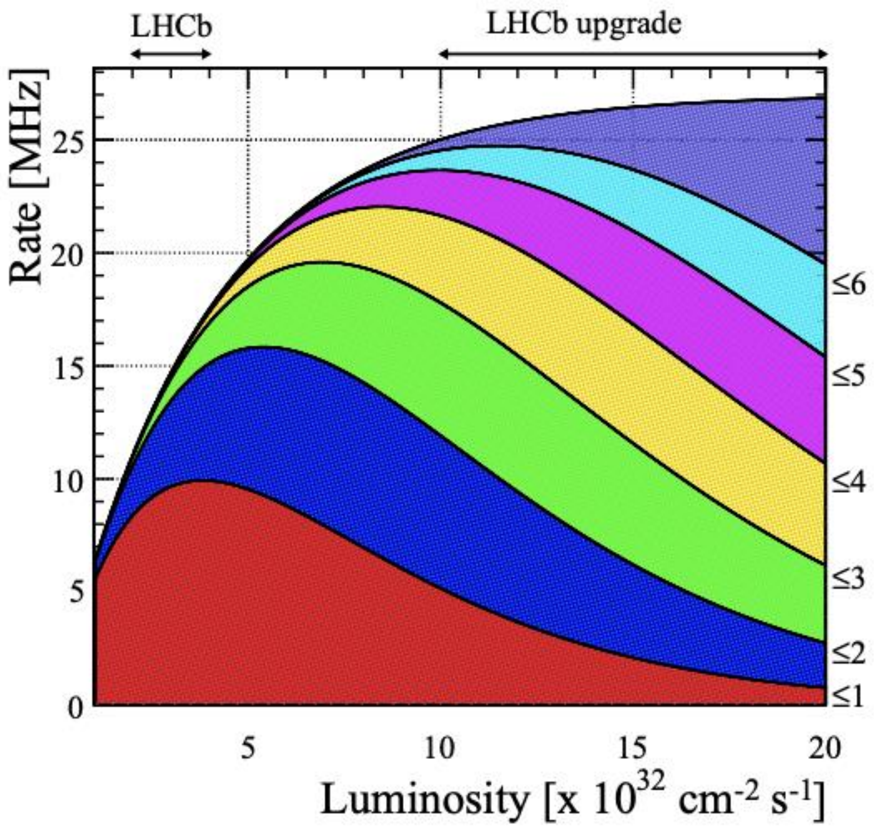
Everything you needed to know, didn't know you needed to know, and don't need to know about Upgrade I

Dr. David Friday

The University of Manchester

The Challenge of Run 3 (Short version)

- The luminosity increase alone will (and is) pushing the Rate up significantly in LHCb.
- The number of interactions per event also increases significantly so there is much more pileup.
- There is also a large increase in the radiation!



But why do it?

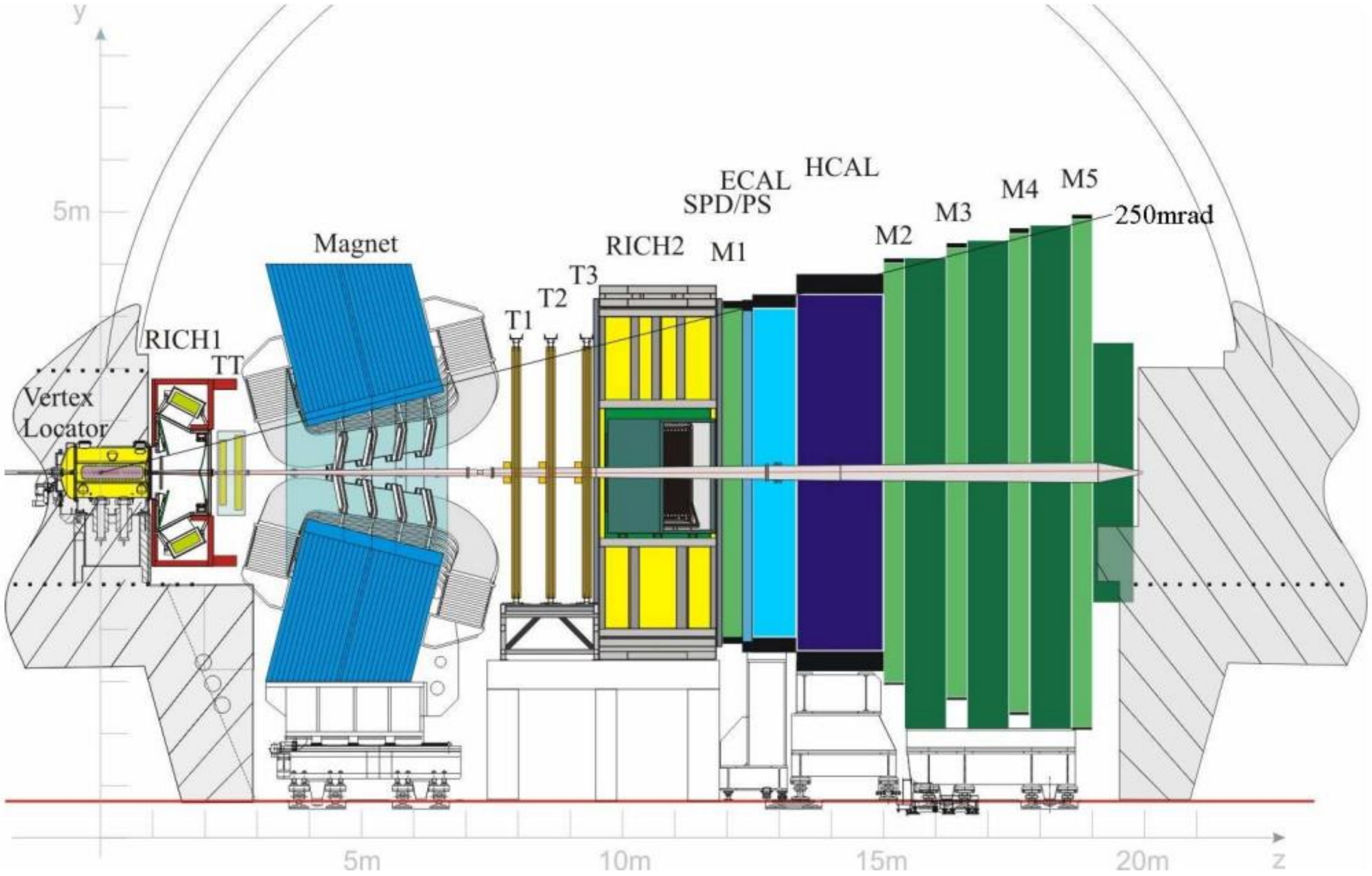
Observable	Current LHCb
EW Penguins	
R_K	$0.745 \pm 0.090 \pm 0.036$
$R_{K^{*0}}$	$0.69 \pm 0.11 \pm 0.05$
CKM tests	
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$
γ, all modes	$(^{+5.0}_{-5.8})^\circ$
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad
$a_{\rm sl}^s$	33×10^{-4}
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6%
$B_s^0, B^0 \to \mu^+\mu^-$	
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90%
$\tau_{B_s^0 \to \mu^+\mu^-}$	22%
$S_{\mu\mu}$	
$b \to c\ell^-\bar{\nu}_l$ LUV studies	
$R(D^*)$	0.026
$R(J/\psi)$	0.24
Charm	
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4}
A_Γ ($\approx x \sin\phi$)	2.8×10^{-4}
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4}

Physics Case for an LHCb Upgrade II, CERN-LHCC-2018-027

σ(stat)/σ(sys)	Largest source of systematic
2.5	Mass shape & trigger eff
2.2	MC correction & residual bkgd
3	Δm_s, time res, tagging, det asymmetry
-	
8	Decay time: bias and efficiency
8	Angular efficiency
8	Decay time resolution
5	Acceptance (angular and time)
1.3	Track reco asymmetry
0.5	External BR(Λ_c)
6	f_d/f_s
9	Decay time acceptance
1	MC sample size
1	F($B_c \to J/\psi$) form factor
2.7	Mass model
2.8	Contribution from sec b→D*X decays
2	Contribution from sec b→D*X decays

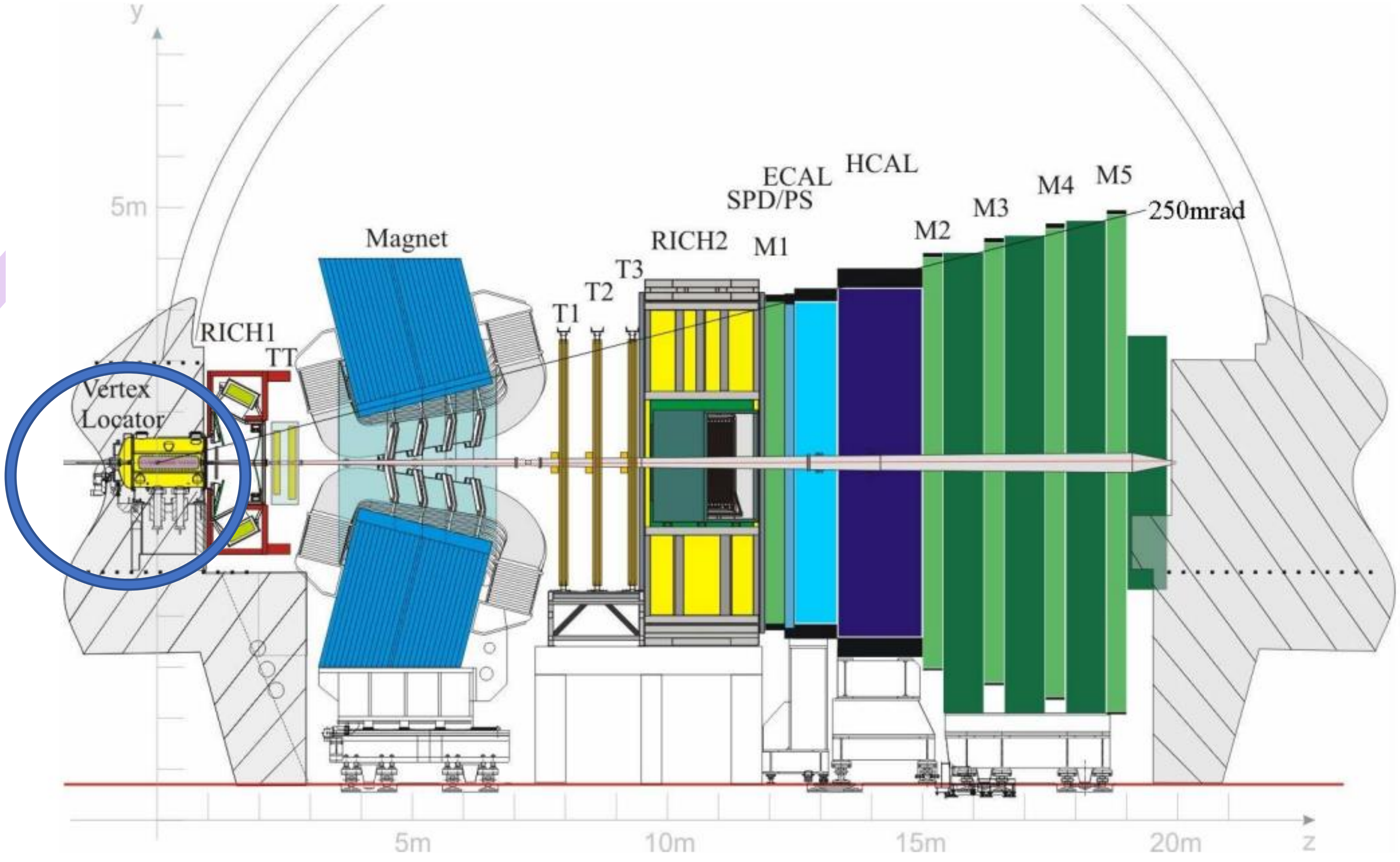
Where we started?

Single-arm spectrometer in the forward region to study beauty and charm



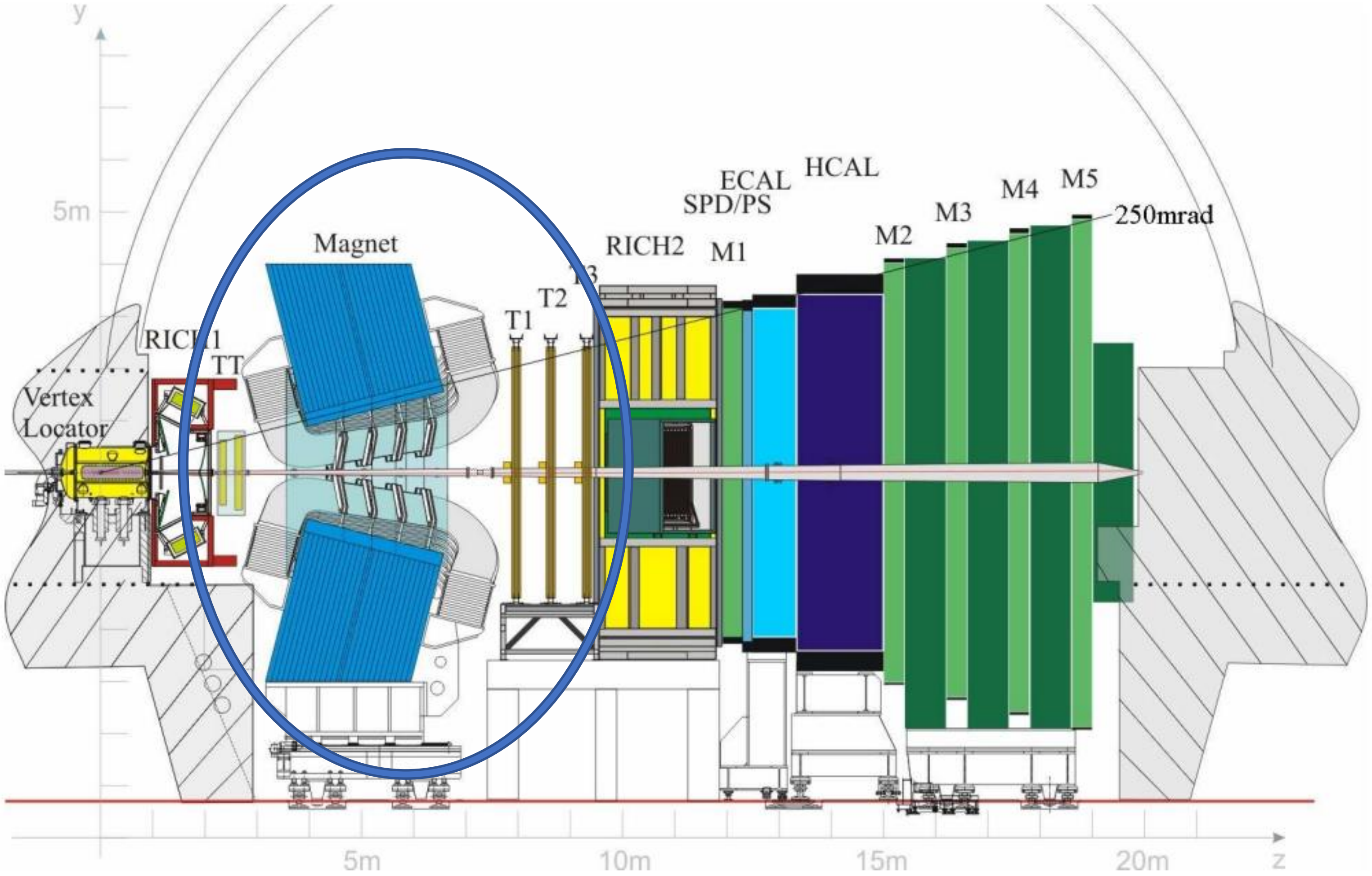
Where we started?

