A proximity-focusing RICH for the ePIC electron endcap

BNL
Duke
INFN Trieste
MSU
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…

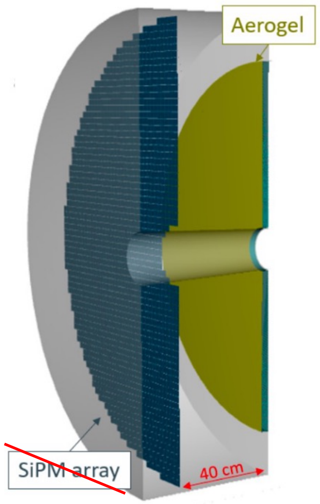
ePIC Cherenkov PID WG meeting, November 4th, 2022

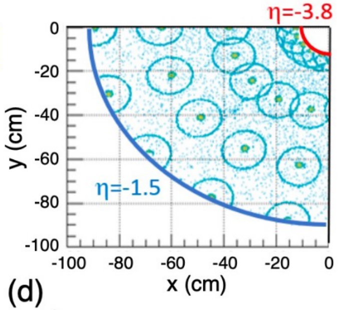
Introduction

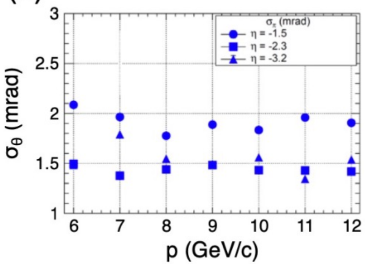
Detector concept

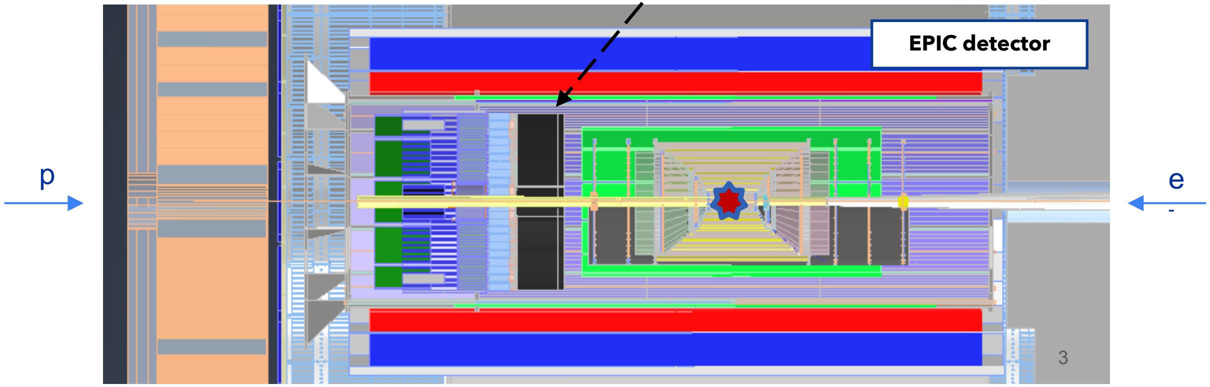
- Recycle pfRICH concept & simulation materials from the ATHENA EIC proposal
  - A “simple” proximity focusing RICH
  - n ~ 1.020 aerogel
  - ~40 cm long expansion volume
- Convert it into a pfRICH+LAPPD configuration ...
- ... complemented by a high-performance sampling digitizer electronics to provide ~10ps timing reference in addition to imaging

