Perspectives in *B* Physics: Results from LHCb

Ulrich Uwer

Heidelberg University

on behalf of the LHCb Collaboration

Outline:

- Introduction
- Unitarity Triangle
- Meson Mixing
- Rare B decays

Supported by

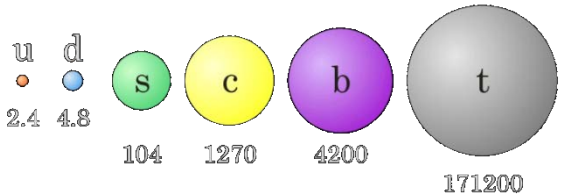
Bundesministerium für Bildung und Forschung

Quark sector in Standard Model

Yukawa couplings to Higgs

$$\mathcal{L}_{\mathrm{Y}}^{\mathrm{quarks}} = -\frac{v}{\sqrt{2}}\left(\overline{d}_{\mathrm{L}}\, Y_d\, d_{\mathrm{R}} + \overline{u}_{\mathrm{L}}\, Y_u\, u_{\mathrm{R}}\right) + \mathrm{h.c}$$

Quark masses



6 parameters

Flavor transitions across generations

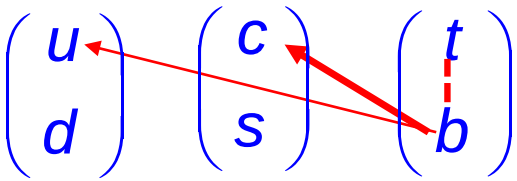
$$\mathbf{V}_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

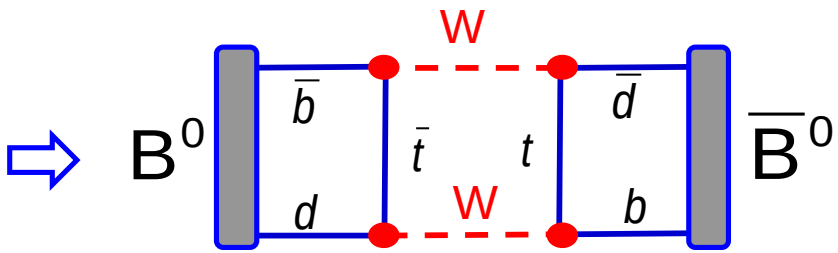
3 +1 parameters

$\Rightarrow$ Rich phenomenology, well tested but very puzzling!

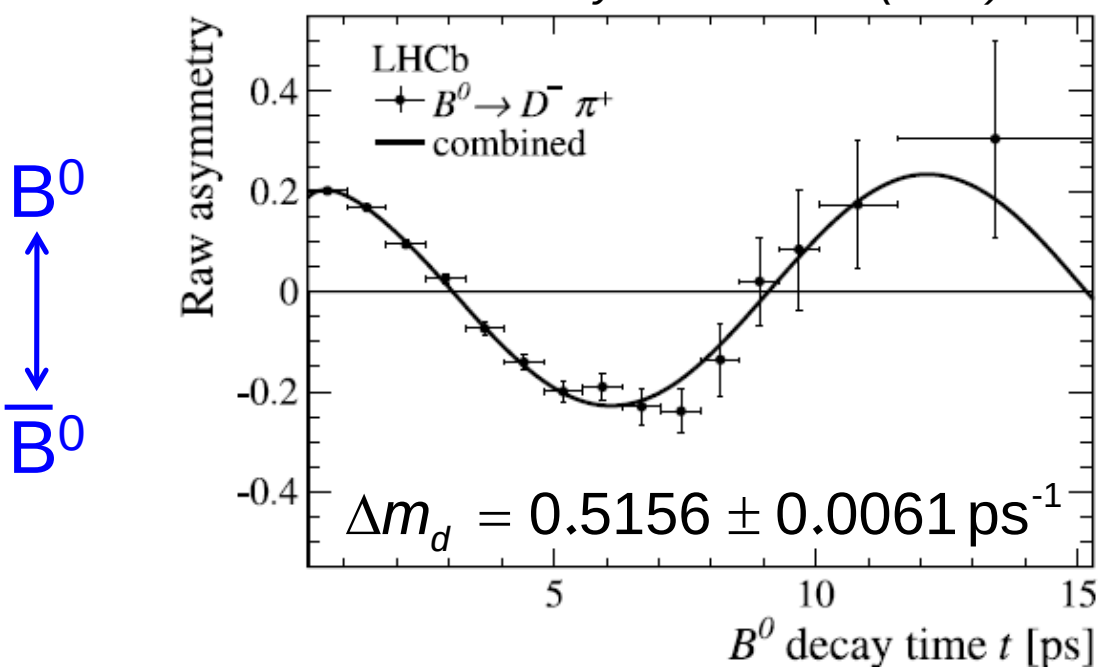
40 years: Discovery of the Υ *[S. W. Herb et al. Phys. Rev. Lett. 39, 245 (1977)]*

Effect of quark mixing - FCNCs





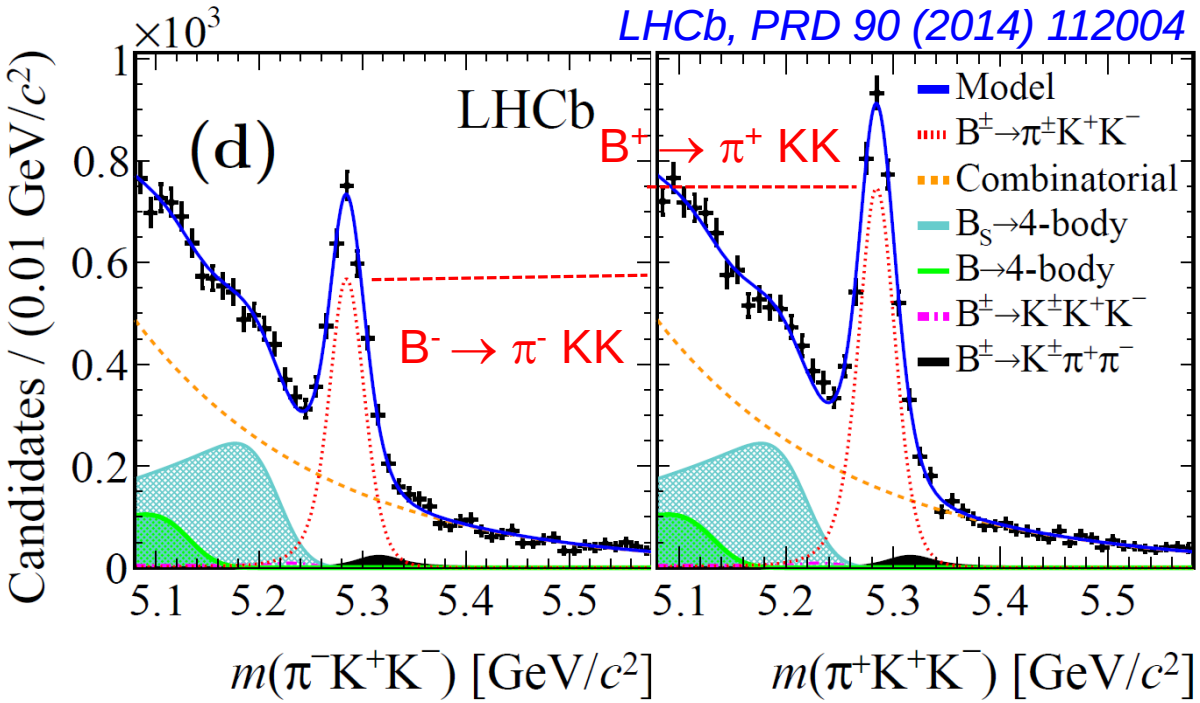
Phys. Lett. B 719 (2013) 318.



Effects of CKM Phases – CP Violation

Example of CP violation: $B^{\pm} \to \pi^{\pm}$ KK

LHCb, PRD 90 (2014) 112004



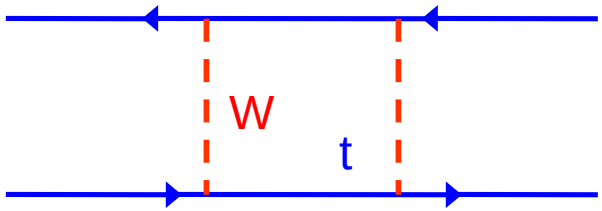
Remark: So far CPV has been seen only in meson decays.
Recently LHCb reported evidence for CPV in baryon decays:

CPV in $\Lambda_b \to p\pi^-\pi^+\pi^-$ w/ 3.3σ

Nature Physics (2017). arXiv:1609.05216

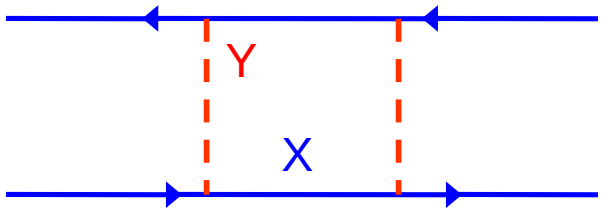
“New Physics” in Quantum-Loops

Standard Model

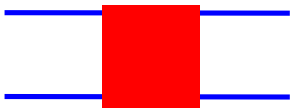


+

New Physics



$$\mathcal{A}_{SM} \quad + \quad \mathcal{A}_{NP}$$



$|\mathcal{A}|^2 \rightarrow$ rates
Phase $\rightarrow$ CP-violation
Lorentz-structure $\rightarrow$ angular distr.

Search for deviations from Standard Model predictions:

Suppressed processes, observables w/ small theoretical errors

High-rate experiments to maximize sensitivity: **LHC(b) / Belle-2**

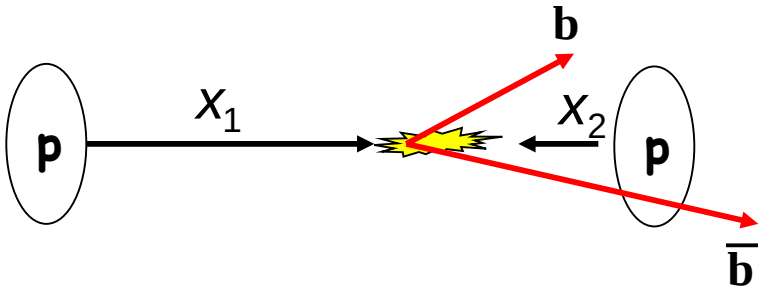
Heavy flavor production at LHC(b)

$\sigma(pp \to b\bar{b}X)$

7 TeV: ≈295 μb
13 TeV: ≈600 μb

PRL 118, 052002 (2017)

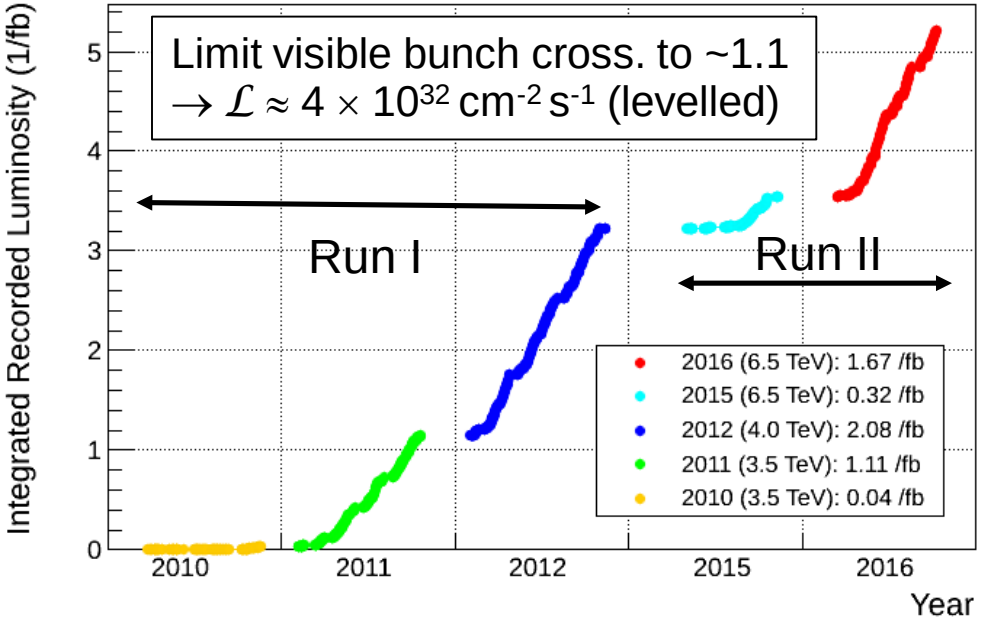
$\sigma(pp \to c\bar{c}X) \approx 20 \times \sigma_{bb}$



Run 1 (in LHCb acceptance)

$p\bar{p}$: 18×10^{13}
$c\bar{c}$: 5.9×10^{12}
$b\bar{b}$: 2.6×10^{11}
} ~ 3fb^{-1}

Run 2: 2 fb^{-1} at 13 TeV
effect. data: ×2



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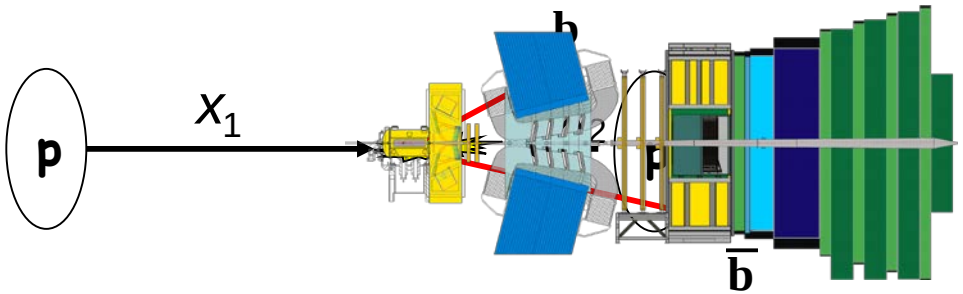

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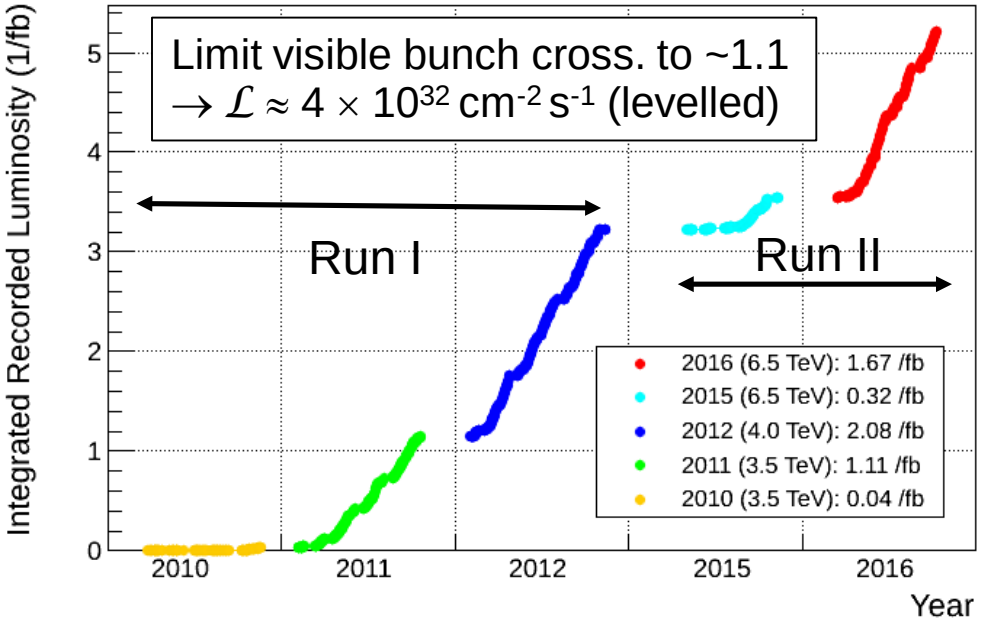
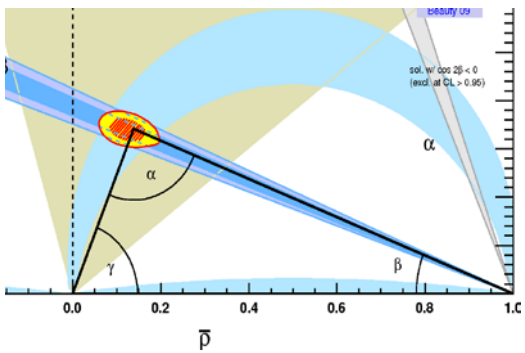


Searching for NP - selected LHCb measurements

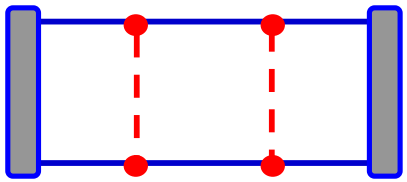
CKM Metrology



γ via direct CPV
sin2β via t-dep. CPV
V_{ub} semilept. decays

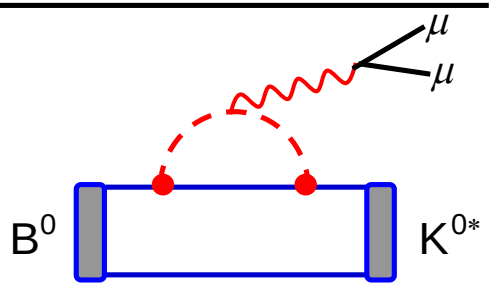
B_s - Mixing

$$\mathcal{A}_{mix} = \left|\mathcal{A}_{mix}\right| e^{-i\phi_{mix}}$$

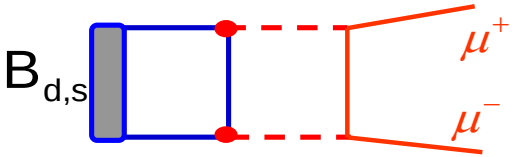


Mixing and mixing phases

Rare decays - FCNCs

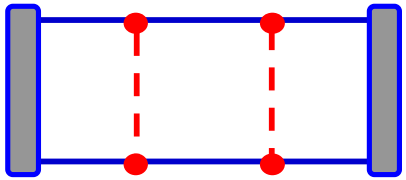


angular distribution



rates

D^0 – Mesons



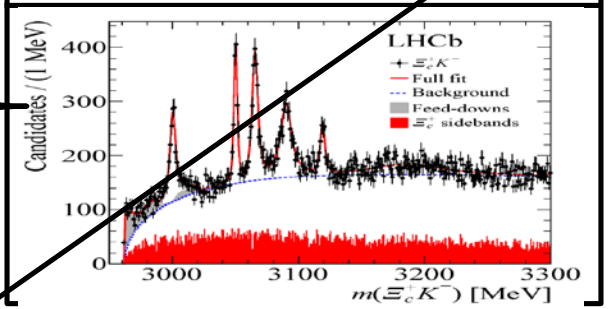
Mixing and CP violation

Penta-Quarks:
PRL 115 (2015) 072001

4-Quark exotics
arXiv:1606.07895;
arXiv:1606.07898

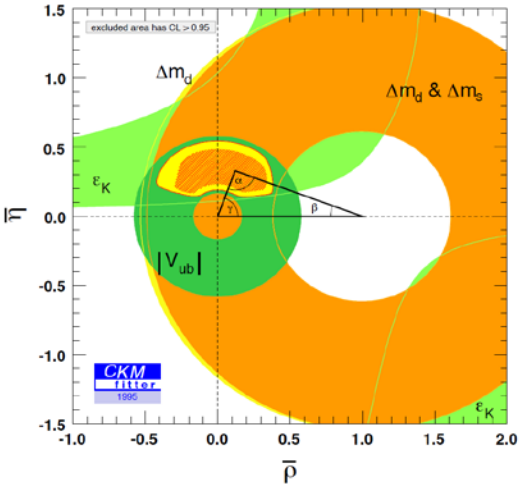
Ω_c states
arXiv:1703.04649

Hadron Spectroscopy

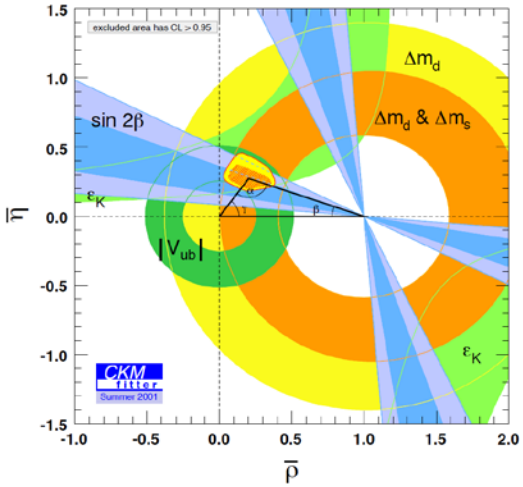


Unitarity Triangle – CKM Metrology

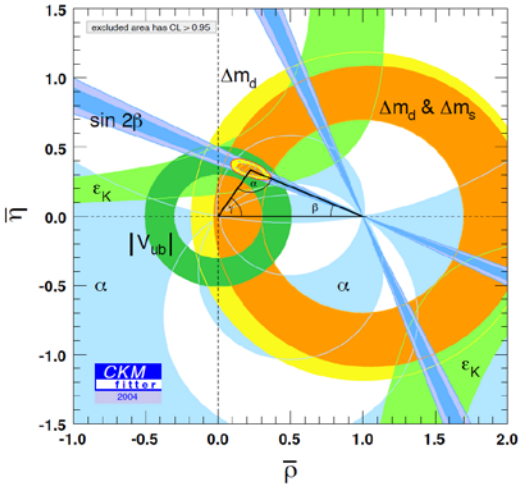
LEP, KTeV, NA48, *BABAR*, Belle, CDF, DØ, LHCb, CMS, ATLAS, …



