CEPC timing detector R&D

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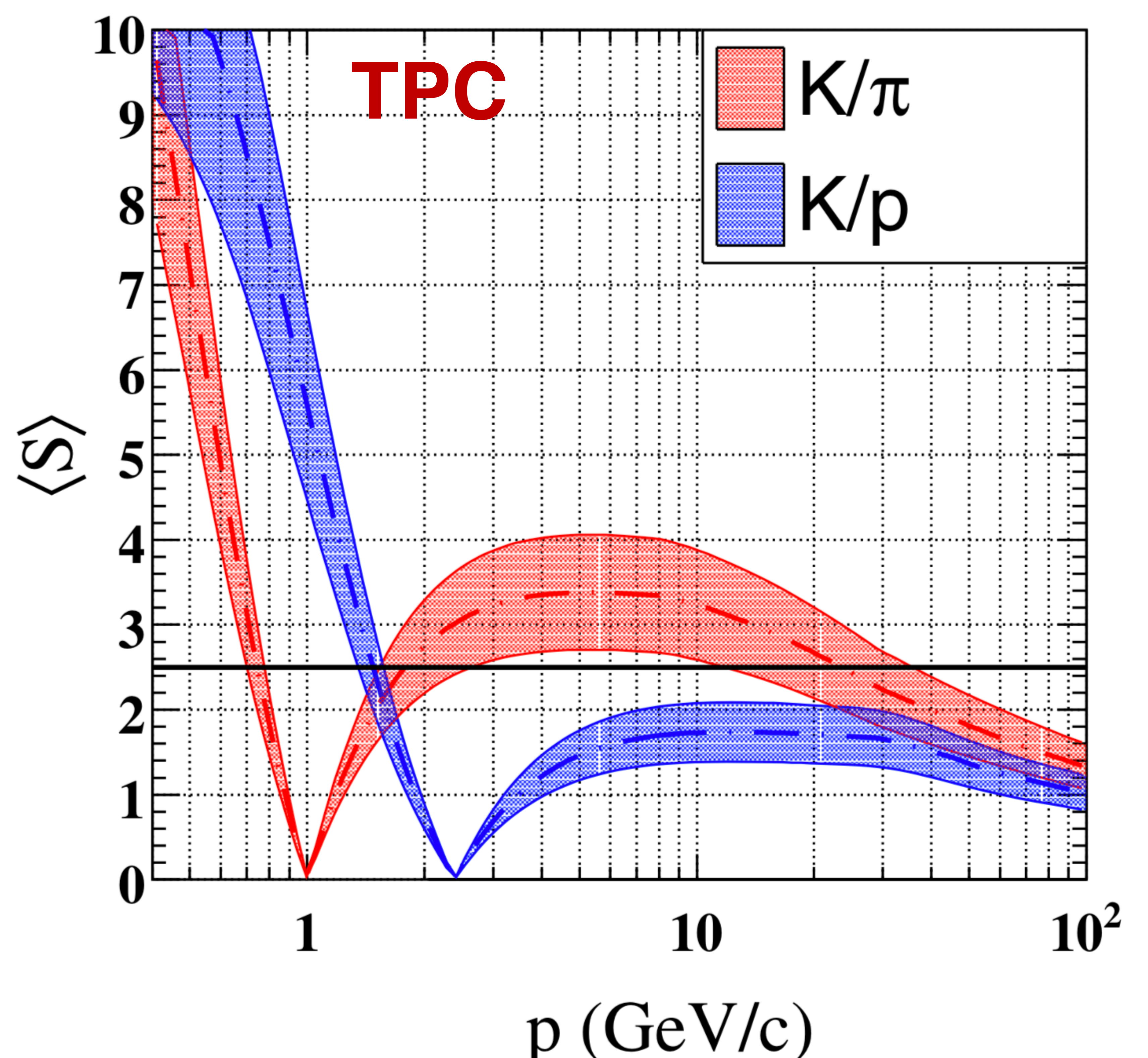
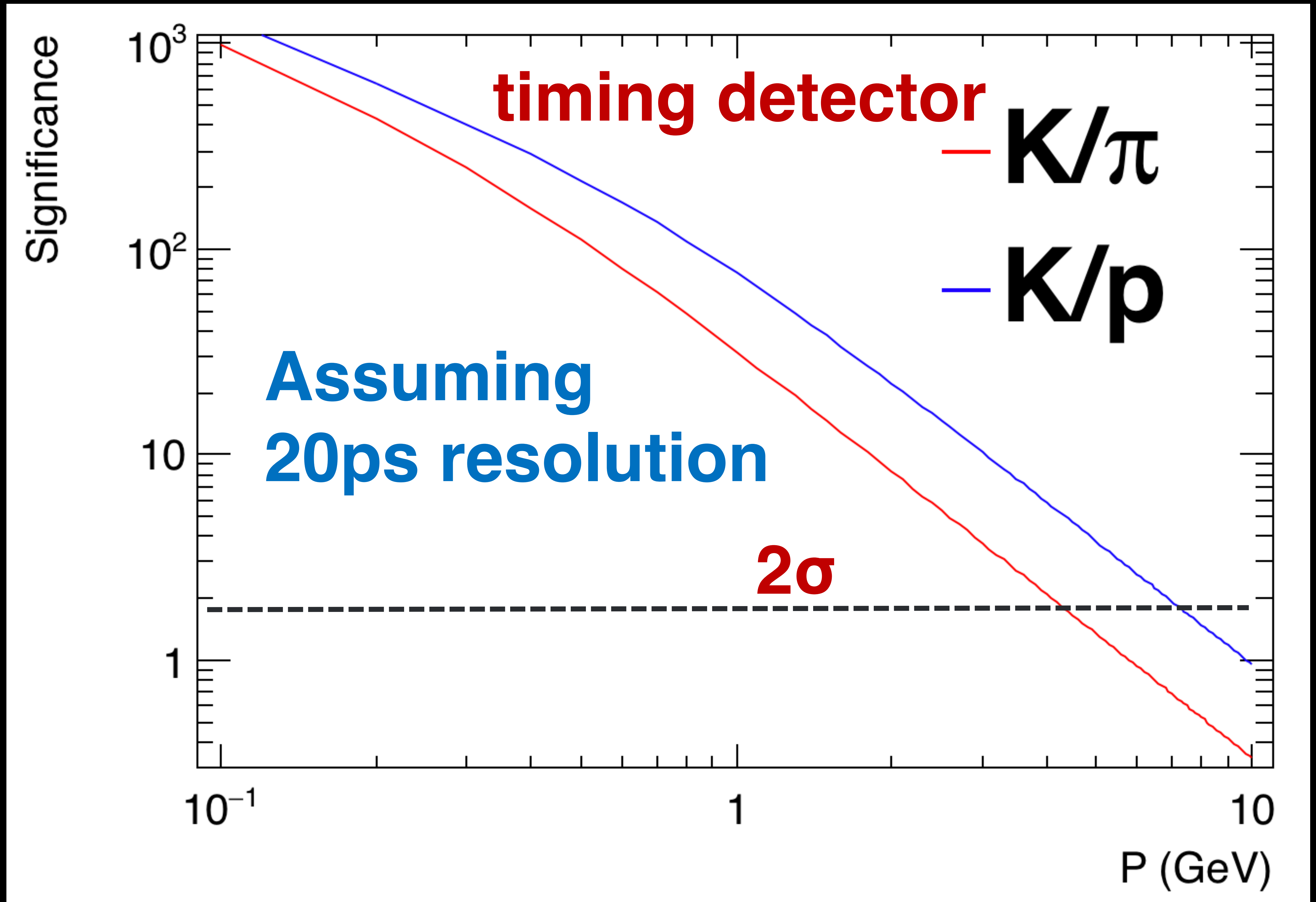
CEPC timing detector : motivation

- CEPC will produce 10^{12} Z boson at Z pole → Rich flavor physics program
- CEPC International Advisory Committee: **one of the key recommendations**

→ **Precision timing detector should be determined as a matter of urgency**

- Gas detector is responsible for particle identification in flavor (dE/dx)
  → Challenge: **0.5-2GeV** for K/pi separation, **>1.5GeV** for K/p separation
- Timing detector is complementary to gas detector
  → **0-4GeV** for K/pi separation, **0-8GeV** for K/p separation

