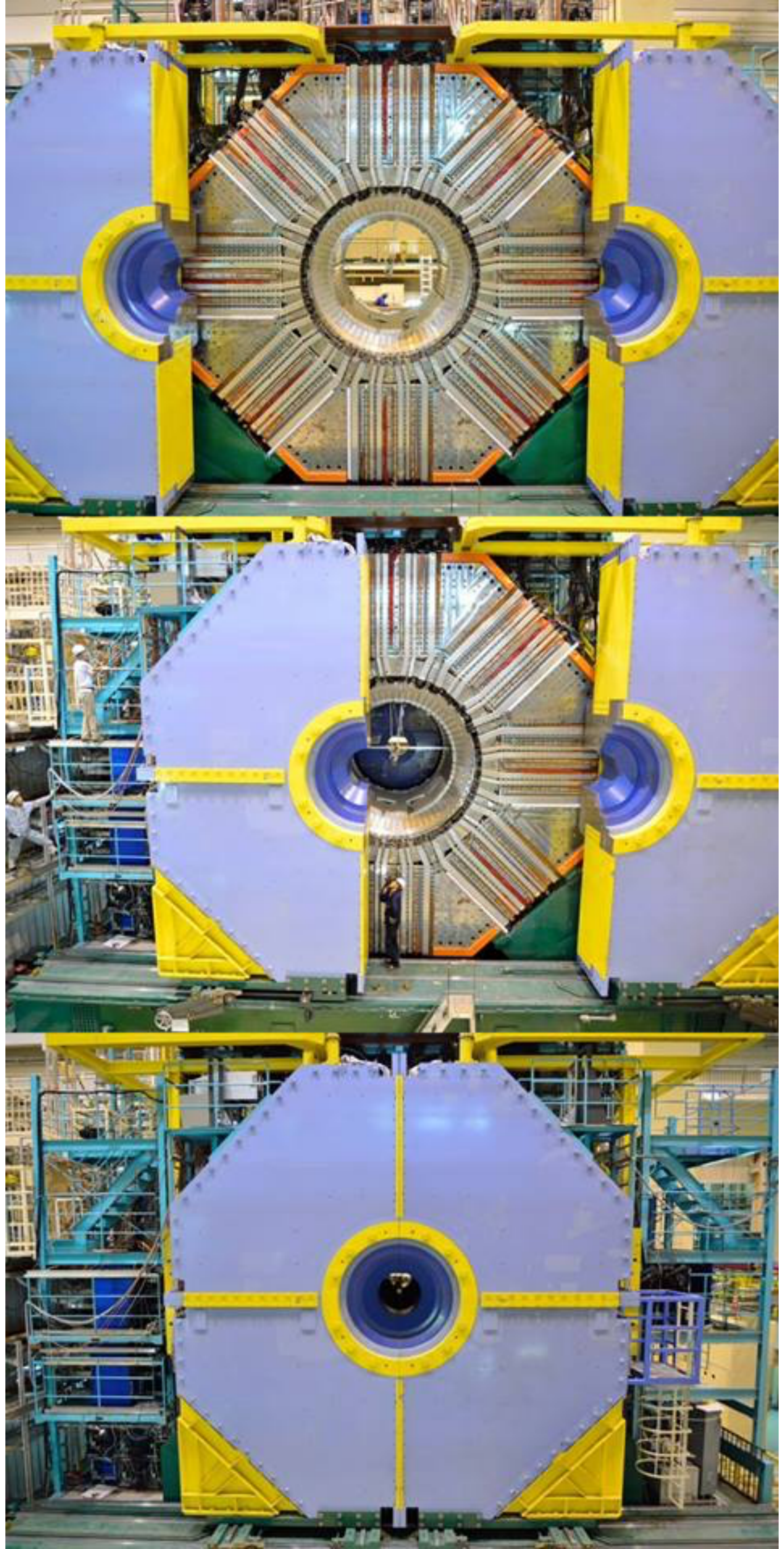


B-physics

Recent results
(Babar, Belle, LHCb, CMS, ATLAS)
& prospects at Belle II

Phillip Urquijo
SUSY 2017 Plenary
TIFR Mumbai
December 2017

SuperKEKB

Belle II

THE UNIVERSITY OF MELBOURNE

Outline (2016-2017 results)

Recent results on modes used for precise tests of NP in B-physics

TREE	$B \to D^{*} \tau \nu$	Belle PRD 94, 072007 (2016), Belle PRL 118, 211801 (2017), Belle arXiv:1709.00129, LHCb arXiv:1711.02505
	$B_c \to J/\psi \, \tau \nu$	LHCb arXiv:1711.05623
	$B \to D^{*} l \nu \, \lvert V_{cb} \rvert$	Belle arXiv:1702.01521
	$B \to \mu \nu$	Belle arXiv:1712.04123
	$B \to D^{(*)} K^{(*)} \Phi_3$	LHCb-CONF-2017-004, LHCb arXiv:1708.06370
LOOP	$B \to \mu\mu$	ATLAS EPJC 76, 513 (2016), LHCb PRL 118, 191801 (2017)
	$B_{(s)} \to \tau \tau$	LHCb PRL 118, 251802 (2017)
	$B \to K^{(*)} l^{+} l^{-}$ LFUV	LHCb PRL 118, 251802 (2017), LHCb JHEP 11, 047 (2016), LHCb JHEP 04, 142 (2017), CMS PLB 753, 424 (2016), Belle PRL 118, 111801 (2017), Babar PRD 93, 052015 (2016)
	$B \to K^{*} \nu \nu$	Belle PRD(R) 96, 091101 (2017)
	$B \to K^{*} \gamma$	Belle PRL 119, 191802 (2017)

Outline (2016-2017 results)

Recent results on modes used for precise tests of NP in B-physics

TREE	$B \to D^* \tau \nu$	Belle PRD 94, 072007 (2016), Belle PRL 118, 211801 (2017), Belle arXiv:1709.00129, LHCb arXiv:1711.02505
	$B_c \to J/\psi \tau \nu$	LHCb arXiv:1711.05623
	$B \to D^* l \nu \lvert V_{cb} \rvert$	Belle arXiv:1702.01521
	$B \to \mu \nu$	Belle arXiv:1712.04123
	$B \to D^{(*)} K^{(*)} \Phi_3$	LHCb-CONF-2017-004, LHCb arXiv:1708.06370
LOOP	$B \to \mu\mu$	ATLAS EPJC 76, 513 (2016), LHCb PRL 118, 191801 (2017)
	$B_{(s)} \to \tau \tau$	LHCb PRL 118, 251802 (2017)
	$B \to K^{(*)} l^+ l^-$ LFUV	LHCb PRL 118, 251802 (2017), LHCb JHEP 11, 047 (2016), LHCb JHEP 04, 142 (2017), CMS PLB 753, 424 (2016), Belle PRL 118, 111801 (2017), Babar PRD 93, 052015 (2016)
	$B \to K^* \nu \nu$	Belle PRD(R) 96, 091101 (2017)
	$B \to K^* \gamma$	Belle PRL 119, 191802 (2017)

LFUV tests

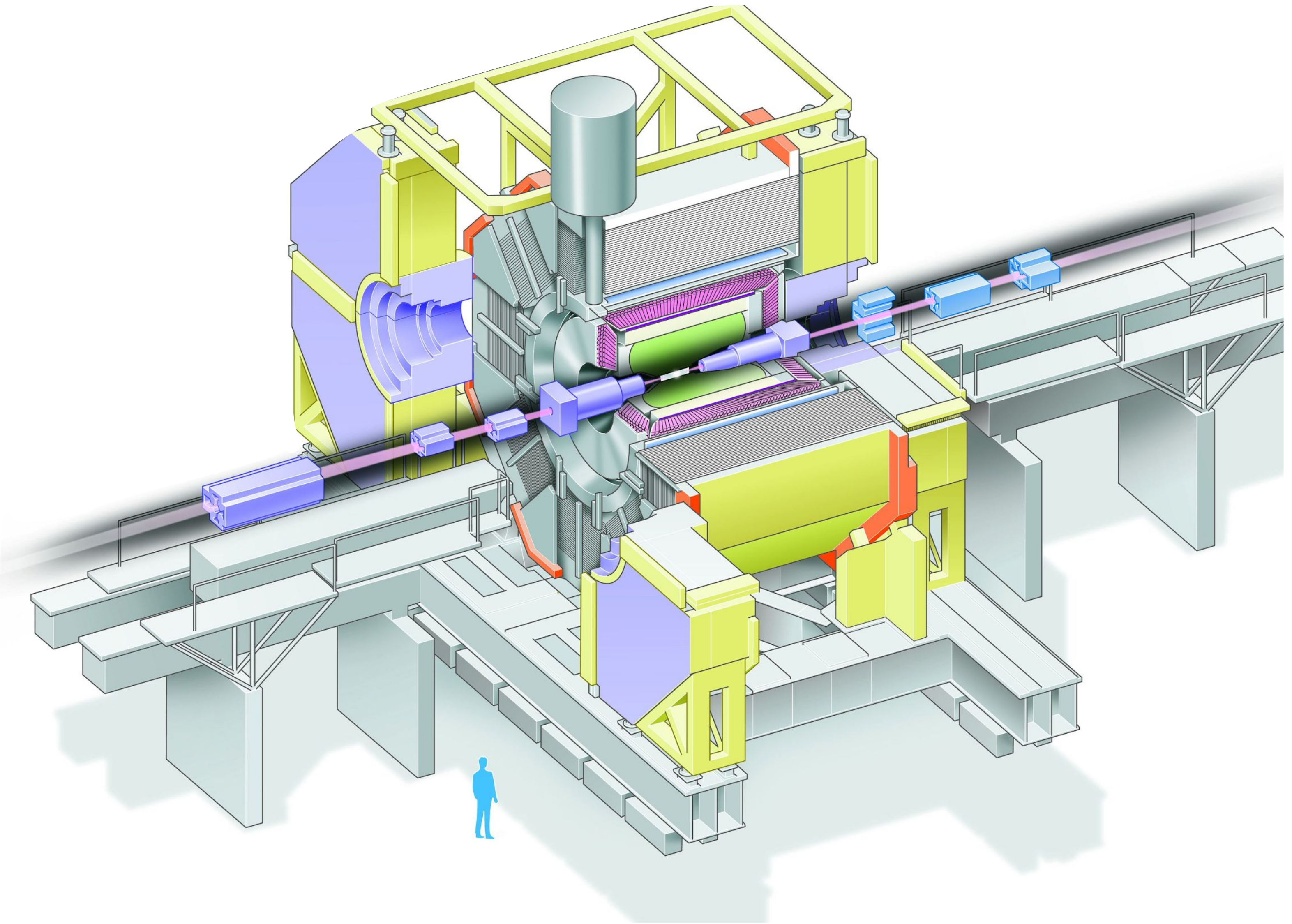
The case for new physics manifesting in B-decays

- Baryon asymmetry in cosmology
  → **New sources of CPV**
- Quark and Lepton flavour & mass hierarchy
  →**extended gauge sector coupling to third generation ($H^{\pm}$, W', Z')**
  →**restored L-R symmetry**
- Finite neutrino masses
  → **LFV and LFUV.**
- 19 free parameters
  → GUTs, **leptoquarks**
- \+ Hidden and dark sectors at the GeV scale.

B-physics experiments

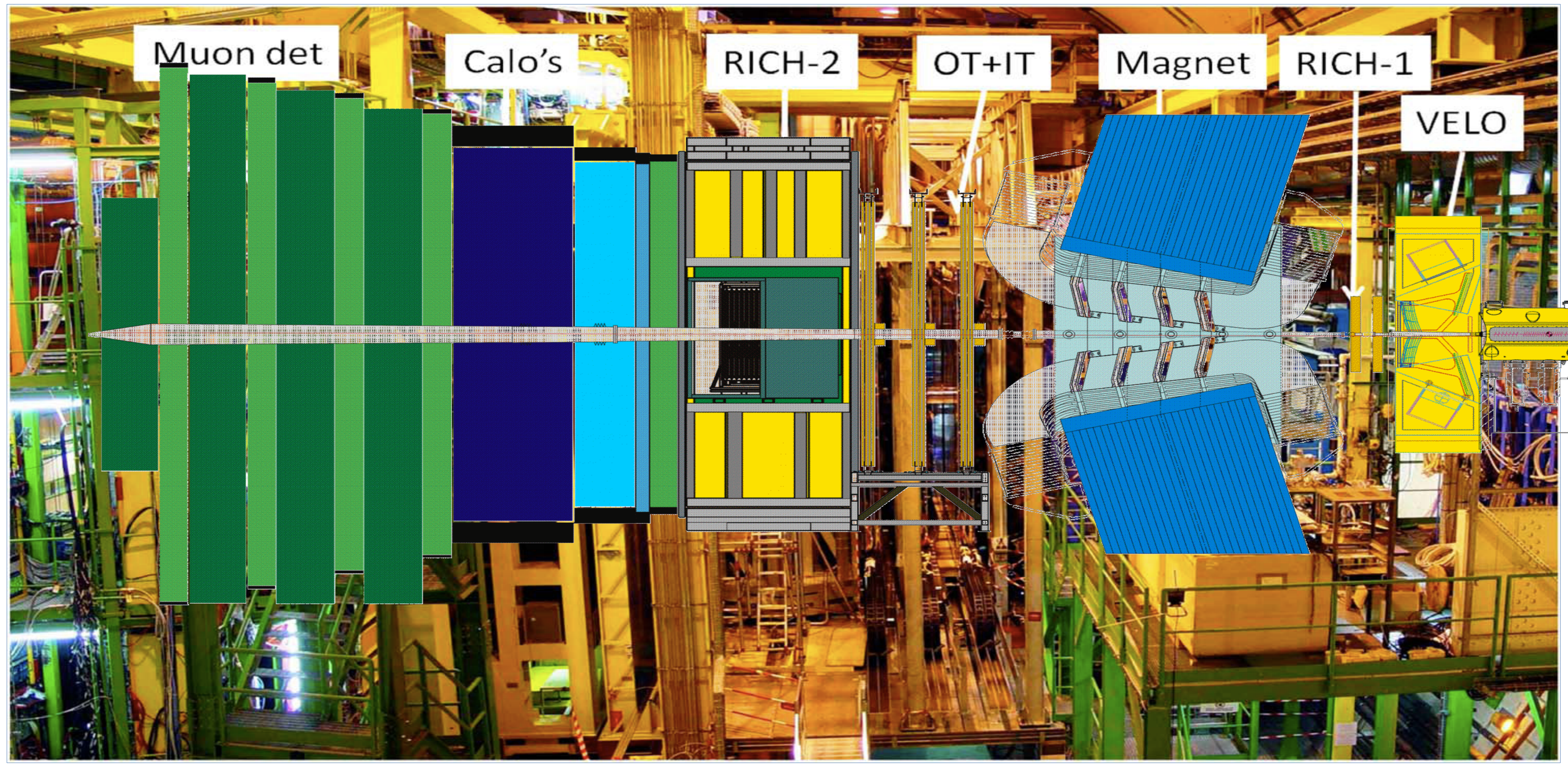
Belle at KEK

- Operated from **1999 to 2010**
- KEKB delivered over **1 ab^{-1}** to Belle, mostly at the Υ(4S) resonance. (**771 million B meson pairs**)
- Along with Babar confirmed **Kobayashi and Maskawa** model of CP violation



LHCb at CERN

- B-physics since **2010**
- **3 fb^{-1} in Run-1 @ 7 & 8 TeV** (2010-2012)
- **3.7 fb^{-1} in Run-2 @ 13 TeV** so far (2015-2018)
- Huge bb production cross section



Lepton non-universality

- Lepton universality in the gauge sector is one of the **key features of the SM**.
- Decays with electrons, muon and taus should all be identical
  - The **only differences are are due to masses**
  - Easy to account for in predictions
- Discovery of **lepton flavour non-universality** is a **key signature of New physics e.g. Leptoquarks, W', Z', H±**
- Identification / reconstruction of leptons is not universal

The **ELECTRON** is a fundamental subatomic particle carrying a negative charge. Its mass is 1/1000 that of the smallest atom. It participates in electromagnetic interactions, and is typically found orbiting the nucleus of an atom.

Fleece and felt with poly-fill for minimum mass.

The **MUON** is a short-lived, heavier version of the electron. It has the same negative charge, but is 200 times more massive than the electron.

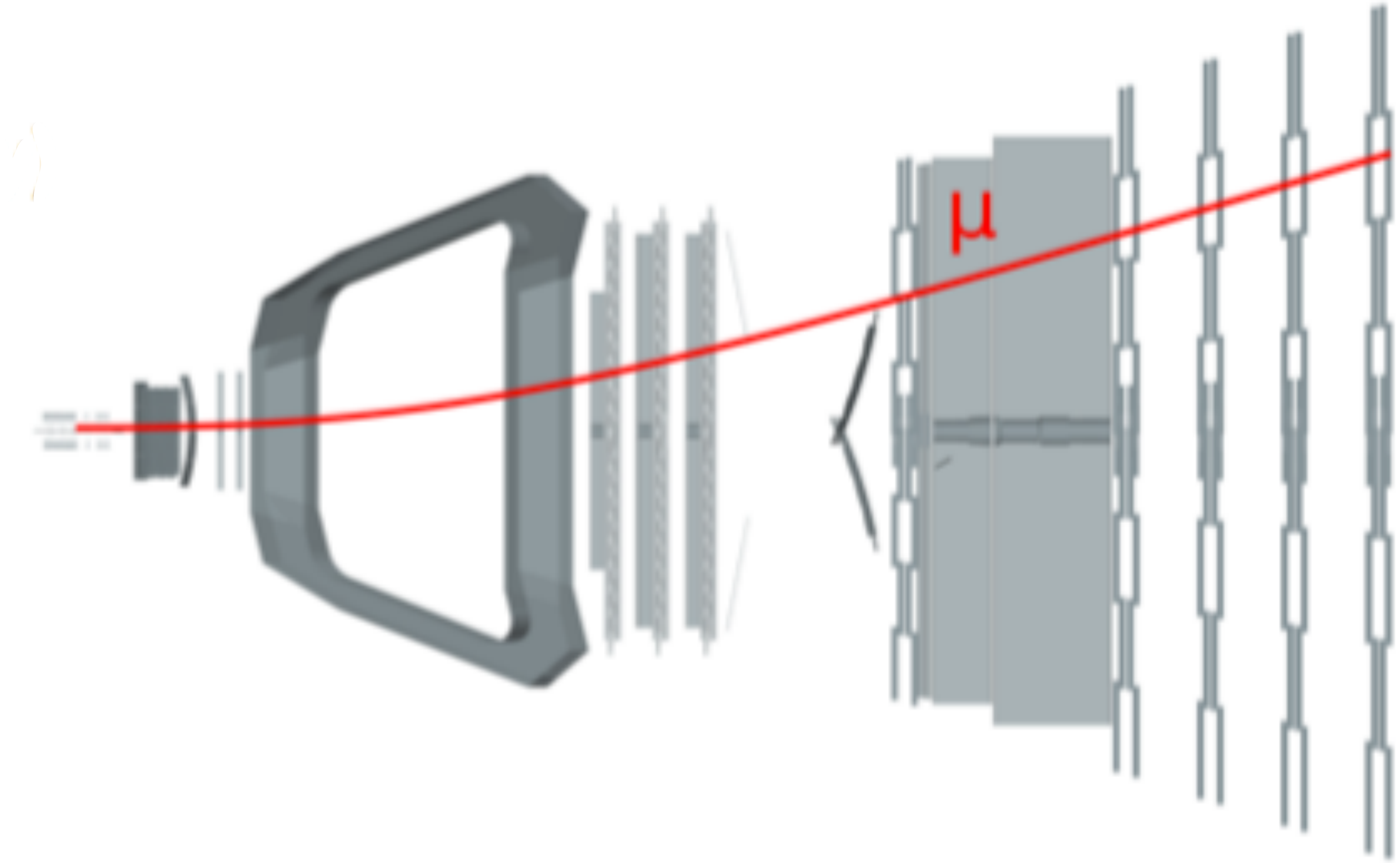
Acrylic felt with poly bead fill for medium mass.

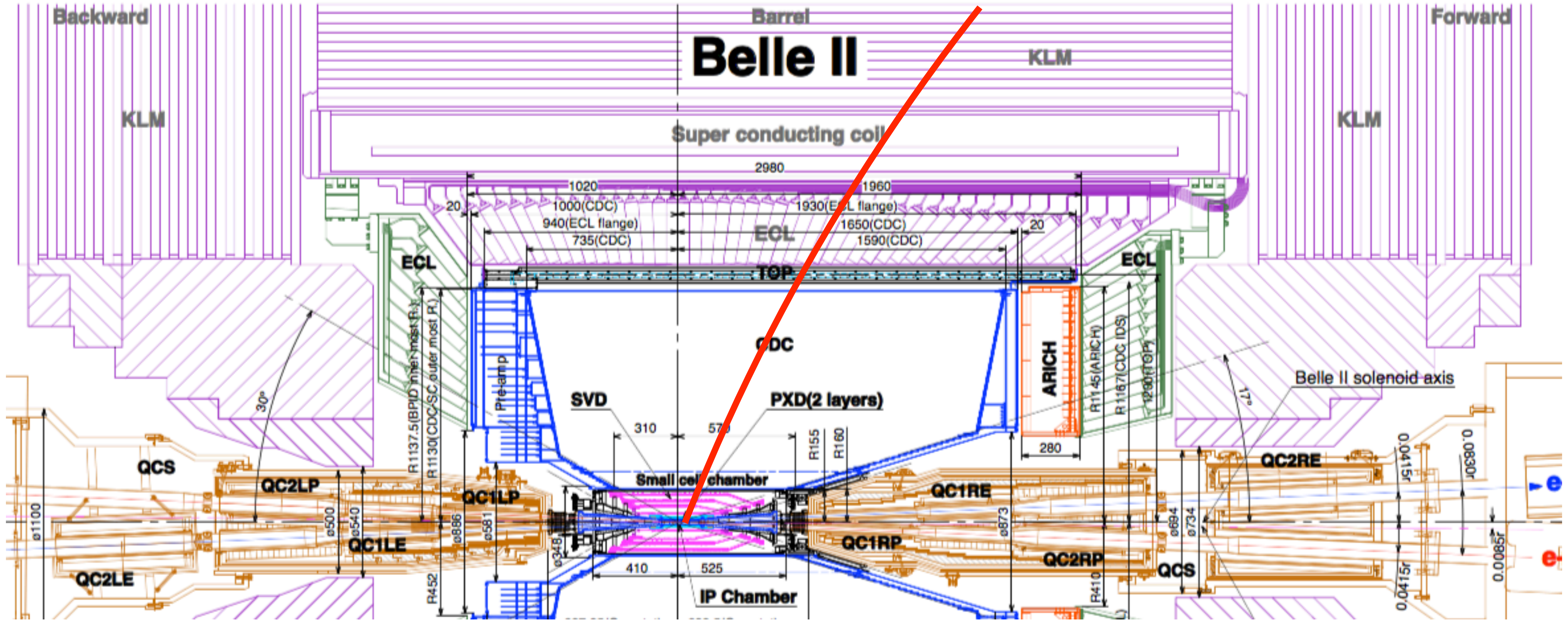
The **TAU** is a short-lived ($3x10^{-13}$ second), heavier version of the muon and electron. It has the same negative charge, but is 3,478 times more massive than the electron.

Acrylic felt with gravel fill for maximum mass.

Muon identification

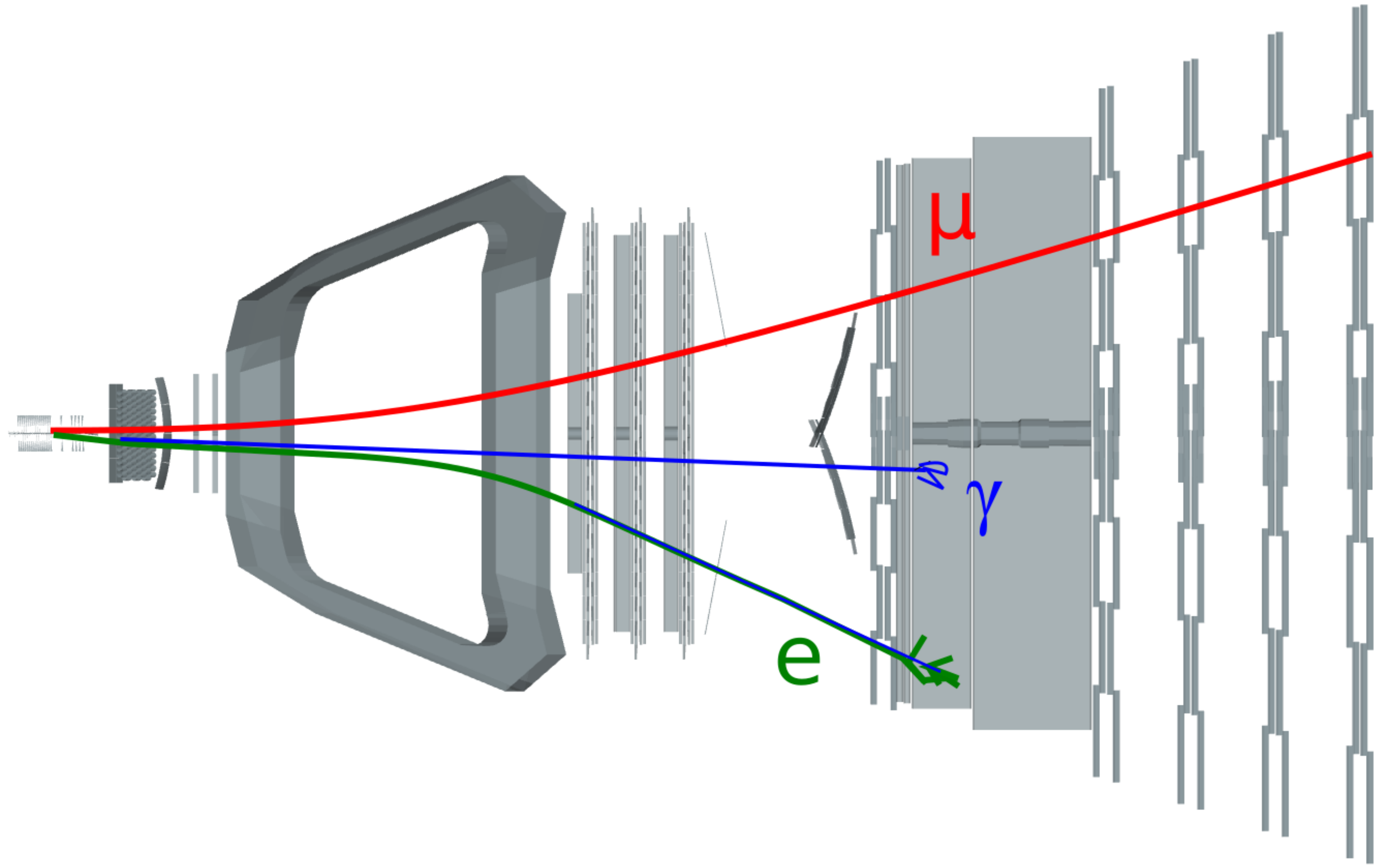
- Muons are the easiest to identify
  - Little to **no radiation** (heavy)
  - **Stable** within particle detectors
  - No strong interactions in absorber material
  - In B-factories, need p > 700 MeV/c to reach muon detectors

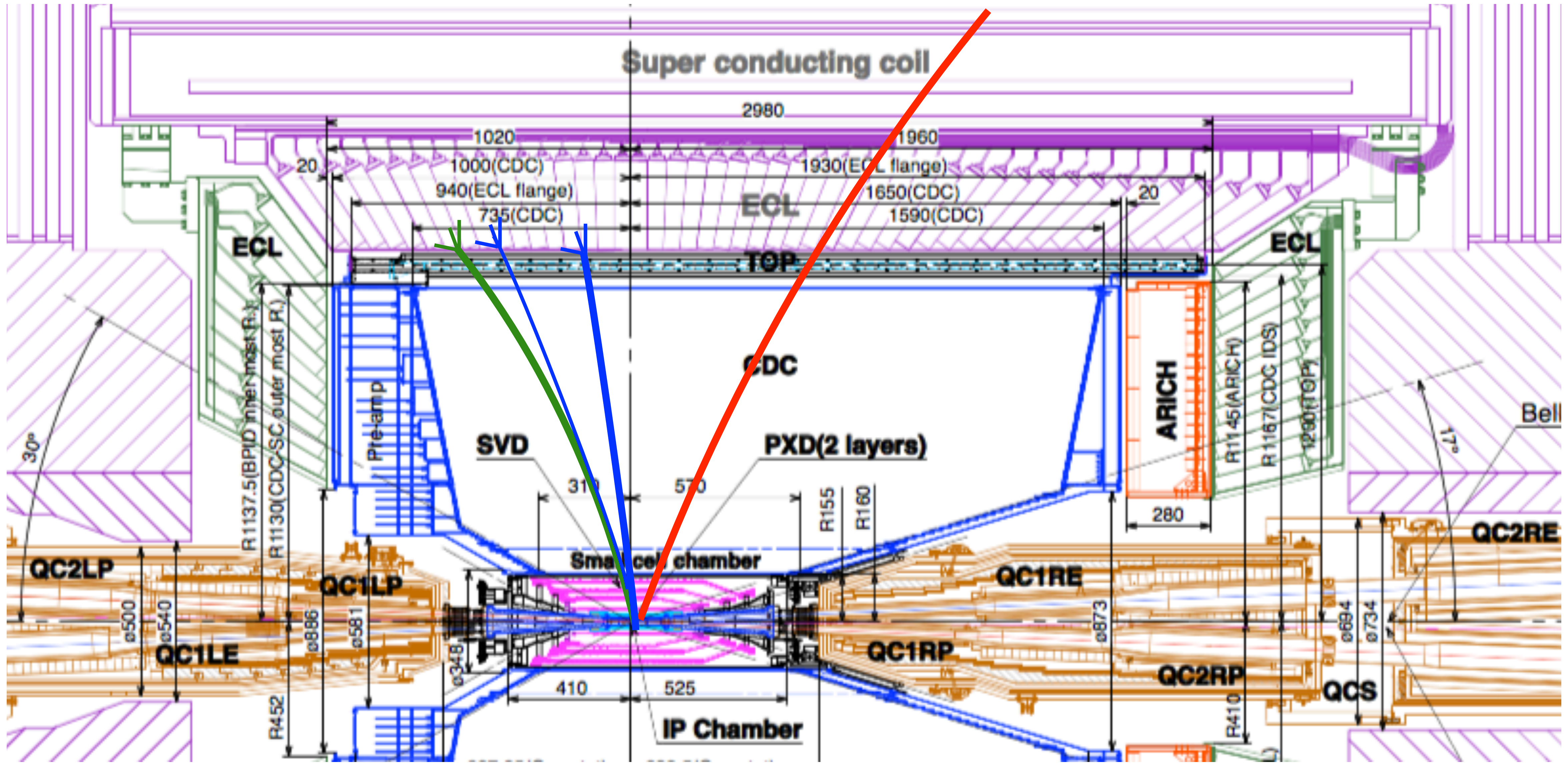




Electron identification

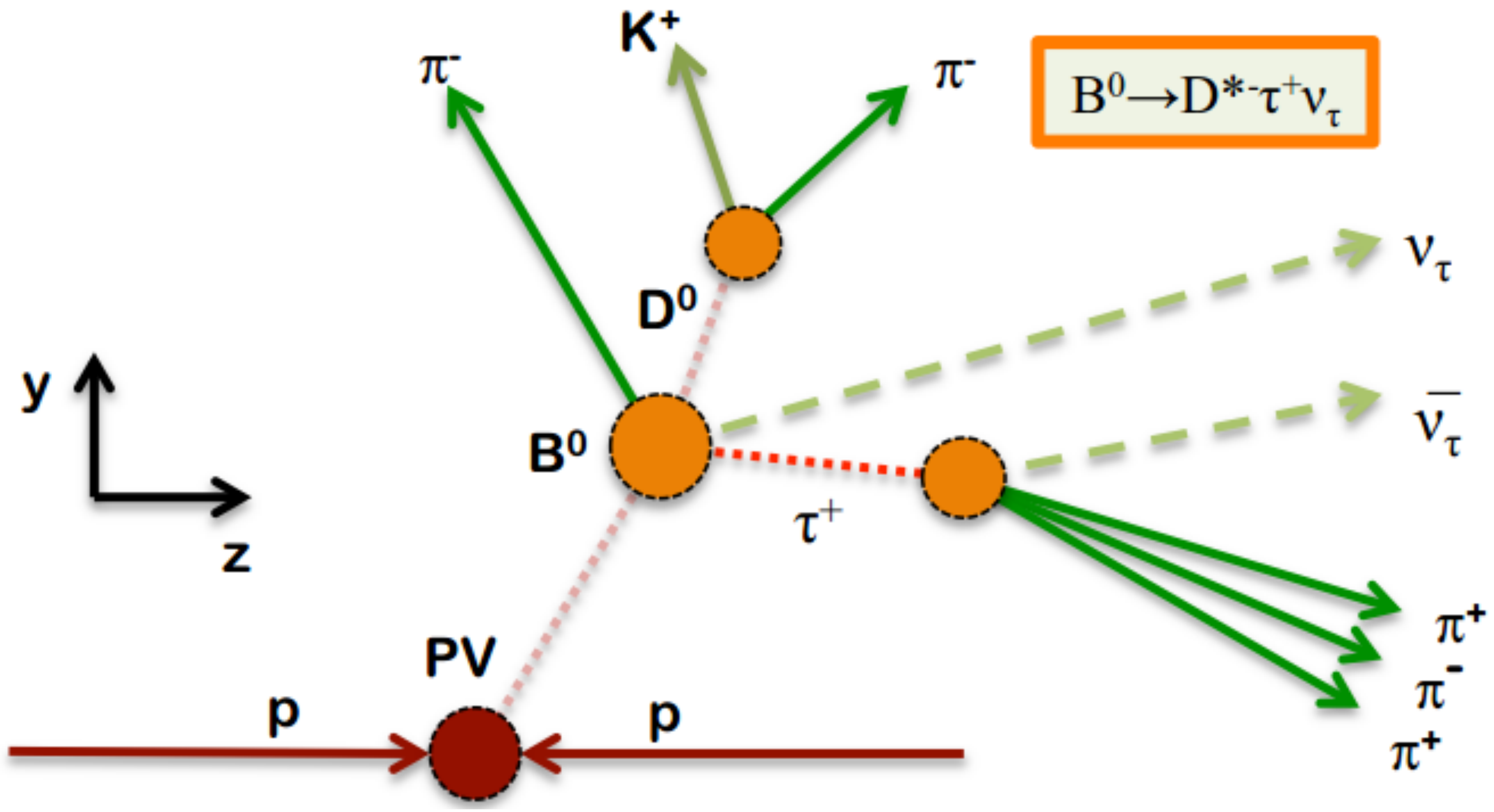
- Electrons are light
  - **Final state radiation**
  - **Bremsstrahlung** in material is likely
    - Measure too low momentum, Too low energy in calorimeter
  - **Photons can fake** prompt electrons through conversions
  - **Bremsstrahlung recovery** partial fixes this but affected by pile-up / beam background

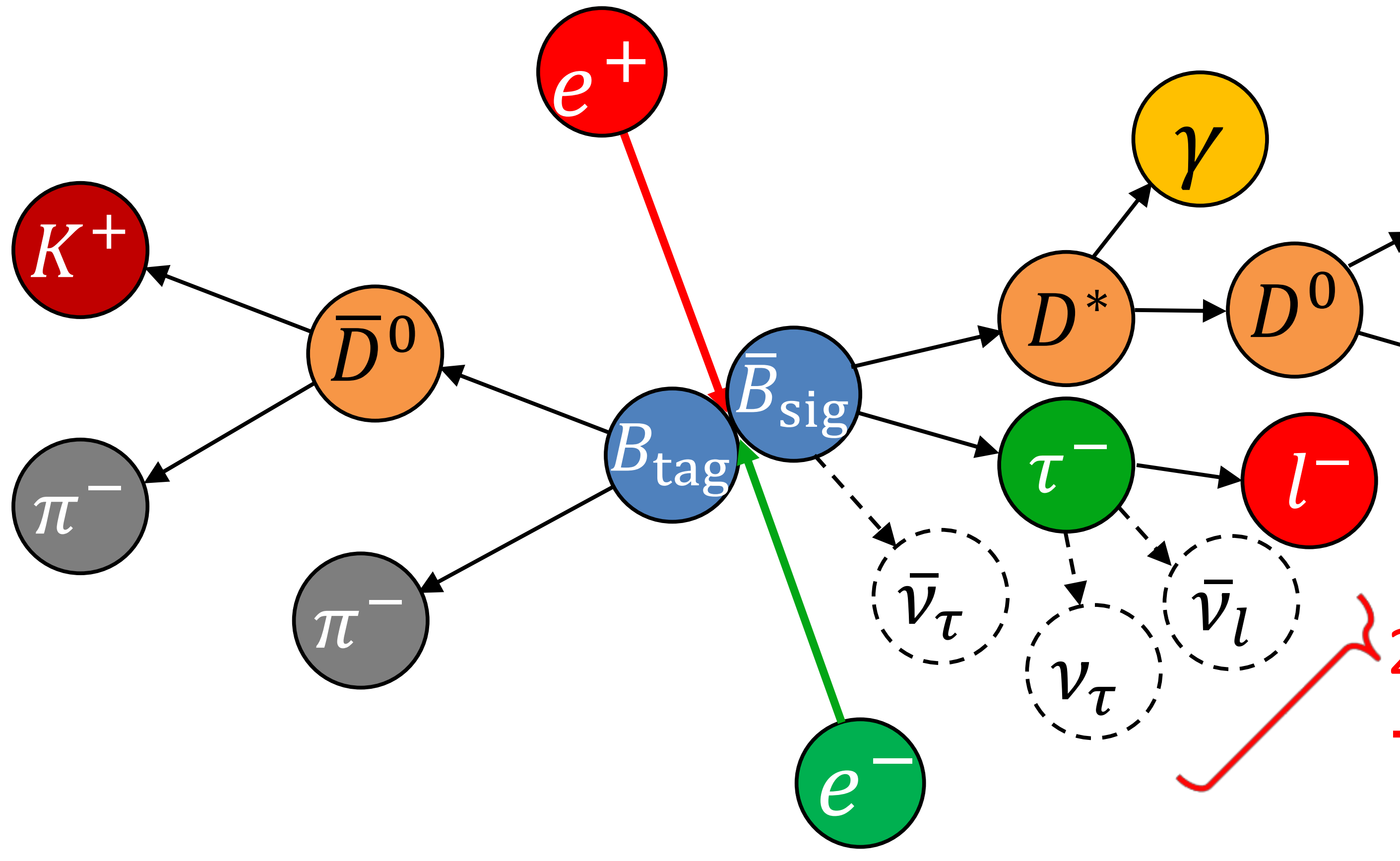




Tau identification (reconstruction)

- Identification / reconstruction of τ leptons is very challenging
  - **Short lifetime** of 10^{-12} s
  - Hadronic decay with **π's and 1 ν**
  - Leptonic decay with **e/μ and 2 ν**
  - Lack of full reconstruction implies **background mimics the the signal where some daughters are lost e.g. K_L, π^0**. Often difficult to constrain with "sideband" data.

