LumiTracker

the LHCb Lumi Telescope

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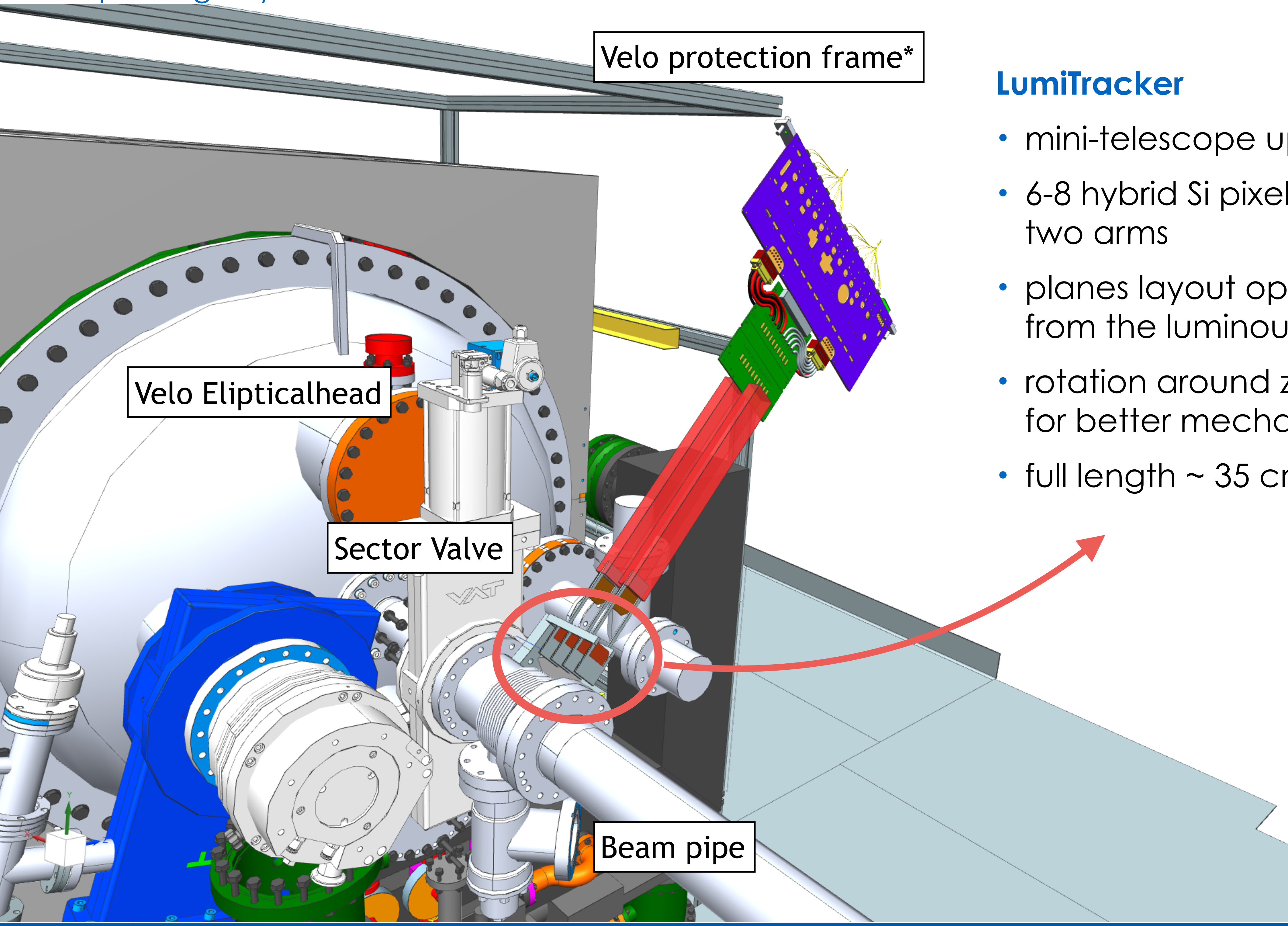
3rd workshop on electromagnetic dipole moments of unstable particles
12/12/2023

The idea

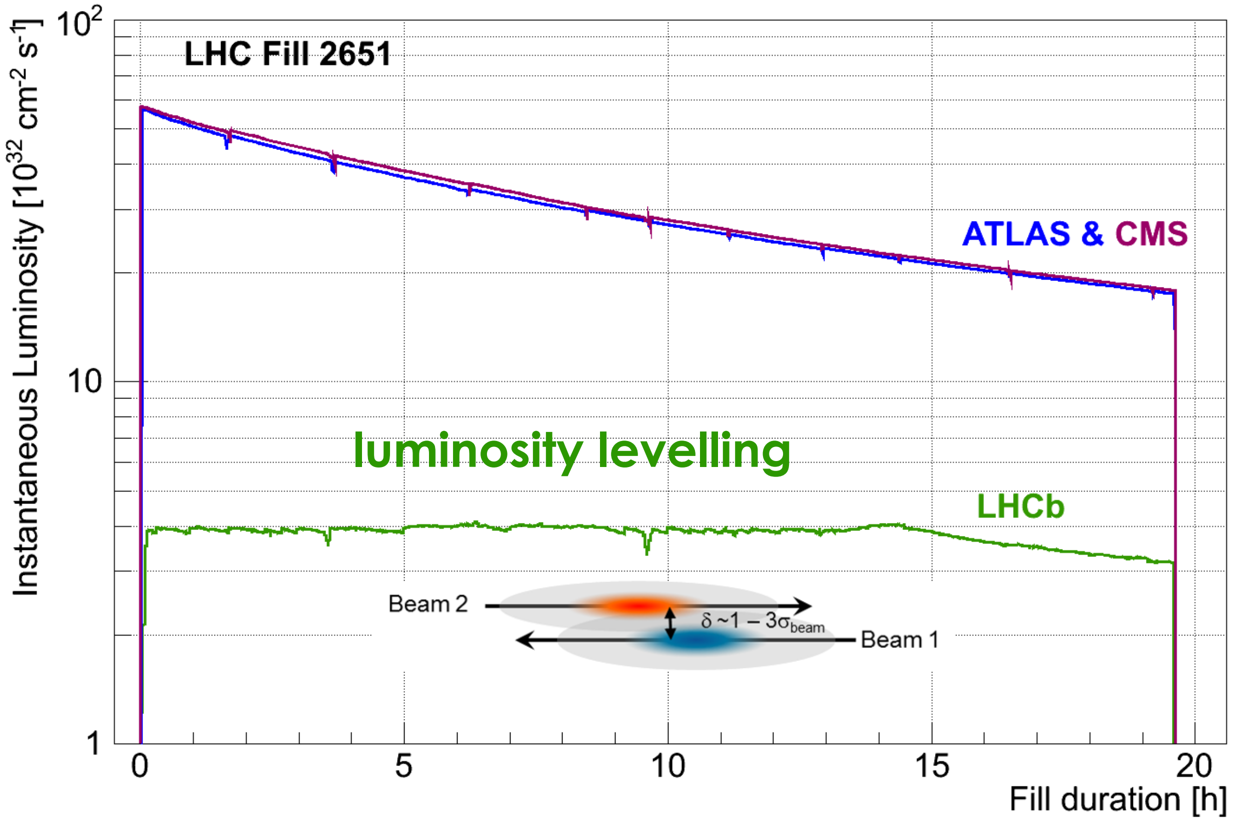
concept design by Freek



LumiTracker

- mini-telescope upstream of the VELO
- 6-8 hybrid Si pixel planes arranged in two arms
- planes layout optimised for tracks from the luminous region
- rotation around z between 30-60 deg for better mechanical integration
- full length ~ 35 cm

The idea: why?



Goal

- provide real-time luminosity measurement per bunch (independently of LHCb)
- luminous region monitoring
- contribute to offline luminosity measurement (integrated in global event stream)

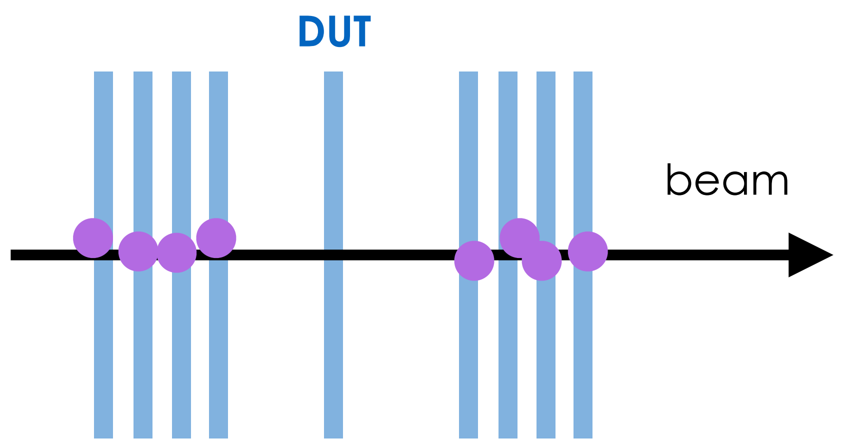
Why?

- luminosity should be provided to the LHC every few seconds (~3s)
- it should be measured with a precision of order 10%
- it should be provided at all times even if LHCb is not taking data or is off
- the measurement should be stable in time
- LHC requires a luminosity measurement per bunch

complementary and providing additional measurement wrt Plume

The idea: why?

beam telescopes
main tool to test and characterise novel sensor technologies reconstructing tracks at high rate

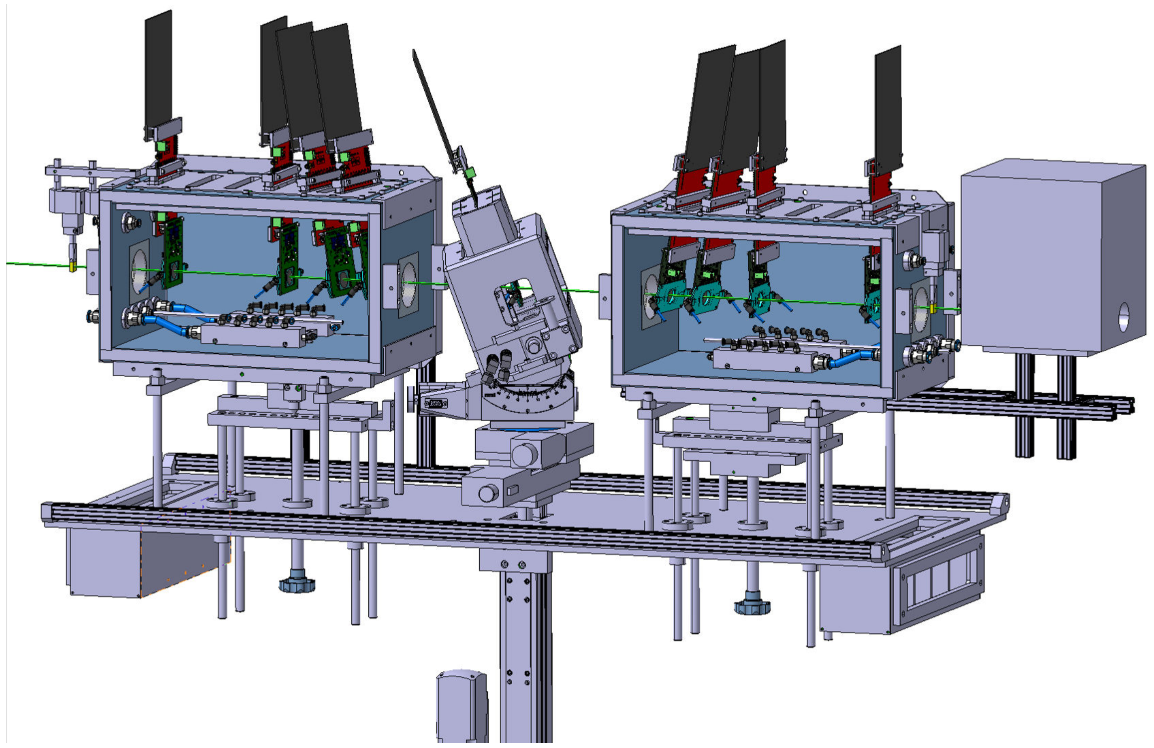


Goal

- use the LumiTracker as a telescope
- a Device Under Test (DUT) could be inserted in the middle of the telescope and replaced at TS
- powerful method to test new sensor + ASIC technologies and corresponding DAQ in LHC conditions

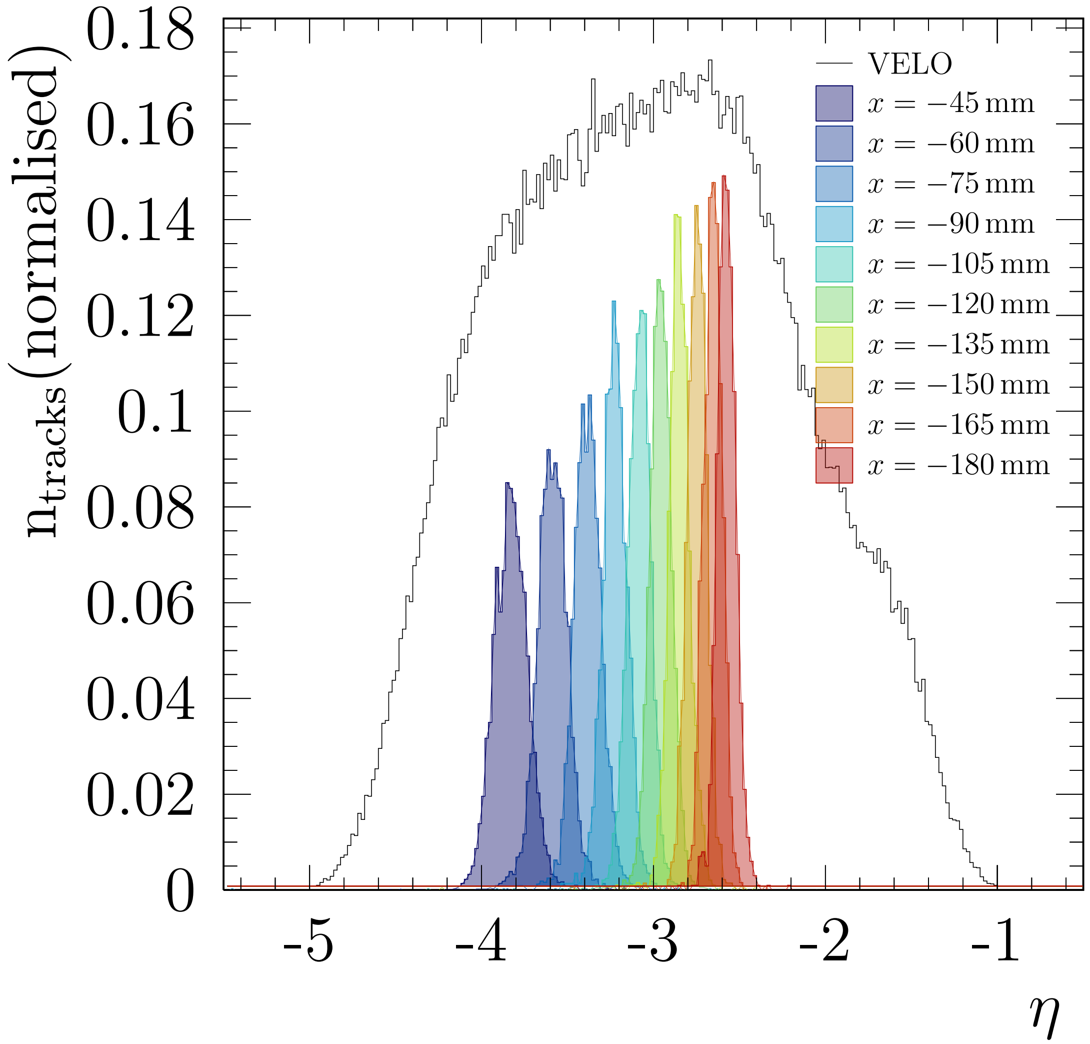
unique opportunity to test DUTs in LHC conditions

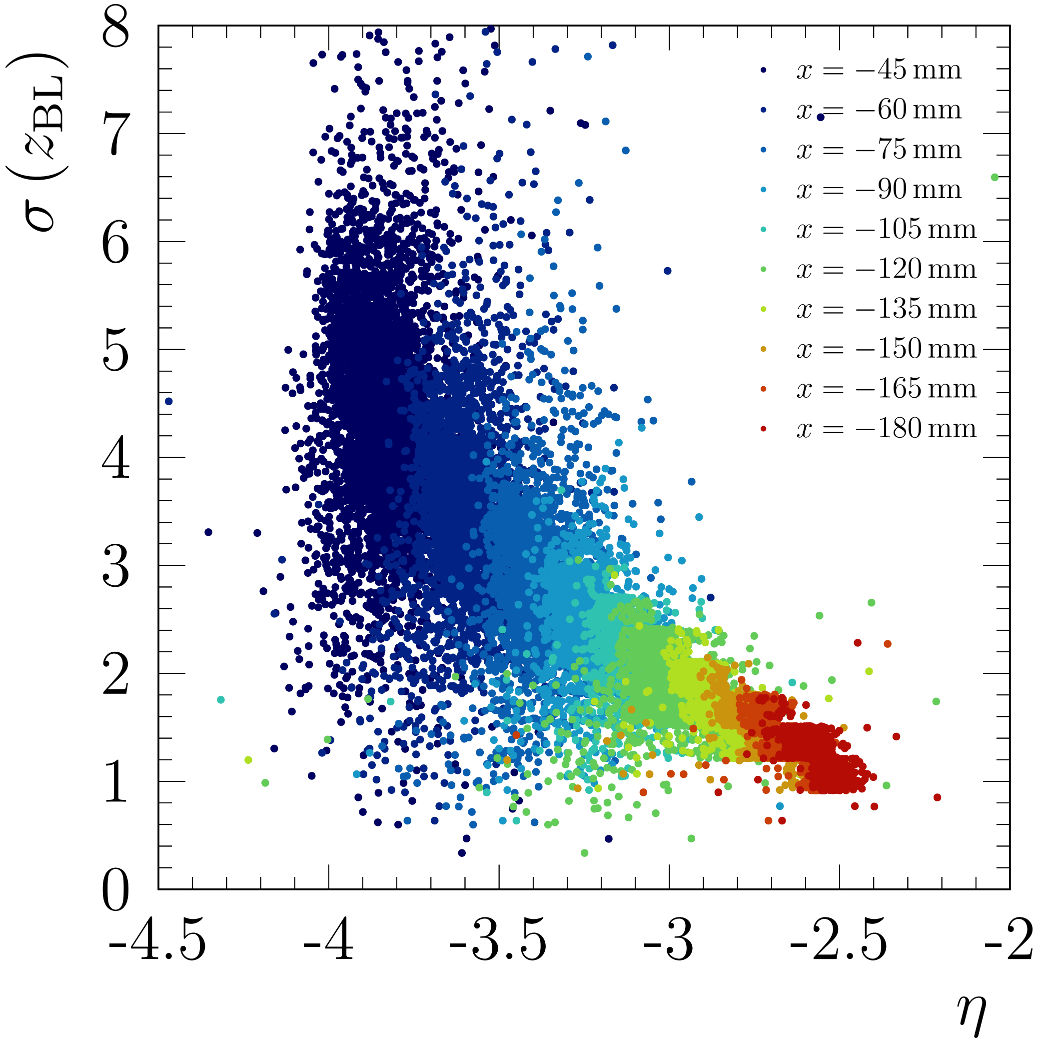
Timepix4 telescope in H8



The idea: where?

