Development of RICH detector with SiPM readout for the charmed baryon spectroscopy experiment (E50) at J-PARC

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1. J-PARC E50 experiment

Charmed baryon spectroscopy experiment (J-PARC E50 experiment)
—For clarification of diquark correlations

Charmed baryon (Y_c^{*+}) production

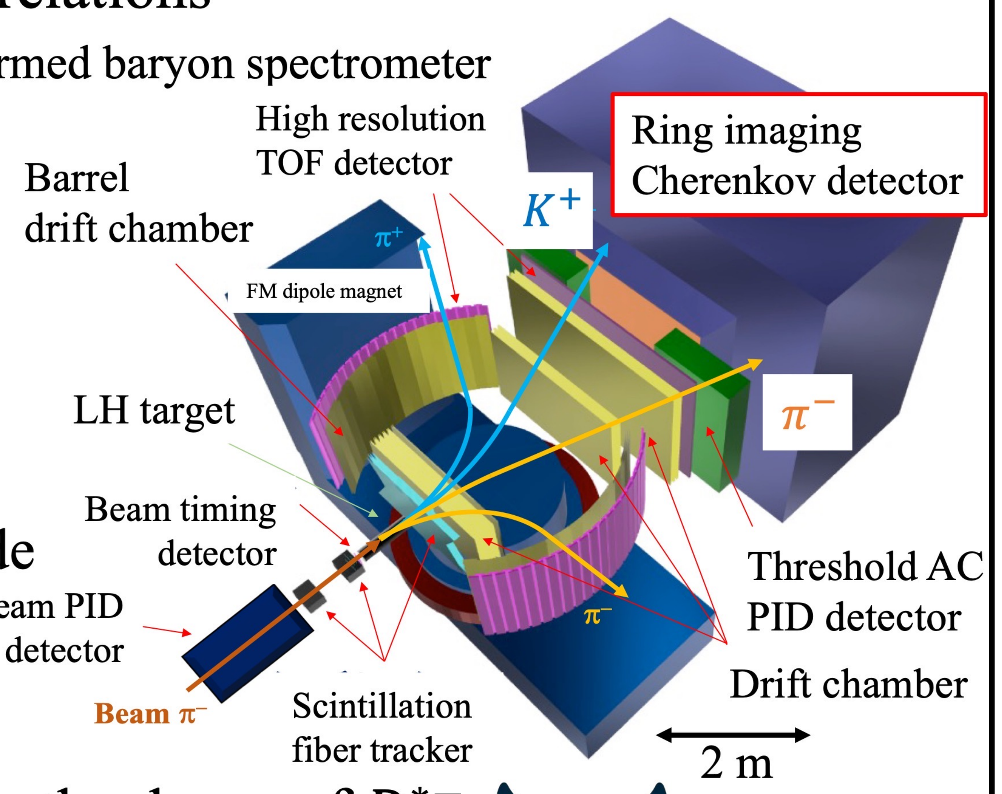
- Beam intensity : ~10^8 /spill
- Beam momentum : 20 GeV/c

