LHC interplay with SuperKEKB

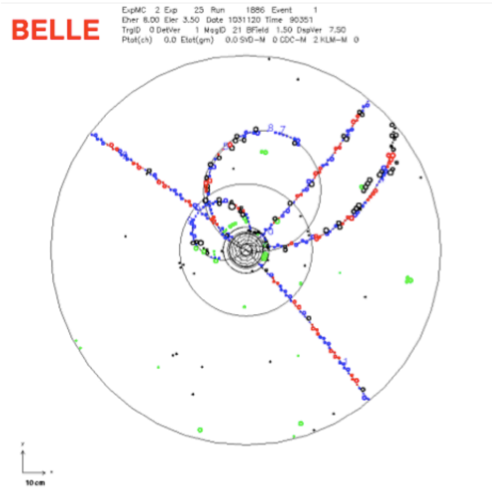
Marie-Hélène Schune
LAL, Orsay

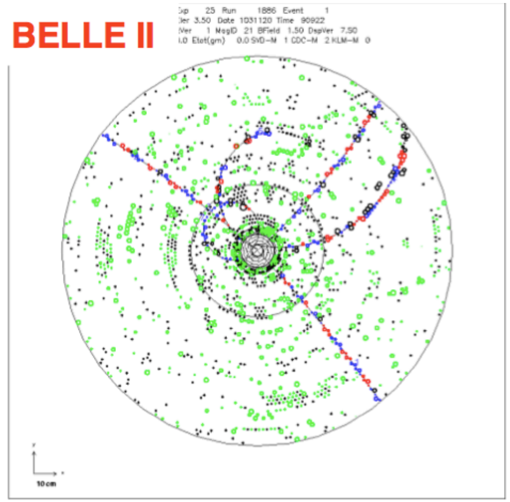
- Environments
- CPV measurements
- Semileptonic decays
- Rare decays

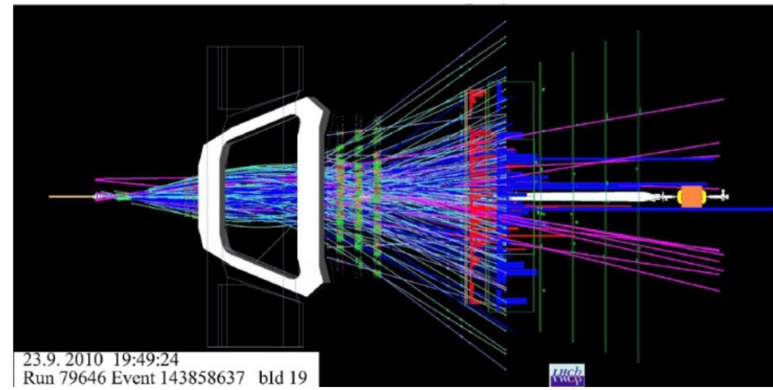
Environments

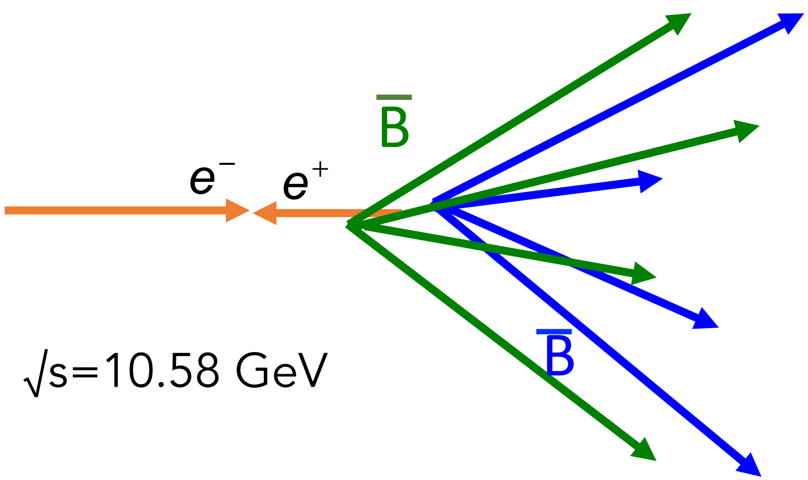
B-Factories

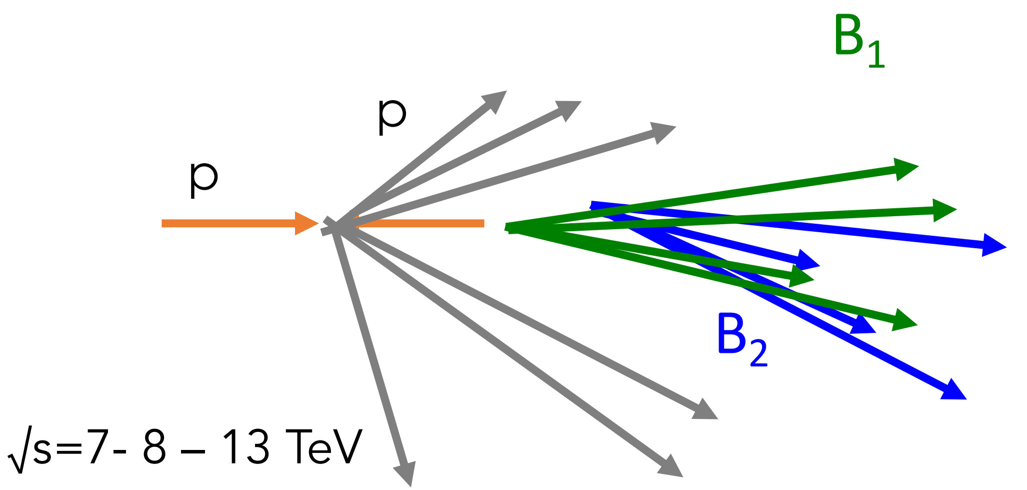
LHCb











Δt

t_B

no fragmentation tracks, B^0 and B^+ only
coherent state

All b-hadron species, incoherent production
Fragmentation

B-Factories !

BaBar and Belle : ~1.1 10^9 $B\overline{B}$

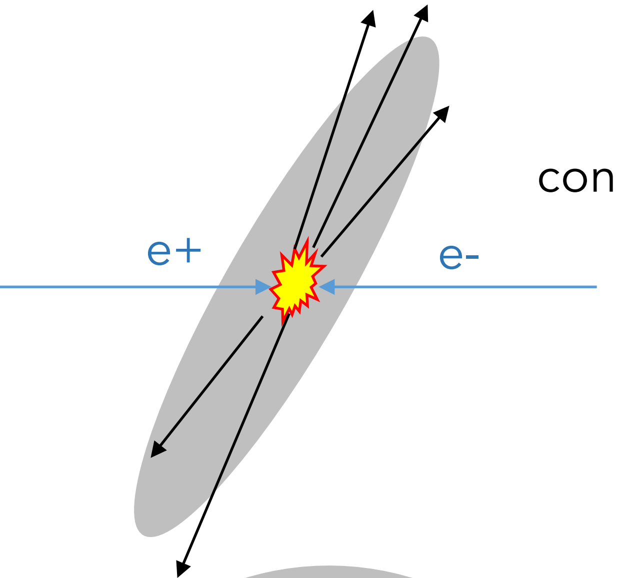
LHCb ~ 10^{12} $b\bar{b}$ in the detector

Period	E (TeV)	Int Lumi (fb^{-1})
2011	7	~ 1
2012	8	~ 2
2015-2018	13	~5.5

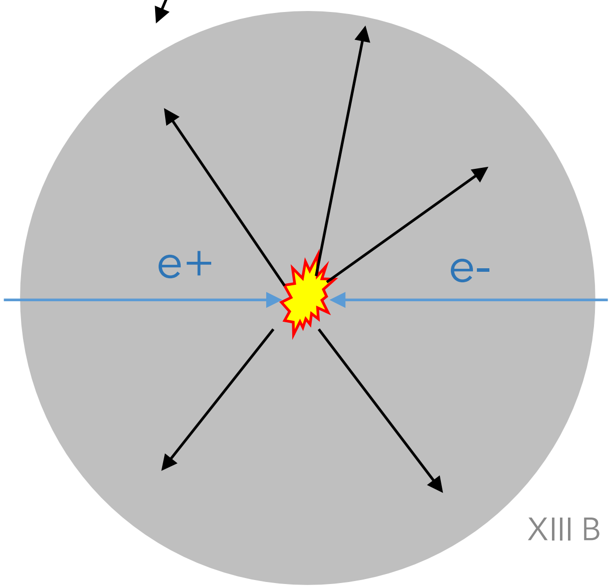
$b\bar{b}$ cross-section is about 5 orders of magnitude larger at the LHC

$\sigma(bb\text{-}\ \Upsilon(4S))\ /\sigma(\text{inelastic}) \sim 1/4$ $\sigma(bb\text{-}\ \text{LHC})/\sigma(\text{inelastic}) \sim 1/300$ at 7 TeV

Continuum suppression at BaBar/Belle(2)



continuum is jet like



BB

Trigger at LHC

LHC : 15 MHz of visible crossing

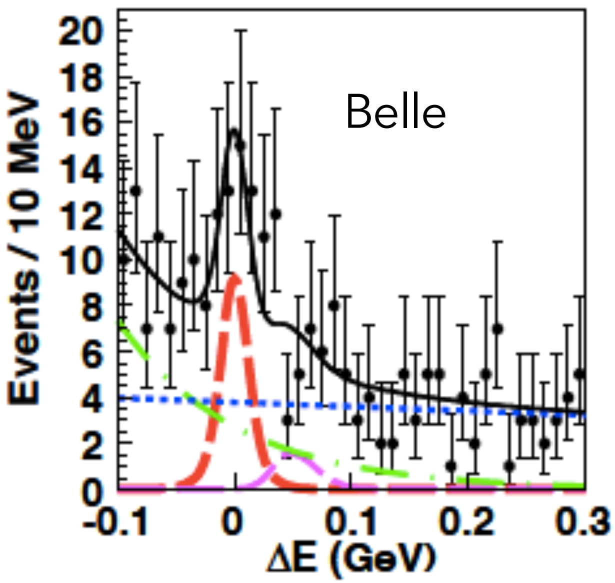
LHCb : readout of the detector : 1 MHz

⟹ hardware trigger

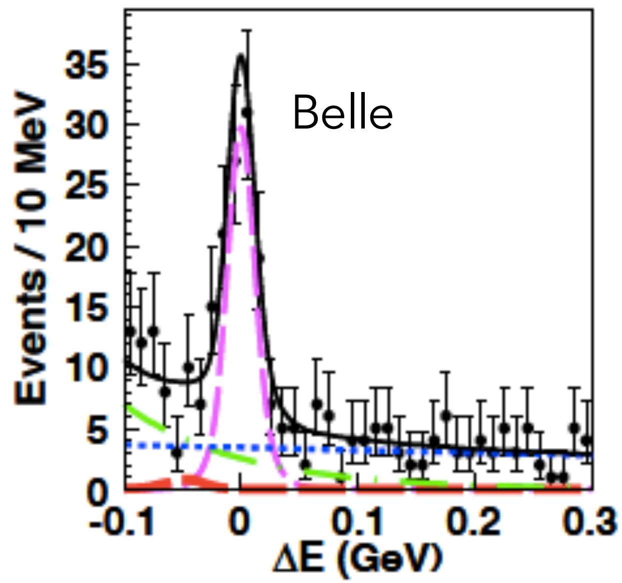
	B-Factories	LHCb
Average B-flight distance	250 → 130 µm	1 cm
Event multiplicity	~10	~100
Number of channels	0,1 M	1,1 M
Trigger efficiency	> 99%	~90% - 20%

Final states with π and K : ex of B→D(→ Kπ) K

B→(K⁺ π)_D K⁻



B→(K⁺ π)_D π⁻

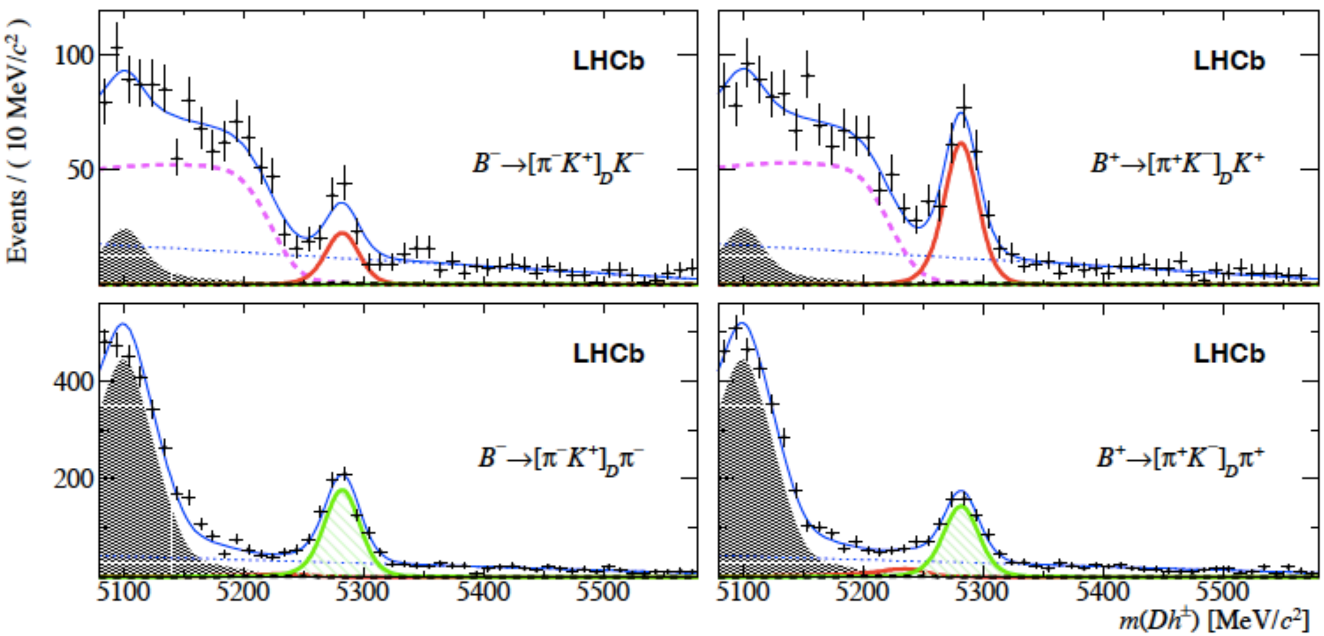


56 events

165 events

PRL 106 (2011) 231803

Belle full statistics



553 events

LHCb Run1

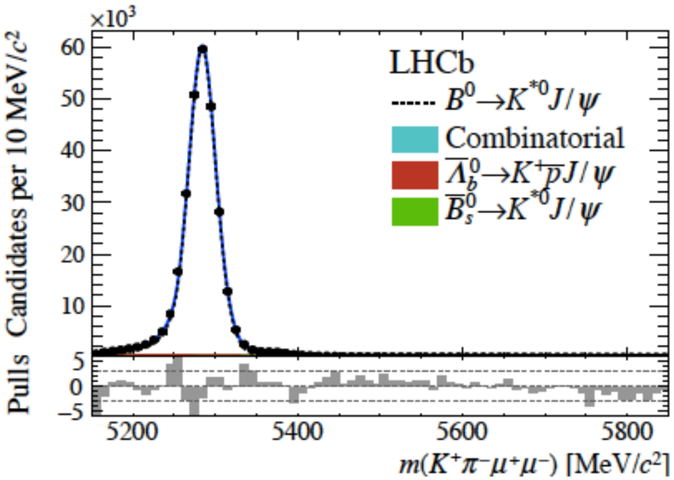
1360 events

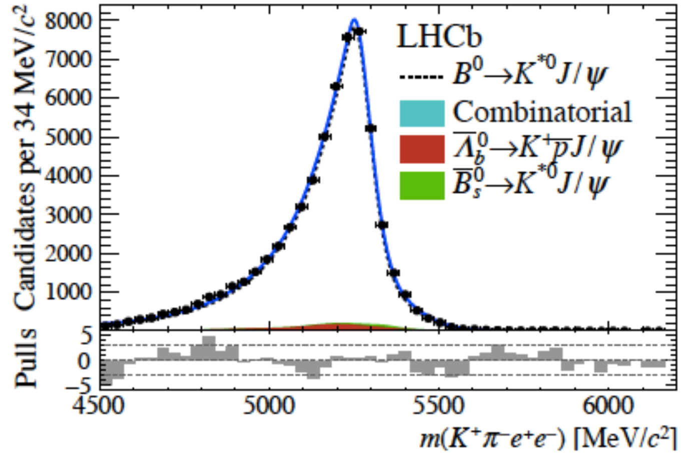
PLB 760 (2016), pp. 117-131

Final states with electrons/muons :

JHEP08 (2017) 055

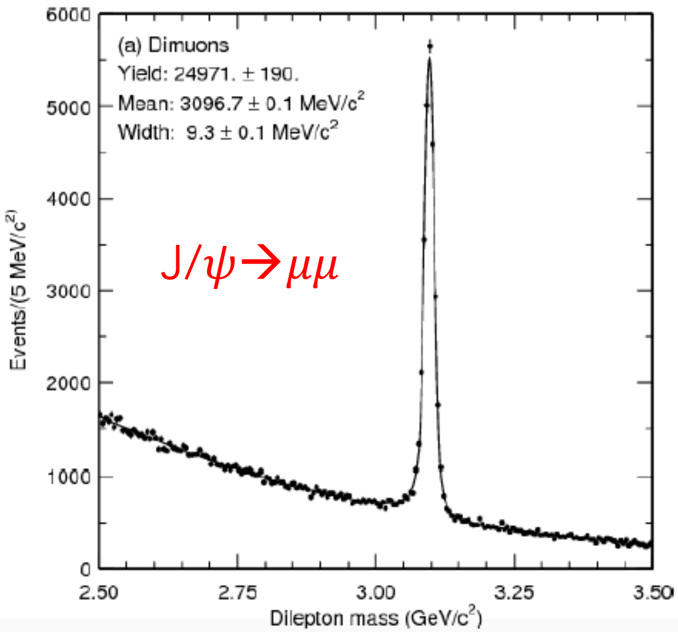
N(B→J/ψ(→$\mu\mu$)K(π)) ~ 5 N(B→J/ψ(→ee) K(π)))

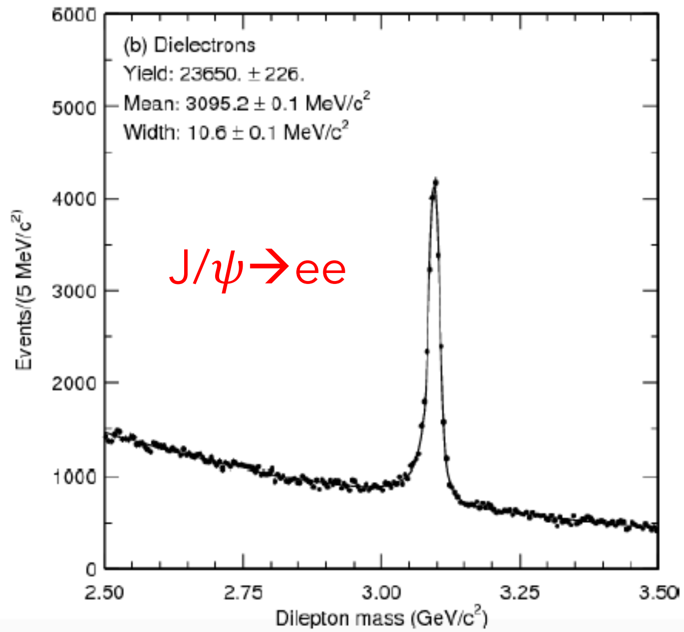




LHCb

N(ee)<<N(μμ)
Significant
brem tail





Phys ReV D67 (2003) 032003

Belle

Similar yields
Low Brem tail

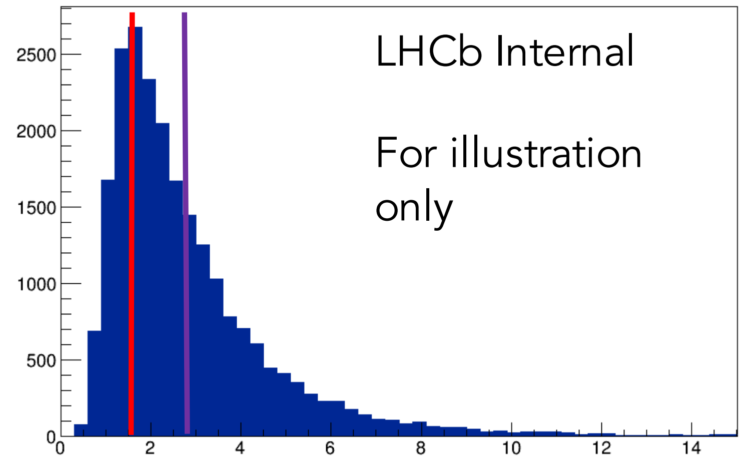
LHC : 15 MHz of visible crossing

LHCb : readout of the detector : 1 MHz

$\Rightarrow$ hardware trigger :

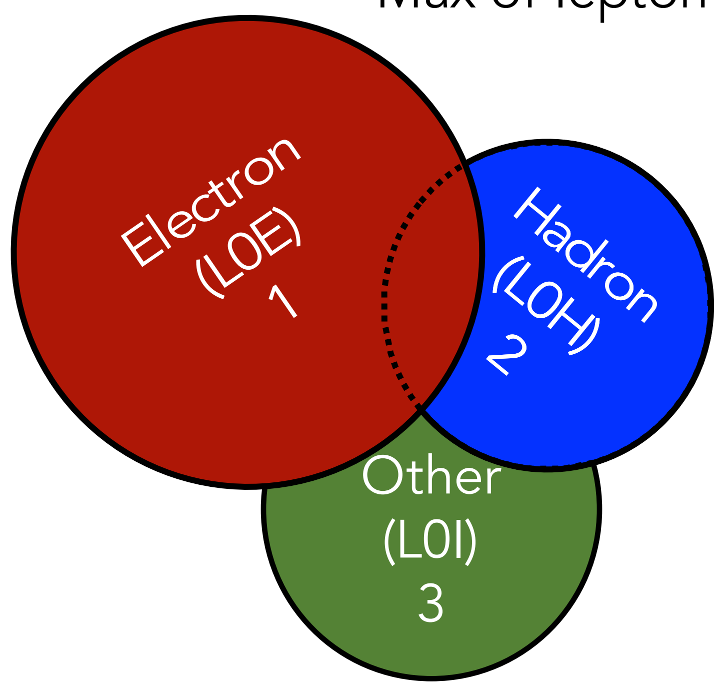
L0 Muon $p_T > 1.5$ - 1.8 GeV
L0 Electron $E_T > 2.5 – 3.0$ GeV
L0 Hadron $E_T > 3.5$ GeV

$K^* \ell\ell$ Generator level, $1.1 < q^2 < 6$ GeV$^2/c^4$



Electron channels :
three exclusive trigger categories

Muon channels :
one single muon trigger category



Tagging

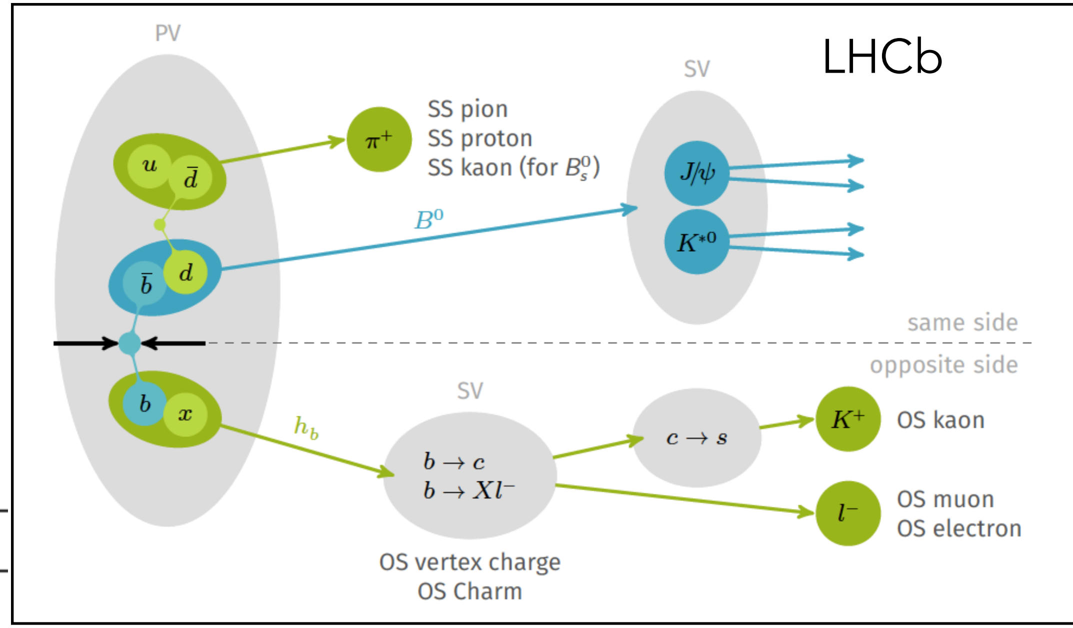
$$Q = \varepsilon_{\text{tag}}(1 - 2w)^2$$

$$\sigma \propto \frac{1}{\sqrt{Q}}.$$ uncertainty on an CP asymmetry

Multivariate tagging algorithms

BaBar

Category	$\varepsilon_{\text{tag}}(\%)$	$Q(\%)$
Lepton	9.7 ± 0.1	8.9 ± 0.1
Kaon I	11.3 ± 0.1	9.6 ± 0.1
Kaon II	15.9 ± 0.1	8.7 ± 0.2
Kaon-Pion	13.2 ± 0.1	3.9 ± 0.1
Pion	16.8 ± 0.1	1.9 ± 0.1
Other	10.6 ± 0.1	0.28 ± 0.03
Total	77.5 ± 0.1	33.1 ± 0.3



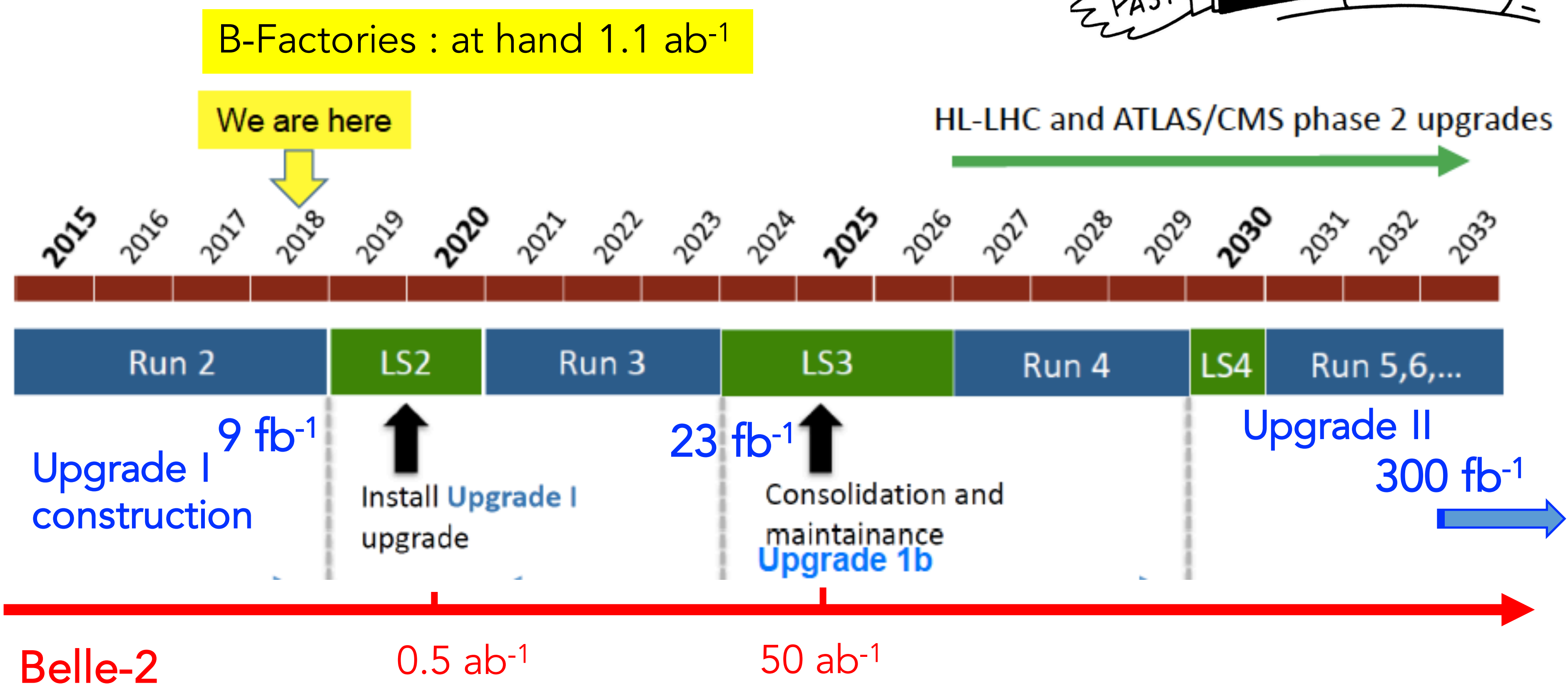
At LHCb Q ~ 6 %

differs significantly from a decay channel to another

Belle-2 : expecting similar performances (37 %)

