LHCb in the HL-LHC era

A very high luminosity flavor physics experiment at LHC

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INFN – Florence and CERN

On behalf of the LHCb collaboration

Workshop on the physics of HL-LHC, and perspectives at HE-LHC

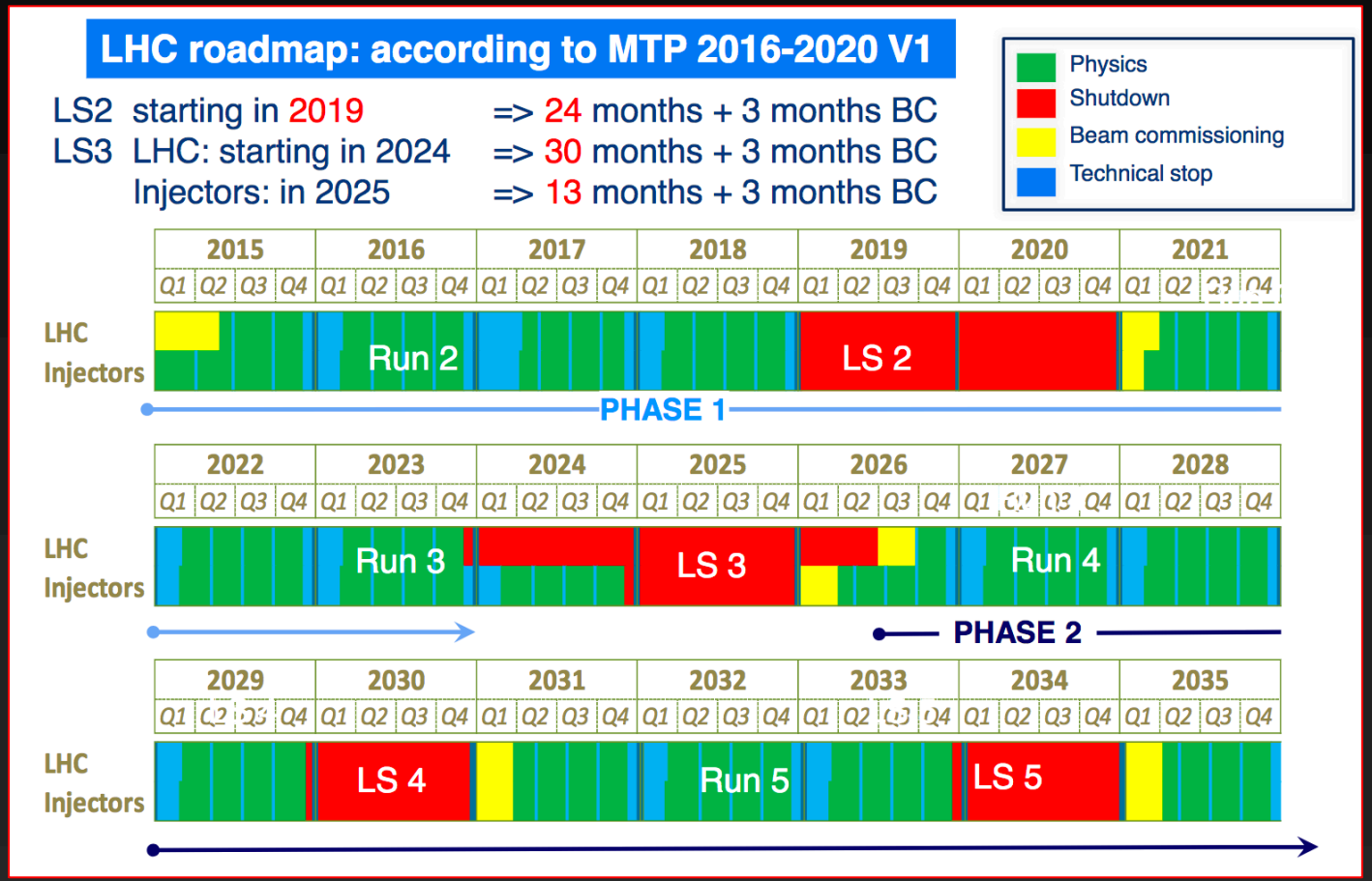
CERN, 30 October 2017 to 1 November 2017

- Setting the stage
- Plans for LHCb future upgrades
- Detector challenges
- Conclusions and outlook

