LHCb Upgrade:
Beyond The Energy Frontier

Presented by: Chris Parkes (LHCb UK PI)

LHCb-UK Institutes: University of Birmingham, University of Bristol, University of Cambridge, University of Edinburgh, University of Glasgow, Imperial College London, University of Liverpool, University of Manchester, University of Oxford, Rutherford Appleton Laboratory, University of Warwick.
CERN, founded 1954

- 20 member states
  - Big 4: Germany, UK, France, Italy - 60%
  - + associates: USA, Russia, China, India...
- 2500 staff, 9000 users
- 600 Universities/Institutes
- 50+ experiments – 4 big LHC experiments

Associated 13 Nobel prize winners
Organisation/Operation

• Grossly simplified concept…

• CERN – provides accelerator, infrastructure
  – 24/7, with say 3 month winter accelerator shutdown

• Users – design, construct, operate, analyse data from experiments
  – Form experimental collaborations
    • Develop organisational structure: spokesman, technical co-ordinator, project leaders for components…
  – Procure & Construct detector elements
Large Hadron Collider - LHC

- Largest Project at CERN
- Proton-Proton Collider
- 27km long tunnel
- Protons collided at four places ALICE, ATLAS, CMS, LHCb Detectors

Chris Parkes, University of Manchester
LHCb and the LHCb upgrade

- LHCb is one of the four main experiments at the CERN Large Hadron Collider
- Studying the origin of the matter-antimatter asymmetry in the Universe
- Collaboration of 600 authors (institute staff, PhD students)
- ~ 20% UK (largest contributing nation)
- Experiment constructed 2000-2008
- Physics operation since 2010
- Will be upgraded (significant elements replaced).
- Construction 2015-2019
- Physics Operation from 2020
- Resources recently recommended from STFC for UK (£6M capital)
- Total upgraded experiment capital construction £45M
Project Structure

Project Management
Principle Investigator: Prof. Chris Parkes

WP1: RICH (Ring Imaging Cherenkov Detector)
Work Package Leader: Prof. Neville Harnew

WP2: VELO (Vertex Locator)
Work Package Leader: Prof. Themis Bowcock

WP3: Computing & Trigger
Work Package Leader: Prof. Pete Clarke

Industrial Liaison
Dr Nigel Watson
Purchasing Process

• Some funds under direct UK control
  Orders placed through UK universities / STFC

• Typically three quotes
• Above £100k tender process (£150k EU rule)
• Best value all round

  • Some funds in partner countries

  • Some orders placed through CERN

Important for high technology items to establish personal contacts, produce prototypes, demonstrate performance
Ring Imaging Cherenkov (RICH)

- Unique at LHC: $\pi/K/\rho$ separation
  - Measure particle velocity through Cherenkov effect
- Two RICH detectors – lower / higher momentum
Beryllium beampipe, VELO exit window and seal and planar mirrors

Gas enclosure and mirrors installed in LHCb pit

Gas Enclosure before installation
The RICH I Mirrors

- Carbon Fibre Mirrors: 1.5% radiation length
- Spherical mirrors
- Glass planar mirrors
Photon detectors and readout

“Level-0” front-end board reads data from the photon detectors and transmits via an ~100m optical link.
**RICH Upgrade - UK**

**Sub-WP**
- Simulation, Reconstruction
  Cambridge (Jones)
- Photon Detectors
  Edinburgh (Eisenhardt)
- Mechanics & Optics
  STFC (Papanestis)
- Electronics / DAQ
  Cambridge (Gibson)

**Selected Hardware Elements**
- Photon Detectors
  (Edinburgh, Glasgow)
- Photon Detector Supports
  (Imperial)
- Digital Board
  (Cambridge)
- RICH-1 Gas Enclosure
  (Oxford)
- Firmware
  /TELL40
  (Birmingham, Oxford)
- Mirrors
  (Bristol)
- Entrance/Exit Windows
  (RAL)

**Installation at CERN**
(STFC)

**WP Leader:** Neville Harnew
• Silicon particle Detector
• Surrounds collision point
• Highest precision detector at LHC
• Closest detector to LHC beams, in vacuum
VELO

collision

module

RF box

p

carbon fibre paddle

cooling block

Chris Parkes, University of Manchester
VELO Upgrade - Module

- Module
- Electronics
- Mechanics

Micro-channel cooling substrate prototype

Dashed line indicates sensitive region

Microchannel cooling connector

Sensor 200 μm
ASIC 200 μm
Si cooling substrate 400 μm

Cross section

Micro channels 200 μm x 70 μm

CO₂ pipe

Stainless steel

3 ASICs per sensor

cooling substrate retracted from module tip

Sensor (4 per module)
VELO Upgrade - UK

Sub-WP

- Software & Firmware
  Warwick (Gershon)

- Electronics
  Glasgow (Eklund)

- Pixel Module
  Manchester (Parkes)

- Mechanics / Integration
  Liverpool (Patel)

Selected Hardware Elements

- Hybrids
  (Liverpool)

- Micro-channel Plates
  (Oxford)

- Opto-elec PCB/Cables
  (Glasgow)

- Pixel Tiles
  (Liverpool)

Module Assembly
  (Manchester)

VELO Half Assembly
  (Liverpool)

System Transported to CERN

WP Leader: Themis Bowcock
UK Groups: Expertise

Selected major responsibilities

- **Edinburgh**: RICH Photon Detectors, Trigger
- **Glasgow**: VELO Electronics;
- **Manchester**: VELO Pixel Module
- **Liverpool**: VELO Mechanics and Integration
- **Birmingham**: RICH Off-detector Readout; VELO Irradiation
- **Warwick**: VELO Software/Firmware; Physics & Simulation
- **Cambridge**: RICH Software; Front End Electronics
- **Oxford**: RICH Gas Enclosure; VELO Microchannel Cooling
- **RAL**: RICH Mechanics; Core Computing
- **Imperial**: RICH MaPMT Housing
- **Bristol**: RICH Mirrors
Case Study-1: VELO

Micron: Produced all Silicon sensors for the LHCb VELO n+-on-n 40μm pitch sensors in two geometries on diffusion oxygenated float zone silicon, laser cut to shape. Now available as a standard catalogue item.

