LHCb status report

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on behalf of the LHCb collaboration

137th LHCC open session, CERN

February 27$^{\mathrm{th}}$, 2019

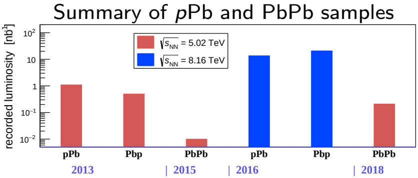
Outline

- Operations
  - End of heavy ion run
  - Computing activities
- Physics

  A selection of new published or preliminary results since last LHCC
  - Spectroscopy
  - *CP* violation
  - Heavy ion physics
- Upgrade
  - Subdetector upgrade
  - Infrastructure activities
  - Commissioning

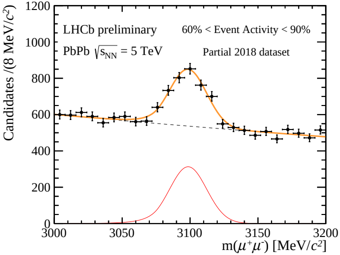
End of 2018 ion run: PbPb collisions at $\sqrt{s_{NN}} = 5$ TeV

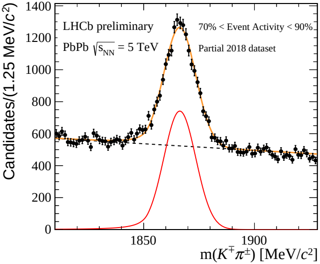
Thanks to the LHC for this successful ion run !



2018 PbPb sample: the largest PbPb statistics

$\sim 20 \times \mathcal{L}_{2015}$





https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2018

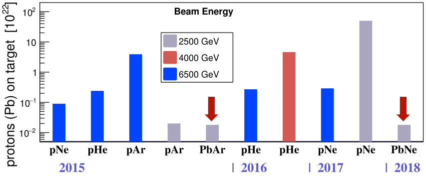
Analysis of 2018 PbPb dataset has started

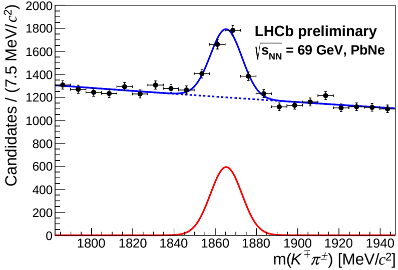
End of 2018 ion run: PbNe collisions at $\sqrt{s_{\mathrm{NN}}} = 69$ GeV

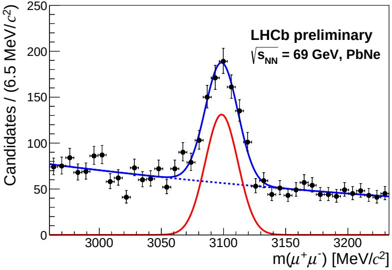
Simultaneously to PbPb, LHCb collected PbNe collisions thanks to the **unique LHC fixed target**

Largest sample of Pb-induced reactions in fixed target configuration

- Same energy as 2017 *p*Ne sample
- Data available, already in use







https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2018

First heavy flavor signal in Pb-induced collisions in LHC fixed-target configuration

Computing activities

Since the start of LHCb, $\mathcal{L}_{pp} \sim 9$ fb^{-1} collected

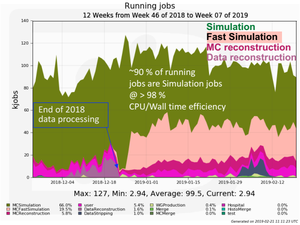
Thanks to the real-time alignment and calibration

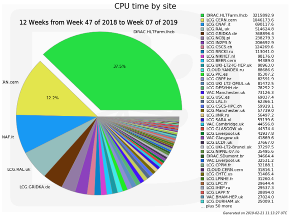
$\rightarrow$ No need for a reprocessing

Full run 2 sample available and already in use

Optimal use of the resources

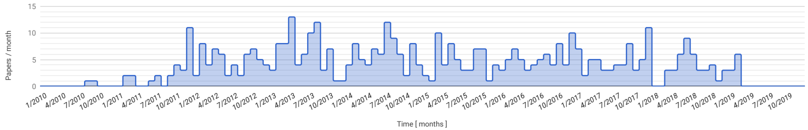
- MC productions are using $\sim$ 90 % of the computing power
- Using the online farm for MC production: $\sim$ 40% of the sample
- Signal MC with 2017 and 2018 conditions available
- Fast simulation
  A palette of faster simulation is available,
  $\rightarrow$ Up to a factor 6 faster than the full simulation
  Increase the use of faster simulation by the analysts
- Restripping campaign of Run1 and Run2 data ongoing



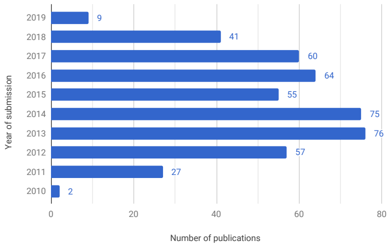


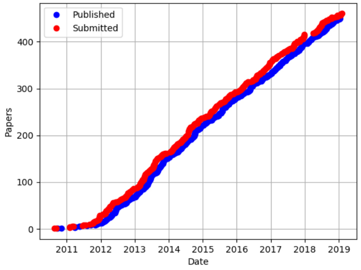
Physics papers since last LHCC

Papers submitted per month



Publications per year





466 papers in total: 12 papers published since the last LHCC session

Physics papers since last LHCC

Submitted

PAPER-2017-041 Measurement of the ratio of branching fractions of the decays $\Lambda_b^0 \to \psi(2S)\Lambda$ and $\Lambda_b^0 \to J/\psi\Lambda$

