Some updates on the Cherenkov Detector

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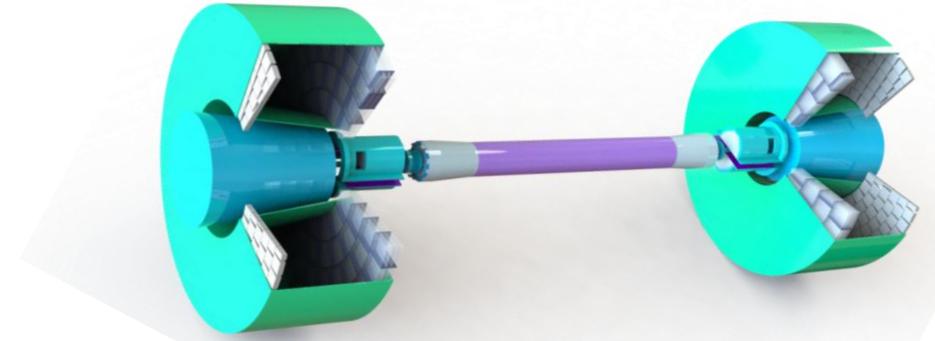
CEPC Day, March 2, 2026

Detector material budget estimation
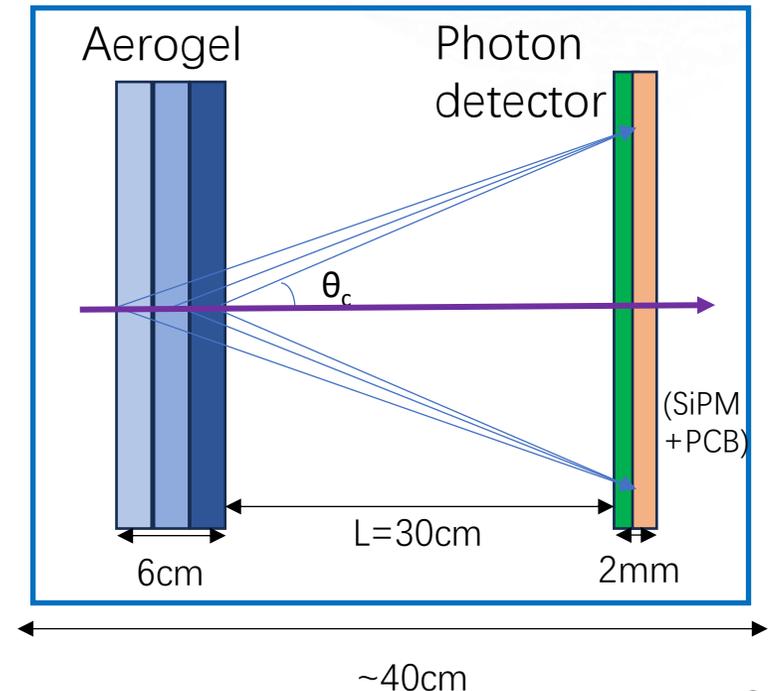
- Total material budget: ~2.83%

| Materials	Thickness	Radiation Length(X0)	Material Budget (T/X0)
Aerogel	6cm	731cm	0.82%
SiPM	1mm	9.36cm	1.06%
PCB(FR-4)	1mm	19.4cm	0.51%
PCB(copper)	30μm	1.43cm	0.21%
Carbon Fiber	0.4mm	40cm	0.10%
Air	40cm	304 m	0.13%
Total			**2.83%**

Some parts are still missing: cables, electronics, cooling etc.

Wall (carbon fiber)
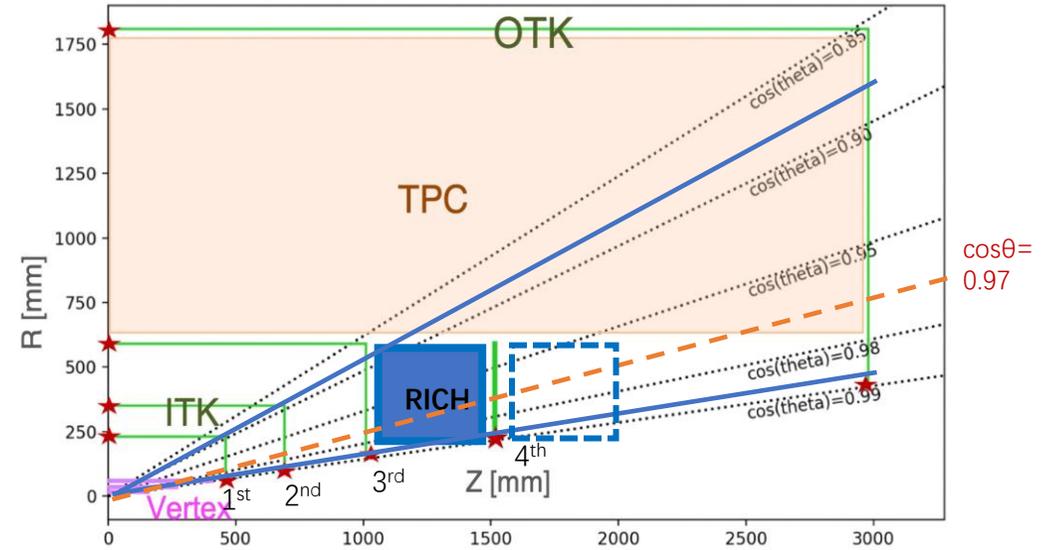
Impact on momentum resolution

