A proximity-focusing RICH for the ePIC electron endcap

BNL
Duke
INFN Trieste
MSU
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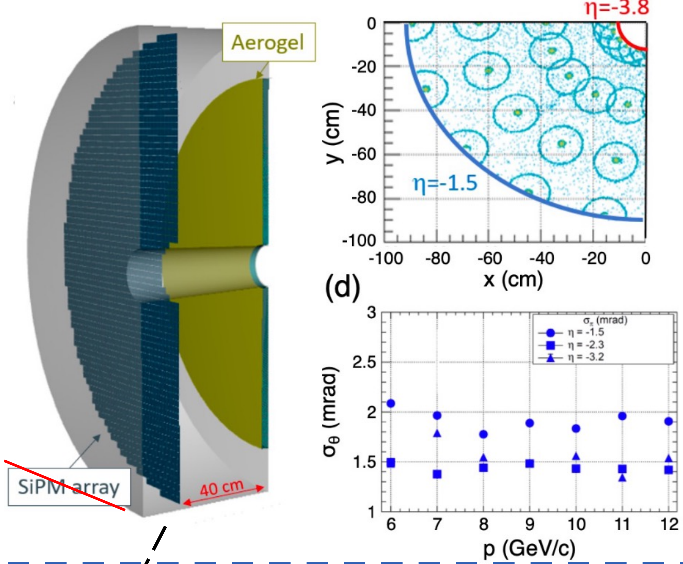
[IJS Ljubljana]
…

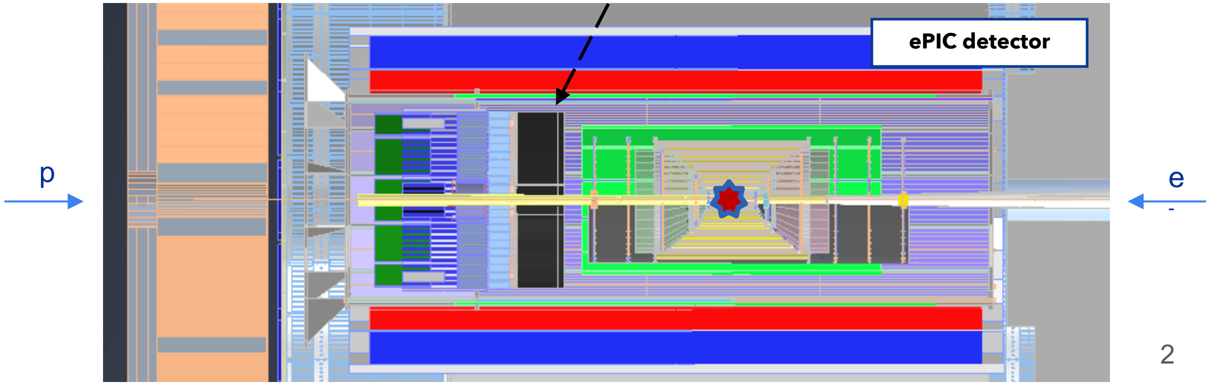
Detector concept

- Recycle pfRICH concept & simulation materials from the ATHENA EIC proposal
  - A “simple” proximity focusing RICH
  - n ~ 1.020 – 1.050 aerogel (perhaps in a two-layer configuration)
  - ~40 cm long expansion volume
- Convert it into a pfRICH+LAPPD configuration ...
- ... complemented by a high-performance electronics to provide ~10ps timing reference in addition to imaging

ATHENA proposal



Yellow Report requirement:
3σ π/K separation up to 7 GeV/c



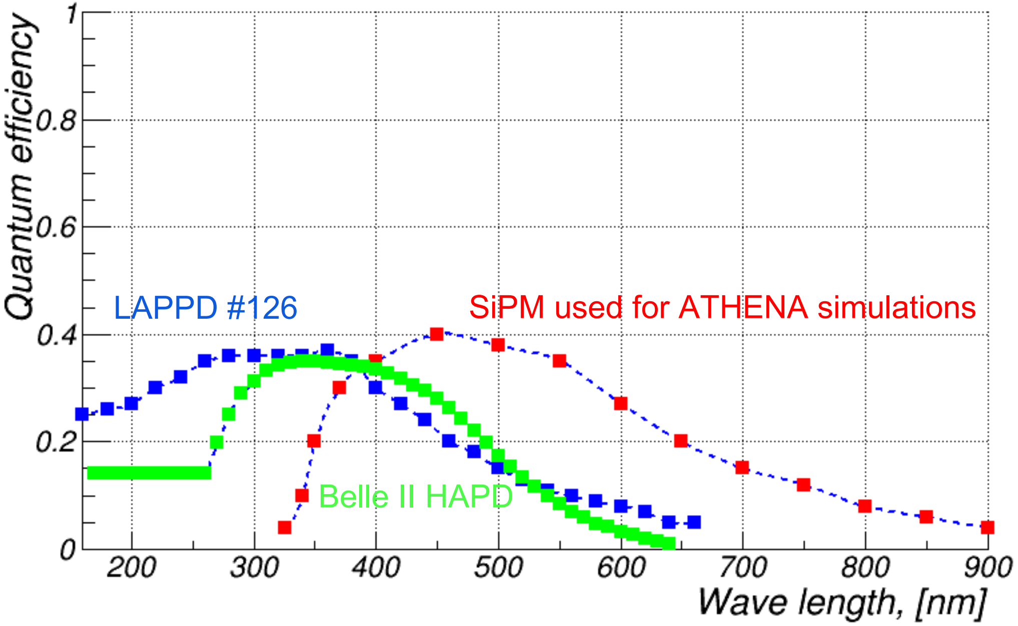
Design considerations

Aerogel

ATHENA configuration: <n> ~ 1.019, acrylic filter with a 350nm cutoff, SiPMs with a peak QE ~ 450 nm -> $<N_{pe}>$ ~ 10

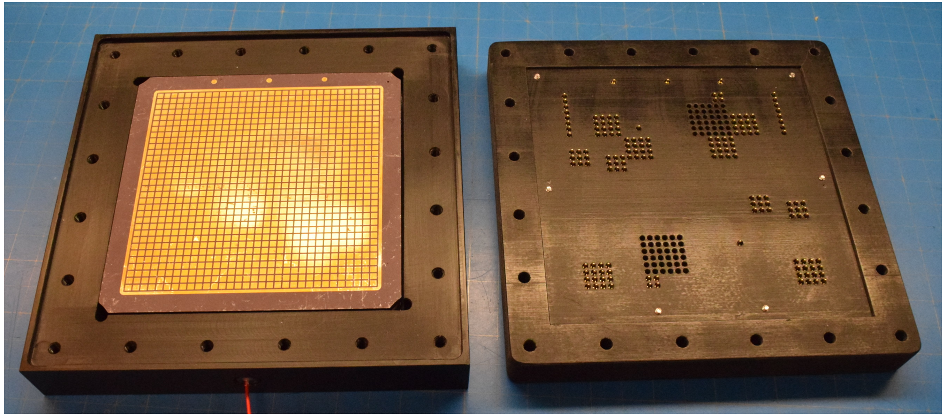
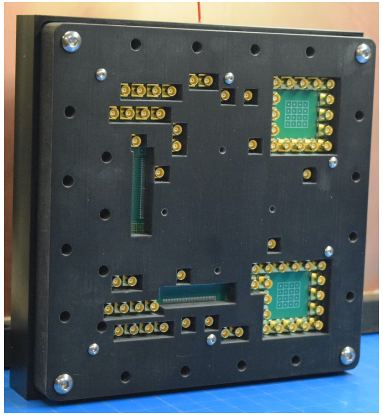
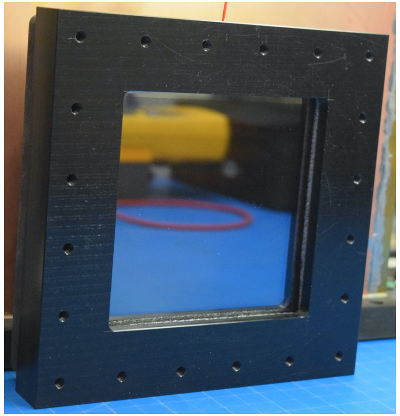
- Consider a different strategy for ePIC pfRICH (similar to Belle II)
  - Rely on aerogel with a higher refractive index and higher transparency in the near UV range
  - Do not use any acrylic filter
  - Fully exploit HRPPD UV QE range