Sensitive to nPV

Future plans



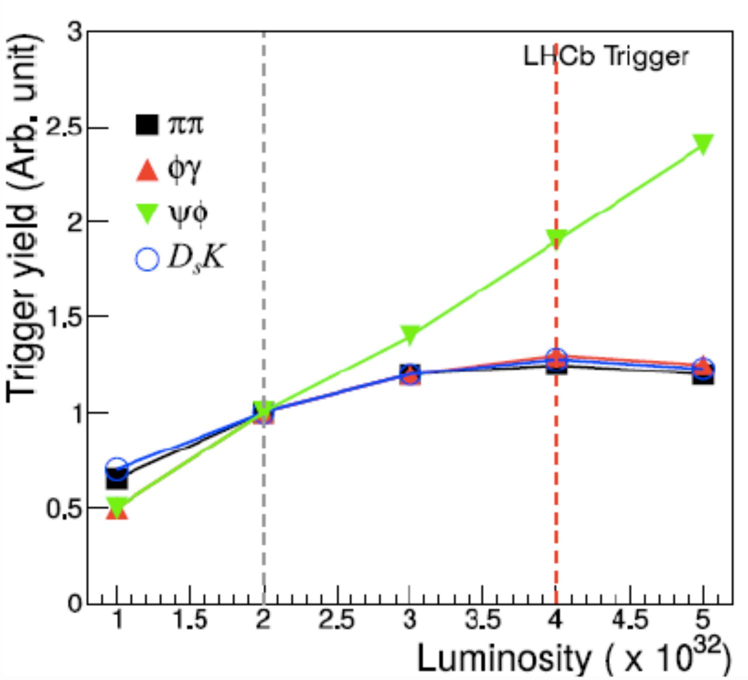
LHCb : arXiv 1808.08865

Belle-2 arXiv 1808.10567

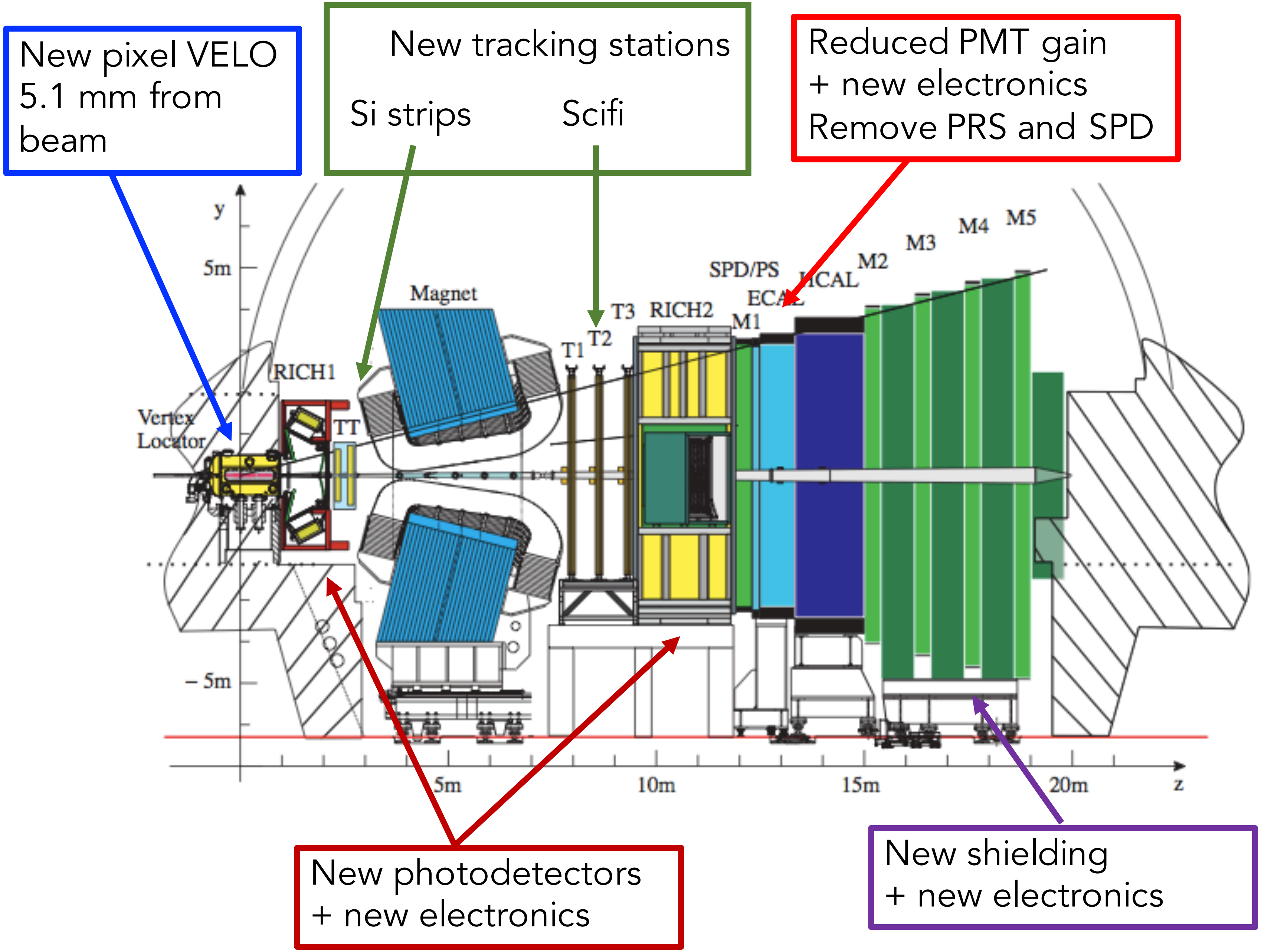
LHCb Upgrade I

- Under construction
- Factor 5 in luminosity increase

Replace 90% of the channels
New RO electronics (40 MHz)
New DAQ and data center
Software trigger only



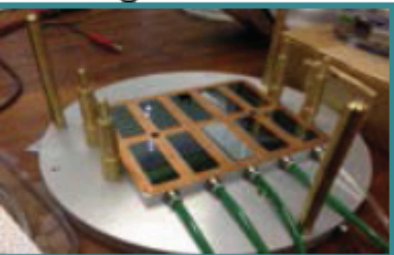
Get rid of this limitation



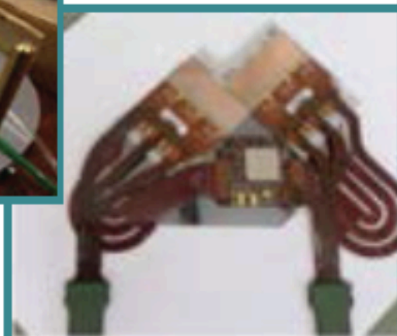
→ Factor 2 increase in efficiency for hadronic B decays (higher for charm)

Installation starts in six months!

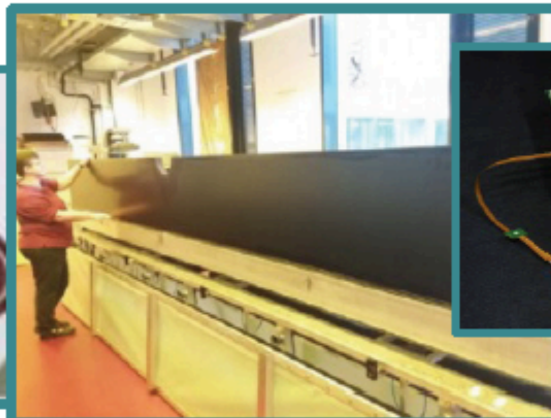
VELO sensor tiles testing device



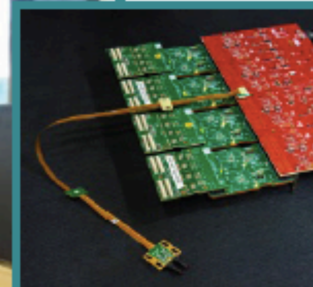
VELO module



SciFI module

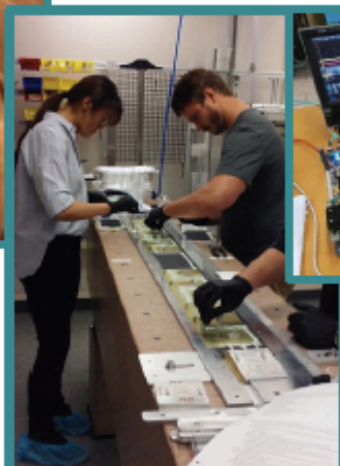


SciFI Readoout



CALO electronics

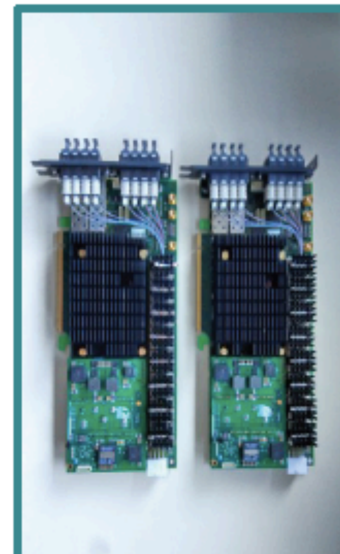
UT sensor



UT staves construction

Test of MUON electronics

RICH MaPMTs under test

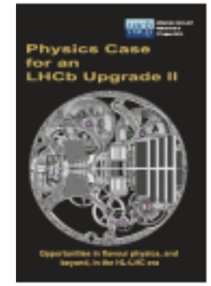


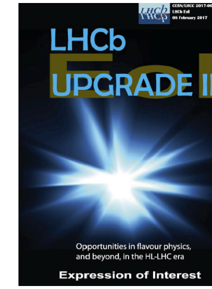
PCIe40 boards

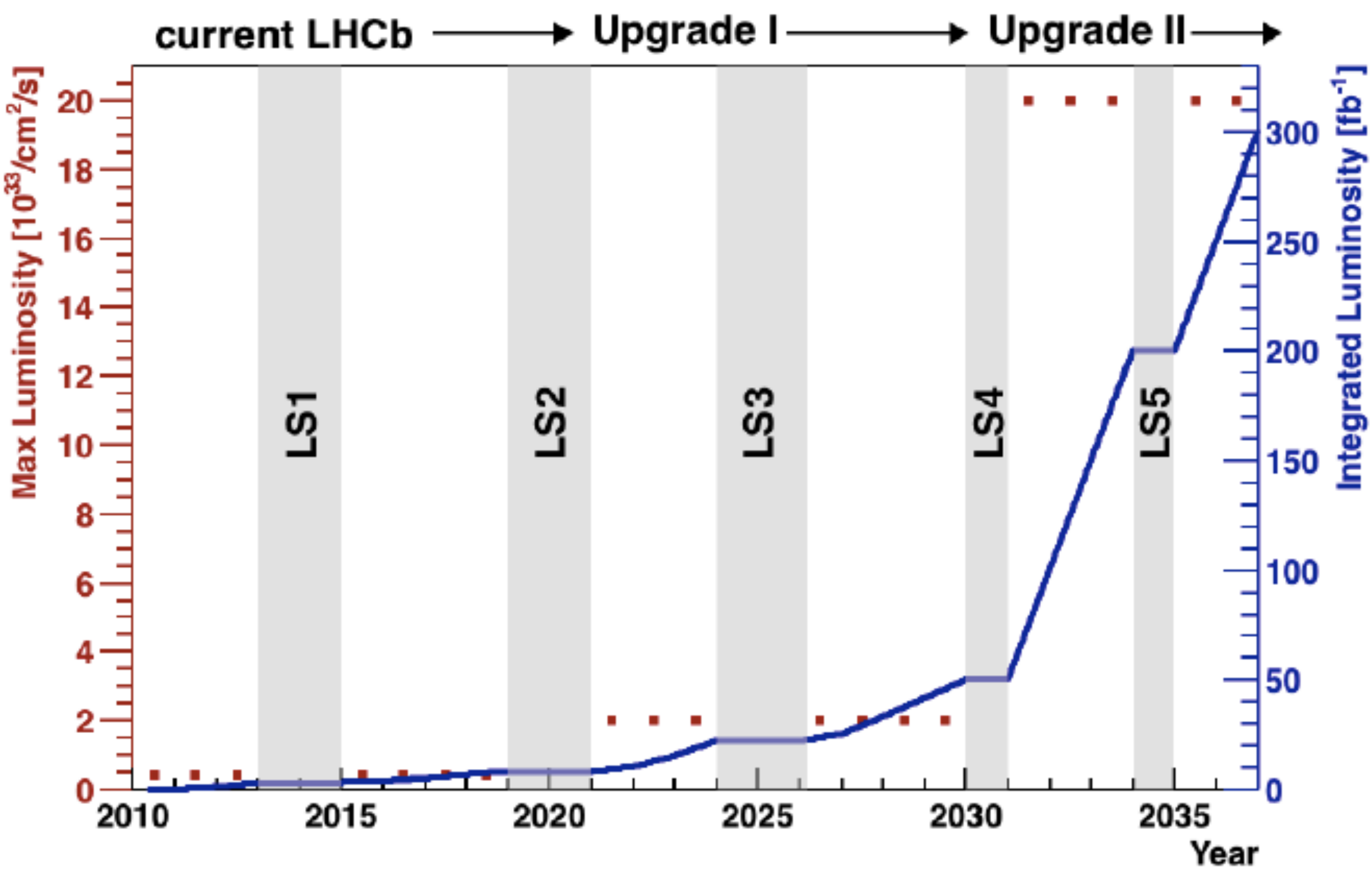
Slide from Monica Pepe Altarelli@ LISHEP 2018

LHCb Upgrade II

- Factor 10 in luminosity increase
- EoI and Physics case submitted to LHCC

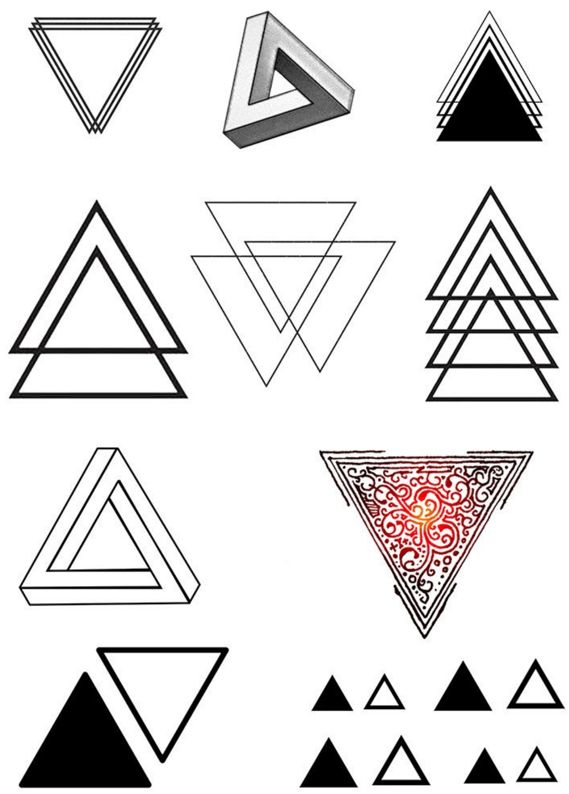






See Mika's talk on Monday for ideas on the detector for Upgrade II and the effect on physics output

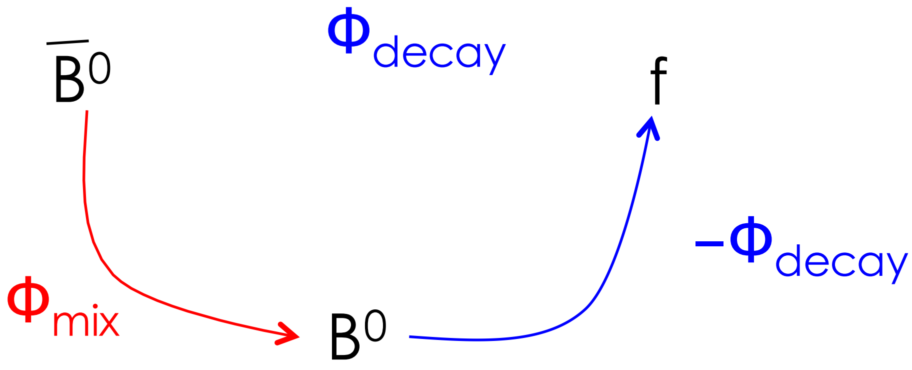
CP violation measurements



With the current precision, CPV well described by the CKM mechanism

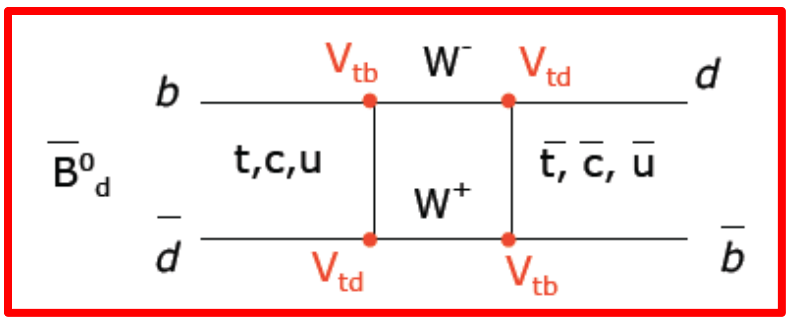
→precise measurements mandatory to search for pieces which do not fit

CPV in the interference between mixing and decay

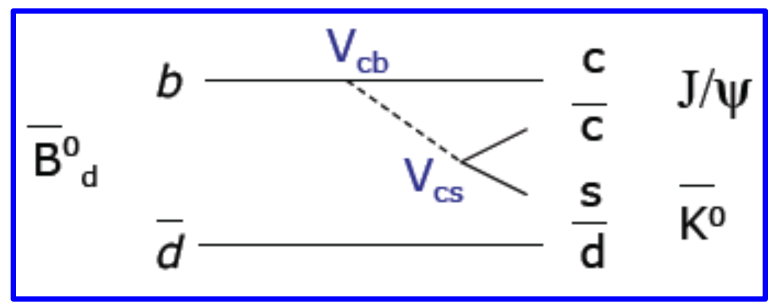


$$\Phi_d = \Phi_{mix} - 2\,\Phi_{decay}$$

Mixing



Decay



B_d system : 2β

B_s system : ϕ_s

Needs :

- Initial Tagging
- Decay time measurement

Sin2β measurement

$$\mathcal{A}_{[c\bar{c}]K^0_S}(t) \equiv \frac{\Gamma(\overline{B}^0(t)\to[c\bar{c}]K^0_S) - \Gamma(B^0(t)\to[c\bar{c}]K^0_S)}{\Gamma(\overline{B}^0(t)\to[c\bar{c}]K^0_S) + \Gamma(B^0(t)\to[c\bar{c}]K^0_S)}$$

$$= \frac{S\sin(\Delta m\, t) - C\cos(\Delta m\, t)}{\cosh(\Delta\Gamma\, t/2) + A_{\Delta\Gamma}\sinh(\Delta\Gamma\, t/2)} \approx S\sin(\Delta m\, t) - C\cos(\Delta m\, t)$$

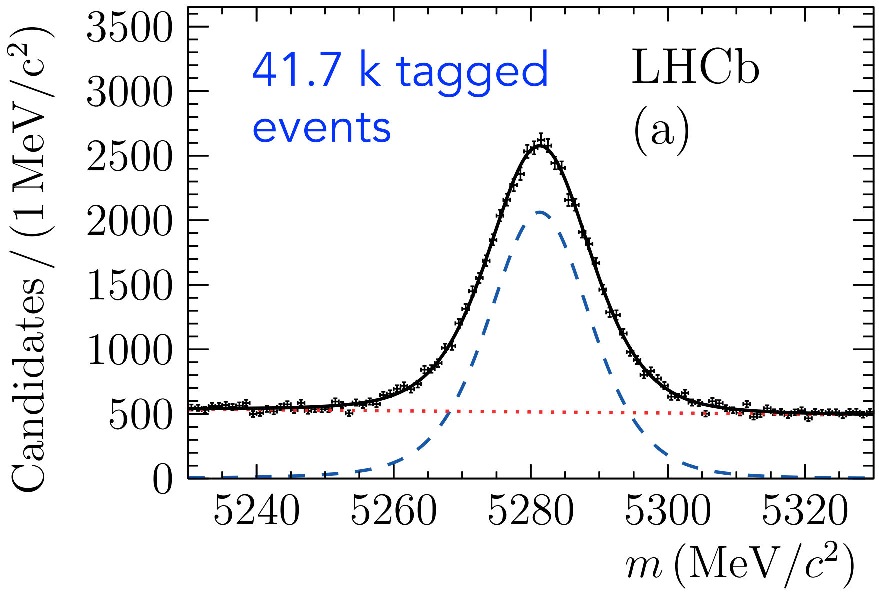
Sin2β

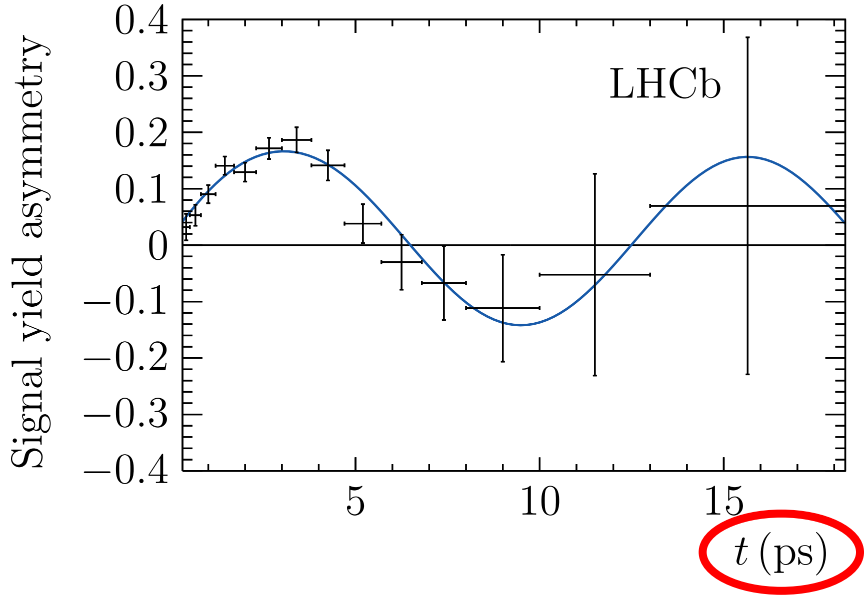
direct CPV
~0 (SM)

Needs :

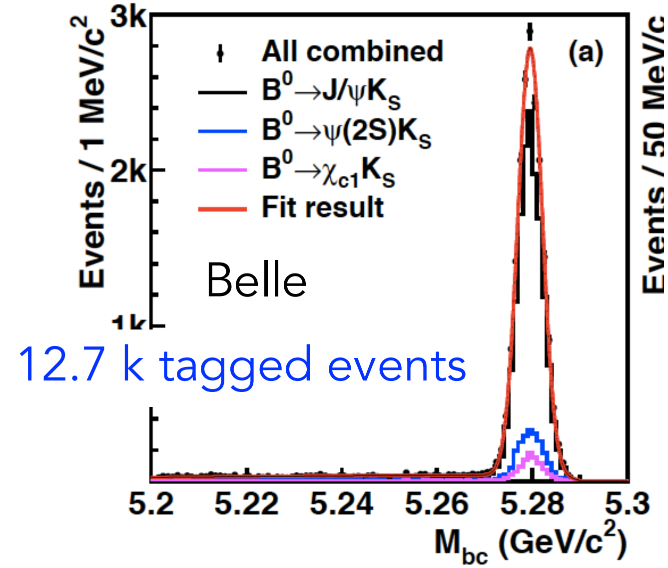
- Initial Tagging
- Decay time measurement

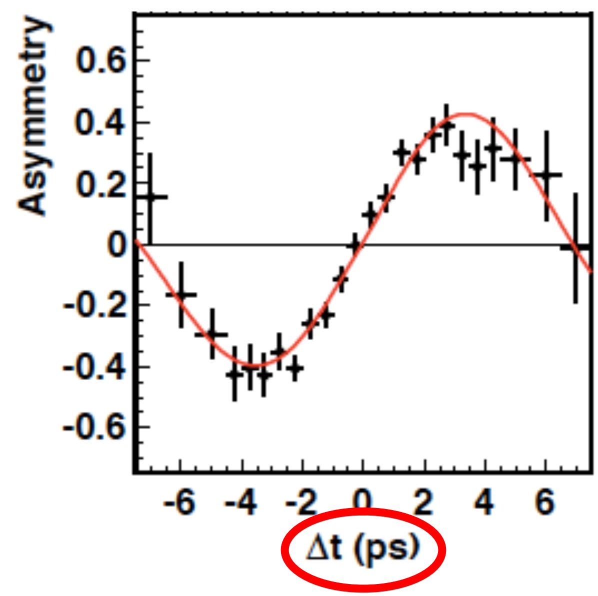
PRL. 115, 031601 (2015)



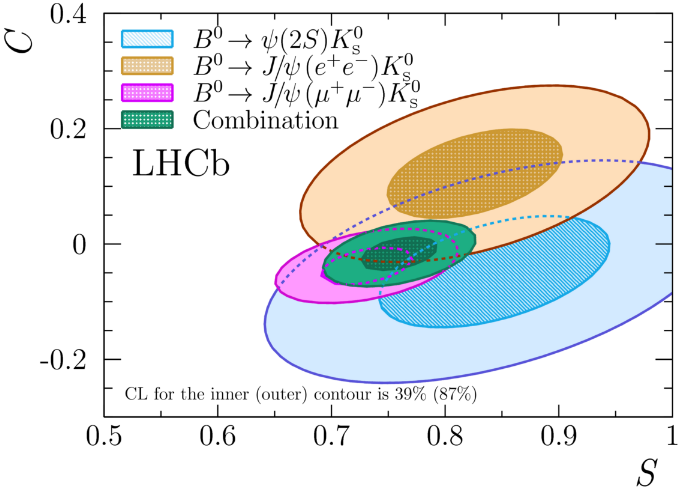


PRL 108, 171802 (2012)

