LHCb Status Report

122nd LHCC Meeting

Andrea Contu *on behalf of the LHCb collaboration*

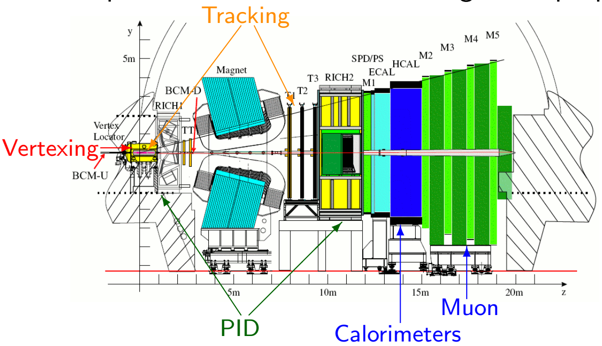
INFN Cagliari - CERN

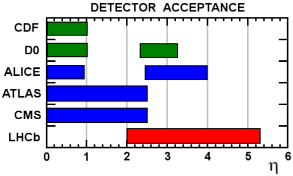
3 June 2015

Outline

LHCb detector [JINST 3 (2008) S080005]

LHCb proved itself to be a forward general purpose detector





- Performance:
  - $\Delta p/p = 0.35\% - 0.55\%$
  - Mass resolution$= 10 - 25\,\mathrm{MeV}/c^2$
  - Impact parameter resolution: $20\,\mu\mathrm{m}$ for high-p_T tracks
  - ECAL $\sigma(E)/E = 10\%(E/\mathrm{GeV})^{-1/2} \oplus 1\%$
  - Excellent particle ID thanks to RICH detectors and Muon stations

Papers since last LHCC

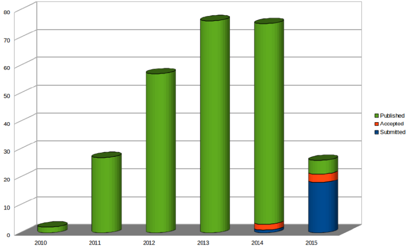
Measurement of the forward Z boson production cross-section in pp collisions at $\sqrt{s} = 7$ TeV, arXiv:1505.07024, 29 May 2015
Study of $B^- \to DK^-\pi^+\pi^-$ and $B^- \to D\pi^-\pi^+\pi^-$ decays and determination of the CKM angle γ, arXiv:1505.07044, 28 May 2015
Study of W boson production in association with beauty and charm, arXiv:1505.04051, 15 May 2015
Search for the $\Lambda_b^0 \to \Lambda\eta'$ and $\Lambda_b^0 \to \Lambda\eta$ decays with the LHCb detector, arXiv:1505.03295, 13 May 2015
Amplitude analysis of $B^0 \to \bar{D}^0 K^+\pi^-$ decays, arXiv:1505.01505, 06 May 2015
Search for the decay $B_s^0 \to \overline{D}^0 f_0(980)$, arXiv:1505.01654, 07 May 2015
Dalitz plot analysis of $B^0 \to \overline{D}^0\pi^+\pi^-$ decays, arXiv:1505.01710, 08 May 2015
Identification of beauty and charm quark jets at LHCb, arXiv:1504.07670, 28 Apr 2015
Quantum numbers of the $X(3872)$ state and orbital angular momentum in its $\rho^0 J/\psi$ decays, arXiv:1504.06339, 23 Apr 2015
A study of CP violation in $B^\mp \to Dh^\mp$ $(h = K, \pi)$ with the modes $D \to K^\mp\pi^\pm\pi^0$, $D \to \pi^+\pi^-\pi^0$ and $D \to K^+K^-\pi^0$, arXiv:1504.05442, 21 Apr 2015
Determination of the quark coupling strength $|V_{ub}|$ using baryonic decays, arXiv:1504.01568, 07 Apr 2015
First observation and measurement of the branching fraction for the decay $B_s^0 \to D_s^{*\mp} K^\pm$, arXiv:1503.09086, 31 Mar 2015
Observation of the $B^0 \to \rho^0\rho^0$ decay from an amplitude analysis of $B^0 \to (\pi^+\pi^-)(\pi^+\pi^-)$ decays, arXiv:1503.07770, 26 Mar 2015
Observation of the $B_s^0 \to \eta'\eta'$ decay, arXiv:1503.07483, 25 Mar 2015
Differential branching fraction and angular analysis of $\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$ decays, arXiv:1503.07138, 24 Mar 2015
Observation of the decay $\overline{B}_s^0 \to \psi(2S)K^+\pi^-$, arXiv:1503.07112, 24 Mar 2015
Measurement of CP violation in $B^0 \to J/\psi K_S^0$ decays, arXiv:1503.07089, 24 Mar 2015
Measurement of the time-dependent CP asymmetries in $B_s^0 \to J/\psi K_{\rm S}^0$, arXiv:1503.07055, 25 Mar 2015
Measurement of CP asymmetries and polarisation fractions in $B_s^0 \to K^{*0}\overline{K}^{*0}$ decays, arXiv:1503.05362, 19 Mar 2015
First observation and amplitude analysis of the $B^- \to D^+K^-\pi^-$ decay, Phys. Rev. D91 (2015) 092002

