# FARICH for high-momentum charge track PID at CEPC

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# Regarding the new tech for high momentum PID

- The current design: dN/dx from TPC and TOF based on AC-LGAD
- Other options?
- We always had PID sessions in the CEPC Workshops, China version
- A specific workshop on PID technologies in Fudan, 2023.


A lot of discussions since more than two years ago.

# Materials for high momentum PID

- Specific workshop at Fudan. ARC from FCC-ee

https://indico.ihep.ac.cn/event/19839

- CEPC Day talk: aerogel Cherenkov counters

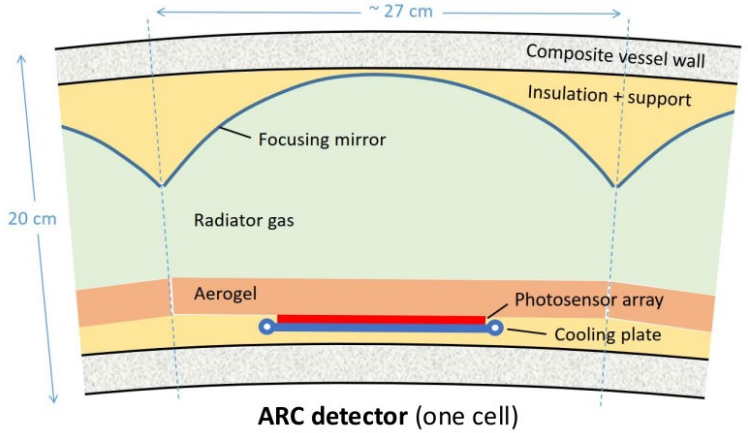
https://indico.ihep.ac.cn/event/22548/

- CEPC workshop at Hangzhou, PID session. SiPM option for LHCb.

https://indico.ihep.ac.cn/event/22089

# ARC for PID at FCC-ee

- **A**rray of **R**ICH **C**ells




**ARC detector** (one cell)

- Adapted to fit into the CLD experiment concept, taking 10% from the tracker volume
  - Radial depth of 20 cm, radius of 2.1 m and a length of 4.4 m
  - Aim to keep material budget below $0.1X_0$
- Aerogel and gas radiators with a spherical mirror
  - Aerogel also acts as thermal insulation between gas and detector

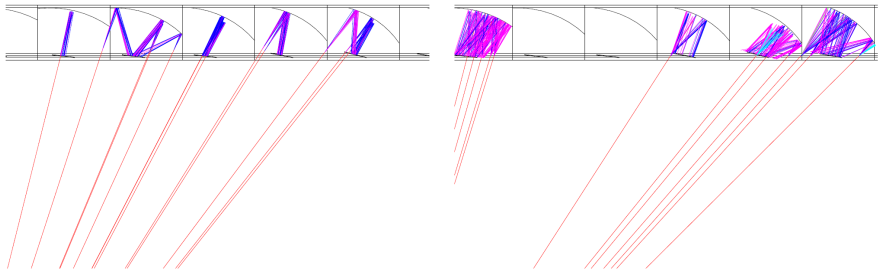


**Figure 11:** Tracking of photons from gas radiator (left) and aerogel radiator (right) through the ARC optics

- All cells are the same size, organised on a hexagonal grid
  - Barrel (endcap) has 945 (384) cells in total, where 18 (21) are unique
  - Hexagonal shape avoids the corners, where performance is worse

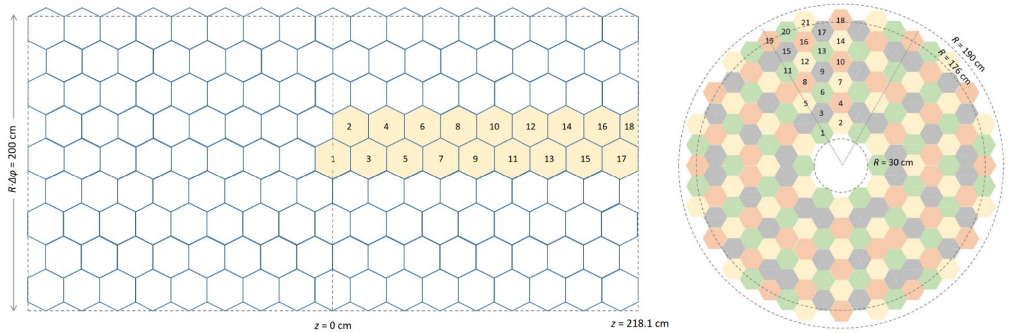
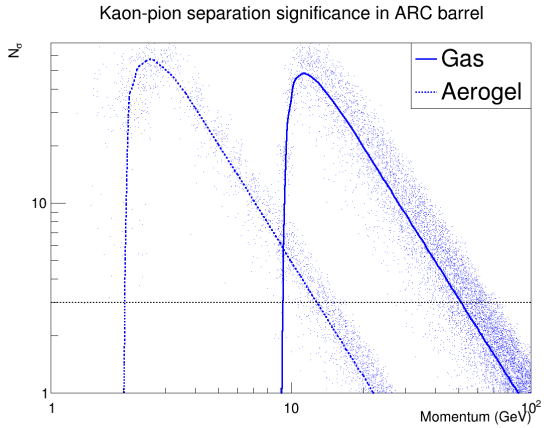
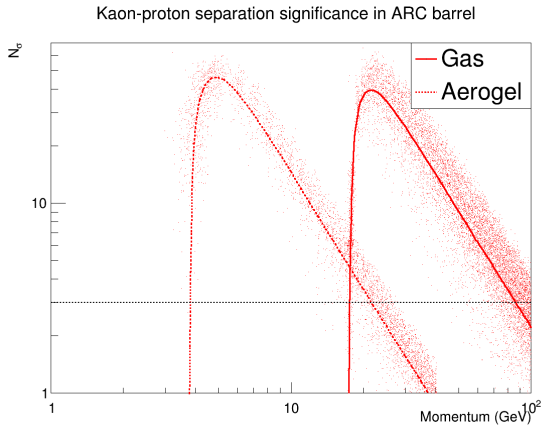



**Figure 6:** Barrel (left) and endcap (right) cells



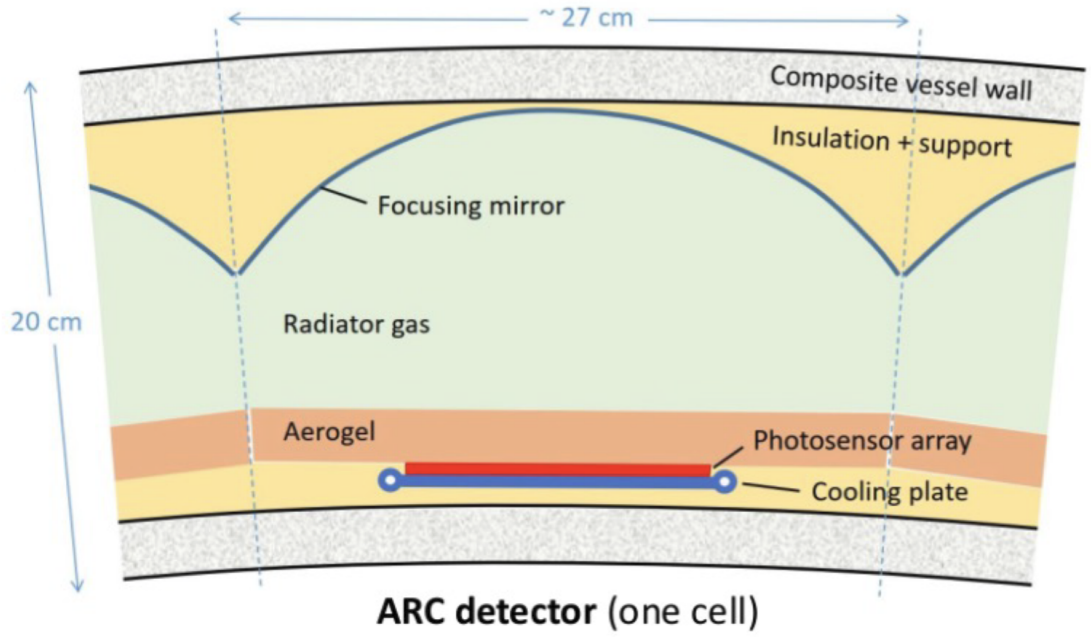

$K - \pi$ separation




$K - p$ separation

- Gas (aerogel) provides over $3\sigma$ pion-kaon separation in the range 10-50 GeV (2-10 GeV)

