The LHCb upgrade I

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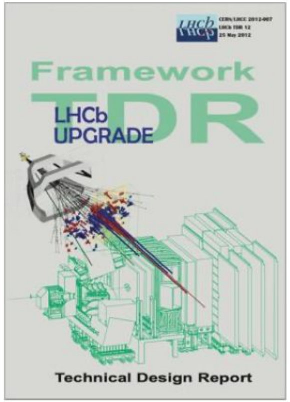
Michel De Cian (Heidelberg University)

on behalf of the LHCb collaboration

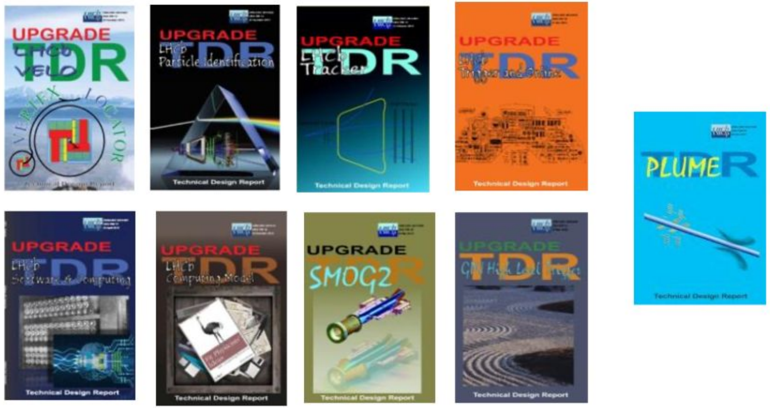
June 16, CERN

LHCb Upgrade I

2007



2012



2012-2021

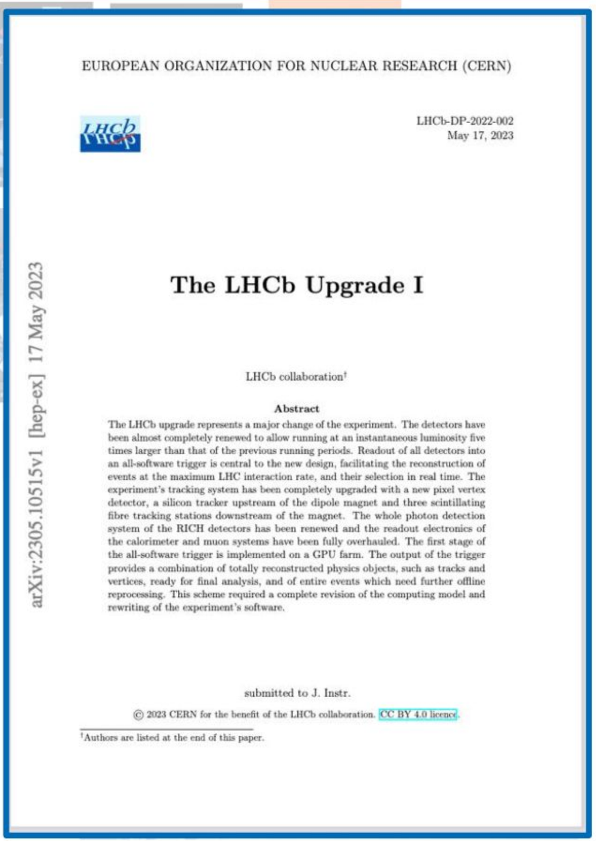
2019

2022/23

LHCb Upgrade I

Many thanks to Giovanni Passaleva, Massimiliano Ferro-Luzzi, contributors, section editors, John Walsh and Editorial Board….

But primarily to **everyone** who has contributed to Upgrade I



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

LHCb-DP-2022-002
May 17, 2023

arXiv:2305.10515v1 [hep-ex] 17 May 2023

The LHCb Upgrade I

LHCb collaboration†

Abstract

The LHCb upgrade represents a major change of the experiment. The detectors have been almost completely renewed to allow running at an instantaneous luminosity five times larger than that of the previous running periods. Readout of all detectors into an all-software trigger is central to the new design, facilitating the reconstruction of events at the maximum LHC interaction rate, and their selection in real time. The experiment's tracking system has been completely upgraded with a new pixel vertex detector, a silicon tracker upstream of the dipole magnet and three scintillating fibre tracking stations downstream of the magnet. The whole photon detection system of the RICH detectors has been renewed and the readout electronics of the calorimeter and muon systems have been fully overhauled. The first stage of the all-software trigger is implemented on a GPU farm. The output of the trigger provides a combination of totally reconstructed physics objects, such as tracks and vertices, ready for final analysis, and of entire events which need further offline reprocessing. This scheme required a complete revision of the computing model and rewriting of the experiment's software.

submitted to J. Instr.

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†Authors are listed at the end of this paper.

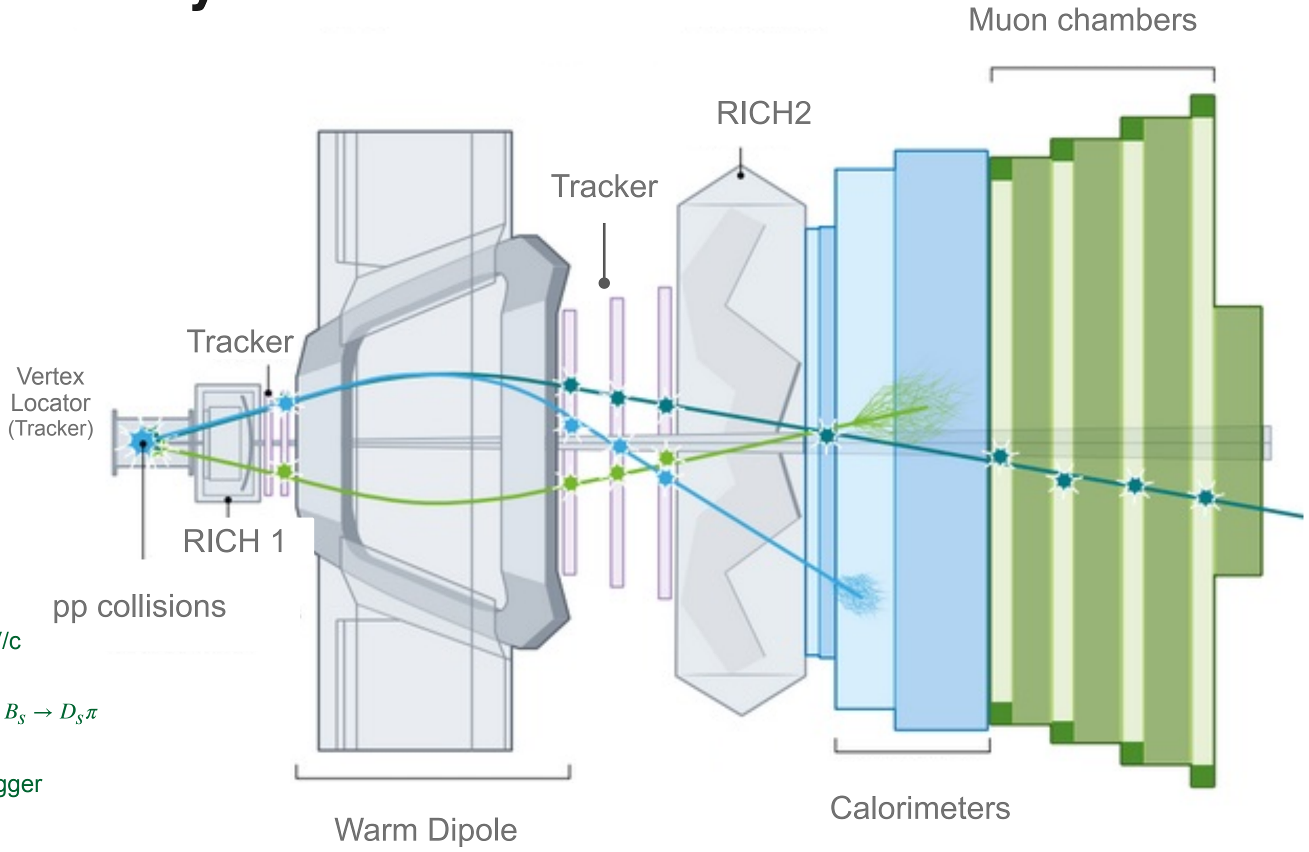
accepted for publication in JINST

https://arxiv.org/abs/2305.10515

LHCb Conceptual Layout

LHCb is a **general-purpose forward detector** at the LHC which is **particularly suited** to precision measurements in the beauty and charm sectors, designed to:

- capture forward production
- trigger on low p_T
- provide particle identification for flavour tagging and distinguishing topologically similar decays e.g. $B \to \pi\pi$, $B \to K\pi$



✓ Δp / p = 0.5% at < 20 GeV/c, 1.0% at 200 GeV/c
✓ IP resolution = 15 + 29 / p_T [GeV/c] μm
✓ decay time resolution 45 fs for $B_s \to J/\psi\ \phi$ and $B_s \to D_s\pi$
✓ Kaon ID 95% for 5% $\pi \to K$ mis-id probability
✓ full real time reconstruction in the high level trigger

LHCb Upgrade I challenge

The LHCb Upgrade I has transformed the detector to cope with new challenges at Run 3 and Run 4

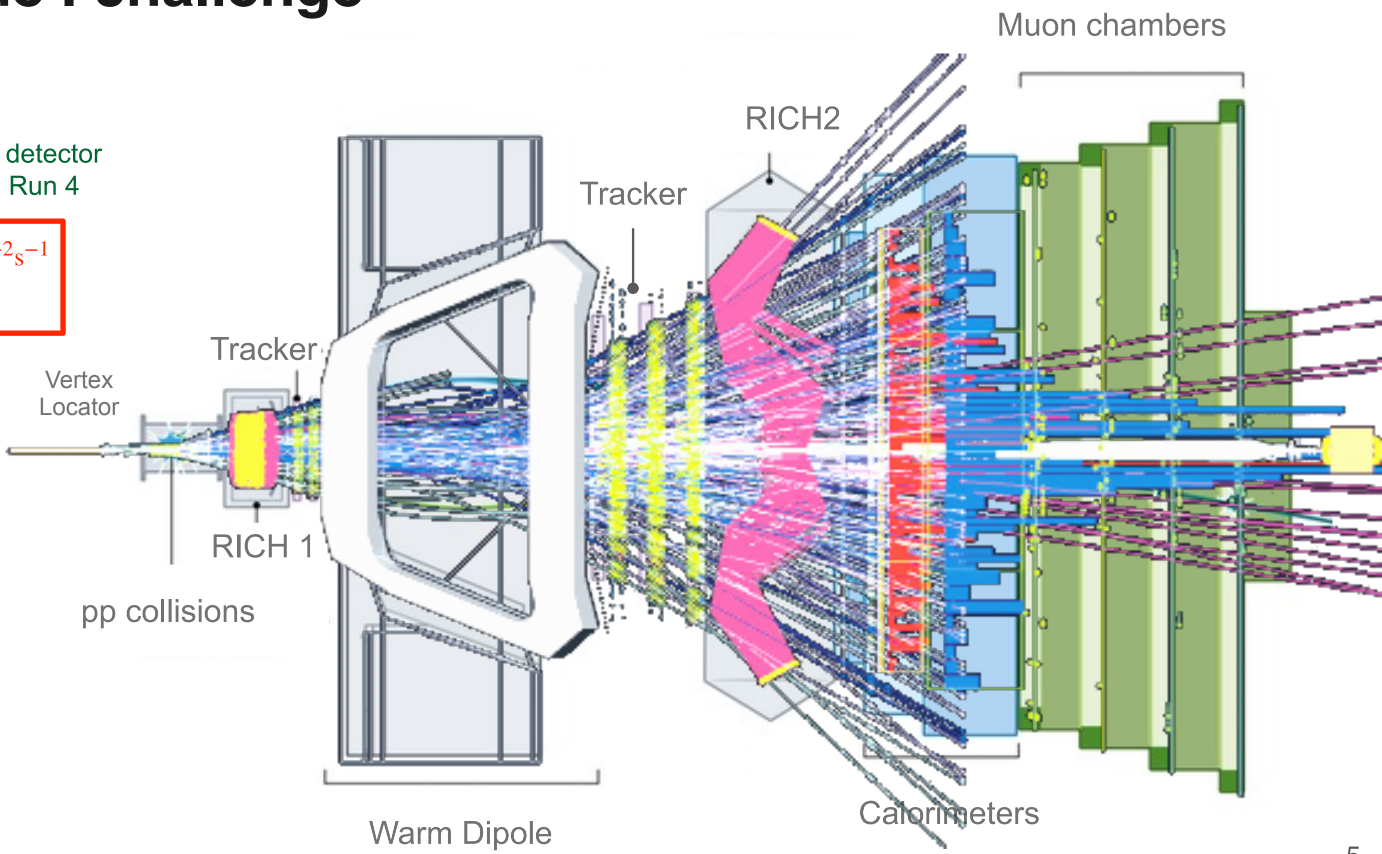
Raise operational luminosity to $2 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$

Move to full 40 MHz Software trigger

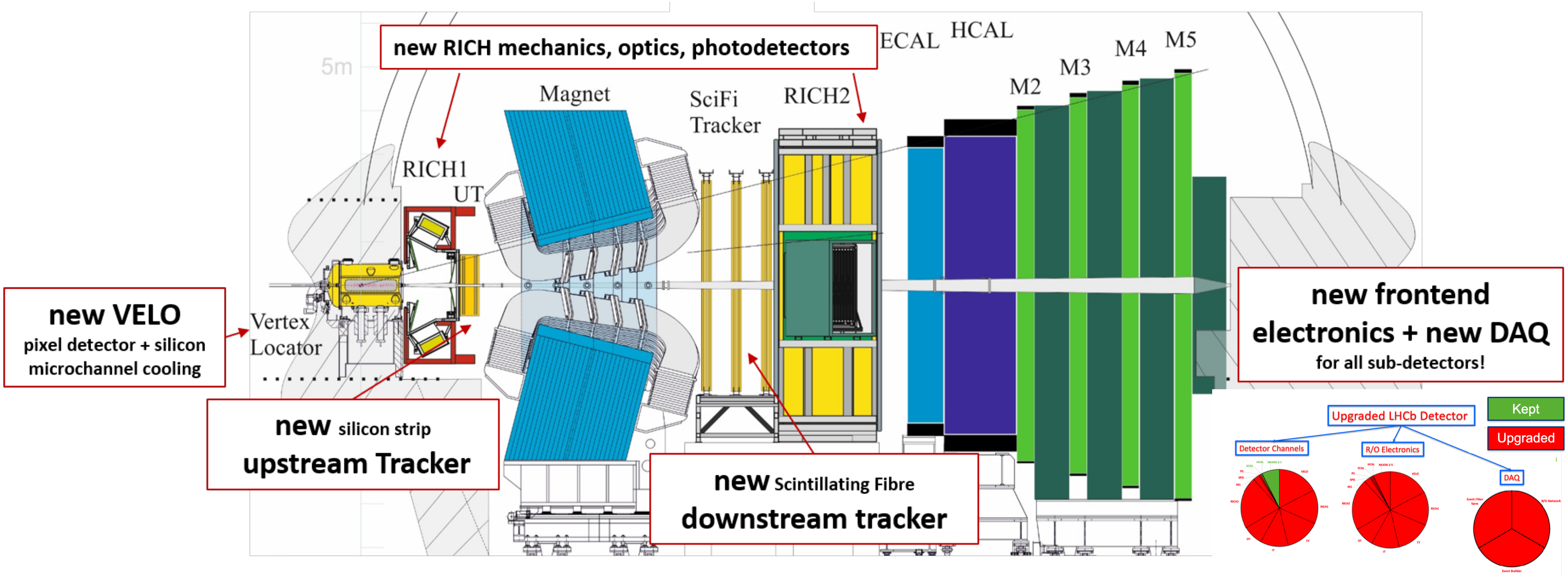
Huge increase in precision and the ability to perform studies beyond the reach of the current detector

Flexible trigger and unique acceptance opens up opportunities in topics apart from flavour → a general purpose detector in the forward region

Only possible with vast improvements in granularity, readout speed, radiation hardness, and trigger innovations



LHCb Upgrade I - what has changed

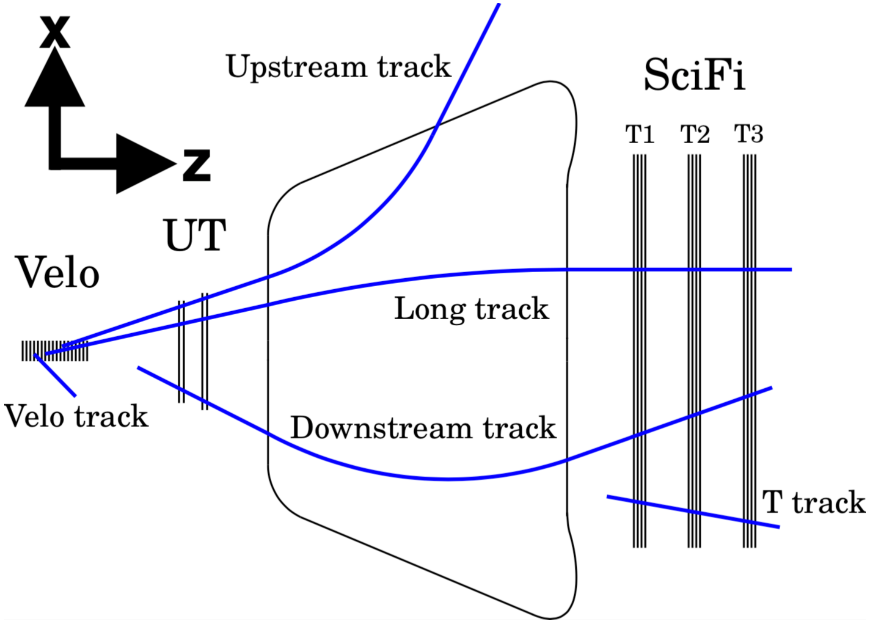


LHCb charged particle reconstruction strategy

Reconstruction down to 2 GeV of momentum and 80 MeV of transverse momentum

Efficiency optimised for pseudorapidities between 2 and 5

Better than 0.5% momentum resolution for hadrons and muons from 2-100 GeV



Long tracks: primary objects for almost all physics analyses, best momentum resolution and identification of point of origin (primary ***pp*** interaction or secondary particle decay)

Downstream tracks: crucial to increase acceptance for V0 particles and increase reach for LLP searches

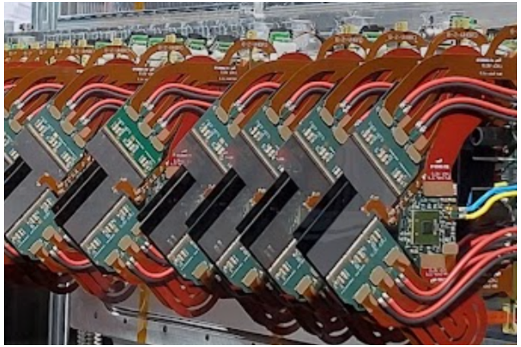
Upstream/T-tracks: primarily used to improve particle identification performance by vetoing deposits associated with these tracks in the PID detectors

Vertex Locator (VELO)

rows of silicon microstrip modules

Silicon VErtex LOcator

strips → pixels

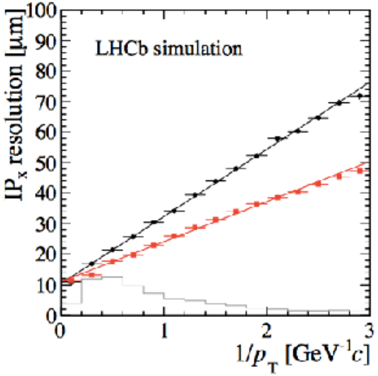


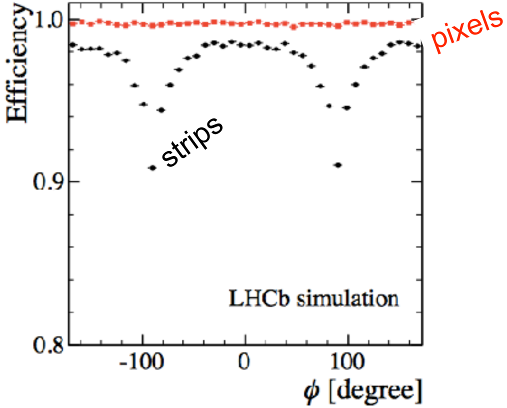
rows of silicon hybrid pixel modules

Pixel design with

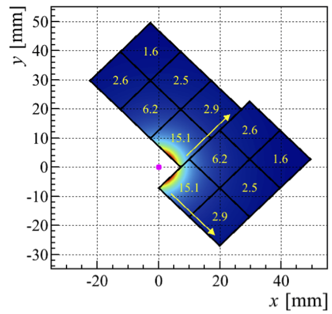
micro-channel cooling,
(with reduced aperture and thinner RF box)

superior to strips for impact parameter resolution and efficiency





VELO - Sensors and ASICs

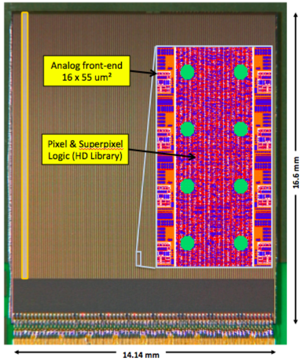


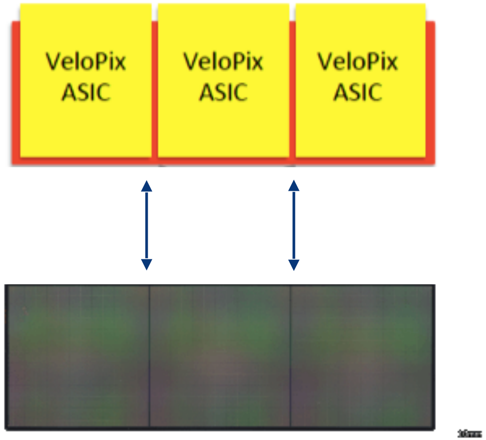
Challenges:

- Very high (8 x 10^{15} n_{eq}/cm^2 for 50 fb^{-1}) & non-uniform irradiation (~ $R^{2.1}$)
- Huge data bandwidth: up to 20 Gbit/s for central ASICs and ~ 3 Tbit/s in total
- Sensor temperature must be maintained < -20°C with minimal cooling material

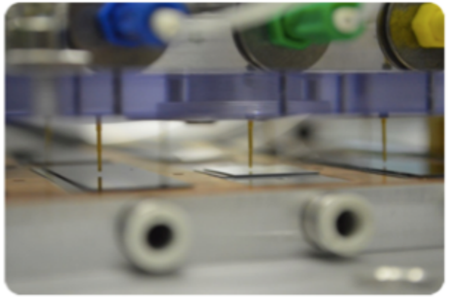
VELOpix ASIC

Velopix	
Technology	65 nm
Pixel size	55 x 55 µm
Pixel layout	3 side buttable, 256 x 256
ASIC area	1.98 cm^2
Event packet	24 bit
Maximum rate	400 Mhits/cm^2/s
Time stamping	25 ns
Readout Bandwidth	20 Gb/s
Readout method	data driven

