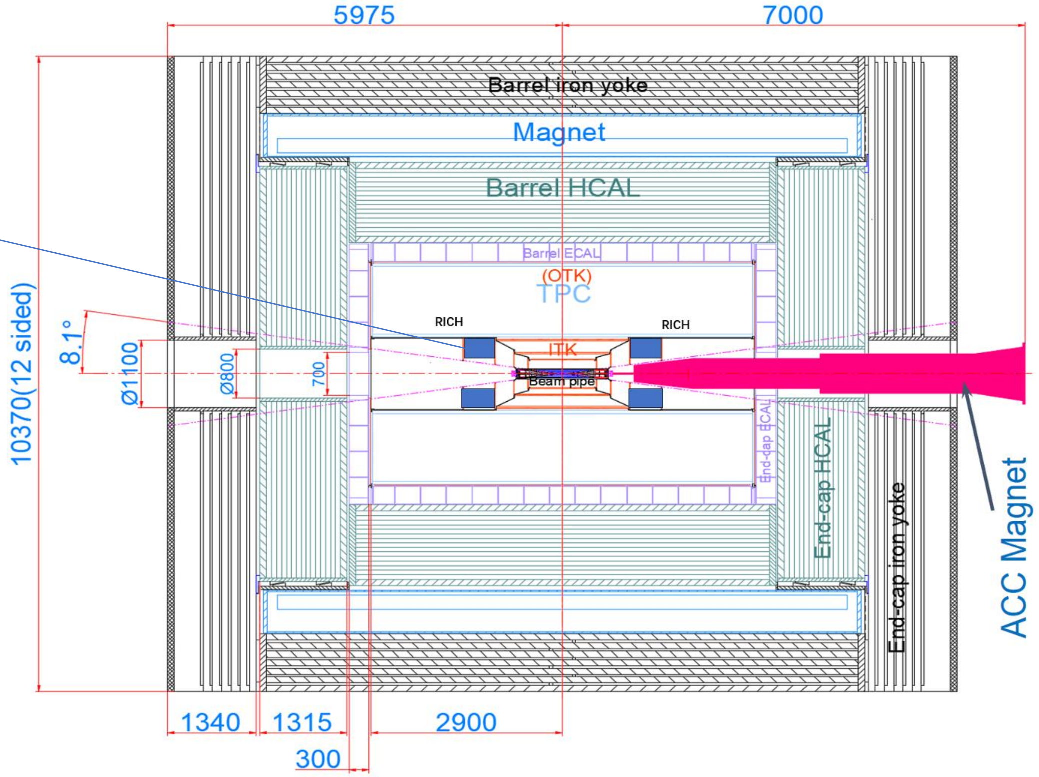
Preliminary consideration of a Cherenkov detector at CEPC

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Cherenkov detector



Zhonghua Qin, IHEP

CEPC Workshop, Nov.9, 2025

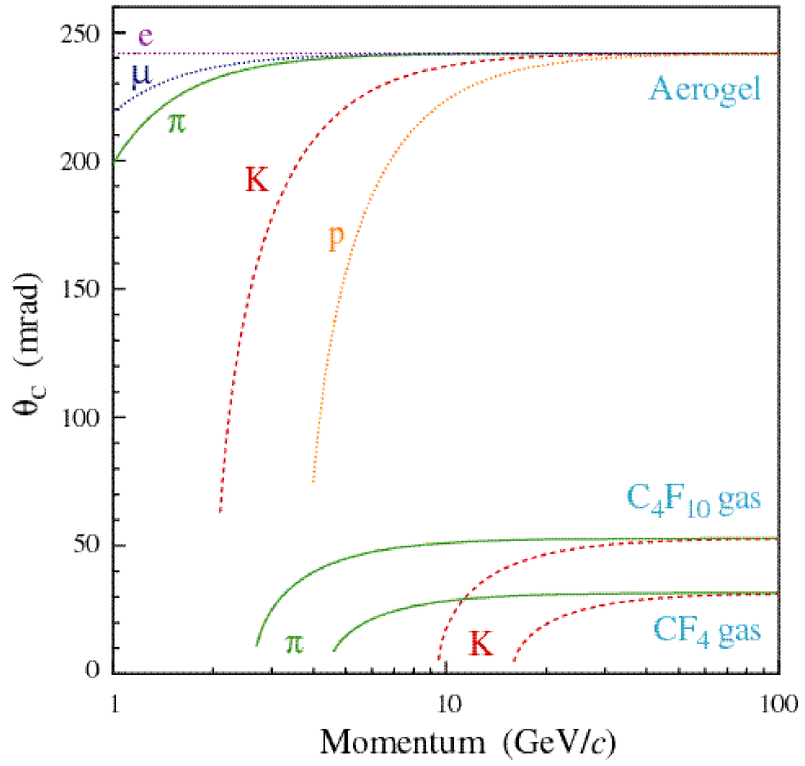
Outline

- A reminder of the Cherenkov detector
- Motivation of a Cherenkov detector for CEPC
- Location of the Cherenkov detector for CEPC
- Technologies used for Cherenkov detector
- Design of the CEPC Cherenkov detector
- R&D on aerogel radiator
- Investigation on photon detectors
- Summary

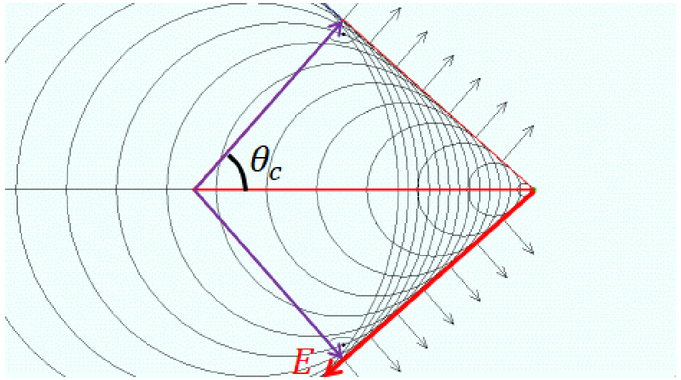
A reminder of Cherenkov detector

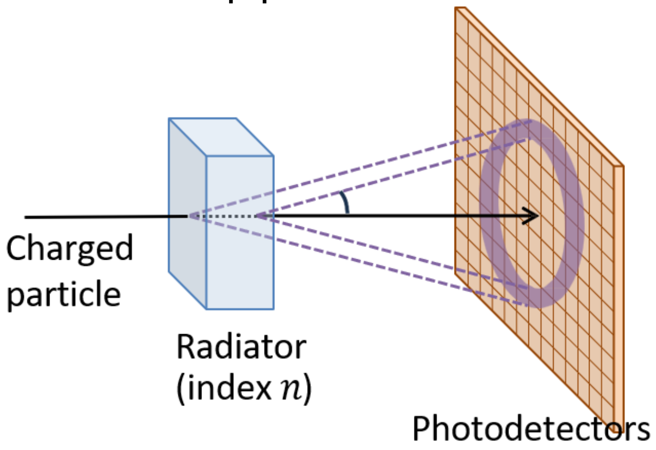
- Cherenkov detector is a powerful tool for charged particle identification, especially for particles with a momentum up to several tens of GeV/c where the ToF is not applicable

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



2-100 GeV/c





RICH 2025, Kodai Matsuoka

Threshold: $\beta > 1/n$

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

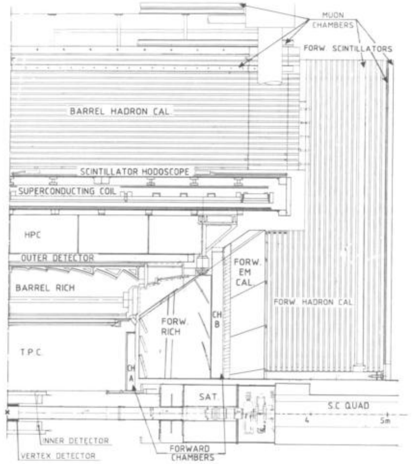
Number of photons: $\frac{dN_\gamma}{dE} = \left(\frac{\alpha}{\hbar c}\right) Z^2 L \sin^2\theta_C$

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

Cherenkov detector widely used by many experiments

- A lot of high energy particle /nuclear/astrophysics/neutrino physics experiments around the world

  -DELPHI, CLEOIII, BABAR, BELLE I & BELLE II, LHCb, ALICE, COMPASS, STAR, PANDA, NA62, CLAS12 , AMS02… (and many neutrino experiments not listed)



DELPHI

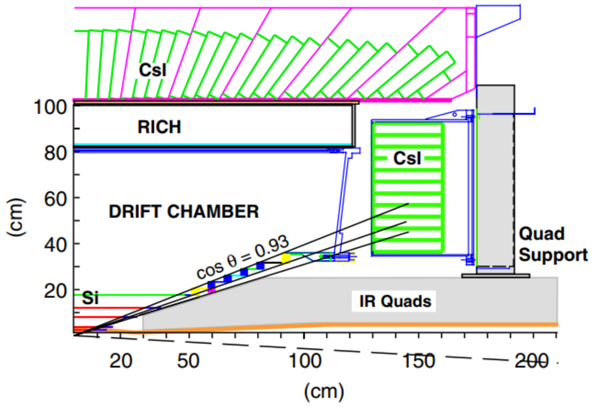
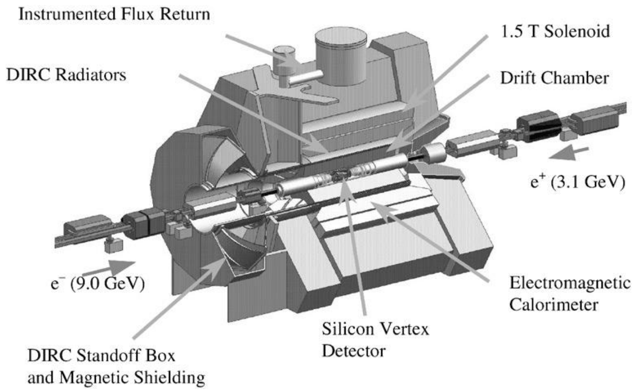


Fig. 3. The CLEO RICH, shown in CLEO-III configuration.

CELOIII



BABAR

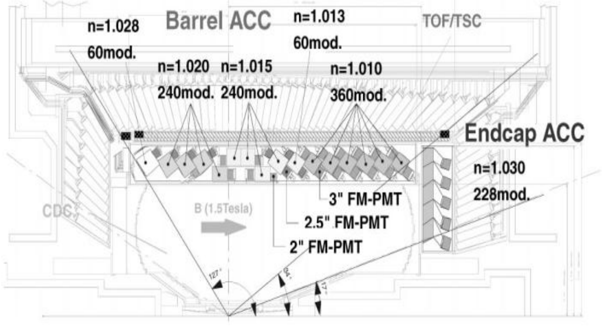
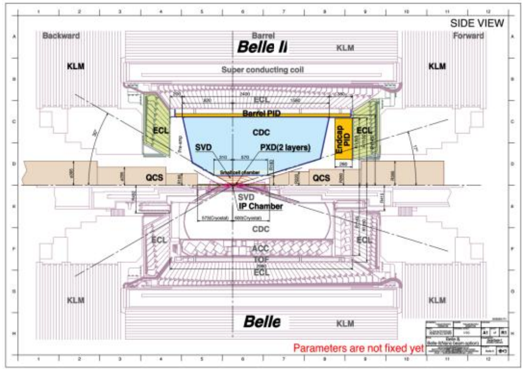


Fig. 1. Schematic drawing of the BELLE-ACC system.

BELLE I



BELLE II

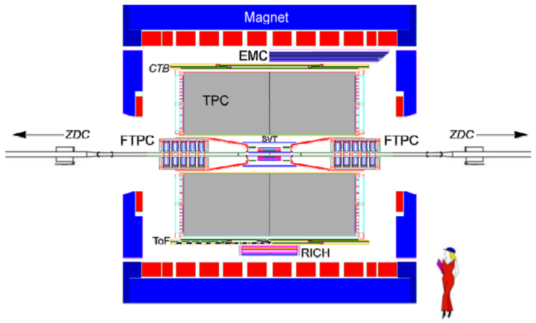
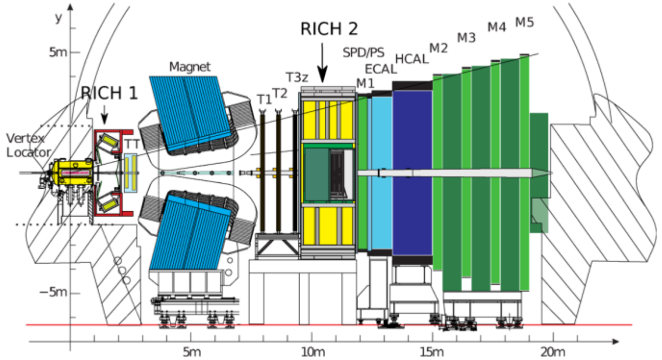
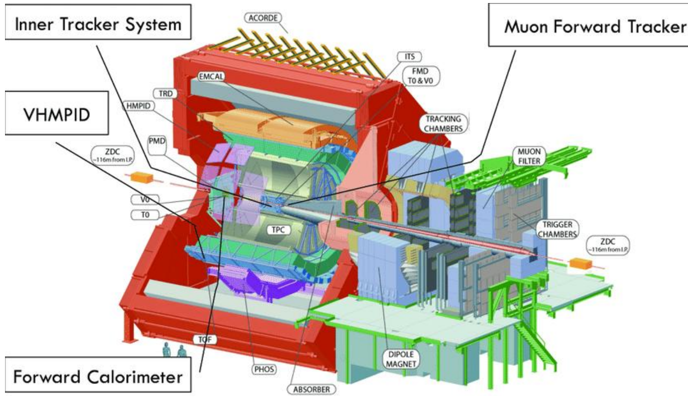


Fig. 2. Cutaway side view of the STAR detector as configured in 2001.