# ARC-FCC: few remarks




**ARC detector** (one cell)

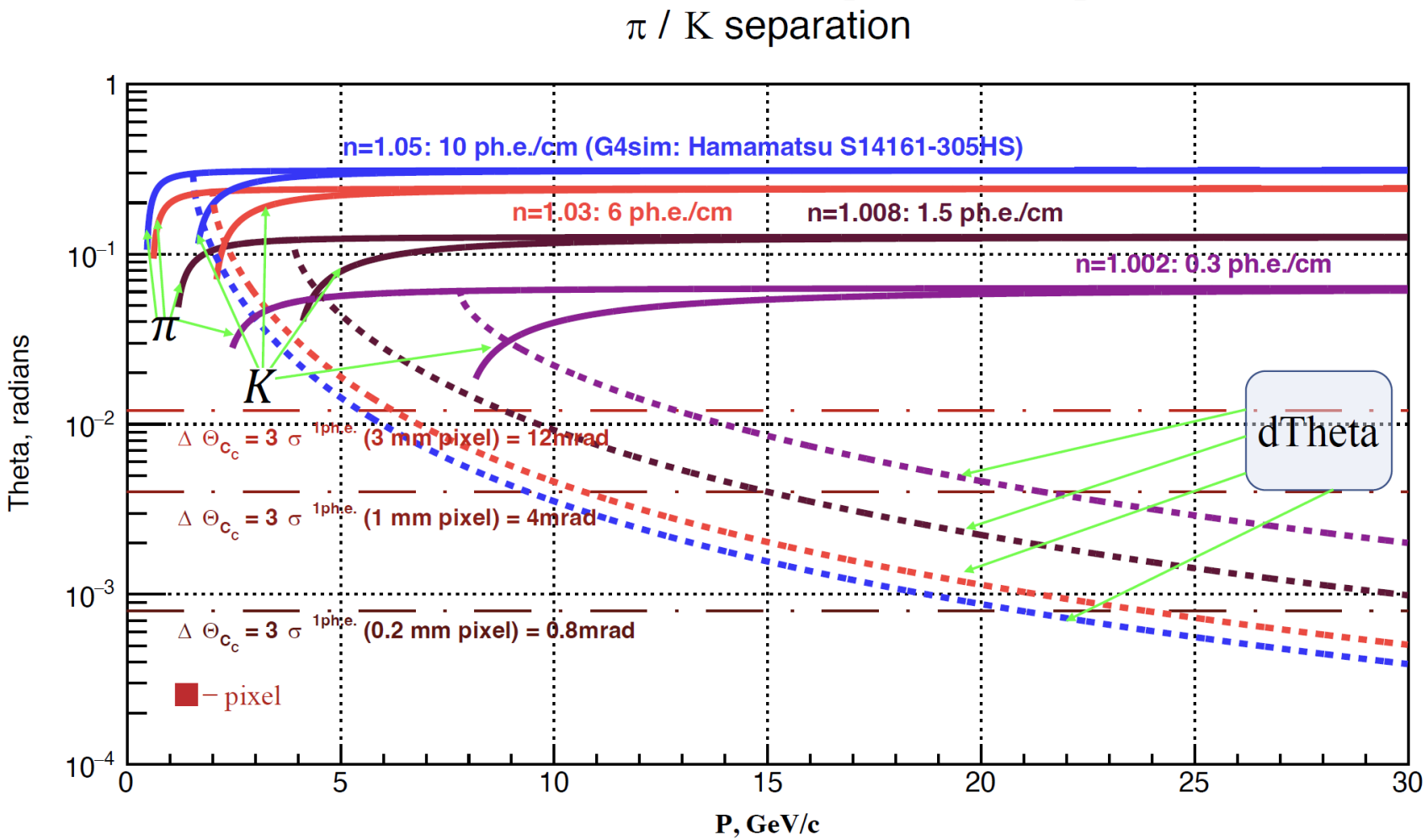
Design inspired by succes of DELPHI and LHCb experiments

- **Light collection through aerogel**
  - Cherenkv light produced in aerogel will pass through aerogel twice
  - Cherenkov light from gas will pass the aerogel too
  - Therefore aerogel transperancy has to be better than for proximity focusing RICH approach preliminary by factor of two
- **Connection of Aerogel with perfluoride gases** ($C_4F_{10}$, $C_5F_{12}$,…). This issue has to be investigated very carefully
  - Refractive index of aerogel will be changed due to replacement of air (n=1.0003) to gas (n=1.004) inside the aerogel pores, as well as light scattering parameters
  - Mechanical destroy of aerogel is possible due to condensation of pressurised $C_4F_{10}$ inside pores [NIM A421 (1999) 249-255]
- To combine aerogel and gas Cherenkov radiators the **system design** has to become **more complex**



- No much information regarding the photosensor.

# RICH detectors capability for π/K–separation



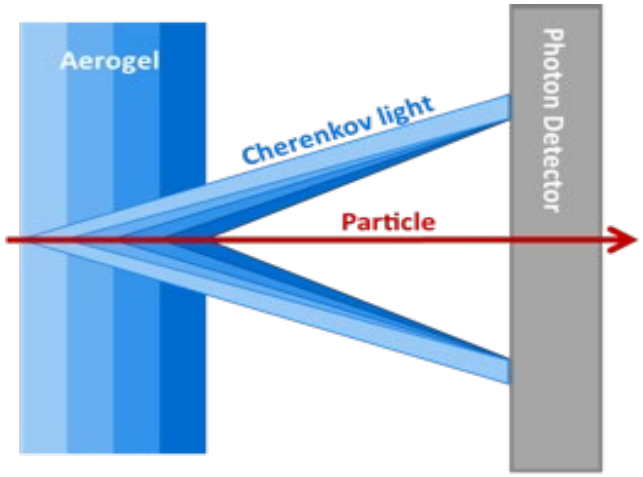

- $\sigma_C^{tr} = {}^{1}/_{\sqrt{N_{pe}}} \cdot \sqrt{\left(\frac{\Delta_{pix}\cdot\cos\theta_C}{L\cdot\sqrt{12}}\right)^2 + \left(\frac{\sigma_n}{n\cdot\tan\theta_C}\right)^2 + \left(\frac{t\cdot\sin\theta_C}{L\cdot\sqrt{12}}\right)^2 + \sigma_{tr}^2} \sim \sqrt{t}$
- $N_{pe}(\beta = 1) \sim 500 \cdot \frac{n^2-1}{n^2} \cdot t \cdot QE$



- At least 5 hits have to be detected to reconstruct Cherenkov ring.
- Thickness of Cherenkov radiator should be:
  - ≥1 cm for n=1.05 (aerogel)
  - ≥4 cm for n=1.008 (aerogel)
  - ≥15 cm for n=1.002 ($C_5F_{12}$)
- Some focusing system is needed to provide impact from thickness at the level of few mrads for base 200÷300 mm!!!

**Let's focus on n=1.008 at current stage**

# Proximity focusing approaches of Cherenkov light from aerogel to increase the precision of $\theta_c$ reconsgtruction

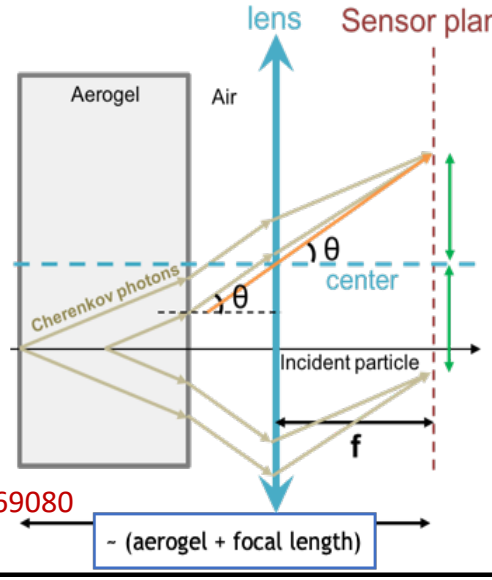


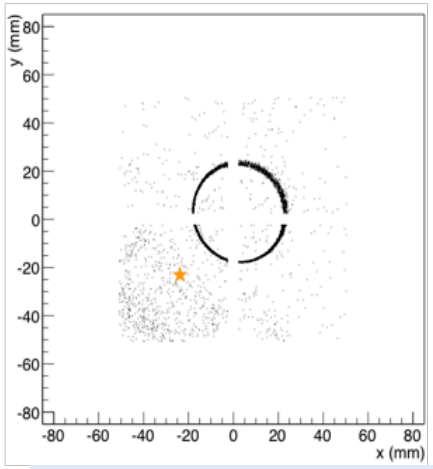

- Thicknesses and refractive indexes in each layer are adjusted in such way that Cherenkov rings from each layer overlap in the same region of the position-sensitive photon detector.
- The number of detected Cherenkov photons increases due to increase of the thickness without degradation of Cherenkov angle resolution due to uncertainties of photon emission point.

