LHCb Status Report

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on behalf of the LHCb collaboration

CERN, Geneva

LHCC Open Session,
CERN, 10.05.2017

Outline

- Operations & EYETS
    - EYETS hardware and software activities
    - Preparation for 2017
- Physics: a selection of new results since last LHCC
    - Fixed target
    - Spectroscopy
    - Observations
    - *CP* violation
    - Rare b-hadron decays
- Upgrade
    - Status and plans

EYETS: Hardware


SPD repair

Hardware:

- open large subdetectors
- venting of the beam pipe
- survey measurements
- online farm WinCC upgrades

Some exceptional interventions:

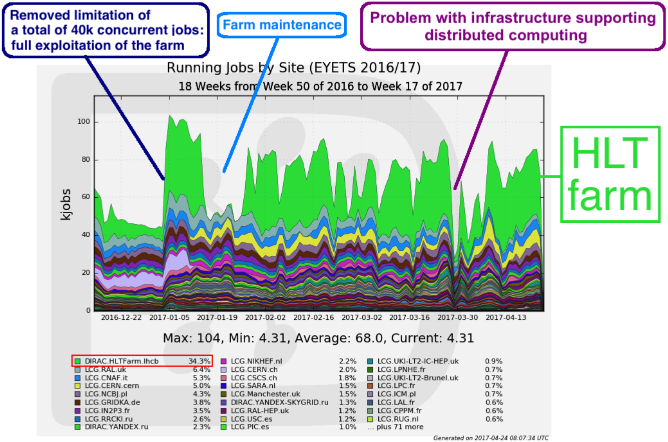
- replacement of the lift
- CO_2 transfer lines installation
- repair Silicon Tracker bond
- Herschel scintillators replacement
- RICH 1&2 HPD exchange
- Replacement of FE board of the outer tracker
- SPD VFE problem required fully opening of the SPD

All planned activities during the EYETS have been successfully accomplished.

The cavern has been closed on 27th April.

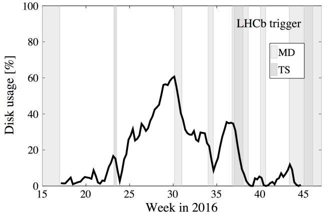
EYETS software activities

- During EYETS we produced $\sim$ 1.4 billion MC events (on disk, after filtering)
- About 1/3 of these events produced on the HLT farm.

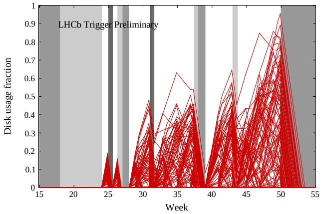


LHCb makes maximum use of computing resources.

Preparation for 2017: trigger



Disk usage in 2016



Simulations of disk usage for 2017

For Run II (2015-2018) LHCb introduced

- split of the High Level Trigger (HLT),
- buffering events between stages,
- performing a real-time alignment and calibration.

Resources monitoring is mandatory.

Taken actions

- Estimation of the disk usage for 2017 data depending on the LHC performance
- Preparation of two trigger configurations (tight and loose)

Other activities

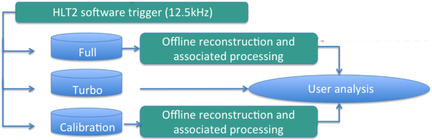
- Bandwidth division retuning
- Further optimization of all HLT lines

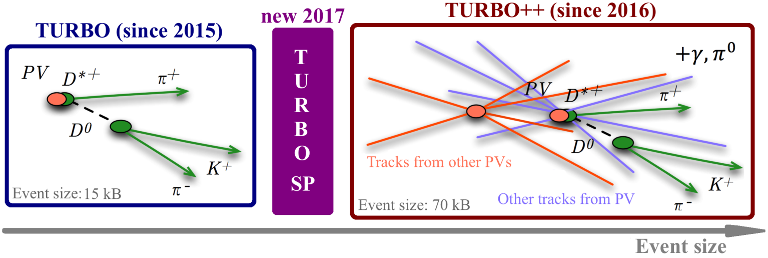
Preparation for 2017: Turbo streams

10.1016/j.cpc.2016.07.022

Turbo: do your selection in the trigger!

- Decays selected exclusively.
- Crucial for analyses with large statistic.
- Save significant amount of disk space.
- About half of the HLT2 lines use Turbo streams.





New: TurboSP (Selective Persistence) save candidate and subset of the reconstruction. Turbo++ (Full Persistence) was an intermediate step, will be replaced by TurboSP.

Turbo paradigm makes maximum use of limited disk, tape and CPU resources.

Preparation for 2017: alignment and calibration

Studies of the 2016 stability for further procedure tunings.

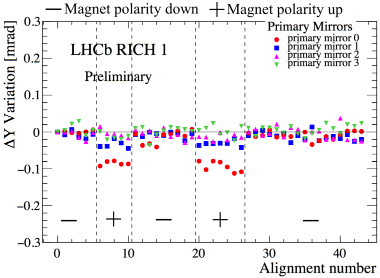
New fully automated approaches:

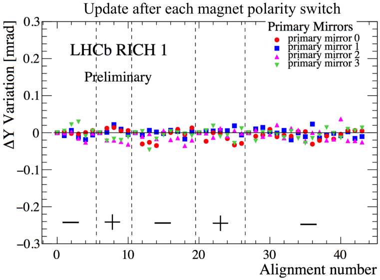
- RICH alignment: update expected after each magnet polarity switch
- π^0 calibration: update once per month

New dedicated calibration lines in the trigger:

- neutral PID,
- electron tracking efficiency.