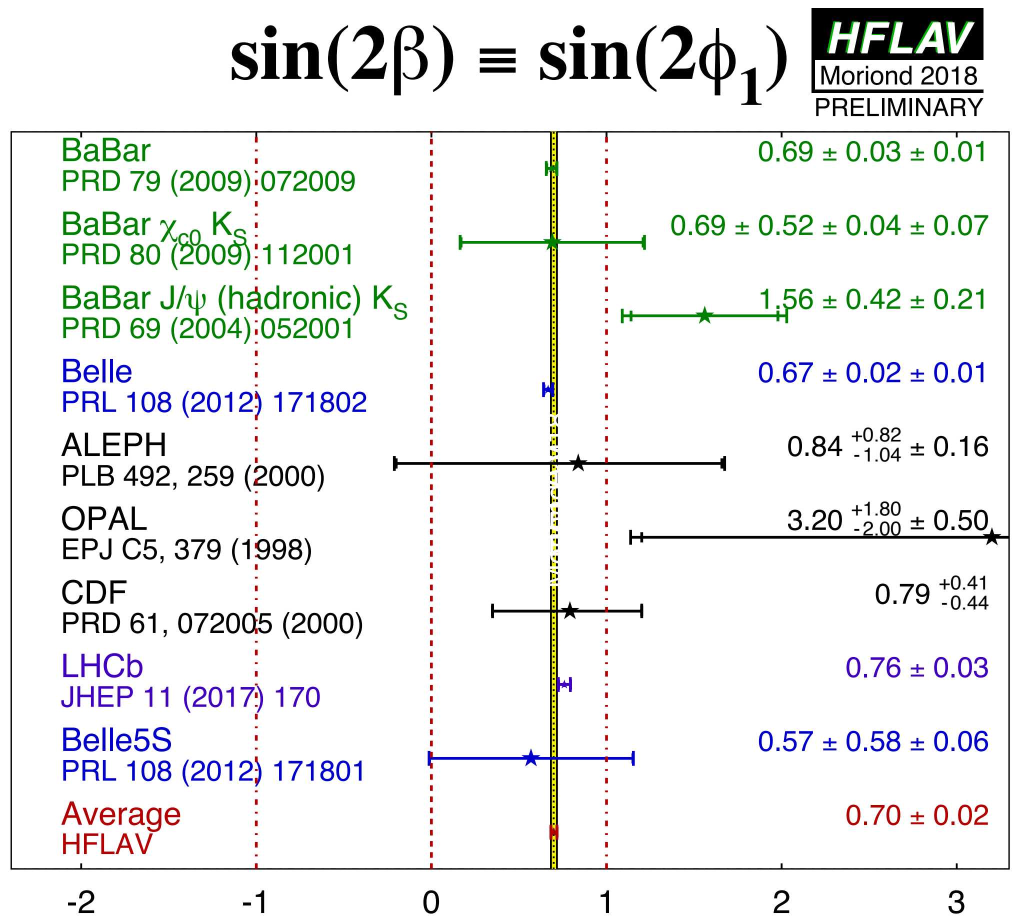




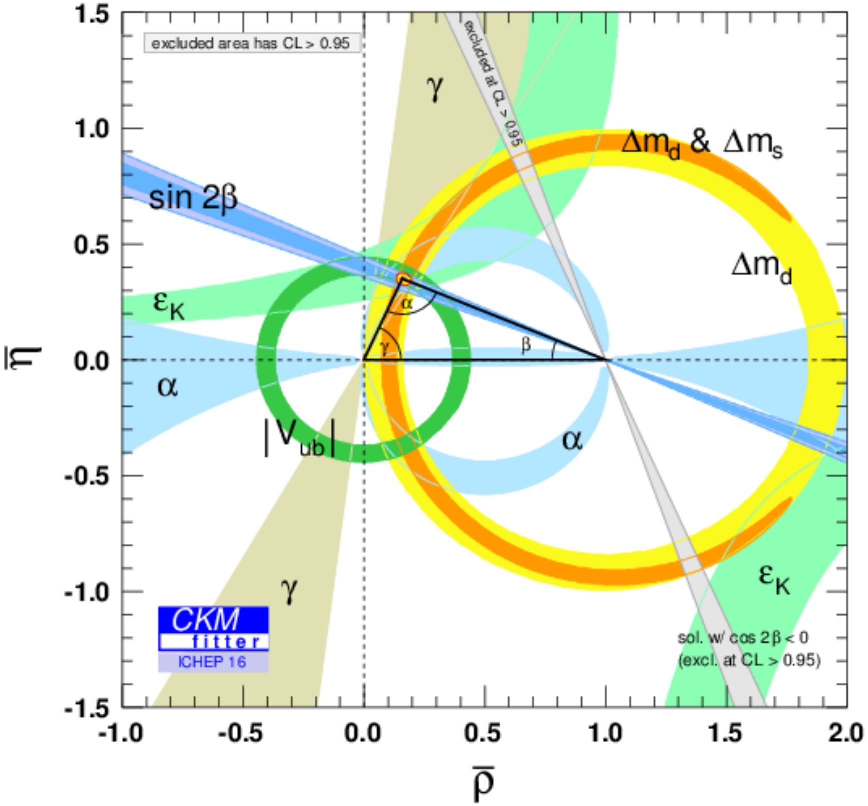
JHEP11 (2017) 170



$$C(B^0 \to [c\bar{c}]K^0_S) = -0.017 \pm 0.029$$
$$S(B^0 \to [c\bar{c}]K^0_S) = \quad 0.760 \pm 0.034$$



LHCb Run1 results still less precise than BaBar+Belle average



Trigonometric ambiguity
→ need to measure cos 2β

Joint BaBar Belle analysis of
$B \to D^{(*)}(\to K_s\pi\pi)h^0$ ($h^0 = \pi^0,\eta,\omega$)

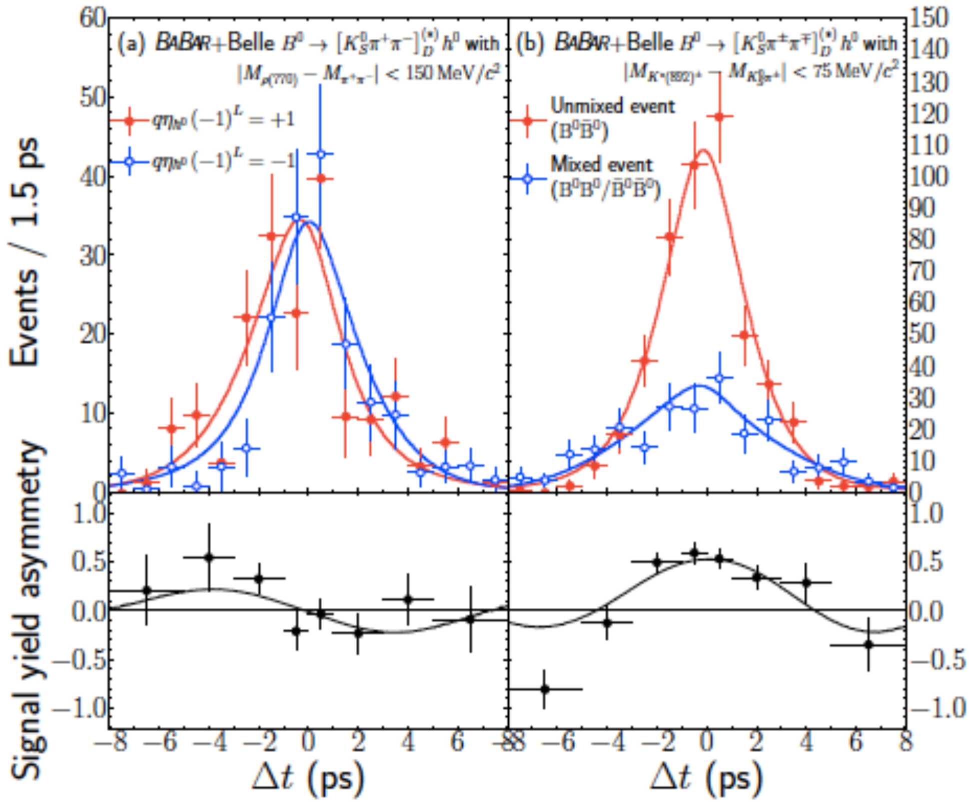
Phys.Lett.B624:1-10,2005

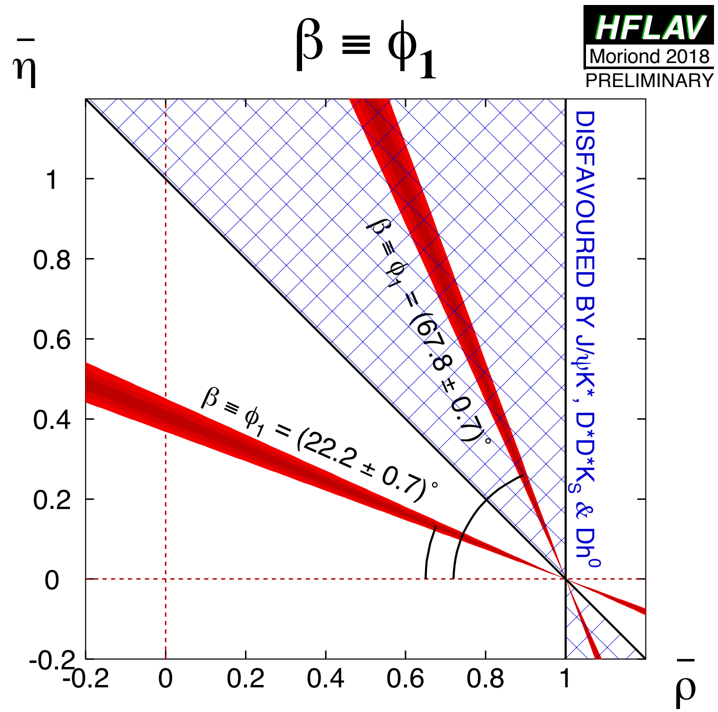
à la GGSZ

$$\frac{e^{\frac{-|\Delta t|}{\tau_{B^0}}}}{2}\Big\{\left[|\mathcal{A}_{\overline{D}^0}|^2 + |\mathcal{A}_{D^0}|^2\right] - q\left(|\mathcal{A}_{\overline{D}^0}|^2 - |\mathcal{A}_{D^0}|^2\right)\cos(\Delta m_d \Delta t) + 2q\eta_{h^0}(-1)^L \,\mathrm{Im}\left(e^{-2i\beta}\mathcal{A}_{D^0}\mathcal{A}^*_{\overline{D}^0}\right)\sin(\Delta m_d\Delta t)\Big\}$$

$$\mathrm{Im}\left(\mathcal{A}_{D^0}\mathcal{A}^*_{\overline{D}^0}\right)\cos 2\beta - \mathrm{Re}\left(\mathcal{A}_{D^0}\mathcal{A}^*_{\overline{D}^0}\right)\sin 2\beta,$$

Two different regions of the $D \to K_s\pi\pi$ phase space





arXiv:1804.061

$$\sin 2\beta = 0.80 \pm 0.14\,(\text{stat.}) \pm 0.06\,(\text{syst.}) \pm 0.03\,(\text{model})$$ in agreement with the WA

$$\cos 2\beta = 0.91 \pm 0.22\,(\text{stat.}) \pm 0.09\,(\text{syst.}) \pm 0.07\,(\text{model})$$ $\cos 2\beta > 0$ at 3.7σ

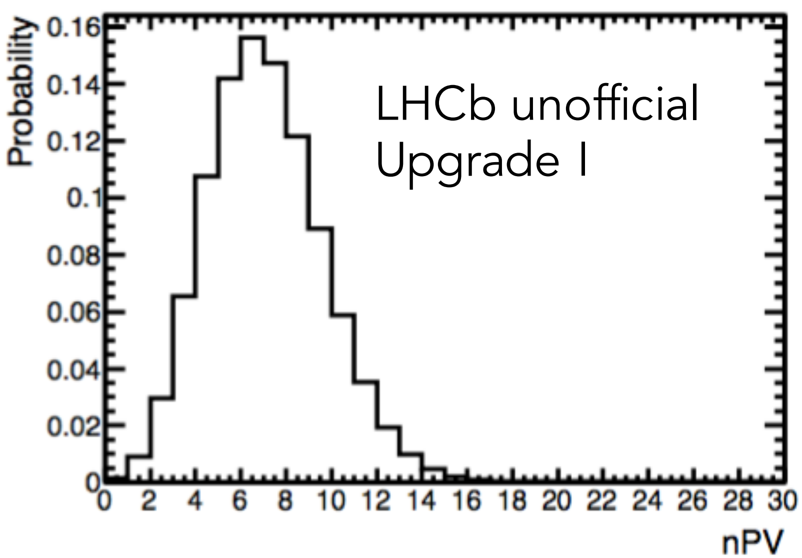
$$\beta = (22.5 \pm 4.4\,(\text{stat.}) \pm 1.2\,(\text{syst.}) \pm 0.6\,(\text{model}))^\circ$$

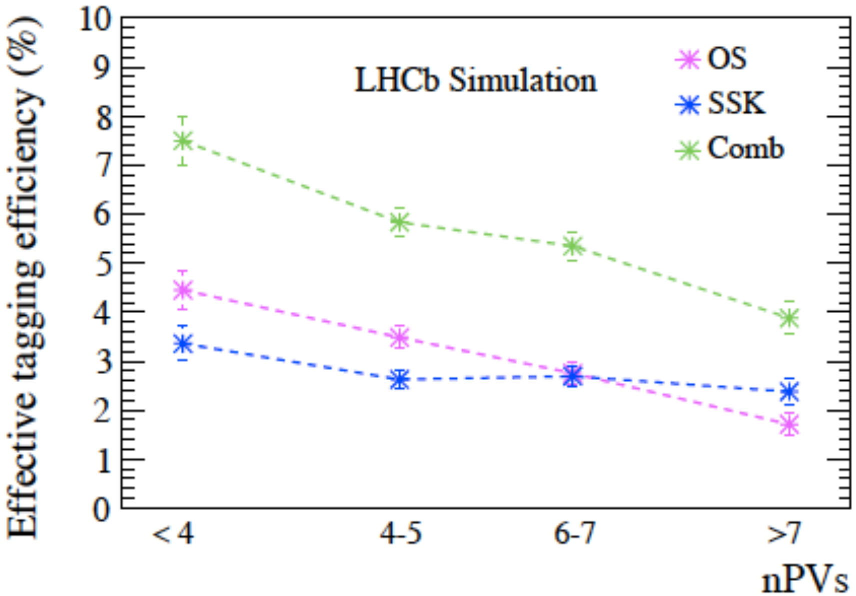
Expected precision on sin 2β

Belle 2 in 2025 : 0.006

	No improvement	Vertex improvement	Leptonic categories
$S_{J/\psi K_S^0}$ (50 ab^{-1})			
stat.	0.0035	0.0035	0.0060
syst. reducible	0.0012	0.0012	0.0012
syst. irreducible	0.0082	0.0044	0.0040

LHCb with 50 fb^{-1} : 0.006 if Flavour Tagging performances are maintained





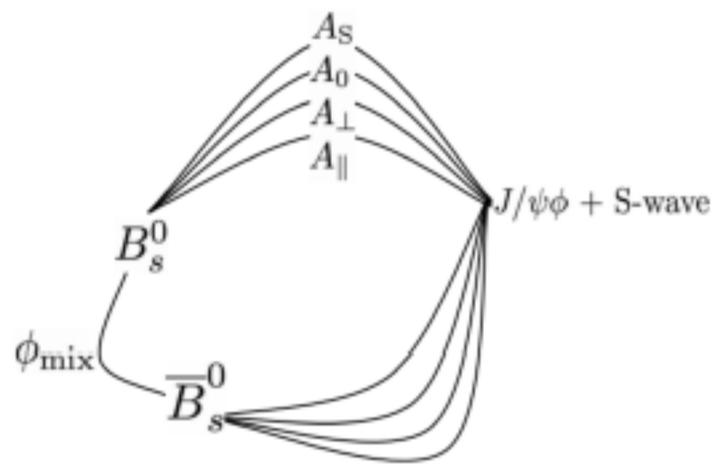
ϕ_s measurement

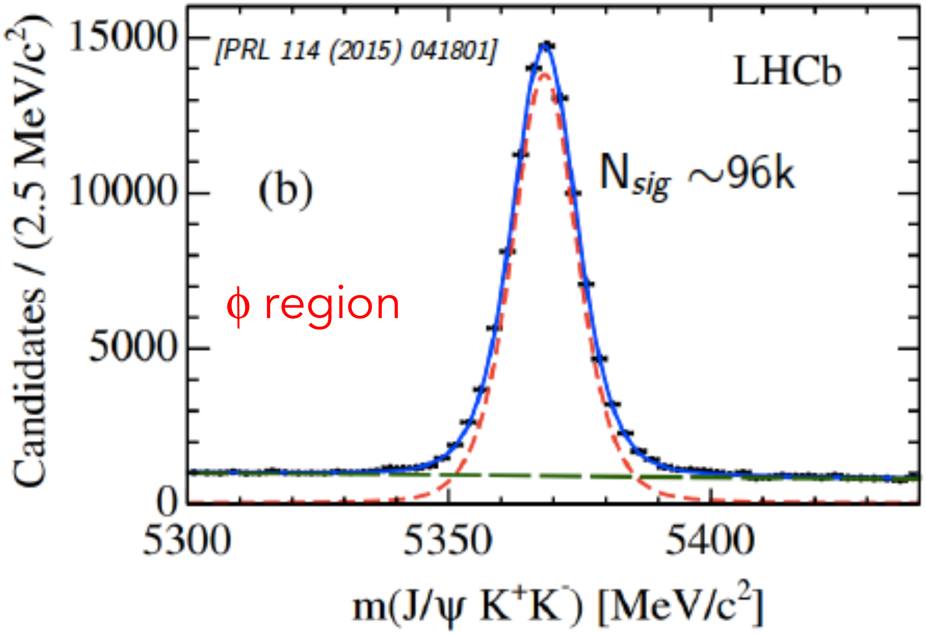
LHCb $B_s \rightarrow J/\psi\ \phi(\rightarrow KK)$, but also

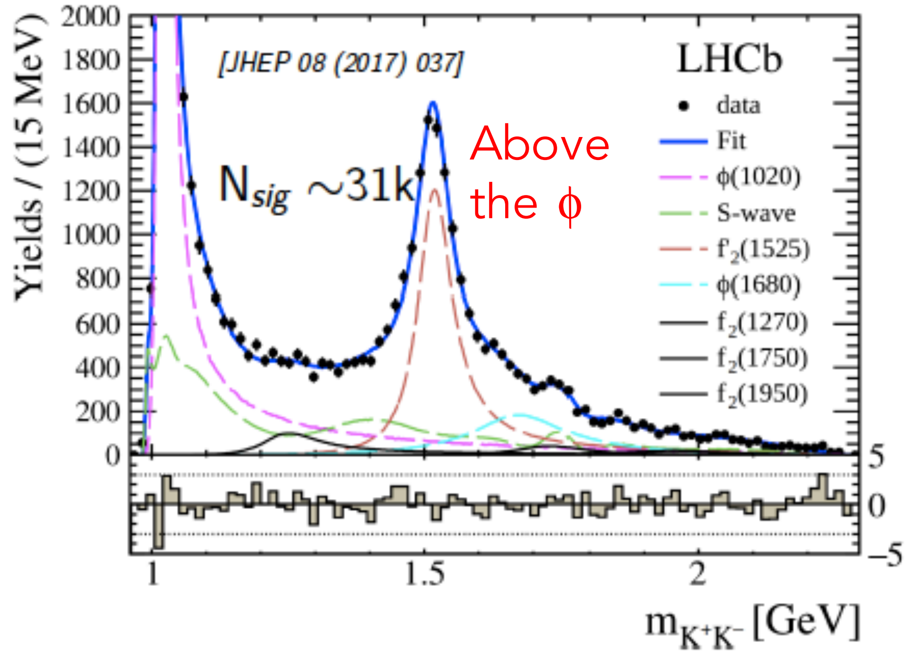
- KK above the ϕ resonance
- $J/\psi\ \pi\pi$

Needs :

- Initial Tagging
- Decay time measurement
- Amplitude analysis

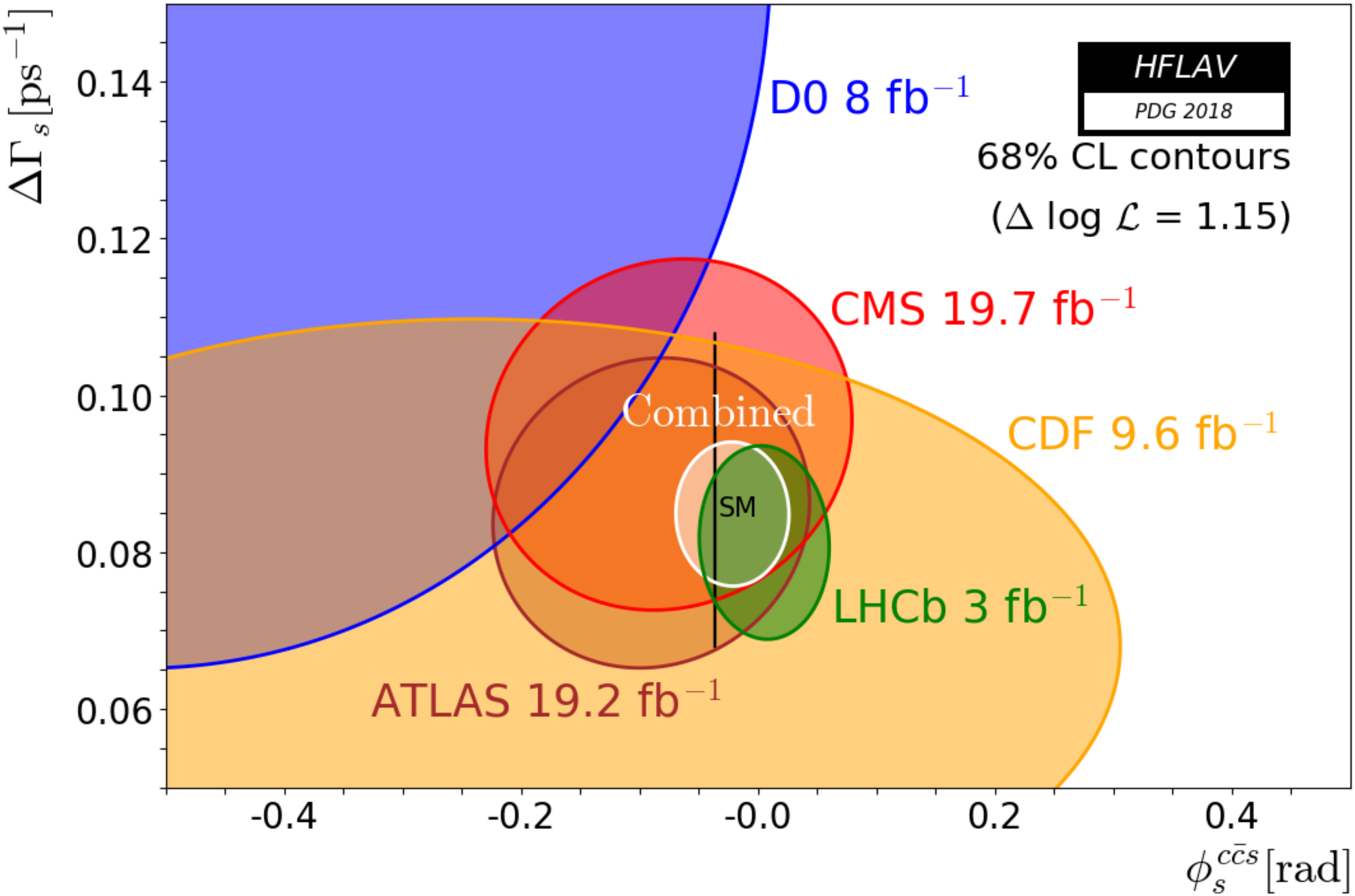






Final LHCb Run I results

$J/\psi K^+K^-$ in ϕ region	-58 ± 59 ± 6 mrad	[PRL 114 (2015) 041801]
$J/\psi K^+K^-$ in high-mass K^+K^- region	119 ± 107 ± 34 mrad	[JHEP 08 (2017) 037]
$J/\psi \pi^+\pi^-$	70 ± 68 ± 8 mrad	[PLB 713 (2012) 378]
Overall	1 ± 37 mrad	



Seems very SM like

$B_s \longrightarrow J/\psi\Phi$ $b \rightarrow c\bar{c}s$

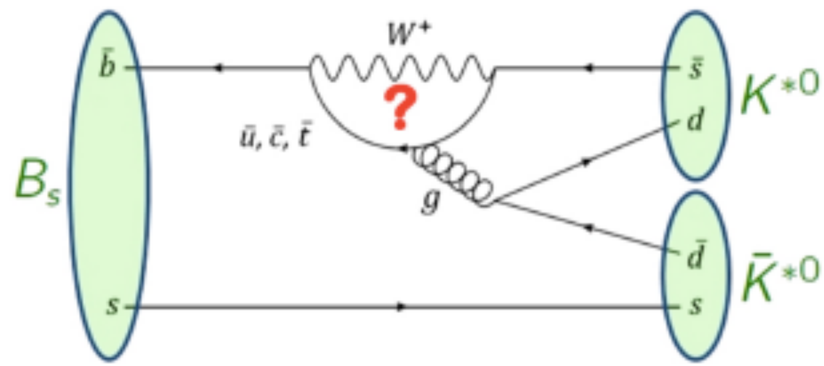
Dominated by a tree diagram

NP can show up in the mixing

$B_s \longrightarrow \Phi\Phi$, $B_s \longrightarrow (K\pi)(K\pi)$

penguin diagram $b \rightarrow s\bar{s}s$

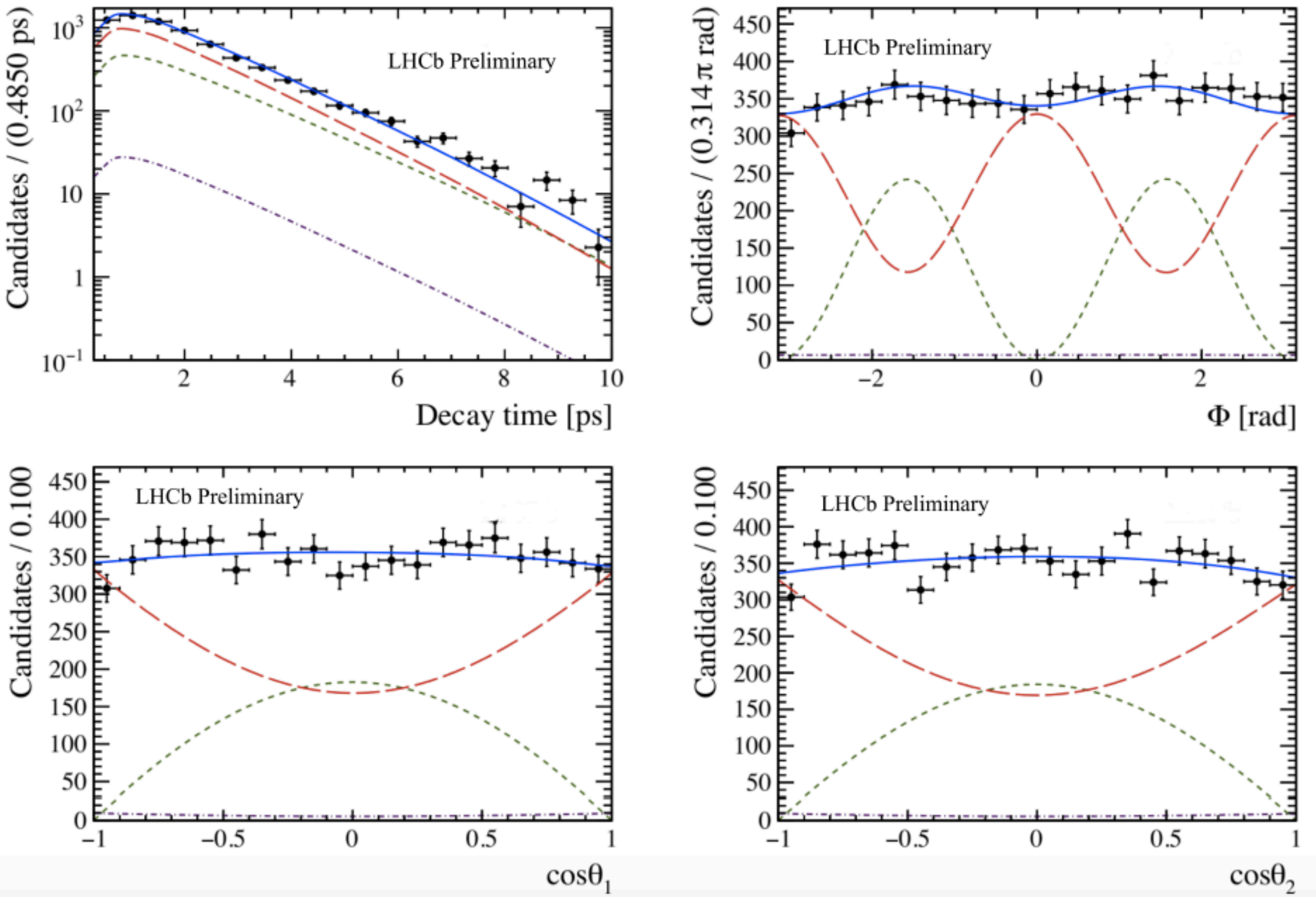
NP can show up in the mixing or in the decay (penguin loops)



