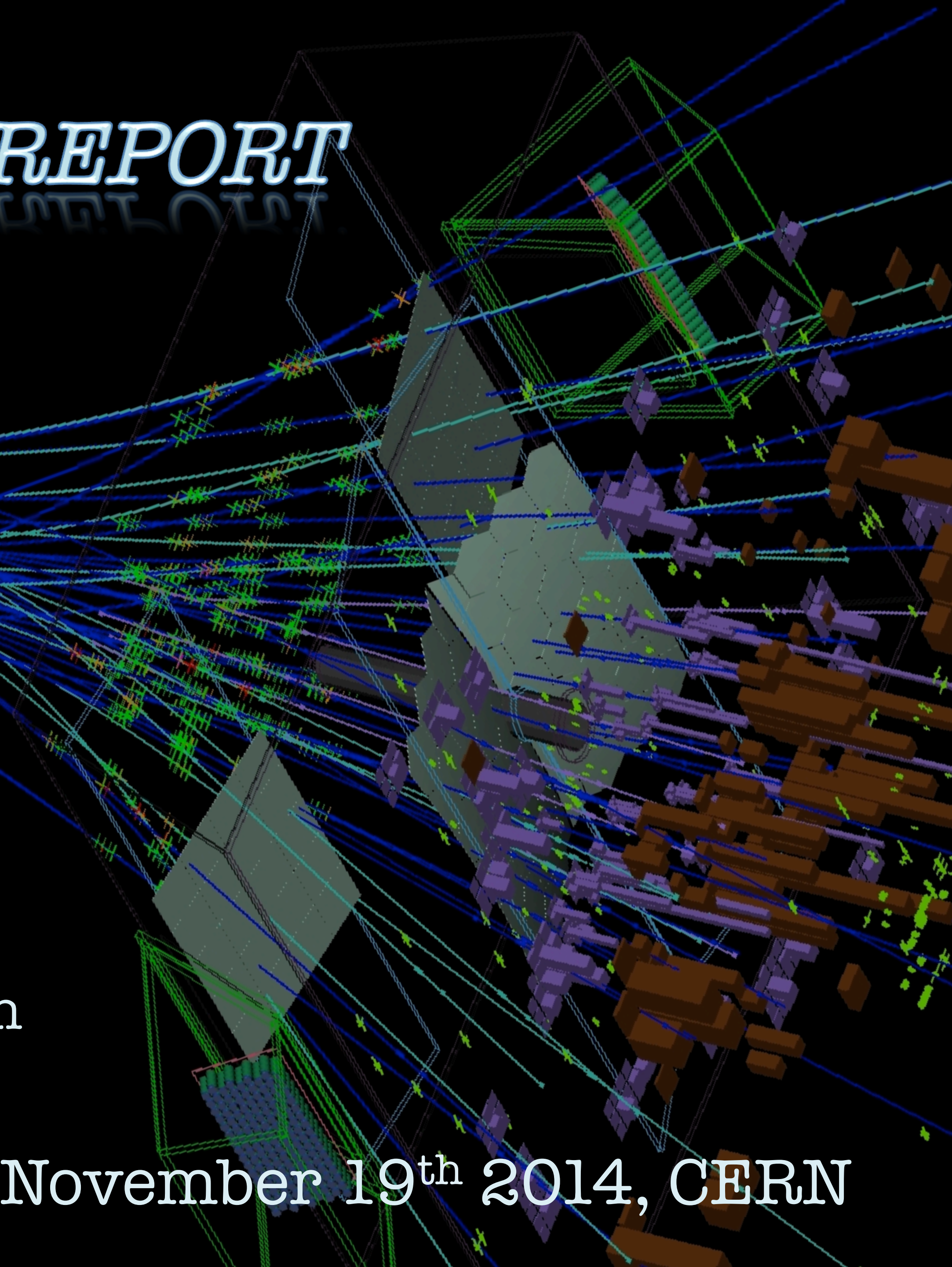
STATUS REPORT

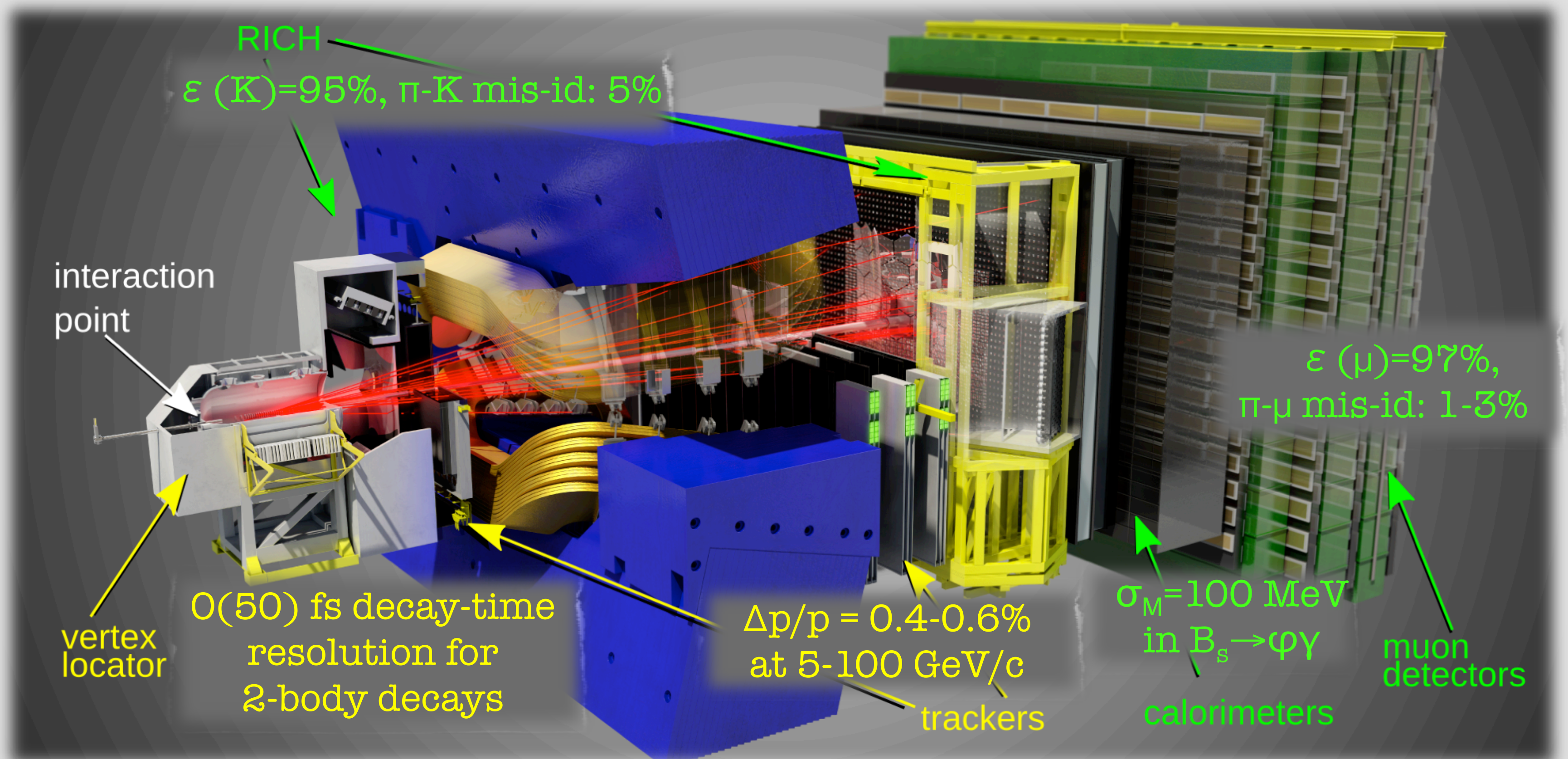


Mirco Dorigo (EPFL)

for the LHCb Collaboration

120th LHCC meeting – November 19th 2014, CERN

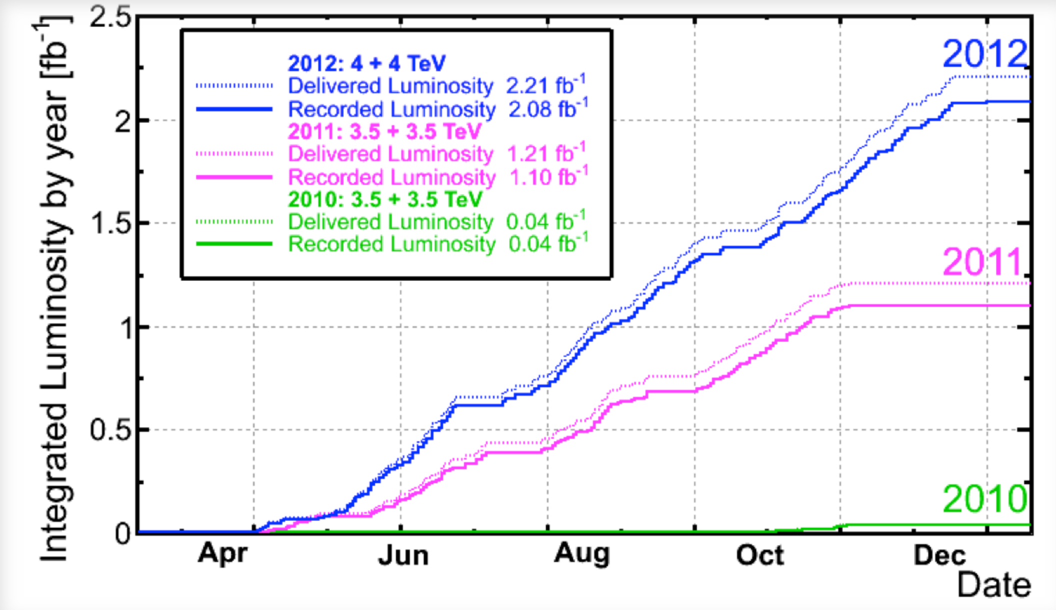
Large Hadron Collider *b*eauty



Search for non-SM physics by studying CP violation and rare decays of *b*- and *c*-hadrons.

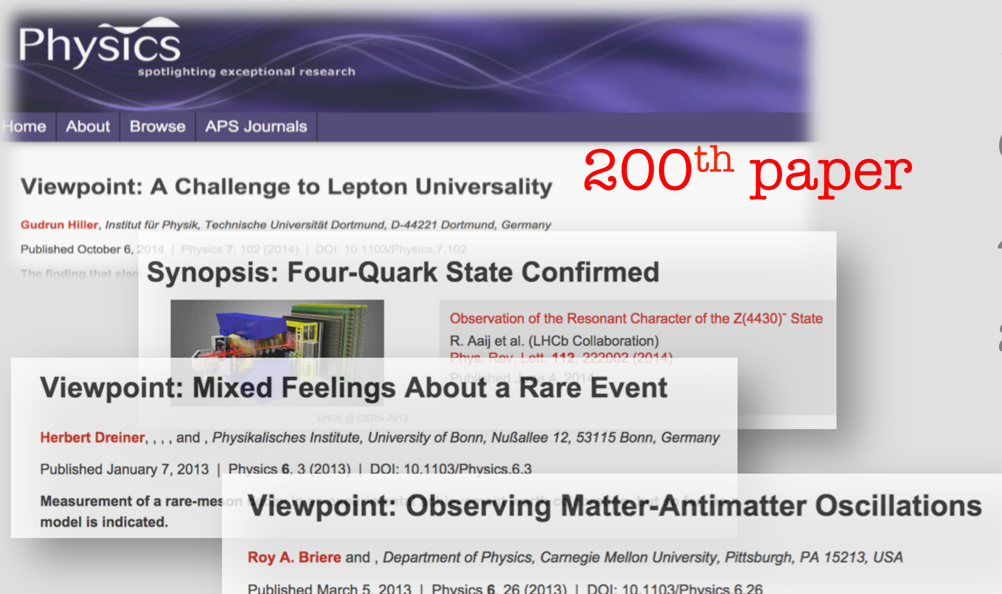
QCD/EW/Exotica measurements in the forward region complementary to central detectors.

Run I analyses, so far

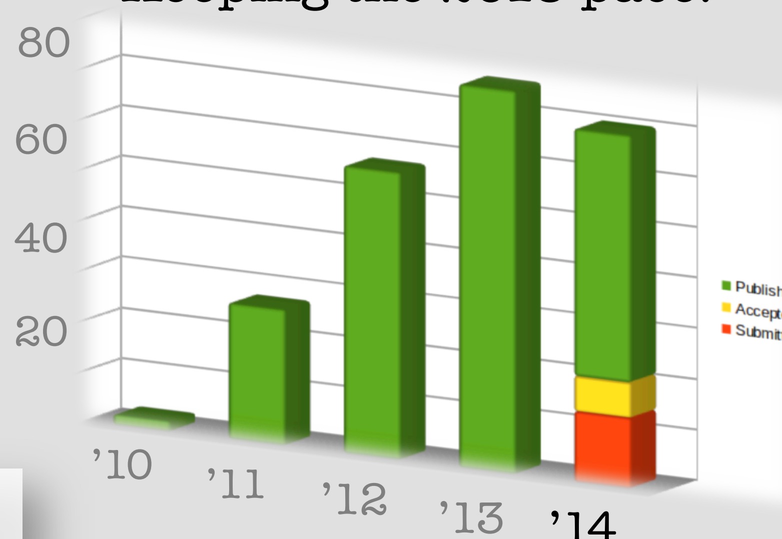


Thanks to the colleagues from the accelerator sector for the excellent performance of the LHC.
Looking forward to being amazed in Run II.

Fruitful sample.
211 papers published with some +100 topcite.
Keeping the 2013 pace.



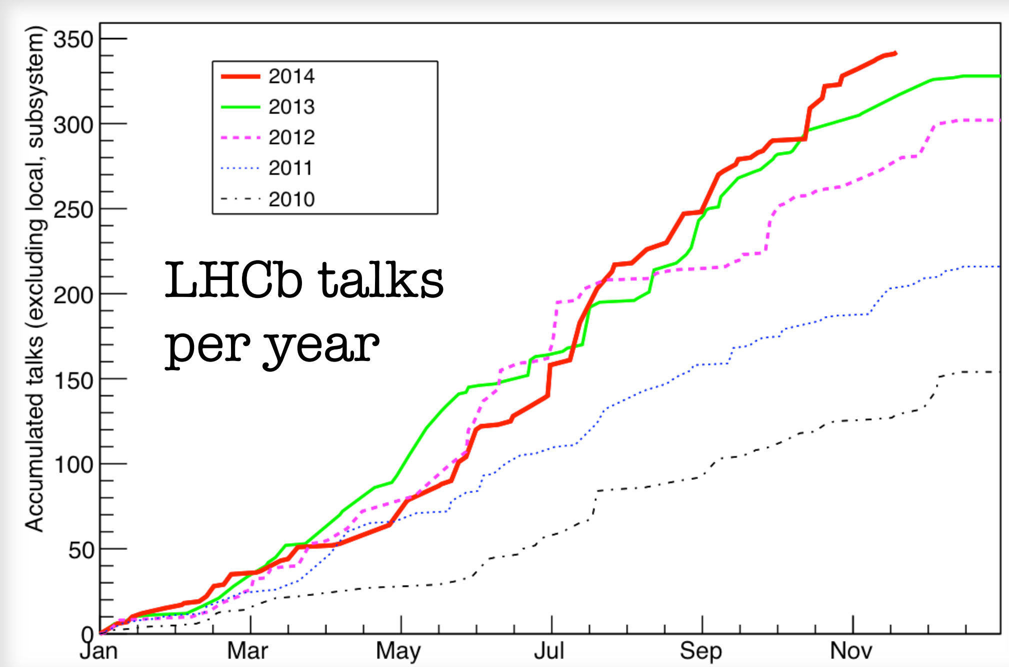
200$^{\text{th}}$ paper

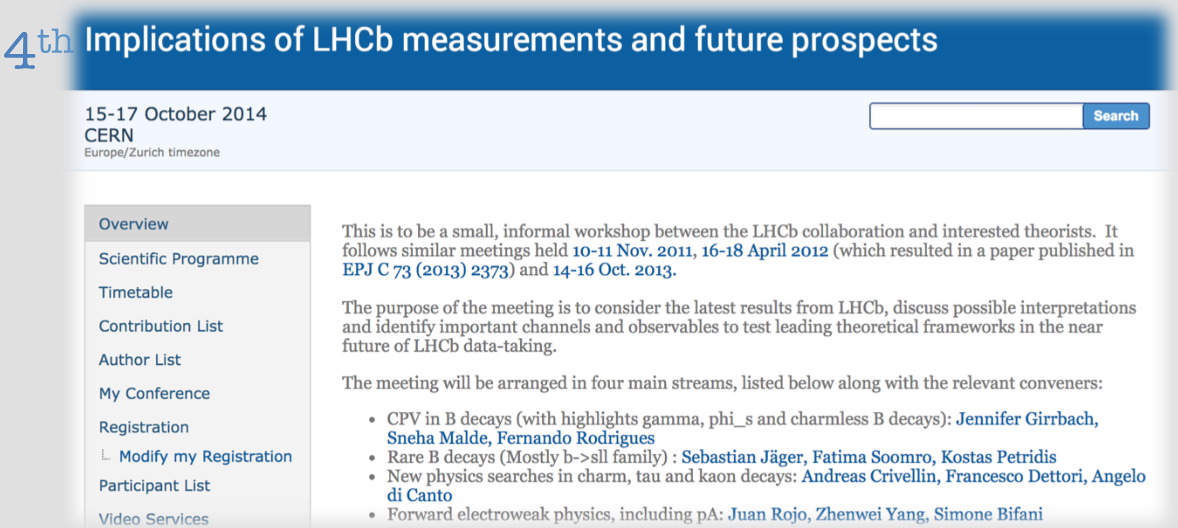


Impact

High rate of talks
in high-profile conferences,
workshops, and seminars.

