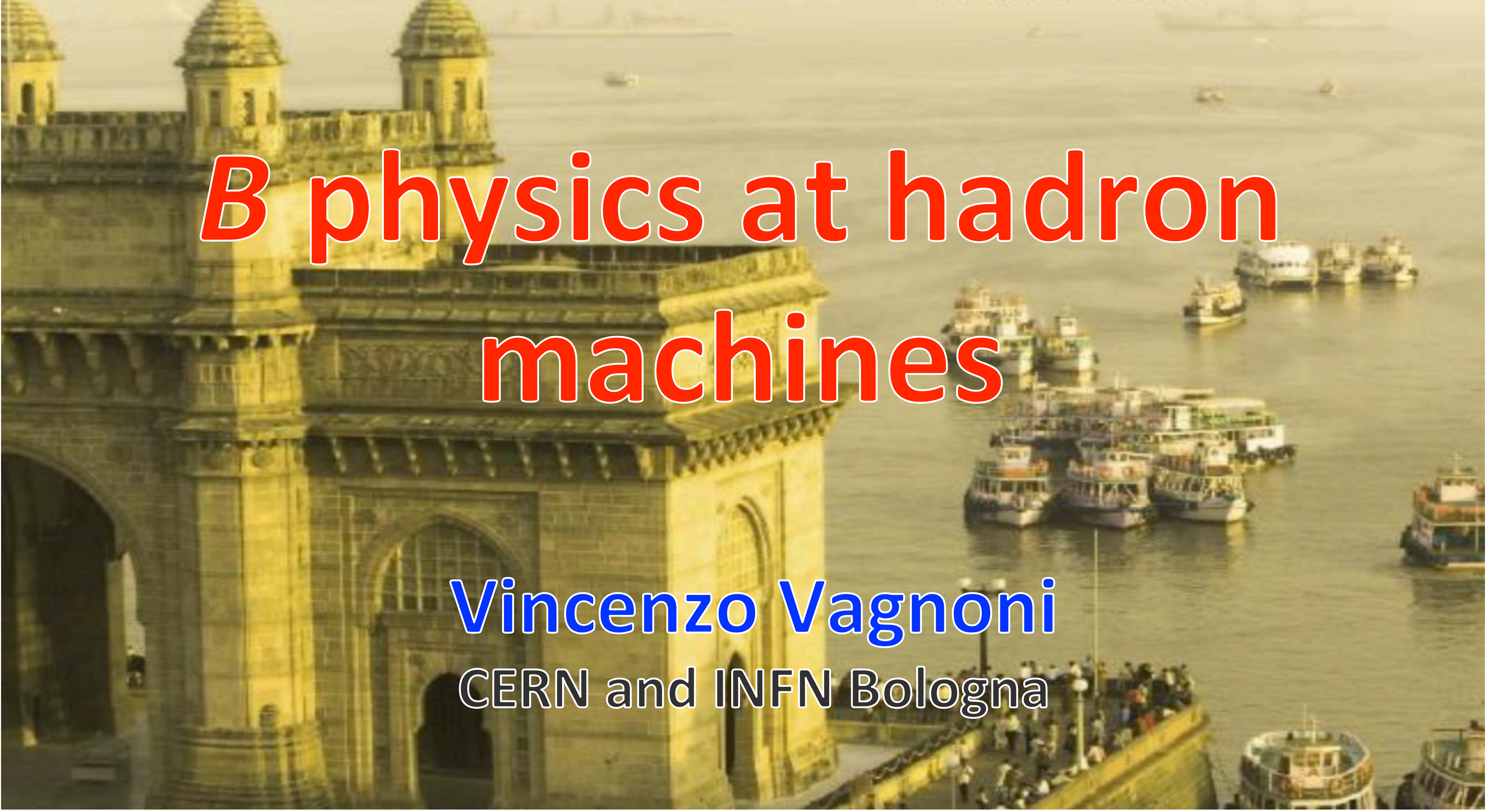


B physics at hadron machines

Vincenzo Vagnoni

CERN and INFN Bologna

on behalf of the LHCb collaboration with results from

ATLAS EXPERIMENT CDF CMS DØ LHCb

9th International Workshop on the CKM Unitarity Triangle

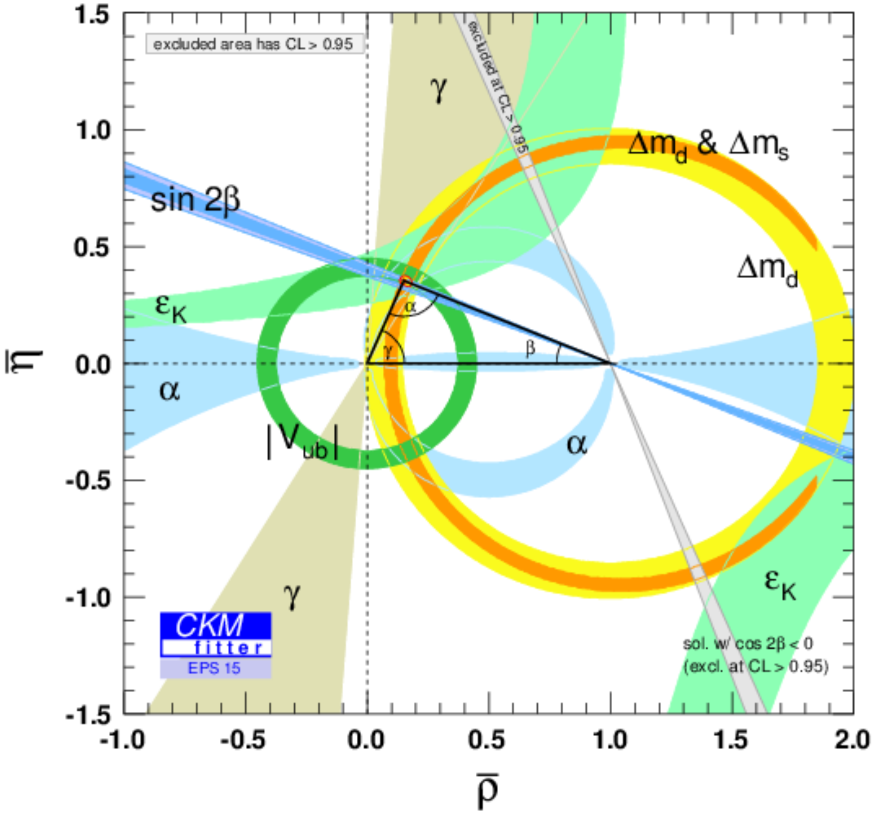
TIFR, Mumbai

Outline

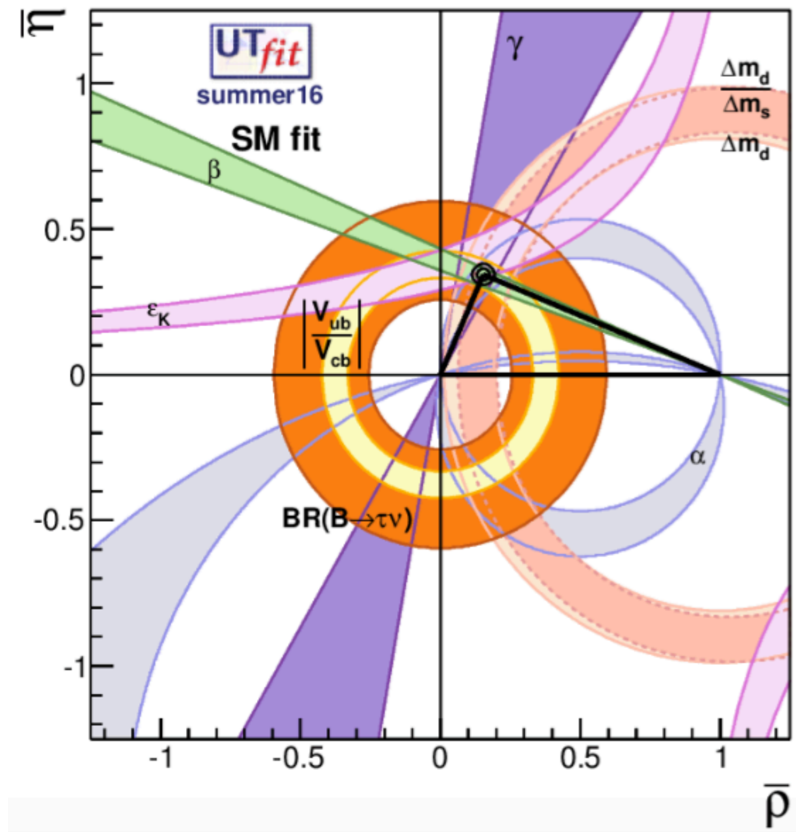
- *CP* violation in the interference between *B*-meson mixing and decay
- *CP* violation in *B*-meson mixing
- *B*-meson width and mass differences
- Photon polarisation in $B_s \rightarrow \phi\gamma$
- Tree-level determination of γ
- Searches for *CP* violation in *b* baryons
- Measurement of $|V_{ub} / V_{cb}|$
- Leptonic and charmless hadronic rare decays
- Angular analysis of $B^0 \rightarrow K^* \mu^+ \mu^-$ decays
- Lepton Flavour Universality tests

An astonishing success

http://ckmfitter.in2p3.fr



http://www.utfit.org



- Don't forget: relevant inputs from Lattice QCD and great work from the Heavy Flavour Averaging Group
  - http://www.slac.stanford.edu/xorg/hfag
- Great success of the Standard Model CKM picture!
  - All of the measurements agree in a highly profound way
  - In the presence of relevant New Physics effects, the various contours would not cross each other in a single point

Nevertheless...

- Although the Standard Model works beautifully up to a few hundred GeV, it must be an effective theory valid up to some scale
- The good reasons to believe that it is incomplete are still there, e.g.
  - Missing dark matter candidate
  - *CP* violation for dynamical generation of BAU largely insufficient
- We must search for
  - New particles, interactions, symmetries (and their breaking)
  - New sources of *CP* violation

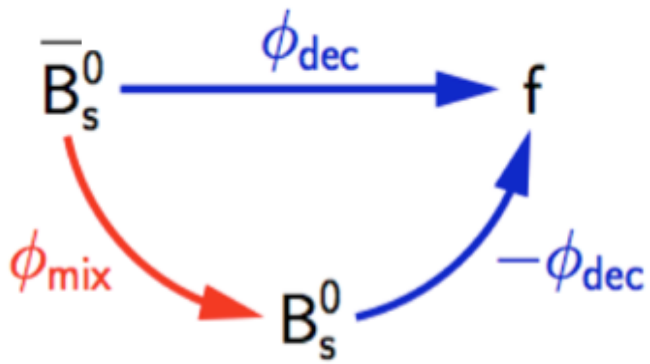
Cross-section vs luminosity

- Several experiments at different machines contributed/contributing to the field in the last 15 years
- Lower luminosity but larger cross section at hadron machines allow for unprecedented samples to be collected

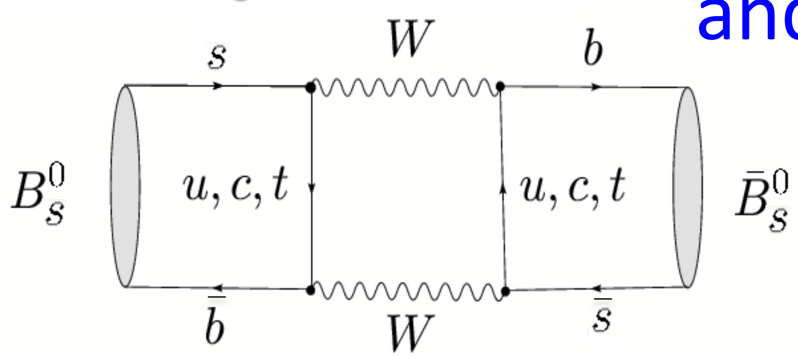
Experiment	$\int \mathcal{L}\, dt$ [fb^{-1}]	σ_{beauty} [μb]	End of life
BaBar + Belle	1600 (total)	0.001 [e^+e^- at Υ(4S)]	2008/2010
CDF + D0	24 (total)	100 [$p\bar{p}$ at 2 TeV]	2011
ATLAS + CMS	150 (so far)	250-500 [pp at 7-13 TeV]	> 2030
LHCb*	5 (so far)	250-500 [pp at 7-13 TeV]	> 2030

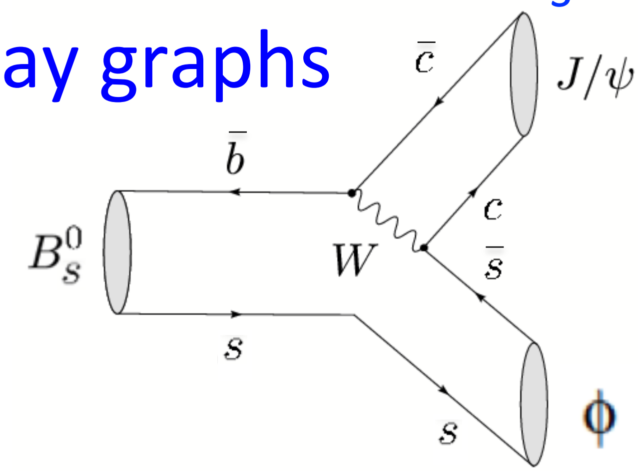
* Forward detector optimised for heavy flavour physics with levelled luminosity to limit pileup effects

