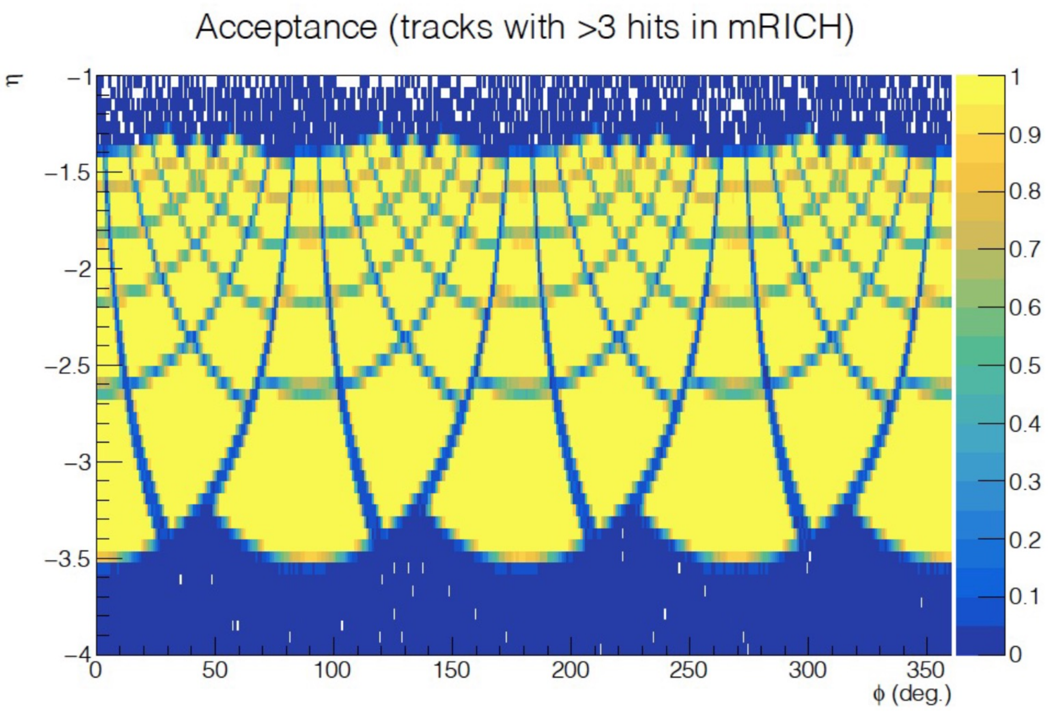
Design considerations for a proximity-focusing RICH for the EIC detector electron endcap

A. Kiselev (BNL)

Cherenkov PID WG Meeting, May 20, 2022 [slides 2..12 - ATHENA 09/30/2021 bi-weekly meeting talk without any modifications]

Objective(s)

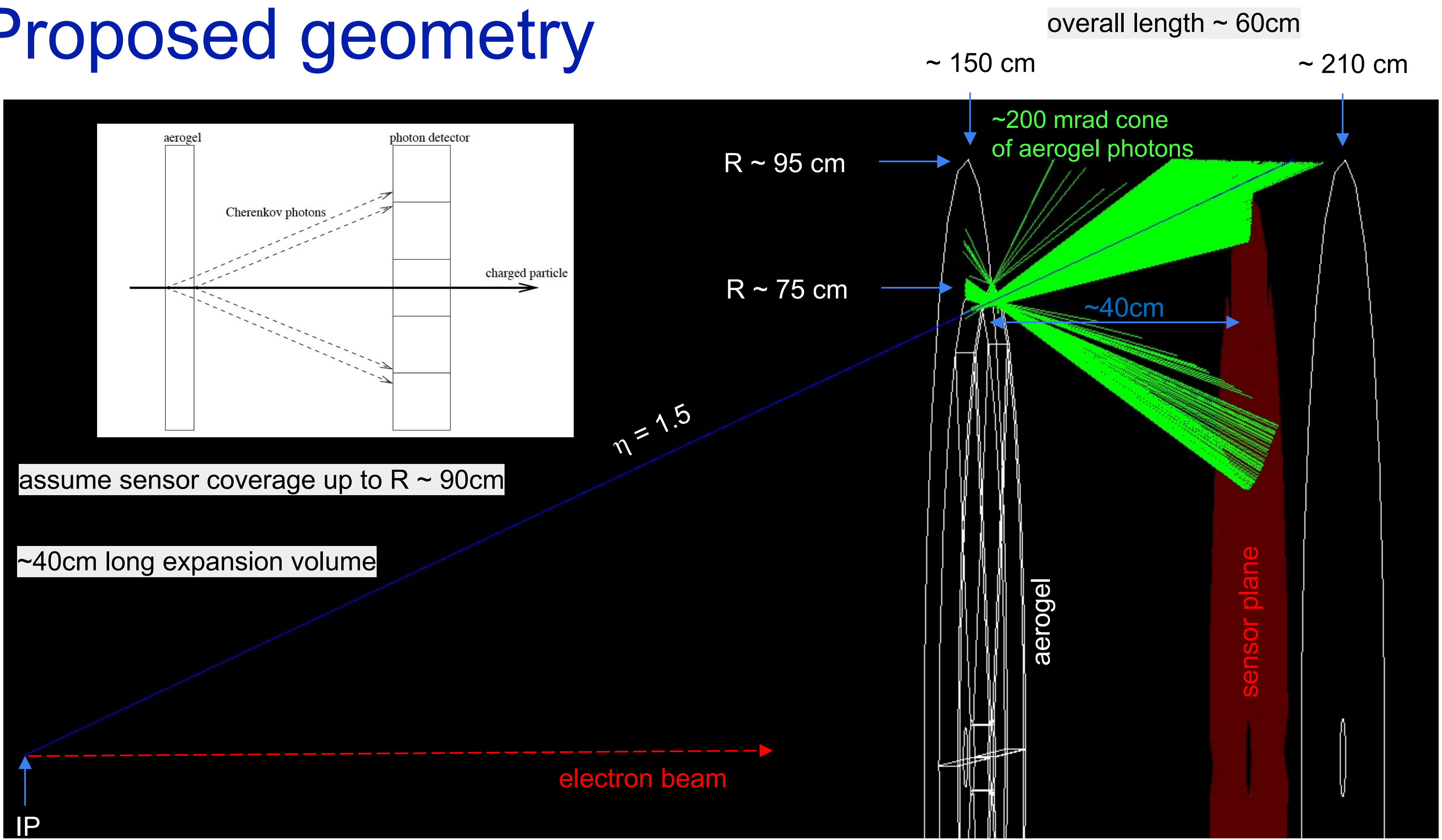
- Look for a "simple" RICH version which
  - Would meet the YR requirements
  - Is kind of "safer" & easier to defend at the proposal writing stage, given the absence of a direct experimental proof of a π/K separation reach by mRICH
  - Has perhaps a similar material budget
  - Is easier to have implemented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

