Operations
New Results
Upgrade

LHCb Status Report
Julian Wishahi on behalf of the LHCb collaboration
127th LHCC Meeting, 21st of September 2016, CERN
Operations

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Data taking status

- amazing LHC performance
  - 80% peak efficiency
  - >50% in stable beams

- great LHCb performance
  - all sub-detectors in good shape
  - data accumulation with ≈90% efficiency
  - collected ≈1.3 fb\(^{-1}\) in 2016
  - more \(bb\)-pairs than in 2012 dataset

- working hard to exploit LHC's record-crunching!
  - originally assumed ≈30% efficiency

thanks to the accelerator teams!
Data taking in Run II – Reminder

- trigger w. split HLT and automatic alignment
  - buffer data after HLT1
  - perform alignment
  - HLT2 processes data continuously and asynchronously
- HLT1 and HLT2 run on the same farm
- strategy is working very well
Data taking in Run II – Buffers

- trigger w. split HLT and automatic alignment
  - buffer data after HLT1
  - perform alignment
  - HLT2 processes data continuously and asynchronously
- HLT1 and HLT2 run on the same farm
- strategy is working very well

Software High Level Trigger

40 MHz bunch crossing rate

L0 Hardware Trigger: 1 MHz readout, high $E_T/P_T$ signatures

450 kHz $h^z$
400 kHz $\mu^+\mu^-$
150 kHz $e/\gamma$

Software High Level Trigger

Partial event reconstruction, select displaced tracks/vertices and dimuons

Buffer events to disk, perform online detector calibration and alignment

Full offline-like event selection, mixture of inclusive and exclusive triggers

12 kHz (700 MB/s) to storage

8 kHz (530 MB/s)
4 kHz (170 MB/s)

Full reconstruction
Turbo/Turbo++
LHC efficiency and LHCb HLT

- defined various scenarios depending on LHCb efficiency and luminosity increase
- monitor status of buffer disks and speed-up the HLT
- small set of trigger configurations for different LHC setups
  - ≈3%/day of disk occupancy decrease when HLT2 running at max
  - increase originally ≈5%/day, can be adjusted by tightening/loosening trigger requirements
Distributed Data Processing in 2016

- increased LHC efficiency also affects CPU/disk and tape needs
  - required adaptation of data processing workflows
  - all offline data processing workflows now operational and backlogs processed
- additional strain due to changes in “Turbo”
  - now also contains reconstruction information
  - reduced offline CPU needs
  - increased disk requirements
- additional disk needs mitigated by
  - reduction of disk replicas
  - data popularity to remove unused datasets
  - parking of 1/3 of the Turbo data on tape
- using resources well above pledges
Preparations for the 2016 pPb run

- LHCb will take part to the pPb run at the end of the year
  - it will represent a big step forward for heavy ion physics at LHCb
  - work ongoing to optimise trigger and event reconstruction
  - we aim to get an integrated luminosity of 20 nb$^{-1}$ at $\sqrt{s_{NN}} = 8$ TeV
  - $pPb$ and $Pbp$ configurations split 50/50

- main physics targets
  - $J/\psi$, $\psi(2S)$, $\Upsilon(nS)$, and Drell-Yan production
    - study cold nuclear matter effects
  - $Z$, $J/\psi$, $\Upsilon$ production to improve nuclear PDFs
  - associated heavy flavour production to study contributions from single and double parton scattering

- details in LHCb-PUB-2016-011
New results
Publication status

- 334 papers submitted
  - +20 papers w.r.t. last LHCC
  - 7 PRL, 5 JHEP, 4 PLB, 2 PRD,
    1 EPJC, 1 Nature Physics
- 15 papers in preparation
- 47 analyses under review
Publications since last LHCC

- Probing matter-antimatter asymmetries in beauty baryon decays
- Search for Higgs-like bosons decaying into long-lived exotic particles
- First experimental study of the photon polarization in radiative $B_s$ decays
- Differential branching fraction and angular moments analysis of the decay $B^0 \rightarrow K^\pm \pi^- \mu^+ \mu^-$ in the $K_{0,2}^*(1430)^0$ region
- Measurement of $CP$ violation in $B^0 \rightarrow D^+ D^-$ decays
- Measurement of the $CP$-violating phase and decay-width difference in $B_s \rightarrow \psi(2S)\phi$ decays
- Measurement of forward $W \rightarrow ev$ production in $pp$ collisions at $\sqrt{s}=8$ TeV
- Search for the suppressed decays $B^+ \rightarrow K^+ K^\pm \pi^-$ and $B^+ \rightarrow \pi^+ \pi^+ K^-$
- Amplitude analysis of $B^\rightarrow D^+ \pi^- \pi^-$ decays
- Search for structure in the $B_s \pi^+$ invariant mass spectrum
Publications since last LHCC (cont.)