One milestone of modern beauty physics



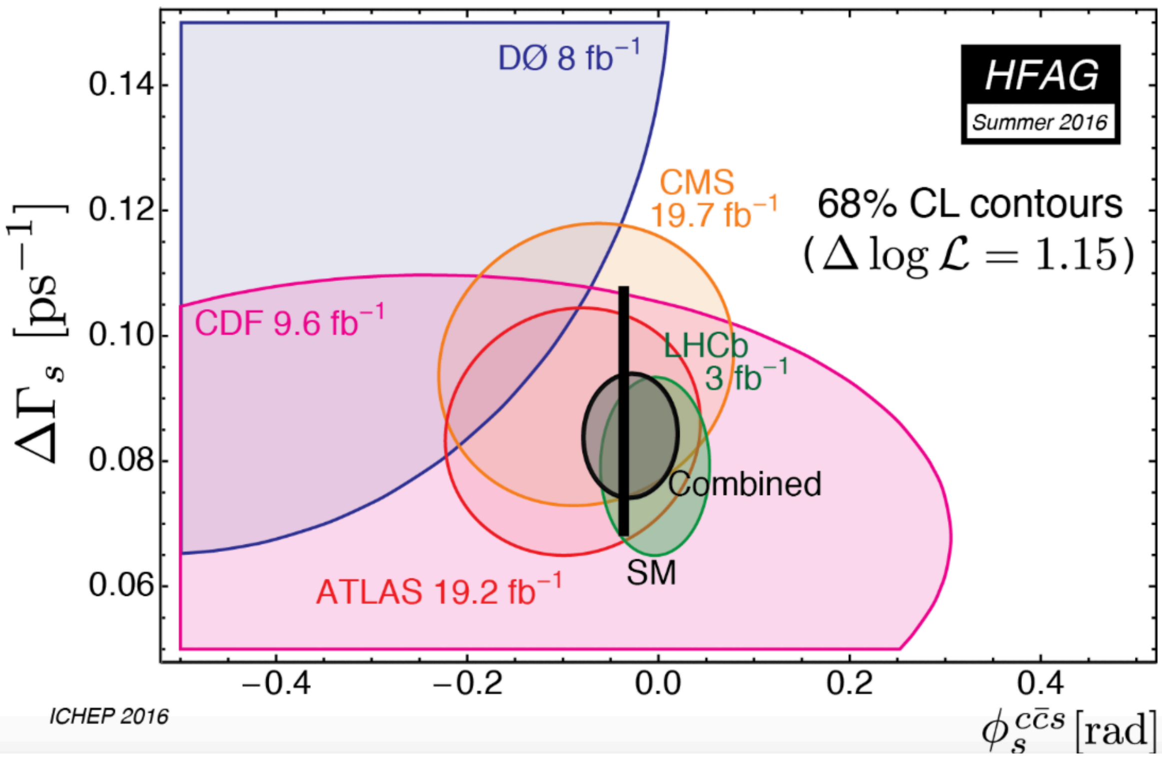
- Golden mode $B_s \rightarrow J/\psi\phi$ proceeds (mostly) via a $b \rightarrow c\bar{c}s$ tree diagram
- Interference between B_s mixing and decay graphs





- Measures the phase-difference ϕ_s between the two diagrams, precisely predicted in the SM to be ϕ_s=–37.4 ± 0.7 mrad → can be altered by New Physics
  – But also affected by small pollution of sub-leading SM amplitudes that must be taken under control

ϕ_s from $b \to c\bar{c}s$ transitions

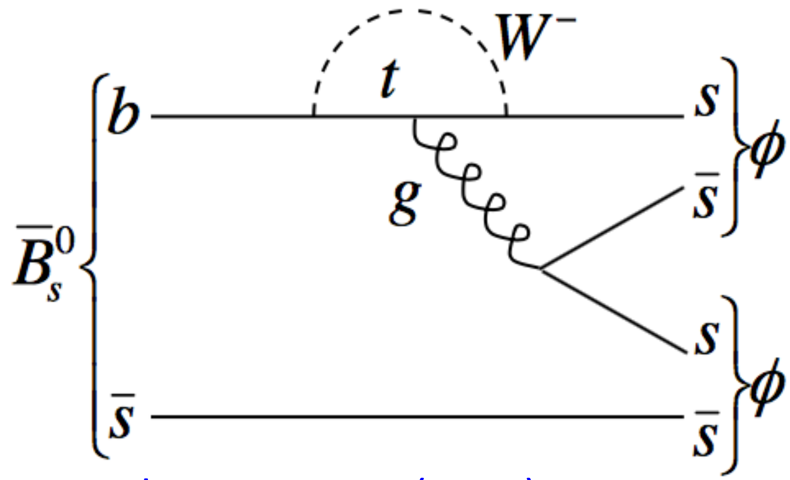


- Several measurements at the Tevatron and the LHC
- World average
  - ϕ_s = –30 ± 33 mrad
- Still compatible with the SM at the present level of precision

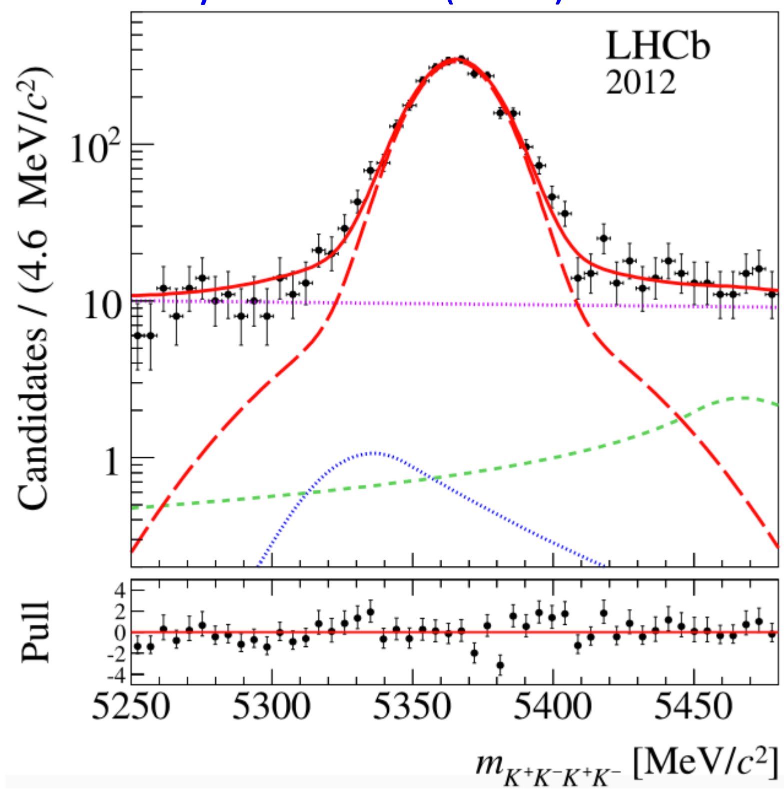
Exp.	Mode	Dataset	$\phi_s^{c\bar{c}s}$	$\Delta\Gamma_s$ (ps^{-1})	Ref.
CDF	$J/\psi\phi$	9.6 fb^{-1}	$[-0.60, +0.12]$, 68% CL	$+0.068 \pm 0.026 \pm 0.009$	Phys. Rev. Lett. **109**, 171802 (2012)
D0	$J/\psi\phi$	8.0 fb^{-1}	$-0.55^{+0.38}_{-0.36}$	$+0.163^{+0.065}_{-0.064}$	Phys. Rev. **D85**, 032006 (2012)
ATLAS	$J/\psi\phi$	4.9 fb^{-1}	$+0.12 \pm 0.25 \pm 0.05$	$+0.053 \pm 0.021 \pm 0.010$	Phys. Rev. **D90**, 052007 (2014)
ATLAS	$J/\psi\phi$	14.3 fb^{-1}	$-0.123 \pm 0.089 \pm 0.041$	$+0.096 \pm 0.013 \pm 0.007$	JHEP **08**, 147 (2016)
ATLAS	above 2 combined		$-0.098 \pm 0.084 \pm 0.040$	$+0.083 \pm 0.011 \pm 0.007$	JHEP **08**, 147 (2016)
CMS	$J/\psi\phi$	19.7 fb^{-1}	$-0.075 \pm 0.097 \pm 0.031$	$+0.095 \pm 0.013 \pm 0.007$	Phys. Lett. **B757**, 97–120 (2016)
LHCb	$J/\psi K^+K^-$	3.0 fb^{-1}	$-0.058 \pm 0.049 \pm 0.006$	$+0.0805 \pm 0.0091 \pm 0.0033$	Phys. Rev. Lett. **114**, 041801 (2015)
LHCb	$J/\psi\pi^+\pi^-$	3.0 fb^{-1}	$+0.070 \pm 0.068 \pm 0.008$	—	Phys. Lett. **B736**, 186 (2014)
LHCb	above 2 combined		-0.010 ± 0.039(tot)	—	Phys. Rev. Lett. **114**, 041801 (2015)
LHCb	$D_s^+D_s^-$	3.0 fb^{-1}	$+0.02 \pm 0.17 \pm 0.02$	—	Phys. Rev. Lett. **113**, 211801 (2014)
LHCb	$\psi(2S)\phi$	3.0 fb^{-1}	$+0.23^{+0.29}_{-0.28} \pm 0.02$	$+0.066^{+0.41}_{-0.44} \pm 0.007$	arXiv:1608.04855

CP violation in $B_s \rightarrow \phi\phi$

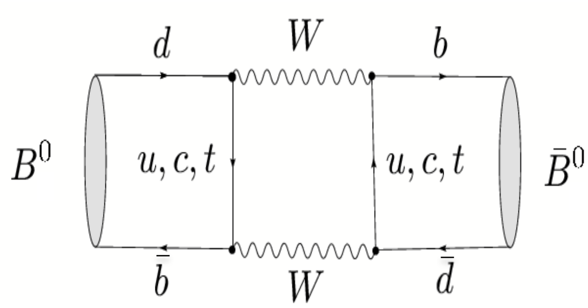
- Gluonic $b \rightarrow s\bar{s}s$ penguin
- LHCb result with full Run 1 data set
  - ~4000 signal candidates
  - $\phi_s^{\phi\phi}$= -170 ± 150 ± 30 mrad
- No sign of discrepancy yet, but overall precision comparable to golden $b \rightarrow c\bar{c}s$ modes
- Great prospects for LHCb Run-3 with higher instantaneous luminosity and improved trigger