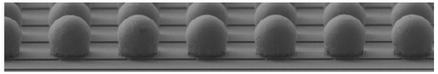




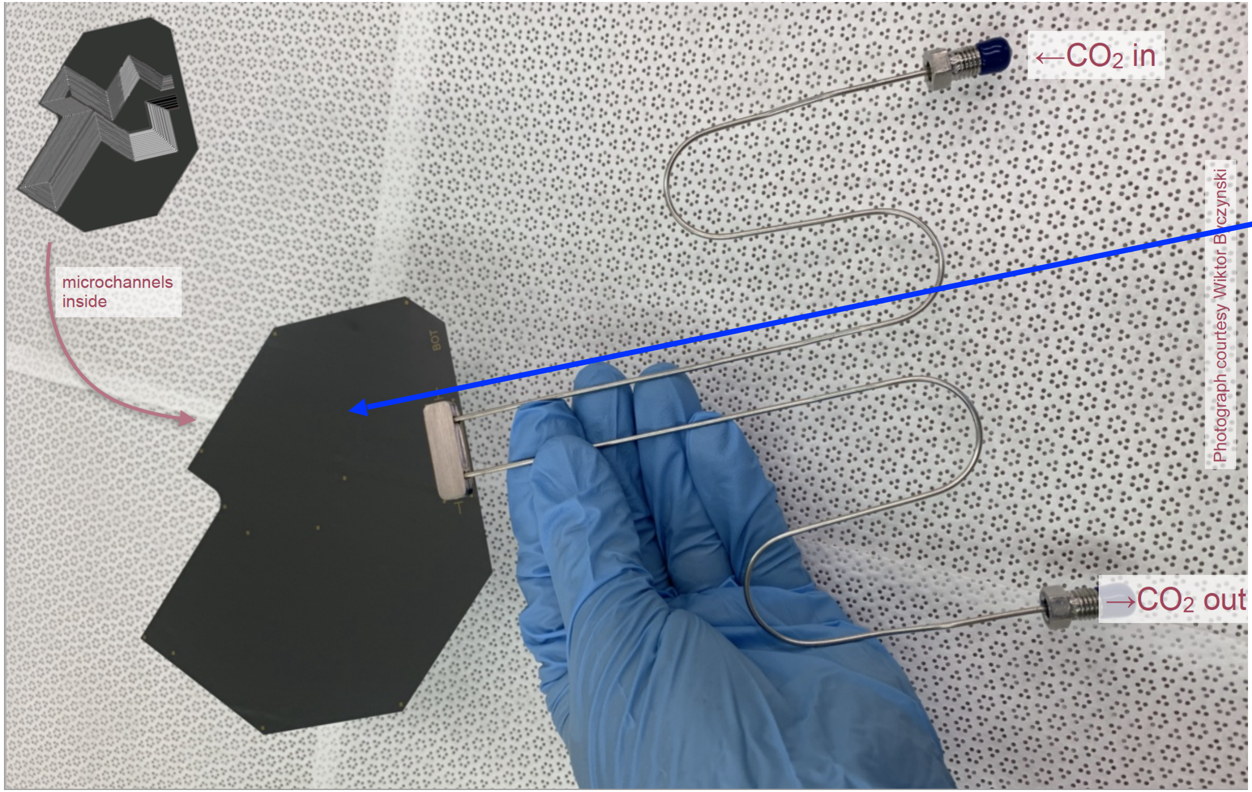
Elongated pixels between ASICs

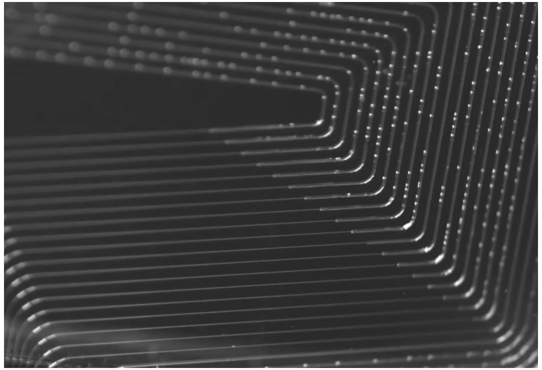


Sensors are bump bonded and automatically probed before vacuum testing to 1000V with spring loaded needle contacts to ASIC backplane

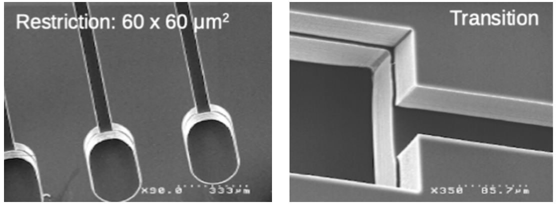


VELO - module cooling





CO_2 circulating in microchannels (click for movie)



SEM production images (courtesy CEA-LETI)

For more information see NIMA (1039) 2022 168874

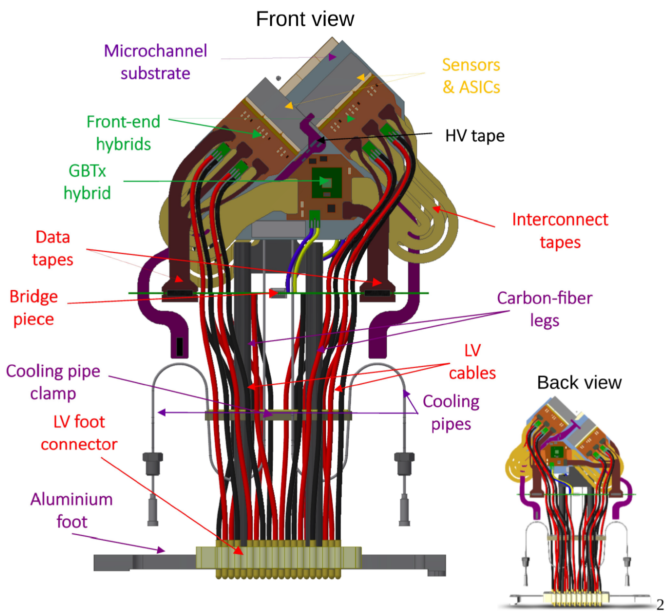
VELO Module Layout

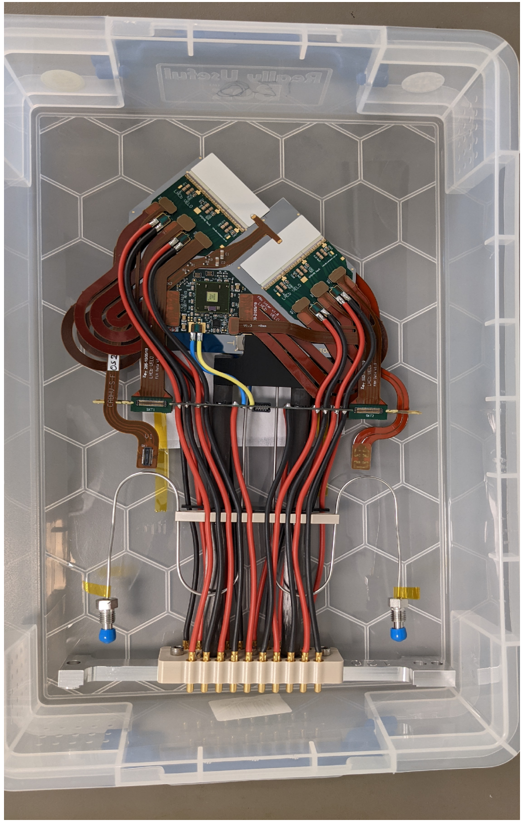
Four sensors per double sided module

Each sensor bump bonded to 3 Velopix ASICs

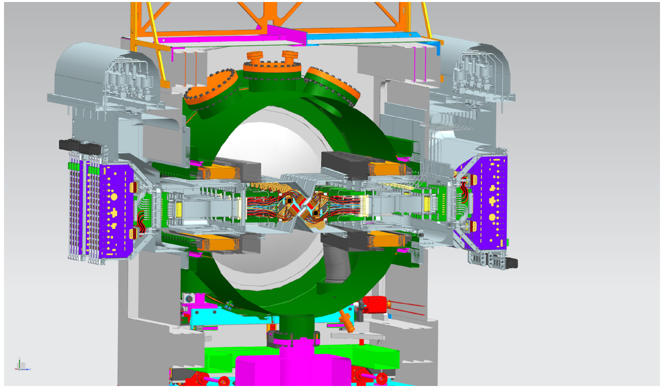
Detector active area 0.12 m^2

52 modules total





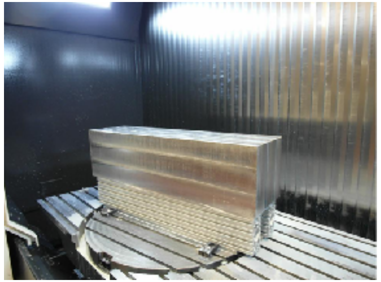
VELO RF box



The VELO is separated from the primary vacuum by the 1.1 m long thin walled "RF box" which also shields the detector and guides the beam wakefields

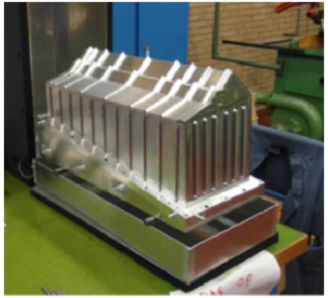
At just 3.5 mm clearance from the beam and 900 μm clearance from the sensors, production represents a huge technical achievement

The final box must withstand 10 mbar pressure variations and be leak tight. In a final chemical etching step the thickness is reduced from 250 μm to 150 μm

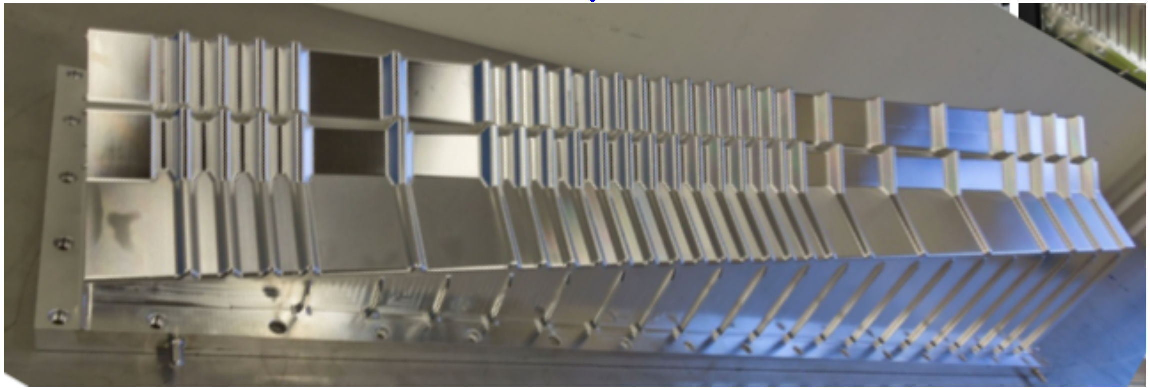


Initial solid forged Al alloy block

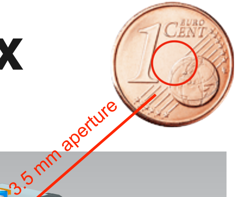
>98% of material removed

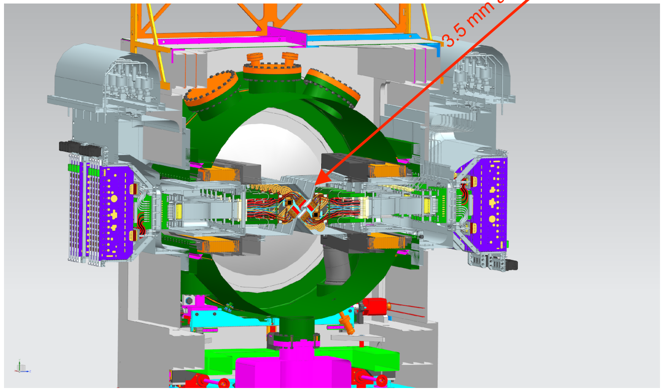


Internal mould support during machining steps



VELO RF box





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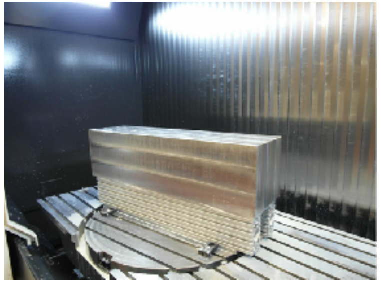
The aperture is so small that during LHC beam injection the VELO halves and boxes must be retracted, i.e. VELO moves for every LHC fill to centre on the beams



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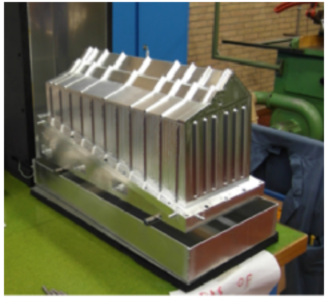
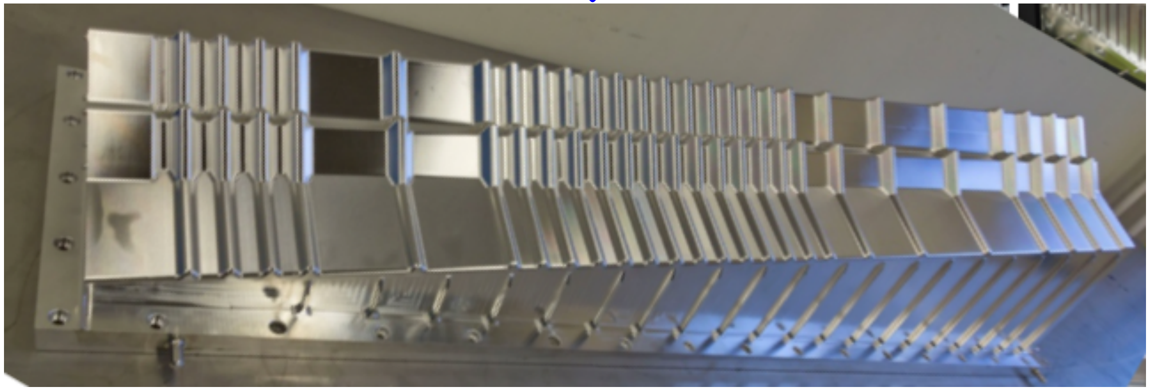
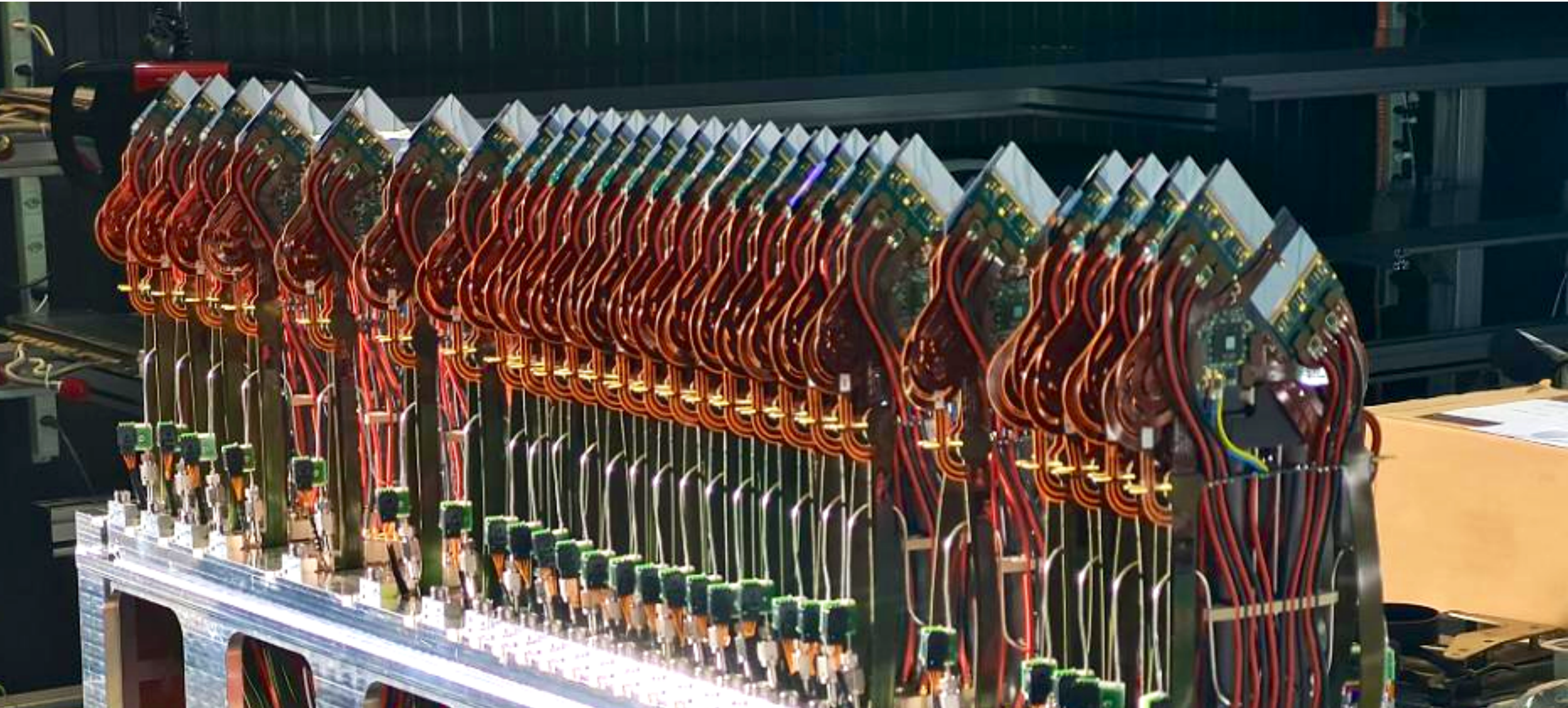


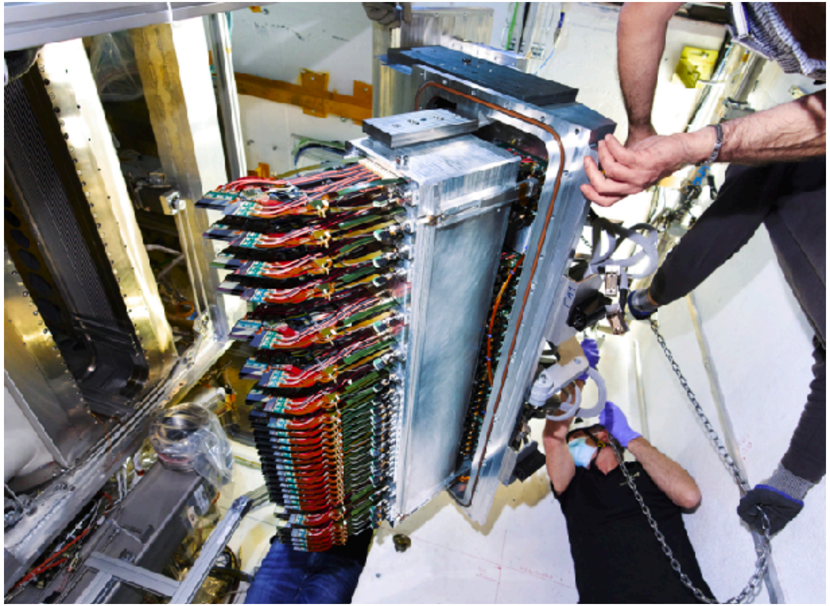
Internal mould support during machining steps



VELO completed half



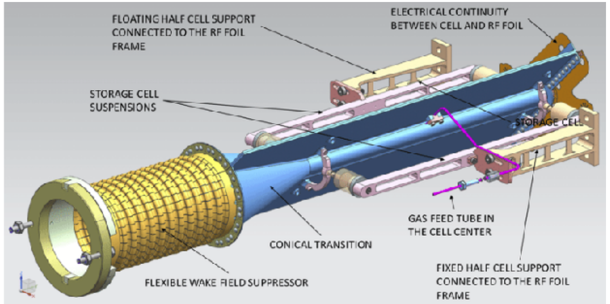
VELO insertion into RF boxes



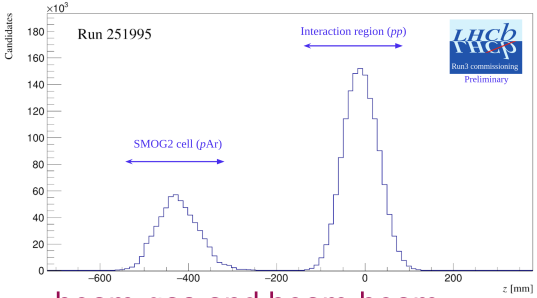
SMOG2

SMOG2 works by injecting gases into a cell just upstream of the VELO

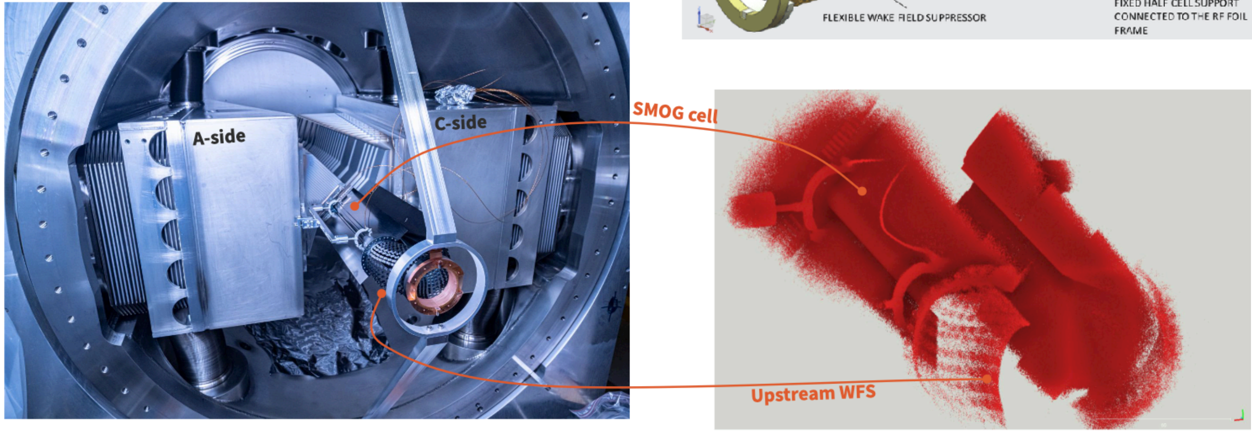
- Fixed target at LHC, a unique system!
- Collisions provided by a TeV-scale beam on gas exploit a unique kinematic region that has been poorly probed.
- Ability to inject H_2 and D_2 in addition to all noble gases
- Studies of Lead-nucleus collisions



Commissioning in 2022



beam-gas and beam-beam <u>simultaneous</u> data taking!



LHCb can work with 2 interaction points! The fixed target system allows to collect large statistics, is transparent to the LHC beam and increases the LHCb data flow of only ~1%

Vacuum incident

On 10th January 2023, during a VELO warm up in neon, there was a loss of control of the protection system

A pressure differential of 200 mbar built up between the two volumes, whereas the foils are designed to withstand 10 mbar only

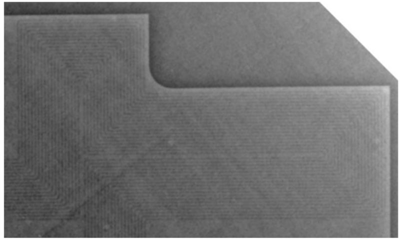
There was no damage to the VELO modules which have performed well throughout this year.

However, the RF boxes have suffered plastic deformation of about 17 mm and have to be replaced. This is a major intervention, postponed to the end of the year.