Inner radius	~59 mm
Outer radius	~650 mm
Total length	~540 mm





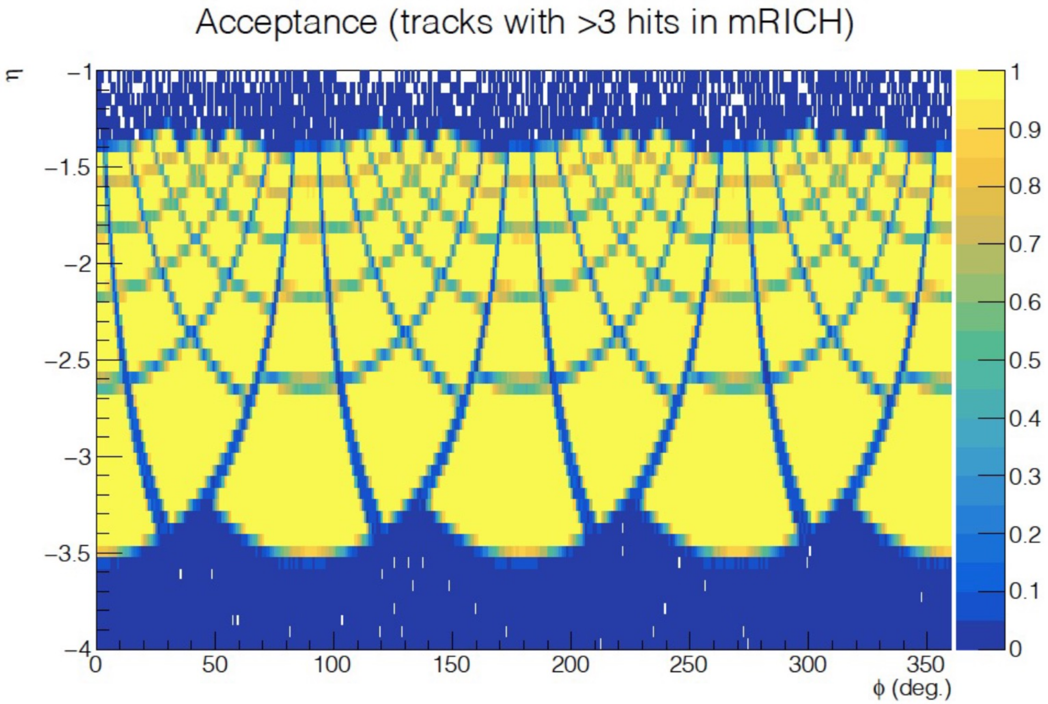




~9.5m along the beam line

Objective(s) as formulated in September 2021

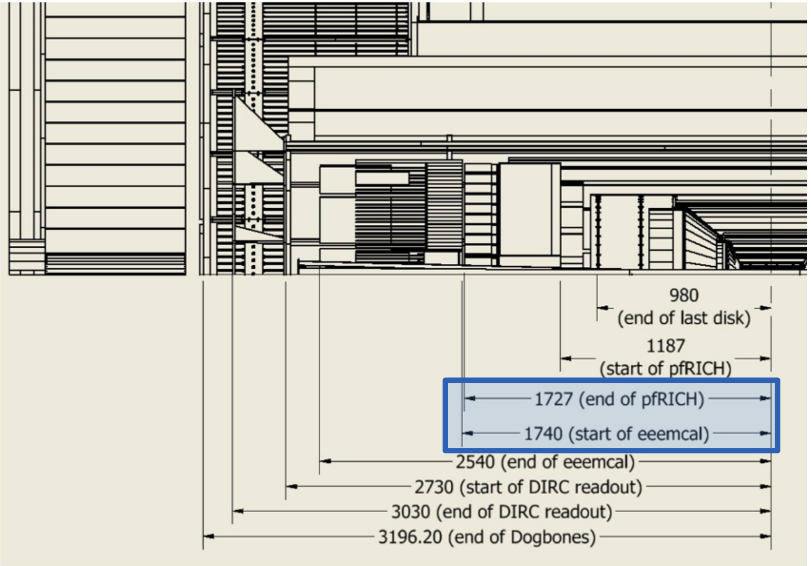
- Look for a “simple” RICH version which
  - Would meet the YR requirements
  - Is kind of “safer” & easier to defend at the proposal writing stage, given the absence of a direct experimental proof of a π/K separation reach by mRICH
  - Has perhaps a similar material budget
  - Is easier to have implemented in the ePIC ~~ATHENA~~ simulation (and reconstruction!) sequence NOW
  - Does not preclude one from thinking of a Fresnel-lens-based upgrade to boost the performance

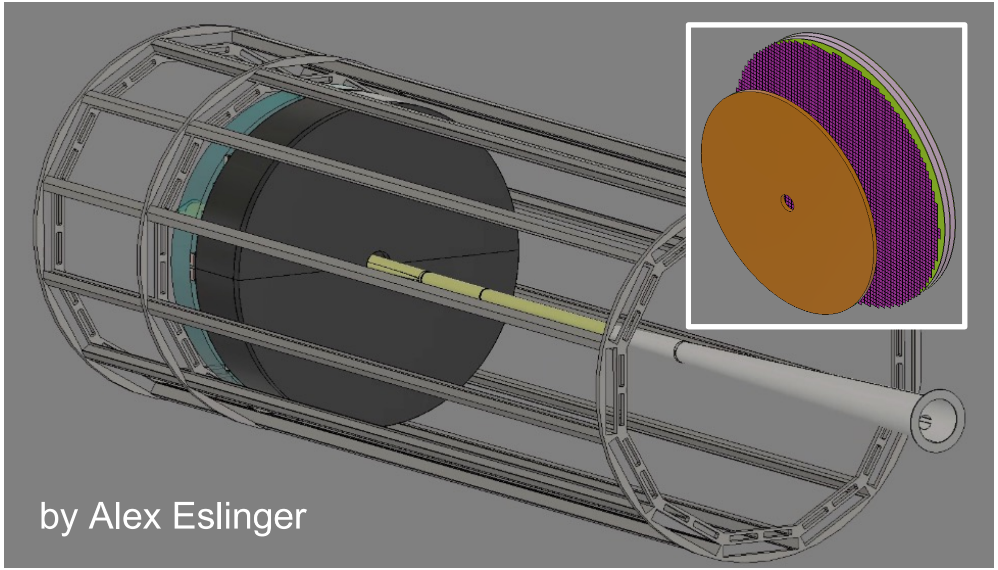


π^- p:05-11.5 GeV/c && $-4 < \eta < -1$ and full azimuth
vertex (x,y,z) = (0,0,0)
Efficiency = (Tracks with at least 3 hit in mRICH)/ (all tracks)

The Yellow Report leaves some wiggle room for interpretation for the hadron PID in the electron endcap: 3σ π/K separation up to 7 GeV/c (page 21) or up to 10 GeV/c (table 3.1)

Boundary conditions in the ePIC e-endcap





Inner radius	59 mm
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Expansion volume length?

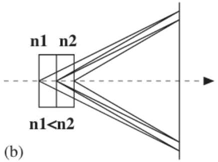
- Basically, need to resize ATHENA standalone eRICH geometry, move it to a proper location, and
  - Replace SiPM panels by HRPPDs (see later)
  - Come up with a realistic aerogel tiling scheme
  - Add conical (and other?) mirrors to improve acceptance
  - Come up with a credible integration scheme

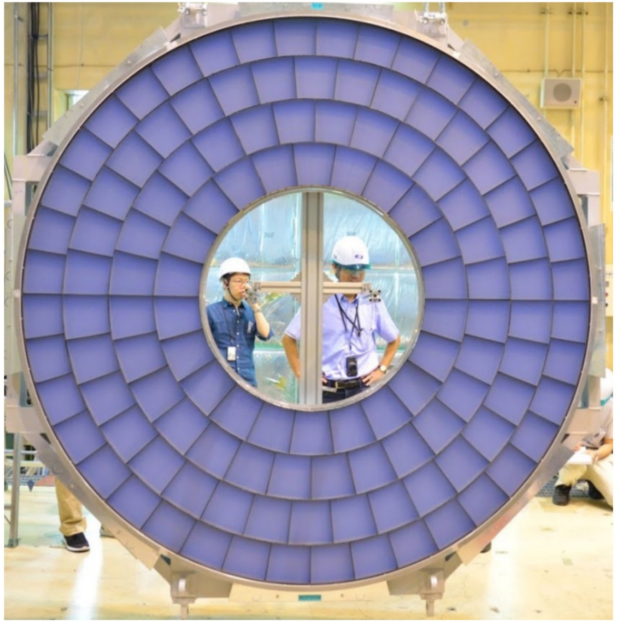
Design considerations

Aerogel

- Moving forward with a 3cm thick n = 1.019 aerogel may not be a good strategy, since LAPPD QE will never be as high as SiPM PDE, therefore $<n_{pe}>$ will go down compared to ATHENA

- Where from can we get the missing photons?
  - Increase aerogel refractive index at a cost of 1-2 GeV/c of the momentum reach?
    - Absorption goes up
    - Emission point uncertainly goes up (following increase in the saturated Cherenkov angle)
  - Increase aerogel thickness?
    - Emission point uncertainty goes up (but will be partly compensated by a high LAPPD spatial resolution on the sensor end)
    - Be aware: photon count **will not increase proportionally** (because of the absorption)
  - Lower down the ~350nm acrylic wave length cutoff?
  - Use Belle II scheme with two different aerogel types?





