LHCb status report

Manuel Schiller
on behalf of LHCb

CERN

May 25th, 2016
- new physics results
  - $a_{sl}^s$, $\Delta m_d$, $\gamma$, (no) tetraquark, ...
- 2016 startup and first data
- heavy ion plans
- upgrade
LHCb experiment

- originally designed to study CPV in rare $b$ and $c$ decays, nowadays GPD in forward region
  - tracking efficiency $> 96\%$
  - excellent vertexing: decay time resolution $\sim 45\,\text{fs}$
  - very good momentum resolution: $dp/p \sim 0.5 - 1.0\%$
  - software trigger (HLT) input rate: 1 MHz
- 314 papers submitted
- 9 further papers in preparation
- 41 new analyses under review
new physics results

overview

13 papers
submitted since
last LHCC week:

■ 5 JHEP
■ 3 PLB
■ 3 PRL
■ 1 EPJC
■ 1 PRD

4 conference
notes since last
LHCC

■ Measurement of the CKM angle $\gamma$ using $B^0 \rightarrow DK^*$ with $D \rightarrow K_S^0 \pi^+ \pi^-$ decays
■ Measurement of forward $W$ and $Z$ boson production in association with jets in proton-proton collisions at $\sqrt{s} = 8$ TeV
■ Model-independent evidence for $J/\psi p$ contributions to $\Lambda_b \rightarrow J/\psi p K^-$ decays
■ Measurement of the properties of the $\Xi_b^*$ baryon
■ A precise measurement of the $B^0$ meson oscillation frequency
■ Model-independent measurement of the CKM angle $\gamma$ using $B^0 \rightarrow DK^*$ decays with $D \rightarrow K_S^0 \pi^+ \pi^-$ and $K_S^0 K^+ K^-$
■ Measurement of the mass and lifetime of the $\Omega_b^-$ baryon
■ Measurement of $CP$ observables in $B^{\pm} \rightarrow DK^{\pm}$ and $B^{\pm} \rightarrow D\pi^{\pm}$ with two- and four-body $D$ meson decays
■ Search for $B_c$ decays to the $p\bar{p}\pi$ final state
■ Observation of $\Lambda_b^0 \rightarrow \psi(2S)pK^-$ and $\Lambda_b^0 \rightarrow J/\psi \pi^+ \pi^- pK^-$ decays and a measurement of the $\Lambda_b^0$ baryon mass
■ Search for violations of Lorentz invariance and $CPT$ symmetry in $B^0_{(s)}$ mixing
■ Observation of the $\Lambda_b \rightarrow \Lambda\phi$ decay
■ Observation of $B^0_s \rightarrow \bar{D}^0 K^0_S$ and evidence for $B^0_s \rightarrow \bar{D}^{*0} K^0_S$ decays
**CP violation in mixing**

- CPV in mixing: \( \Gamma(B_q \rightarrow \bar{B}_q) \neq \Gamma(\bar{B}_q \rightarrow B_q) \) \((q = d, s)\)
- Asymmetry sensitive to CPV in mixing:

\[
A_{\text{raw}} = \frac{N(D^-_q \mu^+) - N(D^+_q \mu^-)}{N(D^-_q \mu^+) + N(D^+_q \mu^-)} \approx \frac{a^q_{sl}}{2} + \text{corrections...}
\]

- Sensitive to potential NP entering in the mixing

**The story so far:**

- **SM:**
  - \( a^d_{sl} = (-4.7 \pm 0.6) \cdot 10^{-4} \)
  - \( a^s_{sl} = (2.22 \pm 0.27) \cdot 10^{-5} \)
  - [arXiv:1511.09466]

- **LHCb:**
  - \( a^d_{sl} = (3 \text{ fb}^{-1}/1 \text{ fb}^{-1}) \)
  - \( a^d_{sl} = (-0.02 \pm 0.19 \pm 0.30) \cdot 10^{-2} \)
  - \( a^s_{sl} = (-0.06 \pm 0.50 \pm 0.36) \cdot 10^{-2} \)
  - [PRL 114, 041601 (2015)]
  - [PLB 728C (2014) 607]

