The *Belle II* **physics program** in light of ***LHCb***

or

‘Why you should be excited about ***Belle II***’

Belle II

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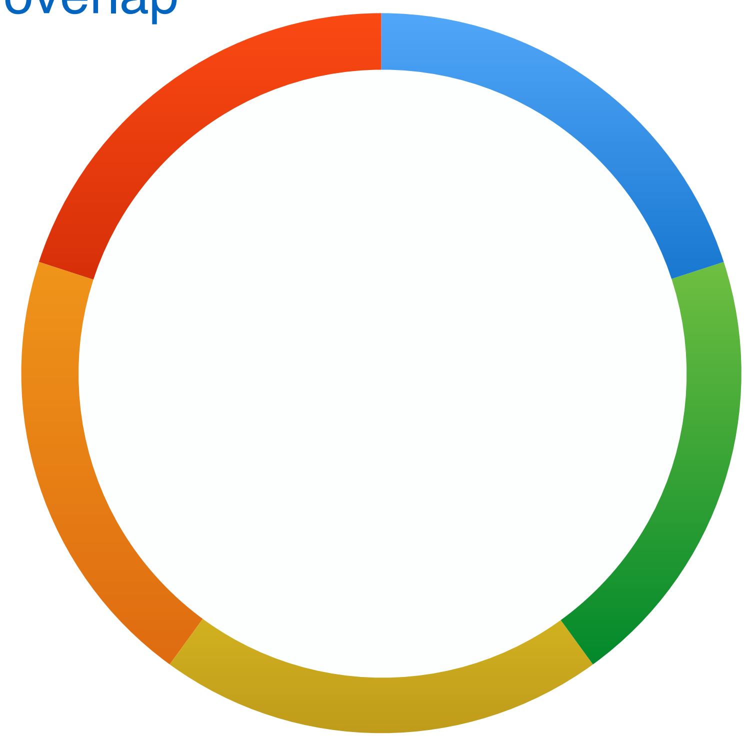
Talk Overview



Belle II & LHCb
On complementarity and overlap

B-Factory results
a rich harvest

The open questions
an attempt of an overview

Belle II Detector
concept and current status

Belle II Physics
from CPV to dark photons

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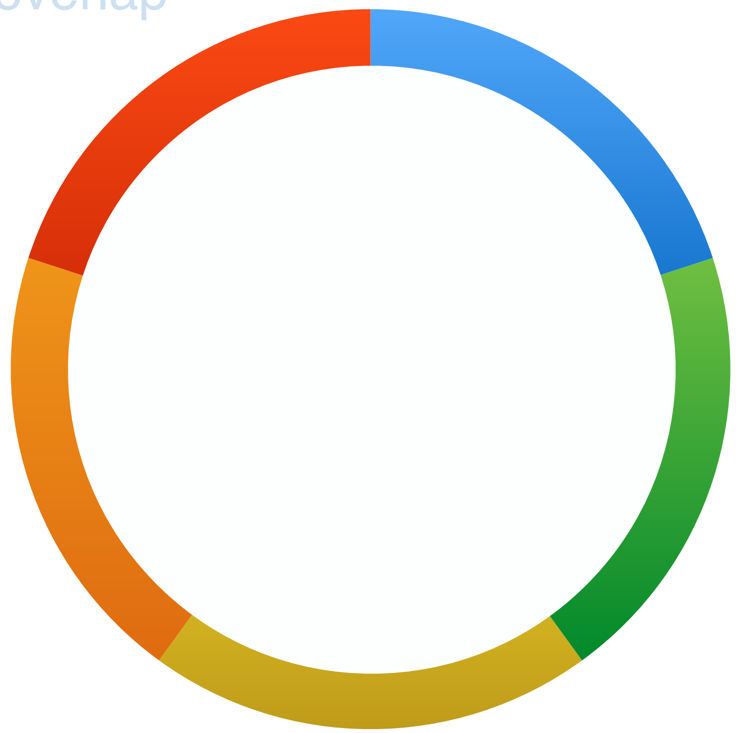

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Three Decades of *B*-Factory results: *a rich harvest*

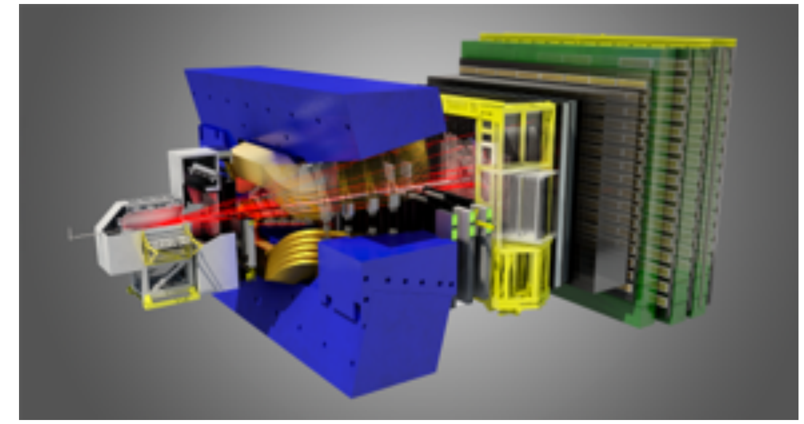
Goals of (heavy) flavour physics:

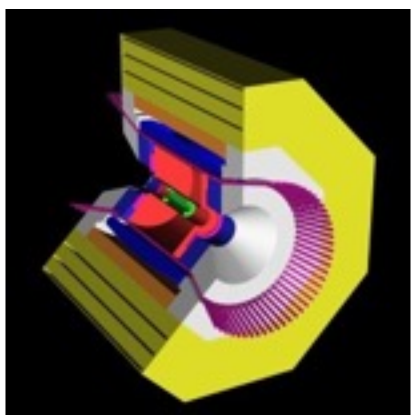
- Study the flavour mixing and *Charge-Parity violation* (*CP*) in all its aspects
- Look for new physics far beyond the current energy frontier in rare and forbidden processes
- By these measurements we hope to get insight into the mystery of the observed flavour structure

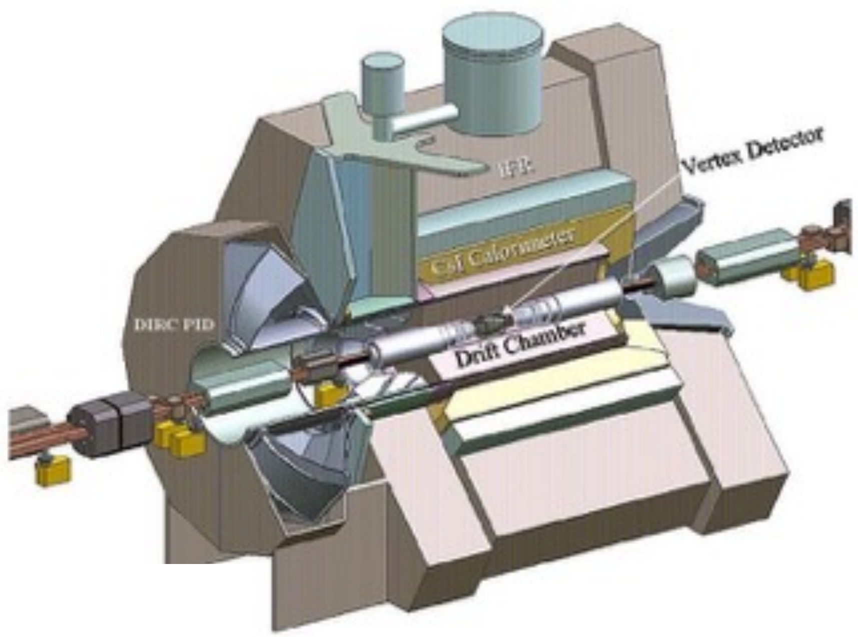
Large contributions from *B*-Factory experiments:

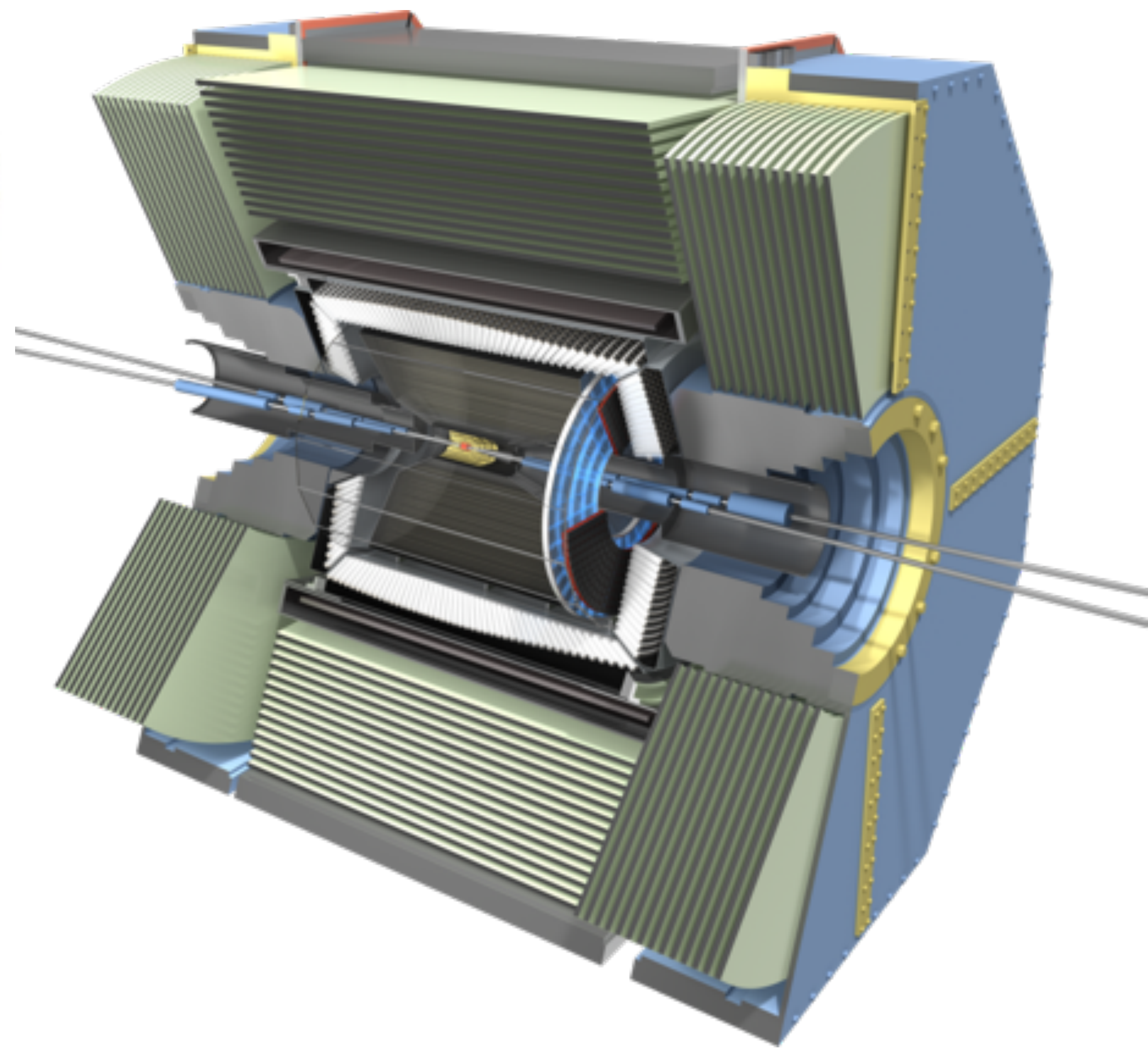
- Symmetric e^+e^- and hadronic experiments set the path
- Flavour physics at the luminosity frontier shaped to large degree by BaBar and Belle experiments; most recently huge contributions from LHCb
- Origin of *CP* in the SM was topic of Noble prize in 2008
  - Laudatio explicitly mentions BaBar and Belle's contributions

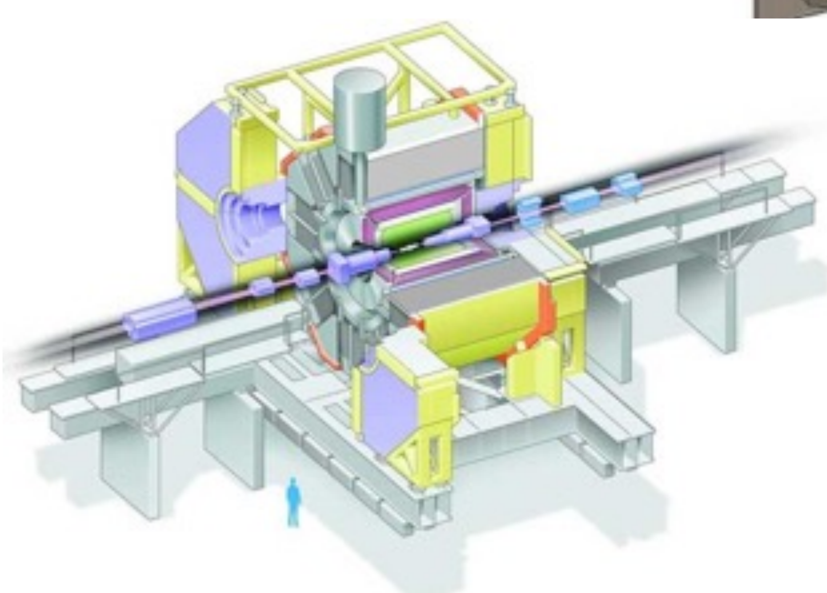
B-Factory Family Album







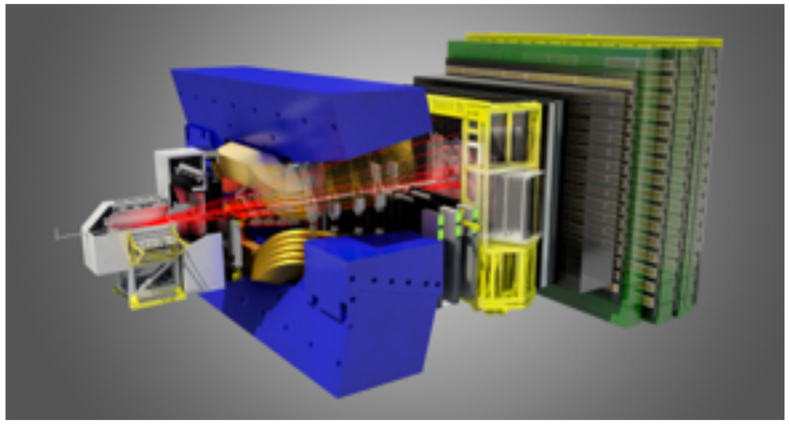




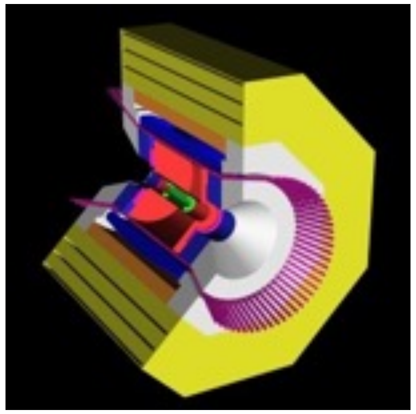
B-Factory Family Album

ARGUS

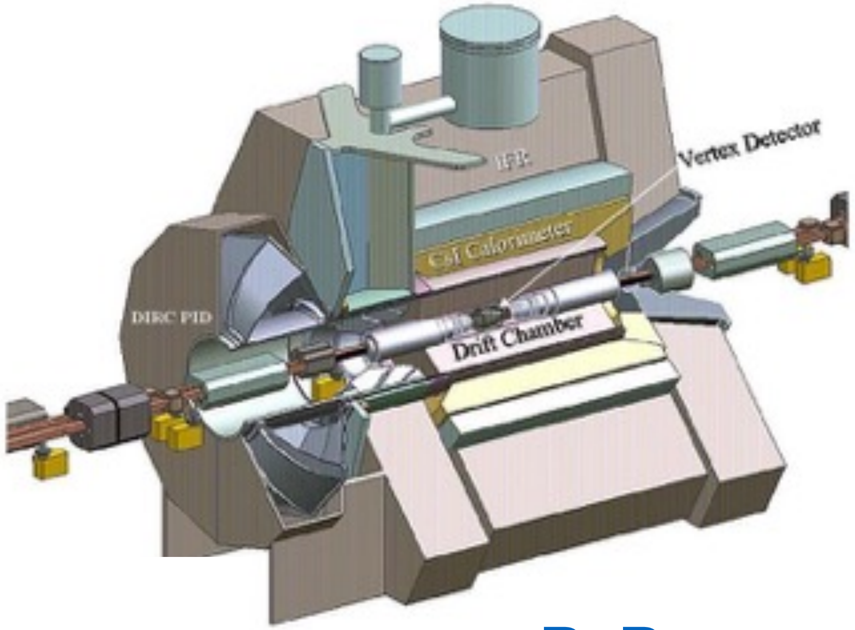
HERA-B



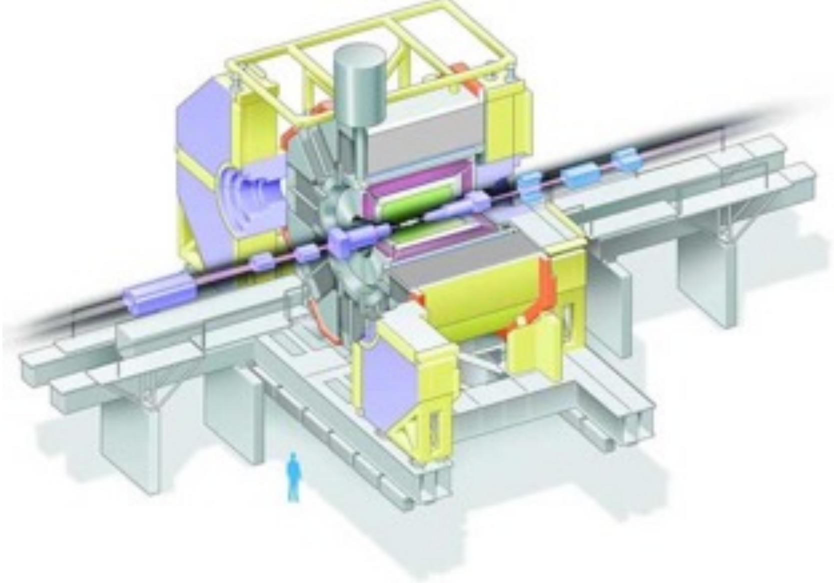
LHCb



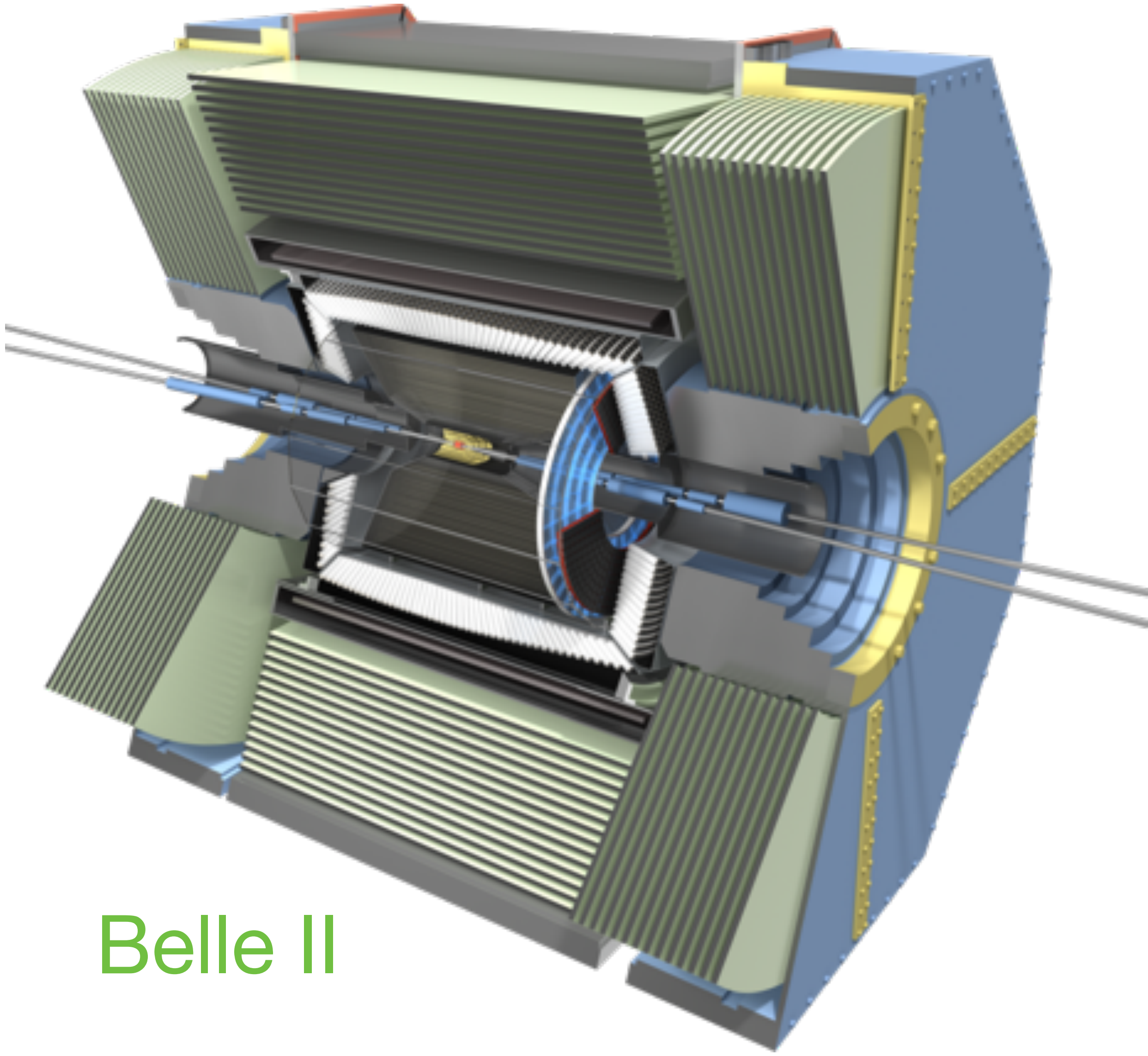
CLEO



BaBar

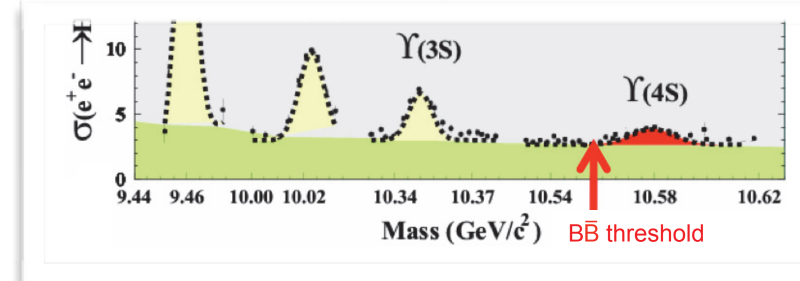


Belle



Belle II

B-Factory Family Album

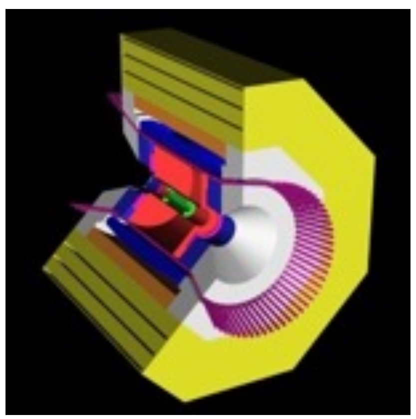


Collision cross section to hadrons in nb

$$e^+ \longrightarrow \Upsilon(4S) \longleftarrow e^-$$

$$\langle b\bar{b} \rangle \quad \sqrt{s} = 10.58\,\mathrm{GeV}$$

ARGUS



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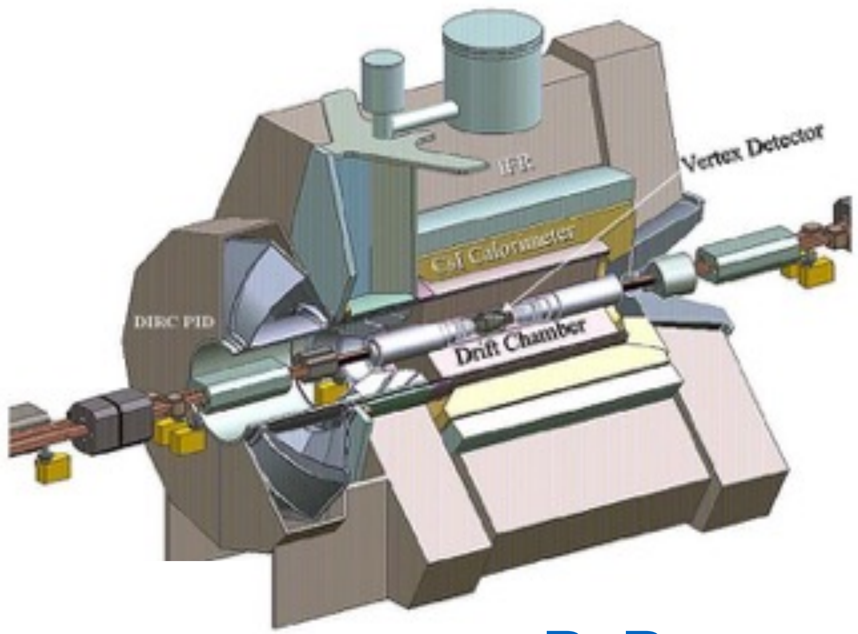
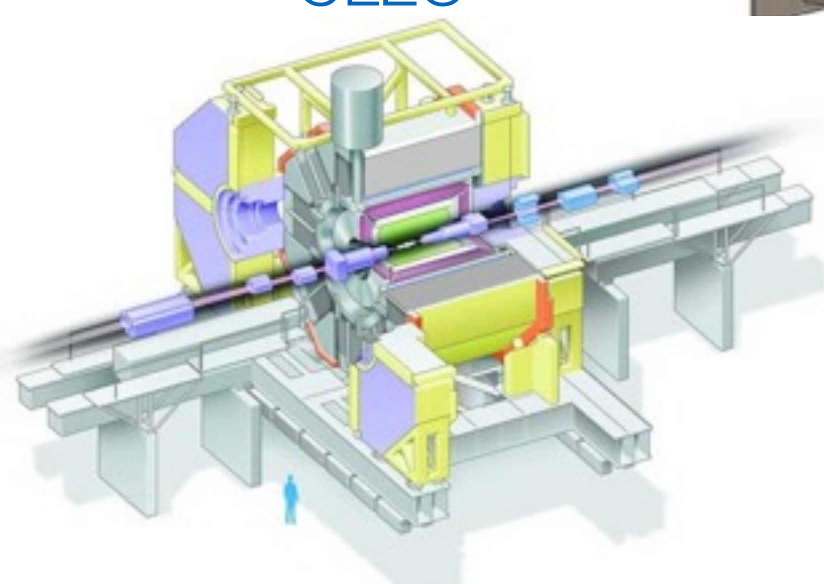
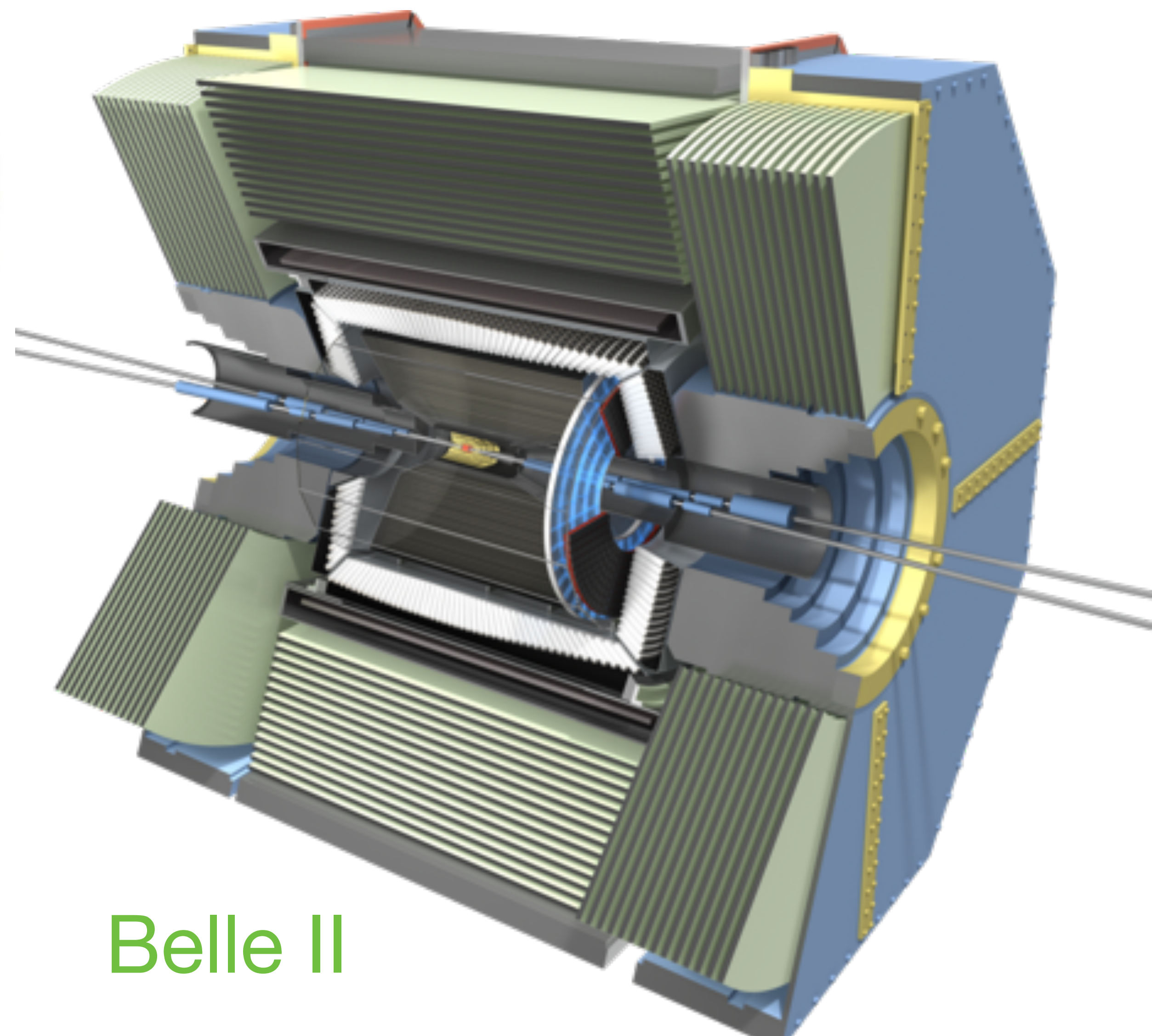