Hawk: Circuit Board Assembly & testing for all LHCb VELO front-end readout board. Obtained Industry award.
Case Study-2: LHCb RICH

- **RICH1 gas enclosure and installation trolley:**
  - NAB Precision Engineering Ltd, Hitchin: materials and manufactured
  - Value 35k GBP

- **RICH2 gas enclosure:**
  - Metalcraft Ltd, Cambridgeshire
  - Value 100kGBP

- **Supracil quartz windows for RICH1 and RICH2:**
  - Heraeus Quartz Tech Ltd, Woking (German mother company, UK registered subsidiary).
  - Value 58kGBP.

- **Assembly of RICH off-detector readout boards:**
  - STI (Surface Technology International).
  - Value 50k GBP

- **Major purchase was the HPD photon detectors**
  - DEP (Photonis) in the Netherlands, £3.5M at current exchange rate.
Case Study-2: Architects

CCD Design & Ergonomics, London

CAD Drawing

Now under construction
Economic Impact

- **VELO**: pioneered n+-on-p sensors
- New product lines at 3 UK companies
- Diamond Light Source
- Hadron cancer treatment
- Patented time-of-flight mass spectrometer

- **RICH**: Hybrid photon detectors, MaPMTs
- Developed with industry
- UK industry mechanics construction
- Medical imaging; PET
In the press....

200+ journal papers to-date

Two new strange and charming particles appear at LHC

Two new particles have been discovered by the LHCb experiment at CERN's Large Hadron Collider near Geneva, Switzerland. One of them has a combination of properties that has never been observed before.

The particles, named DS3*(2860)^- and DS1*(2860)^-, are about three times as massive as protons.
Detector Elements – £600 k including:
  • Silicon pixel detectors
  • ASIC to sensors bump-bonding
  • Cooling substrate Micro-channel etched silicon

Electronics – £1200 k including:
  • The Kapton readout circuit
  • The Optical Links
  • The Opto-electronics readout boards

Mechanics & Infrastructure - £300k including:
  • Bi-phase C0² Cooling systems or elements
  • Vacuum Vessels
  • Support Mechanics
  • Transport
RICH: UK industrial opportunities

- **New photon detectors currently out to tender**
  - (~3.0M GBP).
  Hamamatsu will be extremely competitive for this order
- **RICH1 gas enclosure and associated mechanical items**
  - (~35k GBP)
- **The Quartz window**
  - (~25k GBP).
- **Electronics PCB manufacture and assembly of RICH on-detector readout boards**
  - (~50k GBP)
- **RICH-1 spherical mirrors and planar mirrors**
  - (~£200k and ~£70k respectively)

CMA (Tuscon, Az) will be extremely competitive for the spherical mirrors

£2.2M direct UK investment
Infrastructure - CERN

- Cooling, Safety systems, electrical components
- New buildings equipped for detector construction and testing
- Purchase of raw materials from early 2015
- Specifications (e.g. cooling plant) over next 12mths
- Purchase PC Farm and its housing, initial data centre 2018
Some significant LHCb orders:

<table>
<thead>
<tr>
<th></th>
<th>Specification to be defined</th>
<th>Purchasing process starts</th>
<th>Cost estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling plants (~3)</td>
<td>Q4 2015</td>
<td>Q3 2016</td>
<td>Each 200-300 kCHF</td>
</tr>
<tr>
<td>Gas and fluid piping</td>
<td>Q4 2015</td>
<td>Q1 2017</td>
<td>100-150 kCHF</td>
</tr>
<tr>
<td>Electrical Power Supplies</td>
<td>Q2 2016</td>
<td>Q1 2017</td>
<td>200-300 kCHF</td>
</tr>
<tr>
<td>Optical fibre</td>
<td>Q4 2015</td>
<td>Q1 2016</td>
<td>1.5 MCHF</td>
</tr>
<tr>
<td>Data Centre</td>
<td>Q4 2016</td>
<td>Q3 2017</td>
<td>2-4 MCHF</td>
</tr>
<tr>
<td>Metallic structures</td>
<td>Q4 2016</td>
<td>Q2 2017</td>
<td>400-450 kCHF</td>
</tr>
<tr>
<td>Silicon PM</td>
<td>Q3 2015</td>
<td>Q1 2016</td>
<td>1.4 - 1.8 MCHF</td>
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<tr>
<td>Scintillating Fibres</td>
<td>Q3 2015</td>
<td>Q3 2015</td>
<td>2.2 MCHF</td>
</tr>
<tr>
<td>MaPMT</td>
<td>Q2 2014</td>
<td>Q3 2014</td>
<td>4-5 MCHF</td>
</tr>
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(1.5 CHF = £1)
Summary

• LHCb & LHCb Upgrade
  – LHC experiment where UK is the lead partner
  – Construction of upgrade detector 2015-2020

• Advanced Pixel Detector, VELO
  – UK lead

• Unique Particle Identification System, RICH
  – UK lead

• Computing

• Infrastructure

• Wide range of opportunities of roles for industry

LHCb contacts here today
• Chris.Parkes@cern.ch (Manchester)
• Neville.Harnew@cern.ch (Oxford)
• Nigel.Watson@cern.ch (Birmingham)