$$\pi^- + p \rightarrow Y_c^{*+} + D^{*-}$$

Measure Y_c^{*+} by missing mass

—Reconstruct from D^{*-} decay mode

$$D^{*-} \rightarrow \bar{D}^0\pi^- \rightarrow K^+\pi^-\pi^-$$



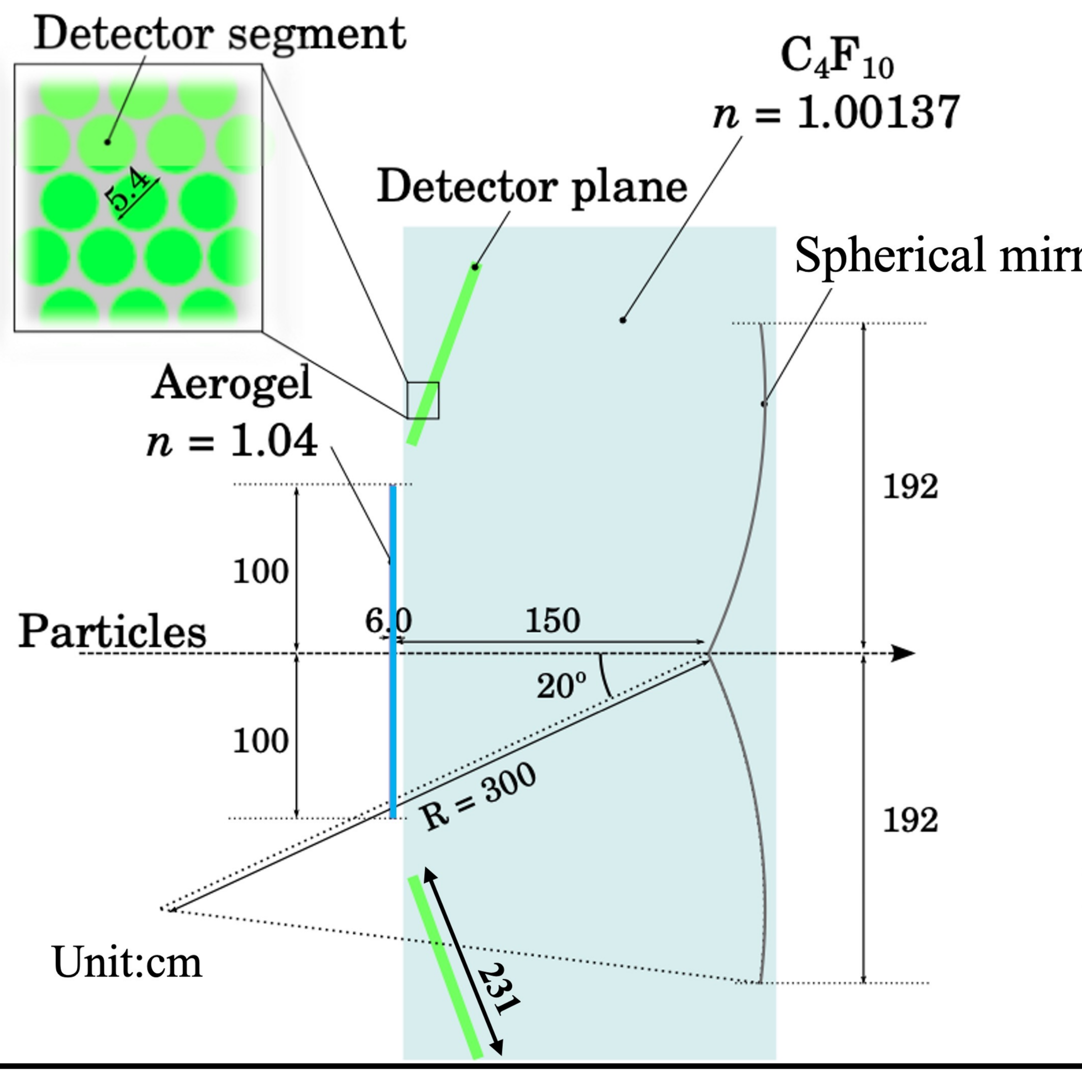
E50 setup

Identification of π^- and K^+ from the decay of D^{*-} in a **wide momentum range (2-16 GeV/c)**

→ **Ring Imaging Cherenkov (RICH) detector**

2. Design of RICH detector by previous study

Purpose of RICH detector :
Identification of scattered particles (π, K, p) in the momentum range : **2 ~ 16 GeV/c**



Two types of radiators

- Aerogel($n = 1.04$)
  - —πK ID for **2 ~ 6 GeV/c**
  - —Kp ID for **2 ~ 10 GeV/c**
  - —Thickness : **6 cm**
- C_4F_{10} gas($n = 1.00137$)
  - —PID for **10 ~ 16 GeV/c**
  - —Thickness : **150 cm**

Spherical mirror

- Radius of curvature : **300 cm**
- Width 541 cm
- Height 384 cm

Detection plane

- 231 cm × 231 cm
- **Segment size : 5.4 cm**

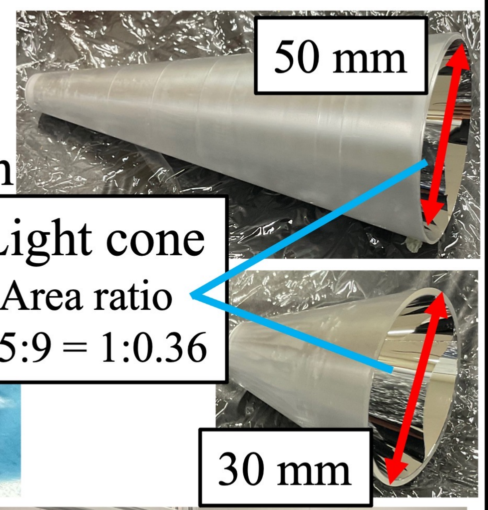
3. Test experiment with prototype detector

