

# A Request for Decision

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CEPC detector TDR plenary, 2024.5.7

**on TPC vs. DC**

# performance comparison

	unit	TPC, Higgs	TPC, Z	DC, Higgs	DC, Z
B-field	T	3	2	3	2
<b>Performance</b>					
material budget barrel	X0	0.55%		1.14%	
material budget endcap	X0	15%		plate 22.5% + cables 1.8%	
Npoint of measurement/full-trk		2300	2300	66	66
point resolution in $r\phi$ , max	$\mu\text{m}$	100 (full)	400 (full)	100	100
point resolution in rz	$\mu\text{m}$	100 - 500	200 - 800	2000	2000
momentum resolution: $\sigma(pT)/pT = a \cdot pT \oplus b$					
<b>a</b>	<b>1/GeV</b>	<b>1.2E-05</b>	<b>2.7E-05</b>	<b>2.1E-05</b>	<b>3.2E-05</b>
<b>b</b>		<b>6.0E-04</b>	<b>9.0E-04</b>	<b>7.7E-04</b>	<b>1.2E-03</b>
K/ $\pi$ separation power @ 20GeV		3 $\sigma$	3 $\sigma$	3.2 $\sigma$	3.2 $\sigma$
dE/dx or dN/dx resolution		2.9%	2.9%	2.5-2.6%	2.5-2.6%
hit rate, max	/s/pad	600	31.5k		70 kHz/cell
occupancy, max		0.001%	1.6%		11%
note		pad 0.5x0.5 mm <sup>2</sup> , ch 2x3e7		cell 18x18mm <sup>2</sup> , 27.6 kCells	

# cost estimation of TPC

## TPC COST ESTIMATION (Unit: \*10K CNY)

- Cost estimation
  - ~**110 Million RMB**
  - Detector: ~50 M
  - Electronic/DAQ: ~60 M
- Easy-to-install modular design
  - Full-size aluminum machining → Modular Machining
  - Full size of the readout coverage
  - High granularity readout

Number		Detector concept/ Detector items	Unit	Unit cost (CNY)	Quantity	total cost (CNY)
		<b>CEPC</b>				
3.2	<b>Time Projection Chamber</b>					11000.00
	<b>3.2.1</b>	<b>Chamber</b>				<b>1300.00</b>
	3.2.1.1	Fieldcage (inner and outer)		400.00	1	400.00
	3.2.1.2	Barrel (inner and outer)		600.00	1	600.00
	3.2.1.3	Cathode and HV crate		200.00	1	200.00
	3.2.1.5	Support board		100.00	1	100.00
	<b>3.2.2</b>	<b>Endplate</b>				<b>2000.00</b>
	3.2.2.1	Aluminum endcap		400.00	2	800.00
	3.2.2.2	MPGD detector module		400.00	2	800.00
	3.2.2.3	Readout bef. Assembly		100.00	2	200.00
	3.2.2.4	pre/Assemnled board		100.00	2	200.00
	<b>3.2.3</b>	<b>Electronics</b>				<b>6000.00</b>
	3.2.3.1	FEE ASIC readout		0.010	200000	2000.00
	3.2.3.2	Cables		0.03	30000	900.00
	3.2.3.3	Optical link, connectors		1.00	300	300.00
	3.2.3.4	DAQ system		0.30	4000	1200.00
	3.2.3.5	Crate and controller		20.00	30	600.00
	3.2.3.6	TPC cooling system		1000.00	1	1000.00
	<b>3.2.4</b>	<b>Alignment and calibration</b>				<b>500.00</b>
	3.2.4.1	Calibration system		500.00	1	500.00
	<b>3.2.5</b>	<b>HV and Gas system</b>				<b>1200.00</b>
	3.2.5.1	HV and low power		400.00	1	400.00
	3.2.5.2	Gas system		300.00	1	300.00
	3.2.5.3	Slow control system		200.00	1	200.00
	3.2.5.4	Online monitoring system		200.00	1	200.00
	3.2.5.5	Testing bef. Assembly		100.00	1	100.00

# cost estimation of DC

1.1		Chamber	10 <sup>4</sup> CNY	unit	3130.00
	1.1.1	End plate	405	2	810.00
	1.1.2	Outer frame structure	500.00	1	500.00
	1.1.3	Inner and outer cylinders	150.00	1	150.00
	1.1.4	Wire	710.00	+20% spare	710.00
	1.1.5	Feedthrough	530.00	+20% spare	530.00
	1.1.6	Wire test system	80	1	80
	1.1.7	Wiring tooling	350	1	350
1.2		Electronics			5170.00
	1.2.1	Readout Channel	0.1727623*1.1 (10% backup]		5170.00
1.3		HV and Gas system			340.00
	1.3.1	High Voltage system	320.00	6HV crates, 50modules	320.00
	1.3.2	Gas system	120.00	1	120.00
total					8740

**on LGAD**

# Outer Tracker options

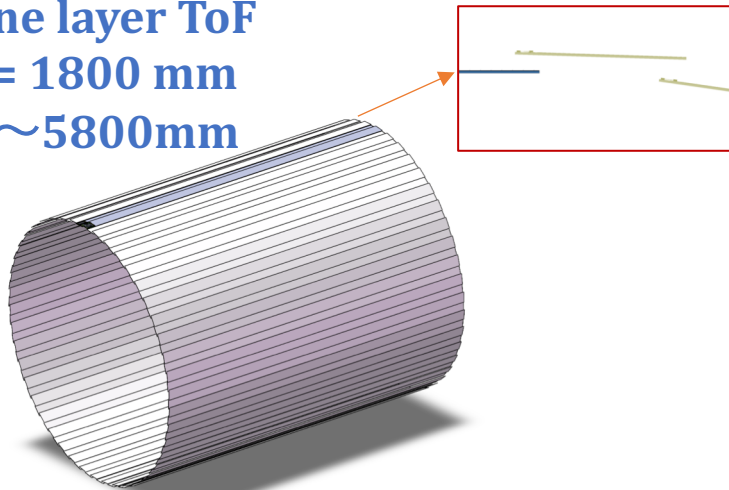
- LGAD can provide pico-second level of temporal resolution → TOF
- Assuming LGAD's spatial resolution as good as that of Si microstrip and pixel → Tracker
- three options for Outer Tracker plus TOF
  - ① LGAD only
  - ② Si microstrip + LGAD
  - ③ Si pixel + LGAD
- cost estimation of BARREL Outer Tracker

# Cost estimation of LGAD

## • The cost of the LGAD

CEPC barrel	Cost (RMB)
LGAD sensor	35M (70m <sup>2</sup> )
Electronics total	4.86M
<b>Total (sensor+elec.)</b>	<b>39.86M</b>
Electronics R&D	14.6M
<b>Total</b>	<b>54.46M</b>

One layer ToF  
 R= 1800 mm  
 H~5800mm



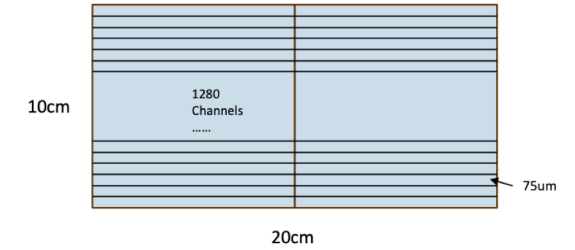
## Parameters of LGAD as TOF+oTracker

	CEPC TOF barrel
Area (m <sup>2</sup> )	~ 70
Granularity	70mm × 0.1mm (10 cm <sup>2</sup> , 128 channel/chip)
Capacitance	~10 pF
Charge	>15fC
Channel number	~ 1 × 10 <sup>7</sup> (10644480)
Module assembly	Wire bonding at strip
<b>MIP Time resolution</b>	<b>~50 ps</b>
<b>Spatial resolution</b>	<b>~ 10 μm (R-Φ), ~ 1 mm (R-Z direction)</b>
Number of Module	3780 (14cm*14cm)
Number of channels per module	2816 (22 chips, 128 channel/chip)
Data size	16 bit (9 TOT, 7 TOA) + channel(7bit, 128) +bunch ID(8bit) + chip ID (4-5 bit) ~40-48 bits