- optimal location and detector layout choices mainly based on:
  - detector occupancy
  - fraction of reconstructed tracks from material interactions
  - resolution of the luminous region
  - reconstruction efficiency for lumi region tracks



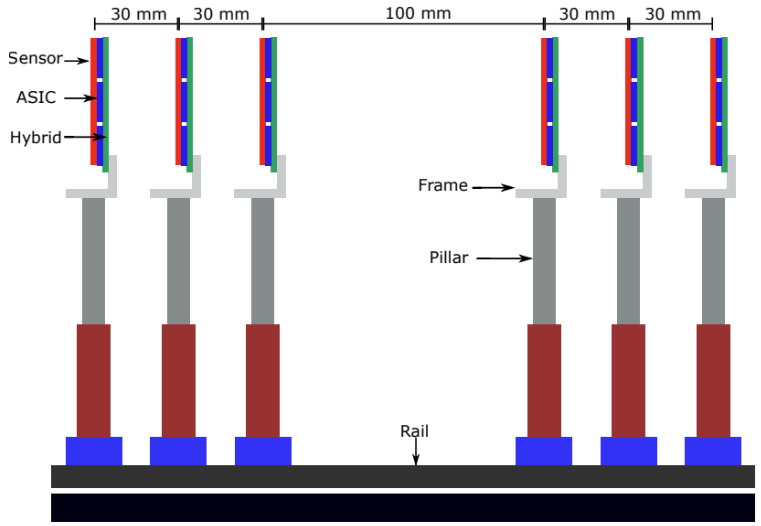


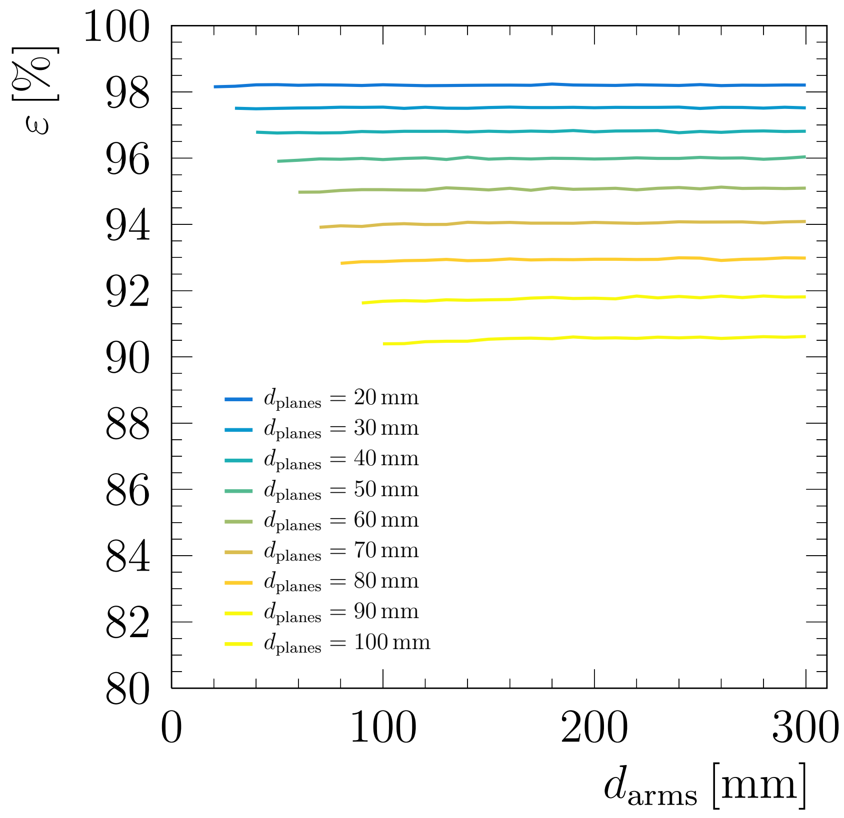
optimal location: z = -1250 mm and radius = 120 mm

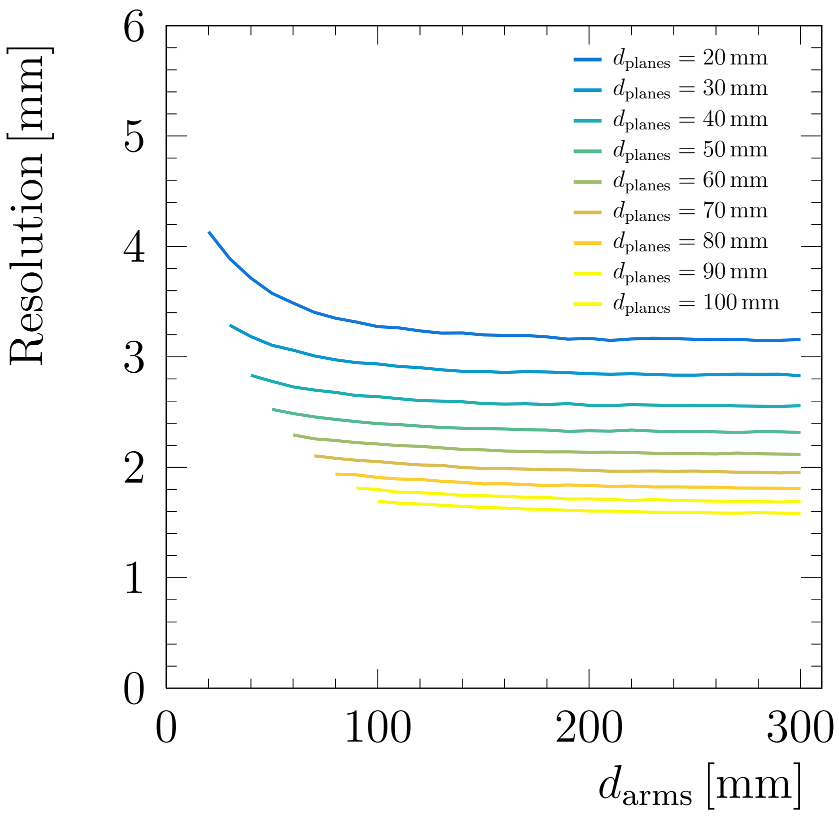
expected fluence < 2×10^{15} 1 MeV n_{eq}/cm^2 for Run 4

The idea: layout?

- layout optimised requiring a min of 4 hits per track
- planes arranged in two arms to balance track efficiency and resolution of lumi region tracks
- same number of planes (3 or 4) per arm for redundancy
- additional advantage: optimal pointing resolution in the middle of the telescope







optimal spacing: 10cm between the arms and 3cm between the planes within the same arm

How to measure luminosity?

Total instantaneous luminosity:

$$\mathscr{L} = \sum_{b=1}^{n_b} \mathscr{L}_b = n_b \langle \mathscr{L}_b \rangle$$

mean bunch luminosity

$$\langle \mathscr{L}_b \rangle = \frac{\langle \mu \rangle f_r}{\sigma_{inel}} = \frac{\langle \mu_{vis} \rangle f_r}{\sigma_{vis}} = \frac{A}{\sigma_{vis}} f_r n_{tracks}$$

with

$$\mu_{vis} = \varepsilon\mu$$
$$\sigma_{vis} = \varepsilon\sigma$$

Linear method

- Based on counting the number of tracks
- The mean number of tracks is proportional to the number of interactions

n_b = number of colliding bunch pairs

f_r = LHC revolution frequency (11245 Hz)

σ_{inel} = total inelastic pp cross-section

μ = number of inelastic pp collision per bunch crossing

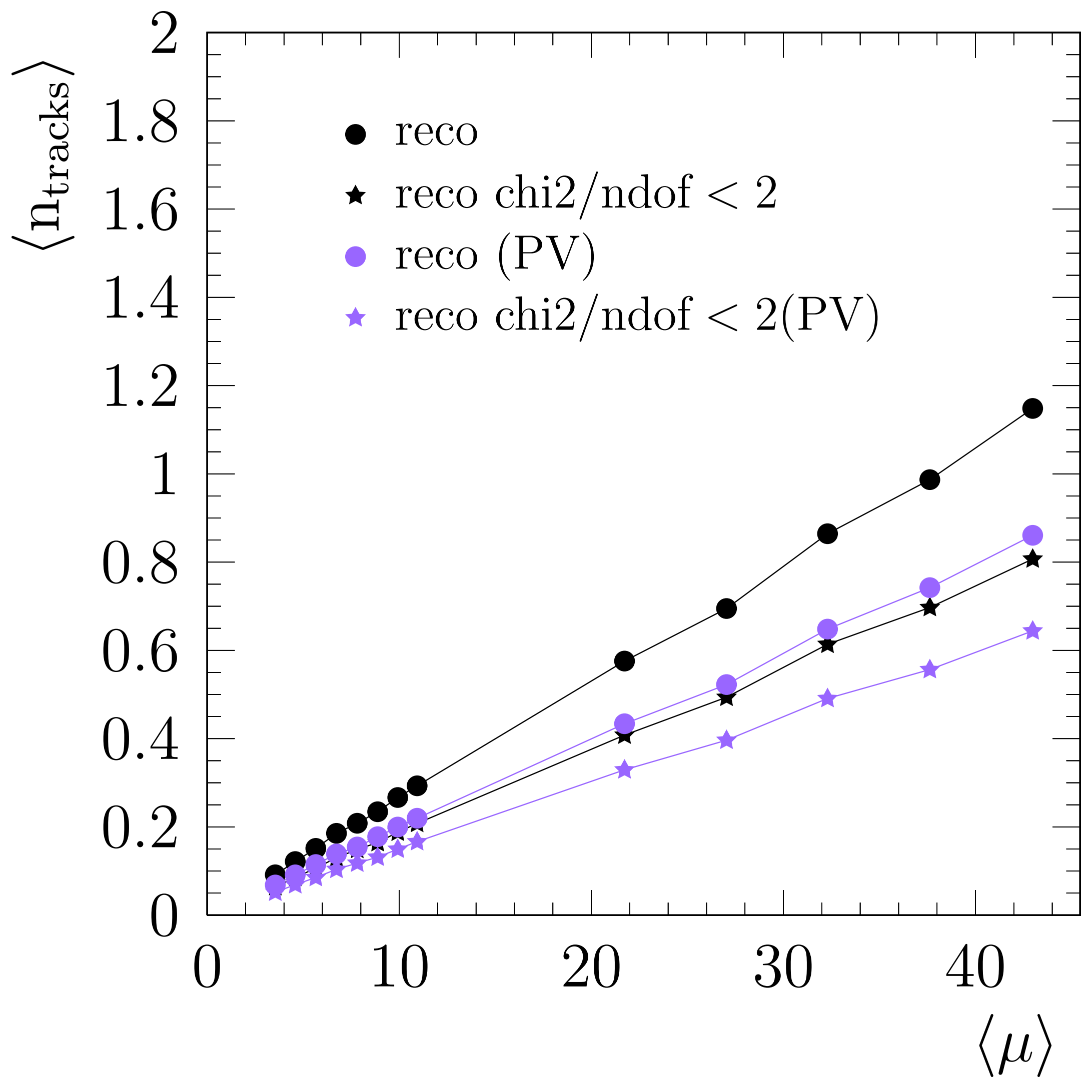
ε = acceptance x efficiency of luminosity detector

μ_{vis} = visible collision per bunch crossing — **What we want to measure!**

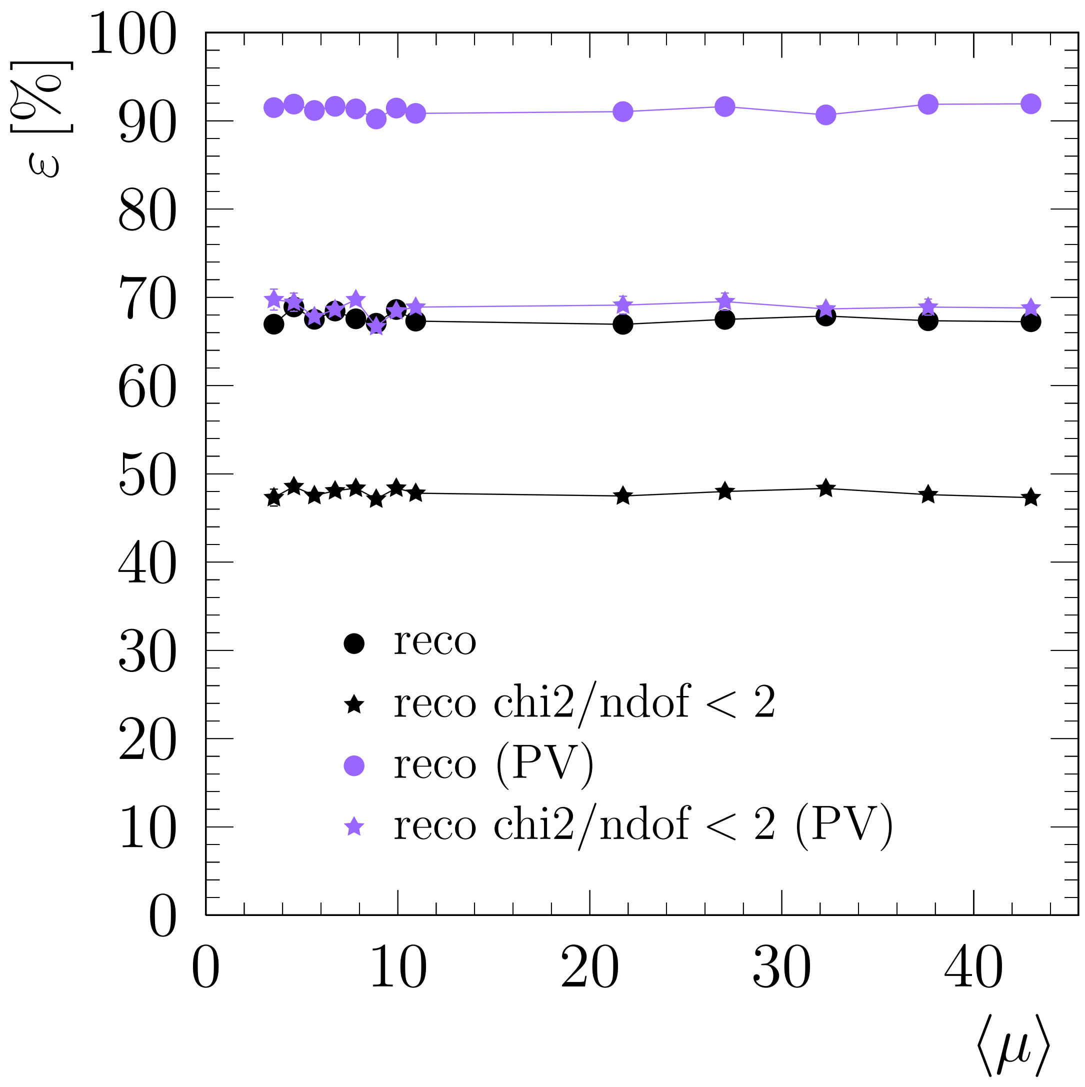
σ_{vis} = effective cross section — **calibration constant (from dedicated van der Meer scan)**

