Physics perspectives for LHCb beyond Run4

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Physics motivations

- **Higgs discovery** explains the electroweak symmetry breaking: triumph of the Standard Model (SM)
- Still many **open questions** in particle physics: dark matter, neutrino masses, matter-antimatter asymmetry of the Universe
- **Tensions** and fine tuning in the SM: e.g. why the Higgs is so light, strong CP problem, fermion masses and mixing
- The absence of NP discoveries at LHC weakens the case for **new particles** at close-by energies
- Future physics programs rely more on **indirect searches**: e.g. electroweak physics precision observables, Higgs couplings, …

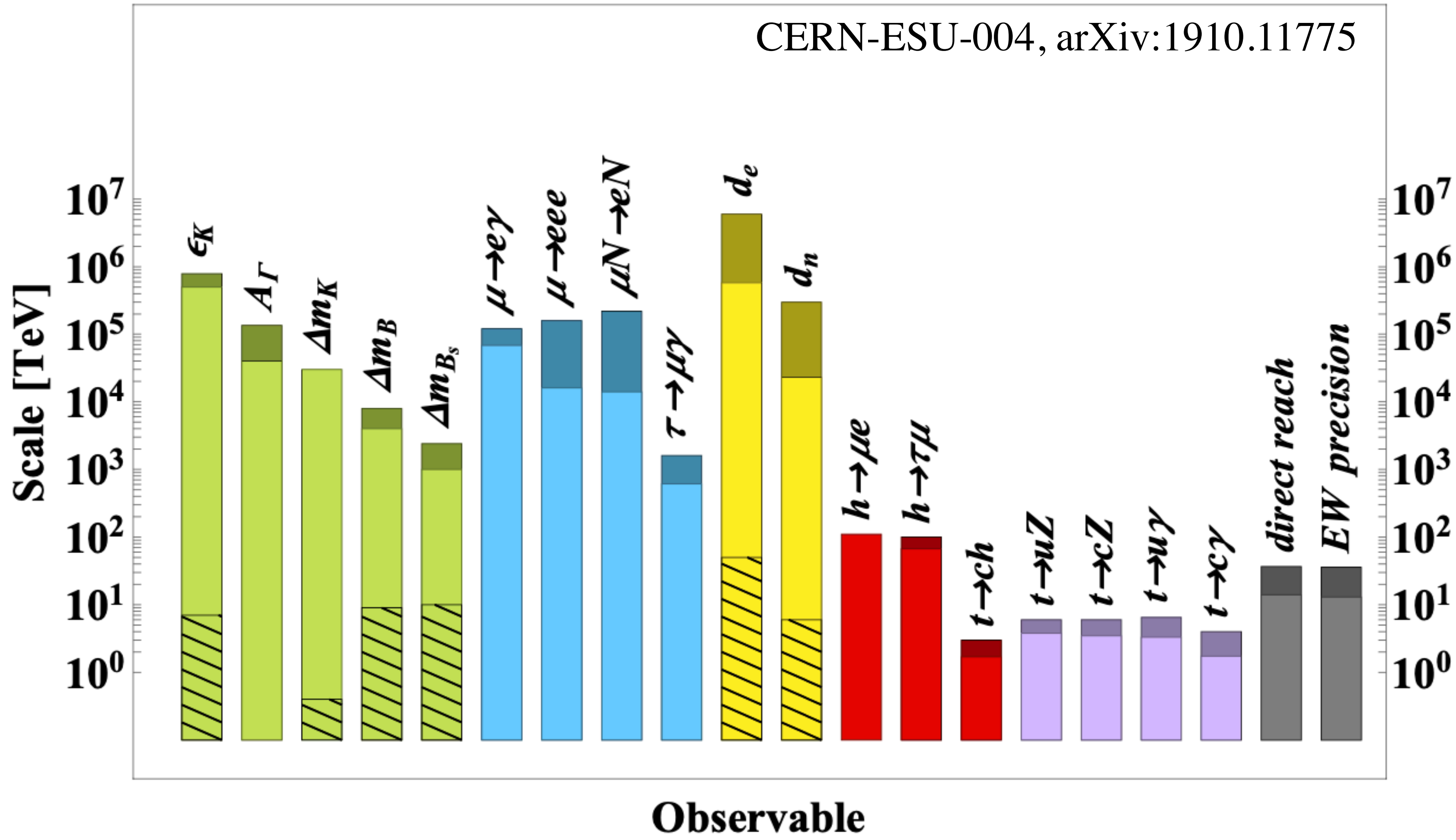
Precision flavour physics

- Model-independent effective Lagrangian $\mathscr{L}_{\text{eff}}$:

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\text{SM}} + \frac{\mathscr{L}_5}{\Lambda_{\text{NP}}} + \frac{\mathscr{L}_6}{\Lambda^2_{\text{NP}}},$$

- $\mathscr{L}_5$ breaks lepton number, $\mathscr{L}_6$ encodes effects of new physics particles of generic mass Λ_{NP}

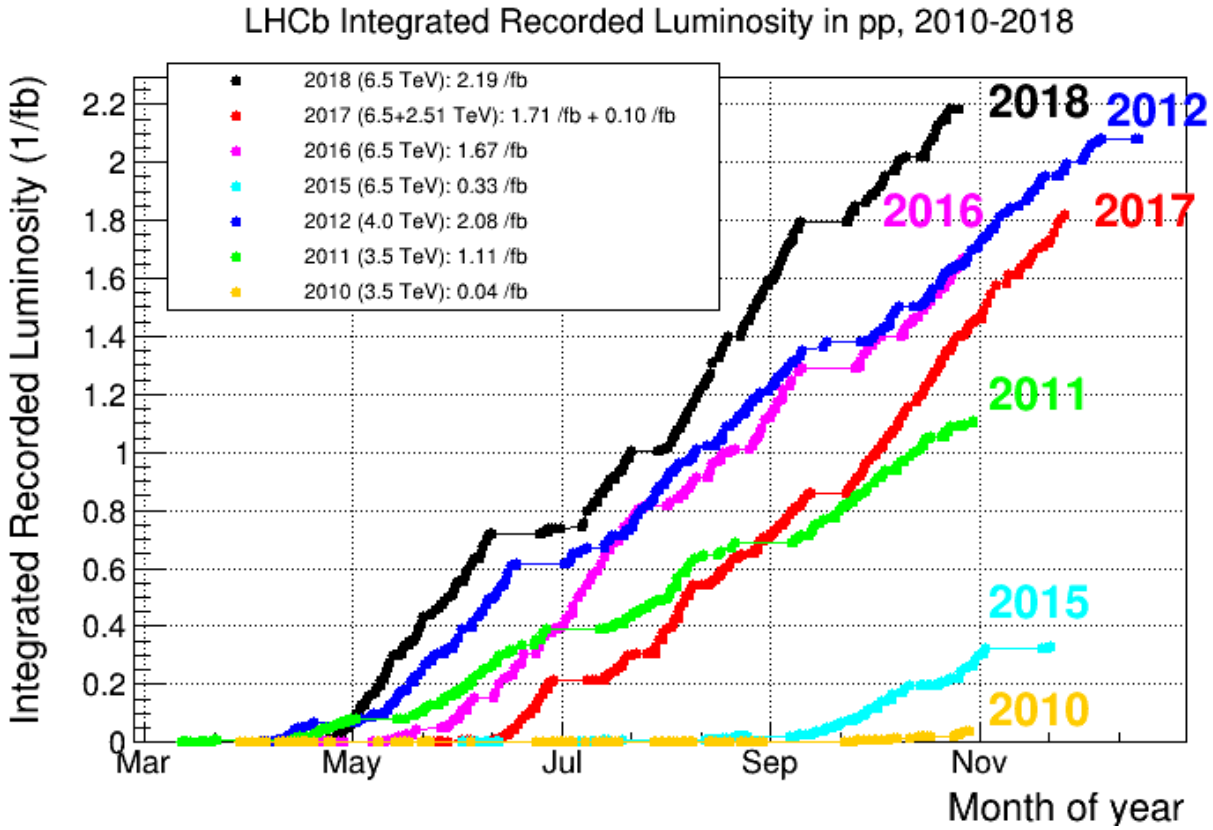
- Reach in **new physics scale** at present and future facilities from generic $\mathscr{L}_6$ contribution compared with reach of direct searches

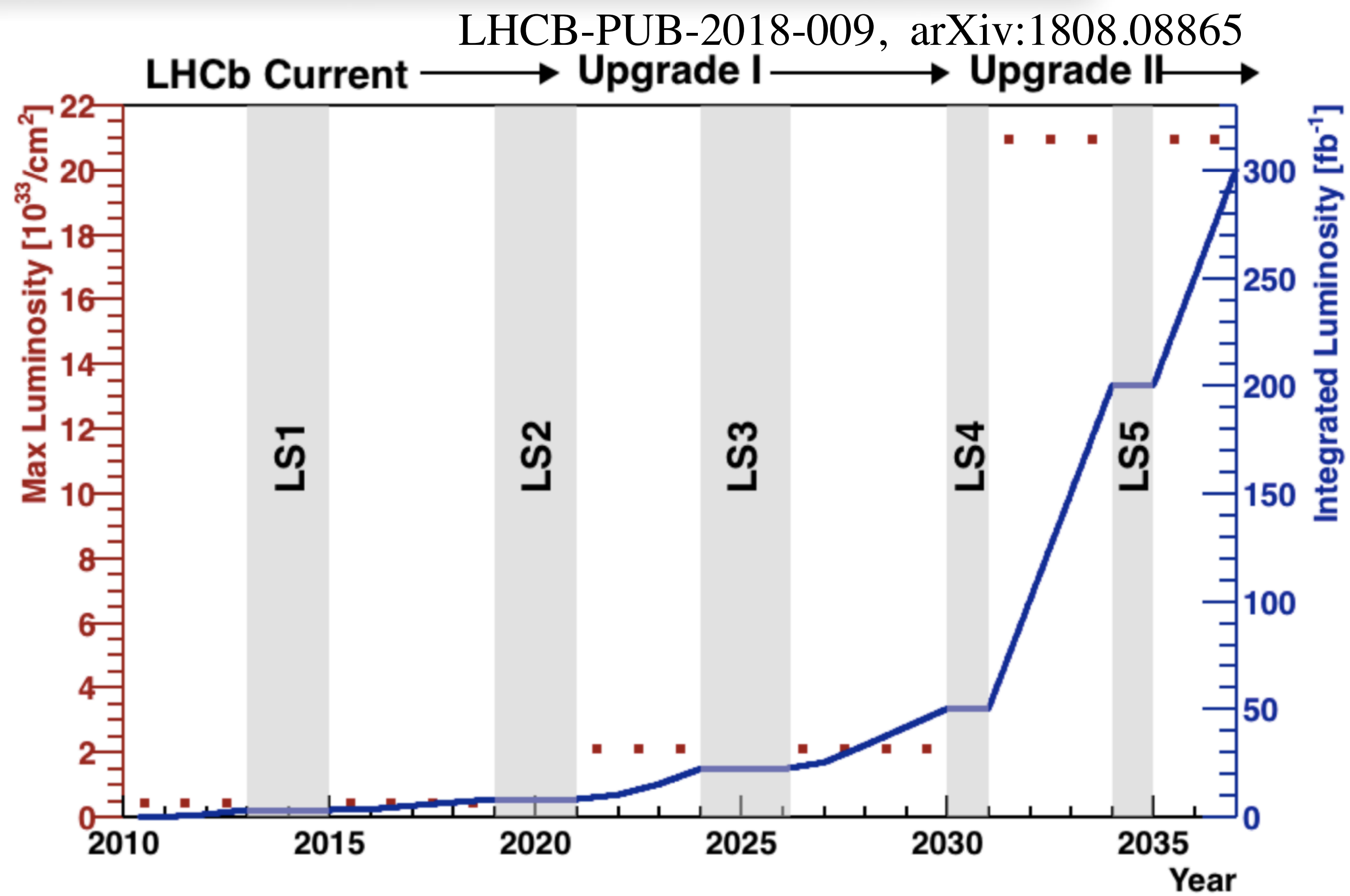


Precision flavour physics at LHCb

- Indirect searches for new physics require
  - **precise** SM predictions, small theoretical uncertainties
    - **clean** observables, e.g. CKM angle γ, leptonic decays, …
    - **calculable** hadronic contributions at subpercent level: non-perturbative techniques, lattice QCD, e.g. V_{ub}, V_{cb}, Δm_s, Δm_d, …
    - **null** tests: no theory inputs, negligible SM contributions, e.g. lepton flavour violation, CP violation in D mixing, …
  - **high statistics** data sample
  - excellent **detector** performance, low systematic uncertainties

LHCb data sample and plans





- Collected 9 fb^{-1} in Run1-Run2. Major detector upgrade during LS2 (Upgrade I- 2020). Aim at 50 fb^{-1} before 2030
- First detector improvements in PID, tracking, and ECAL during LS3 (Upgrade 1b - 2025)
- Major detector upgrade during LS4 (**Upgrade II** - 2030). Aim at >300 fb^{-1} after 2030 - ….

LHCb physics program

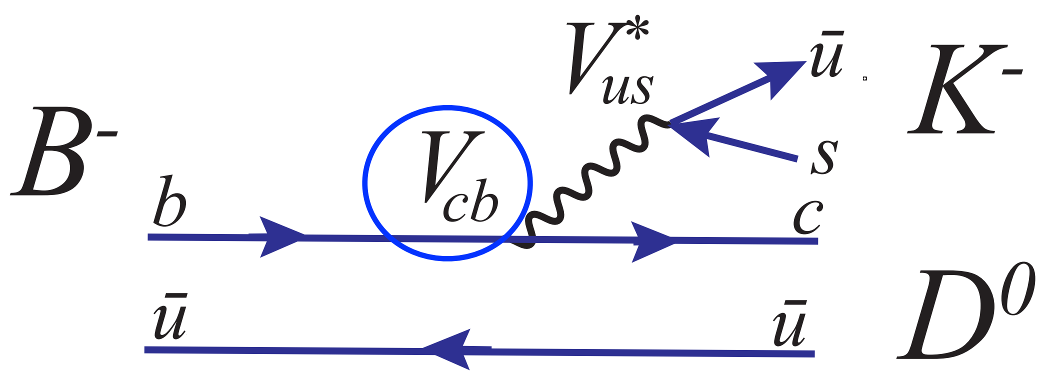
LHCB-PUB-2018-009, arXiv:1808.08865 **see also backup slides for more details**

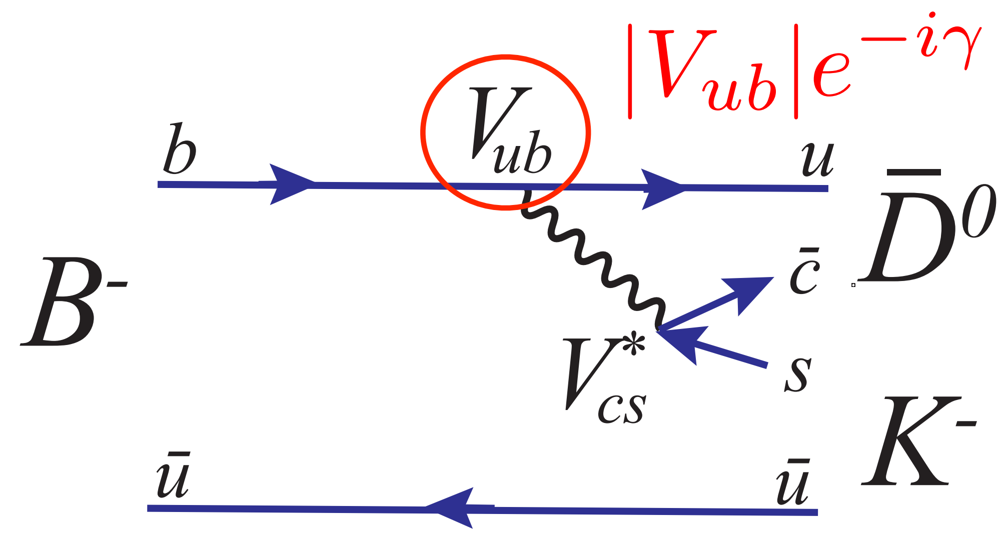
CKM and *CP* violation	sin2β, γ, ϕ_s, $\|V_{ub}/V_{cb}\|$, CPV in B^0, B_s^0, D^0, b-baryons,…
Rare decays	$B_{(s)}^0 \to \mu^+\mu^-$, $b \to s\mu^+\mu^-$, $b \to se^+e^-$, $\Sigma^+ \to p\mu^+\mu^-$,…
Spectroscopy	Tetraquarks, **Pentaquarks**, Ξ_{cc}^{++}, Ω_c^*, Ξ_b^{-*},…
Electroweak QCD, Exotica	Z^0, W^+, top, **$H \to c\bar{c}$, Dark photons, Long-lived particles**,..
Ion, Fixed-target	Heavy ions, **p-Gas**, nuclear effects,…

CKM angle γ from $B^- \to DK^-$ decays

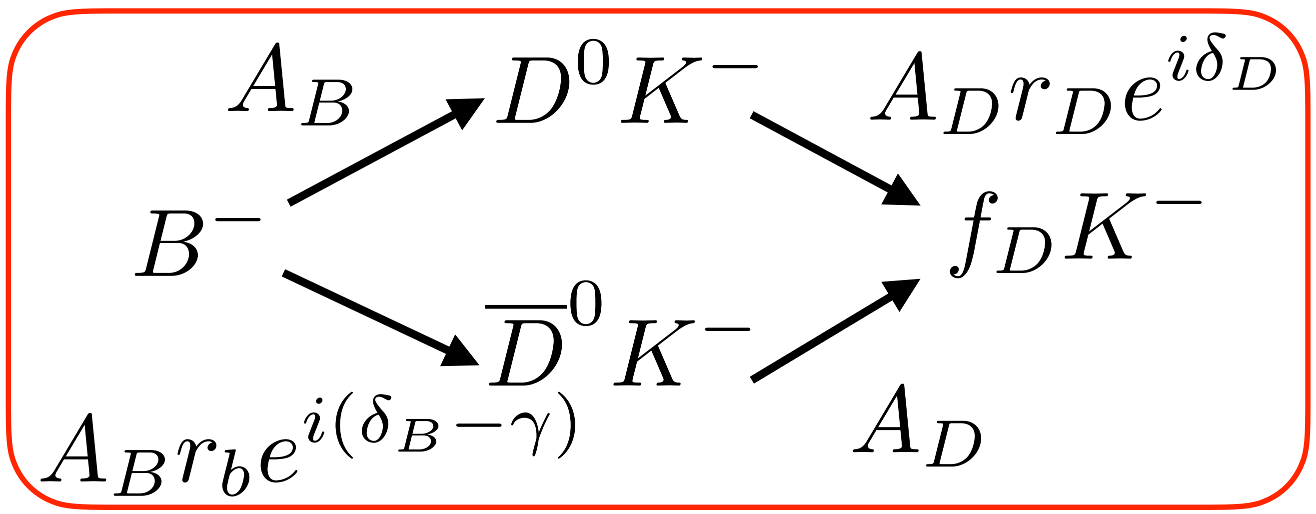
Angle γ determined from tree-level decays

