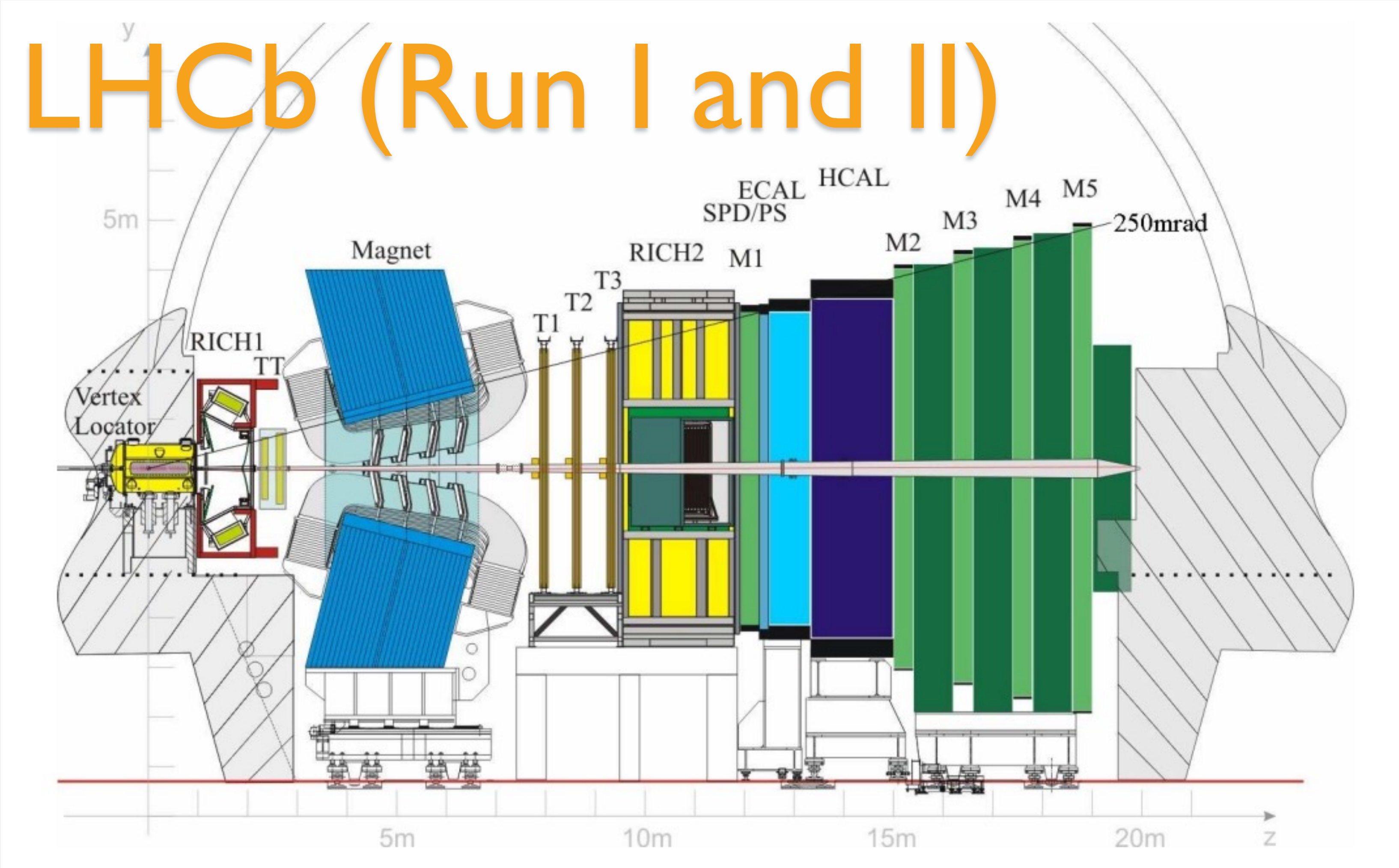
LHCb SILICON VERTEX DETECTOR

Dr. David Friday

TO COME

- What is the LHCb?
- What was the Run I(II) VELO
  - Requirements
  - Technology
  - Performance
- What did the VELO need to become for Run III(IV)?
  - LHCB upgrades?
  - The problem with Luminosity
  - Requirements
  - VELOPIX
  - Geometry
  - Cooling
  - Predicted Performance

WELCOME TO THE LHCb



- Forward-facing spectrometer designed to study CP violation in *pp* collision
- Used primarily for charm and beauty physics
- Fully reconstructs events using a high granularity silicon tracker (VELO) with and downstream tracking and Cherenkov PID

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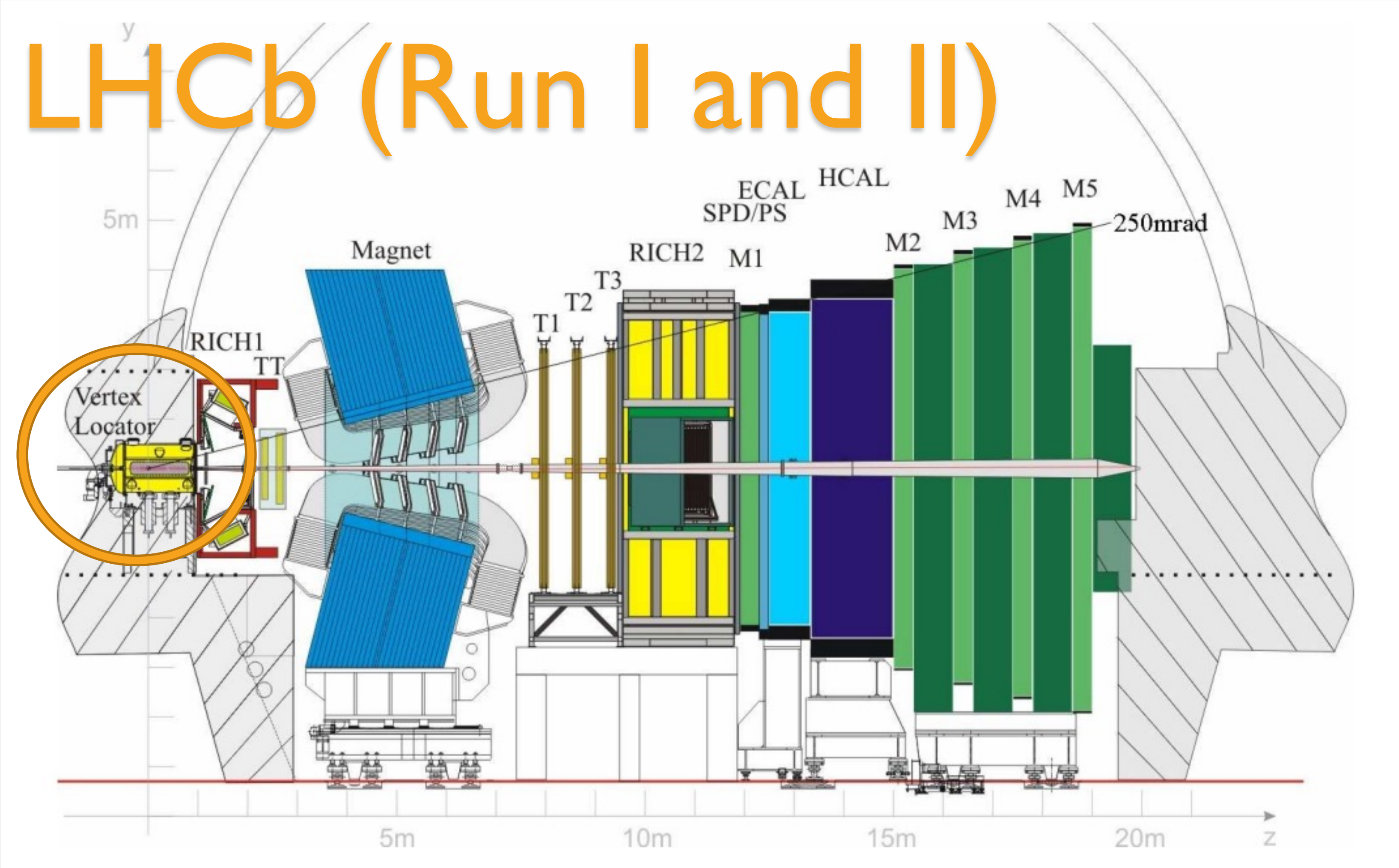