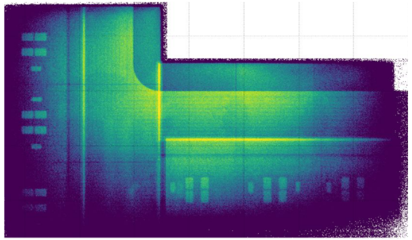
In the meantime, this year the VELO will not be fully closed

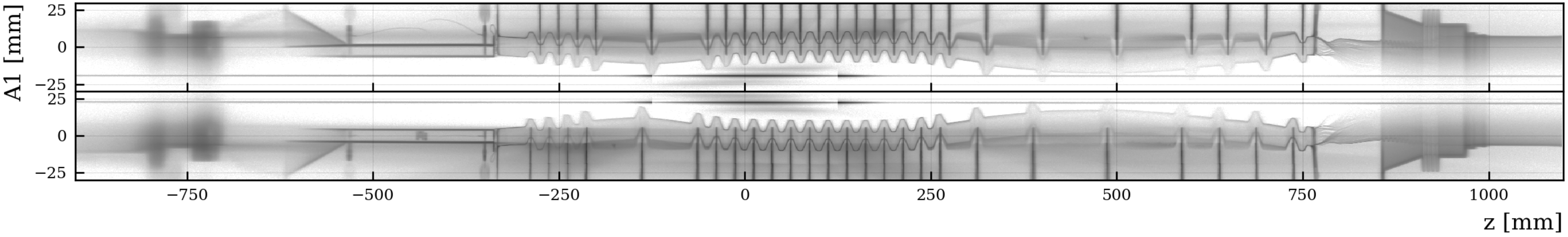
Thanks to the flexible 40 MHz trigger detailed tomography “pictures” of VELO elements can be quickly obtained

Microchannels seen with X-ray of the cooling plate



Microchannels seen with tomography of the modules



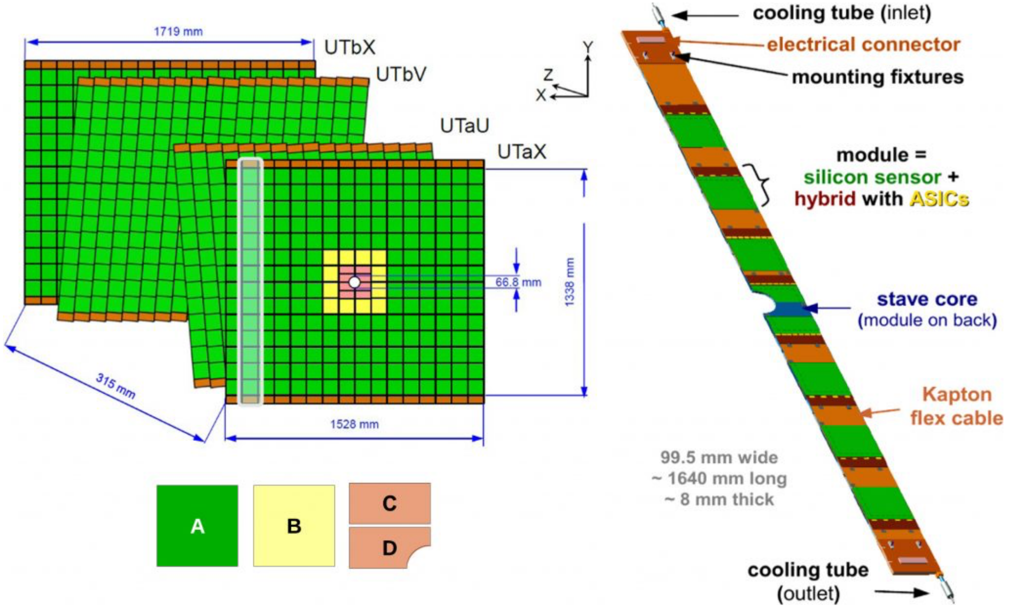


UT

Requirements for new UT Tracker

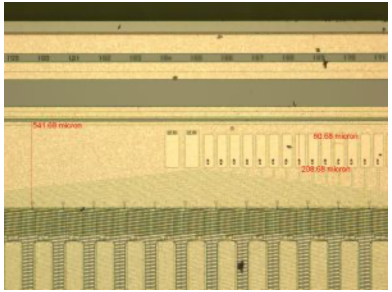
- Tracker must be very light
  - 6% X_o in total
- Read out at 40 MHz
- Keep occupancy below 1% (fast PR)
- 3-hit efficiency > 99%
- Innermost silicon sensor as close to the beam pipe as possible (circular cutout)
- no gap in acceptance for particles produced at PV
- close to 100% acceptance for long-lived strange particles decaying upstream of UT
- Special role in the trigger: with HLT1 forward tracking the modest p reconstruction can be used to remove tracks with p_T below a cut off
- Operate in high radiation environment
  - $3 \times 10^{14}\ n_{eq} / cm^2$
  - implies cooling to < -5˚C

4 planes, X-U-V-X (at 5˚)

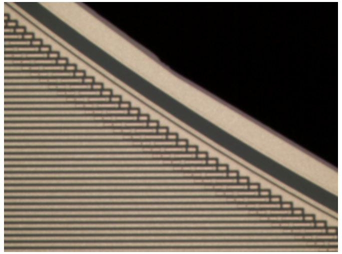


UT

embedded pitch adapter, second metal layer

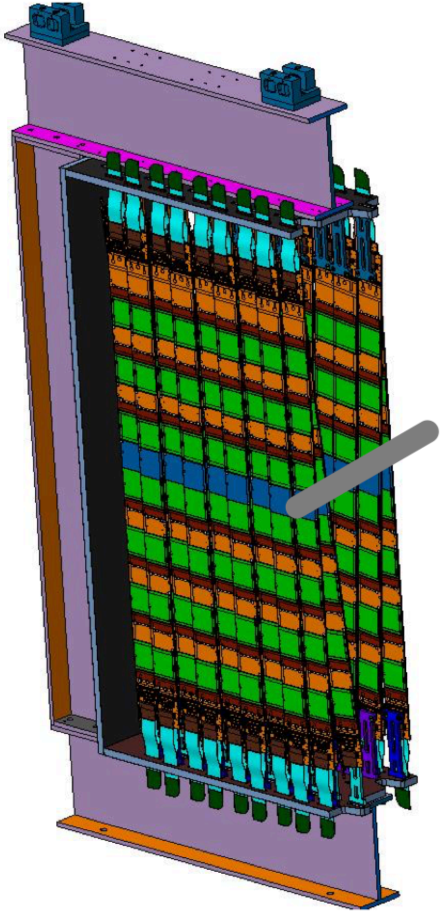


Type D sensor (cutout)

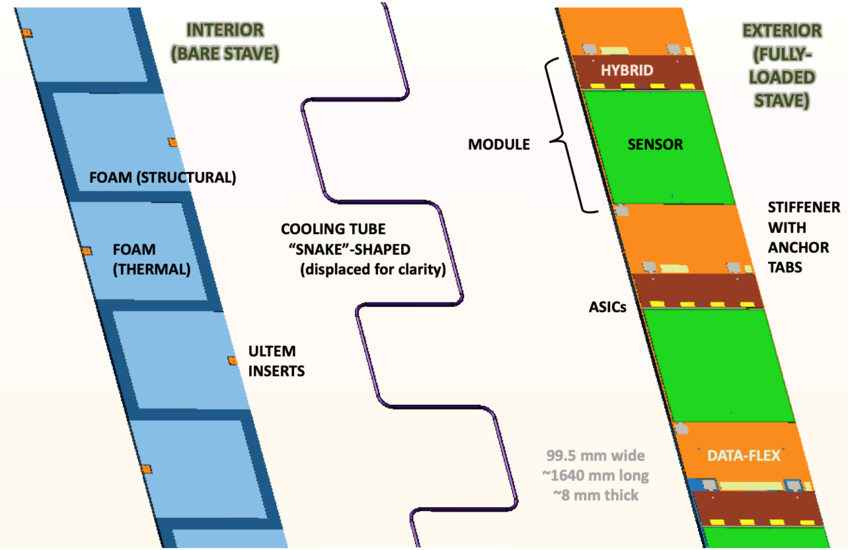


Key technical aspects:

- Four planes of 1000 total 10x10 cm^2 silicon strip sensors
- Custom ASIC readout chips (SALT)
- Stave support structures with silicon on both sides
- n-in-p used for most irradiated internal region, p-in-n for remaining
    - increasing segmentation close to beampipe
- Sensors with circular cut-out to maximise acceptance near beam pipe
- Built-in pitch adapters
- Top-side biasing
- Evaporative CO_2 cooling



UT - Stave Construction



CARBON FIBER SHEETS
(BOTH FRONT AND BACK)

Bare Stave

CFRP facings epoxied to foam core in sandwich structure with embedded Ti cooling tube (OD 2.3 mm)

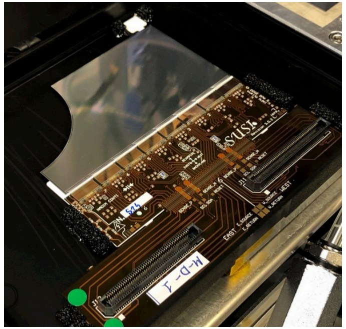
- Cut to precise length in house and brazed to fittings machined in house
- 28-32 bends per tube with custom tool

Aluminimum end-of-stave-mounting blocks

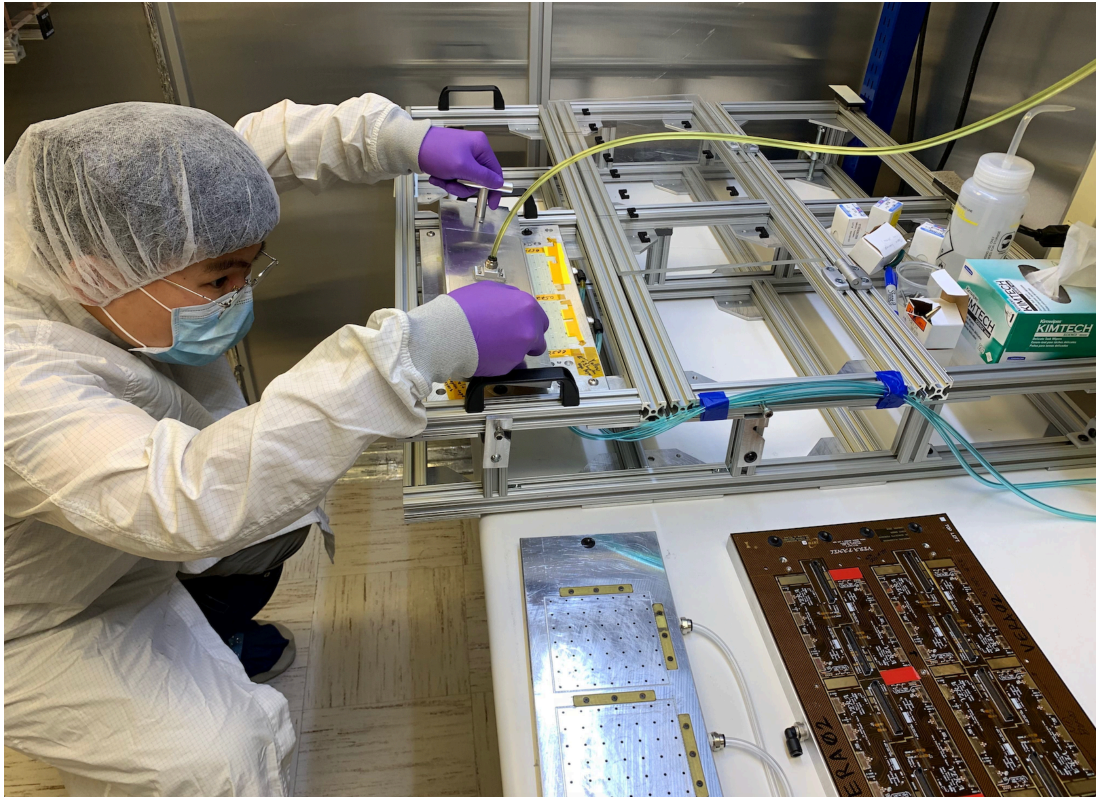
All-epoxy construction

UT - Module Construction

- Boron nitride stiffeners host front end hybrids & sensor
- precision glue deposition with pattern to maximize thermal coupling to the silicon sensor.
- Precision vacuum jigs designed for precise positioning of the components
- Thorough electronics testing at each step of the production.
- Wirebonds are protected with sylgard applied to the bond foot.



Type D Module



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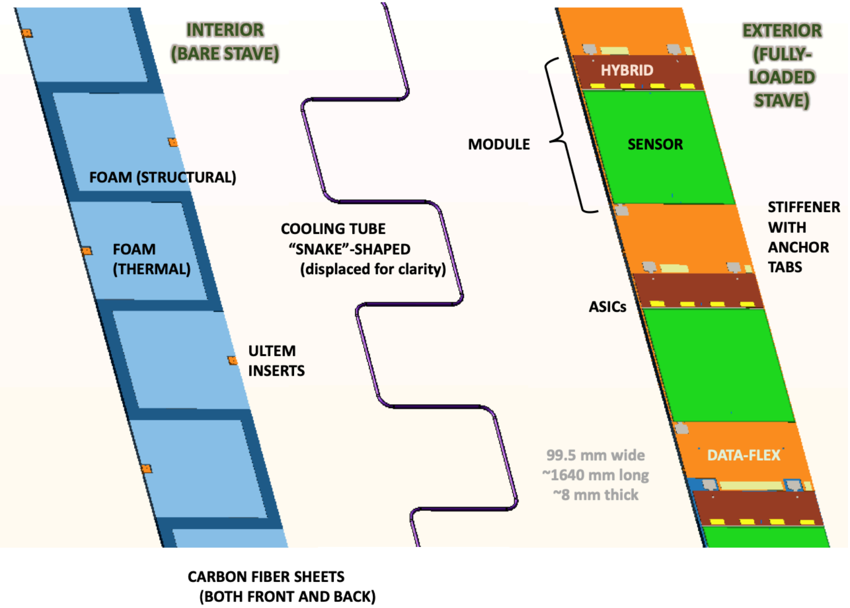


Flex attachment and QA

Two flexes per face attached with epoxy

vacuum pick up tool

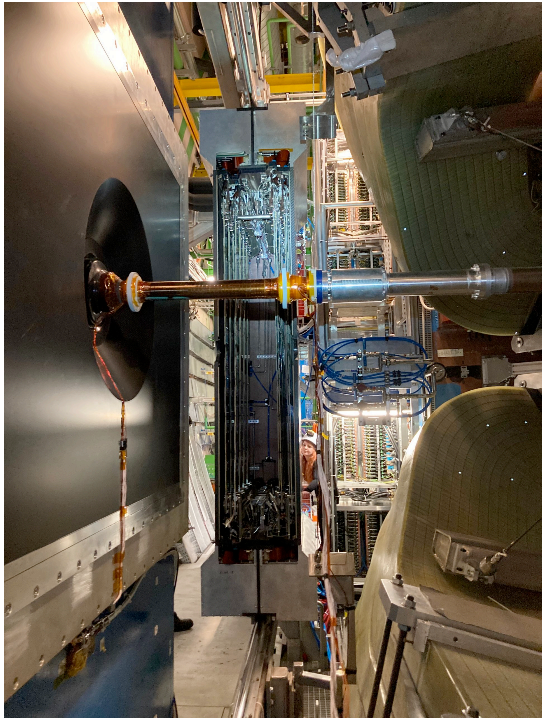
- located with alignment pins
- Gaps controlled by set screws and shim blocks

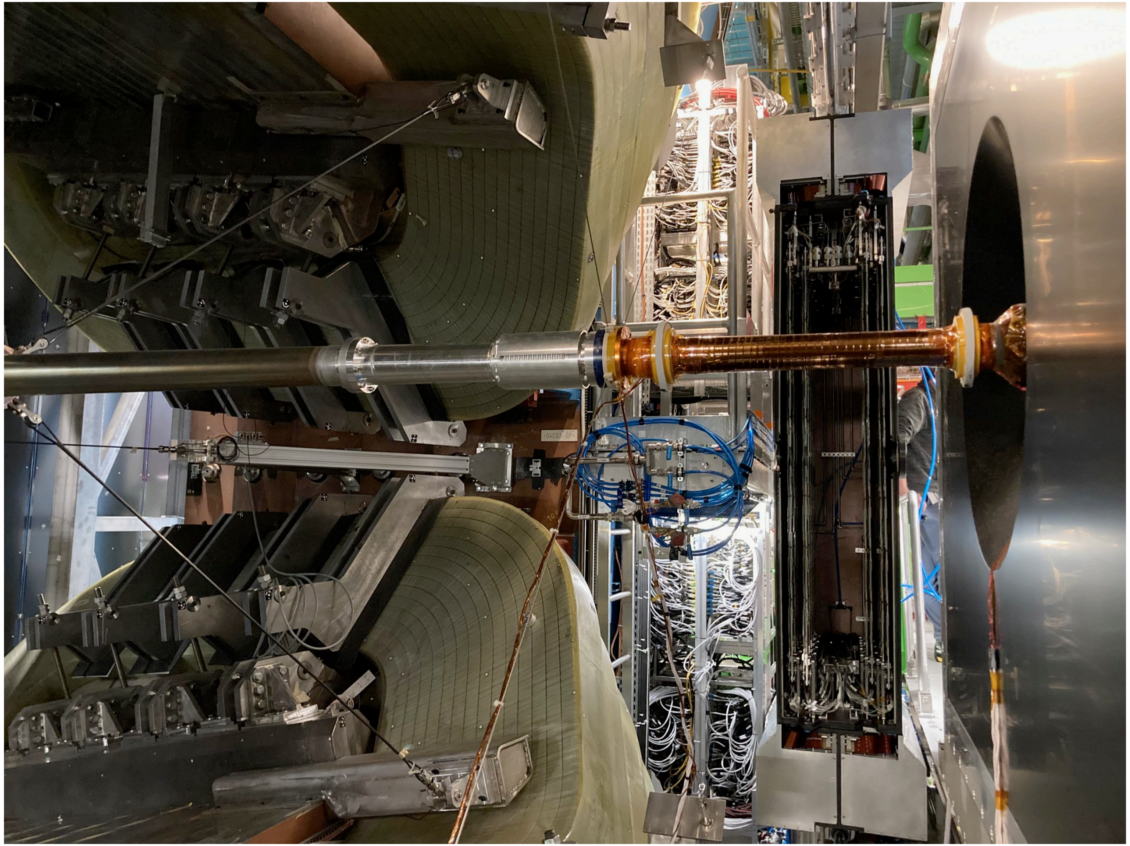
Precision placing of modules on stave

- TIM thermflow used as thermal interface film
- Contact only allowed in certain places to avoid sensors
- module mounting and removal both possible

UT - Assembly at CERN

UT - Installation

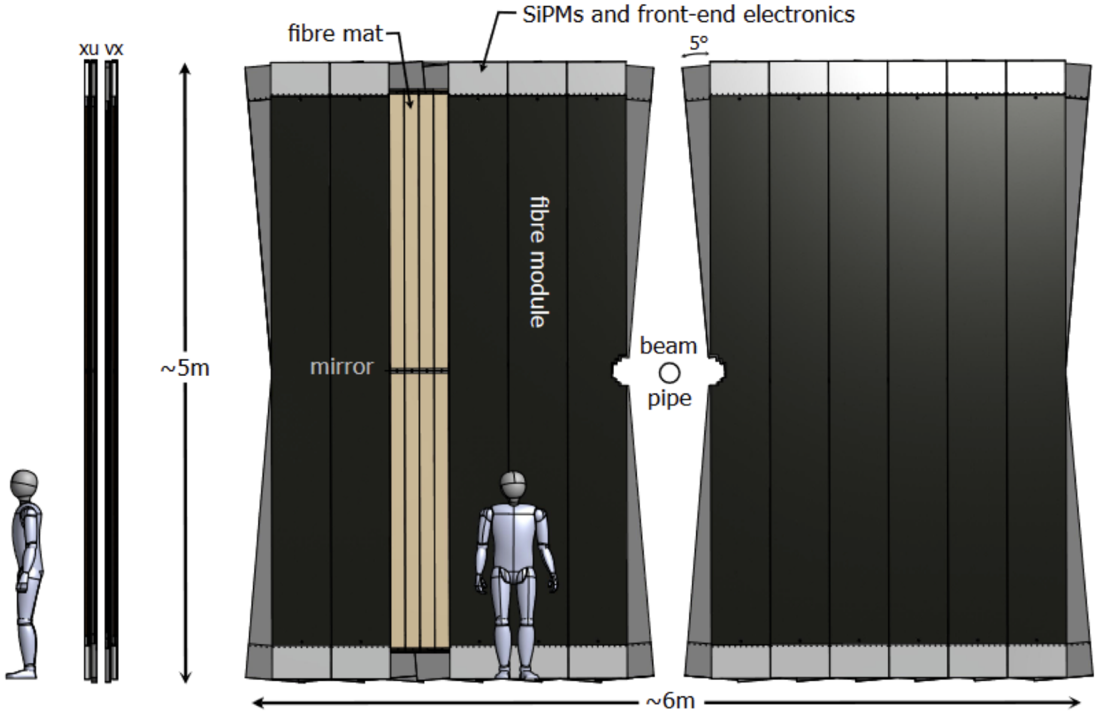




Scintillating Fibre Tracker (SciFi)

Requirements for new SciFi Tracker

- Tracker must be very light
  - 10-12% of an interaction length or radiation length in total
- Cover 5 x 6 m^2 with 3 stations of X-U-V-X layers
- Single hit efficiency 99%
- Spatial resolution better than
- Readout at 40 MHz [25 ns bunch crossing period], no dead-time
- Low noise rate (few fake signals)
- Operate in high radiation environment
  - up to 35 kGy for fibres, 10^{12} n_{eq} / cm^2 for SiPMs front end



Scintillating Fibre Tracker (SciFi)

3 stations

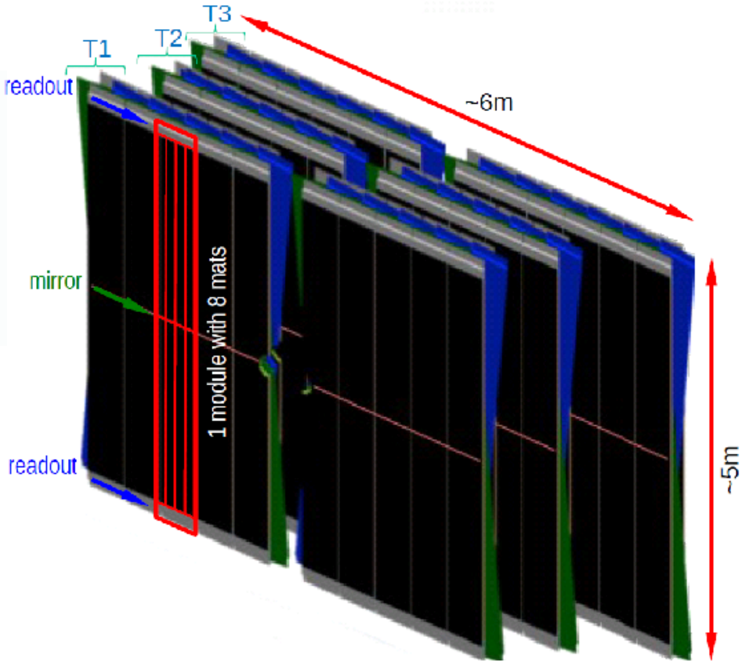
- each with 4 layers measuring X-U-V-X @ 5 degrees

128 0.5 x 5m² **modules**

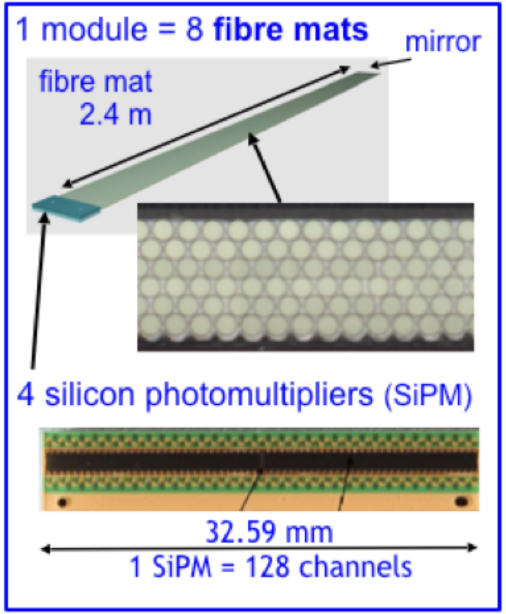
- each containing 8 mats

11,000 km of fibres,
524k channels

Goal: <100 µm precision over a total active surface of ~ 340 m²
Achieved: < 70 µm