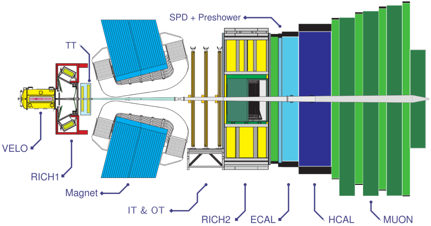
Central production for PID and tracking efficiencies.





Detector commissioning for 2017

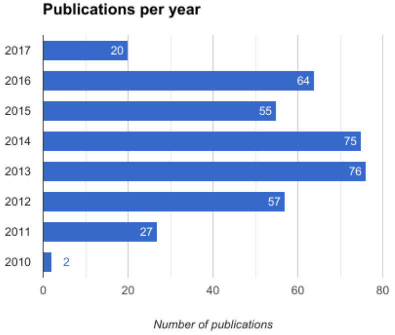
- 4th-14th April: first commissioning week.
- Most of subdetectors in global running.
- 26th April: VELO switch on as soon as it was under vacuum
- 1st May: start shifts during the day



Dedicated scans or data taking for calibration and alignment are ongoing.

We are getting ready for collisions!

Papers Status



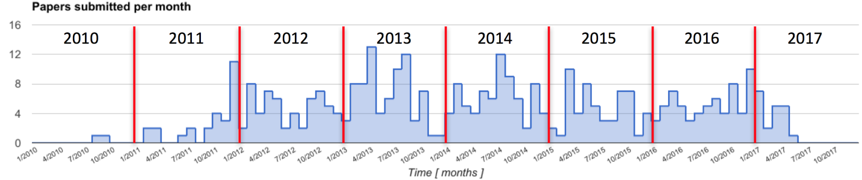
Since the last LHCC report:

- 12 papers,
- 2 conference reports

have been submitted.

In total:

- 376 papers
- 20 in 2017
- 8 further papers within the Editorial Board

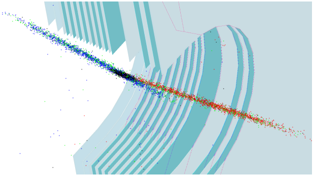


Title	PAPER number	arXiv	Journal	submitted on
Lepton universality test with $B^0 \to K^{*0}\ell^+\ell^-$ decays	2017-013	Not yet	Not yet	Not yet
Measurement of the B_s^0 and D_s^- meson lifetimes	2017-004	Not yet	Not yet	Not yet
Observation of charmless baryonic decays $B_{(s)}^0 \to p\bar{p}h^+h^-$	2017-005	1704.08497	PRL	27.04
Resonances and CP-violation in B_s^0 and $\bar{B}_s^0 \to J/\psi K^+K^-$ decays in the mass region above the $\phi(1020)$	2017-008	1704.08217	JHEP	26.04
First observation of a baryonic B_s^0 decay	2017-012	1704.07908	PRL	27.04
Observation of the decays $\Lambda_b^0 \to \chi_{c1}pK^-$ and $\Lambda_b^0 \to \chi_{c2}pK^-$	2017-011	1704.07900	PRL	25.04
Observation of the decay $B^+ \to D^{*-}K^+\pi^+$	2017-006	1704.07581	PRD(R)	24.04
Measurement of B^0, B_s^0, B^+ and Λ_b^0 production asymmetries in 7 and 8 TeV proton-proton collisions	2016-062	1703.08464	PLB	24.03
Measurement of the $B_s^0 \to \mu^+\mu^-$ branching fraction and effective lifetime and search for $B^0 \to \mu^+\mu^-$ decays	2017-001	1703.05747	PRL	16.03
Observation of five new narrow Ω_c^0 states decaying to $\Xi_c^+K^-$	2017-002	1703.04639	PRL	14.03
Search for the decays $B_s^0 \to \tau^+\tau^-$ and $B^0 \to \tau^+\tau^-$	2017-003	1703.02508	PRL	07.03
Observation of the decay $\Lambda_b^0 \to pK^-\mu^+\mu^-$ and a search for CP violation	2016-059	1703.00256	JHEP	01.03
Observation of the decay $B_s^0 \to \eta_c\phi$ and evidence for $B_s^0 \to \eta_c\pi^+\pi^-$	2016-056	1702.08048	JHEP	26.02

Title	CONF number	CDS	submitted on
Measurement of antiproton production in pHe collisions at $\sqrt{s_{NN}} = 110$ GeV	2017-002	link	21.04
Measurement of J/ψ and D^0 production in pAr collisions at $\sqrt{s_{NN}} = 110$ GeV	2017-001	link	14.03

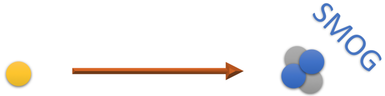
Reminder: SMOG

The LHCb detector can work as
a fixed target experiment.



SMOG: System for Measuring Overlap with Gas, allows injection of a small amount noble gas (He, Ne, Ar,...) inside the LHCb beam.