Performance evaluation by using a prototype detector
—same actual detector elements

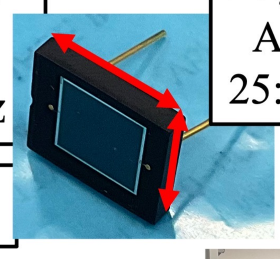
- **SiPM** and **light cones** for Cherenkov lights concentration
- **Reflective spherical mirror**
- **Aerogel**

Purpose of this test experiment

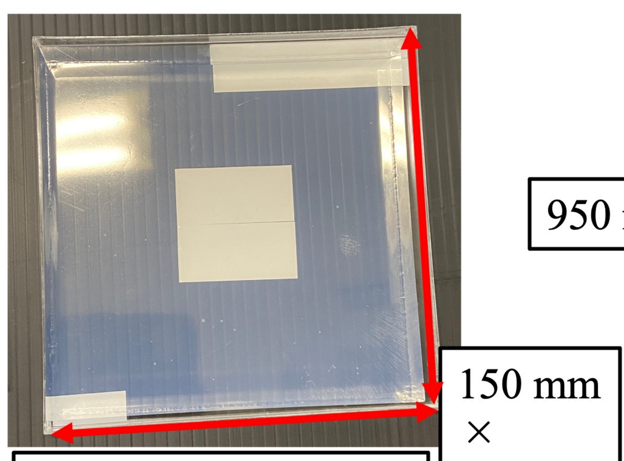
1. Evaluation of angular resolution
2. Various effects affecting resolution
3. Cherenkov light yield



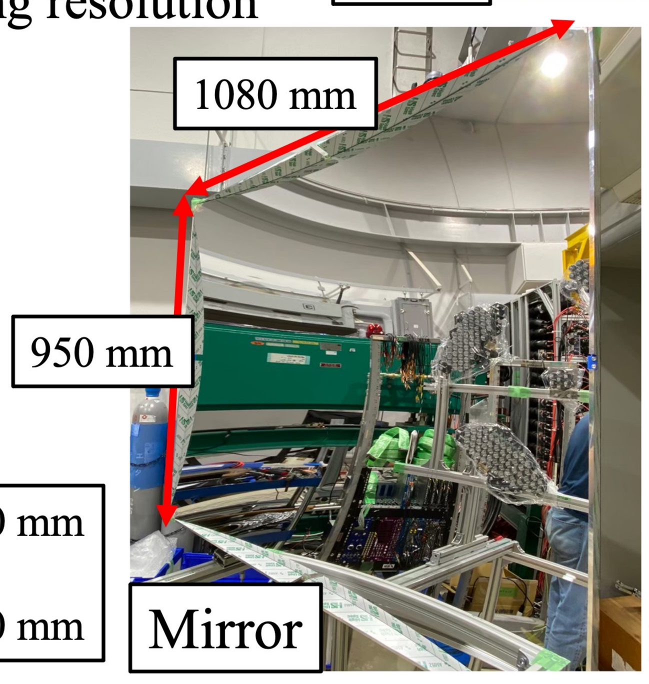
Light cone
Area ratio
25:9 = 1:0.36



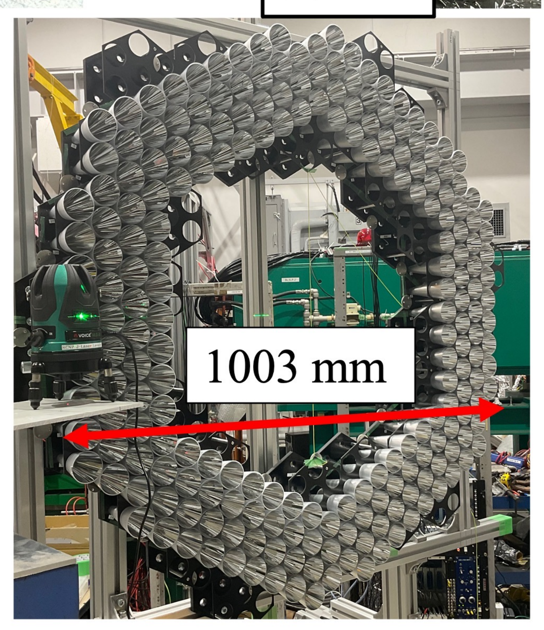
S13360-6075CS
6 mm × 6 mm
DC rate : 2 MHz
SiPM