Linearity

Linearity check



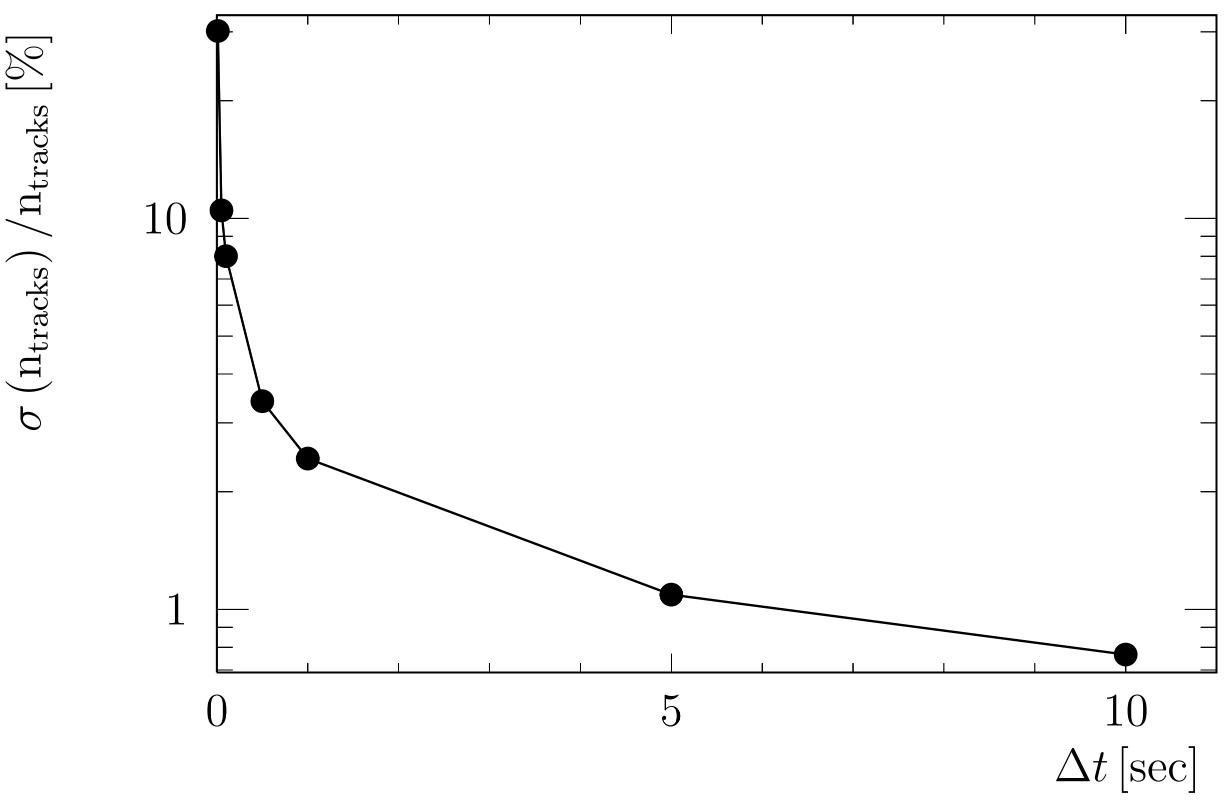
Stability check



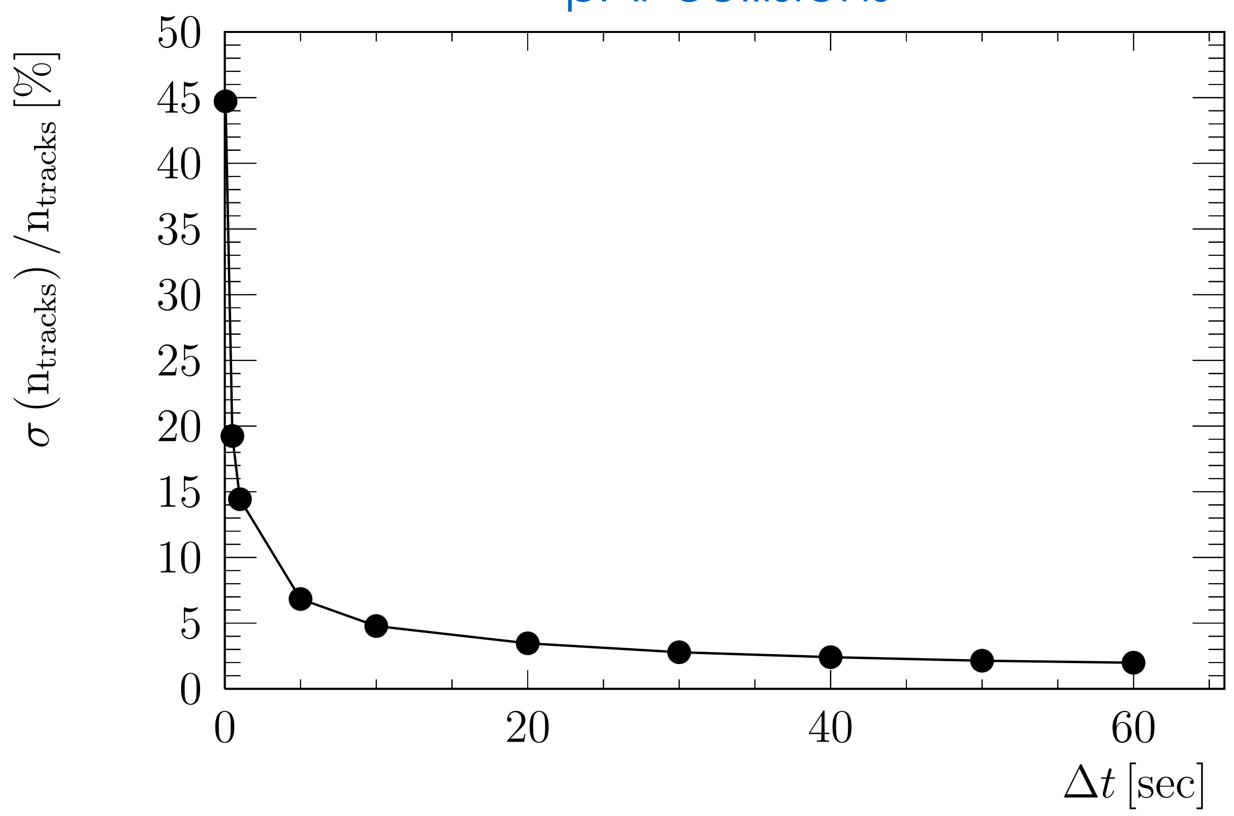
Performance: lumi measurement

relative statistical uncertainty on per bunch luminosity vs integration time

pp collisions



pAr collisions



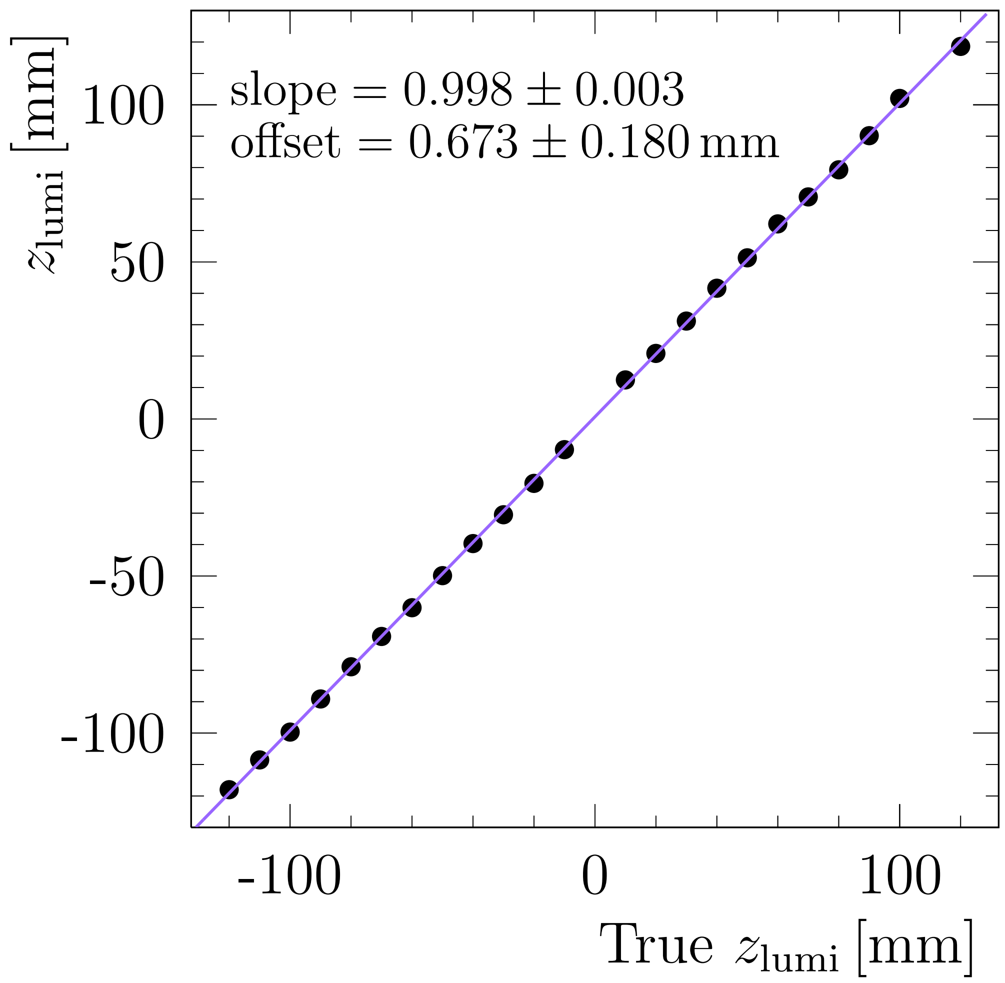
- stat uncertainty on μ ~1% for 5s data taking at ν=7.6

- LumiTracker occupancy for p-gas about a factor 10 lower than pp
- need longer integration times

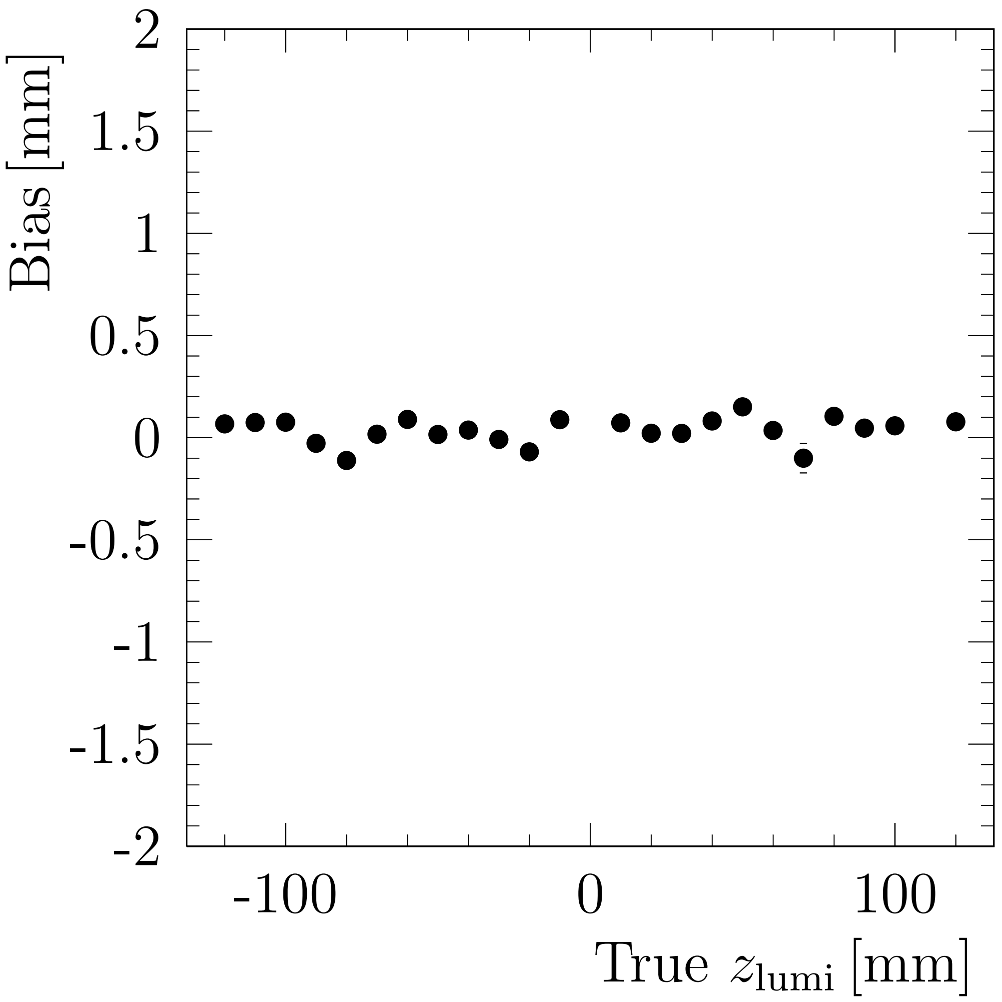
Performance: reconstruction lumi region

- the longitudinal profile of the luminous region can be reconstructed
- the luminous region is approximately gaussian in x, y, z with $\sigma_{x,y}$~30 µm and σ_z~63 mm
- lumi region resolution per track ~few mm

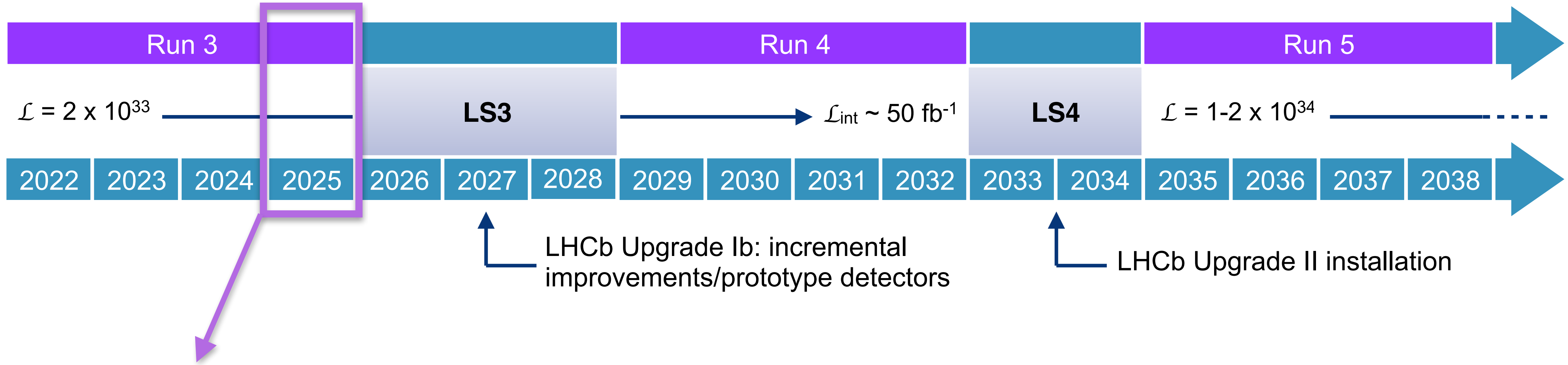
reconstructed position of lumi region



lumi region resolution per track

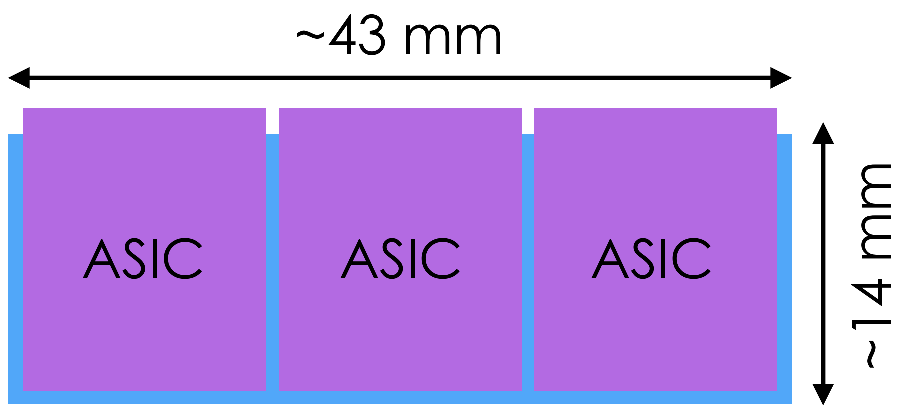


The idea: when?



LumiTracker v1

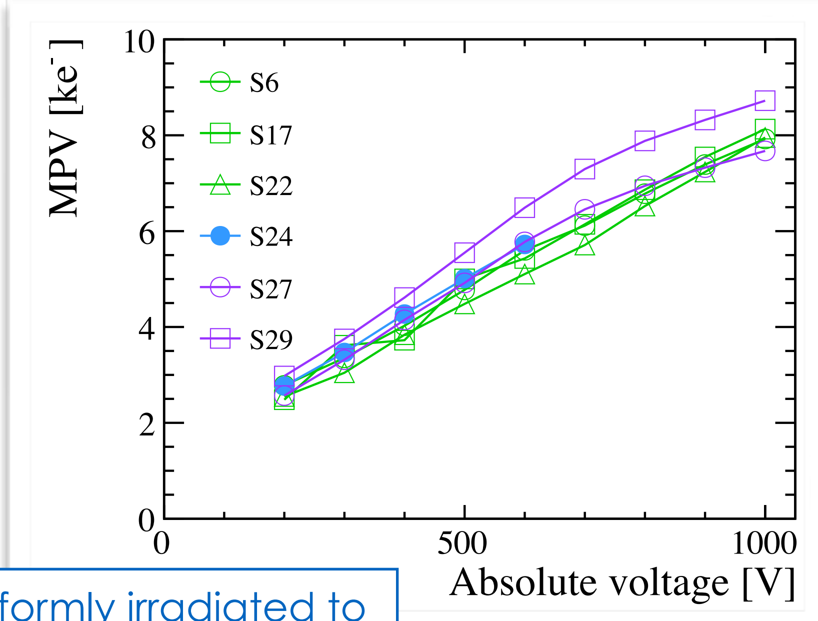
- proof of concept of a luminosity detector based on track counting
- each plane = 200 μm thick n-on-p HPK triple + 3 VeloPix
- DAQ based on VELO components: re-design of the cables only
- fairly straightforward to install: could be done in a winter shutdown
- test of Timepix4 DAQ?



Sensor

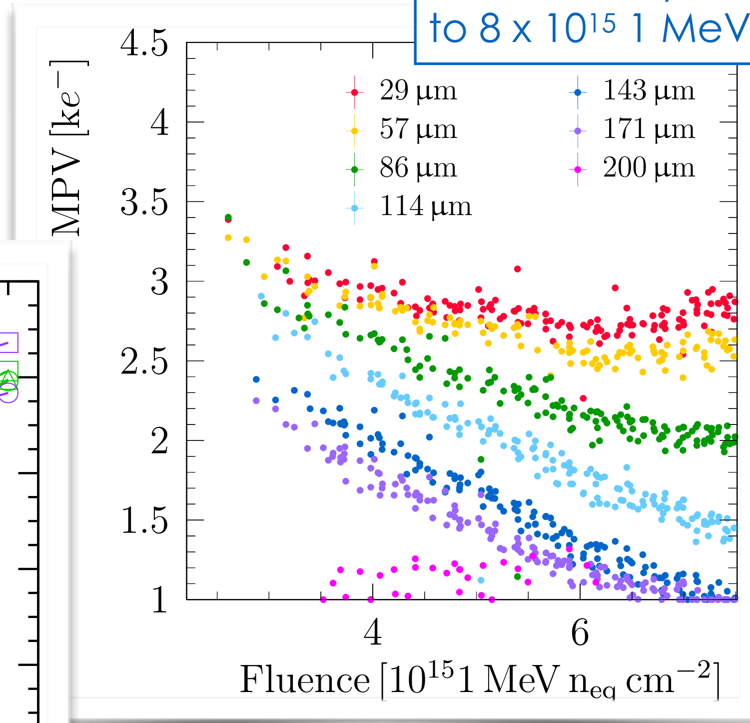
2022 JINST 17 P06038
2021 JINST 16 P07035
2021 JINST 16 P02029