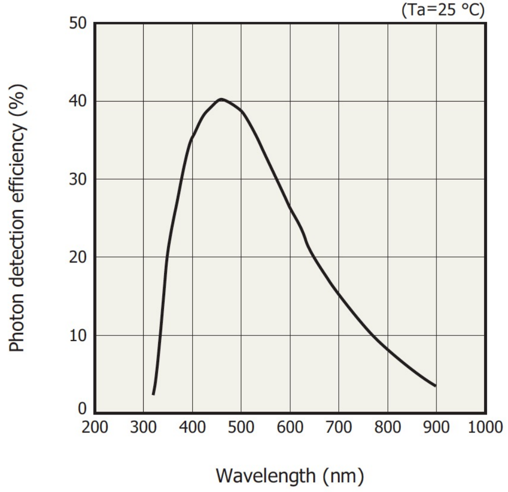
The Yellow Report leaves some wiggle room for interpretation for the hadron PID in the electron endcap: 3σ π/K separation up to 7 GeV/c (page 21) or up to 10 GeV/c (table 3.1)

Proposed geometry

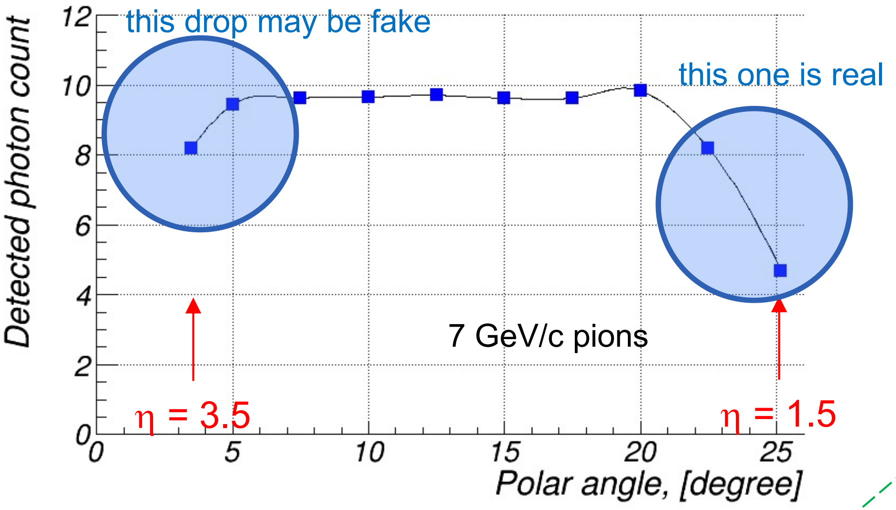


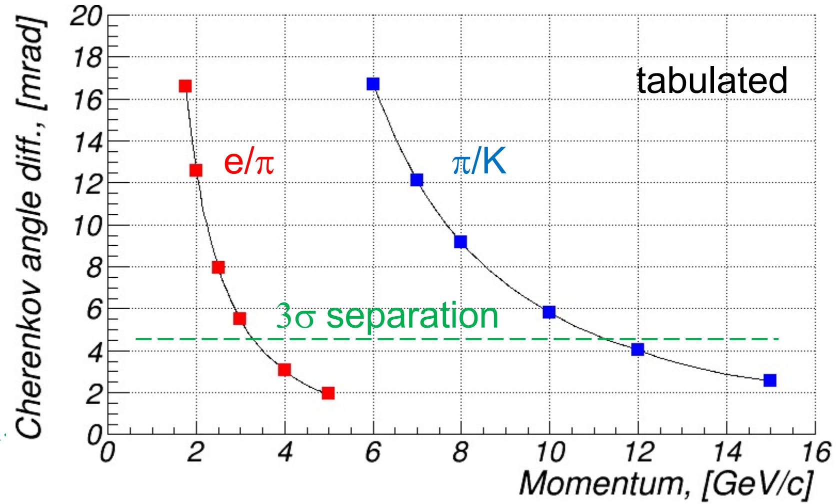
Technical details

- 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



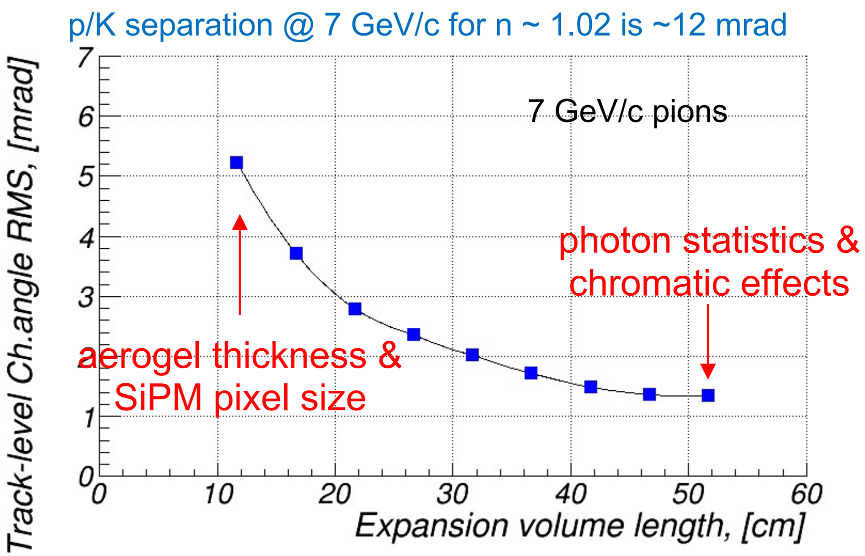
Some performance plots

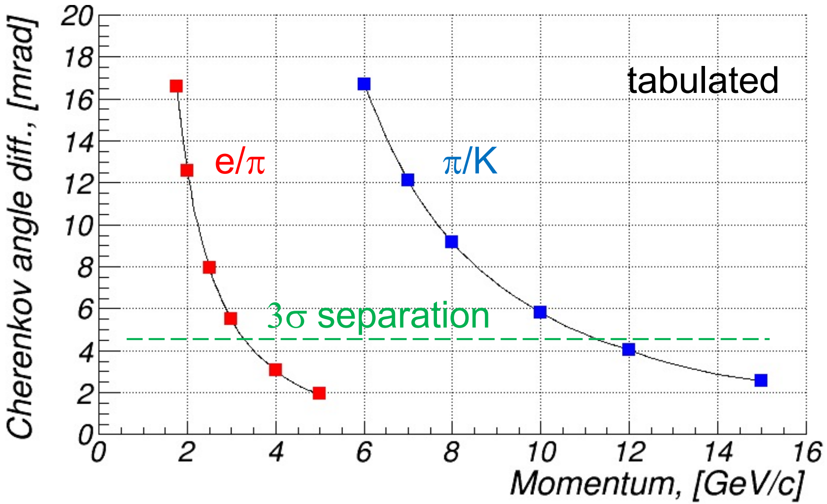




- ~10 p.e. per track and ~1.5 mrad track-level Cherenkov θ resolution as follows from the GEANT -> IRT (indirect ray tracing) pass
- Uniform response across the acceptance

Some performance plots





- 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 / √12) / 400 mm -> 4.3 mrad
- Pixel size contribution:
  - $\sigma_\theta \sim$ (3.4mm / √12) / 400 mm -> 2.5 mrad
- Chromatic distortion:
  - As a matter of fact, $\sigma_n \sim$ 0.00034 for the detected λ range, and dθ/dn ~ 5mrad / 0.001
  - $\sigma_\theta \sim \sigma_n$ * dθ/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?

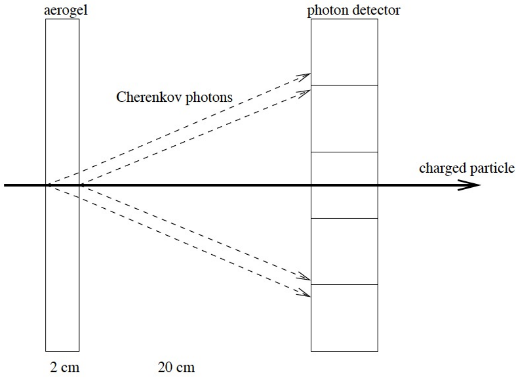
Not much

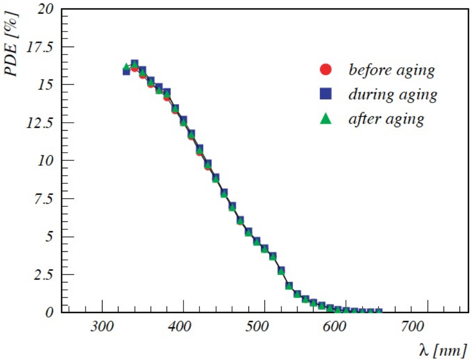
- Aerogel bulk volume refractive index variation (aka forward scattering effect):
  - NIM A876 (2017) 168 [CLAS12 R&D]: σ_θ < 1 mrad for n = 1.05 and 3 cm thick aerogel
  - NIM A556 (2006) 140 [LHCb R&D]: σ_θ ~ 0.9 mrad for n = 1.03 and 5 cm thick aerogel
- Non-flatness of the aerogel-air boundary:
  - 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

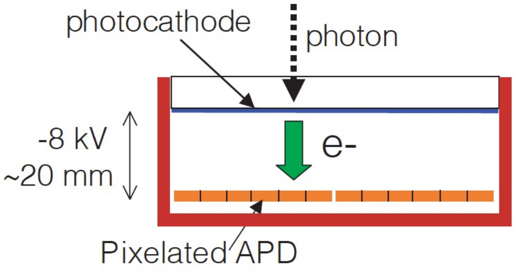
But Belle II ARICH is limited in π/K to ~4 GeV/c?