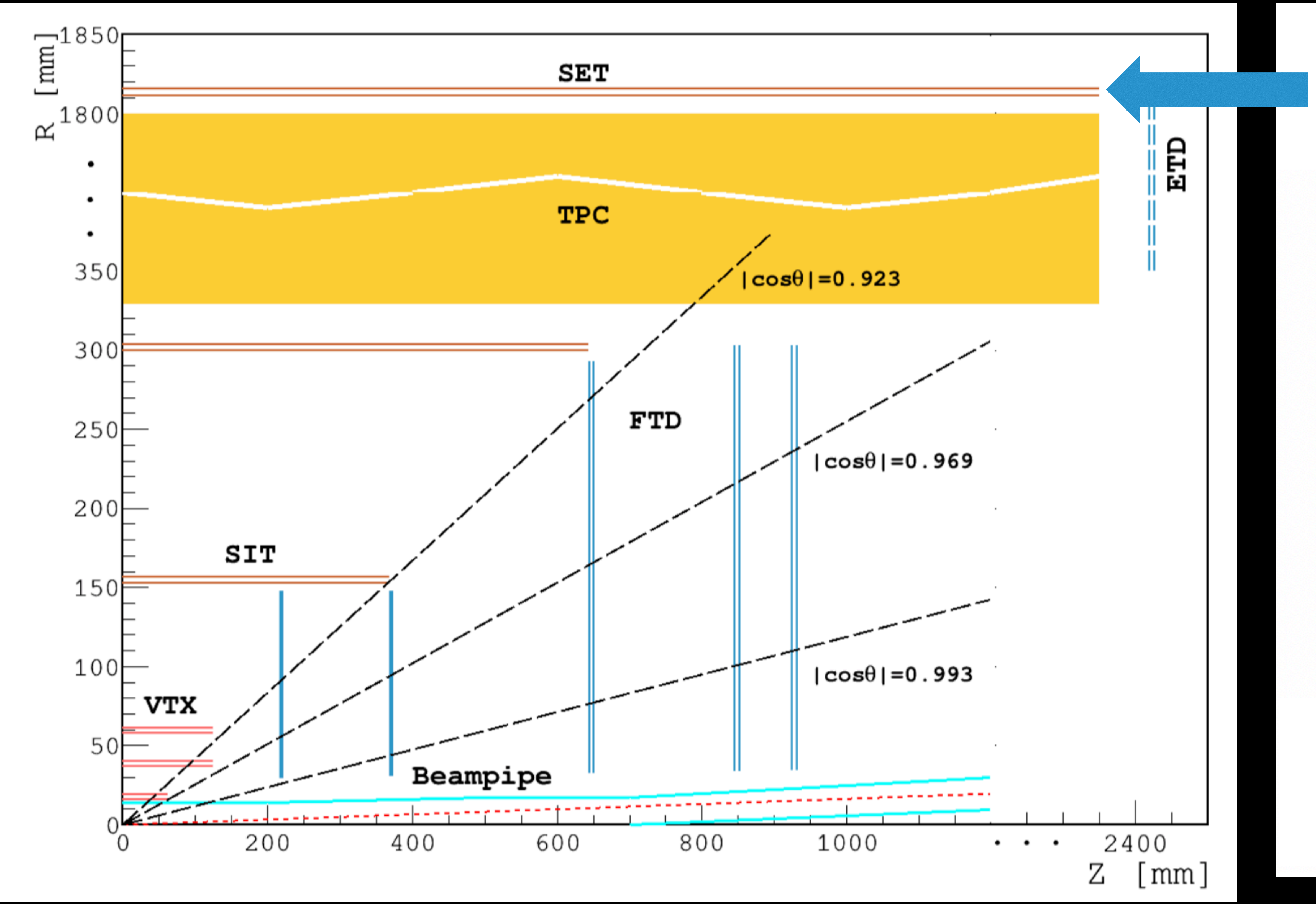




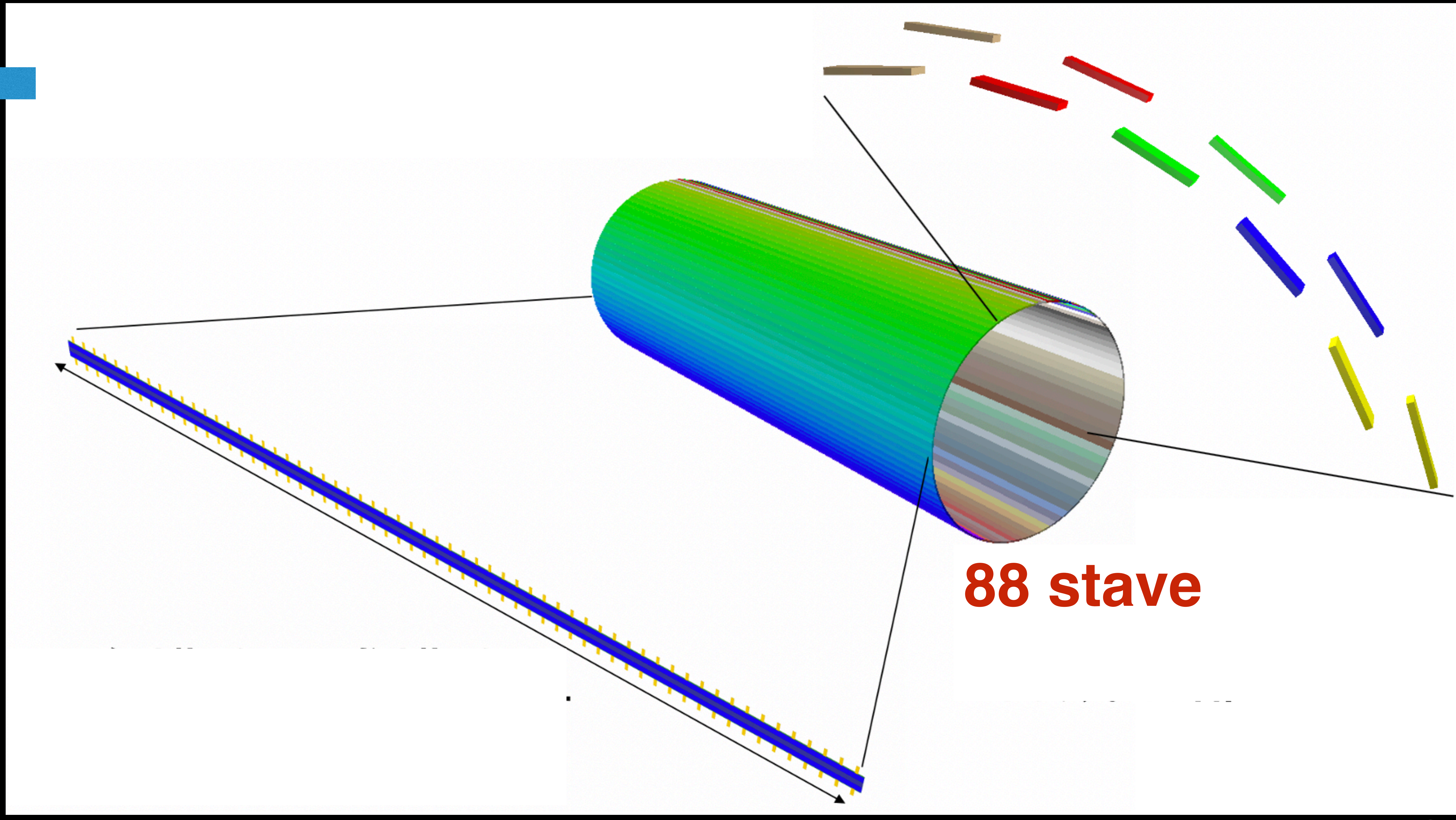
CEPC timing detector : Concept

- Timing detector: Between tracker and calorimeter
- → Close to SET tracker, Radius ~1.8m
- Target time resolution: 20 pico-second(ps)
- Area of detector (Barrel : 50m^2 , Endcap 20m^2)

Baseline detector concept in CDR

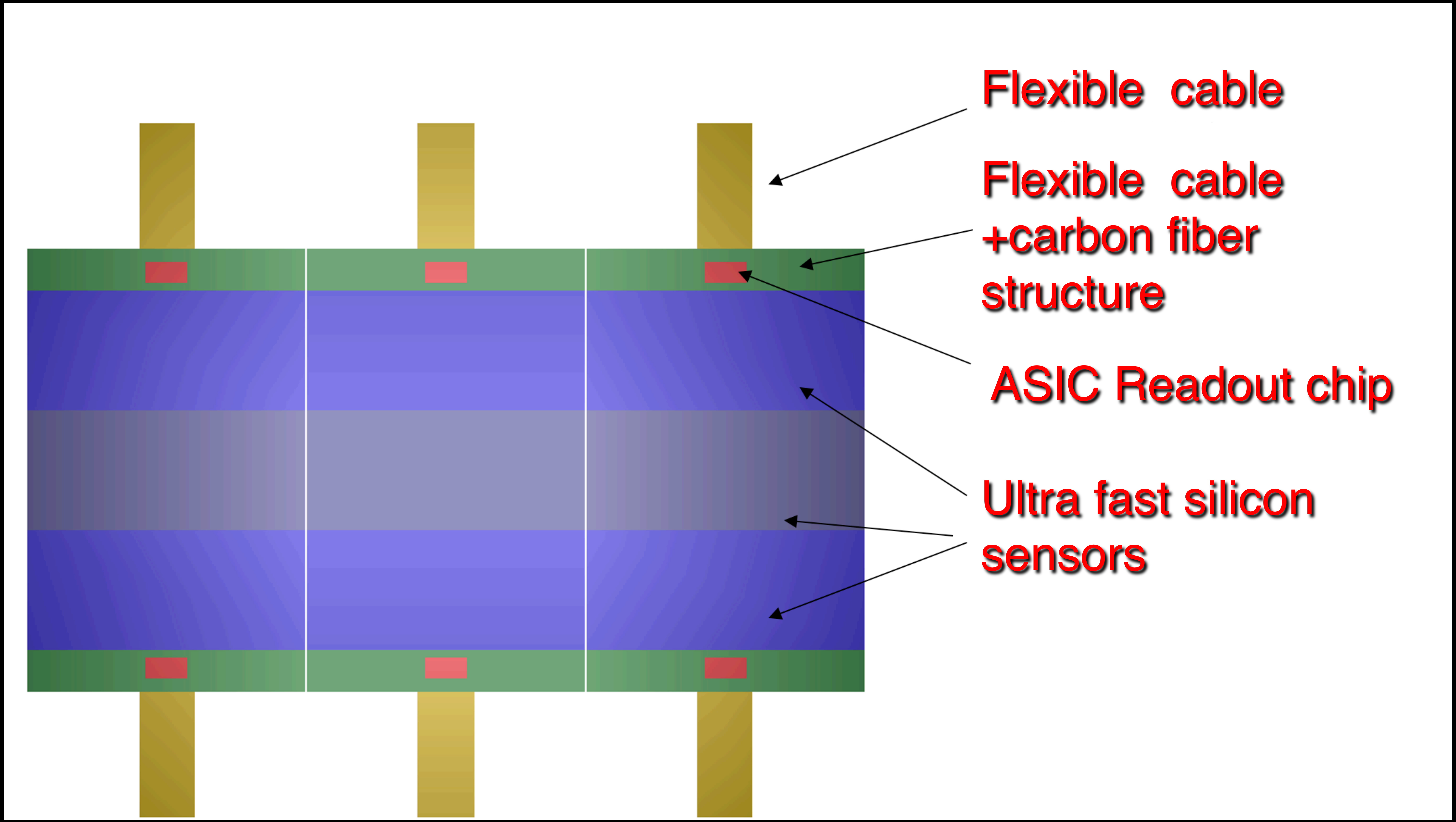


Timing detector in Barrel region



CEPC timing detector : Concept

- Each module size : ~5cm * 15cm
- Further optimization is on going



Impact parameter resolution in silicon detector

The precision of a sensor, $\sigma_{Sensor,}$ depends upon two factors:

$$\sigma^2_{Sensor} \sim \sigma^2_x + \sigma^2_{MS}$$

The accuracy of the single hit σ_x

The average multiple scattering σ_{MS} depends on the material budget of the sensors and services

- Smallest possible σ_x : very accurate sensors
- Smallest possible σ_{MS}: very thin sensors

The sensors need to be very accurate and very thin

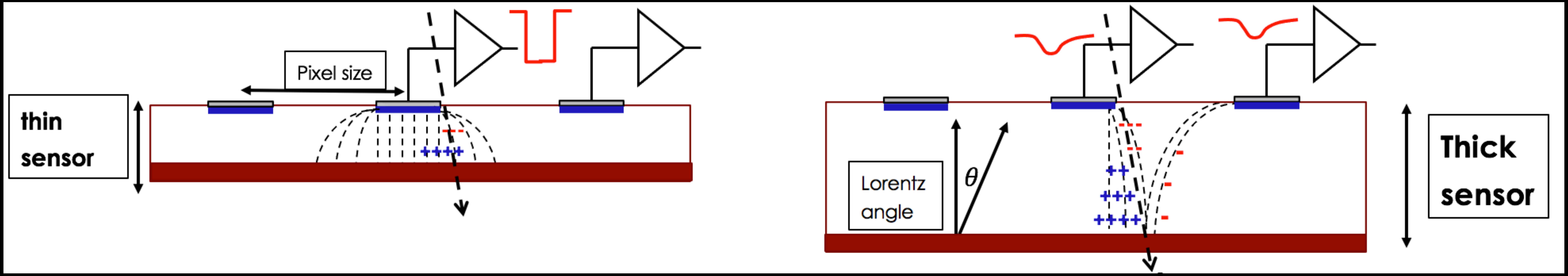
Sensor accuracy σ_x and readout

Binary readout

where the only information is hit/miss (0,1)

