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^{12} Z boson at Z pole: Rich flavor physics program

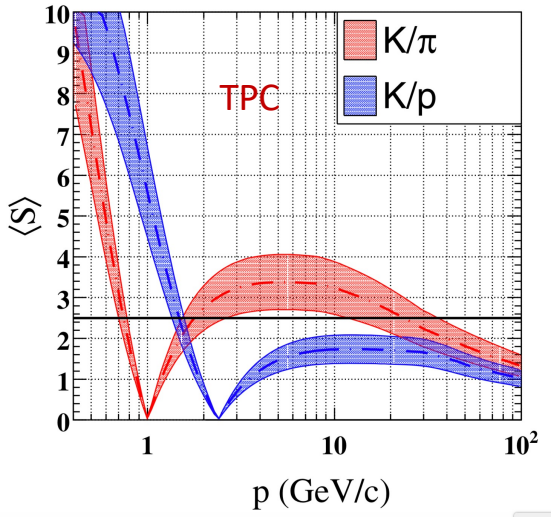
- **Particle separation problems** of Gas detector (dE/dx) for CEPC flavor physics:
  - **0.5-2 GeV for K/pi separation, >1.5 GeV for K/p separation**

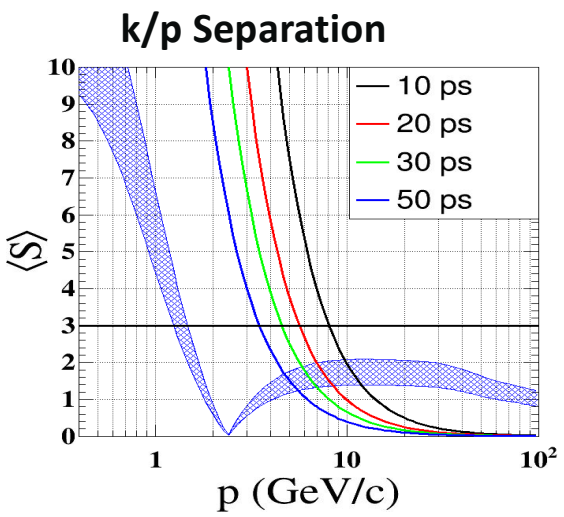
- **CEPC International Advisory Committee: one of the key recommendations**

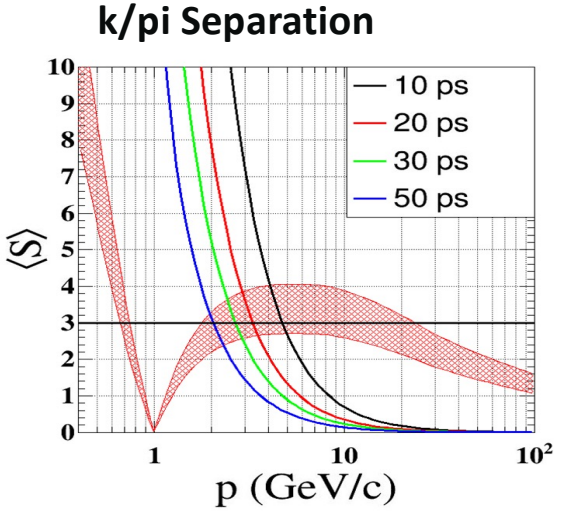
Precision timing detector should be determined as a matter of urgency (4D track)