Aerogel(n=1.04)

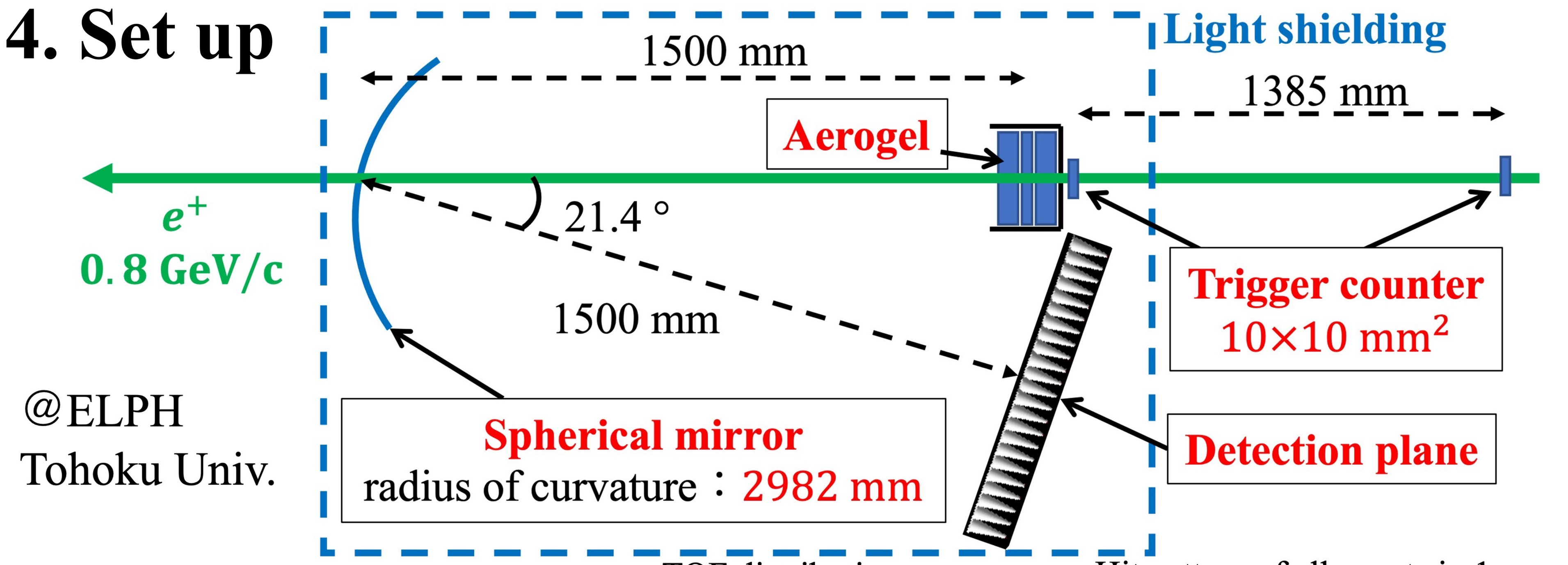


Mirror



Detection plane(216 pcs.)

