

# Highlights & perspectives from the LHCb experiment

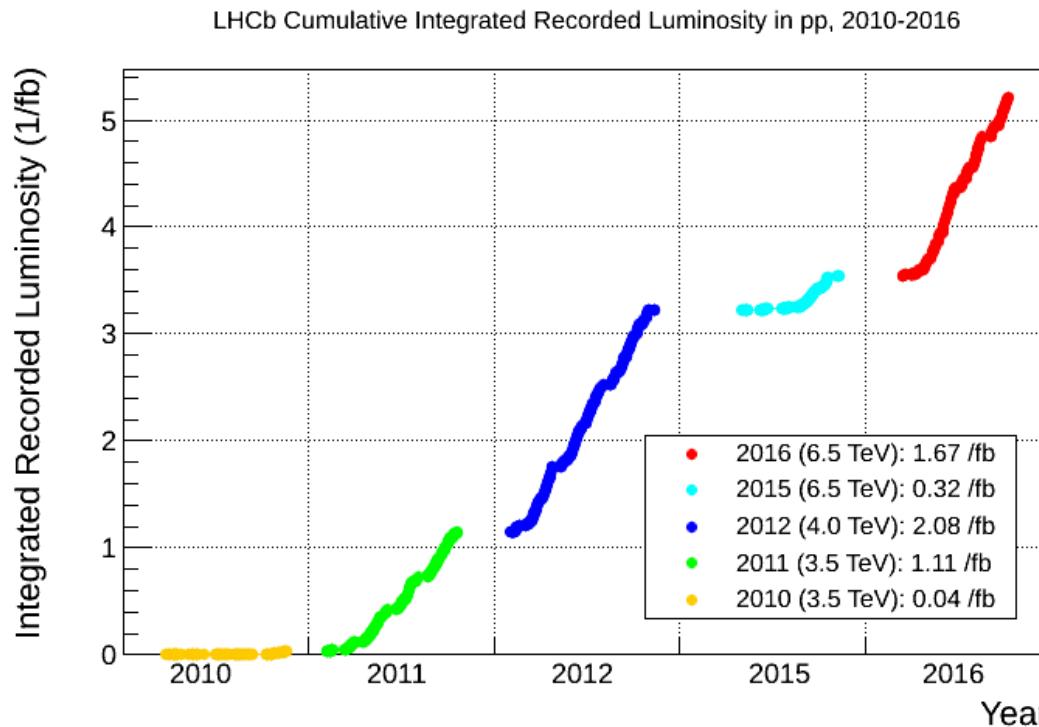
- Run-2 status
- Physics output: selected results
- The LS2 Upgrade, and beyond
- Conclusions

Guy Wilkinson  
(University of Oxford and CERN)  
on behalf of the LHCb collaboration  
LHCP 2017, Shanghai, 15/5/2017

# Run 2 status

# Run-2 data collection: pp collisions

Data taking was highly successful during 2016. We operated with high efficiency (~90%) and coped well with the unforeseen very high machine availability.

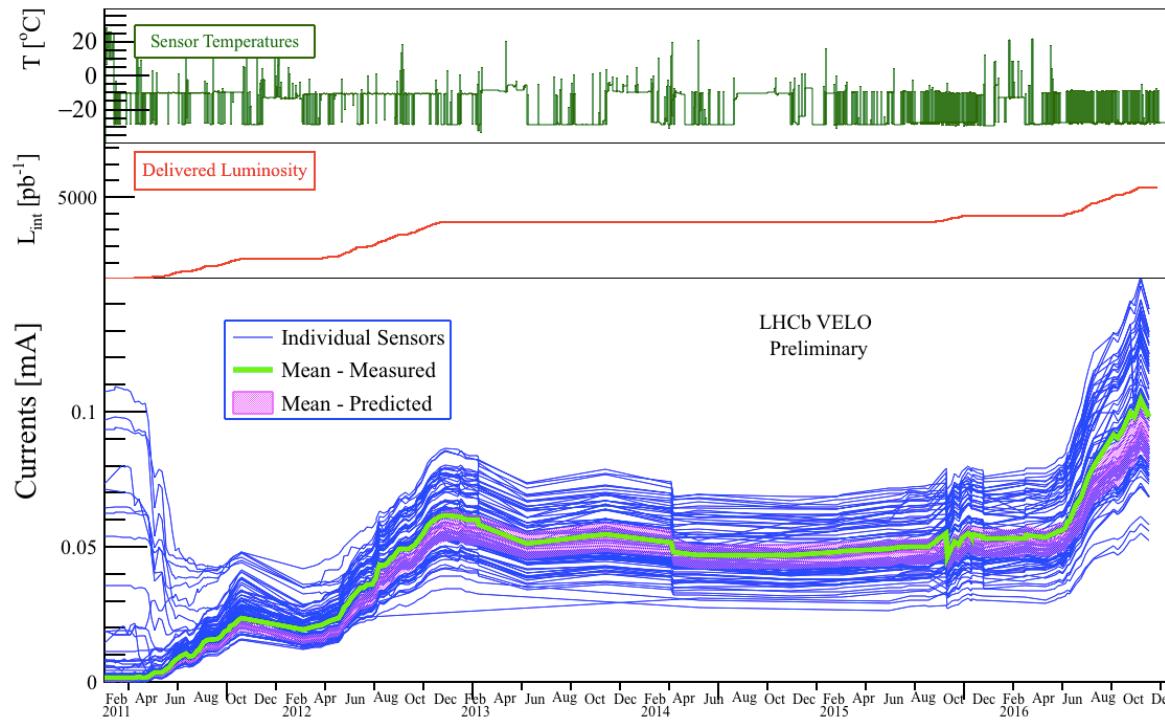


We collected  $\sim 1.7 \text{ fb}^{-1}$ , which given the higher  $E_{\text{CM}}$  & x-sec corresponds to a larger  $b\bar{b}$  sample than collected in all of run 1.

# Understanding of detector & readiness for resumption of data taking

Current detector is ageing gracefully, and as expected.

e.g. leakage currents in VELO are tracking predictions remarkably well



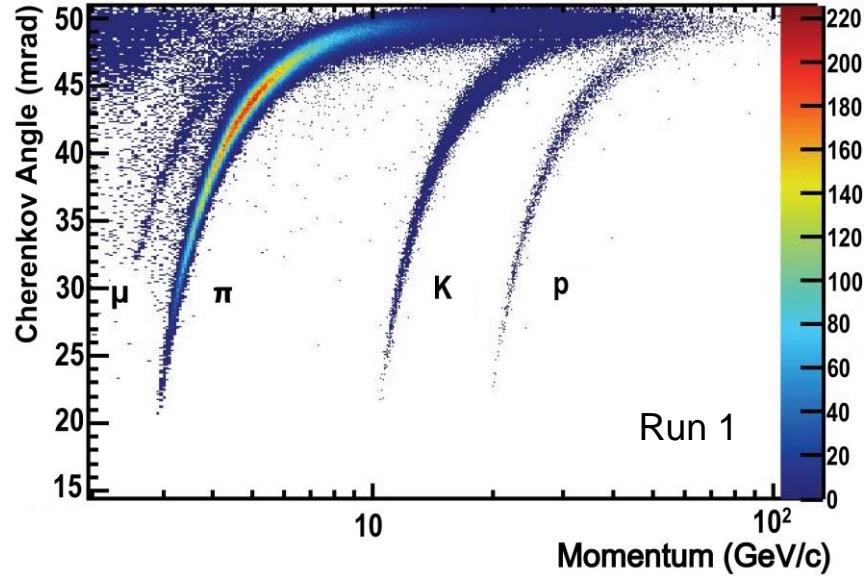
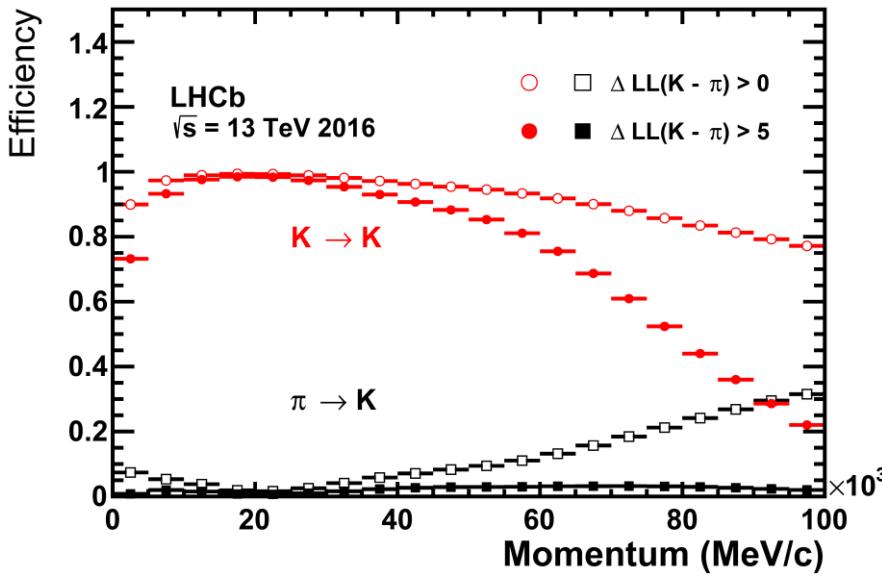
No need to install spare detector during run 2 (although we have one!).

Rather monitor situation and gradually increase operating voltage.

# Understanding of detector & readiness for resumption of data taking

Performance of all sub-detectors remains good, and in some cases is improving !

Contribution of RICH system to particle identification vital for LHCb physics

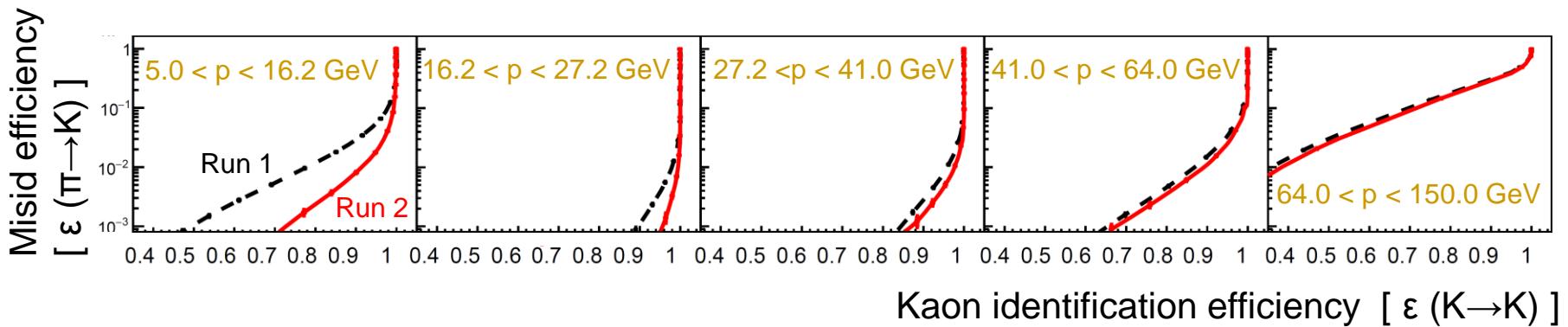


Performance very good in run 2, as in run 1. Let's make a detailed comparison....

# Understanding of detector & readiness for resumption of data taking

Performance of all sub-detectors remains good, and in some cases is improving !

e.g. RICH performance, run 1 vs. run 2 in one bin of pseudo-rapidity ( $3.1 < \eta < 3.6$ ).  
at low momentum benefit from removal of aerogel; at higher momentum, benefit  
from improved alignment and calibration, facilitated by being done in real time.



# Understanding of detector & readiness for resumption of data taking

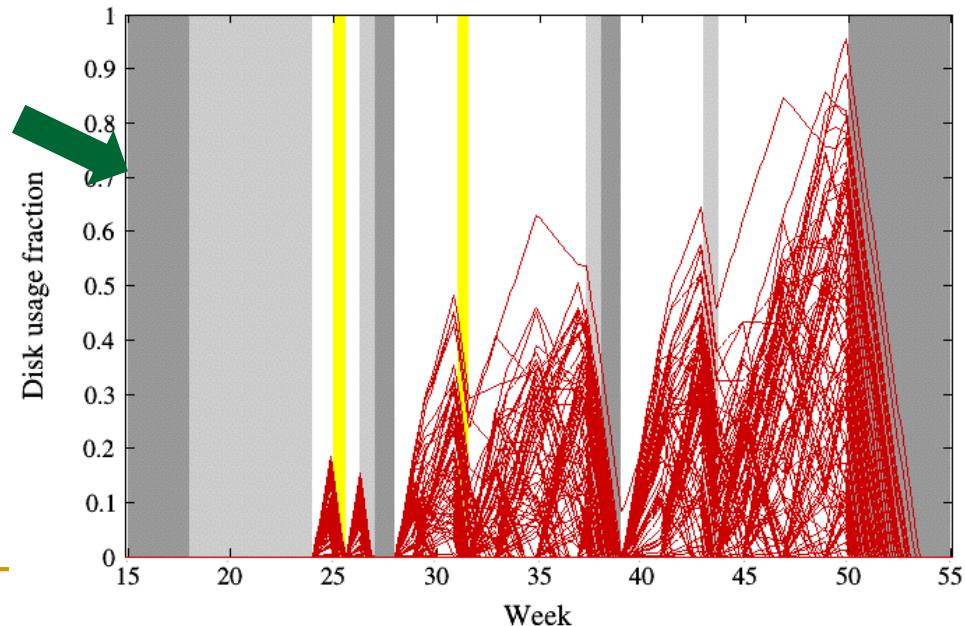
In 2016, thanks to high machine availability, we risked being drowned in data.



We approach 2017 with flexible trigger strategy that will allow us to respond quickly to changes in machine performance, without risk of overflowing disk buffer

Ensemble of simulated 2017 runs, assuming a mean 50% availability

Trigger, detectors and operations good to go. Waiting for collisions !



# Physics output: selected highlights

Production & spectroscopy

CP violation

FCNCs ('rare decays') and friends

64 papers submitted/published last year,  
20 already these year, and several conference reports.

Will give a taste of the most interesting results from the last 6 months,  
and a snapshot of our most important measurement programmes.

No new results today – leave these for my colleagues to show later this week !

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Production & spectroscopy

CP violation

FCNCs ('rare decays') and friends

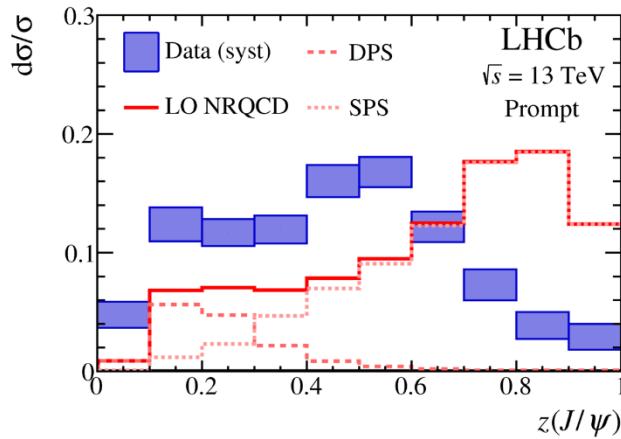
# Production studies in pp

Unique forward acceptance makes LHCb W, Z (& top) studies of great interest.