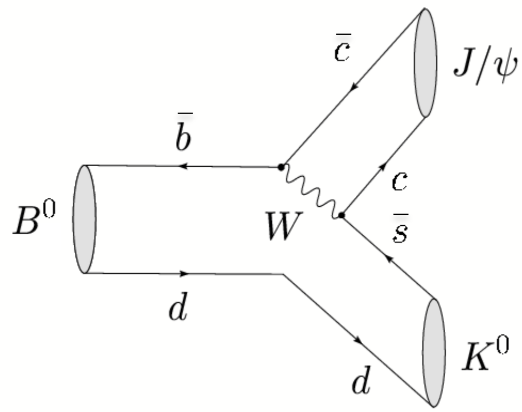


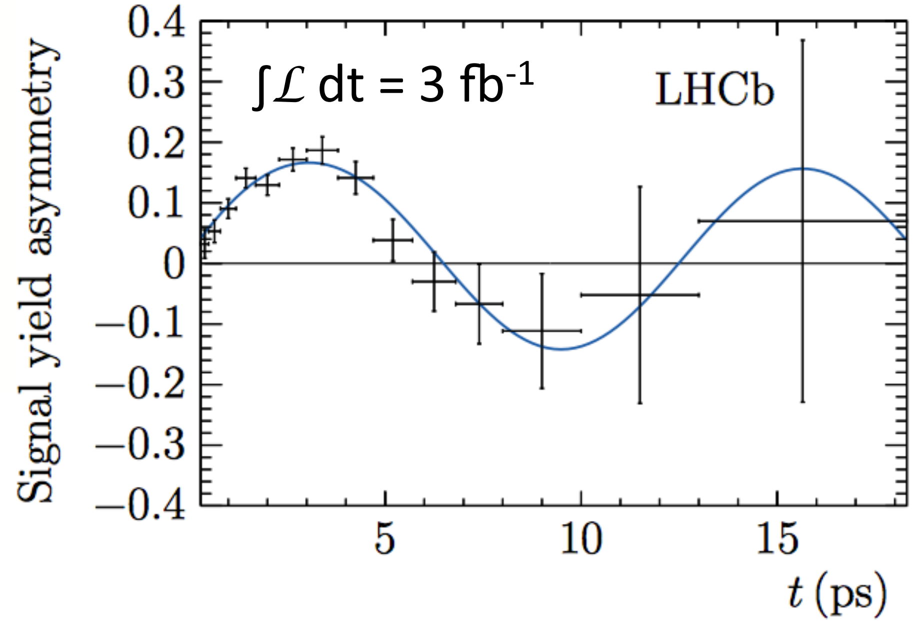
Phys. Rev. D90 (2014) 052011



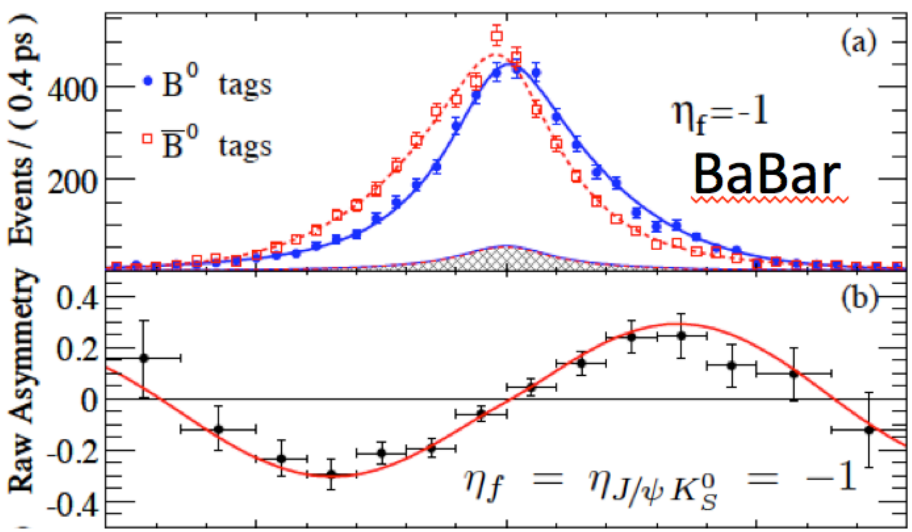
But never forget your first love

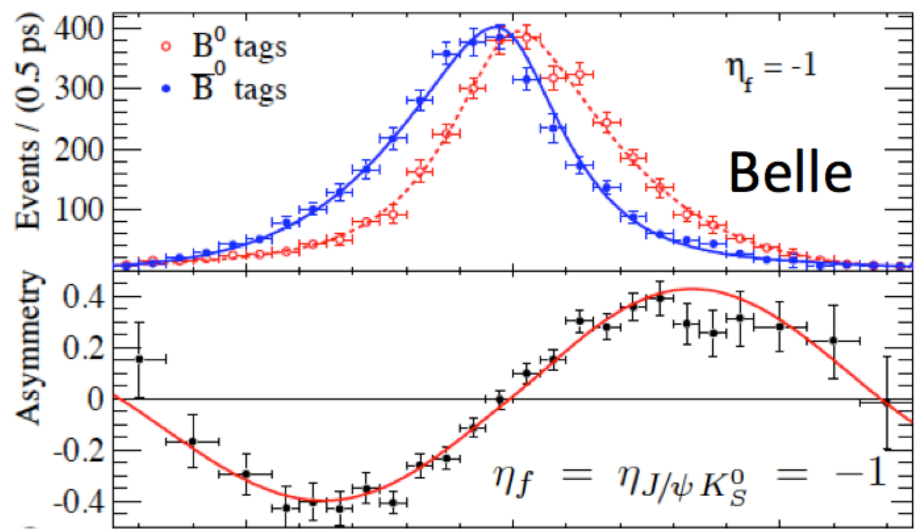






$$\mathcal{A}_{J/\psi K^0_S}(t) \equiv \frac{\Gamma(\overline{B}^0(t) \to J/\psi K^0_S) - \Gamma(B^0(t) \to J/\psi K^0_S)}{\Gamma(\overline{B}^0(t) \to J/\psi K^0_S) + \Gamma(B^0(t) \to J/\psi K^0_S)}$$
$$= S_{J/\psi K^0_S} \sin(\Delta m_d t) - C_{J/\psi K^0_S} \cos(\Delta m_d t).$$





- BaBar: 0.657 ± 0.036 ± 0.012 Phys. Rev. D79 (2009) 072009
- Belle: 0.670 ± 0.029 ± 0.013 Phys. Rev. Lett. 108 (2012) 171802
- LHCb: 0.731 ± 0.035 ± 0.020 Phys. Rev. Lett. 115 (2015) 031601

CP violation from $B^0 \to D^+D^-$

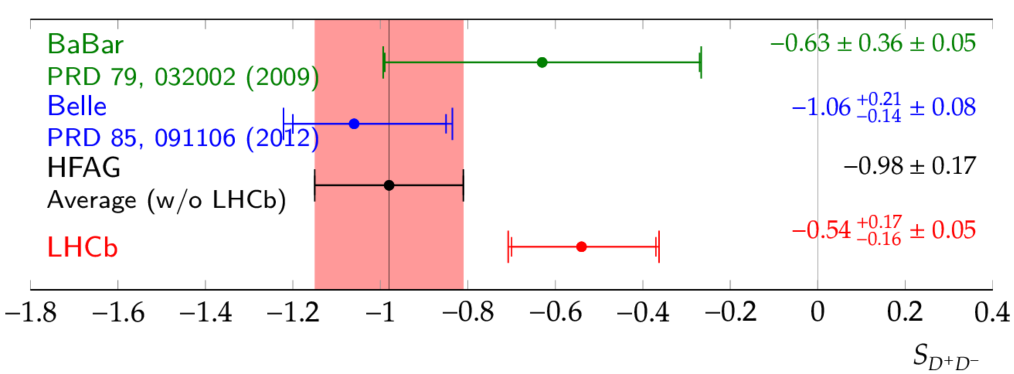
- LHCb recently measured time-dependent *CP* violation in the $B^0 \to D^+D^-$ decay
  - Complementary information on $\sin 2\beta$ through $b \to c\bar{c}d$ transitions
  - Comparison with $B^0 \to J/\psi K_S$ constrains penguin contributions to $B \to DD$
  - Tagging power: $(8.1 \pm 0.6)\%$
- Consistent with SM and no penguin pollution
  - i.e. $S \approx -0.75$ $(-\sin 2\beta)$ and $C=0$

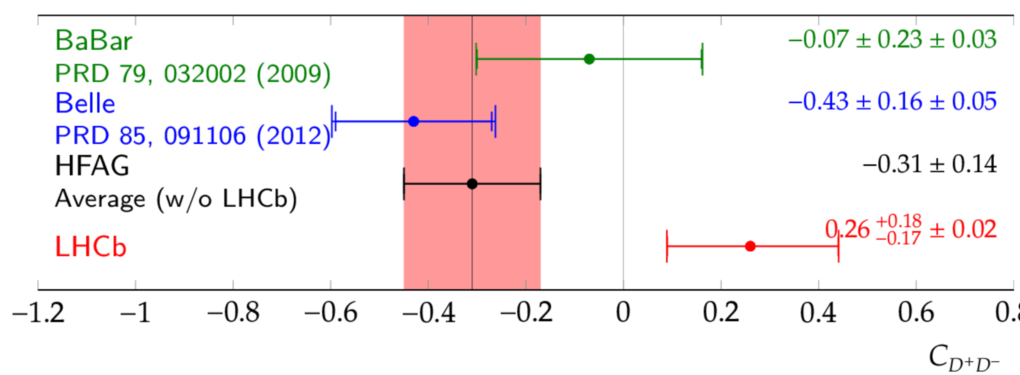
$$A_{DD}(t) = \frac{\Gamma(\overline{B}^0(t) \to D^+D^-) - \Gamma(B^0(t) \to D^+D^-)}{\Gamma(\overline{B}^0(t) \to D^+D^-) + \Gamma(B^0(t) \to D^+D^-)}$$
$$= S_{CP}\sin(\Delta m_d t) - C_{CP}\cos(\Delta m_d t)$$

$$S_{CP} = -0.54\,^{+0.17}_{-0.16}\,(\text{stat}) \pm 0.05(\text{sys})$$

$$C_{CP} = 0.26\,^{+0.18}_{-0.17}\,(\text{stat}) \pm 0.02(\text{sys})$$

LHCb-PAPER-2016-037 arXiv:1608.06620



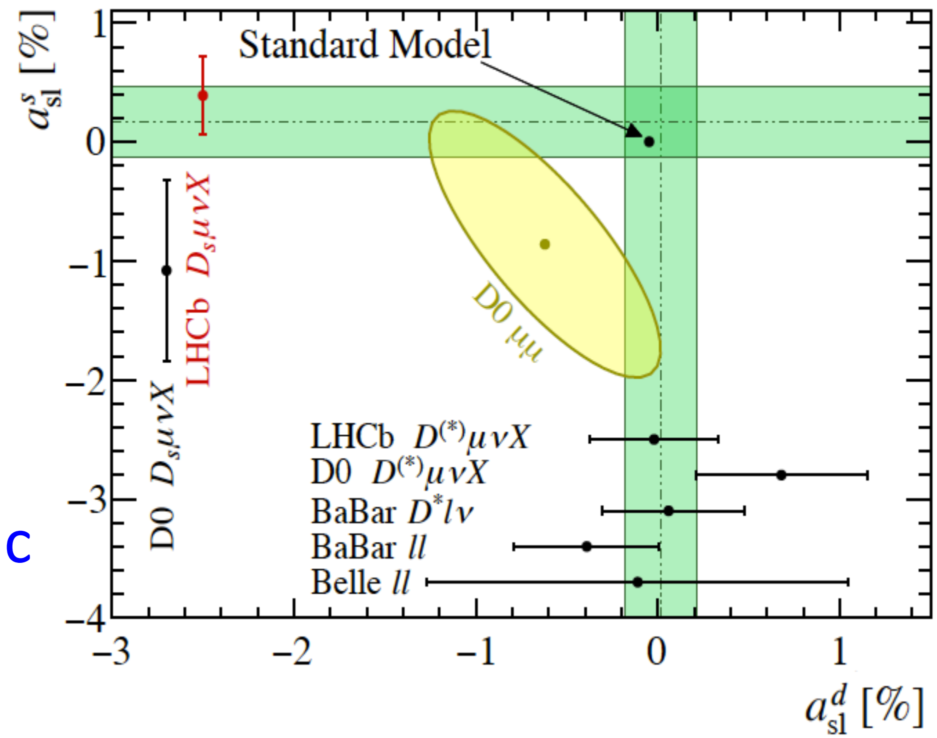


CP violation in B_s-$\bar{B}_s$ mixing

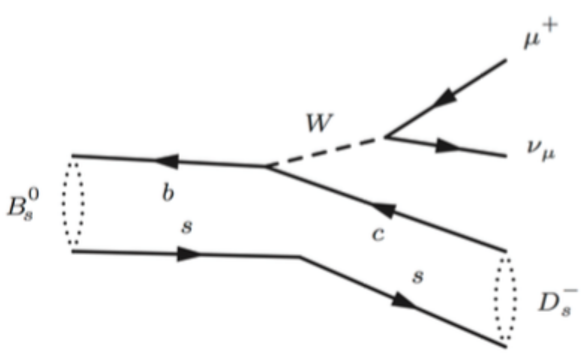
- *CP* violation in neutral *B*-meson mixing manifests itself if

$$\mathcal{P}(B_q \to \bar{B}_q) \neq \mathcal{P}(\bar{B}_q \to B_q)$$

- Interest triggered by a measurement from D0 yielding an anomalous like-sign dimuon asymmetry
  - Phys. Rev. D89 (2014) 012002
- Precise measurements of semileptonic asymmetries from LHCb



- Run-1 measurement of $a_{sl}(B_s)$ using $B_s \to D_s(KK\pi)\mu\nu X$ decays from LHCb



$$\frac{N(D_s^-\mu^+) - N(D_s^+\mu^-)}{N(D_s^-\mu^+) + N(D_s^+\mu^-)}$$

Note: $a_{sl}(B_d)$ and $a_{sl}(B_s)$ are very small in the SM

$a_{sl}^s = (2.22 \pm 0.27) \times 10^{-5}$ for B_s^0

$a_{sl}^d = (-4.7 \pm 0.6) \times 10^{-4}$ for B^0

Artuso, Borissov, Lenz [arXiv:1511.09466]