Belle II aerogel segmentation

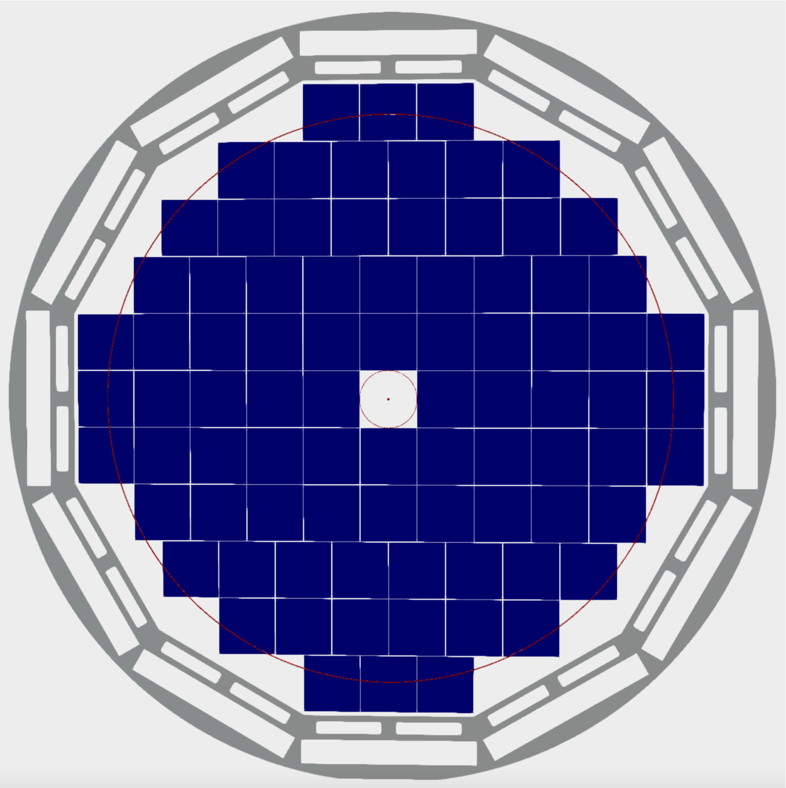
Photosensors: HRPPDs by Incom Inc.

- Low dark count rate and easier integration (as compared to SiPMs)
- High single photon timing resolution
- Low cost (as compared to other MCP-PMTs)
- High resolution t_0 comes as a bonus (provides by photons produced in the window)

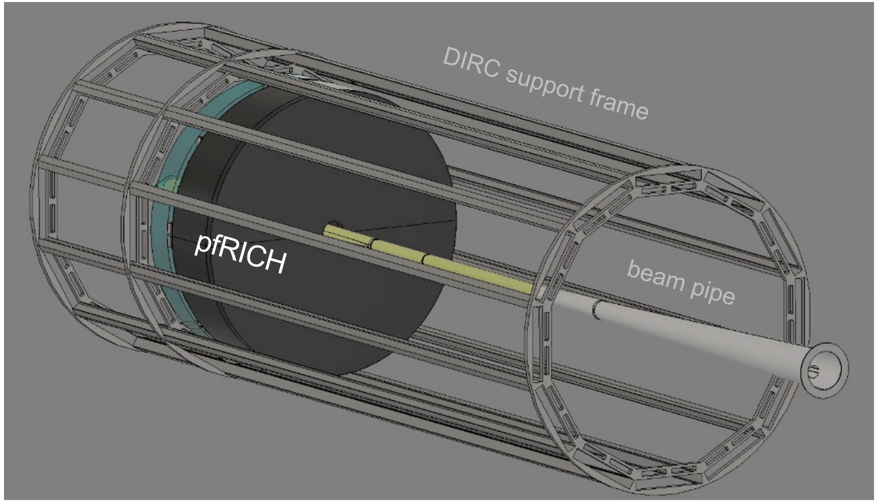
- Should work well in a ~2T field
- Most part of the active LAPPD R&D for EIC is done by the pfRICH-affiliated institutions

- PDE will be lower compared to the SiPMs (and yet needs to be tuned for aerogel radiator)
- Design needs to be improved [there is a substantial ongoing effort in this direction]
    - HV connections
    - Geometric formfactor
    - Material budget

Sensor plane segmentation



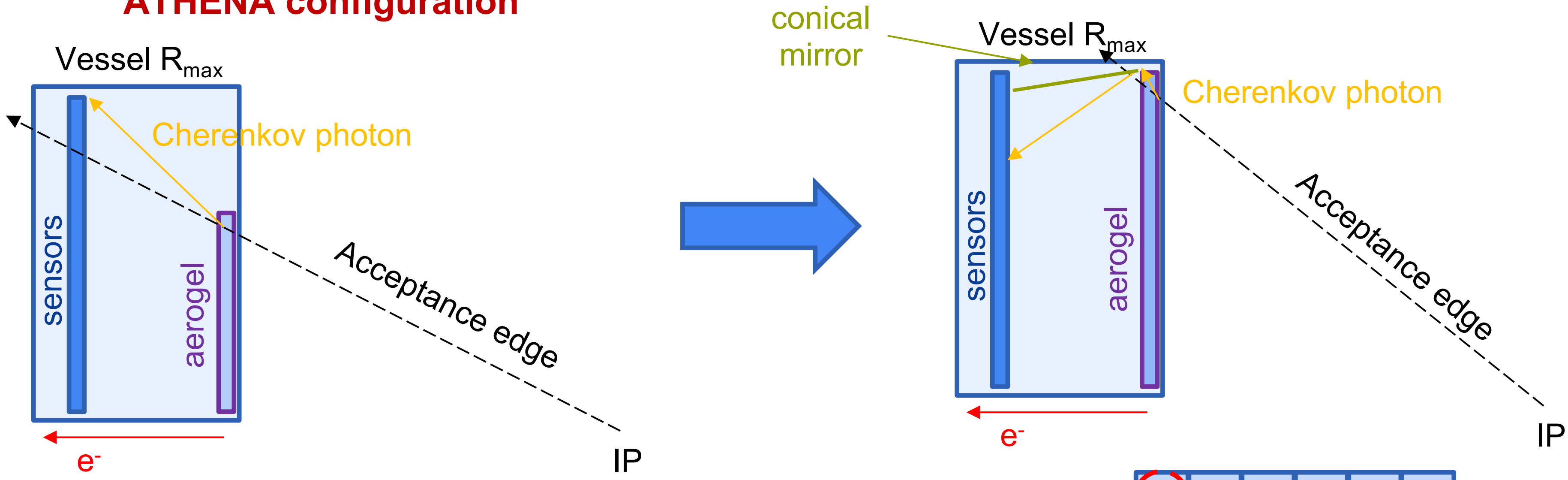
84 HRPPD tiles total



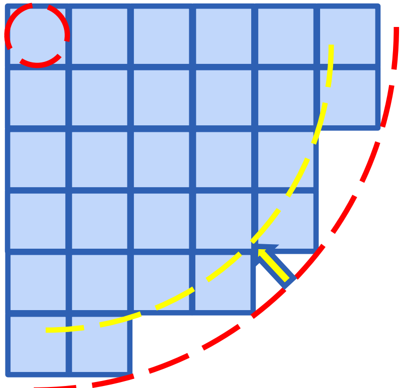
- Flat sensor surface with minimal gaps
- 10cm HRPPDs (12cm x 12cm footprint), either DC- or capacitively coupled
- Grey structure: DIRC support frame boundary