SM

$B_s \longrightarrow \Phi\Phi$

Signal yield of ~ 8500 candidates (Run1 + 2015 – 2016)



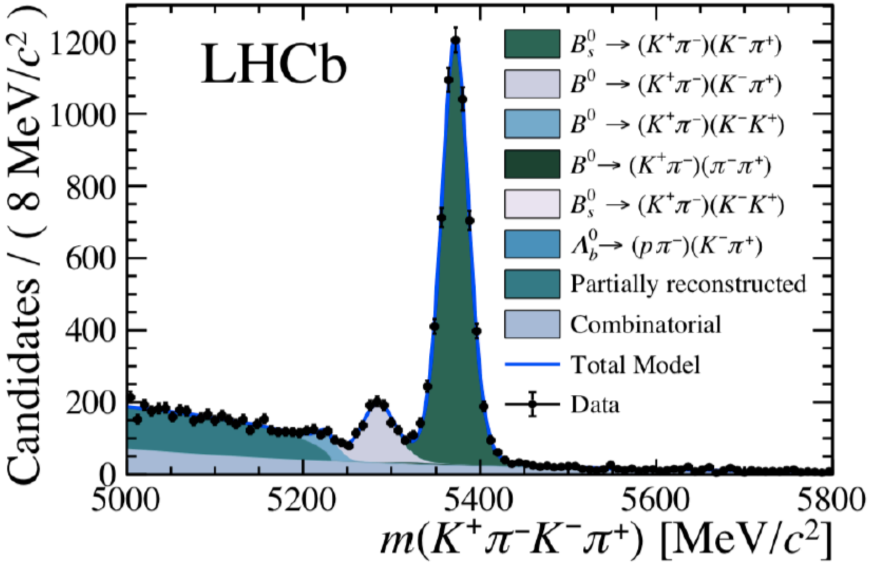
$$\phi_s^{s\bar{s}s} = -0.07 \pm 0.13\,(\text{stat}) \pm 0.03\,(\text{syst})\ \text{rad},$$
$$|\lambda| = 1.02 \pm 0.05\,(\text{stat}) \pm 0.03\,(\text{syst})\,.$$

in good agreement with SM

$B_s \longrightarrow (K\pi)\,(K\pi)$

Decay	Polarization Amplitudes
$B_s^0 \to (K^+\pi^-)_0^*(K^-\pi^+)_0^*$	SS
$B_s^0 \to (K^+\pi^-)_0^*\overline{K}^*(892)^0$	SV
$B_s^0 \to K^*(892)^0(K^-\pi^+)_0^*$	VS
$B_s^0 \to (K^+\pi^-)_0^*\overline{K}_2^*(1430)^0$	ST
$B_s^0 \to K_2^*(1430)^0(K^-\pi^+)_0^*$	TS
$B_s^0 \to K^*(892)^0\overline{K}^*(892)^0$	VV0, VV$\parallel$, VV$\perp$
$B_s^0 \to K^*(892)^0\overline{K}_2^*(1430)^0$	VT0, VT$\parallel$, VT$\perp$
$B_s^0 \to K_2^*(1430)^0\overline{K}^*(892)^0$	TV0, TV$\parallel$, TV$\perp$
$B_s^0 \to K_2^*(1430)^0\overline{K}_2^*(1430)^0$	TT0, TT$\parallel_1$, TT$\perp_1$, TT$\parallel_2$, TT$\perp_2$

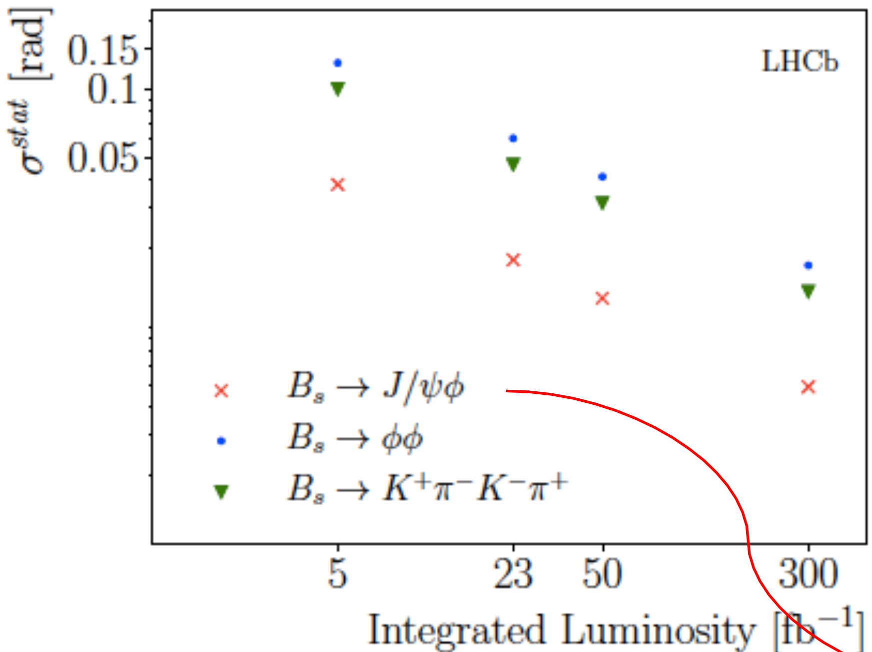
JHEP 03 (2018) 140

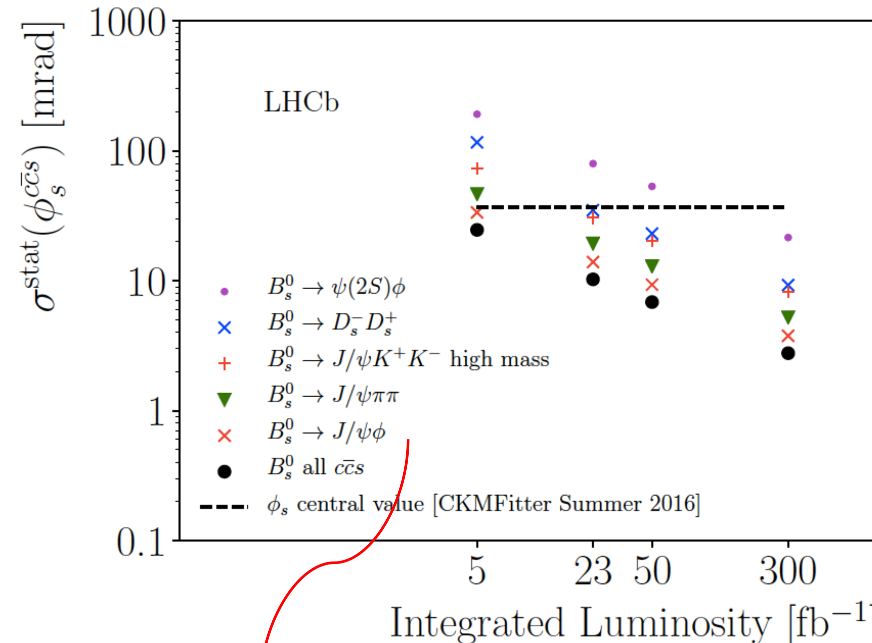


~ 6000 candidates (Run1)

$$\phi_s^{d\bar{d}} = -0.10 \pm 0.13\,(\text{stat}) \pm 0.14\,(\text{syst})\ \text{rad.}$$

Expected precision on ϕ_s





With 3 fb^{-1}
σ_{syst} = 6 mrad

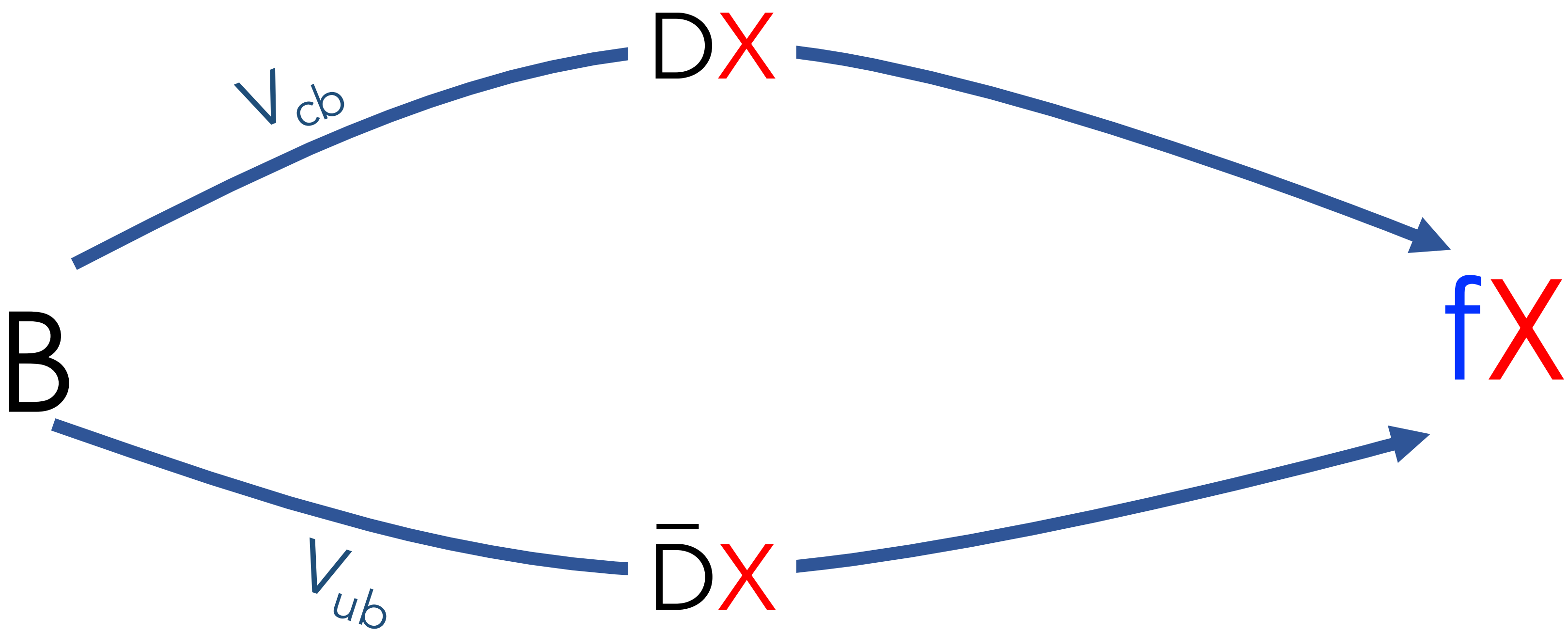
SM prediction based on fit of experimental data : $-36.4 \pm 1.2\,\mathrm{mrad}$

Can be measured in several modes.

Direct CP violation : γ measurement

Pioneered by BaBar and Belle

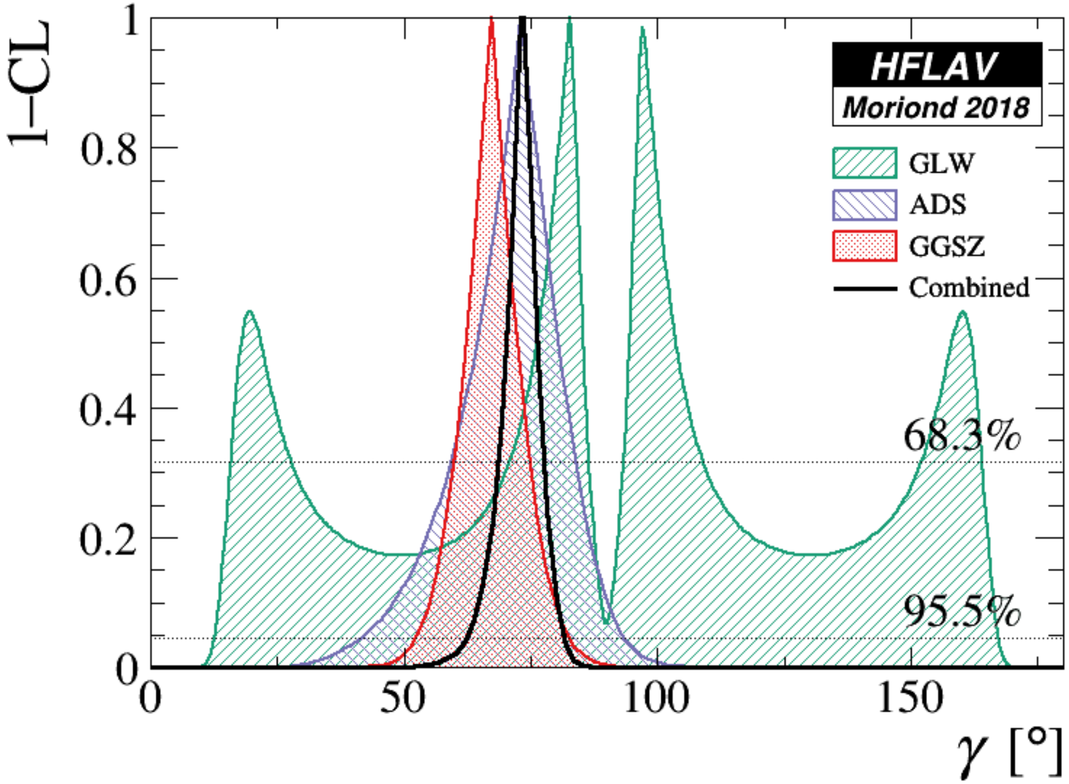
$$\gamma = \arg\left(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$



a lot of choices for f (should be accessible by D and D̄) and X

Theory :
- tree diagrams

Experiment :
- enough information to extract all th. parameters from data

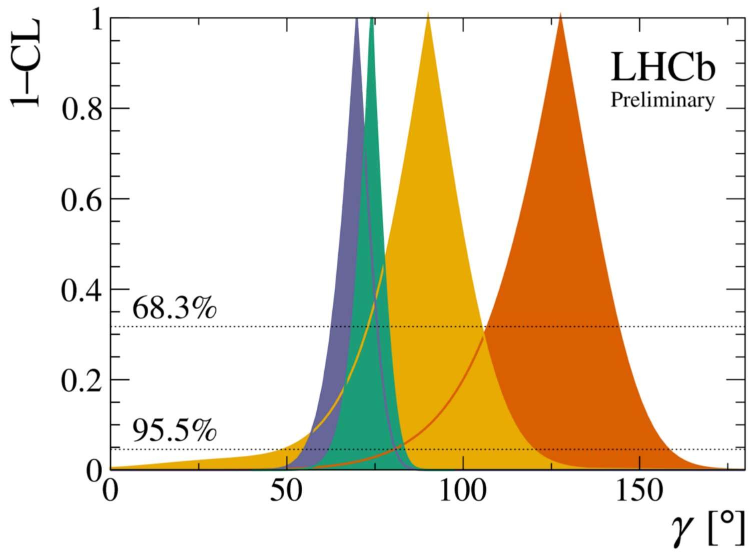


D decay mode : KK, ππ …

D decay mode : Kπ (DCS) …

D decay mode : K_s ππ (Dalitz)

$$\gamma = \left(73.5^{+4.2}_{-5.1}\right)^\circ$$



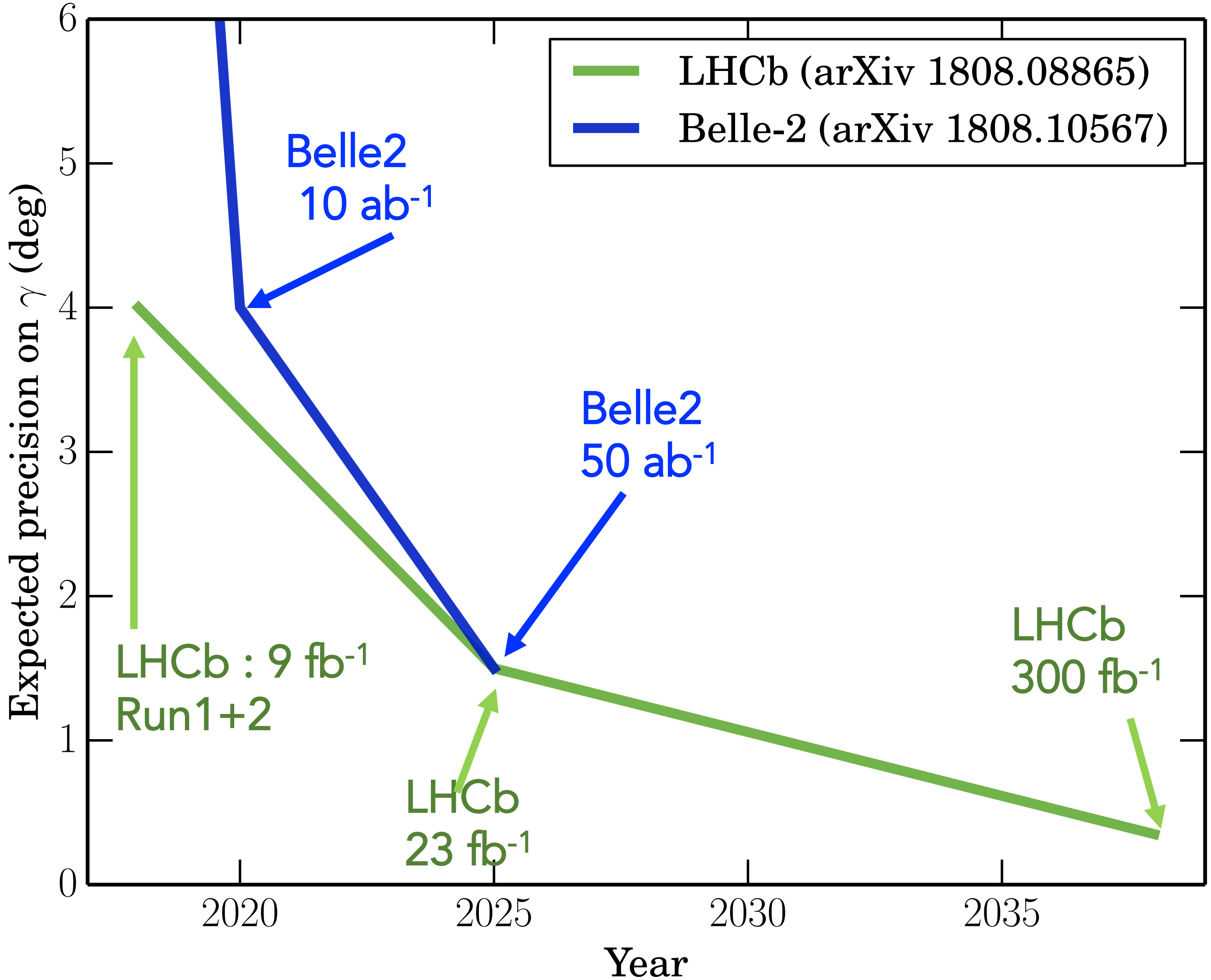
Result currently dominated by LHCb

$$\gamma = \left(74.0^{+5.0}_{-5.8}\right)^\circ$$

- B_s^0 decays
- B^0 decays
- B^+ decays
- Combination

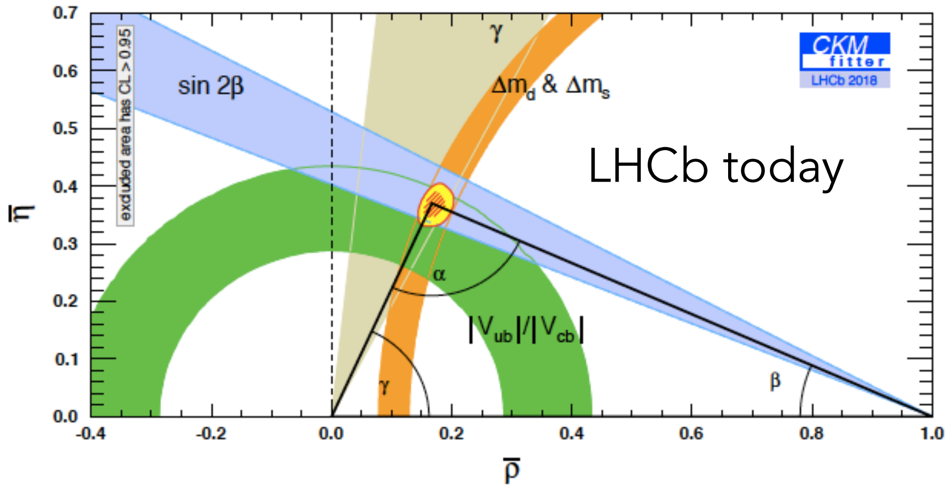
LHCb-CONF-2018-002

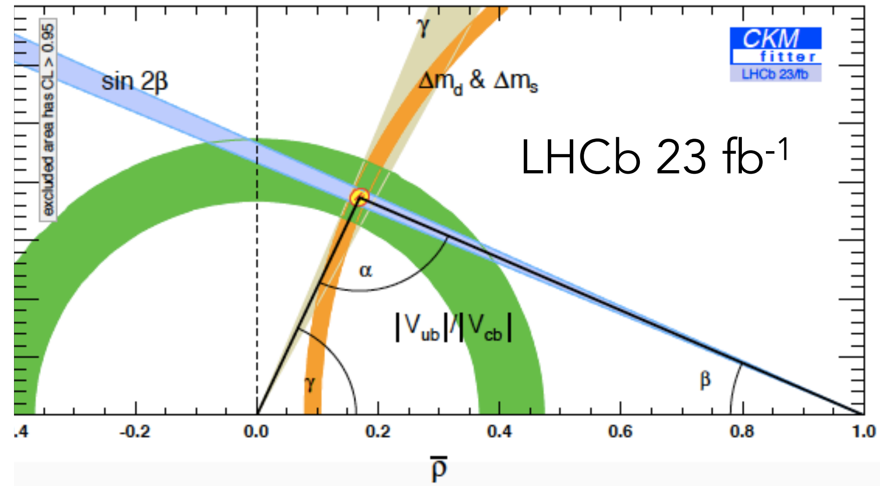
Expected uncertainty on the γ / ϕ_3 angle

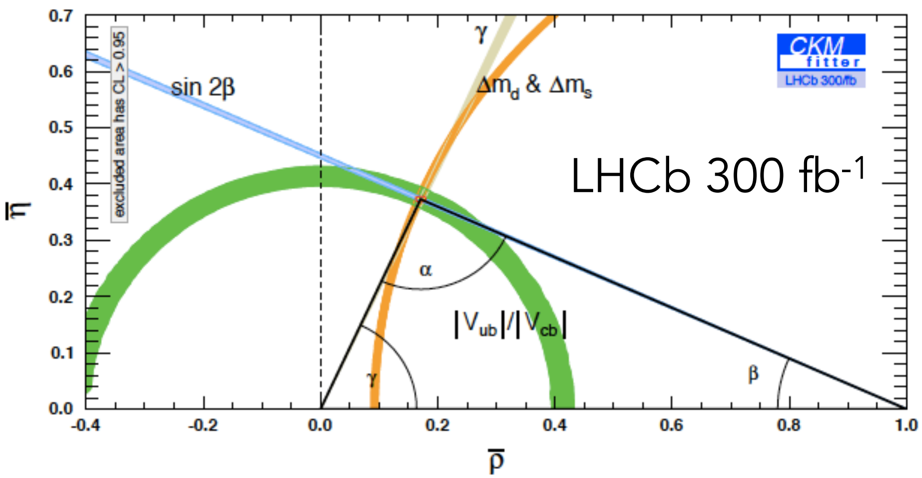


NB : inputs from BESIII and many modes

arXiv 1808.08865







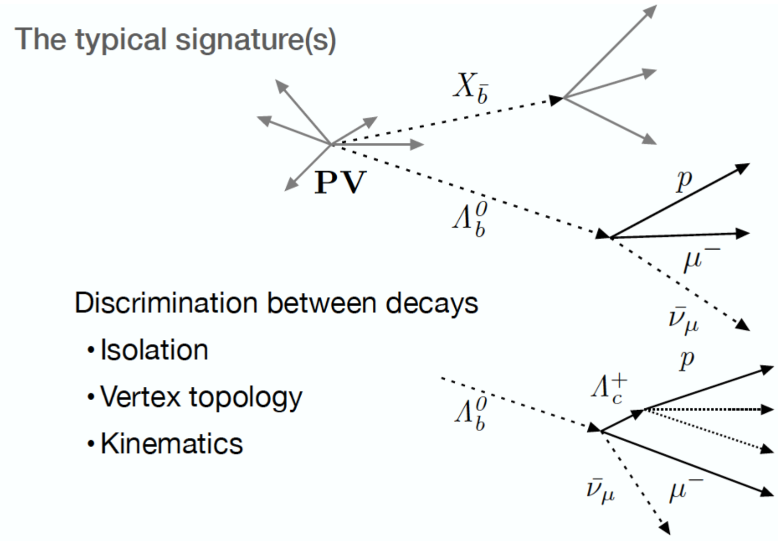
Improvements in lattice QCD calculations on ξ

Ultimately : tests of the CKM paradigm at the per mil level ….
Confront tree and loop measurements

Semileptonic decays

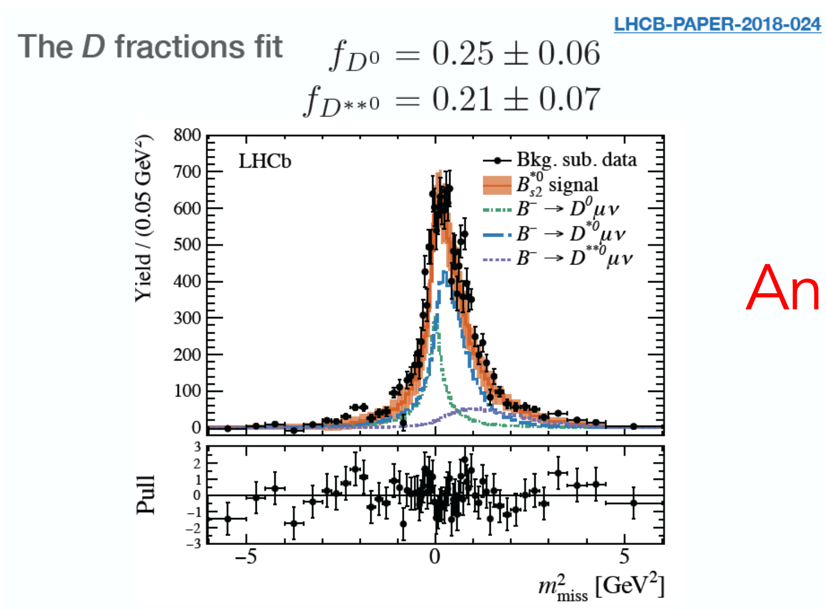
A challenge for LHCb
A part of *b* physics which was thought to be mainly B-Factories domain and SM-pure

Need to “compensate” for the missing neutrino(s)



