Status and upgrade of the LHCb Vertex Locator

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LHCb

- General purpose experiment in the forward region
 - ➔ Heavy flavour physics: beauty and charm
 - ➔ Forward electroweak physics
 - ➔ Central exclusive production
 - ➔ Long-lived exotica

→ M. Martinelli - LHCb Tracking and Alignment - Tracker and applications I (III)

→ E. Gersabeck - LHCb Outer Tracker - Tracker and applications I (III)

LHCb detector

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LHCb detector

VELO status

VELO layout

- Designed to provide 4 space points for tracks with $2 < \eta < 5$

VELO sensors

- 300 μm n-on-n sensors*
*2 n-on-p sensors
- 2048 strips per sensor
- R and Φ geometries
- Pitch varying from $\sim 40\text{ }\mu\text{m}$ to $\sim 100\text{ }\mu\text{m}$
- Stereo angle for Φ strips
- Inner edge: $r = 7\text{ mm}$
- ➡ Active region edge: $r = 8.2\text{ mm}$
- Second metal layer routing lines (see later)

VELO performance

VELO radiation damage

Sensor currents

Operate
at 150V

Efficiency scans

- Scan bias voltage on every 5th module
- Allows determination of cluster efficiencies
- Competes with physics data taking: few scans per year

Effective depletion voltage

2nd metal layer

Strip pitch 40 μm
Strip width $\sim 11 \mu\text{m}$
Routing line width $\sim 11 \mu\text{m}$

2nd metal layer

- Lowered cluster finding efficiency at large radii
- ~100% efficiency in regions without routing lines

- Cluster efficiency affected
- Tracking efficiency OK

Towards LHC run 2

- Replacement detector completed
 - ➔ Insurance for beam incidents
 - ➔ Spare if current detector has too much radiation damage
- Further streamlined operation
 - ➔ 2 VELO shifters 24/7 + 1 on-call expert in 2010
 - ➔ 2 on-call experts in 2012
 - ➔ 1 on-call expert in 2015

VELO upgrade

LHCb upgrade

- Huge physics potential beyond current LHCb reach
- Need higher luminosity
 - ➔ now $4 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
 - ➔ upgrade $20 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- Trigger limitation
 - ➔ particularly for hadronic final states
- Change from 1 MHz to full 40 MHz readout
- Pile up increases from ~ 2 to < 6
- Installation ~ 2018 : LHC long shutdown 2

VELO upgrade layout

sensor unit with 3 ASICs
4 units per module (2 per side) inner edge at 5 mm radius

cooling connector

cooling channels

sensitive region

Material budget

- Low material budget → better performance
- Thinned sensors
- Thinned ASICs
- Retracted substrate
- Low-mass bases
- Thin RF shield

RF shield

- Dual use-case:
 - ➔ RF-field guidance & vacuum barrier
- New design:
 - ➔ L-shaped modules & closer to beam
- New procedures to minimise thickness
 - ➔ Current VELO: pressed Aluminium, 300 μm thickness

Cooling

First prototypes

Inlet

Outlet

Transition

- Continue usage of bi-phase CO_2 cooling
- Use microchannels to cool at heat source
- Main challenge: mechanical stability
- Detectors in vacuum

Cooling

- Operation
 - ➔ 15 bar at -30°C
 - ➔ 60 bar at room temp.
- Required safety margin 150 bar
- Latest samples use hydrophobic bonding
- Withstand 700 bar (pump limit)
- Cycling tests $\pm 40^{\circ}\text{C}$ & 200 bar

Readout rates

- Average (peak) event rate:
26.8 (40) MHz
- Hottest chip:
230 (320) Mtracks/s/chip
- Hit rate:
600 (890) MHits/s/chip

Avg. #particles/chip/event

VeloPix

- Front end chip:
VeloPix based on Timepix3
- <3 W/chip
- Grouping to increase rate capability
 - ➔ 2x4 super pixels
- 4 links of 5 Gbit/s
- First submission summer 2014
- Production end 2015

Timepix3

Readout chain

- Optical transmission from detector to readout boards
- FPGA-based DAQ boards
- Feed into trigger farm
 - ➔ Full event information at 40 MHz
 - ➔ Software trigger

Performance

- Improved impact parameter resolution
 - ➔ Reduced inner radius
 - ➔ Optimised material
- Fast pattern recognition
 - ➔ Align FPGA code with trigger reconstruction
- Improved efficiency for off-axis tracks

LHCb upgrade physics

Table 16: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that which will be achieved by LHCb before the upgrade, and that which will be achieved with 50fb^{-1} by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities. Note that the current sensitivities do not include new results presented at ICHEP 2012 or CKM2012.