Statistics by year of arXiv submission

Year	Internal	Submitted	Accepted	Published	Total	Integral	CONF
2010				2	2	2	7
2011				27	27	29	61
2012				57	57	86	34
2013				76	76	162	13
2014		1	2	72	75	237	4
2015	10	18	3	5	26	262	2
Total	10	19	5	239	263		120

23 Submitted, 8 published

since last LHCC



Physics Results: Highlights

$B_s \to \mu\mu$ CMS+LHCb combination on Nature

LETTER

OPEN

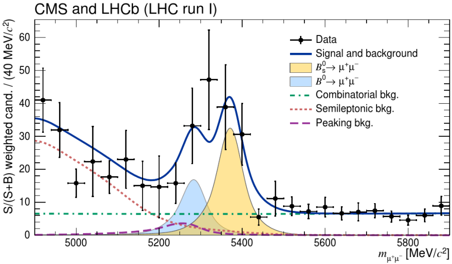
doi:10.1038/nature14474

Observation of the rare $B_s^0 \to \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data

The CMS and LHCb collaborations*

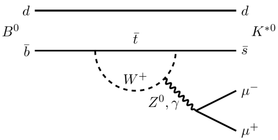
The standard model of particle physics describes the fundamental particles and their interactions via the strong, electromagnetic and weak forces. It provides precise predictions for measurable quantities that can be tested experimentally. The probabilities, or branching fractions, of the strange B meson (B_s^0) and the B^0 meson decaying into two oppositely charged mu... esting because of their sensitivit... model. The standard model ... $B^0 \to \mu^+\mu^-$ decays are very rare, ... ring for every billion B_s^0 meso... occurring for every ten billio... observed branching fractions w... standard model would provid... model should be extended. Bef...

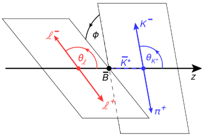
respectively. An example of the charged current is the decay of the π^+ meson, which consists of an up (u) quark of electrical charge +2/3 of the charge of the proton and a down (d) antiquark of charge +1/3. A pictorial representation of this process, known as a Feynman diagram, is shown in Fig. 1a. The u and d quarks are 'first generation' or lowest ... ified in this Letter, the ... at the light d antiquark ... highest mass quarks) ... +1/3 and a mass of ... a proton). The decay ... but highly suppressed ... (helicity suppression) ... rks of different genera-

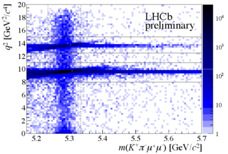


Angular analysis of $B^0 \to K^{*0}\mu\mu$ [LHCb-CONF-2015-002]

- Rare FCNC process, suppressed in the Standard Model (SM)
- New Physics (NP) may affect angular distributions





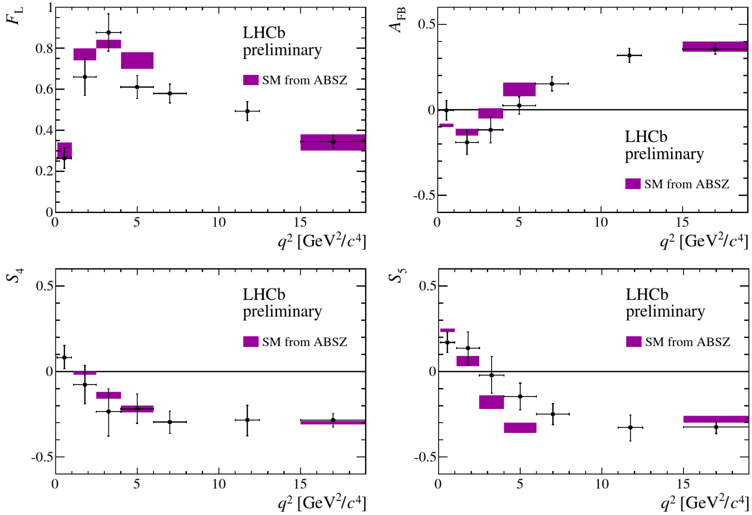


- Decay described by 3 helicity angles $\overrightarrow{\Omega} = (\theta_l, \theta_K, \phi)$ and $q^2 = m^2_{\mu\mu}$