- EIC project meeting with M.Tabata (Chiba University) in December 2022:
  - Belle II - like aerogel can be produced
  - Refractive index up to ~1.05 (ideally: 1.03)
  - Tile size up to ~20cm
  - Smaller sizes can probably even be manufactured with transparent tile sides



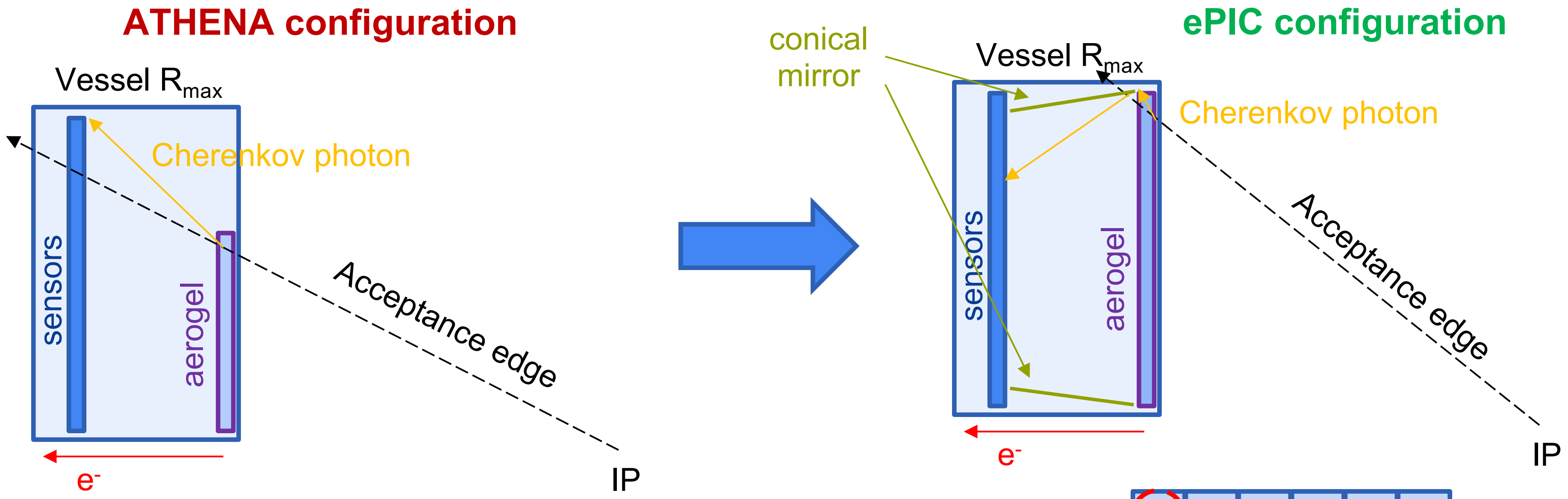
Photosensors: HRPPDs by Incom Inc.

- Low dark count rate and easier integration (as compared to SiPMs)
- High single photon timing resolution
- Low cost (as compared to other MCP-PMTs)
- Should work well in a ~1.7 T field
- High resolution t_0 comes as a bonus (provides by photons produced in the quartz window)

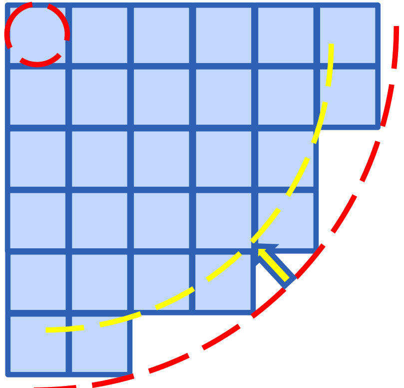




- Most part of the active LAPPD R&D for EIC is done by the pfRICH-affiliated institutions

Acceptance boundaries optimization

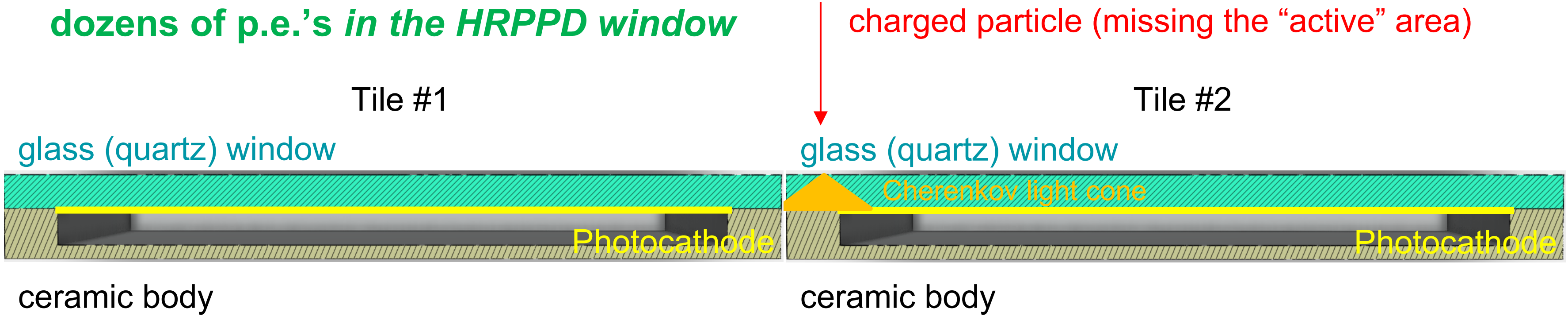


- No reason to lose acceptance *in η*
  - (1) Increase aerogel radius all the way up to ~R_{max}
  - (2) Install a side wall mirror at ~R_{max}
- No reason to lose acceptance *on the sensor plane*
  - Use conical mirrors at ~R_{min} & ~R_{max}



Geometric efficiency for a t_0 reference

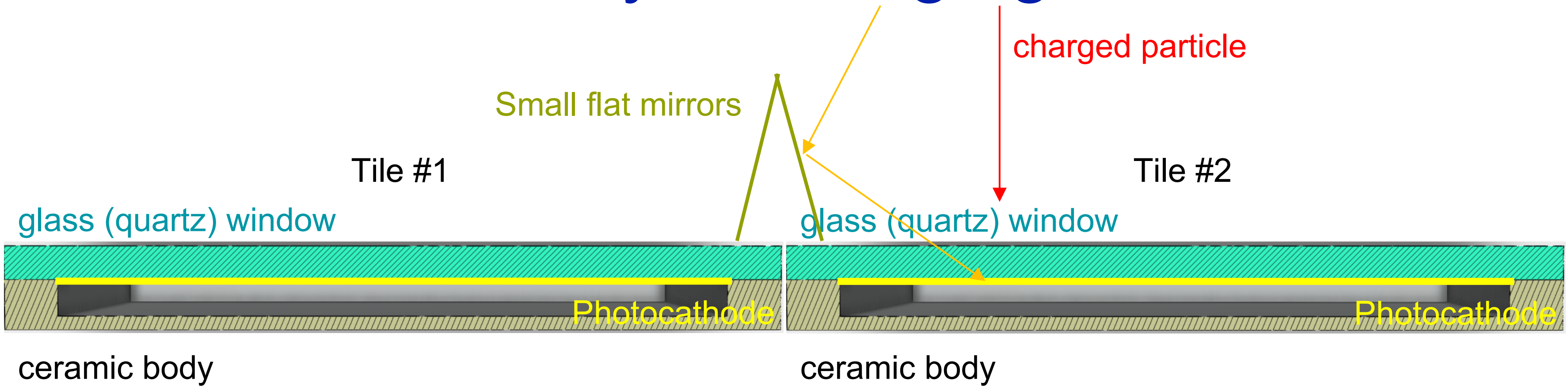
High energy charged particle will produce dozens of p.e.'s *in the HRPPD window*