Acceptance boundaries optimization

ATHENA configuration

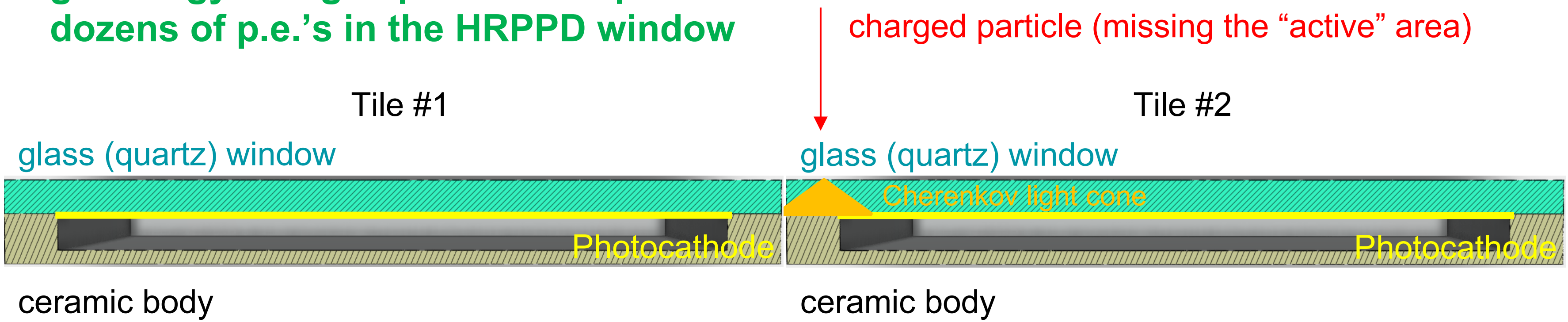


- No reason to lose acceptance *in* η
  - (1) Increase aerogel radius all the way up to $\sim R_{max}$
  - (2) Install a cylindrical mirror at $\sim R_{max}$
- No reason to lose acceptance *on the sensor plane*
  - Use a conical (or a piece-wise flat *tilted*) mirror at $\sim R_{min}$ & $\sim R_{max}$



Geometric efficiency for a t_0 reference

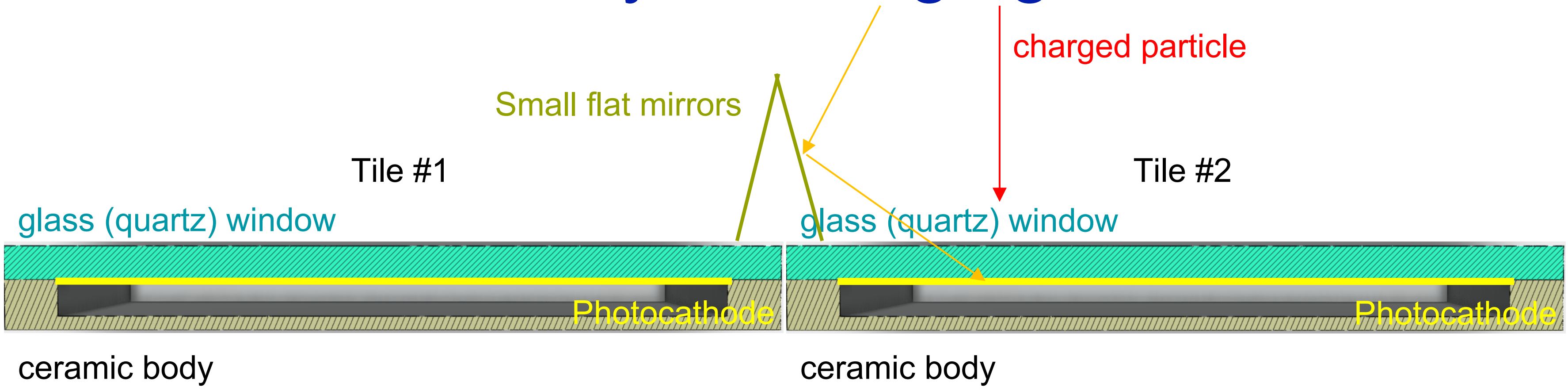
High energy charged particle will produce dozens of p.e.'s in the HRPPD window



- Even that the HRPPD active area (the photocathode and the MCP stack) is much smaller than the tile footprint, the Cherenkov light cone spot in a 5 mm thick (quartz) window has a base of ~11 mm diameter
  - By making the edge area reflective and / or tapered and / or perhaps just relying on a TIR, one should be able to gain timing performance over the whole surface, even though with a degraded resolution towards the tile edges, apparently

Tiling a flat sensor surface without gaps must be a clear benefit

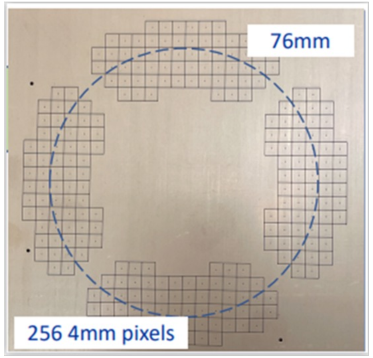
Geometric efficiency for imaging

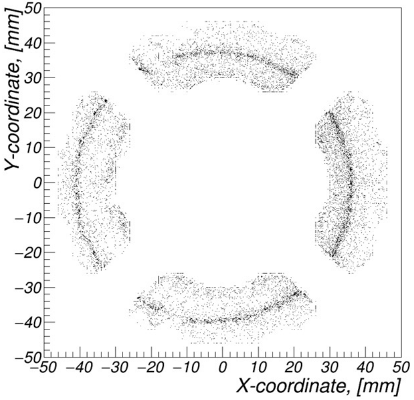


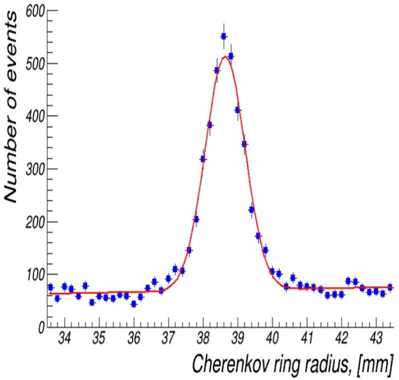
- One should seemingly be able to “save” the Cherenkov photons, which would otherwise miss the photocathode, by funneling them away from the dead area
  - The reconstruction procedure can certainly be adjusted to handle such cases
  - Requires geometry optimization