Strip based vertex detector



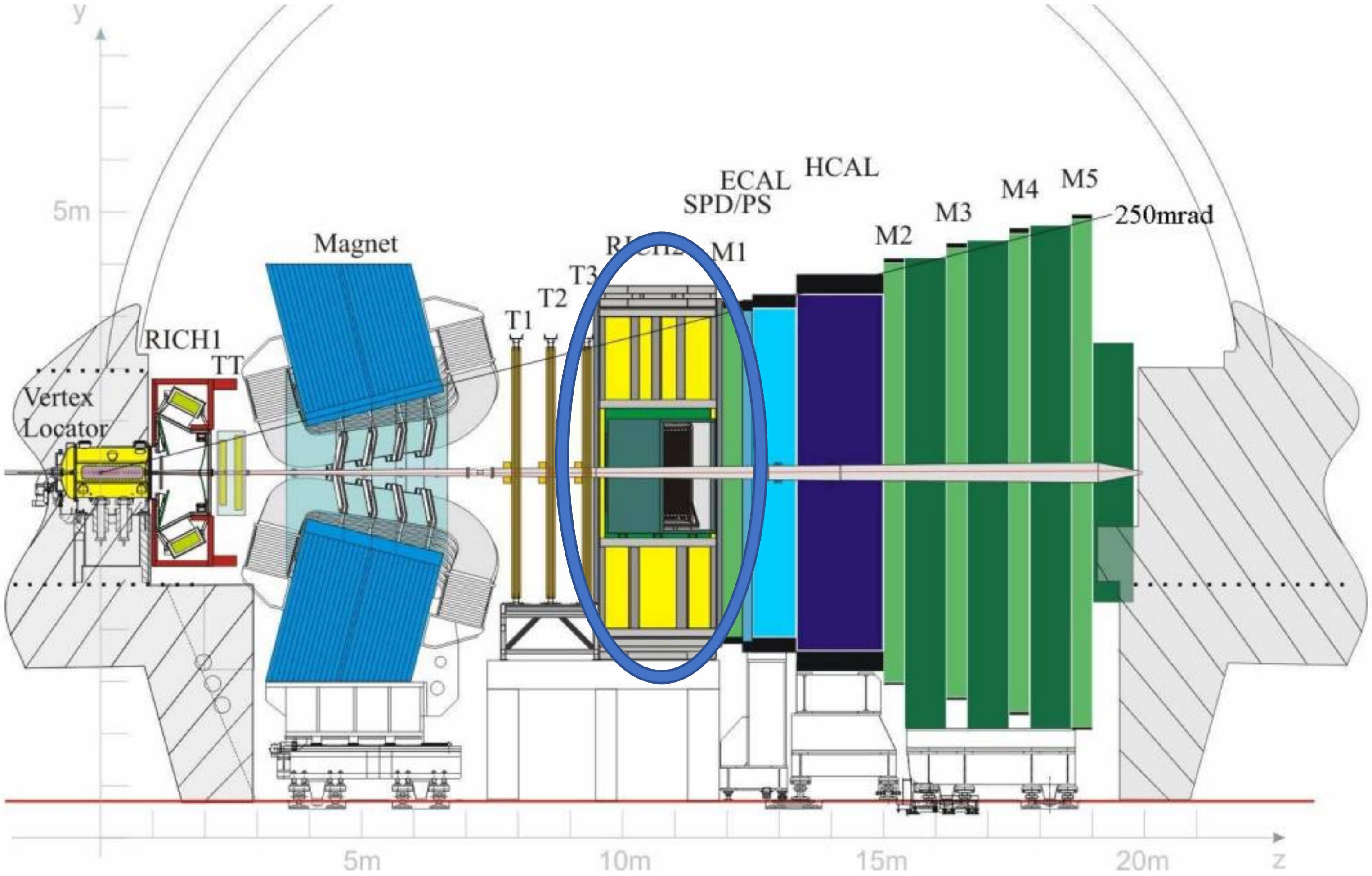
Where we started?

Silicon tracking system TT upstream and T1-T3 downstream



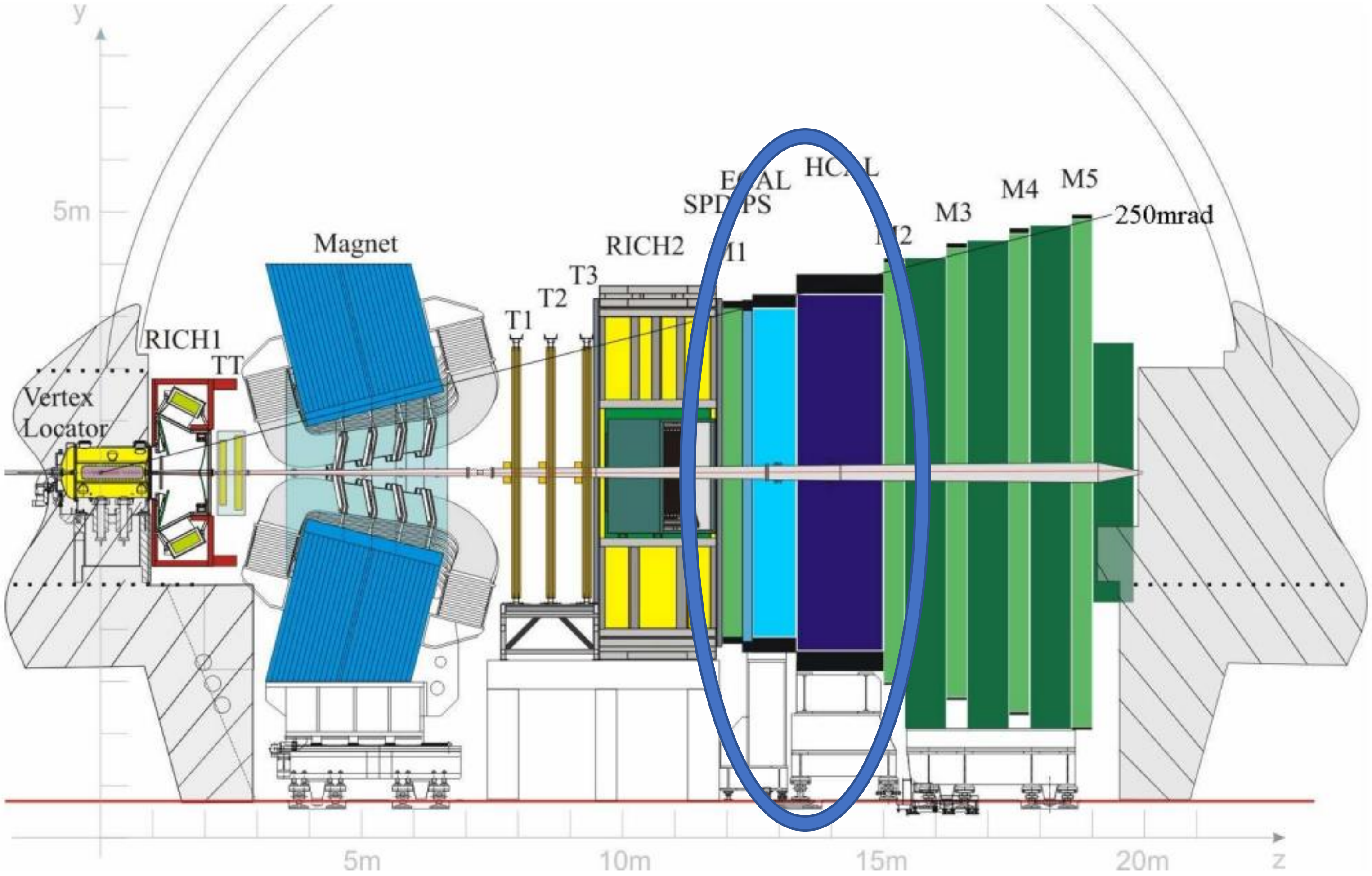
Where we started?

Ring Imaging Cherenkov System



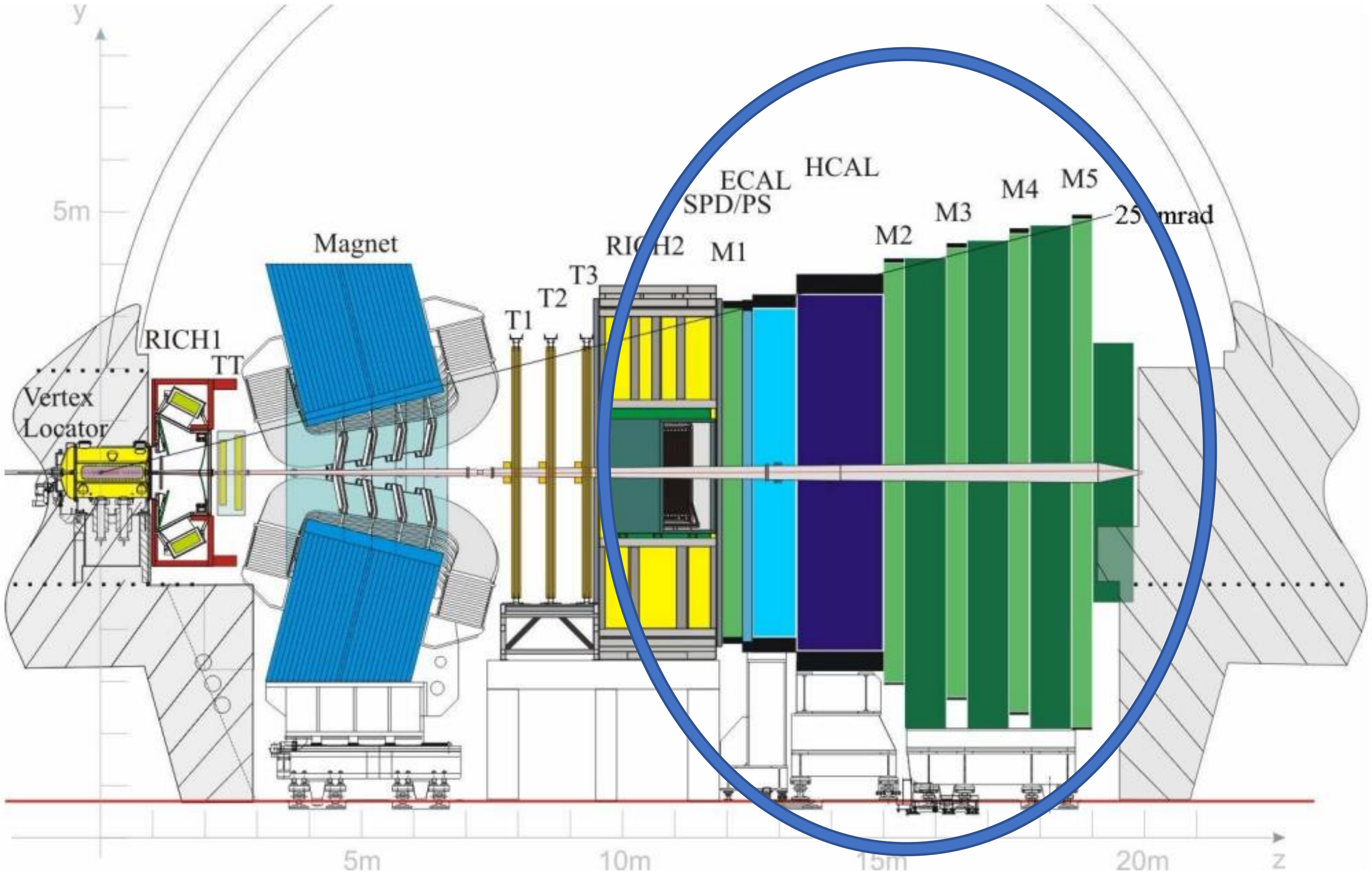
Where we started?

Lots of Calo!



Where we started?

A muon system including M1 located just before the ECAL



Upgrade 1

"And that's what I've done. Maintained it for 20 years. This old brooms had 17 new heads and 14 new handles in its time."

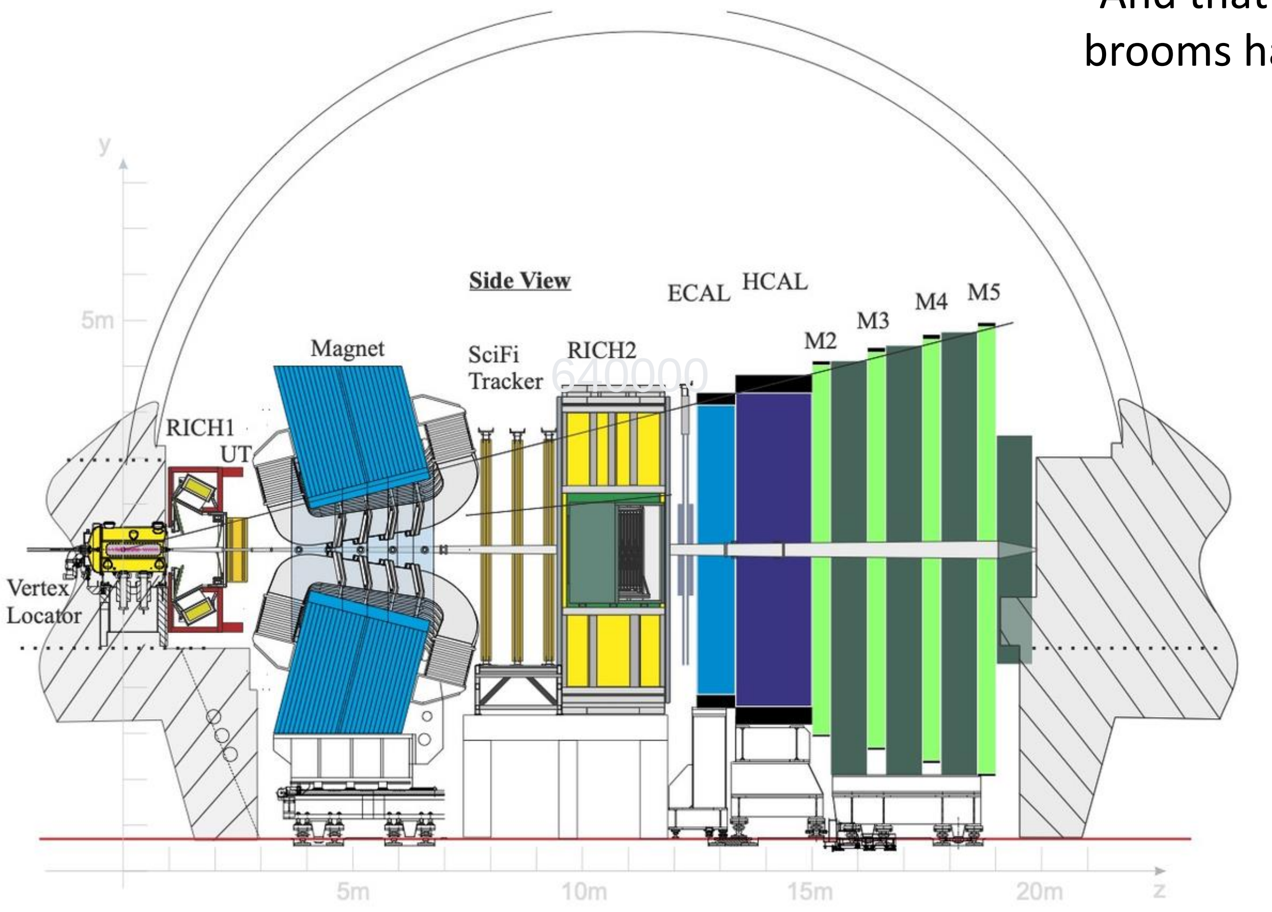
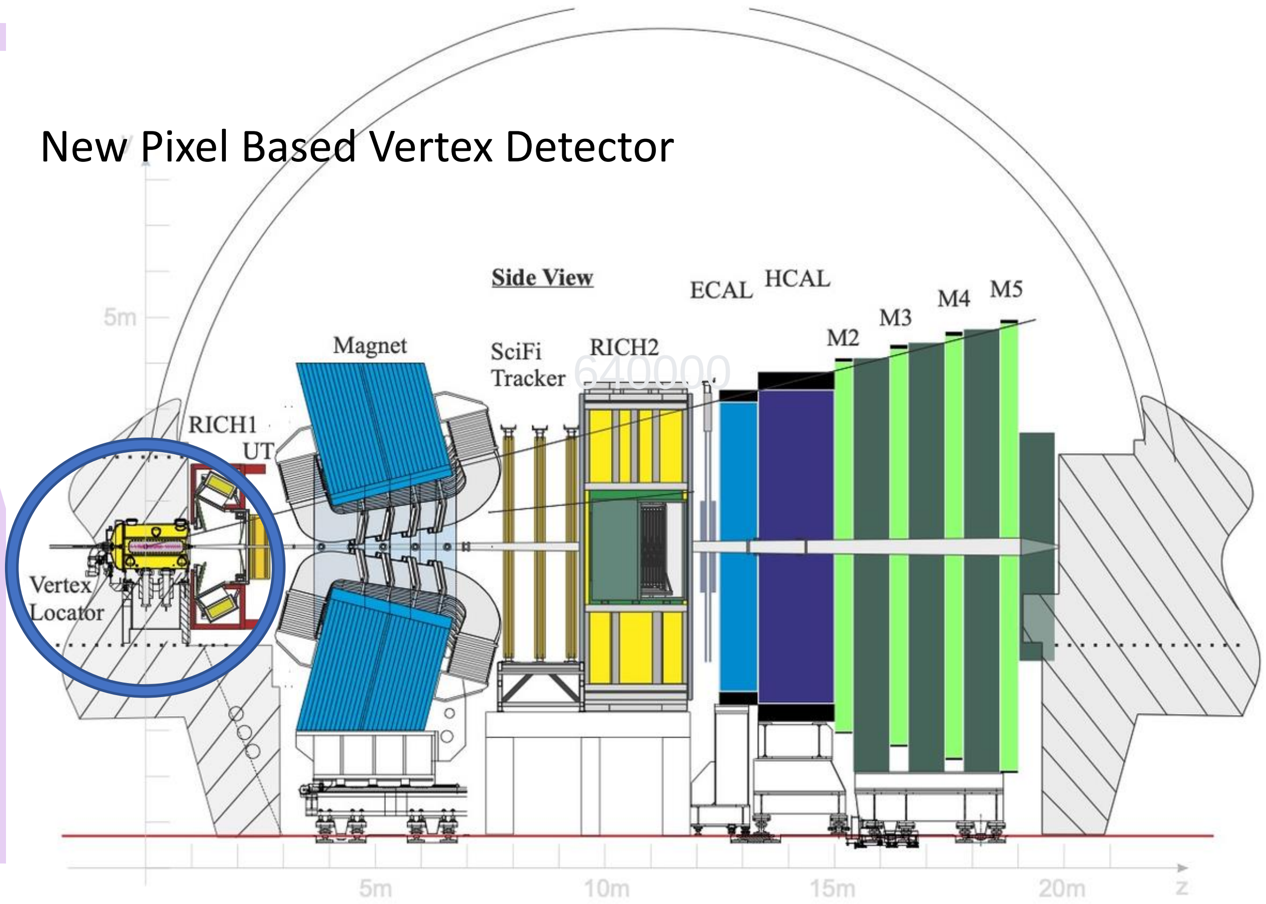


Table 1: Overview of global upgrade settings for simulation.

