LHCb status report

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141st LHCC Meeting - OPEN Session
Overview

- status of Upgrade I
  - installation
  - status of sub-system
  - all-software trigger
    (Real Time Analysis)
- Upgrade II studies
- status of Operations
- Physics results
**LHCb Upgrade I**

- Calo: remove Preshower (PS) and Scintillating Pad Detector (SPD), reduce PMTs gain, replace RO
- all front-end electronics read out @40MHz
- 50 fb$^{-1}$
- $2 \times 10^{33}$ cm$^{-2}$s$^{-1}$

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**CERN-LHCC-2008-007**
**CERN-LHCC-2011-001**
**CERN-LHCC-2012-007**
**CERN-LHCC-2013-021**
**CERN-LHCC-2013-022**
**CERN-LHCC-2014-001**
**CERN-LHCC-2014-016**
**CERN-LHCC-2018-007**
**CERN-LHCC-2018-014**
**CERN-LHCC-2019-005**

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**a new experiment: maintain current reconstruction performance in harsher environment!**
LS2: the story so far

- dismantle shielding wall
- beam pipe removal
- new data centre
- detectors removal
- cables removal
- modifications

A monumental work carried out by the infrastructure team to prepare for the installation of new detectors.
LS2: getting ready for detector installation

- SciFi neutron shielding installation on M1 wall
- Cables installation
- Cooling plants installation
- Platforms modifications
- New HCAL beam shielding

Installation of services nearly completed: getting ready to install and test detectors!
RF foil treatment: etching to $150\,\mu m$, torlon internal coating, NEG outer coating preparation

module production delayed due to assembly problem, resumed now

VELO module test setup preparation @P8 for RF foil installation

Vacuum Feed Through being assembled
Upstream Tracker

staves construction chain:
mechanical support, cooling pipes, flex cables

wire-bonded modules mounted on staves

mass production of staves ongoing ⇒ soon shipments to CERN for assembly
installation delayed due know issues with ASIC, tight schedule
SciFi

fibre mats modules (2.5 m) assembled with SiPM coldbox, readout electronics, mechanics
⇒ C-frames to be assembled in LHCb

C-frames in the assembly hall

transport and integration test in the cavern performed in preparation for installation
new interface for quartz window developed and installed
more work on the gas enclosure before installation

production and qualification of Photon Detectors completed
production and testing of electronics almost finished
RICH2 fully assembled, half commissioned and ready for installation

spherical mirrors and mechanical frame at CERN
CALO & Muon

production of nODE boards completed

commissioning ongoing at CERN: population of M4 and M5

installation of patch panels for both ECAL and HCAL

FEB and control boards under production and test

optical links installed
SMOG 2

new fixed target system (SMOG): significant increase of the luminosity for fixed-target collisions

SMOG system ready to be installed together with VELO RF foil
new data centre **constructed, commissioned** and **connected** to cavern via long distance fibres, old farm moved

long distance fibres light transmission tested and quality assured: only **45** out of **19008** fibres $\sim 0.25\%$ damaged during installation

- PCIe40 cards production well advanced
- quality control ongoing
- getting ready for detector installation and commissioning at P8
Real Time Analysis

aim to process 30 MHz of non-empty bunch crossings at $2 \times 10^{33}$

- software-only trigger
- Full HLT2 reconstruction: no further offline processing needed
- HLT1 performance achieved
- focus on HLT2 selection preparation
- full reconstruction and selection framework in preparation

LHCb Upgrade simulation
Scalar event model, maximal SciFi reconstruction
Scalar event model, fast SciFi reconstruction with tighter track tolerance criteria
Scalar event model, vectorizable SciFi reconstruction with entirely reworked algorithm logic
Fully SIMD-POD friendly event model, vectorizable SciFi and vectorized vertex detector and PV reconstruction, I/O improvements