Scintillating Fibre Tracker (SciFi)



3 stations

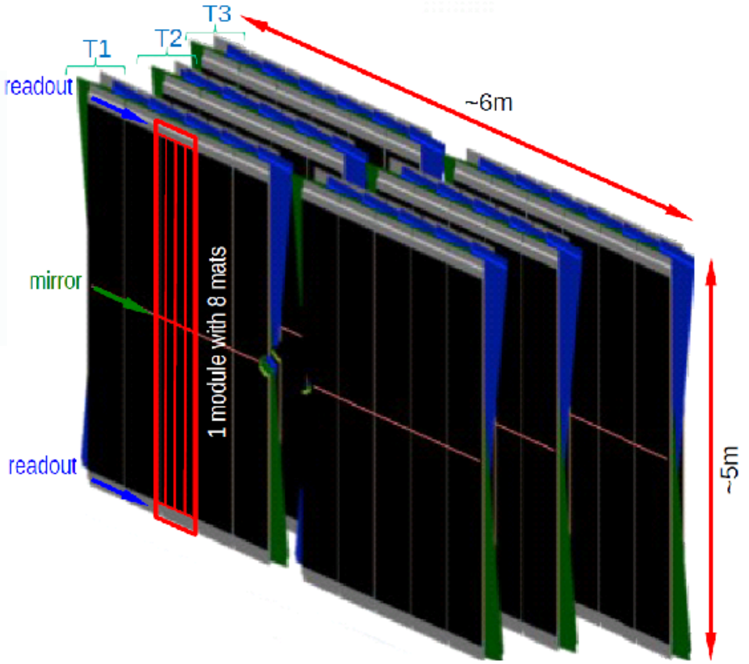
- each with 4 layers measuring X-U-V-X @ 5 degrees

128 0.5 x 5m² **modules**

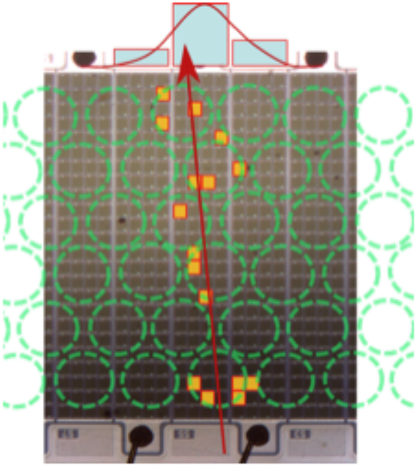
- each containing 8 mats

11,000 km of fibres,
524k channels

Goal: <100 µm precision over a total active surface of ~ 340 m²
Achieved: < 70 µm



Scintillating Fibre Tracker (SciFi)



Light yield for 6-layer mat:
16–20 photo-electrons
(for particles near mat mirror)

3 stations

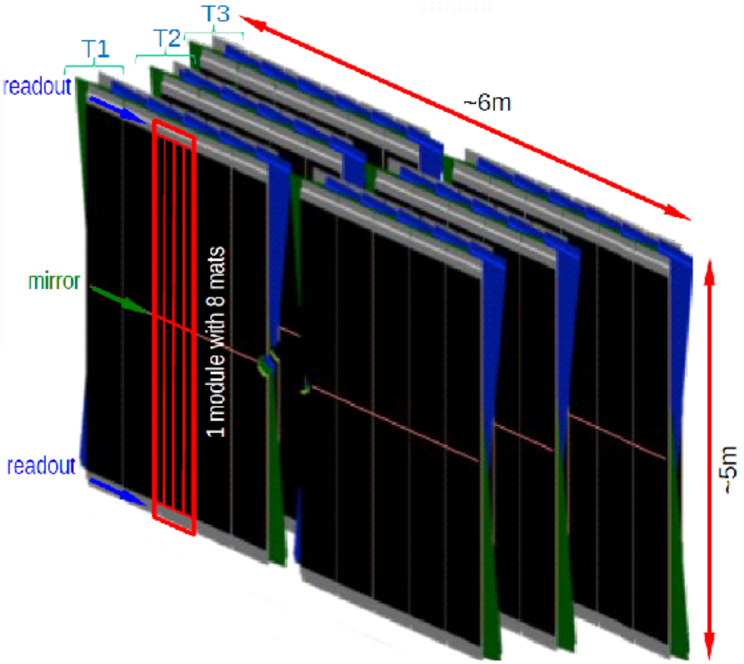
- each with 4 layers measuring X-U-V-X @ 5 degrees

128 0.5 x 5m^2 **modules**

- each containing 8 mats

11,000 km of fibres,
524k channels

Goal: <100 µm precision over a total active surface of ~ 340 m^2
Achieved: < 70 µm

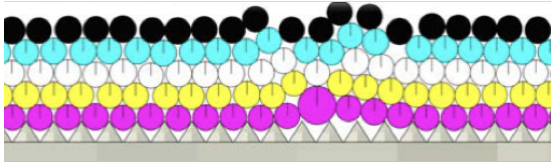


SciFi - module construction

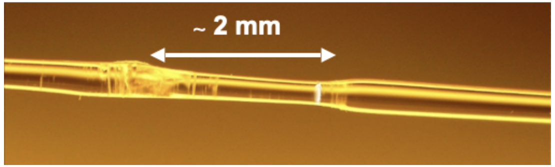
All fibre spools scanned for mechanical defects and irregularities

Any detected bumps >350 µm (typically ~8 per 12500 m) are removed by a “hot drawing” tool.

Problem if there is a bump on a fiber



Bump after shrinking

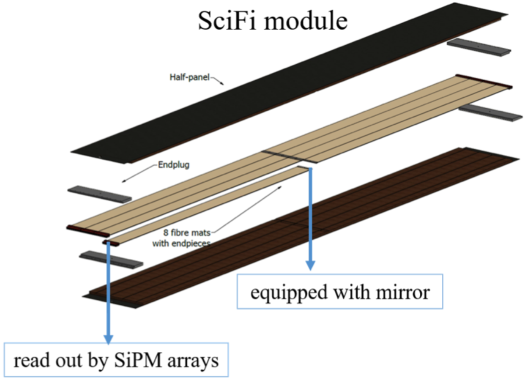


Custom winding machine using a threaded wheel
Mat production at 4 sites (1 mat/6 hours)

8 fibre mats assembled into a module

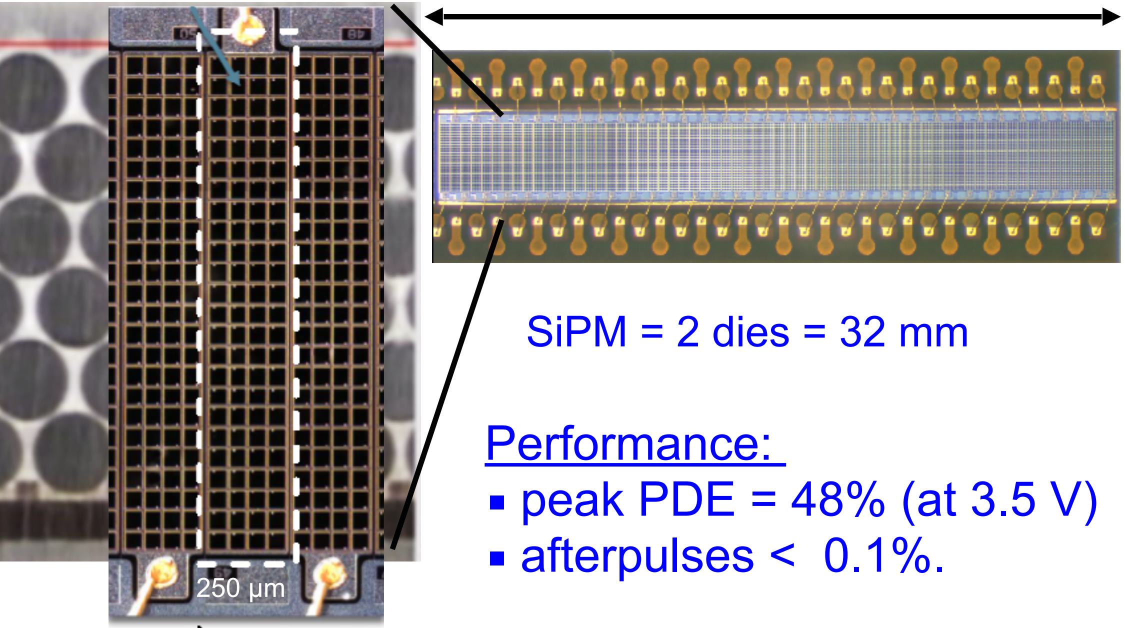
Material budget: 1.1 % X_0 / module

Alignment of mats w/r to straight line better than 50 µm over length of 5 m - **alignment pins** in precision template



SciFi - SiPMs and readout

1 die = 64 channels



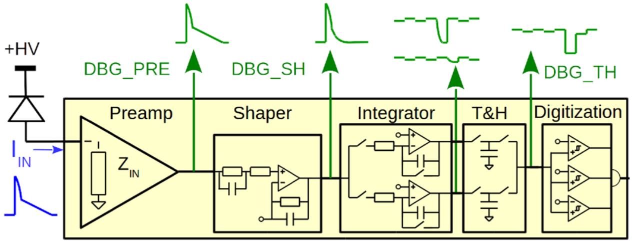
SiPM = 2 dies = 32 mm

Performance:

- peak PDE = 48% (at 3.5 V)
- afterpulses < 0.1%.

Read out to PACIFIC chip:

- 64-channel current mode input , 4 different gain settings
- configurable fast shaper (90% charge collected within 10ns)
- interleaved gated-integrators per channel: minimize dead time
- digitization by 3-comparators/channel:
- tunable threshold for each comparator for clustering
- adjustable input anode DC voltage (4-bit DAC, 50mV/LSB)



SciFi - radiation challenge

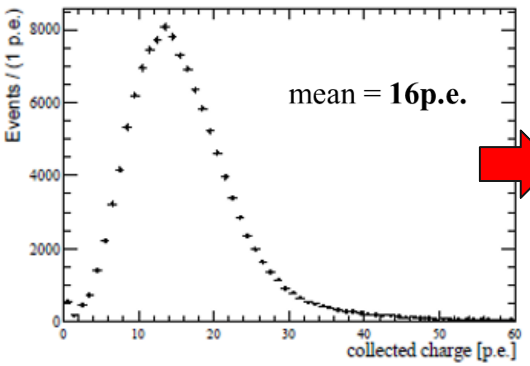
light yield

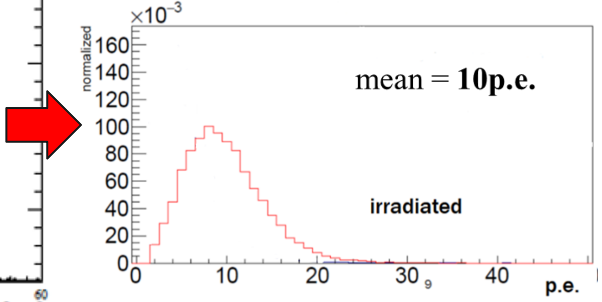
- depends on position along fibre:

16 p.e. closest to beam pipe → 23 p.e. near SiPM

- ~ 40% light yield loss at end of detector lifetime (50 fb^{-1})

at the beam pipe side

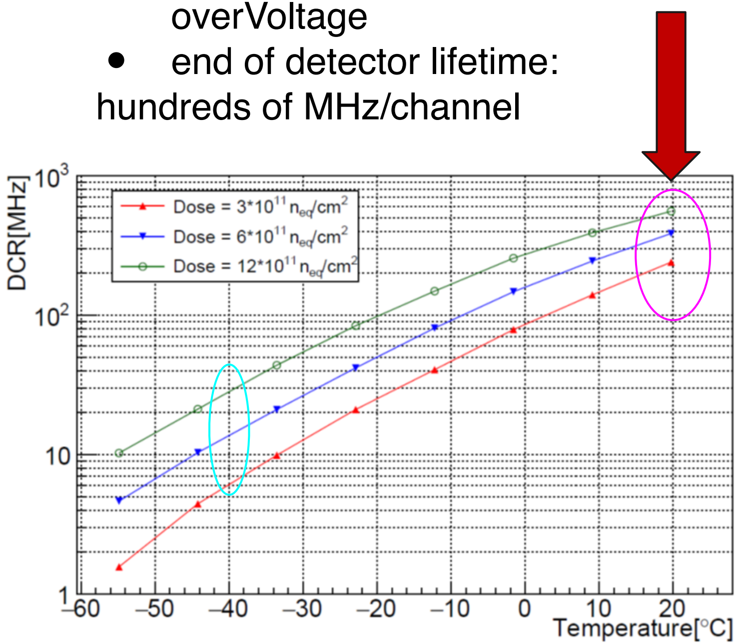




SiPM Dark Count Rate (DCR) :

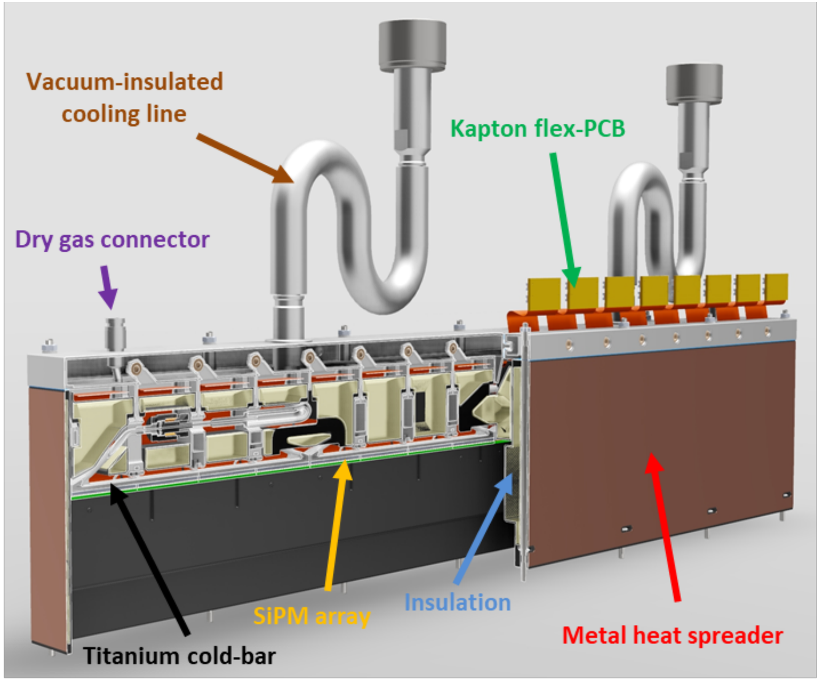
- ~kHz /channel @ 20°C at 3.5V overVoltage
- end of detector lifetime:

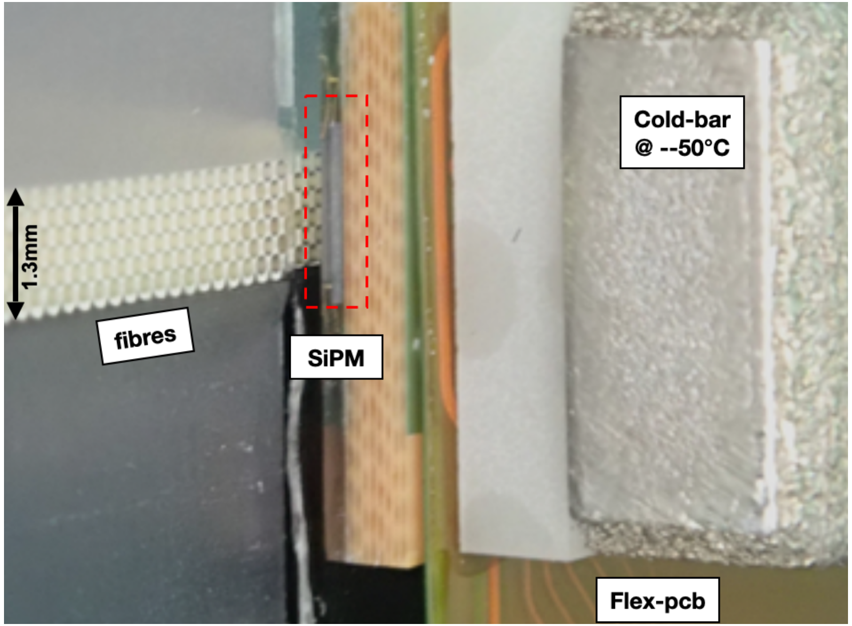
hundreds of MHz/channel

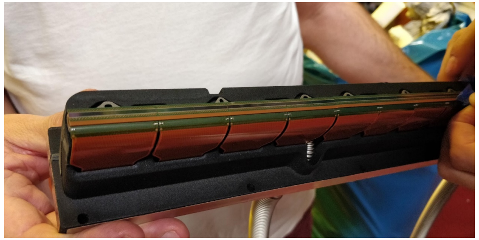


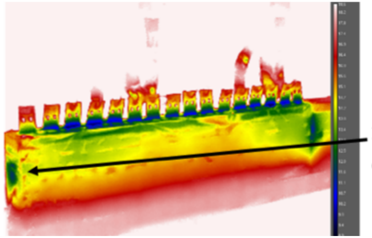
In order to reduce the DCR: operate SiPM arrays at -40°C , cooling system required!

SciFi - SiPM cold boxes









256 cold boxes in total maintain SiPMs at -40°C to control DCR after irradiation at acceptable level

SciFi - FE electronics

PACIFIC Board
read out 2 × SiPM arrays
digitalization

10.2 Gb/s
per SiPM array

Clusterization Board
clusterization & zero suppression

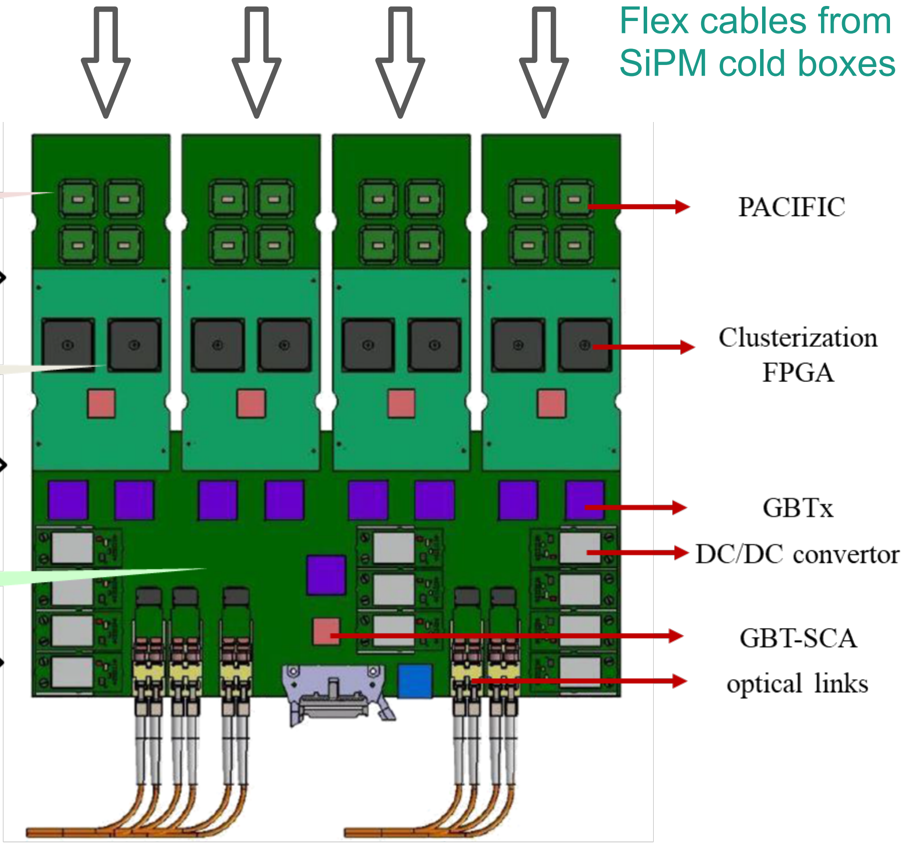
efficiently format hit information

4.48 Gb/s
per SiPM array/FPGA

Master Board
transfer data at high rate via optical link

generate/distribute:
Timing and Fast Control (TFC),
Experimental Slow Control (ECS),
clock

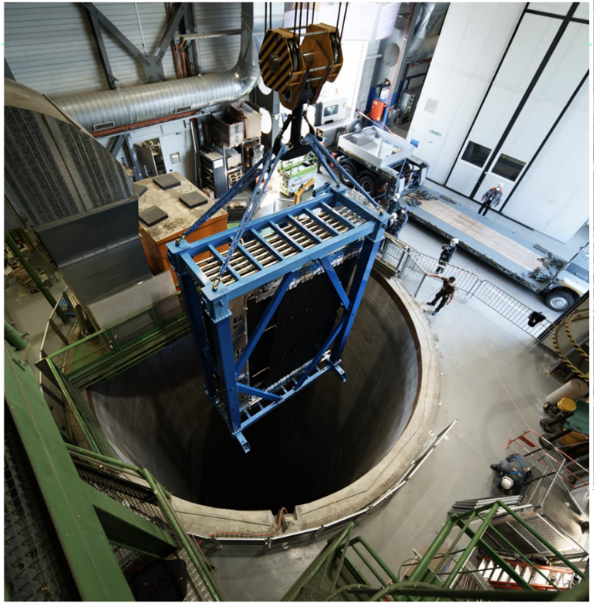
4.8 Gb/s
per GBTx

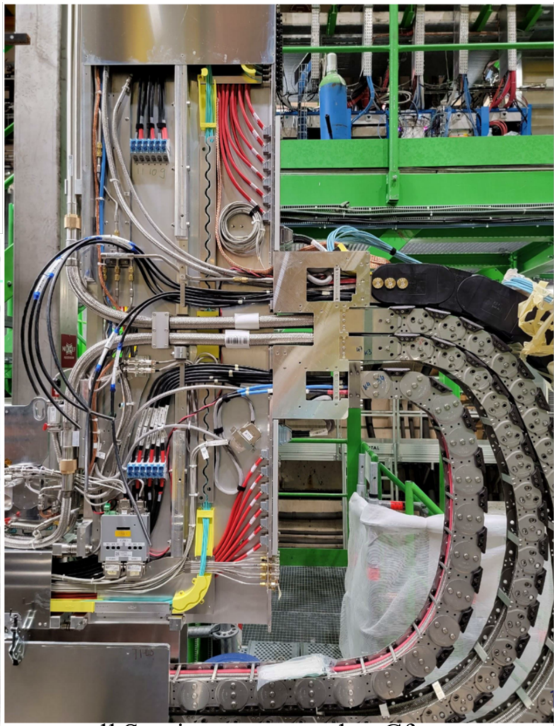


SciFi (528k channels) – 4096 GBT links (20 Tb/s)
~50% bandwidth of whole LHCb Upgrade detector

