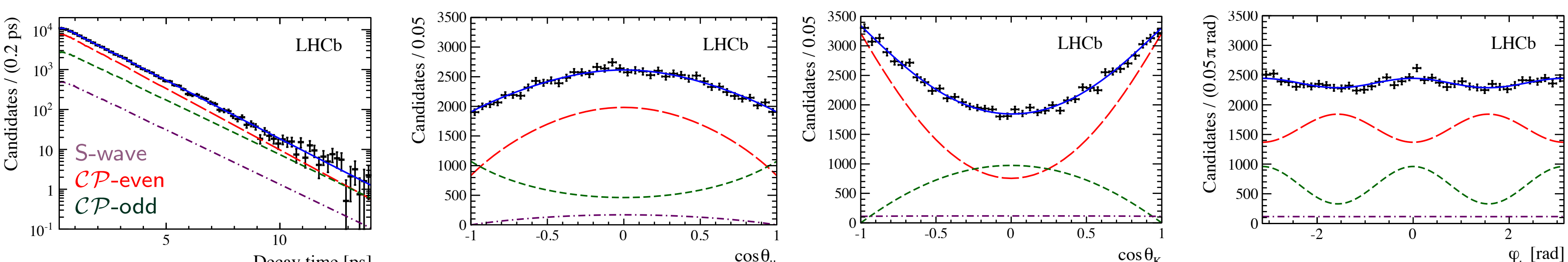


Mixing: $\phi_M = 2\arg(V_{tb}V_{ts}^*)$



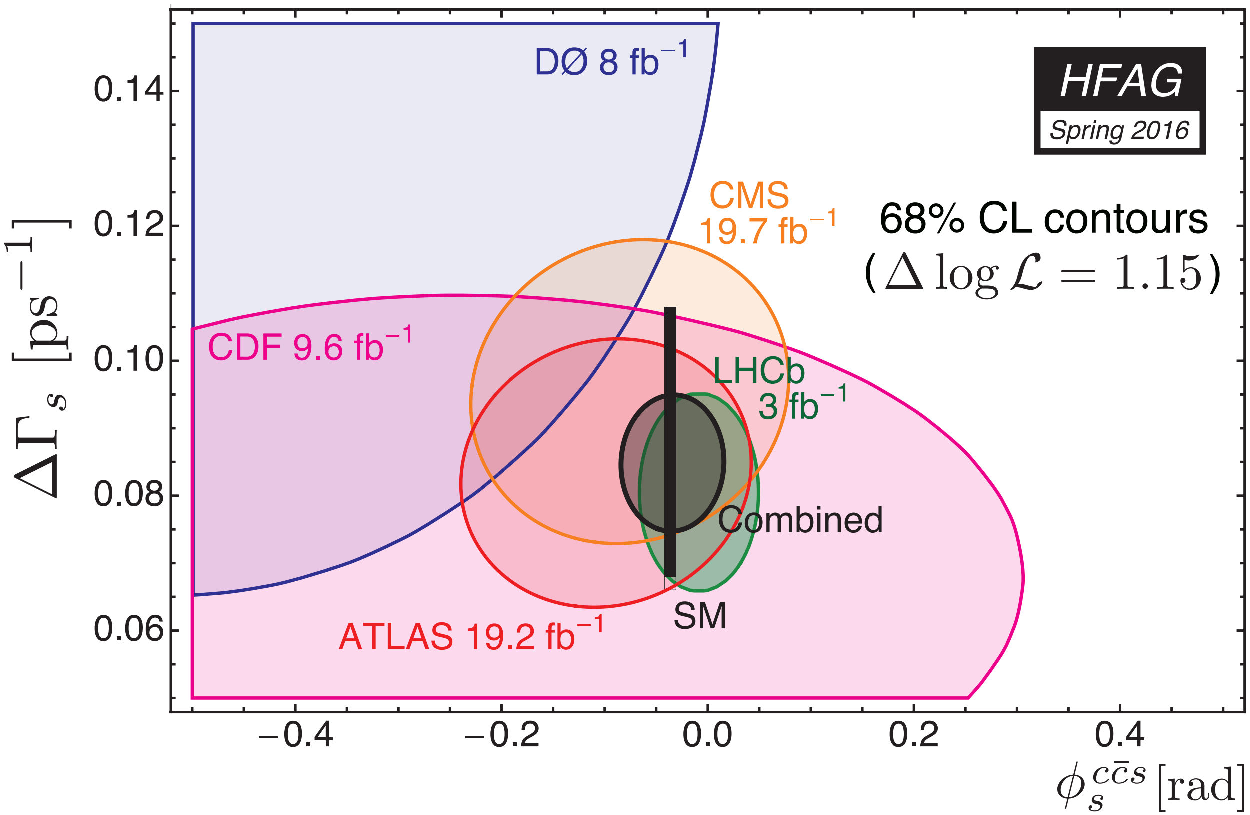
Decay: $\phi_D = \arg(V_{cb}V_{cs}^*)$





Φs Grand combination

HFAG 2016



$\phi_s^{c\bar{c}s} = -0.033 \pm 0.033$ rad

$\Delta\Gamma_s = \quad 0.083 \pm 0.006$ ps^{-1}

Compatible with SM estimations:

[arXiv:1511.09466] [CKMfitter, PRD 84 (2011) 033005]

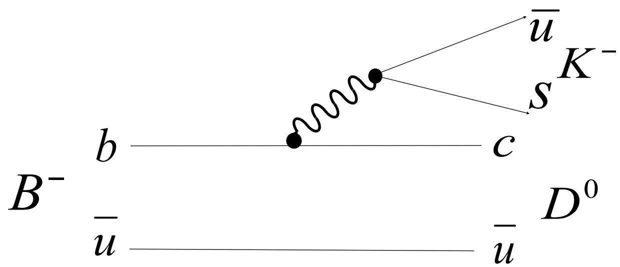
$\phi_s^{c\bar{c}s} = -0.0376\,^{+0.0008}_{-0.0007}$ rad

$\Delta\Gamma_s = \quad 0.088 \pm 0.020$ ps^{-1}

Direct CP Violation

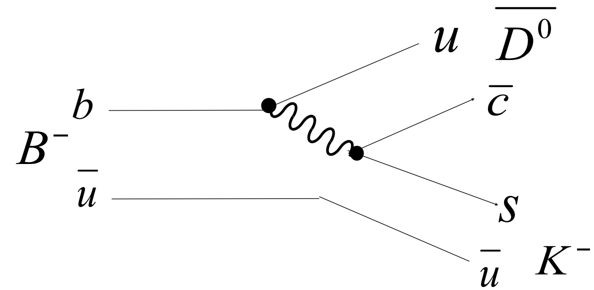
Φ_3/γ Determination

- Theory is "pristine" in these approaches, << 1% on Φ_3
- Accessed via interference between $B^- \to D^0 K^-$ and $B^- \to$ anti-$D^0 K^-$



$A \propto \lambda^3$

Favoured



$A \propto \lambda^3 \sqrt{\rho^2 + \eta^2}\, e^{i\phi_3}$

Suppressed

$$r_B = \frac{|A_{\text{suppressed}}|}{|A_{\text{favoured}}|} \approx \frac{V_{ub} V_{cs}^*}{V_{cb} V_{us}^*} \times [\text{colour supp.}] = 0.1 - 0.2$$

Relative weak phase is Φ_3, Relative strong phase is δ_R

3 D^0 mode categories:

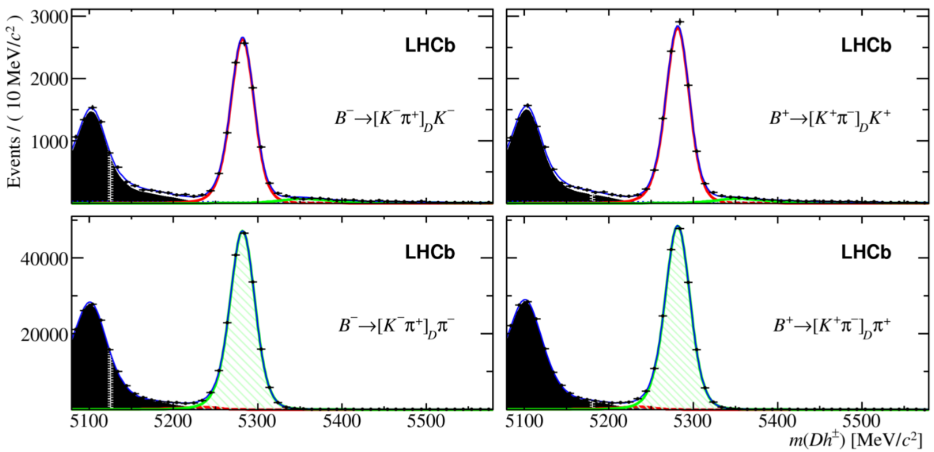
- D_{CP}, CP eigenstates [GLW]
- D_{sup}, Doubly cabibbo suppressed [ADS]
- 3-Body [GGSZ]

3 B modes: D*K, DK, DK*

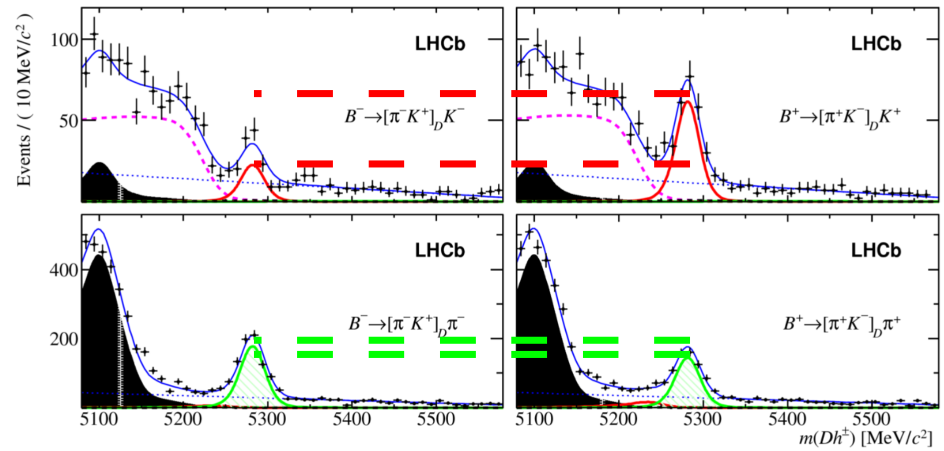
γ from $B^+ \to DK^+$, $D \to KK, \pi\pi$, $K\pi$

LHCb-paper-2016-003

$D \to K\pi$ (favoured)



$D \to \pi K$ ("ADS" suppressed)



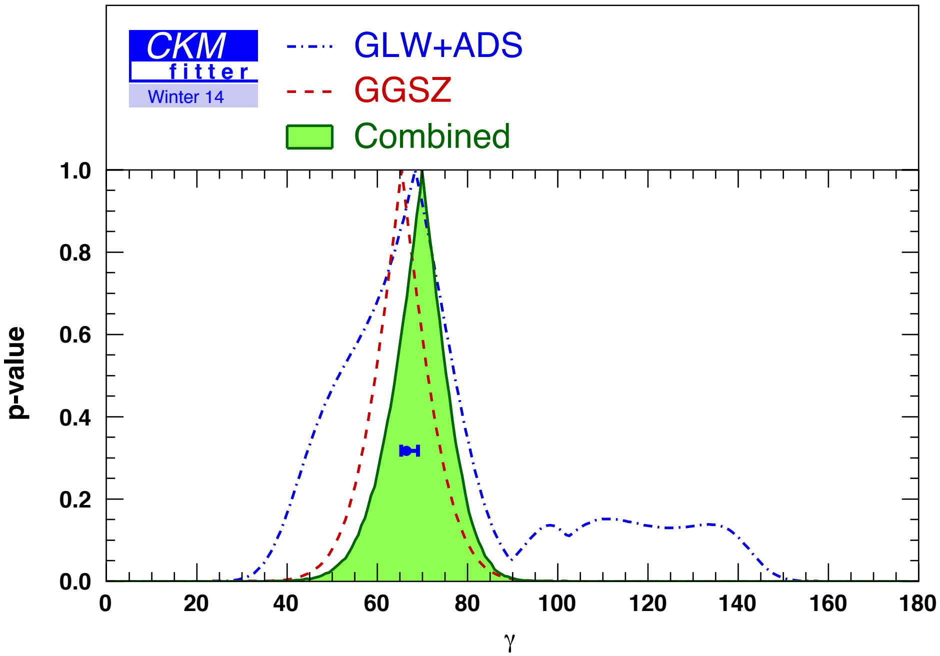
- small asymmetries due to production and detection effects
- $B \to D\pi$ control mode helps to separate effects

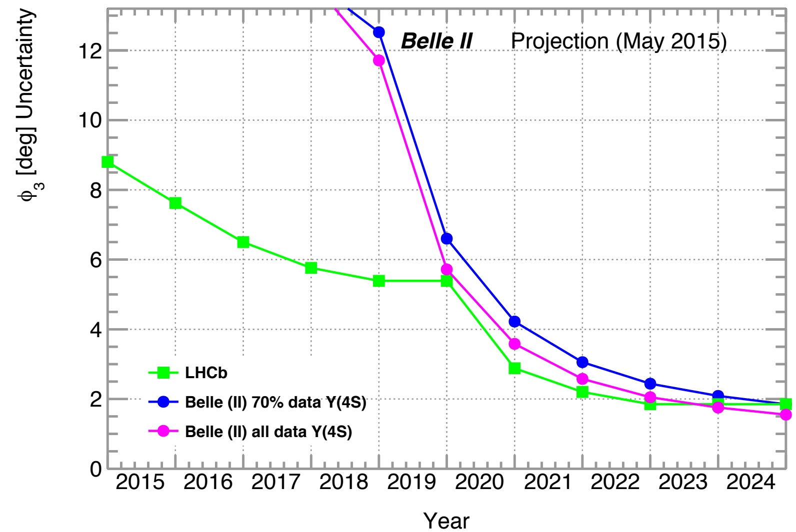
- large CP violating asymmetries –
- **first 5σ observation in a single $B \to DK$ channel**

Φ_3/γ Results

Belle PTEP 043C01 (2016)
LHCb-Paper-2015-059
LHCb-Paper-2016-003
LHCb-Paper-2016-006
LHCb-Paper-2016-007
LHCb-Conf-2016-001

Impact of LHCb is striking, with massive improvements since 2010.





Summer 2010	Winter 2012	Winter 2014
$\gamma[\text{comb}] = (71^{+21}_{-25})^\circ$	$\gamma[\text{comb}] = (66^{+12}_{-12})^\circ$	$\gamma[\text{comb}] = (66^{+8}_{-9})^\circ$
$\gamma[\text{fit}] = (67.2^{+3.9}_{-3.9})^\circ$	$\gamma[\text{fit}] = (67.1^{+4.3}_{-4.3})^\circ$	$\gamma[\text{fit}] = (66.4^{+1.2}_{-3.3})^\circ$

- 2016 global combination update to come.

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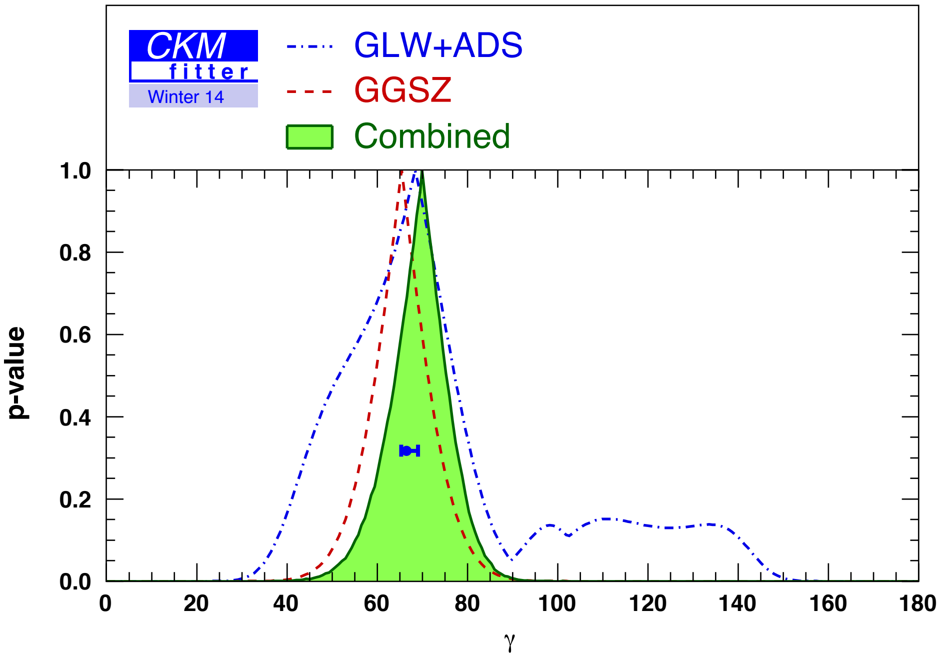

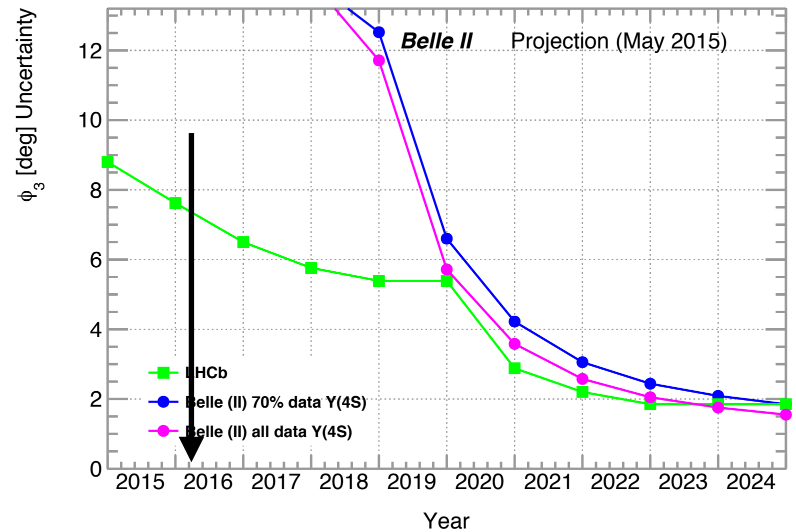

Summer 2010 | Winter 2012 | Winter 2014

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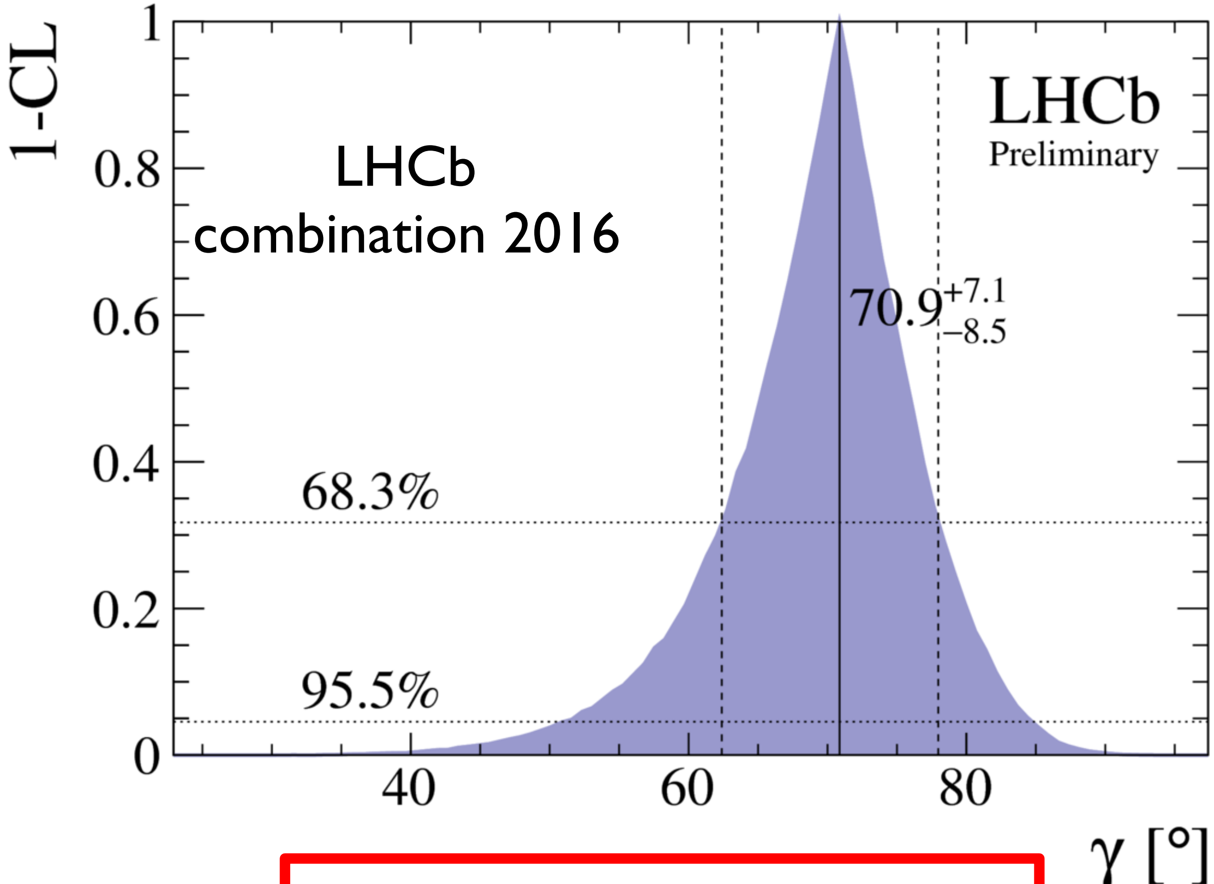
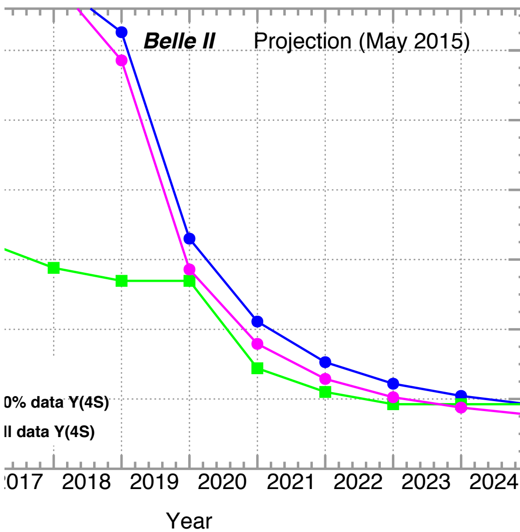
LHCb-Conf-2016-001





2014

$$] = (66^{+8}_{-9})^\circ$$

$$(66.4^{+1.2}_{-3.3})^\circ$$

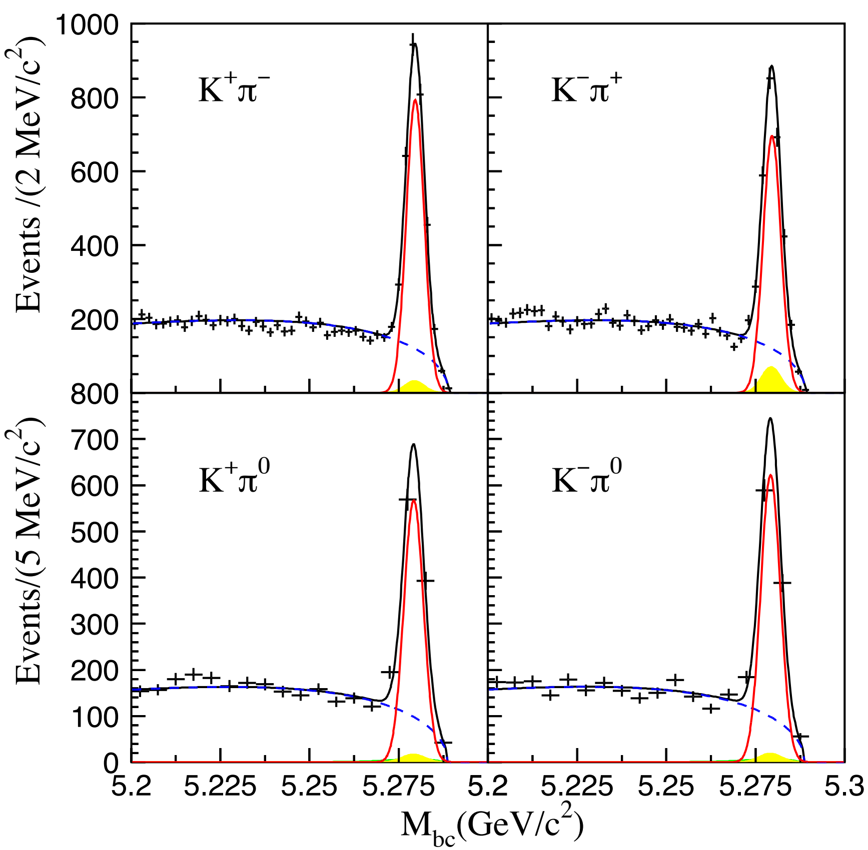
$$\gamma = (70.9\ ^{+7.1}_{-8.5})^\circ$$

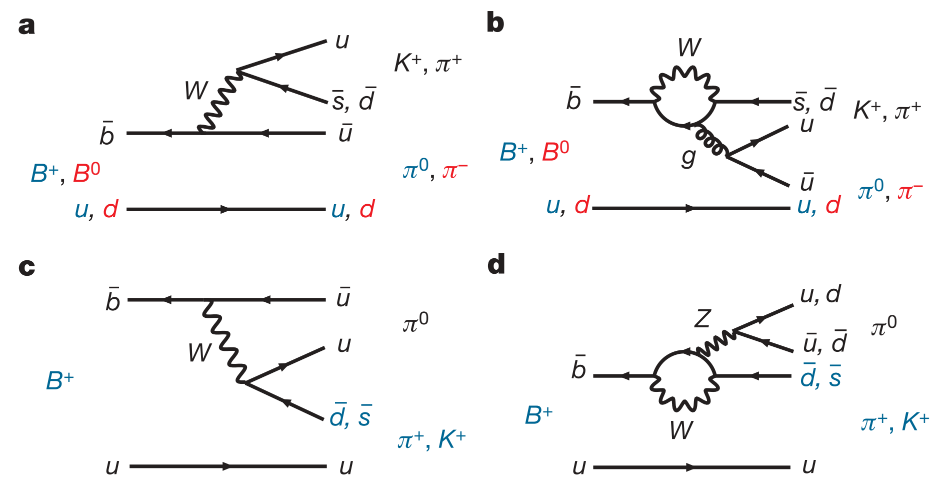
- 2016 global combination update to come.

Direct CP Violation in charmless hadronic decays

Belle, PRD87, 031103(R)(2013)
Belle, Nature 452, 332 (2008)

- First evidence 2008
- Unexpected difference in Acp between B^+ and $B^0 \rightarrow K\pi$





$A_{cp}(K^0\pi^0) = 0.006 \pm 0.06$

$A_{cp}(K^0\pi^+) = -0.015 \pm 0.019$

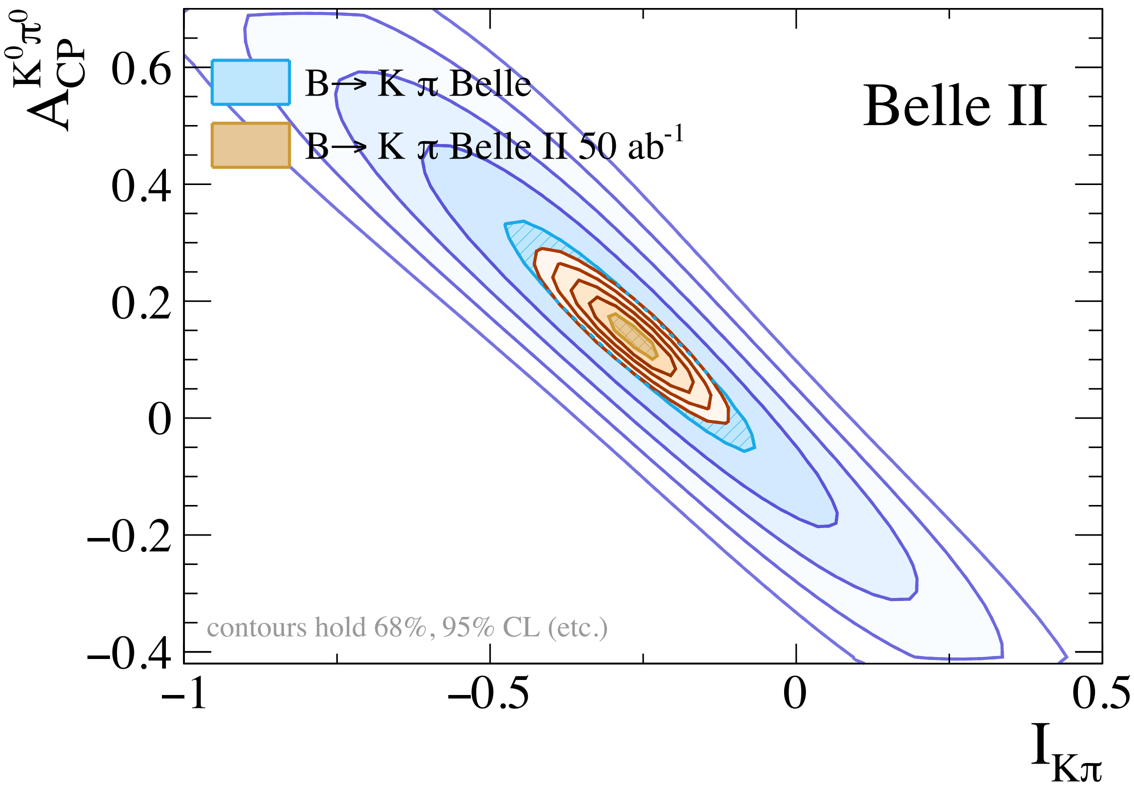
$A_{cp}(K^+\pi^0) = 0.040 \pm 0.021$

$A_{cp}(K^+\pi^-) = -0.082 \pm 0.006$

Direct CPV in B→Kπ: Future

- " isospin sum rule approach" can constrain QCD effects.

