LHCb Status Report

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INFN Cagliari and CERN

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Outline

- Operations: 2017 data taking
- Physics: highlights from the summer conferences
- Upgrade: status and plans
- Conclusions
Status of 2017 data taking

Excellent start of 2017 data taking

LHCb Integrated Luminosity in p-p in 2017

LHCb Efficiency breakdown in 2017

Delivered Lumi: 951.26 /pb
Recorded Lumi: 861.41 /pb

Thanks a lot to the LHC!
Run 2 strategy

- L0 bandwidth optimized for the wide physics programme: retuned for 2017 and updated according to the latest LHC forecasts
- Buffer data on disk after HLT1
- Real-time alignment and calibration evaluation
- Data processed by HLT2 asynchronously

Disk buffer ~ 10 PB

- Two HLT1 configurations have been prepared: loose and tight. Started with loose configuration
- Simulations are made to estimate the disk buffer occupancy up to end of the year
- With current LHC performance, unlikely to exhaust the buffer this year: keep loose configuration
Operations

Trigger

Turbo stream

- Novel approach in Run 2 that exploits the LHCb real-time alignment capabilities
- Crucial for analyses with large statistics
- Great disk space saving
- Fast data availability for physics analyses

New intermediate solution for Turbo in 2017: Turbo SP (Selective Persistence) that allows to save candidates and a subset of the reconstruction
- Allows particles nearby the PV to be chosen for further analysis
- Utility to help select interesting particles
Alignment and calibration

- Real-time alignment per fill
  - Alignment of the full tracking system: VELO, TT, T stations
  - Alignment of PID detector: RICH mirrors and Muon chambers
- Real-time calibration per run or per fill
  - RICH calibration
  - OT time calibration
  - Calorimeter calibration
- Full automatization of Rich mirror alignment and improved Calo calibration
Offline computing

Maximum use of computing resources to process all type of data

- New stripping of Run 2 data, including Pb-Pb data
- processing of 2017 data
- MC productions
- Development of different fast simulation options to save resources
  - Re-decay signal N times, re-using same underlying event
  - Fully simulate only part of the detector, e.g. tracker only
Excellent performance of the tracking and PID detectors
20 new papers submitted since last LHCC week