T.Iijima et al., NIM A548 (2005) 383 and A.Yu.Barnyakov et al., NIM A553 (2005) 70

**Focusing Aerogel RICH (FARICH)**

Lens-Based mRICH Design



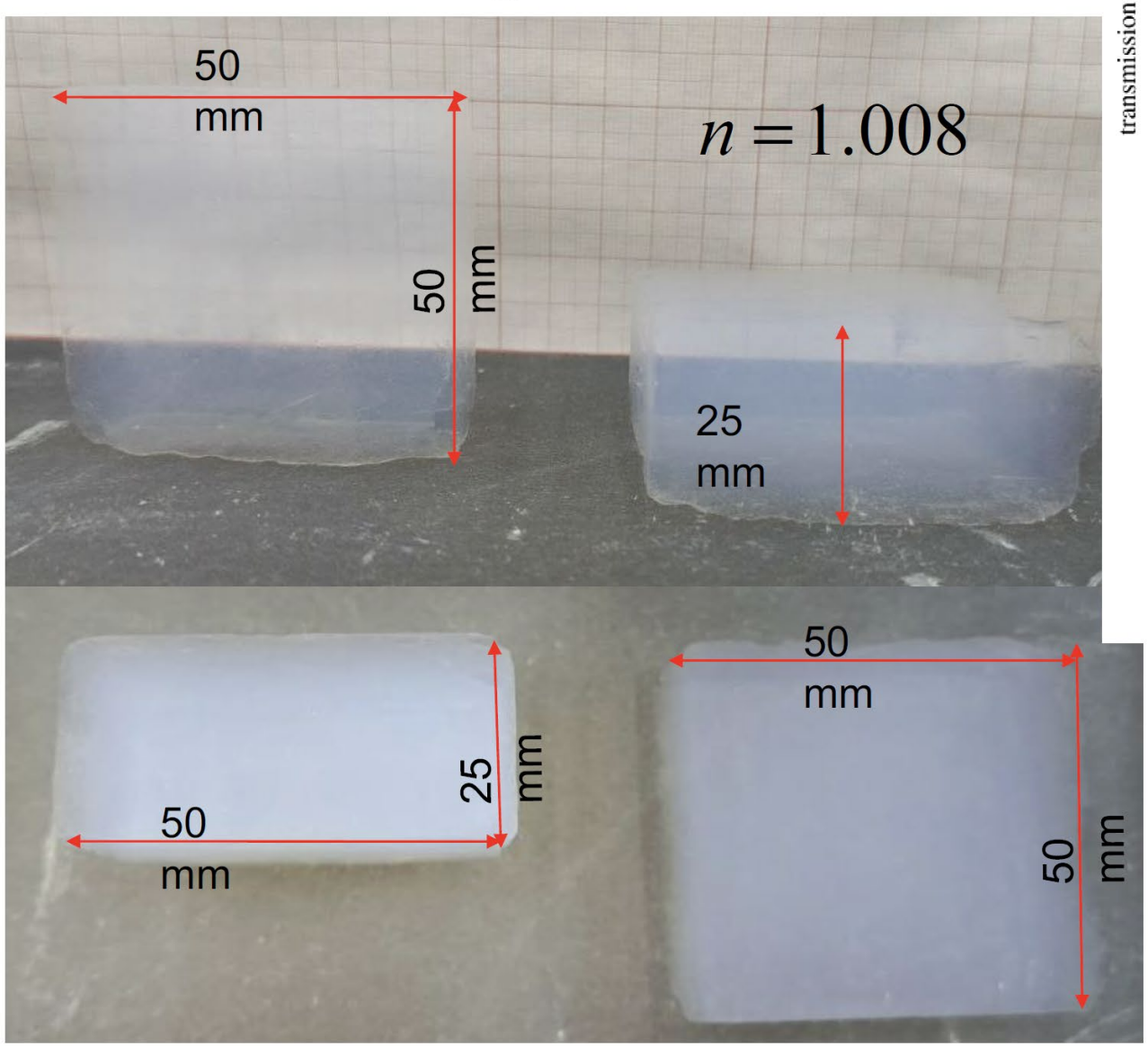



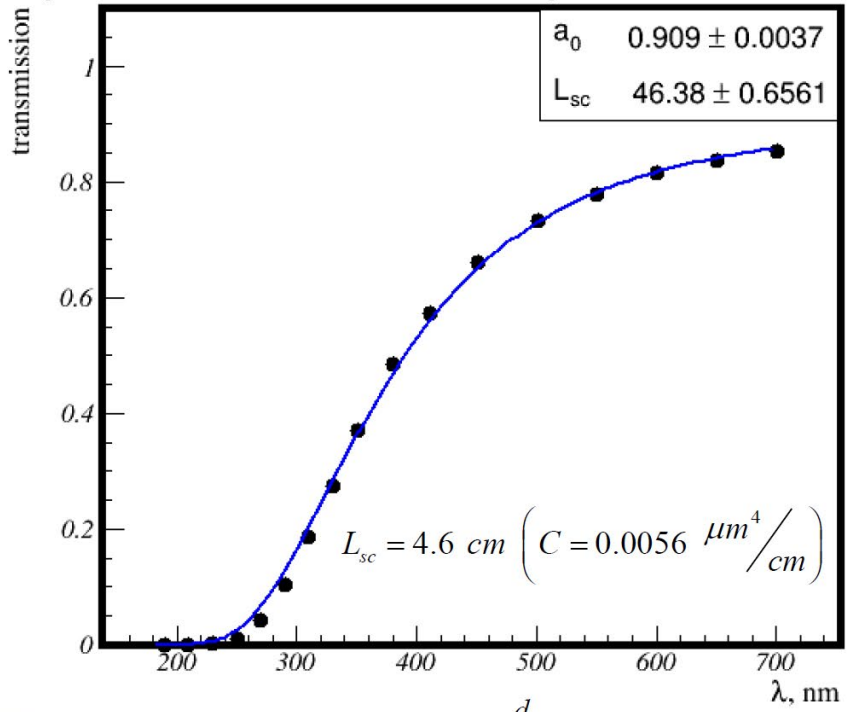

- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring image is shifted toward the central region on the sensor plane

D. Sharma et al., NIM A1061 (2024) 169080

**Aerogel RICH with Fresnel lens = modular RICH**

# Aerogel with n=1.008 (Novosibirsk)



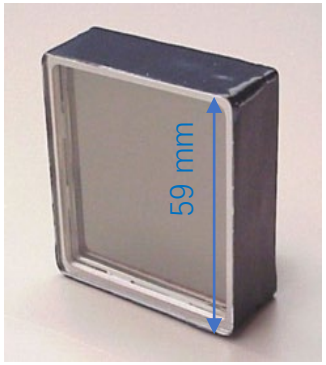

$$T = \frac{I}{I_0} = a_0 \cdot e^{-\frac{d}{L_{sc} \cdot \left(\lambda/400\right)^4}} = a_0 \cdot e^{-\frac{C \cdot d}{\lambda^4}}$$

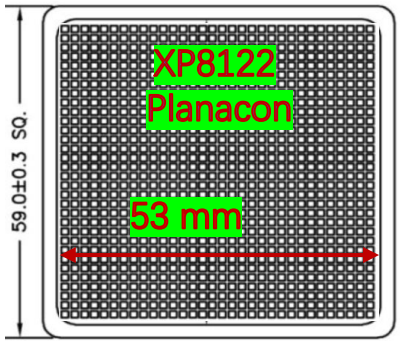
d – thickness of a sample,
λ – wavelength in nanometers,
Lsc – scattering length at 400 nm,
$a_0$ – surface scattering coefficient,
C – clarity coefficient

# Several PMTs with submillimeter position sensetivity

## MCP PMT

- Planacone XP85122

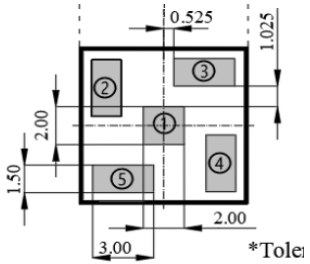



- 32x32 pixels with 1mm size and pithch ~2mm
- To decreas readout electronics channels it is possible to develop *'spread delay lines'* or *'chrge sharing'* approaches
- Expected spatial resolution as small as

$$\sigma_x \approx \frac{1}{\sqrt{12}} \approx 300\mu m$$

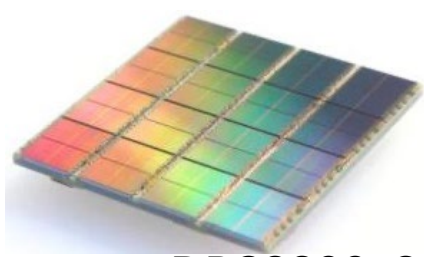
## PSS-SiPM or LG-SiPM




- PSS 11-3030-S (from NDL, China)
- 3x3 or 6x6mm SiPM is read out by 4 digitizers
- Position is reconstructed by charge sharing among 4 pads connected to resistive plane of the SiPM
- Declared resolution for single photon hit is about

$$\sigma_x \approx 200\mu m$$

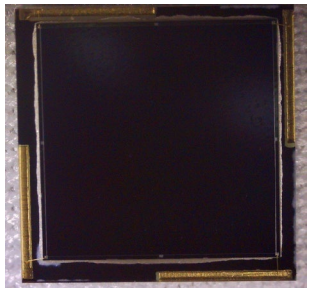
## Digital PC

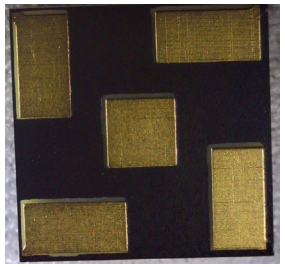


- **DPC3200-22-44 –** 3200 cells/pixel (from Philips)
- Each microcell is connected through controled lattch and could be switched On or Off for readout
- Output data are *'timestamp'* of the first fired microcells and total *'number'* of fired microcells
- Output data could be changed to *'timestamp'* and *'serial number'* of fired microcell and then spatial resolution will be determined microcell sizes:

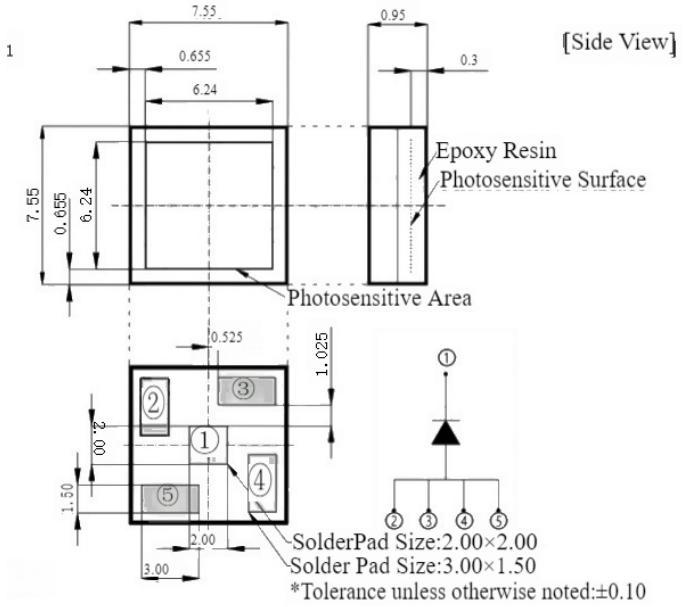
$$\sigma_x \leq 50,25,12\mu m$$

# We do have PSS





We have started the R&D on the readout.

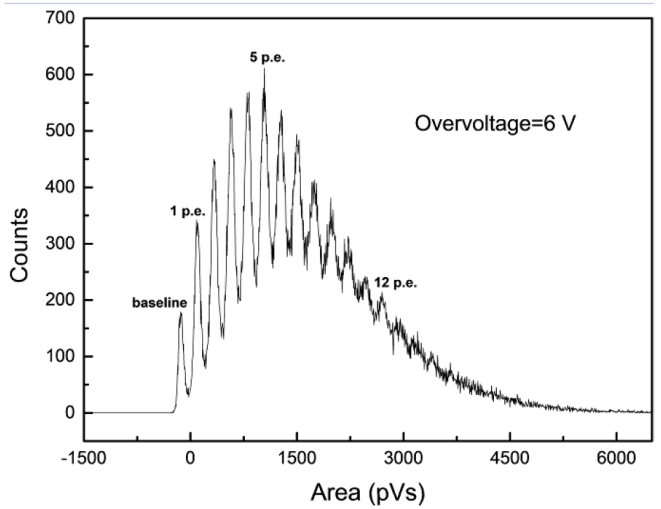



**Position Algorithm**

$$x_c = \frac{L}{2} \cdot k \cdot \frac{(Q_2 + Q_3) - (Q_1 + Q_4)}{(Q_1 + Q_2 + Q_3 + Q_4)}$$

$$y_c = \frac{L}{2} \cdot k \cdot \frac{(Q_3 + Q_4) - (Q_1 + Q_2)}{(Q_1 + Q_2 + Q_3 + Q_4)}$$

L is the length of the active area. $Q_i$ (i = 1, 2, 3, 4) is the shared charge of the corresponding anode. k is the calibration factor.




**Specifications**

| Type | PSS 11-3030-S | PSS 11-6060-S |
|---|---|---|
| Effective Pitch | 10 μm | 20 μm |
| Active Area | 3.0×3.0 mm² | 6.24×6.24 mm² |
| Micro-cell Number | 10000 /mm² | 2500 /mm² |
| Typical Breakdown Voltage ($V_B$) | 26.5 V | 27.5 V |
| Peak PDE @420nm | 32 % | 40 % |
| Recommended Operation Voltage | $V_B$ + 5 V | $V_B$ + 5 V |
| Gain | 2.0 × 10⁵ | 8.0 × 10⁵ |
| Dark Count Rate (DCR) | 650 kHz / mm² | 150 kHz / mm² |
| Configuration of Anodes | Tetra-Lateral Anodes | Square-Bordered Anodes |

**Above parameters are measured at their recommended operation voltage and 20 ℃.**

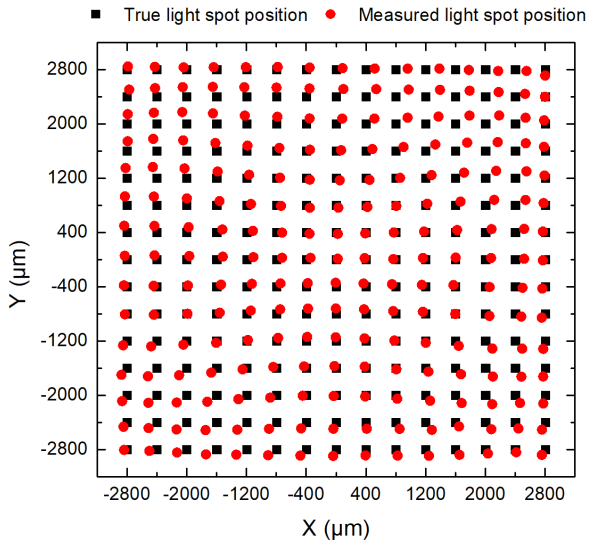
- Four channels to share the charges.
- Determine the position according to the shared charges.
- We can use the high precision FEE.

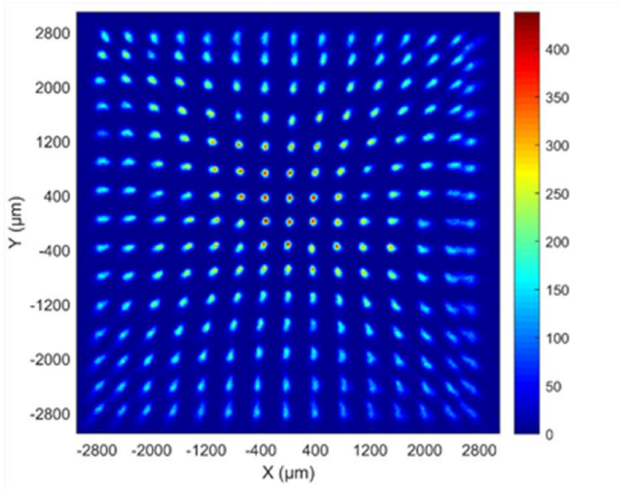
*X.Y. Wang et al., NST34, 169(2023)*

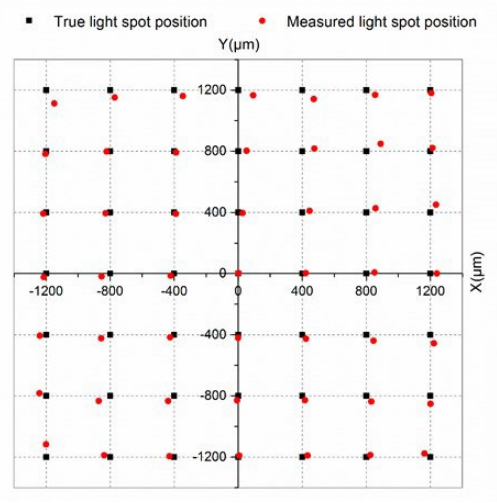
Discussed with Prof. 韩德俊

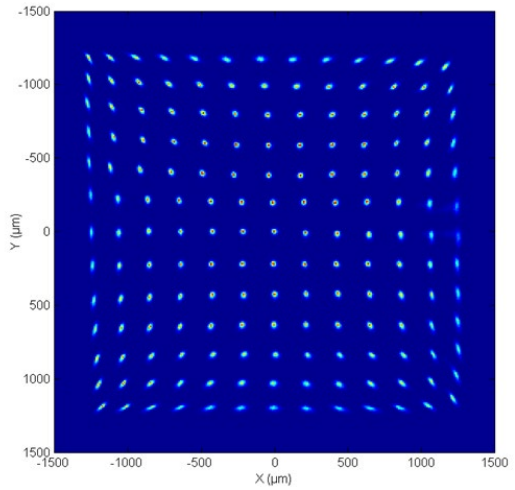
# Position resolution of PSS

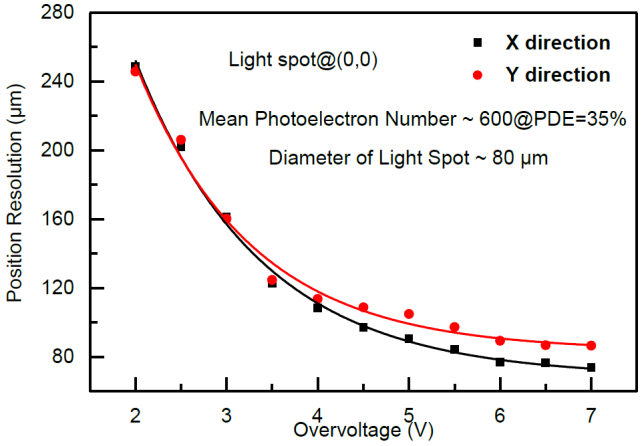
**Very high resolution can be achieved.**
**It also depends on the FEE.**