Type	Observable	Current precision	LHCb 2018	Upgrade (50fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s (B_s^0 \rightarrow J/\psi \phi)$	0.10 [138]	0.025	0.008	~ 0.003
	$2\beta_s (B_s^0 \rightarrow J/\psi f_0(980))$	0.17 [214]	0.045	0.014	~ 0.01
	a_{sl}^s	6.4×10^{-3} [43]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\text{eff}} (B_s^0 \rightarrow \phi\phi)$	—	0.17	0.03	0.02
	$2\beta_s^{\text{eff}} (B_s^0 \rightarrow K^{*0}\bar{K}^{*0})$	—	0.13	0.02	< 0.02
	$2\beta^{\text{eff}} (B^0 \rightarrow \phi K_S^0)$	0.17 [43]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}} (B_s^0 \rightarrow \phi\gamma)$	—	0.09	0.02	< 0.01
	$\tau^{\text{eff}} (B_s^0 \rightarrow \phi\gamma) / \tau_{B_s^0}$	—	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \rightarrow K^{*0}\mu^+\mu^-; 1 < q^2 < 6\text{GeV}^2/c^4)$	0.08 [67]	0.025	0.008	0.02
	$s_0 A_{\text{FB}}(B^0 \rightarrow K^{*0}\mu^+\mu^-)$	25 % [67]	6 %	2 %	7 %
	$A_I(K\mu^+\mu^-; 1 < q^2 < 6\text{GeV}^2/c^4)$	0.25 [76]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \rightarrow \pi^+\mu^+\mu^-) / \mathcal{B}(B^+ \rightarrow K^+\mu^+\mu^-)$	25 % [85]	8 %	2.5 %	$\sim 10\%$
Higgs penguins	$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$	1.5×10^{-9} [13]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) / \mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$	—	$\sim 100\%$	$\sim 35\%$	$\sim 5\%$
Unitarity triangle angles	$\gamma (B \rightarrow D^{(*)}K^{(*)})$	$\sim 10\text{--}12^\circ$ [244] [258]	4°	0.9°	negligible
	$\gamma (B_s^0 \rightarrow D_s K)$	—	11°	2.0°	negligible
	$\beta (B^0 \rightarrow J/\psi K_S^0)$	0.8° [43]	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3} [43]	0.40×10^{-3}	0.07×10^{-3}	—
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3} [18]	0.65×10^{-3}	0.12×10^{-3}	—

Charm CP violation

Charm CP violation

sub- 10^{-4} precision!

Charm CP violation

sub- 10^{-4} precision!

Conclusions

- VELO detector
 - ➡ Reliable high performance vertexing for LHCb
 - ➡ Radiation damage following expectations
 - ➡ Second metal layer effects still tolerable
- VELO upgrade
 - ➡ Pixel detector with VeloPix readout at 40 MHz
 - ➡ Microchannel cooling: first tests very promising
 - ➡ New RF shield production mechanisms under study
 - ➡ VELO upgrade TDR end 2013

Backup

IT scans

Current VELO IP

Bsmumu

40 MHz Front-end readout

RICH

New photon detectors

Calorimeter+Muon

Remove MI, SPD, PS

New calorimeter FE electronics

Tracking

New silicon trackers
Reduce straw coverage
Fibre tracker

Vertex Locator

a) New pixel detector
b) Improved strip detector

Timeline

- Letter of Intent submitted March 2011
→ Physics case fully endorsed by LHCC
- Framework TDR submitted in June 2012
→ Defining cost, milestones and institutes' interests
- Resource Review Board, April 2013
→ First positive signals from several big funding agencies
- TDRs: end 2013
→ Technical choices
- Production and QA
→ 2014-2017
- Installation in 2018
→ Use LHC LS2

CERN/LHCC 2012-007
LHCb TDR 12
25 May 2012

Framework
TDR
LHCb
UPGRADE