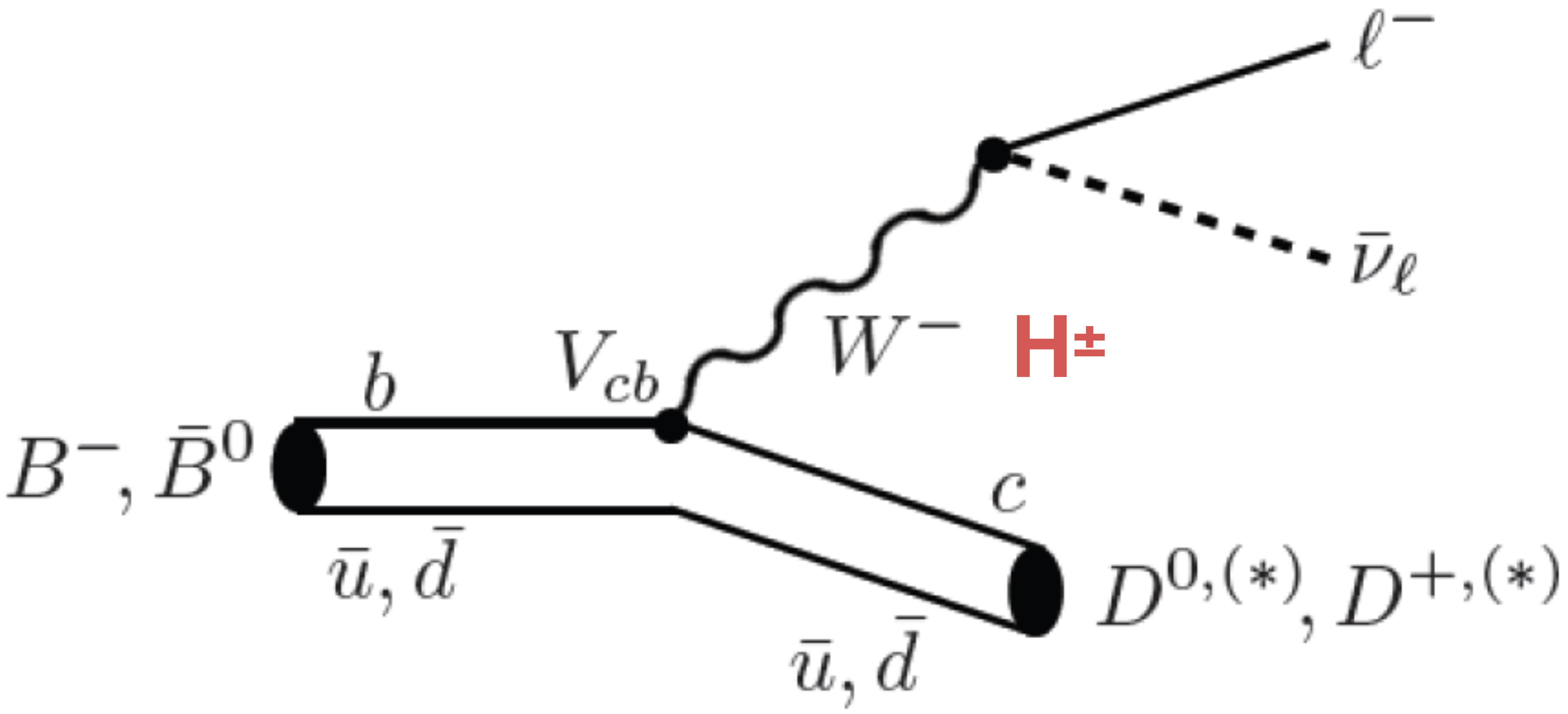




2-3 neutrinos
→ Impossible to fully reconstruct B_{sig}

Tree: Semileptonic decays — Theory

- In the SM, the decay $B^0 \to D^{*-} l^+ \nu$ proceed through a tree level decay



$$\frac{d\Gamma^{SM}(\bar B \to D^{(*)}\ell^-\bar\nu_\ell)}{dq^2} = \underbrace{\frac{G_F^2\,|V_{cb}|^2\,|p^*_{D^{(*)}}|\,q^2}{96\pi^3 m_B^2}\left(1-\frac{m_\ell^2}{q^2}\right)^2}_{\text{universal and phase space factors}}$$

$$\times \underbrace{\left[(|H_+|^2+|H_-|^2+|H_0|^2)\left(1+\frac{m_\ell^2}{2q^2}\right)+\frac{3m_\ell^2}{2q^2}\boxed{|H_s|^2}\right]}_{\text{hadronic effects}} .$$

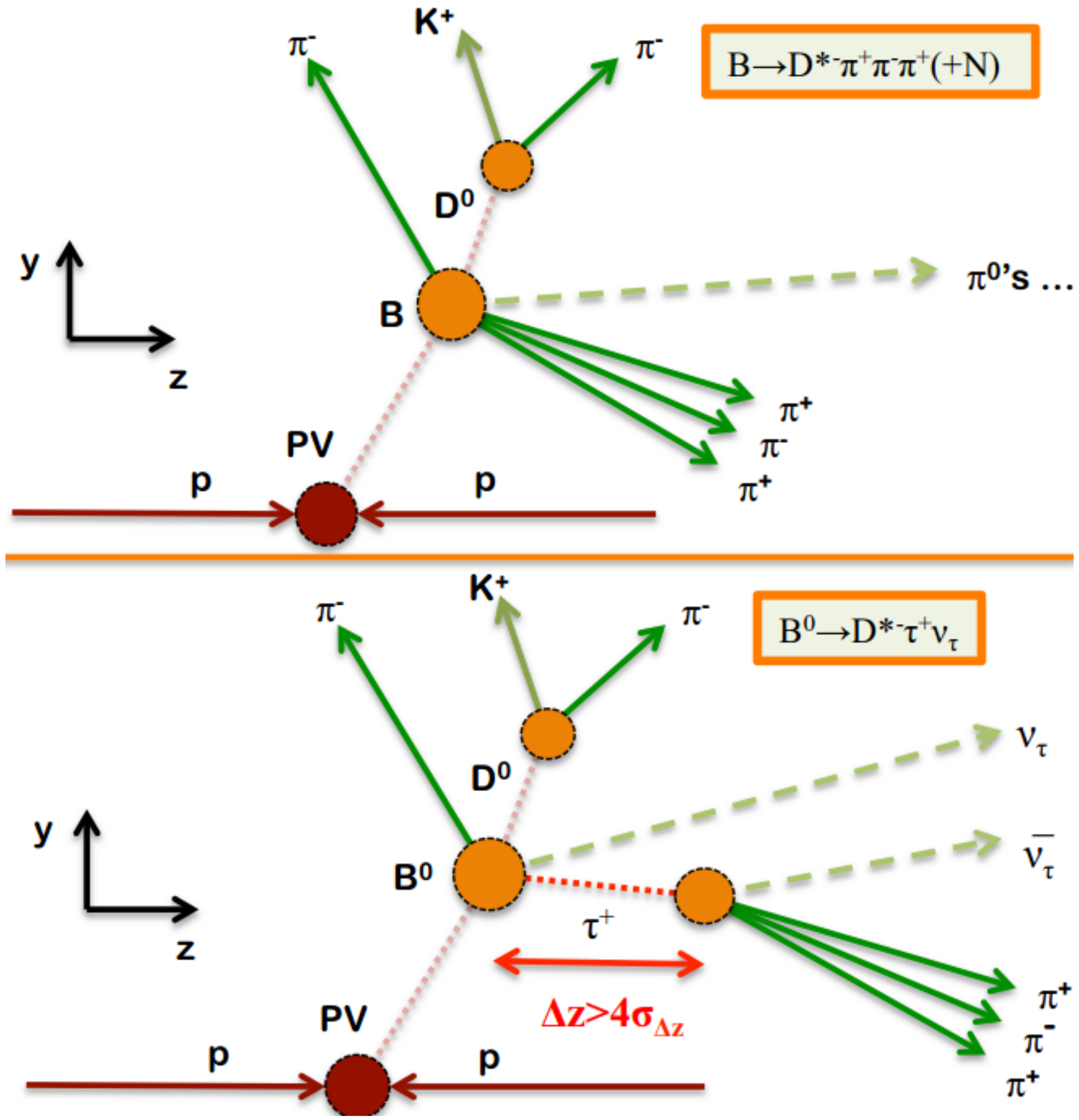
$$R(D^*) = \frac{BF(B \to D^*\tau\nu)}{BF(B \to D^*\mu\nu)} \overset{SM}{=} 0.252 \pm 0.003$$

Semileptonic decays — LHCb Reconstruction

- Latest LHCb measurement uses $\tau \to \pi^+ \pi^- \pi^+ \nu$ decays
- Normalisation with hadronic B decay of similar topology

$$R(D^*) = K_{had}(D^*) \times \frac{BR(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}{BR(B^0 \to D^{*-}\mu^+\nu_\mu)}$$

$$\boxed{K_{had}(D^*) = \frac{BR(B^0 \to D^{*-}\tau^+\nu_\tau)}{BR(B^0 \to D^{*-}\pi^+\pi^-\pi^+)}}$$

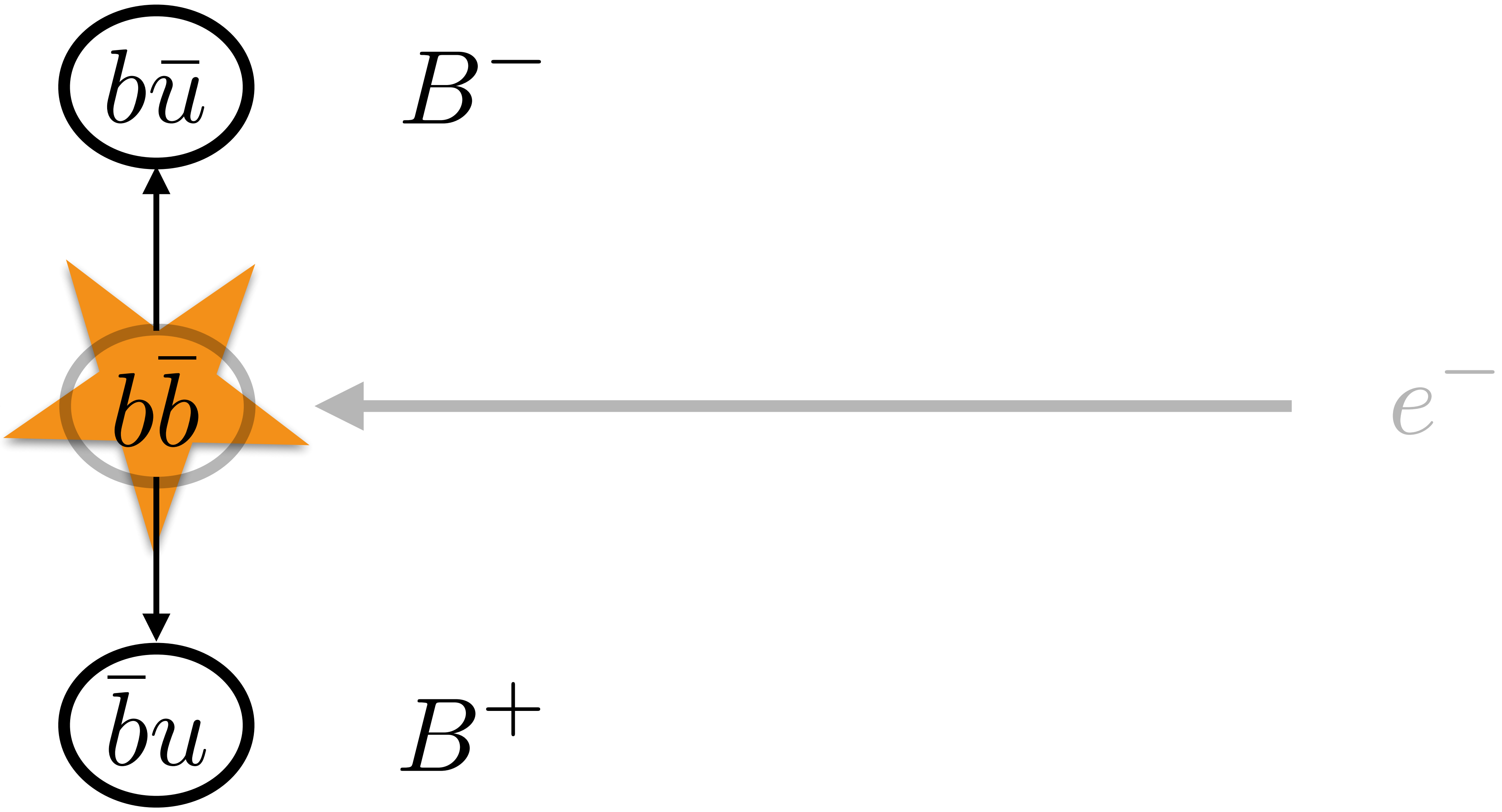


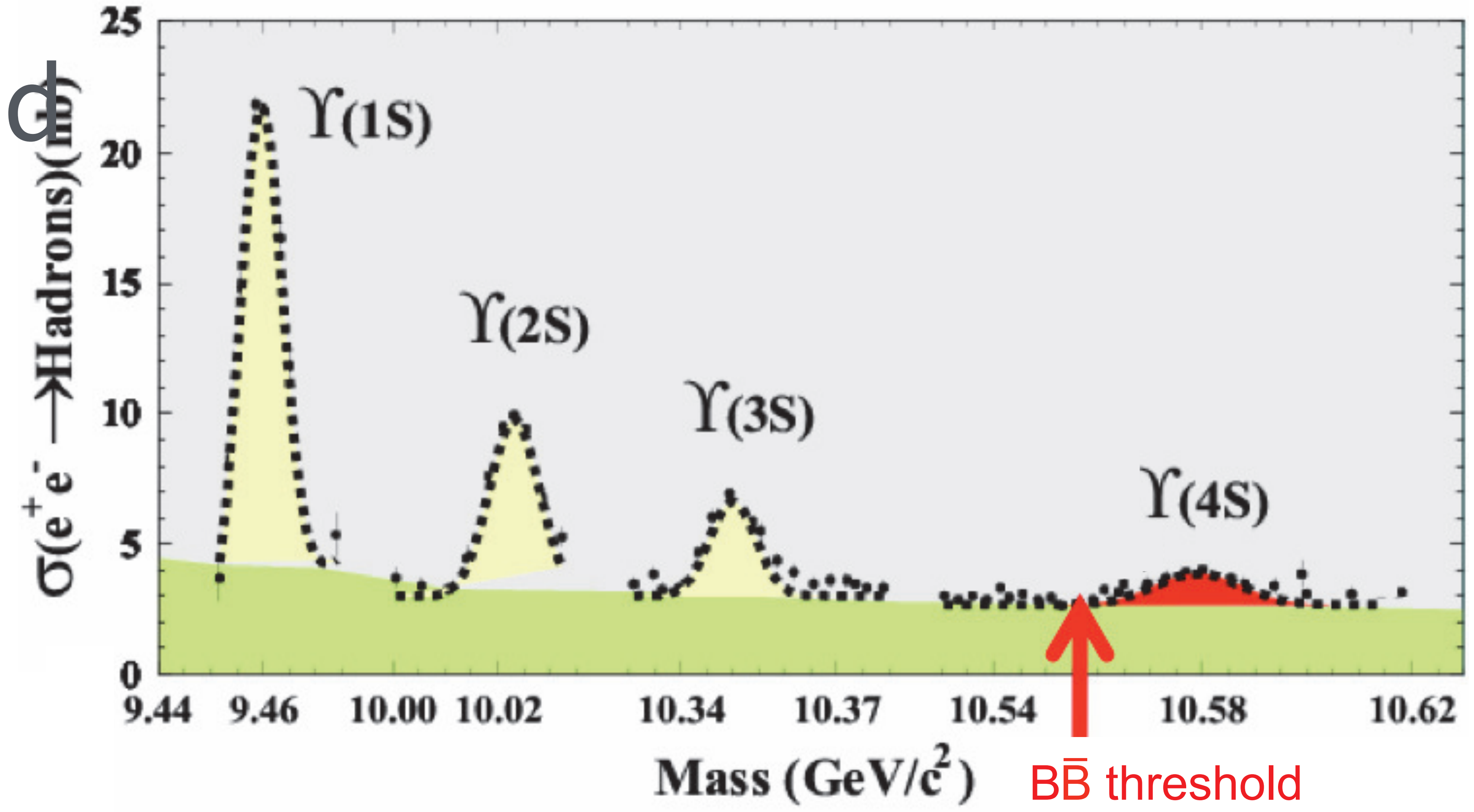
Belle (II) Reconstruction

- Latest Belle analyses use semileptonic and hadronic tagging.
- Normalisation to semileptonic decay modes.
- Based on M_{miss}^2 and $E_{ECL/extra}$

Belle (II) Reconstruction

- Latest Belle analyses use semileptonic and hadronic tagging.
- Normalisation to semileptonic decay modes.
- Based on M_{miss}^2 and $E_{ECL/extra}$



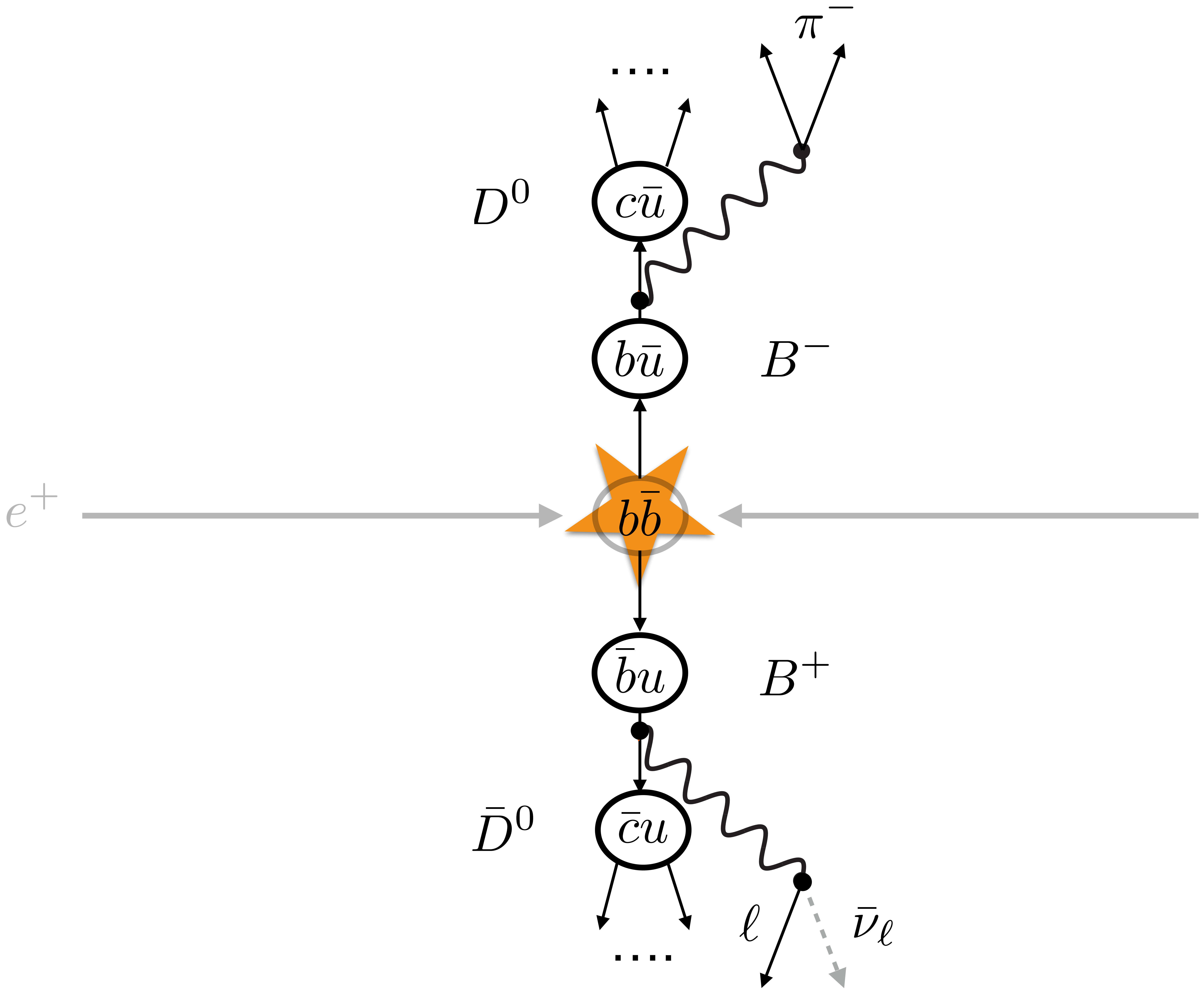


$$\Upsilon(1S) = \langle b\bar{b}\rangle$$

$$\Upsilon(4S) = \langle b\bar{b}\rangle$$

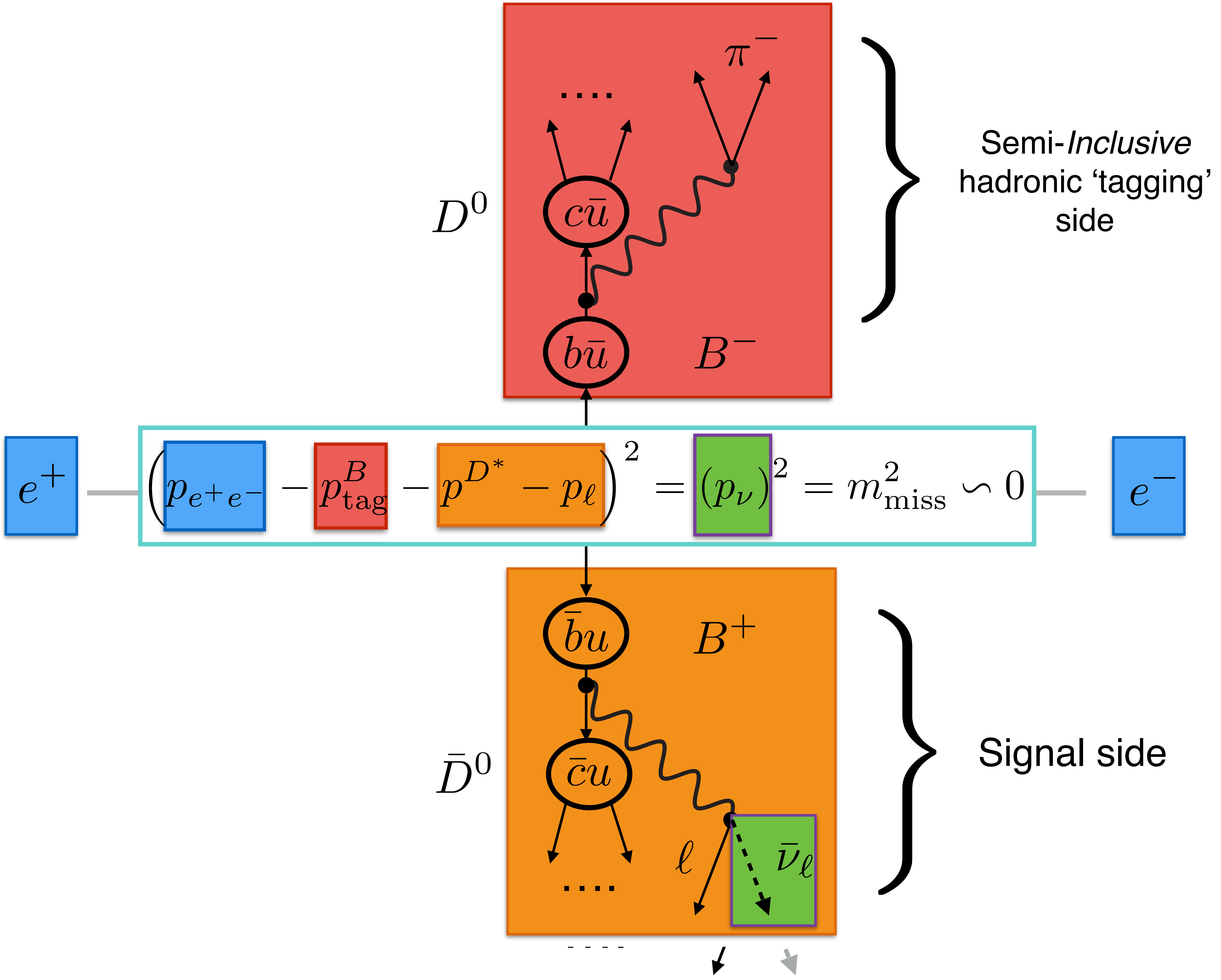
Belle (II) Reconstruction

- Latest Belle analyses use semileptonic and hadronic tagging.
- Normalisation to semileptonic decay modes.
- Based on M_{miss}^2 and $E_{ECL/extra}$



Belle (II) Reconstruction

- Latest Belle analyses use semileptonic and hadronic tagging.
- Normalisation to semileptonic decay modes.
- Based on M_{miss}^2 and $E_{ECL/extra}$



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

Flavour Session: G. Caria

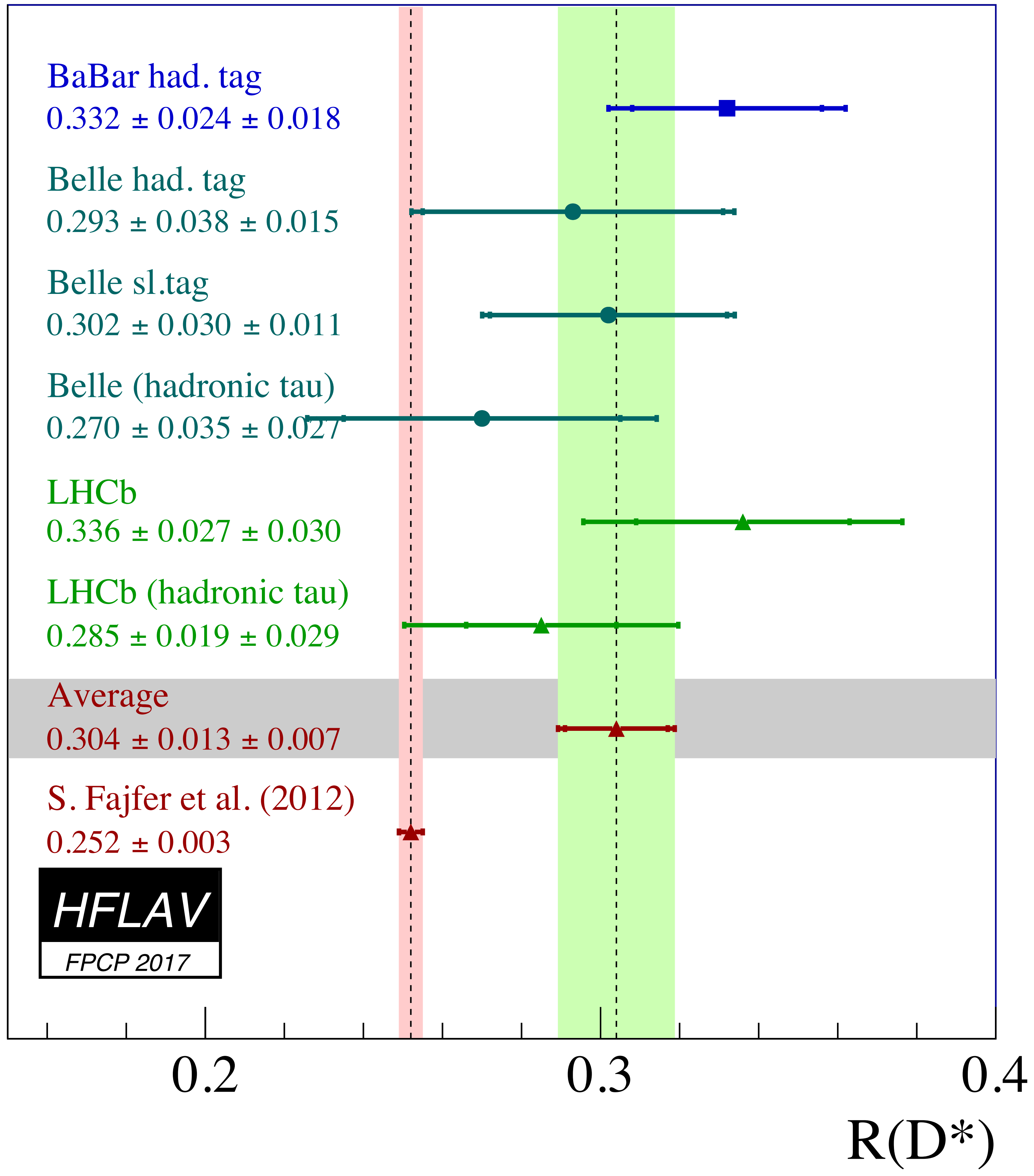
- New R_{D^*} measurements with $\tau \rightarrow h \nu$ from Belle and LHCb.
- Compatible with SM but also with other measurements.

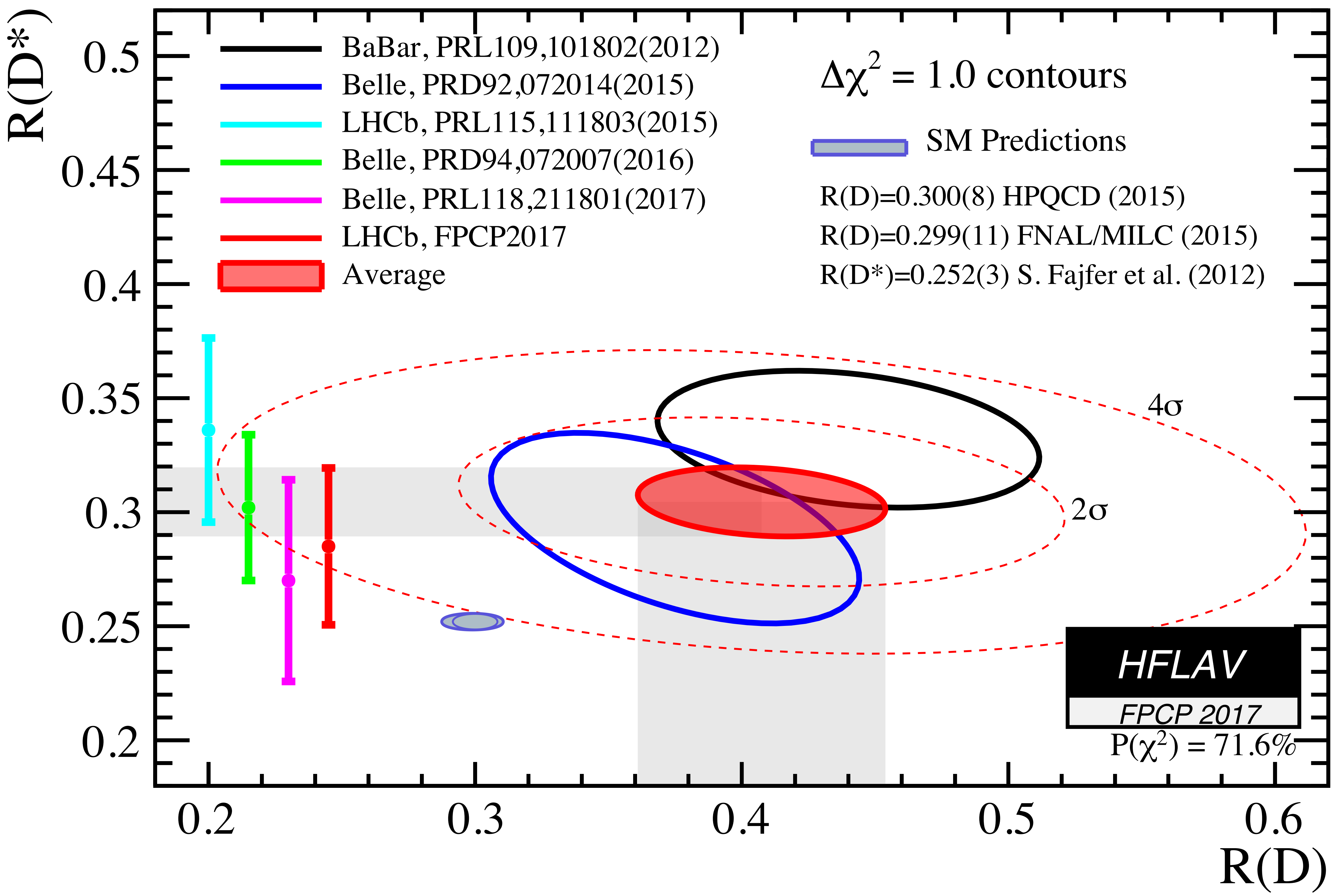
Belle PRD 94, 072007 (2016)

Belle PRL 118, 211801 (2017)
Belle arXiv:1709.00129

LHCb arXiv:1711.02505

LHCb arXiv:1711.05623





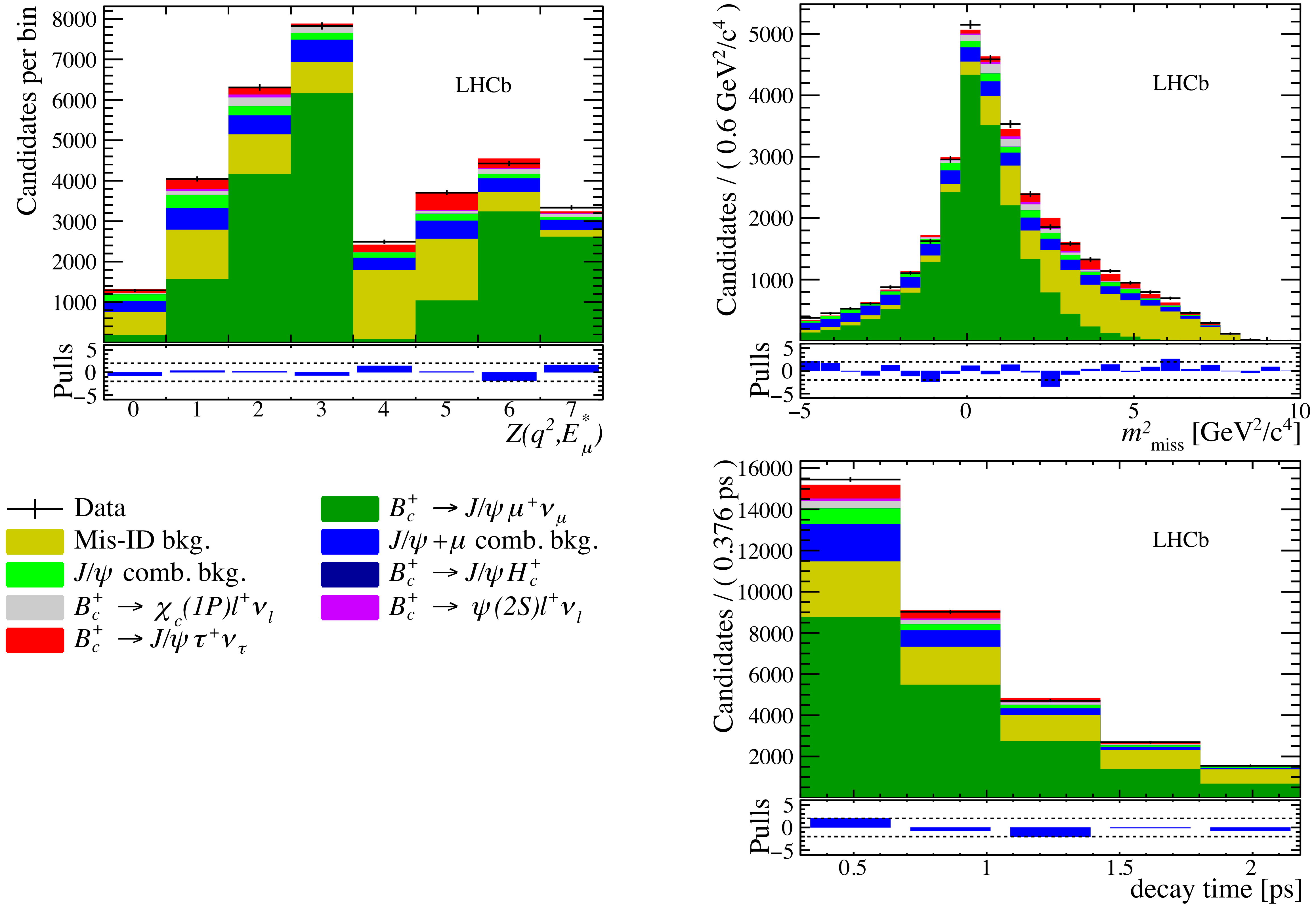
$B_c \rightarrow J/\psi\,\tau\,\nu$ & τ polarisation in $B \rightarrow D^*\,\tau\,\nu$

Flavour Session: G. Caria

- First measurement in B_c system - 2 σ above SM R(J/ψ) ~ 0.25
- First measurement of polarisation - compatible with SM P_τ ~0.5

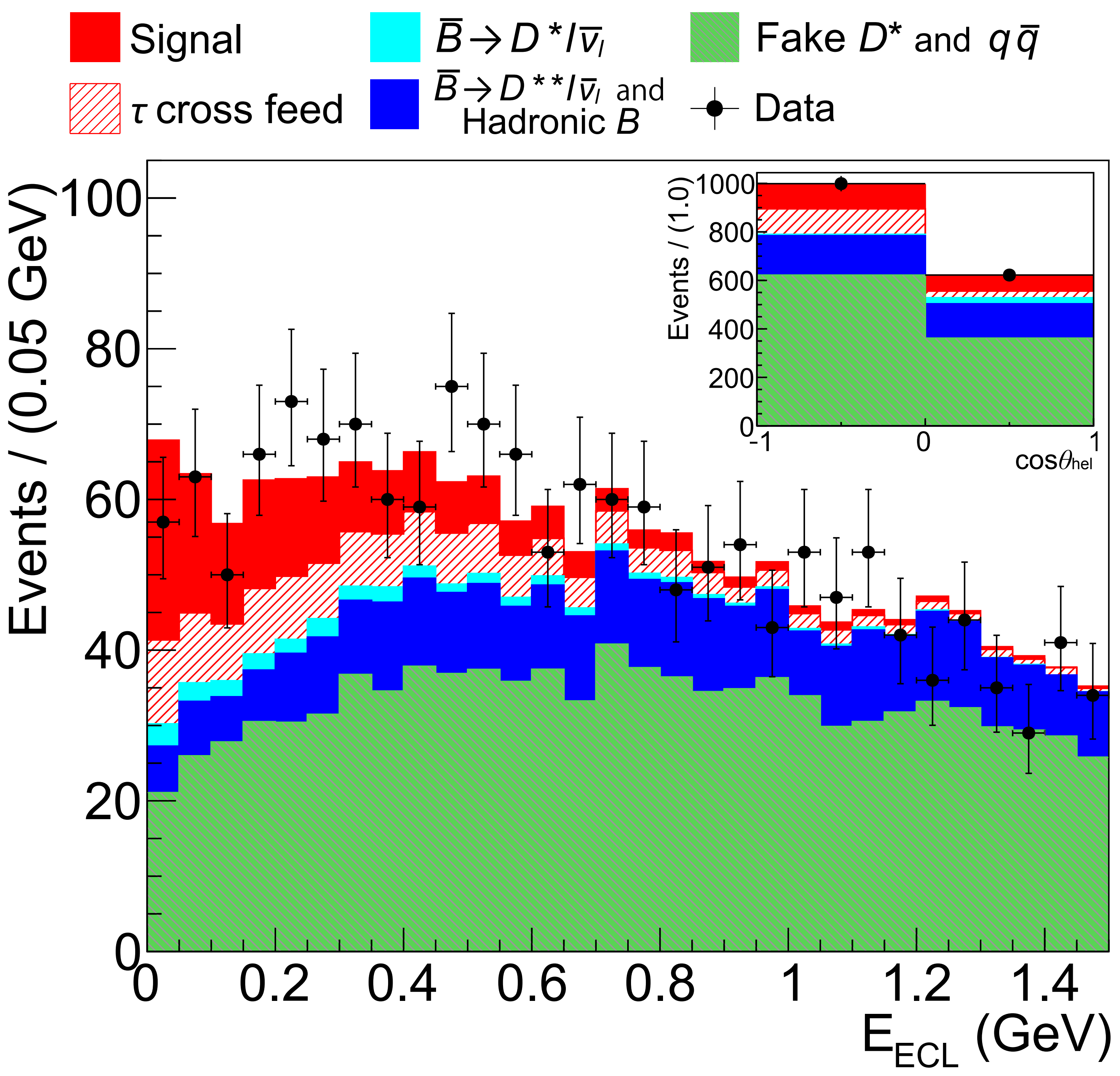
Belle PRL 118, 211801 (2017)
Belle arXiv:1709.00129

LHCb arXiv:1711.05623



$$\mathcal{R}(J/\psi) = \frac{\mathcal{B}(B_c^+ \rightarrow J/\psi\,\tau^+\nu_\tau)}{\mathcal{B}(B_c^+ \rightarrow J/\psi\,\mu^+\nu_\mu)} = 0.71 \pm 0.17\,(\text{stat}) \pm 0.18\,(\text{syst})$$

$$\frac{1}{\Gamma(D^{(*)})}\frac{d\Gamma(D^{(*)})}{d\cos\theta_{\rm hel}} = \frac{1}{2}\left[1 + \alpha P_\tau(D^{(*)})\cos\theta_{\rm hel}\right]$$



$$R(D^*) = 0.270 \pm 0.035(\text{stat.})^{+0.028}_{-0.025}(\text{syst.}),$$
$$P_\tau(D^*) = -0.38 \pm 0.51(\text{stat.})^{+0.21}_{-0.16}(\text{syst.}).$$

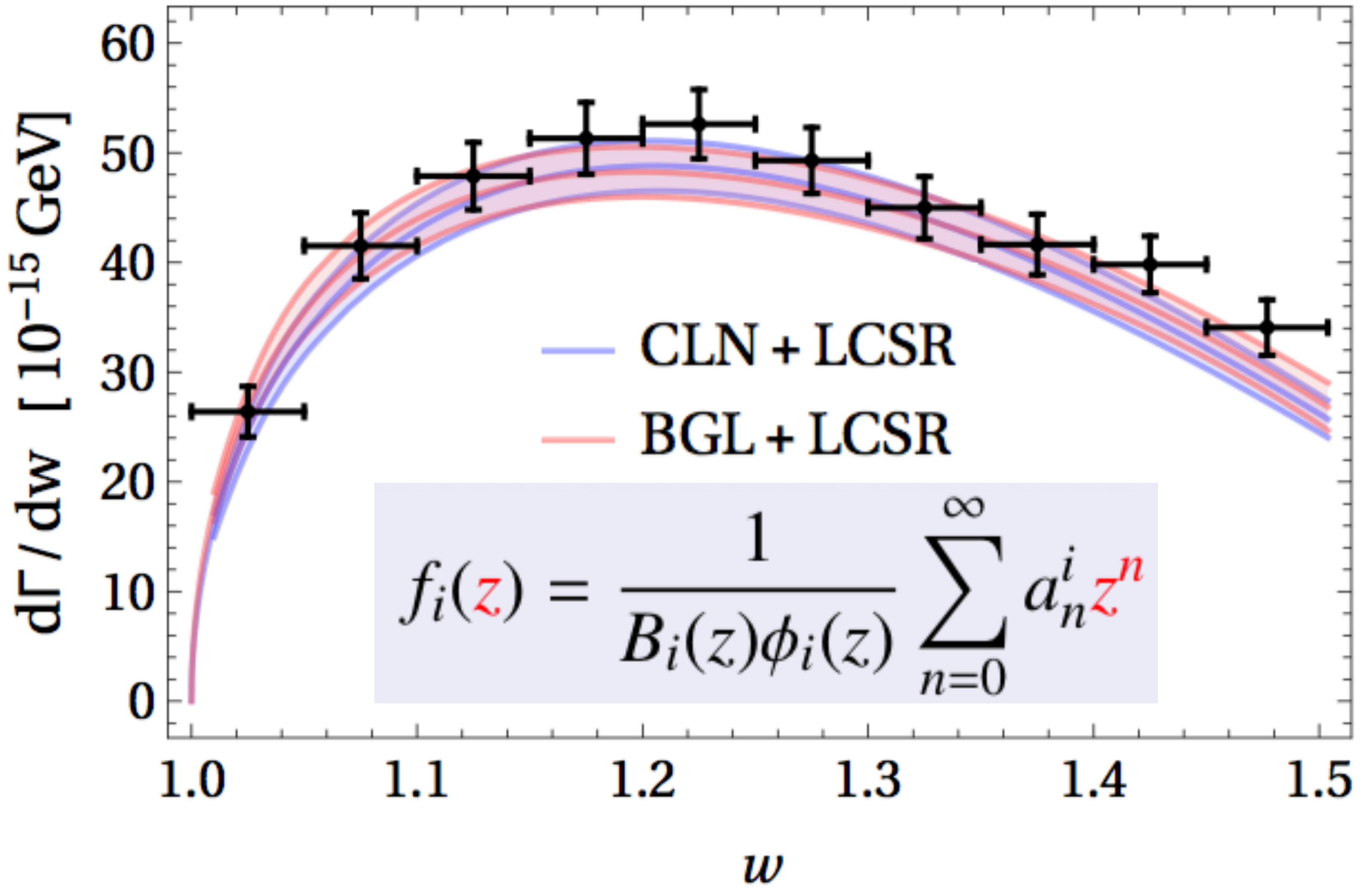
$B \to D^* l \nu$ (l=e,μ) & $B \to \mu \nu$ (Light lepton LFUV tests)

Flavour Session: G. Caria

Belle arXiv:1702.01521

Belle arXiv:1712.04123

- First model independent $|V_{cb}|_{\text{exclusive}}$ with new Belle tagged approach.
- $B \to \mu \nu$ untagged result finds 2.4 σ significance, compatible with SM