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

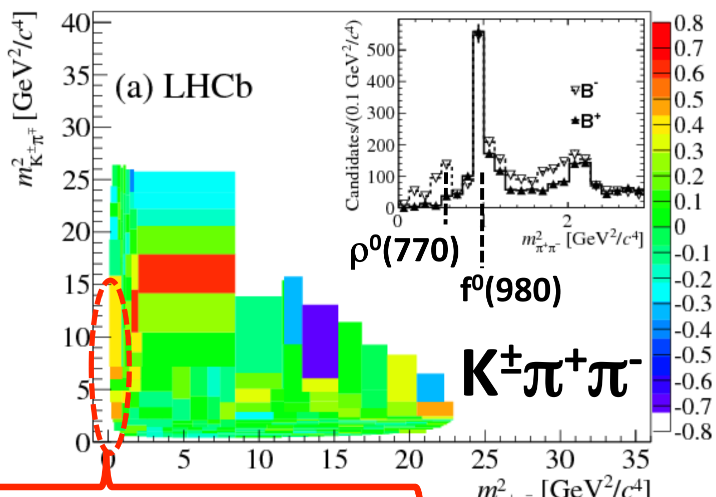


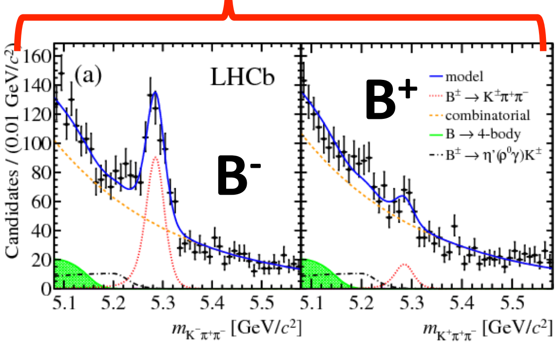
- Need to measure neutral modes very precisely!
- **Good PID & good neutral ID is key.**

B→ K h h, B → π h h @ LHCb

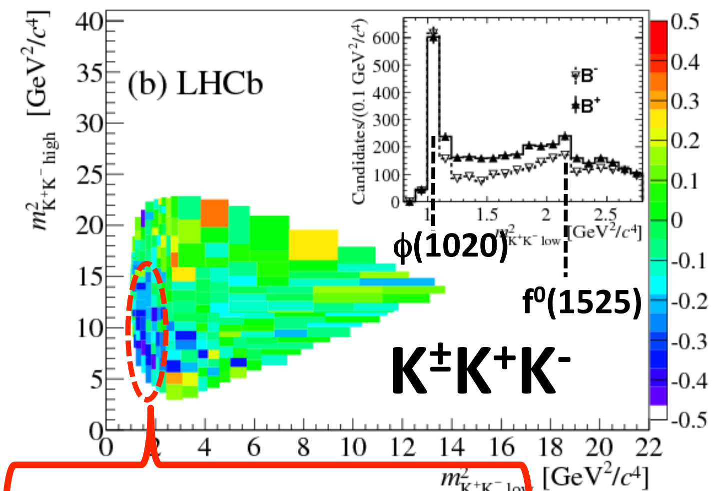
PRL 111 (2013) 101801
PRL 112 (2014) 011801

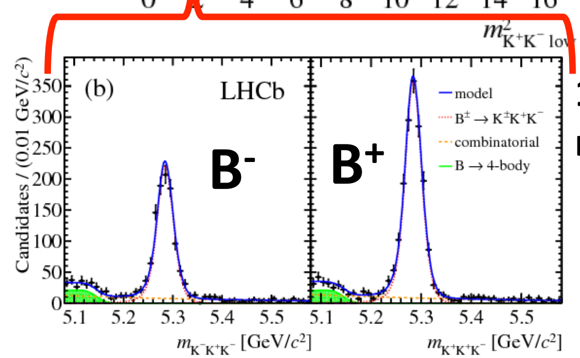
- Puzzling patterns of CPV in $B^{\pm} \to K^{\pm}h^{+}h^{-}$ and $B^{\pm} \to \pi^{\pm}h^{+}h^{-}$
- Large local asymmetries in regions not associated to resonances
  - Possibly final state re-scattering generates strong phase difference





$m^2_{\pi\pi} < 0.66\ \mathrm{GeV}^2/c^4$
$m^2_{K\pi} < 15\ \mathrm{GeV}^2/c^4$





$1.2 < m^2_{KK\,low} < 2.0$
$m^2_{KK\,high} < 15\ \mathrm{GeV}^2/c^4$

$A_{CP}(K^{\pm}\pi^{+}\pi^{-}|\mathrm{local}) = 0.678 \pm 0.078 \pm 0.032 \pm 0.007$

$A_{CP}(K^{\pm}K^{+}K^{-}|\mathrm{local}) = -0.226 \pm 0.020 \pm 0.004 \pm 0.007$

What could it be?

B.Bhattacharya, M. Gronau, J. Rosner Phys.Lett. B726 (2013) 337-343

We have examined the CP asymmetries in three-body decays of $B^\pm$ mesons to charged pions and kaons. Predictions of ratios of asymmetries on the basis of U-spin are seen to be obeyed qualitatively, with violations ascribable to resonant substructure differing for $\pi^+\pi^-$ and K^+K^- substates. Larger CP asymmetries for regions of the Dalitz plot involving low effective mass of these substates can be undertood qualitatively in terms of large final-state strong phases; the weak phases are conducive to such large asymmetries, being nearly maximal. We conclude that further resolution of this problem must rely either on a deeper understanding of the resonant substructure in $B \to PPP$ decays, or further understanding of the hadronization process independently of resonances. We have argued that the approximately equal magnitudes and opposite signs measured for asymmetries in $B^+ \to \pi^+\pi^+\pi^-$ and $B^+ \to K^+\pi^+\pi^-$ may follow from the closure of low-mass $\pi^+\pi^-$ and K^+K^- channels involving only $\pi\pi \leftrightarrow K\bar{K}$ rescattering.

Direct CP violation in Radiative decays

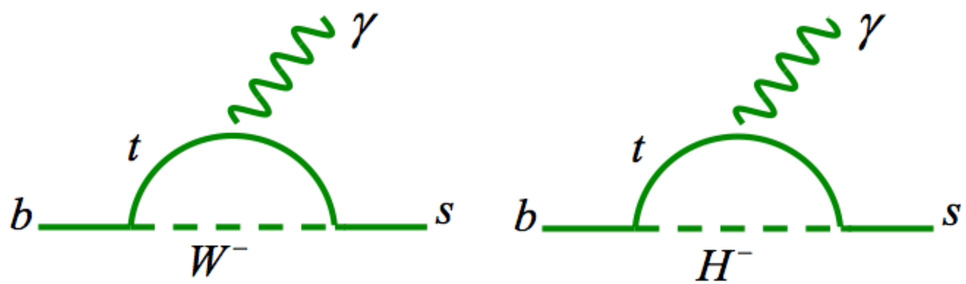
Belle, ACP(b→s+d γ) PRL 114, 151601 (2015)
Babar, ACP(b→s γ), PRD 90 092001 (2014)

$$\mathcal{A}_{CP}(\bar{B} \to X_{s+d}\gamma) \equiv \frac{\Gamma(\bar{B} \to X_{s+d}\gamma) - \Gamma(B \to X_{\bar{s}+\bar{d}}\gamma)}{\Gamma(\bar{B} \to X_{s+d}\gamma) + \Gamma(B \to X_{\bar{s}+\bar{d}}\gamma)}.$$

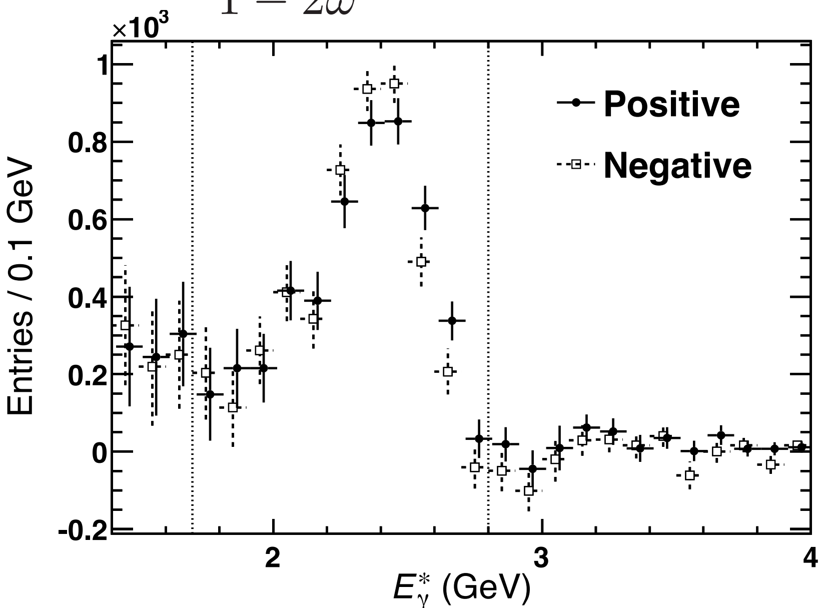
−0.6% < ACP(B → Xsγ) < 2.8% and
−62% < ACP(B → Xdγ) < 14%

Precision Null Test in SM

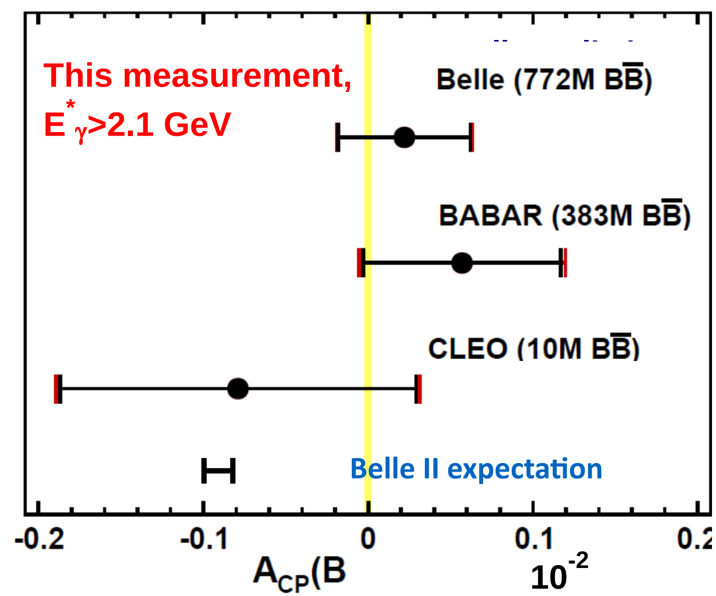
CP violating contributions and their errors cancel almost perfectly up to small U-spin breaking corrections



$$\mathcal{A}_{CP} = \frac{1}{1-2\omega}(\mathcal{A}_{CP}^{\rm meas} - \mathcal{A}_{\rm bkg} - \mathcal{A}_{\rm det})$$



Belle: $A_{CP}(B \to X_{s+d}\gamma) = (2.2 \pm 3.9 \pm 0.9)\%$

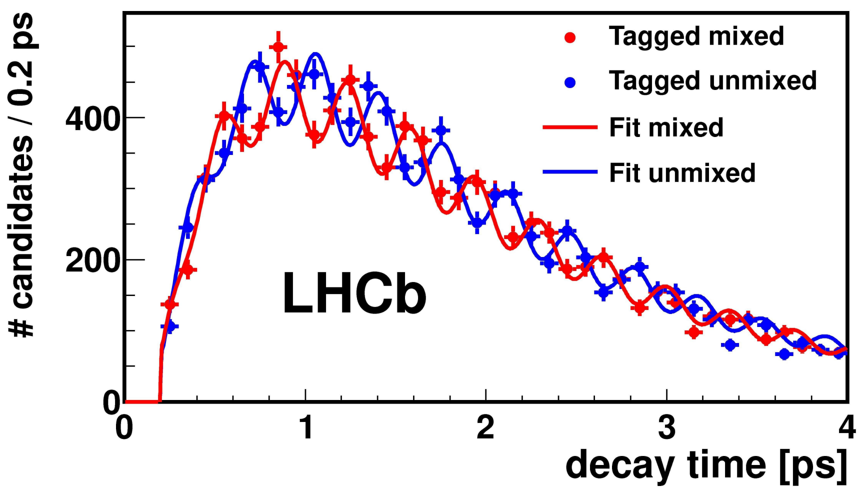


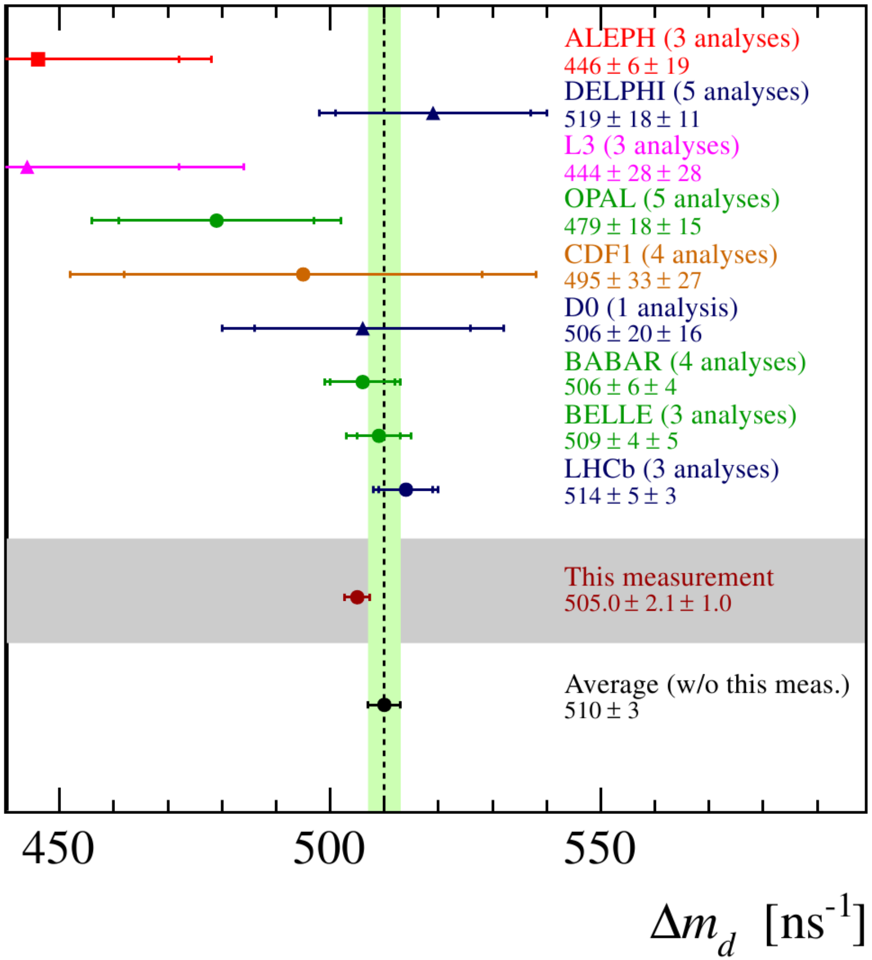
CP Violation in Mixing

$|V_{td}/V_{ts}|$ from mixing (CP-conserving)

LHCb NJP 15 (2013) 053021
LHCb-PAPER-2015-031
ETM 1603.04306
Fermilab/MILC 1602.03560

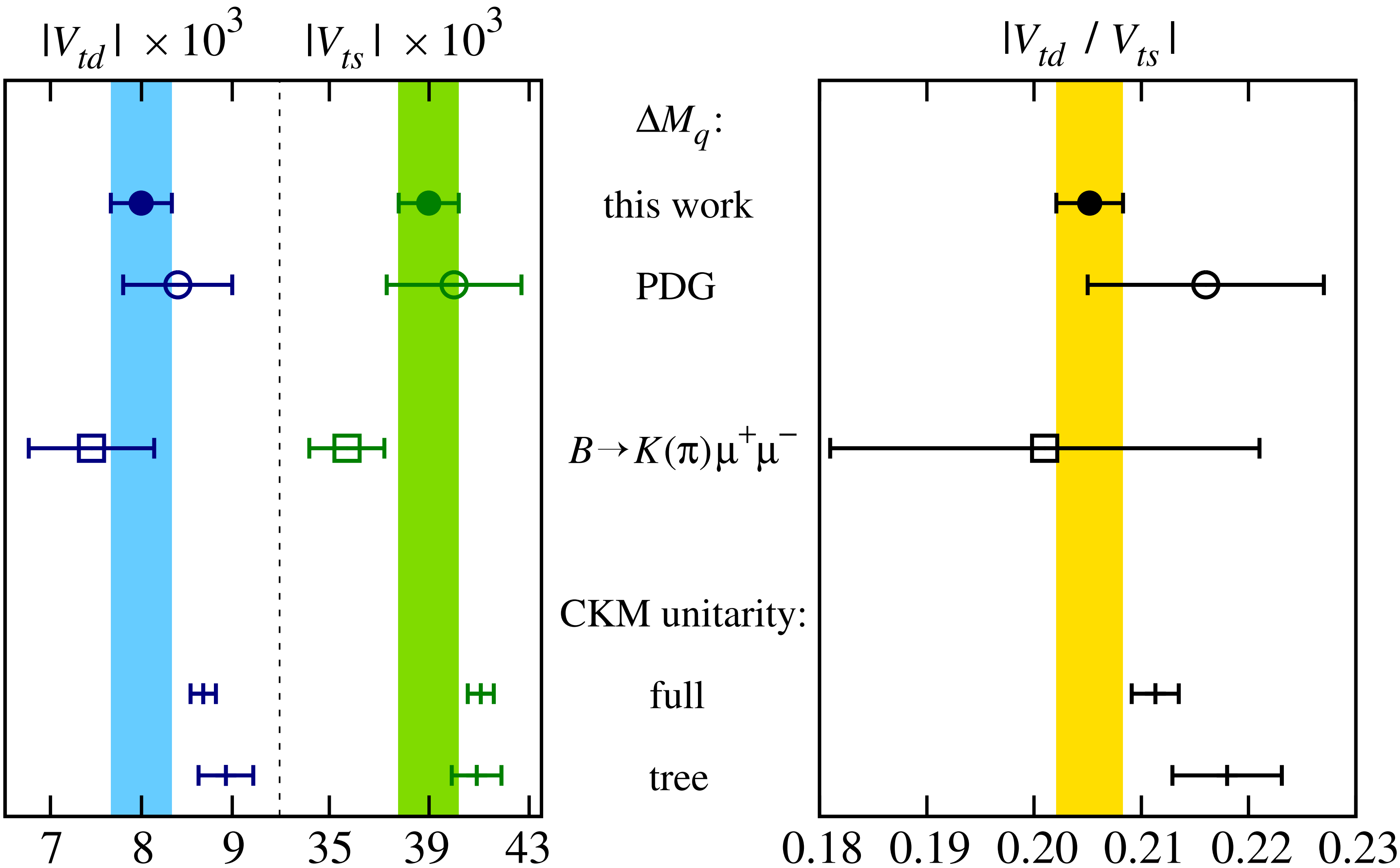
- Δm_s precisely known
  - $\Delta m_s = 17.768 \pm 0.023 \pm 0.006\ \text{ps}^{-1}$
- limitation on $|V_{td}/V_{ts}|$ from lattice
- new prelim. measurement of Δm_d





New bag parameters from LQCD

ETM 1603.04306
Fermilab/MILC 1602.03560



CP violation in mixing

LHCb-Paper-2016-013

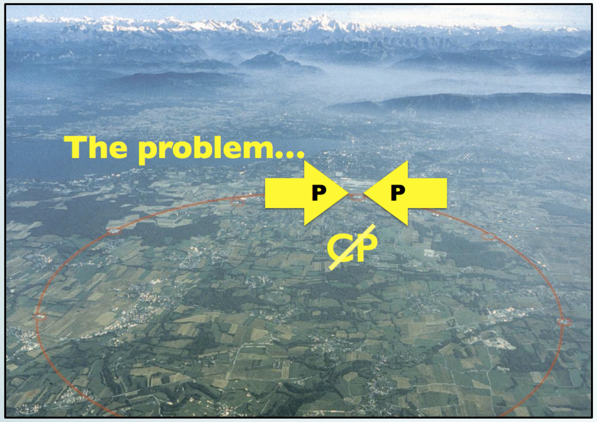
- a_s^{sl} and a_d^{sl} with full Run1 dataset (3/fb)

$$A_{\text{raw}}(t) = \frac{N(f,t) - N(\bar{f},t)}{N(f,t) + N(\bar{f},t)} \approx \underbrace{A_D + \frac{a_{\text{sl}}^d}{2}}_{\text{Offset}} + \underbrace{\left(A_P - \frac{a_{\text{sl}}^d}{2}\right)}_{\text{Amplitude}} \cos(\Delta m_d t)$$

Offset — Amplitude — Mixing

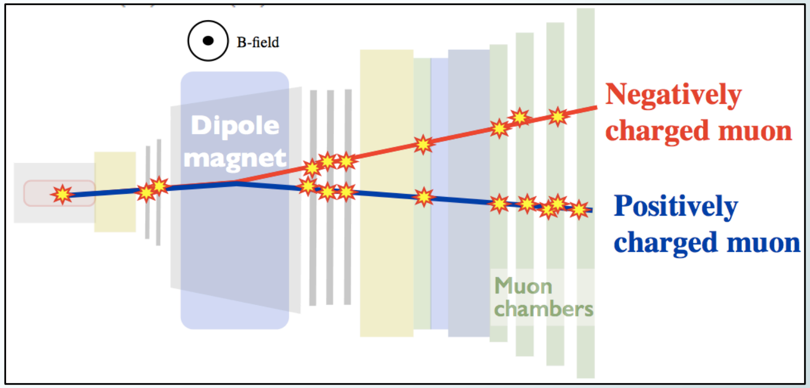
Production asymmetry:

$$A_P = \frac{N(B) - N(\bar{B})}{N(B) + N(\bar{B})}$$

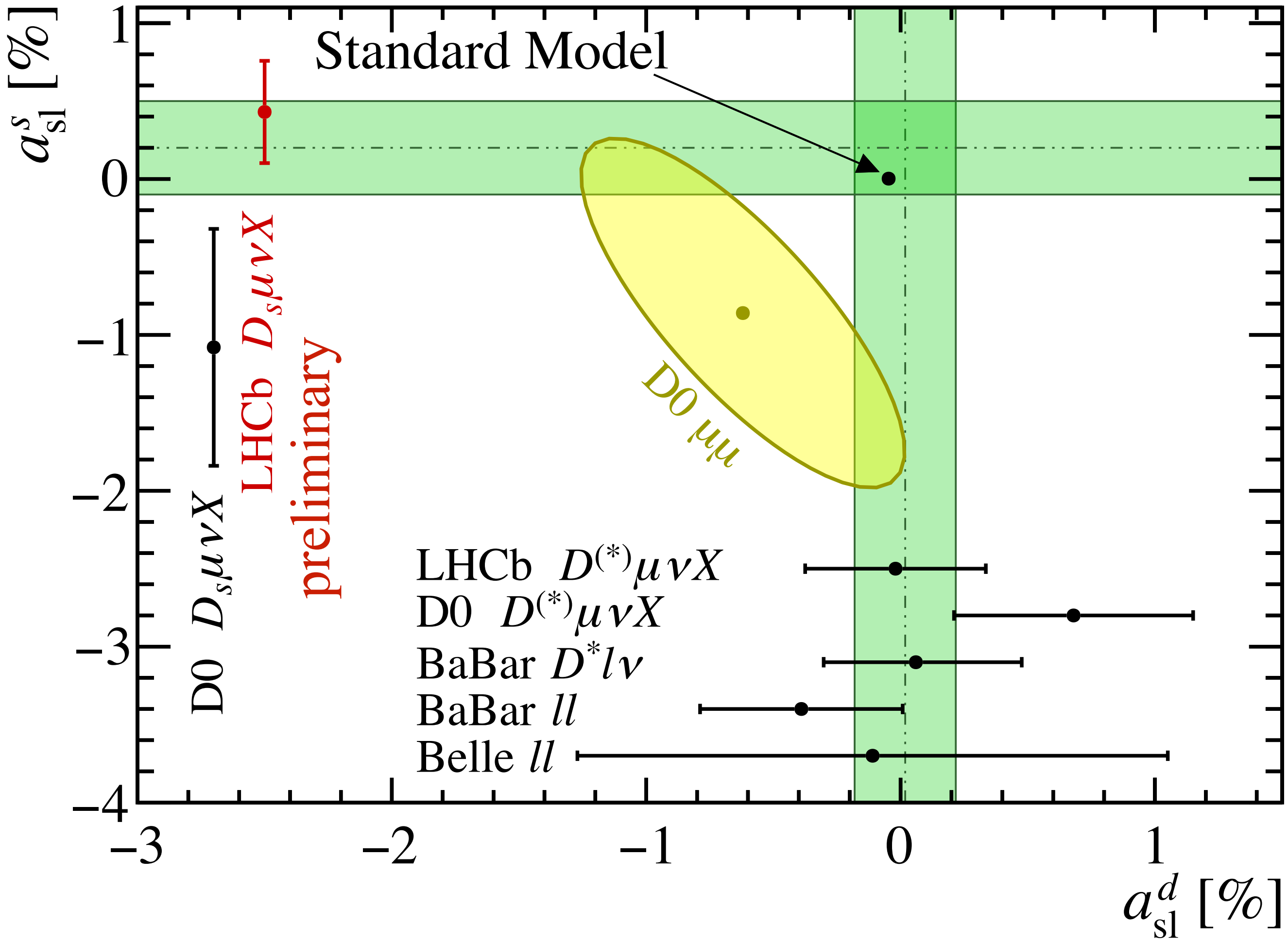


Detection asymmetry:

$$A_D = \frac{\epsilon(D^-\mu^+) - \epsilon(D^+\mu^-)}{\epsilon(D^-\mu^+) + \epsilon(D^+\mu^-)}$$



CP violation in mixing



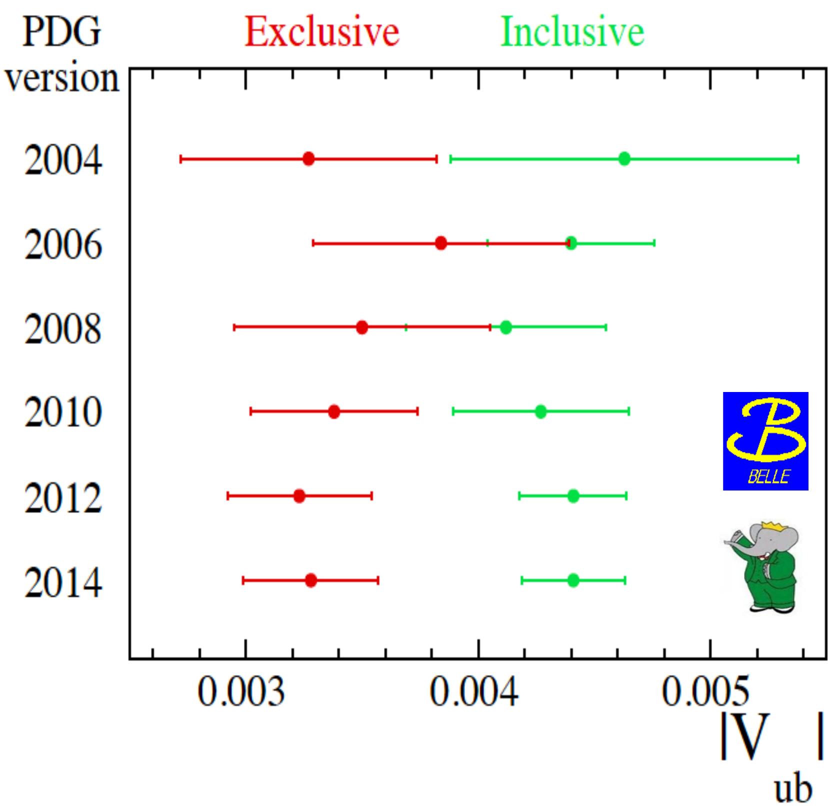
2016	$a^s_{\rm sl} = (0.45 \pm 0.26({\rm stat}) \pm 0.20({\rm syst}))\%$
2015	$a^d_{sl} = (-4.7 \pm 0.6) \times 10^{-4}$

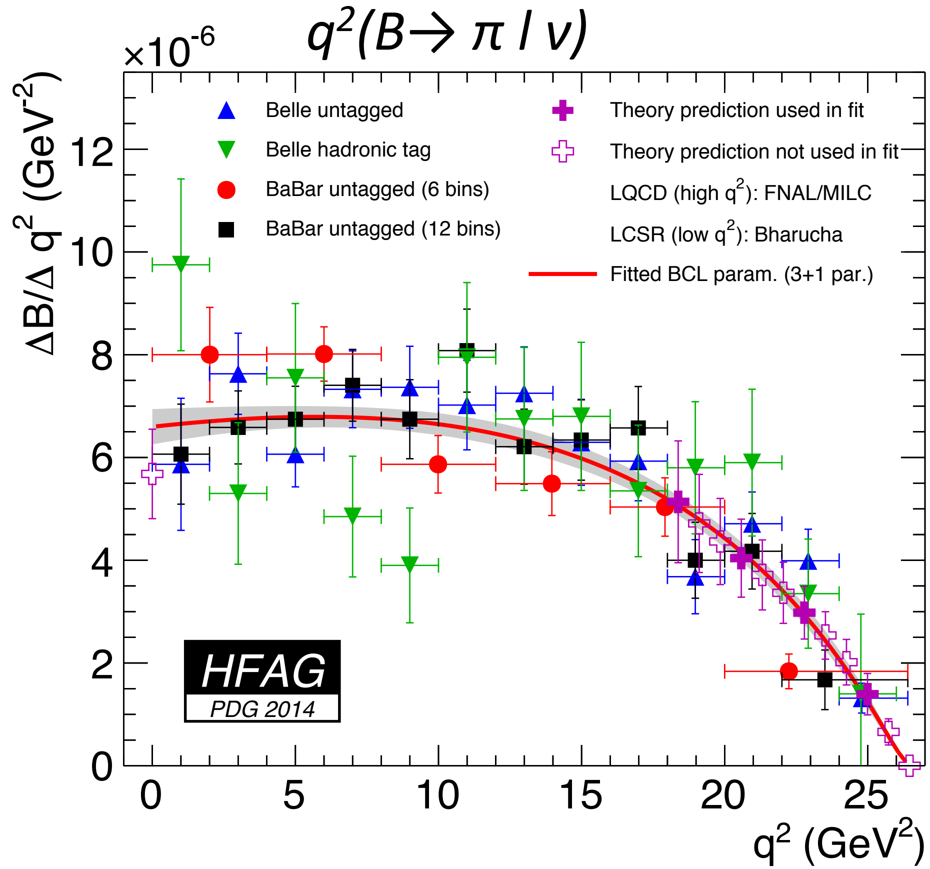
UT precision tests

The $|V_{ub}|$ puzzle: $B \to X_u l \nu$

HFAG, arXiv:1412.7515

- Inclusive versus exclusive determinations (form factor - exclusive vs heavy quark symmetry - inclusive) **3 σ anomaly.**