- **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

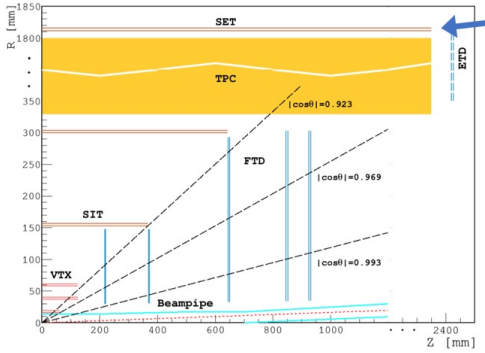




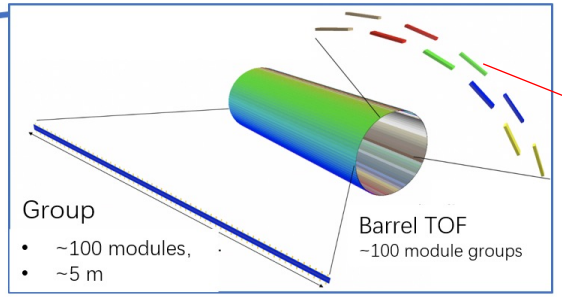


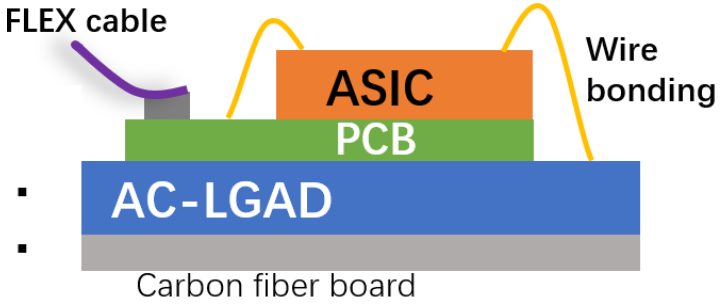
CEPC 4D outer tracker

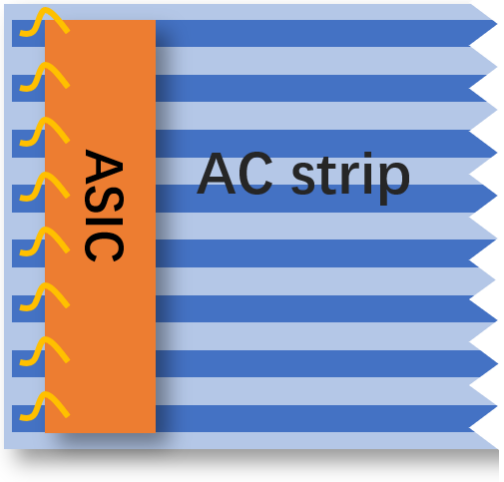
Baseline detector concept in CDR



LGAD timing detector in Barrel region







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^2 , Endcap 20 m^2 , **~ 10^6 channels**
- Strip AC-LGAD (each strip: **4 or 10 cm × 0.05cm**)
  - Timing resolution: 30-50 ps
  - Position resolution: ~ 10 μm @ R-phi direction

Strip AC-LGAD + ASIC：

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

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Time of flight and Tracker

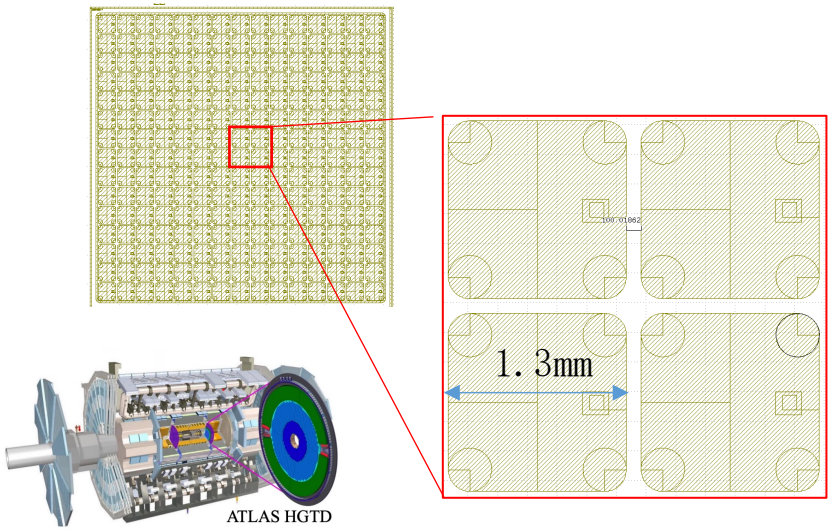
- There were two options for LGAD based
  - Conventional LGAD (TOF only)
    - 30-50ps timing resolution
  - AC-LGAD TOF + outer tracker (SET)
    - 30-50ps timing resolution
    - 10um spatial resolution