# cost estimation of Si $\mu$ -strip

- Electronics + Sensor = 1825 + 3637 = 5462 (10k RMB)



Items	Unit Cost (RMB)	Quantity	Total (10k RMB)
FEE PCB	200	3306	67
FEE ASIC	0.09	4231680	38
Collector + Flex Board	700	684	48
Optical Fiber	200	684	14
Connector (Fiber)	2000	684	137
Connector (Flex)	100	3306	33
Cables (20m)	400	684	28
Electronics Necessary R&D (*)			1460
Sensors	5500	6612	3637
<b>Total</b>			<b>5462</b>

\* Only considered material. Not including encapsulation and wirebonding

# cost estimation of Si pixel

- Note: cost on mechanical support and cooling not considered yet

Category 类别	Item 名称	Total (10k CNY) 小计 (万元)	Unit cost (CNY) 单价 (元)	Unit 单位	Quantity 数量	Note 备注
Sensor chip	Sensor chip	3459	18,000	Wafer	1920	3.3 MCNY for NTO + 18k/wafer; assume 50% yield
Common electronics	Hybrid PCB	417	700	Piece	5964	
	Optical fibre	119	200	20m	5964	
	Optical connector	1193	2,000	Piece	5964	
	PCB connector	60	100	Piece	5964	
	Power cable	239	400	20m	5964	
Total		5487				

**Thanks!**

# Material budget of TPC

## Low material of the TPC endcap

15% $X_0$  in total, including

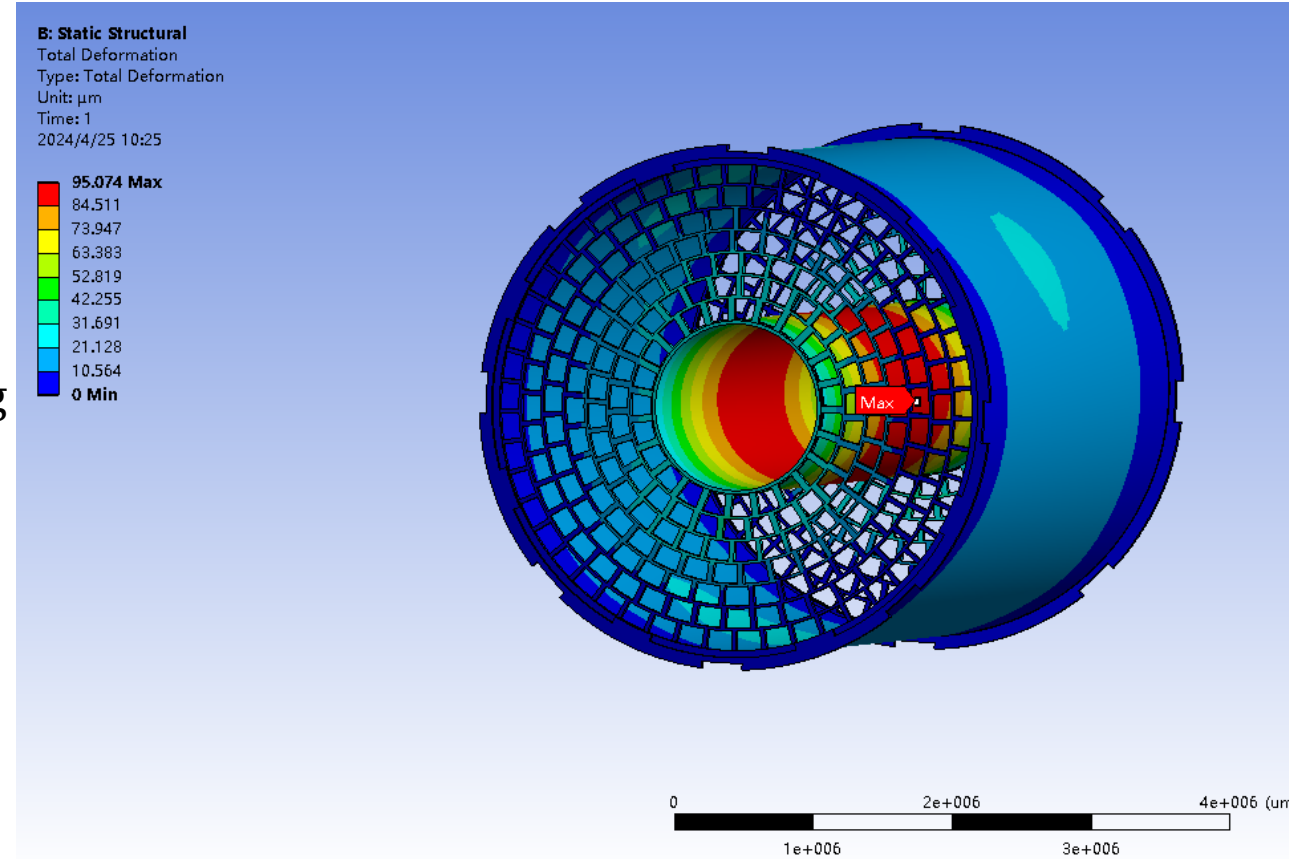
Readout plane, front-end-electronics	4%
Cooling	2%
Power cables	9%

## Low material of the TPC barrel

0.55%  $X_0$  in total, including

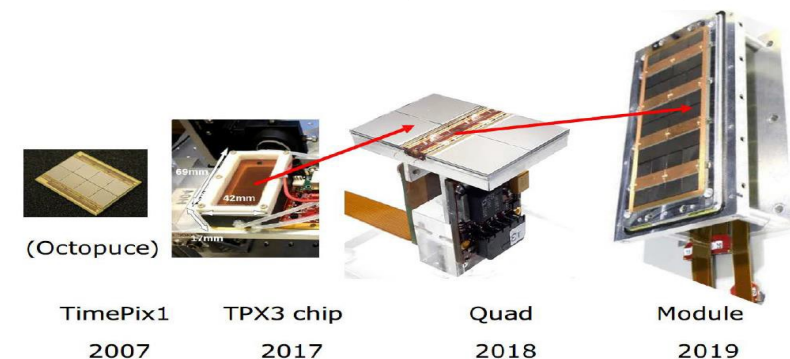
Material budget of TPC barrel

Layer of the barrels	D[cm]	$X_0$ [cm]	d/ $X_0$ [%]
Copper shielding	0.001	1.45	0.07
CF outer barrel	0.010	25.28	0.04
Mirror strips	0.003	1.35	0.19
Polyimide substrate	0.005	32.65	0.02
Field strips	0.003	1.35	0.19
CF inner barrel	0.010	25.28	0.04
<b>Sum of the material budget</b>			<b>0.55</b>

