Preparation and commissioning of LHCb for Run-II of LHC

Albert Puig on behalf of the LHCb collaboration
The LHCb experiment

[JINST 3 S08005 (2008)]
[Int. J. Mod. Phys A 30 (2015)]
The LHCb experiment

Forward-arm spectrometer

$\sigma(b\bar{b}) = 284 \pm 53 \, \mu$b at $\sqrt{s} = 7 \,$TeV \[PLB\, 694\, 209\]

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Excellent particle identification
\(\pi/K\) separation: K ID efficiency of 95% with 5% misidentification
powerful muon identification of 97% with 1–3% misidentification

[PLB 694 209]

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Run-I at LHCb

- Very successful physics program, thanks to the excellent performance of the detector and the LHC
  - Heavy flavor physics: CP violation, very rare $B$ decays, charm physics, CKM matrix
  - Central Exclusive Production
  - Spectroscopy
  - $p$–$Pb$ collisions
  - ...

![Graph showing integrated luminosity over time for 2010, 2011, and 2012 with交付/记录的 luminosity values of 2.21 / 2.08 [fb⁻¹] for 2012, 1.22 / 1.11 [fb⁻¹] for 2011, and 0.04 / 0.04 [fb⁻¹] for 2010.](image)
Run-II: Physics at 13 TeV

- $b\bar{b}$ and $c\bar{c}$ cross-sections expected to increase more than 60% in Run-II
- Larger cross-sections, especially charm, demand a more efficient trigger
  - Solution: move more of the offline selections into the trigger
  - Requirement: offline-like tracking and alignment, Particle Identification (PID) at trigger level
- LHCb to continue pursuing its physics program with increased statistics
- Addition of HeRSChel (High Rapidity Shower Counters for LHCb) to expand the physics reach in Central Exclusive Production studies
Infrastructure LS1 activities

- Enhance detector stability and performance
  - Replacement of 1 section of the beampipe
  - Repair/replacement of problematic hardware and electronics
  - Power supply and cooling system maintenance
  - Consolidation of gas system
- New magnetic field measurement
- New control room (under construction)
Online

• Detector Control PCs moved to Virtual Machines
  - Increased failure recovery speed
  - All control PCs can run in one of two chassis clones

• ECS software changed, operating systems updated

• Bandwidth to storage increased to 1.5GB/s (2 reads and 1 write) ~ 5GB/s raw

• Trigger farm upgrade
  - Double CPU capacity, upgrade of older servers to state-of-the-art
  - Addition of 5PB of mirrored local storage to accommodate the new trigger scheme
Trigger in Run-I

- L0 Hardware trigger, using muons and calorimeter
- High Level Trigger (HLT), implemented in software
  - HLT1: simplified tracking
  - HLT2: full reconstruction, with differences wrt offline
- Deferred trigger
  - L0-accepted data buffered to disk for processing during interfill gaps
  - Extra time used to lower reconstruction thresholds in HLT
Trigger in Run-II

- New trigger strategy based on experience from Run-I and increased needs for Run-II
  - All HLT2 processing deferred
  - Calibration and alignment of subdetectors will be performed on a fill-by-fill basis [see Z. Xu and M. Tobin poster]
  - PID available in HLT2
  - HLT processing much closer to offline
- Larger CPU farm, thus more time
- Increase output rate to 12.5 kHz
Larger HLT2 rate means larger offline storage requirements

Online reconstruction is going to be almost the same as offline

Perform some high-rate analyses online!

• The Turbo stream [S. Benson and A.Puig poster] is designed to save part of the HLT2 bandwidth in a special format that allows bypassing offline reconstruction and directly perform analysis
(Trigger) Optimizations for Run-II

- Optimization and speed up of code
  - Large areas of the code base are heavy on vector algebra, build faster implementation by exploiting vector instructions, with gains of 30% on several important algorithms
  - New algorithms allow to improve the performance and/or reduce execution time

- Add linear extrapolation of tracks from VELO to TT as input to forward tracking
  - x3 faster reconstruction chain and x4 less ghost rate

- Primary vertex reconstruction updated and reoptimized, same for online and offline
Vertex Locator (VELO)

- Primary tracking and vertexing detector
- Silicon strip sensors in $r$ and $\varphi$, separated from LHC vacuum by 300 µm Al foil
- Close to beam (8 mm), so built with retractable halves
- Great performance in Run-I, ready for Run-II
  - Effect of radiation according to expectations
Vertex Locator in Run-II

- Non-uniform bias voltages due to non-uniform radiation damage to ensure good charge collection efficiency (CCE)
  - Special CCE scan data taking for monitoring
- Low voltage system refurbished, replacement of power supplies
- ECS and monitoring software improvements
- VELO alignment performed fill-by-fill
  - Improvement of the performance, since the VELO opens and closes every fill
Silicon tracker

• Two sets of silicon trackers
  - *Upstream of the magnet* (TT), with 1 station of 4 detection layers
  - *Downstream of the magnet* (IT), with 3 stations of 4 detection layers

• Degradation in performance of cooling during Run-I
  - Lubricant mixing with coolant, manual recirculation every 2–3 days in 2012
  - New chiller installed for Run-II
Silicon tracker in Run-II

• IT too low on frame to compensate for beam pipe movement
  - New mechanics installed to adjust to nominal position

• Brandeis CCD Angle Monitor (BCAM) monitoring system installed

• ECS and monitoring software improvements

• Alignment to be performed fill-by-fill
Outer tracker

- Straw tube tracker downstream of magnet with max 50 ns drift time
- It surrounds the IT, with 3 stations of 4 detection layers each
- No aging effects observed during Run-I
  - Addition of O$_2$ to the straw tube gas mixture to help
Outer tracker in Run-II