BaBar



Belle

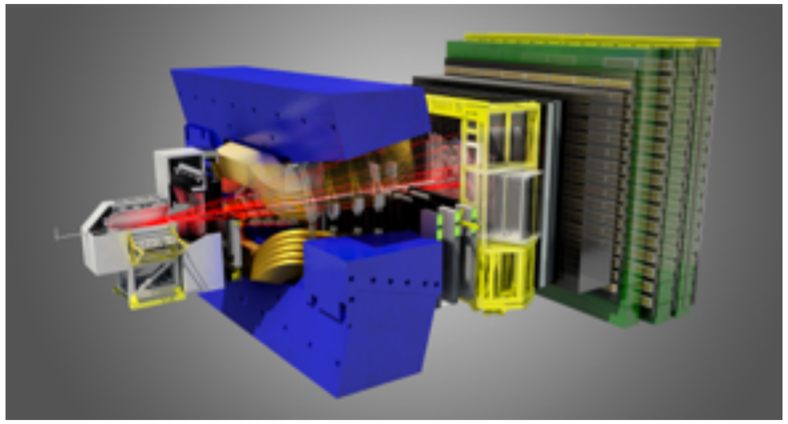


Belle II

B-Factory Family Album

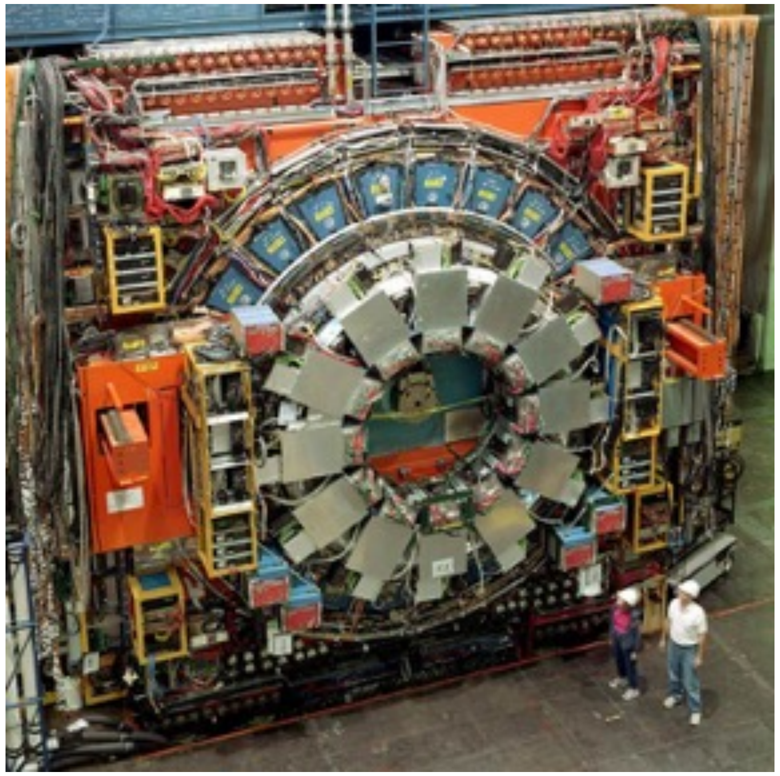
HERA-B

proton-atom collisions



LHCb

proton-proton collisions



CDF

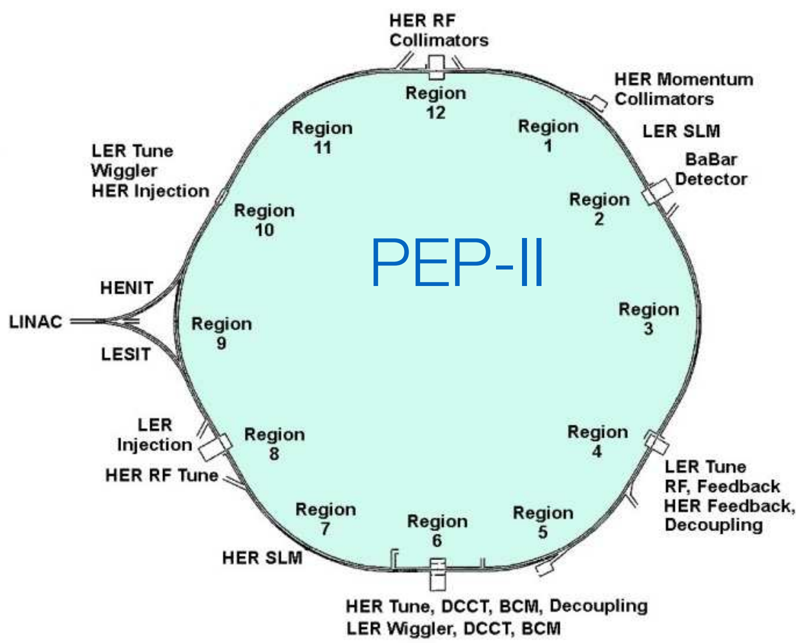
D0

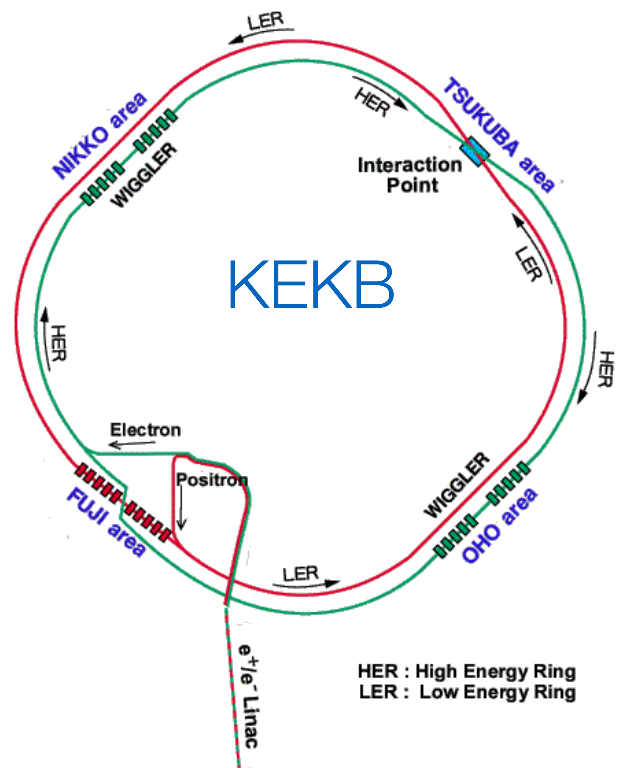
Note:

- Also proton-antiproton collision experiments and results from ATLAS & CMS

Asymmetric B-Factories: BaBar and Belle

Asymmetric B-Factories allowed to directly observe *CP* in the B-meson system through the time evolution of B-meson decays:





$$\sqrt{s} = 10.58\,\mathrm{GeV}$$

$$e^+ \longrightarrow \Upsilon(4S) \longleftarrow e^-$$

$\langle b\bar{b}\rangle$

$$\Upsilon(4S) \to B^0\ \overline{B}^0$$

$\langle b\bar{b}\rangle \longrightarrow \langle \bar{b}d\rangle\ \langle b\bar{d}\rangle$

$$\Delta z \approx c\,\beta\,\gamma\,\tau_B \approx 200\,\mu\mathrm{m}$$

B-meson lifetime

BaBar	$E(e^-) = 9\,\mathrm{GeV}$	$E(e^+) = 3.1\,\mathrm{GeV}$	$\beta\gamma = 0.56$
Belle	$E(e^-) = 8\,\mathrm{GeV}$	$E(e^+) = 3.5\,\mathrm{GeV}$	$\beta\gamma = 0.42$

The CKM Picture of the Standard Model

The CKM Matrix source of *C*harge*P*arity*V*iolation in SM

- Unitary 3x3 Matrix, parametrizes rotation between mass and weak interaction eigenstates in Standard Model

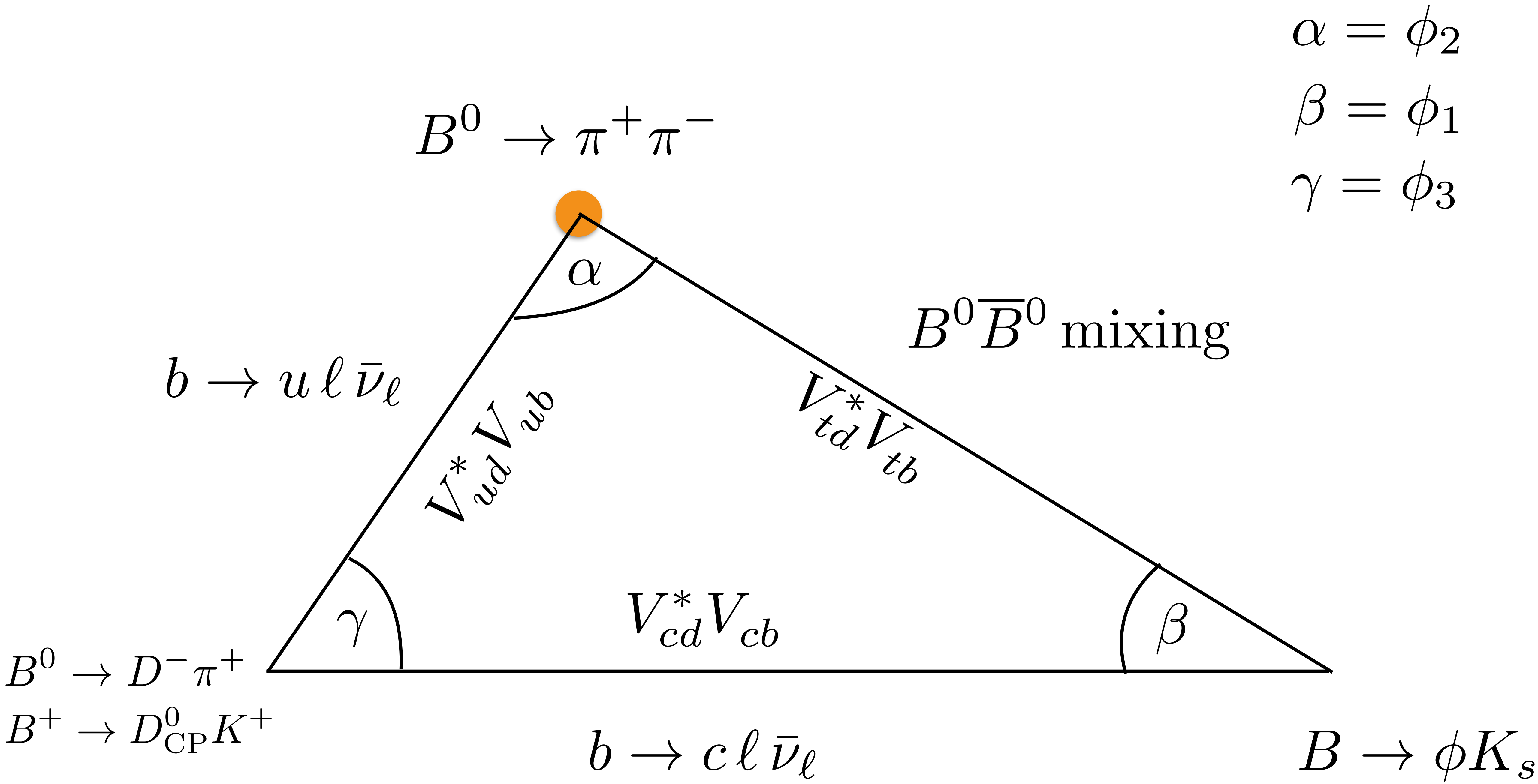
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Weak Eigenstates CKM Matrix Mass Eigenstates

- Fully parametrized by **four** parameters if unitarity holds: three real parameters and one complex phase that if non-zero results in *CPV*
- Can be visualized using triangle equations, e.g.

$$V_{CKM} V_{CKM}^{\dagger} = \mathbf{1} \quad \rightarrow \quad V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$

Over-constraining the CKM matrix allows for non-trivial test of the SM

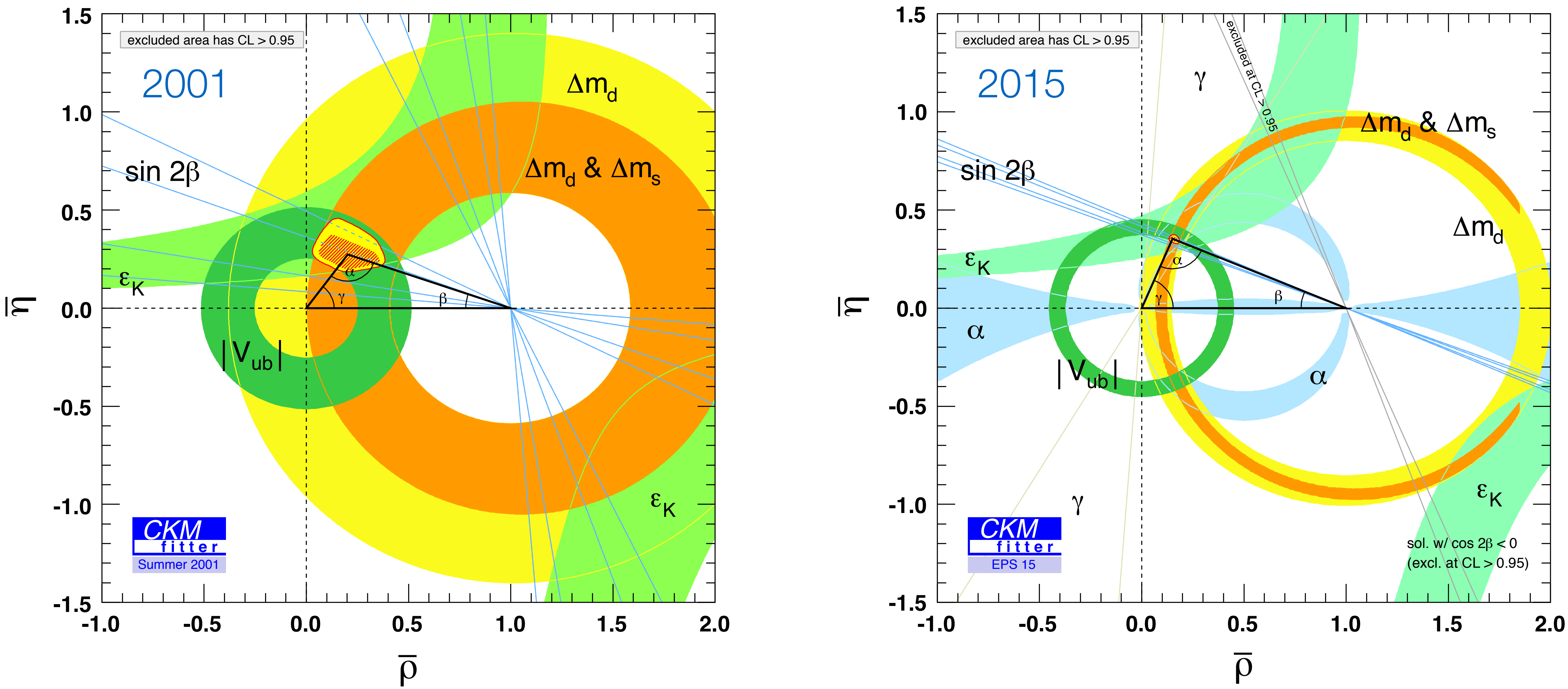


Presence of *CPV* phase encoded in apex of triangle in the complex plane

CKM Picture over the years: *from discovery to precision*

Existence of *CPV* phase established in 2001 by BaBar & Belle

- Picture still holds 15 years later, constrained with remarkable precision
- But: still leaves room for new physics contributions



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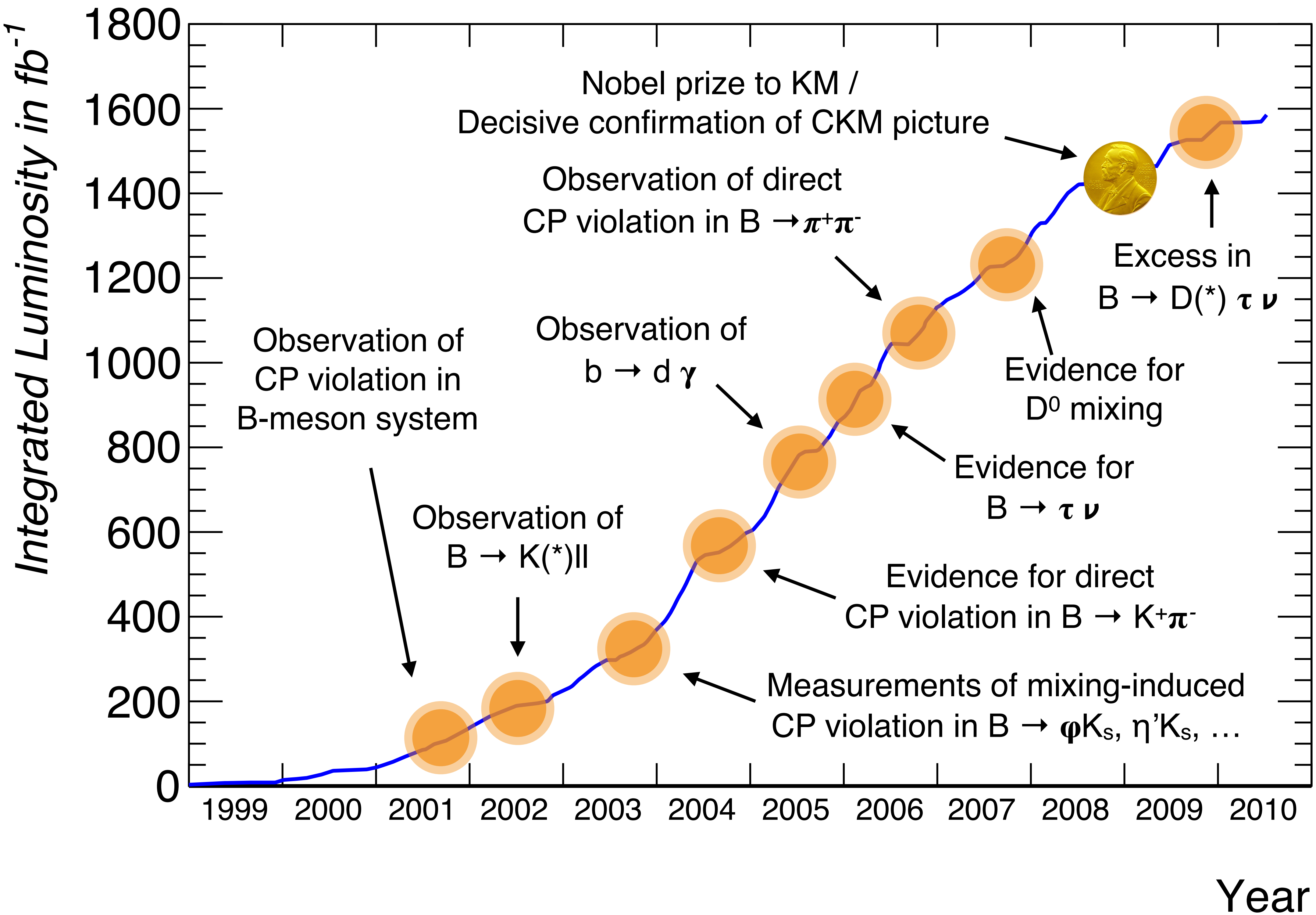
Recap of the last decade of BaBar & Belle: *a rich harvest*



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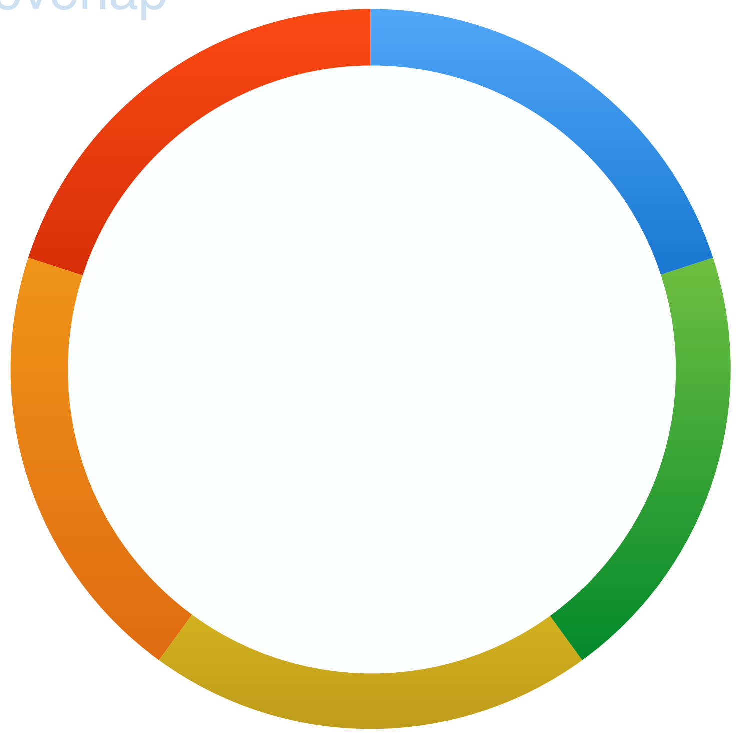

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The open questions
a review of anomalies

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The open questions: *New physics and anomalies*

Can roughly be grouped into two categories:

- Fundamental questions that the SM in current form does not provide, e.g.
  - Where is Dark Matter?
  - What causes the large CPV in the Universe?
  - How awesome are gravitational waves?
- Existing anomalies in the Flavour sector, e.g.
  - Inclusive and exclusive $|V_{qb}|$ disagreement
  - Enhancements in semi-tauonic decays
  - Deviations in penguin decays
  - Very rare B_s and B decays — not an anomaly!

Flavour and energy frontier experiments are *complementary* probes:

Evidence for BSM?		FLAVOR: yes	FLAVOR: no
ATLAS & CMS	yes	complementary information	distinguish models
ATLAS & CMS	no	tells us where to look next	flavor is the best microscope

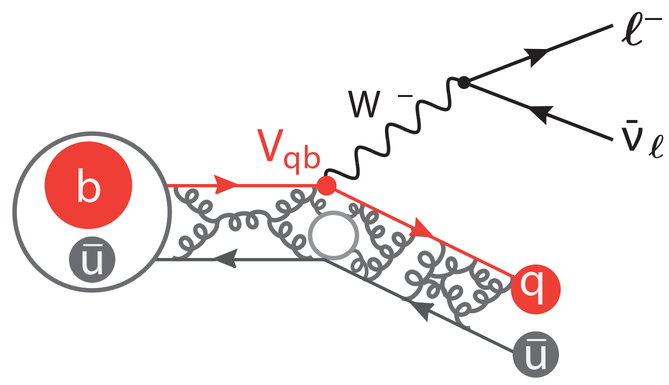
Zoltan Ligeti

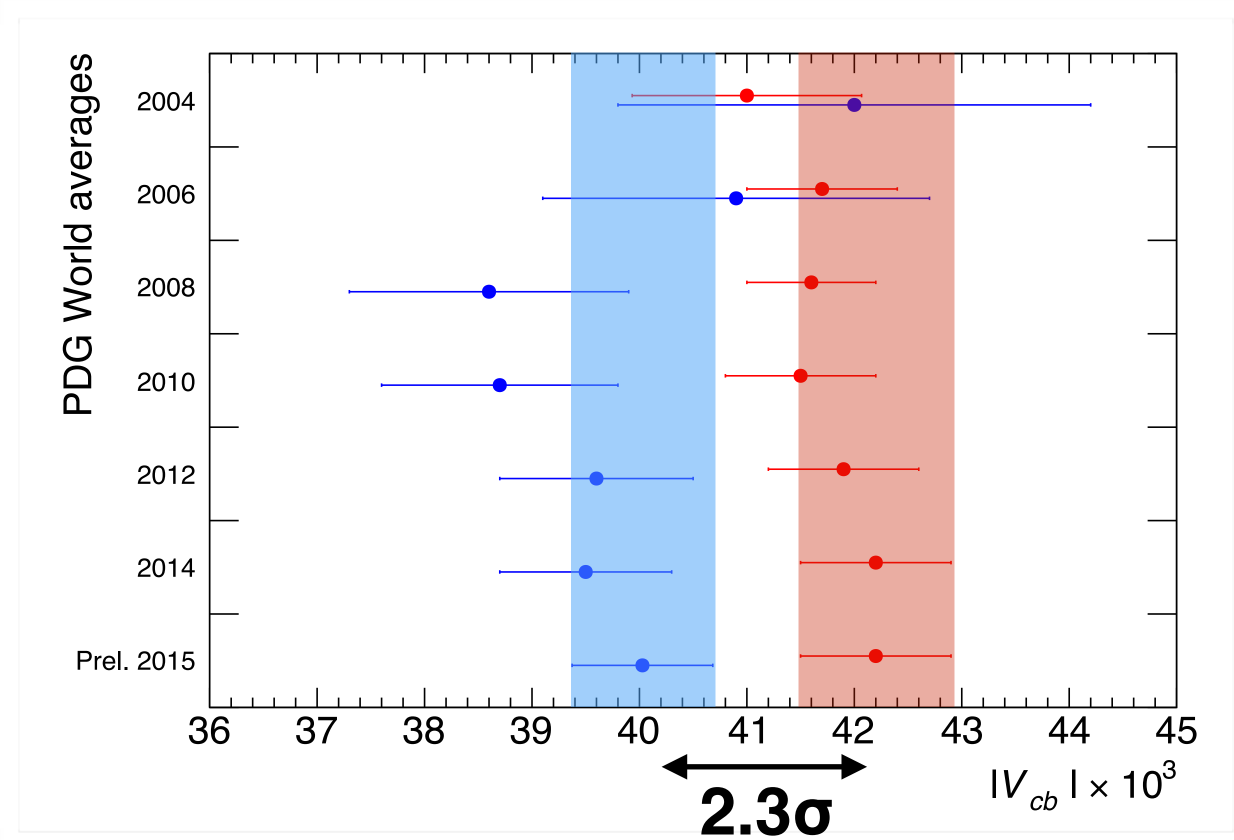
Flavour Anomalies: *$|V_{ub}|$ & $|V_{cb}|$*