- A preliminary simulation result (ITK+TPC+OTK) : ~0.15% degradation at θ=15° (cos θ=0.97) for low Pt region (1 to 10 GeV/c)
- Current setup: Cherenkov detector between 3rd and 4th endcap ITK. Will test the other position

From Changru Li
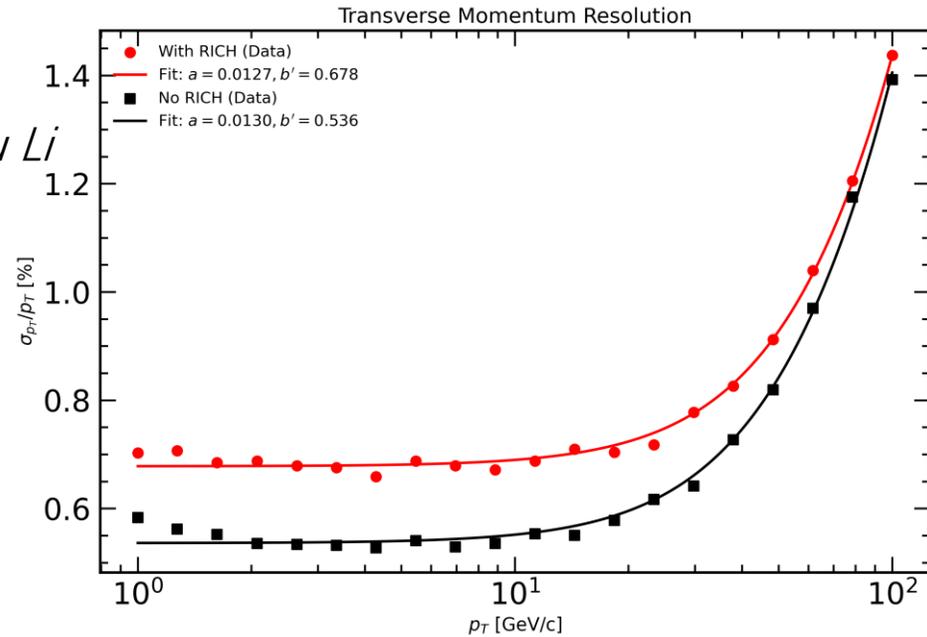
$$\theta_0 = \frac{13.6 \text{ MeV}}{\beta cp} \cdot z \cdot \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \ln \left(\frac{x}{X_0} \right) \right]$$

$$\approx \begin{cases} 2.1 \text{ mrad}, p = 1 \text{ GeV} \\ 0.1 \text{ mrad}, p = 20 \text{ GeV} \end{cases}$$

Coverage: 9.3° <θ <28.8°
or 0.88<cos θ< 0.99

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Consideration on SiPM dark noise

- Estimation of **false hits from dark noise** in the photon detector plane :

  $N_{\text{false hits}}$ = Dark noise rate x Readout time window x Photon detector area

  $= 200 \times 10^3 \times 69 \times 10^{-9} \times 0.8 \times 10^6$

  $= \mathbf{10000}$

  Typical dark noise rate: 200 kHz/mm^2
  Readout time window: 69 ns(same as VTX, ITK, OTK, Ecal, Muon)
  Photon detector area: 0.8 m^2

- With tracking information incorporated:
  - Momentum: Ring diameter (Max. ~ 8 cm),
  - Track: Intersection point (ring center)
  - **false hits can be reduced by a factor of ~100**
  - **relaxes the requirement for SiPM dark noise rate**

