CEPC Time of flight detector R&D based on Low Gain Avalanche Diodes technology

Tianyuan Zhang, Mengzhao Li, Wei Yi,
Mei Zhao, Zhijun Liang,
On behalf of IHEP HGTD group

Institute of High Energy physics, CAS

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Nanjing

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:

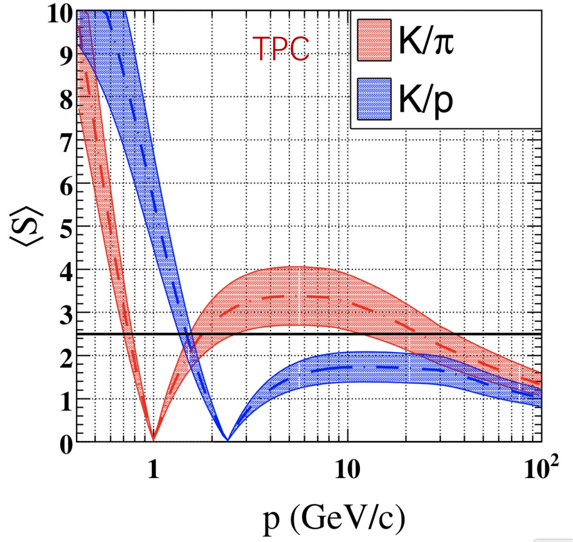
  0.5-2 GeV for K/pi separation, >1.5 GeV for K/p separation

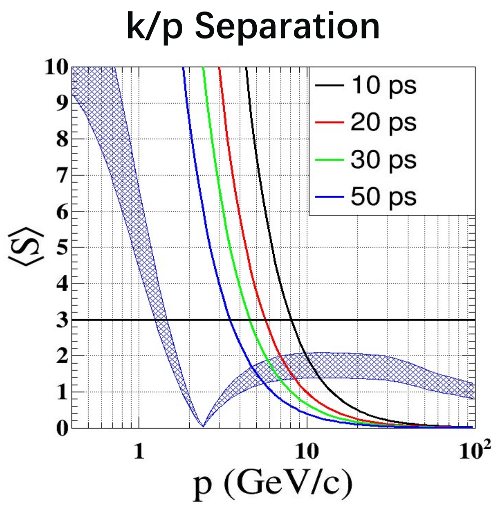
- **CEPC International Advisory Committee: one of the key recommendations**

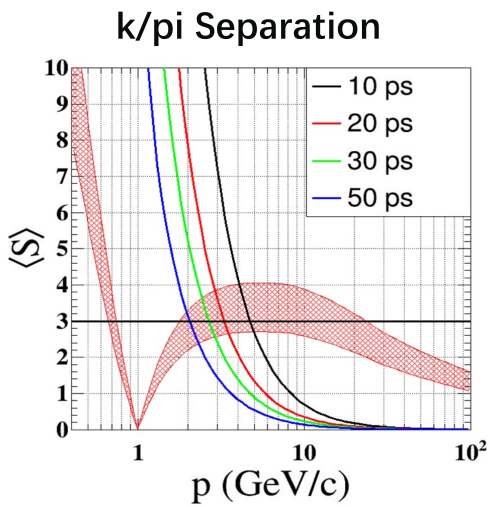
  Precision timing detector should be determined as a matter of urgency (4D track)

- **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





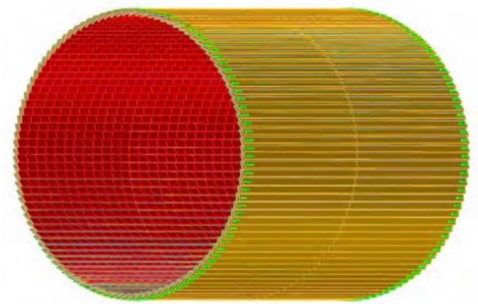


Other LGAD-based TOF detector proposal

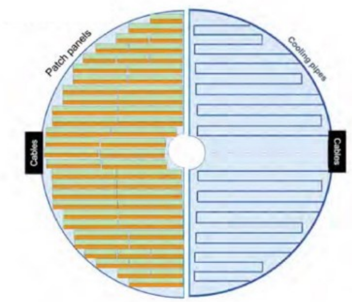
- **Electron-Ion Collider (EIC) ：**
  - Outer layer of Tracker and TOF detector
  - Central detector(ETTL, CTTL, FTTL)， Far-Forward detector AC-LGAD
- **REDTOP: LGAD tracker**
  - 4D tracking reconstruction for multihadron rejection

