中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

LHCb Upgrades

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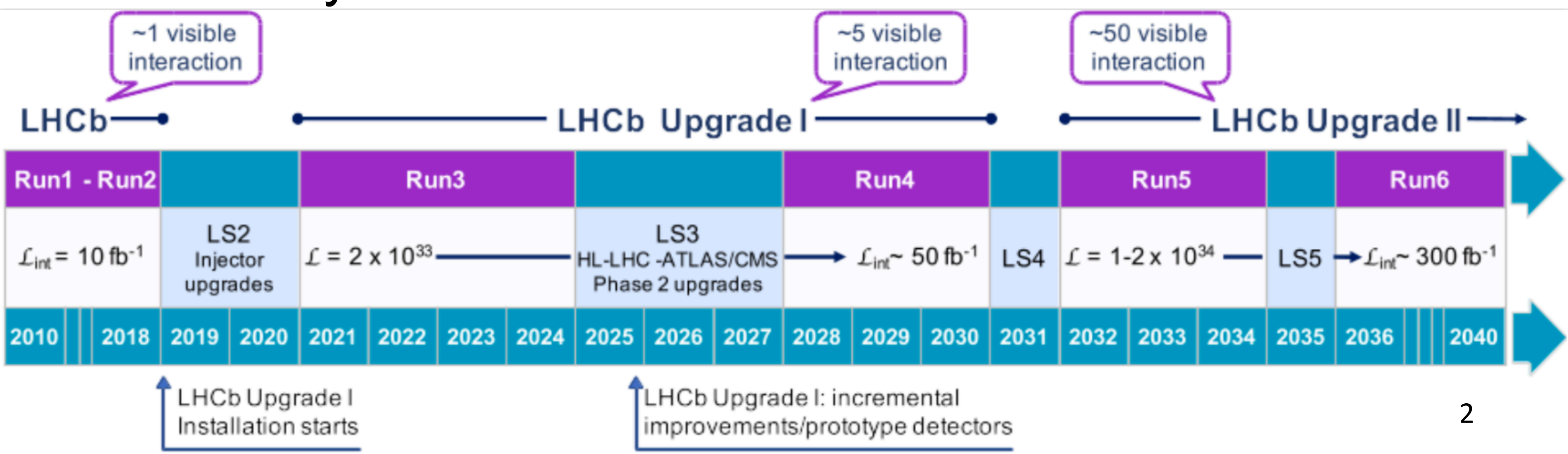
On behalf of the LHCb collaboration

Overview

- Motivation.
  - Flavour physics @ HL-LHC.
- Upgrade I.
  - Status of installation.
- Upgrade Ib.
  - Consolidation plans.
- Upgrade II.
  - Plans & Design.
- Summary.



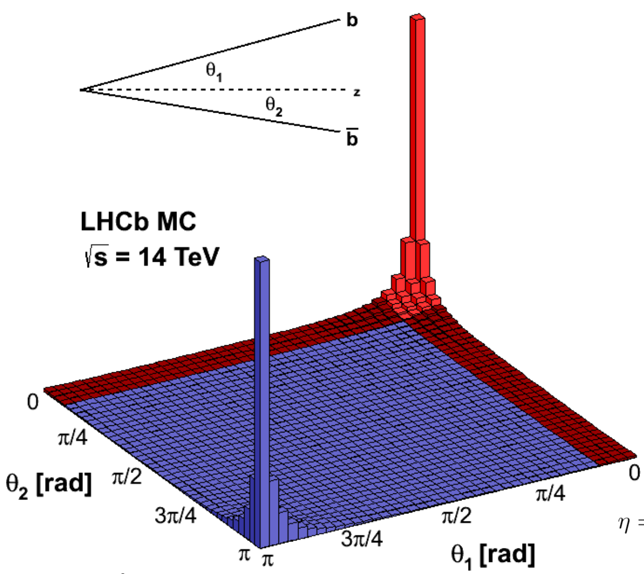
Why LHCb?

- Dedicated heavy flavour experiment at LHC.
  - Measure CP-violation in *b*-sector.
  - Study rare *b*- and *c*- hadron decays.
  - Exploit forward production of *b*-pairs with low angle.

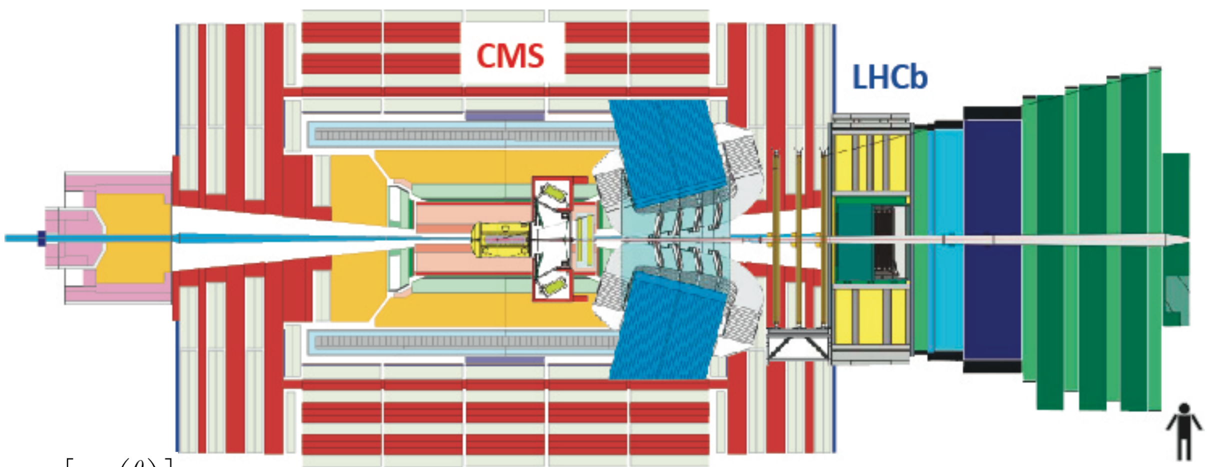
✧ ***Indirect searches for New Physics.***

- Physics program in Runs 1&2 was much much more.
  - Electroweak, QCD, direct searches, heavy ions.

✧ ***General Purpose Detector in forward region.***



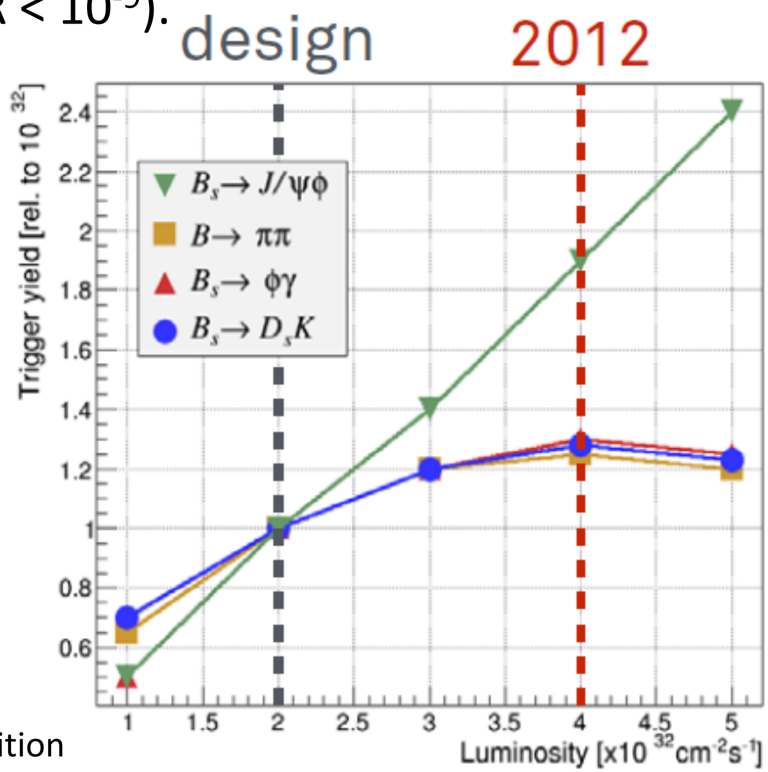
$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



$2 < \eta < 5$

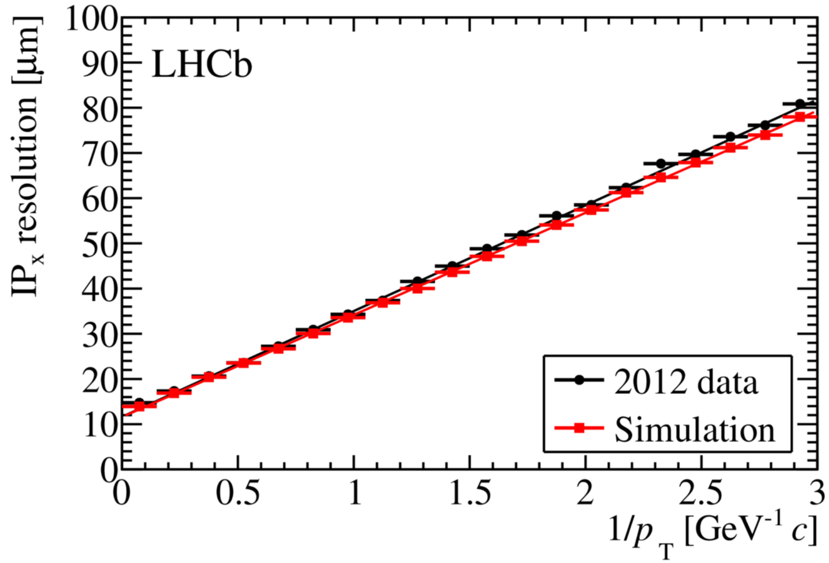
Why upgrade?

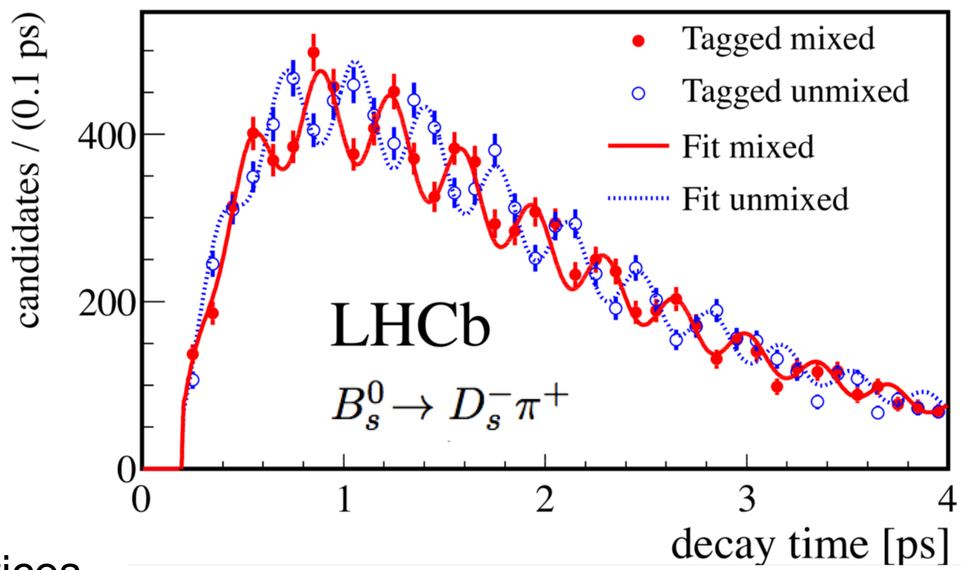
- Some hints of New Physics in LHC Runs 1 & 2.
  - Lepton flavour (non-)universality?
    - Semi-leptonic $B^0 \rightarrow D^{(*)-} l^+ \nu$ (tree level decay) – R(D*).
    - $b \rightarrow s l^+ l^-$ decays e.g. $B^0 \rightarrow K^{(*)0} l^+ l^-$ (FCNC decays) – R(K), R(K*).
  - Angular analysis of $K^* \mu^+ \mu^-$.
  - No “discovery” but coherent set of discrepancies w.r.t. Standard Model.
- More data to further challenge theoretical predictions.
  - Precision tests with very rare decays (BR < 10^{-9}).
- Limited by Level-0 hardware trigger.
  - Maximum rate is 1.1 MHz.
- Higher luminosities:
  - Trigger yield saturates.
  - Harder cuts on E_T and p_T.
  - No real gain in statistics.
- Higher occupancy.
  - Degraded detector performance.
  - Radiation damage of detectors.



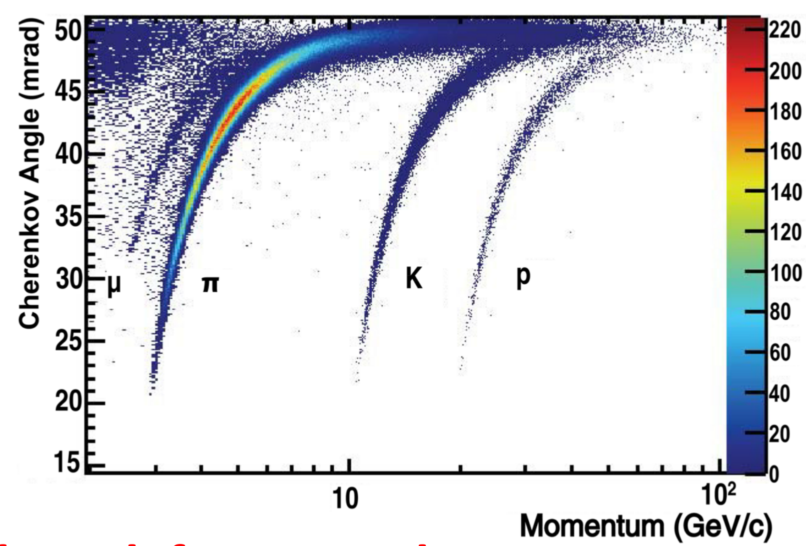
Int. J. Mod. Phys. A 30, 1530022 (2015)

Detector Performance





- Separation of primary and secondary vertices.
  - Impact parameter resolution: (15 +29/p_T[GeV]) μm.
- Proper time resolution.
  - Decay time resolution: ~45 fs ($B_s \to J/\psi\phi$ & $B_s \to D_s\pi$).
- Excellent momentum resolution:
  - Δp / p = 0.5% (<20 GeV) to 1.0% (200 GeV).
- Particle Identification:
  - Separation between γ, $e^\pm$, $mu^\pm$, π, K, p.
- Trigger Selection:
  - Efficient trigger for leptonic and hadronic final states.
  - Fast reconstruction of primary and secondary vertices



Run 1&2 performance is benchmark for Upgrades

CKM Measurements

LHC-B

LETTER OF INTENT

A Dedicated LHC Collider Beauty Experiment
for Precision Measurements of CP-Violation

1995

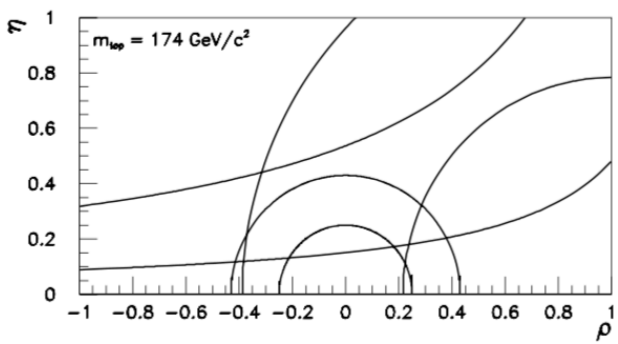
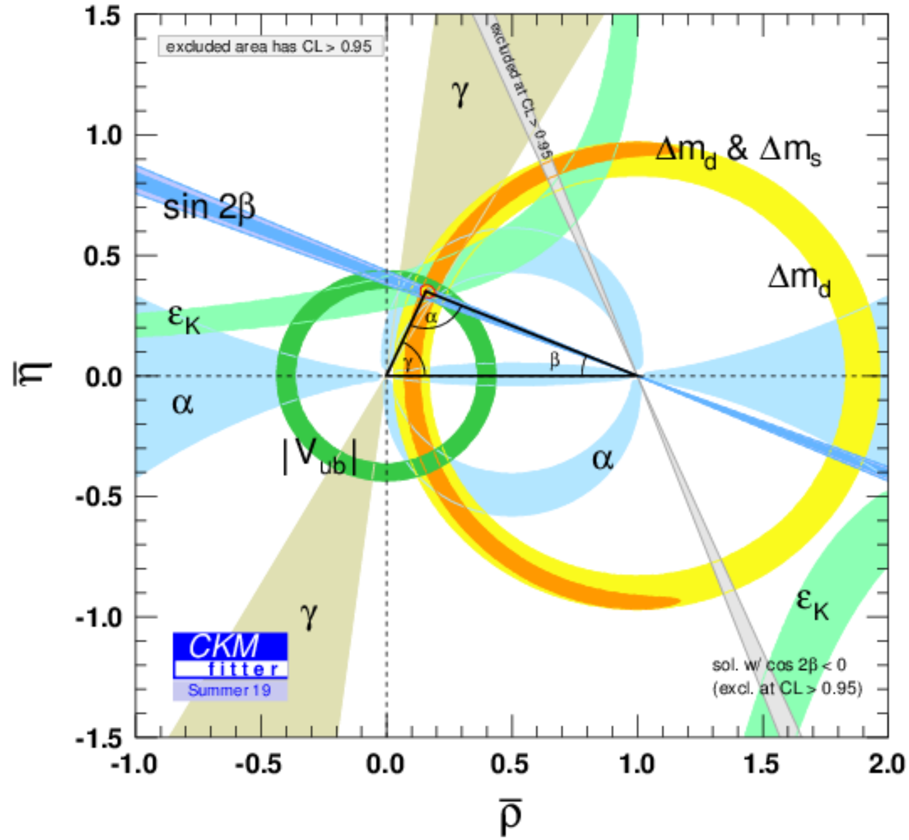


Figure 2.1: Limits on the CKM parameters (1σ) ρ and η for $m_t = 174$ GeV. The annular region cen-

2019



$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Matrix is unitary: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

$$\alpha = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right), \qquad \beta = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right), \qquad \gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right).$$