$|V_{ub}|$ exclusive HFAG = $(3.28 \pm 0.29) \times 10^{-3}$

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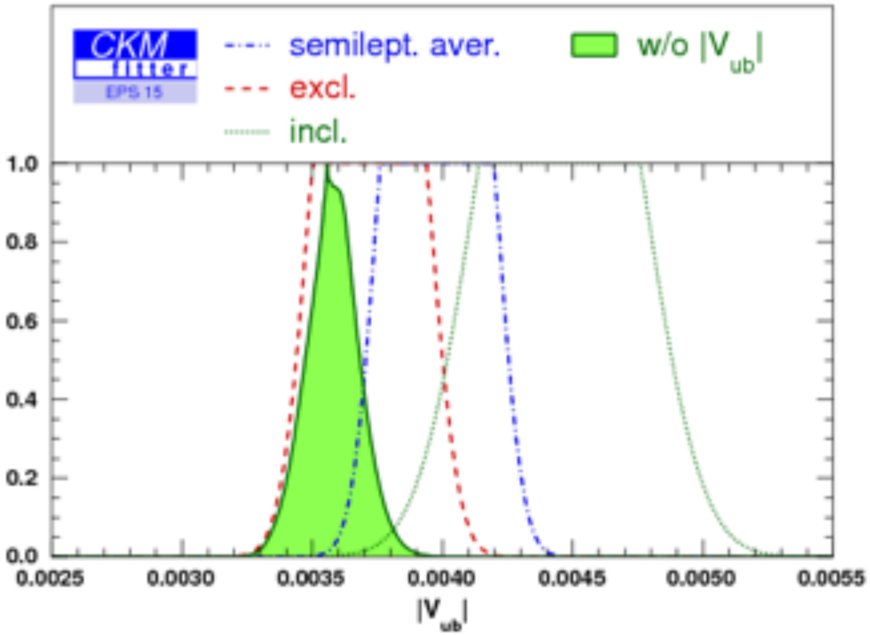
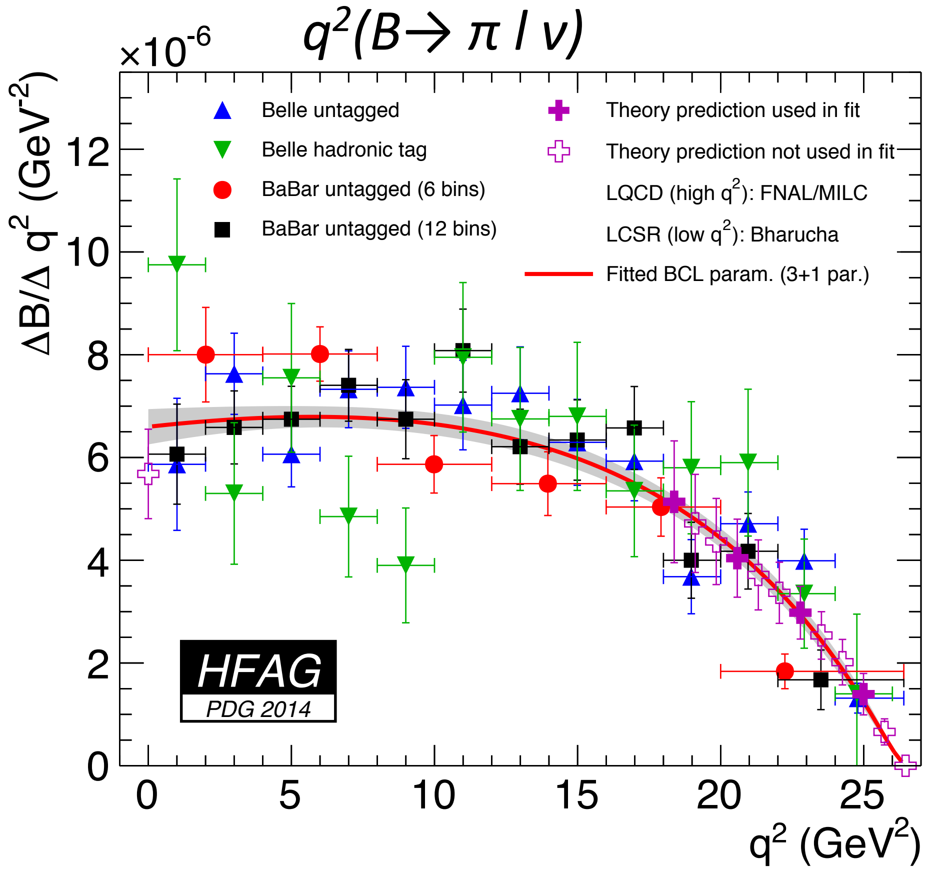


$|V_{ub}|$



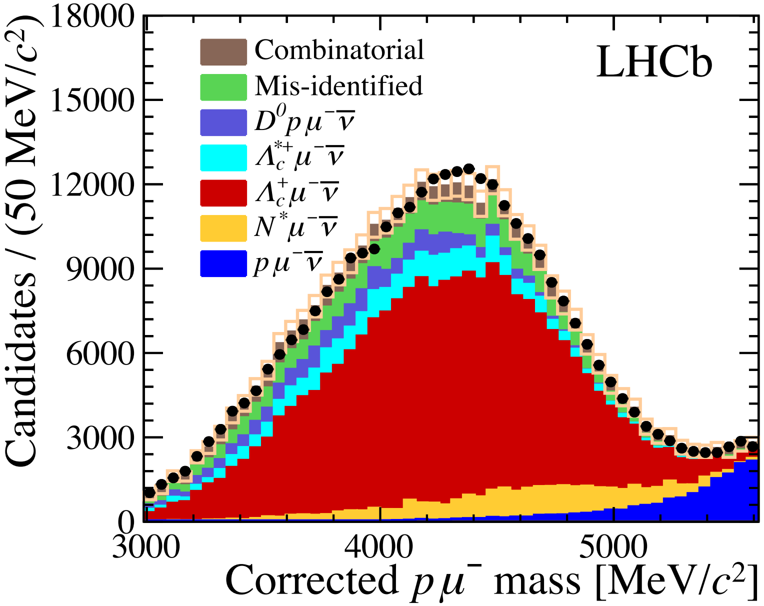
$|V_{ub}|$ exclusive HFAG = $(3.28 \pm 0.29) \times 10^{-3}$

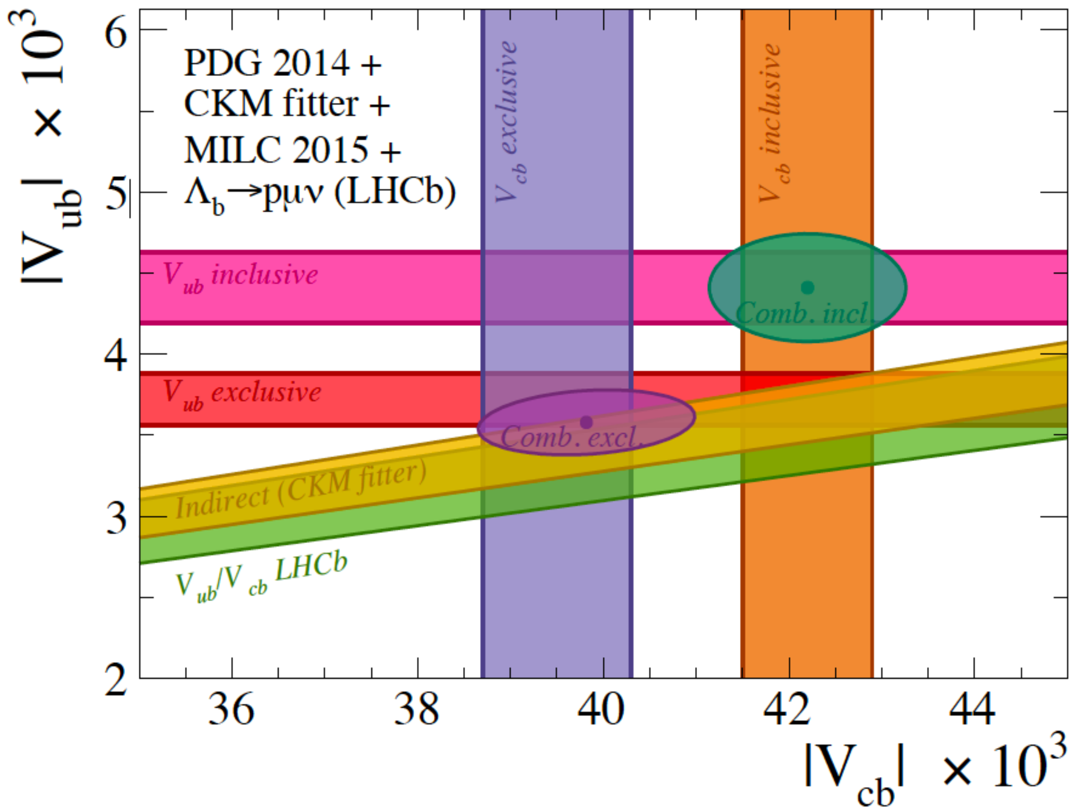
$\Lambda_b \to p\,\mu\,\nu$ / $\Lambda_b \to \Lambda_c\,\mu\,\nu$

LHCb, Nature Physics 10 (2015) 1038

$$\frac{|V_{ub}|^2}{|V_{cb}|^2} = \frac{\int_{15\,\mathrm{GeV}^2}^{q^2_{\max}} \frac{\mathrm{d}\Gamma(\Lambda_b \to p\,\mu^- \bar{\nu}_\mu)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{7\,\mathrm{GeV}^2}^{q^2_{\max}} \frac{\mathrm{d}\Gamma(\Lambda_b \to \Lambda_c\,\mu^- \bar{\nu}_\mu)}{\mathrm{d}q^2}\mathrm{d}q^2}(0.68 \pm 0.07)$$

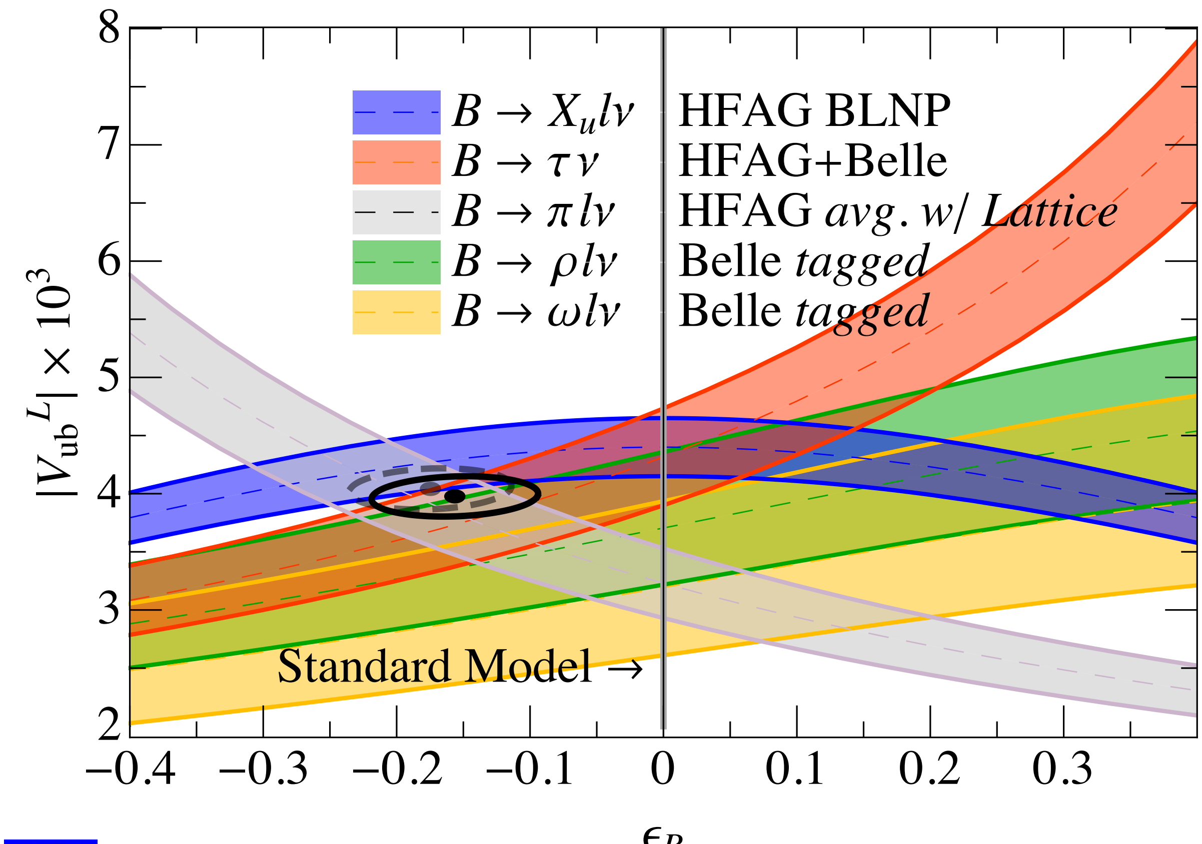
$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004 \pm 0.004$$





Restored Left-Right Symmetry?

- Add new physics: ***right handed currents*** with coupling V_{ub}^R
  - $B \to \pi l \nu$ rate goes as $|V_{ub}^L + V_{ub}^R|^2$
  - $B \to \tau \nu$ rate goes as $|V_{ub}^L - V_{ub}^R|^2$
  - $B \to X_u l \nu$ rate goes as $|V_{ub}^L| + |V_{ub}^R|^2$



1. $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

- → New heavy gauge bosons (W′, Z′, H).
- → $V_L = V_{CKM}$ and V_R — 5 more CP phases.

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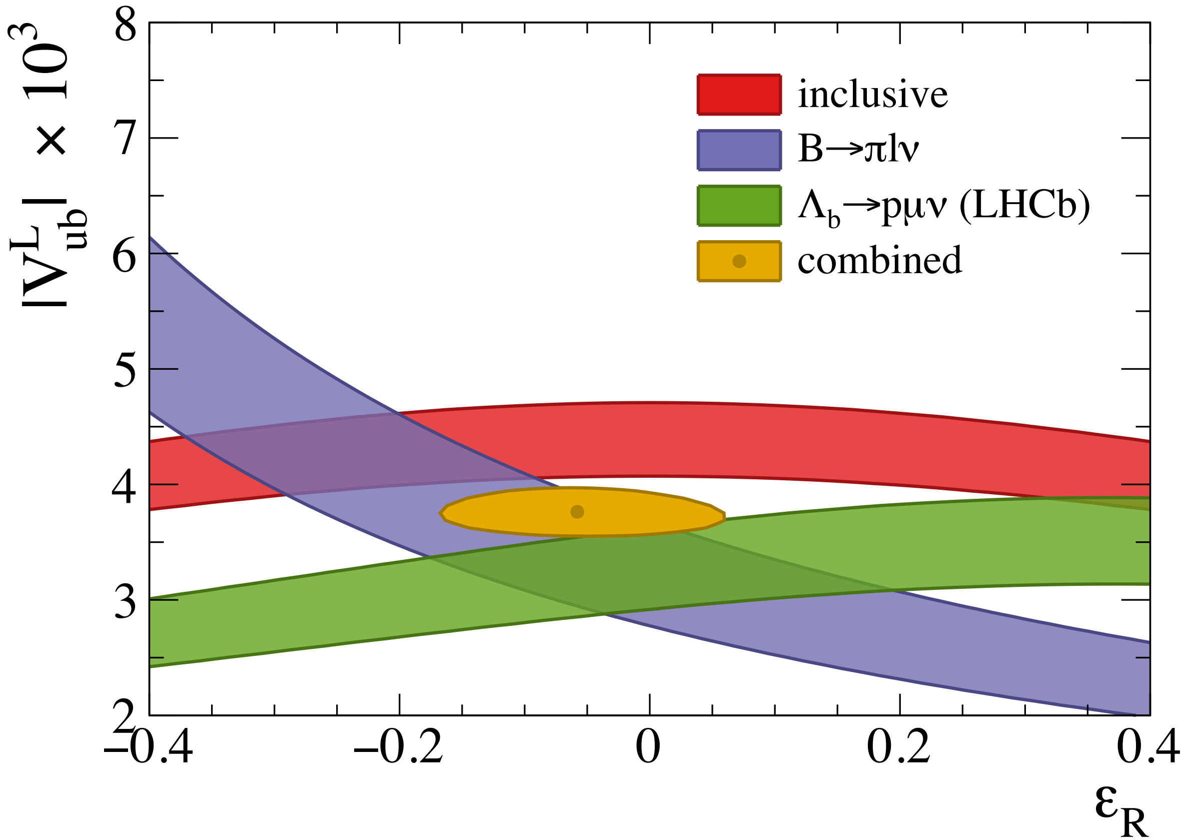

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Summary of CKM Metrology

	Belle	BaBar	Global Fit CKMfitter	LHCb Run-2	Belle II 50 ab^{-1} (2024)	LHCb Upgrade 50 fb^{-1} (2030)	Theory
ϕ_1: ccs	0.9°		0.9°	0.6°	0.3°	0.3°	small
ϕ_2: uud		4° (WA)	2.1°		1°		~1-2°
ϕ_3: DK	14°		2.5°	4°	1.5°	1°	tiny
$\|V_{cb}\|$ inclusive	1.7%		2.4%		1.2%		
$\|V_{cb}\|$ exclusive	2.2%				1.4%		
$\|V_{ub}\|$ inclusive	7%		4.5%		2.2%		
$\|V_{ub}\|$ exclusive	5%			7%**	2.0%	4%**	

Experiment

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

Theory

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

CKMFitter global fit, Input parameters

Data = weak ⊗ QCD → need hadronic inputs; often LQCD with our own Rfit-based averaging scheme.

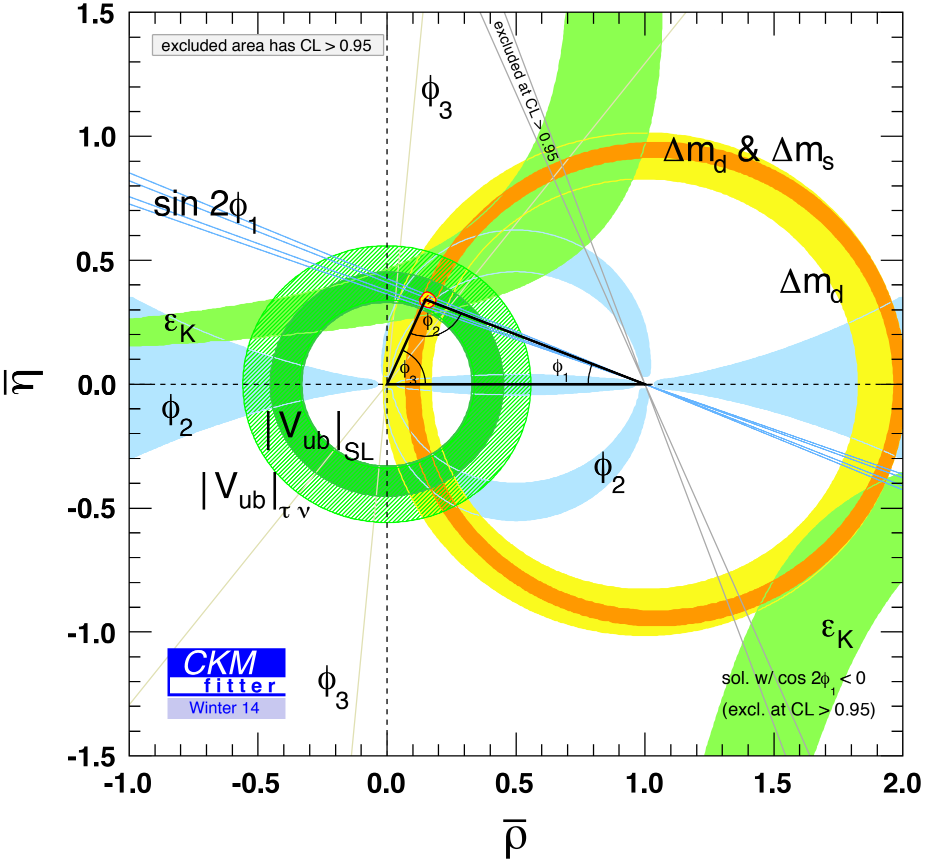
Modulus & Sides	$\|V_{ud}\|$	β decays	PRC 055502 (2009)
	$\|V_{us}\|$	K_{l3} (Flavianet)	$f_+(0)=0.9645 \pm 0.0015 \pm 0.0045$
		$K \to l\nu$, $\tau \to K\nu$	$f_K = (155.2 \pm 0.2 \pm 0.6)$ MeV
	$\|V_{us}/V_{ud}\|$	$K \to l\nu / \pi \to l\nu$, $\tau \to K\nu / \tau \to \pi\nu$	$f_K/f_\pi = 1.1942 \pm 0.0009 \pm 0.0030$
	$\|V_{ub}\|$	Inclusive & Exclusive	$(4.01 \pm 0.08 \pm 0.22)\ 10^{-3}$
	$B \to \tau\nu$	$(1.08 \pm 0.21)\ 10^{-4}$	$f_{Bs}/f_{Bd} = 1.205 \pm 0.003 \pm 0.006$ $f_{Bs} = (224.0 \pm 1.0 \pm 2.0)$ MeV
	$\|V_{cb}\|$	Inclusive & Exclusive	$(41.00 \pm 0.33 \pm 0.74)\ 10^{-3}$
	$\|V_{ub}\|/\|V_{cb}\|$	$Br(\Lambda_b \to p\mu\nu)/Br(\Lambda_b \to \Lambda_c\mu\nu)$	$(1.00 \pm 0.09)\ 10^{-2}$
Mixing	Δm_d	B_d mixing	$B_{Bs}/B_{Bd} = 1.023 \pm 0.013 \pm 0.014$
	Δm_s	B_s mixing	$B_{Bs} = 1.320 \pm 0.017 \pm 0.030$
CP Phase	ε_K	PDG	$B_K = 0.7615 \pm 0.0027 \pm 0.0137$
	β / Φ_1	$J/\psi\ K^{(*)}$ WA	0.691 ± 0.017
	α / Φ_2	$\pi\pi$, $\rho\pi$, $\rho\rho$ WA	Isospin, ~4°
	γ / Φ_3	$B \to D^{(*)} K^{(*)}$	GLW/ADS/GGSZ, ~7°

Generic Analyses for New Physics

CKMfitter PRD 91. 073007 (2015).

- Consistency is only at the 5% level in global fit.

$$\lambda^2 \equiv \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 \equiv \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$



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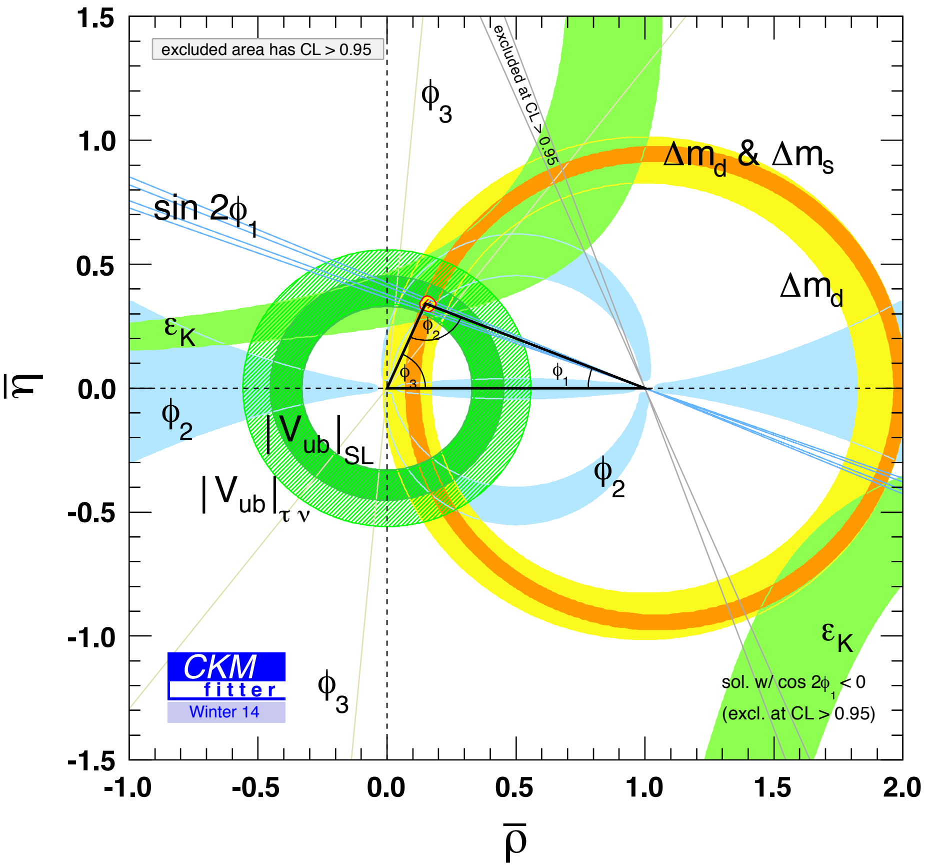
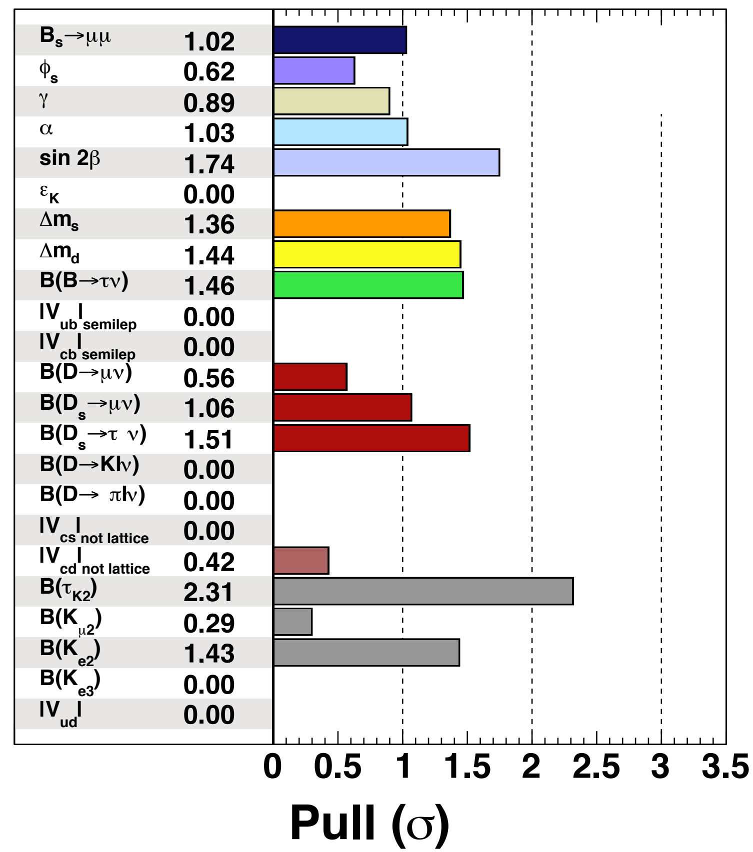
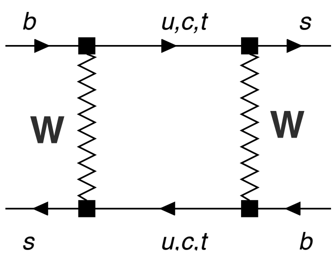


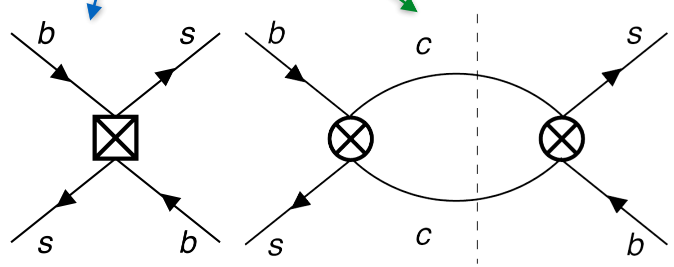


New Physics in mixing: past & future data

- Meson mixing,

$$i\frac{d}{dt}\begin{pmatrix}|B_q(t)\rangle \\ |\bar{B}_q(t)\rangle\end{pmatrix} = \left(M^q - \frac{i}{2}\Gamma^q\right)\begin{pmatrix}|B_q(t)\rangle \\ |\bar{B}_q(t)\rangle\end{pmatrix}$$





- SM: C_{SM}/m_W^2
- NP: C_{NP}/Λ^2

- What is the scale Λ ? How different is C_{NP} from C_{SM} ?
- If deviation from SM seen → upper bound on Λ

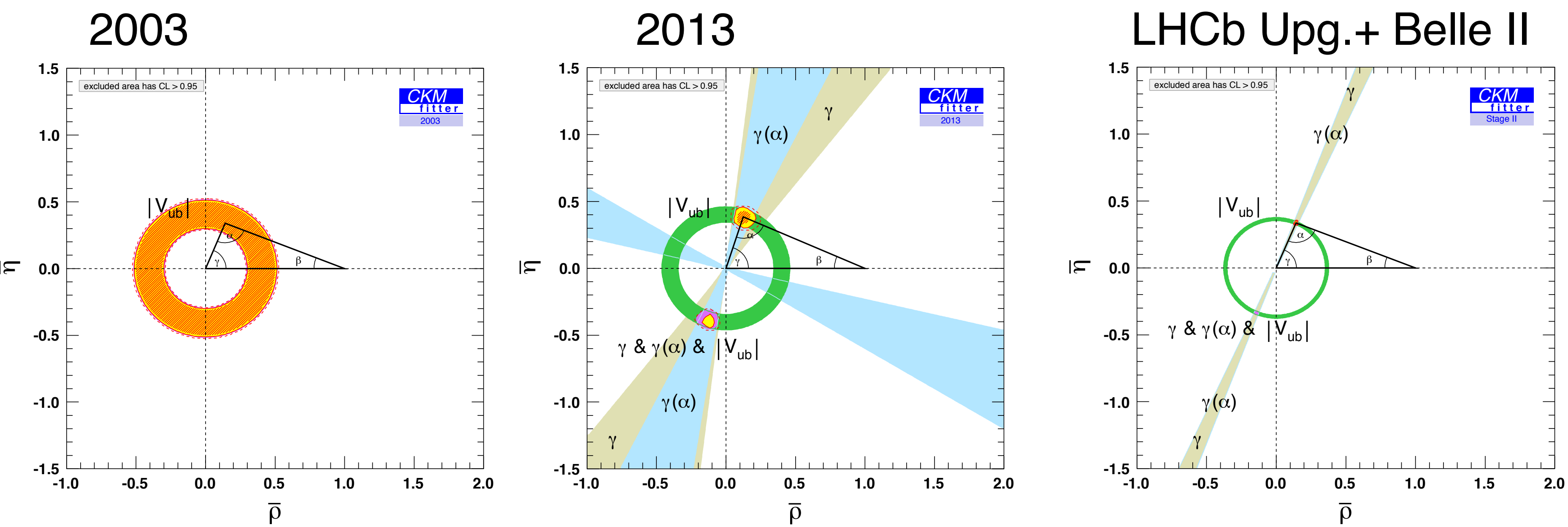
- Assume NP from Trees in negligible, test for NP in loops only - i.e. New Physics only enters M_{12}, the real part of the mixing Hamiltonian.