LHCb-FIGURE-2019-002
Real Time Analysis

studies of VELO tracking efficiency with SMOG 2 collisions with displaced primary vertex

data challenges used to validate reconstruction algorithms, alignment, ecc... on simulation samples

baseline option: HLT1 on CPU
option under study: HLT1 on GPU
review process in plan to arrive at decision on CPU vs GPU within Q1 2020
Green light to proceed to Framework TDR from LHCC and CERN research board: “The recommendation to prepare a framework TDR for the LHCb Upgrade-II was endorsed, noting that LHCb is expected to run throughout the HL-LHC era”

- install new detector for the beginning of Run 5
- operate at $\mathcal{L} \sim 1.5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$
- mean number of interactions per bunch crossing: $\mu \sim 45$
- collect more than 300 fb$^{-1}$
- improve even more LHCb precision (even after first upgrade many measurements still limited by statistics)
- fully exploit HL-LHC
LHCb Upgrade II

a sample of proposed ideas for Upgrade II

- New tracking system
  - Magnet stations for upstream tracks
  - Mighty tracker: silicon+fibres

- RICH
  - replace photon detectors
  - add timing information
  - add TORCH system for PID at low momentum

- Muon shielding replacing HCAL
  - u-Rwell in inner regions

- remove HCAL
  - new ECAL: timing in inner region (SPACAL)

- new VELO
  - higher granularity track timing

extremely challenging projects
lots of R&D projects ongoing
adding timing is the key to cope with the pile-up!
Operations

- smooth operations
- computing resources mostly devoted to MC
- stripping of 2016 data ongoing
- Factor $\sim 4$ increase in number of events produced in 2019 wrt previous years while CPU work increased only by 20% per year
- joint effort of computing, simulation and RTA preparing the resources for upgrade

Running jobs in all sites
15 Weeks from Week 43 of 2019 to Week 06 of 2020

Simulated Events Simulation

All Events Last 365 Days by Simulation Type
- Full: 53.9%
- ReDecay: 35.5%
- PGun: 3.6%
- TrackerOnly: 0.2%
- SplitSim: 6.8%

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LHCb publications

Last year LHCb reached 500 publications! Celebration at the December LHCb week

9 new papers submitted since the last LHCC session
Since the previous session

**Submitted**

- PAPER-2019-028: Search for CP violation and observation of $P$ violation in $\Lambda_b^0 \rightarrow p\pi^-\pi^+\pi^-$ decays
- PAPER-2019-036: Measurement of CP violation in $B^0 \rightarrow D^*\pm D^\mp$ decays
- PAPER-2019-038: Strong constraints on the $K_S^0 \rightarrow \mu^+\mu^-$ branching fraction
- PAPER-2019-039: Isospin amplitudes in $\Lambda_b^0 \rightarrow J/\psi\Lambda(\Sigma^0)$ and $\Xi_b^0 \rightarrow J/\psi\Xi(\Lambda)$ decays
- PAPER-2019-040: Test of lepton universality with $\Lambda_b^0 \rightarrow pK^-\ell^+\ell^-$ decays
- PAPER-2019-041: Measurement of $|V_{cb}|$ with $B_s^0 \rightarrow D_s^{(*)-}\mu^+\nu\mu$ decays
- PAPER-2019-042: First observation of excited $\Omega_b^-$ states
- PAPER-2019-044: Measurement of CP observables in $B^\pm \rightarrow DK^\pm$ and $B^\pm \rightarrow D\pi^\pm$ with $D \rightarrow K_S^0KK\pi$ decays
- PAPER-2019-045: Observation of a new baryon state in the $\Lambda_b^0\pi^+\pi^-$ mass spectrum

**Preliminary**

- PAPER-2019-046: Measurement of the shape of the $B_s^0 \rightarrow D_s^*\mu\nu\mu$ differential distribution
Test of lepton universality with $Λ^0_b \to pK^-e^+e^-$ decays


Run1+2016 (Run2) dataset: $\sim 4.7 \text{ fb}^{-1}$

aim to test lepton flavour universality by measuring ratio of branching fractions:

$$R_{pK}^{-1} = \frac{\mathcal{B}(Λ^0_b \to pK^-e^+e^-)}{\mathcal{B}(Λ^0_b \to pK^-J/ψ(\to e^+e^-))} \bigg/ \frac{\mathcal{B}(Λ^0_b \to pK^-J/ψ(\to e^+e^-))}{\mathcal{B}(Λ^0_b \to pK^-μ^+μ^-)}$$