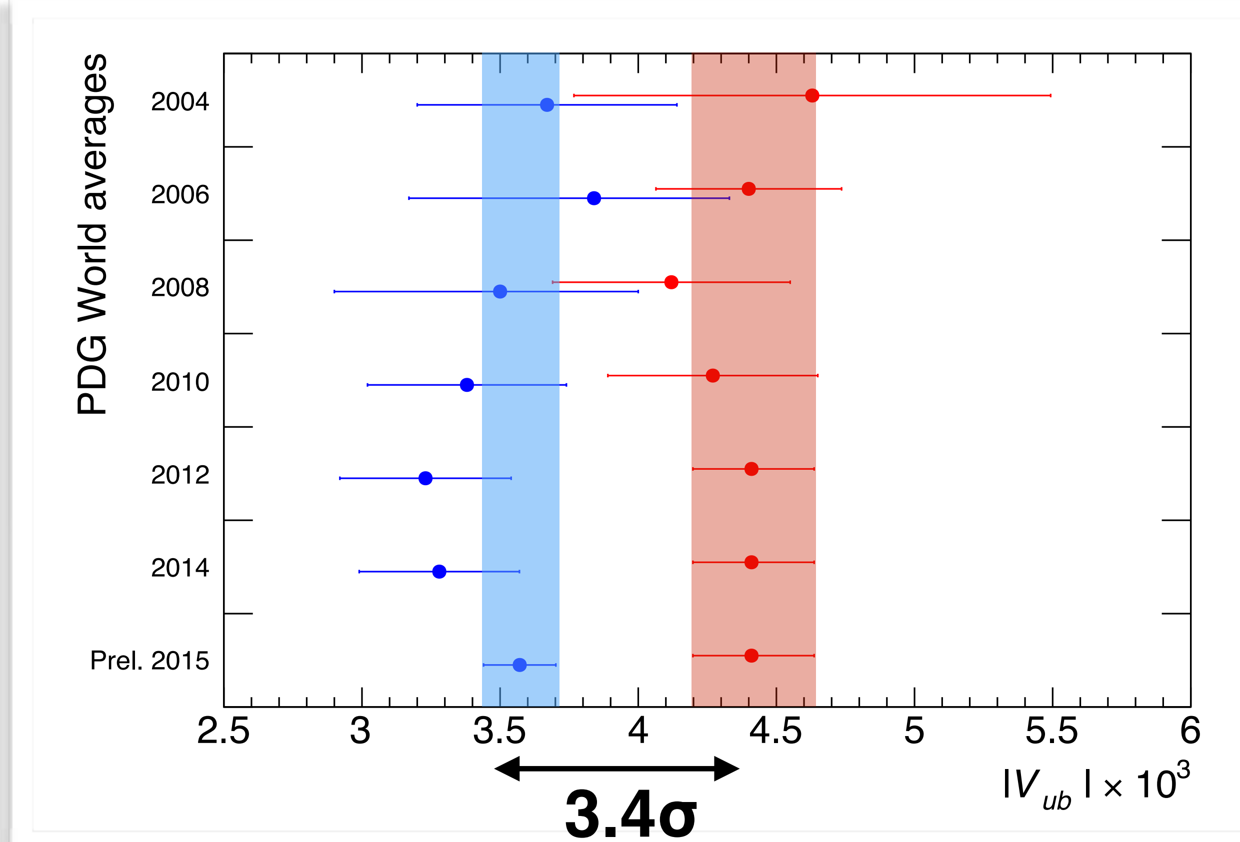
$$|V_{qb}| = \sqrt{\frac{\mathcal{B}(B \to X_q\,\ell\,\bar{\nu}_\ell)}{\Gamma(B \to X_q\,\ell\,\bar{\nu}_\ell)\,\tau_B}}$$

Sizeable tension in *exclusive* and *inclusive* $|V_{ub}|$ & $|V_{cb}|$

- Both methods considered theoretical and experimental mature
- Individual determinations leave a consistent picture







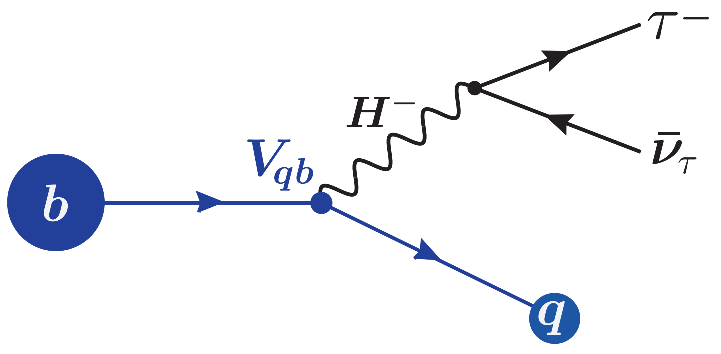
- About **2.3σ** and **3.4σ** disagreement between incl. and excl. for $|V_{cb}|$ & $|V_{ub}|$, respectively

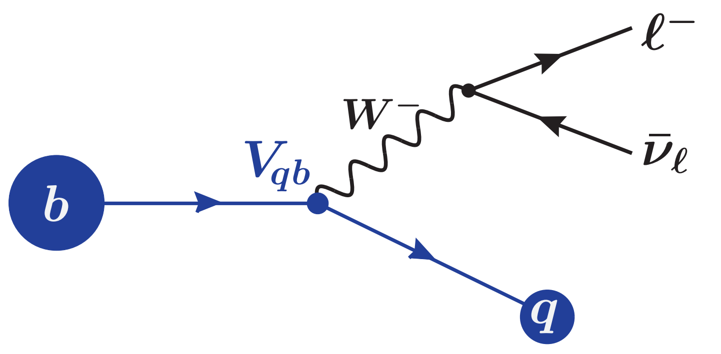
Flavour Anomalies: *R(D) & R(D*)*

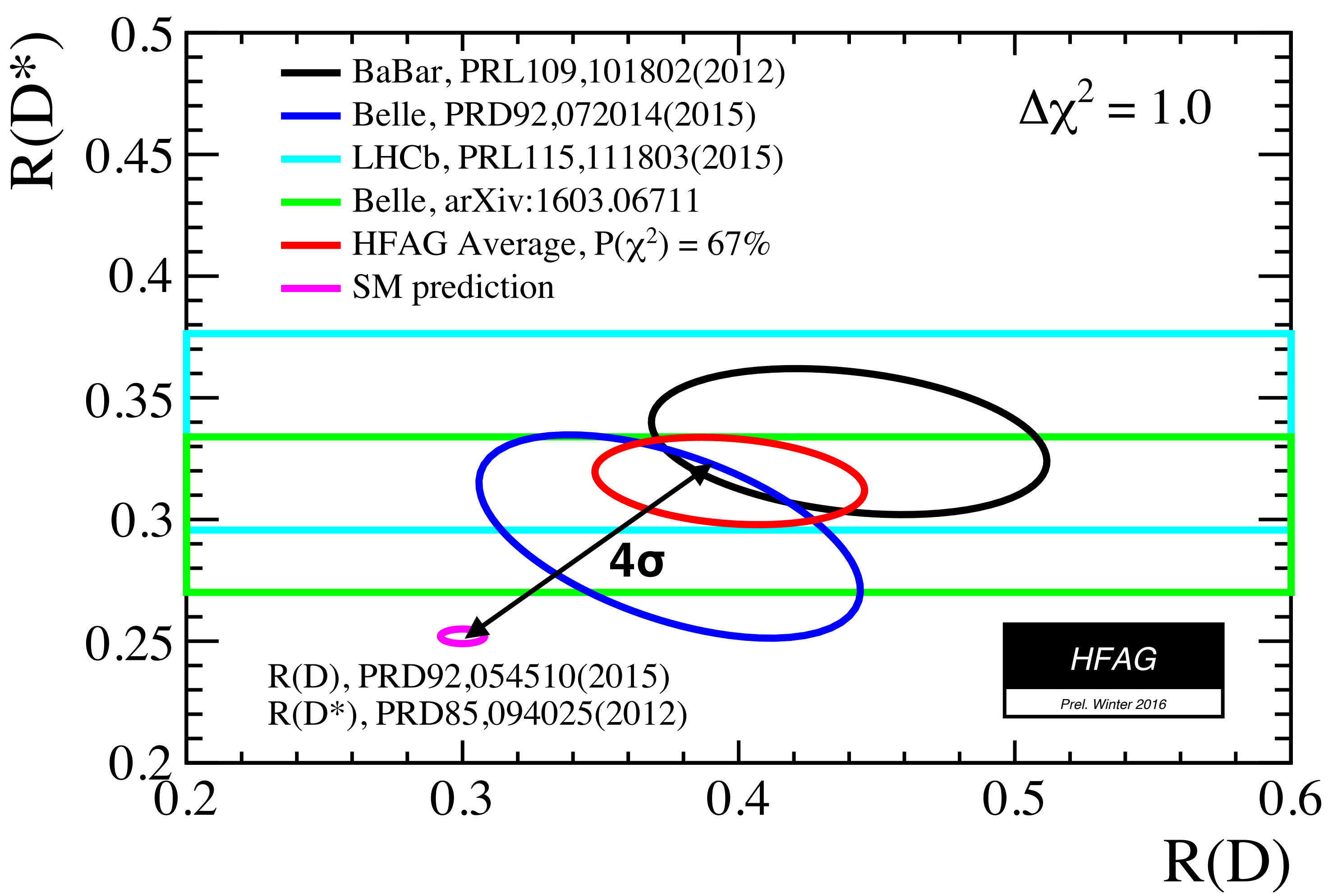
$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\,\tau\,\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\,\ell\,\bar{\nu}_\ell)}$$

Another anomaly in the flavour sector is between that ratio of semitauonic and light lepton branching fractions

- Sensitive to for instance to contributions from a charged Higgs Boson
- In the prediction of this ratio, many of the theory uncertainties cancel
- Excess seen by BaBar, Belle and also LHCb







- About **4σ** disagreement between SM expectation and observation
- Deviations not compatible with type II 2HDM, could be accommodated by type III like scenarios

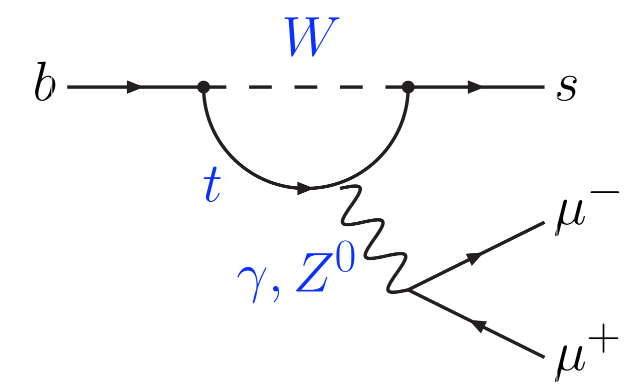
Flavour Anomalies: $b \to s\mu\mu$

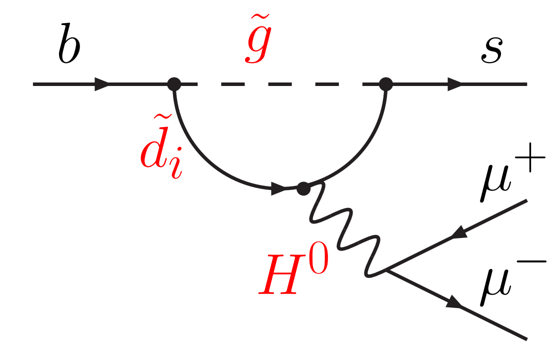
$$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

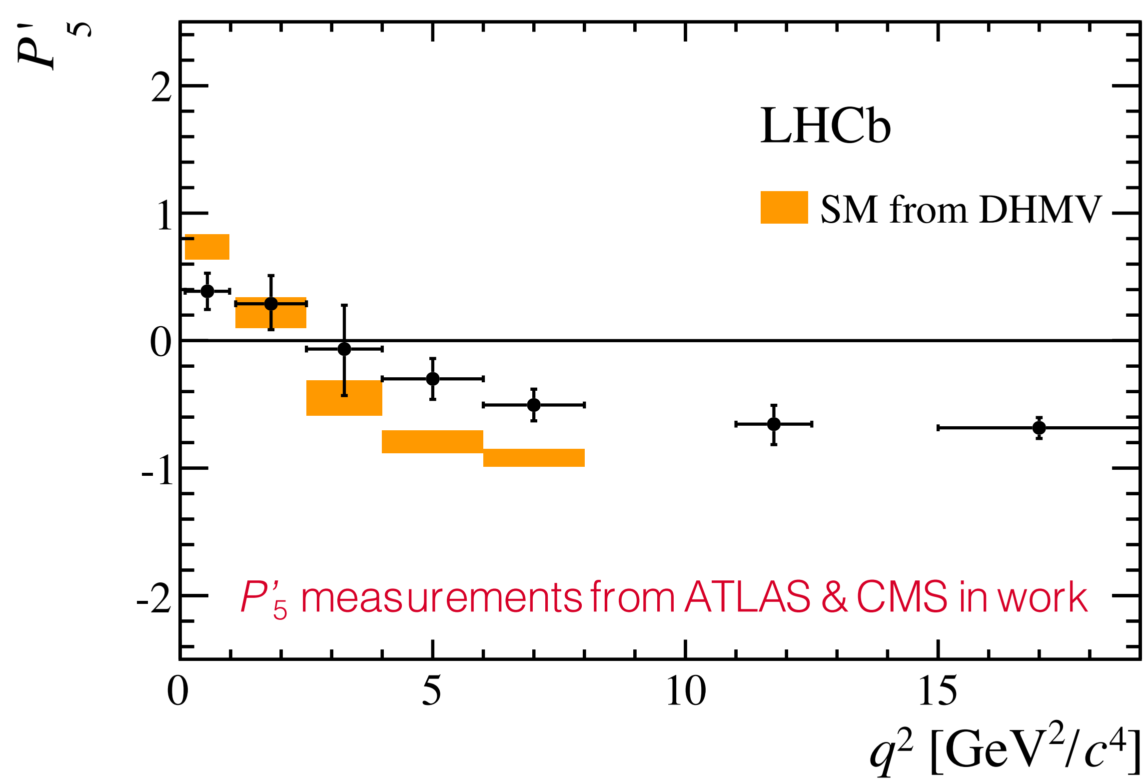
Penguin decays are very sensitive to new physics contributions

In $b \to s\mu\mu$ new physics can enter via new mediators and alter the total rate, but also the angular correlations

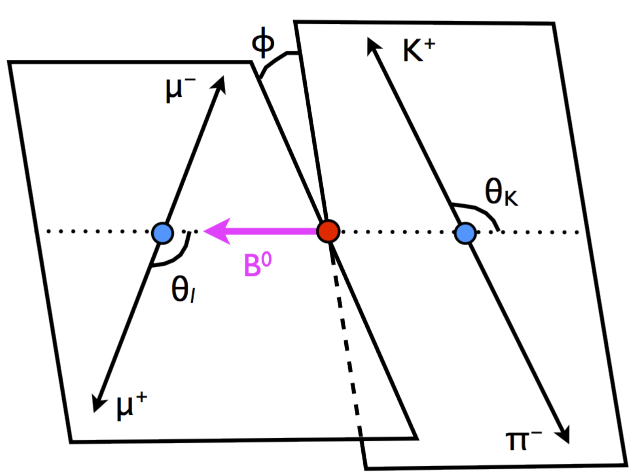
- P_5' is one particular observable depending on the helicity angle and the tilting angle of the decay planes, normalized by the fraction of longitudinal polarized K* mesons
- P_5' can be predicted reliably as many form factor uncertainties cancel







$$B \to K^* \mu\,\mu$$



$$q^2 = (p_B - p_{K^*})^2 = (p_\mu + p'_\mu)^2 = m^2_{\mu\mu}$$

- Deviation from SM of the order **3.4σ**

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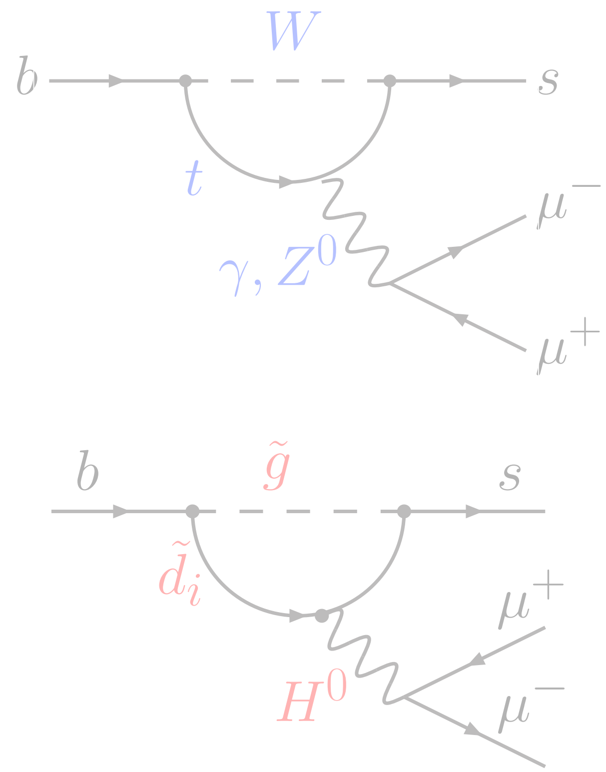
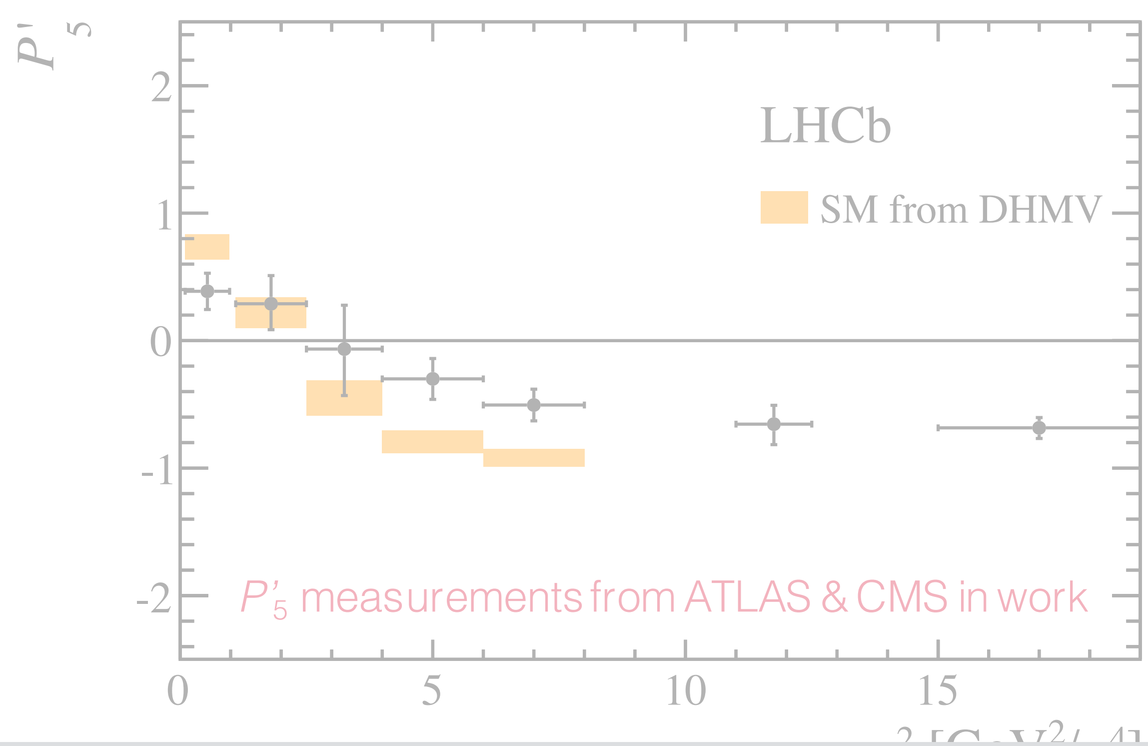
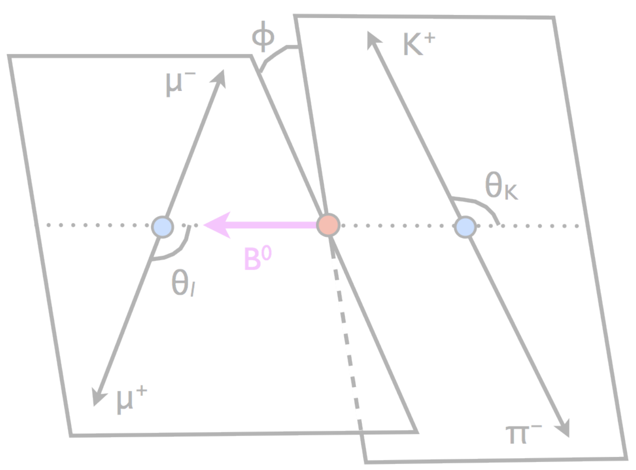




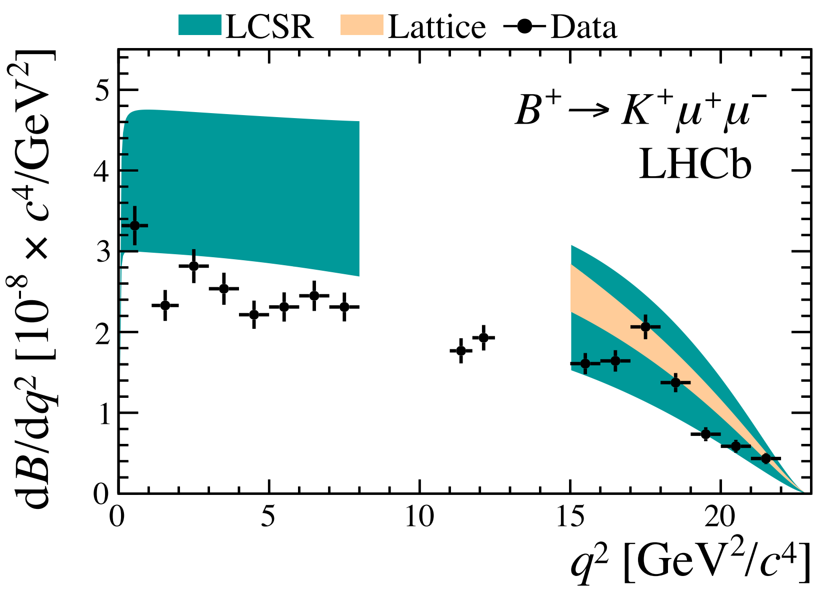
$B \to K^* \mu\mu$

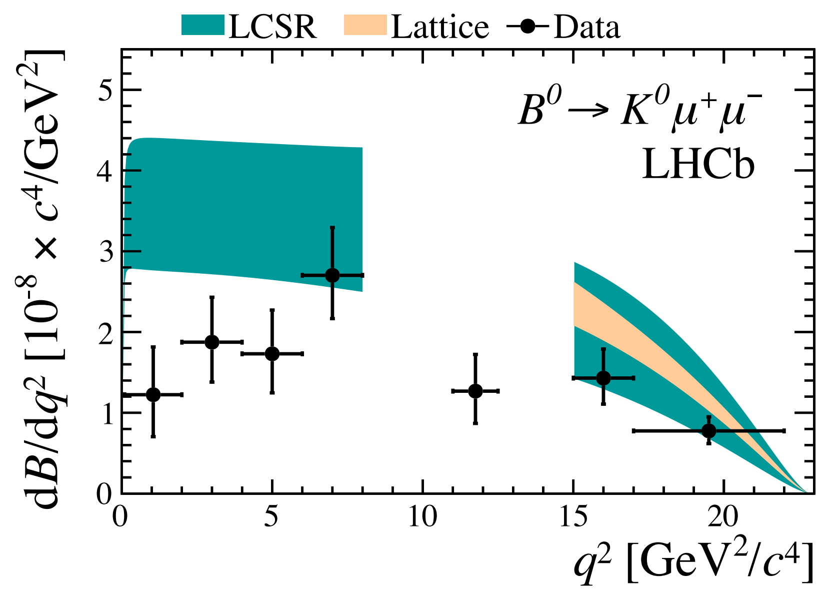


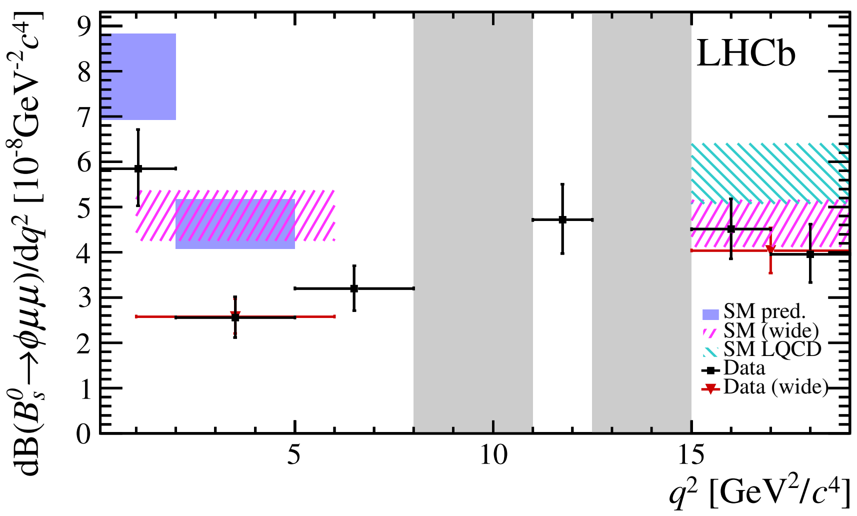
Stay tuned for **Simon Wehle's** talk tonight to see the Belle result

Flavour Anomalies: $b \to s\mu\mu$

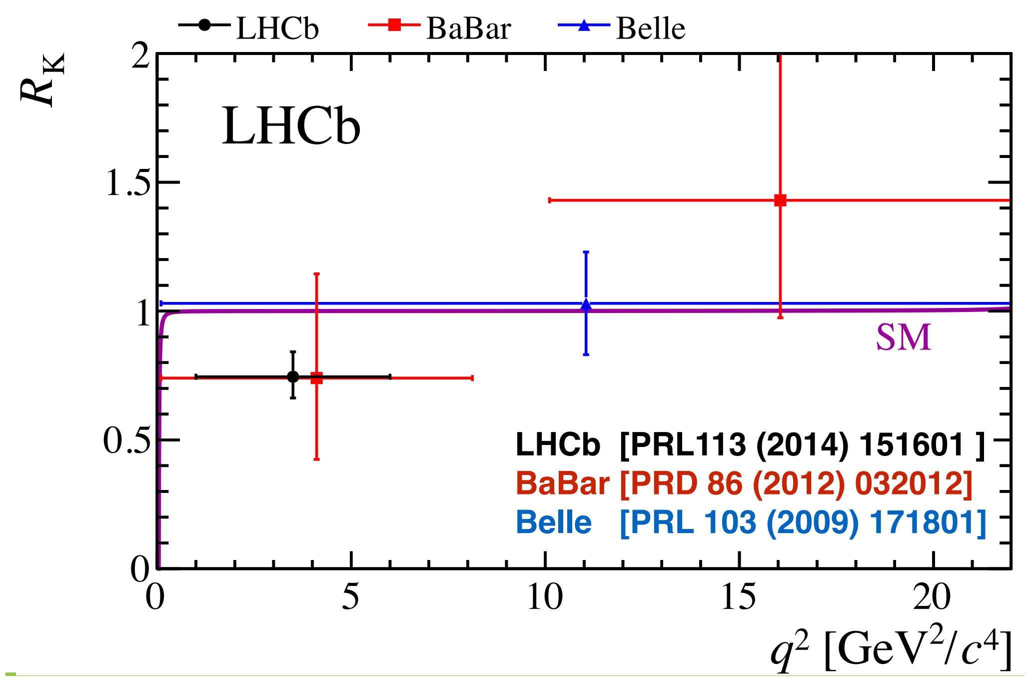
- Similar deviations should be visible in other $b \to s\mu\mu$ transitions







- Interesting deviation in ratio of muon and electron modes:

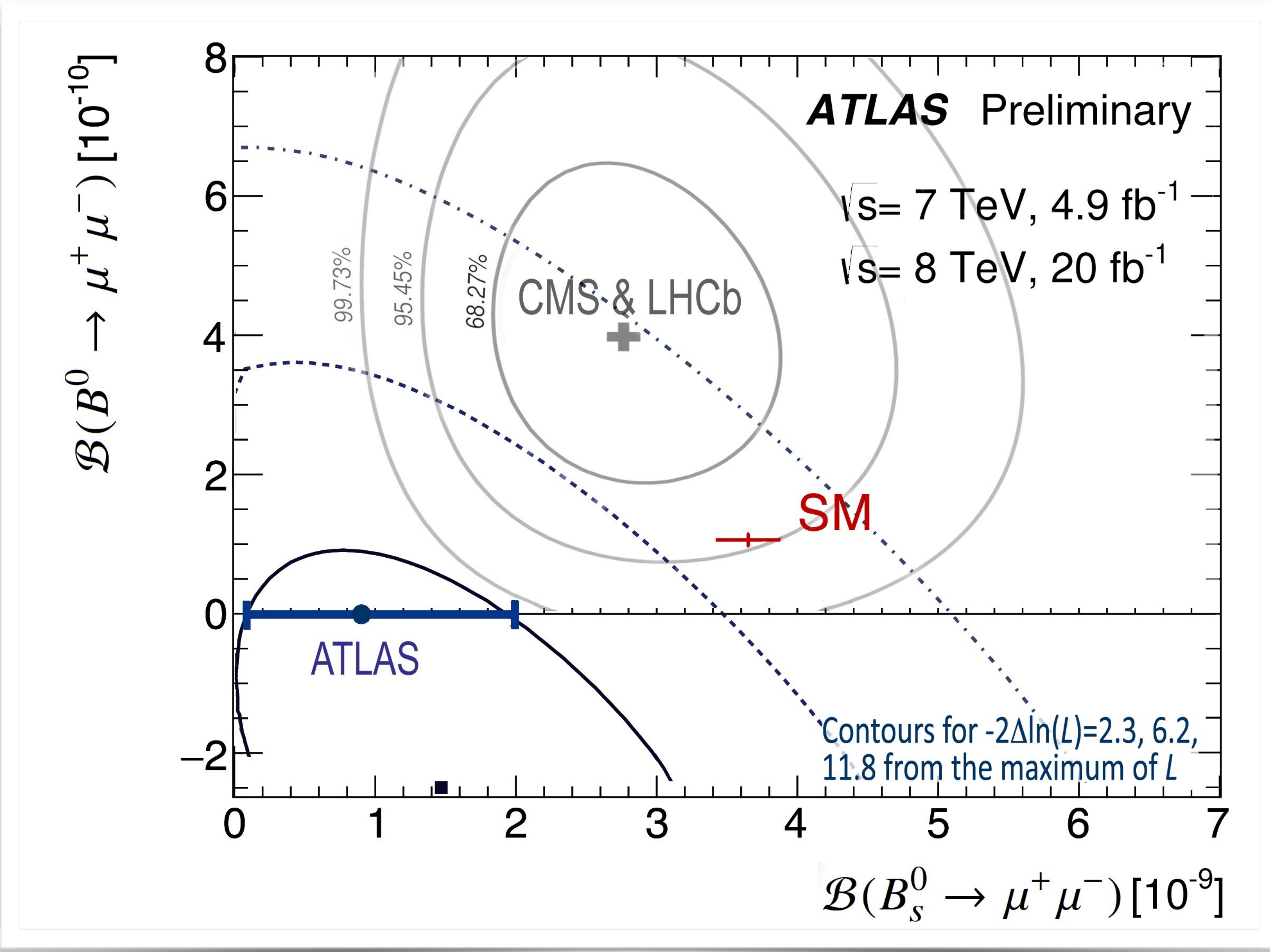


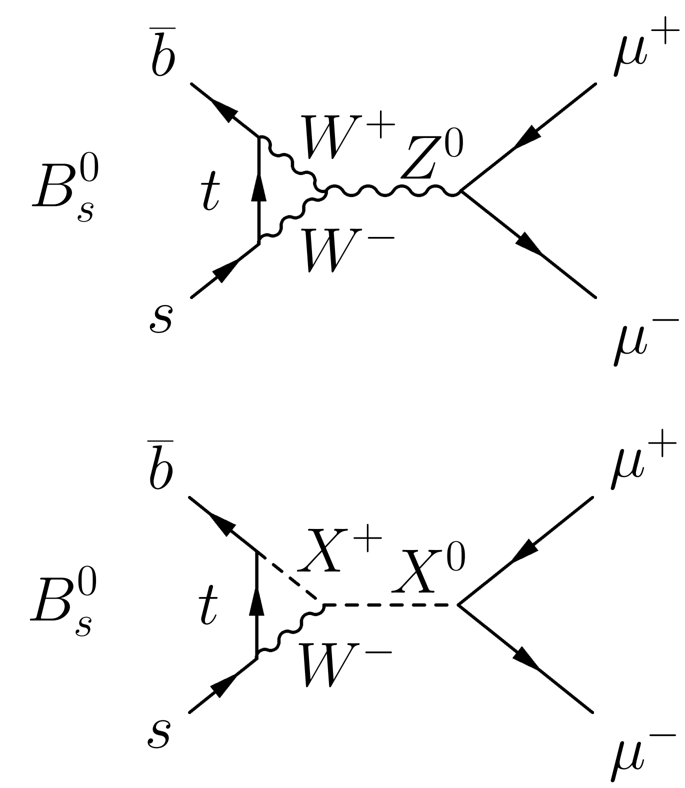
$$R_K = \frac{BR(B^+ \to K^+\mu^+\mu^-)}{BR(B^+ \to K^+e^+e^-)}$$

Not really an anomaly, but another recent flavour result

No anomaly, but beautiful channel to look for new physics $B_s \to \mu\mu$ & $B \to \mu\mu$

- Precise SM prediction, sensitivity through loop induced decay to NP
- Measurements by LHCb, CMS and ATLAS
- Testimony how well hadron machines can use their large b samples





- New ATLAS result: compatible with the SM at about **2.0σ**

Anomalies — what is there to learn?