STAR



LHCb



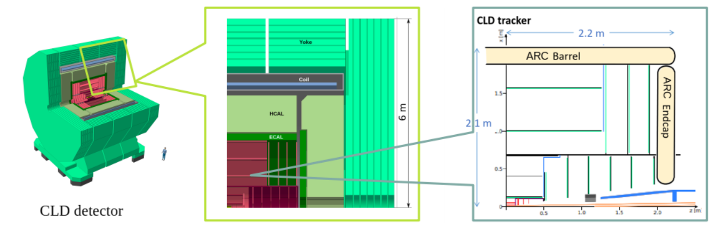
ALICE

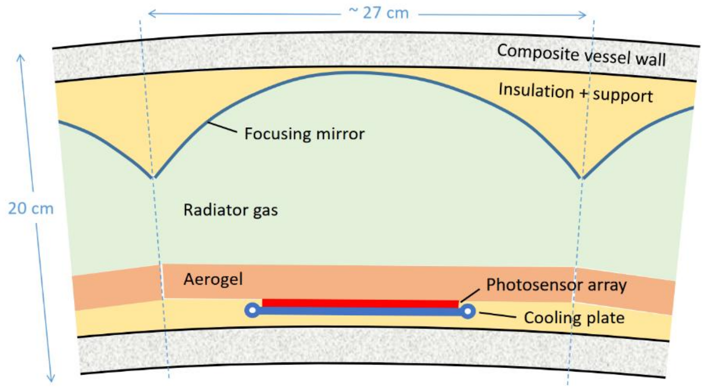
Proposed also by the future experiments

- Such as FCC-ee, EIC, STCF …

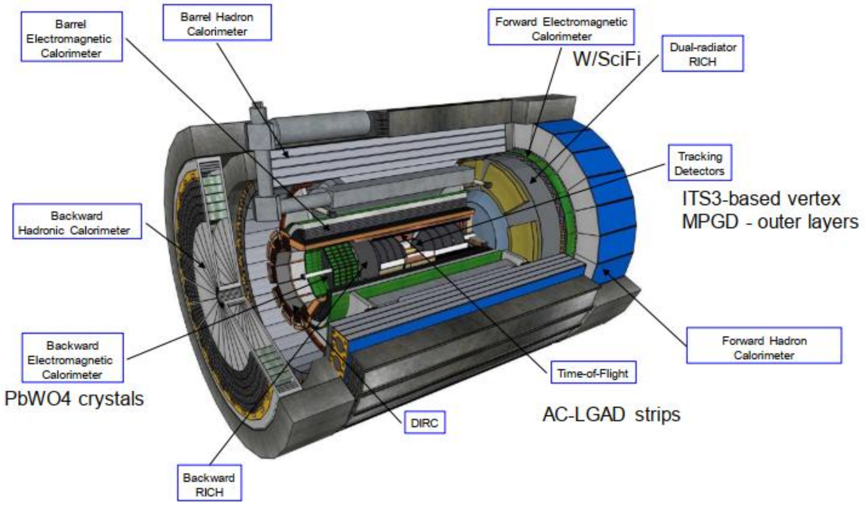
Design of Array of RICH Cells (ARC)

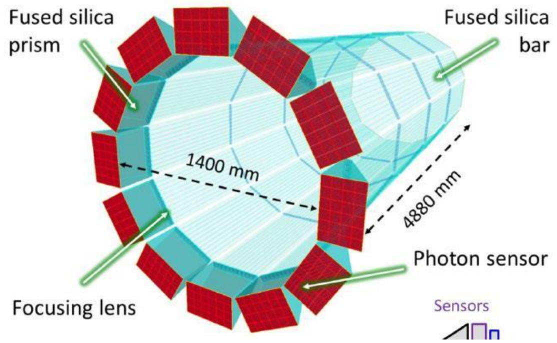
- The ARC was designed to be integrated with the CLD detector, between the tracker and the ECAL
- The ARC thickness is 20 cm, the barrel length is 4.4 m and the endcaps are placed as the bases of the barrel

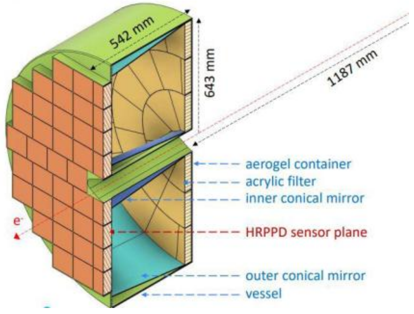




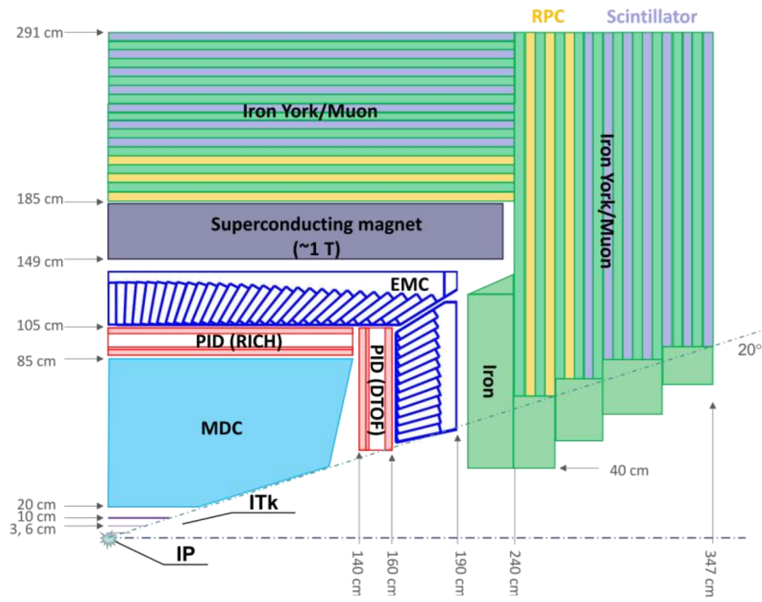
FCC-ee (CLD detector concept)

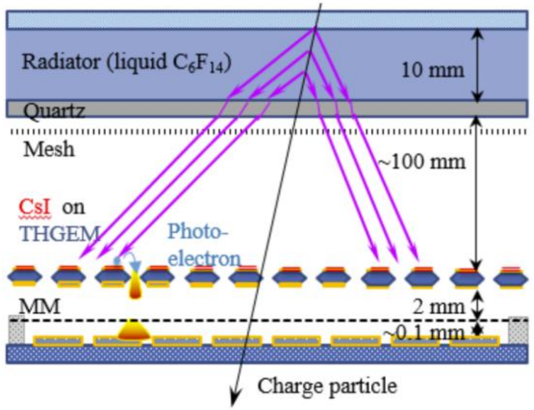






ePIC detector at EIC





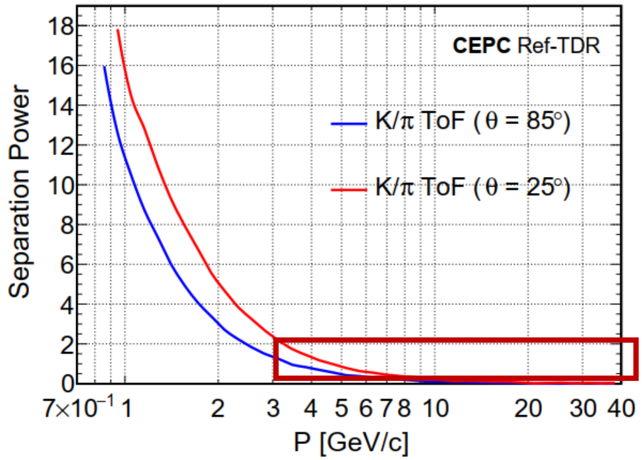
THGEM + MM

STCF

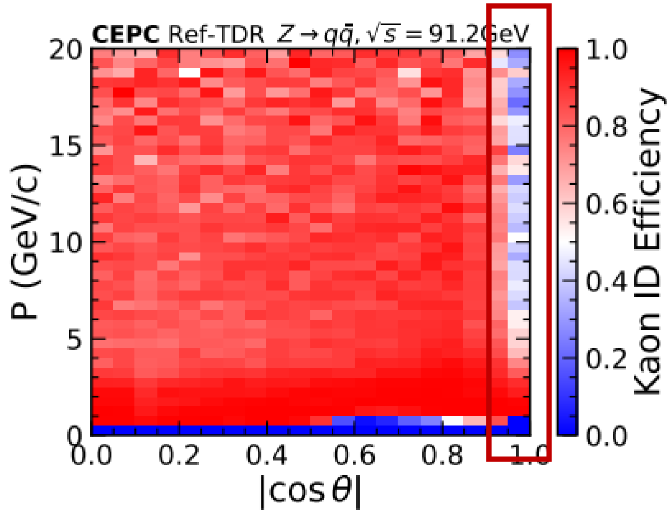
Motivation of the Cherenkov detector for CEPC

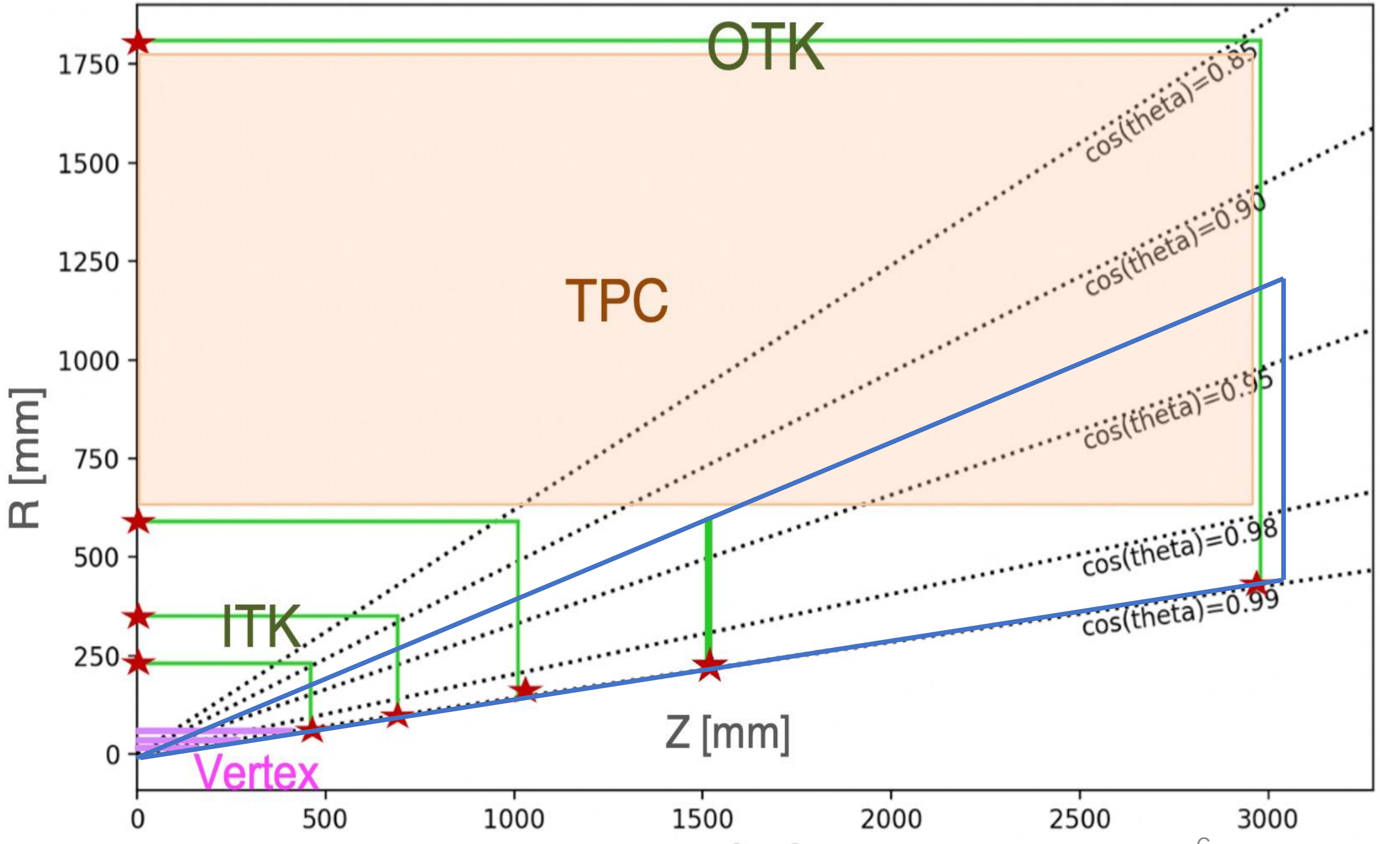
- A Cherenkov detector at CEPC is helpful, for high momentum PID(up to 20 GeV/c) at the endcap/forward region where only short tracks or even no tracks pass through TPC (so dN/dx not good)
- It's critical for flavor physics, Higgs physics (especially Higgs -> ss), etc.

