
CEPC Time of flight and outer tracker with LGAD

Yunyun Fan

Friday, June 28, 2024

Background hit rate of Barrel at ToF

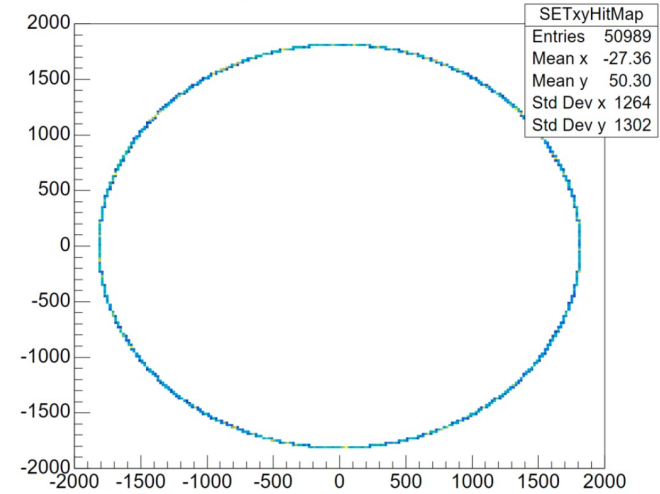
From Zhan Li

At Z pole, with pair production

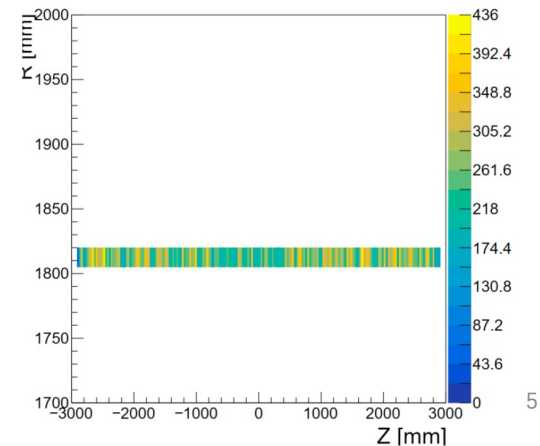
Hit rate – Background, SET

- In 60 bunches: 50989 hits ~ 51k hits
- By simply scaling to 1s (4e7 bunches)
 - 3.4e7 kHz
- Total area: 662,235 cm²
- Hit rate: ~60 Hz/cm²

xyHit Map of SET



Hit Map of SET



2024/6/5

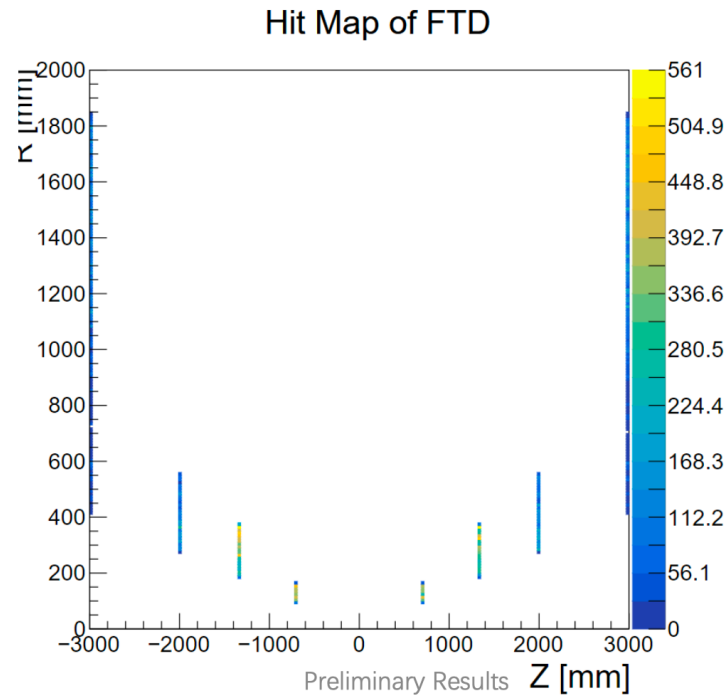
Preliminary Results

Background hit rate of Endcap at ToF

Hit Occupancy – Background, Endcap

- About 12 bunches used (7500 evts)

From Zhan Li



2024/6/5

TOF Physics data rate estimation

- Background dominated the endcap region
- Need to updated with new version of CEPCSW

From Gang Li

	Barrel (Hz/cm ²)	Endcap (Hz/cm ²)
Physics (Z pole)	80	30
Pair production	100	~100k

Hit rate estimation input for electronics

- Z pole
- Strip: 0.1mm x 70 mm

Updated with new CEPCSW

	Hit rate (Hz/cm ²)	Hit rate per ASIC (Hz)	Hit rate per strip (Hz)
Barrel	140	1254.4	9.8
Endcap	780	6988.8	54.6

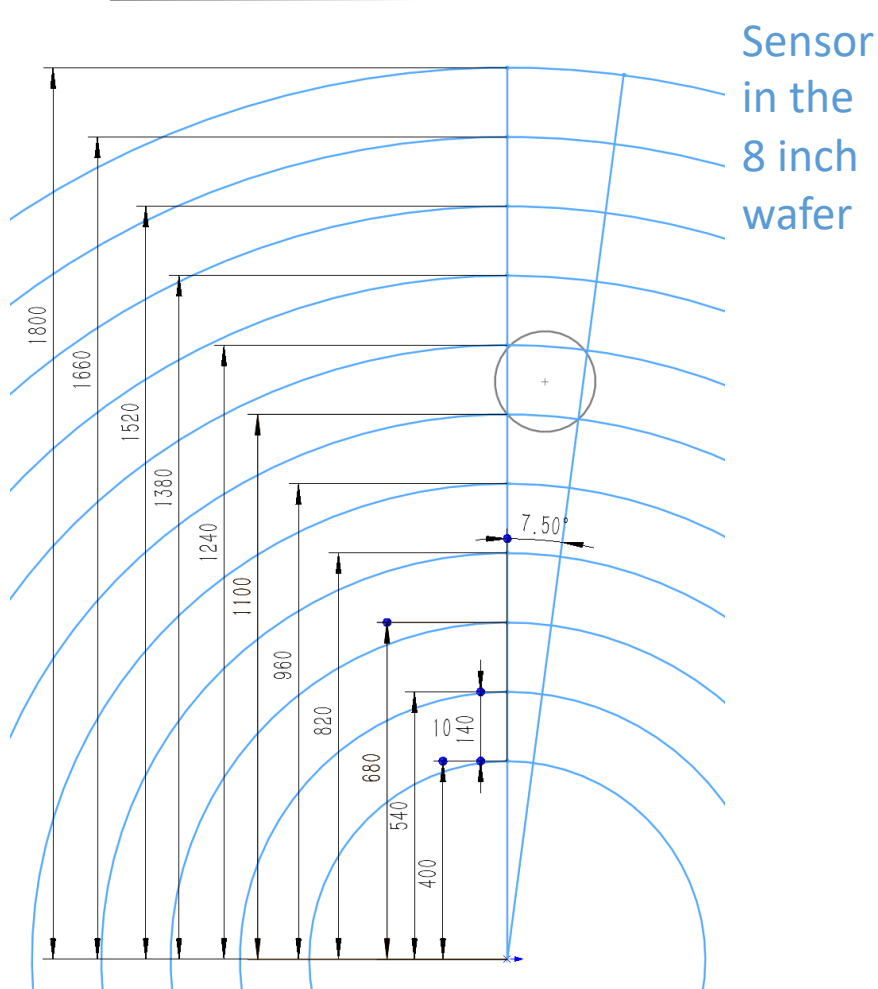
Cluster size: 1-2 strip (most is within 1 strip)

Summary

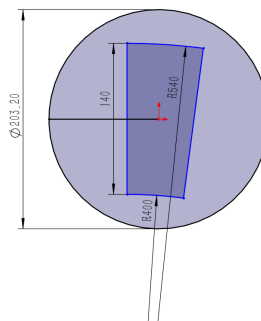
- The updated maximum of the total hit rate at Z pole is 780 Hz/cm^2
 - ✓ Old one is 100K Hz/cm^2
- Plan
- Study the TOT and TOA with AC-LGAD Beta test waveform