$$\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^3(\Gamma + \bar{\Gamma})}{d\overrightarrow{\Omega}} = \frac{9}{32\pi} \Big[\tfrac{3}{4}(1 - F_{\rm L}) \sin^2\theta_K + F_{\rm L}\cos^2\theta_K + \tfrac{1}{4}(1 - F_{\rm L})\sin^2\theta_K \cos 2\theta_l$$
$$- F_{\rm L}\cos^2\theta_K \cos 2\theta_l + S_3 \sin^2\theta_K \sin^2\theta_l \cos 2\phi + S_4 \sin 2\theta_K \sin 2\theta_l \cos\phi$$
$$+ S_5 \sin 2\theta_K \sin\theta_l \cos\phi + \tfrac{4}{3} A_{\rm FB} \sin^2\theta_K \cos\theta_l + S_7 \sin 2\theta_K \sin\theta_l \sin\phi$$
$$+ S_8 \sin 2\theta_K \sin 2\theta_l \sin\phi + S_9 \sin^2\theta_K \sin^2\theta_l \sin 2\phi \Big].$$

- $F_{\rm L}$, $A_{\rm FB}$ and S_i depend on hadronic form factors and short-distance processes. Theoretically clean.
- Full angular analysis using Run I dataset ($3\,\mathrm{fb}^{-1}$)

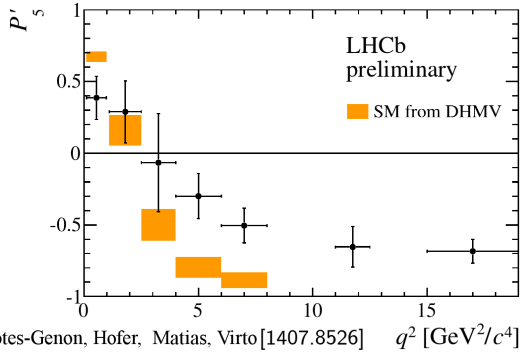
Angular analysis of $B^0 \to K^{*0}\mu\mu$ [LHCb-CONF-2015-002]



SM from Altmannhofer, Bharucha, Straub, Zwicki [1503.05534][1411.3161]

Angular analysis of $B^0 \to K^{*0}\mu\mu$ [LHCb-CONF-2015-002]

- Observable less dependent on form factors $P'_5 = \frac{S_5}{\sqrt{F_L(1-F_L)}}$

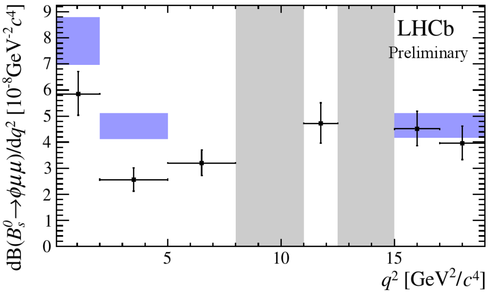


SM from Descotes-Genon, Hofer, Matias, Virto [1407.8526]

- Confirmed tension seen in [PRL 111, 191802 (2013)]
- 2.9 σ deviations in the regions [4.0, 6.0] and [6.0, 8.0] GeV^2
- Naive combinations gives a 3.7 σ significance
- Consistent with previous result

Analysis of the $B_s^0 \to \phi\mu\mu$ decay [LHCb-PAPER-2015-023]

- Similar to $B^0 \to K^{*0}\mu\mu$ (but no sensitivity to P_5')
- Measurement of BF and angular analysis



theory prediction:
arXiv:1411.3161,
arXiv:1503.05534

- Extrapolation to full q^2 range: (using PRD 66 (2002) 034002, PRD 71 (2005) 014029)

$$\frac{\mathcal{B}(B_s^0 \to \phi\mu\mu)}{\mathcal{B}(B_s^0 \to \phi J/\psi)} = (7.40^{+0.42}_{-0.40} \pm 0.20 \pm 0.21) \times 10^{-4}$$

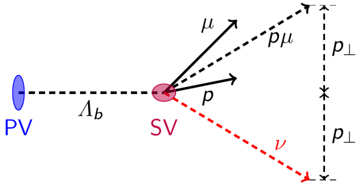
$$\mathcal{B}(B_s^0 \to \phi\mu\mu) = (7.97^{+0.45}_{-0.43} \pm 0.22 \pm 0.23 \pm 0.60) \times 10^{-7}$$

- Confirms tension seen in $1\,\mathrm{fb}^{-1}$ analysis [JHEP 07 (2013) 084]

What people thought LHCb could not do...

