pfRICH design considerations

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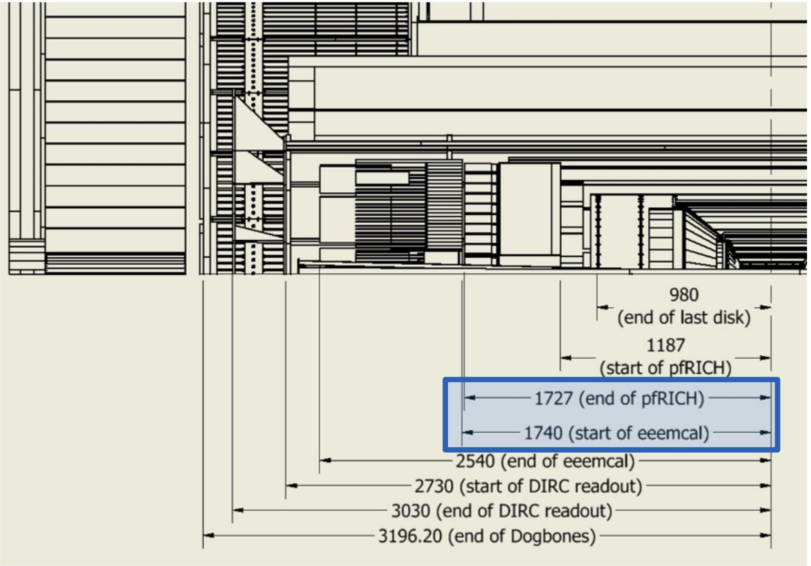
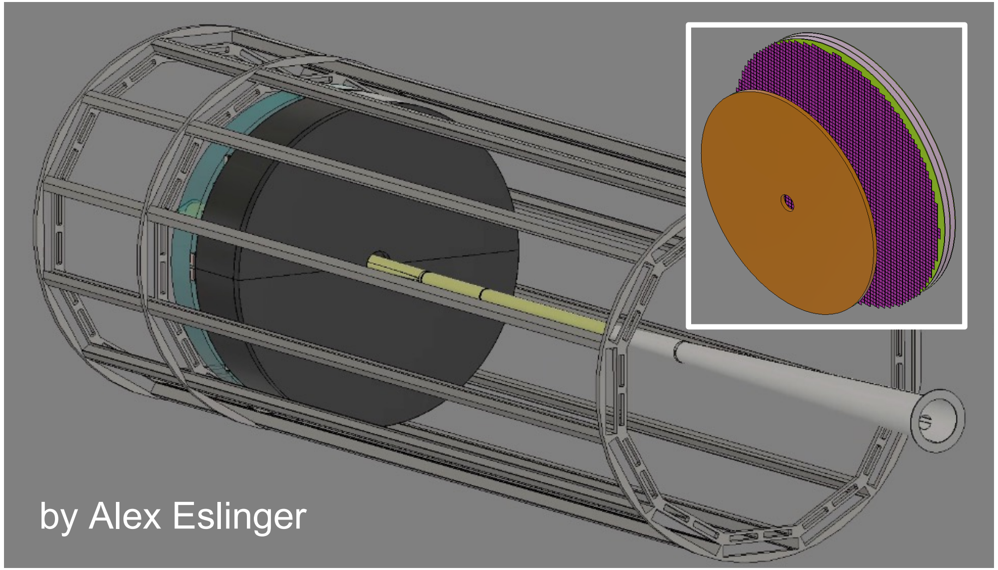
pfRICH meeting, October 19th, 2022

Boundary conditions in the ePIC e-endcap





Inner radius	59 mm
Outer radius	681 mm
Total length	~540 mm

- Space is indeed very limited (was 600 mm in ATHENA)
  - In order to provide credible performance estimates, need to quickly come up with a very good idea about how much space can we realistically allocate for the expansion volume

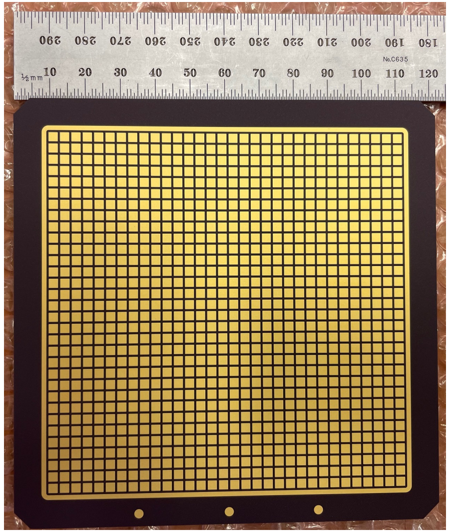
Sensor options: LAPPDs / SiPMs / Planacons