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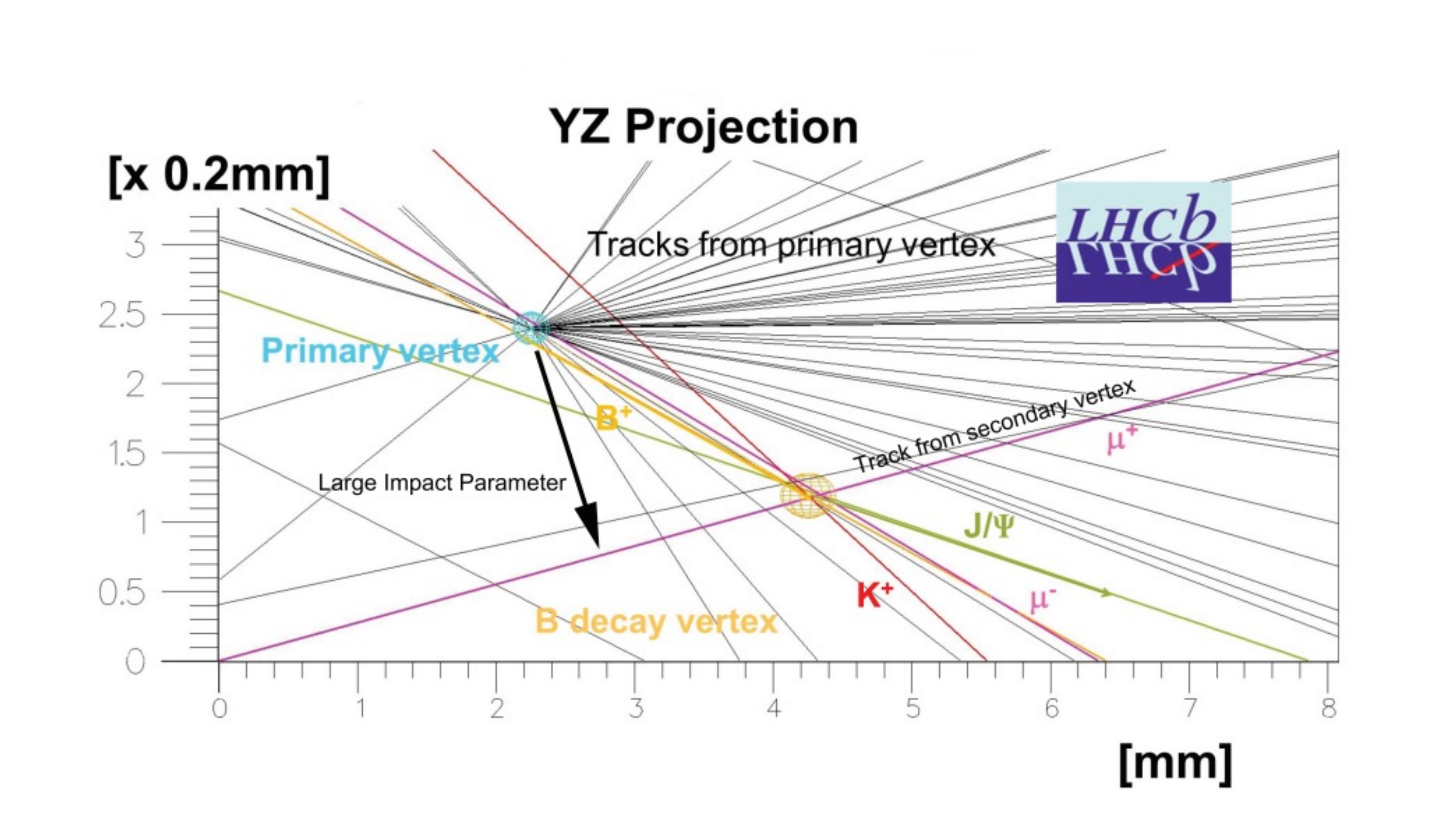
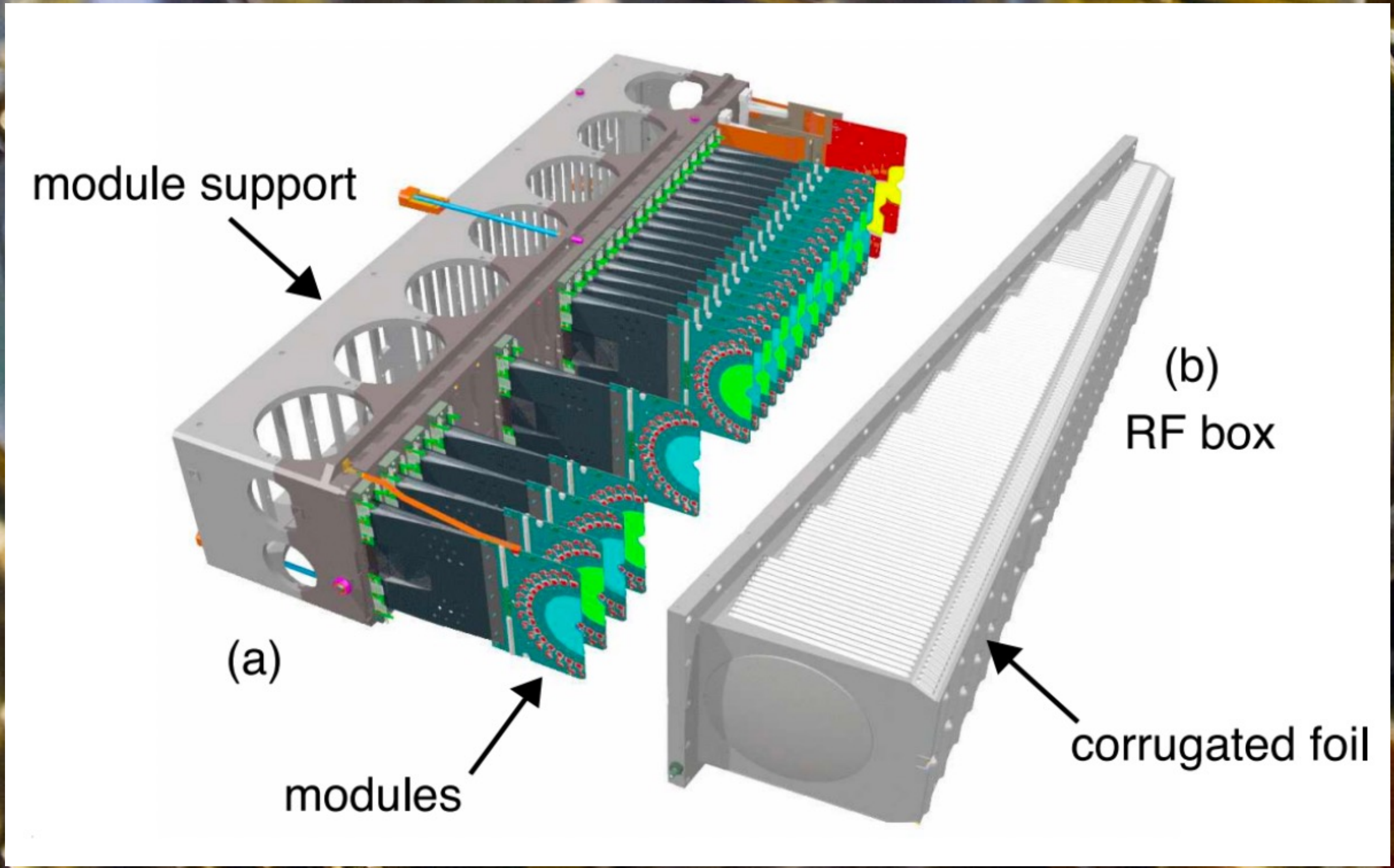
RUN I AND II VELO (A SUMMARY)

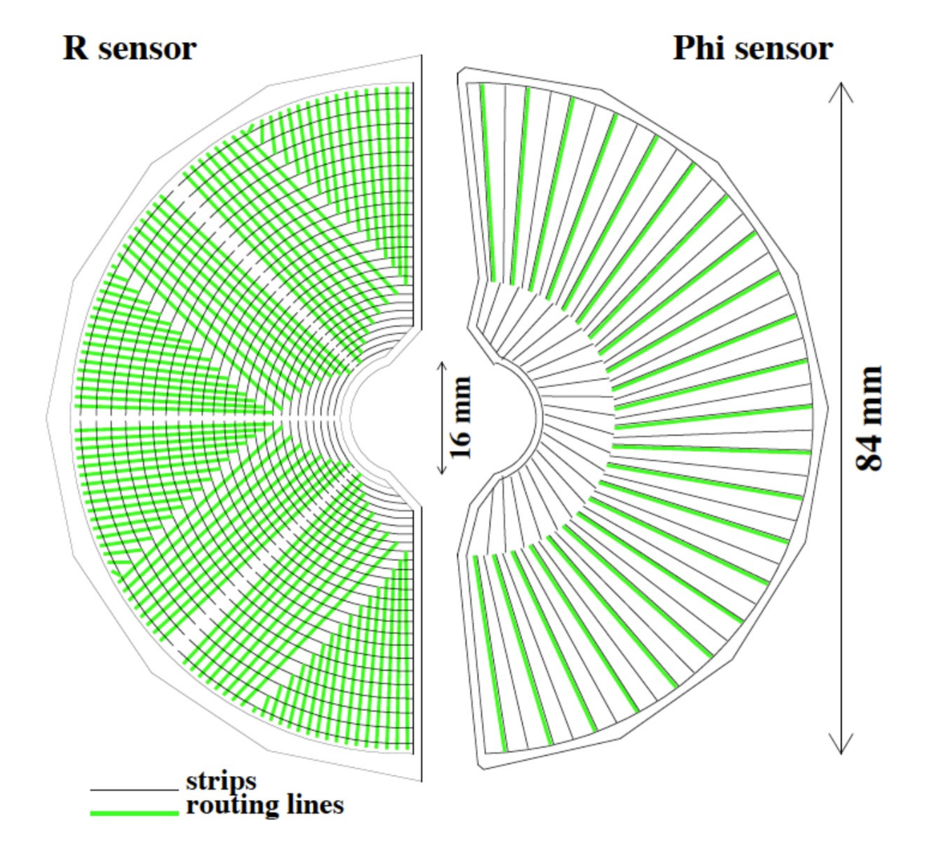
TYPICAL LHCb EVENT



RUN I AND II VELO (A SUMMARY)



RUN I AND II VELO (A SUMMARY)

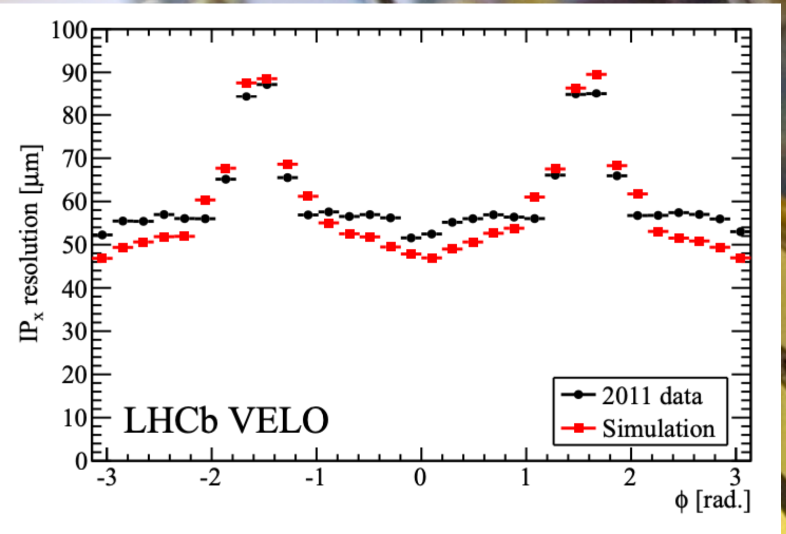


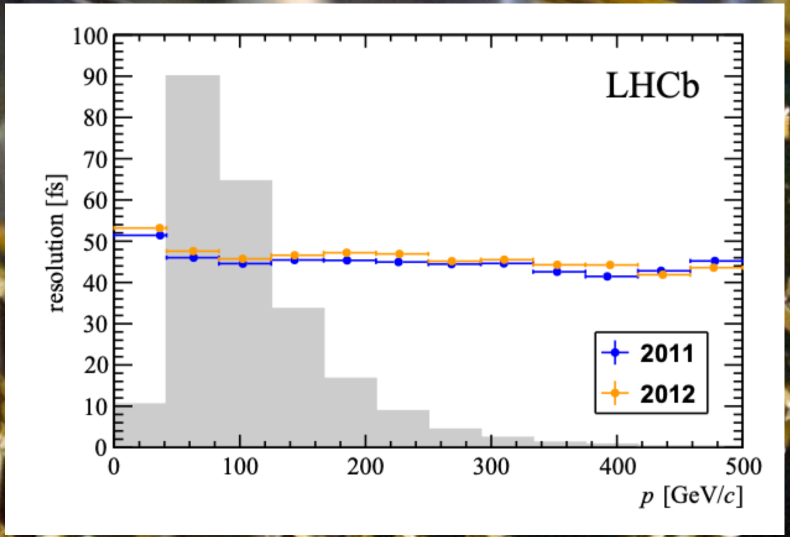
- Oxygenated n^+-on-n sensors with a p+ backplate for radiation tolerance.
- 1.1 MHz readout rate.
- First active component 8.2 mm from the beamline when closed .

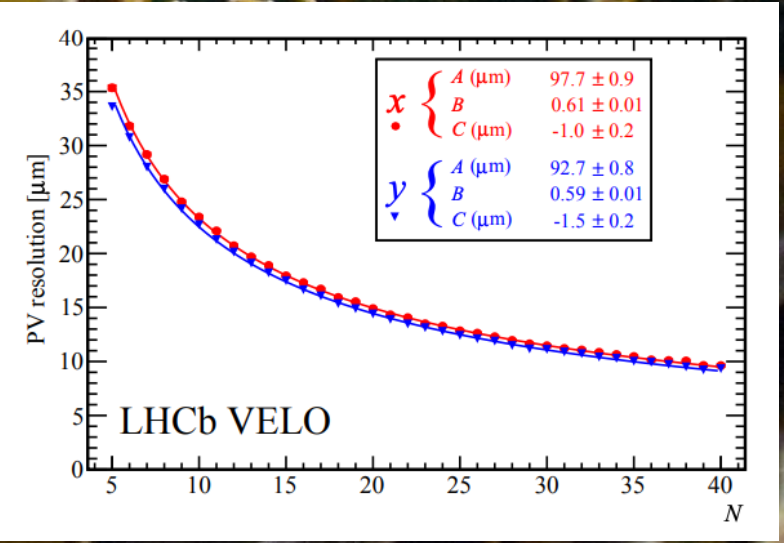
number of stations	25
position of first station upstream	-17.5 cm
position of last station downstream	75 cm
total area of silicon	$0.32\,\mathrm{m}^2$
total number of channels	204, 800
radiation level at 8 mm	$(0.5 - 1.3) \times 10^{14}\ n_{\mathrm{eq}}/\mathrm{cm}^2$ per year
radiation level at 50 mm	240 kRad/year
power dissipation	< 1.5 kW
dimensions of the vacuum vessel (length × Ø)	1.8 m × 1 m

Table 1.1: Global parameters of the VELO system.