- 3 x 3 CKM matrix is unitary.

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

NP in $B_{\{d,s\}}$ & K mixing: Input

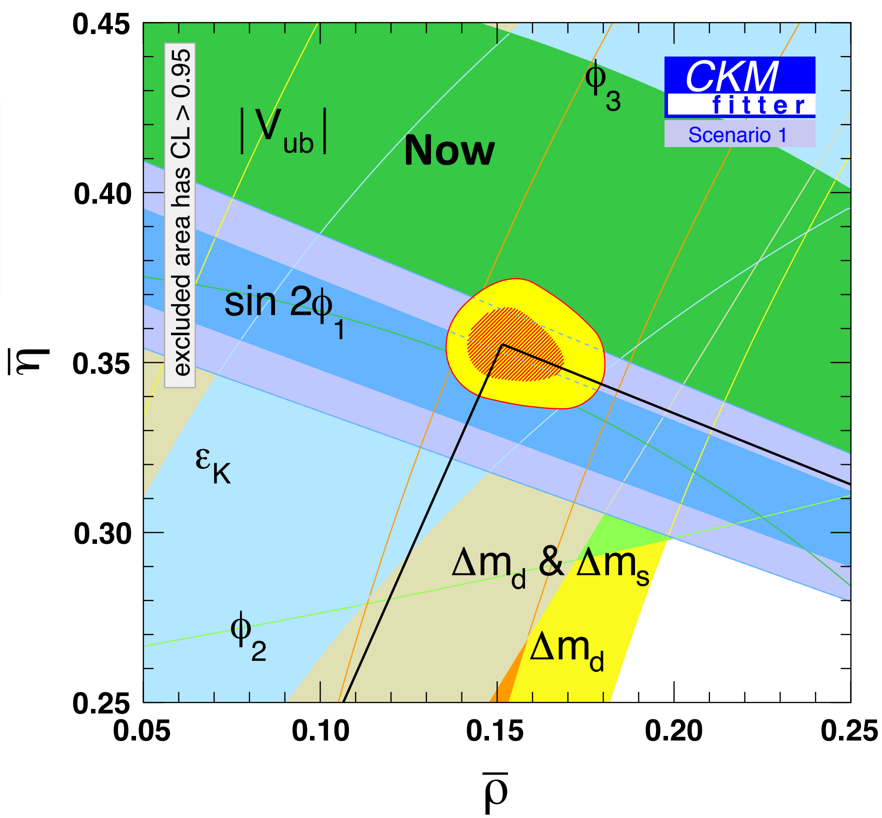
- Observables not affected by NP first used to constrain CKM:
  $|V_{ud}|, |V_{us}|, |V_{cb}|, |V_{ub}|, \Phi_3$ and $\Phi_2 = \pi - \Phi_3 - \Phi_{1eff}$((c anti-c)K)
- NP impact estimated from
  Meson mixing $\Delta m_s, \Delta m_d, |\varepsilon_K|$,
  Lifetime difference $\Delta\Gamma_s$, & semileptonic asymmetry A_{SL},
  Time dep. CP asymmetries β_s, Φ_1, and Φ_2 (decay-mixing interference)



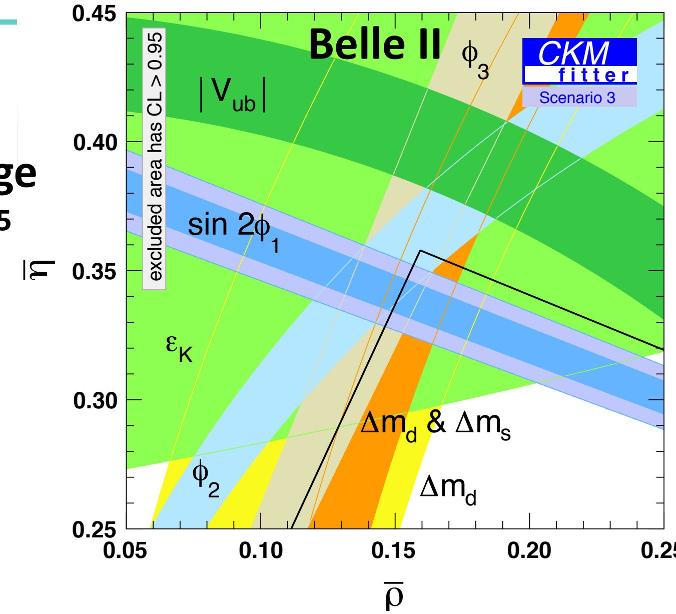
- Qualitative change after 2003: first Φ_3 and Φ_2 constraints

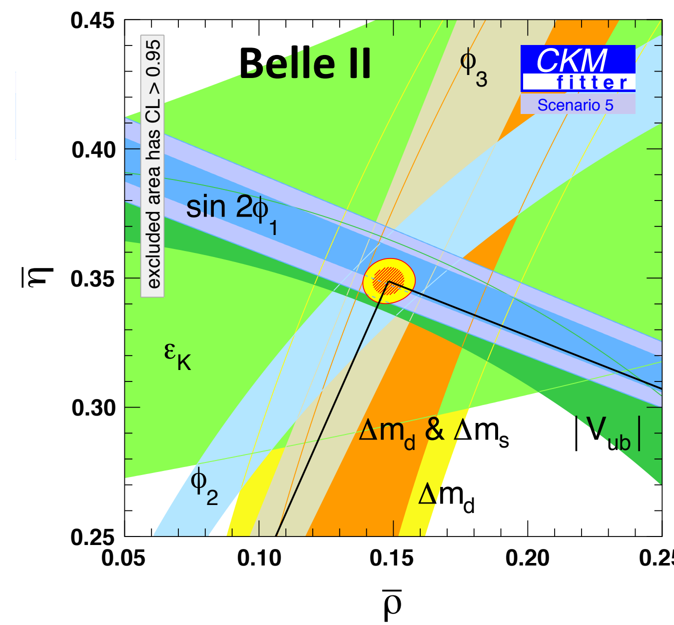
Belle II & LHCb projections

CKMfitter preliminary



World Average
p-value=10^{-5}



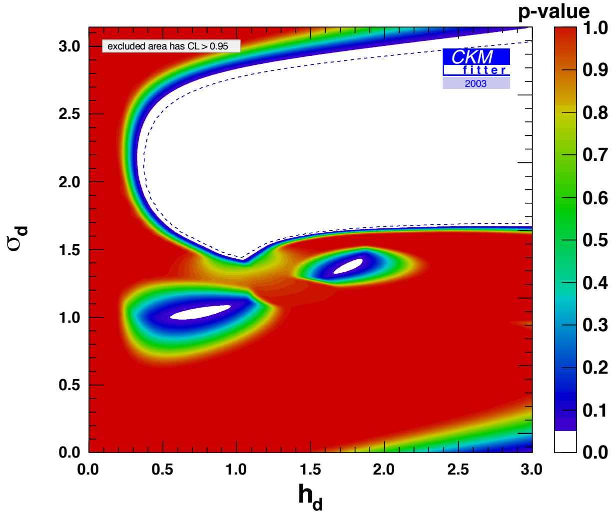


Phase	**J [10^{-5}]**	**SM-like Δ**
2016	3.140 [+0.069 -0.084]	2%
Belle II + LHCb upgrade - SM-like	3.125 ± 0.033	1%

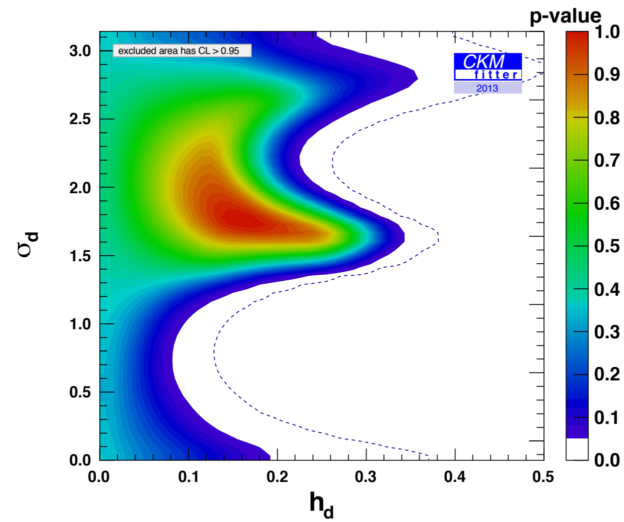
NP in B_d mixing: Fit results

CKMfitter PRD 91, 073007 (2015), PRD 89, 033016 (2014)

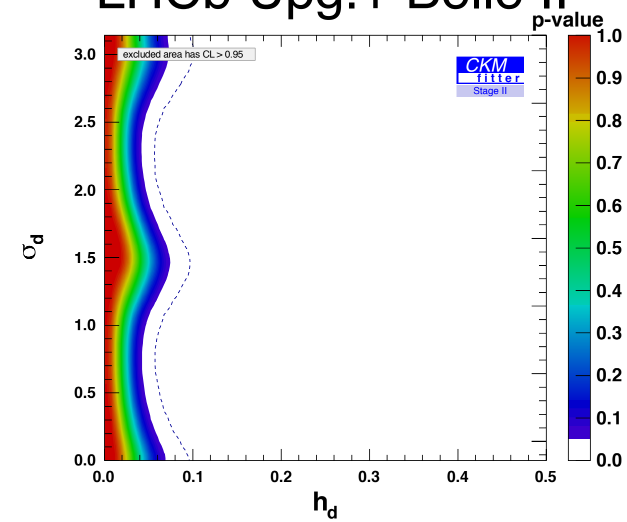
2003



2013



LHCb Upg.+ Belle II



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

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

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

Couplings	NP loop order	Scales (TeV) probed by B_d mixing	Scales (TeV) probed by B_s mixing
$\|C_q\| = \|V_{tb} V_{tq}^*\|$ (CKM-like)	tree level	17	19
	one loop	1.4	1.5
$\|C_q\| = 1$ (no hierarchy)	tree level	2×10^3	5×10^2
	one loop	2×10^2	40

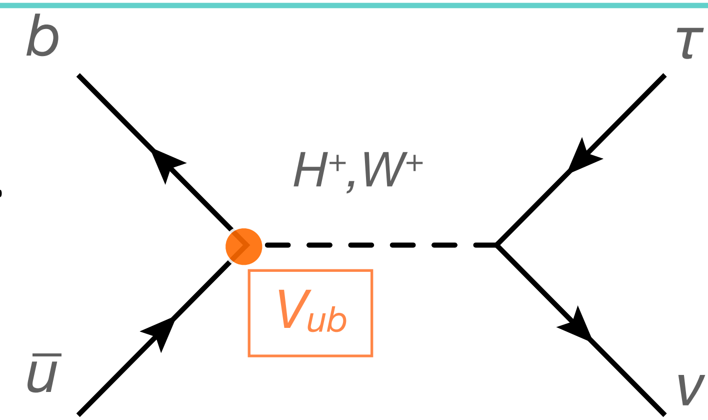
- Stage II: similar sensitivity to gluino masses explored at LHC 14TeV

Areas to watch

Belle II Flagship: H^+ Search in $B^+ \to \tau\upsilon$, $\mu\upsilon$

Helicity suppressed - very small in SM.

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



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

$\mathbf{BF_{SM}}$

$\mathbf{r_H}$

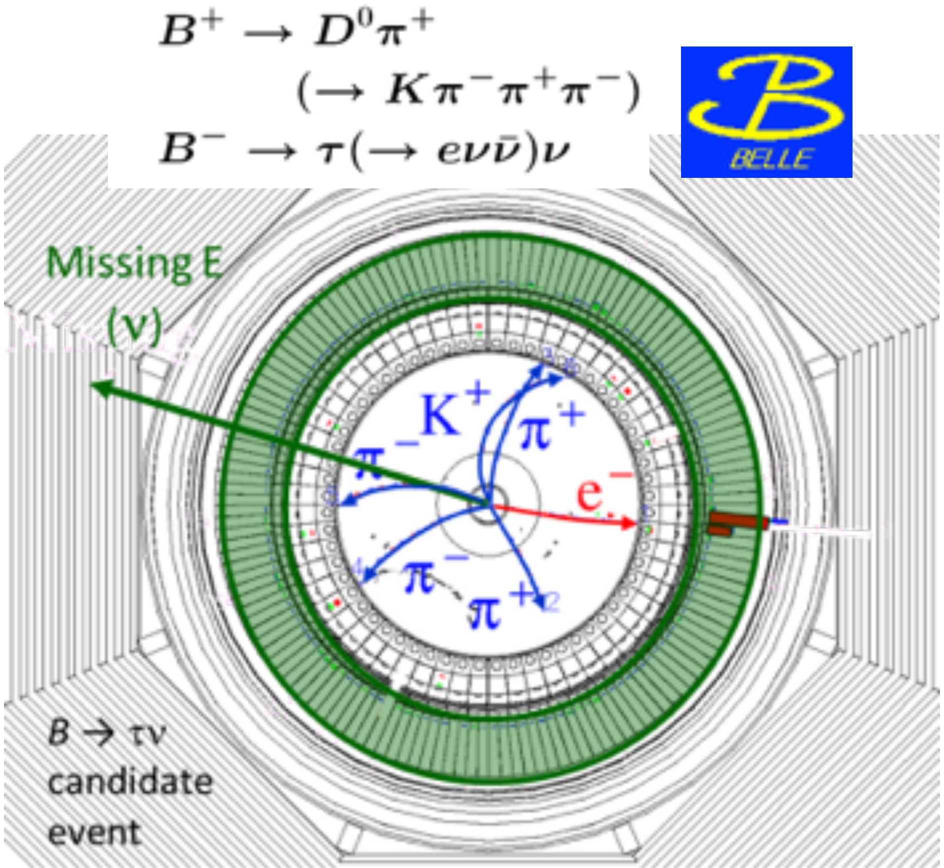
Type	λ_{DD}	λ_{LL}
I	$\cot\beta$	$\cot\beta$
II	$-\tan\beta$	$-\tan\beta$
III	$-\tan\beta$	$\cot\beta$
IV	$\cot\beta$	$-\tan\beta$

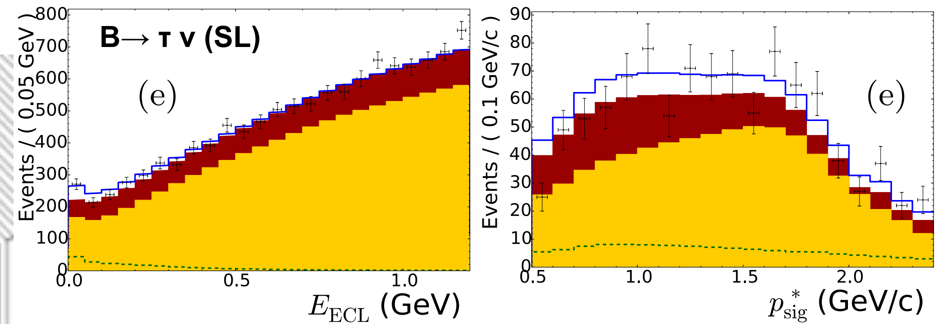
The B meson decay constant

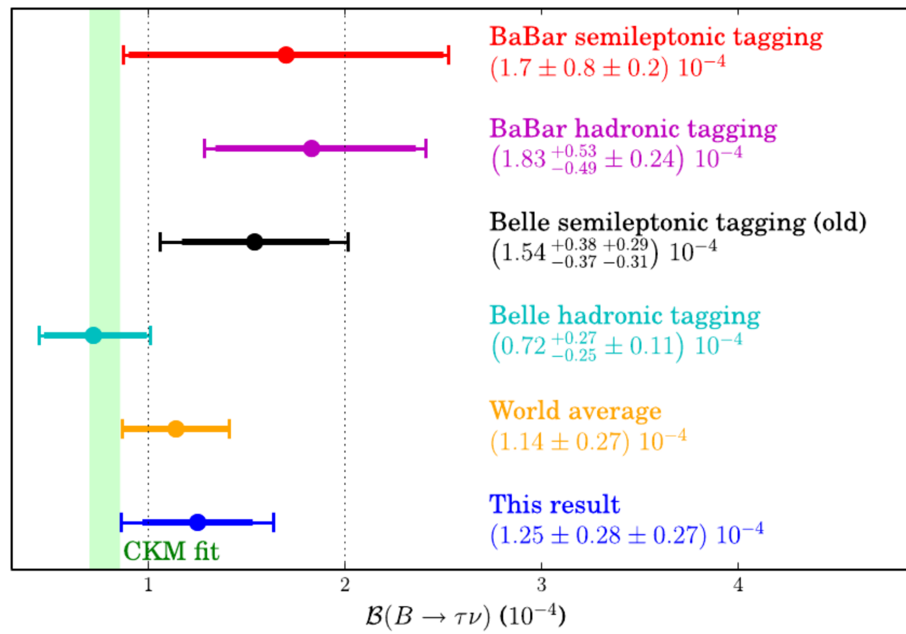
$|V_{ub}|$: from indep. measurements.

B→τν Measurements

Belle, B→ τ ν (Had) PRL110 131801 (2013)
Belle, B→ τ ν (SL) PRD 92, 5, 051102 (2015)



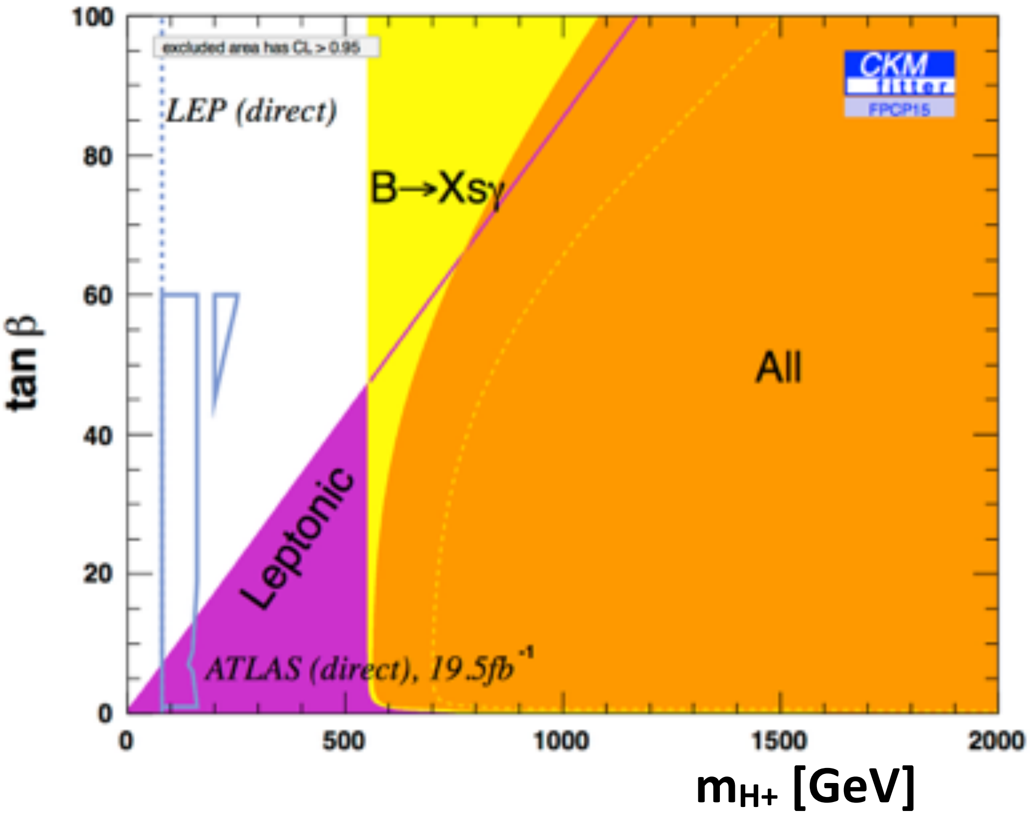




The clean e+e- environment makes this possible

NP Fits with CKMFitter

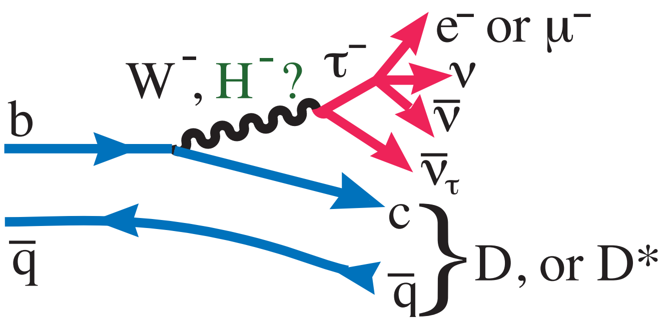
L. Pesantez, PU, CKMFitter, 2015



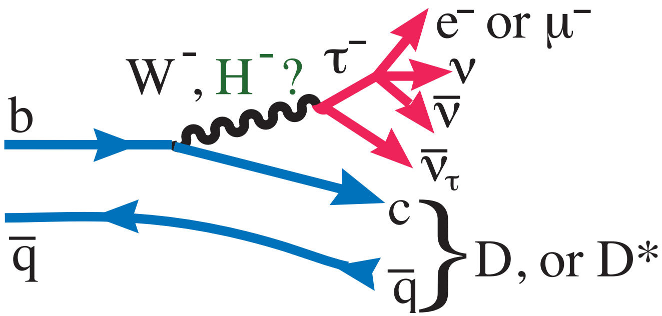
The current flavour results place stronger constraints than direct searches from LHC exps.

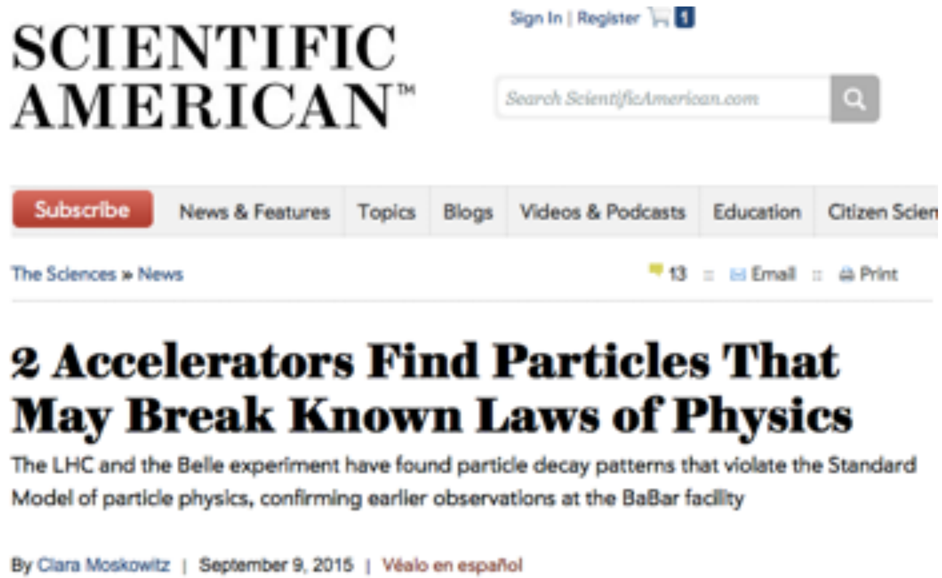
	Belle Ave.	Belle II	
		$5\ ab^{-1}$	$50\ ab^{-1}$
$B\to\tau\nu$	96(1±22%)	10%	3%
$B\to\mu\nu$	<1.7	20%	7%

Most curious hint of NP in heavy flavour



Most curious hint of NP in heavy flavour





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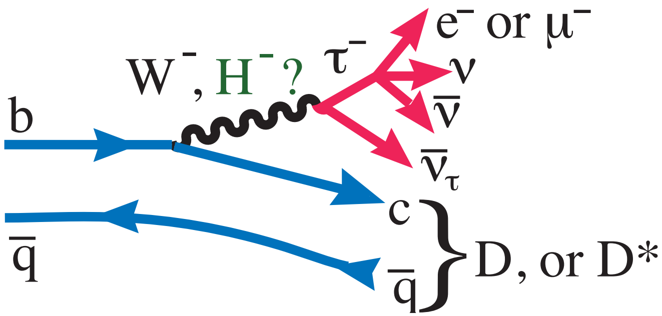
The Sciences » News

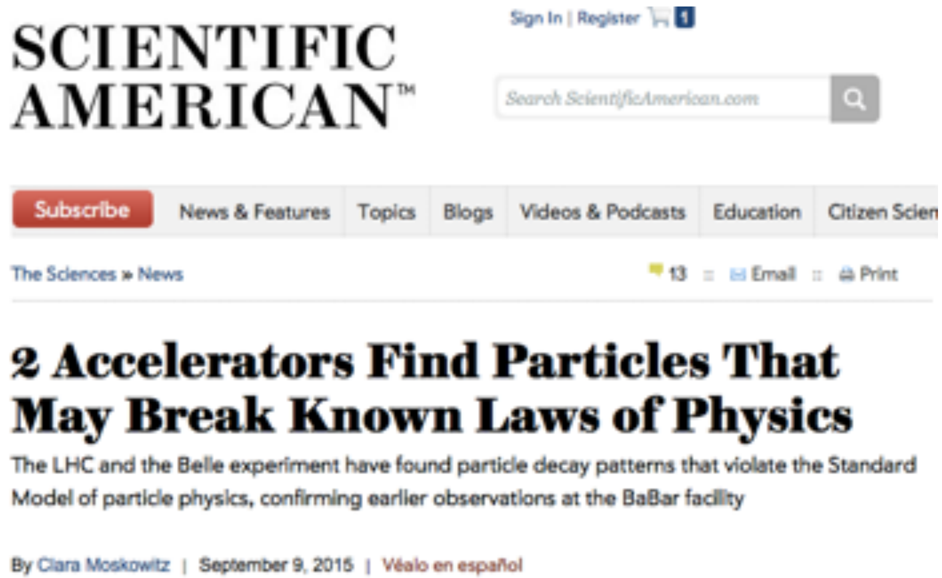
2 Accelerators Find Particles That May Break Known Laws of Physics

The LHC and the Belle experiment have found particle decay patterns that violate the Standard Model of particle physics, confirming earlier observations at the BaBar facility