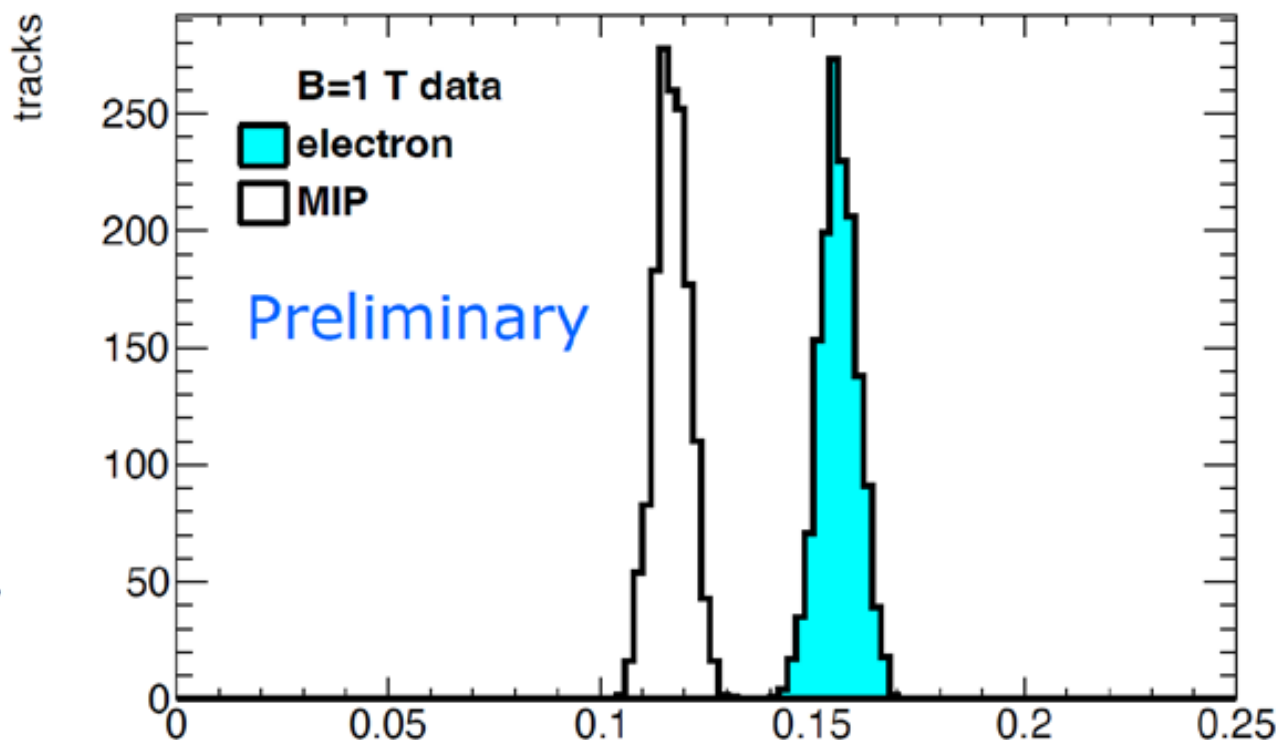


# Pixelated readout TPC beam test for PID

- Pixelated readout TPC is **a good option** at high luminosity Z on circular e+e- collider ( $2 \times 36 \text{ cm}^{-2} \text{ s}^{-1}$ )
  - High spatial resolution **under 2T or 3T magnetic field**
  - Better momentum resolution
  - High-rate operation (MHz/cm<sup>2</sup>)
  - dE/dx and Cluster counting (**in space**)
  - Very low voxel occupancy



Electron resolution  
2.9%  
1 m track 60% and  
coverage  
Linearity MIP-e = 1.07  
  
Ideally this is 1. A number  
larger than 1 means that  
the resolution is +7% larger