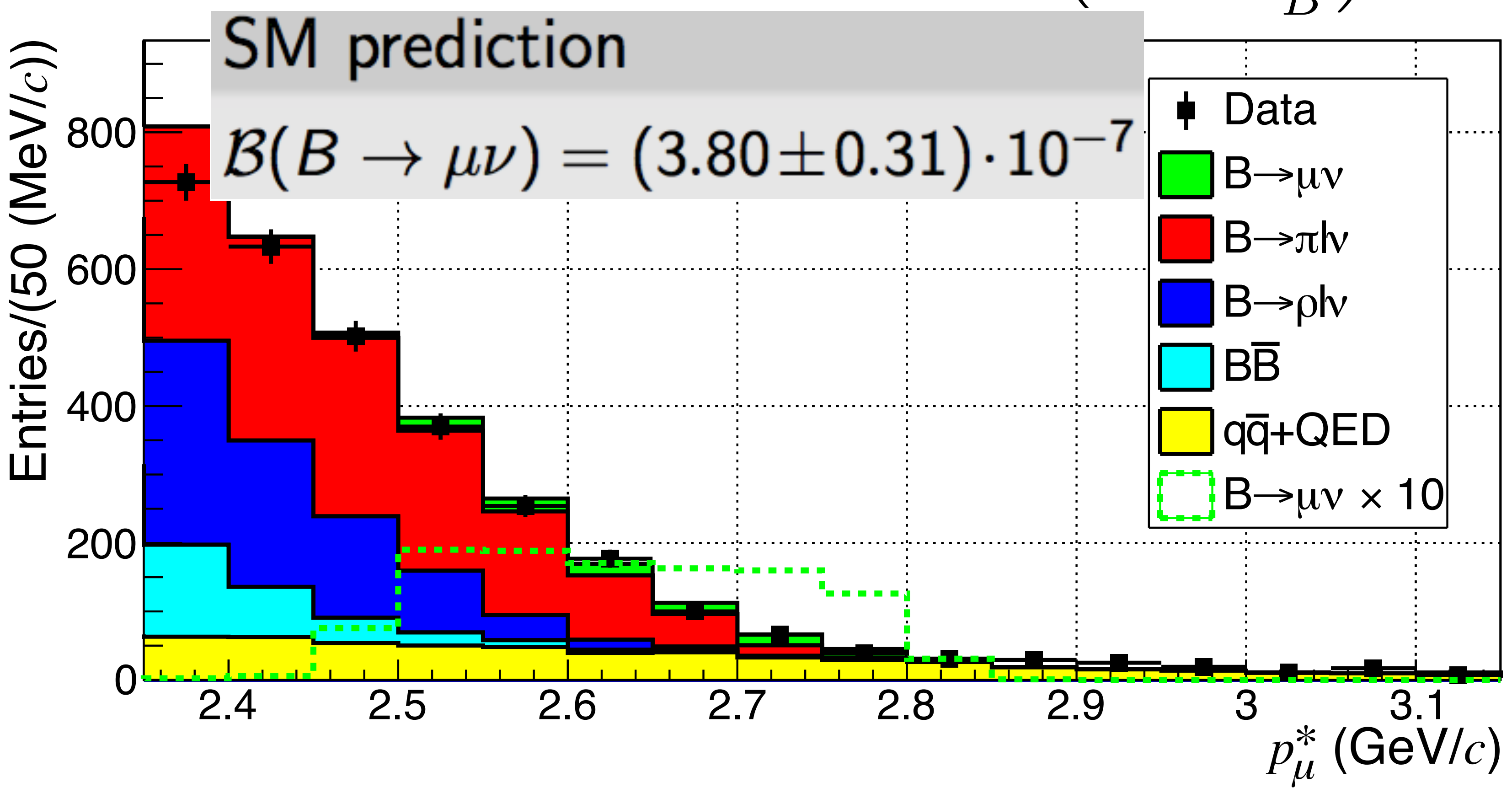
CLN Fit:	Data + lattice
χ^2/dof	34.3/36
$\|V_{cb}\|$	0.0382 (15)

BGL Fit:	Data + lattice
χ^2/dof	27.9/32
$\|V_{cb}\|$	$0.0417\left(^{+20}_{-21}\right)$

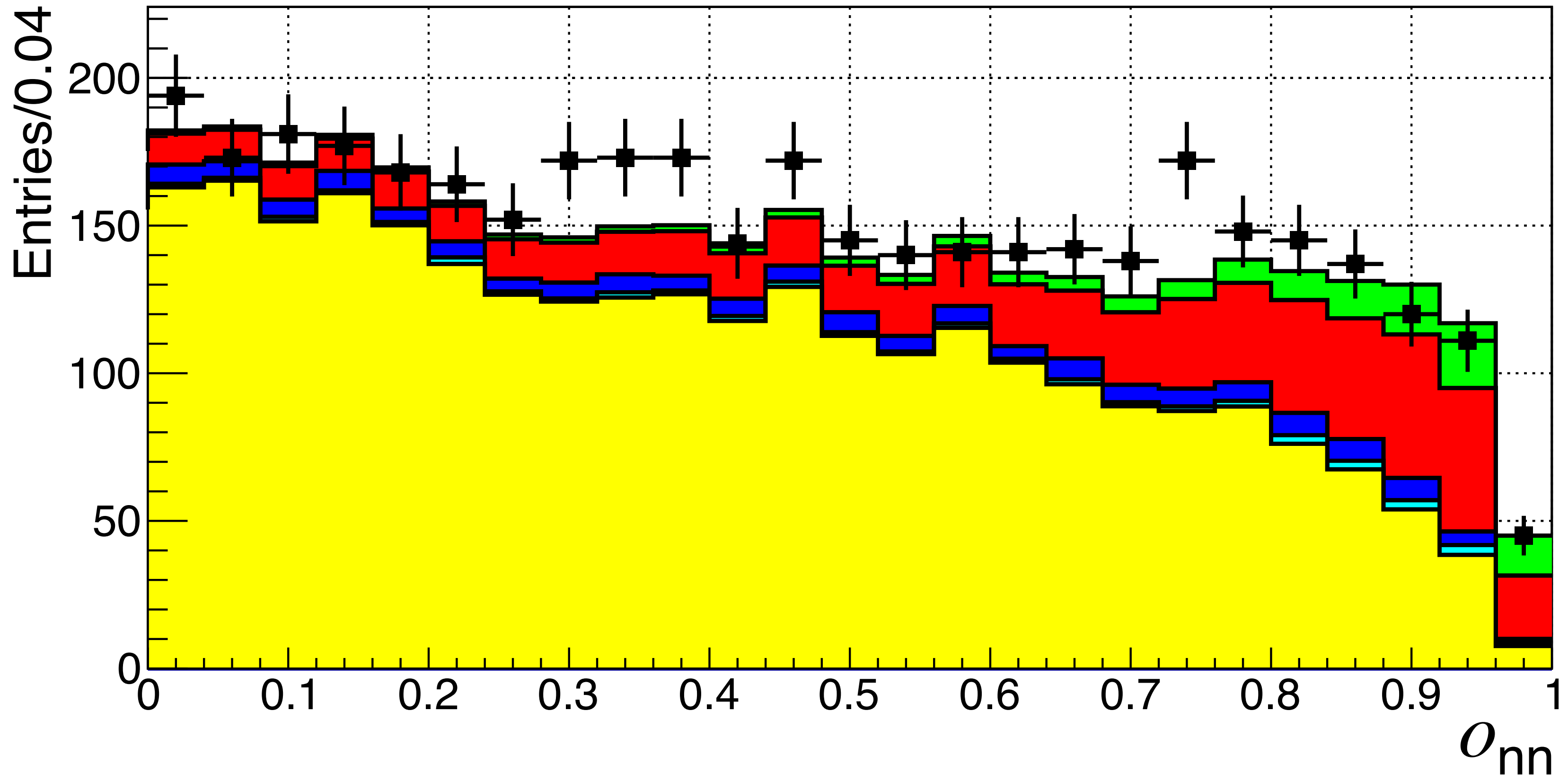
Resolves exclusive-inclusive tension

$$R_{e\mu} = \frac{\mathcal{B}(\bar{B}^0 \to D^{*+} e^- \bar{\nu}_e)}{\mathcal{B}(\bar{B}^0 \to D^{*+} \mu^- \bar{\nu}_\mu)} = 1.04 \pm 0.05 \pm 0.01$$

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



NEW.
Submitted to PRL this week!
$R^{SM}\mu$ = 1.7±0.7



$$\mathcal{B}(B^- \to \mu^- \bar{\nu}_\mu) = (6.46 \pm 2.22 \pm 1.60) \times 10^{-7}$$

Loop: EWP decays

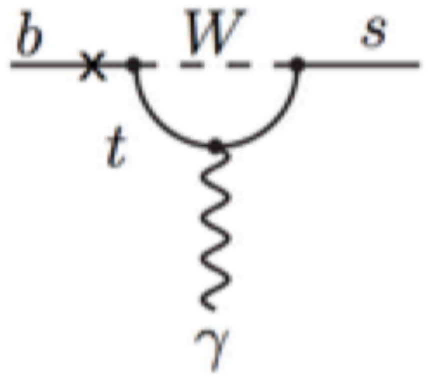
- In electroweak penguin decays there are many more tensions.

$$\mathcal{H}_{\rm eff} \;=\; -\frac{4G_F}{\sqrt{2}}V_{tb}V_{ts}^{*}\sum_i\left(C_i\mathcal{O}_i + C_i'\mathcal{O}_i'\right)$$

left-handed part

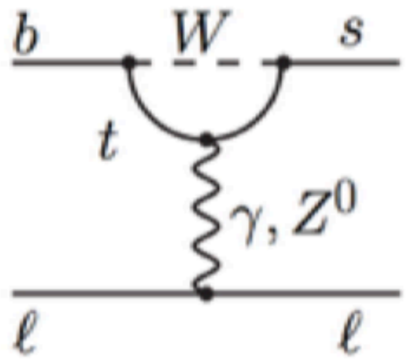
right-handed part suppressed in SM

i=7 photon

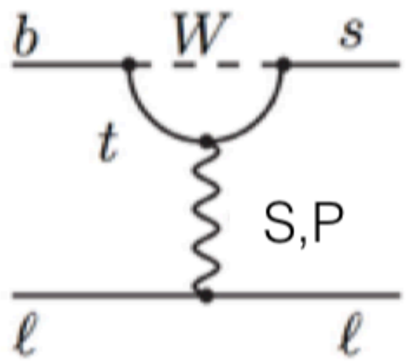


i=9 vector current

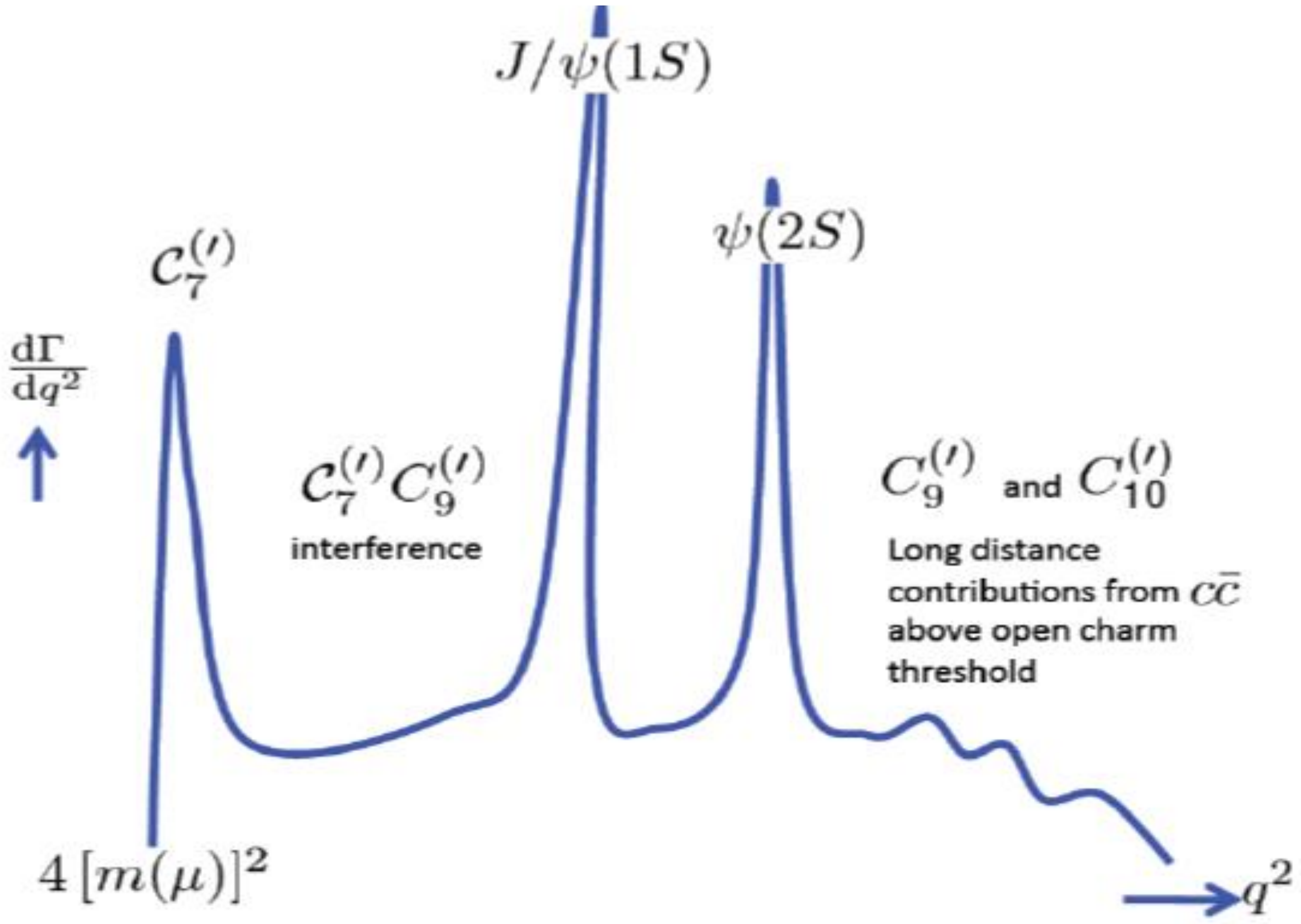
i=10 axial-vector current



i=S, P scalar, pseudo scalar operators



- Wilson coefficients C_i describe short distance effects
- Operators O_i depend on hadronic form factors



B→ X γ C_7

B→ $l^+ l^-$ $C_{10}, C_{S,P}$

B→ X $l^+ l^-$ C_7, C_9, C_{10}

The SM forward-backward asymmetry in b→ s l+ l- arises from the interference between γ and Z0 contributions.

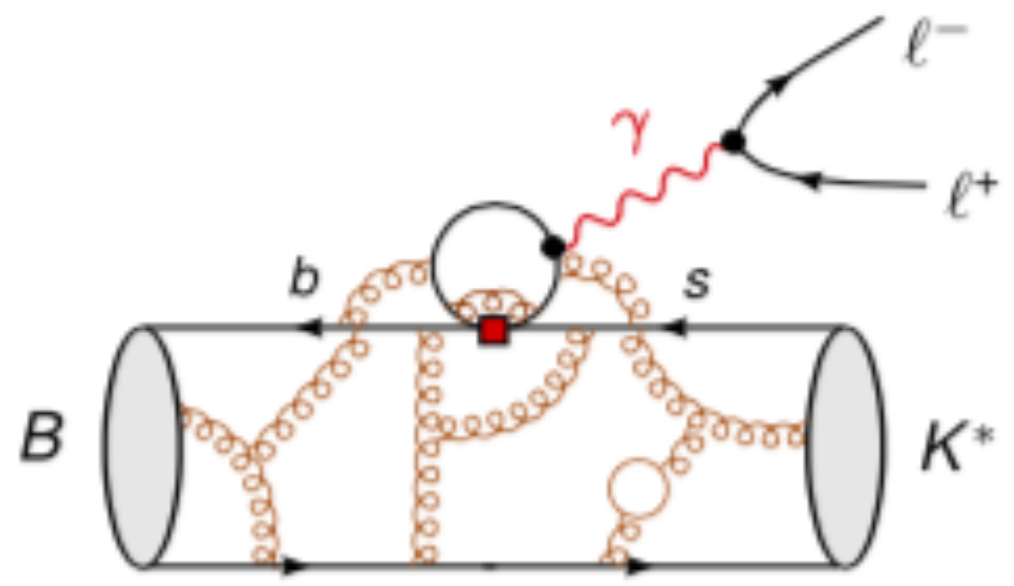
Angular analyses reveal nature of propagators.

$B \rightarrow K^{(*)} \mu\, \mu$, $B \rightarrow K^{(*)} e\, e$

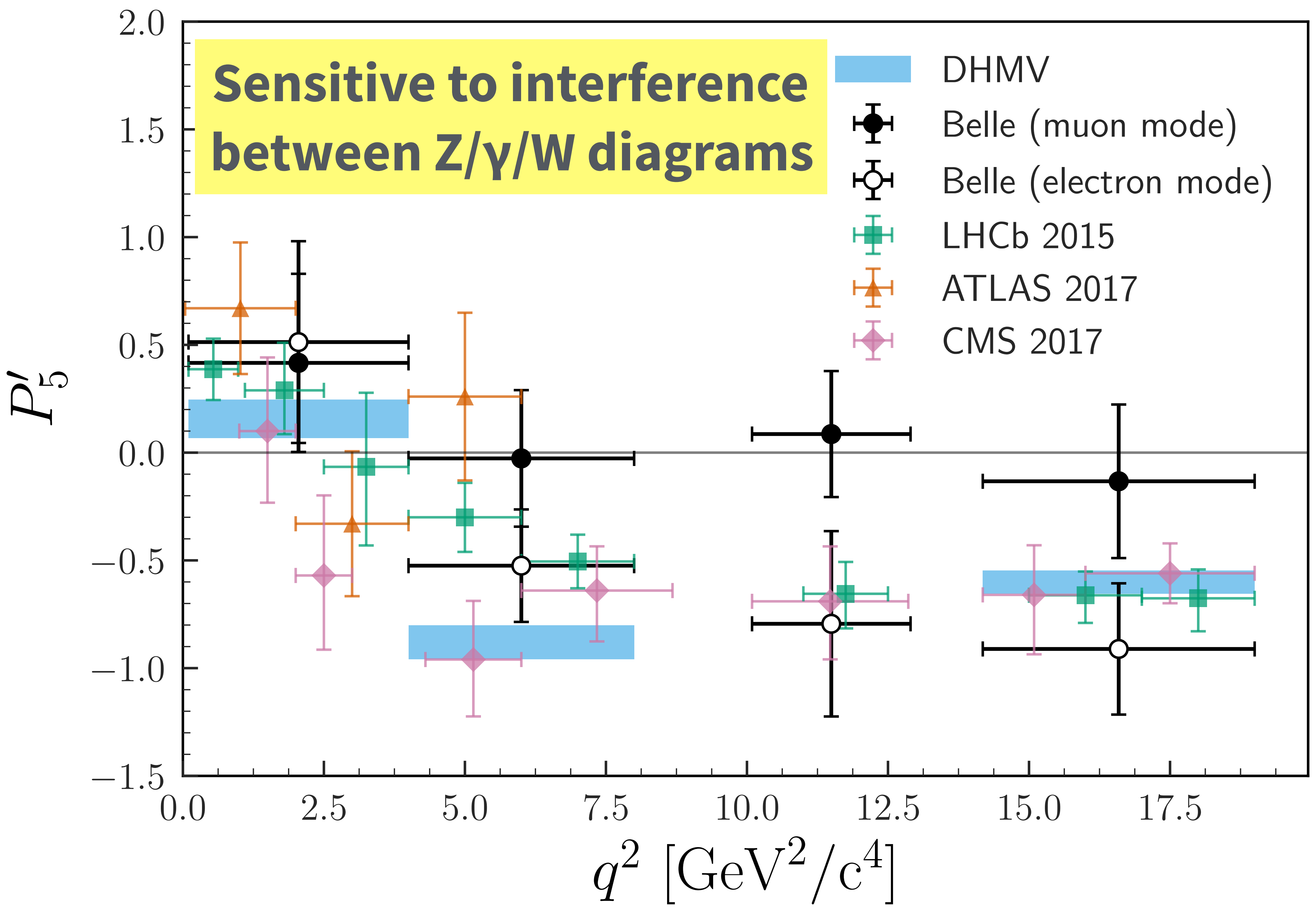
Flavour Session: D. Lancierini, N. Sahoo

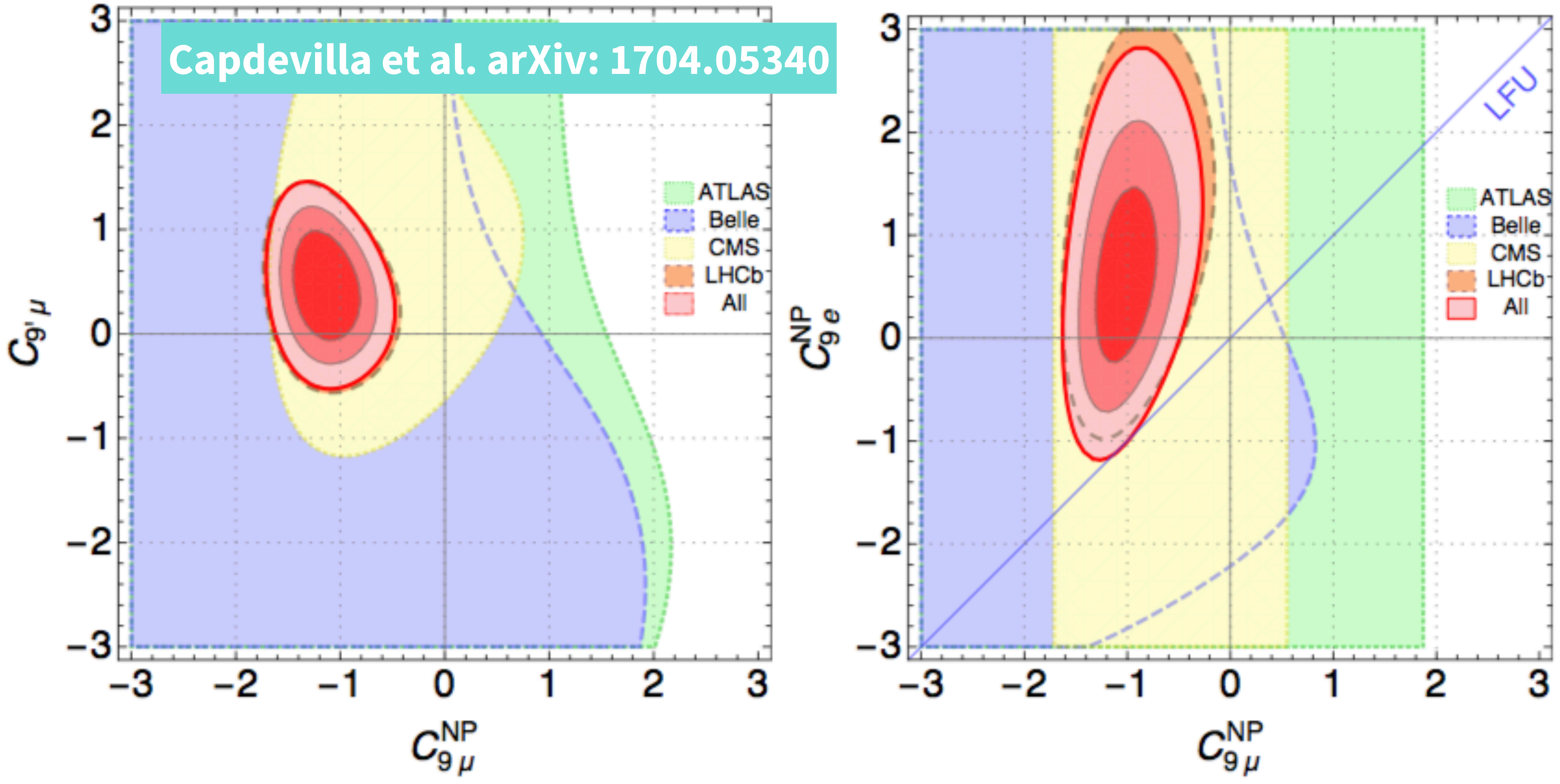
LHCb PRL 118, 251802 (2017)
LHCb JHEP 11, 047 (2016)
LHCb JHEP 04, 142 (2017)
CMS PLB 753, 424 (2016)
Belle PRL 118, 111801 (2017)
Babar PRD 93, 052015 (2016)

- Consistent picture, tensions solved simultaneously by a modified vector coupling (ΔC9 != 0) at >3σ
- Could still be hadronic effects — c anti-c loop



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

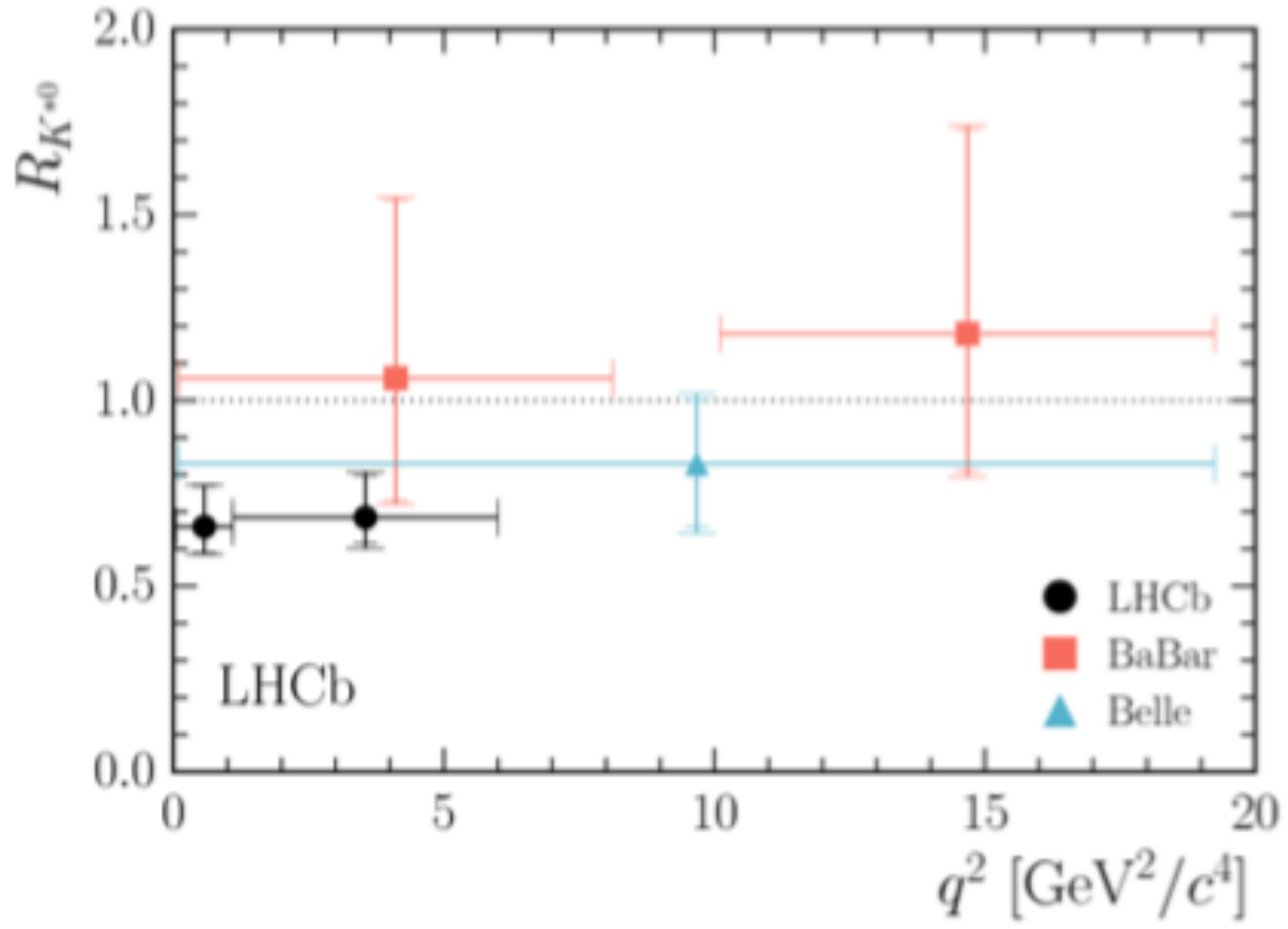

Sensitive to interference between Z/γ/W diagrams


Capdevilla et al. arXiv: 1704.05340

LFUV B → $K^{(*)}$ μ μ, B → $K^{(*)}$ e e

Flavour Session: D. Lancierini, N. Sahoo

- R(K*) directly measured by LHCb
  - Low q^2 : 2.1-2.3σ below SM
    Central q^2 : 2.4-2.5σ below SM
- LFUV probed in angular analysis by Belle — μ (e) 2.6 (1.1) σ tension to SM



LHCb PRL 118, 251802 (2017)

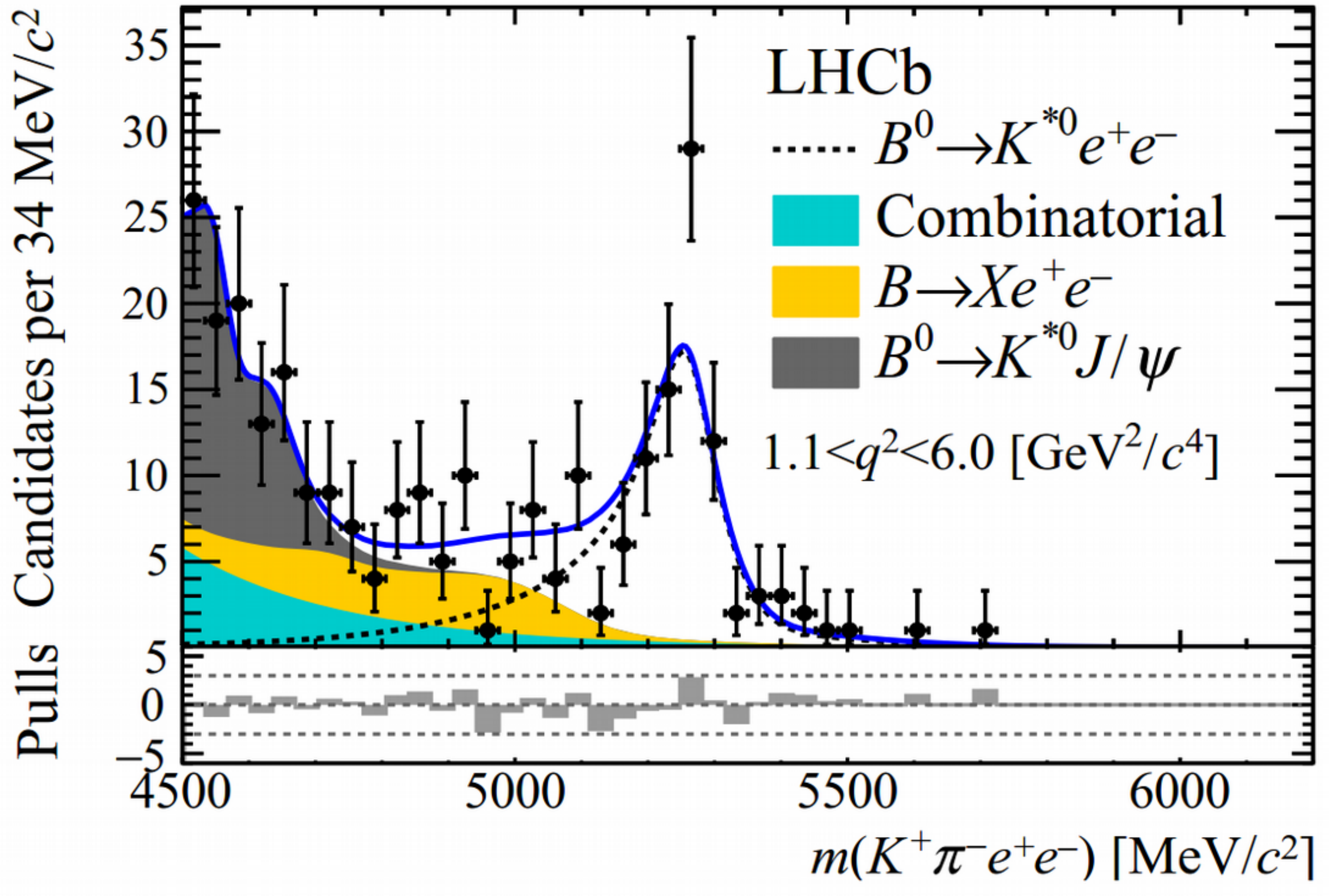
LHCb JHEP 11, 047 (2016)

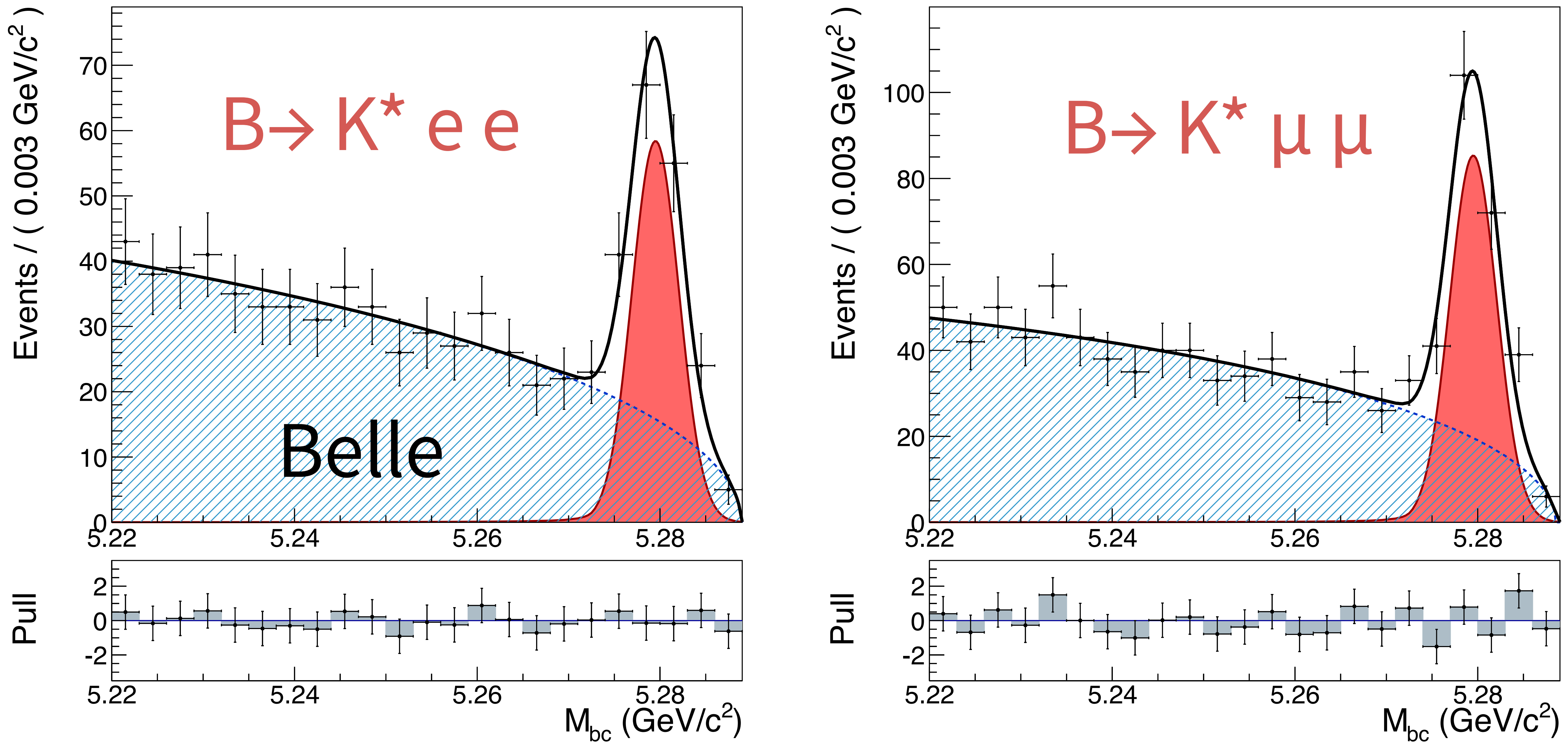
LHCb JHEP 04, 142 (2017)

CMS PLB 753, 424 (2016)

Belle PRL 118, 111801 (2017)

Babar PRD 93, 052015 (2016)





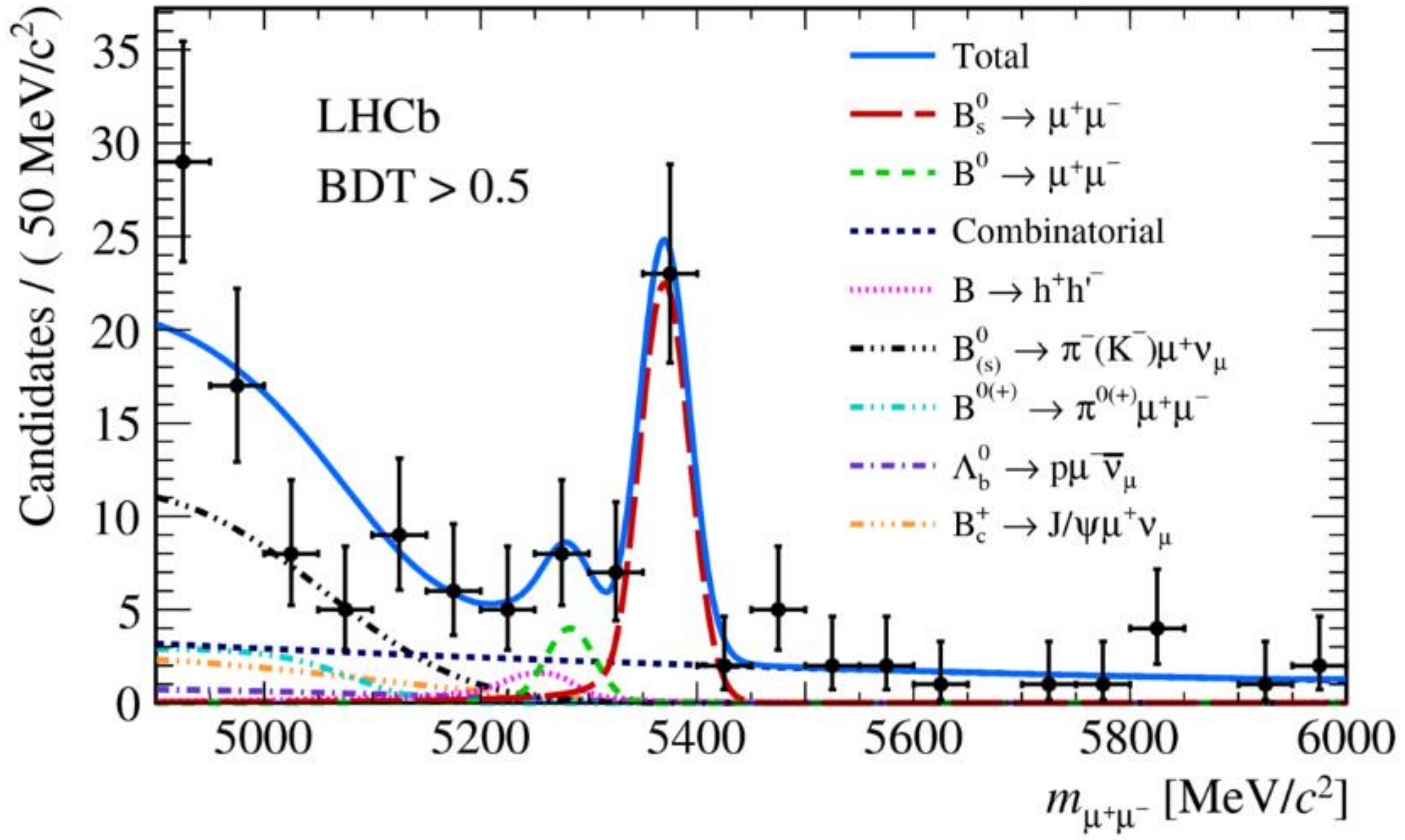
B→ τ τ, B→ μ μ

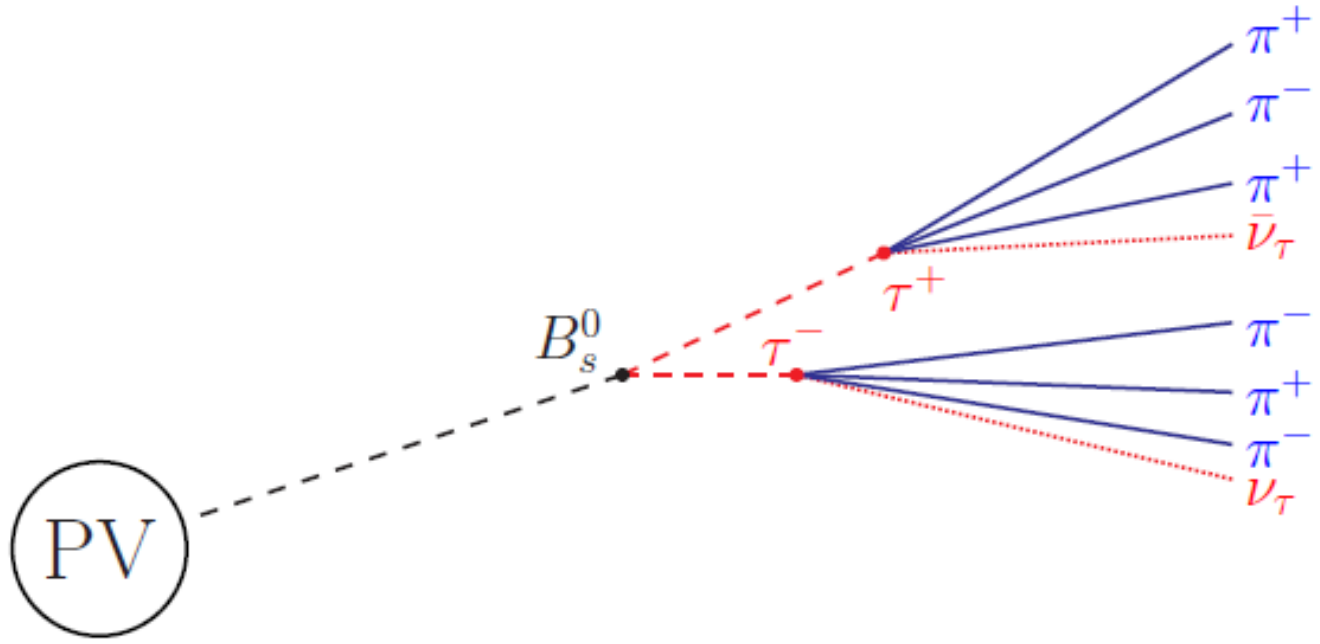
Flavour Session: N. Sahoo, S. Tolk

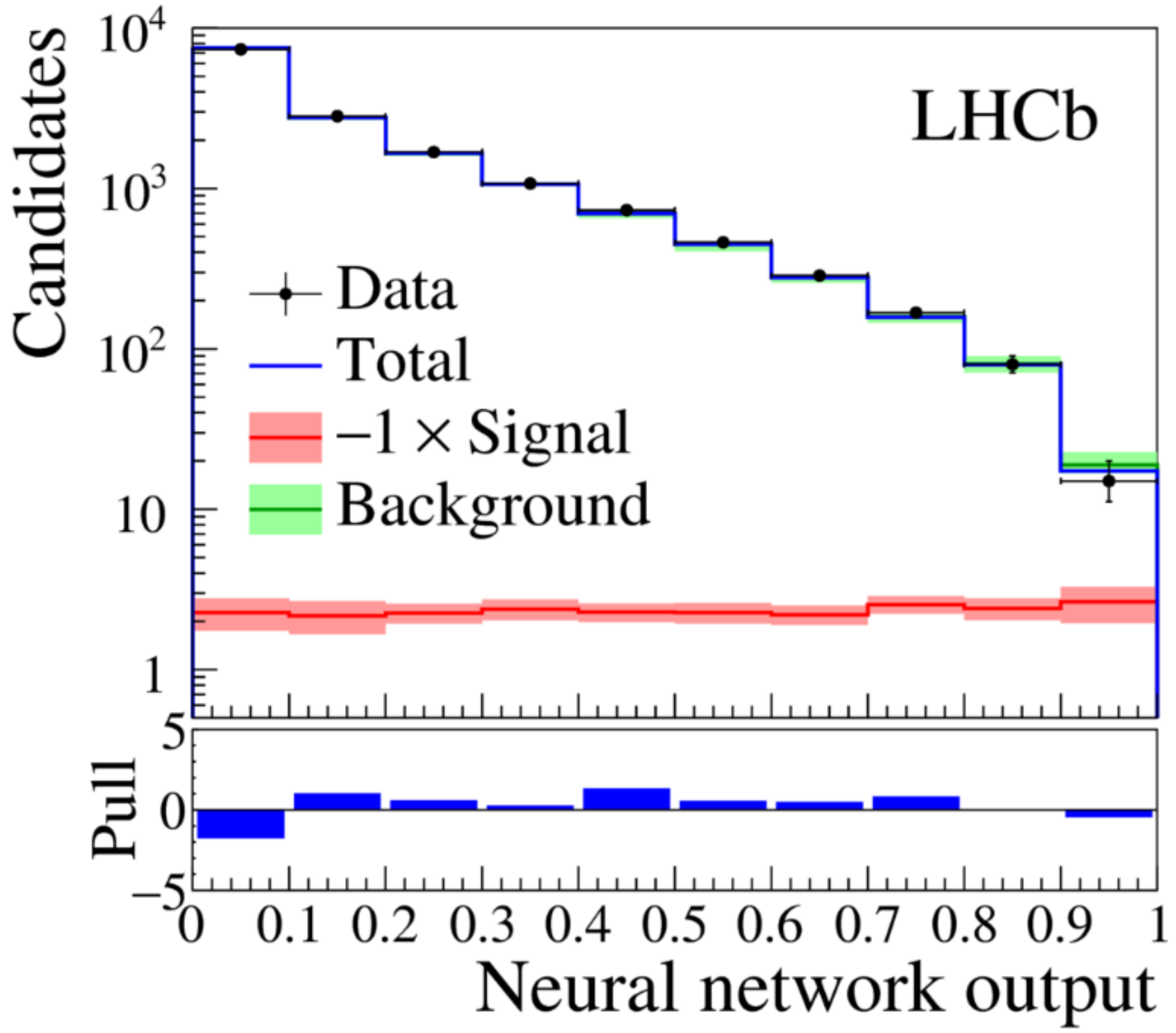
ATLAS EPJC 76, 513 (2016)
LHCb PRL 118, 191801 (2017)
LHCb PRL 118, 251802 (2017)