SciFi - from final assembly to cavern

2022.02.16
Transportation of the entire SciFi to the LHCb cavern completed



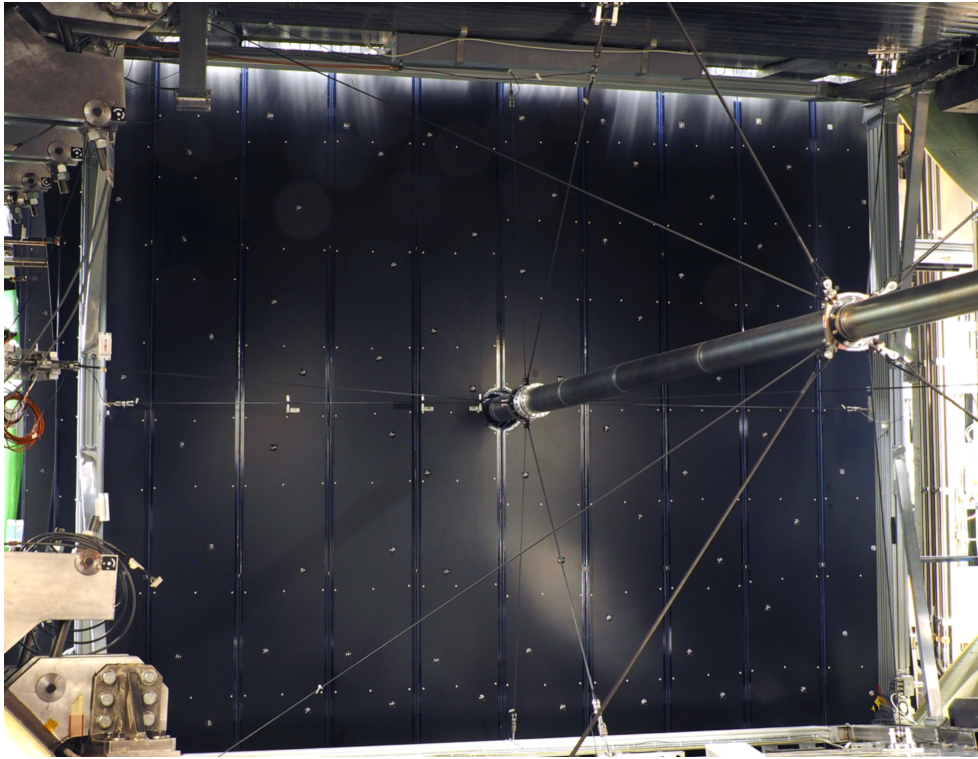


all Services connected to Cframes through cable chains

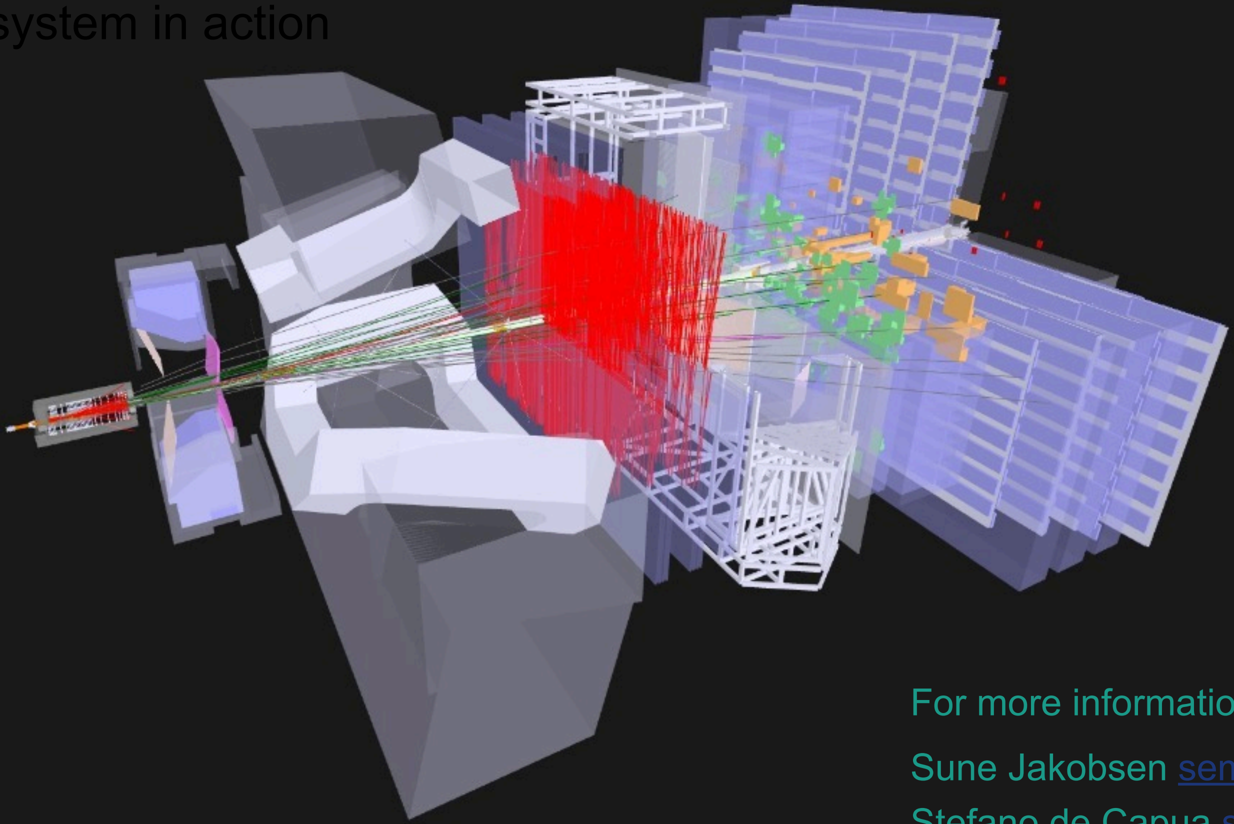
2022.04.07
the last Front-end Box installed,
a complete SciFi in place!

8

SciFi - Cavern installation



Tracking system in action



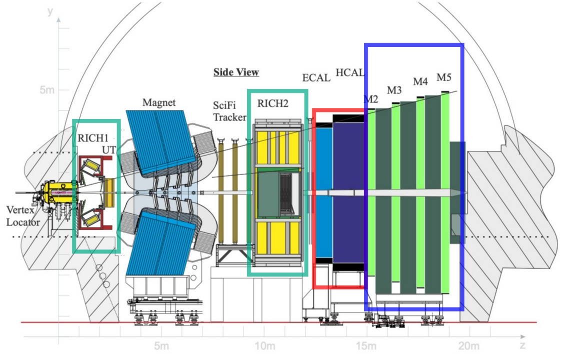
For more information see:

Sune Jakobsen seminar "LHCb SciFi"

Stefano de Capua seminar "LHCb VELO"

Ray Mountain seminar "LHCb UT"

Particle identification at LHCb



Charged hadron identification

- RICH1
- RICH2

Need for new Ring Imaging Cherenkov system to provide PID in the range 2.6-100 GeV/c

- new RICH1 detector
- new opto-electronics chain in RICH2

Photon and electron identification

- ECAL
- HCAL

Need to replace Front-End electronics to cope with the new LHCb readout scheme

Removal of the Scintillating Pad Detector (SPD) and the PreShower (PS): detectors played a central role in the L0 hardware trigger in Run1&2

Muon identification

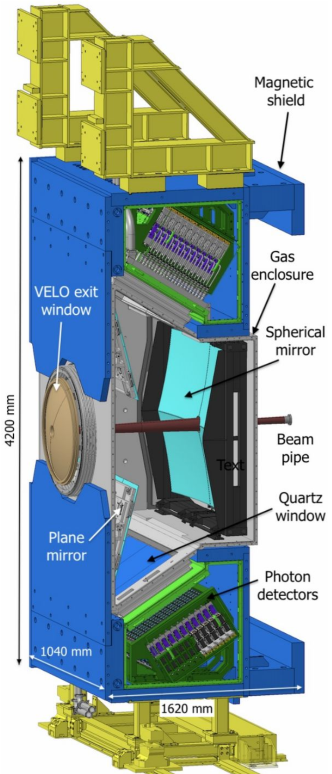
- Muon

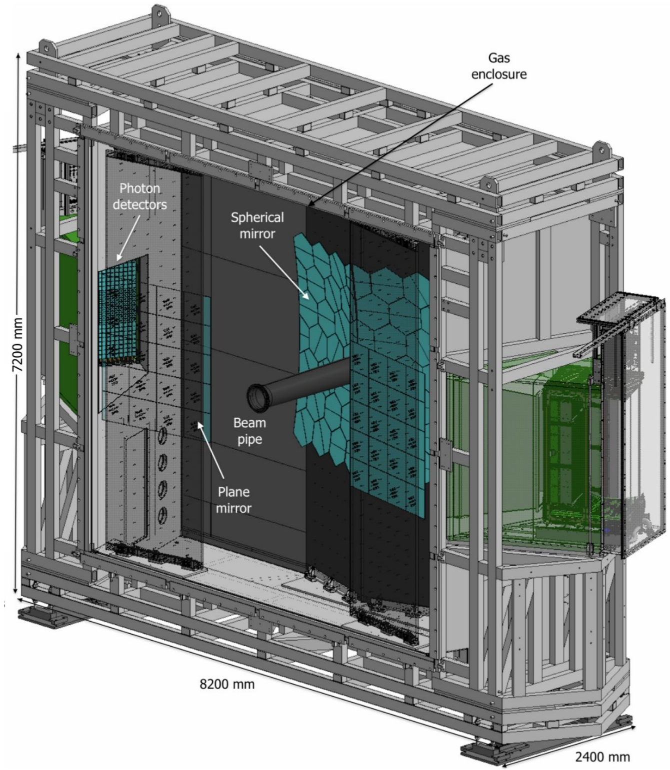
Need to replace Front-End electronics to cope with the new LHCb readout scheme

new beam pipe shielding

Removal of M1 station used for the L0 hardware trigger in Run1&2

The RICH system at LHCb

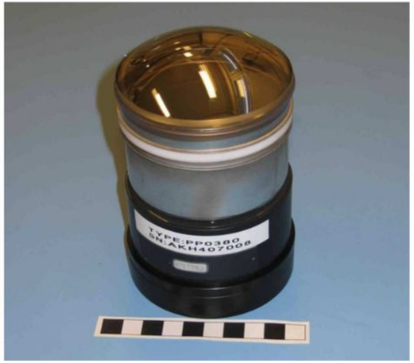




RICH1: upstream of the magnet 2.6- 60 GeV/c over 25 - 300 mrad. Gas radiator: C_4F_{10}. System of spherical and flat mirrors to focus photons on two photon detector planes located above and below the beam pipe, outside the LHCb acceptance.

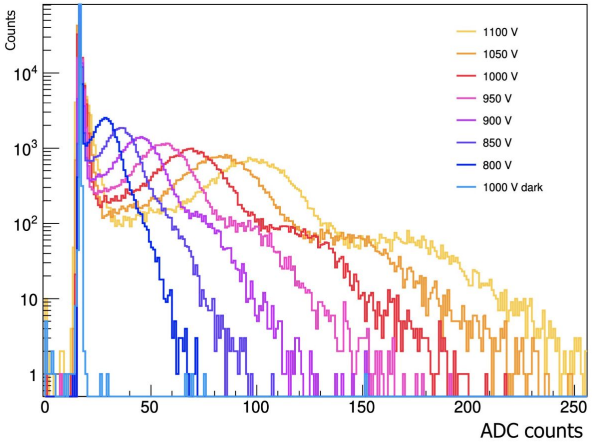
RICH2: downstream of the magnet 30 - 100 GeV/c over 15 mrad - 120 mrad. Gas radiator: CF_4. System of spherical and flat mirrors to focus photons on two photon detector planes located on the sides the beam pipe, outside the LHCb acceptance

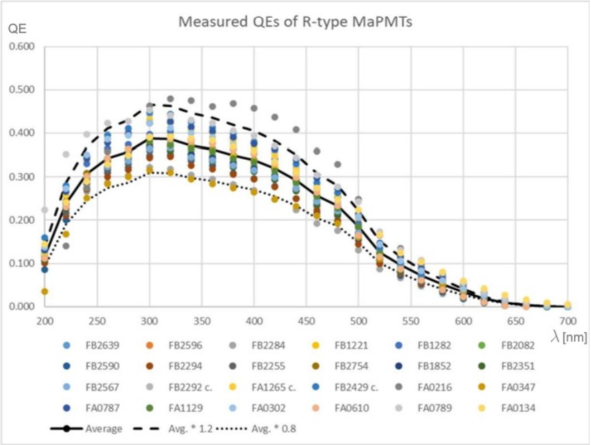
Opto-electronics chain for the RICH Upgrade

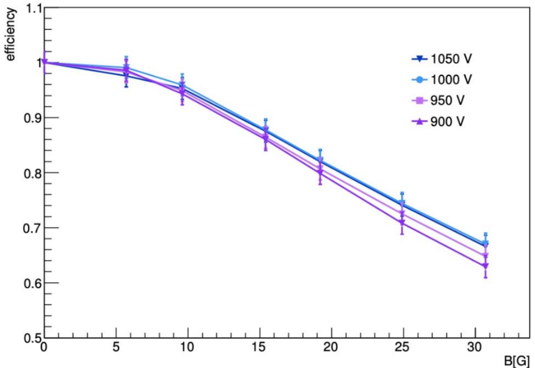


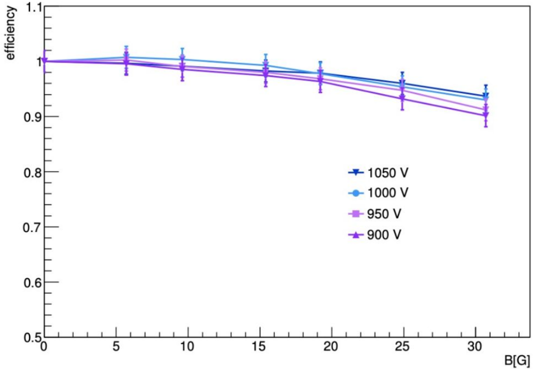
- Hybrid Photon Detectors (HPD) with embedded electronics (1 MHz) operated in Run1&2
- Multi-anode Photomultiplier Tubes (MaPMTs) with external readout selected for Upgrade
- 1-inch Hamamatsu R13742 (custom version of R11265) in RICH1 and central region of RICH2: 8 x 8 pixel matrix, 2.88 x 2.88 mm^2 pixel size
- 2-inch Hamamatsu R13743 (custom version of R12699) in outer region of RICH2: 8 x 8 pixel matrix, 6x6mm^2 pixel size
- 1888 (768) 1-inch MaPMTs are installed in RICH1 (RICH2) and 384 2-inch MaPMTs are installed in RICH2
- Claro ASIC: 8-channel amplifier/discriminator, 0.35 μm CMOS technology from AMS, designed to operate at 40 MHz, developed by the RICH groups

MaPMTs









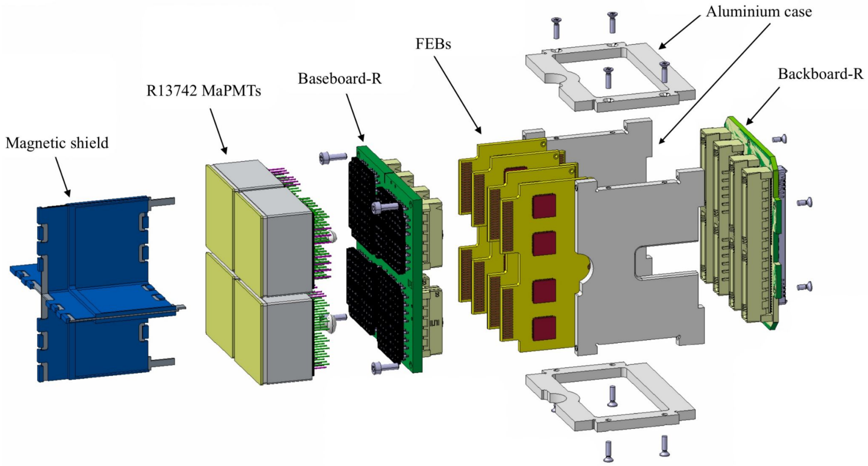
Over 3500 units (including spares) purchased and quality assured

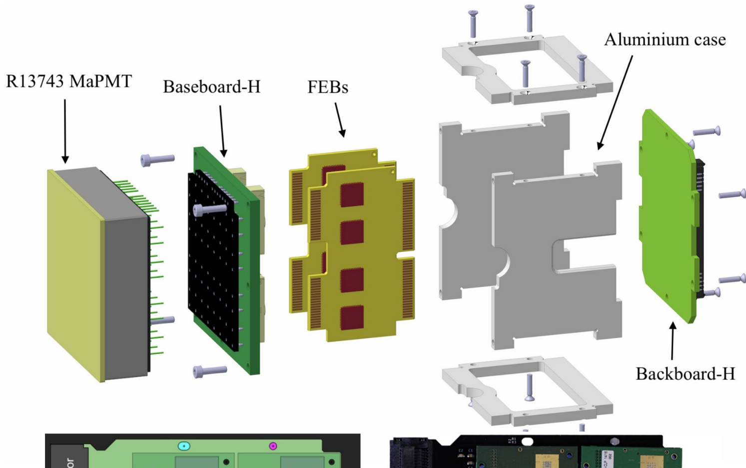
- Gain > 10^6 at 1000V
- Dark Count rate < 2.5 kHz/cm^2
- gain uniformity 1÷4 (R13742) and 1÷3 (R13743)

units characterised by excellent Quantum Efficiency over the spectral range 200-600nm

Stray magnetic field in RICH1 enclosure up to 2 mT → MaPMTs equipped with magnetic shield due to small degradation of signal efficiency expected; no shield in RICH2 MaPMTs

The Elementary Cell and readout

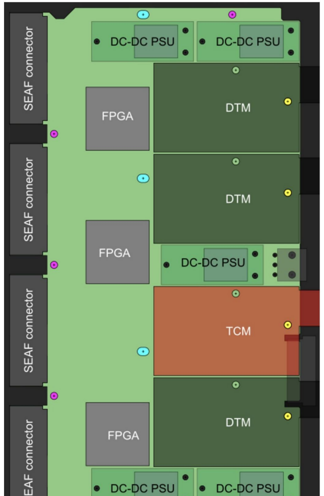


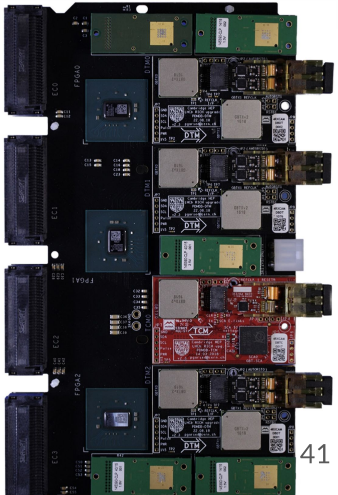


Two types of Elementary Cells (EC): modular unit encasing MaPMTs, FE and ancillary boards:

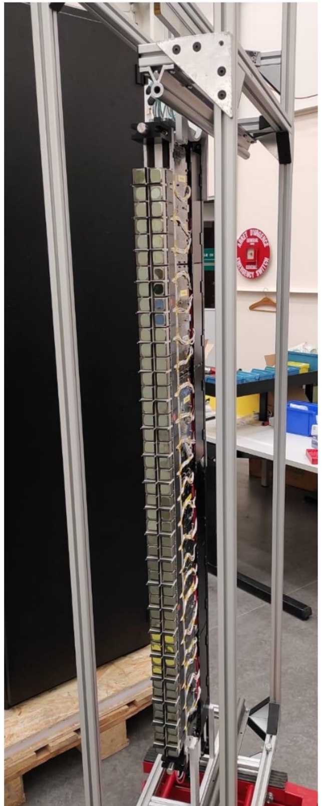
- 4 (1) MaPMTs
- 1 baseboard: HV supply and signal collection
- 4 (2) Front-End boards, each equipped with 8 Claro chips
- 1 backboard to couple to digital readout
- support mechanics

FPGA-based (Xilinx-7) digital readout housing plugins equipped with GBTx, SCA, VTTx and VTRx to interface with fast and slow control and for data transmission





Columns



EC and digital readout arranged in columns: assembly and commissioning at CERN

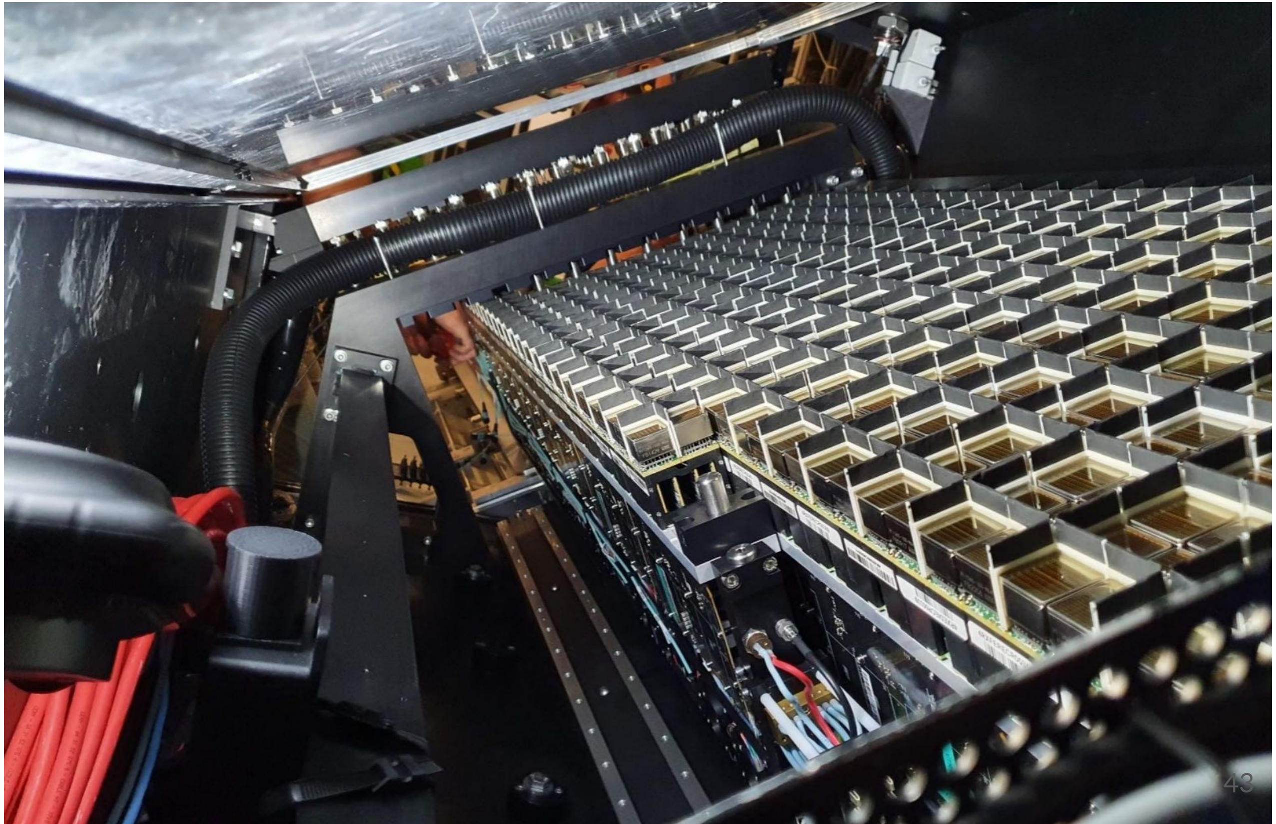
Mechanical support: T-shaped aluminium structure (T-bar) providing positioning at 0.2mm precision

T-bar providing active cooling: 6mm diameter ducts deep-drilled along the spine (1.6m length) to circulate Novec 649 (GWP<1): ~16°C to ensure MaPMT temperature ~25°C

Columns housing services: LV (8V and 2.5V), HV (~900V) and optical fibres for controls and for data transmission

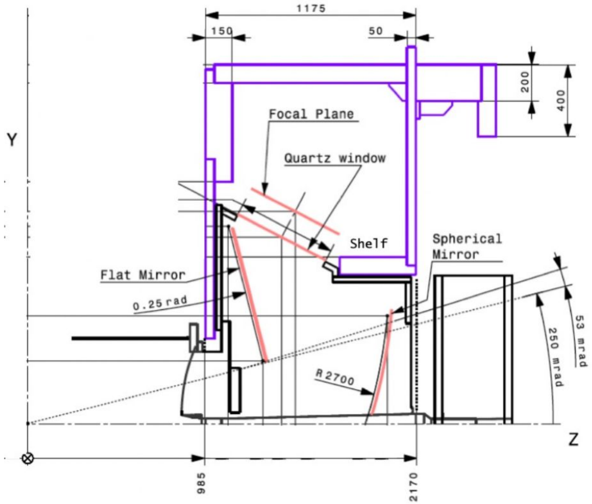
Dedicated harness design for RICH1 and RICH2 due to different mechanical constraints