Reference measurement for SM





- Exploit interference between V_{cb} and V_{ub} amplitudes



$f_D = \pi^+\pi^-, K^+K^-$ GLW

$K^+\pi^-$ ADS

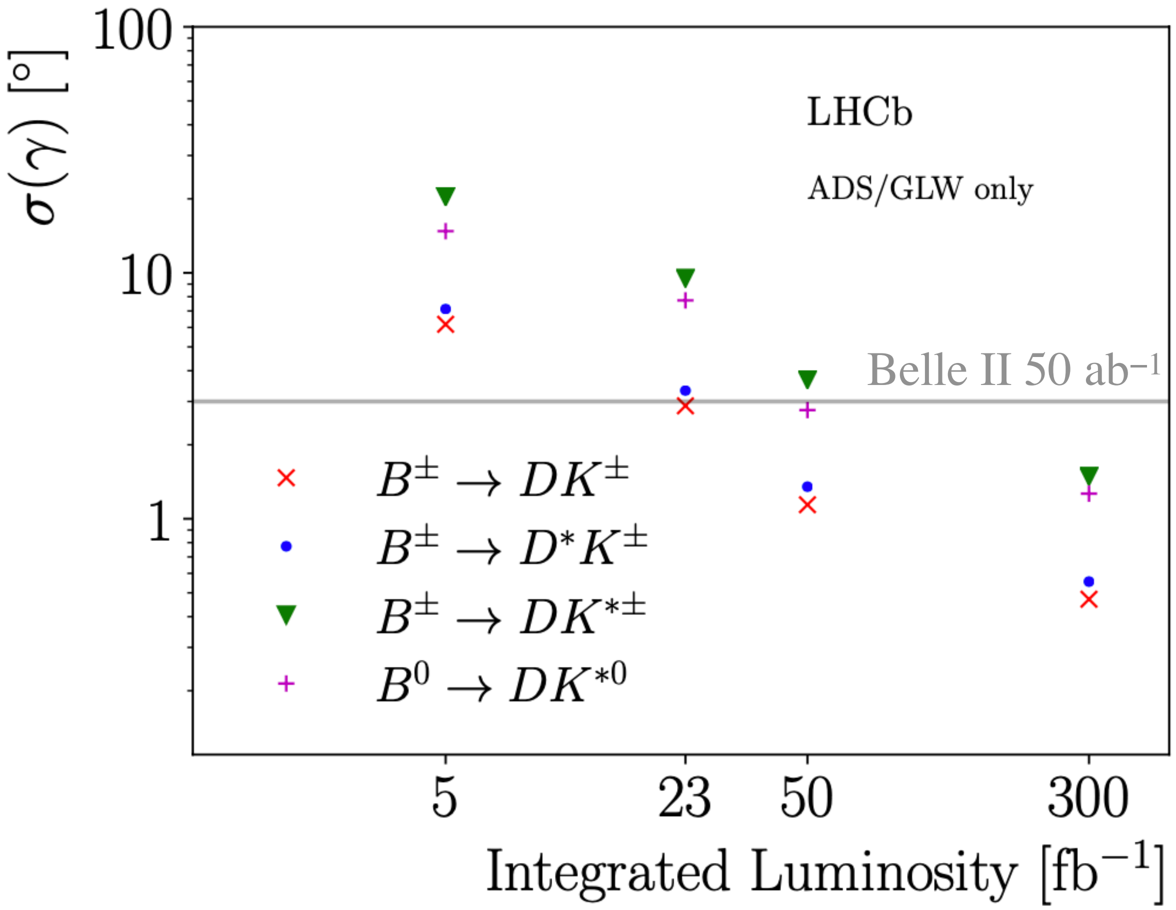
$K^0_S\pi^+\pi^-$ GGSZ

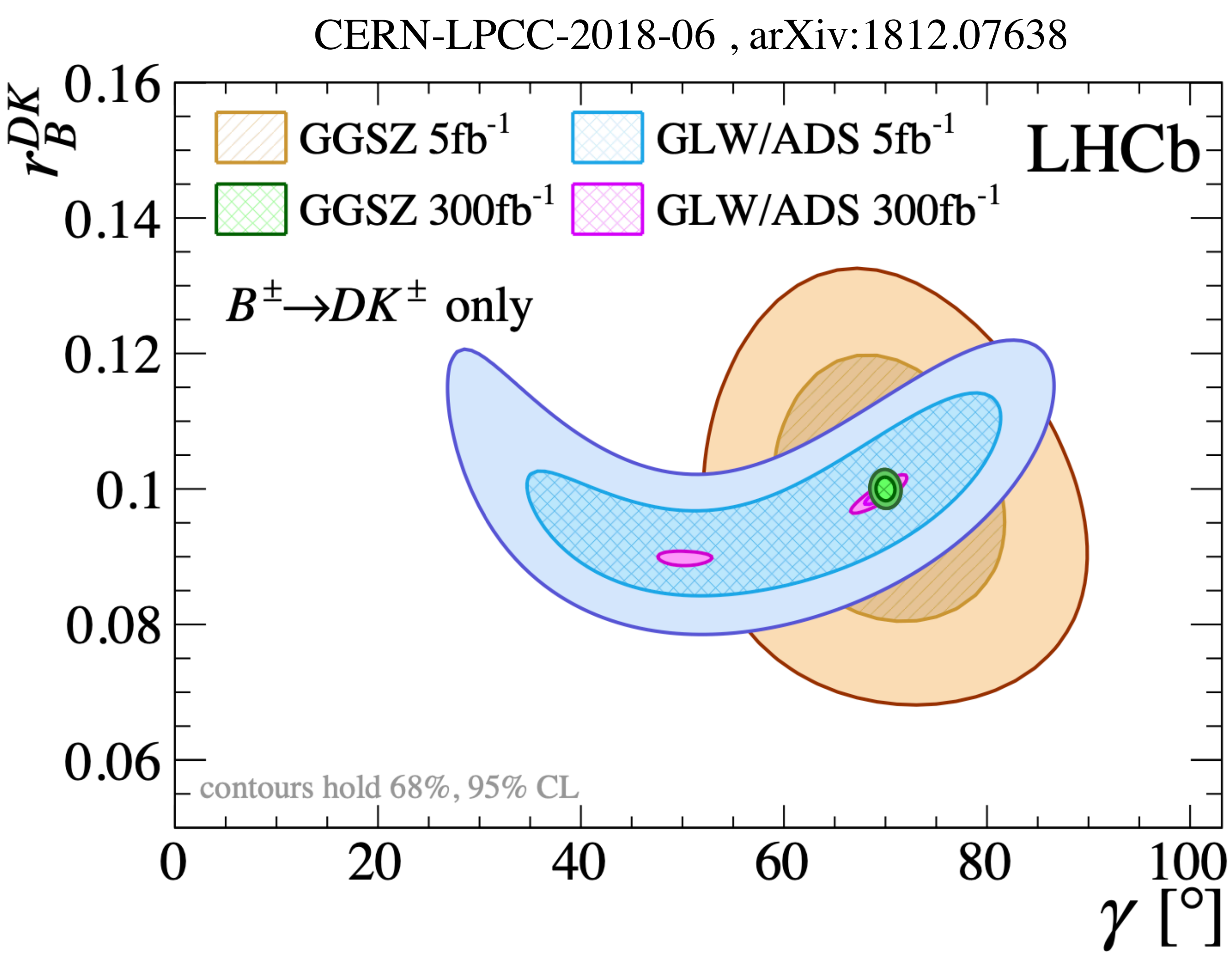
GLW: Gronau, London, Wyler PLB 253 (1991) 483, PLB 265 (1991) 172

ADS: Atwood, Dunietz, Soni PRL 78 (1997) 3257

GGSZ: Giri, Grossman, Soffer, Zupan PRD68 (2003) 054018

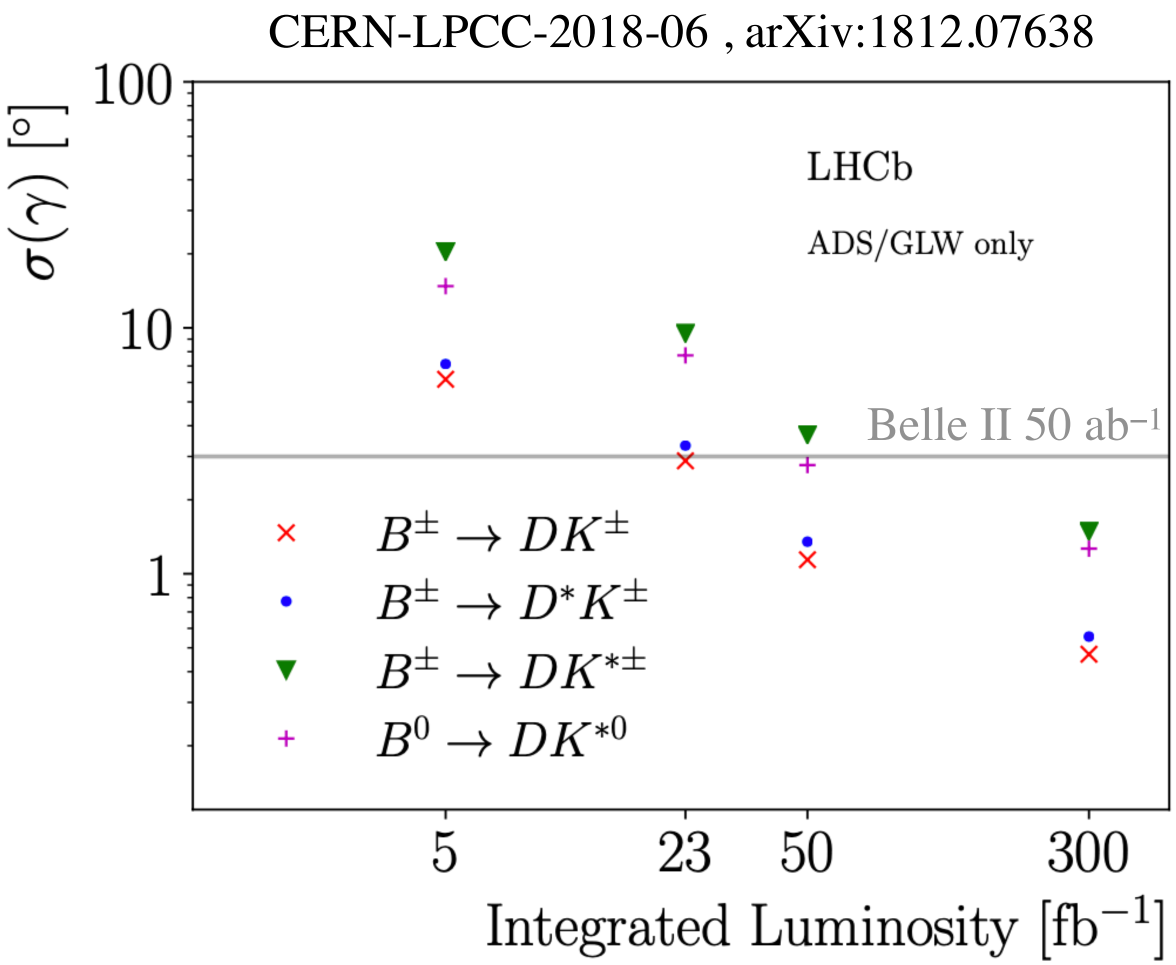
Ultimate γ sensitivity

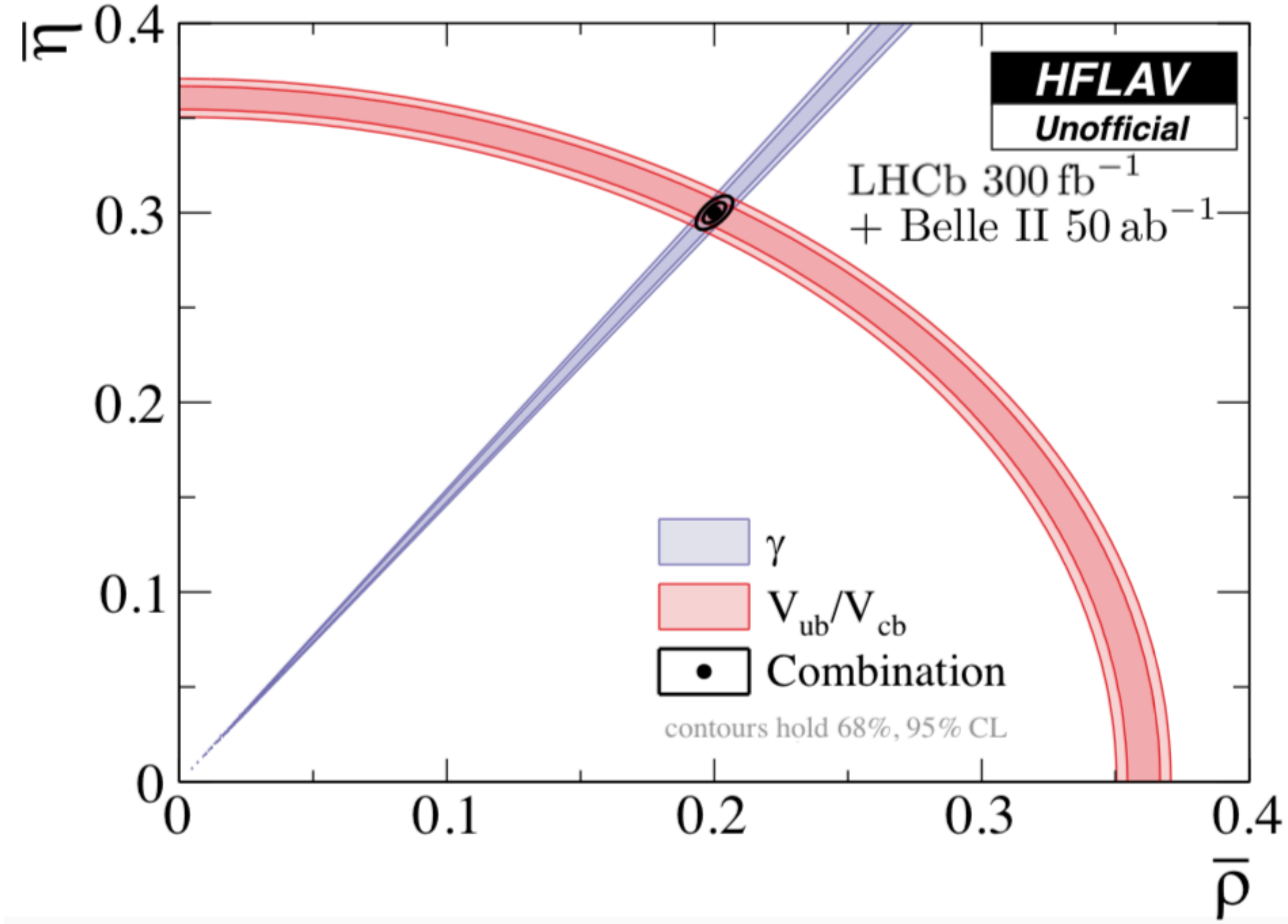




- Uncertainty of 0.35° with 300 fb^{-1}, through a combination of measurements
- Comparison of γ measurements from different B^+, B_d^0, B_s^0, Λ_b^0 modes will become possible

Ultimate γ sensitivity





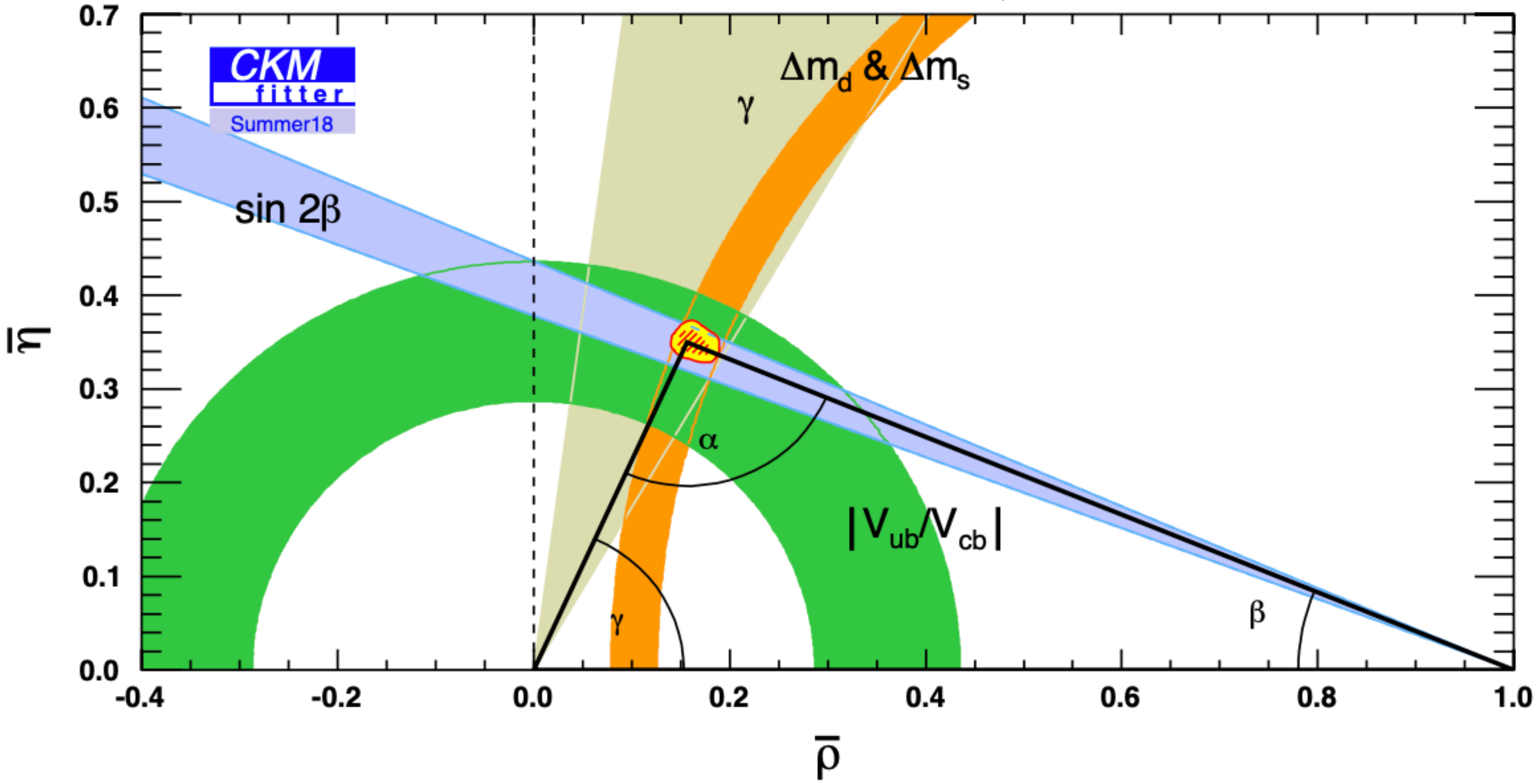
- Uncertainty of 0.35° with 300 fb^{-1}, through a combination of measurements
- Comparison of γ measurements from different B^+, B_d^0, B_s^0, Λ_b^0 modes will become possible