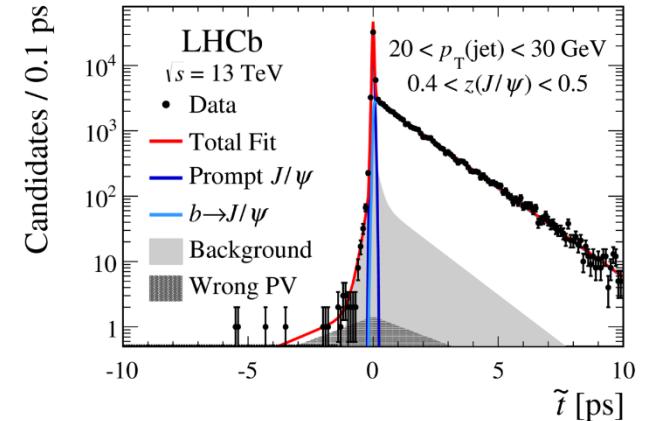
Also, noteworthy, are the continued studies of  $J/\psi$  etc. production, which are probe transition region between perturbative & non-perturbative regimes of QCD.

Recent example from run 2: “Study of  $J/\psi$  production in jets” [PRL 118 (2017) 192001]

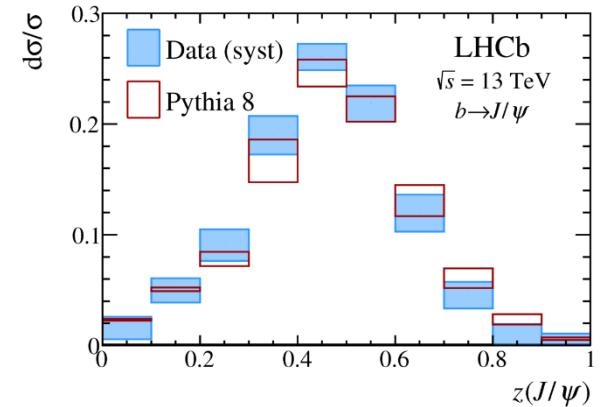
- Technically noteworthy, as relies on ‘TURBO’ stream, *i.e.* analysis solely uses trigger objects
- Measure  $z(J/\psi) \equiv p_T(J/\psi)/p_T(\text{jet})$ .
- Data distribution for prompt  $J/\psi$  disagrees with PYTHIA8 implemented (LO) NRQCD.



$J/\psi$ 's are much less isolated than predicted !

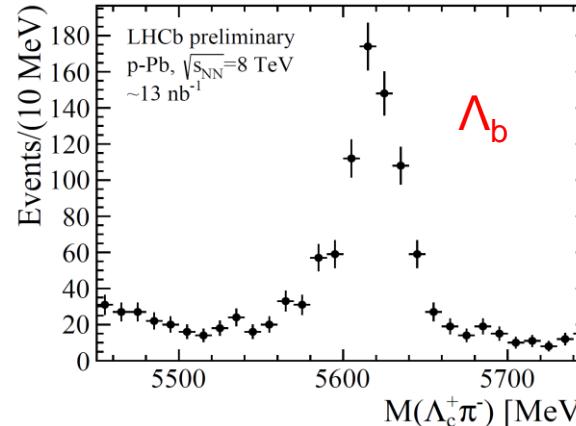
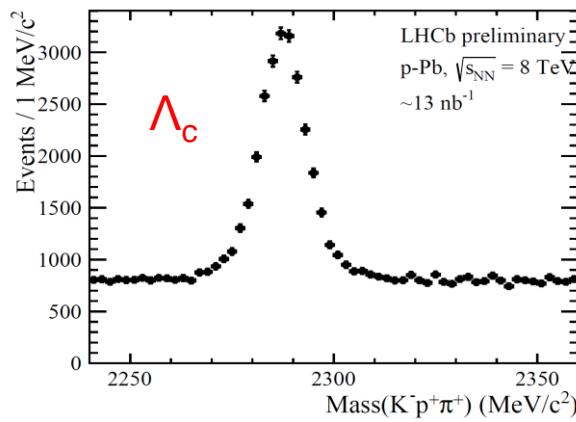
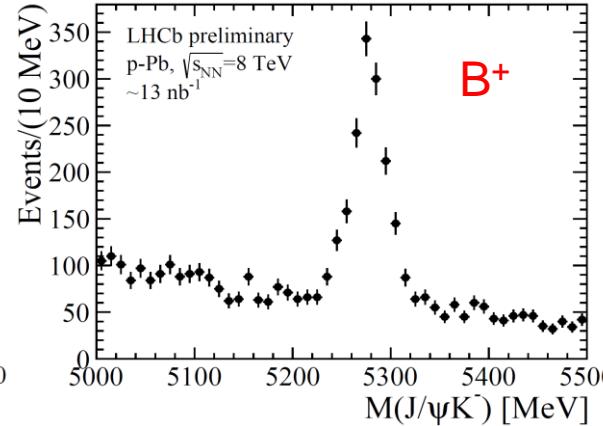
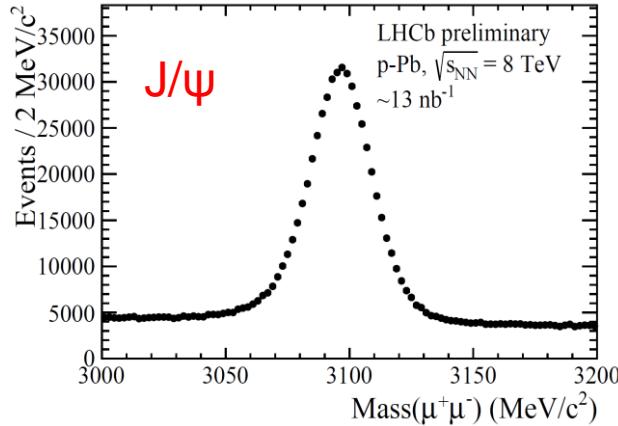


- Good agreement in case of  $J/\psi$ 's from b-hadrons



# Beyond pp – heavy-ion physics

LHCb continues to develop its programme in ion-ion and proton–ion physics.



Excellent  
signal quality  
from 2016  
p-Pb / Pb-p run.

Sample sizes  
 $>\times 10$  than run 1.

First measurements to be presented this week from the 2016 p-Pb / Pb-p run.

# Beyond pp: fixed-target physics

LHCb is the only experiment at the LHC that can operate in fixed-target mode, making use of unique gas-injection SMOG system.

This allows many studies of relevance to heavy-ion physics...  
...but also to particle astrophysics.

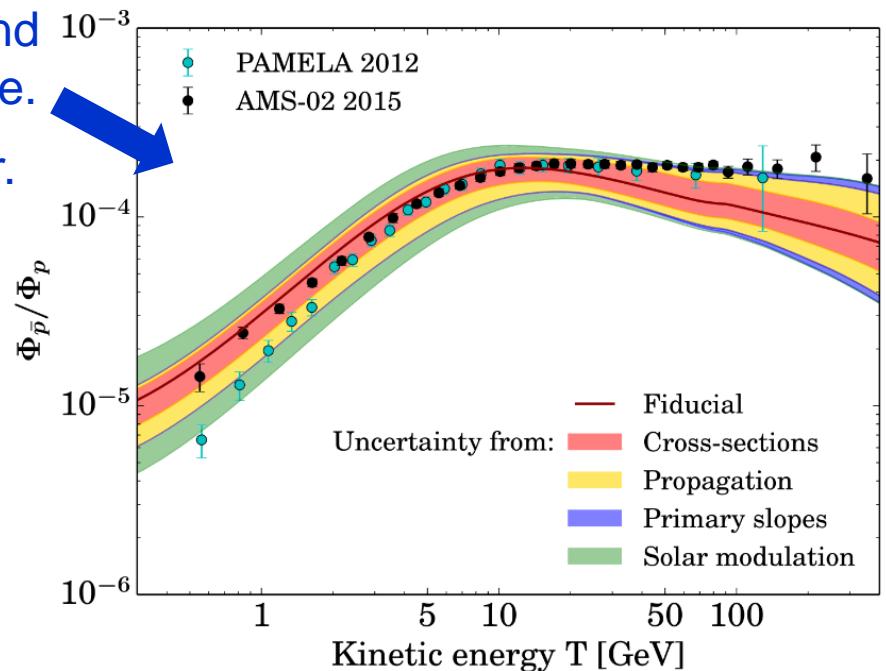
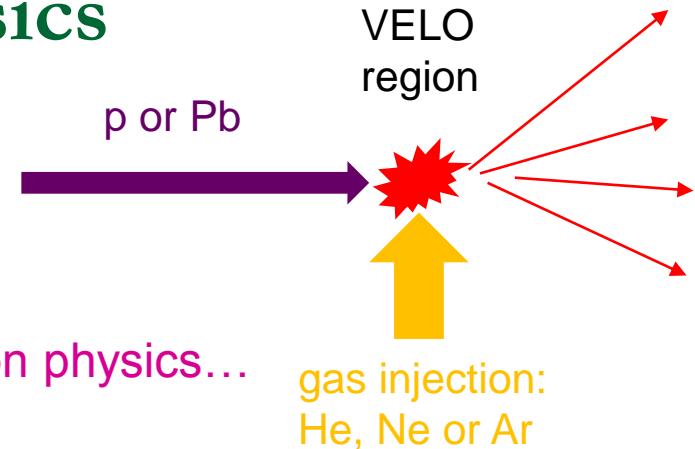
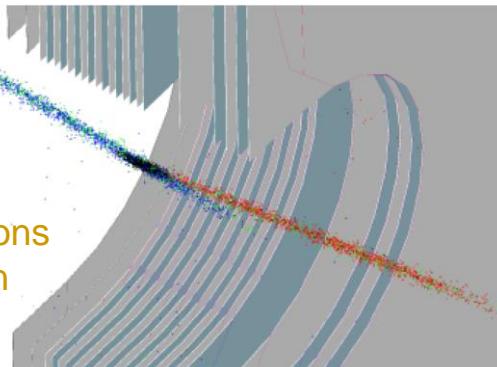
Studies of anti-matter in space (e.g. anti-protons) have shown an apparent excess which is behaviour that might be expected from annihilating dark matter.

However uncertainties from SM background coming from cosmic ray collisions are large.

→ Need to measure cross-sections better.  
e.g.  $p \text{ He} \rightarrow p\bar{p} X$

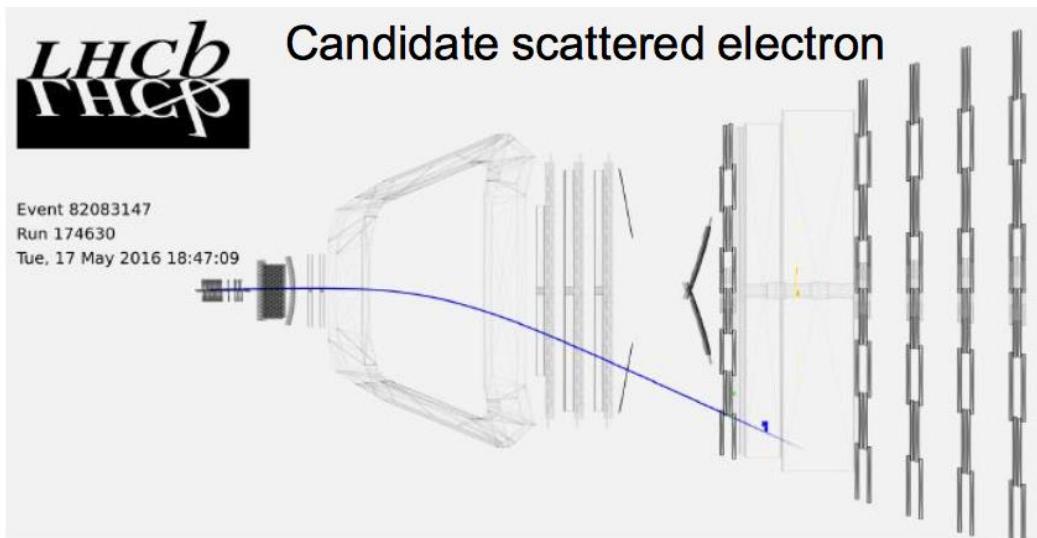
SMOG to the rescue !

beam-gas collisions in VELO region



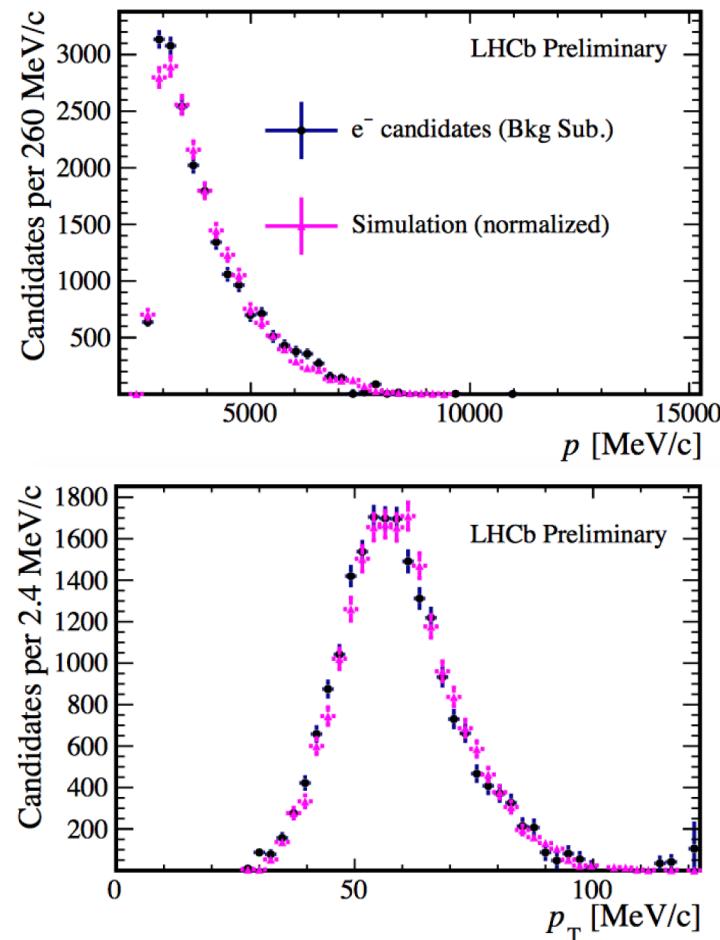
# Fixed-target physics: luminosity determination

In order to determine luminosity, count scattered atomic electrons, since cross-section of  $p + e^- \rightarrow p + e^-$  is well known.



$$\mathcal{L} = 0.443 \pm 0.011 \pm 0.027 \text{ nb}^{-1}$$

Good agreement between data and MC [LHCb-CONF-2017-002]



# Fixed-target physics: p He → p-bar X

[LHCb-CONF-2017-002]

Antiproton cross section  
measured with 10% precision  
at  $\sqrt{s_{NN}} = 110$  GeV.