Photon detector panels

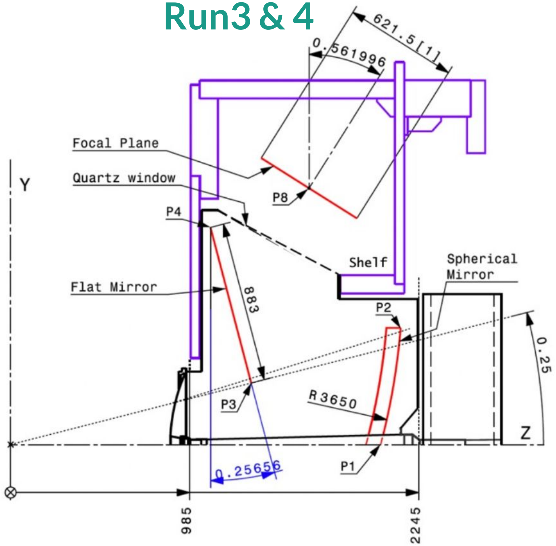


RICH1 optical system and mechanics

Run1 & 2



Run3 & 4

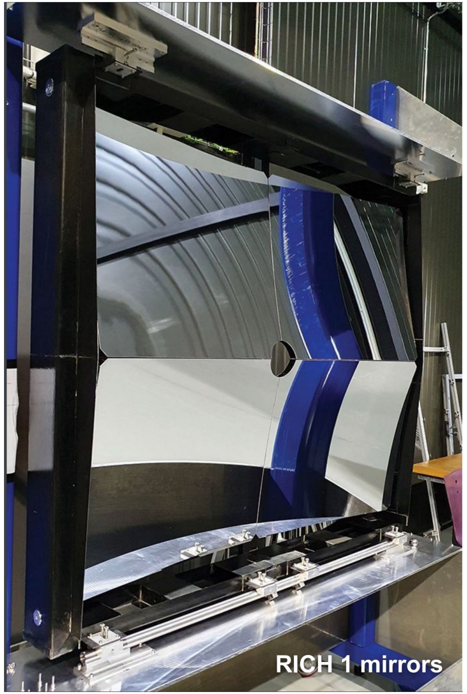


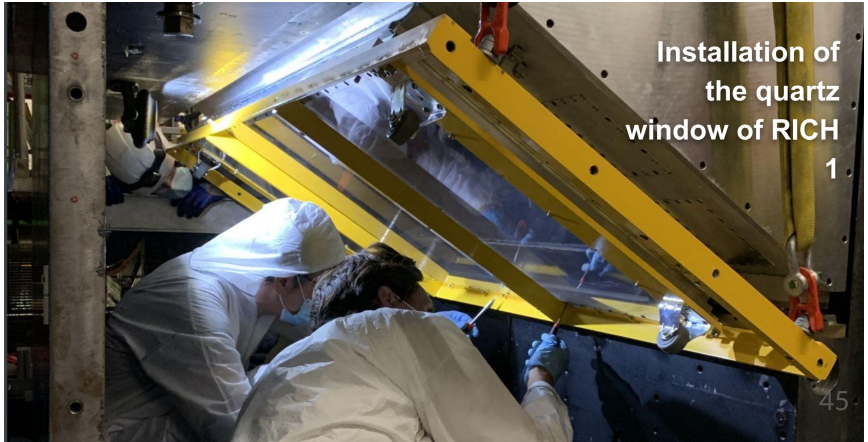
New design of optical layout:

- spherical mirrors focal length increased by √2
- Spherical mirrors in the acceptance: 4 lightweight carbon fibre mirrors
- photon detector panel position moved by 270mm
- new flat mirrors (16 glass planar segments)

- New larger gas enclosure containing C_4F_{10} (aim for leakless system due to GWP) sealed upstream on the Velo to minimize material budget
- Downstream seal: carbon fibre exit window for a total of ~4.8% X_0 in the LHCb acceptance
- Polished fused silica windows sealing above and below: 8mm thick, 655×475 mm^2, each composed by three panes

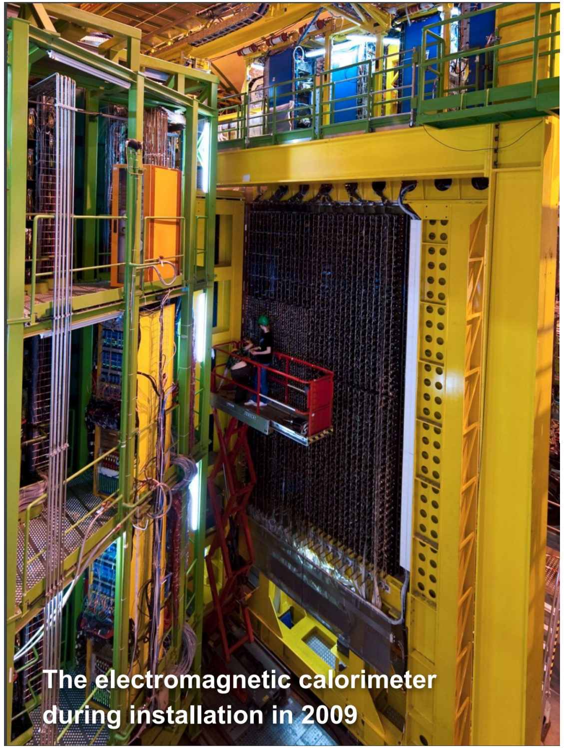
RICH1 installation

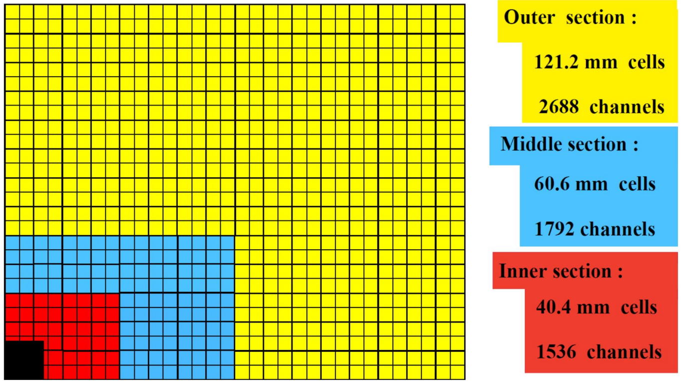


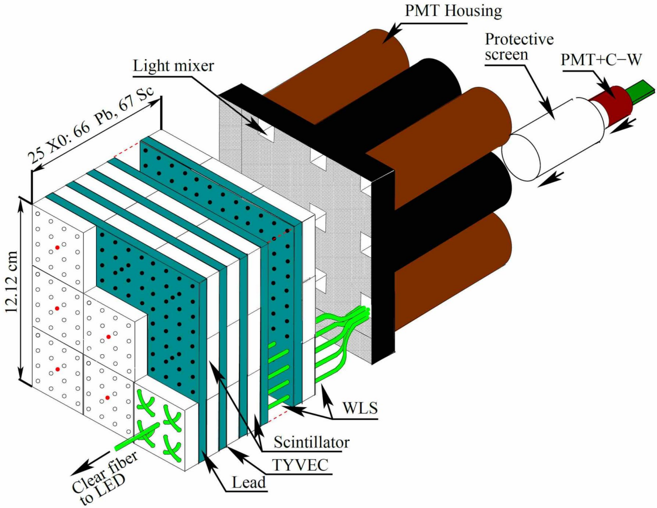


RICH1 and RICH2 installation successfully completed in LS2.
more details in dedicated seminar: “The LHCb RICH Upgrade: from design to early performance” (S. Gambetta)

ECAL





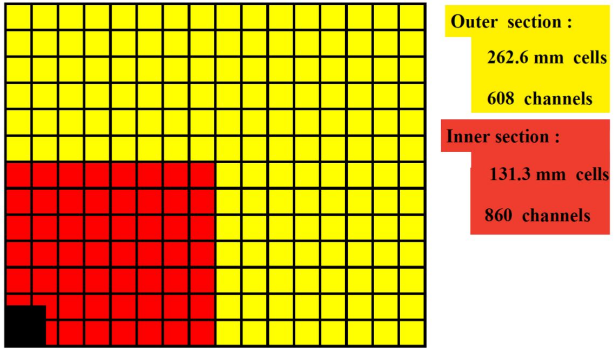


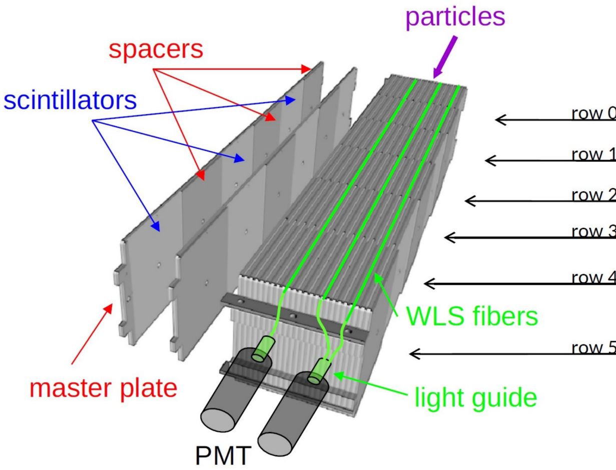
- Shashlik modules (lead + scintillator) for a total of 25 radiation lengths
- Three segmentations for a total of 6061 cells

  $\sigma(E)/E = (9.0 \pm 0.5)\,\% / \sqrt{E} \oplus (0.8 \pm 0.2)\,\% \oplus 0.003/(E \sin\theta)$

- no modification to the active material during LS2: PMT gain lowered by a factor 5 to preserve lifetime of the detector

HCAL



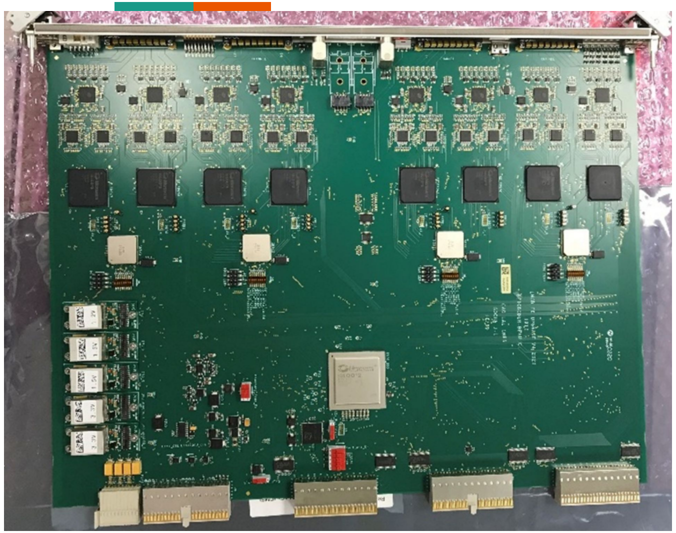


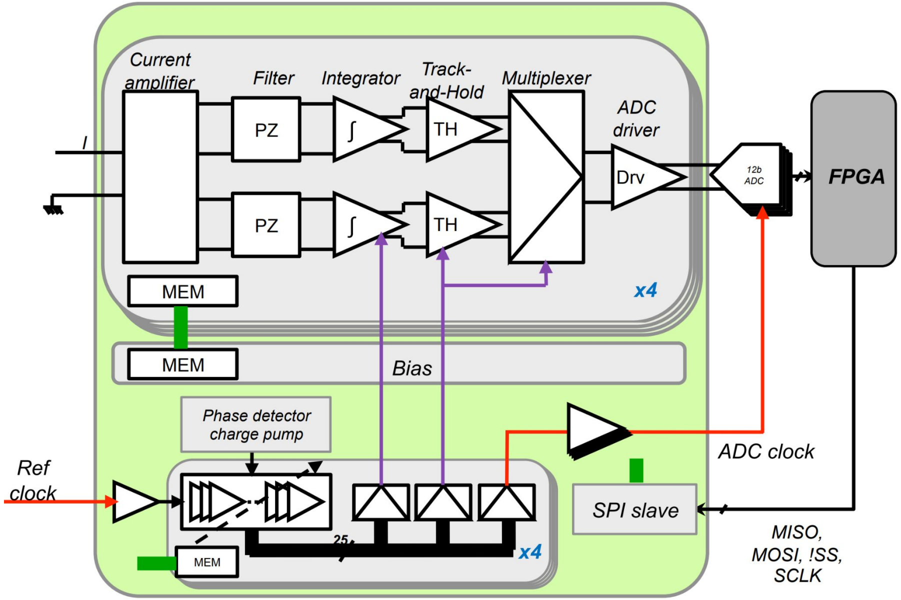
- Sampling tile calorimeter (iron + scintillator), same type of PMTs as in ECAL, for a total of 5.6 interaction lengths
- Two segmentation for a total of 1488 cells

  $\sigma(E)/E = (67 \pm 5)\,\%/\sqrt{E} \oplus (9 \pm 2)\,\%$

- no modification to the active material during LS2: PMT gain lowered by a factor 5 to preserve lifetime of the detector

Calo Upgrade



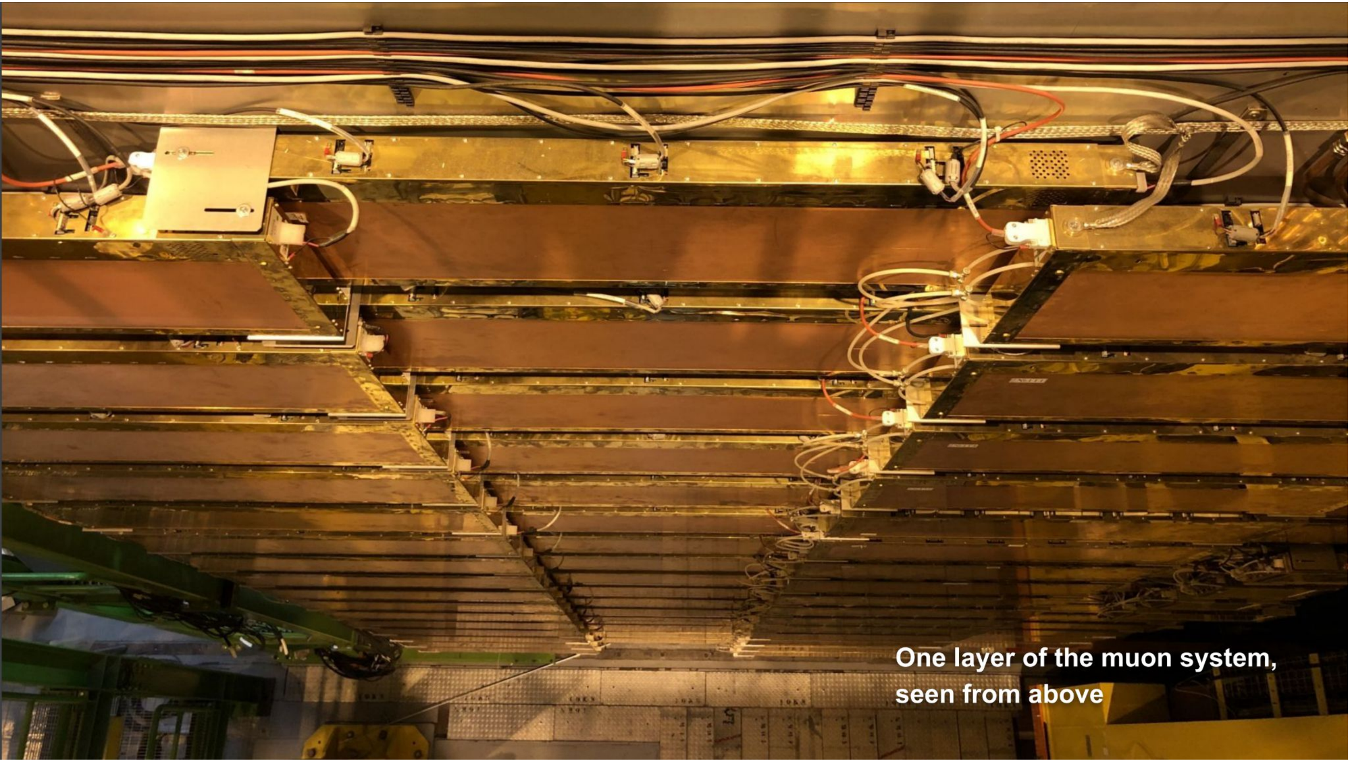


Front-end board (FEB), where the PMT signals are amplified, shaped and digitised: a partial gain compensation of a factor 2.5 was implemented into the FE electronics to compensate for gain reduction

ICECAL ASIC designed for the analog processing stage of the FEB

246 FEBs, 192 for the ECAL and 54 for the HCAL: each board is connected to 32 PMT outputs, the digital section of the FEB is based on a 12 bit ADC → total bandwidth per FEB 12 × 32 × 40 Mbit/s

Muon



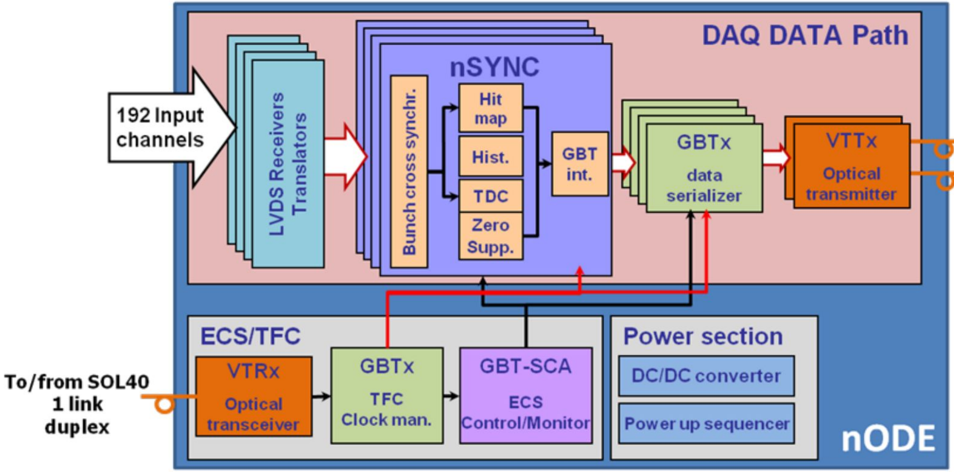
Four stations M2-M5, comprising 1104 multi-wire proportional chambers (MWPC) for a total area of 385 m^2

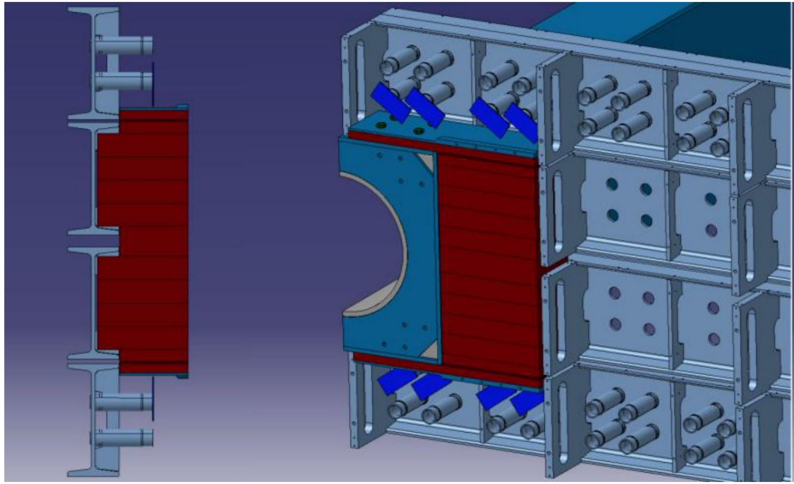
MWPC interleaved with 80 cm thick iron absorbers to filter low energy particles

4 independent layers (or gaps) per MWPC each consisting of anode wires between two cathode planes, to achieve a high efficiency and a high redundancy

no modification to active material during LS2

Muon Upgrade



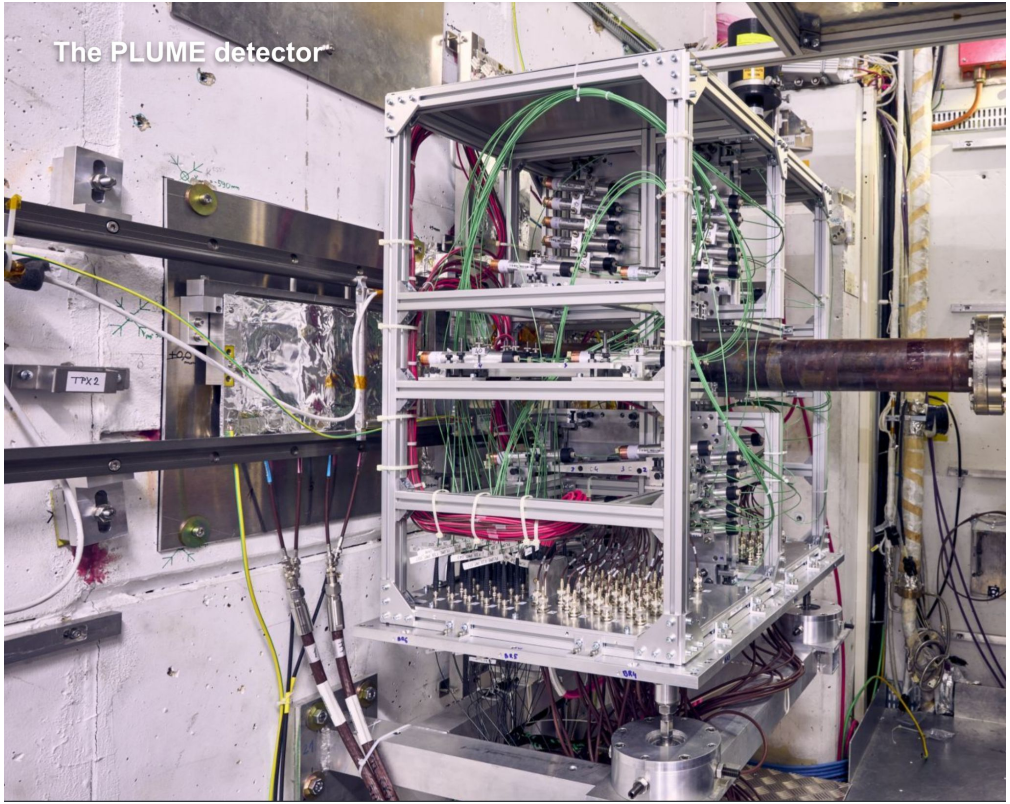


Additional shielding around beam pipe to reduce particle flux in M2 inner region due to higher lumi (tungsten plug)

MWPC signal digitised by front-end CARDIAC boards: new off-detector electronics needed to operate at 40MHz (nODE)

144 nODEs: each nODE handles a maximum of 192 logical inputs; provides interface with Trigger and Fast Control and data compressed, formatted and delivered to back-end

PLUME

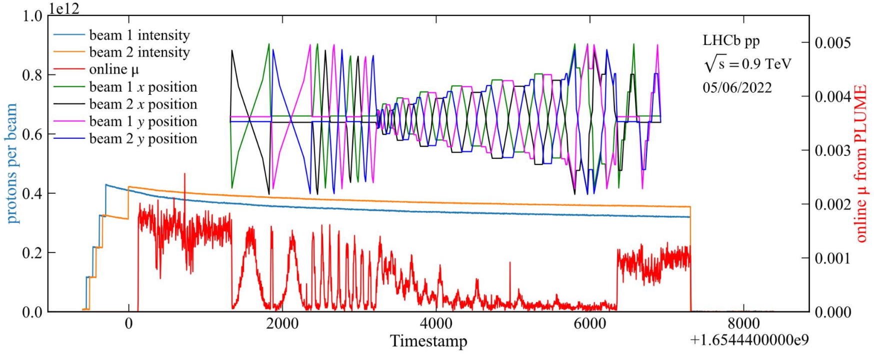


Luminometer placed upstream of the Velo:

48 PMTs (10mm) with 1.2mm thick quartz window and 5mm quartz tablet glued: measure Cherenkov light produced by charged particles in the radiator

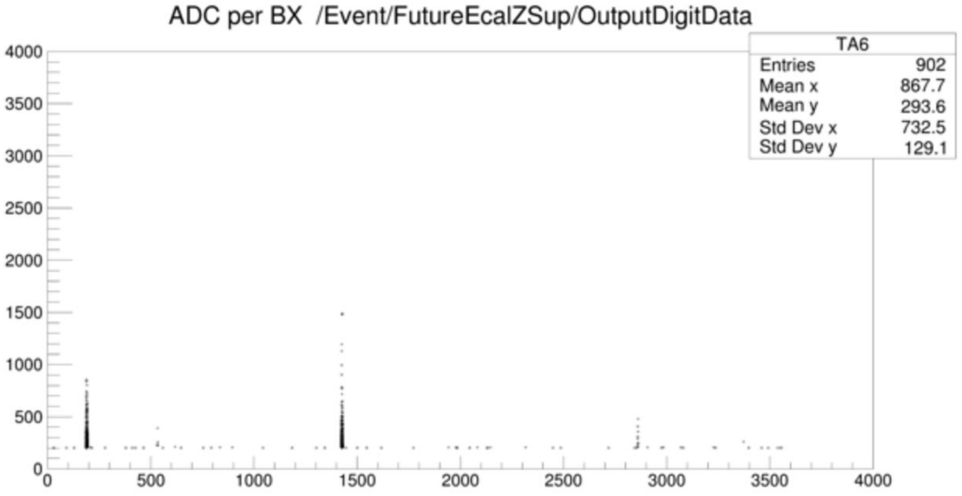
cross-shaped hodoscope with two layers of PMTs pointing to the interaction point

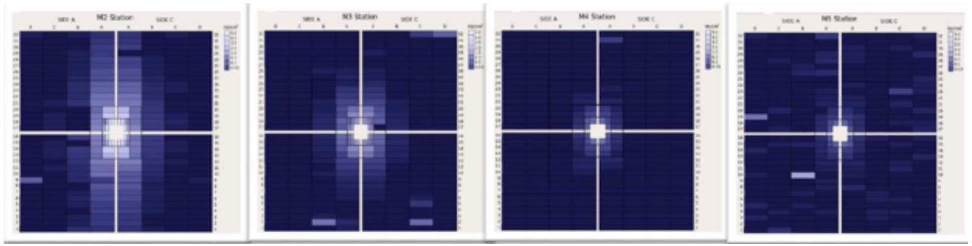
same FE electronics used for Calo Upgrade

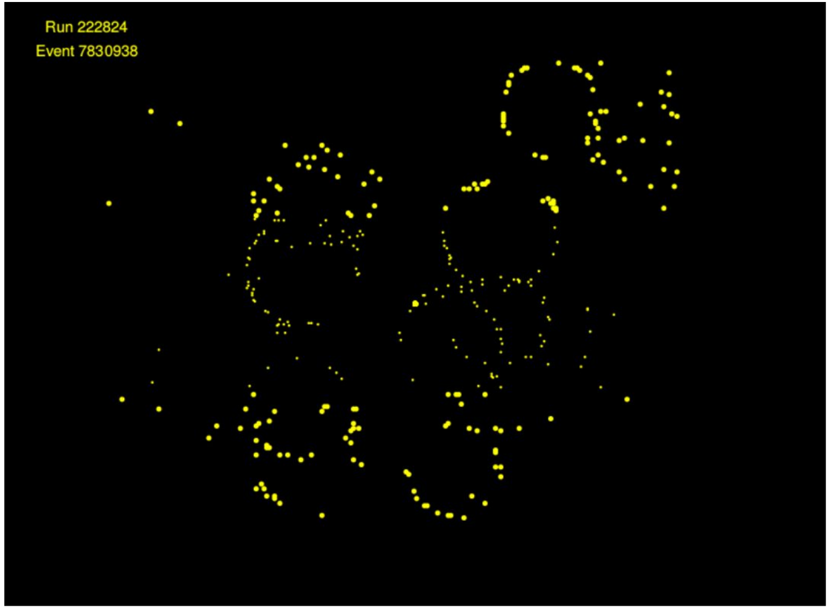


https://cds.cern.ch/record/2813388/

PID detectors in pilot beam





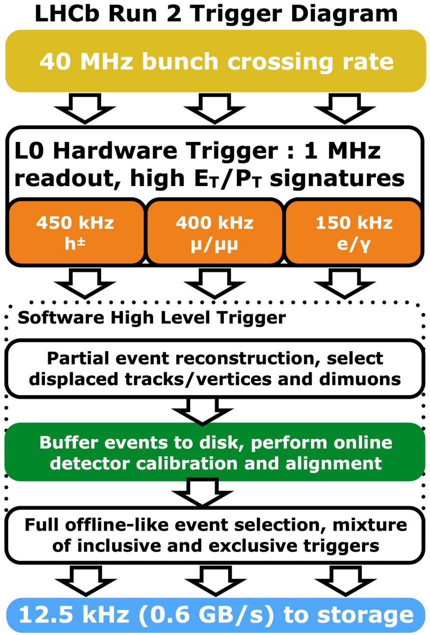


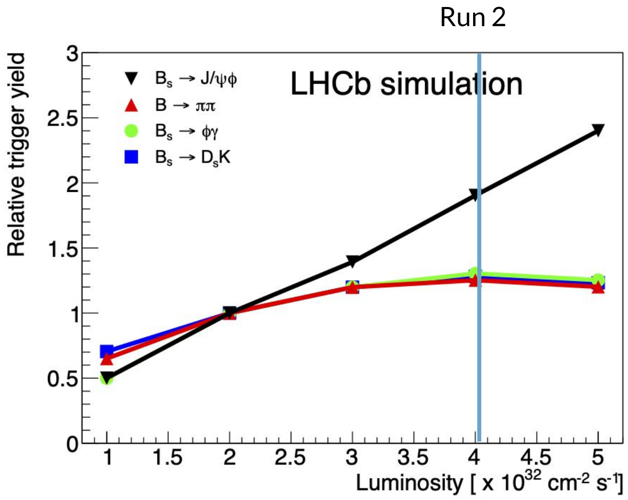
RICH2, ECAL, Muon and PLUME successfully operated already in LHC pilot beam at the end of 2021

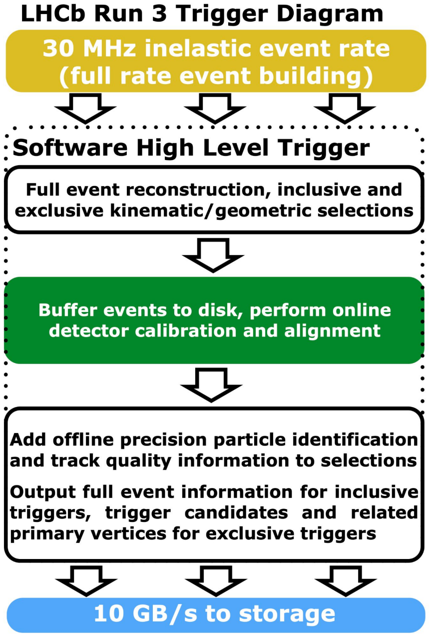
https://ep-news.web.cern.ch/content/lhc-pilot-beam-lhcb-preparation-run-3-start

LHCb-Figure-2020-016

Trigger scheme for Upgrade I

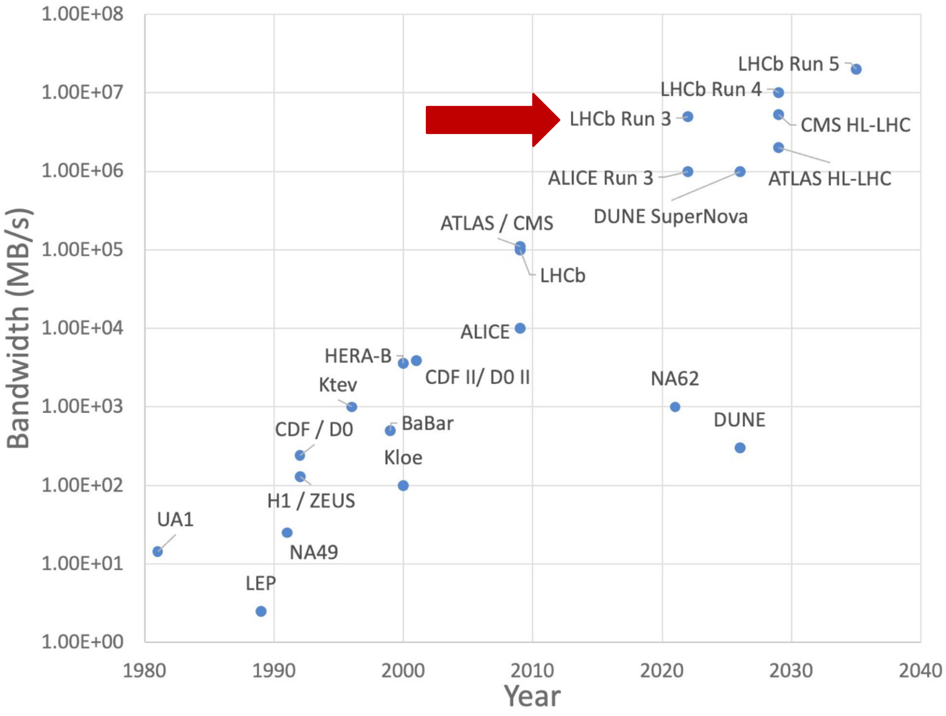






Data flood for Upgrade I

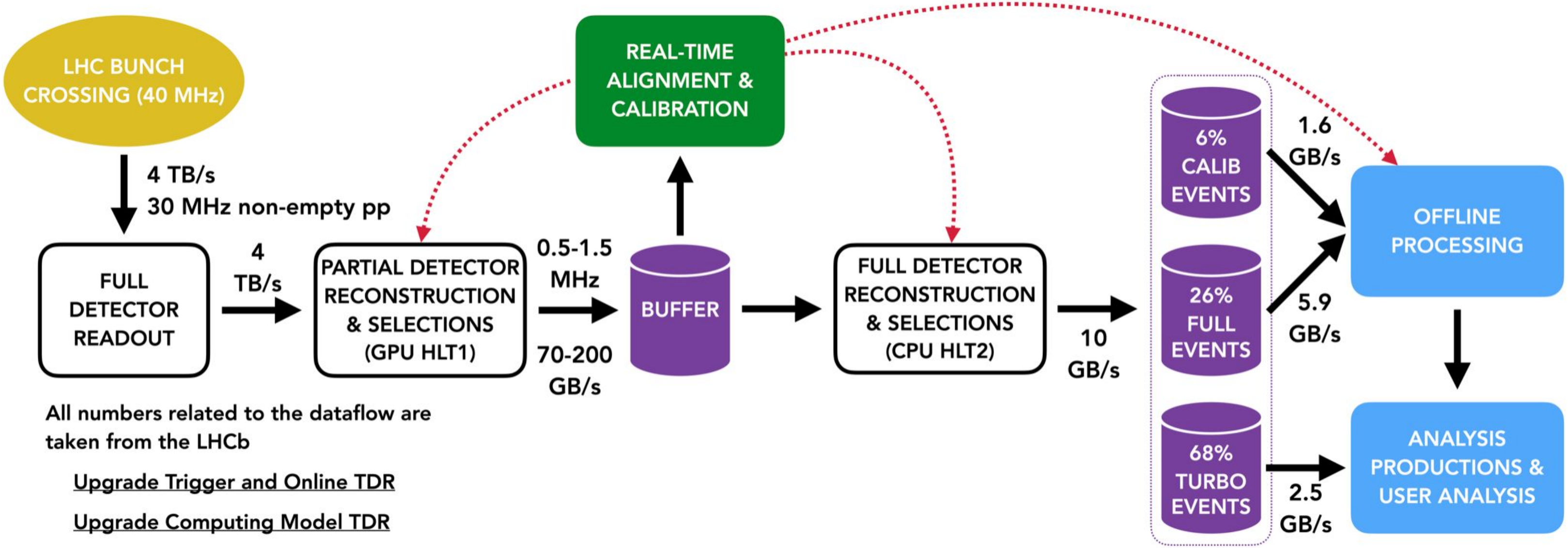
- LHCb is facing the challenges now other experiments will face in > 5 years from now
- Demands some novel approaches …



A. Cerri, Sussex

LHCb-Figure-2020-016

Data flow for Upgrade I



All numbers related to the dataflow are taken from the LHCb

Upgrade Trigger and Online TDR

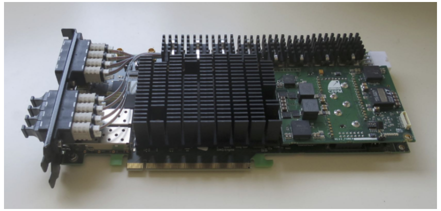
Upgrade Computing Model TDR

T. Colombo

New data centre at point 8

- 2 MW data centre
- 20’000 optical fibres, 250m long to cavern
- PUE = 1.1

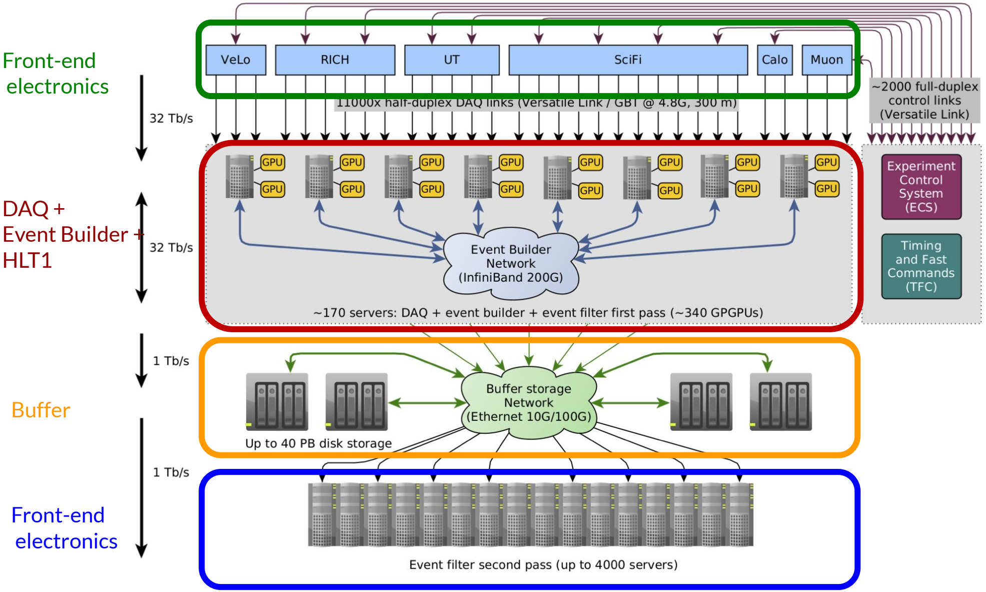
Online network



PCIe 40 readout card

- Custom PCIe 40 cards to receive data from subdetectors (TELL40)
- Up to 4 TB/s data rate through Event Builder network.
  - O(4%) of internet traffic in 2022 *
- ~170 EB servers with 2 GPU cards for HLT1
- 40 PB disk storage
- ~4000 servers in Event Filter Farm for HLT2
- All hosted in new data centre at Point 8

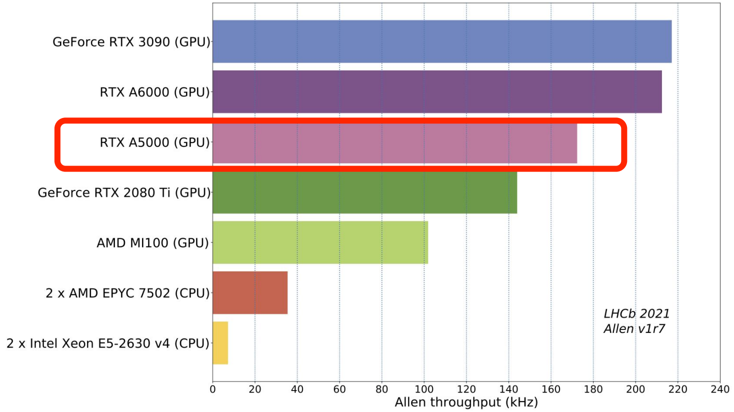
- Velo clustering performed in TELL40 (FPGA)



* Computer weekly 13/9/22

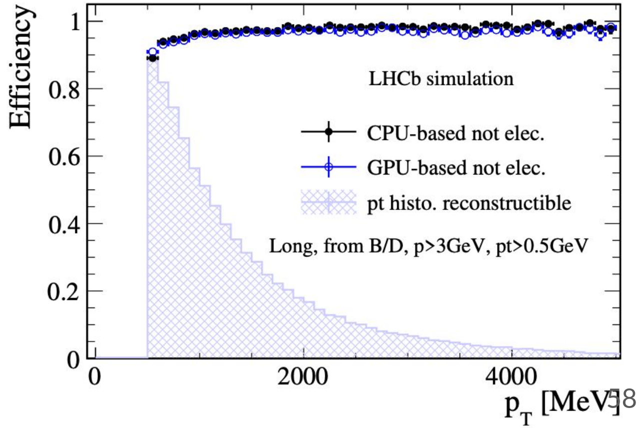
First software trigger stage

Comput Softw Big Sci 6, 1 (2022)



- Run full HLT1 on ~340 GPUs* (from 2023 on) in Event Builder
- Perform partial event reconstruction (tracking + MuonID + simplified Calo), run within the Allen project.
- Run O(50) trigger lines, most of physics programme covered by 1- and 2-track topological lines

- Putting GPUs in Event Builder uses free PCIe slots and decreases network cost after EB
- Performed extensive comparison with HLT1 implementation on CPU to verify performance.
- Large expansion of capabilities since first design



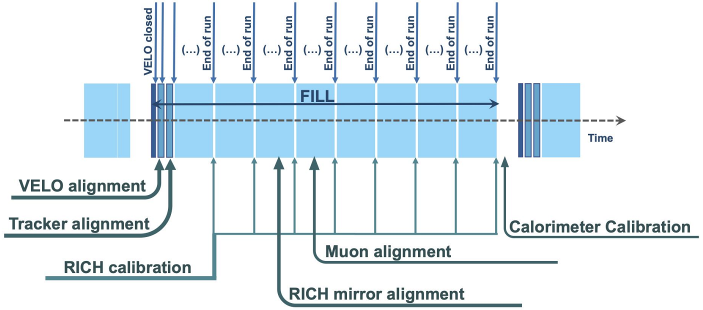
*Nvidia RTA A5000

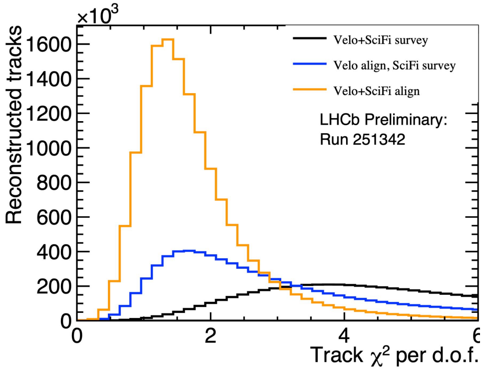
LHCb-Figure-2022-018

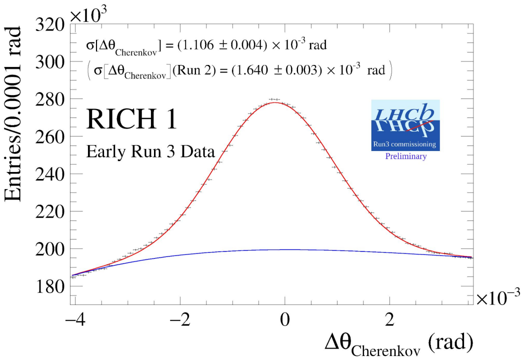
LHCb-Figure-2023-007

Alignment & Calibration

- Buffer has 2 purposes:
  - Run HLT2 out-of-sync
  - Perform alignment & calibration automatically
- Full offline performance in HLT2, and using output of trigger directly for physics analyses.
- Alignment: Spatial position of trackers / Muon and RICH elements
- Calibration: PMT gain calibrations of ECAL and RICH gas refractive index calibrations

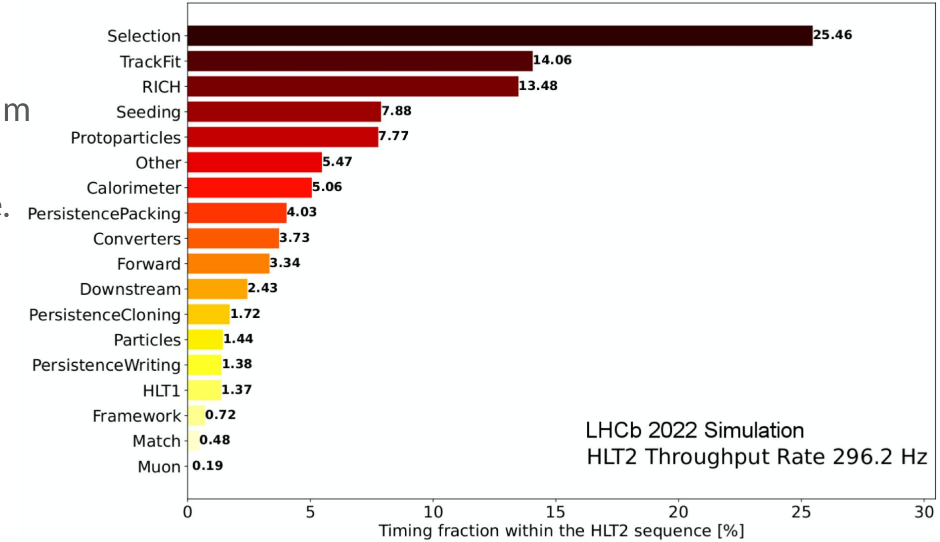






Second software trigger stage

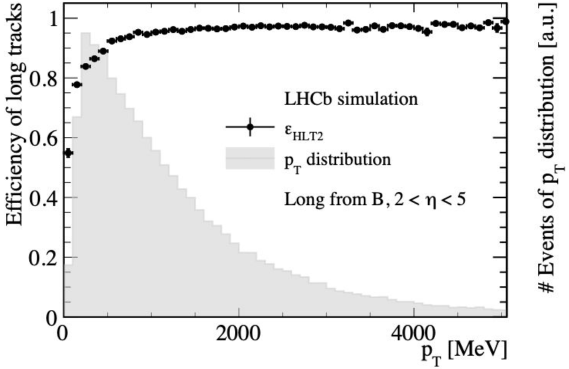
- Performs the full event reconstruction on O(4000) CPU servers
- Run O(1500) trigger lines, covering the full spectrum from strange and charm physics to electroweak physics, including fixed-target (SMOG) programme.
- HLT2 performs the final event reconstruction
- Split selected data in several streams:
  - Signal candidates only directly to disk (TURBO)
  - Full events to further offline processing