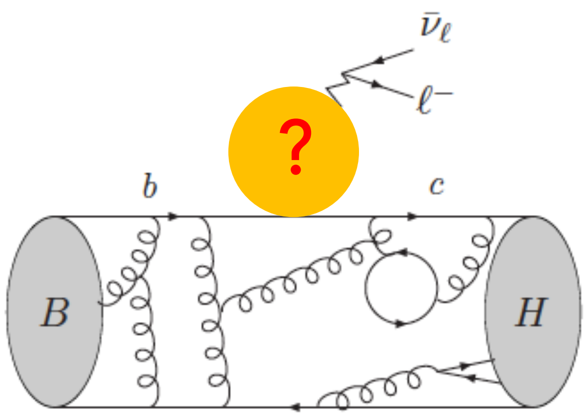
Measurement of $|V_{ub}|/|V_{cb}|$ using

$$\Lambda_b^0 \rightarrow p\mu^-\overline{\nu}_\mu \text{ and } \Lambda_b^0 \rightarrow \Lambda_c^+\mu^-\overline{\nu}_\mu$$



Anatomy of the B→D X l ν decay

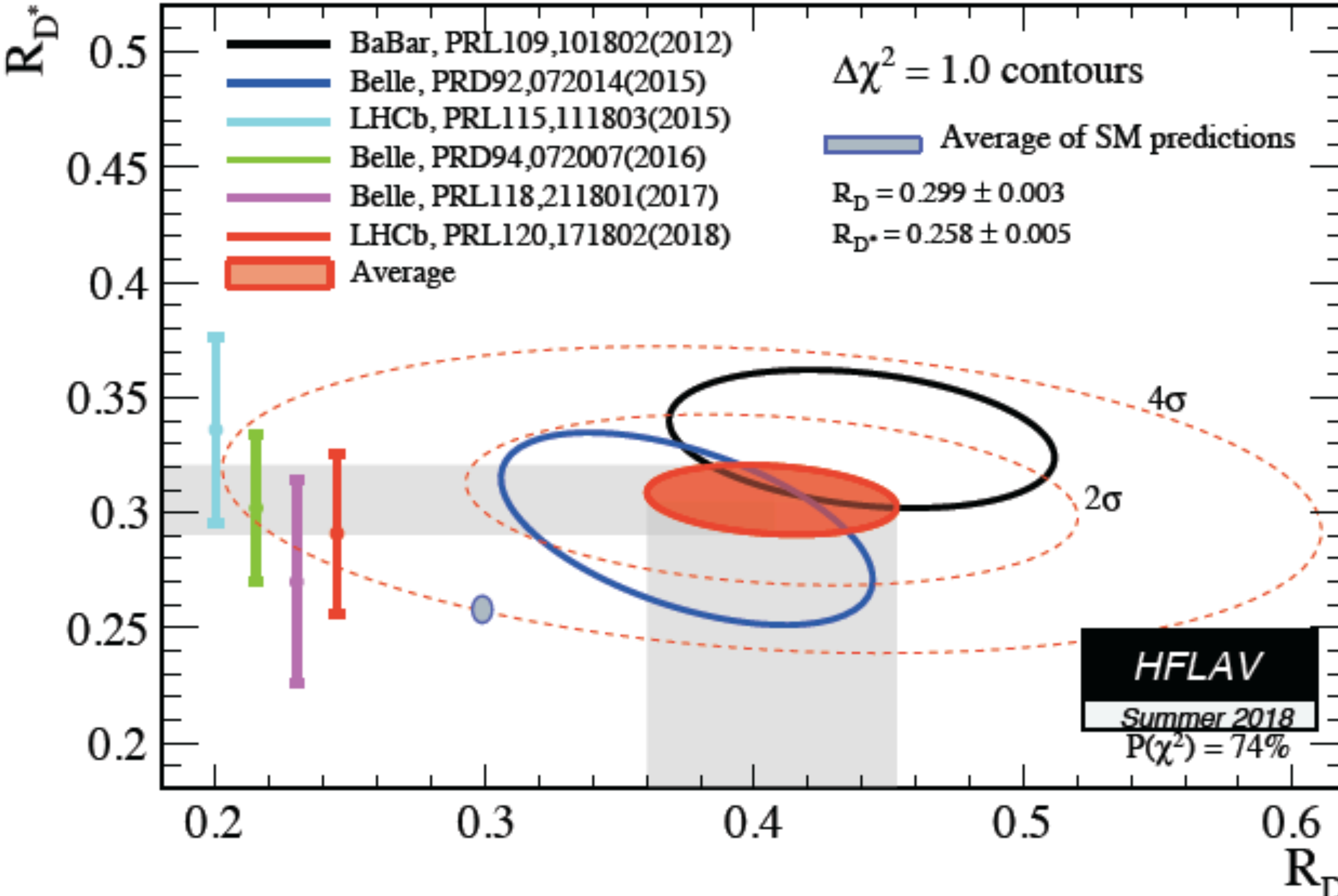
LFU tests with tree diagrams



Large BR : the problem is the background [at least 2 missing neutrinos] !

The rest of the event is not useful for LHCb. Take advantage of the boost

Precise SM predictions [but some discussions though] ~ 1% for R(D*) , much worse for $R_{J/Psi}$



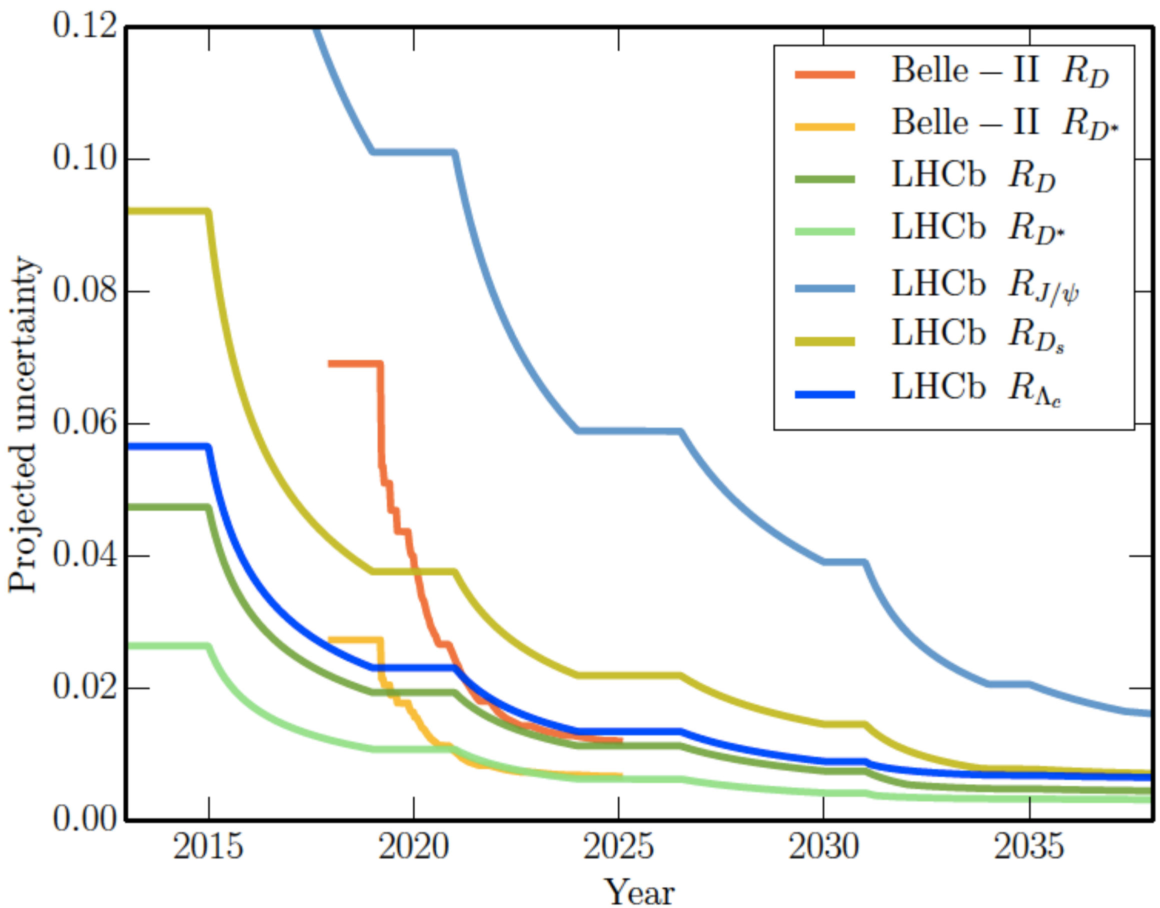
3.8 σ from the SM

A whole set of measurements in the pipeline :

fit to $R(D)\,\&\,R(D^*)$

$R(D_s^{(*)})$: $B_s^0 \to D_s^{(*)}\tau^+\nu_\tau$

$R(\Lambda_b)$: $\Lambda_b \to \Lambda_c^{(*)}\tau^+\nu_\tau$



.004

.003

.012 "Ultimate" syst.

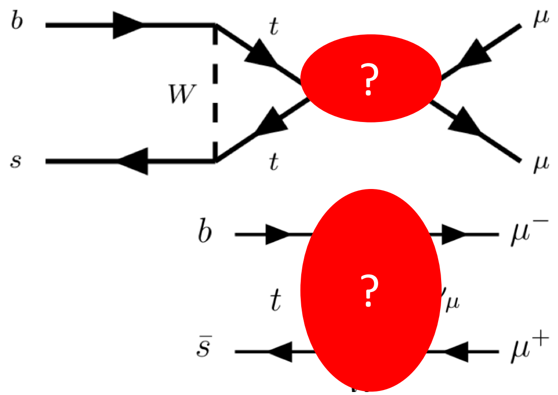
.006 (Guess estimates)

+ additional observables (τ pol)

arXiv:1809.06229

Rare decays (searching for NP)

$B_{d,s} \rightarrow \mu\mu$



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

SM prediction
PRL 112(2014) 101801

SM : very rare (V_{tq}, helicity suppression)

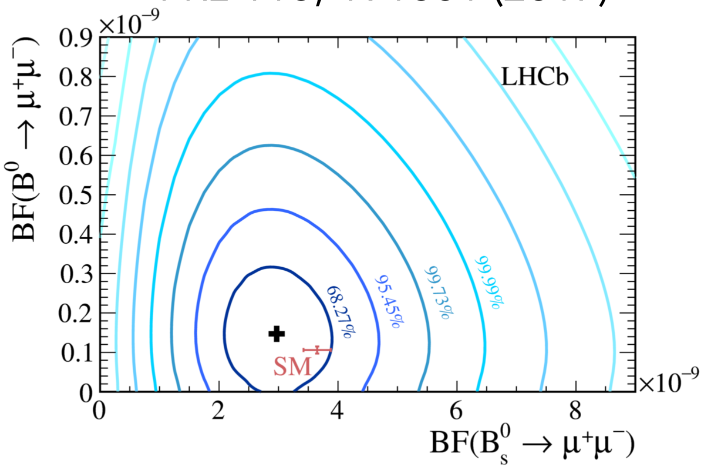
In NP models with an extended Higgs sector the BR can be largely enhanced

$BR^{MSSM} \propto \tan^6\beta / M_A^4$

Clean experimental signature (trigger)

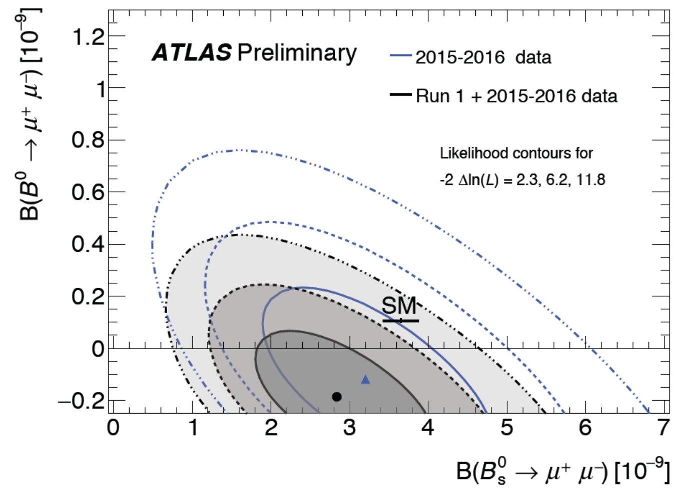
B_s seen by ATLAS, CMS and LHCb

PRL 118, 191801 (2017)

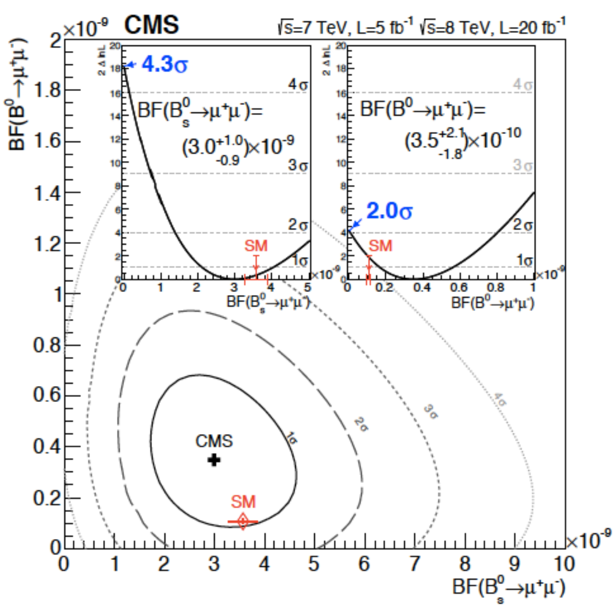


LHCb 2011-2016

ATLAS-CONF-2018-046



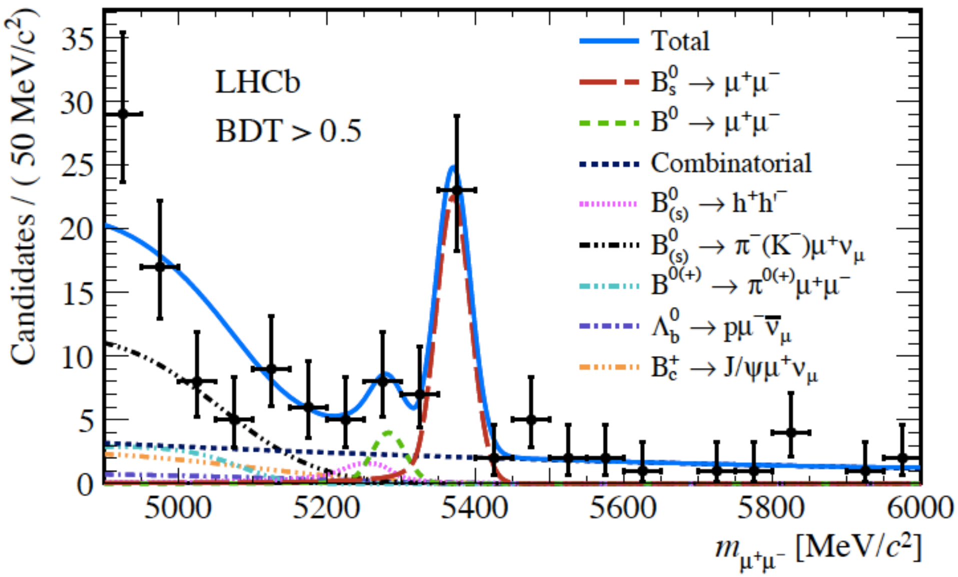
ATLAS 2011 – 2016

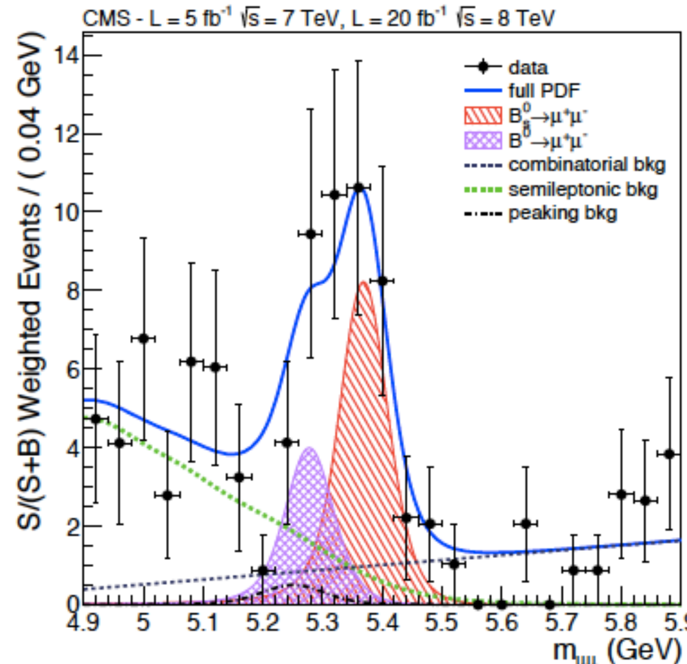


CMS 2011 – 2012

The mass resolution is crucial

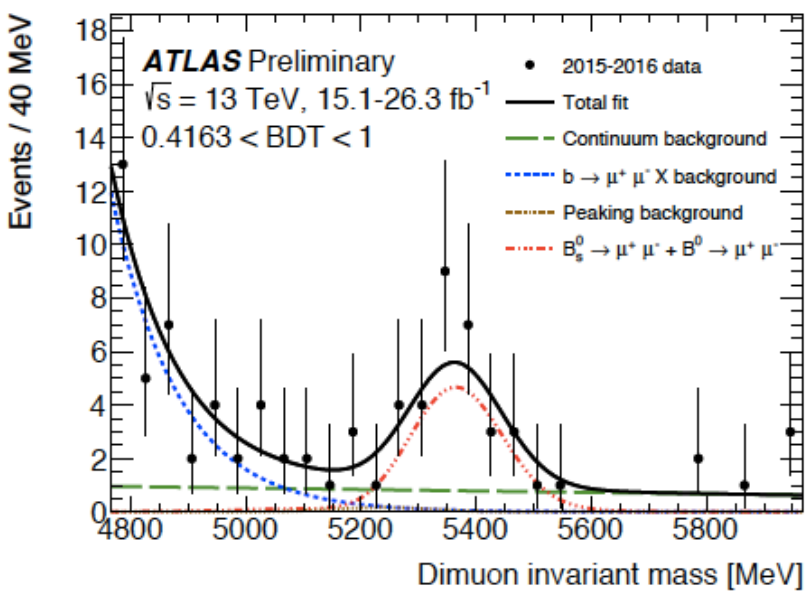
PRL. 118, 191801



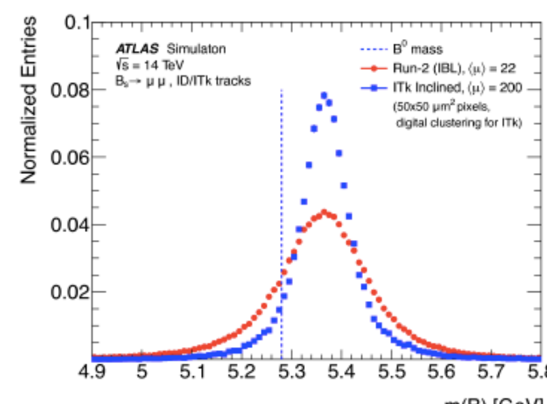


PRL 111 (2013) 101804

→ Significant improvements foreseen for the GPD upgrades

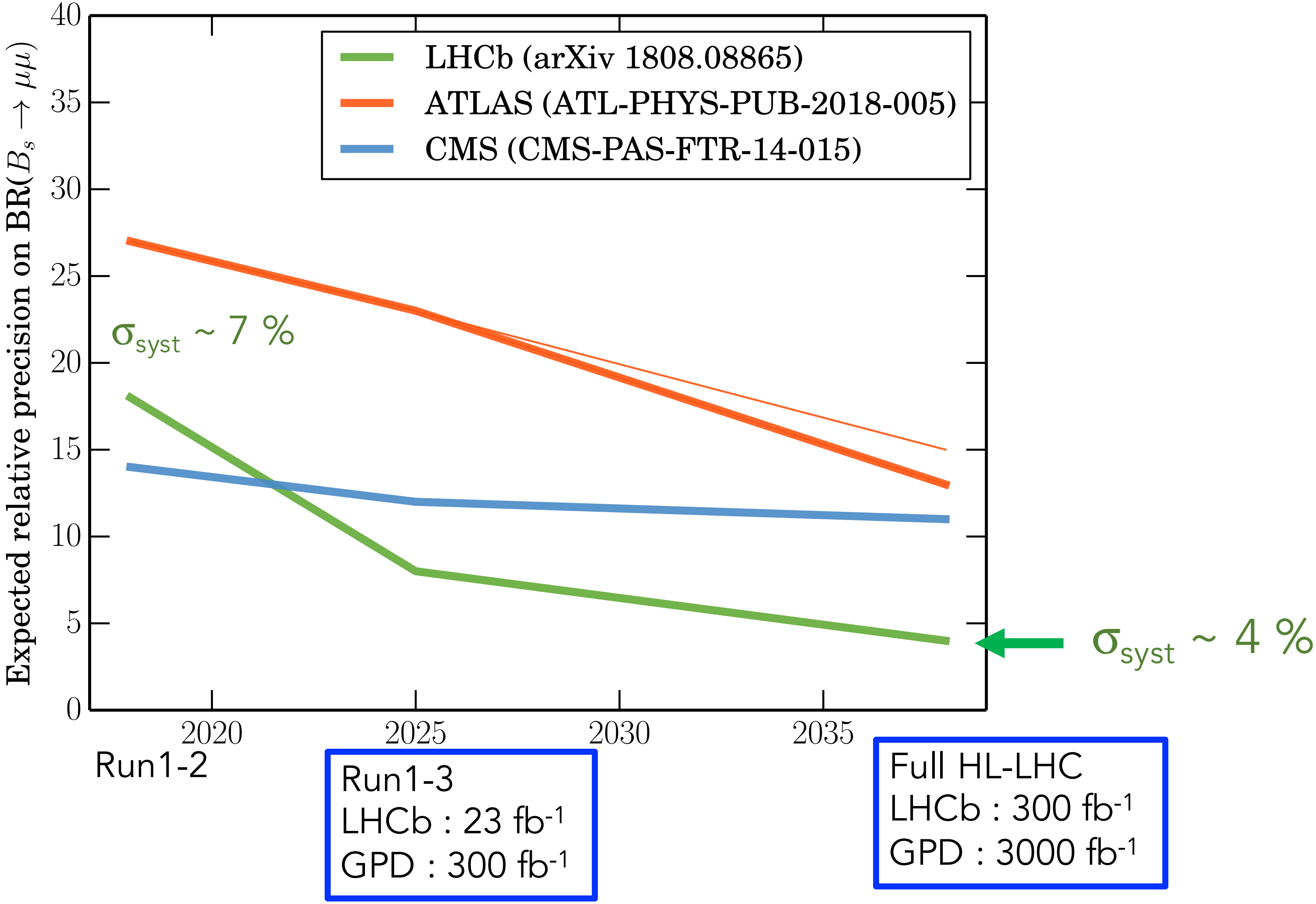


ATLAS-CONF-2018-046

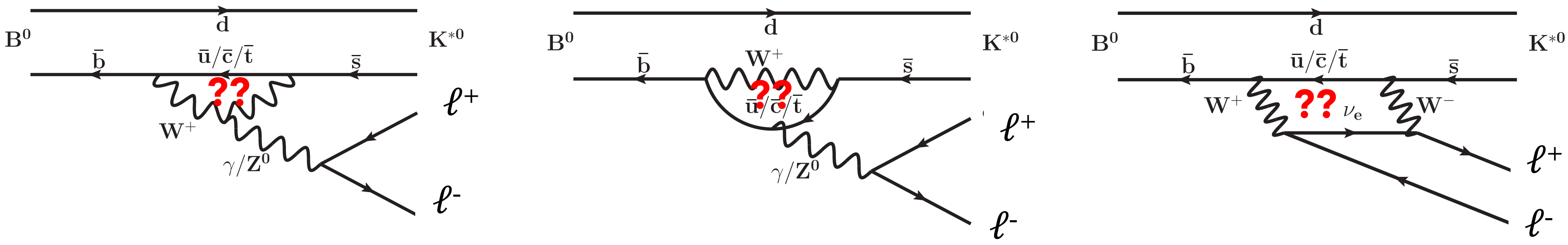


ATL-PUB-2018-005

Expected uncertainty on BR($B_s \to \mu\mu$)



b→ sll transitions



Relative importance of the different diagrams varies with $q^2 = M^2(\ell^+\ell^-)$

Many observables :

- BF (but large theoretical uncertainties due to non-perturbative QCD)
- Ratios of BF (test of Lepton Universality)
- Angular observables

The R_{Hs} ratios

$$R_{H_s} = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(H_b \to H_s \mu^+ \mu^-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\Gamma(H_b \to H_s e^+ e^-)}{dq^2} dq^2}$$