CKM Measurements

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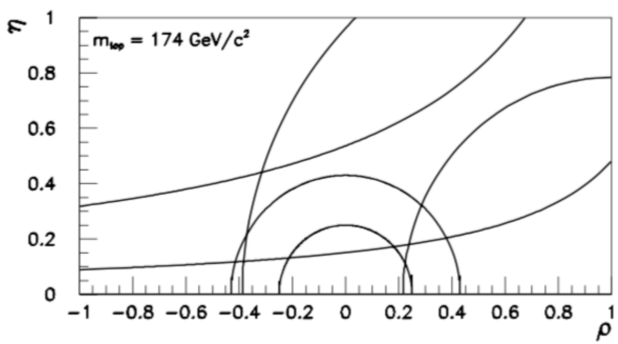

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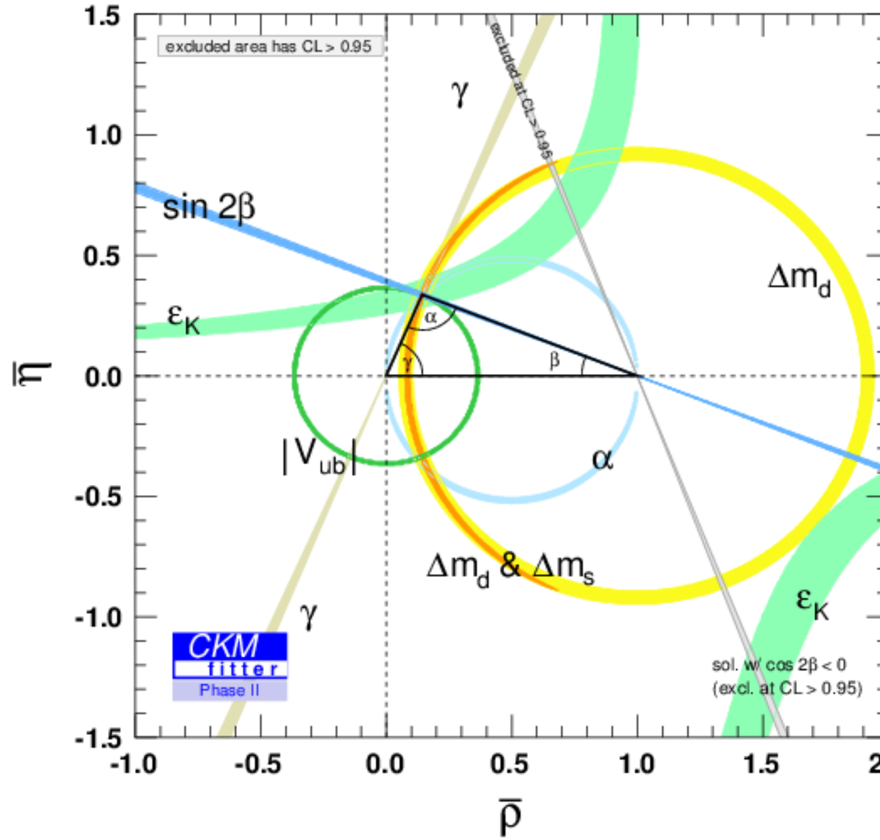
Phase 2



LHCb (300 fb^{-1}), Belle-II (50 ab^{-1})
ATLAS & CMS (3000 fb^{-1})

arxiv:1812.07638

$\sigma_\gamma \approx 5°$ (2019) → 1° (Phase 1) → 0.35° (Phase 2) arXiv:1808.08865

Physics Reach

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\text{GeV}^2c^4)$	0.1	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\text{GeV}^2c^4)$	0.1	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad	14 mrad	–	4 mrad	22 mrad
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad	39 mrad	–	11 mrad	Under study
a_{sl}^s	33×10^{-4}	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6%	3%	1%	1%	–
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90%	34%	–	10%	21%
$\tau_{B_s^0 \to \mu^+\mu^-}$	22%	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**					
$R(D^*)$	0.026	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4}	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4}	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4}	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

** Taken from Physics case for an LHCb Upgrade II (CERN-LHCC-2018-027)*

1. CERN-LHCC-2008-007
2. CERN-LHCC-2011-001
3. CERN-LHCC-2012-007
4. CERN-LHCC-2013-021
5. CERN-LHCC-2013-022
6. CERN-LHCC-2014-001
7. CERN-LHCC-2014-016
8. CERN-LHCC-2018-007
9. CERN-LHCC-2018-014
10. CERN-LHCC-2019-005

UPGRADE I

Conditions:

- Luminosity: 2×10^{33} cm^{-2}s^{-1} (inst.), 50 fb^{-1} (int.)
- 5.2 visible interactions / crossing.

Challenge:

- Maintain current reconstruction performance in harsher environment.
- Read out the complete detector at 40 MHz.

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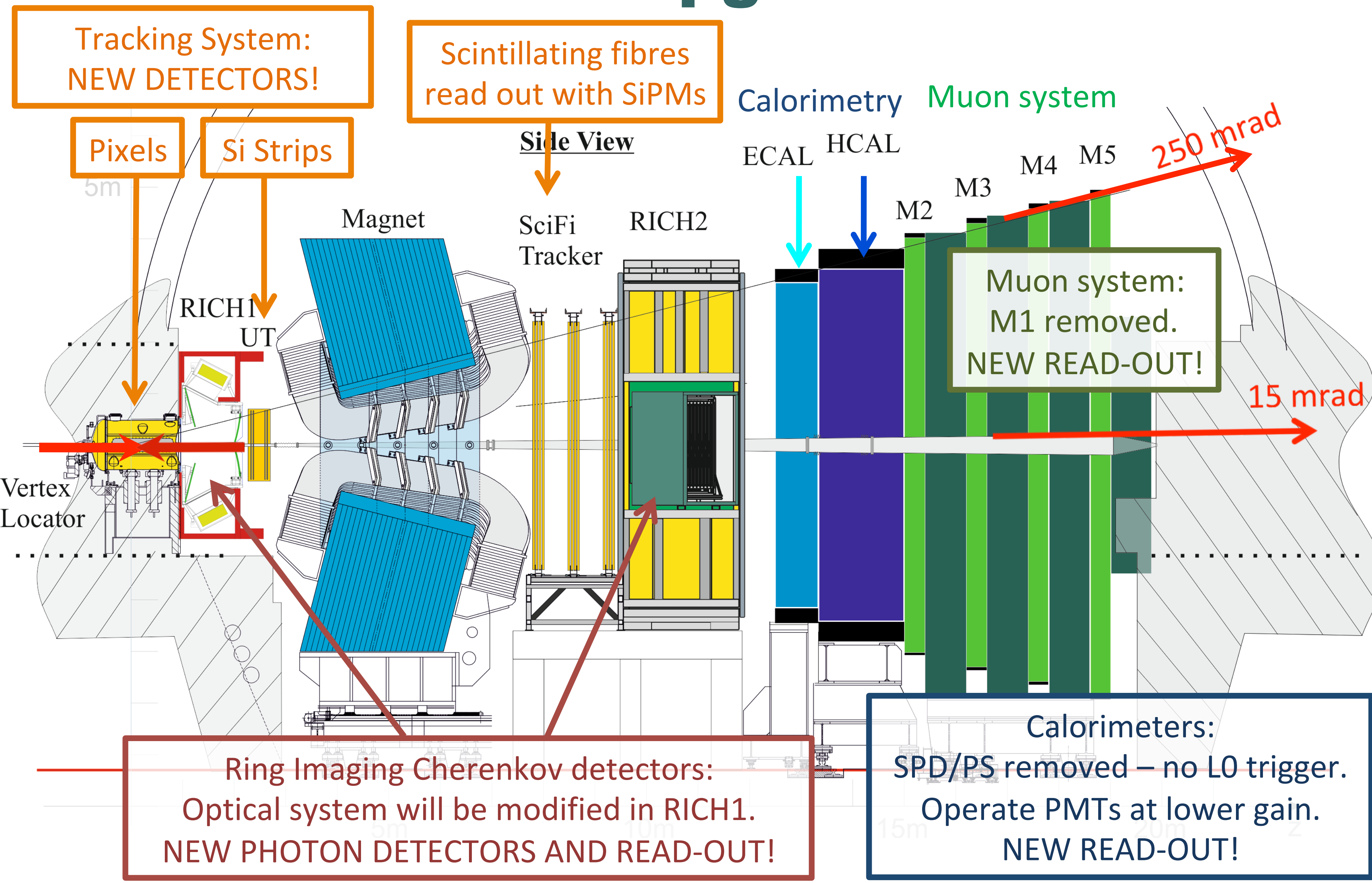
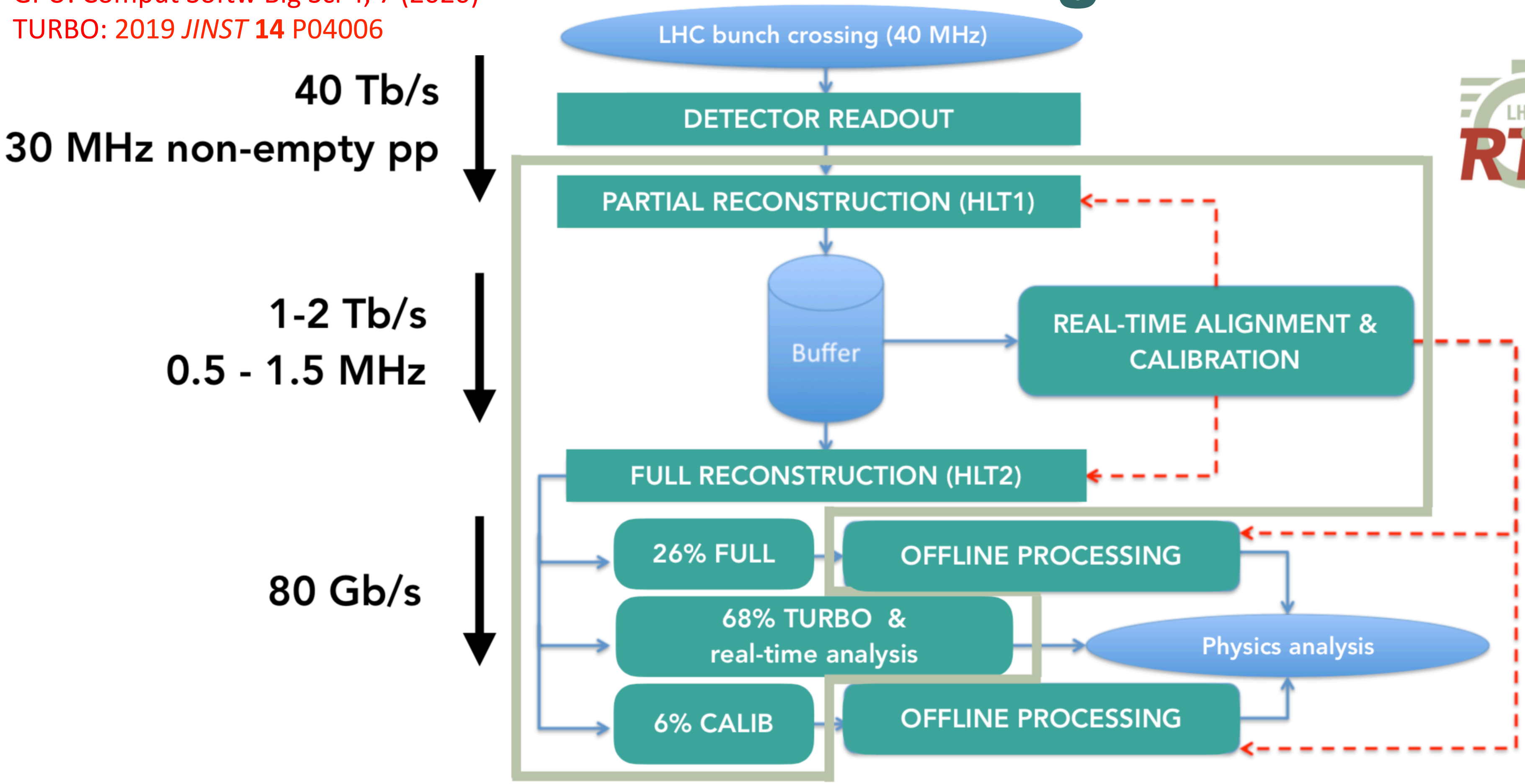
LHCb Upgrade I



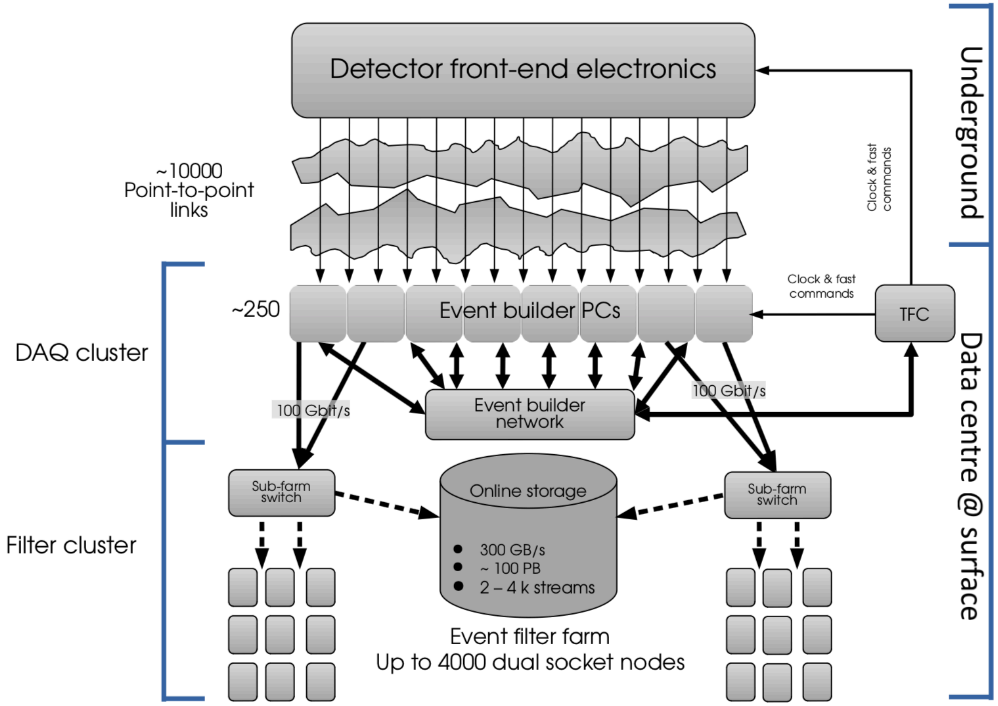
Comput. Phys. Commun. **208** 35-42
Run 2: 2019 *JINST* **14** P04013
GPU: Comput Softw Big Sci 4, 7 (2020)
TURBO: 2019 *JINST* **14** P04006

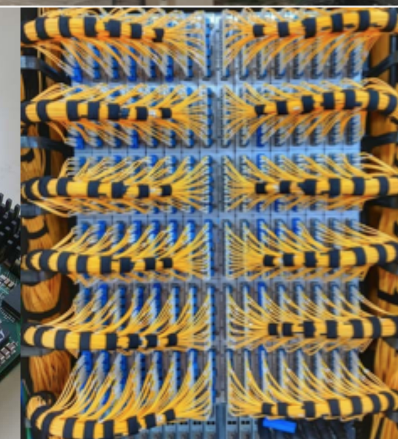
Data Processing



- RTA is integral part of DAQ chain in upgrade data processing.
  - Offline reconstruction in HLT2 à la Run 2.
- TURBO model for exclusive selections.
  - High-level physics objects directly from the HLT → small fraction of raw event size.
- HLT1 reconstruction will run on GPUs.

