A proximity-focusing RICH for the ATHENA electron endcap

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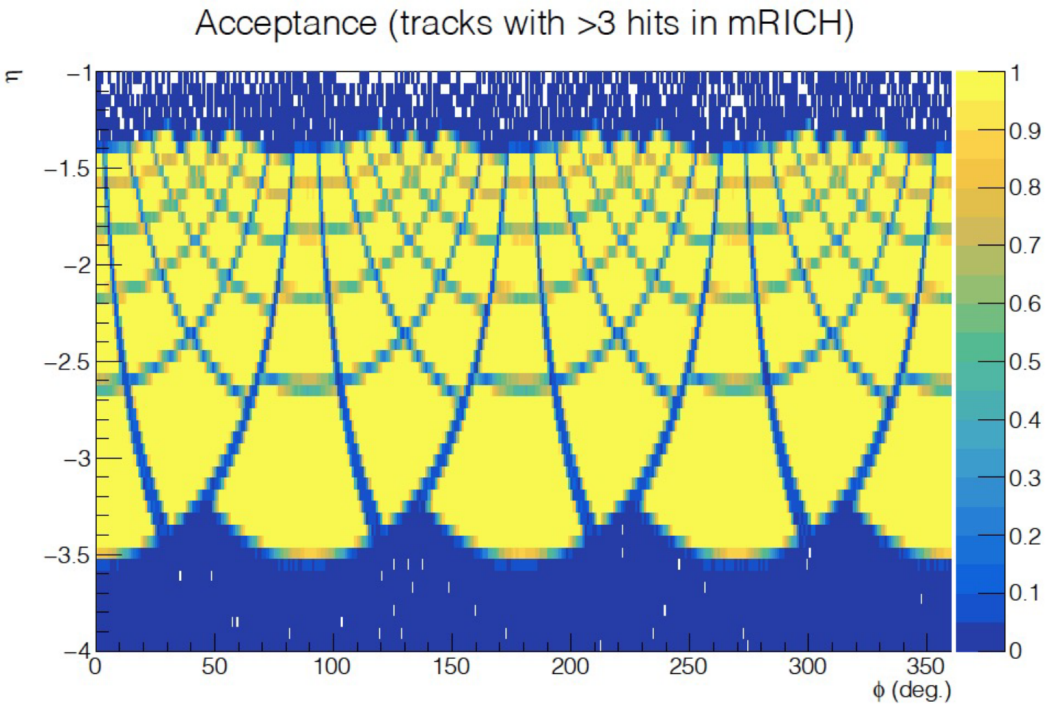
Objective(s)

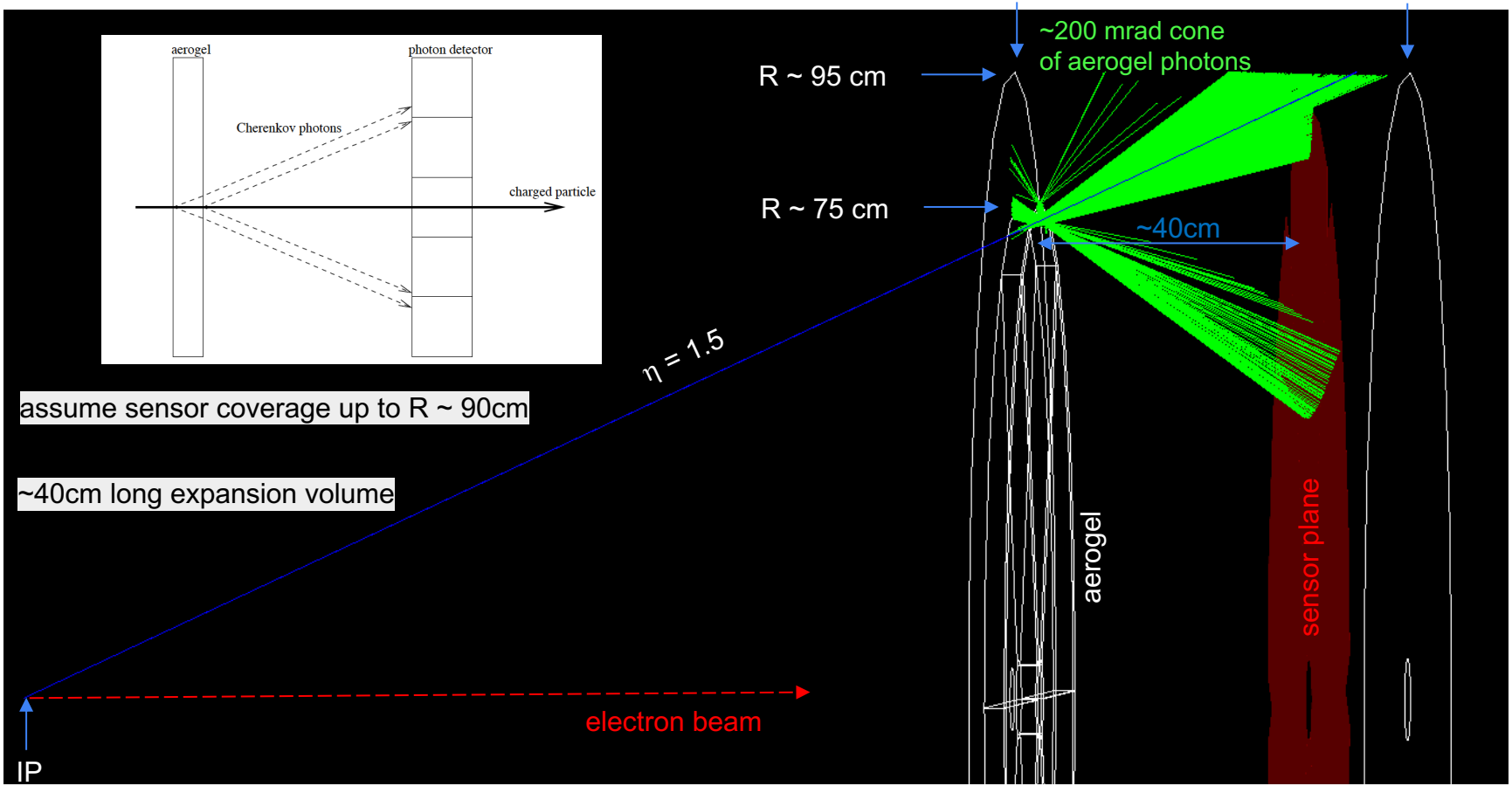
- Look for a “simple” RICH version which
  - Would meet the YR requirements
  - Is kind of “safer” & easier to defend at the proposal writing stage, given the absence of a direct experimental proof of a π/K separation reach by mRICH
  - Has perhaps a similar material budget
  - Is easier to have implemented in the 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)