withstand 1000V at the end of lifetime with charge collection > 6000 e-

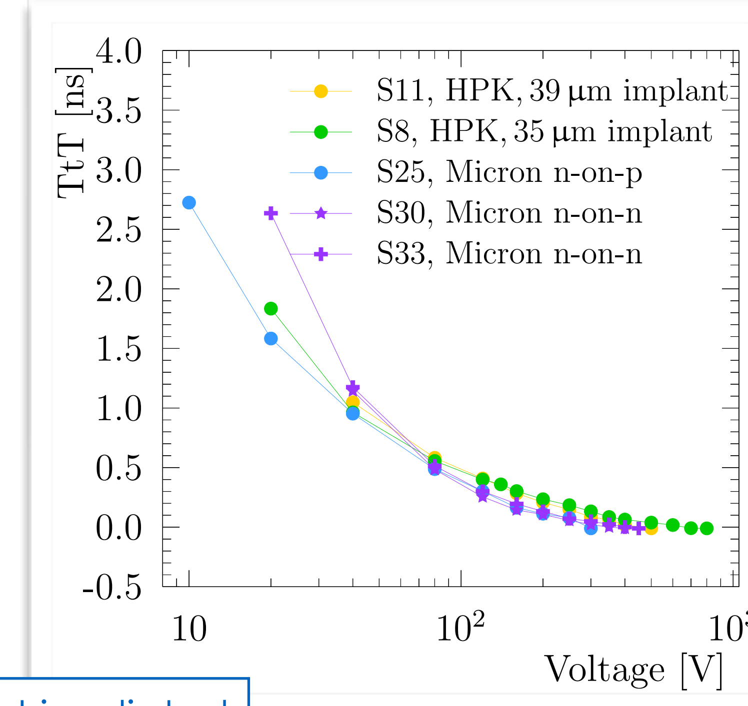


uniformly irradiated to 8 x 10^{15} 1 MeV n_{eq}/cm^2

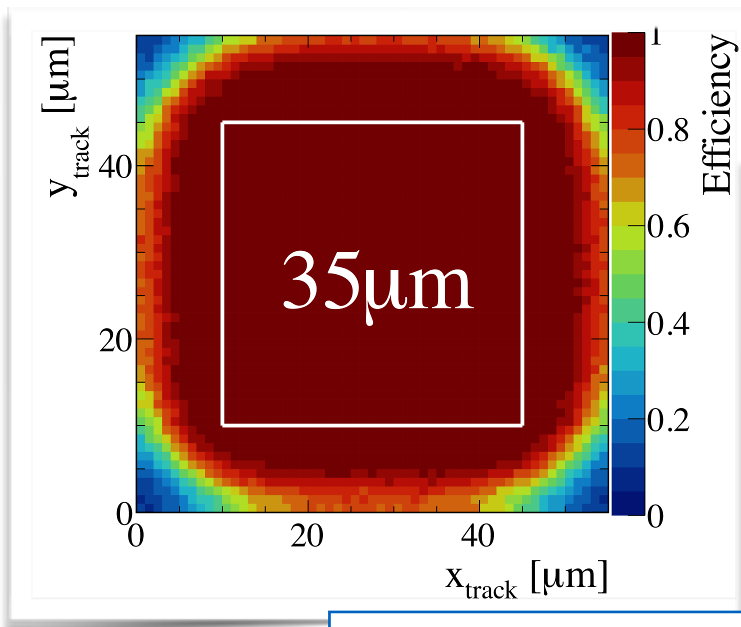
not-uniformly irradiated up to 8 x 10^{15} 1 MeV n_{eq}/cm^2



timing of sensor + ASIC << 25 ns

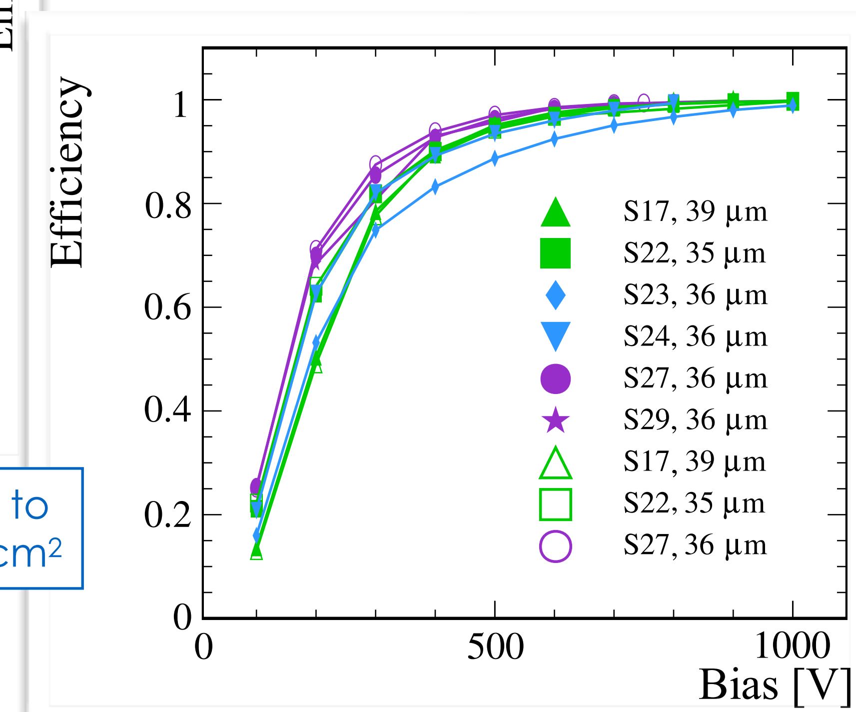


not irradiated

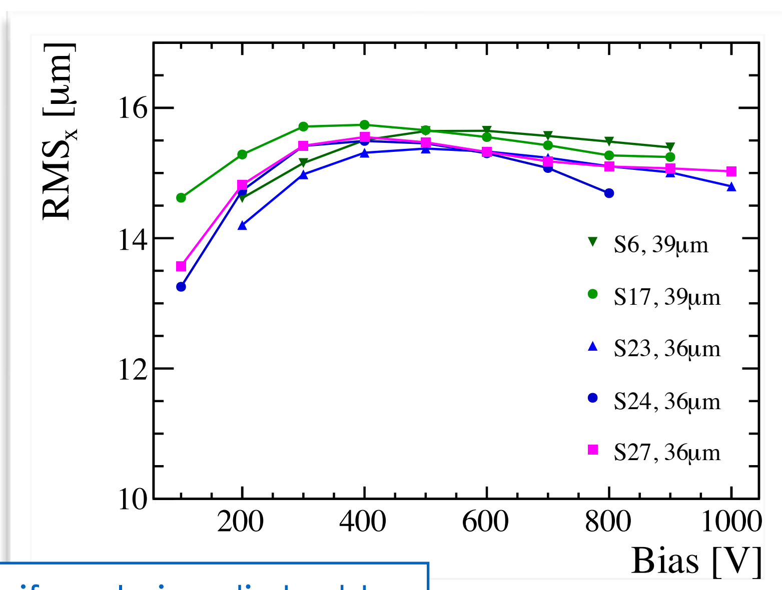


uniformly irradiated to 8 x 10^{15} 1 MeV n_{eq}/cm^2

efficiency > 99% and uniform



excellent spatial resolution



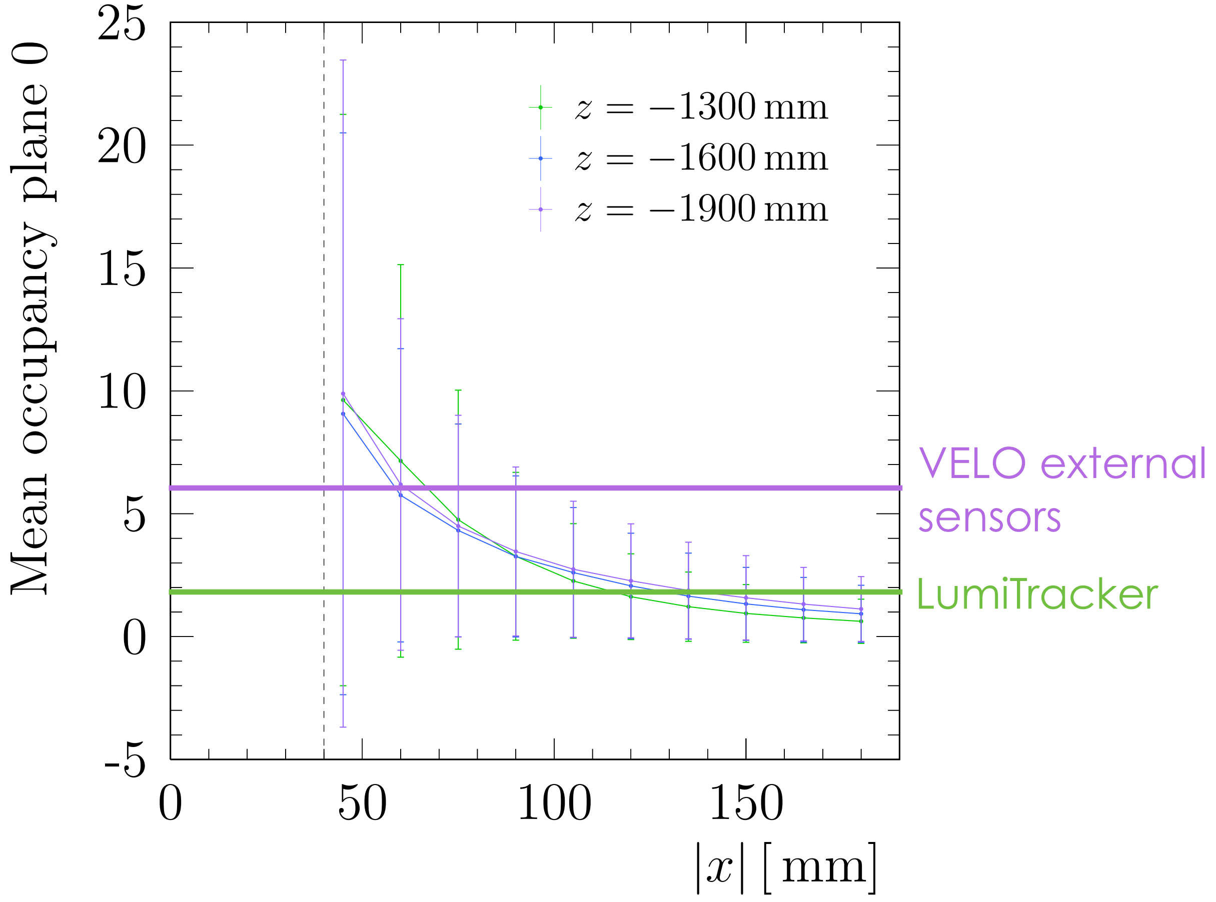
uniformly irradiated to 8 x 10^{15} 1 MeV n_{eq}/cm^2

ASIC

VeloPix

- binary, data driven, zero suppressed readout
- capable to handle significantly higher rate than needed
- radiation hardness > 400 MRad (triple redundancy)
- given the low occupancy, expect only1-2/4 links active: power consumption reduced

expected occupancy



specifications

pixel size	$55 \times 55\,\mu m^2$
matrix size	256×256
timestamp resolution	25 ns
Time over Threshold	low rate only
peak pixel hit rate	900 MHit/s
power consumption	< 3 W/ASIC
radiation hardness	> 400 MRad
single event upset robust	yes
number of links	4
bit rate per link	5.12 Gbps

Commonalities with TWOCRYST tracker?

FE

- 8 tiles ✓
- 4 GBTx ✓
- 8 hybrids

DAQ

- 4 VFB (not vacuum compatible)
- 2 OPB
- cables: LV, HV, interconnect, data

Services

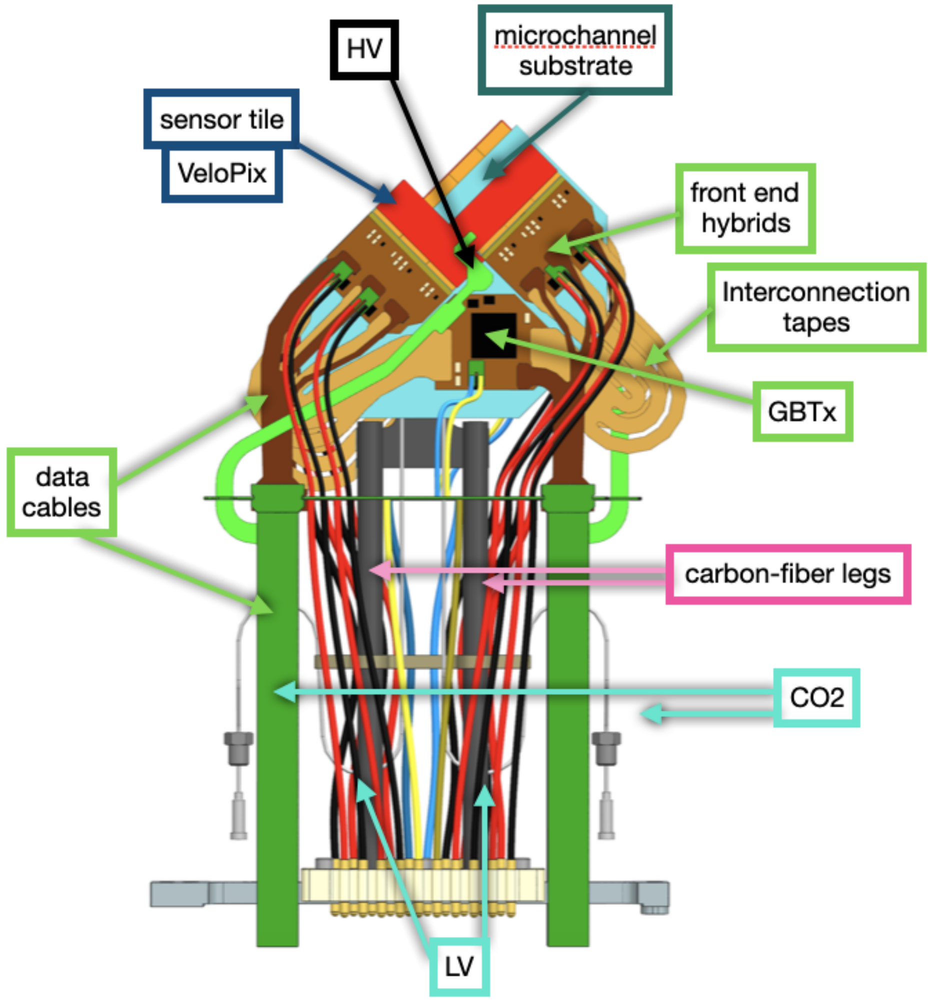
- HV module
- LV module
- temperature and humidity sensors + ELMBs