In summary
- 396 papers in total
- 40 papers in 2017
- Other 10 papers to be submitted shortly
2016-065: Updated search for long-lived particles decaying to jet pairs; arXiv:1705.07332; EPJC
2017-007: Study of charmonium production in $b$-hadron decays and first evidence for the decay $B_0^0 \rightarrow \phi \phi$; arXiv:1706.07013; EPJC
2017-009: Improved limit on the branching fraction of the rare decay $K_S^0 \rightarrow \mu^+ \mu^-$; arXiv:1706.00758; EPJC
2017-010: Updated branching fraction measurements of $B_{d,s}^0 \rightarrow K_S^0 h^+ h'$ decays; arXiv:1707.01665; JHEP
2017-013: Test of lepton universality with $B^0 \rightarrow K^{*0} \ell^+ \ell^-$ decays; arXiv:1706.07013; JHEP
2017-014: Prompt and nonprompt $J/\psi$ production and nuclear modification in $p$Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV; arXiv:1706.07122; PLB
2017-015: Study of prompt $D_0^-$ meson production in $p$Pb collisions at $\sqrt{s_{NN}} = 5$ TeV; arXiv:1707.02750; JHEP
2017-016: Measurement of the shape of the $\Lambda_0^b \rightarrow \Lambda_c^+ \mu^- \bar{\nu}_\mu$ differential decay rate; arXiv:1709.01920; PRD
2017-017: Measurement of the ratio of the $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$ and $B^0 \rightarrow D^{*-} \mu^+ \nu_\mu$ branching fractions using three-prong $\tau$-lepton decays; arXiv:1708.08856; PRL
2017-018: Observation of the doubly charmed baryon $\Xi^{++}_{cc}$; arXiv:1707.01621; PRL
2017-019: Observation of $B^0$ meson decays to $\pi^+ \pi^- \mu^+ \mu^-$ and $K^+ K^- \mu^+ \mu^-$ final states; arXiv:1707.08377; PRL
2017-020: Study of $b\bar{b}$ correlations in high energy proton-proton collisions; arXiv:1708.05994; JHEP
2017-021: Measurement of $CP$ observables in $B^\pm \rightarrow D^{(*)0} K^{\pm}$ and $B^\pm \rightarrow D^{(*)0} \pi^{\pm}$ decays; arXiv:1708.06370; PLB
2017-022: First observation of the rare purely baryonic decay $B^0 \rightarrow p\bar{p}$; arXiv:1709.01156; PRL
2017-023: Search for baryon-number-violating $\Xi^{0}_{cc}$ oscillations; arXiv:1708.05808; PRL
2017-024: Measurement of forward $Z \rightarrow b\bar{b}$ production in $pp$ collisions at $\sqrt{s} = 8$ TeV; arXiv:1709.03458; PLB
2017-025: Bose-Einst. corr. of same-sign charged pions in the forward region in $pp$ collisions at $\sqrt{s} = 7$ TeV; arXiv:1709.01769; JHEP
2017-028: Measurement of the $T$ polarization in $pp$ collisions at $\sqrt{s} = 7$ and 8 TeV; arXiv:1709.01301; JHEP
2017-029: Measurement of $CP$ violation in $B^0 \rightarrow J/\psi(e^+ e^-)K^0_S$ and $B^0 \rightarrow \psi(2S)(\mu^+ \mu^-)K^0_S$ decays; arXiv:1709.03944; JHEP
2017-030: Precise measurement of the $\chi_{c1}$ and $\chi_{c2}$ resonance parameters with the decay $J/\psi \mu^+ \mu^-$; arXiv upcoming; PRL
2017-031: Search for the lepton flavour violating decays $B^0_S \rightarrow e^+ e^-$; PRELIMINARY
2017-032: Study of the semitauonic decay $B^+_c \rightarrow J/\psi \tau^+ \nu_\tau$; PRELIMINARY
2017-033: Search for dark photons produced in 13 TeV $pp$ collisions; PRELIMINARY
First observation of $D^0 \rightarrow h^+ h^- \mu^+ \mu^-$

- First observation of $D^0$ mesons decaying into $\pi^+ \pi^- \mu^+ \mu^-$ and $K^+ K^- \mu^+ \mu^-$
- Data set: 2 fb$^{-1}$ at 8 TeV
- Normalisation decay: $D^0 \rightarrow K^- \pi^+ [\mu^+ \mu^-] \rho^0 / \omega$
- Signal in almost every $q^2 = m^2(\mu \mu)$ bin
- Differential BF investigated
First observation of $D^0 \rightarrow h^+ h^- \mu^+ \mu^-$

- First observation of $D^0$ mesons decaying into $\pi^+ \pi^- \mu^+ \mu^-$ and $K^+ K^- \mu^+ \mu^-$
- Data set: 2 fb$^{-1}$ at 8 TeV
- Normalisation decay: $D^0 \rightarrow K^- \pi^+ [\mu^+ \mu^-] \rho^0 / \omega$
- Signal in almost every $q^2 = m^2(\mu\mu)$ bin

- Total BF (Long-Distance dominated) in agreement with SM predictions
- Expected to tighten constraints on possible short distance contributions

$B(D^0 \rightarrow \pi^- \pi^+ \mu^+ \mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$

$B(D^0 \rightarrow K^- K^+ \mu^+ \mu^-) = (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \times 10^{-7}$

Rarest charm decays measured to date
Physics highlights

Search for the decays $B^0_{(s)} \rightarrow e^\pm \mu^\mp$  NEW

- Lepton-flavour violating decays
- No excess of signal observed wrt background
- Put a limit to the BF

$\mathcal{B}(B^0_s \rightarrow e^\pm \mu^\mp) < 5.4 (6.3) \times 10^{-9}$
$\mathcal{B}(B^0 \rightarrow e^\pm \mu^\mp) < 1.0 (1.3) \times 10^{-9}$

at 90 (95)% CL

- Best upper limits to date and a factor 2-3 better than the previous results from LHCb