ToF standalone
(from Ref-TDR)



Kaon ID efficiency
(from Ref-TDR)

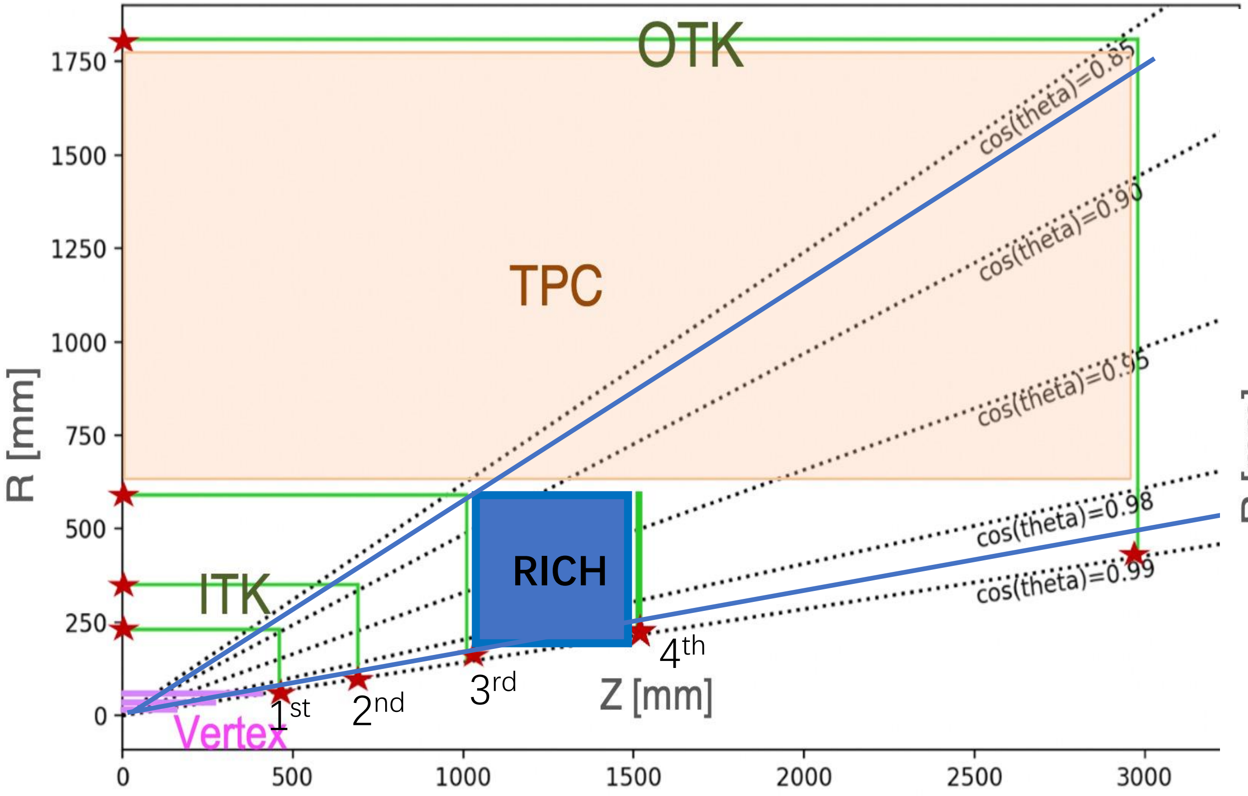




Possible location of the Cherenkov detector at CEPC

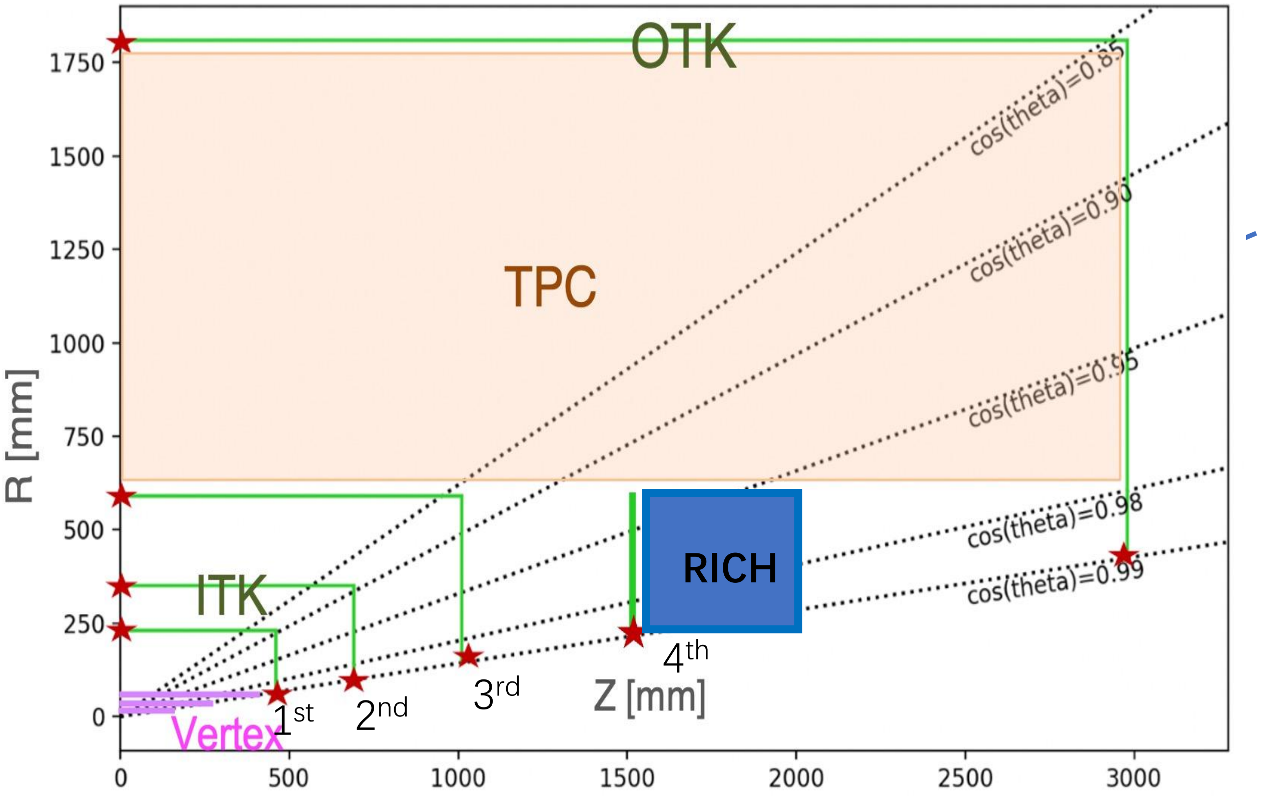
- Two possible locations without changing the other detector design in ref-TDR
- Depending on physics requirement, Cherenkov detector performance and also material budget

Location 1



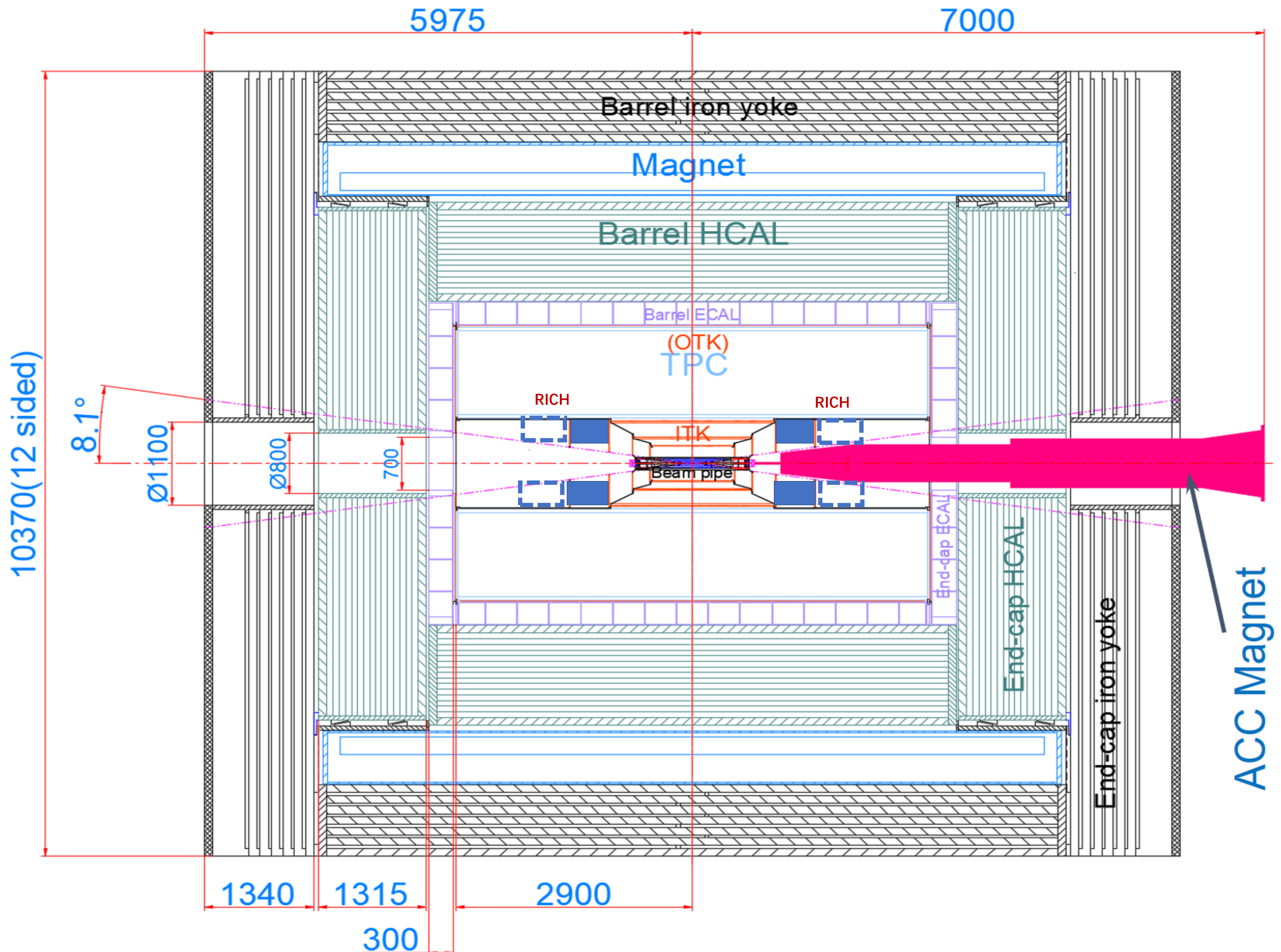
Coverage: 9.3° <θ <28.8°
or 0.99<cos θ< 0.88

