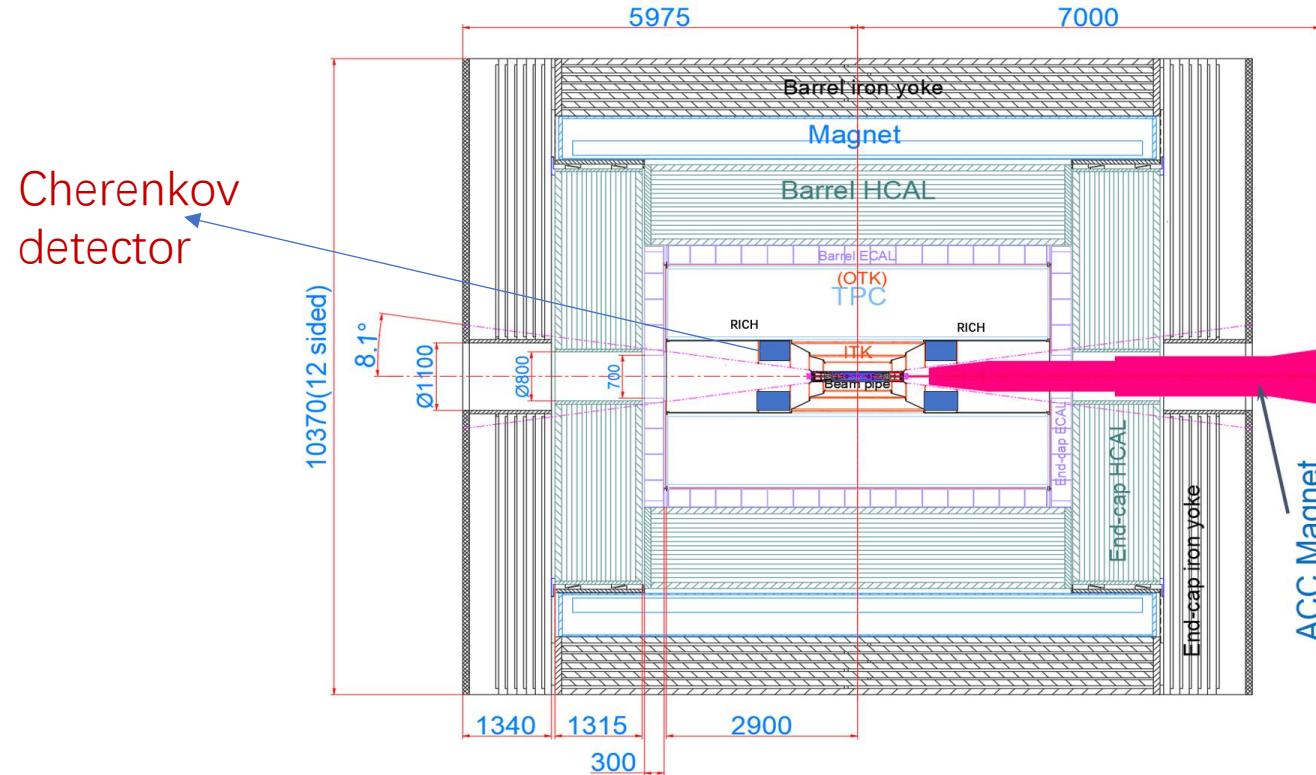


Preliminary consideration of a Cherenkov detector at CEPC



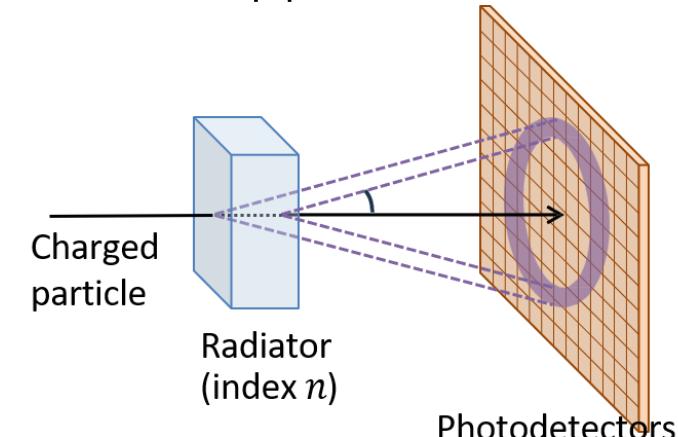
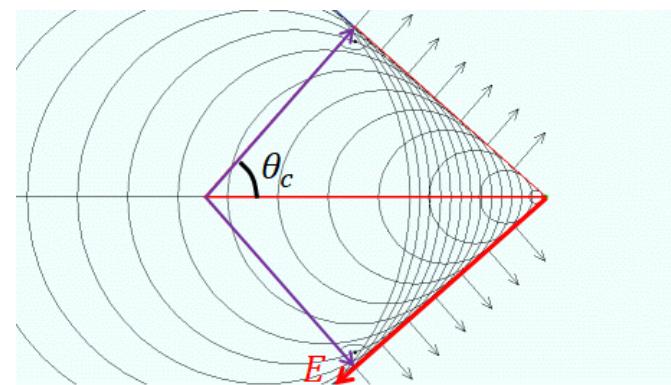
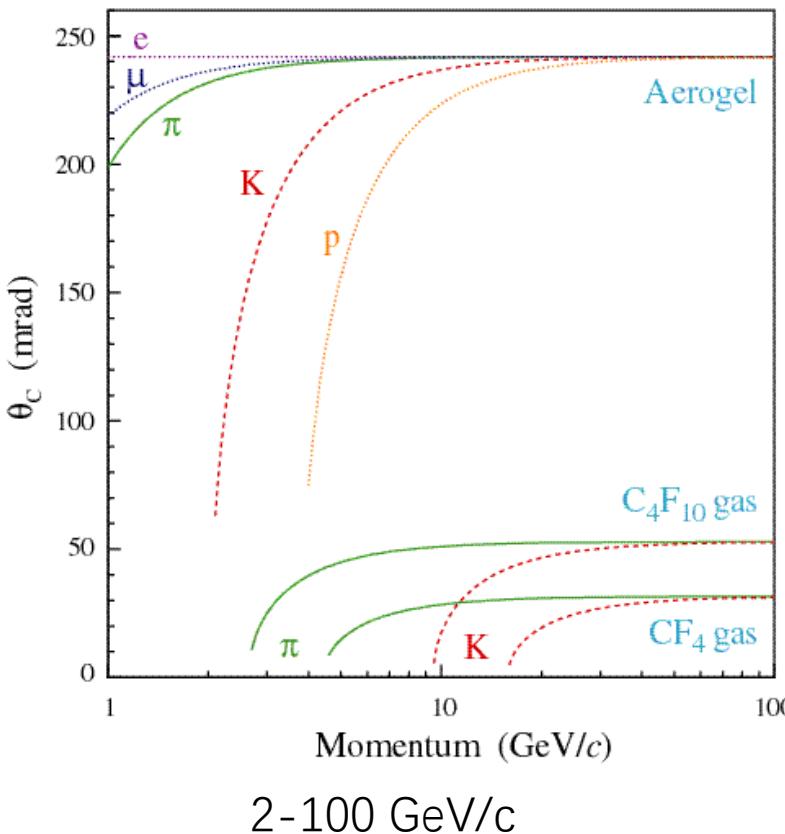
Zhonghua Qin, IHEP

CEPC physics and detector plenary meeting, Jan.7, 2026

A reminder of Cherenkov detector

- Cherenkov detector is a powerful tool for charged particle identification, especially for particles with a momentum up to several tens of GeV/c where the ToF is not applicable

LHCb RICH-1 (Aerogel+ C_4F_{10} gas radiator)
RICH-2 (CH_4 gas radiator)



RICH 2025, Kodai Matsuoka

Threshold: $\beta > 1/n$

Cherenkov angle: $\cos \theta_c = \frac{1}{n\beta}$

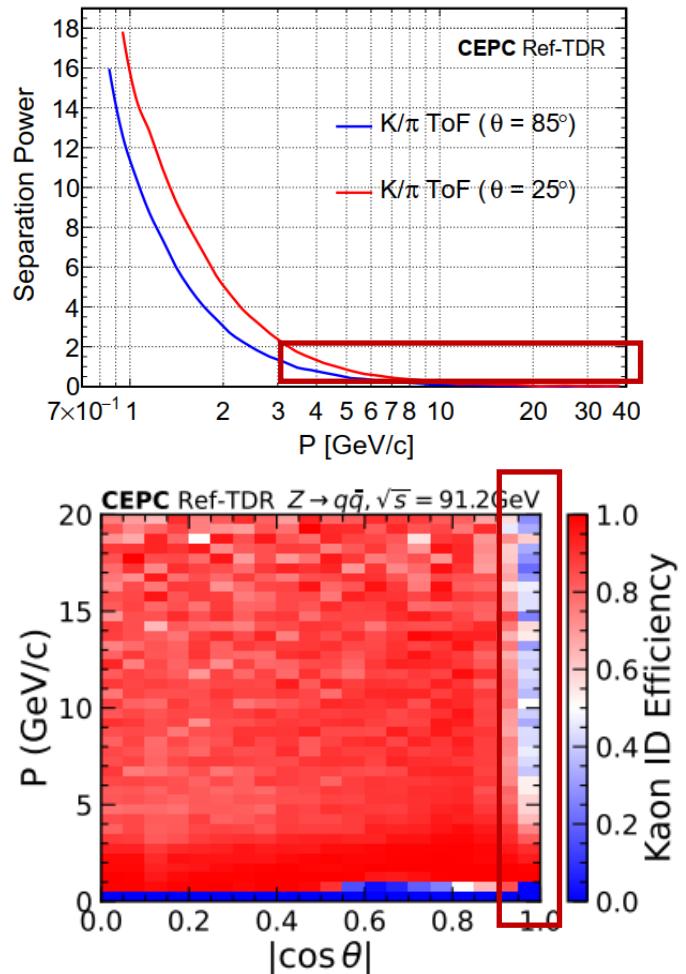
Number of photons: $\frac{dN_\gamma}{dE} = \left(\frac{\alpha}{\hbar c} \right) Z^2 L \sin^2 \theta_C$