4. Set up



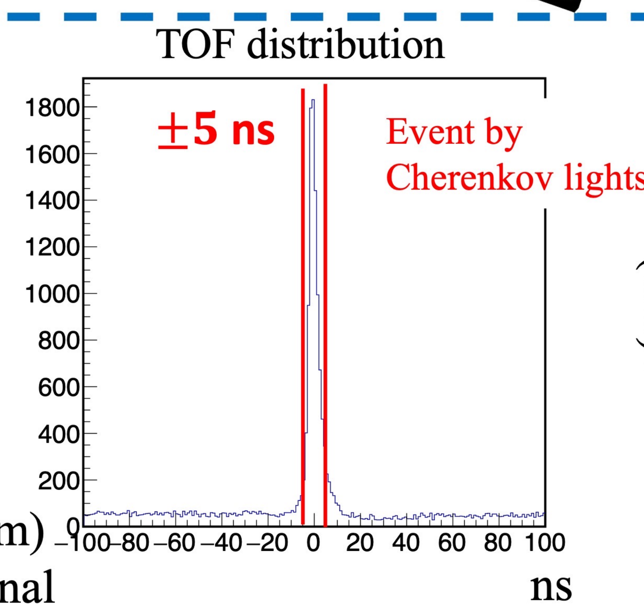
Calculate Cherenkov angle

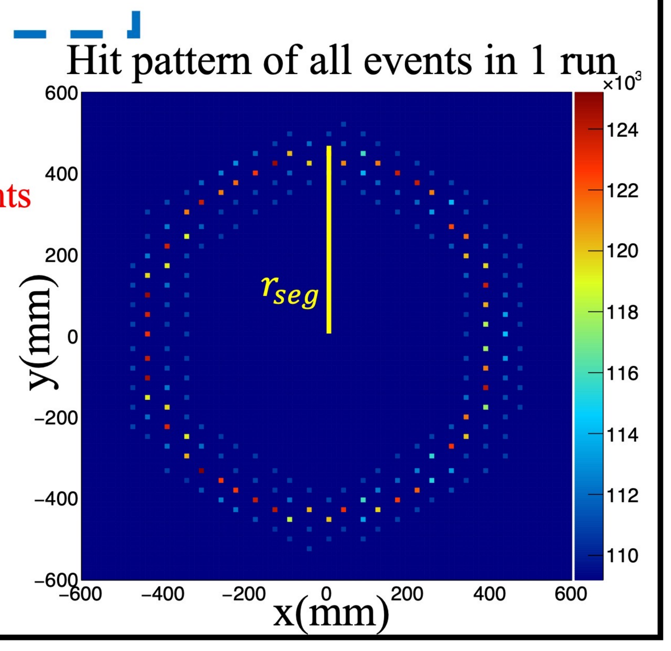
Select Cherenkov light event by TOF distribution

$$\theta_{seg} = \arctan\left(\frac{r_{seg}}{f}\right)$$

$$\Rightarrow \theta = \frac{\Sigma\theta_{seg}}{N}$$

f : Focal length of mirror(1500 mm)
N : Number of SiPM detected signal





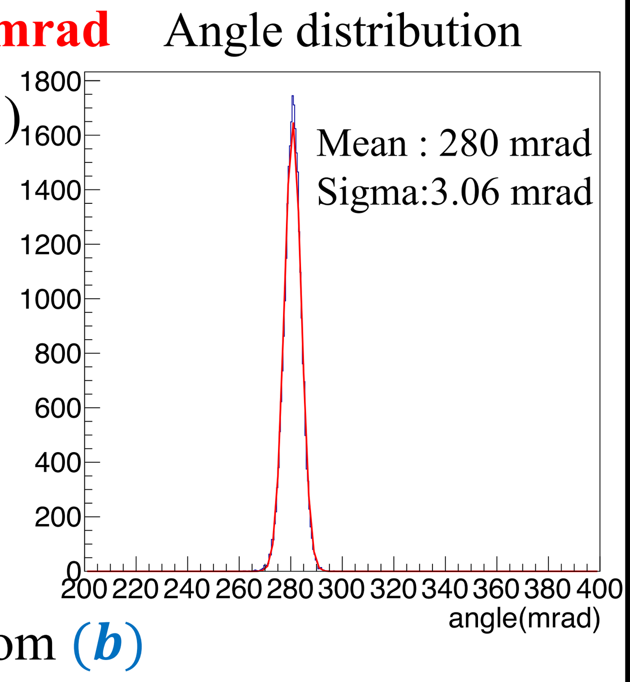
5. Angular resolution breakdown analysis

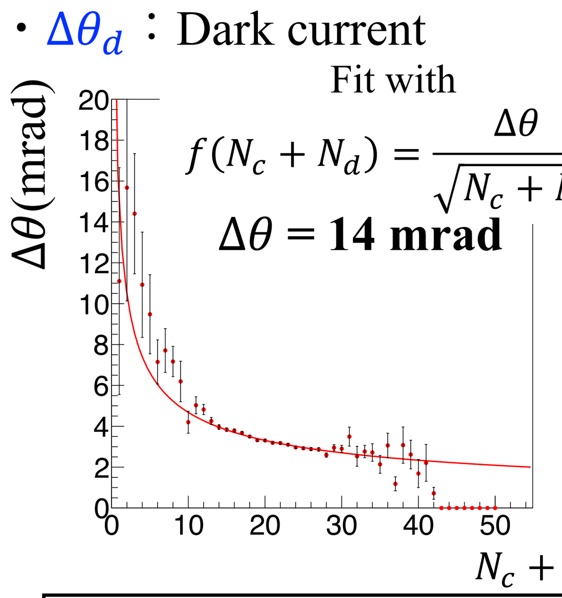
Required angular resolution per multiplicity : $\Delta\theta \leq$ **10 mrad**