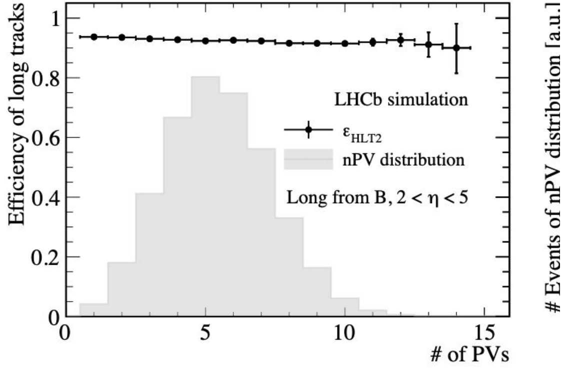


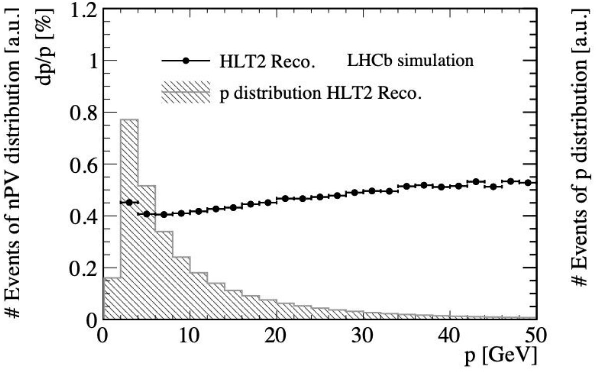
Expected HLT2 performances

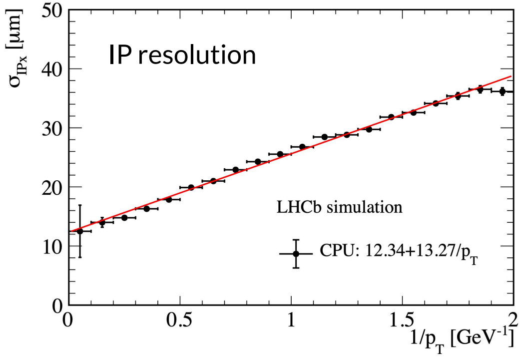
LHCb-Figure-2021-003

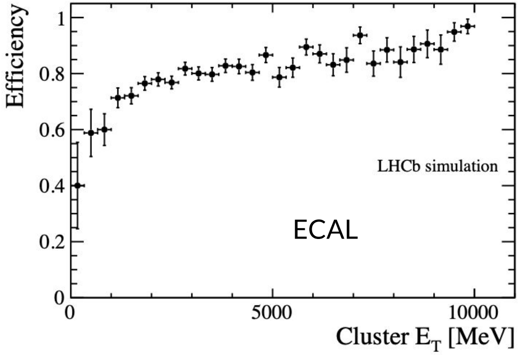
v=7.6

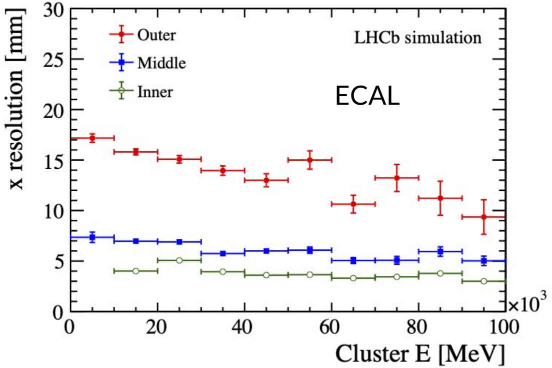








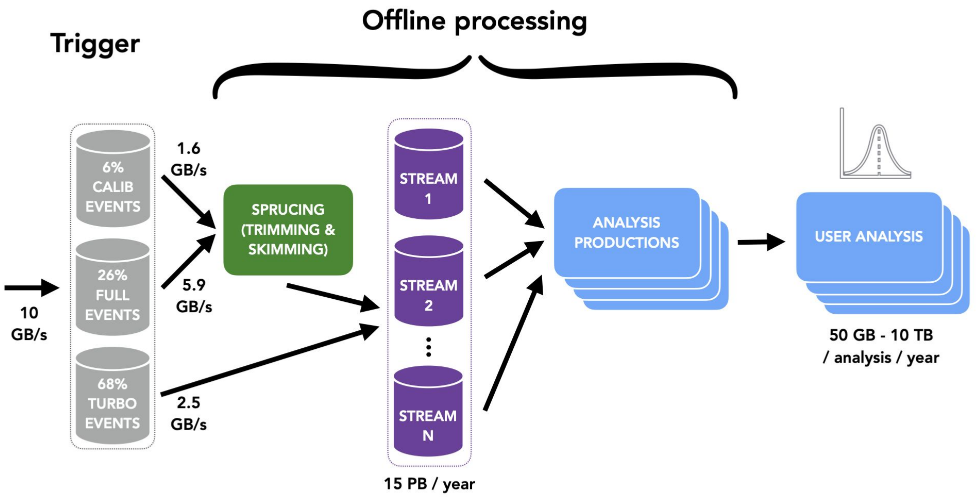




Offline data processing

LHCb-Figure-2020-016

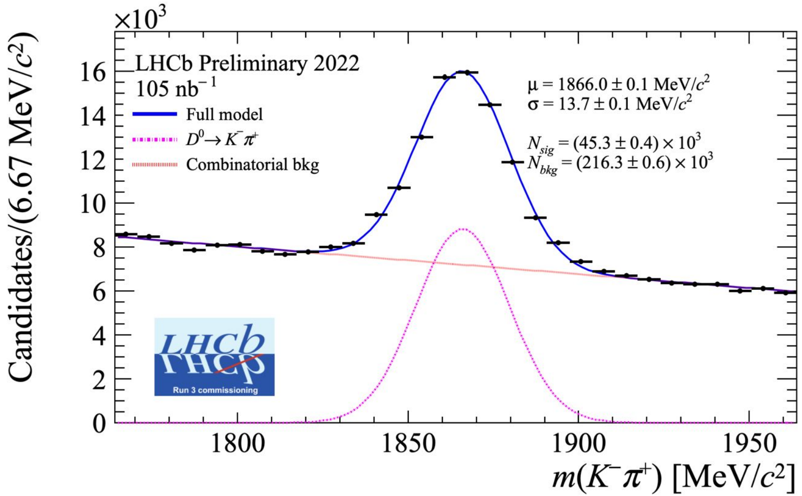
- Part of data will undergo offline event processing ("sprucing") and streaming.
    - start from objects reconstructed in HLT2
- Reduce data up to 80%, possibility of periodic "re-sprucing" to refine data selection.
- Majority of nTuples for user analysis will be generated with Analysis Productions
- Tupling framework has seen a major overhaul, introducing `Fun(ctor)Tuple`

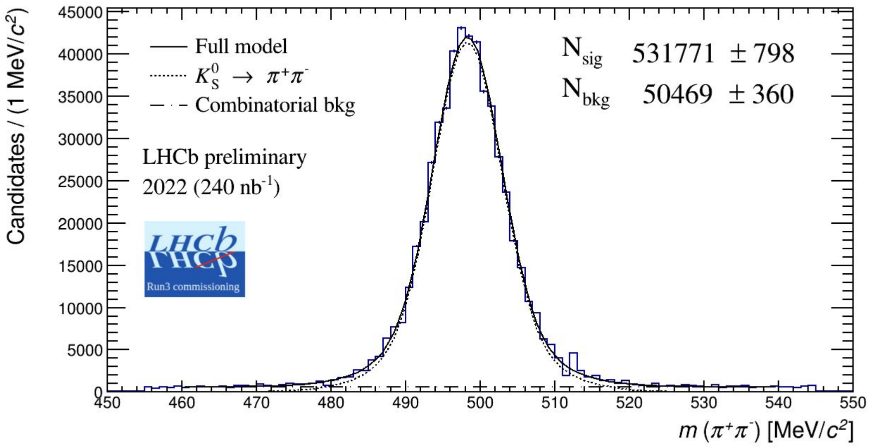


First Run 3 results - HLT1

LHCb-Figure-2023-009

LHCb-Figure-2023-005

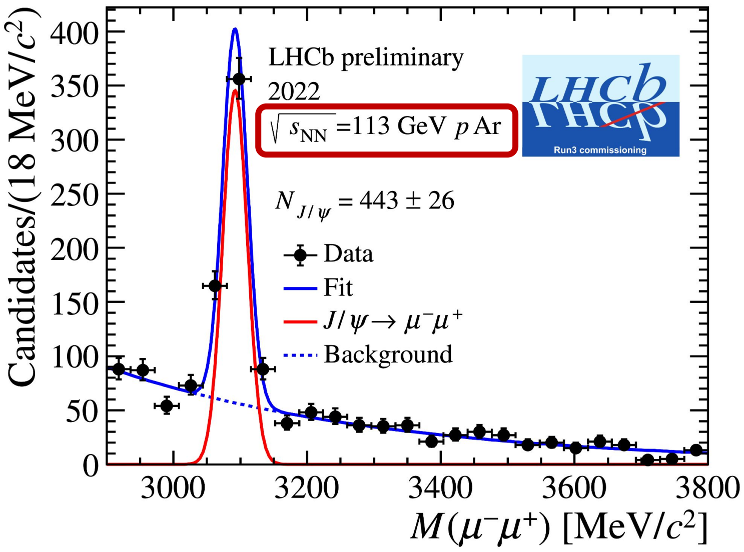


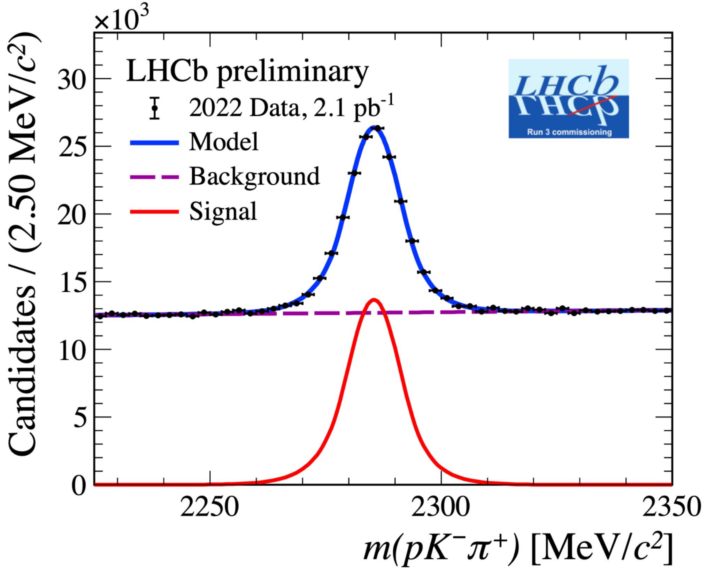


First Run 3 results - HLT2

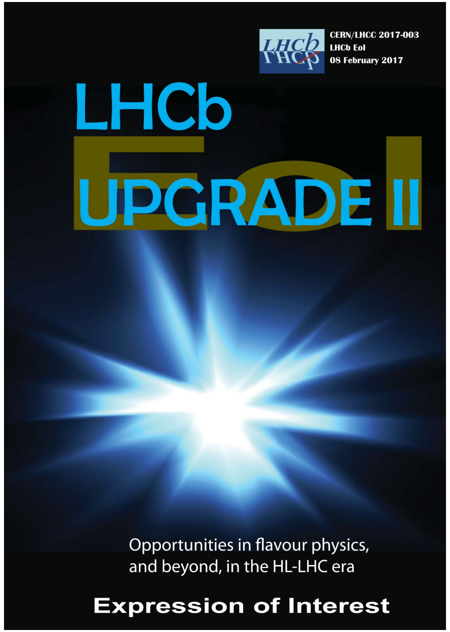
LHCb-Figure-2023-008

LHCb-Figure-2023-011

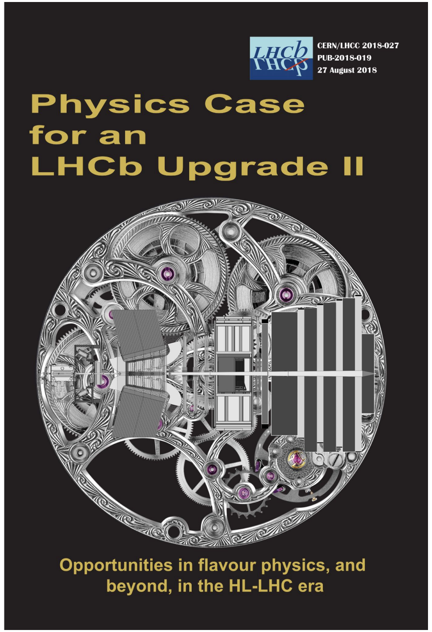




Towards Upgrade II



2017

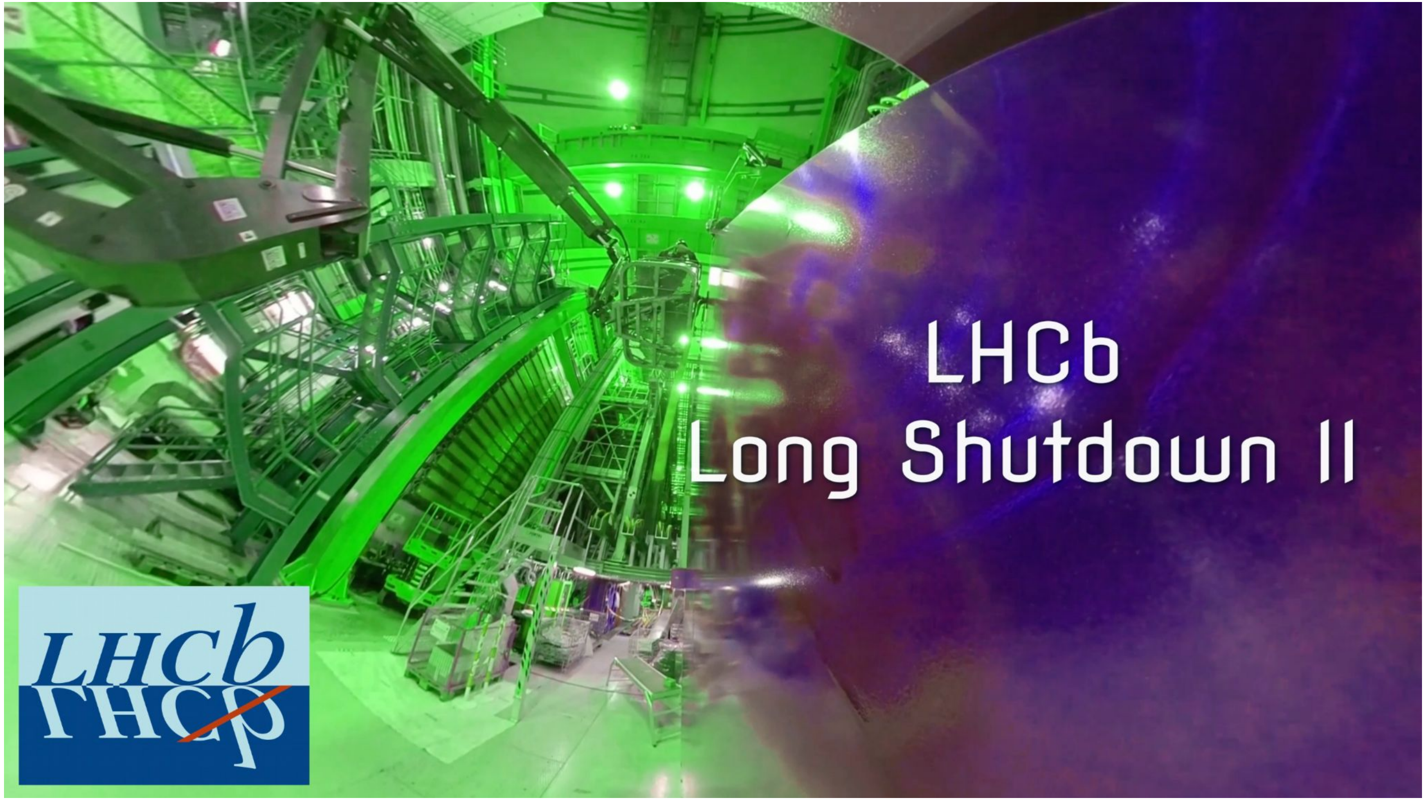


2018

2022

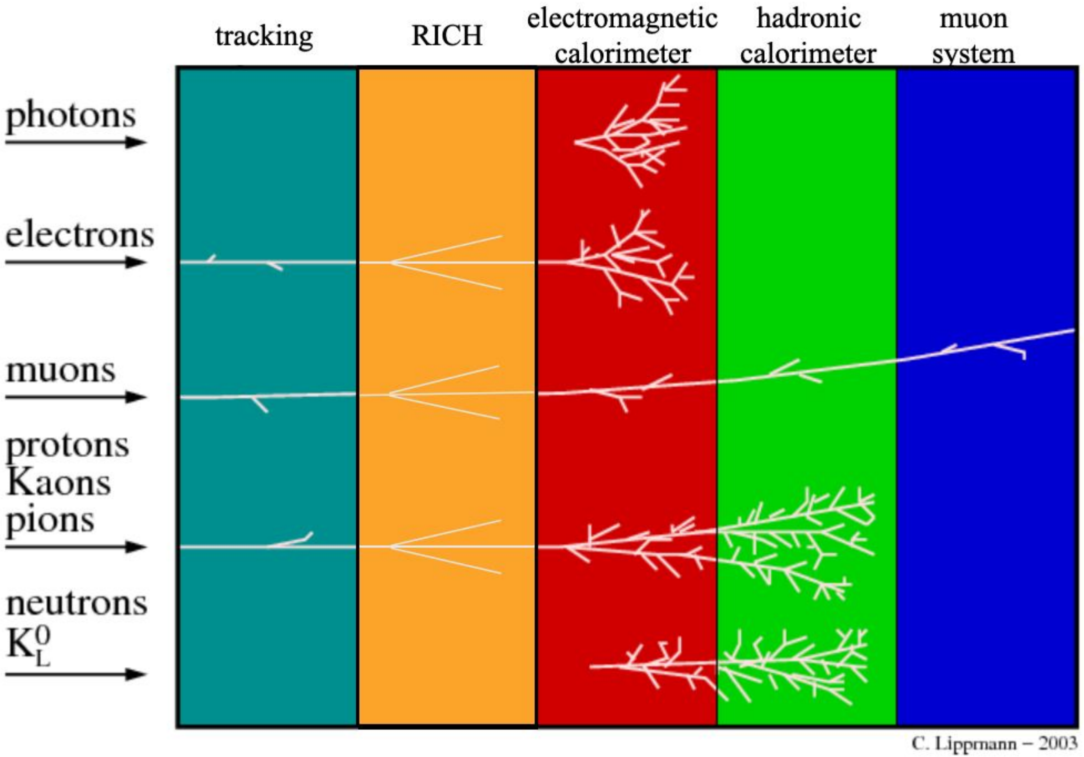
Conclusion

Video R. Lindner



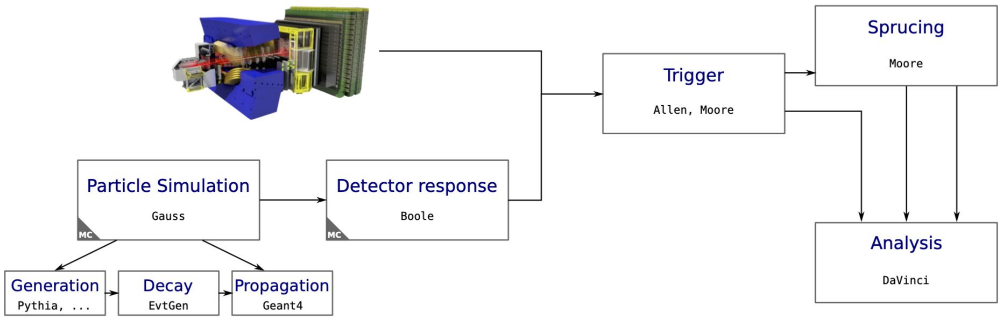
Backup

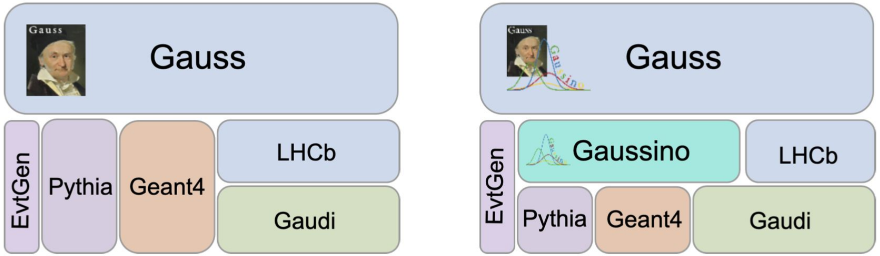
Particle identification at LHCb



Simulation

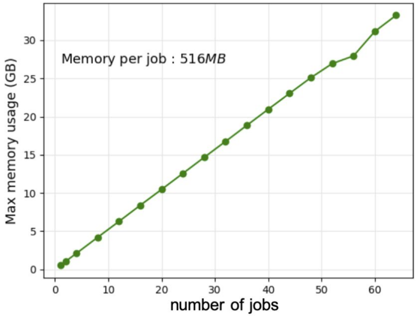
- Simulation shares data flow after collisions and detector response
- New framework "Gaussino", which is experiment-agnostic and can run multithreaded.
- Developed variety of filtered, fast and ultra-fast simulation options, to suit the need of analysts and decrease CPU consumption.

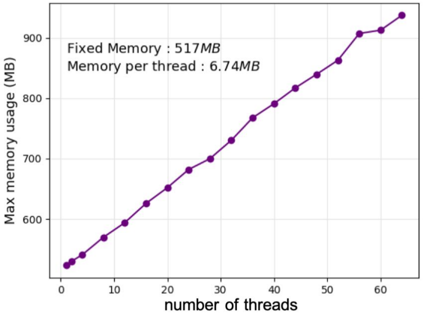


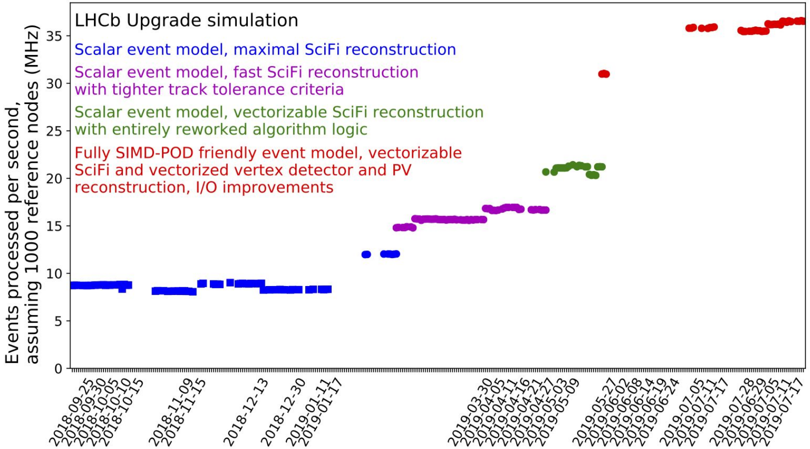


Software developments

- Major effort to enable multi-threading in **`GAUDI`** and modern software paradigms (i.e. SIMD instructions) for LHCb code base.
- New algorithmic structures with defined inputs and outputs at configuration time, and a new configuration framework: **`PyConf`**
- Perform selections using functors that are composable, e.g. **`MIN @ IP`**







Bandwidth per stream

Stream	Rate fraction	TAPE throughput (GB/s)	TAPE bandwidth fraction	DISK throughput (GB/s)	DISK bandwidth fraction
FULL	26%	5.9	59%	0.8	22%
Turbo	68%	2.5	25%	2.5	72%
TurCal	6%	1.6	16%	0.2	6%
Total	100%	10.0	100%	3.5	100%

EB Server

DAQ input
3 custom DAQ cards (PCIe40)
Up to 144 fibers, 300 Gb/s

Event building
2 InfiniBand network cards
400 Gb/s total bandwidth

HLT
2 “workstation-class” GPUs
55 TFLOPs