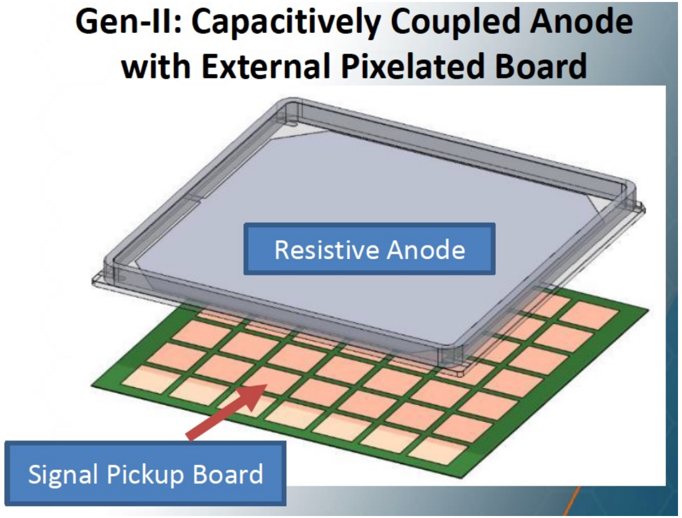
- LAPPDs / HRPPDs
  - Somewhat higher risk, as compared to the SiPMs
  - Guaranteed lower PDE
  - Most part of the active LAPPD R&D for EIC is done by the pfRICH-affiliated institutions (and we may want to double down on this photosensor solution, linking it to a detector subsystem proposal)
  - A very clear differentiation between mRICH+SiPMs vs pfRICH+HRPPD baseline configurations

- SiPMs:
  - Uncertainty with the required space for the cooling system
  - No Time of Flight functionality

- 2” PHOTONIS Planacons:
  - If we could get them with a volume purchase discount (or for the money one would otherwise consider paying for the AC-LGAD ToF), for pfRICH must be *a more consistent alternative solution than the SiPMs*

If LAPPDs: DC- or capacitively coupled ones?



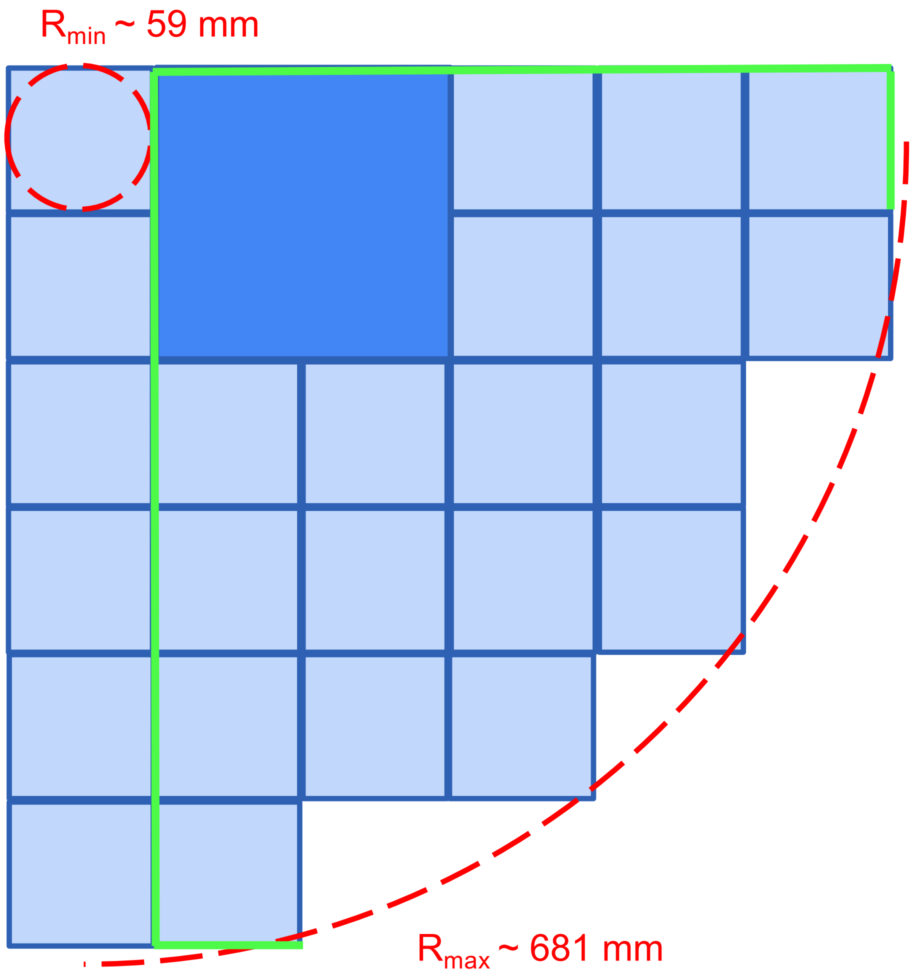


- So far we only have experience with the capacitively coupled LAPPDs
  - Presumably have higher spatial resolution than pitch/√12 of the DC-coupled ones (although DC-coupled models will most likely also exhibit a moderate charge sharing)
  - Pixellation is always our choice rather than given by the manufacturer (this may also change though)
  - Exist in a “20cm” formfactor (cost saving)
  - Must be easier to handle in terms of the mechanical integration (no spring-loaded contacts)