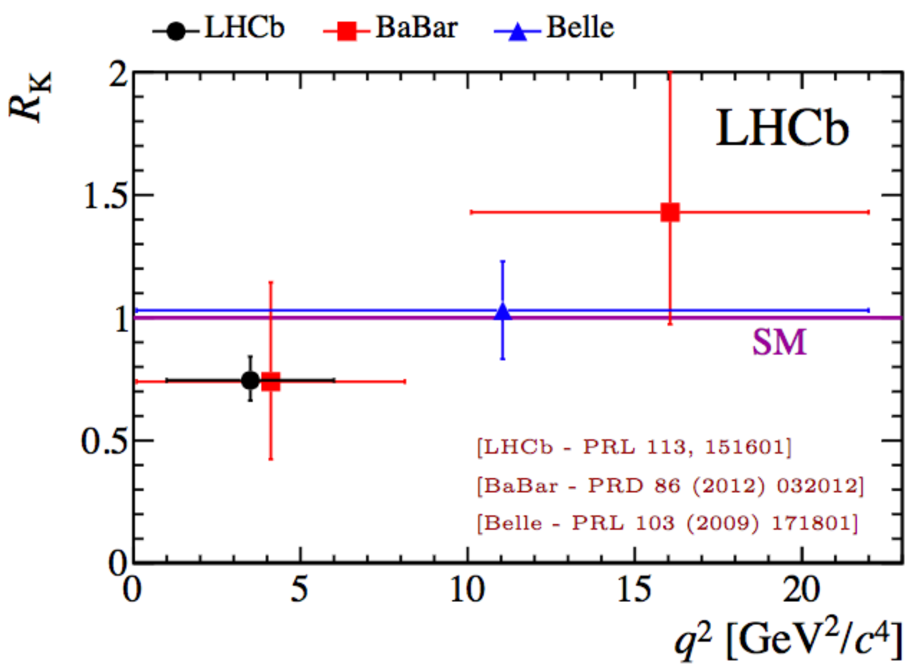
R_{Hs} =1 (at 10^{-3}) in the SM

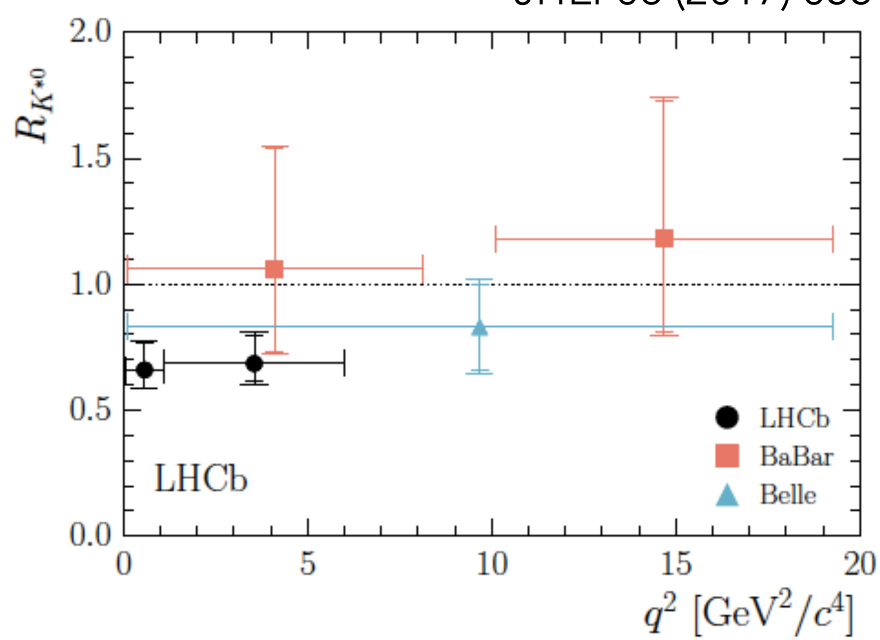
QED effects ~ % arXiv:1605.07633

R_K , R_{K*} , R_ϕ …

- PRD 86 (2012) 032012
- PRL 103 (2009) 171801

JHEP08 (2017) 055

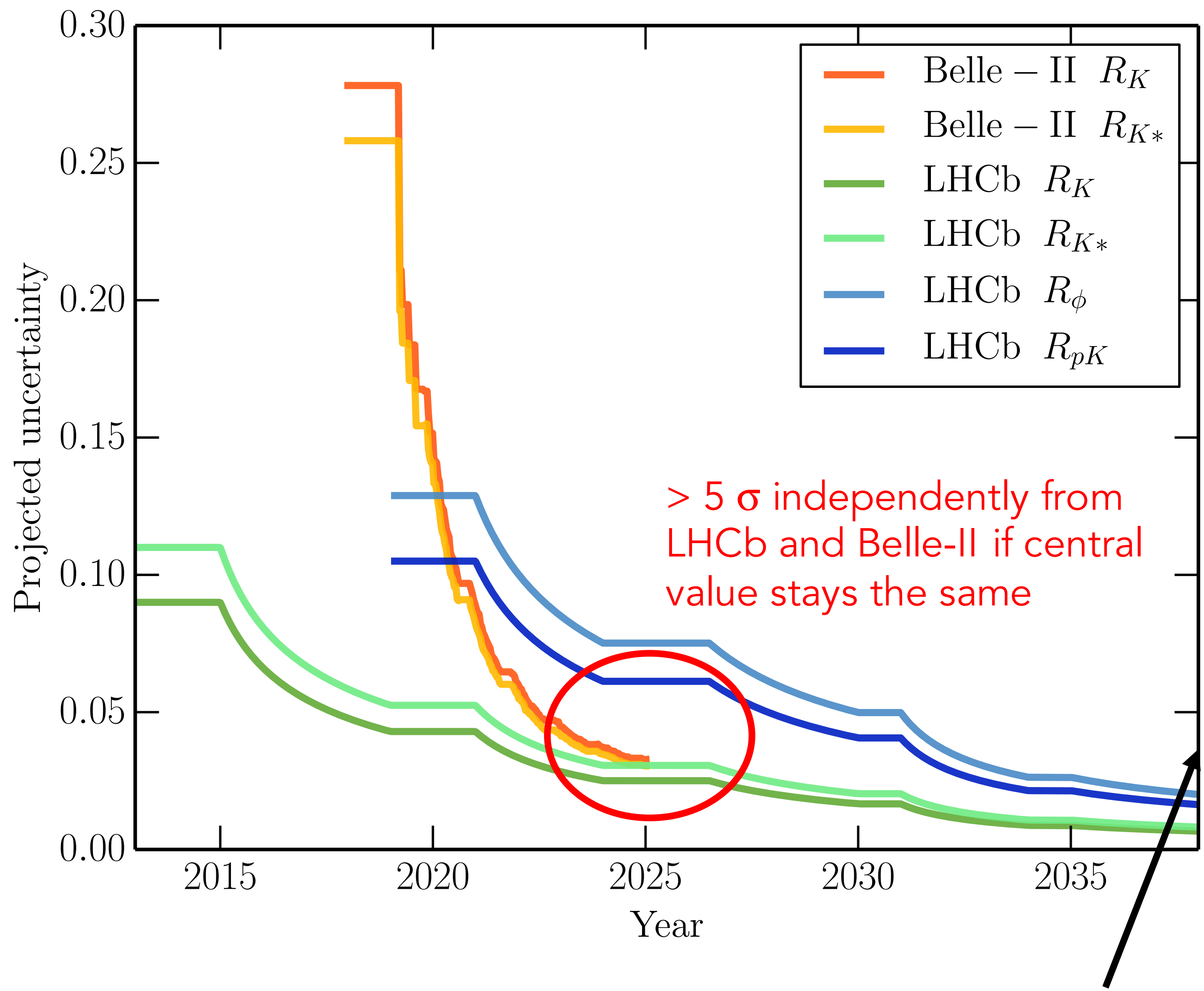




2 – 3 σ effects

Measurements dominated by statistics except for 300 fb^{-1}

arXiv:1809.06229

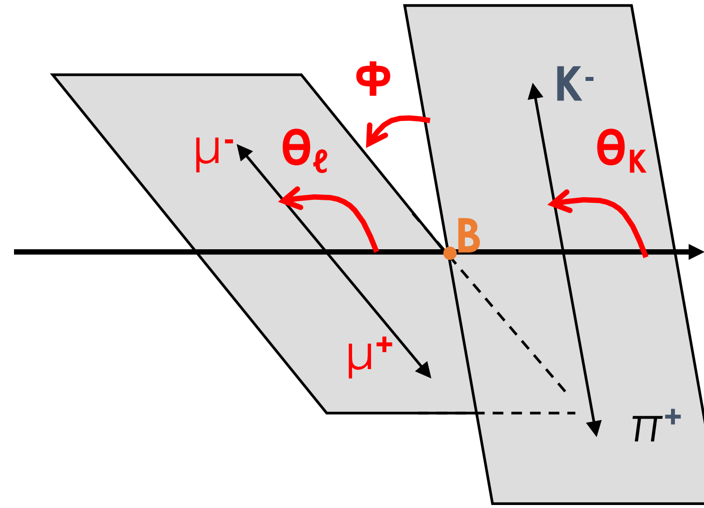


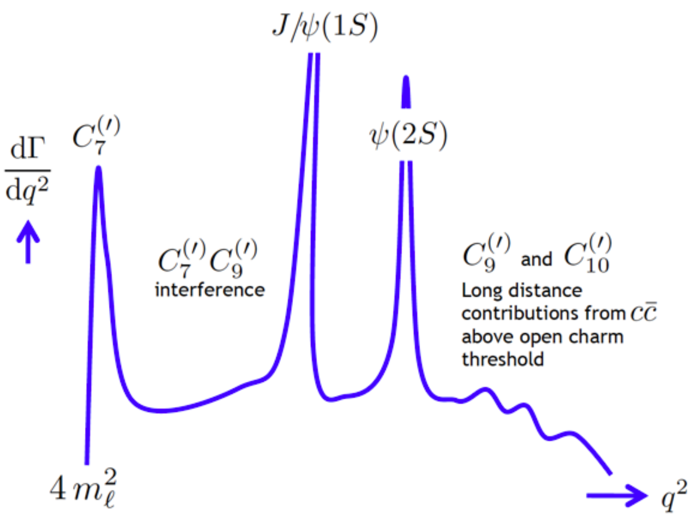
$$R_\pi = \mathcal{B}(B^\pm \to \pi^\pm \mu^+ \mu^-)/\mathcal{B}(B^\pm \to \pi^\pm e^+ e^-)$$

Angular observables

4 particles final state
System described by:

- $q^2 = M^2(\ell\ell)$
- 3 angles





$$\frac{d^4\Gamma[\overline{B}^0 \to \overline{K}^{*0}\mu^+\mu^-]}{dq^2\, d\vec{\Omega}} = \frac{9}{32\pi} \sum_i I_i(q^2) f_i(\vec{\Omega})$$

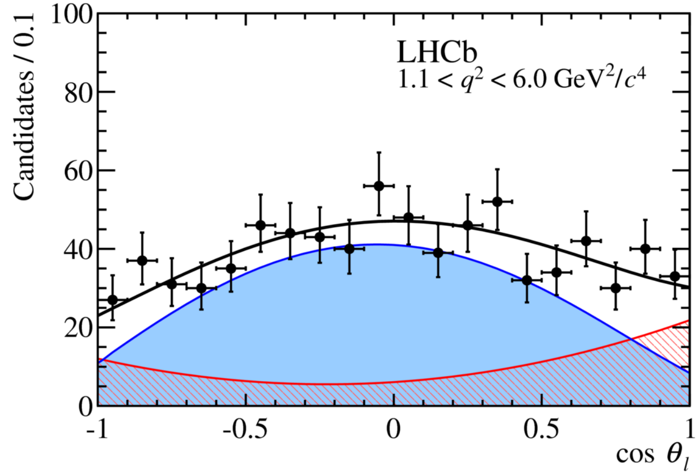
$$\frac{d^4\bar{\Gamma}[B^0 \to K^{*0}\mu^+\mu^-]}{dq^2\, d\vec{\Omega}} = \frac{9}{32\pi} \sum_i \bar{I}_i(q^2) f_i(\vec{\Omega})$$

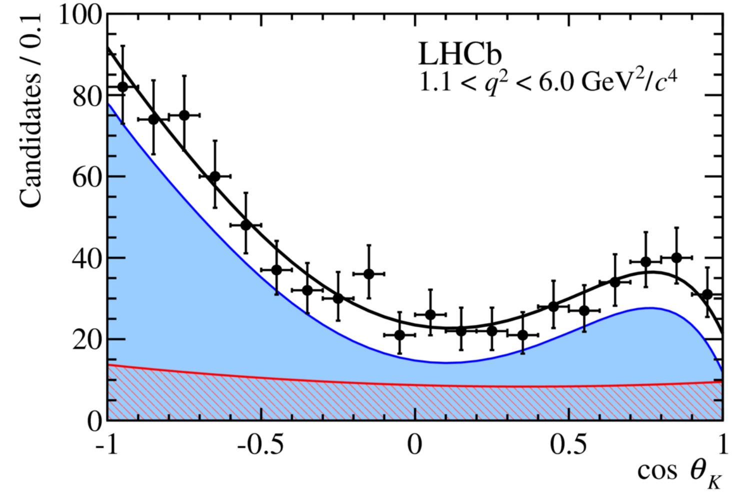
I_i are encoding the matrix elements of the decay
Ratios of I_i to remove FF and be sensitive to the Wilson coefficients

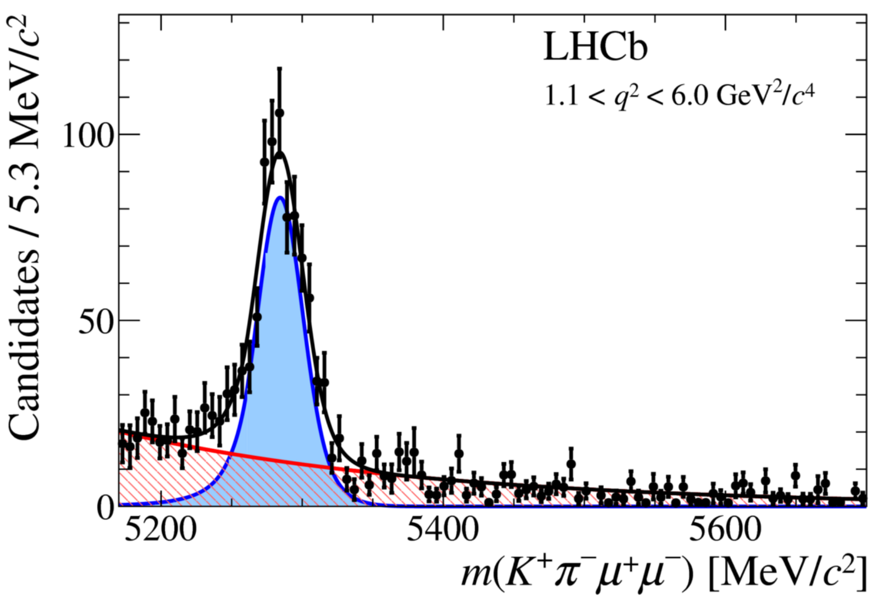
→ Angular analysis in bins of q^2

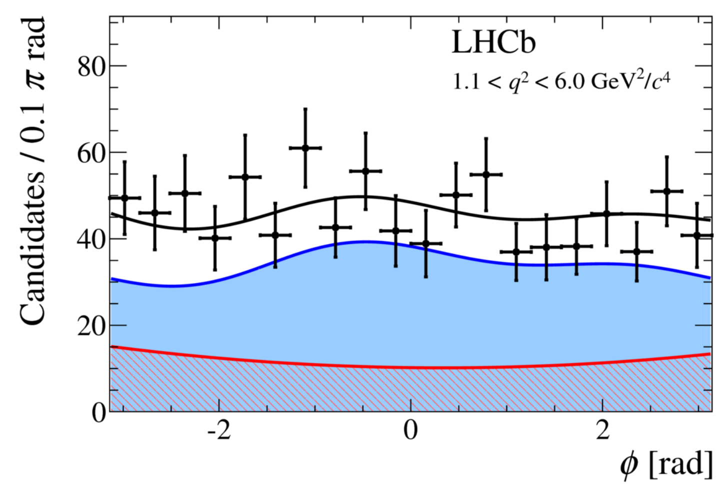
JHEP 02 (2016) 104

an example :

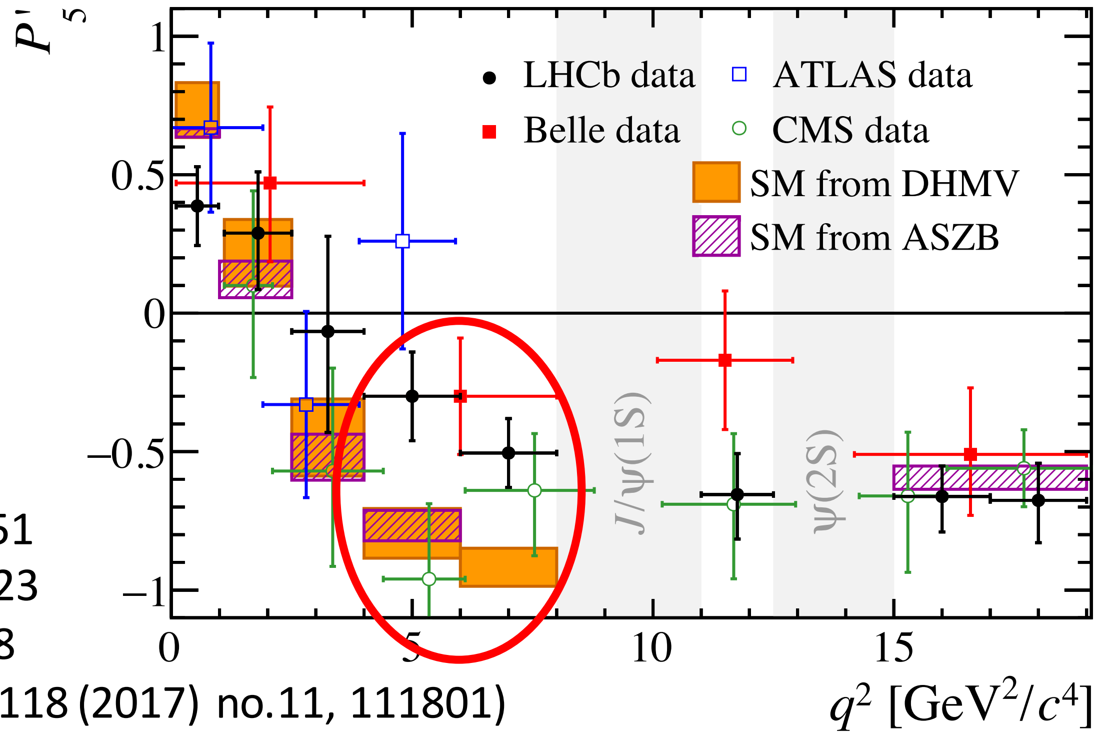








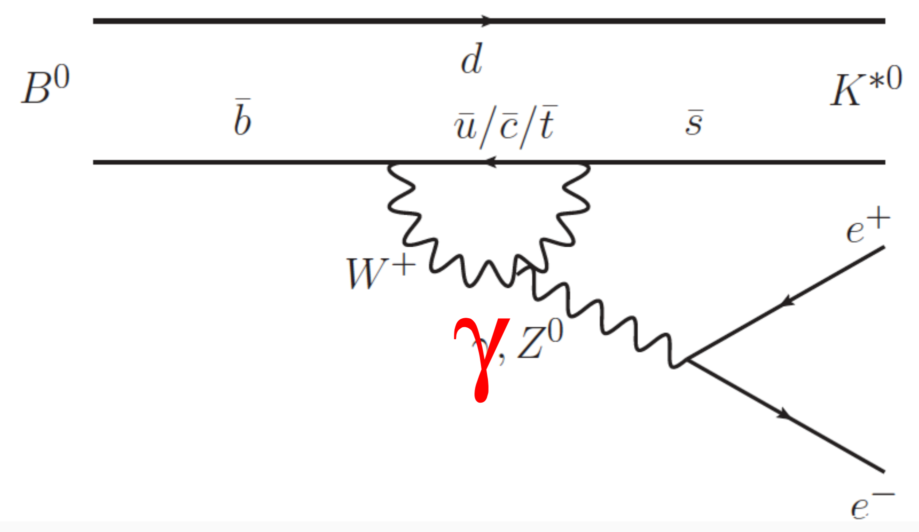
Some tensions



LHCb-PAPER-2015-051
ATLAS-CONF-2017-023
CMS-PAS-BPH-15-008
Belle (Phys.Rev.Lett. 118 (2017) no.11, 111801)

Other observables in better agreement with SM

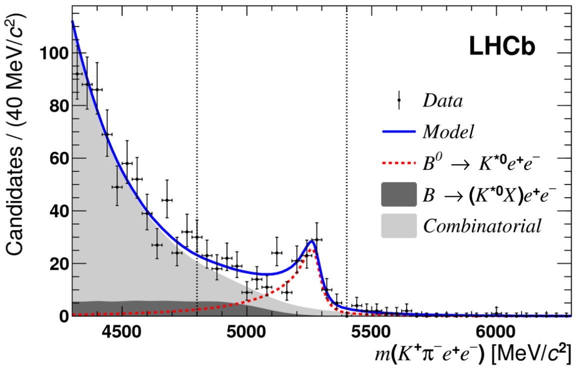
Measurement of the photon polarization with B→K*ee

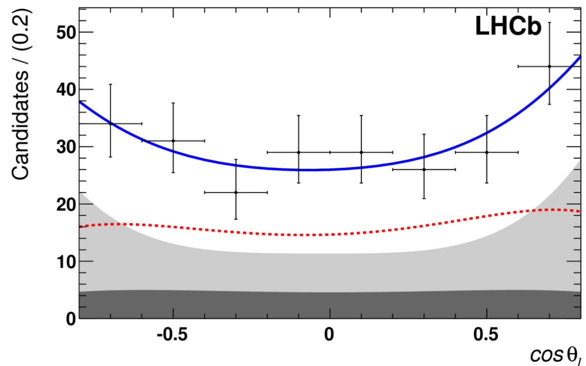


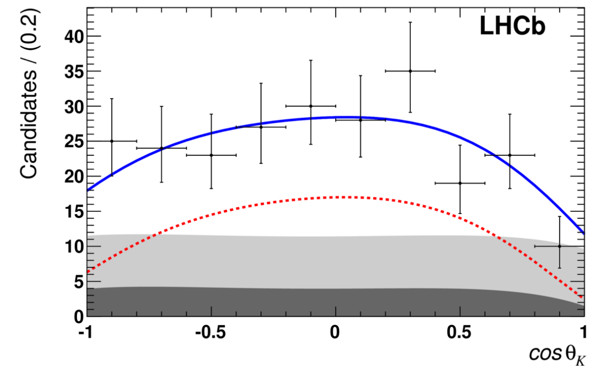
$$A_T^{(2)}(q^2 \to 0) \simeq 2\frac{\mathcal{R}e(C_7'^*)}{|C_7|} \quad \text{and} \quad A_T^{\rm Im}(q^2 \to 0) \simeq 2\frac{\mathcal{I}m(C_7'^*)}{|C_7|}$$

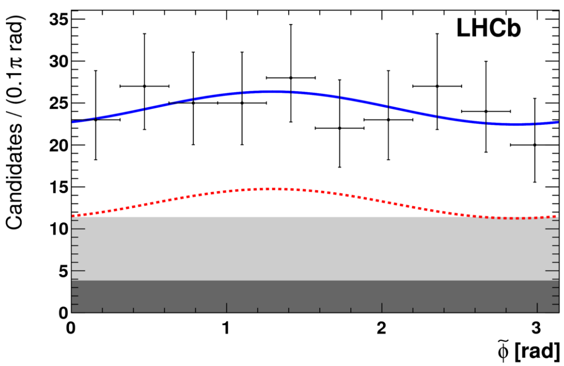
q^2 as low as possible [multiple scattering constraint]

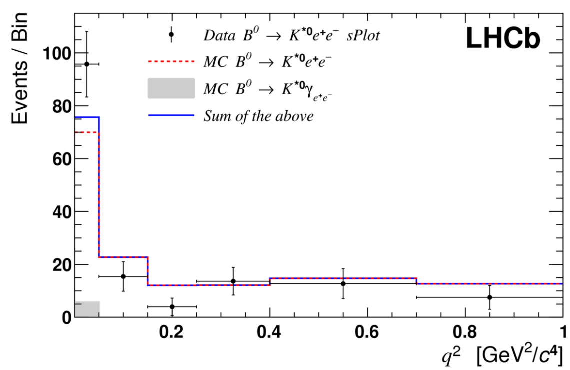
JHEP 04(2105) 064







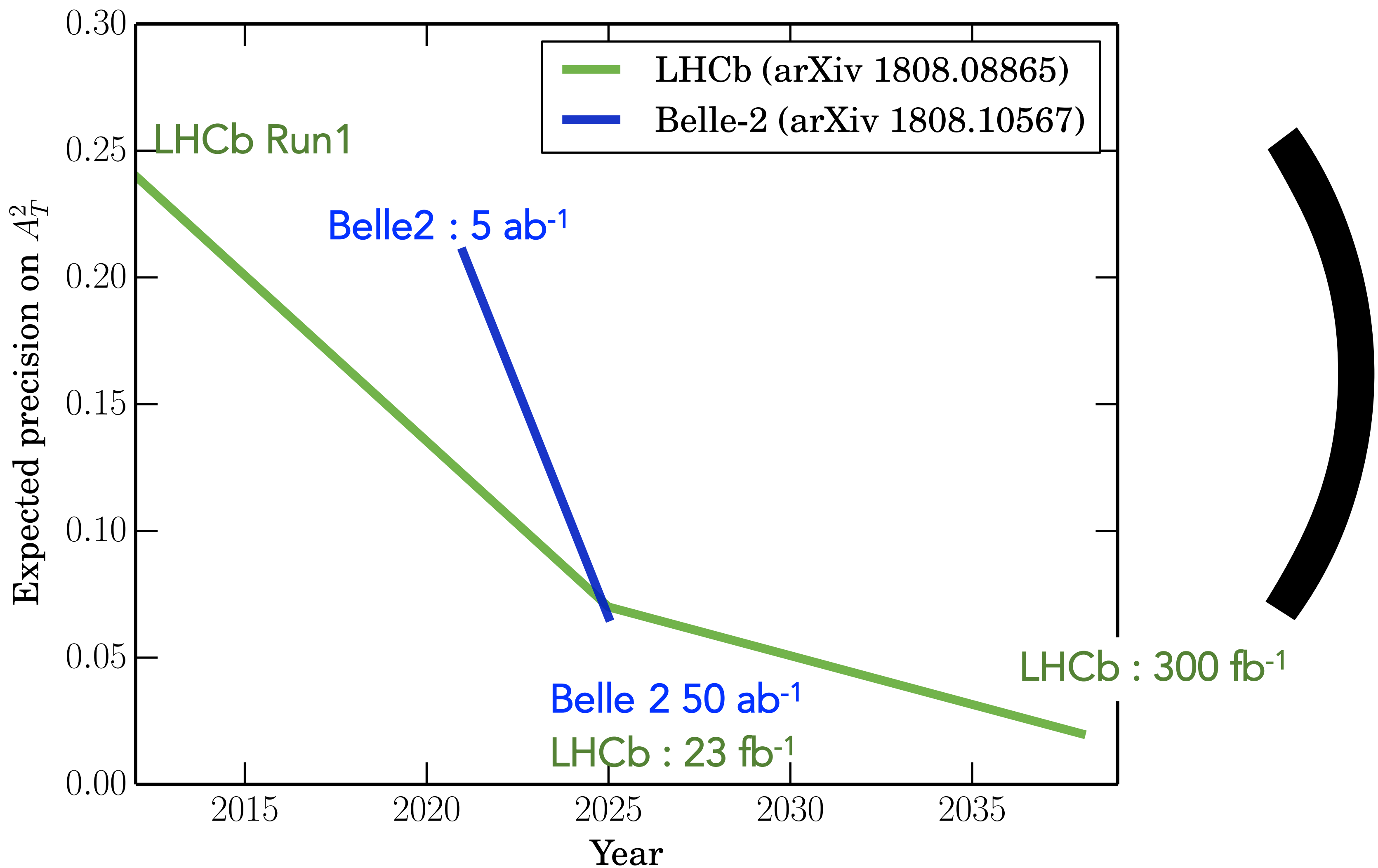




	Corrected values
F_L	$0.16 \pm 0.06 \pm 0.03$
$A_T^{(2)}$	$-0.23 \pm 0.23 \pm 0.05$
A_T^{Im}	$+0.14 \pm 0.22 \pm 0.05$
A_T^{Re}	$+0.10 \pm 0.18 \pm 0.05$

Measurement of the photon polarization to ~ 12 %

Expected uncertainty on A_T^2 / A_T^{Im}



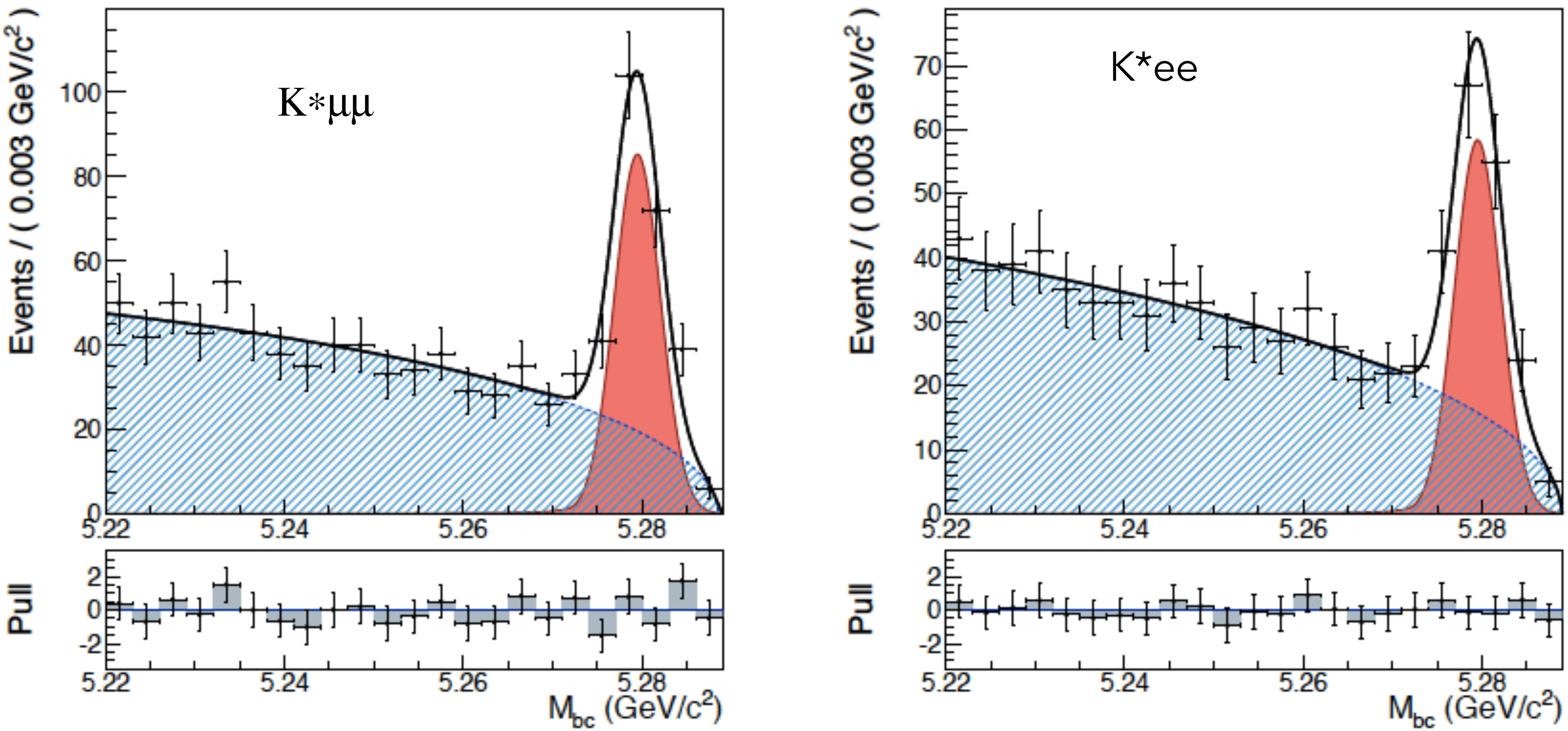
Similar performance expected with very different environments

