LHCb status report

Ricardo Vazquez Gomez (CERN) on behalf of the LHCb collaboration

LHCC open session
28/11/2018
CERN
Operations in 2018

- 2018 has been an exceptional year.
- Record in delivered and recorded luminosity.
- Thanks to the LHC for the fantastic performance.

Since the start of LHCb
>10 fb⁻¹ delivered, >9 fb⁻¹ collected
Matches the aim of the Technical Proposal (1998)
Operations in 2018

- 2018 has been an exceptional year.
- Record in delivered and recorded luminosity.
- Thanks to the LHC for the fantastic performance.

- Heavy ion run still ongoing. Take data in PbPb and PbNe configuration simultaneously thanks to the SMOG system.

\[ \sqrt{s_{NN}} = 8.2 \text{ TeV} \]
\[ \sqrt{s_{NN}} = 110 \text{ GeV} \]
\[ \sqrt{s_{NN}} = 5.0 \text{ TeV} \]
\[ \sqrt{s_{NN}} = 69 \text{ GeV} \]

J/ψ→μμ candidates from PbPb and PbNe after HLT1 (only a fraction of data)
Operations in 2018

- Very stable running conditions through the year.
- Extensive palette of faster simulation options.
  - Current MC productions are heavily using them.
- Gain a factor 6 in number of produced events when used.

\textbf{arXiv:1810.10362}
Physics analysis

- 454 papers in total
  - 38 published in 2018
- Additional 34 analyses in review
Physics papers and conference reports since last LHCC

**Published**

PAPER-2018-023  First measurement of charm production fixed-target configuration at the LHC.
PAPER-2018-032  Observation of two resonances in the $\Lambda_{b}\pi^{\pm}$ systems and precise measurement of $\Sigma_{b}^{\pm}$ and $\Sigma_{b}^{*\pm}$ properties.
PAPER-2018-033  Measurement of the branching fractions of the decays $D^{+}\rightarrow K^{-}K^{+}K^{+}$, $D^{+}\rightarrow \pi^{-}\pi^{+}K^{+}$ and $D_{s}^{+}\rightarrow \pi^{-}K^{+}K^{+}$.
PAPER-2018-034  Evidence for an $\eta_{c}(1S)\pi^{-}$ resonance in $B^{0}\rightarrow \eta_{c}(1S)K^{+}\pi^{-}$ decays.
PAPER-2018-035  Study of $\Upsilon(nS)$ production in pPb collisions at $\sqrt{s_{NN}}=8.16$ TeV.
PAPER-2018-038  Measurement of the charm-mixing parameter $y_{CP}$.
PAPER-2018-041  Search for CP violation through an amplitude analysis of $D^{0}\rightarrow K^{+}K^{-}\pi^{+}\pi^{-}$ decays.

**Preliminary**

PAPER-2018-036  Measurement of the branching fraction and CP asymmetry in $B^{+}\rightarrow J/\psi \rho^{+}$ decays.
PAPER-2018-037  Search for the rare decay $B^{+}\rightarrow \mu^{+}\mu^{-}\mu^{+}\nu_{\mu}$.
PAPER-2018-039  Dalitz plot analysis of the $D^{+}\rightarrow K^{-}K^{+}K^{+}$ decay.
PAPER-2018-042  Study of the $B^{0}\rightarrow \rho(770)^{0}K^{*}(892)^{0}$ mode and amplitude analysis of $B^{0}\rightarrow (\pi\pi)(K\pi)$ decays.
PAPER-2018-043  Model-independent evidence for exotic contributions to $B^{0}\rightarrow J/\psi K^{+}\pi^{-}$ decays.
Charm production in fixed-target mode

- First measurement of heavy flavour production in fix target mode at the LHC.
- Measurement of the production of J/ψ and D⁰ mesons at √s_{NN}=86.6 GeV and √s_{NN}=110.4 GeV in pHe and pAr collisions.
  - Reconstructed as J/ψ→μ⁺μ⁻ and D⁰→K⁺π⁻
- Theory predictions underestimate measured cross-sections.
  - In the plot, predictions are rescaled by 1.78 (1.44) for J/ψ(D⁰) to check the shape.
- At large Bjorken-x (up to 0.37 for D⁰) intrinsic charm contribution can be large.
- No deviations with respect to theoretical predictions (that do not include charm contribution) are observed.