Sensor surface tiling

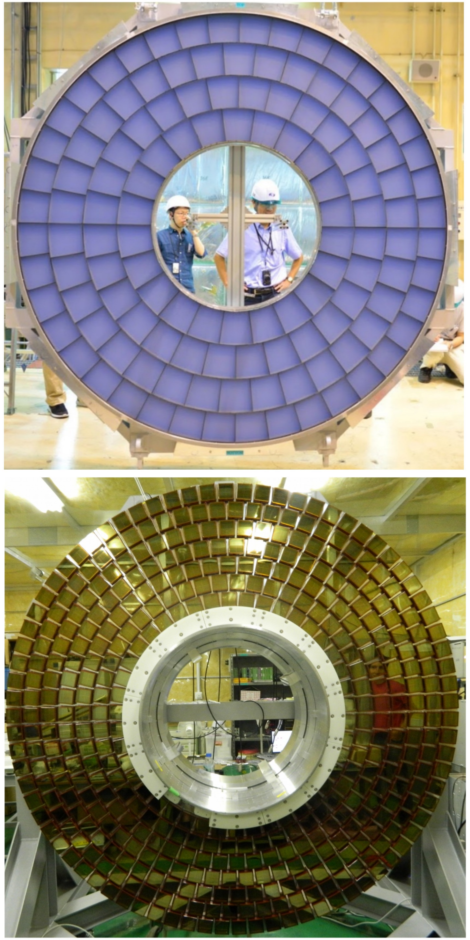
In case of the LAPPDs:

- Assume current “10cm” HRPPD tile size of ~120 mm remains the same in the future
  - 4 x 22 = 88 tiles total
  - Quartz window surface virtually without gaps
  - Request a bit narrower ceramic bodies?
- Most of the tiles can be of “20cm” formfactor
  - (Much) more cost-efficient than “10cm” ones
- Natural segmentation in four 90^0 quadrants
- Outer circumference: should it really be an *ideal* cylinder?
  - But gaps in tiling at R_{max} are not necessarily a problem (see later, can probably be solved by optics)



Projectivity vs flatness; quadrants vs radial bands

- Projectivity and ~100% surface coverage by square sensors is hardly possible
  - Time-of-Flight functionality also requires continuous coverage!
- Flatness of the sensor surface causes (a tolerable?) Cherenkov ring elongation, but also effectively increases the expansion volume at large scattering angles
- Cooling system may be easier in a flat configuration (continuous straight piping across the rear sensor plane surface)
- HRPPDs will not necessarily work well at field-to-surface angles above ~20^0 or so
  - Need to check magnetic field map in this area!
- Yet: should aerogel tiling be radial a la Belle or should it follow the sensor plane segmentation?
  - Assume tile sides are *not* ideal optical surfaces



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Assembly segmentation & sequence

- Radial segmentation (vessel consisting of left and right halves) ...
- ... or segmentation along the beam pipe a la Belle II?
- Sensor plane segmentation (into quadrants?) should not necessarily follow the vessel segmentation in case the vessel consists of left & right halves
- Anyway, what are the immediate obvious limitations to the geometry we are going to optimize / model, which come from the assembly sequence constraints?
  - For instance: at which point aerogel will be mounted into the vessel?