By Clara Moskowitz | September 9, 2015 | Véalo en español

Most curious hint of NP in heavy flavour



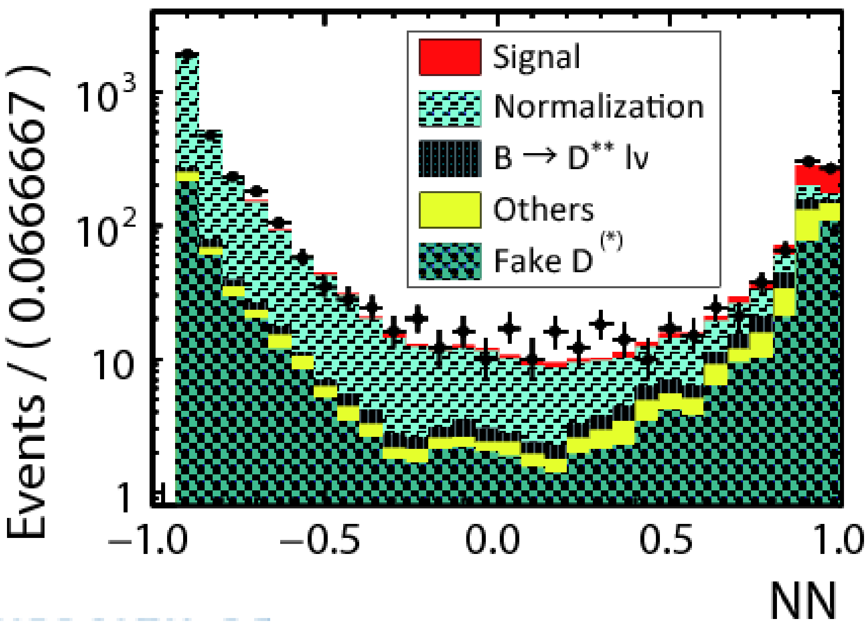


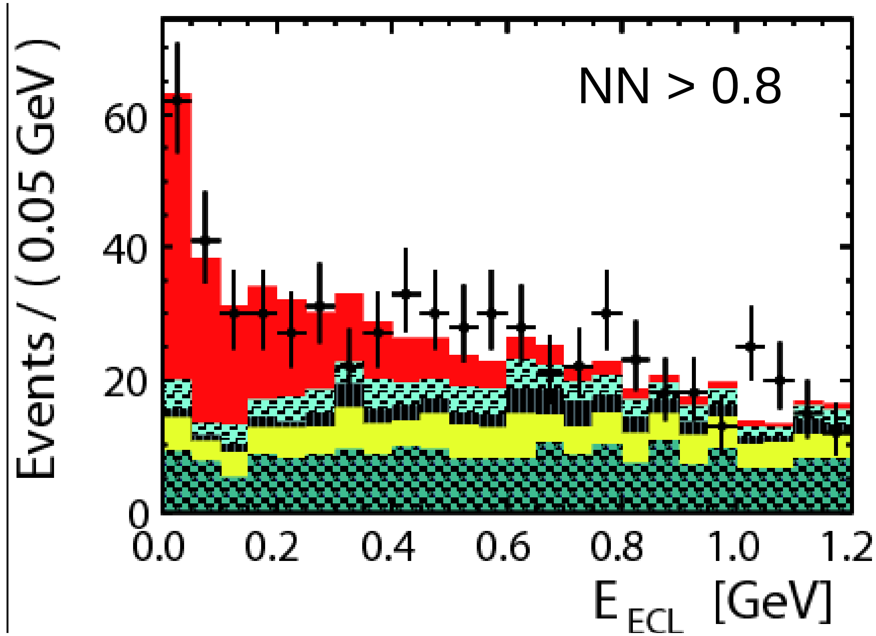
$R(D^{(*)}) = BR(B \to D^{(*)} \tau \nu)/BR(B \to D^{(*)} \mu \nu)$

Babar, Phys.Rev.D 88, 072012 (2013)
Belle, Phys.Rev.D 92, 072014 (2015)
Belle, [arXiv:1603.06711]
LHCb, PRL.115,111803 (2015)

- Reconstruct one B in Υ(4S)→BB event
  - Either hadronic (PR D92 (2015) 072014) or semileptonic (arXiv: 1603.06711) decay mode
  - First application of semileptonic tagging for B →D(*)τν
- Look for signal in the recoil, B→D*τν, D* → Dπ, D→many, τ→lνν,

$R(D^*) = 0.302 \pm 0.030 \pm 0.011$



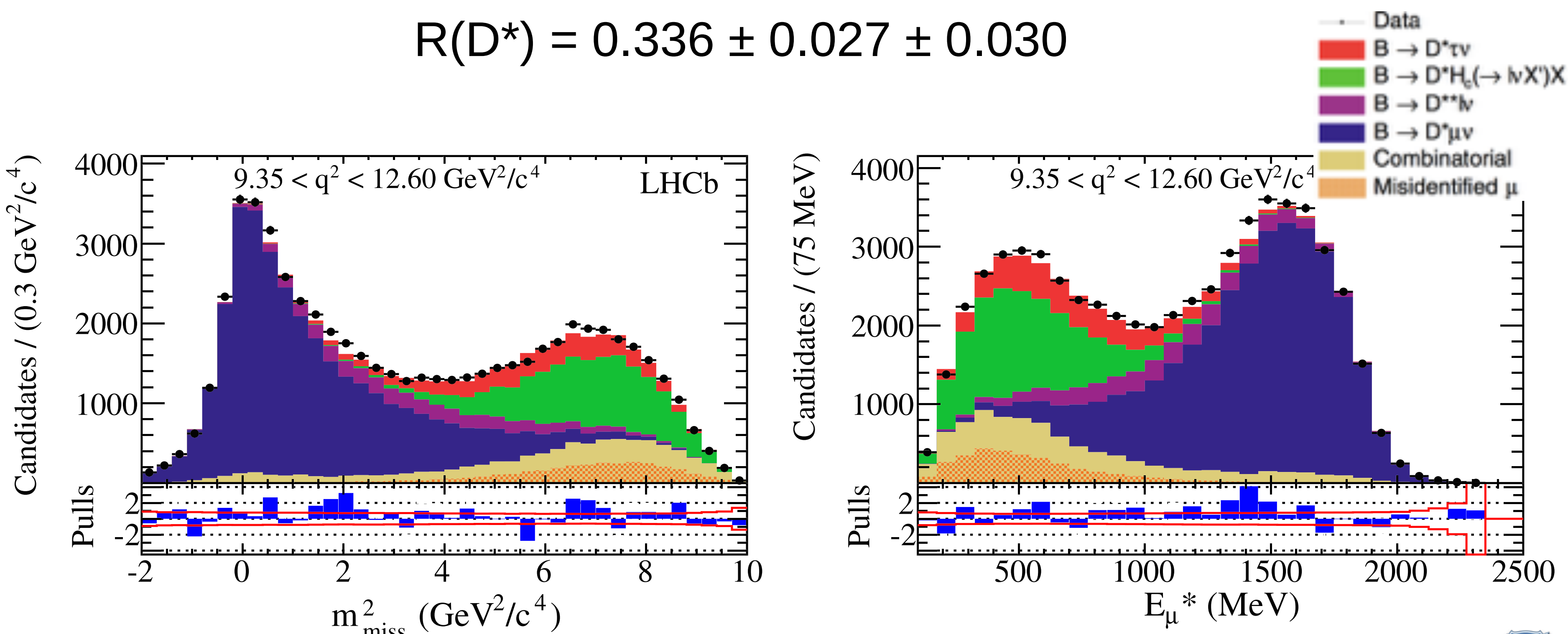


$R(D^{(*)})$ @ LHCb

Babar, Phys.Rev.D 88, 072012 (2013)
Belle, Phys.Rev.D 92, 072014 (2015)
Belle, [arXiv:1603.06711]
LHCb, PRL.115,111803 (2015)

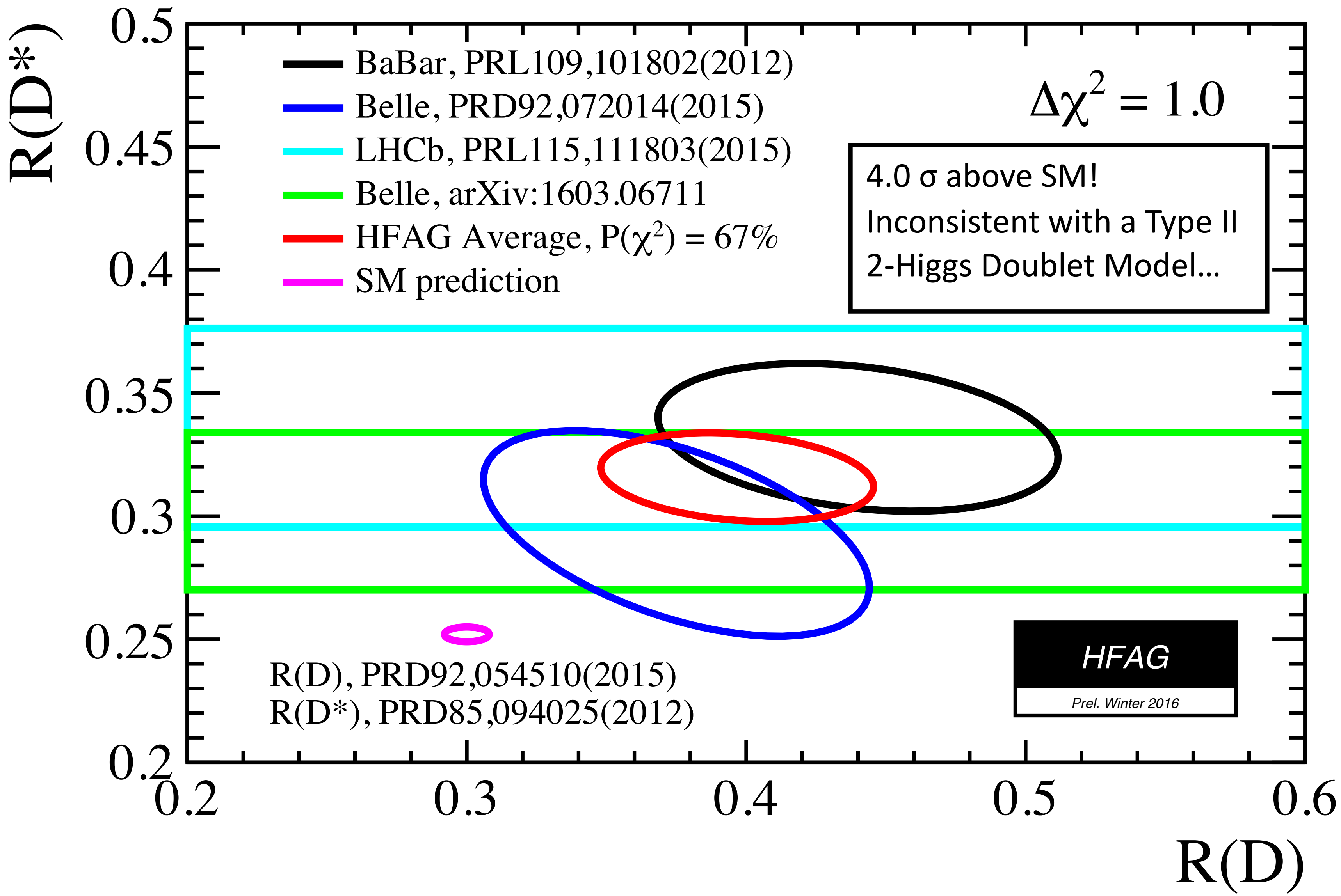
- Identify $B \rightarrow D^{*}\tau\nu$, $D^{*} \rightarrow D\pi$, $D \rightarrow K\pi$, $\tau \rightarrow \mu\nu\nu$
- Assume $p_{B,z} = (p_{D^*} + p_{\mu})_z$ to calculate $M_{miss}^2 = (p_B - p_{D^*} - p_{\mu})^2$
- Require significant B, D, τ flight distances, fit in M_{miss}^2, q^2 and E_{μ}

$$R(D^*) = 0.336 \pm 0.027 \pm 0.030$$



We need more data! (more to come from Belle)

HFAG Winter 2016



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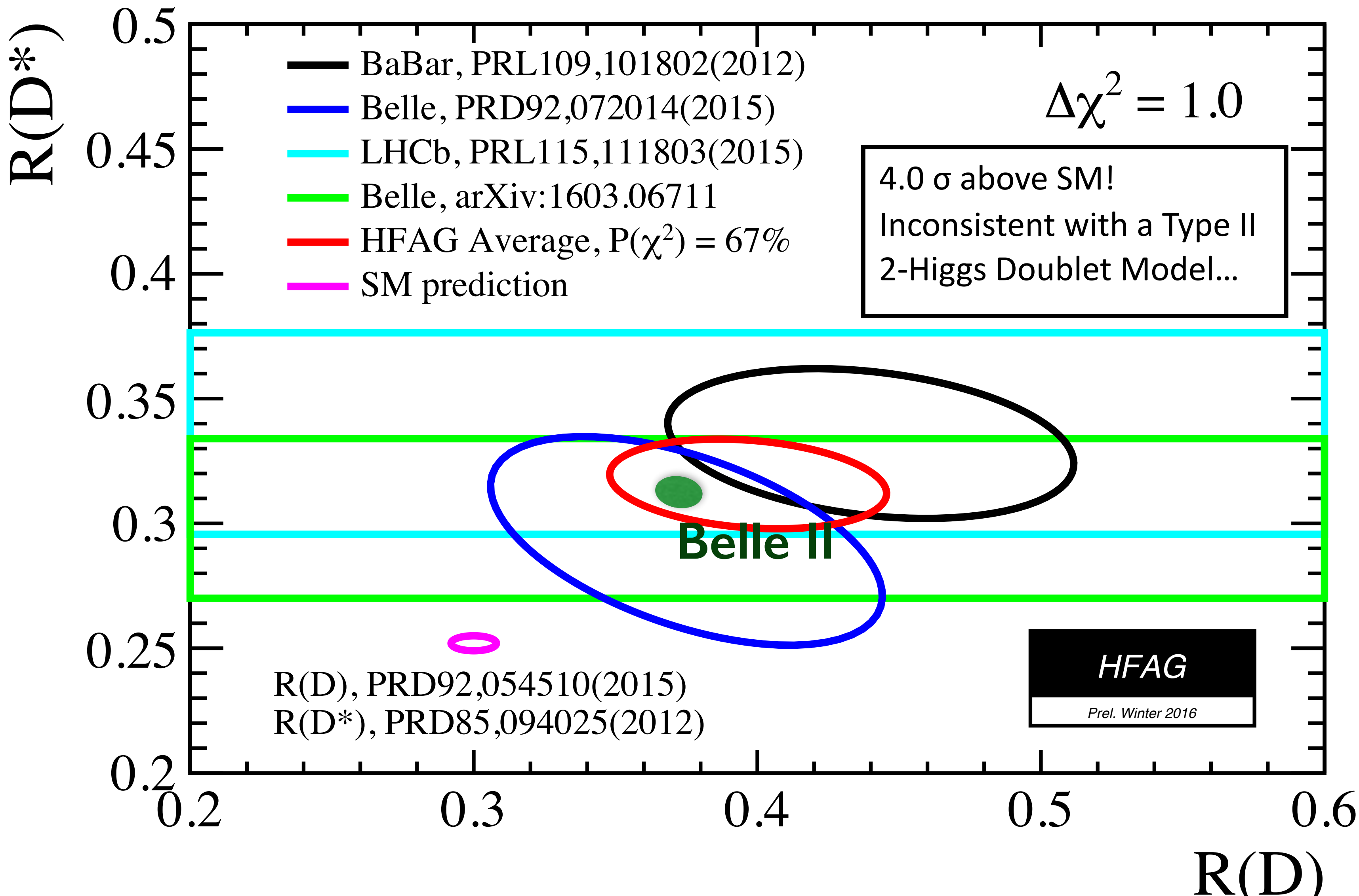
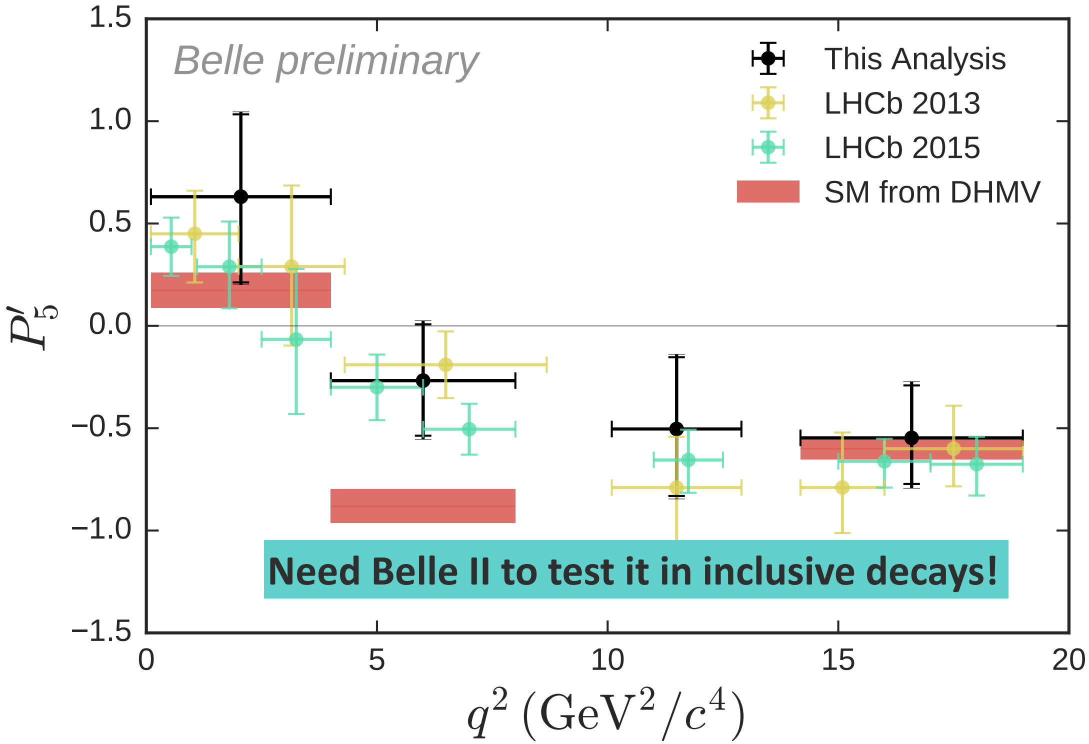


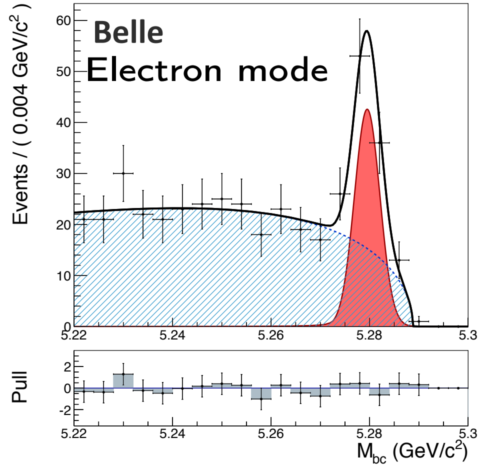
B→ K* l+ l-

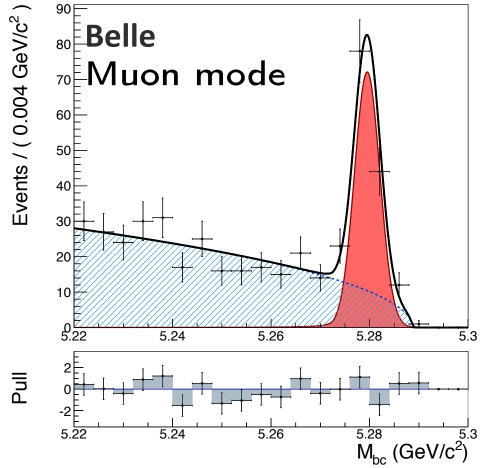
Belle, arXiv:1604.04042
Babar, JHEP 1602 (2016) 104

- P_5' anomaly > 3.5 σ (Belle + LHCb)
- Analysis of longitudinal and transverse polarisation.

$$P_5' = \sqrt{2}\frac{\mathrm{Re}\left(A_0^{\mathrm{L}}A_\perp^{\mathrm{L}*} - A_0^{\mathrm{R}}A_\perp^{\mathrm{R}*}\right)}{\sqrt{\left(|A_0^{\mathrm{L}}|^2 + |A_0^{\mathrm{R}}|^2\right)\left(|A_\parallel^{\mathrm{L}}|^2 + |A_\parallel^{\mathrm{R}}|^2 + |A_\perp^{\mathrm{L}}|^2 + |A_\perp^{\mathrm{R}}|^2\right)}}$$







Golden modes: B physics

PU, j.nuclphysbps 263–264 (2015) 15–23

	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
	$S(B \to K_S^0 K_S^0 K_S^0)$	$0.30 \pm 0.32 \pm 0.08$ [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	$\|V_{cb}\|$ incl.	$41.6 \cdot 10^{-3}(1 \pm 1.8\%)$ [8]	1.2%	
	$\|V_{cb}\|$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\text{ex.}} \pm 2.7\%_{\text{th.}})$ [10]	1.8%	1.4%
	$\|V_{ub}\|$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\text{ex.}} \pm 2.5\%_{\text{th.}})$ [5]	3.4%	3.0%
	$\|V_{ub}\|$ 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
	$S(B \to K_S^0 \pi^0 \gamma)$	$-0.10 \pm 0.31 \pm 0.07$ [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

PU, j.nuclphysbps 263–264 (2015) 15–23

	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
	$\|q/p\|(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$ [52]	0.10	0.07
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ $[^\circ]$	$-6 \pm 11 \pm {}^{4}_{5}$ [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

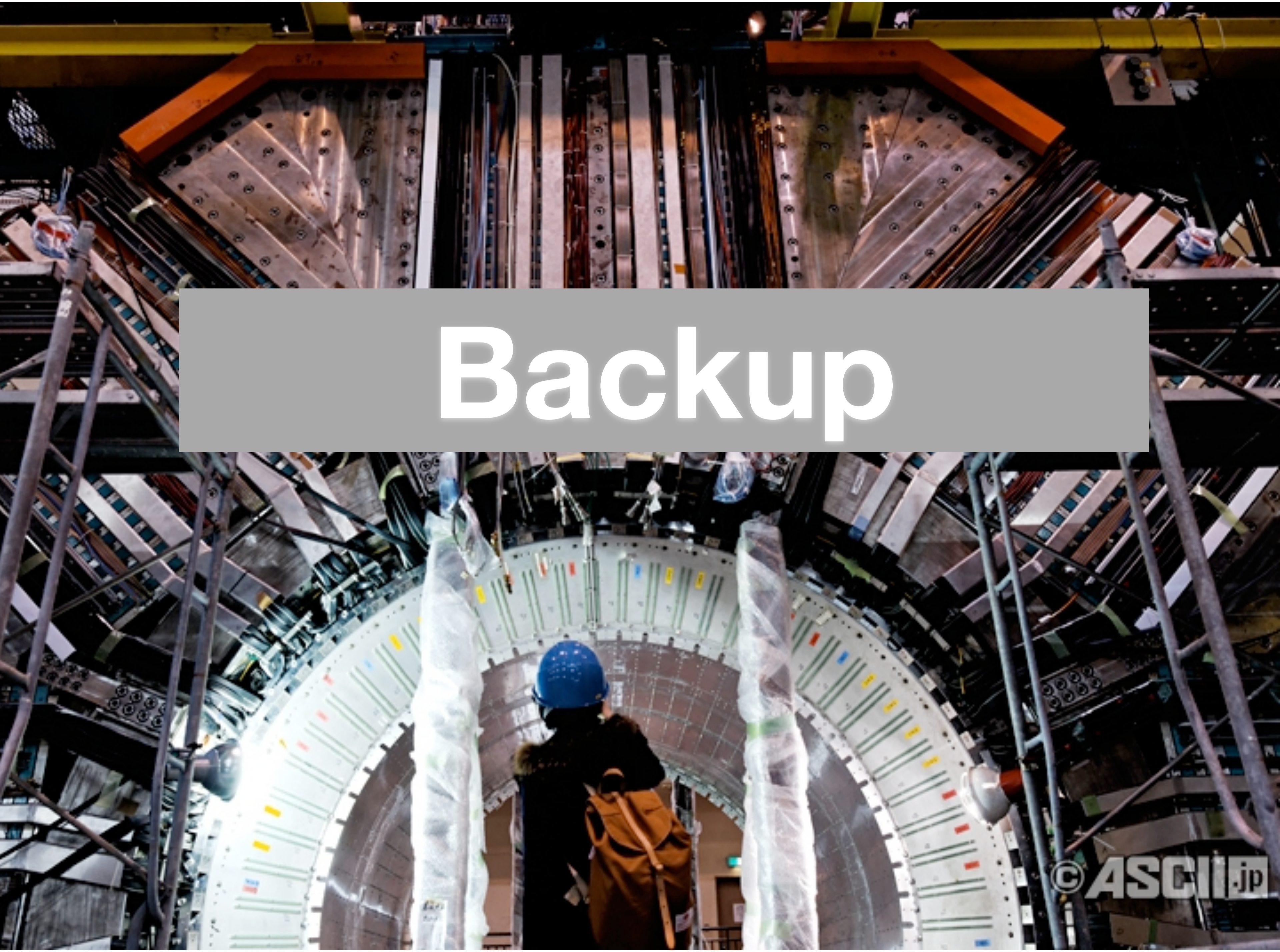
Summary

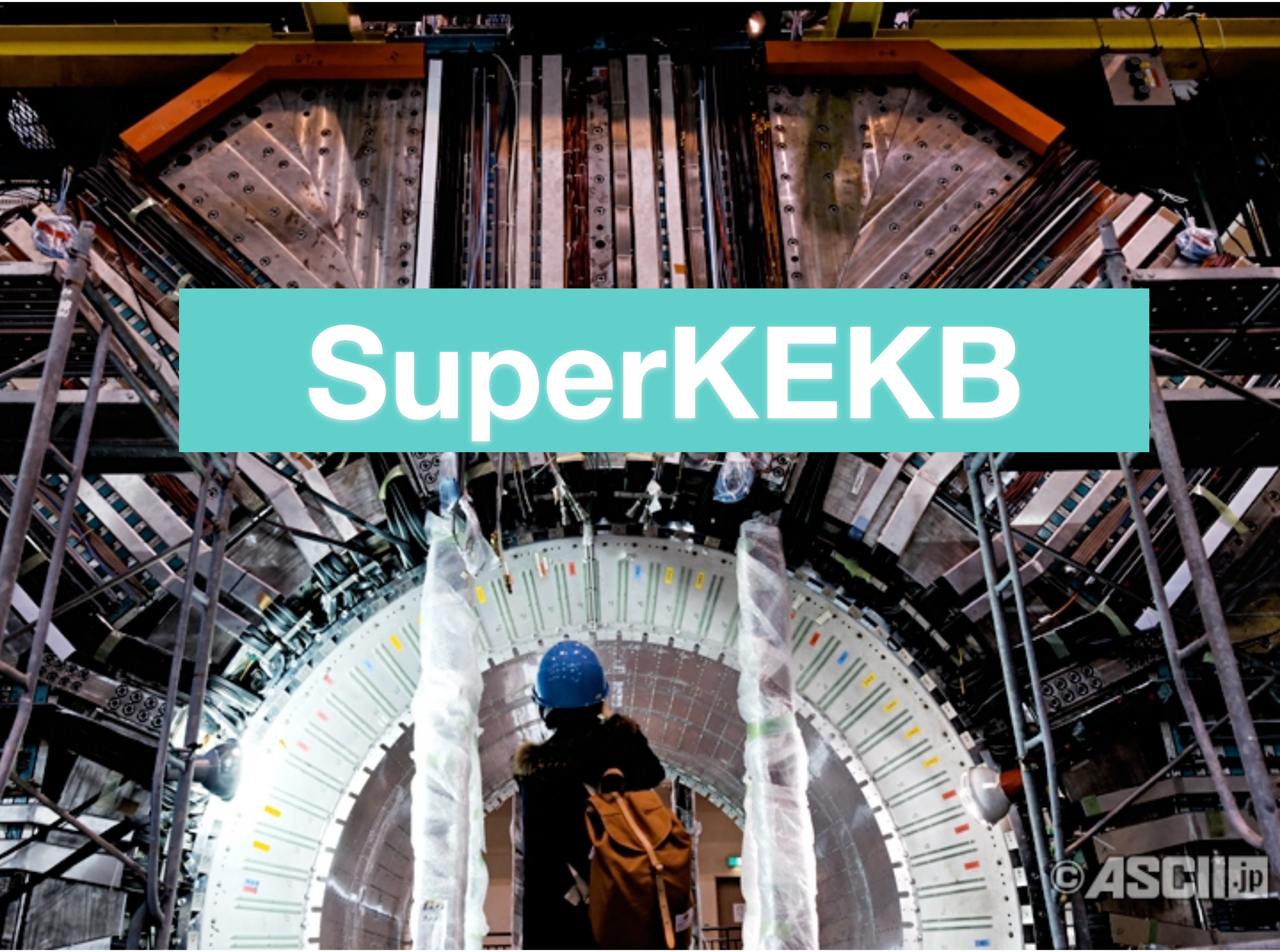
- CP Violation measurements are a key driver of the heavy flavour program.
- ~10% (CP-violating) amplitude of NP still open.
- Very curious anomalies in rare decays hint at charged Higgs-like, and possibly left-right symmetry.

- SuperKEKB has been brought to life - first turns occurred in February. Current now almost 1 Amp! **See C. Kiesling's talk.**
- **Rich physics programs at SuperKEKB/Belle II and LHCb upgrades.**
  - 50 × integrated luminosity @ Belle II
  - New sources of CPV, New gauge bosons, Lepton Flavour Violation, Dark Sectors.
  - Numerous anomalies to probe with the first 5 ab^{-1}.