Many given by PhDs
and young PostDocs.





4th Implications of LHCb measurements and future prospects

15-17 October 2014
CERN
Europe/Zurich timezone

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This is to be a small, informal workshop between the LHCb collaboration and interested theorists. It follows similar meetings held 10-11 Nov. 2011, 16-18 April 2012 (which resulted in a paper published in EPJ C 73 (2013) 2373) and 14-16 Oct. 2013.

The purpose of the meeting is to consider the latest results from LHCb, discuss possible interpretations and identify important channels and observables to test leading theoretical frameworks in the near future of LHCb data-taking.

The meeting will be arranged in four main streams, listed below along with the relevant conveners:

- CPV in B decays (with highlights gamma, phi_s and charmless B decays): Jennifer Girrbach, Sneha Malde, Fernando Rodrigues
- Rare B decays (Mostly b->sll family) : Sebastian Jäger, Fatima Soomro, Kostas Petridis
- New physics searches in charm, tau and kaon decays: Andreas Crivellin, Francesco Dettori, Angelo di Canto
- Forward electroweak physics, including pA: Juan Rojo, Zhenwei Yang, Simone Bifani

Close collaboration with the theory community to explore new avenues and fully exploit our physics potential.

Since last LHCC — New observations

PAPER-2014-049 **Observation of the rare $B_s^0 \to \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data** [submitted to **Nature**, arXiv:1411.4413]

PAPER-2014-061 **Observation of two new Ξ^-_b baryon resonances** [to be submitted to Phys. Rev. Lett., arXiv:1411.4849]

PAPER-2014-050 Measurement of B_c^+ production in proton-proton collisions at $\sqrt{s}$ = 8 TeV [submitted to Phys. Rev. Lett., arXiv:1411.2943]

PAPER-2014-055 Measurement of the Z+b-jet cross-section in pp collisions at s = $\sqrt{s}$ 7 TeV in the forward region [LHCb, submitted to JHEP, arXiv:1411.1264]

PAPER-2014-059 Precision measurement of CP violation in $B_s^0 \to J/\psi K^+K^-$ decays [submitted to Phys. Rev. Lett., arXiv:1411.3104]

PAPER-2014-047 Precision luminosity measurements at LHCb [submitted to JINST, arXiv:1410.0149]

PAPER-2014-048 Precision measurement of the mass and lifetime of the Ξ^-_b baryon [to appear in Phys. Rev. Lett., arXiv:1409.8568]

PAPER-2014-058 Measurement of the CP-violating phase β in $B^0 \to J/\psi \pi^+\pi^-$ decays and limits on penguin effects [submitted to Phys. Lett. B, arXiv:1411.1634]

PAPER-2014-056 Study of $\eta - \eta'$ mixing from measurement of $B^0 \to J/\psi\ \eta^{(\prime)}$ decay rates [submited to JHEP, arXiv:1411.0943]

PAPER-2014-053 Measurement of the semileptonic CP asymmetry in B^0–B^0 mixing [submitted to Phys. Rev. Lett., arXiv:1409.8586]

PAPER-2014-052 Search for the lepton flavour violating decay $\tau^- \to \mu^-\mu^+\mu^-$ [submitted to JHEP, arXiv:1409.8548]

Since last LHCC **Unique measurements**

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Since last LHCC

High precision

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Since last LHCC **11 papers in 8 weeks**

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Observations

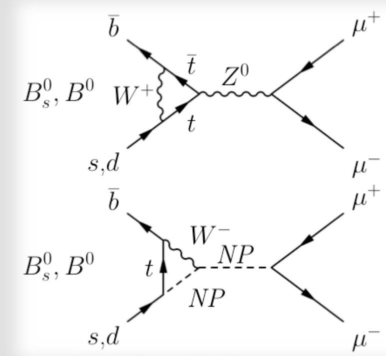
B→μ⁺μ⁻ combination from CMS & LHCb

LHCb-PAPER-2014-049
arXiv:1411.4413

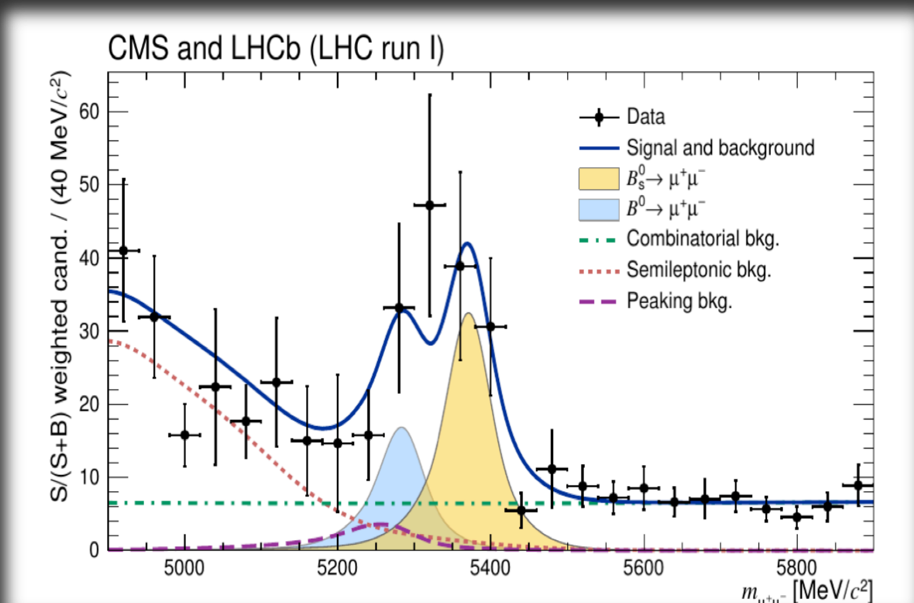
One of the most sensitive probes of physics beyond the SM.

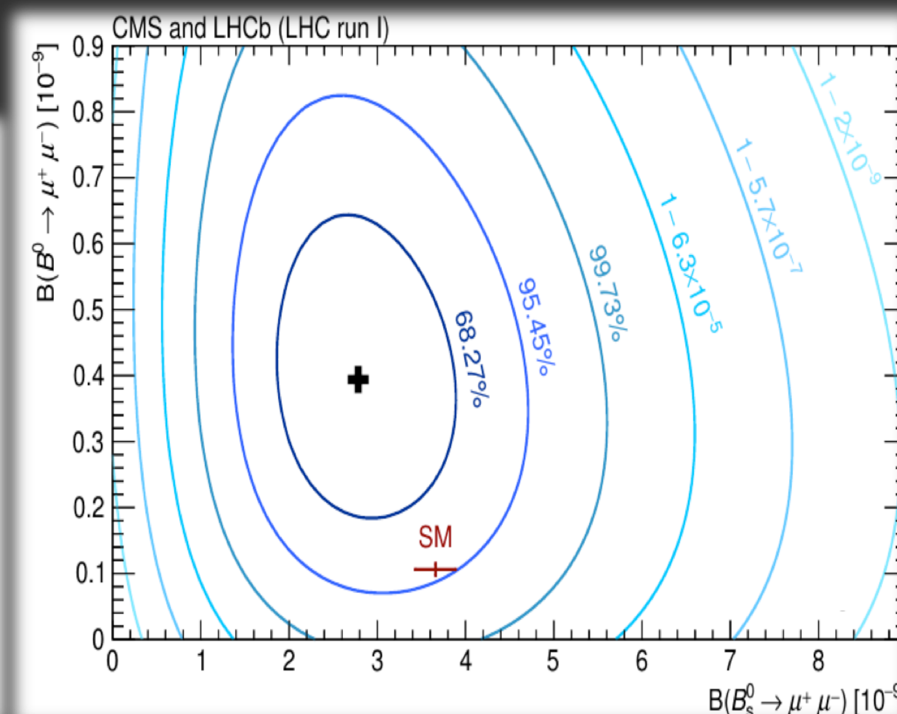
Submitted to Nature.

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(2.8\,^{+0.7}_{-0.6}\right) \times 10^{-9} \quad (6.2\,\sigma)$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left(3.9\,^{+1.6}_{-1.4}\right) \times 10^{-10} \quad (3.0\,\sigma)$$



Agreement with SM predictions.





Two new baryons

LHCb-PAPER-2014-061
arXiv:1411.4849
Hot off the press

Spectrum of known *b*-baryons still sparsely populated.

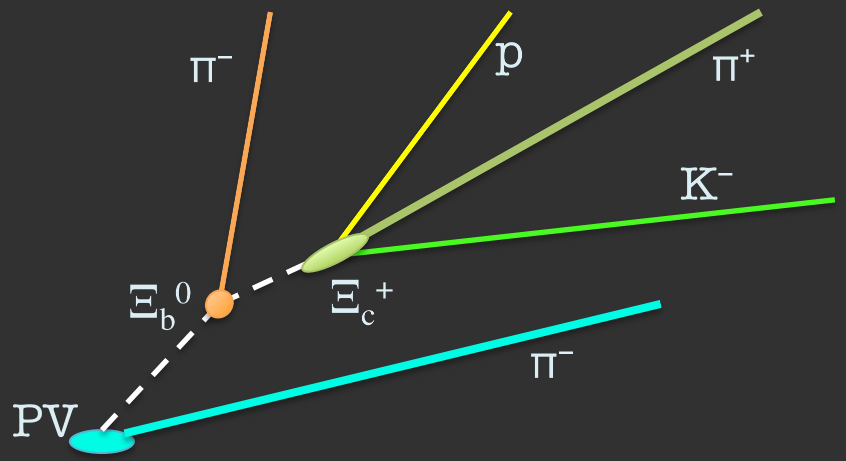
For the Ξ_b (*bsd*, *bsu*) states only the ground states, Ξ_b^- & Ξ_b^0, and one resonance, $\Xi_b(5945)^0$, observed.

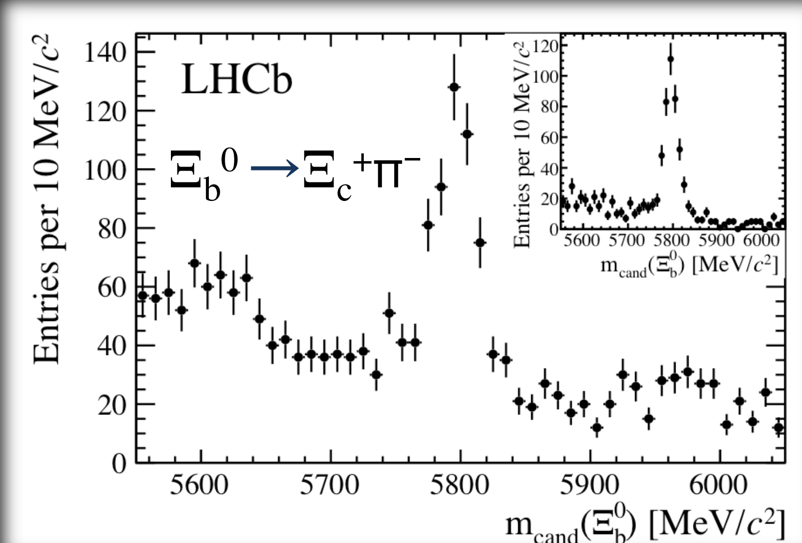
Following Ξ_c pattern: there must be

$\mathbf{\Xi_b}'^-$ $J^P = 1/2^+$, j(sq) =1
$\mathbf{\Xi_b}^{*-}$ $J^P = 3/2^+$, j(sq) =1

Study of $\Xi_b^0\pi^-$ mass spectrum, with $\Xi_b^0 \rightarrow \Xi_c^+ (\rightarrow p\, K^- \pi^+)\, \pi^-$.

Require good tracks and vertices;
PID on kaon and proton;
exploit long Ξ_b^0 lifetime;
Soft π^- and Ξ_b^0 from PV.





Two new baryons

LHCb-PAPER-2014-061
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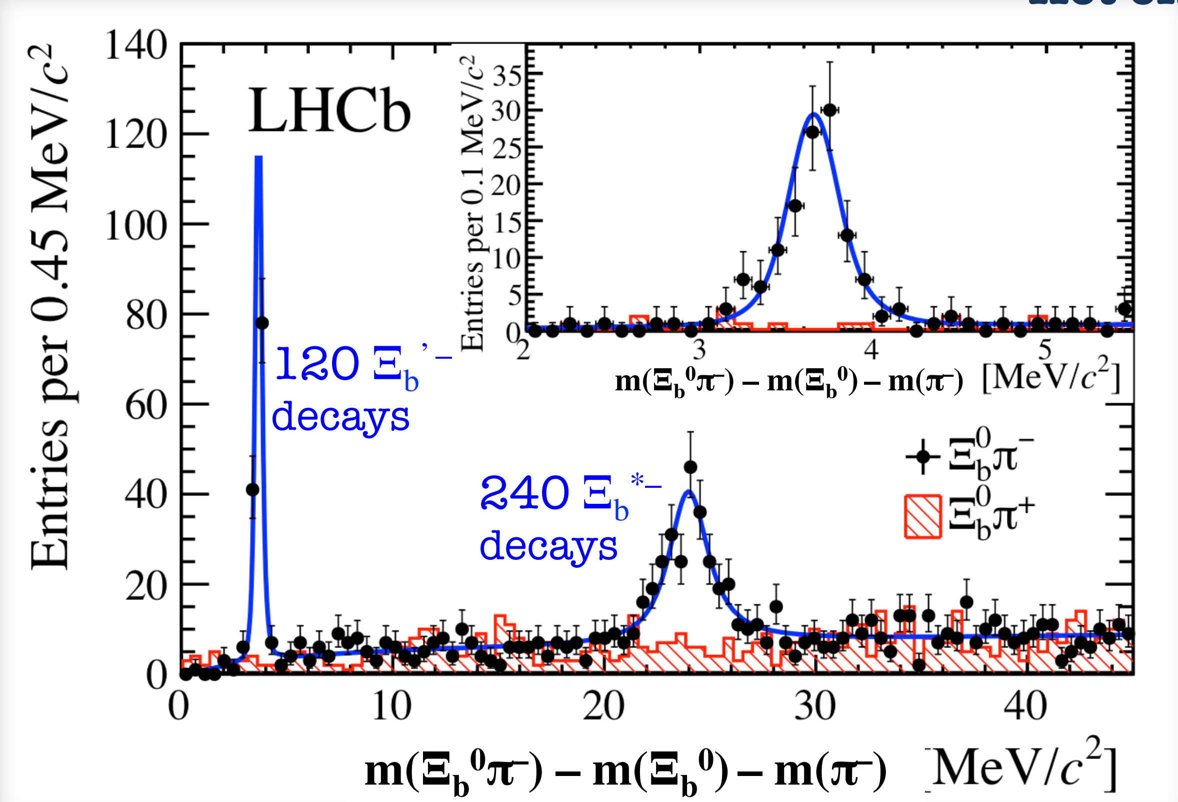


$m(\Xi_b^{'-}) = 5935.02 \pm 0.02 \pm 0.01 \pm 0.50$ MeV
$\Gamma(\Xi_b^{'-}) < 0.08$ MeV at 95% CL

$m(\Xi_b^{*-}) = 5955.33 \pm 0.12 \pm 0.06 \pm 0.50$ MeV
$\Gamma(\Xi_b^{*-}) = 1.65 \pm 0.31 \pm 0.10$ MeV

Production studies

B_c^+ production at 8 TeV

LHCb-PAPER-2014-050
arXiv:1411.2943

B_c^+ unique meson formed by two different heavy flavour quarks.

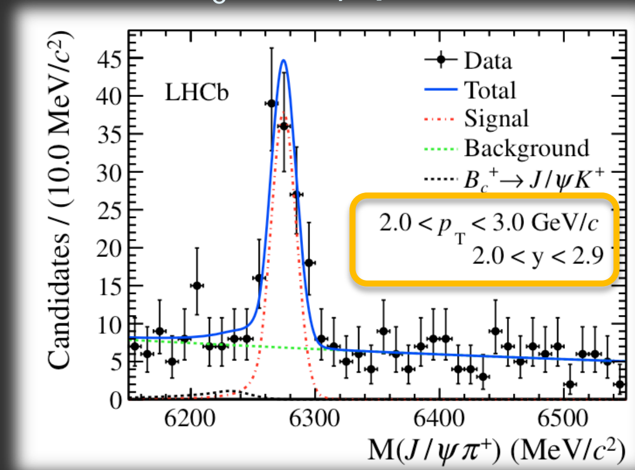
First measurement of the B_c^+ double differential production cross-section at the LHC.