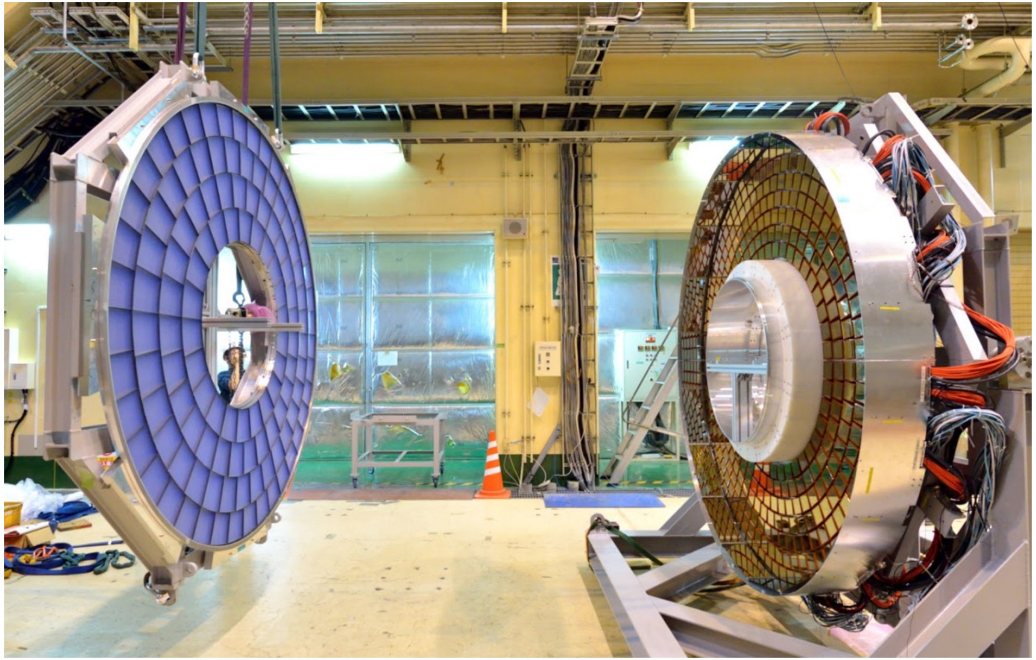

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Photo statistics

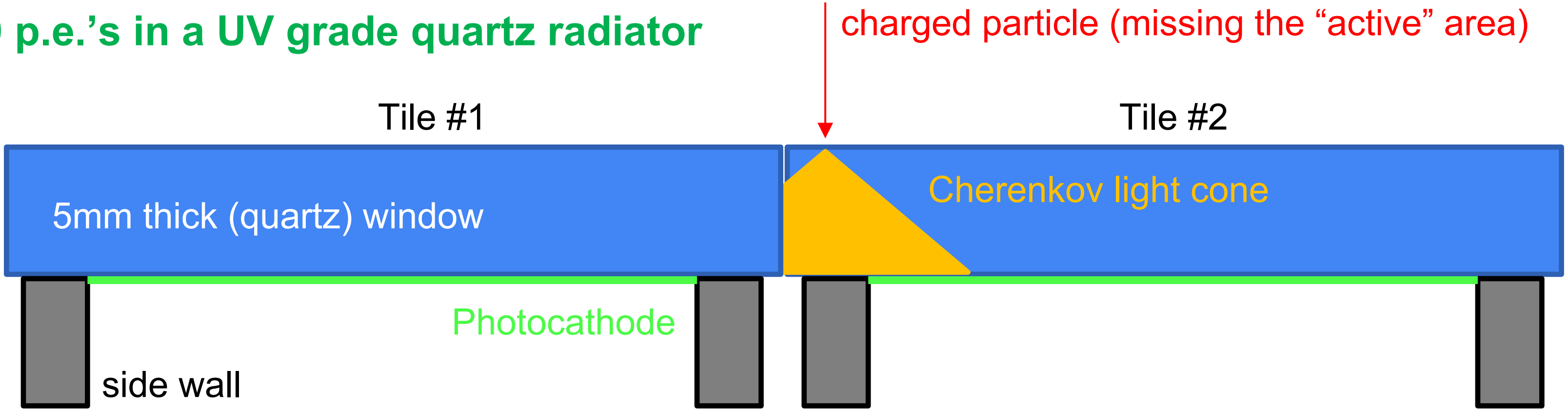
- Moving forward with a 3cm thick n = 1.019 aerogel may not be a good strategy, since LAPPD QE will never be as high as SiPM PDE, and we better find a way to claim $\langle n_{pe} \rangle \sim 8\text{-}10$
  - Using the same aerogel as the mRICH+SiPM detector proposal may not be wise in general

- 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 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 at a cost of Rayleigh scattering background?

  - Anything else?

Towards ~100% time-of-flight geom. efficiency

~100 p.e.'s in a UV grade quartz radiator



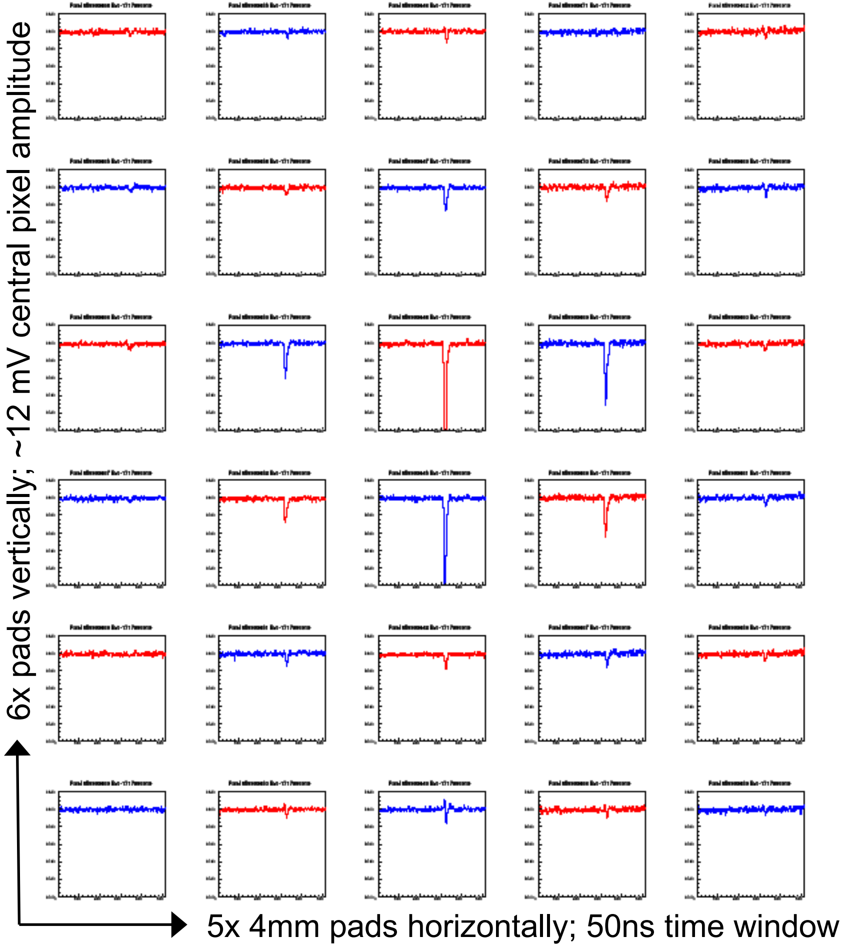
- Even that the HRPPD active area (the photocathode and the MCP stack) is much smaller than the tile footprint, the Cherenkov light cone spot in a 5 mm thick quartz window has a base of ~11 mm diameter
  - By making the edge area reflective (or perhaps just relying on a TIR) one should be able to gain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