- **HFAG:**
  -\( a^d_{sl} = (0.01 \pm 0.20) \cdot 10^{-2} \)
  - \( a^s_{sl} = (-0.48 \pm 0.48) \cdot 10^{-2} \)
  - [arXiv:1412.7515], excl. DØ \( \mu \mu \) result
**CP violation in mixing**

- new untagged, time-integrated, inclusive analysis of $\bar{B}_s \to D_s^- \mu^+ \bar{\nu}_\mu X$
  - using full run 1 data set (3 fb$^{-1}$)
  - using full $D_s^- \to K\pi$ Dalitz space
  
  $$A_{raw} = \frac{N(D_q^- \mu^+) - N(D_q^+ \mu^-)}{N(D_q^- \mu^-) + N(D_q^+ \mu^+)} \approx A_D + \frac{a_{sl}^q}{2} + (A_P - \frac{a_{sl}^q}{2}) \int dt \cos(\Delta m_q t)\varepsilon(t)$$

  $A_D$: detection asymmetry, $A_P$: production asymmetry

- formerly dominant systematics: tracking asymmetry
  - was 0.13% in prev. LHCb measurement, down to 0.03% for $K$ and 0.04% for $\mu$
  - much improved: $J/\psi$ tag-and-probe, $D^*$ partially reconstructed methods + simulation

- $a_{sl}^q = (0.45 \pm 0.26 \pm 0.20)\%$
new physics results

$\Delta m_d$ from $B^0 \rightarrow D(\ast)^{*-} \mu^+ \nu X$

- measure mixing frequency $\Delta m_d$ with full run 1 sample ($3 \text{ fb}^{-1}$)
  - use flavour specific decays:
    - $1.6 M B^0 \rightarrow D^- (K^+ \pi^- \pi^-) \mu^+ \nu X$ decays
    - $0.8 M B^0 \rightarrow D^*^- (\bar{D}^0 (K^+ \pi^-) \pi^-) \mu^+ \nu X$ decays
  - need flavour tagging (4 categories)
  - reconstruct decay time (k-factor corrected),
    fit $N_\pm(t) = e^{-t/\tau} (1 \pm (1 - 2\omega) \cos(\Delta m_d t))$

→ world's most precise single measurement:
$\Delta m_d = (505.0 \pm 2.1(\text{stat.}) \pm 1.0(\text{syst.})) \text{ ns}^{-1}$
CKM angle $\gamma$

- $\gamma = \arg(-V_{ud} V_{ub}^{*} / V_{cd} V_{cb}^{*})$ least well-known angle in the UT

- measurable in interference between 2 amplitudes to same final state
  - one has a weak $b \to u$ transition, the other not
  - plenty of possible channels

- interference causes different decay rates, e.g. in $B^{\pm} \to D(\pi^{+}K^{-})K^{\pm}$
plenty more $B_{(s)} \to D_{(s)} K^{(*)}$ results from run 1 available:

- another recent result: $B^0 \to D^0 (K_S^0 h^+ h^-) K^{*0}$ alone: $\sigma_\gamma \sim 20^\circ$
  - [arXiv:1603.08993], [arXiv:1504.05442],
    [arXiv:1408.2748], [arXiv:1402.2982],
    [arXiv:1602.03455], [arXiv:1505.07044],
    [arXiv:1407.8136], [arXiv:1605.01082],
    [arXiv:1407.6127]

- perform LHCb-wide statistical $\gamma$ combination of $DK$ modes:
  $\gamma = (70.9^{+7.1}_{-8.5})^\circ$ is most precise measurement by single experiment
DØ tetraquark observation

- Feb. 26th: DØ claims exotic state $X(5568) \rightarrow B^0_s \pi^\pm$ with $5.1\sigma$ significance
  (with $B^0_s \rightarrow J/\psi \phi$, $J/\psi \rightarrow \mu^+\mu^-$ and $\phi \rightarrow K^+K^-$)
  - $M = 5567.8 \pm 2.9^{+0.9}_{-1.9}$ MeV/$c^2$, $\Gamma = 21.9 \pm 6.4^{+5.0}_{-2.5}$ MeV/$c^2$
  - fraction of $B^0_s$ from $X(5568)$ decay: $\rho^{D\phi}_X = (8.6 \pm 1.9 \pm 1.4)\%$