PAPER-2018-036 Measurement of the branching fraction and *CP* asymmetry in $B^+ \to J/\psi\rho^+$

PAPER-2018-037 Search for the rare decay $B^+ \to \mu^+\mu^-\mu^+\nu_\mu$

PAPER-2018-039 Dalitz Plot analysis of the $D^+ \to K^-K^+K^+$ decays

PAPER-2018-040 Observation of the doubly Cabibbo-suppressed decay $\Xi_c^+ \to p\phi$

PAPER-2018-042 Study of the $B^0 \to \rho(770)^0 K*(892)^0$ decay with an amplitude analysis of $B^0 \to (pi^+\pi^-)(K^+\pi^-)$

PAPER-2018-043 Model-independent observation of exotic contributions to $B^0 \to J/\psi K^+\pi^-$ decays

PAPER-2018-045 Amplitude analysis of $B_s^0 \to K_S^0 K^\pm\pi^\mp$ decays

PAPER-2018-046 Observation of $B_{(s)}^0 \to J/\psi p\bar{p}$ decays and precision measurements of the $B_{(s)}^0$ masses

PAPER-2018-047 Measurement of the mass and production rate of Ξ_b^- baryons

PAPER-2018-048 Measurement of B^+, B^0 and Λ_b^0 production in *p*Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV

PAPER-2018-050 Measurement of *b*-hadron fractions in 13 TeV *pp* collisions

Preliminary

PAPER-2018-049 Measurement of $\psi(2S)$ production cross-sections in proton-proton collisions at $\sqrt{s} = 7$ and 13 TeV

PAPER-2018-051 Amplitude analysis of $B^\pm \to \pi^\pm K^+K^-$ decays

PAPER-2019-003 Measurement of the *CP*-violating phase ϕ_s from $B_s^0 \to J/\psi\pi^+\pi^-$ decays in 13 TeV *pp* collisions

PAPER-2019-005 Observation of a new charmonium state and study of near-threshold $D\overline{D}$ spectroscopy (to be checked)

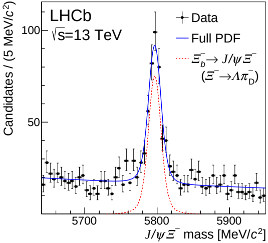
Measurement of the mass and production rate of Ξ_b^- baryons

PAPER-2018-047
arXiv:1901.07075
Accepted by PRD

First study of the production rate of $\Xi_b^- \to J/\psi\,\Xi^-(\Lambda\pi^-)$ baryons in *pp* collisions

- Relative to $\Lambda_b^0 \to J/\psi\Lambda$
- Take into account long decay times of Ξ and Λ

$\mathcal{L}$	7, 8 TeV 1 and 2 fb^{-1}	13 TeV 1.6 fb^{-1}
$N(\Xi_b \to J/\psi\Xi^-(\Lambda\pi_L^-))$	203 ± 13	258 ± 22
$N(\Xi_b \to J/\psi\Xi^-(\Lambda\pi_D^-))$	266 ± 20	357 ± 26
$N(\Lambda_b^0 \to J/\psi\Lambda)$	13307 ± 137	14793 ± 150



Most precise determination of $m(\Xi_b^-) = 5796.70 \pm 0.39 \pm 0.15 \pm 0.17$ MeV$/c^2$

Measurement of Ξ_b^- production asymmetry consistent with 0

$$\frac{f_{\Xi_b^-}\,\mathcal{B}(\Xi_b^- \to J/\psi\Xi^-)}{f_{\Lambda_b^0}\,\mathcal{B}(\Lambda_b^0 \to J/\psi\Lambda)} = \begin{array}{l}\left(10.8 \pm 0.9 \pm 0.8\right) \times 10^{-2} \text{ at } \sqrt{s} = 7,\ 8 \text{ TeV} \\ \left(13.1 \pm 1.1 \pm 1.0\right) \times 10^{-2} \text{ at } \sqrt{s} = 13 \text{ TeV}\end{array}$$

Using $SU(3)$ flavor symmetry, **fragmentation fractions are extracted**

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} = \begin{array}{l}(6.7 \pm 0.5 \pm 0.5 \pm 2.0) \times 10^{-2} \text{ at } \sqrt{s} = 7,\ 8 \text{ TeV} \\ (8.2 \pm 0.7 \pm 0.6 \pm 2.4) \times 10^{-2} \text{ at } \sqrt{s} = 13 \text{ TeV}\end{array}$$

→ **No significant dependence on the center-of-mass energy in the 7 - 13 TeV range**

Observation of the doubly Cabibbo-suppressed decay $\Xi_c^+ \to p\phi$

PAPER-2018-040
arXiv:1901.06222

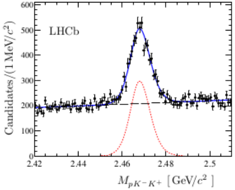
First observation of the doubly Cabibbo-suppressed diagram $\Xi_c^+ \to p\phi$