Location 2



Coverage: 8.8° <θ < 20.3°
or 0.99<cos θ< 0.94

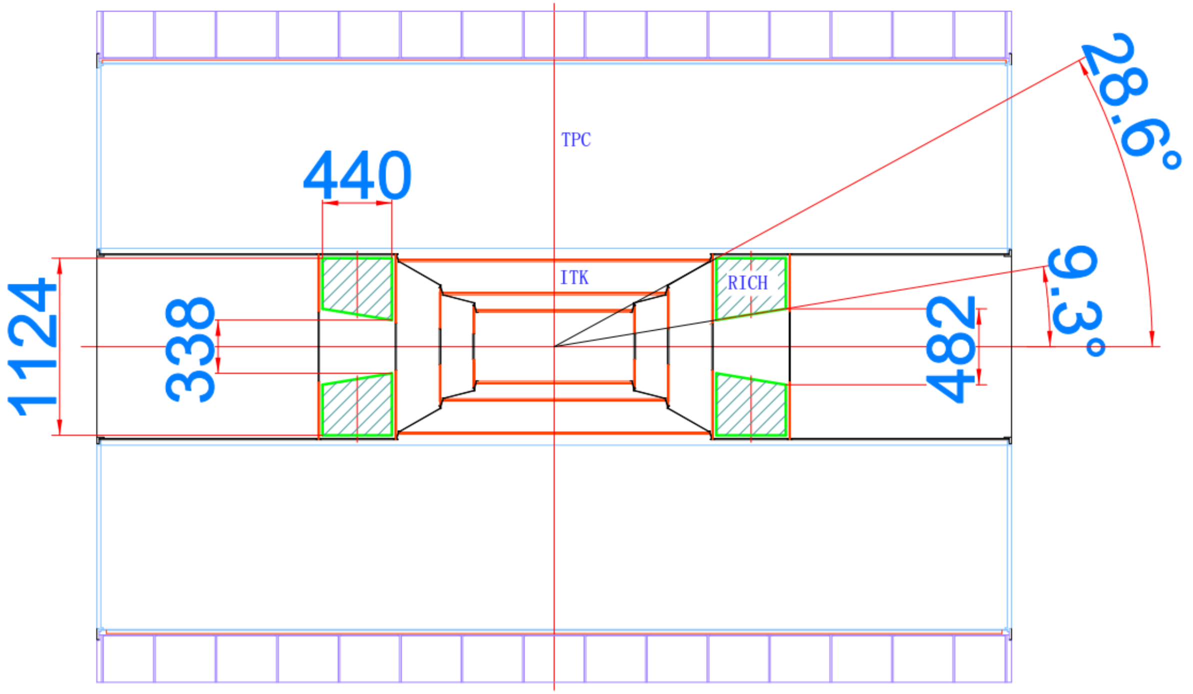
An overall view for the detector



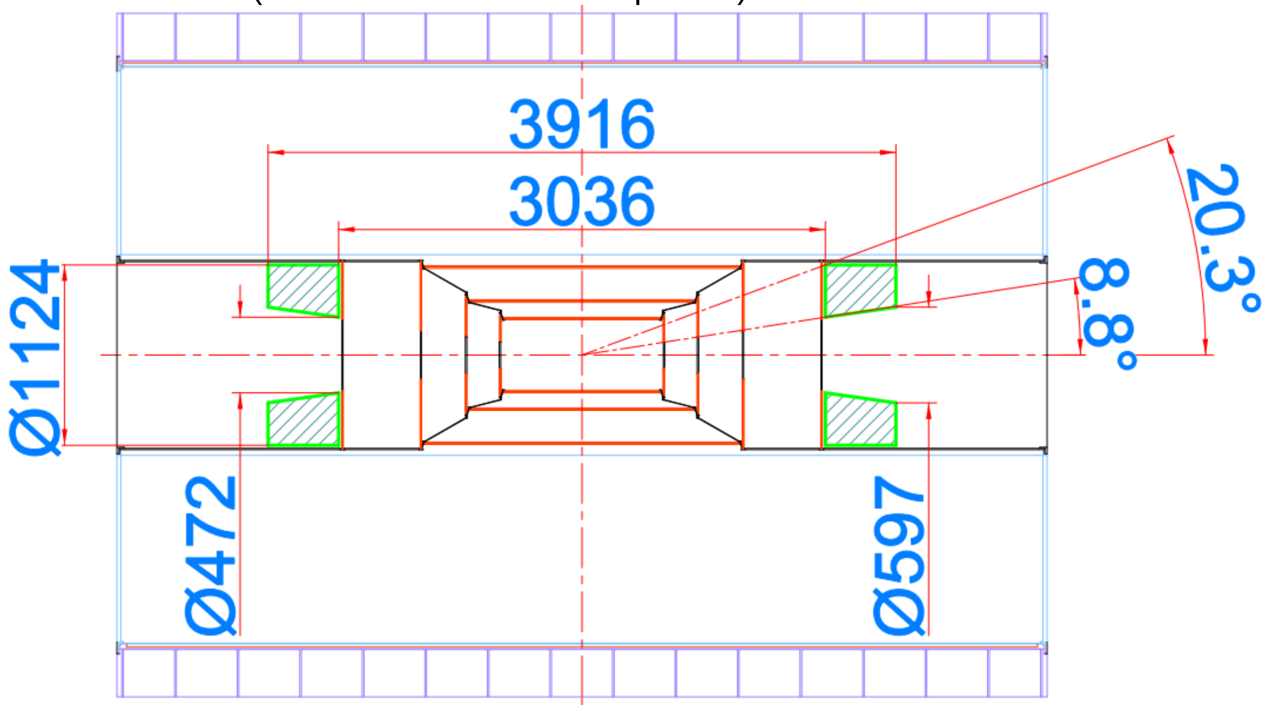
Drawings for the two locations

From Jian Wang, mechanics group

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



Location 2 (outer of 4th endcap IKT)

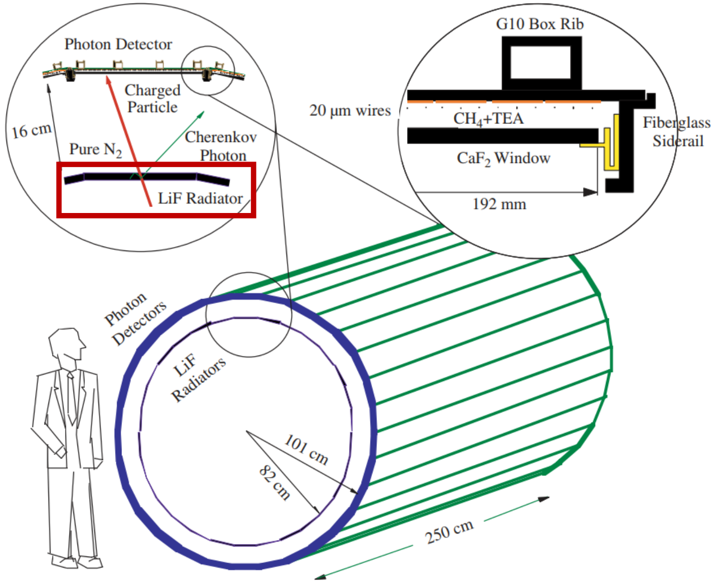


	Inner diameter	Outer diameter	Total area (two endcaps)	Length (single endcap)
Radiator	33.8 cm	112.4 cm	1.81 m^2	44cm
Photon detector	48.2 cm	112.4 cm	1.62 m^2	

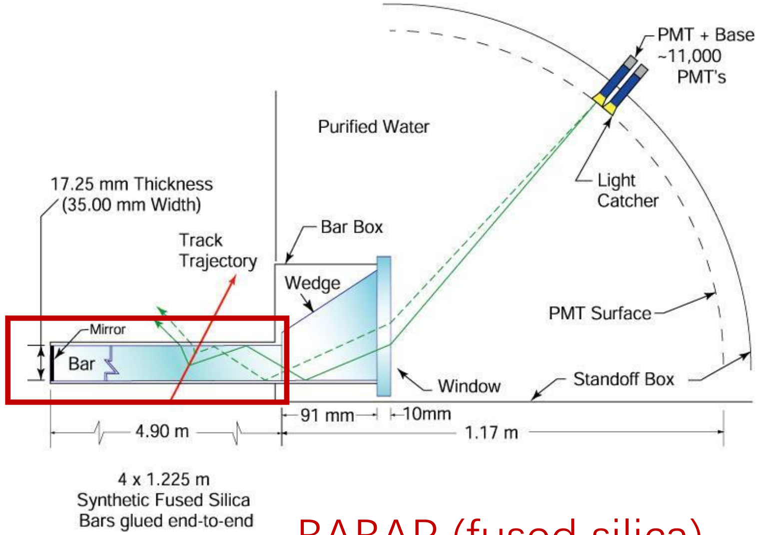
	Inner Diameter	Outer diameter	Total area (two endcaps)	Length (single endcap)
Radiator	47.2 cm	112.4 cm	1.64 m^2	44cm
Photon detector	59.7 cm	112.4 cm	1.43 m^2	

Investigation of technologies used for Cherenkov detector

- Radiator
  - Solid-state or liquid: LiF, NaF, fused Silica, C_6F_{14}(liquid)
  - Gaseous: CF_4, C_4F_{10}, C_5F_{12}
  - Aerogel (silica aerogel)
  - Hybrid: aerogel + gas

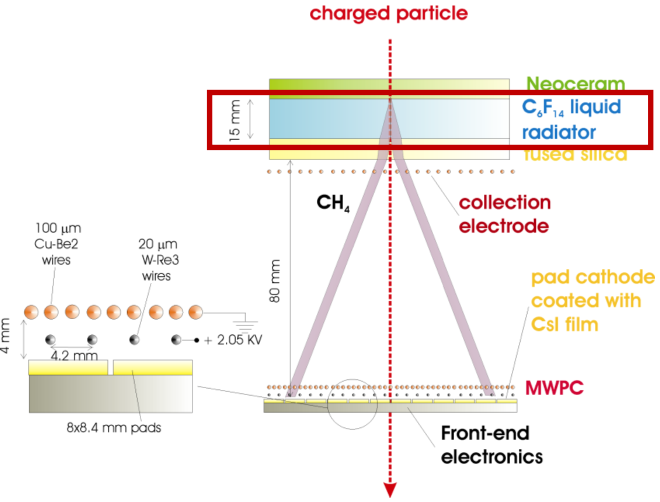


CLEOIII (LiF crystal)

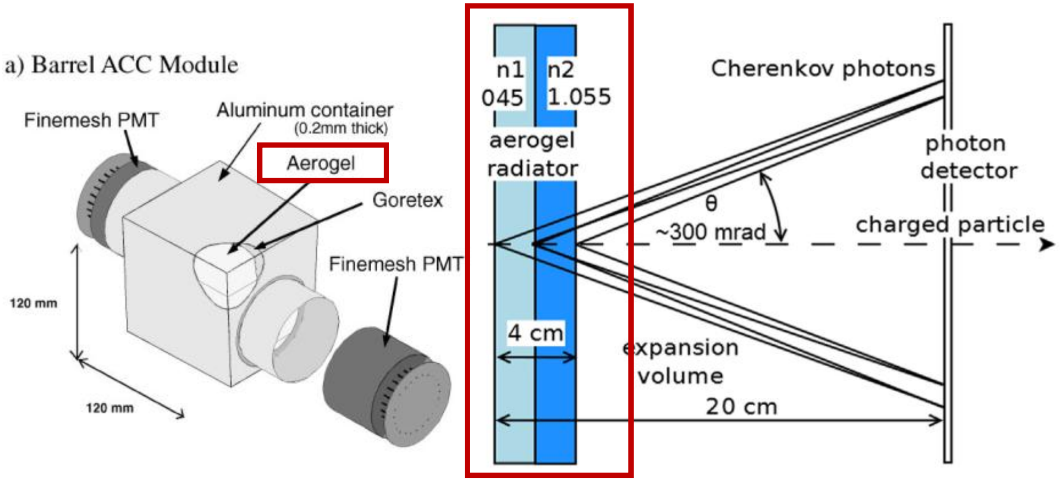


BABAR (fused silica)

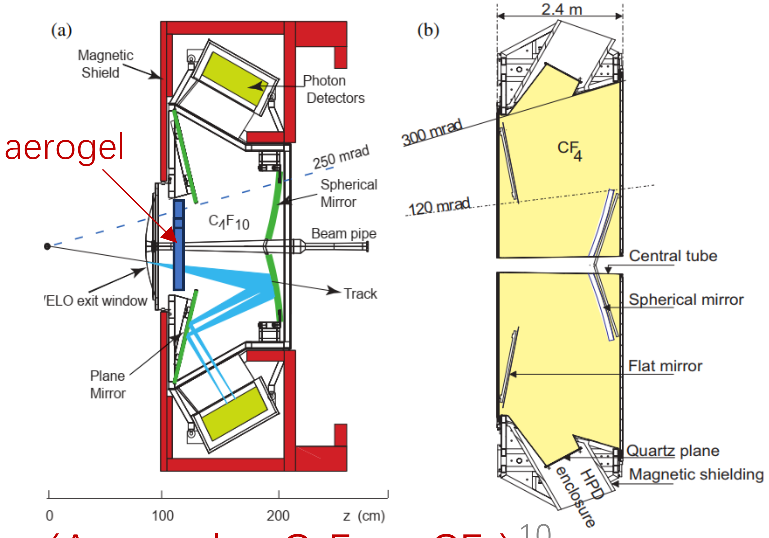
NIM A 554 (2005) 147–194



ALICE (liquid C_6F_{14})