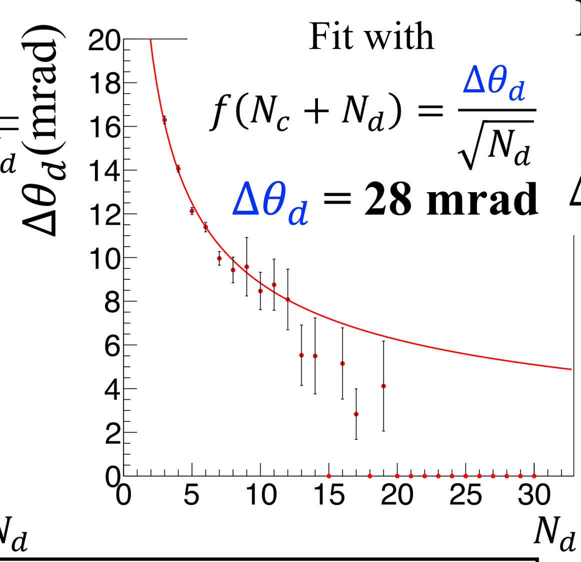
Angular resolution is divided two contributions($\Delta\theta_c$, $\Delta\theta_d$)

$$\Delta\theta^2 = \frac{N_c}{N_c+N_d}\Delta\theta_c^2 + \frac{N_d}{N_c+N_d}\Delta\theta_d^2 \cdots (a)$$

- $\Delta\theta_c$: Angular resolution by Cherenkov lights
  - $\Delta\theta_c^2 = \Delta\theta_{seg}{}^2 + \Delta\theta_{abe}{}^2 + \Delta\theta_{beam}{}^2 \cdots (b)$
    - —$\Delta\theta_{seg}$: Segment size of detection plane
    - —$\Delta\theta_{abe}$: Aberration
    - —$\Delta\theta_{beam}$: Beam incident angle(1.9 mrad)
- $\Delta\theta_d$: Dark current







From (a) 50 mm cone: $\Delta\theta_c = 9.9 \pm 0.4$ mrad
30 mm cone: $\Delta\theta_c = 7.8 \pm 0.4$ mrad

From (b)

$$\Delta\theta_c^2 = \Delta\theta_{seg}{}^2 + \Delta\theta_{abe}{}^2 + \Delta\theta_{beam}{}^2$$

$$\Delta\theta_{abe} = \sqrt{\Delta\theta_c{}^2 - \Delta\theta_{seg}{}^2 - \Delta\theta_{beam}{}^2}$$