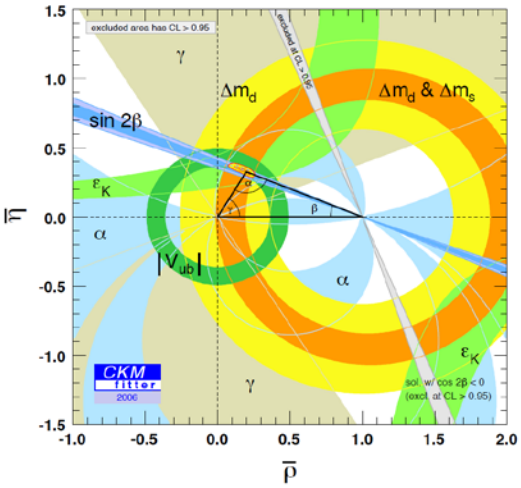
1995



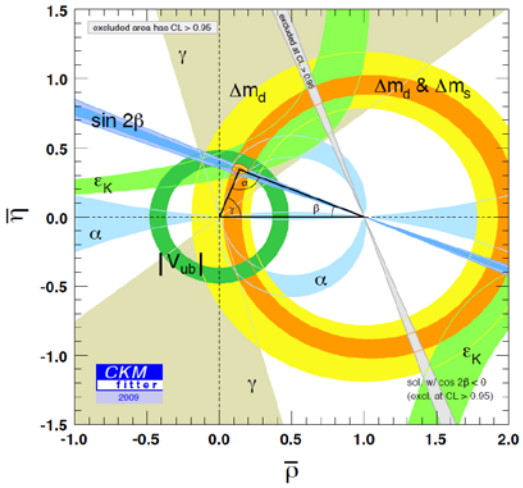
2001



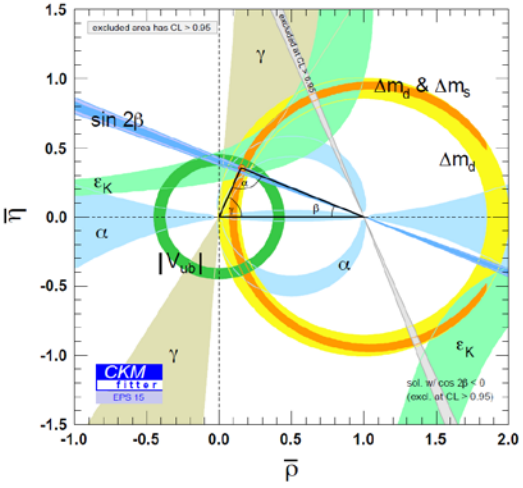
2004



2006



2009



2015

ckmfitter.in2p3.fr

Unitarity Triangle – CKM Metrology

LEP, KTeV, NA48, *BABAR*, Belle, CDF, DØ, LHCb, CMS, ATLAS, …

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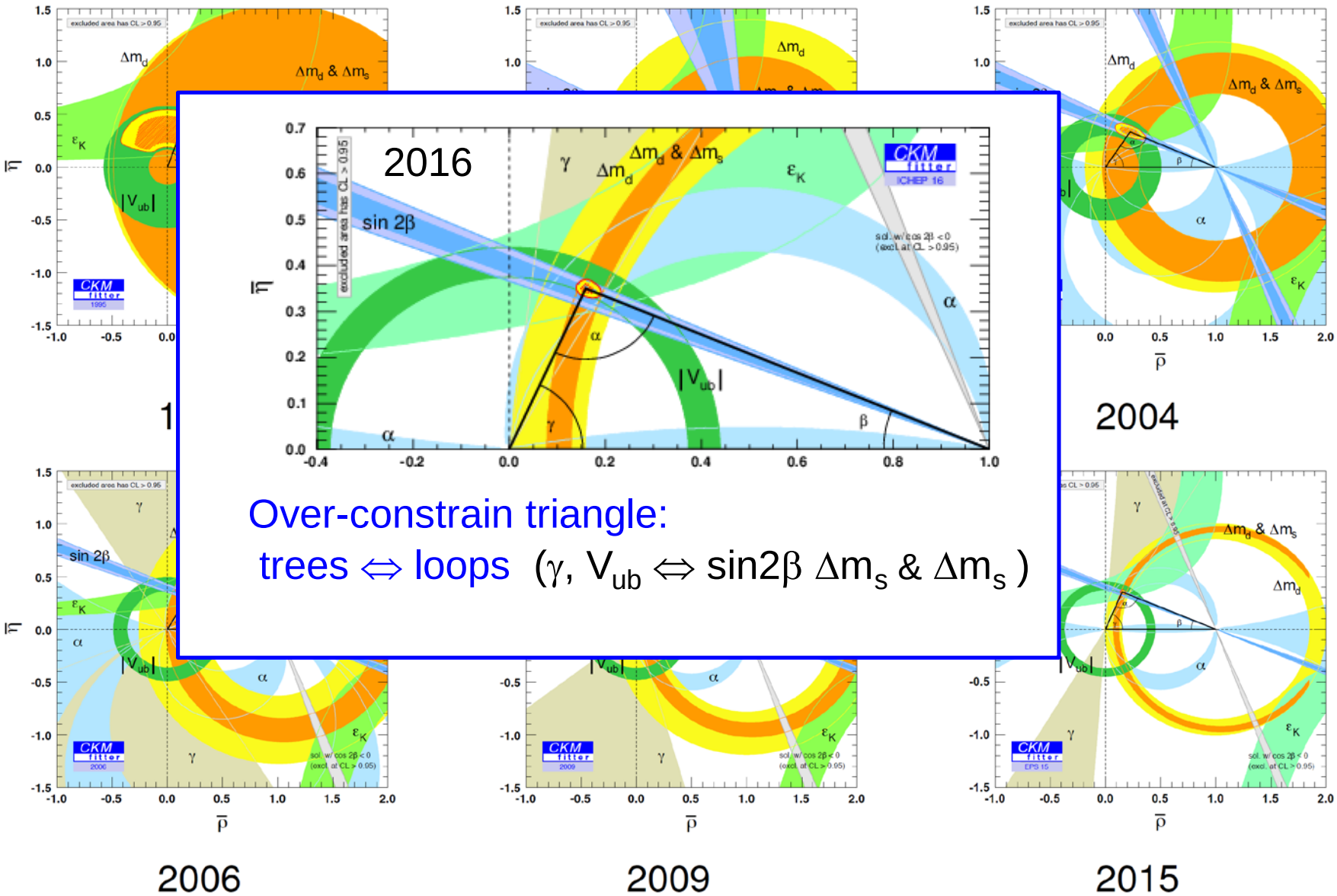
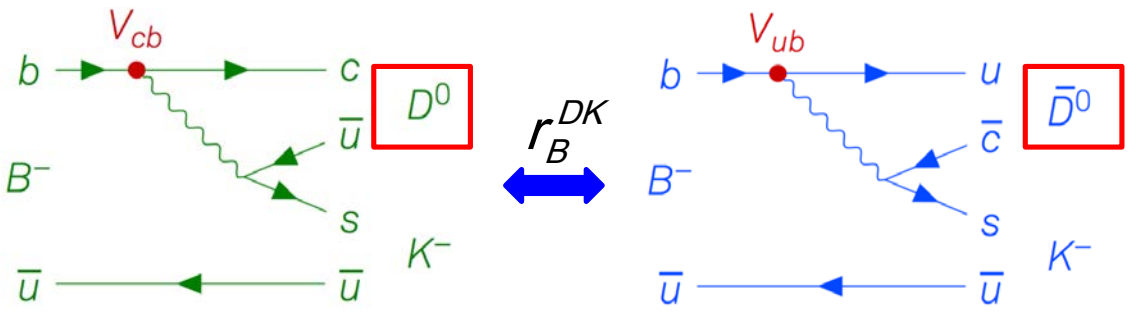


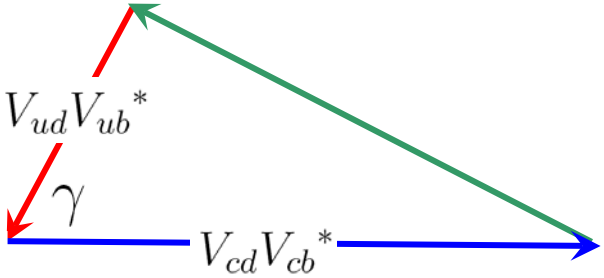
Over-constrain triangle:

trees ⇔ loops (γ, V_{ub} ⇔ sin2β Δm_s & Δm_s)

CKM-Phase γ

Interference between b→c and b→u





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

leads to direct CP violation in B→DK decays

Interference requires the D^0 ($\overline{D}^0$) to decay into a common final state:

f_D = KK, ππ (CP state) — Gronau, London, Wyler (GLW)

f_D = Kπ and πK (CKM favored/suppressed) — Atwood, Dunietz, Soni (ADS)

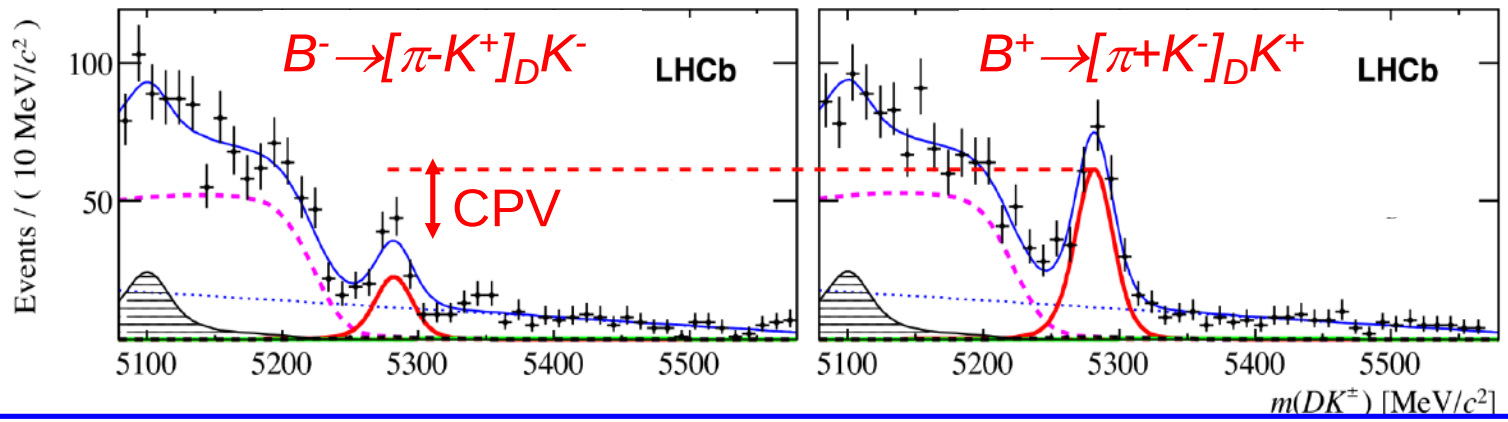
f_D = self conjugated Dalitz-modes — Giri, Grossman, Soffer, Zupan (GGSZ)

Theoretically clean. However, single measurement not very sensitive (BR ~10^{-7}). Need to combine many decay modes.

Two examples for B → DK

ADS

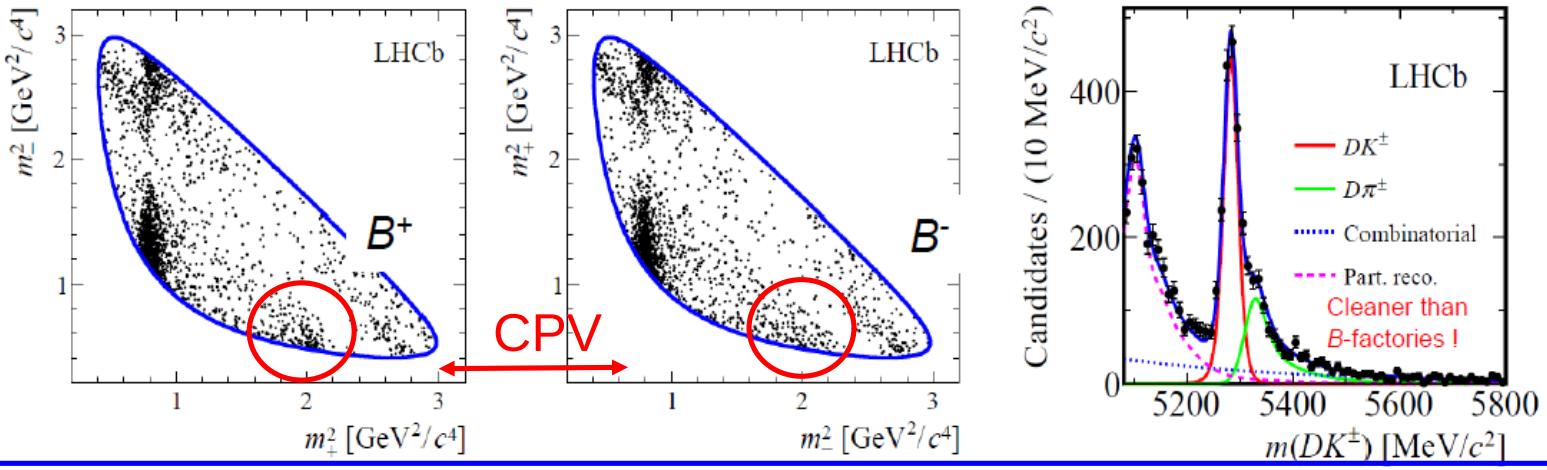
$B^{\pm} \to (K\pi)_D K^{\pm}$ mode (BR ~ 10^{-7}) was soon seen at LHCb.
Being exploited for high-precision CP-violation measurements.



PLB 760 (2016) 117

GGSZ

B^- / B^+ differences in multibody phase space ($D \to K_S\pi\pi$ or $K_S KK$) Benefit from the high purity of signal.



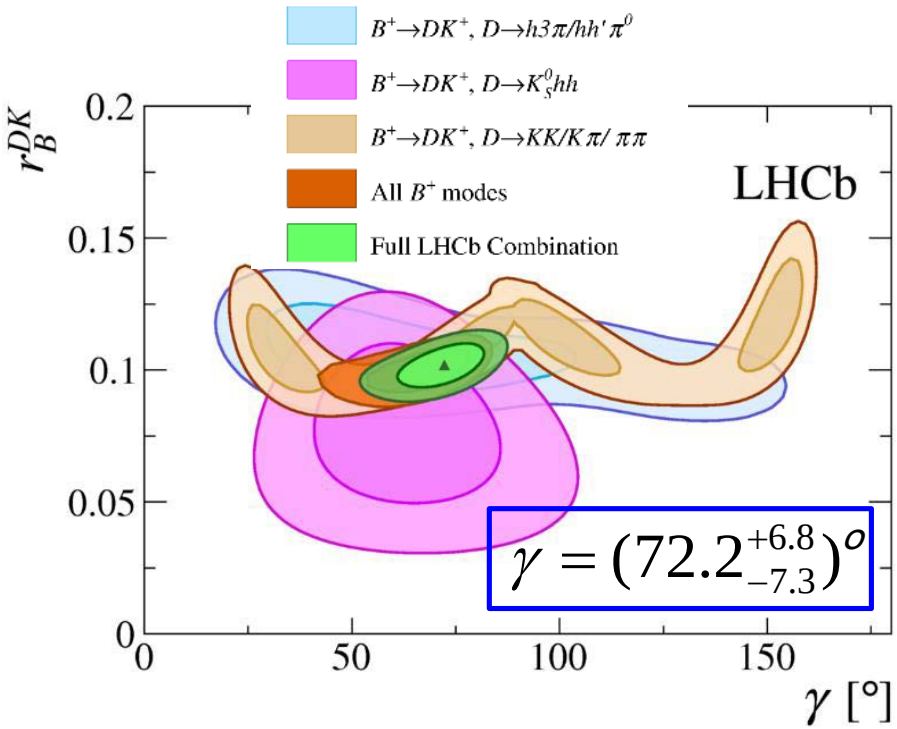
JHEP 10 (2014) 097

Combination of γ (B→DK)

JHEP 12 (2016) 087

B decay	D decay	Method
$B^+ \to Dh^+$	$D \to h^+h^-$	GLW/ADS
$B^+ \to Dh^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS
$B^+ \to Dh^+$	$D \to h^+h^-\pi^0$	GLW/ADS
$B^+ \to DK^+$	$D \to K_S^0 h^+h^-$	GGSZ
$B^+ \to DK^+$	$D \to K_S^0 K^+\pi^-$	GLS
$B^+ \to Dh^+\pi^-\pi^+$	$D \to h^+h^-$	GLW/ADS
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz
$B^0 \to DK^{*0}$	$D \to K_S^0\pi^+\pi^-$	GGSZ
$B_s^0 \to D_s^\mp K^\pm$	$D_s^+ \to h^+h^-\pi^+$	TD

time dependent



Agrees with BaBar and Belle and with prediction from CKM fits

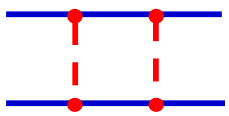
BaBar	$\gamma = (69^{+17}_{-16})^o$	PRD 87, 052015 (2013)
Belle	$\gamma = (68^{+15}_{-14})^o$	arXiv:1301.2033 (2013)
Indirect	$\gamma = (65.3^{+1.0}_{-2.5})^o$	CKM Fitter 2006

Aim for 3 - 4° uncertainty after Run-2.
The LHCb-Upgrade will allow for even higher sensitivity (~1°).