Belle I & Belle II (silica aerogel)



LHCb (Aerogel + C_4F_{10}+ CF_4)

Investigation of technologies used for Cherenkov detector

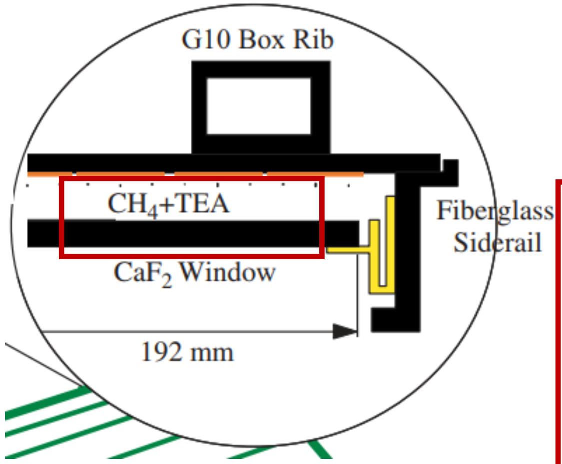
- Photon detector

  - Gaseous chamber: TPC-like / MWPC filled with photoionizing gas (TEA) or photocathode coating (CsI)

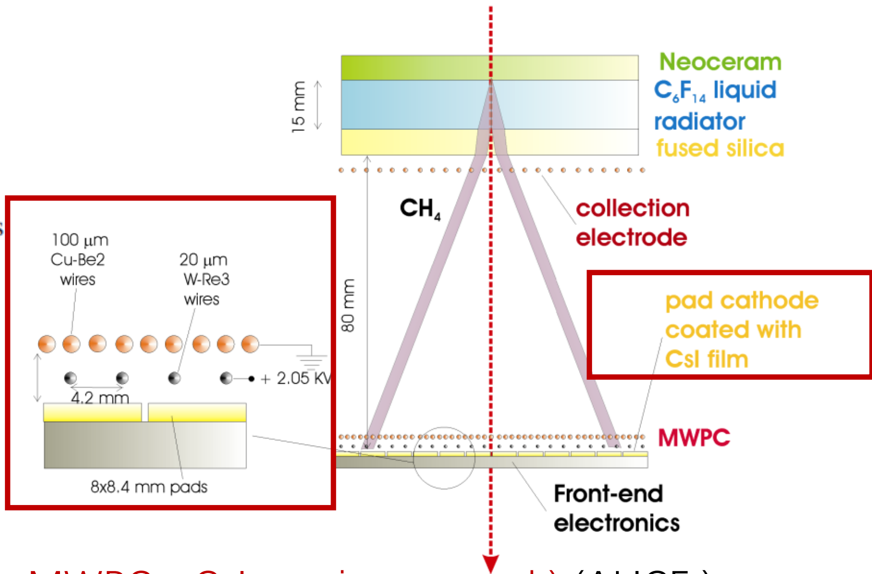
  - PMT: dynode PMT (fine-mesh, metal channel), MCP PMT

  - Hybrid detector: HPD(hybrid photon detector) and HAPD(hybrid avalanche photon detector)

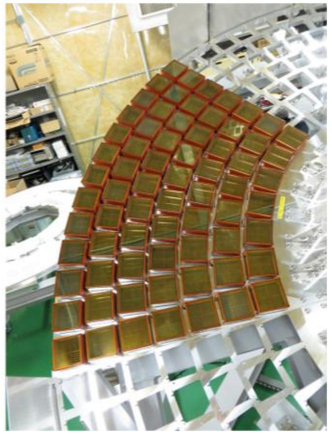
  - SiPM (proposed but not yet used)



MWPC with CH_4 +TEA(triethylamine (CLEO III)

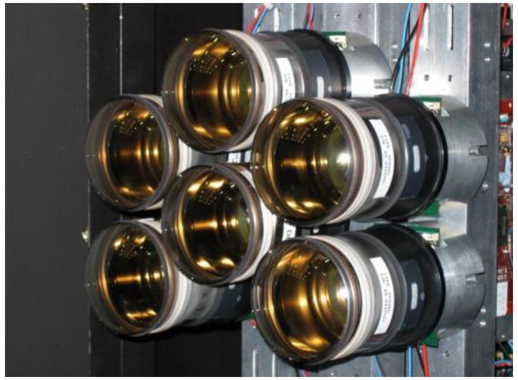


MWPC +CsI coating on pad) (ALICE)



Multi-anode HAPD (Belle II endcap)

MCP PMT (Hamamatsu R10754-07-M16), Belle II barrel(iTOP)



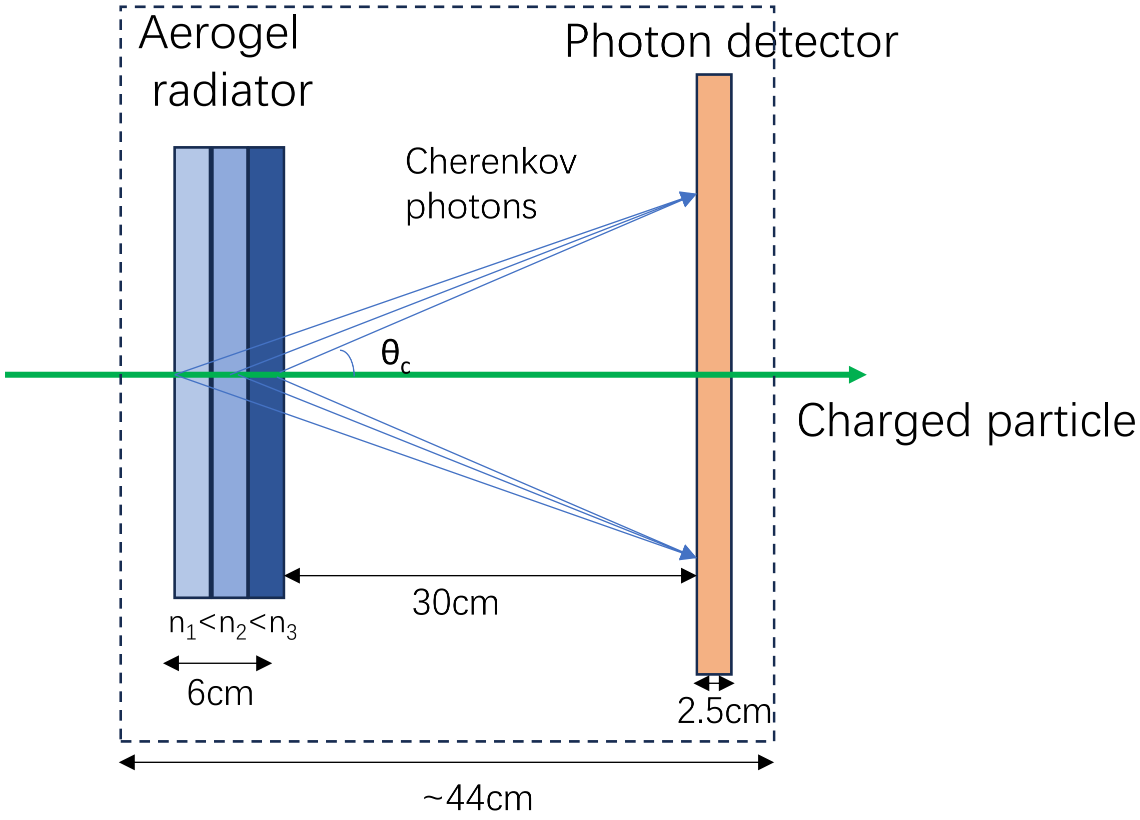
HPD (LHCb RUN1&2)

Multi-anode metal-channel dynode PMT (LHCb RUN3)

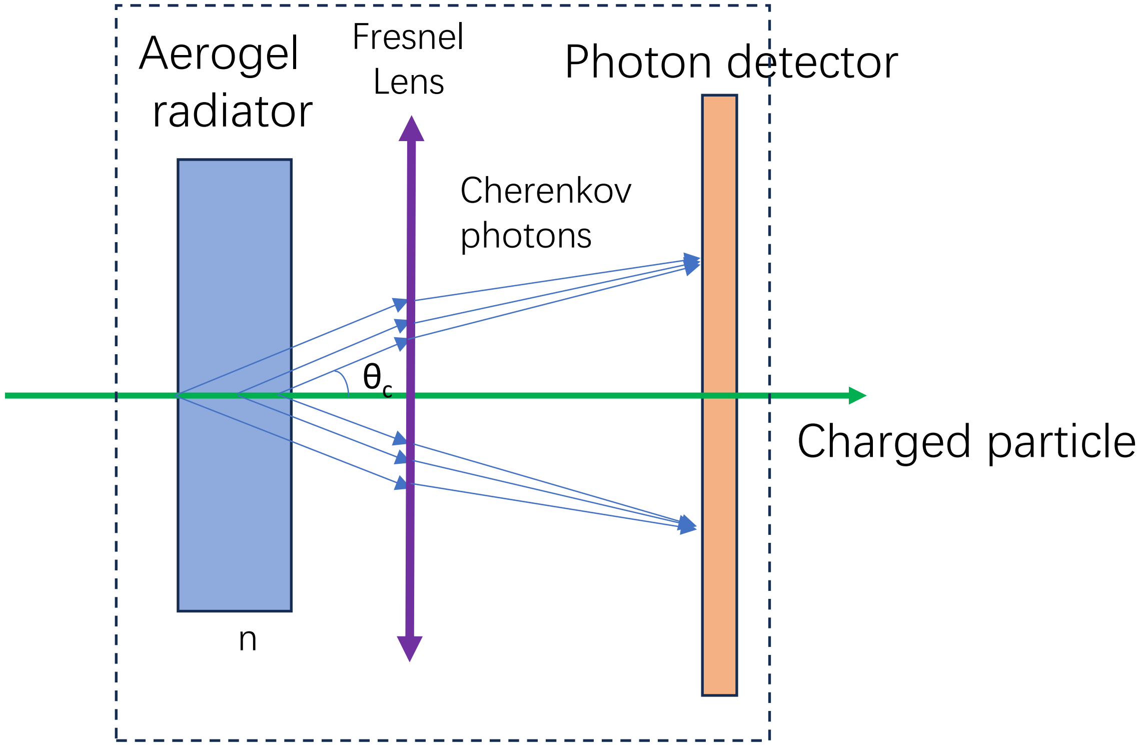
Possible design of CEPC Cherenkov detector

- The proximity focusing method:

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

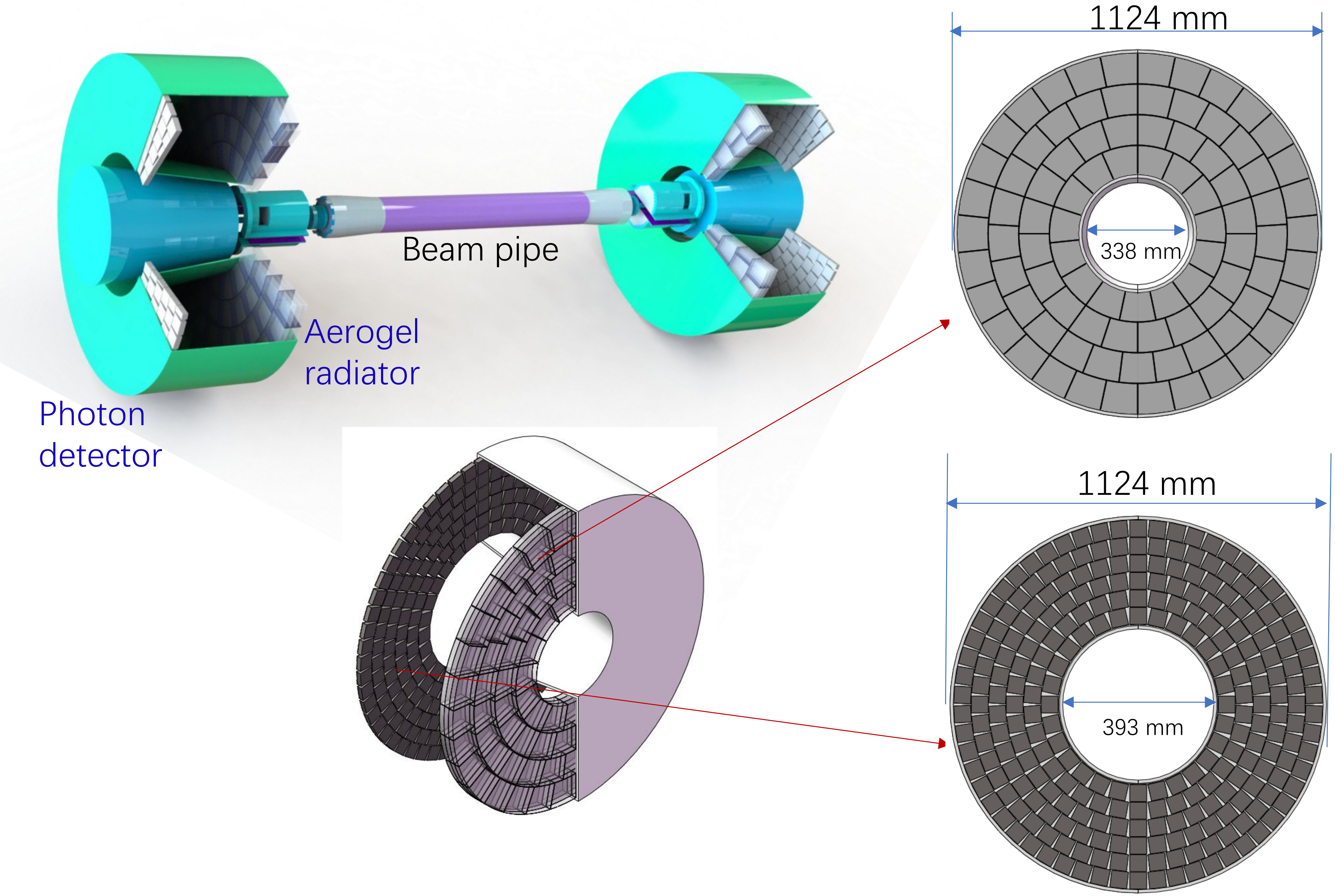


Option1:
Multiple layers of aerogel with varying n, overlapped ring for different emission points