RUN I AND II VELO (A SUMMARY)







- Good vertex resolution with increased track multiplicity (13μm transverse, 71μm beam axis, 25 tracks)
- Stable decay time resolution of 25 fs across momentum range
- Dependence on RF foil location can se seen in the IP resolution
- Track reconstruction quality allowed for excellent alignment (< 5μm disagreement)

UPGRADE 1 LHCb

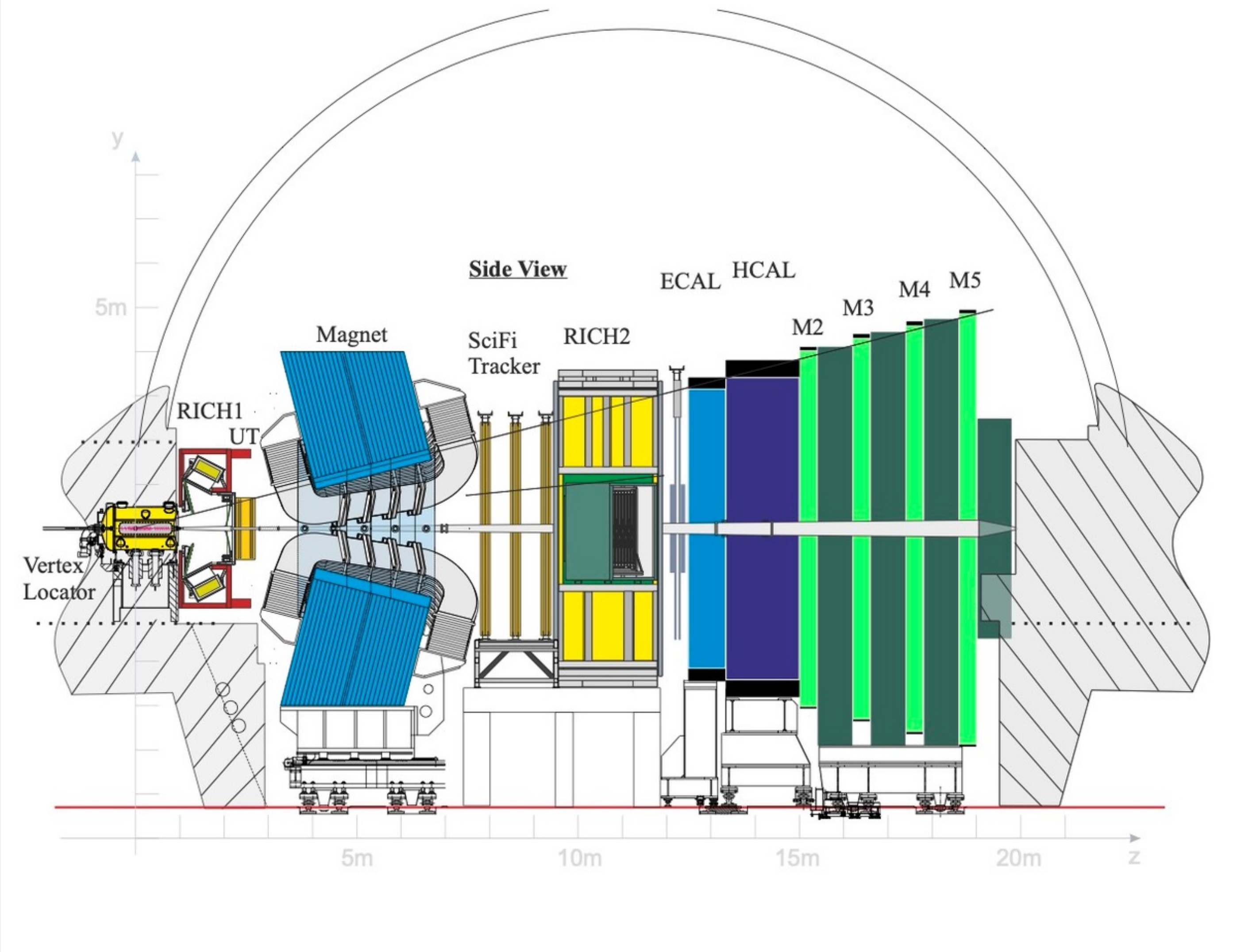


Table 1: Overview of global upgrade settings for simulation.

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	$2 \times 10^{33}\,\text{cm}^{-2}\,\text{s}^{-1}$
Bunch charge	1.2×10^{11} protons
ν (# interactions per crossing)	7.6 (for $\sigma_{\text{tot}} = 102.5\,\text{mb}$)
μ (# visible interactions per crossing)	5.2 (for $\sigma_{\text{vis}} = 70.6\,\text{mb}$)
Bunch x,y RMS	37.70 µm
z RMS luminous region σ_{lumi}	63 mm

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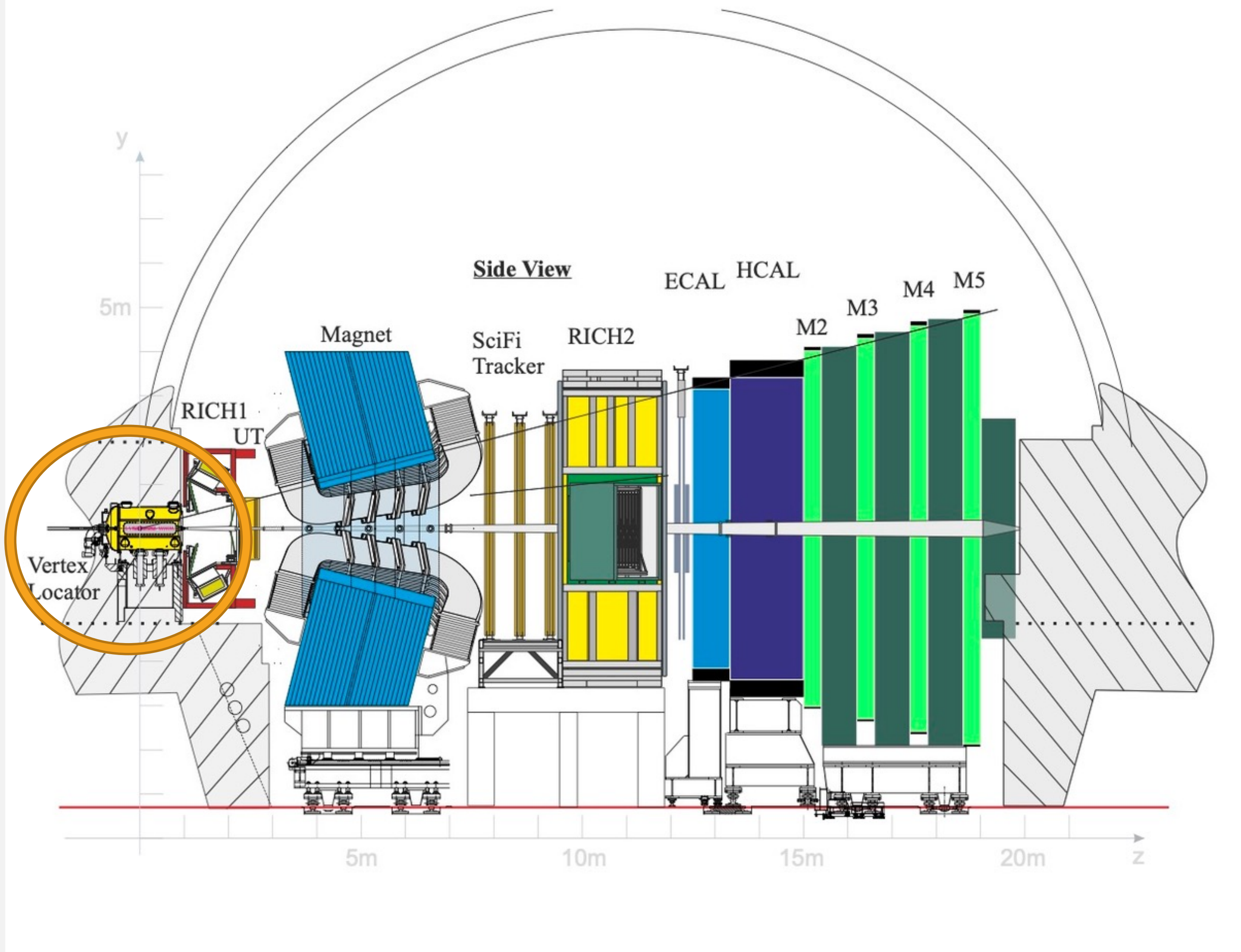

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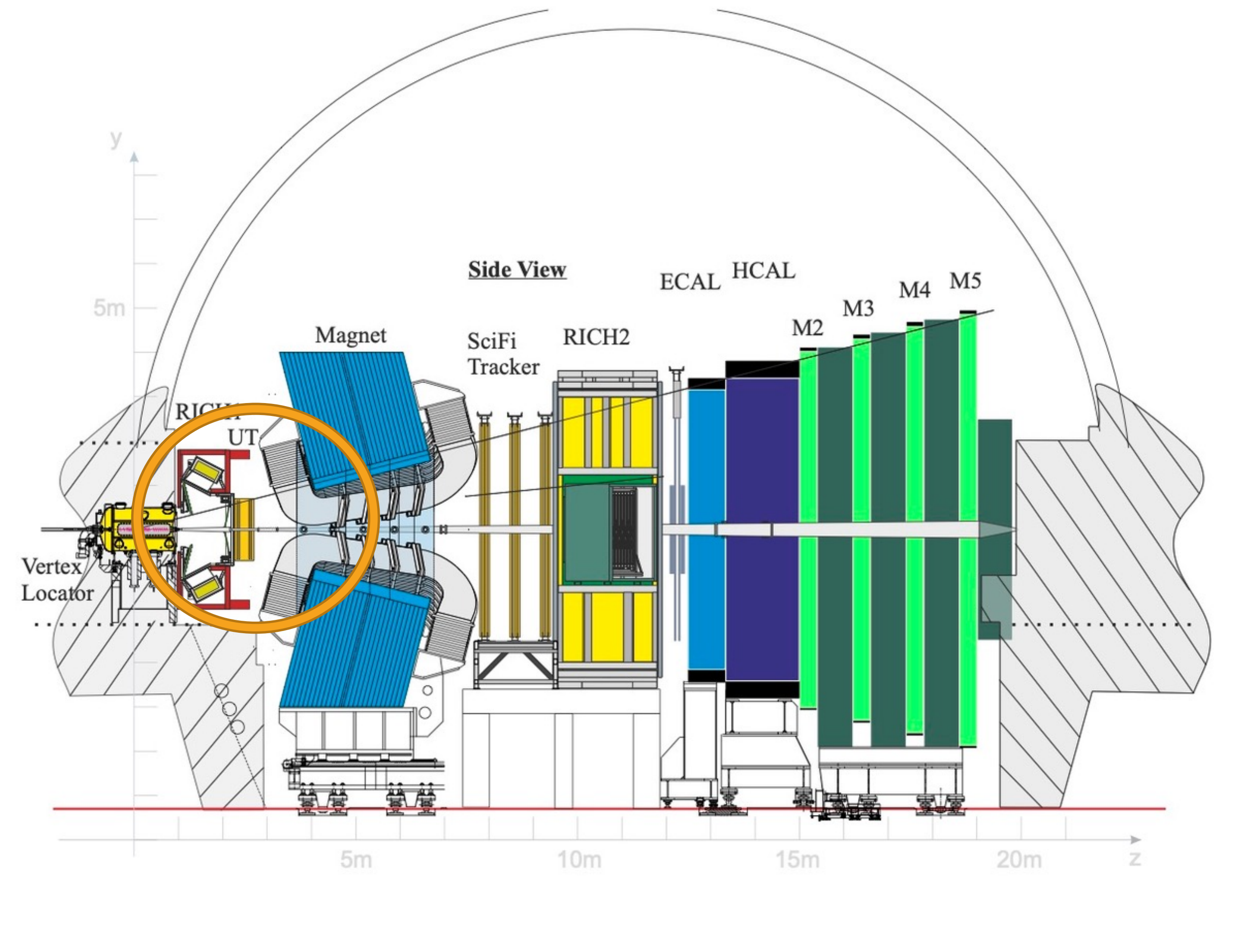
UPGRADE 1 LHCb