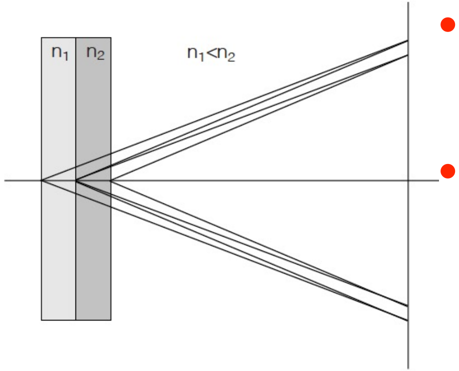
Sure, it is





- 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)



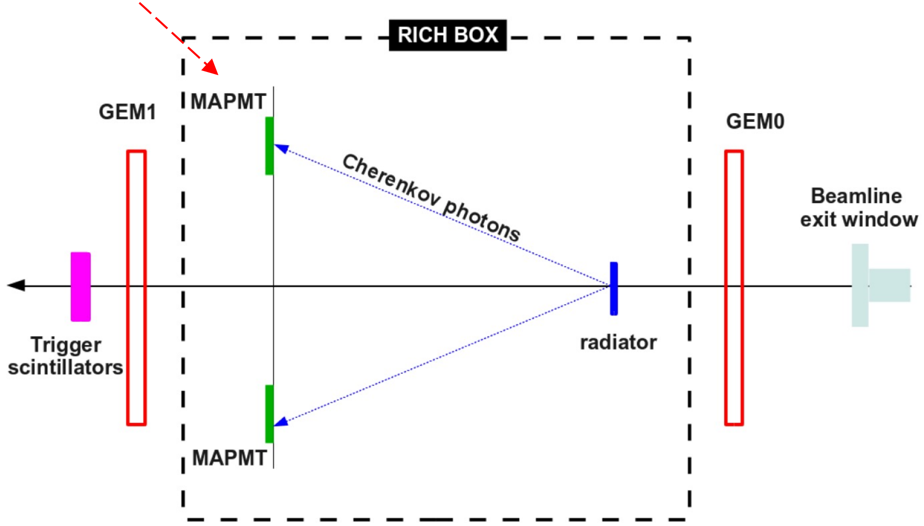


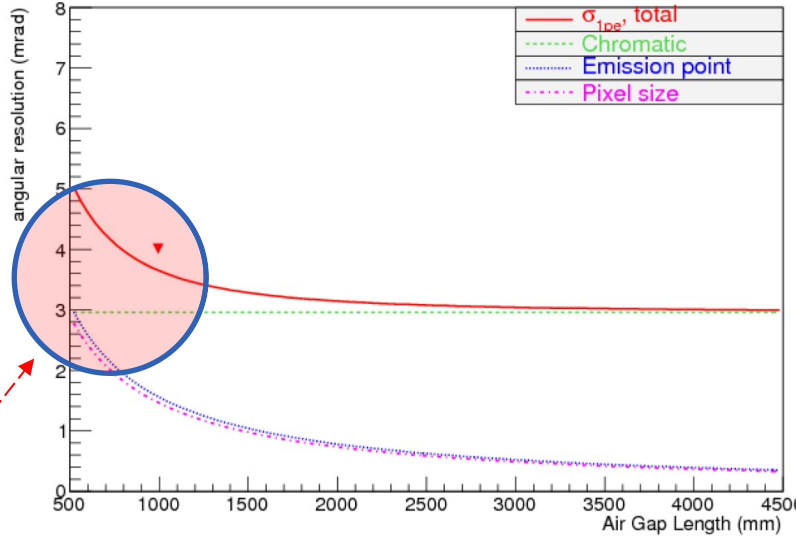
Single photon angle RMS ~ 15 mrad, dominated by the short expansion volume

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





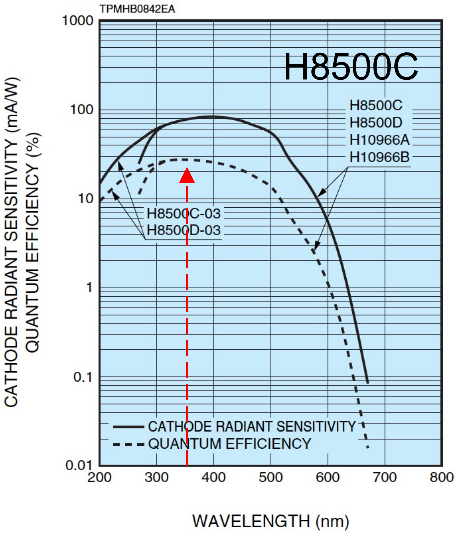
dominated by chromatic effects

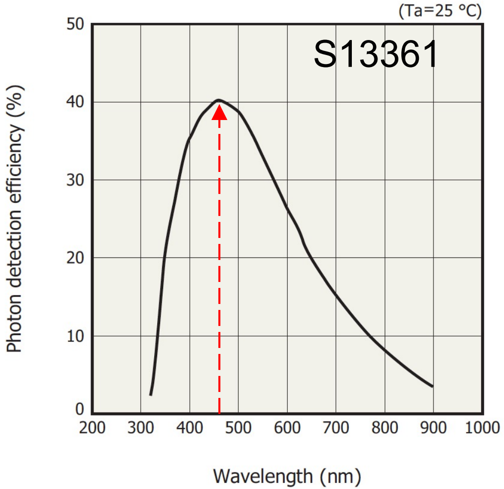
- The geometry:
  - 2cm thick aerogel with n ~ 1.05
  - Expansion volume ~1 m