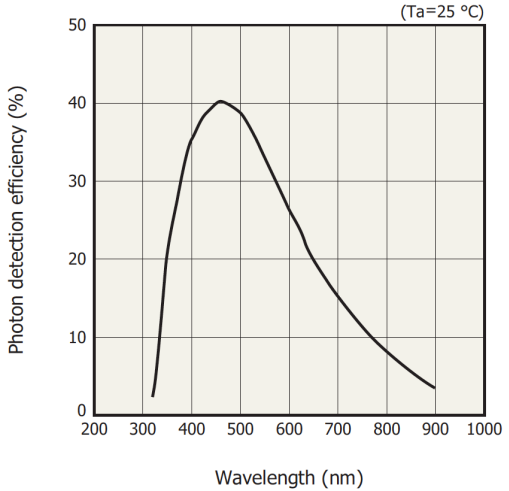
The Yellow Report leaves some wiggle room for interpretation for the hadron PID in the electron endcap: 3σ π/K separation up to 7 GeV/c (page 21) or up to 10 GeV/c (table 3.1)

Proposed geometry

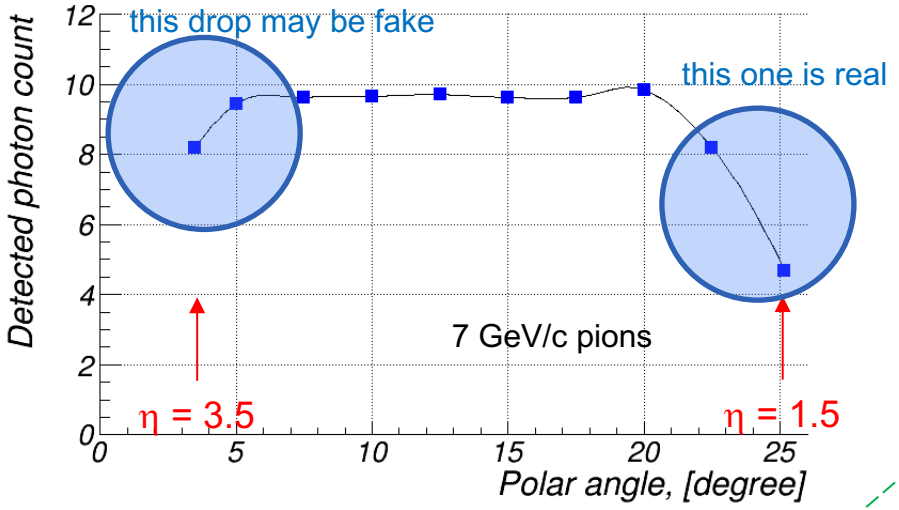


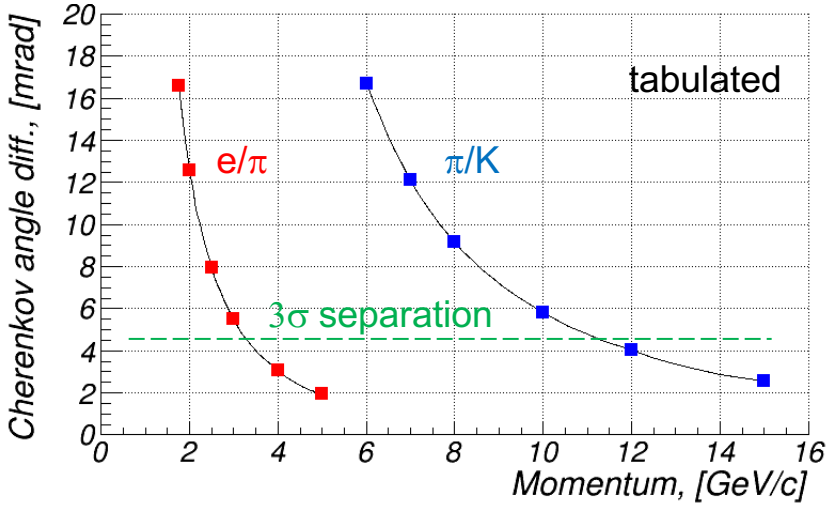
Technical details

- Geometry: proximity focusing, no mirrors
  - Aerogel: parameterizations based on CLAS12 data
    - 3cm thick @ density 110mg/cm^3 (tuned to match <n> ~ 1.02)
    - Rayleigh scattering
    - Absorption length
  - Acrylic layer: 3mm thick, “cutoff” set @ 350nm
  - ~40cm long (air) expansion volume
  - SiPMs (S13361-3050AE-08 8x8 panels)
    - 3.4 mm pitch
    - QE as given by Hamamatsu
    - 85% geometric fill factor & 70% “safety factor” on top of it
- Custom GEANT4 / ROOT software



