LHCb Upgrade

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Centro Brasileiro de Pesquisas Físicas

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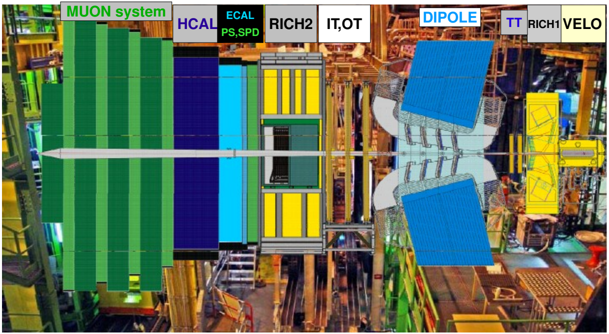
LHCb Experiment: CP violation studies and Rare Decays



- single−arm forward spectrometer, covering $2 < \eta < 5$; b hadron production
- tracking system consists of Vertex Locator followed by one tracking station upstream and three downstream of the 4 Tm dipole magnet with invertible polarity.
- particle identification provided by two Ring Imaging Cerenkov detectors, eletromagnetic and hadronic calorimeters and muons stations.

… see Alberto's talk

LHCb experiment: going deeper

Actual

- operated successfully at $\mathcal{L} = 4 * 10^{32}$ cm^2 s^{-1} @ 50 ns spacing @ $\mu > 1.5$
- collected $\int \mathcal{L}dt = 3$ fb^{-1} (2011+2012), expected additional 5 fb^{-1} until 2018
- excelent detector performance and physics results

going deeper
- Measurements to validate CKM description at sub-10% level
- Exploration: search for NP
- Precision: comparisons with theory

Upgrade

- $\mathcal{L} = 1$ - $2 * 10^{33}$ cm^2 s^{-1} @ 25 ns spacing @ $\mu = 4$
- $\sqrt{s} = 14$ TeV: ratio $\sigma_b \sim 14/7 = 2$
- collecting $\int \mathcal{L}dt = 50$ - 100 fb^{-1} after 10 years data-taking

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- most of info of this talk refers to installation for Long Shutdown 2 (LS2) of LHC in 2018/19

LHCb Upgrade: Challenges

radiation level
occupancy
pile−up
spill−over
material budget
data rate

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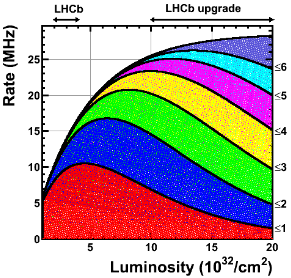
Tracking Pattern Recognition

- multiplicity, vertexing, ghosts

multiple-scattering, secondary hits



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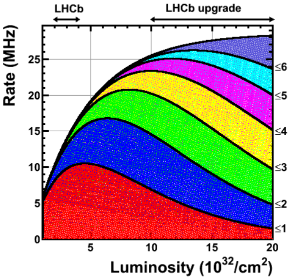
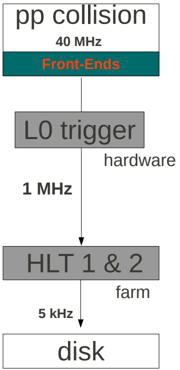
1MHz Trigger saturation !!



Actual Trigger



- calorimeter and Muon systems provide input for L0 trigger
- other detectors read-out at 1 MHz
- 1/40 ratio mostly determined from technical constraints

L0 selection

E_T and p_T cuts about 50% Efficiency for Hadron

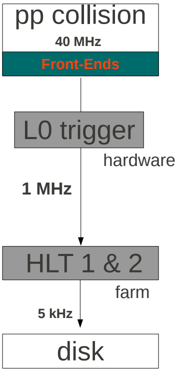
HLT1 selection

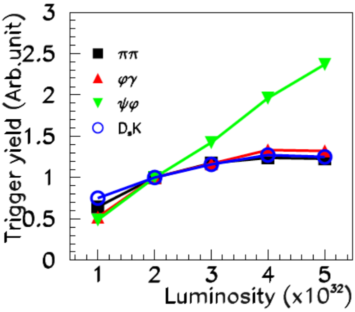
partial event reconstruction
50 kHz output rate