Determination of $|V_{ub}|$ using baryonic decays [arxiv:1504.01568]

- Puzzling discrepancy between exclusive ($B \to \pi l \nu$) and inclusive (any $b \to u l \nu$) determination of $|V_{ub}|$
- LHCb measures $\mathcal{B}\left(\Lambda_b^0 \to p\mu\nu\right)/\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c(\to pK\pi)\mu\nu\right)$: sensitive to $|V_{ub}|/|V_{cb}|$
- Measurement performed at high q^2, where direct calculation from LQCD [arxiv:1503.01421] is more precise



Corrected mass

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

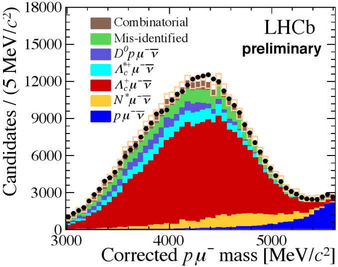
Peaks at $M_{\Lambda_b^0}$

- q^2 determined, up to a two-fold ambiguity, using pointing and $M_{\Lambda_b^0}$: require both solutions to be above $15\,\mathrm{GeV}^2$ to minimize bin migration

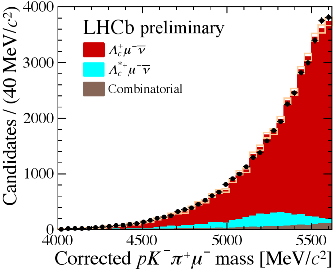
Determination of $|V_{ub}|$ using baryonic decays [arxiv:1504.01568]

- Background reduced using isolation techniques sensitive to the presence of extra tracks in the vicinity of the signal decay vertex

Signal: 17687 ± 733 events



Normalisation: 34255 ± 571 events



- Main systematics from precision on $\mathcal{B}(\Lambda_c \to pK\pi)$, trigger and tracking efficiency, Λ_c decay model

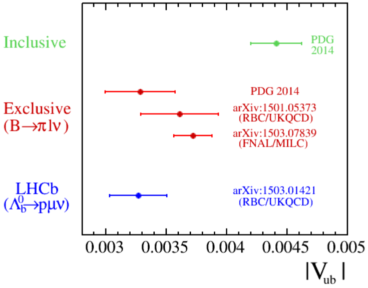
$$\frac{\mathcal{B}\left(\Lambda_b^0 \to p\mu\nu\right)_{q^2>15\,\mathrm{GeV}^2}}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c\mu\nu\right)_{q^2>7\,\mathrm{GeV}^2}} = (1.00 \pm 0.04 \pm 0.08) \times 10^{-2}$$

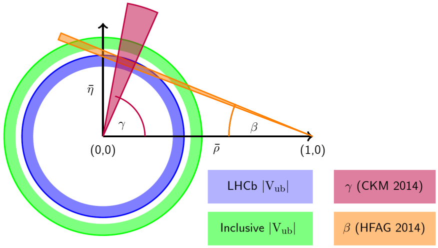
Determination of $|V_{ub}|$ using baryonic decays [arxiv:1504.01568]

- Using differential rates from [arxiv:1503.01421]:

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

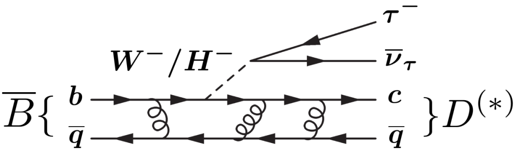
- Using exclusive measurement of $|V_{cb}|$:
  $|V_{ub}| = (3.27 \pm 0.15(exp) \pm 0.17(theory) \pm 0.06(|V_{cb}|)) \times 10^{-3}$
- 3.5σ away from inclusive measurement





See LHC seminar by P. Owen: https://indico.cern.ch/event/360242/

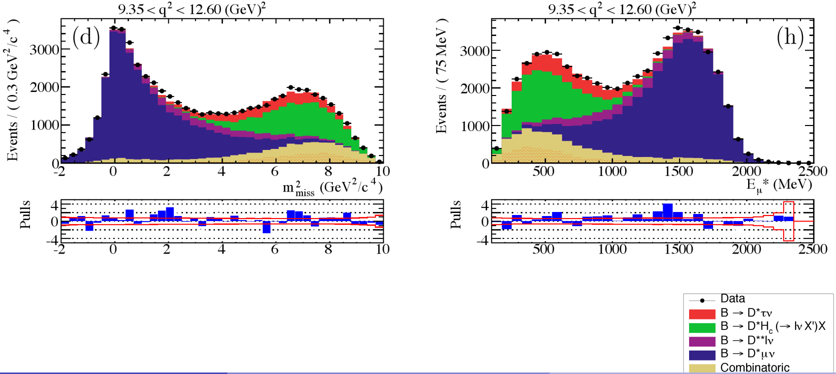
Measurement of the decay $\bar{B}^0 \to D^* \tau^- \bar{\nu}$ [LHCb-PAPER-2015-025]