Some performance plots

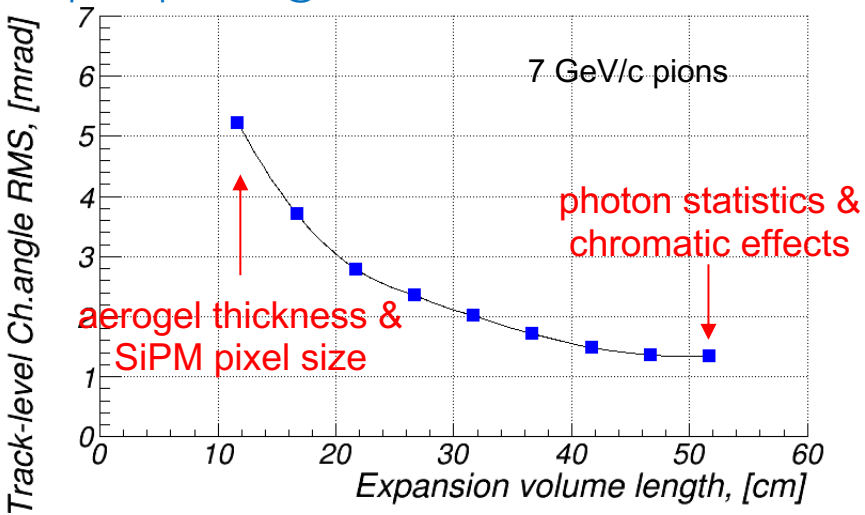


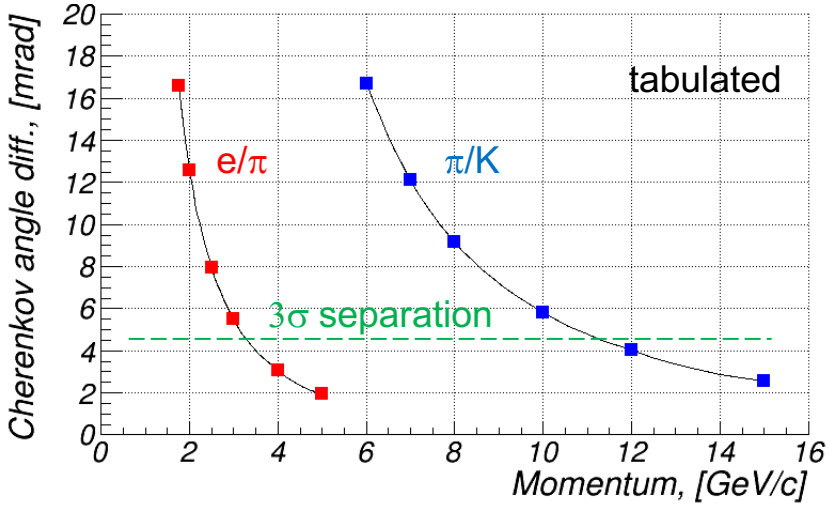


- ~10 p.e. per track and ~1.5 mrad track-level Cherenkov θ resolution as follows from the GEANT -> IRT (indirect ray tracing) pass
- Uniform response across the acceptance

Some performance plots

p/K separation @ 7 GeV/c for n ~ 1.02 is ~12 mrad





- 3σ e/π separation up to ~3 GeV/c and π/K separation up to ~11 GeV/c ?!

- Of course, a more comprehensive study in the ATHENA software framework is needed

Do the numbers make sense, in general?

Seemingly, YES

- Input for back of the envelope calculation:
  - 3cm thick aerogel with <n> = 1.02; expansion volume ~400 mm; 3.4 mm pitch SiPMs
  - Saturated Cherenkov angle for this <n> is ~200 mrad, and we know n_γ~10 makes sense
- Emission point contribution:
  - $\sigma_\theta \sim$ (30mm * 0.2 / $\sqrt{12}$) / 400 mm -> 4.3 mrad
- Pixel size contribution:
  - $\sigma_\theta \sim$ (3.4mm / $\sqrt{12}$) / 400 mm -> 2.5 mrad
- Chromatic distortion:
  - As a matter of fact, $\sigma_n \sim$ 0.00034 for the detected λ range, and $d\theta/dn$ ~ 5mrad / 0.001
  - $\sigma_\theta \sim \sigma_n * d\theta/dn$ = 0.00034 * 5mrad / 0.001 -> 1.7 mrad
- All together in quadrature is ~5.3 mrad, and times $1/\sqrt{n_\gamma}$ ~1.65 mrad
  - [makes sense, compare to ~1.5 mrad from the GEANT -> IRT pass as a final fit result]

What is missing in the simulation?