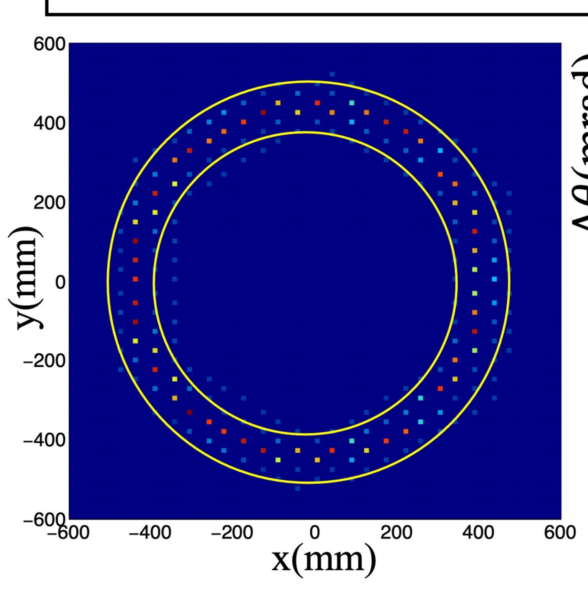
50 mm cone

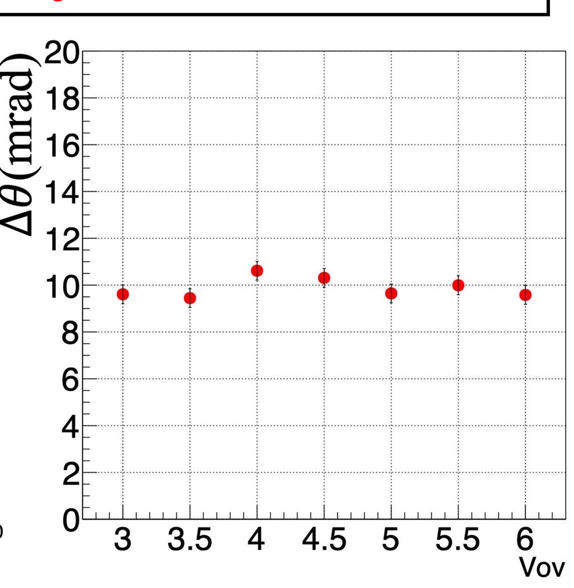
$$\Delta\theta_{abe} = \sqrt{9.9^2 - 7.6^2 - 1.9^2} = 6.1 \pm 0.4 \text{ mrad}$$