- Measurement of $\mathcal{R}(D^*) = \frac{\mathcal{B}(B \to D^* \tau\nu)}{\mathcal{B}(B \to D^* \mu\nu)}$, using $\tau \to \mu\nu\nu$
- Sensitive to charged Higgs or non-MFV couplings favouring τ
- 2.7(2)σ discrepancy wrt SM (2σ for $\mathcal{R}(D)$) already seen by BaBar which strongly disfavours type II Higgs-doublet models
- Theoretically very clean but experimentally challenging in LHCb due to 3 missing νs
- No narrow peak to fit, many backgrounds...
- Presented recently at FPCP (link)

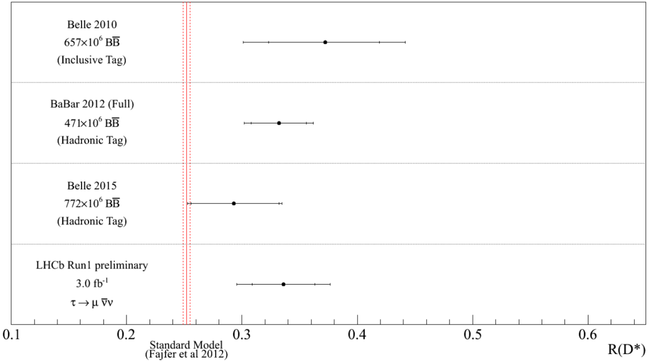
Measurement of the decay $\bar{B}^0 \to D^*\tau^-\bar{\nu}$ [LHCb-PAPER-2015-025]

- Isolation techniques to protect against partially reconstructed background
- Discriminating variables are $m^2_{miss} = (p^\mu_B - p^\mu_D - p^\mu_l)^2$, E^*_μ (μ energy in the B rest frame) and $q^2 = (p^\mu_B - p^\mu_D)$
- Shapes are taken from simulation, validated against data



Measurement of the decay $\bar{B}^0 \to D^* \tau^- \bar{\nu}$ [LHCb-PAPER-2015-025]

- LHCb measurement $\mathcal{R}(D^*) = 0.336 \pm 0.027 \pm 0.030$
- Agreement with SM at $2.1\,\sigma$
- Main uncertainty from the size of the simulated sample $\to$ Still room for improvement!

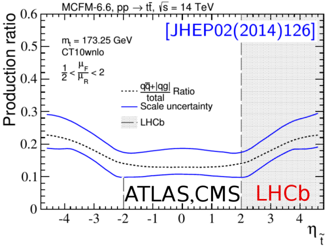


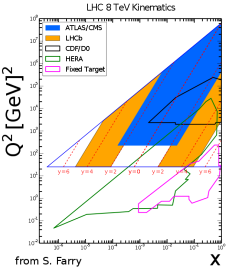
- New measurement from Belle also compatible with SM

Top quark production in the forward region

[LHCb-PAPER-2015-022]

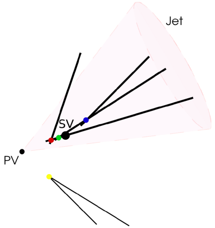
- Dominated by $t\bar{t}$. Test for differential predictions, reduced g-initiated production, probe different x compared to central region





from S. Farry

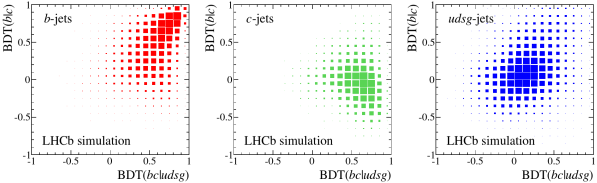
$Q^2(x) = e^{\pm 2y} x^2 s$



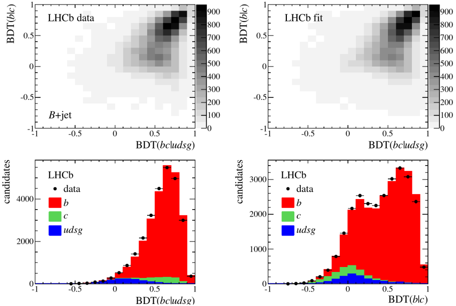
- Use $W + b$ final state, needs b- and c-jet tagging [arXiv:1504.07670]
- Jets formed using a particle flow approach (anti-k_T)
- Identification uses secondary vertices from (b, c) hadron decays

Top quark production [LHCb-PAPER-2015-022]

- Two BDTs trained to separate (b, c) jets from light-parton jets and b jets from c jets

