Particle identification from timing detector

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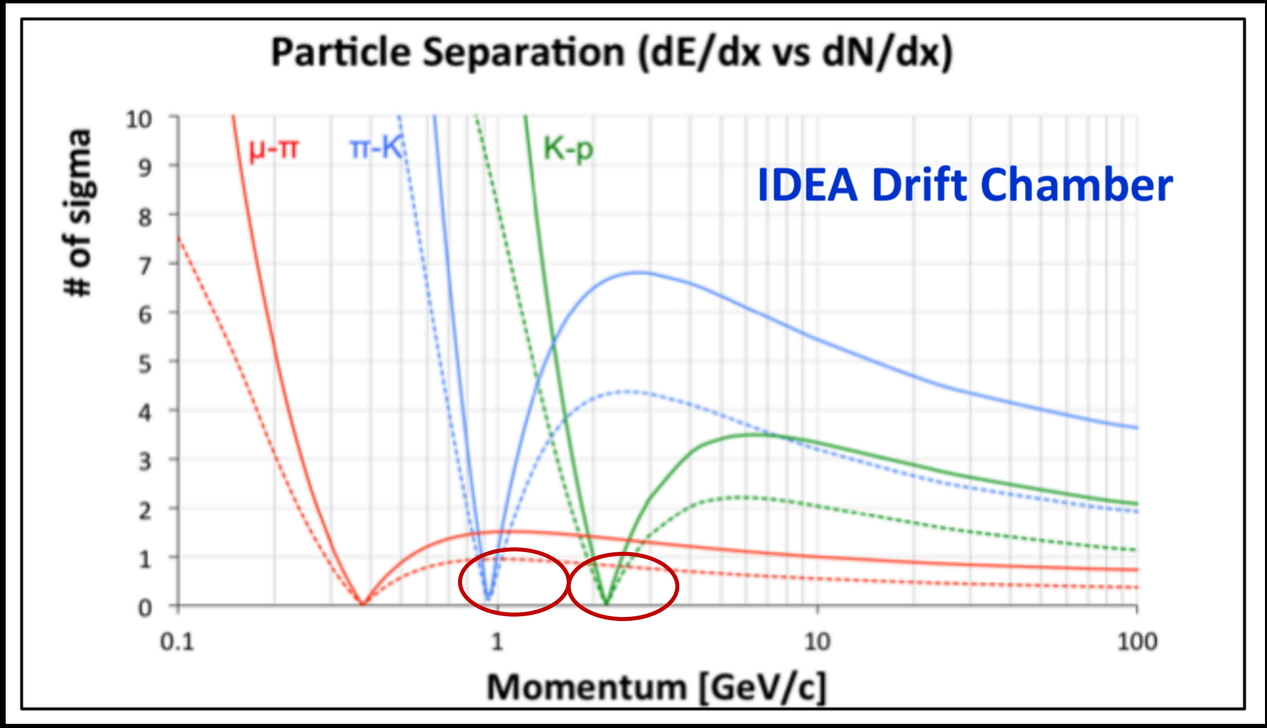
Introduction

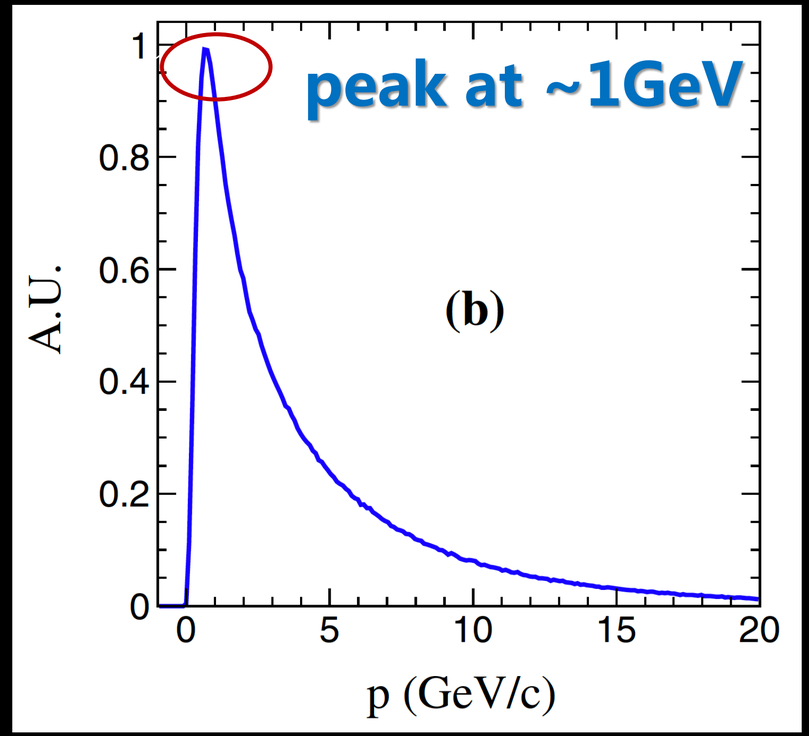
- Fcc-ee/CEPC will produce Tera Z (~10^{12}) Z boson at Z pole → Rich flavor physics
- Gas detector is powerful for particle identification (PID)
  - → good K/π separation up to **100GeV**
  - → Challenge: **0.5-1.5 GeV** for K/π separation, large fraction of Kaon in that region
- Timing detector is complementary to gas detector
- CEPC International Advisory Committee: **one of the key recommendations in 2019**