Option 2:
A single layer of aerogel, focused by a Fresnel lens.

A sketch of the Cherenkov detector



From Jian Wang, mechanical group

Aerogel radiator :
- -90 aerogel tiles in 4 layers
- -each tile of ~10 cm x 10 cm

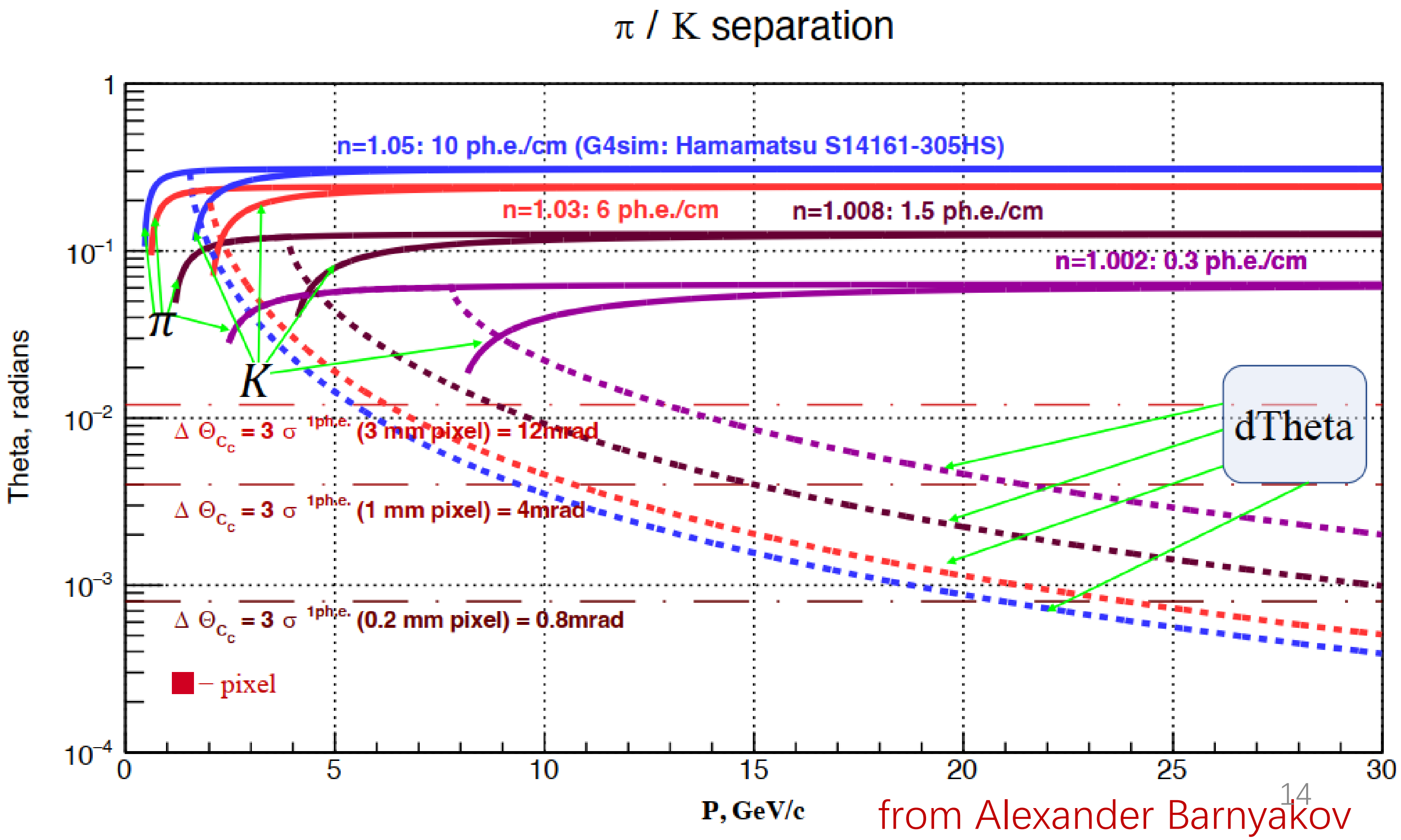
Photon detector:
- -258 PMTs(sensor module) in 6 layers
- -each PMT(sensor module) of ~5 cm x 5 cm

Why uses aerogel as the radiator

- Generally, to have PID in 3-20 GeV/c range
  - Solid-state/liquid radiators have very large refractive indexes (n >1.2)
  - Gaseous radiators' refractive indexes too small (n<1.001)
  - Aerogels have adjustable n (1.0x ~1.00x) , so applicable

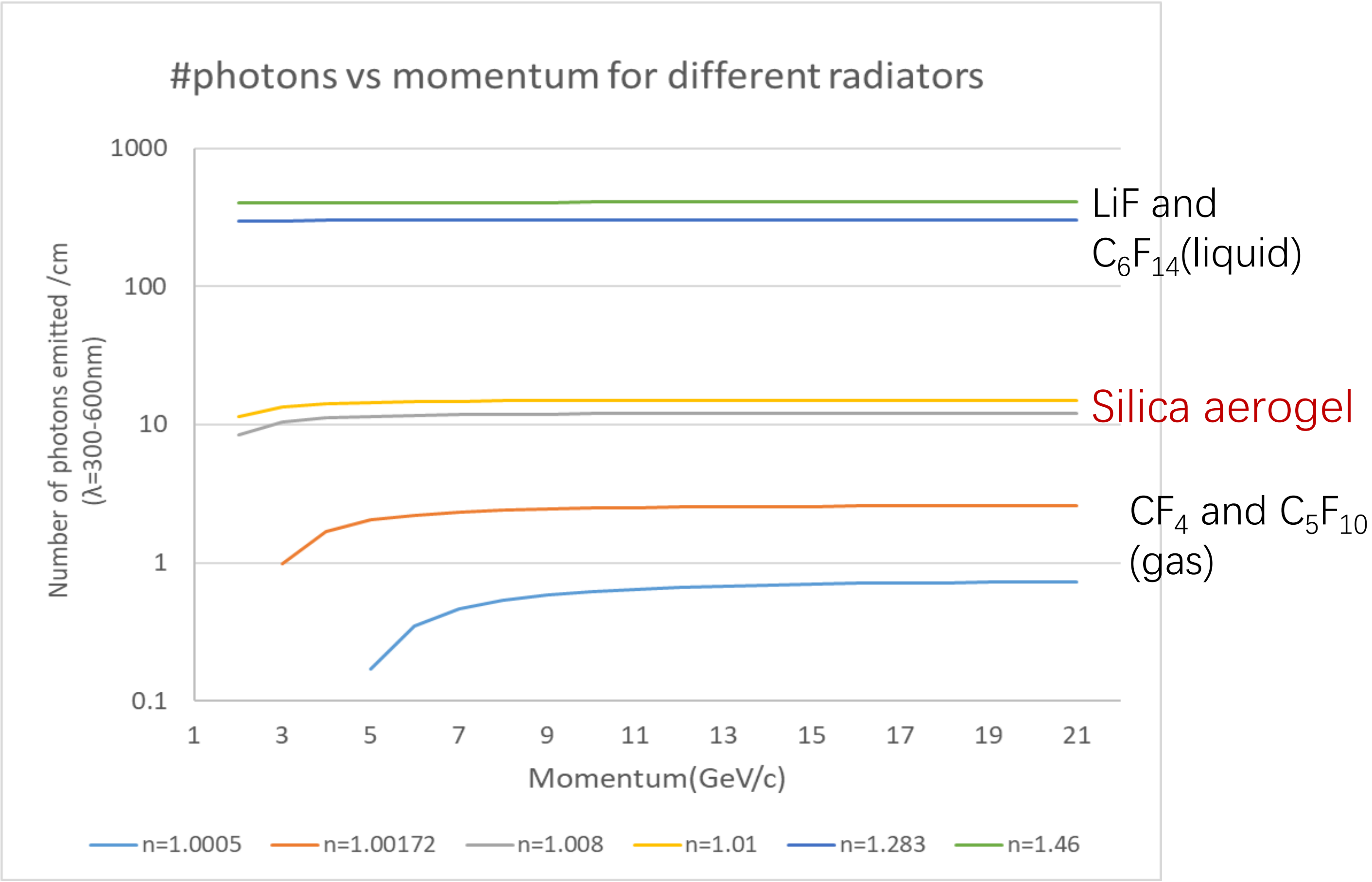
Aerogel from BINP

Hopefully with aerogel (**n=1.008**), π/K can be separated in 3σ, up to 20GeV/c (σ_θ^{1pe}< 4mrad)



from Alexander Barnyakov

The number of photons emitted from different radiators



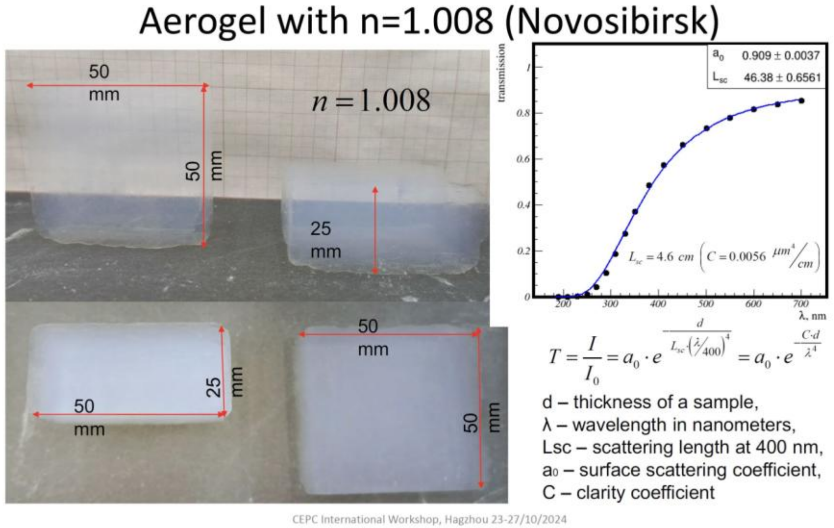
Radiators	Refractive index	Number of photon (p=20GeV, λ= 300-600 nm)
Fused silica, LiF, NaF (solid state)	1.46, 1.392, 1.334	300-400 photons /cm
C_6F_{14} (liquid)	1.283	~300 photons/cm
C_5F_{12}, C_4F_{10}, CF_4, (gaseous)	1.00172, 1.0014, 1.0005,	0.7 – 2.6 photons/cm
Silica Aerogel	1.01 – 1.001 (adjustable)	1.5 -15 photons/cm

