LHCb status and plans

- Recent physics achievements
- Preparations for Run II
- Upgrade progress
- Addendum II to the MoU
- Conclusions

Guy Wilkinson
(University of Oxford and CERN)
on behalf of the LHCb collaboration
15/10/2014
Run-I physics output

Status, as of Monday 13/10/2014

We are still exploiting run-I data at same rate as last year – maybe even higher.

Very important results are still appearing – a very limited selection will follow.

We are finalising some of our ‘flagship’ analyses – aim to publish before Run II

224 papers in total, integrating over published, accepted and submitted

15/10/14
**B_{d,s} \rightarrow \mu\mu: run-I legacy paper & CMS-LHCb combination**

B_{s} \rightarrow \mu\mu very rare (~10^{-9}) and very sensitive to contributions from beyond the Standard Model.

Observing this mode was a top priority in run I, and LHCb already published first evidence of the decay [PRL 110 (2013) 02180; PRL 111 (2013) 101805], later confirmed by CMS.

LHCb and CMS physicists have now performed a combined fit to their datasets, making use of common assumptions. The first combination of results from the LHC!

\[ \text{Br}_{MSSM}^{MSSM} (Bq \rightarrow l^+l^-) \propto \frac{m_b^2 m_l^2 \tan^6 \beta}{M_{A0}^4} \]

Included also are results for the even rarer B_{d} \rightarrow \mu\mu, where a signal may be emerging too. The picture is intriguing and provides encouragement for run II!

\[ \mathcal{B}(B_{s}^0 \rightarrow \mu^+\mu^-) = \left( 2.8 \pm 0.7 \right) \times 10^{-9} \quad (6.2\sigma) \]
\[ \mathcal{B}(B_{s}^0 \rightarrow \mu^+\mu^-) = \left( 3.9 \pm 1.6 \right) \times 10^{-10} \quad (3.0\sigma) \]

LHCb-PAPER-2014-049; CMS-BPH-13-007

to be submitted to Nature
Mapping the unitarity triangle: world’s best measurement of the angle $\gamma$

Standard Model description of CP-violation encoded in the unitarity triangle.

One of most important goals of LHCb is a precise measurement of the angle $\gamma$, which prior to LHC turn-on was known with a precision of $\sim 30^\circ$.

Run-1 $B \to D(K_S\pi\pi)K$ sample, $D$ Dalitz plots

Differences between these distributions related to $\gamma$

Still very important run-I results to come.
The goal is to reach $3-4^\circ$ with run-II data.

Combination of all LHCb analyses…

…a precision better than the B-factories combined

$\left(72.9^{+9.2}_{-9.9}\right)^\circ$
Who ordered that?

Run-I analyses are still yielding surprises, some potentially very significant

Lepton universality tests in $B \to K\ell^+\ell^-$

Determine $R_K$, the low-$q^2$ ratio of $B \to K\mu^+\mu^-$ to $B \to K\mu^+\mu^-$ which is expected to be 1 in SM

$$R_K = 0.745 \pm 0.090 \pm 0.036$$

2.6$\sigma$ from unity, 3.1$\sigma$ if BaBar included.

Follow up studies underway, e.g. $B \to K^*\ell^+\ell^-$

Findings in spectroscopy

Study of the $B_s \to D^0 K^-\pi^+$ Dalitz plot performed to understand nature of previously observed $D_{sJ}^{*}$ resonances

Find that the $D_{sJ}^{*}(2860)^-$ is actually a superposition of spin-1 & spin-3 states

This is the first observation of a heavy-flavour spin 3 particle.
Beyond flavour

LHCb continues to contribute strongly in other fields outside flavour physics, taking advantage of its unique geometry and instrumentation.

**Lead-proton physics**

- **First observation of Z boson production in Pb-p collisions**

**Luminosity measurement for production studies**

- **LHCb has unique ability to reconstruct beam-profile with beam-gas interactions**
  - Lumi measured to 1.12%
  - Best precision ever achieved at a (bunched) hadron collider

This, together with conventional method (van der Meer scan) means LHCb has most precise lumi measurement at the LHC
LS1 activities – preparing for run II

A very busy time – all work being completed on schedule. Detector will be fully closed next month.

Removing RICH photodetectors for maintenance

Closing muon filter

Re-mapping dipole field

Installation of shower counters in tunnel for diffractive physics

Reinserting beampipe

Infrastructure – building a new control room
Run II operation

Several ambitious changes planned for operation during run II aimed at increasing physics output and making optimal use of resources.