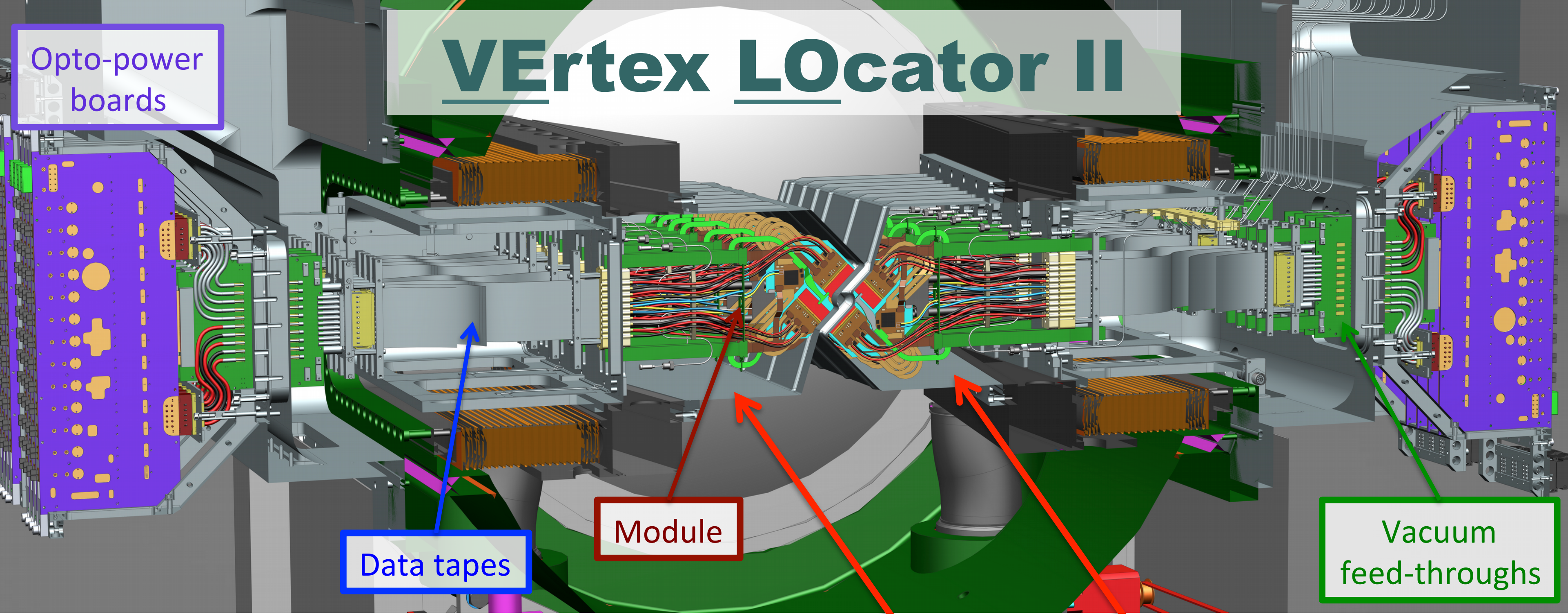
Online



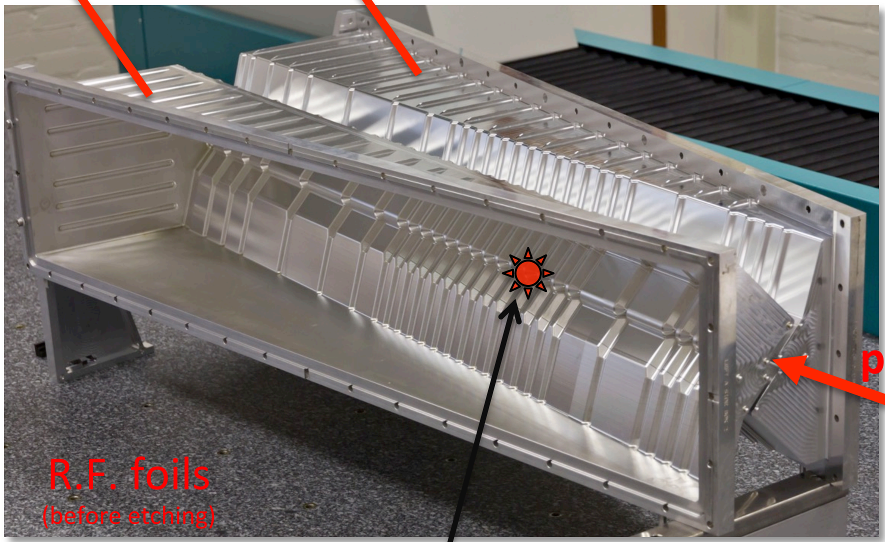



- Data centre on surface.
  - Event Filter Farm and Event Builder network.
- Long distance optical fibres.
  - 19008 fibers installed (0.25% broken).
- Common read-out boards (PCIe40).
  - Large FPGA with 1.15M cells.
  - 48 bi-directional links (10 Gbit/s).
  - Three flavours of firmware.
- GPUs in event builder PCs.

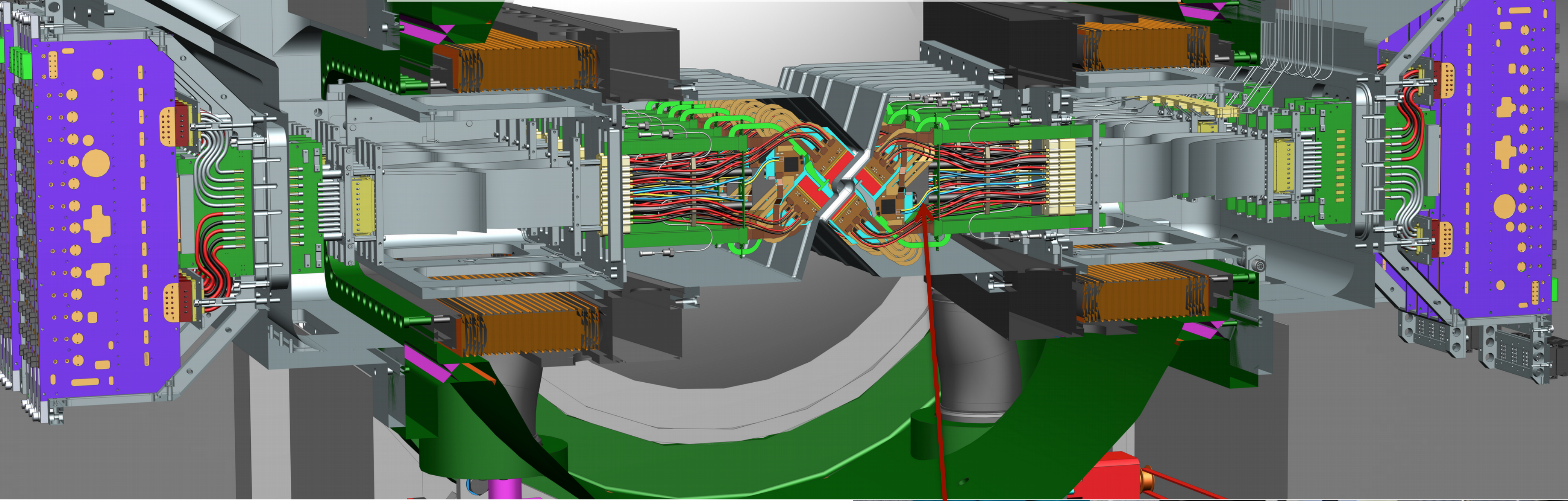
VErtex LOcator II



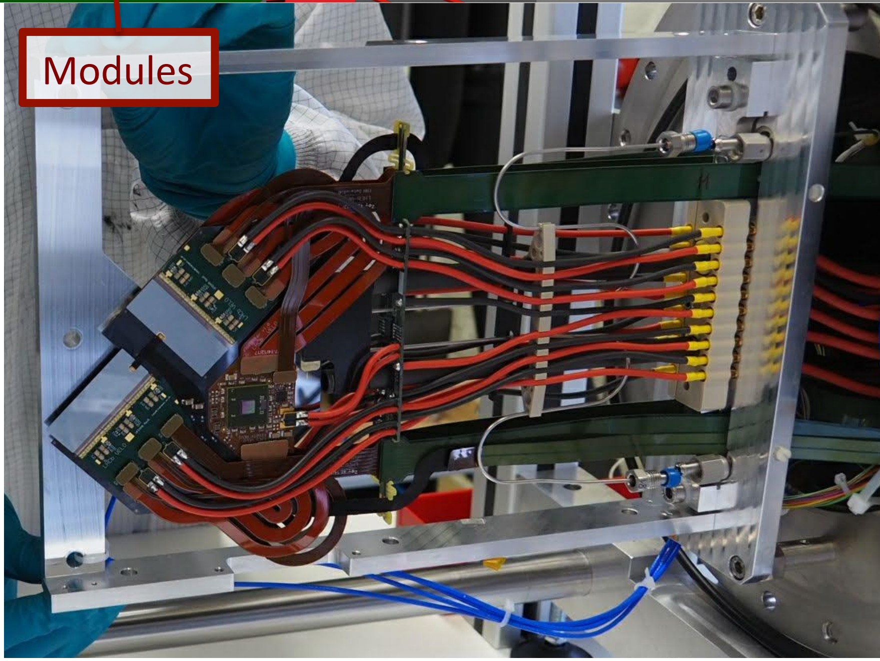
- Two retractable halves
  - 3.5 mm from beam when closed.
  - First measurement at 5.1 mm.
- Operates in secondary vacuum.
  - Aluminium R.F. foils separate detector from beam vacuum.
  - Milled to 250 μm thick then chemically etched to 150 μm.
- 52 hybrid-pixel modules.
  - 41M pixels covering total area ~ 1.2 m^2.



VErtex LOcator II

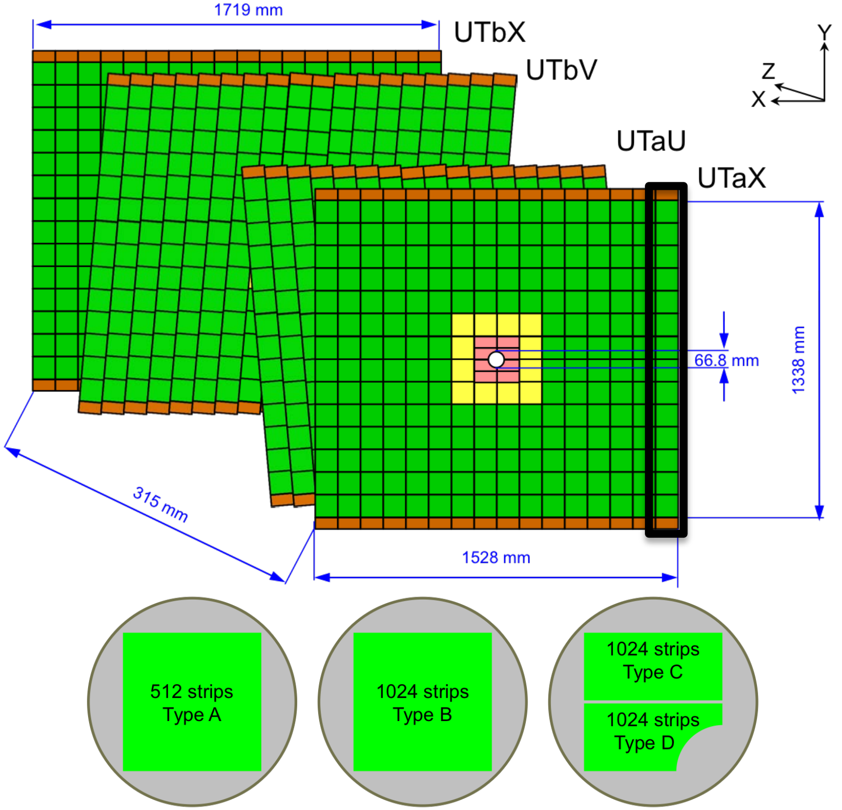


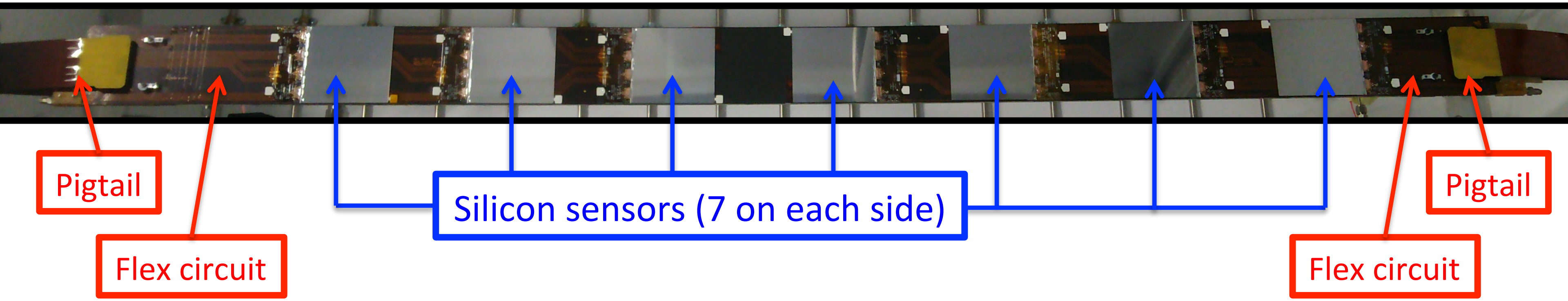
- Hybrid pixel detector.
  - 200 μm n-on-p sensor tiles.
- New read-out ASIC (VeloPix).
  - 256x256 pixel array (55 μm x 55 μm)
  - 12 per module.
- Evaporative CO_2 cooling in silicon micro-channel substrates (T < −20°C).
- High bandwidth:
  - 20 Gbit/s in hottest ASICs with ~ 3 Tbit/s overall.
- Non-uniform irradiation:
  - $8 \times 10^{15}\ n_{eq}\ /\ cm^2$ which falls as $\sim r^{-2.1}$.



Upstream Tracker

- Silicon micro-strip detector.
  - Four layers (x, u, v, x) upstream of magnet.
  - Finer granularity, closer to beam.
- Four types of sensors.
  - n- and p-type with 512 or 1024 strips.
  - 320/250 μm thick; 190/95 μm pitch.
- Modules mounted on double-sided staves.
  - 68 staves / 968 sensors.
  - Bi-phase CO_2 cooling pipe integrated in stave.
- New read-out ASIC (SALT).
  - 128 channels with 6-bit ADC.
  - Pedestal & common-mode subtraction, zero-suppression.
  - Output up to 6 SLVS e-links per ASIC.
  - 1048 4-asic read-out sectors = 4192 ASICs.
- Read-out electronics mounted on detector frame.





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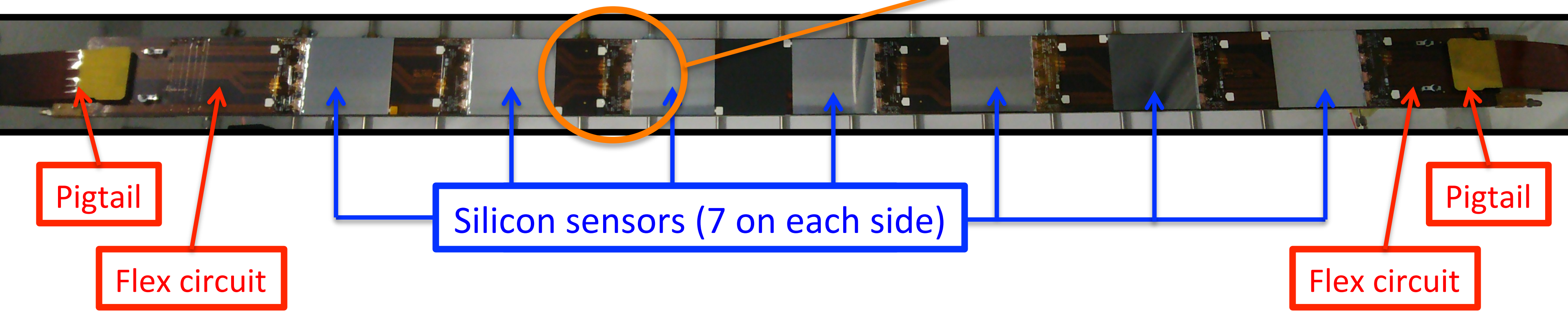
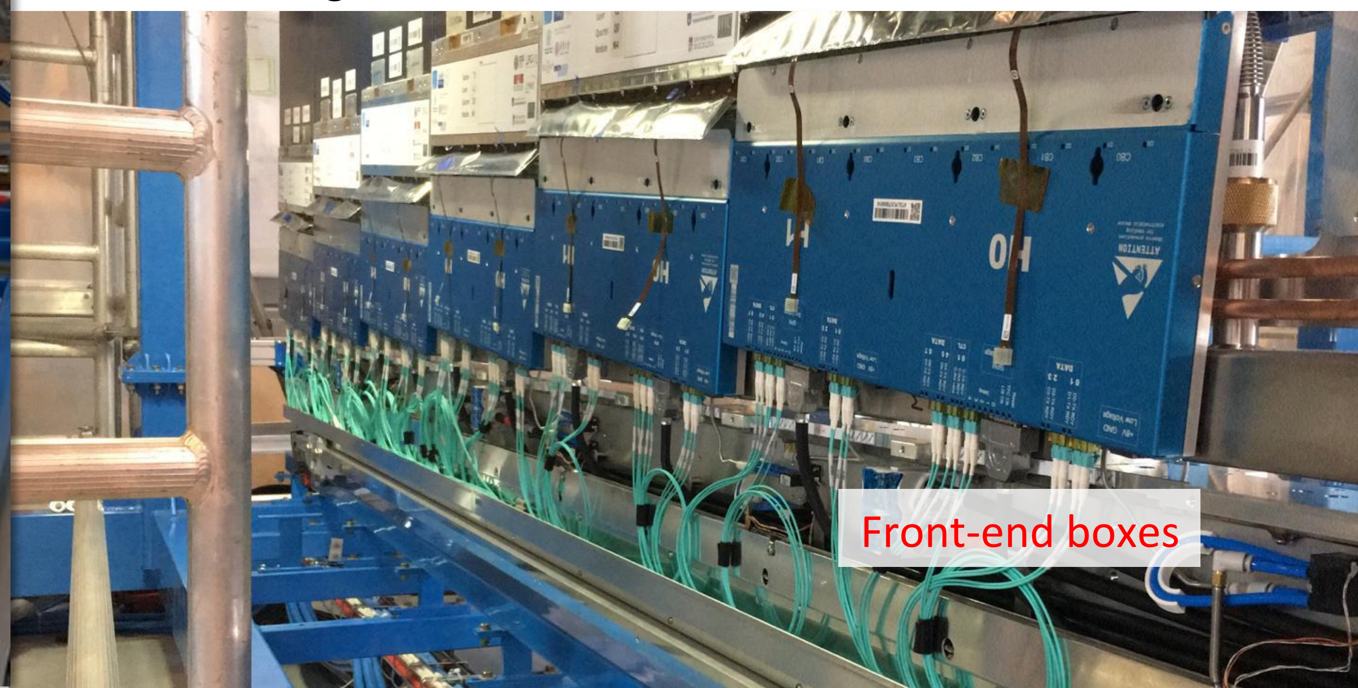


Scintillating Fibre Tracker

- Scintillating fibres read out with SiPMs.
  - 2.4 m long, 250 μm diameter, 6 layers of fibres in module.
  - 12 detection planes − 3 × (x, u, v, x).
- SiPMs outside acceptance.
  - 128 channels with width 250 μm
  - Require cooling to −40°C (neutron radiation).
- New ASIC for read-out (PACIFIC).
  - 64 channels, 130 nm CMOS (TSMC).
  - ADC with three hardware thresholds.
- Clustering on FPGA board in front-end box.