Direct comparison of angular distributions for the muonic and electronic final states

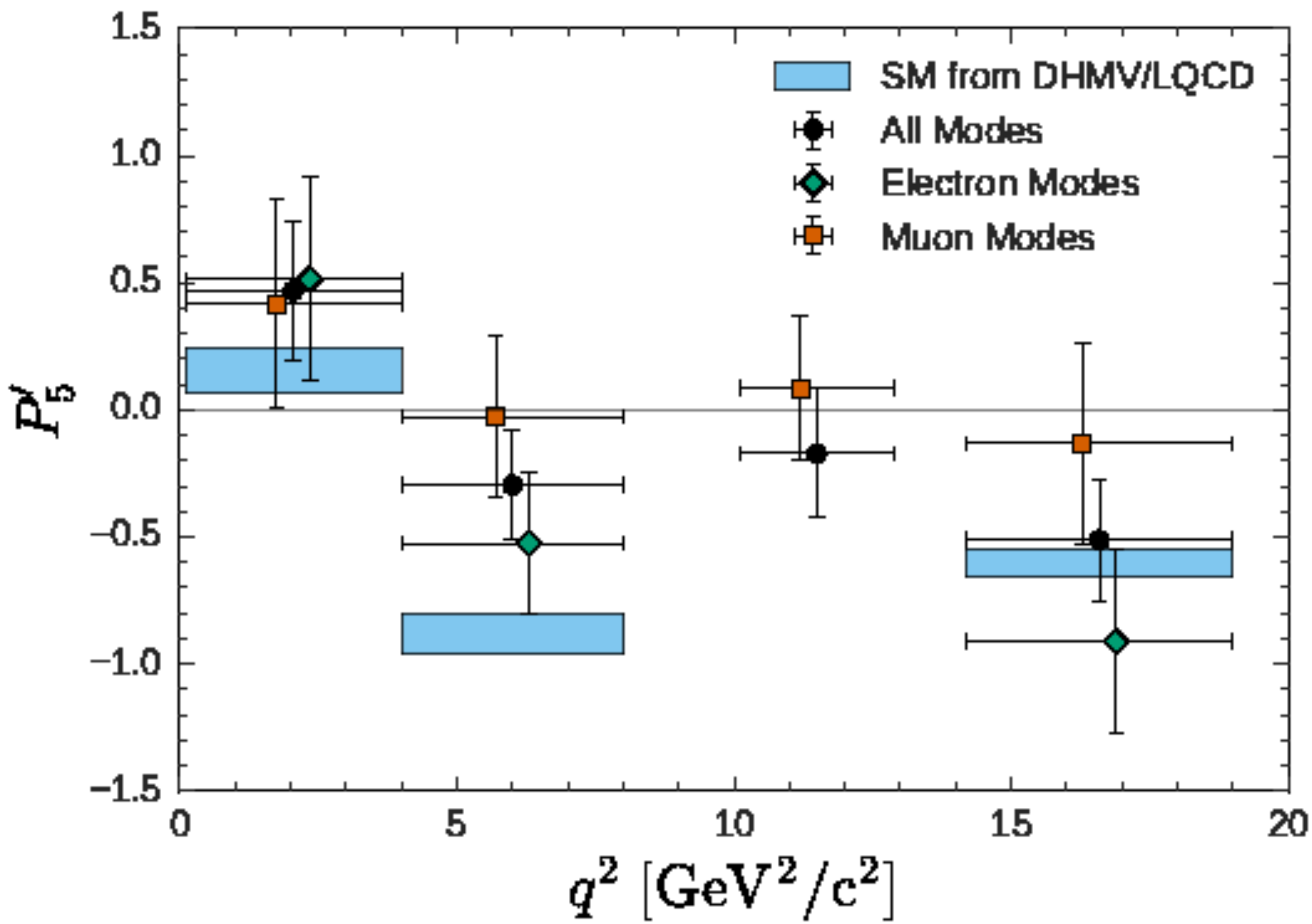
Belle : beam energy constrained mass

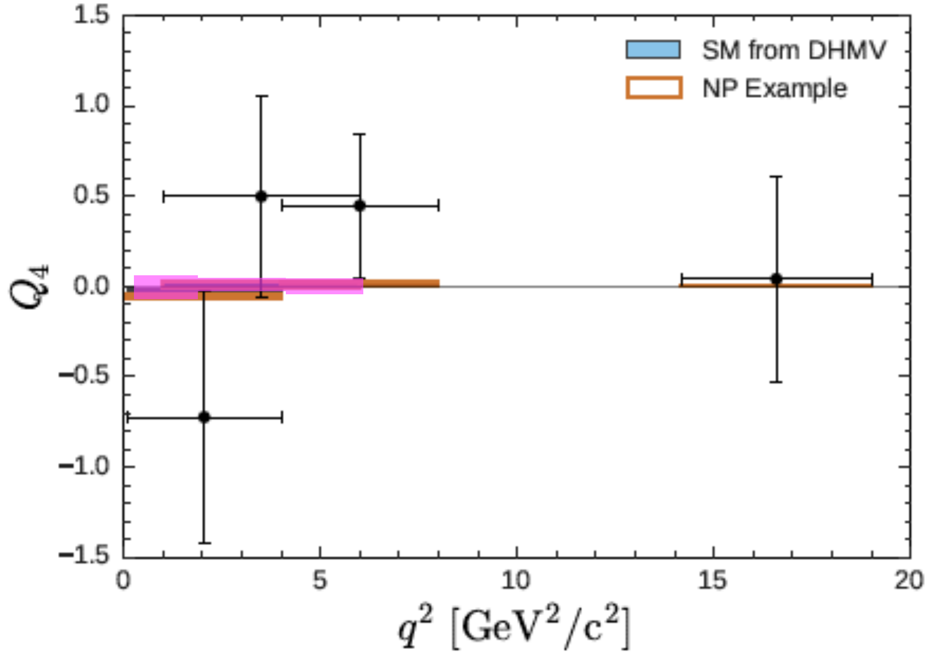
full q^2 region (but the JPsi and Psi(2S))

PRL118 (2017) 111801



PRL118 (2017) 111801

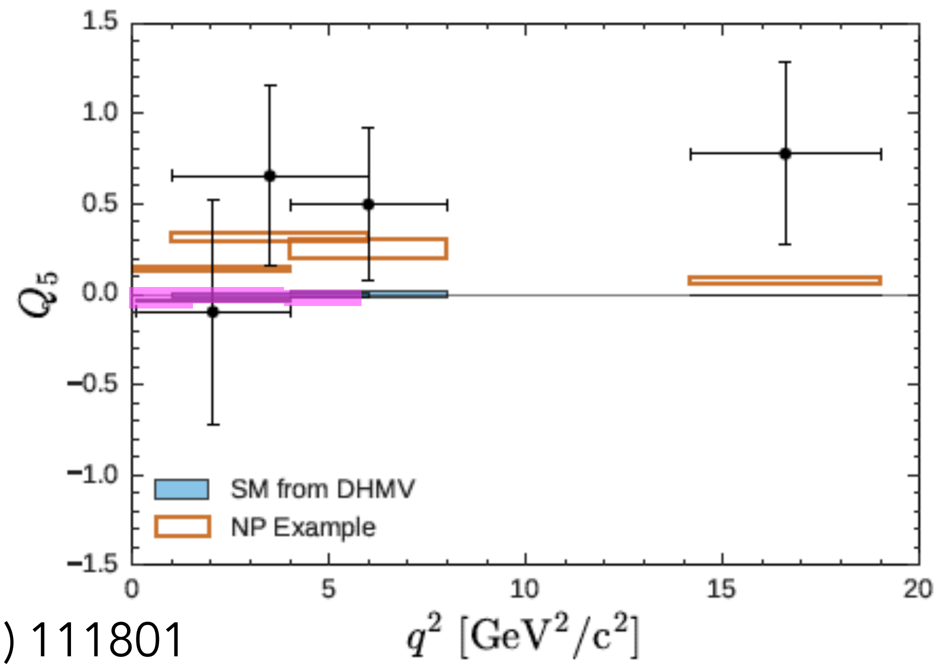




$$Q_i = P_i^{\mu} - P_i^{e}$$

JHEP 10 (2016) 075

Expected precision Belle 2 (50 ab^{-1}) from arXiv 1808.10567



PRL118 (2017) 111801

A significant number of interesting "hints"

Cautiousness is of prime importance :

- Statistical fluctuations
- Experimental artefacts (but the double ratios are expected to be very robust measurements)
- Theoretical uncertainties ?

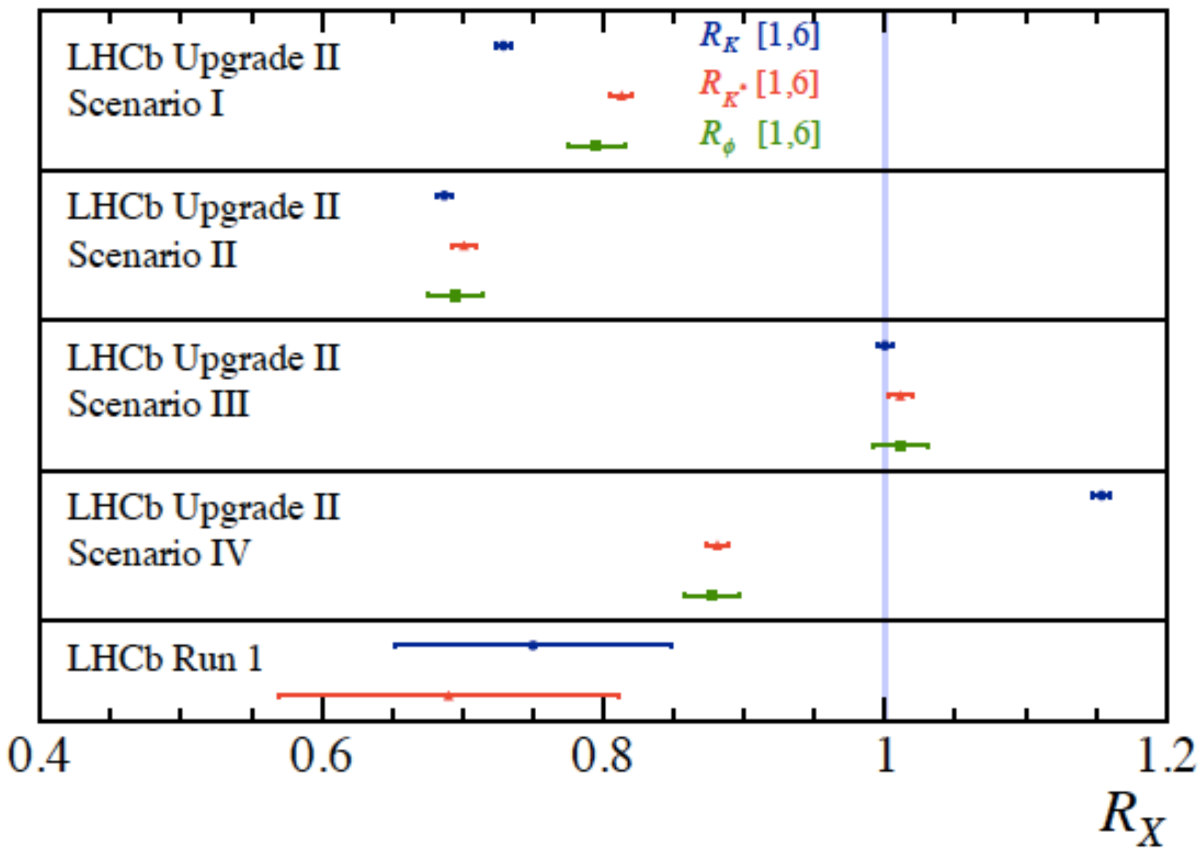
Let's play with NP scenarios

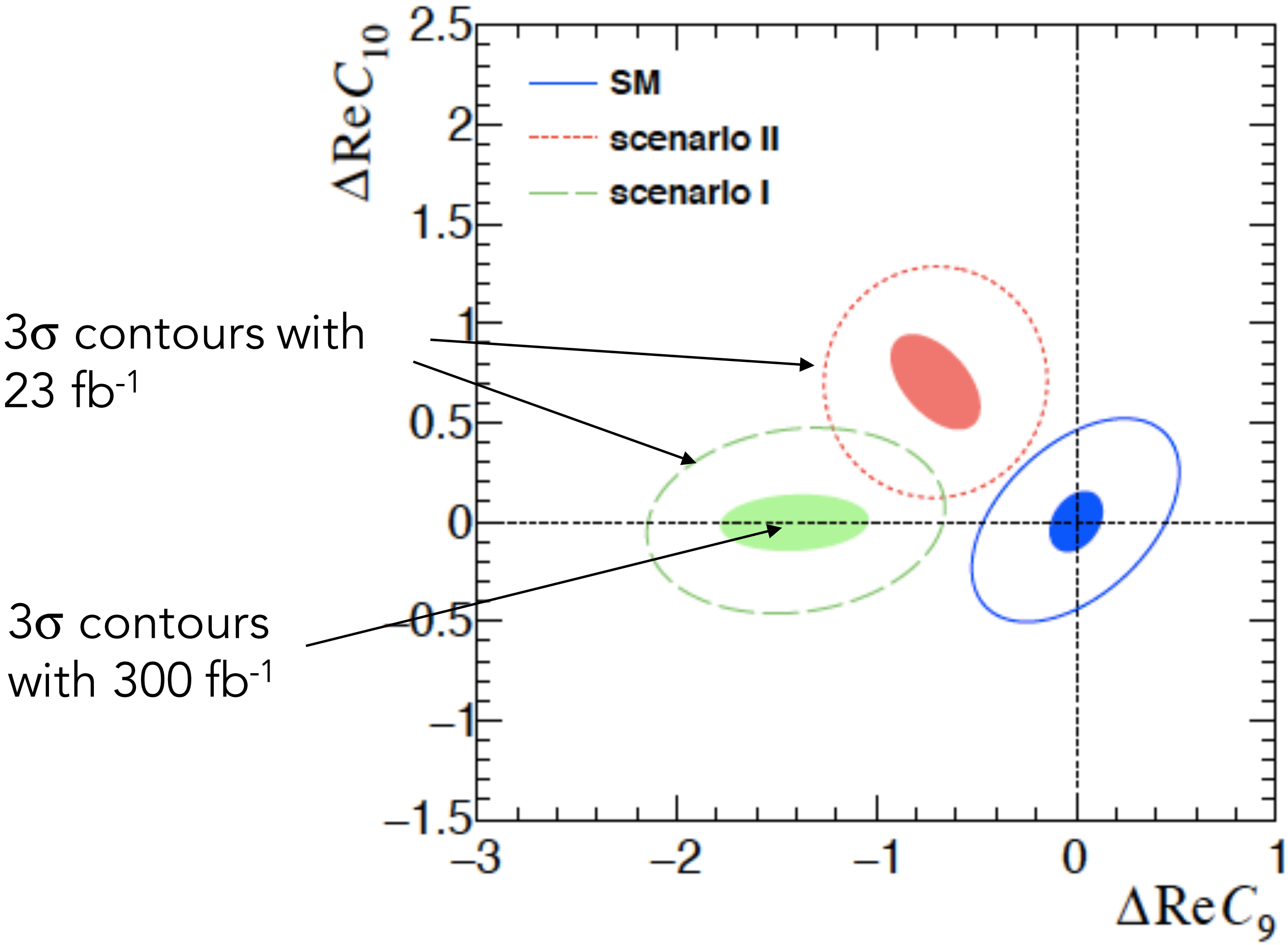
scenario	C_9^{NP}	C_{10}^{NP}	C'_9	C'_{10}
I	-1.4	0	0	0
II	-0.7	0.7	0	0
III	0	0	0.3	0.3
IV	0	0	0.3	-0.3

R_{K/K^*} and angular measurements

same + R_D

Some right-handed couplings.





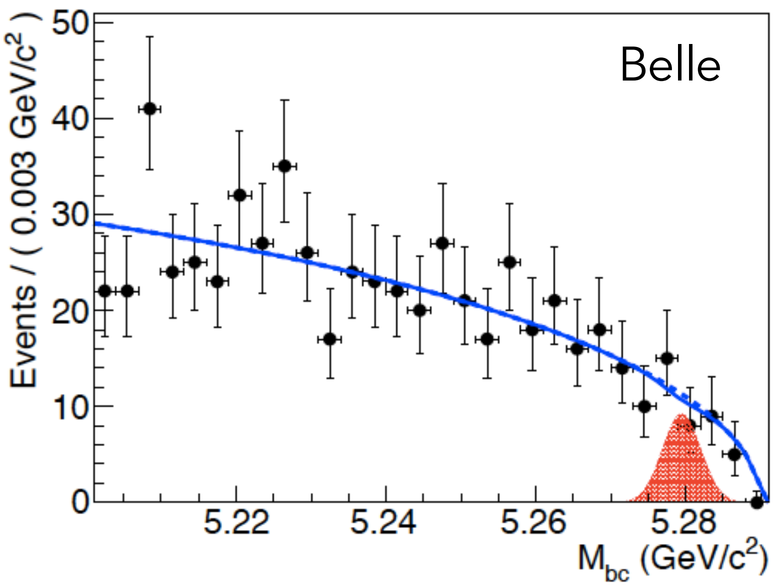
Different NP scenarios can be cleanly separated

A lot of models proposed ….

Some are also pointing to Lepton Flavour Violation

Search for B→ K(*) e μ

arXiv:1807.03267



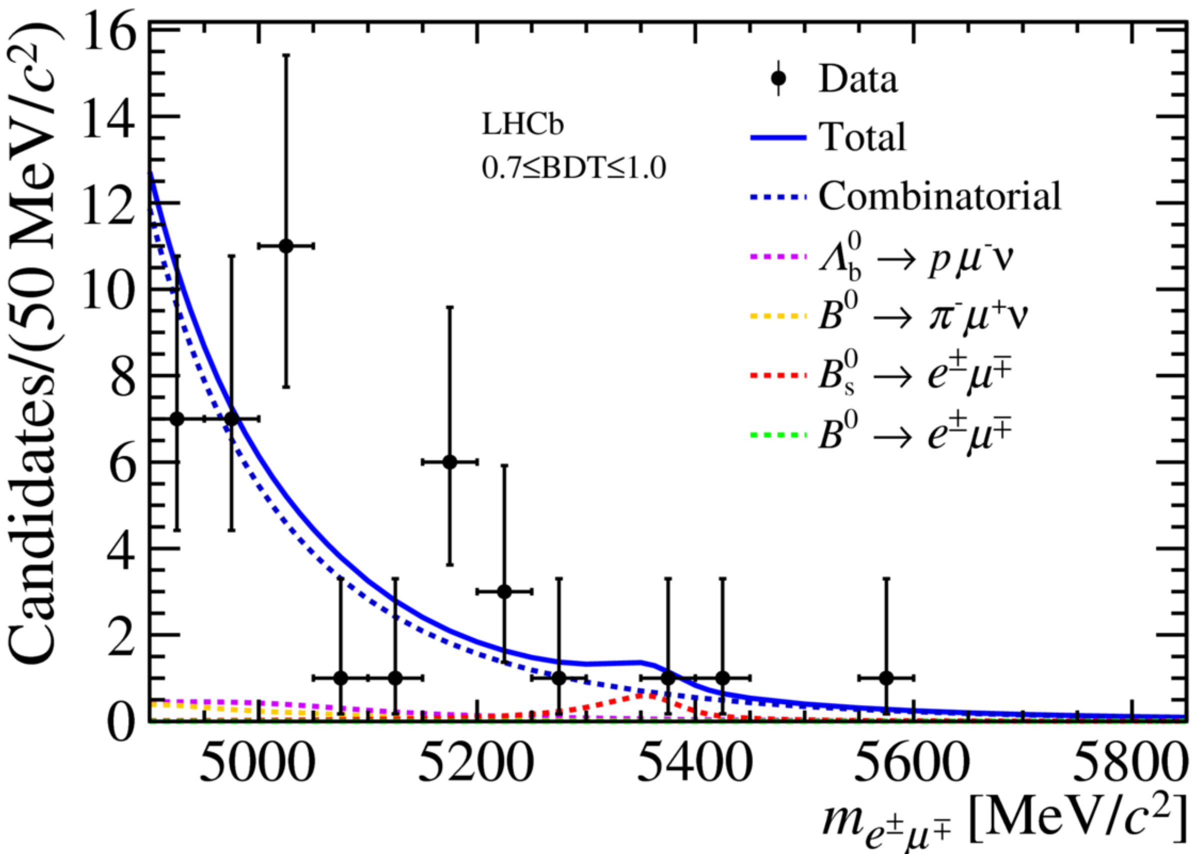
Most stringent limit today for this mode

$$\mathcal{B}(B^0 \to K^{*0}\mu^+e^-) < 1.2 \times 10^{-7}$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^-e^+) < 1.6 \times 10^{-7}$$
$$\mathcal{B}(B^0 \to K^{*0}\mu^\pm e^\mp) < 1.8 \times 10^{-7}$$

90%CL

Search for $B_{(s)} \rightarrow e\,\mu$

JHEP 1803 (2018) 078



Limits :

channel	observed
$\mathcal{B}(B_s^0 \rightarrow e^\pm \mu^\mp)$	$6.3\,(5.4) \times 10^{-9}$
$\mathcal{B}(B^0 \rightarrow e^\pm \mu^\mp)$	$1.3\,(1.0) \times 10^{-9}$

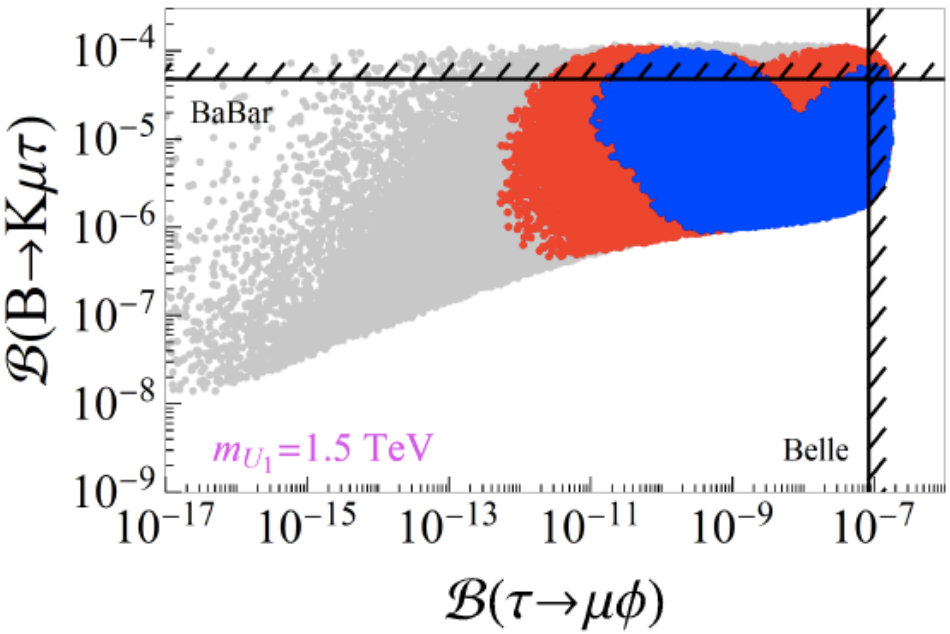
7.2 (6.0) if amplitude dominated by the light eigenstate

Tests of models:

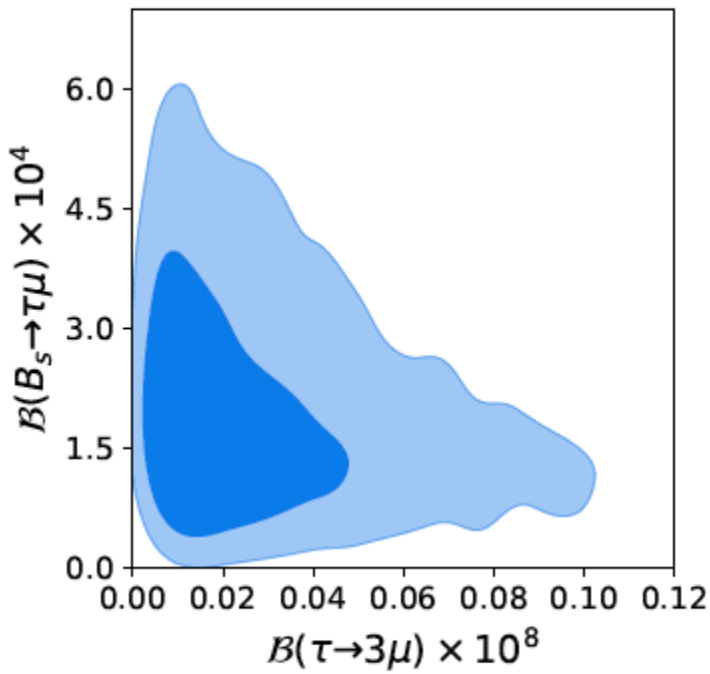
See the talk from Dario Buttazzo on Tuesday

large τ→μ transition in a whole set of models

arXiv:1808.08179



arXiv:1805.09328



Currently excluded by GPD with 36 fb^{-1}

Exclusion extrapolated to 300 fb^{-1} (GPD)

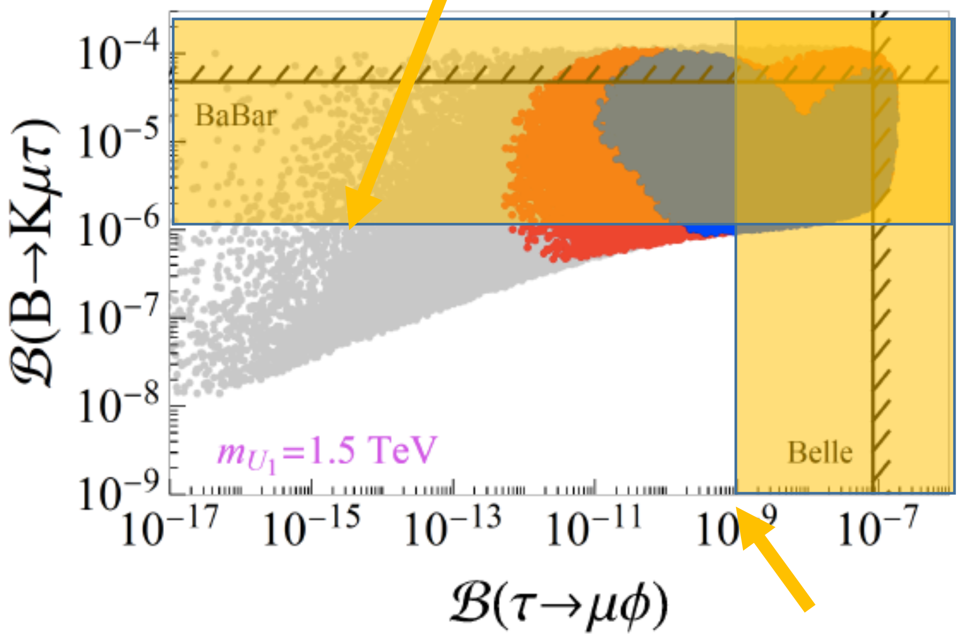
Allowed by 300 fb^{-1} (GPD)