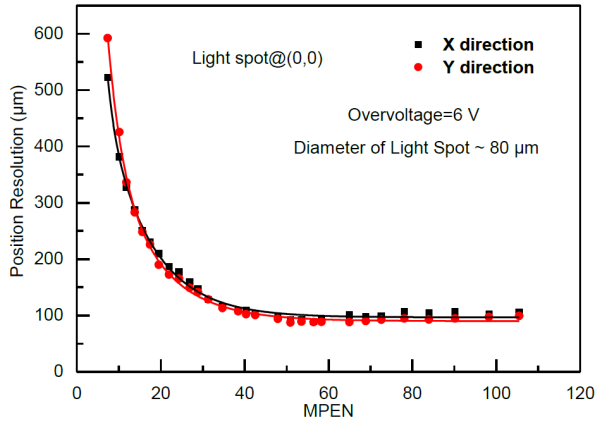


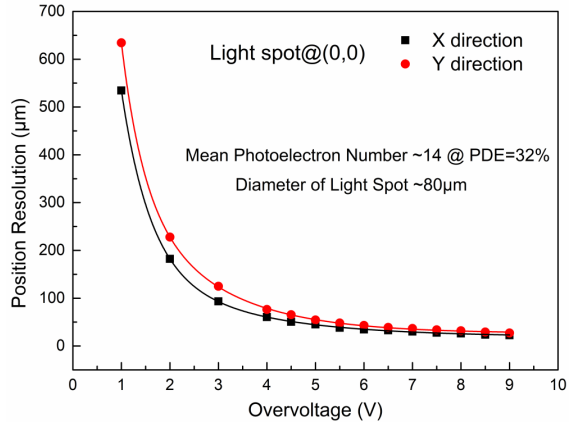



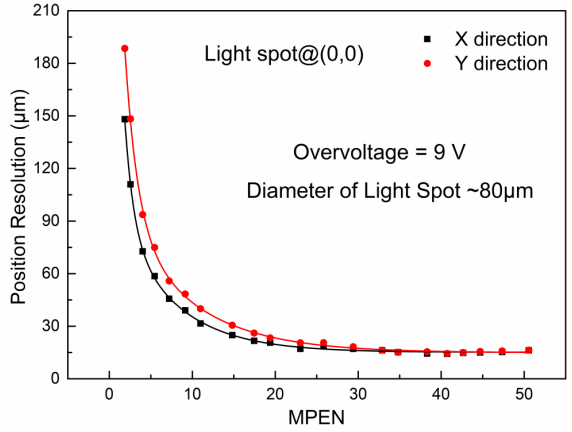




PSS 11-6060-S




PSS 11-3030-S

**Test Conditions: OV=6 V if not specified, Temp.=20 °C.**

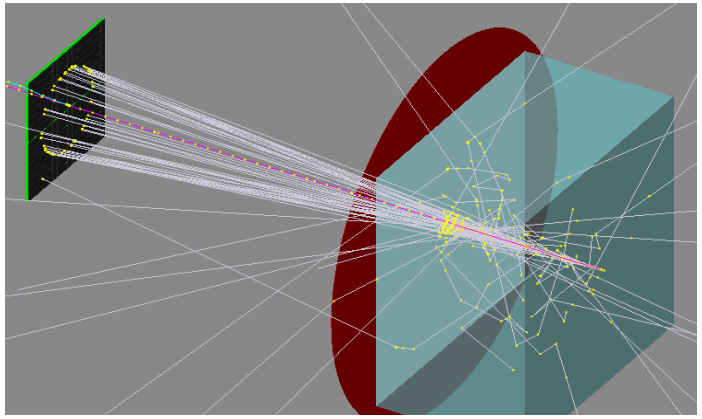
# mRICH GEANT4 sim. with SiPM like PSS 11-3030-S (NDL)

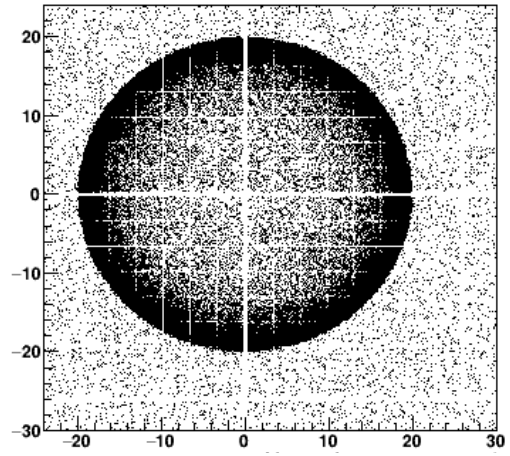
- Aerogel
  - n=1.008
  - t=6 cm
  - $L_{sc}$(400nm)=4.6 cm
- Position-sensitive SiPM
  - pixel 3x3 mm
  - hit position restored by charge sharing

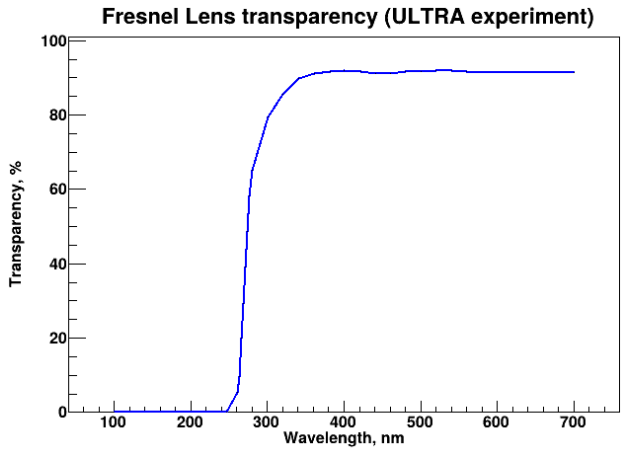
$$\sigma_x = 200\mu m$$

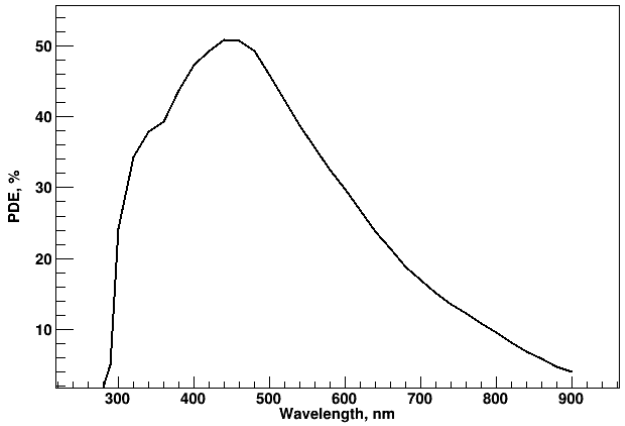
  - PDE from Hamamatsu S14161-3050HS
- Fresnel Lenses
  - Focal length = 6” and 10”
  - Transparency from ULTRA exp.