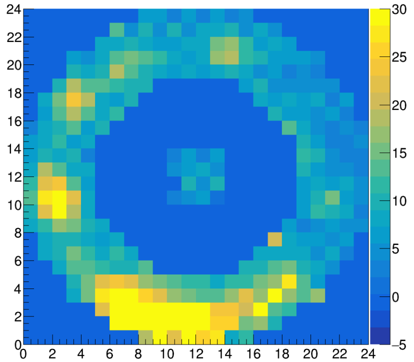
Sensor pixellation

- Input considerations (assume n ~ 1.02 aerogel):
  - Cherenkov saturation angle ~200 mrad times ~40 cm expansion volume -> ~160 mm diameter rings
  - <n_{pe}> ~ 10, on a good day
  - We have beam data showing 4 mm pixellation is good enough to achieve single photon ring radius resolution ~600 μm, even without signal pre-amplification





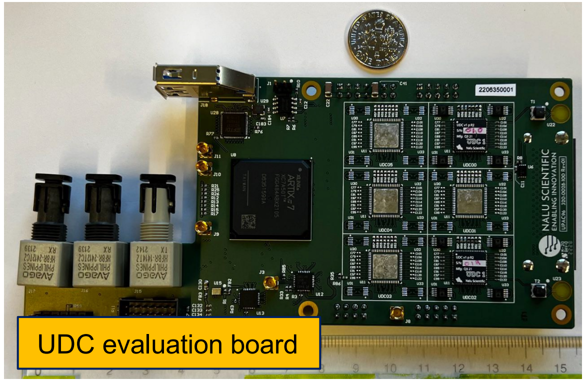


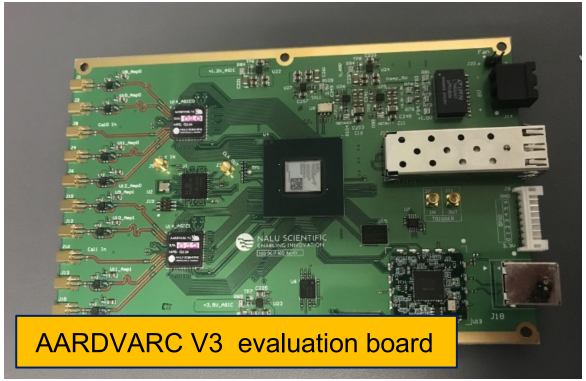


Let's assume occupancy is not a problem for ~4 mm pixels

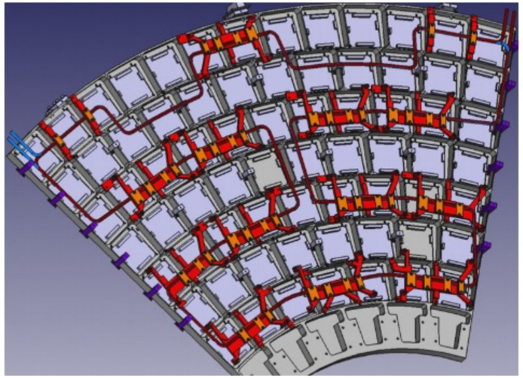
Readout electronics solution

- Assume 24x24 pixellation suffices (~4.2mm pads) -> 576 pixels per 12x12 cm^2 footprint
- A hybrid of Nalu Scientific UDC and AARDVARC v4 chips as a "reference ASIC"?
  - 16-channel ASICs (would be better to have 32- or 64-channel ones, of course) -> defines the layout!
  - Will need a 20 dB preamplifier on die (>12mW additional power per channel)
  - ~10GS/s digitizer, ~2GHz ABW, feature extraction, streaming capability (whatever it means), etc.
  - Few kW of power dissipation for the whole system seems to be a real-life estimate
  - A straightforward water-cooling system (layout a la Belle II) would seemingly suffice
  - Anticipated integration scheme allows for 35-40cm expansion volume