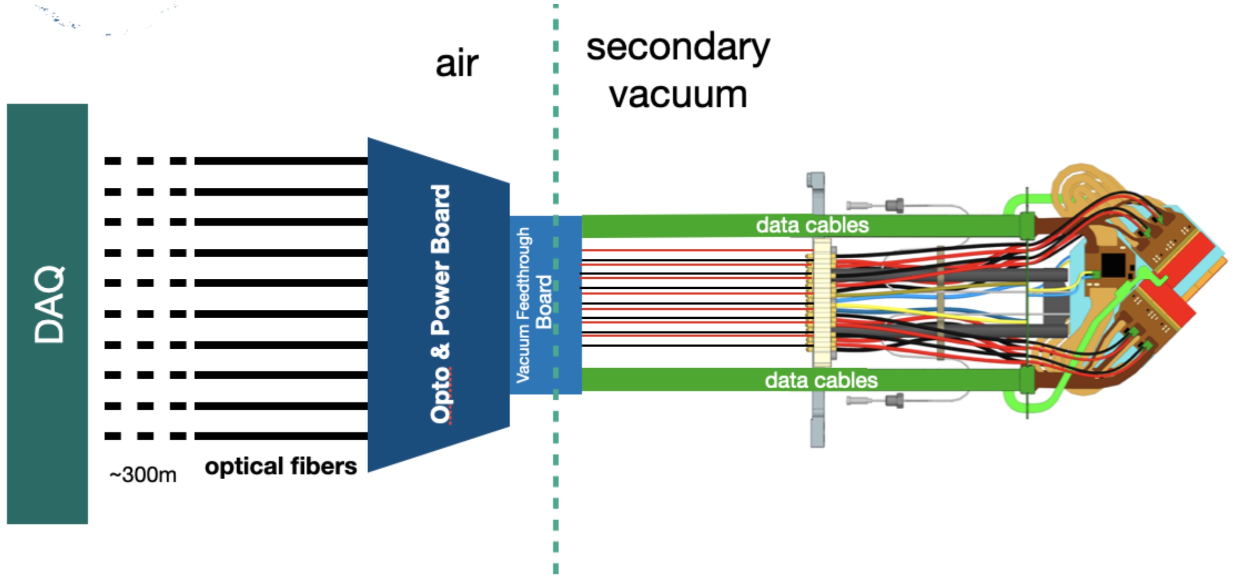
Backend

- 2 TELL40s ✓
- 1 EB node ✓
- 2 EB interfaces ✓
- 2 GPUs ✓

Infrastructure

- water based cooling
- mechanics

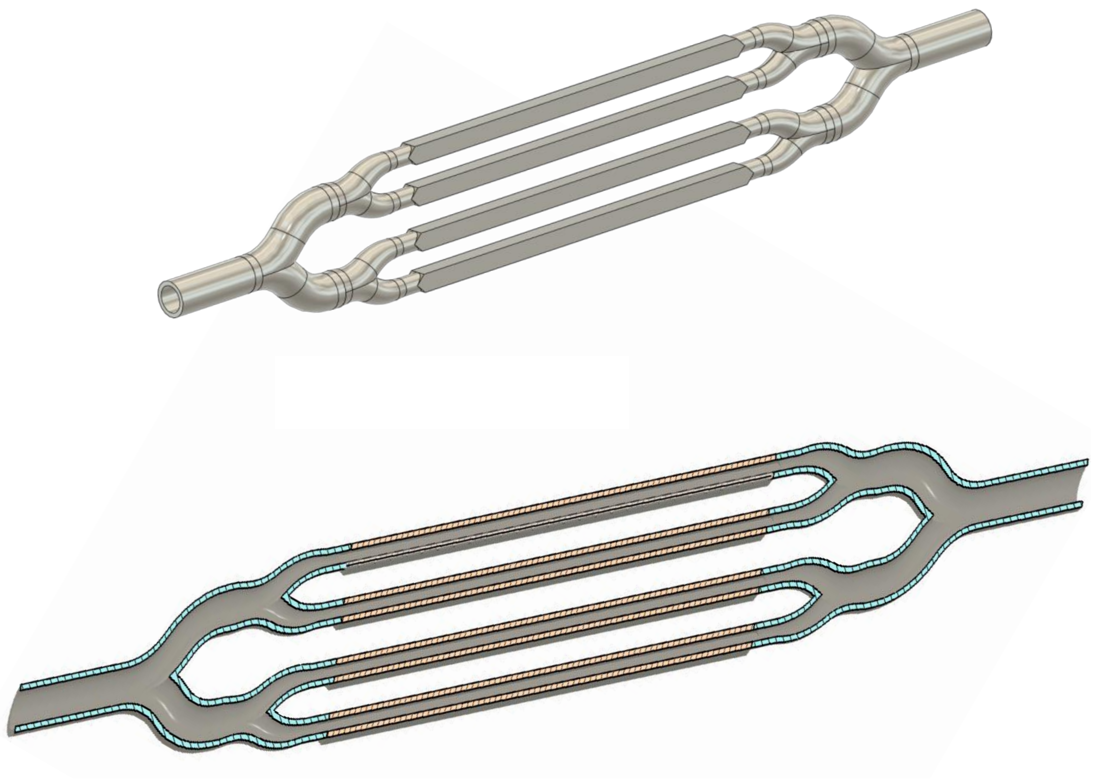




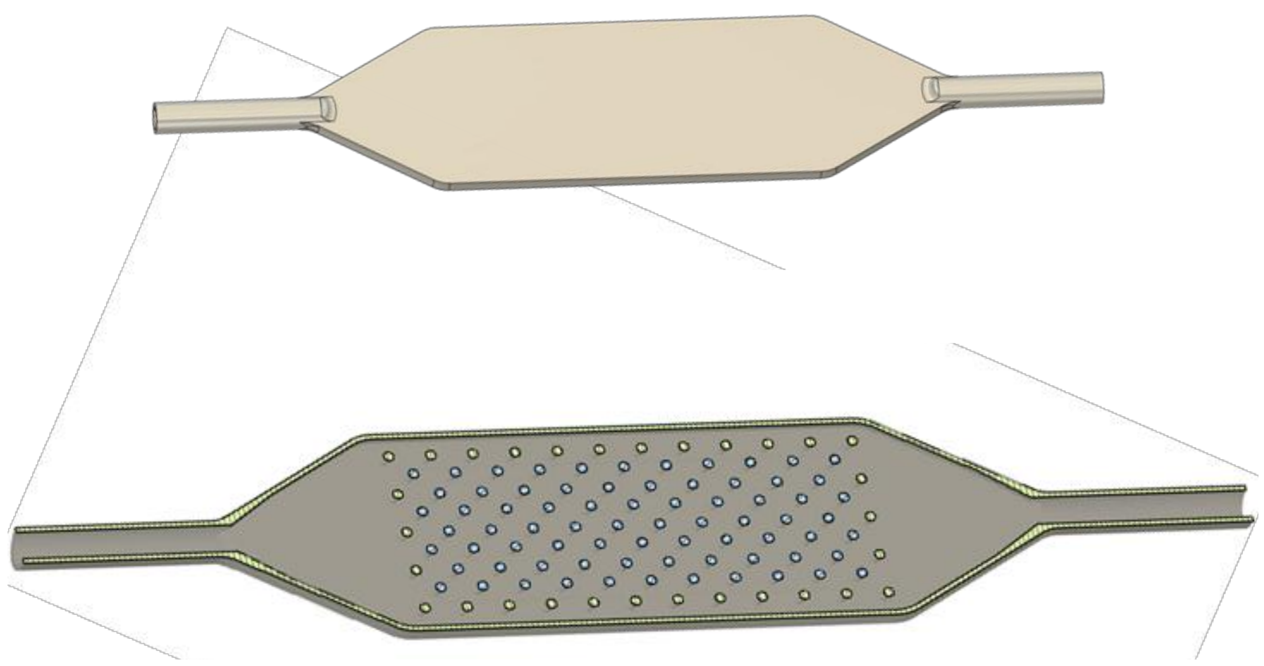
Cooling

- maximum sensor temperature allowed 20 C
- 2 solutions under discussion in 3D printed aluminum (0.5 mm wall thickness) with water flowing at 15 C
- both add ~1 mm of material: further development ongoing
- providing mechanical support for sensor and ASIC

4 tubes prototype



coldplate pins prototype



Cooling

see Lucas' talk

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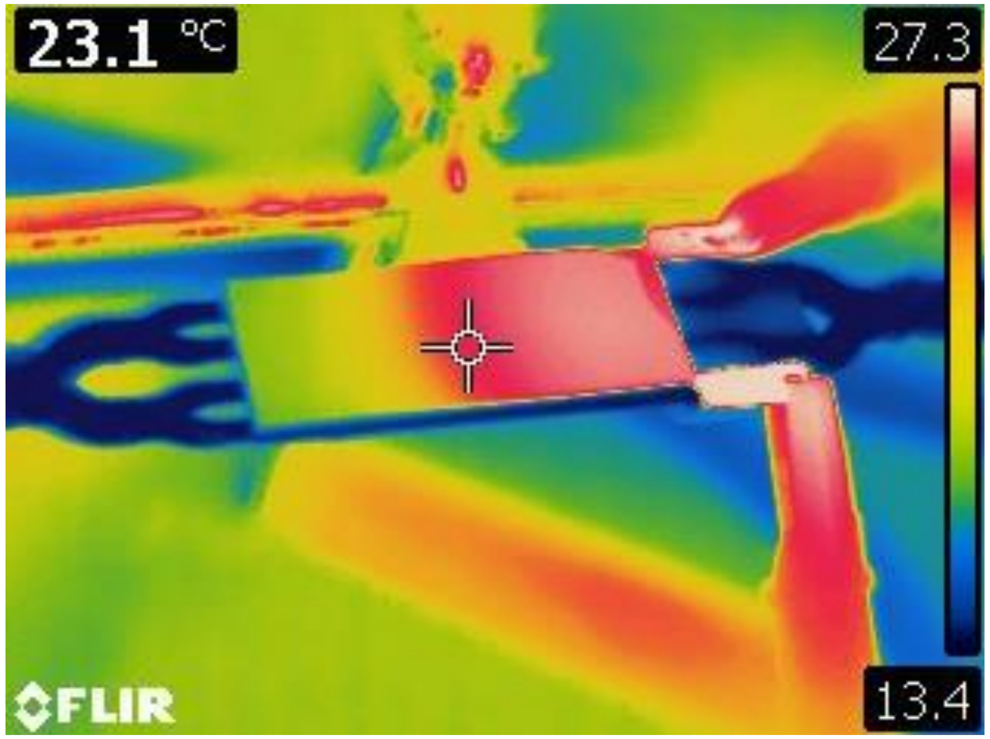

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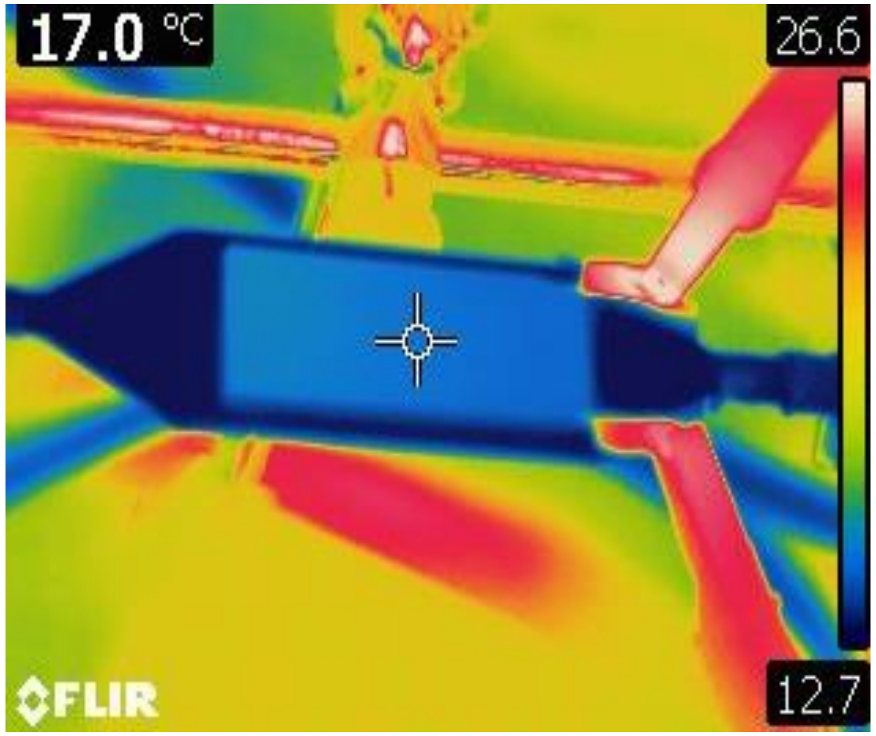

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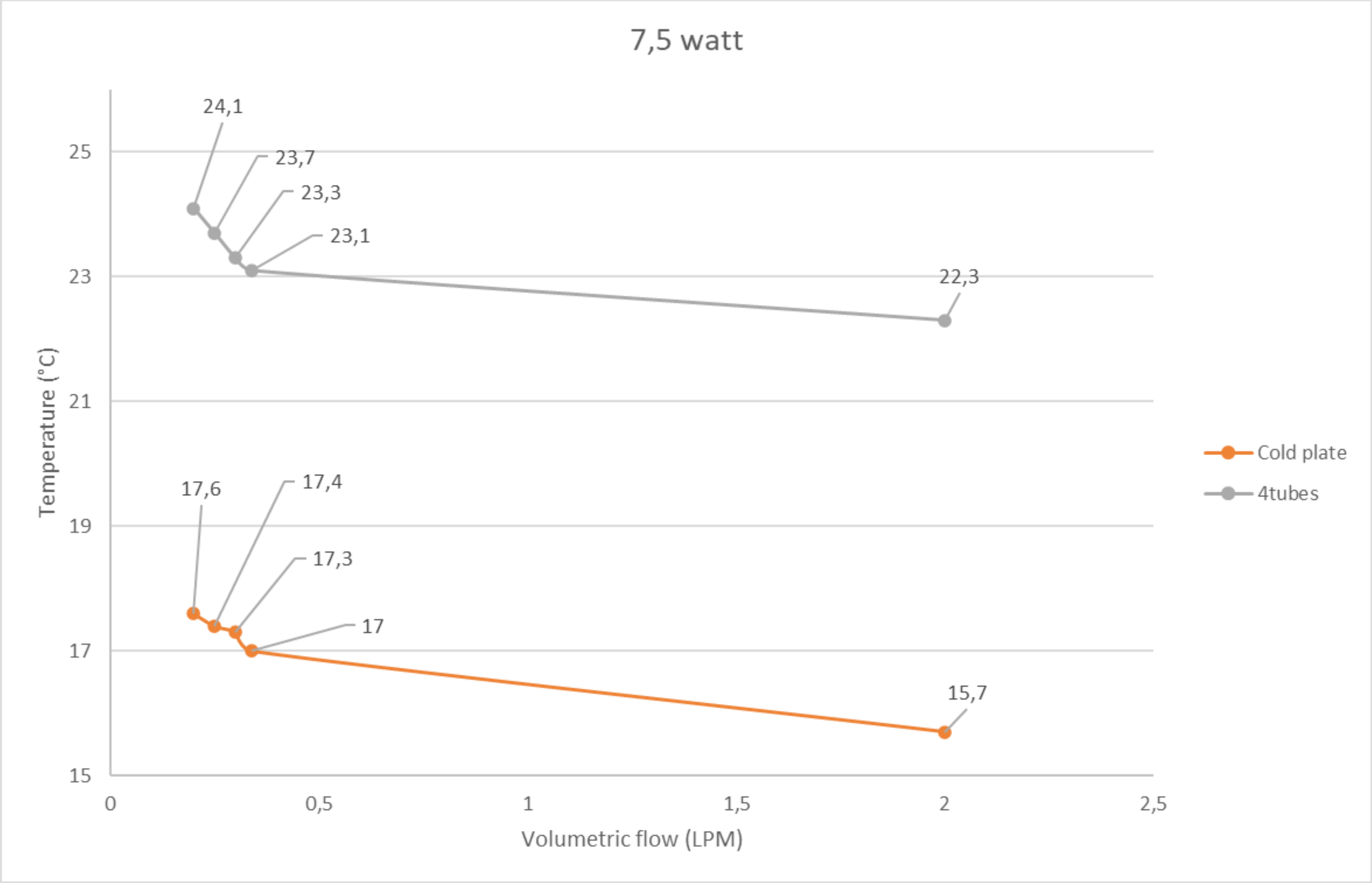
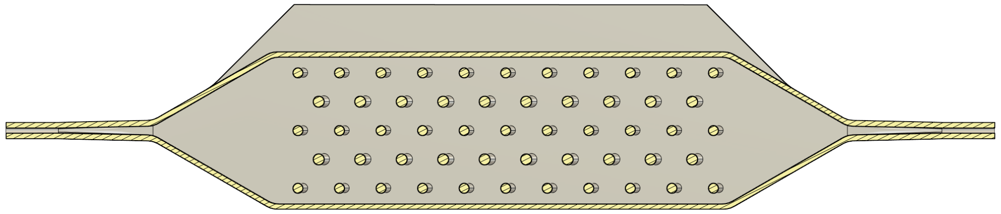
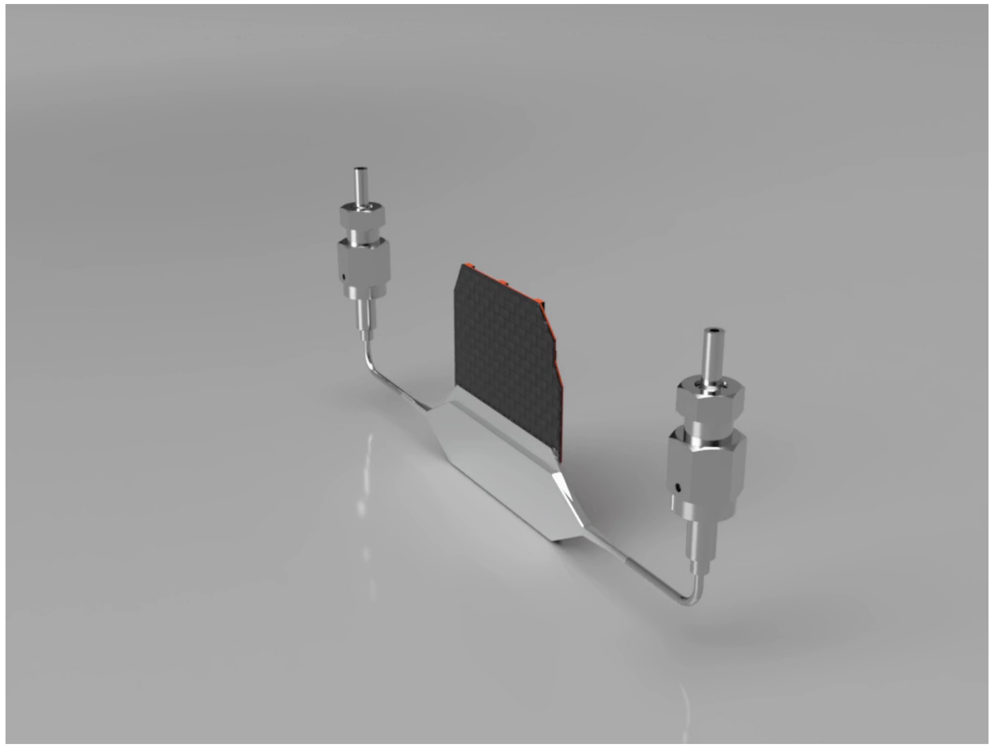


Cooling

VeloPix assembly

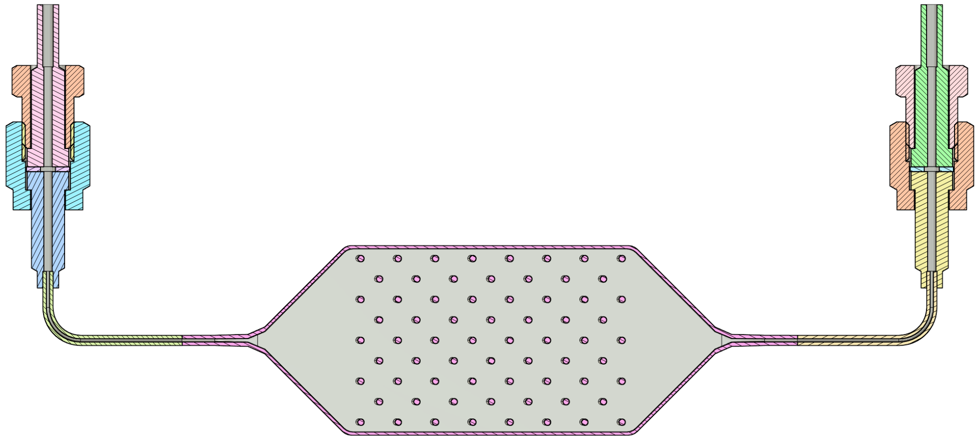
(coldplate pins design)

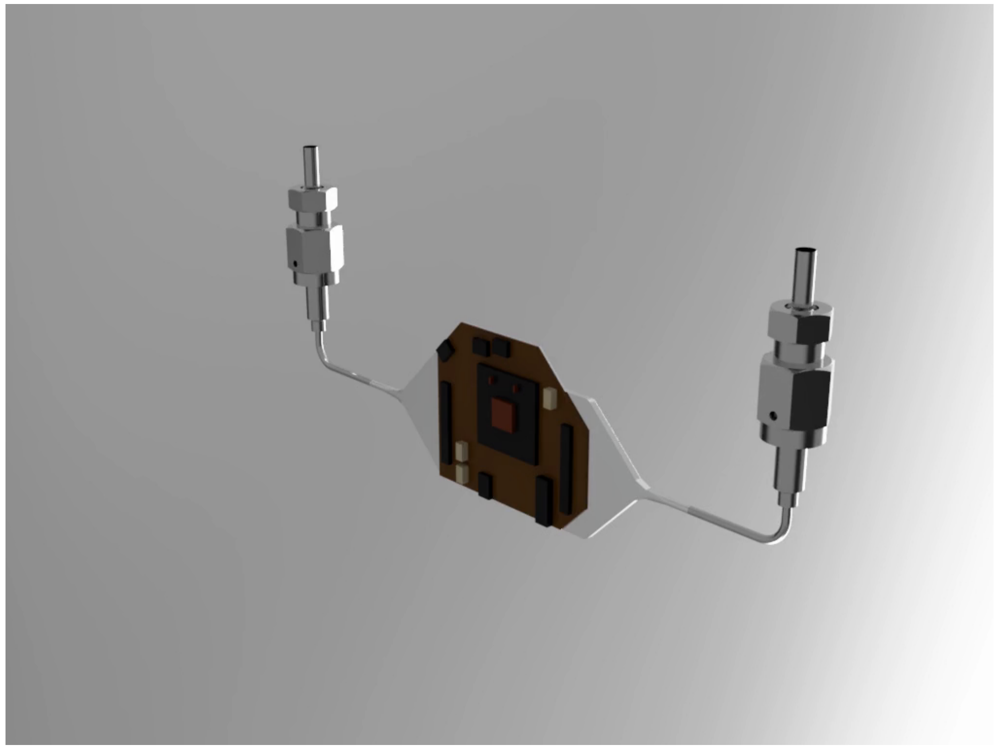




GBTx assembly

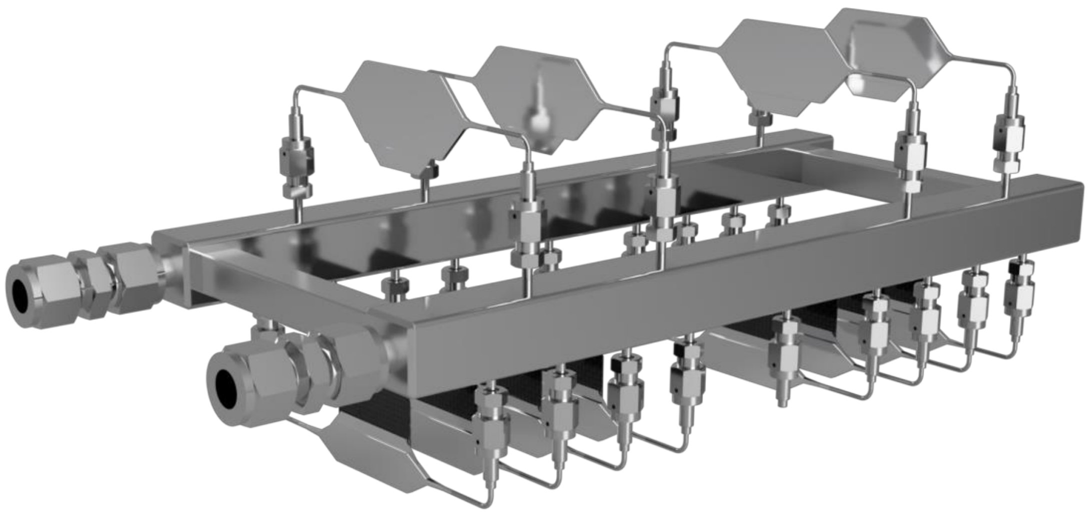
(coldplate pins design)