Phys. Rev. Lett. 117 (2016) 061803

$$a_{sl}^s = (0.39 \pm 0.26(\text{stat}) \pm 0.20(\text{syst}))\%$$

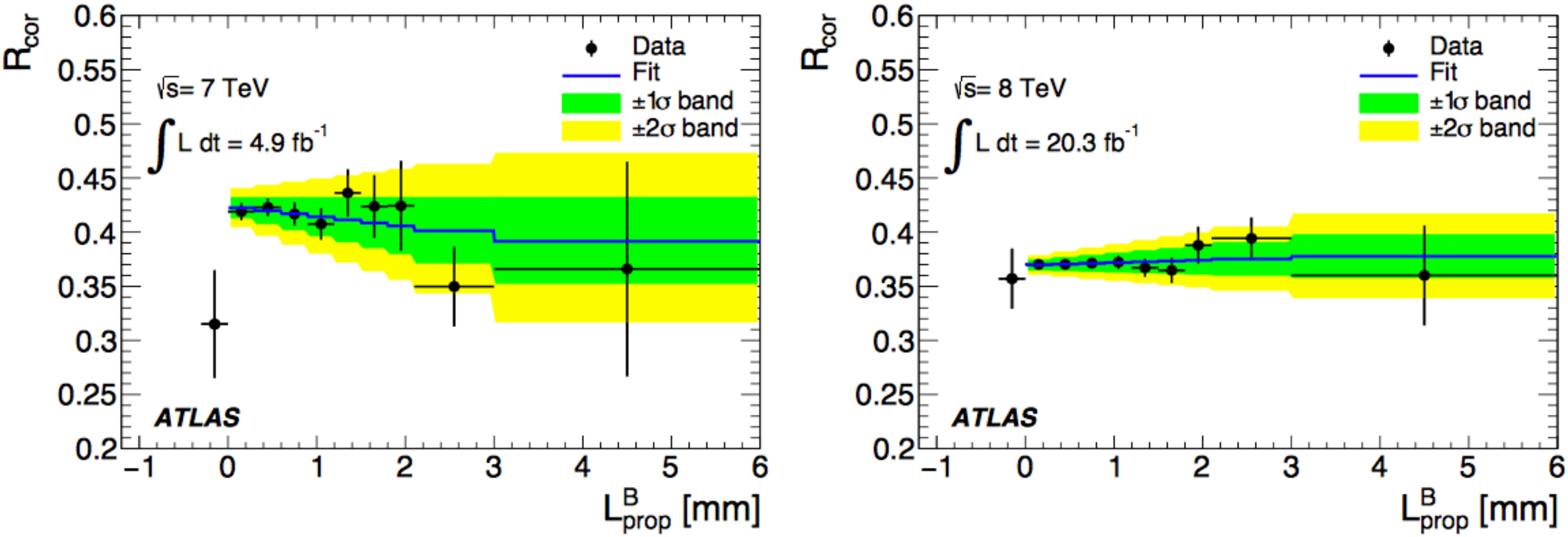
Measurement of the B^0 width difference

- Recent measurement of $\Delta\Gamma_d/\Gamma_d$ by ATLAS
  - Comparing decay-time distributions of $B^0 \rightarrow J/\psi K_S$ and $B^0 \rightarrow J/\psi K^{*0}$

$$\Delta\Gamma_d/\Gamma_d = (-0.1 \pm 1.1\ (\text{stat.}) \pm 0.9\ (\text{syst.})) \times 10^{-2}$$

JHEP 06 (2016) 081

Efficiency-corrected ratio of the observed decay length distributions



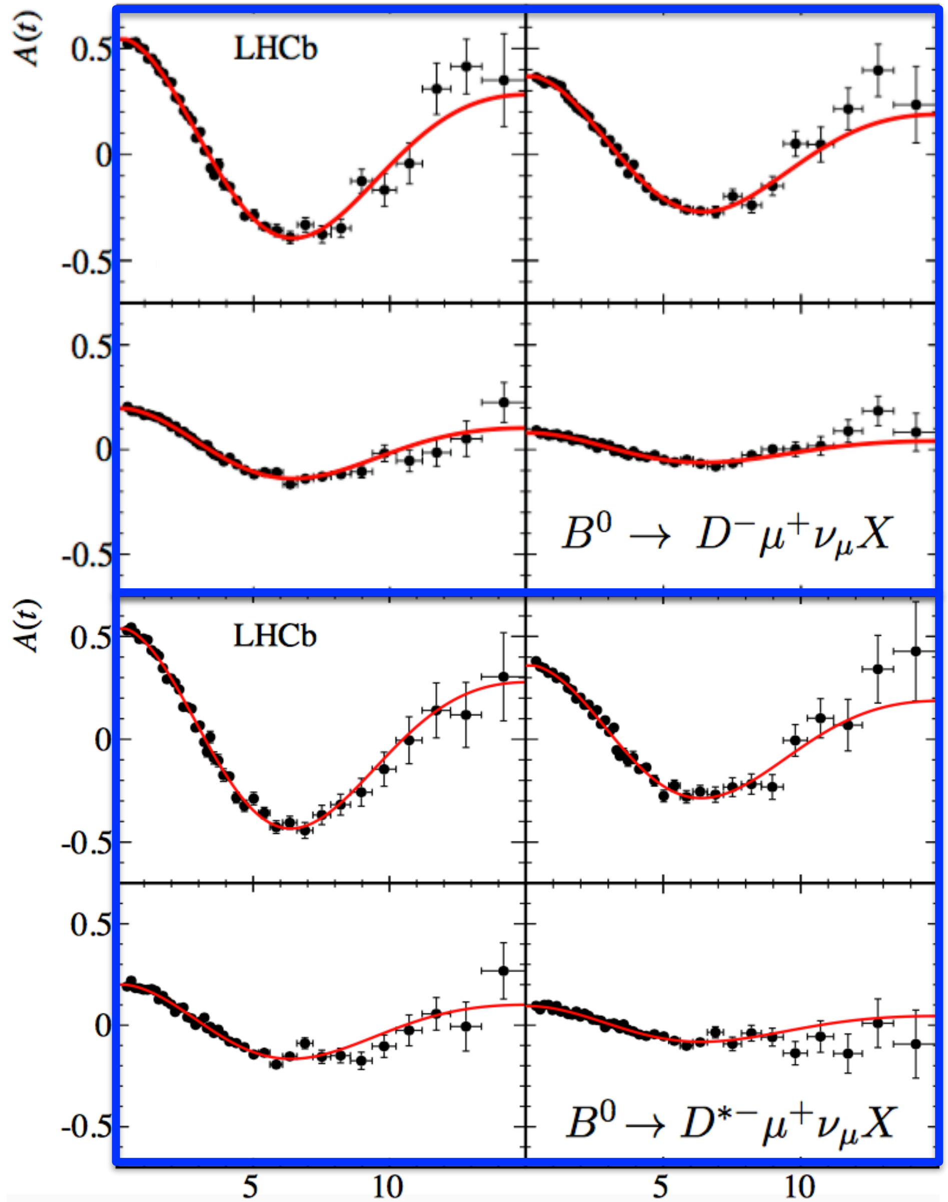
- Most precise measurement from a single experiment to date

Measurement of the B^0 mass difference

- Mixing frequency Δm_d measured with full Run-1 sample
  - 1.6M $B^0 \to D^- \mu^+ \nu X$ decays
  - 0.8M $B^0 \to D^{*-} \mu^+ \nu X$ decays
- Using four tagging categories of different mistag rate

$$\Delta m_d = (505.0 \pm 2.1 \pm 1.0)\,\mathrm{ns}^{-1}$$

- World's best single measurement, more precise than previous world average



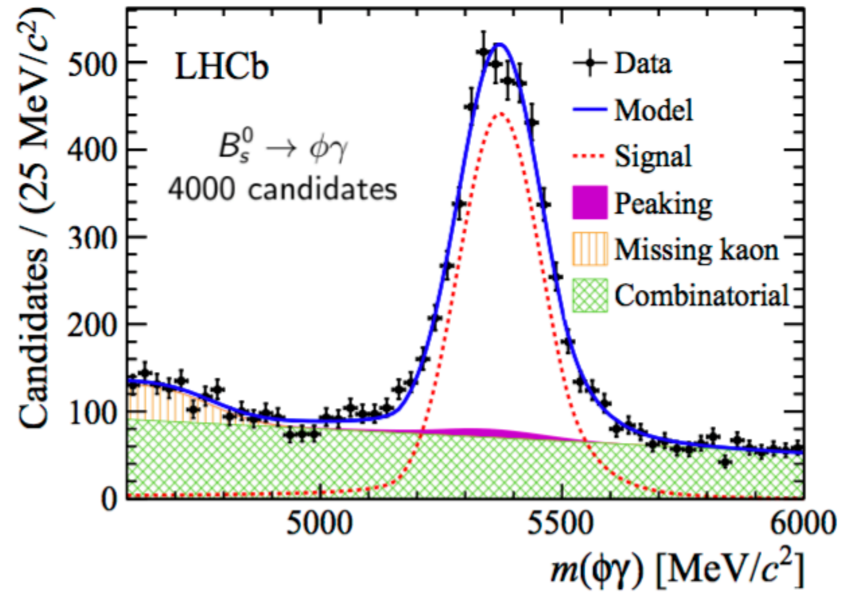
Eur. Phys. J. C (2016) 76

Photon polarisation in $B_s \to \phi\gamma$

- Fit untagged decay-time rate

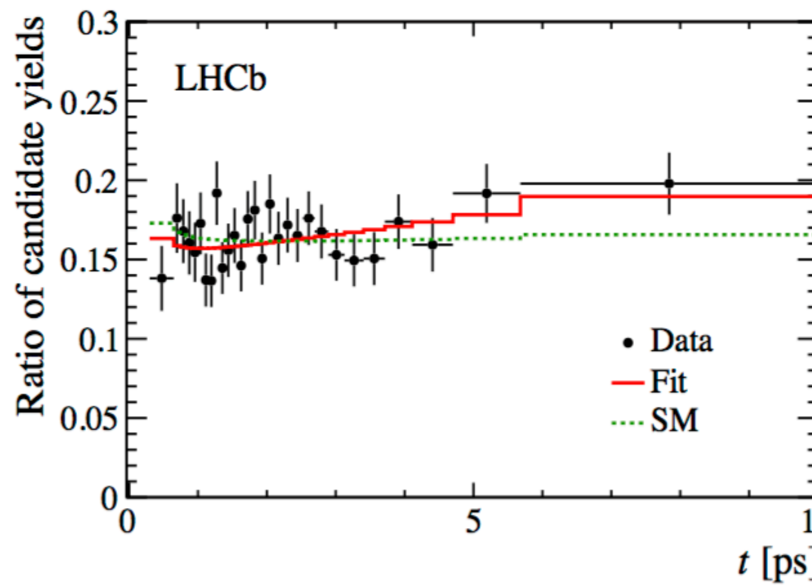
$$\Gamma_{B_s^0\to\phi\gamma}(t) \propto e^{-\Gamma_s t}\left[\cosh\left(\Delta\Gamma_s t/2\right) - \mathcal{A}^{\Delta}\sinh\left(\Delta\Gamma_s t/2\right)\right]$$

$$\mathcal{A}^{\Delta} \approx \sin 2\psi \cos\varphi_s \qquad \tan\psi \equiv \frac{A(\overline{B}^0_s \to \phi\gamma_R)}{A(\overline{B}^0_s \to \phi\gamma_L)}$$



- Control acceptance by using $B^0 \to K^{*0}\gamma$ decays

Ratio of yields $B_s \to \phi\gamma$ / $B^0 \to K^*\gamma$



- First result on photon polarisation!