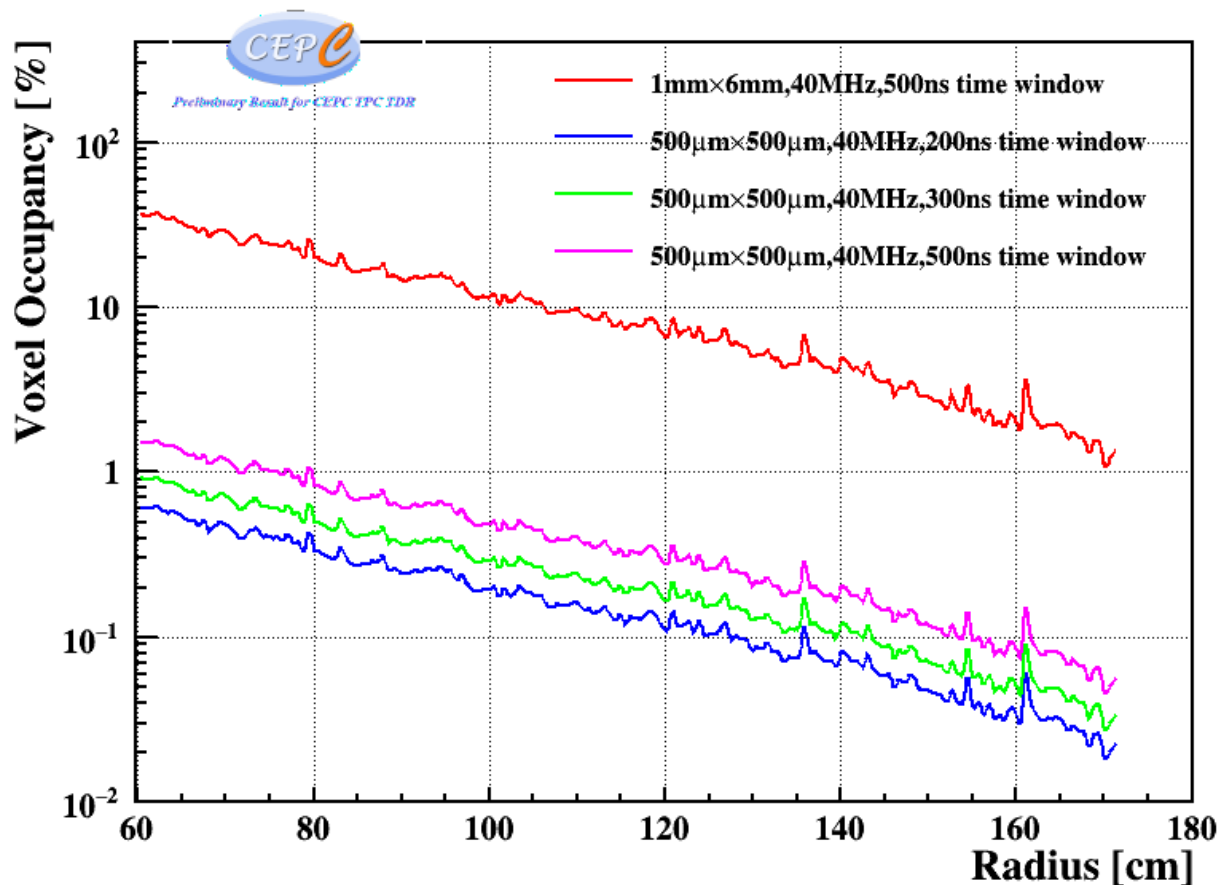


# Voxel Occupancy

➤ 基于CEPC Soft实现对Z-pole模式下，**分析完成了TPC**

## 探测器腔体内占空比研究和确认

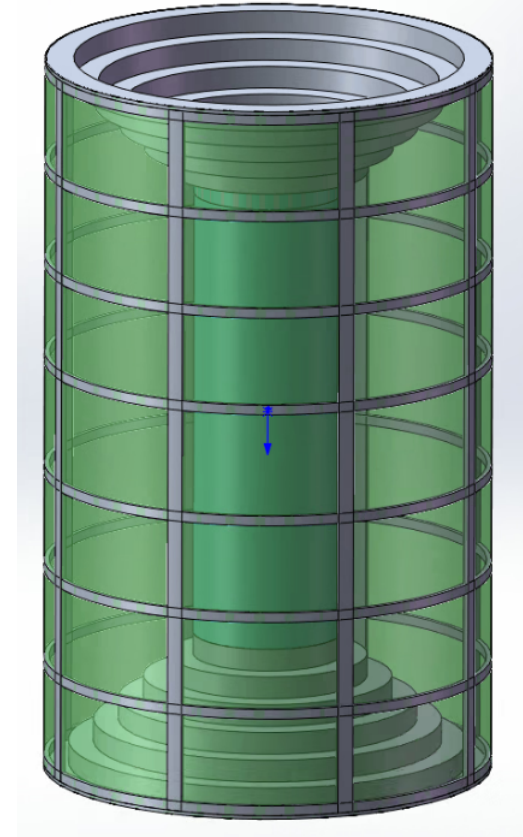
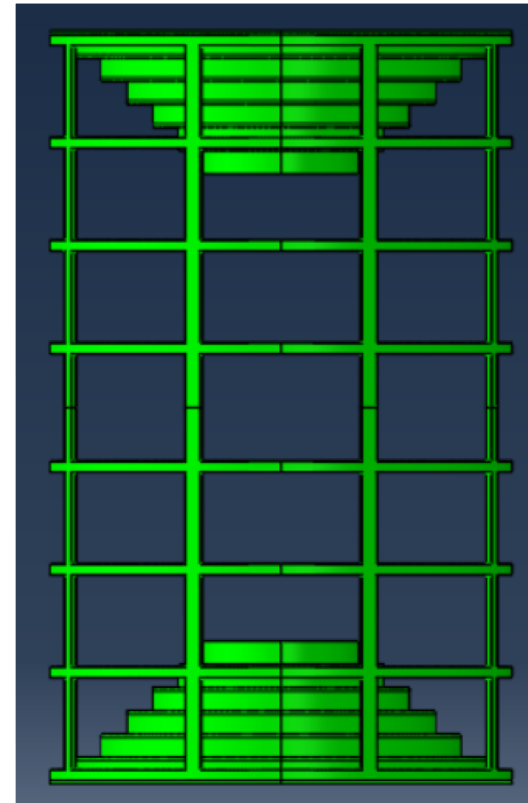
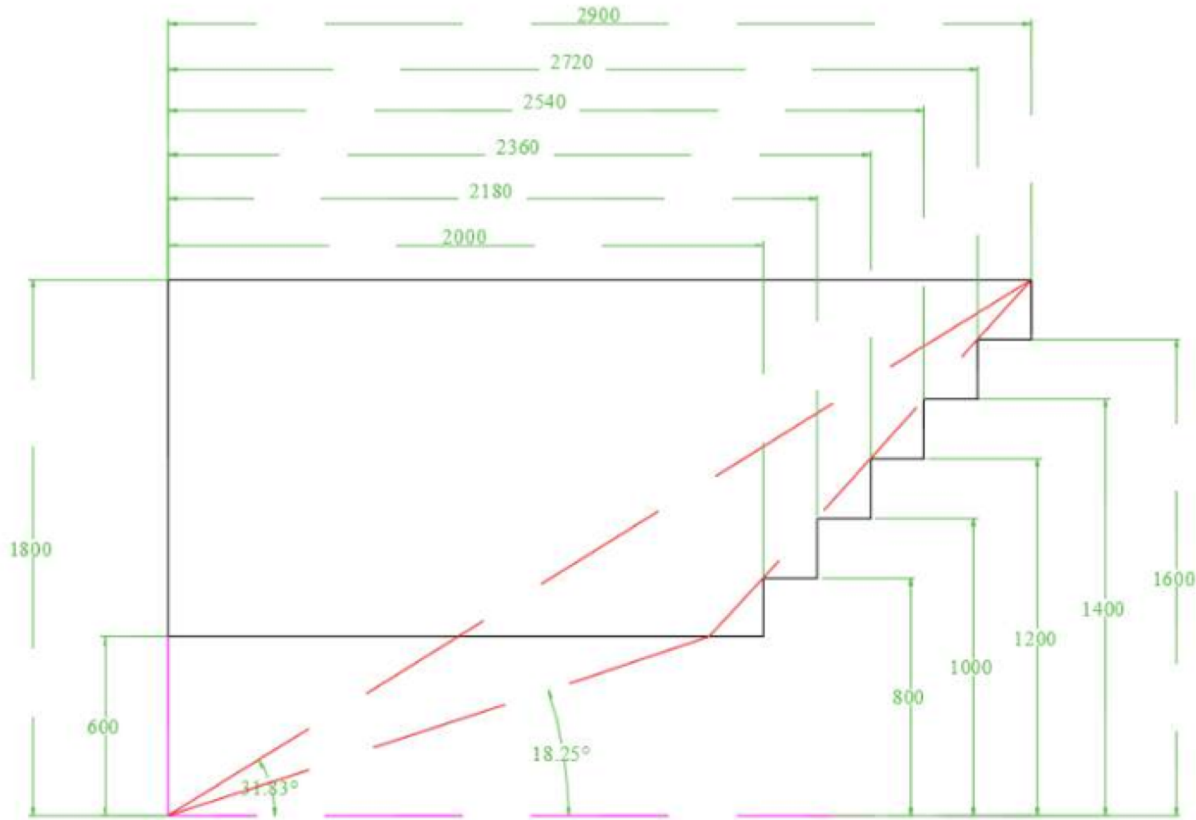
- 对于单个 $500\mu\text{m} \times 500\mu\text{m}$  读出像素，40MHz采样率，单位时间总的Voxel数为 $4 \times 10^7/\text{s}$
- z向Voxel大小为 $V_d \times 25\text{ns} \sim 2\text{mm}$ ，单个Voxel大小 $\sim 0.5 \times 0.5 \times 2 = 0.5 \text{ mm}^3$
- 对于500ns时间窗，z向平均占用**20个voxel**
  - **实际将采用200ns左右时间窗**
- 最内层Voxel Occupancy= $20 \times 31.5\text{k} / 4 \times 10^7 \sim 1.58\%$
- 对于 $1\text{mm} \times 6\text{mm}$  Pad，最内层Voxel Occupancy $\sim 35\%$
- 结果表明：现有MDI设计下，TPC探测器占空比保持非常低，**满足探测与物理需求**



半径方向上不同大小读出像素单元，时间窗下Occupancy

# Drift Chamber

# Overall Design (preliminary)



CF Frame structure: 8 longitudinal hollow beams + 8 annular hollow beams + inner CF cylinder and outer CF cylinder

- Length : 5800mm
- Outer diameter: 3600mm, Inner Diameter: 1200mm;
- Thickness of each end plate: 25mm/20mm, weight :1100kg /880kg