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

CLAS12-related details

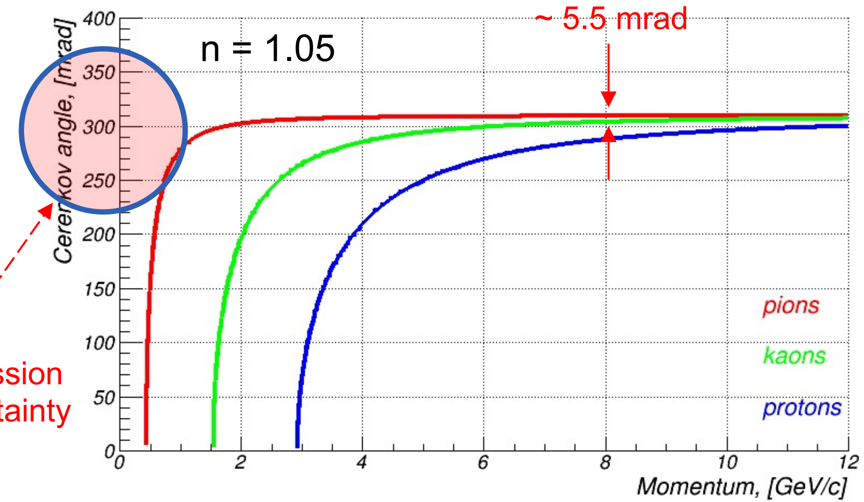
- Not all photons are "equally good"
  - H8500C MaPMT (CLAS12 beam test) has a peak of QE ~ 350nm
  - Proposed S13361 SiPM QE peaks at >450nm

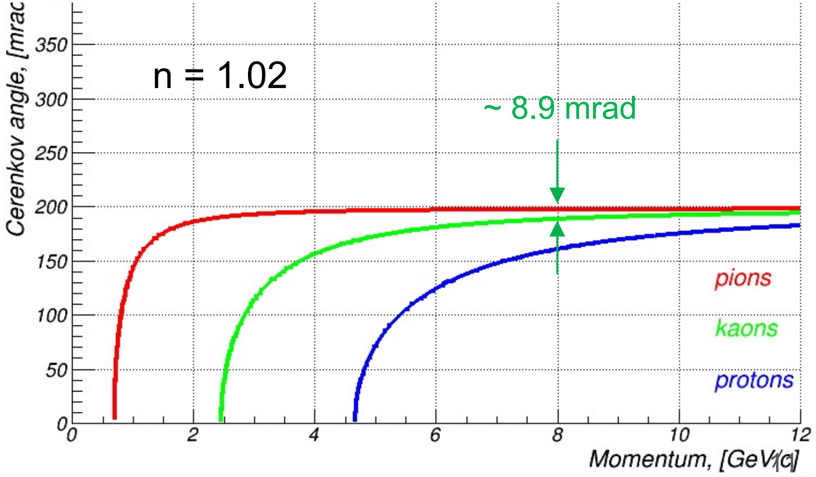




$\sigma_\theta \sim 3.0$ mrad Chromatic effect $\sigma_\theta \sim 1.7$ mrad

Larger emission point uncertainty

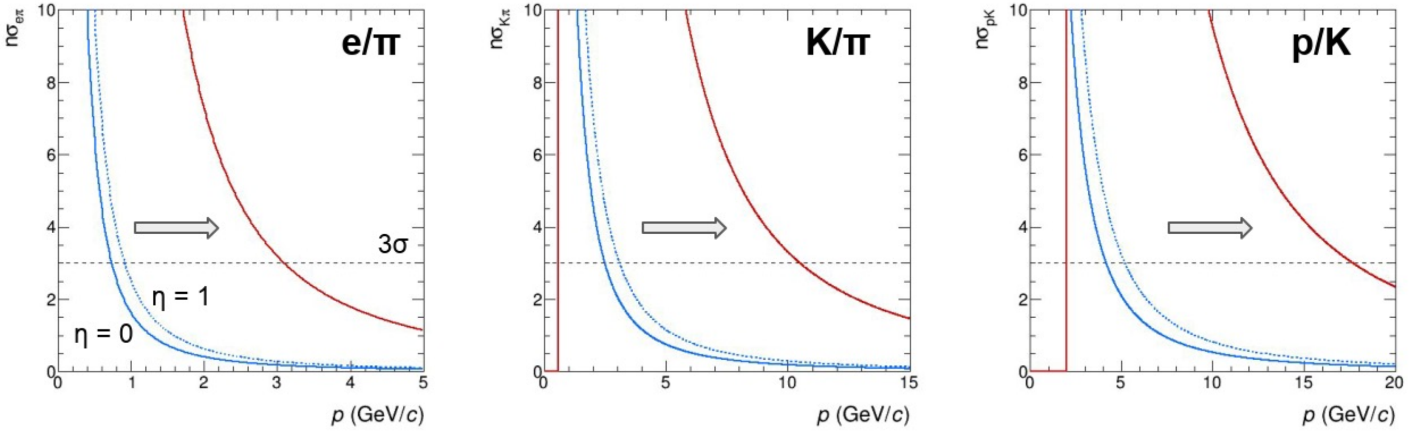




Would such a setup be unique / too ambitious?