• Data sample: 1.0 (7 TeV) + 2.0 (8 TeV) fb$^{-1}$
Search for dark photons

- Search for $A' \rightarrow \mu^+\mu^-$ decay in 2016 data (1.5 fb$^{-1}$)
- Output of Turbo stream
- **Prompt-like search**: $\mu\mu$ threshold up to 70 GeV
- **Long-lived search**: $214 < m(A') < 350$ MeV

![Graph showing the search for dark photons](image)

- Possible coupling via kinetic mixing between the SM hypercharge and $A'$ field strength tensors
- Dark photons may be produced if kinematically allowed

- No evidence for dark photons
- Same sensitivity as BaBar
- First limits above 10 GeV
- Most stringent constraints for $10.6 < m(A') < 70$ GeV
- First exclusion limits to long-lived dark photons at a non-beam-dump experiment
Search for dark photons NEW

- Search for $A' \rightarrow \mu^+ \mu^-$ decay in 2016 data (1.5 fb$^{-1}$)
- Output of Turbo stream
- **Prompt-like search**: $\mu \mu$ threshold up to 70 GeV
- **Long-lived search**: $214 < m(A') < 350$ MeV

![Graph](image-url)

**Prospects**

- **2017**: big improvements in the software-trigger efficiency for low-mass dark photons
- **Run 3**: removal of the hardware-trigger $\rightarrow$ access to $\mathcal{O}(100 - 1000)$ times more decays than 2016

**Dark sector**

- Possible coupling via kinetic mixing between the SM hypercharge and $A'$ field strength tensors
- Dark photons may be produced if kinematically allowed
**Physics highlights**

### $J/\psi$ production in $pPb$ collisions

Data samples recorded in 2016 ($\times 10$ 2013 sample):

- $pPb$ collisions: $13.6 \text{ nb}^{-1}$
- $Pbp$ collisions: $20.8 \text{ nb}^{-1}$

Energy: $\sqrt{s_{NN}} = 8.16 \text{ TeV}$

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**First LHC result with this sample!!**
$J/\psi$ production in $pPb$ collisions

- $J/\psi$ prompt and from b-hadrons cross-section
- Production relative to $pp$ collisions, scaled by the Pb mass number

LHCb-PAPER-2017-014
**J/ψ production in pPb collisions**

- Theoretical calculations can account for the majority of observed dependences
- First beauty-hadron production measurement down to $p_T = 0$ in pPb and Pb$p$ collisions at LHC
Physics highlights

$\gamma$ from $B^\pm \rightarrow (D^{*0} \rightarrow D^0\pi^0/\gamma)K^\pm$

- $\gamma$ is the least well known angle of the unitarity triangle
- Look for the New Physics comparing tree level and loop level decays

| $A_{K\pi}^K$ | $-0.019 \pm 0.005$ (stat) $\pm 0.002$ (syst) |
| $A_{KK}^{\pi\pi}$ | $-0.008 \pm 0.003$ (stat) $\pm 0.002$ (syst) |
| $A_{KK}^{\pi\pi}$ | $+0.126 \pm 0.014$ (stat) $\pm 0.002$ (syst) |
| $A_{K\pi}^{\pi\pi}$ | $-0.008 \pm 0.006$ (stat) $\pm 0.002$ (syst) |
| $A_{K\pi}^{\pi\pi}$ | $+0.115 \pm 0.025$ (stat) $\pm 0.007$ (syst) |
| $R_{KK}$ | $0.988 \pm 0.015$ (stat) $\pm 0.011$ (syst) |
| $R_{K\pi}^{\pi\pi}$ | $0.992 \pm 0.027$ (stat) $\pm 0.015$ (syst) |
| $R_{K/\pi}$ | $(7.768 \pm 0.038$ (stat) $\pm 0.066$ (syst)) $\times 10^{-2}$ |