Backup

Sensor Arrangement and the readout channel



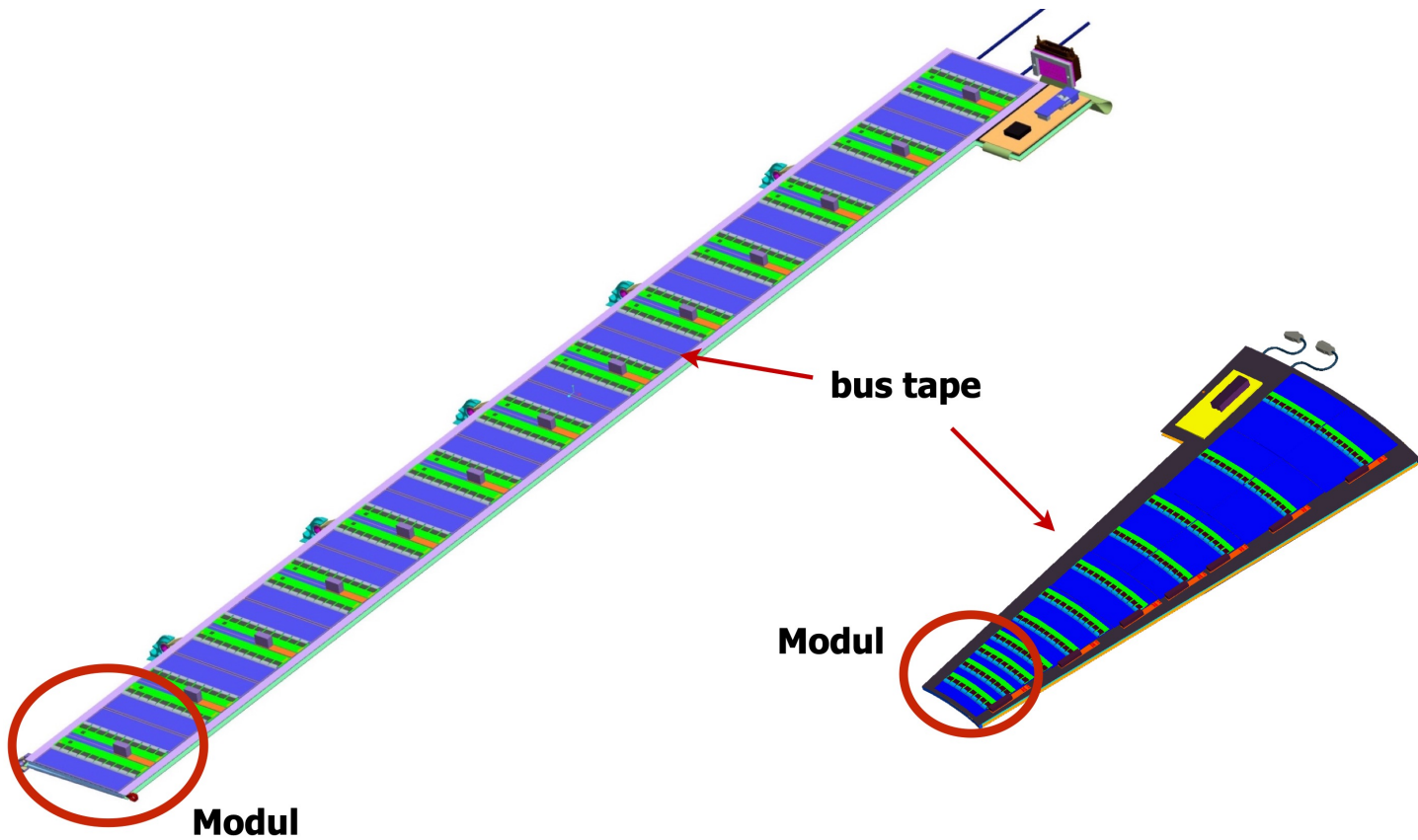
Sensor in the 8 inch wafer



Old number

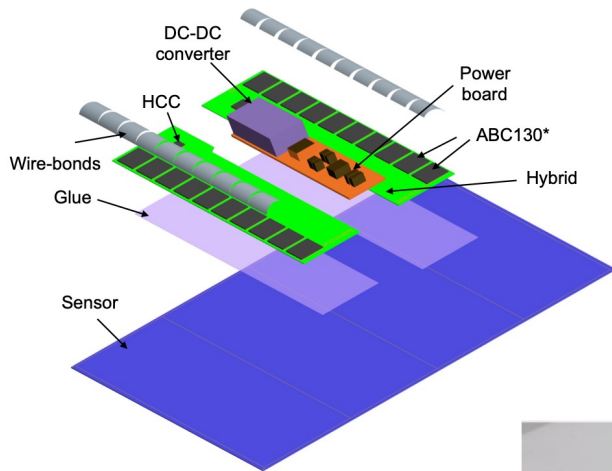
	Maximum Arc (mm)	Readout channel number	Sensor number	Hit Rate Hz/cm ²
R0 (400-540)	52.36	707	1	10 ⁵
	70.686			
R1: 540-680	70.69	891	1	10 ³
	89.012			
R2: 680-820	89.012	1074	1	10 ²
	107.338			
R3:		1257	1	20
	125.664			
R4	125.664	1440	1	20
	143.990			
R5		1624	2	20
	162.316			
R6		1807	2	20
	180.642			
R7		1990	2	20
	198.968			
R8		2173	2	20
	217.294			
R9: 1660-1800		2357	2	20
	235.620			

位置分辨: 10 um (最大pitch 100 um)



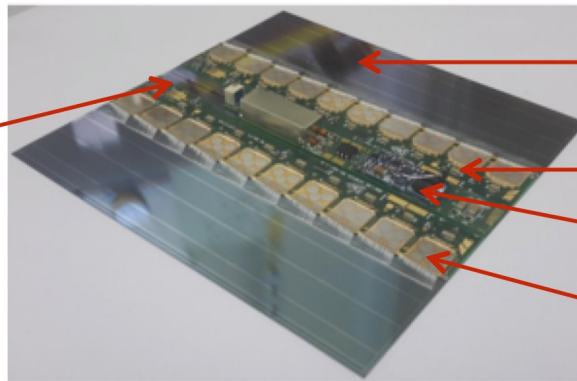


MODULE CONCEPT



- Silicon strip sensor
- Hybrid
 - Kapton circuit board
 - FE-ASICs
 - Power board (DC-DC)

HCC
Multiplexing
ASIC



Sensor

Hybrid

LV/HV power
board

ABC ASIC

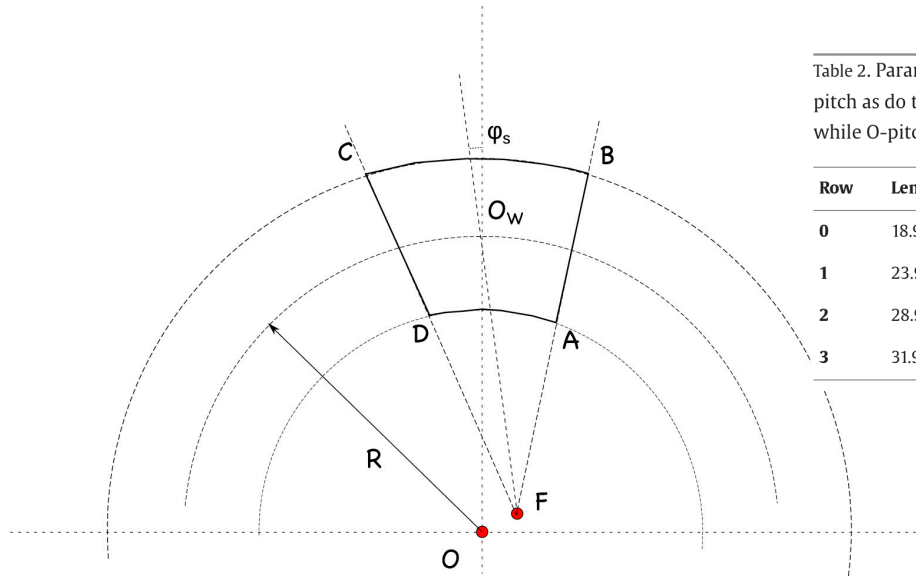
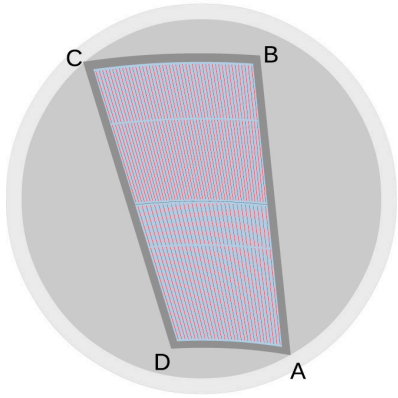


Table 2. Parameters of the four rows in the R0 sensor. The first two have the same angular pitch as do the last two rows. I-pitch corresponds to the pitch at the inner end of the strip while O-pitch at the outer end of the strip.