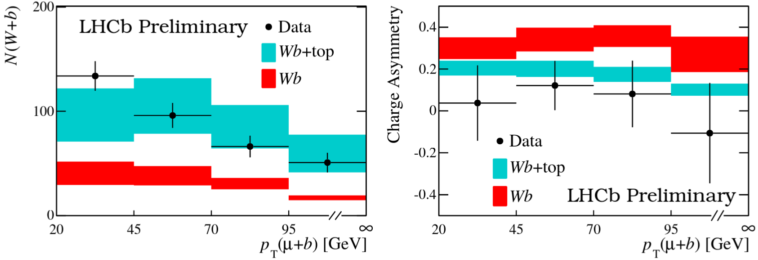


Sample enriched in $b-$ and $c-$ jets



- Variety of data samples for calibration and efficiency measurements
- b tag efficiency: 65%
- c tag efficiency: 25%
- mis-tag rate: well below 1%

Top quark production [LHCb-PAPER-2015-022]



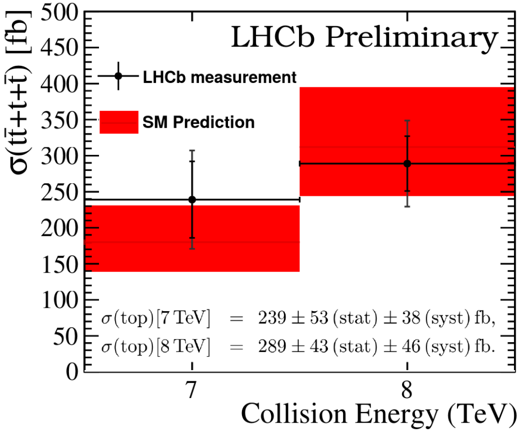
NLO predictions from MCFM [JPG42(2015)1,015005] in the 4FS and CT10 PDF set [PRD82(2010)074024]

- Data cannot be described by *Wb* alone
- Agreement with $Wb + top$ predictions
- 5.4σ observation of top production in the forward region

See LHC seminar by V. Coco: https://indico.cern.ch/event/388144/

Top quark production [LHCb-PAPER-2015-022]

Observed excess used to measure $\sigma(t\bar{t} + t + \bar{t})$

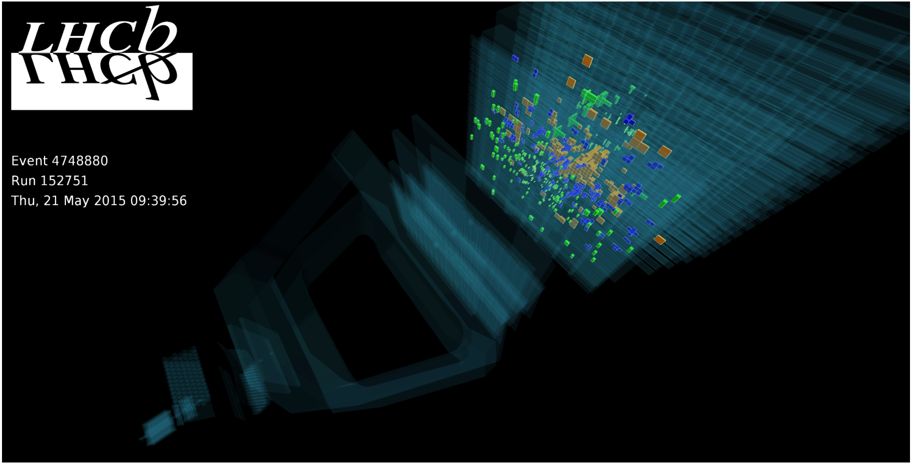


Consistent with NLO SM predictions

See LHC seminar by V. Coco: https://indico.cern.ch/event/388144/

Preparation for Run II

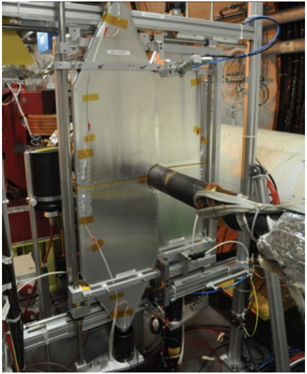
First collisions!