CKM Phase β

PRL 115, 031601 (2015)

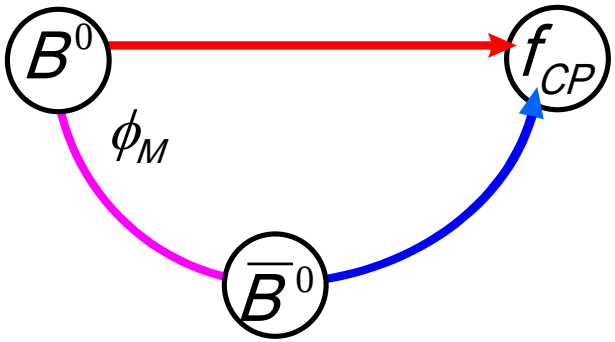
V_{td}



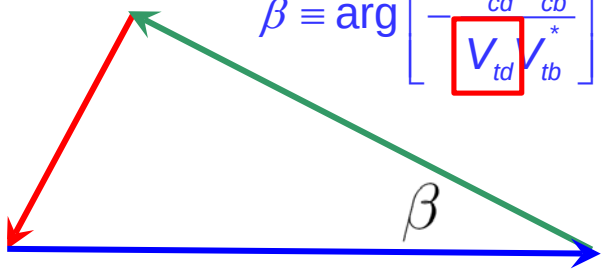
$$\mathcal{A}_{mix} = |\mathcal{A}_{mix}| e^{i\phi_M}$$

SM: $\phi_M = 2\beta$

Interference mixing and decay



$$\beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$$

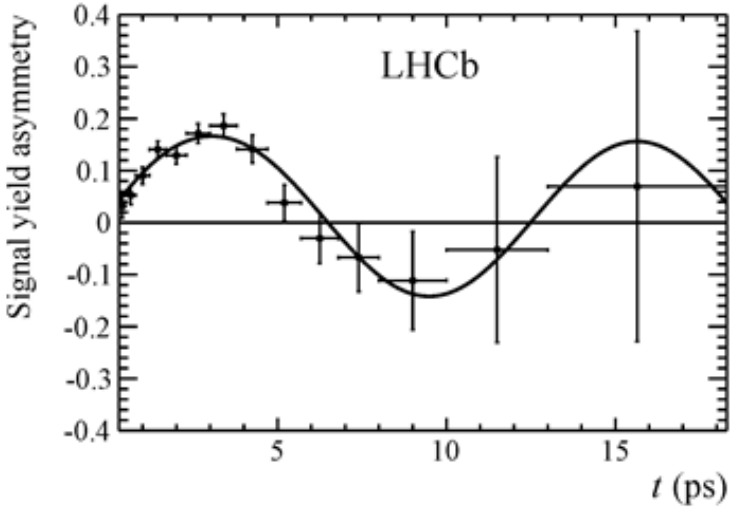


⇒ time dependent CPV: $A_{CP}(t) \sim \eta_{CP} \sin 2\beta \sin(\Delta m t)$

"Golden decay" $B^0 \to J/\psi K_s$ (42560 evts)

$$\sin 2\beta = 0.731 \pm 0.035 \pm 0.020$$

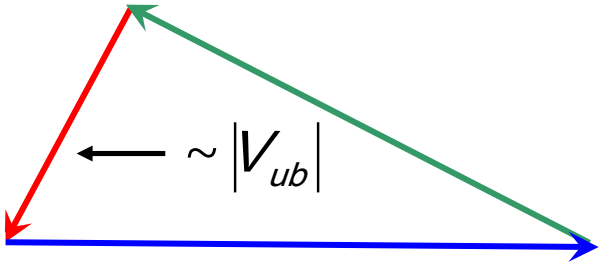
(Stat. error BaBar: ±0.036 Belle: ±0.029)



World average (HFAG) 0.69±0.02

Tensions w/ indirect value from CKM-Fit: 0.740

Unitarity Triangle : $|V_{ub}|$



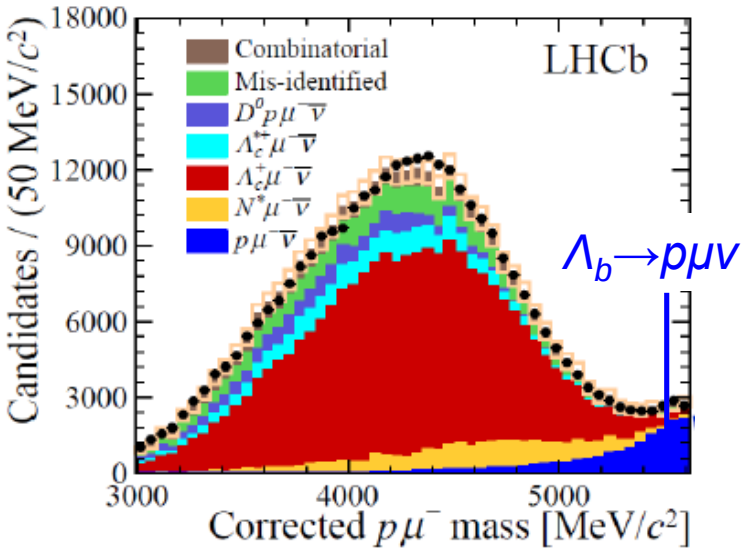
V_{ub} measurement thought impossible at LHC

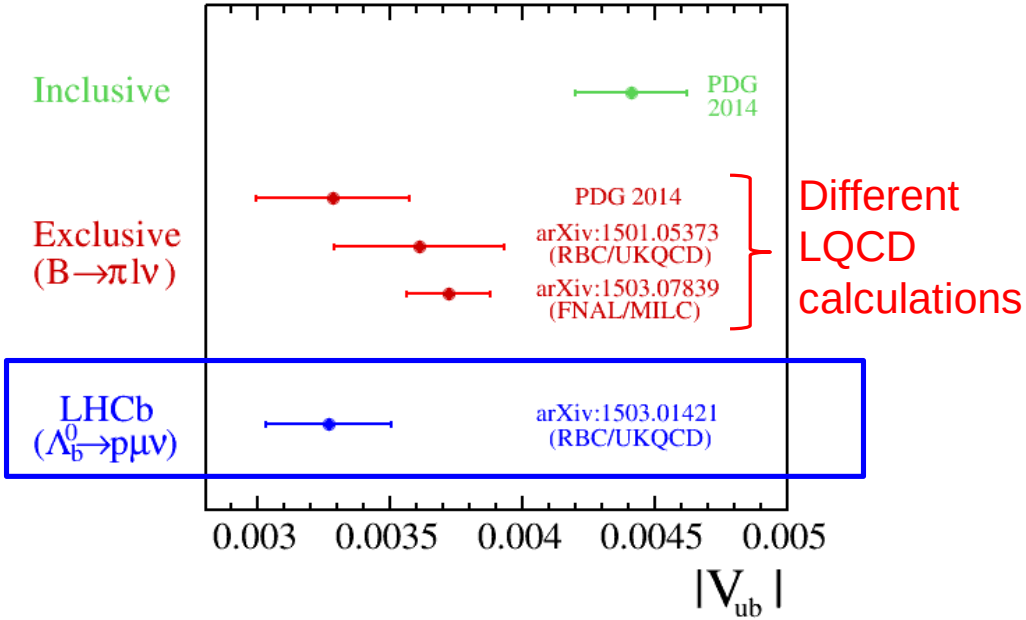
Nature Physics 10 (2015) 1038

- Use baryon decay $\Lambda_b \to p\mu\nu$, benefit from RICH & vertexing capabilities.
- Normalize to $\Lambda_b \to \Lambda_c \mu\nu$ and use lattice QCD to interpret result.

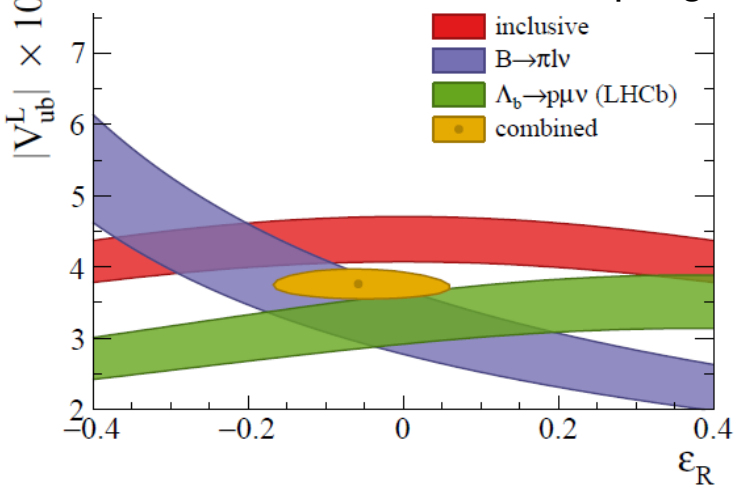
$$|V_{ub}| = (3.27 \pm 0.15 \pm 0.16 \pm 0.06) \times 10^{-3}$$

errors: exp LQCD from V_{cb}

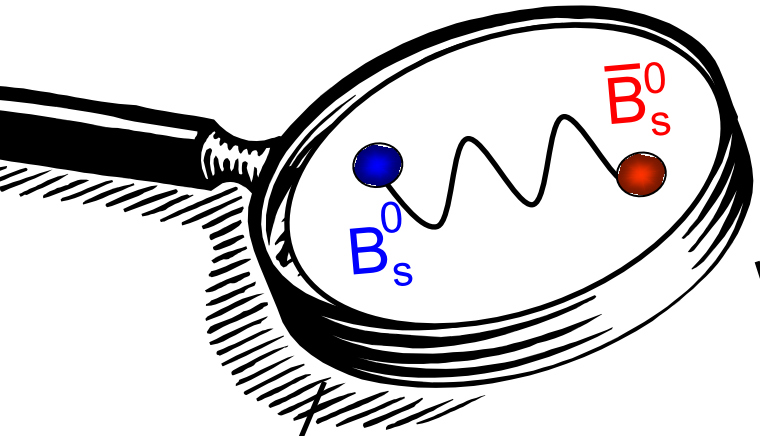




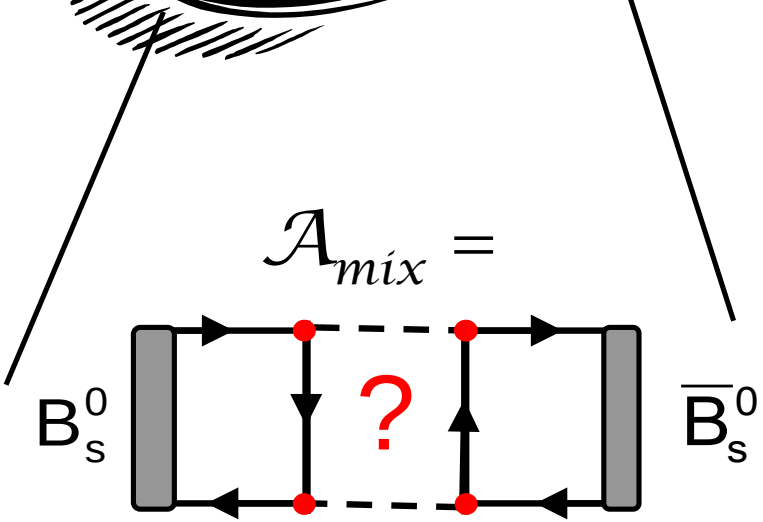
Constraint on LH & RH coupling



B_s - Mixing



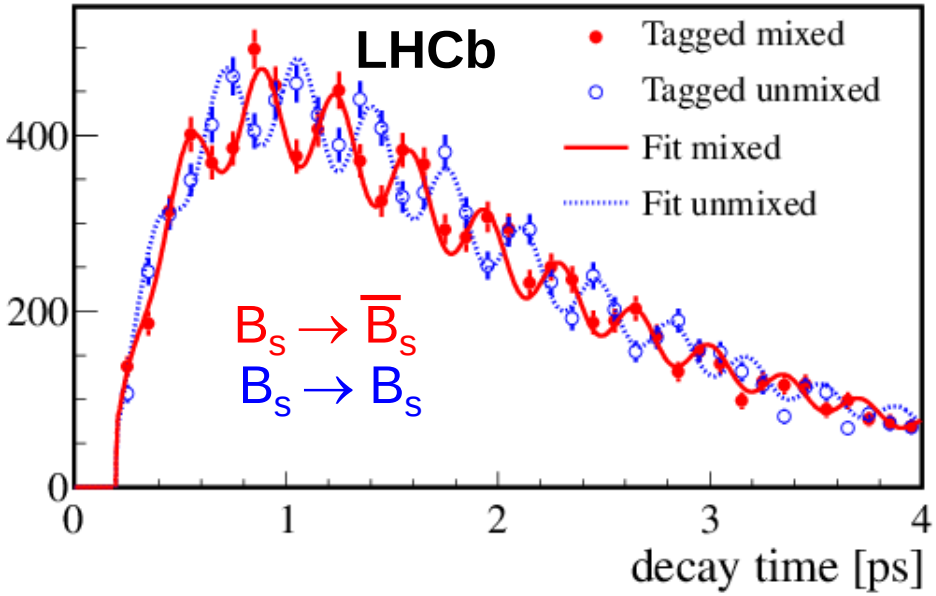
$$\mathcal{A}_{mix} =$$



$$= \left|\mathcal{A}_{mix}\right| \cdot e^{i\phi_M}$$

$$\phi_M \equiv \phi_s \approx -2\arg\left(V_{ts}\right) \approx -2\beta_s$$

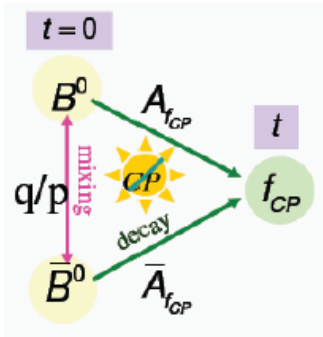
New J. Phys. 15 (2013) 053021



$\Delta m_s = 17.768 \pm 0.023 \pm 0.006\ ps^{-1}$

Theorie *(U.Nierste, 2012)*

$\Delta m_s = 17.3 \pm 1.5\ ps^{-1}$



time-dependent CP asymmetry to measure ϕ_s

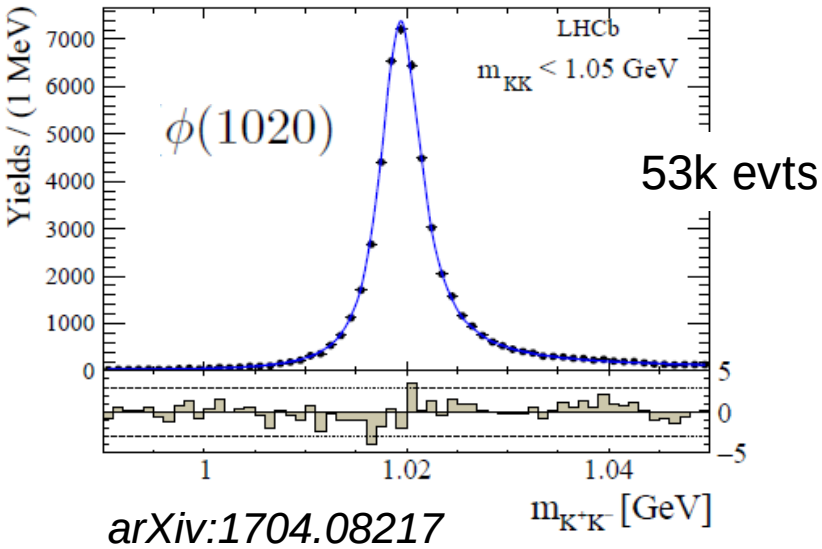
"Golden mode": $B_s \to J/\psi\phi(KK)$

m(KK) ≈ 1.02 GeV (ϕ region)

$\phi_s = 0.058 \pm 0.0490 \pm 0.006$rad

$\Delta\Gamma = 0.0805 \pm 0.0091 \pm 0.0032$ ps^{-1}

PRL 114, 041801 (2015)



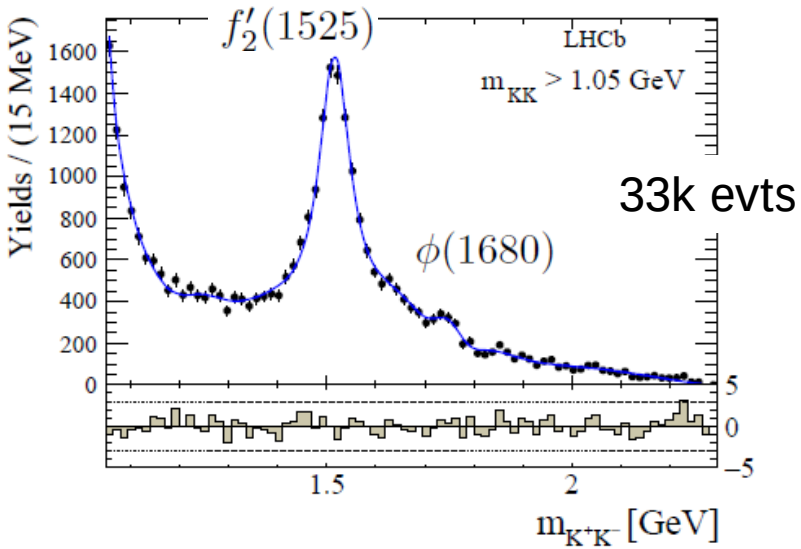
arXiv:1704.08217

m(KK) > 1.05 GeV (above ϕ)

$\phi_s = 0.12 \pm 0.11 \pm 0.03$ rad

$\Delta\Gamma = 0.066 \pm 0.018 \pm 0.019$ ps^{-1}

arXiv:1704.08217



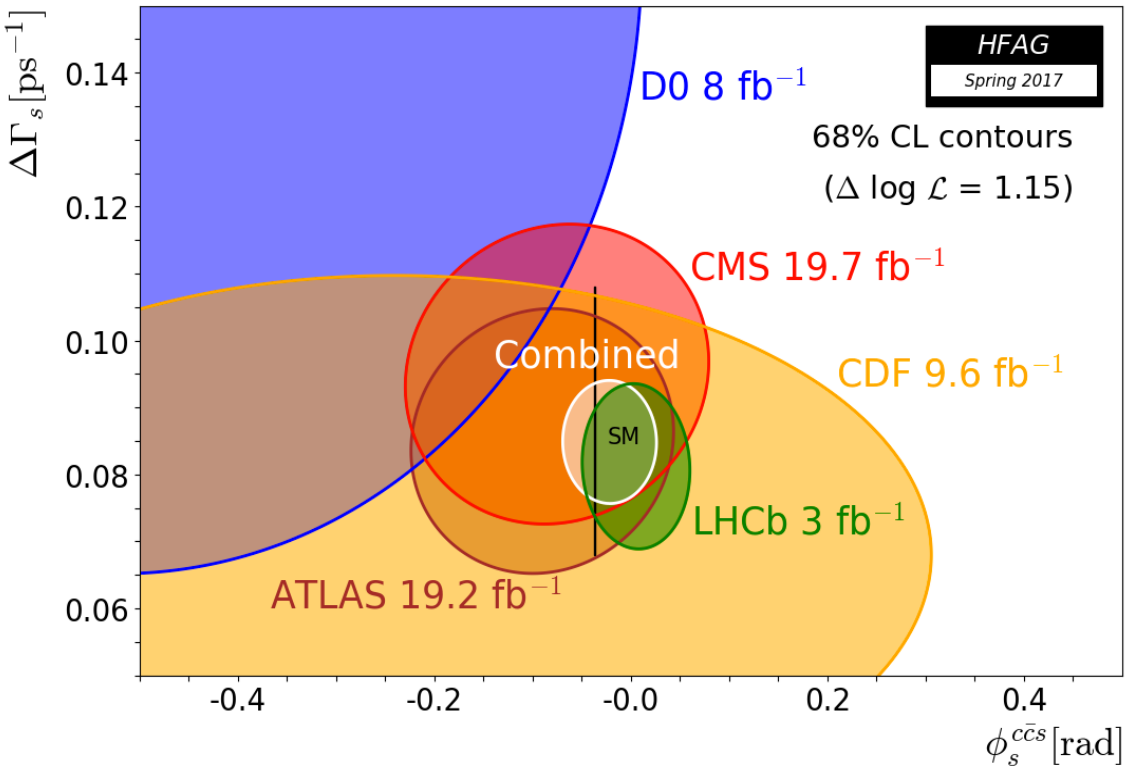
New LHCb average for ϕ_s

$\phi_s = 0.7 \pm 37.3$ mrad

(includes also $B_s \to J/\psi\pi\pi$, D_sD_s data)

Weak phase ϕ_s

ATLAS and **CMS** have also measured ϕ_s in $B_s \to J/\psi\phi$ with full Run-1 statistics.