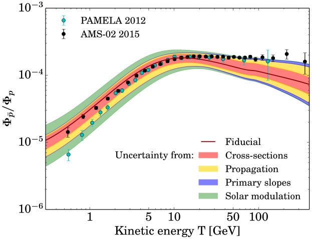
Originally designed for the precise luminosity measurements at the LHC. (2014 JINST 9 P12005)
Nowadays also used for cross-section measurements.



p-He collisions at $\sqrt{s_{NN}} = 110$ GeV, in the $\bar{p}$ momentum range from 12 to 110 GeV/c.
Integrated luminosity: 0.4 nb^{-1}

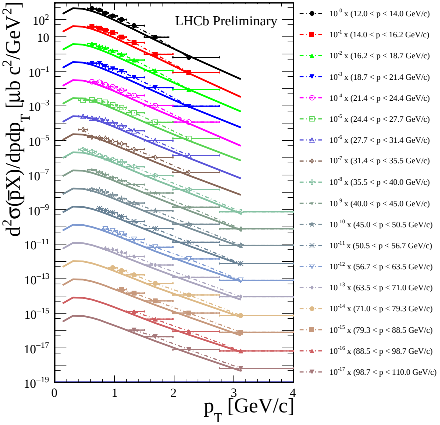
$\sigma(pHe \to \bar{p}X)$ cross section

$\bar{p}/p$ ratio: higher yield of antiprotons and a milder energy dependence with respect to most theoretical predictions.



Prediction uncertainty is limited by cross-section knowledge of p-He, inducing a (20-30)% uncertainty on the ratio.

The LHCb experiment is contributing to cosmic ray physics



Solid curves: the EPOS LHC absolute predictions.

LHCb measurements of $\sigma(pHe \to \bar{p}X)$ reach a $\sim$10% precision.

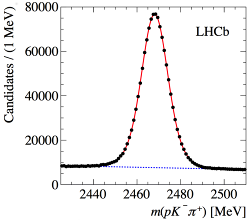
The measurement is larger by $\sim$1.5 w.r.t. EPOS LHC.

Observation: Ω_c^0 states

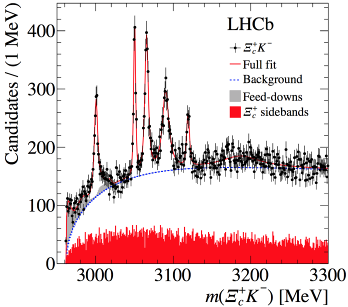
Only the ground states Ω_c^0 ($J^P = 1/2^+$) and Ω_c^{*0} ($J^P = 3/2^+$) are known so far.

Ξ_c^+ are combined with opposite sign kaons and look at the $m(\Xi_c^+ K^-)$ invariant mass spectrum.

5 new Ω_c^0 states observed!



$\sim 10^6\ \Xi_c^+ \to pK^-\pi^+$



Data sample: 1.0 (7 TeV) + 2.0 (8 TeV) + 0.3 (13 TeV) fb^{-1}

Resonance	Mass (MeV)	Γ (MeV)	Yield	N_σ
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$	$1300 \pm 100 \pm 80$	20.4
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$ < 1.2 MeV, 95% CL	$970 \pm 60 \pm 20$	20.4
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$	$1740 \pm 100 \pm 50$	23.9
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$	$2000 \pm 140 \pm 130$	21.1
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$ < 2.6 MeV, 95% CL	$480 \pm 70 \pm 30$	10.4

Highlighted by PRL with an editor-written synopsis.

Observation: $\Lambda_b^0 \to \chi_{cJ} p K^-$

LHCb-PAPER-2017-011

Sister channels to mode $\Lambda_b^0 \to J/\psi p K^-$, in which pentaquarks were found

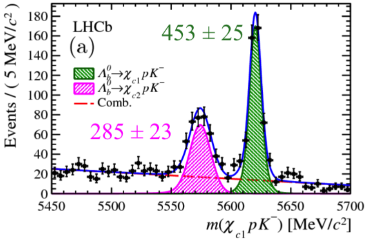
The first step is to observe the decays.

$$\frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p K^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi p K^-)} = 0.242 \pm 0.014 \pm 0.013 \pm 0.009,$$

$$\frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c2} p K^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi p K^-)} = 0.248 \pm 0.020 \pm 0.014 \pm 0.009,$$

$$\frac{\mathcal{B}(\Lambda_b^0 \to \chi_{c2} p K^-)}{\mathcal{B}(\Lambda_b^0 \to \chi_{c1} p K^-)} = 1.02 \pm 0.10 \pm 0.02 \pm 0.05,$$

third uncertainty due to the branching fractions of the $\chi_{c1(2)} \to J/\psi\gamma$

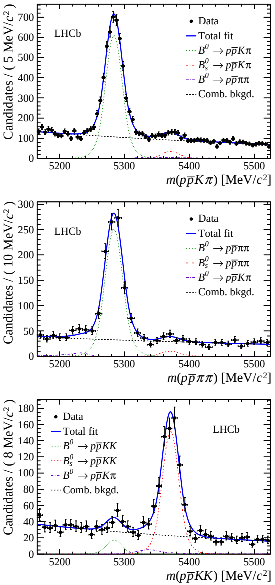


Data sample:
1.0 (7 TeV) + 2.0 (8 TeV) fb^{-1}

Two new decay modes observed with high statistical significance:
$\Lambda_b^0 \to \chi_{c1} p K^-$ (29σ),
$\Lambda_b^0 \to \chi_{c2} p K^-$ (17σ)

Using both decay modes, the mass of the Λ_b^0 baryon is measured:
$m(\Lambda_b^0) = 5619.44 \pm 0.28 \pm 0.25$ MeV/c^2

Observation: $B^0_{(s)} \to p\bar{p}h^+h^-$



A new potential for CP violation measurements.