Separation power: $N_\sigma \approx \frac{|m_1^2 - m_2^2|}{2P^2\sigma[\theta_c(\text{tot})]\sqrt{n^2 - 1}}$

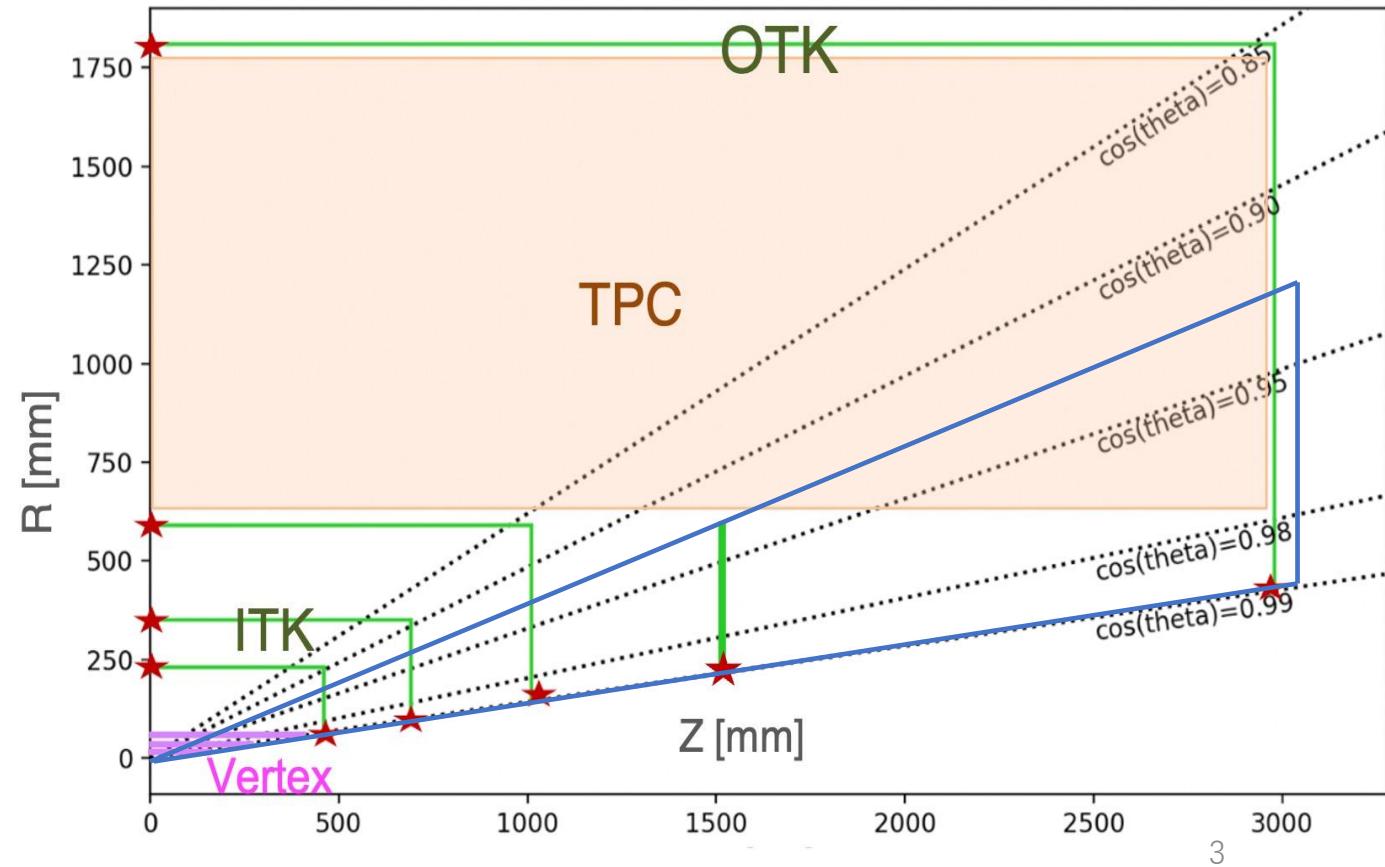
Motivation of the Cherenkov detector for CEPC

- A Cherenkov detector at CEPC is helpful, for high momentum PID(up to 20 GeV/c) at the endcap/forward region where only short tracks or even no tracks pass through TPC (so dN/dx not good)
- It's critical for flavor physics, Higgs physics (especially Higgs \rightarrow ss), etc.

ToF standalone
(from Ref-TDR)

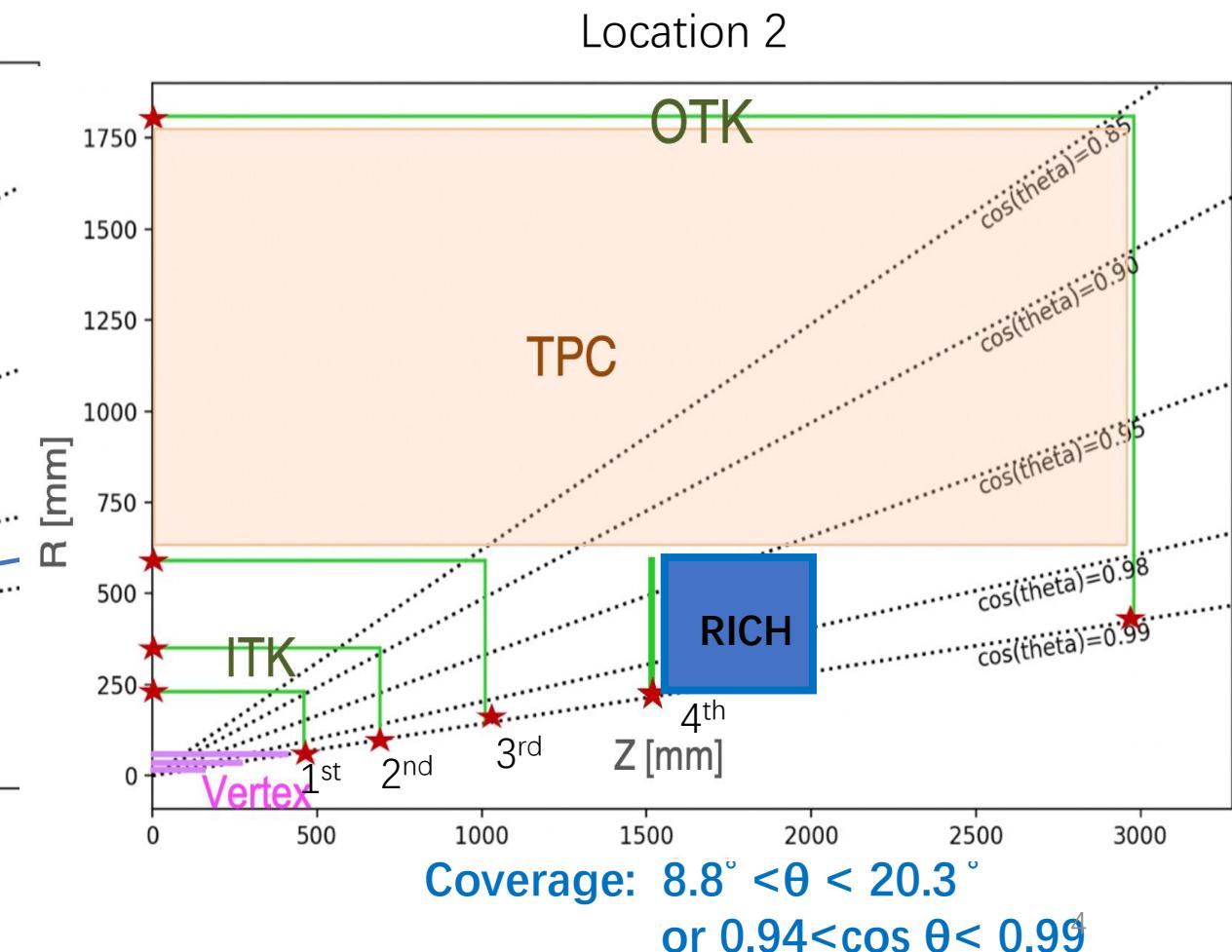
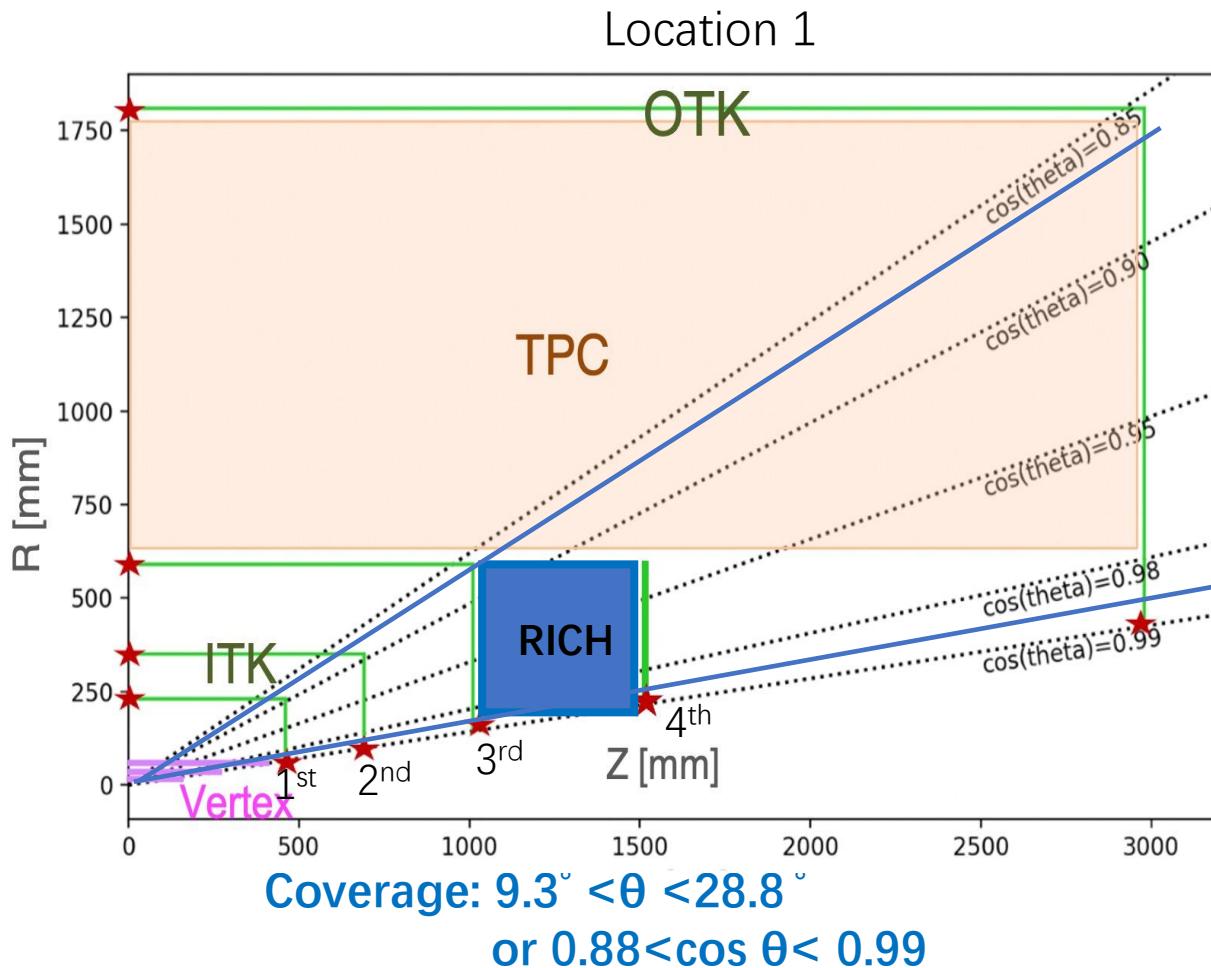