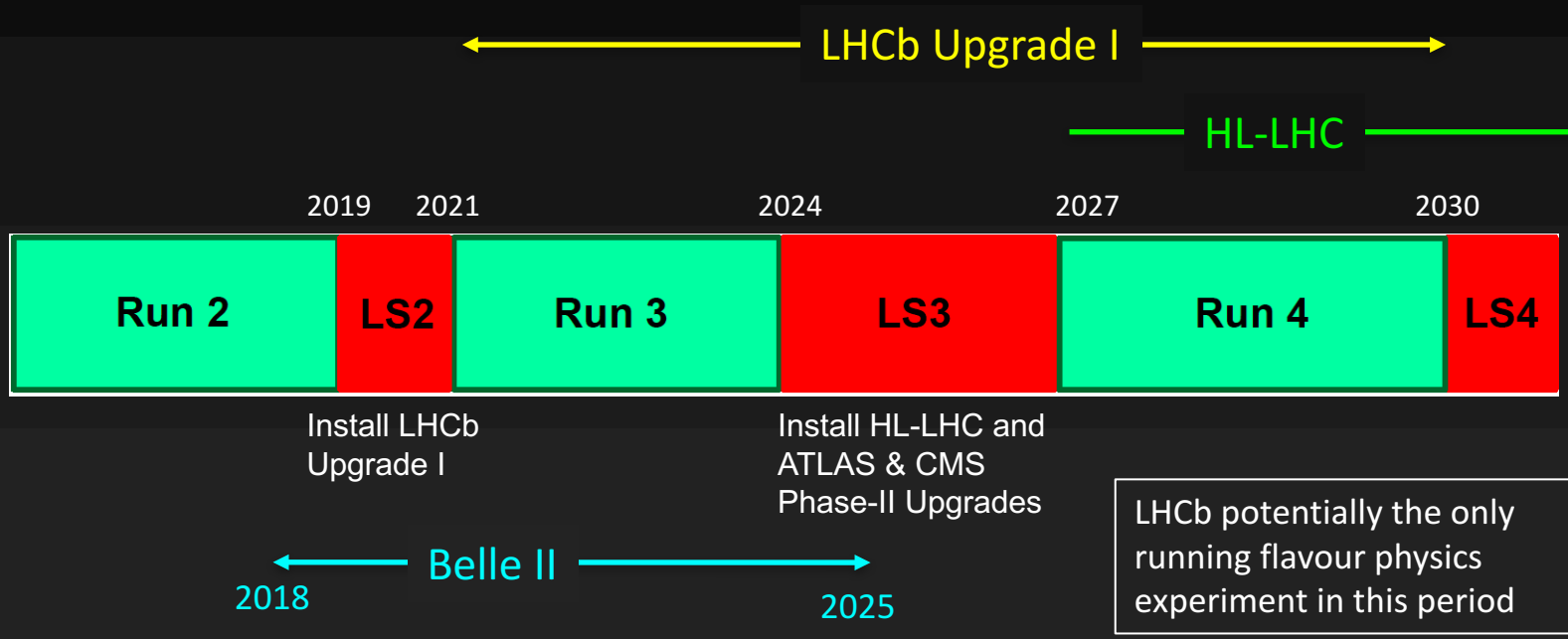
Setting the stage

LHCb timeline in the next decades

LHC schedule up to 2035



Focus on the decade 2020-2030



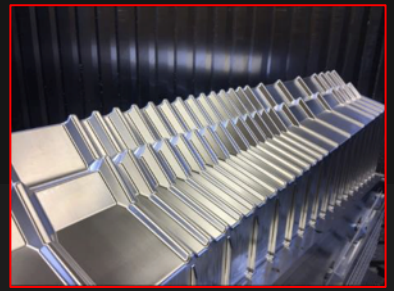
LHCb potentially the only running flavour physics experiment in this period

Status of Upgrade I

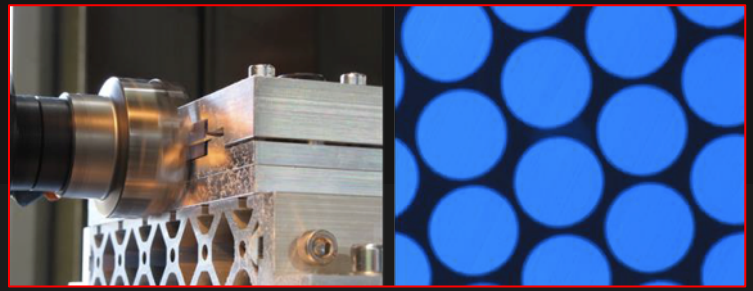
- Construction well advanced, aim at installation in 2019

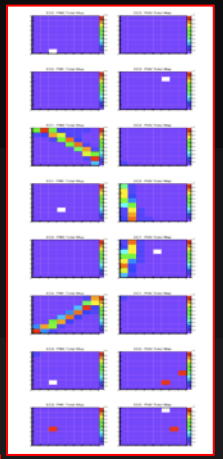
Prototypes of DAQ board (PCIe40)

VELO RF-foil (250 um thick machined aluminum foil)



Machining and light scan of the scintillating fiber mats for the fibre tracker



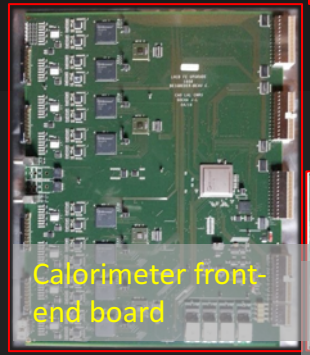


Cherenkov ring from a full RICH MaPMT module

Si µchannel cooling plate for VELO with soldered connector

Upstream Tracker silicon sensor module under test

First scintillating fibre modules arriving at CERN



Calorimeter front-end board

Muon system readout ASIC

The LHCb Upgrade I will enable to integrate 50 fb^{-1} by end of Run 4.

Significant progress beyond then requires a new experiment able to run at much higher luminosity

Proposal for future LHCb upgrades

- Expression of interest for an Upgrade II for LHC run 5

- Starting point: Upgrade I
  - ★ LHC Run-III, Run-IV (2021-2023, 2026-2029)
  - ★ Major upgrade of current experiment
  - ★ Profit from LS3 for a consolidation of Upgrade I

- LHCb Upgrade II
  - ★ Major new experiment to be installed in LS4
  - ★ LHC Run-V (2031-2033)
  - ★ Profit from HL-LHC potential
  - ★ May be the only general heavy flavour experiment on this timescale

- Strong physics case (dedicated talk by V. Vagnoni)

"It is proposed to upgrade the LHCb experiment in order to take full advantage of the flavour-physics opportunities at the High Luminosity LHC (HL-LHC).
.....
This project will extend the HL-LHC's capabilities to search for physics beyond the Standard Model, and implements the highest-priority recommendation of the European Strategy for Particle Physics (Update 2013), which is to exploit the ***full potential of the LHC*** for a variety of physics goals, including flavour."