Data sample: 1.0 (7 TeV) + 2.0 (8 TeV) fb^{-1}

Branching fractions determined as:

$$\frac{\mathcal{B}(B^0_{(s)} \to p\bar{p}hh')}{\mathcal{B}_{\rm vis}(B^0 \to J/\psi K^*(892)^0)} = \frac{\mathcal{N}^{\rm corr}(B^0_{(s)} \to p\bar{p}hh')}{\mathcal{N}^{\rm corr}(B^0 \to J/\psi K^*(892)^0)} \left(\times \frac{f_d}{f_s}\right)$$

Decay channel	Yield $\mathcal{N}$	Significance $[\sigma]$	Branching fraction / 10^{-6}
$B^0 \to p\bar{p}KK$	68 ± 17	4.1	$0.113 \pm 0.028 \pm 0.011 \pm 0.008$
$B^0 \to p\bar{p}K\pi$	4155 ± 83	> 25	$5.9 \pm 0.3 \pm 0.3 \pm 0.4$
$B^0 \to p\bar{p}\pi\pi$	902 ± 35	> 25	$2.7 \pm 0.1 \pm 0.1 \pm 0.2$
$B^0_s \to p\bar{p}KK$	635 ± 32	> 25	$4.2 \pm 0.3 \pm 0.2 \pm 0.3 \pm 0.2$
$B^0_s \to p\bar{p}K\pi$	246 ± 39	6.5	$1.30 \pm 0.21 \pm 0.11 \pm 0.09 \pm 0.08$
$B^0_s \to p\bar{p}\pi\pi$	39 ± 16	2.6	$0.41 \pm 0.17 \pm 0.04 \pm 0.03 \pm 0.02$
$B^0 \to J/\psi K^*(892)^0$	1216 ± 45	–	–

third uncertainty due to the branching fraction of the normalization mode, fourth (where present) due to f_s/f_d.

Four-body charmless baryonic B^0_s decays observed for the first time.

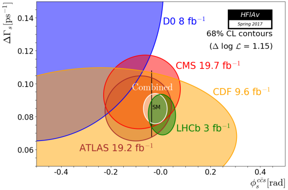
ϕ_s from $B_s^0 \to J/\psi K^+ K^-$

LHCb-PAPER-2017-008

Weak phase ϕ_s

- Standard Model: ϕ_s = -36.3 $\pm$ 1.3 mrad
- Sensitive to New Physics in interference between B_s mixing and decay amplitude.
- Extensively studied in the LHCb experiment with Run I (1.0 (7 TeV) + 2.0 (8 TeV) fb^{-1}) data.

LHCb dominates the world average.

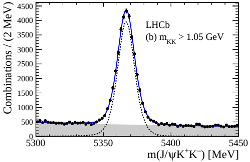


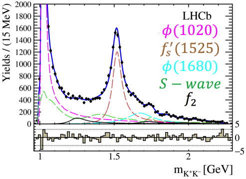
$J/\psi\phi$ (PRL114, 041801 (2015)),
$J/\psi\pi^+\pi^-$ (Phys. Lett. B736, (2014) 186),
$\psi(2S)\phi$ (Phys. Lett. B762 (2016) 253-262),
$D_s^+ D_s^-$ (PRL113, 211801 (2014))

New: to fully explore Run I data:
ϕ_s from $B_s^0 \to J/\psi K^+ K^-$ for $m_{KK} > 1.05$ GeV.

$m_{KK} > 1.05\,\mathrm{GeV}$

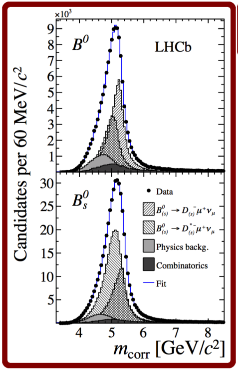
$$\phi_s = 119 \pm 107 \pm 34\,\mathrm{mrad},$$
$$|\lambda| = 0.994 \pm 0.018 \pm 0.006,$$
$$\Gamma_s = 0.650 \pm 0.006 \pm 0.004\,\mathrm{ps}^{-1}$$
$$\Delta\Gamma_s = 0.066 \pm 0.018 \pm 0.010\,\mathrm{ps}^{-1}$$



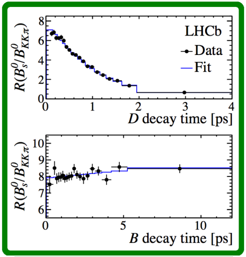


New LHCb average from ($B_s^0 \to J/\psi\phi$, $J/\psi K^+K^-$ for $m_{KK} > 1.05$ GeV, $J/\psi\pi^+\pi^-$):
$\phi_s = 1 \pm 37$ mrad