Kaon ID efficiency
(from Ref-TDR)



Possible location of the Cherenkov detector at CEPC

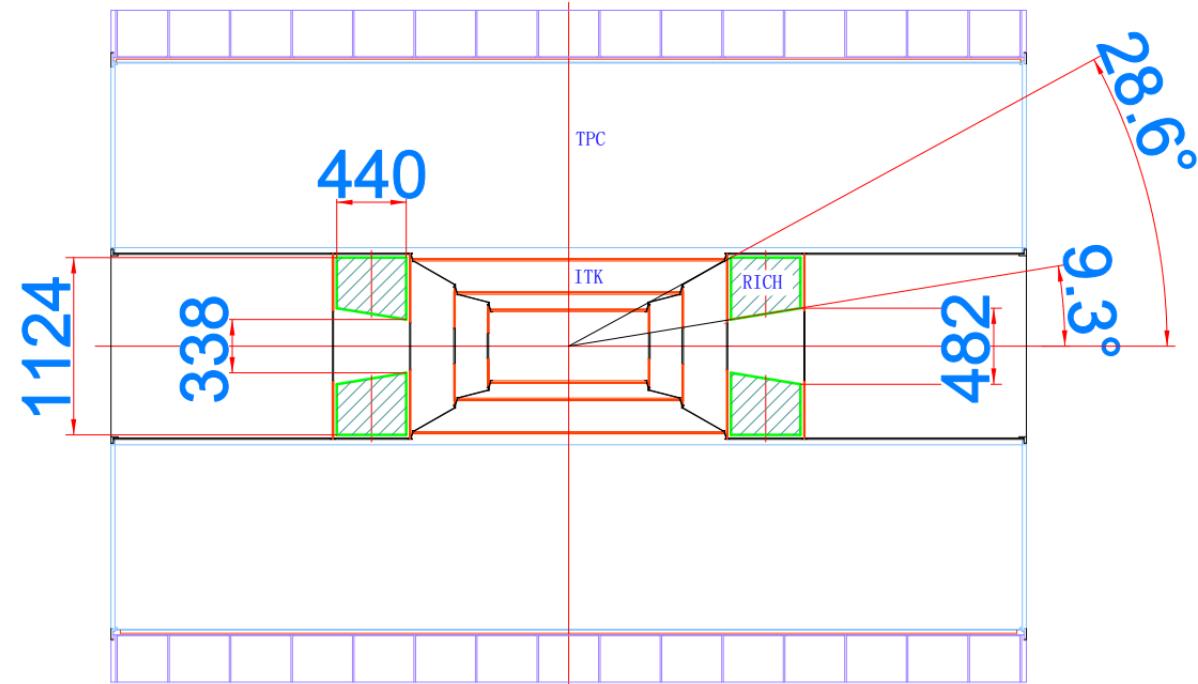
- Two possible locations without changing the other detector design in ref-TDR
- Depending on physics requirement, Cherenkov detector performance and also material budget



Drawings for the two locations

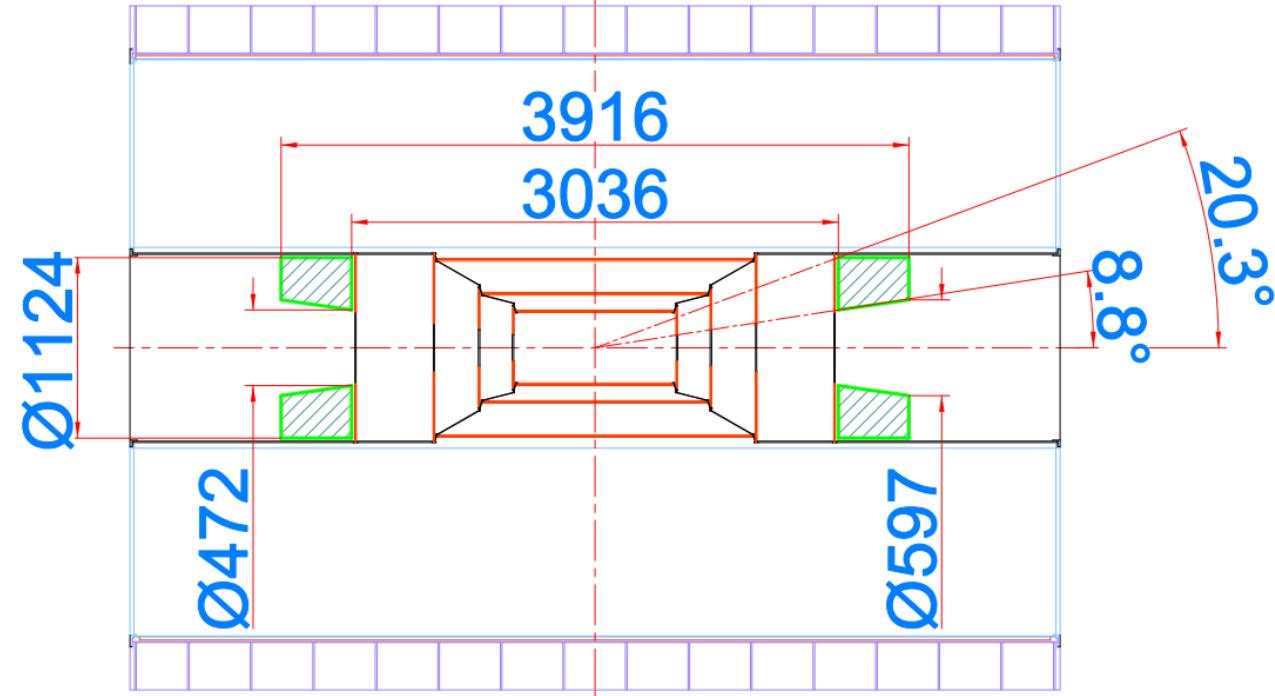
From Jian Wang,
mechanics group

Location 1 (between 3rd and 4th endcap ITK)



| | Inner diameter | Outer diameter | Total area (two endcaps) | Length (single endcap) |
|-----------------|----------------|----------------|--------------------------|------------------------|
| Radiator | 33.8 cm | 112.4 cm | 1.81 m ² | 44cm |
| Photon detector | 48.2 cm | 112.4 cm | 1.62 m ² | |

Location 2 (outer of 4th endcap IKT)

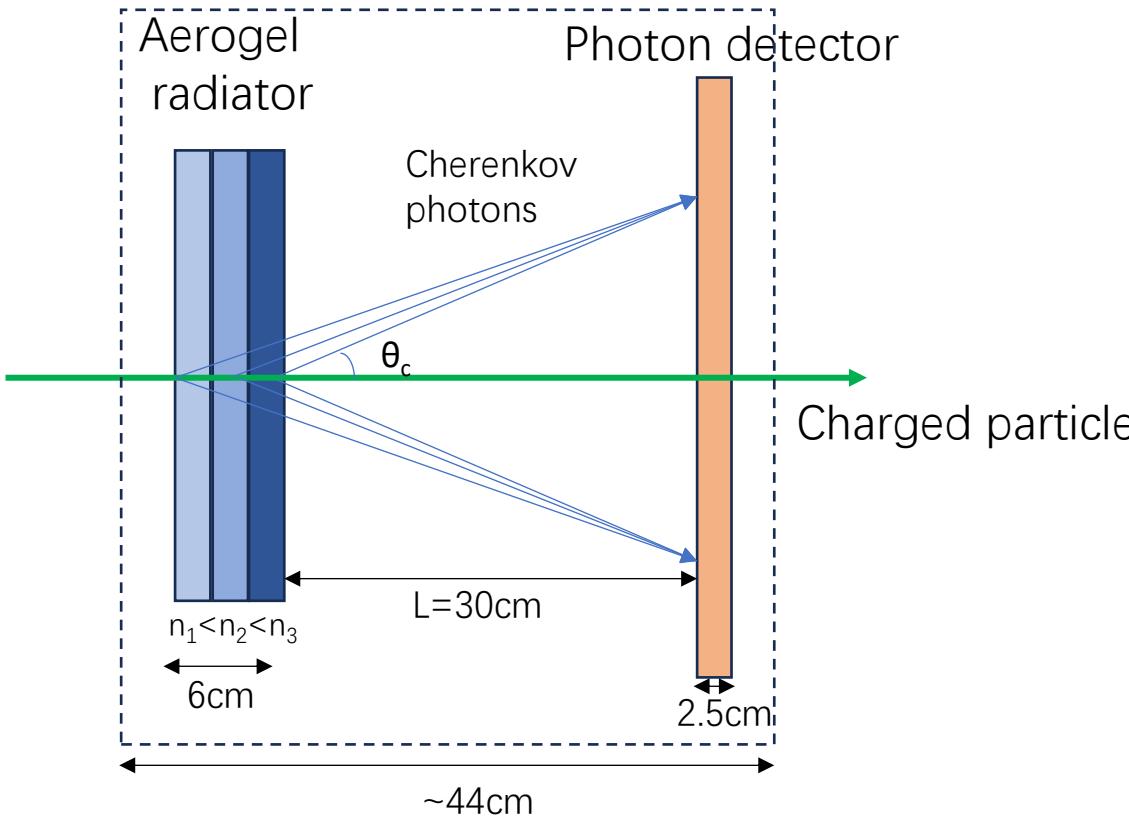


| | Inner Diameter | Outer diameter | Total area (two endcaps) | Length (single endcap) |
|-----------------|----------------|----------------|--------------------------|------------------------|
| Radiator | 47.2 cm | 112.4 cm | 1.64 m ² | 44cm |
| Photon detector | 59.7 cm | 112.4 cm | 1.43 m ² | |