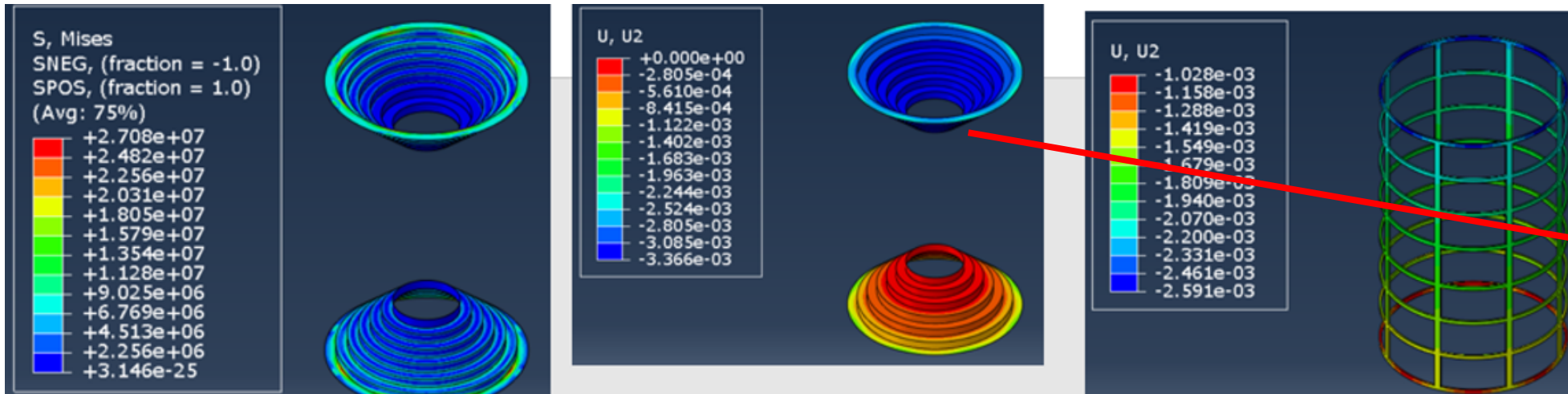
# Results of FEA

Loads: Wire tension

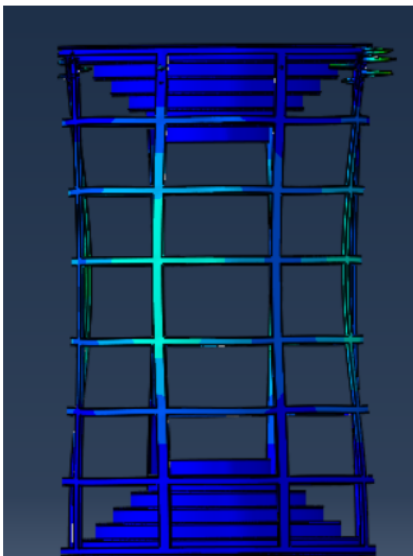
+ Axial self weight

End plate thickness: 20mm

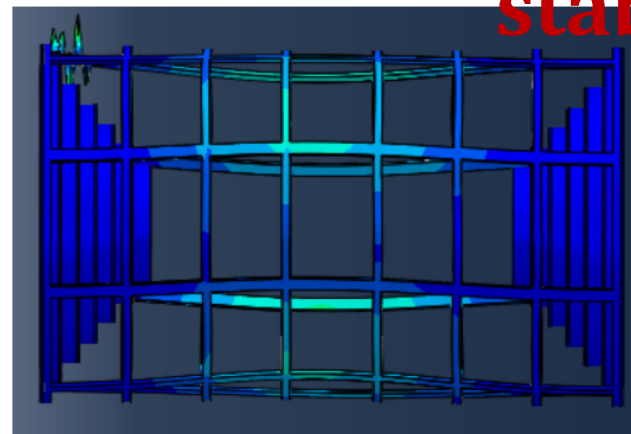
- Stress 27.1MPa,
- Endplate deformation 3.4mm,
- CF frame deformation 1.6mm



**The structure is stable**



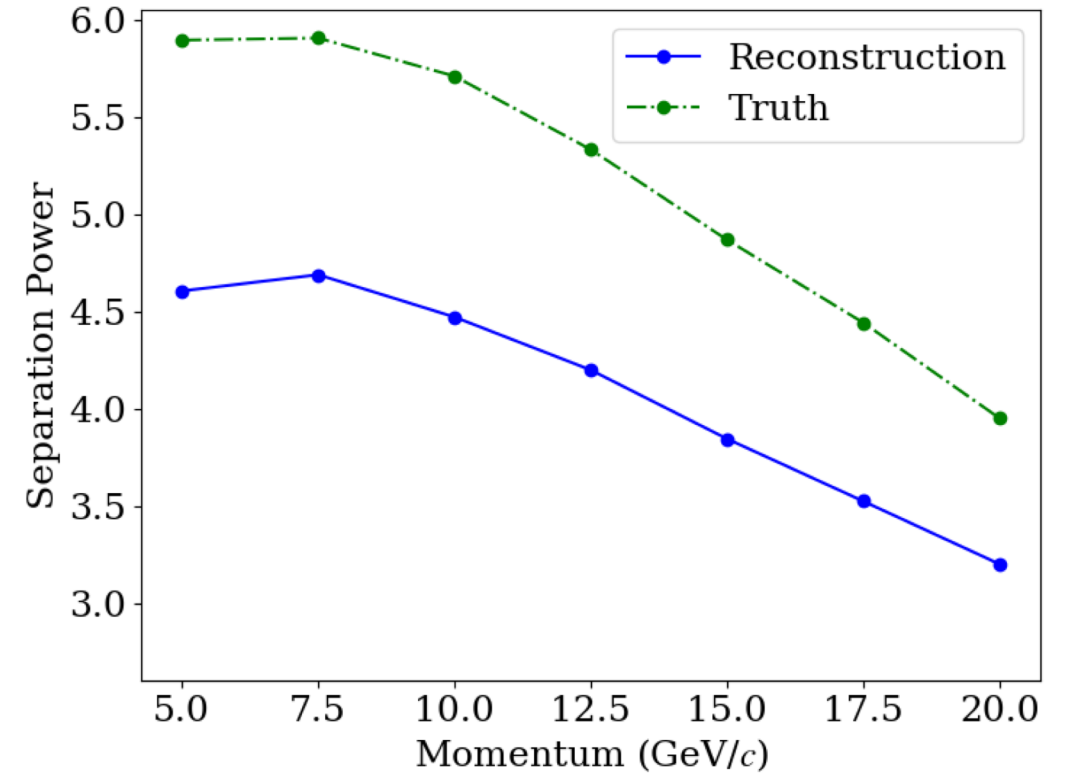
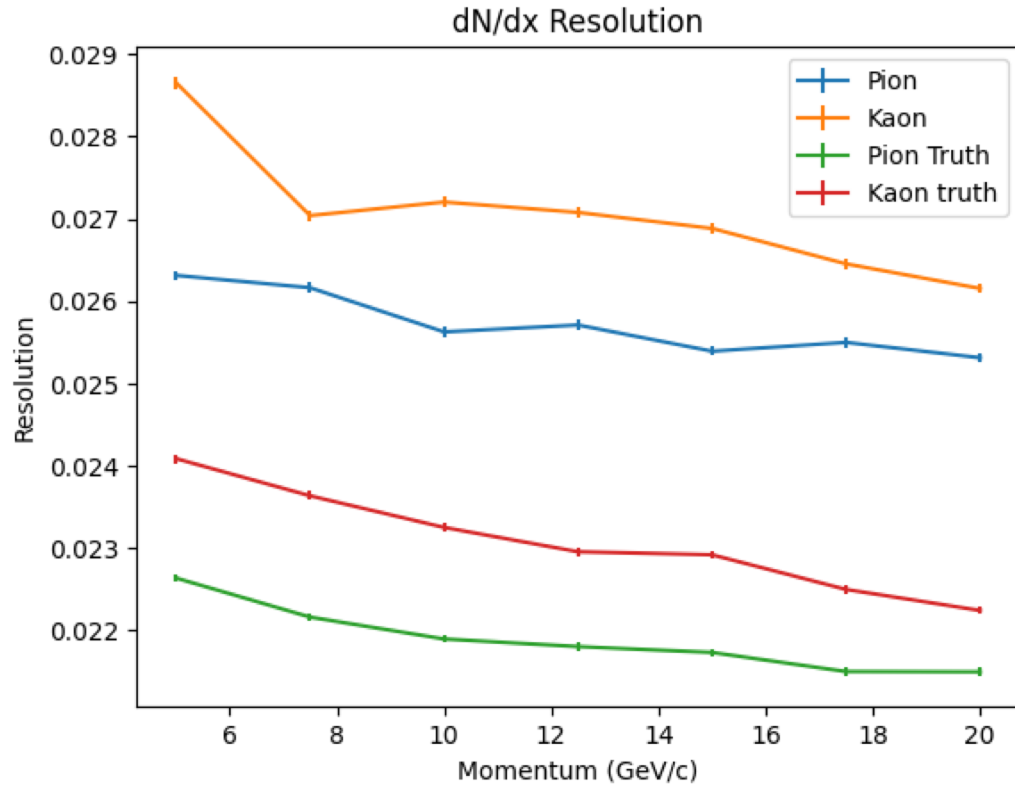
Vertical self weight  
**Buckling coefficient :**  
 ~12



Horizontal self weight  
**Buckling coefficient :** ~14



# dN/dx Resolution and separation power



- dN/dx resolution: 2.5%-2.6% for pion
- 2.6%-2.7% for Kaon

- 1.2 m track length
- For 20 GeV/c K/ $\pi$ , Separation power:  $3.2\sigma$

**LGAD**

# LGAD:

- The cost of the LGAD and AC-LGAD as silicon strip is same .
- The AC-LGAD/LGAD could offer good spatial resolution as showed in picture.