Impressive progress since initial measurements by CDF and D0:
Uncertainty needs to be further reduced to reach SM precision.

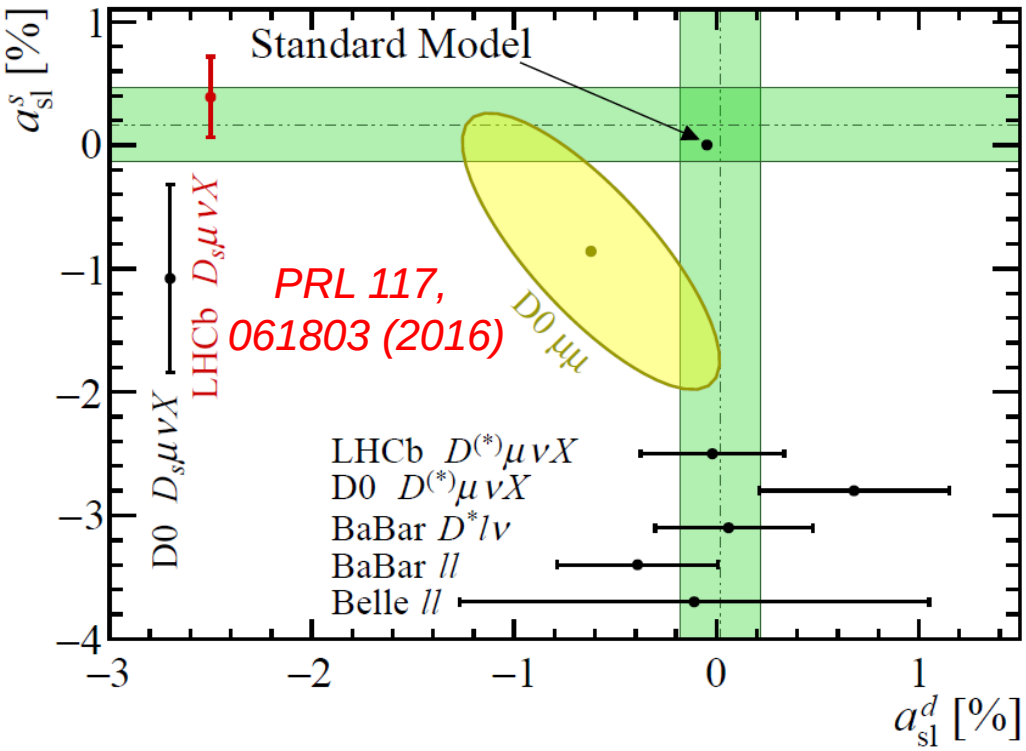
LHCb sensitivity after **upgrade** expected to be better than **3 mrad**.

CP Violation in B-mixing

$$B^0 \longrightarrow \bar{B}^0 \longrightarrow \mu^- X \quad \Big| \quad \bar{B}^0 \longrightarrow B^0 \longrightarrow \mu^+ X$$

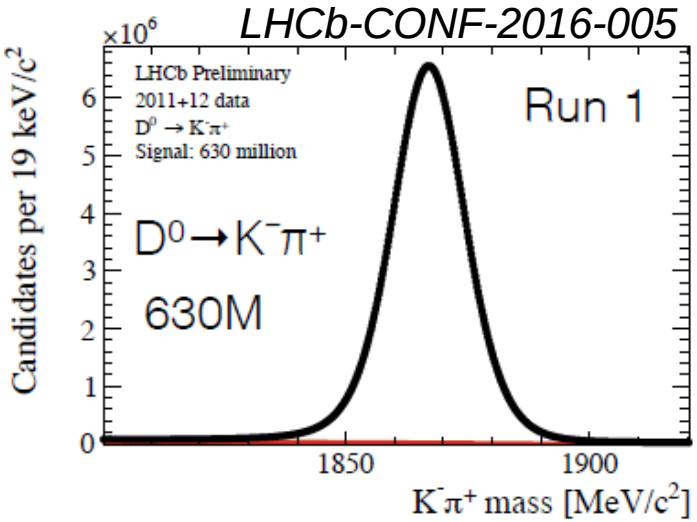
$\not{CP}$

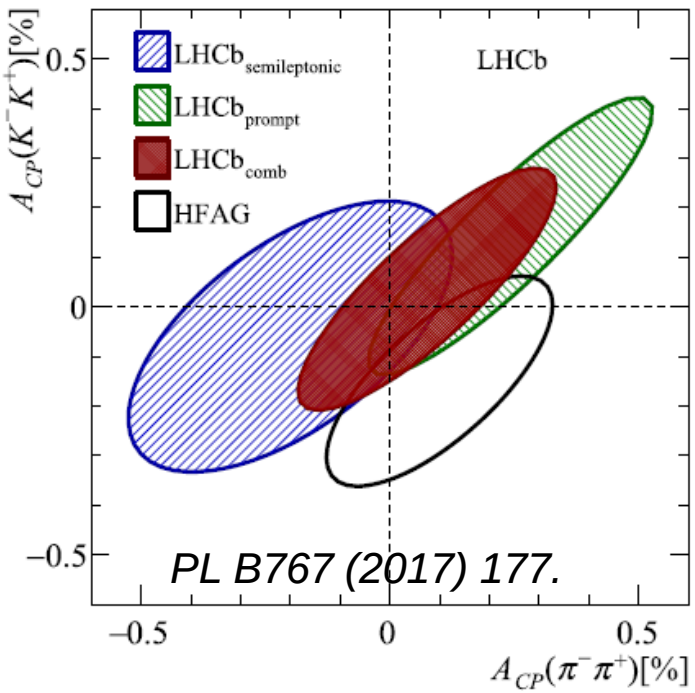
$$a^q_{sl} \equiv \frac{\Gamma(\bar{B}^0_q \to B^0_q \to \mu^+ X) - \Gamma(B^0_q \to \bar{B}^0_q \to \mu^- X)}{\Gamma(\bar{B}^0_q \to B^0_q \to \mu^+ X) + \Gamma(B^0_q \to \bar{B}^0_q \to \mu^- X)}, \quad q = d, s$$



CP Violation in Charm

LHCb-CONF-2016-005





PL B767 (2017) 177.

Direct CP violation: ΔA_{CP} ($D^0 \to h^+h^-$)

- time integrated -

$$\Delta A_{CP} = A_{CP}(KK) - A_{CP}(\pi\pi)$$

D*-tag: ΔA_{CP} = (-0.10 ± 0.08 ± 0.03) %

PRL 116, 191601 (2016)

μ-tag: ΔA_{CP} = (+0.14 ± 0.16 ± 0.08) %

JHEP 07 (2014) 041

+ Measurement of A_{CP}(KK)

LHCb combination

A_{CP} (KK) = (0.04 ± 0.12 ± 0.10) %

A_{CP} (ππ) = (0.07 ± 0.14 ± 0.11) %

PL B767 (2017) 177.

Most precise measurements from a single experiment. No evidence of CP asymmetry.

CP violation – time dependent

arXiv:1702.06490

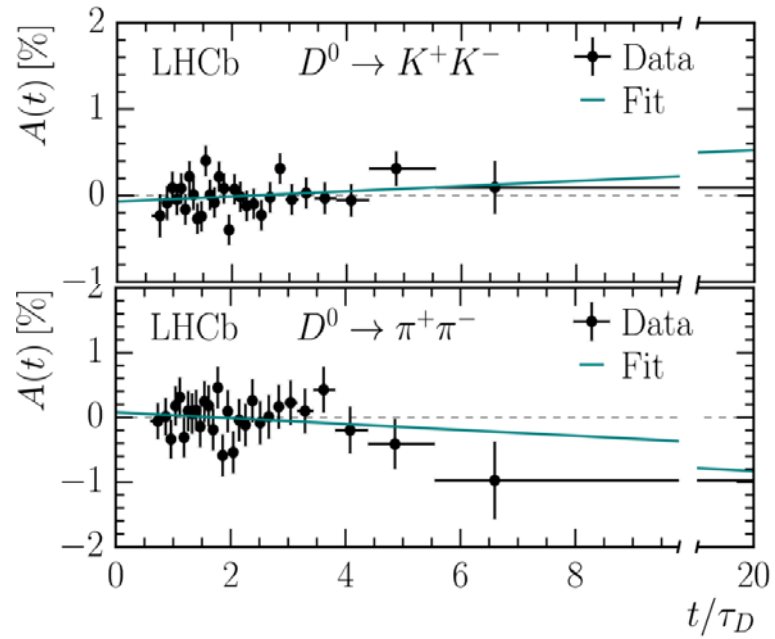
$$A_{CP}(t) \simeq a^{f}_{\rm dir} - A_{\Gamma}\frac{t}{\tau_D}$$

A_Γ (KK) = (-0.30 $\pm$ 0.32 $\pm$ 0.10) × 10^{-3}

A_Γ ($\pi\pi$) = (0.46 $\pm$ 0.58 $\pm$ 0.12) × 10^{-3}

LHCb Run-1 combination

A_Γ = (-0.29 $\pm$ 0.28) × 10^{-3}

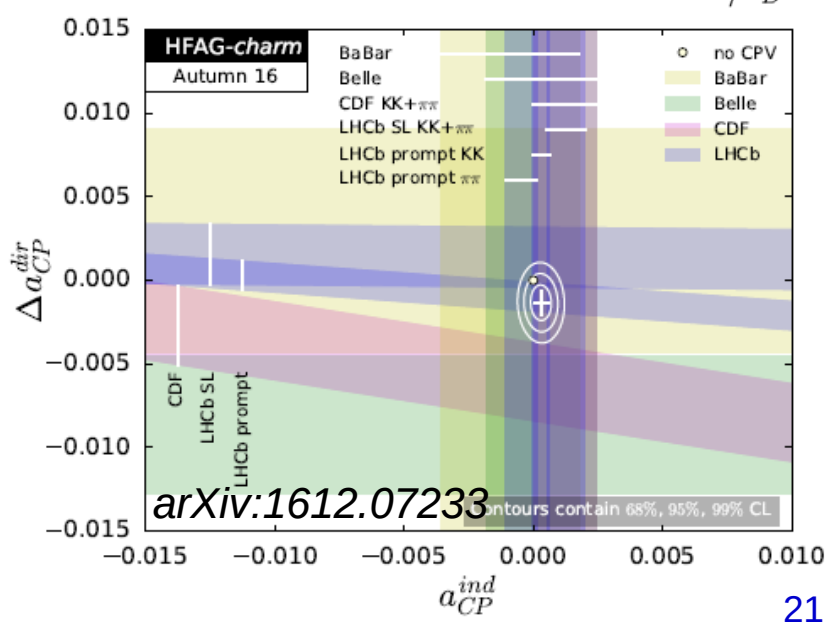


$$A_\Gamma \simeq -a^{\rm ind}_{\rm CP}$$

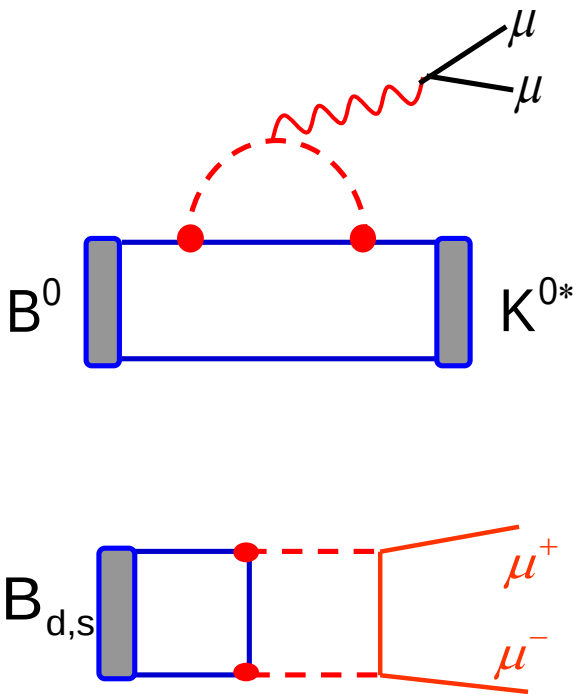
$$\Delta A_{\rm CP} \approx \Delta a^{\rm dir}_{\rm CP} + a^{\rm ind}_{\rm CP}\frac{\Delta\langle t\rangle}{\tau}$$

HFAG arXiv:1612.07233

$$A^{\rm ind}_{\rm CP} = (\ 0.30 \pm 0.26) \times 10^{-3}$$
$$\Delta A^{\rm dir}_{\rm CP} = (-1.34 \pm 0.70) \times 10^{-3}$$

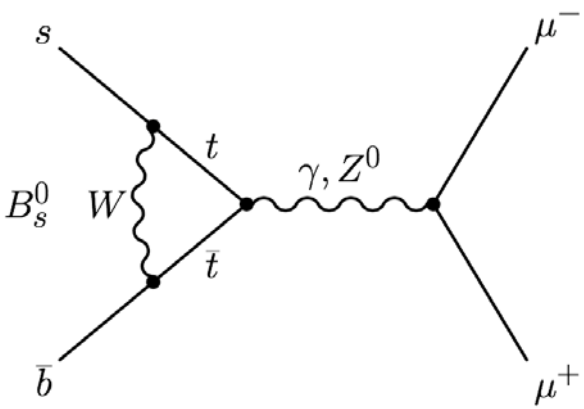


Rare (FCNC) B Decays



Very rare decays $B_{d,s}^0 \to \mu^+ \mu^-$

Standard Modell:

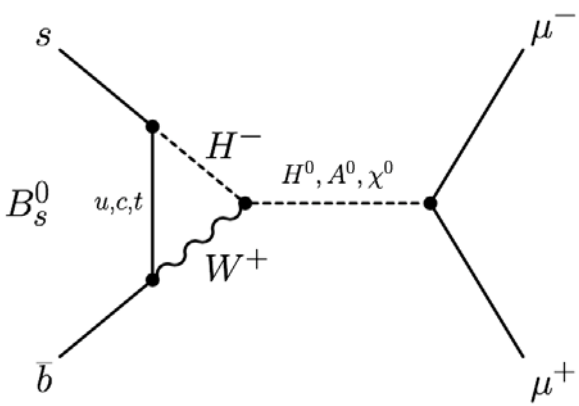


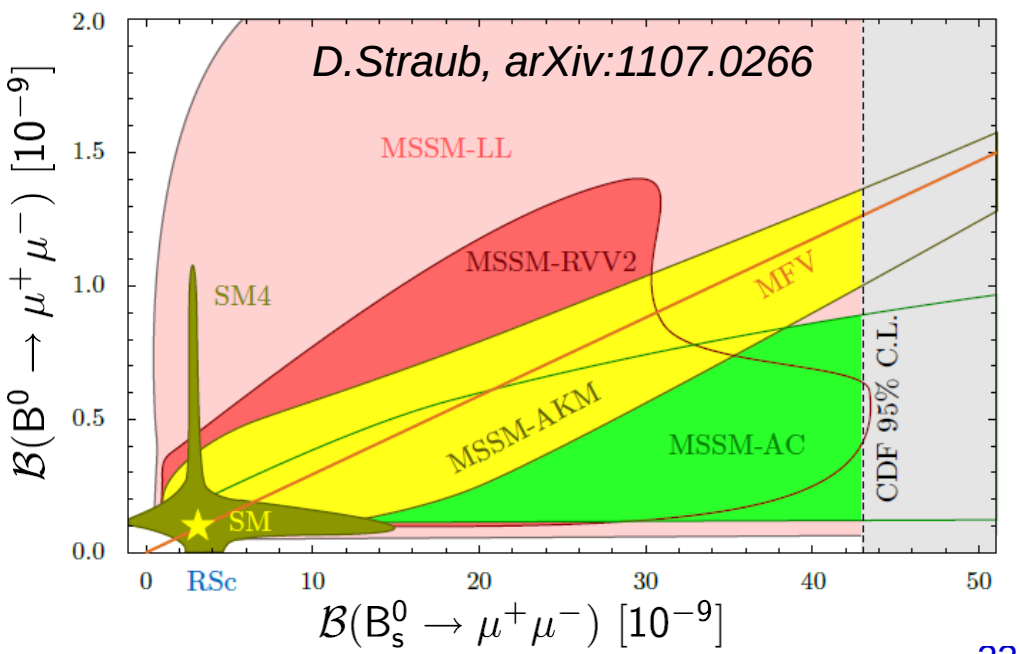
SM prediction: *PRL 112 (2014) 101801*

$BR(B_s \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$

$BR(B_d \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$

Sensitive for *New Physics:*
(pseudo) scalar interactions





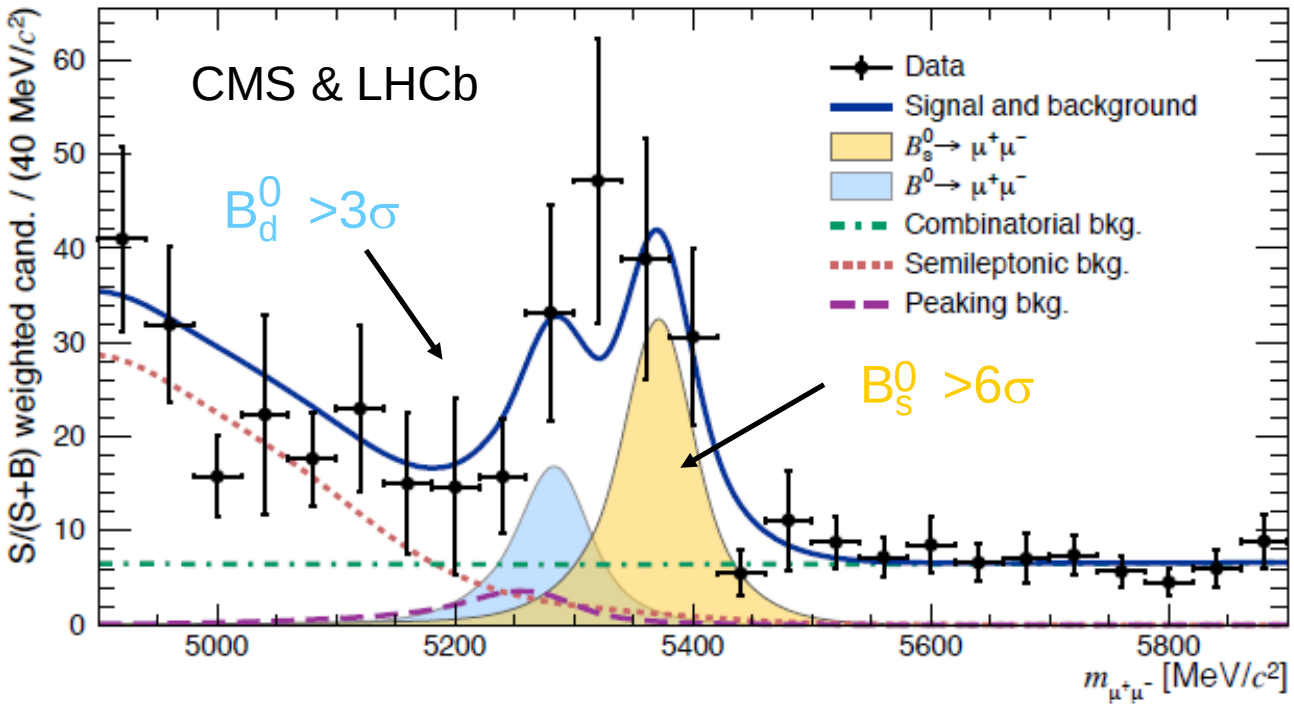
Combined CMS & LHCb Analysis

Nature, 522, 68-72 (2015)
arXiv:1411.4413

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.8\,^{+0.7}_{-0.6}) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.9\,^{+1.6}_{-1.4}) \times 10^{-10}$$

also:

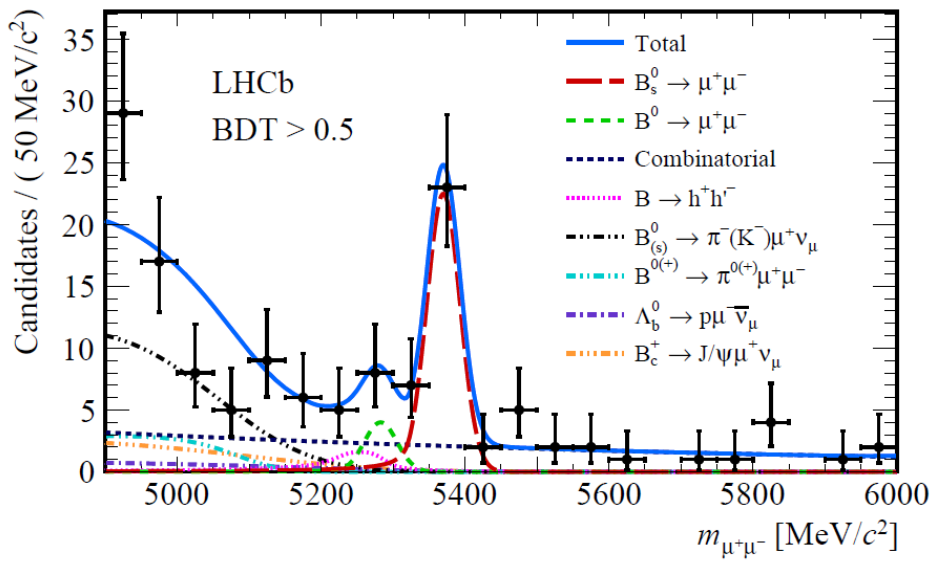
Interesting sociological experiment



LHCb $B_{s,d} \to \mu\mu$ update

arXiv:1703.05747

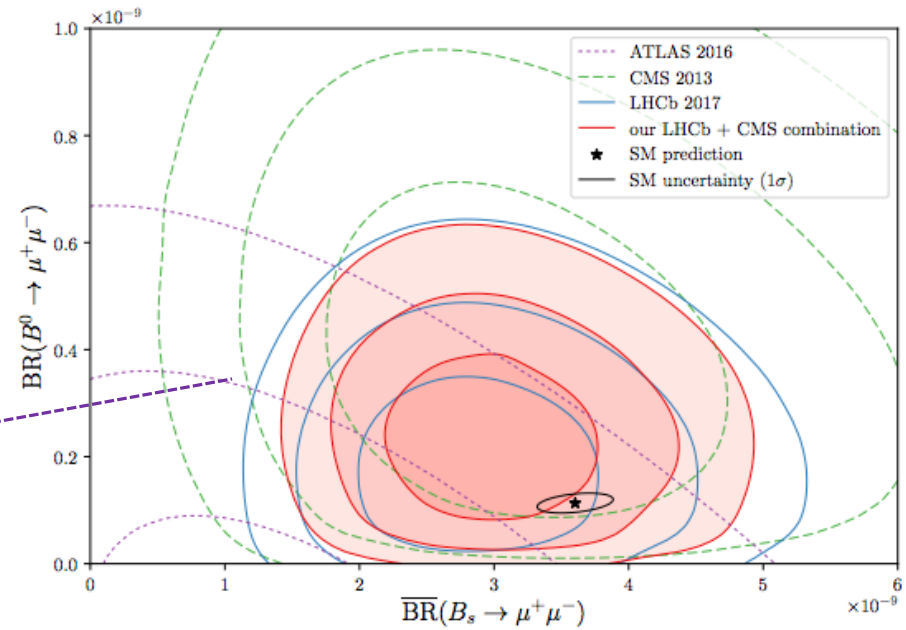
- Include 1.4 fb^{-1} from Run-2: effectively doubles the dataset.
- Refined analysis: better background rejection



7.8σ observation of $B_s \to \mu\mu$:
$BR(B_s \to \mu\mu) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$

No evidence yet for $B_d \to \mu\mu$:
$BR(B_d \to \mu\mu) < 3.4 \times 10^{-10}$ (95%CL)

arXiv:1703.05747



Measurement from ATLAS

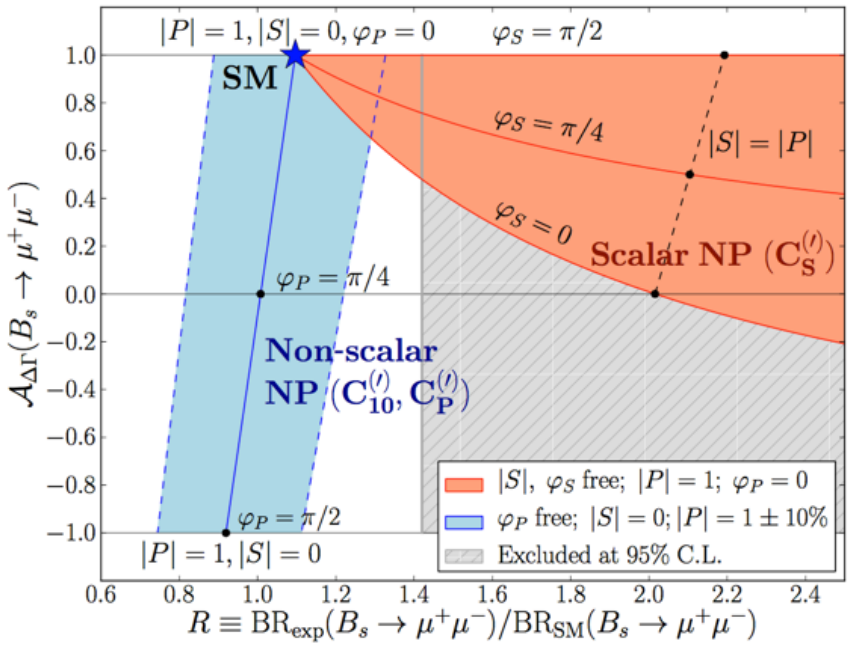
$BR(B_s \to \mu\mu) = (0.9^{+1.1}_{-0.8}) \times 10^{-9}$
$BR(B_d \to \mu\mu) < 4.2 \times 10^{-10}$ @95%C.L.

EPJ C76, 513 (2016)

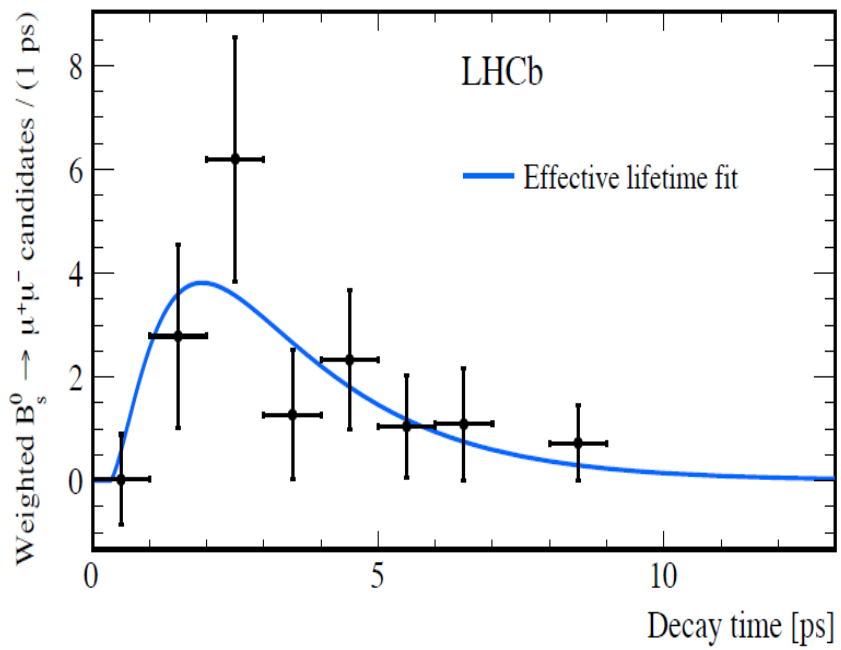
Measurement of effective lifetime

Effective lifetime sensitive to scalar vs non-scalar *New Physics* contributions.

PRL 109 041801 (2012)



arXiv:1703.05747

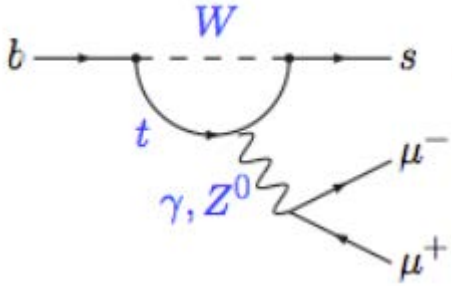


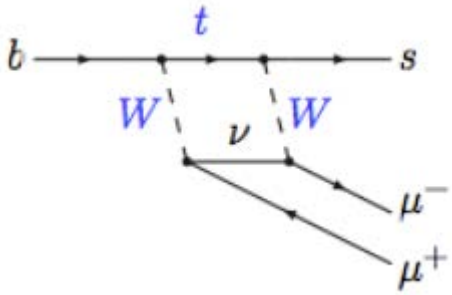
$\mathcal{A}_{\Delta\Gamma}$ depends on effective lifetime $\tau_{\mu\mu}$

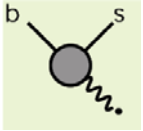
$$\tau(B_s^0 \to \mu^+\mu^-) = 2.04 \pm 0.44_{(\mathrm{stat})} \pm 0.05_{(\mathrm{syst})}\ \mathrm{ps}$$

b → s penguins: B→K*$\ell^+\ell^-$ and friends

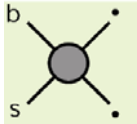
Standard Model:





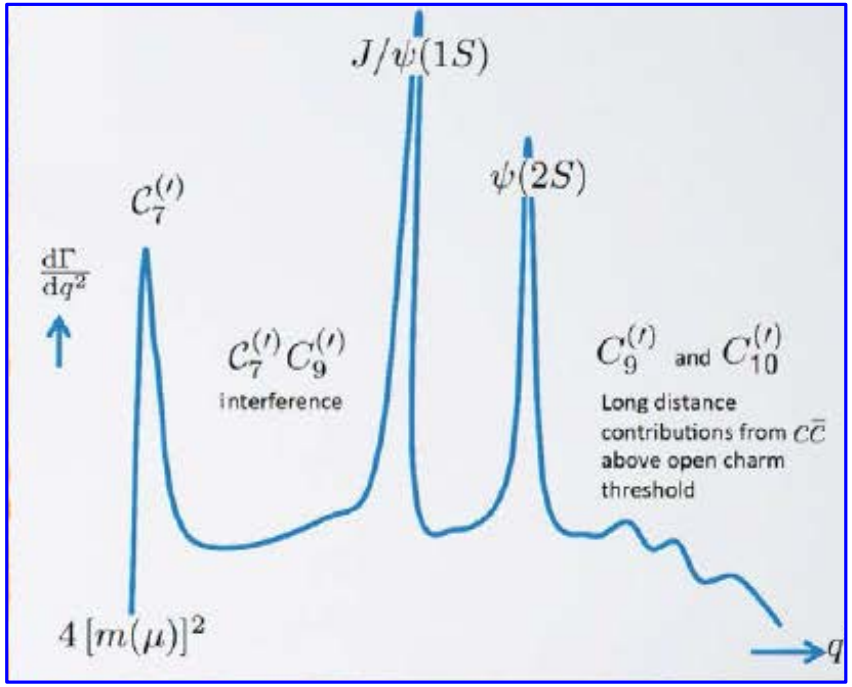


O_7



O_9 O_{10}

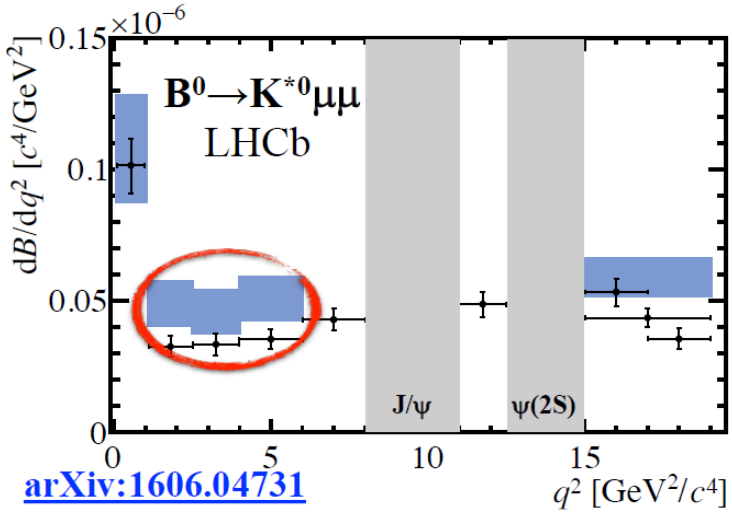
$$H = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum (C_i^{SM} + C_i^{NP}) O_i^{SM} + \sum \frac{c}{\Lambda_{NP}} \; O_{NP}$$



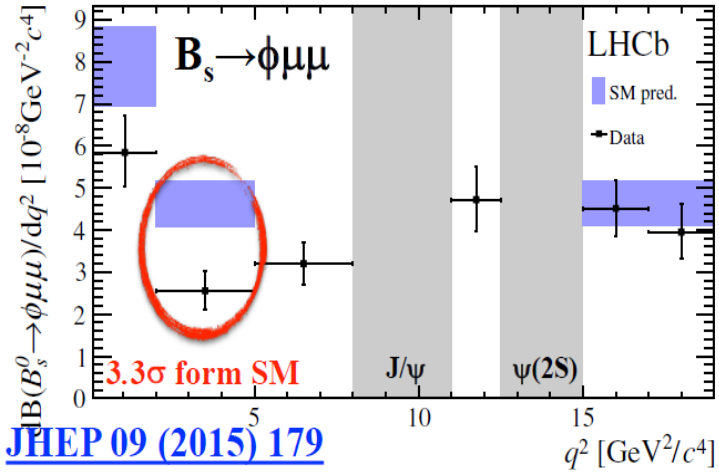
Different q^2 probes different processes

New Physics: New operators (Lorentz structure / μμ/ee coupl), modified Wilson coeff.
Observables: differential BR, angular distributions or lepton flavor violation

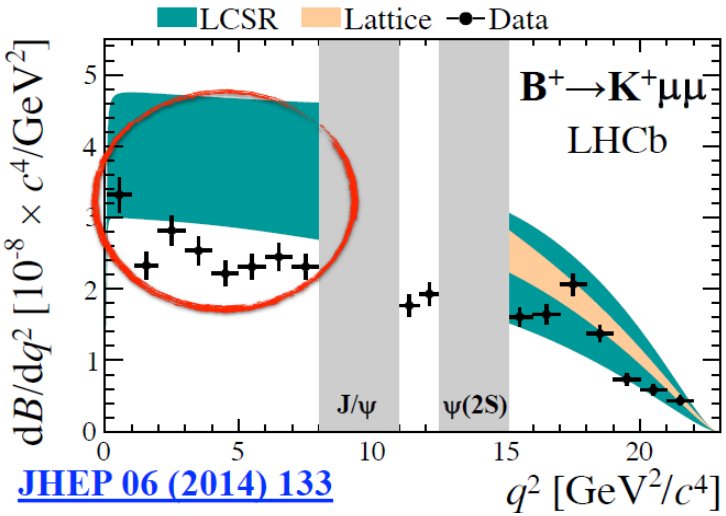
$B \to K^* \ell^+ \ell^-$ and friends: differential BR



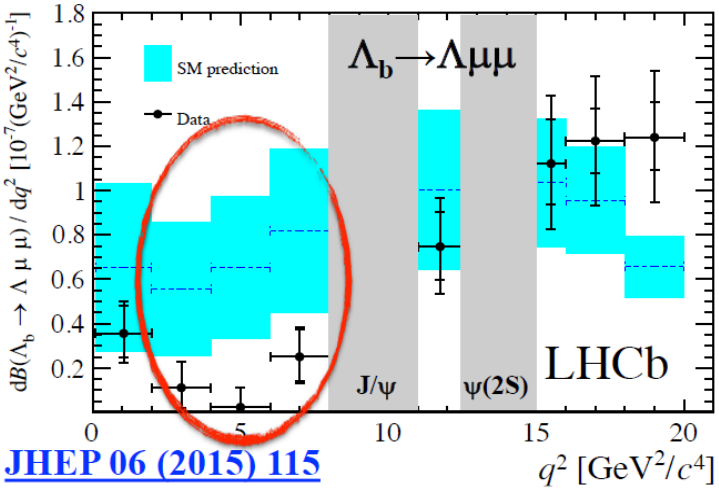
arXiv:1606.04731



JHEP 09 (2015) 179



JHEP 06 (2014) 133



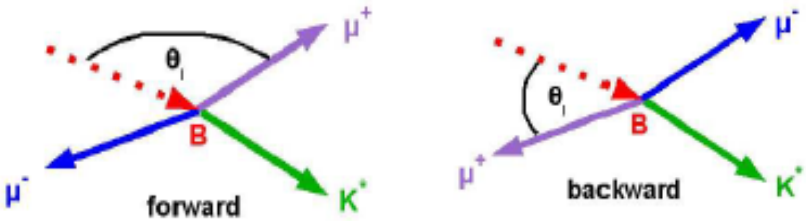
JHEP 06 (2015) 115

Consistent tendency to undershoot prediction at low q^2. Intriguing!