From Jianchun

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

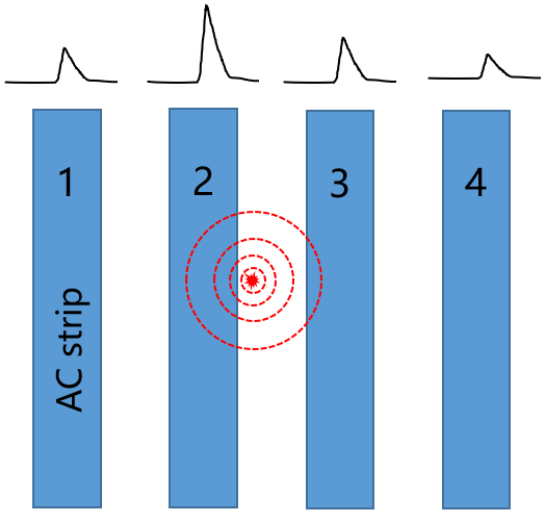
Introduction of AC-LGAD

15×15 LGAD for ATLAS HGTD project



- Dead zone : ~0.1mm
- Pixel size: 1.3mm

AC-LGAD：two layout schemes for AC-pads



Strips AC-LGAD:

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

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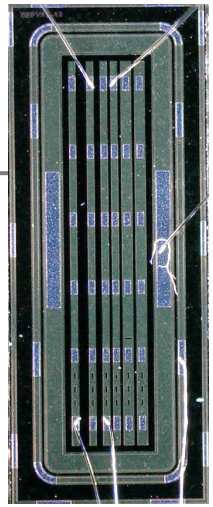
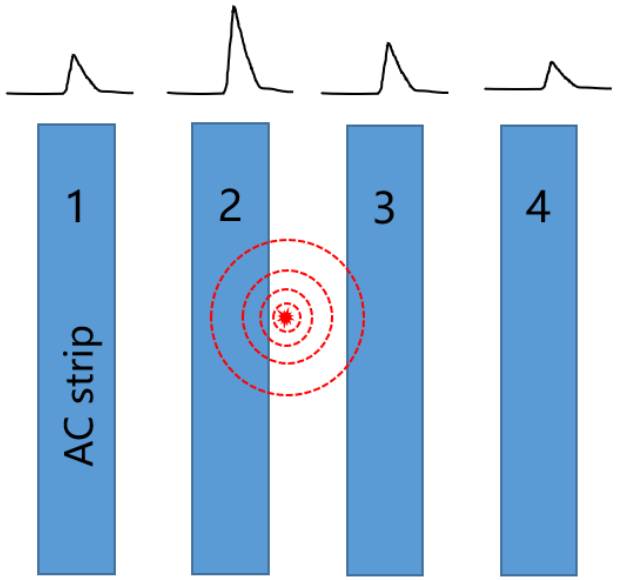
AC-LGAD R & D status