Lifetimes measurement with semileptonic decays: $B_s^0 \to D_s^{(*)}\mu^+\nu_\mu$



$$m_{corr} = p_{\perp,D\mu} + \sqrt{m_{D\mu}^2 + p_{\perp,D\mu}^2}$$



$$\Delta_\Gamma(B) \equiv 1/\tau^{fs}_{B_s^0} - \Gamma_d$$

Signal $B_s^0 \to D_s^{(*)}\mu^+\nu_\mu$ ~407 000 candidates

Reference $B^0 \to D^{(*)}\mu^+\nu_\mu$ ~108 000 candidates

Data sample: 1.0 (7 TeV) + 2.0 (8 TeV) fb^{-1}

Recent results

$\tau^{FS}_{B_s^0} = 1.535 \pm 0.015 \pm 0.014$ ps

(hadronic, LHCb)

$\tau^{FS}_{B_s^0} = 1.479 \pm 0.010 \pm 0.021$ ps

(semileptonic, D0)

$\tau_{D_s^-} = 0.5074 \pm 0.0055 \pm 0.0051$ ps

(FOCUS)

LHCb new results

$\tau^{FS}_{B_s^0} = 1.547 \pm 0.013 \pm 0.010 \pm 0.004$ ps

(third systematics due to τ_B)

$\tau_{D_s^-} = 0.5064 \pm 0.0030 \pm 0.0017 \pm 0.0017$ ps

(third systematics due to τ_D)

Significant improvement of the world's best determination.

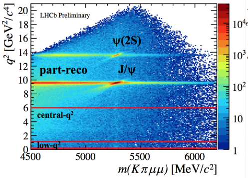
Lepton Flavour Universality: $R_{K^{*0}}$

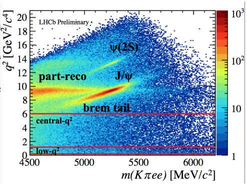
- In Standard Model couplings are equal for $b \to s\mu^+\mu^-$ and $b \to se^+e^-$.
- LFU test with $B^+ \to K^+ll$ published (PRL 113 (2014) 151601)
- Measurement with $B^0 \to K^{*0}l^+l^-$, $K^{*0} \to K\pi$ decays.
- $R_{K^{*0}}$ is calculated as double ratio:

$$R_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to \mu^+\mu^-))} \bigg/ \frac{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}.$$

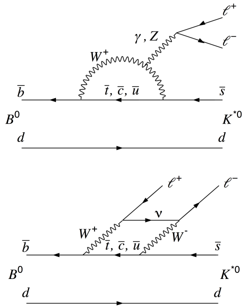
- Measurement performed in two q^2 bins:
  - low: [0.045 - 1.1] GeV^2/c^4
  - central [1.1 - 6.0] GeV^2/c^4

  where q^2 is the squared di-lepton invariant mass.
- Data set: 1.0 (7 TeV) + 2.0 (8 TeV) fb^{-1}

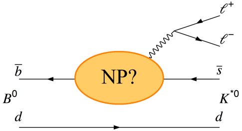




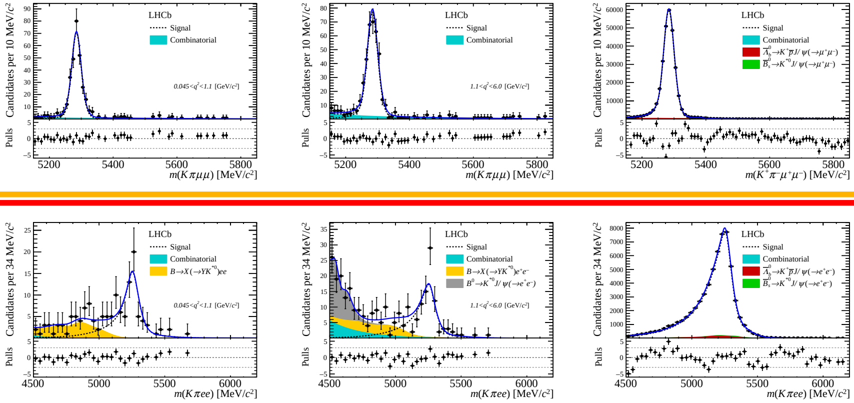
Standard Model (SM)



New Physics?



	low-q^2	central-q^2	$B^0 \to K^{*0} J/\psi$
$B^0 \to K^{*0}\mu\mu$			
$B^0 \to K^{*0}ee$			

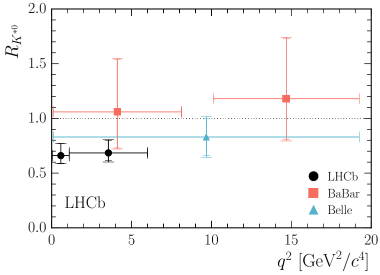


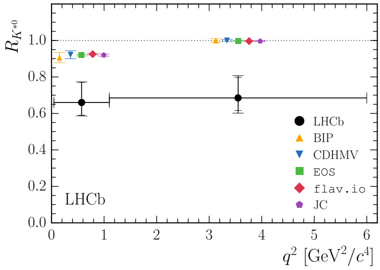
Signal $B^0 \to K^{*0}ee$ candidates: about 90 (110) in low (central) q^2.