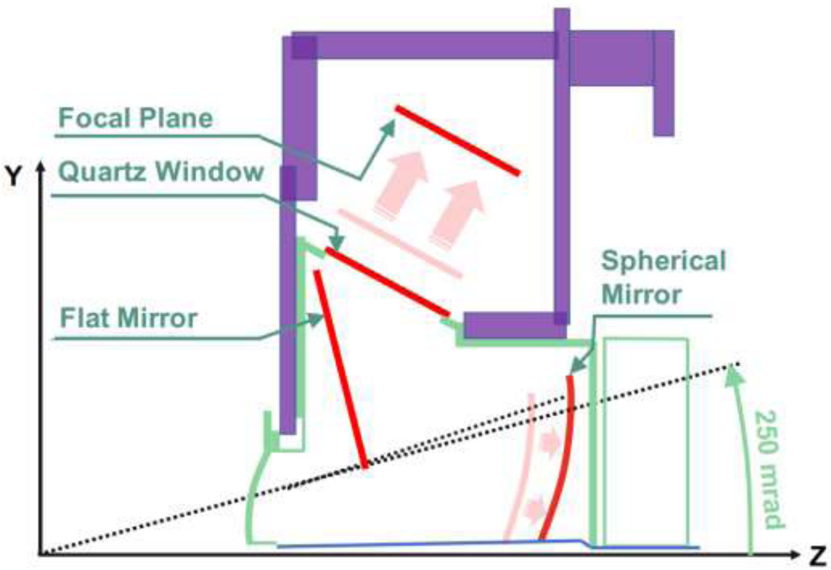
Particle ID

Cherenkov detectors:

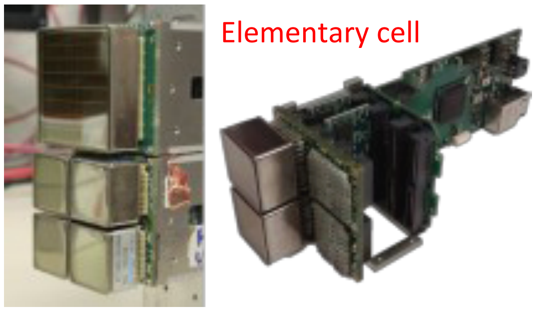
- RICH 1: C_4F_{10} (10 – 65 GeV/*c*).
  - Replace everything (mirrors, gas enclosure, quartz windows).
- RICH 2: CF_4 (15 – 100 GeV/*c*).
- Replace Hybrid Photon Detectors (HPDs) with Multi Anode Photomultiplier Tubes (MaPMTs).
- New 8-channel read-out ASIC (CLARO).

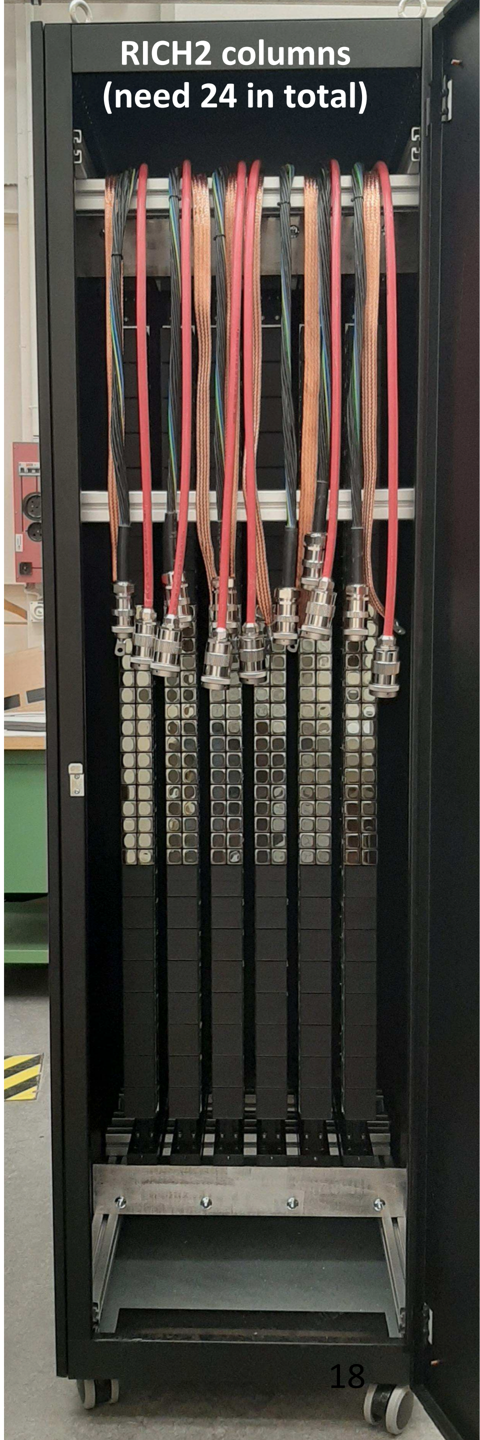
Calorimeters & Muon System

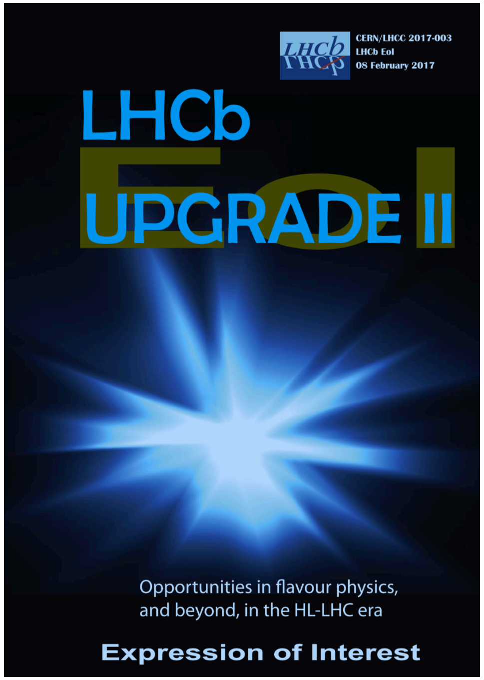
- Remove unnecessary detectors.
- Replace read-out electronics.

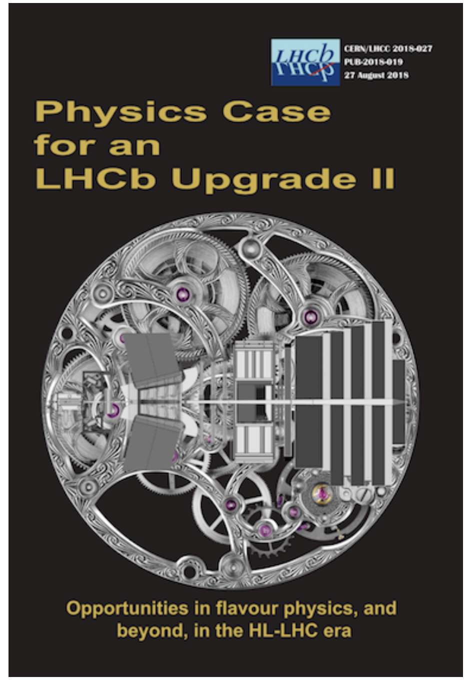


MaPMTs (Hamamatsu)

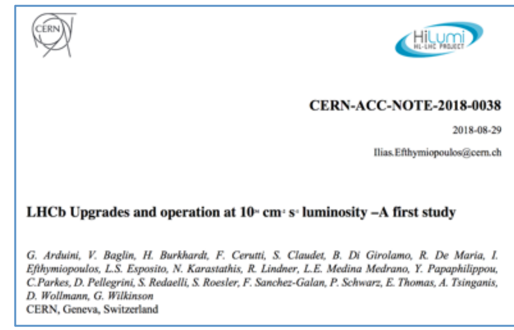








1. CERN-LHCC-2017-003
2. CERN-LHCC-2018-027


CERN-ACC-NOTE-2018-0038

2018-08-29

Ilias.Efthymiopoulos@cern.ch

LHCb Upgrades and operation at 10 cm s luminosity –A first study

G. Arduini, V. Baglin, H. Burkhardt, F. Cerutti, S. Claudet, B. Di Girolamo, R. De Maria, I. Efthymiopoulos, L.S. Esposito, N. Karastathis, R. Lindner, L.E. Medina Medrano, Y. Papaphilippou, C.Parkes, D. Pellegrini, S. Redaelli, S. Roesler, F. Sanchez-Galan, P. Schwarz, E. Thomas, A. Tsinganis, D. Wollmann, G. Wilkinson

CERN, Geneva, Switzerland

UPGRADE II

Conditions:

- Luminosity: 1.5×10^{34} cm^{-2}s^{-1} (inst.), 300 fb^{-1} (int.)
- 40 visible interactions / crossing.

Challenge:

- Maintain current reconstruction performance in much, much harsher environment.
- Develop detectors with timing information for tracking & Particle ID.

LHCb Upgrade II

Tracking System:
NEW DETECTORS!

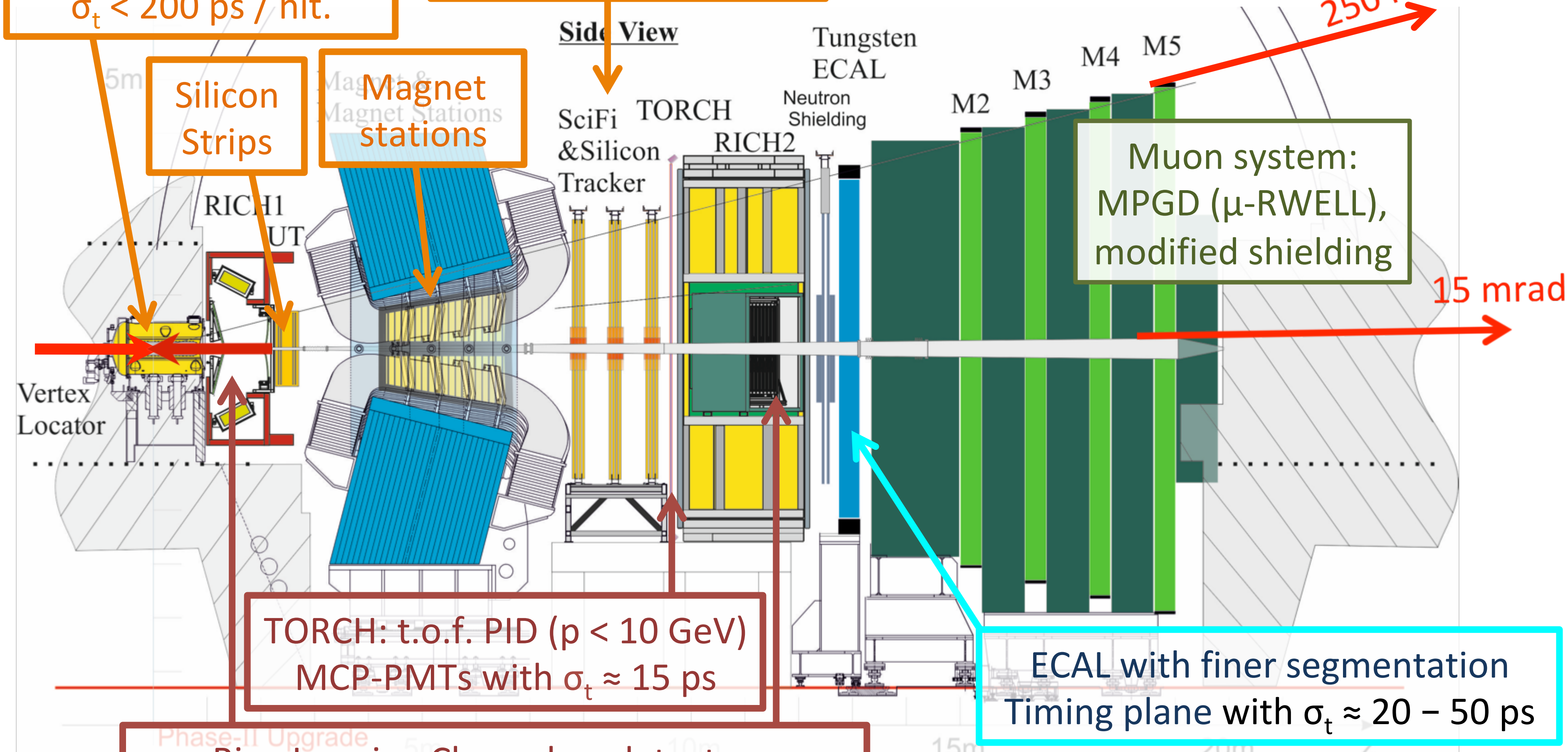
Smaller pixels, thinner sensors. σ_t < 200 ps / hit.

SciFi Tracker + Silicon detectors in central region

+ Accelerators for online reconstruction

Silicon Strips

Magnet stations



Muon system: MPGD (μ-RWELL), modified shielding

TORCH: t.o.f. PID (p < 10 GeV)
MCP-PMTs with $\sigma_t \approx$ 15 ps

ECAL with finer segmentation
Timing plane with $\sigma_t \approx 20 - 50$ ps

Ring Imaging Cherenkov detectors:
Photon detectors with σ_t < 100 ps / photon

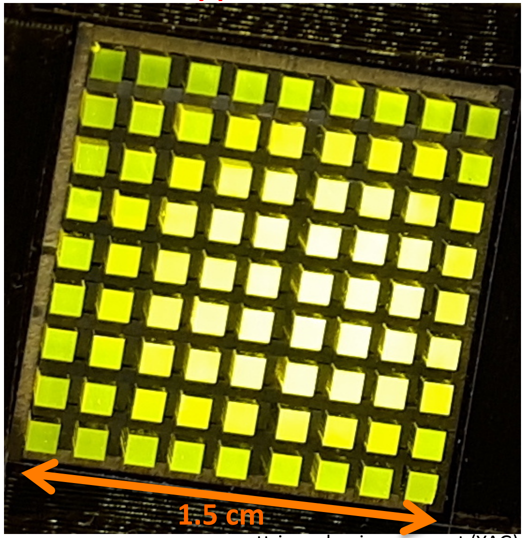
Replace HCAL with 1.7m iron

Detector Technologies

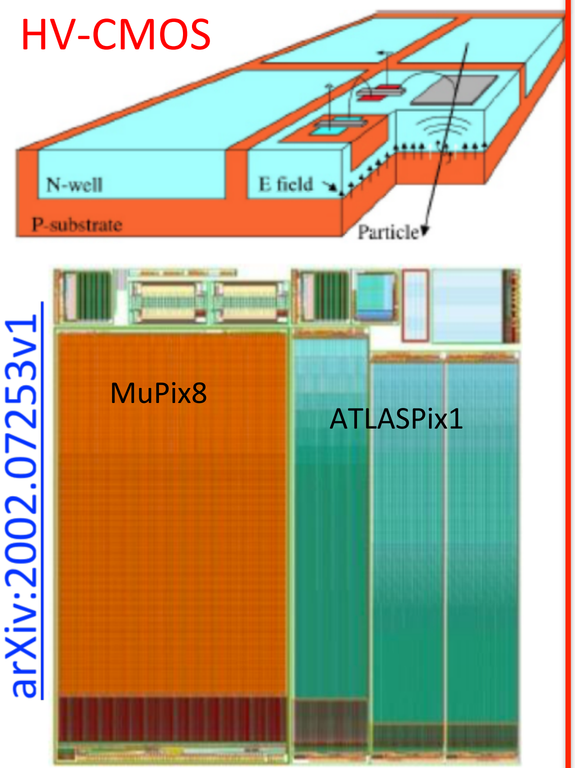
Lots of R&D across collaboration.

- SPACAL with crystal fibres.
- CMOS tracker chip in design.
- Silicon with timing capabilities.
- Photon sensors with timing .
- New MPGDs for high-rate muon detection.

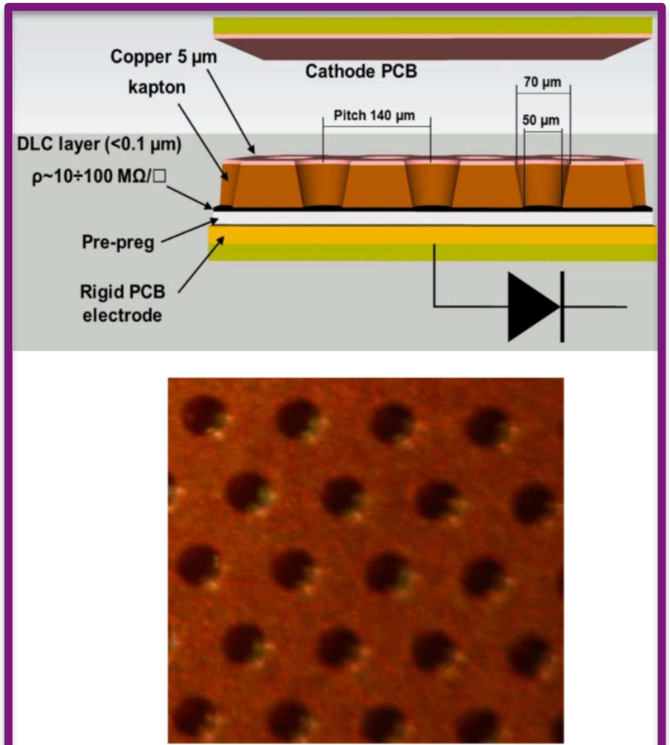
Prototype CALO cell



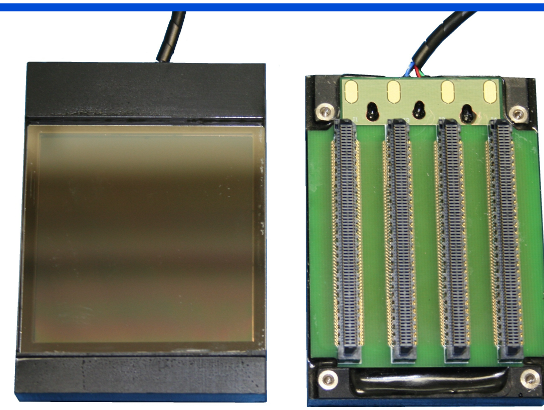
HV-CMOS



arXiv:2002.07253v1



The µ-RWELL amplification stage



MCP-PMTs for TORCH

Summary

CONCLUSIONS

Summary

Upgrade I (2008 – now):

- Significant progress made by all sub-detectors.
  - Installation is underway!
  - All sub-detectors (were) in full production mode.
- Schedule is (increasingly) challenging.
  - Impact of COVID-19 continuously being assessed.