- Data set: Run 1 (3 fb$^{-1}$) + Run 2 (2 fb$^{-1}$)
- $B^+ \rightarrow D^{*0}K^+$ with $D^{*0} \rightarrow D^0\gamma/\pi^0$: experimentally challenging due to the low efficiency
- Partial reconstruction of $D^*$

World’s best measurement!!
\( \gamma \) from \( B^{\pm} \rightarrow (D^{*0} \rightarrow D^0\pi^0/\gamma)K^{\pm} \)

- \( \gamma \) is the least well known angle of the unitarity triangle
- Look for the New Physics comparing tree level and loop level decays
- The \( \gamma \) modes with comparable precision to the world average
- The \( \pi^0 \) modes substantially improve the world averages

- Data set: Run 1 (3 fb\(^{-1}\)) + Run 2 (2 fb\(^{-1}\))
- \( B^+ \rightarrow D^{*0}K^+ \) with \( D^{*0} \rightarrow D^0\gamma/\pi^0 \): experimentally challenging due to the low efficiency
- Partial reconstruction of \( D^* \)

\[ \begin{align*} 
A^{K\pi\gamma}_{K^{\pm}} &= +0.001 \pm 0.021 \text{ (stat)} \pm 0.007 \text{ (syst)} \\
A^{K\pi\gamma}_{\pi} &= +0.000 \pm 0.006 \text{ (stat)} \pm 0.001 \text{ (syst)} \\
A^{K\pi\gamma}_{K} &= +0.006 \pm 0.012 \text{ (stat)} \pm 0.004 \text{ (syst)} \\
A^{K\pi\gamma}_{\pi} &= +0.002 \pm 0.003 \text{ (stat)} \pm 0.001 \text{ (syst)} \\
A^{\gamma}_{K^{\pm}} &= +0.276 \pm 0.094 \text{ (stat)} \pm 0.047 \text{ (syst)} \\
A^{\gamma}_{\pi} &= -0.003 \pm 0.017 \text{ (stat)} \pm 0.002 \text{ (syst)} \\
A^{\gamma}_{K} &= -0.151 \pm 0.033 \text{ (stat)} \pm 0.011 \text{ (syst)} \\
A^{\gamma}_{\pi} &= +0.025 \pm 0.010 \text{ (stat)} \pm 0.003 \text{ (syst)} \\
R^{\gamma}_{K^{\pm}} &= 0.902 \pm 0.087 \text{ (stat)} \pm 0.112 \text{ (syst)} \\
R^{\gamma}_{\pi} &= 1.138 \pm 0.029 \text{ (stat)} \pm 0.016 \text{ (syst)} \\
R^{\gamma}_{K/\pi} &= (7.930 \pm 0.110 \text{ (stat)} \pm 0.560 \text{ (syst)}) \times 10^{-2} \\
B(D^0 \rightarrow D^0\pi^0) &= 0.636 \pm 0.002 \text{ (stat)} \pm 0.015 \text{ (syst)} \\
B(B^- \rightarrow D^{*0}\pi^-) &= (4.664 \pm 0.029 \text{ (stat)} \pm 0.268 \text{ (syst)}) \times 10^{-3} 
\end{align*} \]
Physics highlights

\[ \gamma \text{ from } B^\pm \rightarrow (D^*0 \rightarrow D^0\pi^0/\gamma) K^\pm \]

- \( \gamma \) is the least well known angle of the unitarity triangle
- Look for the New Physics comparing tree level and loop level decays