HLT2 selection

full reconstruction
inclusive and exclusive selections

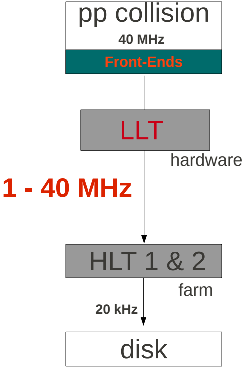
Actual Trigger





- currently any increase in luminosity must be accompanied by an increase in hadronic thresholds due to limited band-width

Trigger solution



- **read-out the whole detector at every bunch crossing**
- replace hardware trigger gradually by fully software-based trigger: high flexibility and efficiency

Overall Scenario for Upgrade

40 MHz read-out

- replace all Front-end electronics
- new architecture for DAQ electronics required: back-end
- silicon detectors (VELO, IT and TT) and Hybrid-photon detector of RICHs must be replaced since front-end electronics are embedded in detector modules

Occupancy

- occupancy up to 40% of Outer-Tracker implies whole tracking stations after magnet to be redesigned
- radiator for low momentum tracks of RICH1, aerogel, must be removed

Material bugdet

- M1 stations of the muon system, the preshower (PS) and scintillator pad detector (SPD) are crucial for the L0 trigger. For the new scenario with LLT they can be removed

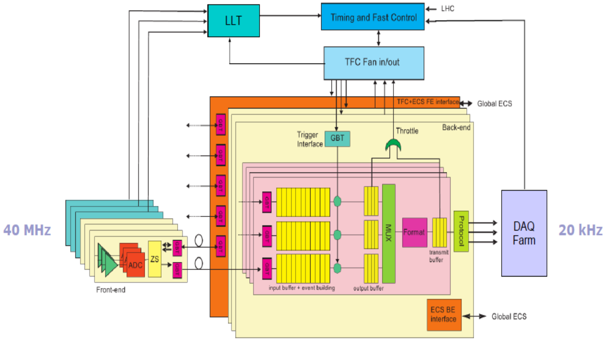
Radiation level

- all detectors must be validated to withstand the hostile environment for the long term operation

Each Subsystem in more details

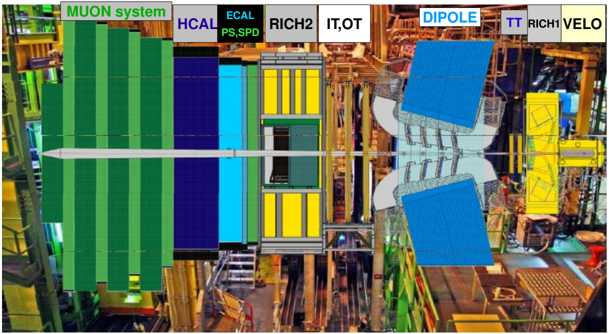
- Electronics
- VELO
- Tracking system
- RICH
- Calorimeter
- Muon system

Electronics Upgrade



- develop common high-speed devices: TELL40 back-end, GBT project
- modularity of TELL40 board; data, ECS, TFC, etc
- data compression in Front-end electronics

Current: VELO

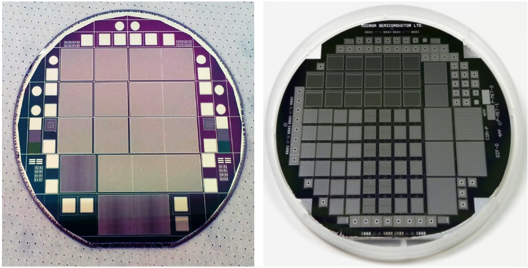


fast pattern recognition
excellent vertex resolution and two track separation
mounted in high precision ($<5\mu$m) positioning system
inner sensor radius: 8 mm from the beam axis during data taking
21 stations in z with R & ϕ resolutions
SSD: pitch = 40-100 μm

Upgrade: VELO

Two options

1. Pixels: high granularity & ease of pattern recognition (↓ ghosts)
   $\Longrightarrow$ 2 hybrid sensors with fast VeloPix ASIC (TimePix/MediPix family 55 μm pitch)



2 PIXEL sensors

Upgrade: VELO

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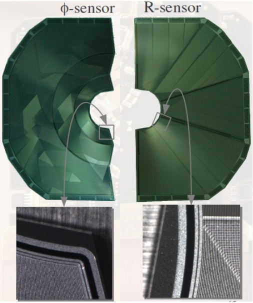
   $\Longrightarrow$ SALT ASIC, same for IT project (8 chs, 6 bit ADC, serializer)