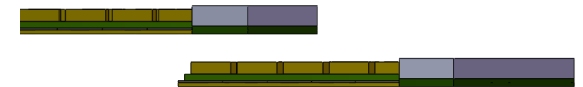
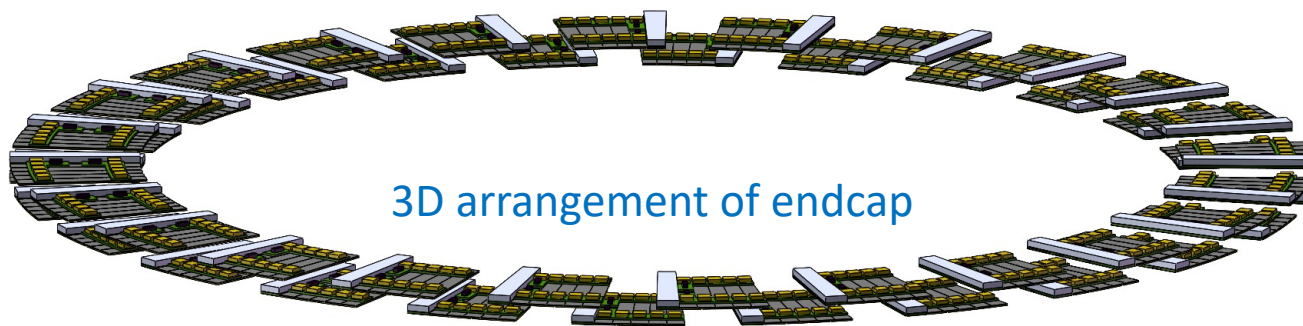
Row	Length (mm)	I-pitch (μm)	O-pitch (μm)	pitch (μrad)
0	18.981	74.314	77.983	193.2745
1	23.981	77.983	82.617	193.2745
2	28.981	73.454	78.434	171.8368
3	31.981	78.434	83.929	171.8368

<https://cds.cern.ch/record/1514636/files/ATL-UPGRADE-PUB-2013-002.pdf>

<https://www.sciencedirect.com/science/article/pii/S0168900218307691>

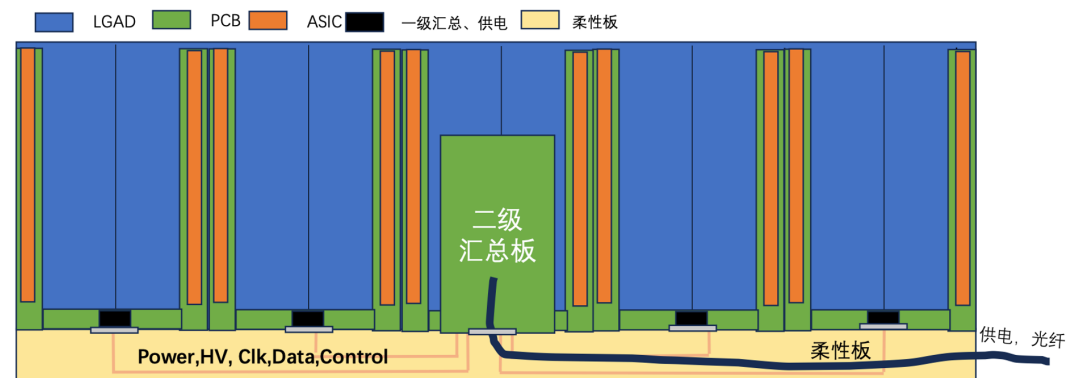
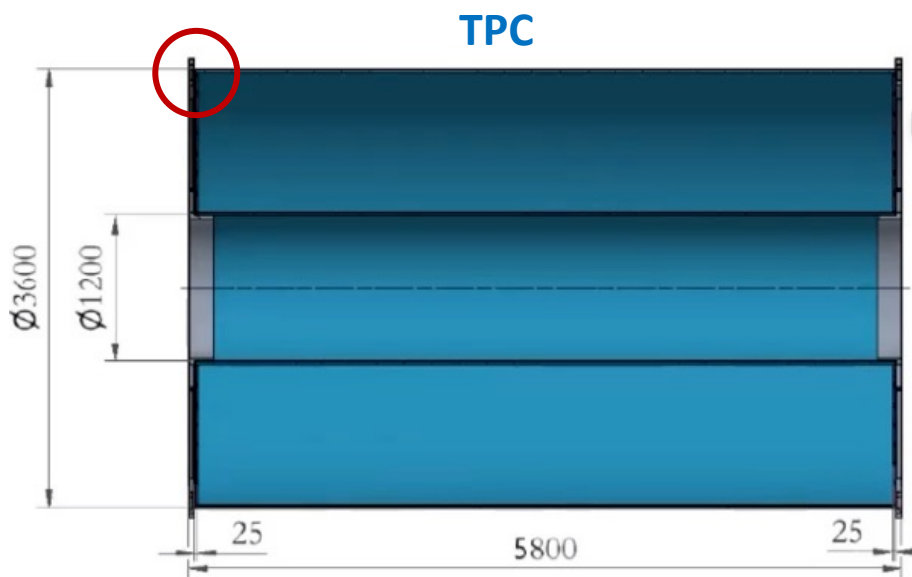
Endcap design

- Need to consider the details of the mechanics
- Need detailed electronics design (How different from the barrel?)
 - ✓ Arc PCB
 - ✓ Hit rate of each channel and ASIC
 - ✓ Cluster size?
 - ✓ TOA TOT
 - ✓ Impedance matching
- Arc LGAD sensor
 - ✓ leakage current



Summary and questions

- Decrease the thickness of barrel from **85 mm to 58 mm**
- Get the preliminary design of the endcap.
- ✓ Need to discuss about the longer TPC at the endcap(**> 1800mm problem**)
- ✓ Need to know the spatial resolution in the z direction (beam direction)
?(important to the power density of electronics)



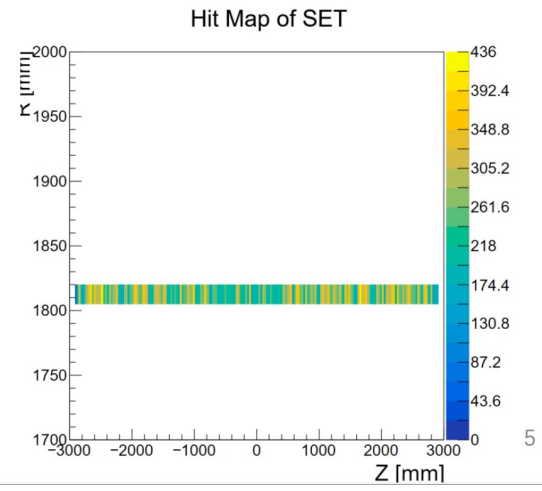
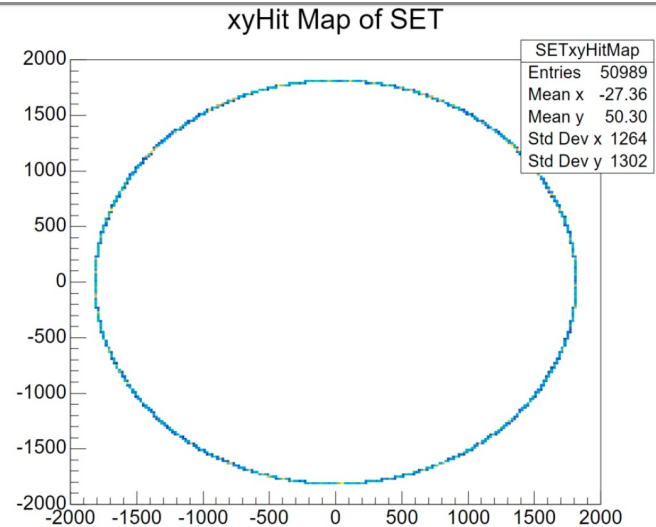
Backup

Pair Production Background

- Z pole
- Average events per bunch (25ns) : ~650
- About 60 bunches used (39000 evts)
- Geometry version: TDR_o1_v01
- Preliminary Results