$B \to K^* \ell^+ \ell^-$ and friends: angular analysis

"Wu-Experiment" with B-mesons

Forward-backward asymmetry



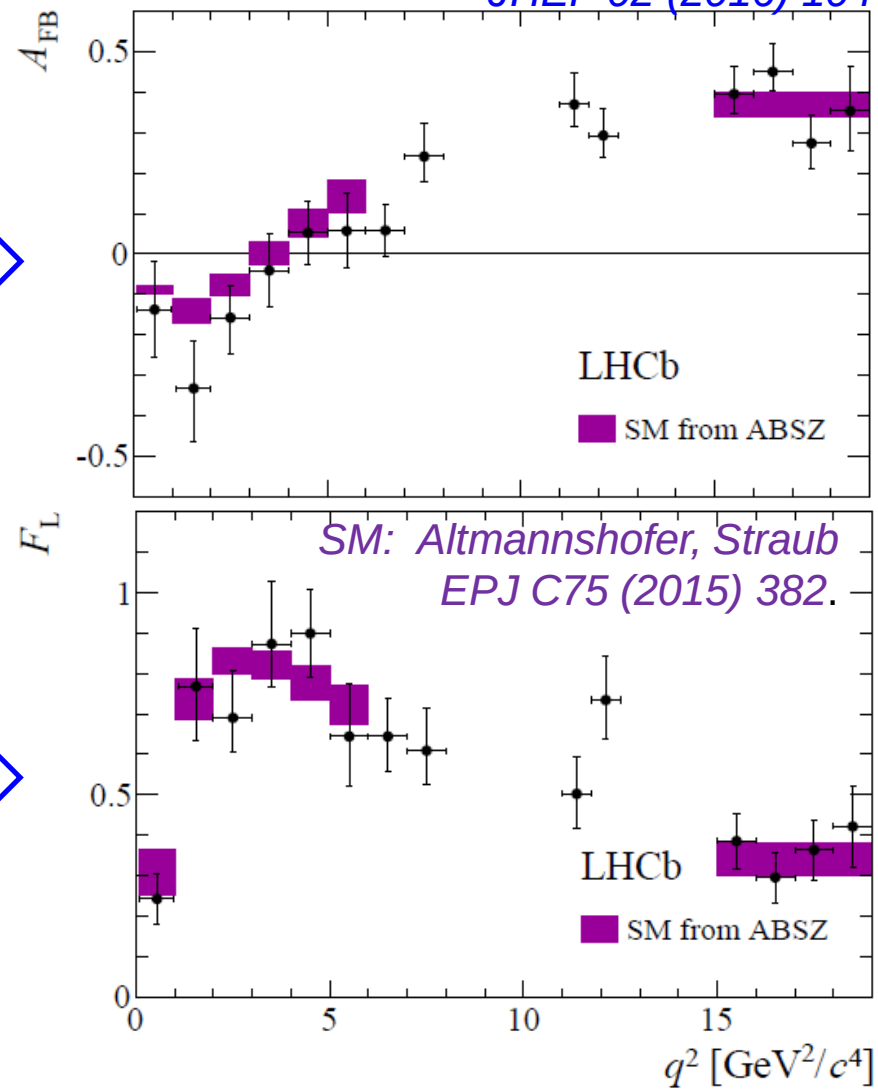
$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

K* longitudinal polarization

General pattern as predicted,
mild tension (e.g. A_{FB}) at low q^2

… other observables, which can be built from the measured amplitudes

JHEP 02 (2016) 104



SM: Altmannshofer, Straub EPJ C75 (2015) 382.

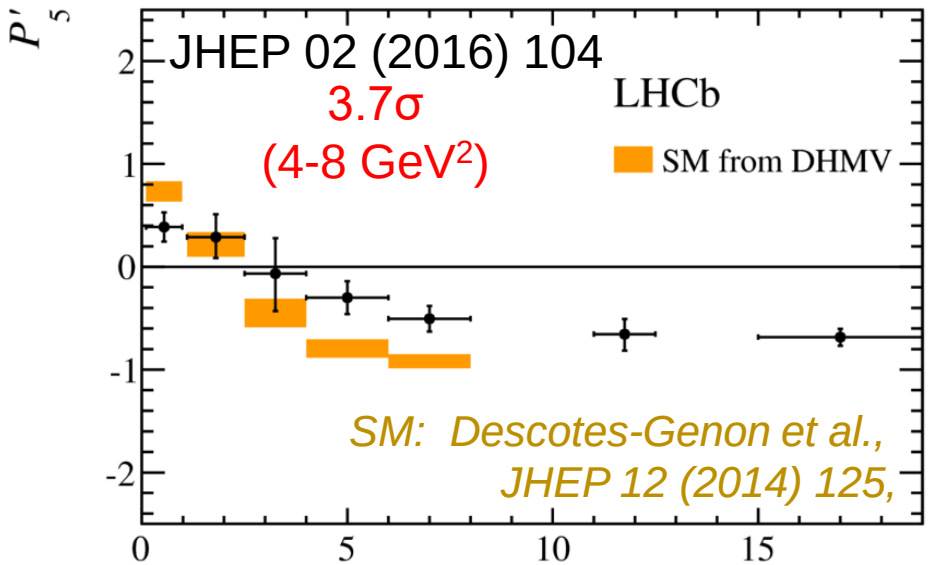
$B \to K^* \ell^+ \ell^-$ and friends: angular analysis

Constructed to be intrinsically robust against form factor uncertainties,

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

(physically hard to visualize)

Effect seen with 1 fb^{-1}, persists with 3 fb^{-1}

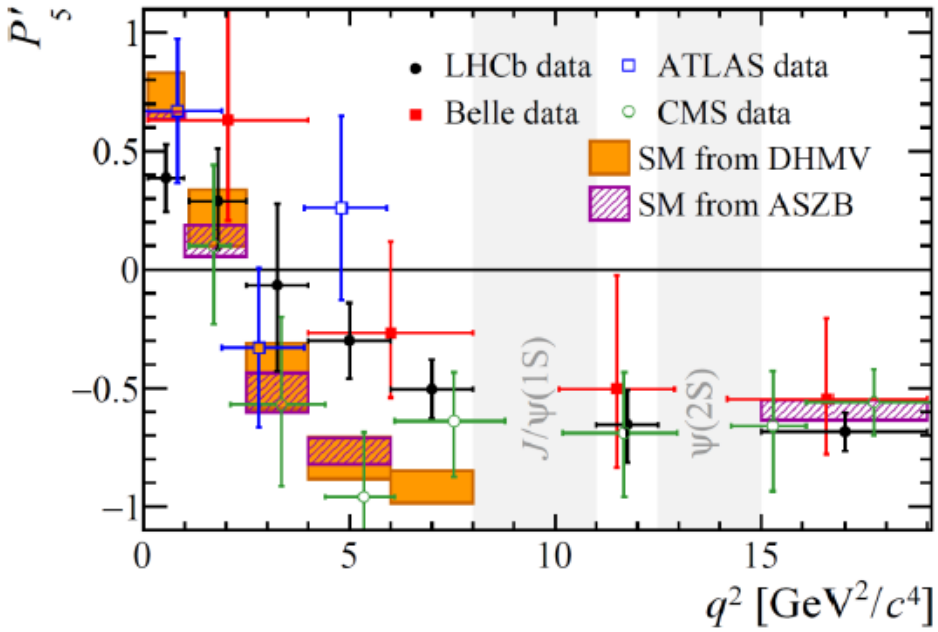


Results encouraged the B-factories to dig deep into their data…

Belle, arXiv:1604.0402

… and als ATLAS and CMS presented measurements at Moriond 2017 (Run 1)

ATLAS-CONF-2017-023
CMS-PAS-BPH-15-007



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

Observed tensions w/ μμ final state.
Do electrons behave the same way?

Very clean observable:
Test of lepton universality in R_K

$$R_K = \frac{\mathcal{B}(B^\pm \to K^\pm \mu\mu)}{\mathcal{B}(B^\pm \to K^\pm ee)} \overset{\text{SM}}{=} 1$$

(measured as double ratio, relative to $B \to KJ/\psi(ll)$)

LHCb measurement for $1<q^2<6$ GeV^2

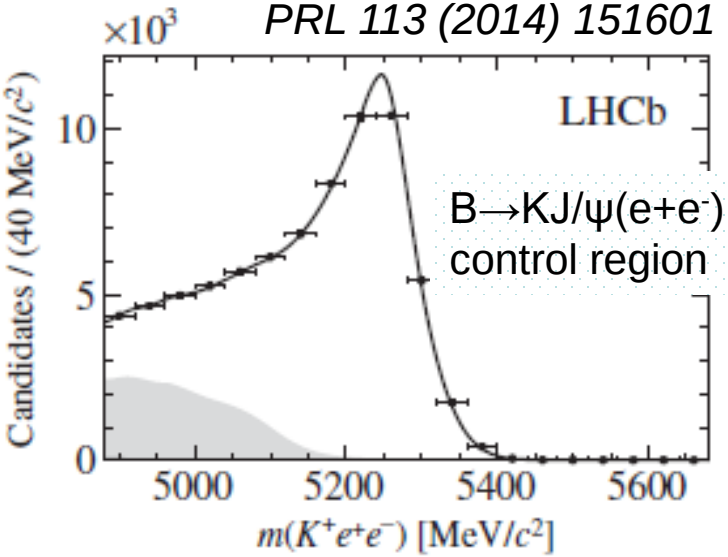
$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

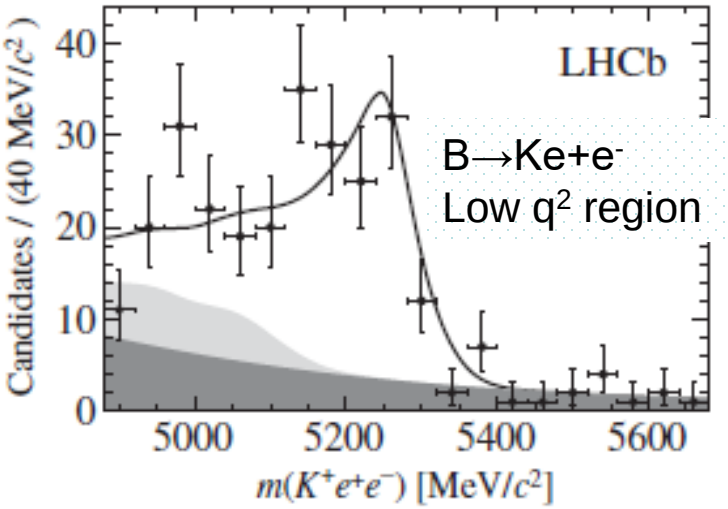
-2.6σ w/r to SM *PRL 113 (2014) 151601*

Statistical fluctuation? What about R_{K^*} ?

Electrons are a bit more difficult…

PRL 113 (2014) 151601





Measurement of R_{K^*}

(in preparation)
LHCb-PAPER-2017-013

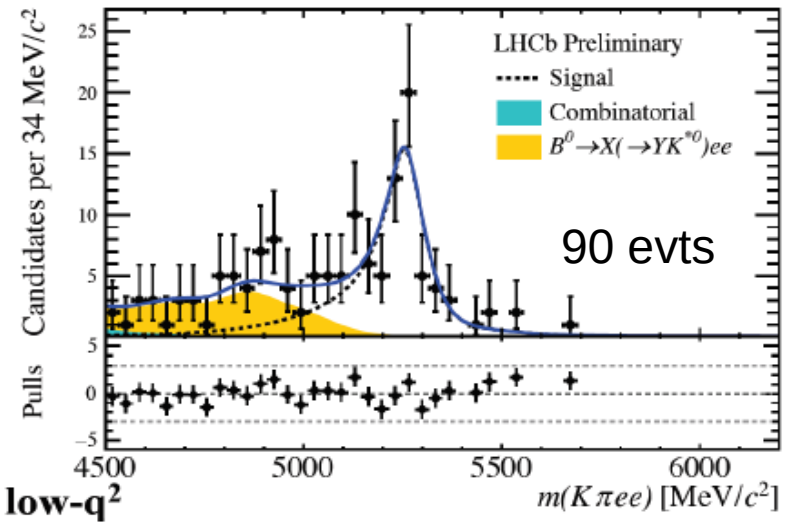
- Analogous measurement for $B \to K^* \ell^+ \ell^-$

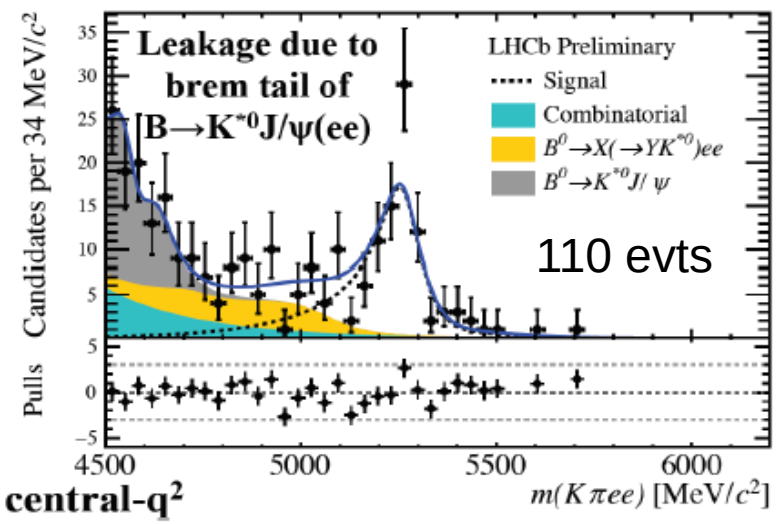
$$R_{K^*} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu\mu)}{\mathcal{B}(B^0 \to K^{*0}ee)}$$

- Again measured as double ratio normalized to $B^0 \to K^* J/\psi(\mu\mu, ee)$
- 3 exclusive triggers for K*ee: On electron, On K*, Not On signal
- Simulation corrected w/ efficiencies (PID, trigger) determined on data,
- *Cross-check:* $B(B^0 \to K^* J/\psi)$ is measured for muon and electron channel – a stringent test !

$$r_{J/\psi} = 1.043 \pm 0.006\,(\text{stat}) \pm 0.045\,(\text{syst})$$

- Analysis performed in two q^2 bins
  - Low: $4m_\mu^2 < q^2 < 1.1\ \text{GeV}^2$
  - Central: $1.1\ \text{GeV}^2\ q^2 < 6\ \text{GeV}^2$



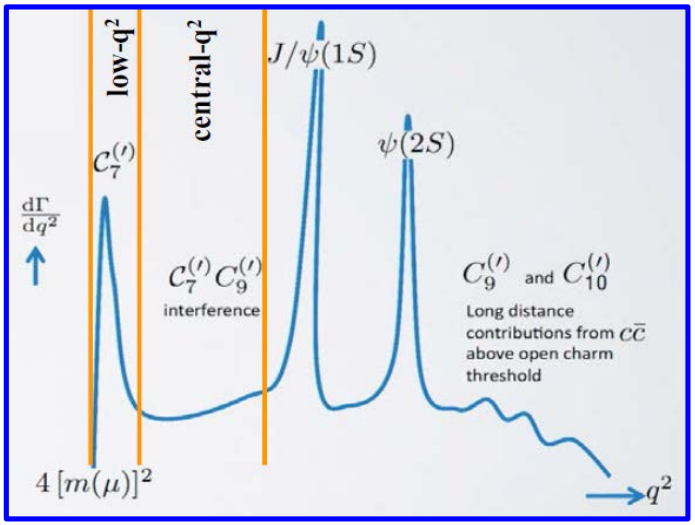


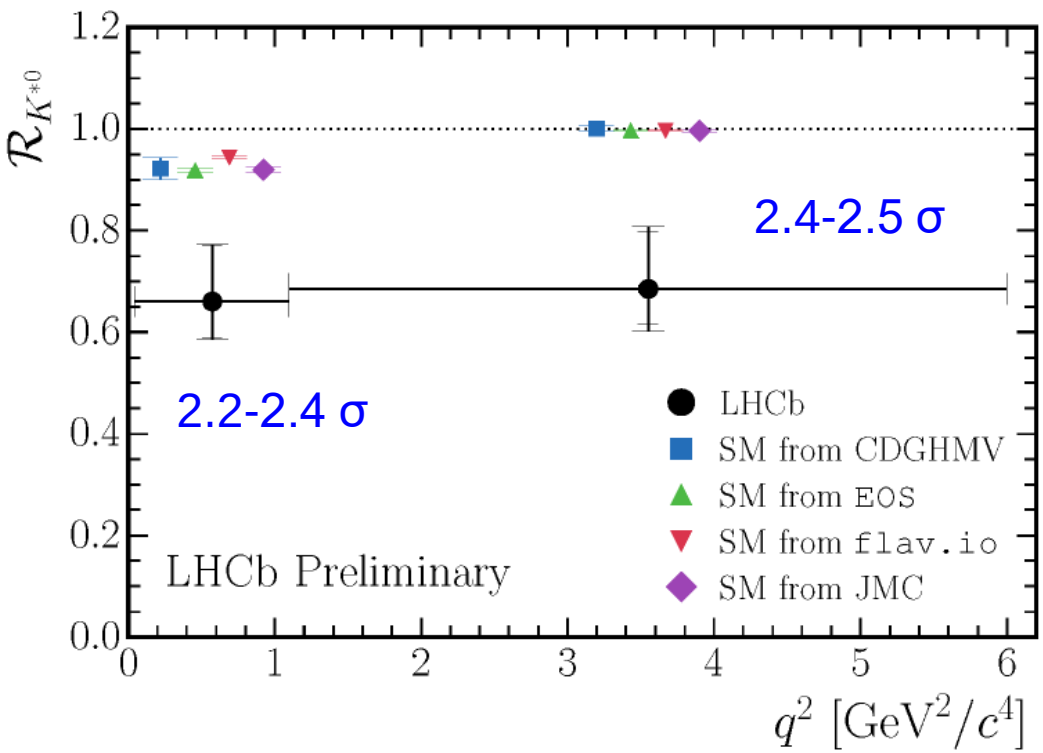
Muon sample 3-5x larger

R_{K^*} Results

(in preparation)
LHCb-PAPER-2017-013

LHCb Preliminary	low-q^2	central-q^2
$\mathcal{R}_{K^{*0}}$	$0.660\,^{+\,0.110}_{-\,0.070} \pm 0.024$	$0.685\,^{+\,0.113}_{-\,0.069} \pm 0.047$
95% CL	[0.517–0.891]	[0.530–0.935]
99.7% CL	[0.454–1.042]	[0.462–1.100]





Systematics:

- correction of simulation
- Kinematic selection
- Residual background due to $B^0 \to K^* J/\psi$

6.5…7.5% for central q^2

(depending on trigger sample)

$B \to K^* \ell^+ \ell^-$ and friends: Interpretation?

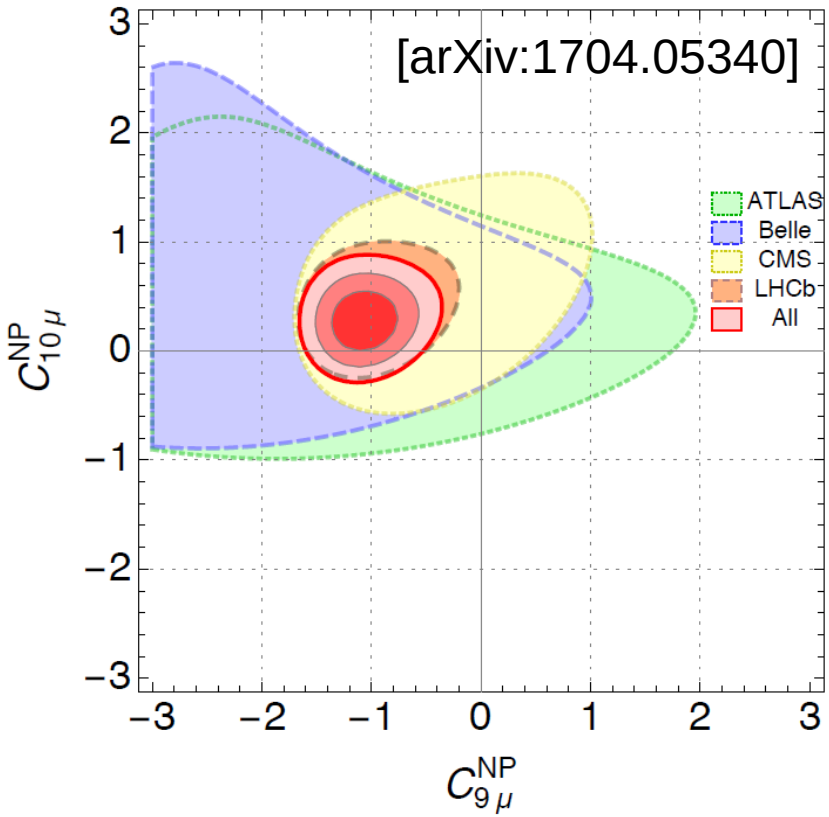
Before the measurements of R_{K^*}:

- Fits give >5σ pulls w.r.t. SM
- allowing for non-SM Wilson coefficients (C_9) improves the p-value of the fits.