Beam energy	7 TeV
Number of bunches colliding at IP8	2400
Bunch z RMS	90 mm
Half angle horizontal	135 µrad
Half angle vertical	120 µrad
Luminosity	$2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
Bunch charge	1.2×10^{11} protons
ν (# interactions per crossing)	7.6 (for $\sigma_{\mathrm{tot}} = 102.5\,\mathrm{mb}$)
μ (# visible interactions per crossing)	5.2 (for $\sigma_{\mathrm{vis}} = 70.6\,\mathrm{mb}$)
Bunch x,y RMS	37.70 µm
z RMS luminous region σ_{lumi}	63 mm

Upgrade 1

New Pixel Based Vertex Detector



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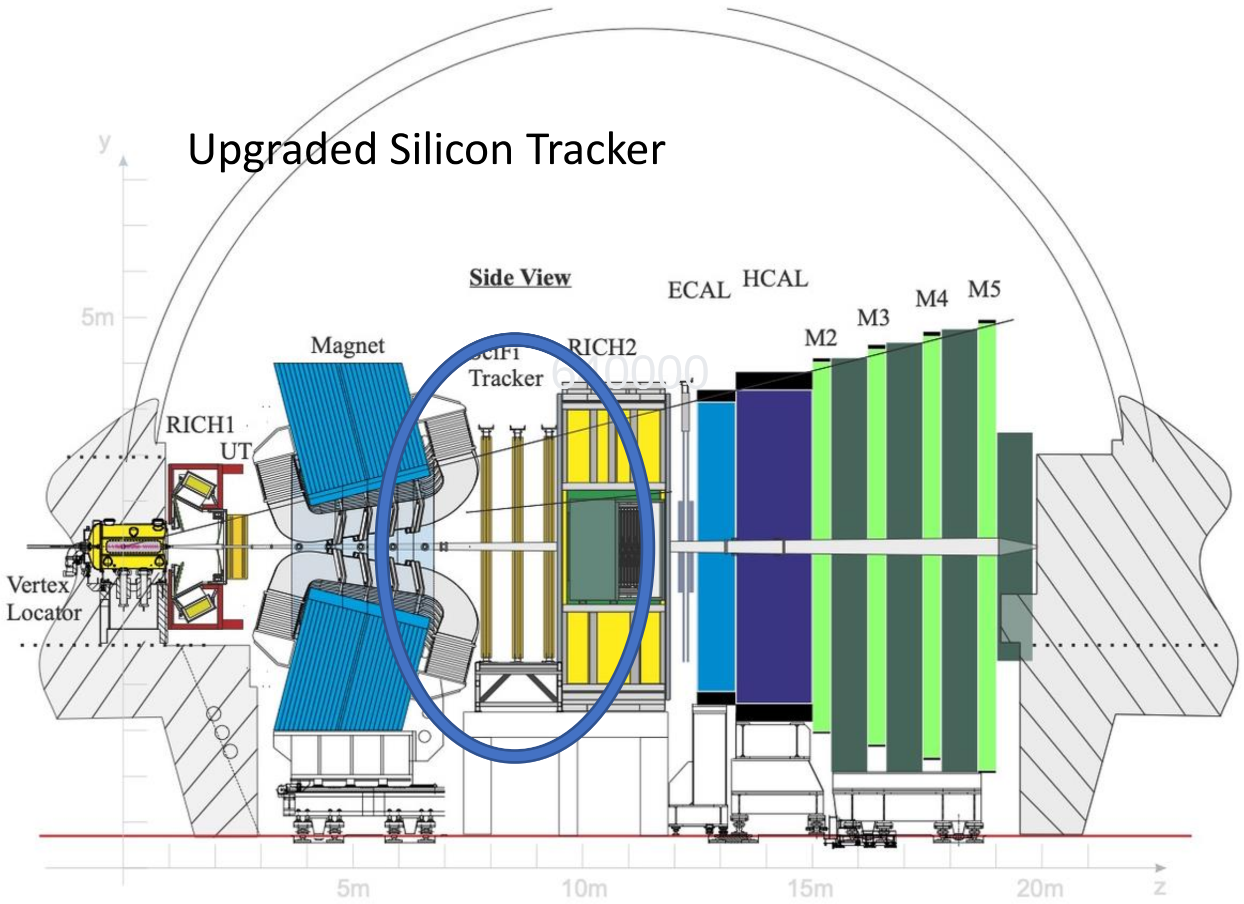
Upgrade 1

Upgraded Silicon Tracker



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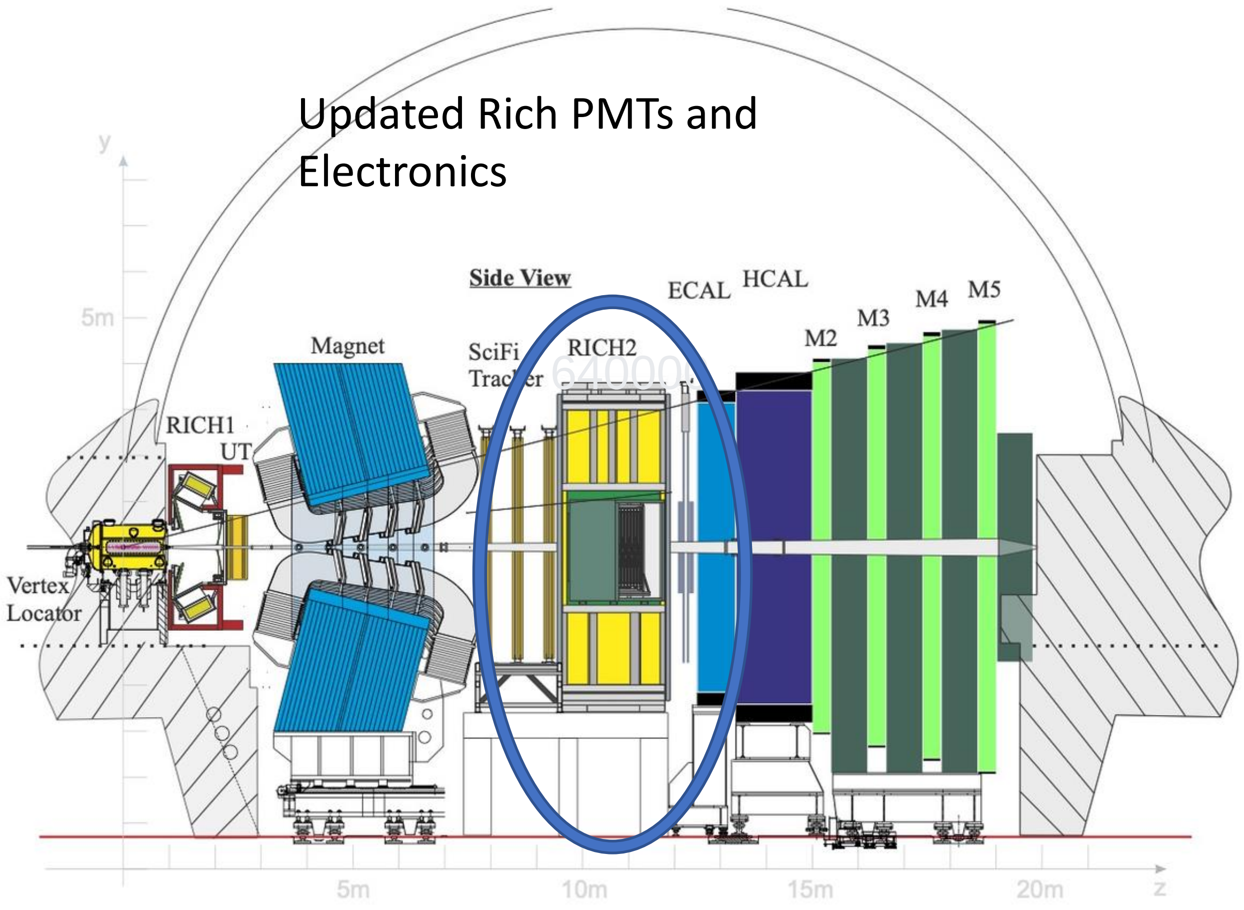
Upgrade 1

Updated Rich PMTs and Electronics



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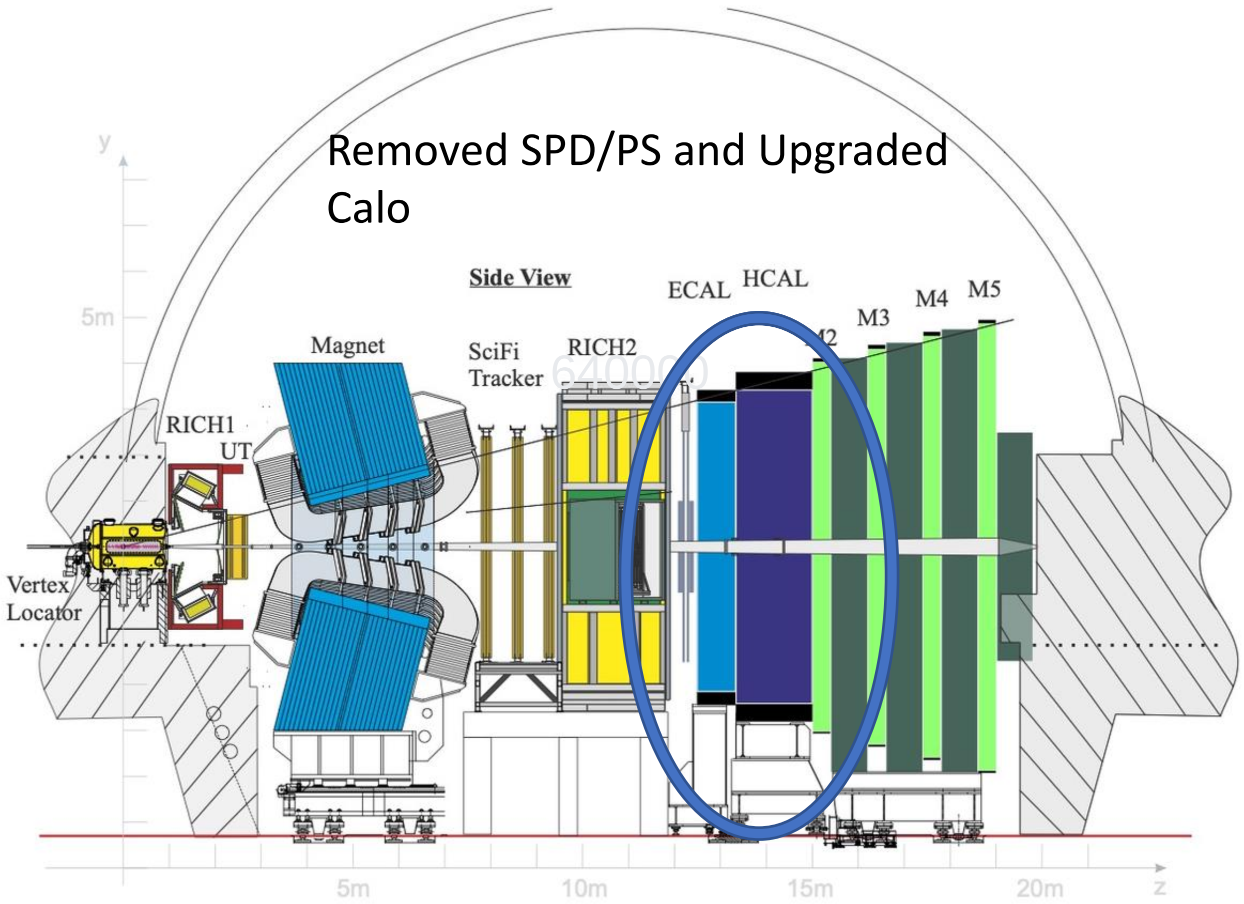

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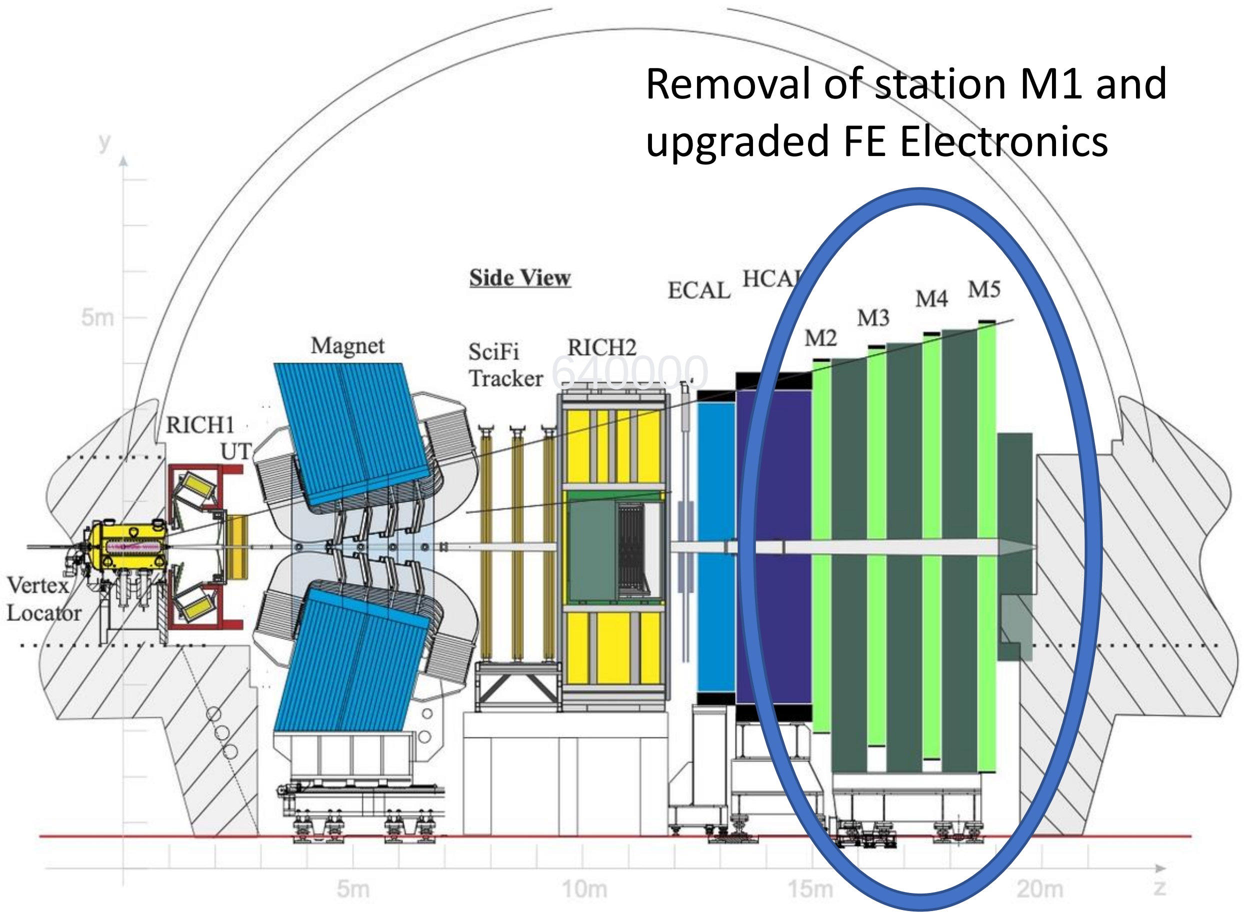