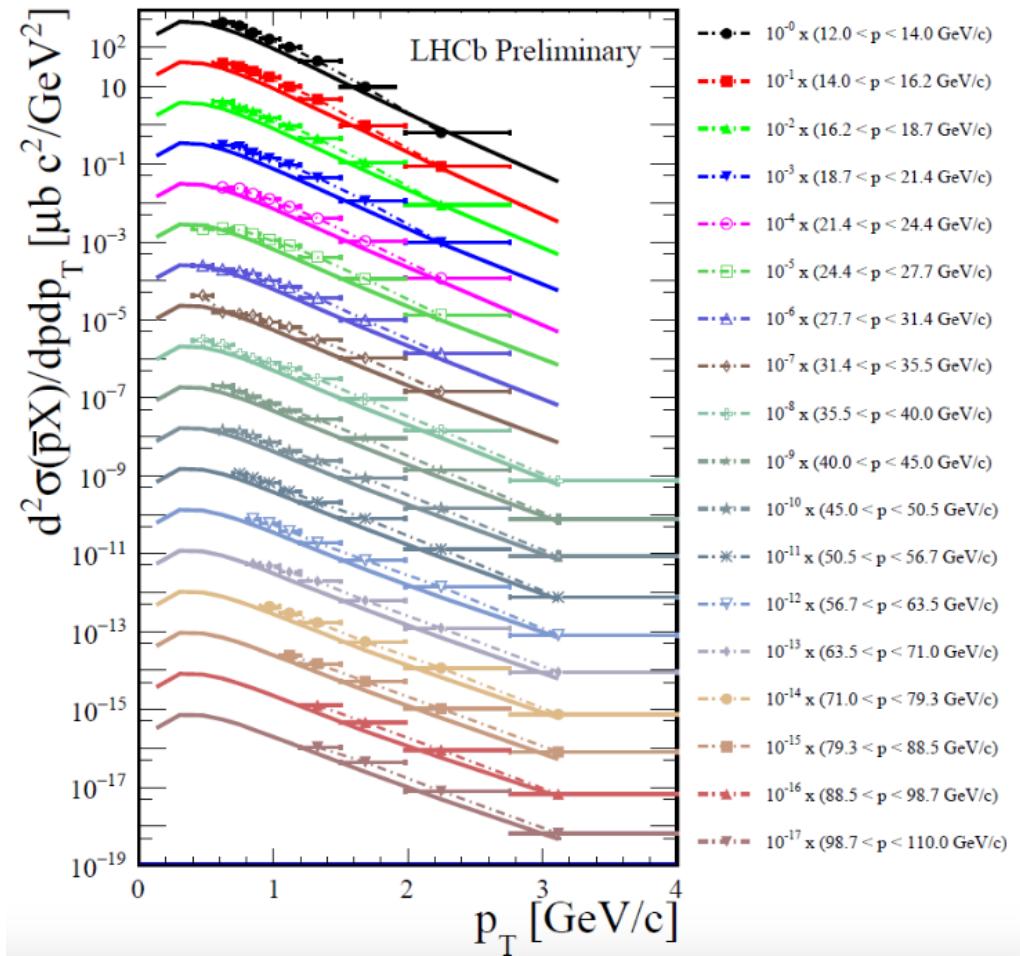
The measurements are larger by  
1.5 than EPOS LHC predictions.

Now being digested by  
cosmic-ray community.

Other production measurements  
are also important:

- antiprotons from  $\Lambda$ ;
- anti-deuterium;
- anti-He.

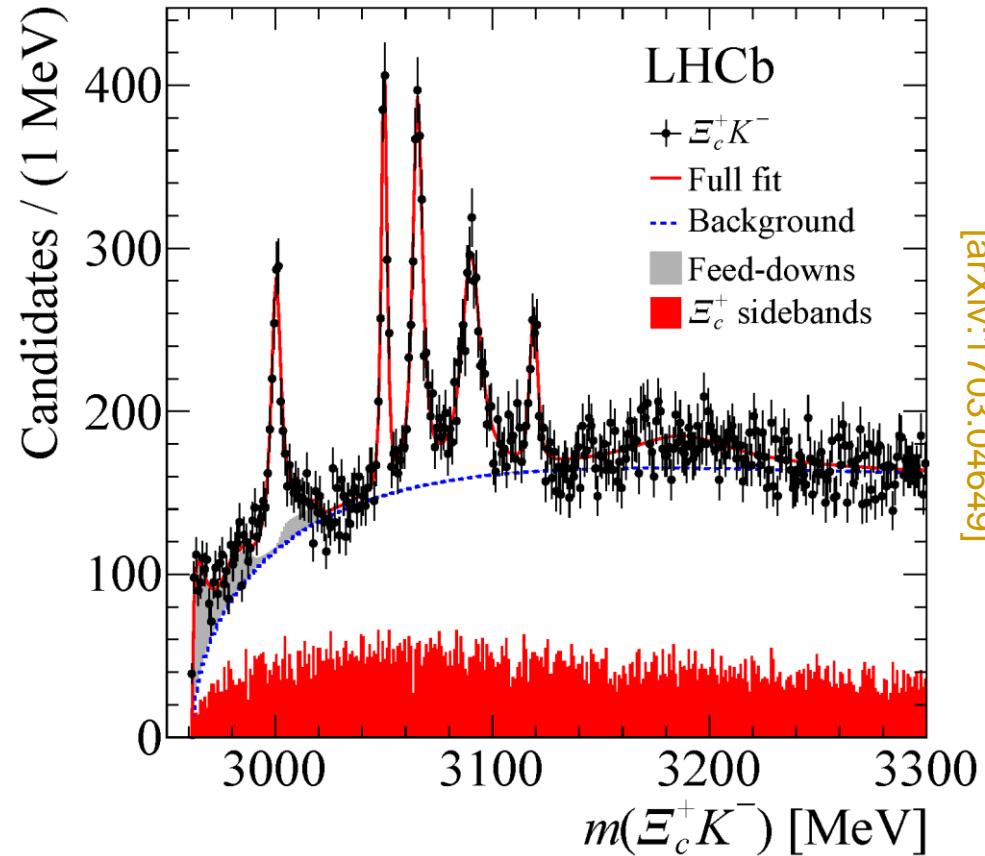
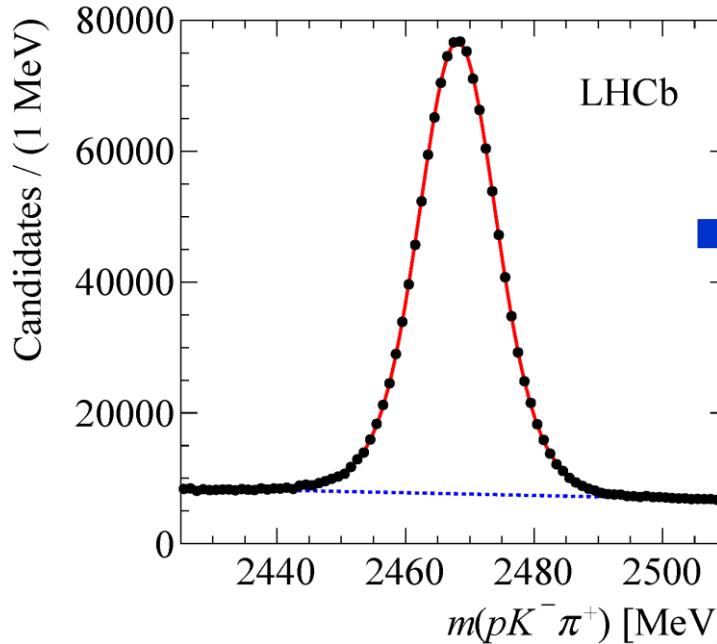
Rich programme to develop!



# Spectroscopy

LHC continues to be a ideal laboratory for hadron spectroscopy.

Take these and add a kaon...



Five (!) new narrow states found in the  $\Xi_c^+ K^-$  spectrum  $\rightarrow$  excited  $\Omega_c^0$  baryons.

# Physics output: selected highlights

Production & spectroscopy

CP violation

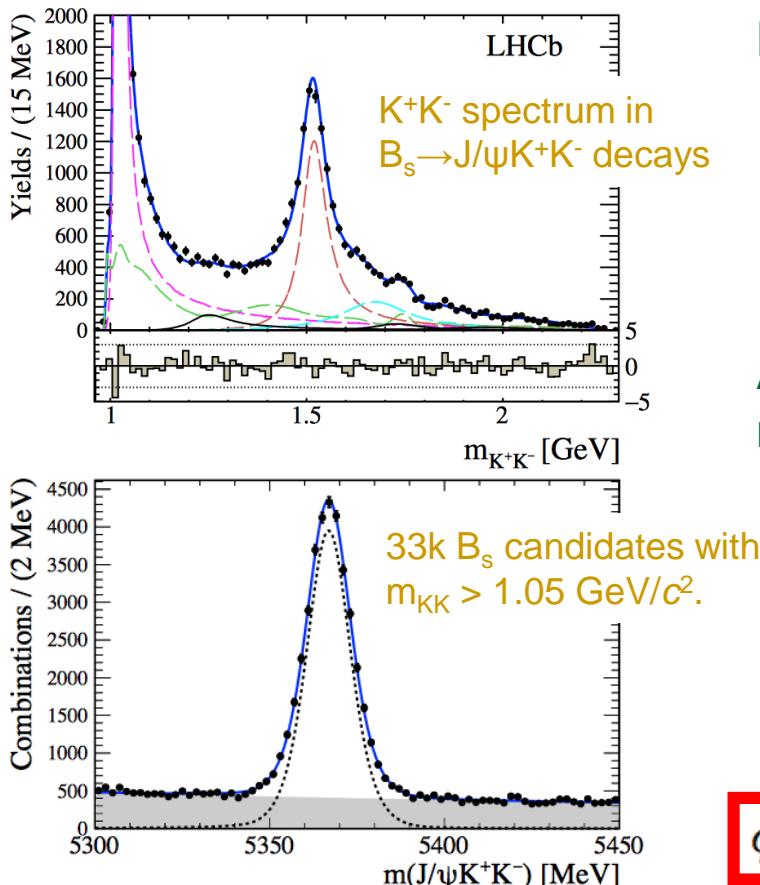
FCNCs ('rare decays') and friends

# CPV in the $B_s$ system: $\varphi_s$

Measurement of  $\varphi_s$ , the CP-violating phase from interference between  $B_s$  mixing and decay in channels such as  $B_s \rightarrow J/\psi\varphi(K^+K^-)$  a flagship measurement of LHCb.

Existing LHCb measurements had used  $B_s \rightarrow J/\psi K^+K^-$  data around the  $\varphi$ , as well as  $B_s \rightarrow J/\psi\pi\pi$ . Now augment this with  $m_{KK} > 1.05 \text{ GeV}/c^2$  data [arXiv:1704.08217].

Challenging, as requires time-dependent amplitude analysis.



High mass region:

$$\begin{aligned}\phi_s &= 119 \pm 107 \pm 34 \text{ mrad}, \\ |\lambda| &= 0.994 \pm 0.018 \pm 0.006, \\ \Gamma_s &= 0.650 \pm 0.006 \pm 0.004 \text{ ps}^{-1}, \\ \Delta\Gamma_s &= 0.066 \pm 0.018 \pm 0.010 \text{ ps}^{-1}.\end{aligned}$$

Averaging with existing low mass result [PRL 114 (2015) 041801] :

$$\begin{aligned}\phi_s &= -25 \pm 45 \pm 8 \text{ mrad}, \\ |\lambda| &= 0.978 \pm 0.013 \pm 0.003, \\ \Gamma_s &= 0.6588 \pm 0.0022 \pm 0.0015 \text{ ps}^{-1}, \\ \Delta\Gamma_s &= 0.0813 \pm 0.0073 \pm 0.0036 \text{ ps}^{-1}.\end{aligned}$$

(  $|\lambda|$  different from unity would indicate direct CPV )

Including  $B_s \rightarrow J/\psi\pi^+\pi^-$  [PLB 736 (2014) 186] :

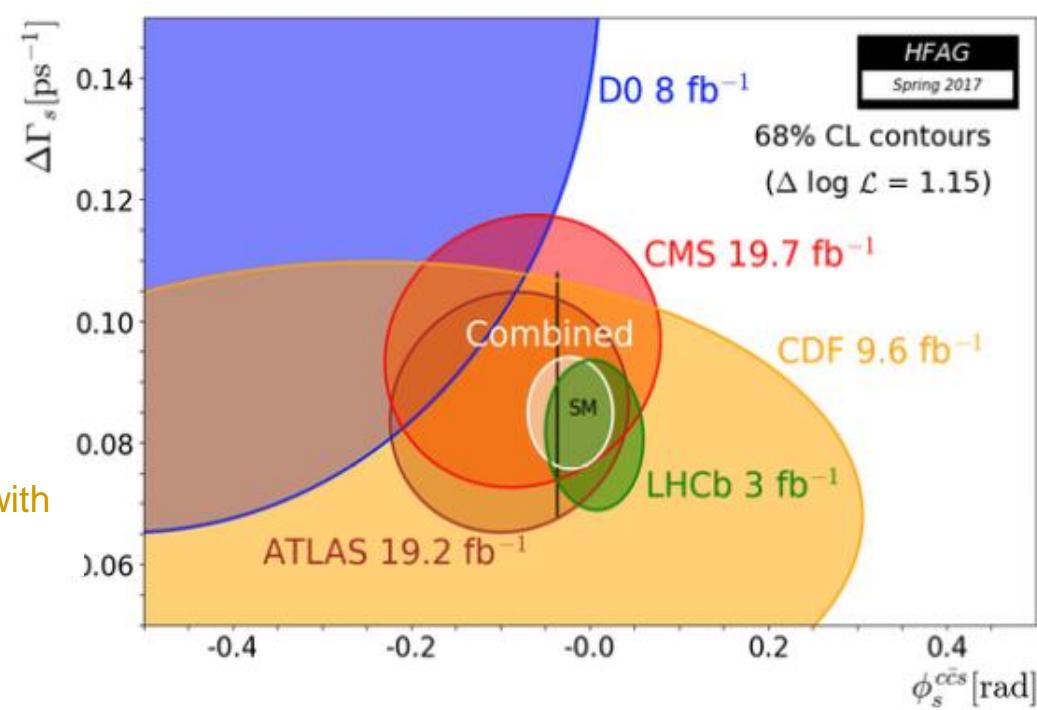
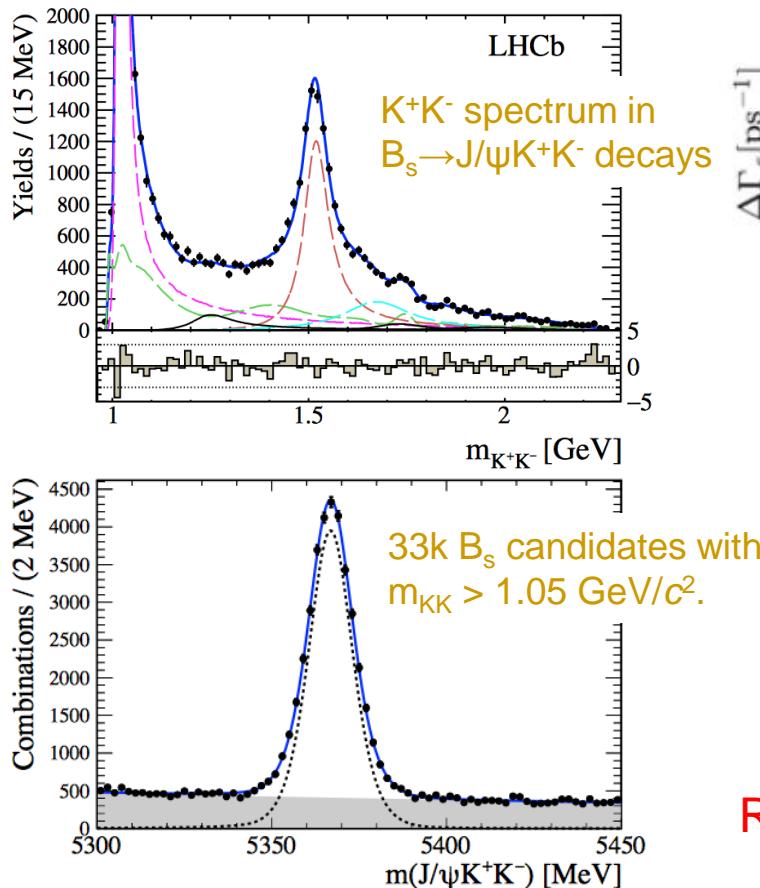
$$\phi_s = 1 \pm 37 \text{ mrad} \text{ and } |\lambda| = 0.973 \pm 0.013$$

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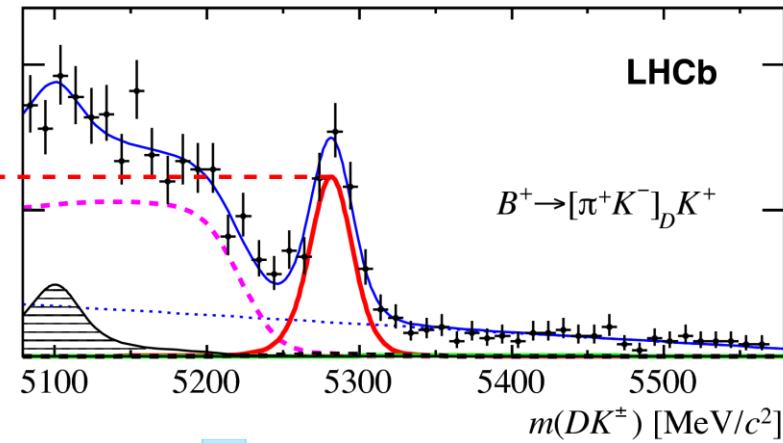
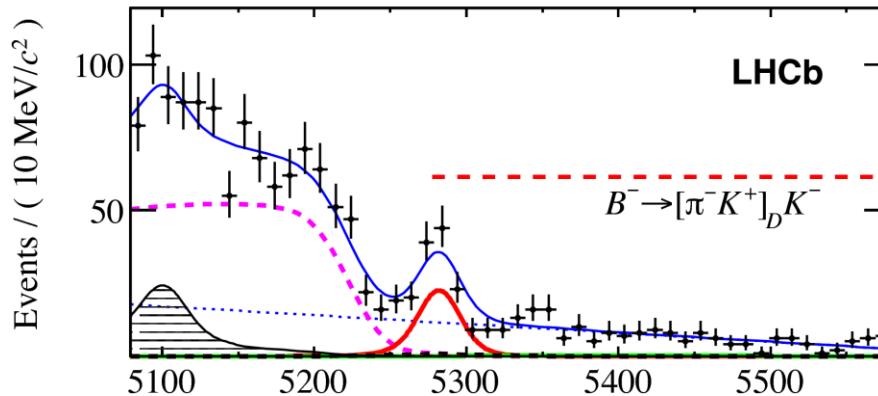
Challenging, as requires time-dependent amplitude analysis.