$$\mathcal{A}^{\Delta} = -0.98\,^{+0.46}_{-0.52}\,^{+0.23}_{-0.20}$$

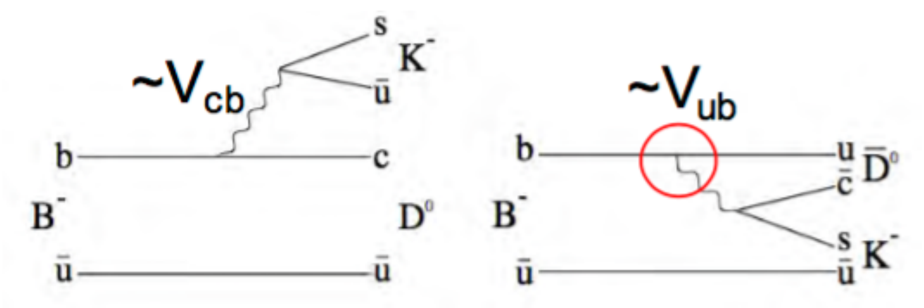
- To be compared with

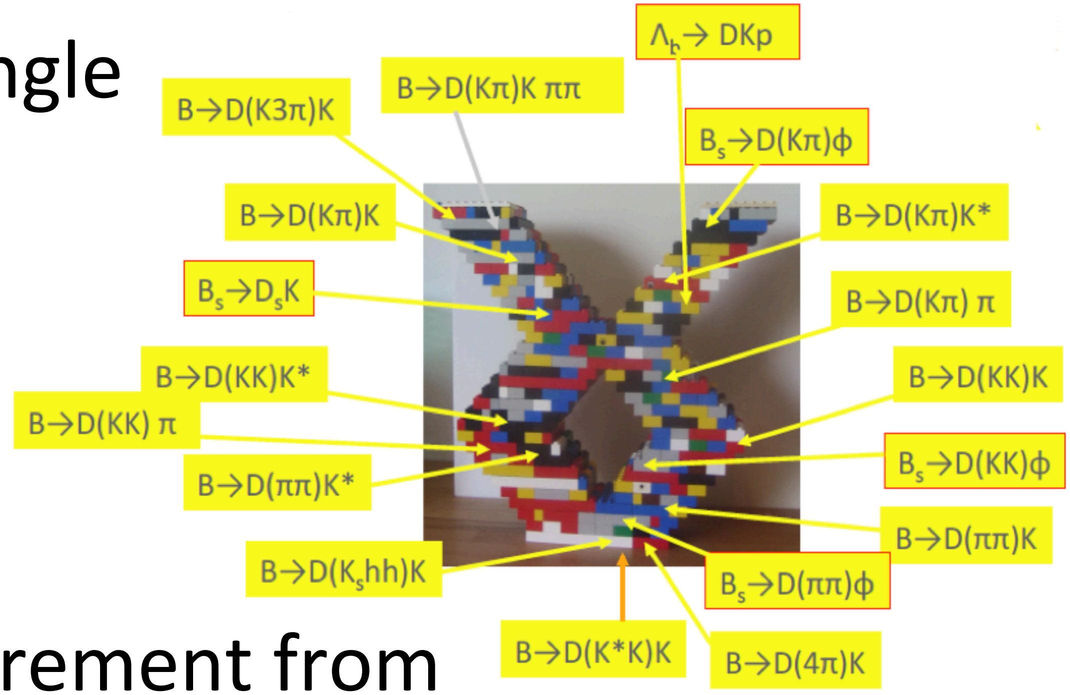
$$\mathcal{A}^{\Delta}{}_{\rm SM} = 0.047\,^{+0.029}_{-0.025}$$

LHCb-PAPER-2016-034 arXiv:1609.02032

Tree-level determination of γ

- γ is still the least known angle of the Unitarity Triangle





- Theoretically clean measurement from tree-level transitions → genuine experimental effort!
- Two main routes
  - Time-independent measurements, e.g. using *B→DK* decays
  - Time-dependent analyses with B_s decays, e.g. $B_s \to D_s K$
- Combining a plethora of independent decay modes is the key to achieve the ultimate precision

Experimental status for γ

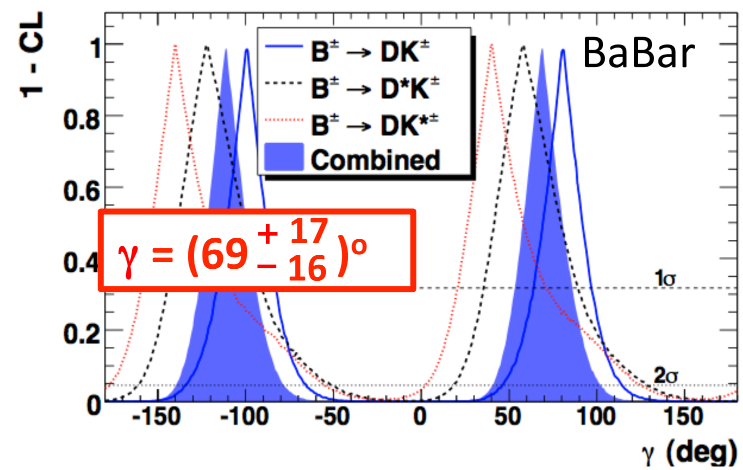
- New combination of all available measurements from LHCb

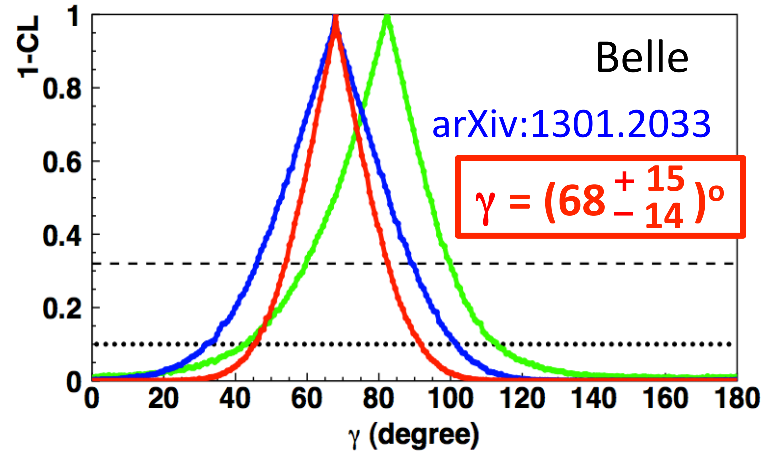
LHCb measurements used in the combination

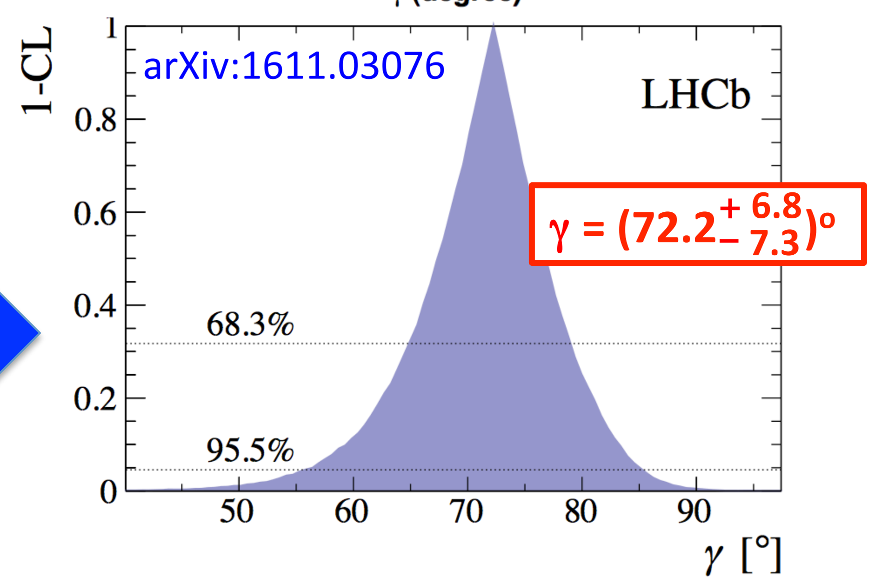
B decay	D decay	Method
$B^+ \to Dh^+$	$D \to h^+h^-$	GLW/ADS
$B^+ \to Dh^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS
$B^+ \to Dh^+$	$D \to h^+h^-\pi^0$	GLW/ADS
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ
$B^+ \to DK^+$	$D \to K^0_S K^+\pi^-$	GLS
$B^+ \to Dh^+\pi^-\pi^+$	$D \to h^+h^-$	GLW/ADS
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	GGSZ
$B^0_s \to D^\mp_s K^\pm$	$D^+_s \to h^+h^-\pi^+$	TD

- Significantly more precise than previous results

Phys. Rev. **D87** (2013) 052015



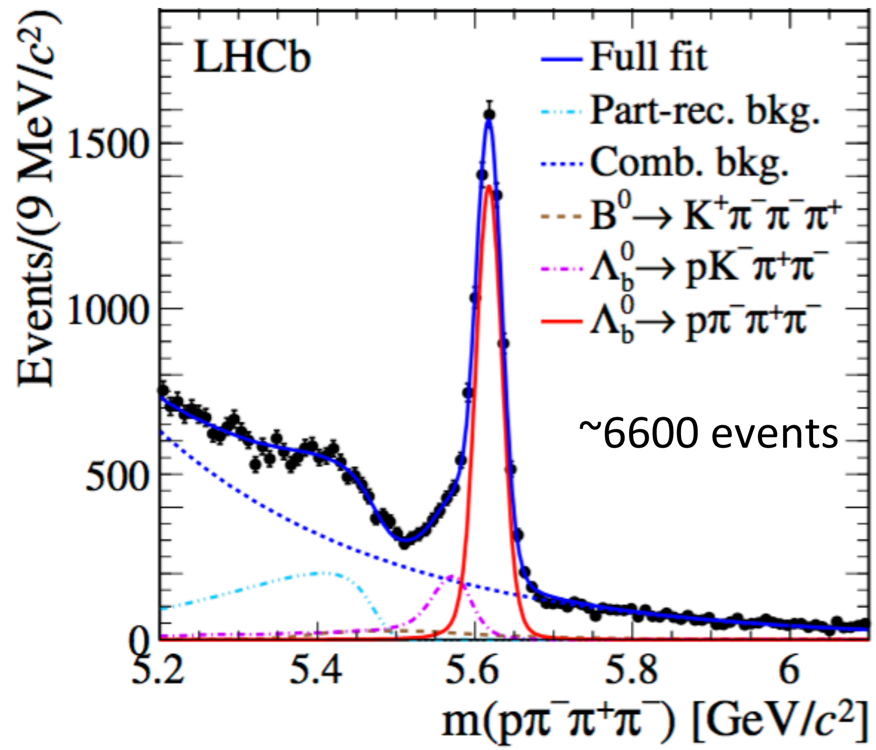




New avenues: search for *CP* violation in $\Lambda_b \to p\pi^-\pi^+\pi^-$ decays from LHCb

LHCb-PAPER-2016-030 arXiv:1609.05216

- *CP* violation has never been observed in the decays of any baryonic particle
- $\Lambda_b \to p\pi^-\pi^+\pi^-$ decays used to search for *CP*-violating asymmetries in triple products of final-state particle momenta



$$C_{\widehat{T}} = \vec{p}_p \cdot (\vec{p}_{h_1^-} \times \vec{p}_{h_2^+}) \qquad \overline{C}_{\widehat{T}} = \vec{p}_{\overline{p}} \cdot (\vec{p}_{h_1^+} \times \vec{p}_{h_2^-})$$

$$\overline{A}_{\widehat{T}}(\overline{C}_{\widehat{T}}) = \frac{\overline{N}(-\overline{C}_{\widehat{T}} > 0) - \overline{N}(-\overline{C}_{\widehat{T}} < 0)}{\overline{N}(-\overline{C}_{\widehat{T}} > 0) + \overline{N}(-\overline{C}_{\widehat{T}} < 0)}$$

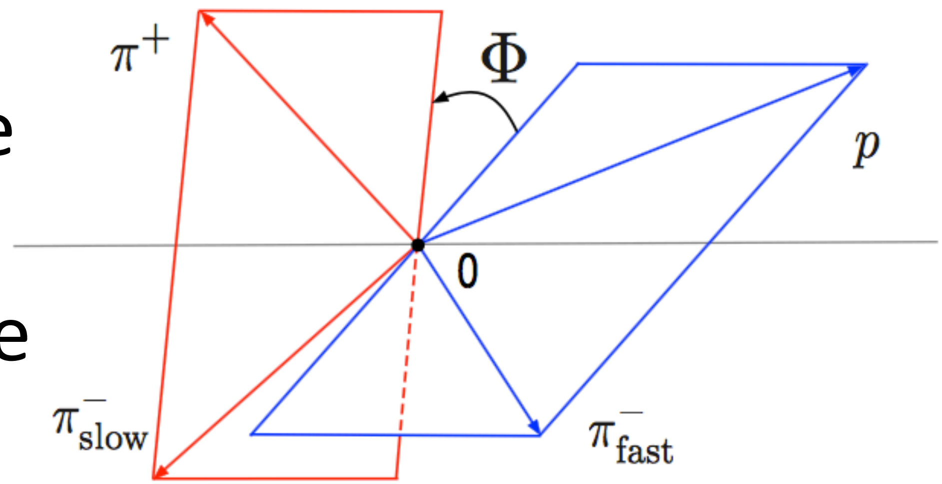
$$A_{\widehat{T}}(C_{\widehat{T}}) = \frac{N(C_{\widehat{T}} > 0) - N(C_{\widehat{T}} < 0)}{N(C_{\widehat{T}} > 0) + N(C_{\widehat{T}} < 0)}$$

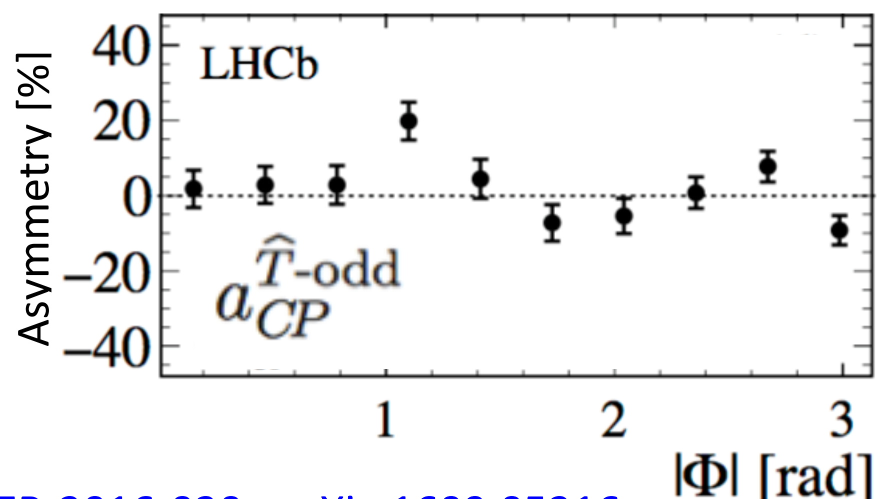
CP-violating observable

$$a_{CP}^{\widehat{T}\text{-odd}} = \frac{1}{2}\left(A_{\widehat{T}} - \overline{A}_{\widehat{T}}\right)$$