- Measurement of the ratio of branching fractions $\text{Br}(B_c \to J/\psi K^+)/\text{Br}(B_c \to J/\psi\pi^+)$
- Measurement of the forward $Z$ boson production cross-section in $pp$ collisions at $\sqrt{s}=13$ TeV
- Observation of $\eta_c(2S) \to pp$ and search for $X(3872) \to pp$ decays
- Measurement of the $B_s \to J/\psi\eta$ lifetime
- Study of $B_c$ decays to the $K^+K^-\pi^+$ final state and evidence for the decay $B_c \to \chi_c^0 \pi^+$
- Amplitude analysis of $B^+ \to J/\psi\phi K^+$ decays
- Observation of $J/\psi\phi$ structures consistent with exotic states from amplitude analysis of $B^+ \to J/\psi\phi K^+$ decays
- Evidence for exotic hadron contributions to $\Lambda_b \to J/\psi p\pi^-$ decays
- Measurements of the S-wave fraction in $B^0 \to K^+\pi^-\mu^+\mu^-$ decays and the $B^0 \to K^*(892)^0\mu^+\mu^-$ differential branching fraction
- Measurement of the $CP$ asymmetry in $B_s$ mixing


$b$-quark production cross-section @13 TeV

- strategy: measure inclusive $b \rightarrow X_c \mu \nu X$ decays
  - right-sign $\mu X_c$ combinations, $X_c = \{D^0, D^+, D_s, \Lambda_c\}$
    - form a good secondary vertex (SV)
    - do not point back to the primary vertex (PV)
  - 2D fit to $m$ and $\ln(\text{IP})$ distribution to identify non-prompt $X_c$
$b$-quark production cross-section

- **cross-section in LHCb acceptance**
  - $\sigma_{bb} = (164.9 \pm 2.3 \pm 14.6) \, \mu b$
  - theory prediction $111^{+51}_{-44} \, \mu b$
  - from FONLL [arXiv:1507.06197]

- **measured ratio**
  - $\sigma_{bb}(13 \, \text{TeV}) / \sigma_{bb}(7 \, \text{TeV}) = 2.30 \pm 0.25 \pm 0.19$
  - theory FONLL predicts $1.70^{+0.21}_{-0.15}$
  - tensions at low $\eta$
central exclusive production
  • diffractive process, protons remain intact
  • interaction mediated by pomerons

cross-section measurements useful for
  • testing QCD
  • description of pomerons
  • probing the gluon PDF, down to x = 2 x 10^{-6}

first result with the inclusion of HeRSChel!

\[
\sigma_{J/\psi \rightarrow \mu^+ \mu^-}(2.0 < \eta_{\mu^+}, \eta_{\mu^-} < 4.5) = 407 \pm 8 \pm 24 \pm 16 \text{ pb} \\
\sigma_{\psi(2S) \rightarrow \mu^+ \mu^-}(2.0 < \eta_{\mu^+}, \eta_{\mu^-} < 4.5) = 9.4 \pm 0.9 \pm 0.6 \pm 0.4 \text{ pb}
\]
Forward $Z$ boson production at $\sqrt{s}=13$ TeV

- measure $\sigma(Z \rightarrow l^+l^-)$ with $l^\pm = e^\pm, \mu^\pm$
- probe lower Bjorken-$x$ than in Run I
- good agreement
  - between the two final state cross-sections
  - differential cross-section distributions vs. theory

- first step towards further Run II studies
  - great potential for LHCb's electroweak programme
Photon polarisation in $B_s \rightarrow \phi \gamma$