- B_s→μμ 5 σ from 1 experiment (partial Run-2)
- Most precise searches for B → τ τ but still far off SM level

SM predictions	ee	μμ	ττ
B^0	$(2.48\pm0.21)10^{-15}$	$(1.06\pm0.09)10^{-10}$	$(2.22\pm0.19)10^{-8}$
B_s	$(8.54\pm0.55)10^{-15}$	$(3.65\pm0.23)10^{-9}$	$(7.73\pm0.49)10^{-7}$







New LHCb analysis : 3fb^{-1} Run1 + $1.4\ \text{fb}^{-1}$ Run2

$$BR(B_S^0 \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$$

$$BR(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$$ (95%CL)

$$BR(B_s^0 \to \tau^+\tau^-) < 6.8 \times 10^{-3}$$ (95%CL)

$$BR(B^0 \to \tau^+\tau^-) < 2.1 \times 10^{-3}$$ (95%CL)

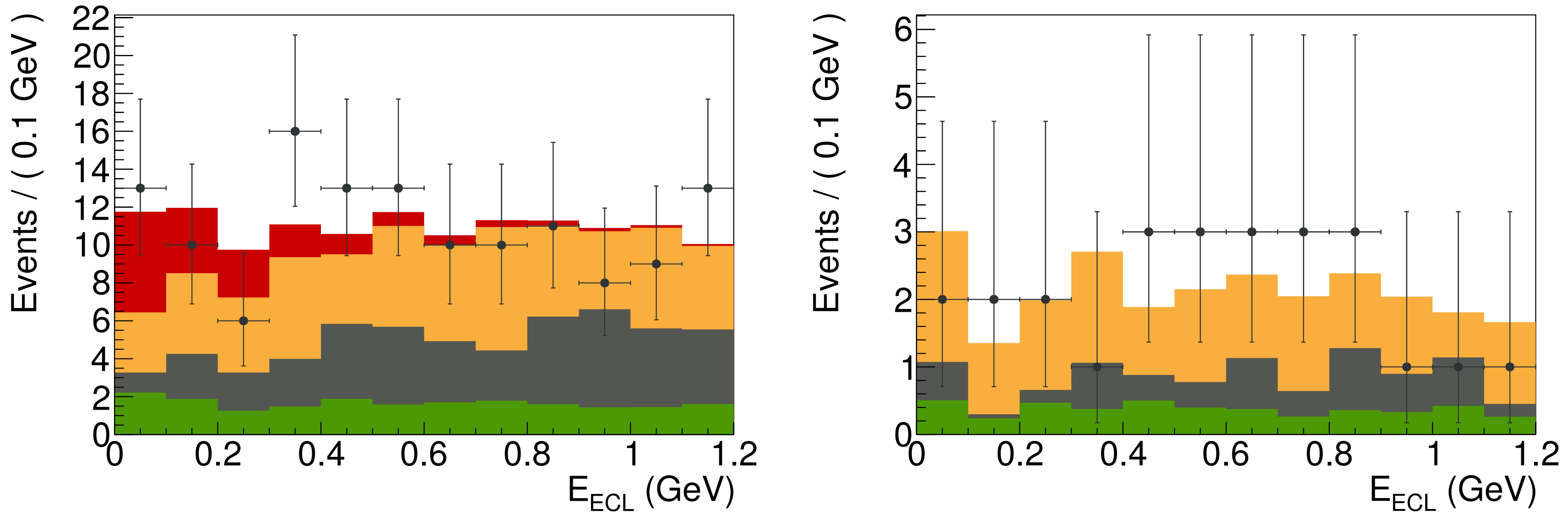
B → $K^{(*)}$ ν ν & B → K* γ

Flavour Session: N. Dash

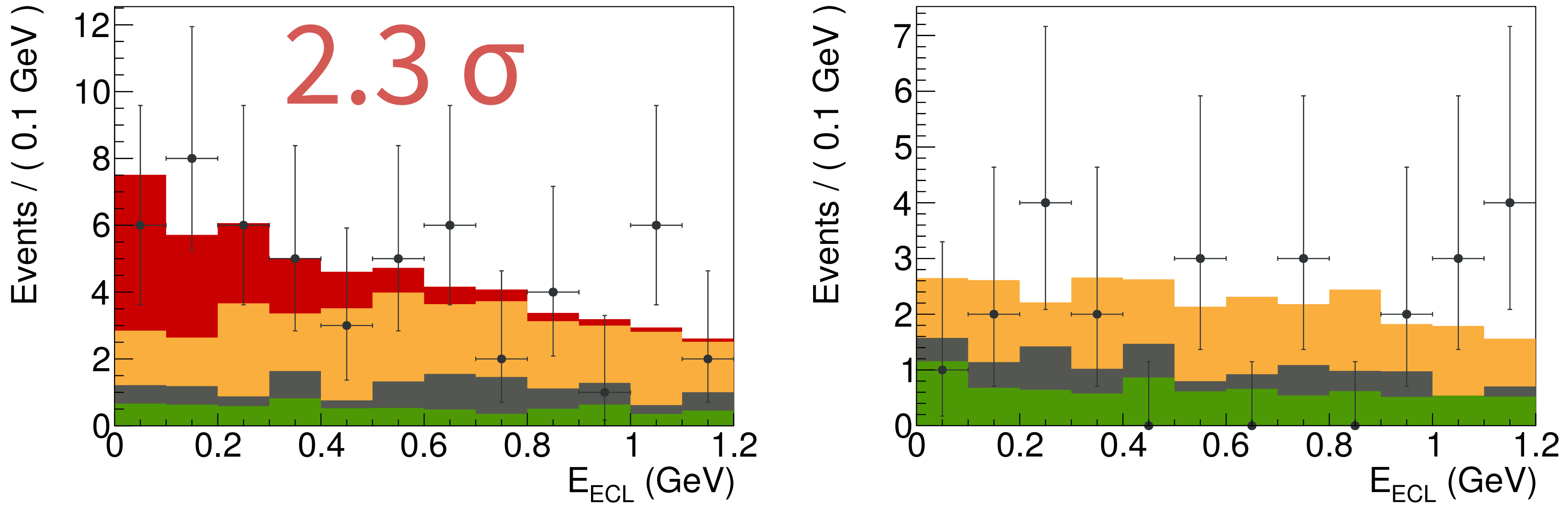
Belle PRD(R) 96, 091101 (2017)

Belle PRL 119, 191802 (2017)

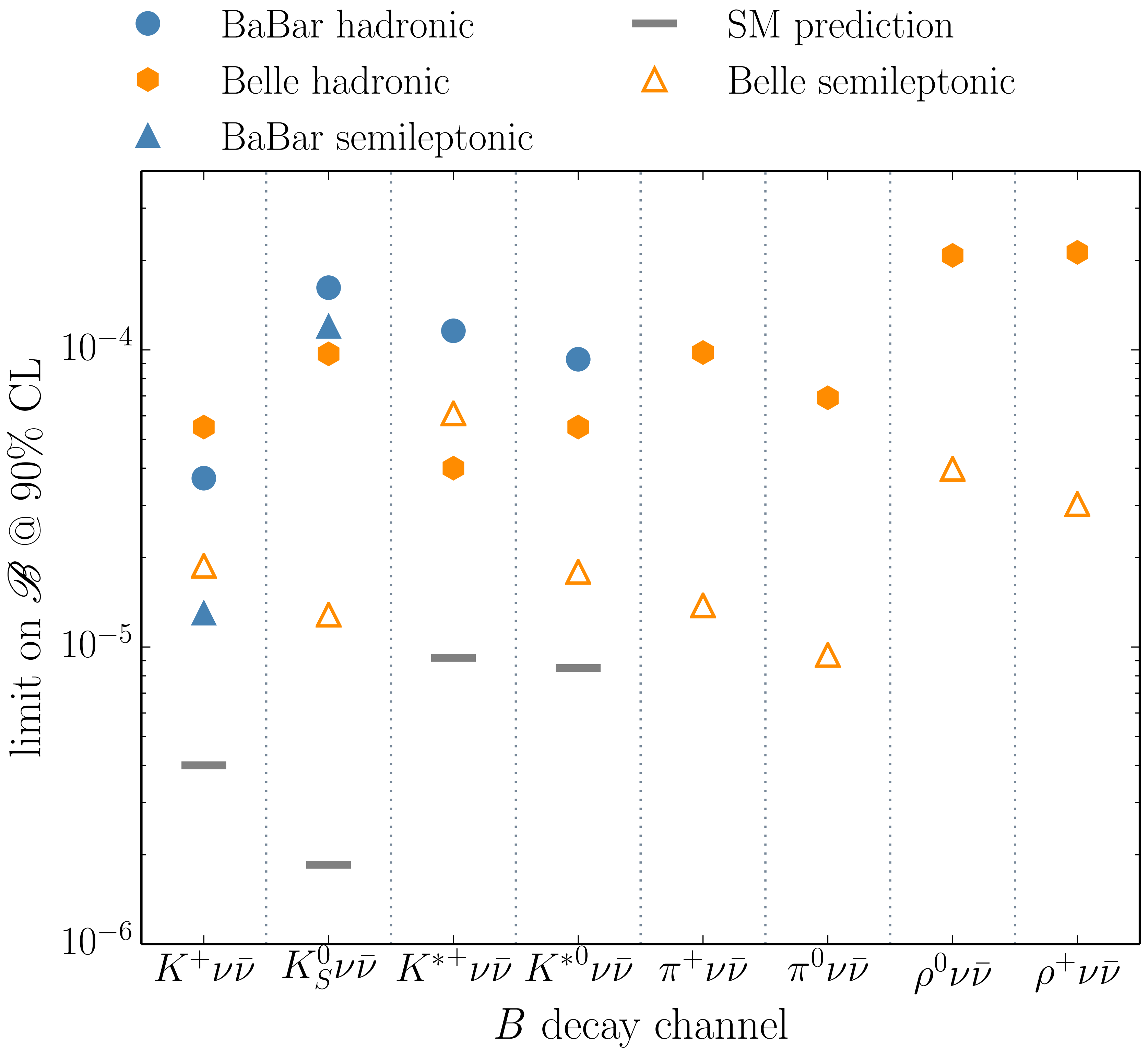
- Best limits on B → $K^{(*)}$ ν ν set by Belle semileptonic tag
  BR Could be greatly enhanced in NP scenarios
- New probes of NP in isospin (first evidence) and direct CP asymmetries (SM-compatible) in K* γ at Belle



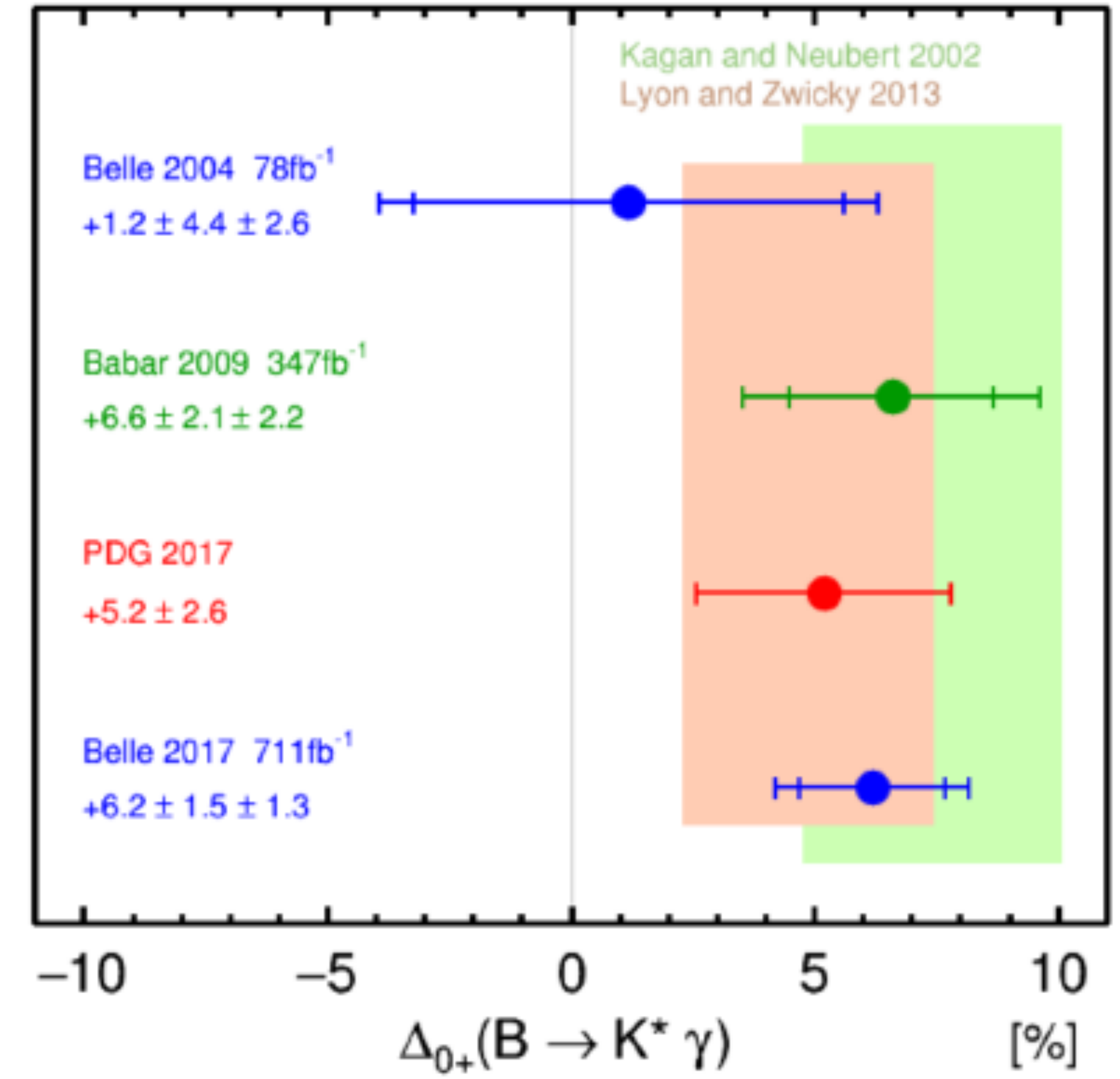
(a) $B^+ \to K^+\nu\bar{\nu}$ (b) $B^0 \to K^0_S\,\nu\bar{\nu}$



(c) $B^+ \to K^{*+}\nu\bar{\nu}$ (d) $B^0 \to K^{*0}\nu\bar{\nu}$

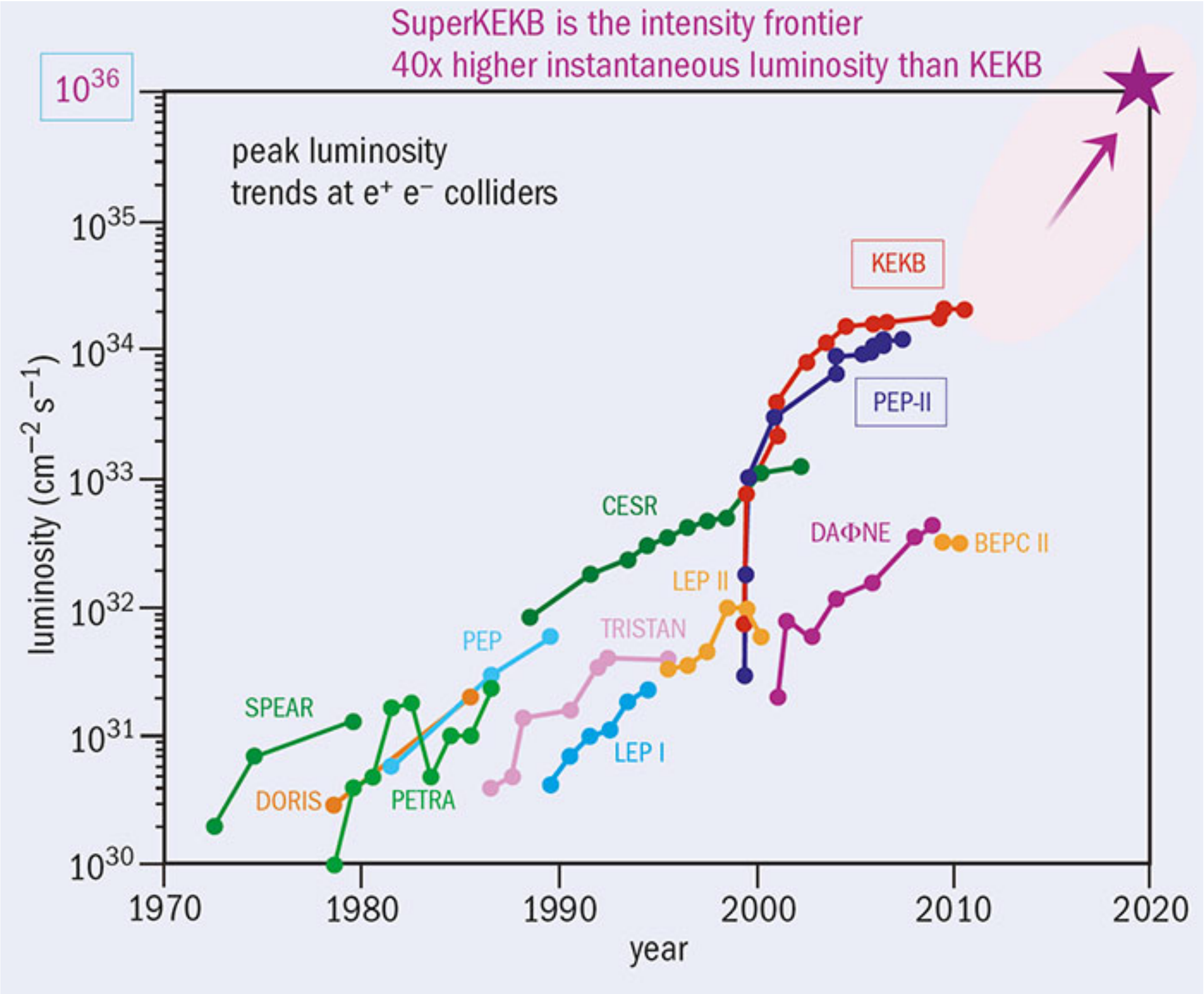


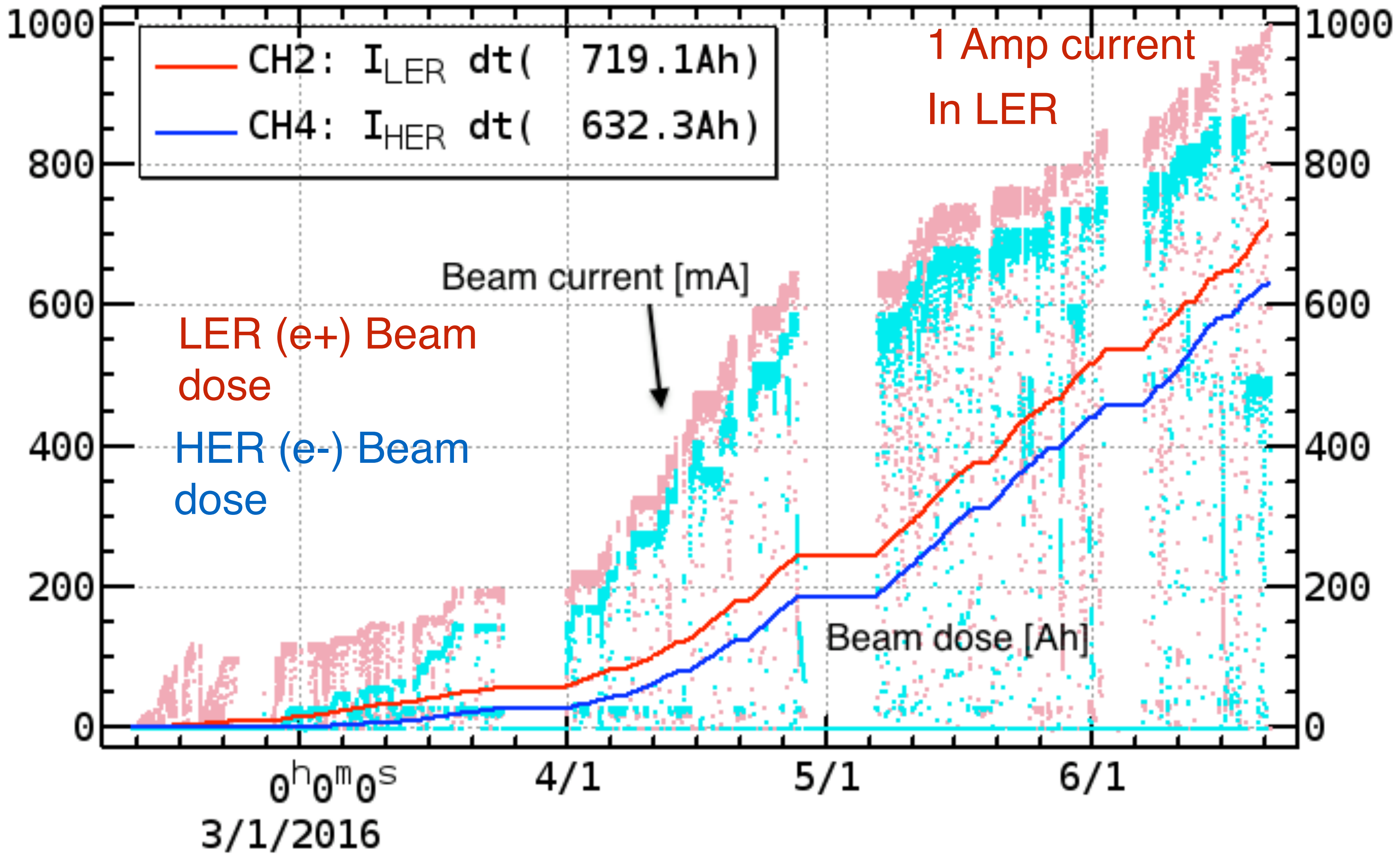
$$\Delta_{0+} = \frac{\Gamma(B^0 \to K^{*0}\gamma) - \Gamma(B^+ \to K^{*+}\gamma)}{\Gamma(B^0 \to K^{*0}\gamma) + \Gamma(B^+ \to K^{*+}\gamma)}$$



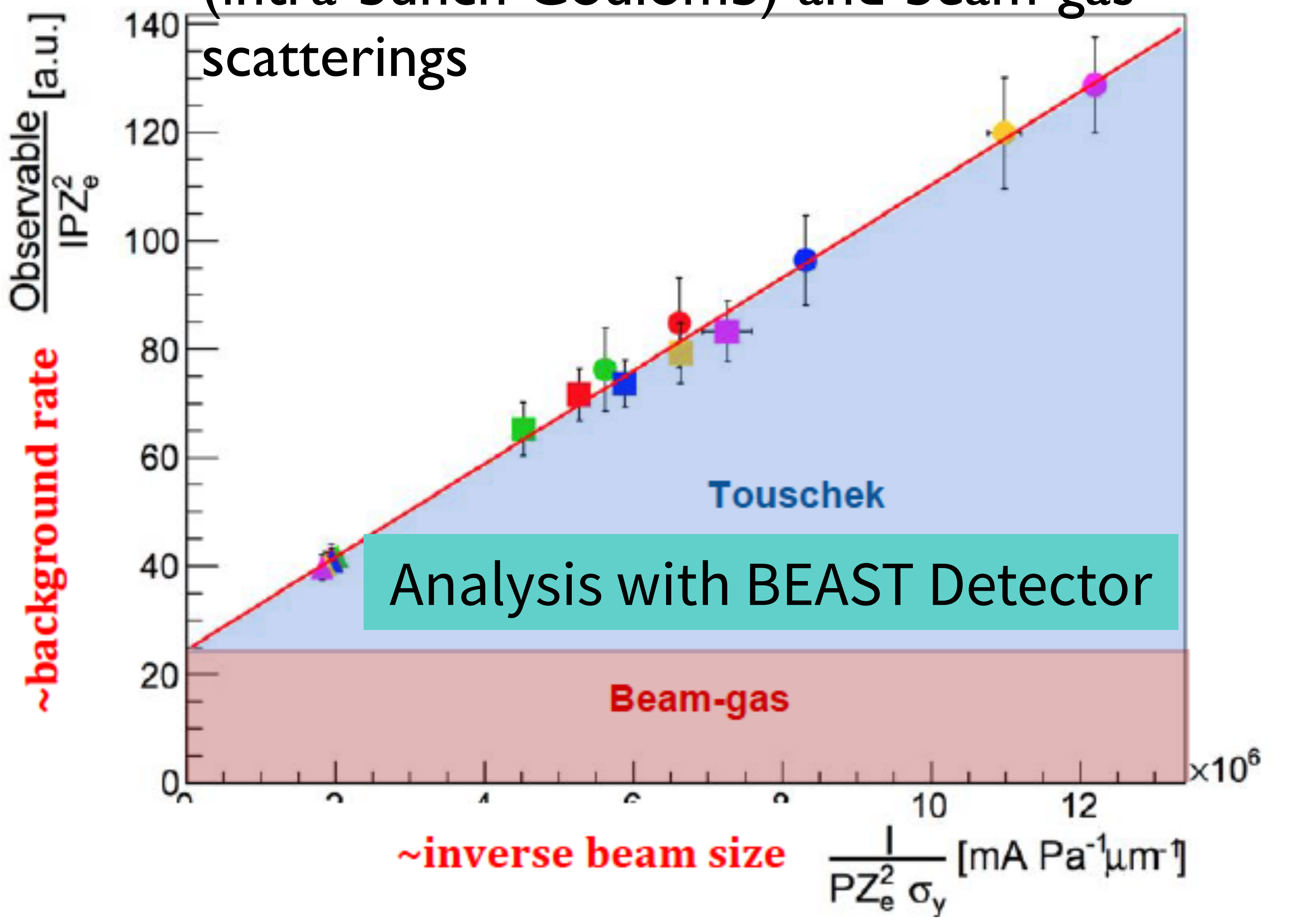
Belle II / SuperKEKB

- Super Flavour Factory at KEK (2018 first collisions)
  - **40x** increase in luminosity, target **8×10^{35} cm^{-2} s^{-1}**
  - Compared to KEKB: **20x** smaller vertical beam size **“World’s most complicated superconducting magnet system” and 2x** current
  - First turns in Feb 10, 2016! 5 Months operation


SuperKEKB is the intensity frontier
40x higher instantaneous luminosity than KEKB



Change beam size to decompose Touschek (intra-bunch Coulomb) and beam-gas scatterings


Analysis with BEAST Detector

Belle II Upgrades

Central beam pipe: decreased diameter from 3cm to 2cm (Beryllium)

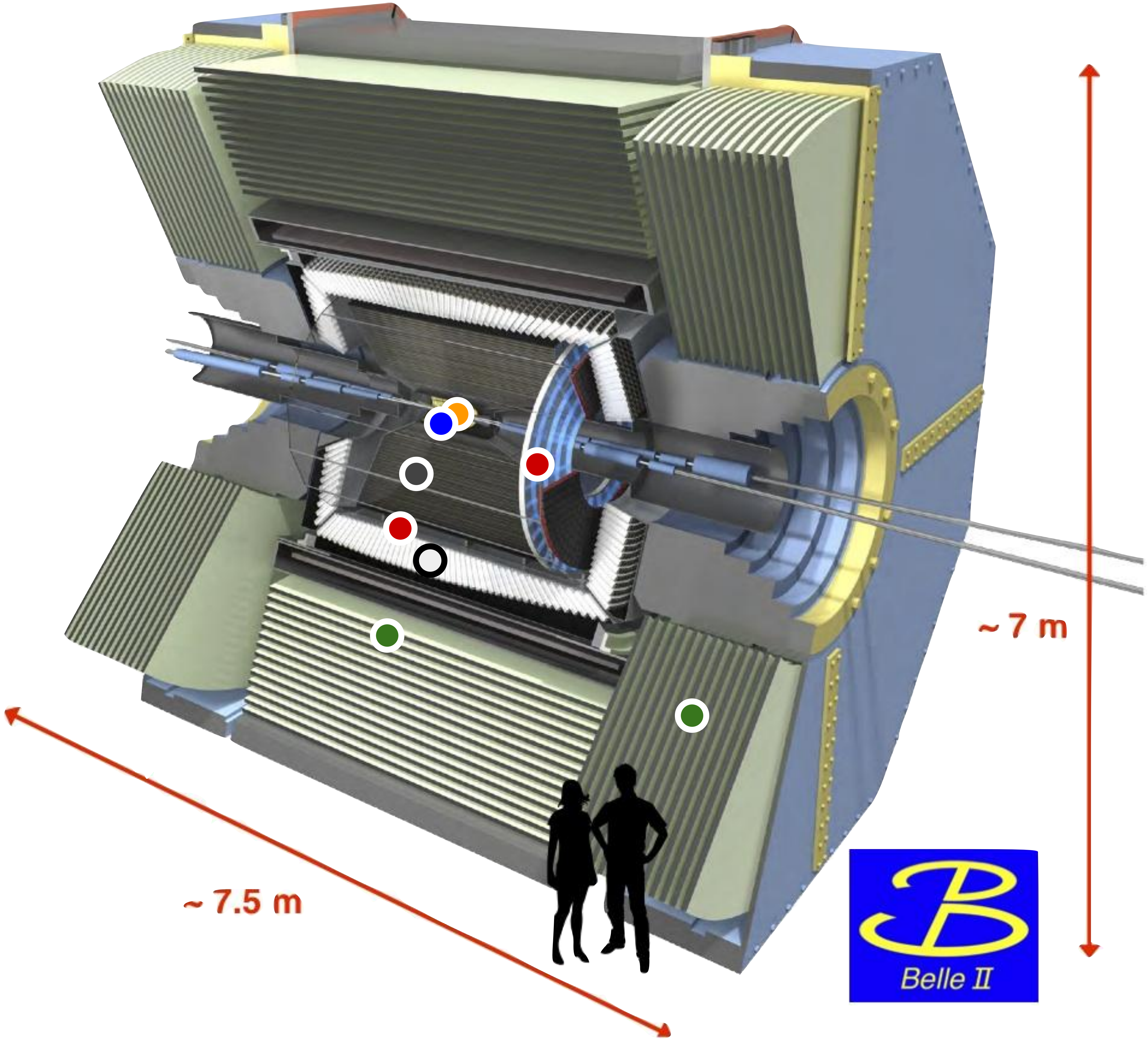
Vertexing: new 2 layers of pixels, upgraded 4 double-sided layers of silicon strips

Tracking: drift chamber with smaller cells, longer lever arm, faster electronics

PID: new time-of-flight (barrel) and proximity focusing aerogel (endcap) Cherenkov detectors

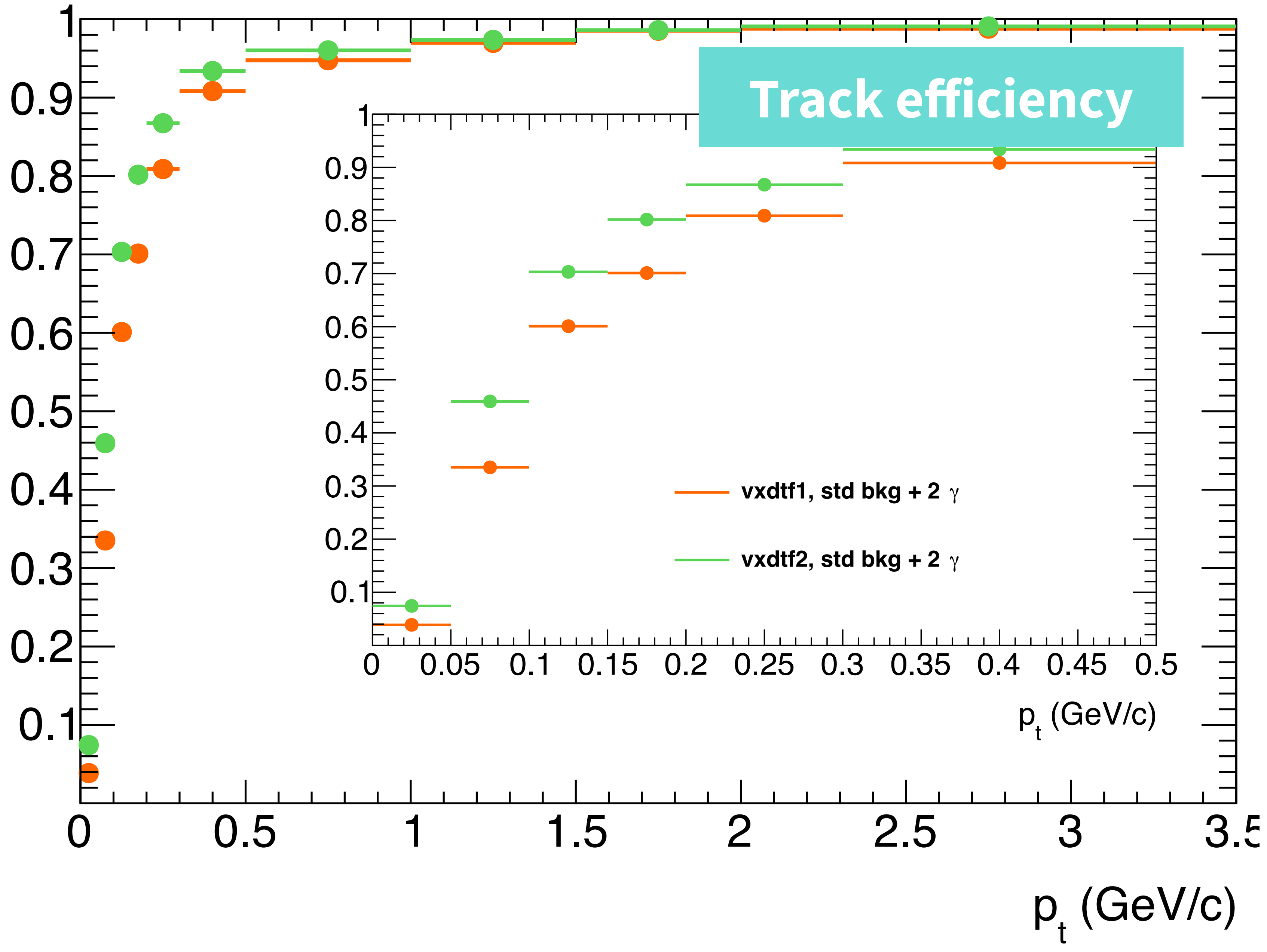
EM calorimetry: upgrade of electronics and processing with legacy CsI(Tl) crystals

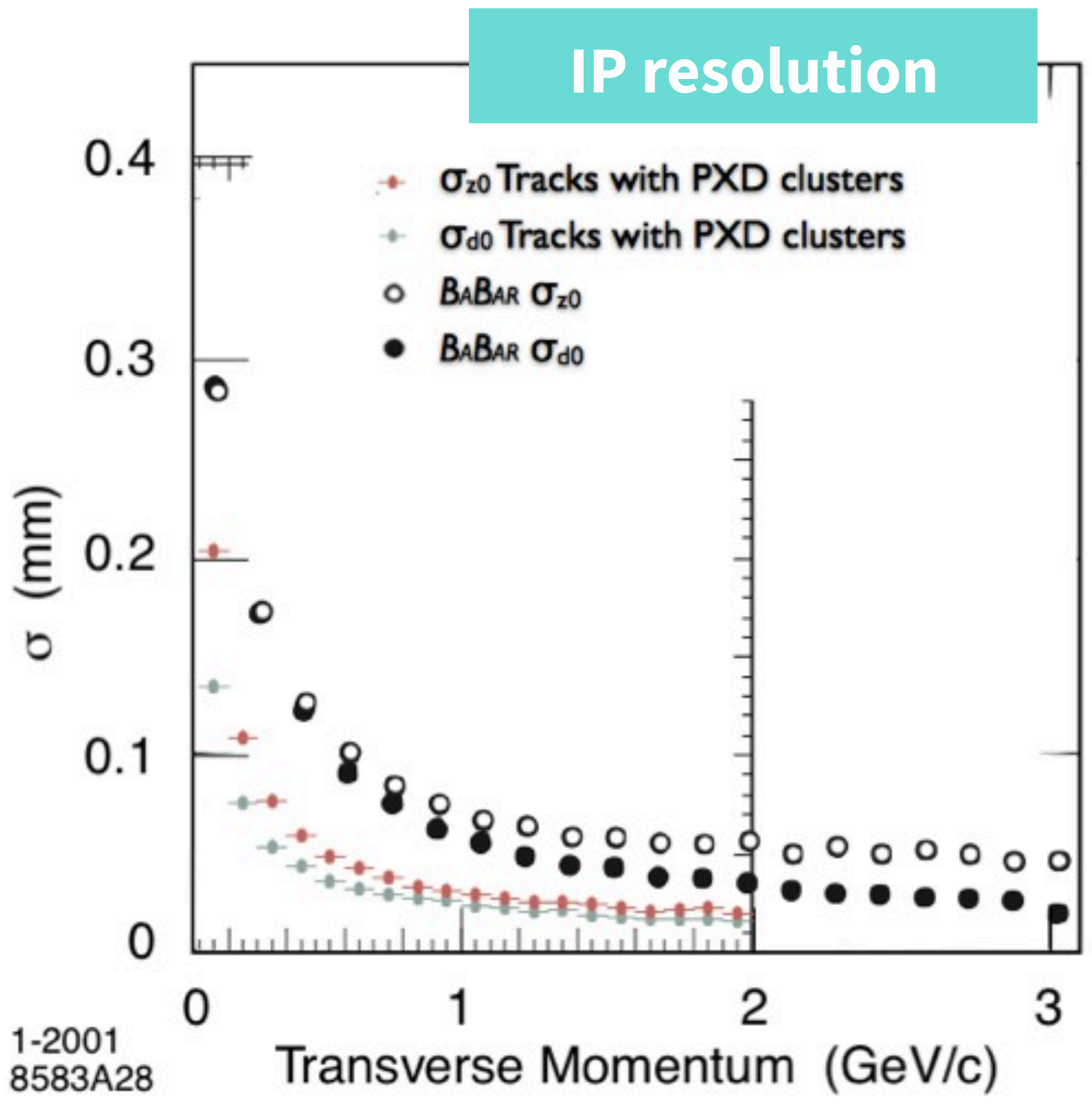
K_L and μ: scintillators replace RPCs (endcap and inner two layers of barrel)