Mechanics

cooling frame with
cooling components



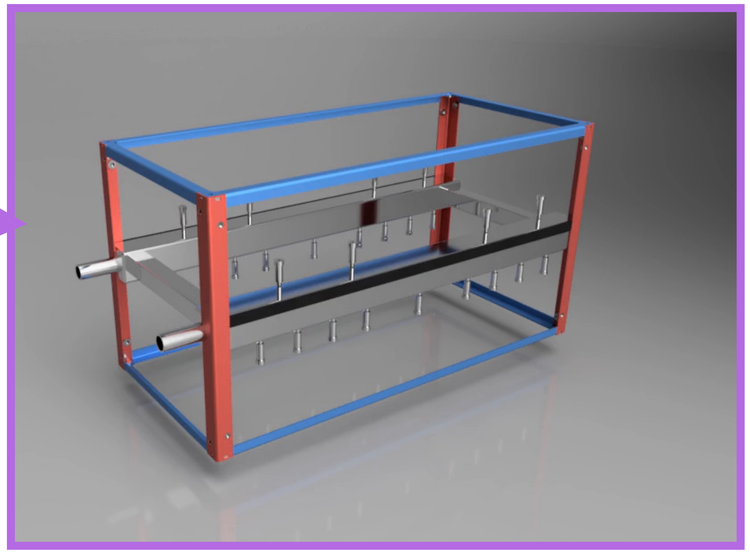
cooling frame

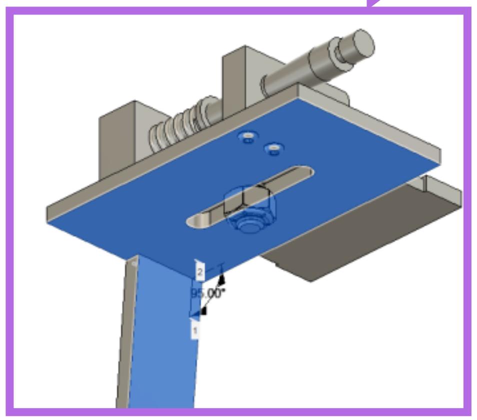
- stainless steel cooling frame
- additional central slot available for DUTs

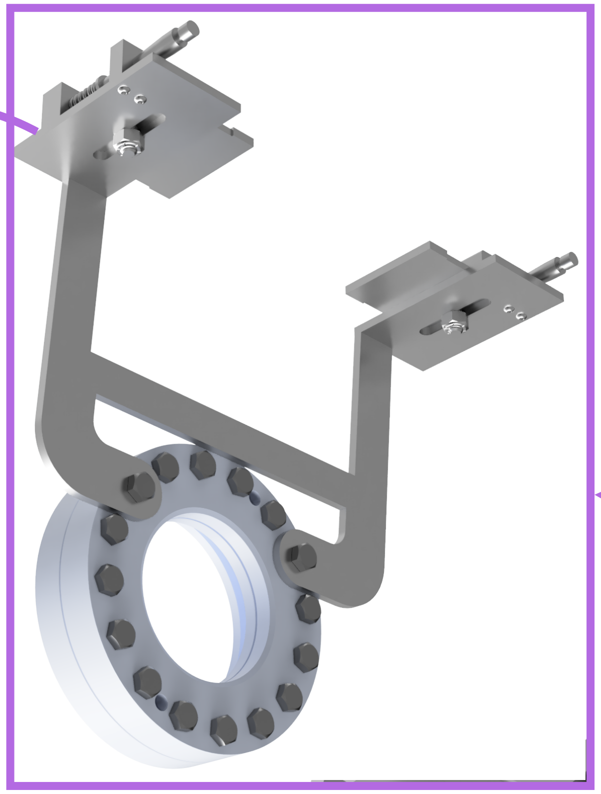
enclosure

- light sealed
- full enclosure angled of ~5 deg wrt IP
- adjustable position along z
- 0.2 mm thick stainless steel
- mylar window now added to the design

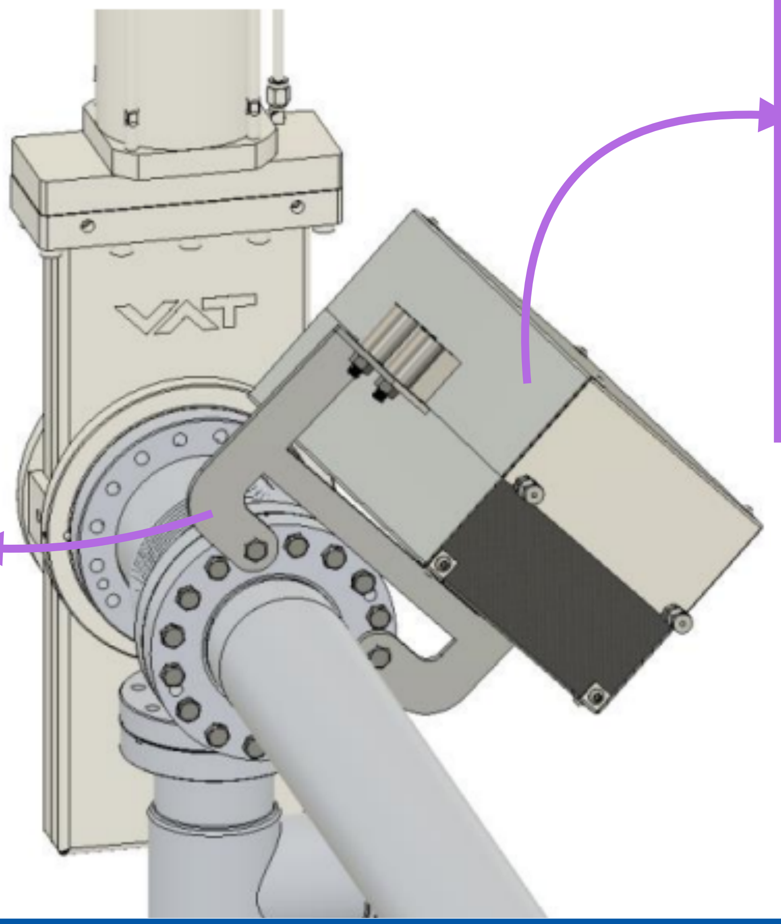
enclosure with cooling frame







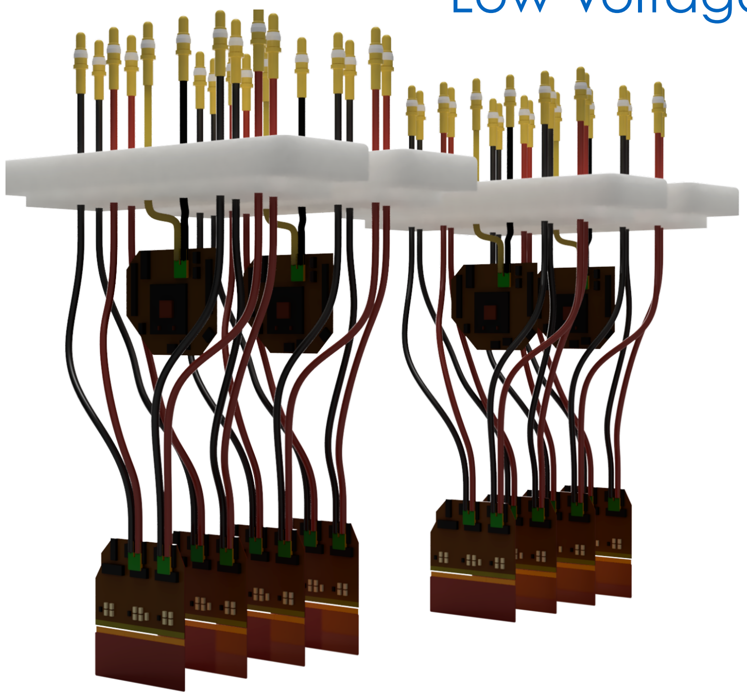
mount to flange



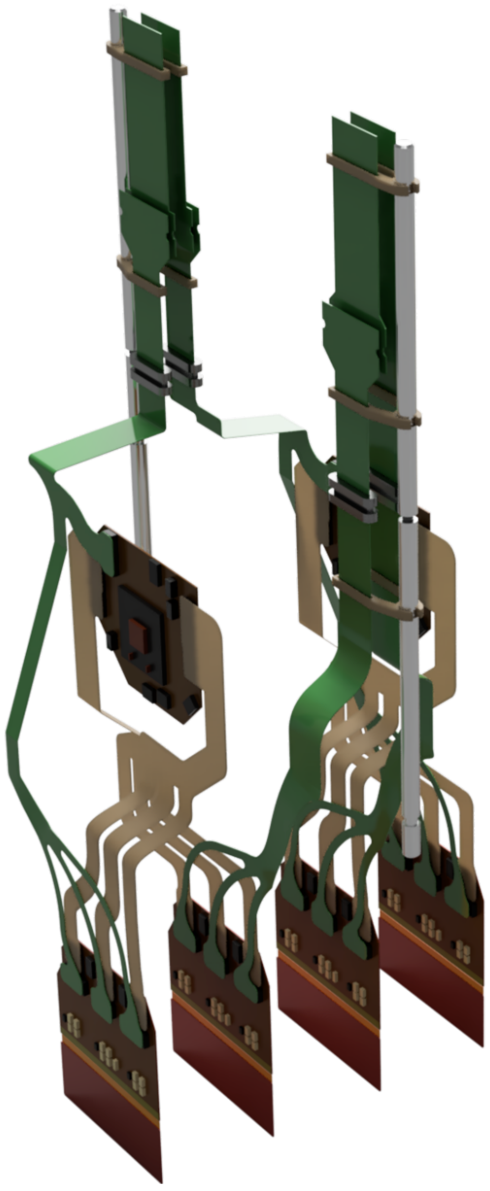
Cabling

- cables routing and mounting designed together with corresponding feedthrough (replacing VELO VFBs)
- re-design of (almost) straight cables ongoing in collaboration with TWOCRYST