STRIPS

Upgrade: VELO

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Radiation hardness

- test beams are coming to validate those sensors for 50 fb^{-1}
- all chips are CMOS radiation-hard 130 nm technology

Upgrade: VELO

Impact parameter resolution

- first order $\sigma_{IP} = r_1^2 \left(\frac{13.6MeV}{c\ pT}\right)^2 \frac{x}{X_0}$

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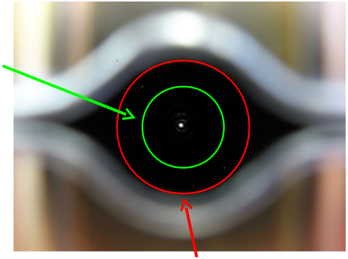
aperture

- aimming at reducing from 5.5 mm to 3.5 mm



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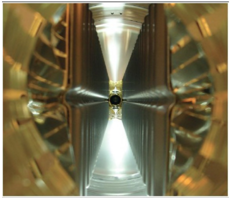
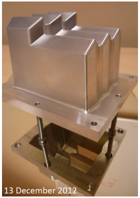
RF foil

- separates primary and secondary vacuua, guides weakfields
- currently contributes with 80% material before r_1 and r_2 points
- good results achieved with 1.5 mm instead 4 mm

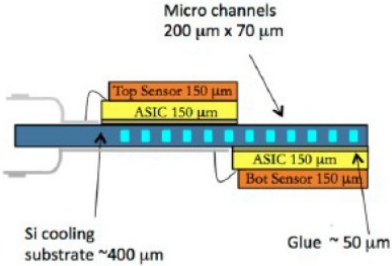




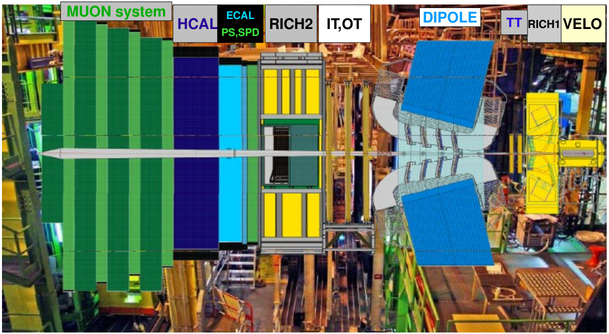
Upgrade: VELO

Cooling

- cooling in LHCb acceptance
- sensors must be at -20^0 C to avoid thermal runaway
- CO_2 evaporate → novel microchannel technique: integration in Si substrate



Actual: Tracking System



- high precision momentum measurement for charged particles: mass resolution & input to photon-ring searches in RICH
- pattern-recognition capabilities are expressed in the track-finding efficiency and probability to reconstruct ghosts: high occupancy OT in central region

$$\text{VELO} \rightarrow \text{TT(Si)}_{\text{downstream}} \rightarrow \text{DIPOLE} \rightarrow \left[\begin{array}{r} \textbf{OT} \ \text{(straw)} \\ \text{IT} \ \text{(2\% area, Si)} \\ \textbf{OT} \ \text{(straw)} \end{array} \right]_{\text{upstream}}$$

Downstream stations

1. replacing the straw tubes of the central regions by Scintillating Fibre with Silicon Photo-Multiplier (SiPM) light collection

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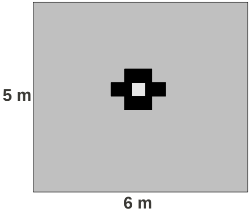

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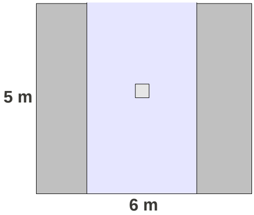

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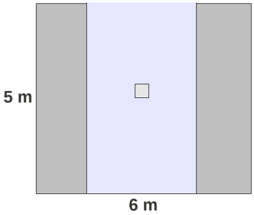
2. alternative: new silicon strip detector with larger coverage, reducing geometry of OT in central region



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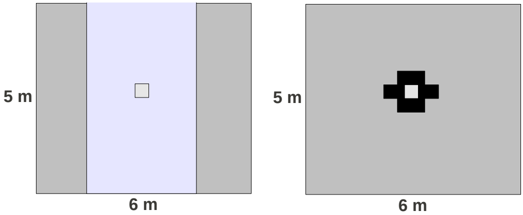