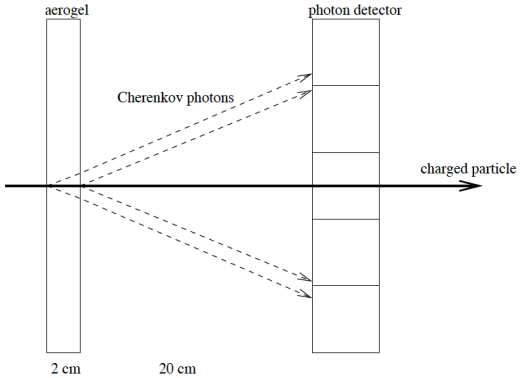
Not much

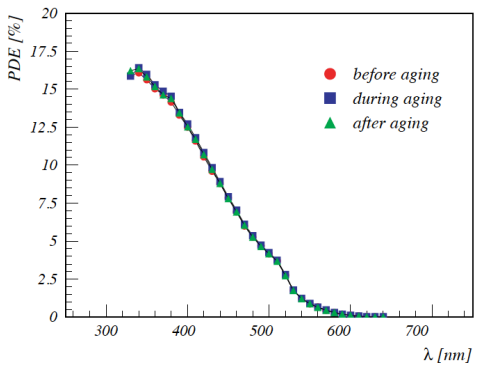
- Aerogel bulk volume refractive index variation (aka forward scattering effect):
  - NIM A876 (2017) 168 [CLAS12 R&D]: σ_θ < 1 mrad for n = 1.05 and 3 cm thick aerogel
  - NIM A556 (2006) 140 [LHCb R&D]: σ_θ ~ 0.9 mrad for n = 1.03 and 5 cm thick aerogel
- Non-flatness of the aerogel-air boundary:
  - NIM A876 (2017) 168 [same CLAS12 paper]: one should be able to maintain the distortions at a level of σ_θ < 1mrad even for n = 1.05 aerogel (n = 1.02 case would be ~2.5 times more relaxed with the same surface quality)

-> compare to ~4.5 mrad single photon Cherenkov angle resolution estimate following from the GEANT -> IRT pass

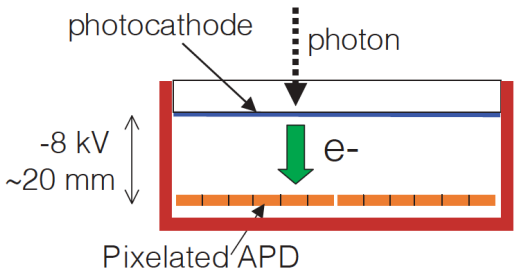
But Belle II ARICH is limited in π/K to ~4 GeV/c?

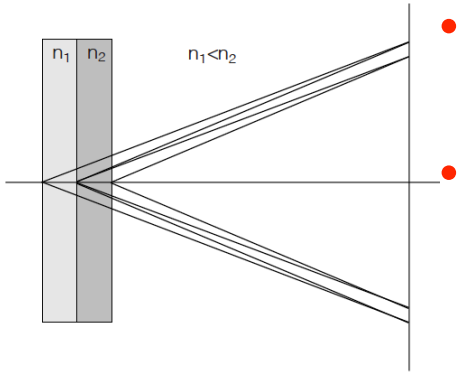
Sure, it is





- As short as 20cm expansion volume
  - This is your denominator to calculate the Cherenkov θ in a proximity focusing setup
- Emission point uncertainty
  - Dual radiator configuration certainly helps with focusing (at ~4 GeV/c), but <n> ~ 1.05 aerogel produces large ~ 300 mrad saturated rings





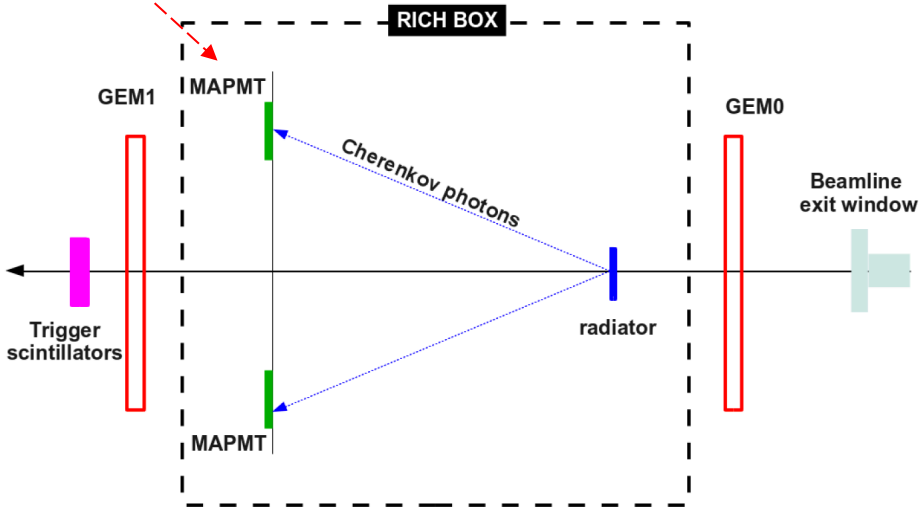
- Detection point uncertainty
  - HAPDs had rather large ~6mm pixel size
- Chromatic effects
  - HAPD PDE spectrum shifted towards small wave length (see next slides)