- 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

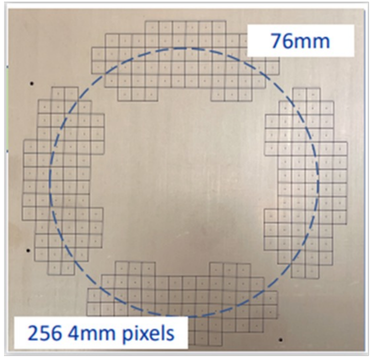
Geometric efficiency for imaging

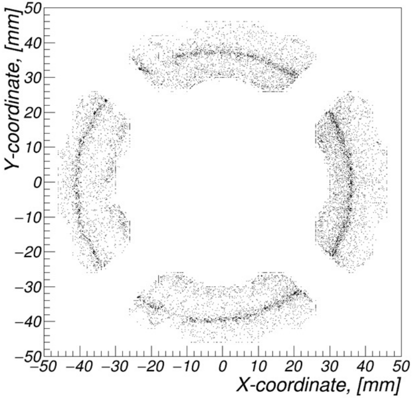


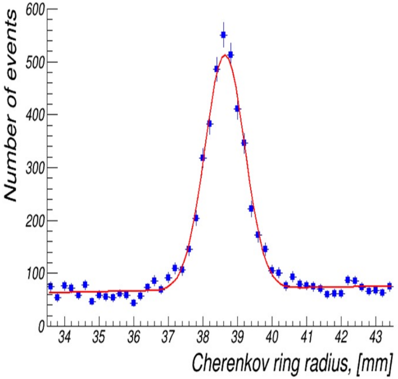
- *If really needed*, one should be able to "save" the Cherenkov photons, which would otherwise miss the photocathode, by funneling them away from the sensor dead area
  - The IRT-based reconstruction procedure is already adjusted to handle such cases

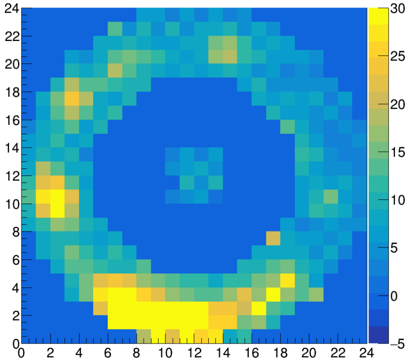
Sensor pixellation

- Given the anticipated ring diameter and $\langle n_{pe} \rangle$, expect average hit separation of ~5 cm







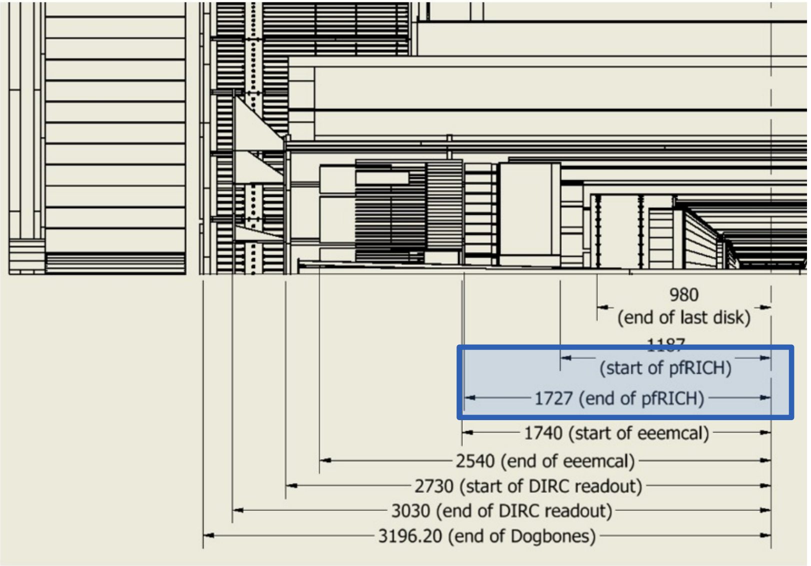


- Capacitively coupled LAPPDs with 4 mm pixellation are good enough to achieve single photon ring radius resolution ~600 μm (beam test data), even without signal pre-amplification

Consider pixel size of ~4 mm as a [temporary] design choice

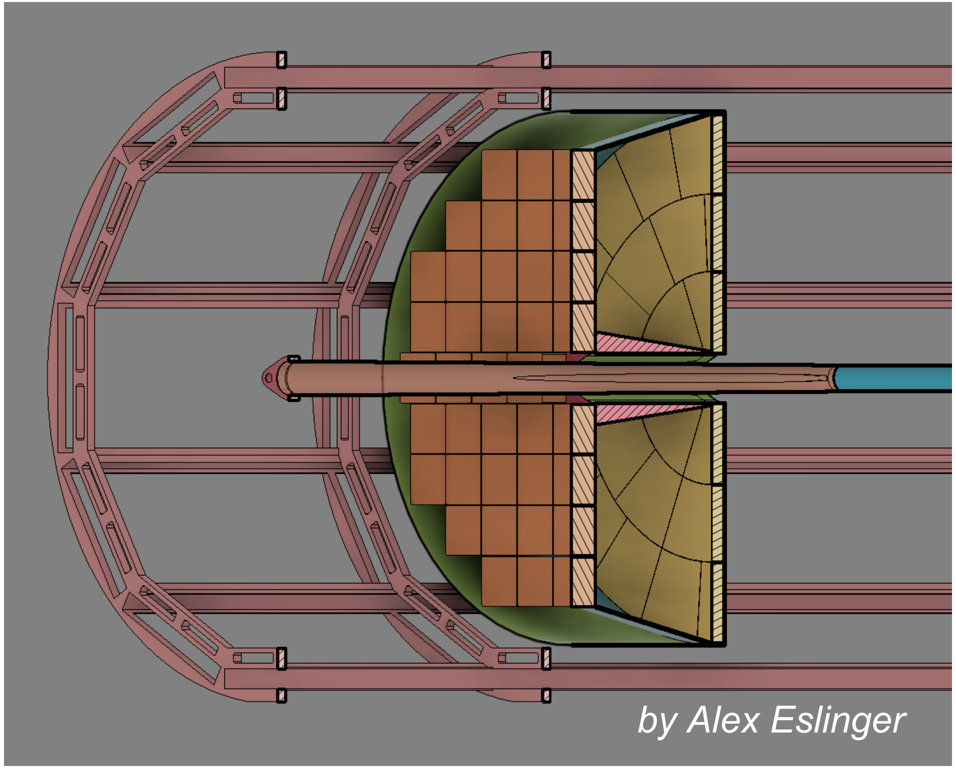
Integration model

Boundary conditions in the ePIC e-endcap



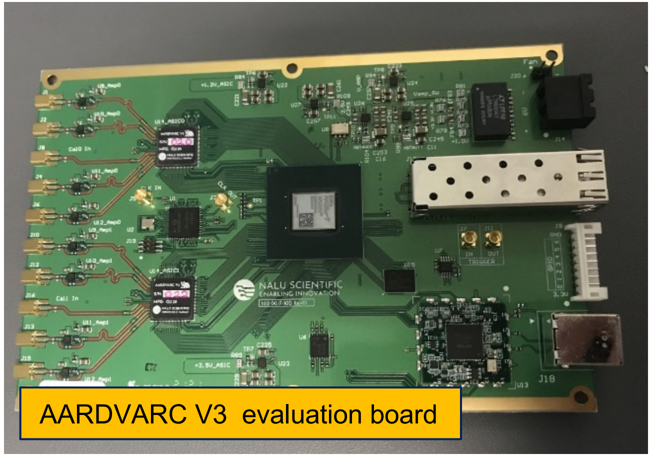
Inner radius	~59 mm
Outer radius	~650 mm
Total length	~540 mm