If one carries out many measurements, one of course will every once in a while measure something that does not fit *(cf. look elsewhere effect)*

It is interesting though, that some measurements show persistent differences that either cannot be statistical in nature or show up for several experiments that use not the same observables to measure things

- Could point to a common systematic error all measurements underestimate (our limited understanding of QCD could be the culprit) and similar models for backgrounds are used
- Or are we seeing the emergence of the first sign of New Physics?

To discern one from the other we need to keep measuring

- Future results from the LHC and the intensity frontier will either confirm or reject these anomalies

The Belle II experiment will play an important role in this

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Transformation of a *B*-Factory into a **Super** *B*-Factory

To achieve the necessary sensitivity to further push the intensity frontier, the instantaneous luminosity needed to increase from **2.1×10^{34} cm^{-2} s^{-1} to 8×10^{35} cm^{-2} s^{-1}**

The key to this is a beam-configuration called the **nano-beam scheme** that squeeze the beam to have a very small vertical spot size of about 50 nm

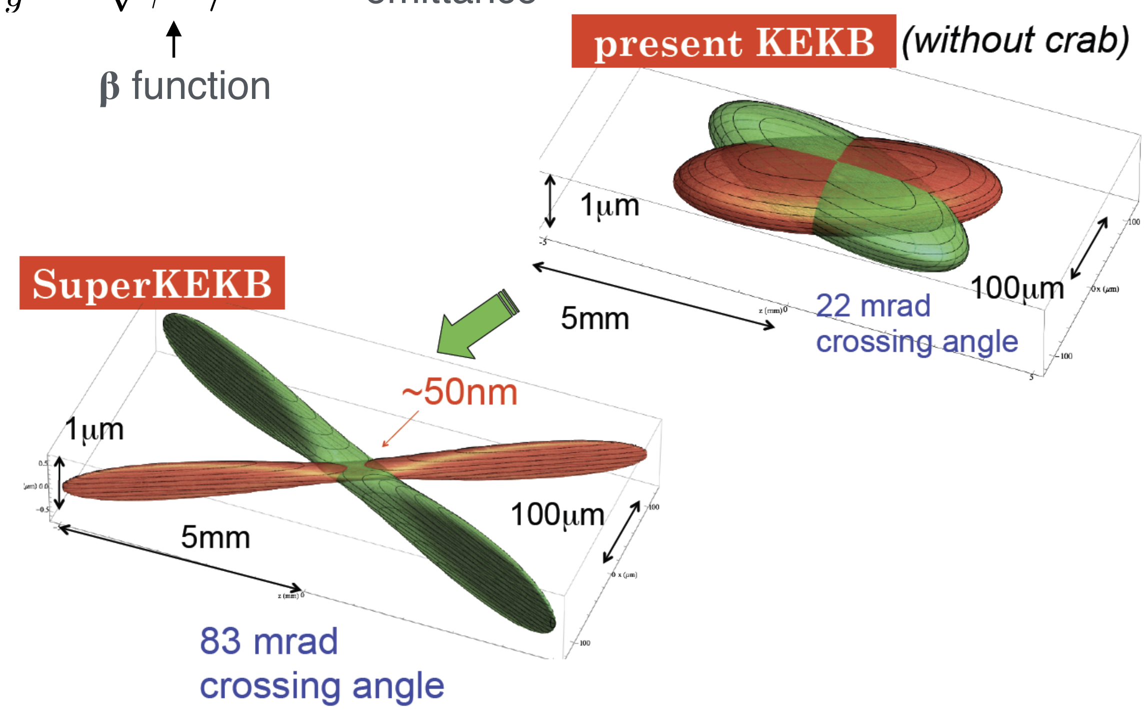
LER / HER	KEKB	SuperKEKB
Energy [GeV]	3.5 / 8	4.0 / 7.0
β_y^* [mm]	5.9 / 5.9	**0.27 / 0.30**
β_x^* [mm]	1200	**32 / 25**
$I_\pm$ [A]	1.64 / 1.19	**3.6 / 2.6**
$\zeta_{\pm y}$	0.129 / 0.09	**0.09 / 0.09**
ε [nm]	18 / 24	**3.2 / 4.6**
# of bunches	1584	2500
Luminosity [10^{34} cm^{-2} s^{-1}]	2.1	80

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

Lorentz factor, beam current, beam-beam parameter, beam size aspect ratio, vertical β function, geometric factors

$$\zeta_{\pm y} \sim \sqrt{\beta^*/\epsilon}$$

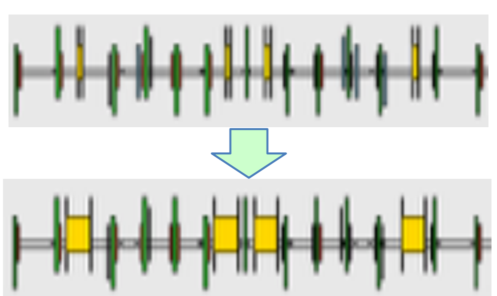
← emittance; ↑ β function



Major upgrade of existing accelerator needed

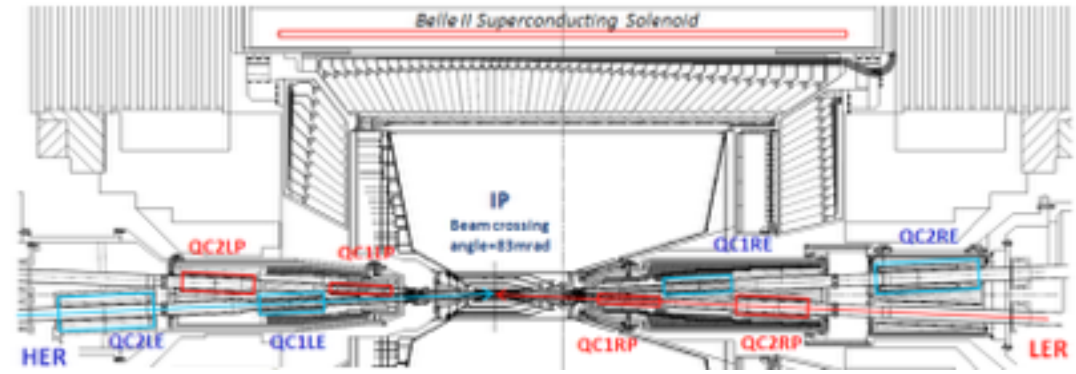
Transformation of a *B*-Factory into a **Super** *B*-Factory

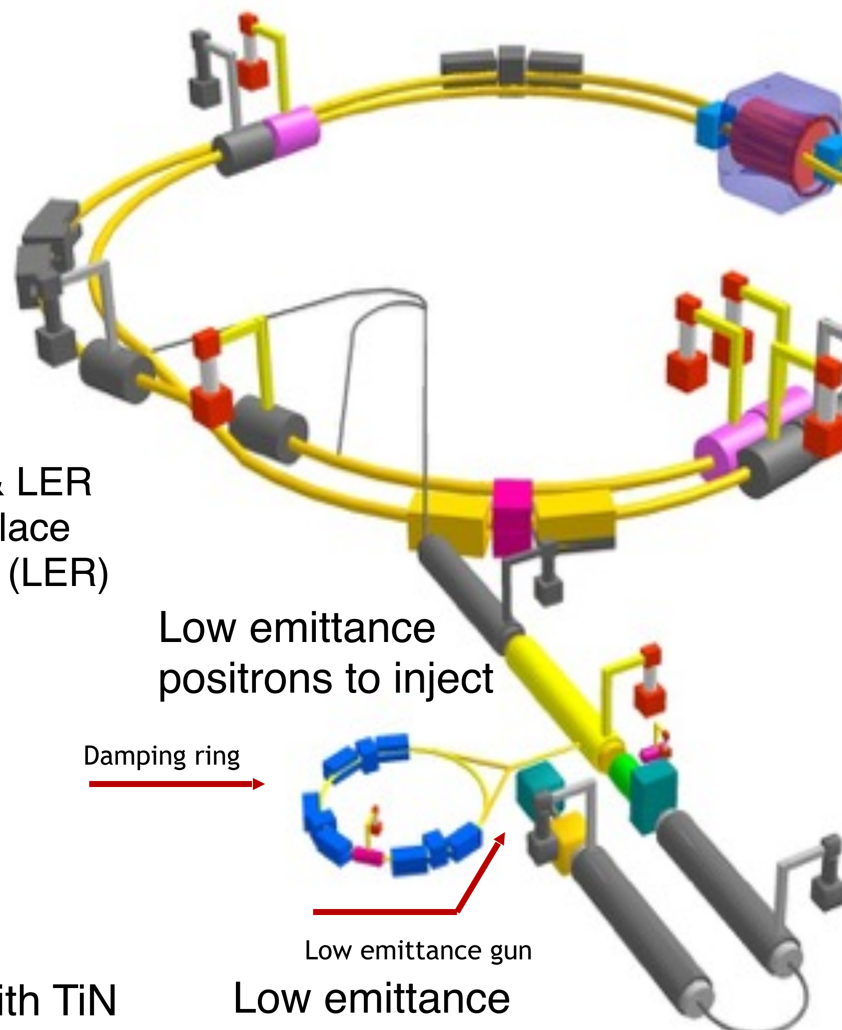
Redesign the lattices of HER & LER to squeeze the emittance. Replace short dipoles with longer ones (LER)



Replaced old beam pipes with TiN coated beam pipes with antechambers

New superconducting final focusing magnets near the IP



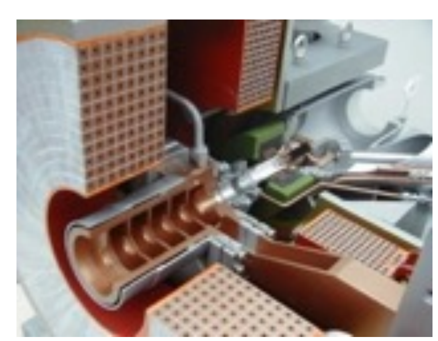


Low emittance positrons to inject

Low emittance electrons to inject

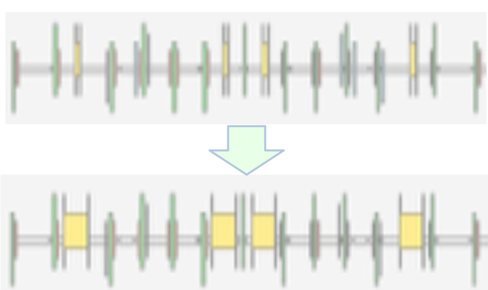
Reinforced RF (radio frequency) system for higher beam currents, improved monitoring & control system

Upgrade positron capture section



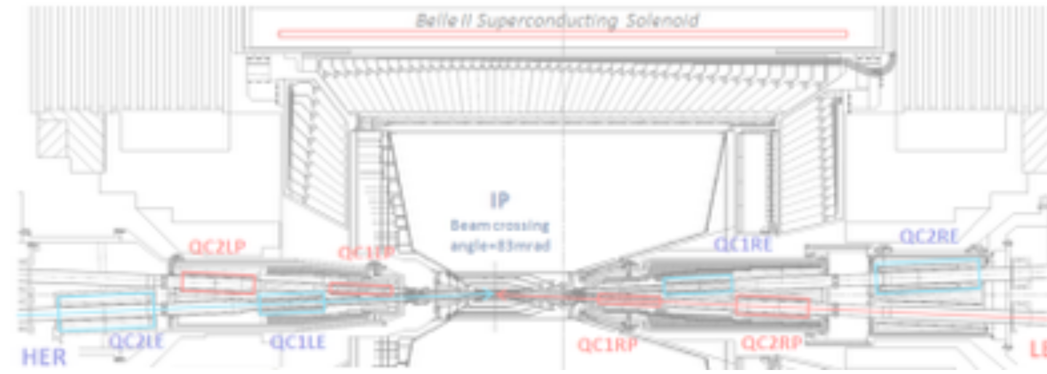
Transformation of a *B*-Factory into a **Super** *B*-Factory

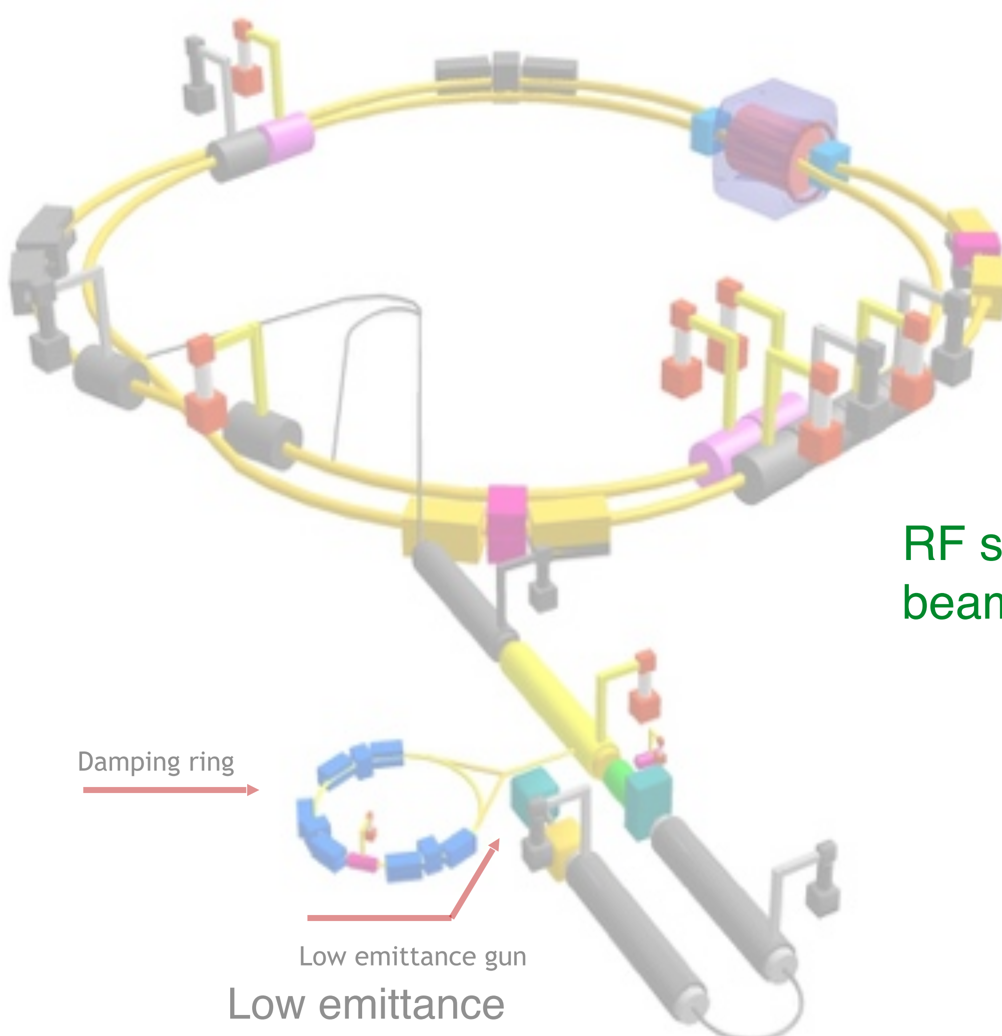
All magnets installed ✔



Beam pipes replaced ✔

Work on final focus magnets progressing well



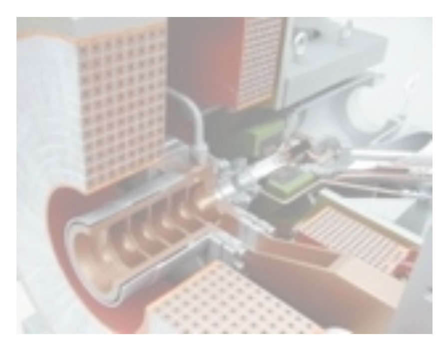


Low emittance electrons to inject

RF system for higher beam currents upgraded ✔

new positron dampening ring is being constructed

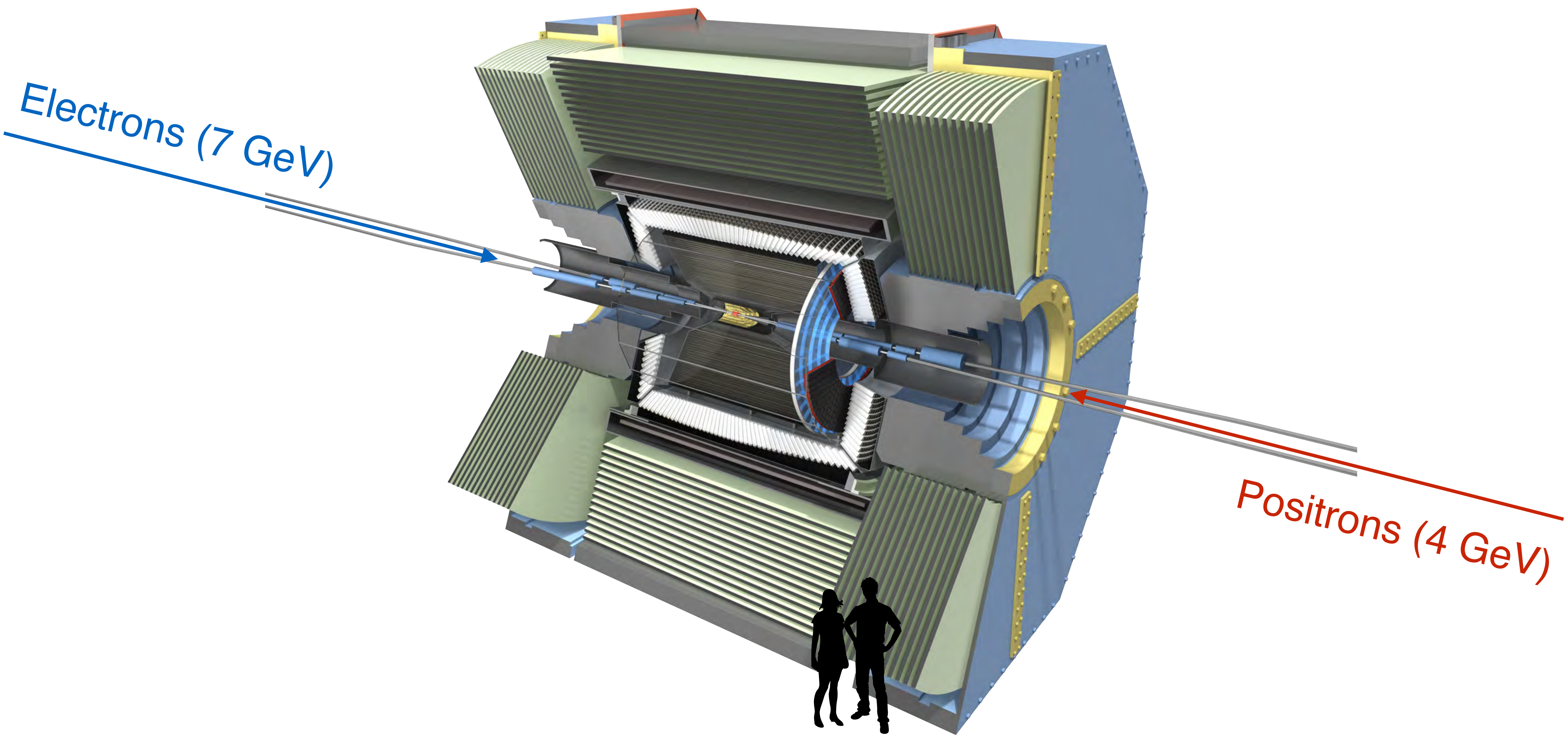
Upgrade positron capture section



The Belle II Detector

To cope with the higher luminosity, a new detector is needed

Design concept similar to the B-Factory detectors Belle and BaBar



Needs to cope e.g. with 20 times larger beam backgrounds, many technological challenges

The Belle II Detector

To cope with the higher luminosity, a new detector is needed

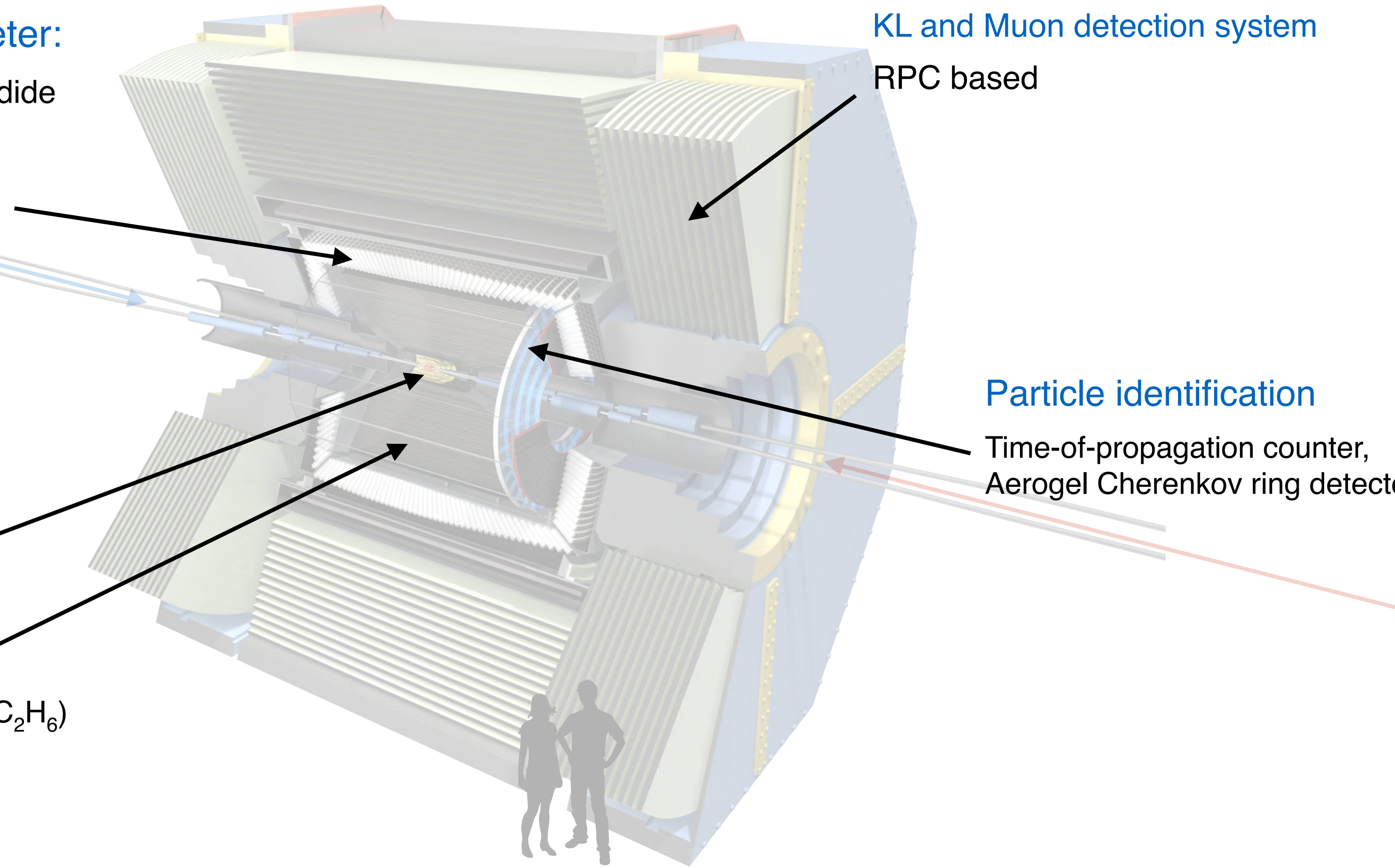
Design concept similar to the B-Factory detectors Belle and BaBar

Electromagnetic Calorimeter:

Thallium activated Caesium Iodide scintillation crystals

KL and Muon detection system

RPC based



Particle identification

Time-of-propagation counter, Aerogel Cherenkov ring detector

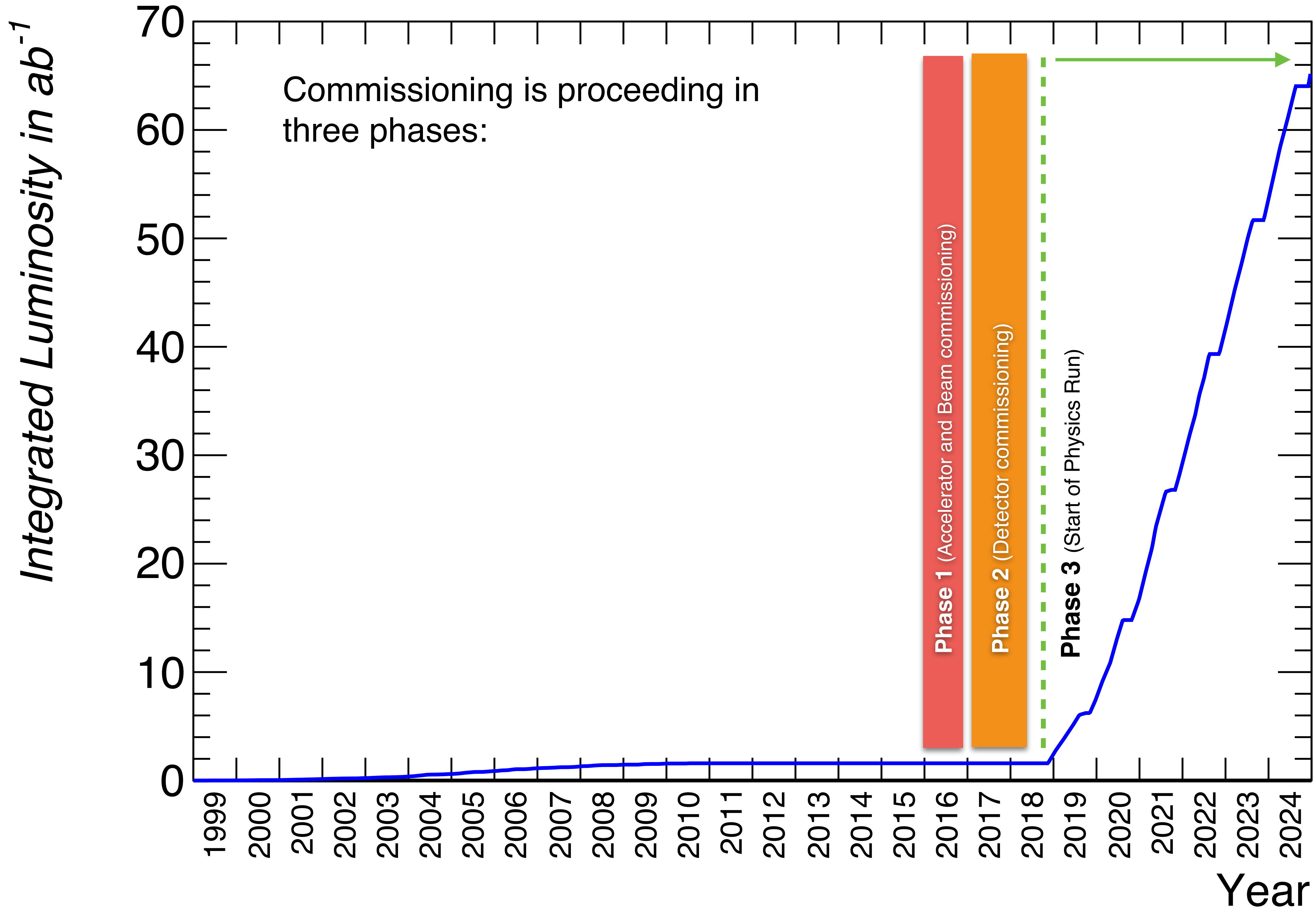
Vertex detectors

2 layers of Pixel (DEPFET) + 4 layers of strips (DSSD)