*(NIM A570 (2007) 22-35)*
*Fresnel technology inc.*



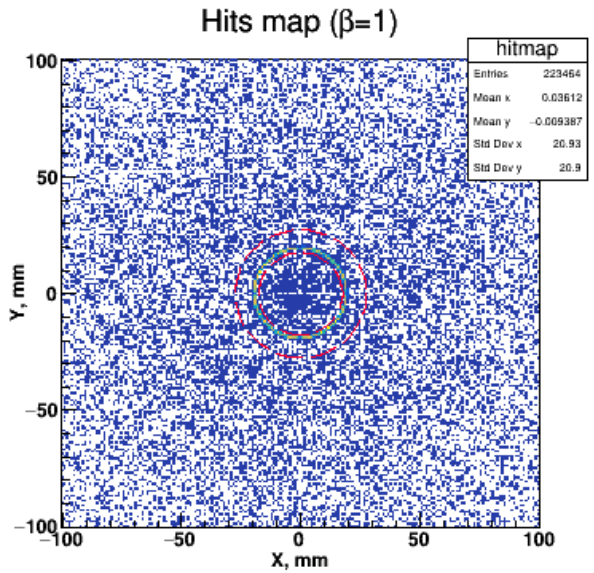


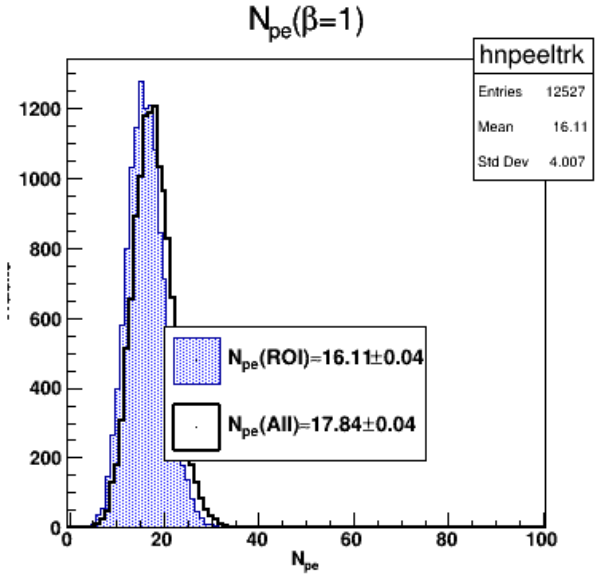



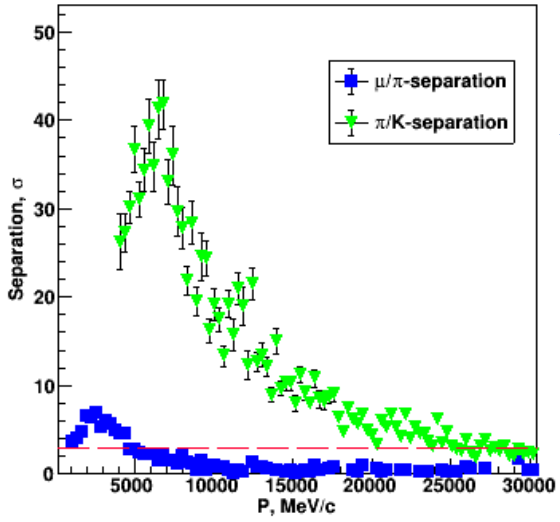




It is possible to increase the PDE at shorter wavelength.

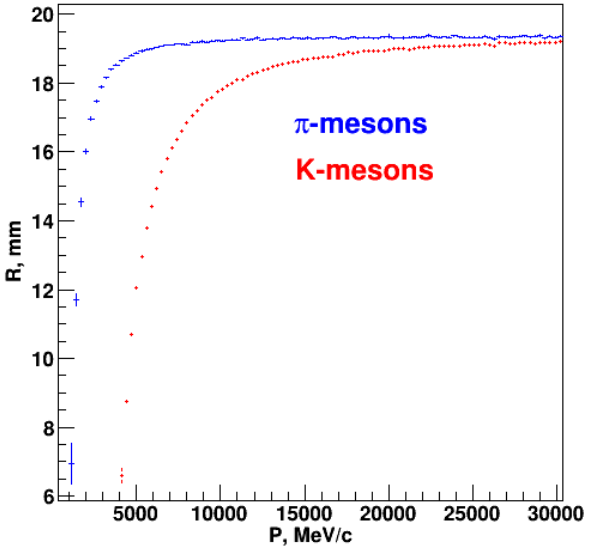
# mRICH sim. results for Fresnel lens 6” and 10”

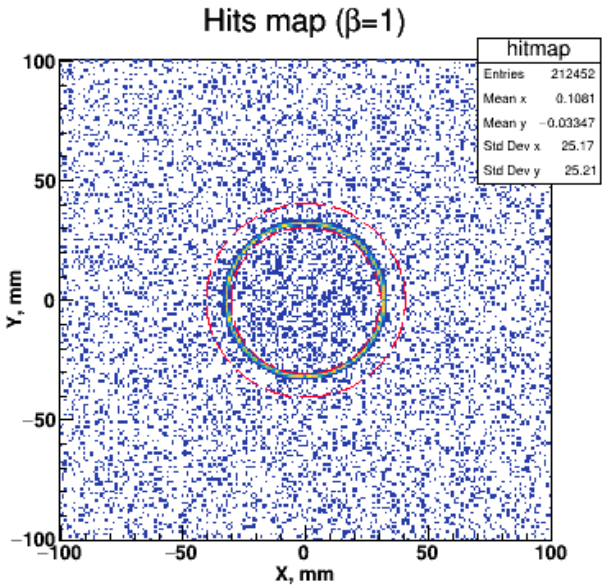


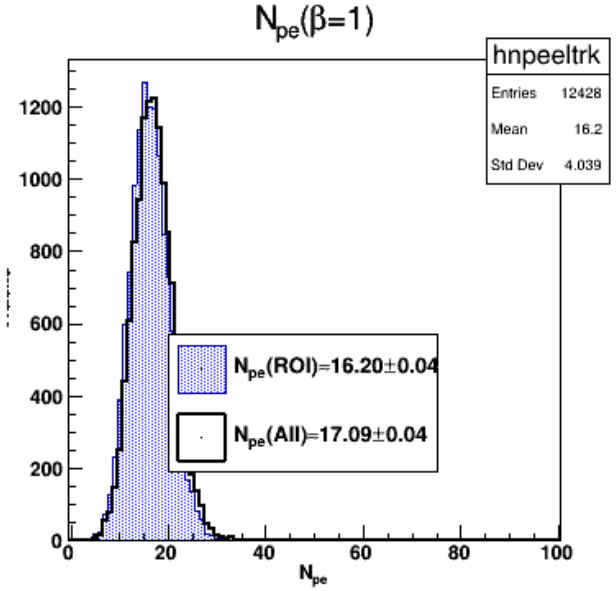



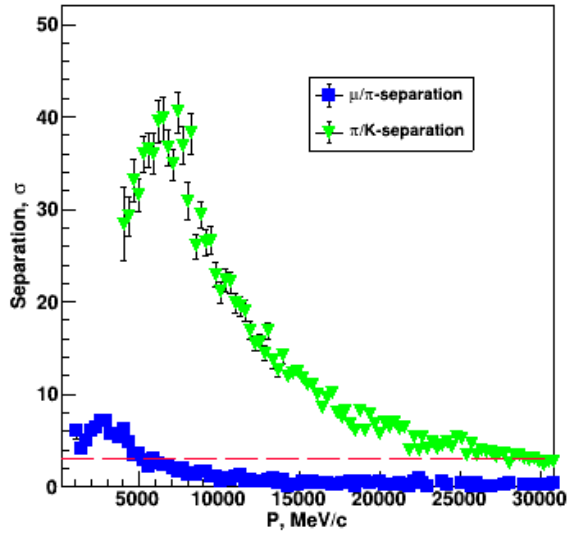




Fresnel Lens with F=6”



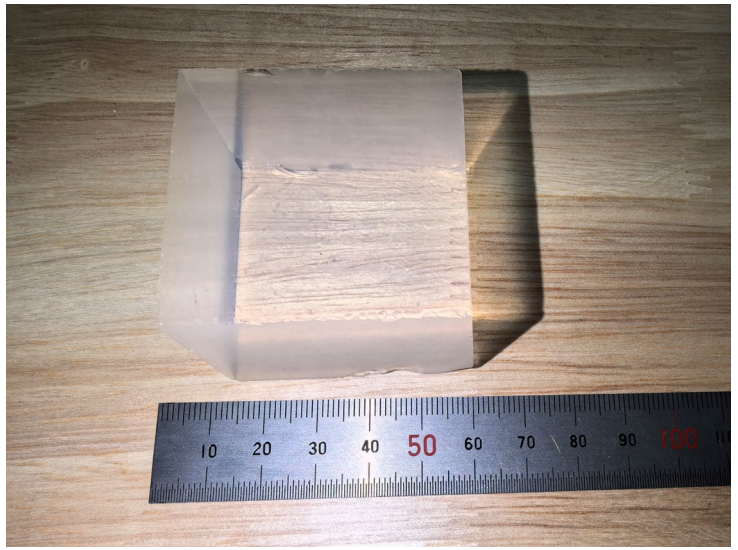




Fresnel Lens with F=10”

# FARICH for CEPC

## $n_{max}$=1.008

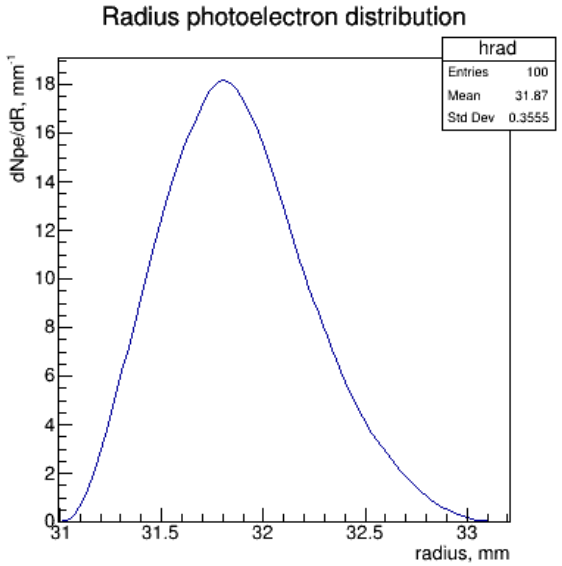


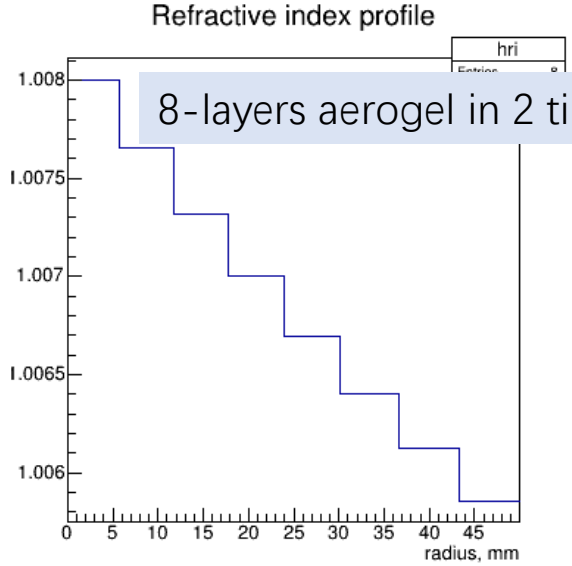

Aerogel from BINP


Aerogel from KEK/Belle.