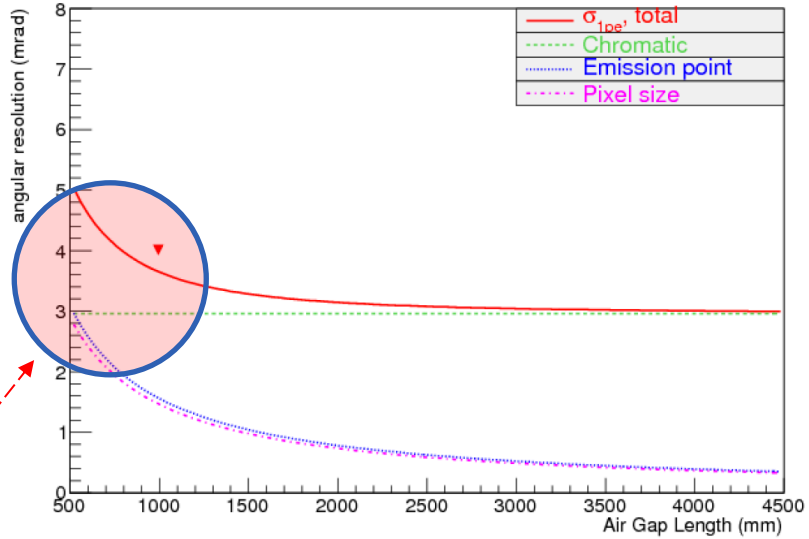
Single photon angle RMS ~ 15 mrad, dominated by the short expansion volume

But CLAS12 RICH is limited in π/K to ~6 GeV/c?

~6mm pixel size

NO, it is not: see EPJ A52 (2016) 23 -> 4σ π/K separation at 8 GeV/c





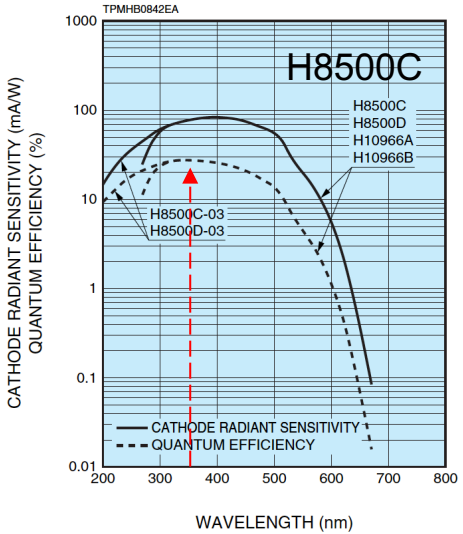
dominated by chromatic effects

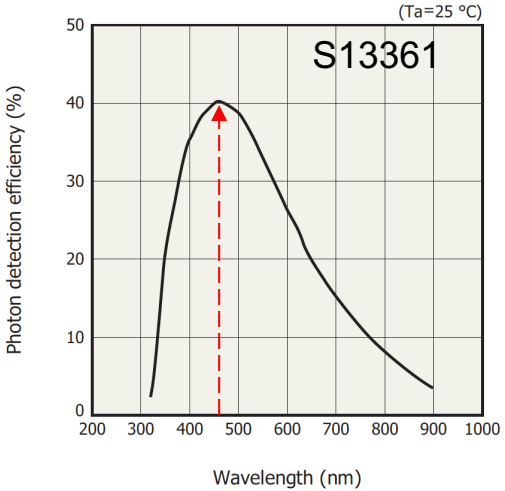
- The geometry:
  - 2cm thick aerogel with n ~ 1.05
  - Expansion volume ~1 m

Yet single photon angle RMS ~ 4.5 mrad, same order as in the presented 40cm long setup. Why?

CLAS12-related details

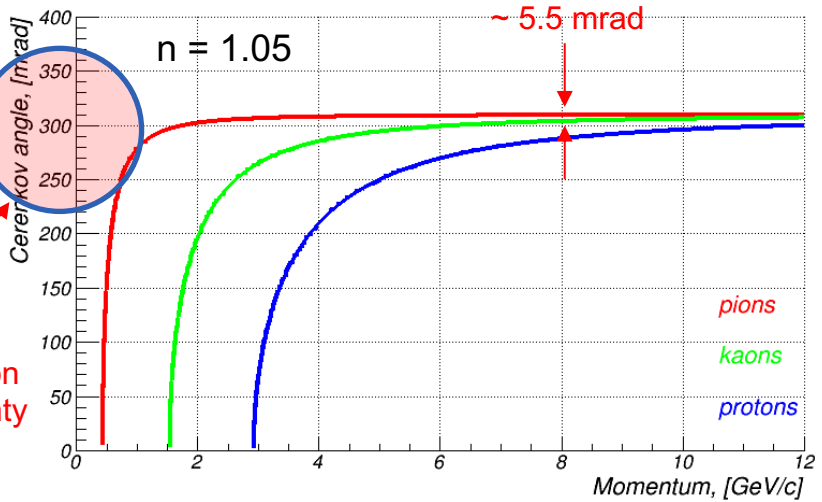
- Not all photons are “equally good”
  - H8500C MaPMT (CLAS12 beam test) has a peak of QE ~ 350nm
  - Proposed S13361 SiPM QE peaks at >450nm