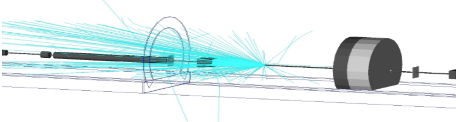


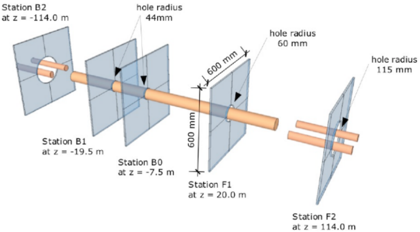
- Collision at 450 GeV delivered on 5-6 May: global time alignment, data taken with the full detector
- 13 TeV collisions delivered on 21 May

Herschel

- Opportunity to study Central Exclusive Production (CEP) in Run II
- Need to tag background at very high rapidity ($5 < |\eta| < 8$)





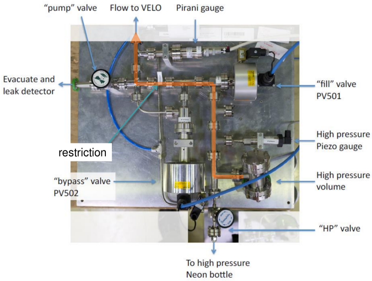


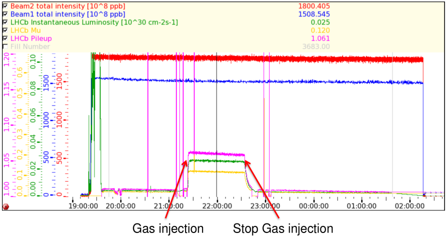
Stations at >100 m from interaction region!

- Detector installation completed
- Working fine in TED runs
- Final commissioning of readout and trigger electronics

SMOG test

- SMOG (System from Measuring the Overlap with Gas) used to inject gas into the VELO to perform a measurement of the luminosity based on Beam-Gas imaging method
- Test of readout chain including L0, HLT1 and HLT2 trigger



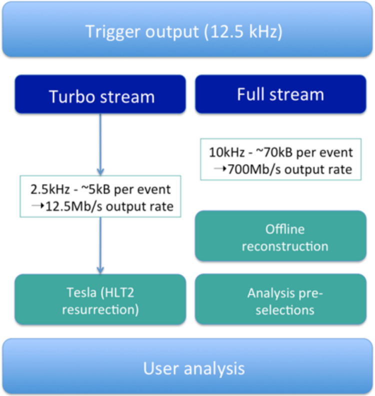


- Test was successful. Gas injection is working and trigger for luminosity and calibration ready

Trigger in Run II

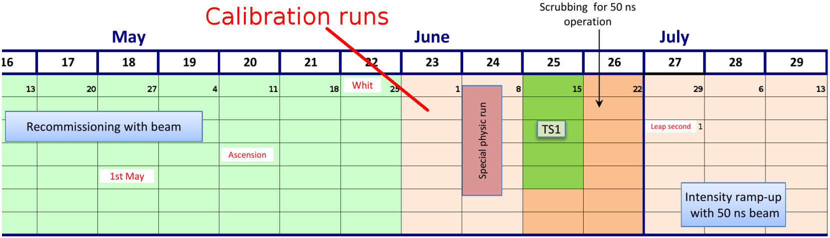
New trigger strategy based on Run I experience and larger CPU farm.
Necessary to increase physics output within existing computing constraints

- Calibration and alignment performed at each fill
- HLT reconstruction much closer to offline
  - PID in HLT2
  - Introduced turbo stream to saves HLT candidates only to reduce event size
  - Turbo stream output will not need offline reconstruction and will be used directly to perform analysis



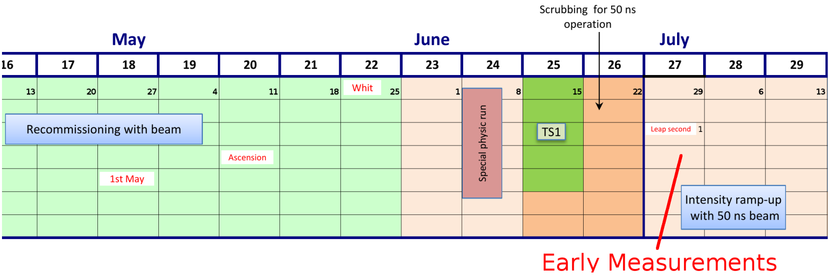
Detector status and plans

- New: automatic voltage adjustment in the Calo to correct for detector ageing
- Shift table well covered for the coming months
- Detector is ready to collect data for calibration run this week
  - Luminosity levelling to $\mu \sim 1.1$ (same as in 25 ns run)
  - Spatial and timing alignment calibration
  - Test whole dataflow (offline included)
  - VdM scans



50 ns ramp-up period

- Collect a large sample of minimum bias data
- Focus on production measurements at new collision energy
- Important input to model tuning and planning of LHCb's precision program
- Turbo stream validation

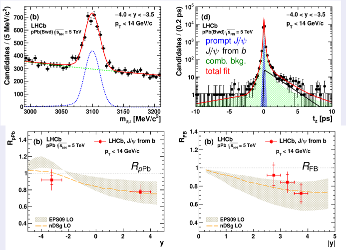


Heavy Ion Run

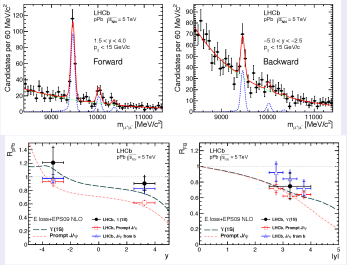
Heavy Ions at LHCb?