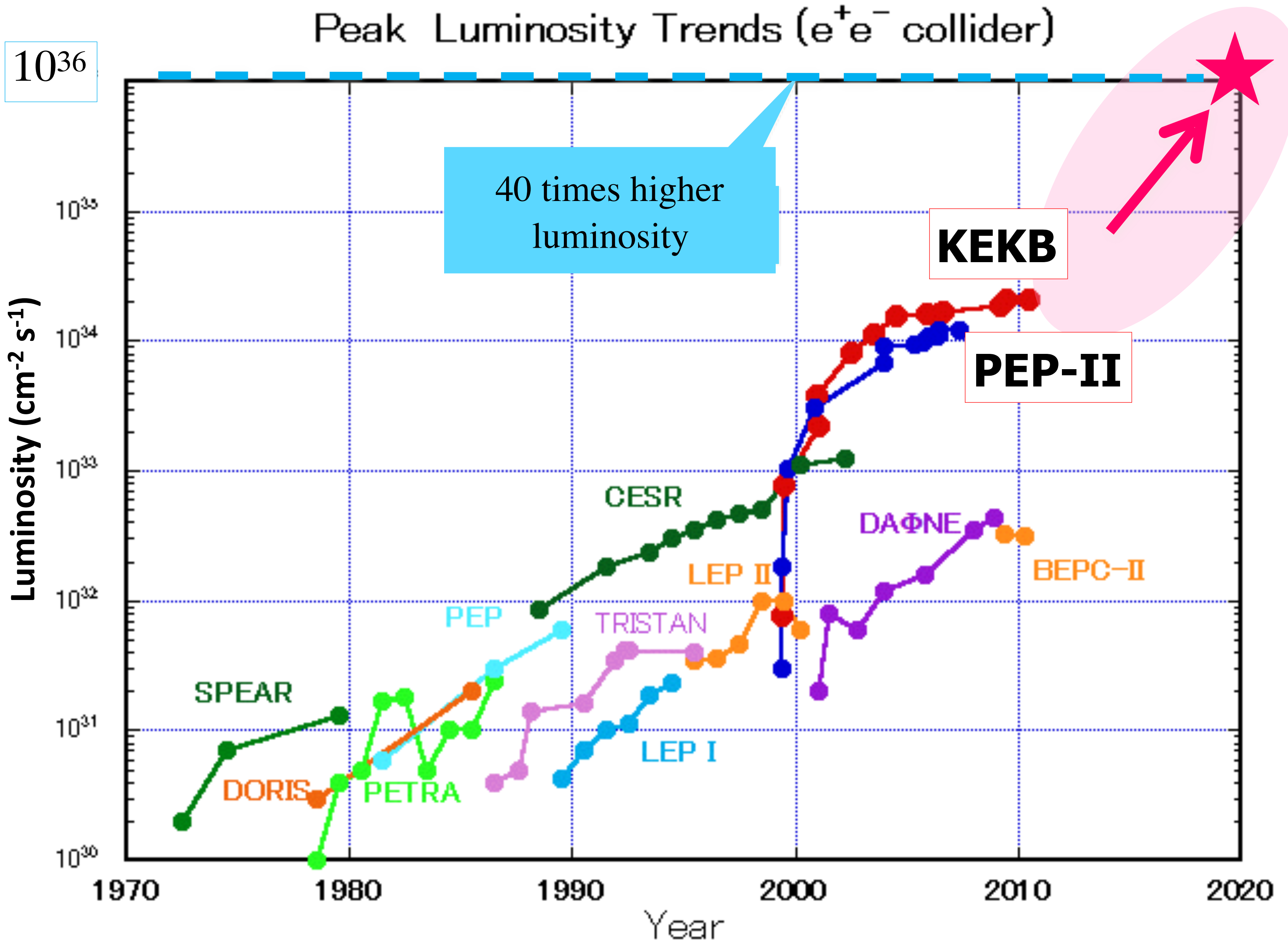
- **Belle II Theory Interface Platform - 2 workshops per year https://belle2.cc.kek.jp/~twiki/bin/view/B2TiP**

Backup

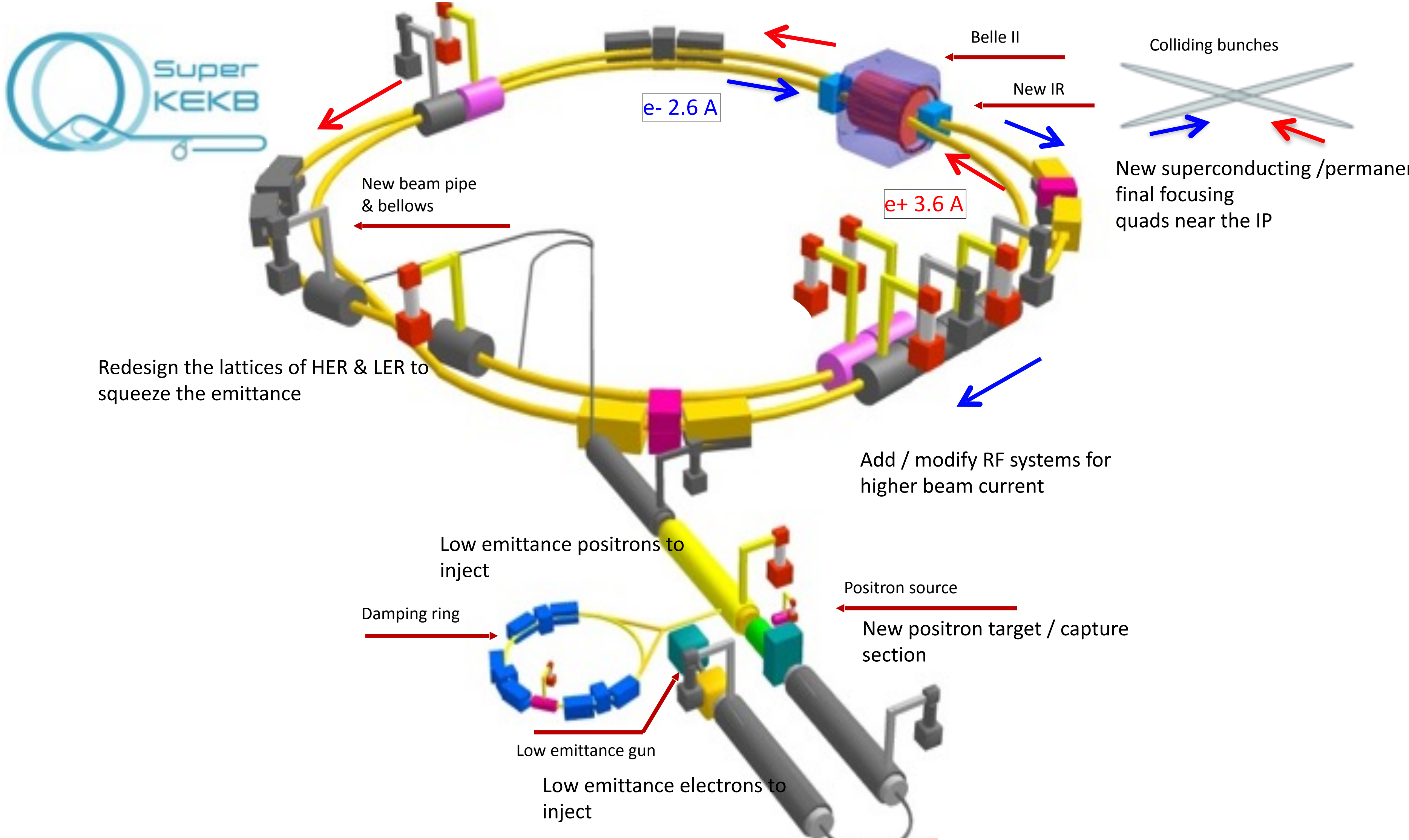



SuperKEKB
© ASCII.jp

Belle II at the e+e- intensity frontier: @509 MHz

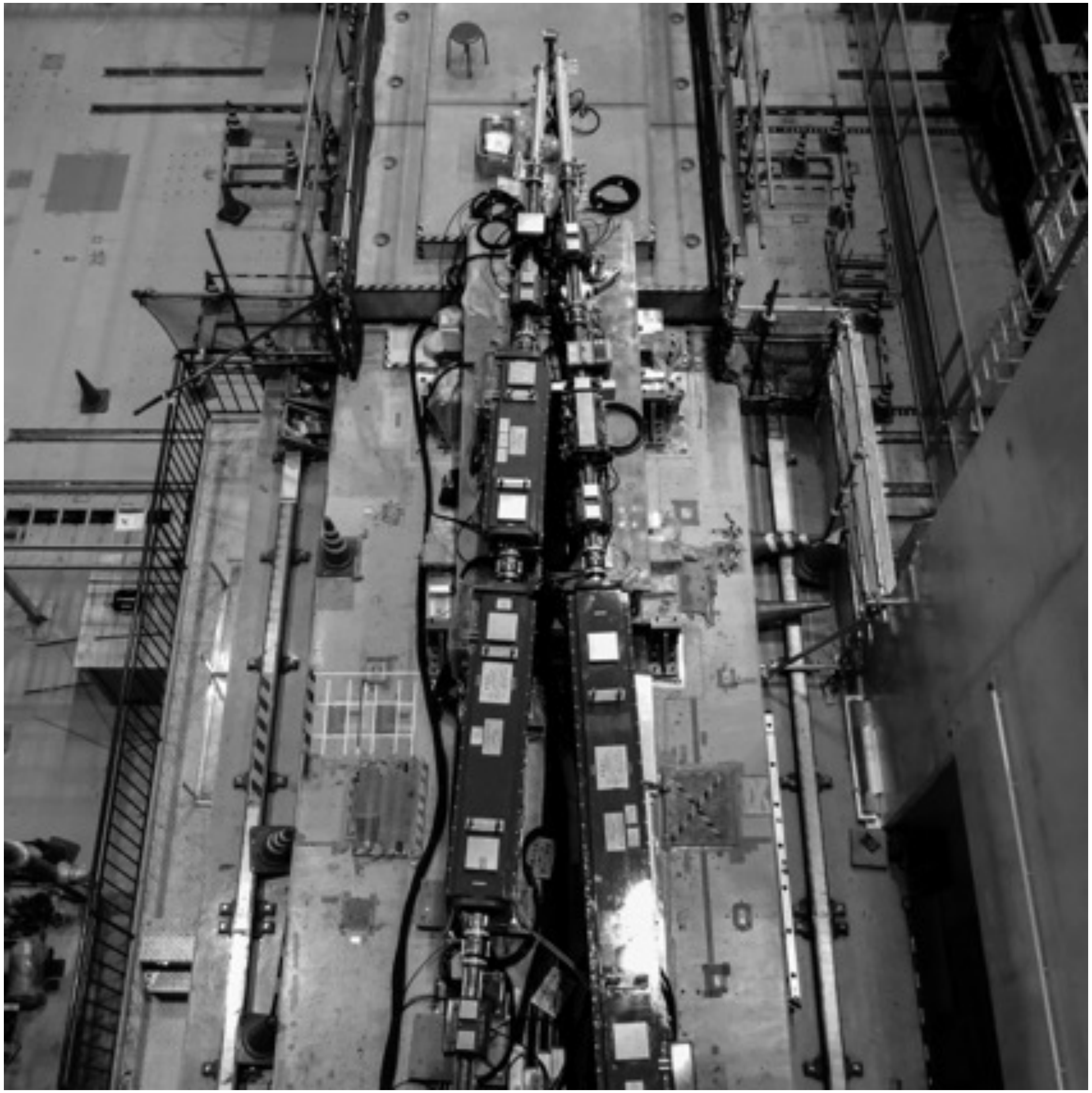


KEKB to SuperKEKB

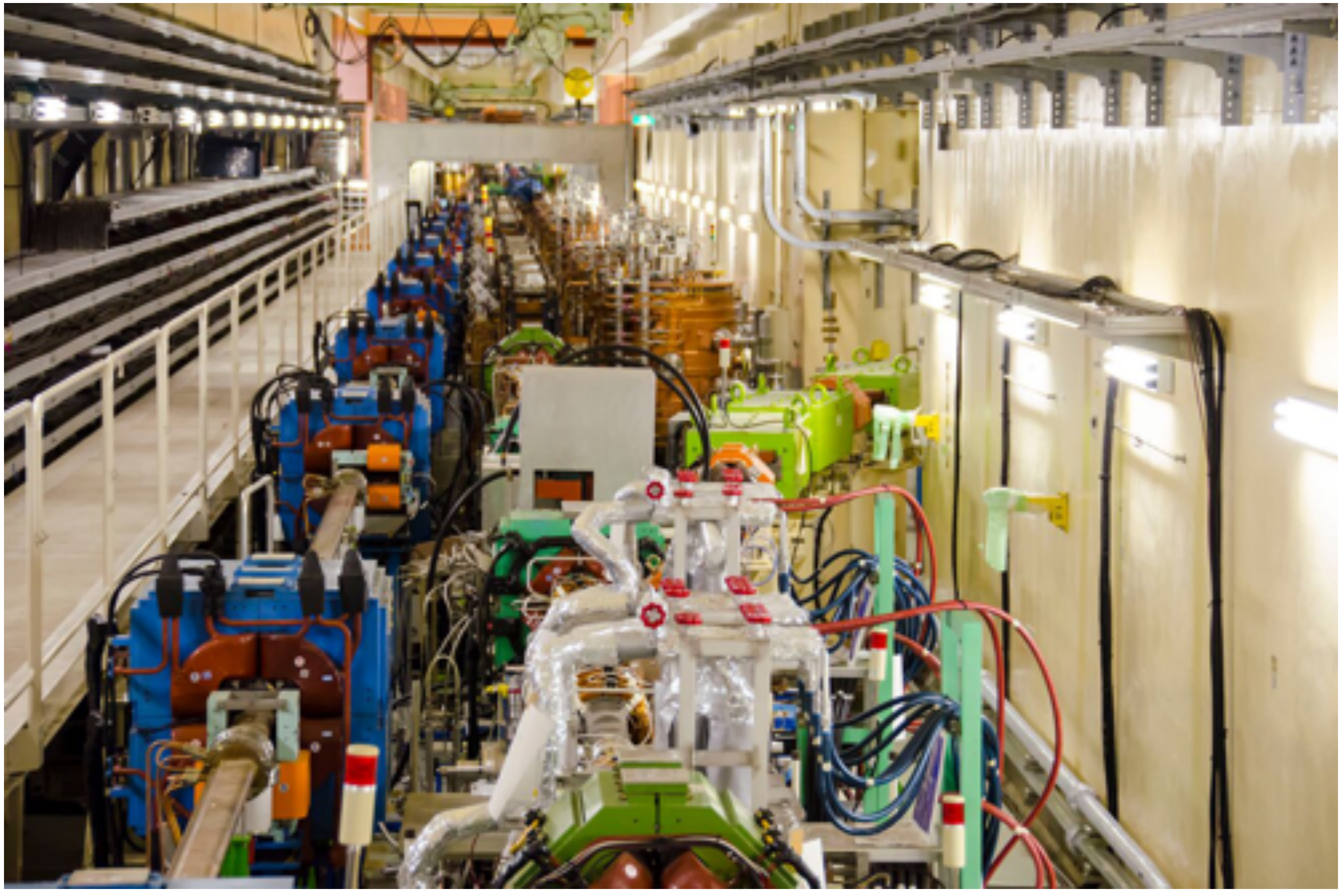


To obtain x40 higher luminosity

SuperKEKB near Belle II collision region, Late 2015



Feb 2016 News: First Turns at SuperKEKB (4 GeV e+'s and 7 GeV e-'s)



May 23, 2016 (LER beam current at 790 mA, HER at 730 mA)

First new particle collider since the LHC (*intensity frontier* rather than energy frontier; $e^+ e^-$ rather than p p)

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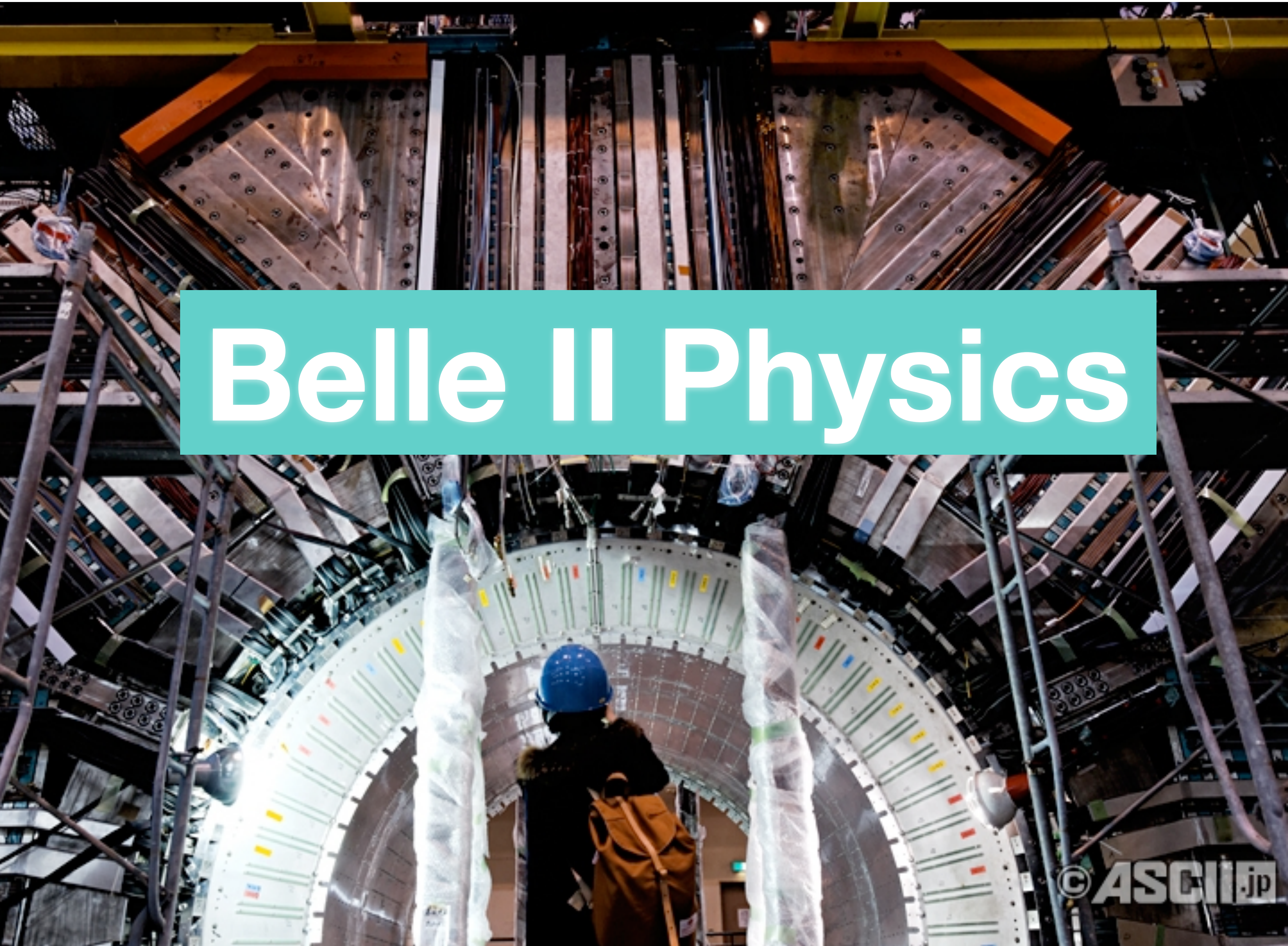
First new particle collider since the LHC (*<u>intensity frontier</u>* rather than energy frontier; $e^+ e^-$ rather than p p)

Compare the Parameters for KEKB and SuperKEKB

	KEKB Design	KEKB Achieved : with crab	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
$\beta_y{}^*$ (mm)	10/10	5.9/5.9	0.27/0.30
$\beta_x{}^*$ (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\varepsilon_y / \varepsilon_x$ (%)	1	0.85/0.64	0.27/0.24
σ_y(mm)	1.9	0.94	0.048/0.062
σ_x(cm)	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6 - 7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	80

Nano-beams are the key (vertical spot size is ~50nm !!)

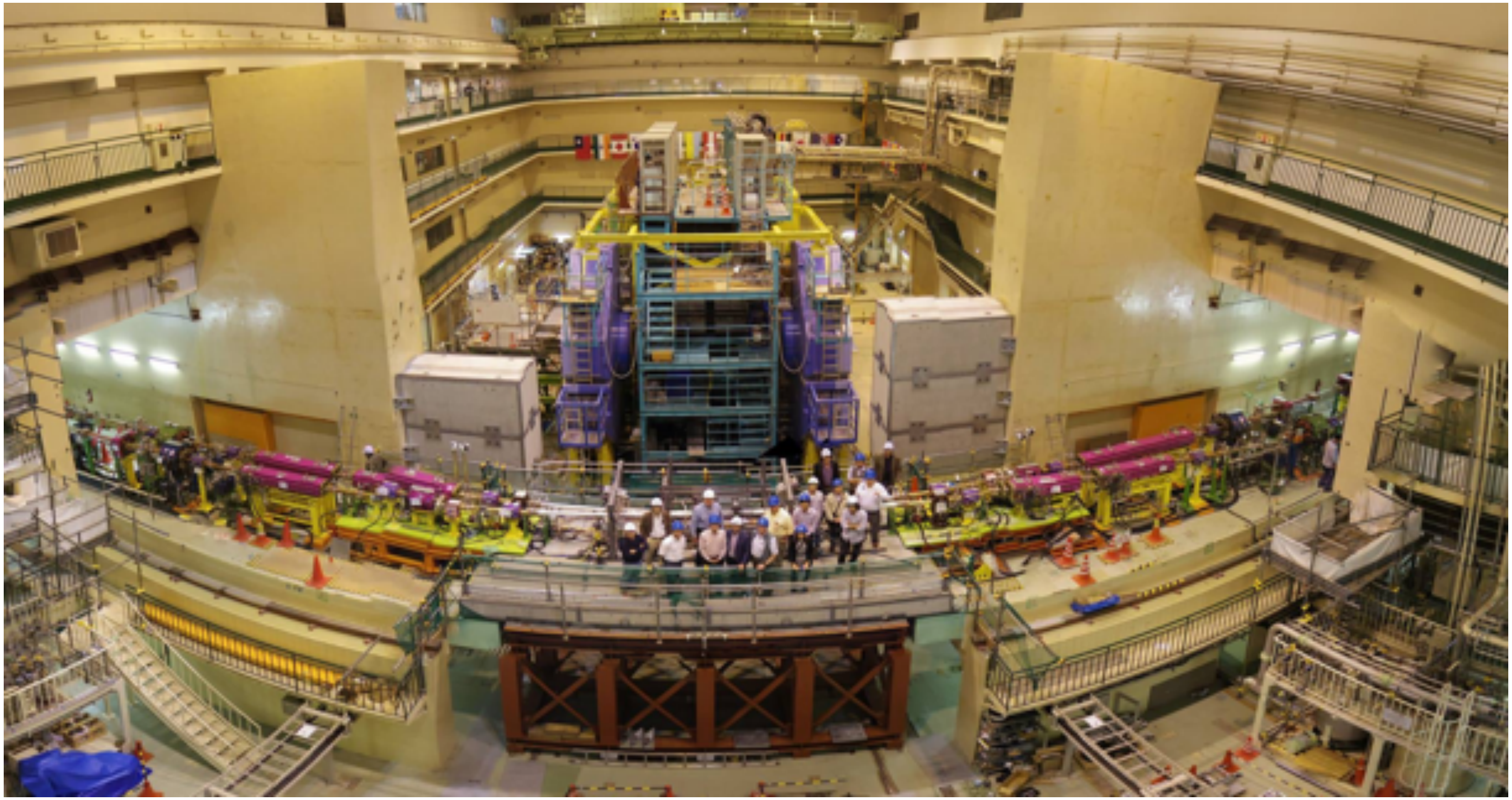
Belle II Physics



Belle II Mission

To search for new phenomena that may solve the missing antimatter puzzle

Builds on 2008 Nobel Prize success, M Kobayashi and T Maskawa "for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature”. → **Belle experiment credited**



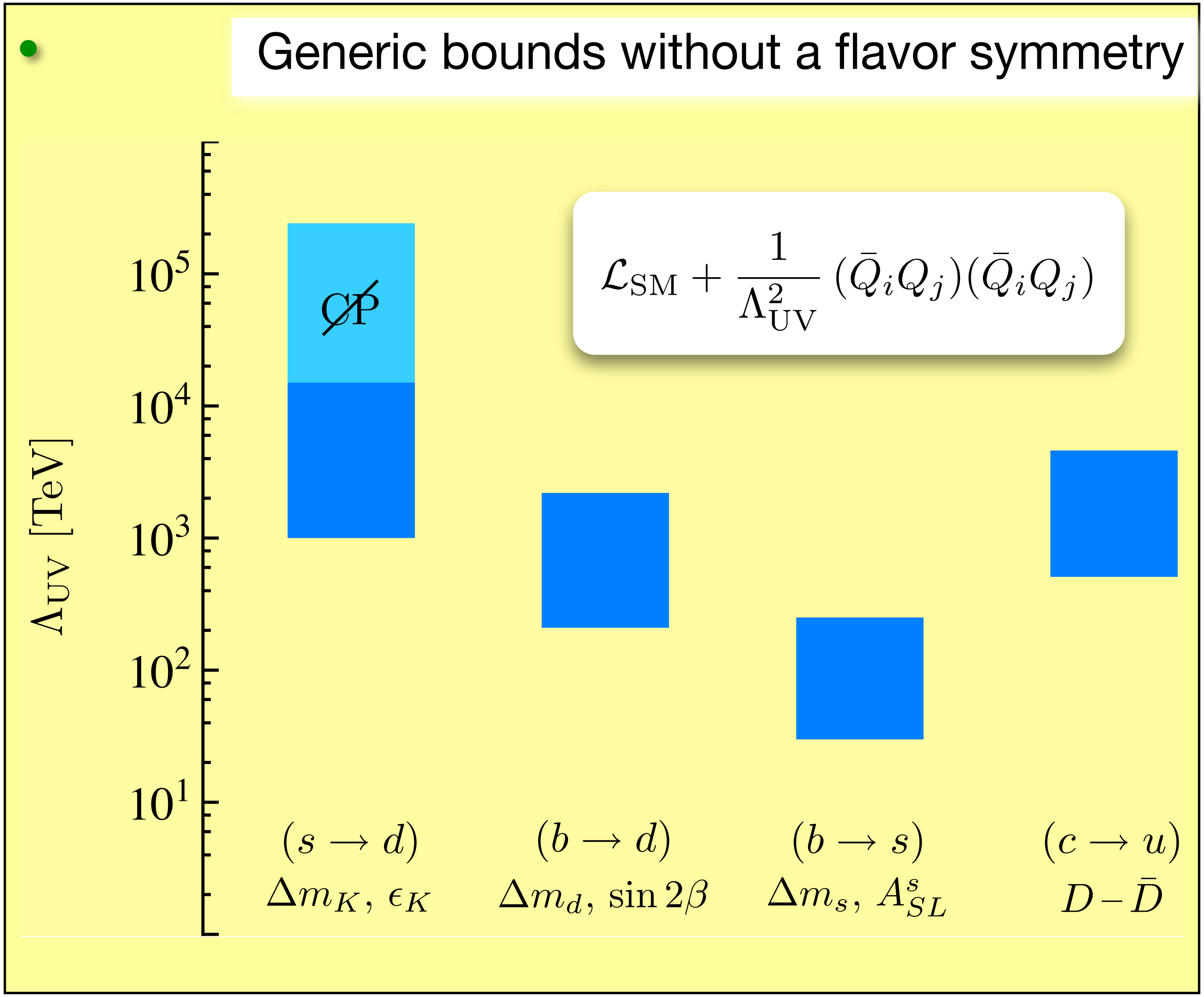
The case for new physics manifesting in Belle II

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
- Finite neutrino masses
  → Tau LFV.
- Quark and Lepton flavour & mass hierarchy
  → higher symmetry, massive new particles, extended gauge sector
- 19 free parameters
  → Extensions of SM relate some, (GUTs)
- + Puzzling nature of exotic "new" QCD states.