Run-1 legacy result – now focus is on run-2 data.

# CPV and the Unitarity Triangle: $\gamma$

Almost all the best channels for the determination of the CKM angle  $\gamma$  have now been analysed for run 1. For example, suppressed ‘ADS’ mode,  $B^- \rightarrow (\pi^- K^+)_D K^-$  (+CC):



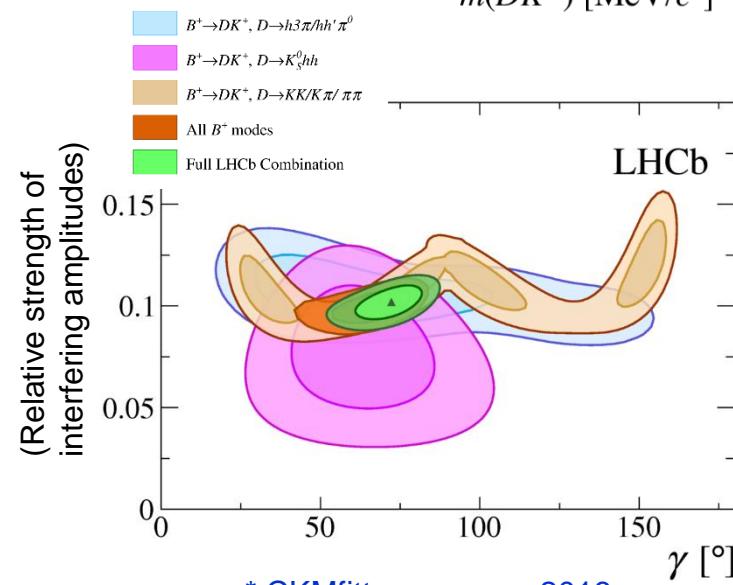
Combination of LHCb  $B \rightarrow DK$   
results obtained so far

$$\gamma = (72.2^{+6.8}_{-7.3})^\circ$$

Uncertainty significantly better than that obtained with combined B-factory results.

Agrees with prediction \*  
from rest of triangle  $\gamma^{\text{indirect}} = (65.3^{+1.0}_{-2.5})^\circ$

No theory or experimental showstopper.  
Aim for factor ~2 improvement from run 2.



\* CKMfitter, summer 2016

[PLB 760 (2016) 117]

[JHEP 12 (2016) 087]

# Physics output: selected highlights

Production & spectroscopy

CP violation

FCNCs ('rare decays') and friends

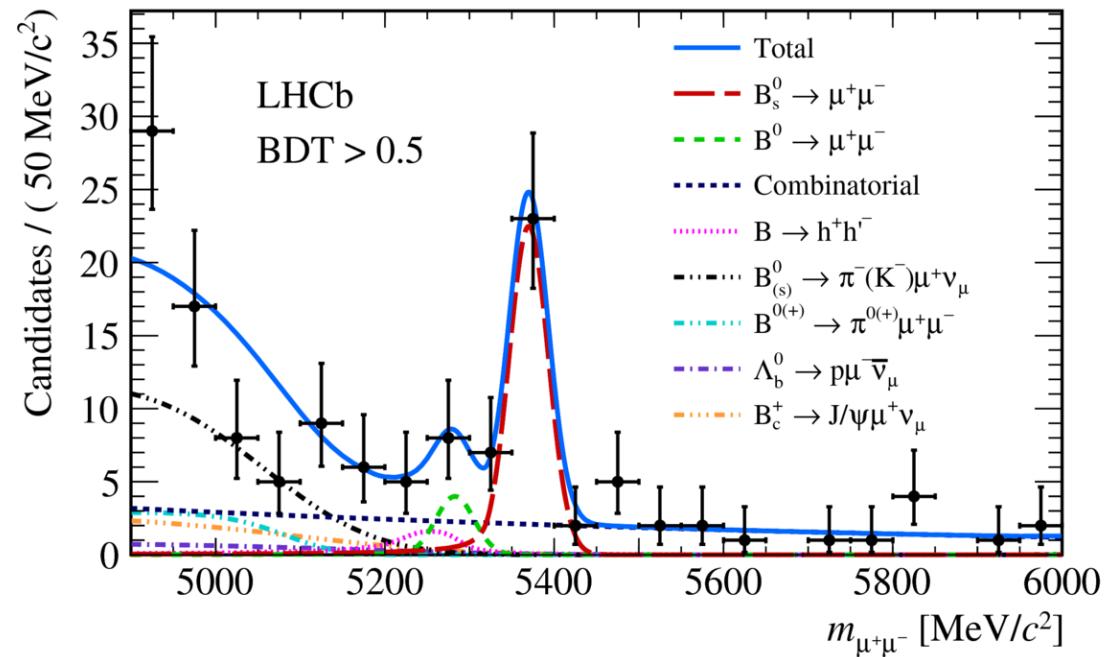
# The golden mode: $B_s \rightarrow \mu^+ \mu^-$

[PRL 118 (2017) 191801]

Recall:  $B_s \rightarrow \mu\mu$  is ultra-rare in the Standard Model ( $\sim 3 \times 10^{-9}$ ) & very sensitive to New Physics contributions. LHCb found first evidence in Run 1 [PRL 110 (2013) 021801], & then a combined LHCb-CMS analysis yielded a  $5\sigma$  observation [Nature 522 (2015) 68].

We have now returned to this critical observable with an improved analysis (~50% combinatoric background than previously). Run 1 + 1.4  $\text{fb}^{-1}$  of Run-2 data.

- 7.8  $\sigma$  signal & first single-experiment observation !
- Precise measurement of branching fraction  
$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$$
- No evidence yet of the corresponding  $B_d^0$  decay



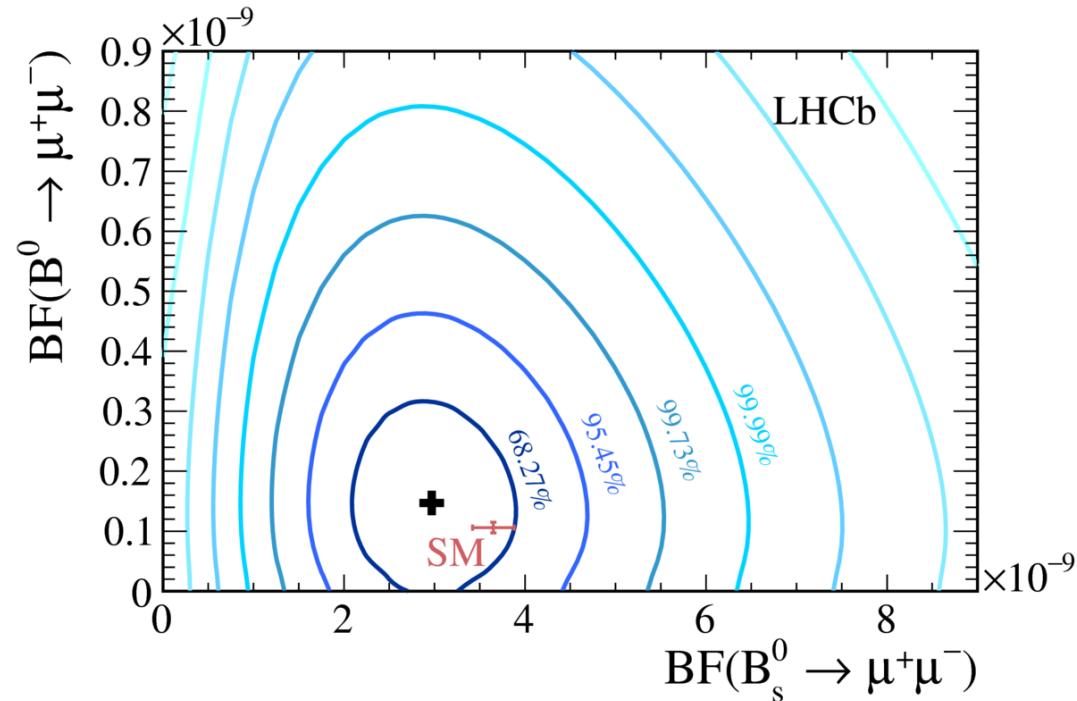
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Results are very compatible with Standard Model, and will tighten further constraints on New Physics models with an extended scalar sector.



# The golden mode: $B_s \rightarrow \mu^+ \mu^-$

[PRL 118 (2017) 191801]

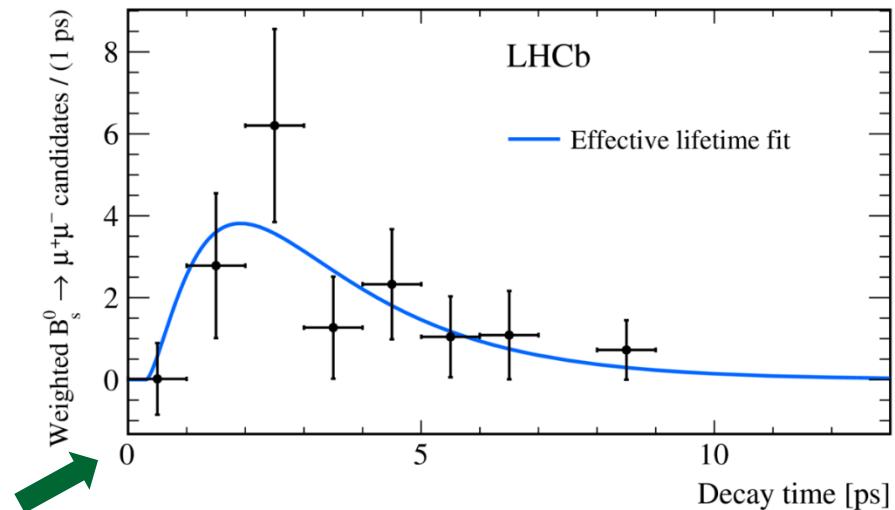
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We have now returned to this critical observable with an improved analysis (~50% combinatoric background than previously). Run 1 +  $1.4 \text{ fb}^{-1}$  of Run-2 data.

This is not the end of the story !

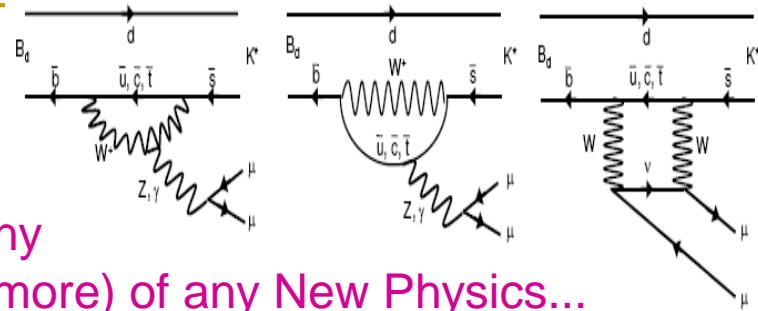
Vital that these branching ratios are measured ever more precisely - a key goal of the LHCb Upgrade.

In addition, we may start to probe over observables associated with the decay, e.g. the effective lifetime.



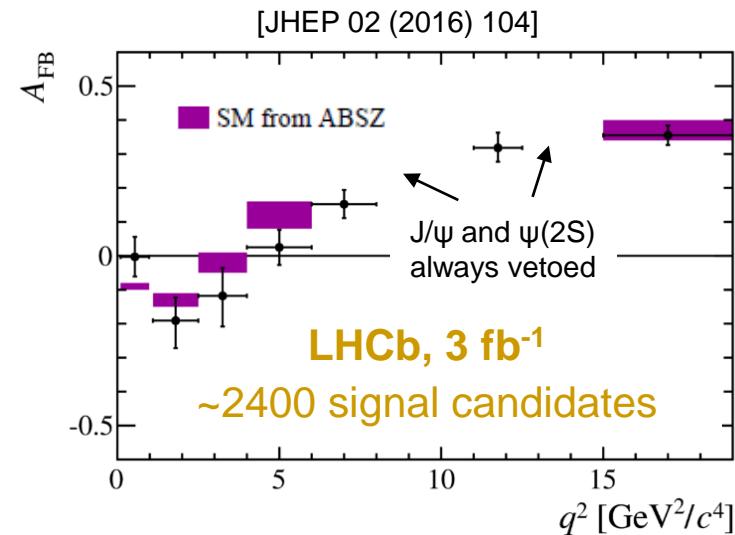
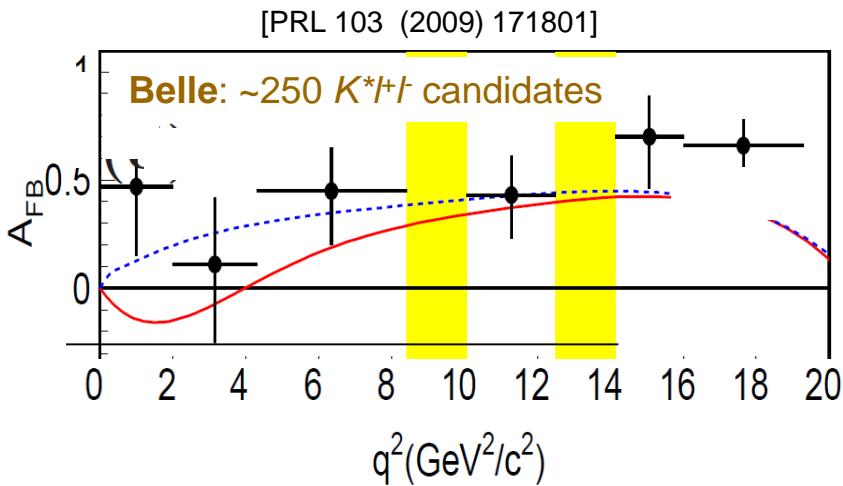
Proof-of-principle measurement

# $B^0 \rightarrow K^* l^+ l^-$ and friends



$b \rightarrow (s,d)l^+l^-$  decays such as  $B^0 \rightarrow K^* l^+ l^-$  offer many observables which probe helicity structure (& more) of any New Physics...

The B-factory experiments had inadequate statistics for meaningful tests. This has now all changed, e.g. forward-backward asymmetry vs  $q^2$  (dilepton mass).