EIC： AC LGAD-based
Outer layer of Tracker and TOF detector

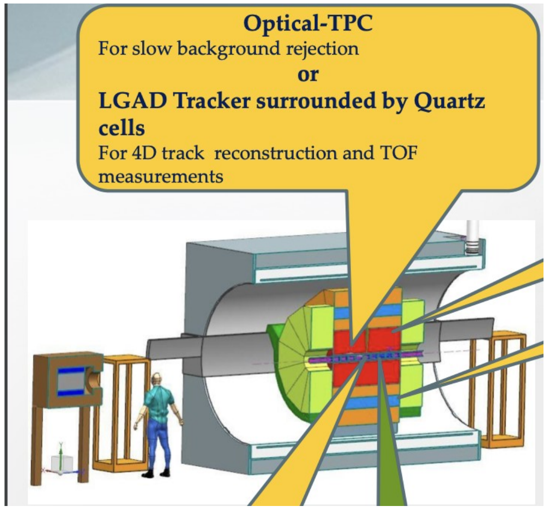
Barrel AC-LGAD detector



Hadron endcap AC-LGAD detector



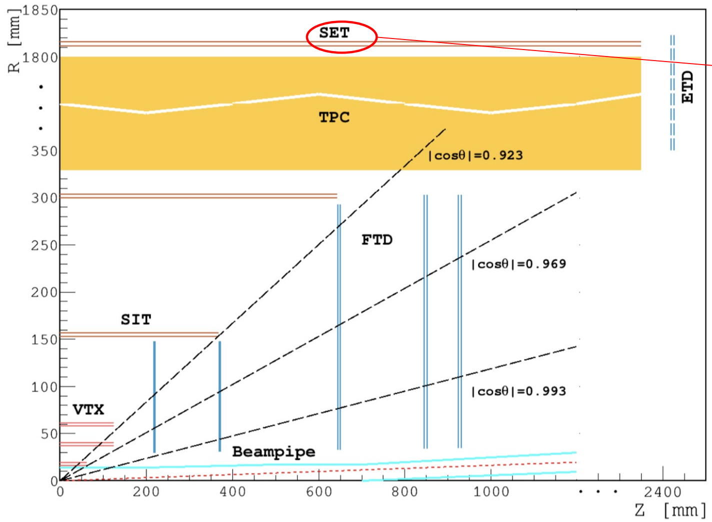
REDTOP: LGAD tracker

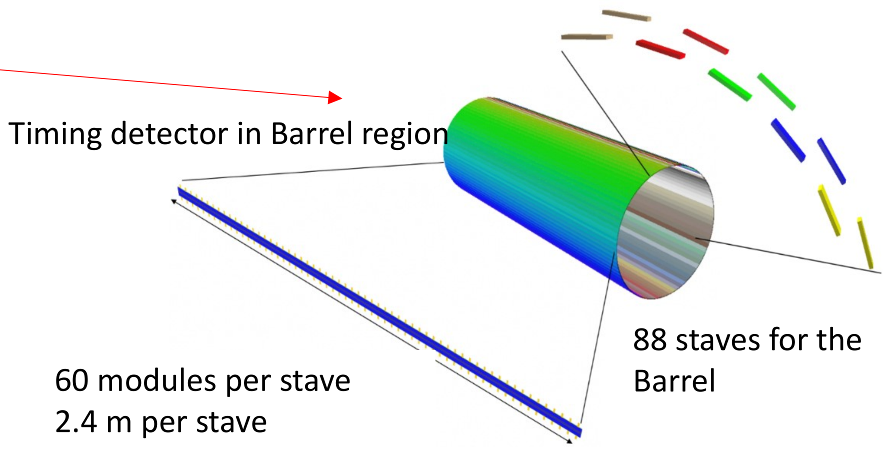


CEPC timing detector: Concept

- CEPC time of flight detector based on LGAD (EIC proposed LGAD-based TOF detector)
  - Area of detector (Barrel : 50 m^2 , Endcap 20 m^2), **~ 106 channels**
  - Strip-like sensor (each strip: 4cm × 0.1 cm)
  - Should be part of SET (silicon wrapper layer outside TPC or drift chamber)
    - Serve as Timing detector and part of the tracker
    - Timing resolution: **30-50 ps**
    - Spatial resolution: **~ 10 μm**