Unitarity triangle fit

CERN-LPCC-2018-06 , arXiv:1812.07638

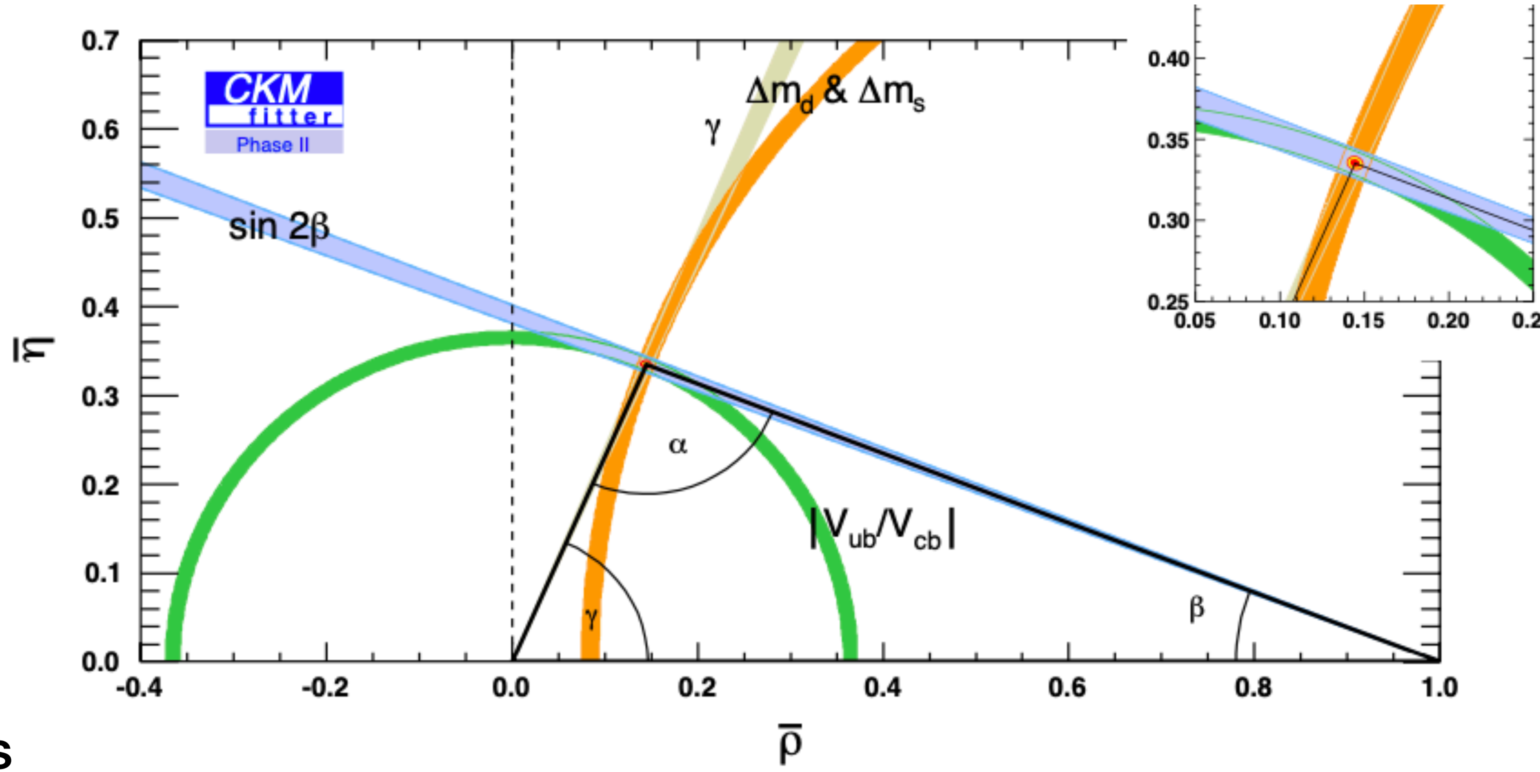
- **Present** constraints on $\bar{\rho}, \bar{\eta}$ parameters using LHCb results and lattice QCD calculations

$$\bar{\rho} = 0.157^{+0.010}_{-0.006}$$
$$\bar{\eta} = 0.350^{+0.008}_{-0.007}$$



- **Future** constraints on $\bar{\rho}, \bar{\eta}$ parameters using expected improvements from LHCb with 300 fb^{-1} and lattice QCD

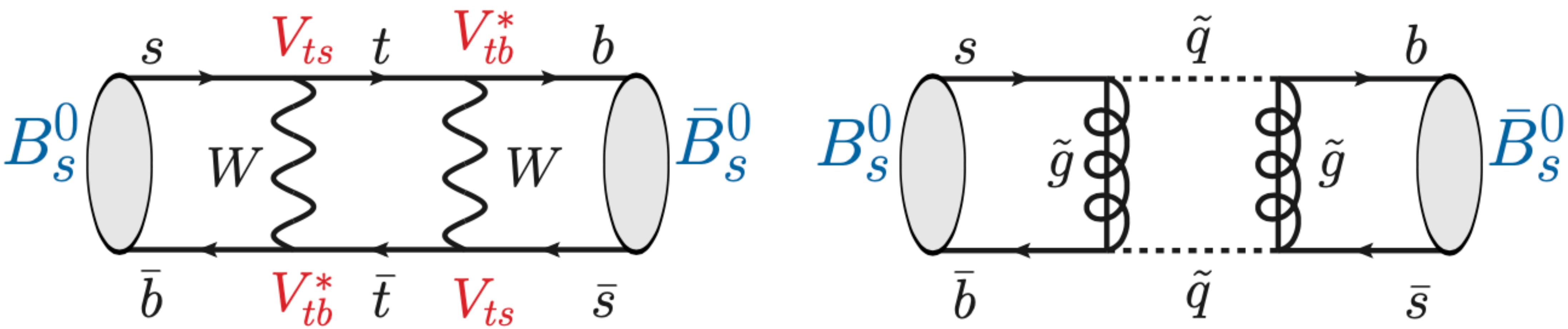
$$\sigma(\bar{\rho}) \approx 0.0018$$
$$\sigma(\bar{\eta}) \approx 0.0015$$



UTfit results are reported in the backup slides

CP violation in $B_{(s)}$ mixing

Search for potential new physics effects through **virtual corrections** in flavour oscillation box diagrams



- So-called semi-leptonic asymmetry

$$A_{SL} = \frac{\mathrm{Prob}\left(\bar{B}^0 \to B^0\right) - \mathrm{Prob}\left(B^0 \to \bar{B}^0\right)}{\mathrm{Prob}\left(\bar{B}^0 \to B^0\right) + \mathrm{Prob}\left(B^0 \to \bar{B}^0\right)} = \frac{|p/q|^2 - |p/q|^2}{|p/q|^2 + |p/q|^2}$$

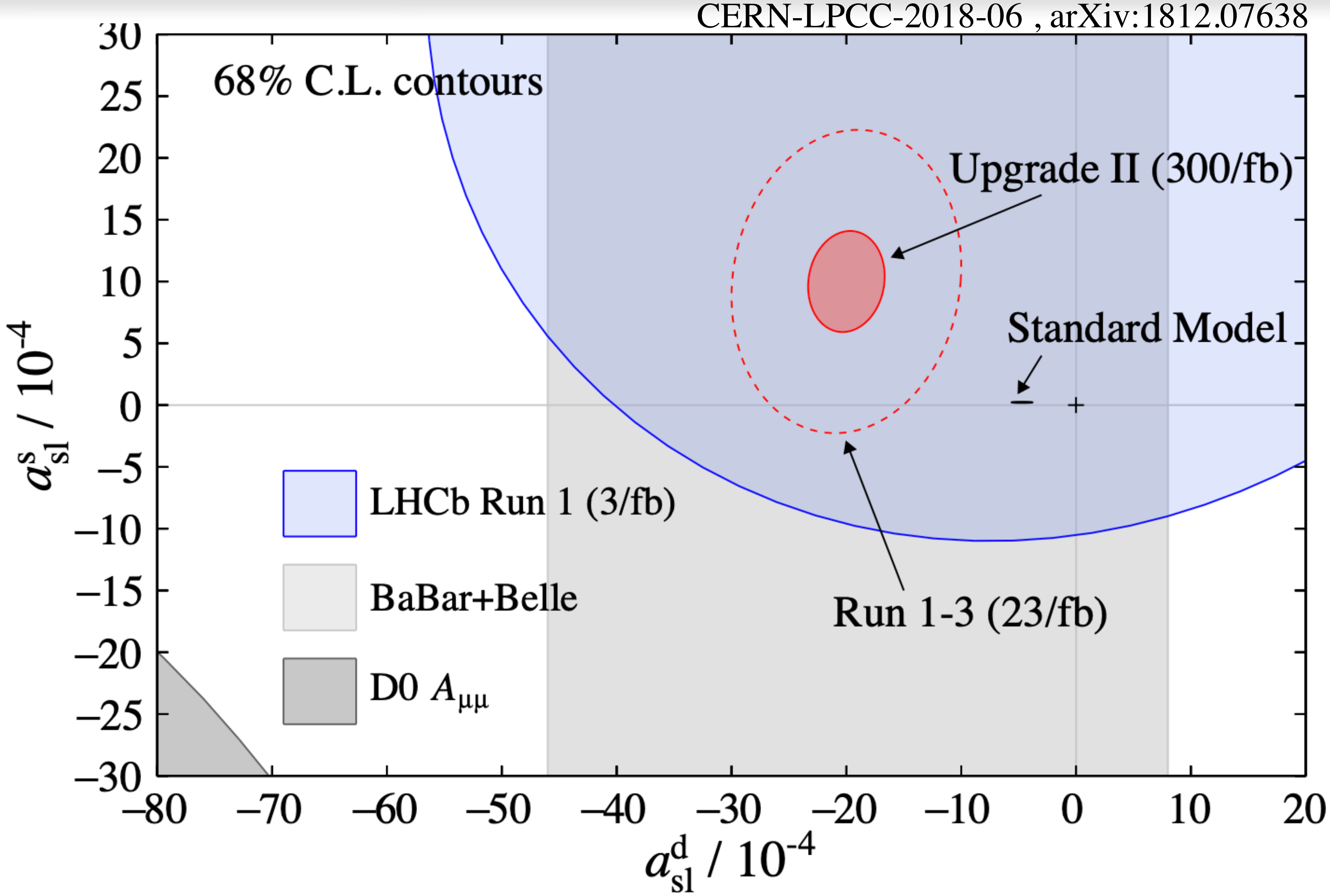
- SM predictions:

$$A_{SL}^{SM} = \begin{cases} -(4.7 \pm 0.6) \times 10^{-4} \text{ for } B_d^0 \\ +(2.2 \pm 0.3) \times 10^{-5} \text{ for } B_s^0 \end{cases}$$

Rev.Mod.Phys. 88 (2016) no.4, 045002

Future landscape for semileptonic asymmetries

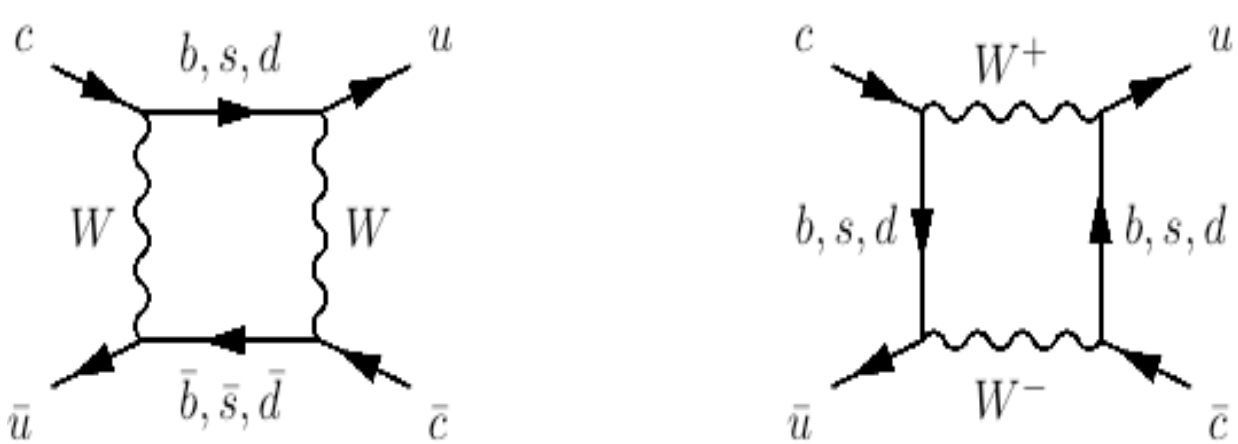
CERN-LPCC-2018-06 , arXiv:1812.07638



Sample ($\mathcal{L}$)	$\delta a^s_{sl}/10^{-4}$	$\delta a^d_{sl}/10^{-4}$
Run 1 (3 fb^{-1}) [13, 120]	33	36
Run 1-3 (23 fb^{-1})	10	8
Run 1-5 (300 fb^{-1})	3	2
Current theory [118, 126]	0.03	0.6

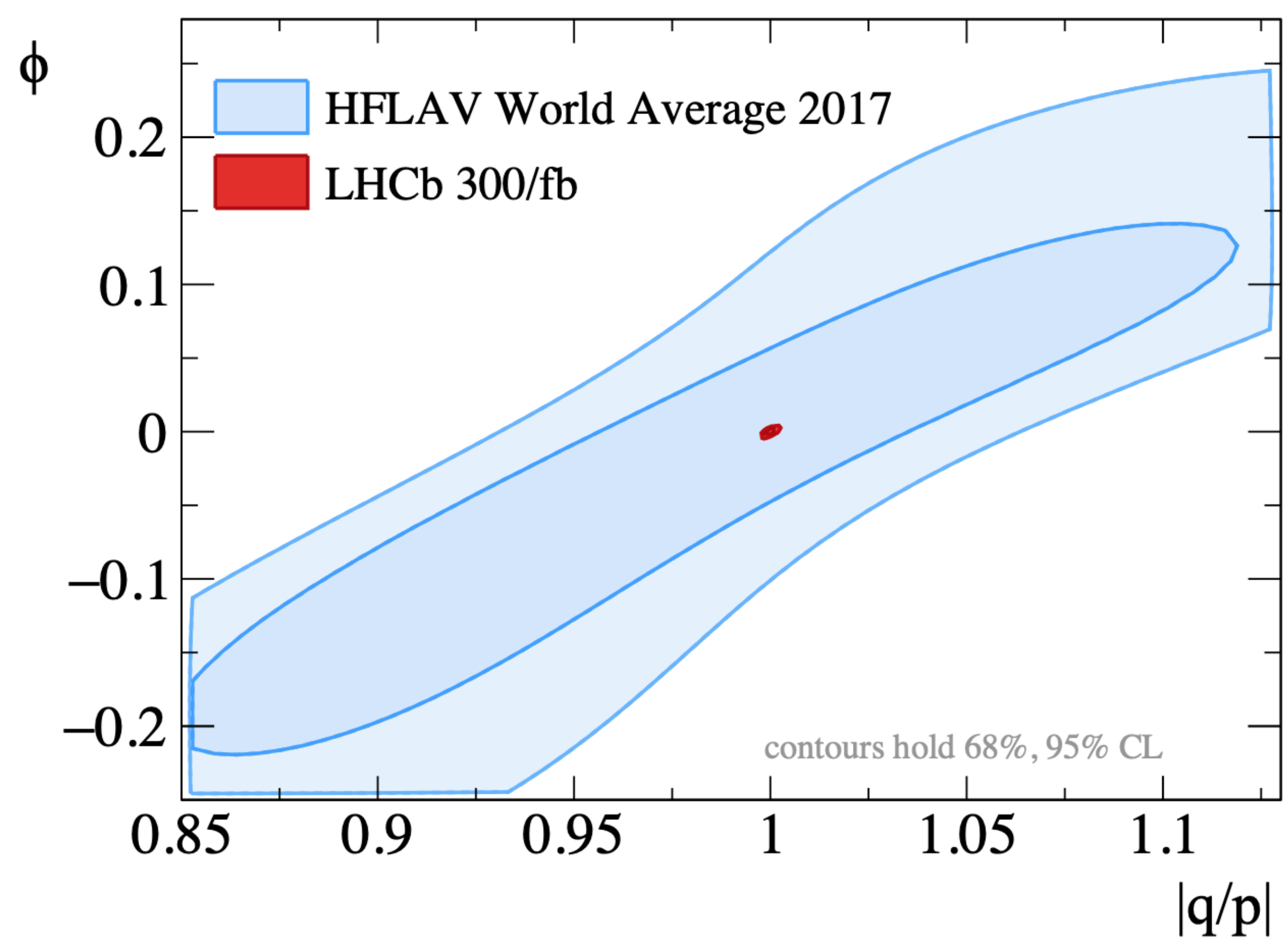
CP violation in D^0 mixing

- **Null test**: SM amplitudes for mixing are approximately real and are GIM or CKM suppressed
- CP violation in mixing $|q/p| \neq 1,\ \phi \neq 0$ would represent a signature of new physics



- Sensitivities at 300 fb^{-1} :
  $\phi \approx 0.1°,\ |q/p| \approx 0.001$
- Test SM predictions for ϕ

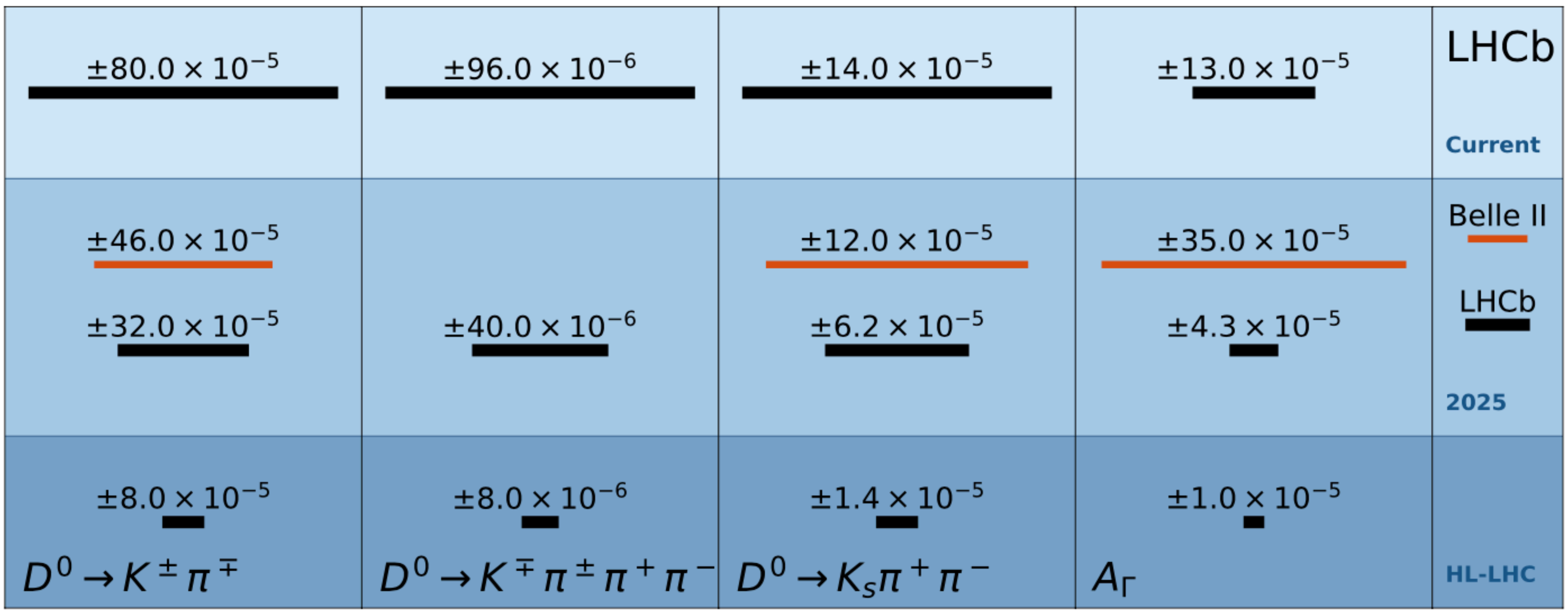
CERN-LPCC-2018-06 , arXiv:1812.07638



CP violation in D^0 mixing

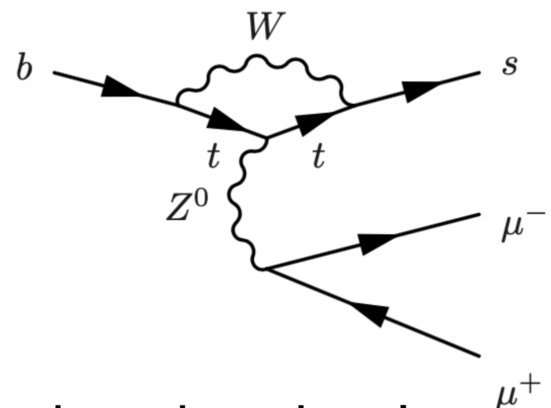
- Predicted constraints on indirect CP violation asymmetry from LHCb and Belle II experiments in 2025 and from LHCb with 300 fb^{-1}