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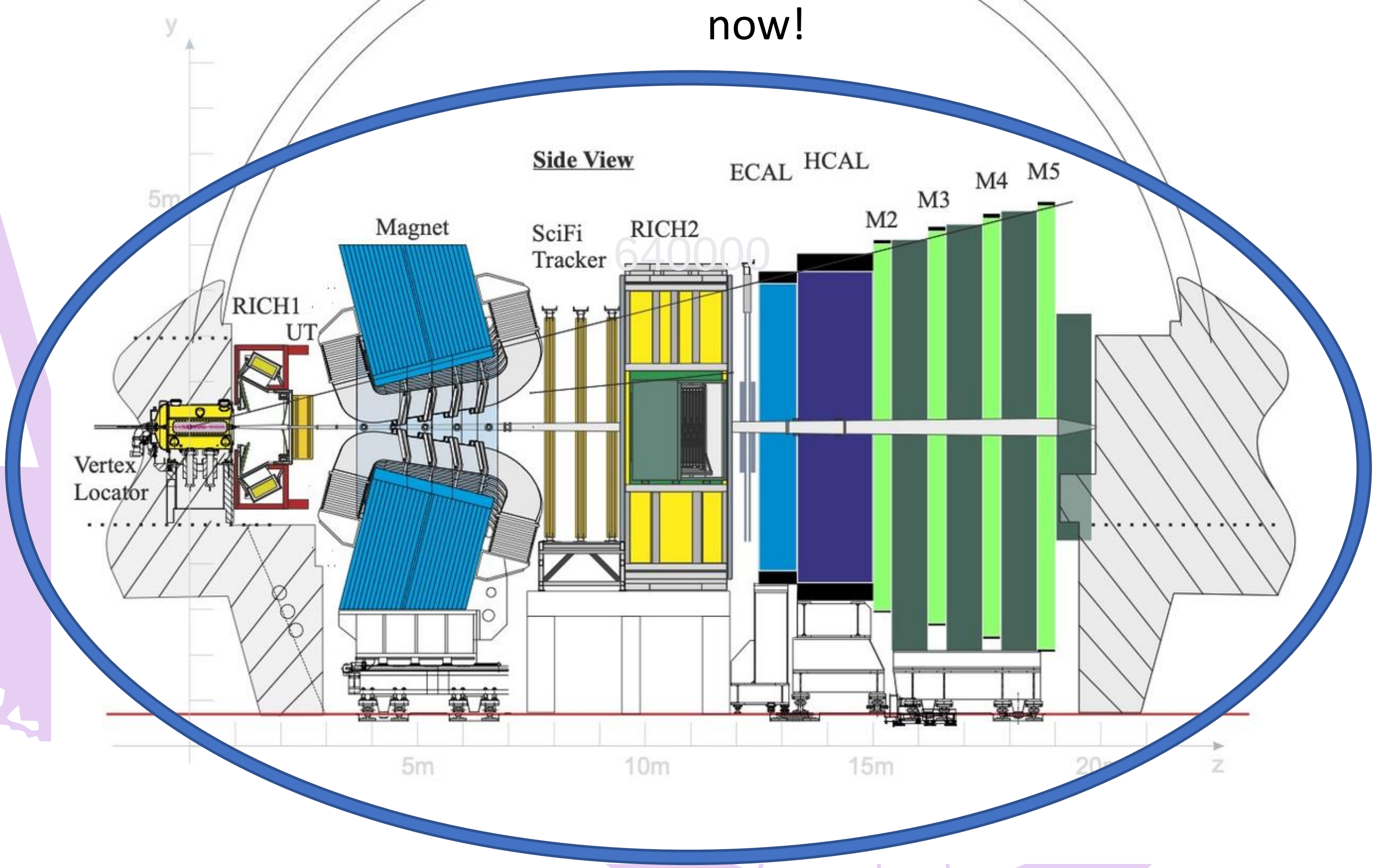
Upgrade 1

L0 is gone, Only Software triggers now!



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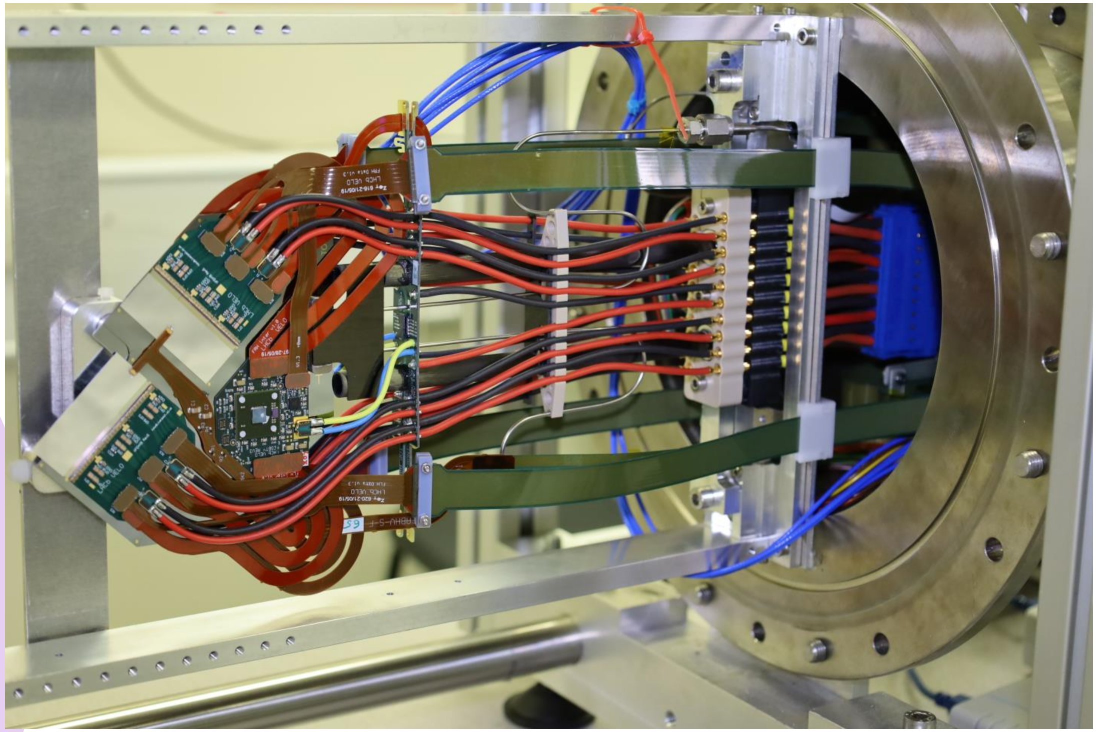
What is the VELO?

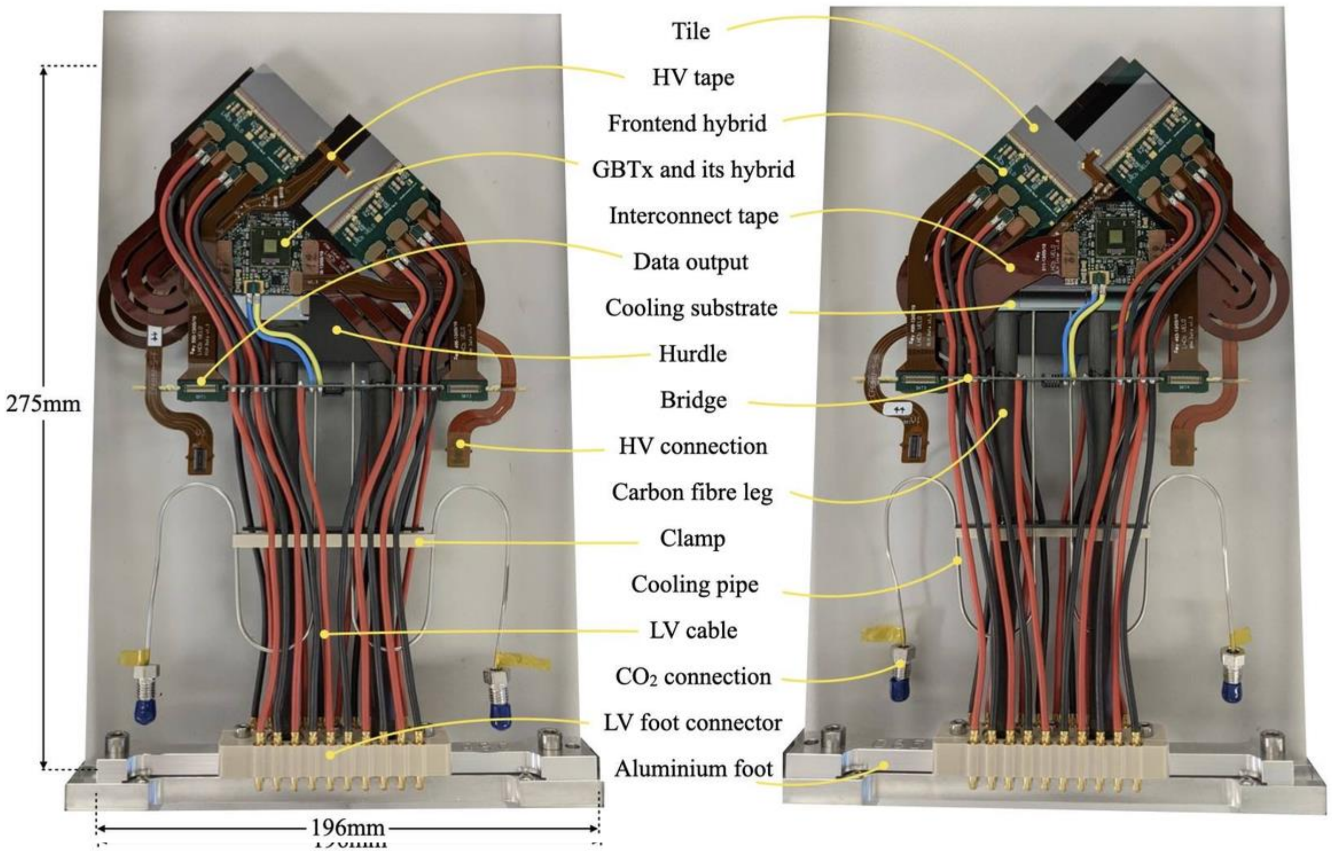
- The VELO (VErtex LOcator) is a hybrid pixel detector designed to cover the forward region of the pp interaction point.

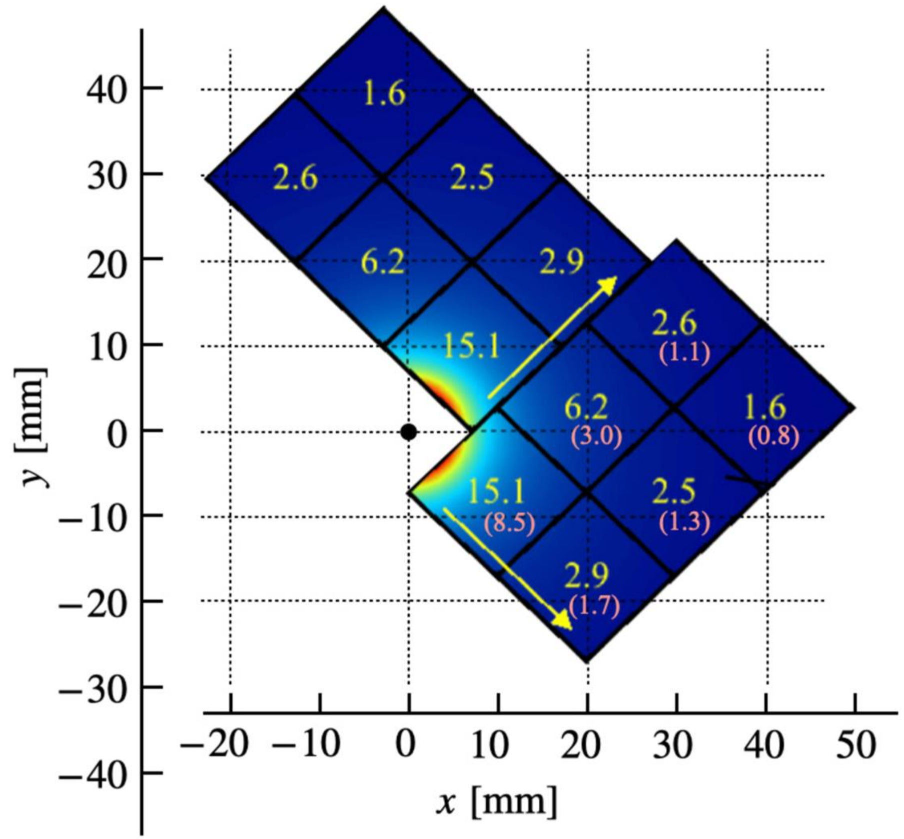
- Novel features include (but are not limited to)

  - Improved radiation tolerance!
  - Microchannel cooling!
  - Digital readout!
  - Superpixels!



Anatomy of the VELO (small picture)





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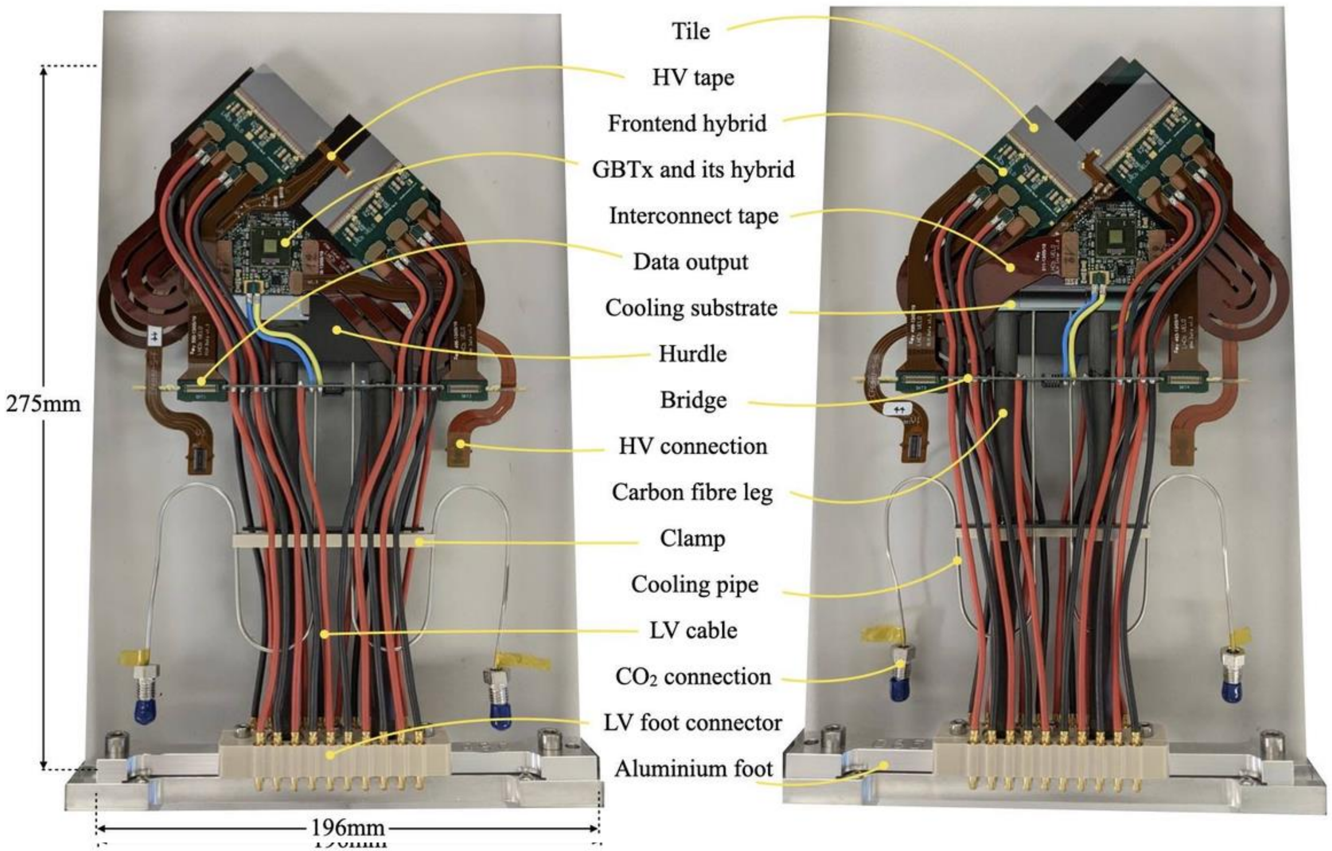