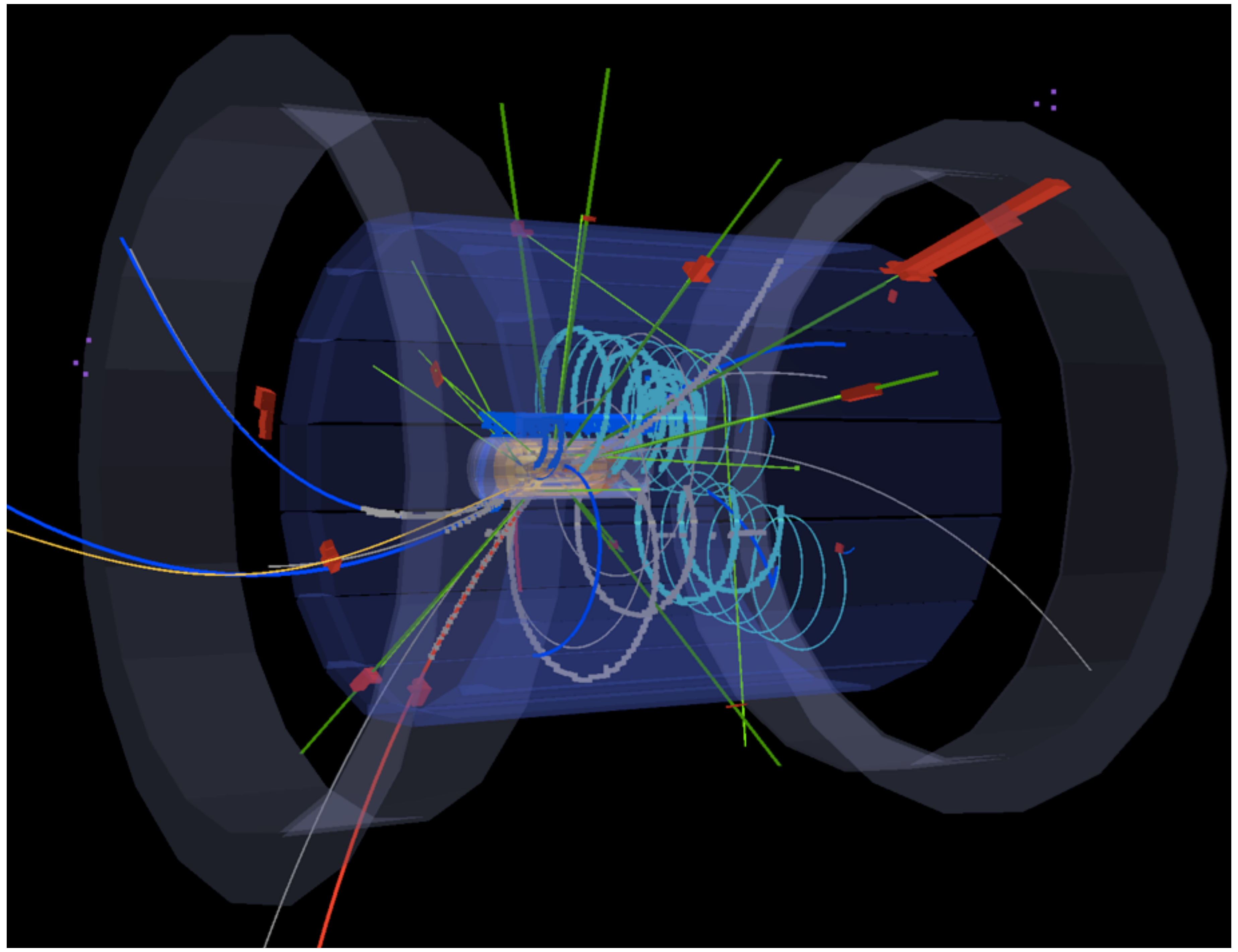


Belle II Reconstruction

- Novel silicon—dedicated tracking. Good for D* recon. $\langle p_{\pi\text{-slow}}\rangle \sim 100$ MeV.
- Impact parameters: σ_{d0} Belle II ~ 0.5 x σ_{d0} Babar
- Vertex: σ_z Belle II ~ 0.5 x σ_z Belle
- Mass: σ_M Belle II ~ 0.7 x σ_M Belle

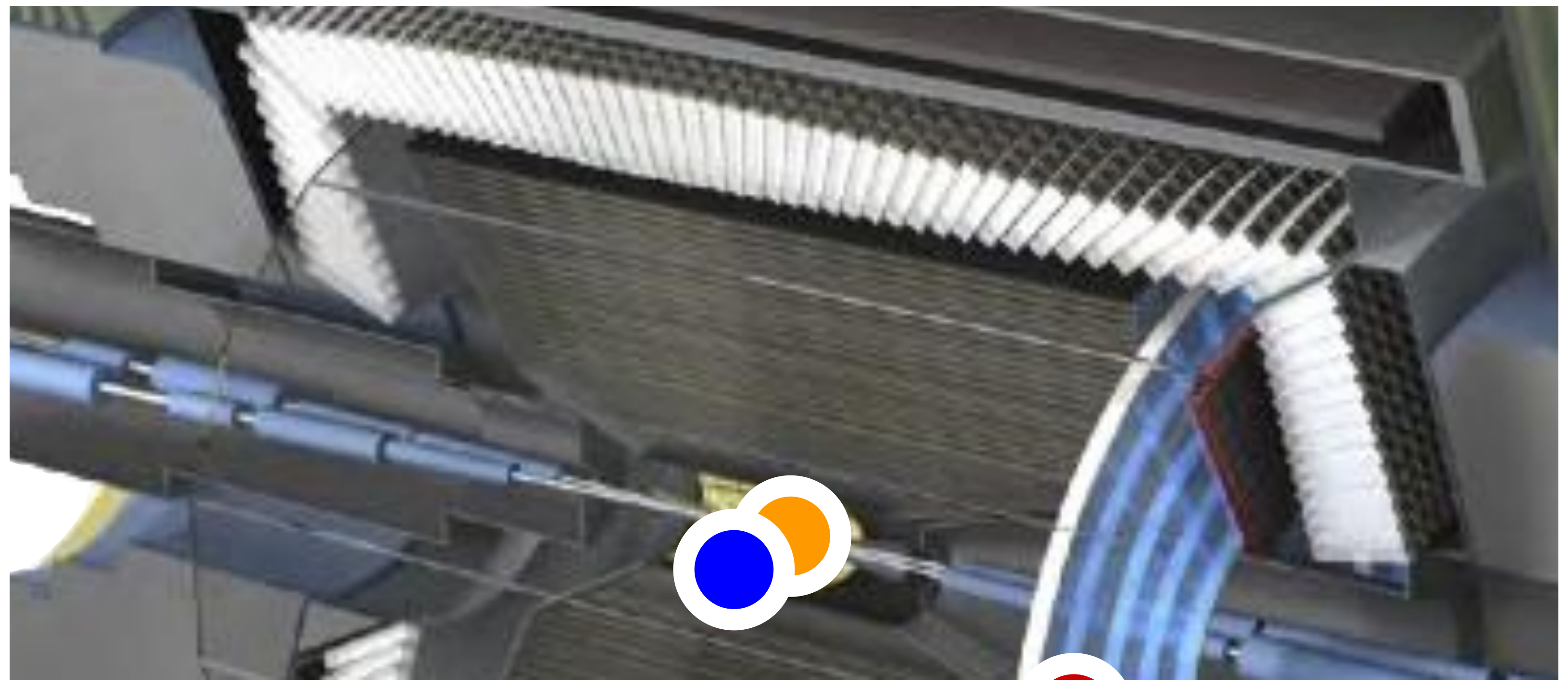


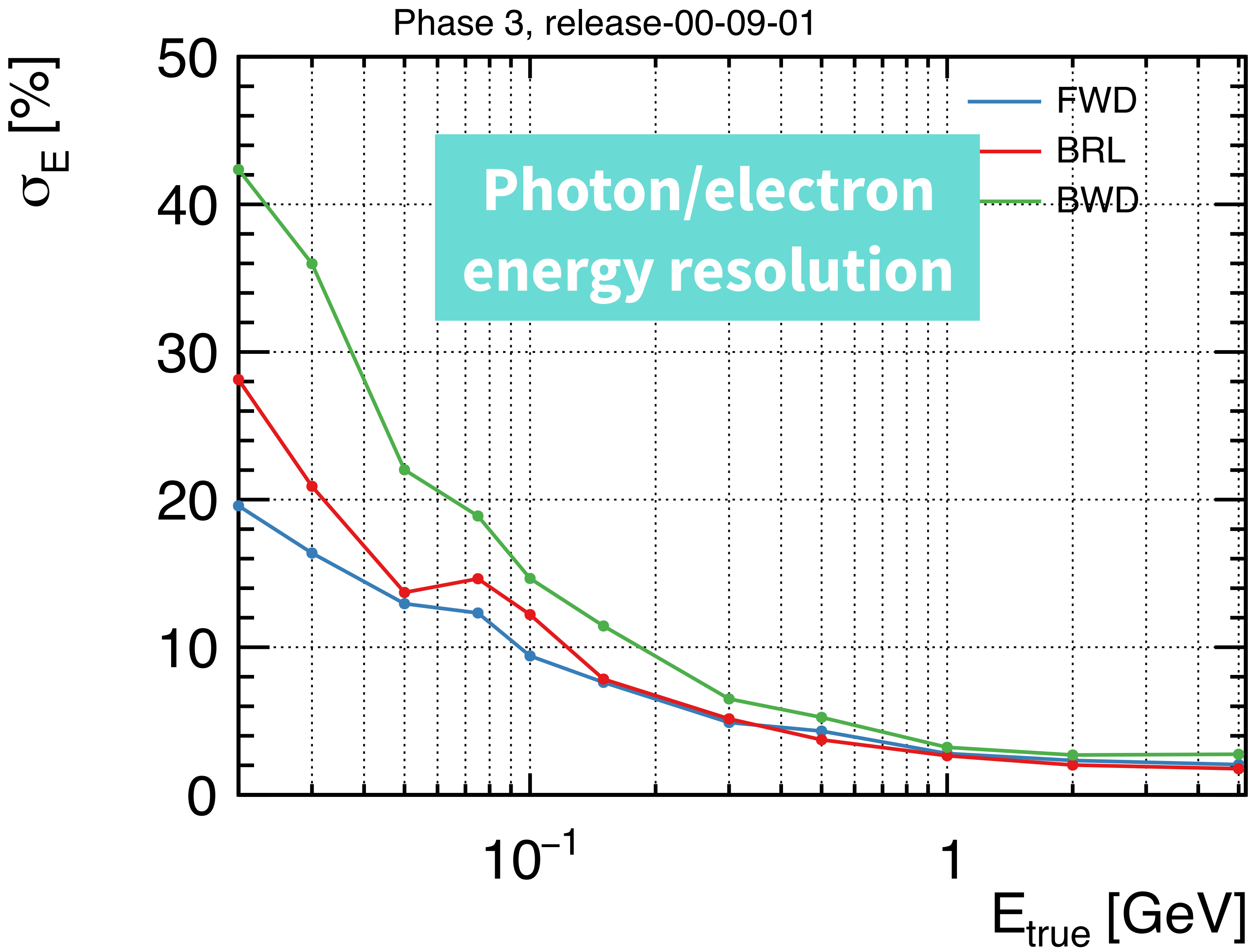


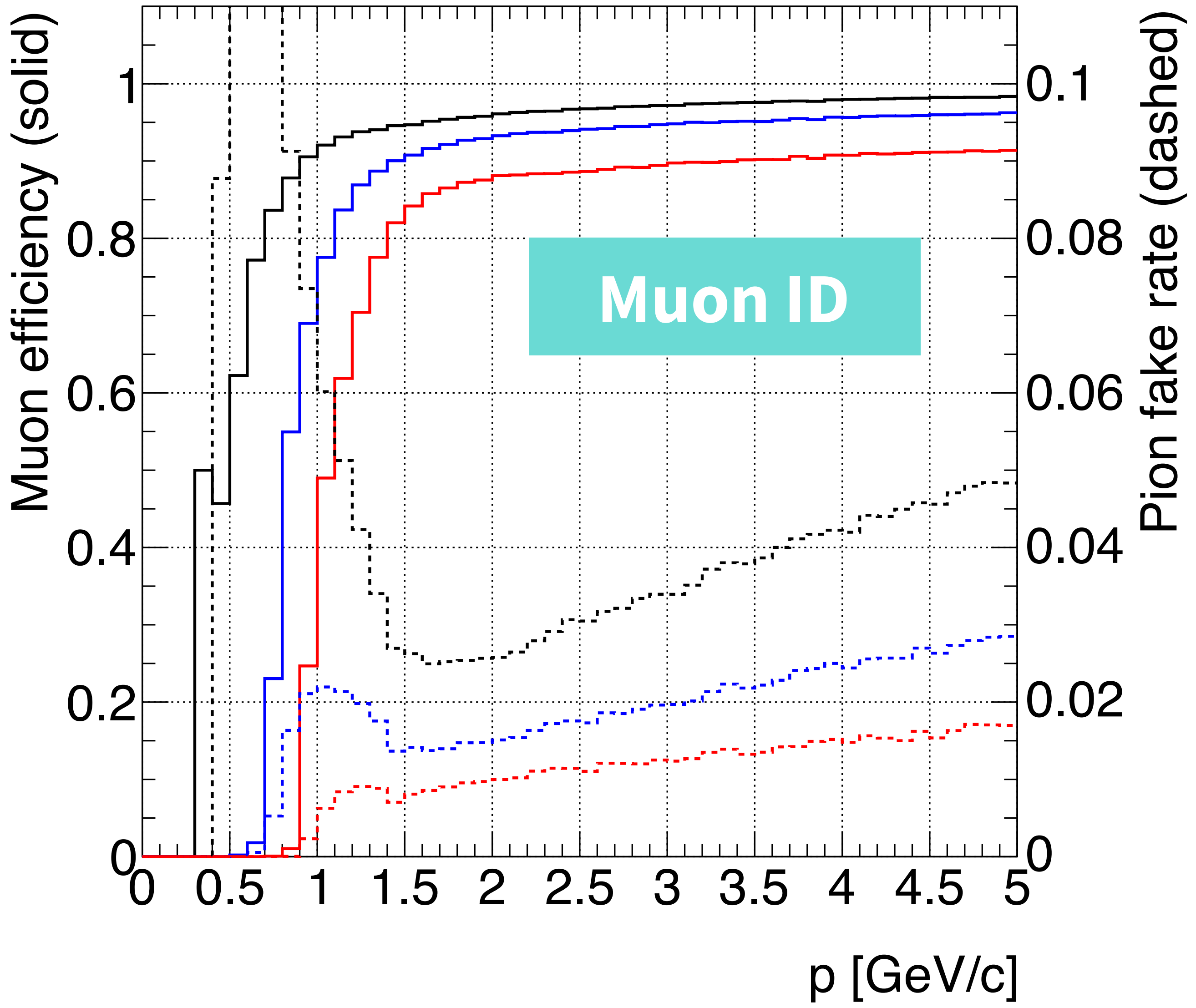


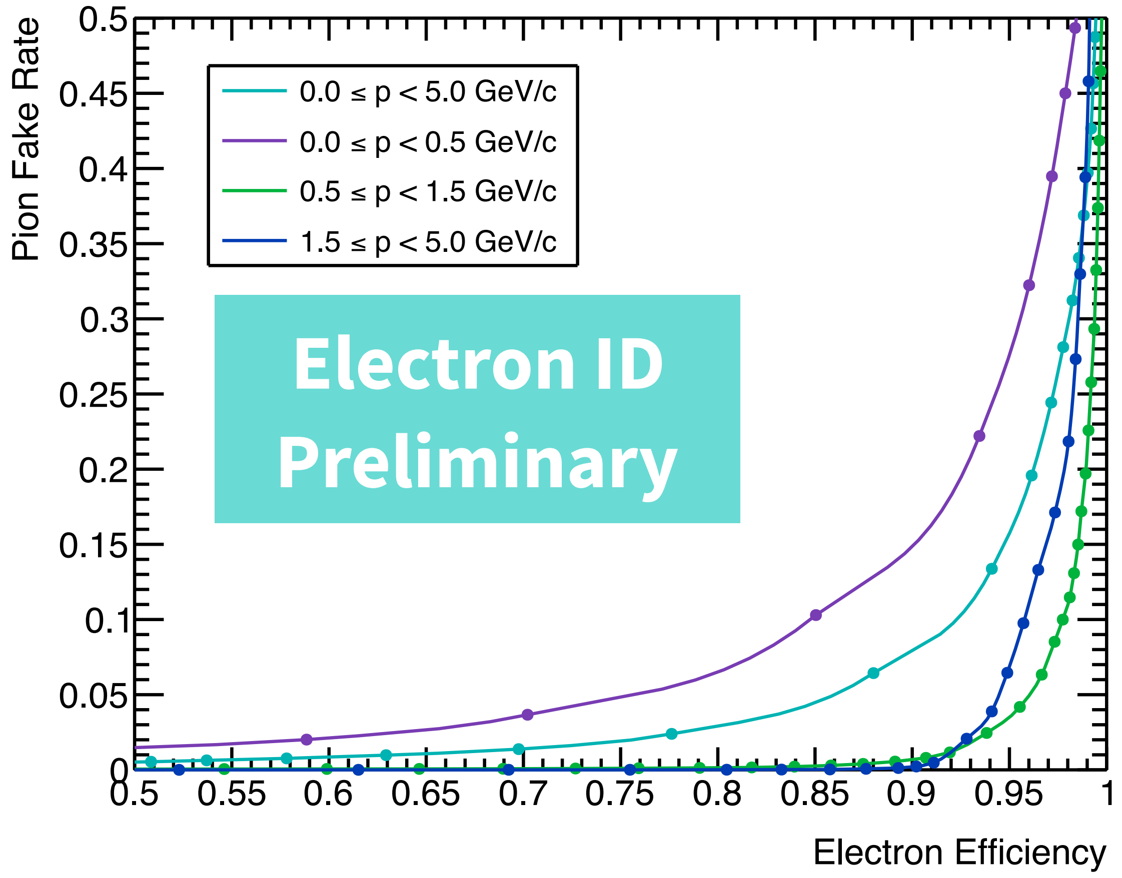
Belle II Reconstruction

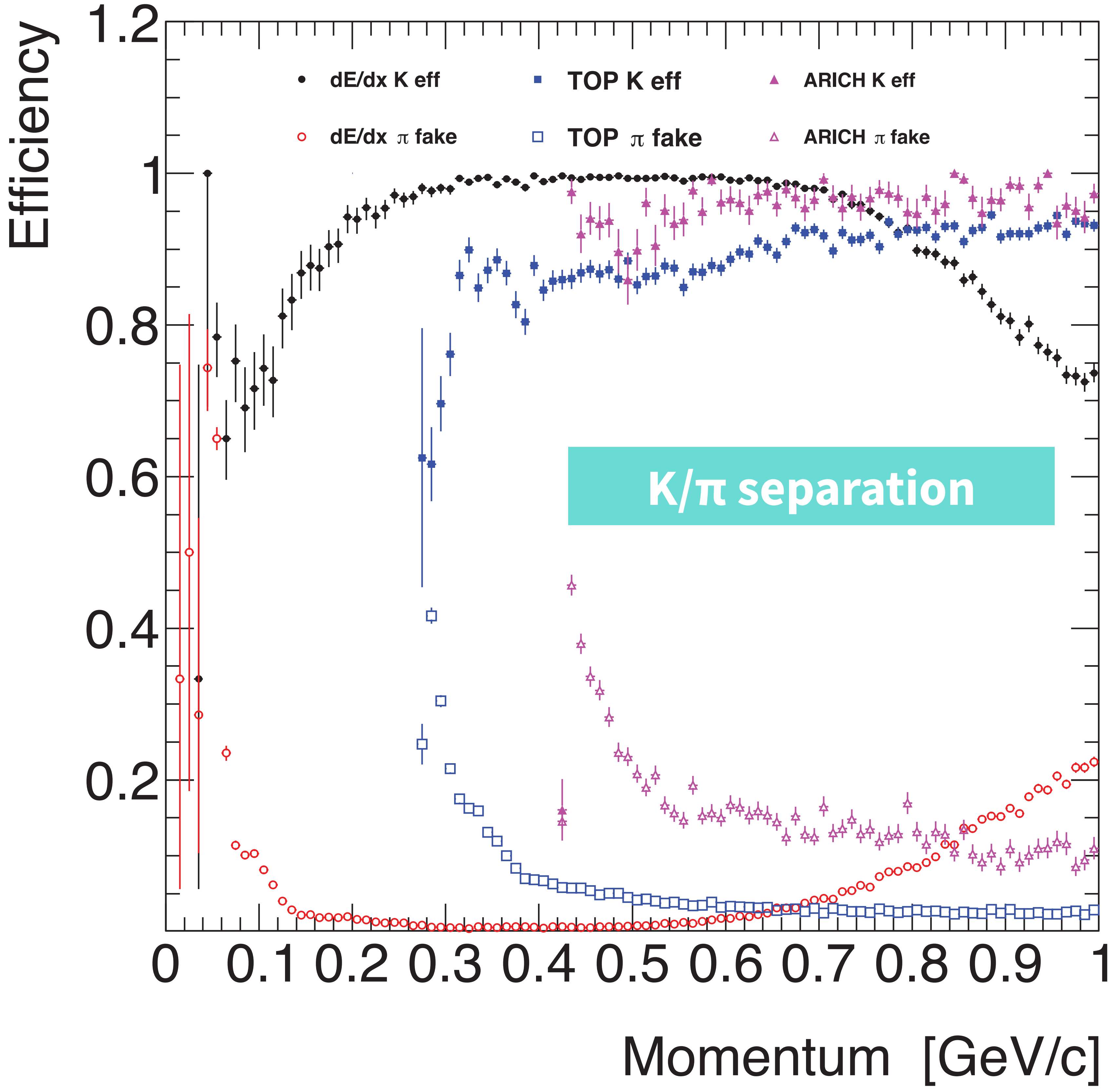
- Photon resolution and lepton ID as good as Belle even under high beam background
- K/π separation ~3x better in TOP/ARICH acceptance region





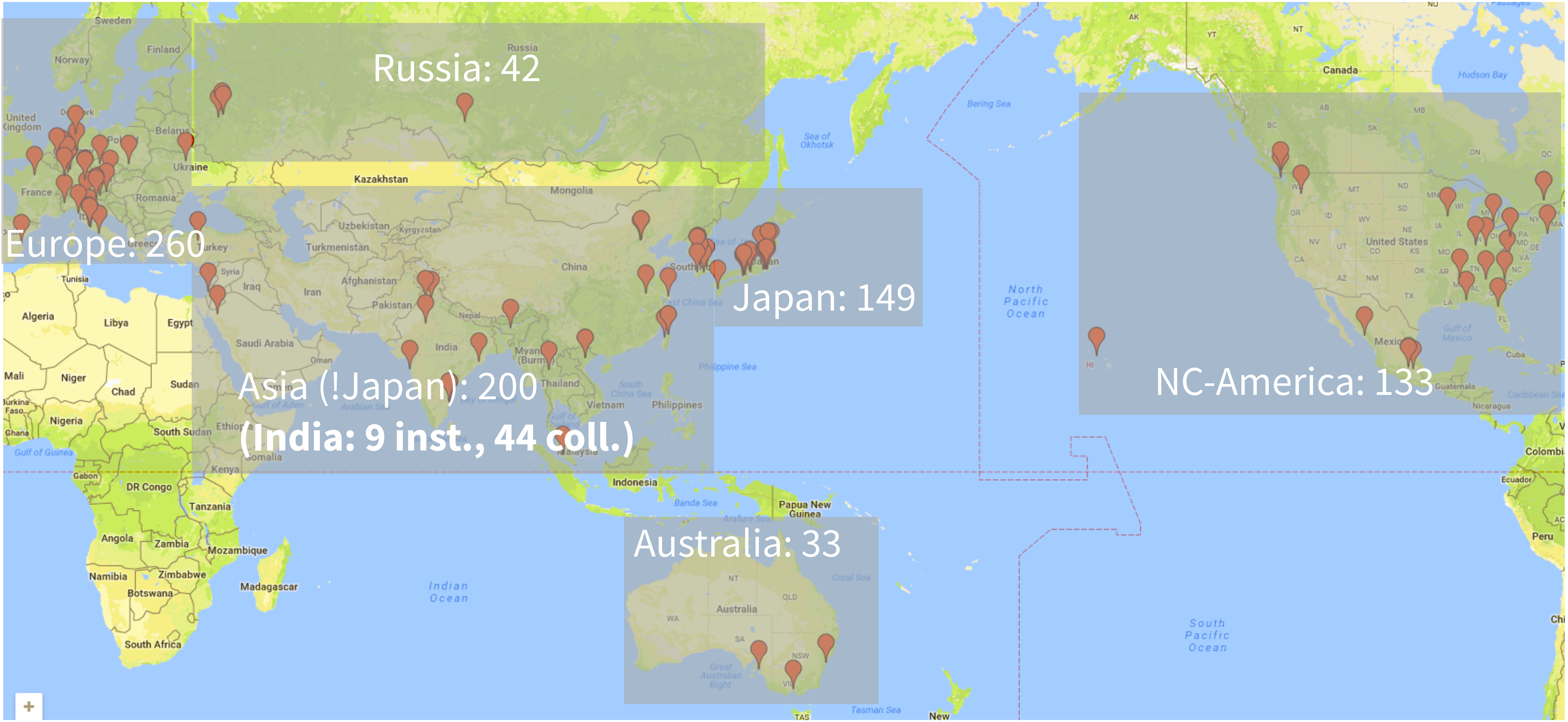




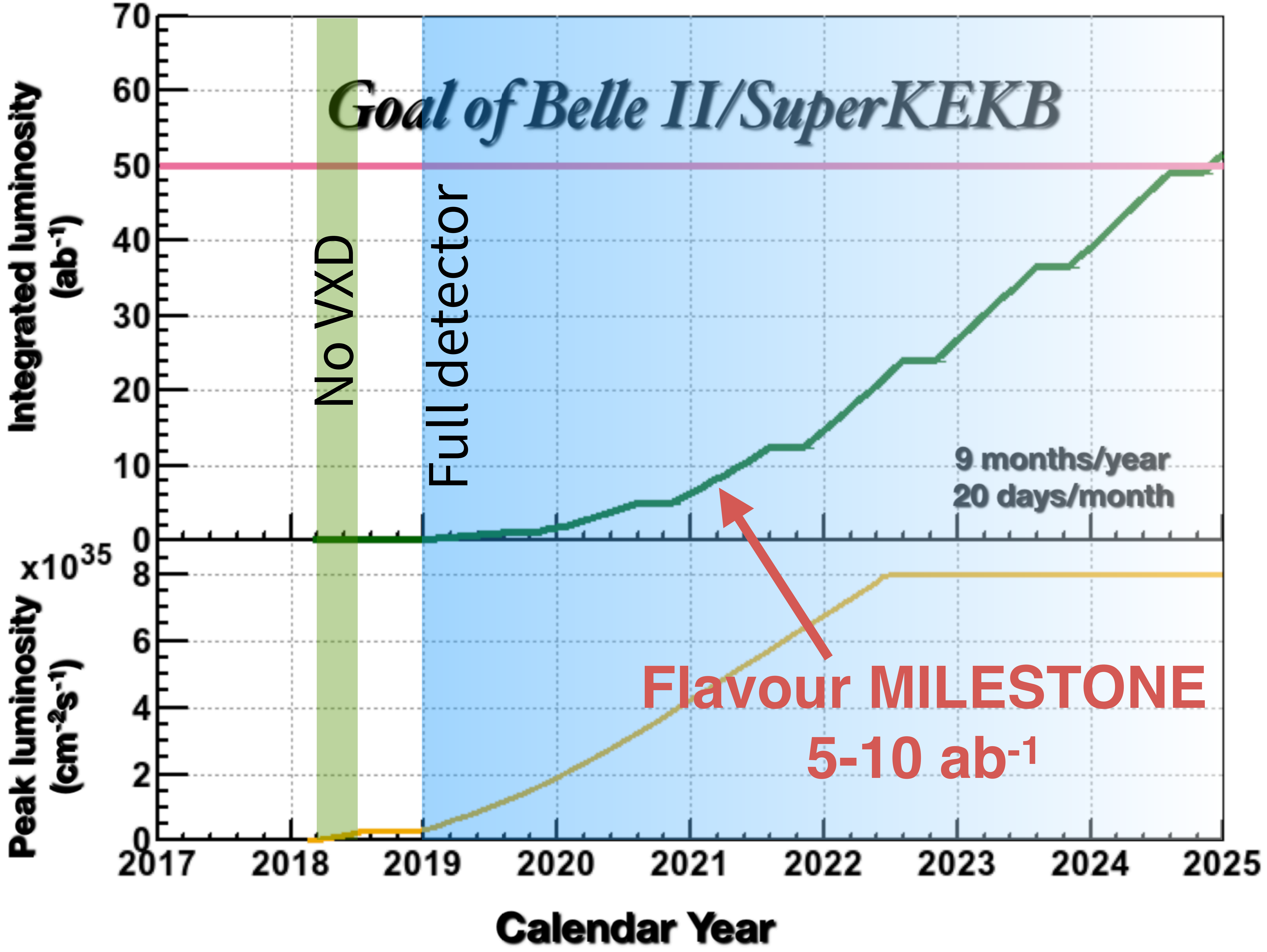


Belle II Collaboration

- 784 collaborators, 106 institutions, 25 countries/regions



SuperKEKB / Belle II Luminosity projections



Flavour MILESTONE
5-10 ab^{-1}

Phase 2:
Peak luminosity reaches
1 x 10^{34} $cm^{-2}s^{-1}$ (Belle)
20 fb^{-1} for physics near Υ(4S)

Feb 1, 2018: Global cosmic ray runs.

Feb 23, 2018: First HER beam. Belle II off.

March 2, 2018: First LER beam.

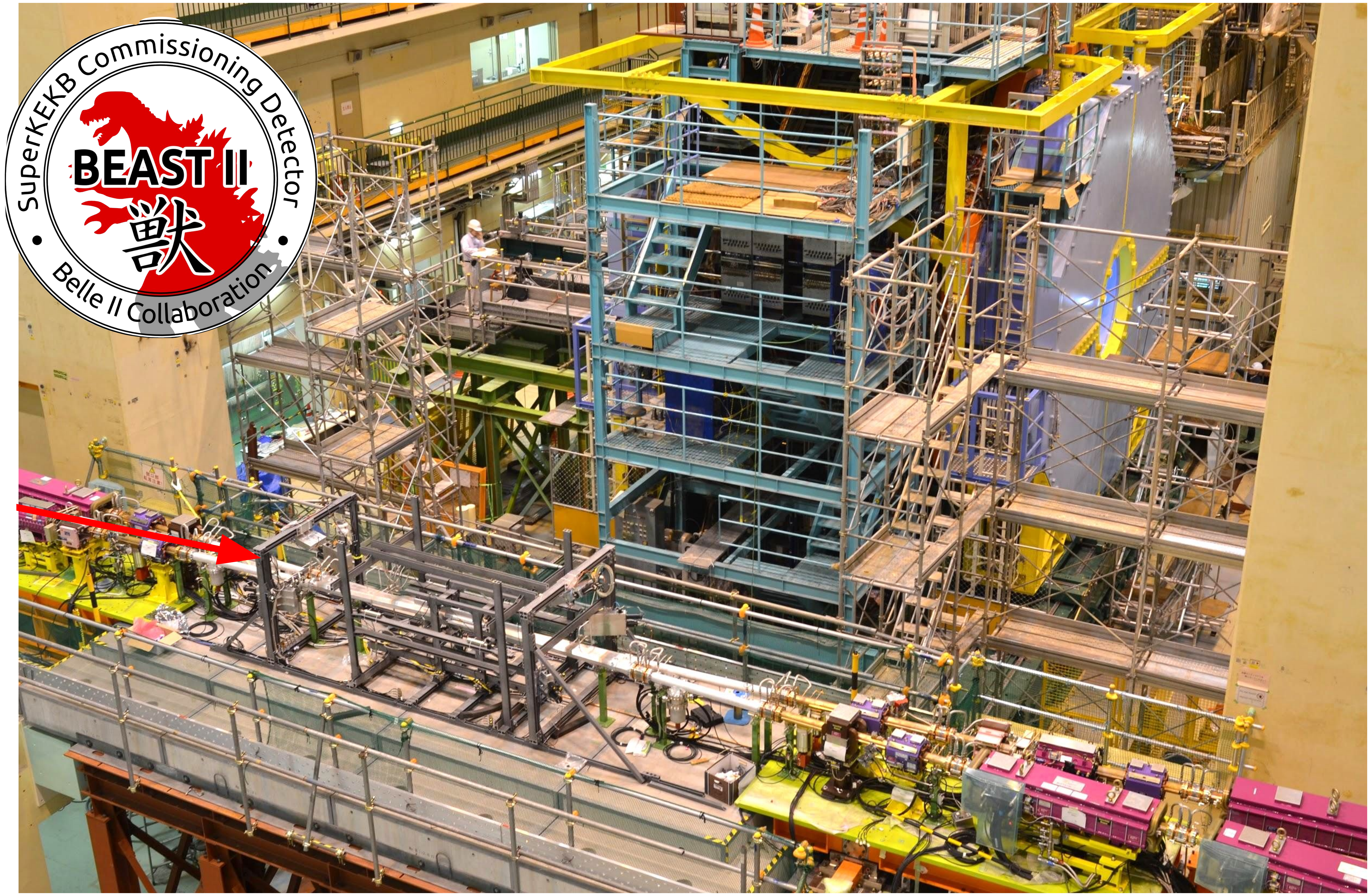
April 2018: First collisions "**Phase 2**"

July 2018: End of commissioning run.

Phase 3:
50 ab^{-1} by 2025
50x Belle, 100x Babar

Early 2019: "**Phase 3**"

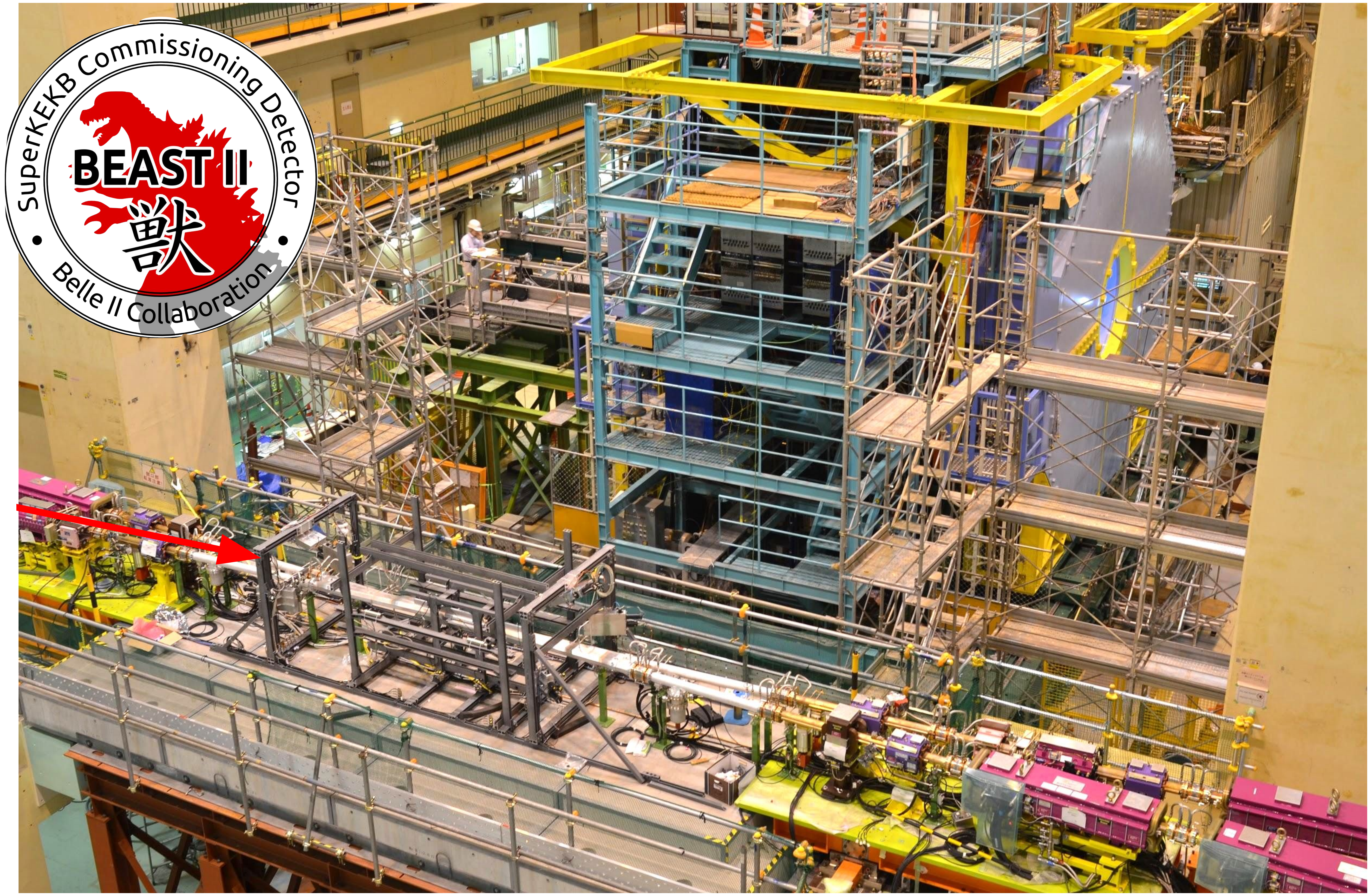
2016	2017	2018	2019
Phase 1		Phase 2	Phase 3



2016 | 2017 | 2018 | 2019

Phase 1 | Phase 2 | Phase 3

- Phase I (complete): Circulate both beams, **no collisions, no Belle II.** Tune accelerator optics. Beam studies with BEAST II **early 2016**



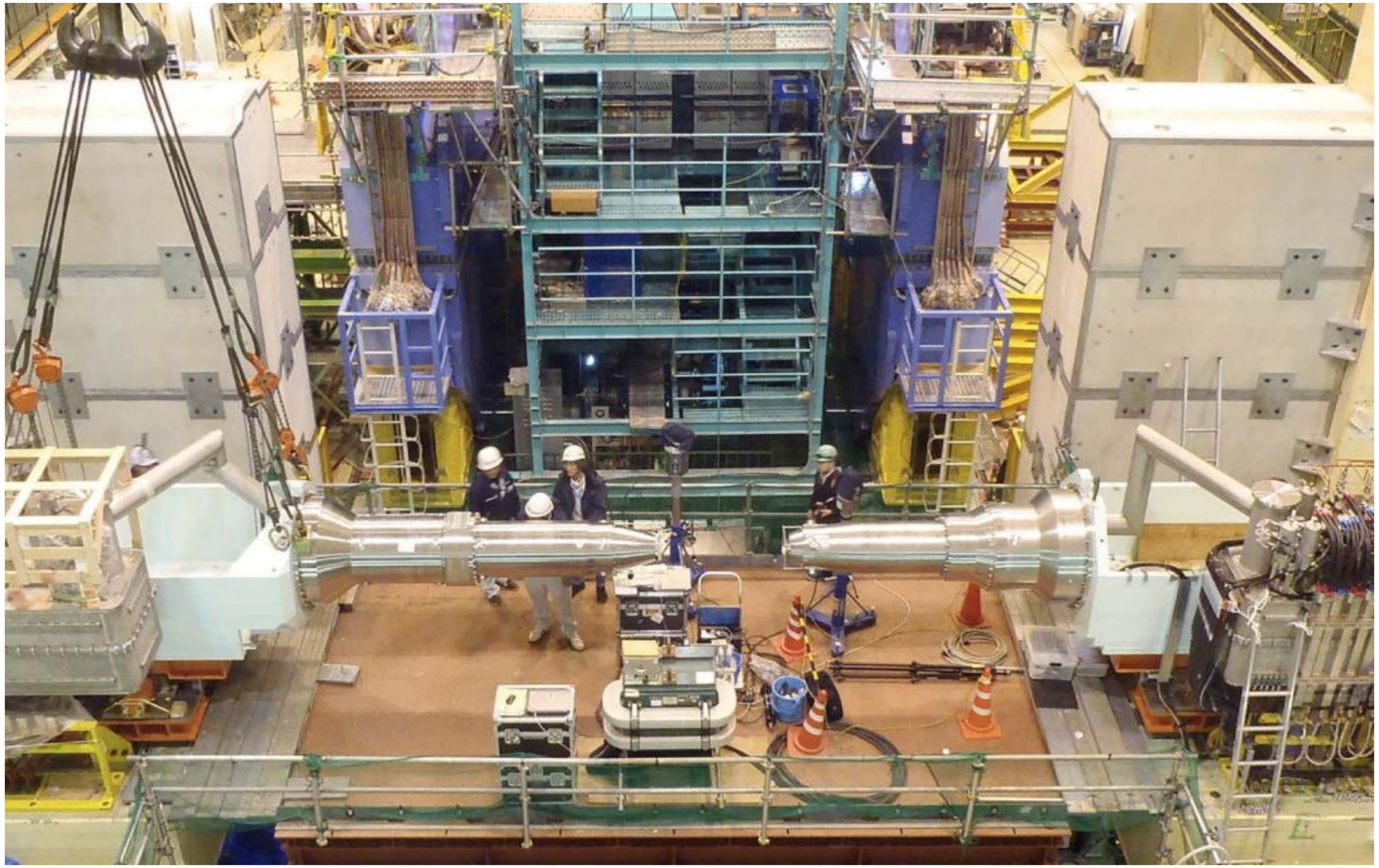
2016 | 2017 | 2018 | 2019

Phase 1

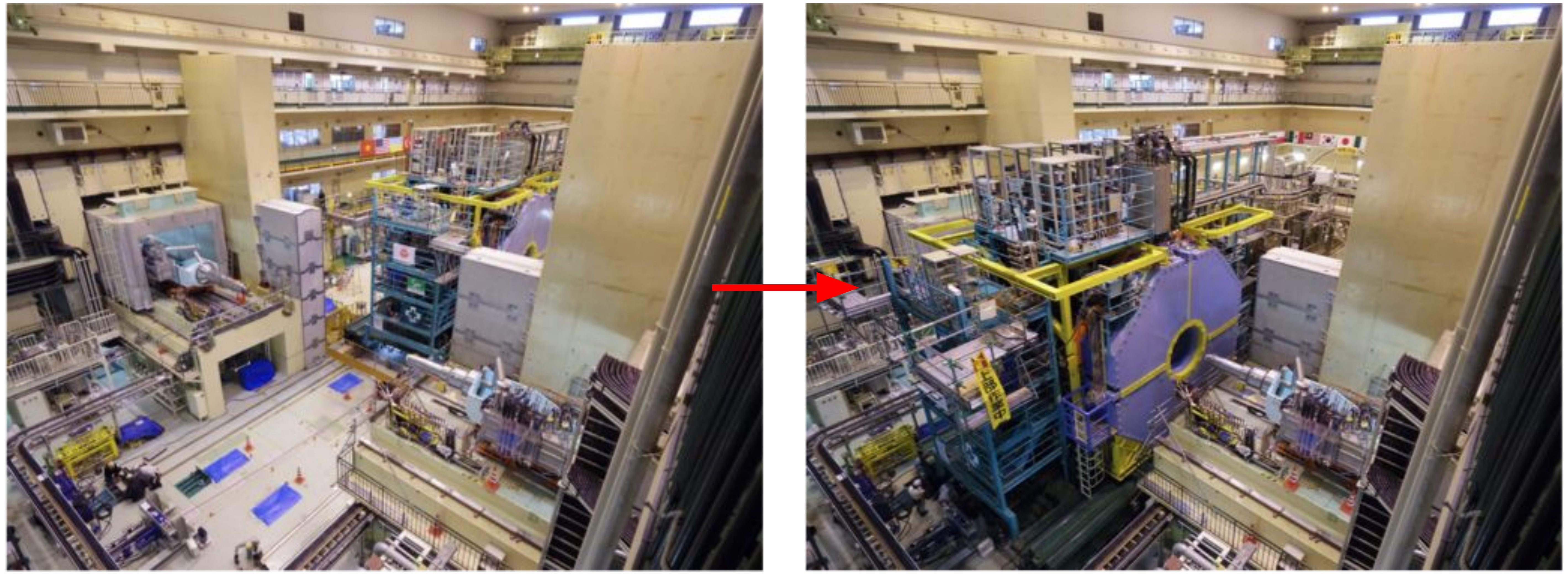
Phase 2

Phase 3

- Phase I (complete): Circulate both beams, **no collisions, no Belle II.** Tune accelerator optics. Beam studies with BEAST II **early 2016**
- Install final focusing magnet systems (complete) **late 2016**