Evolution towards a HL flavour experiment at LHC

- Running at higher luminosity is limited by detector not by LHC !
- Upgrade I: $4 \times 10^{32} \rightarrow 2 \times 10^{33}$ cm^{-2} s^{-1}
  - ★ Remove hardware trigger limitations: Fully Software Trigger, **40MHz readout**
  - ★ Exploit advances in detector technology
  - ★ Better utilise LHC capabilities
  - ★ Collect >50 fb^{-1} data

Upgrade I (LS2)
- HL-LHC not needed
- But compatible with HL-LHC phase

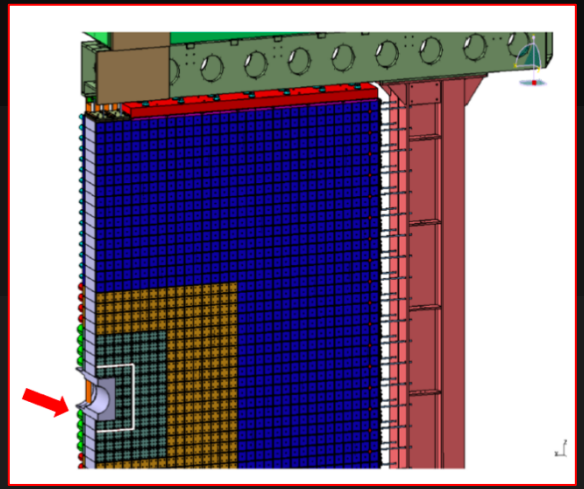
- Upgrade II: $2 \times 10^{33} \rightarrow 1\text{-}2 \times 10^{34}$ cm^{-2} s^{-1}
  - ★ need largely new detectors
  - ★ Radiation damage !
  - ★ Need to cope with high pileup
  - ★ Collect > 300 fb^{-1} data

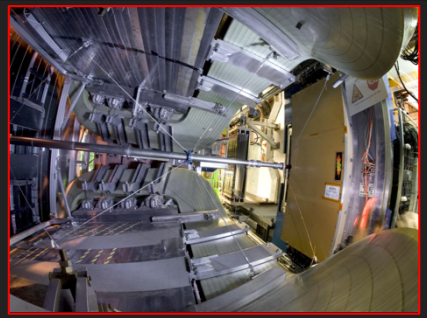
Upgrade II (LS4)
- Profit from HL-LHC phase luminosities

LS3 consolidation

LS3 consolidation of Upgrade I LHCb

- Profit from LS3 to implement some consolidations of the upgraded LHCb
  - ★ With an eye to LS4 upgrade II…
- Some already planned and mandatory
  - ★ e.g. replace innermost part of ECAL due to radiation damage
- Other proposed to improve LHCb performance and physics acceptance
  - ★ e.g. tracking stations inside the magnet



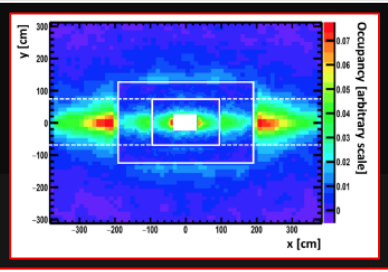


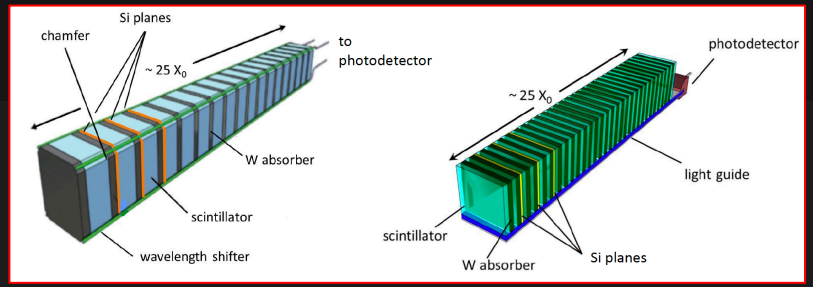
LS3 consolidation: Electromagnetic Calorimeter

- Inner ECAL replacement required due to radiation damage
  - ★ Partial replacement only
- Strong Physics Interest: γ, π^0, e^-
- Improve position resolution
  - ★ Reduced Moliere radius, cell granularity

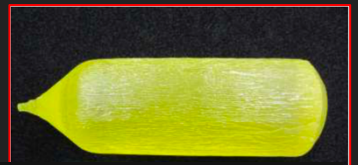
- A suitable technology is a tungsten modular sampling-calorimeter
  - ★ Option with a clear light guide and no wavelength shifter
- Introduce timing to mitigate pile-up
  - ★ Silicon timing planes
- R&D on
  - ★ Silicon planes
  - ★ New rad-hard crystals
  - ★ New rad-hard light guides