Lepton Flavour Universality: $R_{K^{*0}}$

	low-q^2	central-q^2
$R_{K^{*0}}$	$0.660 \, ^{+\,0.110}_{-\,0.070} \pm 0.028$	$0.685 \, ^{+\,0.113}_{-\,0.069} \pm 0.047$
95% CL	[0.517,0.891]	[0.530,0.935]
99.7% CL	[0.454,1.042]	[0.462,1.100]

Compatibility with the Standard Model:
low-q^2: 2.1-2.4σ
central-q^2: 2.4-2.5σ





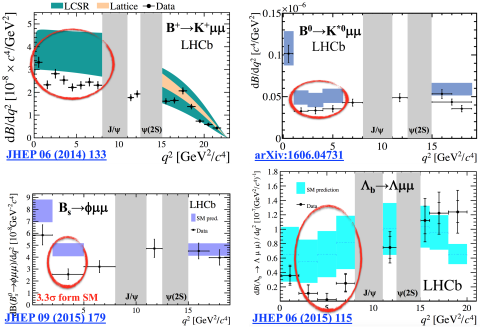
More information: CERN Seminar given by Simone Bifani

Other related anomalies

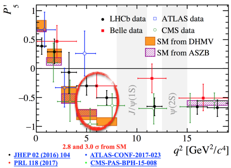
- The result is interesting in context of other measurements:
  - test of LFU with $B^+ \to K^+ ll$
  - differential branching fractions
  - angular analyses
- First week after CERN $R_{K^{*0}}$ seminar: 15 theory papers.

- More statistics needed.
- Run II analyses are ongoing.
- Stay tuned!

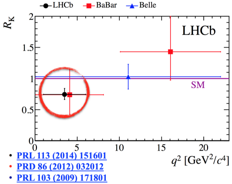
Differential branching fractions



Angular analysis



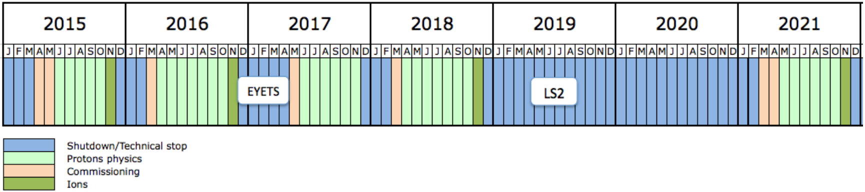
LFU test $B^+ \to K^+ ll$



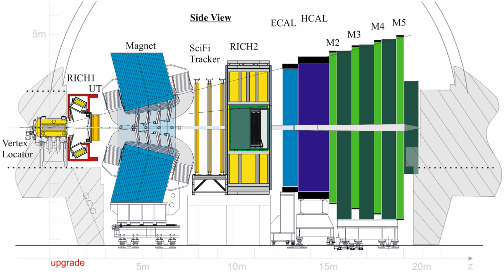
Outlook of forthcoming new results

Run-2 data already on tape (more than doubles the Run-1 statistics for heavy flavours).

- Updates of LFU and related measurements with $b \to sll$ using Run-2 are top priority.
    - Besides additional statistics, improvements in the analyses can bring the experimental uncertainties down significantly.
- New measurements of LFU with semitauonic decays
    - e.g. using $B \to D^*\tau\nu$, $B_c \to J/\psi\tau\nu$ etc.
- Updates of CP violation measurements in the B_s-meson sector
    - ϕ_s analysis with $J/\psi KK$ and $J/\psi\pi\pi$ ongoing.
- Updates on pentaquark analyses.
- New results in heavy flavour spectroscopy.
- First results from the 2016 heavy ion run.
- And many others...



- Detector read out at 40MHz
- Software trigger
- New tracking system:
  VELO, UT, SciFi
- Upgraded PID system

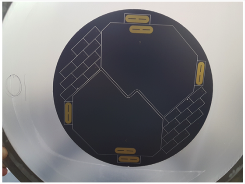


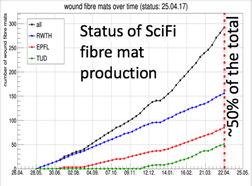
LHCb is approaching an upgrade phase.

Upgrade (after LS2)

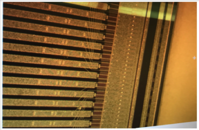
LHCC in-depth review last Monday.

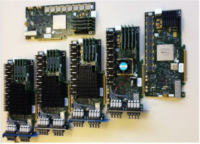
- Upgrade construction phase ongoing.
- Delivery of important components (e.g. RICH MaPMTs, SciFi fibres) well underway.
- Most front-end ASICS in production, wafers expected in summer.
- Final submission of UT (SALT) and VELO (VeloPix) ASICS in summer.
- Computing and software framework development progressing:
  TDR expected in Q4 2017
- Assembly and installation infrastructure in preparation.


VELO μchannel cooling substrate wafer diced




Muon system electronics under test


UT silicon sensor with embedded pitch adapter


PCIe40 DAQ boards

Conclusions

- All tasks accomplished for EYETS. The cavern is closed.
- Smooth commissioning and preparation for 2017.

- 12 more papers submitted and 2 conference reports since last LHCC report.
  - Lepton Flavour Universality tested with $B^0 \to K^{*0} l^+ l^-$.
  - Many new observations.
  - LHCb is also contributing to cosmic ray physics with fixed target cross-section measurement.
- Many new results coming soon for summer conferences.

- Upgrade activities ongoing.
- We are approaching the installation phase.