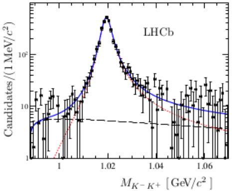
- 2 fb^{-1} in pp collisions at $\sqrt{s} = 8$ TeV (2012)
- Measurement relative to the singly Cabibbo-suppressed $\Xi_c^+ \to pK^-\pi^+$ decays
- Yields of $\Xi_c^+ \to pK^-K^+$: $N_{pKK} = 3790 \pm 120$
- *sPlot* technique used to separate ϕ contribution in the K^-K^+ mass region $M_{K^-K^+} < 1.07$ GeV$/c^2$

  → Fraction of ϕ contribution $f_\phi = (90.0 \pm 2.7)\%$

  → Evidence of a non-ϕ contribution (3.5 σ)

$$\frac{\mathcal{B}(\Xi_c^+ \to p\phi)}{\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)} = (19.8 \pm 0.7 \pm 0.9 \pm 0.2) \times 10^{-3}$$





First observation of $\Xi_c^+ \to p\phi$ decays with a statistical significance $> 15\,\sigma$

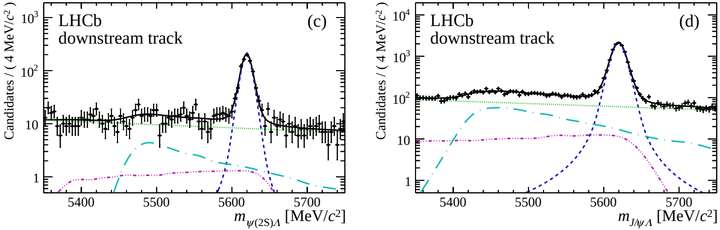
Measurement of the ratio of $\Lambda_b^0 \to \psi(2S)\Lambda$ and $\Lambda_b^0 \to J/\psi\Lambda$

PAPER-2017-041
arXiv:1902.02092

- Information on the production of charmonia in b-hadron decays
- ATLAS measured $\frac{\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)}{\mathcal{B}(\Lambda_b^0 \to J/\psi\Lambda)} = 0.501 \pm 0.033(\text{stat}) \pm 0.019\ (\text{syst})$ Phys. Lett. **B751** (2015) 63
  $\rightarrow$ at 2.8 σ from the covariant quark model prediction
- Most experimental uncertainties cancel in the ratio
- 3 fb^{-1} pp collisions at $\sqrt{s_{\text{NN}}} = 7, 8$ TeV

Exploit the dimuon final states not originating from any PV and the long decay time of Λ

Results in 2 tracks classes (with/ without hits in the VELO) in agreement



Signal: blue

Background:

combinatorial: green

$B^0 \rightarrow \psi K_S^0$: cyan

$\Xi_b^- \rightarrow \psi\Xi^-$: violet

$$\frac{\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)}{\mathcal{B}(\Lambda_b^0 \to J/\psi\Lambda)} = 0.513 \pm 0.023(\text{stat}) \pm 0.016\ (\text{syst}) \pm 0.011(\mathcal{B})$$

LHCb confirms the discrepancy observed by ATLAS and sets additional constraint

Observation of a new charmonium state, study of $D\overline{D}$ spectra

PAPER-2019-005

First measurement using the full LHCb dataset, 9 fb^{-1}, collected from 2011 to 2018

Analysis of the $D^0\overline{D}^0$ and D^+D^- mass spectra

- Prompt production of $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ decays
- Exploit long decay time of D^0, D^+
- Select only D^0, D^+ within $\pm$ 20 MeV/c^2 of the know D-meson mass

First time observations

New narrow charmonium state: $X(3842)$

$\rightarrow$ Significance $> 5\sigma$

$\mu_{X(3842)} = 3842.71 \pm 0.16 \pm 0.12$ MeV/c^2

$\Gamma_{X(3842)} = 2.79 \pm 0.51 \pm 0.35$ MeV

Possible interpretation: $\psi_3(1^3D_3)$, $\mathrm{J}^{\mathrm{PC}} = 3^{--}$

Prompt hadroproduction of $\chi_{c2}(3930)$

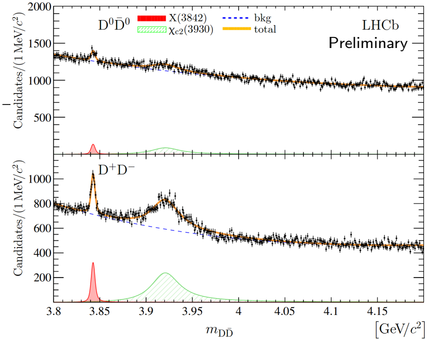
$\mu_{\chi_{c2}(3930)} = 3921.90 \pm 0.55 \pm 0.19$ MeVc^2

$\Gamma_{\chi_{c2}(3930)} = 36.64 \pm 1.88 \pm 0.85$ MeV

Prompt hadroproduction of $\psi(3770)$

$\mu_{\psi(3770)} = 3778.13 \pm 0.70 \pm 0.63$ MeVc^2

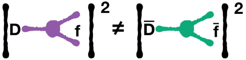
The mass peak is outside this mass range, see it in back up