- New VELO
- New Upstream Tracker (UT)



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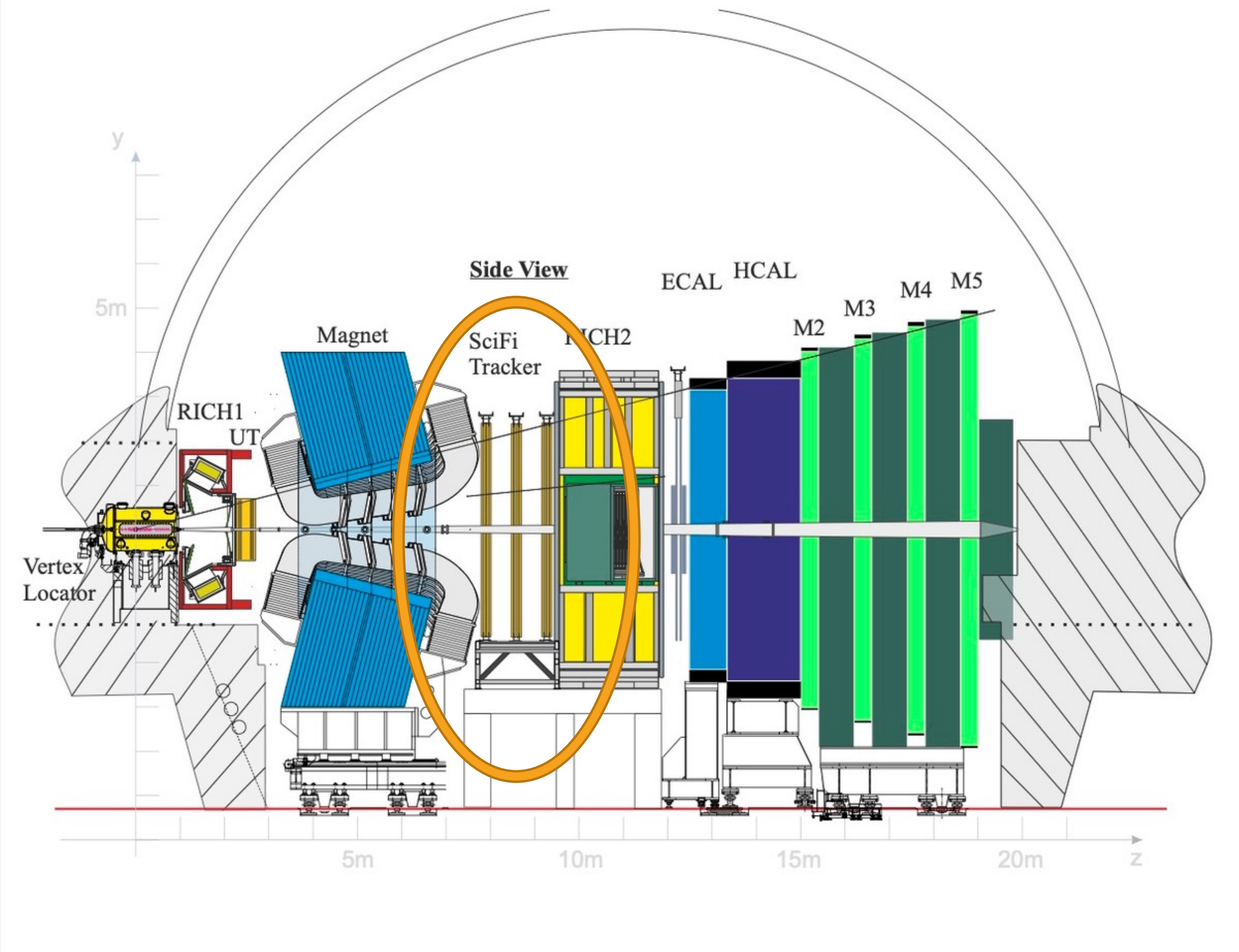

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- New Upstream Tracker (UT)
- New Scintillating Fiber Tracker (SciFi)

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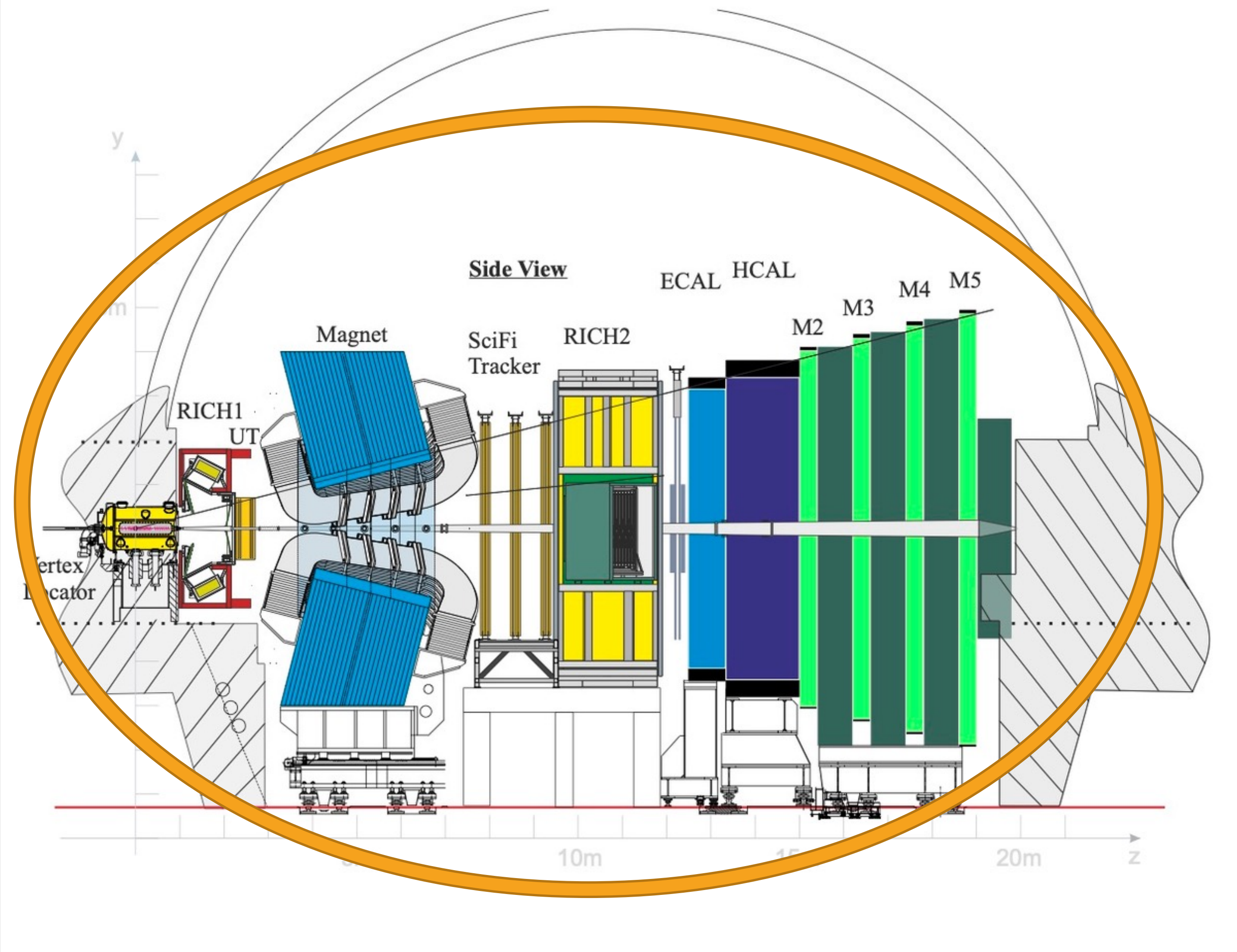
UPGRADE I LHCb



- New VELO
- New Upstream Tracker (UT)
- New Scintillating Fiber Tracker (SciFi)
- New Software ONLY trigger

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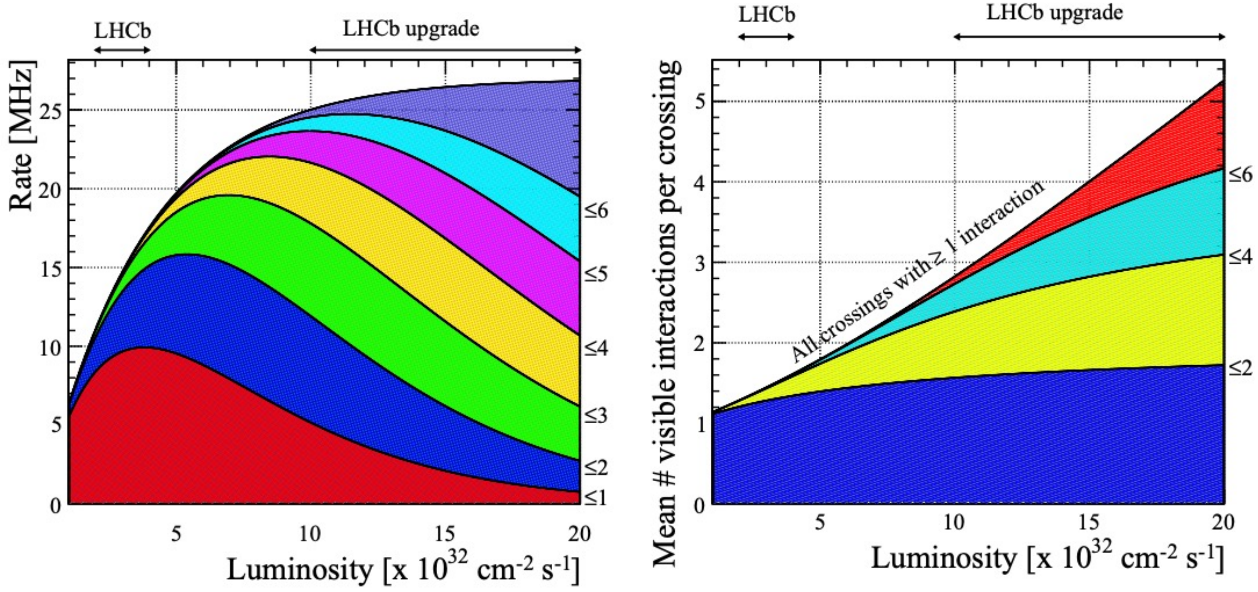
LUMINOSITY



- With increased luminosity we will see increased challenges related to readout rate.
- Increased luminosity also drives an increase in multiplicity!