σ_{J/ψ} = 1225.6±100.7 nb/nucleon
σ_{D⁰} = 156.0±13.1 μb/nucleon
Y(nS) production in pPb collisions

- Measure suppression of Y(nS) due to cold nuclear matter effects in pPb collisions at $\sqrt{s}=8.16$ TeV. Use nuclear modification factor. Should be unity in absence of modifications.

$$R_{pPb}(p_T, y^*) = \frac{1}{208} \frac{d^2\sigma_{pPb}(p_T, y^*)/dp_Tdy^*}{d^2\sigma_{pp}(p_T, y^*)/dp_Tdy^*}$$

- Suppression can be due to collision with comoving particles (comovers) with similar rapidities.

  **For Y(1S):**
  $R_{pPb}$ is consistent with unity in the PbP region. Suppression in the pPb region.

  **For Y(2S):**
  Same behaviour as for Y(1S) with smaller values of $R_{pPb}$.

Measure the double ratio of excited to ground state in pPb vs pp. Stronger suppression for higher n compared with ground state.

Well described by the comovers models.
Measurement of charm-mixing

- Mixing in $D^0$ mesons works as for other neutral mesons, but it's tiny. ($x = \Delta m/\Gamma$, $y = \Delta \Gamma/2\Gamma$).

- Effective $D^0$ lifetime to CP-even eigenstates ($\Gamma_{CP^+}$ from $D^0 \rightarrow \pi^+\pi^-$, $D^0 \rightarrow K^+K^-$) is different from lifetime to CP-mixed states ($\Gamma$ from $D^0 \rightarrow K^+\pi^-$).

- If no CP is present the mixing parameter $y = \frac{\Delta \Gamma}{2\Gamma}$ is equal to $y_{CP} \equiv \frac{\Gamma_{CP^+} - \Gamma}{\Gamma}$.

- Measurement using time-dependent ratio between CP-even ($D^0 \rightarrow \pi^+\pi^-(K^+K^-)$) and CP-mixed ($D^0 \rightarrow K^+\pi^-$) final states.

- Use $D^0$ mesons from semileptonic B decays: $B \rightarrow D^0\mu\nu X$. Reduce selection biases.

- First publication using faster simulation options.

\[
\frac{\Gamma_{CP^+}}{2\Gamma} \equiv y_{CP} = (0.57 \pm 0.13\text{ (stat)} \pm 0.09\text{ (syst)})\
\]

consistent and as precise as world average.

Result is consistent with $y = (0.62 \pm 0.07)\%$

This shows no evidence of CP violation in charm mixing.
CP violation in $D^0 \rightarrow K^+ K^- \pi^+ \pi^-$

- Multibody decay with rich resonant structure. May provide enhanced sensitivity to CP violation due to variation of the strong phases → requires amplitude analysis.

- Use isobar formalism to describe the amplitudes. Each amplitude is built as a series of two-body decays.

- Use $D^0$ from semileptonic B decays: $D^0 \mu \nu X$. The muon charge tags the flavour of the $D^0$.

- Decay described by 5 dimensions.

  - $m(\pi^+ \pi^-)$, $m(K^+ K^-)$, $\theta_\pi$, $\theta_K$, $\phi$

26 amplitudes have been identified to contribute. Most precise description of the decay.

Fit CP asymmetries for each of the contributing amplitudes. None of them show CP violation. Large non-SM effects are ruled out.