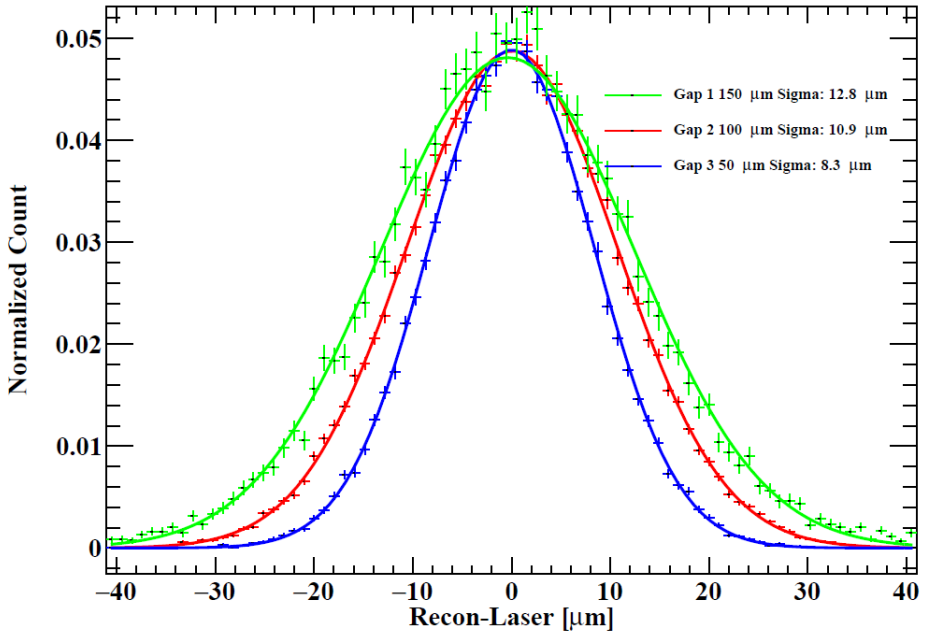


Strips AC-LGAD:

- Strip length 5.6mm, width 100um
- Different Pitch size:
  - **150um、200um、250um**

- Laser test result of strip AC-LGAD sensor
  - It can reach about ~10μm resolution with 150um pitch strip detector
  - While timing resolution of AC-LGAD is still can reach 30-50ps

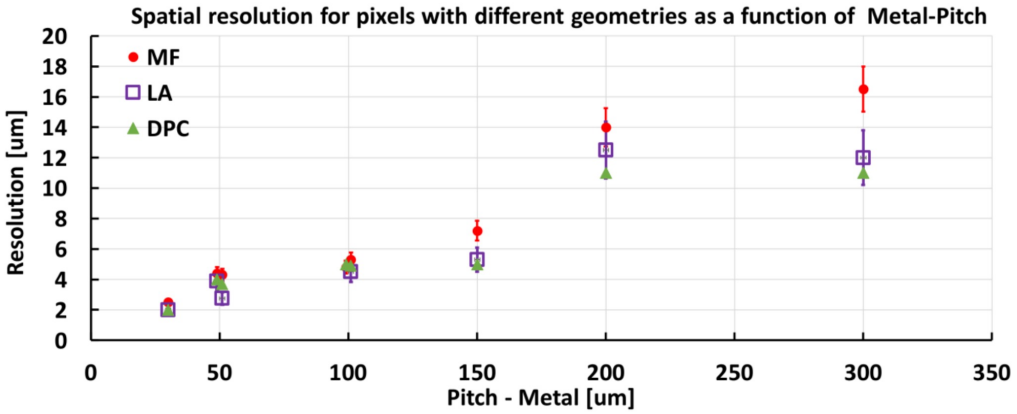




AC-LGAD R & D status

- Aim for ~10 μm spatial resolution (1D) with 4cm × 0.05cm strip size (500 μm pitch)
  - It is possible to achieve that with AC-LGAD strip detector
  - While keeping 30-50 ps timing resolution

Spatial resolution Vs. pitch size



[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)

Sensors	Pitch size [μm]	Spatial resolution [μm]	Time resolution [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 (m^2)	6.4	~ 70
Granularity	mm^2 (1.3 mm ×1.3mm)	~ cm^2 (100mm × 0.2mm)
Channel number	**~ 3.6 × 10^6**	**~ 3.5×10^6**
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^2 area)

Cost (RMB)	ATLAS HGTD	CEPC LGAD TOF
LGAD Sensor	17M (6.4m^2)	35 M (70m^2 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