Analog readout

where the amplitude of the signal is recorded



$$\sigma_x = k\,\frac{pitch}{\sqrt{12}},\; k \sim 0.5 - 1$$

- σ_x depend on the pixel size

  pixel = 100 μm ➔ $\sigma_x = 20\ \mu m$
- σ_{MS} small : sensors might be thin

Thin, NOT accurate

$$x_i = \frac{A_i x_i}{\sum_1^2 A_l x_l}$$

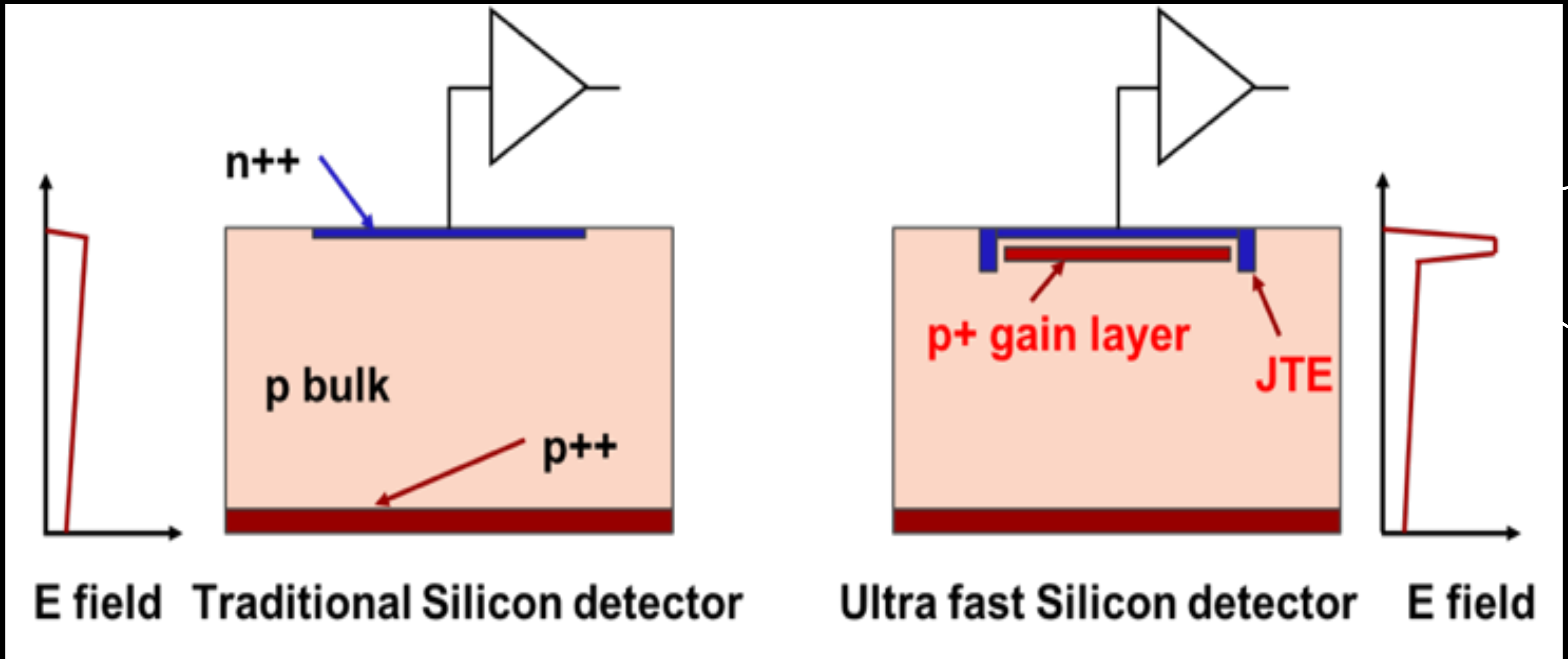
- σ_x << pixel size
- σ_{MS} large

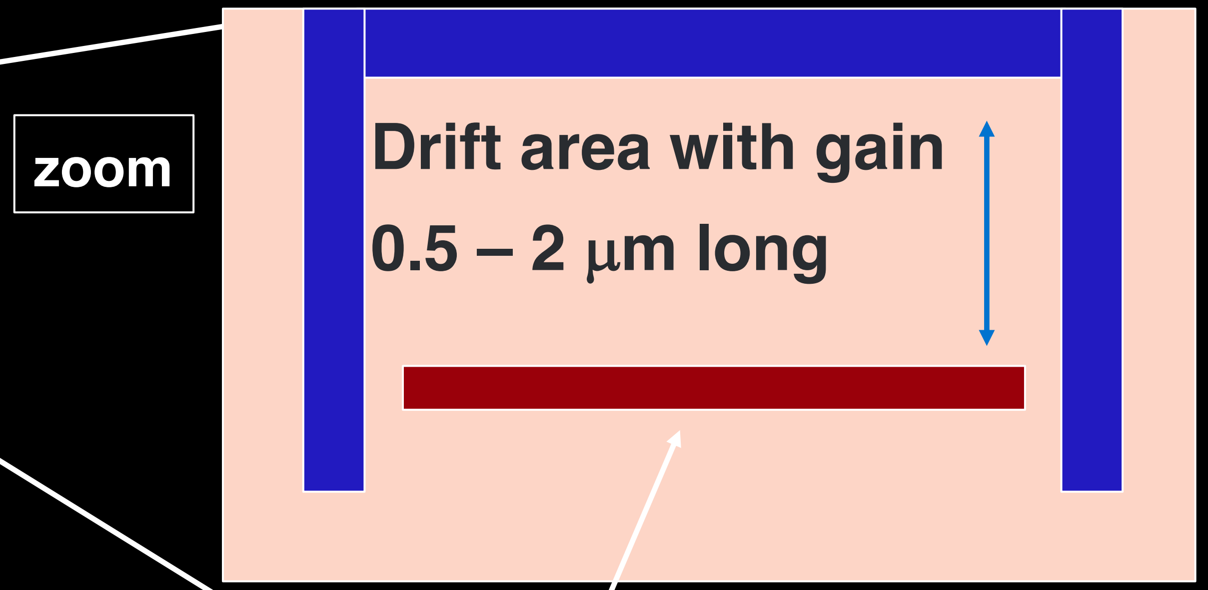
  Sensors have to be thick to maintain efficiency
- Need B field (or floating electrodes)

Accurate, NOT thin

The sensors are either very accurate OR very thin

Ultra Fast Silicon sensor: Low gain avalanche diode (LGAD)





The gain layer:
a parallel plate capacitor with high field

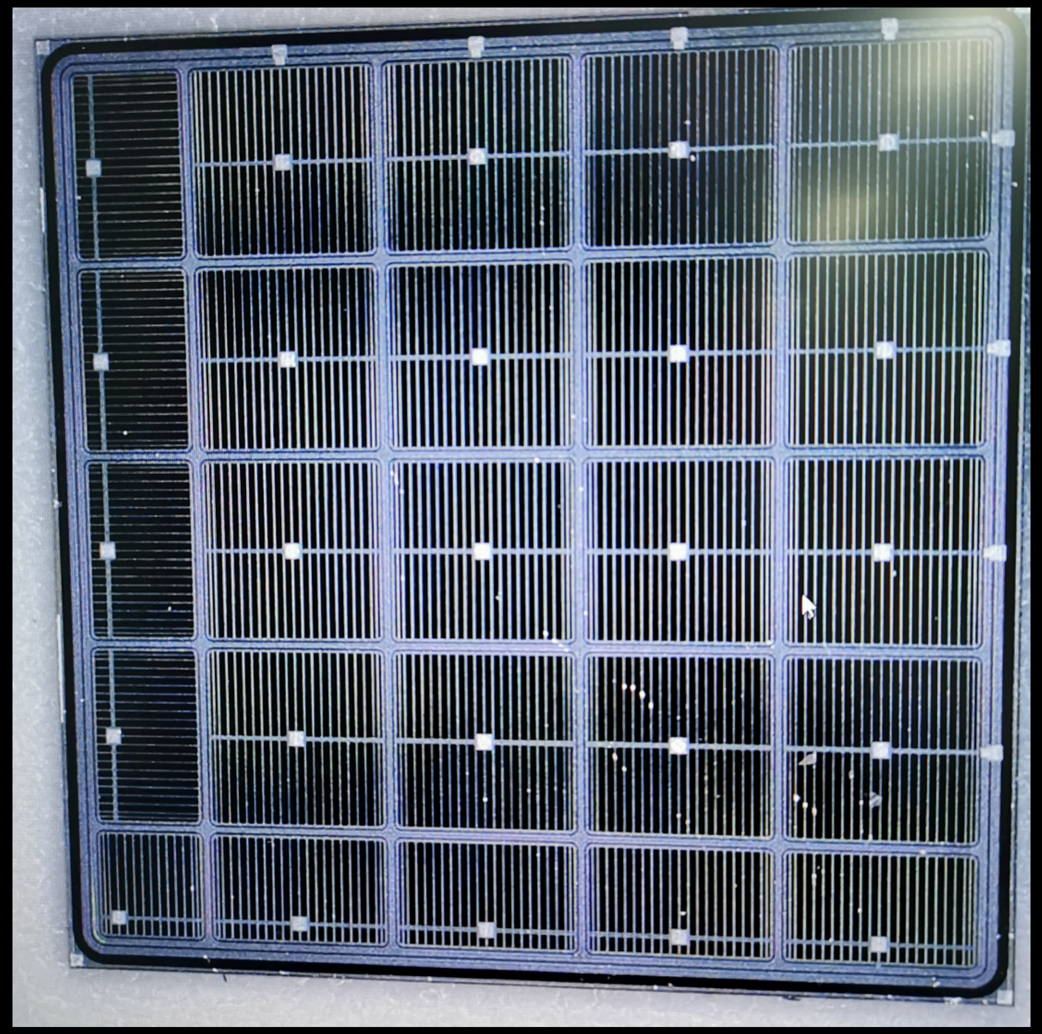
The LGAD sensors, as proposed and first manufactured by CNM
(National Center for Micro-electronics, Barcelona):
High field obtained by adding an extra doping layer
E ~ 300 kV/cm, closed to breakdown voltage

- **The low-gain mechanism, obtained with a moderately doped p-implant, is the defining feature of the design (first proposed by CNM, Barcellona, 2015).**
- **The low gain allows segmenting and keeping the shot noise below the electronic noise, since the leakage current is low.**