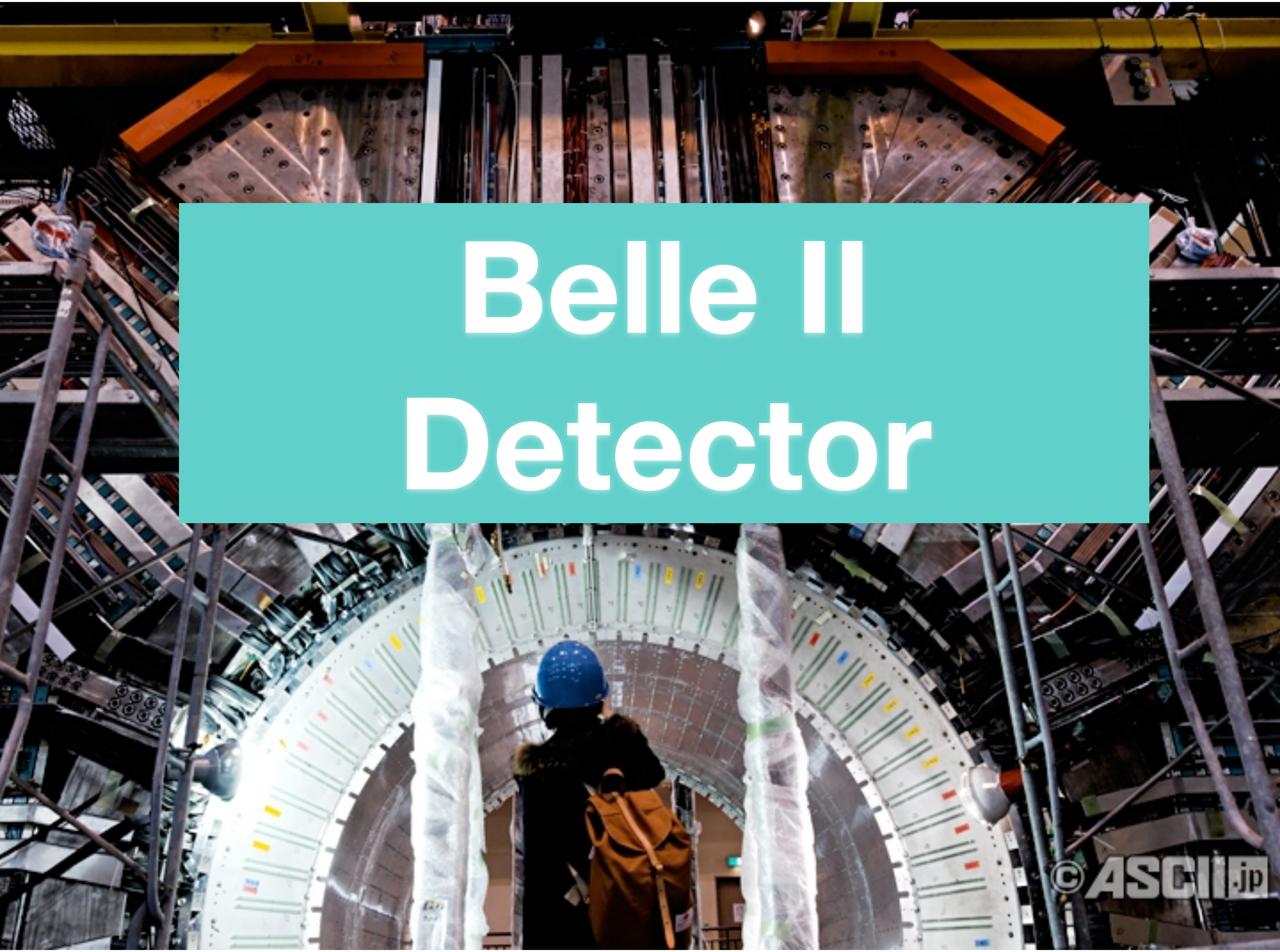
Generic Bounds on New Phenomena



- Ways out

1. New particles have masses ≫ 1 TeV
2. New particles / degenerate masses
3. Mixing angles are small

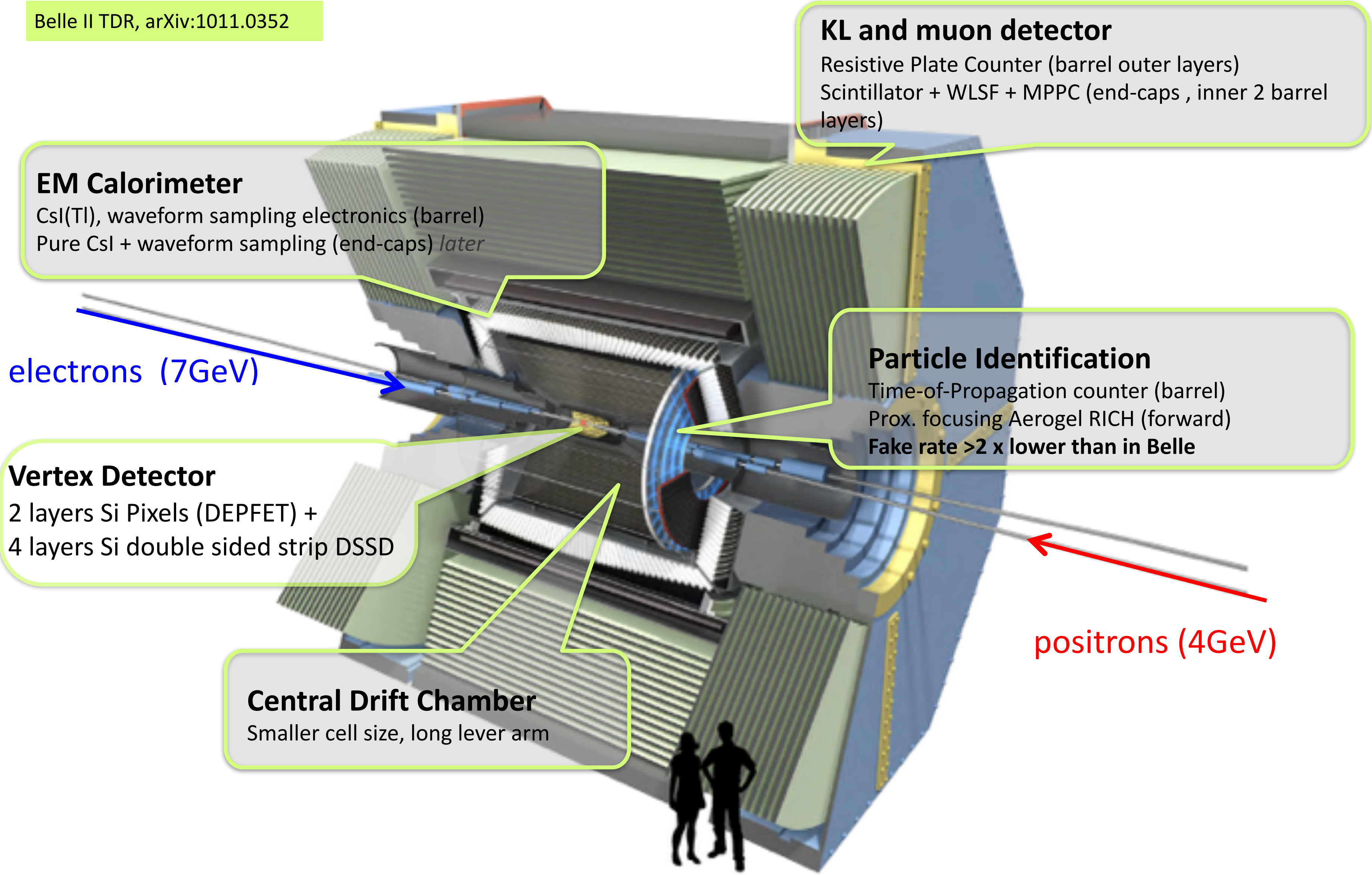
Belle II Detector



Belle II Detector

[600+ collaborators, 99 institutes, 23 nations]

Belle II TDR, arXiv:1011.0352



Belle II Detector

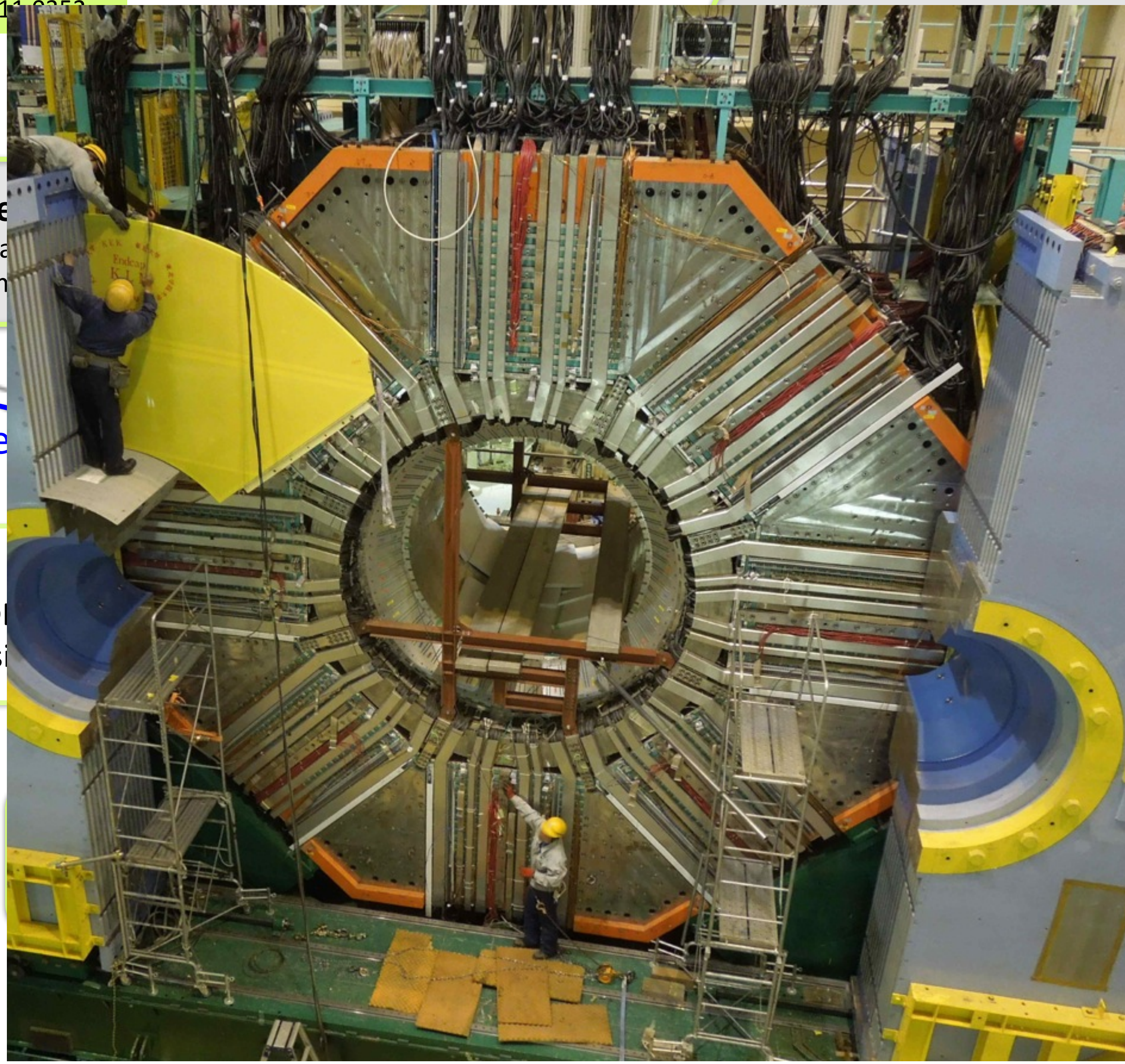
[600+ collaborators, 99 institutes, 23 nations]

Belle II TDR, arXiv:101

EM Calorimete
CsI(Tl), waveform sa
Pure CsI + wavefor

electrons (7Ge

Vertex Detector
2 layers Si Pixels (D
4 layers Si double si



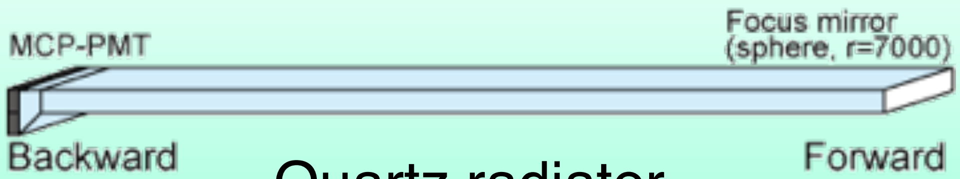
ter layers)
aps , inner 2 barrel

r (barrel)
(forward)
Belle

ns (4GeV)

Time-of-Propagation(TOP) Detector

Barrel PID: Time of Propagation Counter (TOP)

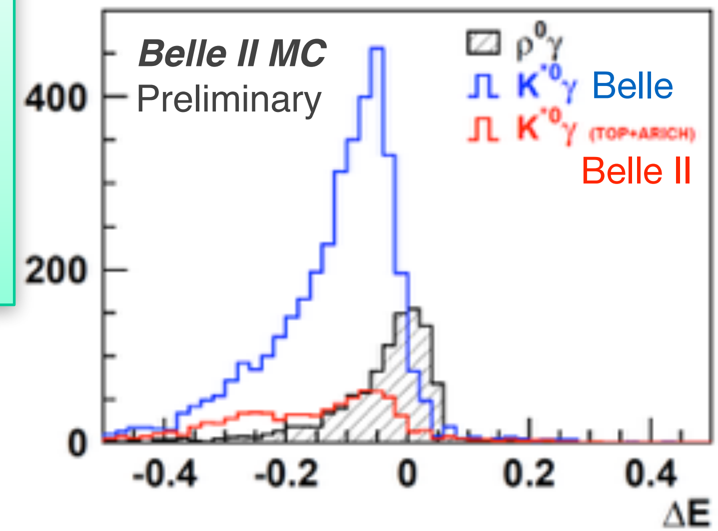


Quartz radiator

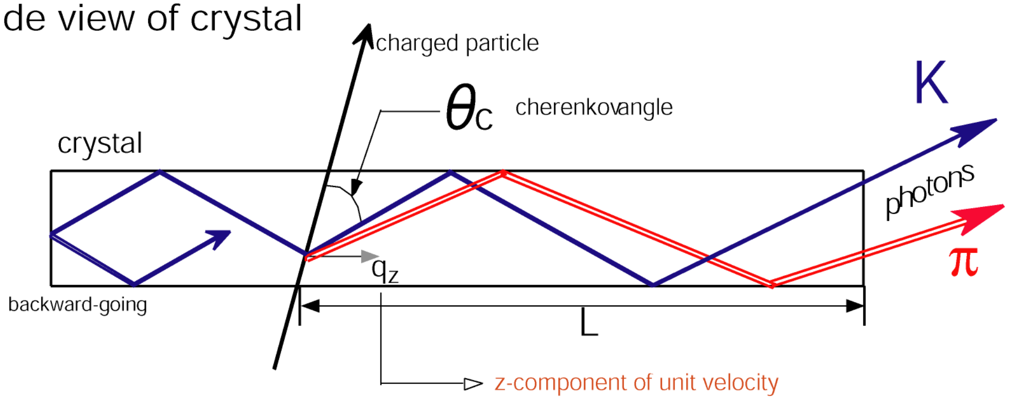
Focusing mirror

measure t, x and y

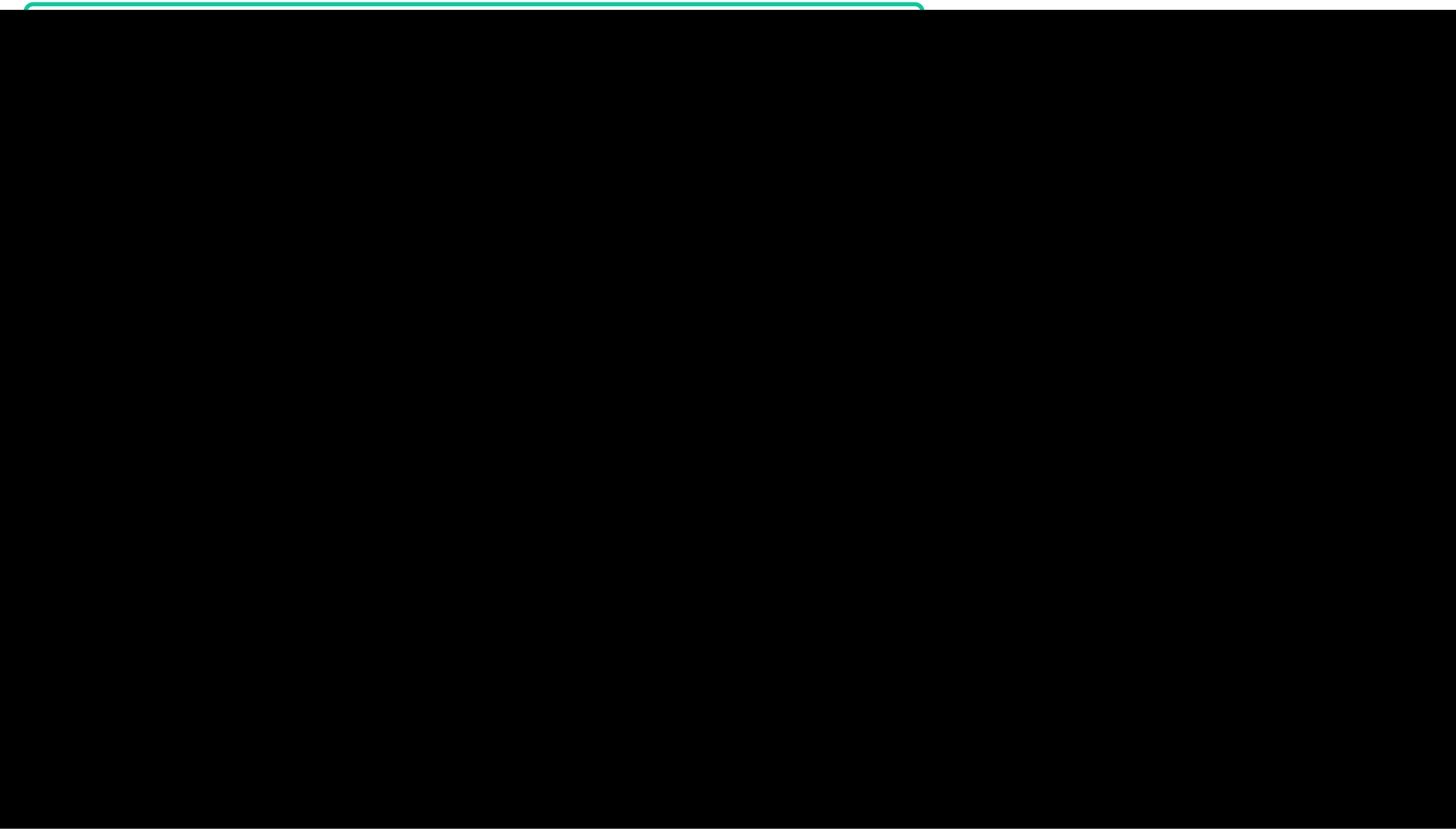
TOP + ARICH PID



Side view of crystal

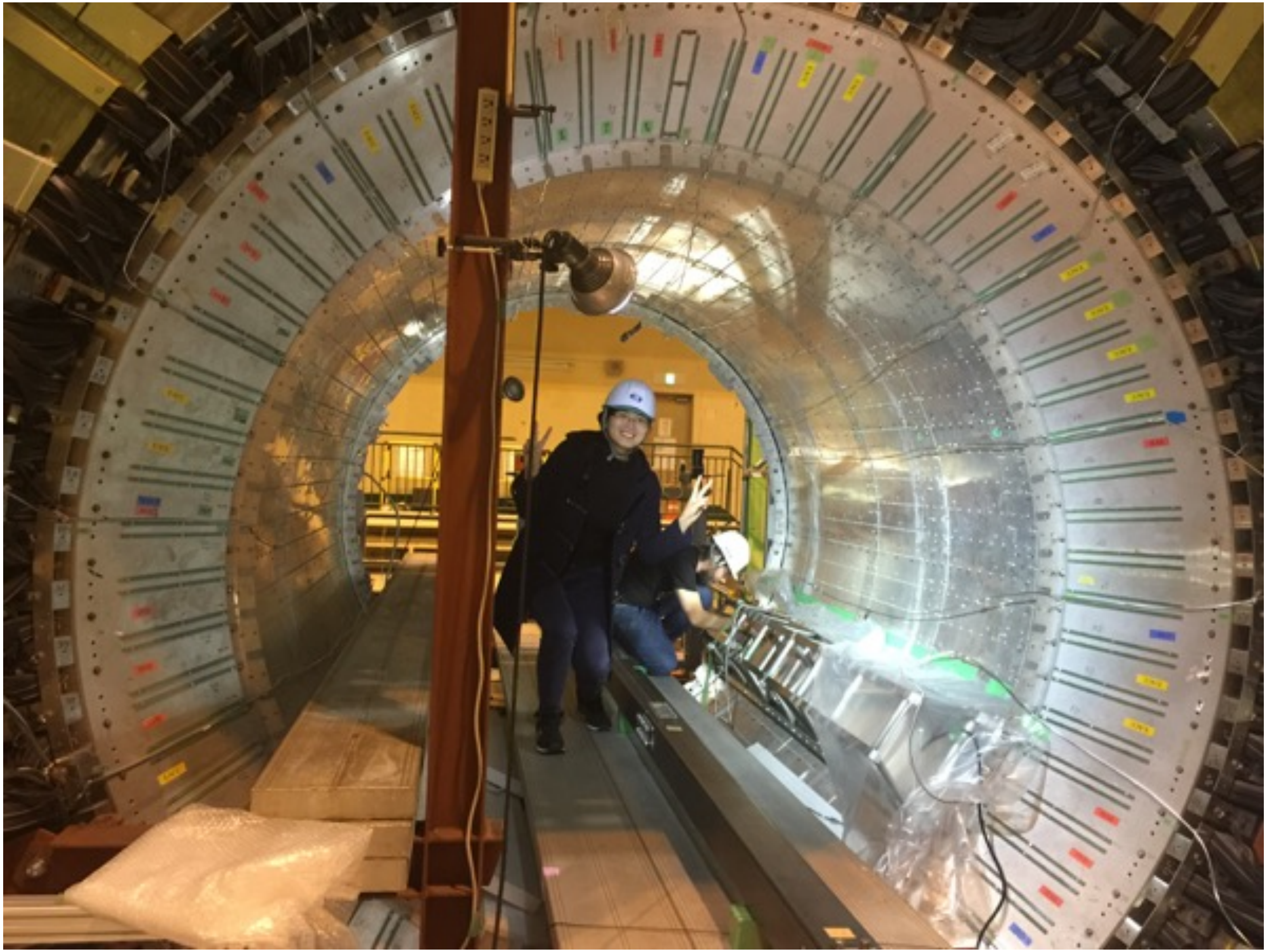


Time-of-Propagation(TOP) Detector

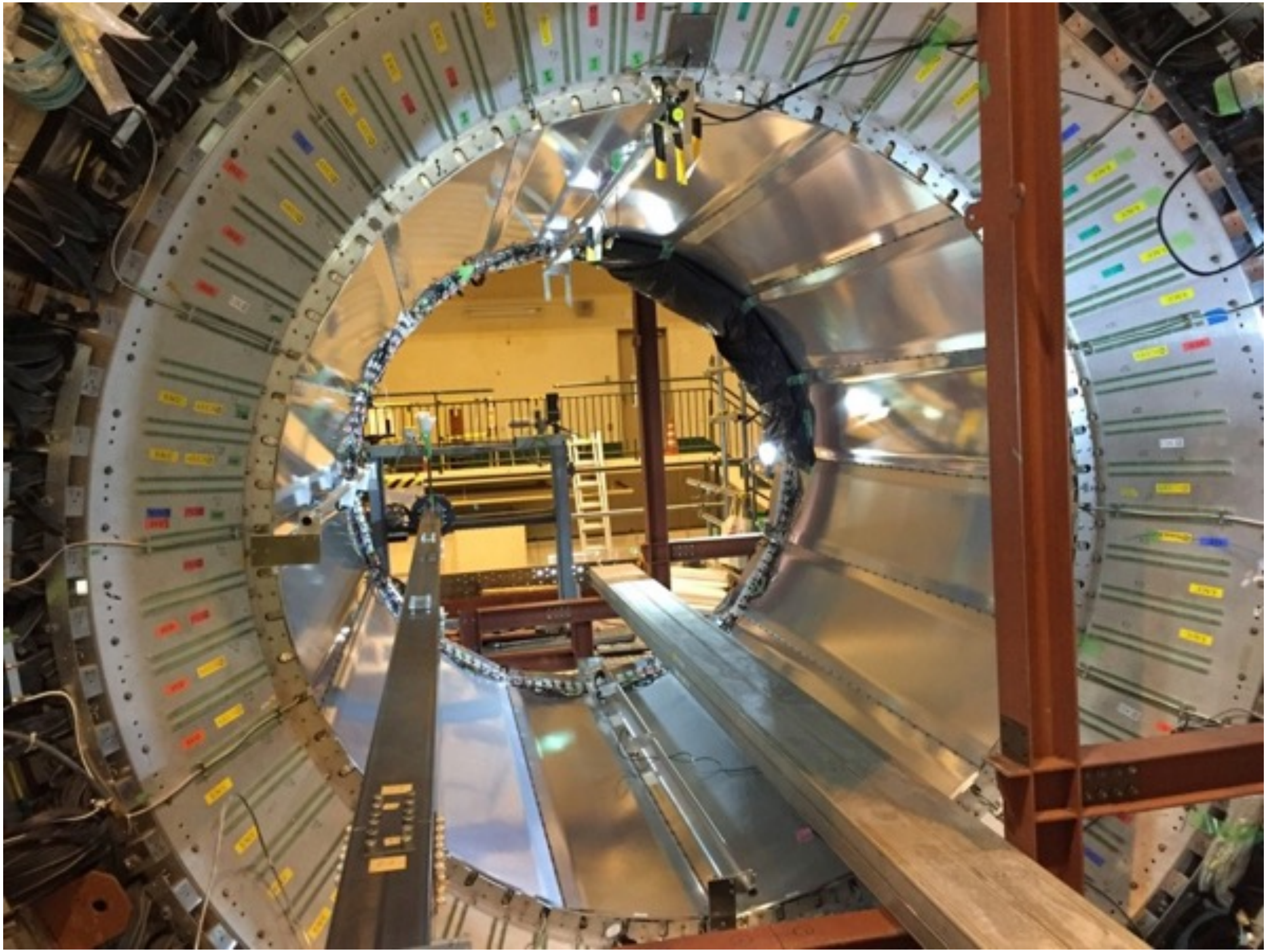


1st Time of Propagation Detector delivered to Tsukuba Hall, Jan 2016

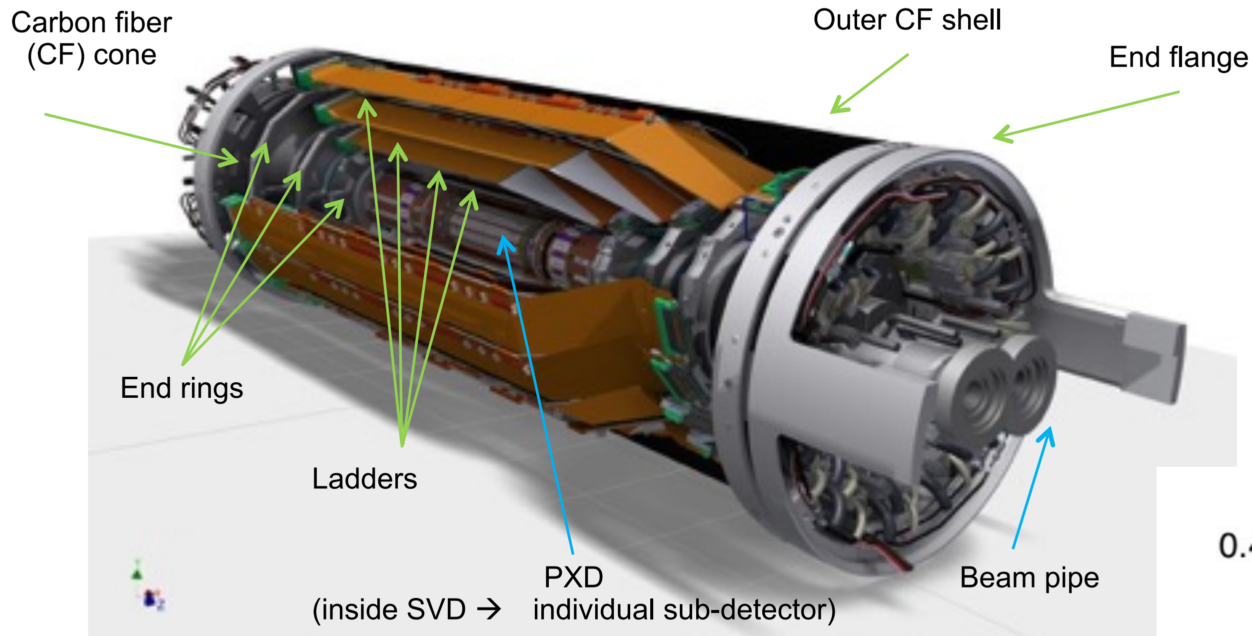
Feb: 1st TOP bar

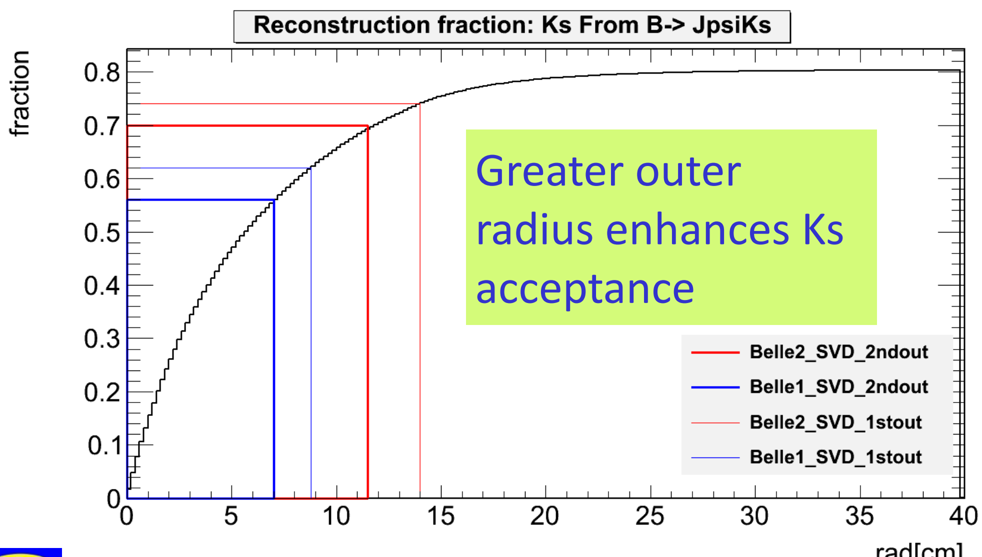


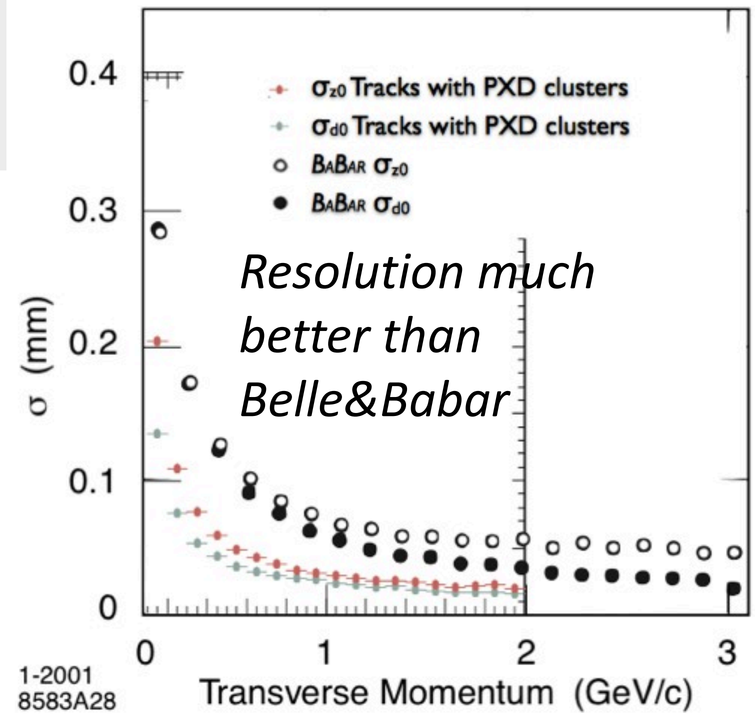
Feb: 1st TOP bar May: fully installed!