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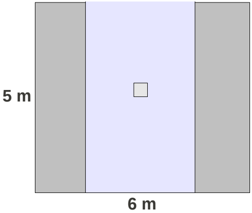

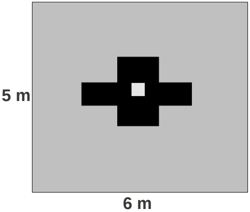

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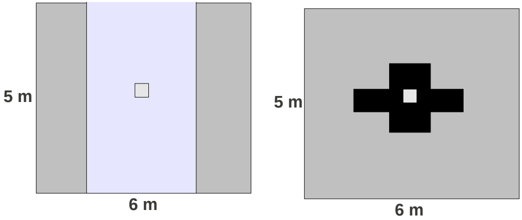
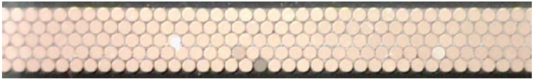


Upstream stations: TT → UT

- improve pattern recognition, ghost rejection and trigger performance by rebuilding silicon strip detector with finner segmentation and reduced thickness

Scintillating Thin Fibres

- same spatial resolution: fibres 250 μm diameter (2.8 ns decay-time, attenuation lenght $>$ 4 m)
- modules comprising five layers, 2.5 m long (spatial accuracy $\sim$ 10μm)



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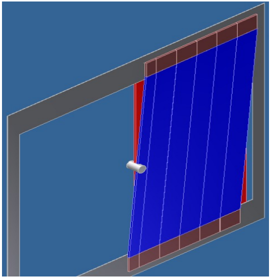

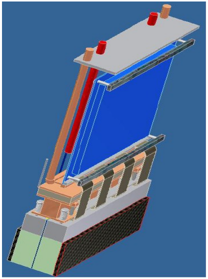

Scintillating Thin Fibres

- same spatial resolution: fibres 250 μm diameter (2.8 ns decay-time, attenuation lenght > 4 m)
- modules comprising five layers, 2.5 m long (spatial accuracy $\sim$ 10μm)
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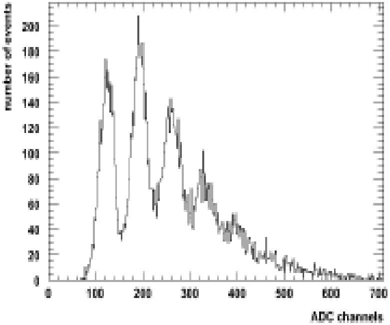
- efficient light collection: SiPM (128 sensors/chip), $\sim$ 18 pe, 0.5 pe rms noise



Scintillating Thin Fibres

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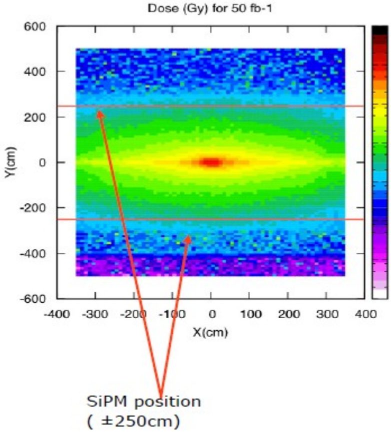

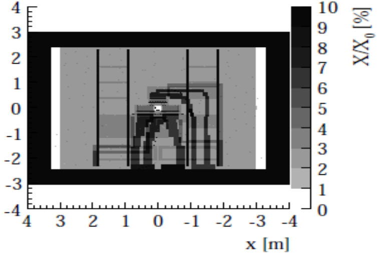

Actual non-uniform density of material

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- simple electronics (high gain in geiger mode of SiPM & less radiation level)

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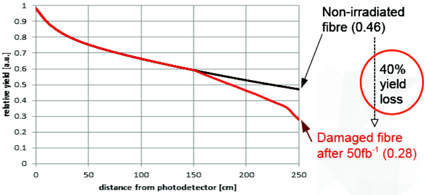
Radiation damage under control

- SiPM: **critical** $\rightarrow$ shielding lowers the 1 MeV n-eq fluence by factor 2-5
- Fibres: degradation in light yield restored with mirror
  green fibre less sensitive



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$\Rightarrow$ AN INTERNAL REVIEW ON THE VIABILITY OF THE SCINTILLATING FIBRE OPTION SHOWED NO SHOWSTOPPER