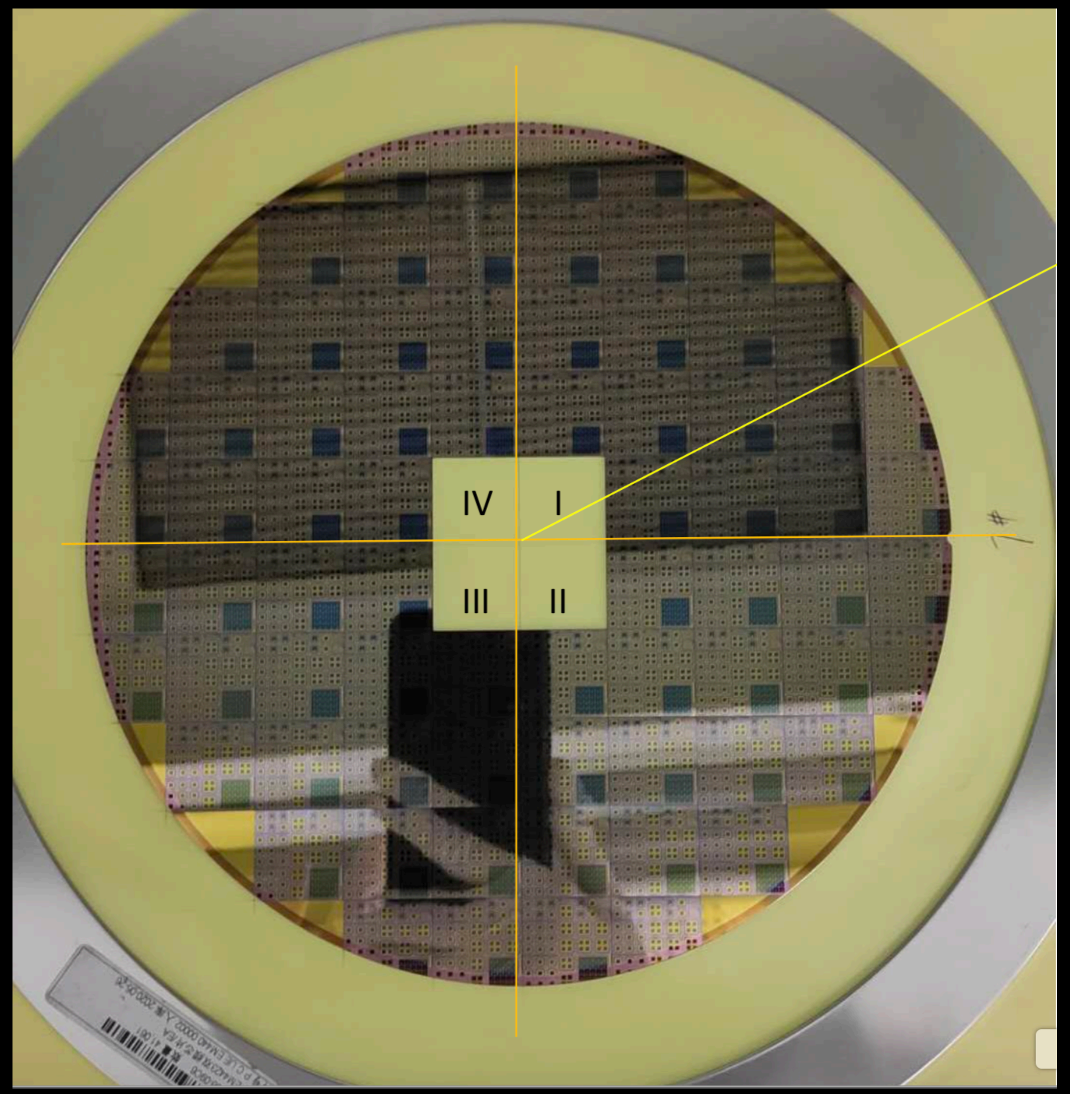
CEPC timing detector : R & D status

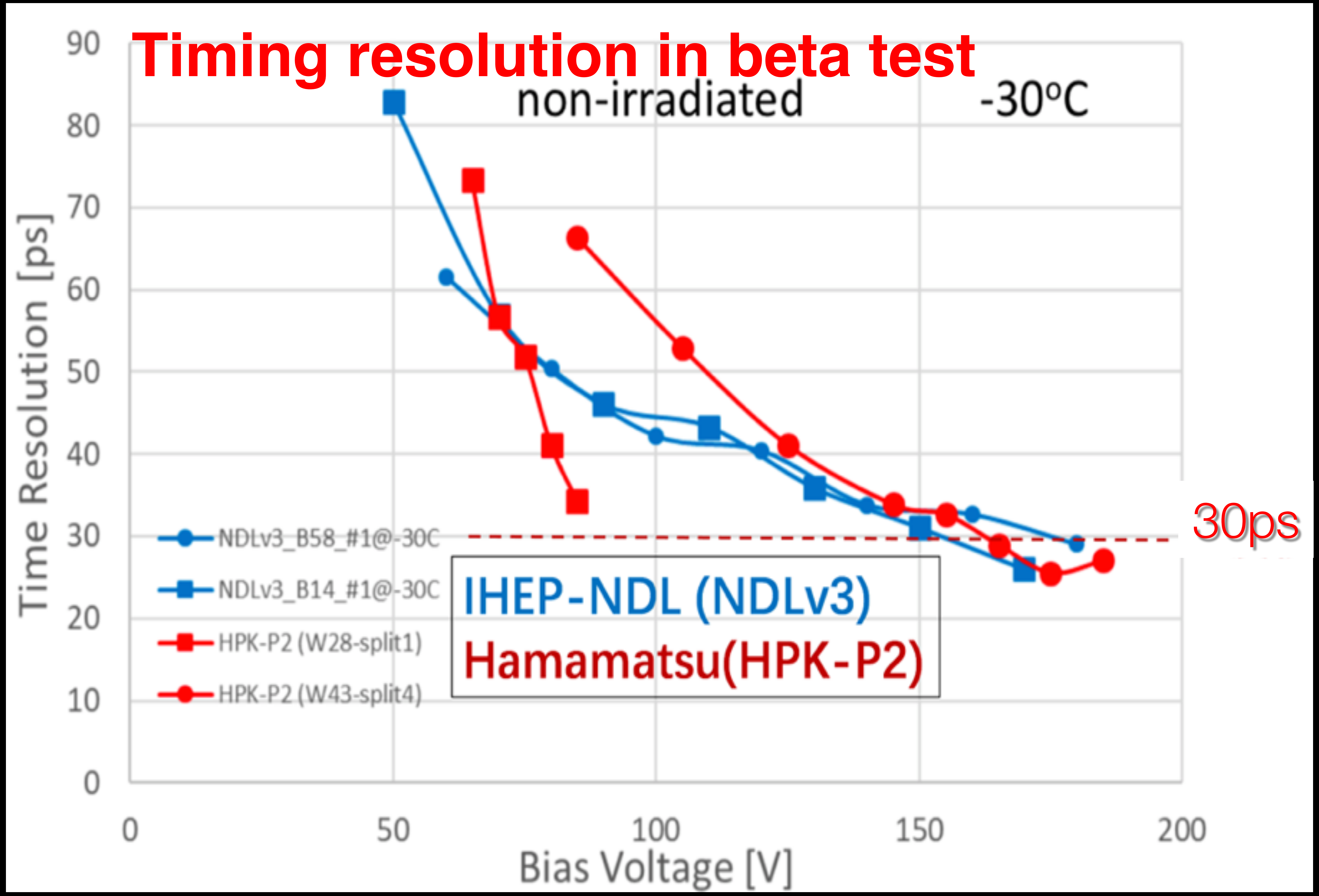
- IHEP and Beijing Normal U. developed IHEP-NDL LGAD sensors
→ Can reach 25 pico-second(ps) , similar performance compared to HPK sensors
- IHEP and Institute of micro-electronics (IME) developed IHEP-IME sensors
- → IHEP team (Mei Zhao ...) designed, IME fabricated, about 32 ps

IHEP-NDL sensor



IHEP-IME sensors
8 inch wafer





CEPC timing detector :IHEP Test beam 2020

- Timing detector team (3 postdocs and 4 students) participate IHEP test beam

→ Tuning the beam, taking shifts, commissioning the detectors

- Postdoc: Bo Liu, Yunyun Fan, Xuan Yang
- Students: Mengzhao Li, Shuqi Li, Han Cui, Chengjun Yu

CEPC timing detector :IHEP Test beam 2020

- ➢ IHEP E3 Beam line: Proton/ pion mixed beams, 0.5-1GeV
- ➢ Four detectors are used, data taking with Oscilloscope

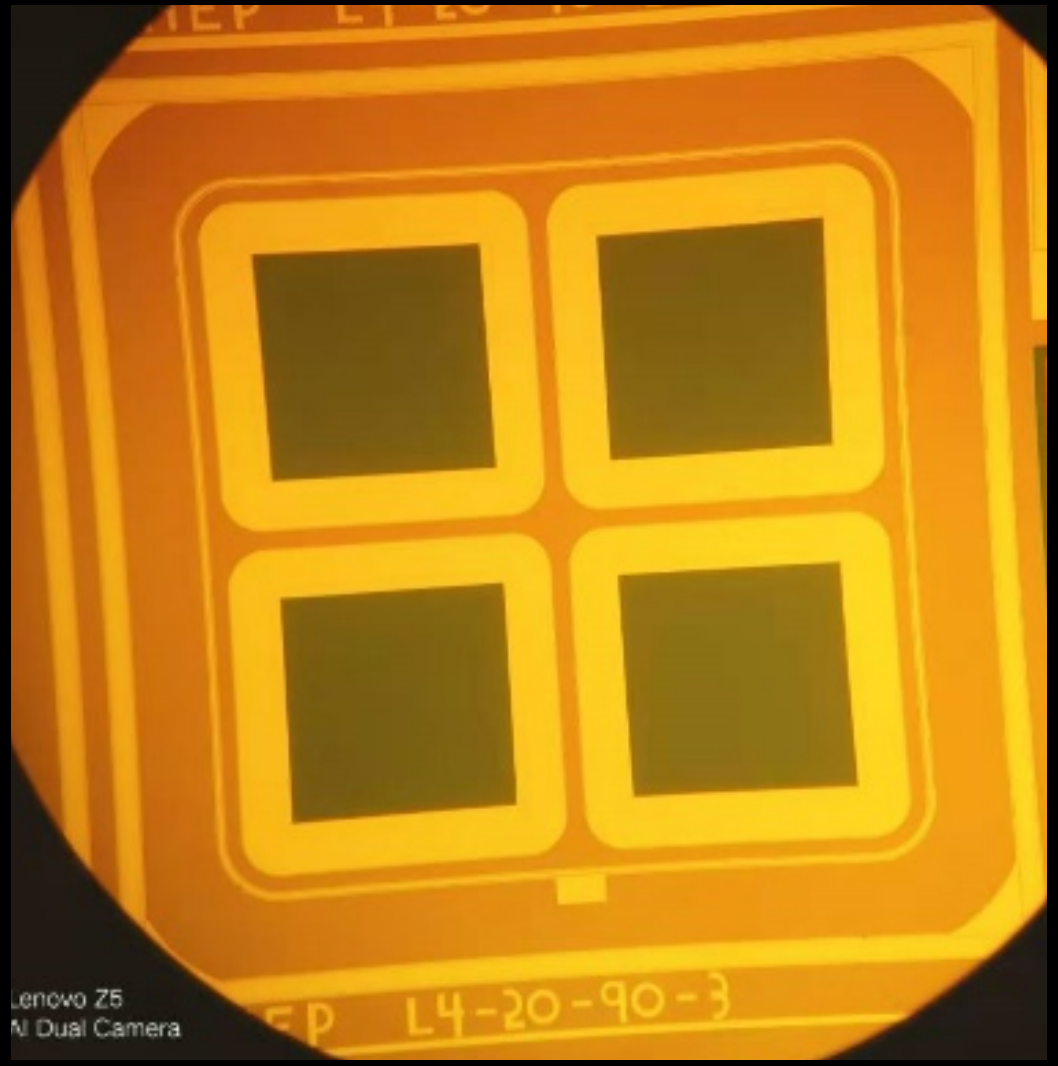
→ One IHEP-IME 2×2 LGAD. Area: 3mm×3mm, time resolution: 39ps