Upgrade II (2017 – ??):

- Lots of active R&D across collaboration.
- Sub-detectors developing baseline designs.
- Framework TDR expected in 2021.


LHCP2020
May 25-30, 2020
Online
The Eighth
Annual Conference
on Large Hadron
Collider Physics

Merci à tous!

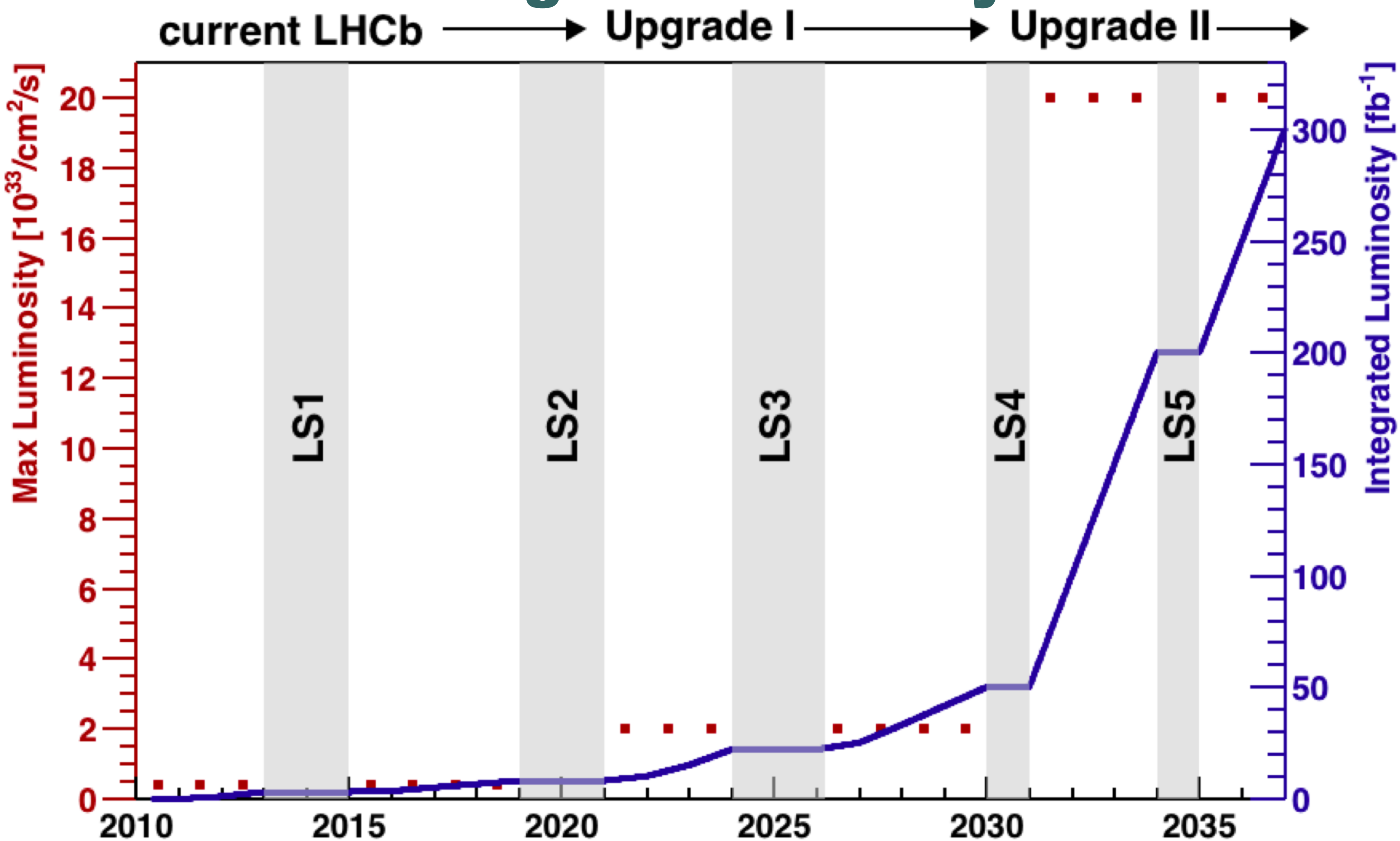
MORE?

BACK UP

UPGRADE 1

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Target Luminosity



$L_{inst.} = 4 \times 10^{32}\ cm^{-2}s^{-1}$ → $L_{inst.} = 2 \times 10^{33}\ cm^{-2}s^{-1}$ → $L_{inst.} = 1 - 2 \times 10^{34}\ cm^{-2}s^{-1}$

$\mu \approx 1$ → $\mu \approx 5.2$ → $\mu \approx 28 - 55$

* μ is average number of visible *pp* interactions per bunch crossing.

CKM Measurements

LHC-B

LETTER OF INTENT

A Dedicated LHC Collider Beauty Experiment
for Precision Measurements of CP-Violation

1995

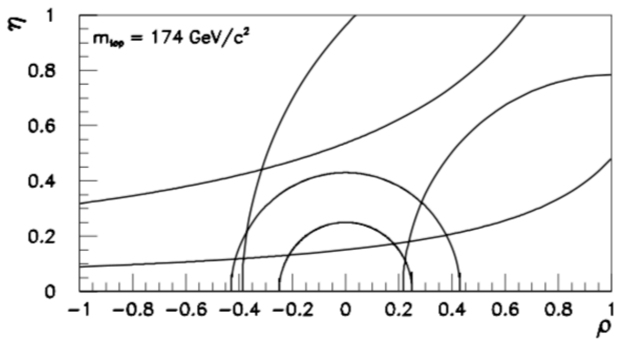
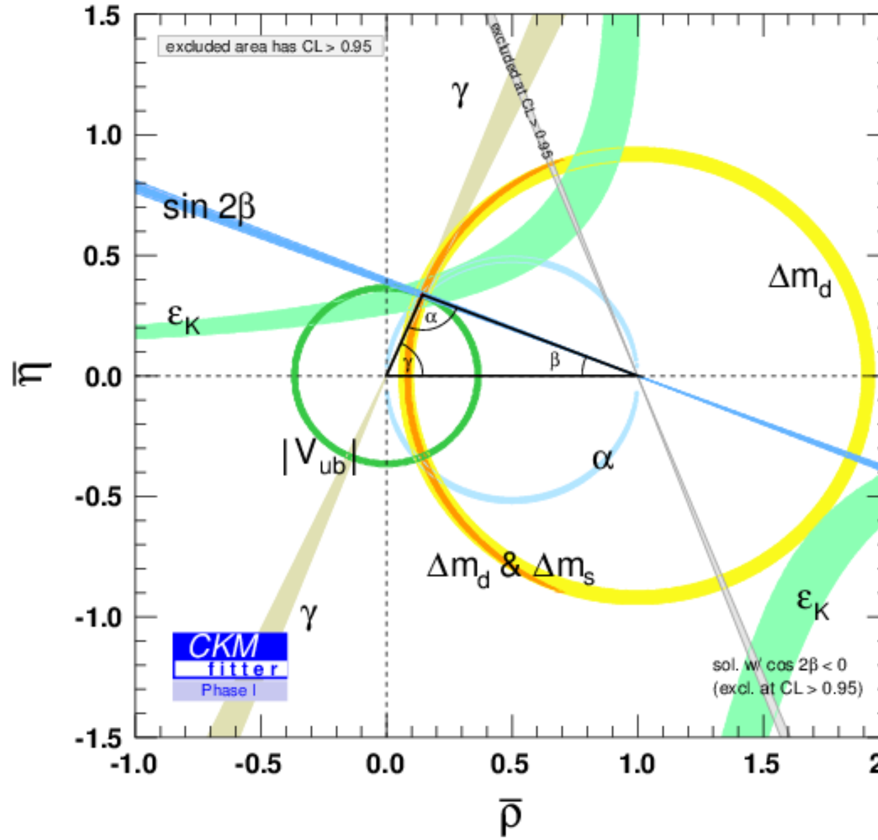


Figure 2.1: Limits on the CKM parameters (1σ) ρ and η for m_t = 174 GeV. The annular region cen-

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Phase 1

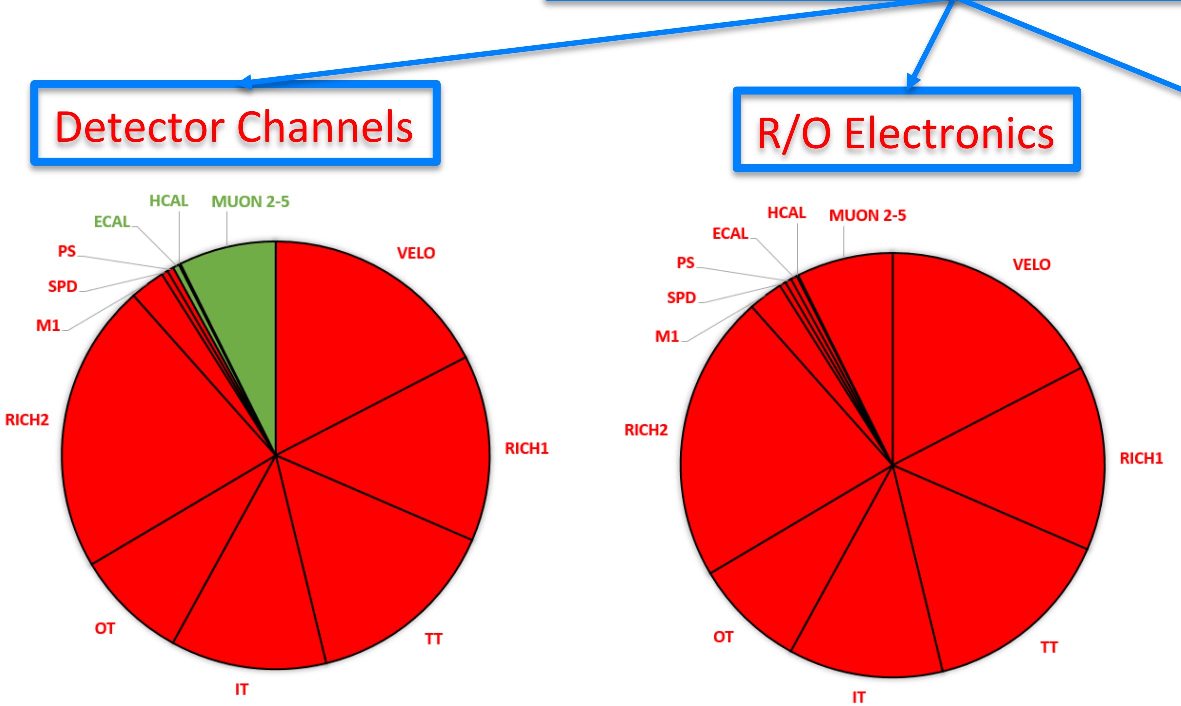


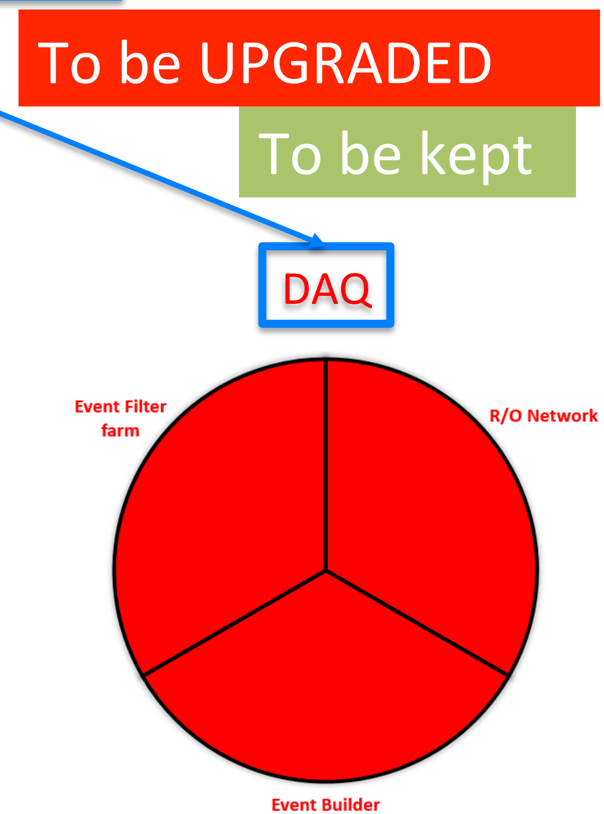
LHCb ($23 fb^{-1}$), Belle-II ($50 ab^{-1}$)
ATLAS & CMS ($300 fb^{-1}$)

arxiv:1812.07638

$\sigma_\gamma \approx 5°$ (2019) → 1° (Phase 1) → 0.35° (Phase 2)

Upgraded LHCb Detector

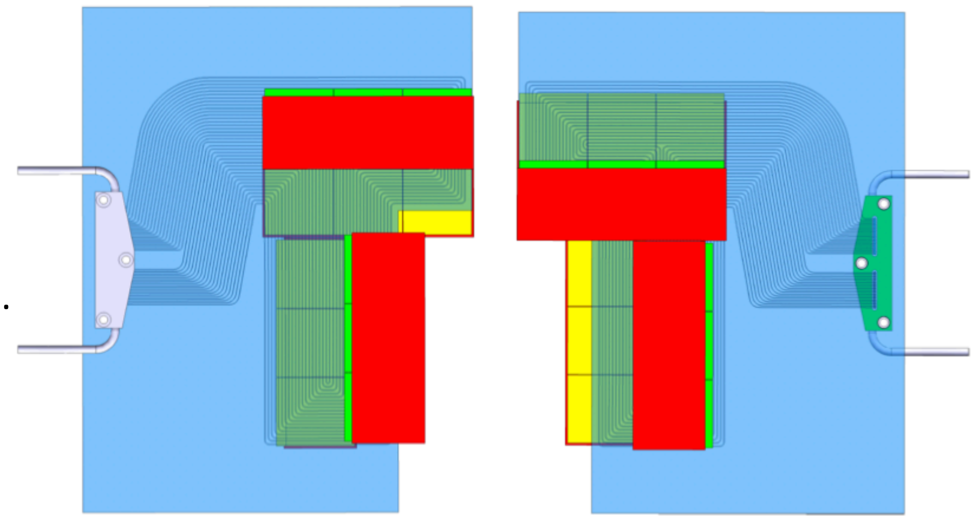


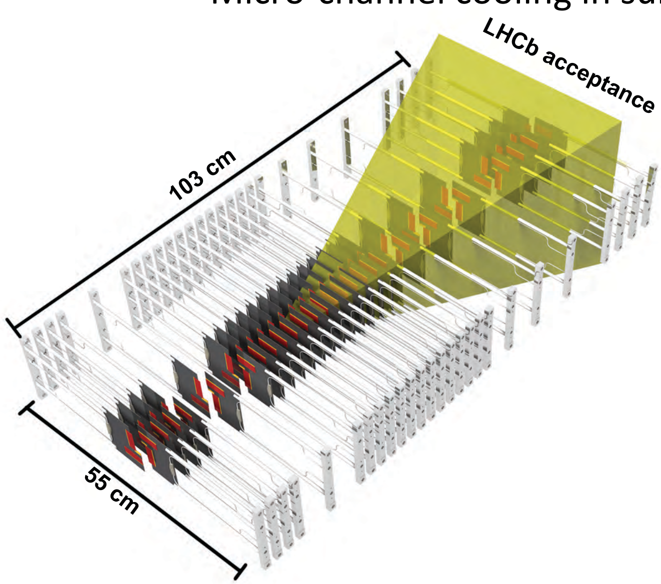


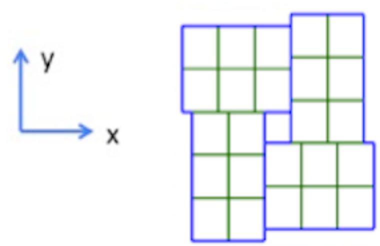
- Remove Level-0 hardware trigger.
  - Read out every bunch crossing (40 MHz).
  - Replace all front-end electronics.
- Trigger-less read-out system.
  - Full software trigger for every 25 ns bunch crossing.
- Higher occupancy.
  - Redesign and replace tracking detectors.
- Installation during Long Shutdown 2 (on-going).

VELO II

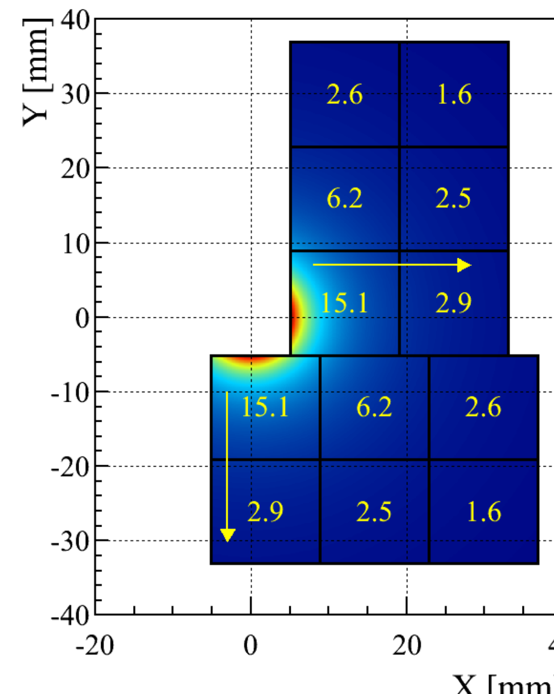
- Hybrid pixel detector.
  - Easier pattern recognition.
  - Thinner sensors (300 μm → 200 μm).
- Move closer to beam
  - First measurement: 8.13 mm → 5.1 mm.
- New RF foil.
  - Reduce material before first measurement.
- New ASIC (VeloPix)
  - Based on Medipix/TimePix.
  - 256x256 (55 μm x 55 μm)
  - 12 per module.
- Non-uniform irradiation.
  - Extremely high data rates.
  - Micro-channel cooling in substrate.