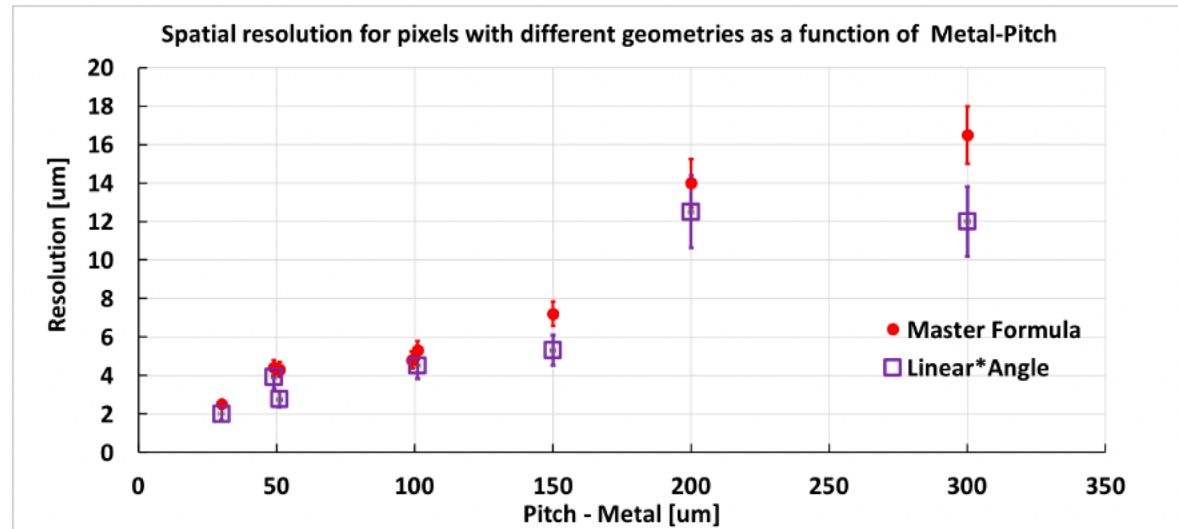
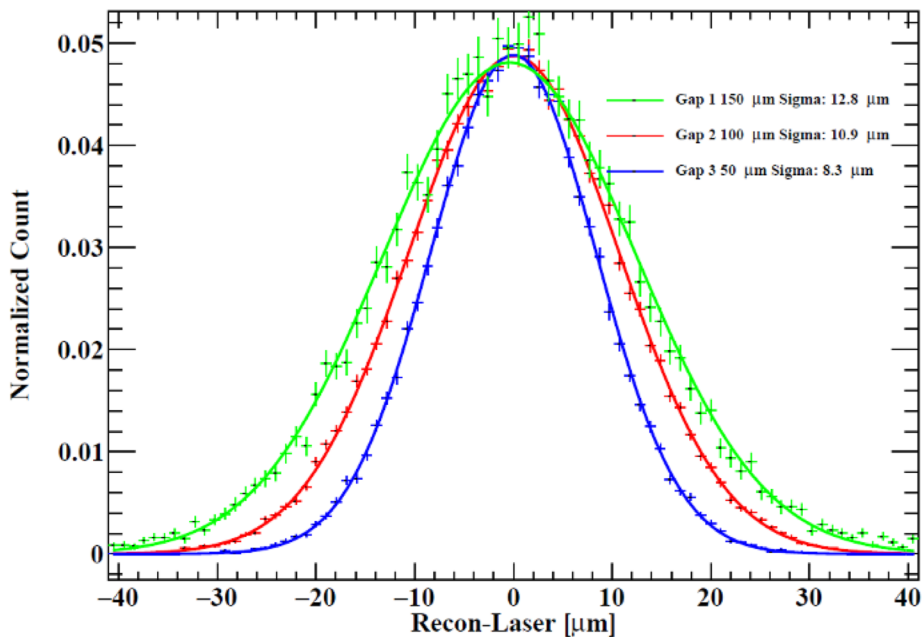
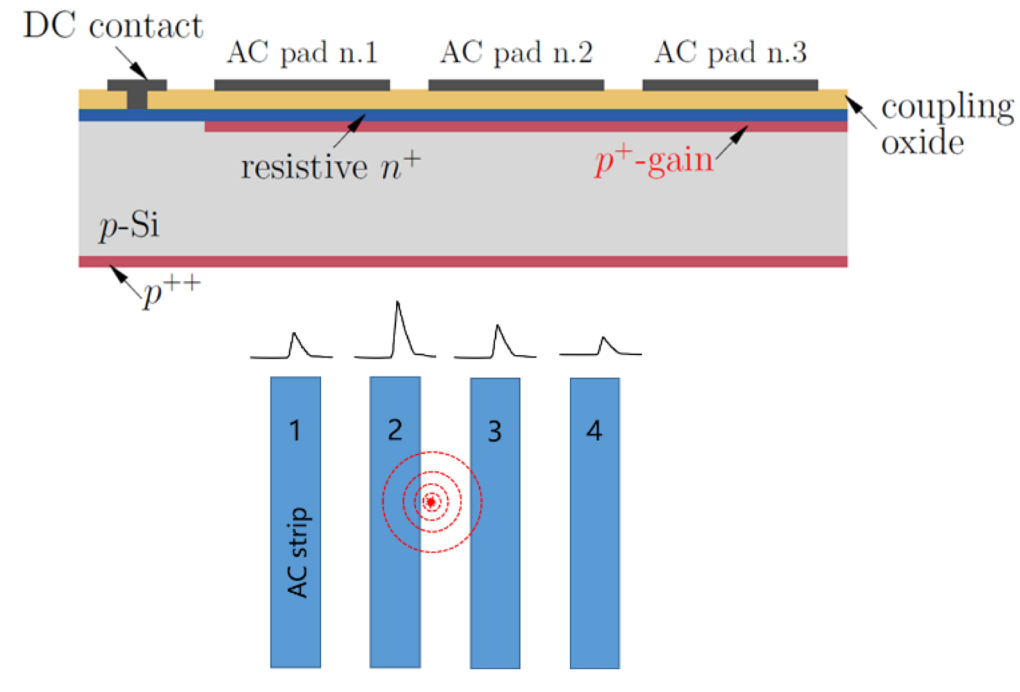
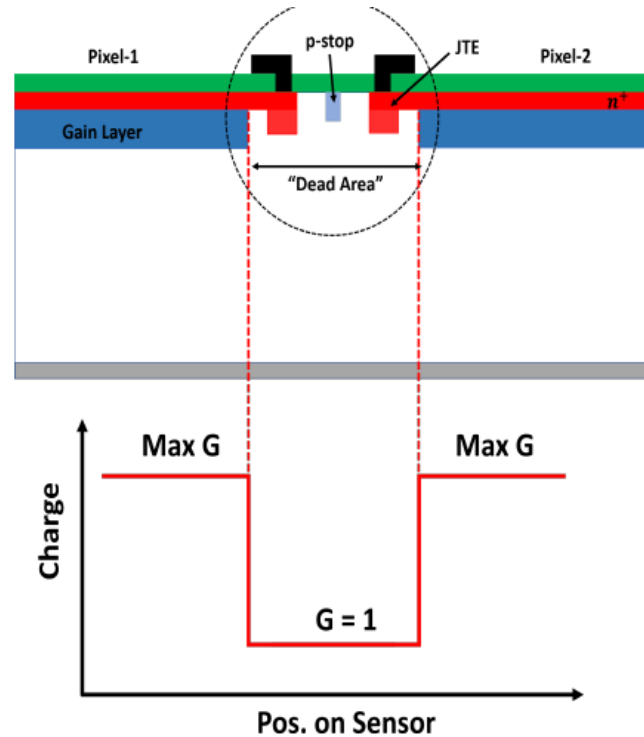


Figure 12: Spatial resolution for different RSD pad-pitch geometries as a function of the interpad distance obtained by reconstructing hit positions with both the MF (red points) and LA (purple squares) models.