→Two HPK 5×5 LGAD. Area: 6.5mm×6.5mm, time resolution: 60-70ps

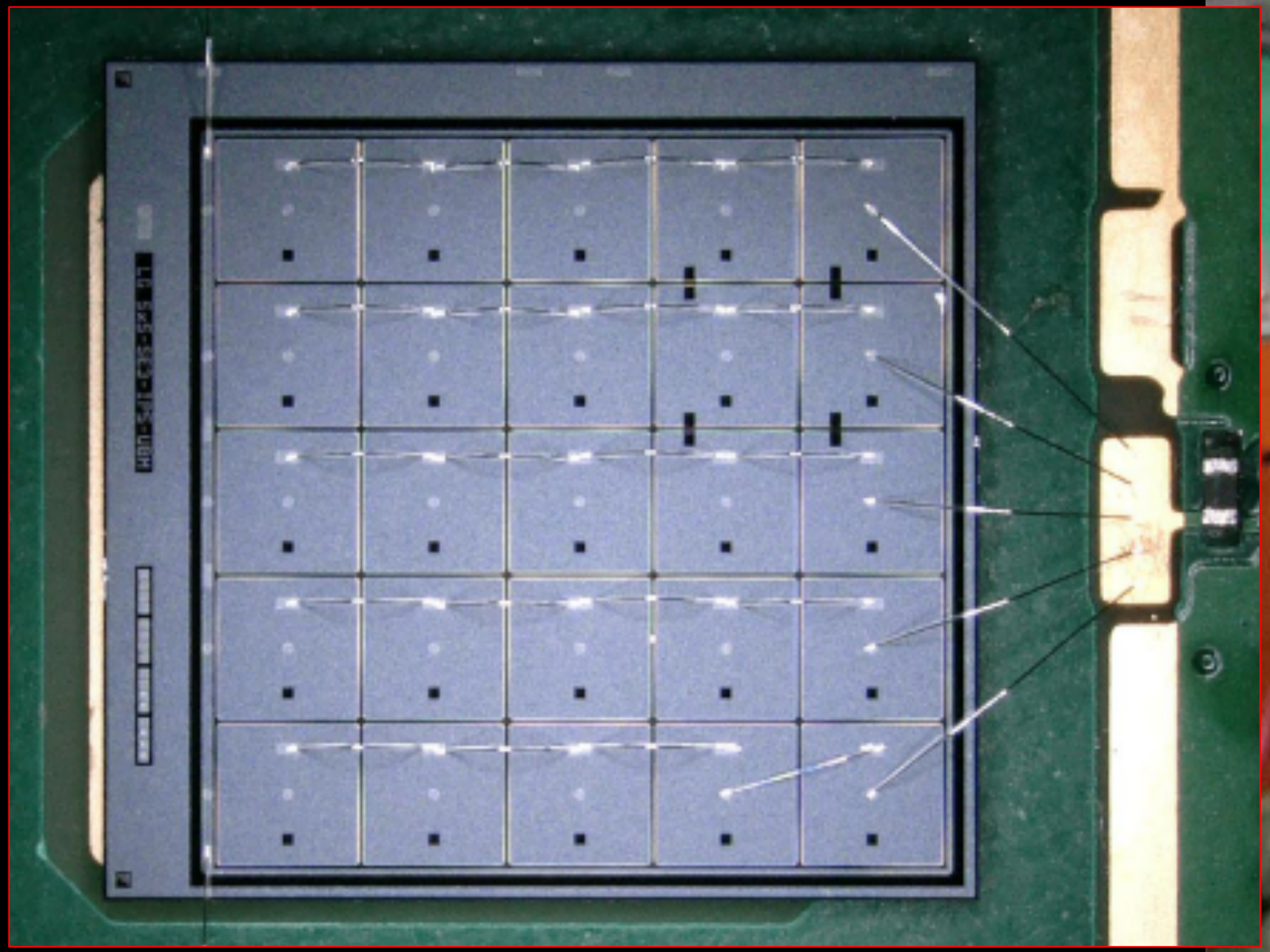
→One HPK 15×15 LGAD. Area: 20 mm ×20 mm, low signal level