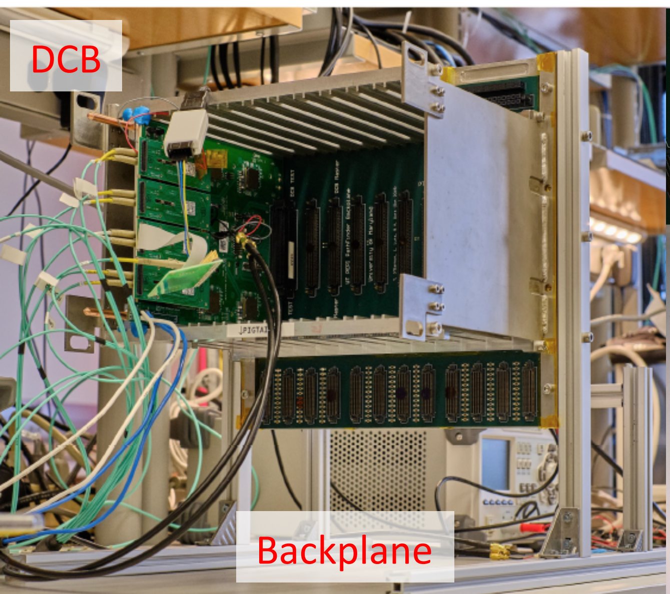


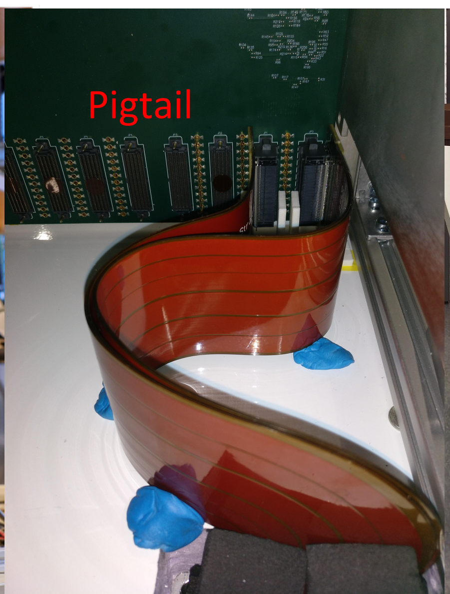
VELO fully closed
(stable beams)

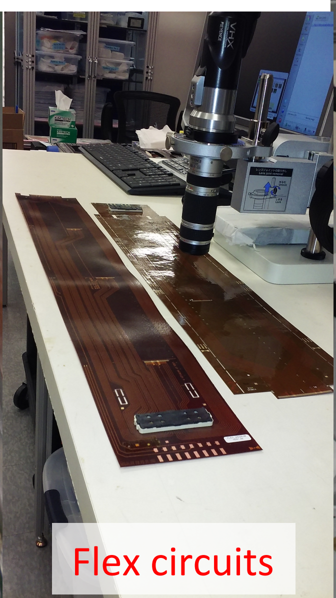


Upstream Tracker

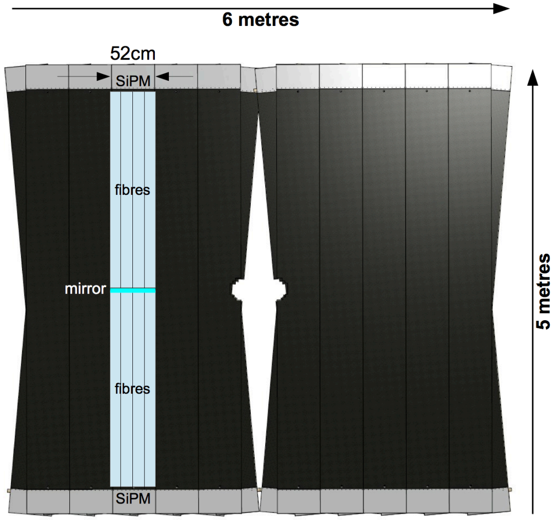
- Near-detector electronics outside acceptance.
  - Distributes TFC&ECS signals.
  - Collects serial data from ASICs (320 Mbps).
  - Transmits optical serial data via GBTx/VTTx (~4.8 Gbps).
  - Connected to stave via pigtail flex cables.
- Two versions of read-out ASIC (SALT).
  - Problems found in previous iterations have been solved.
    - Analogue power issues, 40 MHz oscillations.
  - 4- (8-) ASIC modules assembled with SALT v3.5 (v3.8).
- Full read-out chain validated in system test.
  - First tests with final powering and grounding scheme.
  - CO_2 cooling tests at −30°C.

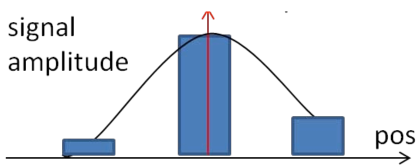


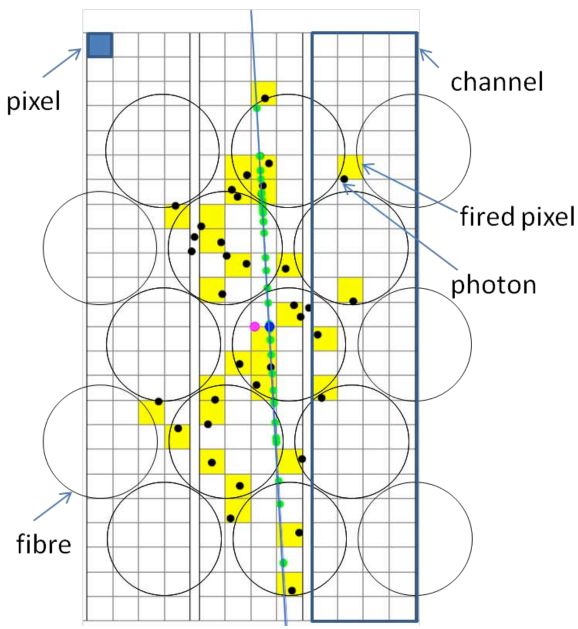


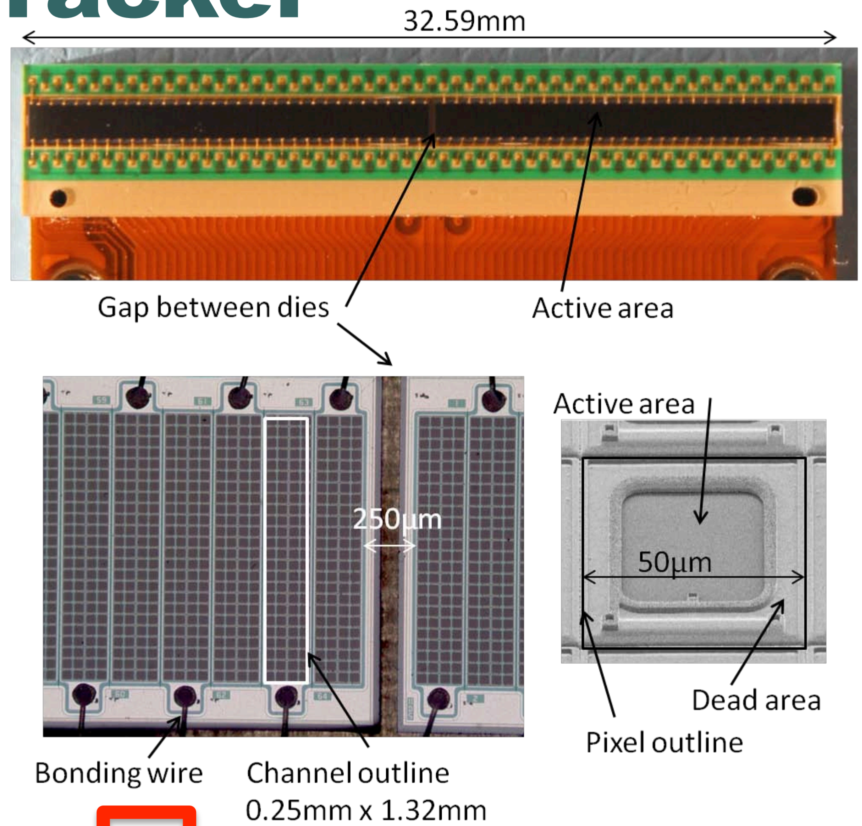


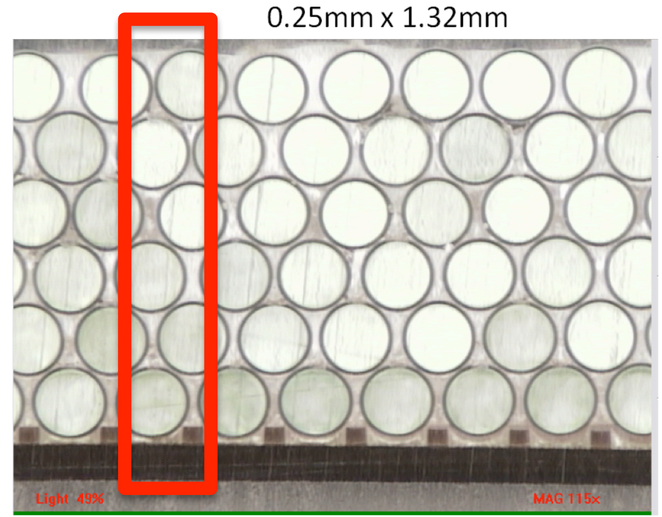
SciFi Tracker











RICH

RICH1:
Change everything but the magnetic shielding

- mirrors, gas enclosure, quartz windows
- Photon detectors, electronics, detector mechanics

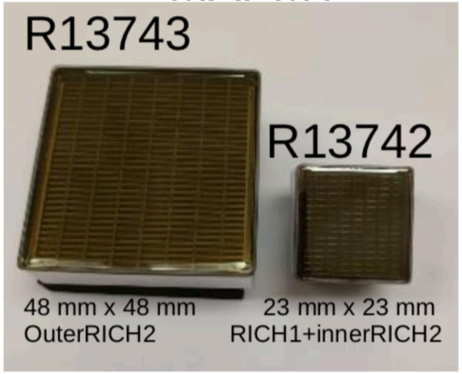
=> 22 columns

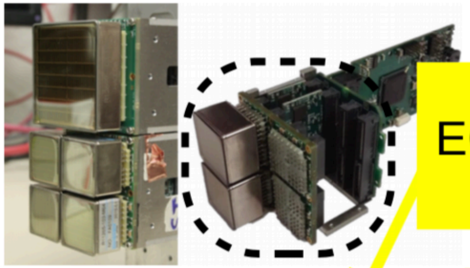
RICH2:
Change only detectors

- Photon detectors, electronics, detector mechanics

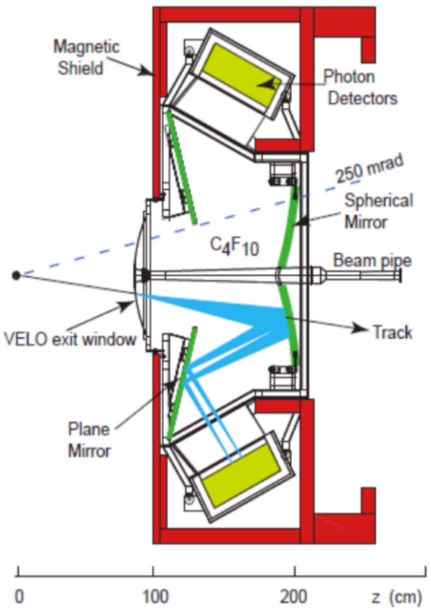
=> 24 columns

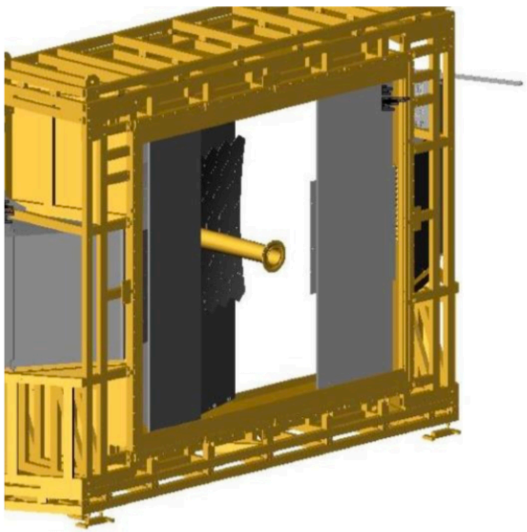
MAPMT



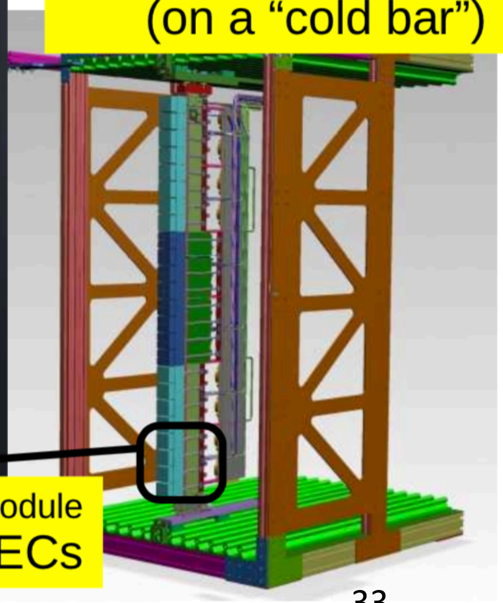


Elementary Cell
EC = 4 or 1 xMAPMT +Baseboards





A column = 6 PDMs (on a "cold bar")



Photon Detector Module
PDM = 4 ECs

Installation

RICH 1

RICH 1 mechanics installed:

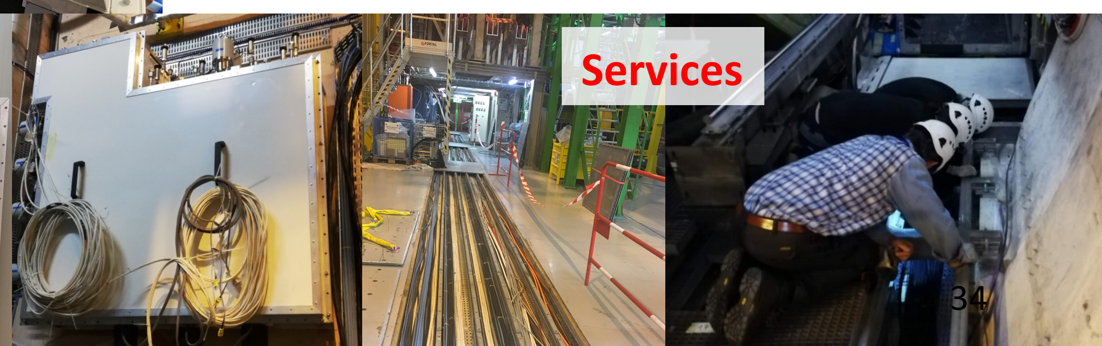
- Magnetic shielding shelves, MaPMT supports, gas enclosure.

Detector Services:

- 100% of long distance copper cables installed.
- 100% of optical fibres installed & tested.
  - Few fibres with power loss > threshold.
- 100% of long distance pipes installed.

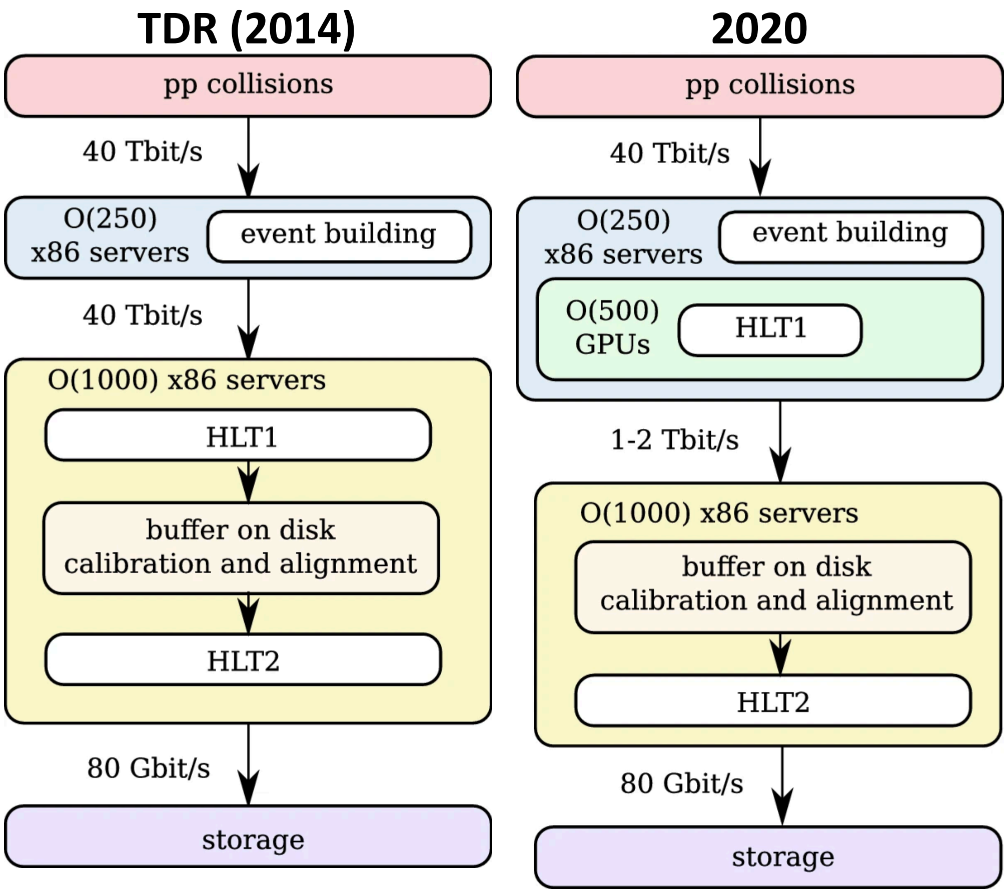
CO_2 cooling plants (VELO & UT):

- CO_2 cooling plants and distribution boxes installed.
- Connections and first tests performed.
- Cleaning required to remove “oil”.