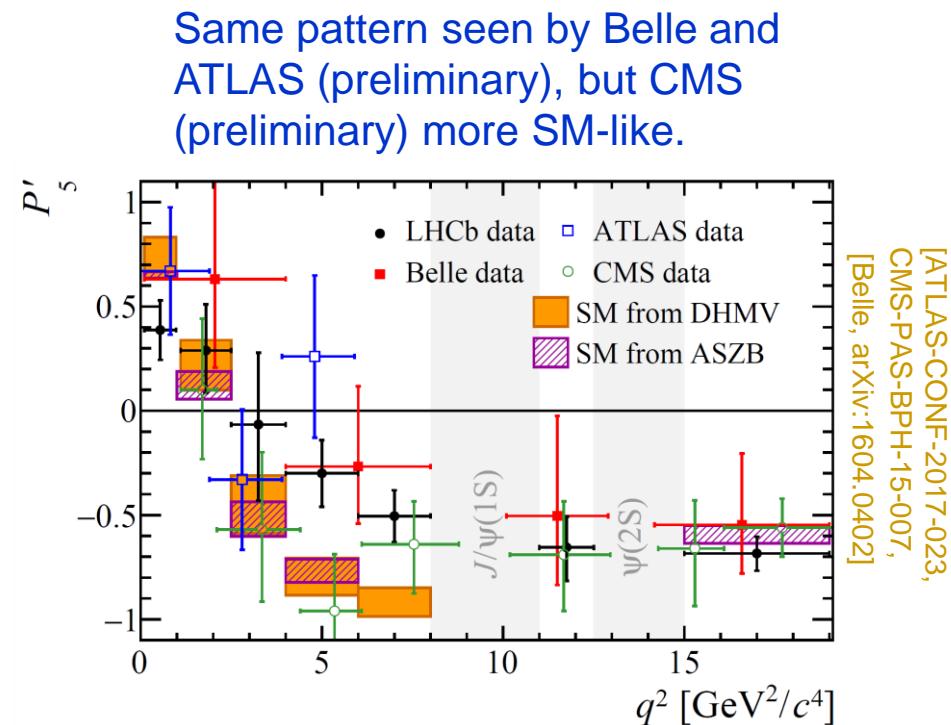
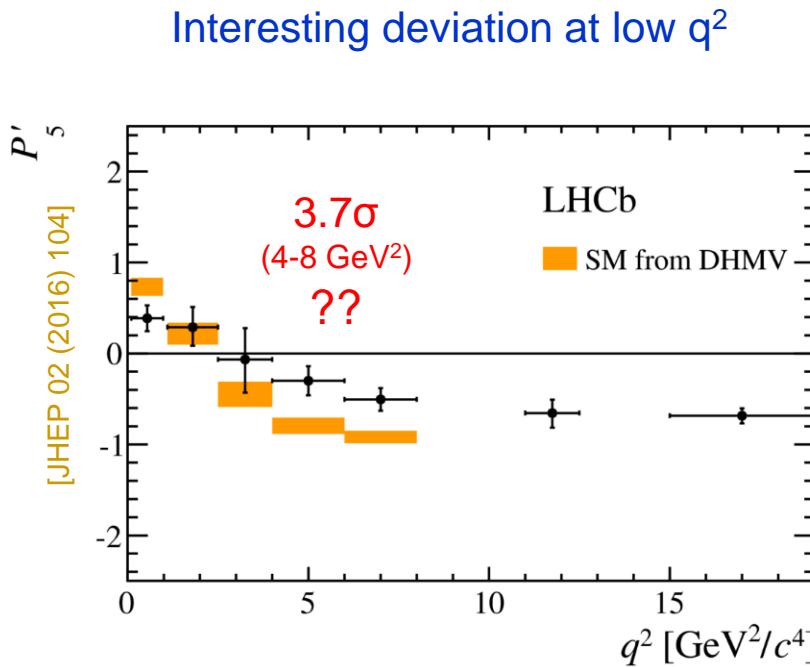


But there are many other observables, which can be built from the measured amplitudes, & are constructed to be intrinsically robust against form factor uncertainties, e.g. “ $P_5'$ ”

General pattern as predicted;  
mild tension at low  $q^2$

# $B^0 \rightarrow K^* l^+ l^-$ and friends: the $P_5'$ conundrum

One such observable is  $P_5'$ : What this describes physically is hard to visualise, but it is constructed from angular observables in a manner that is robust against form-factor uncertainties, and also easily relatable to the short-distance physics.

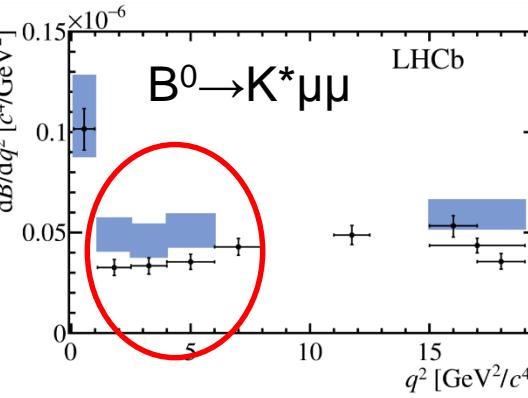
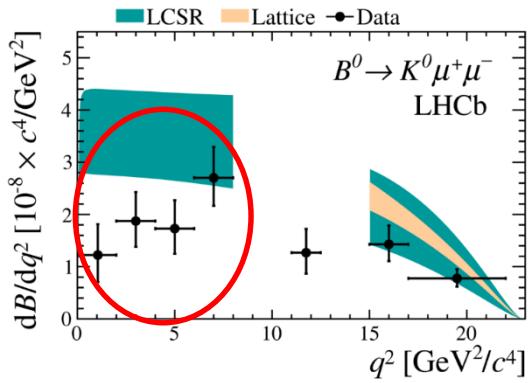


A word of caution. The SM uncertainties shown here are from one group. There are other values on the market, and some are more conservative.

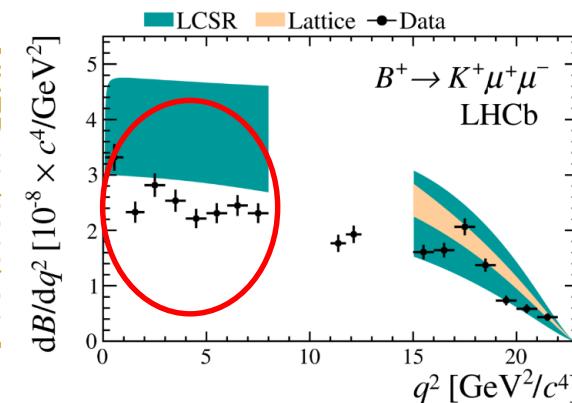
# $B^0 \rightarrow K^* l^+ l^-$ and friends: differential x-secs

$P_5'$  is not the only funny thing going on in  $b \rightarrow (s,d)l^+l^-$  decays.

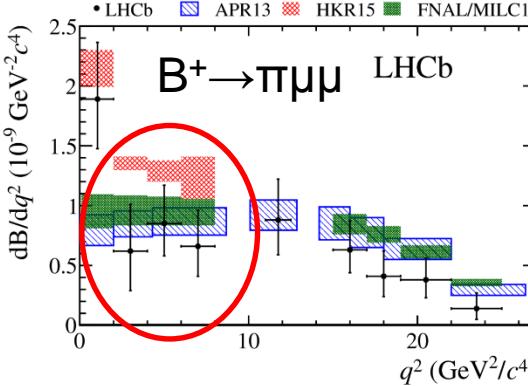
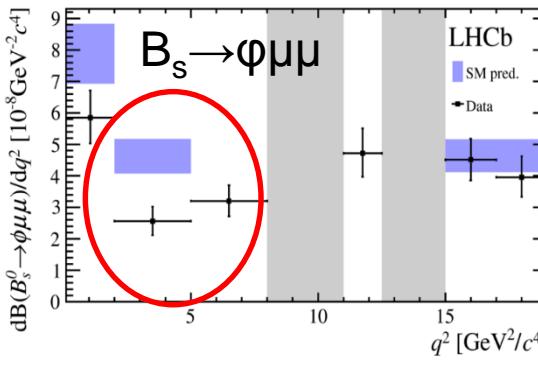
[JHEP 06 (2014) 133]



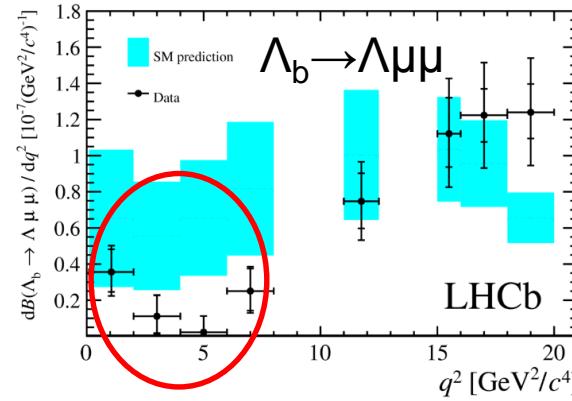
[JHEP 11 (2016) 047]



[JHEP 09 (2015) 179]



[JHEP 10 (2015) 034]



[JHEP 06 (2014) 133]

[JHEP 06 (2015) 009]

Consistent tendency for differential x-sections to undershoot prediction at low  $q^2$ .  
Intriguing – but maybe the uncertainties in theory are larger than claimed ?

# Lepton universality tests with $b \rightarrow s l^+ l^-$ decays

The cleanest way to probe these decays are with lepton universality (LU) tests, i.e. comparing decays with di-electrons and di-muons. Negligible theory uncertainty.

- First done [PRL 113 (2014) 151601] by LHCb with  $B^+ \rightarrow K^+ l^+ l^-$  decays

$R_K$  = ratio of dimuon to dielectron decay rates, for  $1 < q^2 < 6 \text{ GeV}^2$

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

$2.6\sigma$  low – a statistical fluctuation ?

- An analogous measurement has now been performed with  $B^0 \rightarrow K^* l^+ l^-$  [LHCb-PAPER-2017-013] :

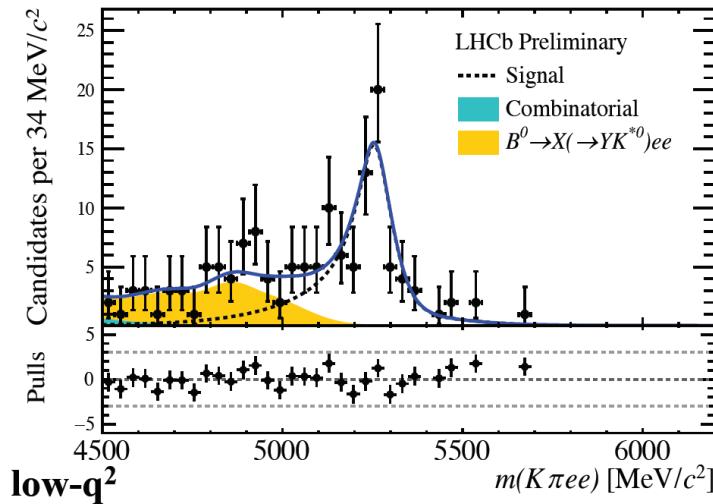
$$\mathcal{R}_{K^{*0}} = \frac{\mathcal{B}(B^0 \rightarrow K^{*0} \mu^+ \mu^-)}{\mathcal{B}(B^0 \rightarrow K^{*0} J/\psi (\rightarrow \mu^+ \mu^-))} \Bigg/ \frac{\mathcal{B}(B^0 \rightarrow K^{*0} e^+ e^-)}{\mathcal{B}(B^0 \rightarrow K^{*0} J/\psi (\rightarrow e^+ e^-))}$$

This double ratio (also employed for  $R_K$ ), involving the control mode  $B^0 \rightarrow J/\psi K^*$ , ensures that all 1<sup>st</sup> order systematics in efficiency cancel – robust !

Measure in similar  $q^2$  region as for  $R_K$  ('central  $q^2$ ': 1.1 - 6  $\text{GeV}^2$ ), but also perform measurement in a low  $q^2$  bin ( 0.045 - 1.1  $\text{GeV}^2$ ).

# Lepton universality tests with $b \rightarrow s l^+ l^-$ decays: $R_{K^*}$

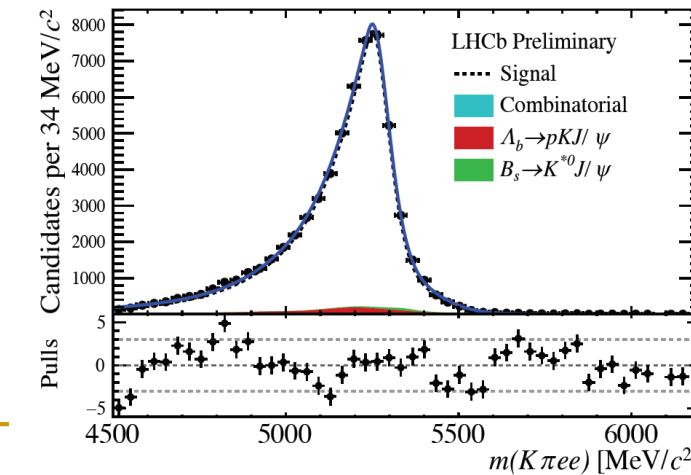
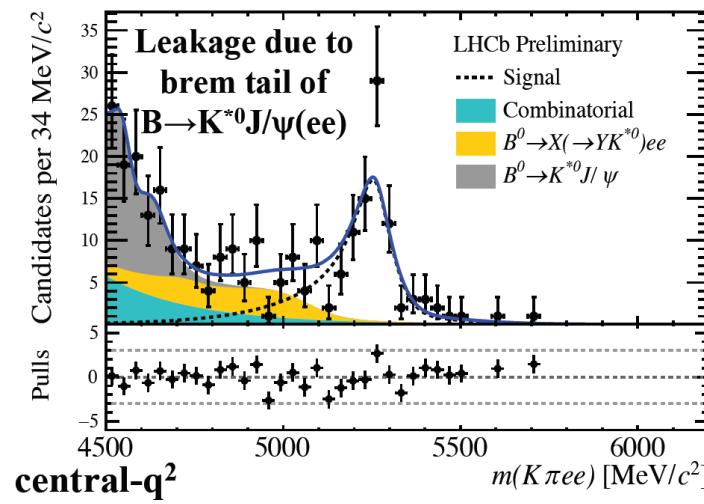
## Mass spectra in di-electron final state



Around 90 and 110 signal candidates in low- $q^2$  and central  $q^2$ , respectively.