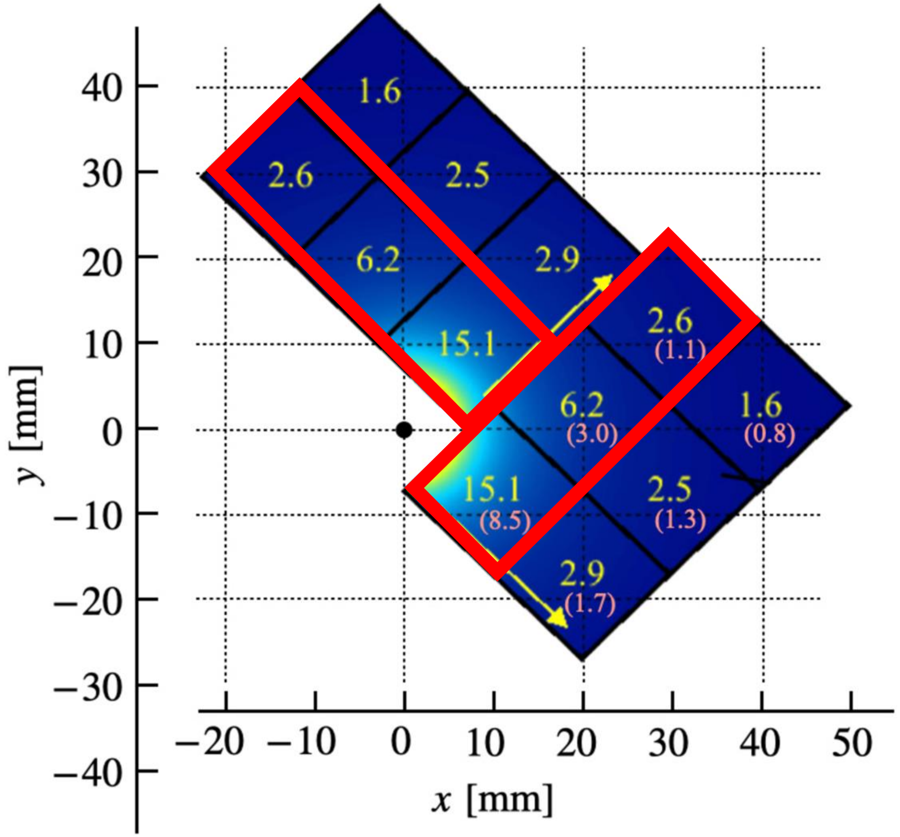

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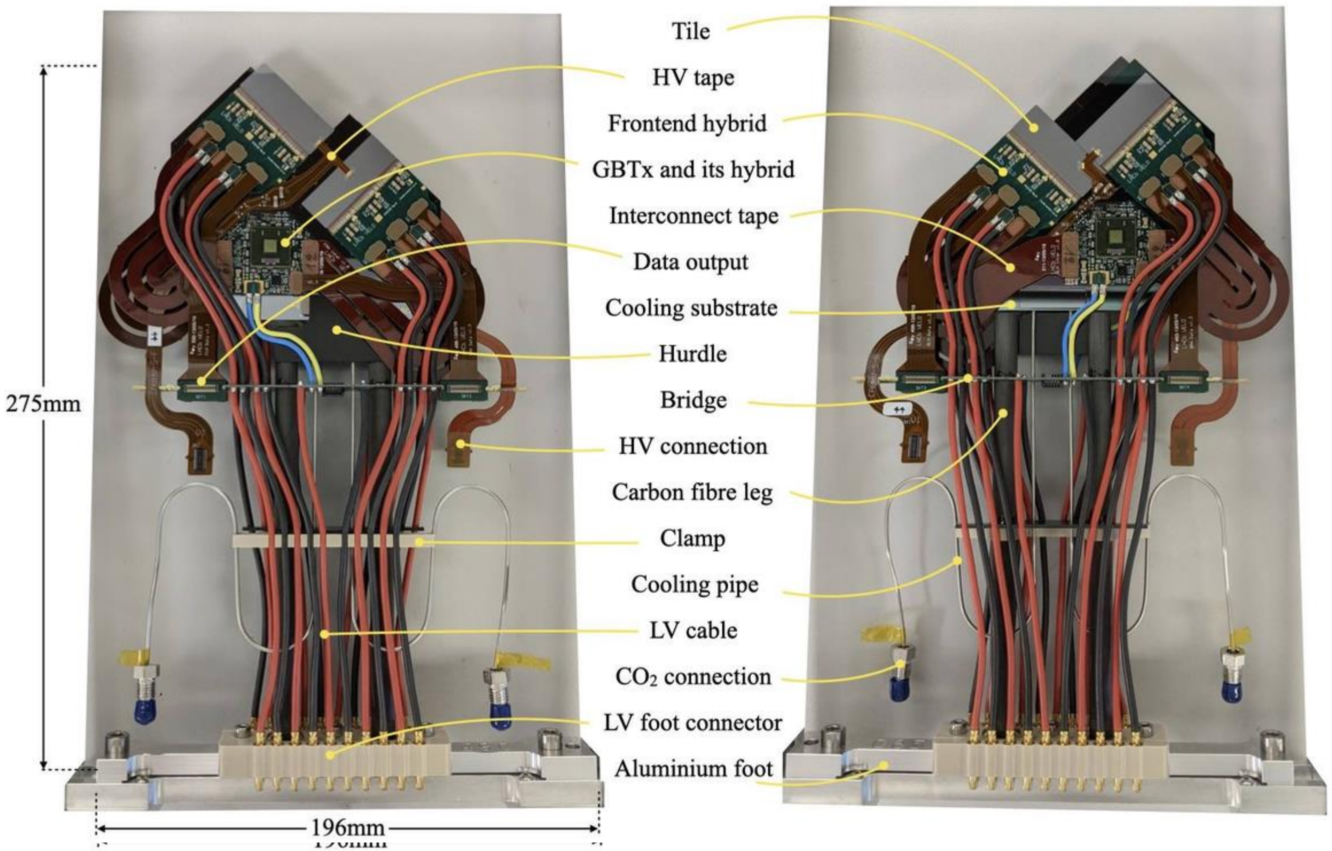
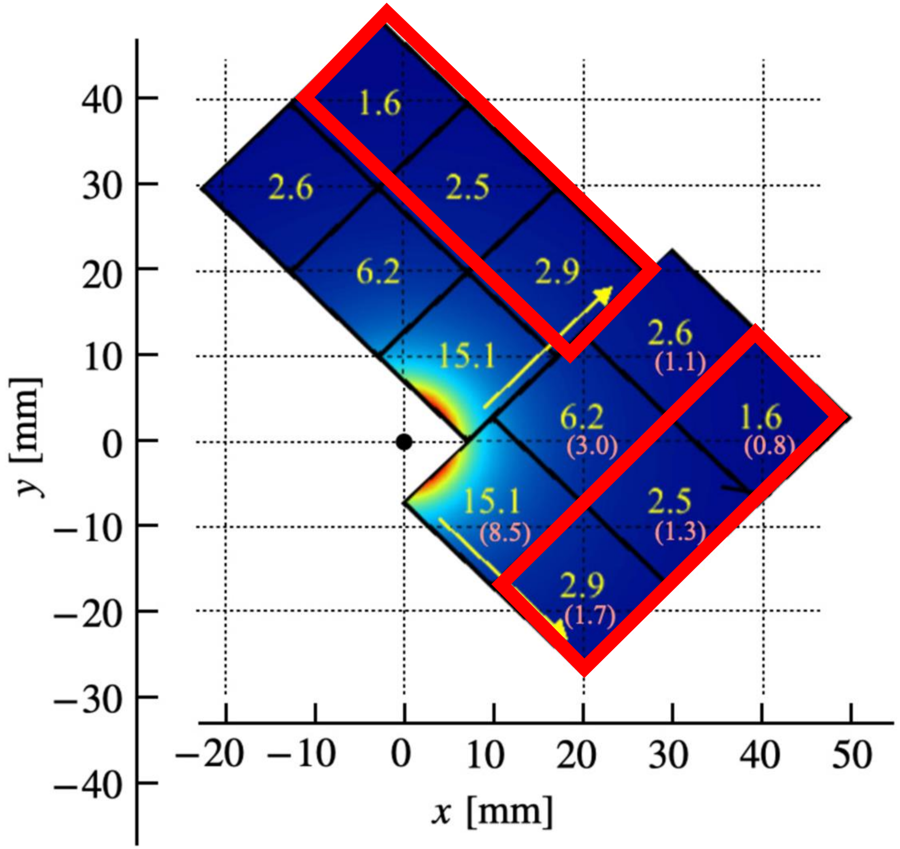
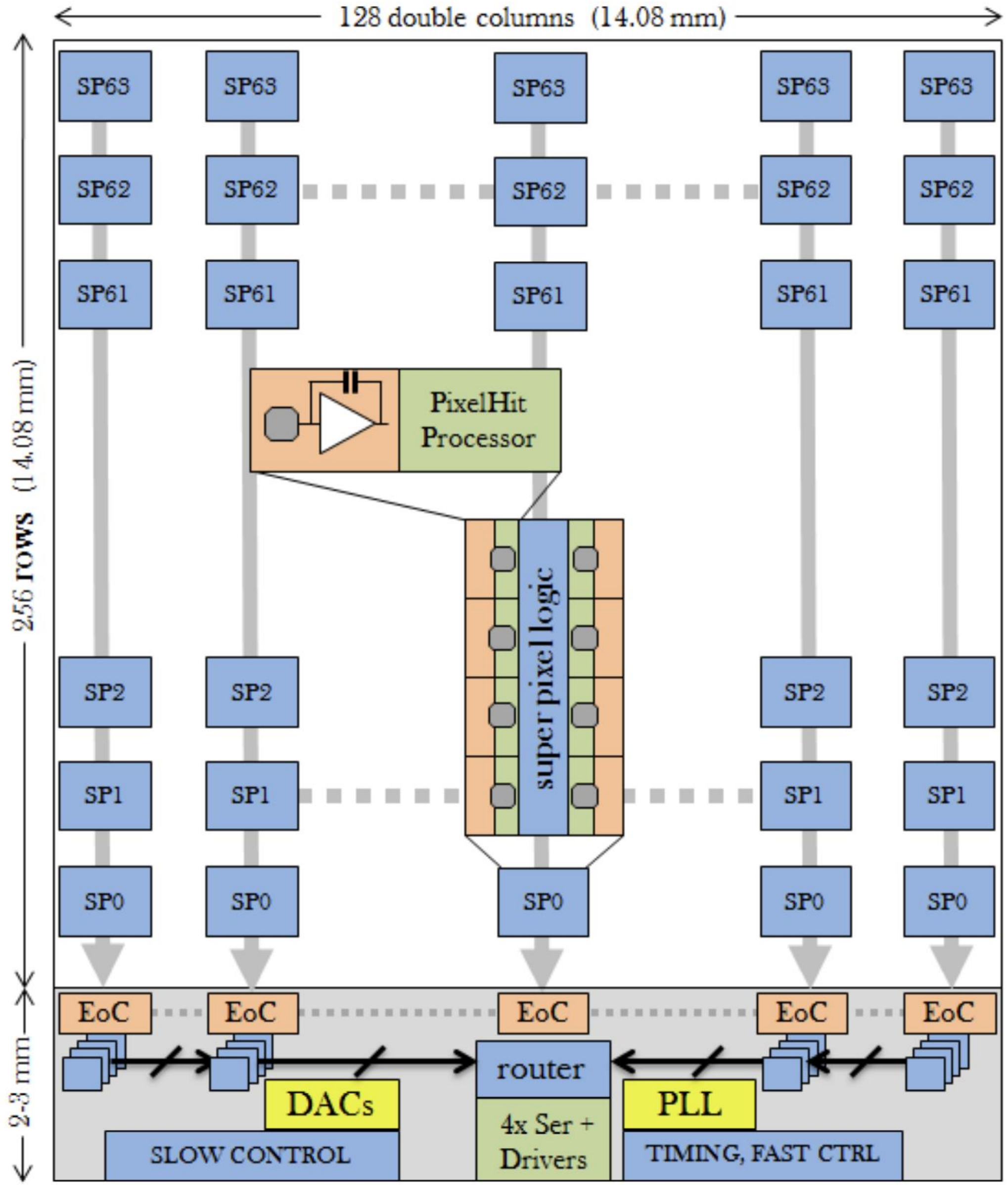




Superpixel Monitoring

- Each 256 x 256 pixel array contains 64 x 128 Superpixels. This groups pixels in 2 x 4 grids.
- Superpixels are read out in column form, takes 64 clock cycles to fully read out.
- Superpixel packets are only 23 bits.
- 30% reduction in data volume.

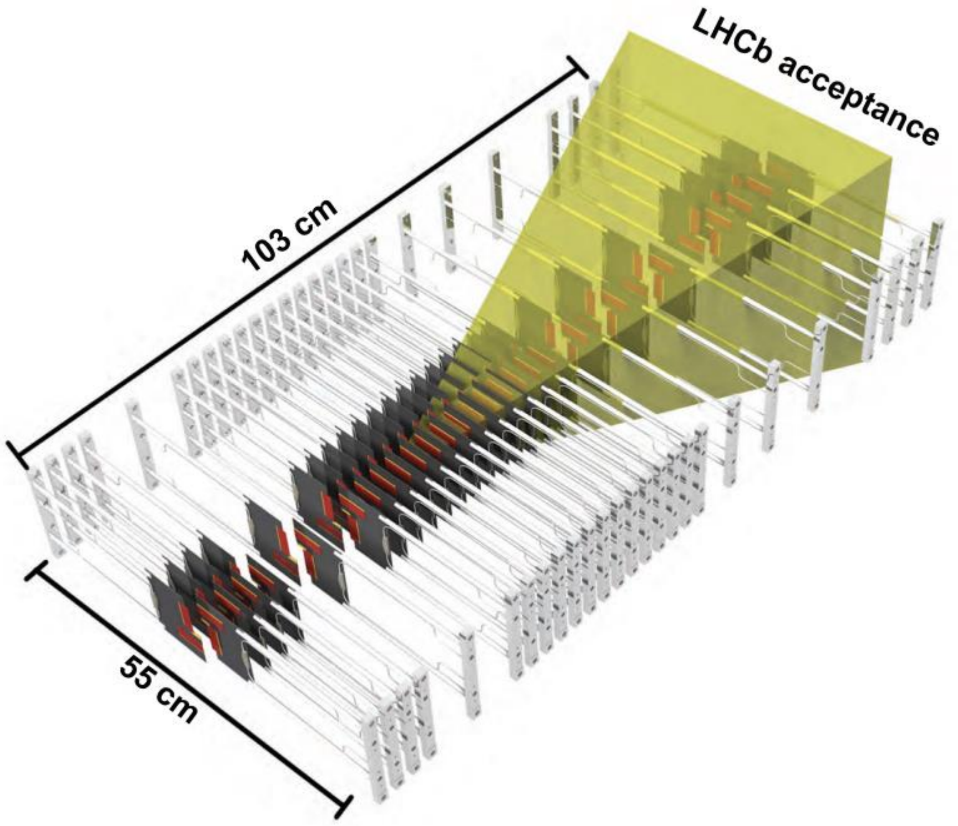
23b SPP	=	6b Address	9b Time Stamp	8b Hitmap



Anatomy of the VELO (big picture)

Table 3: System parameters of the VELO upgrade.

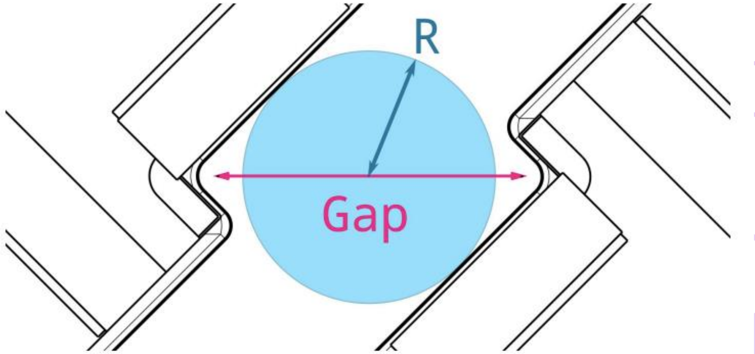
# modules	52
# ASICs per module	12
# ASICs total	624
# silicon sensors	208
silicon sensor thickness	200 µm
# pixels	41 M
pixel dimensions	55×55 µm^2
position of first station upstream	-289 mm
position of last station downstream	751 mm
radiation level at 5.1 mm radius	1.1 - 1.8 $\times 10^{14}$ 1 MeV n_{eq}/ fb^{-1}
radiation level at 50 mm radius	1.7 - 2.6 $\times 10^{12}$ 1 MeV n_{eq}/ fb^{-1}
Total active area	1243 cm^2
Peak total data rate	2.85 Tbit/s
# optical links	1664

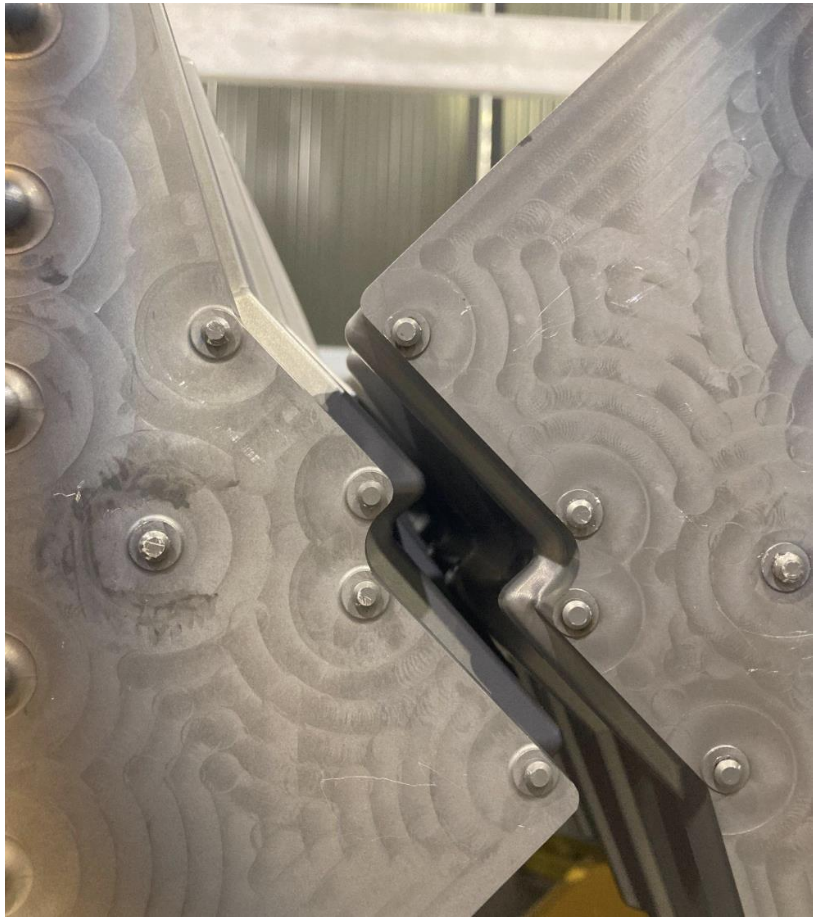


What issue faced the VELO?