- Phase I (complete): Circulate both beams, **no collisions, no Belle II.** Tune accelerator optics. Beam studies with BEAST II **early 2016**
- Install final focusing magnet systems (complete) **late 2016**
- Belle II roll-in (complete) **March 2017**



2016	2017	2018	2019
Phase 1		Phase 2	Phase 3

2016 2017 2018 2019

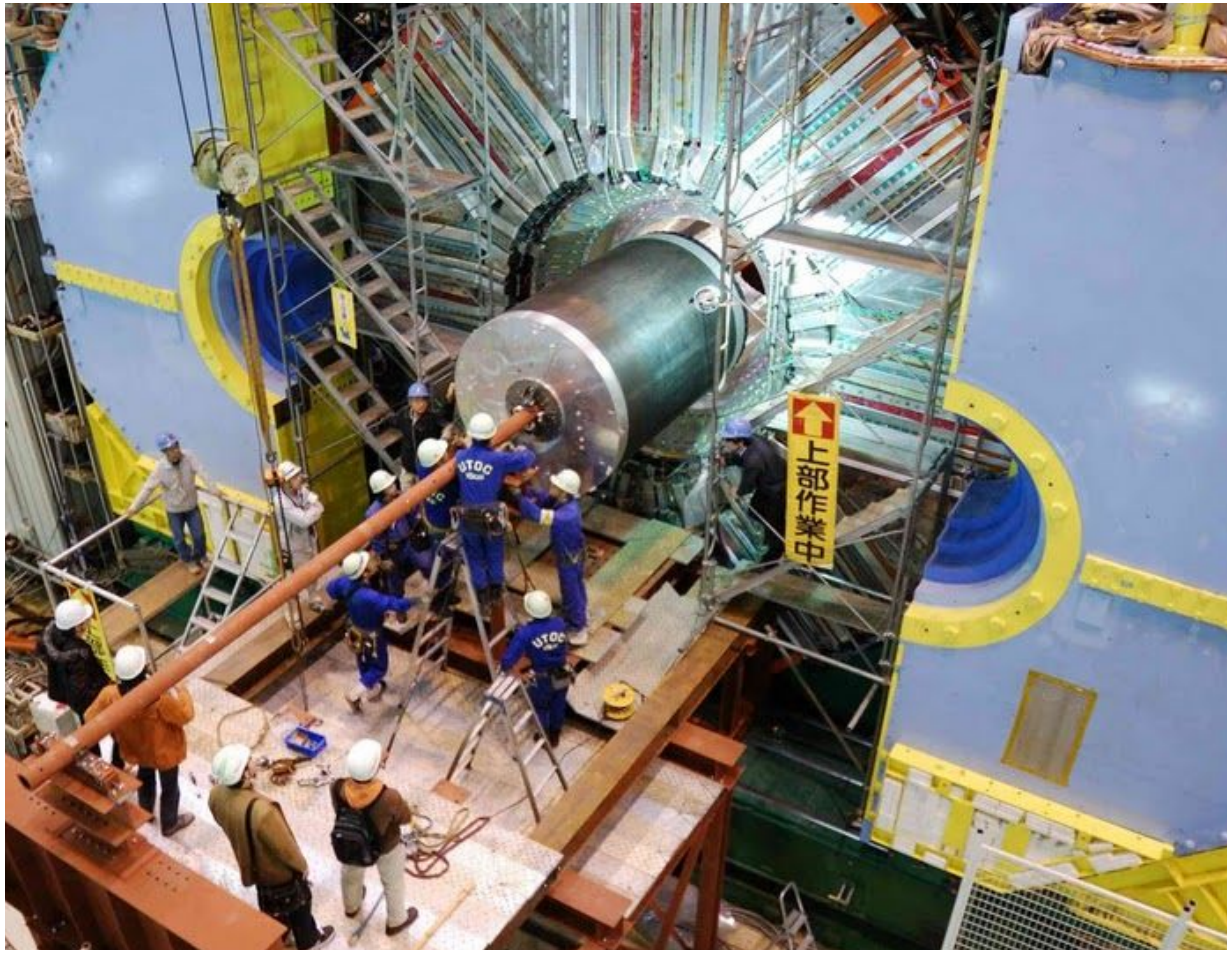
Phase 1 Phase 2 Phase 3

Belle II Detector Installation

- Barrel Cherenkov particle ID (TOP) installed **May 2016**

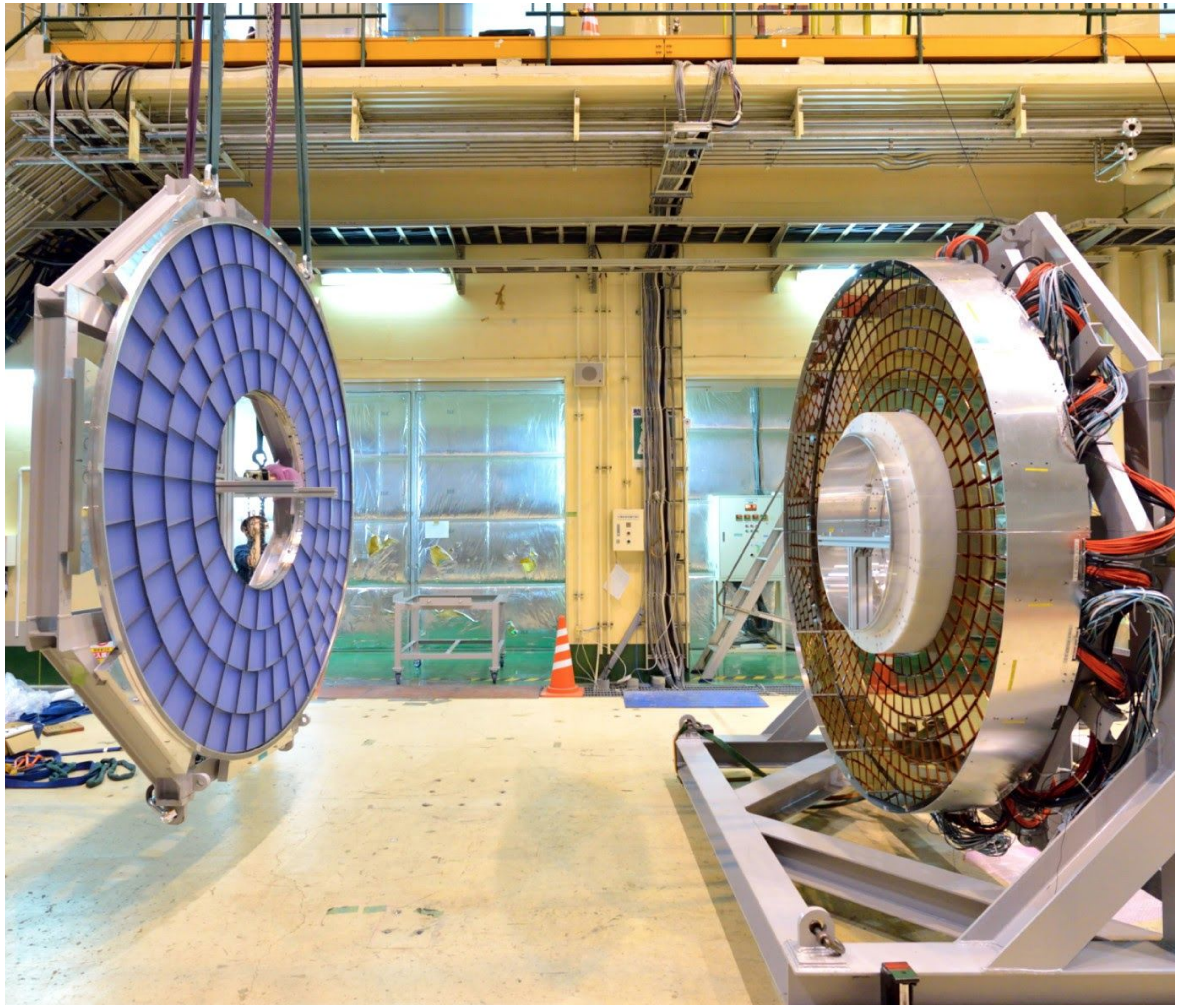
2016 2017 2018 2019

Phase 1 Phase 2 Phase 3



Belle II Detector Installation

- Barrel Cherenkov particle ID (TOP) installed **May 2016**
- Drift chamber (CDC) installed **October 2016**

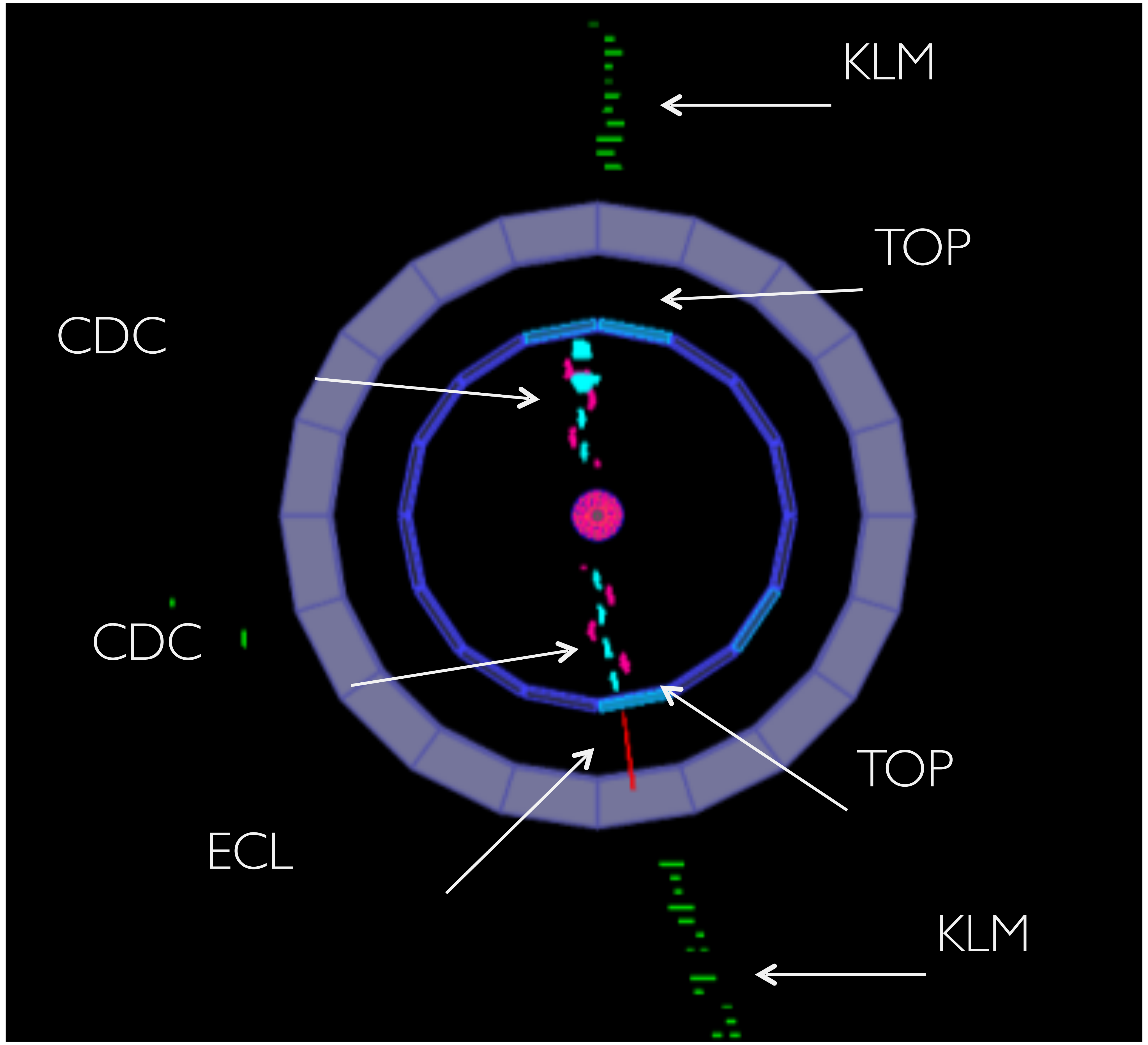


Belle II Detector Installation

- Barrel Cherenkov particle ID (TOP) installed **May 2016**
- Drift chamber (CDC) installed **October 2016**
- End-cap Cherenkov particle ID (ARICH) integration **August 2017**

2016 | 2017 | 2018 | 2019

Phase 1 | Phase 2 | Phase 3



Hits in four outer subdetectors

Belle II Detector Installation

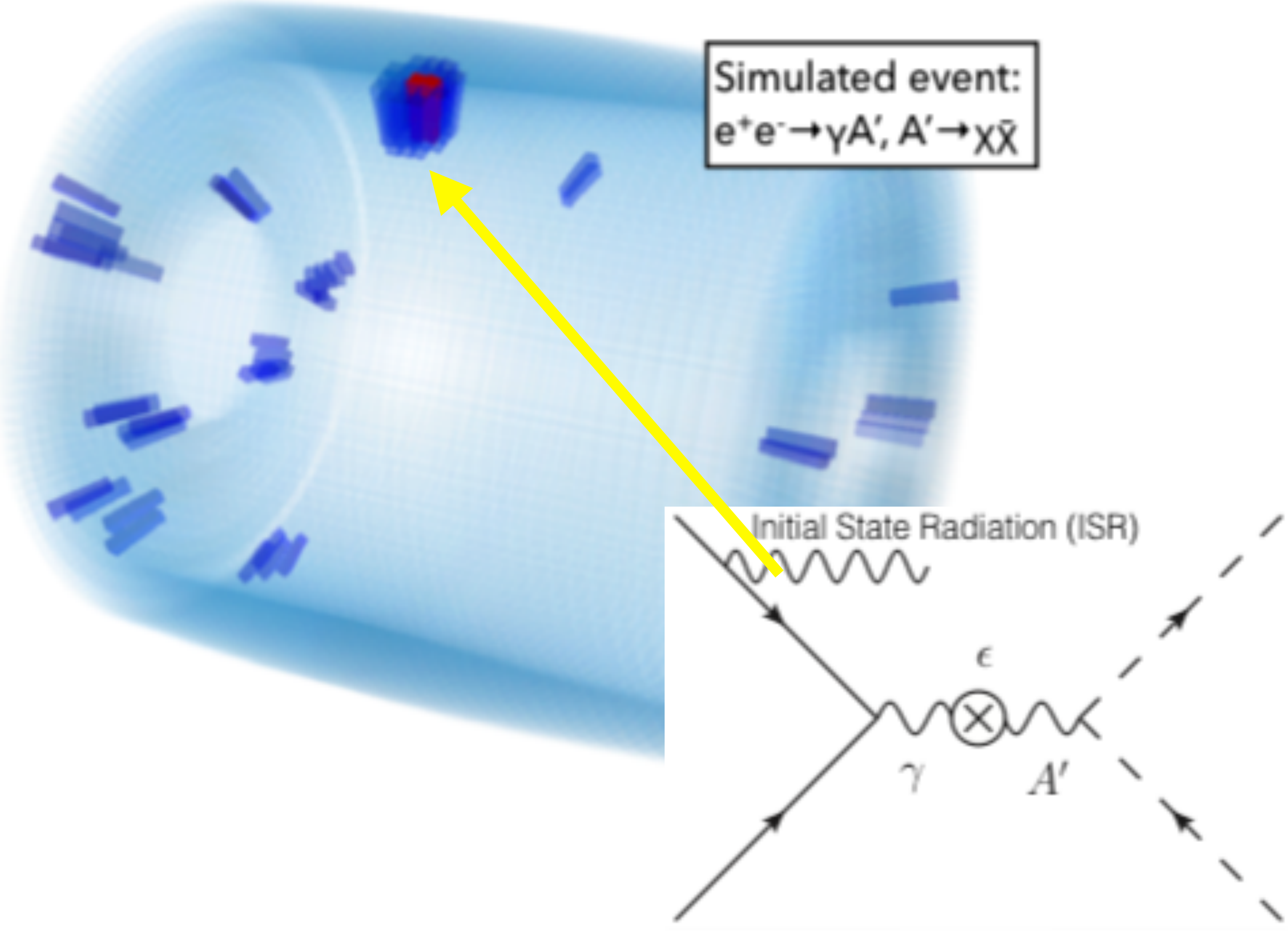
- Barrel Cherenkov particle ID (TOP) installed **May 2016**
- Drift chamber (CDC) installed **October 2016**
- End-cap Cherenkov particle ID (ARICH) integration **August 2017**
- Global Cosmic Run DAQ **July 2017—**
- Vertex detector will be integrated after **phase 2**

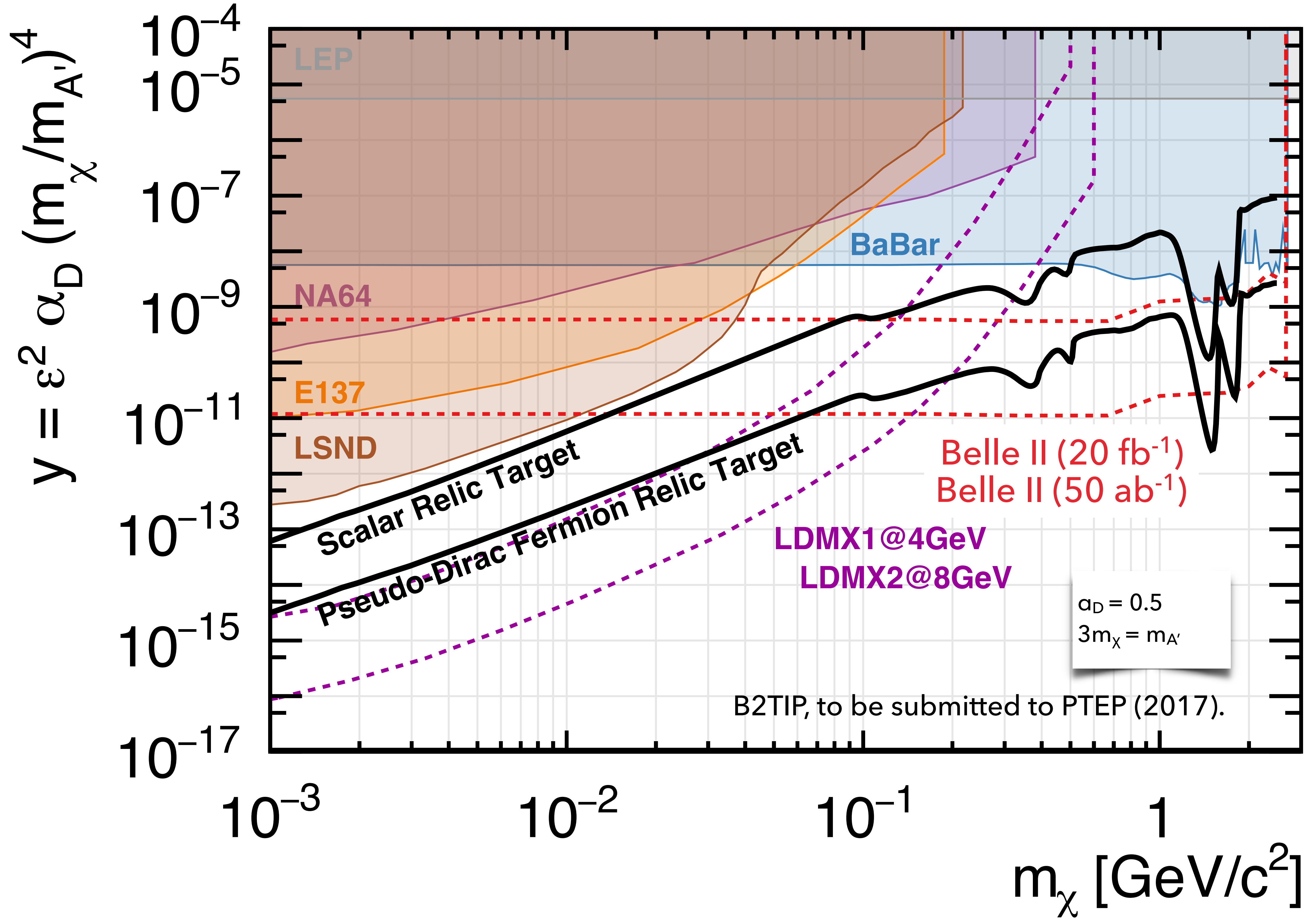
Dark Sectors in early data (aside: not B-physics)

DM Session: A .Fodor

Belle II Physics Book

- In 2018 new Belle II triggers will be used to search for dark matter and dark photons.





B2TIP, to be submitted to PTEP (2017).

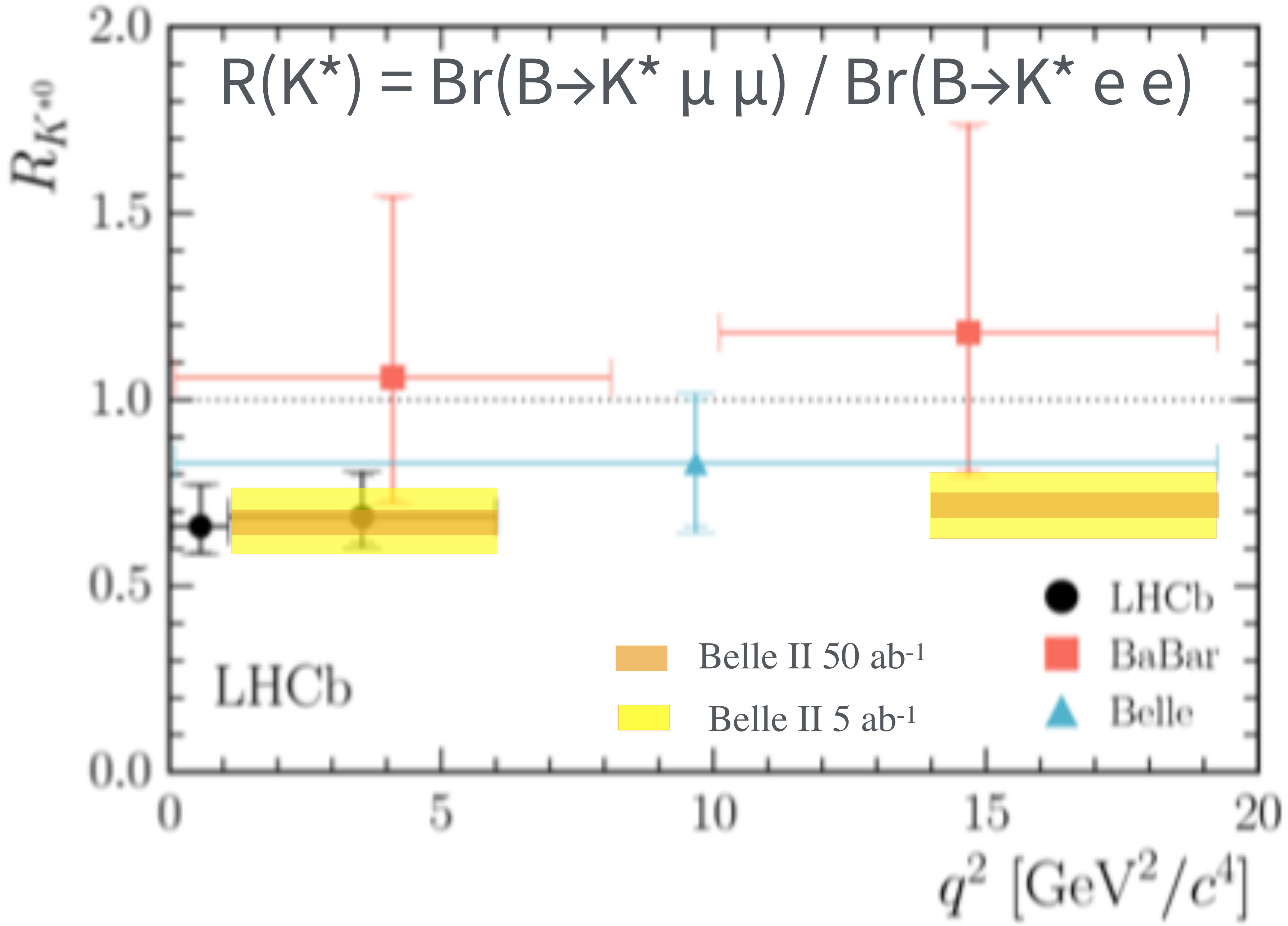
Belle II: b → s Loop

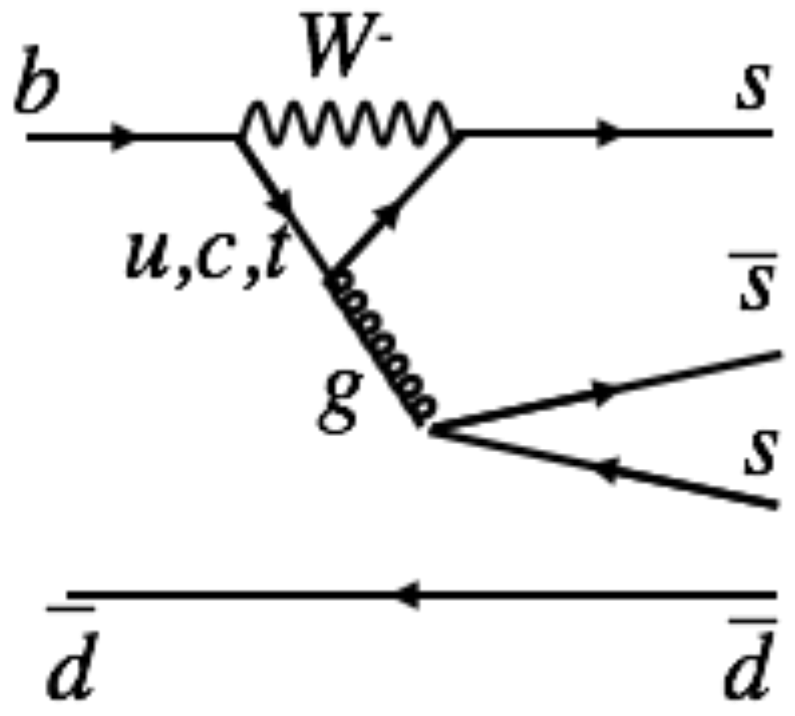
Flavour Session: S. Sandilya

Belle II Physics Book

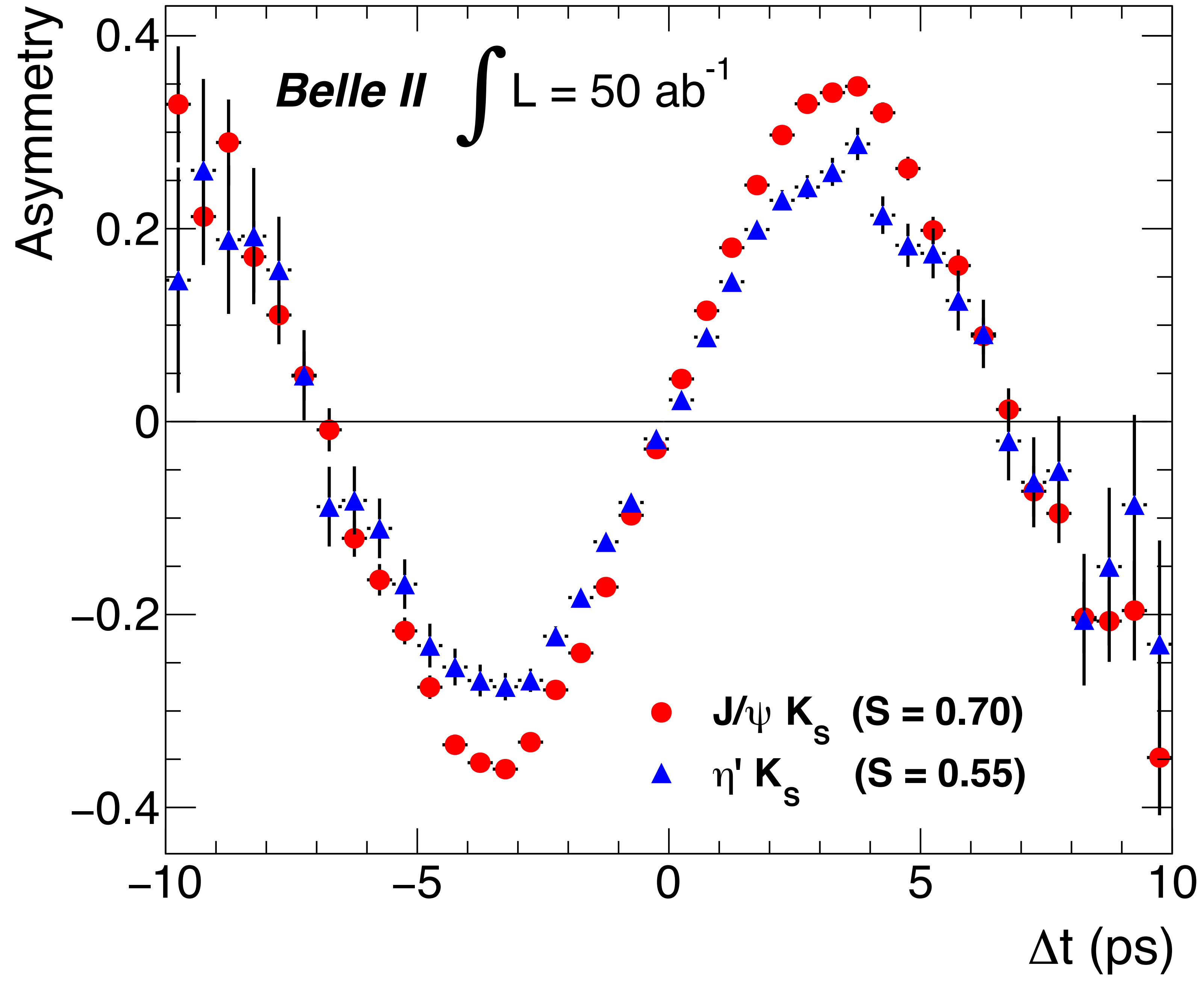
- Probe **LFUV to few % accuracy** each in **B→K/K*/Xs l l** through full q^2 range: *better* E_{e-} resolution than LHCb
- Time dependent CP-violation in **B → η' K_S** will reach 0.015 precision by 50 ab^{-1} — stat. limited
  TDCPV b→s tests to be dominated by Belle II

	WA (2017)		5 ab^{-1}		50 ab^{-1}	
Channel	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$	$\sigma(S)$	$\sigma(A)$
$J/\psi K^0$	0.022	0.021	0.012	0.011	0.0052	0.0090
ϕK^0	0.12	0.14	0.048	0.035	0.020	0.011
$\eta' K^0$	0.06	0.04	0.032	0.020	0.015	0.008
ωK^0_S	0.21	0.14	0.08	0.06	0.024	0.020
$K^0_S \pi^0 \gamma$	0.20	0.12	0.10	0.07	0.031	0.021
$K^0_S \pi^0$	0.17	0.10	0.09	0.06	0.028	0.018





B→J/ψ Ks	B_{CP} µm	B_{tag} µm	Δt ps
Belle II	22	52	0.71
Belle	63	89	0.92

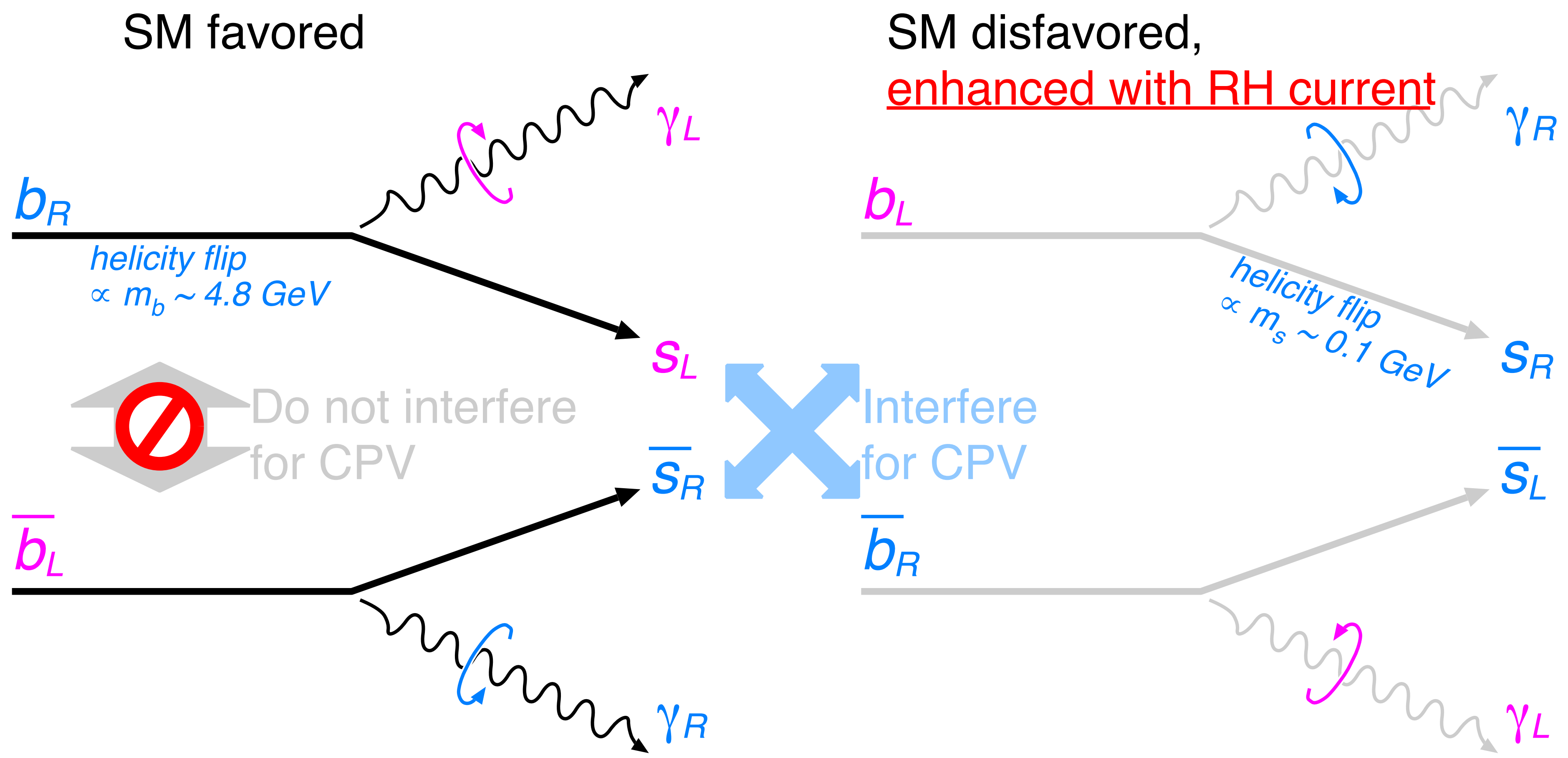


Belle II: b → d Loop

Flavour Session: S. Sandilya

Belle II Physics Book

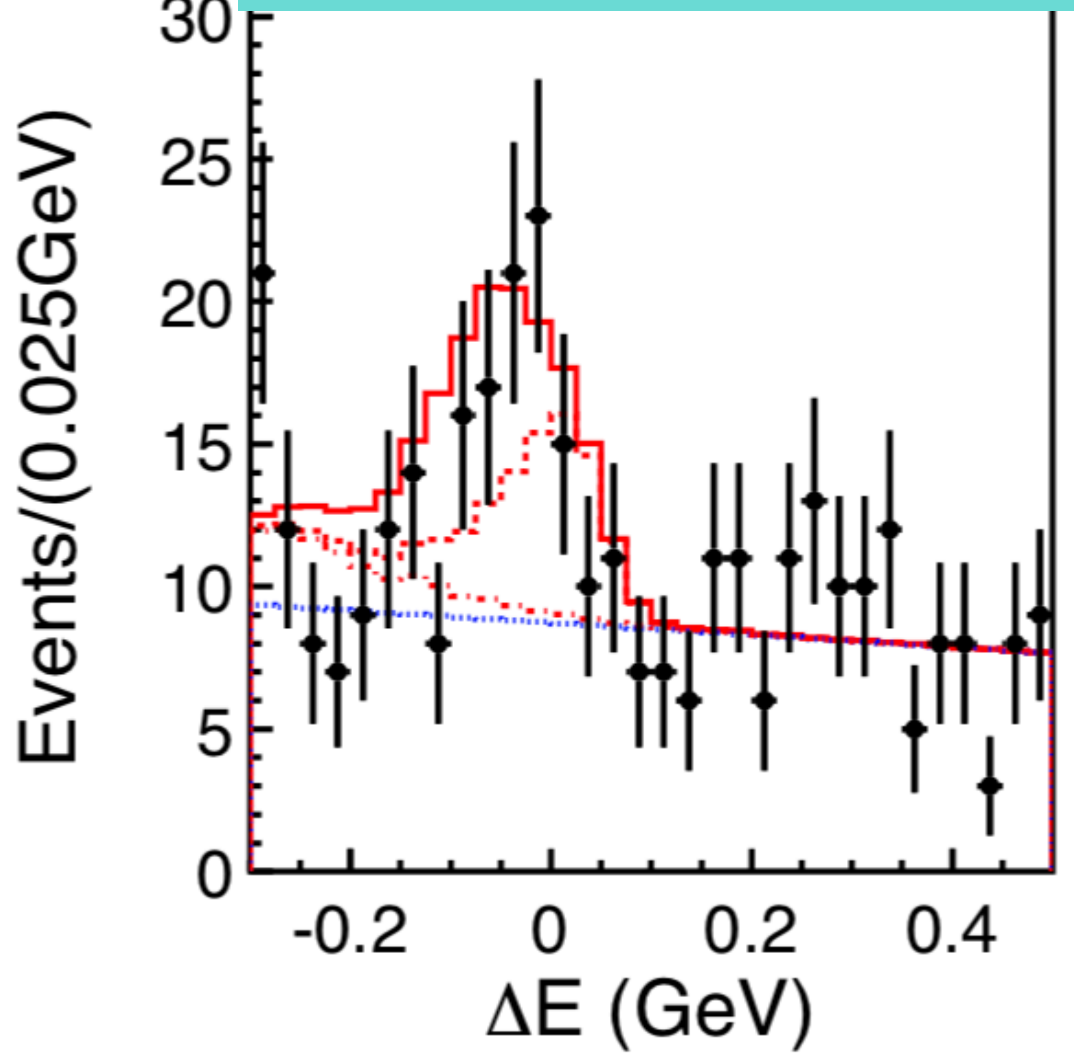
- **b→d** couplings not thoroughly studied yet (other than mixing)