Use the exclusive decay mode $B_c^+ \to J/\psi\, \pi^+$ compared to $B^+ \to J/\psi\, K^+$

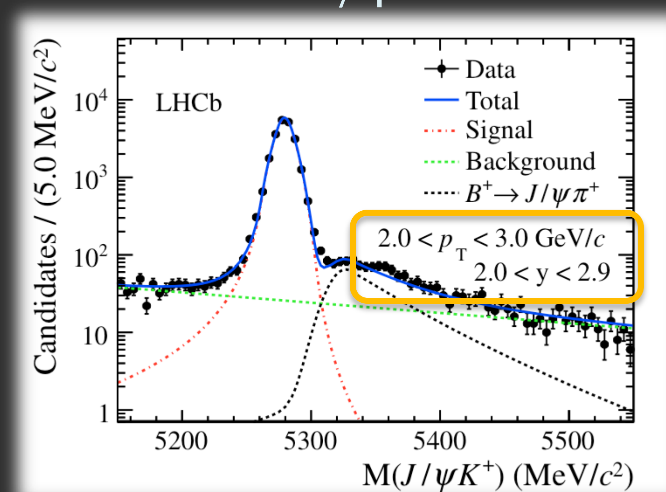
$$R(p_\mathrm{T}, y) = \frac{d\sigma_{B_c^+}(p_\mathrm{T}, y)\ \mathcal{B}(B_c^+ \to J/\psi\, \pi^+)}{d\sigma_{B^+}(p_\mathrm{T}, y)\ \mathcal{B}(B^+ \to J/\psi\, K^+)}$$

in 10 bins of p_T in [0,20] GeV and 3 bins of y in [2.0,4.5].

$B_c^+ \to J/\psi\, \pi^+$



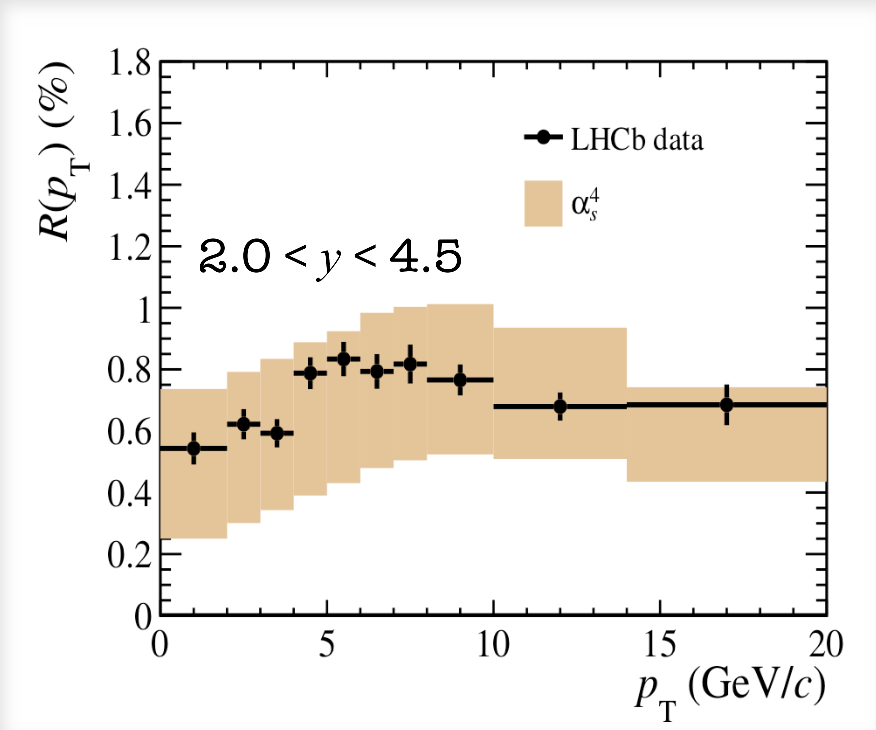
$B^+ \to J/\psi\, K^+$

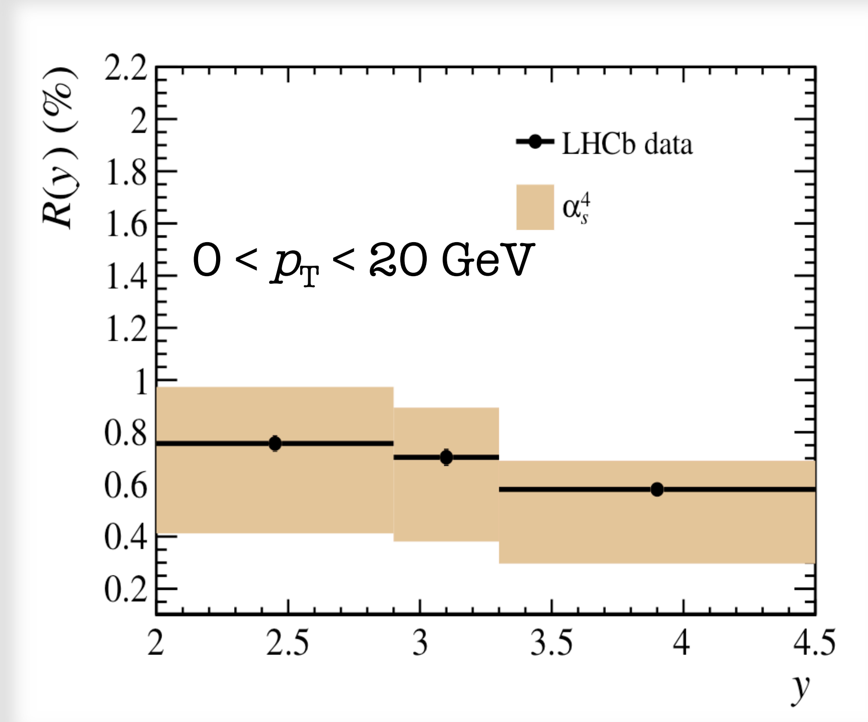


B_c^+ production at 8 TeV

LHCb-PAPER-2014-050
arXiv:1411.2943

Significant dependencies observed in p_T and y.





Integrating over p_T and y:

$$R = (0.683 \pm 0.018 \pm 0.009)\%$$

Z+b-jet at 7 TeV in the forward region

LHCb-PAPER-2014-055
arXiv:1411.1264

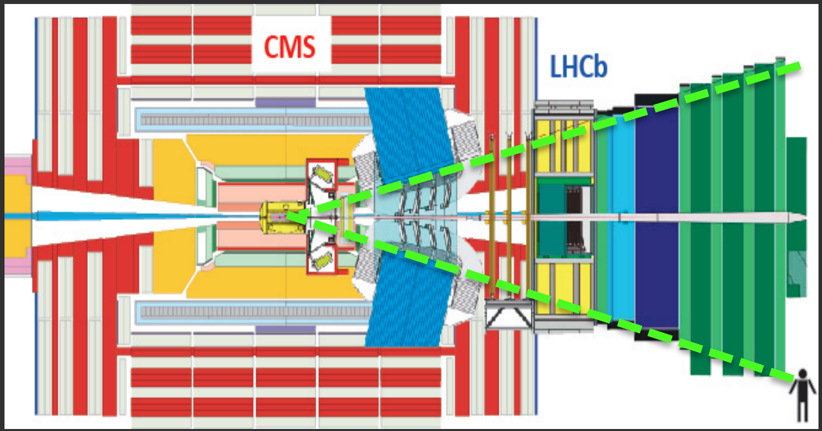
Z+b-jet production with $|\eta| < 2.1$ measured by ATLAS and CMS.

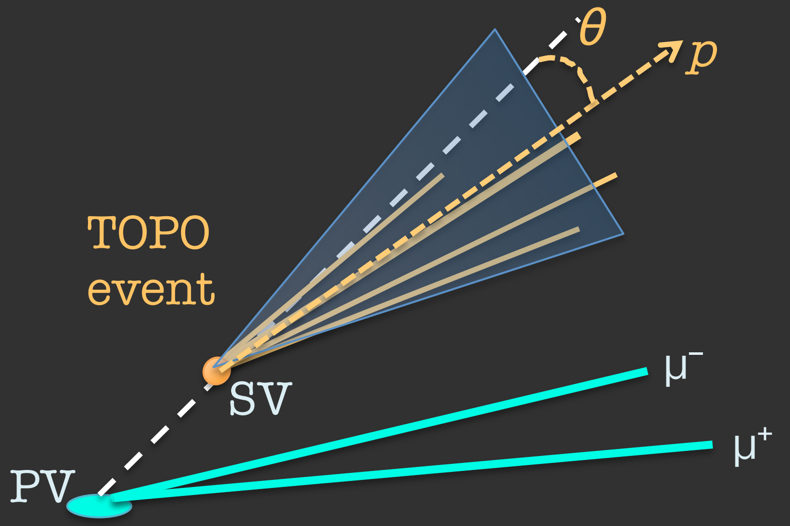
LHCb, with $2 < \eta < 4.5$: complementary kinematic region. Sensitive to the proton PDF at low and high values of Bjorken x variable where the uncertainties are largest.

$Z \to \mu^+\mu^-$, with $p_T(\mu) > 20$ GeV. Tag the jet with the SV vertex [arXiv:1406.4789].

Fit the M_{corr} distribution of TOPO events:

$$M_{\mathrm{corr}} \equiv \sqrt{M^2 + p^2 \sin^2\theta} + p \sin\theta$$

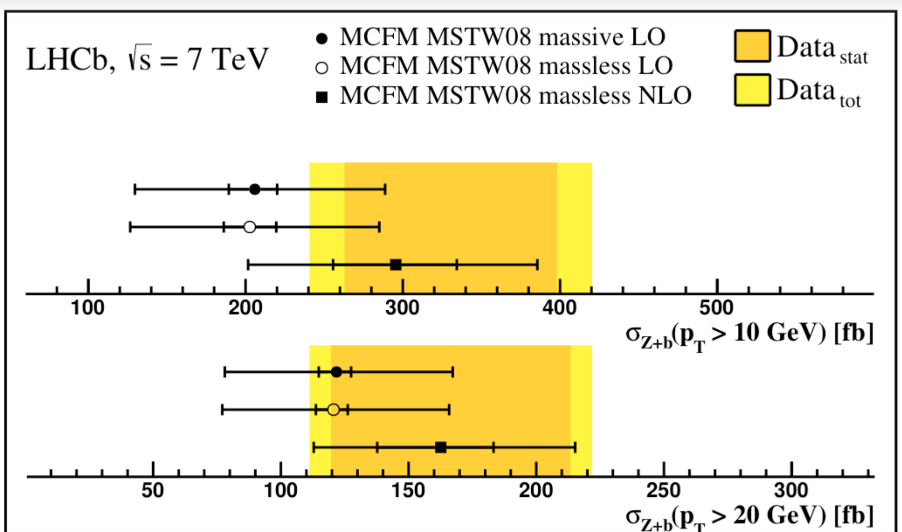




Z+b-jet at 7 TeV in the forward region

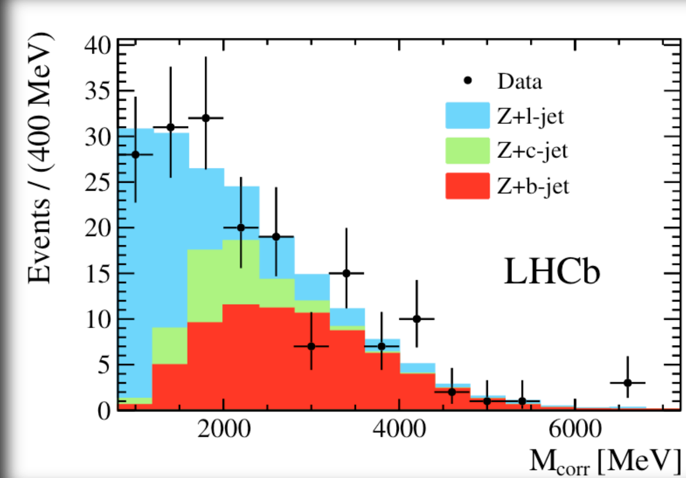
p_T(jet)>10 GeV: $\sigma = 330 \pm 68 \pm 58 \pm 12$ fb
p_T(jet)>20 GeV: $\sigma = 167 \pm 47 \pm 29 \pm 6$ fb

In agreement with leading-order and next-to-leading order calculations using massless and massive bottom quarks.

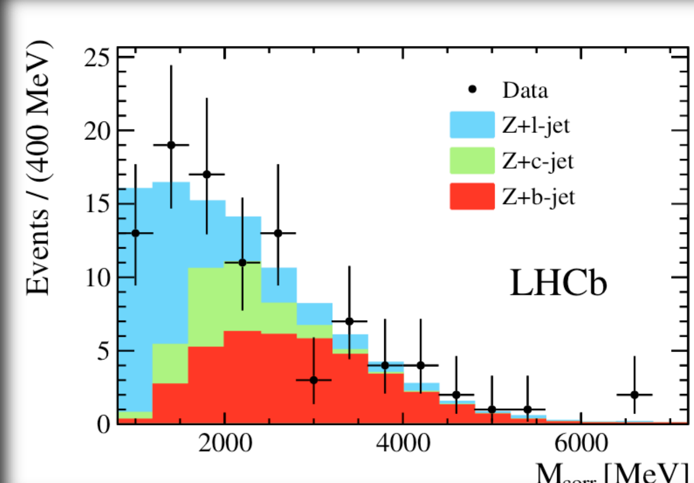


LHCb-PAPER-2014-055
arXiv:1411.1264

p_T(jet)>10 GeV, ≈72 Z+b-jet events



p_T(jet)>20 GeV, ≈40 Z+b-jet events



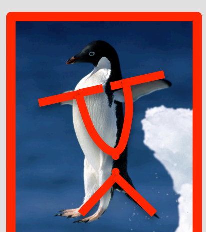
Precision measurements of CP violation

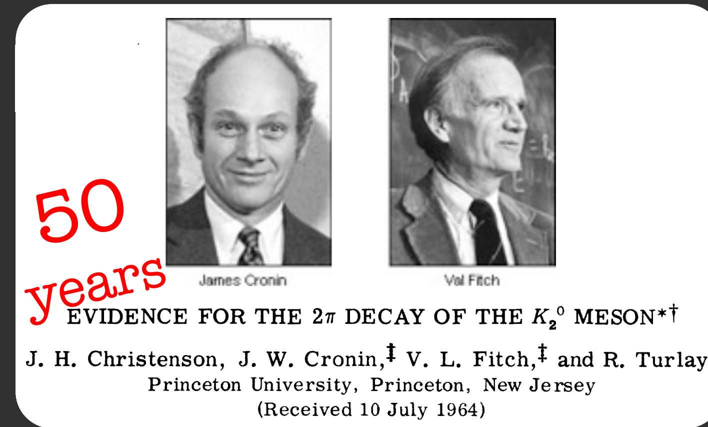
Going to high precision

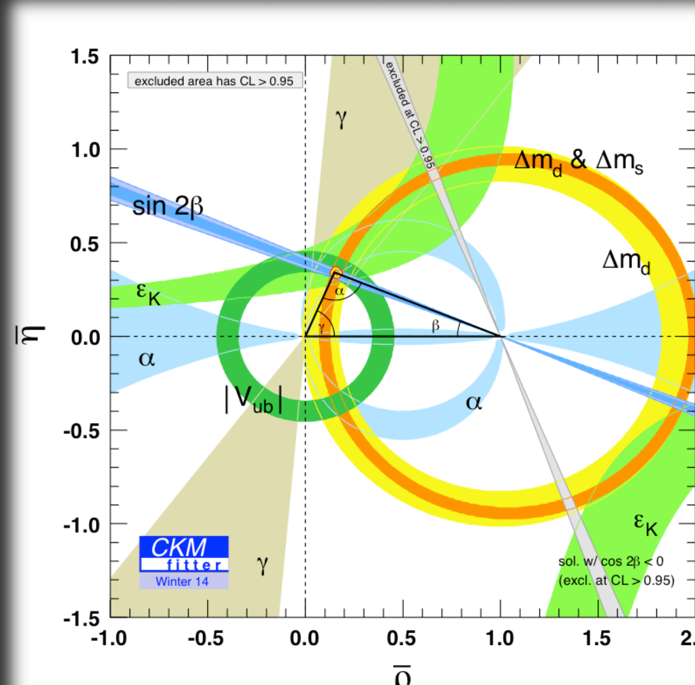
The CKM paradigm explains satisfactorily CPV data in leading B/D/K transitions, barring 10-15% corrections.

Moving to the (high) precision era. Looking for signs of non-SM physics. Need to control higher-order amplitude (QCD penguin loop), that can not longer be neglected, and can be confused with NP contributions:

$$\beta^{meas} = \beta^{SM} + \beta^{NP} + \delta^{penguin}$$







UT constraints dominated by sin2β

ϕ_s CP violating phase

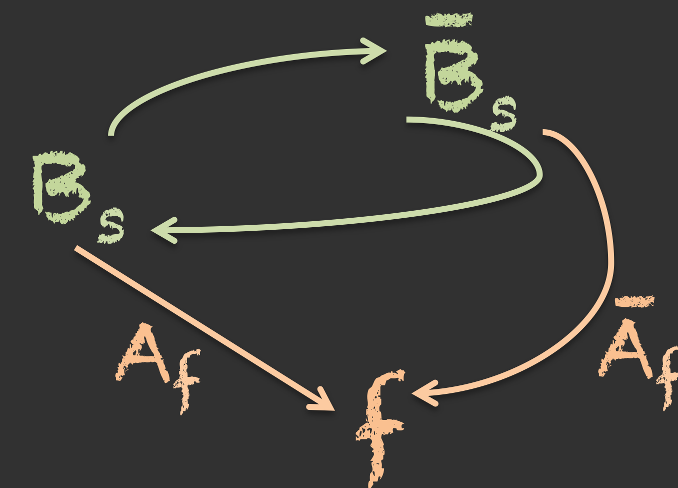
CP-violating phase ϕ_s, very sensitive to NP.
Precise determination from global CKM fits assuming SM:

$\phi_s = -0.0363 \pm 0.0013$ rad [CKMfitter]
neglecting penguins.