- dilepton mass-squared range: $0.1 < q^2 < 6 \text{ GeV}^2$
- $Λ^0_b \to pK^-e^+e^-$ never observed before, efficiency and mass fit blind
- $r_{J/ψ}^{-1}$ central value blind, should be compatible with $1$

$r_{J/ψ}^{-1} = 0.96 \pm 0.05$

$R_{pK}^{-1} = 1.17^{+0.18}_{-0.16} \pm 0.07$
$|V_{cb}|$ and $B_s^0 \to D_s^{(*)}$ form factors using $B_s^0$ semileptonic decays

- semileptonic $B$ decays used to constrain the CKM matrix element $|V_{cb}|$
- requires form-factor modelling
- measurements carried out by $B$-factories only using $B^0$ and $B^+$ decays
- $B_s^0$ decays allow for lower theoretical uncertainty from lattice QCD

more details at the CERN seminar: https://indico.cern.ch/event/868248/
Measurement of $|V_{cb}|$ with $B_s^0 \rightarrow D_s^{(*)-} \mu^+ \nu_\mu$ decays


- use $B_s^0 \rightarrow D_s^{(*)-} \mu^+ \nu_\mu$ decays from Run1 data to measure $|V_{cb}|$ and form-factor functions
- do not reconstruct photon from $D_s^{*-} \rightarrow D_s^- \gamma$
- decays parametrised with two form-factor models: CLN (Caprini-Lellouch-Neubert) and BGL (Boyd-Grinstein-Lebed)
- $B^0 \rightarrow D^- \mu^+ \nu_\mu$ decays used as normalisation channel
- no significant difference found for $|V_{cb}|$ determined in the two parametrisations
- first determination of $|V_{cb}|$ from exclusive decays at a hadron collider and the first using $B_s^0$ decays

$|V_{cb}|_{\text{CLN}} = (41.4 \pm 0.6 \text{(stat)} \pm 0.9 \text{(syst)} \pm 1.2 \text{(ext)}) \times 10^{-3}$

$|V_{cb}|_{\text{BGL}} = (42.3 \pm 0.8 \text{(stat)} \pm 0.9 \text{(syst)} \pm 1.2 \text{(ext)}) \times 10^{-3}$
Measurement of the shape of the $B_s^0 \rightarrow D_s^* \mu \nu \mu$ differential distribution

- $B_s^0 \rightarrow D_s^{*-} \mu^+ \nu \mu$ decays from 2016 (Run2) data
- fully reconstruct $D_s^{*-} \rightarrow D_s^- \gamma$ decays
- extract the differential decay rate as a function of the dilepton momentum transfer squared
- confirms the trend observed that the parametrisation is not responsible for inclusive vs exclusive differences in $|V_{cb}|$

First observation of excited $\Omega_b^-$ states

Run1&2 dataset: $\sim 9 \text{ fb}^{-1}$

- much interest in LHCb’s recent observation of five new resonances decaying to $\Xi_c^+ K^-$ (LHCb-PAPER-2017-002)
- search for excited $\Omega_b^-$ states can help understanding of these states
- four narrow peaks observed for the first time
- simultaneous unbinned Maximum Likelihood fit to Right Sign and Wrong Sign distributions

![Graphs showing data and fit distributions for different states](image)

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<tbody>
<tr>
<td>$\Omega_b(6316)^-$</td>
<td>$523.74 \pm 0.31 \pm 0.07$</td>
<td>$6315.64 \pm 0.31 \pm 0.07 \pm 0.50$</td>
<td>$&lt; 2.8 (4.2)$</td>
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<tr>
<td>$\Omega_b(6330)^-$</td>
<td>$538.40 \pm 0.28 \pm 0.07$</td>
<td>$6330.30 \pm 0.28 \pm 0.07 \pm 0.50$</td>
<td>$&lt; 3.1 (4.7)$</td>
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<tr>
<td>$\Omega_b(6340)^-$</td>
<td>$547.81 \pm 0.26 \pm 0.05$</td>
<td>$6339.71 \pm 0.26 \pm 0.05 \pm 0.50$</td>
<td>$&lt; 1.5 (1.8)$</td>
</tr>
<tr>
<td>$\Omega_b(6350)^-$</td>
<td>$557.98 \pm 0.35 \pm 0.05$</td>
<td>$6349.88 \pm 0.35 \pm 0.05 \pm 0.50$</td>
<td>$&lt; 2.8 (3.2)$</td>
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$1.4_{-0.8}^{+1.0}$ $\pm 0.1$
Observation of a new baryon state in the $\Lambda_b^0 \pi^+ \pi^-$ mass spectrum