Tiling a flat sensor surface without gaps is a clear benefit

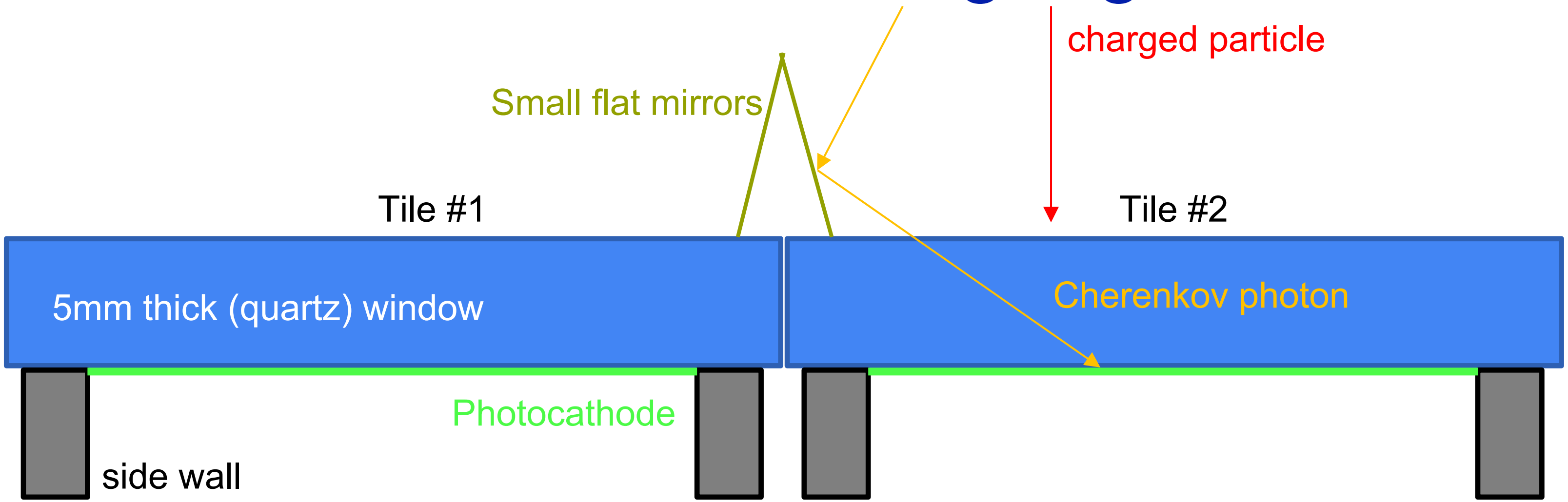
Time-of-flight functionality vs gas radiator

There is (at least) one problem here

- A signal produced by a charged particle in the LAPPD window is huge (several dozens of Cherenkov photons at once)
- Capacitive coupling spreads this large signal to the neighboring pixels
- A combination of the two effectively makes the pixel area ~15-20 mm diameter around the track hit point blinded for single Cherenkov photons produced in the gas radiator
  - This imposes an additional constraint on the gas refractive index (should be large enough)



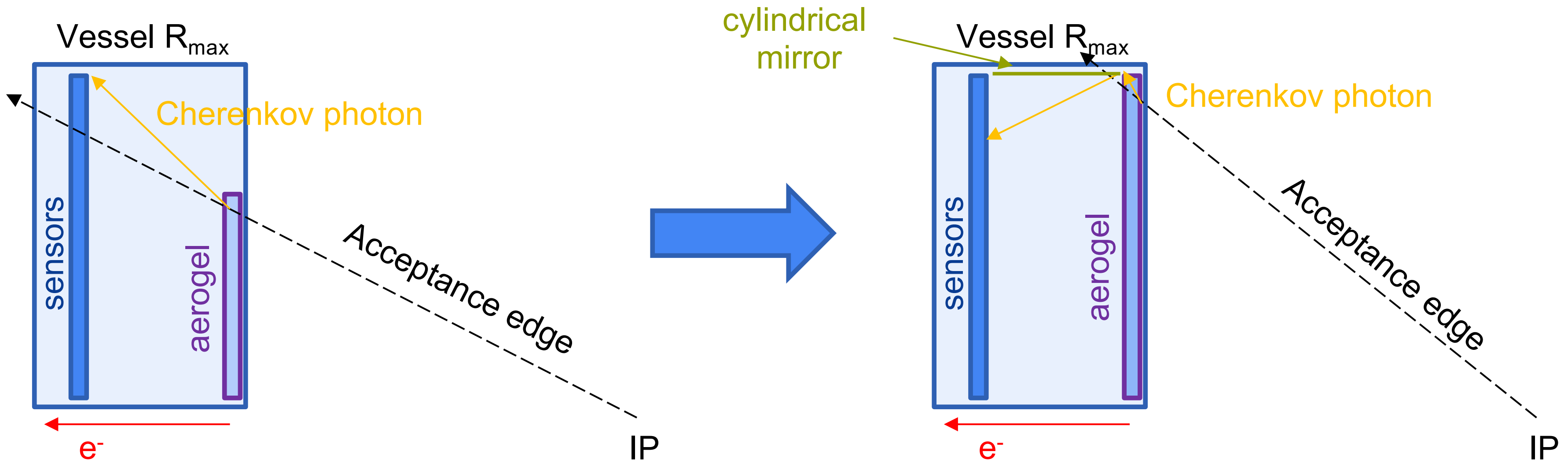
Towards ~100% Cherenkov light geom. efficiency