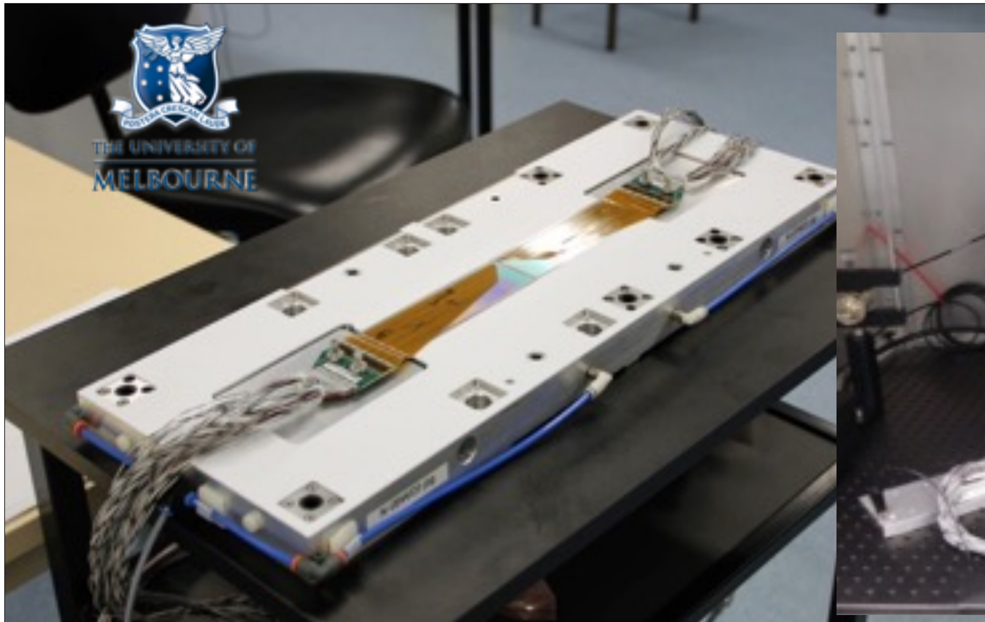
Silicon Vertex Detector

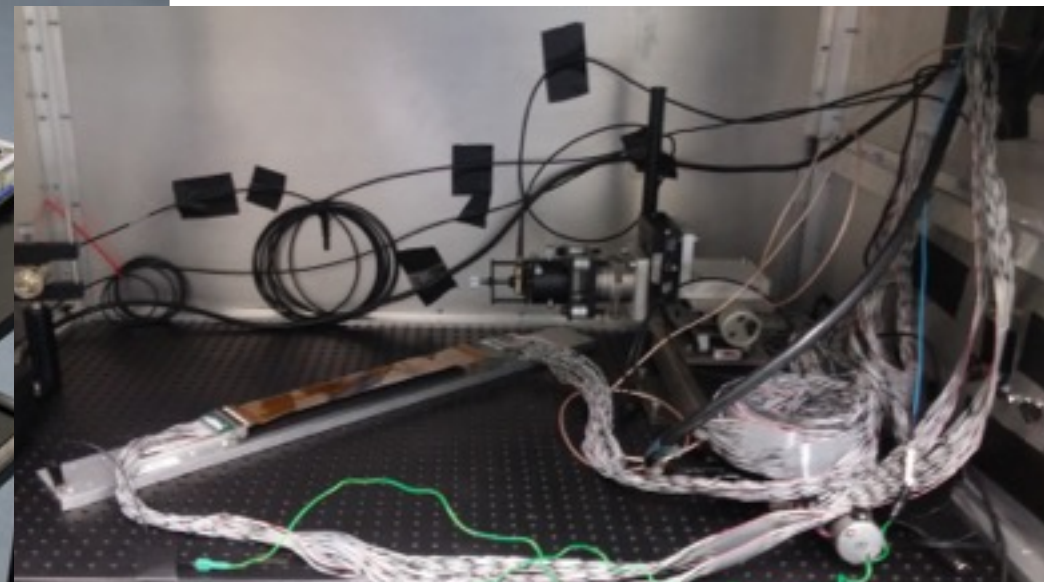


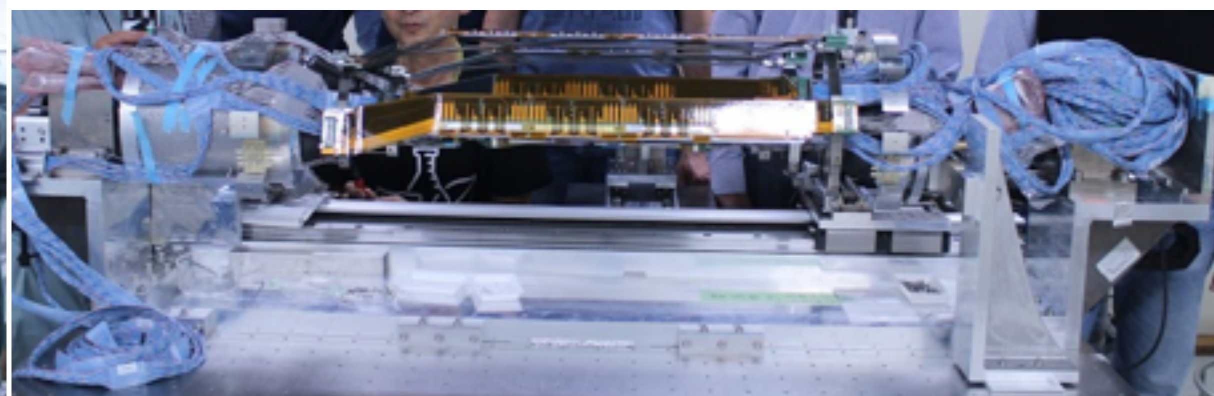




SVD L3 Construction & Mechanical test with close-to-final parts



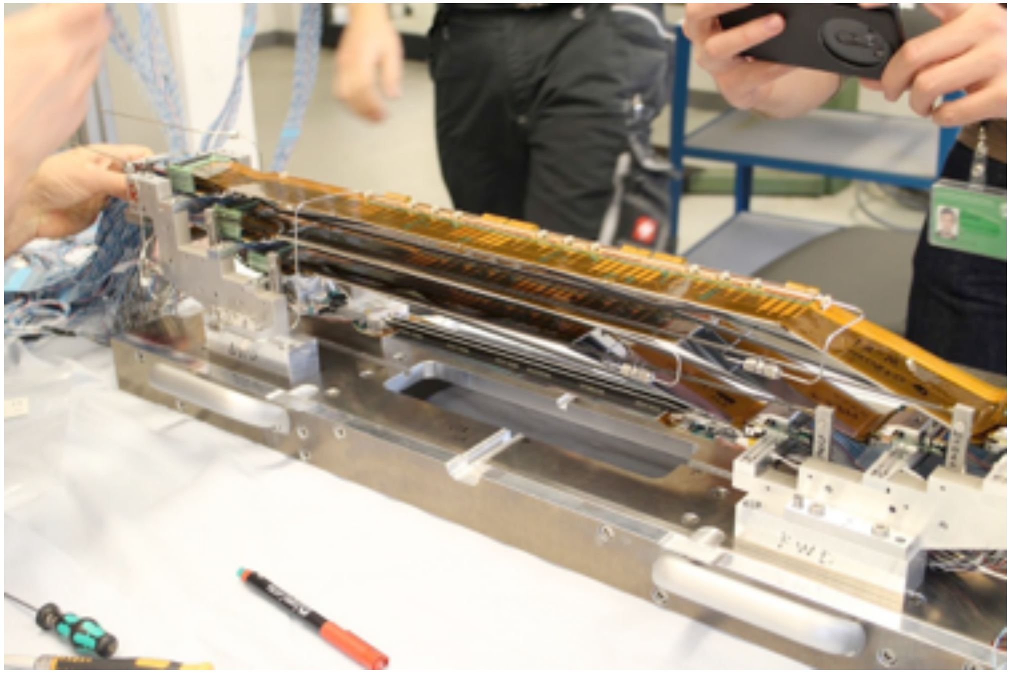




April 2016: 2 *full-sized* Belle II pixel modules at DESY

Test full-sized PXD modules in a beam.

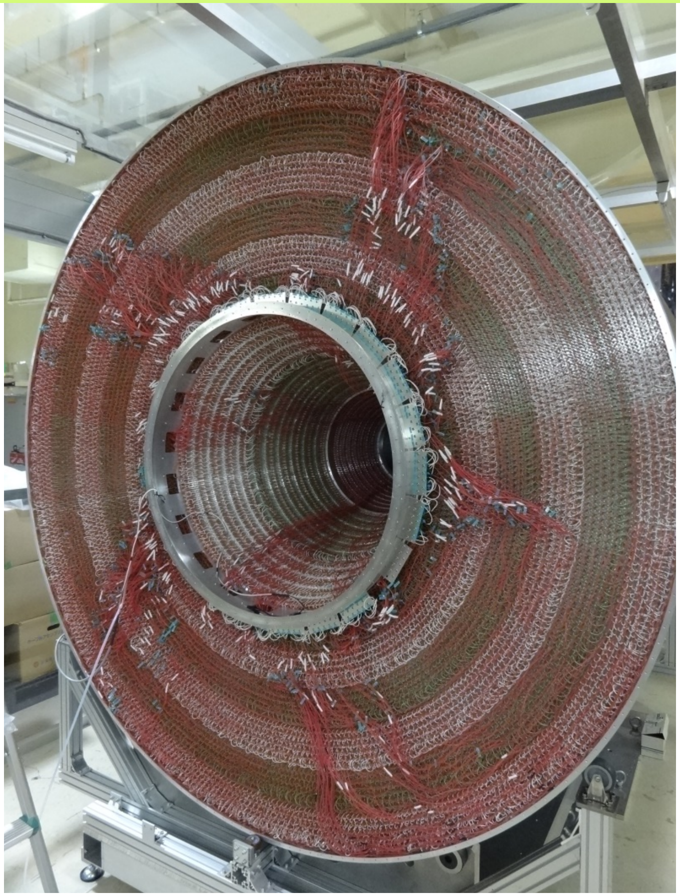
Working examples of L3, L4, L5, L6 SVD ladders



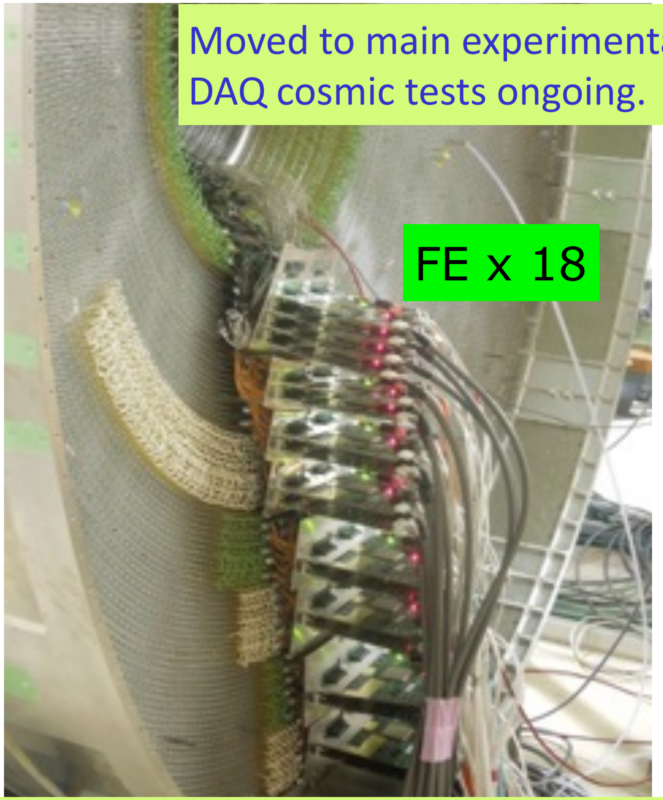
Test the integrated PXD-SVD system. This includes ROI (region of interest) extrapolation from the SVD tracker to the PXD, which is needed to reduce the *large data volume*.

CDC

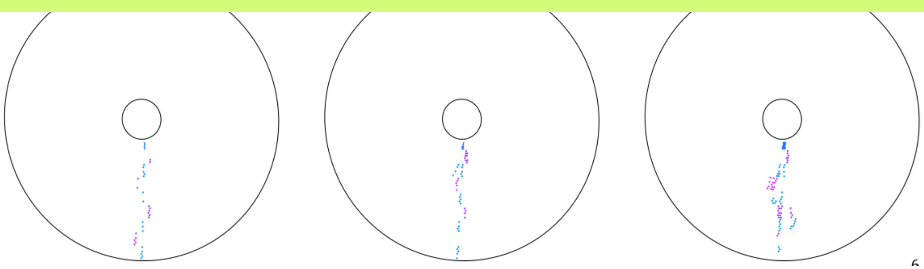
Wire chamber built. Installing electronics



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



Installation of FE boards and cosmic ray tests in progress



CDC

Wire chamber built. Installing electronics

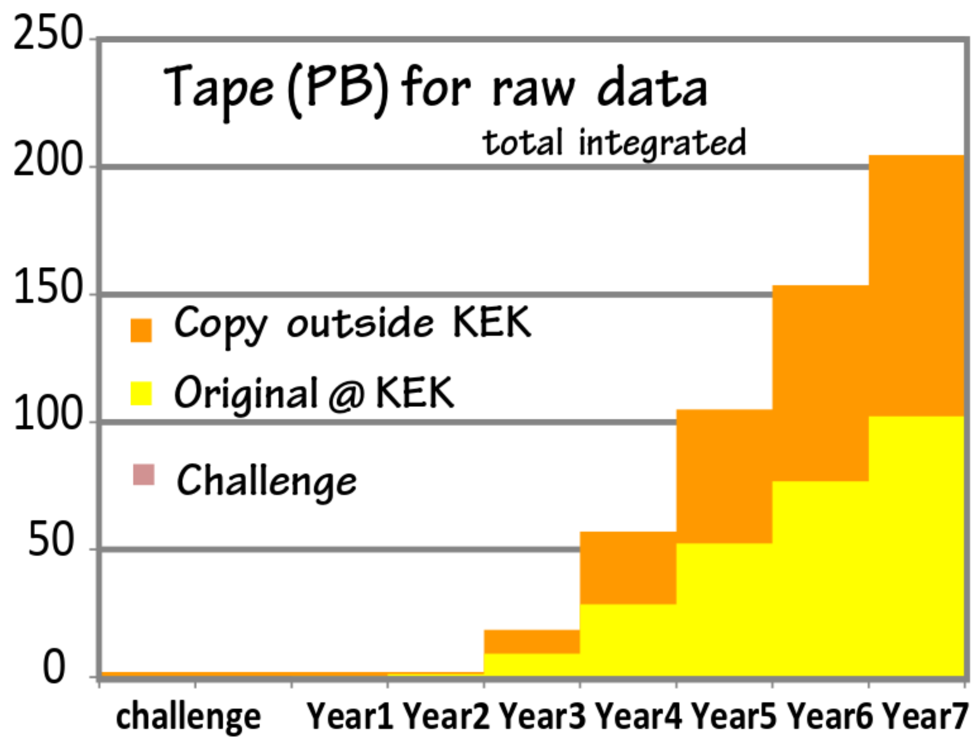
Moved to main experimental hall in Jan 2015

[redacted]

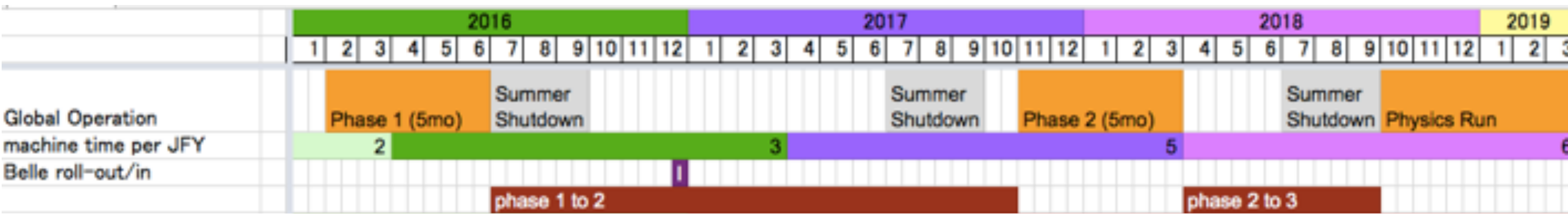
Trigger & dataset

- HLT output estimated to be ~11 nb = 11 kHz at nominal luminosity .
- Largest dataset in particle physics outside of LHC.

Trigger Hut, KEK, C-H Li (UniMelb)



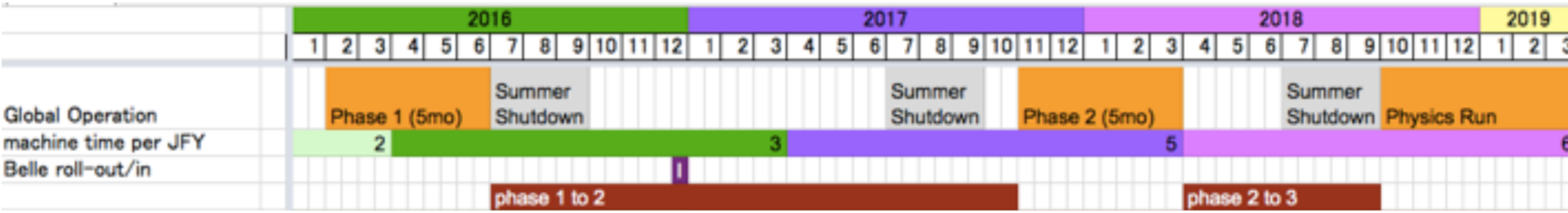
Belle II Schedule



When do we start Belle II ?

QCSL at KEK, Dec 2015

Belle II Schedule



When do we start Belle II ?

BEAST PHASE I: Started in Feb 2016 (Belle II roll-in at the end of the year)

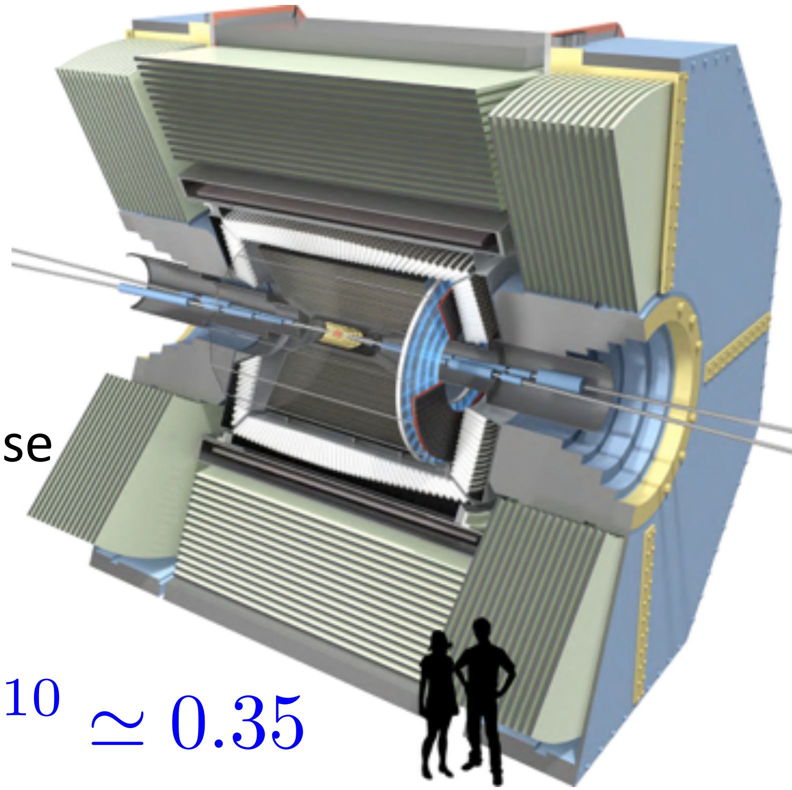
BEAST PHASE II: Starts in Nov 2017 [first collisions, limited physics without vertex detectors]

Belle II Physics Running: Late 2018 [vertex detectors in]

QCSL at KEK, Dec 2015

Strengths of e^+e^- @ Υ(4S)

- **Unique capabilities of Belle II:**
  - Exactly 2 B mesons produced (at Υ(4S))
    - High flavour tagging efficiency.
    - B full-reconstruction tagging with precise initial interaction kinematics.
  - Detection of photons, π^0, $\rho^\pm$, $\eta^{(\prime)}$, K_L
  - Clean ("see" decays with several neutrinos).



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

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

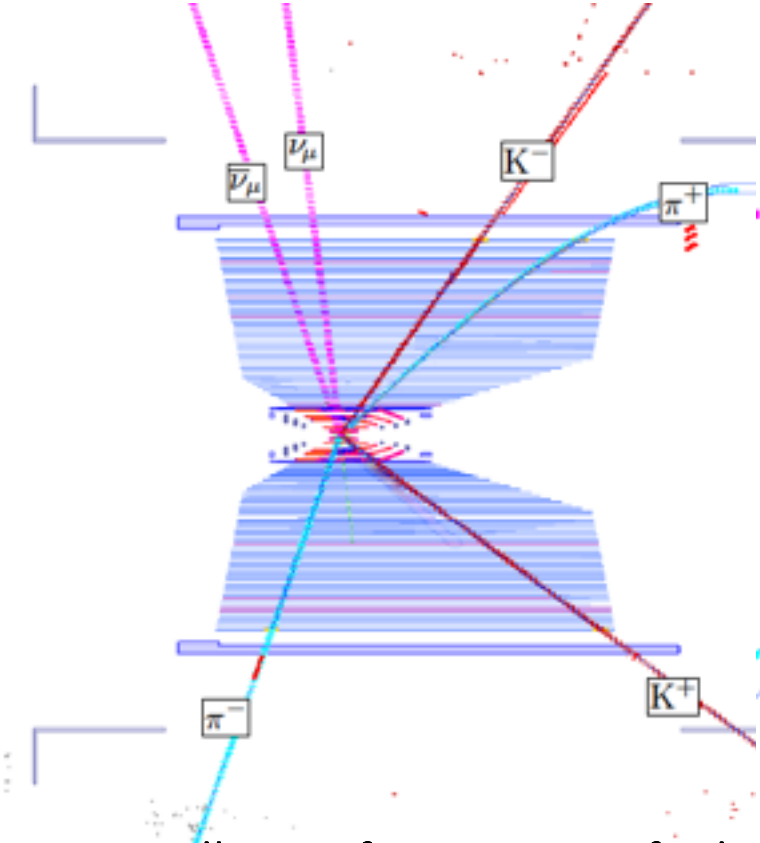
PID & Tracking will be MUCH better

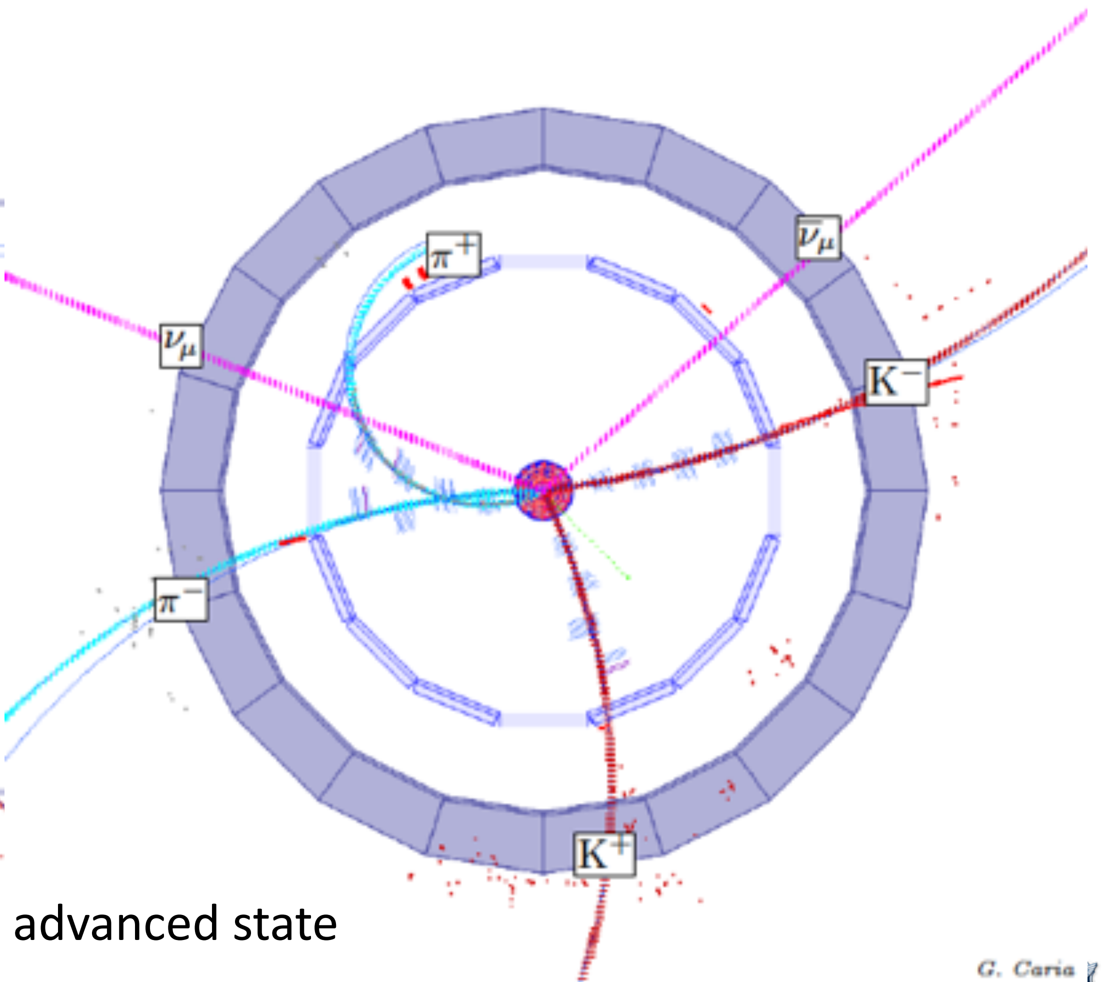
“Missing Energy Decay” in a Belle II GEANT4 MC simulation

Signal $B \rightarrow K \nu \nu$ tag mode: $B \rightarrow D\pi$; $D \rightarrow K\pi$

View in r-z

Zoomed view of the vertex region in r--phi





➔Belle II Software is in a fairly advanced state

CKMfitter

The CKMfitter group

- More results on http://ckmfitter.in2p3.fr

Jérôme Charles	Theory	CPT Marseille (FR)
Olivier Deschamps	LHCb	LPC Clermont-Ferrand (FR)
Sébastien Descotes-Genon	Theory	LPT Orsay (FR)
Ryosuke Itoh	Belle/Belle II	KEK Tsukuba (JP)
Heiko Lacker	ATLAS/BABAR	Humboldt-Universität Berlin (DE)
Evan Machefer	LHCb	LPC Clermont-Ferrand (FR)
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Alejandro Perez	BABAR	IPHC Strasbourg (FR)
Wenbin Qian	LHCb	LAPP Annecy-Le-Vieux (FR)
Vincent Tisserand	LHCb/BABAR	LAPP Annecy-Le-Vieux (FR)
Karim Trabelsi	Belle/Belle II	KEK Tsukuba (JP)
PU	Belle/Belle II	U. of Melbourne (AU)
Luiz Vale Silva	Theory	LPT Orsay (FR)

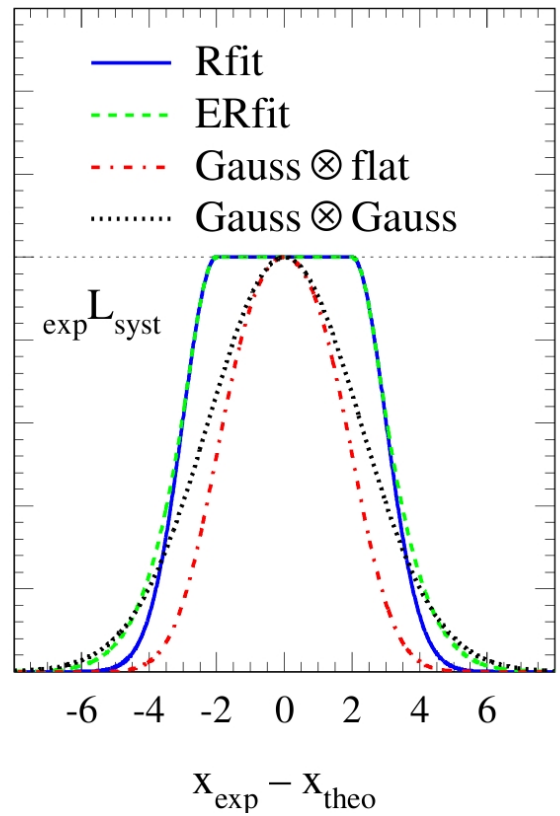
CKMfitter Methodology

- Global fit to CKM parameters q = (A,λ,ρ¯,η¯...)

- Use Frequentist approach to build (p-value) functions
  - In the case of Gaussian (Experimental) uncertainties

$$\mathcal{L}(q) = \prod_{\mathcal{O}} \mathcal{L}_{\mathcal{O}}(q) \qquad \chi^2(q) = -2\ln\mathcal{L}(q) = \sum_{\mathcal{O}} \left(\frac{\mathcal{O}_{\rm th}(q) - \mathcal{O}_{\rm exp}}{\sigma_{\mathcal{O}}} \right)^2$$

  - Estimator q^ maximum likelihood:
    - **$\chi^2(\hat{q}) = \min_q \chi^2(q)$**
  - Confidence level for a given q_0 obtained from **$\Delta\chi^2(q_0) = \chi^2$**



- Dedicated **RFit** scheme for the treatment of theoretical s
systematics are considered as additional nuisance parame

$$x = \mu + \sigma N[0,1] + \Delta_x$$

Observation (x) · Parameter (μ) · Gaussian stat. error (σN[0,1]) · Systematic bounded in [-Δ;Δ] (Δ_x)

Unitarity Triangle