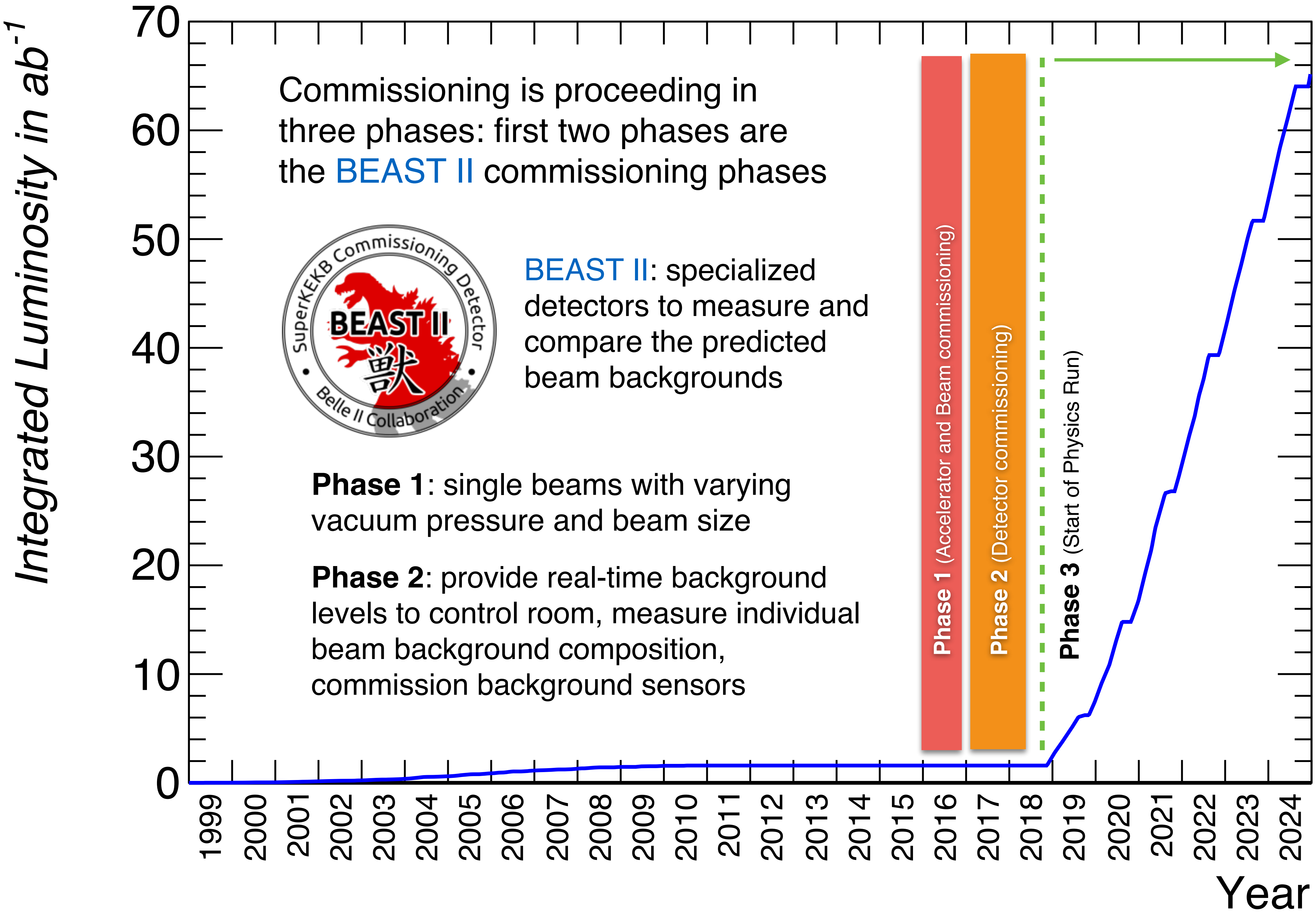
Central drift chamber:

Gas mixture of Helium and Ethan (C_2H_6)

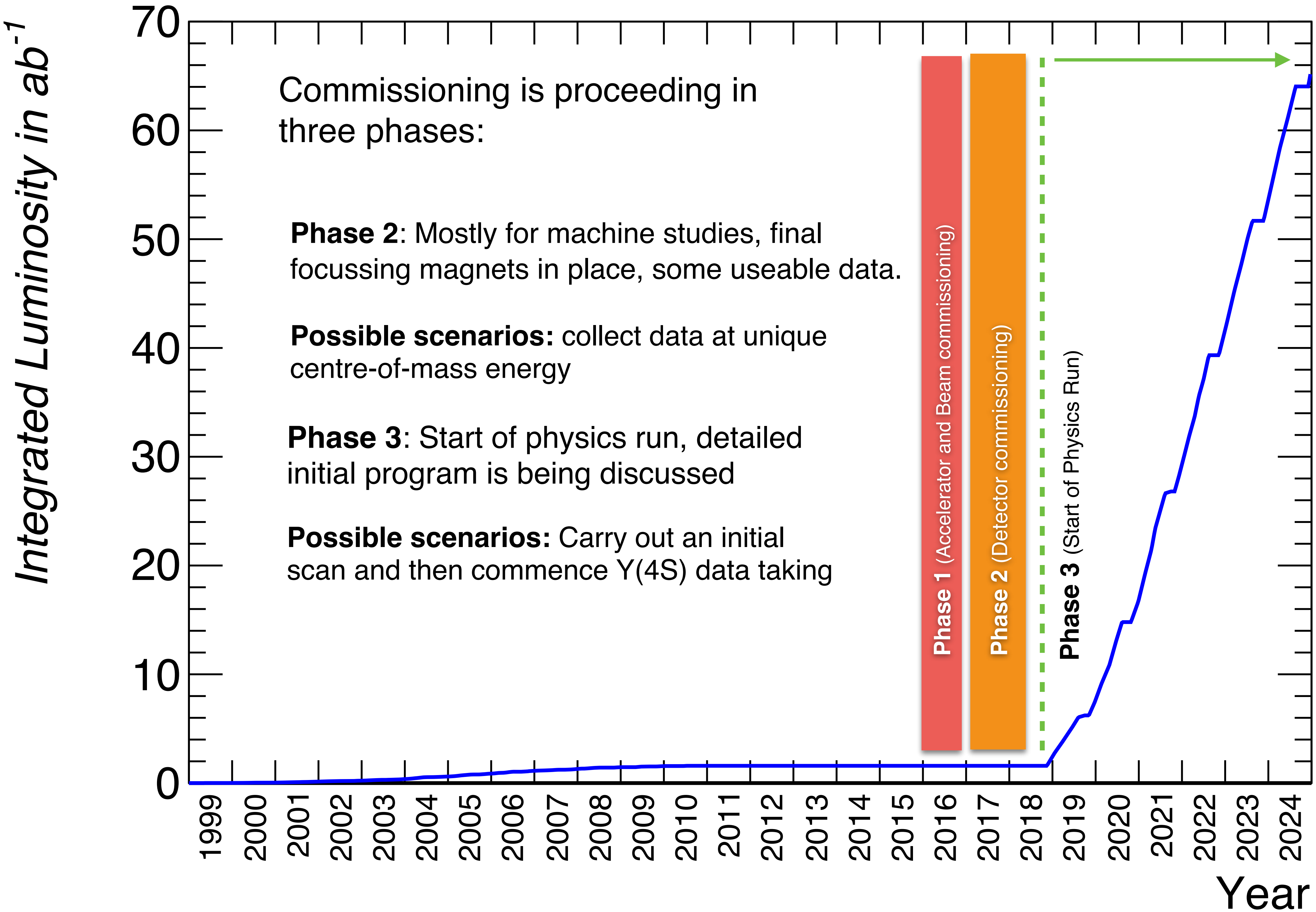
Belle II / SuperKEKB Luminosity projections

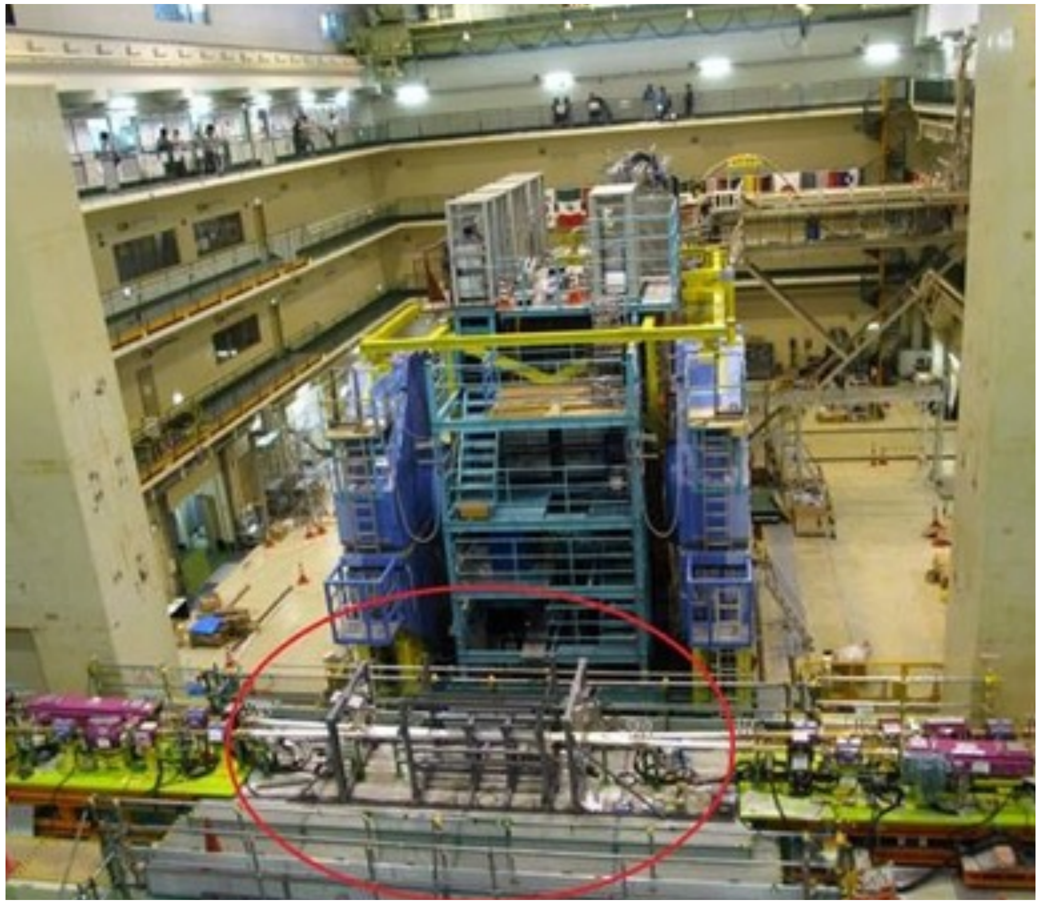


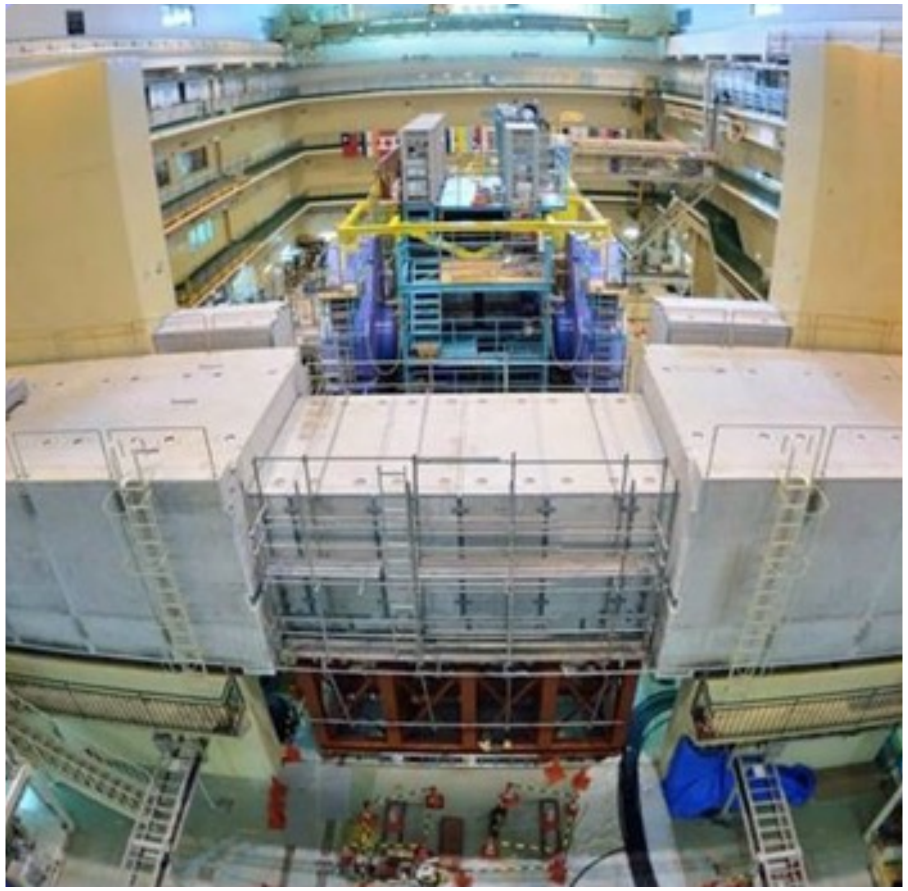
Belle II / SuperKEKB Luminosity projections



Belle II / SuperKEKB Luminosity projections







Belle II & LHCb

On complementarity and overlap

B-Factory results

a rich harvest

Belle II Physics

from CPV to dark photons

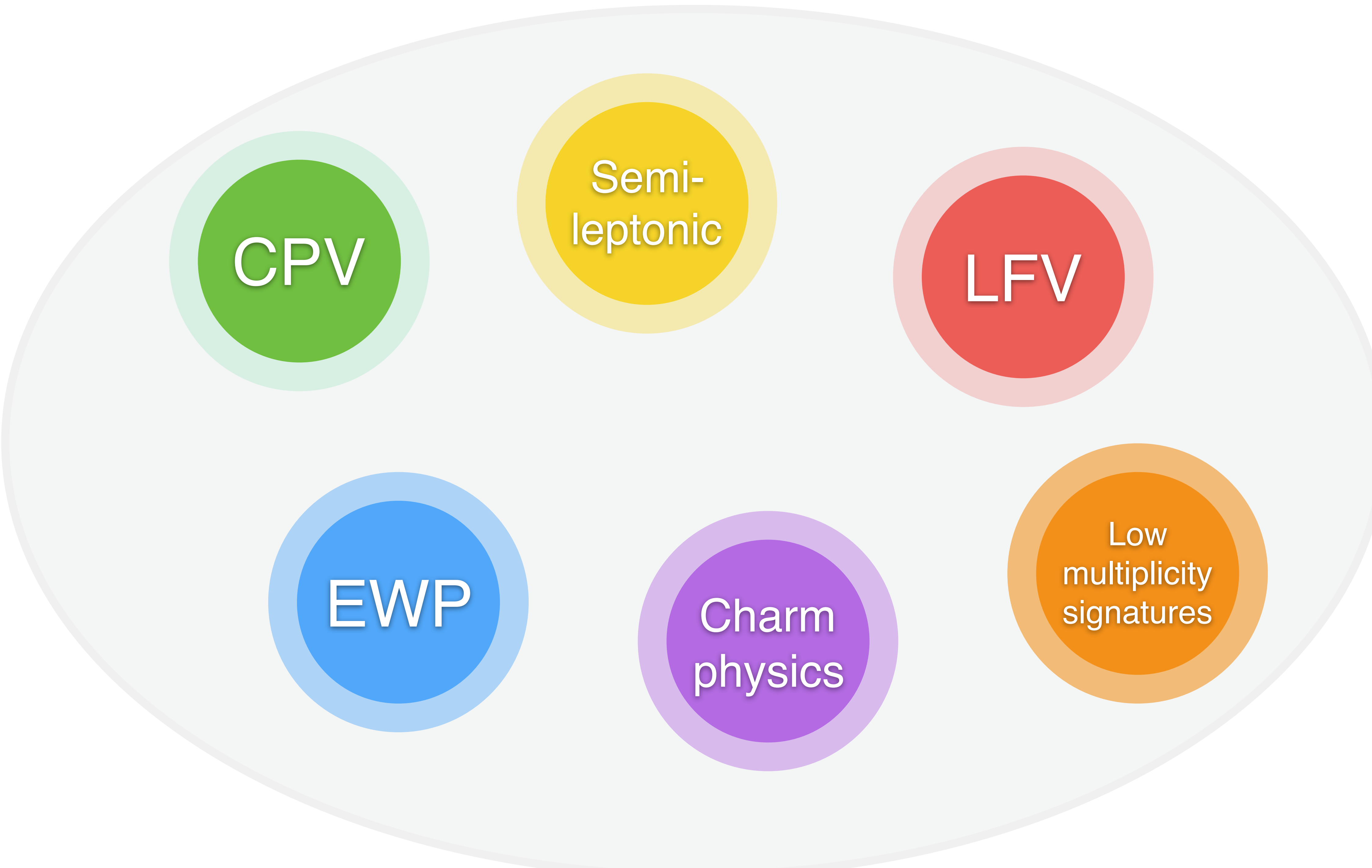
The open questions

a review of anomalies

Belle II Detector

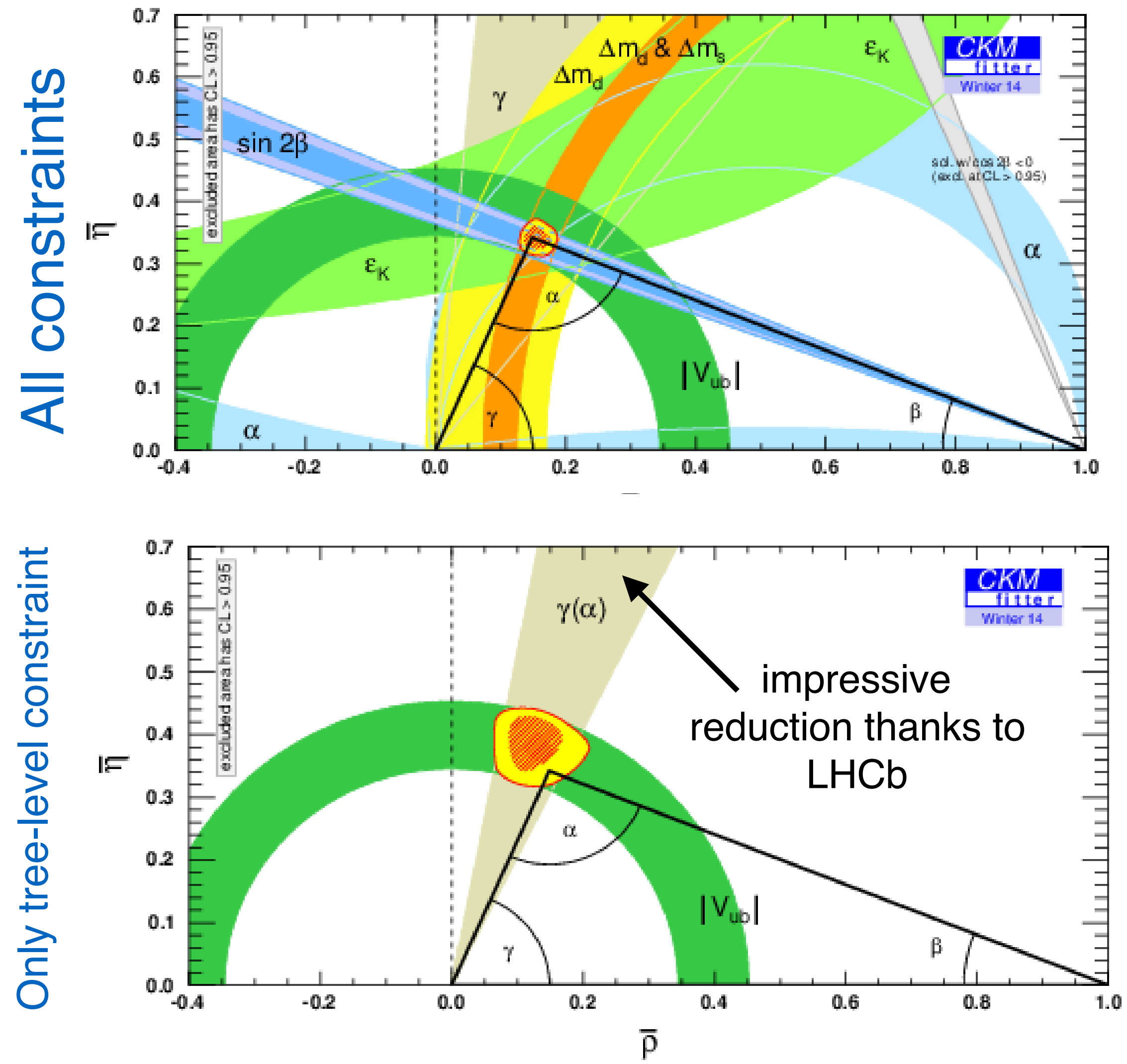
concept and current status

Super B-Factory measurement candy bowl



CPV

$$\phi_1 \equiv \beta \equiv \arg[-(V_{cd}V_{cb}^*)/(V_{td}V_{tb}^*)].$$

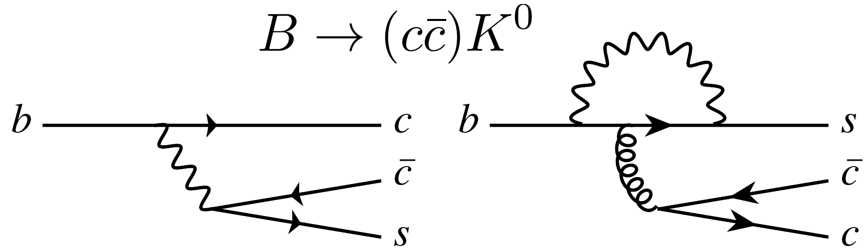


Search for new sources of CPV

- CKM fit dominated by $\sin(2\beta = 2\,\phi_1)$ precision
- If new sources of CPV is present expect tree-constraints and loop constraints to not agree
- Current precision leaves room for new CPV physics

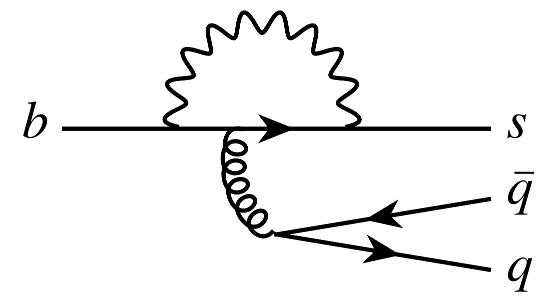
Precision measurements of $\sin(2\beta)$ will remain an important topic to check the consistency of the Unitary triangle and for the search of new physics

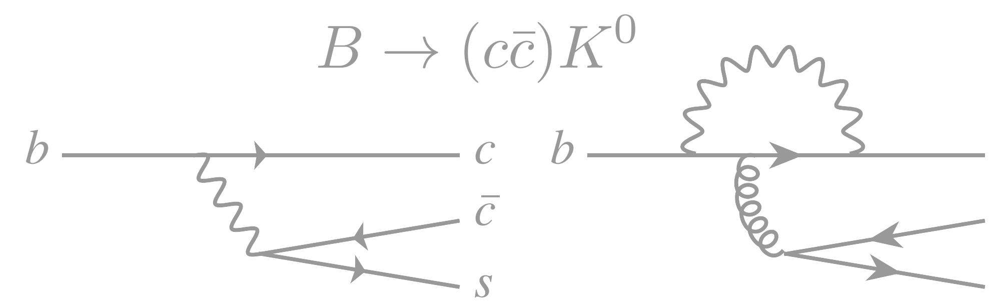
$B \to (c\bar{c})K^0$



Error on $\sin(2\beta)$	stat.	tot.
B-Factories	3.5%	3.9%
Belle II 5/ab	1.3%	1.8%
Belle II 50/ab	0.4%	**1.2%**

CPV





One of the most promising ways to search for new sources of CPV is to compare the mixing-induced CP asymmetries in penguin transitions with tree-dominated modes

$$B \to \eta' K^0$$

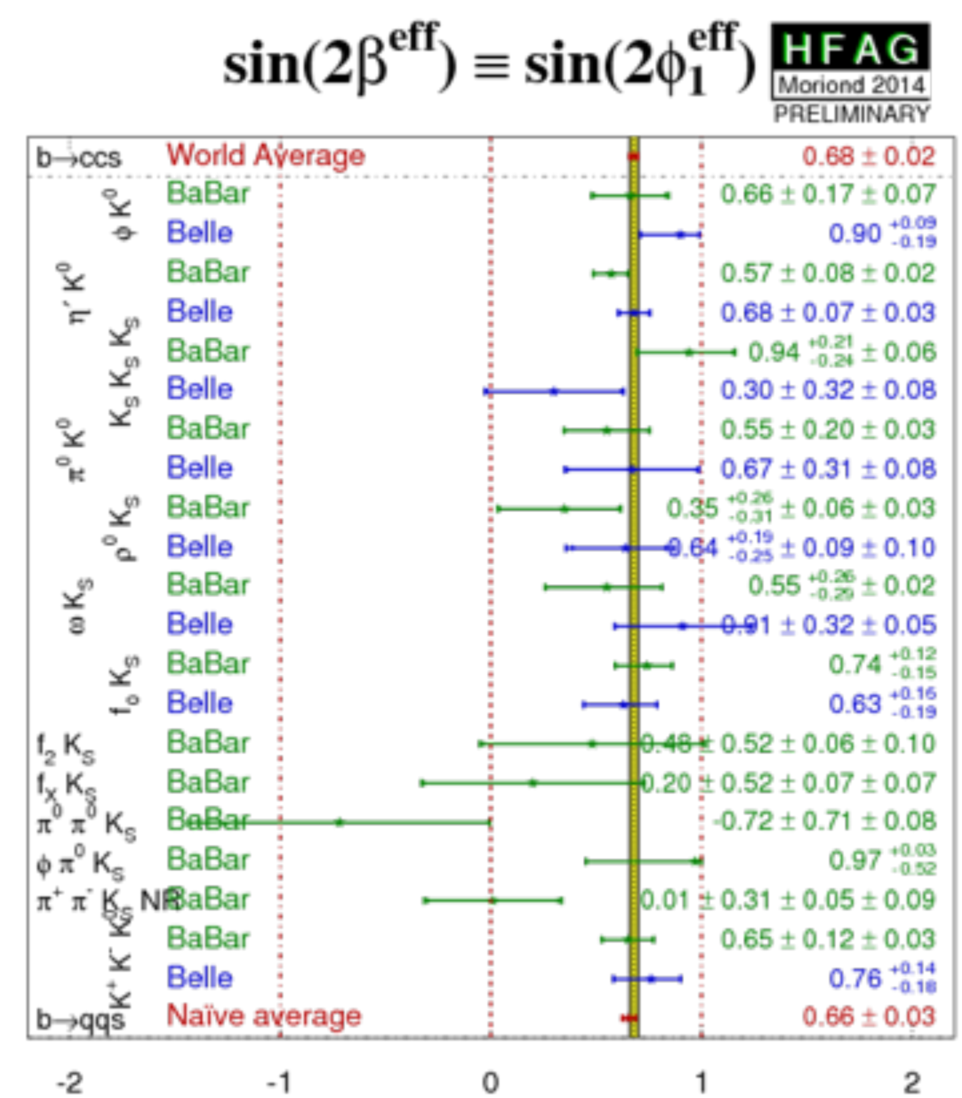
Error on sin(2β)	tot.
B-Factories	9.4%
Belle II 5/ab	4.2%
Belle II 50/ab	**1.6%**

$$B \to \phi K^0$$

Error on sin(2β)	tot.
B-Factories	17.8%
Belle II 5/ab	7.9%
Belle II 50/ab	**2.7%**

$$B \to K^0 K^0 K^0$$

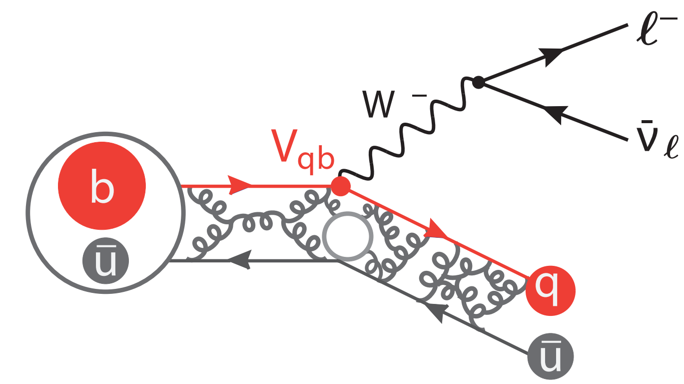
Error on sin(2β)	tot.
B-Factories	33.9%
Belle II 5/ab	15.1%
Belle II 50/ab	**4.9%**



Semi-leptonic

Precision measurements of CKM matrix elements will be a priority

Exclusive measurements will profit from the large Belle II data samples



- Popular measurement method involves ***fully hadronic reconstruction of secondary B-meson*** in event.
- Very low efficiency due to low hadronic Branching Fractions (of the order 0.2-0.3%)

$\Upsilon(4S)$ → B^0 → semileptonic signal mode

$\Upsilon(4S)$ → $\overline{B}^0$ → hadronic decay

Neutrino of signal decay the only missing particle!

had. tagged
$B \to D^* \ell \bar{\nu}_\ell$

Error on $|V_{cb}|$	stat.	tot.
B-Factories	0.6%	3.6%
Belle II 5/ab	0.2%	1.8%
Belle II 50/ab	0.1%	**1.4%**

had. tagged
$B \to \pi \ell \bar{\nu}_\ell$

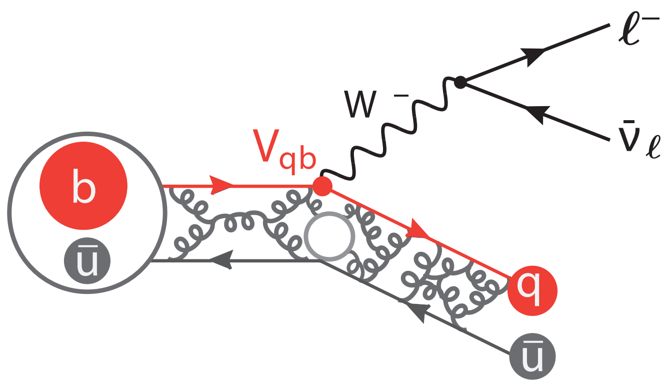
Error on $|V_{ub}|$	stat.	tot.
B-Factories	5.8%	10.8%
Belle II 5/ab	2.2%	4.7%
Belle II 50/ab	0.7%	**2.4%**

untagged
$B \to \pi \ell \bar{\nu}_\ell$

Error on $|V_{ub}|$	stat.	tot.
B-Factories	2.7%	9.4%
Belle II 5/ab	1.0%	4.2%
Belle II 50/ab	0.3%	**2.2%**

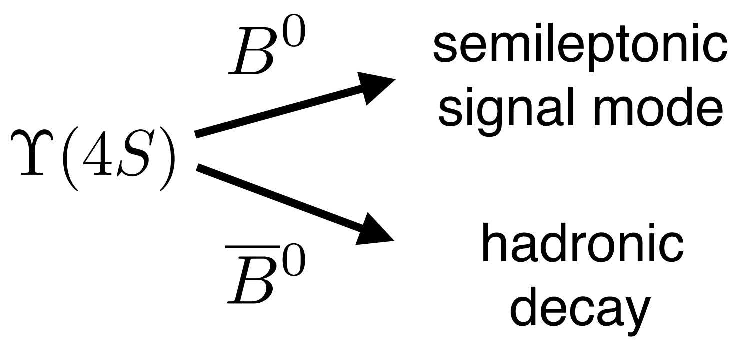
Semi-leptonic

Precision measurements of CKM matrix elements will be a priority



Improvements on *inclusive measurements* less clear.