<table>
<thead>
<tr>
<th>$J^P$</th>
<th>$KK$</th>
<th>$\pi\pi$</th>
<th>$K\pi$</th>
<th>$KK\pi$</th>
<th>$K\pi\pi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0^+$</td>
<td>$a_0(980)$</td>
<td>$f_0(980)$</td>
<td>$f_0(980)$</td>
<td>$K_0^*(1430)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$f_0(1370)$</td>
<td>$f_0(1370)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1^+$</td>
<td></td>
<td>$a_1(1260)$</td>
<td></td>
<td>$K_1(1270)$</td>
<td>$K_1(1400)$</td>
</tr>
<tr>
<td>$1^-$</td>
<td>$\phi(1020)$</td>
<td>$\rho(770)$</td>
<td>$\omega(782)$</td>
<td>$K^*(892)$</td>
<td>$K^*(1410)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\rho(1450)$</td>
<td></td>
<td>$K^*(1680)$</td>
<td>$K^*(1680)$</td>
</tr>
<tr>
<td>$2^+$</td>
<td>$f_2(1270)$</td>
<td>$a_2(1320)$</td>
<td>$f_2(1270)$</td>
<td>$K_2^*(1430)$</td>
<td>$K_2^*(1430)$</td>
</tr>
</tbody>
</table>
BR and CP asymmetries in $B^+ \rightarrow J/\psi \rho^+$

- $A_{CP}$ in this decay can be used to place constraints on penguin pollution in measurements of $\phi_s$ from $B_s \rightarrow J/\psi \phi$ assuming SU(3) flavour conservation.

- Simultaneous fit to $B^+ \rightarrow J/\psi \rho^+$ and $\rho^+ \rightarrow \pi^+\pi^0$.

- Use $B^+ \rightarrow J/\psi K^{*+}$ to assess the $\pi^0$ reconstruction efficiency from data.

\[ \mathcal{B}(B^+ \rightarrow J/\psi \rho^+) = (3.81^{+0.25}_{-0.24} \pm 0.35) \times 10^{-5} \]

\[ A^{CP}(B^+ \rightarrow J/\psi \rho^+) = -0.045^{+0.056}_{-0.057} \pm 0.008 \]

Most precise measurements and consistent with isospin symmetric channel $B^0 \rightarrow J/\psi \rho^0$
Search for \( B^+ \to \mu^+\mu^-\mu^+\nu_\mu \)

- Similar to \( B^+ \to \mu^+\nu_\mu \) but with 3 charged particles in the final state.
- Rare decay with twofold interest.
  - Helicity suppressed \( \to \) sensitive to non-SM particles.
  - Purely leptonic decay \( \to \) is sensitive to \( V_{ub} \)
- Only prediction available based on vector meson dominance
  - \( \text{BR}(B^+ \to \mu^+\mu^-\mu^+\nu_\mu) \approx 1.6 \times 10^{-7} \)
- Set limit as no events are observed.

\[ \text{BR}(B^+ \to \mu^+\mu^-\mu^+\nu_\mu) < 1.6 \times 10^{-8} @ 95\% \text{ CL} \]

Tension with predictions based on purely vector meson dominance.
Active discussion with theory community.
Expect revised calculations.
Exotic contributions in $B^0 \rightarrow J/\psi K^{+\pi^-}$

- Belle claimed a new exotic resonance $Z_c(4200)^-$ together with evidence of $Z_c(4430)^-$ in $B^0 \rightarrow J/\psi K^{+\pi^-}$ decays.

- General concern about these broad exotic states is to disentangle contributions from non-exotic components.

- Describe full angular distribution using only $K^*$ resonances. Will help in establishing the presence of any exotic structure in a model independent way.

- Structures around 4200 and 4600 MeV cannot be described by only $K^*$ resonances.
  - Significances are $>>5$ standard deviations.

- A model dependent analysis is ongoing to understand their origin.
What we have achieved with Run1 + Run2 harvest

CKM unitary triangle as of summer 2011

CKM unitary triangle as of summer 2018

Great reduction of parameter phase space in the CKM triangles.

Not everything is due to LHCb, but it’s certainly a major contributor.

\[ \gamma, \Delta m_{s/d}, \phi_s \]

- On non CKM measurements.
  - Observation of $B_s \rightarrow \mu^+\mu^-$; anomalies in EWP: $R(K)$, $R(K^*)$; anomalies in semileptonic decays: $R(D^*)$, observation of exotic states: pentaquarks; …
What to expect from Run1+Run2 harvest: new measurements

• More data will allow to inspect new decays and/or observables that did not offer sensitivity in the past. e.g: $B_s \rightarrow \mu^+\mu^-$ lifetime.