- 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

Acceptance at the DIRC inner radius

Our present configuration



- No modularity -> no reason to lose this acceptance *in* η
  - (1) Increase aerogel radius all the way up to ~R_{max}
  - (2) Install a cylindrical (or a piece-wise flat) mirror at ~R_{max}

  - Requires a moderate change to IRT algorithm

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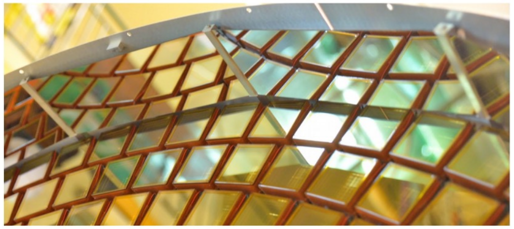
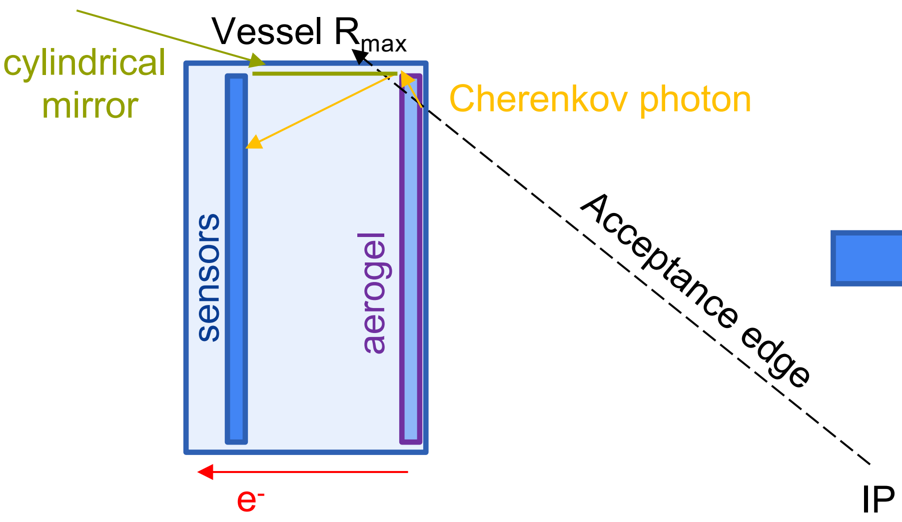
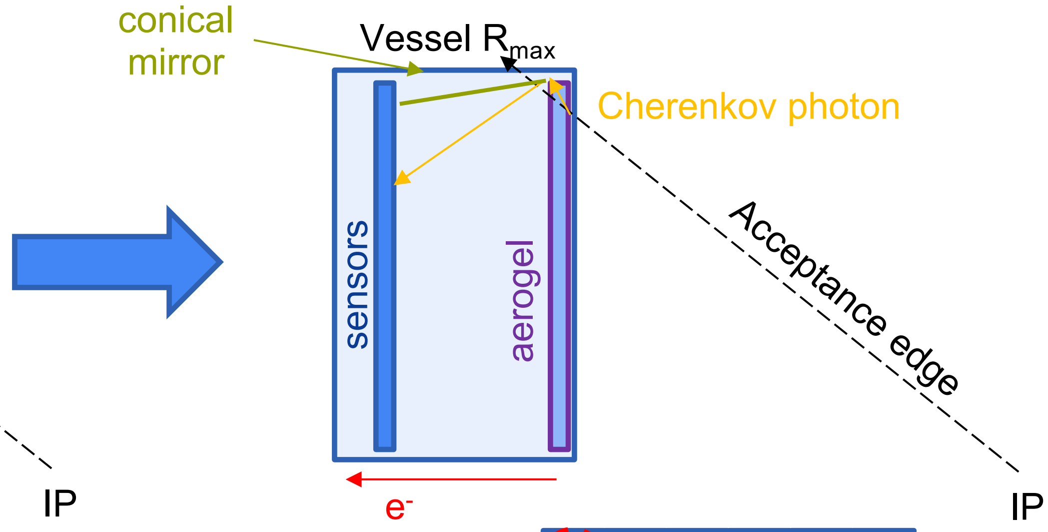
Mirrors from the edge



