# LGAD based time of flight and outer tracker

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#### LGAD development for CEPC time of flight detector: Motivation

- CEPC will produce 10<sup>12</sup> Z boson at Z pole: Rich flavor physics program
- Particle separation problems of Gas detector (dE/dx) for CEPC flavor physics:
  - 0.5-2 GeV for K/pi separation, >1.5 GeV for K/p separation
- CEPC International Advisory Committee: one of the key recommendations

Precision timing detector should be determined as a matter of urgency (4D track)

Timing detector is complementary to gas detector: improves the separation ability

**0** - **4** GeV for K/pi separation, **0** – **8** GeV for K/p separation





#### CEPC 4D outer tracker



#### CEPC 4D outer tracker concept design:

- Should be part of SET (silicon wrapper layer outside TPC or drift chamber)
- Serve as Timing detector and part of the tracker
- Barrel : 50 m<sup>2</sup> , Endcap 20 m<sup>2</sup> , ~ 10<sup>6</sup> channels
- Strip AC-LGAD (each strip: **4 or 10 cm** imes **0.05cm**)
  - Timing resolution: 30-50 ps
  - Position resolution: ~ 10  $\mu$ m @ R-phi direction
    - ~ 1mm @ z direction



Wire

#### Strip AC-LGAD + ASIC :

- TOT->amplitude->charge sharing->position
- TOA+TOT->timing (time-amplitude correction)



### Time of flight and Tracker

- There were two options for LGAD based
  - Conventional LGAD (TOF only)
    - 30-50ps timing resolution
  - AC-LGAD TOF + outer tracker (SET)
    - 30-50ps timing resolution
    - 10um spatial resolution

				From Jianchun	
System	Technologies				
	SPD ITrk				
Tracker	Pixelated TPC	PID Drift Ch			
& PID	SSD OTrk	SPD OTrk		AC-LGAD	
	LGAD ToF			OTrk	



#### Introduction of AC-LGAD





- No dead area
- Lower readout electronics, no bump bonding
- Position information: 2 layers for (x,y)



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#### AC-LGAD R & D status



- Laser test result of strip AC-LGAD sensor
  - It can reach about  $\sim 10 \mu m$  resolution with 150um pitch strip detector
  - While timing resolution of AC-LGAD is still can reach 30-50ps



Strips AC-LGAD:

Different Pitch size:

Strip length 5.6mm, width 100um

150um、200um、250um



#### AC-LGAD R & D status

> Aim for  $\sim 10 \,\mu$  m spatial resolution (1D) with 10cm × 0.05cm strip size (500  $\mu$ m pitch)

- It is possible to achieve that with AC-LGAD strip detector
- While keeping 30-50 ps timing resolution





[1]M. Mandurrino et al., "Demonstration of 200-, 100-, and 50-μm pitch Resistive AC-Coupled Silicon Detectors (RSD) with 100% fill-factor for 4D particle tracking", IEEE Electron Device Lett. 40(11), 1780-1783 (2019), DOI: 10.1109/LED.2019.2943242

[2] A. Apresyan, et al., Measurements of an AC-LGAD strip sensor with a 120 GeV proton beam, Journal of Instrumentation, 15 (2020) P09038, 2020.

#### Spatial resolution Vs. pitch size (by IHEP, FBK and BNL )

	Pitch size	Spatial resolution	Time resolution
Sensors	[µm]	[µm]	[ps]
IHEP AC-LGAD	2000	15	22 (laser)
FBK AC-LGAD	500	11	32 (laser)
BNL AC-LGAD	100	-	45 (beta source)



#### ATLAS HGTD VS CEPC TOF detector

- > ATLAS HGTD technology may need to adjust a bit to be used in CEPC
  - Need to develop large-area pad/strip LGAD sensor for CEPC application
  - Reduce the dead area between channels (AC-LGAD development)

	ATLAS HGTD	CEPC TOF
Area (m²)	6.4	~ 70
Granularity	<mark>mm²</mark> (1.3 mm ×1.3mm )	<mark>~ cm<sup>2</sup></mark> (100mm × 0.2mm)
Channel number	~ 3.6 × 10 <sup>6</sup>	~ 3.5×10 <sup>6</sup>
Module assembly	Bump bonding	Wire bonding at strip
MIP Time resolution	30-50 ps	30-50 ps
Spatial resolution	~ 300 µm	~ 10 µm
Dead area between	~50µm	no dead area