- $|V_{cb}|$ systematically and theory limited; need new approaches.
- $|V_{ub}|$ will gain; but need to improve on understanding of background and methodology



Neutrino of signal decay the only missing particle!

$$B \to X_c \ell \bar{\nu}_\ell$$

Error on $\|V_{cb}\|$	stat.	tot.
B-Factories	1.5%	1.8%
Belle II 50/ab	0.5%	**1.2%**

$$B \to X_u \ell \bar{\nu}_\ell$$

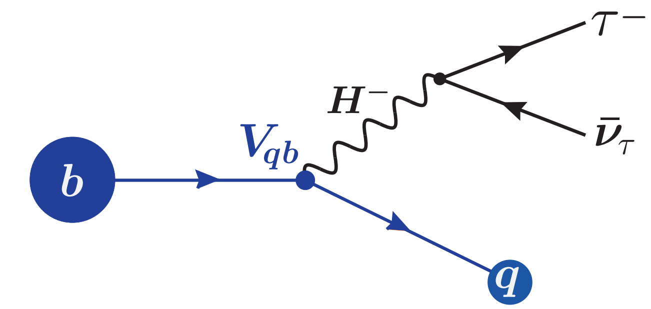
Error on $\|V_{ub}\|$	stat.	tot.
B-Factories	4.5%	6.5%
Belle II 5/ab	1.1%	3.4%
Belle II 50/ab	0.4%	**3%**

Semi-leptonic

Semi-tauonic decay modes are highly sensitive to new physics

Clean measurement is a major Belle II goal

Can target inclusive and light meson modes; target higher excited states and carry out differential measurements



$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\,\tau\,\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\,\ell\,\bar{\nu}_\ell)}$$

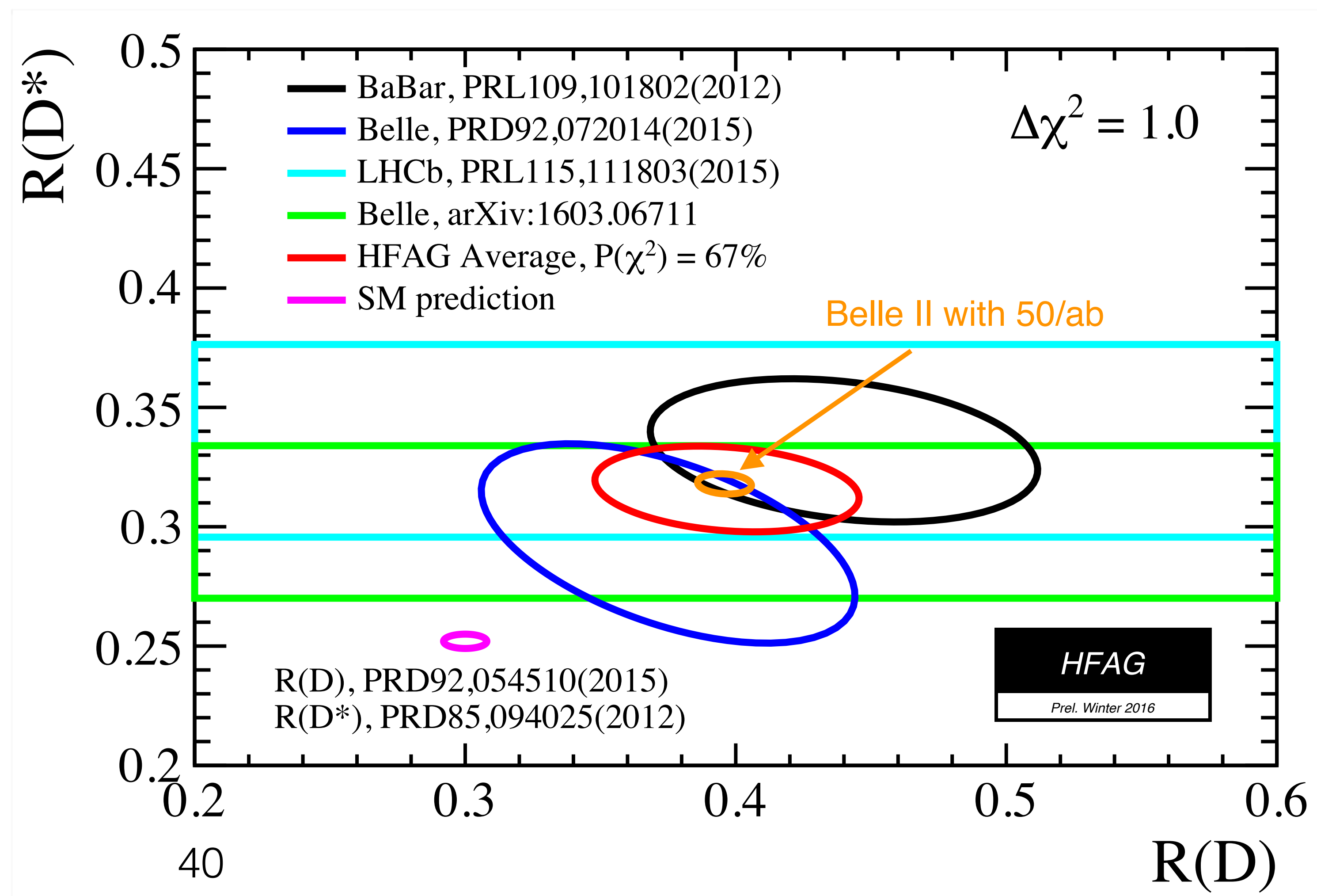
$$R(X) \quad R(\pi) \quad R(D^{**})$$

$R(D)$

Error	stat.	tot.
B-Factories	13%	16.2%
Belle II 5/ab	3.8%	5.6%
Belle II 50/ab	1.2%	**3.4%**

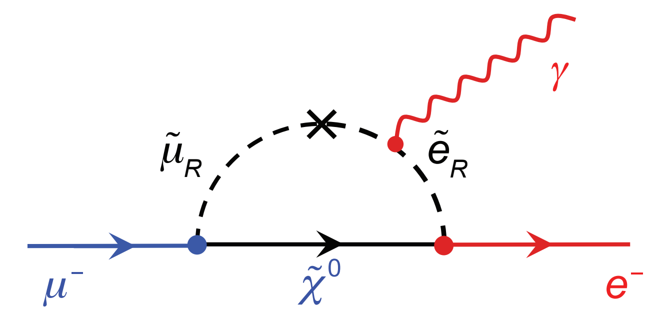
$R(D^*)$

Error	stat.	tot.
B-Factories	7.1%	9.0%
Belle II 5/ab	2.1%	3.2%
Belle II 50/ab	0.7%	**2.1%**

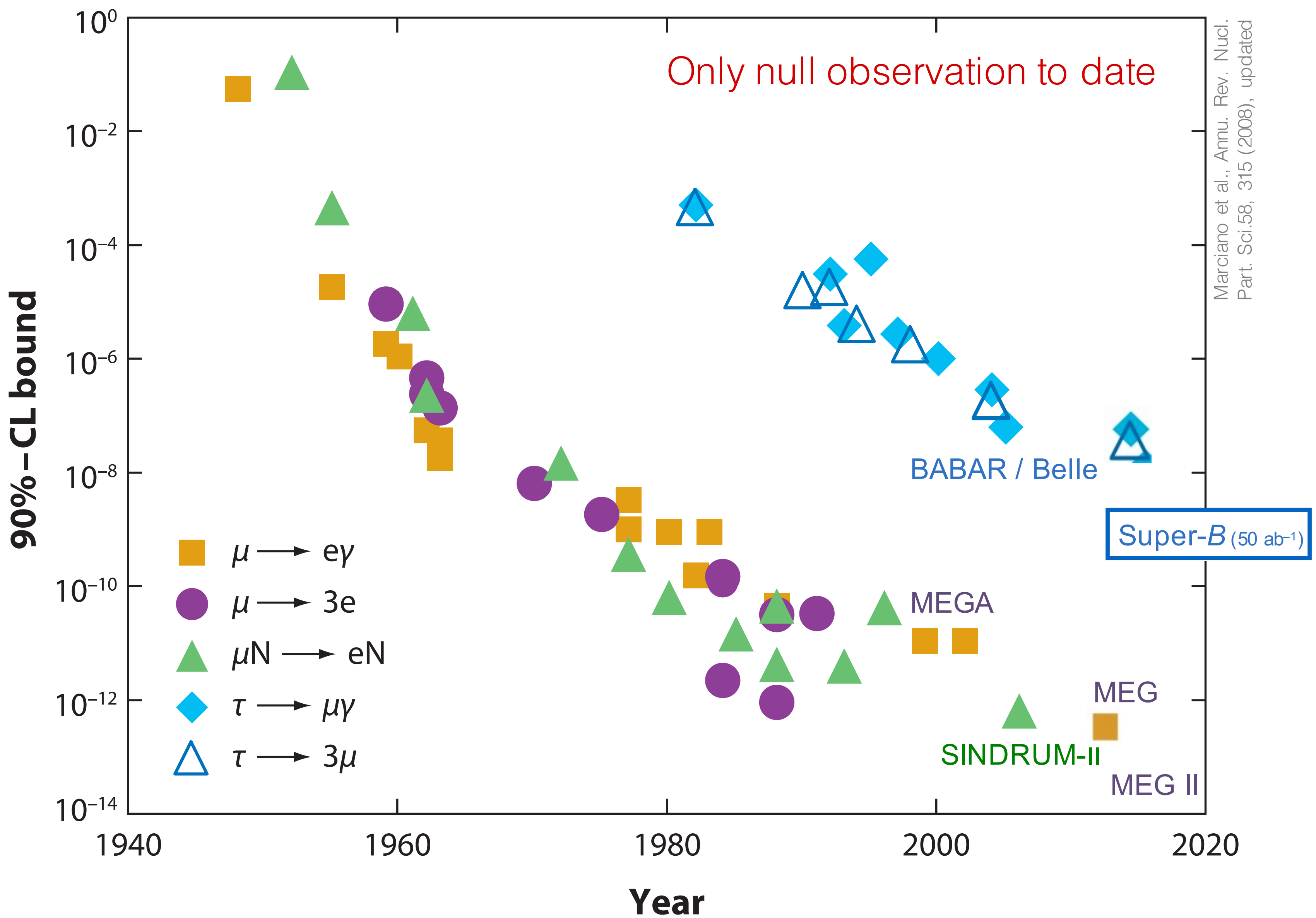


LFV

Charged lepton flavour violation:
SM-free signals!



LFV signals are expected in many BSM scenarios, such as the MSSM or as a consequence of Seesaw models

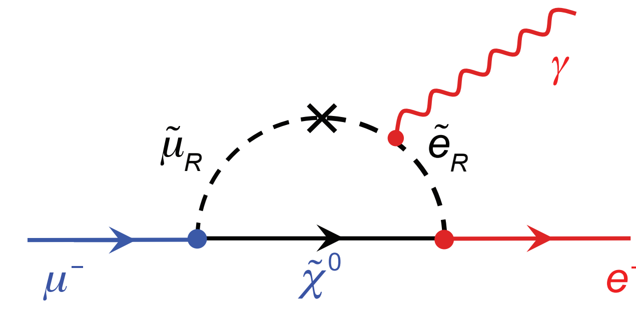


Spectacular perspectives: Mu2e / COMET PRISM / PRIME

LFV

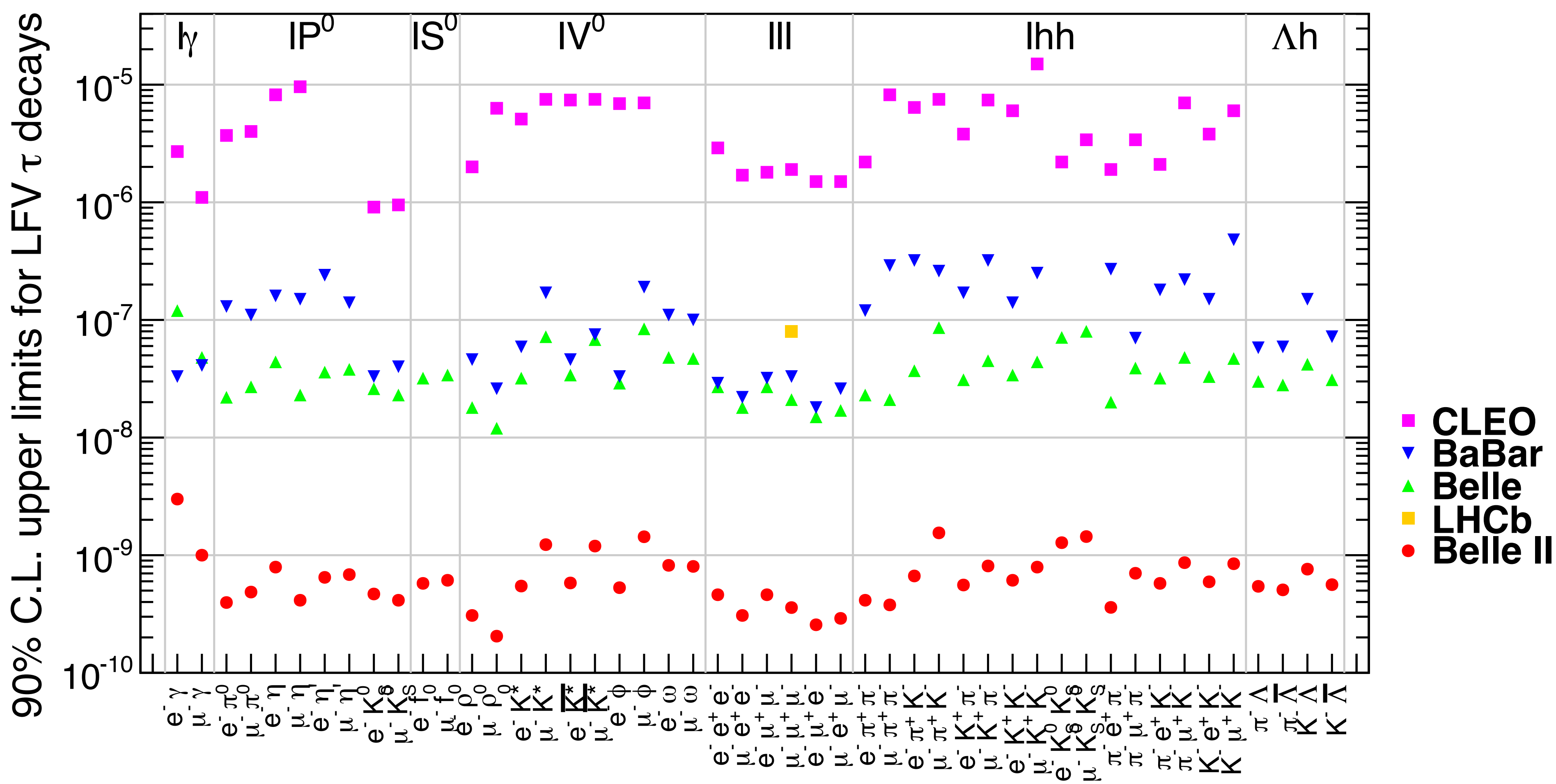
Charged lepton flavour violation:

SM-free signals!



LFV signals are expected in many BSM scenarios, such as the MSSM or as a consequence of Seesaw models

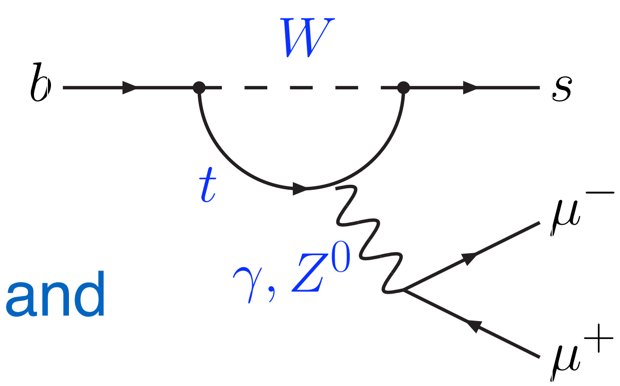
Belle II will be able to improve current limits by a factor of 100 for $\tau \to 3l$ and a factor of >10 for $\tau \to l\,\gamma$



EWP

Electroweak penguin production very sensitive to New Physics

- Radiative penguins offer interesting probe for $|C_7|$
  - A_{CP} measurements of $B \rightarrow X_{d/s}\,\gamma$ and $B \rightarrow X_{d+s}\,\gamma$
- Leptonic penguins access $|C_7|$, $|C_9|$ and $|C_{10}|$
  - Can measure full repertoire of kinematic, angular and CP observables
- Belle II can access inclusive and exclusive decays
  - Way to deal with QCD independent; valuable cross check when anomalies show up *(cf. slide 19)*
  - Measured $B \rightarrow X_s\, ll$ A_{FB} *sensitive to* $|C_7|$, $|C_9|$ *ratio*



untagged

$B \to X_s \gamma$

Error	stat.	tot.
B-Factories	4.2%	12.3%
Belle II 5/ab	1.5%	6.6%
Belle II 50/ab	0.5%	**5.4%**

had. tagged

$B \to X_s \gamma$

Error	stat.	tot.
B-Factories	13.4%	16.8%
Belle II 5/ab	4.8%	7.5%
Belle II 50/ab	1.5%	**5.1%**

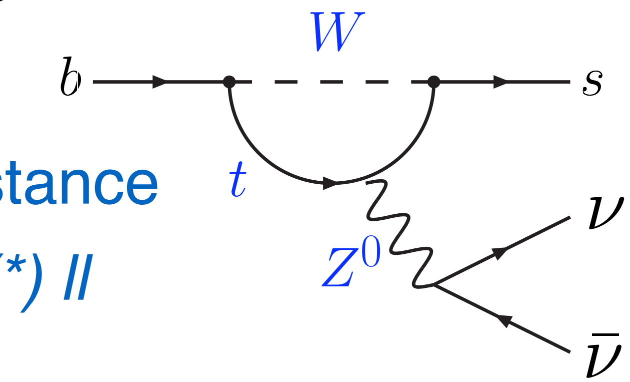
$B \to X_s \ell\ell$ C_7/C_9 ratio

Error	tot.
B-Factories	19%
Belle II 5/ab	9%
Belle II 50/ab	**6%**

EWP

Electroweak penguin production very sensitive to New Physics

- Belle II will be able to probe modes with neutrinos and τ leptons
  - $B \rightarrow K(*) \nu\nu$ theoretically very clean, no long distance effects from resonances (J/ψ, etc.) as for $B \rightarrow K(*)\, ll$



had. tagged

$B \to \tau\tau$ SM ~ 2 x 10^{-10}

Error	90% CL
B-Factories	< 4.1 x 10^{-3}
Belle II 5/ab	< 0.8 x 10^{-3}
Belle II 50/ab	**< 0.3 x 10^{-3}**

$B_s \to \tau\tau$ SM ~ 9 x 10^{-7}

Error	90% CL
B-Factories	< 13 x 10^{-3}
Belle II 5/ab	**< 2 x 10^{-3}**

had. tagged

$B^0 \to K_S \nu\bar{\nu}$ SM ~ 2.2 x 10^{-6}

Error	stat.
B-Factories	590%
Belle II 5/ab	220%
Belle II 50/ab	**94%**

$B^0 \to K^{*0} \nu\bar{\nu}$ SM ~ 9.5 x 10^{-6}

Error	stat.
B-Factories	112%
Belle II 5/ab	42%
Belle II 50/ab	**22%**

$B^+ \to K^+ \nu\bar{\nu}$ SM ~ 4.7 x 10^{-6}

Error	stat.
B-Factories	130%
Belle II 5/ab	49%
Belle II 50/ab	**22%**

$B^+ \to K^{*+} \nu\bar{\nu}$ SM ~ 10.2 x 10^{-6}

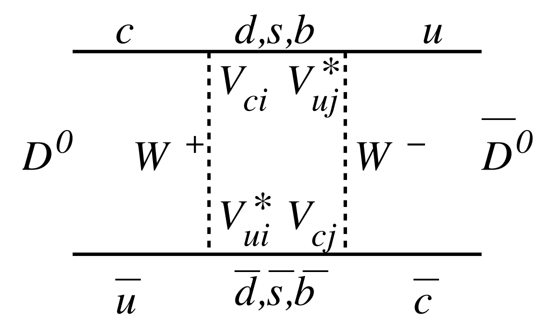
Error	stat.
B-Factories	120%
Belle II 5/ab	45%
Belle II 50/ab	**22%**

Charm physics

Charm physics experienced a large boost in interest from the theory side as well from experimental efforts.

Charm will be one of the important subjects to be studied by Belle II

- Leptonic charm decays are sensitive to NP contributions
- Measurement of D^0 mixing and CPV parameter measurement



- Charm mixing frequency extremely low, challenging high-statistics measurement

y_{CP}

Error	tot. (in 10^{-3})
B-Factories	2.4
Belle II 5/ab	1.1
Belle II 50/ab	**0.5**

A_Γ SM ~ < x 10^{-4}

Error	tot. (in 10^{-4})
B-Factories	22
Belle II 5/ab	10
Belle II 50/ab	**3**

Low multiplicity signatures

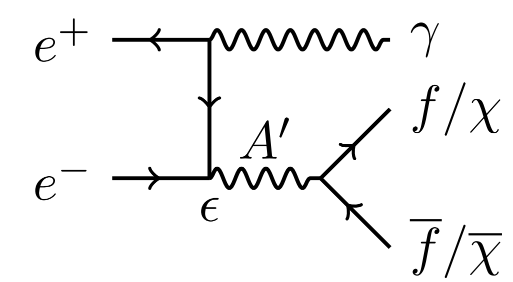
Belle II can probe ‘dark forces’ with dedicated Triggers

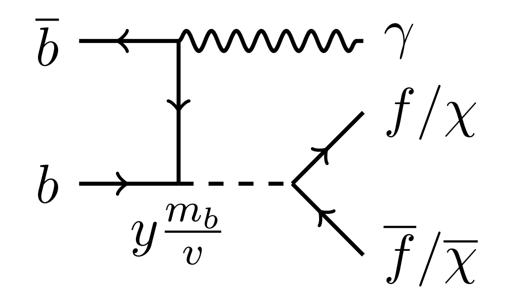
- ‘dark forces’: involving dark-matter particles that serve as ‘portals' between the SM and a dark-matter sector

dark photon mass coupling strength

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{m^2_{A'}}{2}A'_{\mu}A'^{\mu} - \frac{\epsilon}{2}F'_{\mu\nu}F^{\mu\nu}$$

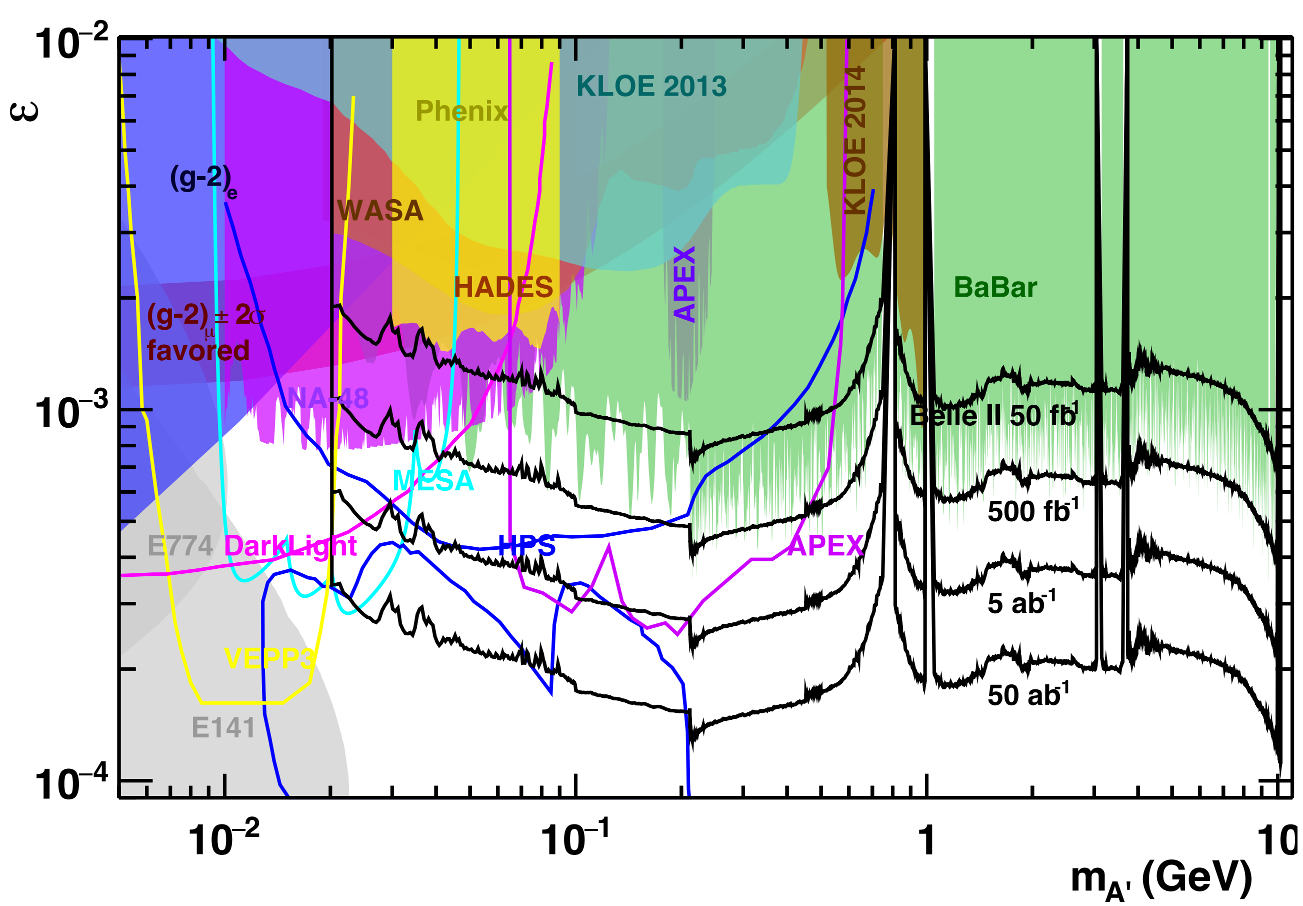
- Motivated by rise in cosmic-ray positron fraction
  (which does not necessarily have to be due to New Physics)
- Also models with dark Higgs bosons that could be produced in Υ(nS) decays.