First measurement already performed using *pA* pilot run in 2013

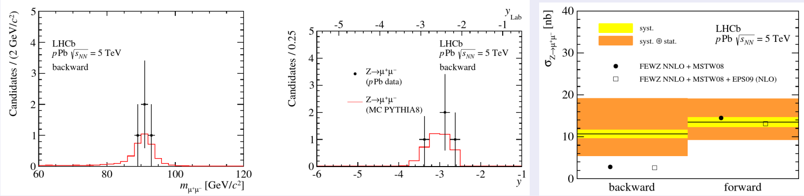
J/ψ production [JHEP 02 (2014) 072]



Υ production [JHEP 07 (2014) 094]

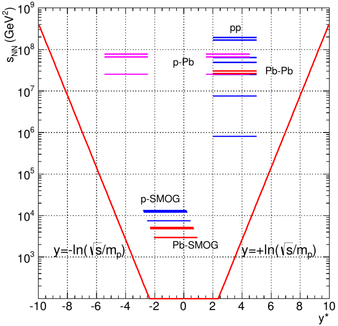


Z production [JHEP 09 (2014) 030]



Heavy Ions at LHCb?

- LHCb did not participated in Pb-Pb collision runs
- Growing interest in the physics community for LHCb measurements in this area
- Physics motivations driven by the unique rapidity coverage
  - **Heavy Flavours**: Production of D, B mesons and quarkonia searching as probes for QGP
  - **Soft-QCD**: Structure of nucleons, hadronisation, CEP, properties of matter in extreme conditions,...



- Use pp as reference and p-Ion to investigate Cold Nuclear Matter effects
- Possibility to run in a fix target scenario by injecting gas using the SMOG system

Heavy Ion at LHCb?

- Everything indicates that LHCb can do this type of physics
- The collaboration is seriously considering this possibility
- Focus on peripheral collisions in Pb-Pb
- Use of SMOG as a fix target
  - Various gases could be injected
- Machine and the other experiments are informed of our plans
- Assessing operational aspects
- Decision should be taken soon

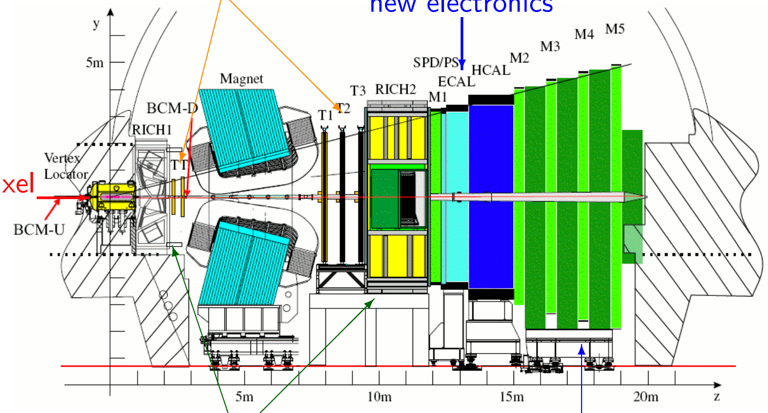
Upgrade

Upgrade overview

New tracking stations

Reduce PMT gain + new electronics

New pixel VELO



New PMT + new electronics

New electronics + More shielding

All sub-detectors readout at 40 MHz for software trigger

Upgrade status

- Excellent progress on all sub-systems
  - VELO: successful testbeam of prototype sensors, progress with new RF foil
  - Upstream Tracker: testbeam evaluation of sensors, series of EDRs in June
  - SciFi: progress in fibres understanding and production, progress in mechanics (EDR in summer)
  - RICH: progress with photodetectors: successful EDRs for ASIC, FE board & elementary cell
  - Calo: Design of new front-end boards started
  - Muon: Work on spare MWPCs, simplified readout (no hardware Low Level Trigger)
- An LS2 schedule exists, funding mostly in place
- Many important EDRs in the coming months

Conclusions

- LHCb still producing exciting Run I results:
  - 263(249) paper submitted (published) so far, 23(8) since last LHCC
  - Intriguing new results shown at recent conferences, follow-up measurements planned in Run II
  - Physics scope enlarging more and more
  - Participation in Ion Run is under serious consideration
- LHCb is ready for Run II
- Upgrade well under way and steadily progressing