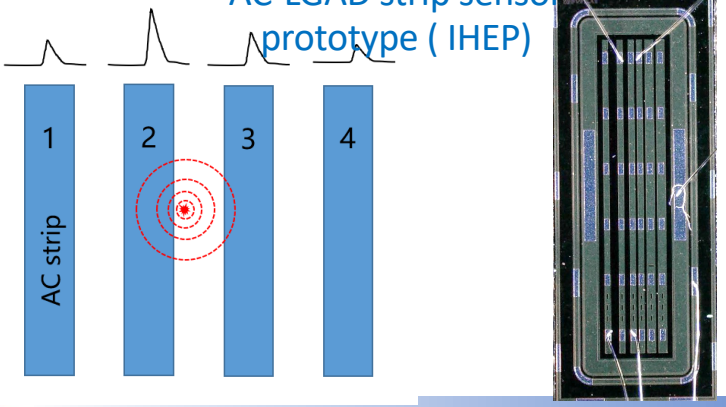
- Major cost is LGAD silicon sensor (70m^2 area)
  - Lower requirement on radiation hardness
  - Much easier to design and fabricate
- Aiming to reduce the cost of LGAD based strip silicon sensor
  - 0.5M RMB per m^2
  - A factor of 2 lower than ATLAS ITK strip sensor from HPK
  - A factor of 5 lower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

Cost (RMB)	Area (m^2)	Sensor Cost (RMB)	Cost per m^2
ATLAS ITK strip	165	165M	1M
ATLAS HGTD	6.4	17M	2.65M
CEPC LGAD based TOF	70	35M	0.5 M

Plan of LGAD outer tracker + TOF (reference TDR)

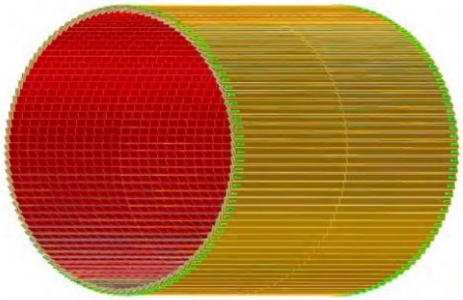
- Detector feasibility study and geometry physics optimization
- Module and support structure and cooling design
- Cost breakdown and estimation
  - The most important: Realistic cost estimation based on ATLAS HGTD experience
- LGAD sensor :
  - Testing full-size AC-LGAD strip sensor, verify its spatial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

AC-LGAD strip sensor prototype (IHEP)

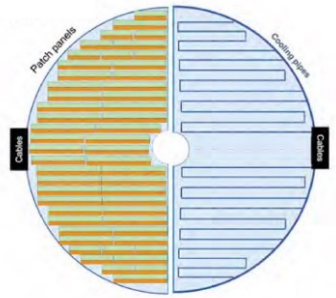


AC-LGAD based
Outer tracker+ TOF in EIC (BNL)