NO, not really

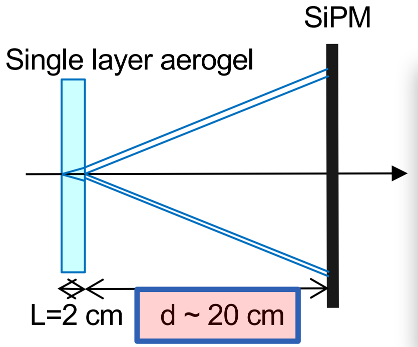
see ALICE PID upgrade slides by A. Di Mauro

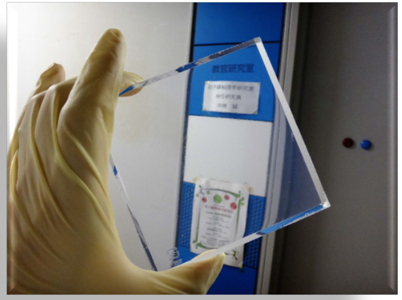


3 separation up to

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

Simulations in the ATHENA software framework

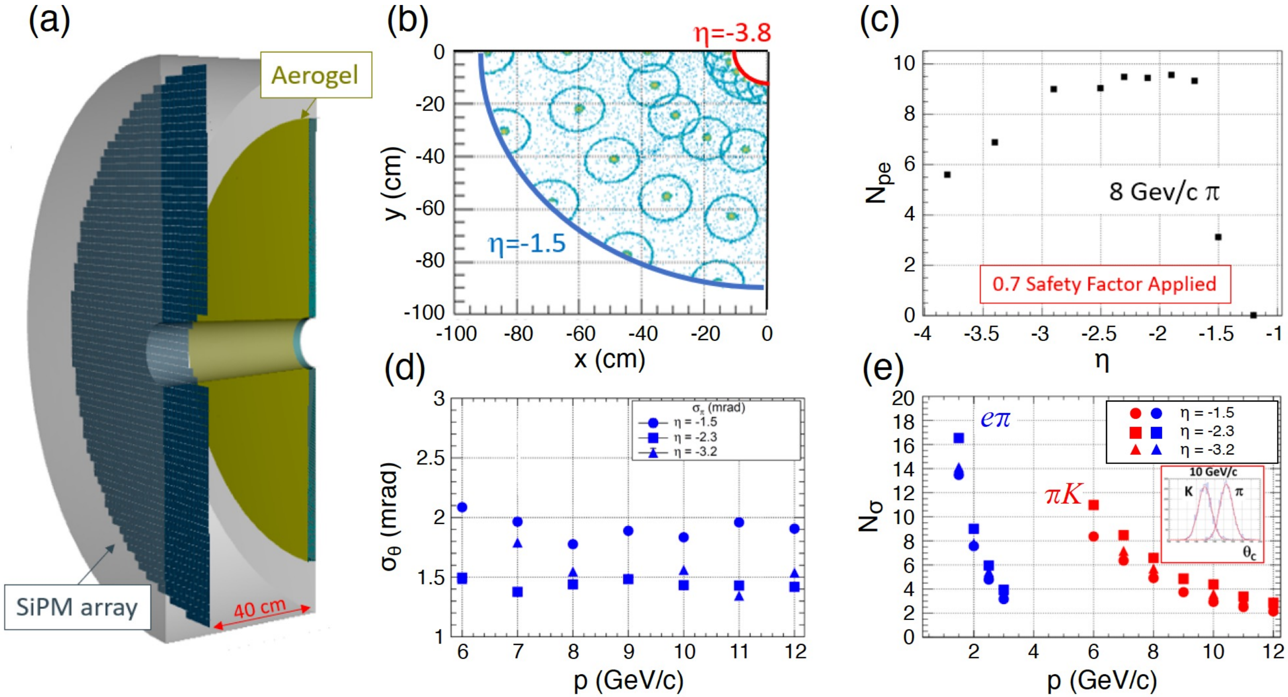
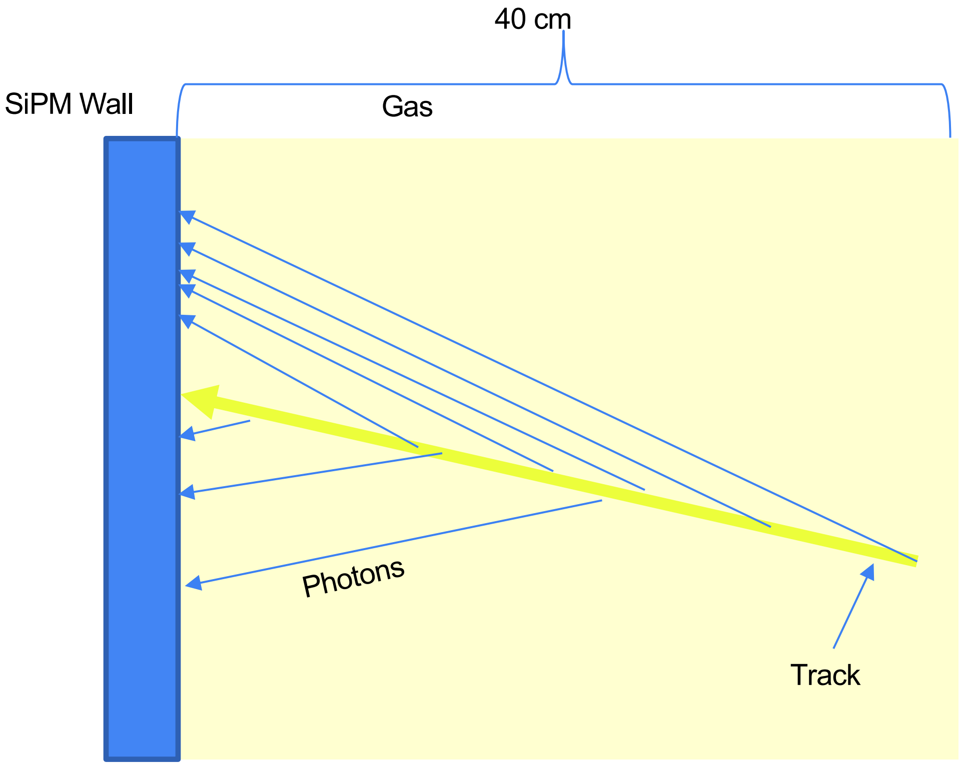