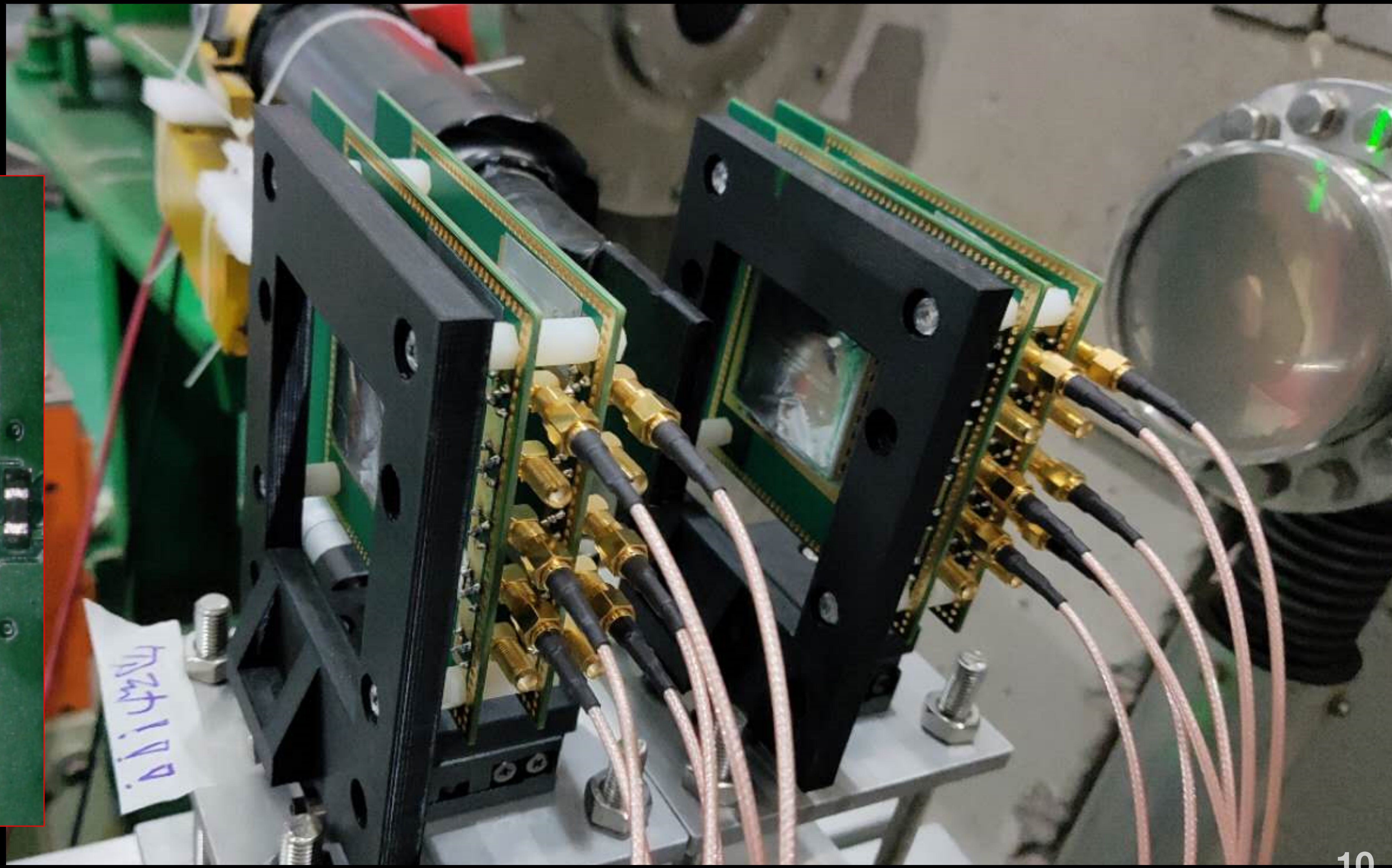
Timing detector in IHEP test beam

IHEP-IME
2×2 LGAD



HPK 5×5 LGAD
Single channel readout

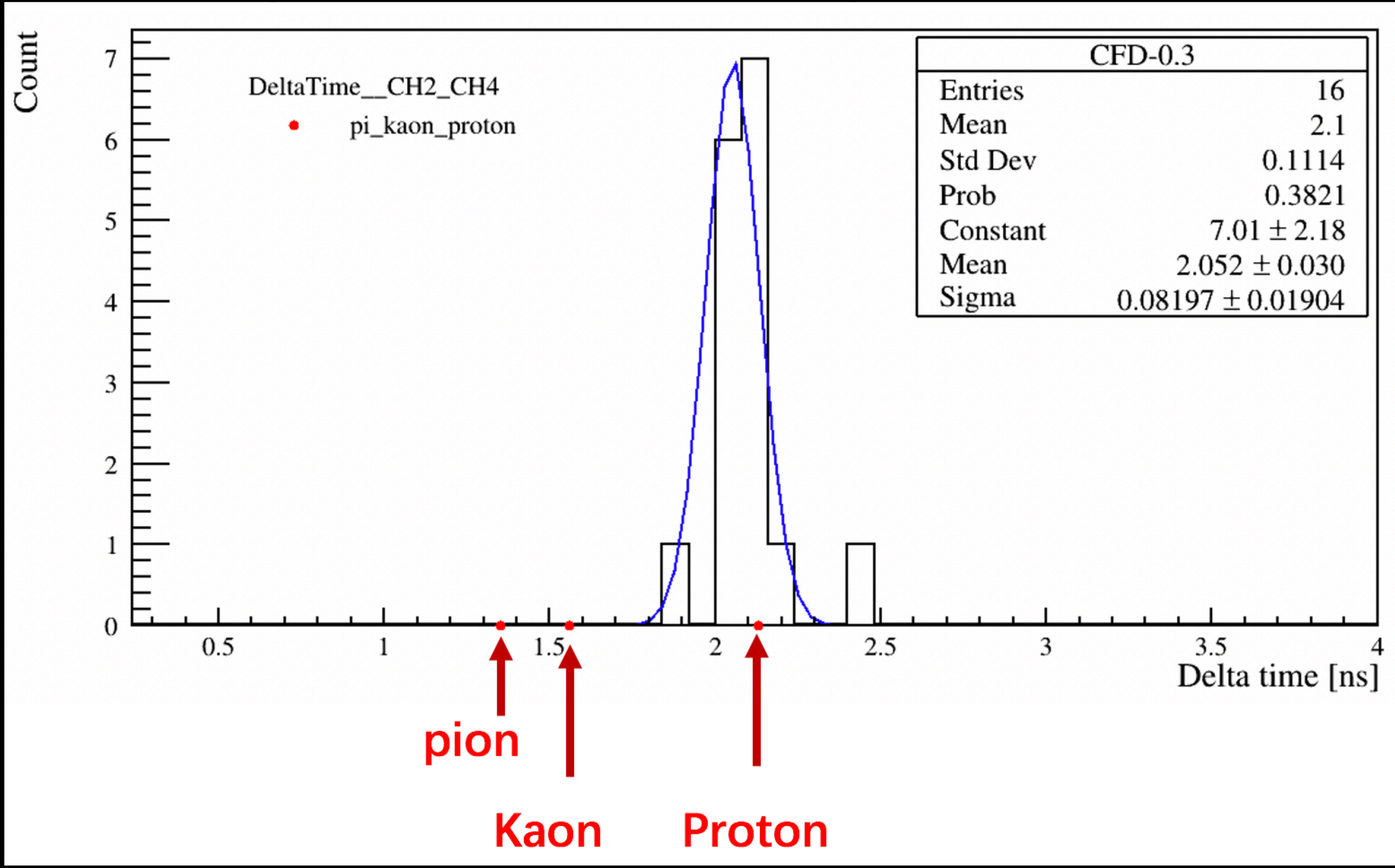


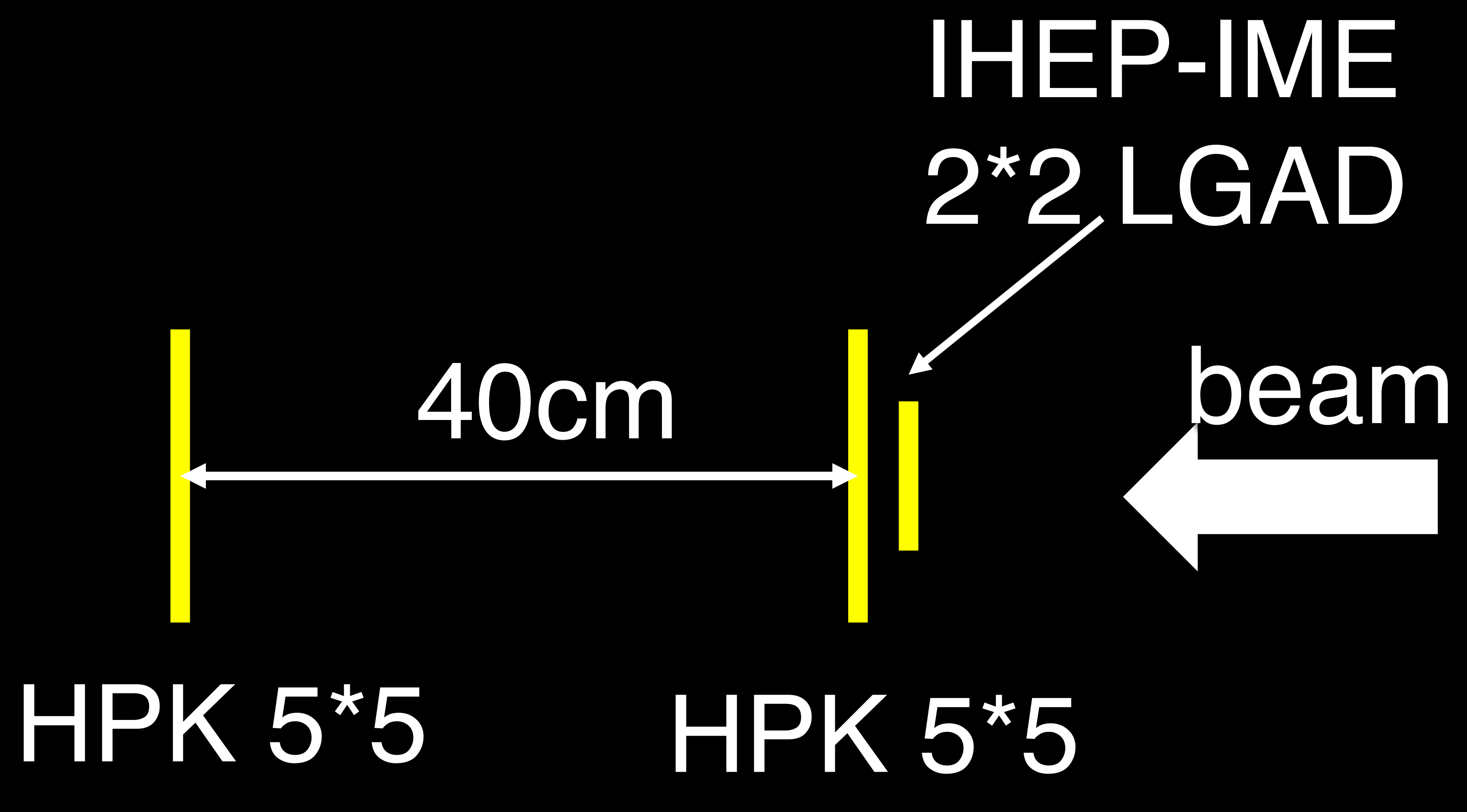


Typical signal events for silicon timing detector

Day 1 in test beam: particle identification

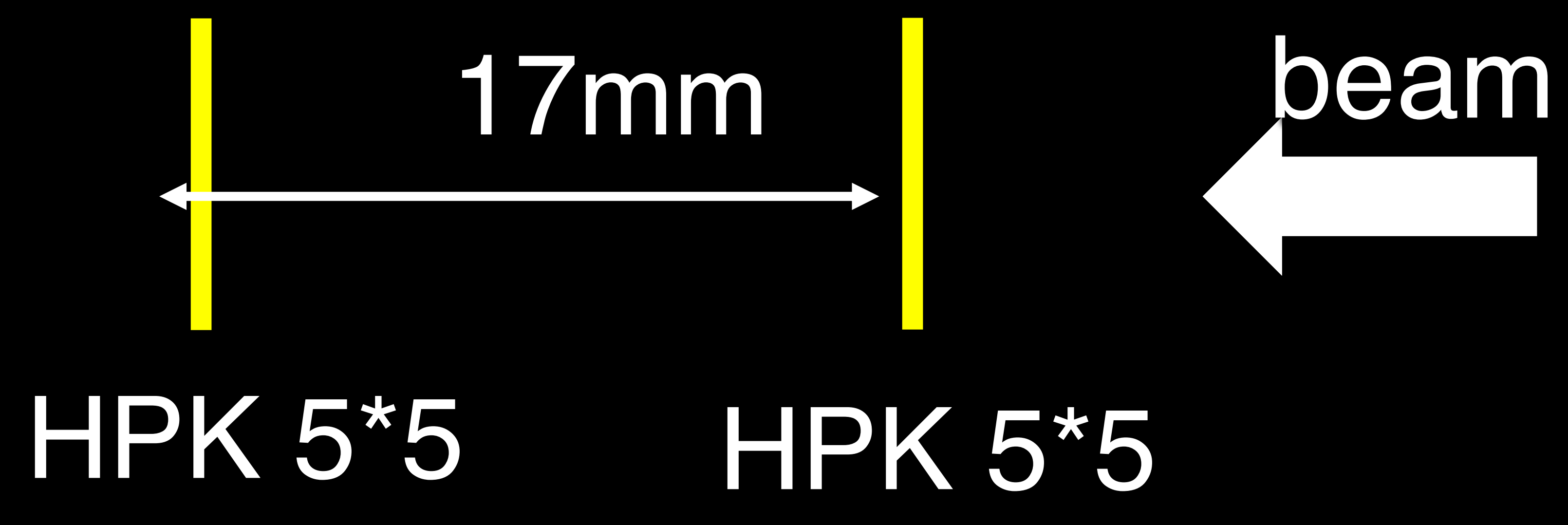
- Distance of two HPK sensors: 40cm
- Most of E3 line particles are proton
- Well separated from Kaon and pion





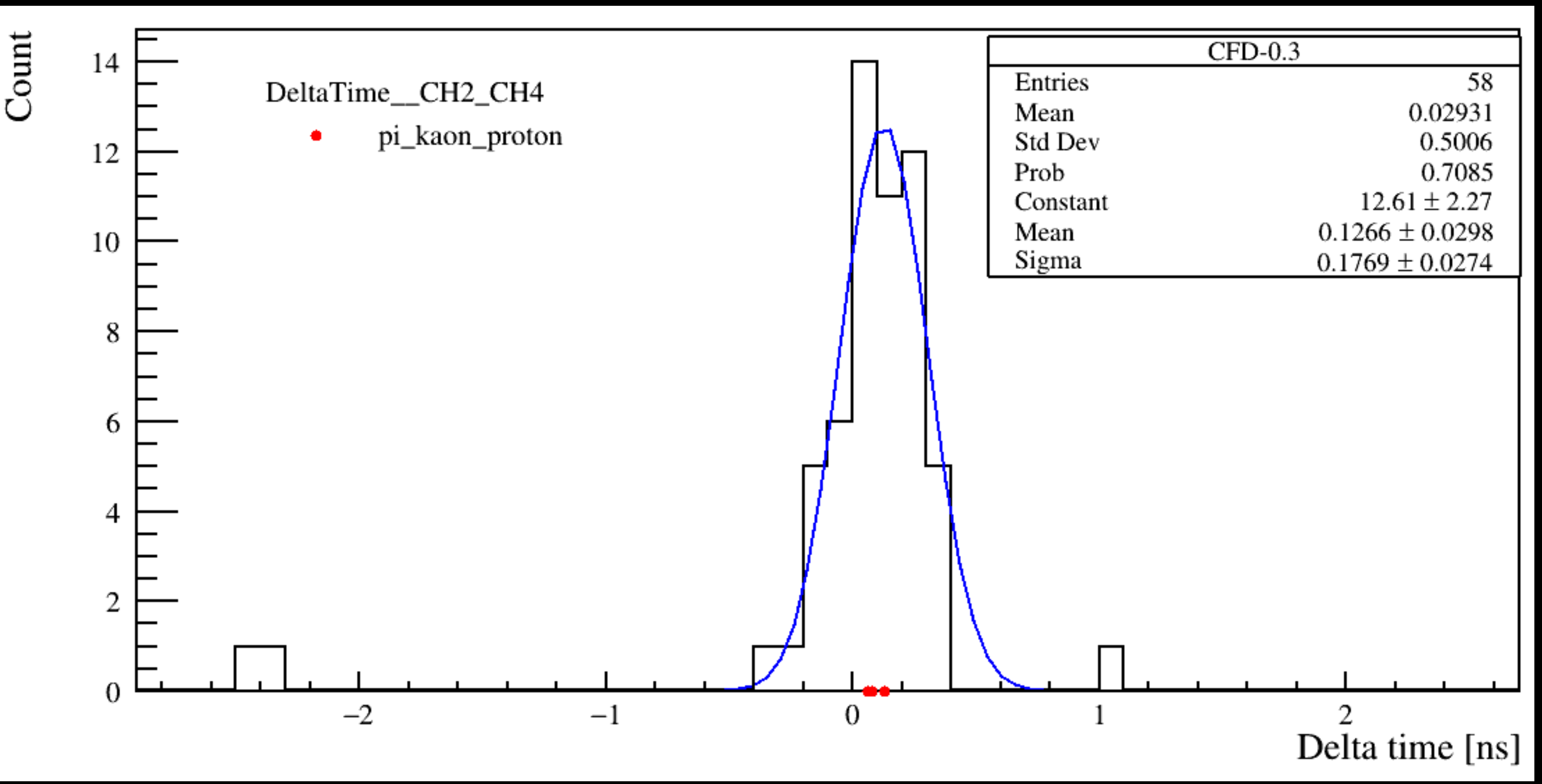
10.28 20:00 ~ 10.29 16:00
20 hours , 16 events
800MeV beam