**Trigger**

LHCb 2015 Trigger Diagram

- **40 MHz bunch crossing rate**
- **L0 Hardware Trigger**: 1 MHz readout, high $E_T/P_T$ signatures
  - 450 kHz $h^2$
  - 400 kHz $\mu/\mu$
  - 150 kHz $e/\gamma$

**Software High Level Trigger**

- Partial event reconstruction, select displaced tracks/vertices and dimuons
- Buffer events to disk, perform online detector calibration and alignment
- Full offline-like event selection, mixture of inclusive and exclusive triggers

**Output streams**

- **12.5 kHz to storage**
  - Full Stream 5 kHz
  - Parked Stream 5 kHz
  - Turbo Stream 2.5 kHz

- Turbo-stream will need no offline processing. If this works well then it has important implications for Upgrade.

This splitting of HLT into two steps enables more info to be used in HLT2 (e.g. RICH) → improved signal-to-background separation (and helps test ideas we wish to use in Upgrade trigger).
The Upgrade in a nutshell

Indirect search strategies for New Physics, e.g. precise measurements & the study of suppressed processes in the flavour sector become ever-more attractive following the experience of LHC 1 run that direct signals are elusive.

Our knowledge of flavour physics has advanced spectacularly thanks to LHCb. Maintaining this rate of progress beyond run II requires significant changes.

The LHCb Upgrade

1) Full software trigger
   - Allows effective operation at higher luminosity
   - Improved efficiency in hadronic modes

2) Raise operational luminosity to $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

Necessitates redesign of several sub-detectors & overhaul of readout

Huge increase in precision, in many cases to the theoretical limit, and the ability to perform studies beyond the reach of the current detector.

Flexible trigger and unique acceptance also opens up opportunities in other topics apart from flavour (‘a general purpose detector in the forward region’).
Upgrade overview

Current detector
Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger
Upgrade overview

Current detector → upgraded detector

All sub-detectors read out at 40 MHz for software trigger

Replacement of full tracking system
Upgrade overview

Current detector → upgraded detector

RICH 1 redesigned; new photodetectors installed for RICH 1 and RICH 2

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Upgrade overview

Current detector → upgraded detector

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All sub-detectors read out at 40 MHz for software trigger

Replacement of full tracking system

Calorimetry and muons:
- Redundant components of system removed; new electronics added; more shielding included
Completion of upgrade TDRs

All* upgrade TDRs have now been approved by the Research Board (the last two since the April RRB). We have final & achievable technology choices for all systems.

We have now organised ourselves for the next phase of the programme, i.e. final stages of R&D, engineering and production readiness reviews, and production.

* Caveat: a computing TDR is foreseen for Q1 2017

15/10/14 LHCb - RRB, October 2014
Organisation of Upgrade Activities

New body, Upgrade Planning Group, established to oversee Upgrade Activities

- Spokesperson (chair)
- Deputy Spokesperson
- Technical Coordinator
- Physics Coordinator (or representative)
- Upgrade Detector Coordinator
- Upgrade Performance Coordinator
- Upgrade Resources Coordinator
- Upgrade Data Processing Coordinator

New positions created for this body

Upgrades activities for each sub-system are pursued within existing ‘Projects’ (i.e. VELO Project deals with current detector and Upgrade) – this optimises use of expertise and resources, and keeps lines of communication clear.

Exceptions are the new detectors: the Upstream Tracker and the Scintillating Fibre Tracker, where new Projects have been created.
High-level milestones have been defined for each sub-system, in order to track progress.

These will be monitored, both internally and in conjunction with the LHCC.

**Example: RICH milestones**

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<tr>
<th>Item</th>
<th>Milestone</th>
<th>Date</th>
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<td>CLARO + front-end board</td>
<td>Engineering Design Review (EDR)</td>
<td>Nov 14</td>
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<td>CLARO + front-end board</td>
<td>Production Readiness Review (PRR)</td>
<td>Mar 15</td>
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<td>Elementary cell</td>
<td>PRR</td>
<td>Mar 15</td>
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<td>Photon detector module</td>
<td>EDR, optoelectronic chain module and assembly</td>
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<td>MaPMT</td>
<td>Place order and start production</td>
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<td>Digital board</td>
<td>EDR, DB hardware with basic firmware + ECS</td>
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<td>Digital board</td>
<td>PRR</td>
<td>Sep 15</td>
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<td>RICH1 mirrors + supports</td>
<td>EDR, spherical and flat mirrors with their supports</td>
<td>Jun 15</td>
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<tr>
<td>RICH1 mirrors + supports</td>
<td>PRR</td>
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<td>RICH mechanics</td>
<td>EDR, including gas envelope, PMT boxes, photon funnel</td>
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<td>Jul 16</td>
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<td>Installation</td>
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<td>Sep 18</td>
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Milestones