VELO SPECIFICATION (ENVIRONMENTAL AND MECHANICAL)

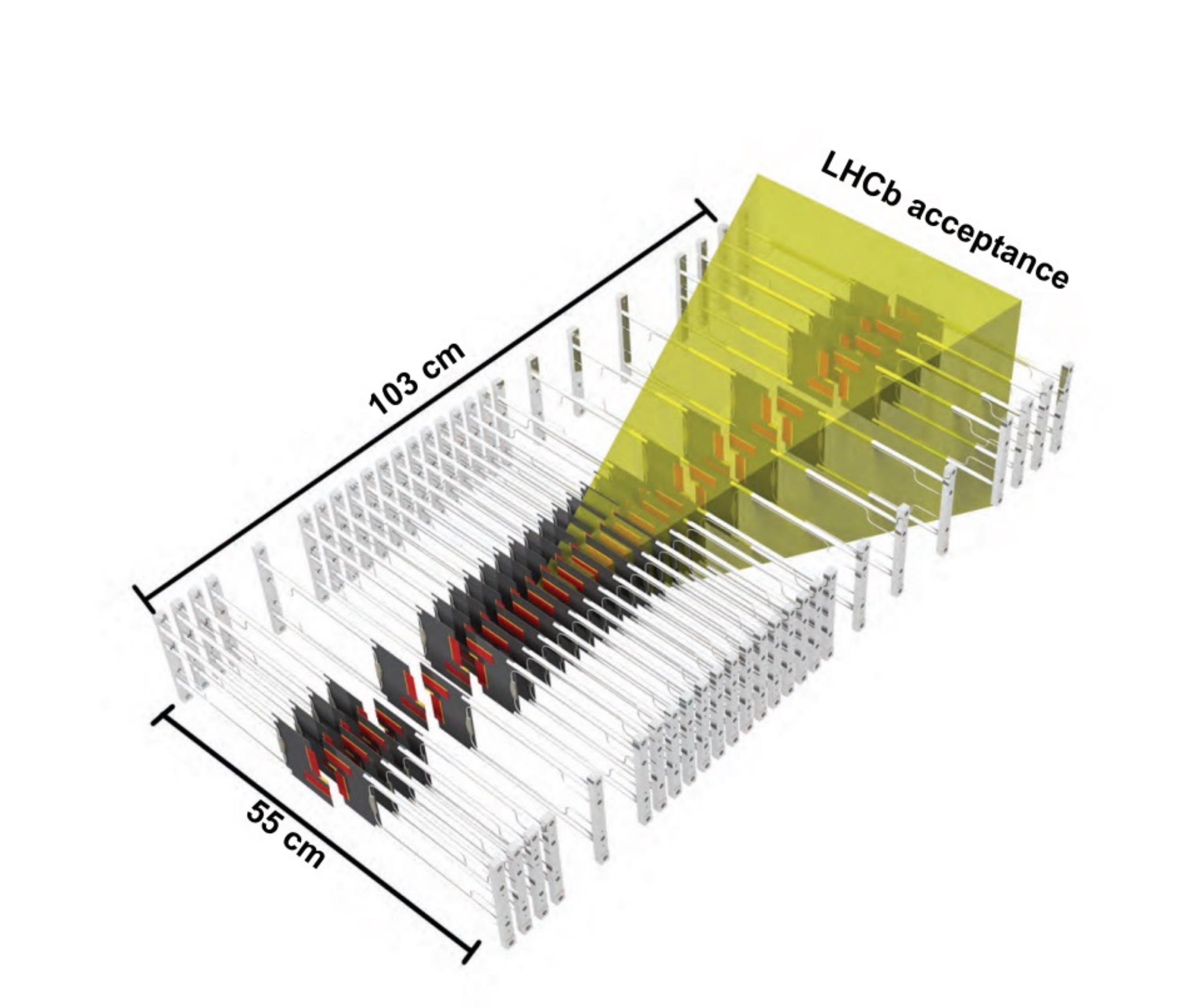
- Radiation tolerance is a vital consideration in the design and operation of the detector. n_{eq} increasing by order 10.
- Maintaining VELO acceptance vital for physics insight! Both in angular coverage and geometric efficiency.
- Efficient cooling, both for sensor performance and radiation tolerance.

Global parameters	
Radiation tolerance	8×10^{15} 1 MeV n_{eq}/cm^2 at tip
HV tolerance	1000 V
Radiation length	IP resolution as good as current VELO
Outgassing per module	$< 5 \times 10^{-6}$ mbar·l/s
Silicon temperature	< -20°C for $T_{coolant} = -40$°C
Operational temperature range	-40°C to 40°C
Max. ASIC power consumption	3 W × 12 pixel ASICs
Max. total power consumption	< 1000 W per side
Module layout parameters	
Max. dimensions per half	275 mm (height) × 180 mm (width) 1.2 m (length)
Angular coverage	$2 \leq \eta \leq 5$ at $\sigma_{lumi} = 63$ mm
Number of hits per track	≥ 4 for >99% of tracks
Geometrical efficiency	> 99% for $R \leq 10$ mm
Overlap	Design to include tracks passing from A to C sides
Station pitch	> 24 mm
General mechanical parameters	
Mechanical deformations	< 20 μm in x, y < 100 μm in z
Mounting precision	Tolerance of < 100 μm in z, allow overclosure
Module shape	Impose on foil minimum radius of curvature of 2 mm

LHCb ACCEPTANCE

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



VELOPIX

- VELOPIX is closely related to Timepix3.
- 130 nm CMOS technology.
- 55 x 55 pixel size to reach resolution requirements.
- A 40 MHz readout rate.
- Trigger-less binary output to reduce readout.
- Novel Superpixel readout.
- Hits are NOT time stamped. Completely data driven approach.

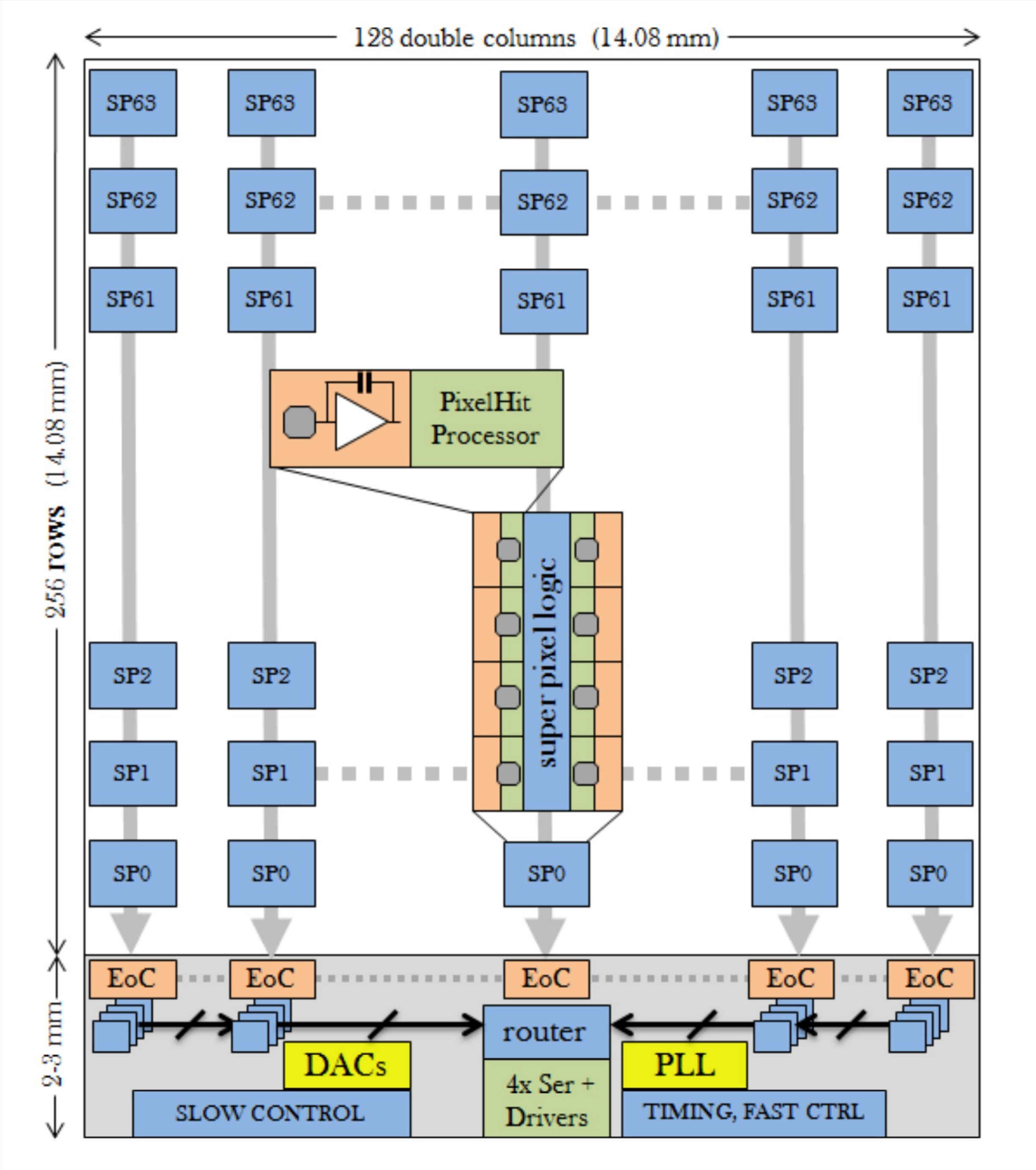
Table 1. Specifications of the VeloPix compared to Timepix3.

Feature	VeloPix	Timepix3
Readout type	Trigger-less, binary	Trigger-less, ToT
Timing resolution, range	25 ns, 9 bits	1.5625 ns, 14 bits
Power consumption	$< 1.5\ W/cm^2$	$< 1\ W/cm^2$
Sensor type	Planar silicon, e^- collection	Various, e^- and h^+ collection
Pixels, pixel size	256×256, $55 \times 55\ \mu m^2$	256×256, $55 \times 55\ \mu m^2$
Radiation hardness	400 Mrad, SEU tolerant	No
Peak hit rate (ASIC, pixel)	900 Mhits/s, 50 khits/s	80 Mhits/s, 1.2 khits/s
# links, total bit rate	4× SLVS, 20.48 Gbps	8× SLVS, 5.12 Gbps
Technology	130 nm CMOS	130 nm CMOS

SUPERPIXELS?