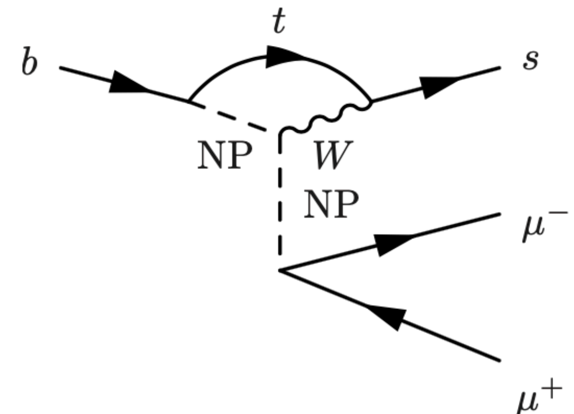
CERN-LPCC-2018-06 , arXiv:1812.07638



$B^0_{s,d} \to \mu^+\mu^-$ rare decays

- Flavour changing neutral current processes are **rare** in the SM. Effects from **new physics** contributions can change rates. Small **theory** uncertainties

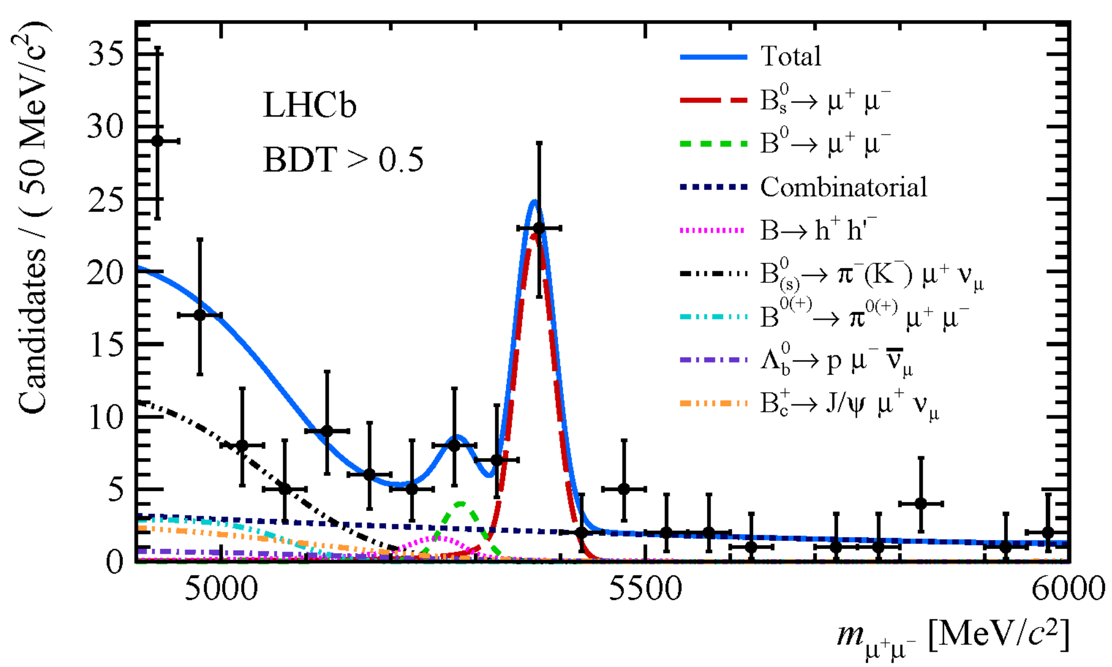




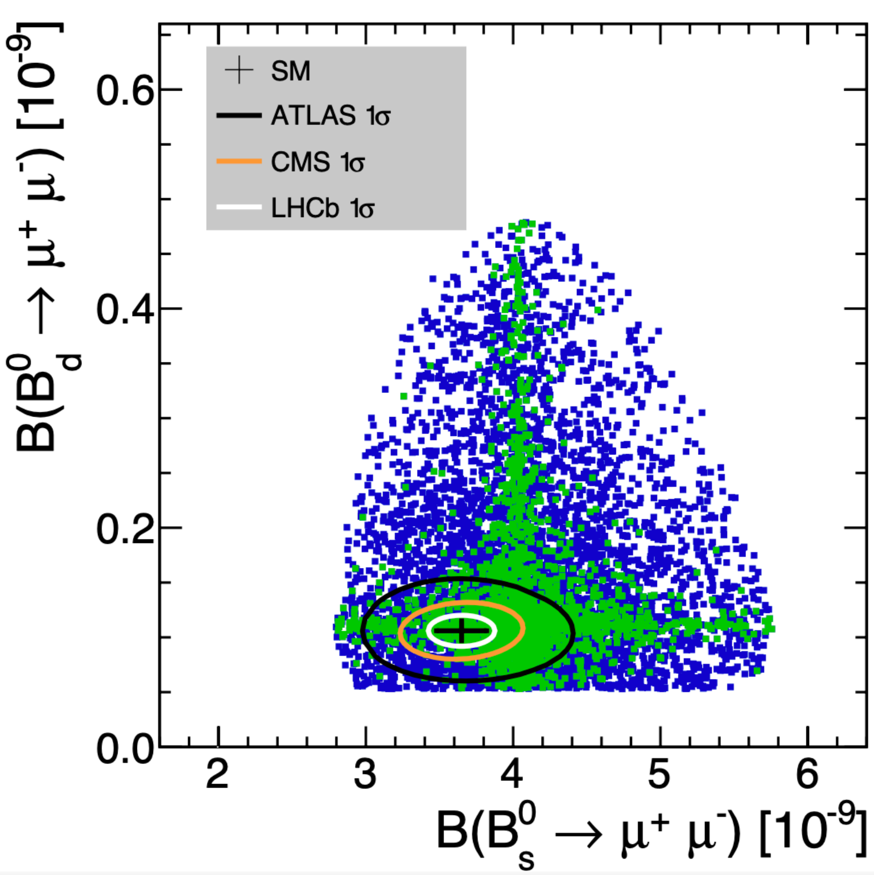
First observation in single experiment

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

4.4fb^{-1} **PRL 118, 191801 (2017)**



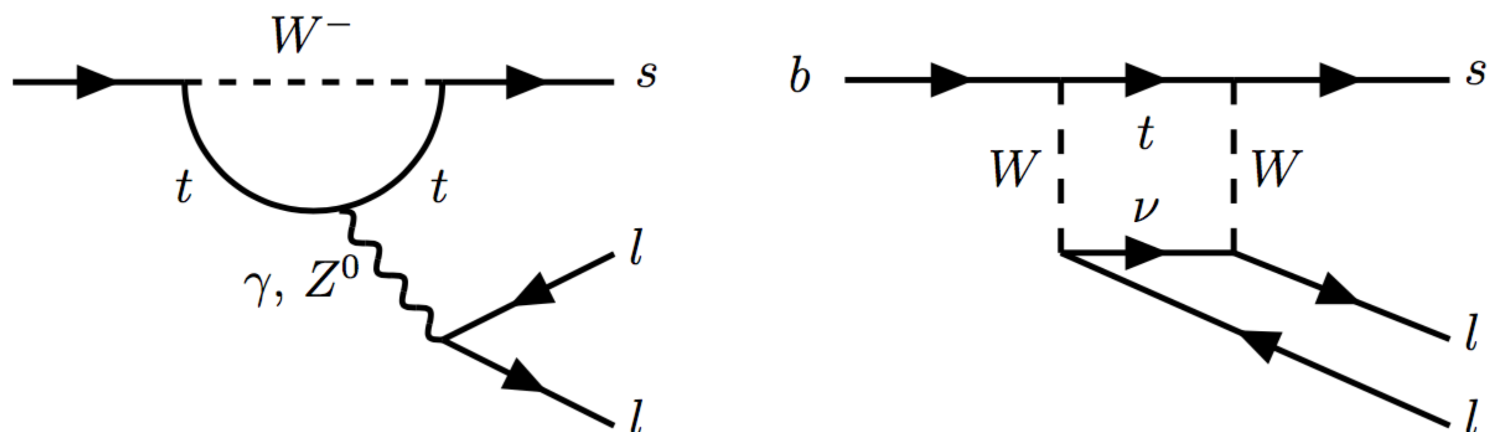
Sensitivity vs new physics predictions

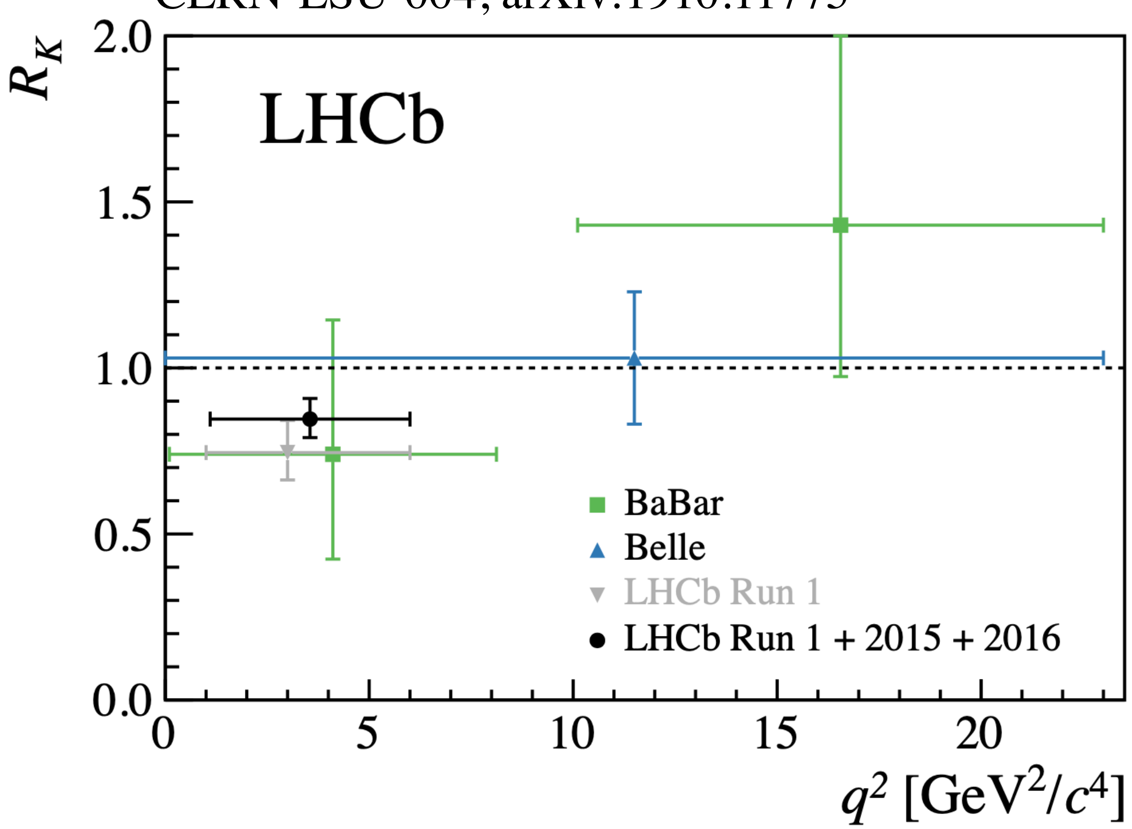


CERN-LPCC-2018-06 , arXiv:1812.07638

Lepton flavour universality (LFU)

- LFU in the SM: same **EW couplings** for $\ell = e, \mu, \tau$. Theoretically **clean** mode. Electron reconstruction is challenging in LHCb due to energy loss

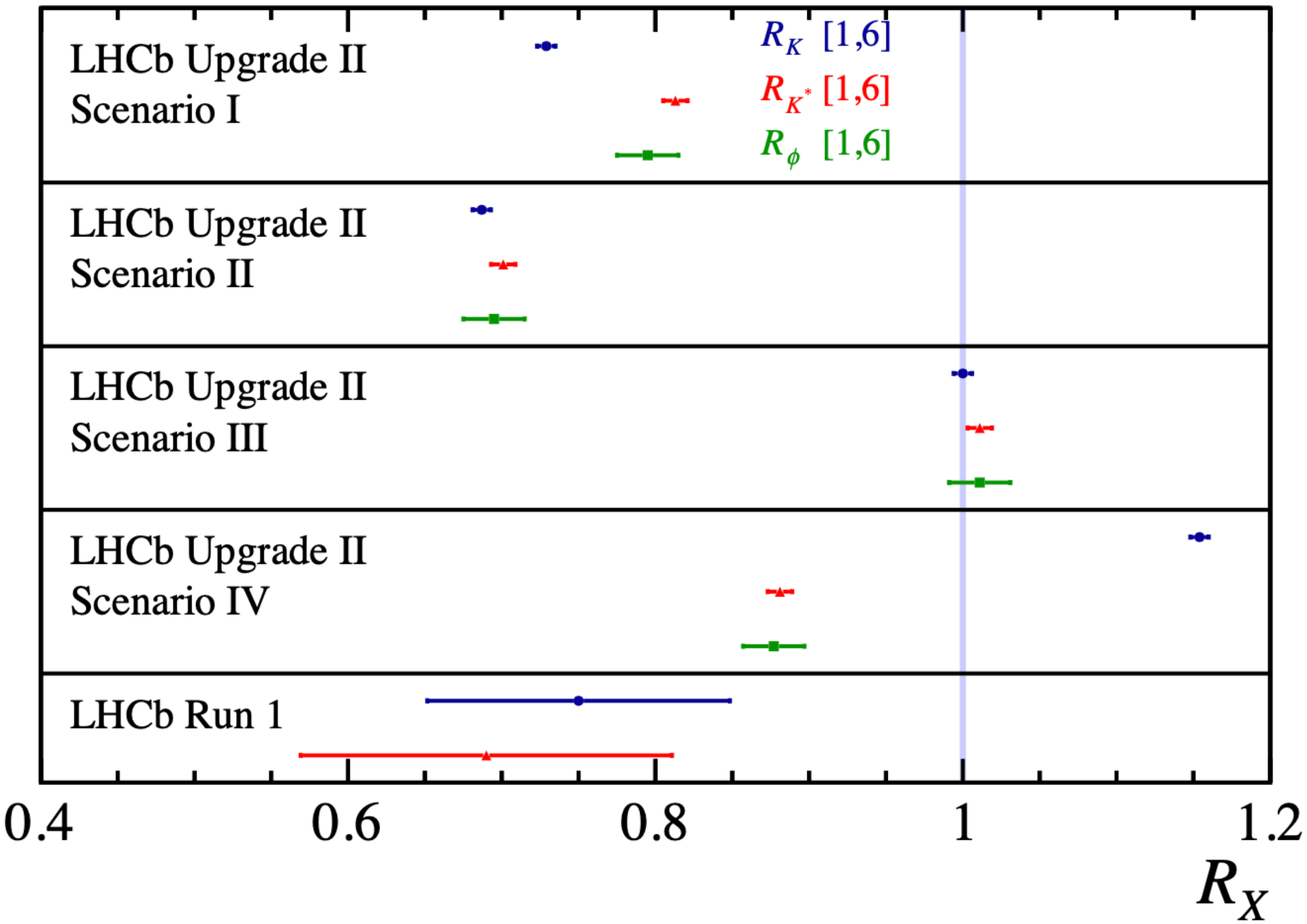




$$R_X = \frac{\mathcal{B}(B \to X\mu^+\mu^-)}{\mathcal{B}(B \to Xe^+e^-)}$$

Projected sensitivities for R_X

CERN-LPCC-2018-06 , arXiv:1812.07638



- Projected sensitivities for R_X measurements in different new physics scenarios

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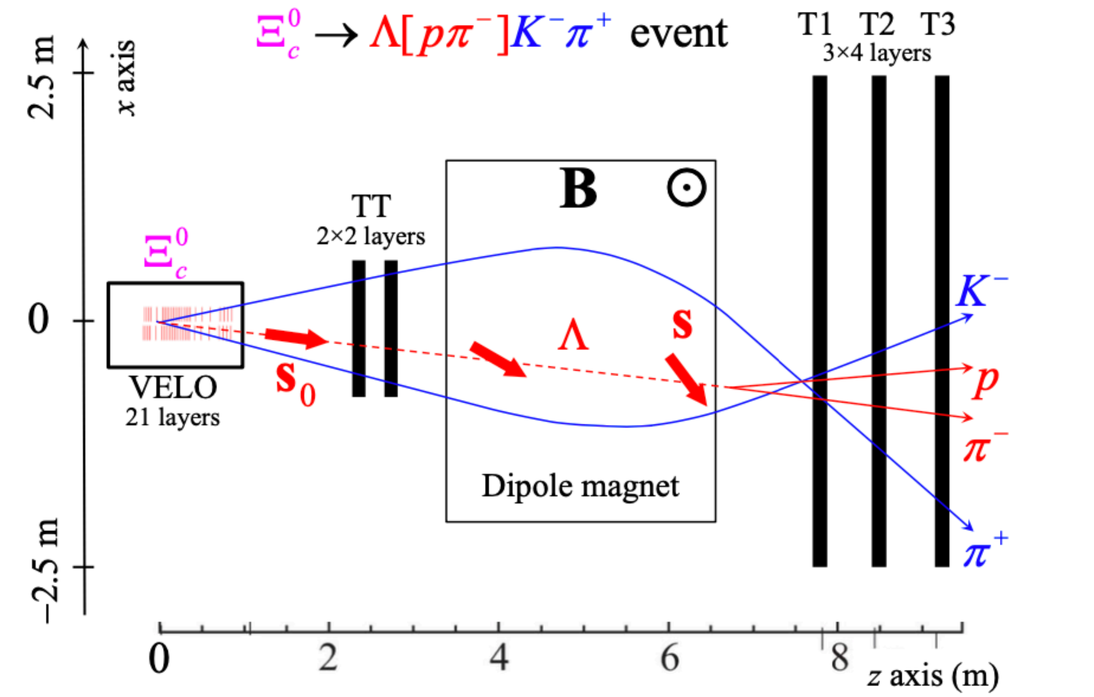
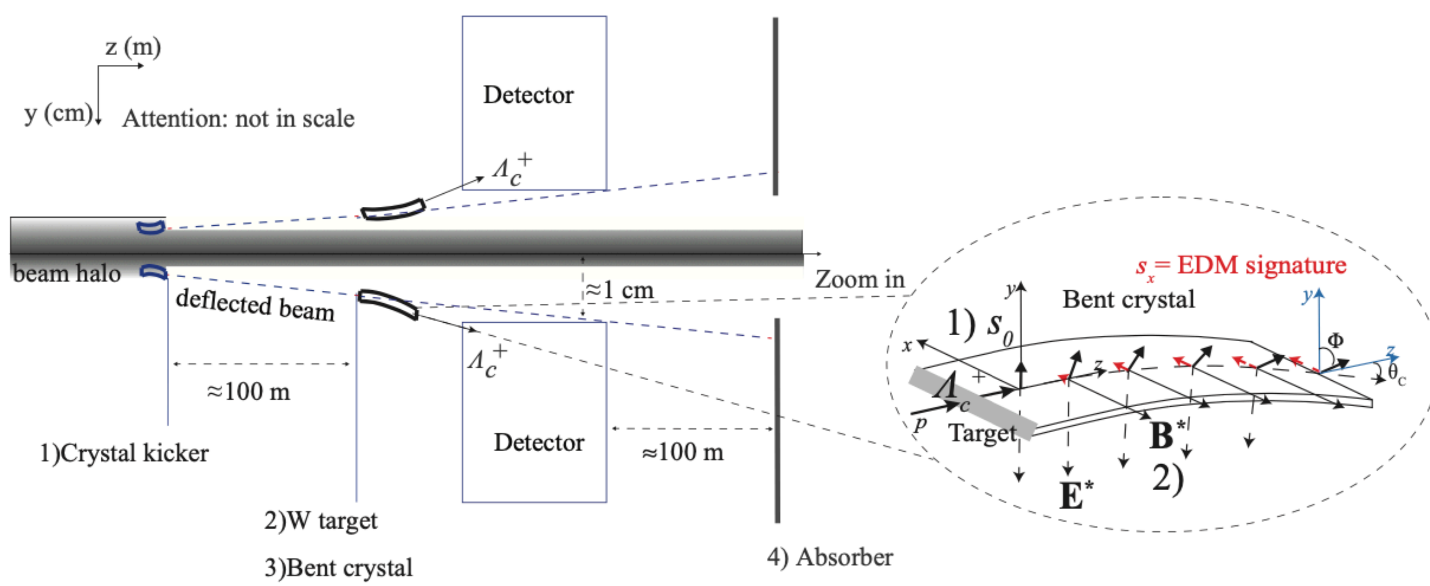
R_X precision	Run 1 result	$9\,\text{fb}^{-1}$	$23\,\text{fb}^{-1}$	$50\,\text{fb}^{-1}$	$300\,\text{fb}^{-1}$
R_K	$0.745 \pm 0.090 \pm 0.036$ [274]	0.043	0.025	0.017	0.007
$R_{K^{*0}}$	$0.69 \pm 0.11 \pm 0.05$ [275]	0.052	0.031	0.020	0.008
R_ϕ	–	0.130	0.076	0.050	0.020
R_{pK}	–	0.105	0.061	0.041	0.016
R_π	–	0.302	0.176	0.117	0.047