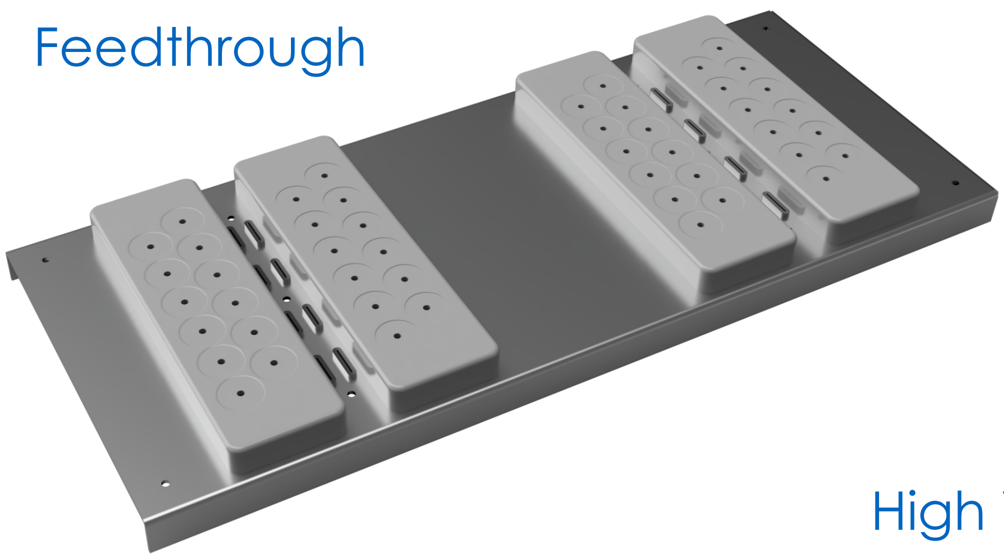
Low Voltage



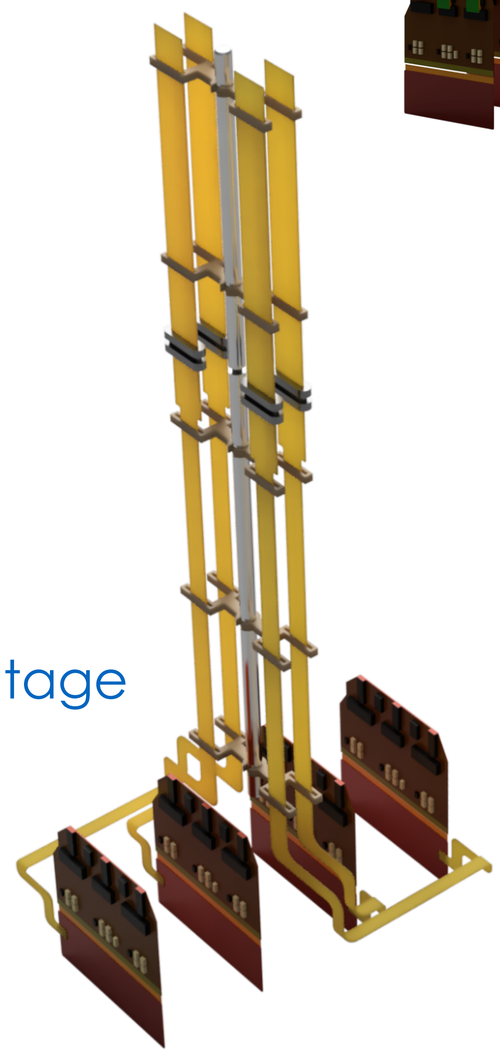
Data



Feedthrough

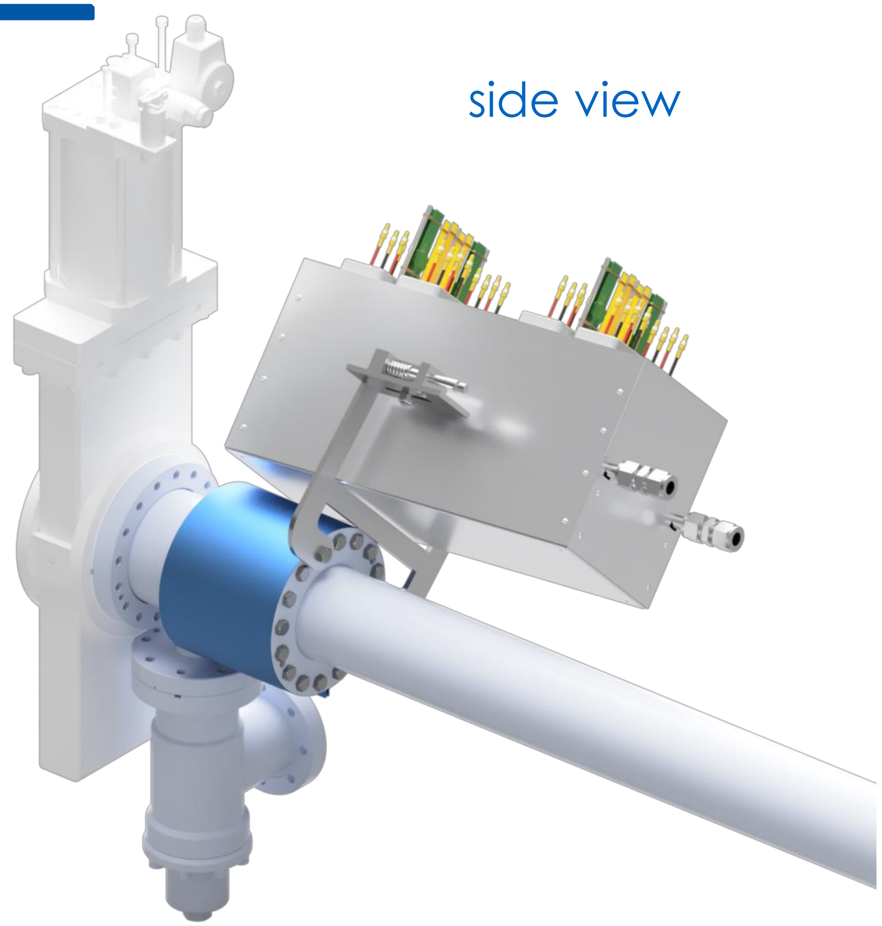


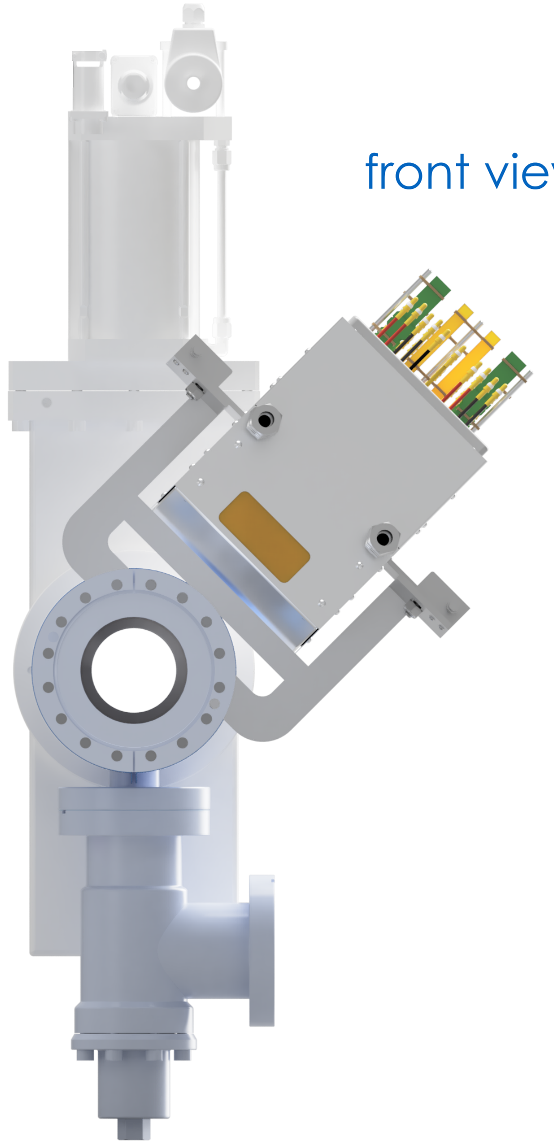
High Voltage



Mechanics summary

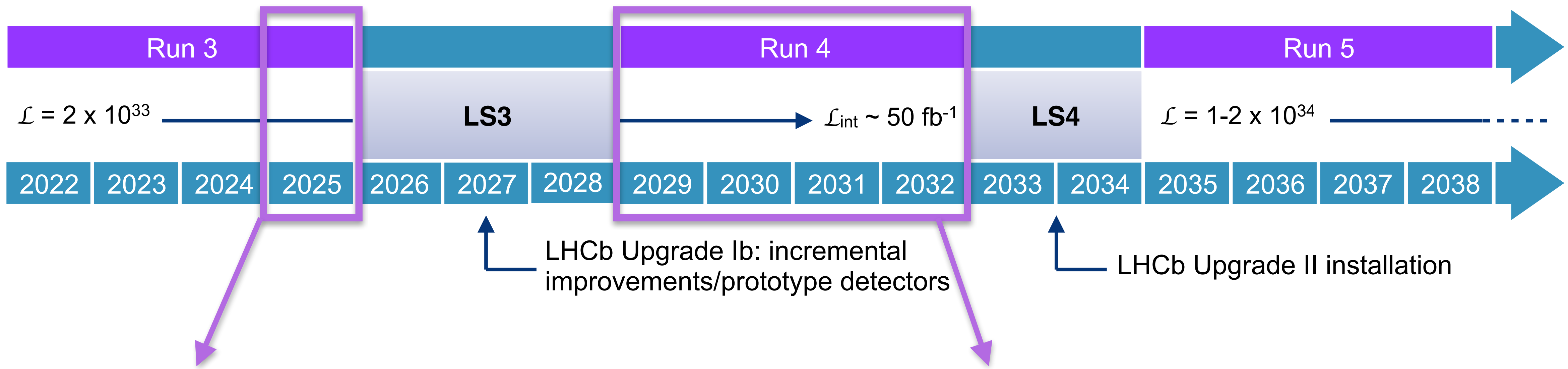
- inspired by the Timepix4 telescope design
- whole telescope is tilted to optimise the acceptance for tracks from the luminous region
- mount on flange and wires mounting designed
- cooling frame + 0.2 mm thick enclosure in stainless steel





Weight of all concepts and components in grams (g) CAD	
The Mount	1360
The Enclosure	536
The Cooling frame	1950
The Cooling concepts	131
The wiring and electronics	395
Total	4372

Timeline



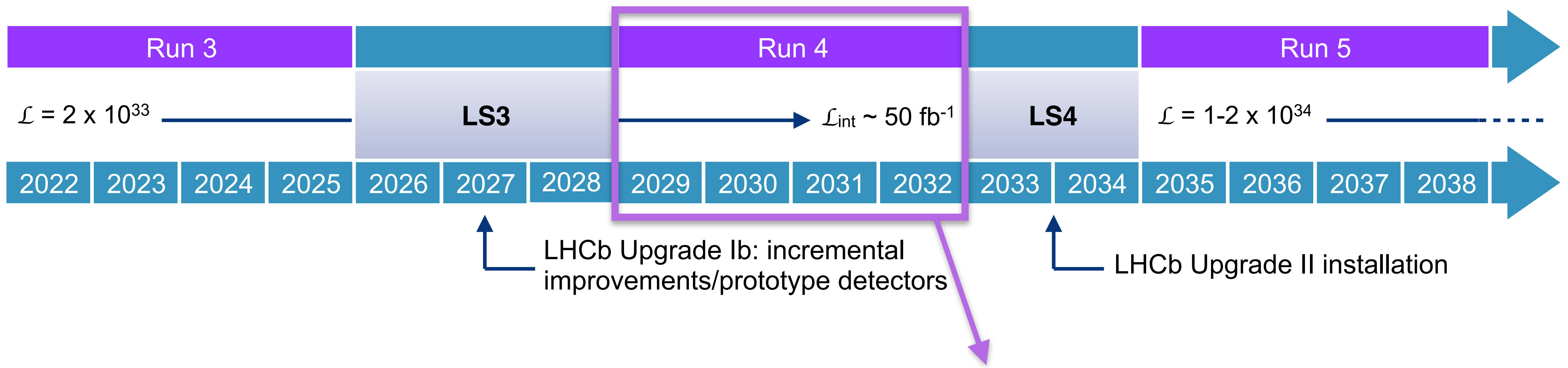
LumiTracker v1

- proof of concept of a luminosity detector based on track counting
- each plane = 200 μm thick n-on-p HPK triple + 3 VeloPix
- DAQ based on VELO components: re-design of the cables only
- fairly straightforward to install: could be done in a winter shutdown

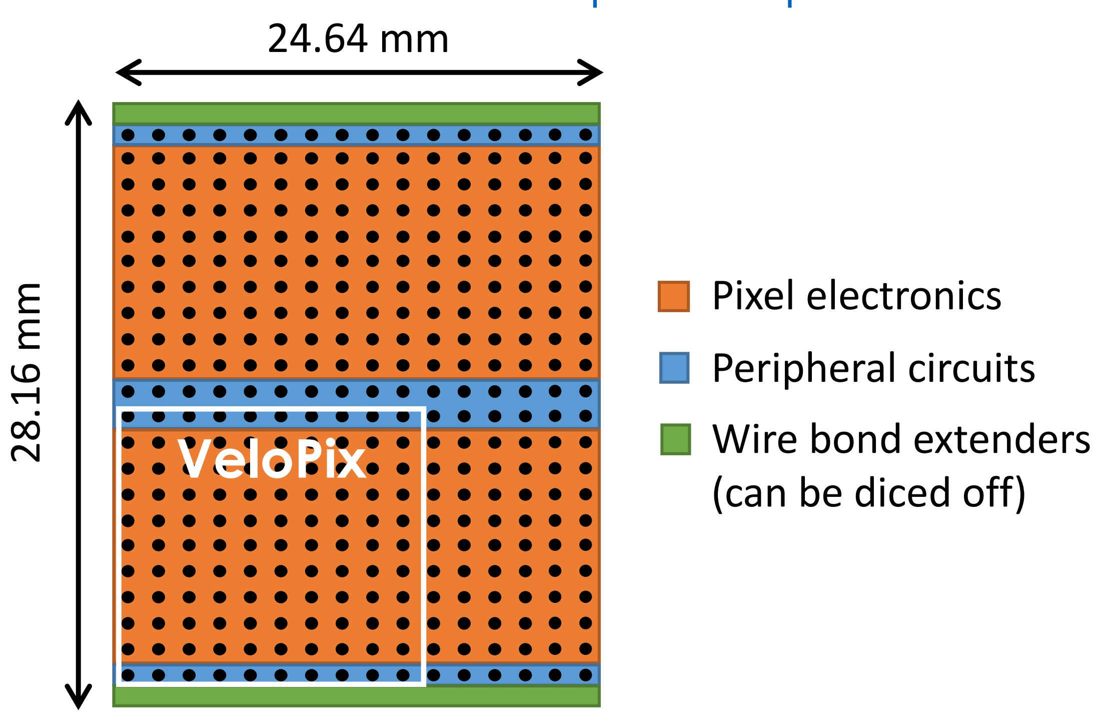
LumiTracker v2

- each plane: Timepix4 (~195 ps TDC) + fast sensor
- timing the track has multiple purposes:
  - improve luminosity measurement by better discriminating the secondaries
  - measurement of satellites and ghost charges
  - measurement of Machine Induced Background
  - more accurate luminous region reconstruction by folding in timing
  - platform to test DUTs in the LHC: a DUT could be inserted in the middle of the telescope and replaced at TS

Timeline



Timepix4 chip



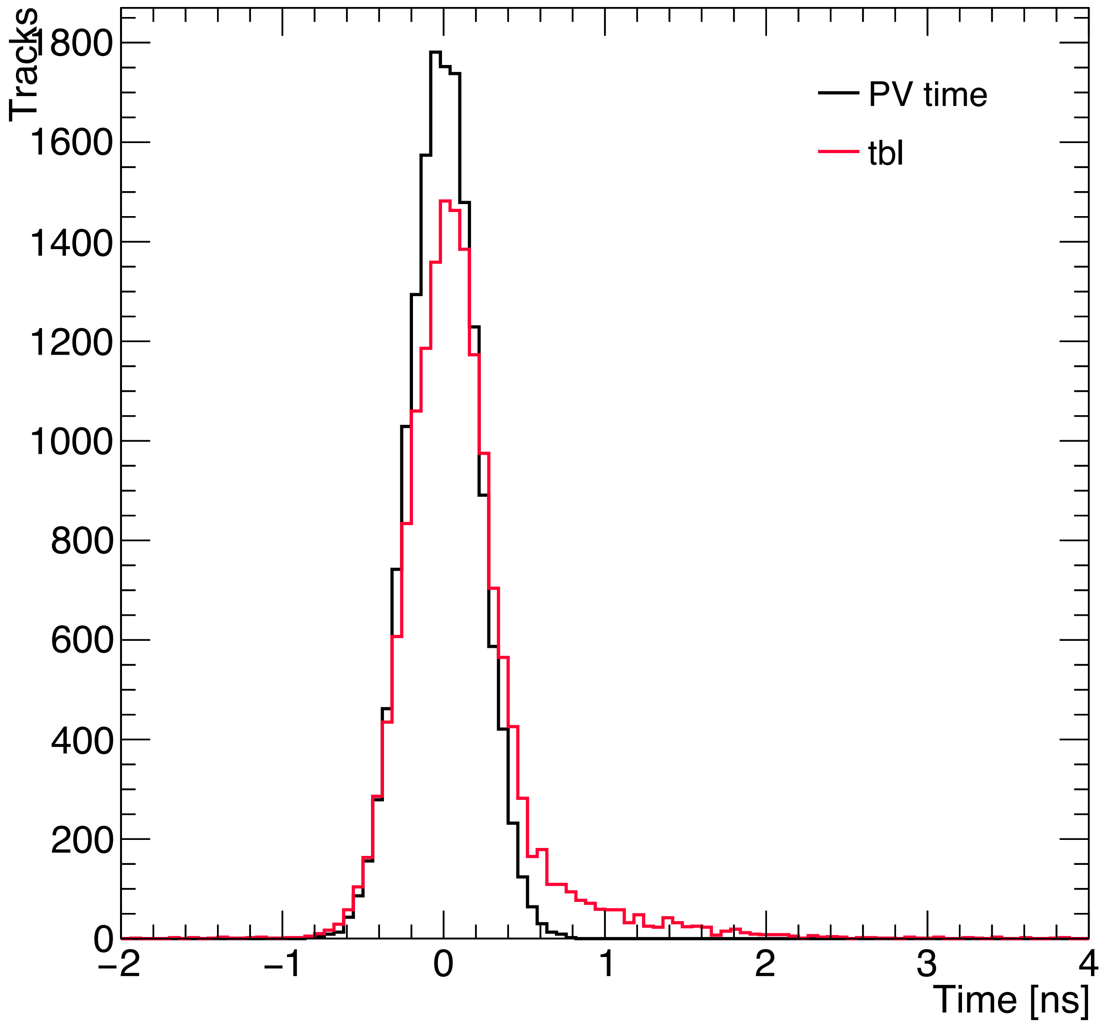
LumiTracker v2

- each plane: Timepix4 (~195 ps TDC) + fast sensor
- same mechanical structure as LumiTracker v1
- need to adapt the cooling plate/tubes to the Timepix4 size and shape
- DAQ to be fully developed

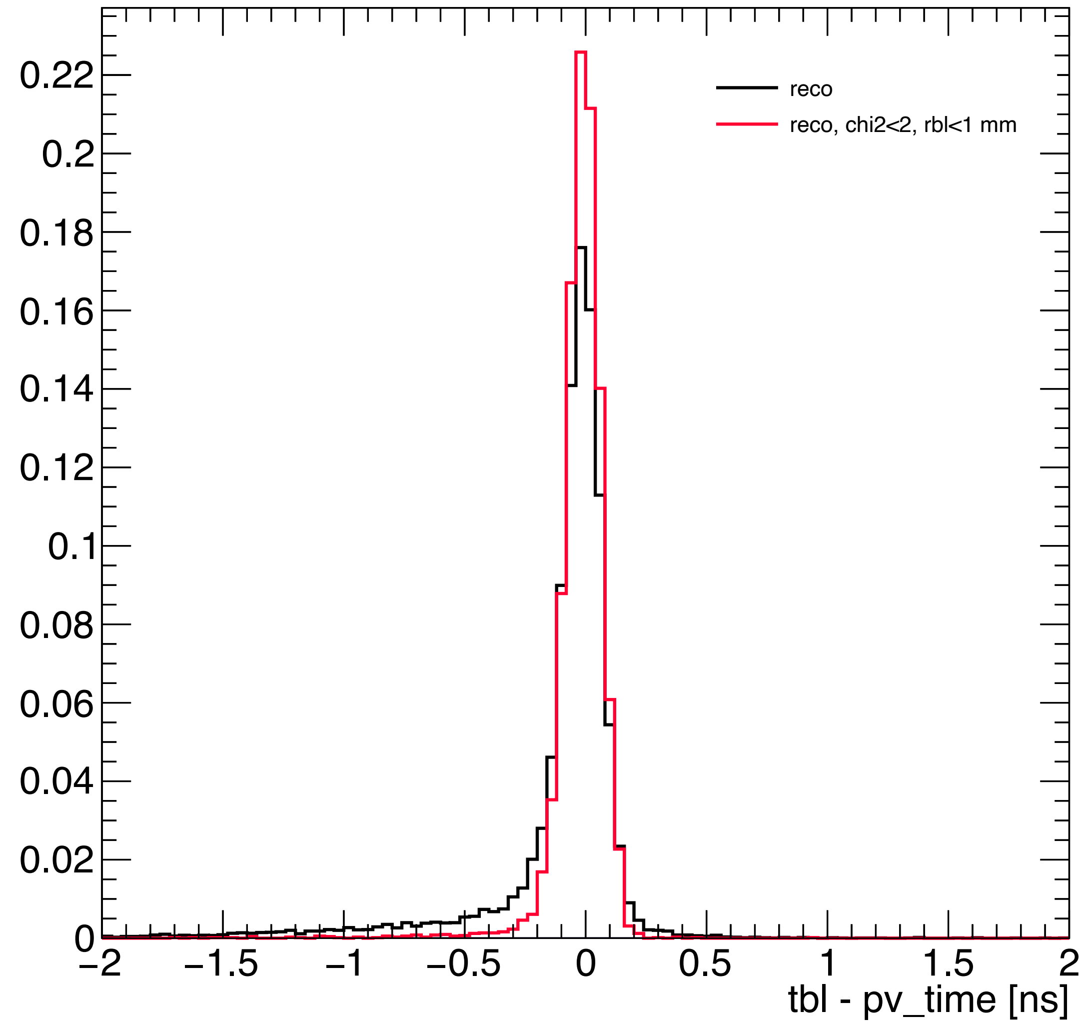
LumiTracker v2: performance

- first look at performance by smearing the true hit time by 150 ps

reconstructed tracks



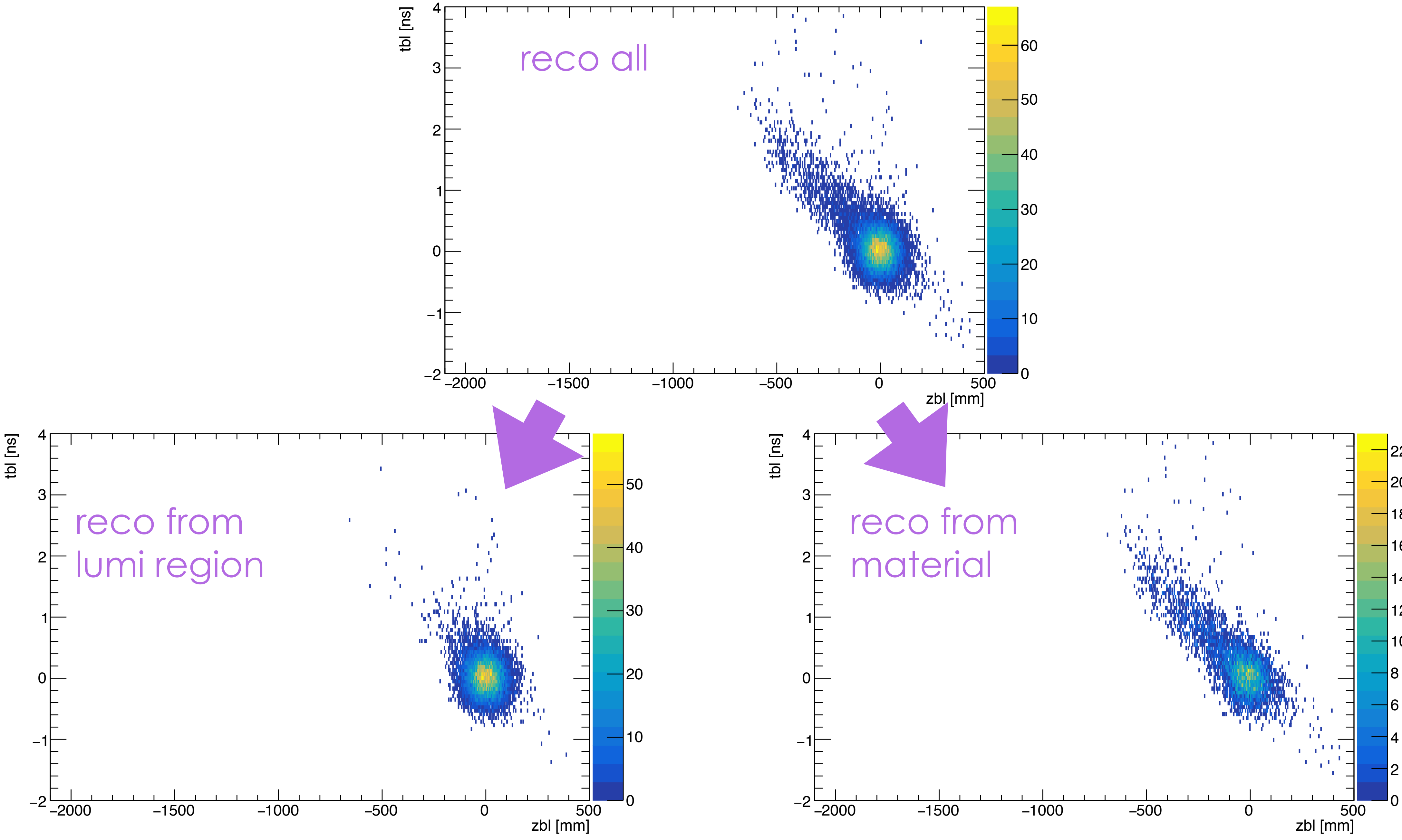
time resolution



- tail in reconstructed distribution due to secondaries from material interaction
- resolution with strict selection on track pointing: σ~70 ps, bias~-10 ps
- bias compatible with time of flight dispersion