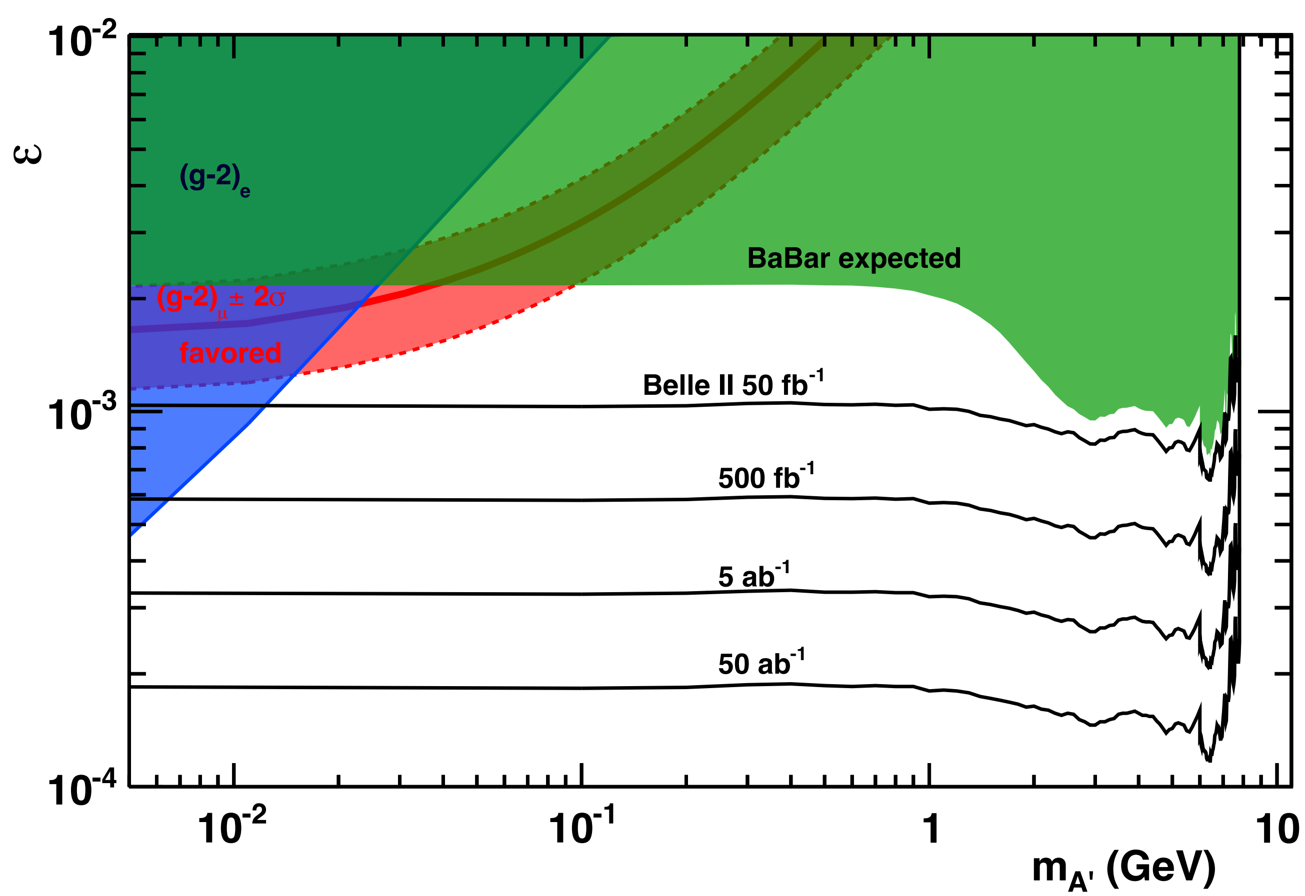


Belle II will probe a unique piece of phase space, and even a small data sample will have a sizeable impact on todays limits

(Prompt) dilepton final state



invisible final state



Belle II & LHCb
On complementarity and overlap

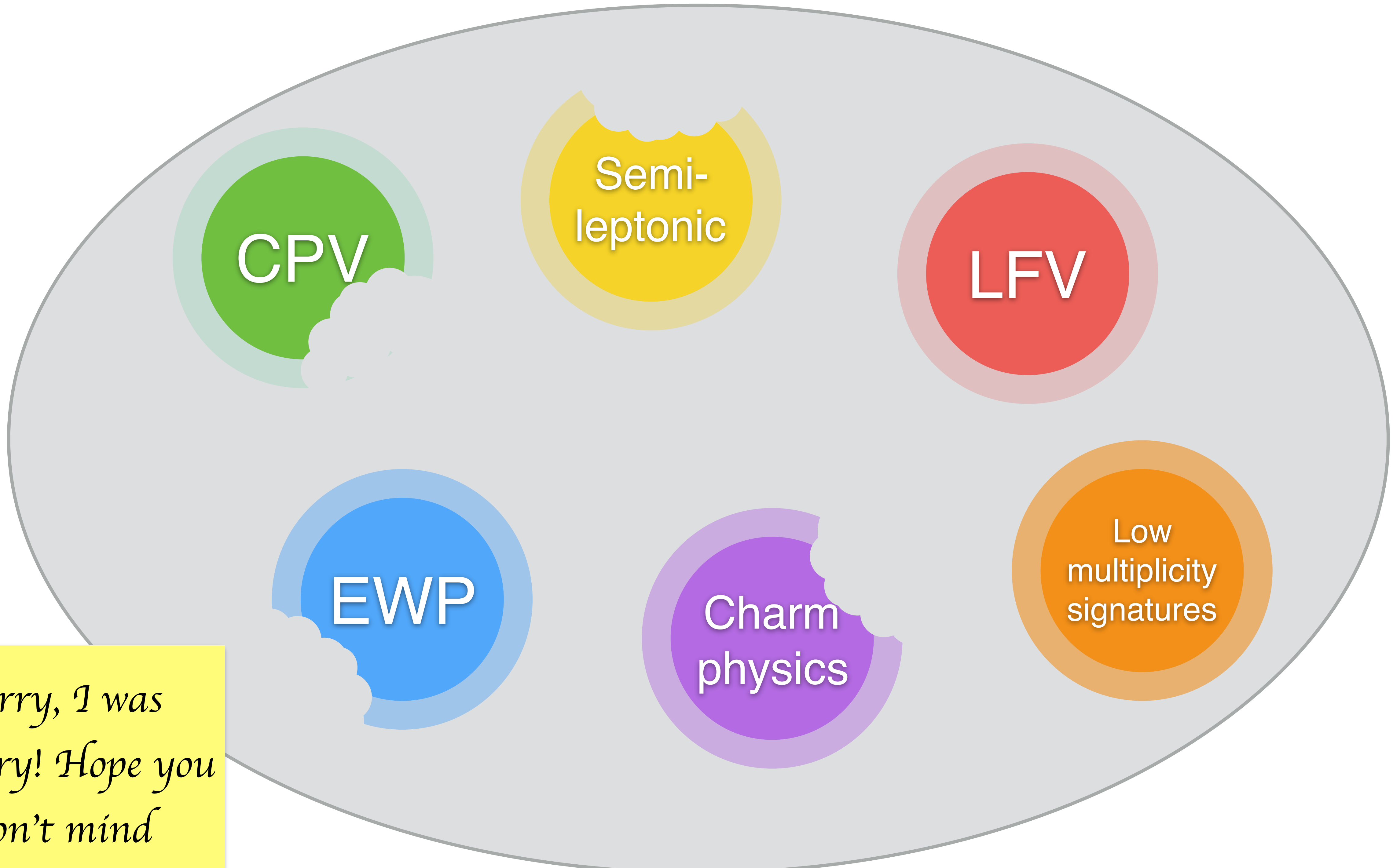
B-Factory results
a rich harvest

Belle II Physics
from CPV to dark photons

The open questions
a review of anomalies

Belle II Detector
concept and current status

Super B-Factory measurement candy bowl after LHCb had a treat



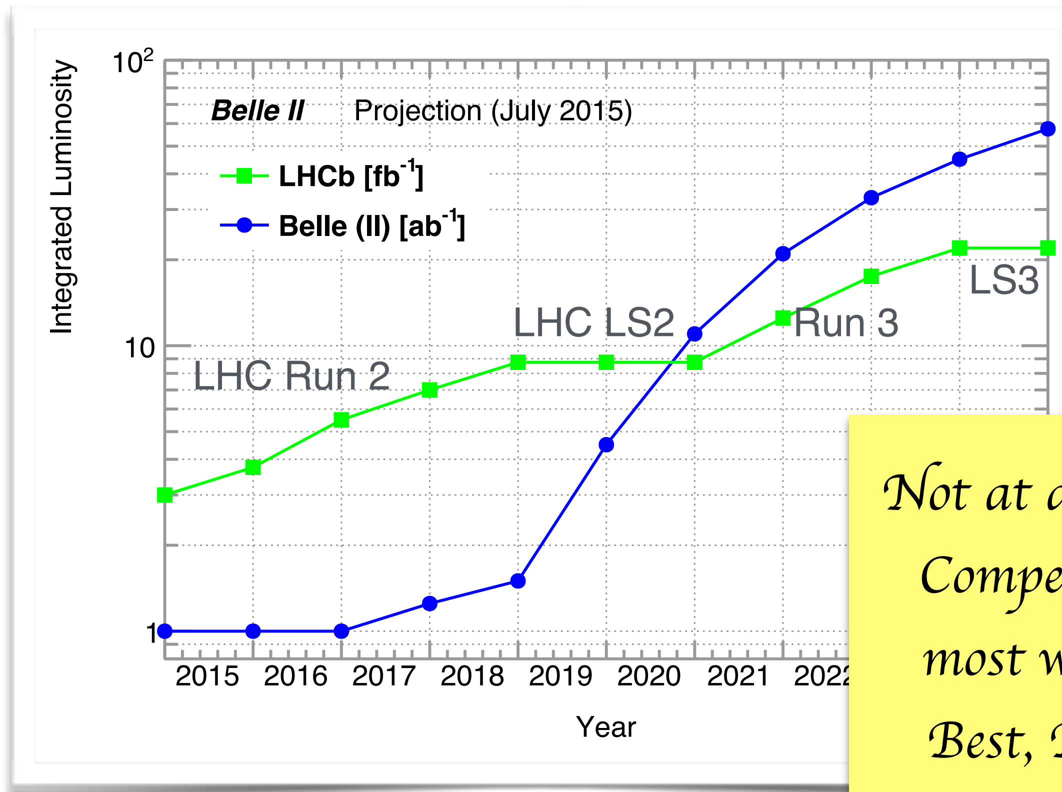
Sorry, I was hungry! Hope you don't mind
Best, LHCb

Belle II & LHCb: *On complementarity and overlap*

Rivalry and competition are a good thing:

- All *B*-factory results profited from scrutiny of the other team
- In the past schedules lined up nicely — with LHCb and Belle II things seem to lie a bit differently
  - LHCb is a running experiment, exceeding initial expectations
  - Belle II will record first collisions next year but won't start prior the end of 2018 with its physics run
- The provocative question one could ask is **'Will there be anything interesting left to measure?'**

- There are *overlaps* between the *physics programs*, but also enough unique strengths
  - *Large Baryonic samples* and *decays into visible particles* play into LHCb's corner
  - *Missing particles, inclusive measurements, low multiplicity final states* with little constraints are Belle II's forte
  - For some channels there will be a head-and-neck run — which is great!



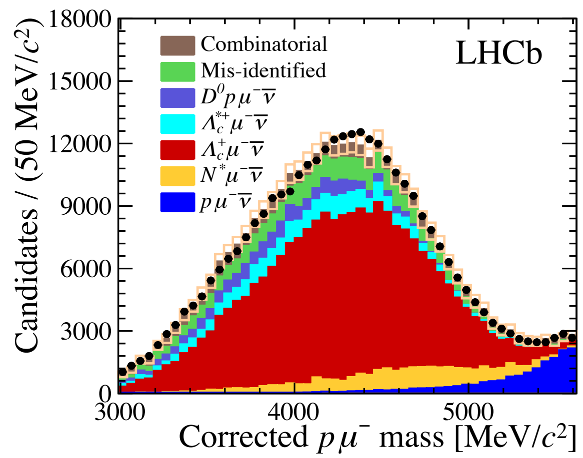
Estimates for 2024 data sets

LHCb 22/fb
Belle II 50/ab

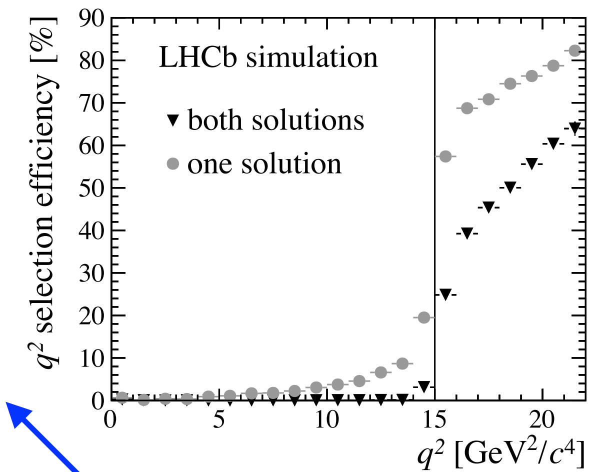
Not at all LHCb, Competition is most welcome! Best, Belle II

Semi-leptonic

Nature Physics 10 (2015) 1038



Signal(!)



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

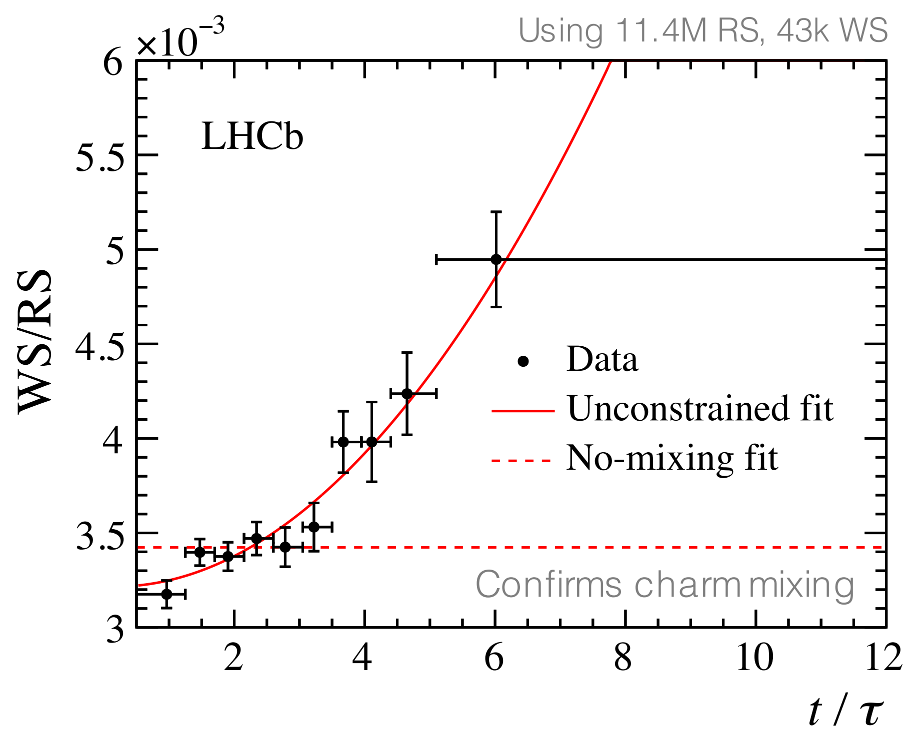
$$|V_{ub}| = (3.27 \pm 0.15 \pm 0.16 \pm 0.06) \times 10^{-3}\,,$$

Error on $|V_{ub}|$	tot.
LHCb 22/fb	**3.6%**
Belle II 50/ab	**2.2%**

2024 data sets

Charm physics

Using 11.4M RS, 43k WS

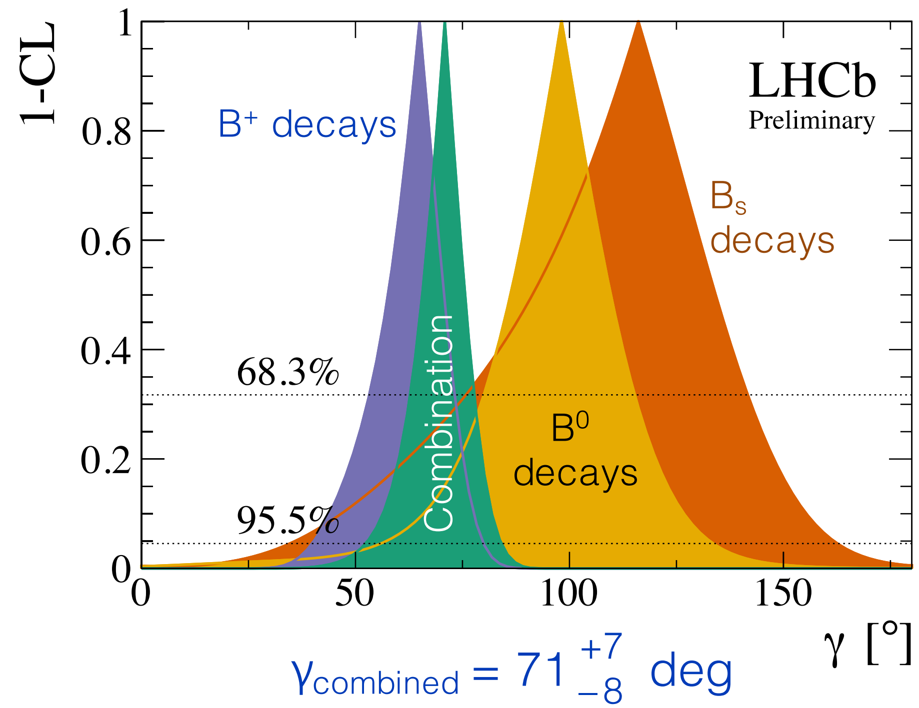


New, full 3 fb^{-1} result:

$\Delta A_{CP} = -0.10 \pm 0.08_{stat} \pm 0.03_{syst}$ %

Error on ΔA_{CP}	tot.
LHCb 22/fb	**0.03%**
Belle II 50/ab	**0.03%**

CPV

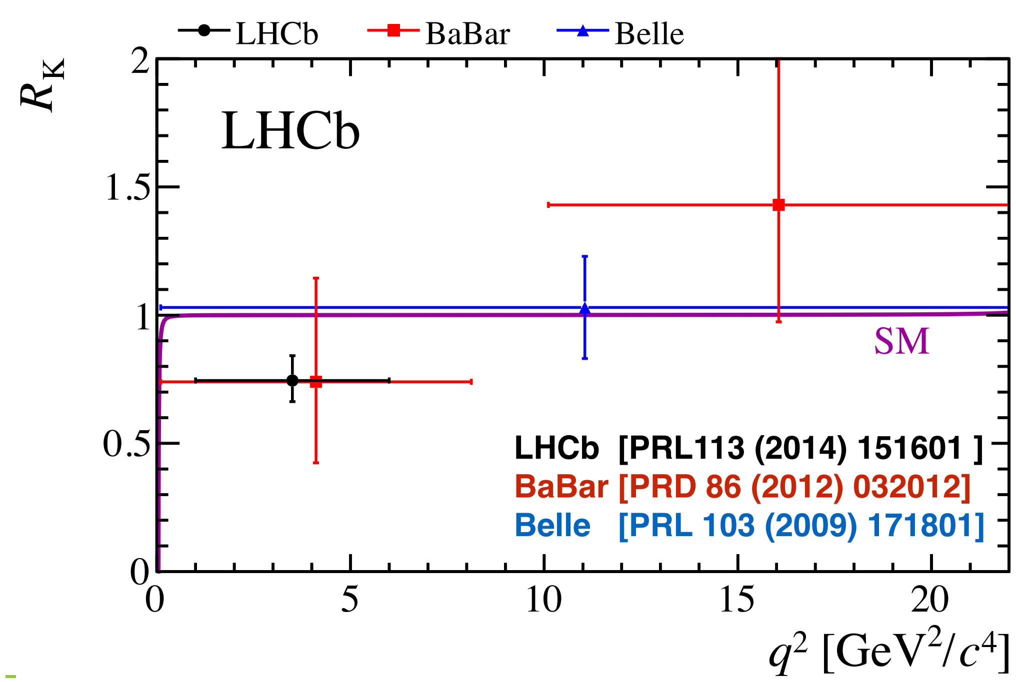


CKM fit: 68 ± 2 deg

Error on γ	tot.
LHCb 22/fb	**2°**
Belle II 50/ab	**1.5°**

Error on sin(2β) from B → J/ψ K_S	tot.
LHCb 22/fb	**0.014**
Belle II 50/ab	**0.007**

EWP



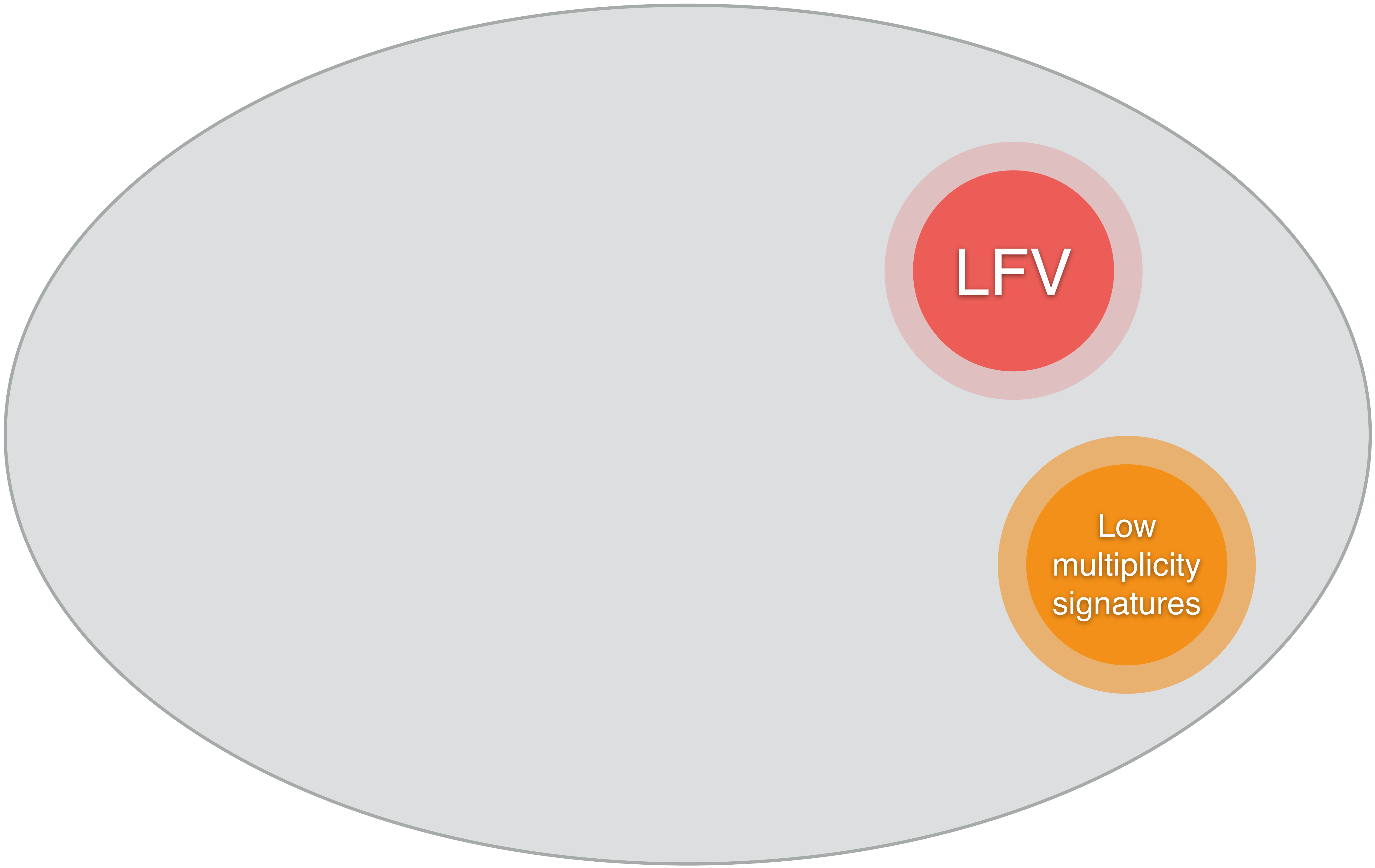
$$R_K = \frac{BR(B^+ \to K^+\mu^+\mu^-)}{BR(B^+ \to K^+e^+e^-)}$$

R_K	low q^2	high q^2
LHCb 22/fb	**4.4%**	**-**
Belle II 50/ab	**3%**	**3%**

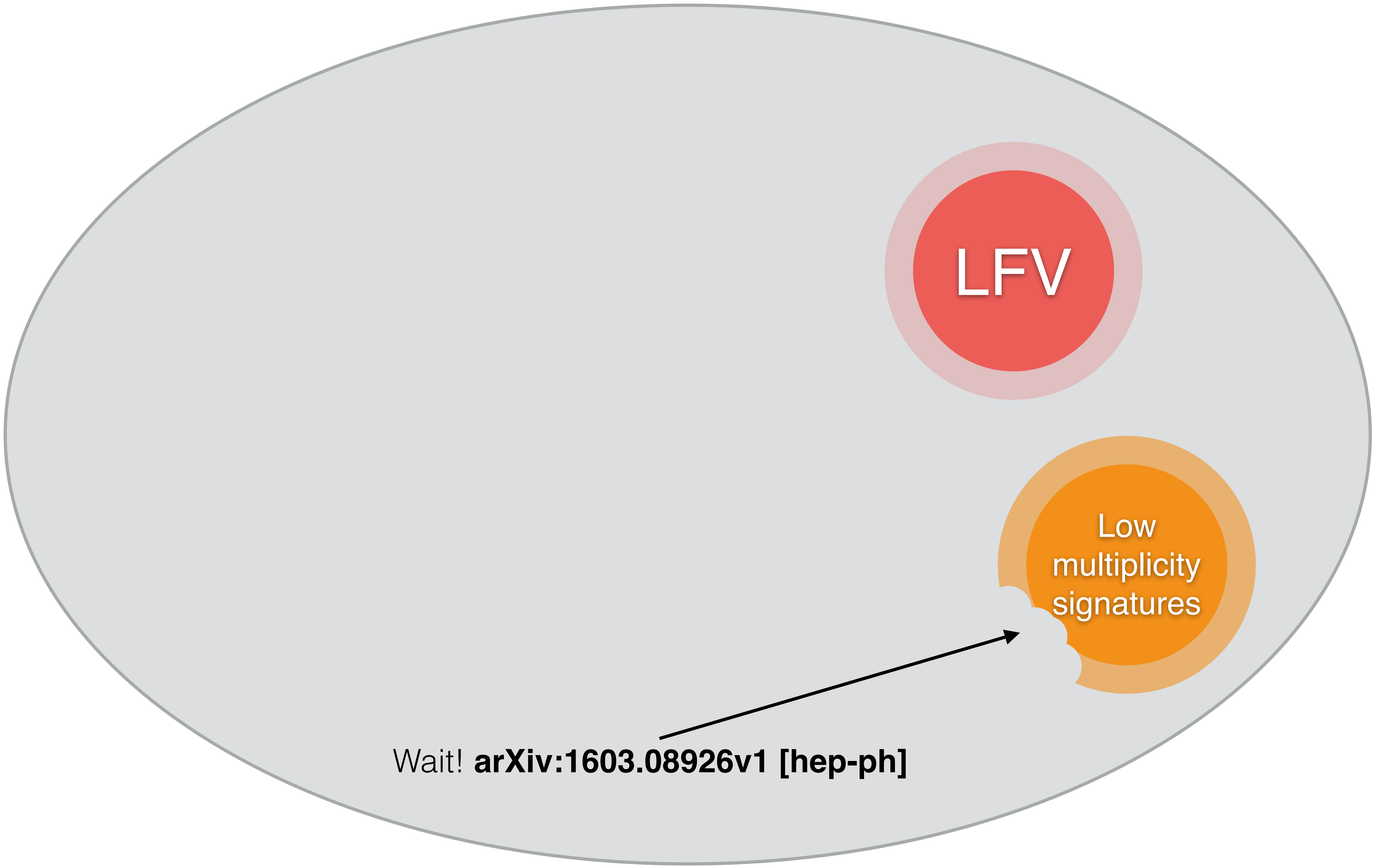
R_{K^*}	low q^2	high q^2
Belle II 50/ab	**4%**	**4%**