See also talk on calorimetry by Preema Pais

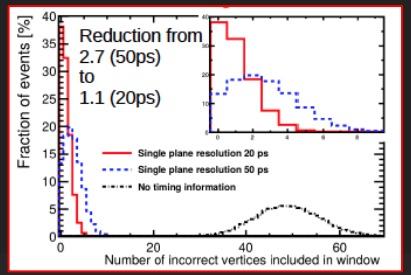




JoP: Conf. Ser. 587 (2015) 012039, arXiv:1405.6202

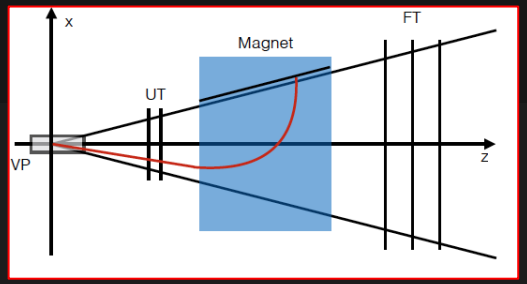


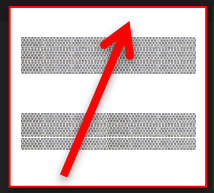
Ce-doped GAGG crystals ($Gd_3Al_2Ga_3O_{12}$)

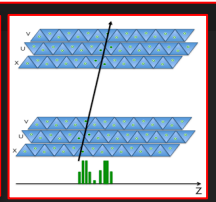


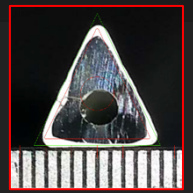
LS3 consolidation: Magnet Side Stations

- Improve tracking acceptance for low momentum particles
- Install tracking stations on the dipole magnet internal sides









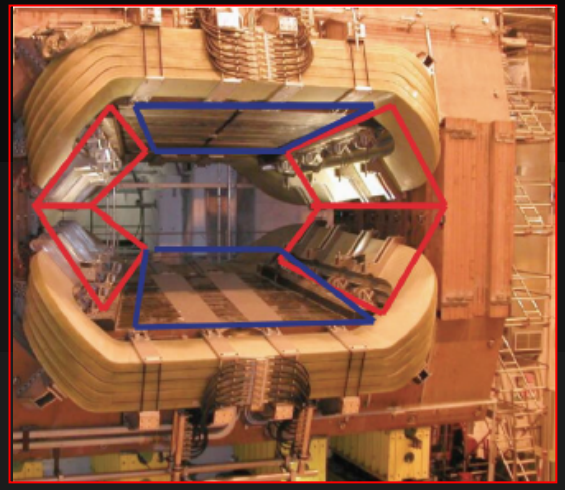
Scintillating fibers

Extruded scintillators bars

Physics motivation

- prompt charm decays
- $R(\Lambda_c^*)$
- $R(D^*)$
- $\sum_b$
- B^*
- multi body B decays
- radiative decays in dielectrons
- gluon PDF
- soft physics in heavy ion

R(K$^{(*)}$)



Gain wrt UT+FT tracking

channel	gain
$D^* \to D(\pi K)$	21%
$\Lambda_b \to \Lambda_c^* \tau\nu$	60%
$B \to D^* \tau\nu$	26%
$\sum_b \to \Lambda_b \pi$	29%

Expect improvement in PID for low momentum tracks

LS4 Upgrade II

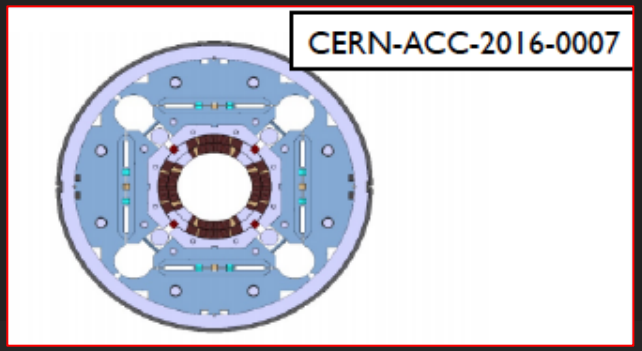
Machine requirements

Accelerator: Can LHCb Upgrade II run ?

Some preliminary scenarios:

	β^* [m]	Maximum $\mathcal{L}$ [$\times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$]		Target levelling $\mathcal{L}$ [$\times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	Fill length [h]		Levelling time [h]		$\int \mathcal{L}\,dt$ [$\mathrm{fb}^{-1}/\mathrm{yr}$]		
		−	+		−	+	−	+	−	+	
	3	1.04	0.78	0.20	8.1	8.1	8.1	8.1	10	10	Phase-I (best case)
Can be done	2	1.53	1.04	1.00	7.7	7.8	2.8	0.4	39	31	
	2	1.53	1.04	/	7.6	7.8	/	/	43	31	No levelling
Will be very tough	1	2.90	1.66	1.00	7.5	7.6	6.0	3.5	48	42	
	1	2.90	1.66	2.00	7.3	7.5	2.3	0	73	48	
	1	2.90	1.66	/	7.2	7.5	/	/	80	48	No levelling

- LHCb can collect ~ 50 fb^{-1} per year **without** affecting ATLAS/CMS



- LHCb IP not designed for HL-LHC experiment: shielding is an issue
- Inner Triplet quadrupole need to be replaced at **~300 fb^{-1}**
  - Probably prohibitively expensive
- LHC side impressive studies on additional requirements
  - **No showstoppers !**
- Luminosity difference between two magnet polarities still needs further studies