However, beam background and secondary particles are not included in this estimate.
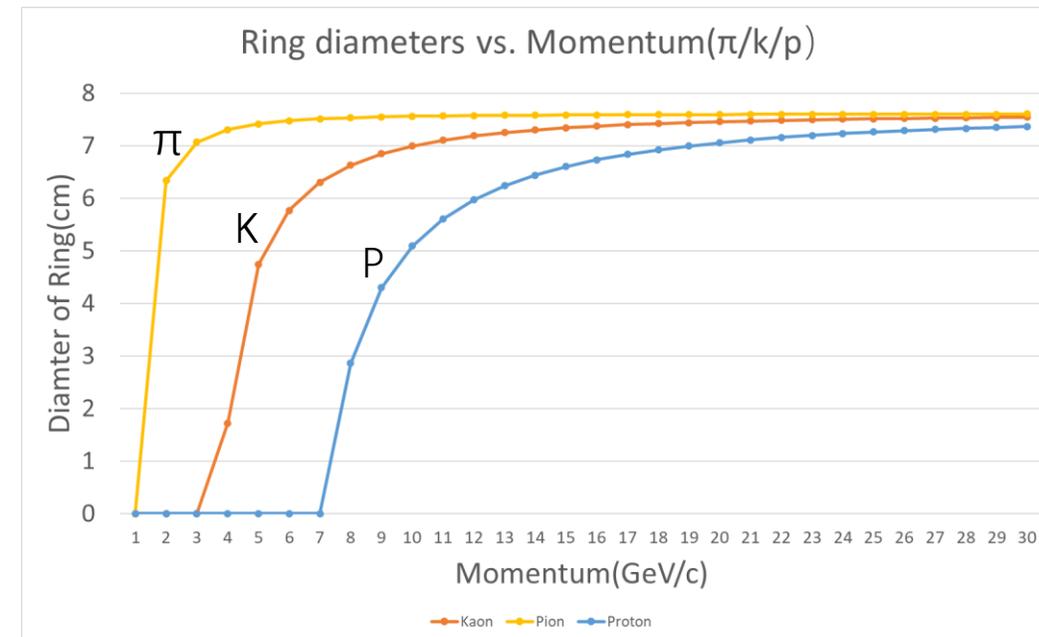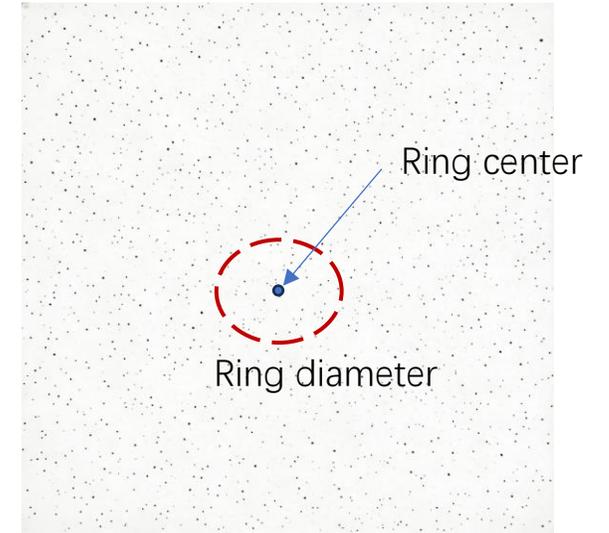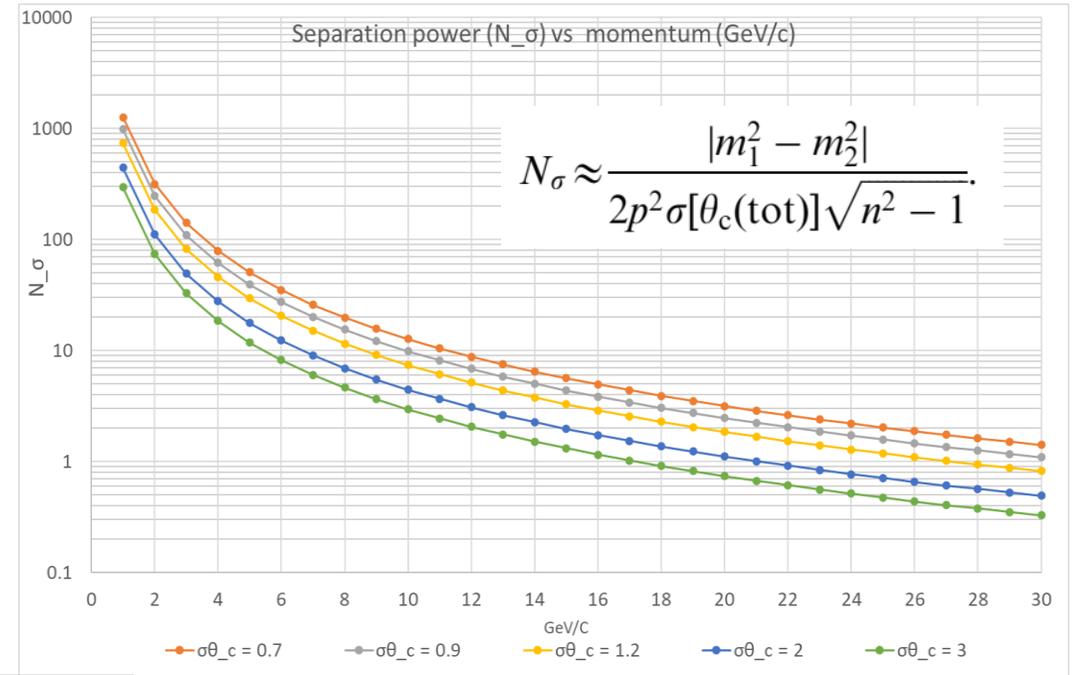
Consideration on SiPM spatial resolution