What issue faced the VELO?

- Due to a vacuum incident (Just a small 200 mbar differential) the RF Foil (right) was heavily deformed reducing our closure.
- However, after inspection, it appears the motion system and front end electronics were **unaffected**.
- We maintained a closure of 49mm (Gap) 10.5mm (Radius).





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- Old foil has been removed using precision tools and YETS activities progressing well!
- Only 2 open questions?

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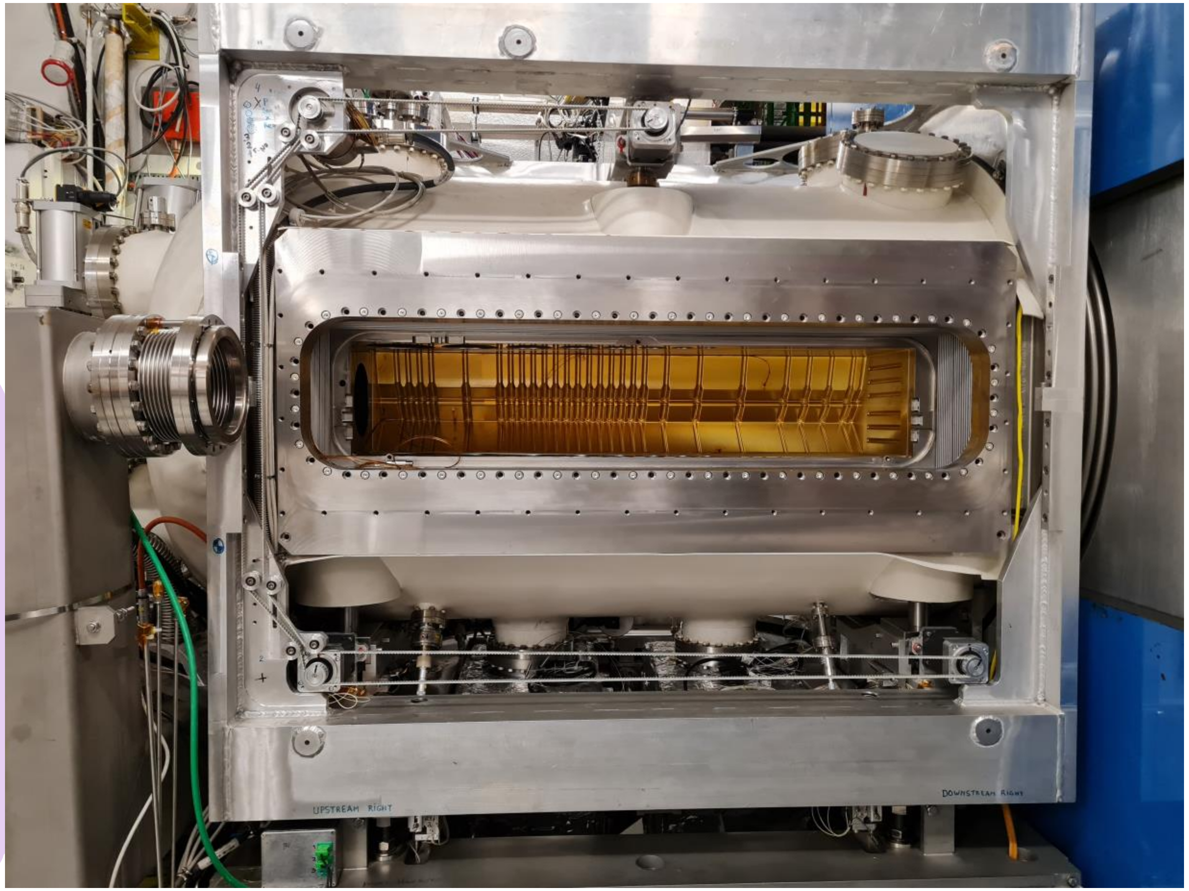
Huge effort from the VELO team!

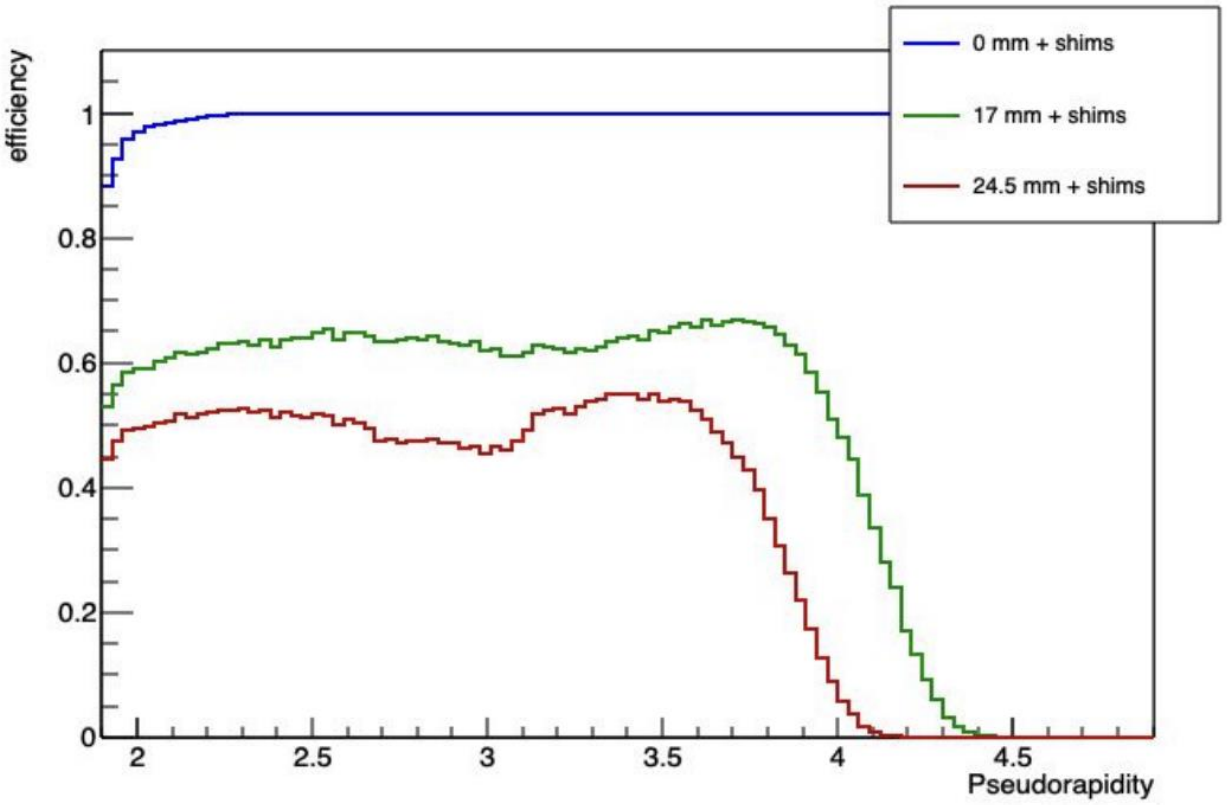
How well?



What are the current issues facing the VELO?

- Old foil has been removed using precision tools and YETS activities progressing well
- Only 2 open questions?
- **How** has the opening affected the Ion data?
- **How** smoothly will commissioning the motion system go?

“ray tracing” study [4 hits on tracks] - P. Collins



The UT

- The UT is a **core part** of the LHCb physics case being required to constrain important decays such as $K_S^0 \to \pi\pi$ that **decay beyond** the VELO acceptance.
- Depending on channel up to **73%** of these decays are completely constrained by the UT and later trackers.
- The UT also **boosts the momentum resolution** significantly!
- Finally, the UT deals very well with spooky ghost tracks!

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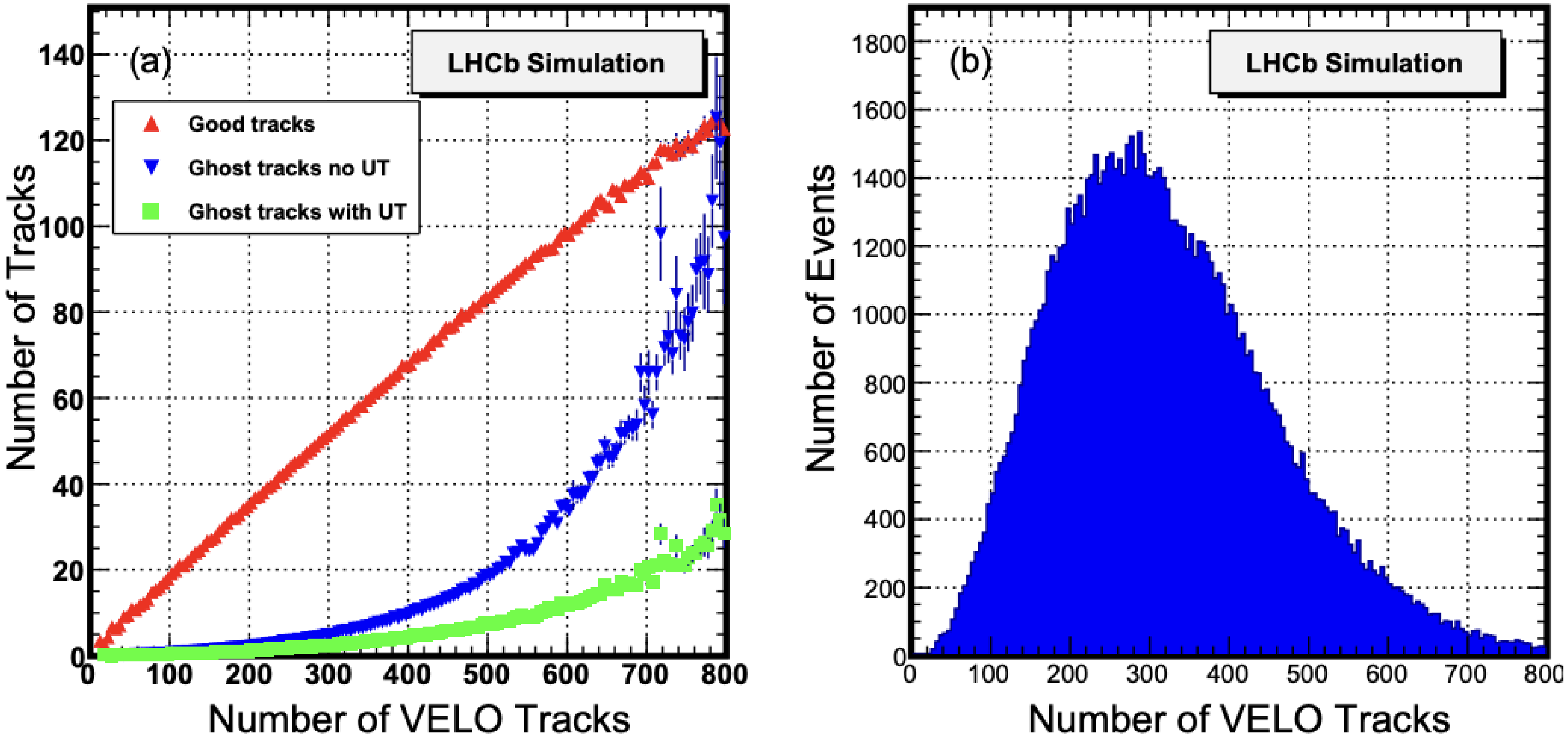
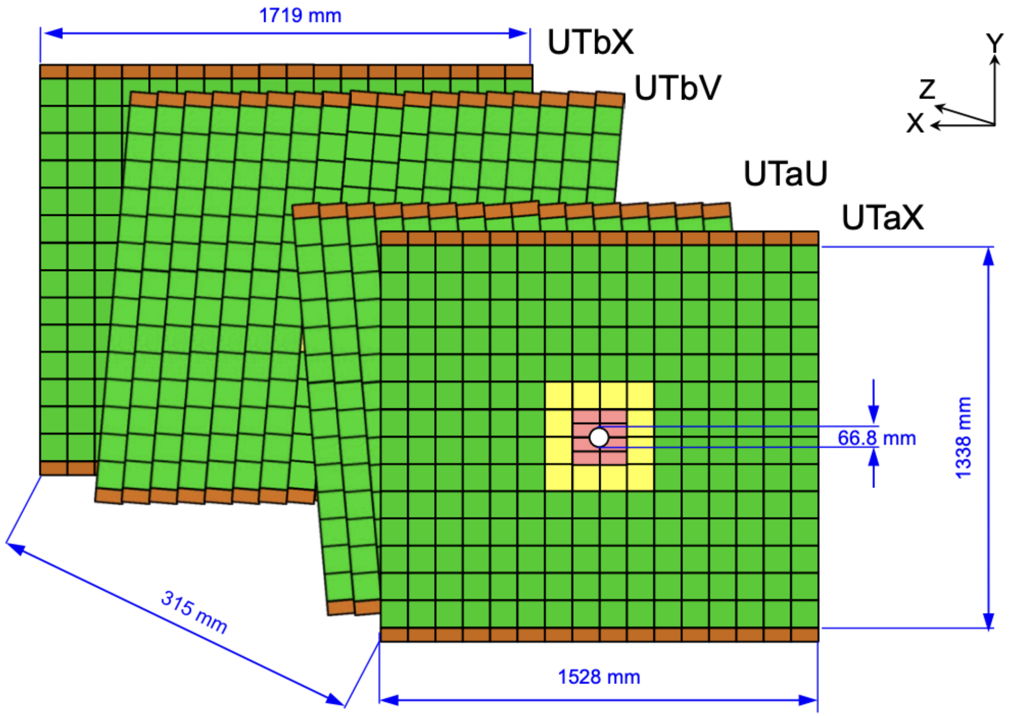

(a)
LHCb Simulation
Good tracks
Ghost tracks no UT
Ghost tracks with UT
Number of Tracks
Number of VELO Tracks
(b)
LHCb Simulation
Number of Events
Number of VELO Tracks

The UT – Construction

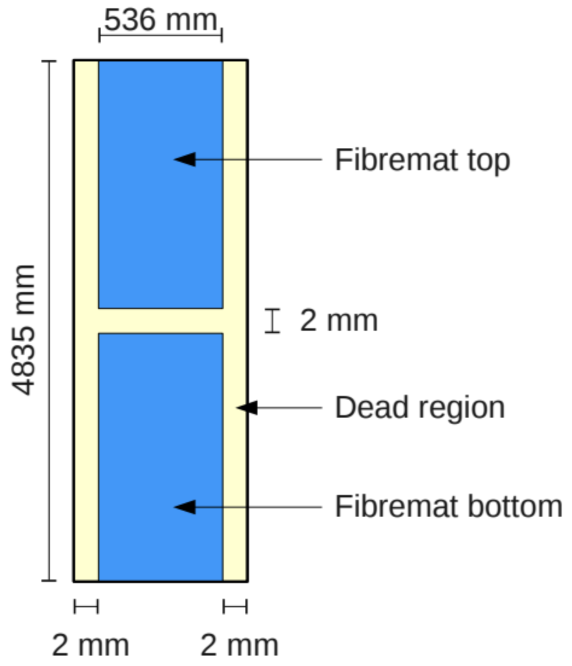
- Four-layer silicon strip detector
  - Finer granularity than TT, innermost sensors closer to beam pipe
  - Inner layers tilted by a stereo angle (±5%)
  - Four different types of sensors
  - Mounted to lightweight staves (10 cm wide, 1.6 m long)
  - Novel readout chip (SALT ASIC)

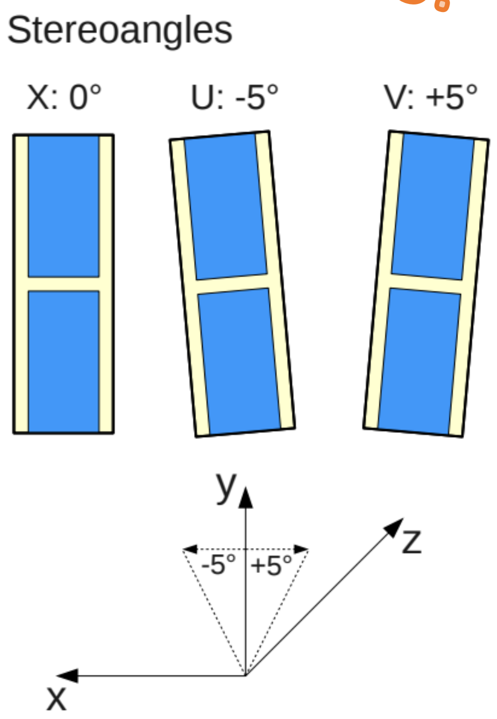


The SciFi

- 3 x 4 layers of scintillating fiber mats
- Each mat with 6 layers of fibres
- 8 mats assembled into a module
- 11,000 km of fibres in total
- Coverage up to 3m from the beam pipe

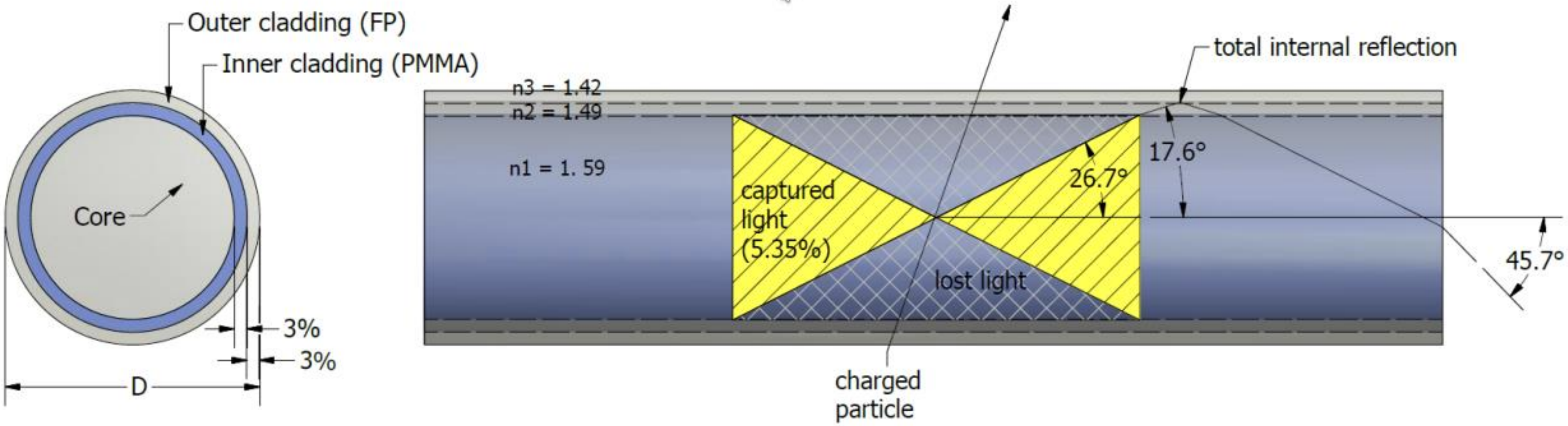
That's stereo!





