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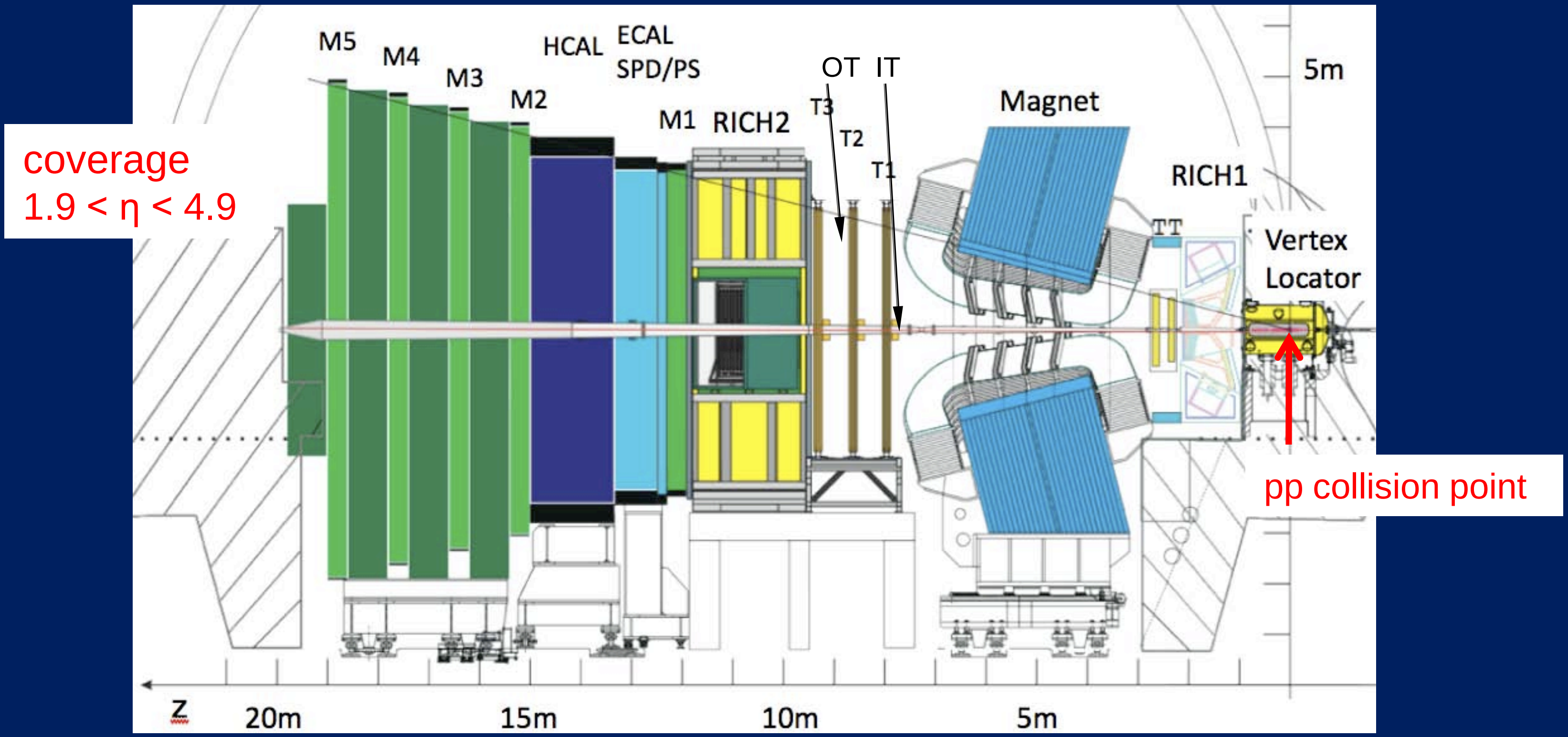
The LHCb upgrade

Burkhard Schmidt for the LHCb Collaboration

Outline:

- Present LHCb detector and trigger
- LHCb upgrade – main drivers
- Overview of the sub-detector modifications
- Conclusions

Present LHCb Detector



- Forward spectrometer designed to exploit huge $\sigma_{b\bar{b}}$ at the LHC
- Detector shows excellent performance
  - see talk of M. v. Beuzekom this morning

- LHCb physics goals:
  - Search for New Physics via CP asymmetries and rare decays
  - Collect ~5 fb^{-1} at $L \sim 3 \times 10^{32} cm^{-2} s^{-1}$ over 5 years before 2nd LHC long shutdown in 2018

Search for New Physics at LHCb

Two classes of measurements:

Exploration:

- Focus on decay modes or observables a priori very sensitive to New Physics, but which have not been accessible to previous experiments.

Precision studies:

- Measurement of known parameters with improved sensitivity, to allow for more precise comparisons with theory.

As new exploration topics appear, existing studies migrate to precision studies.