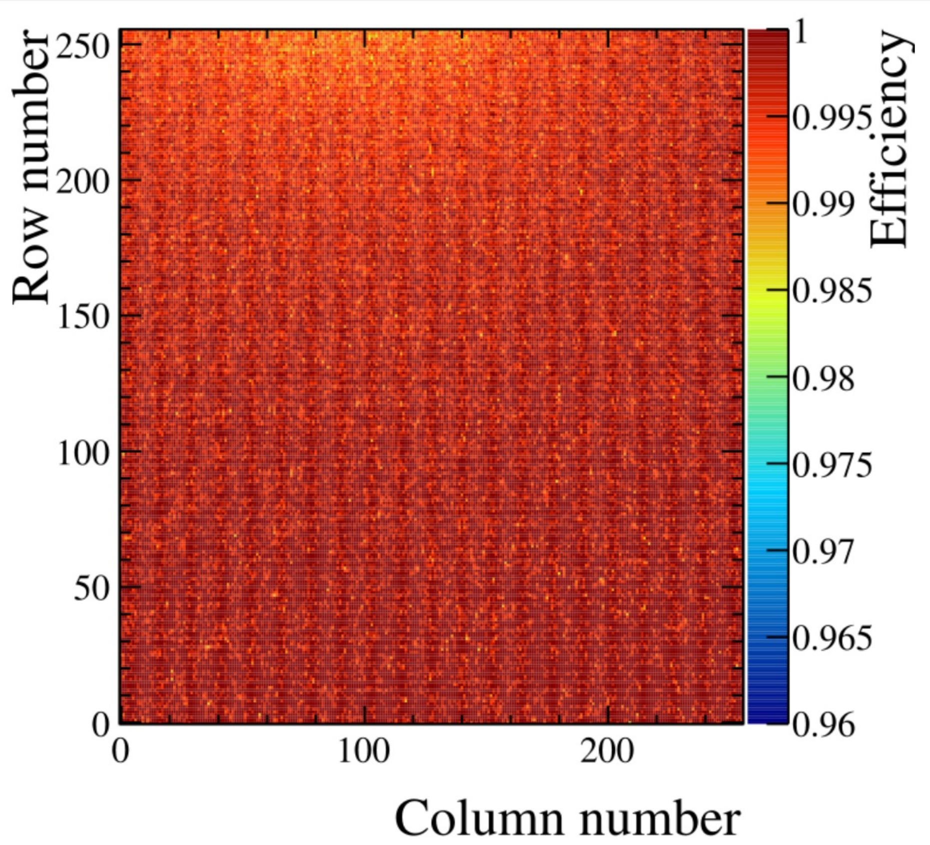
- Each 256 x 256 pixel array contains 64 x 128 Superpixels. This groups pixels in 2 x 4 grids.
- Superpixels are read out in column form, takes 64 clock cycles to fully read out.
- Superpixel packets are only 23 bits.
- 30% reduction in data volume.

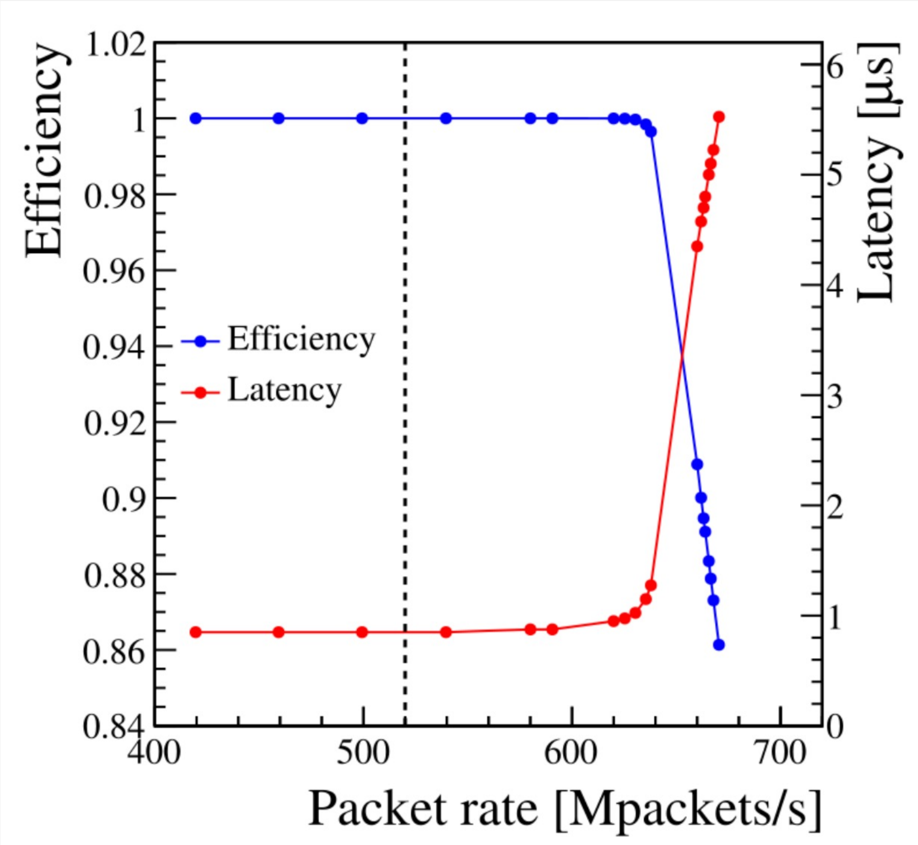
23b SPP	=	6b Address	9b Time Stamp	8b Hitmap

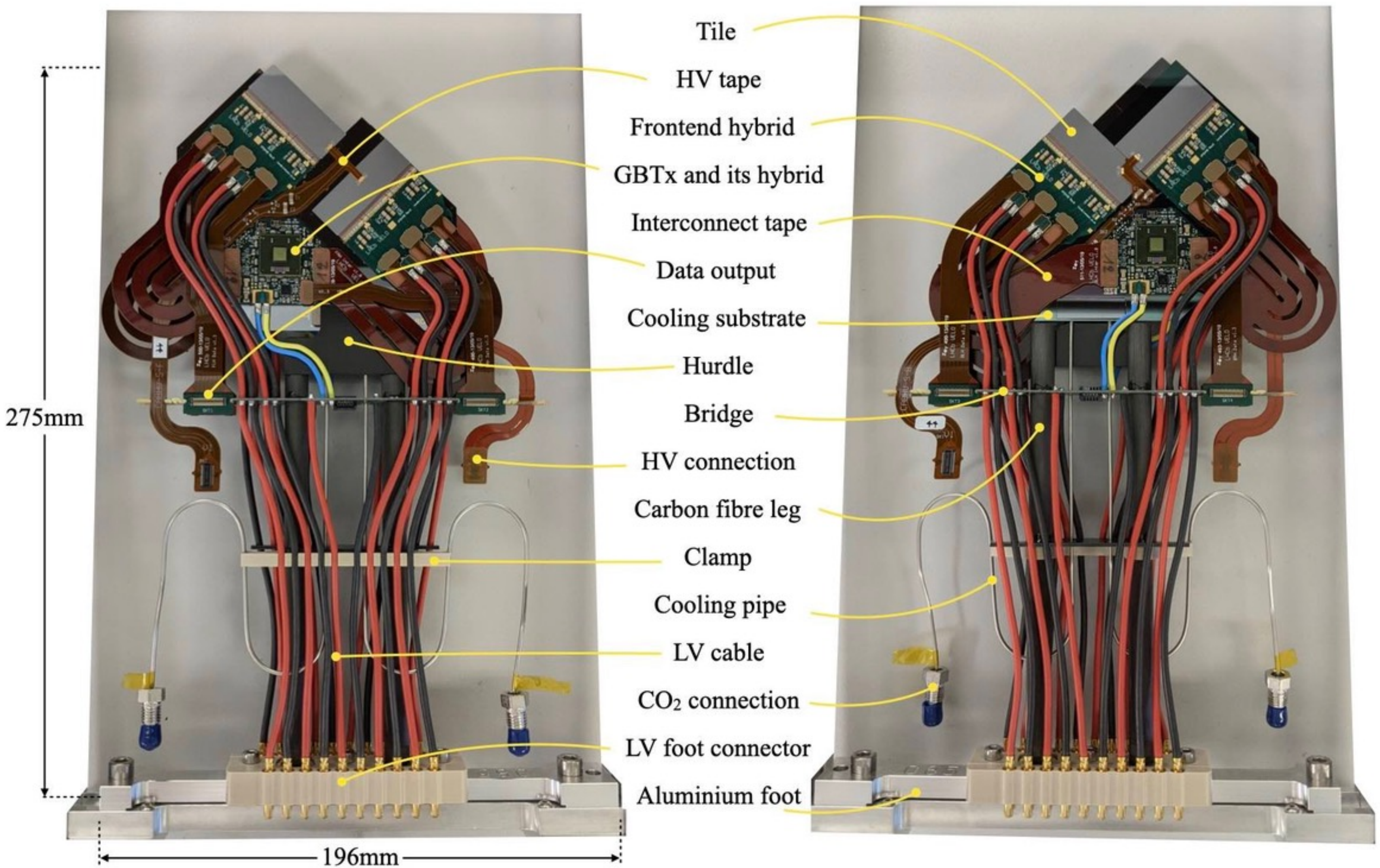


EFFICIENCY (FROM SIMULATION)

- In the hottest ASIC up to 1.6% of data at peak can be lost locally at the top of column.
- Both Latency and Efficiency suffer when maximum bandwidth is exceeded.