# FARICH option for π/K–separation above 20 GeV/c

## 8-layer aerogel $n_{max}$=1.008; pixel≈0.2mm




8-layers aerogel in 2 tiles

Focal distance is 300 mm

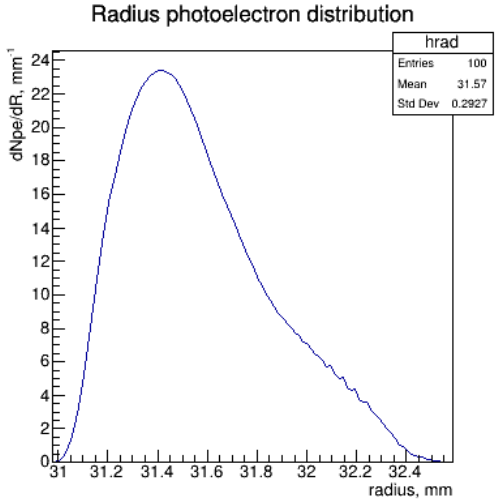
PSS 11-3030-S (NDL)
4-ch $3mm \times 3mm$ with $\sigma_x \approx 0.2mm$

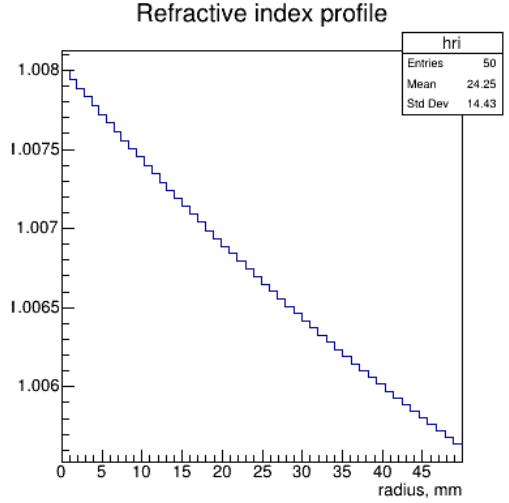
- $N_{pe}$≈16

$\sigma_C^{tr}$≈0.33 mrad!!!

**It looks good enough for reliable π/K–separation @ 30 GeV/c**

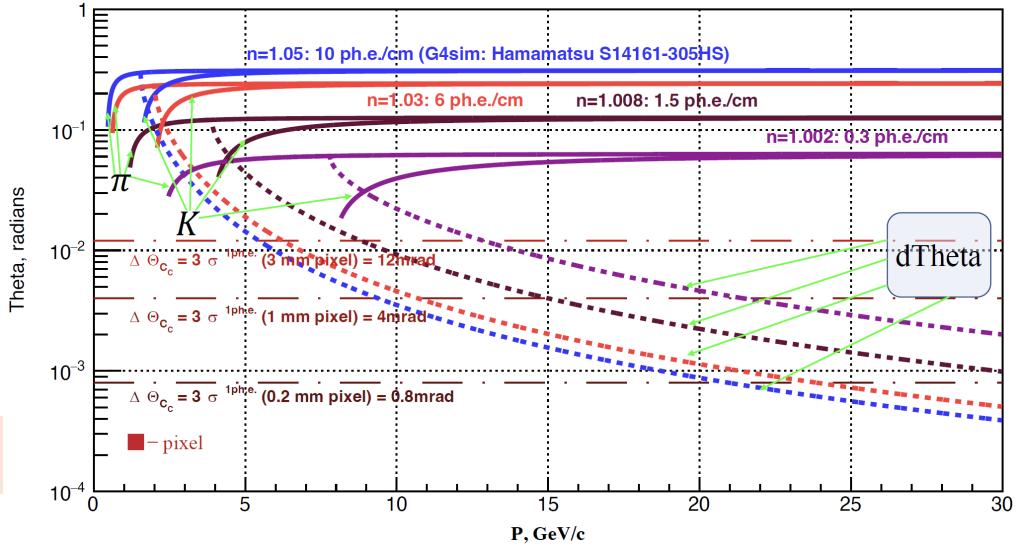
## Gradient aerogel $n_{max}$=1.008; pixel≈0.7mm