Figure 2.11: a) Configuration of the pfRICH. b) Response in $\frac{1}{4}$ of the detector to 1000 artificial events with regularly spaced 8 GeV/c pions. This highlights the aerogel rings, gas-blobs, and indicates the properly scaled (rather small) background. c) Number of detected photoelectrons for single 8 GeV/c pions vs. η. d) Cherenkov-angle resolution as a function of momentum in three regions of η. e) Shows the separation power, demonstrating full realization the Yellow Report performance goal. (FullSim)

Gas radiator?



- Threshold Cherenkov produces a blob of photons
  - Information is more-or-less only YES radiating or NOT radiating
  - Not ring-imaging, no need for good single-photon angular resolution
- Need an appreciable number of photons in the blob to distinguish from noise
  - Especially true for SiPMs, large dark rate
- Need a visible-range photodetector for aerogel to work properly
  - Likely can't use CsI or other VUV photocathodes

Gas radiator?

Electron has $\beta \approx 1$ for effectively all energies, number of Cherenkov photons is saturated

All gases at atmospheric pressure

Gas	<N Photons> at saturation	<N Dark Counts> 100 kHz in $1.2^*\theta_{C@\beta=1}$	Pion Threshold
CF4	3.62	0.16	~4.2 GeV
C2F6	5.92	0.16	~3.5 GeV
C3F8	8.08	0.16	~3.0 GeV
C4F10	9.87	0.16	~2.8 GeV
Argon	2.39	0.16	~5.9 GeV

<N Dark Counts> scales linearly with dark rate, even 1 MHz is not 100% deadly for threshold, assuming timing cut can be placed properly (may be challenging in practice)

Clearly one will have to use a heavy gas or pressurize to get a high enough number of photons

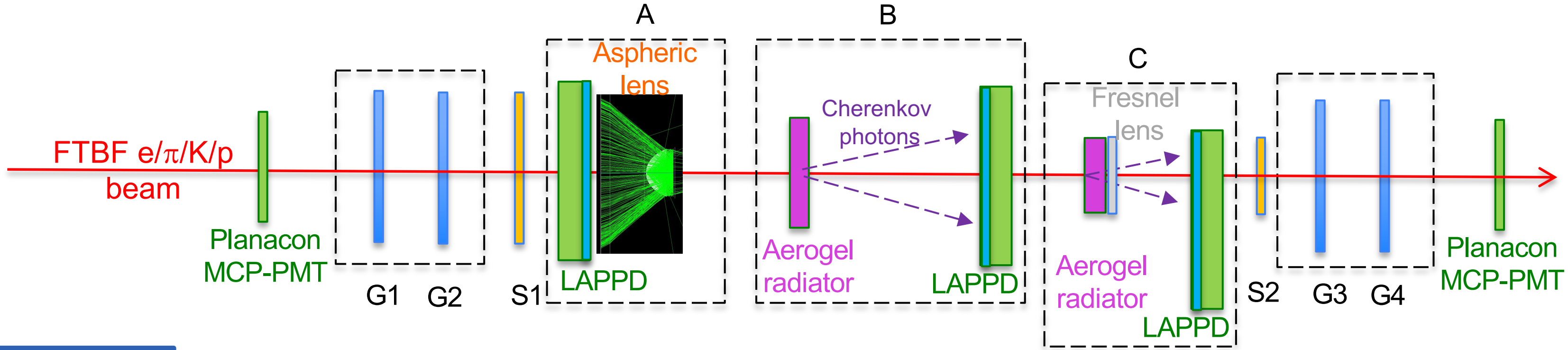
Pressurizing gas near aerogel may be an issue. Not sure which gases play well with aerogel at a windowless interface

by Henry Klest, 09/30/2021

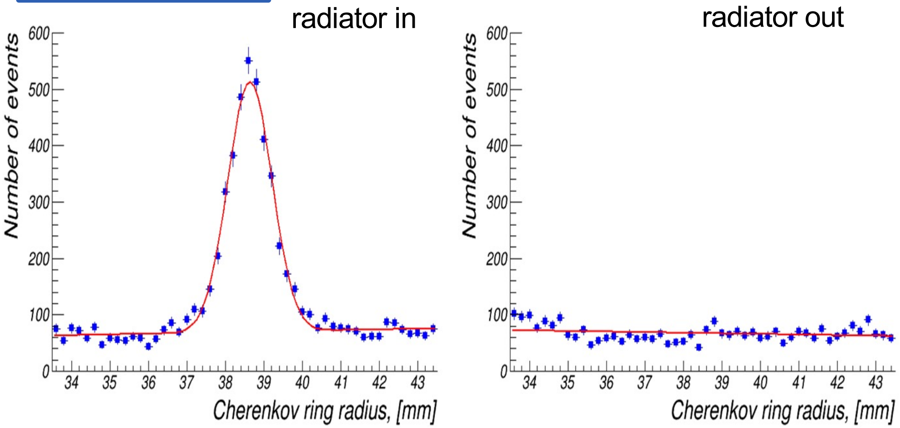
Off-topic material

eRD110 LAPPD beam test in June 2022

The A .. C part is on the moveable table



σ_R ~ 600 μm



(A) Single photon ring radius resolution (June 2021 data)