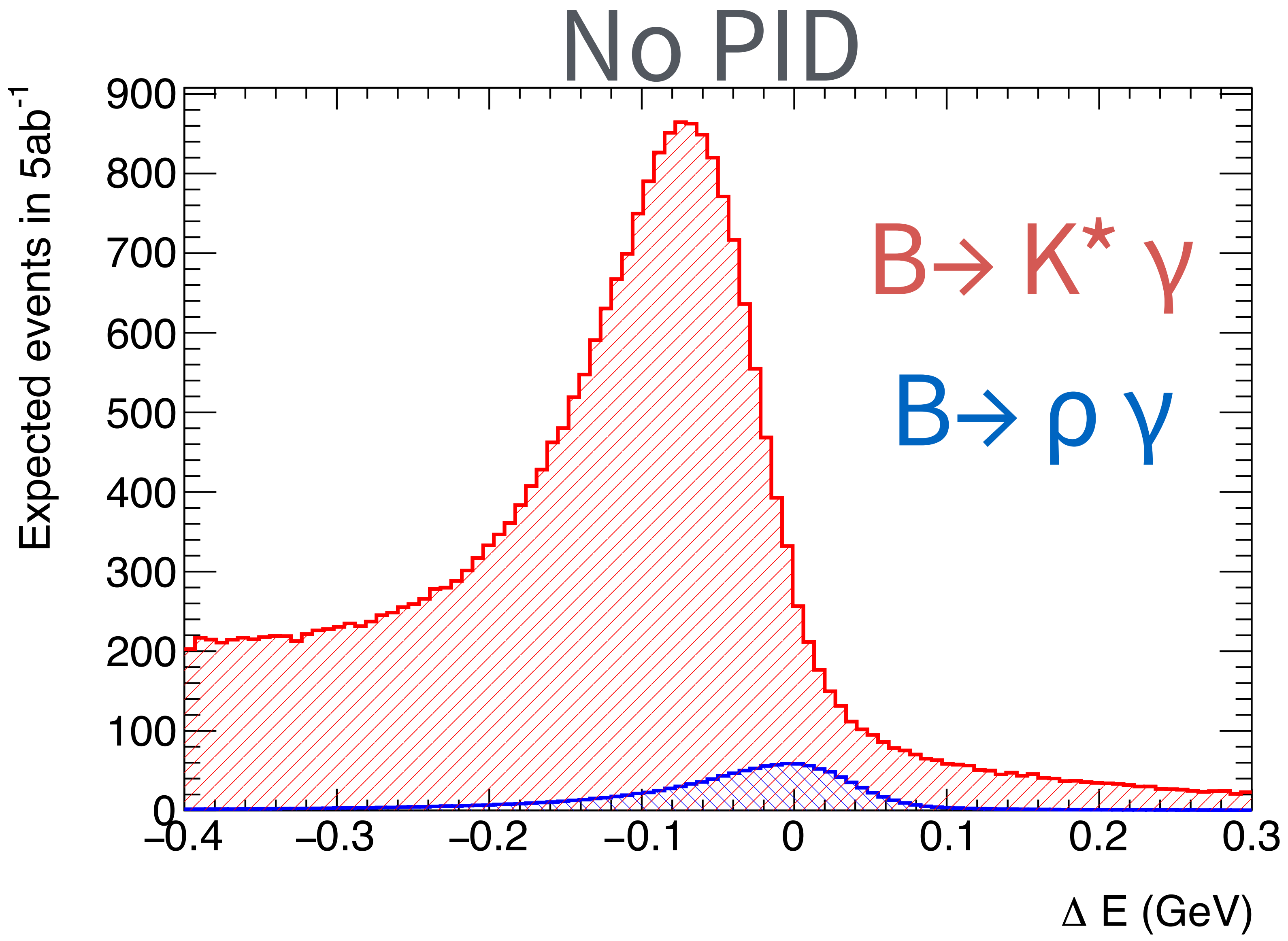

SM favored

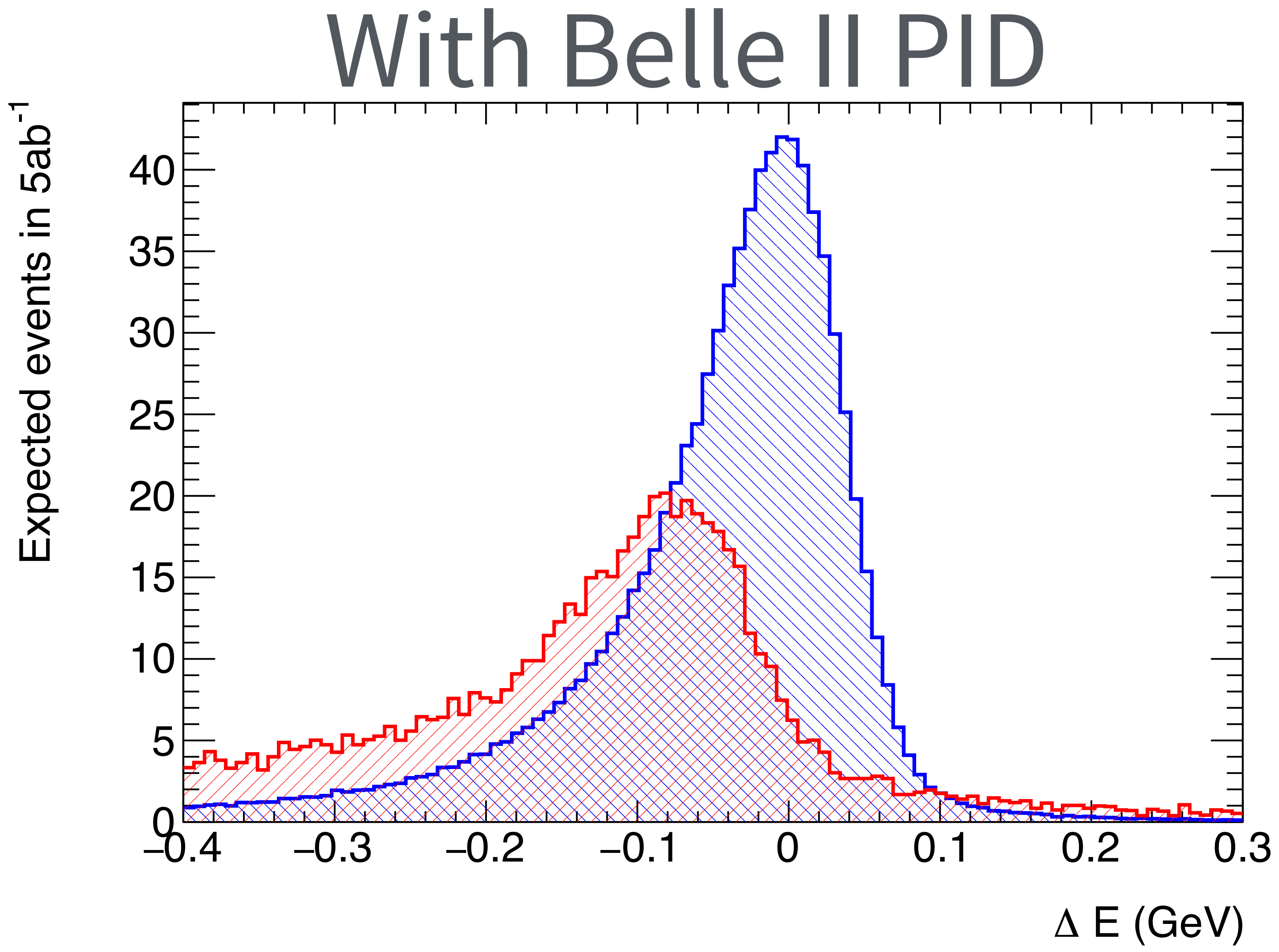
SM disfavored, enhanced with RH current

Observables	Belle 0.71 ab^{-1}	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\Delta_{0+}(B \to \rho\gamma)$	18%	5.4%	1.9%
$A_{\mathrm{CP}}(B^0 \to \rho^0\gamma)$	44%	12%	3.8%
$A_{\mathrm{CP}}(B^+ \to \rho^+\gamma)$	30%	9.6%	3.0%
$\Delta A_{\mathrm{CP}}(B \to \rho\gamma)$	53%	16%	4.8%
$S_{\rho^0\gamma}$	63%	19%	6.4%

Belle PRL 100, 021602 (2008)




No PID

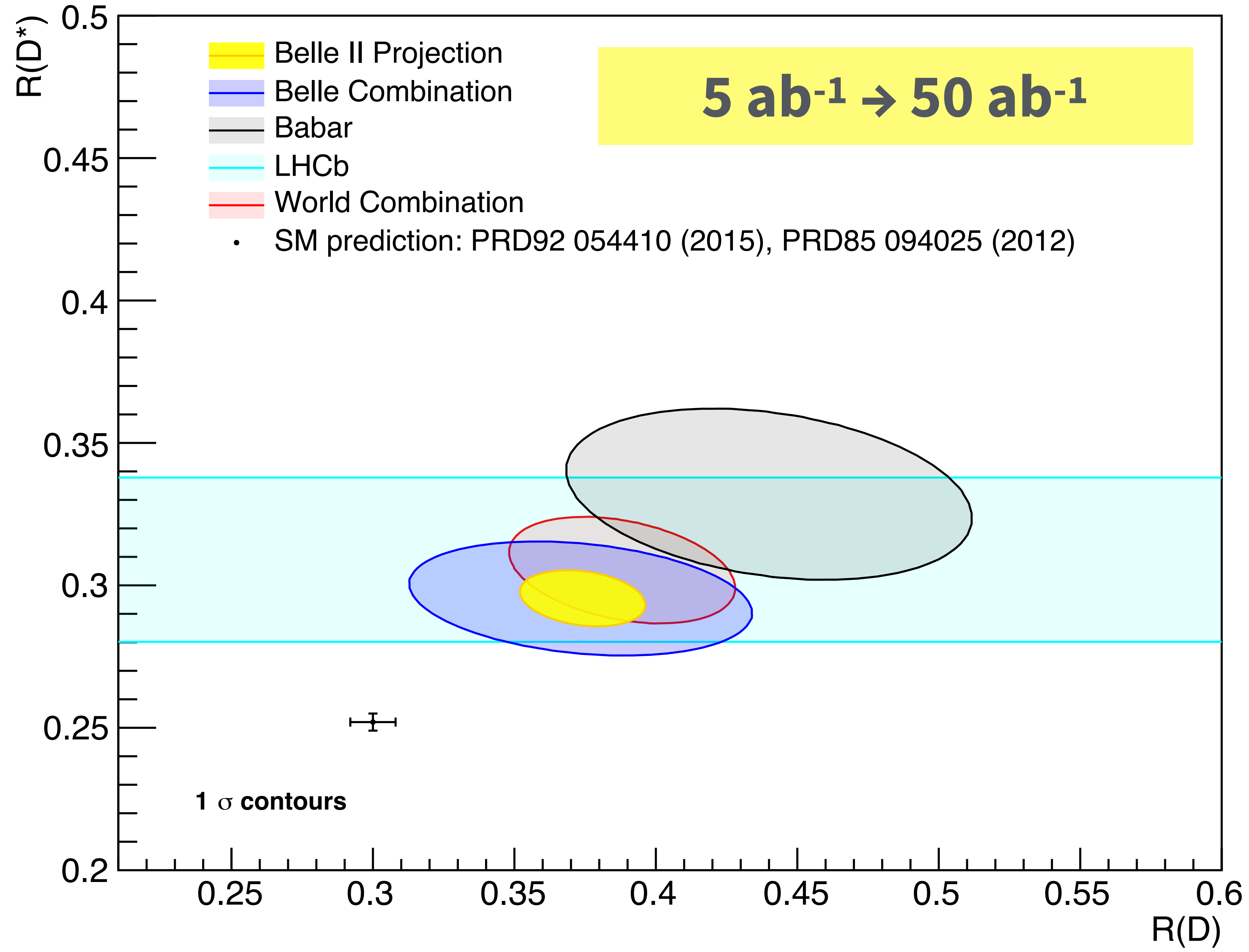

With Belle II PID

Belle II: b → c Tree

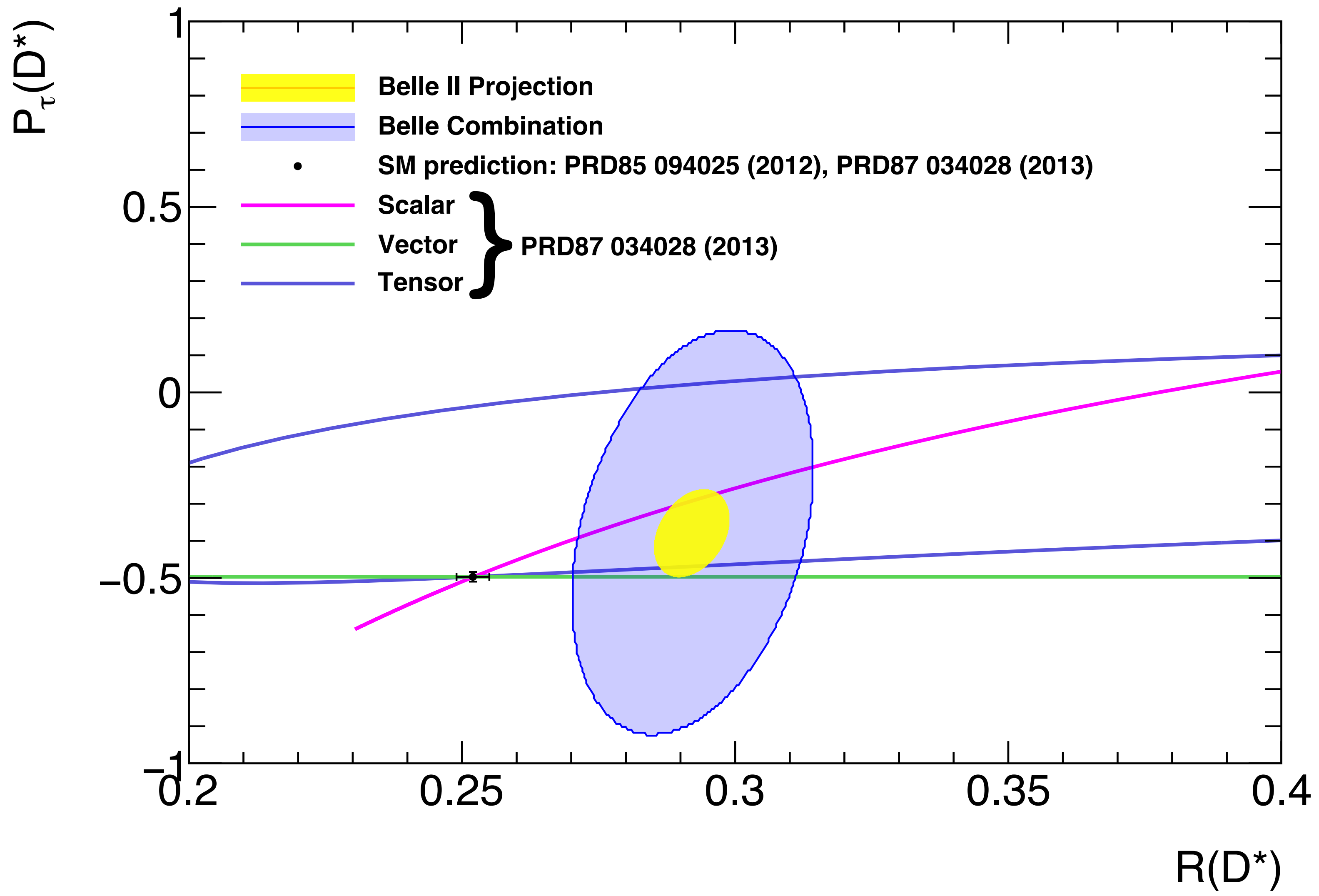
Flavour Session: M. Nayak

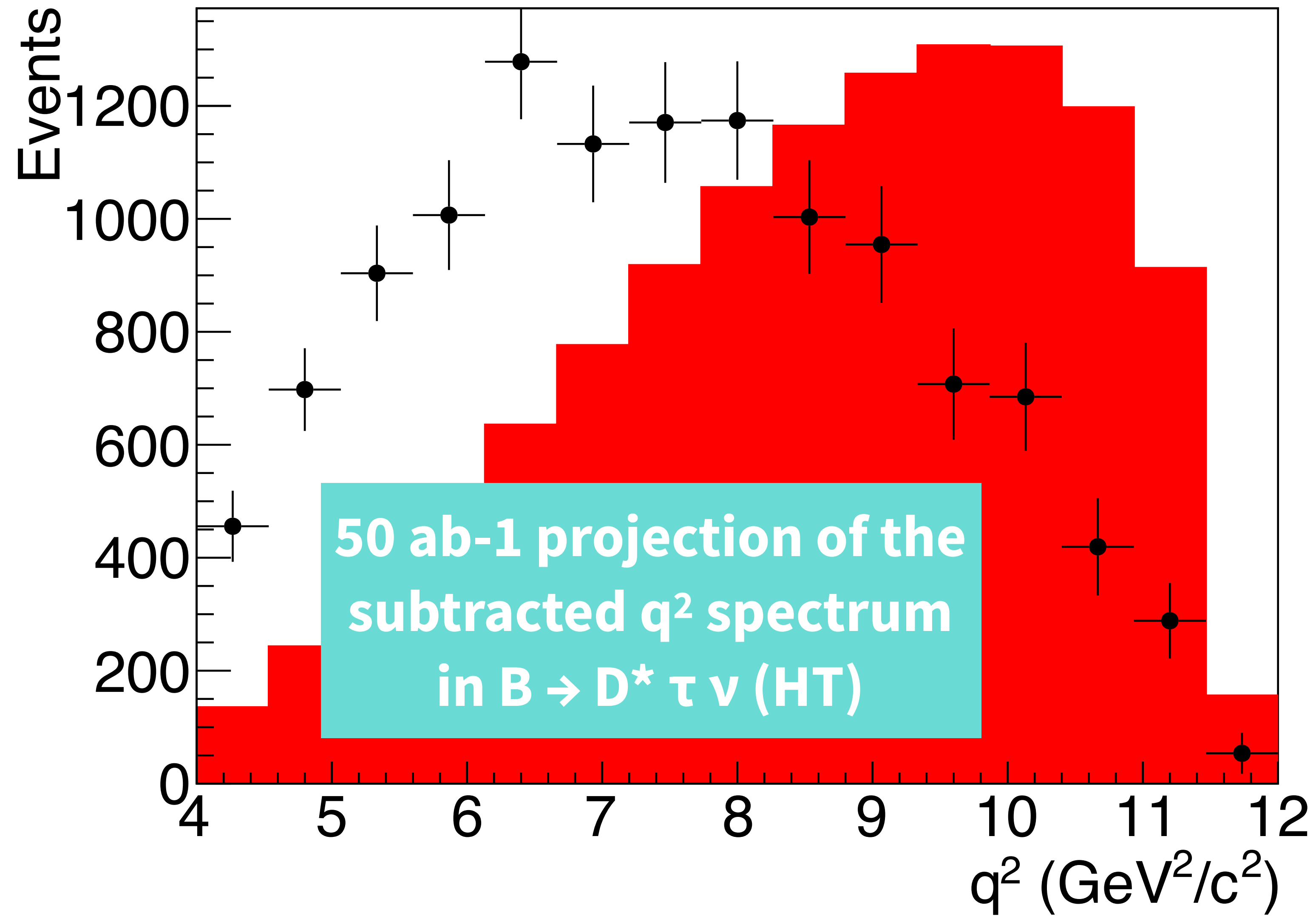
Belle II Physics Book

- Combination of Babar, Belle & LHCb 4 σ from SM.
- Belle II should confirm/deny this anomaly with 5 ab^{-1}
  - Tag{Had, SL, Inclusive} x Signal {τ → l ν ν , τ → h ν} ~ 6 statistically independent approaches.
  - B → D* τ ν: 5 ab^{-1} ~ 3% (down from about 8%)
  - B → D τ ν: 5 ab^{-1} ~ 6% (down from 16%) - though Belle yet to release R(D) with SL tag.



5 ab^{-1} → 50 ab^{-1}





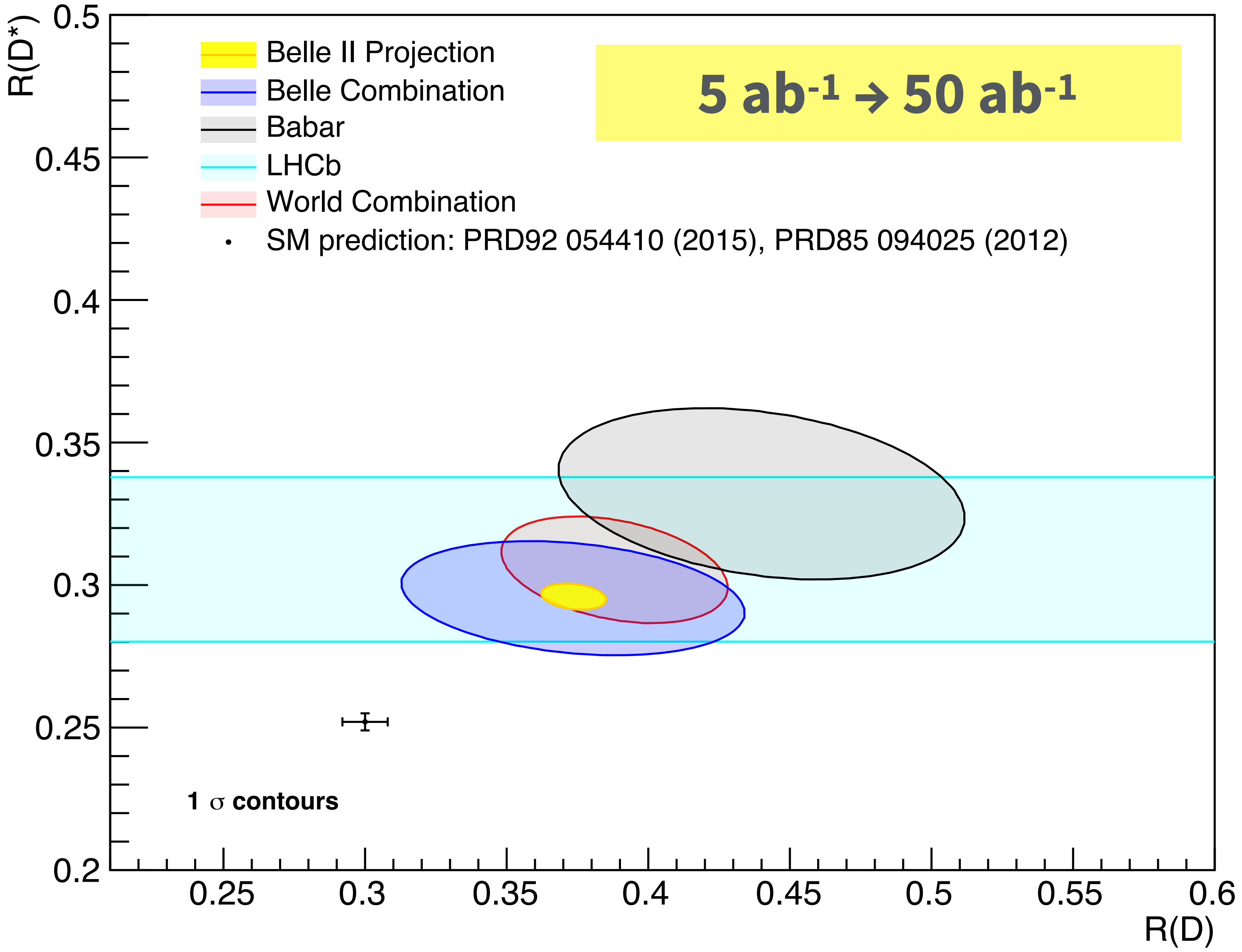
50 ab-1 projection of the subtracted q² spectrum in B → D* τ ν (HT)

Belle II: b → c Tree

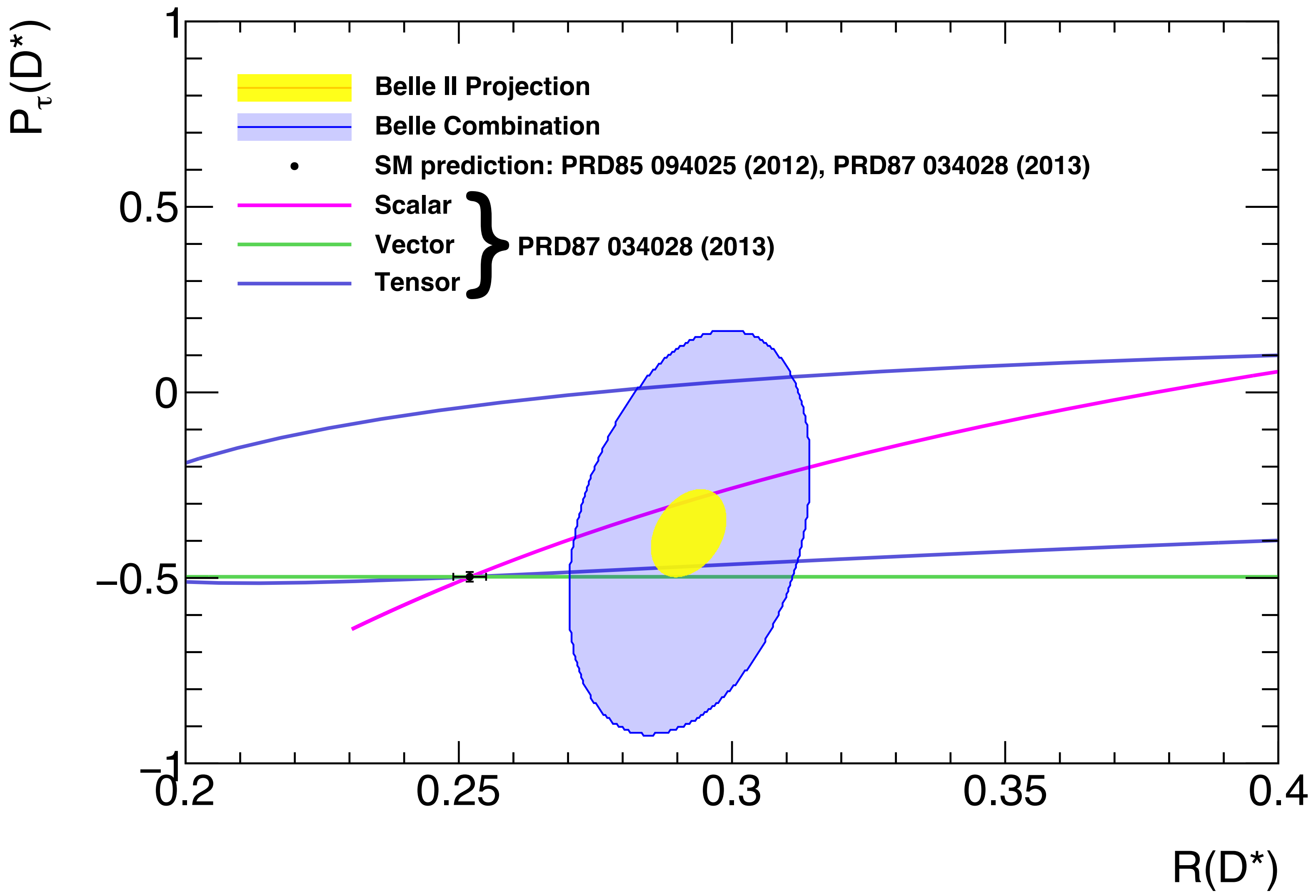
Flavour Session: M. Nayak

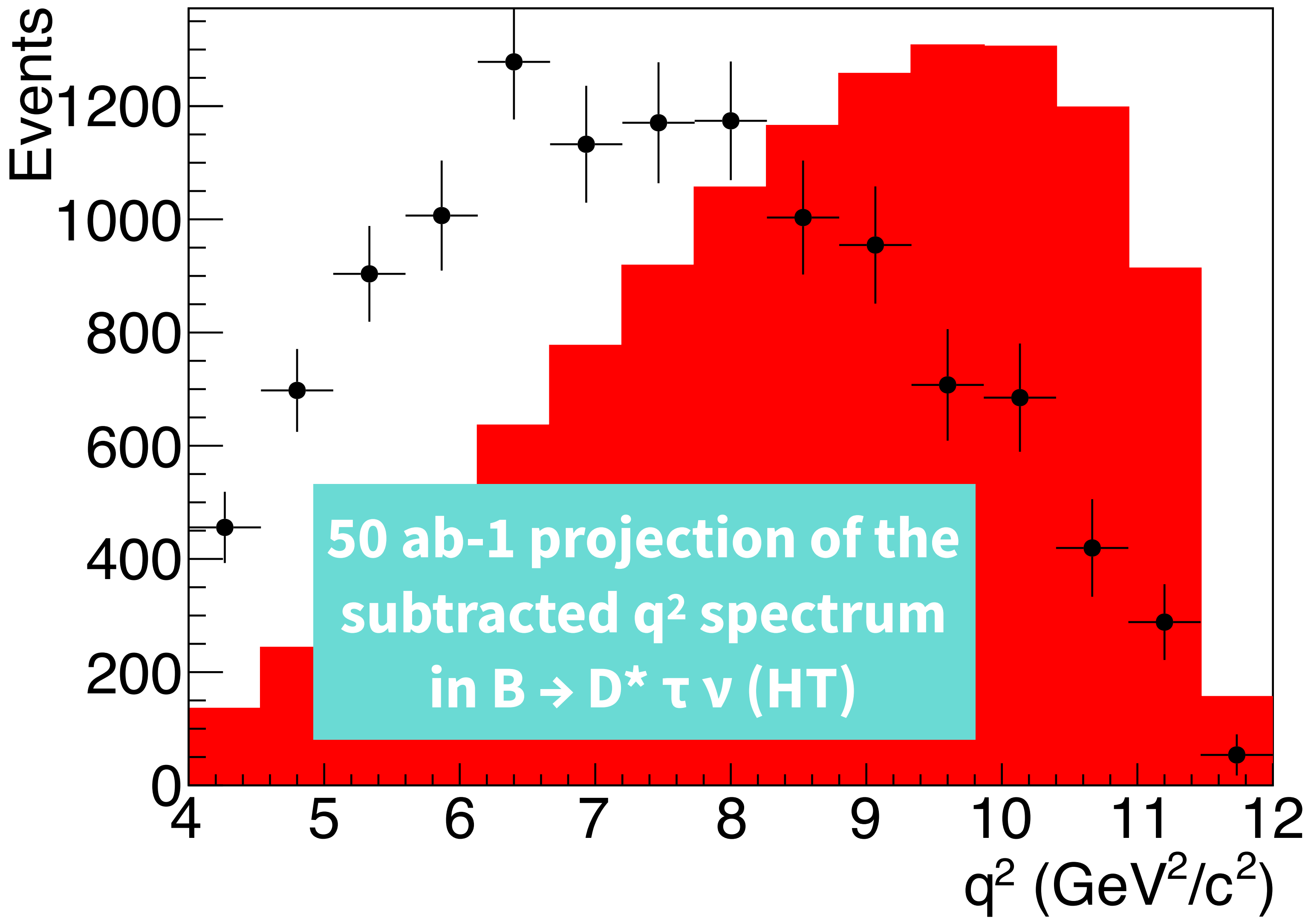
Belle II Physics Book

- Combination of Babar, Belle & LHCb 4 σ from SM.
- Belle II should confirm/deny this anomaly with 5 ab^{-1}
  - Tag{Had, SL, Inclusive} x Signal {τ → l ν ν , τ → h ν} ~ 6 statistically independent approaches.
  - B → D* τ ν: 5 ab^{-1} ~ 3% (down from about 8%)
  - B → D τ ν: 5 ab^{-1} ~ 6% (down from 16%) - though Belle yet to release R(D) with SL tag.



5 ab^{-1} → 50 ab^{-1}



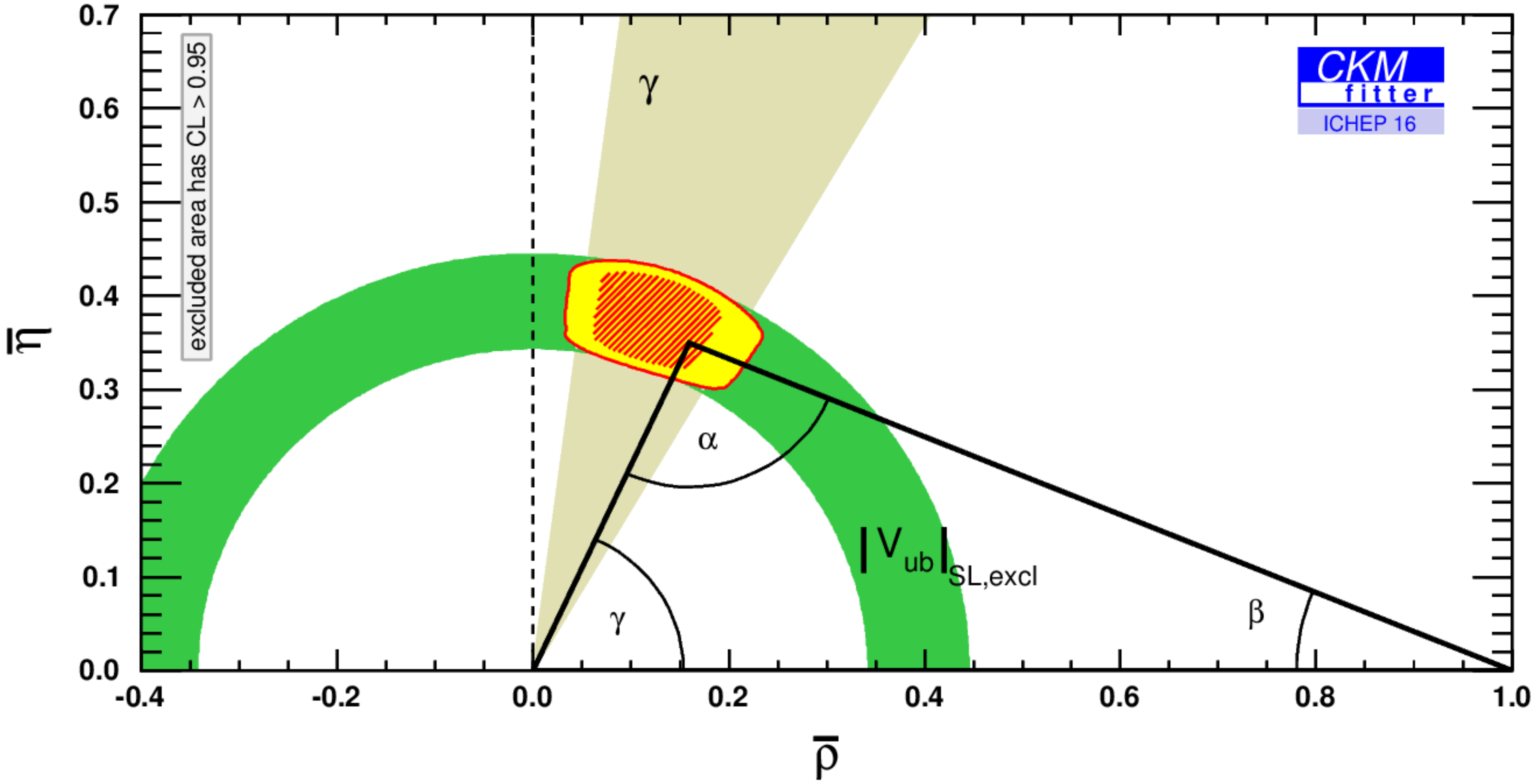


50 ab-1 projection of the subtracted q^2 spectrum in B → D* τ ν (HT)

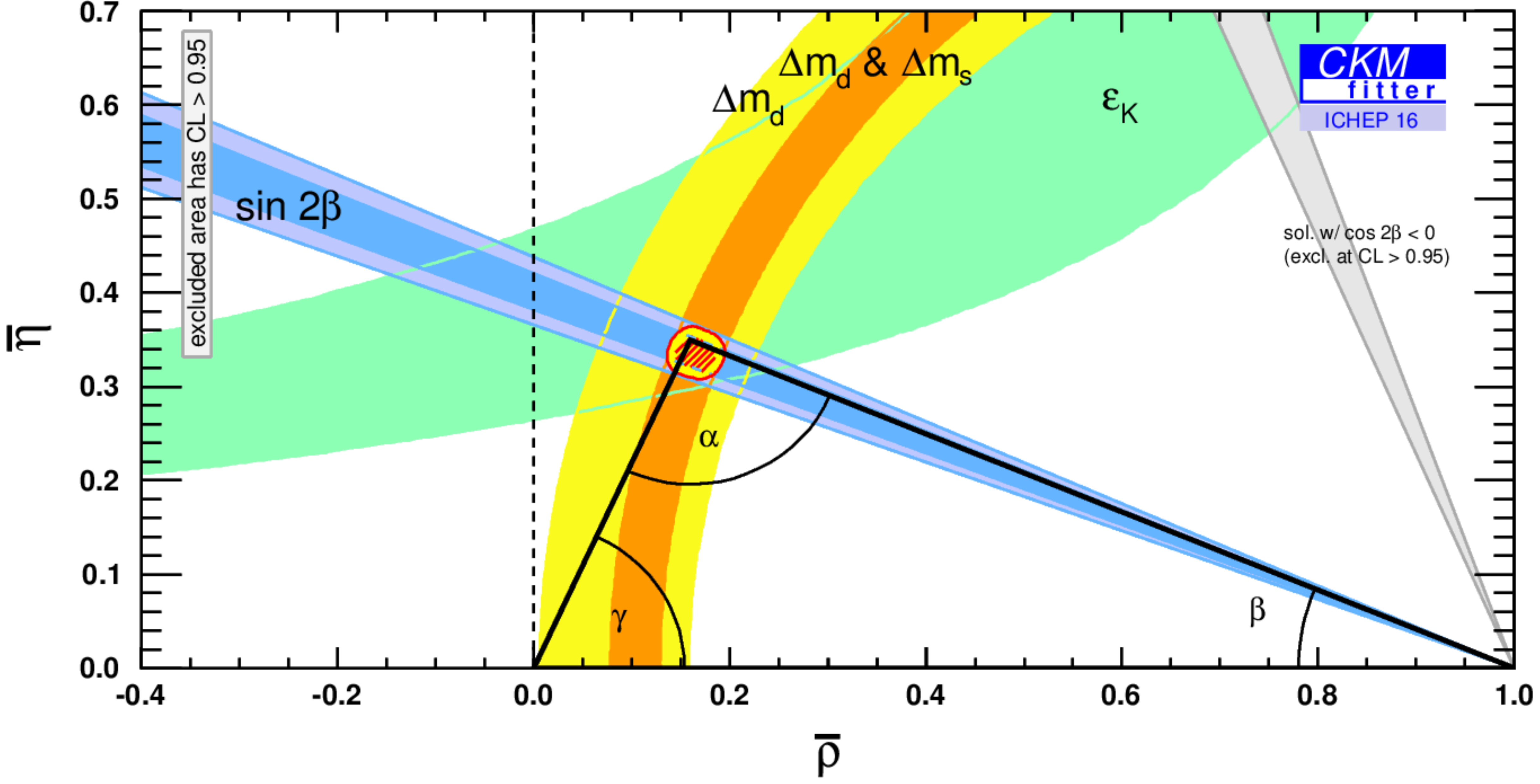
Improving the SM

- If there is no NP is flavour physics, the unitarity triangle should be the same in all measurements
  - Comparing tree level decays and loop level decays is a way to look for inconsistencies

Tree level: small NP effect?



Loop level: Large NP effect?