- at least 4 quarks with $u, d, s, b$ flavours, theory community buzzing with models to explain state

\[ N_{B_s} \sim 5500, \sigma_m \sim 30 \text{MeV}/c^2 \]
LHCb tetraquark non-observation

- Mar. 20th: LHCb looks in 3 fb$^{-1}$ of data
  - exploit experience from previous analyses
  - $\sim 110k$ ultra-clean $B_s$ (in $D_s\pi$ and $J/\psi\phi$ modes)

- $X(5568)$ not seen by LHCb:
  - $\rho_X^{LHCb}(p_T(B_s) > 5\text{GeV}) < 0.9(1.0)\% @ 90(95)\% \text{ CL}$
  - $\rho_X^{LHCb}(p_T(B_s) > 10\text{GeV}) < 1.6(1.8)\% @ 90(95)\% \text{ CL}$

- bottom right plot: LHCb data with claimed $X(5568)$ at $\rho_X = 8.6\%$ superimposed

- looking forward to hearing from other experiments

- publication in preparation
13 papers, 4 conference notes released since last LHCC

many interesting results in the pipeline:

- run 1 lepton universality
- $W$ and $Z$ cross-sections
- CP violation in charm
- exotic particles and states
- spectroscopy
- ...

stay tuned for the summer conferences – there are exciting times ahead!
2016 startup and first data

- 2016 data taking has started
  - we thank the machine for a smooth experience!
  - well, there’s the occasional “weasel” (literal and other)
  - generally smooth experience, problems are resolved quickly and effectively

- reminder: new in run 2:
  - real-time calibration and alignment in the software trigger
  - software trigger has offline reconstruction (and quality!)
  - TURBO stream: save trigger candidates at \( \frac{1}{10} \) size

- 2016 is like 2015, only better…
2016 startup and first data

- Data are being taken successfully, all detectors work.
- New control room ready just in time.

- Huge effort to validate incoming data: done on day 2 after start of data taking.
- Successfully took VdM scan, also SMOG data (fixed target p-He collisions).

- Improvements for this year numerous:
  - TURBO++ stream (next slide)
  - Retuning to optimise performance.
HLT improvements: TURBO++ stream

- already in 2015: TURBO stream: fully reconstructed HLT candidate for analysis at a fraction of the event size

- new: TURBO++ stream is TURBO plus:
  - persist arbitrary variables like isolation with HLT candidate
  - can now save HLT candidate + any reconstructed particles
  - can do qualitatively new things (at higher rate & statistics per storage space) on HLT output
    - entire analysis can be done on trigger output, incl. flavour tagging
    - e.g. in charm spectroscopy: $D^* \rightarrow D^0(K^-\pi^+)\pi^+$

M. Schiller for LHCb (CERN)
HLT improvements: TURBO++ stream

$B_s \rightarrow J/\psi K^+ K^-$

$D^*+ \rightarrow D^0 (K \pi) \pi^+$

$LHCb preliminary \quad \sqrt{s} = 13 \text{ TeV}$
Event display with a $J/\psi \rightarrow \mu\mu$ candidate from PbPb data

LHCb has become a player in heavy ion physics, too
**heavy ion plans**

- **pPb run at \( \sqrt{s_{NN}} = 8 \text{ TeV} \)**
  - high lumi run for all experiments
  - LHCb asks for 20 nb\(^{-1}\), pPb and PbP split 50/50
  - \( J/\psi, \psi(2S), \Upsilon(nS) \), and Drell-Yan production to 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

- **pPb run at \( \sqrt{s_{NN}} = 5 \text{ TeV} \) (prefer \( p \) as beam 1)**
  - low pile-up minimum bias data for ALICE
  - can use SMOG system to study \( p-\text{He} \) collisions at this beam energy
  - \( \bar{p} \) production valuable input for cosmic ray physics in light of AMS-02’s \( \bar{p} \) excess

\[\text{[AMS Coll., CERN 15.04.2015]}\]
Overview of the detector upgrade

- LS 2 activity!
- 40 MHz readout of all sub-detectors; data processed with software trigger
  - VELO: new pixel detector
  - Upstream Tracker (UT): silicon strips
  - Fibre tracker (FT): scintillating fibres
  - RICH: new PMTs, readout electronics
  - CALO: reduced PMT gain, new electronics
  - MUON: more shielding, upgraded readout electronics
Executive Summary: DAQ & Trigger for Run3

LHCb upgrade just had an in-depth review...