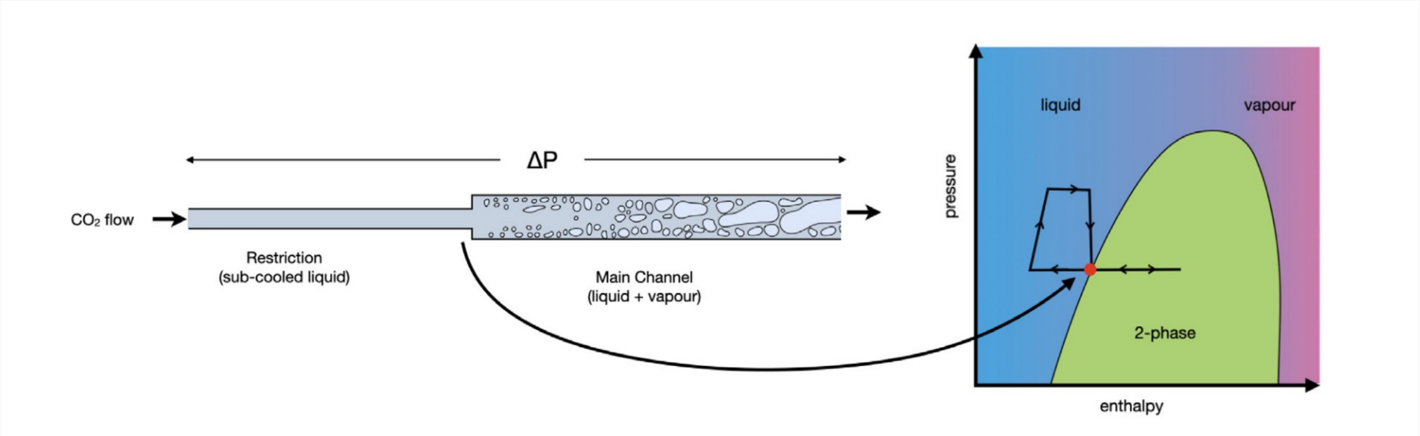


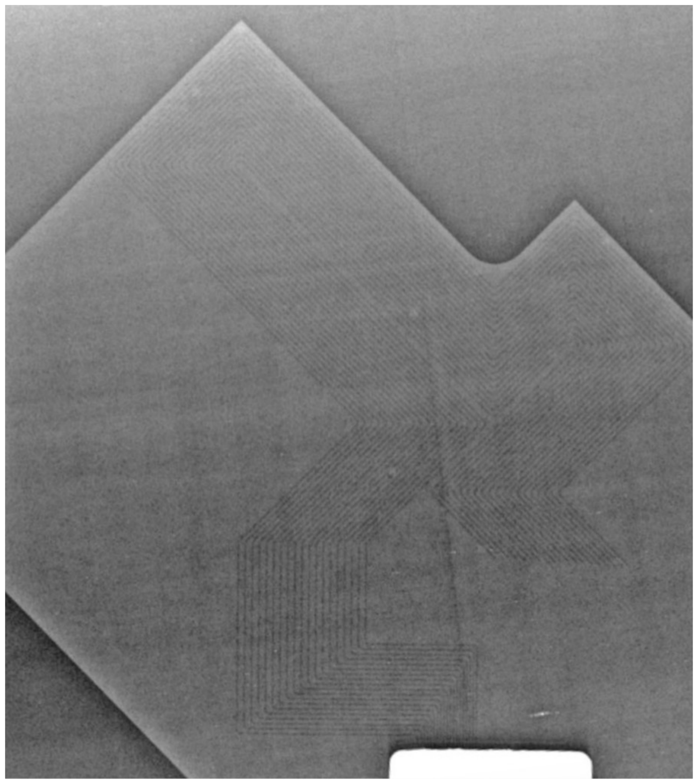


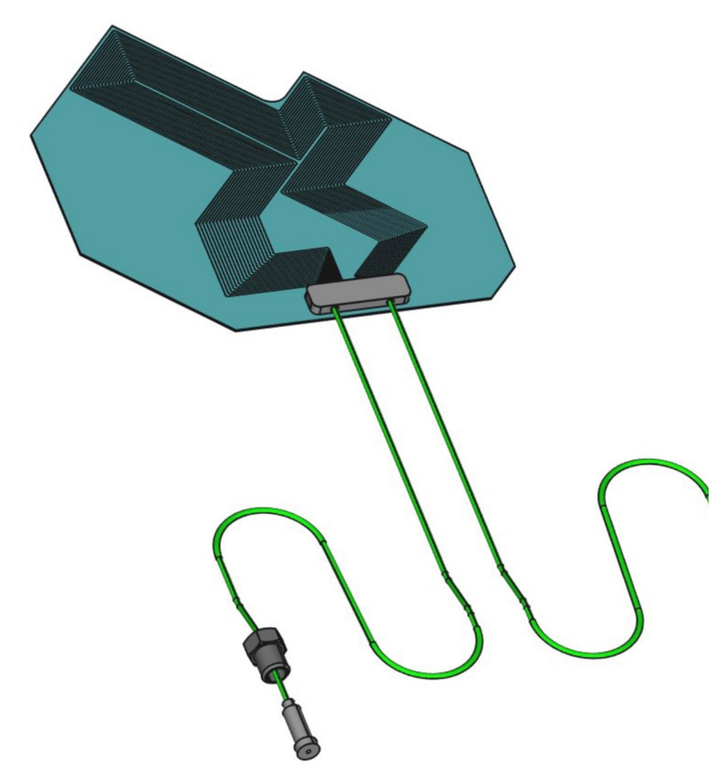

Tile
HV tape
Frontend hybrid
GBTx and its hybrid
Interconnect tape
Data output
Cooling substrate
Hurdle
Bridge
HV connection
Carbon fibre leg
Clamp
Cooling pipe
LV cable
CO_2 connection
LV foot connector
Aluminium foot
275mm
196mm

MICROCHANNEL COOLING

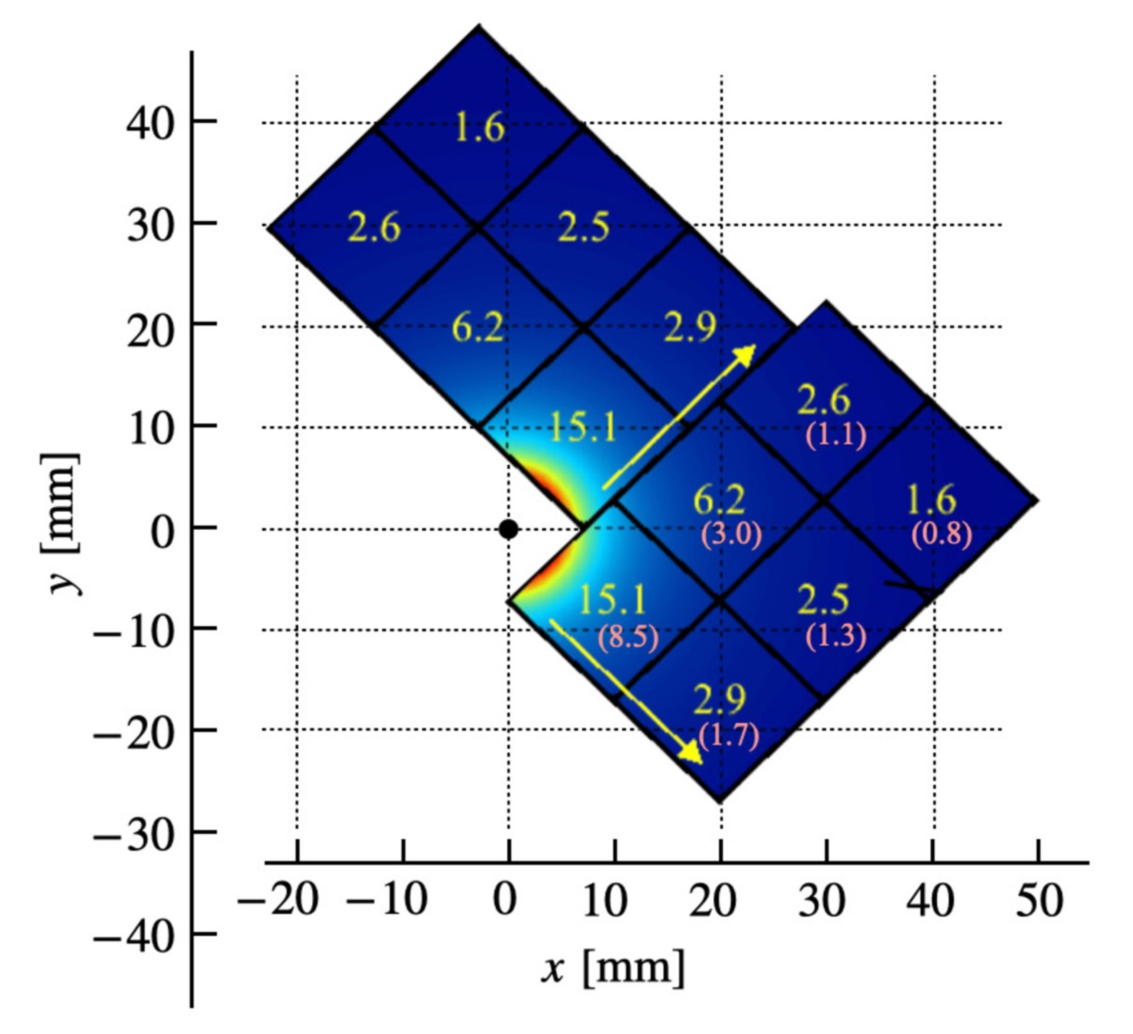
- Cooling system designed to extract 40 W per module (2 kw for the whole VELO!)
- CO_2 evaporative cooling system to maintain operational temperature (below -20).
- Operated at 14 bar at -30 degrees, 62 bar at room temperature and tested up to 187 bar.
- Each module has 20 microchannels with lengths varying from 271mm to 332m.



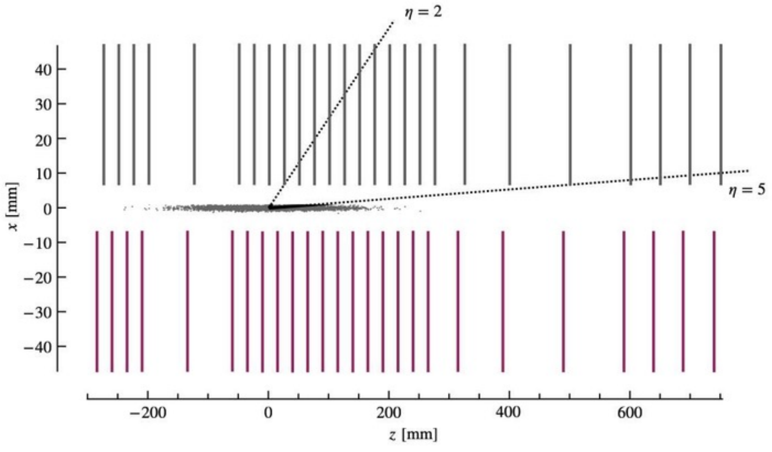


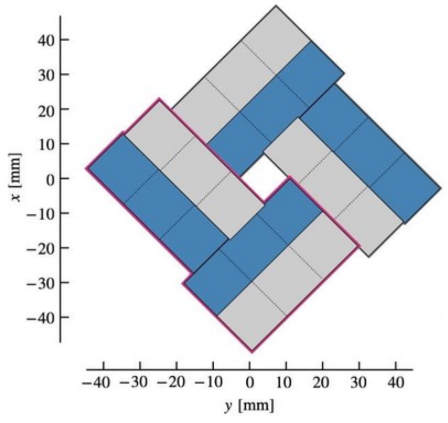


LAYOUT AND OCCUPANCY



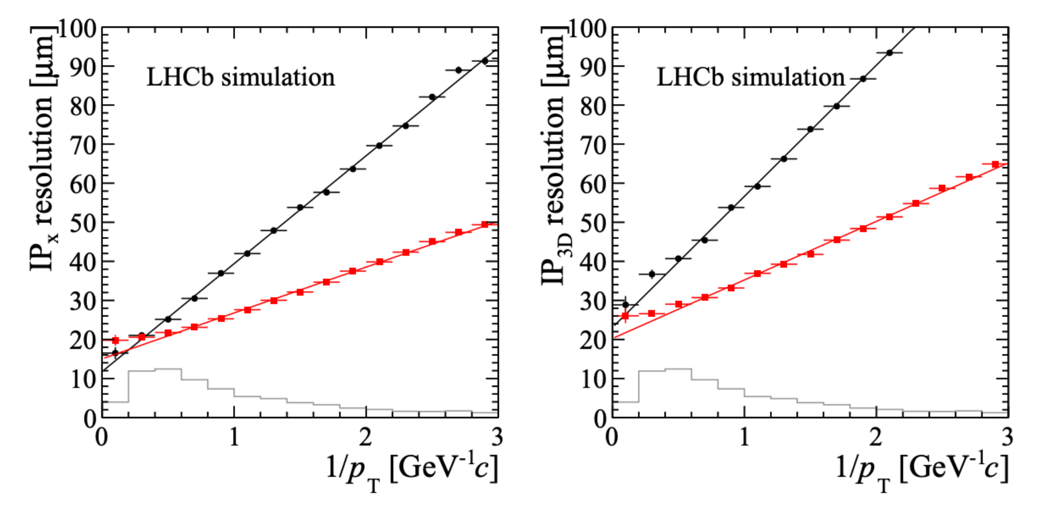
- Rotation is purely for installation.
- Peak readout of 15.1 Gbit/s from simulation.
- Inner and outer sensors spaced for equal occupancy.
- 12.5mm side displacement to provide complete azimuthal coverage.
- Ray tracing used to optimize module position.