Further opportunities

- New ideas for direct measurements of heavy baryon electric and magnetic **dipole moments**
- Λ **baryon**: spin precession induced by the LHCb magnetic field
- Λ_c^+, Ξ_c^+ **baryons**: spin precession of channeled particles in bent crystals. A new fixed-target setup in front of LHCb has been proposed

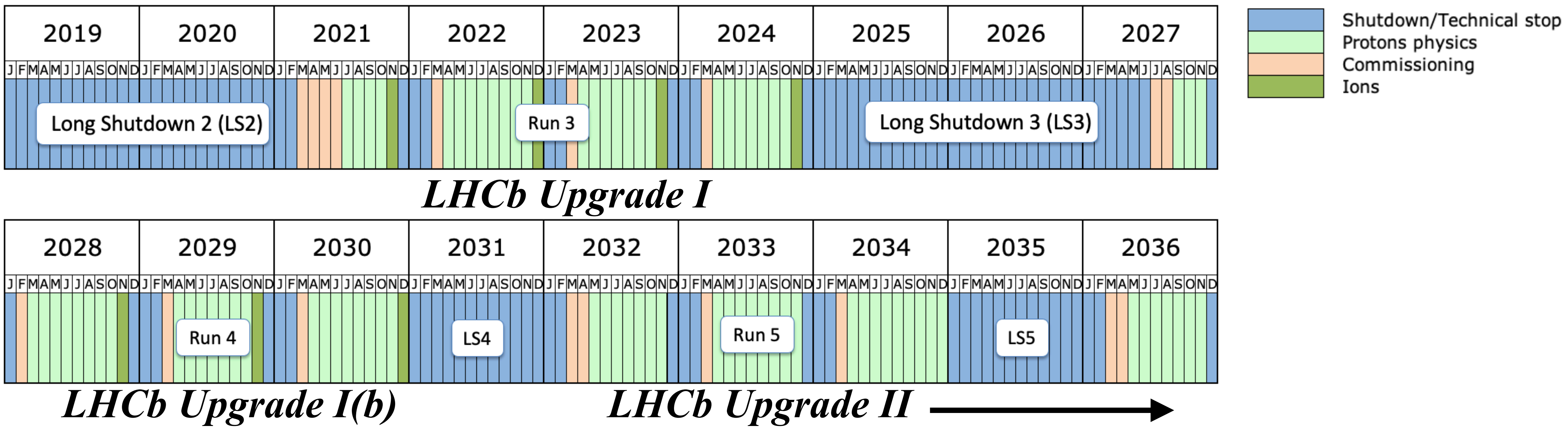
LHCB-PUB-2018-009, arXiv:1808.08865





Summary and prospects

- Precision **flavour physics** is a fundamental tool for discovery: great physics reach compared to direct and electroweak precision searches
- **Theoretically clean** processes and improvements in lattice-QCD motivate better experimental measurements of flavour observables



- **LHCb Upgrade II** (1b): a unique opportunity for fully exploit flavour physics potential at HL-LHC
- Ultimate test of CKM, **unique** new physics searches in FW region. You are welcome to join the enterprise!

References

1) R. K. Ellis et al., Physics Briefing Book : Input for the European Strategy for Particle Physics Update 2020, CERN-ESU-004, e-Print: 1910.11775 [hep-ex]

2) A. Cerri et al., Report from Working Group 4 : Opportunities in Flavour Physics at the HL-LHC and HE-LHC, CERN Yellow Rep. Monogr. 7 (2019) 867-1158, e-Print: 1812.07638 [hep-ph]

3) I. Bediaga et al., Physics case for an LHCb Upgrade II - Opportunities in flavour physics, and beyond, in the HL-LHC era, LHCB-PUB-2018-009, e-Print: 1808.08865 [hep-ex]

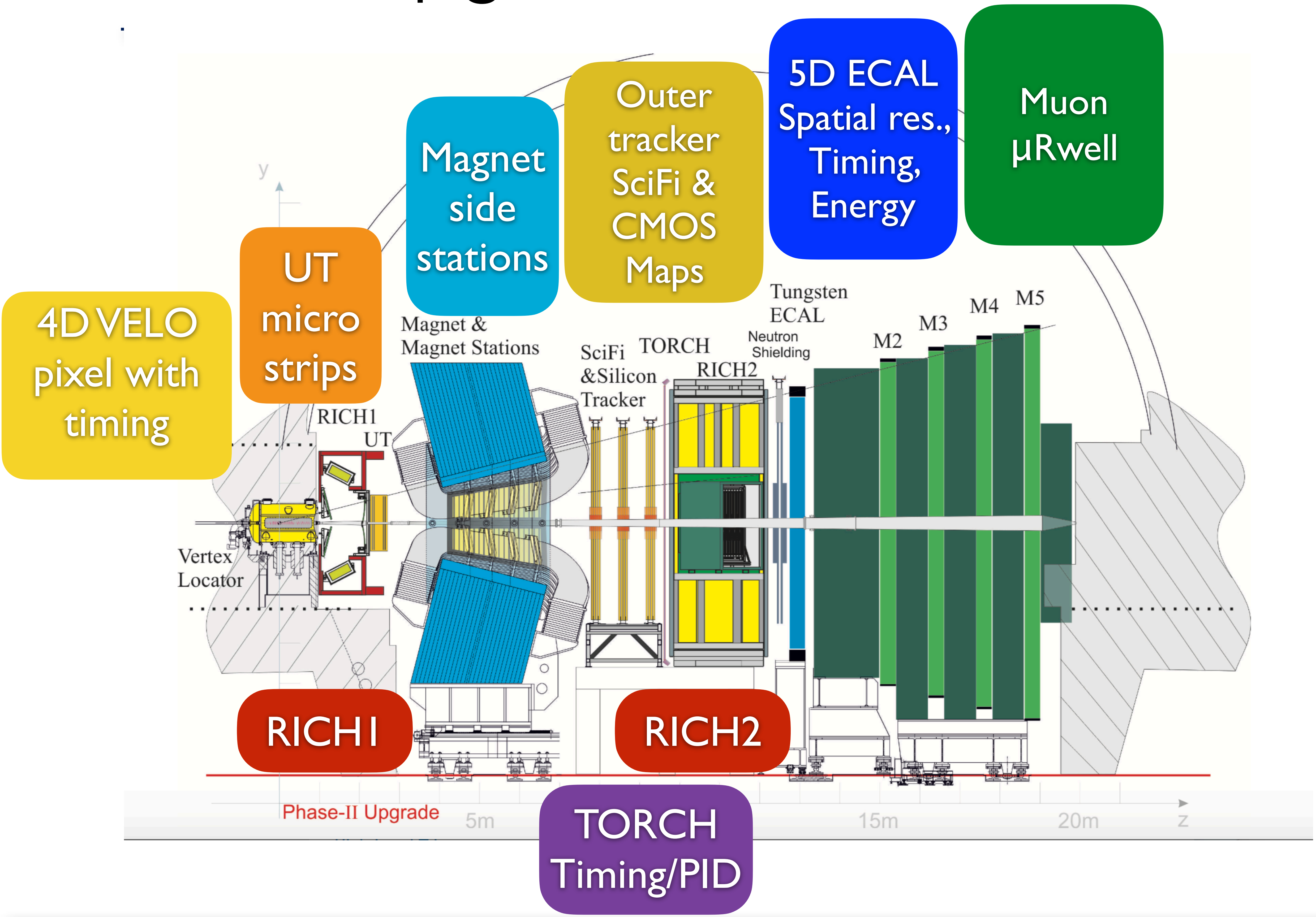
4) M. Ciuchini, Flavour physics from the European strategy viewpoint, 5th Workshop on LHCb Upgrade II, 30 March 2020 [url: https://indico.cern.ch/event/897697]

Backup slides

Detector challenges

- Aim at $\mathscr{L}=2\times10^{34}\,cm^{-2}s^{-1}$, about 55 visible interactions per crossing
- Tracking: 1500-3500 charged particles/crossing, fluence in excess of 10^{15} 1MeV n_{eq}/cm^2
- PID: cope with high occupancy, upgrade the coverage at low ~10 GeV, and high momenta ~100 GeV
- ECAL: sustain radiation dose ≲200 Mrad, energy resolution $\sigma(E)/E\sim10\%/\sqrt{E}\oplus1\%$, reduce Moliere radius
- TDAQ: biggest data processing challenge in HEP history
- Detectors must be faster, harder, finer, stronger, smarter

LHCb Upgrade II detector



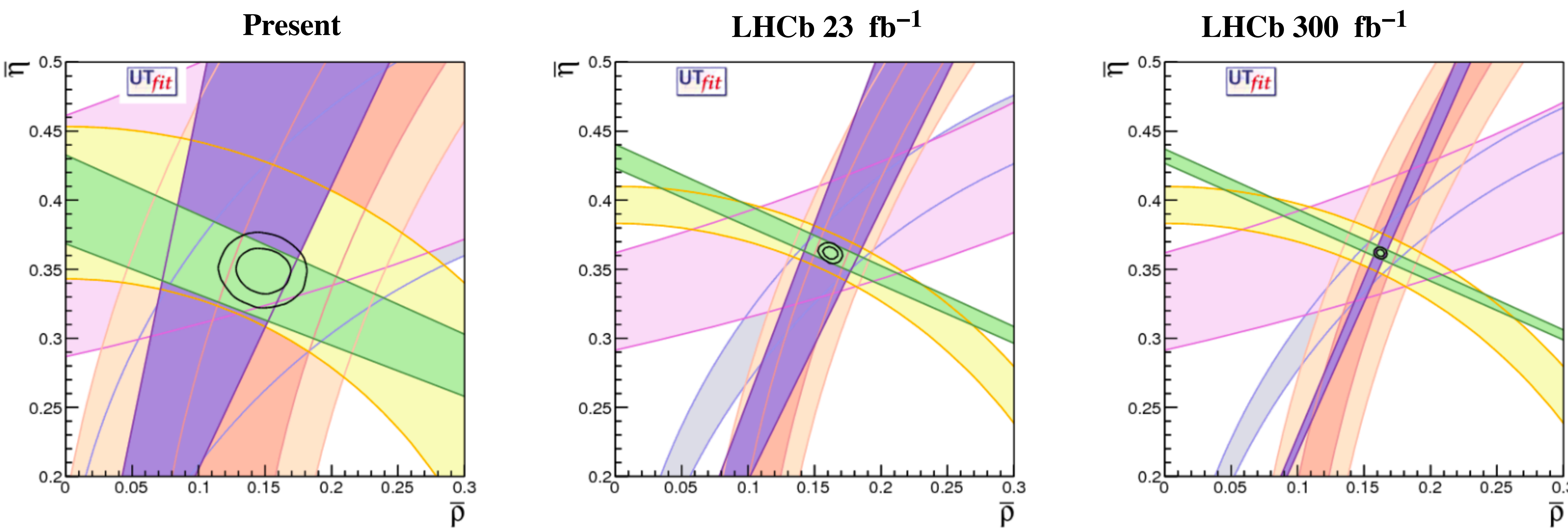
Prospects for future measurements at LHCb

Observable	Current LHCb	LHCb 2025	Upgrade II
EW Penguins			
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [5]	0.025	0.007
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [6]	0.031	0.008
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	0.02, 0.02, 0.05
CKM tests			
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [7]	4°	1°
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [8]	1.5°	0.35°
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [9]	0.011	0.003
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [10]	14 mrad	4 mrad
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [11]	35 mrad	9 mrad
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [12]	39 mrad	11 mrad
a_{sl}^s	33×10^{-4} [13]	10×10^{-4}	3×10^{-4}
$\lvert V_{ub}\rvert / \lvert V_{cb}\rvert$	6% [14]	3%	1%
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$			
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [15]	34%	10%
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [15]	8%	2%
$S_{\mu\mu}$	–	–	0.2
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**			
$R(D^*)$	0.026 [16, 17]	0.0072	0.002
$R(J/\psi)$	0.24 [18]	0.071	0.02
Charm			
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [19]	1.7×10^{-4}	3.0×10^{-5}
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [20]	4.3×10^{-5}	1.0×10^{-5}
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [21]	3.2×10^{-4}	8.0×10^{-5}
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K3\pi)$ 8.0×10^{-6}

Unitarity triangle fit

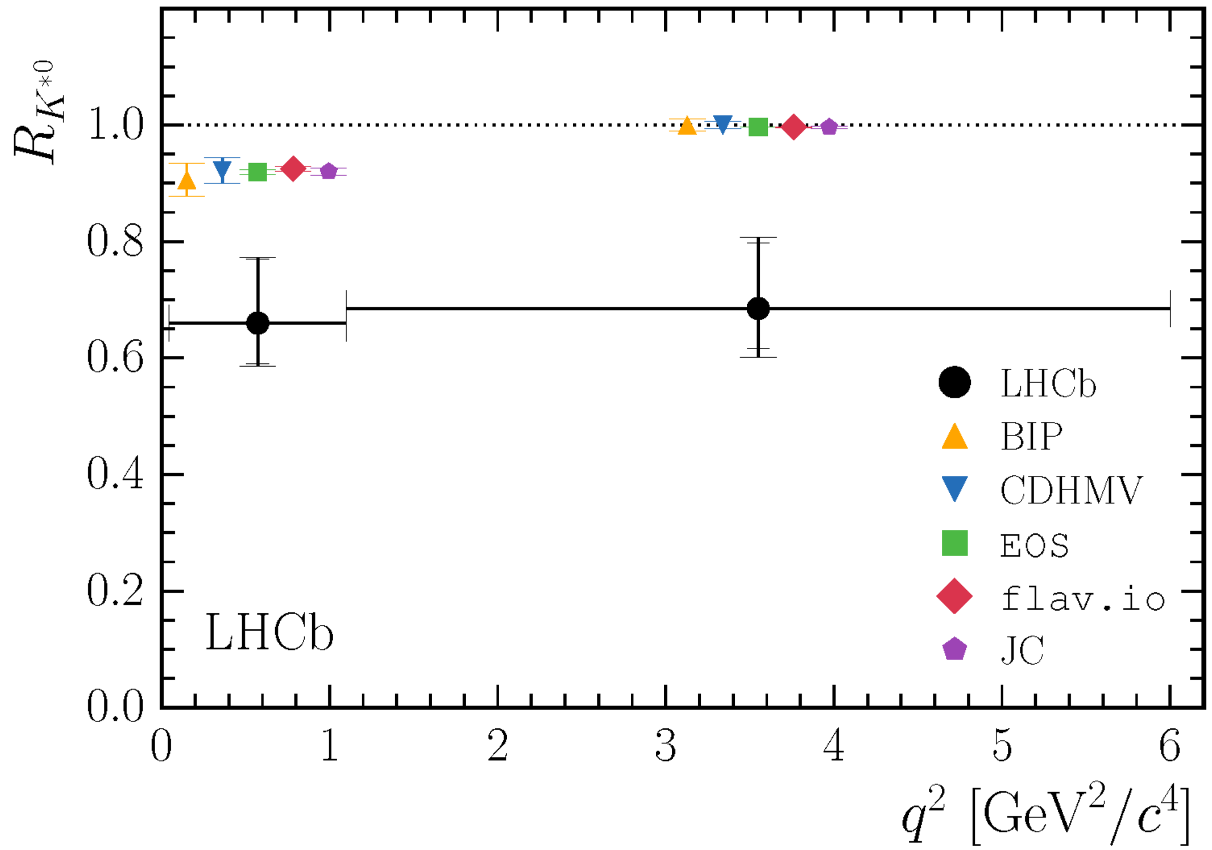
UTFit results

CERN-LPCC-2018-06 , arXiv:1812.07638



		λ	$\bar{\rho}$	$\bar{\eta}$	A	$\sin 2\beta$	γ	α	β_s
	Current	0.12%	9%	3%	1.5%	4.5%	3%	2.5%	3%
23 fb^{-1}	Phase 1	0.12%	2%	0.8%	0.6%	0.9%	0.9%	0.7%	0.8%
300 fb^{-1}	Phase 2	0.12%	1%	0.6%	0.5%	0.6%	0.8%	0.4%	0.5%

$B^0 \to K^{*0}\ell^+\ell^-$ and lepton universality



3fb^{-1} JHEP 08 (2017) 055

$$R_{K^{*0}} = \frac{BR(B^0 \to K^{*0}\mu^+\mu^-)}{BR(B^0 \to K^{*0}e^+e^-)}$$

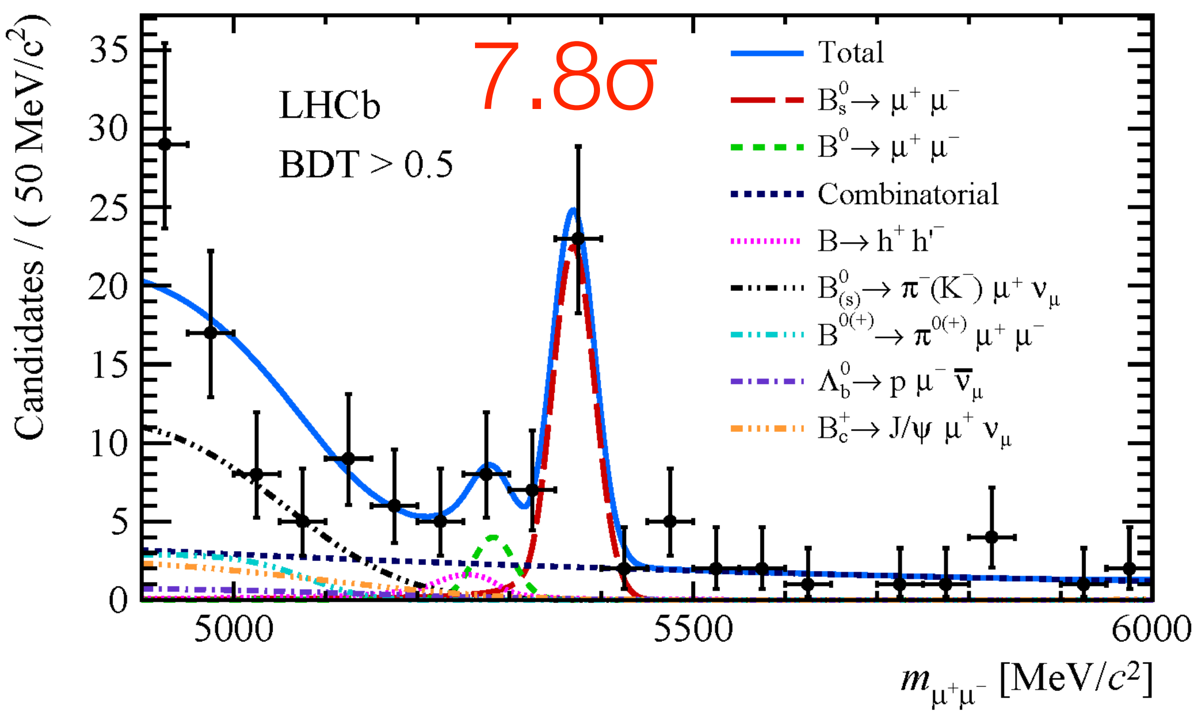
$$R_{K^{*0}} = \begin{cases} 0.66 \,^{+\,0.11}_{-\,0.07}\,(\text{stat}) \pm 0.03\,(\text{syst}) & \text{for } 0.045 < q^2 < 1.1 \;\; \text{GeV}^2/c^4\,, \\ 0.69 \,^{+\,0.11}_{-\,0.07}\,(\text{stat}) \pm 0.05\,(\text{syst}) & \text{for } 1.1 \quad\; < q^2 < 6.0 \;\; \text{GeV}^2/c^4\,. \end{cases}$$