When both B_s^0 and $\overline{B}_s^0$ can decays to f :

$$\mathcal{A}_{CP} = \frac{\Gamma(B_s^0 \to f) - \Gamma(\overline{B}_s^0 \to f)}{\Gamma(B_s^0 \to f) + \Gamma(\overline{B}_s^0 \to f)} \simeq \frac{\mathcal{C}_f \cos(\Delta m_s t) - \mathcal{S}_f \sin(\Delta m_s t)}{\cosh(\Delta\Gamma_s t/2) + \mathcal{S}'_f \sinh(\Delta\Gamma_s t/2)}$$

direct probe of the CPV phase
$C_f \approx 0$ $S_f \approx \sin\phi_s$ $S'_f \approx \cos\phi_s$



$|B_{L,H}\rangle = p|B_s\rangle \pm q|\bar{B}_s\rangle$

$\Delta m_s = m_H - m_L$

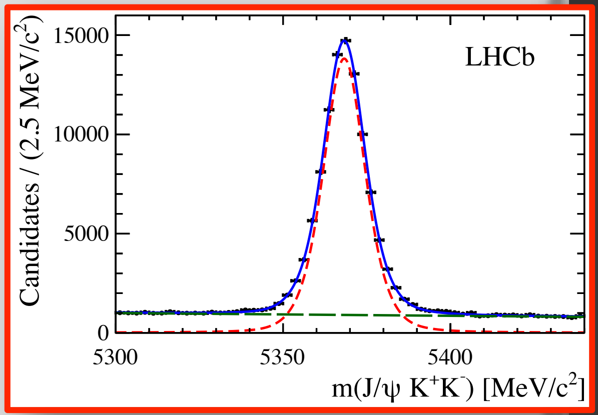
$\Delta\Gamma_s = \Gamma_L - \Gamma_H$

$\phi_s = -\arg(q/p\, \bar{A}_f/A_f)$

$B_s^0 \to J/\psi K^+ K^-$

LHCb-PAPER-2014-059
arXiv:1411.3104

96K signal events in the Run I data set



B mass

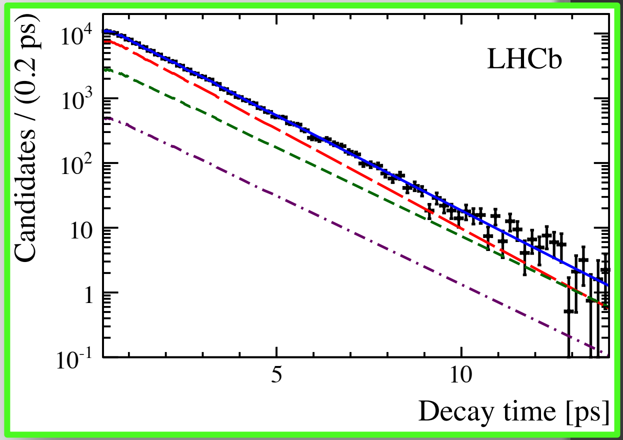
Separate signal from background

production flavour

Distinguish B from $\overline{\mathrm{B}}$ at the production

$$\mathcal{A}_{CP} = \frac{\Gamma(\boxed{B_s^0} \to f) - \Gamma(\boxed{\overline{B}_s^0} \to f)}{\Gamma(B_s^0 \to f) + \Gamma(\overline{B}_s^0 \to f)}$$

46 fs time resolution. Reduces the asymmetry by O(25%) (only).



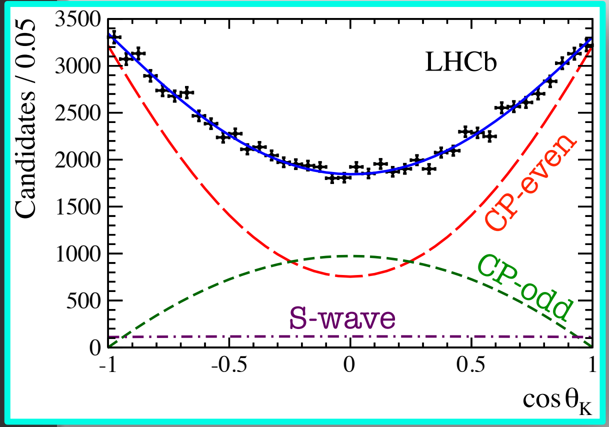
decay time

Trace the time evolution and fast B_s oscillations

decay-angles

Disentangle CP-even/CP-odd final state

Angular acceptance from simulations. 10-20% deviations from uniformity.



Flavour Tagging

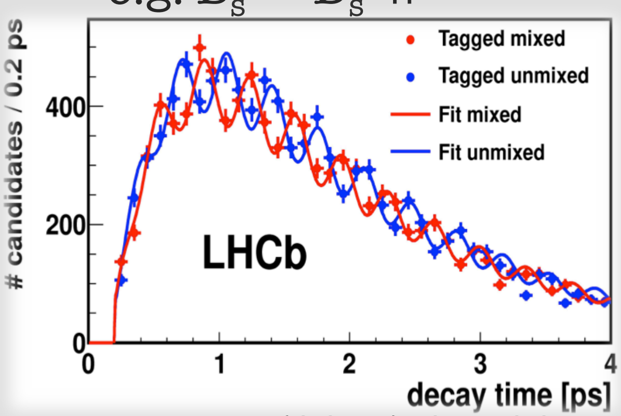
2 set of algorithms, re-optimized for the analysis of the Run I data.

Opposite Side Taggers,
$\varepsilon_{\text{eff}} = 2.55\%$, +15% w.r.t. 2011.

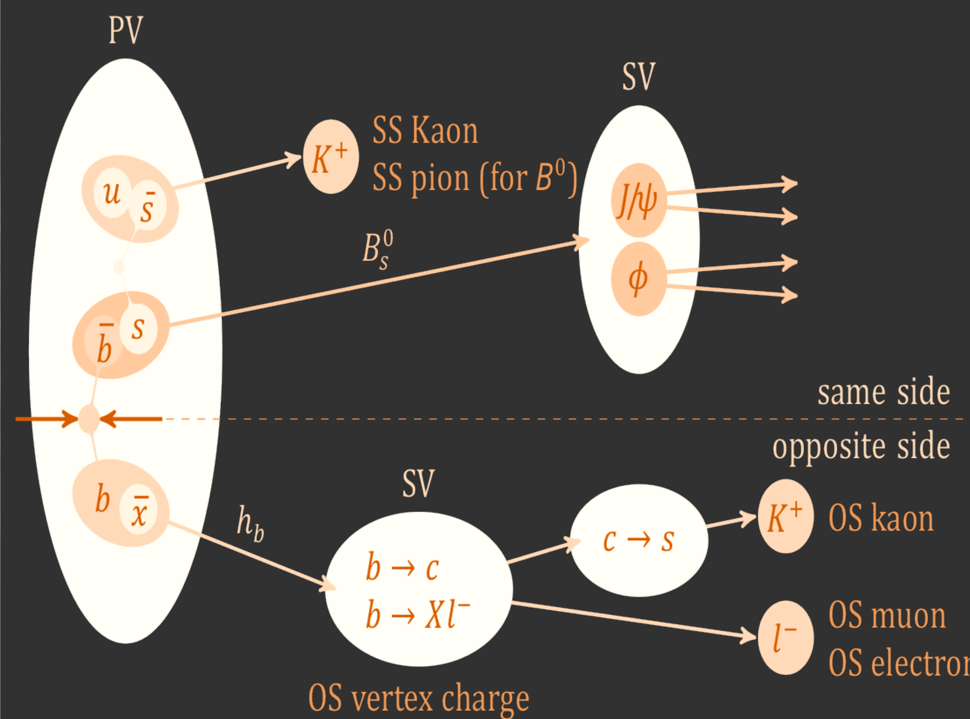
Same Side Kaon Tagger,
$\varepsilon_{\text{eff}} = 1.25\%$, +40% w.r.t 2011.
New algorithm, Neural Net based.

Calibrate mistag rate ω in control samples of flavour specific decays

e.g. $B_s^0 \to D_s^- \pi^+$



NJP 15 (2013) 053021



Tagging power:

$$\varepsilon_{\text{eff}} = \varepsilon\,(1 - 2\omega)^2$$

$$\varepsilon = N(\text{tagged})/N(\text{total})$$

$$\omega = N(\text{wrong tag})/N(\text{tagged})$$

$B_s^0 \to J/\psi K^+K^-$

LHCb-PAPER-2014-059
arXiv:1411.3104

$\Gamma_s = 0.6603 \pm 0.0027 \pm 0.0015\ \mathrm{ps}^{-1}$
$\Delta\Gamma_s = 0.0805 \pm 0.0091 \pm 0.0033\ \mathrm{ps}^{-1}$
CP-violating phase:
$\phi_s = -0.058 \pm 0.049 \pm 0.006$ rad
consistent with the SM.
World's best measurements.

Measure also CP violation in the decay. No evidence.

For the first time, measure CP violation independently for the 4 polarisation states. No difference found.

Combine with measurement in $B_s^0 \to J/\psi\, \pi^+\pi^-$ decays [PLB 736 (2014) 186], accounting for correlations between systematics and common parameters:

$$\phi_s = -0.010 \pm 0.039 \text{ rad}$$

$B_s^0 \to D_s^+ D_s^-$

LHCb-PAPER-2014-051
arXiv:1409.4619

Another decay to look for ϕ_s.
May have different (smaller) penguin contributions than $J/\psi h^+h^-$.
First time-dependent measurement in this decay.

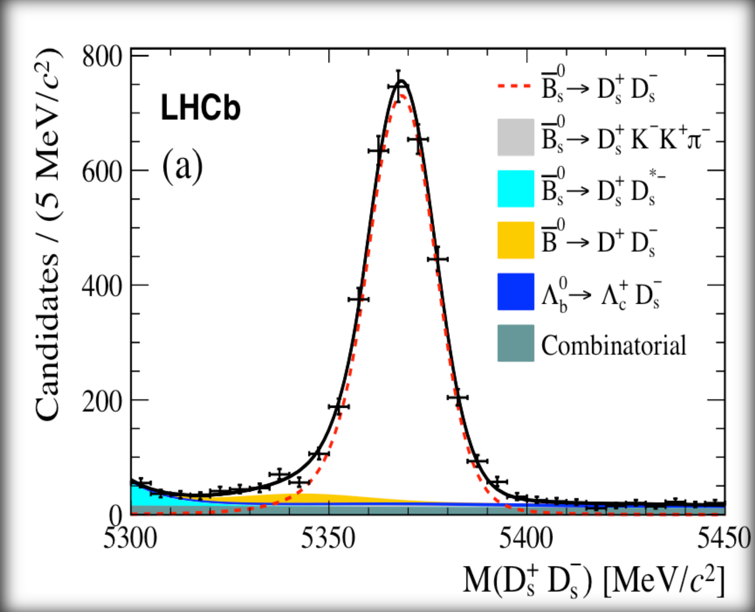
CP-even final state, no angular analysis needed. Benefit from larger tagging power in hadronic decays, combining OS and SSK: $\varepsilon_{\mathrm{eff}} = 5.33\%$

Similar decay-time resolution of $J/\psi h^+h^-$ modes, 54 fs.

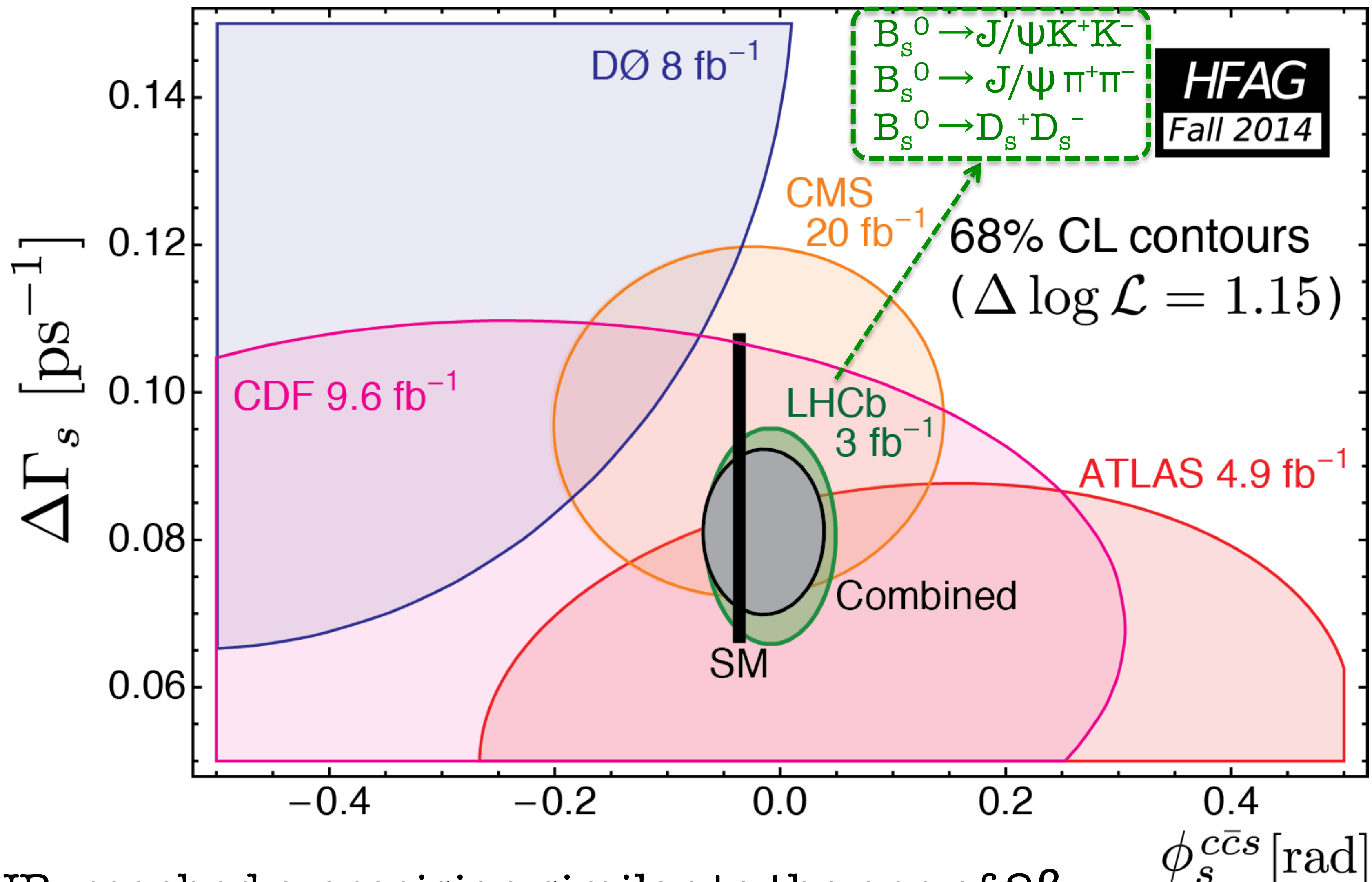
$$\phi_s = 0.02 \pm 0.17 \pm 0.02 \text{ rad}$$

Consistent with SM prediction.

≈3350 signal candidates

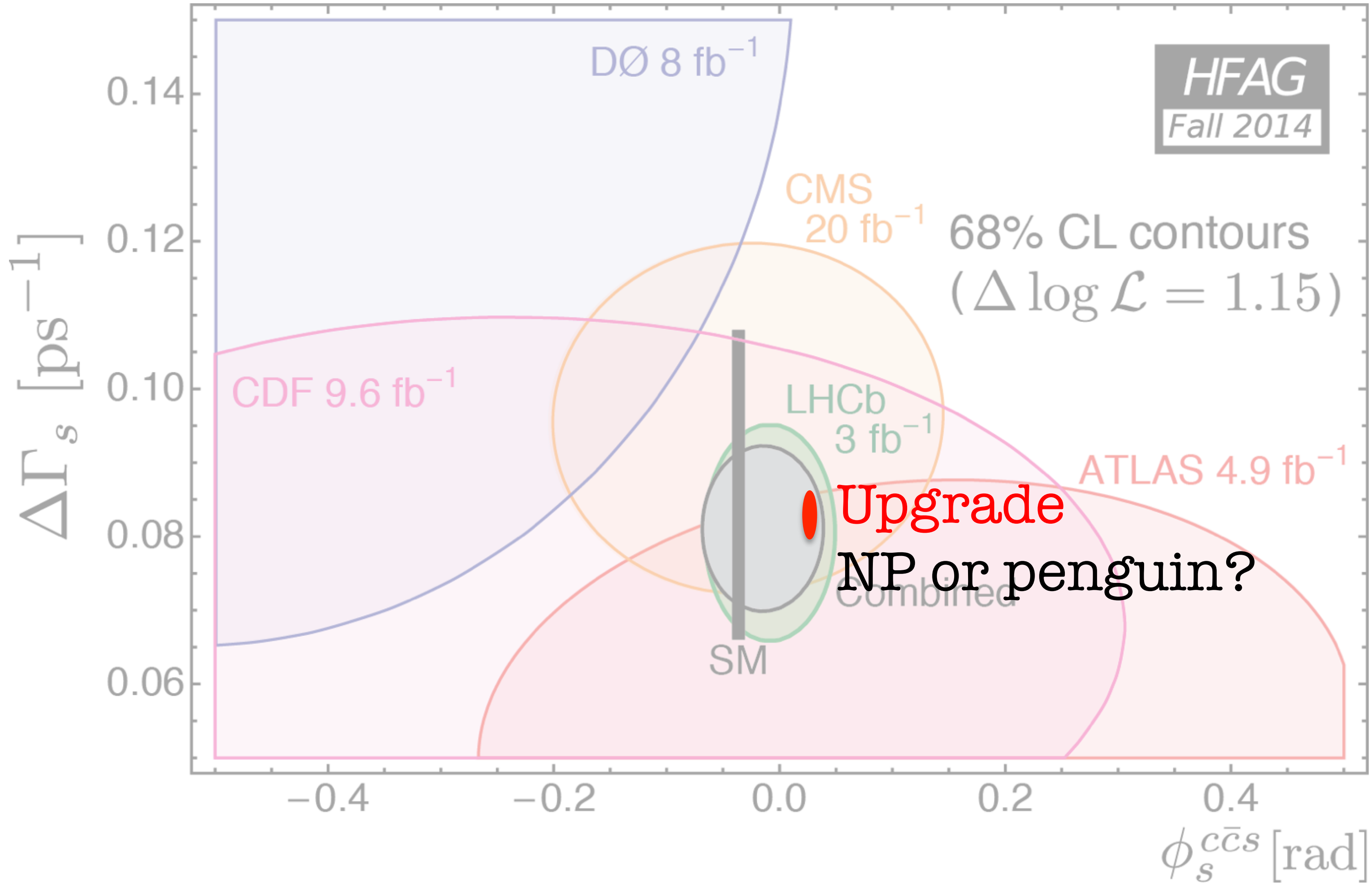


The Impact



NB: reached a precision similar to the one of 2β.