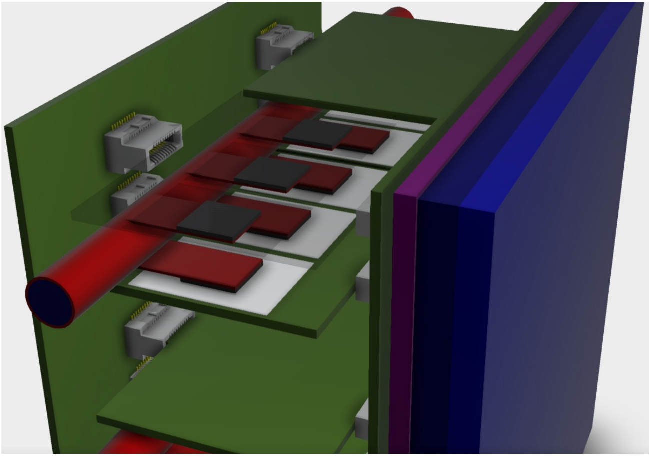
- Must fit into the DIRC support frame



- Limited length along the beam line
- Severe constraints around the beam pipe

Readout electronics concept



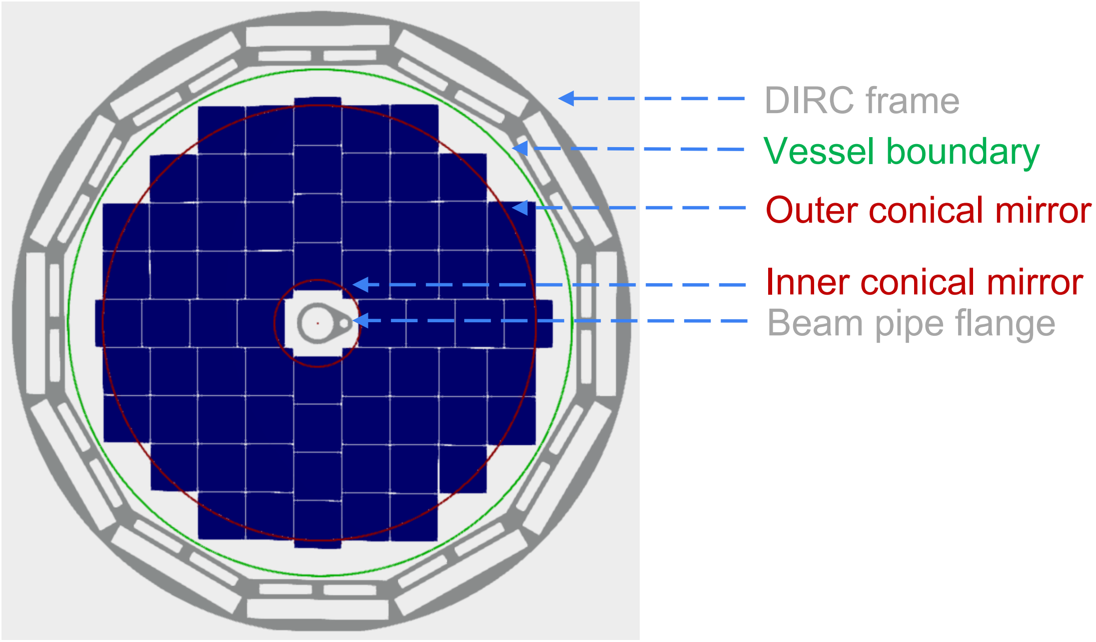


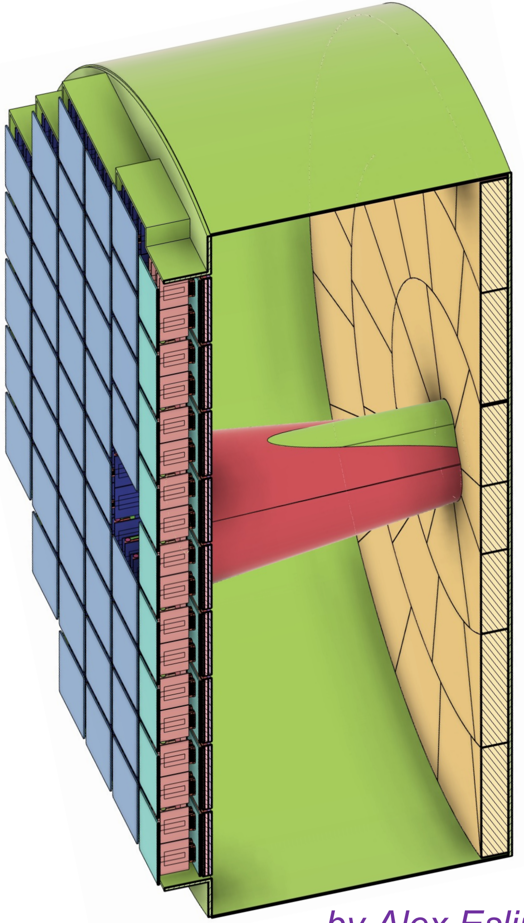
- Assume 24x24 HRPPD pixellation suffices (~4.2mm pads) -> 576 pixels per ~12x12 cm^2 footprint
- A hybrid of Nalu Scientific UDC and AARDVARC v4 chips assumed as a “reference ASIC”
  - Shown: 16-channel ASICs assumed (would be better to have 32- or 64-channel ones, of course)
  - ~10GS/s digitizer, ~2GHz ABW, feature extraction, streaming capability (whatever it means), etc.
  - 0dB buffer amplifier (12 mW/ch) available in ARRDVARC V4 -> need a similar solution for a ~20dB preamp
  - Few kW of power dissipation for the whole pfRICH-like system seems to be a realistic estimate

A coordinated effort with eRD109 and other PID subsystems is required

Integration model

Sensor plane tiling scheme



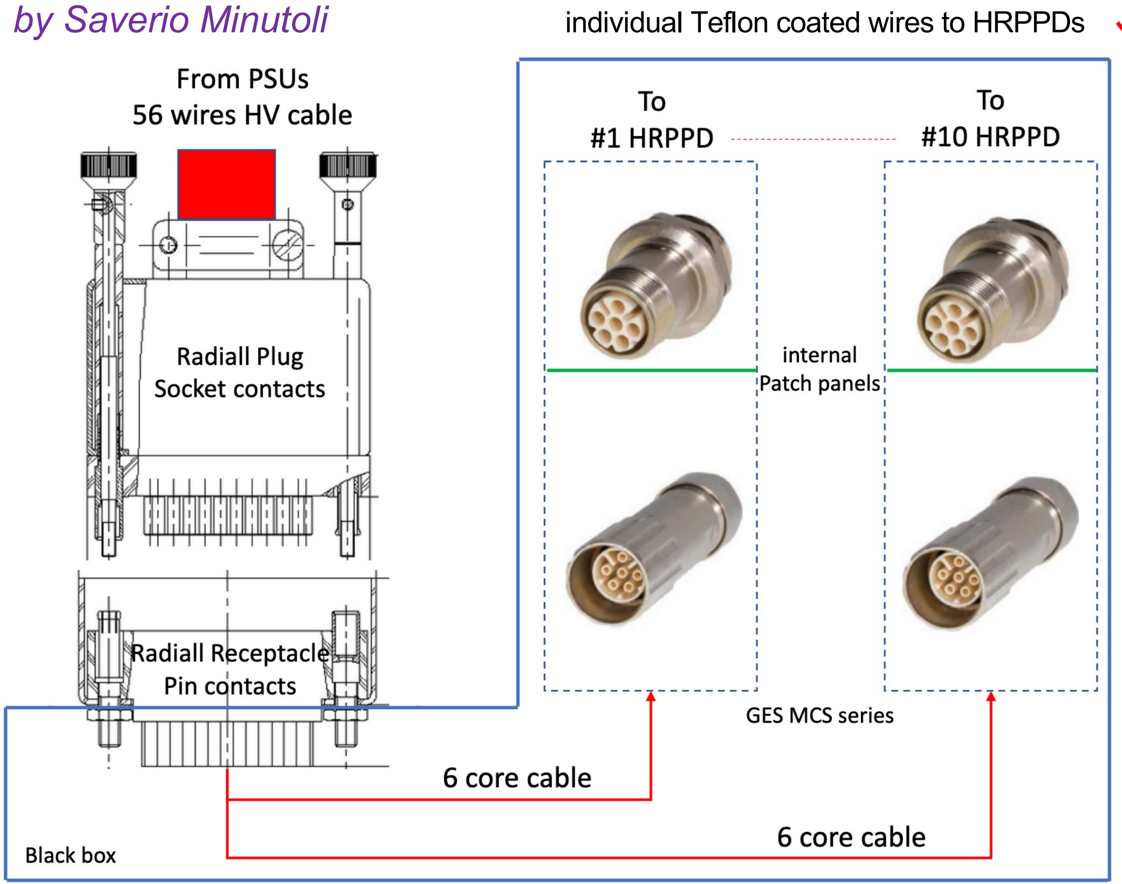


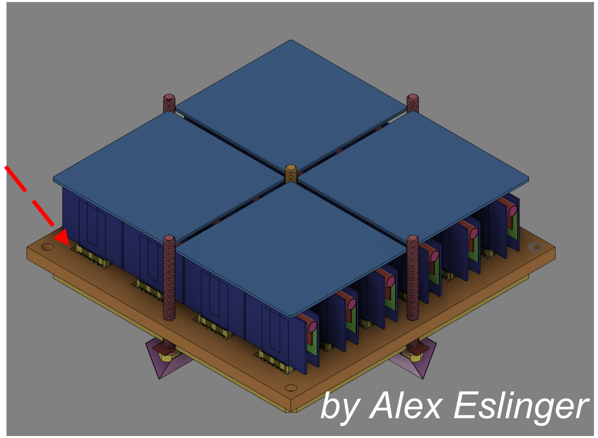
by Alex Eslinger

- A detailed pfRICH CAD model exists
  - Vessel, aerogel, mirrors, sensor plane, electronics mockup
- Services layout and installation procedure require more work