Tensions with the SM at 2.1-2.3σ and 2.4-2.5σ in the two q^2 regions, respectively

$B_s \to \mu^+\mu^-$ results and prospects

First observation in single experiment 4.4fb^{-1} **PRL 118, 191801 (2017)**

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

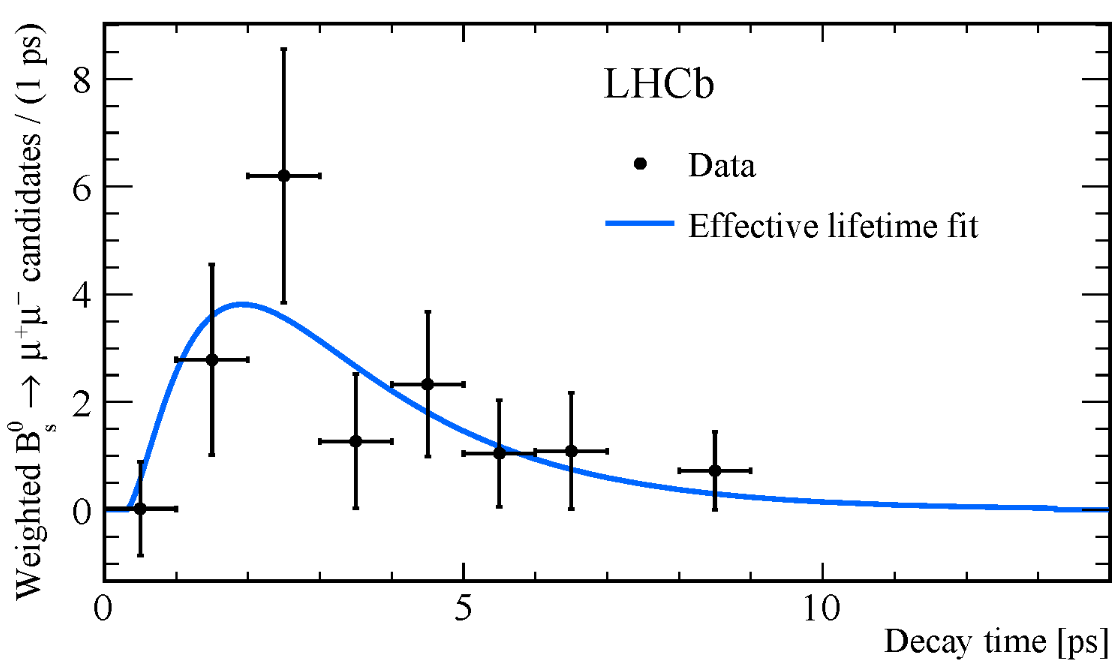


Prospects with 300 fb^{-1}:

$$R \equiv \frac{BF(B^0 \to \mu^+\mu^-)}{BF(B^0_s \to \mu^+\mu^-)}$$

$$\sigma(R) \sim 10\%$$

$$\sigma(\tau_{\mu^+\mu^-}) \sim 0.03\text{ps}$$



$$\tau(B^0_s \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05 \text{ ps}$$

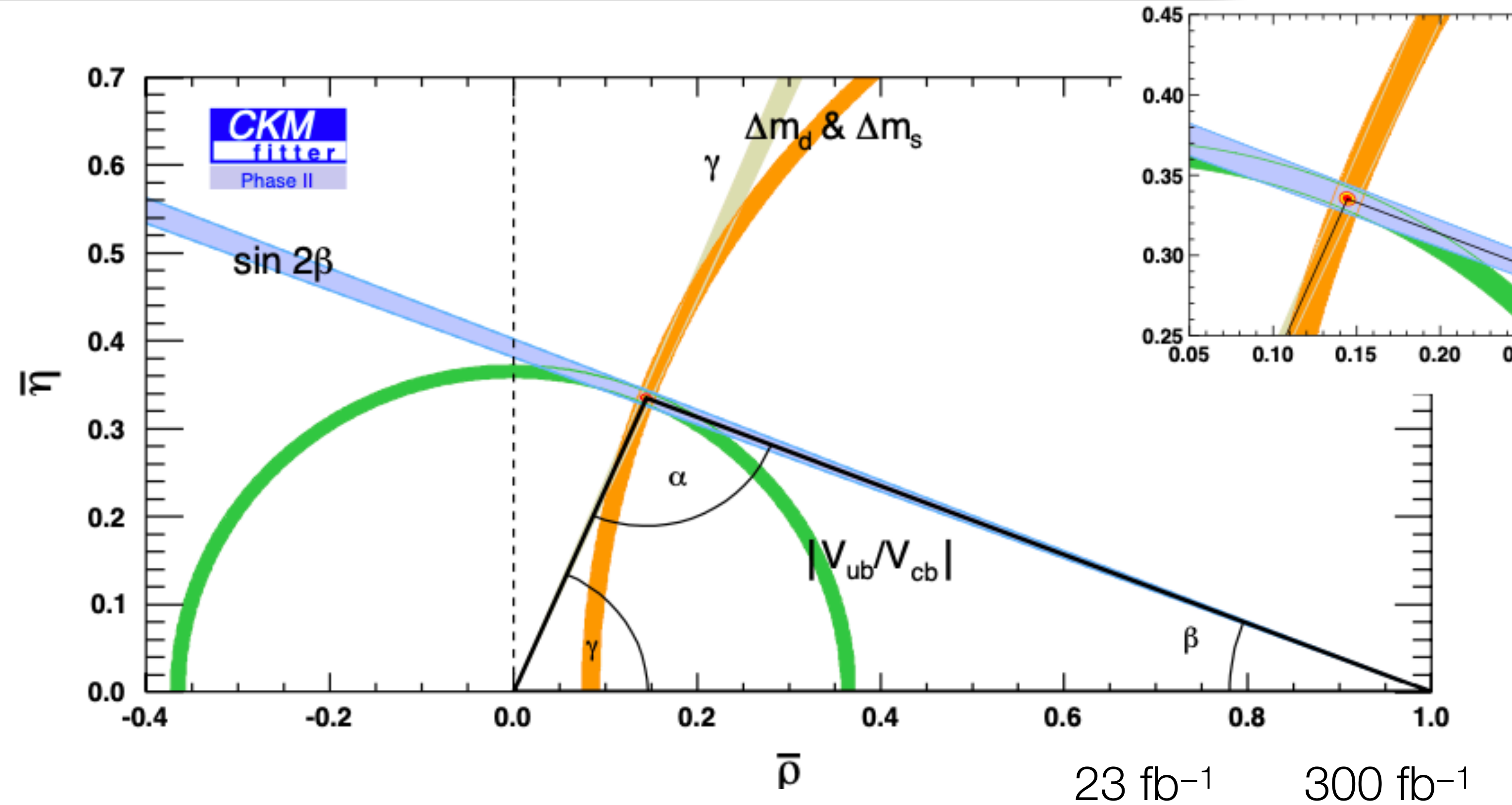
First effective lifetime measurement

$$\tau_{\mu^+\mu^-} = \frac{\tau_{B^0_s}}{1 - y_s^2}\left[\frac{1 + 2A^{\mu^+\mu^-}_{\Delta\Gamma} y_s + y_s^2}{1 + A^{\mu^+\mu^-}_{\Delta\Gamma} y_s}\right]$$

discriminate different NP models

CKM fits

- In figure: constraints on $\bar{\rho}, \bar{\eta}$ parameters using only LHCb and lattice QCD expected improvements with 300 fb^{-1}



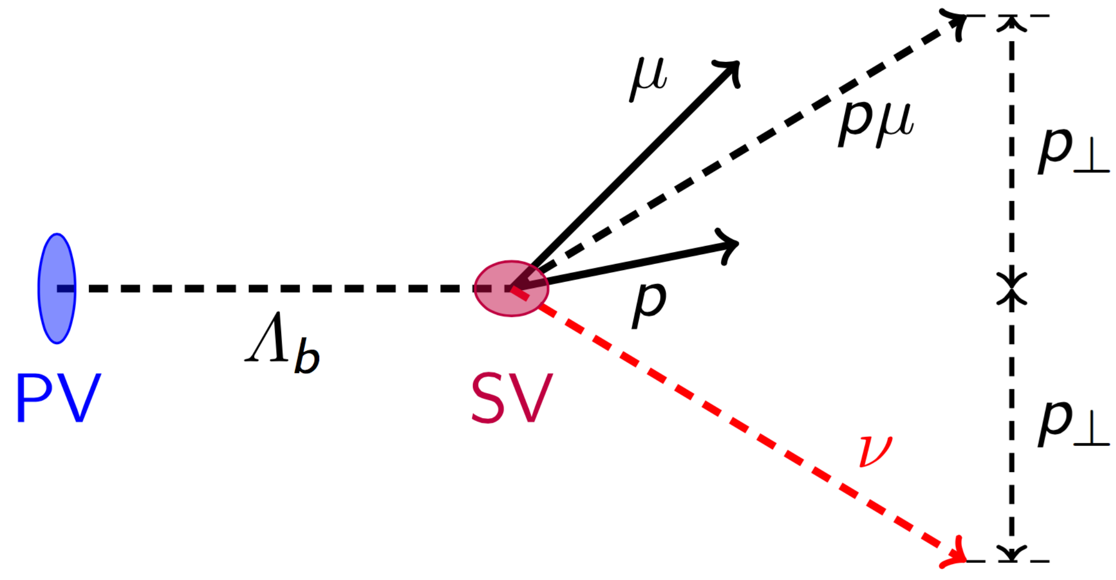
			23 fb^{-1}	300 fb^{-1}
Quantity	Ref.	present error	short-term	mid-term
$(\Delta m_s/\Delta m_d)_{\rm exp}$	[33]	0.4%	-	-
ξ for $(\Delta m_s/\Delta m_d)_{\rm theor}$	[309]	1.4%	0.3%	0.3%
$B \to \pi$: $\lvert V_{ub}\rvert_{\rm exp}$	[309, 334, 340]	2.3%	1.6%	1.1%
$B \to \pi$: $\lvert V_{ub}\rvert_{\rm theor}$	[309]	2.9%	1%	1%
$B \to D$: $\lvert V_{cb}\rvert_{\rm exp}$	[309, 340]	2.0%	1.4%	-
$B \to D$: $\lvert V_{cb}\rvert_{\rm theor}$	[309]	1.4%	0.3%	0.3%
$B \to D^*$: $\lvert V_{cb}\rvert_{\rm exp}$	[340]	1.2%	-	-
$B \to D^*$: $\lvert V_{cb}\rvert_{\rm theor}$	[309]	1.4%	0.4%	0.4%
$\Lambda_b \to p(\Lambda_c)$: $\lvert V_{ub}/V_{cb}\rvert_{\rm exp}$	[334]	6%	1%	1%
$\Lambda_b \to p(\Lambda_c)$: $\lvert V_{ub}/V_{cb}\rvert_{\rm theor}$	[309]	4.9%	1.2%	1.2%

- In figure: constraints on $\bar{\rho}, \bar{\eta}$ parameters using only LHCb and lattice QCD expected improvements with 300 fb^{-1}

		λ	$\bar{\rho}$	$\bar{\eta}$	A	$\sin 2\beta$	γ	α	β_s
	Current	0.12%	9%	3%	1.5%	4.5%	3%	2.5%	3%
23 fb^{-1}	short-term	0.12%	2%	0.8%	0.6%	0.9%	0.9%	0.7%	0.8%
300 fb^{-1}	mid-term	0.12%	1%	0.6%	0.5%	0.6%	0.8%	0.4%	0.5%

$|V_{ub}/V_{cb}|$ measurement with $\Lambda_b^0 \to p\mu^-\bar{\nu}_\mu$

2fb^{-1} data at 8 TeV - Nature Phys. 11 (2015) 743-747



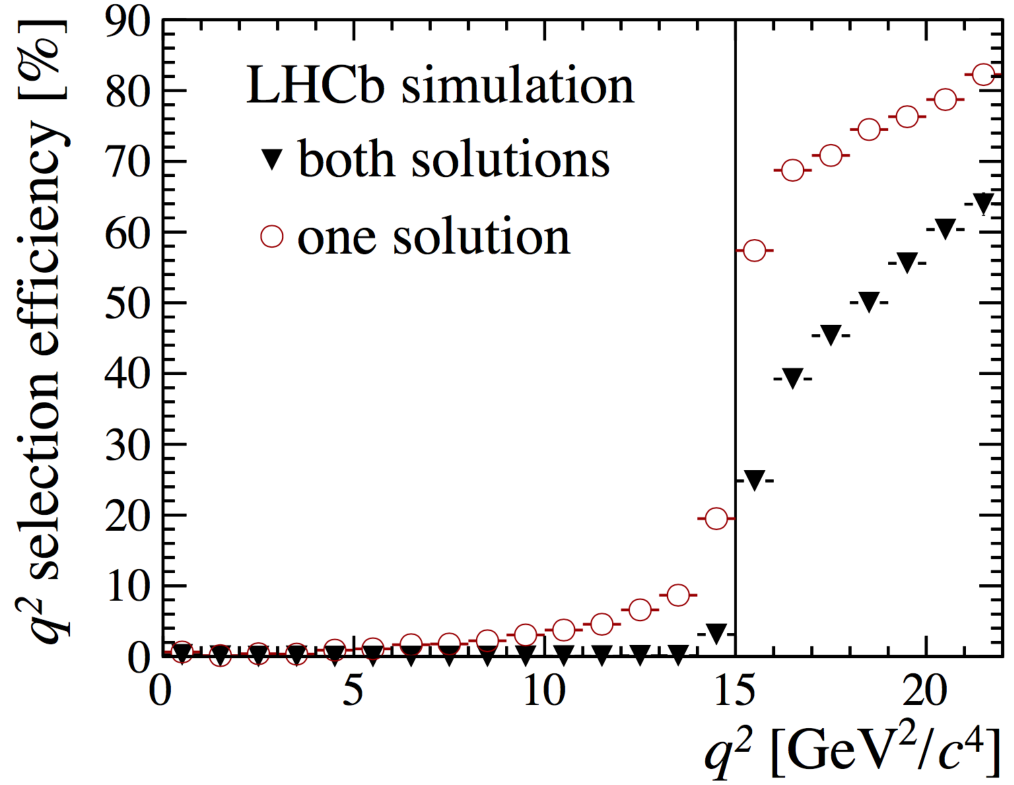
Normalise yields to $\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$, V_{cb} mediated decay, cancel many systematic uncertainties

Apply tight vertex cut, PID on proton and muon, track isolation to reject 90% of background (using boosted decision tree)

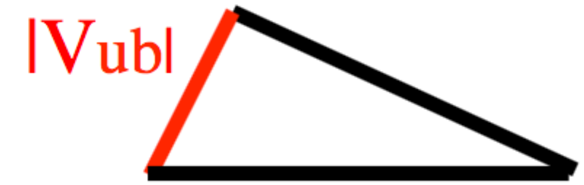
Use corrected mass to reconstruct the signal and retain events with $\sigma(M_{\rm corr}) < 100{\rm MeV}$

$$M_{corr} = \sqrt{p_\perp^2 + M_{p\mu}^2} + p_\perp$$

- Use Λ_b^0 flight direction and mass to determine q^2 with two-fold ambiguity (neutrino). Require both solutions >15 GeV^2, minimise migration to low q^2 bins



$|V_{ub}/V_{cb}|$ results



2fb^{-1} data at 8 TeV - Nature Phys. 11 (2015) 743-747

Measure:

$$|V_{ub}|^2 = |V_{cb}|^2 \frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\bar{\nu}_\mu)_{q^2>15\mathrm{GeV}^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\bar{\nu}_\mu)_{q^2>7\mathrm{GeV}^2}} R_{FF}$$

world average	measured	LQCD [1]
$(39.5 \pm 0.8) \times 10^{-3}$	$(1.00 \pm 0.04 \pm 0.08) \times 10^{-2}$	0.68 ± 0.07

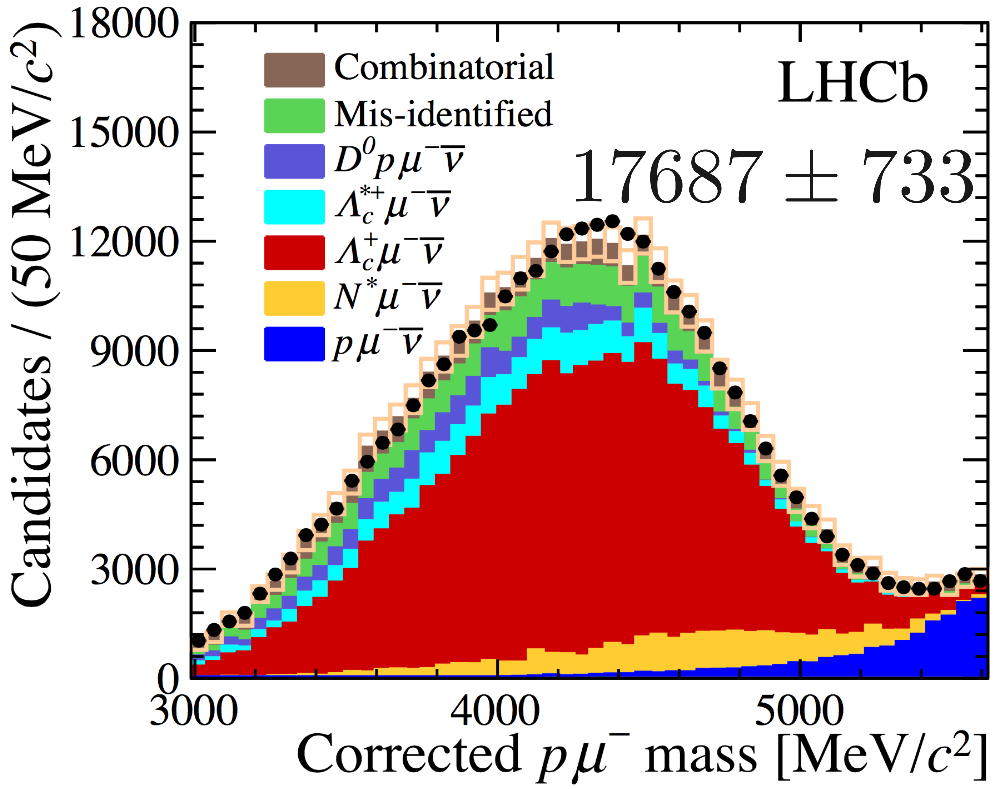
[1] W. Detmold, C. Lehner, and S. Meinel, arXiv:1503.01421