Baseline detector concept in CDR





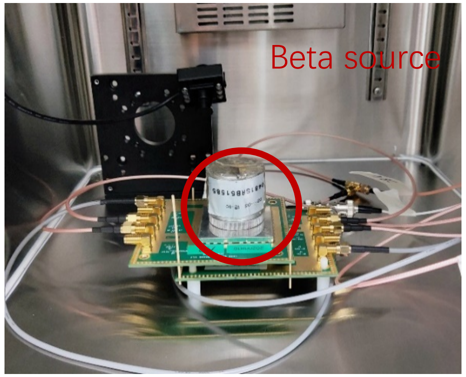
ATLAS HGTD VS. CEPC TOF detector

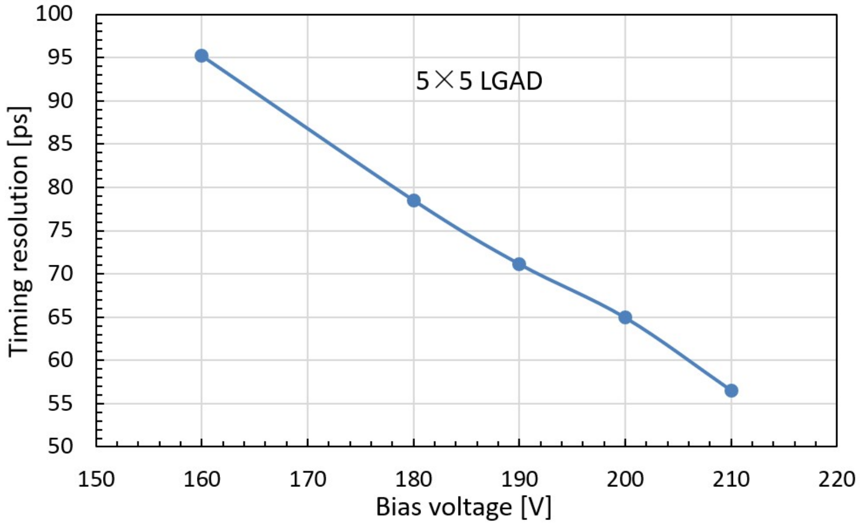
- ATLAS HGTD technology may need to adjust a bit to be used in CEPC
  - Need to develop large-area pad/strip LGAD sensor for CEPC application
  - Reduce the dead area between channels (AC-LGAD development)

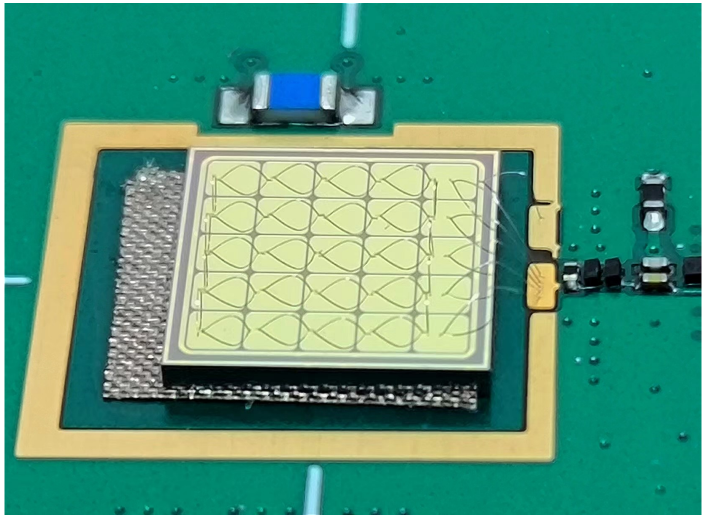
	ATLAS HGTD	CEPC TOF
Area (m^2)	6.4	~ 70
Granularity	mm^2 (1.3 mm ×1.3mm)	~ cm^2 (4cm × 0.05cm)
Channel number	**~ 3.6 × 10^6**	**~ 3.5×10^6**
Module assembly	Bump bonding	Wire bonding at strip
MIP Time resolution	30-50 ps	30-50 ps
Spatial resolution	~ 300 µm	~ 10 µm
Dead area between	~50µm	no dead area

The Large-pad LGAD

- **Time resolution test of large aera LGAD: ~55 ps**
  - Area for one channel : 6.5 mm x 6.5 mm
  - 5 x 5 LGAD connected by wire bonding
    - To mimic the large aera LGAD
  - This result is before any sensor optimization for CEPC