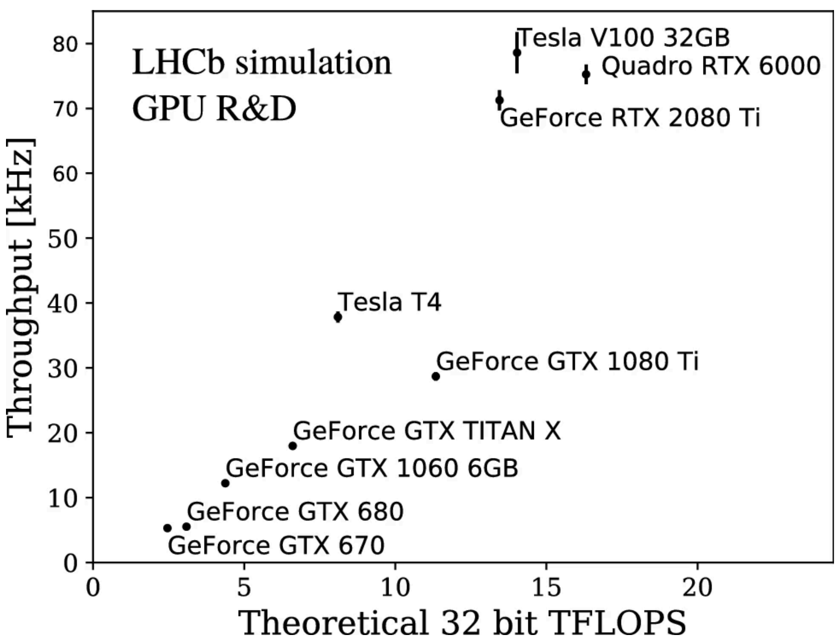


Comput Softw Big Sci 4, 7 (2020)

HLT1 on GPUs



Three good GPU candidates



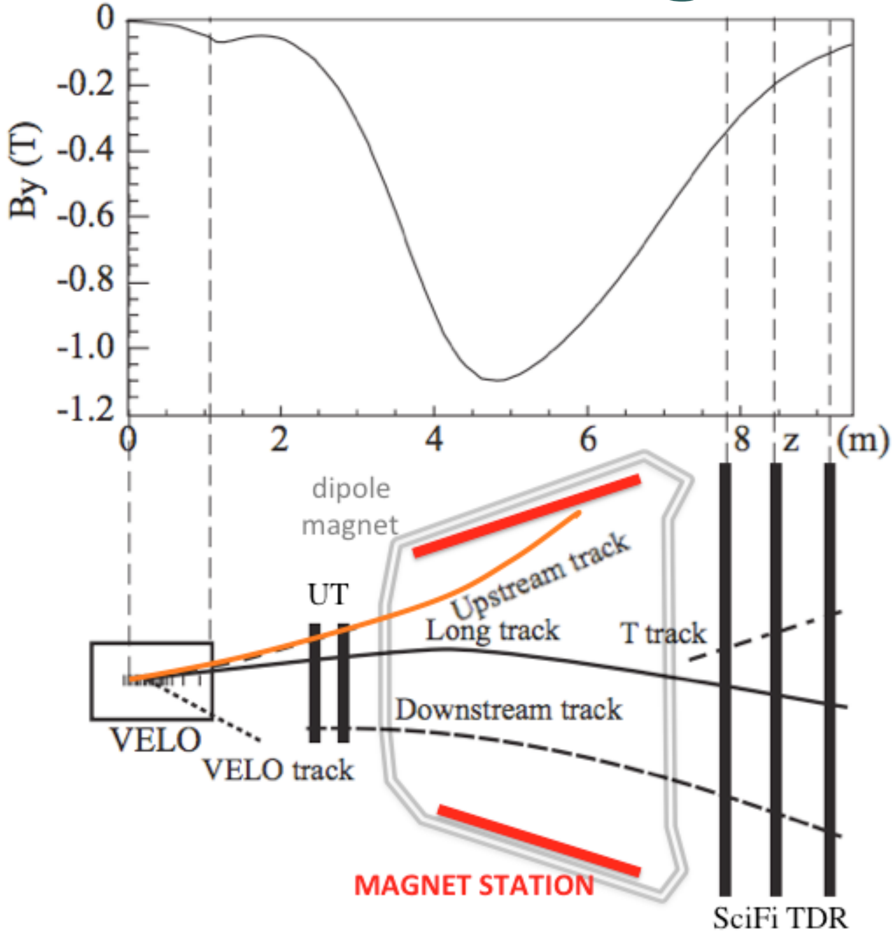
- Each event builder server has two GPU slots = 500 GPUs.
- HLT1 ***must*** run at visible collision rate (30 MHz).
  - Minimum throughput rate per GPU is 60 kHz.
- See presentation by Dorothea Vom Bruch for more details (27/5).

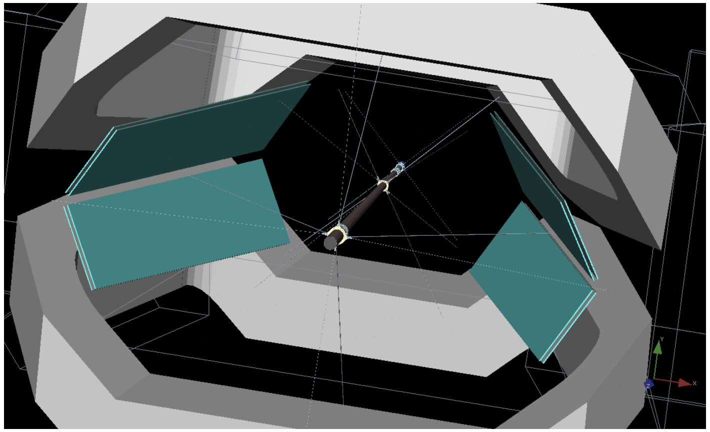
Magnet tracking stations

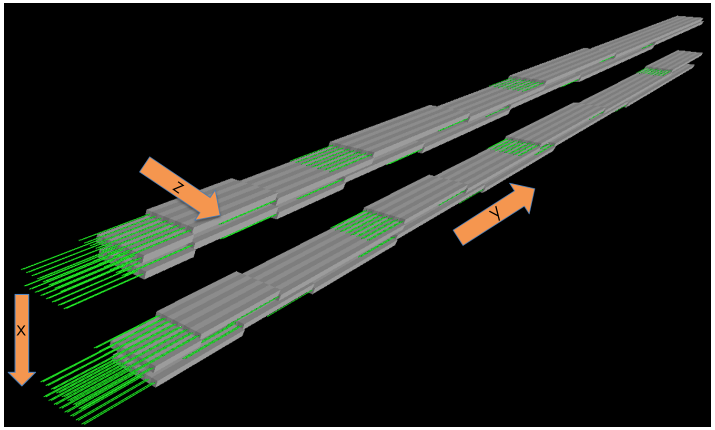
Time Of internally Reflected CHerenkov light (TORCH).

UPGRADE 1B

Magnet Stations



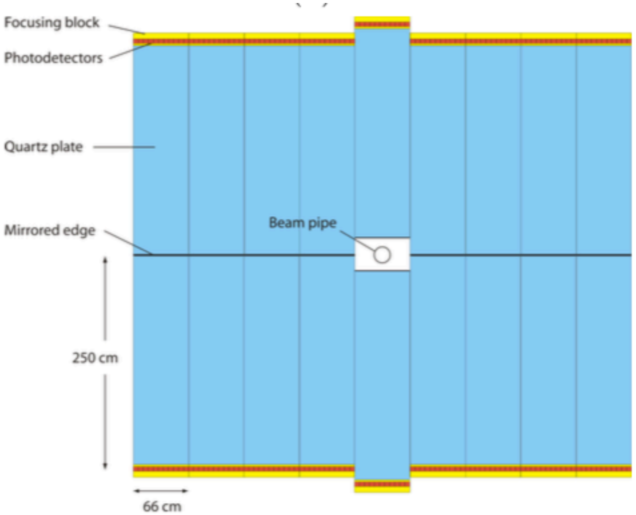


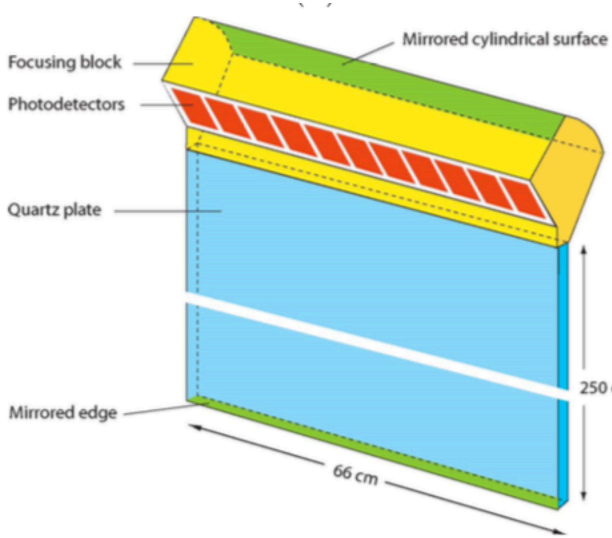


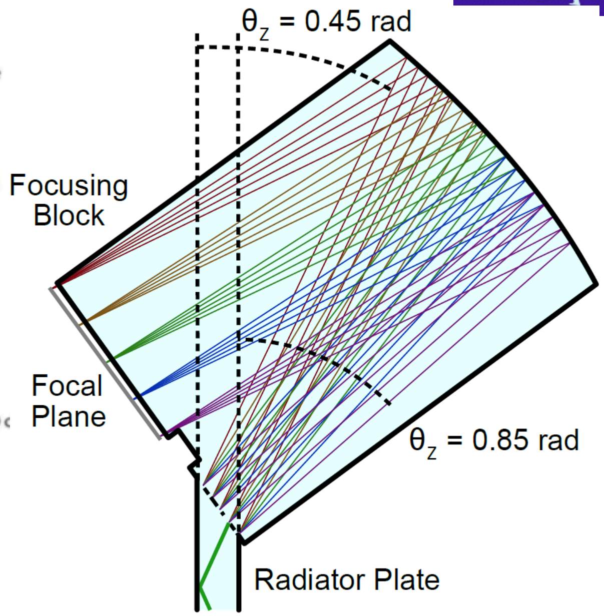
- Tracking stations on internal walls of magnet.
  - Reconstruction low momentum tracks.
- Scintillator bars read out with SiPMs outside acceptance.
  - Re-use existing SciFi Tracker electronics (ASIC, read-out boards, etc).

TORCH

NIM A 639 (1) (2011) 173



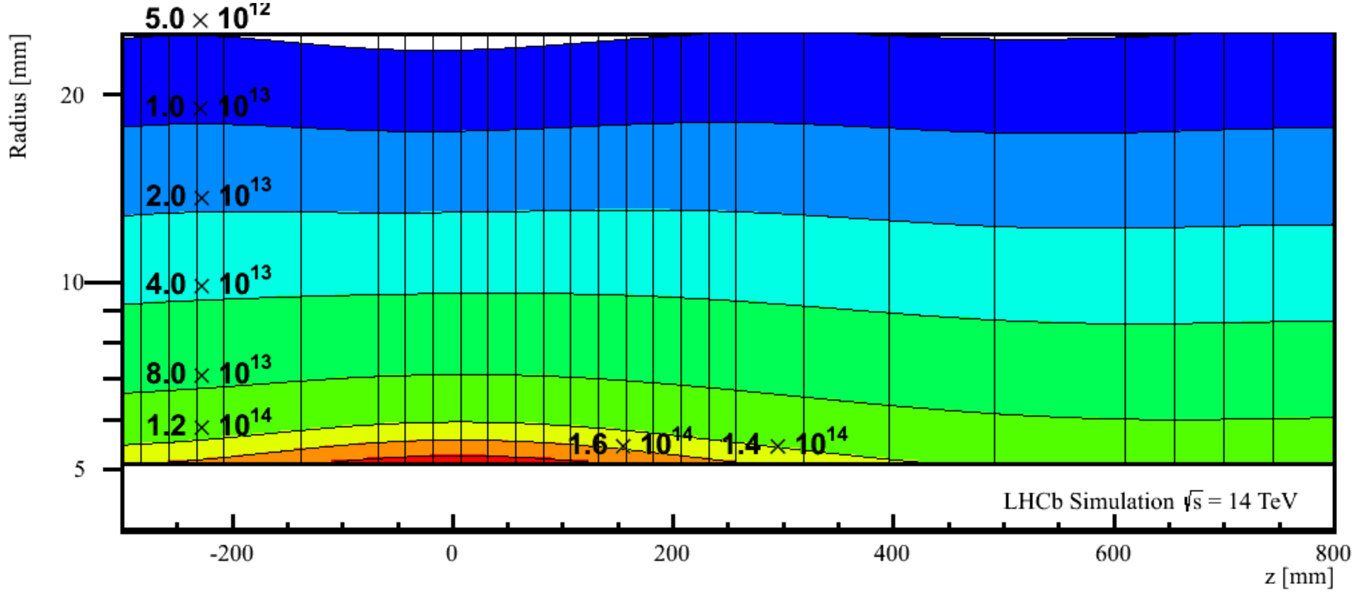




- Time Of internally Reflected CHerenkov light.
  - Large area time-of-flight detector.
  - Provide PID in momentum range 1 – 10 GeV/c.
- Cherenkov light produced in quartz plates.
  - Photons travel to detector plane via total internal reflection.
- Focusing block focuses image on detection plane.
- Multichannel plate PMTs with 35 ps time resolution.
  - Resolutions of 88 – 130 ps achieved in test beams.
- Possible installation in Upgrade 1b.

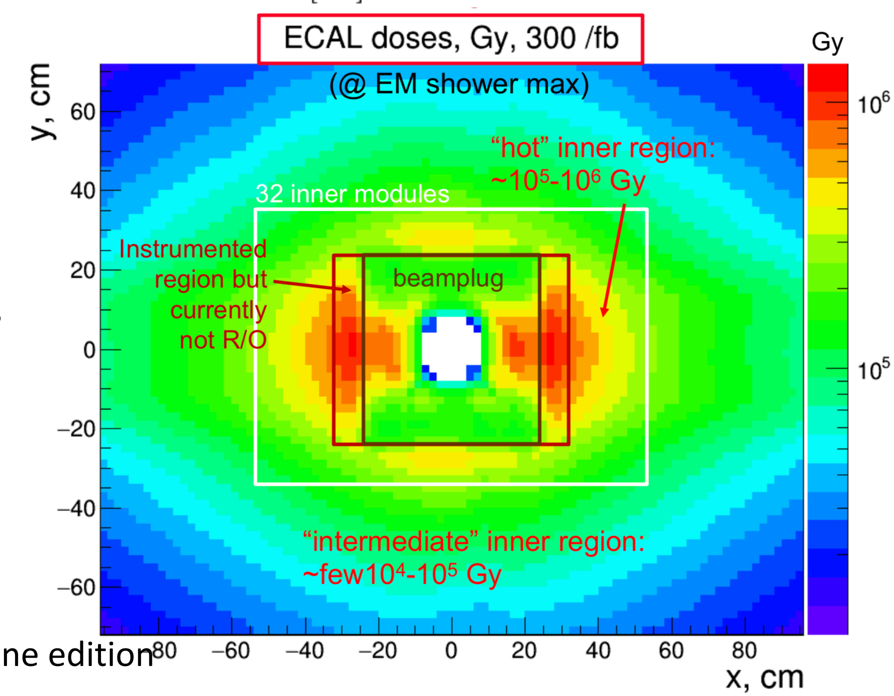
UPGRADE 2

Radiation Environment

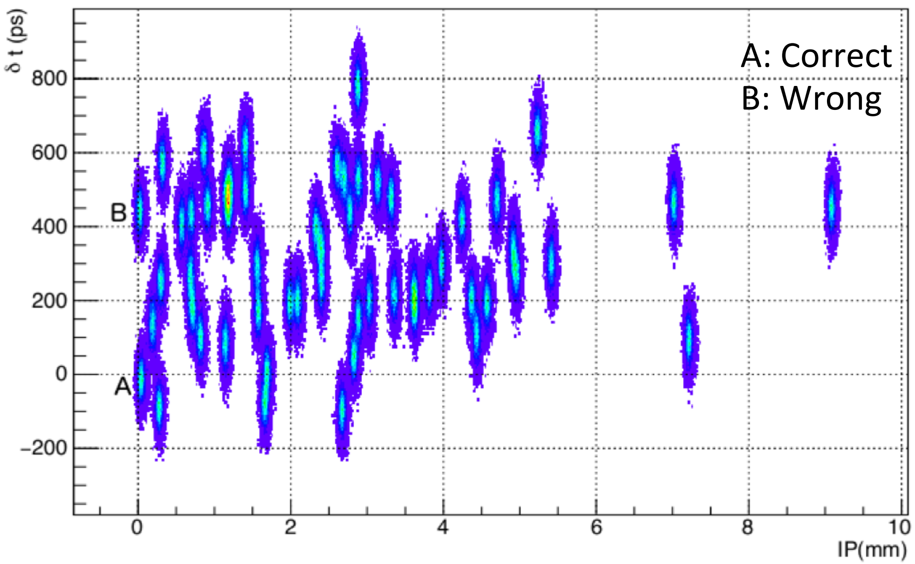


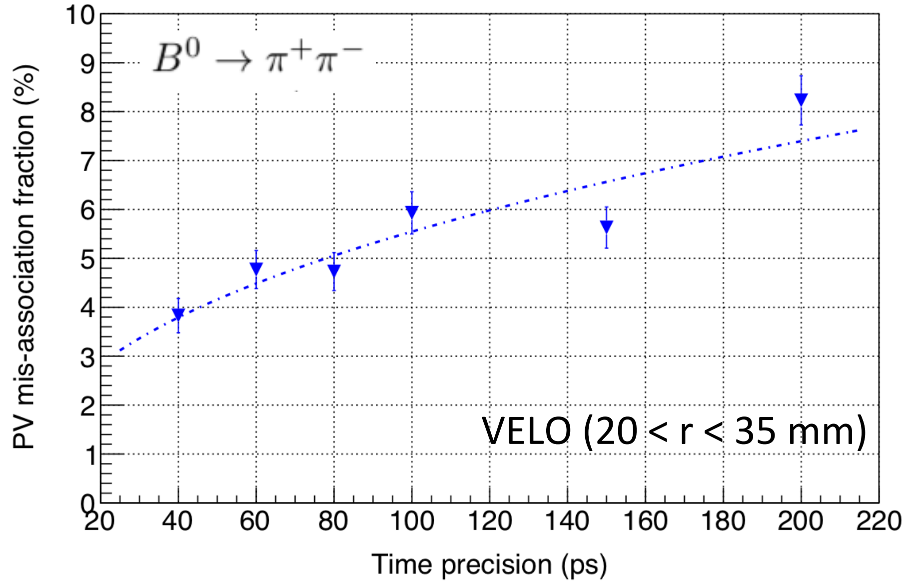
VELO, Upgrade 1
Fluence per fb^{-1}
(1 MeV n_{eq}/cm^2)

- Expected dose / fluence:
  - VELO: 5×10^{16} n_{eq}/cm^2.
  - ECAL: 1 MGy; $\leq 5 \times 10^{15}$ n_{eq}/cm^2.
  - Tracker: 3×10^{14} n_{eq}/cm^2 (silicon).
  - SiPMs: 13.2×10^{11} n_{eq}/cm^2 (run 3&4).
- Non-uniform irradiation profile.
- Need radiation hard detectors and/or extreme cooling solutions.
- Make hot-swappable detectors!