LS4 Upgrade II

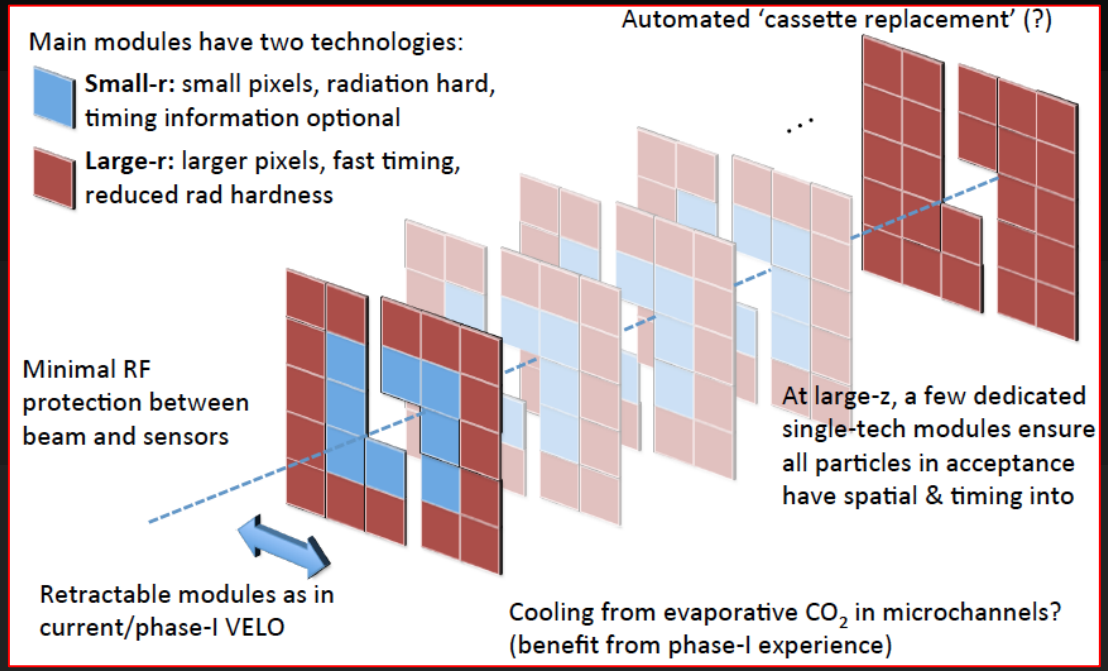
Detector challenges - tracking

Detector challenges: vertex detector

- x10 particle multiplicity
  - ★ Higher granularity – smaller pixels
- x10 vertex multiplicity
  - ★ timing
- x10 radiation damage
  - ★ Novel rad-hard sensors
  - ★ Replacement

- R&D starting

See also talks by M. Williams and G. Ciezarek

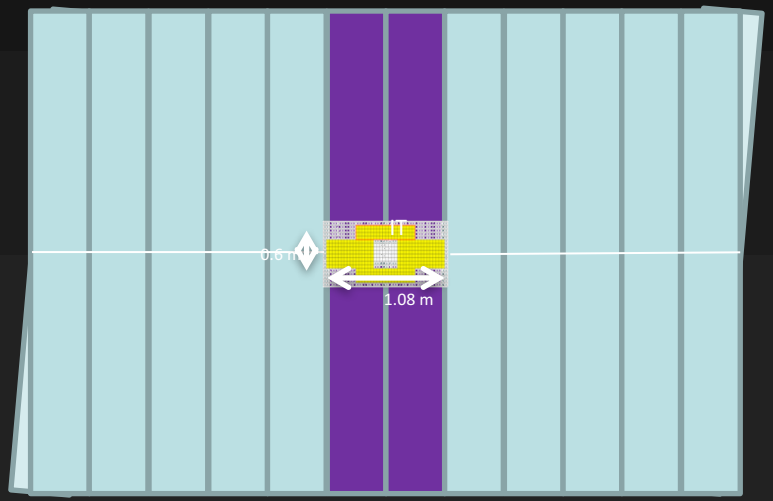


Detector challenges: tracker

- Adapt the scintillating fibre tracker to higher luminosities in two steps

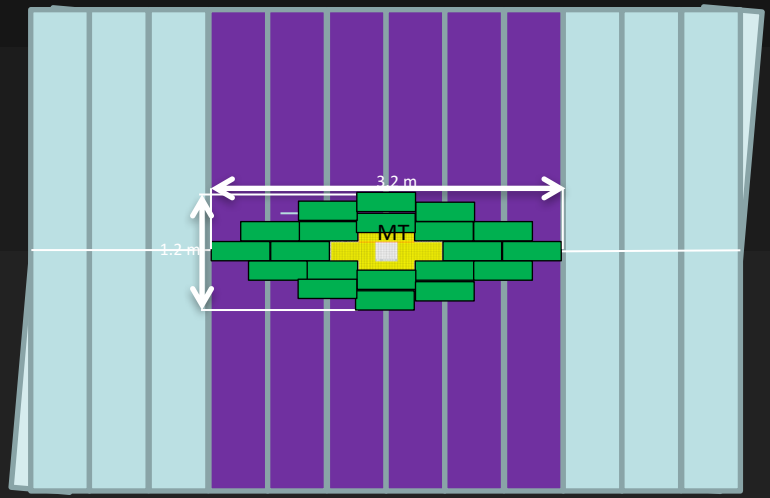
STEP 1 – LS3 consolidation

- Replace 2 inner SciFi modules
- Add a Si Inner Tracker $O(5)m^2$



STEP 2 – Upgrade II

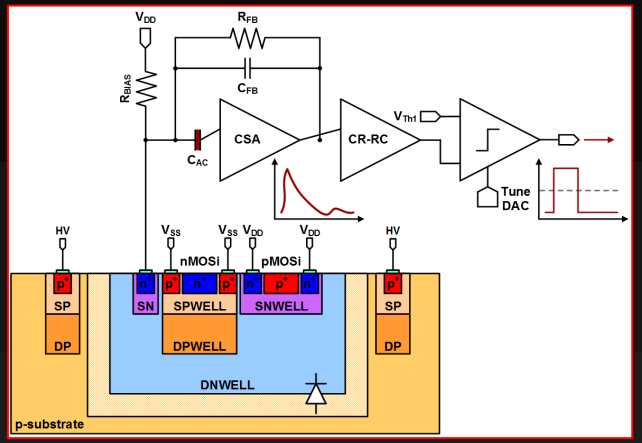
- Replace all SciFi modules
- Add a Si Middle Tracker $O(20)m^2$