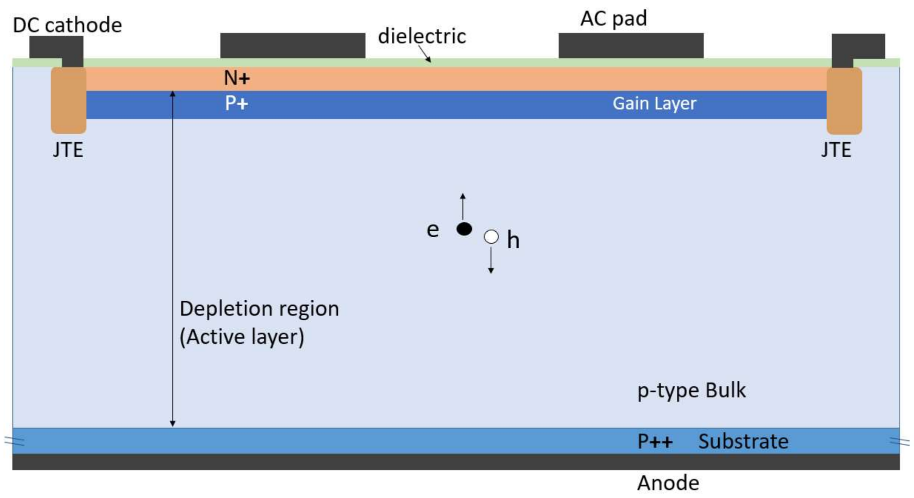






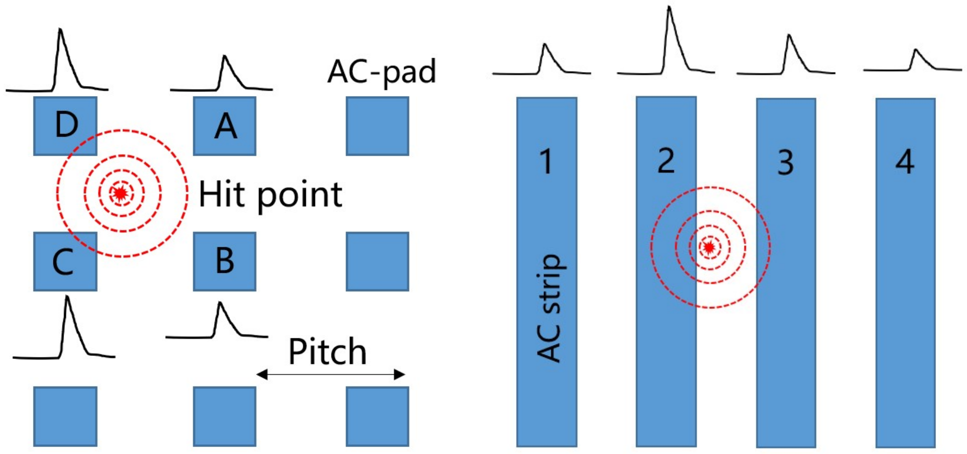
5*5 Large area LGAD sensor Connected by wire bonding

The AC-LGAD introduction



AC-LGAD：two layout schemes for AC-pads

(No dead area between channels)



- Metal AC-pads separated from the n+ layer by a thin dielectric (SiO_2, Si_3N_4)
- **No dead zone (100% fill factor)**
- **Position resolution: 5~10 um**
- **Time resolution ~ 30ps**
- Radiation hardness： same as LGAD

Pixels AC-LGAD:
- Position information: **1 layer (x,y)**
- Bump bonding

Strips AC-LGAD:
- Position information: **2 layers for (x,y)**
- Lower readout electronics density, no bump bonding

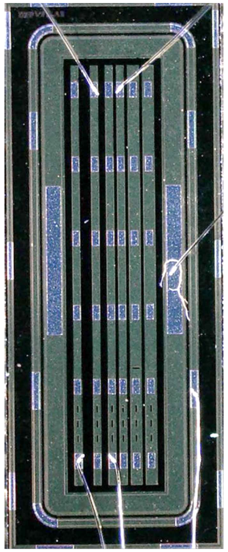
IHEP AC-LGAD R & D

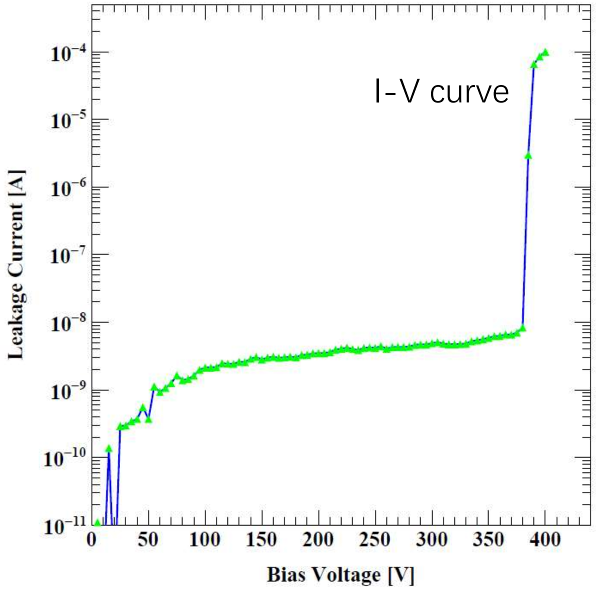
Strips AC-LGAD：

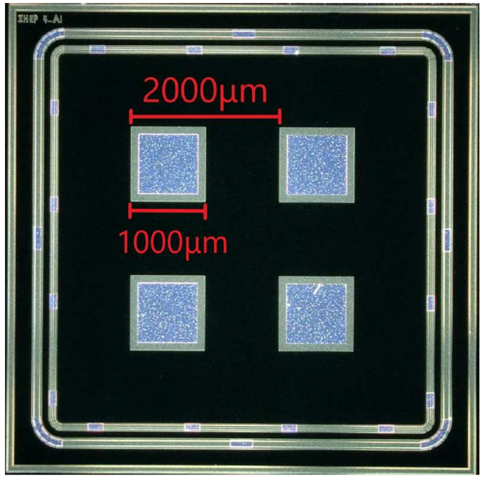
- Strip length 5.6mm, width 100um
- Different Pitch size：
  150um、200um、250um