Possible design of CEPC Cherenkov detector

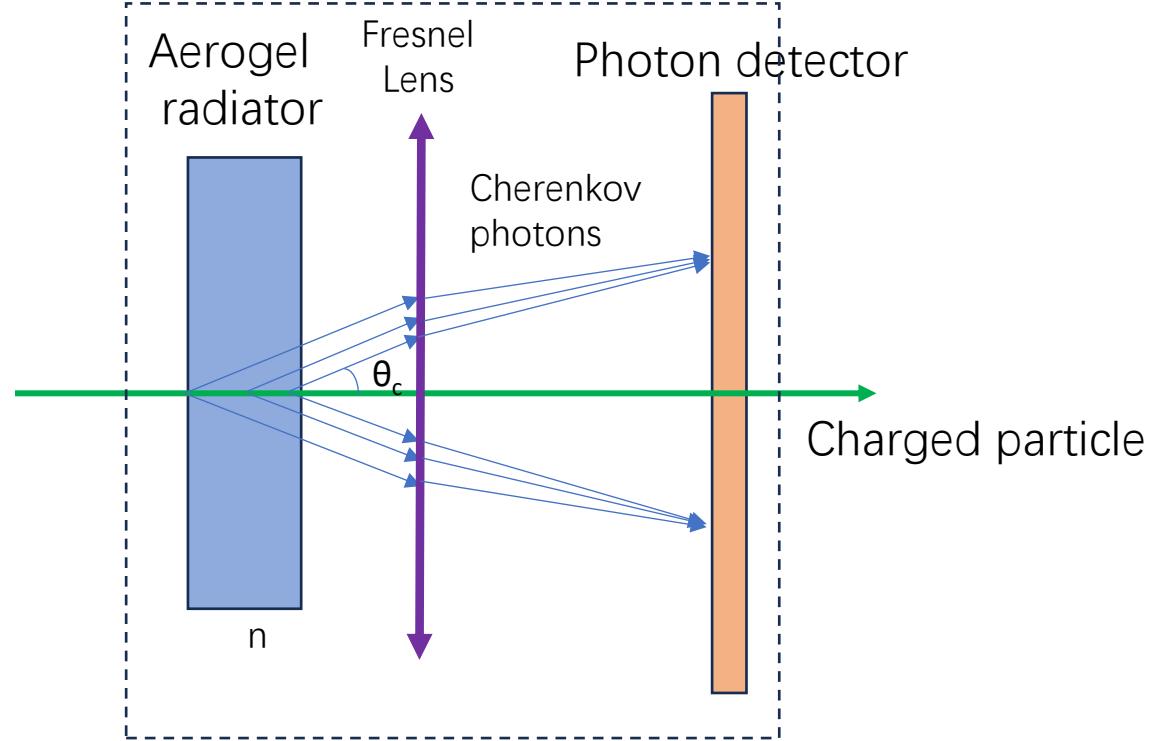
- The proximity focusing method:

Reference: T.Iijima, NIM A548 (2005) 383; A.Yu.Barnyakov, NIM A553 (2005) 70; D. Sharma, NIM A1061 (2024) 169080



Option 1:

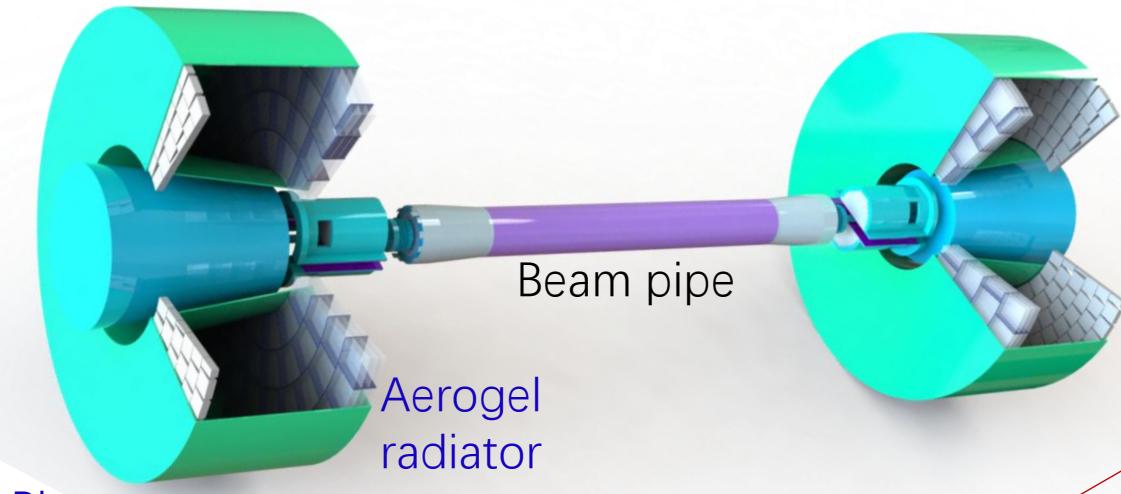
Multiple layers of aerogel with varying n , overlapped ring for different emission points



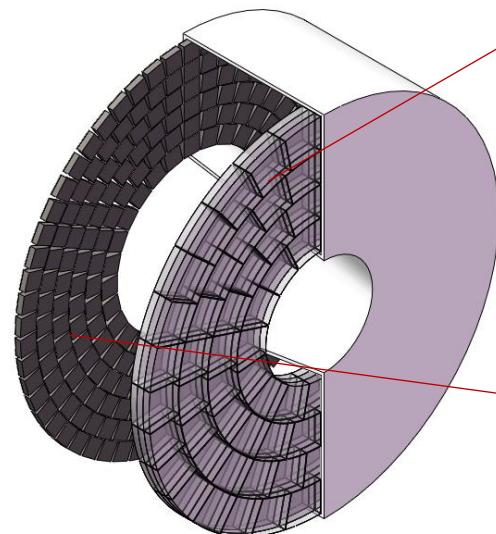
Option 2:

A single layer of aerogel, focused by a Fresnel lens.

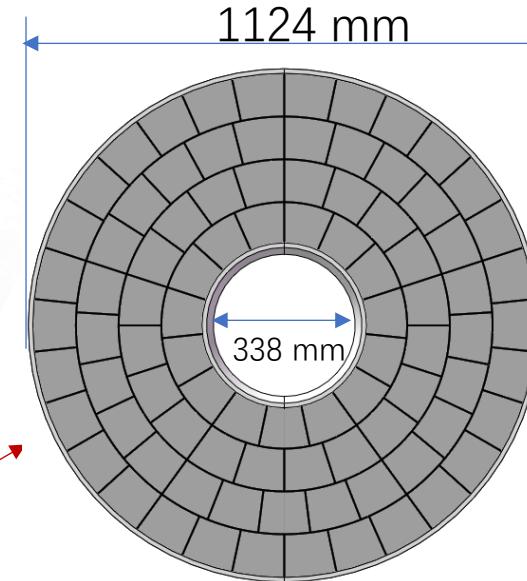
A schematics of the Cherenkov detector



Photon
detector



Aerogel
radiator



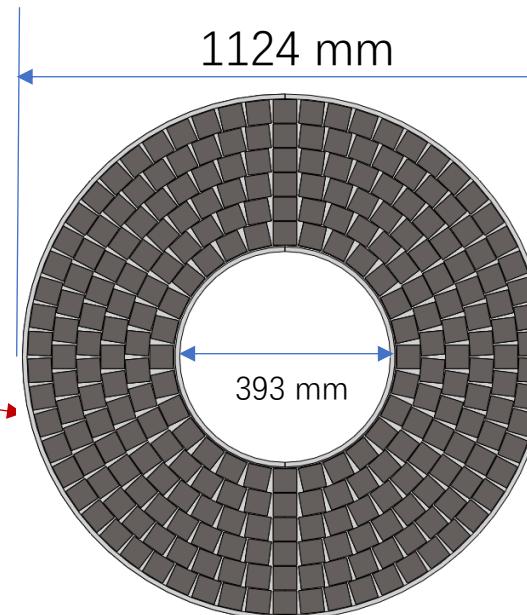
1124 mm

338 mm

From Jian Wang,
mechanical group

Aerogel radiator :

- 90 aerogel tiles in 4 layers
- each tile of $\sim 10 \text{ cm} \times 10 \text{ cm}$ in size



1124 mm

393 mm

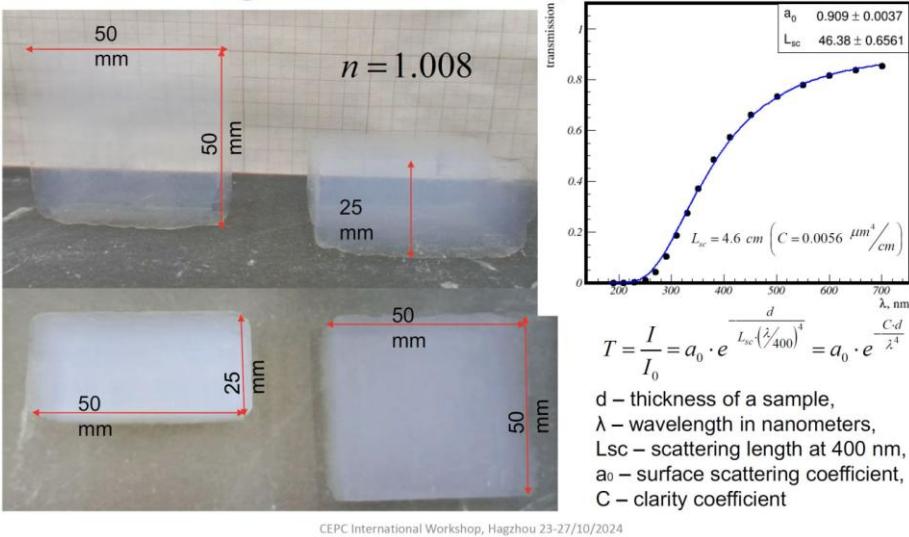
Photon detector:

- 258 photosensor module in 6 layers
- each module of $\sim 5 \text{ cm} \times 5 \text{ cm}$ in size

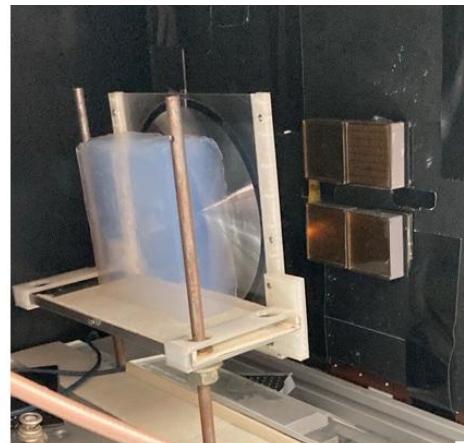
Past and ongoing R&Ds on aerogel radiator

- Led by Alexander Barnyakov from BINP

Aerogel with $n=1.008$ (Novosibirsk)



Some results of beam tests at the BINP with mRICH design

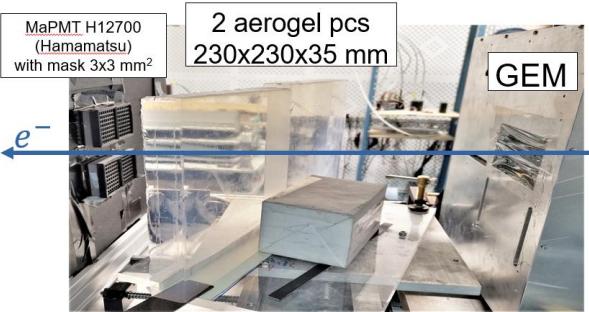


Aerogel:

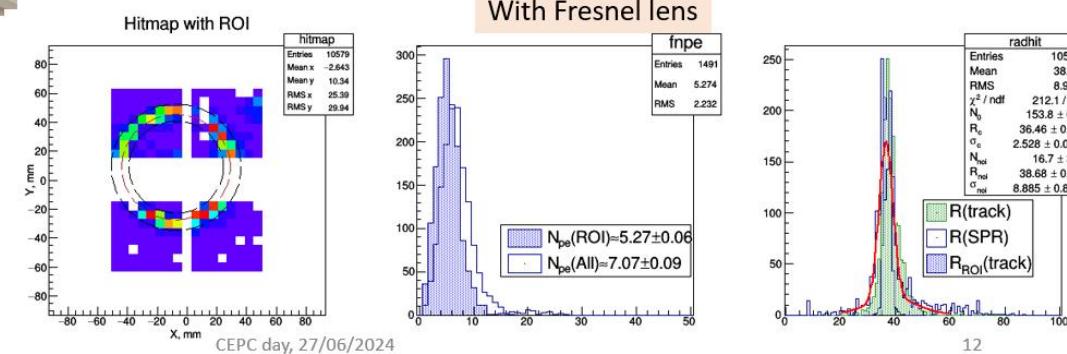
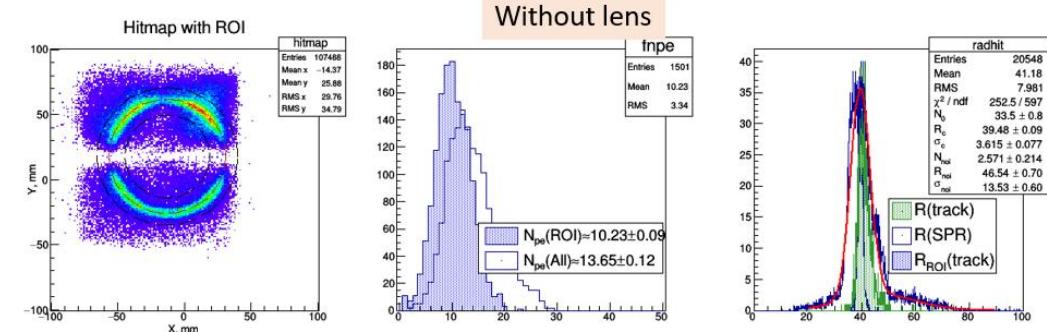
- $n=1.028$
- $L_{sc}(400\text{nm})=48.2 \pm 0.7 \text{ mm}$
- Thickness=40mm

Fresnel lens:

- Acrylic (PMMA)
- $L_f=6''$
- Manufacturer: Edmund
- PMT:
- 4 Hamamatsu H12700
- pixel 6x6 mm



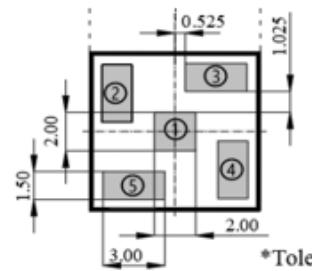
Single photon Cherenkov angle resolution is investigated with relativistic electrons at BINP beam test facilities
"Extracted beams of VEPP-4M complex".



Past and ongoing R&D for photon detector

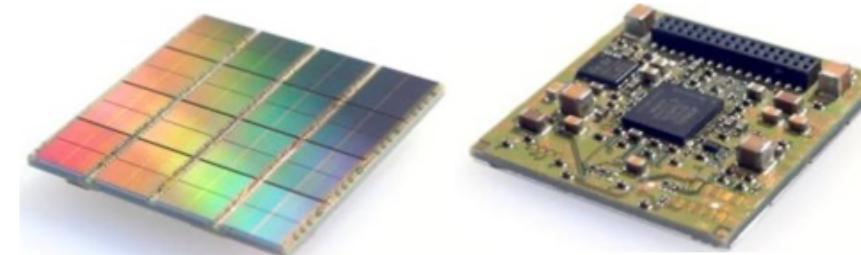
- Investigation of the photon sensor (by Xiaolong, Fudan Uni.)

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 $\sigma_x \approx 200\mu\text{m}$

Digital PC



- DPC3200-22-44** – 3200 cells/pixel (from Philips)
- Each microcell is connected through controlled latch 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:
 $\sigma_x \leq 50, 25, 12\mu\text{m}$

Investigation of MCP PMT as photon sensor

For Belle II, barrel RICH (iTOP)

HAMAMATSU
PHOTON IS OUR BUSINESS

MICROCHANNEL PLATE
PHOTOMULTIPLIER TUBE
R10754-07-M16

FEATURES

- 16 matrix multianode
- Small dead space
- Fast time response
- High magnetic field immunity
- Long life time



APPLICATIONS

- High energy physics
- Multichannel time resolved fluorescence detection measurement
- Light detection and ranging

SPECIFICATIONS

GENERAL

| Parameter | Description / Value | Unit |
|--|------------------------|-----------------------------|
| Spectral response | 160 to 850 | nm |
| Wavelength of maximum response | 380 | nm |
| Window material | Synthetic silica | — |
| Photocathode | Material | Multialkali |
| | Minimum effective area | 23 x 23 |
| Dynode | Dynode structure | 2 stages Microchannel plate |
| | Channel diameter | 10 |
| Number of anode pixels | 16 (4 x 4 matrix) | — |
| Anode pixel size | 5.28 x 5.28 | mm |
| Operating ambient temperature ^a | -30 to +45 | °C |
| Storage temperature ^a | -30 to +50 | °C |

MAXIMUM RATINGS (Absolute maximum values)

| Parameter | Value | Unit |
|--|-------|------|
| Supply voltage Between anode and cathode | 2700 | V |
| Average anode current | 2 | μA |

CHARACTERISTICS (at 25 °C, 2200 V)

| Parameter | Min. | Typ. | Max. | Unit |
|---|-----------|-----------------|------|-------|
| Cathode sensitivity Luminous (2856 K) | 80 | 110 | — | μA/lm |
| Blue sensitivity index | — | 7.5 | — | — |
| Anode luminous sensitivity | 22 | 110 | — | A/lm |
| Gain | — | 1×10^6 | — | — |
| Dark current (After 30 minutes storage in darkness) | — | 5 | 30 | nA |
| Time response | Rise time | — | 195 | ps |
| | Fall time | — | 310 | ps |
| | Width | — | 400 | ps |
| T.T.S. (FWHM) ^b | — | 75 | — | ps |

^a No condensation

^b Transit-time spread (T.T.S.) is the fluctuation in transit time between individual pulse and specified as an FWHM (full width at half maximum) with the incident light having a single photoelectron state. This value includes the jitter of the electronics about 30 ps.

VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

| Electrode | K | 1st MCP-in | 1st MCP-out | 2nd MCP-in | 2nd MCP-out | P |
|--------------------|---|------------|-------------|------------|-------------|---|
| Distribution ratio | 1 | 5 | 5 | 5 | 3 | |

Supply voltage: 2200 V, K: Cathode, P: Anode

Subject to local technical requirements and regulations, availability of products included in this promotional material may vary. Please consult with our sales office.
Information furnished by HAMAMATSU is believed to be reliable. However, no responsibility is assumed for possible inaccuracies or omissions. Specifications are subject to change without notice. No patent rights are granted to any of the circuits described herein. ©2020 Hamamatsu Photonics K.K.