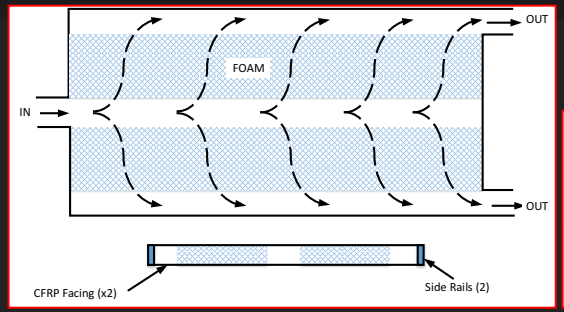


- SciFi Neutron "torture": may just survive 300 fb^{-1}

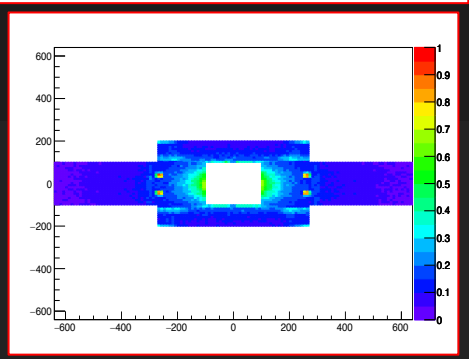
Detector challenges: Inner Tracker – HV-CMOS

- A possible technological solution for Si inner tracker: HV-CMOS
- Sensor & Electronics on same chip
- Commercial Foundries
- Low cost (few CHF/cm^2)
- High granularity
- High signal/noise
- Low material (50µm)
- Radiation tolerant (>10^{14} 1 MeV n_{eq}/cm^2)





Support/Cooling Prototype



Occupancy peak
0.7 hits/cm^2/event

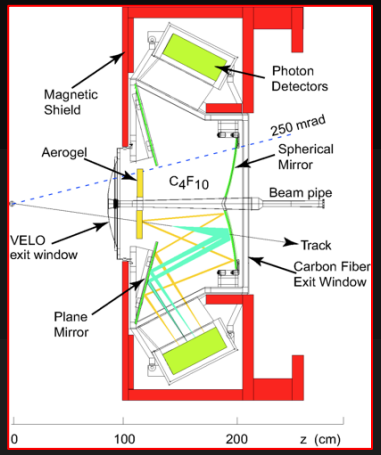
R&D/applications for ATLAS/Mu3e (see e.g arXiv:1611.02669v1 [physics.ins-det])

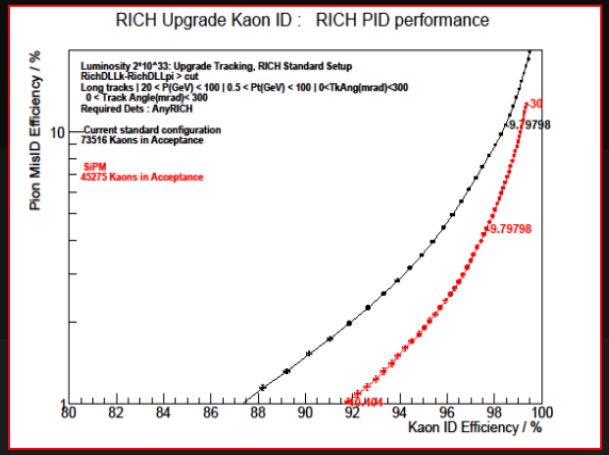
LS4 Upgrade II

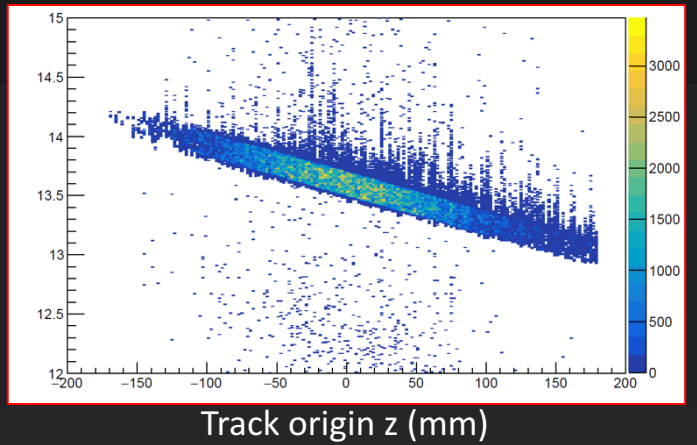
Detector challenges - PID

Particle Identification: RICH

- Granularity
  - ★ in Upgrade II RICH I peak occupancies would exceed 100%
  - ★ Increase pixel granularity 7mm^2 →1mm^2
- Time resolution
  - ★ Disentangle busy events
- Use B-field insensitive photodetectors
  - ★ SiPM or MCP
- Concepts for improving optical and chromatic uncertainty
- Equip central region in LS3 consolidation?