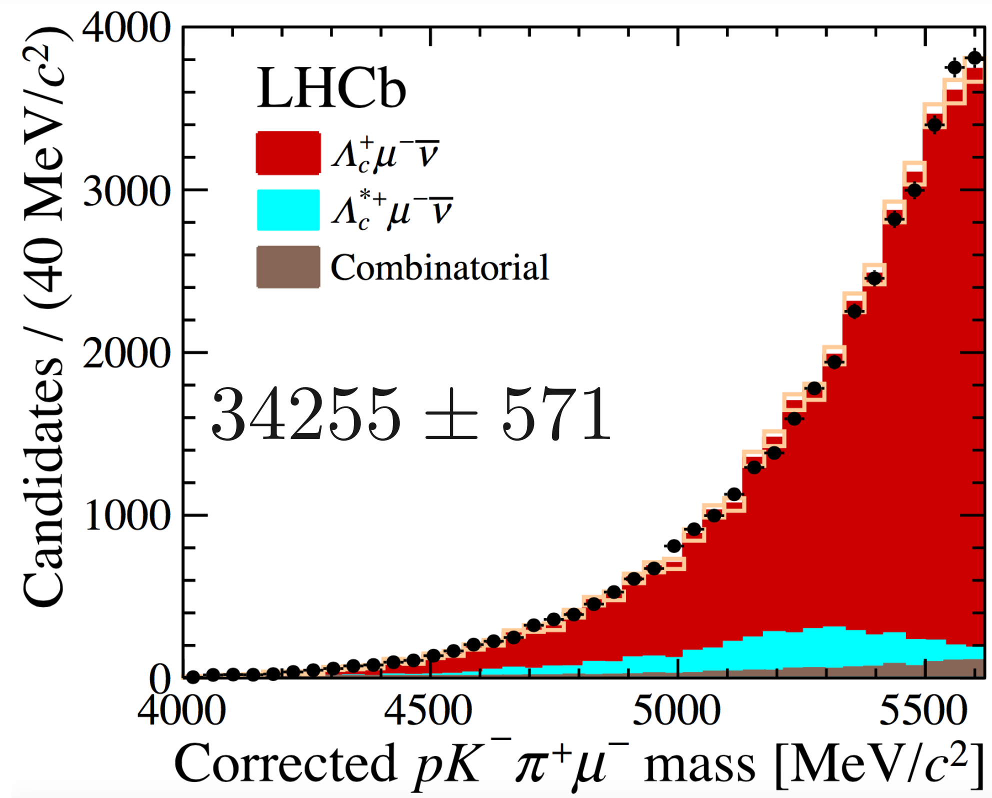
Most precise measurement

$$|V_{ub}| = (3.27 \pm 0.15 \pm 0.17 \pm 0.06) \times 10^{-3}$$

exp. LQCD $|V_{cb}|$

- Background contributions estimated using ad hoc control samples
- Largest exp. uncertainty from $\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$
- Important and independent determination of V_{ub} from B factories



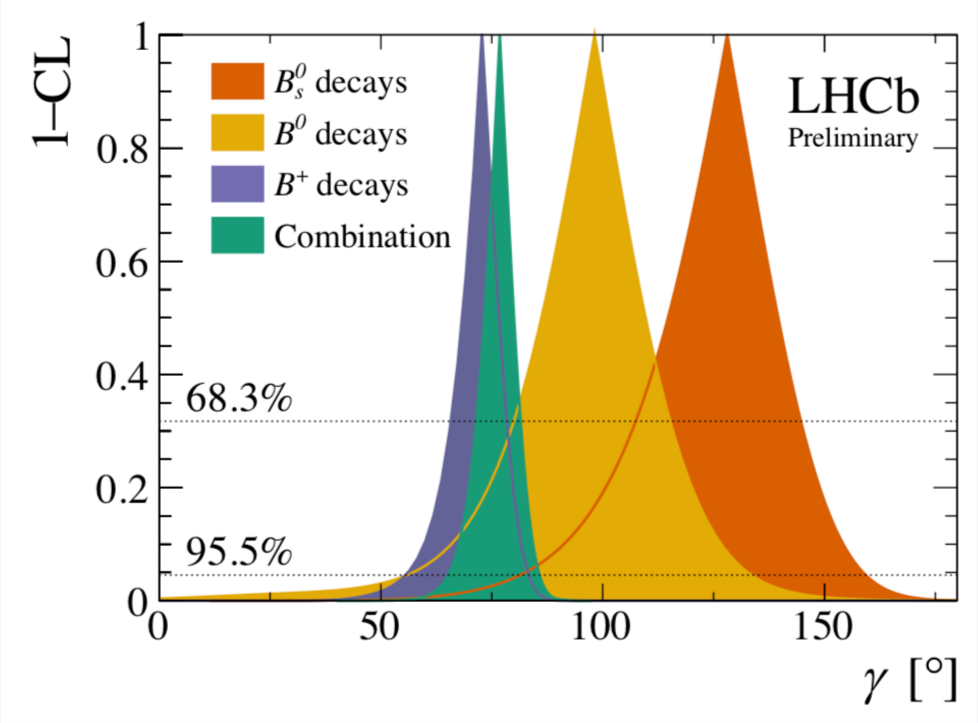


γ from combination of measurements

Combination of B→DK measurements

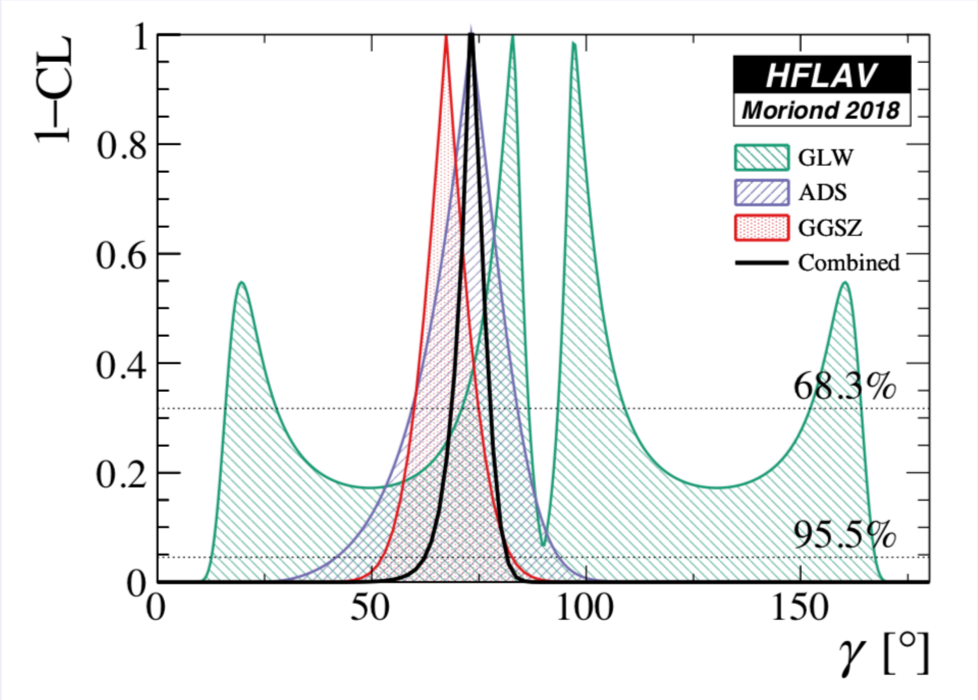
LHCb Average - [LHCb-CONF-2018-002]

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



World Average (HFLAV) - [Spring update]

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



Indirect constraints are: $\gamma = (65.3^{+1.0}_{-2.5})^\circ$ $(\sim 2\sigma)$

Comparison between B_s^0 and B^+ initial states $\sim 2\sigma$

BaBar $\gamma = (69^{+17}_{-16})^\circ$ PRD 87, 052015 (2013)

Belle $\gamma = (68^{+15}_{-14})^\circ$ arXiv:1301.2033 (2013)

$B_{(s)}$ flavour oscillations

Flavour oscillations occur when flavour eigenstates differ from mass eigenstates

$$|B_{L,H}\rangle = q|B^0\rangle \pm q|\overline{B}^0\rangle$$

- Study time evolution of flavour defined states: $\Delta m = m_H - m_L > 0 \quad \Delta\Gamma = \Gamma_L - \Gamma_H$

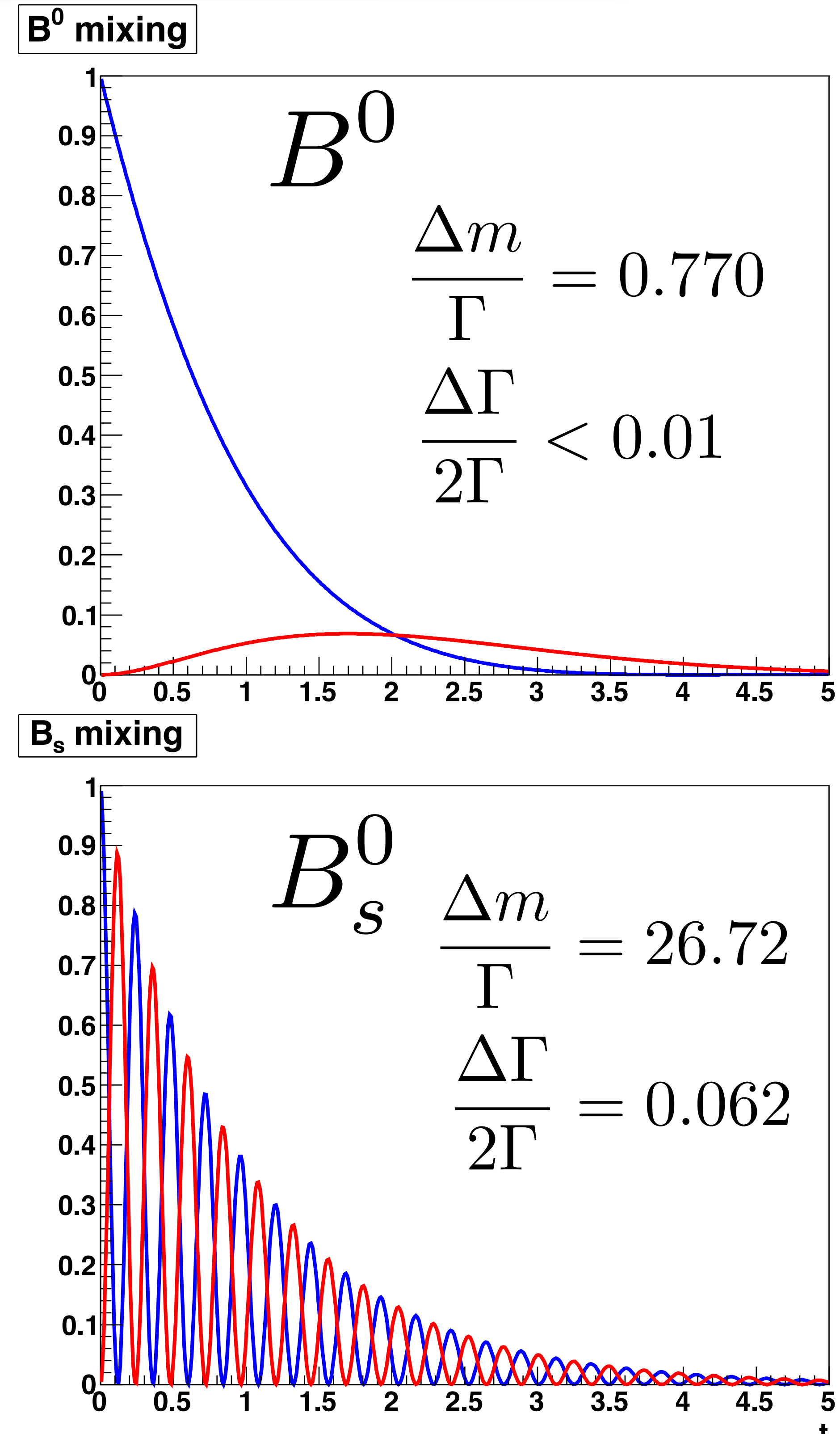
$$\mathrm{Prob}(B^0 \to B^0) = \frac{\Gamma e^{-\Gamma t}}{2}[\cosh(\Delta\Gamma/2t) + \cos(\Delta m t)]$$

$$\mathrm{Prob}(B^0 \to \overline{B}^0) = \frac{\Gamma e^{-\Gamma t}}{2}[\cosh(\Delta\Gamma/2t) - \cos(\Delta m t)]|q/p|^2$$

$$\mathrm{Prob}(\overline{B}^0 \to B^0) = \frac{\Gamma e^{-\Gamma t}}{2}[\cosh(\Delta\Gamma/2t) - \cos(\Delta m t)]|p/q|^2$$

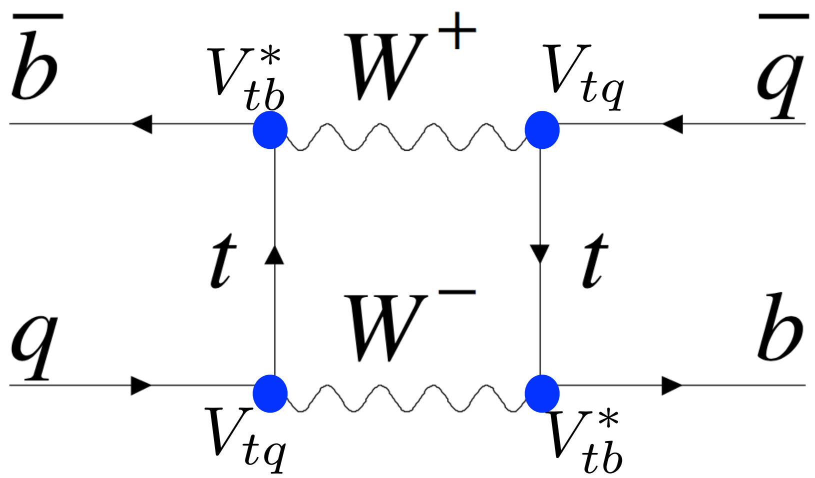
$$\mathrm{Prob}(\overline{B}^0 \to \overline{B}^0) = \frac{\Gamma e^{-\Gamma t}}{2}[\cosh(\Delta\Gamma/2t) + \cos(\Delta m t)]$$

- In SM ΔΓ>0 (very small for B^0) and |q/p|~1, very small CPV in B^0 and B_s mixing



Measurement of Δm_d and Δm_s

Flavour oscillations via box diagram

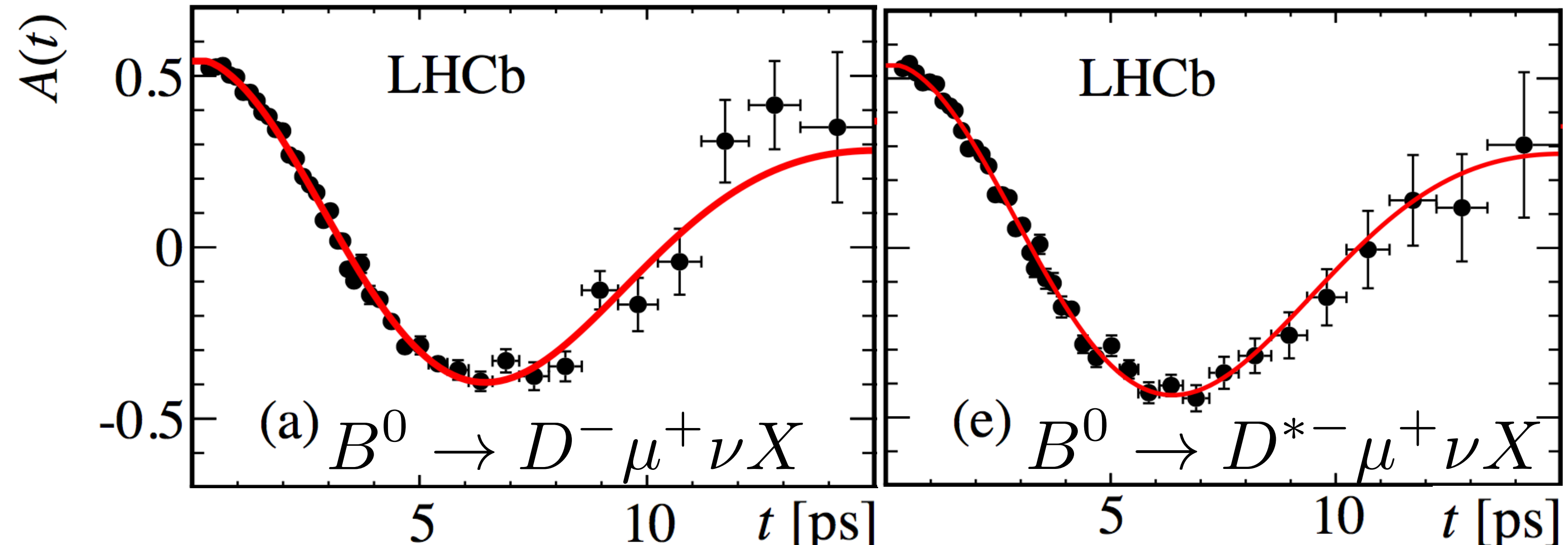


$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \left| \frac{V_{ts}}{V_{td}} \right|^2 (1.206 \pm 0.019)^2$$

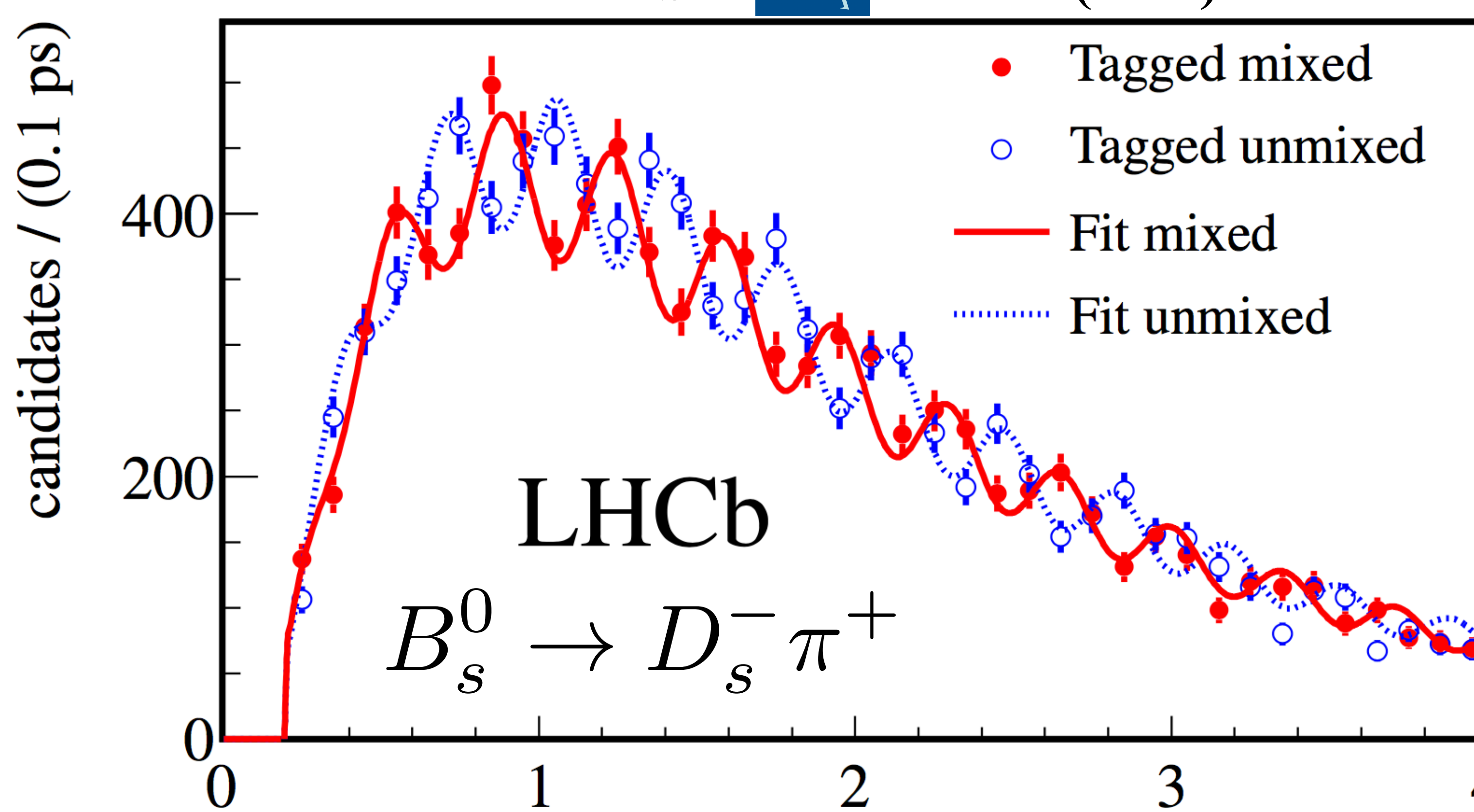
MILC, PRD 93 (2016) 113016

Theory uncertainty from LQCD dominates extraction of $|V_{ts}/V_{td}|$

$\Delta m_d = (505.0 \pm 2.1 \pm 1.0)\,\text{ns}^{-1}$ **3fb^{-1}** **EPJC 76 (2016) 412**