Barrel AC-LGAD detector



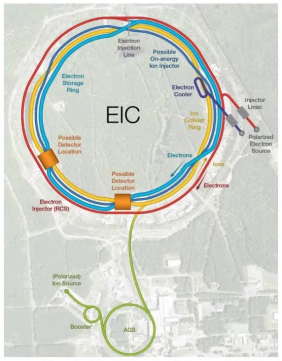
Hadron endcap AC-LGAD detector



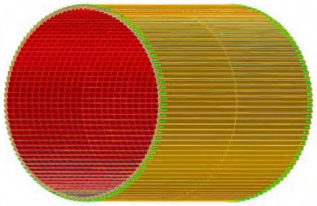
Backup

Application of AC-LGAD

Electron-Ion Collider (EIC)： Timing-tracker

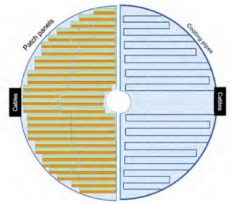


Barrel AC-LGAD detector



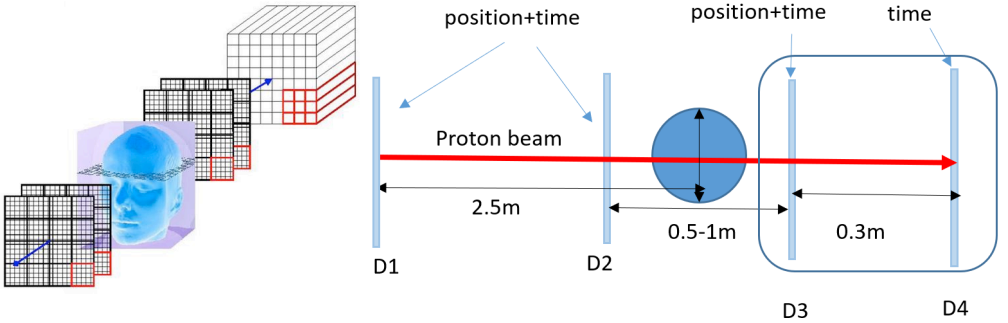
10.9 m^2

Hadron endcap AC-LGAD detector

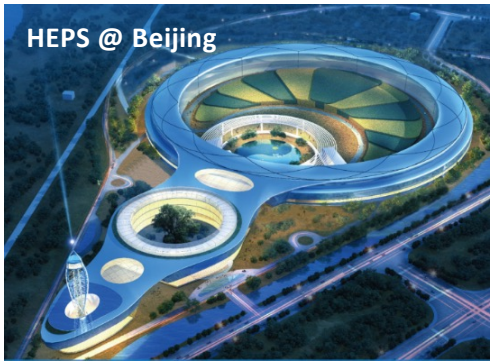


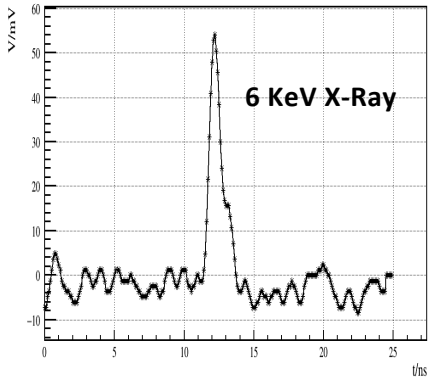
2.22 m^2

Nuclear Medicine Instruments：