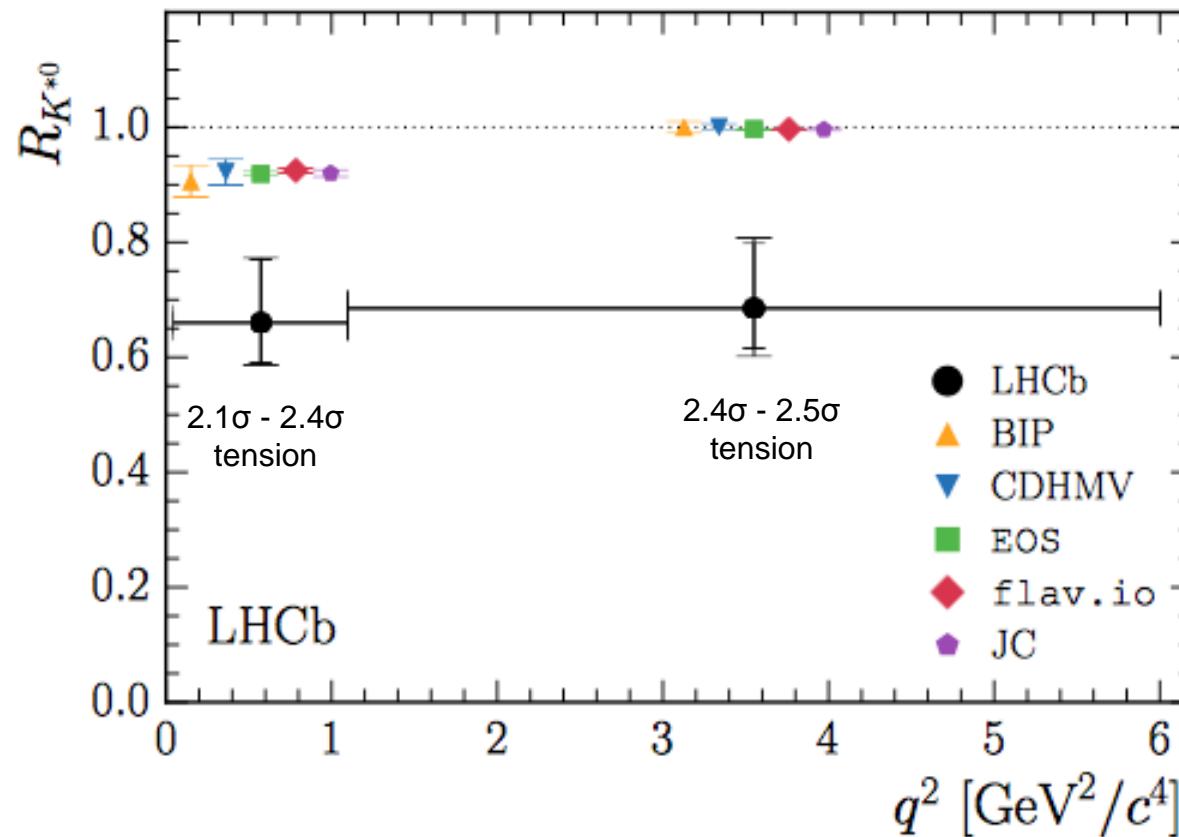
58k in control channel

Muon samples 3-5x larger



# Lepton universality tests with $b \rightarrow s l^+ l^-$ decays: $R_{K^*}$

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



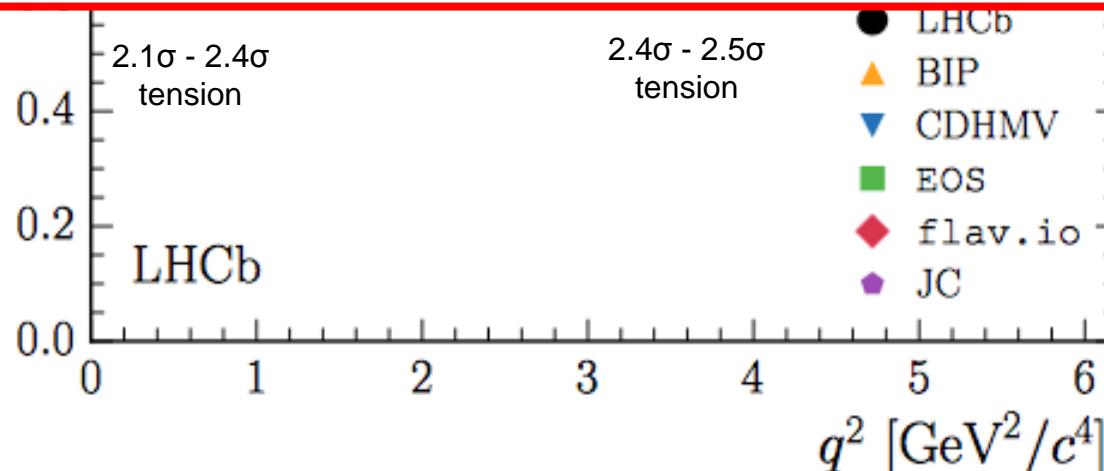
# Lepton universality tests with $b \rightarrow s l^+ l^-$ decays: $R_{K^*}$

LHCb Preliminary	low- $q^2$	central- $q^2$
$\mathcal{R}_{K^{*0}}$	$0.660 \pm 0.110 \pm 0.024$	$0.685 \pm 0.113 \pm 0.047$
95% CL	[0.517–0.891]	[0.530–0.935]

Intriguing! What happens next?

- New  $R_K$  measurement, including run-2 data.
- Measure  $R_\phi$ , analogous observable with  $B_s$  decays, including run-2 data.
- Run-2 update of  $R_{K^*}$ .
- Seek to include high- $q^2$  region above  $\psi(2S)$ .

Available data should be sufficient to clarify picture.



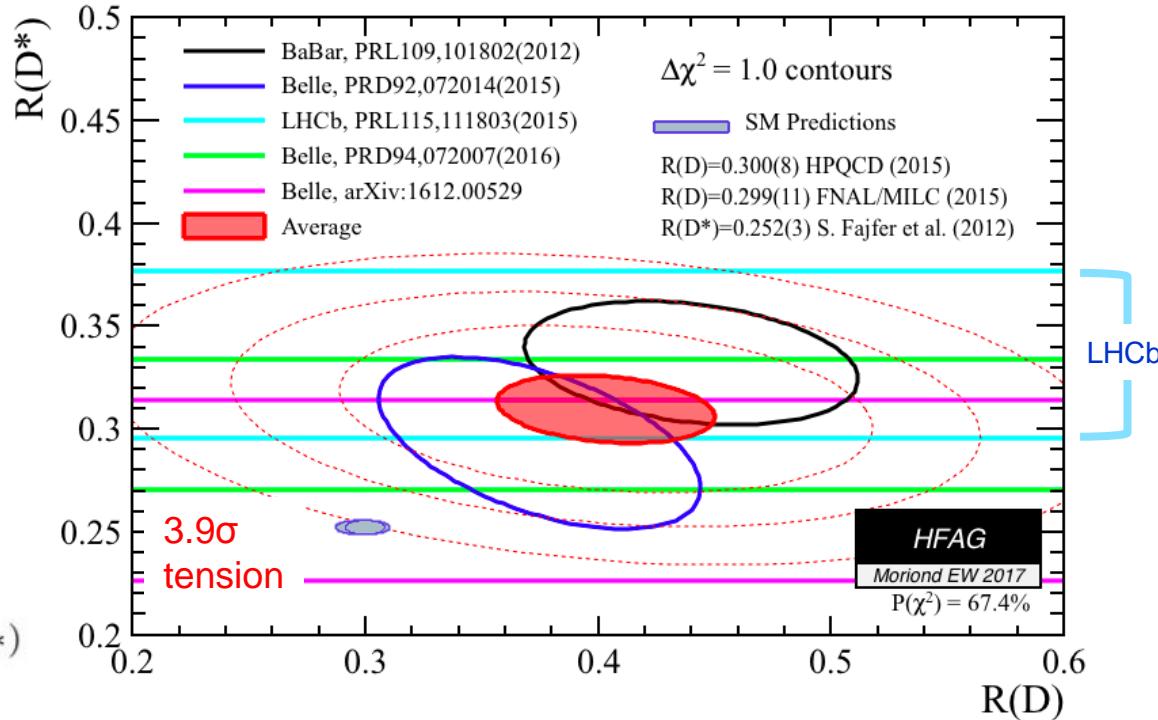
# Other hints of lepton universality violation

Remember, there is another class of decays,  $b \rightarrow c\bar{v}$ , (tree level – not a FCNC!) where there is a stubborn longstanding tension between data and the SM expectation.

$$R(D^{(*)}) \equiv \frac{\text{BR}(B \rightarrow D^{(*)}\tau\nu)}{\text{BR}(B \rightarrow D^{(*)}\mu\nu)}$$

$\overline{B} \{ \begin{matrix} b \\ \bar{q} \end{matrix} \} \begin{matrix} \xrightarrow{\text{d}} \\ \xleftarrow{\text{d}} \end{matrix} \begin{matrix} c \\ \bar{q} \end{matrix} \} D^{(*)}$

$W^-/H^- \rightarrow \tau^- \bar{\nu}_\tau$

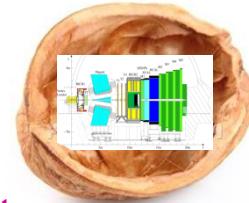


Most measurements are from B-factories, but LHCb result with  $B \rightarrow D^*\tau\nu$ ,  $\tau \rightarrow \mu\nu\nu$  [PRL 115 (2015) 111803] is a very important (if unexpected) piece of the picture.

LHCb will have more to say on this *very soon* (measurements underway with hadronic  $\tau$  decays, simultaneous fits of  $B \rightarrow D\tau\nu$ ,  $D^*\tau\nu$  and  $B_c \rightarrow J/\psi\tau\nu$ ).

# The LS2 Upgrade, and beyond

# The Upgrade in a nutshell



Indirect search strategies for New Physics, e.g. precise measurements & the study of suppressed processes in the flavour sector become ever-more attractive following the experience of run-1 LHC that direct signals are elusive

Our knowledge of flavour physics has advanced spectacularly thanks to LHCb. Maintaining this rate of progress beyond run 2 requires significant changes.

## The LHCb Upgrade

### 1) Full software trigger

- Allows effective operation at higher luminosity
- Improved efficiency in hadronic modes

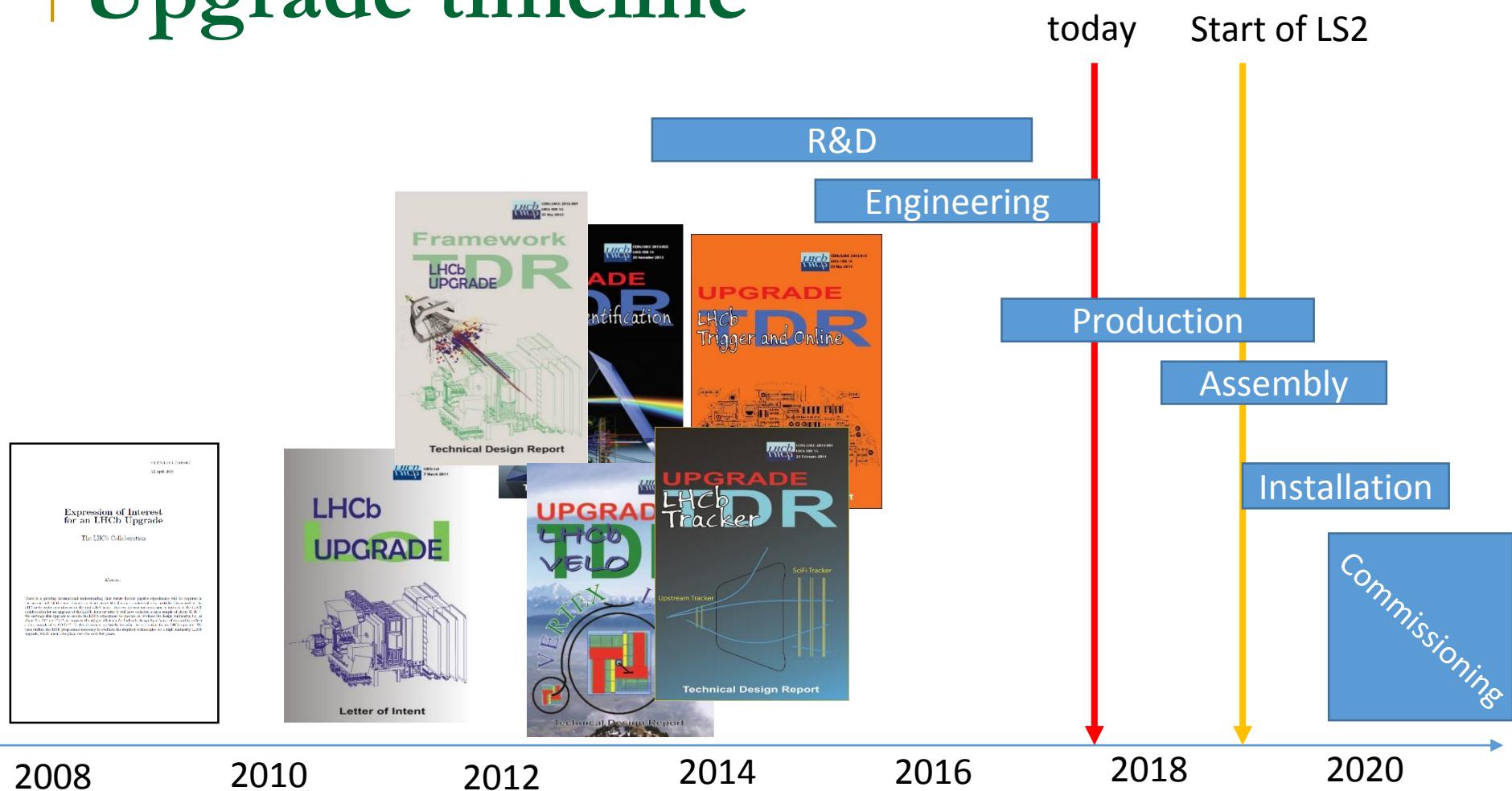
### 2) Raise operational luminosity to $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

Necessitates redesign of several sub-detectors & overhaul of readout

 *Huge increase in precision:* Upgrade + run 2 yield in hadronic modes  $\sim 60x$  that of run 1; also perform studies *beyond the reach of the current detector*.

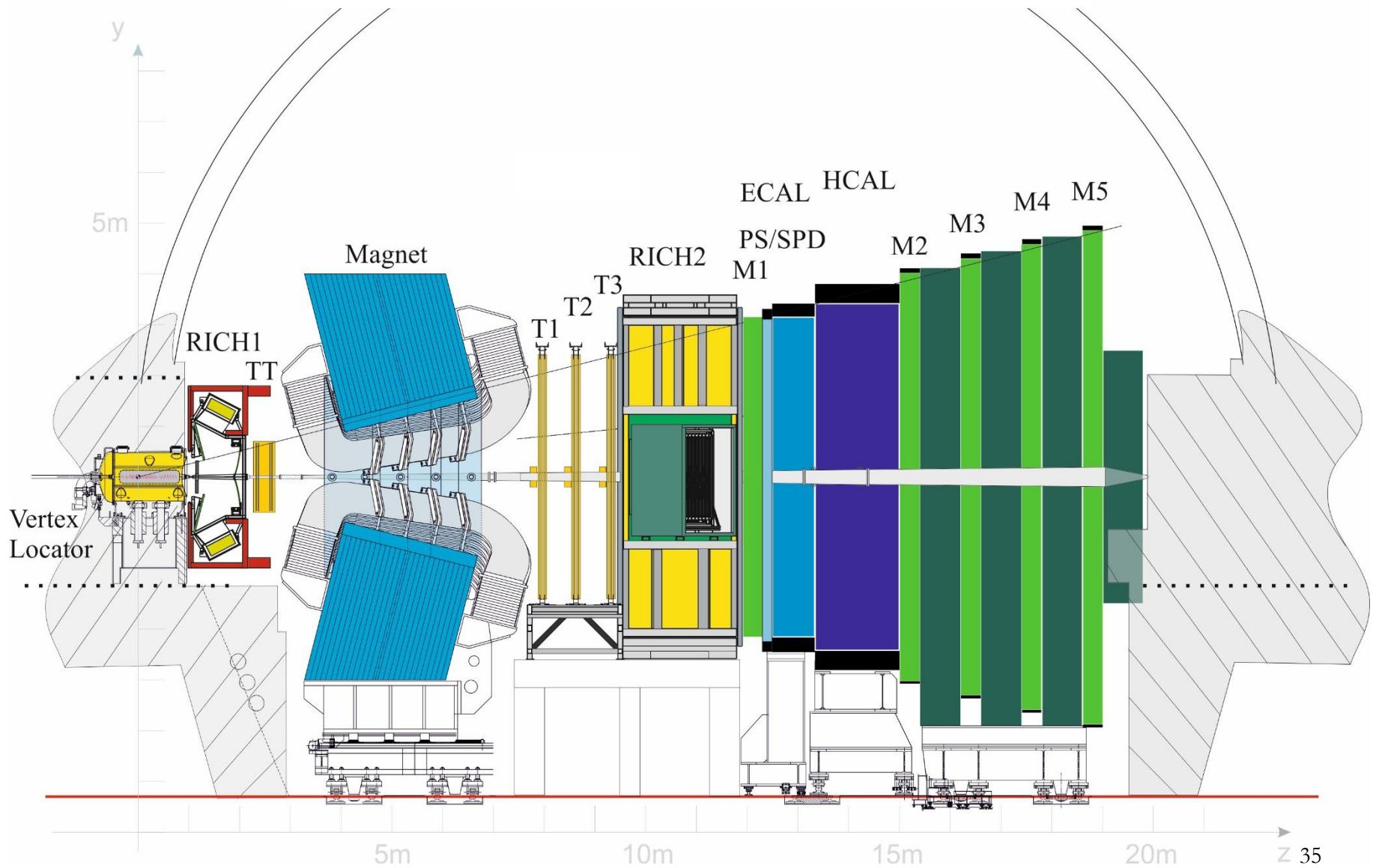
Flexible trigger and unique acceptance also opens up opportunities in other topics apart from flavour ('a general purpose detector in the forward region')

# Upgrade timeline



Goal: to operate throughout the 2020s & to have accumulated  $50 \text{ fb}^{-1}$  by end of run 4.