Services example: HV distribution

by Saverio Minutoli

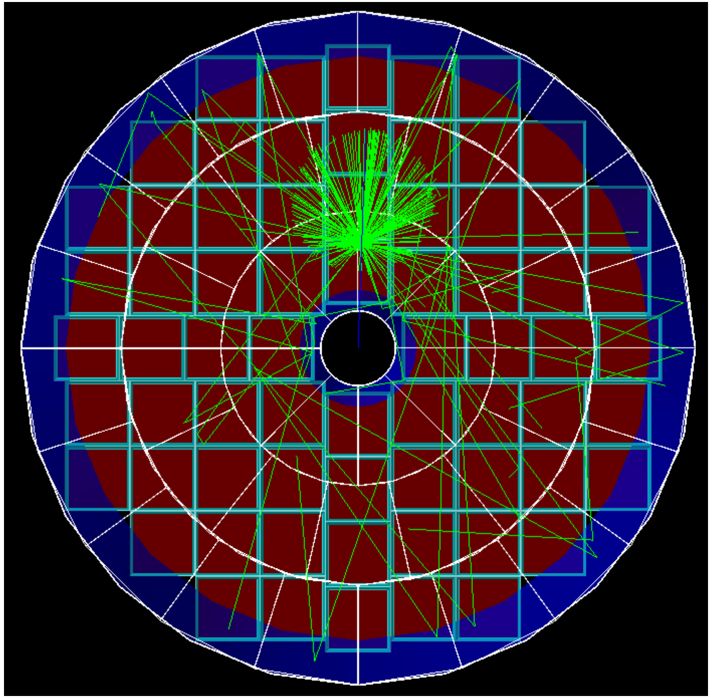




- 68 HRPPD tiles total
- 5 HV levels + ground per tile
- Therefore, need at most ten cables and 52-pin connectors (with spares)

GEANT implementation

Standalone GEANT environment

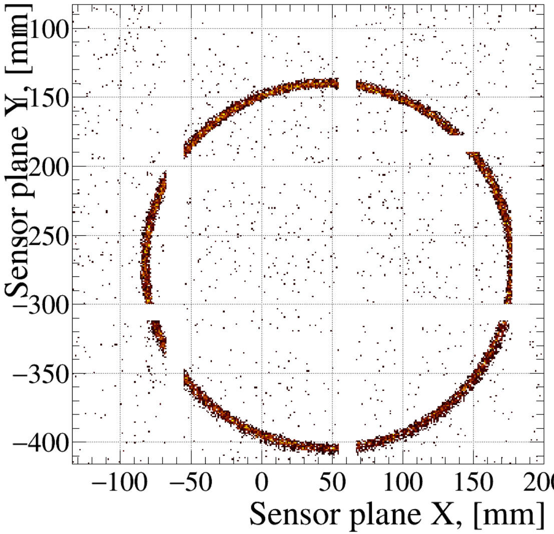


- Vessel: full available length (54 cm), starting at Z = -1187mm
- Gas volume filled with nitrogen
- Aerogel: 2 cm thick, segmented in <20 cm blocks
- <n> ~ 1.044 (Belle II parameterization)
- No acrylic filter

- Sensor plane at 12 cm from the rear side of the vessel
- Detailed HRPPD description (window, photocathode layer)
- QE plot as provided by Incom + 70% safety factor
- Tile segmentation matching suggested HRPPD formfactor
- Active area 80% of the tile footprint, as suggested by Incom for future HRPPD models

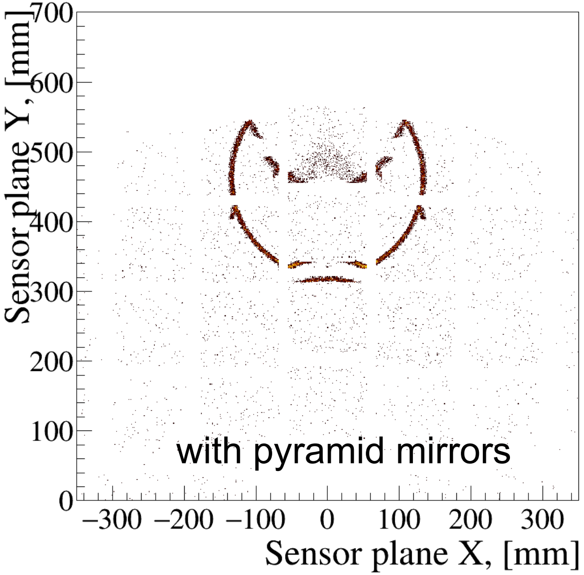
- IRT: conical & pyramid mirrors (and multiple optical paths per sensor) implemented

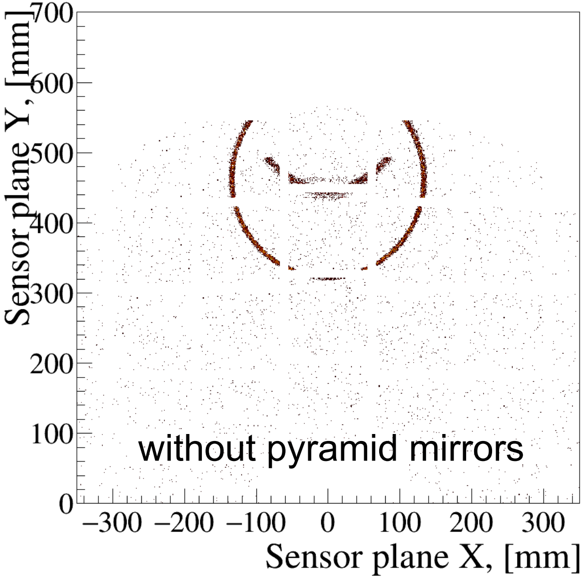
Accumulated Cherenkov ring images



Full ~260mm diameter rings at η = -2.5

η = -2.0: part of the ring is reflected by a conical mirror



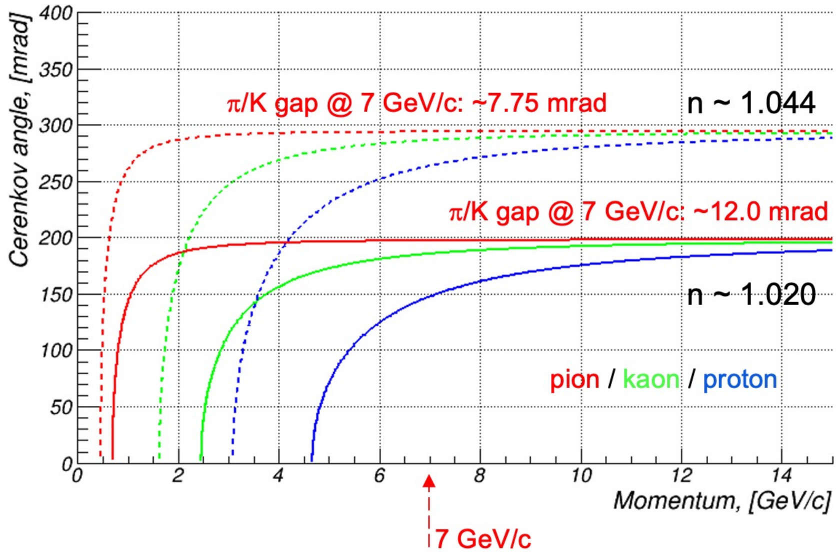


by Chandradoy Chatterjee

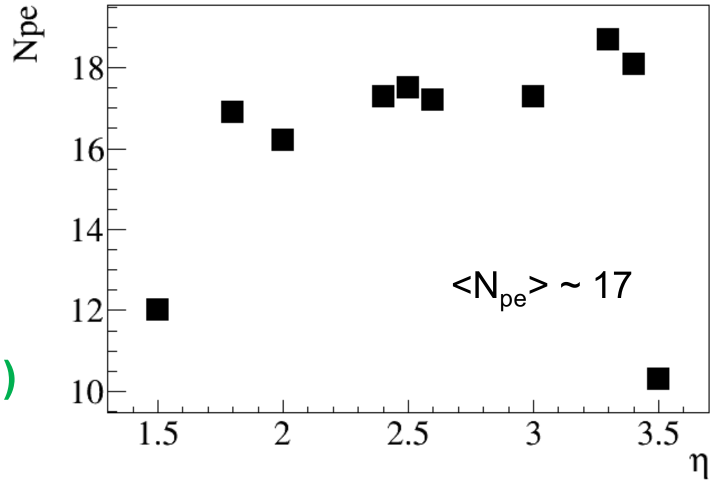
Default configuration: with inner and outer conical mirrors, but no pyramid ones