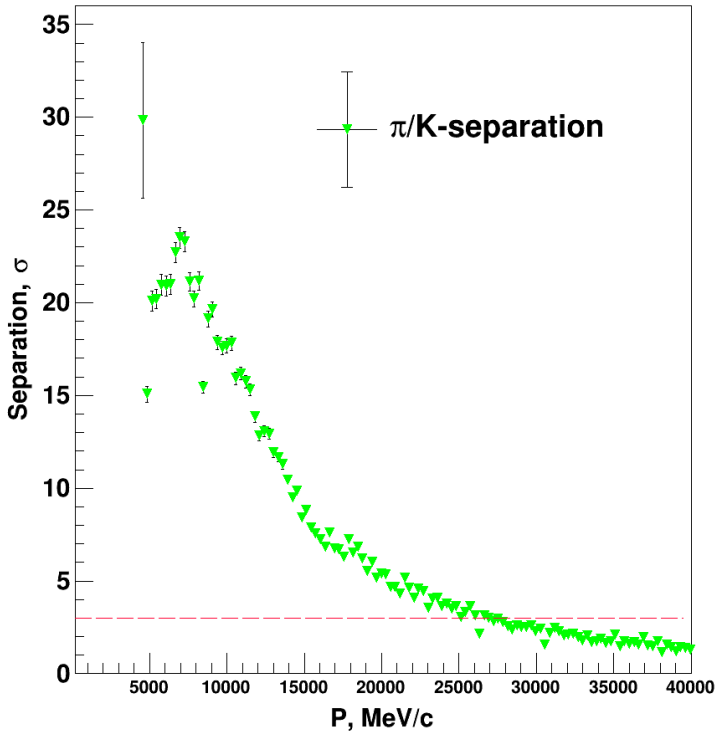



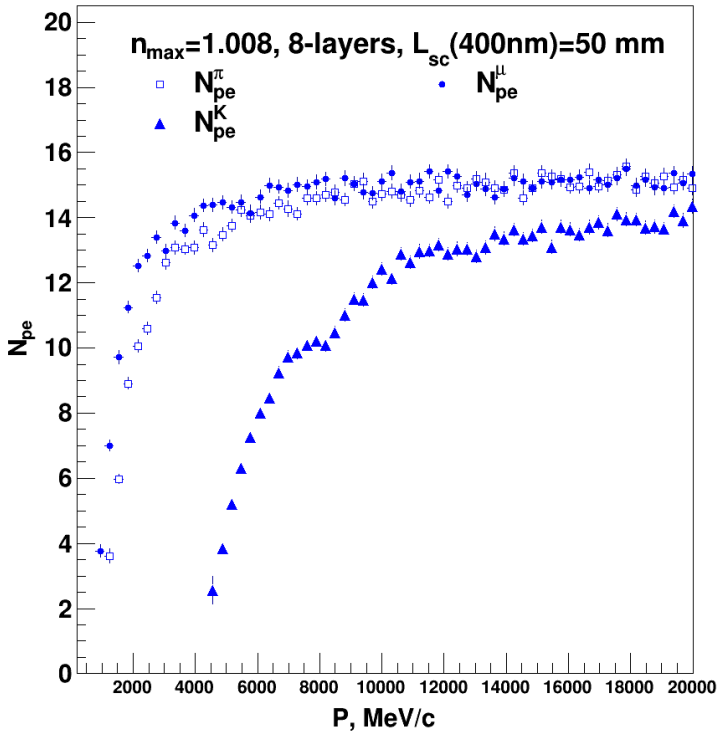

The possibility to produce of gradient aerogel was demonstrated in

*NIM A766 (2014) 88-91 and NIM A766 (2014) 235-236*



# FARICH for π/K–separation at 30 GeV/c: G4sim results

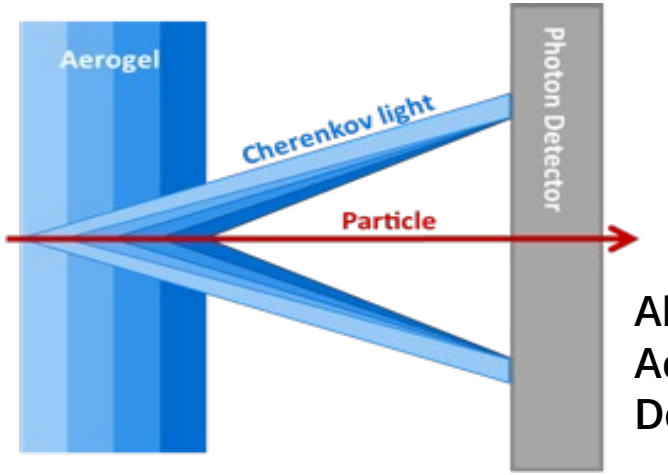


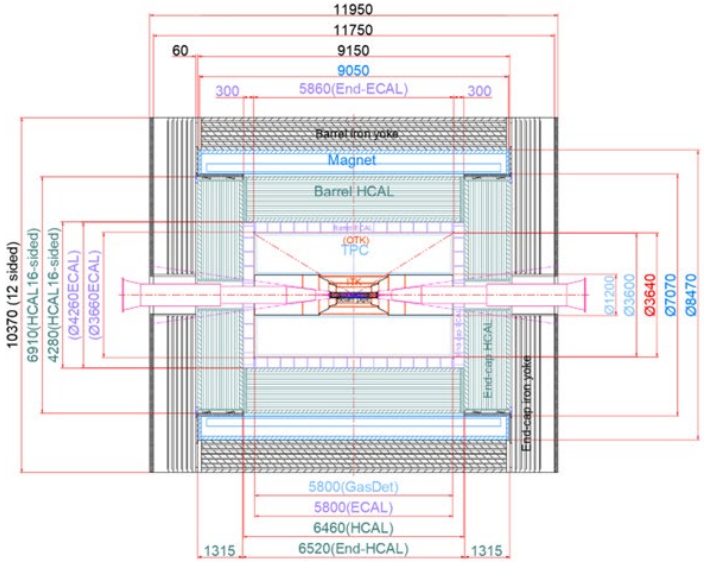

A lot of R&D to enhance the performance.

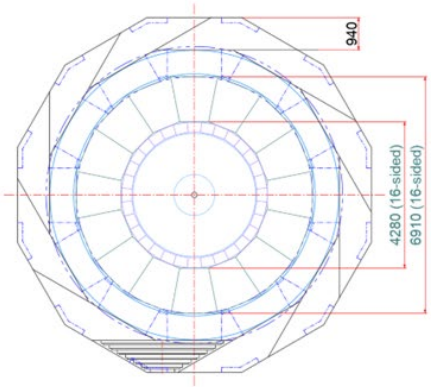
# Discussion on FARICH - Advantages

- Simple structure: Aerogel Layers + SiPM arrays
  - Russian groups have a lot of experiences in Aerogels.
  - We have advantages in SiPM and readouts in China.
- It is possible to achieve a very high position resolution using PSS, with limited number of readout channels.
  - $1.1 \times 10^5$chs with $2.8 \times 10^4$ PSS 11-6060-S SiPMs for $1\ m^2$.
  - $4.4 \times 10^5$chs with $1.1 \times 10^5$ PSS 11-6060-S SiPMs for $1\ m^2$.
- The readout can focus on single photon detection.
- Endcap PID: $\phi 1.2 - 3.6m$, about $81\ m^2$
  - Do we have to cover such a large area with SiPMs?




**About 30 cm between Aerogerl and Photon Detector.**

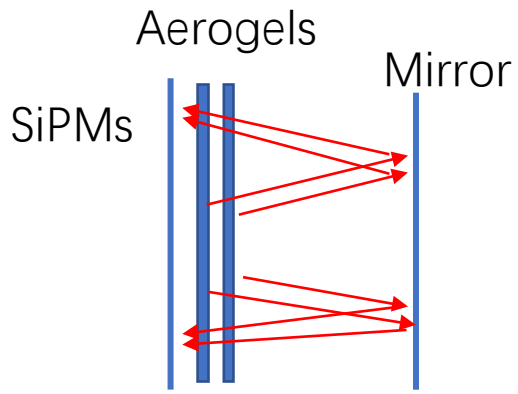


# Is it possible to improve the design?

Enari Y. et al. MCP-PMT Timing Property for Single Photons. NIMA528,763(2004))

- Design new FEE focusing on single photon detection, with very low baseline noise, high gain, and high time resolution.
- Time information can be used to veto the DCR.
  - In Belle II iTOP, time resolution of single photon is ~ 50 ps.
  - We can get a Time-of-Flight with the Cherenkov photons.
- With a position resolution of $\sim 50\mu m$, we can
  - Use aerogels with larger n,
  - Fewer layers or aerogels?
  - Reduce the distance between the aerogels and the photon detector;
  - A smaller number of SiPMs? Allows space between SiPMs.
- How about using a flat mirror?
  - Double the flight length, reduce the multiple hits on one PSS.
  - Remove more short wavelength photons, to reduce the dispersion?



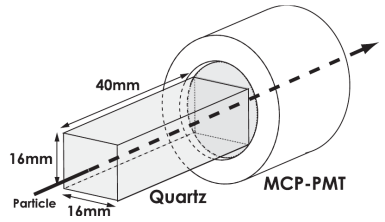




Fig. 12. Schematic drawing of the test TOF counter. HPK10 is used as the MCP-PMT.

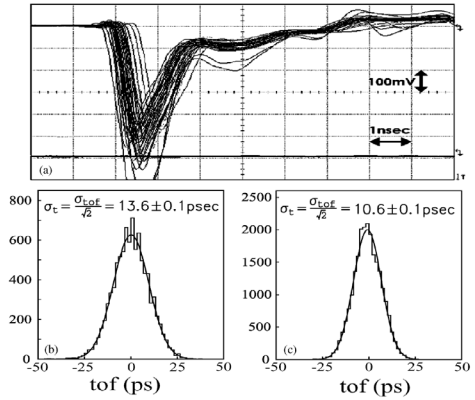
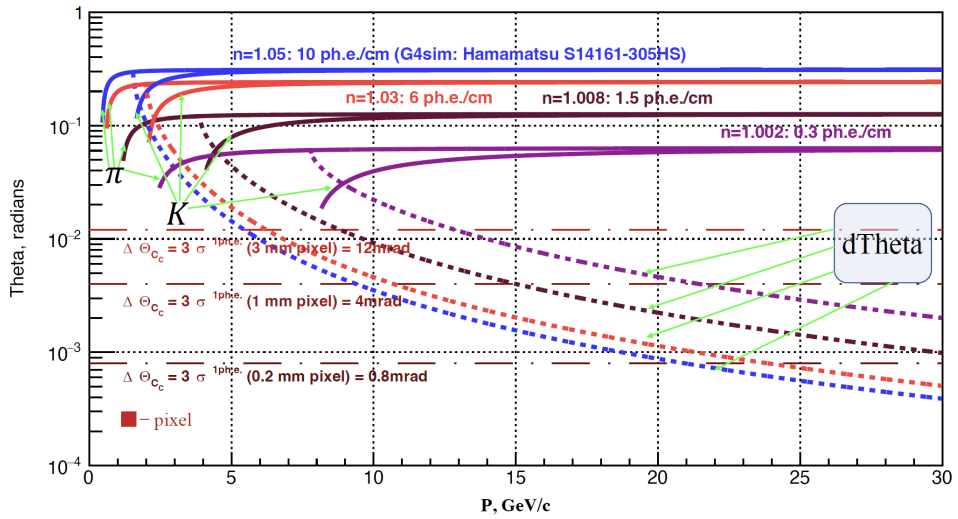



Fig. 13. (a) shows HPK10s output signal for 3 GeV/$c$ pion beam; (b) and (c) are the distributions of the time difference between two test counters without and with a quartz radiator, respectively. Their resulting time resolutions of the single counter are obtained as $\sigma_t = \sigma_{tof}/\sqrt{2} = 13.6 \pm 0.1$ ps and $10.6 \pm 0.1$ ps.



# Discussion on FARICH - Disadvantage

- DCR increases with the radiation, especially the neutrons.
  - Need to count the backgrounds according to MDI.
  - Need tests on radiation hardness.
  - If possible, design new PSS with higher radiation hardness.
- The costs for SiPMs and readouts
  - Can we reduce the area coverage?
  - Optimize the design of PSS for lower cost? Huawei (海思) produces SiPMs with PDE up to ~70%.

# Summary

- We started the consideration and R&D for high momentum PID since the workshop at Fudan, 2023.
- Combination of aerogel and SiPM shows good potential for $K-\pi$ separation around $30\ \mathrm{GeV}/c$.
  - Russia has advantages in aerogel, while China has advantages in SiPM.
- The NDL PSS may offer position resolution $\sim 50\mu m$, which is a ideal photosensor for Cherenkov photons.
- We start the discussion, and look for more R&D in the future. 抛砖引玉。

**Thank you!**