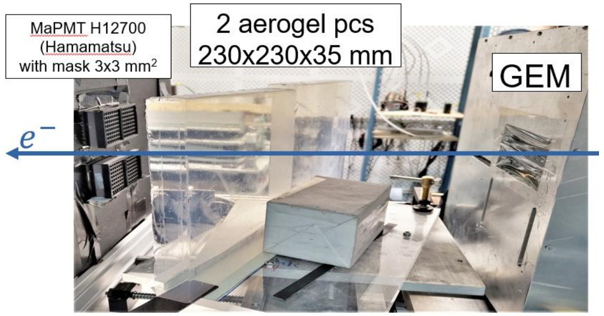
$$\frac{dN_\gamma}{dE} = \left(\frac{\alpha}{\hbar c}\right) Z^2 L \sin^2\theta_C$$

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

Past and ongoing R&Ds on aerogel

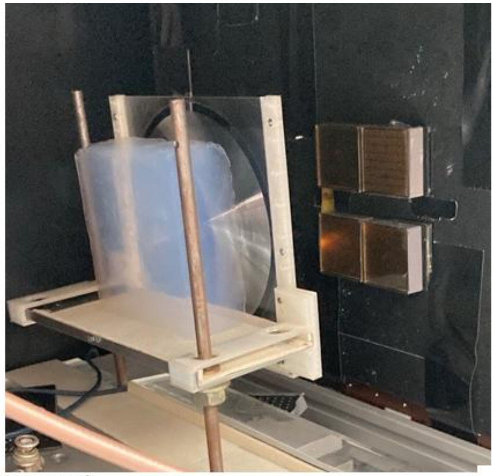
- Led by Alexander Barnyakov from BINP





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

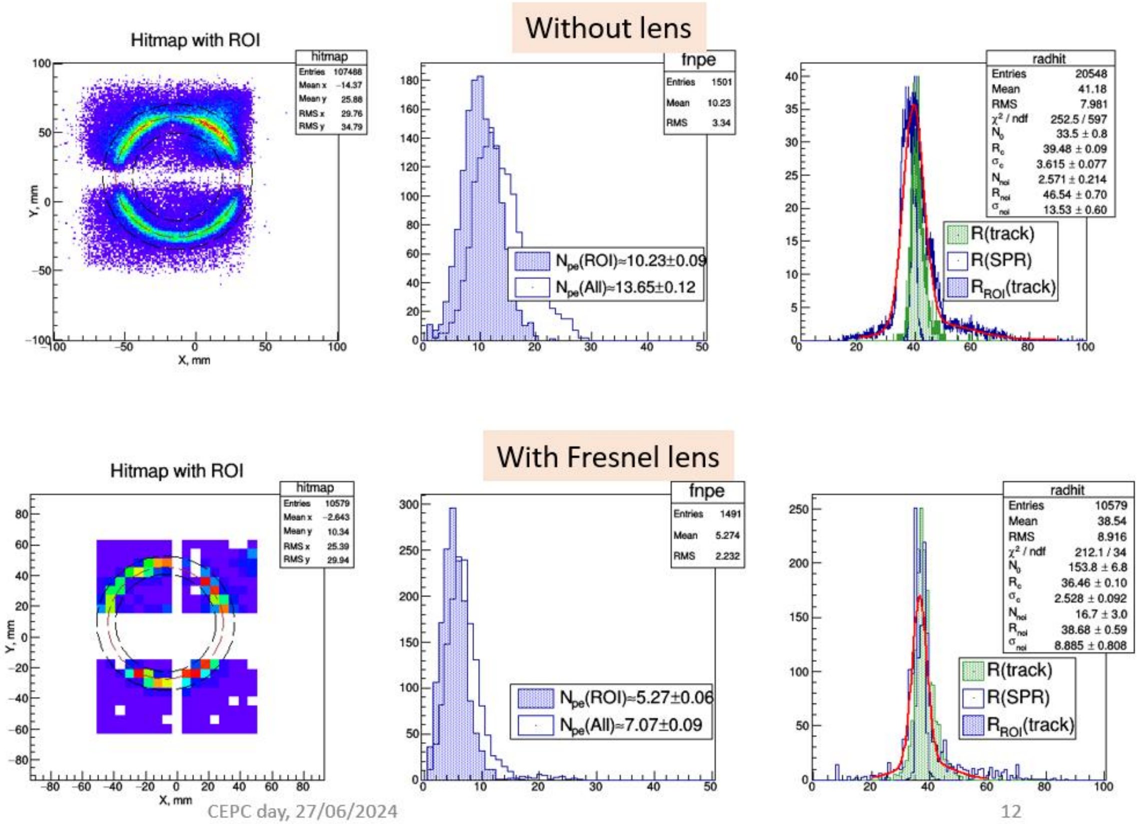
Some results of beam tests at the BINP with mRICH design



Aerogel:
- n=1.028
- L_{sc}(400nm)=48.2±0.7 mm
- Thickness=40mm

Fresnel lens:
- Acrilic (PMMA)
- L_f=6''
- Manufacturer: Edmund

PMT:
- 4 Hamamatsu H12700
- pixel 6x6 mm



What a photon detector can be used ?

- General requirements

requirements	for what reasons
single photon detection capability	very small number of photons from the radiator
low dark noise	
high detection efficiency	
high magnetic field tolerance	3 Telsa magnetic field
High radiation tolerance	relatively high beam background in the forward region
small material budget	inside TPC and ITK
good time/spatial resolution	help to resolve the Cherenkov ring
reasonable cost	also important issue
low risk on construction and operation	

.

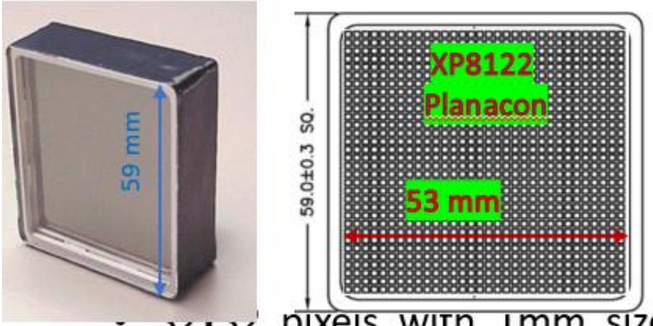
Only qualitative requirements now, to be quantitative after more study

Past and ongoing R&D for photon detector

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

MCP PMT

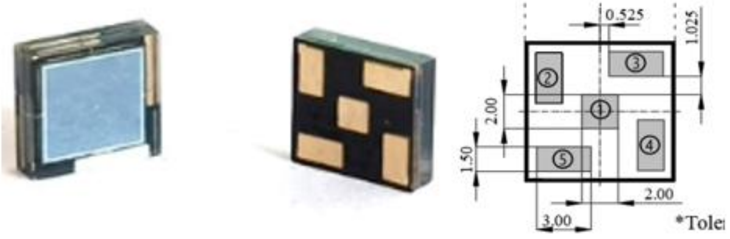
- Planacone XP8122



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

$$\sigma_x \approx \frac{1}{\sqrt{12}} \approx 0.3\mu m$$

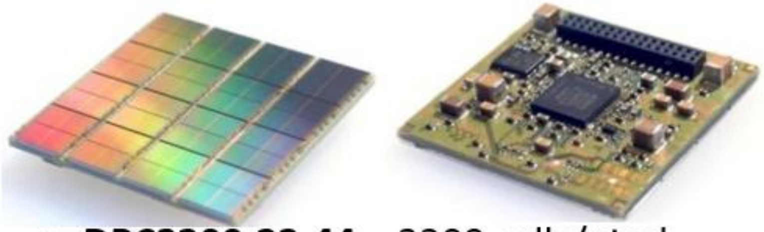
PSS-SiPM or LG-SiPM



- 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:

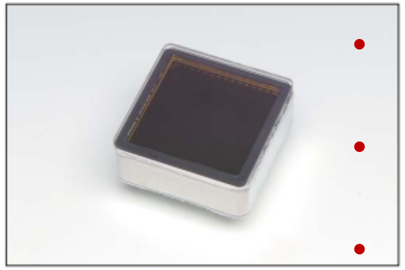
$$\sigma_x \leq 50,25,12\mu m$$

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



- Effective area: 23mm x 23mm
- Anode matrix: 4 x 4
- Anode size: 5.28mmx5.28mm
- QE: ~20%
- TTS（FWHM): 75ps
- HV: 2.7kV

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 × 23	mm
Dynode	Dynode structure	2 stages Microchannel plate	—
	Channel diameter	10	μm
Number of anode pixels		16 (4 × 4 matrix)	—
Anode pixel size		5.28 × 5.28	mm
Operating ambient temperature Ⓐ		-30 to +45	°C
Storage temperature Ⓐ		-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) Ⓑ	—	75	—	ps

Ⓐ No condensation
Ⓑ 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.

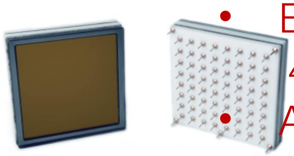
VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

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

N6021光电倍增管 N6021 MCP–PMT

"FPMT", NNVT&IHEP



- Effective area: 46mm x 46mm
- Anode matrix: 8 x 8
- Anode size: 5.75mmx5.75mm
- QE: 21%
- TTS (σ) : 15ps(MPE) 50ps(SPE)
- dark noise rate: 500 Hz/anode
- HV: 2 kV

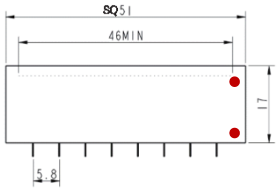
应用领域 Application
- 医学影像/Specialized Medical Imaging
- Cherenkov – RICH, TOF, TOP, DIRC
- 高能物理/High Energy Physics
- 国土安全/Security

产品特点 Features
- 响应快 High Speed
- 增益高 High Gain
- 噪声低 Low Noise

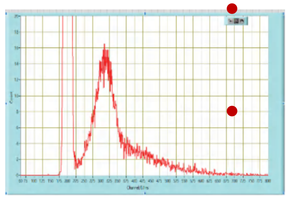
技术参数 Specifications

玻璃材料/Window material	AVG glass
光电阴极/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 ×8

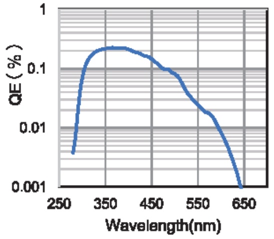
N6021		Min.	Typ.	Max.	Unit
阴极参数 Cathode parameters	光谱范围/Spectral response		280–650		nm
	量子效率峰值波长/Quantum efficiency peak wavelength		380		nm
	积分灵敏度/Luminous sensitivity		60		μ A/lm
	量子效率@410nm/QE @410nm		21		%
	辐射灵敏度/Radiant sensitivity@410nm		72		mA/W
阳极参数 Anode parameters	工作电压/Supply voltage		2000	2500	V
	增益/Gain		2×10^6		
	暗计数/Dark count rate@0.2pe(单阳极)		500	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 response	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
工作环境温度/Operating ambient temperature			-30~+50		℃
储藏温度/Storage temperature			-50~+50		℃



N6021 光电倍增管外型结构
N6021 PMT dimentional 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

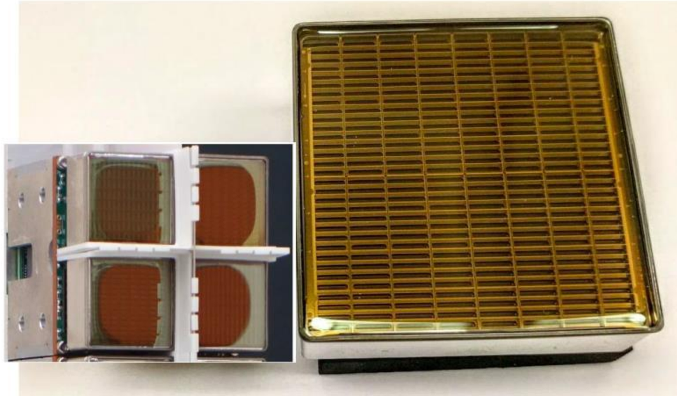
Sajan Easo's talk in CEPC workshop in Hangzhou, 2024