Belle II cooling scheme



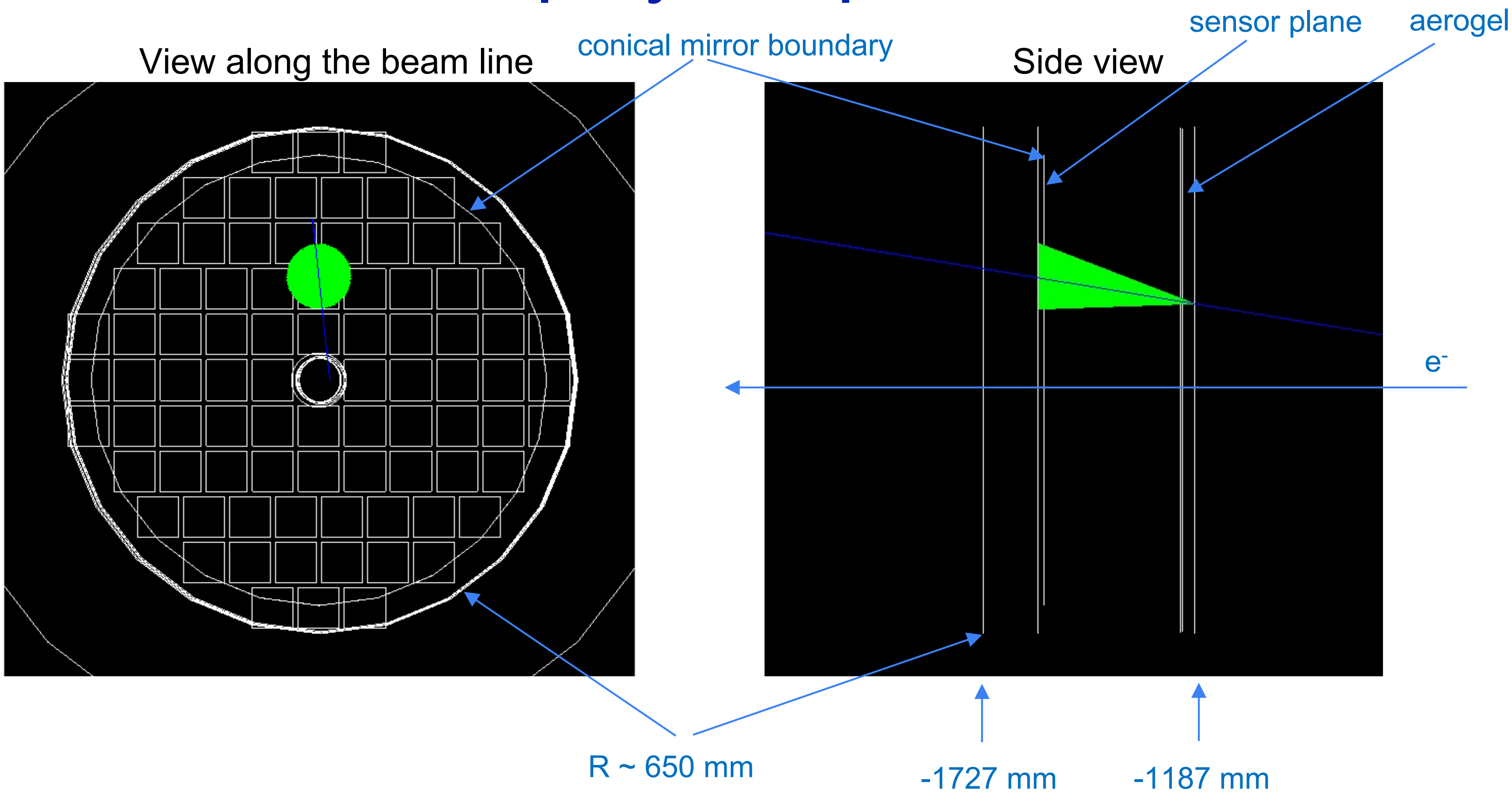
GEANT implementation

Technical details

- 3cm thick n = 1.020 aerogel (no segmentation yet)
- Vessel length as given by the project (54 cm)
- Expansion volume 37 cm
- Tile segmentation matching suggested HRPPD formfactor
- Active area 80% of the tile footprint, as suggested by Incom for future HRPPD models

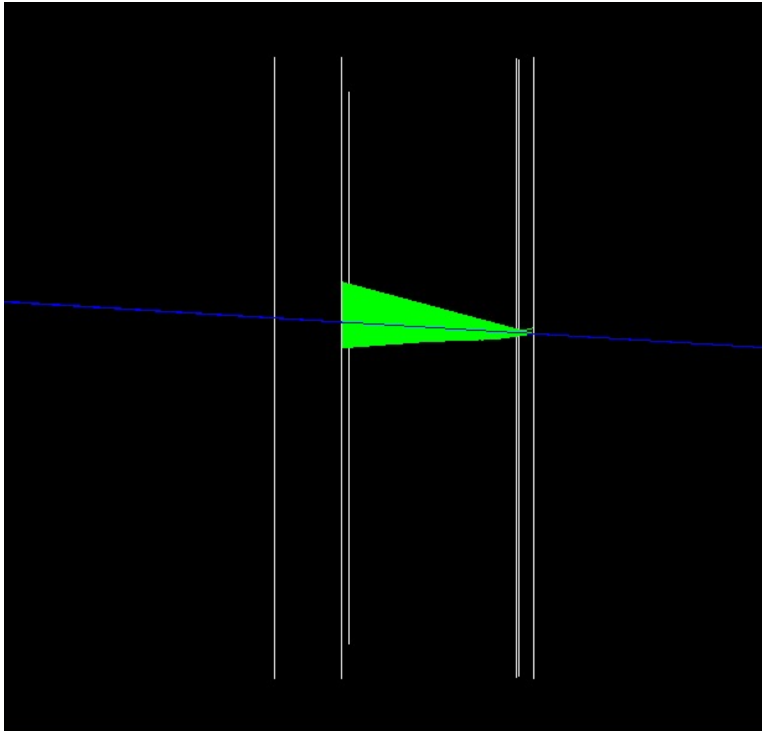
- Work in still in the "acceptance tuning" stage
- "Official" ePIC IRT codes are integrated, ...
- ...yet need to teach IRT algorithm how to work with conical mirrors and multiple optical paths for a given combination of the photon emission point and hit location