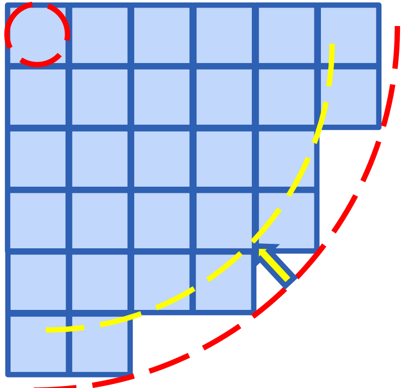
Acceptance at the DIRC inner radius, cont'd





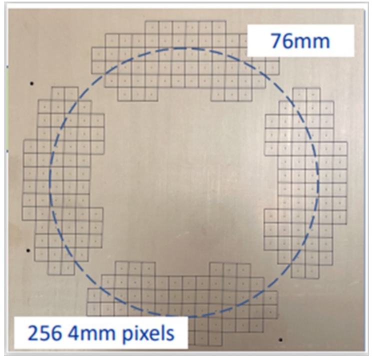
- No reason to lose this acceptance *on the sensor plane* either
  - Use a conical (or a piece-wise flat *tilted*) mirror at ~R_{max}

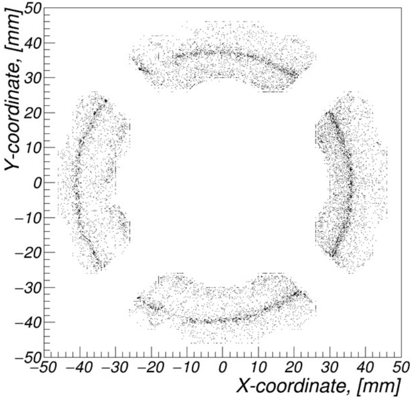
- Use the same trick around the beam pipe?

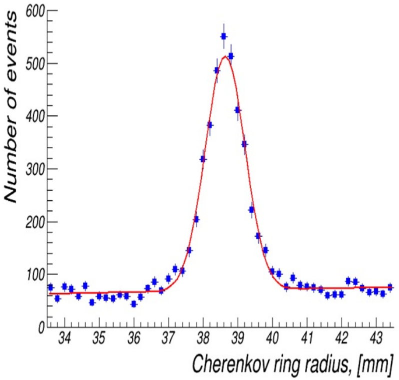


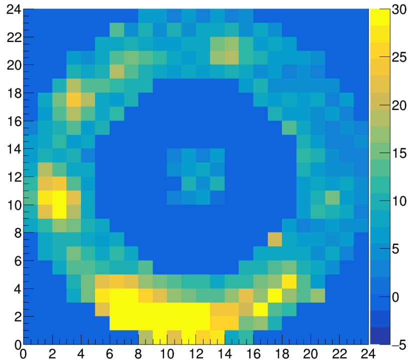
Sensor pixellation

- Input considerations (assume n ~ 1.02 aerogel):
  - Cherenkov saturation angle ~200 mrad times ~40 cm expansion volume -> ~160 mm diameter rings
  - $\langle n_{pe} \rangle$ ~ 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