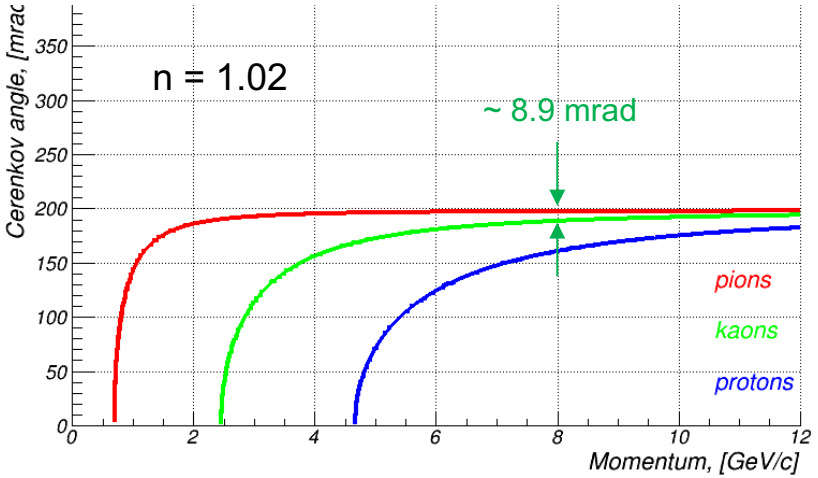




$\sigma_\theta \sim 3.0$ mrad Chromatic effect $\sigma_\theta \sim 1.7$ mrad

Larger emission point uncertainty

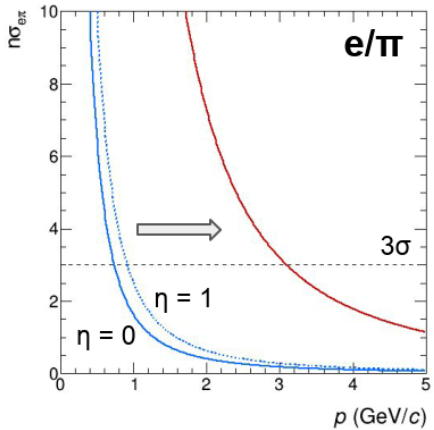


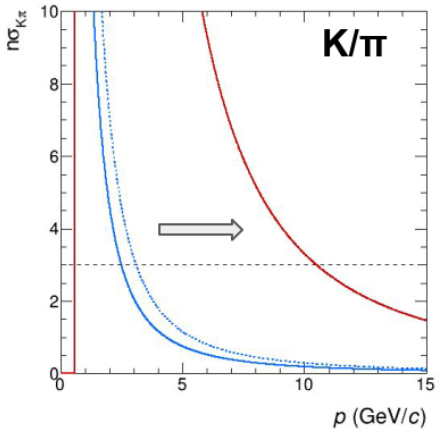


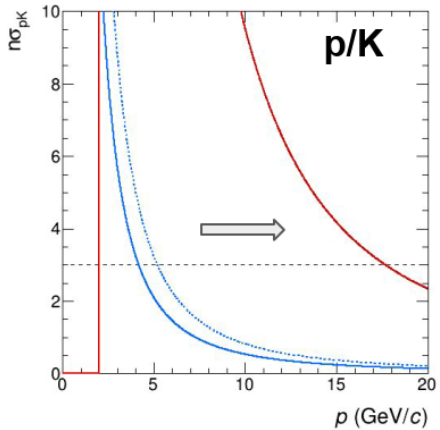
Would such a setup be unique / too ambitious?

NO, not really

see ALICE PID upgrade slides by A. Di Mauro



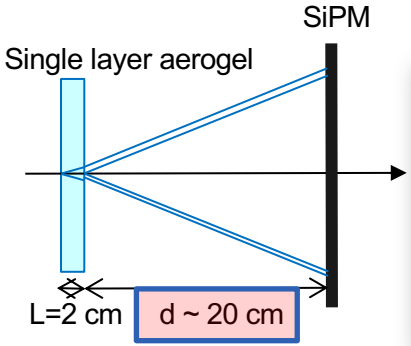


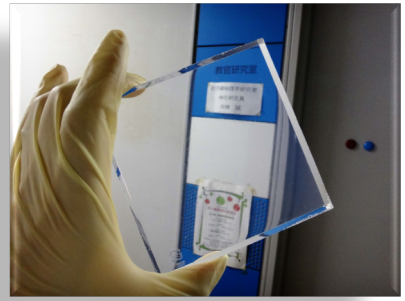


3 separation up to

e/π	~ 3 GeV/c
K/π	~ 10 GeV/c
p/K	~ 18 GeV/c

valuable extension of TOF capabilities





$$\sigma_{\vartheta_c}\text{ (p.e.)} = \sqrt{\sigma^2_{\vartheta_c}\text{ (chromatic)} + \sigma^2_{\vartheta_c}\text{ (geometric)} + \sigma^2_{\vartheta_c}\text{ (pixel)} + \sigma^2_{\vartheta_c}\text{ (noise)}} = 7.2\text{ mrad}$$

1.1 mrad	6.1 mrad	3.7 mrad

-> therefore reaching ~10 GeV/c in p/K separation with a **40cm long expansion volume** may not sound too insane

What is coming next?