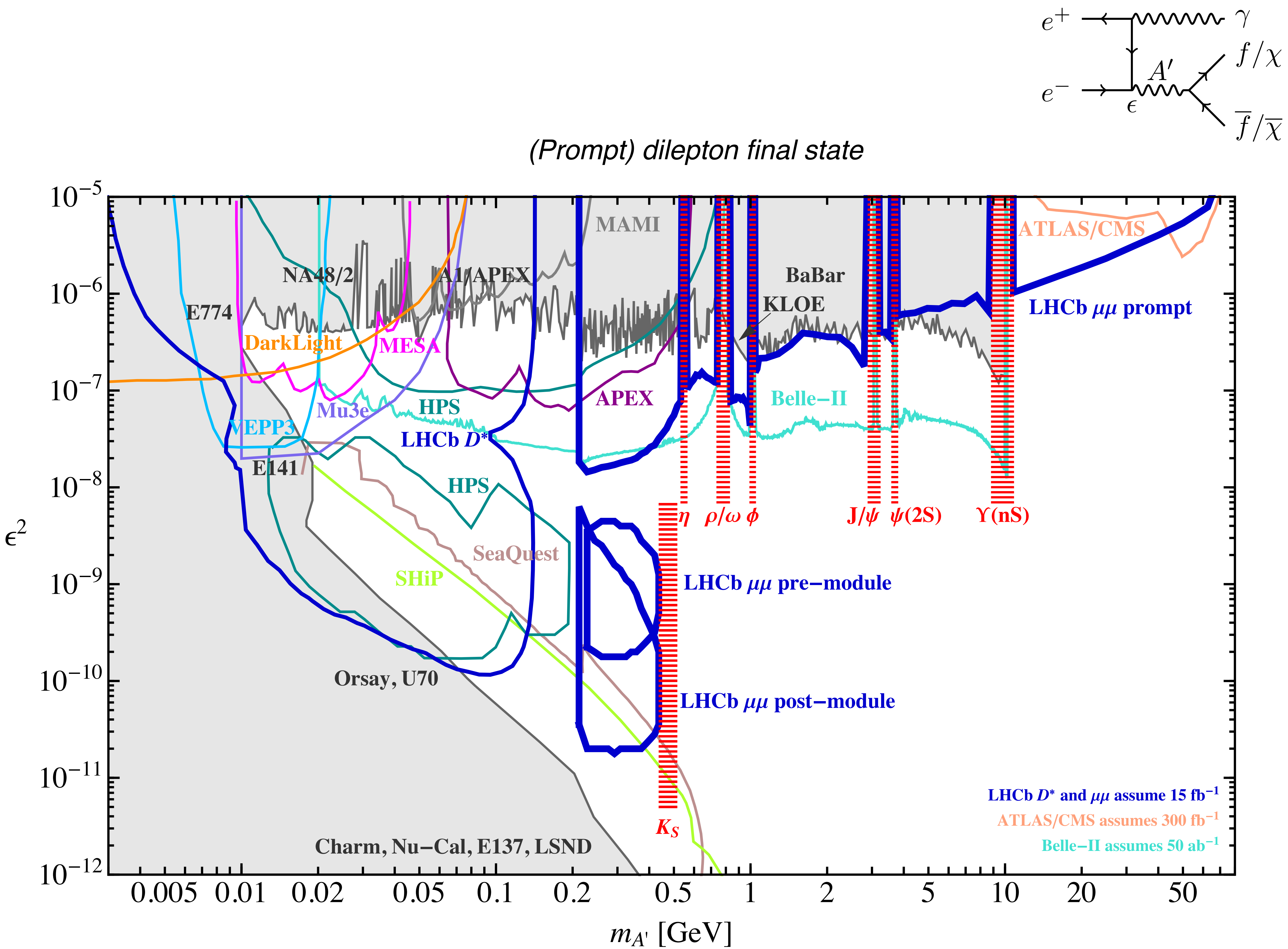
R_{X_s}	low q^2	high q^2
Belle II 50/ab	**5%**	**5%**

And there are the untouched pieces…



And there are the untouched pieces…





e^+
e^-
γ
A'
ϵ
f/χ
$\overline{f}/\overline{\chi}$
(Prompt) dilepton final state
MAMI
ATLAS/CMS
NA48/2
A1/APEX
BaBar
KLOE
LHCb $\mu\mu$ prompt
E774
DarkLight
MESA
APEX
Belle−II
HPS
Mu3e
VEPP3
LHCb D^*
E141
HPS
SeaQuest
SHiP
η
ρ/ω
ϕ
J/ψ
ψ(2S)
Υ(nS)
LHCb $\mu\mu$ pre−module
LHCb $\mu\mu$ post−module
Orsay, U70
K_S
Charm, Nu−Cal, E137, LSND
LHCb D^* and $\mu\mu$ assume 15 fb^{-1}
ATLAS/CMS assumes 300 fb^{-1}
Belle−II assumes 50 ab^{-1}
ϵ^2
$m_{A'}$ [GeV]

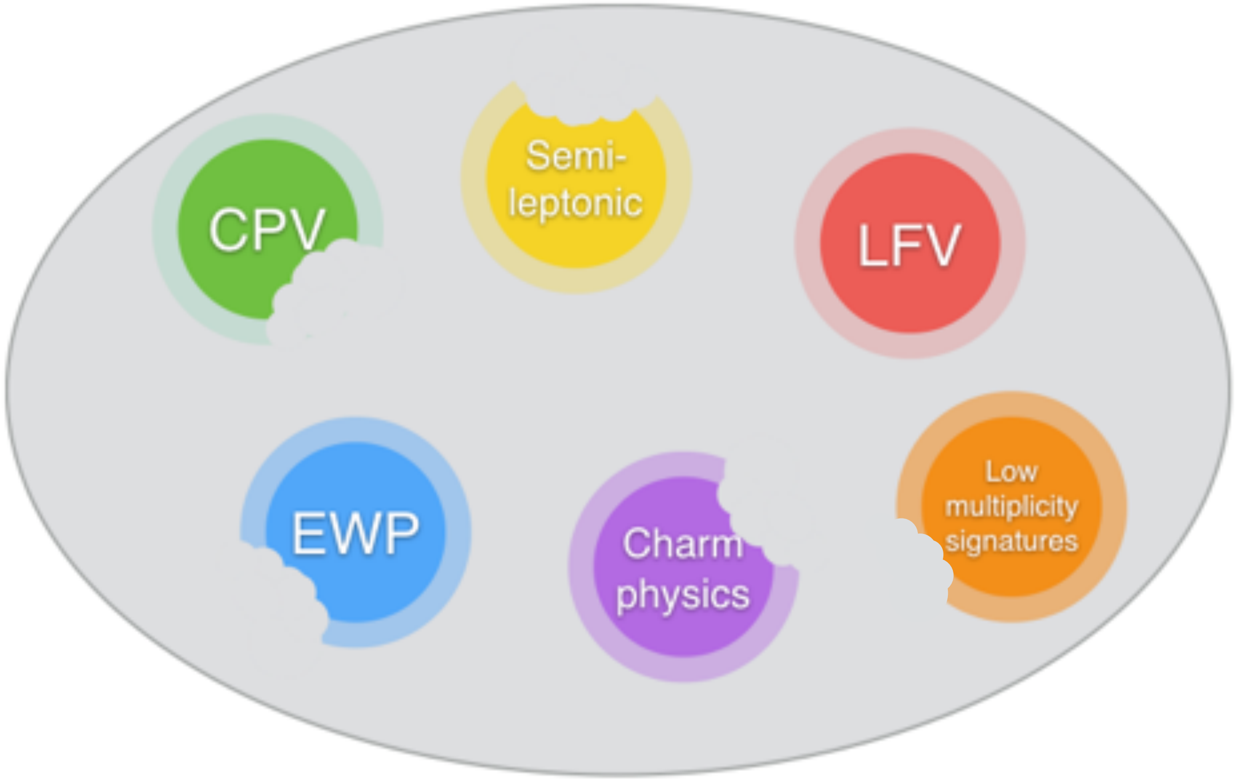
Summary

I hope this got you a tad excited about Belle II and its physics potential

Things will become increasingly interesting at the intensity frontier with the LHCb upgrade and the turn-on of Belle II at the end of 2018

- Belle II and LHCb have competing topics, but also unique focal points and strengths

The sensitivity gain of the era of the Super B-Factories will keep things interesting



Stay tuned and keep snacking!

Special Thanks to

The organizers for inviting me *and*

Phillip Urquijo

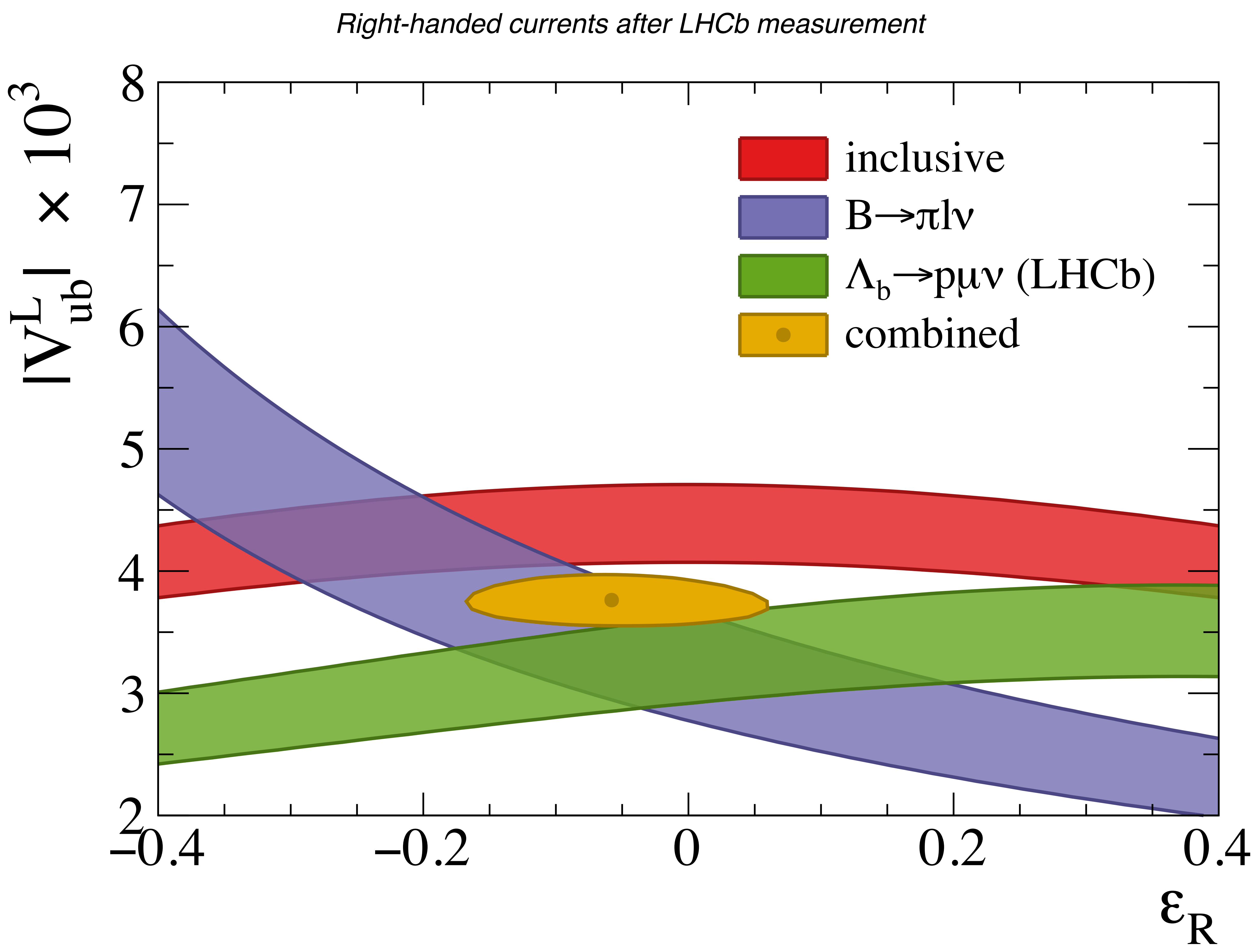
Christoph Schwanda

Marcello Rotondo

Andreas Warburton

Tim Gershon

Backup



Right-handed currents after LHCb measurement
$|V_{ub}^{L}| \times 10^3$
ε_R
inclusive
$B \rightarrow \pi l \nu$
$\Lambda_b \rightarrow p \mu \nu$ (LHCb)
combined
2
3
4
5
6
7
8
−0.4
−0.2
0
0.2
0.4

B-Factories and LHCb $|V_{ub}|$ Systematics

TABLE VIII: Systematic errors in % for $\mathcal{B}(B^0 \to \pi^- \ell^+ \nu)$ from the four-mode fit for bins in q^2 and the total q^2 range. The total errors are derived from the individual contributions taking into account the complete covariance matrix.

$B \to \pi \ell \nu$							
q^2 range (GeV^2)	0-4	4-8	8-12	12-16	16-20	>20	0-26.4
Track efficiency	3.4	1.5	2.3	0.1	1.5	2.8	1.9
Photon efficiency	0.1	1.4	1.0	4.6	2.8	0.3	1.8
Lepton identification	3.8	1.6	1.9	1.8	1.9	3.0	1.8
K_L efficiency	1.0	0.1	0.5	4.5	0.4	2.0	1.4
K_L shower energy	0.1	0.1	0.1	0.8	0.9	3.8	0.7
K_L spectrum	1.6	1.9	2.2	3.1	4.4	2.3	2.5
$B \to \pi \ell \nu FF\ f_+$	0.5	0.5	0.5	0.6	1.0	1.0	0.6
$B \to \rho \ell \nu FF A_1$	1.7	1.2	3.4	2.0	0.1	1.6	1.7
$B \to \rho \ell \nu FF A_2$	1.3	0.8	2.6	1.0	0.1	0.4	1.1
$B \to \rho \ell \nu FF V$	0.2	0.3	0.9	0.7	0.1	0.5	0.5
$\mathcal{B}(B^+ \to \omega \ell^+ \nu)$	0.1	0.1	0.1	0.2	0.3	1.5	0.2
$\mathcal{B}(B^+ \to \eta \ell^+ \nu)$	0.1	0.1	0.2	0.2	0.2	0.5	0.2
$\mathcal{B}(B^+ \to \eta' \ell^+ \nu)$	0.1	0.1	0.1	0.1	0.1	0.3	0.1
$\mathcal{B}(B \to X_u \ell \nu)$	0.2	0.1	0.1	0.1	1.1	1.6	0.4
$B \to X_u \ell \nu$ SF param.	0.4	0.1	0.2	0.2	0.5	4.2	0.7
$B \to D \ell \nu$ FF ρ^2_D	0.2	0.1	0.5	0.3	0.2	0.7	0.3
$B \to D^* \ell \nu$ FF R_1	0.1	0.4	0.8	0.6	0.3	0.6	0.5
$B \to D^* \ell \nu$ FF R_2	0.5	0.2	0.1	0.2	0.1	0.4	0.2
$B \to D^* \ell \nu$ FF $\rho^2_{D^*}$	0.7	0.2	0.6	0.8	0.4	1.1	0.6
$\mathcal{B}(B \to D \ell \nu)$	0.2	0.2	0.3	0.4	0.5	0.5	0.3
$\mathcal{B}(B \to D^* \ell \nu)$	0.4	0.1	0.3	0.3	0.3	0.7	0.3
$\mathcal{B}(B \to D^{**} \ell \nu)_{\mathrm{narrow}}$	0.4	0.1	0.1	0.3	0.1	0.5	0.2
$\mathcal{B}(B \to D^{**} \ell \nu)_{\mathrm{broad}}$	0.1	0.1	0.1	0.5	0.1	0.2	0.2
Secondary leptons	0.5	0.2	0.3	0.2	0.2	0.7	0.3
Continuum	5.3	1.0	2.6	1.8	3.1	6.1	2.0
Bremsstrahlung	0.3	0.1	0.1	0.1	0.1	0.4	0.2
Radiative corrections	0.5	0.1	0.1	0.2	0.2	0.6	0.3
$N_{B\overline{B}}$	1.2	1.0	1.2	1.2	1.1	1.6	1.2
B lifetimes	0.3	0.3	0.3	0.3	0.3	0.7	0.3
$f_\pm / f_{00}$	1.0	0.4	0.8	0.8	0.5	1.3	0.8
Total syst. error	8.2	3.9	6.7	8.3	6.9	10.6	5.0

Source	Relative uncertainty (%)
$\mathcal{B}(\Lambda_c^+ \to p K^+ \pi^-)$	$^{+4.7}_{-5.3}$
Trigger	3.2
Tracking	3.0
Λ_c^+ selection efficiency	3.0
$\Lambda_b^0 \to N^* \mu^- \overline{\nu}_\mu$ shapes	2.3
Λ_b^0 lifetime	1.5
Isolation	1.4
Form factor	1.0
Λ_b^0 kinematics	0.5
q^2 migration	0.4
PID	0.2
Total	$^{+7.8}_{-8.2}$

B-Factories R(D) / R(D*) Systematics

Source of uncertainty	Fractional uncertainty (%)						Correlation		
	$\mathcal{R}(D^0)$	$\mathcal{R}(D^{*0})$	$\mathcal{R}(D^+)$	$\mathcal{R}(D^{*+})$	$\mathcal{R}(D)$	$\mathcal{R}(D^*)$	D^0/D^{*0}	D^+/D^{*+}	D/D^*
Additive uncertainties									
PDFs									
MC statistics	6.5	2.9	5.7	2.7	4.4	2.0	−0.70	−0.34	−0.56
$\overline{B} \to D^{(*)}(\tau^-/\ell^-)\overline{\nu}$ FFs	0.3	0.2	0.2	0.1	0.2	0.2	−0.52	−0.13	−0.35
$D^{**} \to D^{(*)}(\pi^0/\pi^\pm)$	0.7	0.5	0.7	0.5	0.7	0.5	0.22	0.40	0.53
$\mathcal{B}(\overline{B} \to D^{**}\ell^-\overline{\nu}_\ell)$	1.0	0.4	1.0	0.4	0.8	0.3	−0.63	−0.68	−0.58
$\mathcal{B}(\overline{B} \to D^{**}\tau^-\overline{\nu}_\tau)$	1.2	2.0	2.1	1.6	1.8	1.7	1.00	1.00	1.00
$D^{**} \to D^{(*)}\pi\pi$	2.1	2.6	2.1	2.6	2.1	2.6	0.22	0.40	0.53
Cross-feed constraints									
MC statistics	2.6	0.9	2.1	0.9	2.4	1.5	0.02	−0.02	−0.16
$f_{D^{**}}$	6.2	2.6	5.3	1.8	5.0	2.0	0.22	0.40	0.53
Feed-up/feed-down	1.9	0.5	1.6	0.2	1.3	0.4	0.29	0.51	0.47
Isospin constraints	–	–	–	–	1.2	0.3	–	–	−0.60
Fixed backgrounds									
MC statistics	4.3	2.3	4.3	1.8	3.1	1.5	−0.48	−0.05	−0.30
Efficiency corrections	4.8	3.0	4.5	2.3	3.9	2.3	−0.53	0.20	−0.28
Multiplicative uncertainties									
MC statistics	2.3	1.4	3.0	2.2	1.8	1.2	0.00	0.00	0.00
$\overline{B} \to D^{(*)}(\tau^-/\ell^-)\overline{\nu}$ FFs	1.6	0.4	1.6	0.3	1.6	0.4	0.00	0.00	0.00
Lepton PID	0.6	0.6	0.6	0.5	0.6	0.6	1.00	1.00	1.00
$\pi^0/\pi^\pm$ from $D^* \to D\pi$	0.1	0.1	0.0	0.0	0.1	0.1	1.00	1.00	1.00
Detection/Reconstruction	0.7	0.7	0.7	0.7	0.7	0.7	1.00	1.00	1.00
$\mathcal{B}(\tau^- \to \ell^-\overline{\nu}_\ell\nu_\tau)$	0.2	0.2	0.2	0.2	0.2	0.2	1.00	1.00	1.00
Total syst. uncertainty	12.2	6.7	11.4	6.0	9.6	5.5	−0.21	0.10	0.05
Total stat. uncertainty	19.2	9.8	18.0	11.0	13.1	7.1	−0.59	−0.23	−0.45
Total uncertainty	22.7	11.9	21.3	12.5	16.2	9.0	−0.48	−0.15	−0.27

Table 1: Systematic uncertainties in the extraction of $\mathcal{R}(D^*)$.

Model uncertainties	**Absolute size ($\times 10^{-2}$)**
Simulated sample size	2.0
Misidentified μ template shape	1.6
$\overline{B}^0 \to D^{*+}(\tau^-/\mu^-)\overline{\nu}$ form factors	0.6
$\overline{B} \to D^{*+}H_c(\to \mu\nu X')X$ shape corrections	0.5
$\mathcal{B}(\overline{B} \to D^{**}\tau^-\overline{\nu}_\tau)/\mathcal{B}(\overline{B} \to D^{**}\mu^-\overline{\nu}_\mu)$	0.5
$\overline{B} \to D^{**}(\to D^*\pi\pi)\mu\nu$ shape corrections	0.4
Corrections to simulation	0.4
Combinatorial background shape	0.3
$\overline{B} \to D^{**}(\to D^{*+}\pi)\mu^-\overline{\nu}_\mu$ form factors	0.3
$\overline{B} \to D^{*+}(D_s \to \tau\nu)X$ fraction	0.1
Total model uncertainty	**2.8**
Normalization uncertainties	**Absolute size ($\times 10^{-2}$)**
Simulated sample size	0.6
Hardware trigger efficiency	0.6
Particle identification efficiencies	0.3
Form-factors	0.2
$\mathcal{B}(\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau)$	< 0.1
Total normalization uncertainty	**0.9**
Total systematic uncertainty	**3.0**

LHCb and Belle $\sin(2\beta = 2\,\phi_1)$

Origin	$\sigma(S_{J/\psi\,K^0_S})$	$\sigma(C_{J/\psi\,K^0_S})$
Tagging calibration	0.034	0.001
Tagging efficiency difference	0.002	0.002
Decay time resolution	0.001	0.002
Decay time acceptance	0.002	0.006
Background model	0.012	0.009
Fit bias	0.004	0.005
Total	0.036	0.012

$$S_{J/\psi\,K^0_S} = 0.73 \pm 0.07\,(\text{stat}) \pm 0.04\,(\text{syst}),$$
$$C_{J/\psi\,K^0_S} = 0.03 \pm 0.09\,(\text{stat}) \pm 0.01\,(\text{syst}),$$

TABLE III: Systematic errors in $\mathcal{S}_f$ and $\mathcal{A}_f$ in each f_{CP} mode and for the sum of all modes.

		$J/\psi K^0_S$	$\psi(2S)K^0_S$	$\chi_{c1}K^0_S$	$J/\psi K^0_L$	All
Vertexing	$\mathcal{S}_f$	±0.008	±0.031	±0.025	±0.011	±0.007
	$\mathcal{A}_f$	±0.022	±0.026	±0.021	±0.015	±0.007
Δt	$\mathcal{S}_f$	±0.007	±0.007	±0.005	±0.007	±0.007
resolution	$\mathcal{A}_f$	±0.004	±0.003	±0.004	±0.003	±0.001
Tag-side	$\mathcal{S}_f$	±0.002	±0.002	±0.002	±0.001	±0.001
interference	$\mathcal{A}_f$	${}^{+0.038}_{-0.000}$	${}^{+0.038}_{-0.000}$	${}^{+0.038}_{-0.000}$	${}^{+0.000}_{-0.037}$	±0.008
Flavor	$\mathcal{S}_f$	±0.003	±0.003	±0.004	±0.003	±0.004
tagging	$\mathcal{A}_f$	±0.003	±0.003	±0.003	±0.003	±0.003
Possible	$\mathcal{S}_f$	±0.004	±0.004	±0.004	±0.004	±0.004
fit bias	$\mathcal{A}_f$	±0.005	±0.005	±0.005	±0.005	±0.005
Signal	$\mathcal{S}_f$	±0.004	±0.016	< 0.001	±0.016	±0.004
fraction	$\mathcal{A}_f$	±0.002	±0.006	< 0.001	±0.006	±0.002
Background	$\mathcal{S}_f$	< 0.001	±0.002	±0.030	±0.002	±0.001
Δt PDFs	$\mathcal{A}_f$	< 0.001	< 0.001	±0.014	< 0.001	< 0.001
Physics	$\mathcal{S}_f$	±0.001	±0.001	±0.001	±0.001	±0.001
parameters	$\mathcal{A}_f$	< 0.001	< 0.001	±0.001	< 0.001	< 0.001
Total	$\mathcal{S}_f$	±0.013	±0.036	±0.040	±0.021	±0.012
	$\mathcal{A}_f$	${}^{+0.045}_{-0.023}$	${}^{+0.047}_{-0.027}$	${}^{+0.046}_{-0.026}$	${}^{+0.017}_{-0.041}$	±0.012

Decay mode	$\sin 2\phi_1 \equiv -\xi_f \mathcal{S}_f$	$\mathcal{A}_f$
$J/\psi K^0_S$	$+0.670 \pm 0.029 \pm 0.013$	$-0.015 \pm 0.021^{+0.045}_{-0.023}$
$\psi(2S)K^0_S$	$+0.738 \pm 0.079 \pm 0.036$	$+0.104 \pm 0.055^{+0.047}_{-0.027}$
$\chi_{c1}K^0_S$	$+0.640 \pm 0.117 \pm 0.040$	$-0.017 \pm 0.083^{+0.046}_{-0.026}$
$J/\psi K^0_L$	$+0.642 \pm 0.047 \pm 0.021$	$+0.019 \pm 0.026^{+0.017}_{-0.041}$
All modes	$+0.667 \pm 0.023 \pm 0.012$	$+0.006 \pm 0.016 \pm 0.012$

LHCb γ Systematics for B -> Dh

$$A^{K\pi\pi^0}_{\mathrm{ADS}(K)} = -0.20 \pm 0.27 \pm 0.04$$
$$A^{K\pi\pi^0}_{\mathrm{ADS}(\pi)} = 0.438 \pm 0.190 \pm 0.011$$
$$A^{KK\pi^0}_{\mathrm{qGLW}(K)} = 0.30 \pm 0.20 \pm 0.02$$
$$A^{\pi\pi\pi^0}_{\mathrm{qGLW}(K)} = 0.054 \pm 0.091 \pm 0.011$$
$$A^{KK\pi^0}_{\mathrm{qGLW}(\pi)} = -0.030 \pm 0.040 \pm 0.005$$
$$A^{\pi\pi\pi^0}_{\mathrm{qGLW}(\pi)} = -0.016 \pm 0.020 \pm 0.004$$
$$A^{K\pi\pi^0}_{K} = 0.010 \pm 0.026 \pm 0.005$$
$$R^{K\pi\pi^0}_{\mathrm{ADS}(K)} = 0.0140 \pm 0.0047 \pm 0.0021$$
$$R^{K\pi\pi^0}_{\mathrm{ADS}(\pi)} = 0.00235 \pm 0.00049 \pm 0.00006$$
$$R^{KK\pi^0}_{\mathrm{qGLW}} = 0.95 \pm 0.22 \pm 0.05$$
$$R^{\pi\pi\pi^0}_{\mathrm{qGLW}} = 0.98 \pm 0.11 \pm 0.05$$
$$A_{\mathrm{Prod}} = -0.0008 \pm 0.0055 \pm 0.0050,$$

	PID	PDFs	Sim	A_{instr}	Total
$A^{K\pi\pi^0}_{\mathrm{ADS}(K)}$	3.4	39.6	8.7	5.7	41.1
$A^{K\pi\pi^0}_{\mathrm{ADS}(\pi)}$	1.6	7.5	4.5	6.9	11.3
$A^{KK\pi^0}_{\mathrm{qGLW}(K)}$	5.1	10.2	18.8	2.1	22.1
$A^{\pi\pi\pi^0}_{\mathrm{qGLW}(K)}$	0.9	7.9	7.3	0.9	10.8
$A^{KK\pi^0}_{\mathrm{qGLW}(\pi)}$	0.8	2.2	1.2	4.4	5.1
$A^{\pi\pi\pi^0}_{\mathrm{qGLW}(\pi)}$	0.3	0.9	0.7	4.2	4.4
$A^{K\pi\pi^0}_{K}$	0.4	0.9	1.4	4.2	4.6
$R^{K\pi\pi^0}_{\mathrm{ADS}(K)}$	0.3	2.0	0.6	0.1	2.1
$R^{K\pi\pi^0}_{\mathrm{ADS}(\pi)}$	0.02	0.05	0.02	0.01	0.06
$R^{KK\pi^0}_{\mathrm{qGLW}}$	23.8	24.9	36.5	7.7	50.8
$R^{\pi\pi\pi^0}_{\mathrm{qGLW}}$	8.1	20.7	42.5	5.3	48.3
A_{Prod}	0.3	0.3	0.5	5.0	5.0