Pixels AC-LGAD：

- Pitch size 2000um, pad size 1000um
- Different N+ dose：
  10P，5P，1P，0.5P，0.2P



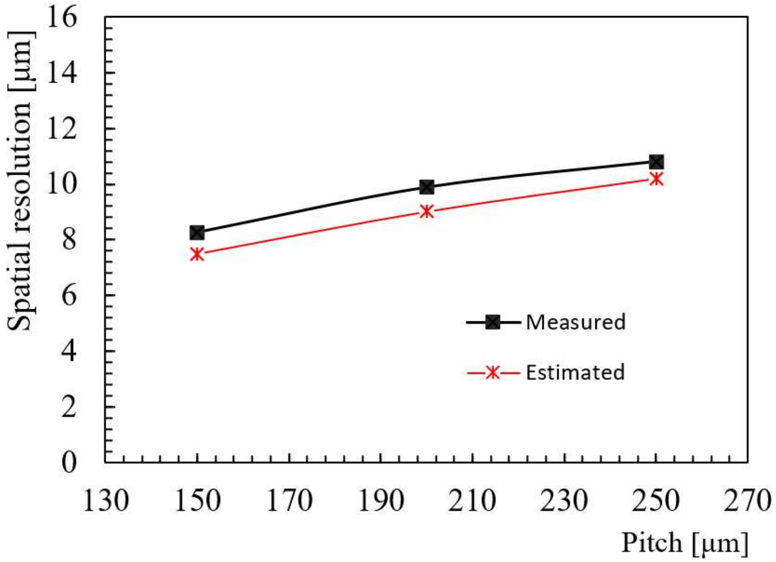




Spatial resolution of AC-LGAD

- **Laser test result of strip AC-LGAD sensor**
  - It can reach about ~8μm resolution with 150um pitch strip detector
  - While timing resolution of AC-LGAD is still can reach 30-50ps

➢ **Aim for ~10μm 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



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）

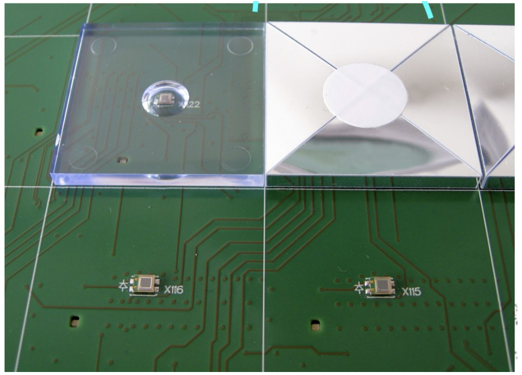
Radiation SiPM application

CEPC calorimeter, Space station scientific experiment (Herd …)

- Scintillator+SiPM: compact structure, large dynamic range, and good energy linearity
- Urgent need to solve problem 1: Currently, SiPM has average radiation resistance, which poses a challenge for long-term use in strong radiation environments such as space or colliders.
- Urgent need to solve problem 2: High dark count limits the detection sensitivity of low background experiments.

	Long term Satellite or Space station application	CEPC requirement
TID does	100 krad	>100 krad
Fluence	$\sim 10^{10}$ n_{eq}/cm^2	$>10^{13}$ n_{eq}/cm^2

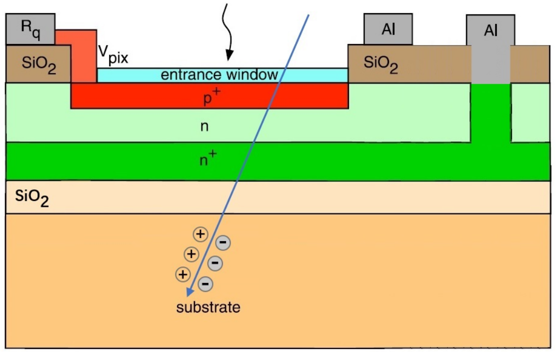
CEPC PFA calorimeter prototype



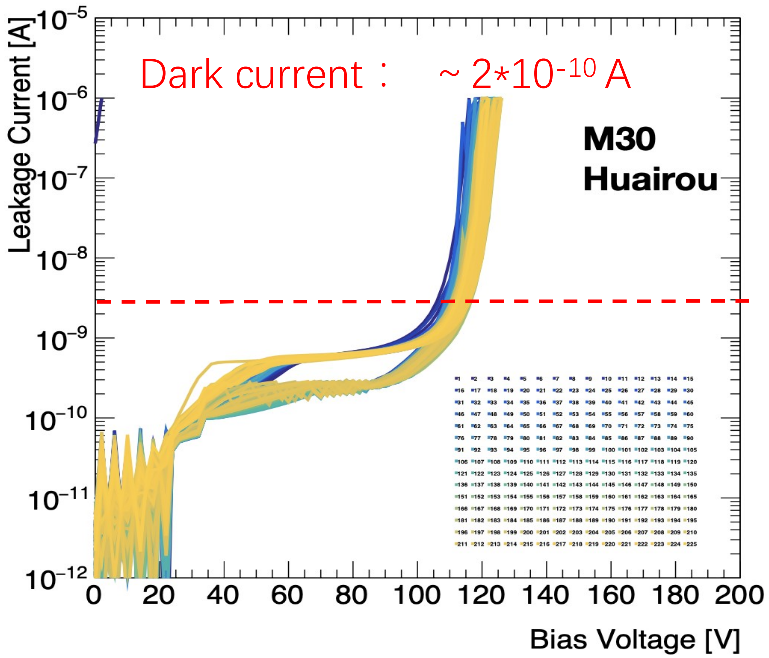
SiPM dark count after irradiation

- Bulk damage after irradiation → dark count increased
- Potential Solution:

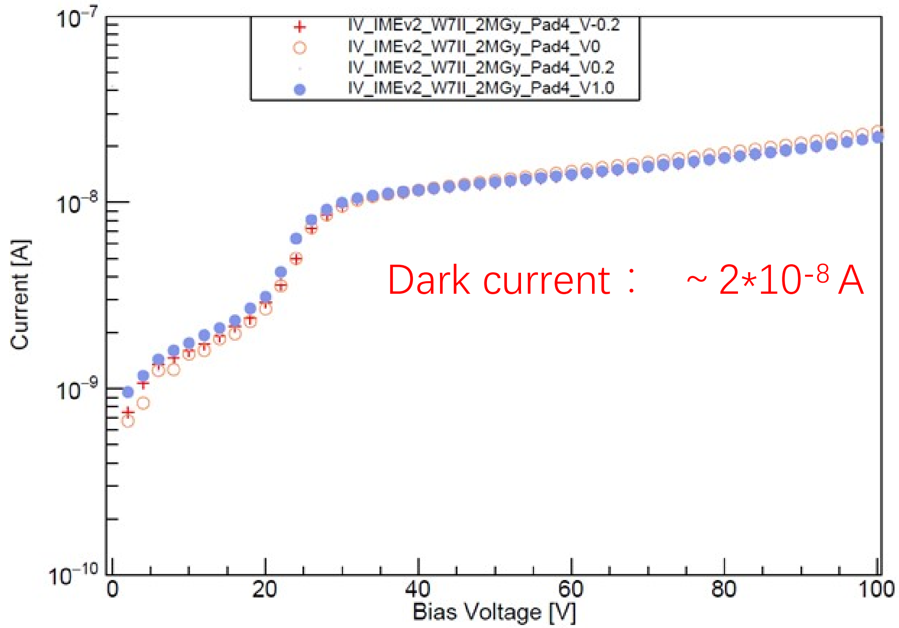
Design a special wafer to isolate the dark current from bulk damage



Leakage current of **LGAD** before irradiation

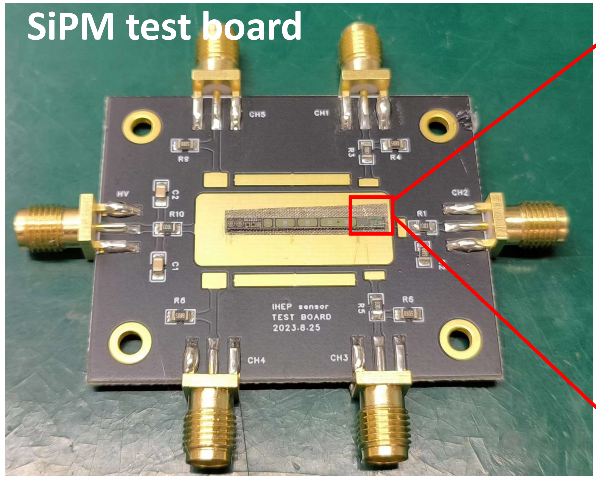


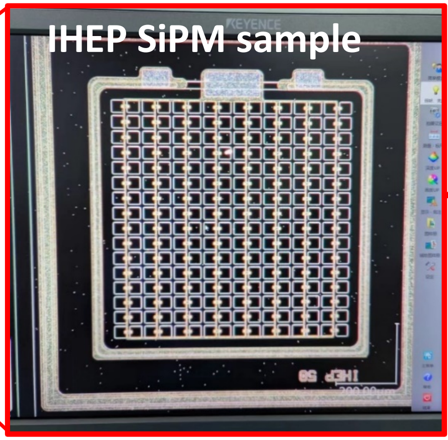
Leakage current of LGAD after irradiation

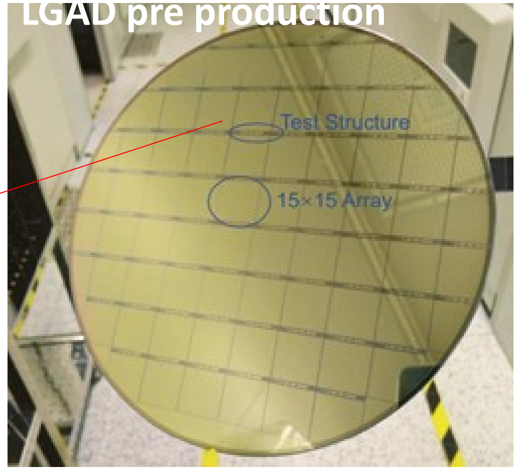


The status of SiPM developed by IHEP

SiPM is a key component in major scientific projects such as CEPC, LACT, and HERD.