Milestones of all systems, plotted against time

LHCb upgrade milestone evolution

Date markers: Aug-13, Dec-14, May-16, Sep-17, Feb-19, Jun-20
**Vertex Locator (VELO)**

New, pixel (50 x 50 \(\mu m^2\)) based VELO

- Good 3D pattern recognition
- Excellent resolution
- Micro-channel cooling → minimises material
- Radiation resistance
- Closer to beam line (5 mm, cf. 8 mm currently)

Exciting progress since TDR, e.g.:

- optimised, rotated module design
- cooling prototype
- prototype sensors
- front-end chip (VeloPix)

Improved performance

LHCb simulation

One half of VELO system:
Upstream Tracker (UT)

Critical silicon strip tracking plane just before magnet.

- Variable granularity to match occupancies
- Stave system inspired by ATLAS IBL
- Fully active within acceptance
- Less material than current detector (‘TT’)

Recent progress on e.g. data/power flex, on mechanics, and on evaluating sensor performance in test-beam.

New test-beam this month will evaluate irradiated sensors.
Imminent design review is expected to lead to submission of ASIC prototype

UT now assigned ‘project’ status with Marina Artuso (Syracuse) as Project Leader
Scintillating Fibre Tracker (SciFi)

Large scale tracking system based on mats of 2.5m long scintillating fibres of 250μm diameter, readout by SiPMs

- 3 stations of X-U-V-X (+/- 5° stereo)
- each plane made of 5 layers

Benefits include single detector technology, fast pattern recognition, good resolution…

Test benches available to study fibre quality; close collaboration with industrial partner to solve problems

Large scale production will occur in several centres: equipment being prepared
Scintillating Fibre Tracker (SciFi)

New Project created under Ulrich Uwer (Heidelberg) with an organisational structure appropriate for a task of this magnitude.

Brazil, CERN, China, France, Germany, NL, Russia, Spain, Switzerland
RICH system

Two very significant changes are required:

- High luminosity means higher occupancy in RICH 1. To recover performance, optics must be changed → new mechanics

- 40 MHz readout requires new photodetectors

A candidate upgrade photodetector in an ‘elementary cell’

EDRs already occurring for front-end chip and for design of elementary cell

Photodetector tendering underway now. Order must be placed next year!
Calorimeter system

• Removal of SPD/PS system (not needed in trigger anymore)

• Reduce the photodetector gain by factor 5, and compensate for this modification in FE electronics

Two options for analogue part FE under evaluation:

i) dedicated ASIC
ii) based on discrete commercial elements

• Radiation damage in the hottest, inner part of the ECAL, assessed by measurement & simulation, No need for any intervention during LS2

Rather, replacement campaign will occur during LS3 – sufficient modules already exist

Measurements of response for module irradiated in tunnel

Region for replacement

Decision imminent! Meanwhile prototype of FE board exists
Muon system

CERN, Italy, Russia

Muon system modifications required for Upgrade:

- Removal of M1 (not needed in new trigger)
- Design of new off-detector readout electronics compliant with 40 MHz readout
- Additional shielding in front of M2

Other essential and important work needed e.g. production of spare chambers – underway!

- Cathode panel production
- Refurbished wiring machine

Building blocks of new SYNC ASIC are already designed
Trigger & online

Upgraded detector will be readout at 40 MHz, and events processed by full software trigger running on event-filter farm (a low level trigger, LLT, based on Calo and Muon information will be available to throttle rate into farm, if needed)

TDR demonstrated tracking and algorithms can be performed within CPU budget

Big increases in efficiency!

Design of PCIe40 readout board progressing well and prototype expected soon
Addenda 1 & 2 to MoU

Addendum presented today complements Common Project addendum of April

Requested funds total is identical to that in Frame Work TDR (LHCC/2012-007)

Timely provision of resources is essential to enable orders to be placed and milestones to be met, so that installation can be completed during LS2!
## Detector ‘money matrix’ (kCHF)

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| Underfunding     | 904             |
Conclusions

LHCb continues to harvest rich results from Run I, with many more important papers still foreseen.

LHCb will be ready and fully operational for Run II. Ambitious, but realisable, changes to operation planned to increase physics output and optimise resources.

Upgrade preparations are entering a new, exciting phase:
- all system TDRs approved: we have all technologies defined
- final R&D, procurement, and construction underway/about to start
- resources now needed to be on track for installation in LS2!
Backups
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