New avenues: search for *CP* violation in $\Lambda_b \to p\pi^-\pi^+\pi^-$ decays from LHCb

- Local *CP*-violating effects studied as a function of the the relative orientation between the decay planes formed by the $p\pi^-$ and the $\pi^+\pi^-$ systems (Φ)
- An evidence for *CP* violation at the 3.3σ level is found
- This represents the first evidence of *CP* violation in the baryon sector

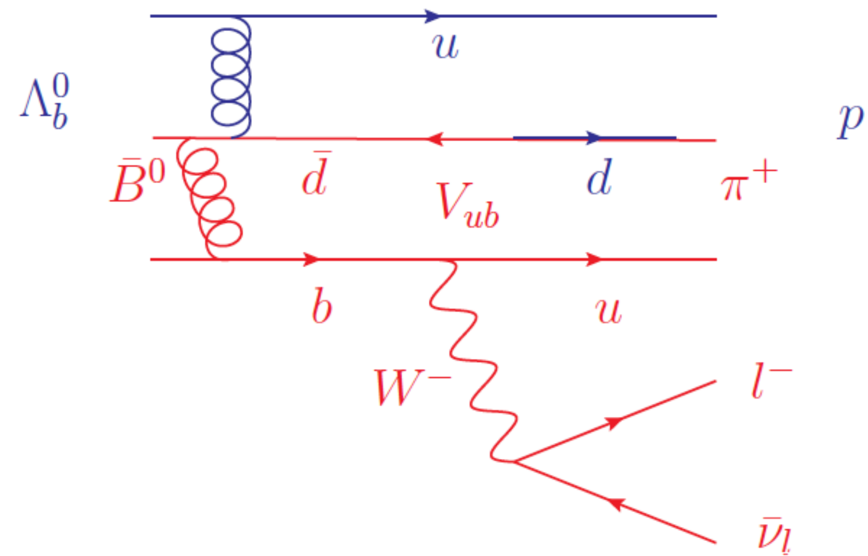




LHCb-PAPER-2016-030 arXiv:1609.05216

$|V_{ub}/V_{cb}|$ from $\Lambda_b \rightarrow p\mu\nu$ decays at LHCb

- Measure $\mathfrak{B}(\Lambda_b \rightarrow p\mu\nu)$ relative to $\mathfrak{B}(\Lambda_b \rightarrow \Lambda_c\mu\nu)$ in the high q^2 region where the theory uncertainty is smaller   Nature Physics 10 (2015) 1038



$$\frac{\mathcal{B}(\Lambda_b \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}^2/c^4}}{\mathcal{B}(\Lambda_b \to \Lambda_c\mu\nu)_{q^2>7\,\mathrm{GeV}^2/c^4}} = \frac{N(\Lambda_b \to p\mu^-\overline{\nu}_\mu)}{N(\Lambda_b \to (\Lambda_c \to pK\pi)\mu^-\overline{\nu}_\mu)} \times \frac{\epsilon(\Lambda_b \to (\Lambda_c \to pK\pi)\mu^-\overline{\nu}_\mu)}{\epsilon(\Lambda_b \to p\mu^-\overline{\nu}_\mu)} \times \mathcal{B}(\Lambda_c \to pK\pi)$$

- Use Belle measurement of $\mathfrak{B}(\Lambda_c \rightarrow pK\pi)$
  - Phys. Rev. Lett. 113 (2014) 042002

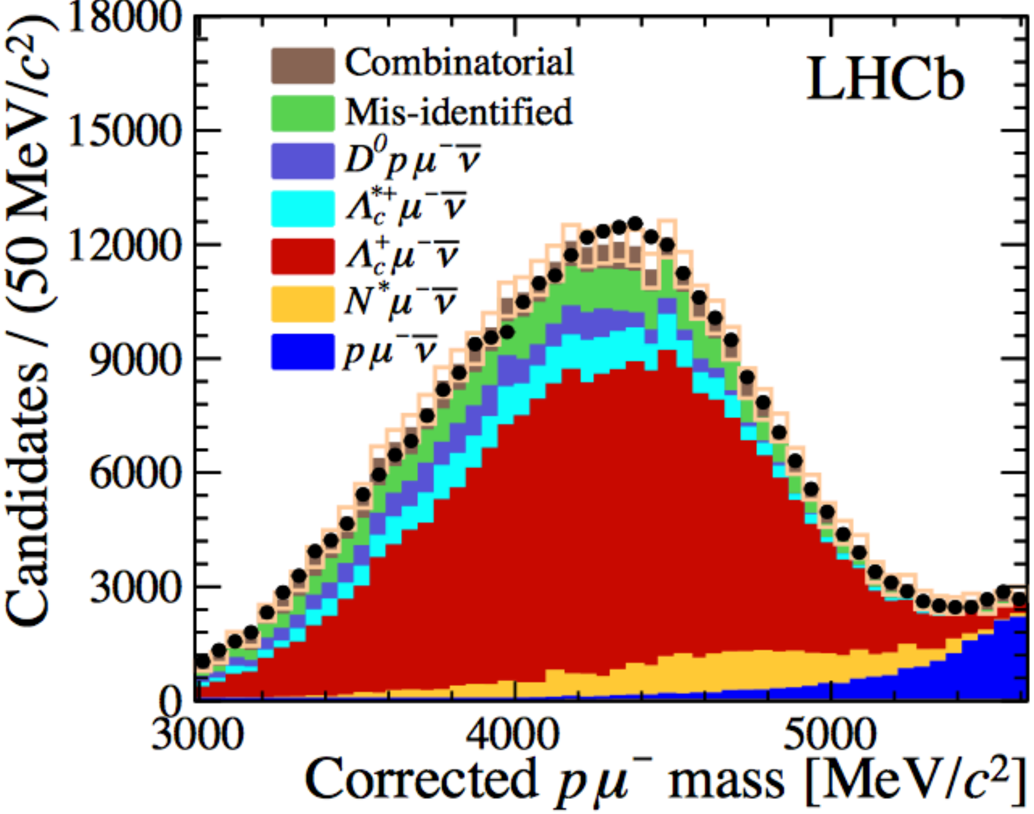
$$R_{exp} = R_{theory}(|\mathrm{V_{ub}}|^2/|\mathrm{V_{cb}}|^2)$$

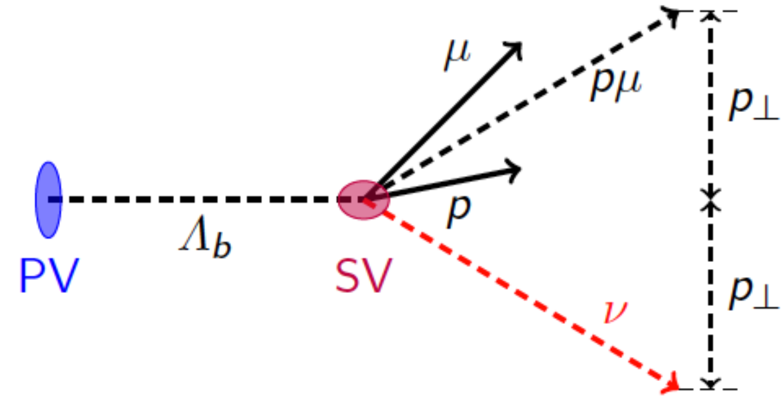
$$R_{theory} = 1.471 \pm 0.095 \pm 0.109$$

Phys. Rev. D92 (2015) 034503

$|V_{ub}/V_{cb}|$ from $\Lambda_b \rightarrow p\mu\nu$ decays at LHCb

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





$$N(\Lambda_b \rightarrow p\mu^-\overline{\nu}_\mu) = 17687 \pm 733$$

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

$$\frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}/c^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)_{q^2>7\,\mathrm{GeV}/c^2}} = (1.00 \pm 0.04 \pm 0.08) \times 10^{-2}$$

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004(\mathrm{expt}) \pm 0.004(\mathrm{lattice})$$

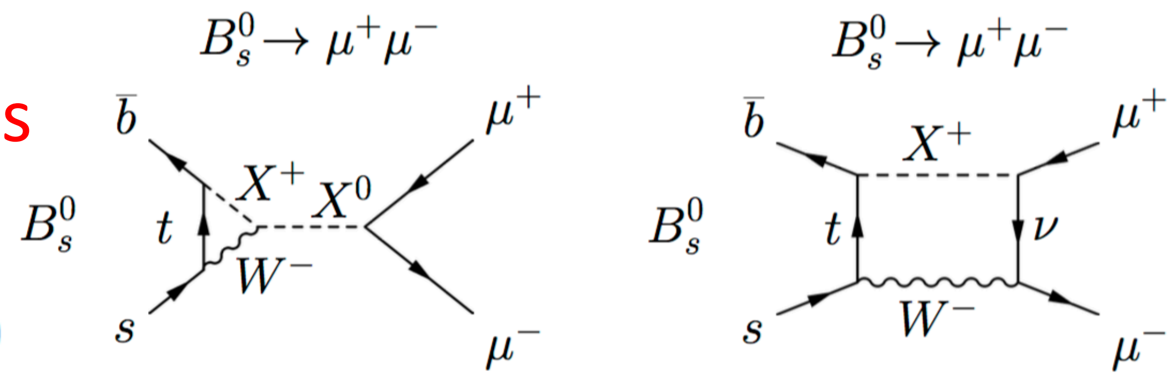
Nature Physics 10 (2015) 1038

Rare decays as another avenue to New Physics $B_{d,s} \to \mu^+\mu^-$ from CMS and LHCb

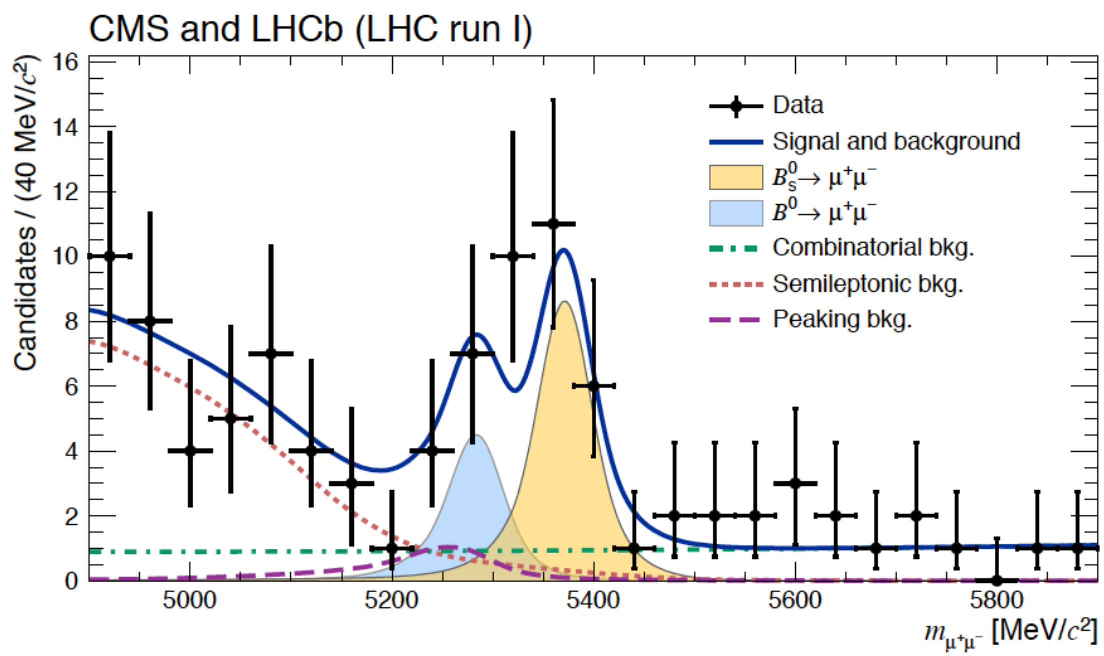
- CMS and LHCb have performed a combined fit to their full Run 1 data sets