Present LHCb detector

collect ~5 fb^{-1} with L~$3x10^{32}cm^{-2}s^{-1}$

Exploration example :

- search for $B_s \rightarrow \mu\mu$ down to SM value

Precision studies:

- Measure CKM angle γ to 3-4^{o} to permit meaningful CKM tests

⇒

Upgraded LHCb Detector

collect > 50 fb^{-1} with L~$1x10^{33}cm^{-2}s^{-1}$

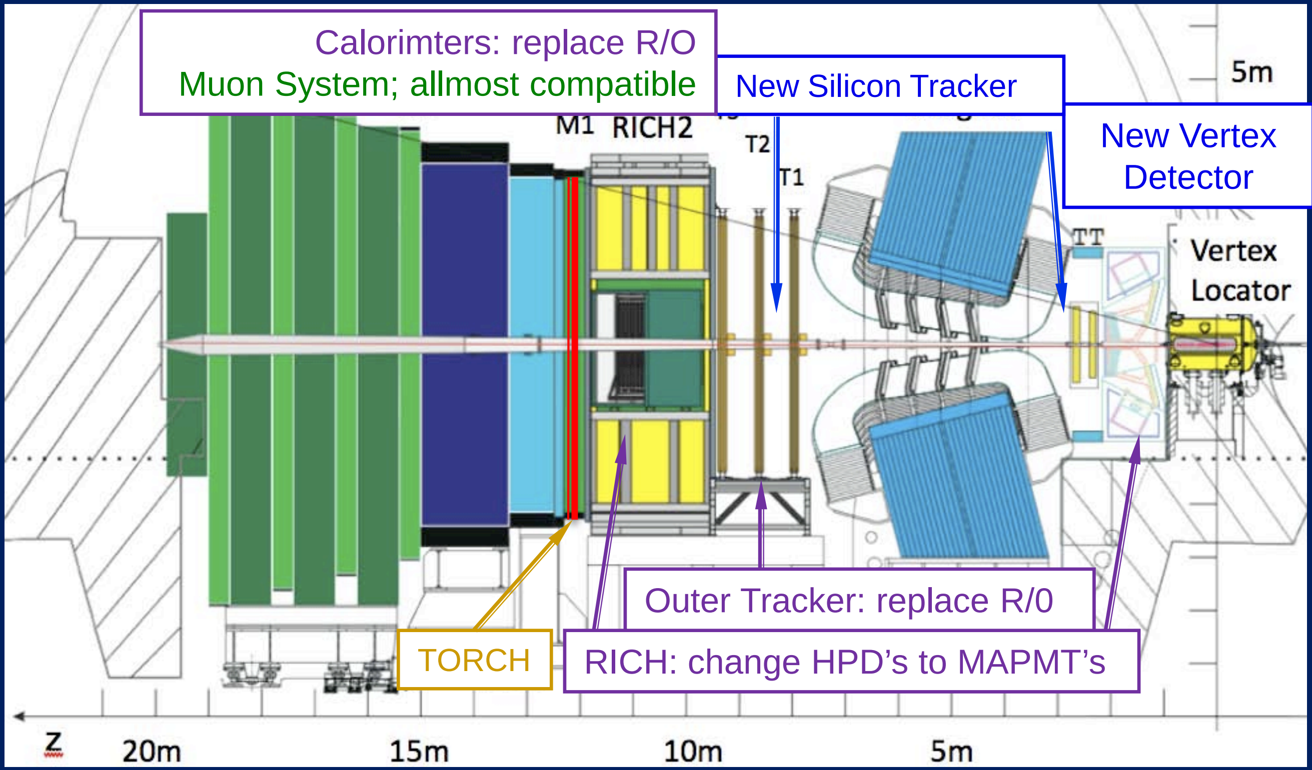
Precision studies:

- Measure BR($B_s \rightarrow \mu\mu$) to precision of ~10% (assuming SM value)

Exploration example:

- Search for $B^0 \rightarrow \mu\mu$

Upgraded LHCb Detector



LHCb Upgrade

collect > 50 fb^{-1}

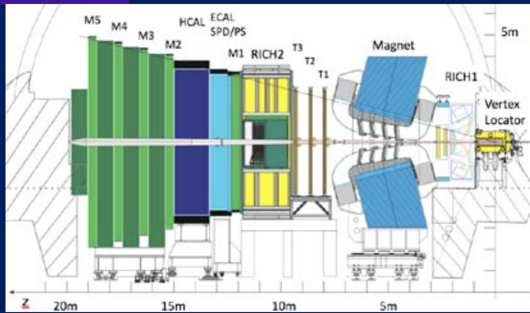
~5 fb^{-1}/year

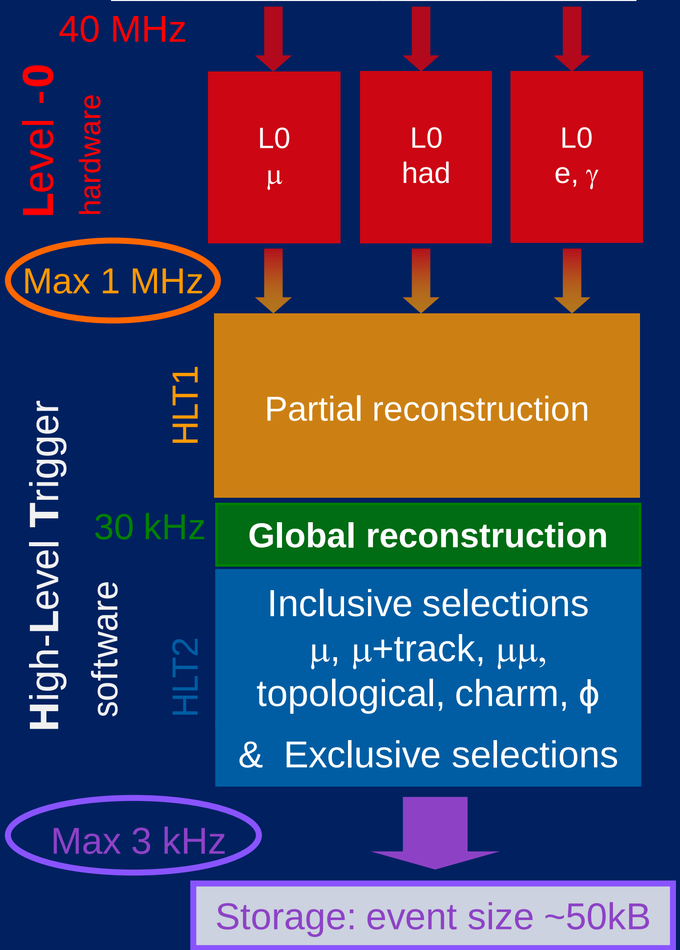
$\sqrt{s}$ = 14 TeV

$\mathcal{L} = 10^{33}\ cm^{-2}s^{-1}$

- LHCb goals with the upgrade:
  - Quark flavour physics main component, but expand physics program to include:
    - Lepton flavour physics
    - Electroweak physics
    - Exotic searches
  - General purpose detector in the forward region with 40 MHz readout and a full software trigger.

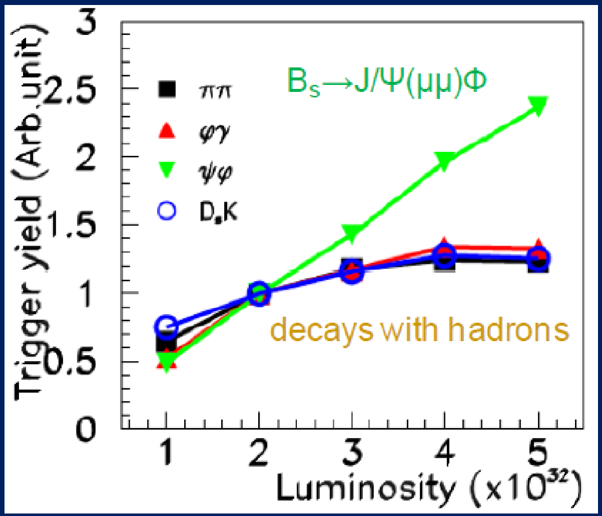
LHCb Trigger – limitations





- Final states with muons
- → Linear gain

- Hadronic final states
- → Yield flattens out
- → Must raise p_T cut to stay within 1 MHz readout limit



- To profit of a luminosity of $10^{33}cm^{-2}s^{-1}$, information has to be introduced that is more discriminating than E_T.

Upgrade strategy:
40MHz readout rate
Fully software trigger
20kHz output rate

Upgraded LHCb environment: $\mathcal{L}$ & Pile-up

LHCb design operation :

- $\mathcal{L}$ ~ 2x10^{32} cm^{-2}s^{-1} with 25ns bunch spacing

  → Average pile-up ~ 0.4

LHCb Upgrade :