Search for *CPV* in $D_s^+ \to K_S^0\pi^+$, $D^+ \to K_S^0 K^+$, $D^+ \to \phi\pi^+$

PAPER-2019-002

CP violation in charm decays has not yet been observed



Most promising channels are Cabibbo-suppressed decays
$\to$ CPV may arise from the interference between the tree and the penguin amplitude

Measurement of $\mathcal{A}_{CP}$ in $D_s^+ \to K_S^0\pi^+$, $D^+ \to K_S^0 K^+$, and $D^+ \to \phi\pi^+$ decays

- Easy-to-reconstruct and high statistics channels
- Analyze 3.8 fb^{-1} of Run 2 data - most precise previous results from LHCb Run 1 data
- Measure raw asymmetries $A(D_{(s)}^+ \to f^+) \approx \mathcal{A}_{CP}(D_{(s)}^+ \to f^+) + A_P(D_{(s)}^+) + A_D(f^+)$ with A_P the production asymmetry, A_D the final state detection asymmetry
- Combine with $D^+ \to K_S^0\pi^+$, $D_s^+ \to K_S^0 K^+$, and $D_s^+ \to \phi\pi^+$ raw asymmetries , where CPV can be neglected $\to$ A_D and A_P are canceled

$$\mathcal{A}_{CP}(D_s^+ \to K_s^0\pi^+) = \Big(1.3 \pm 1.9\,(\mathrm{stat}) \pm 0.5\,(\mathrm{syst})\Big) \times 10^{-3}$$
$$\mathcal{A}_{CP}(D^+ \to K_s^0 K^+) = \Big(-0.09 \pm 0.65\,(\mathrm{stat}) \pm 0.48\,(\mathrm{syst})\Big) \times 10^{-3}$$
$$\mathcal{A}_{CP}(D^+ \to \phi\pi^+) = \Big(0.05 \pm 0.42\,(\mathrm{stat}) \pm 0.29\,(\mathrm{syst})\Big) \times 10^{-3}$$

No evidence of CPV is found

Measurement of CP-violating phase ϕ_s from $B_s^0 \to J/\psi\pi^+\pi^-$ PAPER-2019-003

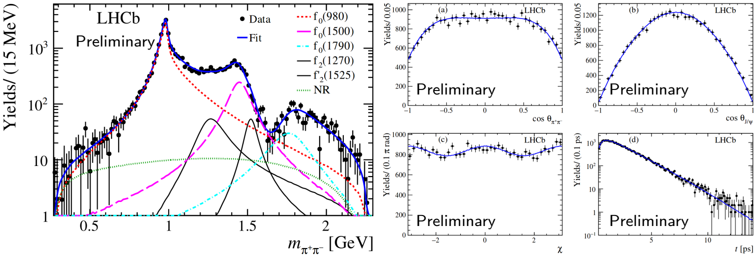
ϕ_s arises from the interference between B_s^0 direct decay and via mixing

- CKM fitter constraint $\phi_s = -36.5^{+1.3}_{-1.2}$ mrad
- Golden channel: $B_s^0 \to J/\psi\phi$ but can be measured in $B_s^0 \to J/\psi\pi^+\pi^-$

Time-dependent amplitude analysis of $B_s^0 \to J/\psi\pi^+\pi^-$ using 2015 and 2016 data

Flavor tagging exploits opposite and same side taggers: $\varepsilon D^2 = (5.06 \pm 0.38)\%$

Fit entire $\pi^+\pi^-$ mass spectrum, assuming same CP-violation quantities for all resonances



CP-odd fraction $> 97\%$, decay width difference $\Gamma_H - \Gamma_L = -0.050 \pm 0.004 \pm 0.004$ ps^{-1}

$$\phi_s = -0.057 \pm 0.060 \pm 0.011 \text{ rad}$$

Combination with Run-1 results for this channel: $\phi_s = 0.002 \pm 0.044 \pm 0.012$ rad

Measurement of B^+, B^0 and Λ_b^0 production in pPb

PAPER-2018-048
arXiv:1902.05599

First measurement of beauty-hadron production via exclusive decay channels in nuclear collisions in LHCb kinematic regime $\sqrt{s_{\mathrm{NN}}} = 8.16$ **TeV**

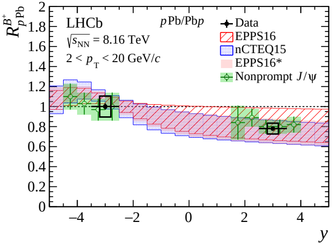
***p*Pb collisions**
$\mathcal{L} = 12.2 \pm 0.3\ \mathrm{nb}^{-1}$, $1.5 < y < 3.5$

Pb*p* collisions
$\mathcal{L} = 18.6 \pm 0.5\ \mathrm{nb}^{-1}$, $-4.5 < y < -2.5$

Decay	pPb	Pbp
$B^+ \to \overline{D}^0 \pi^+$	1958 ± 54	1806 ± 55
$B^+ \to J/\psi K^+$	883 ± 32	907 ± 33
$B^0 \to D^- \pi^+$	1151 ± 38	889 ± 34
$\Lambda_b^0 \to \Lambda_c^+ \pi^-$	484 ± 24	399 ± 23