Such as proton therapy and proton CT



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
- …

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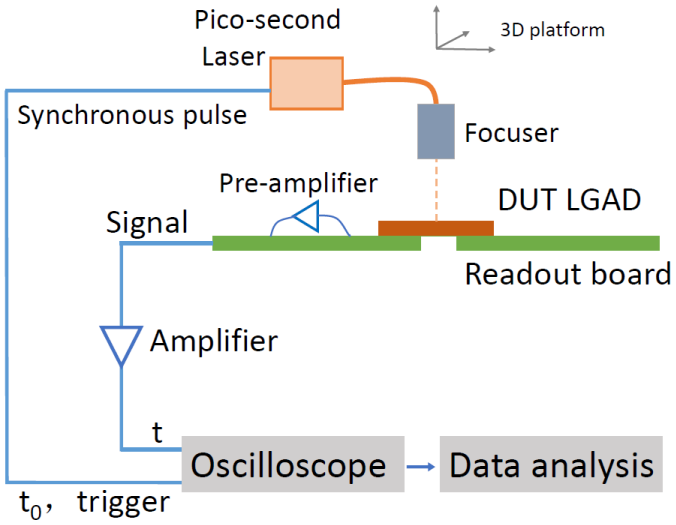
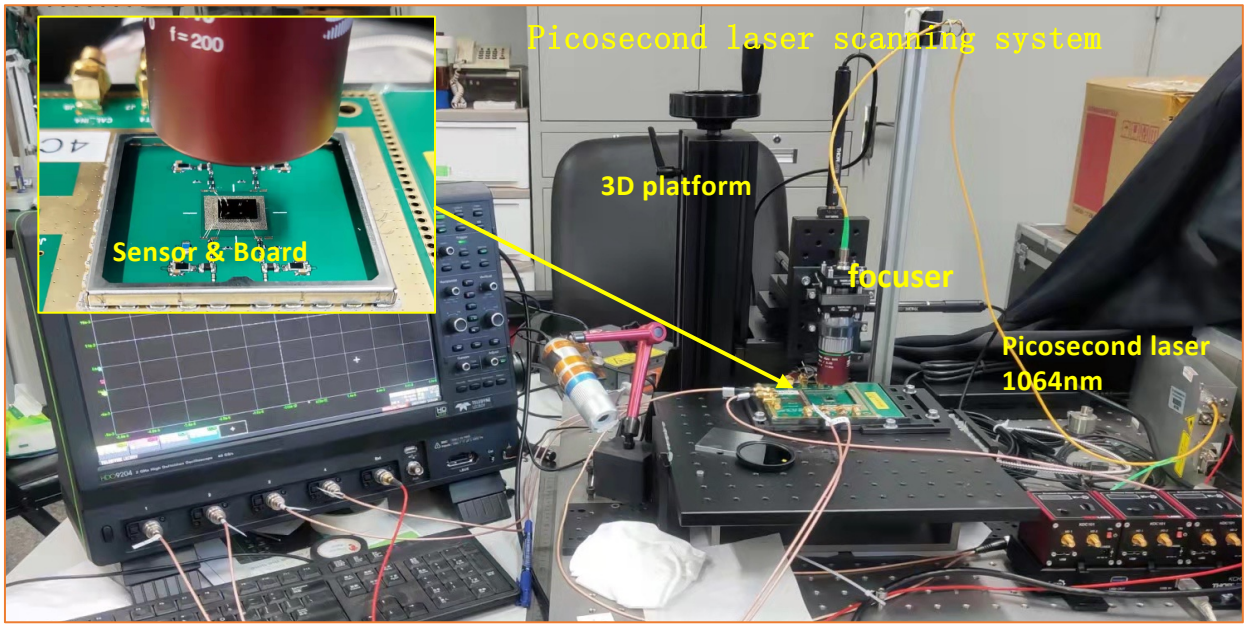
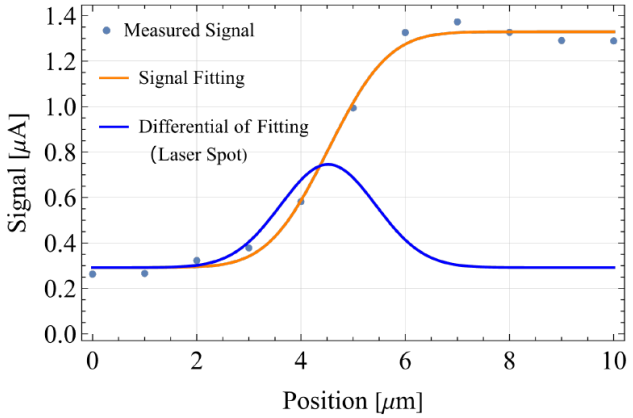
4.1 AC-LGAD sensor test： Picosecond laser test

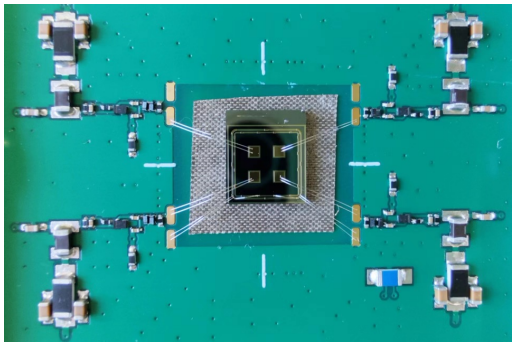






Picosecond laser scanning system

- Displacement accuracy 1 μm
- Automated scanning
- Picosecond laser 1064nm
- Spot size 2~5 μm