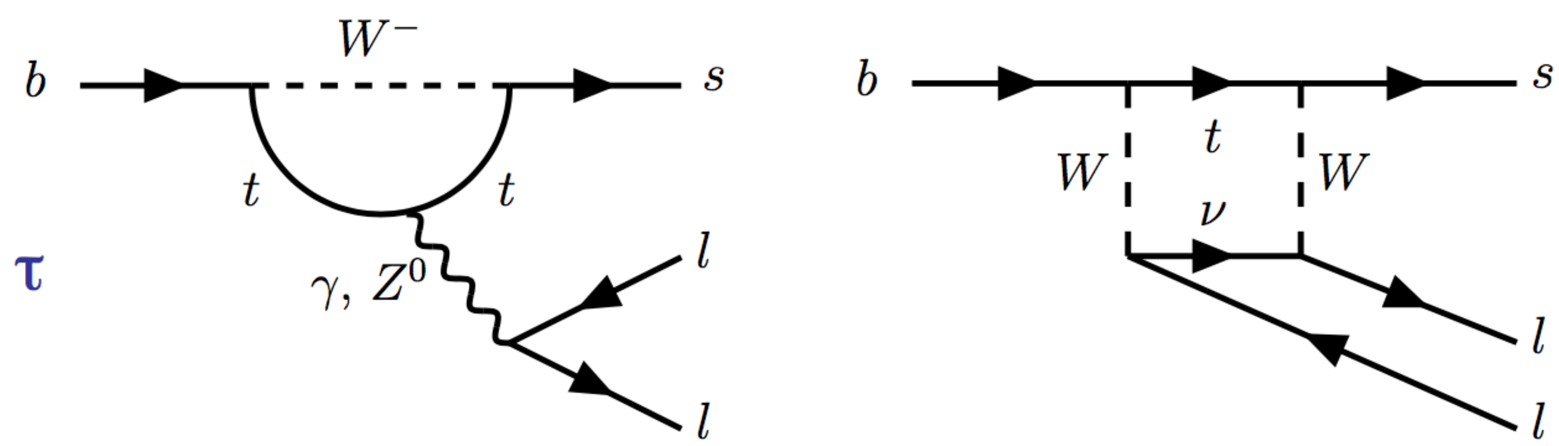
1fb^{-1} **NJP 15 (2013) 053021**



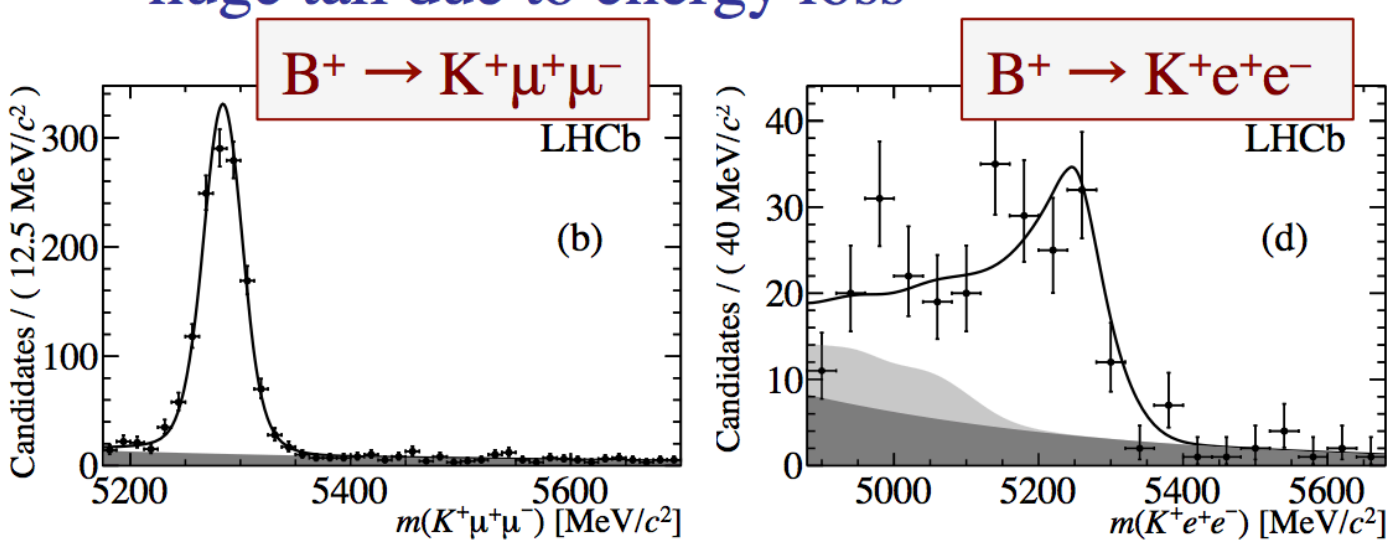
$\Delta m_s = 17.768 \pm 0.023(\text{stat}) \pm 0.006(\text{syst})\,\text{ps}^{-1}$

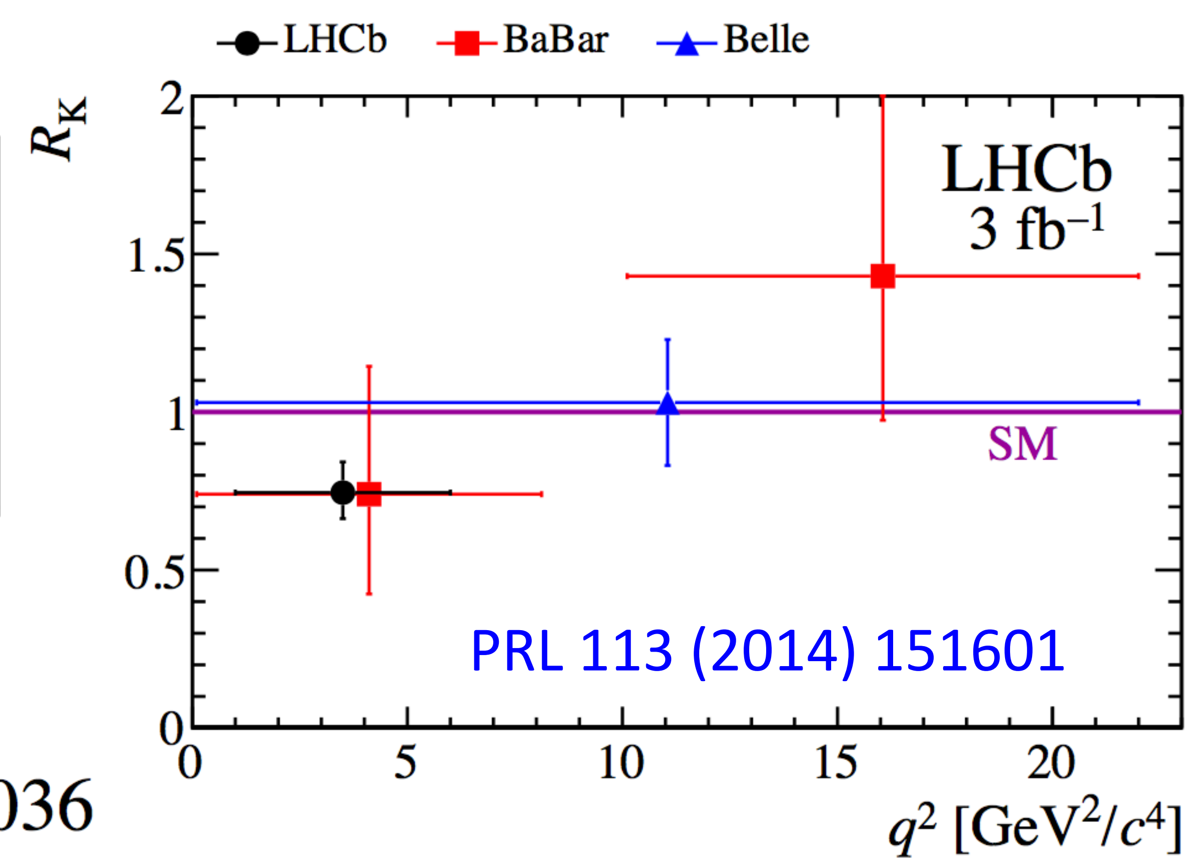
$B^+ \to K^+ \ell^+ \ell^-$ and lepton universality

- **Lepton Flavour Universality (LFU) in the SM:**
  - same EW couplings for $\ell = e, \mu, \tau$



- **LHCb:**
  - electron reconstruction challenging, huge tail due to energy loss





  - for low q^2 region ($1<q^2<6$ GeV^2/c^4):

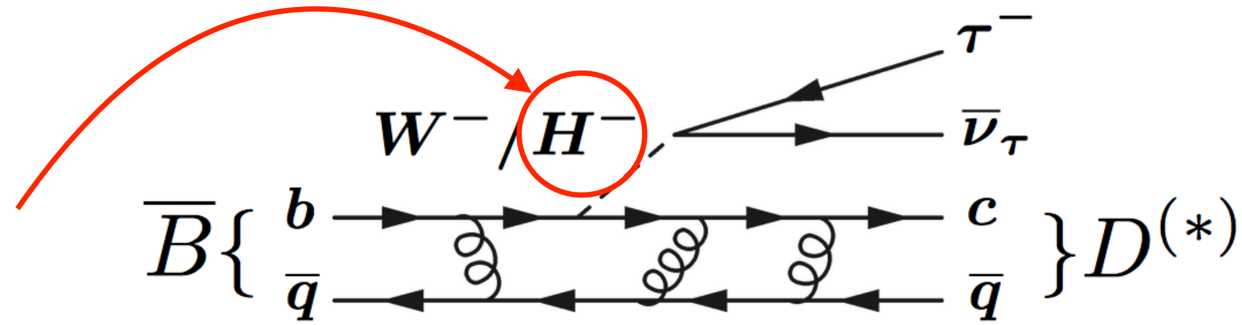
$$R_K = \frac{BR(B^+ \to K^+\mu^+\mu^-)}{BR(B^+ \to K^+e^+e^-)} = 0.745\,^{+0.090}_{-0.074} \pm 0.036$$

2.6σ from SM value of $1 \pm O(10^{-3})$

Test of lepton flavour universality

LFU test with B→D$^{(*)}\ell\nu$

tree level decay, sensitive to
possible H+ contribution

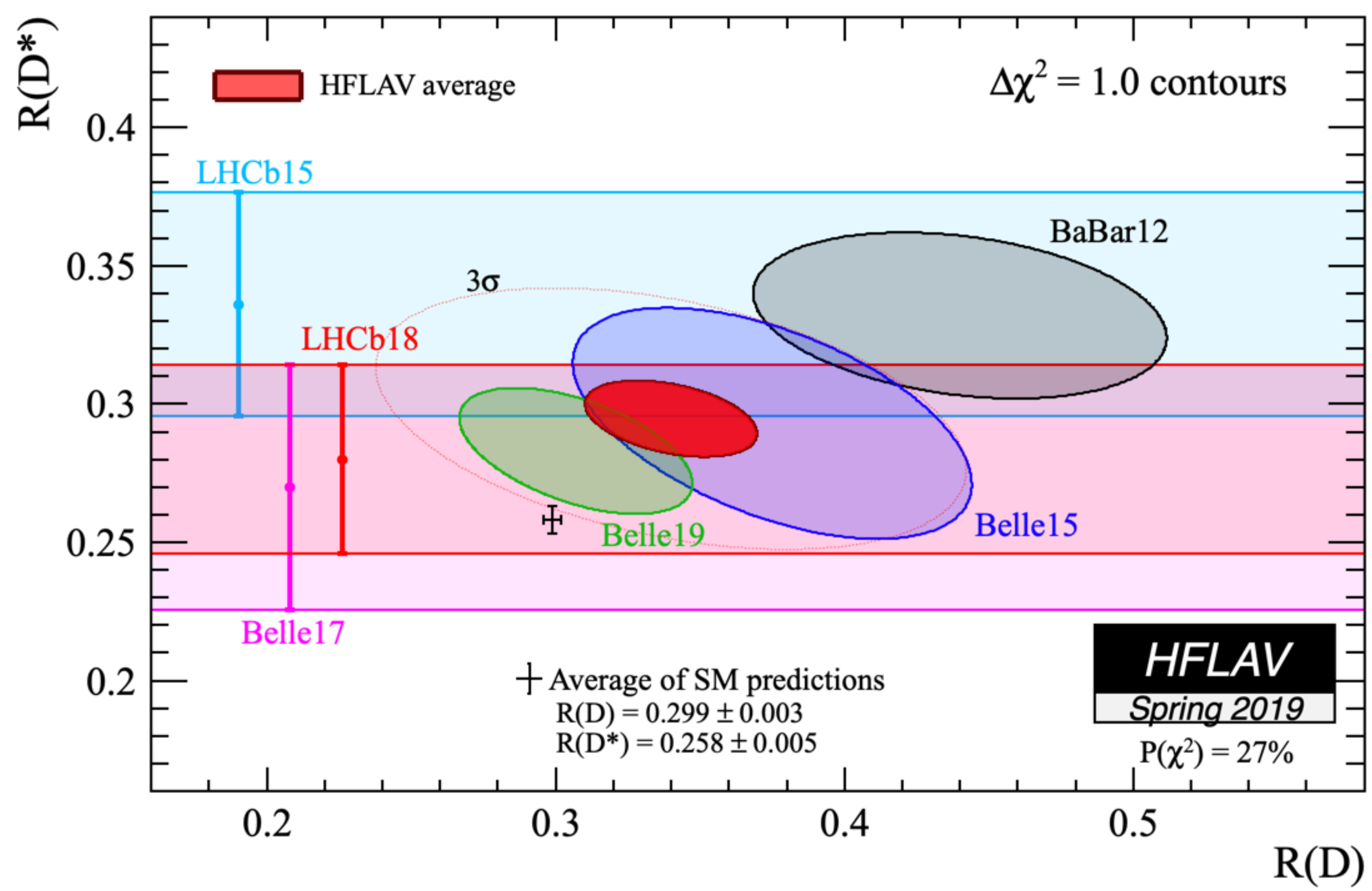


R(D) and R(D*) definition

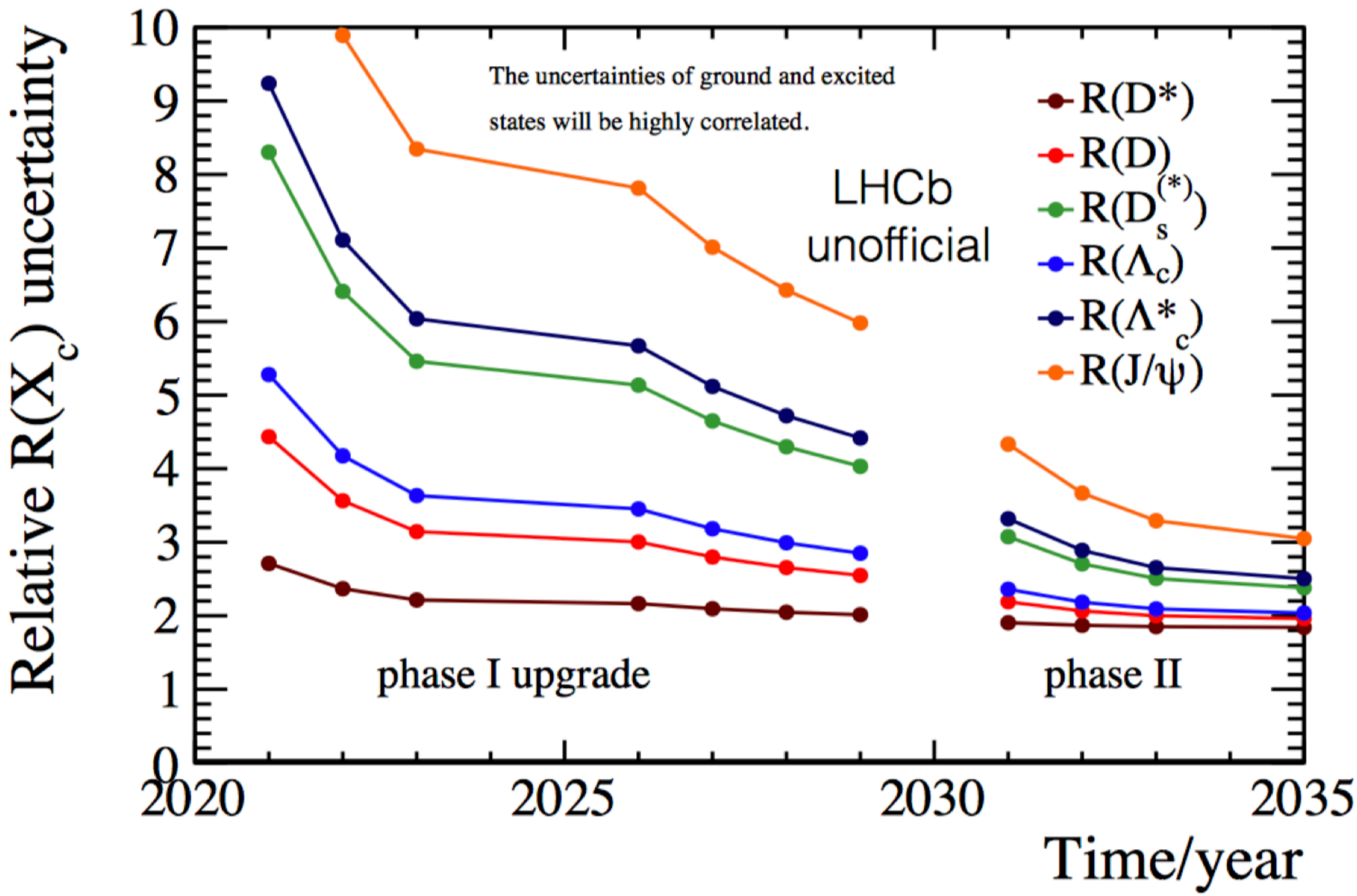
$$R(D^{(*)}) = \frac{B^0 \to D^{(*)-}\tau^+\nu_\tau}{B^0 \to D^{(*)-}\ell^+\nu_\tau}$$

$$\ell = \mu, e$$

- Experimental challenge
  - tau reconstruction, missing neutrinos
- **3.1 σ** from **SM** (**2D average**)



Semitauonic measurements



Phase-II will substantially benefit R(Xc) measurements of B_s, Λ_b^0, B_c hadrons, not accessible at Belle II

EDM limits

- Summary of current EDM limits and future planned sensitivities