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

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10}$$

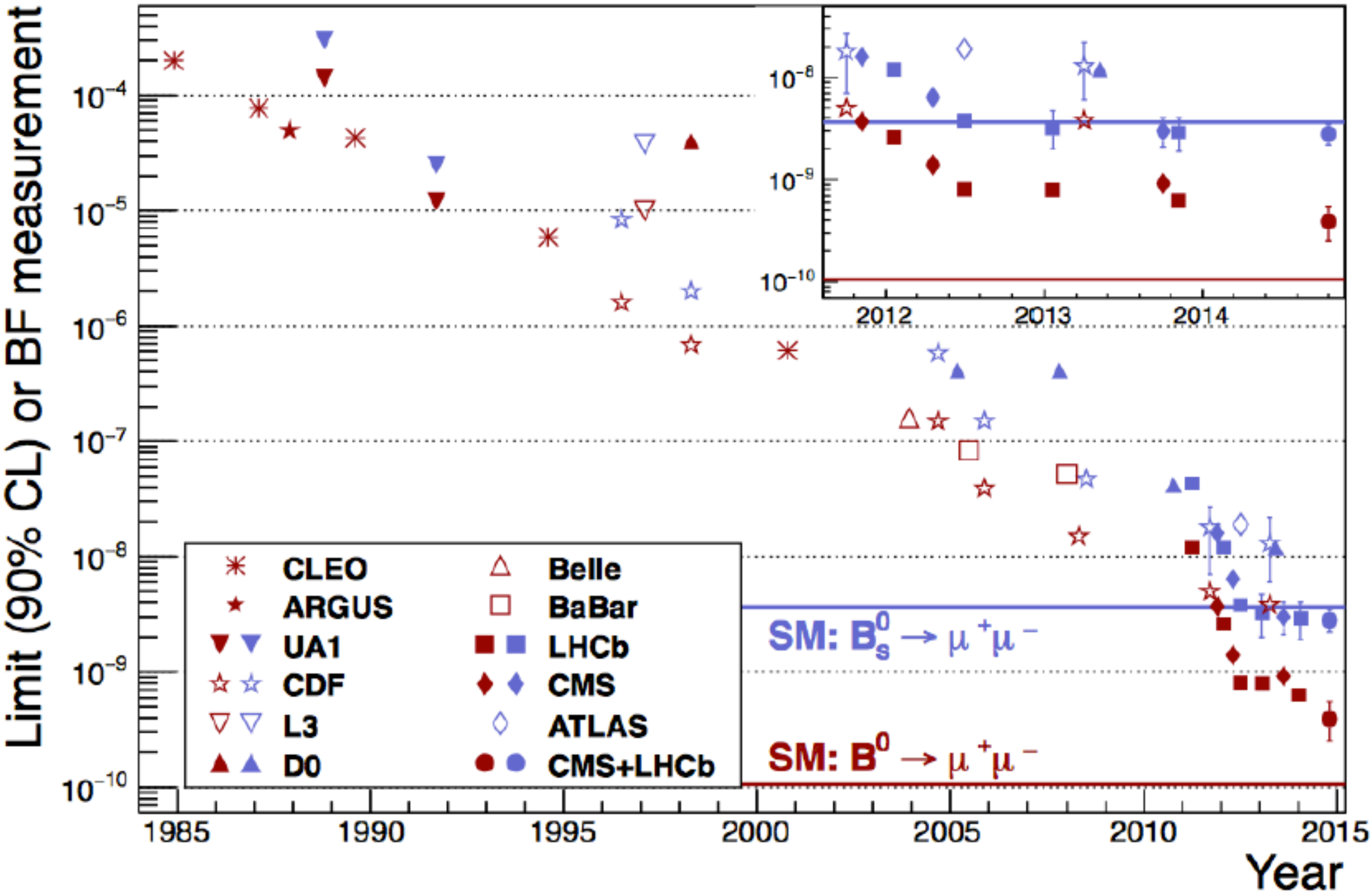


- $B_s \to \mu\mu$ 6.2σ significance was first observation
  - Compatibility with the SM at 1.2σ
- Excess of events at the 3σ level observed for the $B^0 \to \mu\mu$ hypothesis with respect to background-only
  - Compatible with SM at 2.2σ



Nature 522 (2015) 68

$B_{d,s} \rightarrow \mu^+\mu^-$ history



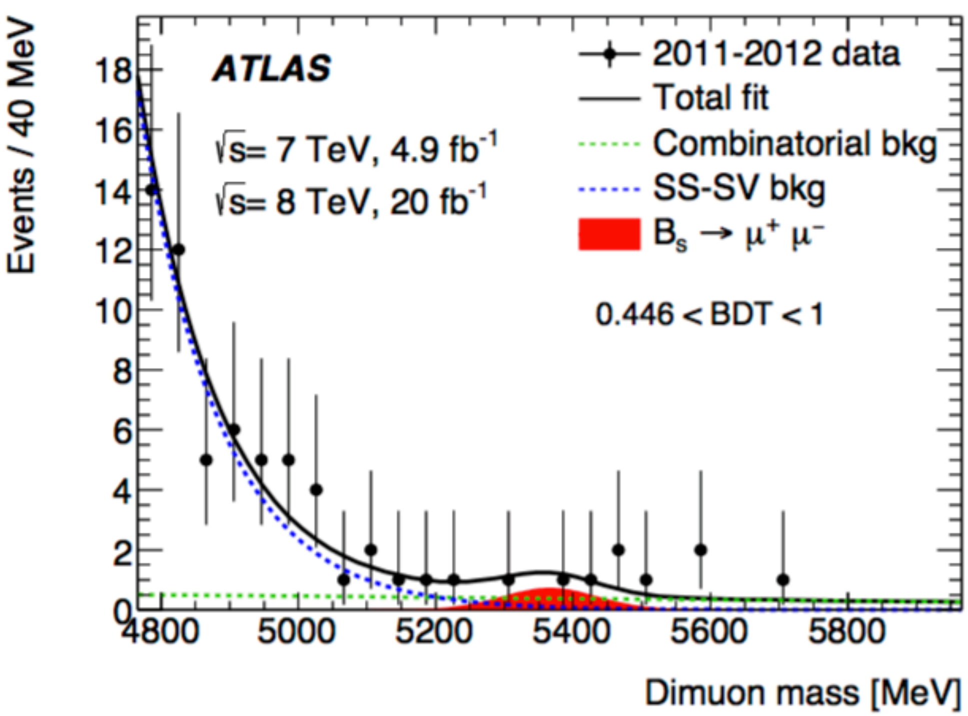
$B_{d,s} \to \mu^+\mu^-$ searches at ATLAS

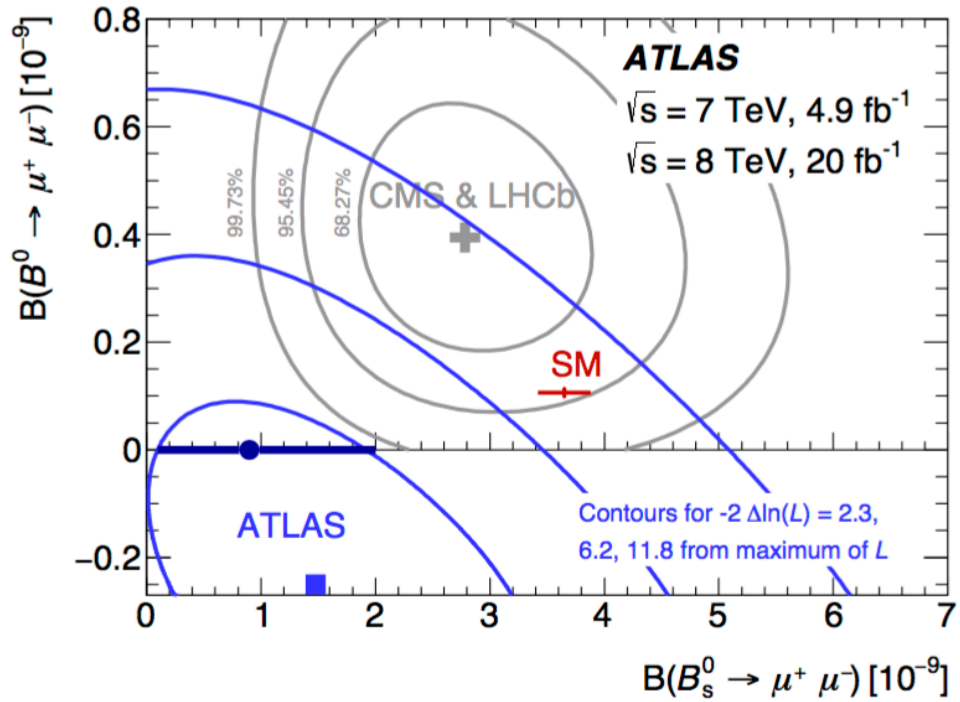
- Recently also ATLAS published their searches with the full Run-1 dataset
  - No significant signal is seen
  - A *p*-value of 4.8% (2σ) is found for the compatibility of the results with the SM prediction

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(0.9^{+1.1}_{-0.8}\right) \times 10^{-9}$$

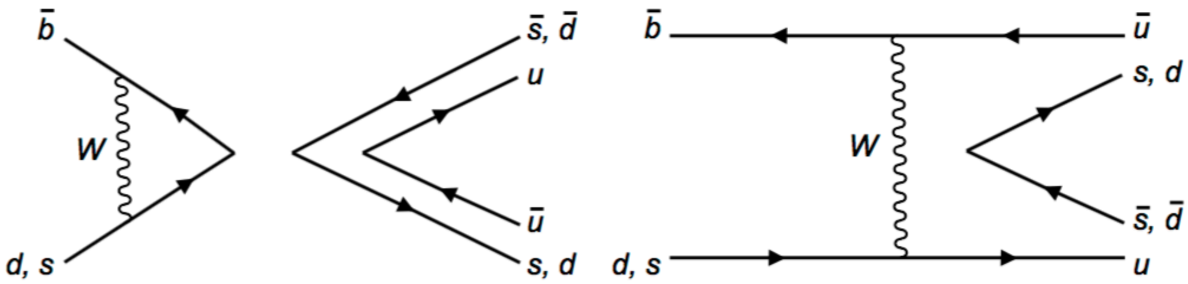
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.2 \times 10^{-10} \text{ (95\% CL)}$$

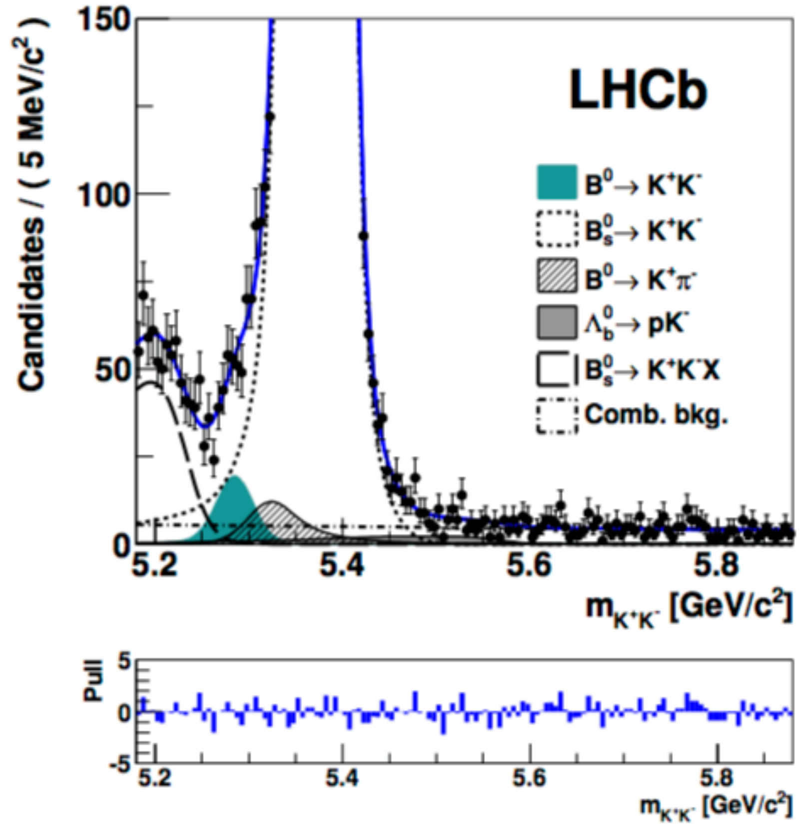
Eur. Phys. J. C76 (2016) 513





Charmless rare decays from LHCb





- Particular class of decays that can proceed only through so-called annihilation diagrams
- $B^0 \to K^+K^-$ decay observed for the first time after many years of searches
  - Significance 5.8σ

$$\mathcal{B}(B^0 \to K^+K^-) = (7.80 \pm 1.27 \pm 0.81 \pm 0.21) \times 10^{-8},$$