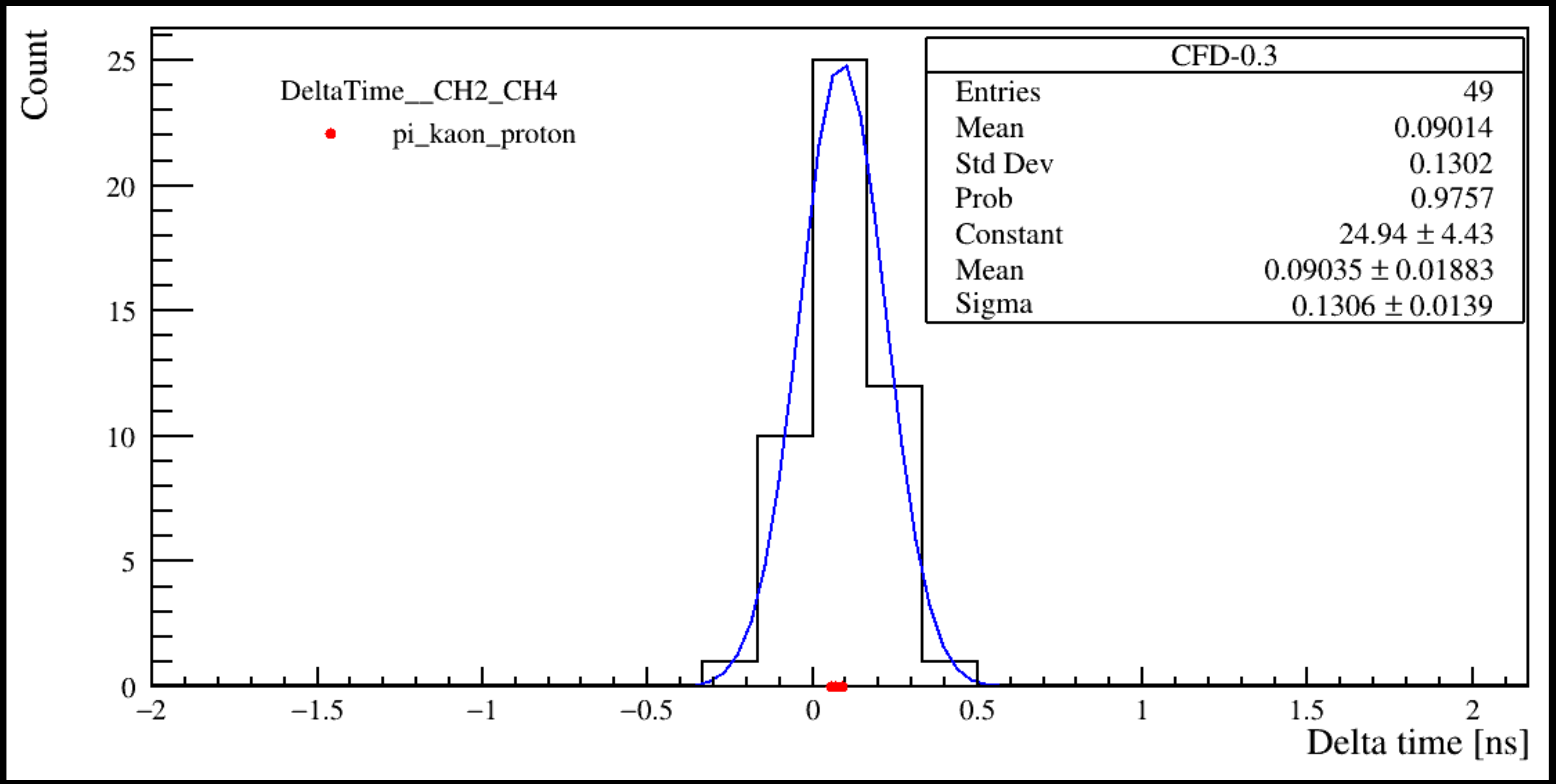
Day 2 in test beam



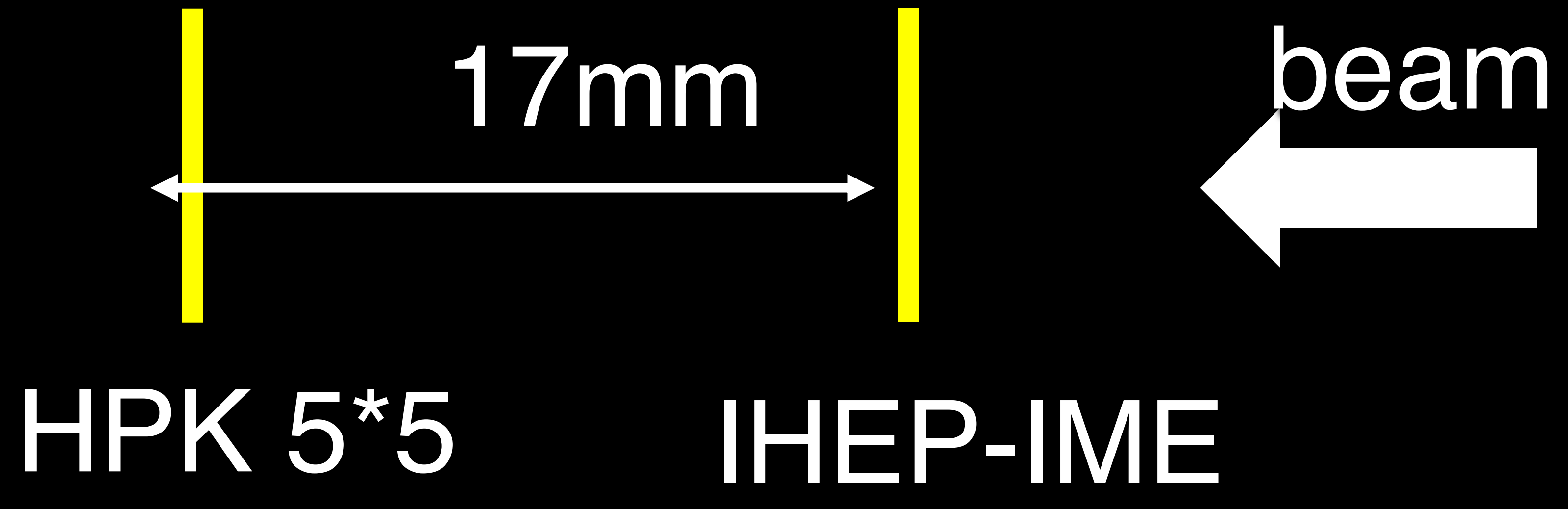
- Energy 500MeV ~21h
- double triggered events : 55
- Time resolution: 125ps

Distance 17mm
- Energy 800MeV ~14h
- double triggered events: 49
- Time resolution: 91ps