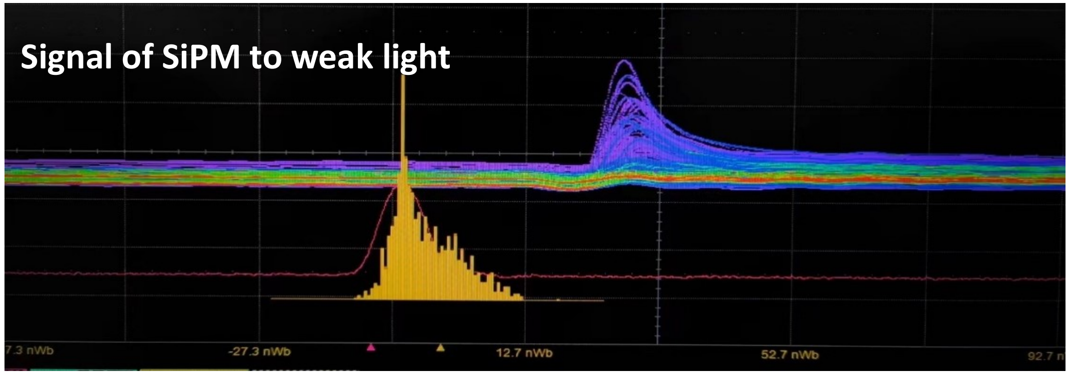




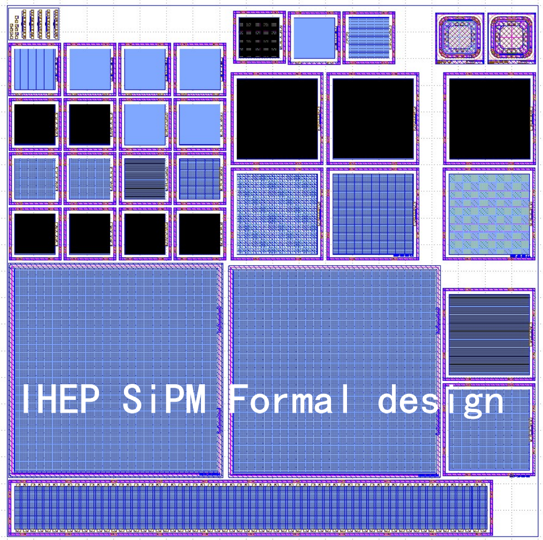


SiPM sample produced along with LGAD pre-production

- Pixel size： 50µm
- 16 x 16 pixels



- The structural design and some processes of SiPM have been validated.
- Energy resolution needs to be optimized.



Formal tape-out plan:

- Submit design layout at the end of October
- Complete the first version of tape-out by the end of the year

SiPM size:

- 7.6mm×7.6mm
- 3.0mm×3.0mm
- 1.5mm×1.5mm
- 152 x 152 pixels

Pixel size：
100um、 50um、 20um、 10um

SiPM Test Plan

- Irradiation test plan:

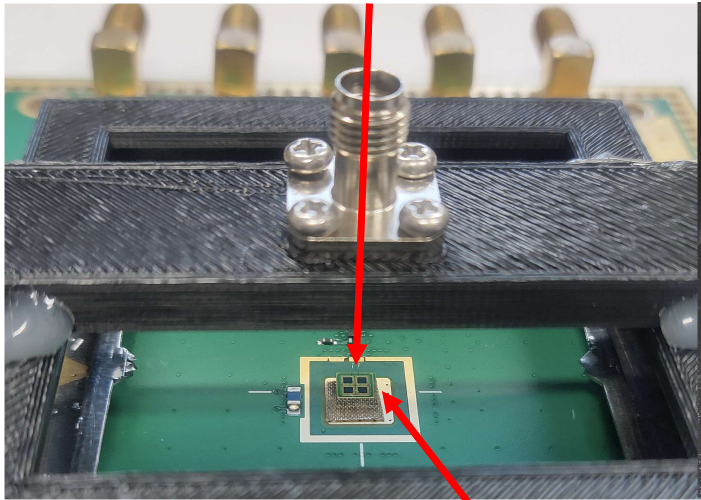
Plan to collaborate with the Dongguan spallation team to conduct proton irradiation of SiPM

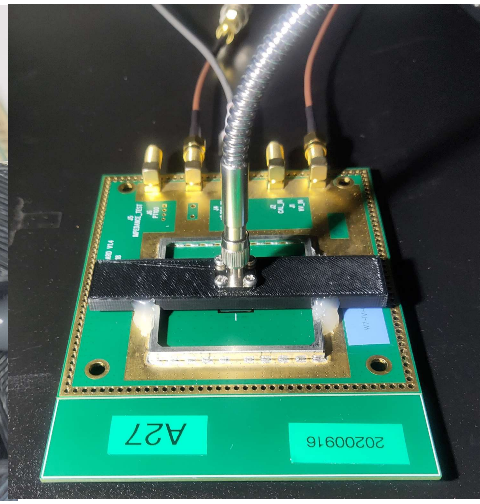
- Performance test plan:

Existing single photon testing platforms and low-temperature testing platforms

Current low light testing based on LGAD sensors

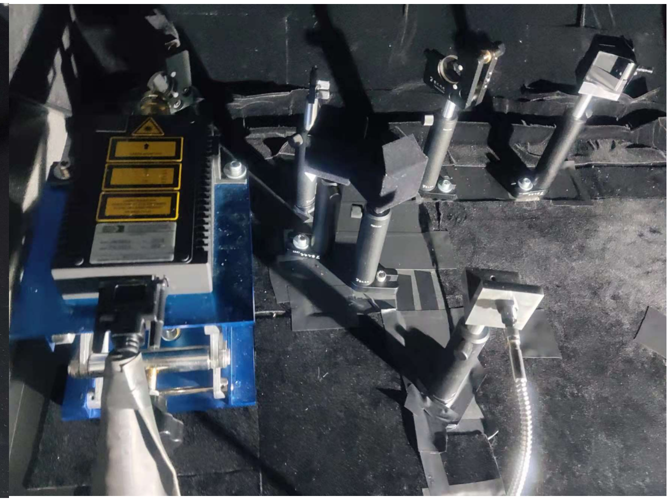
Fiber Coupling





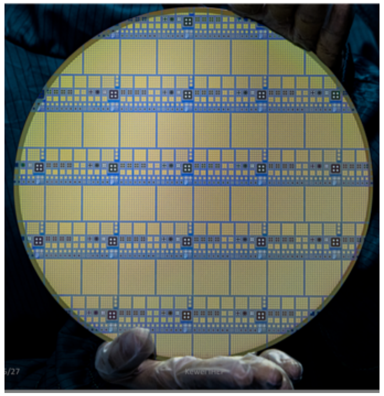
LGAD Sensor

Single photon testing platform
(based on picosecond lasers)

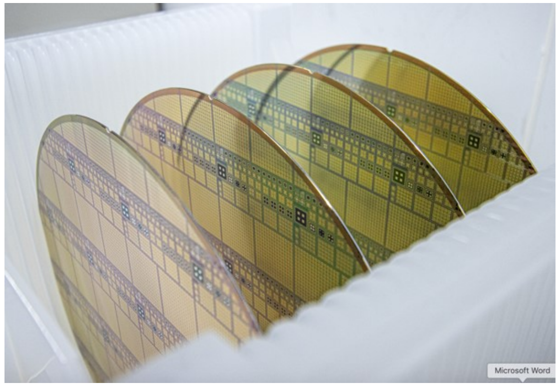


Time line for radiation hard SiPM

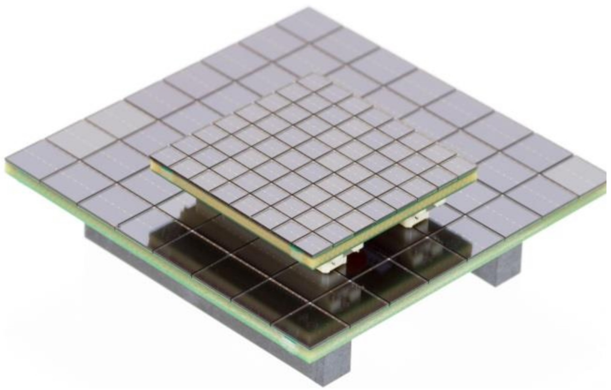
- 2023 1st half: SiPM irradiation hard design validated in LGAD engineering run
- 2023 2nd half: 1st Dedicated SiPM engineering run submission
- 2024: 1~2 more dedicated SiPM engineering run
- 2025: built modules or working device based on radiation hard SiPM



Simulation and exploration of various process parameters



SiPM multiple flow sheets to determine process parameters



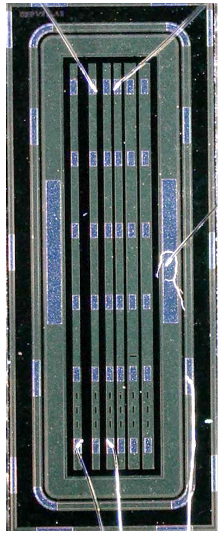
2023

2024

2025

Summary

- AC-LGAD is a new 4D detector （position + time）
- IHEP has designed pixels and strips AC-LGAD sensors
- **The best spatial resolution of strips AC-LGAD ~8μm （pitch 150um）**
- Aim for AC-LGAD sensor：
  pitch size 4cm × 0.05cm， 30 ps， 10 μm



- **Development for radiation hard SiPM**
  - Aim for CEPC and Astrophysics application
- **Key technology has been validated in ATLAS HGTD detector project**
  - Radiation hard LGAD sensor developed by IHEP team
- Radiation SiPM R & D project
  - **Formal tape-out plan will be submitted in this month**
  - Dedicated engineering run by the end of this year

Thanks for Your Attention

tyzhang@ihep.ac.cn