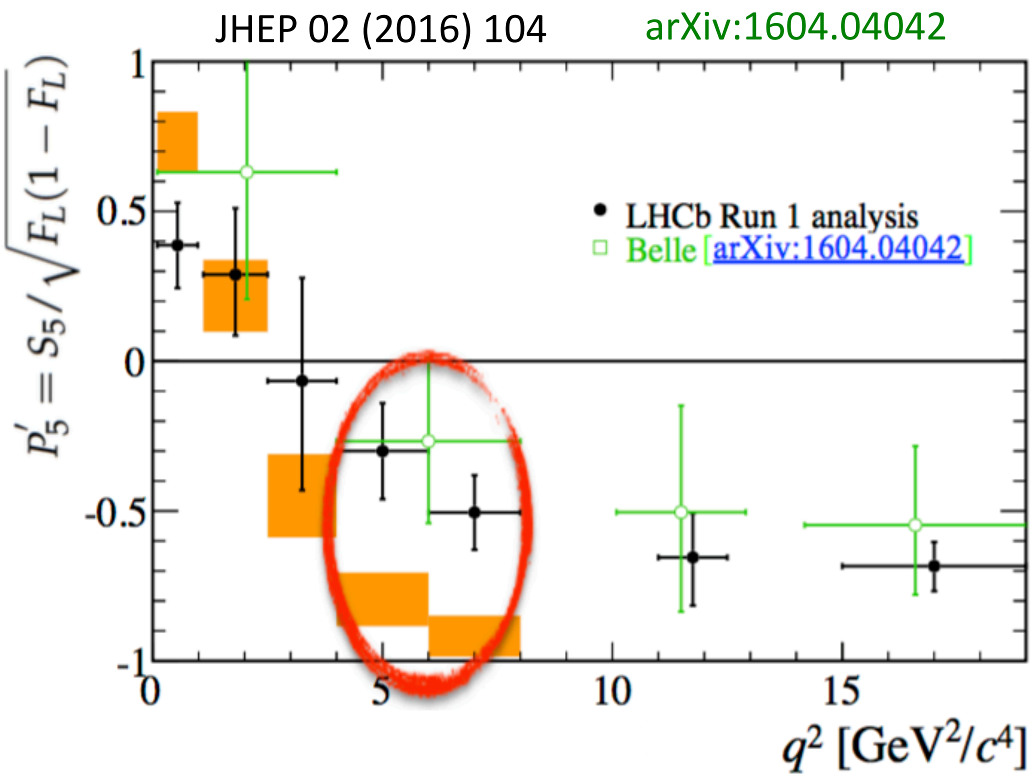
$$\mathcal{B}(B^0_s \to \pi^+\pi^-) = (6.91 \pm 0.54 \pm 0.63 \pm 0.19 \pm 0.40) \times 10^{-7}$$

- The $B^0 \to K^+K^-$ is the rarest *B*-meson decay into a fully hadronic final state ever observed

LHCb-PAPER-2016-036 arXiv:1610.08288

Angular analysis of $B^0 \rightarrow K^* \mu^+ \mu^-$

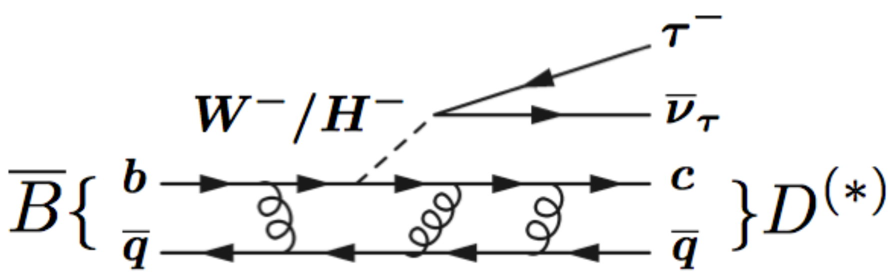
- Well established "anomaly"
  - Observables are q^2 (dimuon mass squared) and 3 angles
  - Angular distributions provide many observables sensitive to different sources of New Physics see e.g. JHEP 05 (2013) 137

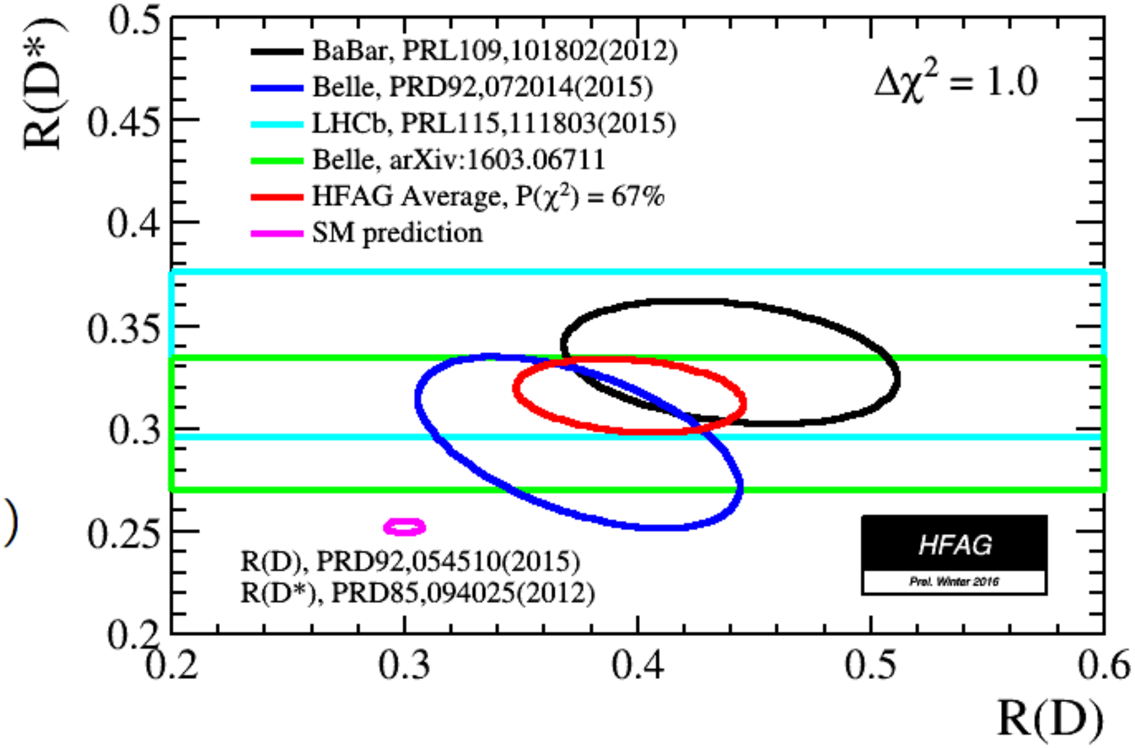


  - Some global theoretical fits require non-SM contributions to accommodate the data see e.g. JHEP 06 (2016) 092
  - However, genuine QCD effects can also be an explanation → more efforts needed to clarify the picture see e.g. JHEP 06 (2016) 116

LFU in $B \to D^{(*)}\tau\nu$

- Ratio $R_D^{(*)} = \mathfrak{B}(B \to D^{(*)}\tau\nu) / \mathfrak{B}(B \to D^{(*)}\mu\nu)$ is sensitive e.g. to charged Higgs scenarios





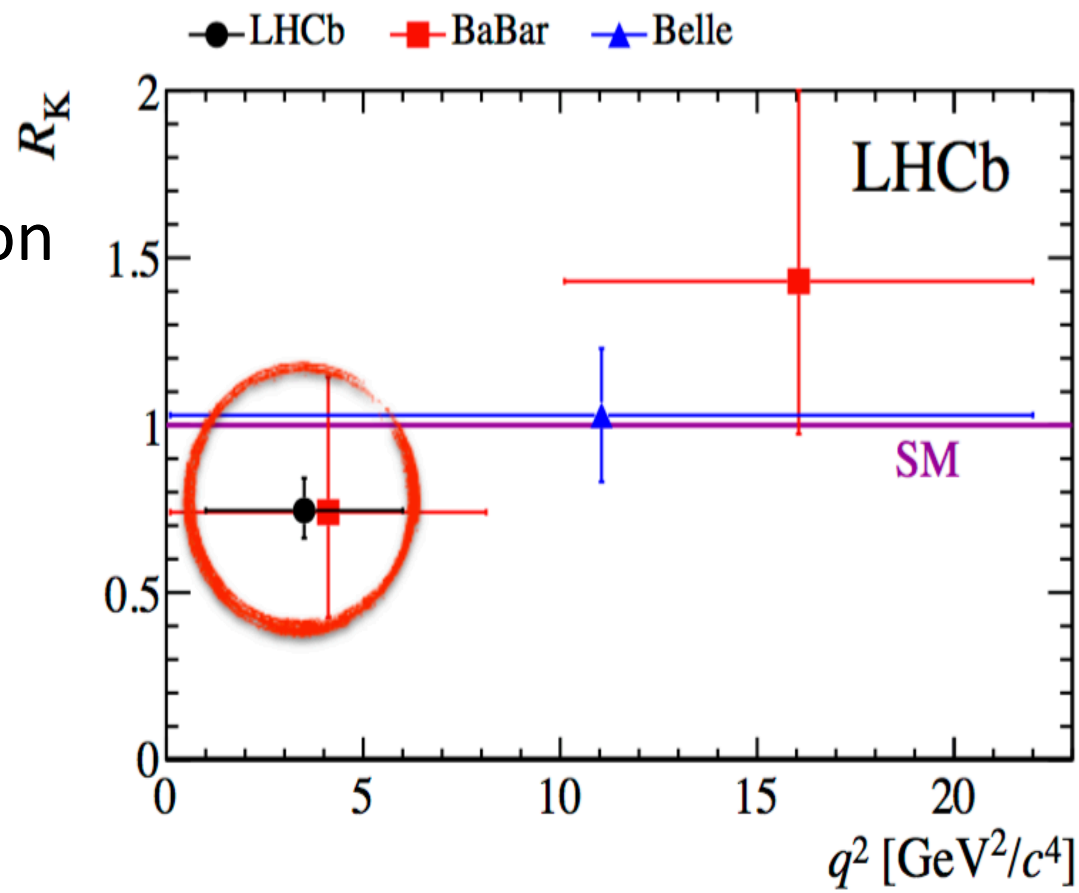
- Measurements of $R(D)$ and $R(D^*)$ by BaBar, Belle and LHCb
  - Overall average shows a 4σ discrepancy from the SM
- More analyses about $b \to c\tau\nu$ are ongoing at Belle and LHCb
- LHCb can also perform measurements with other *b* hadrons
  - e.g. B_s, B_c and Λ_b decays will help to better understand the global picture → stay tuned!

More LFU tests

- Ratio (R_K) of branching fractions of $B^+ \to K^+\mu^+\mu^-$ to $B^+ \to K^+e^+e^-$ expected to be unity in the SM with excellent precision

$$R_K = \frac{\int_{q^2_{\min}}^{q^2_{\max}} \frac{d\Gamma[B^+\to K^+\mu^+\mu^-]}{dq^2} dq^2}{\int_{q^2_{\min}}^{q^2_{\max}} \frac{d\Gamma[B^+\to K^+e^+e^-]}{dq^2} dq^2}$$

  - Observation of LFU violation would be a clear sign of New Physics
  - LHCb observed a 2.6σ deviation from SM in the low q^2 region
  - New measurements expected soon, e.g. R_{K*}



Phys. Rev. Lett. 113 (2014) 151601

LHC luminosity prospects

	LHC era			HL-LHC era	
	Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2021-24)	Run 4 (2027-30)	Run 5+ (2031+)
ATLAS, CMS	25 fb^{-1}	100 fb^{-1}	300 fb^{-1}	⟶	3000 fb^{-1}
LHCb	3 fb^{-1}	8 fb^{-1}	⟶	50 fb^{-1}	*300 fb^{-1}

* assumes a future LHCb upgrade to raise the instantaneous luminosity to $2x10^{34}$ $cm^{-2}s^{-1}$

- LHC is delivering luminosity at an incredibly high pace in Run-2
  - And remember that beauty production cross section roughly doubles passing from 7 to 13-14 TeV *pp* collisions
- LHCb (phase-1) upgrade comes already after Run-2, whereas the HL (phase-2) ATLAS and CMS upgrades come after Run-3
- But LHCb is now promoting a phase-2 upgrade for Run 5+ too

http://www.hep.manchester.ac.uk/theatre-of-dreams/index.html

Concluding remarks

- LHC is nowadays a gold mine for our physics, and this is just started
  - Impressive harvest so far!
  - Still to exploit full Run-1 potential, and beginning to deploy that of Run-2
  - And exciting times ahead with Belle II approaching data taking
- Some interesting anomalies to be studied more in depth during Run-2 and beyond
- In the current unclear state with perspectives in fundamental physics, it is necessary to have a programme as diversified as possible
  - In the unfortunate event that no direct evidence of NP pops out of the LHC, flavour physics can play a key role to indicate the way for future developments of elementary particle physics
  - And otherwise, flavour physics will be a crucial ingredient to understand the structure of what lies beyond the SM
- Just an appetiser today → new results to come in the course of the week not unveiled today!