But still!



DØ 8 fb^{-1}
HFAG
Fall 2014
CMS
20 fb^{-1}
68% CL contours
$(\Delta \log \mathcal{L} = 1.15)$
CDF 9.6 fb^{-1}
LHCb
3 fb^{-1}
ATLAS 4.9 fb^{-1}
Upgrade
NP or penguin?
Combined
SM
0.14
0.12
0.10
0.08
0.06
$\Delta\Gamma_s$ [ps^{-1}]
−0.4
−0.2
0.0
0.2
0.4
$\phi_s^{c\bar{c}s}$ [rad]

$\sin 2\beta^{eff}$ from $B^0 \to J/\psi\, \pi^+\pi^-$

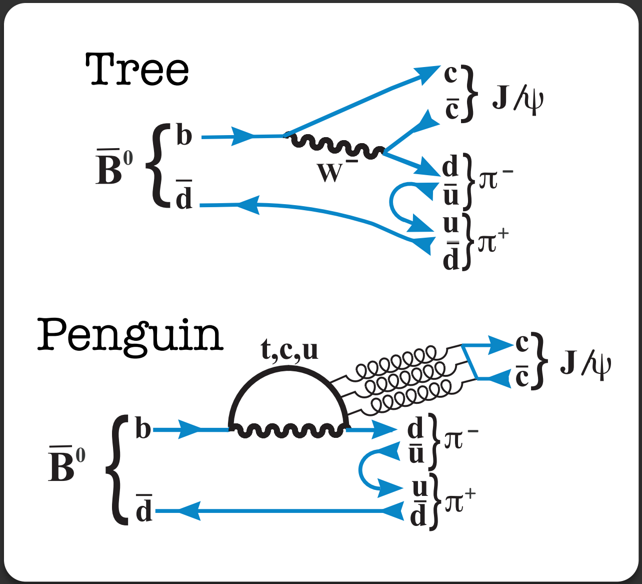
In $B^0 \to J/\psi\, \pi^+\pi^-$ decays penguins amplitudes are enhanced w.r.t. $B^0 \to J/\psi K_S{}^0$, golden mode for $\sin 2\beta$.

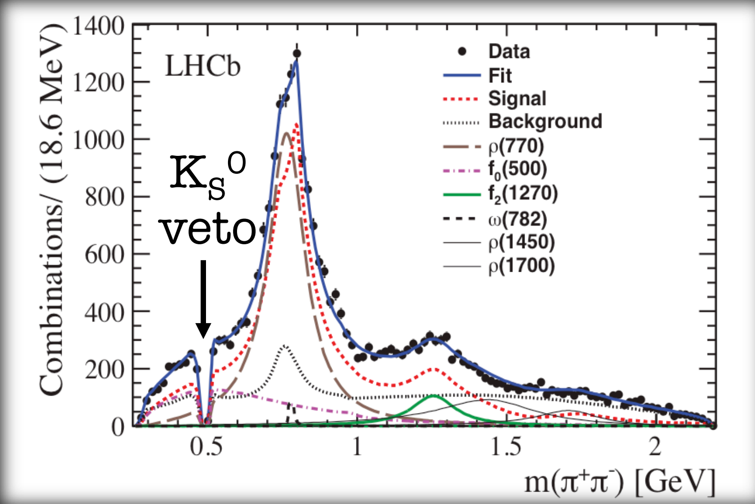
Measure "β angle" (β^{eff}) in $B^0 \to J/\psi\, \rho$ and compare with β measured in $B^0 \to J/\psi K_S{}^0$ allows to extract limits on the $\delta^{penguin}$.

Not a precision measurement of $\sin 2\beta^{eff}$ but set stringent constraints on the penguin effects.

Extend amplitude analysis [Phys. Rev. D90 (2014) 012003] to perform a flavour-tagged time-dependent analysis.

LHCb-PAPER-2014-058
arXiv:1411.1634





65% is $\rho(770)^0 \to \pi^+\pi^-$

$\mathrm{Sin}2\beta^{\mathrm{eff}}$ from $B^0 \to J/\psi\, \pi^+\pi^-$

LHCb-PAPER-2014-058
arXiv:1411.1634

$$2\beta^{J/\psi\,\rho} = 2\beta^{\mathrm{eff}} = (41.7 \pm 9.6^{+2.8}_{-6.3})^\circ$$

$$\Delta 2\beta_f = 2\beta^{J/\psi\,\rho} - 2\beta^{J/\psi\,K^0_S} = (-0.9 \pm 9.7^{+2.8}_{-6.3})^\circ$$

Sets limits on the penguin contribution to ϕ_s in $B_s^0 \to J/\psi h^+h^-$

$[-1.05^\circ, 1.18^\circ]$ at 95% CL, *

assuming approximate SU(3) symmetry. The limits depends on the difference of strong phases and relative magnitudes between tree and penguin amplitudes, but do not exceed $\pm 1.8^\circ$.

Effect of penguin contributions in $B^0 \to J/\psi K_S^0$ should be limited to similar values.

*N.B. Currently, $\sigma(2\beta) = \pm 1.6^\circ$ and $\sigma(\phi_s) = \pm 2^\circ$ [HFAG].

Run I, coming soon

Many important analyses soon from the full 3 fb^{-1} data set:

$B^0 \rightarrow K^{*0}\mu^+\mu^-$ angular analysis

$\sin 2\beta$ from $B^0 \rightarrow J/\psi K_S^0$

Time-dependent $B_s^0 \rightarrow \phi\gamma$ [new!]

D^*-tagged $\Delta A_{CP}(D^0 \rightarrow hh)$

Semileptonic asymmetry A_{sl}^s

Several ADS/GLW γ analyses

Time-dependent $B \rightarrow hh$

… … …

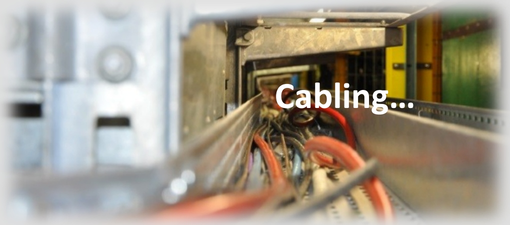
and other surprises!

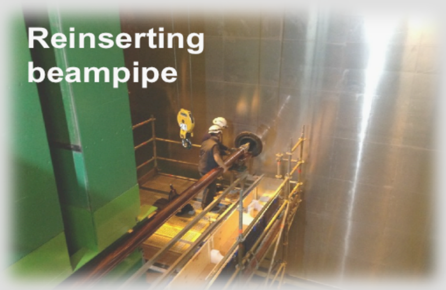
What's next?

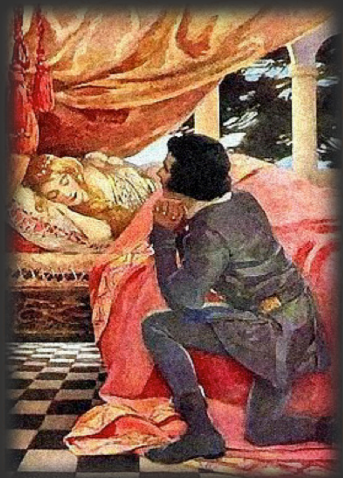
- Run II preparation

Wake up the Beauty for Run II

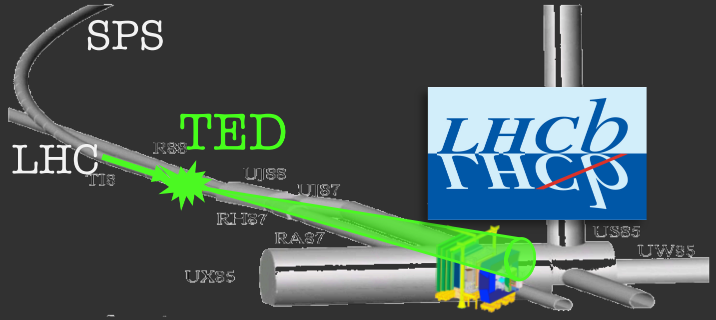
A very busy time since last LHCC.
All work completed on schedule.
Detector fully closed last Friday.







Ready for
commissioning week.
Shots on injection line beam stopper (TED) on 22-23/11.



Herschel

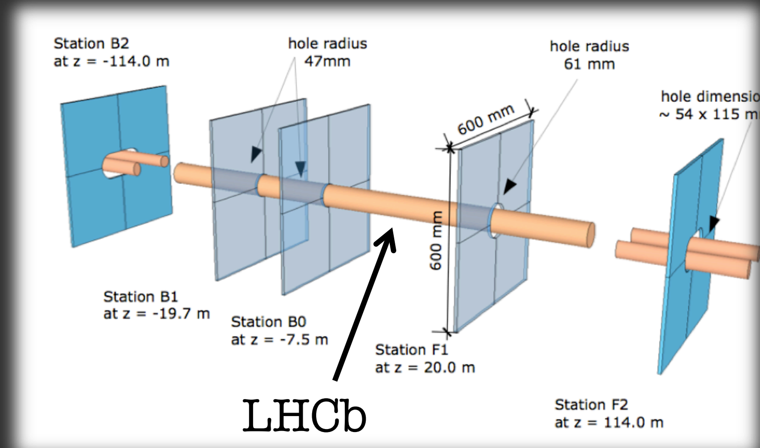
Forward and Backward Scintillator Shower Detectors

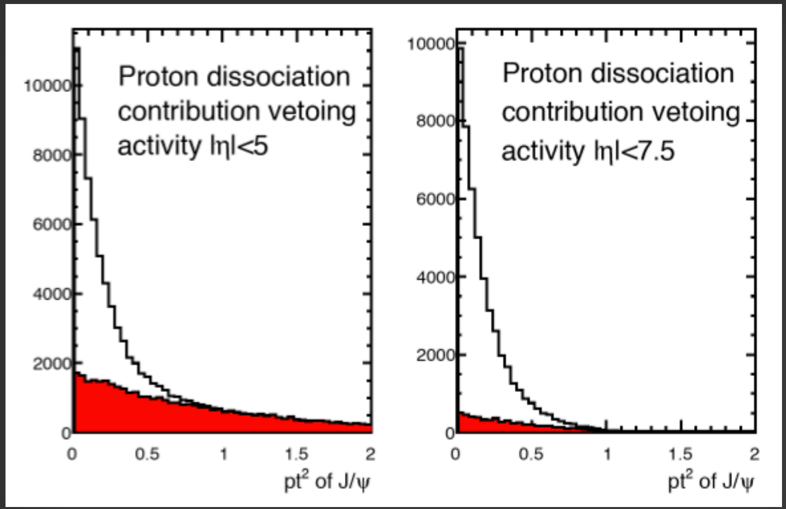
Scintillator planes deployed symmetrically around LHCb. Extension of rapidity gap coverage by 2-3 units.

Can provide input to trigger. Allows control of non-exclusive backgrounds.

Can exploit the Run II LHCb data with low pileup. Potential for diffractive physics, beam background studies, luminosity.

Ready for commissioning and TED runs.



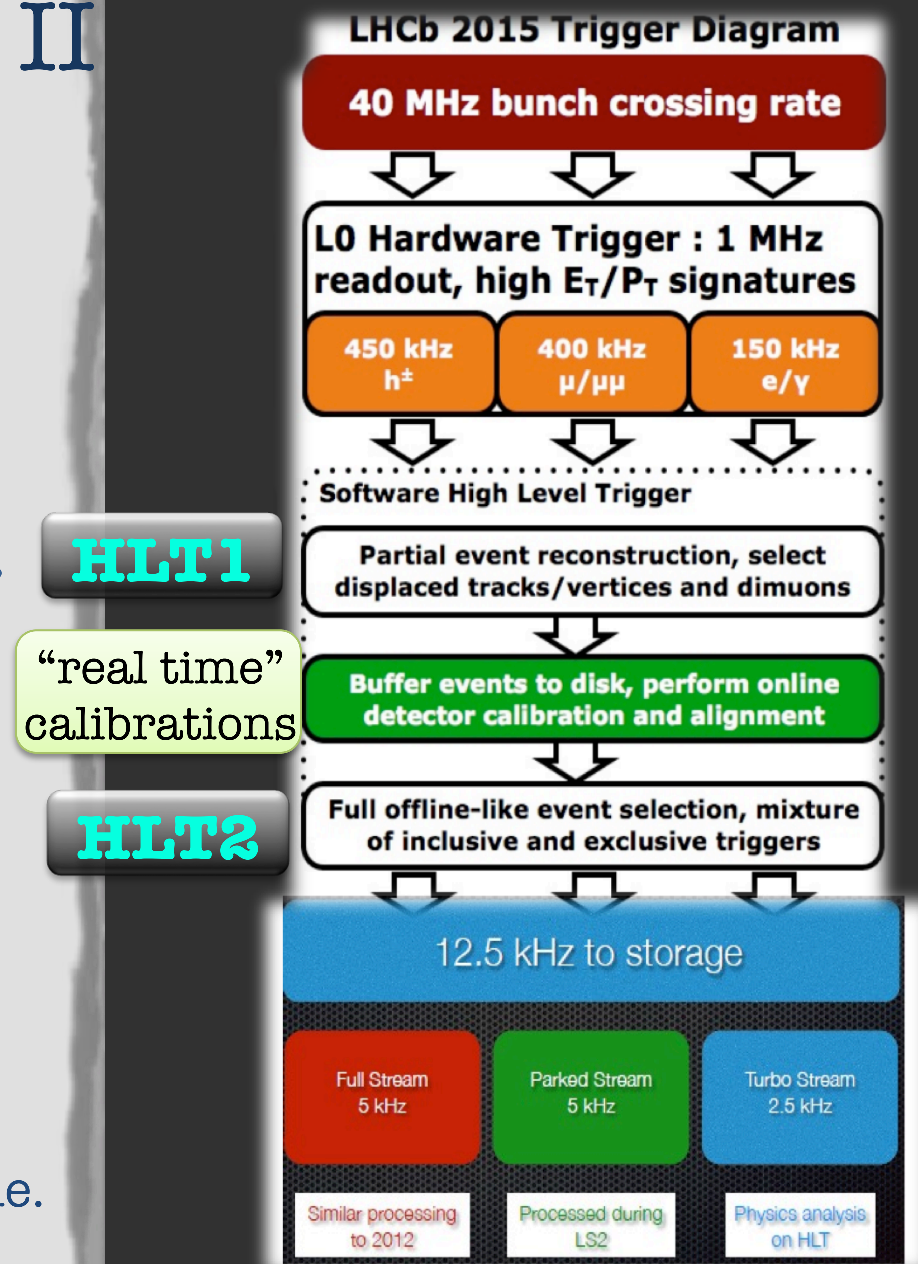


Operations in Run II

Ambitious changes for operations during Run II aimed at increasing physics output and making optimal use of resources

Splitting of HLT into two steps. Perform calibrations and alignment before HLT2. Enables more info to be used in HLT2 (*e.g.* PID). Test ideas for Upgrade trigger.

Turbo-stream will need no offline processing. If this works well then it has important implications for Upgrade.