- $\mathcal{L}$ ~ 1x10^{33} cm^{-2}s^{-1} with 25ns bunch spacing

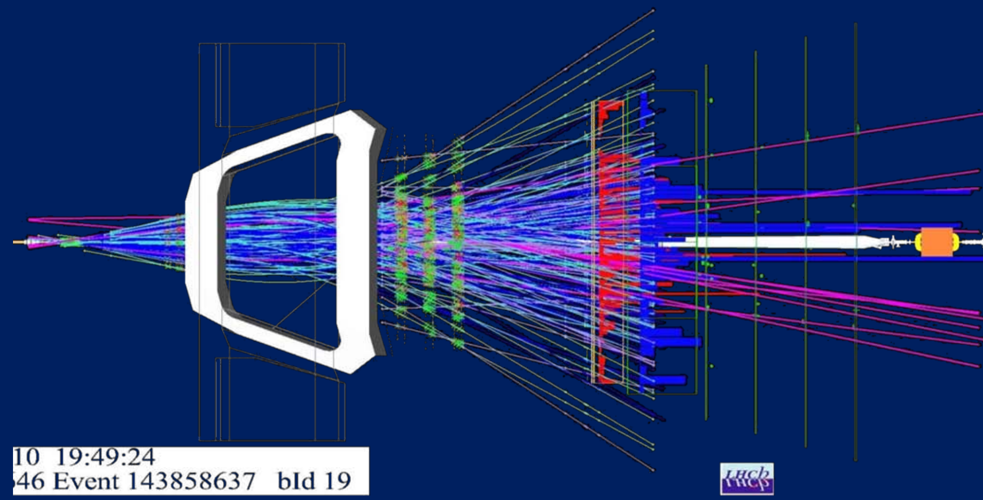
  → Average pile-up ~ 2.1

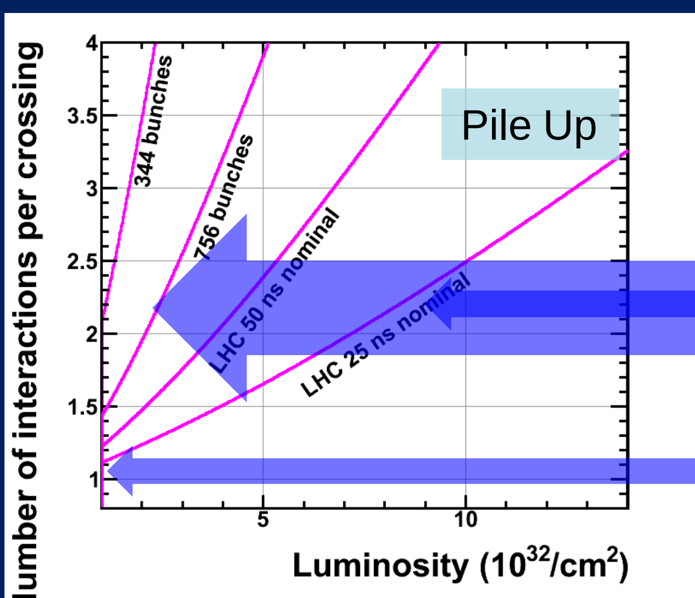
Present LHCb operation:

- $\mathcal{L}$ ~ 3x10^{32} cm^{-2}s^{-1} with 50ns bunch spacing

  (LHC has up to 1380 bunches per beam)

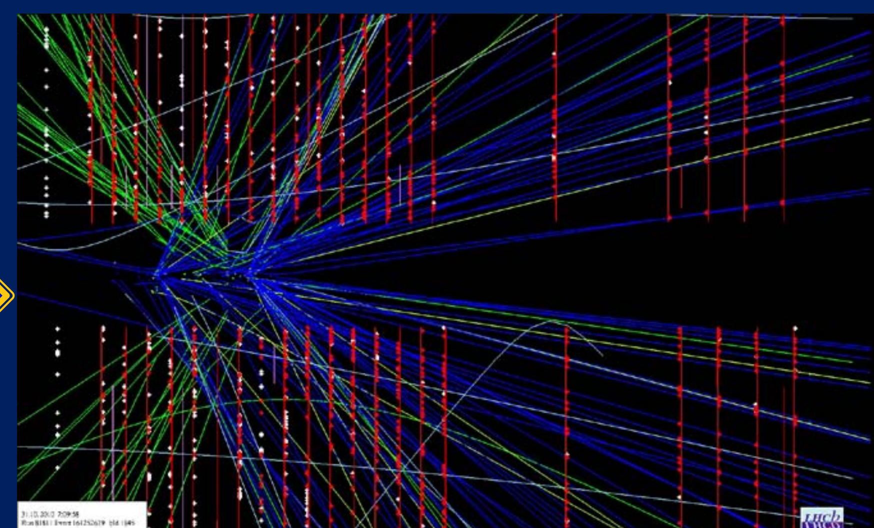
→ Average pile -up of 1.2 - 2.5 has been successfully used