Thank You

Cross-check

Control of the absolute scale of the efficiencies via the ratio

$$r_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+e^-))}$$

which is expected to be unity and measured to be

$$1.043 \pm 0.006\,(\mathrm{stat}) \pm 0.045\,(\mathrm{syst})$$

Result observed to be reasonably flat as a function of the decay kinematics and event multiplicity.

Extremely stringent test, which does not benefit from the cancellation of the experimental systematics provided by the double ratio.

Cross-check

- $BR(B^0 \to K^{*0}\mu\mu)$ in good agreement with arXiv:1606.04731.
- If corrections to simulations are not accounted for, the ratio of the efficiencies changes by less than 5%
- Further checks performed by measuring the following ratios:

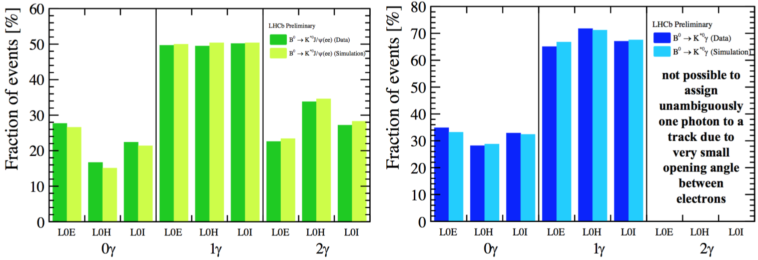
$$r_\gamma = \frac{\mathcal{B}(B^0 \to K^{*0}\gamma(\to e^+e^-))}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}$$

$$\mathcal{R}_{\psi(2S)} = \frac{\mathcal{B}(B^0 \to K^{*0}\psi(2S)(\to \mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to \mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^0 \to K^{*0}\psi(2S)(\to e^+e^-))}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}$$

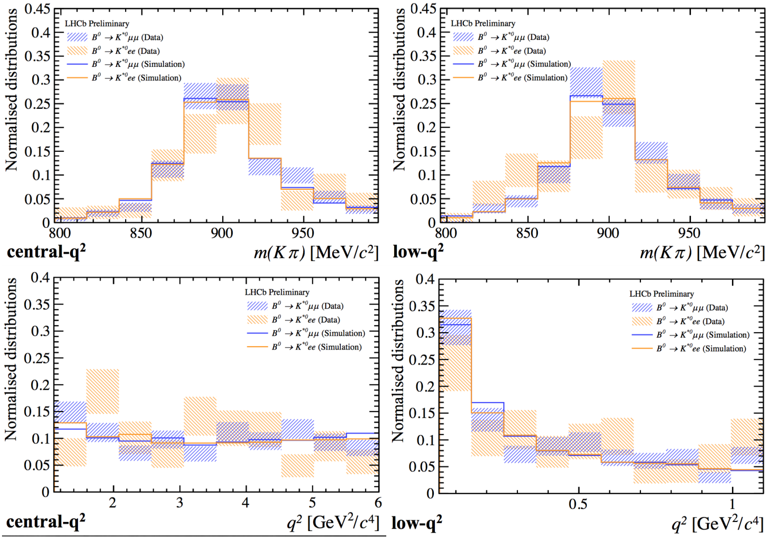
which are found to be compatible with the expectations.

Cross-check

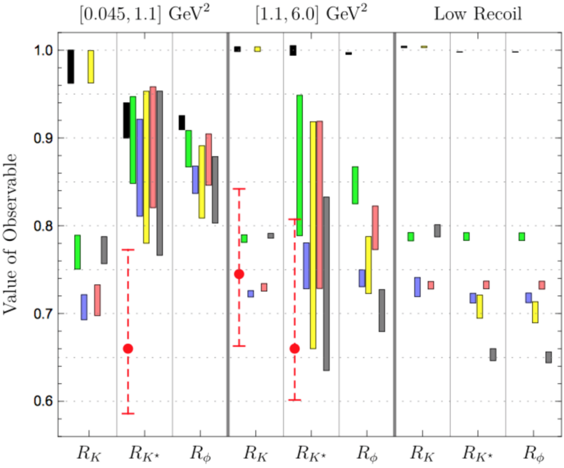
Relative population of bremsstrahlung categories compared between data and simulation using $B^0 \to K^{*0} J/\psi(ee)$ and $B^0 \to K^{*0}\gamma(ee)$ events



Cross-check


LHCb Preliminary
$B^0 \to K^{*0}\mu\mu$ (Data)
$B^0 \to K^{*0}ee$ (Data)
$B^0 \to K^{*0}\mu\mu$ (Simulation)
$B^0 \to K^{*0}ee$ (Simulation)
Normalised distributions
$m(K\pi)$ [MeV/c^2]
q^2 [GeV^2/c^4]
central-q^2
low-q^2