Nuclear effects are studied through: **double-differential cross-sections (y, p_T), nuclear modification factors and forward-to-backward cross-section ratio**

- Significant nuclear suppression at $y > 0$
- Unique measurement of Λ_b^0 production
- Λ_b^0/B^0 production cross-sections consistent with the pp measurements
- Λ_b^0/B^0 and B^0/B^+ ratios consistent with being independent of y and p_T



→ Valuable input for future fits of nPDF

Projections for LHC future runs

LHCb-CONF-2018-005: LHCb projections for pPb collisions during LHC Runs 3 and 4

Assumptions: $\sqrt{s_{\rm NN}} = 8.8$ TeV, $\mathcal{L}_{pPb} = 500$ nb^{-1}
3 weeks of pPb collision during Run 3 and 4

Projections based on existing LHCb analyses

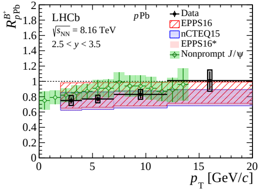
Drell-Yan production clean probe of nPDF at small Bjorken-x

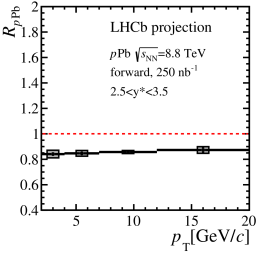
$D^0\overline{D}^0$ **correlations**: possible modification of parton intrinsic transverse momentum

Nuclear modification of heavy flavor production

→ **Unique potential to constrain nPDF and gluon saturation**

B^+ production



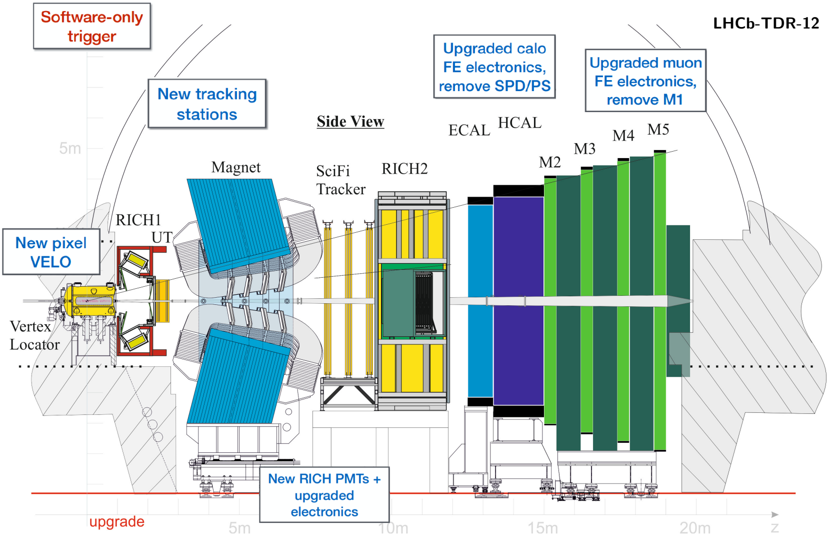


LHCb-CONF-2018-006: Prospects for searches for long-lived particles

Exploit the excellent triggering, tracking and vertexing capabilities of the upgraded LHCb

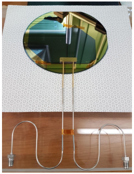
→ **Competitive upper limits for beyond SM particles with low masses and lifetimes**

LHCb upgrade I



VELO upgrade: pixel silicon detector

Microchannel production



15 prototypes fully assembled with preproduction grade

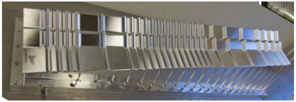
1st production grade delivery in 2 weeks

Tile assembly

Production of sensors/ASICs complete

70% of tiles bump bonded and tested

RF box production

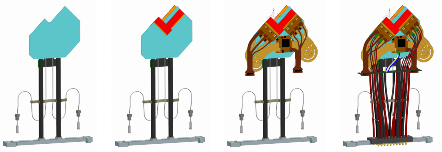


250μm aluminium box separating the VELO from LHC vacuum

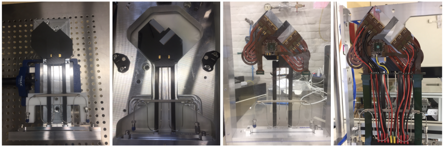
1st pair of boxes complete

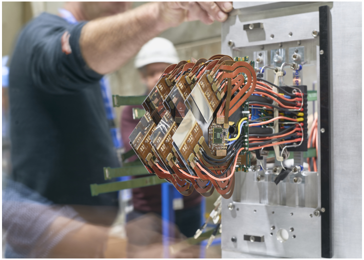
Production started on 2nd pair

Etching validation ongoing



Mechanical construction | Precision tile placement 10μm | Flex circuit placement | Wire bonding, HV/LV /data cable attachment





3 modules successfully operated in SPS testbeam (Oct 2018)

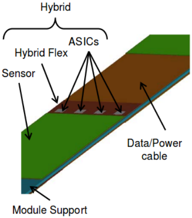
Upstream Tracker (UT)