Performance plot examples

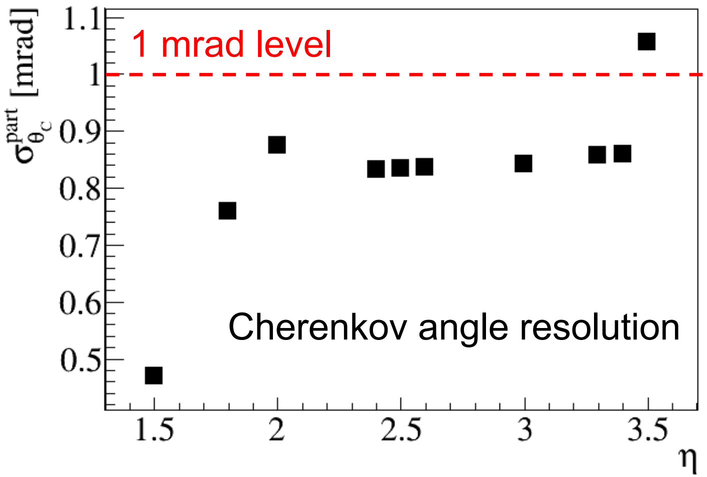
A combination of a more UV-transparent aerogel and HRPPD UV-extended QE spectrum can be a winning strategy, even that π/K gap at high momenta gets smaller as compared to the ATHENA case (<n> ~ 1.019, SiPM peak QE @ 450 nm)



>7 σ π/K separation @ 7 GeV/c



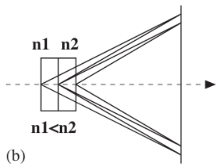
by Chandradoy Chatterjee



Fallback options

- In case ...
  - Tracker requests some space back (and pfRICH ends up with <40cm long expansion volume)
  - HRPPD *PDE* turns out to be substantially smaller than ~30%
  - A higher level of π/K separation at and above 7 GeV/c is required

- ... one can also consider *more sophisticated extensions*
  - Flat funneling mirrors in the acceptance
  - Dual aerogel configuration a la Belle II



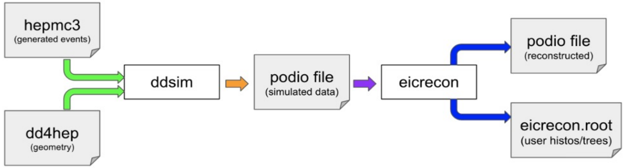
  - Fresnel lenses in an open-vessel configuration?

Other studies

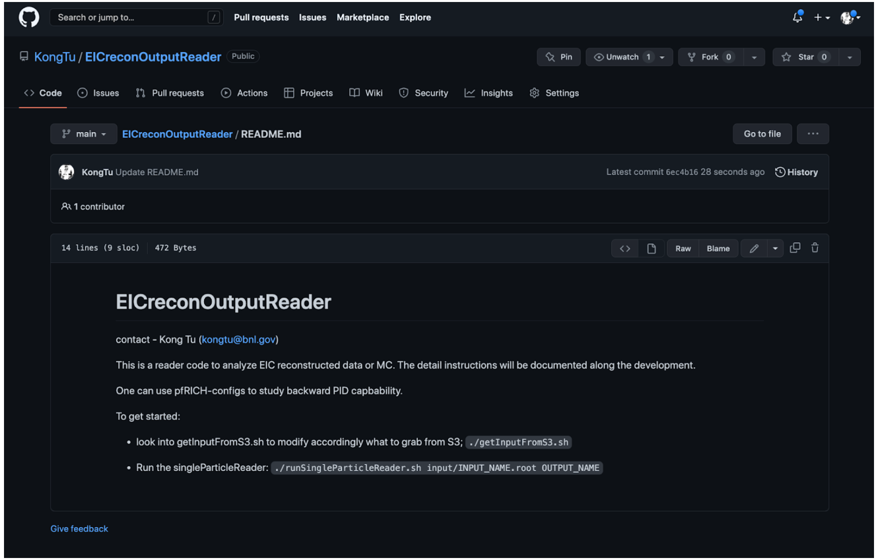
Mixed EICrecon / “Delphes” environment

by Kong Tu, Jan Vanek & Chandradoy Chatterjee

- First create Delphes-like PID smearing matrices using standalone GEANT4 detector-level modeling
- Then use EPIC official software stack



- With “eicrecon.root” & access to full reco’d tracks, apply pfRICH *delphes-like* parametrization for PID.
- We can make use of the official simulation campaign files (single particle, DIS, SIDIS, etc.)

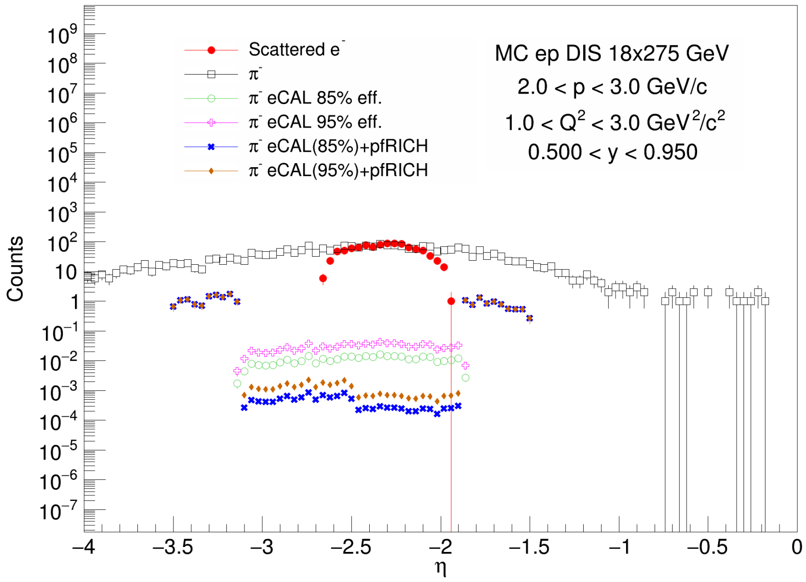


https://github.com/KongTu/EICreconOutputReader

Mixed EICrecon / “Delphes” environment

by Kong Tu, Jan Vanek & Chandradoy Chatterjee

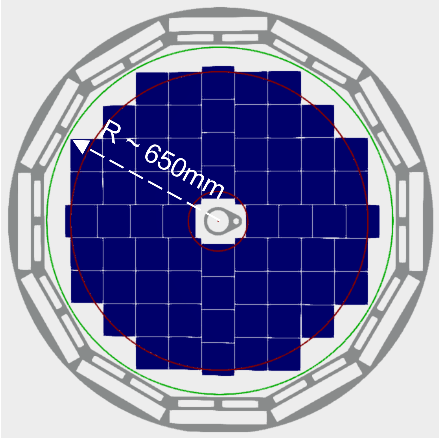
- An example study with PYTHIA 8 MC generator for e/π separation.
- eCal pion rejections are based on 2 scenarios, 85% and 95% efficiency by cutting on E/p, study by D. Kalinkin (thanks!)
- pfRICH parametrization is based on the e/π table (up to 5 GeV/c).
- Next step is to try on fully reconstructed tracks, lower energies, etc.



pfRICH may be *more* beneficial at high-y / low-x regions, where multiplicity of pion in backward is higher; pfRICH may be *more* useful on rejecting pions at lower energy configuration, e.g., 10x100 and 5x41 GeV.