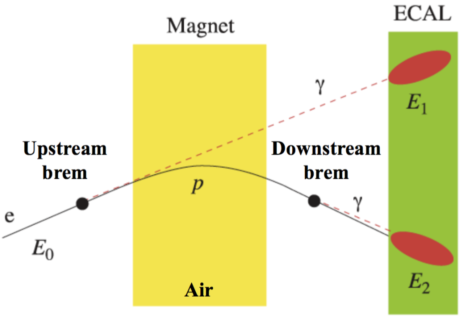
New Physics context



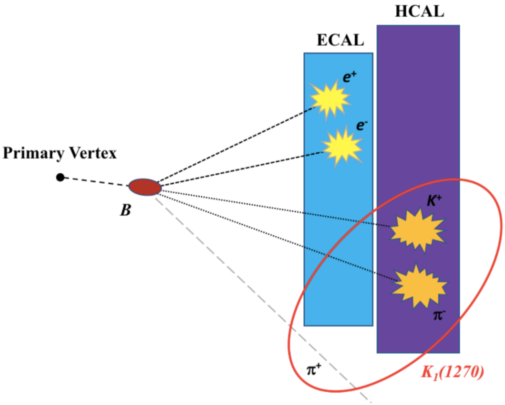
New Physics: 15 papers

Global model-independent analyses	**6**
Tree-level Z′	**1**
Loop-level Z′	**1**
Tree-level leptoquark	**2**
Loop-level leptoquark	**1**
Composite Higgs	**1**
Light degrees of freedom	**2**
RPV SUSY	**1**

Bremsstrahlung



Partially reconstructed backgrounds



Yields

	$B^0 \to K^{*0}\ell^+\ell^-$		$B^0 \to K^{*0}J/\psi\,(\to \ell^+\ell^-)$
	low-q^2	**central-q^2**	
$\mu^+\mu^-$	$285\ {}^{+\ 18}_{-\ 18}$	$353\ {}^{+\ 21}_{-\ 21}$	$274416\ {}^{+\ 602}_{-\ 654}$
e^+e^- (L0E)	$55\ {}^{+\ 9}_{-\ 8}$	$67\ {}^{+\ 10}_{-\ 10}$	$43468\ {}^{+\ 222}_{-\ 221}$
e^+e^- (L0H)	$13\ {}^{+\ 5}_{-\ 5}$	$19\ {}^{+\ 6}_{-\ 5}$	$3388\ {}^{+\ 62}_{-\ 61}$
e^+e^- (L0I)	$21\ {}^{+\ 5}_{-\ 4}$	$25\ {}^{+\ 7}_{-\ 6}$	$11505\ {}^{+\ 115}_{-\ 114}$

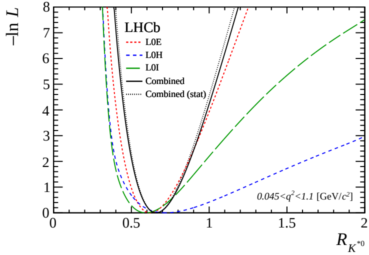
Systematic

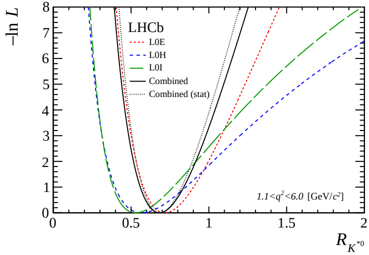
	low-q^2			central-q^2		
Trigger category	L0E	L0H	L0I	L0E	L0H	L0I
Corrections to simulation	2.5	4.8	3.9	2.2	4.2	3.4
Trigger	0.1	1.2	0.1	0.2	0.8	0.2
PID	0.2	0.4	0.3	0.2	1.0	0.5
Kinematic selection	2.1	2.1	2.1	2.1	2.1	2.1
Residual background	–	–	–	5.0	5.0	5.0
Mass fits	1.4	2.1	2.5	2.0	0.9	1.0
Bin migration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

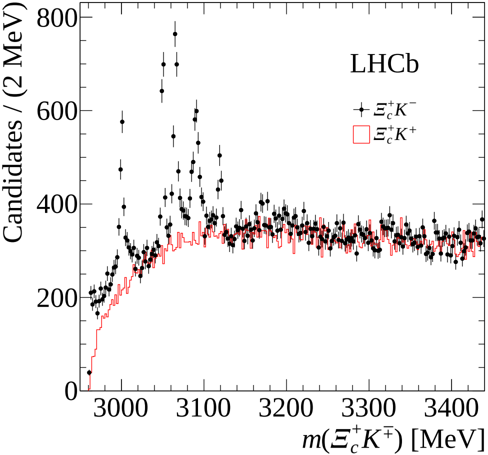
Systematics

- Corrections to simulation: besides the uncertainty due to the size of the samples, an additional systematic is determined using different parameterisations of the corrections.
- Kinematic selection: a systematic uncertainty for Data/MC differences in the description of the bremsstrahlung tail and the MVA classifier is determined by comparing simulation and background subtracted $B^0 \to K^{*0} J/\gamma(ll)$ data.
- Residual background: both data and simulation are used to assess a systematic uncertainty for residual background contamination due to $B^0 \to K^{*0} J/\gamma(ee)$ events with a $K \leftrightarrow e$ or $p \leftrightarrow e$ swap
- Mass fit: a systematic uncertainty is determined by running pseudo-experiments with different descriptions of the signal and background fit models.
- Bin migration: the effect of the model dependence and description of the q2 resolution in simulation are assigned as a systematic uncertainty.
- r_J/ψ flatness: the ratio is studied as a function of several properties of the event and decay products, and the observed residual deviations from unity are used to assign a systematic uncertainty

Likelihoods







$$m(\Xi_c^+ K^-) = m([pK^-\pi^+]_{\Xi_c^+} K^-) - m([pK^-\pi^+]_{\Xi_c^+}) + m_{\Xi_c^+},$$