- Geometry details to be finalized (consider more conventional n ~ 1.03? remove plexiglass? fill with CF_4? projectivity?) …
- … and ported to dd4hep
  - already consistent with the DIRC and the tracker (as shown at the I/GD meeting yesterday)
  - the backward EmCal will need to be adjusted anyway because of the beam pipe flange complication)
- Reconstruction codes to be incorporated into the production chain
  - they are identical to the dRICH ones (same IRT algorithm)
  - can *probably* be taken as a whole (optics description, stepping code collecting photon information, output tree with all the relevant microscopic information)

Si Disks	Z Position (cm)	nner Radius (cm)	Outer Radius (cm)	% X/X0
Rear Disk 5	-145		43.23	0.24
Rear Disk 4	-109		43.23	0.24
Rear Disk 3	-73	3.5	43.23	0.24
Rear Disk 2	-49	3.18	36.26	0.24
Rear Disk 1	-25	3.18	18.5	0.24

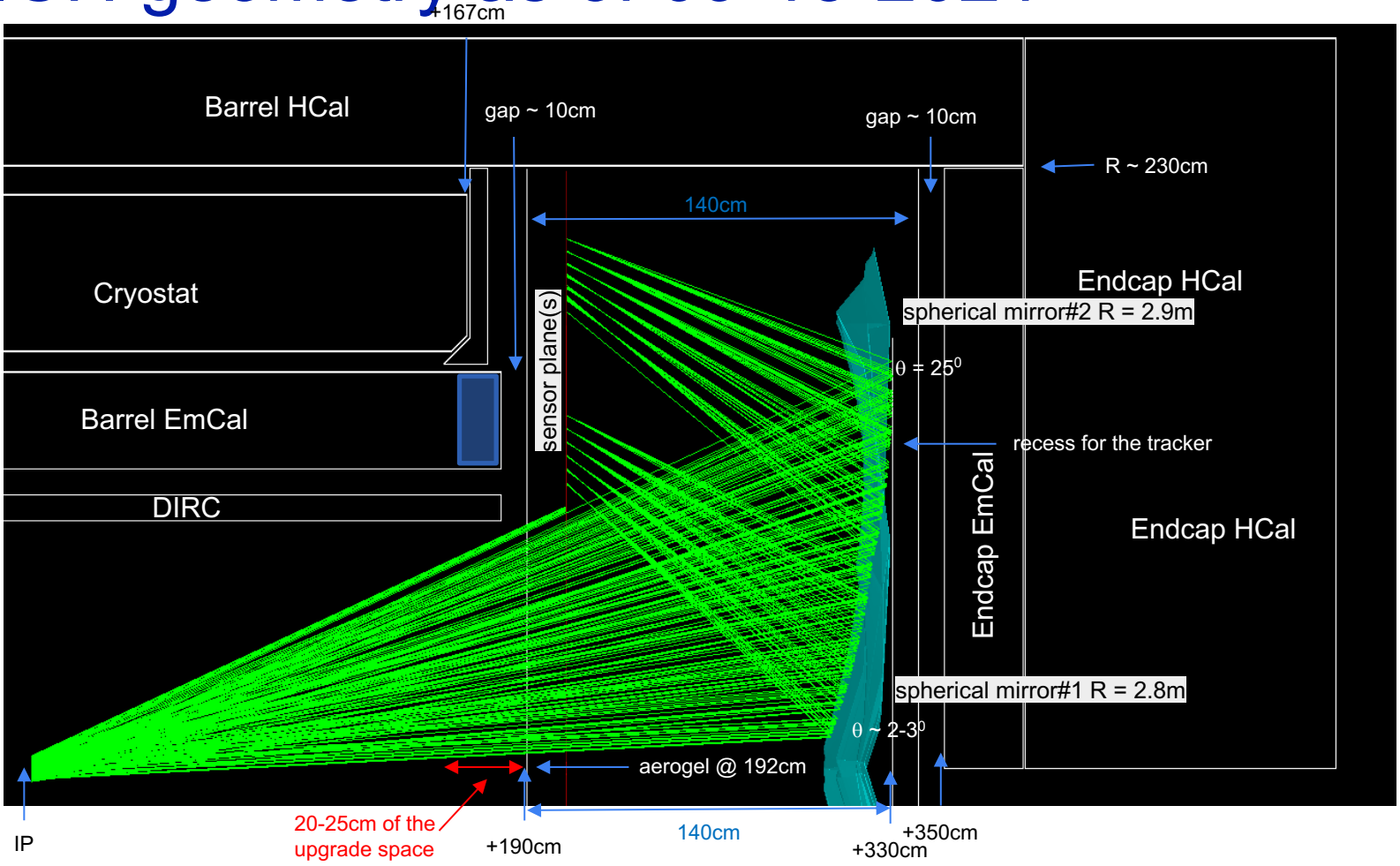
GEM Rings	Z Position (cm)	nner Radius (cm)	Outer Radius (cm)	% X/X0	Resolution [um]**
Rear Disk 1	-102	43.5	75.5	0.4	250 x 50
Rear Disk 2	-144.5	43.5	88.5	0.4	250 x 50