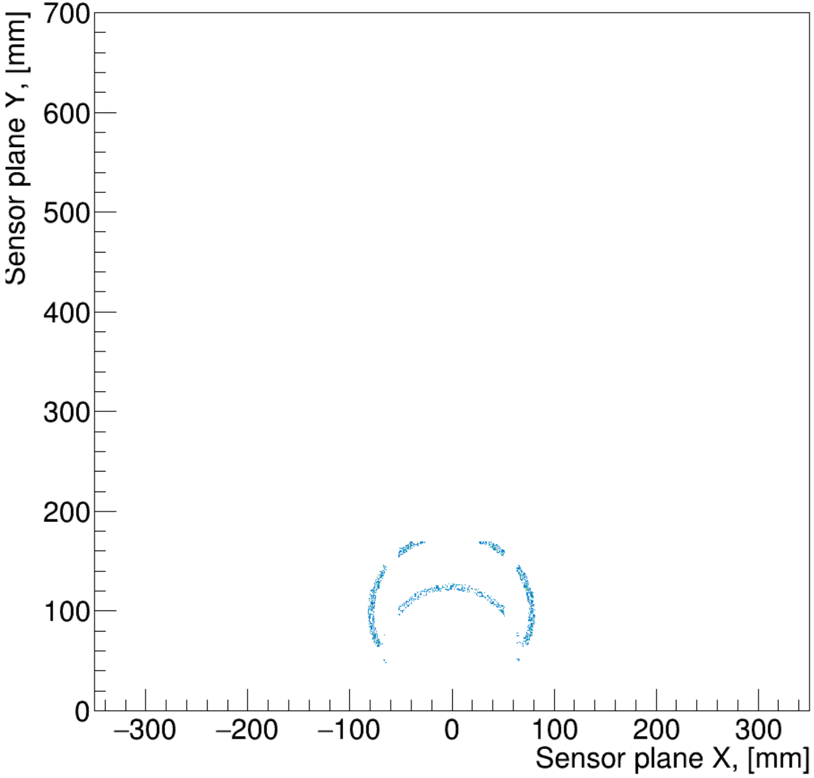
GEANT event display snapshots



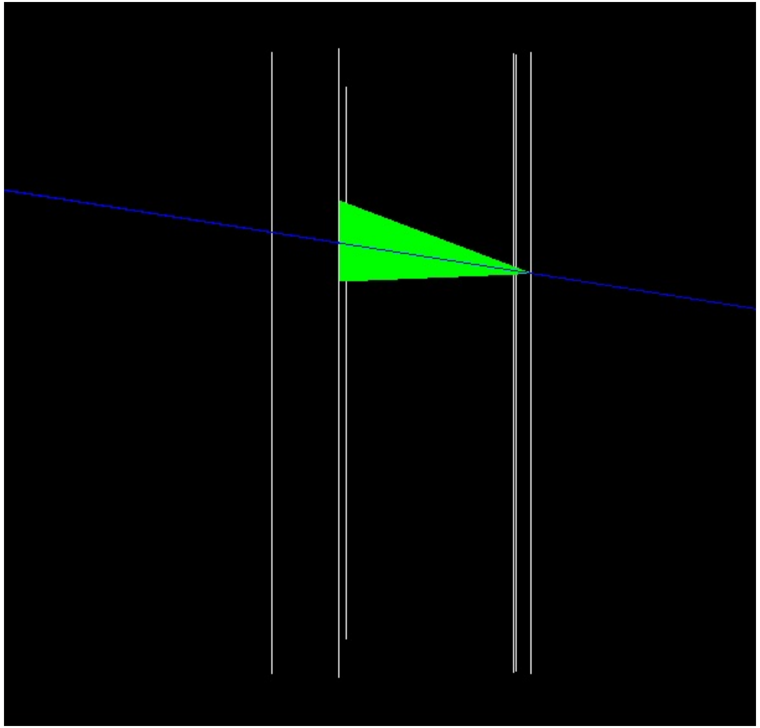
8 GeV/c pions at η = -2.5 (accumulated over several events)