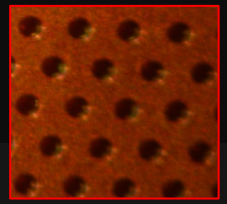


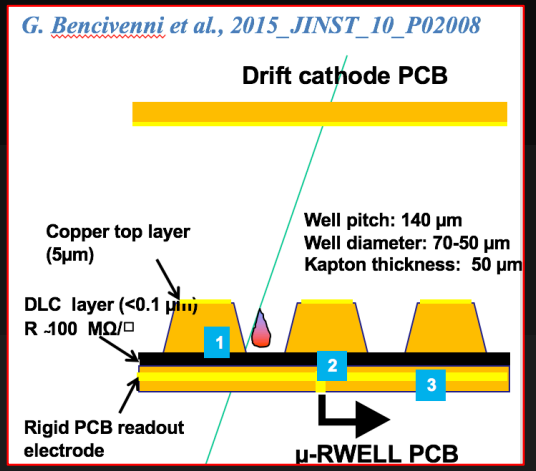




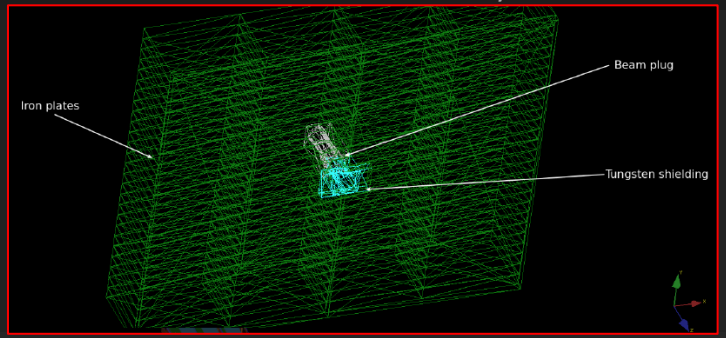
Particle Identification: Muon system

- High occupancy expected:
  - ★ innermost regions close to beam pipe and behind the calorimeters
  - ★ Up to 3 MHz/cm^2
  - ★ Current detector highly inefficient because of dead time
  - ★ MWPC would suffer from aging
- Proposed solutions:
  - ★ Improved shielding behind CALOs
  - ★ μ-RWELL chambers
    - Meet radiation requirements
    - Cheap
    - Easy to assemble

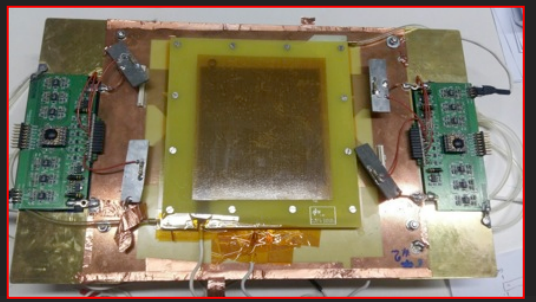




Simulation by Peter Griffith

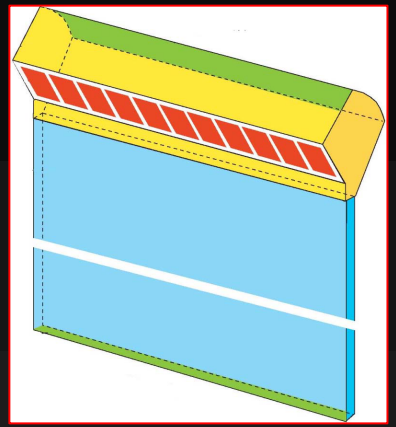


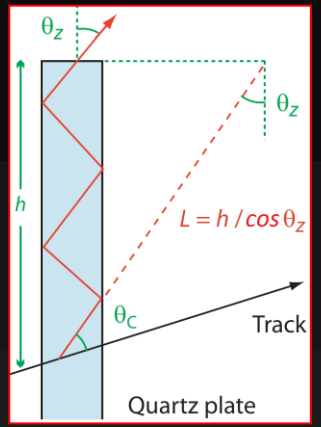
Prototypes tested

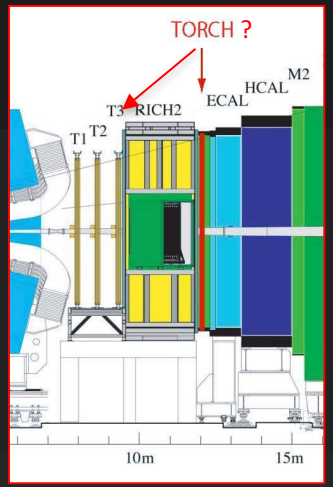


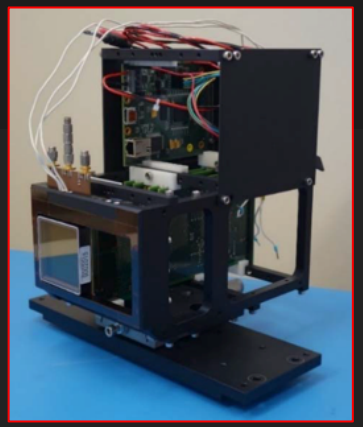
Particle Identification: TORCH

- TORCH: Time Of Internally Reflected CHereknov Light
- Technology:
  - ★ Quartz radiator, MCP-PMT
  - ★ Demonstrator tested: 85 ps/photon resolution (goal 70 ps/photon → 15 ps/track with 30 photons/track)
  - ★ Full-scale in construction
- Can provide PID for low momentum particles (<10 GeV) via ToF
- Combined with a converter, can provide timing for high energy photons for vertex association