A short update on the *forward* dRICH

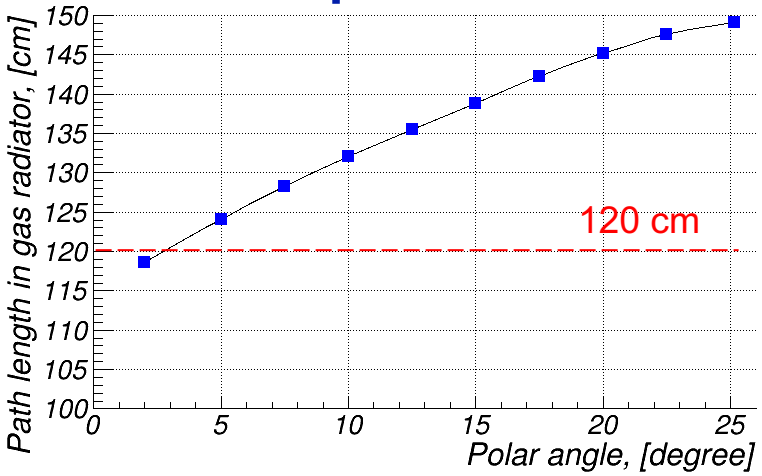
Objectives

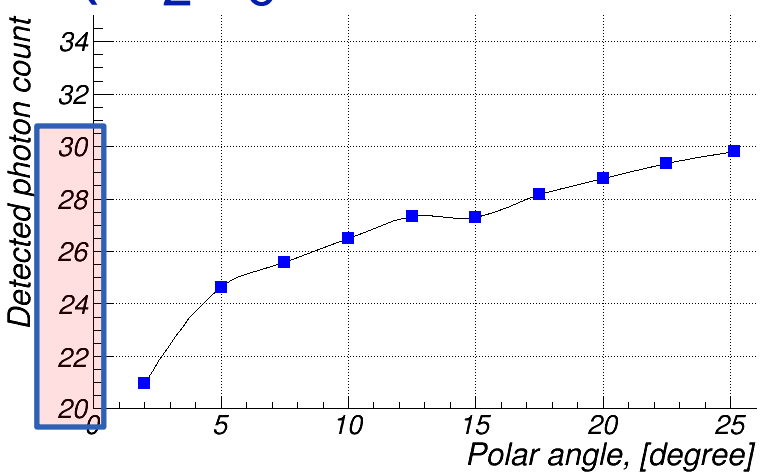
- Seemingly, it was not possible to guarantee high dRICH performance in the previously allocated fiducial volume, therefore:
  - Solenoid was shifted by 25cm towards the e-endcap (which also helped to balance the forces); new magnetic field map by Valerio as of September 28th
  - dRICH gained extra ~15cm of space
  - This extra space seems to be sufficient to come up with a credible optics configuration, see the next slides
- New configuration:
  - Two spherical mirrors per 60-degree sector
  - 15cm gap between the flat vertical sensor plane and the vessel wall
  - Angular coverage ~ [1.5 .. “4.0”] in η
  - “Upgrade space” of 20-25cm upstream of the vessel

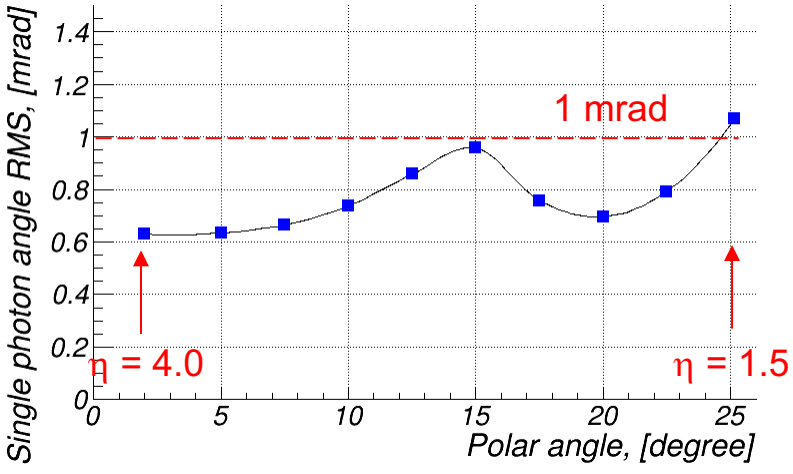
dRICH geometry as of 09-15-2021

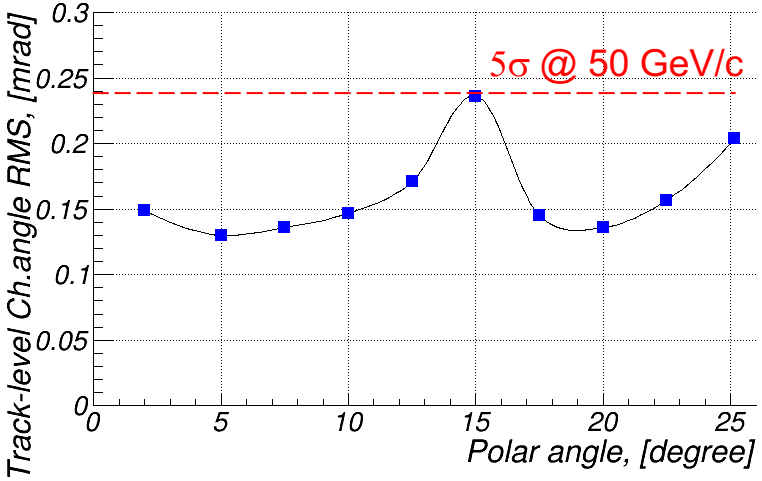


Selected performance plots (C_2F_6, 50 GeV/c π^+)









Action items

- Finalize aerogel performance evaluation (use the same generalized iterative IRT code as for the e-endcap RICH)
- Verify performance in the magnetic field
- Replace truth information by ring-finder-like one where possible; merge aerogel and gas measurements in a singe σ count
- Factorize reconstruction part out
- Implement in dd4hep geometry (by Chris Dilks)