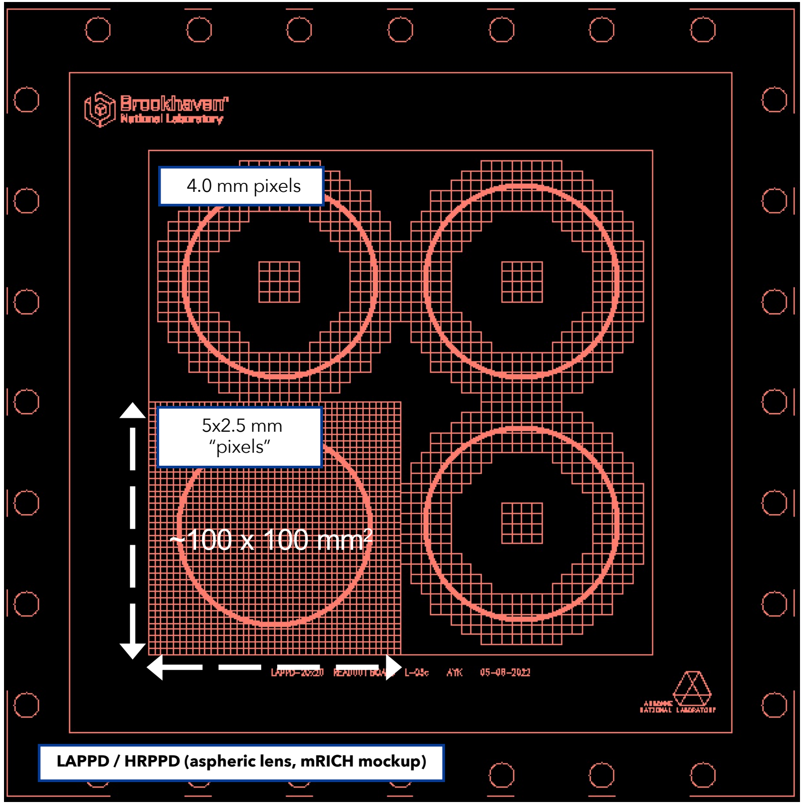
- G1 .. G4 – COMPASS GEM reference tracker
- S1 .. S2 – trigger scintillator counters
- Configurations:

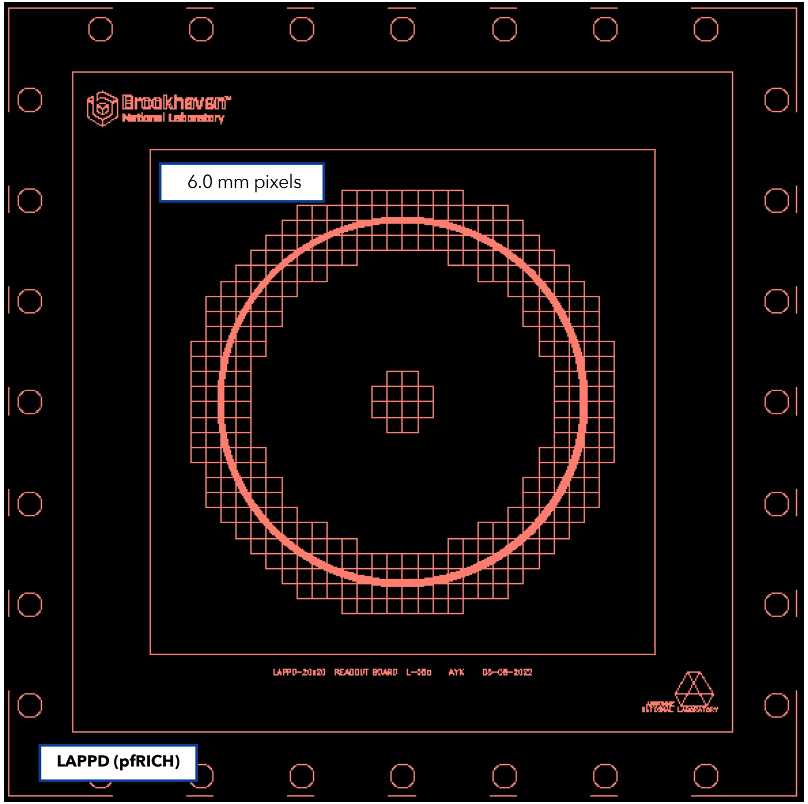
  (A) Aspheric lens, 120 GeV protons, “calibration” setup

  (B) pfRICH-like, <10 GeV/c, π/K separation performance

  (C) mRICH-like, <10 GeV/c, π/K separation performance
  @ normal incidence, without mirrors

eRD110 LAPPD beam test in June 2022





First attempt to demonstrate *simultaneous* ring imaging and time-of-flight performance (may be too ambitious though)