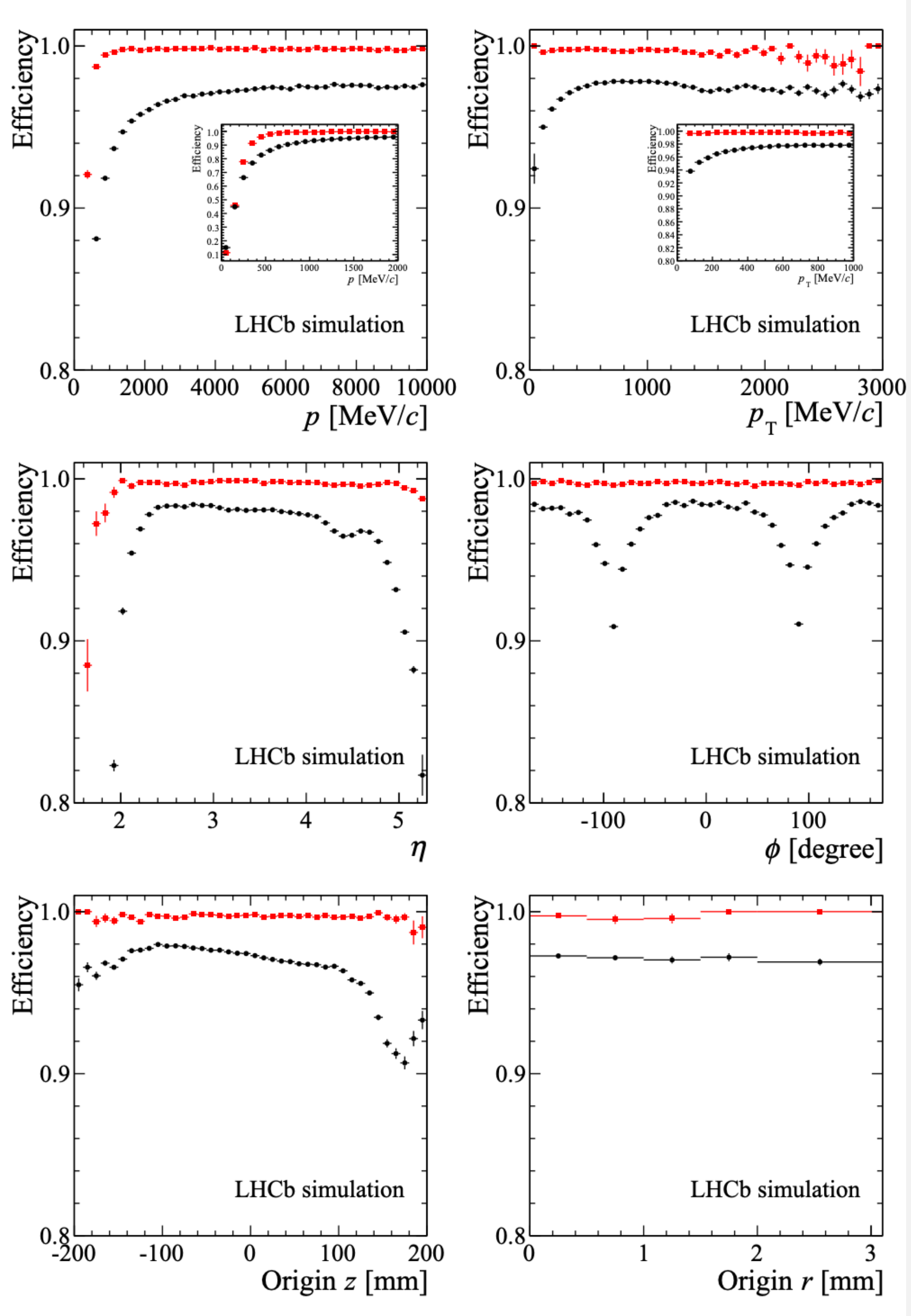




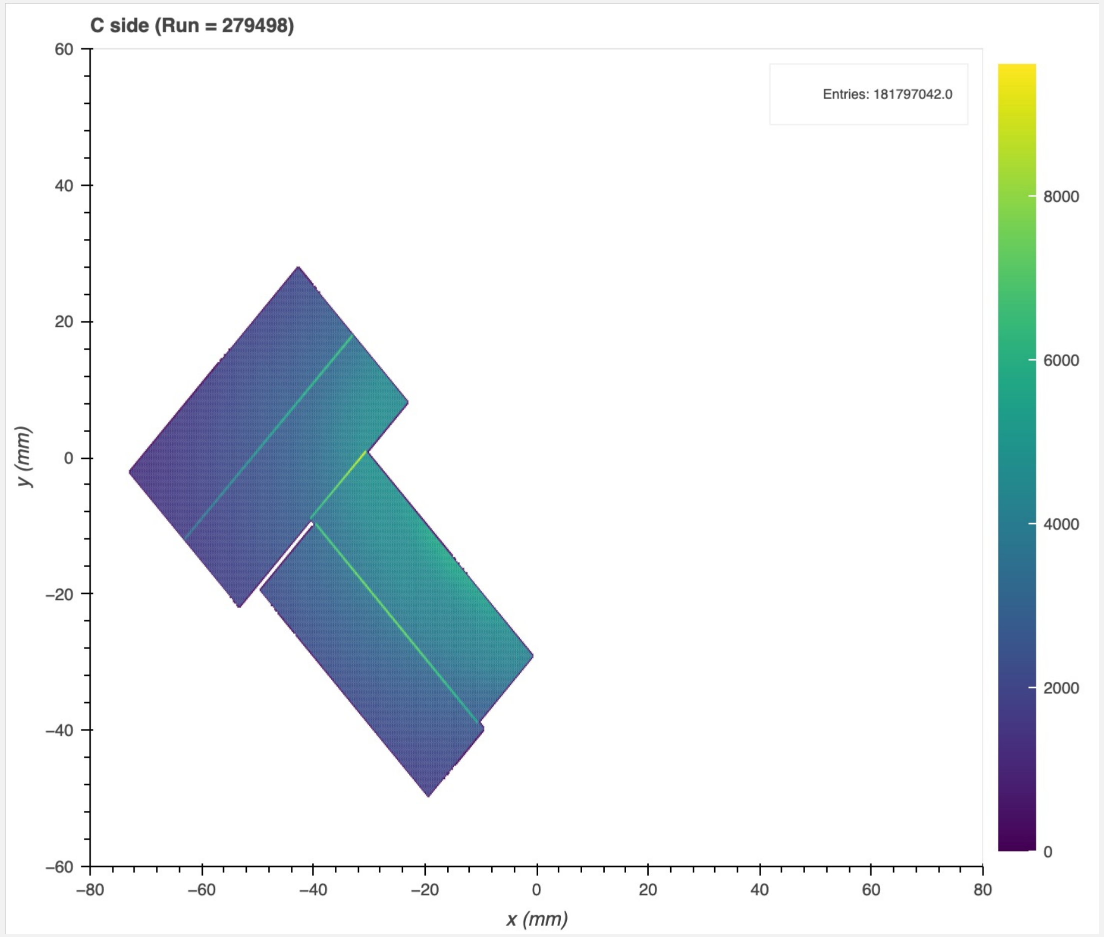
IMPROVEMENTS TO THE EFFICIENCY

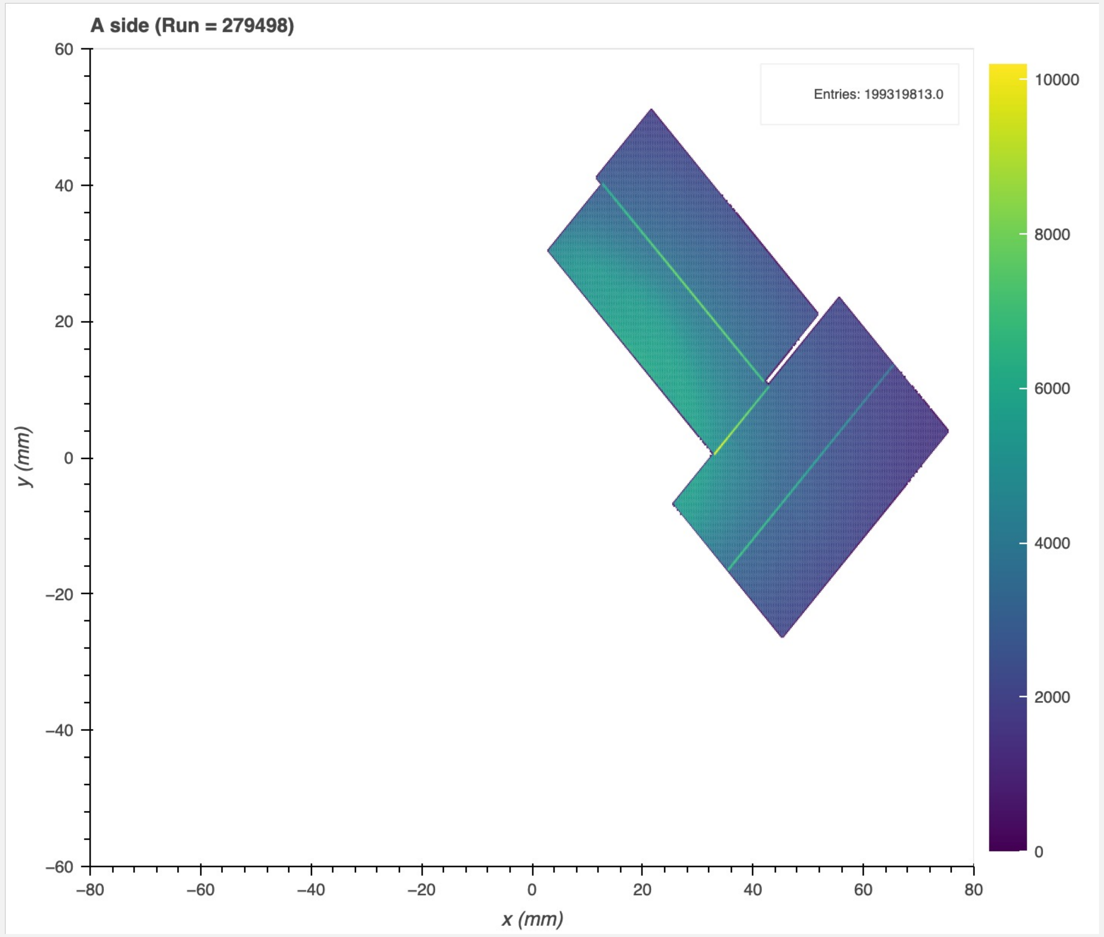
- Compared to the Run 1(II) VELO (black) the efficiency in almost all areas is improved.
- Module and foil overlap far improved seeing an increase in pseudo rapidity and eta.
- Key reconstruction quantities such as IP resolution also see improvement.





CLUSTERING IN RUN 3





SUMMARY

- The VELO contains many novel techniques and technologies that allow it to act as an efficient VERTEX and TRACKING detector.
  - VELOPIX
  - Superpixels
  - Cooling
- The main questions leading into future upgrades are READOUT, RADIATION and RESOLUTION.