Data handling

Optimising the resources

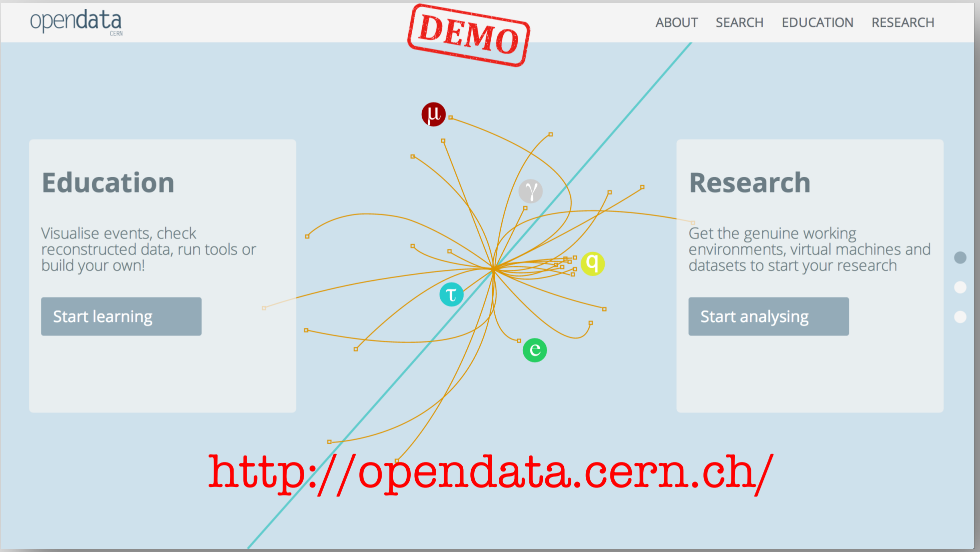
Offline re-selection (re-stripping) of Run I dataset, prototype for Run II, with a new, reduced data format (μDST). Will be legacy Run I data set. Allows to **save more than 50% of disk space w.r.t. previous selection**, adding reconstruction info (price to pay: production twice slower).

Data preservation & Open access

Create a framework to **preserve all information** related to an analysis, from user code to final results, internal and public documentations.
In development with Cern-IT, CMS and ALICE.

LHCb joined Cern Open data portal

with the data samples for the international Masterclass Program. Other will be added, according to the LHCb open data policy.



http://opendata.cern.ch/

Looking ahead

- Upgrade activities

After Run II

Indirect search strategies for non-SM physics become ever-more attractive following the experience of Run I that direct signals are elusive.

Knowledge of flavour physics has advanced spectacularly thanks to LHCb and will improve with Run II. Expect to triple the current statistics.

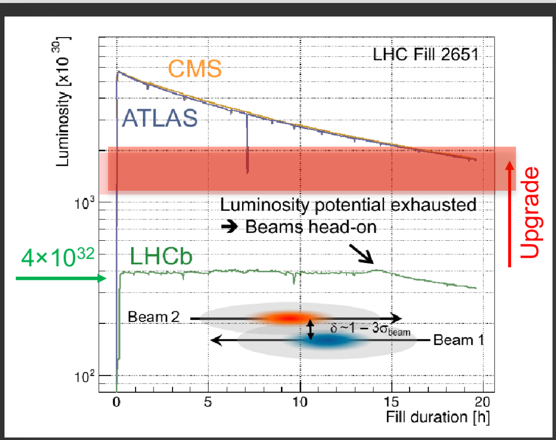
Maintaining this rate of progress beyond Run II unattainable.
LHCb already runs at twice its design luminosity, trigger design limits do not allow to go much higher.

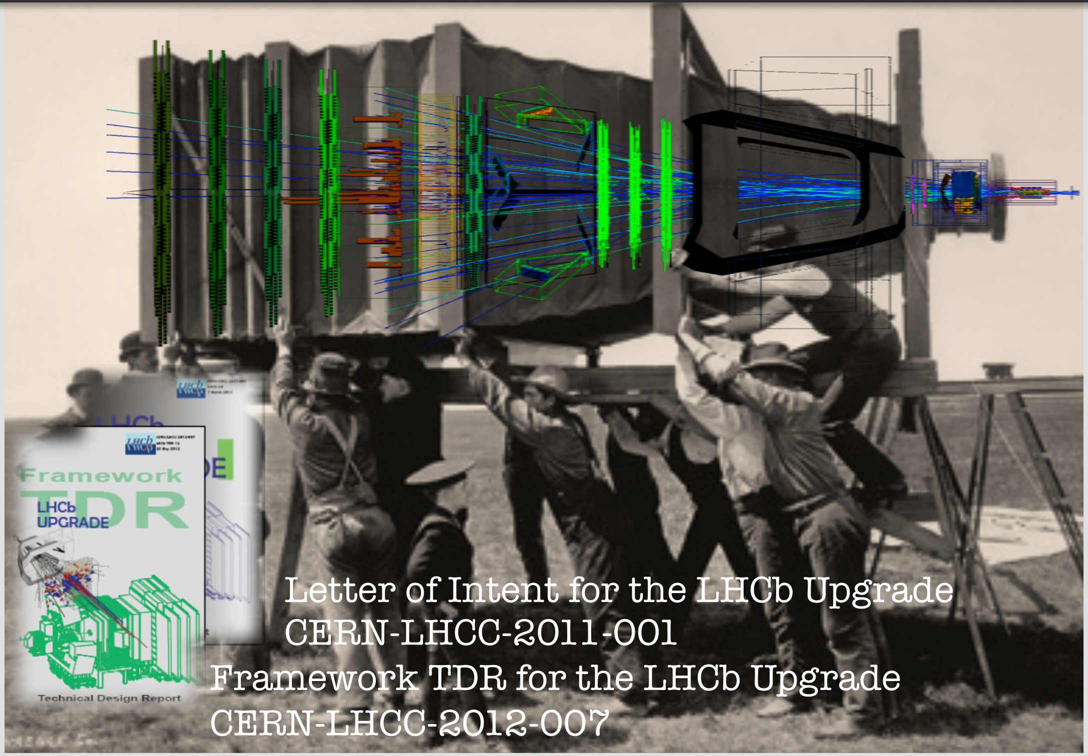
At this pace, need almost 5 years to double Run II data.

Upgrade

Raise operational luminosity to 2 x 10^{33} cm^{-2} s^{-1}.

Full software trigger. Allows effective operation at higher luminosity. Improved efficiency in hadronic modes.



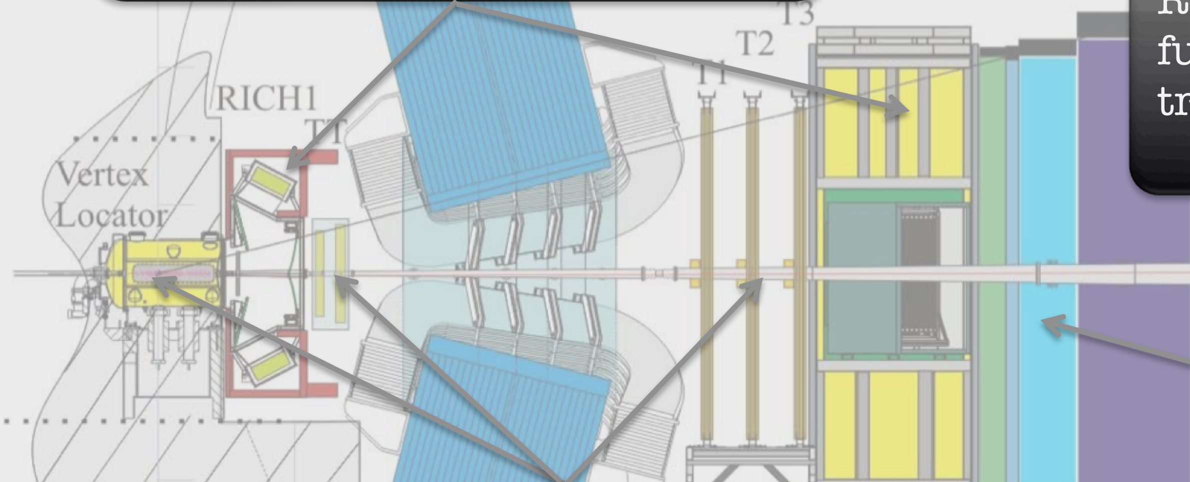


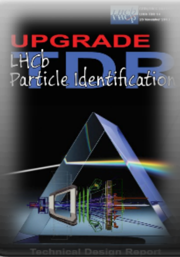
Letter of Intent for the LHCb Upgrade
CERN-LHCC-2011-001
Framework TDR for the LHCb Upgrade
CERN-LHCC-2012-007

Remove L0 bottleneck, all detector read out at 40 MHz. Necessitates redesign of several sub-detectors & overhaul of readout.

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

Upgrade Overview



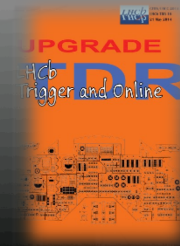


RICH

New photo-detectors for RICH 1 and RICH 2;
RICH1 redesign.

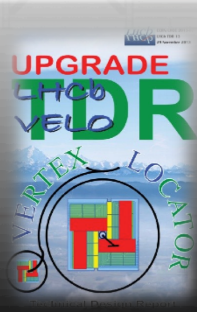
Trigger & DAQ

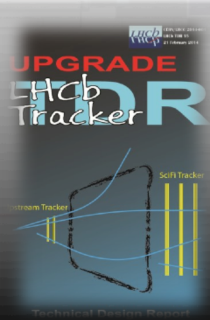
Read-out at 40 MHz;
Replace FE and BE electronics;
Remove L0,
full software trigger



Tracking

Replace all detectors:
VELO (Si pixels);
Upstream Tracker (Si strips);
Downstream Tracker (Sci-Fi).





Calo & Muon

Remove components used only for L0.
Add new electronics;
Include more shielding.

All upgrade TDRs approved by RB.

To the next phase

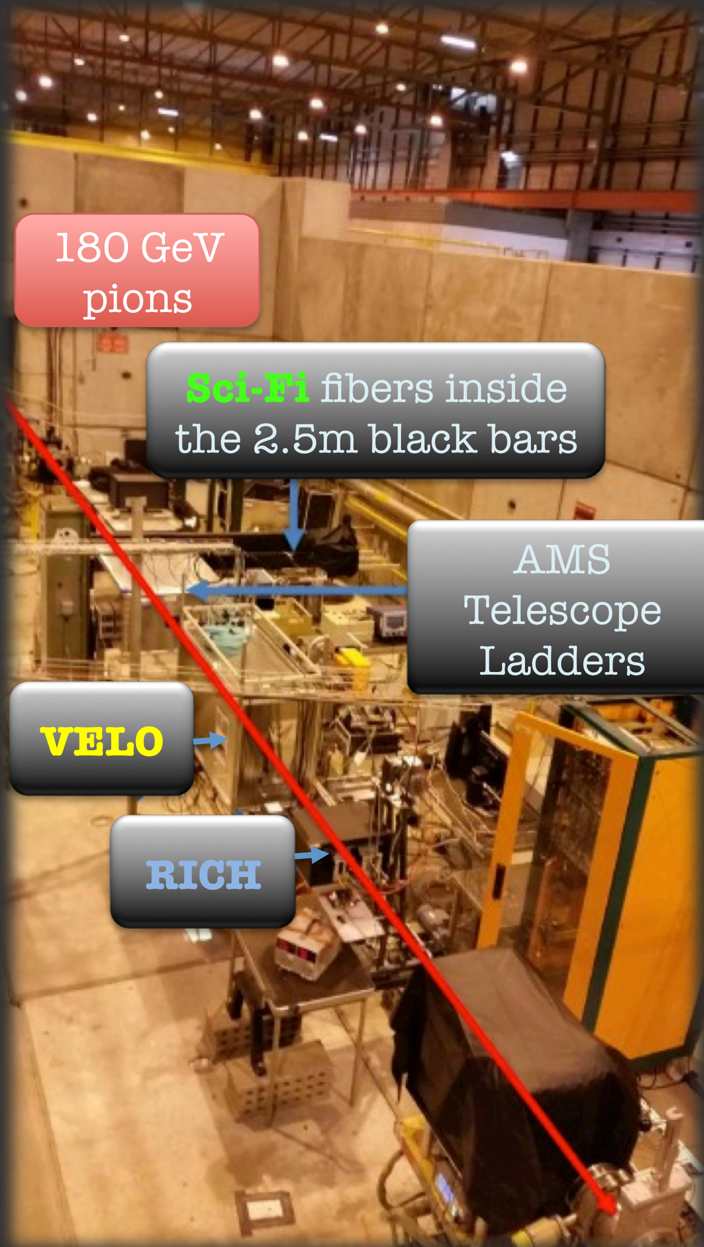
Final & achievable technology choices for all systems established.
Organised for final stages of R&D, engineering and production readiness reviews, and production.

High-level milestones defined for each sub-system in order to track progress.

Division of resource allocation finalised and presented to the October RB.

Test beams recently for:

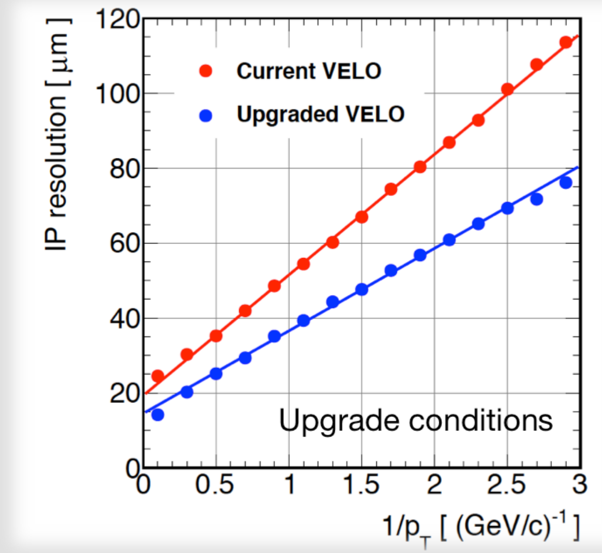
- **VELO**
- **UT**
- **Sci-Fi**
- **RICH**



VELO

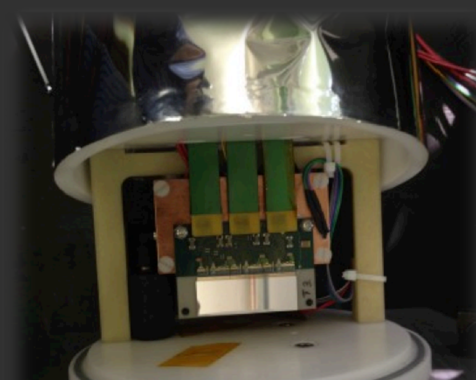
New, pixel (50 x 50 μm²) based

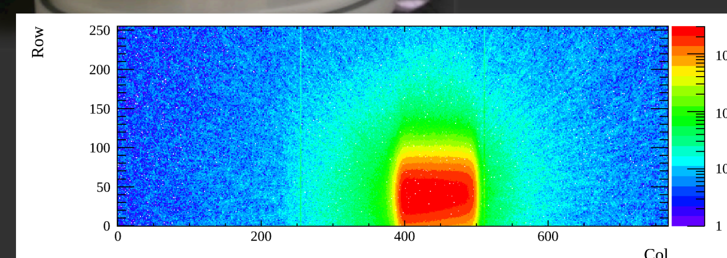
- Good 3D pattern recognition
- Excellent resolution
- Micro-channel cooling, minimises material
- Radiation resistance
- Closer to beam line (5 mm, *cf.* 8 mm now)



Recent Test beam

- ✓ Tested and fully characterised first single and triple Hamamatsu prototype sensor assemblies, non-irradiated.
- ✓ Took first beam data with triple chip assembly
- ✓ Getting ready for irradiated sensors

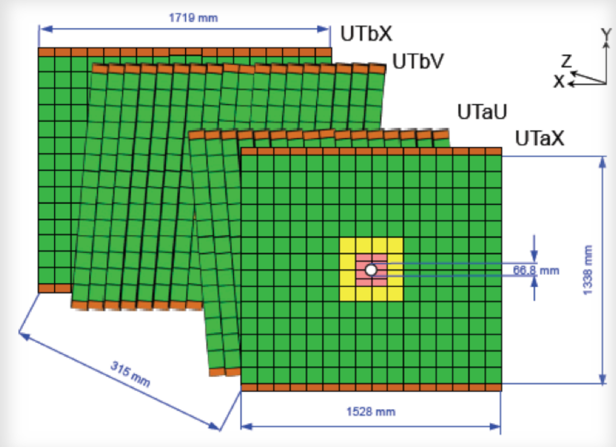




Upstream Tracker

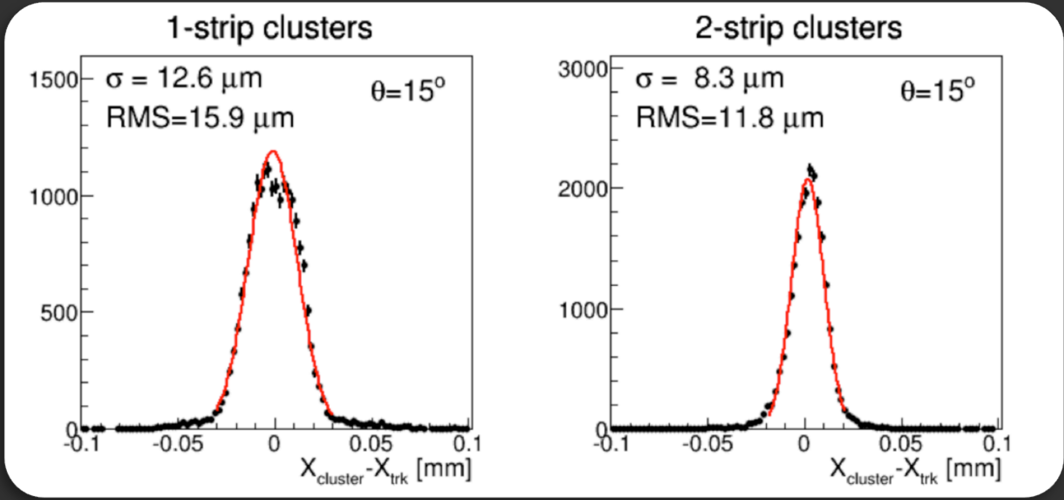
Critical silicon strip tracking planes just before magnet.