30 mm cone

$$\Delta\theta_{abe} = \sqrt{7.8^2 - 4.5^2 - 1.9^2} = 6.0 \pm 0.4 \text{ mrad}$$

Separated all contributions





Dark current noise reduction
—using only segments around the Cherenkov ring

radius of Cherenkov ring : 279 mm
cut range : ring radius ± 75 mm

$\Delta\theta$ ~ **10 mrad**

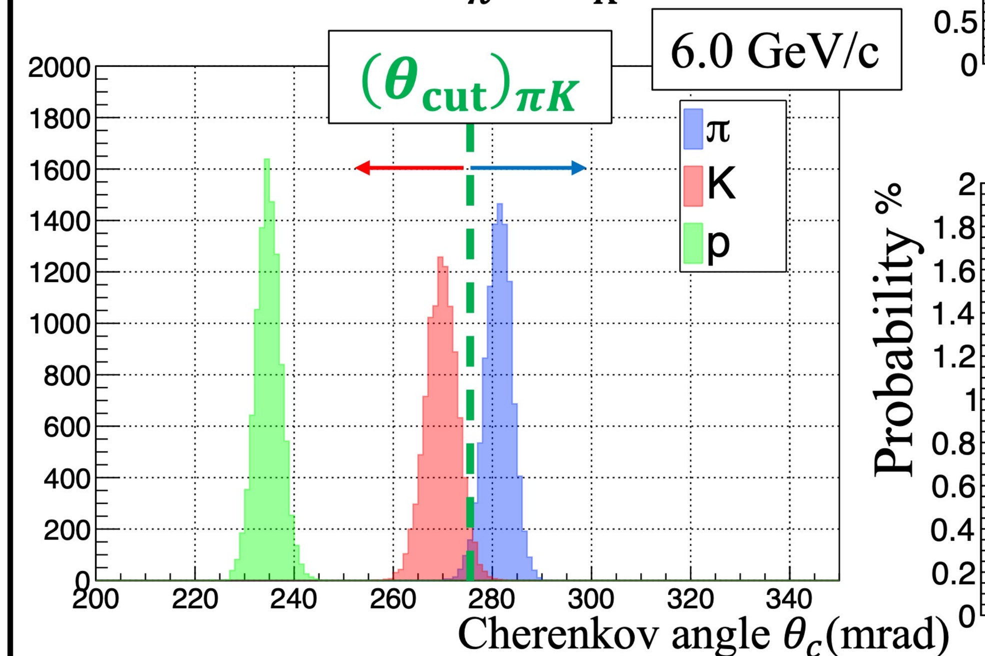
Achieved angular resolution requirement

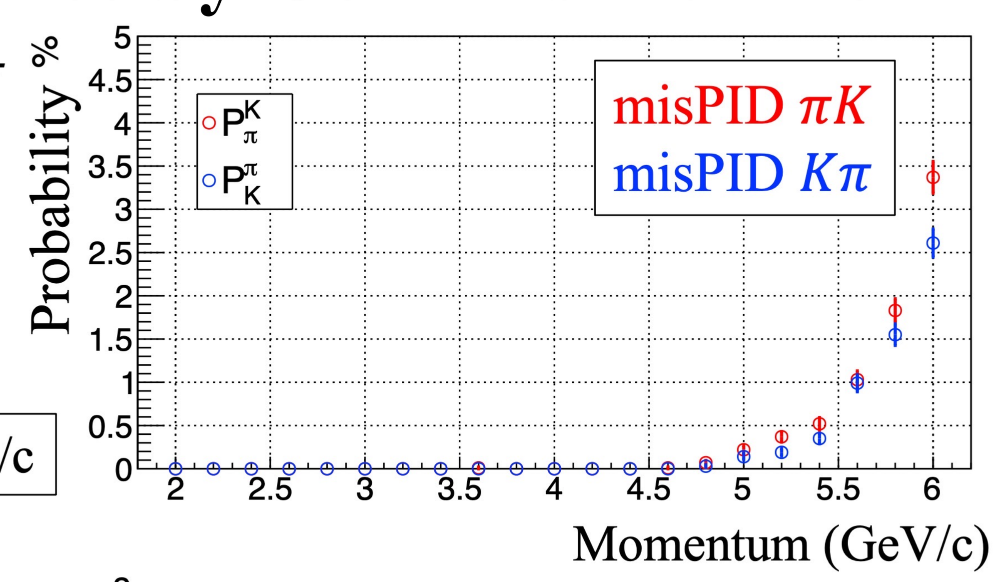
6. $\pi/K/p$ ID performance by Geant4 simulation

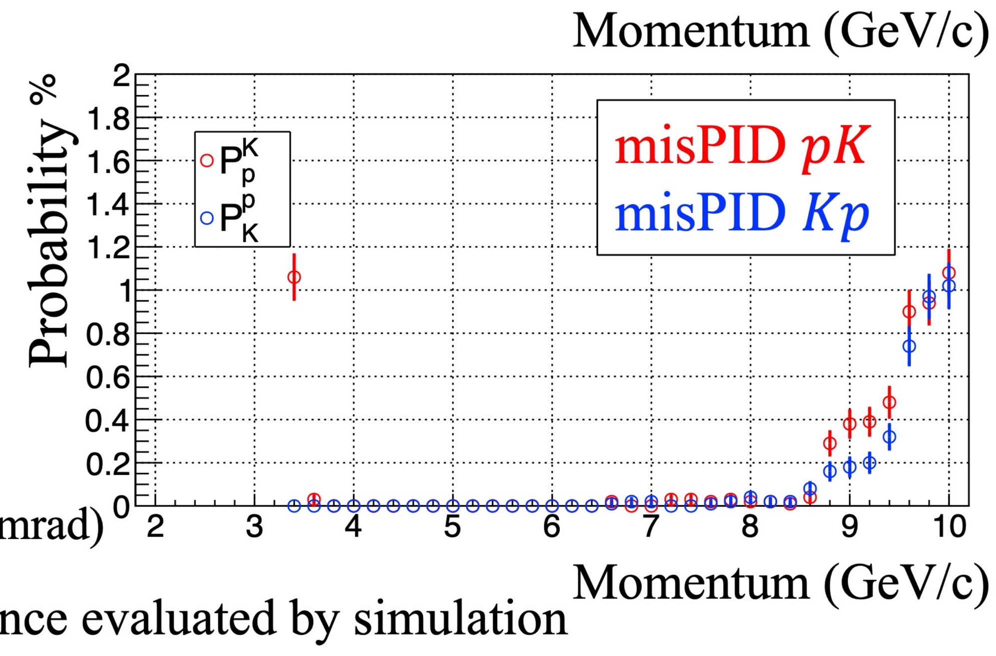
Threshold θ_{cut} from peak θ and σ of Cherenkov angle distribution

e.g. threshold π/K : $(\theta_{cut})_{\pi/K}$

$$(\theta_{cut})_{\pi/K} = \frac{\theta_\pi\sigma_K + \theta_K\sigma_\pi}{\sigma_\pi + \sigma_K}$$







Required Performance in the momentum range for PID using **aerogel**
misPID $\pi K \leq$ **3.5%**
misPID $pK \leq$ **2.4%**

Performance evaluated by simulation in same momentum range
misPID $\pi K \leq$ **3.5%**
misPID $pK \leq$ **1.7%**

Achieved performance requirements

7. Summary and Outlook

Summary

- Constructed a prototype detector with the same detector elements as the actual detector and performed a test experiment.
- Using a 50 mm light cone and the designed optical system (spherical mirror, SiPM, and light cone), achieving the required performance of 10 mrad is feasible.
- Achieved the required PID performance.

Outlook

- Reducing dark current
  - —by cooling SiPMs
  - —Analysis method selecting segments only around the Cherenkov ring
- Performance evolution using gas