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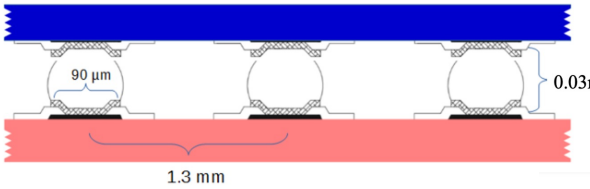
Plan and funding needed

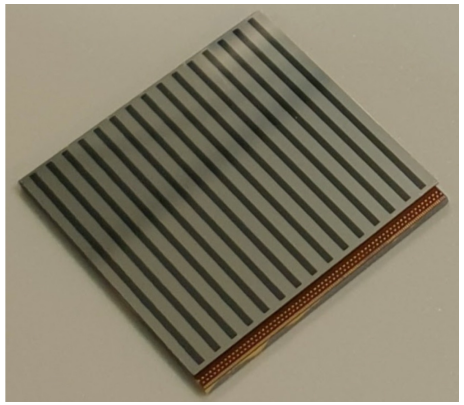
- AC-LGAD sensor
  - Small MPW chips developed, but there is no full-size sensor
  - Still need 2~3 round of engineering run (2M RMB)
- ASIC:
  - Expect to develop based on ASIC chip developed TOF-PET (1.5M RMB)
  - Still need at least one engineering run to modify this ASIC chip for AC-LGAD
    - Sensor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

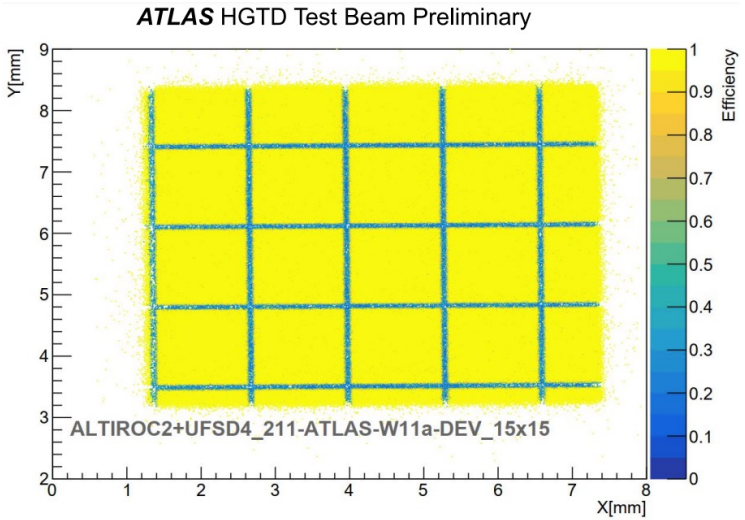
HGTD Module assembly

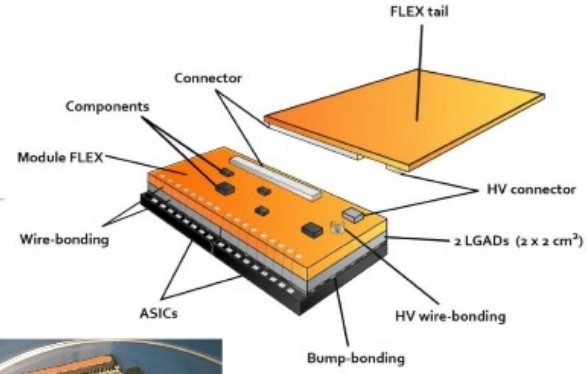
- 225 front-end channels (15 ×15) in each module
  - Fast ASIC and LGAD connected by bump bonding
  - Dead area between pixels is about 50 µm

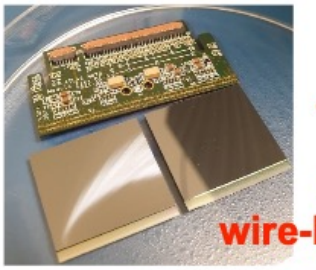




15 ×15 pixels efficiency map
In module beam test







glue+
wire-bonds