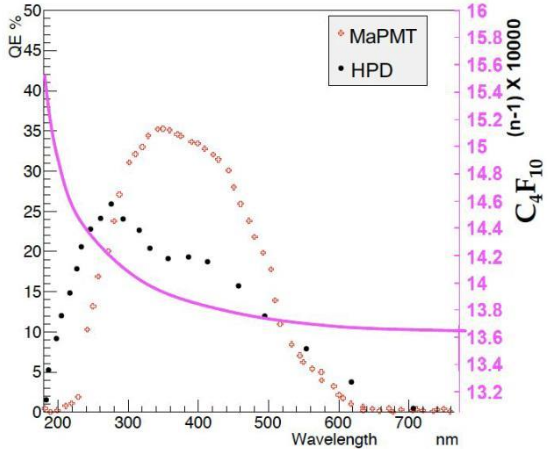
Nucl. Inst. Meth. A 876 (2017) 206-208

MultiAnode PhotoMultipliers

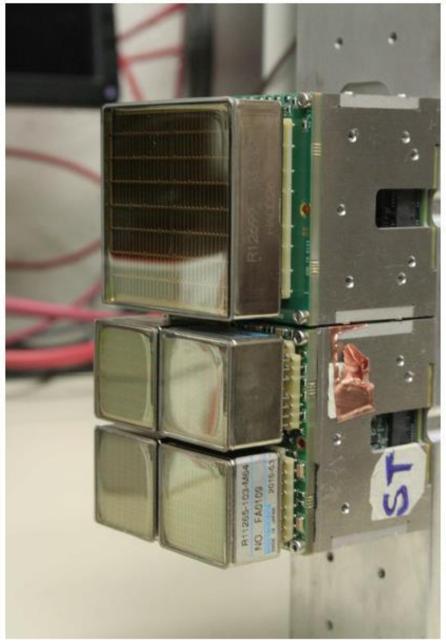
LHCb

- 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

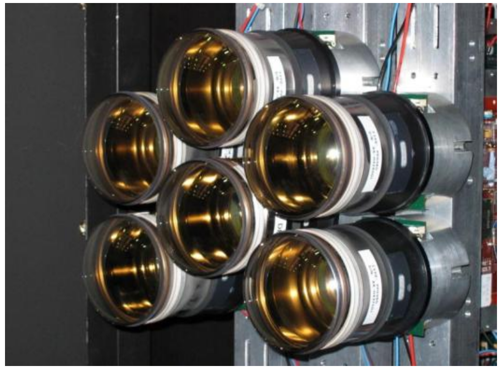
Parameter		Description	Unit
Spectral Response Range		185 to 650	nm
Peak Wavelength		350	nm
Photocathode Material		Bialkali	-
Window	Material	UV Glass	-
	Thickness	0.8	mm
Dynode	Structure	Metal Channel Dynode	-
	Number of Stage	12	-
Anode	Number of Pixels	64 (8 x 8 Matrix)	-
	Pixel Size	2.88 x 2.88	mm
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

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

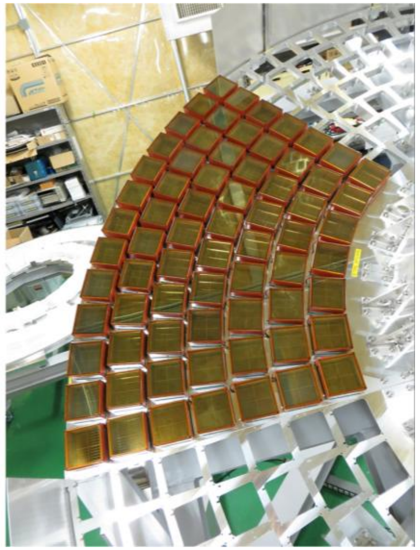
Type No.	Spectral response	Photocathode	Window material	Window type	Effective area	T.T.S. (Transit Time Spread) *1 (FWHM)
R14713U-07	220 nm to 870 nm	Multialkali	Synthetic silica	Plano-concave	ϕ3 mm	20 ps

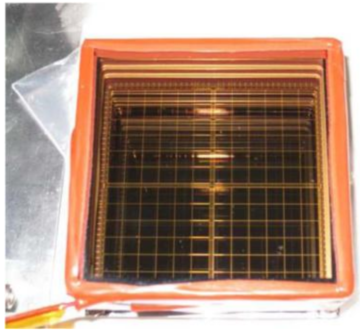
●H13223-40

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.

- 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

Table 1
Requirement for the HAPD performance.

Item	Typical	Requirement
QE (λ = 400 nm)	28%	≥24%
Bias Voltage	250–500 V	
High voltage	−8.5 kV	
Dark current (bias)	1–100 pA	<1 μ A / channel
Dark current (HV)		<300 pA
Avalanche gain	40	>30
Bombardment gain	1800	>1500
Number of bad channels		≤10

A preliminary summary of the photon detectors

Photon detector types	Quantum efficiency	Spatial resolution	Dark noise rate	Time resolution	Magnetic field tolerance	Radiation tolerance	Material budget	Cost estimation	Risk on construction &operation
Gaseous chamber (MWPC, MPGD)	poor (~28% at VUV region, 160-170nm)	good (~1-2 mm, charge centroid method)	good (~1 Hz/cm^2)	poor (~1-50 ns)	poor (due to charged particles drifting)	good (no silicon)	good (~4% X0)	Good (several 10 RMB/cm^2)	poor (complex with gas, high voltage, pho-tocathode)
PMT (dynode or MCP PMT)	medium (~20-35% at 400nm)	medium (~3-5 mm with multi-anode)	good (~5-100 Hz/cm^2)	medium for dynode(~200 -500ps); good for MCP(<50ps)	medium (specially designed dynode or MCP)	good (no silicon)	poor (~10% X0)	poor (~1000 RMB/ cm^2)	good (simple for construction and running)
HPD and HAPD	medium (~25-30 % at 400 nm)	medium (~2.8-6 mm with multi-anode)	medium (~2.5-5 KHz/cm^2)	medium (~50-200ps)	medium (with high voltage)	medium (partially silicon)	poor (~10% X0)	poor (~1000 RMB/cm^2)	medium (high voltage 8-20kV needed)
SiPM	good (~45-50% at 400nm)	medium (~3-6 mm depending on the size)	poor (~10 MHz /cm^2, room temperatur e)	medium (~50-100ps)	good (small thickness)	poor (atom displace-ment)	good if no cooling (~4% X0); poor if with cooling (~10% X0)	medium if no cooling (~100 RMB/ cm^2); poor with cooling	good (simple for construction and running)

- No clear conclusion now, need more investigation, with SiPM and MCP PMT more preferred

Summary and Next step

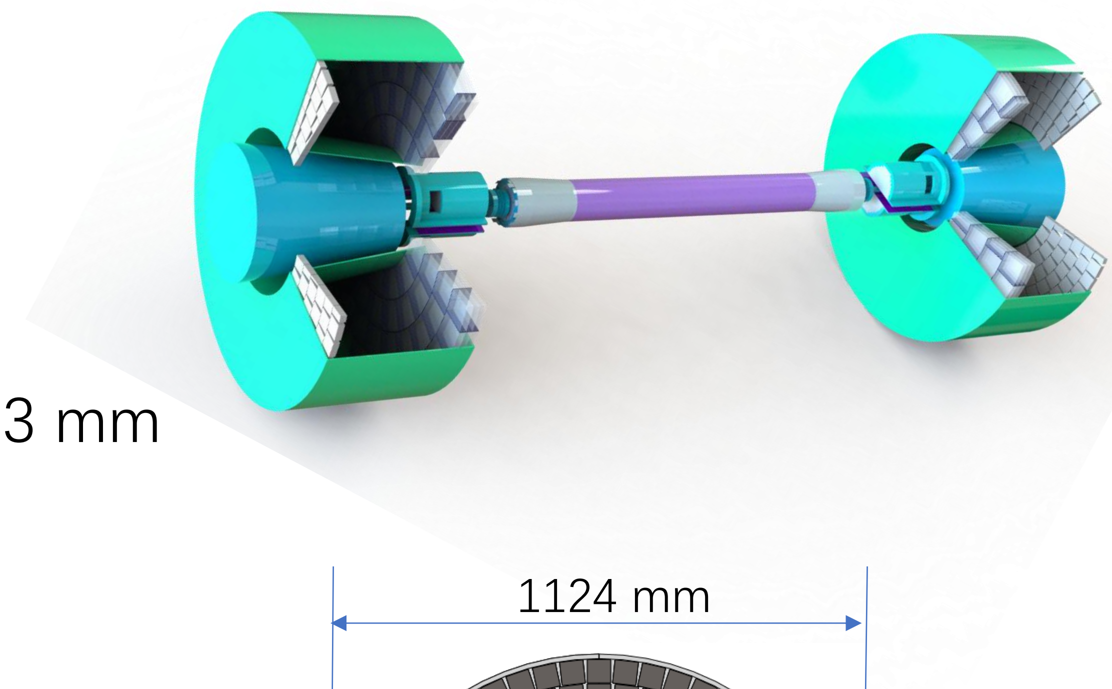
- A Cherenkov detector will be beneficial for CEPC and it's under proposing
- Some consideration/design for the Cherenkov detector have been done but at early stage.
- Many R&Ds on aerogel have been done by BINP group and still ongoing
- Photon detectors are under investigating
- A lot of things (reflection mirror, mechanical supporting, cooling, cabling, readout electronics, etc.) need to be considered
- Also, more study needed for a clear physics motivation and for location decision

Thanks a lot to Xiaolong, Jianchun and Alexander Barnyakov for the valuable discussion and input!

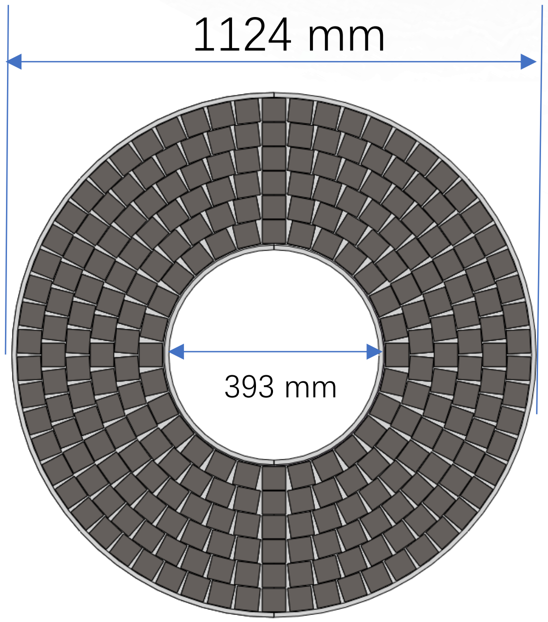
Thank you for your comments and suggestions, and welcome to join us!

Backup

Preliminary requirements for the photon sensor (SiPM)



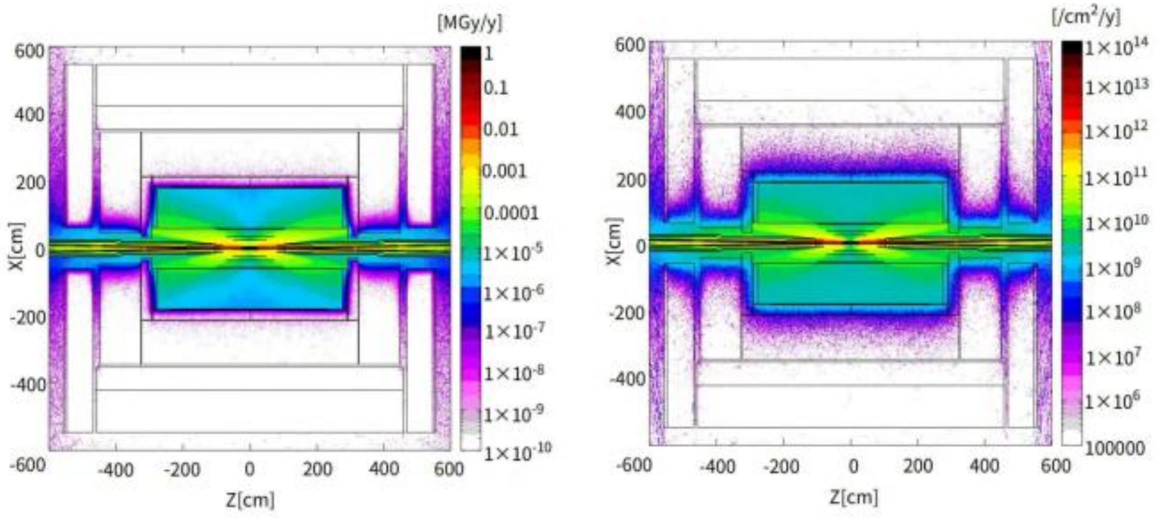
- Wavelength: 100 nm – 600 nm
- Photon detection efficiency: 50% at 420nm
- Size of single SiPM: 1 mm x 1 mm or 3 mm x 3 mm
- Pixel size: 10 -20 μm
- Module size: 3 cm x 3 cm or 5 cm x 5 cm
- Time resolution: 100 ps
- Radiation hardness: 10^{13} N_{eq} /cm^2
- Low dark noise (< 100 kHz / mm^2)
- Quantity: 0.8 m^2 x 2 = 1.6 m^2



Beam related background
(From ref-TDR of CEPC detector)

Table 3.6: Beam-induced background levels in sub-detectors at Higgs and Low-Lumi-Zoperation 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



(a) **(b)**

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 $10^{13}(1\ MeVn_{eq})cm^{-2}$ per year as shown in b.).