LHCb upgrade: scope and R&D goals

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On behalf of the LHCb collaboration
Outline

• The LHCb upgrade
  ★ Physics motivations
  ★ Overview

• Status of the project
  ★ Tracking detectors
  ★ PID detectors
  ★ Trigger and Online

• Conclusions
LHCb upgrade: physics motivations

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

- LHCb Run-I results show that no large deviations from the SM are visible.

- Precision measurements are needed but results on key observables sensitive to NP are statistically limited and will remain so until the end of Run-II. For example:

<table>
<thead>
<tr>
<th>Observable</th>
<th>Error after Run-I</th>
<th>Error after Run-II</th>
<th>Theoretical precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{BR}(B_s \rightarrow \mu\mu) )</td>
<td>(1 \times 10^{-9})</td>
<td>(0.5 \times 10^{-9})</td>
<td>(0.3 \times 10^{-9})</td>
</tr>
<tr>
<td>( \varphi_s (B_s \rightarrow J/\psi \phi) )</td>
<td>(0.04)</td>
<td>(0.025)</td>
<td>(0.003)</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>(7^\circ)</td>
<td>(4^\circ)</td>
<td>negligible</td>
</tr>
</tbody>
</table>

- To go further in precision beyond Run-II requires significant changes. Increase statistics ⇒ increase luminosity and signal yields!
Main goal: increase significantly the statistics collected by the experiment keeping the present excellent performances.

- Full software trigger at 40 MHz bunch crossing rate
  - Allows effective operation at higher luminosity
  - Improved efficiency in hadronic modes

- Raise operational luminosity to a levelled 2 x 10^{33} \text{ cm}^{-2} \text{ s}^{-1}

All the above necessitates redesign of several sub-detectors and overhaul of readout

- The gain is a 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
Current LHCb detector
Upgraded LHCb

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

replacement of full tracking system

true all subdetectors are read out at 40 MHz

Calorimetery and muons:
- Redundant components of system removed; new electronics added; more shielding included
All* upgrade TDRs have now been approved by the CERN Research Board. We have final & achievable technology choices for all systems.

* a computing TDR is foreseen for Q1 2017

Transition from R&D to construction phase!
Tracking detectors: VELO

Pixel based vertex detector. 50x50 um² pixels
- Good 3D pattern recognition
- Excellent resolution

Challenges and R&D:
- Radiation resistance
- Minimise material -> micro-channel cooling
- Readout at 40 MHz. VeloPix chip is used (an evolution of TimePix3)

Sensor prototyping with different vendors

Micro-channel cooling prototype

The layout is critical: 5 mm distance to the beam when closed!

RF-foil prototype

A very thin vacuum tight RF foil is being studied. Challenging!
Tracking detectors: UT

- Silicon detector plane upstream the magnet
- Critical for tracking at trigger level
- Modules assembled in long staves inspired by ATLAS IBL

Full acceptance and minimal material budget
Requires R&D on:
- Materials for mechanical structure
- Cooling
- Low mass flex cables

All these studies are well advanced

Prototype of low mass flex cable

Prototypes of mechanical structure and concept of hybrid assembly
Tracking detectors: Scintillating Fibre tracker

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

About 10000 km of scintillating fibres! Fibre quality control is an issue. R&D in strict collaboration with the manufacturers ongoing

1) A good fibre mat and 2) a mat with a fibre with wrong diameter

Various SiPM vendors and arrangements have been tested and qualified. R&D on SiPM radiation hardness performed: cooling is critical. Neutron shielding is also important.
Two main changes needed on RICH detectors:
- modify RICH1 optics to cope with increased occupancy
- 40 MHz readout implies new photodetectors and new FE electronics

Photon detectors are MaPMTs housed in modular “cells”. Characterization of candidate MaPMTs well advanced

A very low noise fast analogue ASIC has been designed for the FE.
- Design almost finalized
- Extensive radiation test campaign
Reduce the photodetector gain by factor 5, and compensate for this modification in FE electronics.

Two options for analogue part FE under evaluation:

- Dedicated ASIC
- Custom board with commercial components

Both have pros and cons. Decision on technology imminent.

Prototype FE board for data transmission and trigger interface already produced and tested.

Irradiation tests demonstrated that there is no need for replacement of innermost cells until LS3.
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
- MWPC will have more than 10 years of running by LS2 and should stand another 10 years: refurbish the spare stock!

MWPC production sites at INFN and PNPI have been refurbished and reactivated

Critical building blocks of the readout electronics already designed (here a fully digital PLL for the TDC)
Trigger and Online

Upgraded detector will be readout at 40 MHz, and events processed by full software trigger running on event-filter farm.

- TDR demonstrated tracking and algorithms can be performed within CPU budget. Large gains in sensitivity are obtained. Factor 2 to 4 for fully hadronic final states depending on the selected output rate.

- The architecture of the readout system is based on an event builder where massive data exchange occurs on a high speed network. Data are then shipped to the EFF Commercial PCs and readout boards based on the PCIe GEN3 industry standard are used for the EB.
Conclusions

• The LHCb upgrade is entering the construction phase

• R&D on several aspects (detectors, electronics, DAQ and trigger systems) is in the final phase

• LHC Run-II will be used to test several ideas that will go into the upgrade DAQ and trigger schemes