# Current detector



# Required modifications

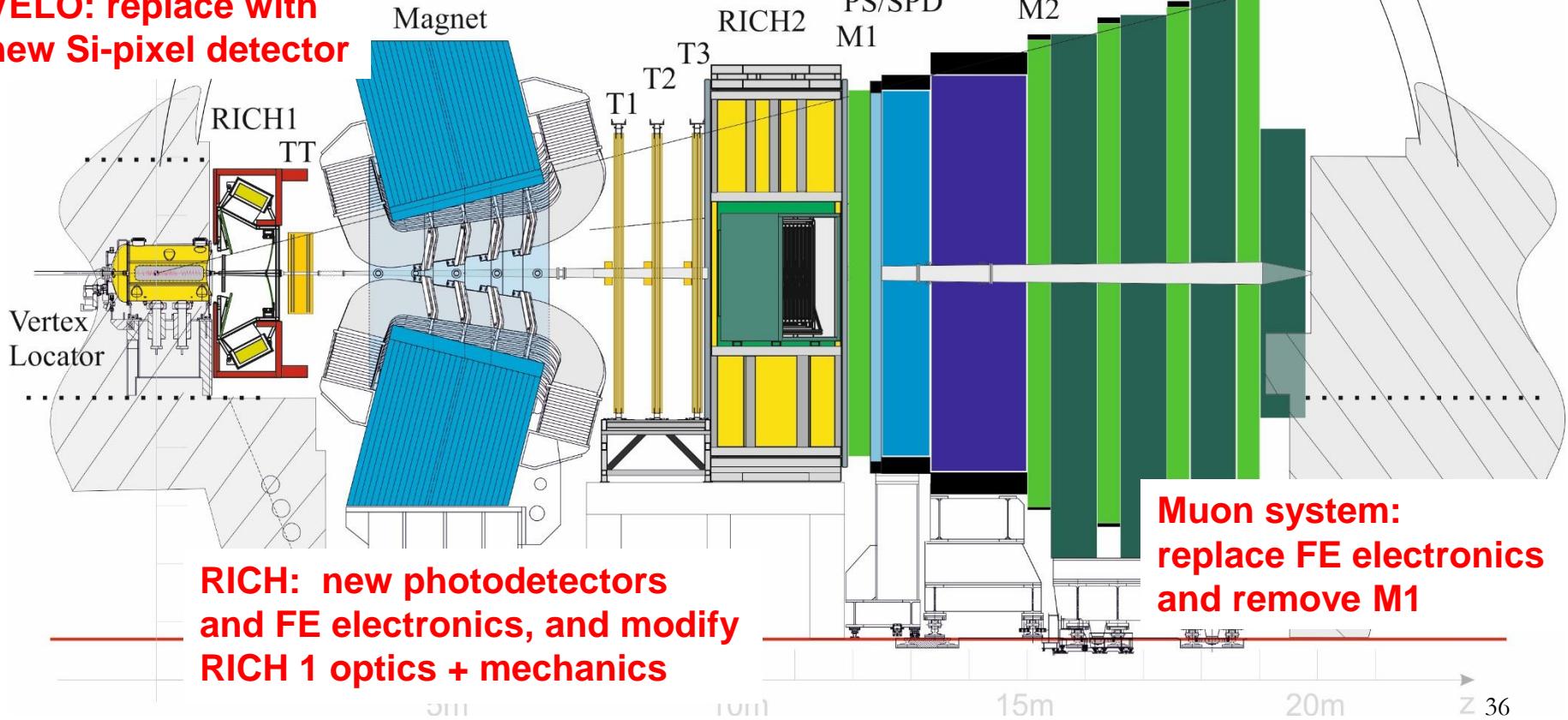
Full s/w trigger →  
Replace read-out  
boards and DAQ



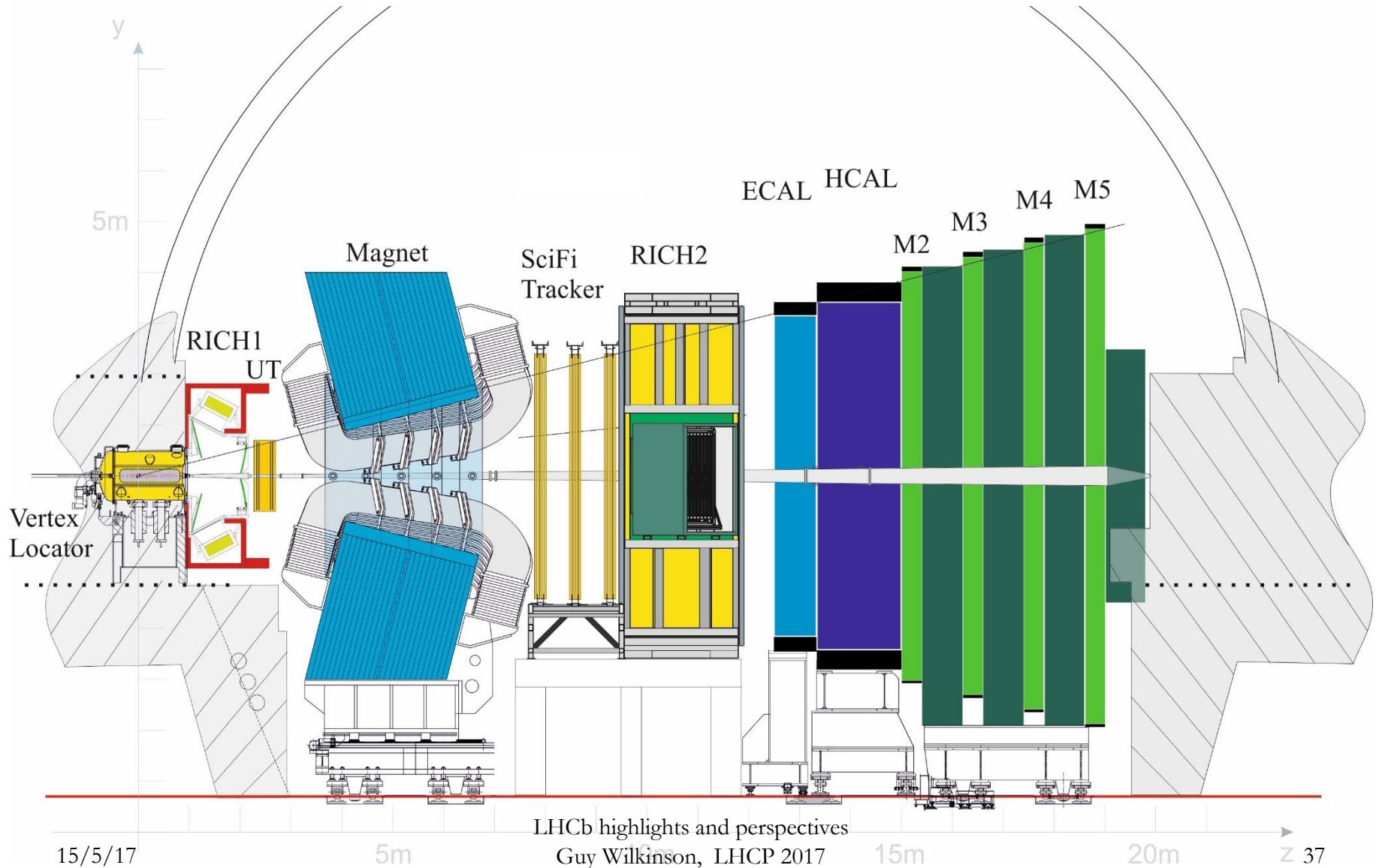
OT & IT: replace with scintillating fibre (SciFi) tracker

Calo system:  
replace FE electronics  
and remove PS/SPD

VELO: replace with new Si-pixel detector



# Upgraded detector



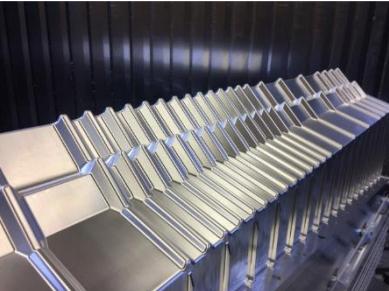
# Upgrade progress

Excellent progress on all aspects of the Upgrade project.

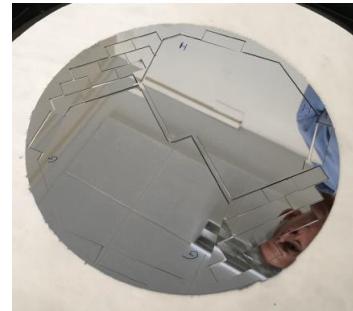
Prototype readout boards



RF box for VELO



Diced wafer with microchannel cooling substrates for VELO



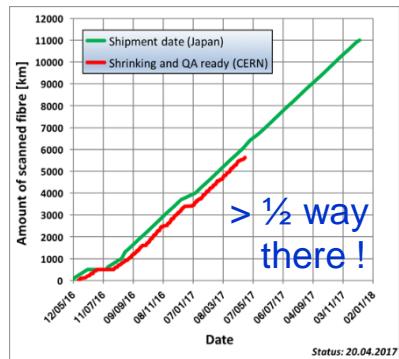
RICH photodetectors



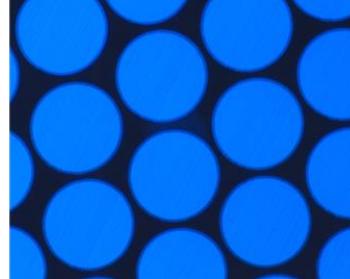
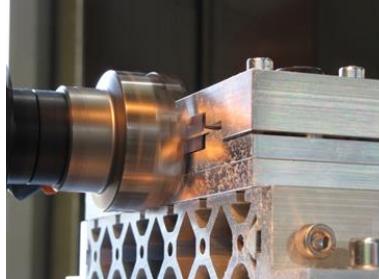
Testing Upstream Tracker 'flex cables'



Delivery of tracker scintillating fibres (SciFi)



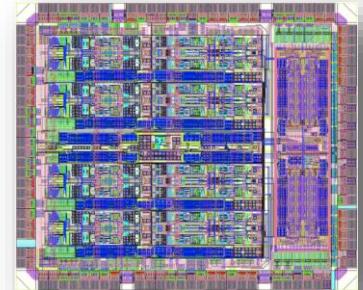
Machining of SciFi mat and scan of fibres



MWPC for muon system



ECAL front-end ASIC



Timescale tight, but still on-track for installation in LS2.

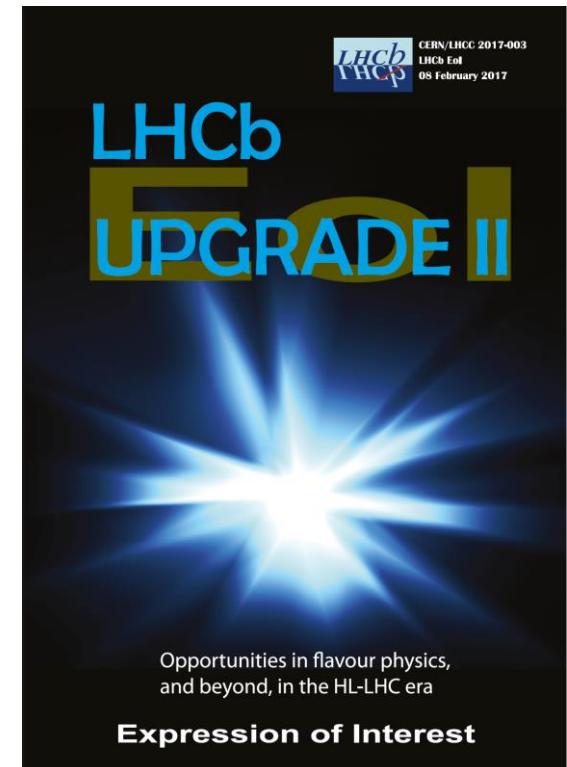
# Looking further forward...

Serious thinking now underway about a phase-II Upgrade that would occur in LS4 (~2030) & allow full exploitation of flavour potential of the machine in HL-LHC era.

Expression of Interest submitted to  
February LHCC [[CERN-LHCC-2017-003](#)]

- Install in LS4 (~2030), after Phase-I Upgrade.
- Detector to be able to operate at  $\sim 2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ;
- Integrate  $\sim 300 \text{ fb}^{-1}$ ;
- Comprehensive flavour physics programme and general-purpose forward physics (as now), but targeting clean measurements currently limited by statistics, and new observables;
- Modest activities foreseen for LS3 in consolidation of Phase I & in preparation for next step.

Significant detector challenges, but many benefits to be gained from R&D for ATLAS & CMS Phase-II Upgrades, e.g. fast timing.



# Conclusions

- 2016 another successful year of data taking for LHCb in pp, as well as p-Pb/Pb-p and SMOG. Many thanks to the machine ! All ready for 2017 resumption.
- Many interesting results across a wide range of physics topics. The most intriguing come from  $b \rightarrow s l^+ l^-$  and lepton-universality studies. Data on tape, and from rest of run 2, should bring clarity.
- Great progress on the LS2 (Phase-I) Upgrade. Tight, but remains on schedule. First thoughts being given to Phase-II Upgrade on timescale of ~2030.