\[
\begin{align*}
A_{K}^{\pi,\gamma} &= +0.001 \pm 0.021 \text{ (stat)} \pm 0.007 \text{ (syst)} \\
A_{K}^{\pi,\gamma} &= +0.000 \pm 0.006 \text{ (stat)} \pm 0.001 \text{ (syst)} \\
A_{K}^{\pi,\rho,0} &= +0.006 \pm 0.012 \text{ (stat)} \pm 0.004 \text{ (syst)} \\
A_{K}^{\pi,\rho,0} &= +0.002 \pm 0.003 \text{ (stat)} \pm 0.001 \text{ (syst)} \\
A_{K}^{\rho,\gamma} &= +0.276 \pm 0.094 \text{ (stat)} \pm 0.047 \text{ (syst)} \\
A_{K}^{\rho,\gamma} &= -0.003 \pm 0.017 \text{ (stat)} \pm 0.002 \text{ (syst)} \\
A_{K}^{\rho,\rho} &= -0.151 \pm 0.033 \text{ (stat)} \pm 0.011 \text{ (syst)} \\
A_{K}^{\rho,\rho} &= +0.025 \pm 0.010 \text{ (stat)} \pm 0.003 \text{ (syst)} \\
R_{CP}^{\gamma} &= 0.902 \pm 0.087 \text{ (stat)} \pm 0.112 \text{ (syst)} \\
R_{CP}^{\gamma} &= 1.138 \pm 0.029 \text{ (stat)} \pm 0.016 \text{ (syst)} \\
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B(D^0 \rightarrow D^0\pi^0) &= 0.636 \pm 0.002 \text{ (stat)} \pm 0.015 \text{ (syst)} \\
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\end{align*}
\]

- Data set: Run 1 (3 fb\(^{-1}\)) + Run 2 (2 fb\(^{-1}\))
- \( B^+ \rightarrow D^*0K^+ \) with \( D^*0 \rightarrow D^0\gamma/\pi^0 \): experimentally challenging due to the low efficiency
- Partial reconstruction of \( D^* \)

- Evidence for CP violation in \( B^- \rightarrow (D\pi^0)K^- \) at 4.3 \( \sigma \)
Physics highlights

\[ \gamma \text{ from } B^{\pm} \to (D^{*0} \to D^0\pi^0/\gamma)K^{\pm} \]

- \( \gamma \) is the least well known angle of the unitarity triangle
- Look for the New Physics comparing tree level and loop level decays

- Data set: Run 1 (3 fb\(^{-1}\)) + Run 2 (2 fb\(^{-1}\))
- \( B^+ \to D^{*0}K^+ \) with \( D^{*0} \to D^0\gamma/\pi^0 \): experimentally challenging due to the low efficiency
- Partial reconstruction of \( D^* \)

LHCb \( \gamma \) combination [LHCb-CONF-2017-004]

Notably including the following updates:

- \( B^{\pm} \to D^0K^{*\pm} \) [LHCb-CONF-2016-014]
- \( B^{\pm} \to D^{*0}K^{*\pm} \) [LHCb-PAPER-2017-021]
- \( B^0_s \to D^{\mp}_s K^\pm \) [LHCb-CONF-2016-015]
- \( B^{\pm} \to D^0K^{\pm} \) [LHCb-PAPER-2017-021]

\[ \gamma = (76.8^{+5.1}_{-5.7})^\circ \]
$B^{\pm} \rightarrow DK^{*\pm}$

Data set: Run 1 (3 fb$^{-1}$) + Run 2 (2 fb$^{-1}$)

Look at 2 and 4 body $D^0$ decay modes

- CP asymmetries in the GLW modes consistent with and more precise than the previous ones
- Limited sensitivity to $\gamma$

Signal significance:
- Two-body ADS: 4.2 $\sigma$ First evidence
- Four-body ADS: 2.8 $\sigma$