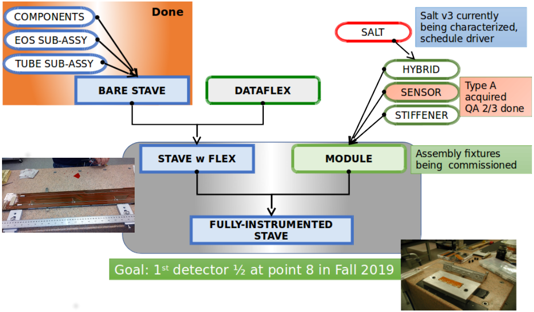
4 planes of Si microstrip detector in a box that opens during access and beam pipe bake-out

Planes constructed with **staves**

Low mass flex circuits provide electrical connection between dedicated front end ASICs (SALT) and PEPI electronics

Hybrid-sensor modules mounted on both side to achieve full coverage





First results from the new SALT v3 are encouraging

Schedule for UT installation remains very critical

Scintillating Fibre Tracker (SciFi)

Production well advanced

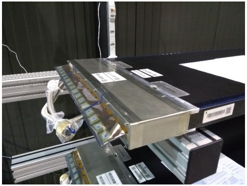
Assembly hall fully prepared

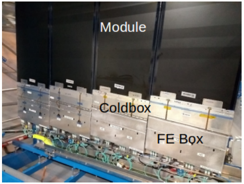
- Module production finished
- SiPM production will finish in March
- Electronics production:
  Front-end chip produced and tested
  Front-end boards ∼ 20% produced
- Mechanical components for 1st C-frame ready
  Assembly will start in week 10
- Installation of first 6 frames in LHCb is foreseen to start in November

Full-size prototype C-frame

- Commissioning of vacuum insulated SiPM cooling (-40°)
- Commissioning of readout and experiment controls well advanced

Coldbox mounting started: modules for first frame already finished

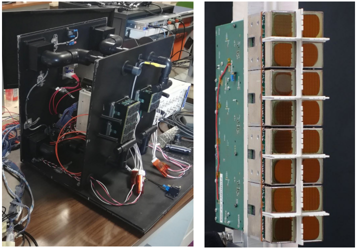




RICH upgrade

- Production of all electronics components started
- Elementary Cell Quality assurance started
- Quality Assurance of plugin modules started
- First colums at CERN in few weeks
- Commissioning lab in preparation

RICH upgrade on track



Setup for the Quality Assurance of the EC

Test racks for the commissioning

Mechanics of a RICH column

Calorimeter and Muon system upgrade

Calorimeter

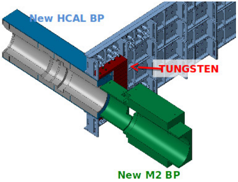
- New front-end electronics
  Prototypes have been tested intensively → Production is starting soon
  Control boards prototypes have been tested → Final version reached
- Preparation of the SPD/PS/Lead dismantling, removal of the ECAL/HCAL electronics
- Reconstruction software for the calorimeters objects

Muon system: **New detector electronics - read-out at 40 MHz**

- nSYNCs, nODE, nSB are under production, **first boards delivered**
- Tests are ongoing in Cagliari, Roma1, LNF, **first results are positive**
- First boards **at CERN in April** to start the tests on the apparatus

Improved shielding in front of M2

- Drawings have been finalized
- Orders are being placed
- All parts are expected at CERN in the next few months



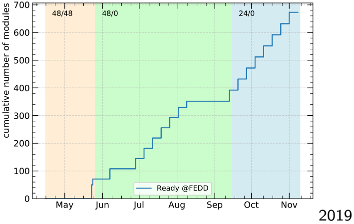
→ **Calorimeter and Muon system upgrade on track**

Online

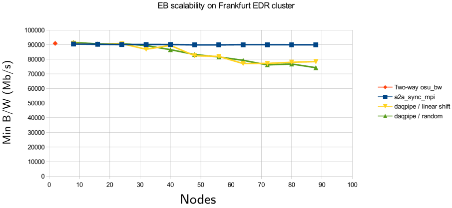
The preparation of the online system is progressing according to schedule

First 2 containers of the LHCb data centre installed and ready at IP8

Beginning of February, delivery of half of the long distance fibres at IP8



Residual PCIe40 modules problem solved
→ Production started at full steam



Promising results for the scalability of the dedicated event builder

Upgrade of the fixed-target system: SMOG2

The use of a storage cell will significantly improve the performances of the fixed target

- Increase of the **luminosity by up to 2 orders of magnitude**
- Potentially allow injection of $\mathbf{H_2}$, $\mathbf{D_2}$, He, $\mathbf{N_2}$, $\mathbf{O_2}$, Ne, Ar, (Kr, Xe)
- New gas feed system, gas density measured with strongly improved precision
- Well defined interaction region upstream the nominal interaction point

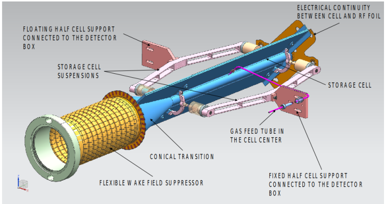
Engineering Design Review in Nov 2018

Presented and discussed by **several LHC WGs**: Vacuum, Impedance, MPP, TREx

Status reviews foreseen in 2019 Q1 and Q2
→ In cooperation with LHC experts during all the way up to installation