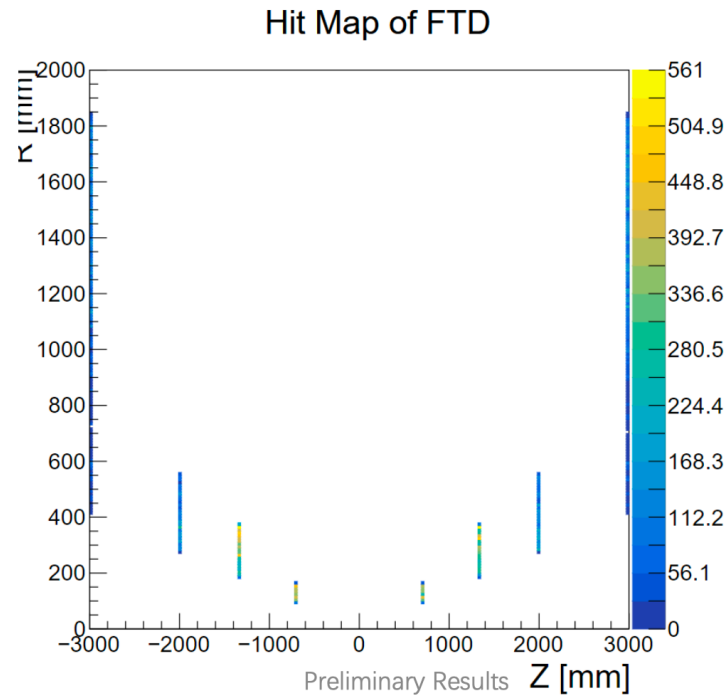
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 - 3.4e7 kHz
- Total area: 662,235 cm²
- Hit rate: ~60 Hz/cm²



Hit Occupancy – Background, Endcap

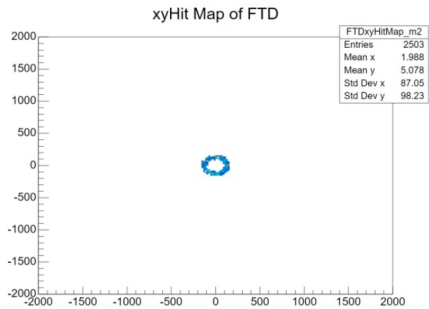
- About 12 bunches used (7500 evts)



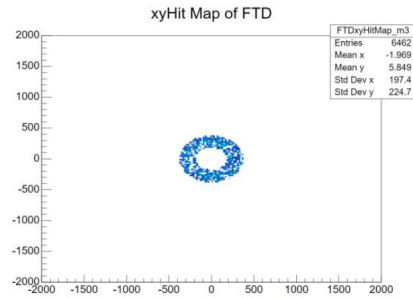
2024/6/5

Hit Map – Background, Endcap

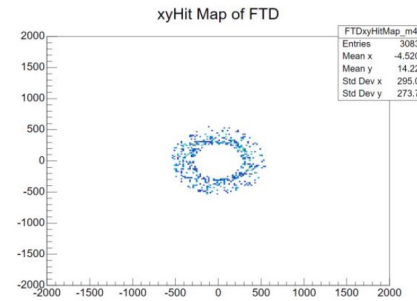
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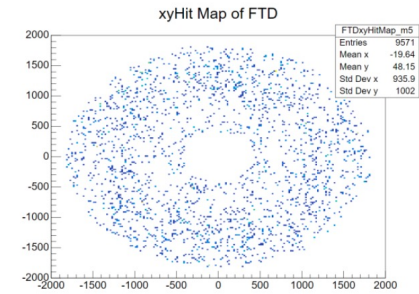
~40kHz/cm²



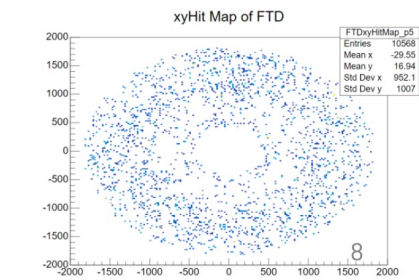
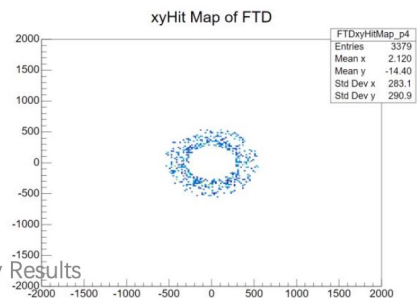
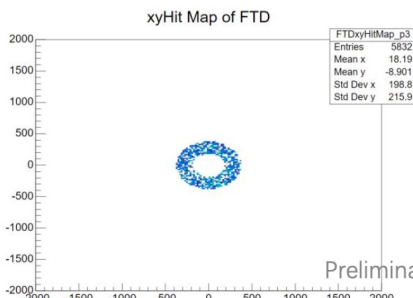
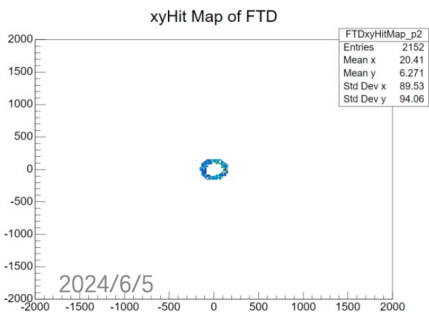
~15kHz/cm²



~4kHz/cm²



~750Hz/cm²



noise input for electronics

- Z pole
- Strip: 0.1mm x 70 mm

noise	Hit rate (Hz/cm ²)	Hit rate per ASIC (Hz)	Hit rate per strip (Hz)
Barrel	60	537.6	4.2
Endcap	750	6720	52.5

Cluster size: 1-2 strip (most is within 1 strip)

TOF data rate estimation

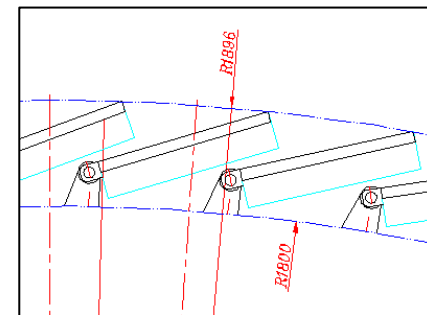
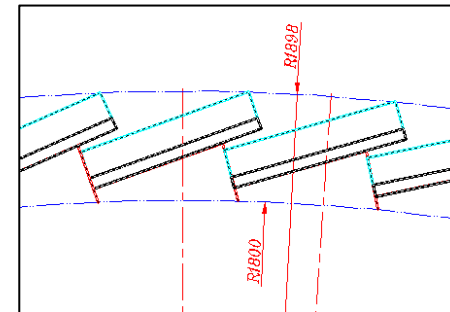
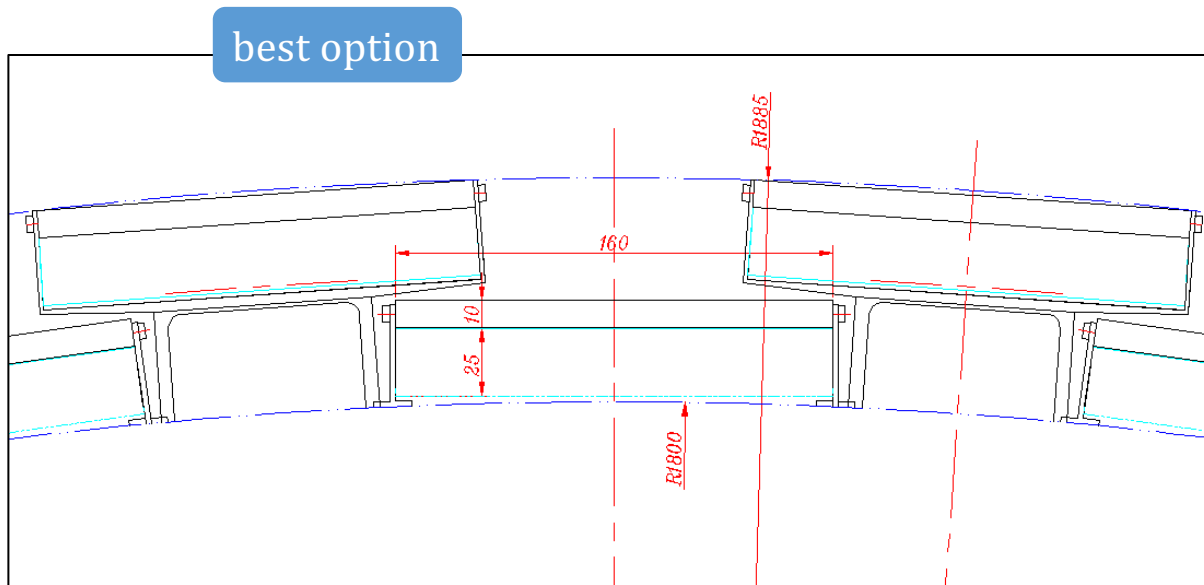
From Gang Li