Magnetic field @ HRPPD location

by Zhengqiao Zhang



- Tolerance to the magnetic field *strength* is not the whole story
  - Field *direction* should be reasonably aligned with the normal to sensor surface

• Oba et al., 1981

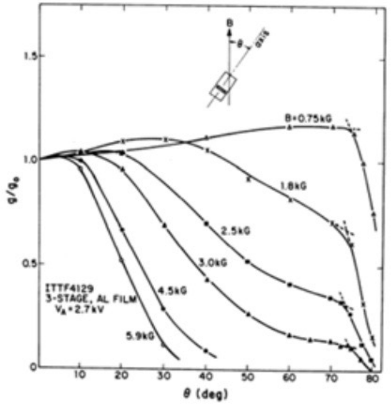


Fig. 11. Dependency of the output degradation in F4129 on the off-axis magnetic field.

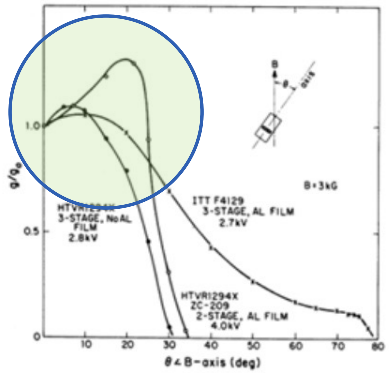
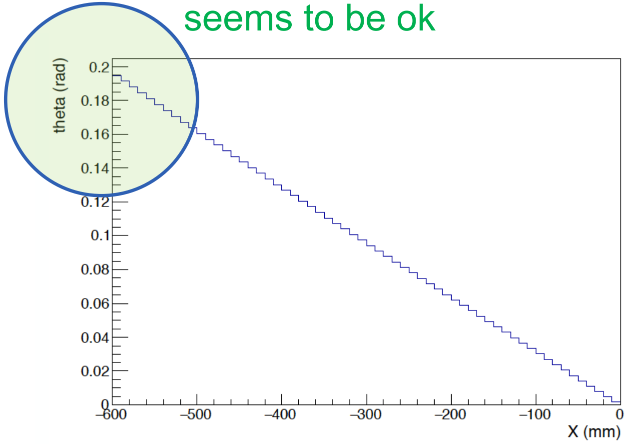


Fig. 10. Output degradation in three MCP-PMTs in the off-axis magnetic field.

seems to be ok

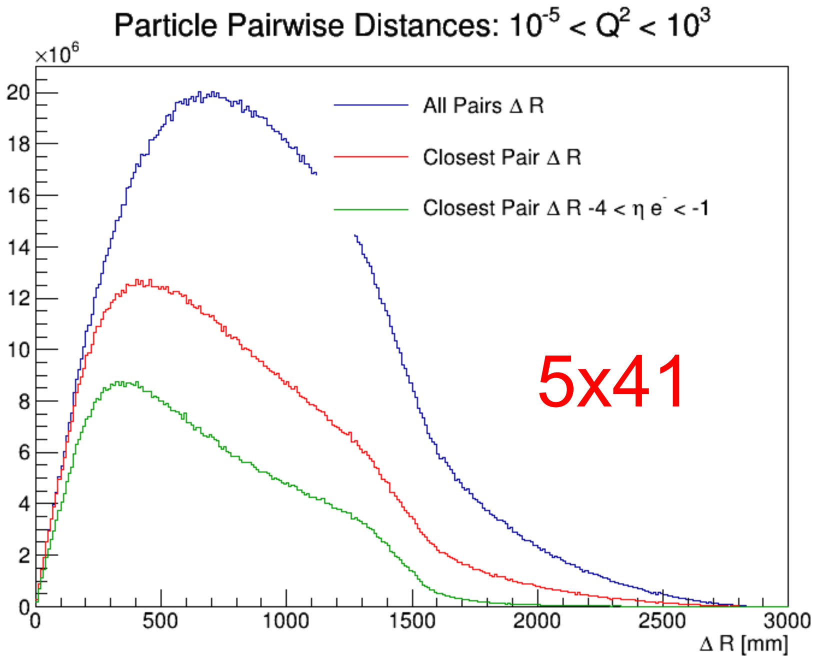


pfRICH: field-to-sensor-normal angle

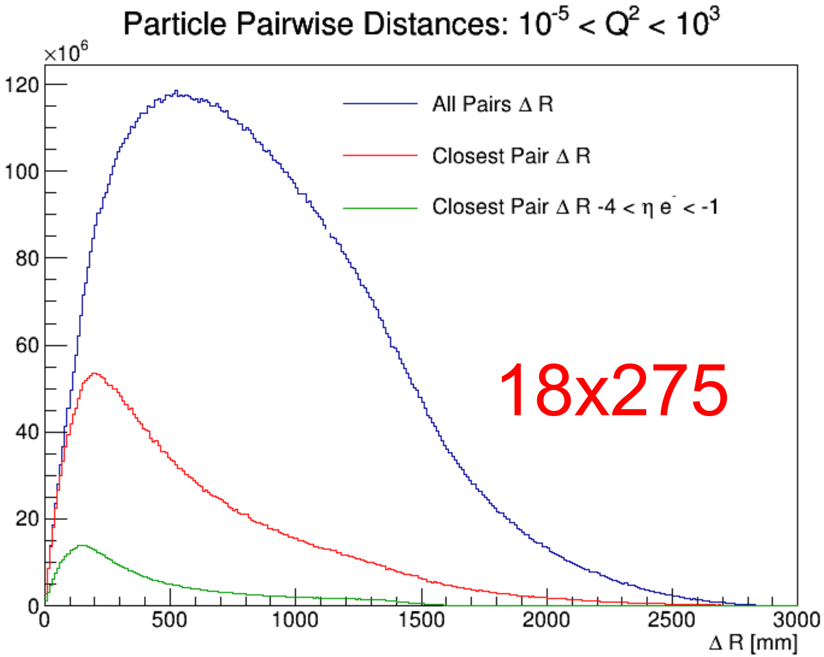
Direct measurements at Argonne will be done in March

Occupancy studies

Particle Pairwise Distance: $-4 < \eta < -1$



Blue = distance between each pair of particles in acceptance
Red = distance between closest two particles in acceptance
Green = same as red, but for events with electron in acceptance



- Distance is in x-y plane at a z position of -1700 mm from the interaction point

by Brian Page

Summary

- Work on the proximity focusing RICH for ePIC e-endcap is well advanced
  - Design choices
  - GEANT simulations
  - CAD model and integration
  - Several other accompanying studies
- We will certainly be ready for the March Collaboration review

A Proximity-Focusing RICH for the ePIC Experiment
– Proposal –

(DRAFT)

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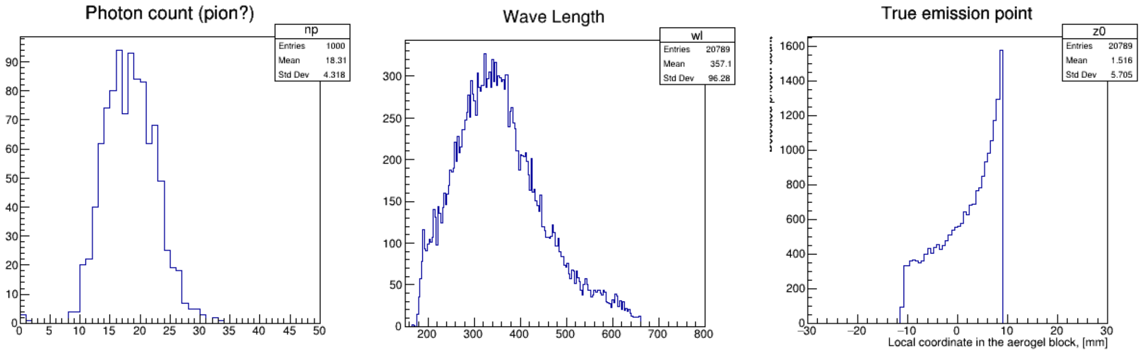
Indico category: https://indico.bnl.gov/category/458/

Mailing list: eic-projdet-pfrich-l@lists.bnl.gov

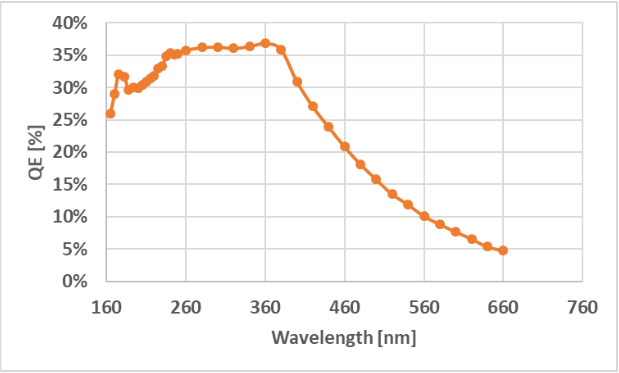
Backup

Wavelength range

- Is it really hopeless to work with aerogel in a deep UV range?