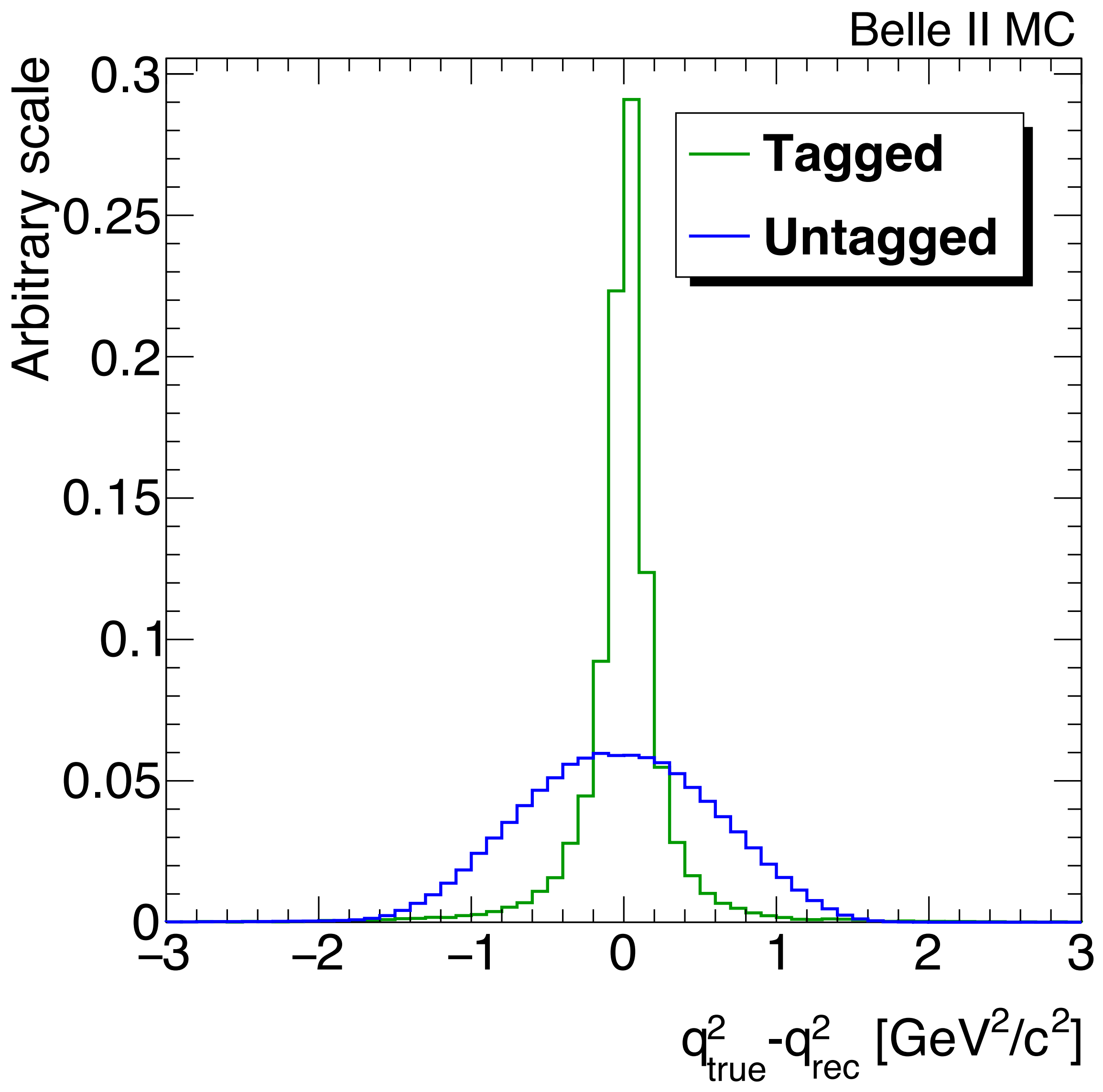
Belle II: b → u Tree

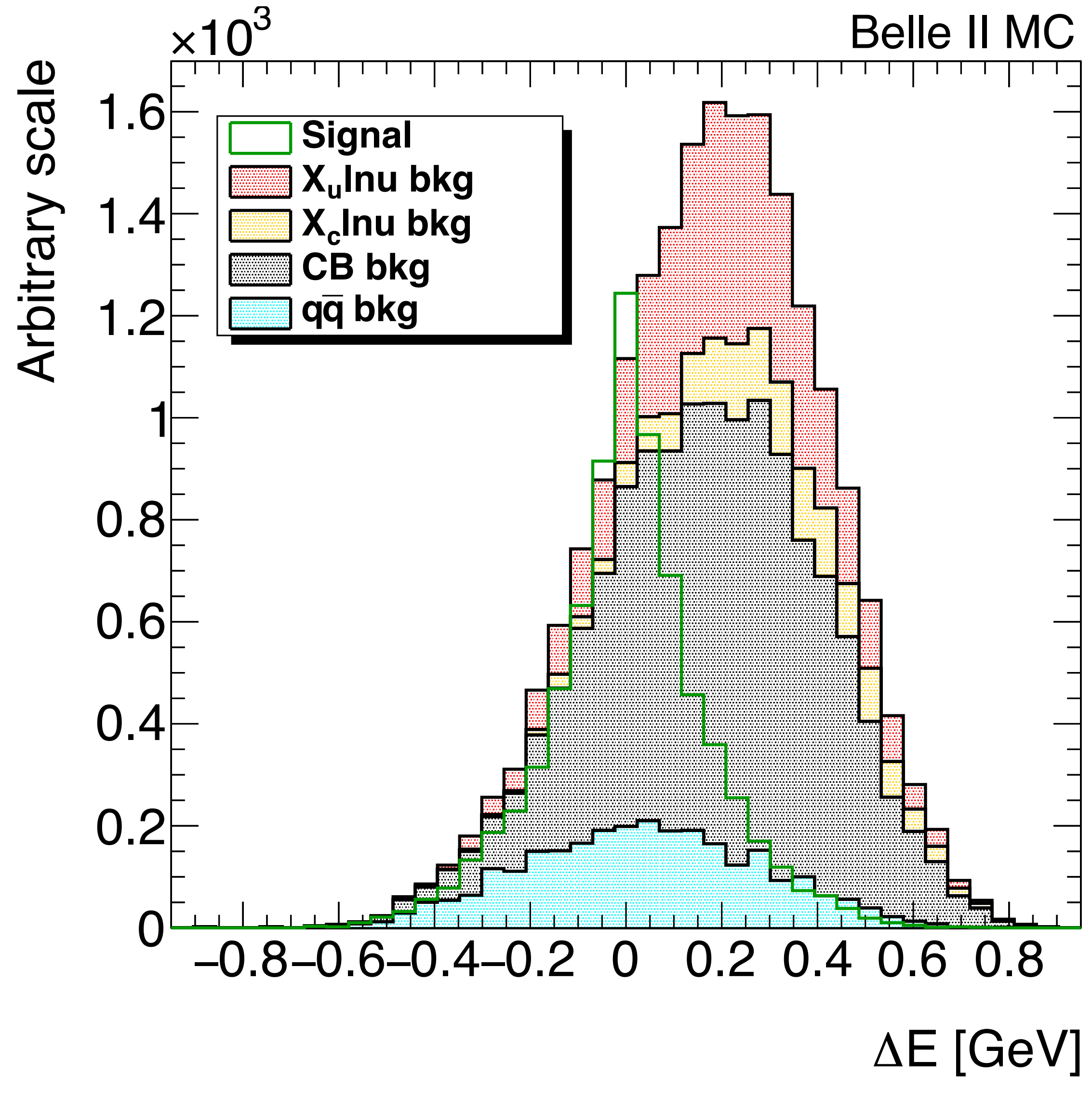
Flavour Session: M. Nayak

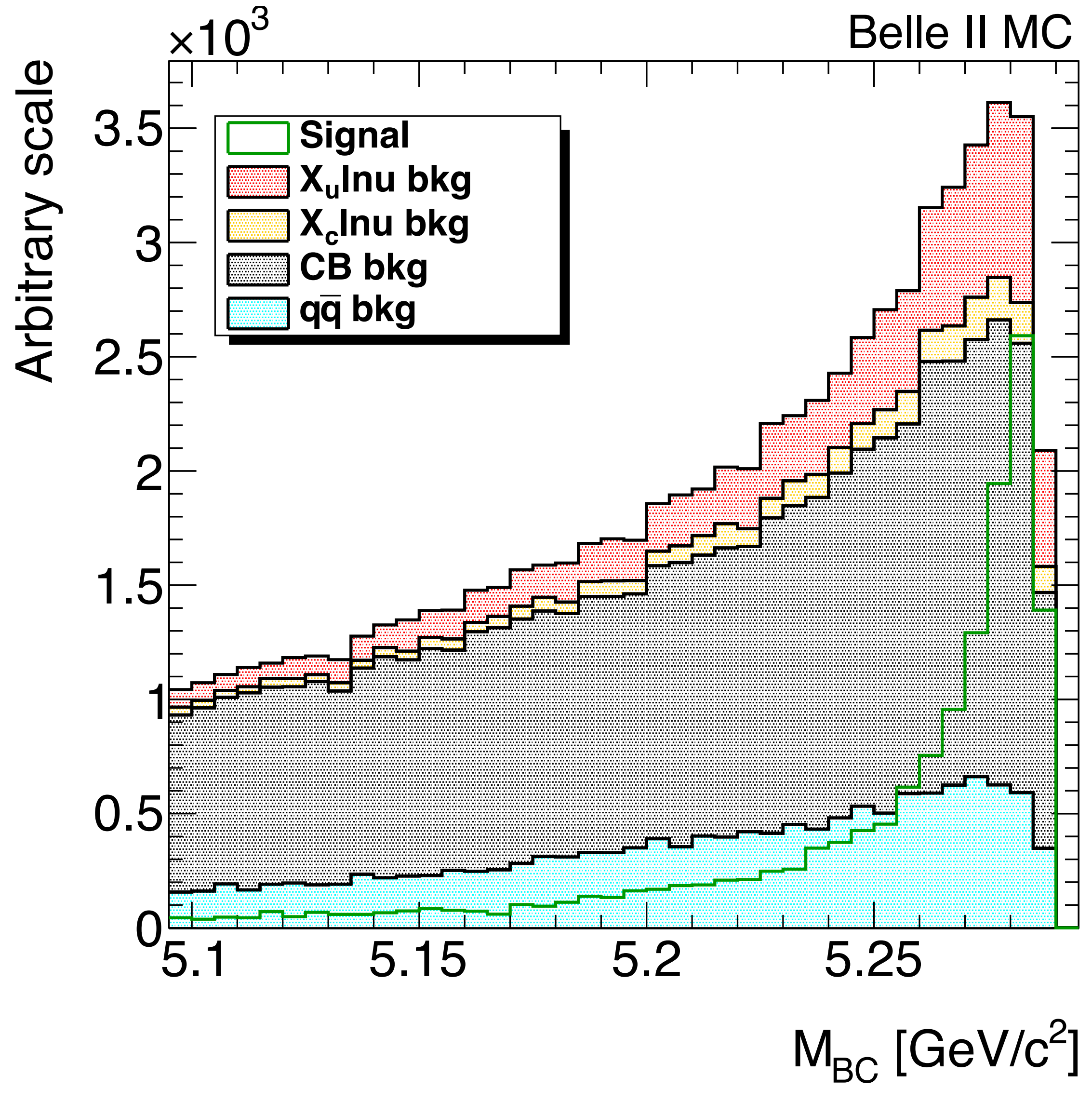
Belle II Physics Book

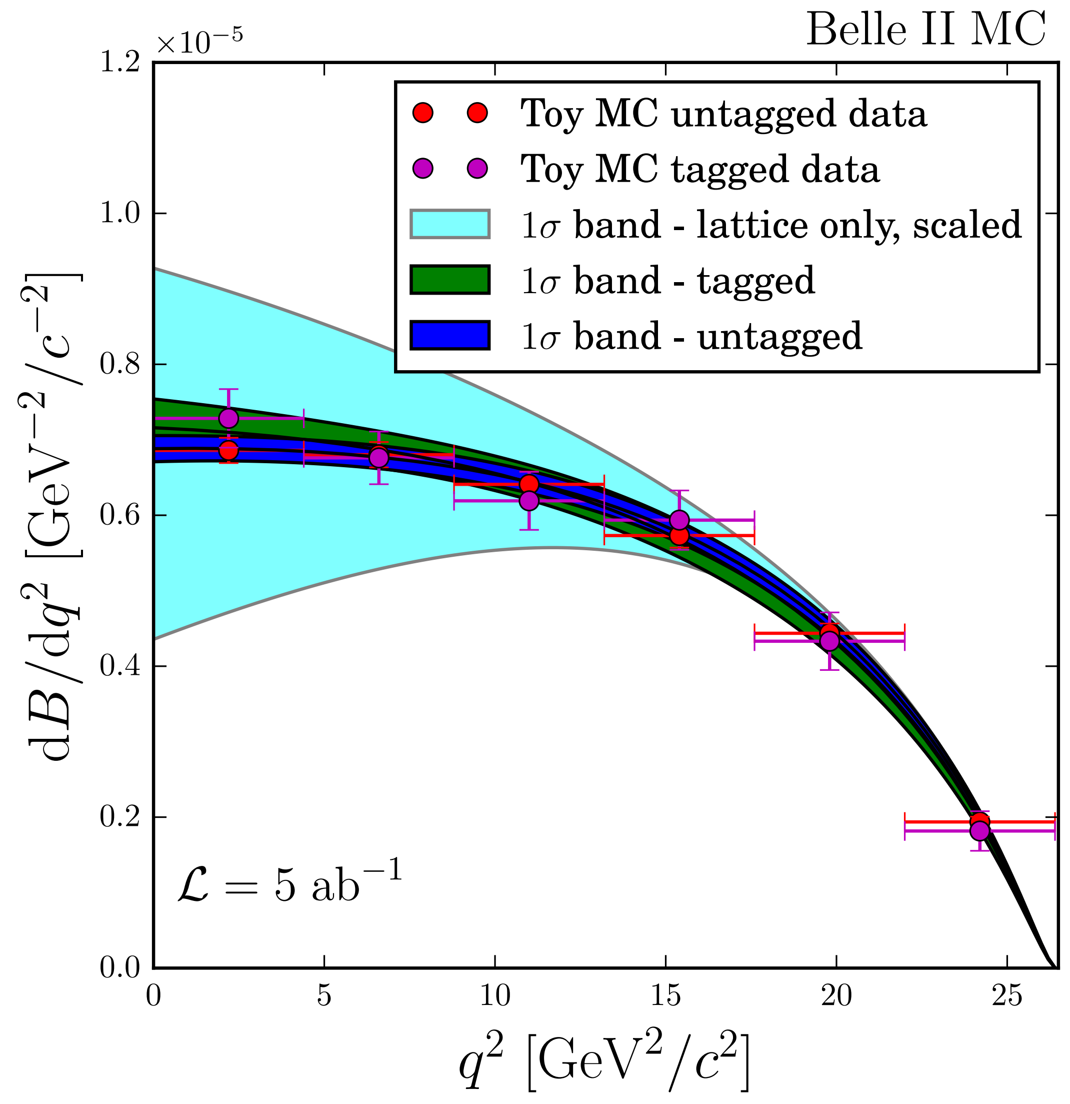
- $|V_{ub}|$ should be measured to ~1-2% accuracy with $B \to \pi l \nu$ (based on Belle II full sim.)
  - Can do LFUV tests, e/μ/τ
- Br($B \to \tau \nu$) 10% precision at 5 ab^{-1} (3% by 50 ab^{-1})
- Br($B \to \mu \nu$) discovered by 5-6 ab^{-1}

L [ab^{-1}]		σ V_{ub} [%]
1	tagged	6.2
	untagged	3.6
5	**tagged**	**3.2**
	untagged	**2.1**
	leptonic	**5**
50	tagged	1.7
	untagged	1.3
	leptonic	1.5 - 2





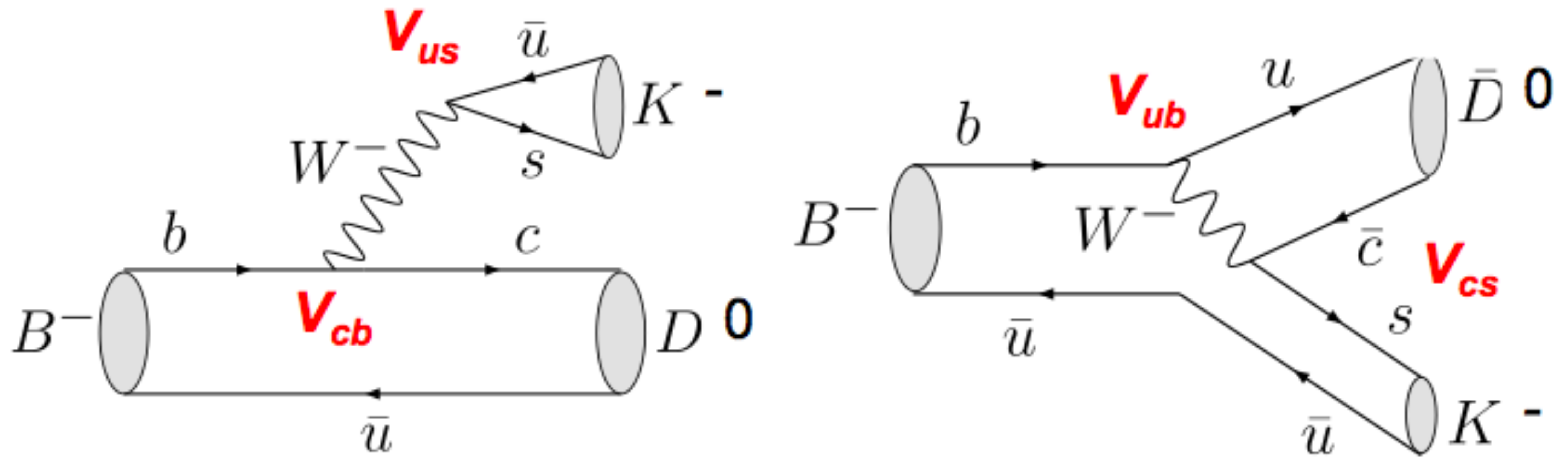


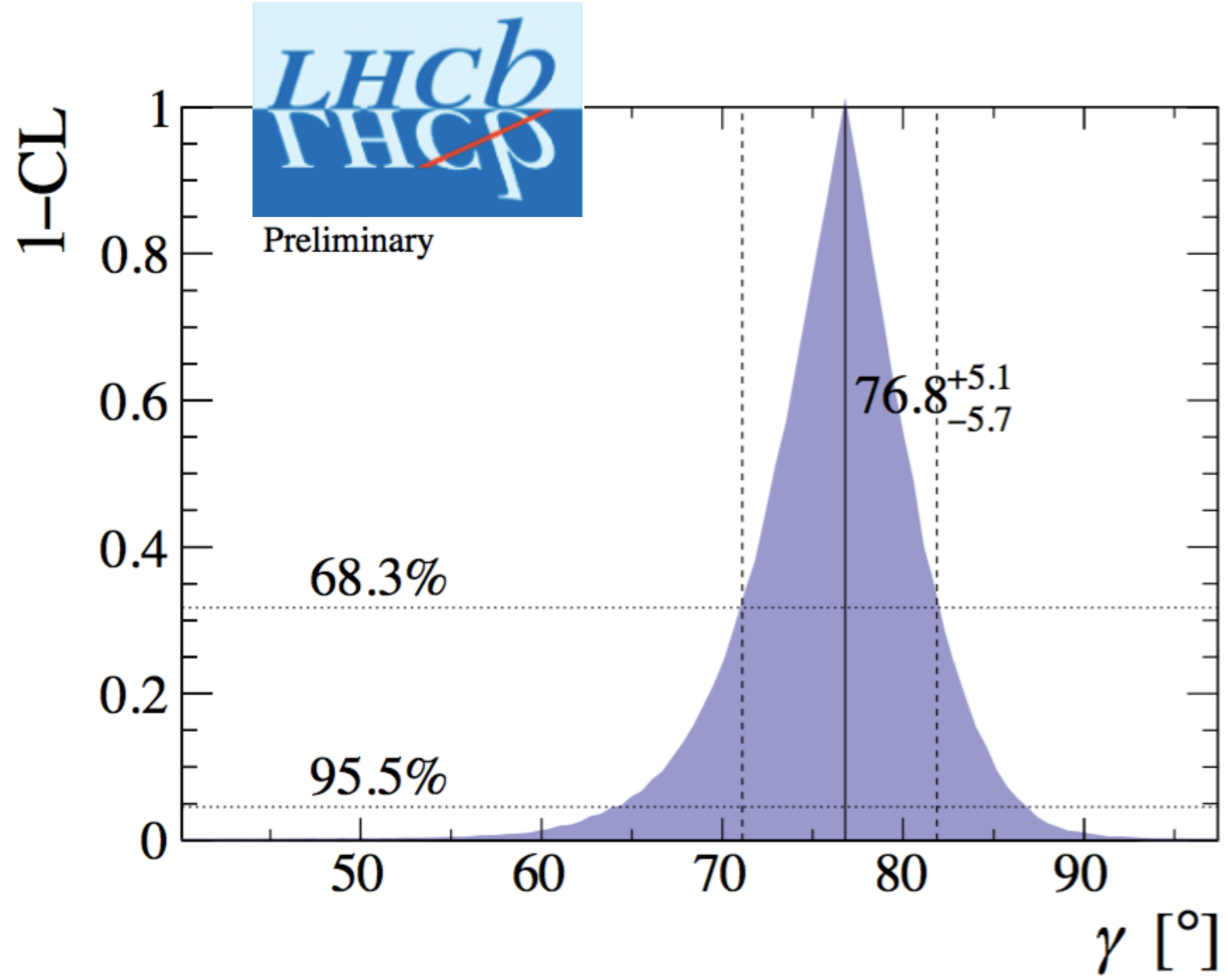


UT Precision Φ_3 / γ : LHCb Run 1+2

LHCb-CONF-2017-004
LHCb arXiv:1708.06370

- If D^0 and anti-D^0 decay to the same final state, both diagrams contribute to the observed rate
- The subsequent interference allows to determine the relative phase between these diagrams $\delta \pm \gamma$, $\gamma = \mathrm{Arg}(V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$

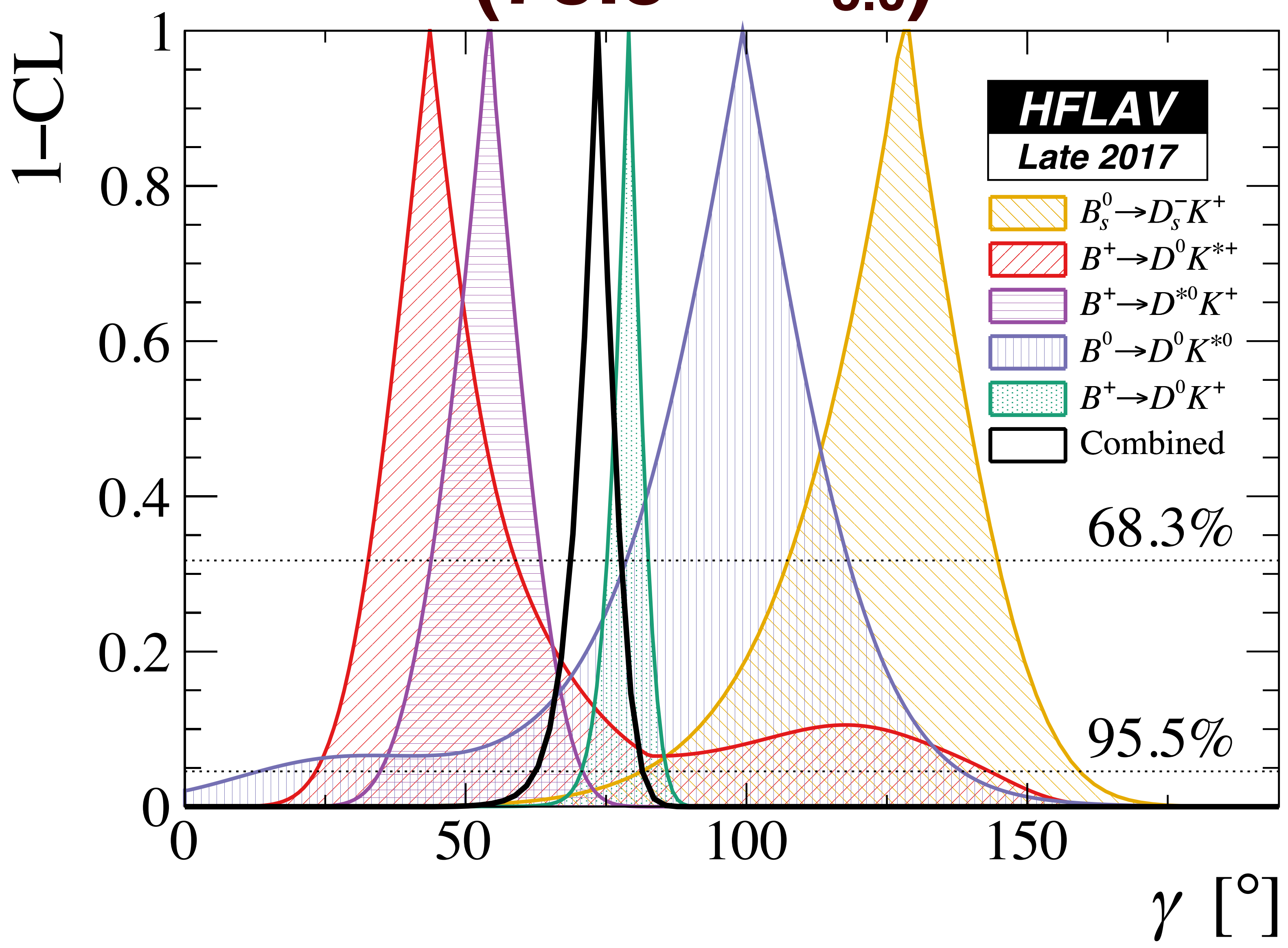




CKMFitter

$\gamma = 65.33\ ^{+0.96}_{-2.54}{}^{o}$

$(73.5\ ^{+4.3}_{-5.0})°$

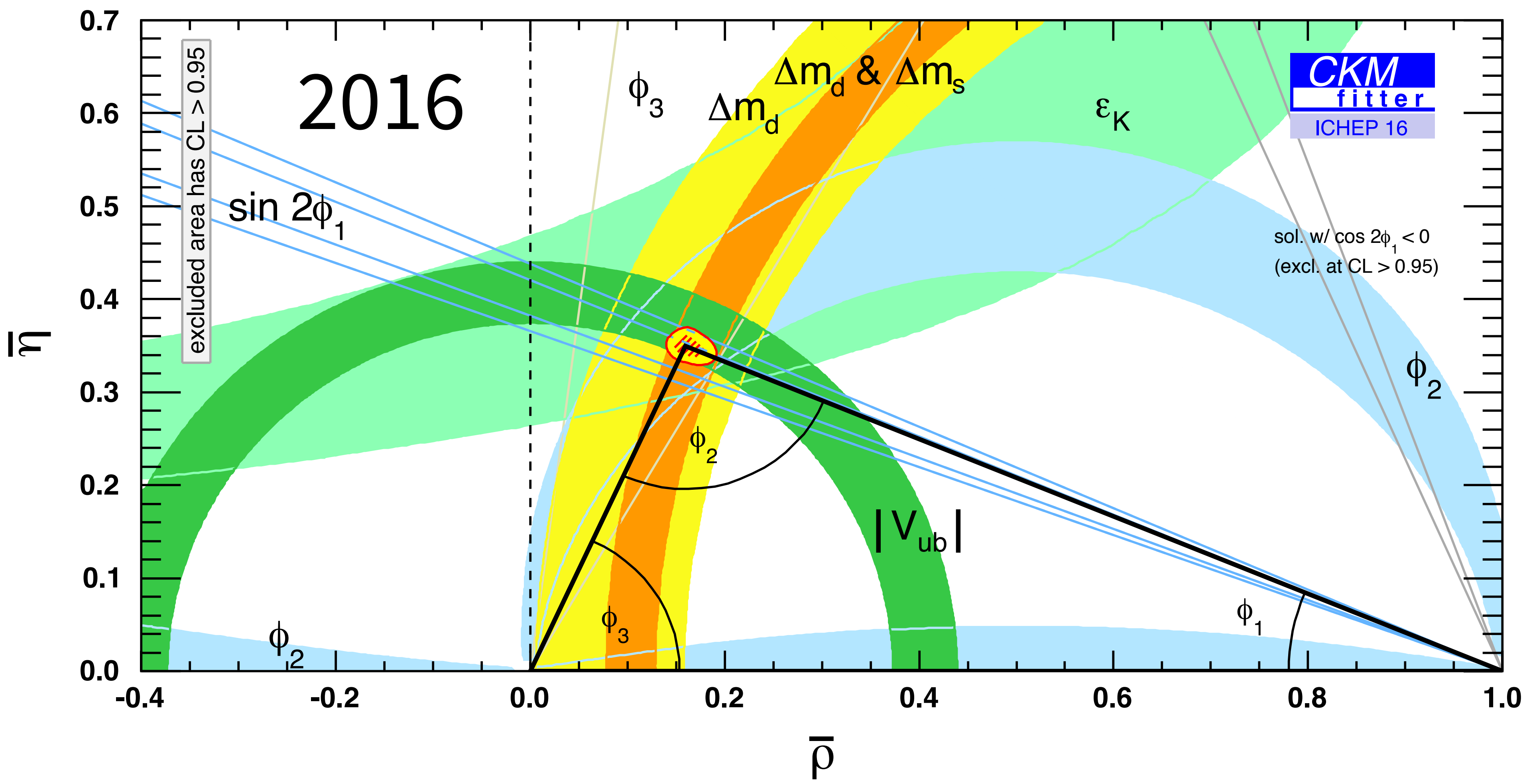


30% improvement since 2016

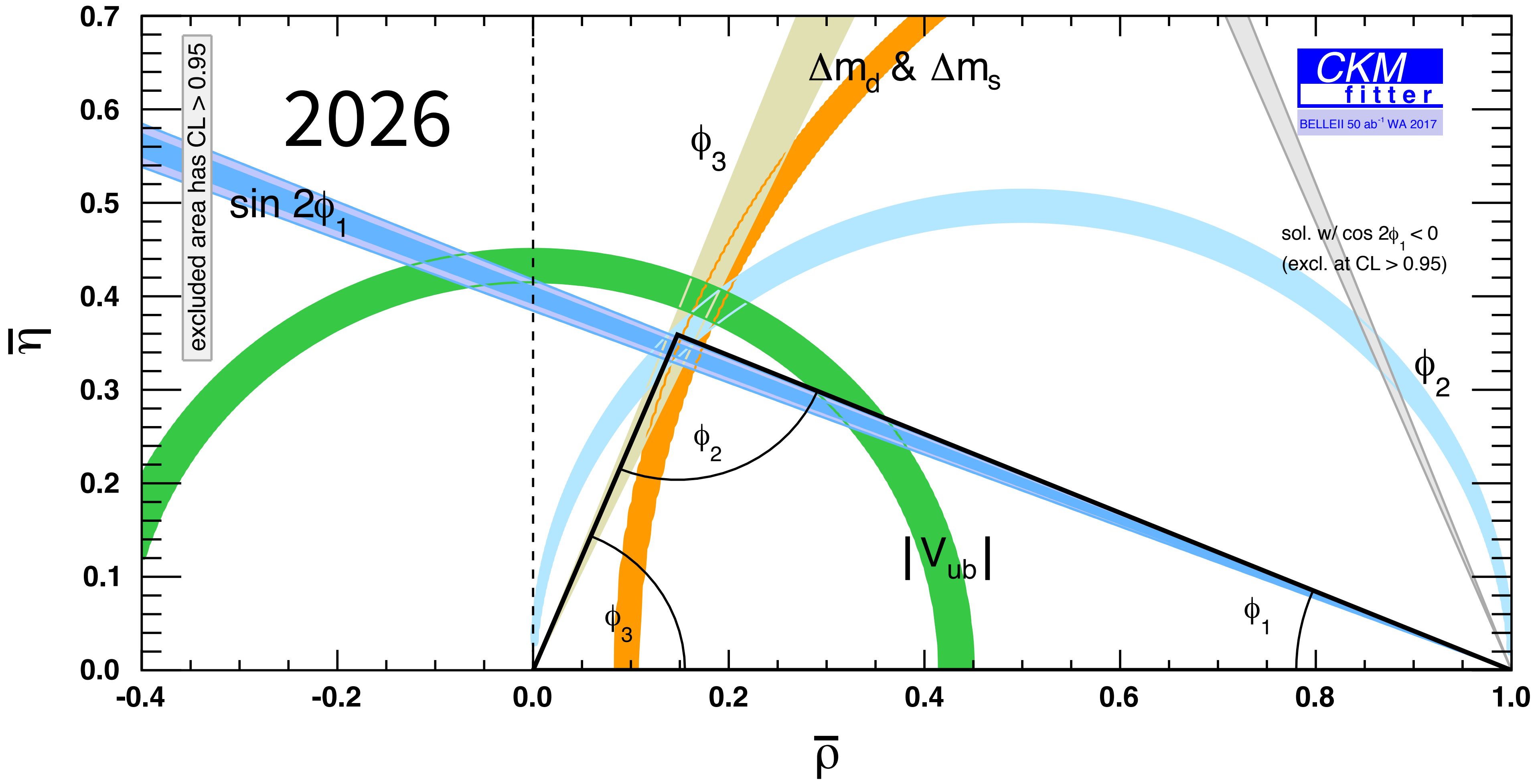
LHCb dominates WA precision < 5°

CKM Global Fit Projection: Belle II + LHCb upgrade

Belle II Physics Book



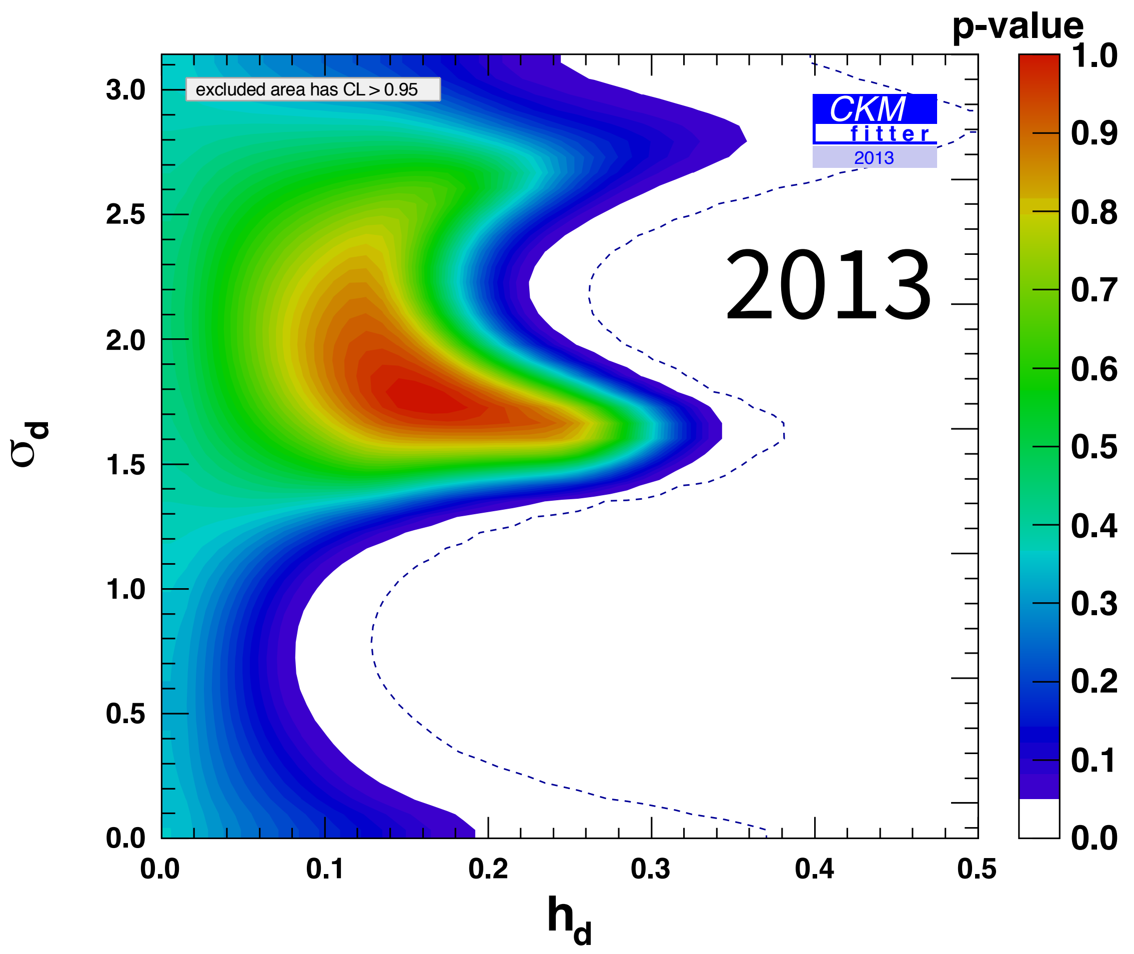
Φ3 ~ 1-1.5° at LHCb & Belle II

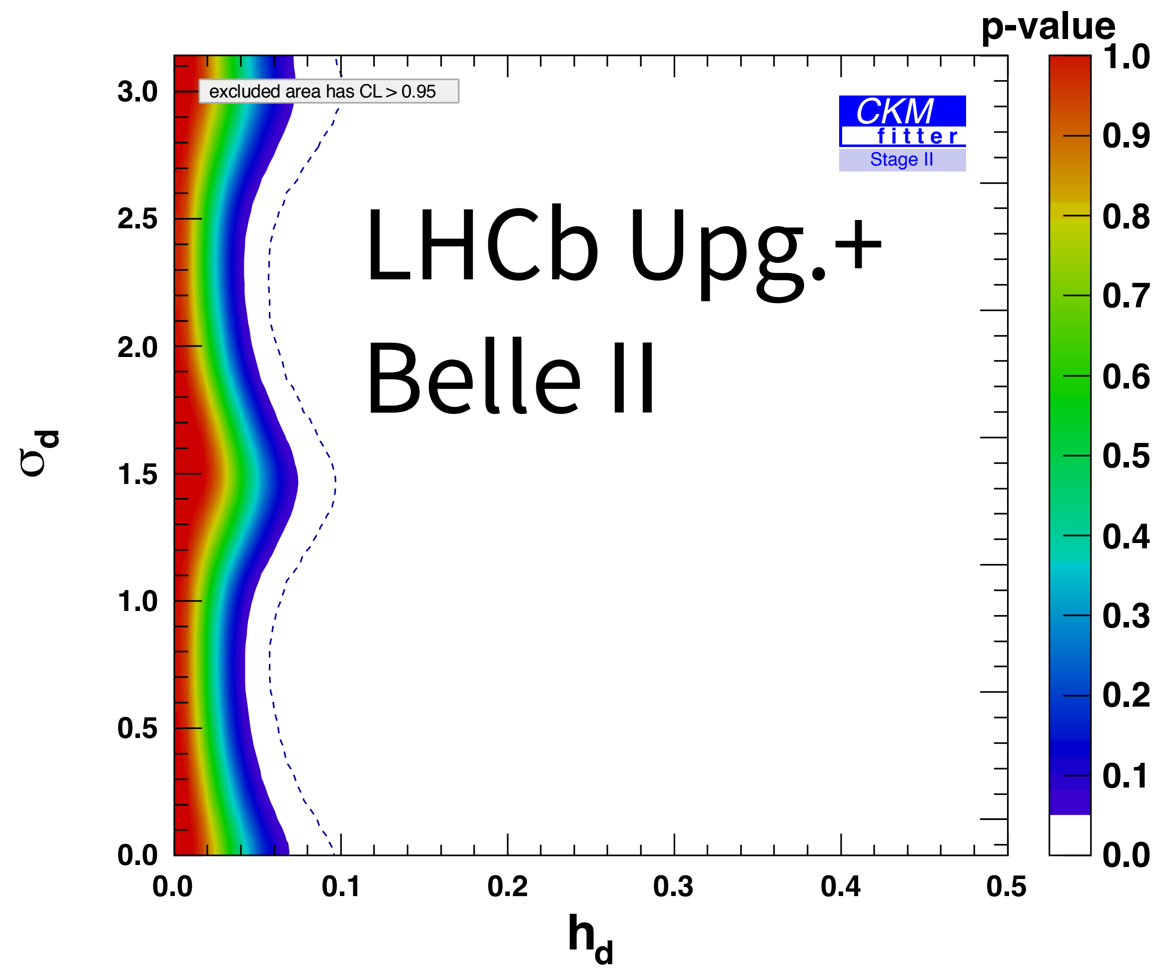


- New physics in mixing

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

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





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

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

By ~2026,

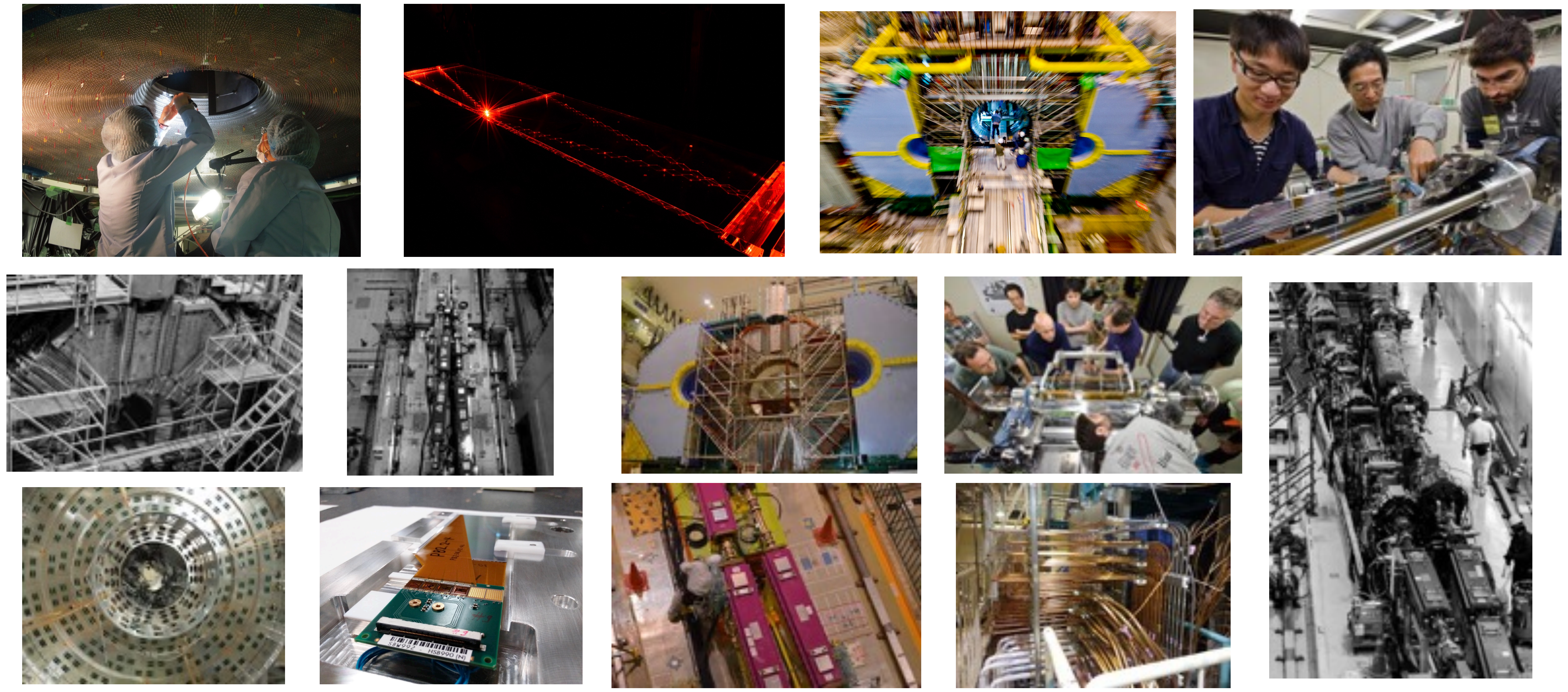
- Λ ~ 20 TeV (tree)
- Λ ~ 2 TeV (loop)

Summary

- Anomalous behaviour in semileptonic B decays observed by multiple experiments - **violations of lepton flavour universality**
- **We have to be cautious: e are difficult to reconstruct at LHC, τ are easily mimicked in all experiments.**
- LHCb and Belle II are focusing on improved LFUV tests
  - More **LHCb Run-2** results due soon
  - **SuperKEKB / Belle II will commence collisions in April 2018**

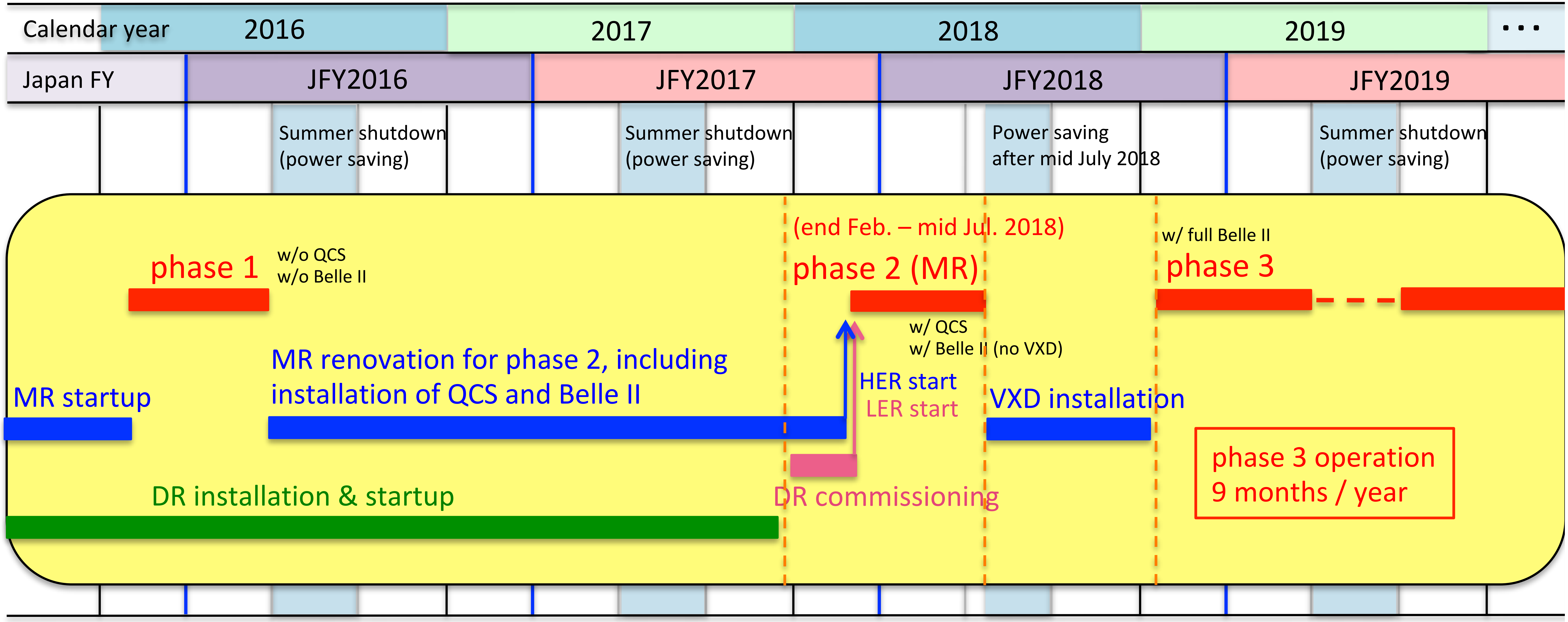
Belle II news broadcasts

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



Backup

Construction timeline



Calendar year 2016 2017 2018 2019 …

Japan FY JFY2016 JFY2017 JFY2018 JFY2019

Summer shutdown (power saving)

Summer shutdown (power saving)

Power saving after mid July 2018

Summer shutdown (power saving)

phase 1

w/o QCS
w/o Belle II

(end Feb. – mid Jul. 2018)

phase 2 (MR)

w/ QCS
w/ Belle II (no VXD)

w/ full Belle II

phase 3

MR startup

MR renovation for phase 2, including installation of QCS and Belle II

HER start
LER start

VXD installation

phase 3 operation
9 months / year

DR installation & startup

DR commissioning

- Phase 2 Verification of nano-beam scheme. Target L> 10^{34} cm^{-2}s^{-1} Understand beam background