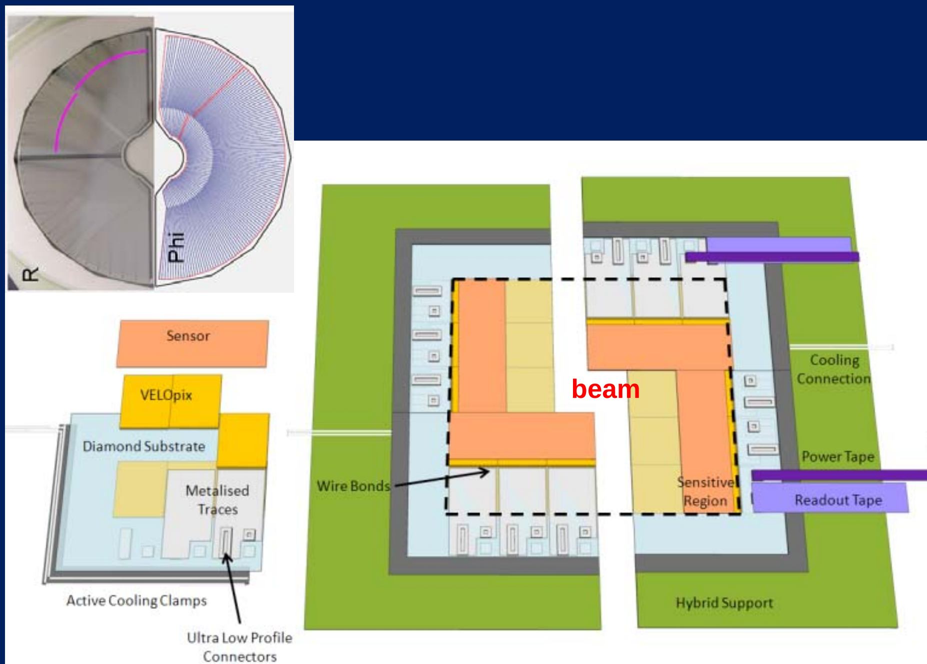


Upgrade
Current

Design



VELO Upgrade



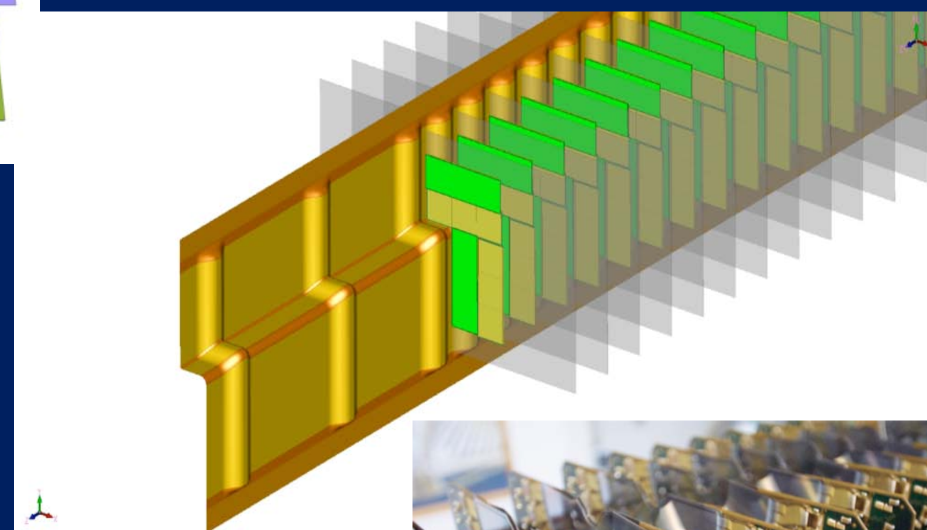
Challenges: Data rates <rate$_{max}$> = 200MHz cm^{-2}
Irradiations$_{max}$= 5.10^{15} 1 MeV n$_{eq}$cm^{-2}
Low material budget

Two options:

- Pixel detector: VELOPIX based on TimePix
  - 55 µm x 55 µm pixel size

  → Advantageous for pattern recognition
- Strip detector: based on proven design
  - reduced strip pitch 30 µm

  → Better IP-resolution performance



R&D ongoing

- Module layout and mechanics
- Sensor options:
  - Planar Si, 3D, Diamond
- CO_2 cooling
- FE - electronics
- RF-foil of vacuum box

Main Tracker upgrade: IT, TT

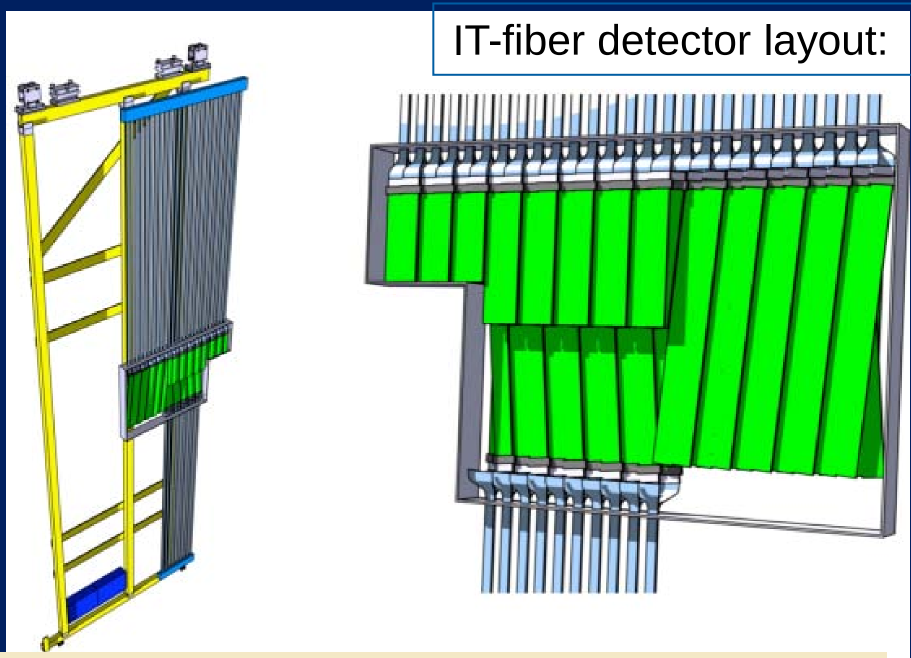
Current IT and TT Si-strip detectors must be replaced:

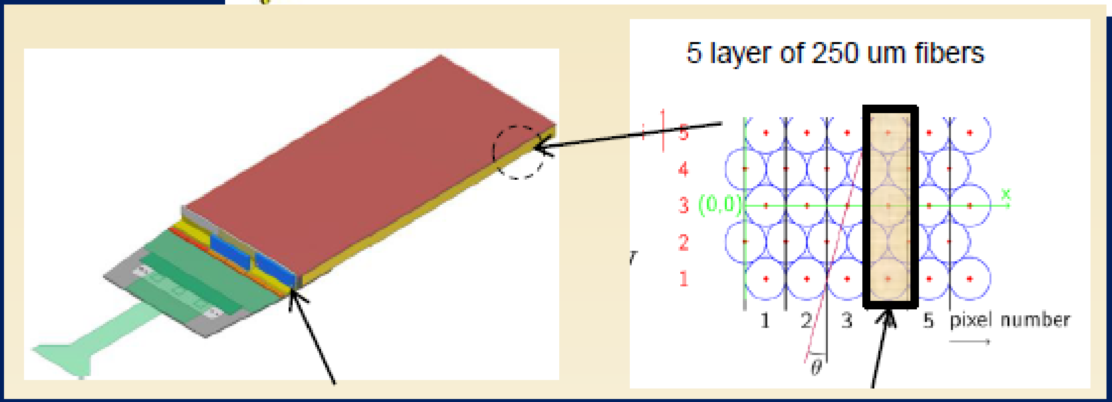
- 1 MHz Readout electronics integrated

Two technologies:

- Silicon strips:
  - Current technology
  - Development of a rad-hard FE chip @ 40MHz

- 250 µm Scintillating Fiber Tracker
  - Fibers coupled to a Silicon Photo-Multiplier
  - SiPM radiation tolerance under study
  - R/O ASIC for SiPM under investigation





SiPM array

SiPM cell coverage

Main Tracker upgrade: OT

Current tracker works already with upgrade pile-up level

spill-over for 25ns bunch-spacing not yet tested

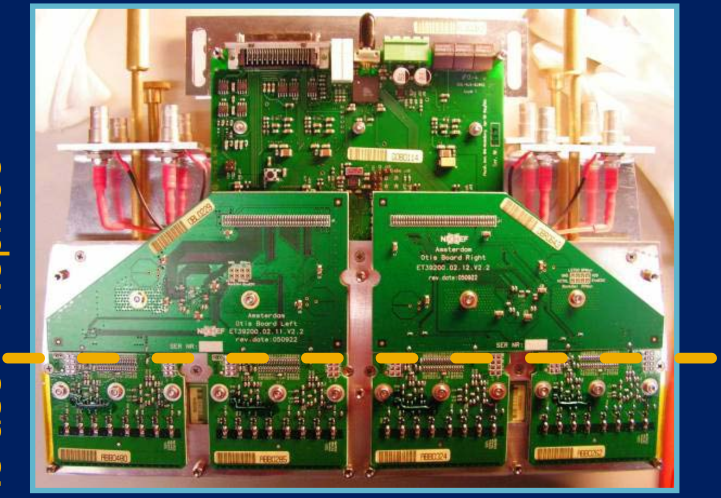
OT straw detector remains for the outer part

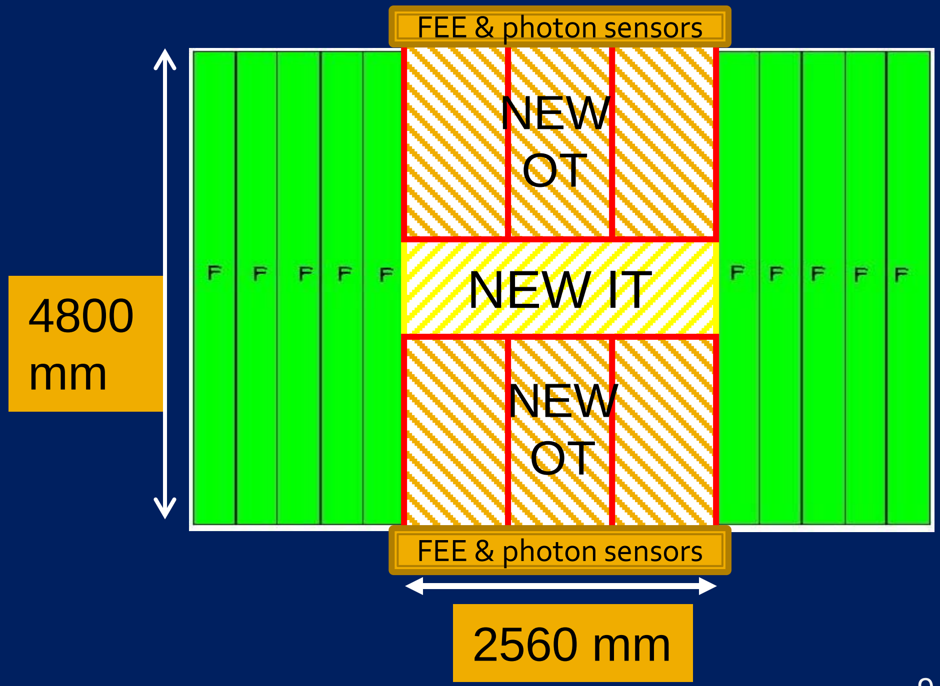
- Detector aging in hot area is under investigation
- Consider module replacements with 1mm Scintillating Fiber Tracker in hottest region

- Replace straw tracker TDC chip by 40 MHz version

Replace

Re-use





PID upgrade: RICH detectors

- Retain RICH-1 and RICH-2 detectors
- Replace Photo-detectors
  - At present: Pixel HPDs with 1 MHz R/O chip integrated
  - Readout for the upgrade: MaPMTs & R/O with 40 MHz custom ASIC

MaPMTs (Hamamatsu):

R7600 vs R11265 :

- 8x8 pixels, 2.0x2.0 mm^2, 2.3 mm pitch (2.9 mm)
- 18.1x18.1 mm^2 active area (23.5x23.5 mm^2)
- CE (simulation) : 80% (90%)
- Fractional coverage: 50% (80%)