\[ A_{K\pi} = -0.004 \pm 0.023 \text{ (stat)} \pm 0.008 \text{ (syst)} \]
\[ A_{K\bar{K}} = 0.06 \pm 0.07 \text{ (stat)} \pm 0.01 \text{ (syst)} \]
\[ A_{\pi\pi} = 0.15 \pm 0.13 \text{ (stat)} \pm 0.02 \text{ (syst)} \]
\[ R_{KK} = 1.22 \pm 0.09 \text{ (stat)} \pm 0.01 \text{ (syst)} \]
\[ R_{\pi\pi} = 1.08 \pm 0.14 \text{ (stat)} \pm 0.03 \text{ (syst)} \]
\[ R_{K\pi}^+ = 0.020 \pm 0.006 \text{ (stat)} \pm 0.001 \text{ (syst)} \]
\[ R_{K\bar{K}}^+ = 0.002 \pm 0.004 \text{ (stat)} \pm 0.001 \text{ (syst)} \]
\[ A_{K\pi\pi\pi} = -0.013 \pm 0.031 \text{ (stat)} \pm 0.009 \text{ (syst)} \]
\[ A_{\pi\pi\pi\pi} = 0.02 \pm 0.11 \text{ (stat)} \pm 0.01 \text{ (syst)} \]
\[ R_{\pi\pi\pi} = 1.08 \pm 0.13 \text{ (stat)} \pm 0.03 \text{ (syst)} \]
\[ R_{K\pi\pi\pi}^+ = 0.016 \pm 0.007 \text{ (stat)} \pm 0.003 \text{ (syst)} \]
\[ R_{K\bar{K}\pi\pi}^- = 0.006 \pm 0.006 \text{ (stat)} \pm 0.004 \text{ (syst)} \]
CPV in $B^0 \rightarrow [c\bar{c}]K_S^0$

- Decay-time-dependent CP violation in $B^0 \rightarrow J/\psi(e^+e^-)K_S^0$ and $B^0 \rightarrow \psi(2S)(\mu^+\mu^-)K_S^0$

$$A_{CP}(t) = \frac{S \sin(\Delta mt) - C \cos(\Delta mt)}{\cosh(\Delta \Gamma t/2) + A_{\Delta \Gamma} \sinh(\Delta \Gamma t/2)} \quad \Delta \Gamma = 0 \approx S \sin(\Delta mt) - C \cos(\Delta mt)$$

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

$C = 0.12^{+0.07}_{-0.07} \text{ (stat)} + 0.02 \text{ (syst)}$

$S = 0.83^{+0.07}_{-0.08} \text{ (stat)} + 0.01 \text{ (syst)}$

$C = -0.05^{+0.10}_{-0.10} \text{ (stat)} + 0.01 \text{ (syst)}$

$S = 0.84^{+0.10}_{-0.10} \text{ (stat)} + 0.01 \text{ (syst)}$

$S_{J/\psi K_S^0} \approx \sin 2\beta$
CPV in $B^0 \rightarrow [c\bar{c}]K^0_S$

- Decay-time-dependent CP violation in $B^0 \rightarrow J/\psi(e^+e^-)K^0_S$ and $B^0 \rightarrow \psi(2S)(\mu^+\mu^-)K^0_S$

$$A_{CP}(t) = \frac{S \sin(\Delta mt) - C \cos(\Delta mt)}{\cosh(\Delta \Gamma t/2) + A_{\Delta \Gamma} \sinh(\Delta \Gamma t/2)}$$

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

LHCb average of all charmonium modes $J/\psi(\ell\ell, \mu\mu)$, $\psi(2S)(\mu\mu)$

$$C(B^0 \rightarrow [c\bar{c}]K^0_S) = -0.017 \pm 0.029$$
$$S(B^0 \rightarrow [c\bar{c}]K^0_S) = 0.760 \pm 0.034$$

- $\sin 2\beta$ improved by 20%
- Expected to improve the precision of the world average
- Consistent with CKM prediction of $\sin 2\beta = 0.740^{+0.020}_{-0.025}$
Lepton Flavor Universality: \( R(D^*) \)

- In SM amplitudes for processes involving \( e, \mu, \tau \) must be identical up to effects depending on lepton mass
- Comparison between semitauonic and semimuonic decays sensitive to NP

\[
R(D^*) = \frac{\mathcal{B}(B^0 \rightarrow D^* \rightarrow \tau^+ + \nu)}{\mathcal{B}(B^0 \rightarrow D^* \rightarrow \mu^+ + \nu)}
\]