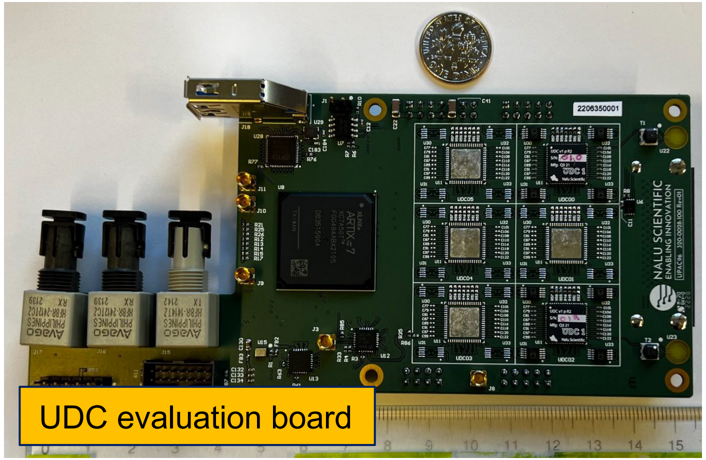


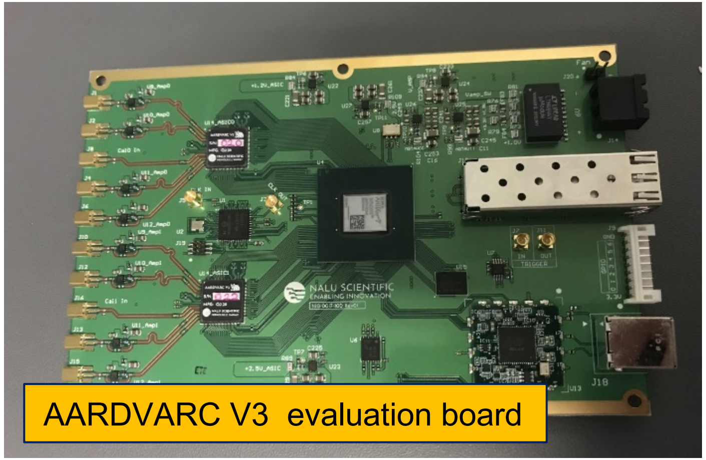


Let's assume occupancy is not a problem for ~4 mm pixels

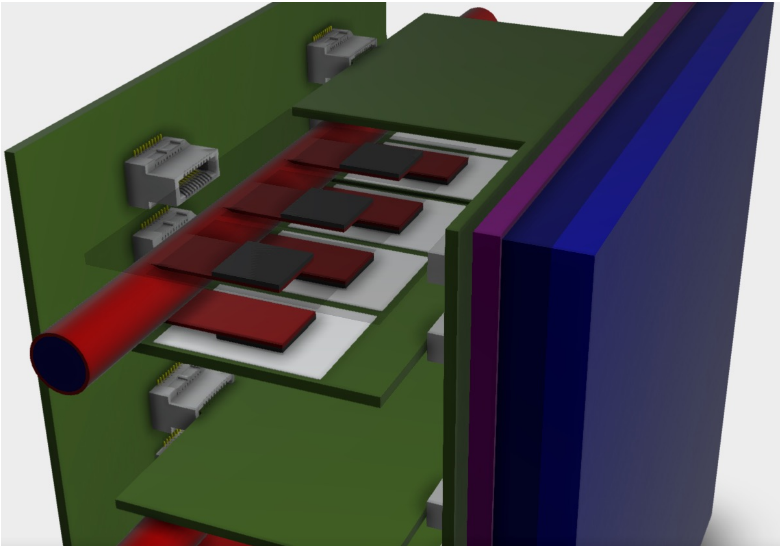
Readout electronics solution

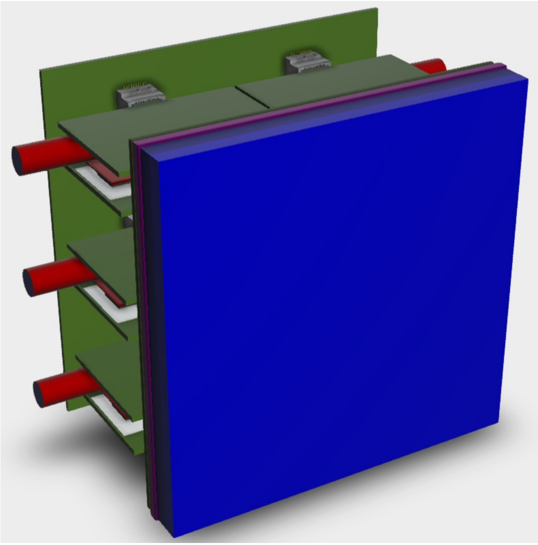
- Assume 24x24 pixellation suffices (~4.2mm pads) -> 576 pixels per 12x12 cm^2 footprint
- A hybrid of Nalu Scientific UDC and AARDVARC v4 chips as a “reference ASIC”
  - 16-channel ASICs (would be better to have 32- or 64-channel ones, of course) -> defines the layout!
  - 20 dB preamplifier on die (~6mW 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

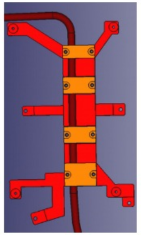


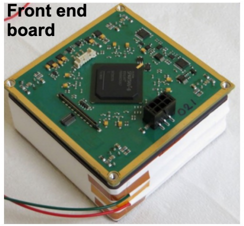


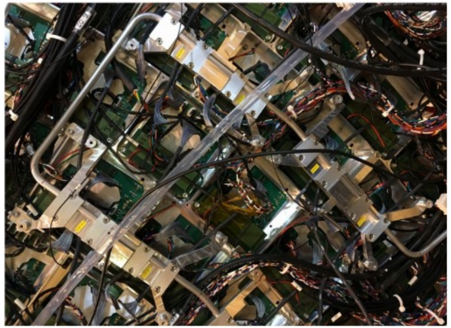
Readout electronics solution, cont'd

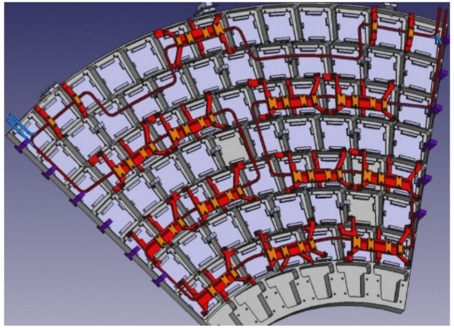












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This suffices to estimate material budget, cooling needs and (most importantly) space remaining for the expansion volume

- Should fit into <10 cm space behind the LAPPD anode base plate
- Real estate conservatively assumes 16-channel UDC chips
- Cooling can seemingly be integrated in the same space

Or should we aim at a planar configuration a la Belle II from the start?