Belle II aerogel#1 in pfRICH GEANT simulations



HRPPD 126 QE curve

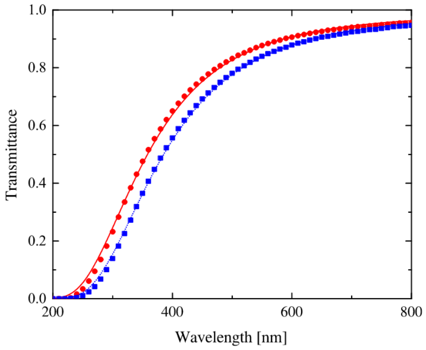


Fig. 2. Transmittance as a function of wavelength for the Belle II RICH aerogel samples of $n = 1.045$ (red) and 1.055 (blue) [2]. The thickness for both samples is 20 mm . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)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~5mm @ 180nm (units: [mm])

$$\frac{dE}{dx} = 4\pi^2 e^2 \int_{\beta n>1} \frac{1}{\lambda^3}\left(1-\frac{1}{\beta^2 n^2}\right) d\lambda$$


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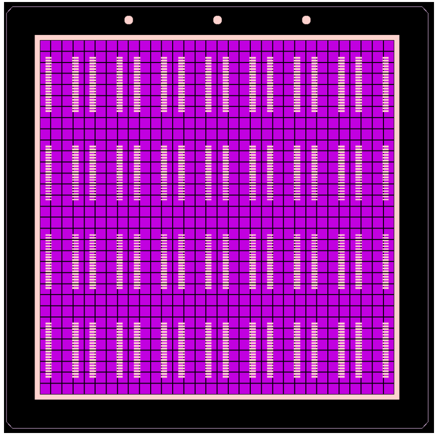
~5mm @ 250nm (units: [mm])

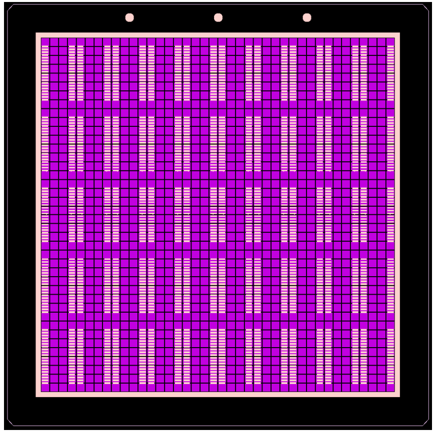
Obviously, more studies needed

HRPPD re-design effort for EIC

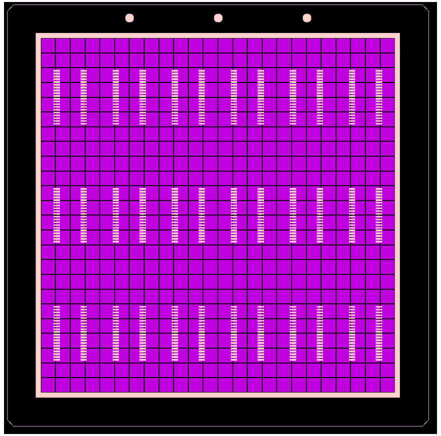
Variety of HRPPD anode base plate pixellation, with 40-pin Samtec connector footprints on the outer side



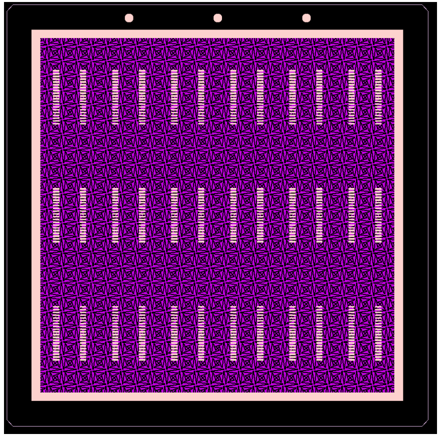
32 x 32 square pads (present layout)



40 x 40 square pads (DIRC)



24 x 24 square pads (pfRICH)

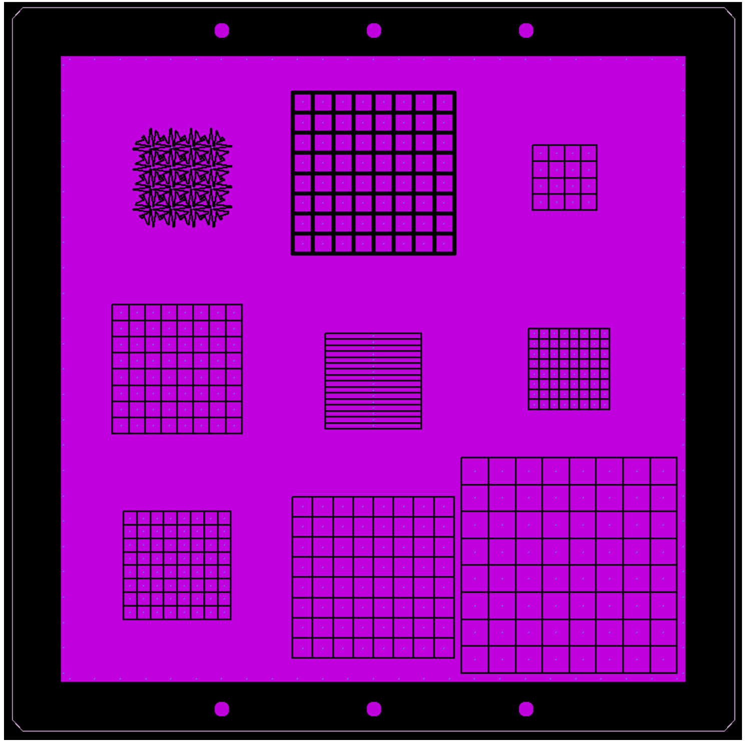


24 x 24 charge sharing pads (pfRICH)

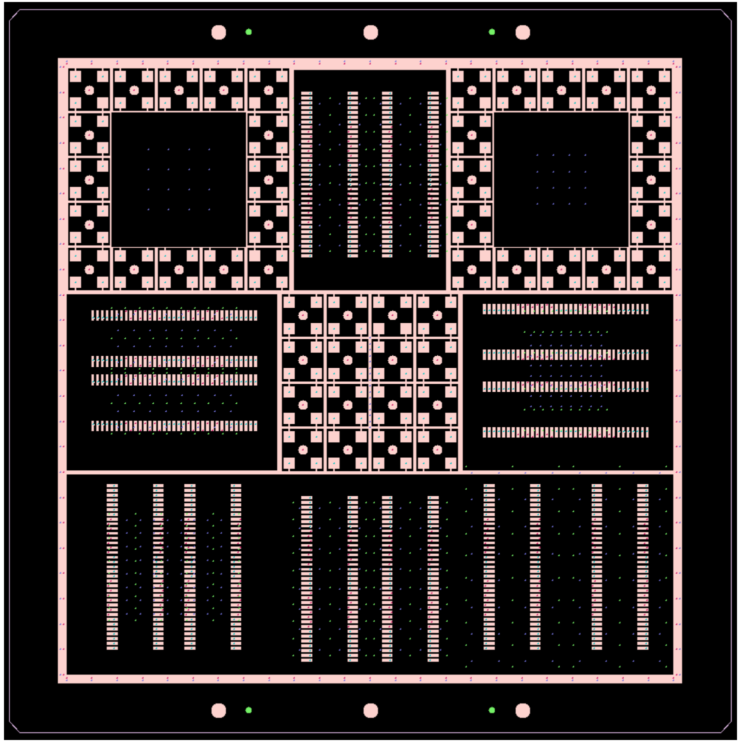
- Polish ceramic manufacturer (Techtra) can produce such layouts in house
- First iteration will be a test bench HRPPD tile with a mixed layout, to test them all at once
  - AK to provide a final set of drawings for this layout
  - Tooling and fabrication will take 2-3 months

HRPPD re-design effort for EIC

pad (inner) size



connector (outer) side



- Will use existing side walls / windows; pad size tuned to the new active area size of 108 mm
  - Pixellation patterns 24x24, 32x32, 40x40, 48x48, 64x64 + 1D charge cloud profiling field