Alternative: Silicon Strip detector

- Silicon: Large experience on this technology
- increase IT size
- reduce material (IT and OT occupancy dominated by secondaries)

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- increase IT size
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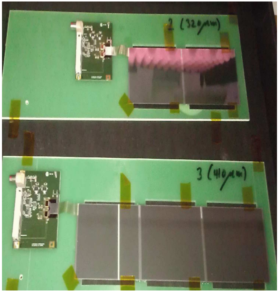
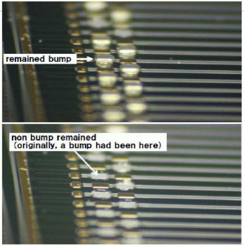
- 2/3 sensor Long Ladder prototype





Straw-Tubes

actual Outer-Tracker: 2.5 m $\times$ 5 mm kapton straw-tube

200 μm resolution obtained $\delta \sim 1$ ns drift-time measurement

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Minor changes

- digital part of front-end electronics: using FPGA Actel ProASIC3 family of low cost and power, sufficiently rad-hard is a good option for the new TDC
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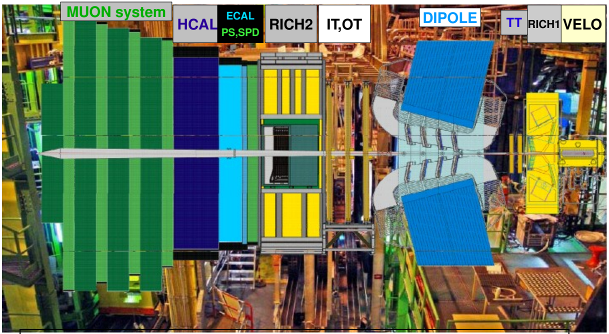
Ageing

- gain loss seen in the past was caused by glue components inside the gas volume under control: Flushing, O_2 and HV training
- until now no deterioration seen, likely to sustain up to 50 fb^{-1} for outer modules

Actual: RICH



Ring-Imaging-Cerenkov using hybrid photon detector
(1) $\pi \leftrightarrow$ K 2-60 GeV aerogel and C_4F_{10}
(2) $\pi \leftrightarrow$ K up to 100 GeV CF_4
Eff $>$ 95% Misid $\sim$ 5%

Upgrade: RICH

HPD removed due to embedded front-end at 1 MHz

- R&D focused on MaPMT (potential candidate is Hamamatsu R11265)
- Custom readout ASIC being developed

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- alternative: HPD with external read-out

Upgrade: RICH

Aerogel will be removed. However, occupancy seems to remain an issue

Two alternatives under investigation

1. RICH1 upgrade optics with increased mirror radius to spread out the rings

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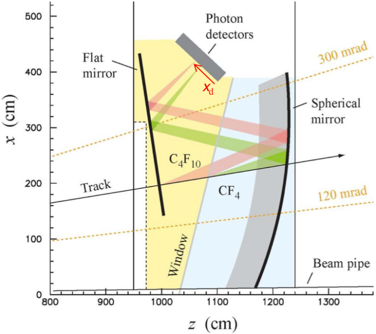
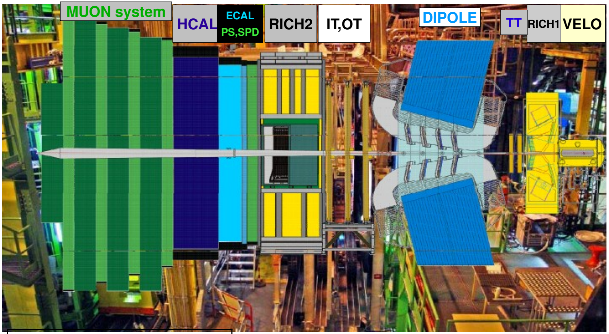
Two alternatives under investigation

1. RICH1 upgrade optics with increased mirror radius to spread out the rings
2. Twin-Ring-Identification system (TRIDENT)
   - merge both RICHs including complex lens system