- In LHCb \( R(D^*) \) with hadronic 3-prong \( \tau \) decays:

\[
R(D^*) = K(D^*) \times \frac{\mathcal{B}(B^0 \rightarrow D^* \rightarrow 3\pi)}{\mathcal{B}(B^0 \rightarrow D^* \rightarrow \mu^+ + \nu)}
\]

\[
K(D^*) = \frac{\mathcal{B}(B^0 \rightarrow D^* \rightarrow \tau^+ + \nu)}{\mathcal{B}(B^0 \rightarrow D^* \rightarrow 3\pi)}
\]

- Separating secondary and tertiary vertices with excellent resolution

- \( R(D^*) \) in tension with SM at 3.4 \( \sigma \)
- \( R(D) \) and \( R(D^*) \) combination in tension with SM at the level of 3.9 \( \sigma \)

- Dataset: Run 1 data
- Measurement in bins of \( q^2, t_\tau, \) BDT
Physics highlights

**Lepton Flavor Universality: \( R(D^*) \)**

- **LHCb hadronic**
  \[ R(D^*) = 0.285 \pm 0.019 \pm 0.025 \pm 0.013 \]

- **LHCb muonic**
  \[ R(D^*) = 0.336 \pm 0.027 \pm 0.030 \]

- **Preliminary LHCb average**
  \[ R(D^*) = 0.306 \pm 0.027 \]

- **New world average**
  \[ R(D^*) = 0.304 \pm 0.015 \text{ (3.4 \( \sigma \) above SM)} \]

\[ N_{D^*+\tau\nu} = 1300 \pm 85 \]
\[ K(D^*) = (1.93 \pm 0.13 \pm 0.17) \]

\[ \mathcal{B}(B^0 \rightarrow D^{*-}+\tau^+\nu_\tau) = (1.39 \pm 0.09 \pm 0.12 \pm 0.06)\% \]
Lepton Flavor Universality: $R(D^*)$

\[ N_{D^*\tau\nu} = 1300 \pm 85 \]
\[ K(D^*) = (1.93 \pm 0.13 \pm 0.17) \%

- **LHCb hadronic**
  \[ R(D^*) = 0.285 \pm 0.019 \pm 0.025 \pm 0.013 \%

- **LHCb muonic**
  \[ R(D^*) = 0.336 \pm 0.027 \pm 0.030 \%

- **Preliminary LHCb average**
  \[ R(D^*) = 0.306 \pm 0.027 \%

- **New world average**
  \[ R(D^*) = 0.304 \pm 0.015 \text{ (3.4 \sigma above SM)} \%

\[ \mathcal{B}(B^0 \rightarrow D^{*+}\tau^+\nu_\tau) = (1.39 \pm 0.09 \pm 0.12 \pm 0.06)\% \]

\[ R(D) \text{ and } R(D^*) \text{ combination at 4.1 \sigma from SM} \]
Lepton Flavor Universality: $R(J/\psi)$  

- Generalization of $R(D^*)$ to the $B_c$ sector

$$R(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi \mu^+ \nu_\mu)}$$

- $B_c$ decay form factors unconstrained experimentally: theoretical prediction not yet precise $0.25-0.28$

- Reconstruct signal with $\tau \to \mu \nu_\mu \nu_\tau$ (17%)

- Dataset: Run 1 (3 fb$^{-1}$)

$$R(J/\psi) = 0.71 \pm 0.17 \pm 0.18$$  
(about 2 $\sigma$ from SM)

Excellent future prospects:

- Run I + Run II data with extra MC allow finer binning in missing mass
- Form factors systematics reduced by LQCD work + dedicated form factor study
- Only LHCb can perform this measurement
Observation of $\Xi_{cc}^{++}$

- Doubly charmed baryons predicted by quark model
- Observation of $\Xi_{cc}^{+}$ claimed by SELEX [Phys. Lett. B 628 (2005) 18-24]
- No evidence observed by BaBar, FOCUS, Belle and LHCb
- Search in LHCb for $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^-$
- Data sample: 2.0 (8 TeV) + 2.0 (13 TeV) fb$^{-1}$

![Graph showing data and signal distributions for LHCb 8 TeV and 13 TeV]