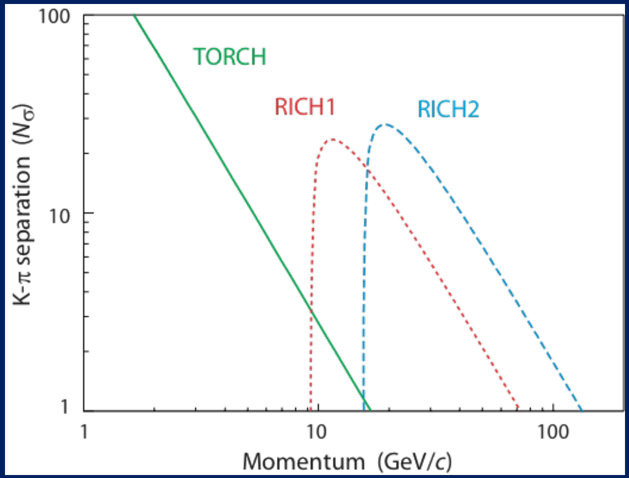
Prototyping using 40 MHz Maroc-3 R/O chip

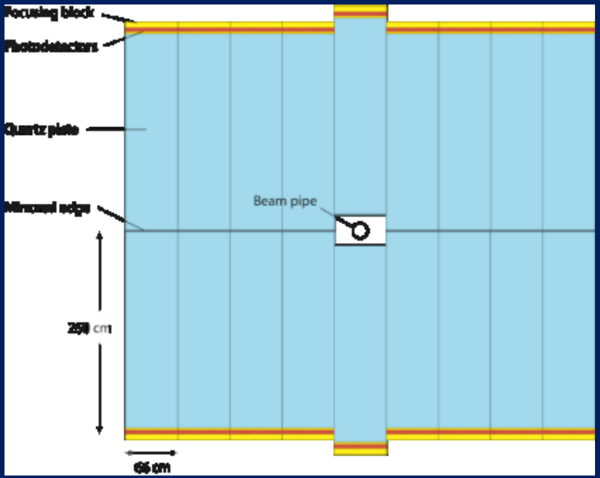
- Gain compensation
- Binary output

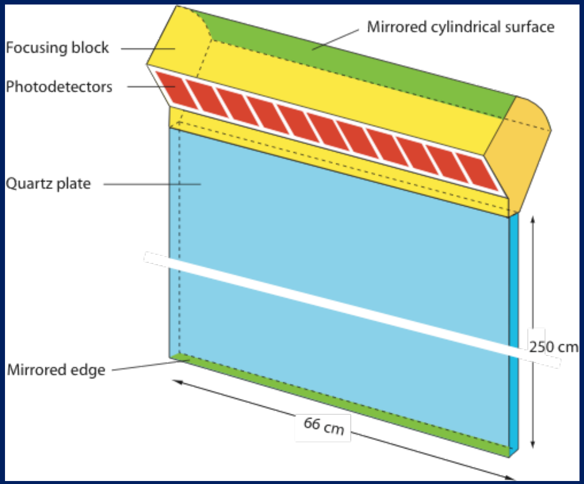
PID upgrade: TORCH

Add Time of Flight detector based on a 1 cm quartz plate, for the identification of p<10 GeV hadrons (replacing Aerogel) combined with DIRC technology:

- **TORCH** = **T**ime **O**f internally **R**eflected **CH**erencov light
- reconstruct photon flight time and direction in specially designed standoff box
- Measure ToF of tracks with ~15 ps (~70 ps per photon)



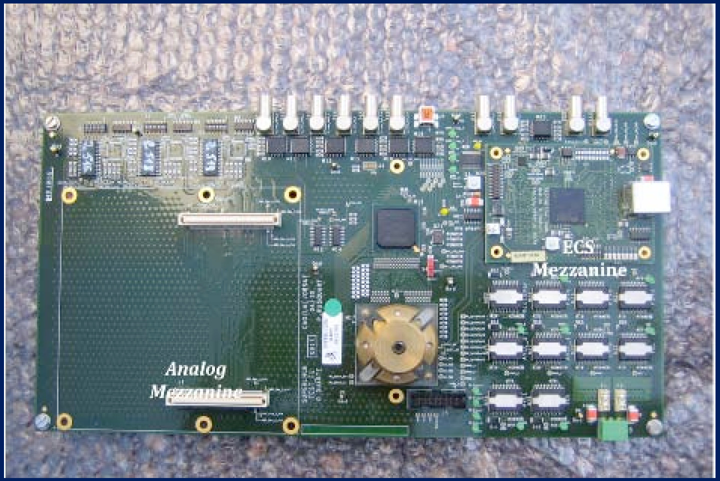




→ could be installed later than 2018

Calorimeter and Muon System

- ECAL and HCAL are maintained
  - Keep all modules & PMTs
  - Reduce the PMTs gain by a factor 5
- PS and SPD will be removed
  - e / γ / hadron separation in HLT with the whole detector info
- New FEE to compensate for lower gain and to allow 40 MHz readout