New R_{K^*} measurement:

- Fits into this picture (certainly for the central q^2 binTriggered a several papers.

Example: arXiv:1704.05340



Situation intriguing - more work needed:

<u>Theory:</u> Theoretical error of some observables.

<u>Experiment:</u> LHCb Run-2 updates on R_K, R_{K^*} and even R_φ

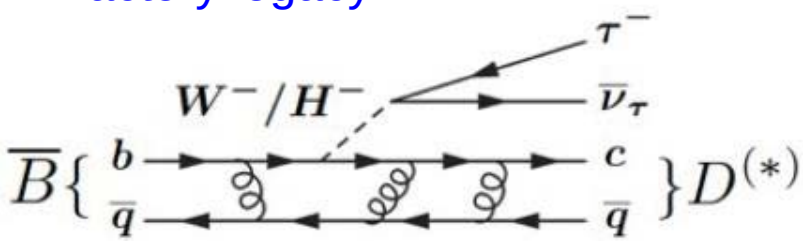
Other Hints for LFV

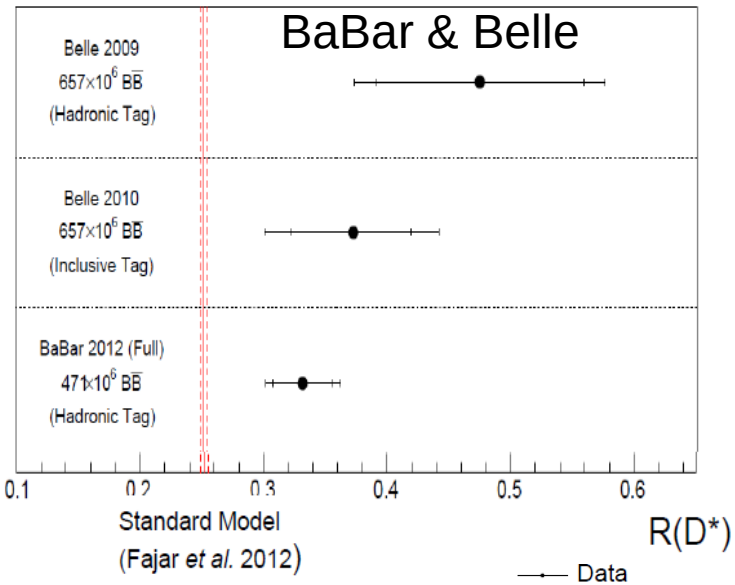
PRL 115 (2015) 111803

$$R(D^*) \equiv \mathcal{B}(B \to D^* \tau \nu) \,/\, \mathcal{B}(B \to D^* \mu \nu)$$

$B \to D^* \tau \nu$:

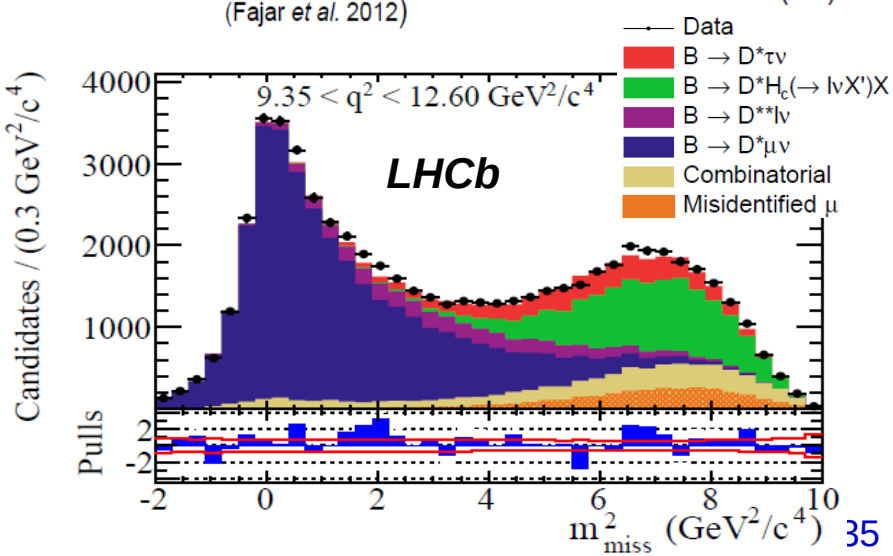
- Tree decay, not rare, only difficult
- sensitivity to possible charged Higgs
- *B*-factory legacy





Was thought to be impossible at LHCb (cannot reconstructing full event):

- Reconstruct $\tau \to \mu\nu\nu$
- disentangle signal from $B^0 \to D^* \mu \nu$ and other backgrounds by fitting E_μ^* and $m^*_{miss}{}^2$ (rest frame of B) in bins of q^2



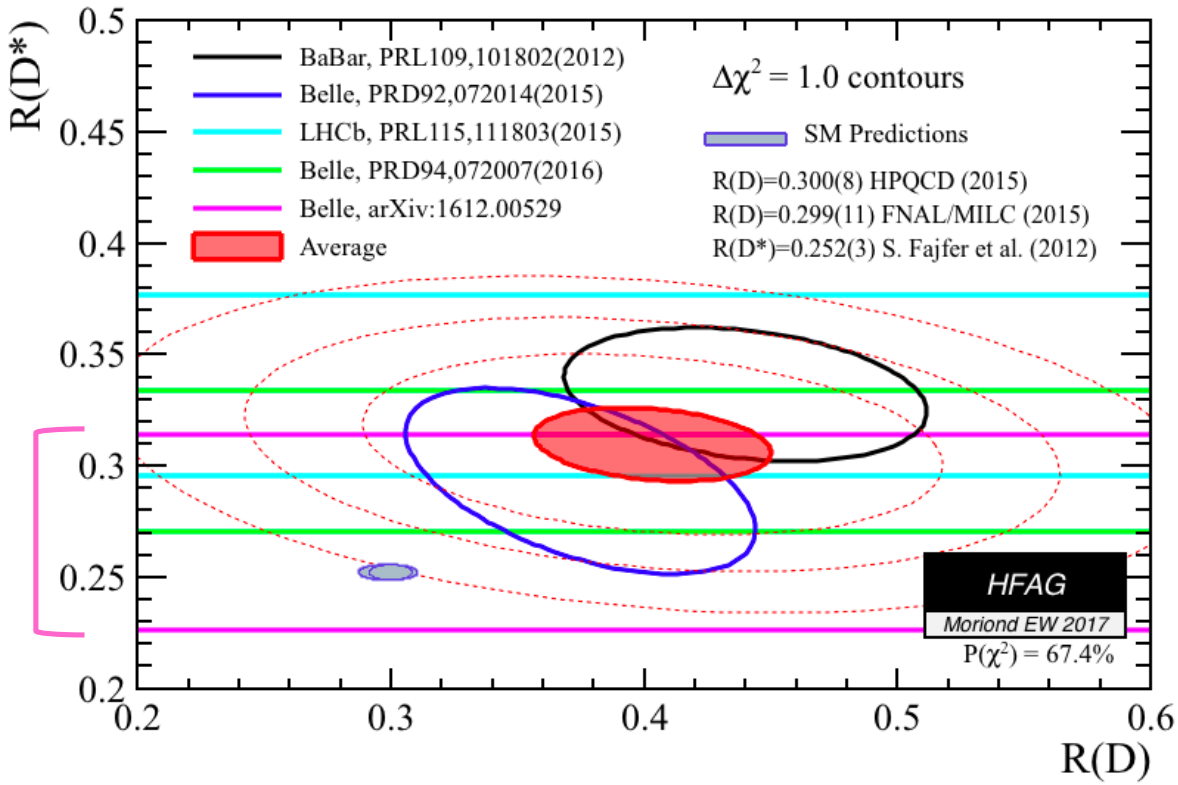
$R(D^*) \equiv \mathcal{B}(B \to D^* \tau \nu) / \mathcal{B}(B \to D^* \mu \nu)$

PRL 115 (2015) 111803

+2.1σ above SM

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

Systematics dominated by model uncertainties.



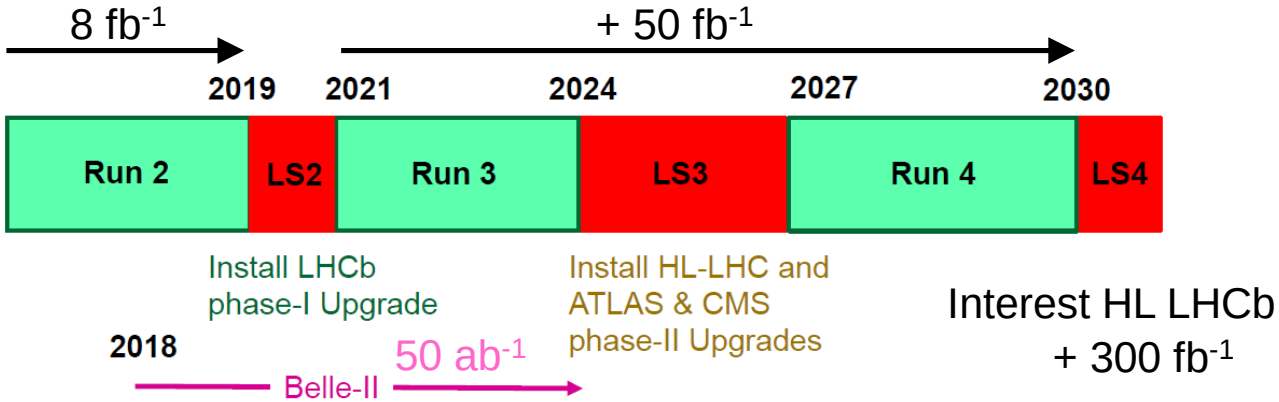
Belle 2016

LHCb

- New HFAG average 3.9σ away from SM prediction (0.252±0.003).
- New measurements including *R(D*)* w/ *τ→πππν* will come soon

At the End

- Precision flavor physics is an excellent tool to search for effects *of New Physics* beyond the TeV scale.
- Flavour-physics measurements at the LHC are adding to the impressive knowledge from the B-factories and Tevatron.
- Many of these results show good compatibility with the SM (for now), some signs of tension (LFV) are emerging.
- LHCb's physics program beyond flavour physics: EW precision measurements, direct NP searches, forward physics, fixed target physics, heavy ion physics
- Future:



Interest HL LHCb
+ 300 fb^{-1}

Supported by

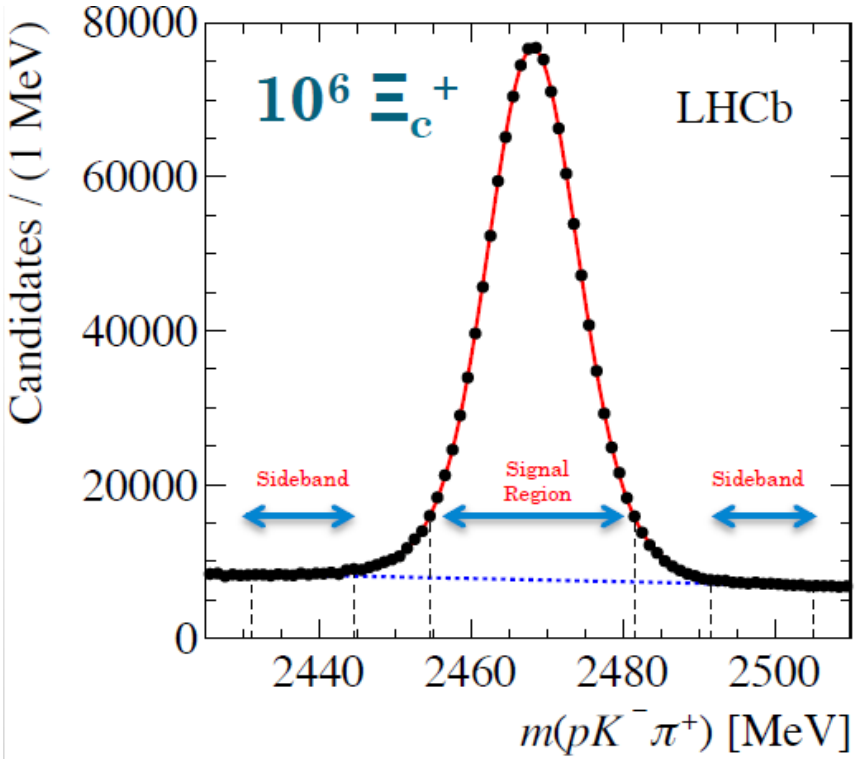
Bundesministerium für Bildung und Forschung

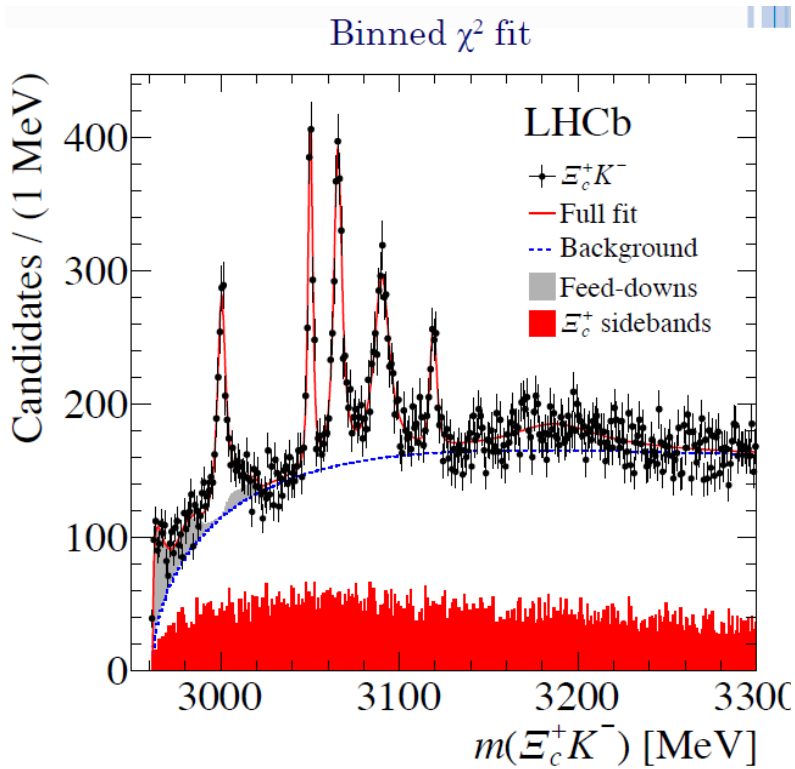
Backup

Spectroscopy: New Ω_c states

arXiv:1703.04639

Ξ_c^+ candidates are combined to kaons with opposite charge
(tight PID requirement and $p_T(\Xi_c^+K^-) > 4.5$ GeV)





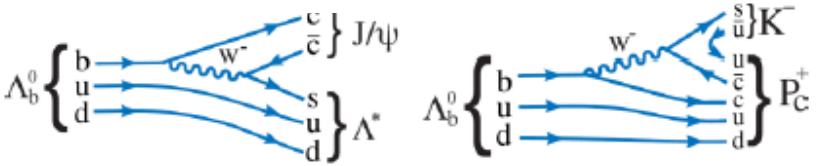
Spectroscopy: New Ω_c states

arXiv:1703.04639

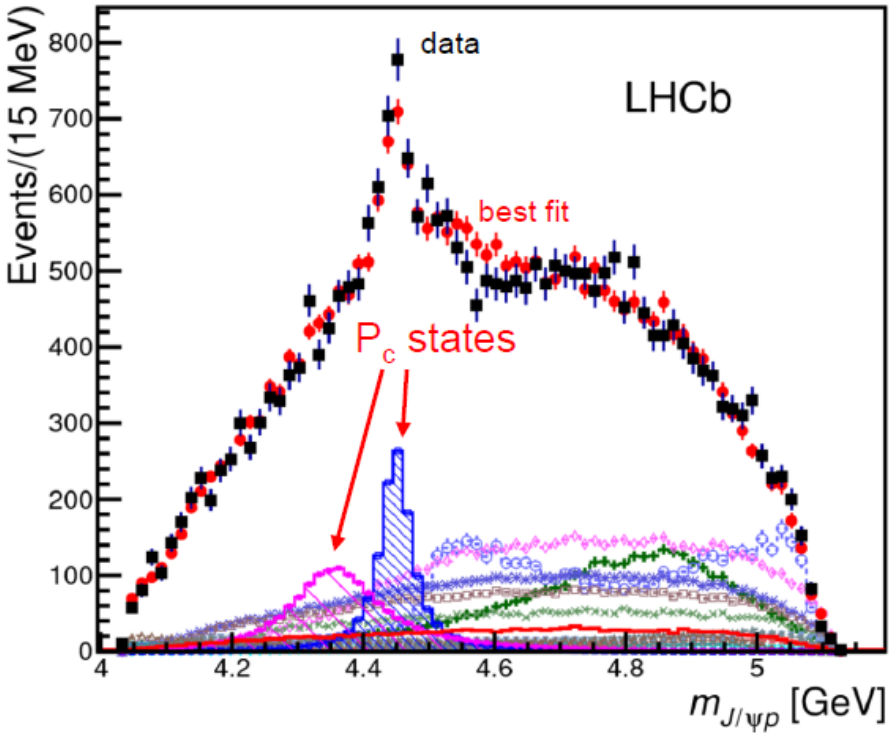
Resonance	Mass (MeV)	Γ (MeV)	Yield	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	$1300 \pm 100 \pm 80$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$	$970 \pm 60 \pm 20$	20.4
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	$1740 \pm 100 \pm 50$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	$2000 \pm 140 \pm 130$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$	$480 \pm 70 \pm 30$	10.4
		$< 2.6\,\mathrm{MeV}, 95\%$ CL		
$\Omega_c(3188)^0$	$3188 \pm 5 \pm 13$	$60 \pm 15 \pm 11$	$1670 \pm 450 \pm 360$	
$\Omega_c(3066)^0_{\mathrm{fd}}$			$700 \pm 40 \pm 140$	
$\Omega_c(3090)^0_{\mathrm{fd}}$			$220 \pm 60 \pm 90$	
$\Omega_c(3119)^0_{\mathrm{fd}}$			$190 \pm 70 \pm 20$	

J/Ψp resonances - pentaquark states

PRL 115 (2015) 072001



Need to add two states with content uudccbar.
Best fit has J=3/2 and 5/2 with opposite parities.