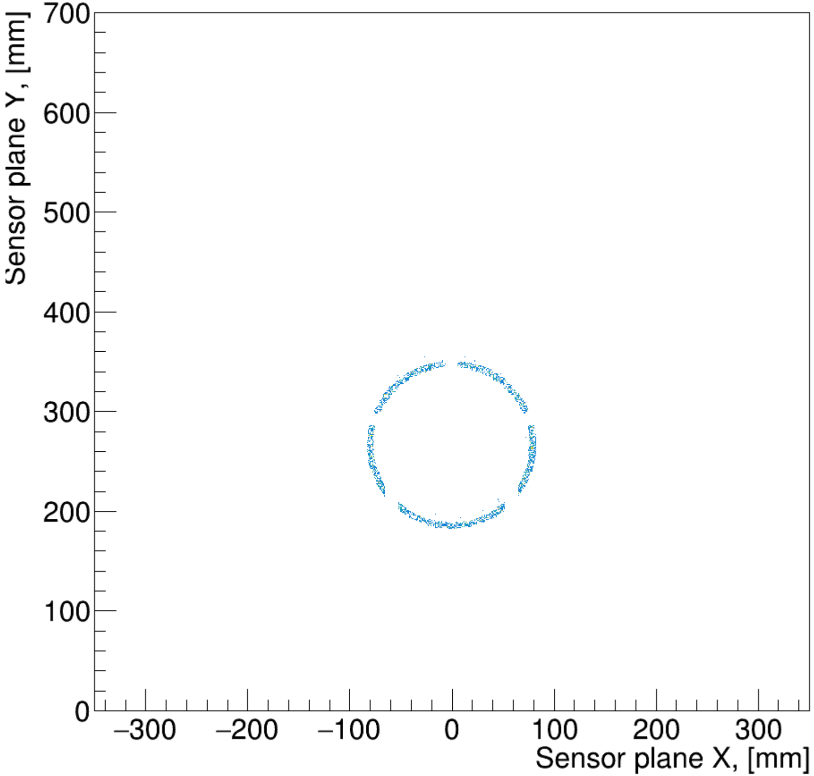
Acceptance boundaries & rings: η = -3.5



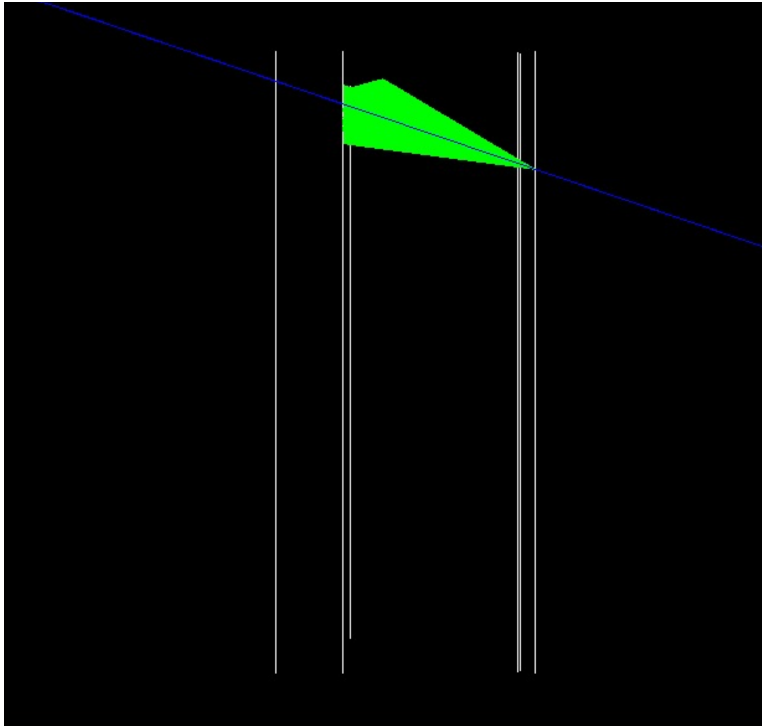


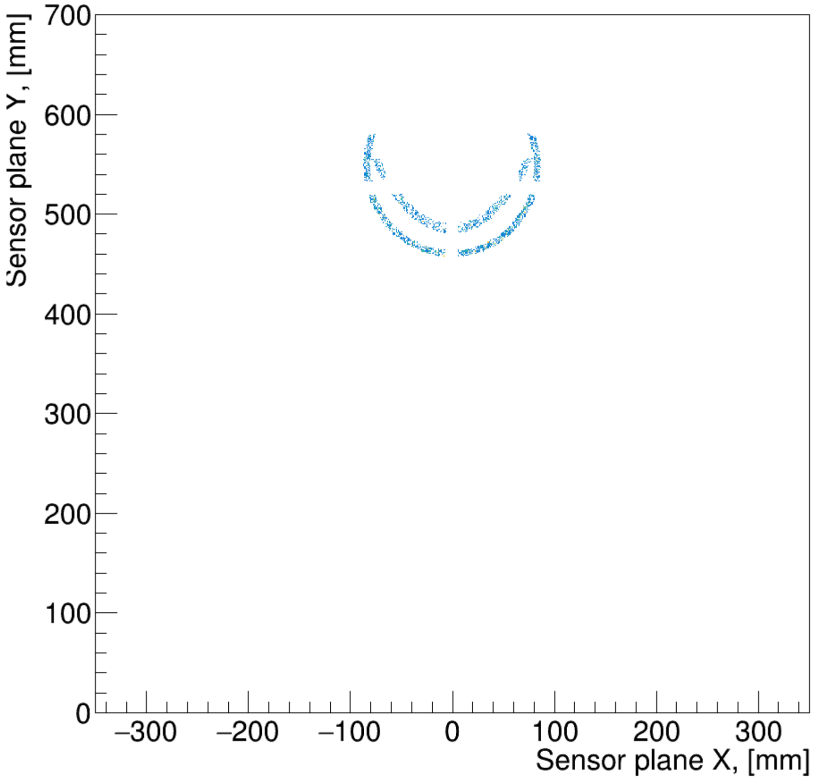
Acceptance boundaries & rings: η = -2.5



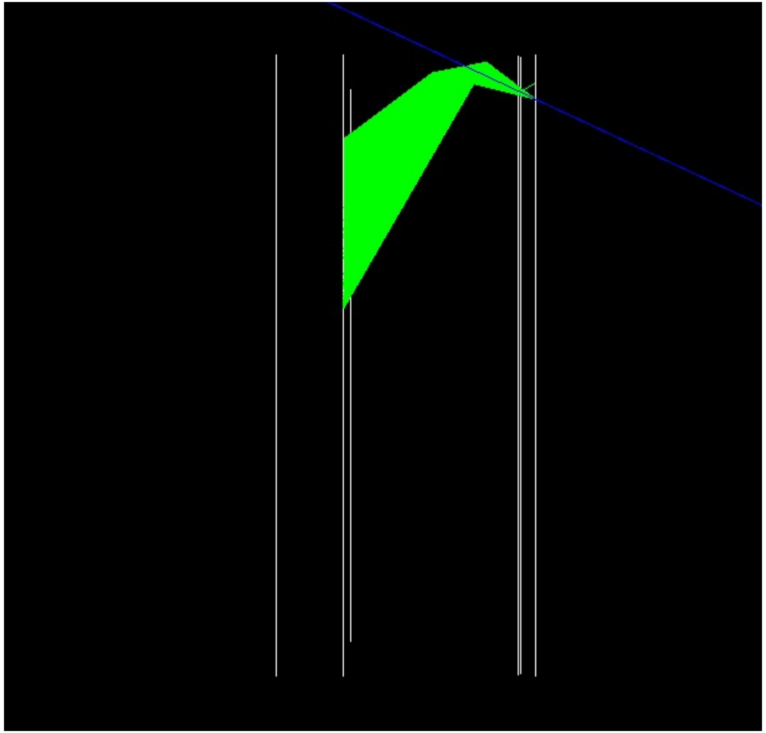


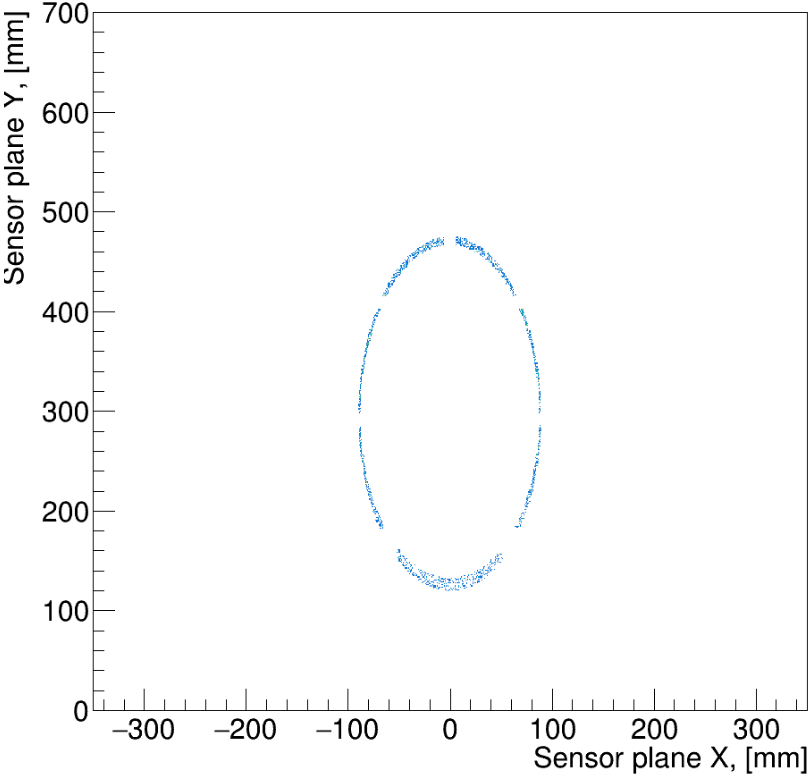
Acceptance boundaries & rings: η = -1.8





Acceptance boundaries & rings: η = -1.5





All in all, looks like pfRICH will have a healthy acceptance in η range between -1.5 and -3.5

Outlook

- pfRICH performance modeling (in a standalone GEANT4 suite)
  - Geometry, acceptance, sensor QE, aerogel configuration, photon count
  - Use (and update accordingly) the ”official” IRT library for the performance evaluation
  - Move the stuff to the ePIC official software framework once tuning is over
- Other ePIC detectors performance modeling (like e-endcap EmCal)
  - Keep dd4hep geometry database (including realistic pfRICH material) up to date
- Physics modeling
  - Use ePIC software framework output + a Delphes-like parameterization of the pfRICH-related PID
- Engineering design, cooling, services: have it all “done” on a ~month time scale
- Wrap this first effort up in a concise document