• More data helps in understanding better the detector. e.g: increased trigger efficiencies, improved analysis tools.

• With Run1 + Run2 data we can expect (some selected measurements):
  • Evidence for $B_d \rightarrow \mu^+\mu^-$
  • Precision on $\gamma$ of $\sim3$ degrees
  • If central values stay, anomalies can reach $5\sigma$
  • Precision on charm mixing few $\times 10^{-4}$
  • Precision on $\phi_s \sim30$ mrad (SM is less than 1 mrad).
Predicting the future is not always easy

- None of the anomalies were present at the time.

<table>
<thead>
<tr>
<th>Type</th>
<th>Observable</th>
<th>Current precision</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s^0$ mixing</td>
<td>$2\beta_s (B_s^0 \rightarrow J/\psi \phi)$</td>
<td>0.10 [138]</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>$2\beta_s (B_s^0 \rightarrow J/\psi f_0(980))$</td>
<td>0.17 [214]</td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td>$a_s^0$</td>
<td>$6.4 \times 10^{-3}$ [43]</td>
<td>$0.6 \times 10^{-3}$</td>
</tr>
<tr>
<td>Gluonic penguins</td>
<td>$2\beta_s (B_s^0 \rightarrow \phi \phi)$</td>
<td>–</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>$2\beta_s (B_s^0 \rightarrow K^{*0}K^{*0})$</td>
<td>–</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>$2\beta_s (B^0 \rightarrow \phi K_S^0)$</td>
<td>0.17 [43]</td>
<td>0.30</td>
</tr>
<tr>
<td>Right-handed currents</td>
<td>$\tau (B_s^0 \rightarrow \phi \gamma)/\tau_{B_s^0}$</td>
<td>–</td>
<td>0.09</td>
</tr>
<tr>
<td>Electroweak penguins</td>
<td>$S_2(B^0 \rightarrow K^{*0} \mu^+ \mu^-; 1 &lt; q^2 &lt; 6 \text{ GeV}^2/c^4)$</td>
<td>0.08 [67]</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>$S_0 , A_{FB}(B^0 \rightarrow K^{*0} \mu^+ \mu^-)$</td>
<td>25% [67]</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>$A_1(K \mu^+ \mu^-; 1 &lt; q^2 &lt; 6 \text{ GeV}^2/c^4)$</td>
<td>0.25 [76]</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>$B(B^+ \rightarrow \pi^+ \mu^+ \mu^-)/B(B^+ \rightarrow K^+ \mu^+ \mu^-)$</td>
<td>25% [85]</td>
<td>8%</td>
</tr>
<tr>
<td>Higgs penguins</td>
<td>$B(B_s^0 \rightarrow \mu^+ \mu^-)$</td>
<td>$1.5 \times 10^{-9}$ [13]</td>
<td>$0.5 \times 10^{-9}$</td>
</tr>
<tr>
<td></td>
<td>$B(B^0 \rightarrow \mu^+ \mu^-)/B(B_s^0 \rightarrow \mu^+ \mu^-)$</td>
<td>–</td>
<td>$\sim 100%$</td>
</tr>
<tr>
<td>Unitarity triangle</td>
<td>$\gamma (B \rightarrow D^{(<em>)} K^{(</em>)})$</td>
<td>$\sim 10$–$12^\circ$ [244, 258]</td>
<td>$4^\circ$</td>
</tr>
<tr>
<td></td>
<td>$\gamma (B_s^0 \rightarrow D_s K)$</td>
<td>–</td>
<td>$11^\circ$</td>
</tr>
<tr>
<td>angles</td>
<td>$\beta (B^0 \rightarrow J/\psi K_S^0)$</td>
<td>0.8° [43]</td>
<td>0.6°</td>
</tr>
<tr>
<td>Charm</td>
<td>$A_{CP}$</td>
<td>$2.3 \times 10^{-3}$ [43]</td>
<td>$0.40 \times 10^{-3}$</td>
</tr>
<tr>
<td>$CP$ violation</td>
<td>$\Delta A_{CP}$</td>
<td>$2.1 \times 10^{-3}$ [18]</td>
<td>$0.65 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Upgrade I