Presented at the LHC Machine Committee
→ No showstopper emerged

Storage cell upstream the VELO detector



Expand the physics reach of SMOG paving the way to new and unique measurements

Heavy quark and Drell-Yan production, polarization in baryon production, cosmic rays physics
→ Physics opportunities detailed in **CERN-PBC-Notes-2018-007 (LHCb-PUB-2018-015)**

Infrastructure activities

December 2018 Activity successfully finished / Activity ongoing

- Dismantling of the LHCb Main Shielding wall
- Removal of BCM/BLS and Herschel
- Velo racks displacement
- Removal of pipes and cables

January 2019

- Dismantling of the beam pipe, removal of Moedal
- RICH2 upstream window protection installation
- Assembly of the OT cage
- Removal of pipes and cables and the IT stations

February 2019

- Removal of the IT stations
- Removal of the RICH1 shielding doors
- Removal of pipes and cables

Next activities: Removal of the OT stations and M1

LHCb LS2 pit activities overall schedule at the EDMS document 1826213
Follow our new activities by watching our weekly video:
`http://lhcb-media.web.cern.ch/lhcb-media`

Commissioning activities

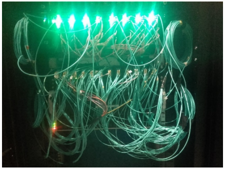
Local commissioning activities have started more intensively

- 3 upgrade commissioning meetings
- 2 sub-detectors workshops: UT and VELO
- Experiment Control System, online, monitoring workshops
- **SciFi and RICH commissioning setup**
- Online "vertical slice" fully in operations

PCIe40 "acceptance" server
Used to test and accept boards after production

PCIe40 vertical slice server fully cabled

- Used 8 pre-production PCIe40
- Synchronous readout with 48 links eachs: ~ 1 Tb/s potential
- Testbench for Event builder
- Continuous integration



Short-term (Q2) goal: readout part of a detector with new electronics

- Working firmware/software with production releases
- New cards and central timing distribution system

Conclusions

LHCb operations

- 10 years of successful operations including ion runs
- First significant Pb collisions sample with the unique LHC fixed target configuration
- Optimal use of the computing resources

LHCb physics

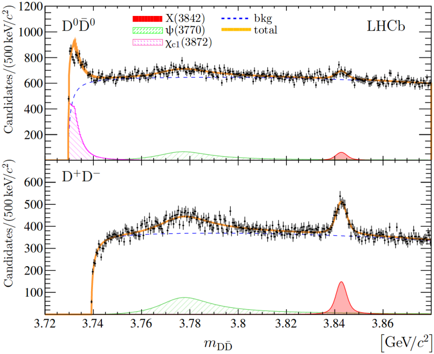
- 466 papers since 2010
- First result using the full LHCb statistics (9 fb^{-1}) submitted
- New results using Run 2 data and the full LHCb statistics coming in the next weeks

LHCb upgrade

- Dismantling and installation ongoing
  Follow our weekly video: `http://lhcb-media.web.cern.ch/lhcb-media`
- Intensive activities: subdetector, online, electronics
- Upgrade of the fixed-target discussed with several LHC WG and LHCC
- LHCb upgrade II: 4th dedicated workshop open to all who are interested

Extra slides

About PAPER-2019-005

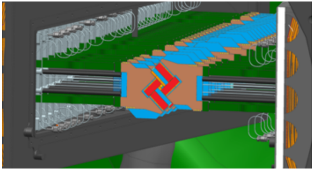


- $X(3842), \chi_{c2}$ are prompt, while $\psi(3770)$ has a 35% component from B-decays
- $D\overline{D}$ purity: $\sim$ 90%
- Resolutions are cross-checked using control channels
- Fit in $D^0\overline{D}^0$ mass near-threshold region, $\chi_{c1}(3872) \rightarrow$ Does not affect $\psi(3770)$ parameters
- Other narrow or wide resonances were added into the fit
  $\rightarrow$ Non-zero contributions from $\psi(4040), \psi(4160), \chi_{c0}(3860)$
  $\rightarrow$ Taken into account in the systematic uncertainties

VELO upgrade

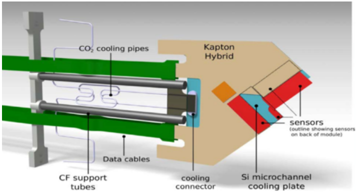
Challenges in Run 3

- Vertexing, tracking performance with $\sim 5\times$ increase in interactions per bunch crossing
- Increased radiation (order of magnitude higher than current doses)



VELO upgrade

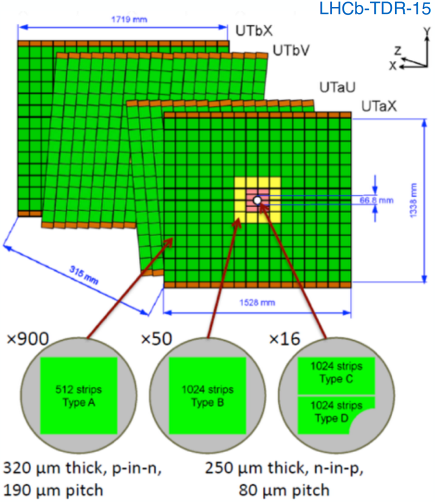
- Silicon hydrid pixel
- 52 modules, 2 retractables halves
- 4 silicon sensors per module, 55 μm $\times$ 55 μm
- Front-end readout: 3 chips bump-bonded to each sensor
- Sensor and readout electronics mounted on cooling substrat
  Sensor temperature maintained at -20C,
  novel technique of evaporated CO_2 cooling in substrate mucro-channels
- Minimal material within acceptance