Tests of models:

See the very nice talk from Dario Buttazzo on Tuesday

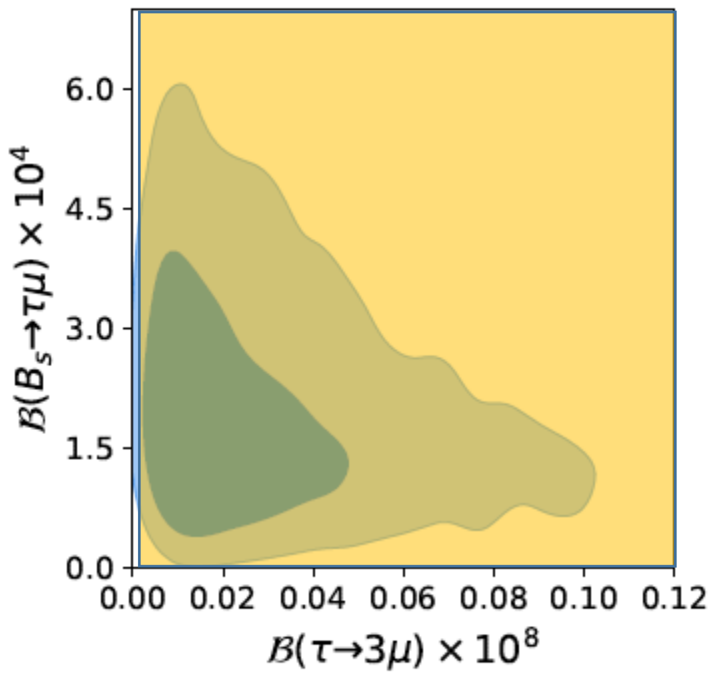
LHCb 300 fb^{-1}
Belle 2 50 ab^{-1}

arXiv:1808.08179



Belle 2 50 ab^{-1}

arXiv:1805.09328



Belle-2 (50 ab^{-1})
BR($\tau\to3\mu$) <~ 3 10^{-10} [90 %CL]

LHCb (9 fb^{-1} : Run1 Run2)
BR($B\to\tau\mu$)<~ few 10^{-5} [90 % CL]

Currently excluded by GPD with 36 fb^{-1}

Exclusion extrapolated to 300 fb^{-1} (GPD)

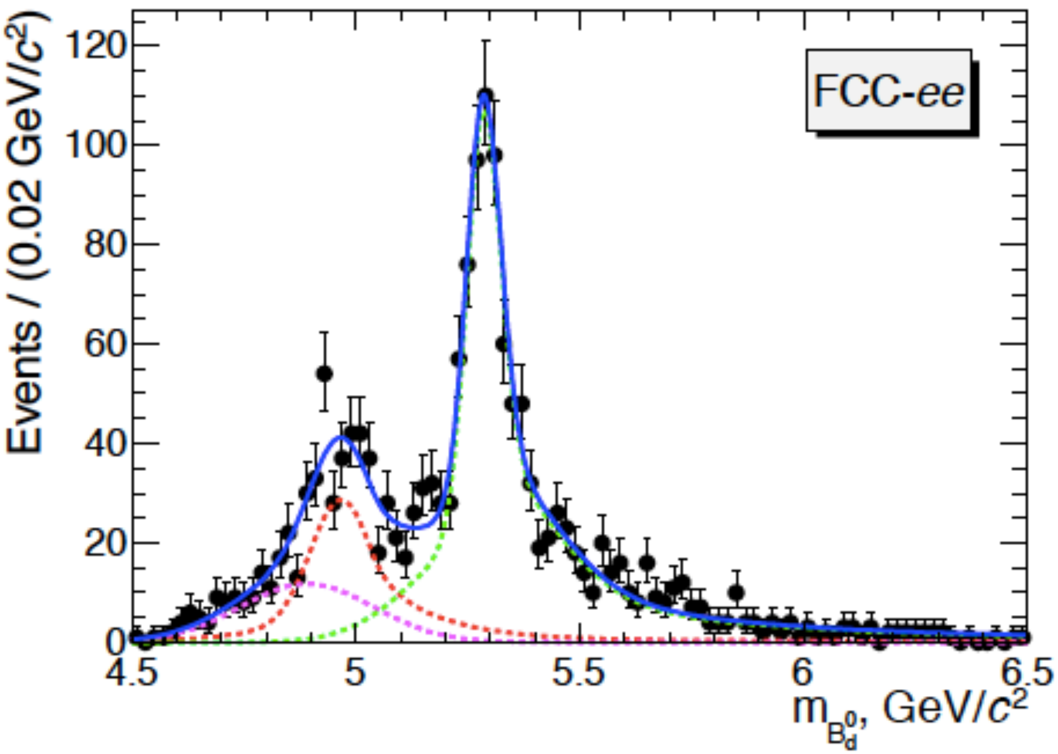
Allowed by 300 fb^{-1} (GPD)

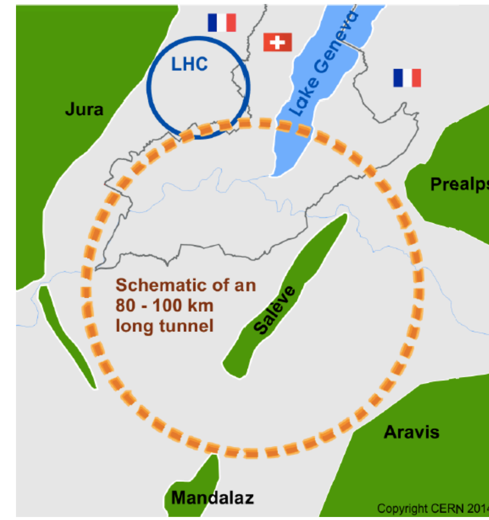
The ultimate place to do b-physics ?

At the Z^0 peak : ~ 10^{12} $b\bar{b}$ pairs

$B^0 \rightarrow K^{*0} \tau\tau$

arXiv:1705.11106





BR assumed to be SM
few thousands signal events
τ polarization measurement

High precision-vertex detector (σ_{vertex} ~ 2.5 μm
a factor 10 better than LHCb

Real life considerations

- But **a lot** of efforts will be needed to make use of huge statistics of 300 fb^{-1}
  - Computing, storage, bookkeeping
  - Analysis infrastructure
  - Personpower for many additional modes
  - Subtle systematic effects at sub-% level
  - Combination with cross-feed between tens (or hundreds) of modes

All of that is doable, but again, **a lot** of efforts will be needed.

(Anton)

This is also true for LHCb Upgrade 1 and Belle II !

Summary

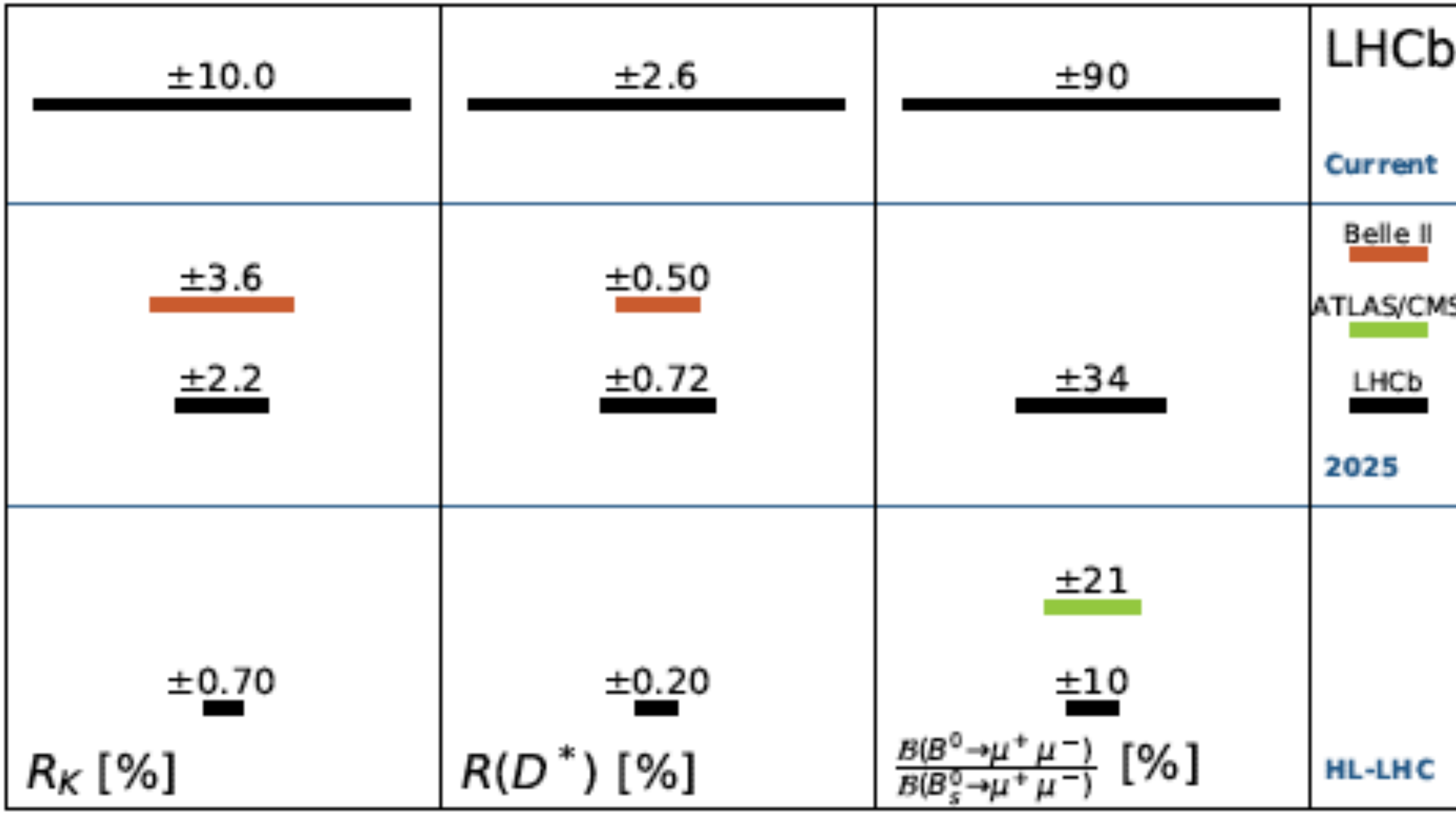
We are in an ideal situation :

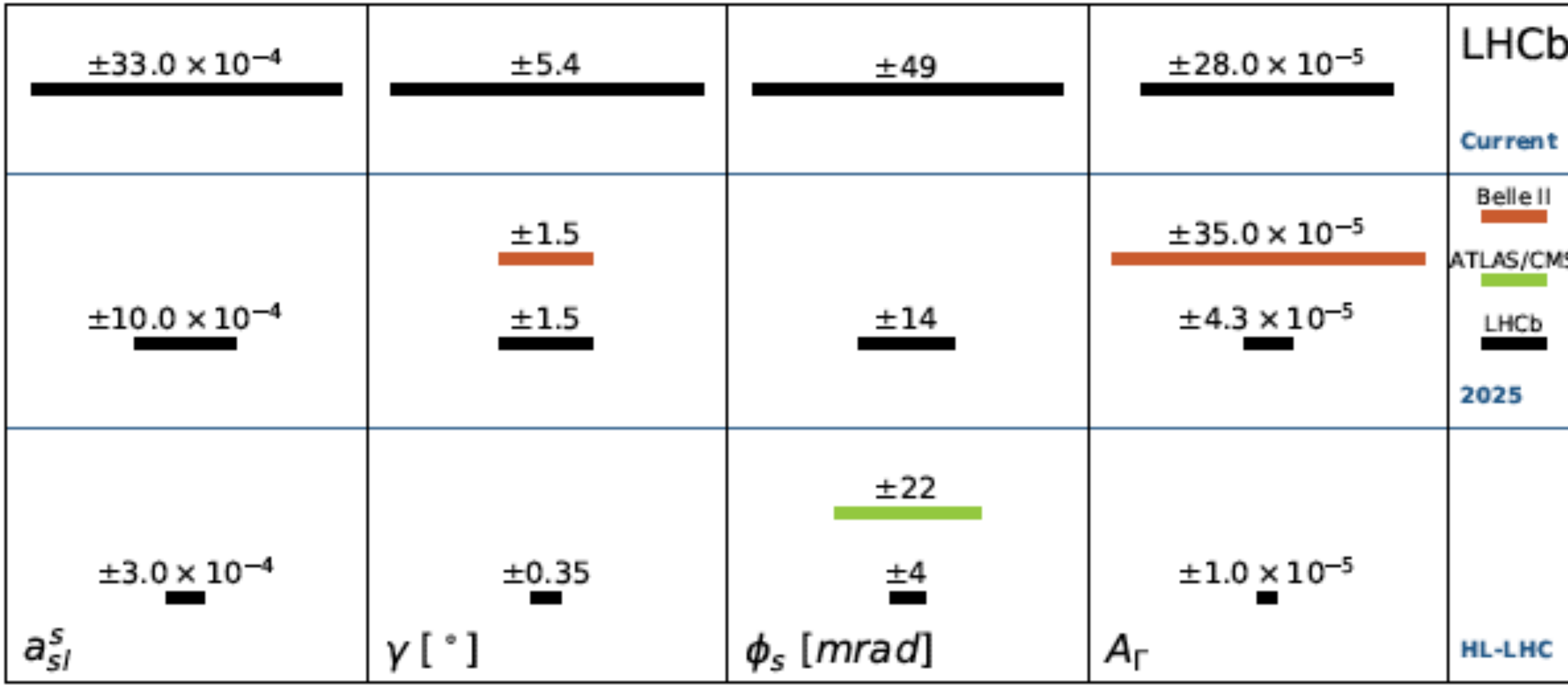
Some modes are better suited for Belle-2 (inclusive measurements, modes with several neutrals)

Some modes are unique for LHCb (B_s, B_c, b-baryons, extremely rare modes)

In many cases similar expected sensitivities … with very different detectors

Interesting times ahead !


LHCb
±10.0
±2.6
±90
Current
Belle II
ATLAS/CMS
LHCb
±3.6
±0.50
±2.2
±0.72
±34
2025
±21
±0.70
±0.20
±10
R_K [%]
$R(D^*)$ [%]
$\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B_s^0\to\mu^+\mu^-)}$ [%]
HL-LHC


LHCb
Current
±33.0 × 10−4
±5.4
±49
±28.0 × 10−5
Belle II
ATLAS/CMS
LHCb
2025
±1.5
±35.0 × 10−5
±10.0 × 10−4
±1.5
±14
±4.3 × 10−5
HL-LHC
±22
±3.0 × 10−4
±0.35
±4
±1.0 × 10−5
a^s_{sl}
γ [°]
ϕ_s [mrad]
A_Γ

Backup slides

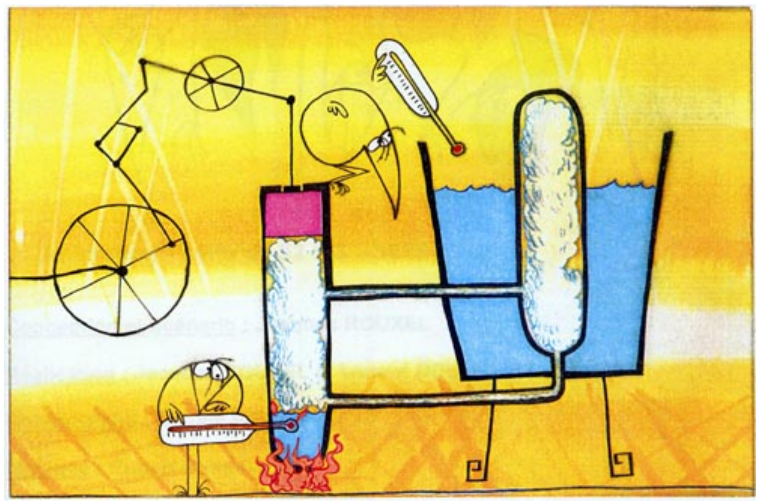
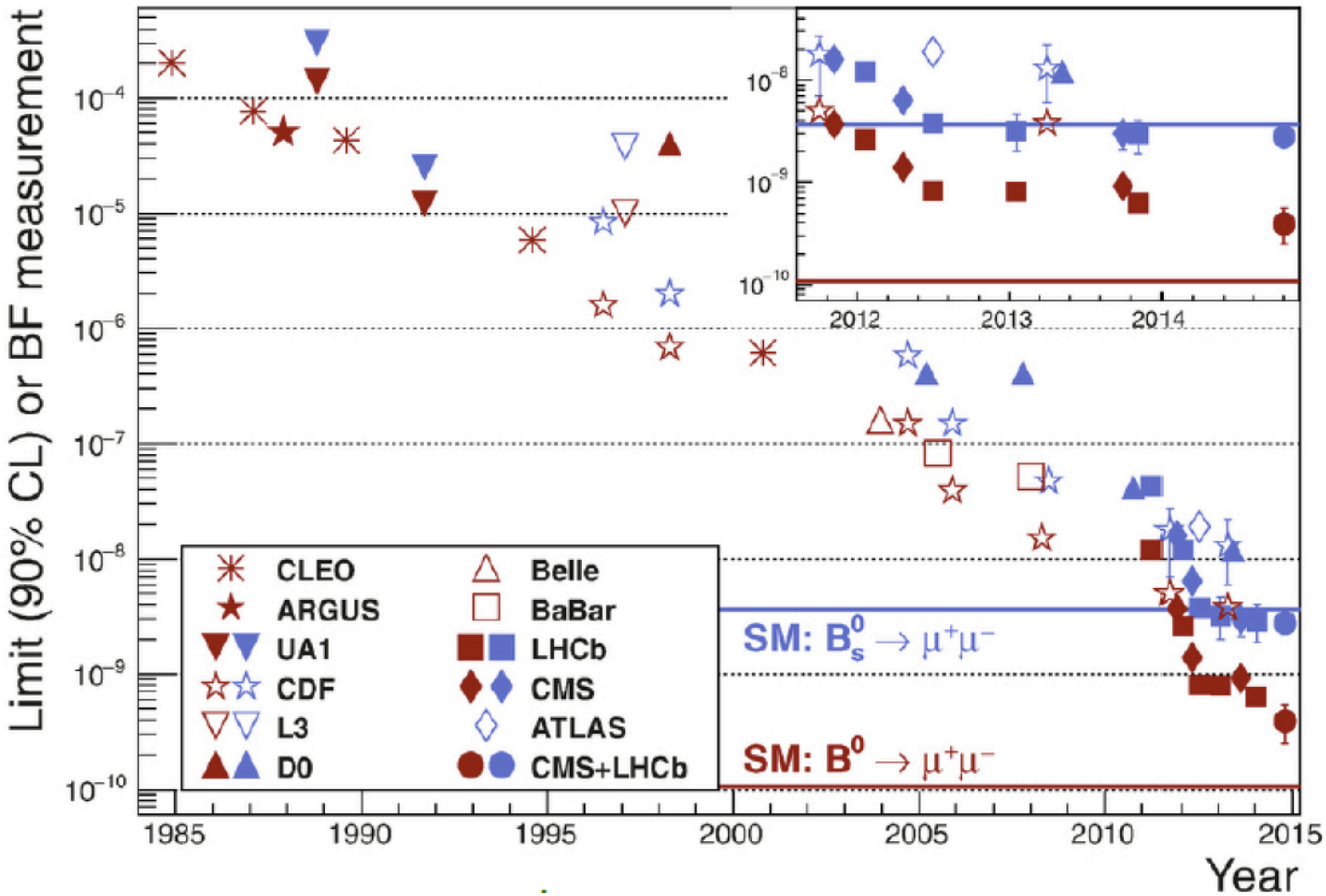


Table 10.1: Summary of prospects for future measurements of selected flavour observables for LHCb, Belle II and Phase-II ATLAS and CMS. The projected LHCb sensitivities take no account of potential detector improvements, apart from in the trigger. The Belle-II sensitivities are taken from Ref. [608].

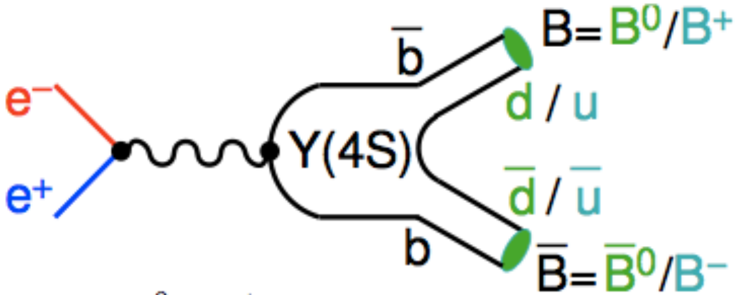
Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [609]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [610]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [611]
$a_{\rm sl}^s$	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
B_s^0, $B^0 \to \mu^+\mu^-$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [612]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$b \to c\ell^-\bar{\nu}_l$ LUV studies					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [613]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

$B_{(s)}^0 \to \mu^+\mu^-$



Clean experimental signature (trigger)

B-Factories



$B^0 : B^+ \approx 1:1$

$M(\Upsilon(4S))=10.58$ GeV $J^{PC}= 1^{--}$

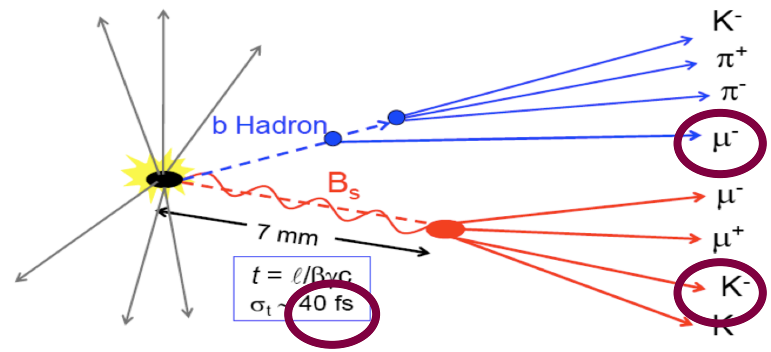
only (B^+, B^0) are produced (no fragmentation)

(B^+, B^0) are produced nearly at rest in the $\Upsilon(4S)$ cms

Two pseudoscalar bosons with L=1, antisymmetric wave function

If the two B could oscillate independently: they could become a state made up of two identical mesons (=bosons), this would be a symmetric state …

LHCb



Two independent b-hadrons produced

Time measured from primary vertex

All types of b-hadrons : B_s and Λ_b also

Fragmentation tracks

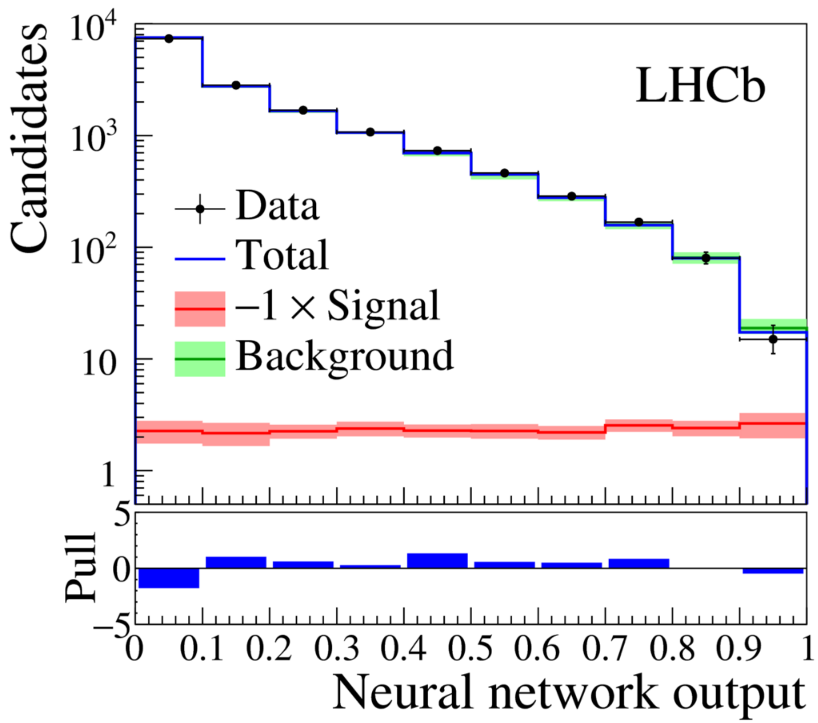
$B_{d,s} \to \tau\tau$

$$\mathrm{Br}^{\mathrm{SM}}_{B_s\tau^+\tau^-} = (7.73 \pm 0.49) \cdot 10^{-7}$$

$$\mathrm{Br}^{\mathrm{SM}}_{B_d\tau^+\tau^-} = (2.22 \pm 0.19) \cdot 10^{-8}$$

PRL112 (2014) 101801

$$\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$$



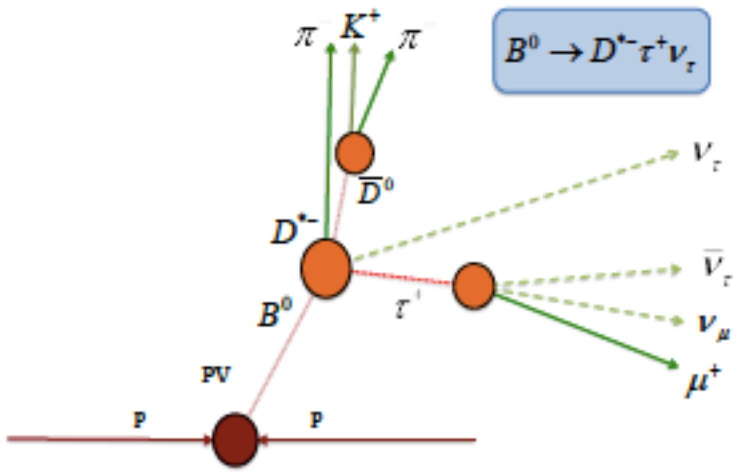
PRL 118 251802 (2017)

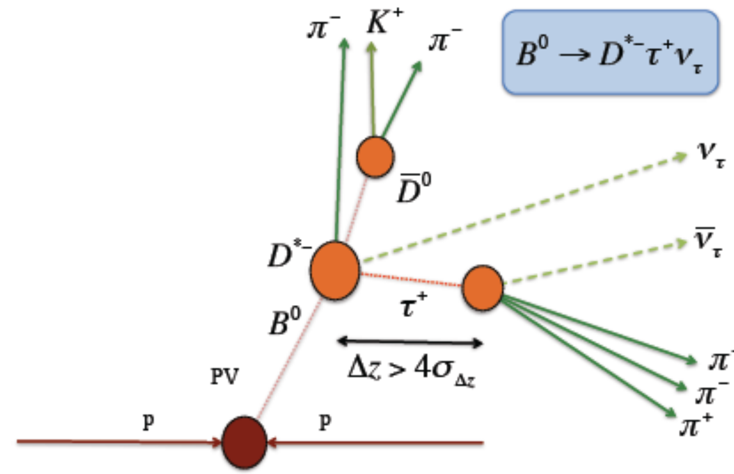
$$\mathcal{B}(B^0_s \to \tau^+\tau^-) < 6.8 \times 10^{-3}$$ @ 95 % CL

$$\mathcal{B}(B^0 \to \tau^+\tau^-) < 2.1 \times 10^{-3}$$

→ < 5 10^{-4} at the end of Upgrade II

Two experimental approaches for the τ reconstruction





LHCb results on the R ratios
Run1 data

Observable	τ decay	Value
R_{D^*}	$\tau^- \to \pi^-\pi^+\pi^-(\pi^0)\,\nu_\tau$	$0.291 \pm 0.019 \pm 0.029$
R_{D^*}	$\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau$	$0.336 \pm 0.027 \pm 0.030$
$R_{J/\psi}$	$\tau^- \to \mu^-\overline{\nu}_\mu\nu_\tau$	$0.71 \pm 0.17 \pm 0.18$