- Variable granularity to match occupancies
- Stave system inspired by ATLAS IBL
- Fully active within acceptance
- Less material than current detector (TT)



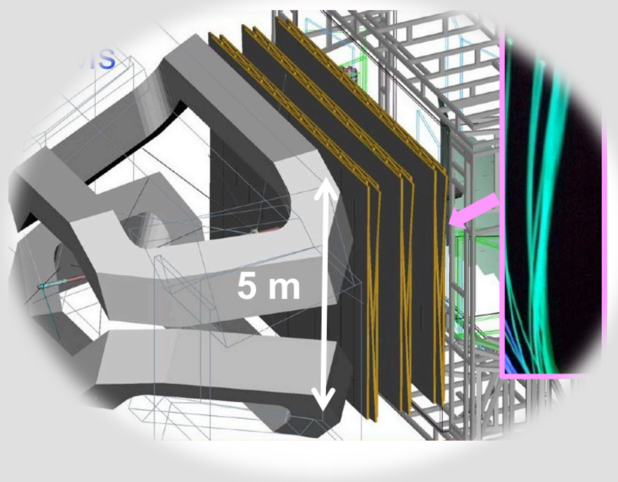
UT test beam

- ✓ Tested 8 detectors, irradiated up to 20 MRad
- ✓ Sensor cooled down to -10°C
- ✓ Bias scans and angle scans



Downstream Tracker

Large scale tracking system based on mats of 2.5 m long scintillating fibres of 250 μm diameter, readout by SiPMs
- single detector technology
- fast pattern recognition
- good resolution



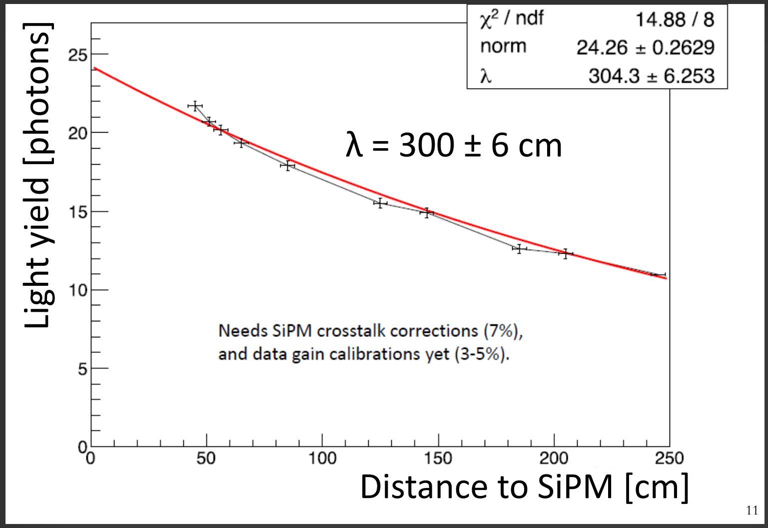
Sci-Fi test beam

✓ Measure light yield and attenuation length of fibres.

✓ Measure spatial resolution.

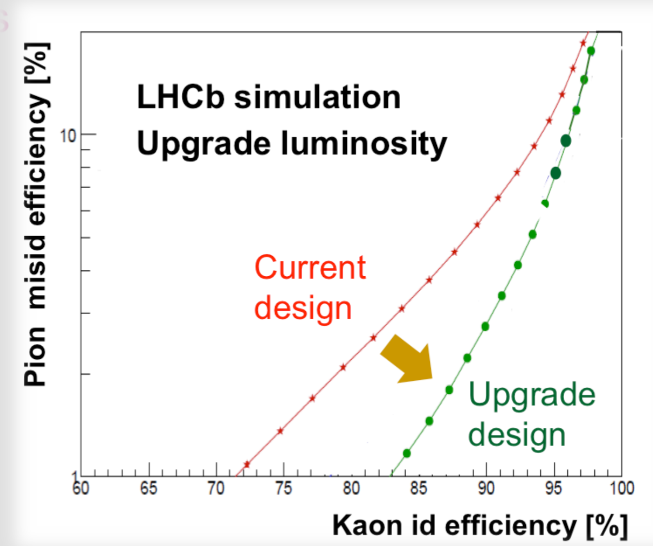
✓ Compare results to simulation and laboratory measurements.

✓ Provide inputs for tuning of simulations



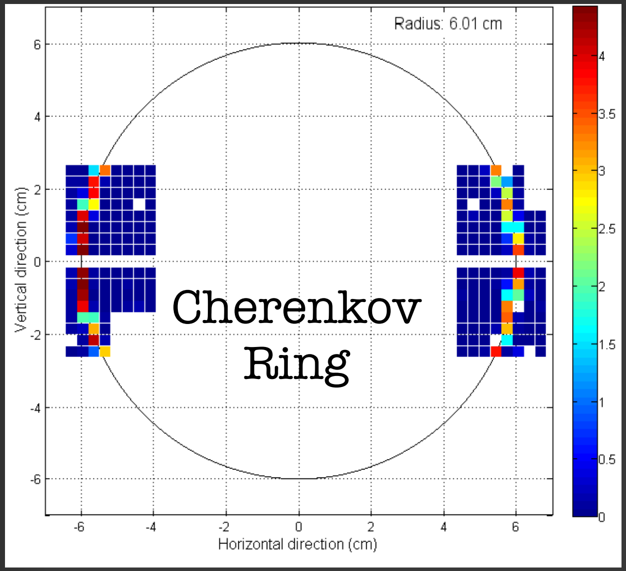
RICH system

- Keep both RICHs
- Replace photodetecorts with multi-anode PMTs to allow 40MHz read-out
- Improve RICH1 optics design (inside the present magnetic shield envelope) to reduce occupancy



Test beam

- ✓ Study PMT attenuation and threshold adjustments with dark counts.
- ✓ Measurements with beam; HV scan; study number of hits and lens position.
- ✓ Fit of the Cherenkov rings.



The target

Huge increase in precision, in many cases to the theoretical limit.

Type	Observable	LHC Run 1	LHCb 2018	**LHCb upgrade**	Theory
B_s^0 mixing	$\phi_s(B_s^0 \to J/\psi\,\phi)$ (rad)	0.049	0.025	**0.009**	~ 0.003
	$\phi_s(B_s^0 \to J/\psi\, f_0(980))$ (rad)	0.068	0.035	**0.012**	~ 0.01
	$A_{\rm sl}(B_s^0)$ (10^{-3})	2.8	1.4	**0.5**	0.03
Gluonic penguin	$\phi_s^{\rm eff}(B_s^0 \to \phi\phi)$ (rad)	0.15	0.10	**0.018**	0.02
	$\phi_s^{\rm eff}(B_s^0 \to K^{*0}\bar{K}^{*0})$ (rad)	0.19	0.13	**0.023**	< 0.02
	$2\beta^{\rm eff}(B^0 \to \phi K_S^0)$ (rad)	0.30	0.20	**0.036**	0.02
Right-handed currents	$\phi_s^{\rm eff}(B_s^0 \to \phi\gamma)$ (rad)	0.20	0.13	**0.025**	< 0.01
	$\tau^{\rm eff}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	5%	3.2%	**0.6%**	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.04	0.020	**0.007**	0.02
	$q_0^2\, A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	10%	5%	**1.9%**	$\sim 7\%$
	$A_{\rm I}(K\mu^+\mu^-; 1 < q^2 < 6\,{\rm GeV}^2/c^4)$	0.09	0.05	**0.017**	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	14%	7%	**2.4%**	$\sim 10\%$
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ (10^{-9})	1.0	0.5	**0.19**	0.3
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	220%	110%	**40%**	$\sim 5\,\%$
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	7°	4°	**0.9°**	negligible
	$\gamma(B_s^0 \to D_s^{\mp}K^{\pm})$	17°	11°	**2.0°**	negligible
	$\beta(B^0 \to J/\psi\, K_S^0)$	1.7°	0.8°	**0.31°**	negligible
Charm *CP* violation	$A_\Gamma(D^0 \to K^+K^-)$ (10^{-4})	3.4	2.2	**0.4**	–
	ΔA_{CP} (10^{-3})	0.8	0.5	**0.1**	–

Conclusions

- ✧ LHCb continues to harvest rich results from Run I.

  Most measurements in good agreement with the SM, but almost all limited by statistics.

  Full data sample not (yet) completely exploited. Many important papers still foreseen.

- ✧ LHCb will be ready and fully operational for Run II.

  Ambitious, but realisable, changes to operation planned to increase physics output and optimise resources.

- ✧ Upgrade entered a new, exciting phase.

  All technologies defined; final R&D, procurement, and construction about to start.

  Will allow (in several cases) approaching in precision the theoretical uncertainty.

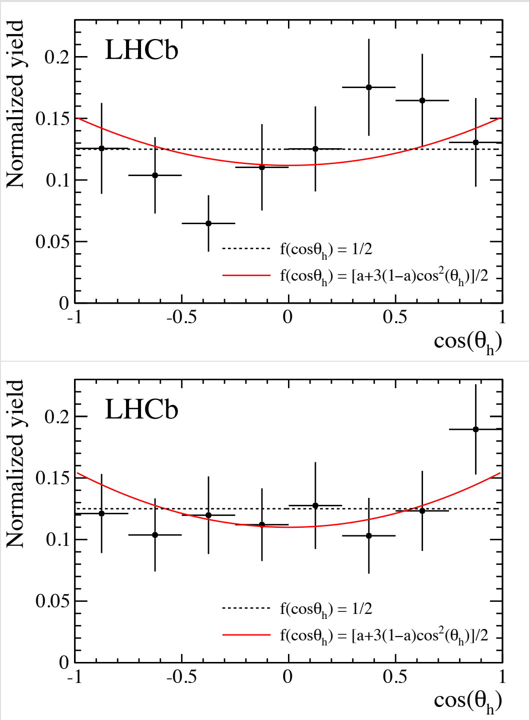
Backup

Two new baryons

LHCb-PAPER-2014-061
Hot off the press

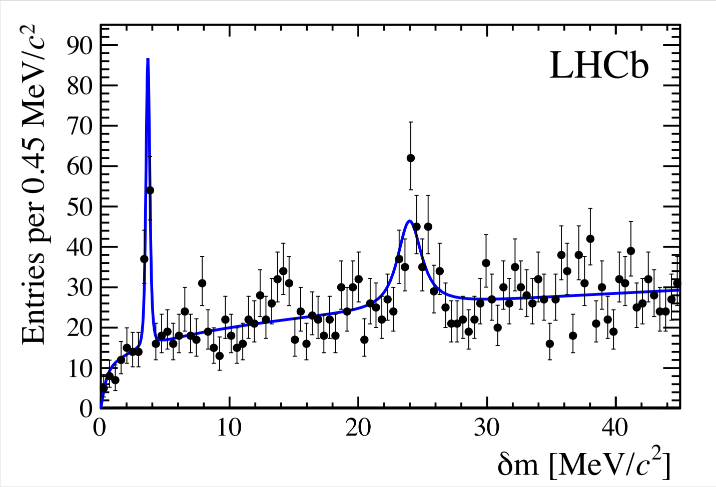
Systematics:

Source	$\delta m(\Xi_b')$	$\delta m(\Xi_b^*)$	$\Gamma(\Xi_b^*)$
Simulated sample size	0.002	0.005	
Multiple candidates	0.004	0.048	0.055
Resolution model	0.002	0.003	0.070
Background description	0.001	0.003	0.019
Momentum scale	0.003	0.014	0.003
RBW spin and radial parameter	0.000	0.023	0.028
Sum in quadrature	0.006	0.055	0.095
Statistical uncertainty	0.018	0.119	0.311



Checked angular distributions.
Consistent with spin expected,
though other J cannot be excluded.

Study of $\Xi_b^0\pi^-$ mass spectrum with additional Ξ_b^0 decays, such as $\Xi_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K^- \pi^+) K^- \pi^+ \pi^-$, confirm the observations.



Two new baryons

LHCb-PAPER-2014-061
Hot off the press

Measured also the relative production rates

$$\frac{\sigma(pp \to \Xi_b^{\prime -} X)\mathcal{B}(\Xi_b^{\prime -} \to \Xi_b^0 \pi^-)}{\sigma(pp \to \Xi_b^0 X)} = 0.118 \pm 0.017 \pm 0.007,$$

$$\frac{\sigma(pp \to \Xi_b^{*-} X)\mathcal{B}(\Xi_b^{*-} \to \Xi_b^0 \pi^-)}{\sigma(pp \to \Xi_b^0 X)} = 0.207 \pm 0.032 \pm 0.015,$$

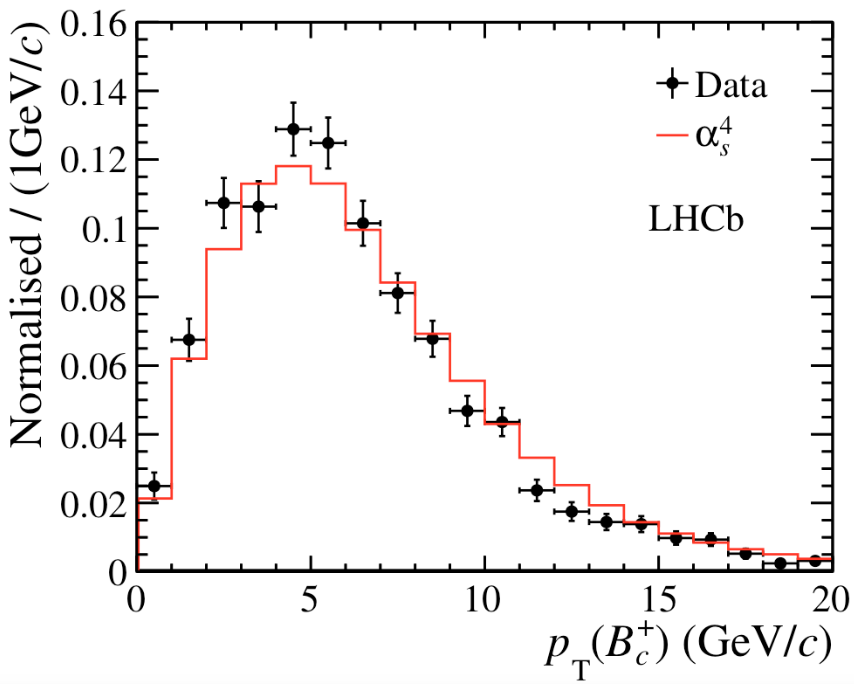
$$\frac{\sigma(pp \to \Xi_b^{*-} X)\mathcal{B}(\Xi_b^{*-} \to \Xi_b^0 \pi^-)}{\sigma(pp \to \Xi_b^{\prime -} X)\mathcal{B}(\Xi_b^{\prime -} \to \Xi_b^0 \pi^-)} = 1.74 \pm 0.30 \pm 0.12,$$

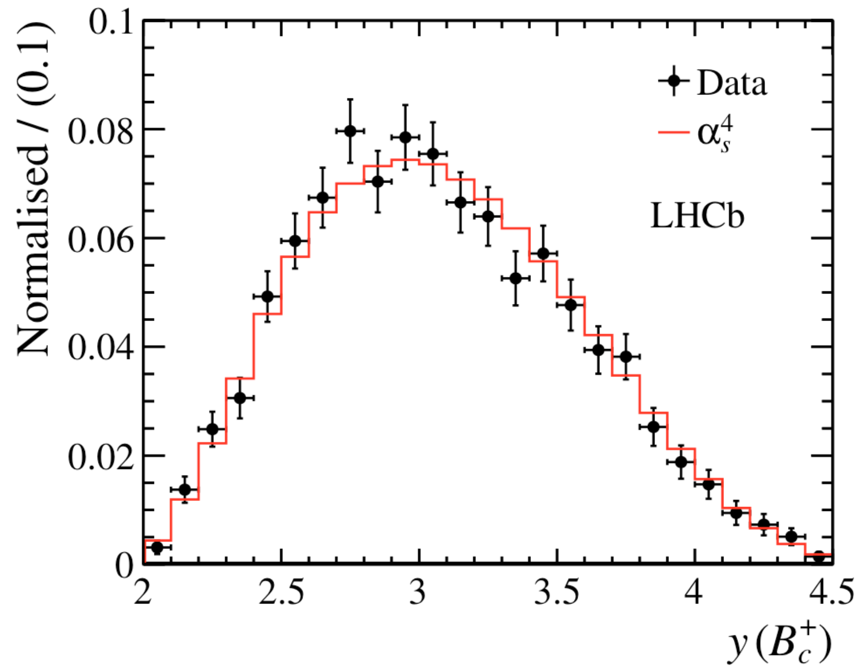
The cross section measured within LHCb acceptance is extrapolated to the full kinematic range with Pythia.

B_c^+ production at 8 TeV

LHCb-PAPER-2014-050

Good agreement with BCVEGPY generator.