The SciFi

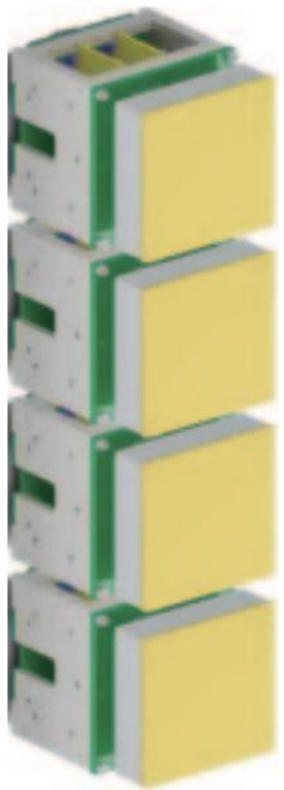
- The scintillating fibers work by collecting light from particles travelling through them. 3 offset layers per station give the SciFi the best possible coverage of the LHCb acceptance.



Rich

- RICH1 has new flat mirrors for better photon yield
- Focal plane, optics modified to increase size of Cherenkov rings
- Photo-detectors have been upgraded
- Two new types of multi-anode photomultiplier tubes (MaPMTs) with finer granularity have been installed

Photon Detection Module (PDM)



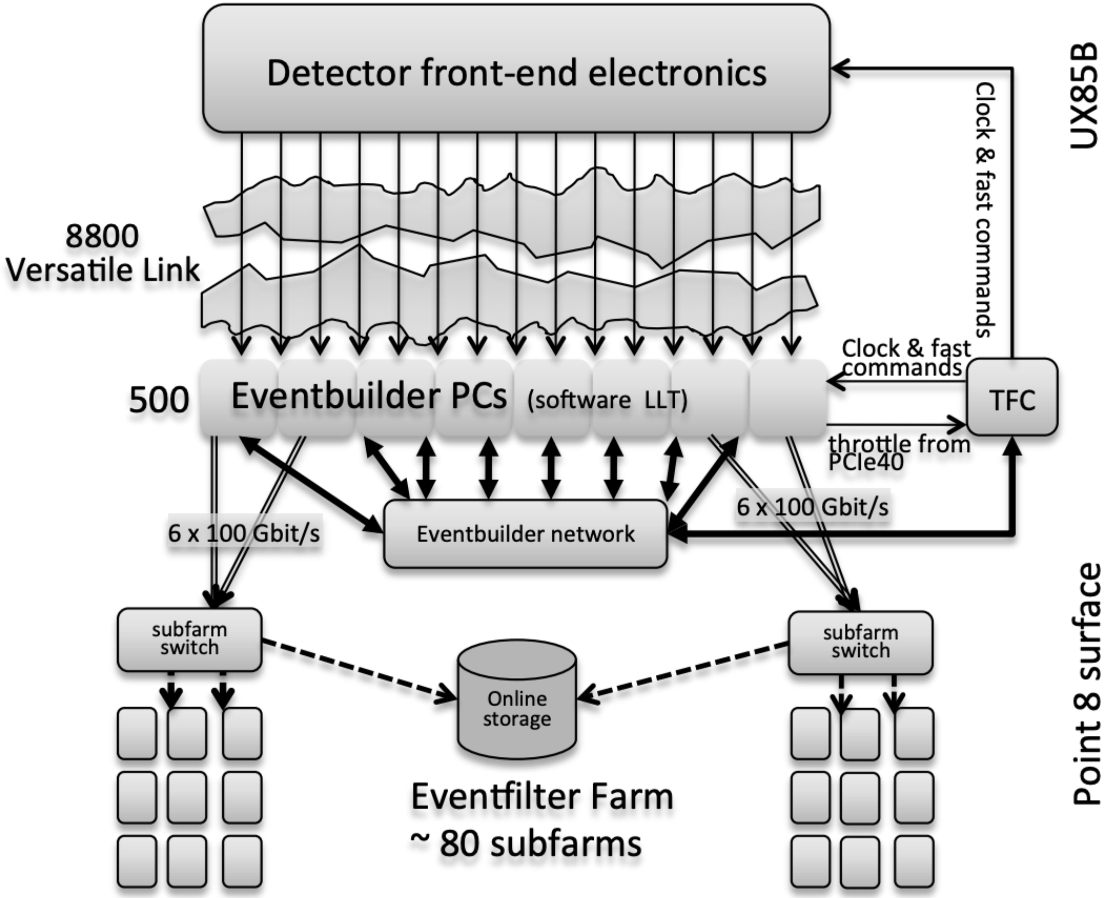
What I don’t go into depth on!

- SMOG 2. It was installed and provides a unique fixed target program to the LHCb. Learn about anti-proton production, Central exclusive production, Strangeness production and other cool things with this targeted gas injection system!

- Calo and Muon upgrades. Both have made substantial upgrades to the from ends but the technology otherwise has remained relatively stable!

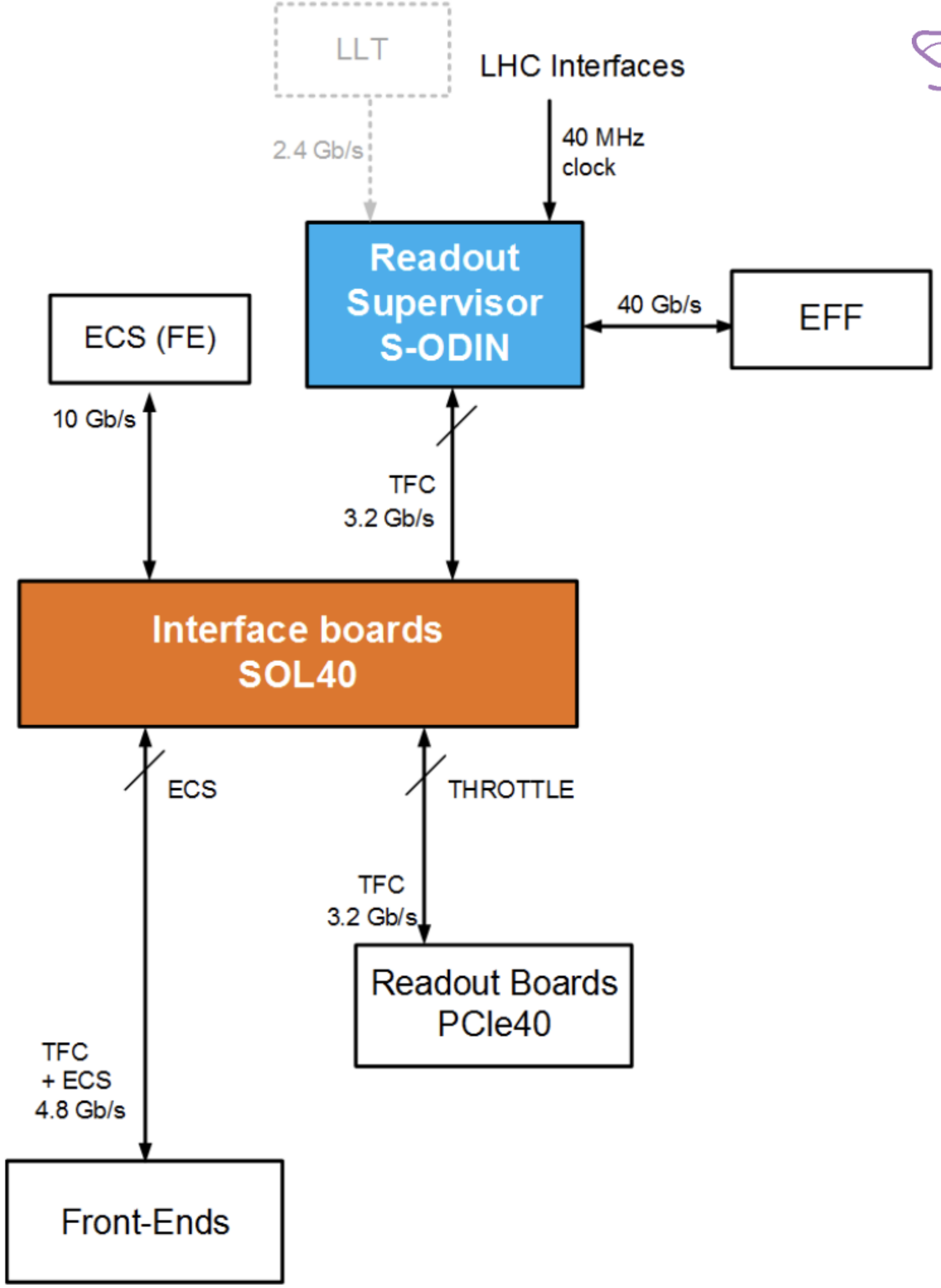
Readout!

- With the removal of the L0 hardware trigger **all** bunch crossings can be triggered on and sent to the Event Builder nodes on the surface!
- That's around 19000m of optical fibres with a yield of 99.75%



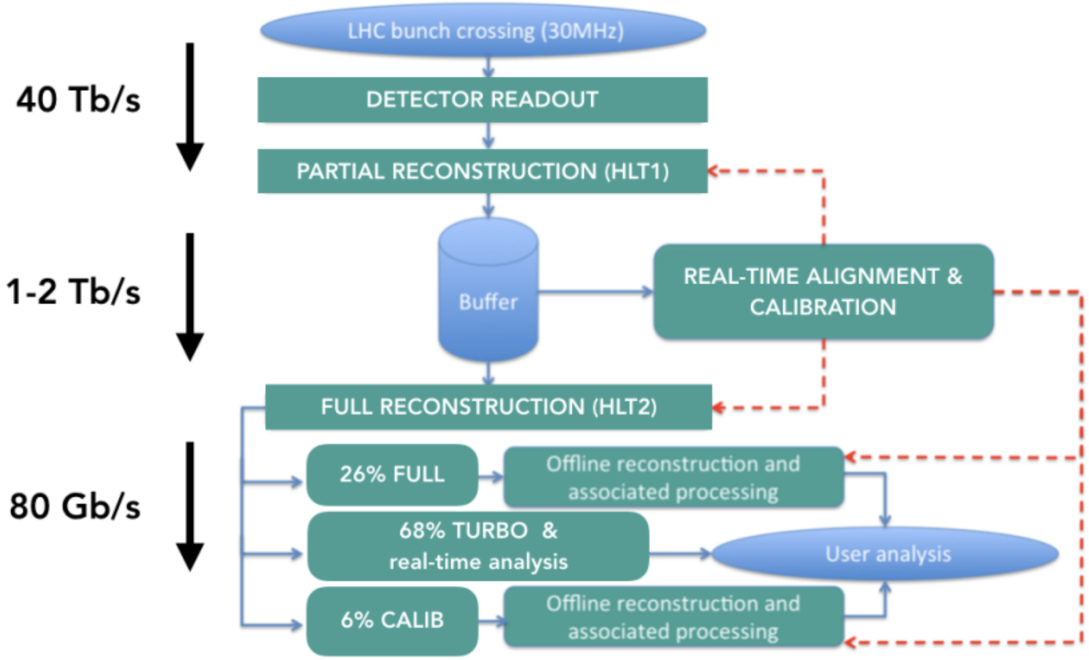
Readout

- What this means at the detector end is that the LHC clock synchronizes all LHCb front end electronics via the SOL40's
- These readout the front ends and transmit them to the ECS. Timing calibration of the from ends ensure the correct packets are synchronized.



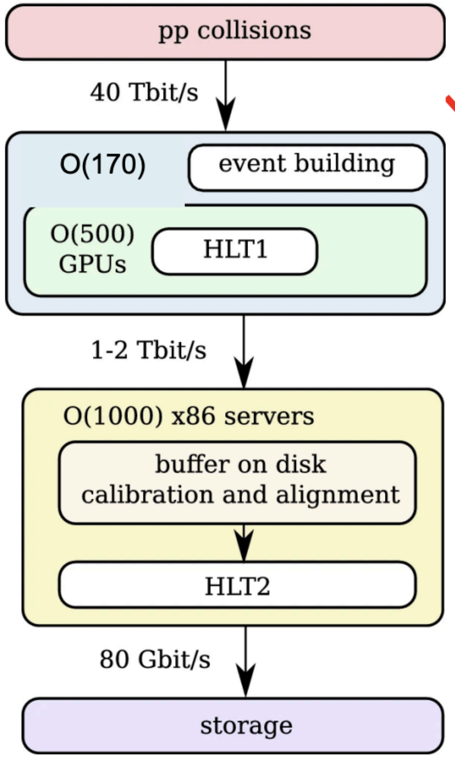
Allen! (motivation)

- Traditionally the HLT sequence is made of 2 stages. HLT1 which uses a stripped down reconstruction to veto any “no physics” events before a disk buffer.
- Then HLT2 that completes and triggers on the full event reconstruction. Depending on the buffer size HLT2 doesn’t need the same speed as HLT1



Allen

- Allen project for fully software trigger on GPUs
  - Implemented on C++, CUDA and python
  - Running also for CPU and HIP (AMD, experimental)
  - It can run standalone!