# Candidate of ToF for CEPC

## Candidate of ToF for CEPC

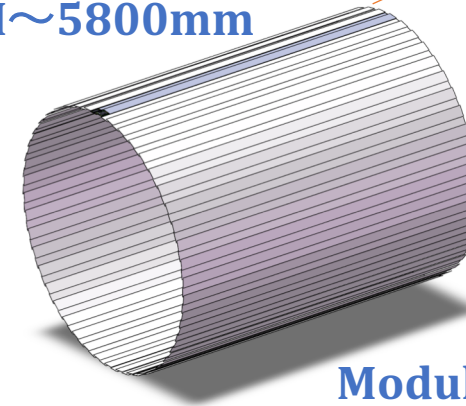
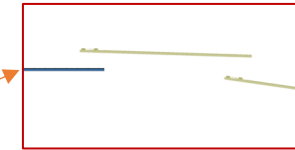
- LGAD: high timing resolution (30 ps) , low gain, high S/N,
- AC-LGAD: 4 dimension detection, no dead region



# LGAD: Arrangement of the ToF with strip LGAD: Barrel

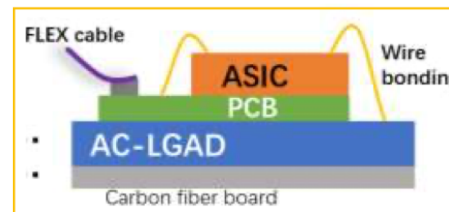
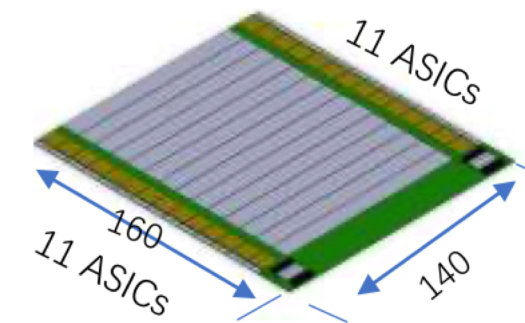
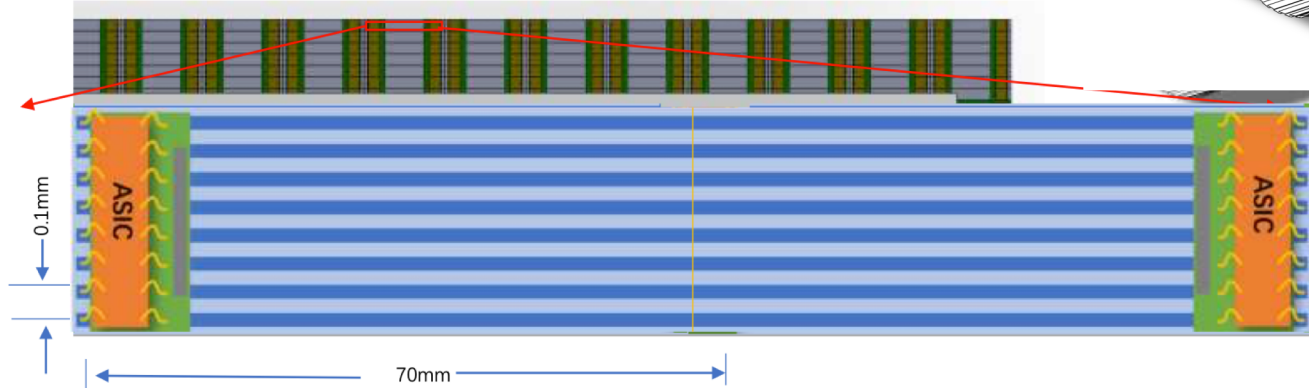
- One layer: 3780 modules
  - 90 ladders, 45 ladders each side,
    - ✓ 42 modules/ladder,
    - ✓ 22 ASIC/module, 128 Channel/ASIC

One layer ToF  
 $R = 1800 \text{ mm}$   
 $H \sim 5800 \text{ mm}$



Module  
140mm x 160mm

Ladder



# LGAD: Arrangement of the TOF with strip LGAD : Endcap

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

Module  
Longest side:  
140mm

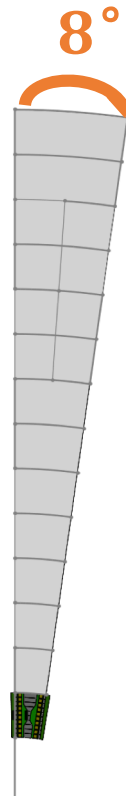
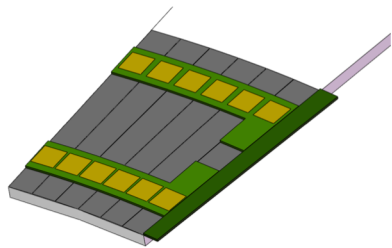
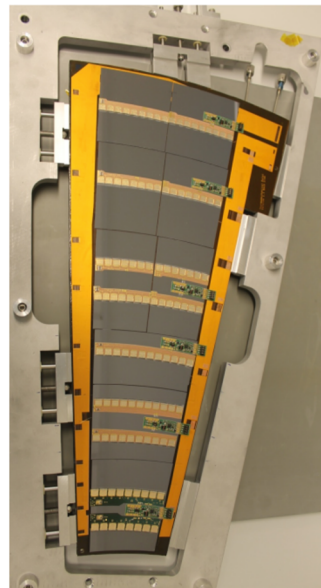


Figure 9.18: Photo of the thermo-mechanical petal prototype.



	CEPC TOF <b>endcap</b>
Area (m <sup>2</sup> )	$\sim 19.4$
Granularity	70mm $\times$ 0.1mm
Capacitance	$\sim 10$ pF
Charge	$>15$ fC
Channel number	$\sim 2 \times 10^6$
Module assembly	Wire bonding at strip
MIP Time resolution	$\sim 50$ ps
Spatial resolution	$\sim 10$ $\mu$ m (r or $\phi$ )
Number of Module	$\sim 900$ (14cm*) ( $8^\circ \times 45$ (petals number) = $360^\circ$ )
Number of channels per module	2816 (22 chips, 128 channel)



# LGAD: Electronic System Cost of LGAD ToF and OTracker

Items	Unit	Unit cost (RMB)	Quantity	Total cost (10k RMB)	备注
FEE板PCB	块	200	3780	76	
FEE ASIC (8mm*3mm)	通道	0.09	1.06E7	190	
二级汇总板+柔性板	块	700	540	38	
光纤	根 (20m)	200	540	10	
Connector (光纤)	对	2000	540	110	
Connector (柔性板)	对 (1m)	100	3780	40	
Cables(1LV+10HV)	根 (20m)	400	540	22	
Total				486	
Necessary R&D	Type			1460	FEE ASIC, 数据汇总ASIC, 高压模块, LpGBT_like,

$7\text{modules} \times 6\text{ staves} \times 90\text{ladders} = 3780\text{ modules}$

假设PoL和LpGBT能买到, total计算未含数据汇总芯片, 高压模块

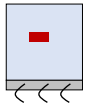
ASIC价格根据 SMIC 55nm计算, 工程批价格360万, 量产后价格2万/wafer

不含封装和打线

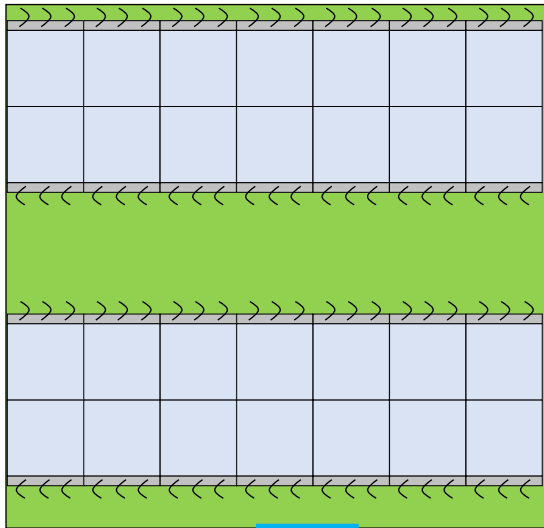
**Si pixel**

# Event rate assumption

- Assuming:
  - ◆ Physics event rate 112 kHz => 1 MHz for all event including physics, bkg, noise
  - ◆ Track multiplicity: 100
  - ◆ Cluster size: 3
- CMOS sensor
  - ◆ Pixel size:  $25 \times 150 \text{ um}^2$ .
  - ◆ Bits per hit: 48 bit.
- Outer tracker
  - ◆ Radius 1800 mm.
  - ◆ Length 5800 mm.
- Hit density: 0.74 kHz /  $\text{cm}^2$ .
- Data rate per chip: 140 kb/s