Run1&2 dataset: $\sim 9 \text{ fb}^{-1}$

- $\Lambda_b(6146)$ and $\Lambda_b(6152)$ from LHCb-PAPER-2019-025
  
  $$m_{\Lambda_b^{**0}} = 6072.3 \pm 2.9 \pm 0.6 \pm 0.2 \text{ MeV}$$
  
  $$\Gamma_{\Lambda_b^{**0}} = 72 \pm 11 \pm 2 \text{ MeV}$$

- $m_{\Lambda(5912)^0} = 5912.21 \pm 0.03 \pm 0.01 \pm 0.21 \text{ MeV}$

- $m_{\Lambda(5920)^0} = 5920.11 \pm 0.02 \pm 0.01 \pm 0.21 \text{ MeV}$

- $\Lambda_b(5912)$ and $\Lambda_b(5920)$ from LHCb-PAPER-2012-012

observation of new baryon $\Lambda_b^{**0}$, consistent with the first radial excitation of the $\Lambda_b^0$ baryon, the $\Lambda_b(2S)^0$, in two different channels

see also recent CMS result: arXiv:2001.06533
Conclusions

- **Upgrade I:**
  - good progress for different sub-systems
  - few issues encountered but generally under control
  - new schedule for LS2: no major changes to the LHCb schedule but allows to recover the contingency lost
  - installation of new detectors ongoing
  - software progressing in parallel to be ready to operate in new conditions

- **Upgrade II:**
  - several R&D activities ongoing
  - preparation for framework TDR

- **Physics:**
  - Run1&2 data analysis progressing: new results being published
  - many more in the pipeline

THANK YOU FOR YOUR ATTENTION!
Extra slides
VELO Upgrade

- hybrid pixel sensors, higher granularity (55µm pixel size)
- first sensor closer to the beam: 5.1mm
- reduced thickness for RF foil
- microchannel two-phase CO₂ cooling system (sensors at −20°C against radiation damage)
- improved IP resolution
- DAQ capable of handling ~40 Tb/s

intense testbeam campaign to validate sensors and radiation tolerance
  - charge collection
  - charge collection efficiency
  - spatial resolution

[LHCB-TDR-013]
VELO modules

Mechanical Construction

Precision tile placement to 10 μm

Flex circuit placement

Wire bonding and HV/LV/data cable attachment

Three modules in SPS testbeam

front end hybrid

GBTx

Tiles

interconnect cables

data cables

LV cables
Upstream Tracker

- Reconstruct particles decaying after the VELO
- Reconstruct low-momentum tracks deflected out of the T-acceptance
- 4 planes of silicon strip as for TT
- Finer segmentation: from $183 \mu m \times 10 cm$ to $95 \mu m \times 4.9 cm$, $95 \mu m \times 9.7 cm$, $190 \mu m \times 9.7 cm$
- Better coverage, no gaps
- Lower material budget
- Higher radiation hardness
- Front-end in the active area, close to sensors: better signal to noise ratio
- Intense campaign of testbeams to validate the custom developed front-end chip
Scintillating fibres mats transport signal outside the acceptance volume.
- 2.5m long fibres with diameter of $250\mu m$.
- Each mat composed by 6 layers of fibres.
- Signal readout by SiPMs at $-40^\circ C$.
- Homogeneous coverage with high granularity.
- Spatial efficiency better than $70\mu m$.
- Single hit efficiency $> 99\%$.

[LHCB-TDR-015]