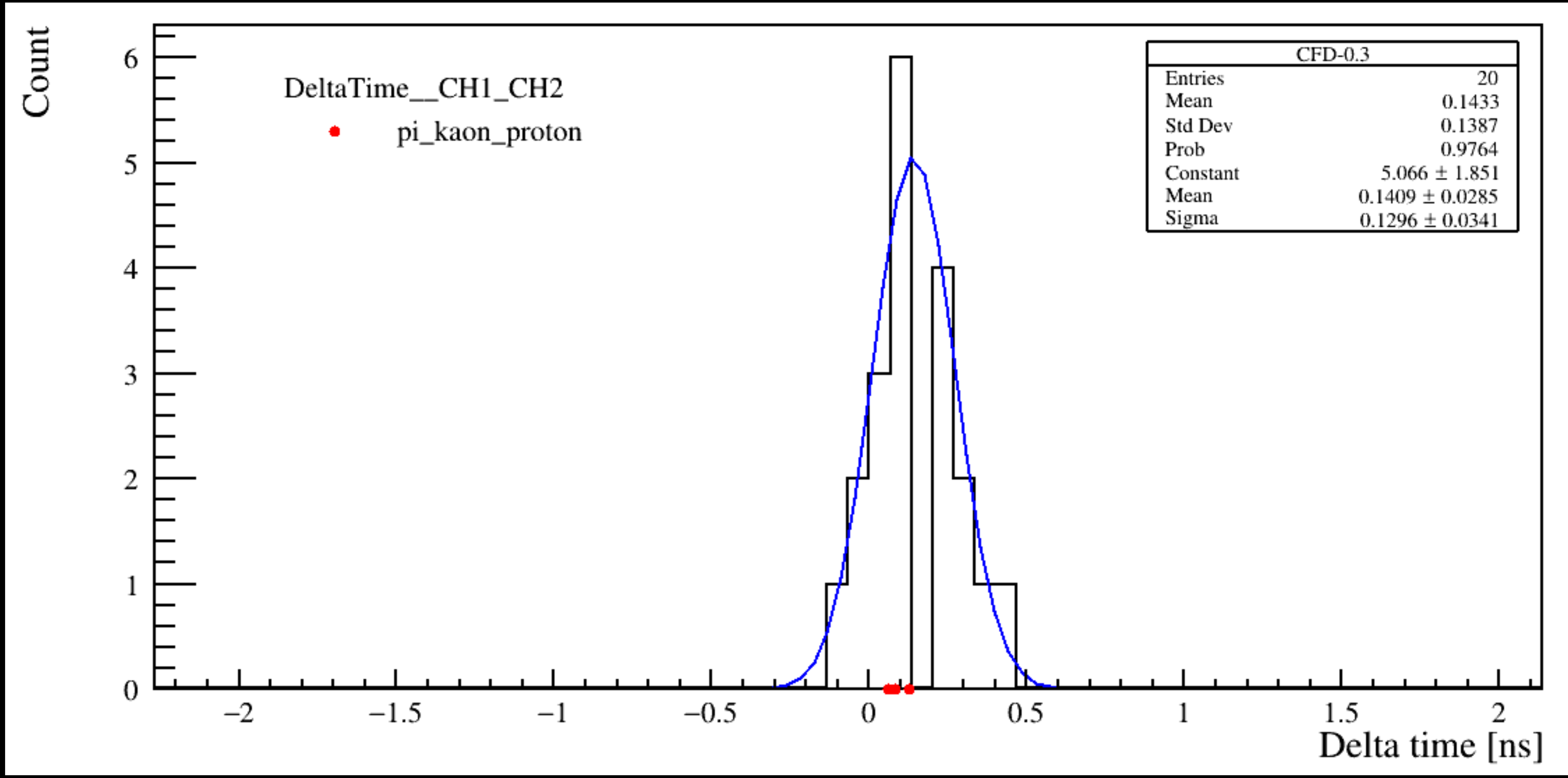


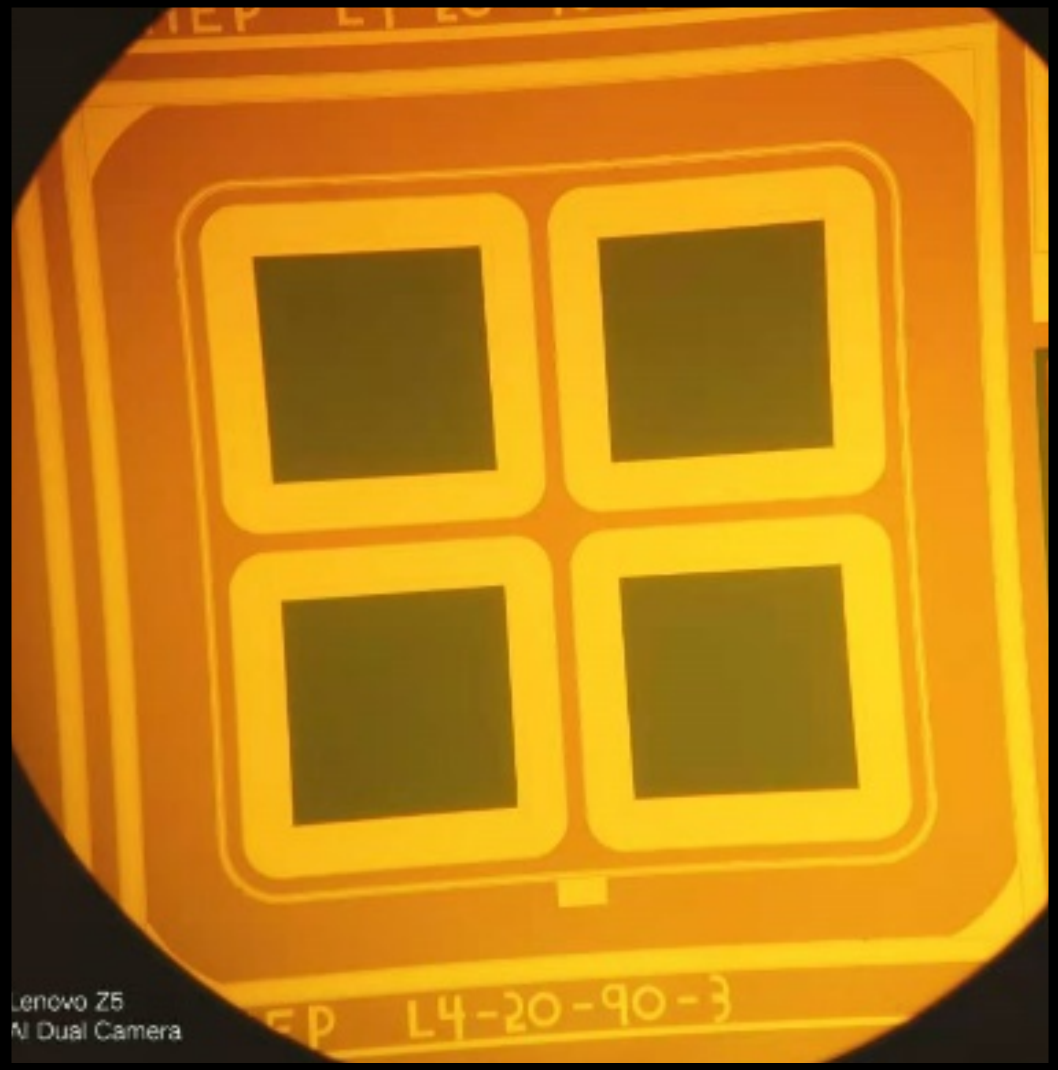


IHEP-IME LGAD performance



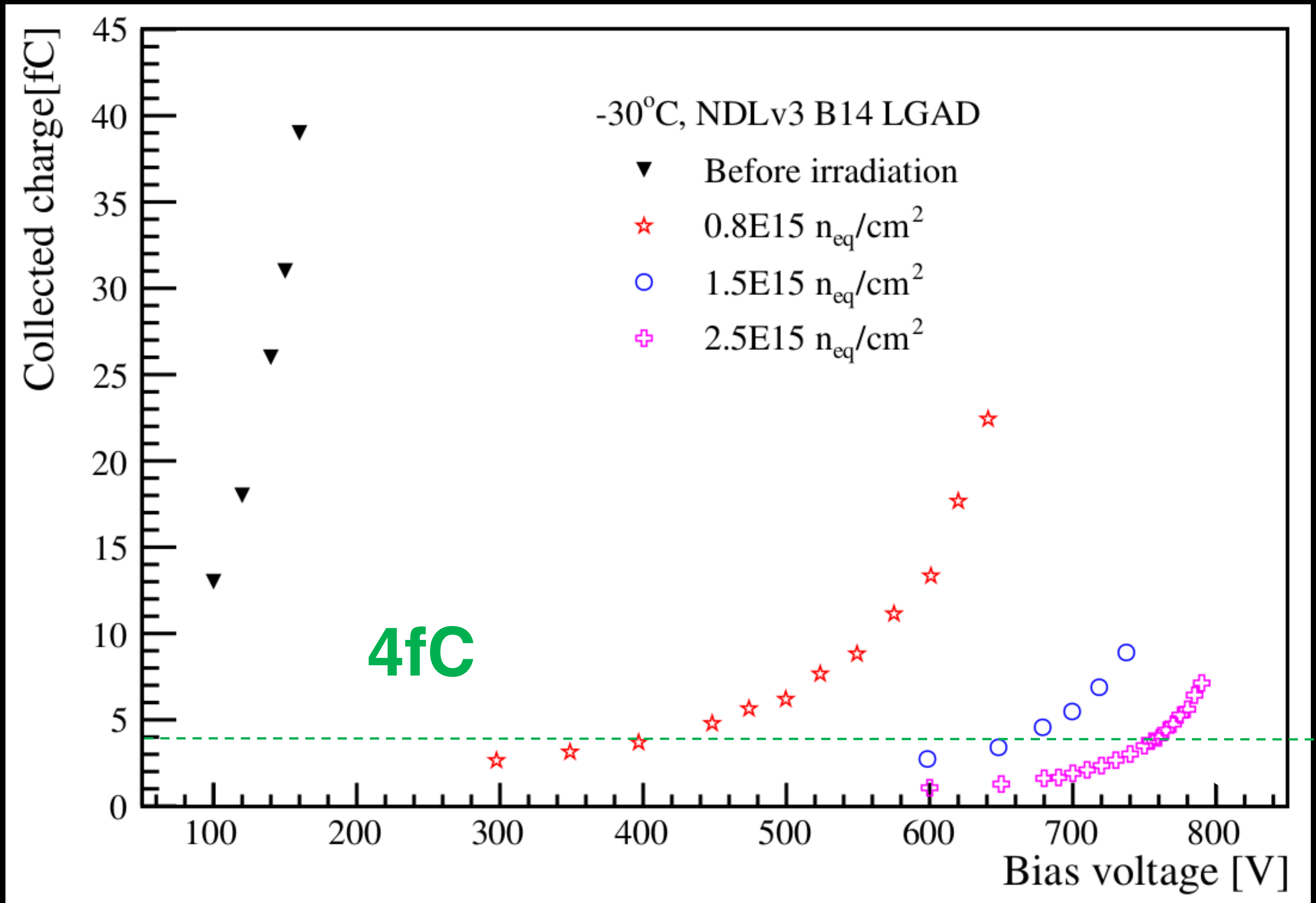
Distance 17mm
- **5 days**
- **double triggered events: 20**
- **Time resolution: 90ps**

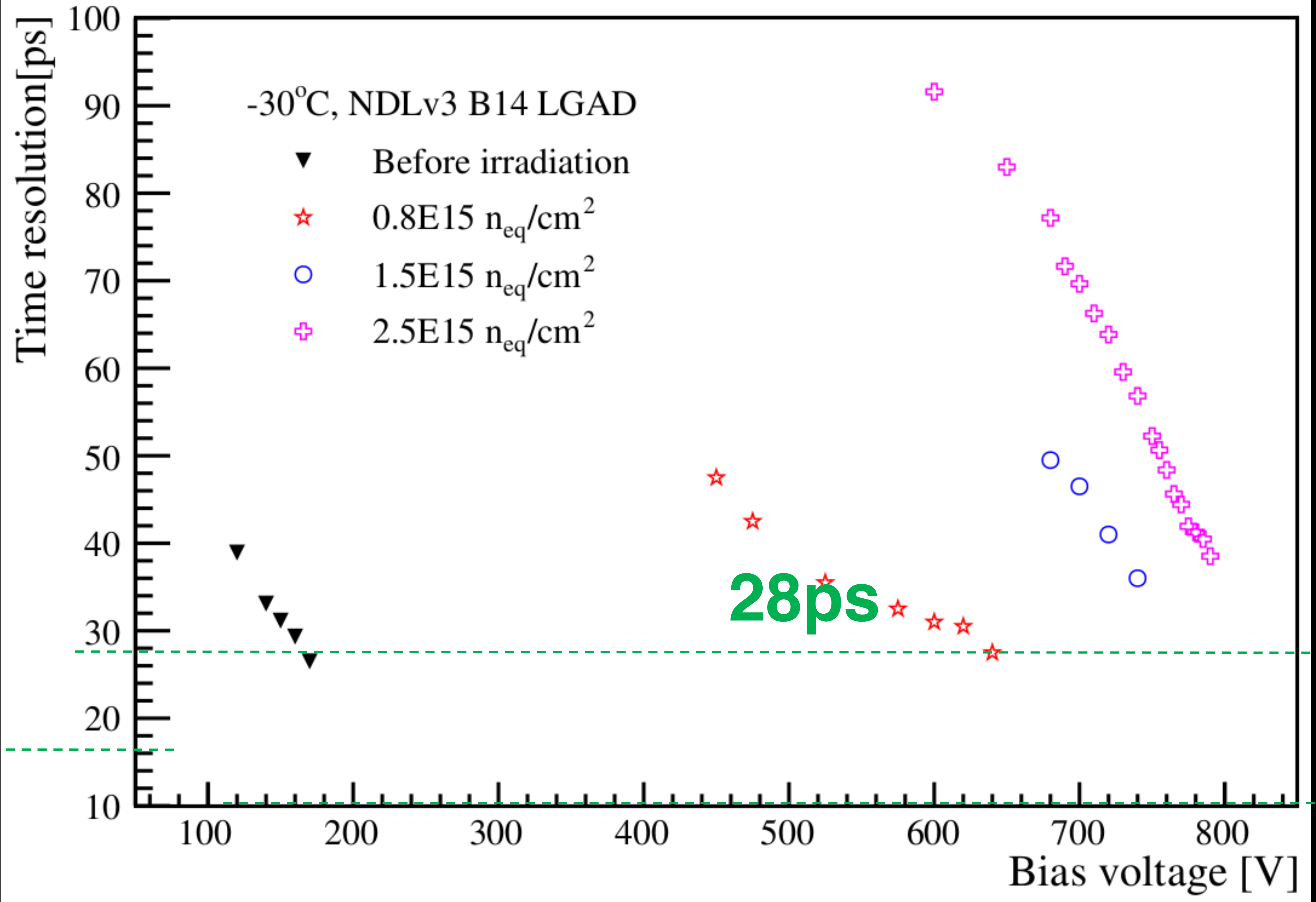




Radiation tolerance study

- Radiation tolerance (per year): 1 MRad & 2×10^{12} 1 MeV neq/cm2





0.8 e15

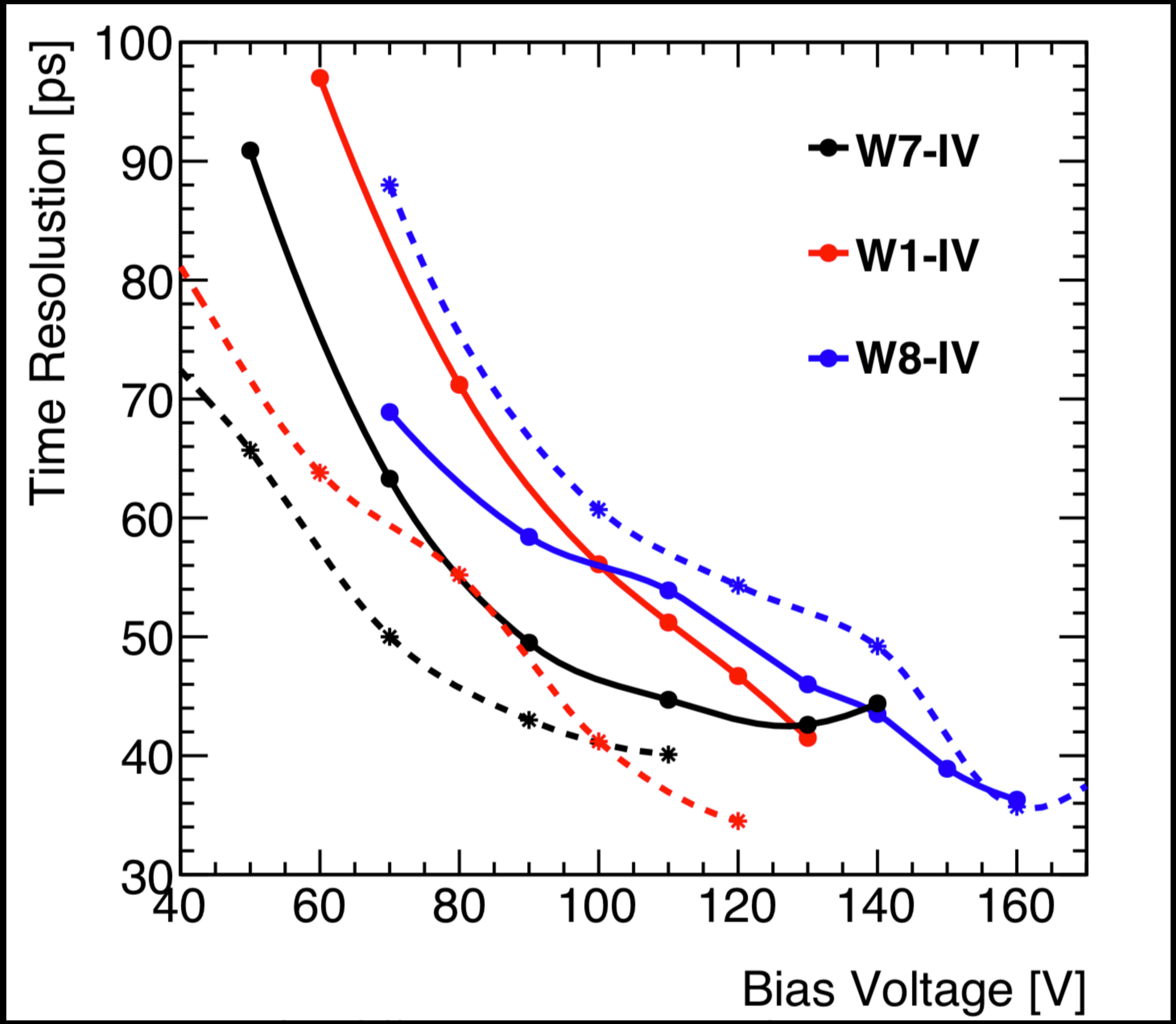
- Collected charge: 4fC @ 400V
- Resolution: 28ps @ 650V

Summary

- One option of CPEC timing detector using LGAD technology has been studied
- Verify silicon timing detector in test beam
- IHEP team has developed IHEP-NDL and IHEP-IME LGAD sensors prototypes, and both can reach 20~30 ps timing resolution
- The radiation tolerance is OK

Thank you for your attention !

Beta test results for IHEP-IME sensor



Outlook: Testbeam with ATLAS HGTD module

- **Time resolution: 45ps**
- **Position resolution: ~1mm**
- **Area : 6.5mm*6.5mm --> (2cm*4cm)**