- Highly significant peak: $7.6\sigma$ (2012), $12.9\sigma$ (2016)
- Combined yield: 426 $\pm$ 39
- The mass is measured with the 2016 sample

$$m(\Xi_{cc}^{++}) = 3621 \pm 0.72 \text{ (stat)} \pm 0.31 \text{ (syst)} \text{ MeV}/c^2$$
Observation of $\Xi_{cc}^{++}$

- Doubly charmed baryons predicted by quark model
- Observation of $\Xi_{cc}^{++}$ claimed by SELEX [Phys. Lett. B 628 (2005) 18-24]
- No evidence observed by BaBar, FOCUS, Belle and LHCb
- Search in LHCb for $\Xi_{cc}^{++} \rightarrow \Lambda_{c}^{+} K^{-} \pi^{+} \pi^{-}$

- Significant displacement consistent with a weak decay
- Inconsistent with SELEX measurement

Next steps

- Study of the production mechanisms
- Precise lifetime measurement
- Branching fraction and production rate measurements
- Searches in additional decay modes
- Search for other states, i.e. $\Xi_{cc}^{+}$, double-heavy beauty barions

Lattice QCD calculations

$m(\Xi_{cc}^{++}) = 3606 \pm 11 \pm 8$ MeV / $c^2$

[arXiv: 1704.02647]
Studies of $\chi_c$ Dalitz decays

- Observation of $\chi_{c1,2} \rightarrow J/\psi \mu^+ \mu^-$
- Relevant breakthrough in the $\chi_c$ spectroscopy

Data set: Run 1 (3 fb$^{-1}$) + Run 2 (2 fb$^{-1}$)
- Event topology with four muons in the final state provides a clean signature

$4755$ and $3969$ candidates

Background subtracted dimuon mass distributions agree well with the theoretical expectation of photon-mediated amplitudes

$m(\chi_{c1}) = 3510.71 \pm 0.04 \text{ (stat)} \pm 0.09 \text{ (syst)} \text{ MeV}/c^2$

$m(\chi_{c2}) = 3556.10 \pm 0.06 \text{ (stat)} \pm 0.11 \text{ (syst)} \text{ MeV}/c^2$

$m(\chi_{c1}) - m(\chi_{c2}) = 45.39 \pm 0.07 \text{ (stat)} \pm 0.03 \text{ (syst)} \text{ MeV}/c^2$

$\Gamma(\chi_{c2}) = 2.10 \pm 0.20 \text{ (stat)} \pm 0.02 \text{ (syst)} \text{ MeV}$

Results consistent with and have similar precision to current world averages
LHCb Upgrade

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- **40 MHz readout software trigger**
- **VELO** new pixel detector
- **Upstream Tracker** silicon strips
- **SciFi Tracker** scintillating fibres
- **RICH** new PMTs, readout electronics, optics
- **Muon chambers** more shielding, upgraded readout electronics
- **Calorimeters** reduced PMT gain, new electronics
Upgrade status

- Upgrade construction phase ongoing
  - Key front-end ASICs (VeloPix v2 and UT SALT) submitted and expected by end of September
  - SciFi front-end final ASIC (PACIFIC5) received and successfully tested
  - First VELO microchannel soldered
  - The MiniDAQ2 production is completed

- Test-beam at the SPS North area for:
  - **UT**: first test of full size 10x10 cm$^2$ sensor
  - Final test of n-type sensor before submitting production order
  - **RICH**: first Ring from a complete Photon Detector Module, Mini-DAQ1 and Online Presenter in a Test Beam

- First 20 modules of SciFi arrived in August at the Pit
Conclusions

- LHCb operation
  - Excellent performance during the 2017 data taking
  - Detector fully commissioned and operational
  - Optimal and dynamic use of resources to maximise the physics output
- LHCb physics program
  - 20 papers submitted since the last LHCC report
  - Many new and important results over the summer, some of them shown here for the first time
- LHCb upgrade is progressing well
  - Huge progress over the past few months
  - First pieces of the new detector arrived at Pit
Backup