N6021光倍增管 N6021 MCP-PMT

应用领域 Application

医学影像/Specialized Medical Imaging
Cherenkov - RICH, TOF, TOP, DIRC
高能物理/High Energy Physics
国土安全/Security

产品特点 Features

响应快 High Speed
增益高 High Gain
噪声低 Low Noise

技术参数 Specifications

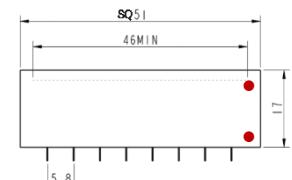
| | | | |
|---------------------------|---------------|--|--|
| 玻璃材料/Window material | AVG glass | | |
| 光阴极/Photocathode material | 双碱/Bialkali | | |
| 倍增结构/Multiplier structure | 2片微通道板型/2 MCP | | |
| 阳极结构/Anode structure | 8 x 8 | | |

| | N6021 | Min. | Typ. | Max. | Unit |
|---|--------------------------------------|---------|-----------------|------|-------|
| 光谱范围/Spectral response | | 280-650 | | | nm |
| 量子效率峰值波长/Quantum efficiency peak wavelength | | 380 | | | nm |
| 积分灵敏度/Luminous sensitivity | | 80 | | | μ A/m |
| 量子效率@410nm/QE @410nm | | 21 | | | % |
| 辐射灵敏度/Radiant sensitivity@410nm | | 72 | | | mA/W |
| 工作参数/Operational parameters | 工作电压/Supply voltage | 2000 | 2500 | 2500 | V |
| | 增益/Gain | | 2×10^8 | | |
| | 暗计数/Dark count rate@0.2pe(单阳极) | 500 | 5000 | 5000 | Hz |
| | 能量分辨率/Charge resolution | 35 | | | % |
| | 单光电子谱峰谷比/Peak to valley ratio | 3 | | | |
| 时间参数/Time parameters | 上升时间/Rise time | 300 | | | ps |
| | 脉冲宽度/Pulse width | 650 | | | ps |
| | 下降时间/Fall time | 800 | | | ps |
| | 渡越时间弥散/TTS@σ (SPE) | 50 | | | ps |
| | 渡越时间弥散/TTS@σ (MPE) | 15 | | | ps |
| 环境参数/Environmental parameters | 工作环境温度/Operating ambient temperature | -30~+50 | | | °C |
| | 储藏温度/Storage temperature | -50~+50 | | | °C |

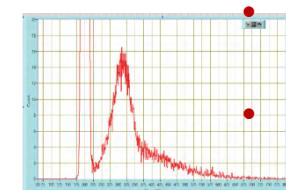
“FPMT”, NNVT&IHEP



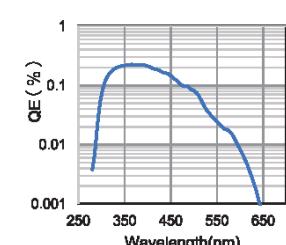
- Effective area: 46mm x 46mm
- Anode matrix: 8 x 8



N6021 光电倍增管外型结构
N6021 PMT dimensional outline



典型单光电子谱
Typical single photoelectron spectrum



典型光谱响应曲线
Typical spectral response chara

Investigation of Multi-anode Dynode PMT

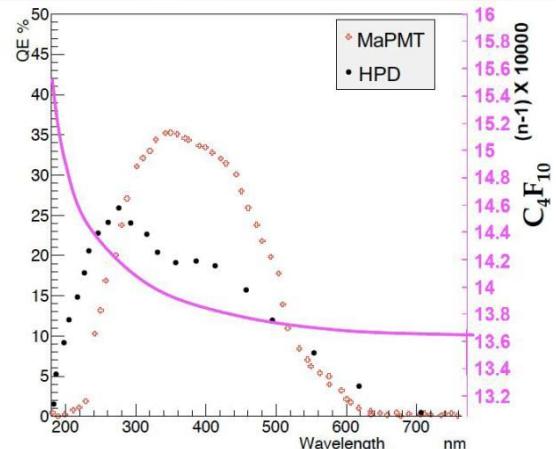
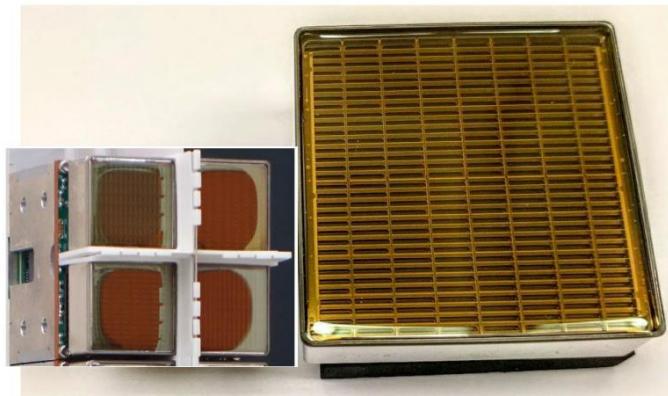
For LHCb RUN3

Sajan Easo's talk in CEPC workshop in Hangzhou, 2024
Nucl. Inst. Meth. A 876 (2017) 206-208

MultiAnode PhotoMultipliers

LHCb

- Hamamatsu MaPMTs
 - 3100 R13742 and 450 R13743, including spares
 - Super-bialkali photocathode
 - UV glass window
 - Minimum gain 1×10^6 at 1 KV
 - 1:4 pixel gain spread in 1" PMTs, 1:3 pixel gain spread in 2" PMTs
 - Low dark count rate
 - Single photon spectrum well separated from the noise pedestal
- Higher QE of MaPMT in the green
 - Chromatic error reduction
- Sensitive to magnetic fields
 - Shielding applied



- Effective area:
23mm x 23mm (1") or
46mm x 46 mm (2")
- Anode matrix: 8 x 8
- Anode size:
2.88mm x 2.88mm
or 5.76mmx5.76mm
- QE: 35%
- High voltage: 1.1 kV

HAMAMATSU

TENTATIVE DATA SHEET

Dec. 2015

MULTIANODE PHOTOMULTIPLIER TUBE

R13742

Exclusive for HPF-BS/ CERN and HPI/ INFN
MILANO (for LHCb/RICH)

Super Bialkali Photocathode (SBA), UV Window, 1 Inch Square
8 x 8 Multianode and Fast Time Response

General

| Parameter | Description | Unit |
|--|----------------------|-------|
| Spectral Response Range | 185 to 650 | nm |
| Peak Wavelength | 350 | nm |
| Photocathode Material | Bialkali | - |
| Window Material | UV Glass | - |
| Thickness | 0.8 | mm |
| Dynode Structure | Metal Channel Dynode | - |
| Number of Stage | 12 | - |
| Anode Number of Pixels | 64 (8 x 8 Matrix) | - |
| Pixel Size | 2.88 x 2.88 | mm |
| Effective Area | 23 x 23 | mm |
| Dimensional Outline (W x D x H) | 26.2 x 26.2 x 17.4 | mm |
| Packing Density (Effective Area / External Size) | 77 | % |
| Weight | 27 | g |
| Operating Ambient Temperature | -30 to +50 | deg C |
| Storage Temperature | -80 to +50 | deg C |

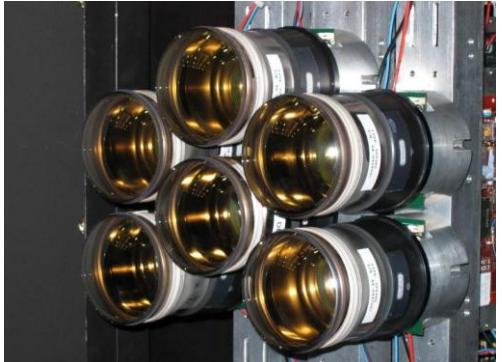
Maximum Ratings (Absolute Maximum Values)

| Parameter | Value | Unit |
|--|-------|------|
| Supply Voltage (Between Anode and Cathode) | 1100 | V |
| Average Anode Output Current in Total | 0.1 | mA |



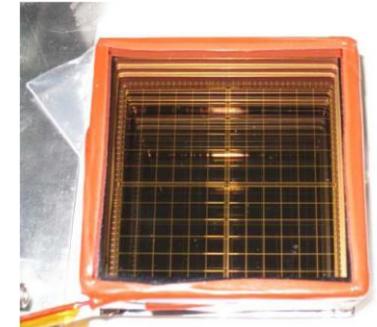
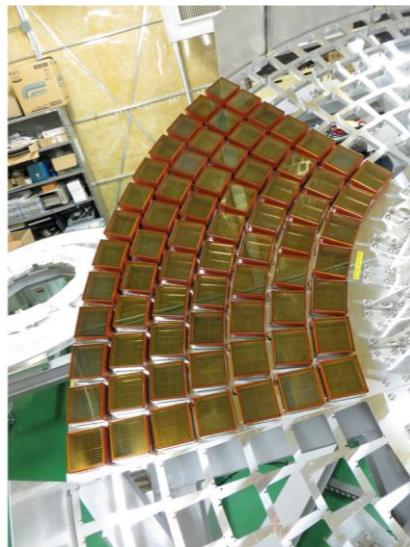
Investigation of HPD and HAPD

- HPD(Hybrid Photon Detector) for LHCb
Run1 and Run2



Effective area: 70mm in diameter
PD size: ~2.5mm x 2.5mm
QE: 27%
High voltage: 20 kV

- HAPD(Hybrid Avalanche Photon Detector) for BelleII endcap RICH (customized)



Effective area: 70mm x70mm
APD matrix: 12 x 12
APD size: ~5mm x 5mm
QE: 28%
High voltage: 8.5 kV

PRODUCT VARIATIONS

●R10467U Series

| Type No. | Spectral response | Photocathode | Window material | Window type | Effective area | T.T.S.(Transit Time Spread) ^{*1} (FWHM) |
|------------|-------------------|--------------------|--------------------|---------------|----------------|--|
| R10467U-06 | 220 nm to 650 nm | Bialkali | Synthetic silica | Plano-concave | φ6 mm | 50 ps |
| R10467U-07 | 220 nm to 870 nm | Multialkali | Synthetic silica | Plano-concave | φ6 mm | 30 ps |
| R10467U-40 | 300 nm to 740 nm | GaAsP | Borosilicate glass | Flat | φ3 mm | 90 ps |
| R10467U-42 | 300 nm to 840 nm | Extended red-GaAsP | Borosilicate glass | Flat | φ3 mm | 130 ps |
| R10467U-50 | 380 nm to 900 nm | GaAs | Borosilicate glass | Flat | φ3 mm | 130 ps |

●R11322U-40

| Type No. | Spectral response | Photocathode | Window material | Window type | Effective area | T.T.S. (Transit Time Spread) ^{*1} (FWHM) |
|------------|-------------------|--------------|--------------------|-------------|----------------|---|
| R11322U-40 | 300 nm to 740 nm | GaAsP | Borosilicate glass | Flat | φ5 mm | 170 ps |

●R14713U-07

| Type No. | Spectral response | Photocathode | Window material | Window type | Effective area | T.T.S. (Transit Time Spread) ^{*1} (FWHM) |
|------------|-------------------|--------------|------------------|---------------|----------------|---|
| R14713U-07 | 220 nm to 870 nm | Multialkali | Synthetic silica | Plano-concave | φ3 mm | 20 ps |

●H13223-40

| Type No. | Spectral response | Photocathode | Window material | Window type | Effective area | T.T.S. (Transit Time Spread) ^{*1} (FWHM) |
|-----------|-------------------|--------------|--------------------|-------------|----------------|---|
| H13223-40 | 300 nm to 740 nm | GaAsP | Borosilicate glass | Flat | φ3 mm | 90 ps |

^{*1}At the single photon state and the full illumination on photocathode, specified as FWHM (Full Width at Half Maximum).