- Studies performed to assess the effect of 25 ns running on performance
  - Since maximum drift time is 50 ns, spillover effects are expected to be larger

- The spillover from neighbouring bunch crossings is seen in the drift time distribution
  - Straw occupancy is increased as a result

- Operation of the detector will be as expected
RICH

• Two Ring Imaging CHERenkov detectors
• Excellent separation of $K, \pi, p$
• Hybrid Photon Detectors (HPDs)
  - Able to detect individual photons
  - Aging problems seen in Run-I due to vacuum degradation (~3% failure per year)
RICH1 Aerogel removal

- Difficult to integrate in Run-II HLT
  - Large rings, many photon candidates, very CPU intensive
- Harsher environment than designed
  - Higher instantaneous luminosity, photon multiplicity
  - Slightly lower Aerogel performance than expected
- Removal of Aerogel provides
  - Improved $\pi/K$ separation, lower radiation length
  - More accurate efficiency determination (same algorithms online and offline)
RICH in Run-II

• Fill-by-fill calibration, allowing the use of accurate PID information in HLT2
  - Gas refractive index
  - HPD image drift
  - Mirror alignment

• 82 new HPDs with almost zero ion feedback
  - Improved design with getter strips
  - Best HPDs in RICH1 to avoid frequent refurbishment
  - HPD settings improved for L0 rate of 1 MHz
Calorimeters

• Sampling calorimeters

• Composed of 4 detectors
  - SPD/PS read out with multi-anode pixel PMT
  - ECAL/HCAL read out with single anode PMT

• During Run-I
  - Regular HV calibration needed
  - Aging in ECAL/HCAL PMTs, gain adjustments during interfill gaps
Calorimeters in Run-II

- Replacement of fibers for ECAL LED monitoring system by quartz ones
  - Aging due to radiation damage, not seen in detector fibers
- Calibration to be performed fill-by-fill
  - Automatic
  - More frequent gain adjustments
  - Method based on detector occupancy
Muon system

• 5 stations of drift chambers interleaved with iron absorbers
  - Multi Wire Proportional Chambers (MWPC)
  - Triple GEM in inner region of M1

• First station (M1) placed upstream of the calorimeters to improve transverse momentum in L0 trigger
Muon system in Run-II

- HV channel doubling to improve redundancy
- Improvement of MWPC grounding to reduce noise and increase stability
- Reconditioning of some chambers to prevent discharges by flipping HV polarity
  - $O_2$ used as cleaning agent
- Shielding added behind last station (30t of iron) to reduce backsplash
HeRSChel

- Low pileup in Run-II offers good opportunity for Central Exclusive Production (CEP) studies in LHCb
- In Run-I, large background from diffractive events with high-rapidity particles outside the LHCb acceptance
- HeRSChel idea is to tag background in a very forward region ($5<|\eta|<8$)
  - Potential integration into L0 trigger
  - Luminosity measurement and understanding of machine backgrounds also benefitted
HeRSChel

• Install scintillation counters in the tunnel (where accessible) to detect showers from high-rapidity particles hitting the beampipe
  - 5 stations of 4 plastic scintillators with PMT

• Similar systems successfully deployed at CDF and CMS
HeRSChel status

- Detector installation finished
- TED runs show detectors are working well
- Final comissioning of readout and trigger electronics
  - Comission LED system integrated to the LHCb readout
  - Install electronic system to integrate to central trigger
  - Implement the trigger logic in front-end FPGA chips
First collisions

- First collisions delivered on 5–6 May
  - 1 colliding + 1 non-colliding nominal bunch at 450 GeV
  - Global time alignment done
  - Calorimeter sides time-aligned
  - Data taken with complete detector

- 13 TeV collisions delivered on 21 May
SMOG test

• Inject gas into the VELO with SMOG (System for Measuring the Overlap with Gas) and test the luminosity calibration configuration

• Test readout chain including HLT1
  - L0 configuration as in physics
  - HLT1 rate of ~5kHz with 200Hz physics
  - Afterwards, run HLT2 processing pass
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Start gas injection
Stop gas injection
SMOG test: subdetectors

- VELO position monitoring working
- Silicon Tracker and Outer Tracker timing OK
- Cherenkov rings seen in RICH1 and RICH2
- Calorimeter time alignment begun, new automatic gain adjustment running
- Muon timing checked to be consistent with 2012
- HerSCHel showing signal
Conclusions

- A lot of work has been done during LS1 to get LHCb ready for Run-II: consolidation of infrastructure, upgrades and refurbishment of detectors, etc
- A new trigger scheme has been implemented, allowing for better reconstruction and more physics rate
  - Online reconstruction to offline level, so analysis selections can be performed at HLT2
- A new detector (HerSCHel) has been installed to expand the physics program
- First collisions successful, detector in good shape
- Eagerly awaiting 13 TeV data, stay tuned for the first measurements!
Thank you!
Trigger optimizations for Run-II

• Pattern recognition: vectorization of Hough transform

• Track reconstruction
  - Adjustment of precision of magnetic field, Bethe-Bloch energy loss computation
  - Vectorization of magnetic field interpolation, matrix operations in Kalman filter

• Coding improvements
  - Reduce copying of `std::string`, usage of `dynamic_cast`
  - Use contiguous containers (`std::vector`, `std::array`)
  - Improve memory usage with `reserve`, bitfields instead of booleans, ...
  - Write vectorized APIs, use SIMD