#### CEPC LGAD TOF Cost estimation

- Estimated cost is about 80M RMB (uncertainty 30%)
- Major cost is LGAD silicon sensor (70m<sup>2</sup> area)

Cost (RMB)	ATLAS HGTD	CEPC LGAD TOF
LGAD Sensor	17M (6.4m <sup>2</sup> )	35 M (70m <sup>2</sup> area)
Electronics and power supply	21M	21M
Module assembly	10.5M	10M
Mechanics, cooling	17.5M	10 M
DAQ, slow control	2.3M	2M
Detector global assembly	1.1M	2 M
Installation and commissioning	0.6M	1 M
Total	~70M	81M



### CEPC LGAD TOF Cost estimation (2): silicon sensor

- Major cost is LGAD silicon sensor (70m<sup>2</sup> area)
  - Lower requirement on radiation hardness
  - Much easier to design and fabricate
- Aiming to reduce the cost of LGAD based strip silicon sensor
  - 0.5M RMB per m<sup>2</sup>
  - A factor of 2 lower than ATLAS ITK strip sensor from HPK
  - A factor of 5 lower than ATLAS HGTD sensor

Cost (RMB)	Area (m <sup>2</sup> )	Sensor Cost (RMB)	Cost per m <sup>2</sup>
ATLAS ITK strip (6 inch)	165	165M	1M
ATLAS HGTD (8 inch)	6.4	17M	2.65M
CEPC LGAD based TOF (8 inch)	70	35M	0.5 M (in next 5 year)



### CEPC LGAD TOF Cost estimation (3): silicon sensor

- Aiming to reduce the cost of LGAD based strip silicon sensor
  - 0.5M RMB per m<sup>2</sup>
  - A factor of 2 lower than ATLAS ITK strip sensor from HPK
    - 8 inch line in IHEP, engineering run fee is lower
  - A factor of 5 lower than ATLAS HGTD sensor
    - Yield is higher in AC-strip, less processing due to lower radiation requirement

Cost (RMB)	Cost per unit	Yield	Number of wafer per m <sup>2</sup>	CEPC LGAD TOF Cost per m <sup>2</sup>
Wafer	0.0015 M	80%	64	0.1 M
Engineering run	0.005 M	80%	64	0.32M
Testing				0.08 M
Total				0.5M



# Plan of LGAD outer tracker + TOF (reference TDR)

- Detector feasibility study and geometry physics optimization
- Module and support structure and cooling design
- Cost breakdown and estimation
  - The most important: Realistic cost estimation based on ATLAS HGTD experience
- LGAD sensor :
  - Testing full-size AC-LGAD strip sensor, verify its spatial resolution
- ASIC R & D:
  - Plan to collaboration with IHEP TOF-PET ASIC team. (similar TDC requirement)





### Backup



### Strip direction resolution from double side readout





# Timing resolution (different dimension of strip )



#### **Application of AC-LGAD**





X-ray detectors @ advanced light sources





#### other applications

- Beam Telescope for Beam Test Platform
- LiDAR: Positioning and Navigation
- Track and time detectors in other particle physics and nuclear physics experiments

• ...



#### 4.1 AC-LGAD sensor test :





#### Picosecond laser test



#### Picosecond laser scanning system

- Displacement accuracy 1  $\mu$ m ٠
- Automated scanning ٠
- Picosecond laser 1064nm ٠
- Spot size 2~5 µm •





# Plan and funding needed

- AC-LGAD sensor
  - Small MPW chips developed, but there is no full-size sensor
  - Still need 2~3 round of engineering run (2M RMB)
- ASIC:
  - Expect to develop based on ASIC chip developed TOF-PET (1.5M RMB)
  - Still need at least one engineering run to modify this ASIC chip for AC-LGAD
    - Sensor capacitance and raising time is difference
    - Clock structure and logic is different

	CEPC TOF
AC-LGAD runs	2 M RMB
ASIC engineering run	1.5 M RMB
Total	3.5 M RMB



# HGTD Module assembly

- 225 front-end channels (15 imes 15) in each module
  - Fast ASIC and LGAD connected by bump bonding
  - Dead area between pixels is about 50 μm





FLEX tail

IV connecto

2 LGADs (2 x 2 cm<sup>2</sup>)

HV wire-bonding

Connecto

Components

ASIC

Module FLEX