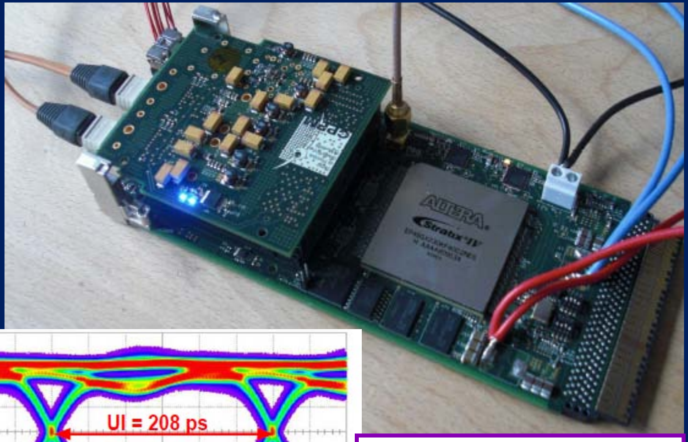
New digital electronics prototype

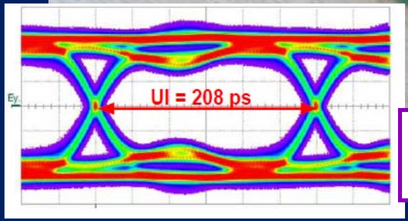
- Muon detectors are already read out at 40 MHz in the present L0 trigger
  - Front-end electronics can be kept
  - Remove detector M1
    - muon ID LLT and HLT
    - room for TORCH
  - MWPC aging :
    - Expect up to 0.7 C/cm on wires for 50 fb^{-1} in hottest region
    - tested up to 0.44 C/cm with no loss of performance
    - 1C/cm is considered as an upper limit for safe operation of MWPCs

Common developments

TELL40: Common **B**ack-**E**nd readout **module**:

- Modular mezzanine-based approach
- Format under investigation:
  - Advanced-TCA motherboard
- Tests of high-speed links on proto-board:
  - 12-way Optical I/Os, GBT compatible
- Transmission to the DAQ using 10 Gb Ethernet

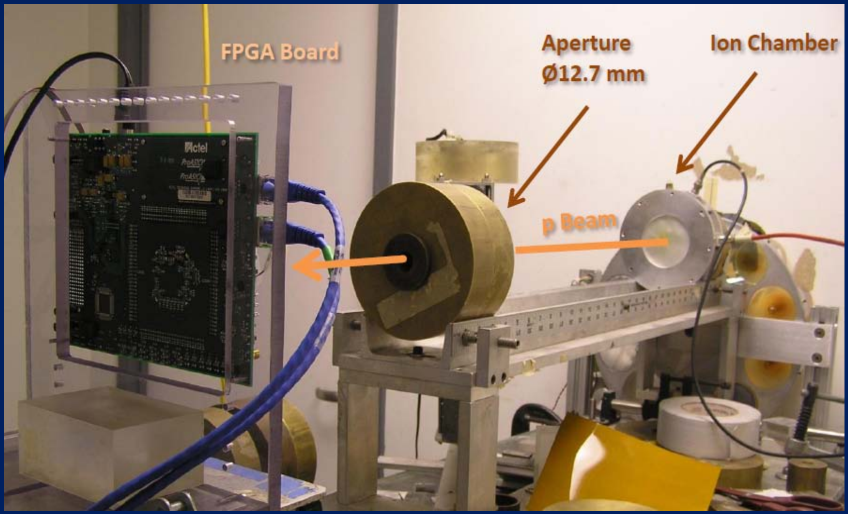




Eye-diagram from one channel @ 4.8 Gbit/s

ACTEL Flash FPGA for front-end modules

- Advantages over ASICs:
  - re-programmable, faster development time.
- Can they survive the radiation?
- Irradiation program started (on A3PE1500)
  - Preliminary results : up to 30 krad ok



The schedule

2010-2012
LHC data taking at 7TeV
Ramping up to a few x 10^{33}

Long shutdown 1
2013- 2014

2015-2017
LHC data taking up to 14 TeV
Ramping up to design luminosity

Long shutdown 2
2017-2018

2019-2021
LHC data taking at design energy and luminosity

Long shutdown 3
Towards HL-LHC

2011 – 2013 :

- Carry out Detector R&D for the upgrade
- Prepare TDRs
- Secure funding

2014 – 2017:

- Construction of detector components VELO, IT/TT, RICH

2017 – 2018:

- Installation and commissioning of the upgraded detector

2019 onwards:

- Data-taking with the fully upgraded LHCb detector

Conclusions

- LHCb has a firm plan to upgrade by 2018:
  - Readout entire detector at 40 MHz with a fully software-based trigger
  - Enormous samples of exclusive b- and c- decays, particularly in the B_s sector
  - Independent of the LHC luminosity upgrade.
- Upgrade LOI submitted to the LHCC in March 2011
  - LHCC considers “the physics case compelling” and the 40 MHz readout as the right upgrade strategy.
  - LHCC encouraged LHCb to prepare a TDR as soon as possible.
- Given its forward geometry, its excellent tracking and PID capabilities and the foreseen flexible software-based trigger, the upgraded LHCb detector
  - is an ideal detector for the next generation of flavour physics experiments
  - provides unique and complementary possibilities for New Physics studies beyond flavour.