Torch demonstrator

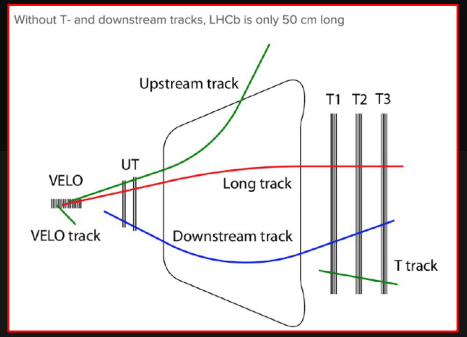
The TORCH project is funded by an ERC Advanced Grant under the Seventh Framework Programme (FP7), code ERC-2011-ADG proposal 299175.

LS4 Upgrade II

Detector challenges – data processing and trigger

Detector challenges: data processing and trigger

- Data processing in a HL flavour experiment is a real challenge
- Every bunch crossing contains a potentially interesting event
  - ★ Must process as much as possible in real time
- Paradigm is fully software trigger as in LHCb Upgrade I
  - ★ One order of magnitude more complex problem in Upgrade II !



- Timing is key ingredient
  - ★ for a full optimization detectors AND trigger have to be designed synergistically
  - ★ For example, consider timing capabilities also for tracking stations

- Studies are underway to asses benefits from dedicated high-performance processors (GPUs, FPGAs etc.) to solve specific low-level tasks.
- For example: embedded tracker unit to process downstream tracks
  - ★ Targeting long lived particles (Λ, K_S, K_L, long lived BSM particles)
  - ★ Algorithms implemented on commercial FPGA boards
  - ★ Run before HLT, aim at recovering downstream tracks at HLT level

LS4 Upgrade II

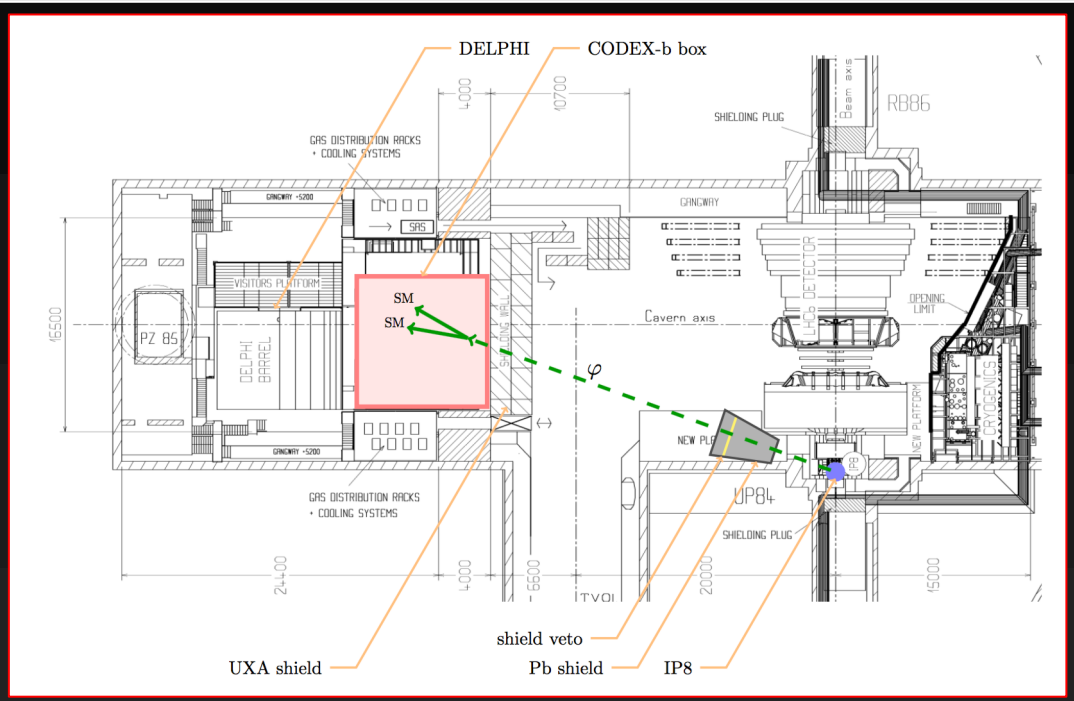
Further developments

Further developments

- The unique forward geometry of LHCb inspires also more “exotic” proposals

- e.g. CODEX-b (arXiv:1708.09395)
  A Compact Detector for Exotics at LHCb
  - ★ A proposal for an extension/new subsystem of LHCb dedicated to search of long-lived particles

See dedicated talk by Dean Robinson



Conclusions and outlook

- LHCb is developing a plan to evolve to a very HL flavour physics experiment
  - ★ Targeting LS4/Run 5
  - ★ Aim at >300 fb^{-1}
- Staged upgrade
  - ★ LS3 consolidation of Upgrade I to fully exploit the planned 50 fb^{-1}
  - ★ LS4: installation of Upgrade II running at 1-2x$10^{34}cm^{-2}s^{-1}$
- R&D starting
  - ★ Technological challenges in all detectors
  - ★ Timing is a key feature
- Submitted and EoI, preparing a physics case document ☞ input to European strategy for particle physics