- decay-time dependent decay rate
  \[ \Gamma_{B^0_s \rightarrow \phi \gamma} (t) \propto e^{-\Gamma_s t} \left[ \cosh (\Delta \Gamma_s t / 2) - \mathcal{A}^\Delta \sinh (\Delta \Gamma_s t / 2) \right] \]
  - photon polarisation parameter
  \[ \mathcal{A}^\Delta \approx \sin 2\psi \cos \varphi_s \]
  mixing phase
  \[ \tan \psi \equiv \frac{|A(B^0_s \rightarrow \phi \gamma R)|}{|A(B^0_s \rightarrow \phi \gamma L)|} \]
  - angular observables in $B^0 \rightarrow K^*0 e^+ e^-$ also sensitive
  - well measurable due to large decay width difference
  \[ \Delta \Gamma_s = 0.083 \pm 0.006 \text{ ps}^{-1} \]
- use $B^0 \rightarrow K^{*0} \gamma$ as control channel
  - here $\Delta \Gamma_d \approx 0$, thus can determine decay-time related effects
Photon polarisation in $B_s \rightarrow \phi \gamma$

- experimental challenges
  - $P(t) = [\text{Physics } \times \text{ Acceptance}] \otimes \text{Resolution}$
    - resolution from simulations
    - control acceptance by using $B^0 \rightarrow K^{*0} \gamma$
  - comb. & partially reconstructed backgrounds
  - peaking backgrounds

![Graphs and diagrams showing photon polarisation in $B_s \rightarrow \phi \gamma$](image-url)
Photon polarisation in $B_s \to \phi \gamma$

- experimental challenges:
  - $\mathcal{P}(t) = [\Phi(t)/\Phi(0)]_0^t$ for $t < t_0$
  - resolution
  - control acceptance
  - comb. & param. uncertainties
  - peaking backgrounds

result: $A^\Delta = -0.98^{+0.46+0.23}_{-0.52-0.20}$

- first measurement of polarisation in $B_s$ mesons
- consistent with SM expectation within $2\sigma$
- statistically limited
Flavour tagged analyses

- decay-time dependent $CP$ analyses
  - require the knowledge of the initial $B$ production flavour
  - flavour tagging algorithms exploit event information
- recent analyses
  - “Measurement of the $CP$-violating phase and decay-width difference in $B_s \rightarrow \psi(2S)\phi$ decays”
    - tagging power of 3.9%
  - “Measurement of $CP$ violation in $B^0 \rightarrow D^+D^-$ decays”
    - precision on CPV significantly improved w.r.t. $B$ factories
    - exploiting new tagging algorithms
    - tagging power of 8.1%!
CP violation in $b$-baryons

- strategy: use $\Lambda_b \rightarrow p\pi^-\pi^+\pi^-$ decays
  - search for $CP$-violating asymmetries in triple-products of final-state momenta
  - study local CPV as a function of the angle $\Phi$ between the $p\pi^-$ and $\pi^+\pi^-$ decay planes

- evidence for $CP$ violation at $3.3\sigma$
- first evidence for $CP$ violation in baryons!
Search for indirect $CP$ violation in $D^0$ mixing

- decay-time dependent asymmetry in $K^+K^-$ and $\pi^+\pi^-$ final states

$$A_{CP}(t) = \frac{\Gamma(D^0(t) \rightarrow f) - \Gamma(D^0(t) \rightarrow f)}{\Gamma(D^0(t) \rightarrow f) + \Gamma(D^0(t) \rightarrow f)} \approx a_{CP}^{dir} + \frac{t}{\tau_D} a_{CP}^{ind}$$

$$A_{\Gamma} = -a_{CP}^{ind}$$

$A_{\Gamma} = \frac{\hat{\Gamma}(D^0 \rightarrow f) - \hat{\Gamma}(D^0 \rightarrow f)}{\hat{\Gamma}(D^0 \rightarrow f) + \hat{\Gamma}(D^0 \rightarrow f)}$

- analyses
  - use initial $D^{*\pm} \rightarrow D^0\pi^\pm$ for tagging the production flavour
  - challenge: avoid experimental biases
    - detector and reconstruction asymmetries
    - non-uniform decay-time acceptance
Search for indirect CPV in $D^0$ mixing

- two independent analyses
  - binned fit [LHCb-CONF-2016-009]
    - perform the analysis in bins of decay time
    - reduces effects from acceptance
    \[ A_F = (-0.12 \pm 0.30) \times 10^{-3} \]
  - unbinned fit [LHCb-CONF-2016-010]
    - evaluate per-event decay-time acceptance function
    \[ A_F = (-0.07 \pm 0.34) \times 10^{-3} \]

- consistent within 1σ (incl. correlations)
- world's best measurements!
Direct CP violation in $D^0$ decays

- measure asymmetry of decay rate

\[
A_{\text{raw}}(D^0 \to f) = \frac{N(D^0 \to f) - N(\bar{D}^0 \to \bar{f})}{N(D^0 \to f) + N(\bar{D}^0 \to \bar{f})}
\]