- Background dominated the endcap region
- Need to updated with new version of CEPCSW

	Barrel (Hz/cm ²)	Endcap (Hz/cm ²)
Physics (Z pole)	80	30
Pair production	100	~100k

Geometric layout: Barrel-OTk

- TPC is limited within $R = 1.8$ m
- LGAD: minimum radial requirement is 85(58) mm (R1800-1858 mm) after comparing different deployments
 - two layers of ladders
 - ladder thickness 35 (25.1 mm) mm: 25 (15.1) mm of sensors and electronics, 10 mm of support embedded with cooling tubes



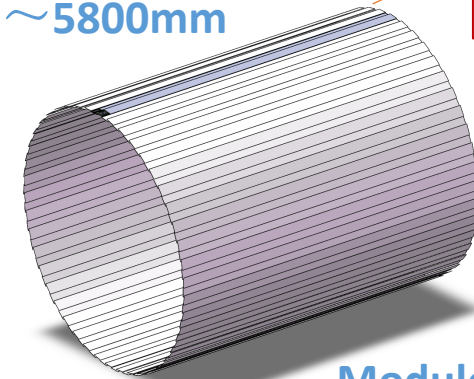
Need reasonable hit rate at endcap

- Need reasonable hit rate at endcap
 - ✓ The present rate 10^5 hit/cm² (from haoyu) is too high to realize at ASIC side

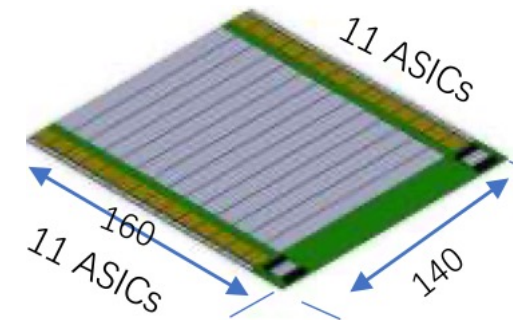
Arrangement of the ToF with strip LGAD: Barrel

- One layer: 3780 modules
 - 90 ladders, 45 ladders each side,
 - ✓ 42 modules/ladder,
 - ✓ 22 ASIC/module, 128 Channel/ASIC

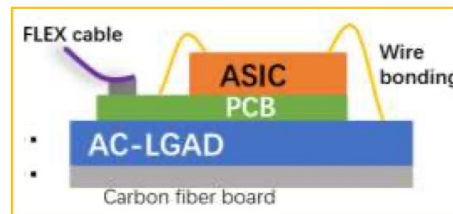
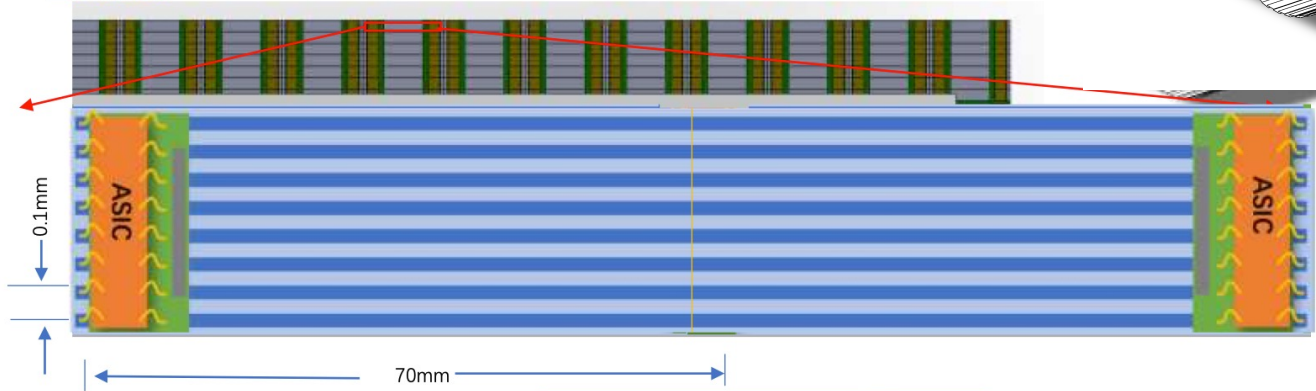
One layer ToF
R= 1800 mm
H~5800mm



Module
140mm x 160mm



Ladder



Arrangement of the ToF with strip LGAD : Endcap

- Petals: one petal each $8^\circ \times 45 = 360^\circ$
- Total modules: ~ 450 (14cm \times)
- R: 400 mm - 1800 mm

Module
Longest side: 140mm

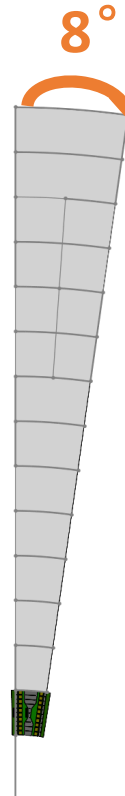
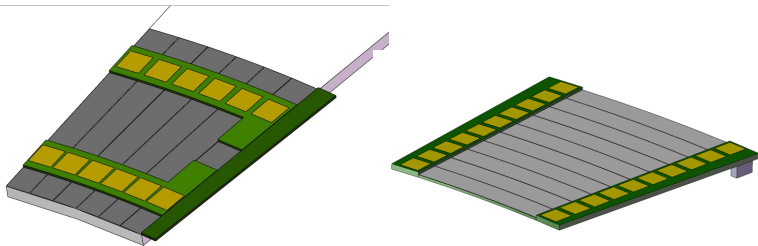
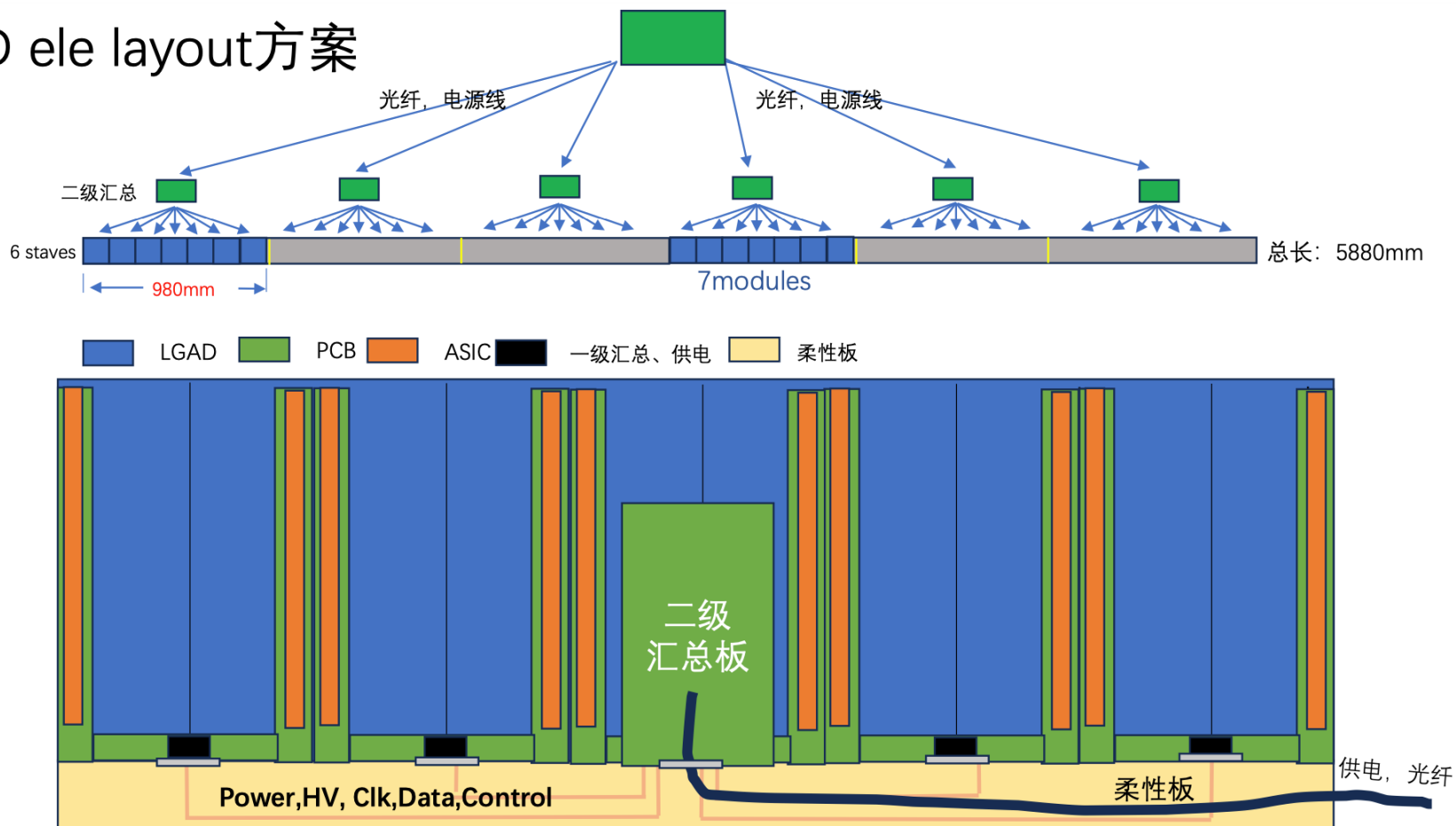


Figure 9.18: Photo of the thermo-mechanical petal prototype.