$P_c(4380)$:

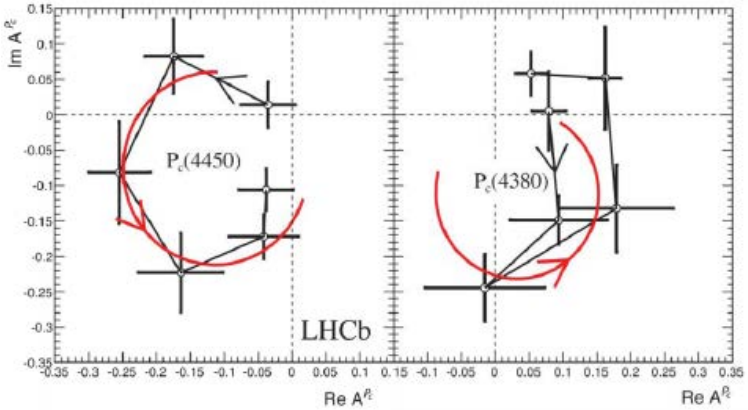
$M = 4380 \pm 8 \pm 29\,\mathrm{MeV}$,

$\Gamma = 205 \pm 18 \pm 86\,\mathrm{MeV}$

$P_c(4450)$:

$M = 4449.8 \pm 1.7 \pm 2.5\,\mathrm{MeV}$

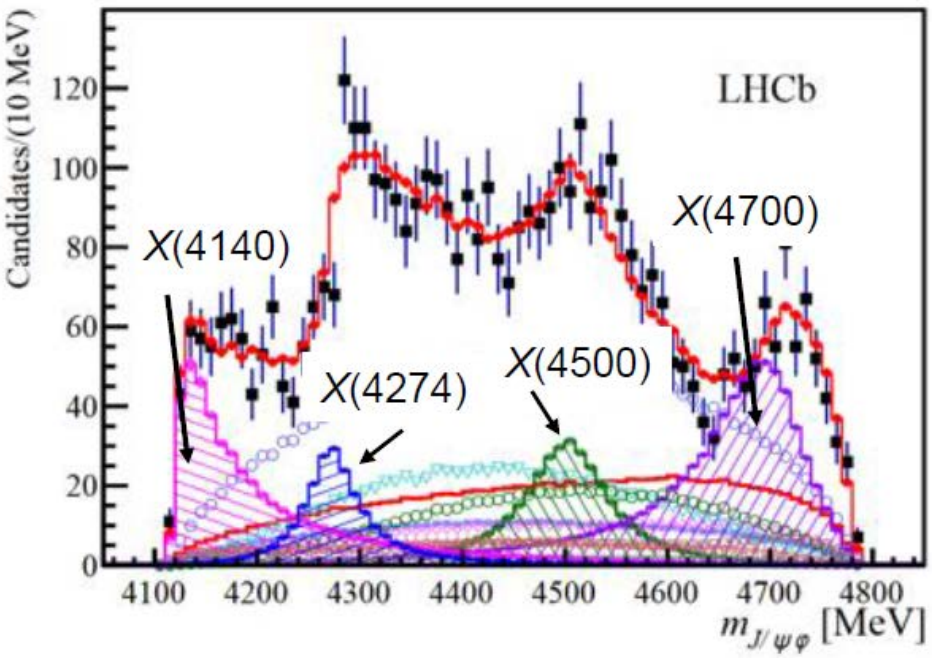
$\Gamma = 39 \pm 5 \pm 19\,\mathrm{MeV}$



Four-quark exotics: J/ψΦ-structures

arXiv:1606.07895
arXiv:1606.07898

Long standing interest in J/*ψΦ* spectrum in $B^+ \to J/\psi \Phi K^+$, where CDF saw a narrow structure [PRL 102 (2009) 242002] dubbed the *X*(4140). Confirmed by D0 [PRD 89 (2014) 012004] & CMS [PRL B 734 (2014) 261] , but not by LHCb in early 0.37 fb^{-1} analysis [PRD 85 (2012) 091103(R)].



A good description of spectrum requires four (!) non-standard contributions, all of which are present at >5σlevel.
X(4140) found to have larger width than previous analyses, and its quantum numbers are found to be 1^{++}.
This structure can also be described by a below threshold D_sD_s*cusp.

SEARCH FOR X(5568)±

PRL 117 (2016) 152003

Claimed observation/evidence of an exotic state ($\bar{b}s\bar{u}d$) by DØ collaboration

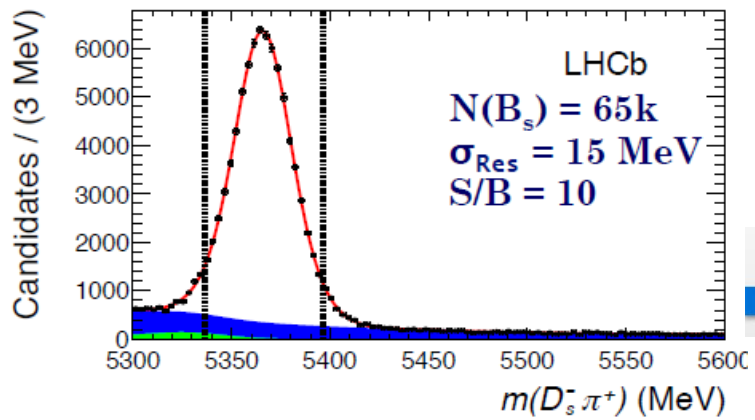
✓ $X(5568)^{\pm} \to B_s^0\pi^{\pm}$, $B_s^0 \to J/\psi\,\phi$, $J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$

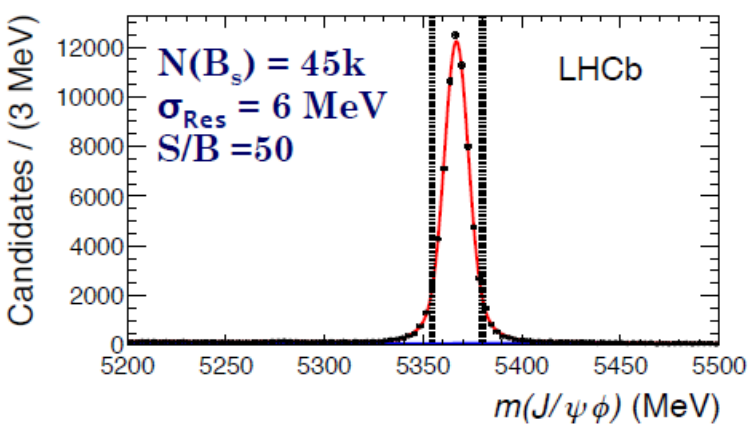
$$M = 5567.8 \pm 2.9^{+0.9}_{-1.9}\ \mathrm{MeV}/c^2$$

N.B. $m(\Xi_b) \sim 5790$ MeV

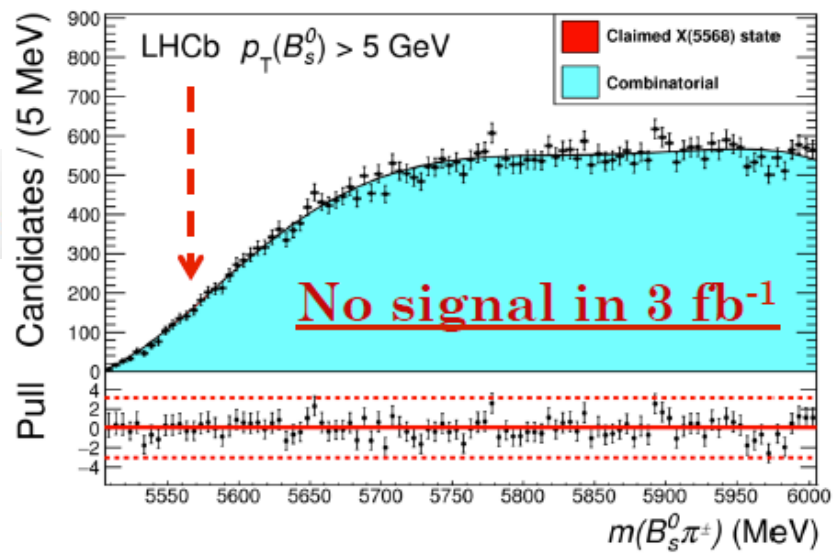
$$\Gamma = 21.9 \pm 6.4^{+5.0}_{-2.5}\ \mathrm{MeV}/c^2$$

✓ Fraction of B_s^0 from $X^{\pm}$ decay: $\rho_X^{D\emptyset} = (8.6 \pm 1.9 \pm 1.4)\ \%$



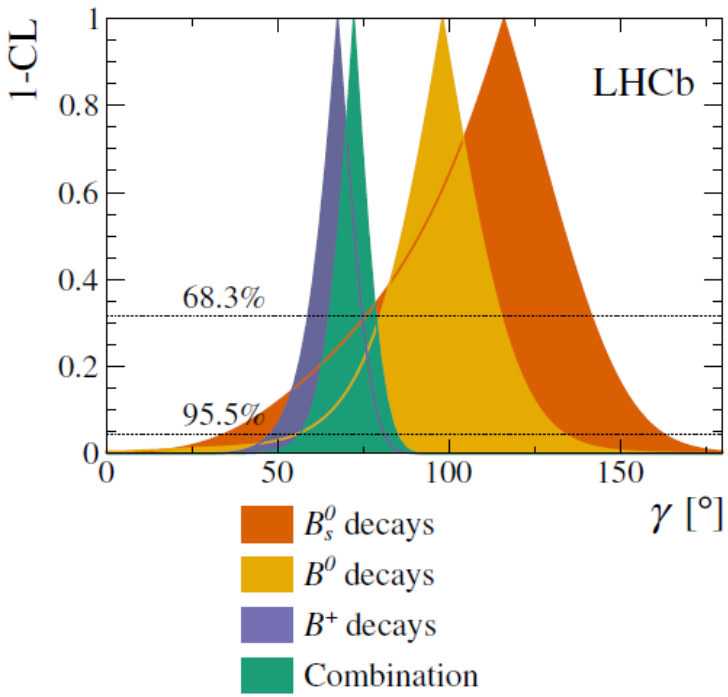


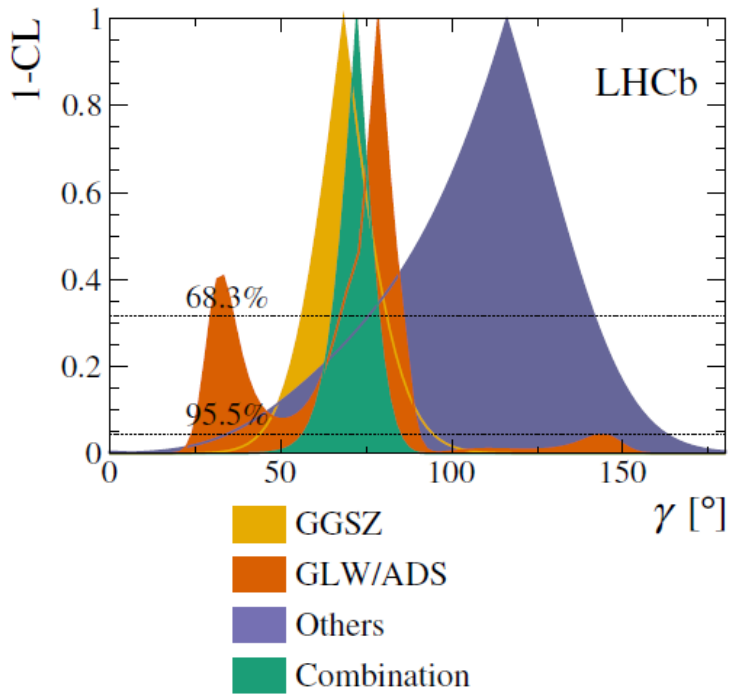
$B_s + \pi^{\pm}$



Combination of γ (B→DK)

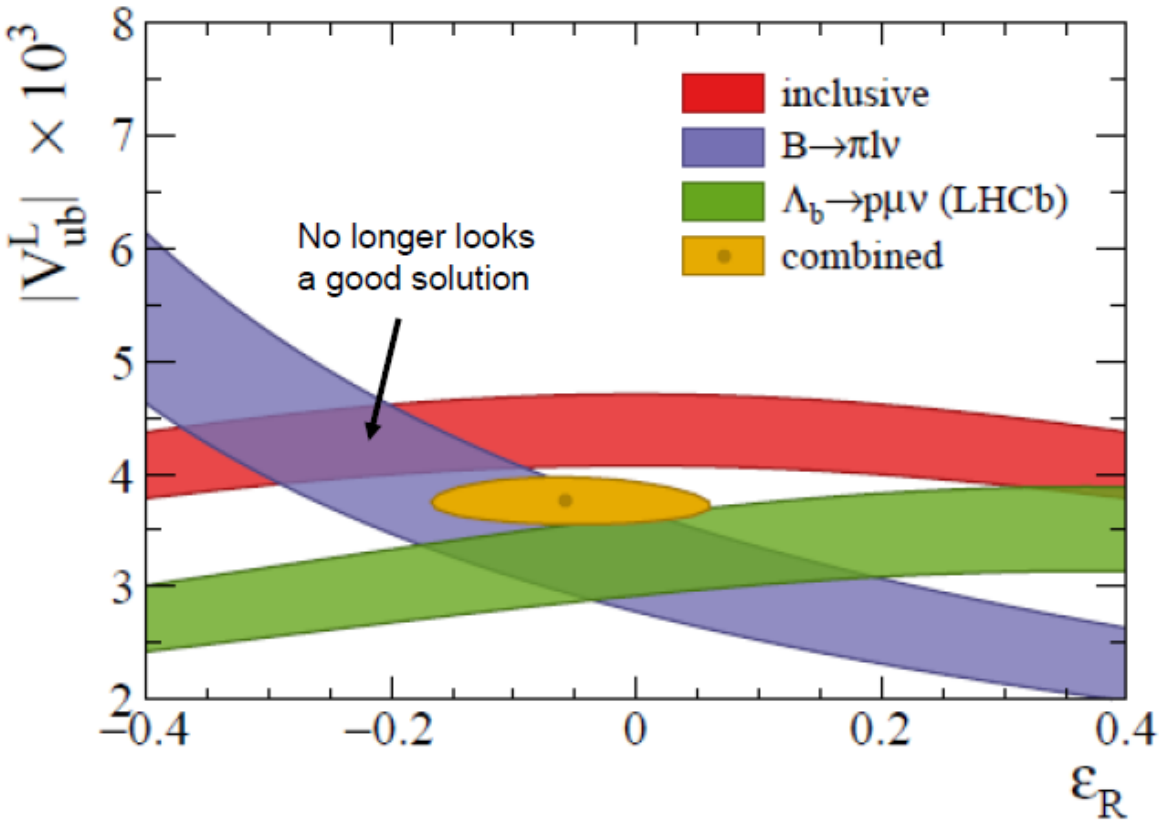
JHEP 12 (2016) 087





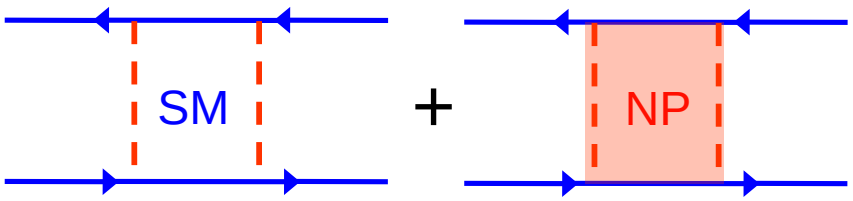
Possible Interpretation

Attempts to explain the "V_{ub} inclusive vs exclusive" puzzle with help of right-handed currents: different sensitivity of the baryon result disfavors hypothesis



LHCb result provides new ways to access V_{ub} .
Look for complementary measurements, *e.g.* with $B_s \to K\mu\nu$.

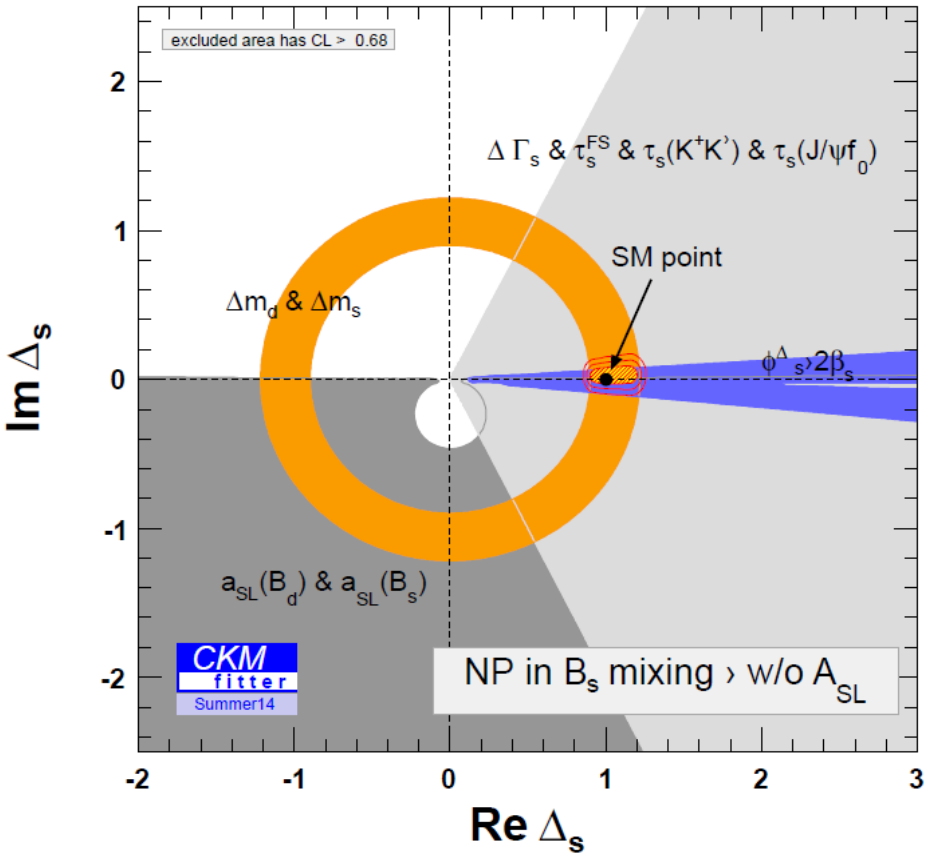
Constraints on New Physics



$$\mathcal{A}_{mix} = \mathcal{A}_{mix}^{SM} + \mathcal{A}_{mix}^{NP}$$
$$= \mathcal{A}_{mix}^{SM} \cdot (1+\Delta)$$

$B_s^0\ (\bar{b}s)$	< 20%
$B_d^0\ (\bar{b}d)$	< 30%

arXiv:1501.05013



Need to increase precision to disentangle NP phases of few degrees in Bd and Bs mixing

Systematics of R_{K^*}

	low-q^2			central-q^2		
Trigger category	L0E	L0H	L0I	L0E	L0H	L0I
Corrections to simulation	2.5	4.8	3.9	2.2	4.2	3.4
Trigger	0.1	1.2	0.1	0.2	0.8	0.2
PID	0.2	0.4	0.3	0.2	1.0	0.5
Kinematic selection	2.1	2.1	2.1	2.1	2.1	2.1
Residual background	–	–	–	5.0	5.0	5.0
Mass fits	1.4	2.1	2.5	2.0	0.9	1.0
Bin migration	1.0	1.0	1.0	1.6	1.6	1.6
$r_{J/\psi}$ **flatness**	1.6	1.4	1.7	0.7	2.1	0.7
Total	4.0	6.1	5.5	6.4	7.5	6.7

Physics Reach

Obervable	LHCb 2017 (7 fb^{-1})	Upgrade (+ 50 fb^{-1})	Theory Uncertainty
B_s Mixing phase ϕ_s	0.025	0.008	~0.003
$BR(B_s \to \mu\mu)$	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
$BR(B_d \to \mu\mu)$ / $BR\ B_s \to \mu\mu$	~100%	~35%	~5%
CKM angle γ	4°	0.9^o	small
CPV in D (ΔA_{CP})	0.7×10^{-3}	0.1×10^{-3}	