Executive Summary

The VELO will be upgraded to a 40 MHz readout pixel detector situated at a distance of 5.1 m from the LHC beams.

Pre-production sensors and Timepix3 prototypes have shown excellent performance; PPRs moving ahead with small delays.

Electronics, readout and DAQ integration proceeding on schedule.

RF5k is a very challenging project on track.

ValidPix ASIC is (submitted?)

Mechanics faces a challenge to be ready for the EDR. Extra effort has been identified to boost this part of the project.

Microchannel cooling plates which form the cooling backbone of the modules are delayed; schedule is being compressed to accommodate.

Module design and production in all other aspects is on track.

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Executive Summary

- Rather precise programme of work has emerged from brainstorming in the last few months
  - Very ambitious, but necessary
  - On the short term:
    - Individual tasks described
    - First software hackathon scheduled on May 26-27th
    - Review progress in forthcoming computing workshops
  - Weeks of May 30th and November 14th
  - 2016 is a crucial year
  - We must use it to define what changes are needed
  - Can we afford to put them in place
  - Can we afford to NOT put them in place (physics performance)
  - Any technology not demonstrated for the TDR will almost certainly not be adopted
  - In particular where changes are intrusive and require long lead times for implementation, integration, commissioning

Finding (and retaining) effort is the weakest aspect

Conclusions

We have achieved significant progress & we are poised to transition to construction of all the important components of the upstream tracker in 2016

Some schedule delays (mostly driven by electronics components) but well on-track to be ready for installation in July 2019
LHCb upgrade

…so I will have to pick a few points to summarise

- good progress on all subsystems
  - entering production phase for many subprojects
  - where possible, perform work proactively (LS2 is short!):
    - installation of $CO_2$ cooling lines, optical fibres (for DAQ), shielding in MUON during EYETS
    - software, HLT in particular, is employing some of the techniques needed for upgrade: nice demonstrator!
- progress monitored through milestones
began discussion about evolution beyond current upgrade
- plans discussed in a recent workshop in Manchester

LS3 is ideal opportunity to
- consolidate existing improvements
- further modest developments
  → could significantly enhance LHCb’s capabilities in specific areas
- example: side chambers in magnet to improve acceptance of low momentum tracks (e.g. slow π from $D^*$ and high multiplicity decays)

longer term (LS4): phase 2 upgrade, allowing operation at high lumi ($\sim 2 \cdot 10^{34} \text{ s}^{-1}\text{cm}^{-2}$)
- physics case under development
- machine aspects being studied (thanks to HiLumi LHC team!), and so far are promising

more information will be presented to LHCC in near future
- LHCb physics programme continues to yield new results
  - $a_{sl}^s$, $\Delta m_d$, exotic states, UT angle $\gamma$
  - plenty more, stay tuned for the summer conferences

- successful startup in 2016
  - 2016 will be like 2015, only better…
  - we’re taking data successfully
  - 2016 HLT has become even better, allowing qualitatively new analyses

- heavy ion run is being planned with exciting physics objectives

- LHCb upgrade is progressing well
  - many subprojects entering construction phase
  - test new technologies and prepare where possible already during run 2
  - thinking about the upgrade beyond LS2
backup slides
EYETS: replacement lift and cranes

Replacement of Lift (AS713) and overhead cranes (P720-721)

- both inherited from DELPHI, 30 years old
- not compliant with modern standards (e.g. EN80-20)
- electrical components no longer available

→ increased maintenance and repair cost

- baseline: proceed with both in parallel
- provisional planning: 9 weeks (from 07/02/17 to end of TS)

→ work on detectors shall be completed by end of January 2017
EYETS: upgrade preparation, standard work

- preparation for the LHCb upgrade

  **aim:** reduce as much as possible LS2 workload
  - installation of $CO_2$ cooling transfer lines for UT and VELO
    - from UXA to UXB, through shielding wall
    - will allow early commissioning of cooling plants
  - installation of additional shielding for MUON
    - at M2 beam plug, replace iron by tungsten
    - expect 60% rate reduction in M1
  - installation of optical support path
    - fibres from US/UX border to patch panels at detector

+ standard EYETS workload:

  - maintainance and test of all infrastructure, detector services and safety systems