● To achieve 3σ K/π separation at 20 GeV/c, a good Cherenkov angle resolution (σ(θc(tot)) of 0.7 mrad is needed;

$$N_\sigma \approx \frac{|m_1^2 - m_2^2|}{2p^2 \sigma[\theta_c(tot)]\sqrt{n^2 - 1}}.$$

● Resolve the spatial resolution from the Cherenkov angle resolution formula:

$$\sigma\big(\theta c(tot)\big) = \frac{\sigma(\theta c(1pe))}{\sqrt{Npe}}$$

$$= \frac{1}{\sqrt{Npe}} \left(\sqrt{\sigma_{spatial}^2 + \sigma_{thick}^2 + \sigma_{track}^2 + \sigma_{chromatic}^2} \right)$$

$$= \frac{1}{\sqrt{Npe}} \left(\sqrt{\left(\frac{\Delta_{size}}{L\sqrt{12}}\right)^2 + \left(\frac{t \sin\theta_C}{L\sqrt{12}}\right)^2 + \sigma_{track}^2 + \left(\frac{\Delta_n}{n \tan\theta_C}\right)^2} \right)$$

Assume $\Delta size = 1mm$, $t = 20mm$, $\sigma_{track} = 0.5mm$, $\Delta_n = 0.0001(n = 1.008)$, $Npe = 15$,

Then $\sigma\big(\theta c(tot)\big) \approx$ **0.7 mrad**

A SiPM of 1mm x 1mm, or
$\sigma_{spatial}$ = 280 μm is desirable

Currently under checking the chromatic dispersion of aerogel in 300-700 nm wavelength range

Preliminary requirements for SiPM

Discussed with Yong Liu, Zhijun etc..

Parameters	preliminary requirement
Wavelength	300 nm – 700 nm
Photon detection efficiency	>50% at 420nm
SiPM active area (two types)	1 mm x 1 mm (conventional) 3 mm x 3 mm (position sensitive)
Dark noise rate	< ~10 kHz/mm^2 (to be further studied)
Spatial resolution	~280 μm
Radiation tolerance	~10^{13} $N_{eq.}$ /cm^2 (to be further studied)

Additional parameters such as pixel pitch, cross talk, etc. need to added later

PS: for radiation hardness:
-NIEL in forward region: ~1x10^{11} Neq. /cm^2 /year
-So the requirement for SiPM: 1x10^{12} Neq./cm^2, or 1x10^{13} Neq./cm^2 more conservatively

Detector R&D goals with IHEP innovation fund

In 2-3 years:

- Complete the detector conceptual design report (CDR)
    - including radiator, photodetector, mechanics, preliminary simulation, detector performance studies
    - CDR will be reviewed by international experts (put on arXiv or published)
- Construct a detector prototype
    - A small-scale of prototype is currently planned: an aerogel block (~10x10 cm^2 or 20x20 cm^2) +
a SiPM module (~20x20 cm^2)
    - Will see if a larger prototype is needed later
- Perform cosmic-ray tests/beam tests
    - Cosmic-ray tests are convenient but cannot provide quantitative detector parameters
    - Beam tests are beneficial but require an appropriate test facility

In addition:
- A general NSFC program is currently under application, also plan to apply for an NSFC-RSF joint fund.

Summary and outlook

- A preliminary material budget of ~2.83% is estimated (partial components to be supplemented); first simulation on momentum resolution shows ~0.15% degradation at low pT, with test the other position

- Dark noise-induced false hits can be reduced by ~100x with tracking info, but need to consider other sources of false hits (beam background, secondaries)

- Requirements for some SiPM parameters are defined, while other parameters require further studies

- R&D goals are set under the IHEP fund, some refinements need more considerations