Goals:
• $L = 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
• 5 interactions per bunch crossing
• 50 fb$^{-1}$ at the end of Run4

Less than 10% of detector channels will be kept
100% of R/O electronics will be replaced
LS2 plans

2018/2019 Dismantling current detector
2019/2020 Installation of new detector
2020 Global commissioning
2021 Commissioning with beam and data taking
Upgrade I: Online

- First two containers for the Event Filter Farm were installed mid October.
  - Commissioning already started.
  - Share capacity with CERN-IT.
- 24 DAQ FPGA modules delivered.
- Production of long distance optical fibres and patch cords has been ordered.
- Alternative architecture for the event builder is being tested.
Upgrade I: Velo Pixel and Upstream Tracker

**Velo Pixel**
- Prototype tested in testbeam.
- 3 full electrical modules readout with complete electronic chain.
- Sensors and chips produced and tested with >90% yield.
- Project reaching end phase: module serial production is about to start.

**Upstream Tracker**
- Front end ASIC (SALT) v3 submitted in October. Improved power distribution and front-end stabilisation.
- Expect to test mid January.
- More than 50% of sensors delivered and tested.
- Test of special sensor that will surround the beam pipe done.
Upgrade I: RICH

• Chassis + services ready for production. Will be first element to enter.

• Received full ASIC production.

• First serial Elementary Cells produced, column assembly to start soon.

• Preparing commissioning at ComLab@CERN with conditions as close to reality as possible.

• Test beam operation successfully achieved at SysLab@CERN
  • Includes complete DAQ/TELL40.
Upgrade I: SciFi

- Prototype frame partially equipped at LHCb pit.
- Bare module production is almost finished.
- First batch of cold boxes (28) has arrived to CERN.
- Started mounting module + cold-box at CERN.
Upgrade I: Calo and Muon

**CALO**
- Test of FEB production is completed.
- FEB tested on testbeam.
- FPGAs will arrive at the end of January.

**MUON**
- ECR for new shielding is done. Plugs have been ordered.
- Production of electronics boards follows the schedule and will be ready for installation.
• Document describing offline computing model for LHCb from Run 3 onwards and related computing resources needs.

LHCb-TDR-018 is ready
Conclusions

- LHCb has operated extremely well in its 10 years -4 days of existence.
  - pp, pPb, PbPb, pA runs provide a unique dataset.
  - Many precise measurements of SM parameters and some anomalies.
  - Flavour structure and CP violation are still major pending questions.
- LHCb is dead (almost) retired, long live to LHCb!
  - Continue exploiting Run1 + Run2 datasets.
  - Upgrade preparations are proceeding well.
  - Extensive work in testbeams for different subsystems during the last month.
  - Computing model TDR is ready and will be discussed during this LHCC session.
BACKUP
Velo Stepper motor

- Problem in fill 7474.
  - Broken while VELO was closing, took VELO open data. Prevented next LHC injection.
  - Fuse in power card blown, replacements blown too.
  - A bridge rectifier on the board found to be shorted.
  - Rectifier from spare boards removed and replaced the broken one.
  - Another blown fuse discovered and replaced => everything back to work.
- Successfully closed/opened in the next fill.
Corrected mass at LHCb

- Recover partially the momentum loss by the neutrino using the corrected mass.
- The visible transverse momentum with respect to the B flight direction is equal to the transverse momentum carried out by the neutrino.

\[ m_{\text{corr}} = \sqrt{m_{\text{vis}}^2 + |p'_T|^2 + |p'_T|} \]
What to expect from Run1+Run2 harvest

Many of the analysis are based on Run 1 data only.

With the increase in energy, the integrated luminosity of Run 2 represents an six-fold increase relative to Run 1.

BEWARE: a simple scaling by sqrt(6) will give a wrong estimate due to systematic uncertainties.