These Values include the jitter of the electronics about 30 ps.

Table 1

Requirement for the HAPD performance.

| Item | Typical | Requirement |
|--------------------------|-----------|------------------------------------|
| QE ($\lambda = 400$ nm) | 28% | $\geq 24\%$ |
| Bias Voltage | 250–500 V | |
| High voltage | –8.5 kV | |
| Dark current (bias) | 1–100 pA | $< 1 \mu\text{A} / \text{channel}$ |
| Dark current (HV) | | $< 300 \text{ pA}$ |
| Avalanche gain | 40 | > 30 |
| Bombardment gain | 1800 | > 1500 |
| Number of bad channels | | ≤ 10 |

General requirements for the photon detector of CEPC Cherenkov detector

| Requirements | For what reasons |
|--|--|
| single photon detection capability | very small number of photons (~10) from aerogel radiator |
| low dark noise | |
| high detection efficiency | |
| high tolerance of magnetic field | 3 tesla magnetic field in CEPC |
| high radiation tolerance | high beam background in the forward region |
| small material budget | inside TPC and ITK |
| good timing and spatial resolution | help to resolve the Cherenkov ring, improve the Cherenkov angle resolution |
| reasonable cost | |
| low risk on construction and operation | important issues for a large project |

Comments on the different photon detector options

- The commercial/traditional PMTs/HPD/HAPD have a very large material budget ($> 10\% X_0$), which is not applicable for a Cherenkov detector inside the tracker (e.g. TPC, ITK.)
- The MCP-PMT (N6021 from NNVT, under developing for the other project) also has large material budget (close to $10\% X_0$), and large anode size (5.75 mm x 5.75 mm)
- SiPM has relatively low material budget ($\sim 1\% X_0$ for SiPM + PCB), but dark noise and radiation tolerance are generally concerned, and high spatial resolution is also needed in our case

Consideration of SiPM dark noise rate

- An estimation of **fake hits from dark noise** in a readout time window in the whole photon detector plane :

$$\begin{aligned} N_{\text{false hits}} &= \text{Dark noise rate} * \text{readout time window} * \text{photon detector size} \\ &= 200 * 10^3 * 69 * 10^{-9} * 0.8 * 10^6 \\ &= 10000 \end{aligned}$$

typical dark noise rate: 200 kHz/mm²

readout time window (the same as VTX, ITK, OTK, ECal and Muon) : 69 ns

photon detector size: 0.8 m²

- Too many fake hits, any solutions then?

- reduce readout time window ? how much room?

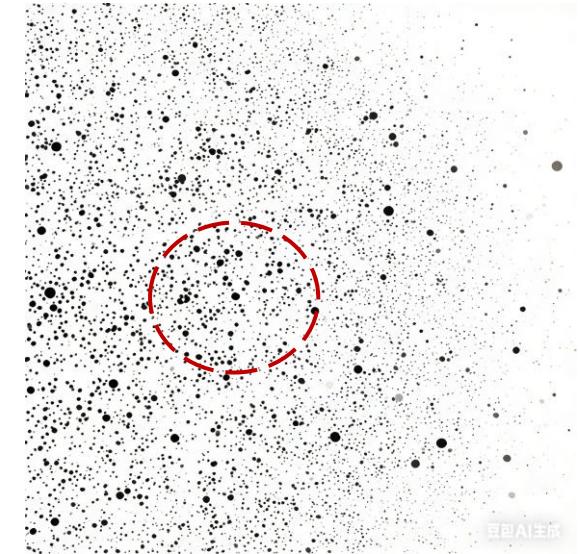
- lower the working temperature of SiPM?

- for JUNO TAO, Temp. 20 °C -> -50°C, DCR. 100kHz/mm² -> 100 Hz/mm²)

- find the ring/real hits offline by using track information from tracker systems.

- new SiPM design with lower noise: factor 10 to 100 lower?

- or a combination of all the above ?



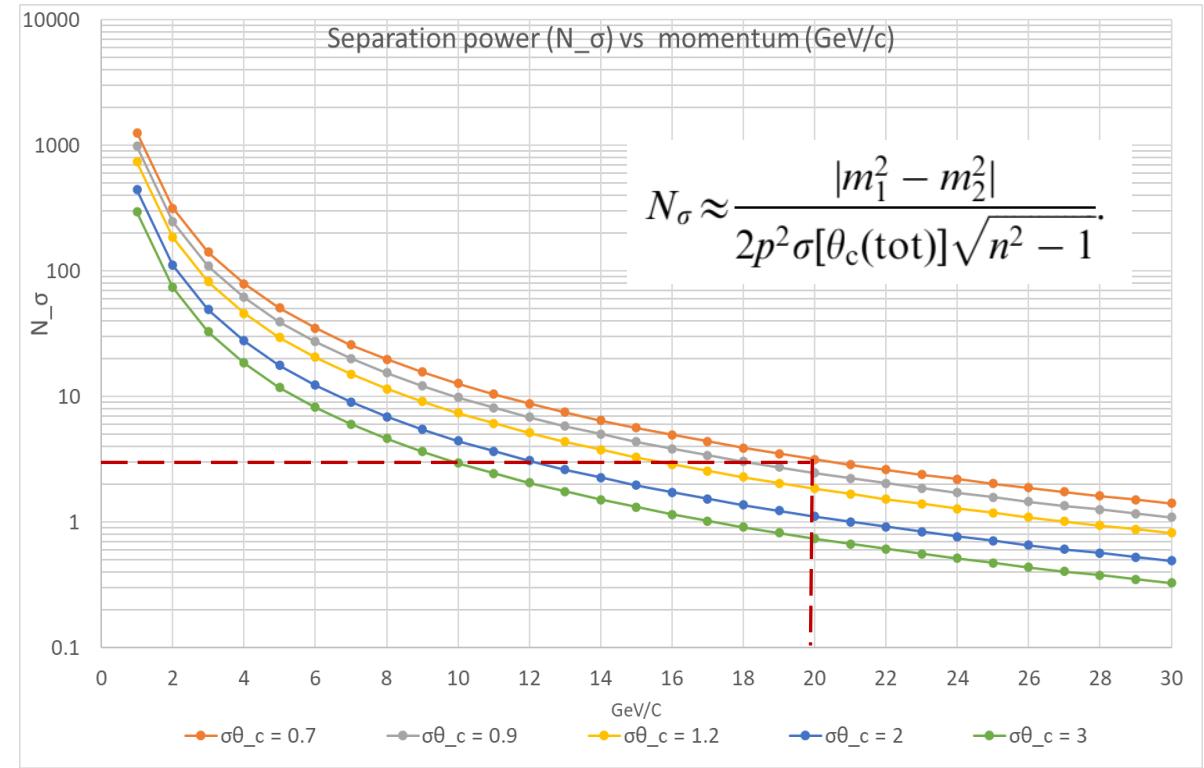
Just for illustration, a plot from AI

Consideration of SiPM spatial resolution

- To achieve 3σ K/ π separation at 20 GeV/c, a good Cherenkov angle resolution ($\sigma(\theta_c(tot))$) of **0.7 mrad** is needed;
- Resolve the spatial resolution from the Cherenkov angle resolution formula:

$$\begin{aligned}
 \sigma(\theta_c(tot)) &= \frac{\sigma(\theta_c(1pe))}{\sqrt{Npe}} \\
 &= \frac{1}{\sqrt{Npe}} \left(\sqrt{\sigma_{spatial}^2 + \sigma_{thick}^2 + \sigma_{track}^2 + \sigma_{chromatic}^2} \right) \\
 &= \frac{1}{\sqrt{Npe}} \left(\sqrt{\left(\frac{\Delta_{size}}{L\sqrt{12}}\right)^2 + \left(\frac{t \sin \theta_c}{L\sqrt{12}}\right)^2 + \sigma_{track}^2 + \left(\frac{\Delta_n}{n \tan \theta_c}\right)^2} \right)
 \end{aligned}$$

Assume $\Delta_{size} = 1\text{mm}$, $t = 20\text{mm}$, $\sigma_{track} = 0.5\text{mm}$, $\Delta_n = 0.0001$ ($n = 1.008$), $Npe = 15$,
Then $\sigma(\theta_c(tot)) \approx 0.7 \text{ mrad}$



A SiPM with size of 1mm x 1mm, or $\sigma_{spatial} = 280 \mu\text{m}$ is desirable

Consideration of SiPM radiation tolerance

From CEPC Ref-TDR detector:

Table 3.6: Beam-induced background levels in sub-detectors at Higgs and Low-Lumi-Z operation modes, including a safety factor of two.