B_c^+ production at 8 TeV

LHCb-PAPER-2014-050

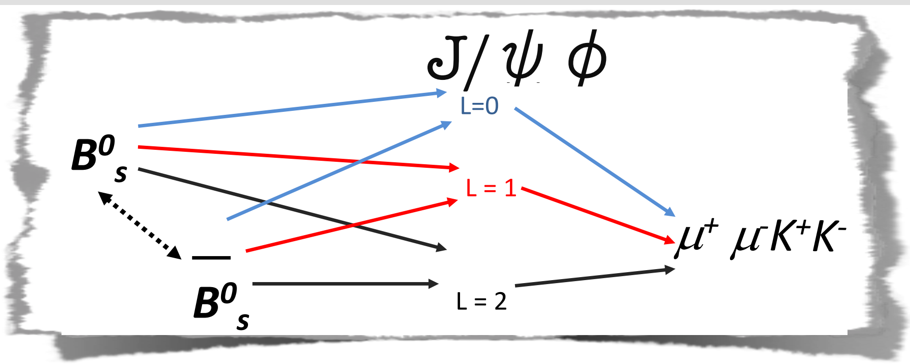
Table 2: $R(p_{\mathrm{T}}, y)$ in multiples of 10^{-2} as a function of p_{T} in three y bins and in the whole y range. The first uncertainty is statistical and the second systematic.

p_{T} (GeV/c)	$2.0 < y < 2.9$	$2.9 < y < 3.3$	$3.3 < y < 4.5$	$2.0 < y < 4.5$
$0 < p_{\mathrm{T}} < 2$	$0.67 \pm 0.10 \pm 0.01$	$0.73 \pm 0.10 \pm 0.01$	$0.35 \pm 0.06 \pm 0.01$	$0.54 \pm 0.05 \pm 0.01$
$2 < p_{\mathrm{T}} < 3$	$0.70 \pm 0.09 \pm 0.02$	$0.72 \pm 0.09 \pm 0.02$	$0.50 \pm 0.06 \pm 0.01$	$0.62 \pm 0.05 \pm 0.01$
$3 < p_{\mathrm{T}} < 4$	$0.62 \pm 0.08 \pm 0.01$	$0.58 \pm 0.08 \pm 0.01$	$0.57 \pm 0.07 \pm 0.02$	$0.59 \pm 0.05 \pm 0.01$
$4 < p_{\mathrm{T}} < 5$	$0.83 \pm 0.08 \pm 0.02$	$0.60 \pm 0.07 \pm 0.01$	$0.81 \pm 0.08 \pm 0.02$	$0.79 \pm 0.05 \pm 0.01$
$5 < p_{\mathrm{T}} < 6$	$0.90 \pm 0.09 \pm 0.02$	$0.78 \pm 0.09 \pm 0.01$	$0.76 \pm 0.09 \pm 0.02$	$0.83 \pm 0.06 \pm 0.01$
$6 < p_{\mathrm{T}} < 7$	$0.84 \pm 0.09 \pm 0.01$	$0.99 \pm 0.11 \pm 0.02$	$0.64 \pm 0.08 \pm 0.01$	$0.79 \pm 0.06 \pm 0.01$
$7 < p_{\mathrm{T}} < 8$	$0.95 \pm 0.10 \pm 0.01$	$0.74 \pm 0.11 \pm 0.01$	$0.65 \pm 0.09 \pm 0.01$	$0.82 \pm 0.06 \pm 0.01$
$8 < p_{\mathrm{T}} < 10$	$0.80 \pm 0.08 \pm 0.01$	$0.57 \pm 0.08 \pm 0.01$	$0.80 \pm 0.09 \pm 0.02$	$0.77 \pm 0.05 \pm 0.01$
$10 < p_{\mathrm{T}} < 14$	$0.70 \pm 0.06 \pm 0.01$	$0.75 \pm 0.09 \pm 0.01$	$0.60 \pm 0.08 \pm 0.01$	$0.68 \pm 0.05 \pm 0.01$
$14 < p_{\mathrm{T}} < 20$	$0.74 \pm 0.09 \pm 0.01$	$0.68 \pm 0.15 \pm 0.03$	$0.55 \pm 0.13 \pm 0.02$	$0.68 \pm 0.07 \pm 0.01$
$0 < p_{\mathrm{T}} < 20$	$0.76 \pm 0.03 \pm 0.01$	$0.70 \pm 0.03 \pm 0.01$	$0.58 \pm 0.03 \pm 0.01$	$0.68 \pm 0.02 \pm 0.01$

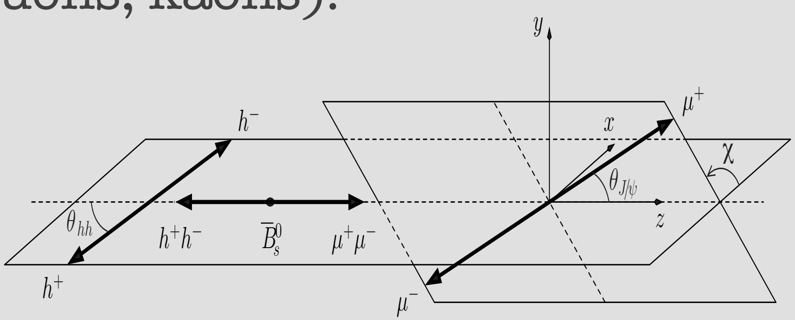
$B_s^0 \to J/\psi K^+K^-$

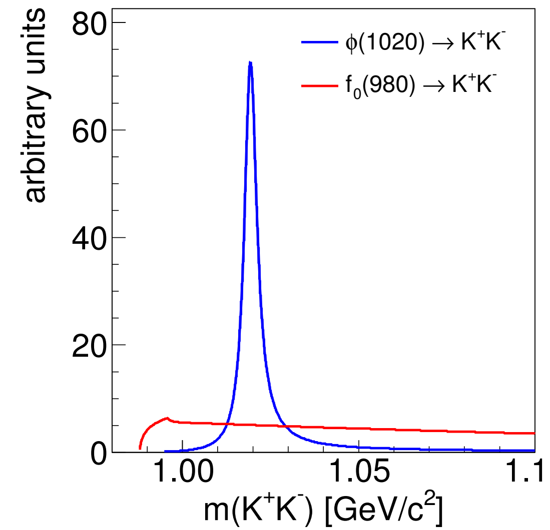
For K^+K^- around the ϕ mass:

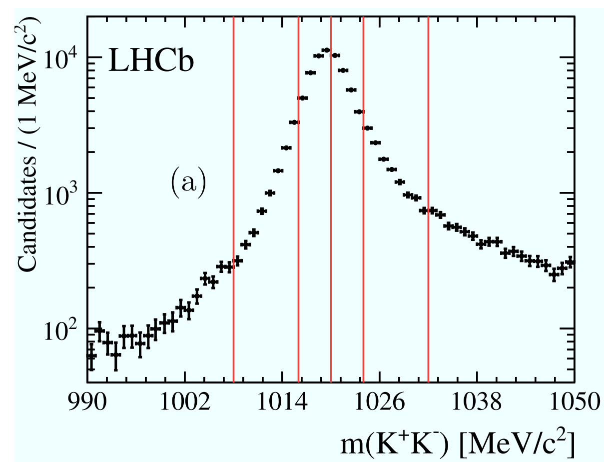
- P-wave (3 polarization amplitudes)
- S-wave ($f_0(980)$ and non-resonant)



Disentangle the amplitudes by fitting helicity angles of final state particles (muons, kaons).







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$B_s^0 \to J/\psi K^+K^-$

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Results

Parameter	Value
Γ_s [ps^{-1}]	$0.6603 \pm 0.0027 \pm 0.0015$
$\Delta\Gamma_s$ [ps^{-1}]	$0.0805 \pm 0.0091 \pm 0.0033$
$\lvert A_0\rvert^2$	$0.5241 \pm 0.0034 \pm 0.0067$
$\lvert A_\perp\rvert^2$	$0.2504 \pm 0.0049 \pm 0.0036$
$\delta_\parallel$ [rad]	$3.26\ ^{+0.10}_{-0.17}\ ^{+0.06}_{-0.07}$
$\delta_\perp$ [rad]	$3.08\ ^{+0.14}_{-0.15} \pm 0.06$
ϕ_s [rad]	$-0.058 \pm 0.049 \pm 0.006$
$\lvert\lambda\rvert$	$0.964 \pm 0.019 \pm 0.007$
Δm_s [ps^{-1}]	$17.711\ ^{+0.055}_{-0.057} \pm 0.011$

Polarisation amplitudes:

$$A_k = |A_k| e^{-i\delta_k}$$

$$k = 0, \parallel, \perp, S$$

CPV parameters:

$$\lambda_k = \eta_k \frac{q}{p} \frac{\bar{A}_k}{A_k}$$

$$\phi_k = \arg(\lambda_K)$$

Polarisation dependent fit:

Parameter	Value
ϕ_s^0 [rad]	$-0.045 \pm 0.053 \pm 0.006$
$\phi_s^\parallel - \phi_s^0$ [rad]	$-0.018 \pm 0.043 \pm 0.009$
$\phi_s^\perp - \phi_s^0$ [rad]	$-0.014 \pm 0.035 \pm 0.006$
$\phi_s^{\mathrm{S}} - \phi_s^0$ [rad]	$0.015 \pm 0.061 \pm 0.021$
$\lvert\lambda^0\rvert$	$1.012 \pm 0.058 \pm 0.013$
$\lvert\lambda^\parallel/\lambda^0\rvert$	$1.02 \pm 0.12 \pm 0.05$
$\lvert\lambda^\perp/\lambda^0\rvert$	$0.97 \pm 0.16 \pm 0.01$
$\lvert\lambda^{\mathrm{S}}/\lambda^0\rvert$	$0.86 \pm 0.12 \pm 0.03$

$B_s^0 \to J/\psi K^+K^-$

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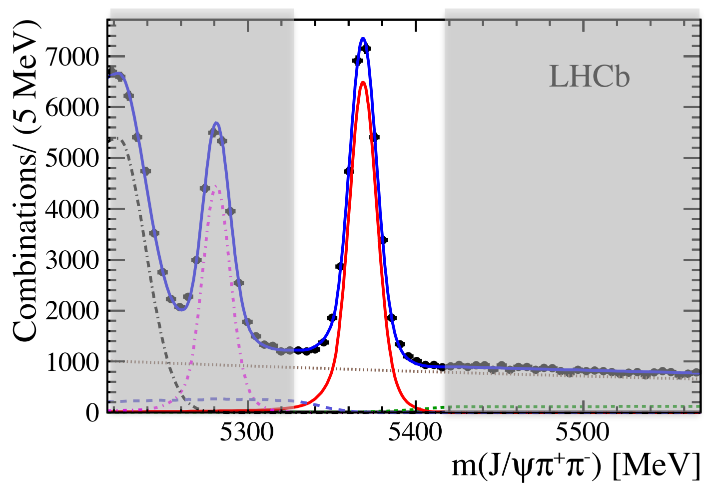
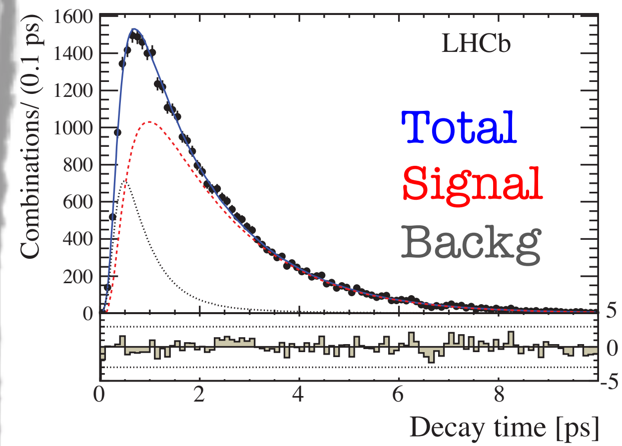
Systematics:

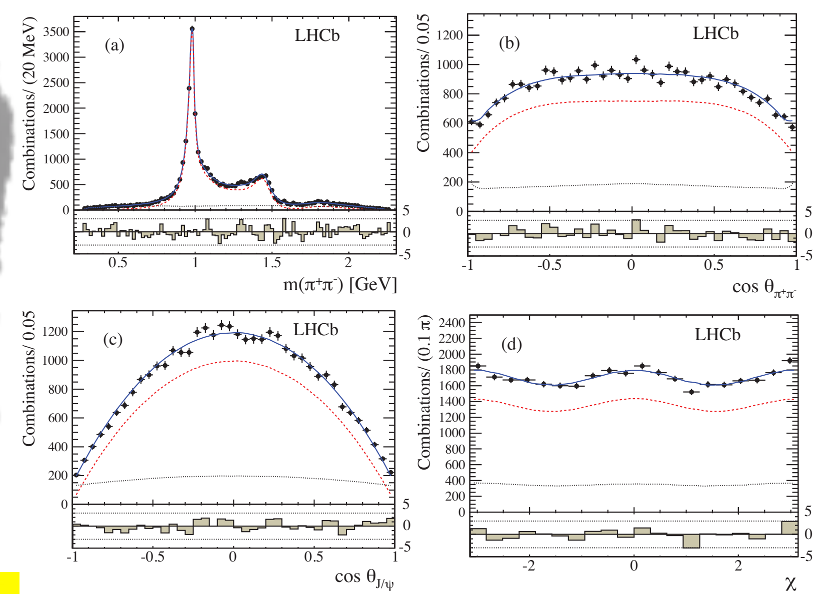
Source	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	$\lvert A_\perp\rvert^2$	$\lvert A_0\rvert^2$	$\delta_\parallel$ [rad]	$\delta_\perp$ [rad]	ϕ_s [rad]	$\lvert\lambda\rvert$	Δm_s [ps^{-1}]
Total stat. uncertainty	0.0027	0.0091	0.0049	0.0034	$^{+0.10}_{-0.17}$	$^{+0.14}_{-0.15}$	0.049	0.019	$^{+0.055}_{-0.057}$
Mass factorisation	–	0.0007	0.0031	0.0064	0.05	0.05	0.002	0.001	0.004
Signal weights (stat.)	0.0001	0.0008	–	0.0001	–	–	–	–	–
b-hadron background	0.0001	0.0004	0.0004	0.0002	0.02	0.02	0.002	0.003	0.001
B_c^+ feed-down	0.0005	–	–	–	–	–	–	–	–
Angular resolution bias	–	–	0.0006	0.0001	$^{+0.02}_{-0.03}$	0.01	–	–	–
Ang. efficiency (reweighting)	0.0001	–	0.0011	0.0020	0.01	–	0.001	0.005	0.002
Ang. efficiency (stat.)	0.0001	0.0002	0.0011	0.0004	0.02	0.01	0.004	0.002	0.001
Decay-time resolution	–	–	–	–	–	0.01	0.002	0.001	0.005
Trigger efficiency (stat.)	0.0011	0.0009	–	–	–	–	–	–	–
Track reconstruction (simul.)	0.0007	0.0029	0.0005	0.0006	$^{+0.01}_{-0.02}$	0.002	0.001	0.001	0.006
Track reconstruction (stat.)	0.0005	0.0002	–	–	–	–	–	–	0.001
Length and momentum scales	0.0002	–	–	–	–	–	–	–	0.005
S-P coupling factors	–	–	–	–	0.01	0.01	–	0.001	0.002
Fit bias	–	–	0.0005	–	–	0.01	–	0.001	–
Quadratic sum of syst.	0.0015	0.0033	0.0036	0.0067	$^{+0.06}_{-0.07}$	0.06	0.006	0.007	0.011

ϕ_s with $J/\psi\,\pi^+\pi^-$

27100 $B_s^0 \to J/\psi\,\pi^+\pi^-$ candidates







Include the full amplitude analysis, and fit B mass, decay time, $m_{\pi\pi}$, helicity angles. Time acceptance from control sample of $B^0 \to J/\psi\, K^*$ decay.

$\phi_s = 0.070 \pm 0.068 \pm 0.008$ rad

Consistent with the SM.

arXiv:1405.4140

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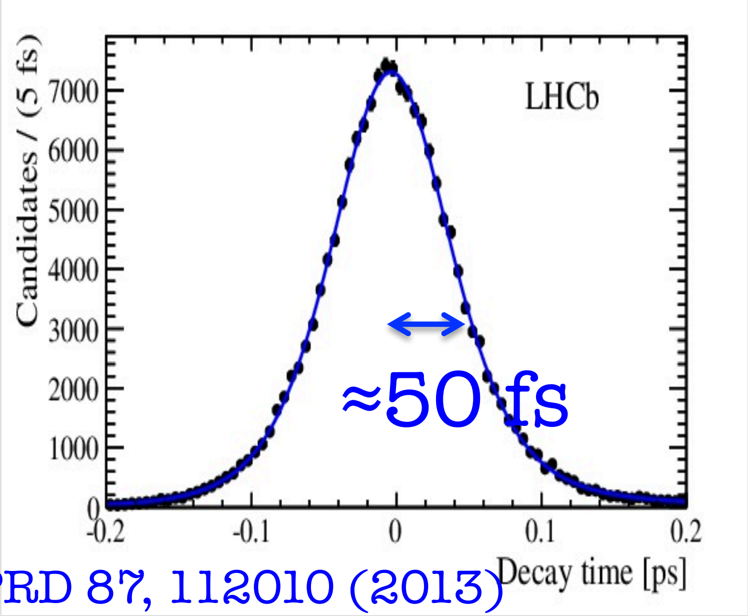
Asymmetry Dilutions

The mistag probability dilutes the asymmetry by O(75%).

Decay time resolution

Measured in control sample of prompt background with real J/ψ.

Reduce the asymmetry by O(30%).



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