- expect very small CP violation in the SM
- determine experimental asymmetries from control channels

\[
A_{CP}(D^0 \to KK) = A_{\text{raw}}(D^0 \to KK) - A_{P}(D^{++}) - A_{D}(\pi^+) \]

- combined results w. previous analyses

\[
A_{CP}^{\text{comb}}(KK) = (0.04 \pm 0.12 \pm 0.10) \%
\]

\[
A_{CP}^{\text{comb}}(\pi\pi) = (0.07 \pm 0.14 \pm 0.11) \%
\]

Run I

Julian Wishahi for LHCb | LHCb Status Report | 127th LHCC Meeting | September 2016 | CERN
Observation of four exotic-like particles

- $X \rightarrow J/\psi \phi$ decays in $B^\pm \rightarrow J/\psi \phi K^\pm$ decays
- “history”
  - CDF observed a narrow structure, $X(4140)$, and hint for another structure, $X(4274)$
  - exotic: narrow and above $D_s D_s$ threshold
  - also seen by D0 and CMS
- new, unique analysis by LHCb
  - first full amplitude analysis (6D likelihood fit)
  - measurement of quantum numbers
  - $X(4140)$ and $X(4274)$ seen (both $J^{PC}=1^{++}$)
    - $X(4140)$ described as $D_s^* D_s^{*-}$ cusp is preferred by fit
  - 2 additional structures, $X(4500)$ and $X(4700)$ (both $J^{PC}=0^{++}$)

- Measurement of quantum numbers
- Observation of new, narrow structures
- Comparison with other experiments
- Unique analysis by LHCb
- First full amplitude analysis

X(4140) @8.4σ  X(4274) @6.0σ
X(4500) @6.1σ  X(4700) @5.6σ
Search for $K_S \rightarrow \mu^+\mu^-$ decays

- $K_S \rightarrow \mu^+\mu^-$ has not been observed
  - in SM: FCNC transition with additional suppression due to small CPV
    - SM prediction: $BR(K_S \rightarrow \mu^+\mu^-) = (5.0 \pm 1.5) \times 10^{-15}$
    - experimental upper limit $< 11 \times 10^{-9}$ @95% CL

- analysis using 2 fb$^{-1}$ of Run I
  - normalisation channel $K_S \rightarrow \pi^+\pi^-$
  - fit the kaon mass in bins of trigger selection and MVA output

- preliminary upper limit
  \[ BR(K_S \rightarrow \mu^+\mu^-) < 6.9 \times 10^{-9} \ @95\% \ CL \]
Publication status

- 334 papers submitted
  - +20 papers w.r.t. last LHCC
  - 7 PRL, 5 JHEP, 1 EPJC, 1 Nature Physics
- 15 papers in preparation
- 47 analyses under review
- many more results in preparation, including high precision flavour physics results with Run II
LHCb Upgrade in LS2 – Overview

**40 MHz readout software trigger**

**VELO**
- new pixel detector

**Upstream Tracker**
- silicon strips

**RICH**
- new PMTs, readout electronics, optics

**SciFi Tracker**
- scintillating fibres

**Muon chambers**
- more shielding, upgraded readout electronics

**Calorimeters**
- reduced PMT gain, new electronics
LHCb Upgrade in LS2 – Status

- In general a good progress on all subsystems
  - Many engineering design and production readiness reviews successfully completed during the summer
  - Small delays for some of the milestones

- Many detectors entering (pre-)production phase
  - Several crucial front-end ASICS successfully submitted and under test
    - VELOPIX for VELO, SALT-128 for Upstream Tracker, CLARO for RICH
  - Large component production started
    - Delivery of MA-PMTs for RICH started
    - SciFi Tracker fibre delivery on schedule, fibre mat production started

- Preparation of LS2 work and worksite organisation is ongoing, profit from EYETS
Conclusion

Peter Jakobs, “Espresso”, CC BY-NC-ND 2.0
Summary & Conclusion

LHCb's physics program

- lots of new, diverse results over the summer
- many long-expected results presented, and many more to come!

LHCb operation = LHC's superb efficiency + LHCb's flexibility

- optimal and dynamic use of resources to maximise the physics output
- effects on computing are under control in 2016
- already overtook 2012 data taking in terms of $bb$-pairs recorded
- we are preparing for the $pPb$ runs

LHCb upgrade is progressing well

- huge progress over the past few months
- working hard to keep up with our milestones