| Sub-Detectors | Ave. Hit Rate | | Max. Hit Rate | | Max. Occupancy [%] | |
|-----------------------------------|----------------------|----------------------|---------------|------------|----------------------|----------------------|
| | Higgs | Low-Lumi-Z | Higgs | Low-Lumi-Z | Higgs | Low-Lumi-Z |
| VTX [MHz/cm ²] | 0.22 | 0.52 | 12 | 39 | 2.1×10^{-2} | 1.3×10^{-2} |
| ITK-Barrel [kHz/cm ²] | 0.92 | 1.7 | 2.6 | 6.6 | 6.4×10^{-3} | 1.3×10^{-2} |
| TPC [kHz/cm ²] | 2.4 | 5.2 | 26 | 24 | 0.15 | 0.14 |
| OTK-Barrel [kHz/cm ²] | 0.74 | 1.3 | 1.2 | 2.2 | 4.2×10^{-3} | 9.2×10^{-4} |
| ECAL-Barrel [MHz/bar] | 1.4×10^{-2} | 2.2×10^{-2} | 1.7 | 0.66 | 1.6 | 0.4 |
| HCAL-Barrel [kHz/gs cell] | 4.6×10^{-3} | 8.4×10^{-3} | 14 | 24 | 8.0×10^{-4} | 8.0×10^{-4} |
| ITK-Endcap [kHz/cm ²] | 3.0 | 5.4 | 24 | 50 | 2.4×10^{-3} | 5.0×10^{-3} |
| OTK-Endcap [kHz/cm ²] | 1.9 | 3.1 | 8.2 | 13 | 7.4×10^{-2} | 12×10^{-2} |
| ECAL-Endcap [MHz/bar] | 0.062 | 0.10 | 7.2 | 13 | 7.0 | 1.8 |
| HCAL-Endcap [kHz/gs cell] | 0.24 | 0.24 | 640 | 340 | 8.0×10^{-2} | 6.0×10^{-3} |
| MD-Endcap [Hz/cm ²] | 1.4 | 0.92 | 2.5 | 14 | 0.18 | 0.05 |

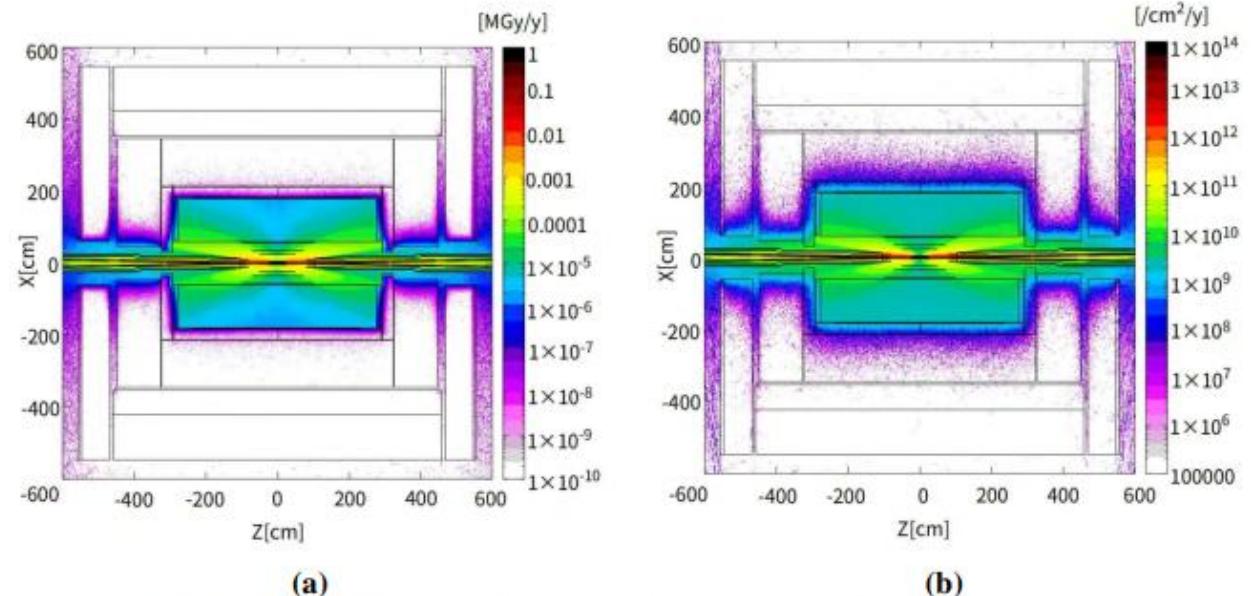


Figure 3.12: The TID and NIEL distributions at Higgs mode on the CEPC detector. The highest TID is lower than 1 MGy per year as shown in a.), while the highest level of NIEL is in the order of $10^{13} (1 \text{ MeV} n_{eq}) \text{ cm}^{-2}$ per year as shown in b.).

NIEL in the forward region where Cherenkov detector is possible put: $\sim 1 \times 10^{11} \text{ Neq.}/\text{cm}^2/\text{year}$

- So the requirement for SiPM:
 $1 \times 10^{12} \text{ Neq.}/\text{cm}^2$, or more conservatively $1 \times 10^{13} \text{ Neq.}/\text{cm}^2$?

The preliminary specifications of SiPM (still to be discussed/worked out)

| Items | preliminary requirement |
|-----------------------------|---|
| Wavelength | 200 nm – 600 nm |
| Photon detection efficiency | 50% at 420nm |
| SiPM size | 1 mm x 1 mm or 3 mm x 3 mm |
| Time resolution | 100 – 200 ps |
| Dark noise rate | ~ 1-10 kHz/mm ² ? |
| Spatial resolution | ~ 280 µm |
| Radiation tolerance | ~ 10^{13} N _{eq.} /cm ² ? |

A near future plan

In a couple of months:

- Work out the final specifications for the Cherenkov detector
 - overall specifications
 - specification for photon detector and aerogel radiator
- Set up a simulation/reconstruction framework in CEPCSW, finish some preliminary simulation/reconstruction
 - a student will work with software group soon
 - hopefully more students joining later
- Keep investigation and test on the photon detector for SiPM
 - SiPM of charge sharing (Fudan university)
 - SiPM with lower noise and high radiation tolerance (IHEP)
- Others?

A long-term plan

- Towards CDR in 1-2 years

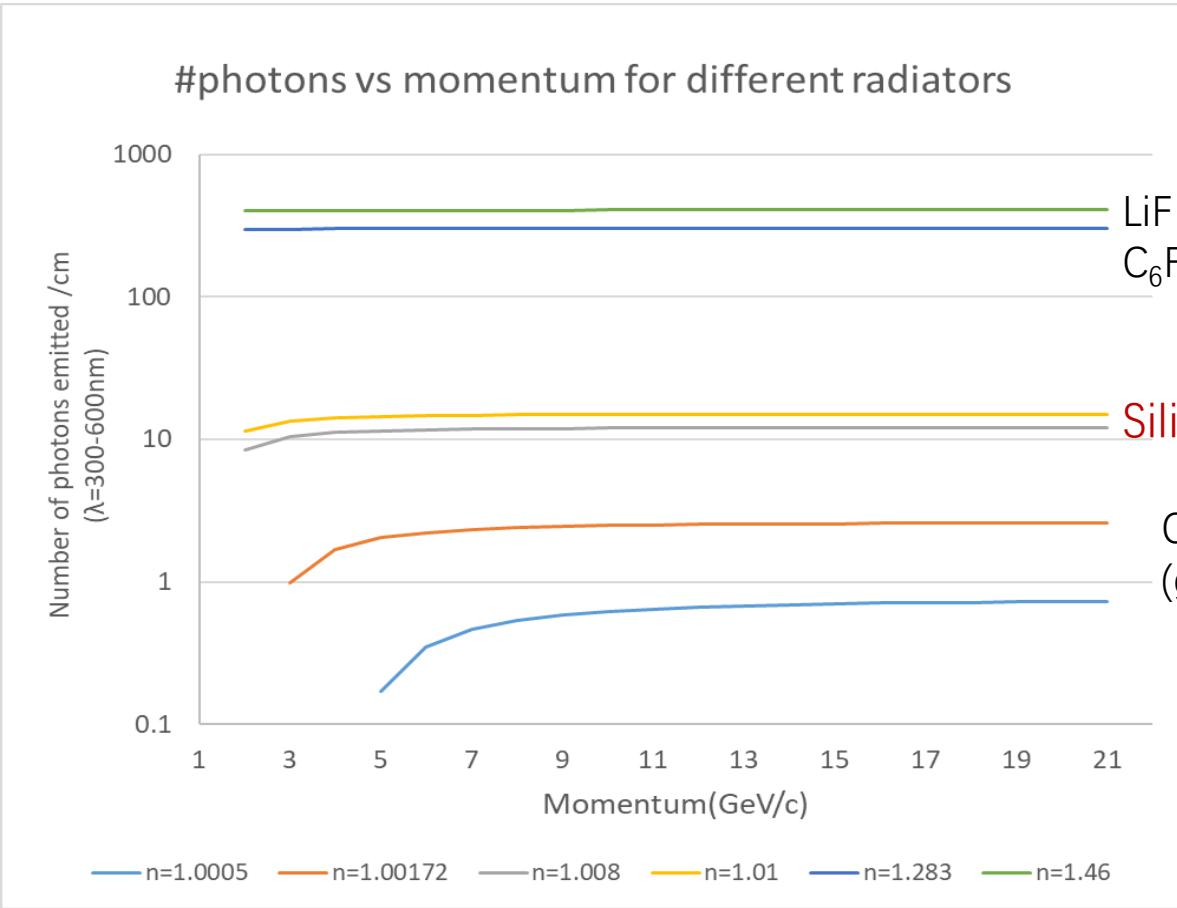
- a benchmark detector design with all components included
- a simulation/reconstruction framework for determining the detector position
 - a key technology development on photon detector and related readout electronics, aerogel radiator
 - a demonstrator of the benchmark detector option

- Towards TDR in 3-5 years

- a full design of all components of the detector
- a prototype of the detector and beam test
- a full simulation/reconstruction software

Thank you!

The number of photons emitted from different radiators



| Radiators | Refractive index | Number of photon ($p=20\text{GeV}$, $\lambda=300-600\text{nm}$) |
|---|---------------------------|--|
| Fused silica, LiF, NaF (solid state) | 1.46, 1.392, 1.334 | 300-400 photons /cm |
| C_6F_{14} (liquid) | 1.283 | ~ 300 photons/cm |
| C_5F_{12} , C_4F_{10} , CF_4 , (gaseous) | 1.0005 | 0.7 – 2.6 photons/cm |
| Silica Aerogel | 1.01 – 1.001 (adjustable) | 1.5 - 15 photons/cm |

$$\frac{dN_\gamma}{dE} = \left(\frac{\alpha}{\hbar c}\right) Z^2 L \sin^2 \theta_C$$

$$\approx 370 \sin^2 \theta_c \text{ (eV}^{-1} \text{cm}^{-1}\text{)}$$