Upstream Tracker - UT

4 layers of silicon strip detector

- Finer granularity
  innermost sensors closer to beam pipe
- Inner layers tilted by a stereo angle
- 4 different types of sensors
- Mounted to lightweight staves
  10 cm wide, 1.6m long
- Novel readout chip (SALT ASIC)



Scintillating Fibre Tracker - SciFi

3 × 4 layers of scintillating fiber mats

- Each mat with 6 layers of fibres
- 8 mats assembled into a module
- 11,000 km of fibres in total

Coverage up to 3m from the beam pipe

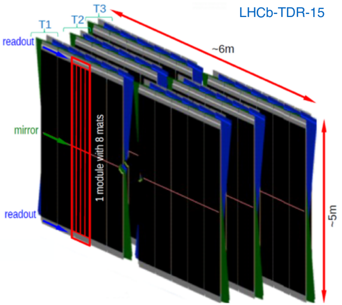
Single photon efficiency ∼ 99%

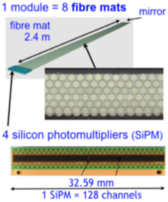
Fibre readout by silicon photo-multipliers

- 128-channels SiPM arrays, channel size 250 μm
- Cooled to -40C to minimize dark count rate after high irradiation

Photon detection efficiency ∼ 45%

SiPM signal processed by custom ASIC chip





RICH upgrade

New glass flat mirrors for RICH1

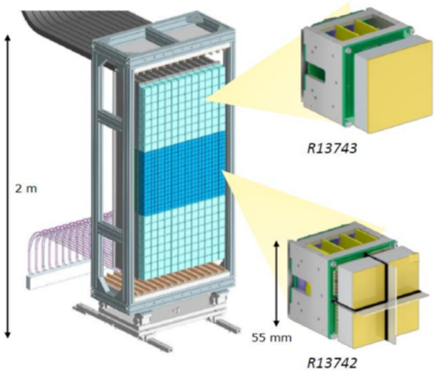
Focal plane, optics modified to increase size of Cherenkov rings

Photo-detectors to be upgraded

2 types of multi-anode photomultiplier tubes with finer granularity

New Front-End electronics at 40 MHz

Single photon angular resolution improved by 50% (RICH1) and 20% (RICH2)



Calorimeter and Muon Station upgrade

Current calorimeters will be kept for Run 3 but

- Front-End electronics rebuilt
- SPS/PS removed

PMT gain reduced by a factor of 5 to reduce degradation

To compensate, the front-end gain is increased by the same factor

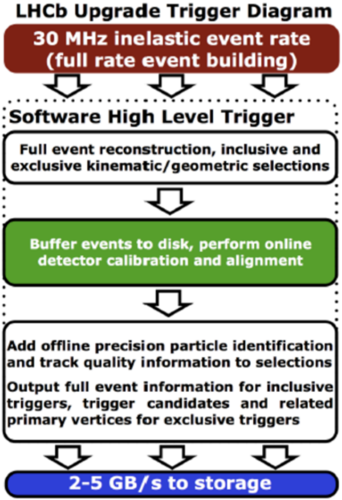
→ Custom low-noise FE ASIC developed

Reconstruction improved for high occupancy environment

Muon detector electronics upgraded during LS2

- First GEM layer to be removed
- 36 new PAD chambers to be installed in inner region

Calorimeter and Muon Station upgrade



Software-only trigger in the upgrade
Current L0 hardware trigger to be removed

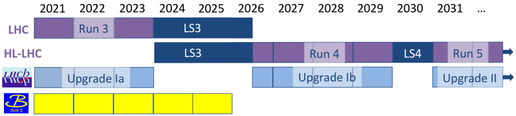
→ Must fully process events at 30 MHz

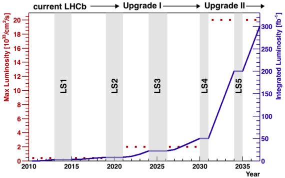
Information needed from all sub-detectors at initial trigger stage

Events stored in buffer, for online alignment, calibration

Event sized reduced to write to disk at 2−5 Gb/s

Upgrade II: overview

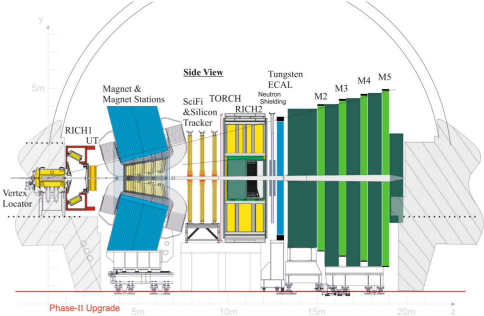




HL-LHC

- Expect factor 10 increase in luminosity, interactions per bunch crossing
- Aim at exploiting HL-LHC phase to collect > 300 fb^{-1}

$\rightarrow$ Huge challenge for detectors and TDAQ system



Upgrade II: Physics

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [609]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [610]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [611]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [612]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [613]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x\sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x\sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–