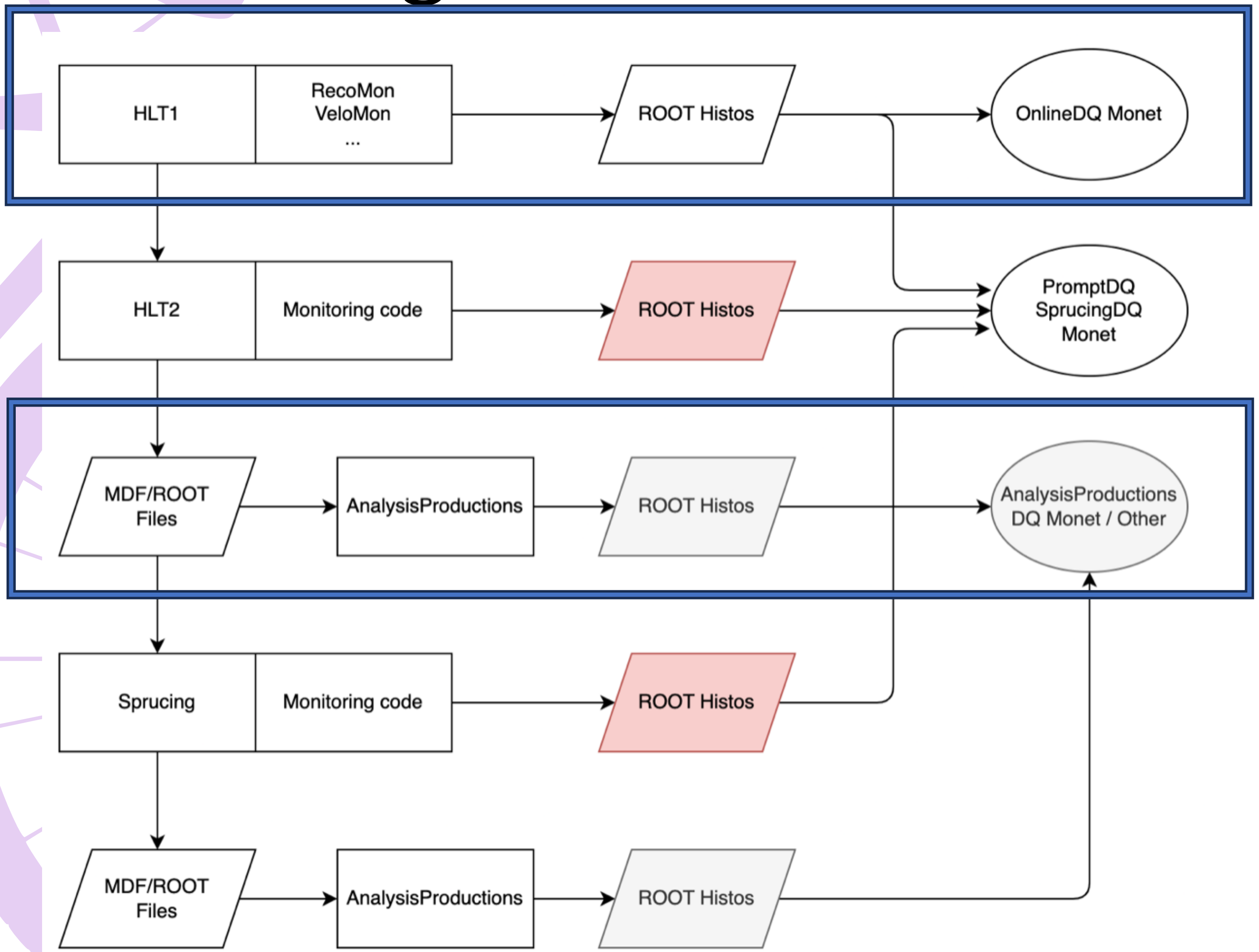
3 GPUs+PCIe40 card / EB server

HLT1 runs at visible collision rate

~30 MHz

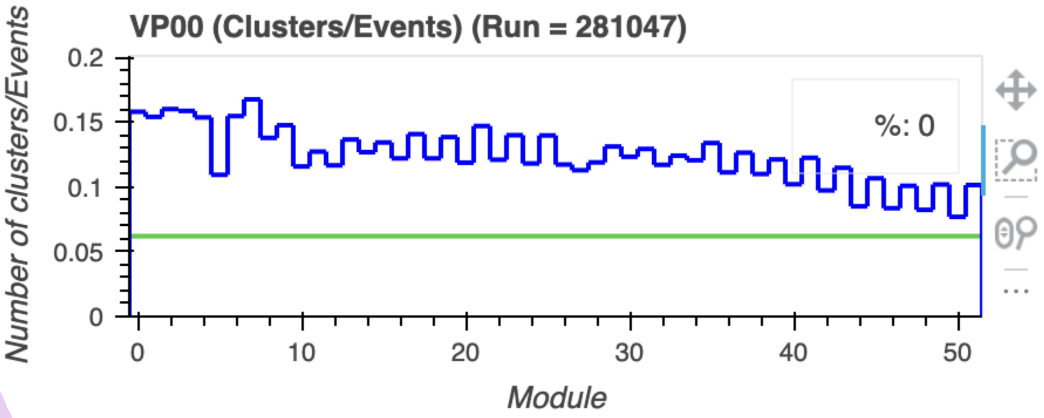
✓ 60 kHz per GPU

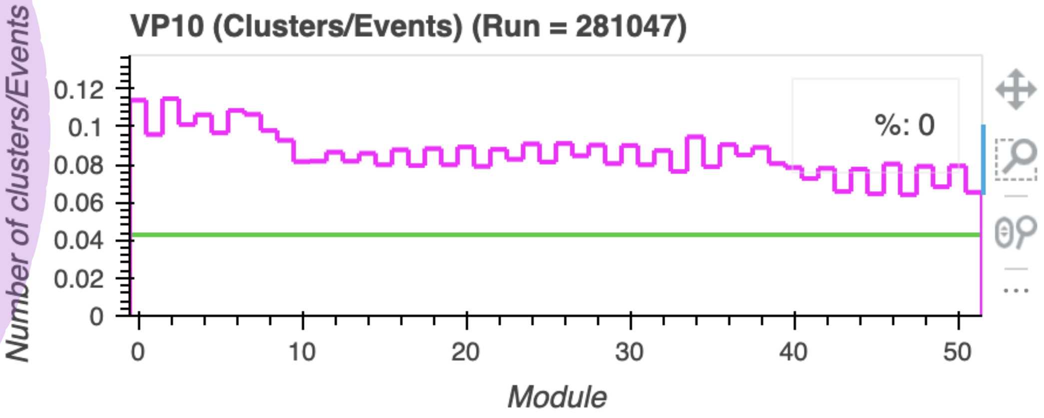
Online Monitoring workflow



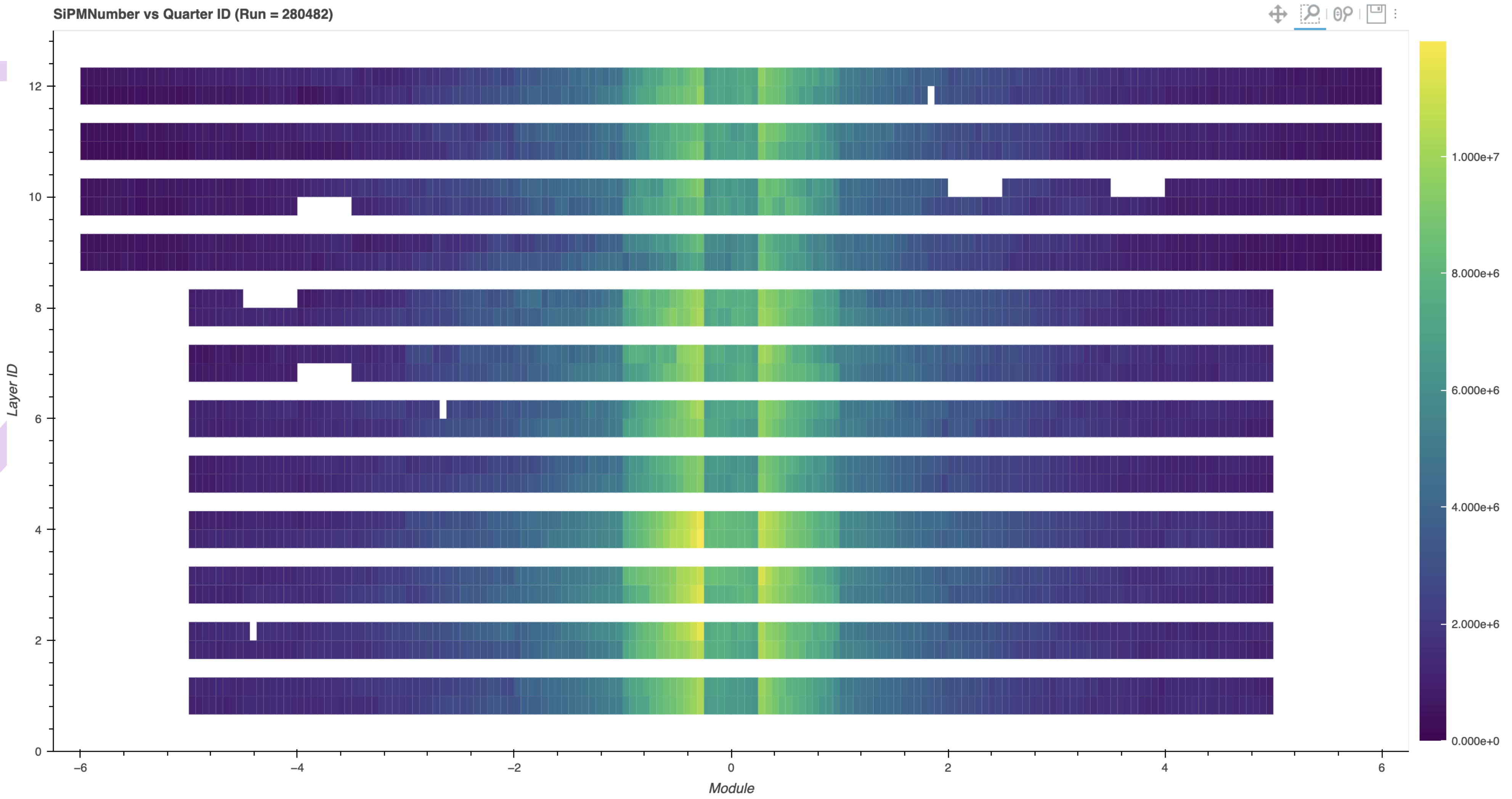
Real Time Monitoring (VELO)

- We monitor the clustering across all ASIC channels from the front ends.
- At a high level this allows for Data Shifters to quickly identify if an ASIC has any 'hot pixels' or is inefficient.
- Generally, this is the first place a VELO issue will present itself.

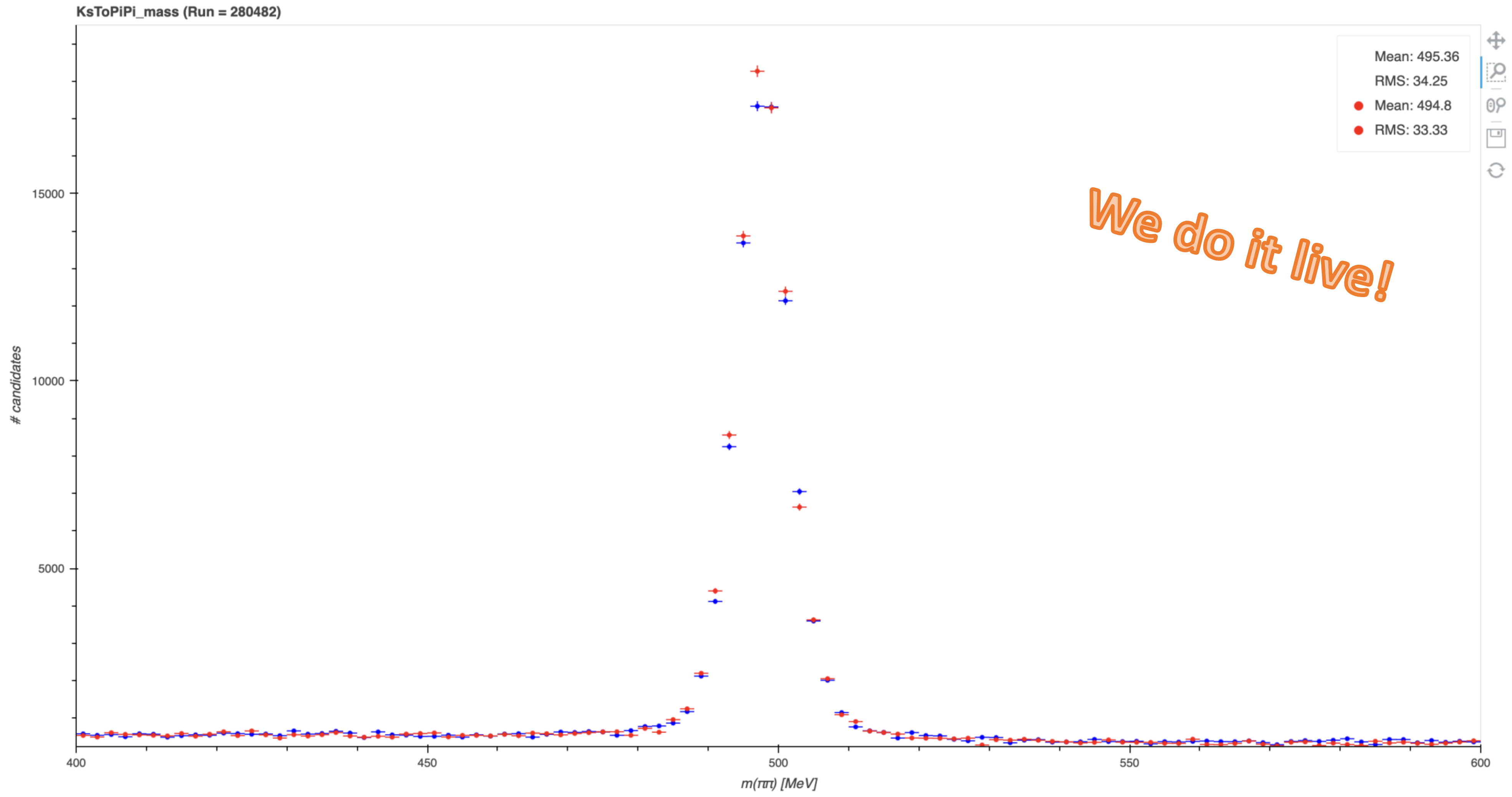




Real Time Monitoring (SciFi)!



Real Time Monitoring (RTA)

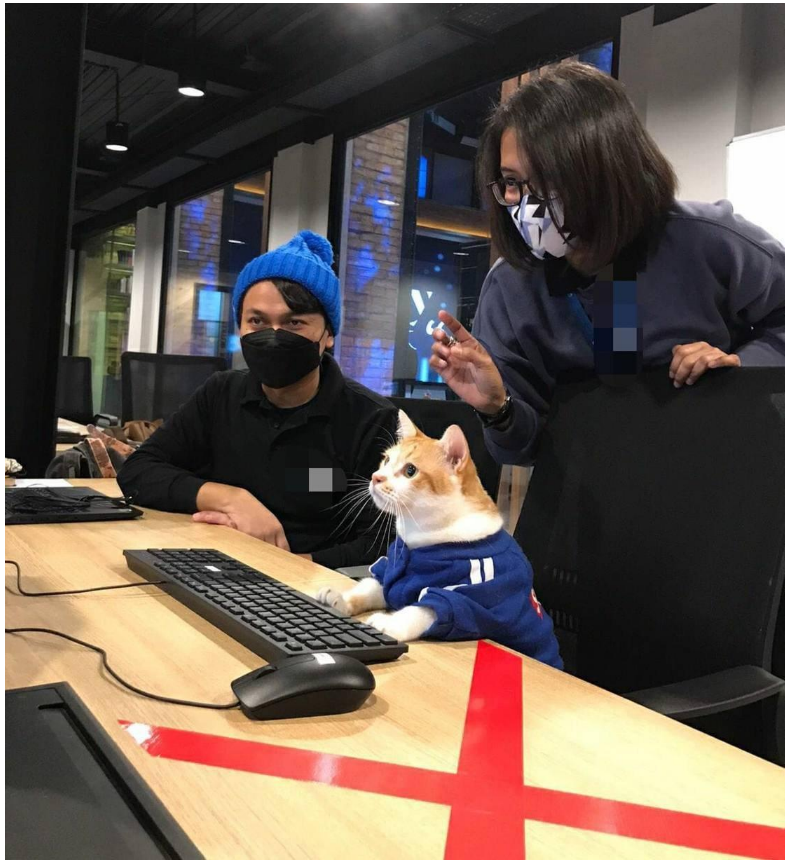


The sales pitch (Supporting Run 3)

- If we want to make the most of data taking we need the support of the whole collaboration!

- Shifters make up the heart of the LHCb
  - This includes roles such as **Shift Leader (must be prepared to push buttons)**
  - The Data manager, who monitors the quality of data live!
  - And the 24/7 piquet roles rotated across sub systems in case there's a specific issue!

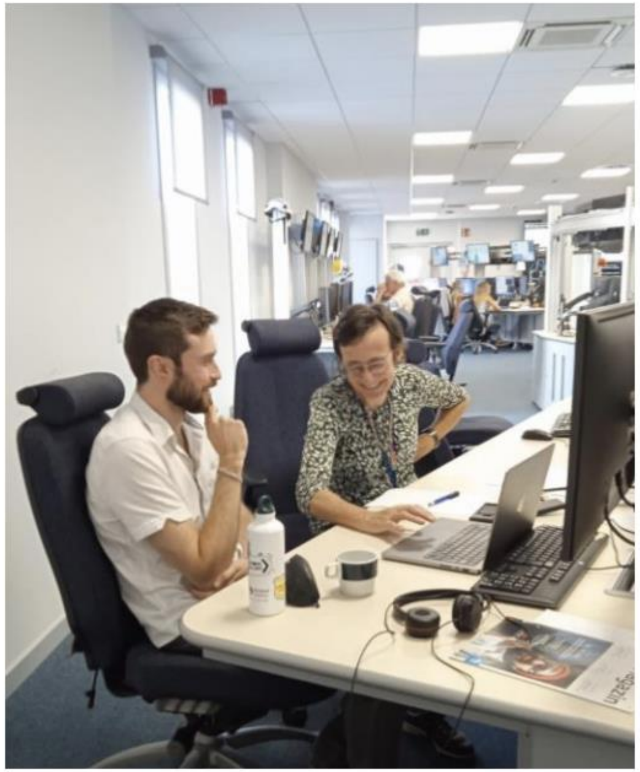
- There's no quota's and it's completely voluntary. But great fun, you get to learn a lot starting up and no existing technical expertise required!



Miw-on Piquet

Closing thoughts

VELO operations is fun



- Although the Upgrade is complete we still need commissioning effort. There's plenty of opportunity to get involved with performance and commissioning studies!
- Where there's an upgrade there's an **upgrade 2**. For high luminosity we need effort on Mighty Tracker, Torch, 3D silicon tracker R&D. **You** might well define what the future LHCb looks like!