Layout of the Electronic System for LGAD ToF & oTracker

LGAD ele layout方案



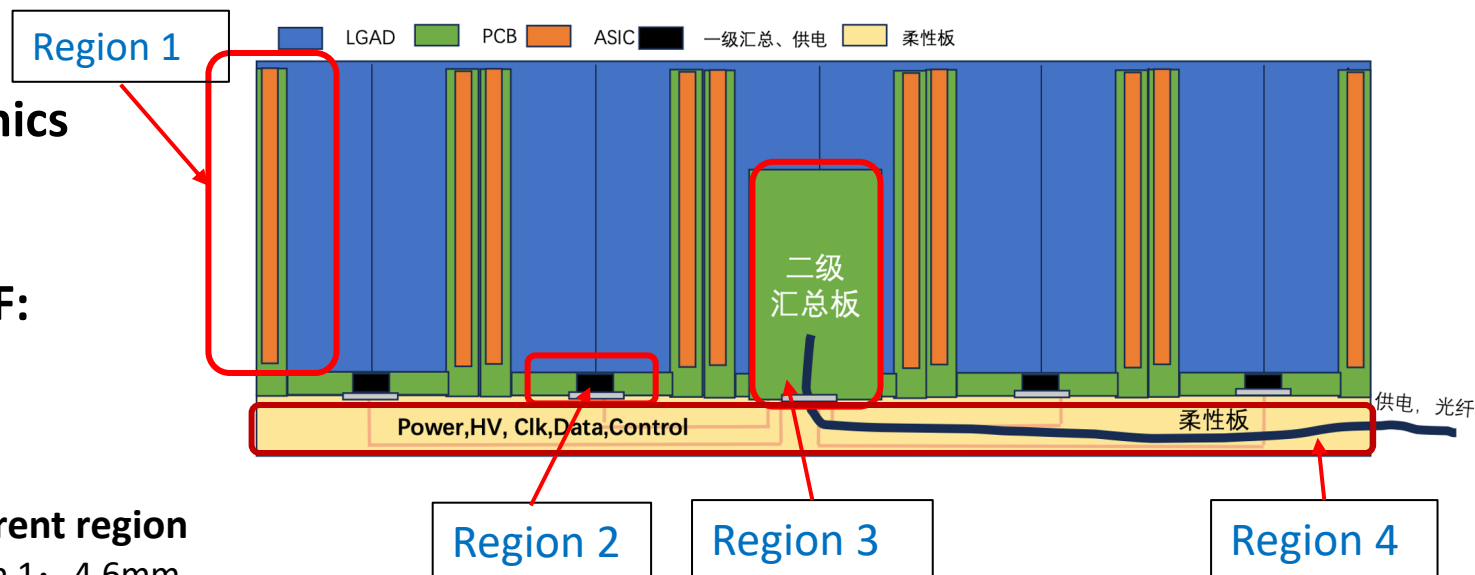
Re-estimate the Electronics Thickness

Thickness of electronics
+ sensor:

25 mm -> 15.1 mm

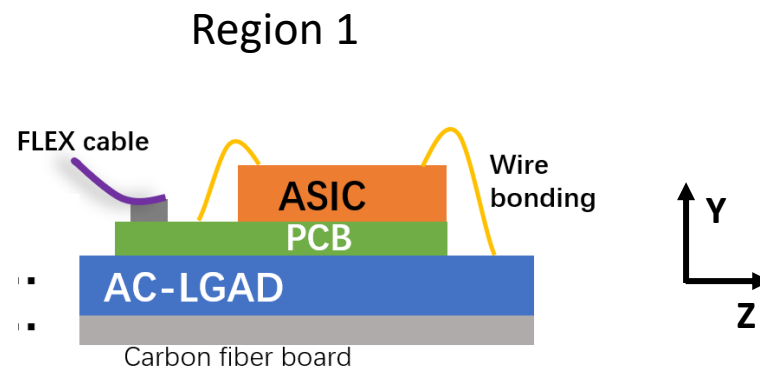
Total thickness of ToF:

85 mm -> 58 mm



Detail thicknesses of different region

- The thickness of the region 1: 4.6mm
 - ✓ PCB: 1.6 mm
 - ✓ ASIC: 3 mm
- The thickness of the region 2:
 - ✓ 一级汇总供电: 3 mm
 - ✓ PCB: 1.6 mm
- The thickness of the region 3: **14.6 mm**
 - ✓ 电源模块: 6 mm
 - ✓ 光电复合电缆: 5mm
 - ✓ 弯折走线空间: 2mm
 - ✓ PCB: 1.6 mm
- The thickness of the region 4: 6 mm
 - ✓ 柔性板厚度: 1 mm
 - ✓ 二级汇总电缆: 5 mm (高低压供电, 光纤)



Detector Impact – Vertex -- Higgs

- Preliminary results. Without any safety factor. Take the highest bin value as result.
 - Pair Could be used as reference of design, Beam Loss could not. Further optimization/mitigation will be performed.

	Higgs
BXRate(Hz)	1.34e6

- Result File link:
 - Pairs: /cefs/higgs/shihy/work/cepc_bkg/Results/Ref-TDR/20240312/Higgs/Pairs.root
 - BeamLoss: /cefs/higgs/shihy/work/cepc_bkg/Results/Ref-TDR/20240312/Higgs/BeamLoss.root(available when

Layer	Hit Density(kHz · cm ⁻²)		TID(krad · yr ⁻¹)		1 MeV equivalent neutron fluence (n _{eq} × 10 ¹² · cm ⁻² · yr ⁻¹)	
	Pair	Beam Loss	Pair	Beam Loss	Pair	Beam Loss
1	760	110.0634	185	75.28	1.8	0.20506
2	490	90.1943	112	62.51	1.75	0.16436
3	70	45.72336	6.4	12.63	0.01	0.030855
4	66	43.73305	5.4	12.08	0.01	0.030824
5	42	27.91237	1.1	3.15	0.004	0.007239
6	40	27.60218	1.0	3.34	0.004	0.010251

Detector Impact – Vertex – Z-pole

- Preliminary results. Without any safety factor. Take the highest bin value as result.
 - Pair Could be used as reference of design, Beam Loss could not. Further optimization/mitigation will be performed.