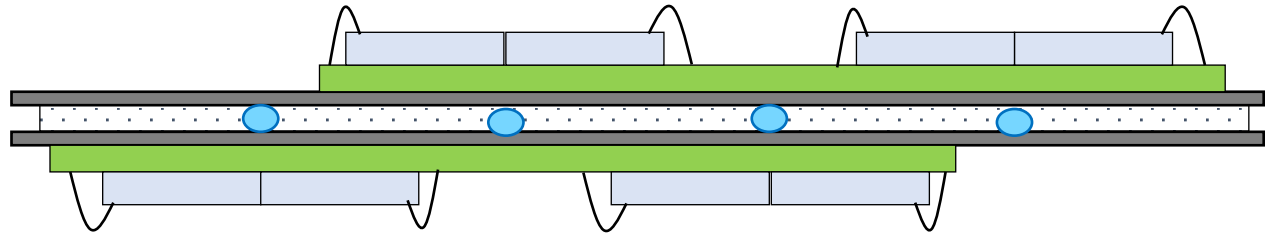
Sensor chip  
20×20 mm<sup>2</sup>



Module: 28 chips

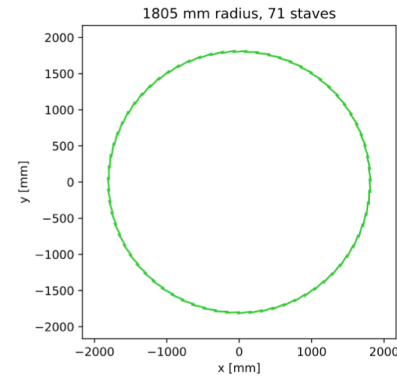
\* Rate per module: 4.0 Mb/s

\* Note: lpGBT supports up to 28 e-links

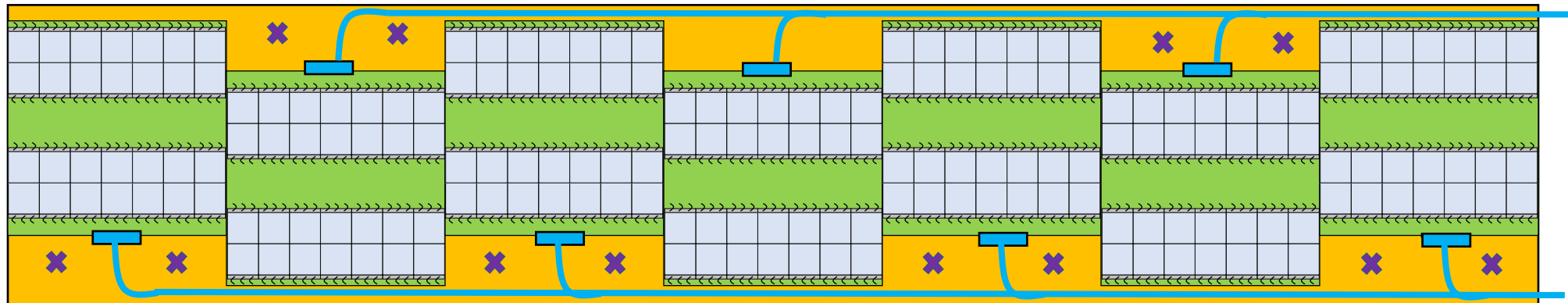


Modules mounted on both sides of staves to cover inefficient area  
Cooling pipes embedded in stave/ladders

1 ladder (5880 mm) = 42 modules × 2 sides



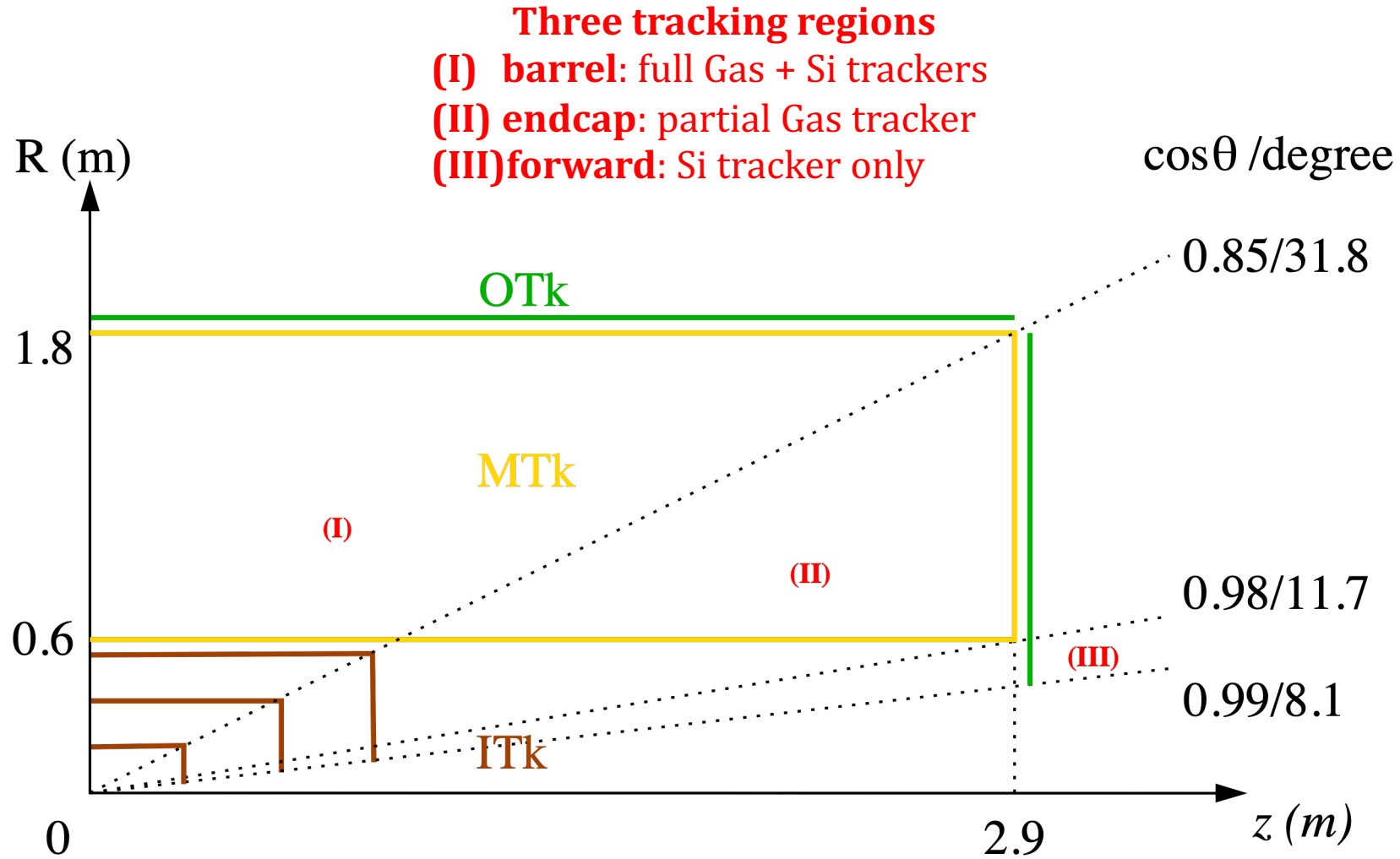
71 staves  
5964 modules  
1.67 million chips



□ Sensor chip  
□ Hybrid PCB

— Optical convertor & fibre  
× Mechanical support (one side only)

# CEPC tracking system, draft



# CDR layout for acronyms