# For more information...

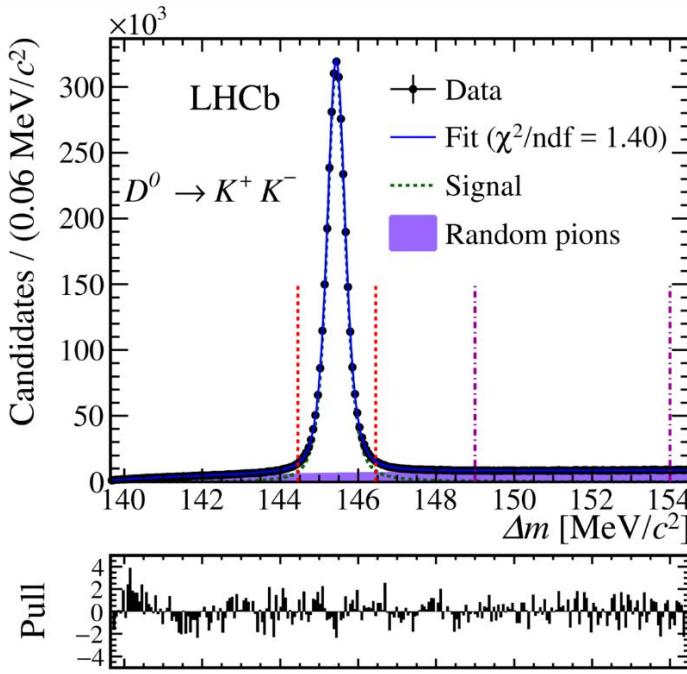
- Plenary talks
- Vector boson production, Will Barter, session EWK
  - Forward heavy ion and fixed target physics, Burkhard Schmidt, session HI
  - CP violation in beauty and charm, Francesca Dordei, session HF
  - Lepton flavour universality tests, Francesco Polci, session HF
  - Heavy flavour production and spectroscopy, Zhenwei Yang, session HF
  - LHCb Upgrade, Silvia Gambetta, session Upgrade
- (& those of ALICE/ATLAS/CMS colleagues containing LHCb results.)
- Parallel talks:
- Measurements of particle production, soft-QCD, and double parton scattering at LHCb, Liupan An, session QCD
  - Physics with jets at LHCb, Xabier Cid Vidal, session QCD
  - Heavy Flavour production at LHCb, Patrick Spradlin, session QCD
  - Tests of of Lepton Flavour Universality with  $b \rightarrow sll$  transitions at LHCb, Guido Andreassi, session HF
  - Tests of of Lepton Flavour Universality with semileptonic decays at LHCb, Federico Betti, session HF
  - Mixing and CP violation results in charm decays at LHCb, Silvia Borghi, session HF
  - Rare decays at LHCb, Marcin Chrzaszcz, session HF
  - Mixing and CP violation results in  $b$ -hadron decays at LHCb, Xuesong Liu, session HF
  - LHCb results on hadron spectroscopy, including exotic states, Jiesheng Yu, session HF
  - Measurements of heavy flavour production in  $pp$  collisions at LHCb, Yanxi Zhang, session HF
  - Exotica searches at LHCb, Martino Borsato, session Searches
  - SUSY indirect searches with LHCb, Hannah Mary Evans, session Searches
  - New results on collectivity with LHCb, Renata Kopecna, session HI
  - Fixed-target physics at LHCb, Emilie Maurice, session HI
  - New results on jets, heavy flavor & quarkonium with LHCb, Jia-Jia Qin, session HI
  - Single boson production and differential cross sections measurements in LHCb, Menglin Xu, session EWK
  - Novel LHCb strategy for particle identification and its performance, Fabio Ferrari, session LHC experiments
  - Tracking and vertex reconstruction at LHCb for Run 2, Hang Yin, session LHC experiments
  - Real-time physics: performance and novel developments at LHCb experiment, Roel Aaij, session LHC experiments
  - SciFi: a large Scintillating Fibre Tracker for LHCb, Plamen Hopchev, session Upgrade
  - Masterclasses in LHCb, Francesca Dordei, session Outreach
- & also contributions to poster session.

# Backups

# CPV searches in charm

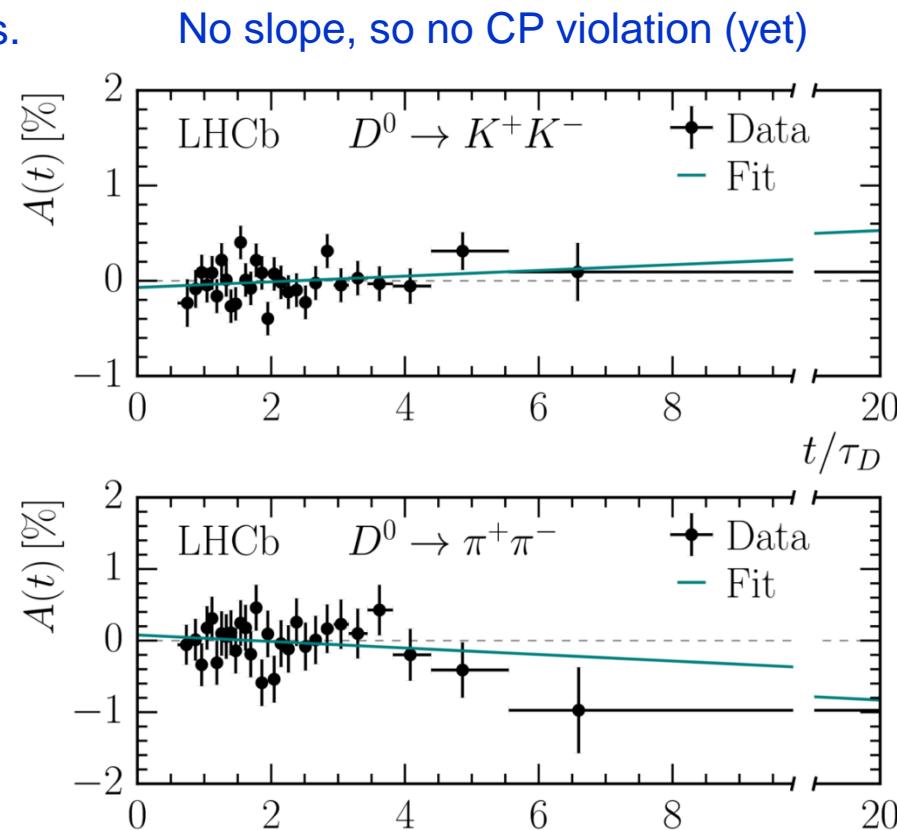
Another important task is to probe for CP violation in charm, both direct & indirect, which is very small in the SM. For example, look for time-dependent CP asymmetry, expressed in  $A_\Gamma$  parameter, in decay to  $CP$  eigenstate, e.g.  $D^0 \rightarrow K\bar{K}$  or  $\pi\bar{\pi}$ .

Massive, clean & well-understood samples.  
(i.e. 9.6M tagged  $K^+K^-$  vs BaBar 140k)



$$A_\Gamma(D^0 \rightarrow K^+K^-) = (-0.30 \pm 0.32 \pm 0.14) \times 10^{-3}$$

$$A_\Gamma(D^0 \rightarrow \pi^+\pi^-) = ( -0.46 \pm 0.58 \pm 0.16) \times 10^{-3}$$



$10^{-4}$  precision, and systematics  $t/\tau_D$  under good control. Excellent prospects for run 2 and beyond !

[arXiv:1702.06490]

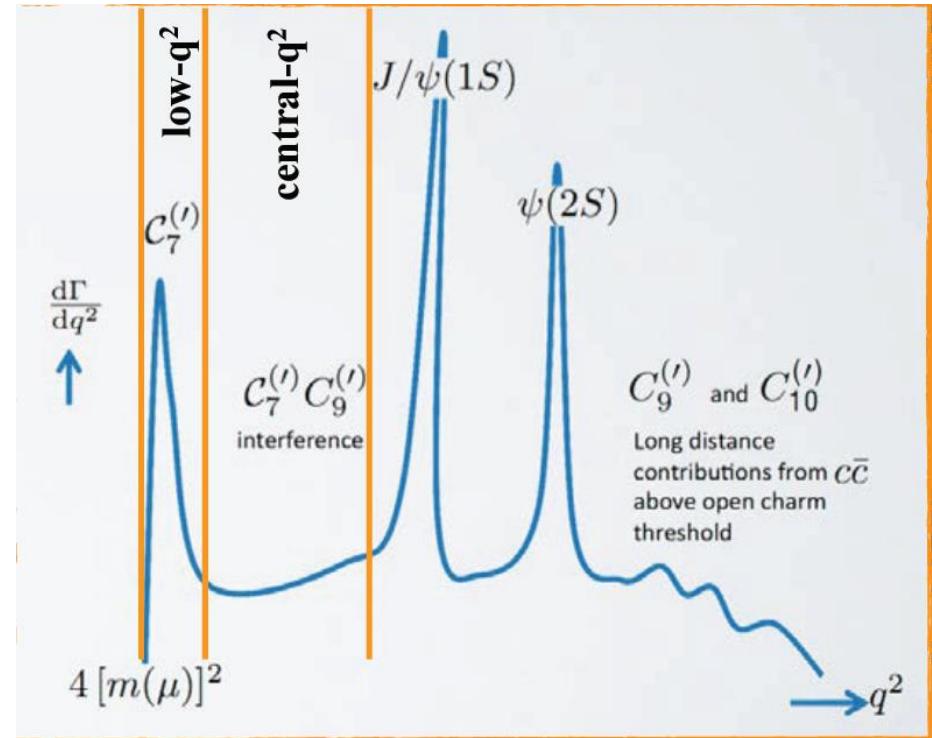
# $B^0 \rightarrow K^* l^+ l^-$ and friends: lepton universality tests $R_{K^*}$

Measurement performed  
in two  $q^2$  regions:

Low:  $0.045 < q^2 < 1.1 \text{ GeV}^2$

Central:  $1.1 < q^2 < 6.0 \text{ GeV}^2$

(high  $q^2$  region, above resonances,  
is certainly of interest, but this  
presents different experimental  
challenges, and requires a  
separate analysis)



For  $K^* e^+ e^-$ , three exclusive trigger categories are used, depending on whether triggered on electron(s) (L0E),  $K^*$  candidate(s) (L0H), or not on signal (TIS)

# Systematics on $R_{K^*}$ (%)

Trigger category	low- $q^2$			central- $q^2$		
	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

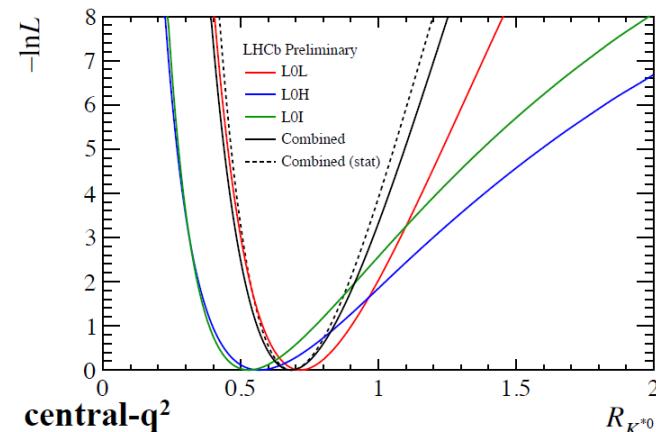
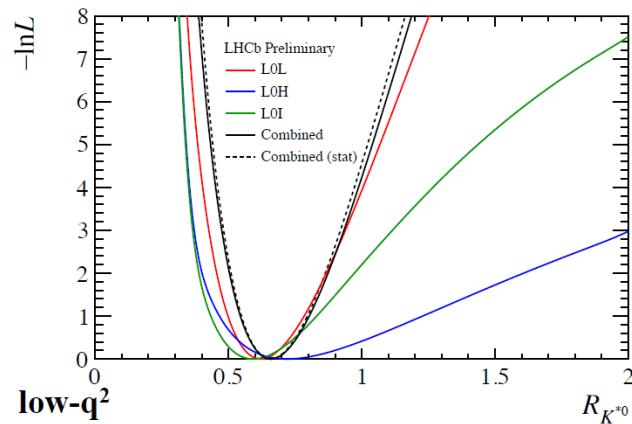
Statistical uncertainty around 4x larger at low- $q^2$ , and 2x larger at central- $q^2$ .

# $B^0 \rightarrow K^* l^+ l^-$ and friends: lepton universality tests $R_{K^*}$

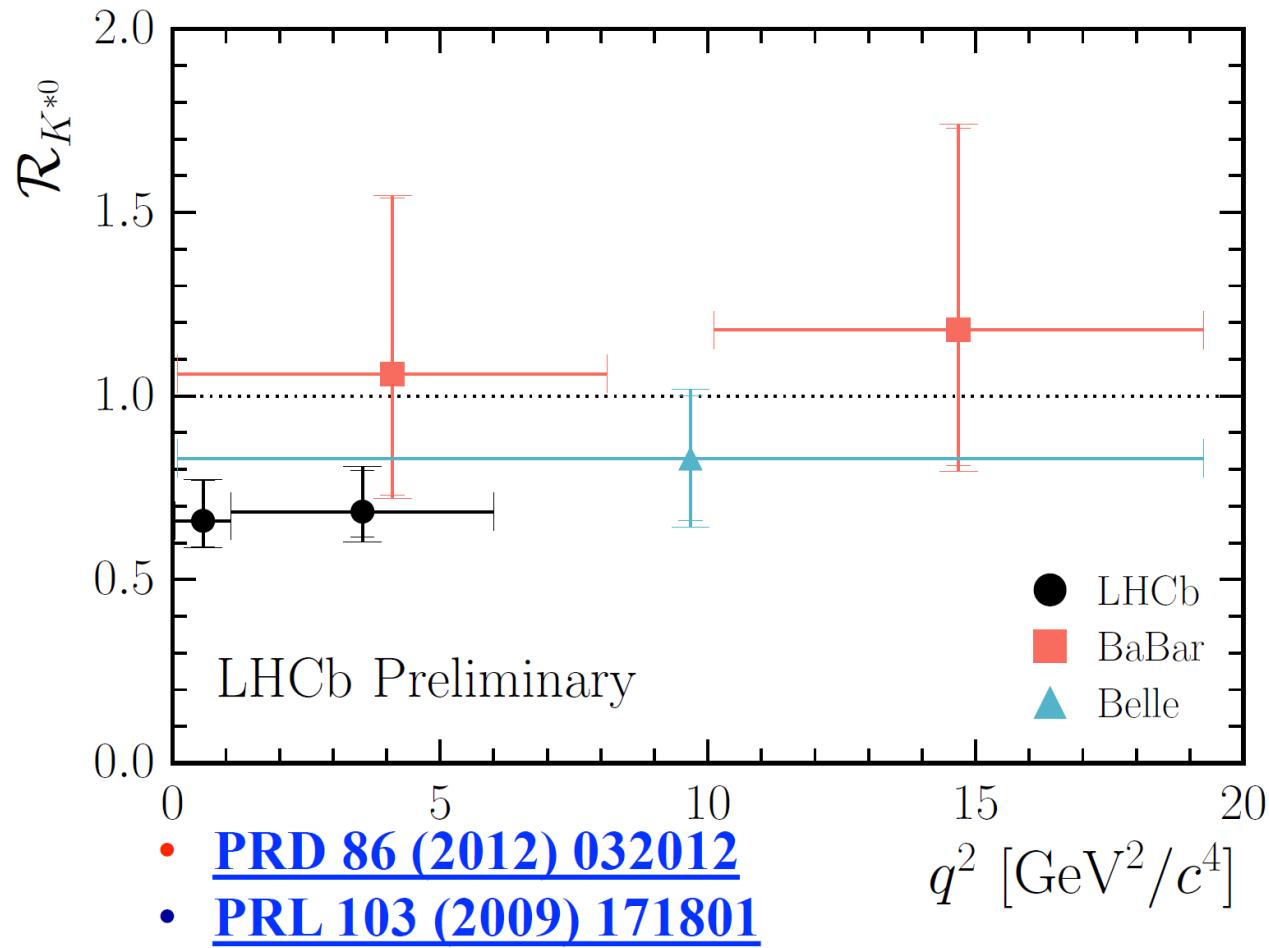
Preliminary results:

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

Good compatibility between trigger classes:



# All measurements: $R_{K^*}$



# $B^0 \rightarrow K^* l^+ l^-$ and friends: what does it all mean ?

Already much theoretical interest in  $b \rightarrow (s,d)l^+l^-$  sector prior to latest result.

Typical approach – global analysis of all observables and fit to Wilson coefficients.

What is intriguing, and undeniable, is that a coherent picture emerges. The  $R_{K^*}$  result fits this picture well (certainly, at central- $q^2$ ).

One example [arXiv:1704.05340].

These fits can give  $>5\sigma$  pulls w.r.t. SM, & have led to excited discussion of Z's, leptoquarks etc.

The experimentalist's view:

- Hypotheses non fingo !
- Recall, for several of observables there is no consensus on the theory errors.
- Excitement premature: we should wait until we see highly significant deviations in one or more LFU observables. Wait for run-2 updates on  $R_K$ ,  $R_{K^*}$  & indeed  $R_\phi$ .