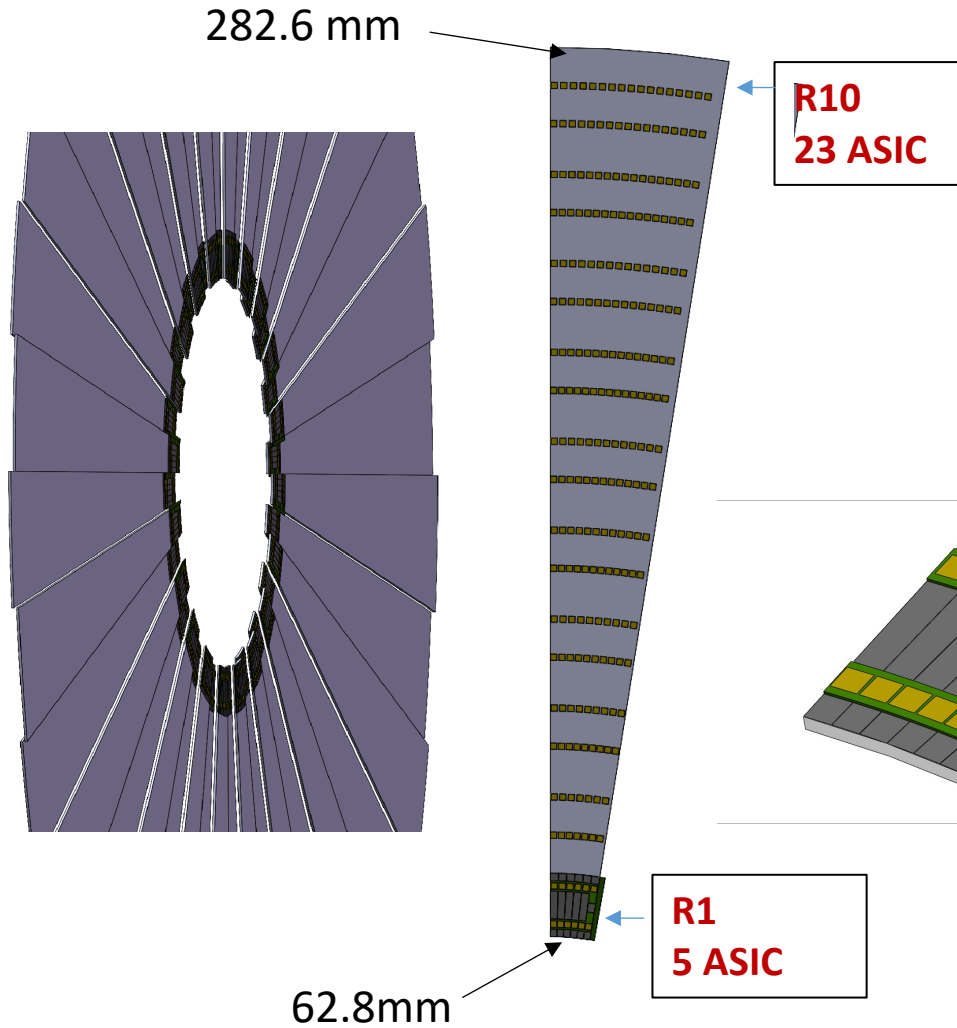
- Result File link:

- Pairs: /cefs/higgs/shihy/work/cepc_bkg/Results/Ref-TDR/20240312/Z/Pairs.root
- BeamLoss: /cefs/higgs/shihy/work/cepc_bkg/Results/Ref-TDR/20240312/Z/BeamLoss.root

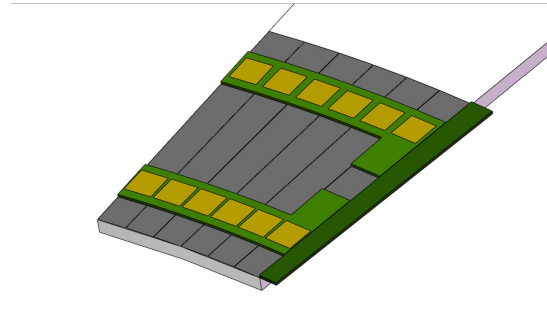
	Z
BXRate(Hz)	3.93e7

Layer	Hit Density(kHz · cm ⁻²)		TID(krad · yr ⁻¹)		1 MeV equivalent neutron fluence (n _{eq} × 10 ¹² · cm ⁻² · yr ⁻¹)	
	Pair	Beam Loss	Pair	Beam Loss	Pair	Beam Loss
1	16200	316763	8613	12198874	35.61	1081.16
2	11400	253791	5353	7569336	34.60	1252.93
3	1490	133919	252	6819307	0.5	555.51
4	1410	161755	232	7585843	0.45	609.69
5	825	100452	67.0	3660636	0.16	318.95
6	786	102476	59.6	3408929	0.14	592.95

Endcap design 1



- Double layer to reduce the dead area
 - ✓ 20 petals/layer
 - ✓ 10 row/petal,
 - ✓ 9° per row,
- 140 mm / row at R direction, same pitch (100 μ m)
- The differences between the ASIC number of R10 and R1 : $23 \text{ ASIC} / 5 \text{ ASIC} = \sim 4.5$

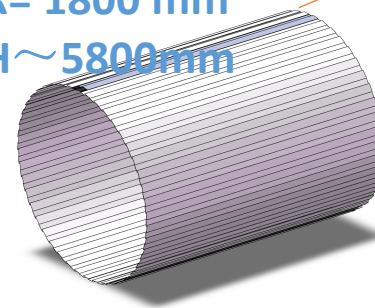


4 module, maximum arc < 140 mm
10 module, maximum arc > 140 mm

CEPC TOF

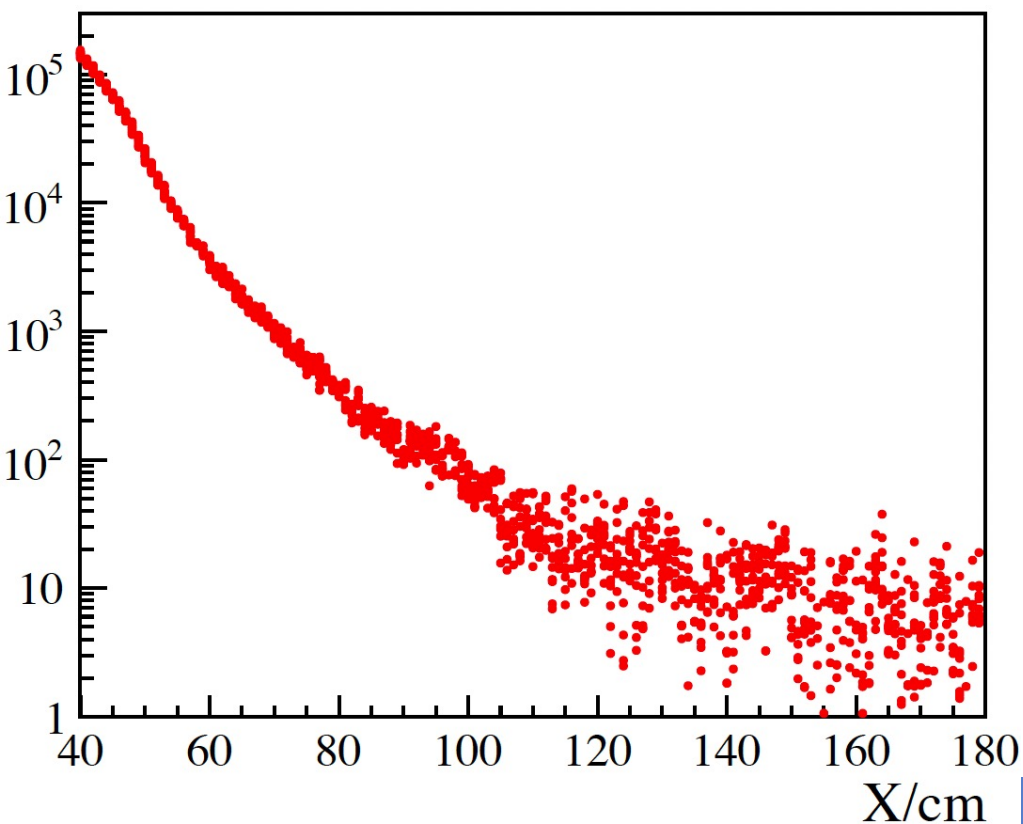
- Pair production background from Haoyu
- Need to updated with new version of CEP CSW