LumiTracker v2: performance

- difficult to discriminate secondaries from primary tracks just by using timing or extrapolated position only
- …but potentially exploitation of the correlation could be very powerful (WIP)



Outlook

- feasibility studies, projected performance and integration with LHCb described in LHCb-INT-2020-026

LumiTracker v1 todo:

- validate the recent developments in mechanics and cooling with simulation
- converge on the choice of cooling substrate (further development probably needed)
- procurement of the parts ongoing in collaboration with TWOCRYST, currently missing:
  - hybrids
  - cables (partly to be redesigned)
  - OPBs
  - HV+LV modules
  - temperature and humidity sensors + ELMBs
- aiming at installation during YETS 24/25 (subject to approval)

LumiTracker v2:

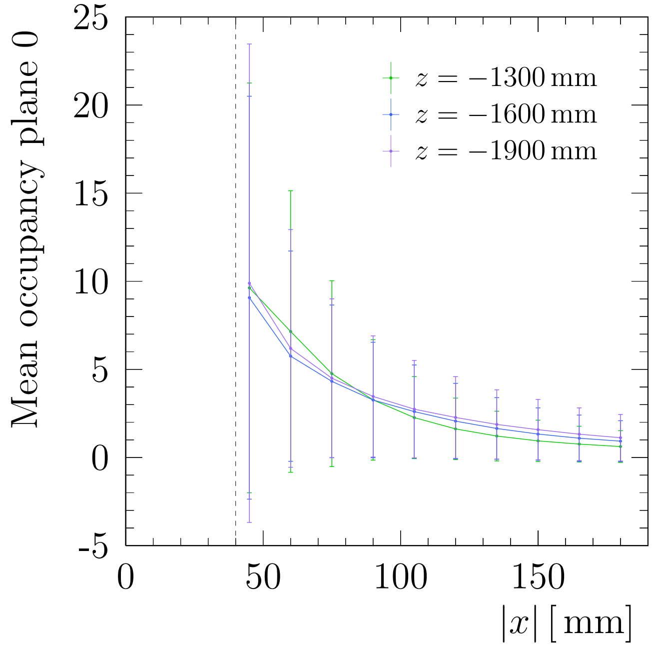
- very promising as luminometer and beam monitoring device
- could be exploited as platform for testing VELO upgrade 2 prototypes with LHC beam in Upgrade 1b

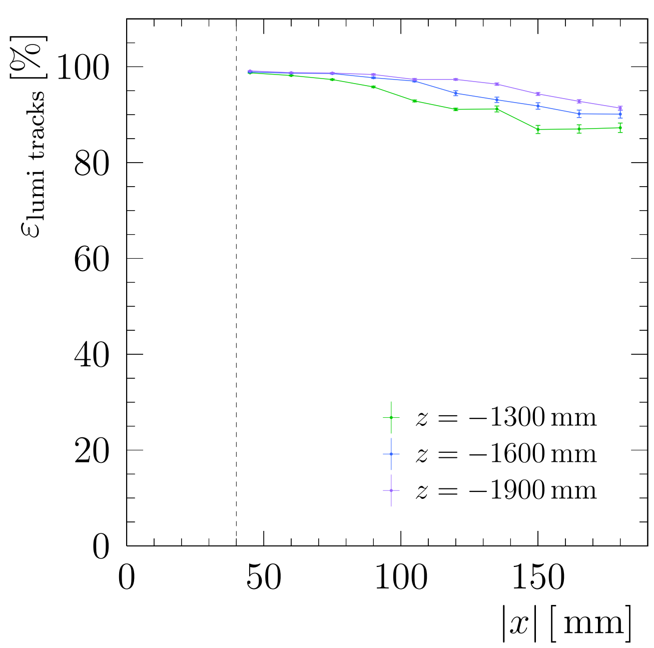
Hope to keep collaborating with TWOCRYST in the future!

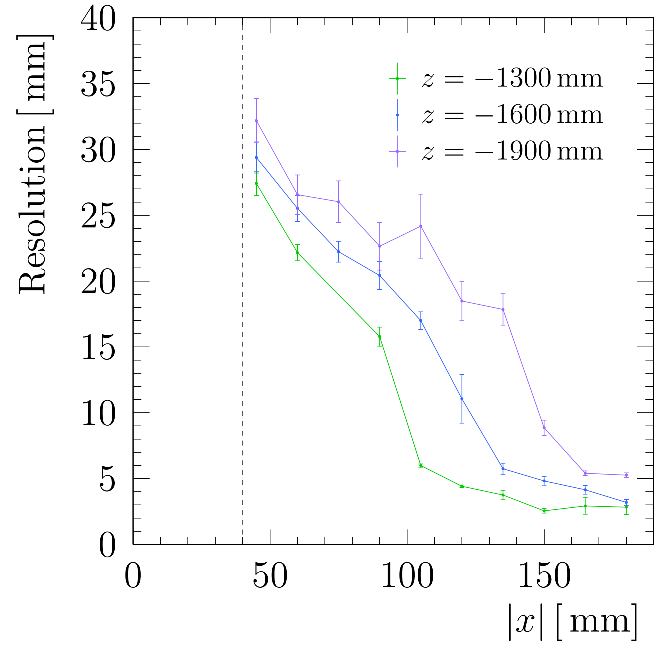
Back Up

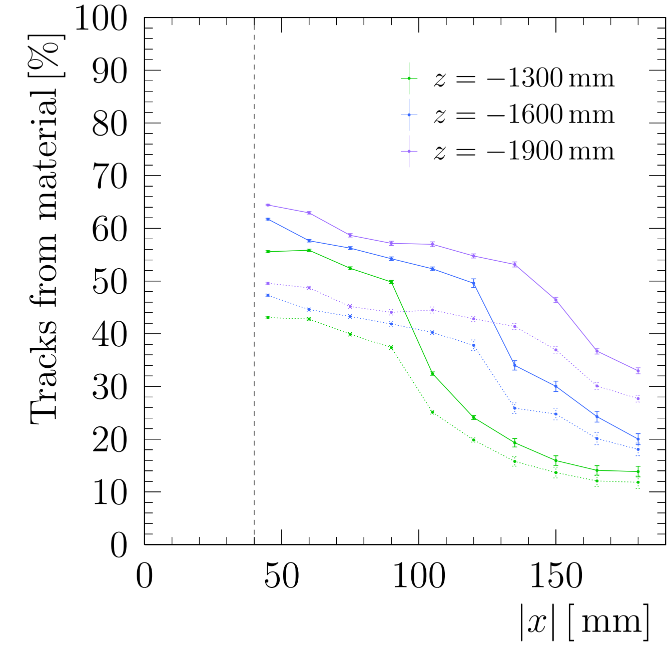
The idea: where?

- optimal location and detector layout choices mainly based on:
  - detector occupancy
  - fraction of reconstructed tracks from material interactions
  - resolution of the luminous region
  - reconstruction efficiency for lumi region tracks



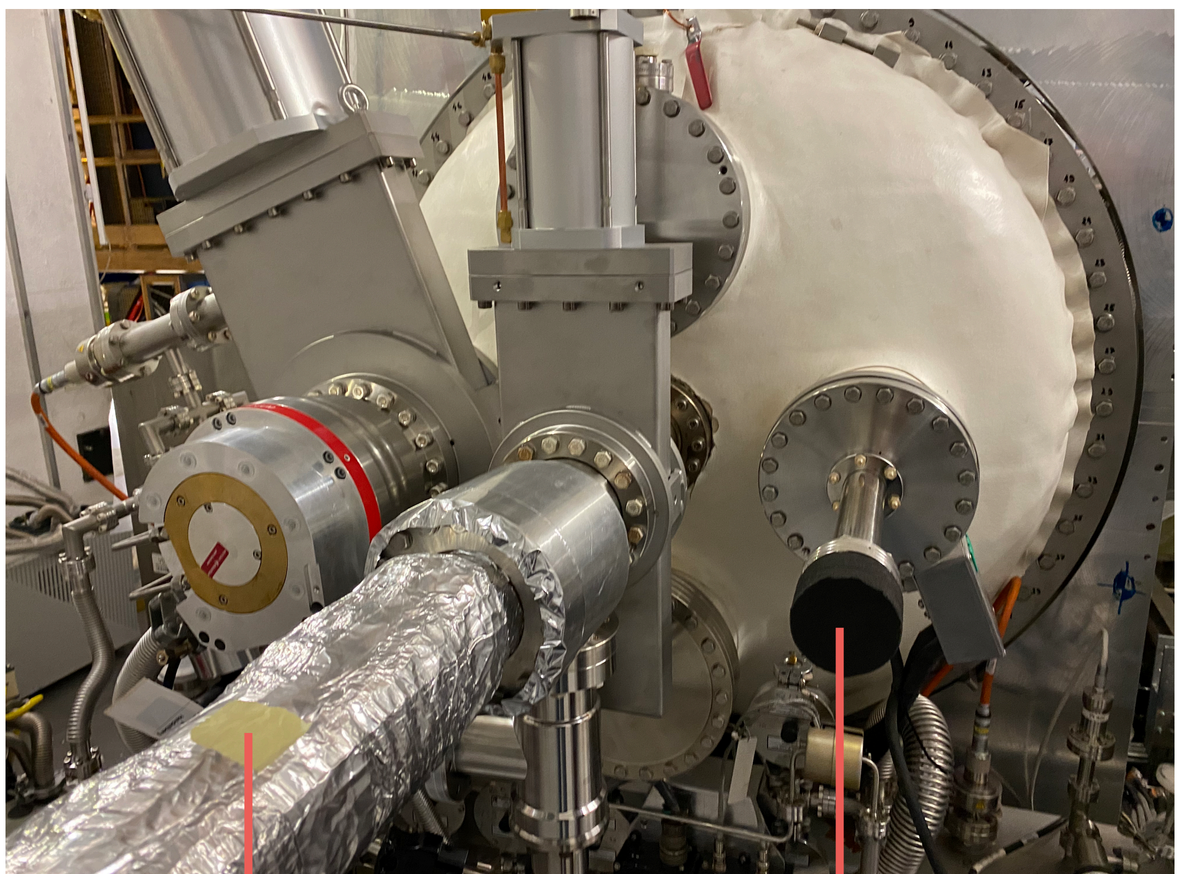


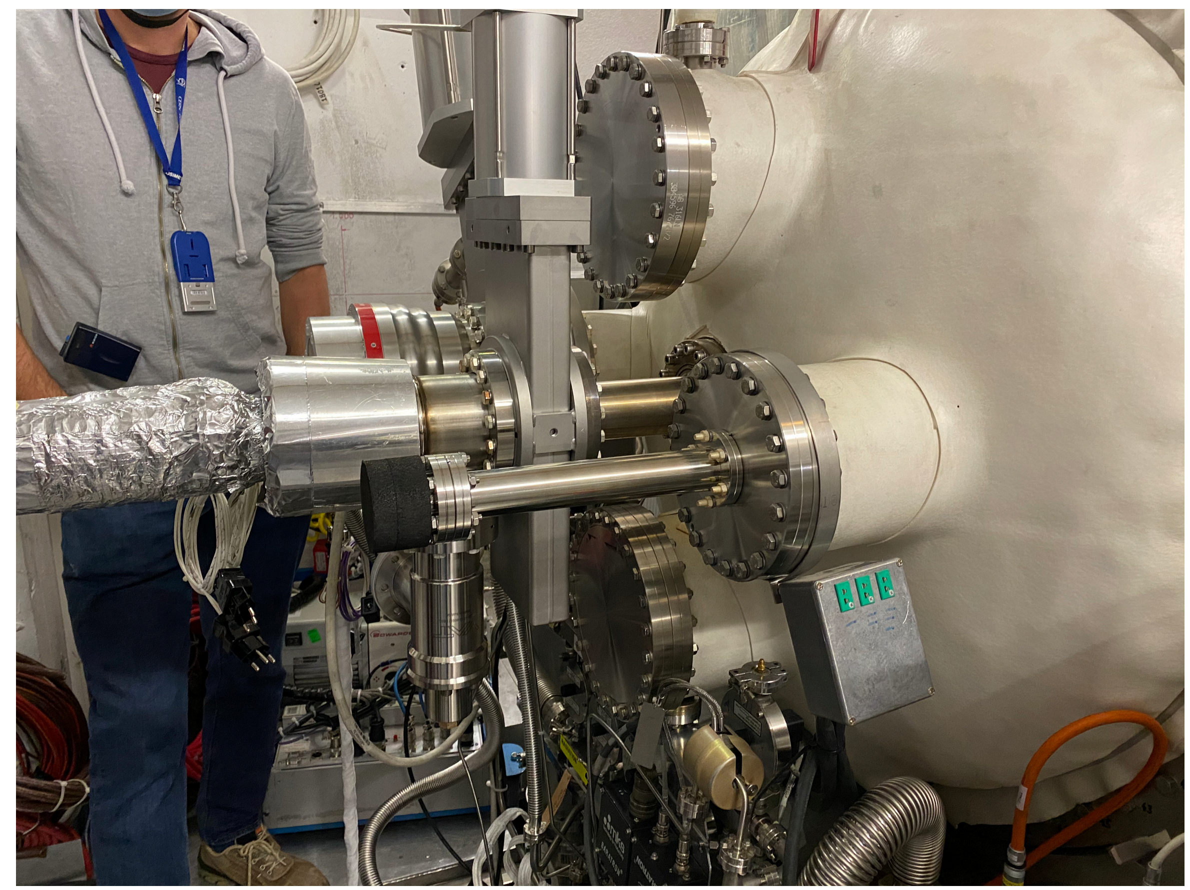




Rotation of LumiTracker

- Freek suggested to move the LumiTracker at positive y and rotate to better fit the cables
- The rotation mechanically would work between 30 and 60 deg



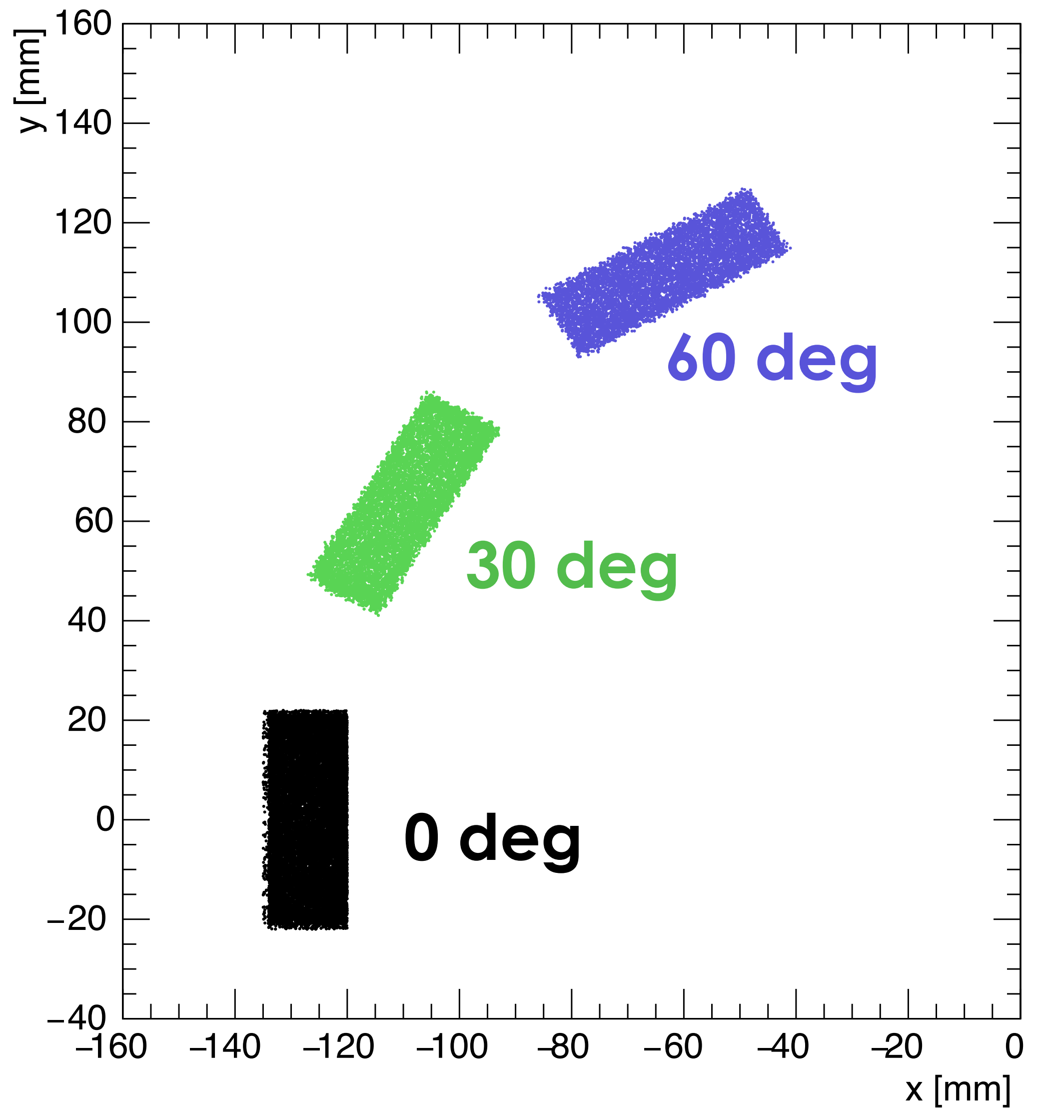


edge of PLUME box

a pipe will stick out from here

Optimisation of the angle

- if we keep the radial position constant, all the considerations done so far for the position are still valid
- the difference is that now we have staggering both in x and y



Optimisation of the angle