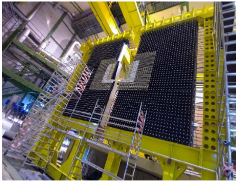
Actual: CALORIMETERS



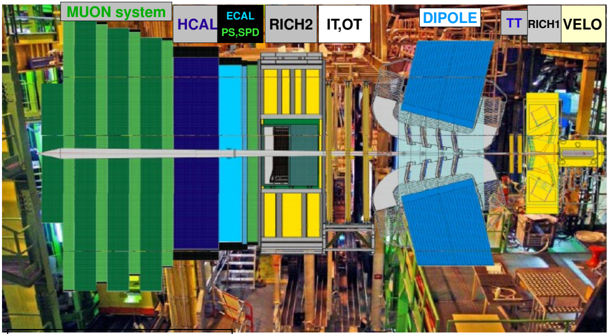
ECAL

$25X_0$ lead + Scint

δ E $= 9.4\%/\sqrt{E}$

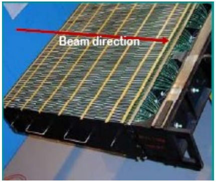


Actual: Calorimeters



ECAL
$25X_0$ lead + Scint
δ E $= 9.4\%/\sqrt{E}$

HCAL
$5.6\lambda_I$ Fe + Scint
δ E $= 69\%/\sqrt{E}$



Upgrade: Calorimeters

- Photon-Shower and Scintillator Pad detector removed
- ECAL & HCAL for $\uparrow \mathcal{L}$
  - reduce HV of PMT to preserve anode current

$$\Downarrow$$

compensate with increase amplifier gain $\rightarrow$ Noise level

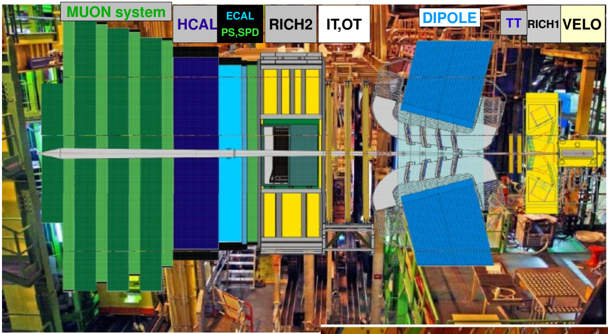
$$\Downarrow$$

  - new FEs: $\underbrace{\text{ANALOGICAL (ASICs + FPGA)}}_{\text{noise issue}}$ and $\underbrace{\text{DIGITAL (GBT)}}_{\text{40 MHz read-out}}$

Radiation level

- Some ECAL modules in the inner region might have to be replaced (as foreseen by infrastructure design)

Actual: Muon System



5 stations/4 regions 435 m^2
1368 MWPC & 24 GEMs
Eff > 97% Misid 1-3%

Upgrade: Muon System

detectors

- M1 will not be needed in the upgrade
- M2-M5 can accumulate 50 fb^{-1}
- high rates in some regions might not be adequate in the longer run (low energy neutrons and secondaries)
  - spares (expected 1-2% replacement)
  - new technologies (triple-GEM, high-granularity MWPCs)

Front-end electronics

- Front-end electronics are almost compatible
- new OnDetector module with GBT is foreseen
- new version of CARDIAC is envisaged (to avoid obsolescence after more than 15 years)

Summary

- LHCb plans upgrade to be able to exploit higher luminosity with better efficiency
- it is achieved by *triggerless read-out* and *software-based trigger*
- to be ready for LS2
- ongoing detector R&D programme to meet challenges in terms of
  - 40 MHz read-out
  - radiation tolerance
  - robust and fast reconstruction
  - material budget
- key technology choices to be taken in the next months for:
  - VELO: pixel or microstrips
  - downstream tracking: scintillator thin fibre or silicon strips
  - RICH: new optics of RICH1 or new RICH detector (TRIDENT)

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THE LHCb UPGRADE HAS RECENTLY BEEN APPROVED BY THE CERN RESEARCH BOARD

Summary

More information

- Letter of Intent for the LHCb Upgrade, CERN-LHCC-2011-001
- Framework TDR for the LHCb Upgrade, CERN-LHCC-2012-007
- Implications of LHCb measurements and future prospects, CERN-PH-EP-2012-334

Other LHCb contributions

- Search of CP-Violation in charm decays, Matt Coombes
- CP-violation in B(s) decays to final states including charm(onia), Bruno Souza De Paula
- Rare Decays, Francesco Polci
- Production in the forward region, Murilo Santana Rangel
- CP-Violation in charmless hadronic B decays, Fernando Luiz Ferreira Rodrigues
- LHCb overview, Alberto Correa Dos Reis