One layer ToF
R= 1800 mm
H~ 5800mm



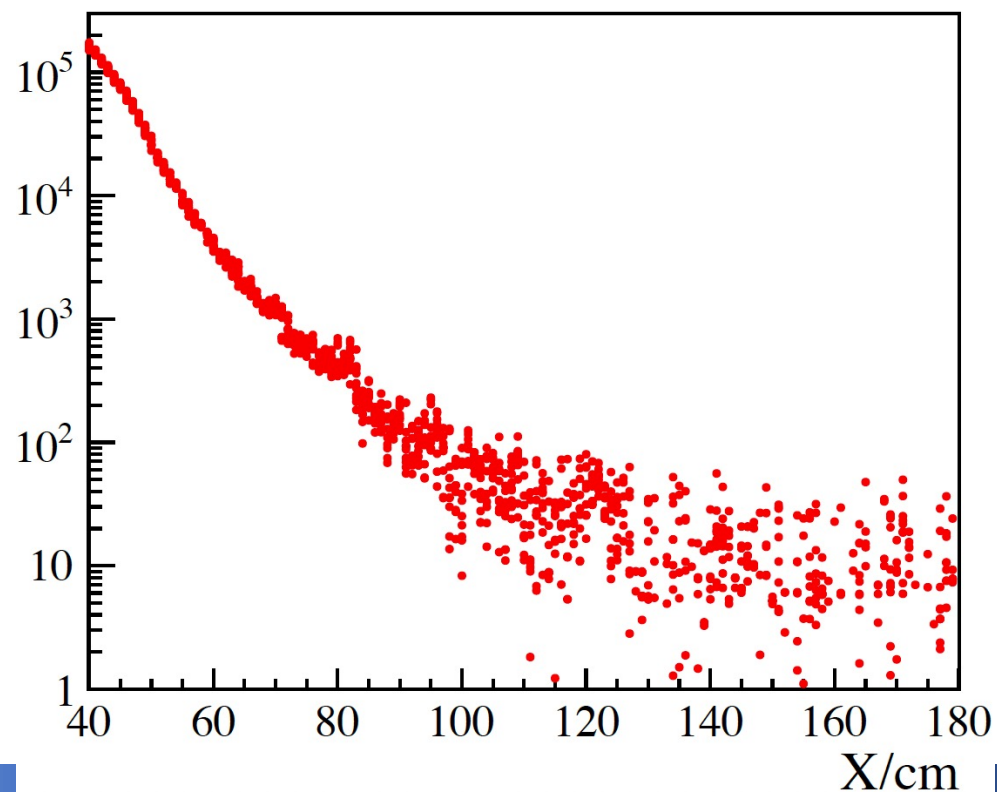
Rate(Hz/cm²)

ZH runs



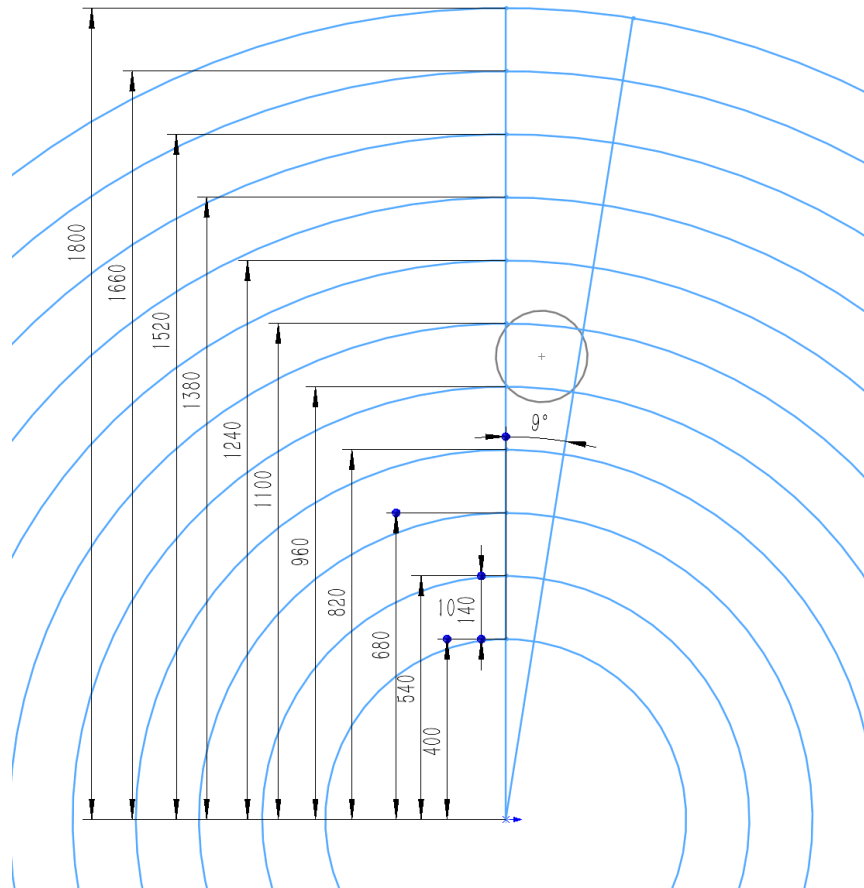
Rate(Hz/cm²)

Z pole (high lumi)



7.5°

Radius	Arc (mm)
400	52.36
470	61.52
540	70.69
610	79.85
680	89.01
750	98.17
820	107.34
890	116.5
960	125.66
1030	134.83
1100	143.99
1170	153.15
1240	162.32
1310	171.48
1380	180.64
1450	189.8
1520	198.97
1590	208.13
1660	217.29
1730	226.46
1800	235.62



Petal with 9°

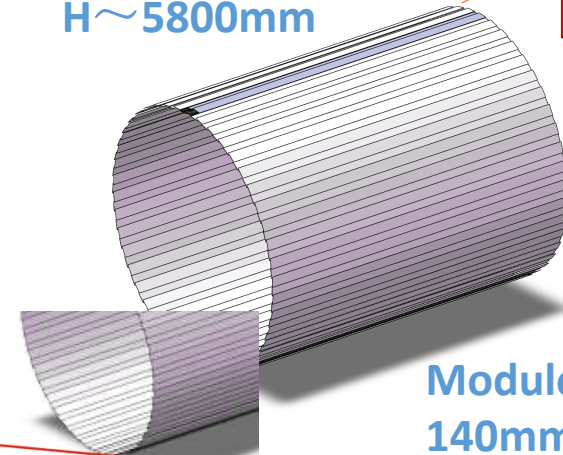
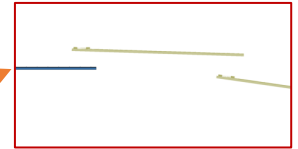
5 single

5 double sensor

Arrangement of the ToF with strip LGAD: Barrel

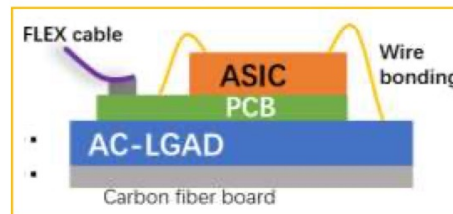
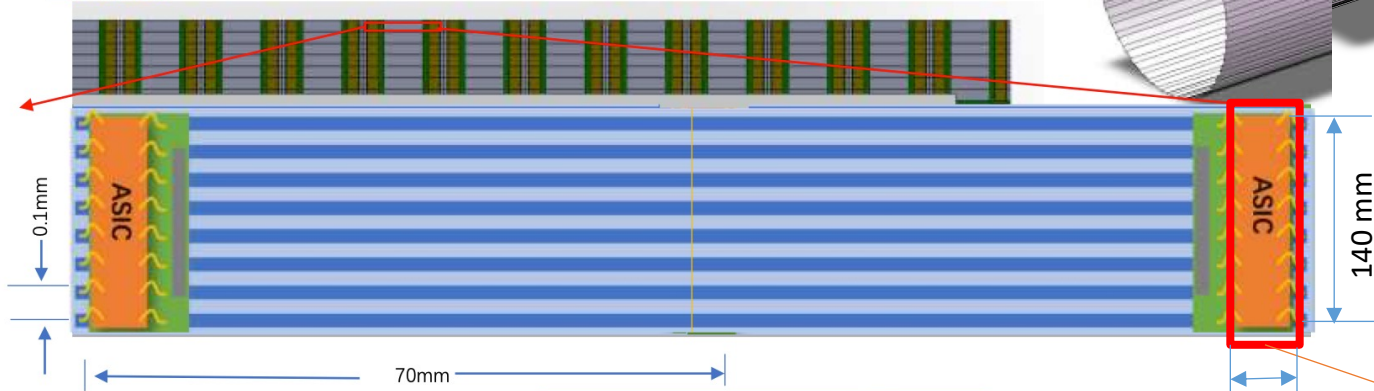
- One layer: 3780 modules
 - 90 ladders, 45 ladders each side,
 - ✓ 42 modules/ladder,
 - ✓ 28 ASIC/module, 128 Channel/ASIC

One layer ToF
R= 1800 mm
H~5800mm



Module
140mm x 160mm

Ladder



Power distribution:
5.12 W/cm² – 7.68 W/cm²
Dimension of ASIC group :
15mm x 140 mm

Power distribution

- Power distribution per channel 20 mW /channel –to 30mW/channel
- 128 channel/ASIC, 2.56kW/ASIC – 3.84 kW/ASIC
- ASIC dimension: 10 mm x 15 mm
- For one barrel module:
140mm 14 ASIC per module

	Per channel	Per ASIC	Per module (28 ASIC)
Pwer distribution	20 mW-30 mW	2.56 W – 3.84 w	71.68 W- 107.52 W

Power distribution per module (single readout) : 5.12 W/cm² – 7.68 W/cm²