4-D Tracking



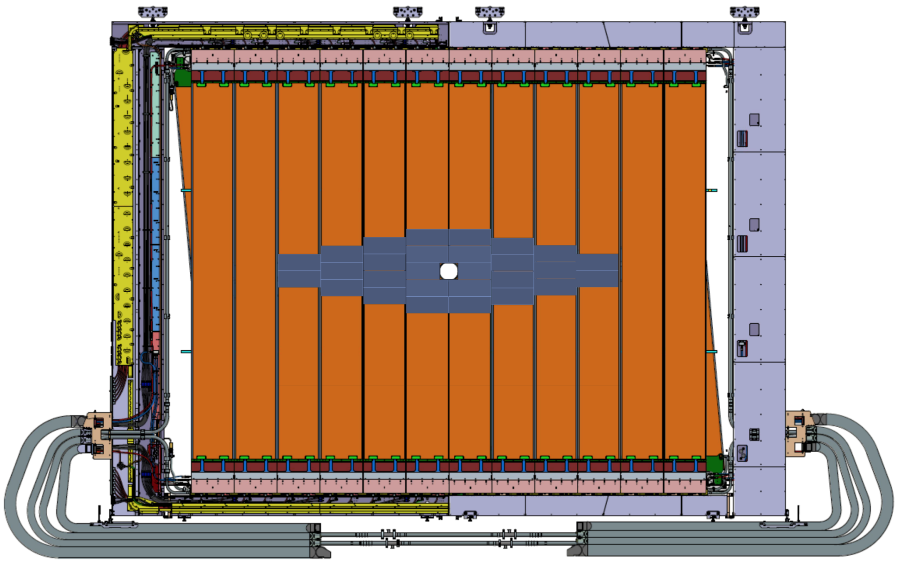


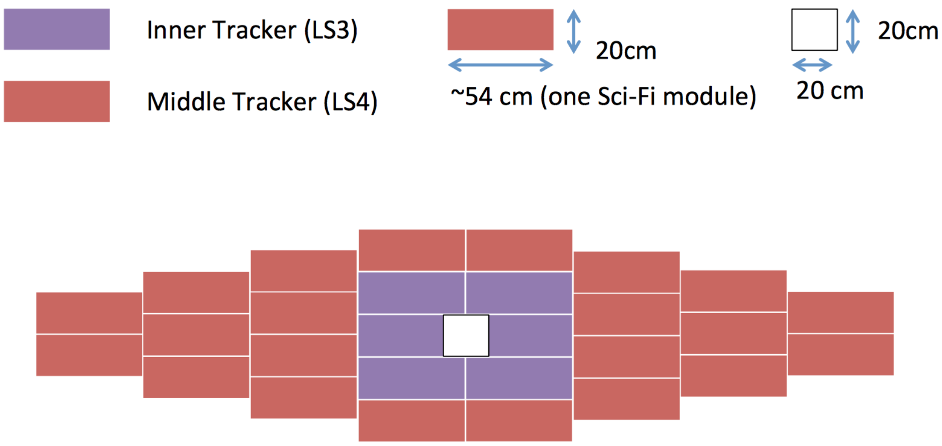
- Reconstruction of PV critical for LHCb.
  - 40 visible interactions / crossing @ 1.5 × 10^{34} $cm^{-2}s^{-1}$.
- Add timing information.
  - Reduces combinatorics and minimises PV mis-association.
- PV mis-association rate ~ 20% without timing.
  - Reduce to ~5% with timing precision between 50 – 100 ps.

VELO III

- Silicon sensors with timing capability.
  - Aim for 50 ps per hit → 15 ps per track.
  - Several candidates: LGAD, 3D, MAPS.
- Higher occupancy:
  - Reduce pixel size
  - 55 x 55 μm^2 → 27.5 x 27.5 μm^2.
- Minimise material.
  - Thinner sensors.
  - Remove r.f. foil and operate in primary vacuum.
- Fluence ~ 8 x 10^{16} n_{eq} / cm^2.
  - Require radiation hard sensors.

Downstream Tracking



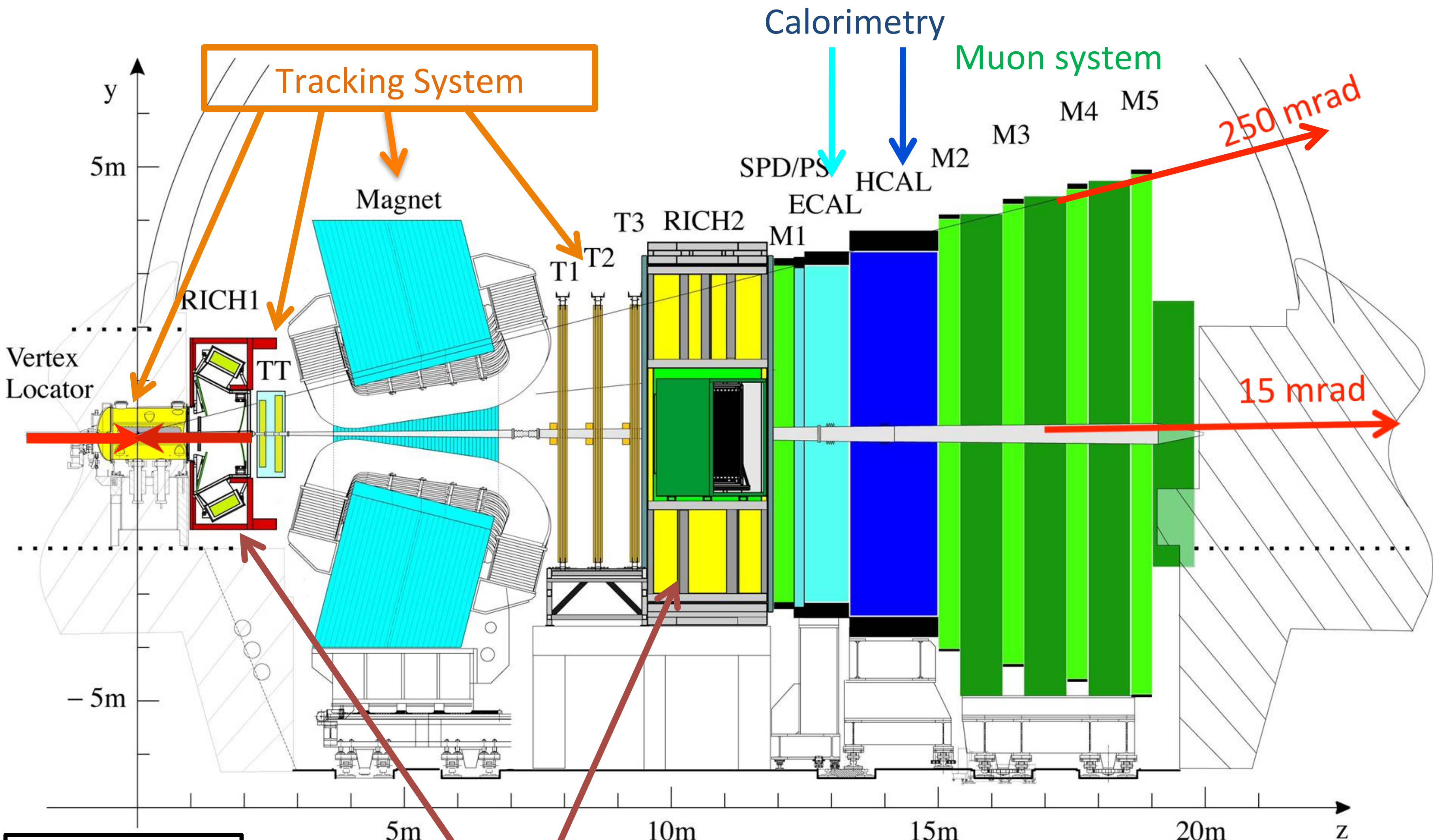


- Add silicon detectors in central region.
  - Segmentation in y-direction → reduce ghost rate.
- Replace SciFi modules around beam-pipe in LS3.
  - Hybrid modules with shorter fibres.
  - Silicon sensors around beam-pipe (HV-CMOS).
- New radiation hard fibres being studied.
- Cryogenic cooling proposed for SiPMs (−80°C).

LHCB I

2008 JINST 3 S08005

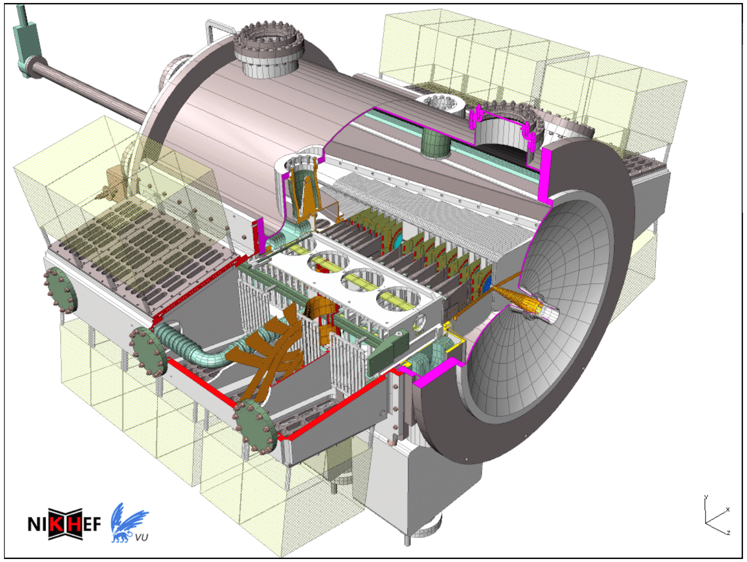
LHCb detector

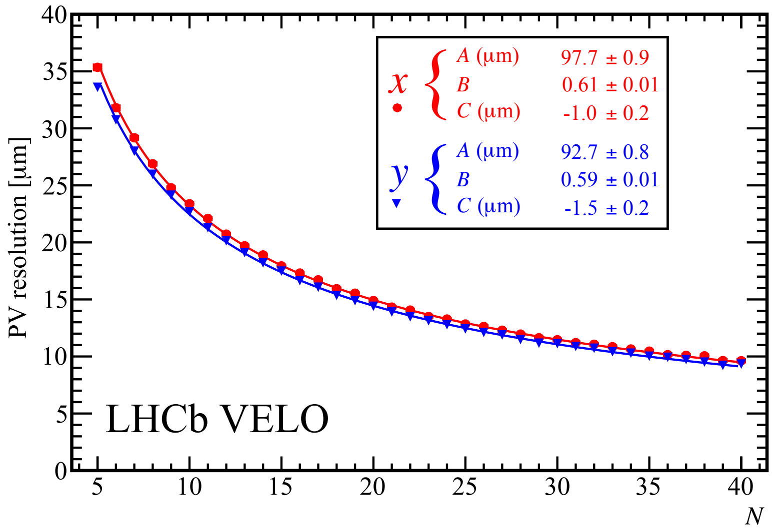


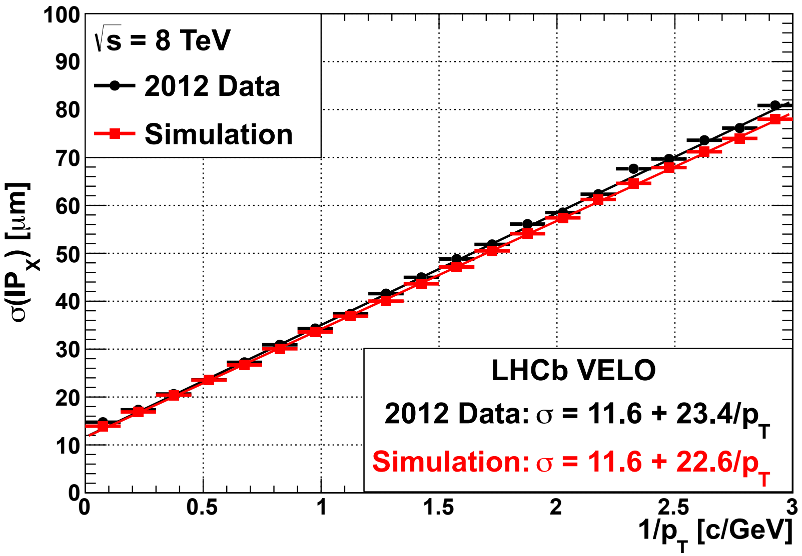
2 < η < 5

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

LHCb VErtex LOcator I (VELO)

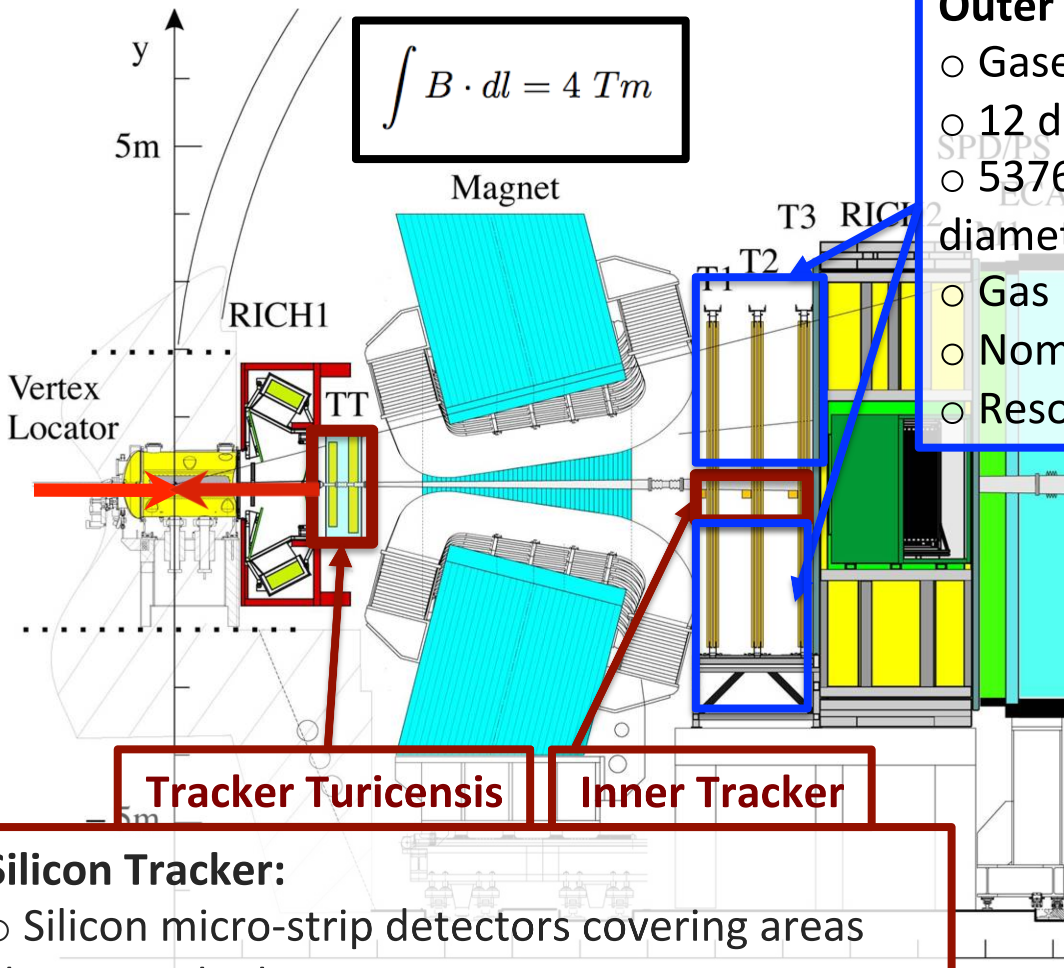






- Two retractable halves
  - 5 mm from beam when closed.
  - 30 mm during injection.
  - First measurement at 8.13 mm.
- Operates in secondary vacuum.
  - 300 μm aluminium foils separates detector from beam vacuum.
- 21 R-Φ modules per half.
  - Silicon microstrip sensors.
  - Pitch: 38 – 101 μm.
- Best resolution: 4 μm!

LHCb Tracker



Outer Tracker:

- ○ Gaseous straw tube detector.
- ○ 12 detection layers (~ 4 x 6 m^2).
- ○ 53760 straw tubes (2.4 m long, 4.9 mm diameter).
- ○ Gas mixture: Ar/CO_2/O_2 (70%/28.5%/1.5%).
- ○ Nominal operating voltage is 1550 V.
- ○ Resolution ≈ 200 µm.

Silicon Tracker:

- ○ Silicon micro-strip detectors covering areas closest to the beam pipe.
- ○ Pitch: 183 µm (TT), 198 µm (IT).
- ○ Thickness: 500 µm (TT), 320/410 µm (IT)
- ○ Strips up to 37 cm long.
- ○ Resolution ≈ 50 µm.