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

PID performance IDEAL drift Chamber



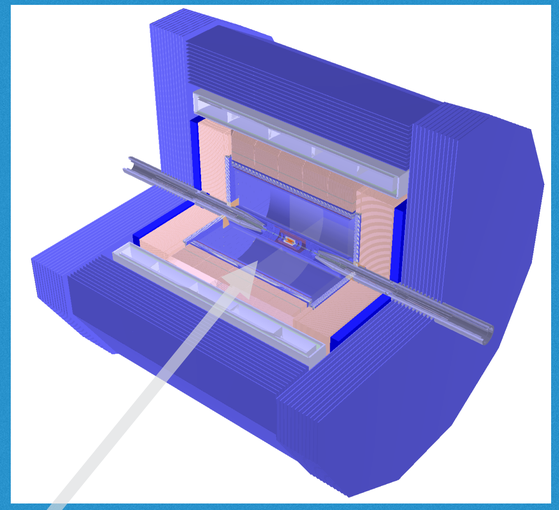
Kaon momentum distribution at Z pole



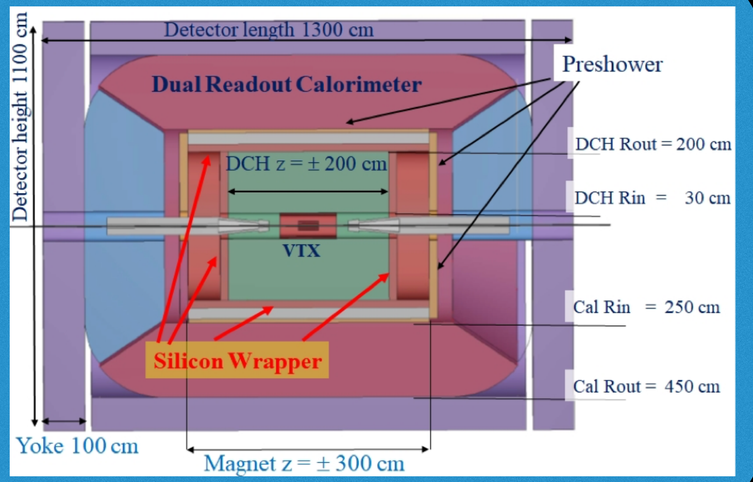
Timing detector in Detector concept

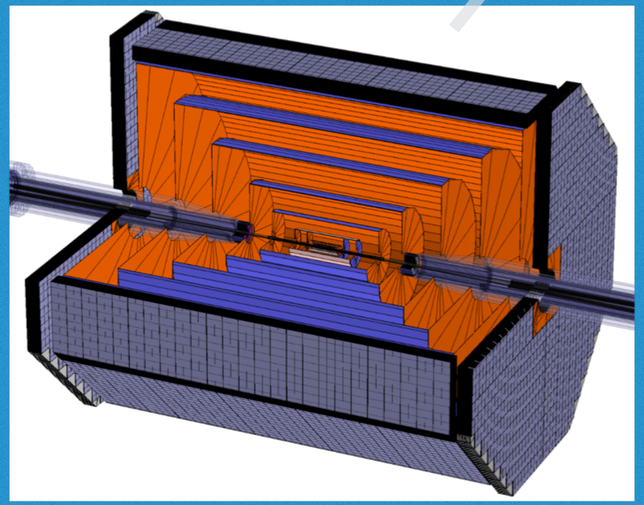
- **Take CEPC as example, timing detector was not included in CDR layout**
- **Timing detector can be placed between tracker and calorimeter**

Baseline detector
ILD-like
(3 Tesla)



Low magnetic field concept (2 Tesla)





Full silicon tracker concept

IDEA Concept
also proposed for FCC-ee

CEPC plans for 2 interaction points

Technology for timing detector

- **Silicon based timing detector (LGAD)**
- **Belle II time of flight detector : TOP**
- **TORCH**
- **Multigap resistive plate chamber (mRPC)**

Silicon timing detector : ATLAS and CMS

- Both ATLAS and CMS aim to be 10 m^2 level silicon timing detector

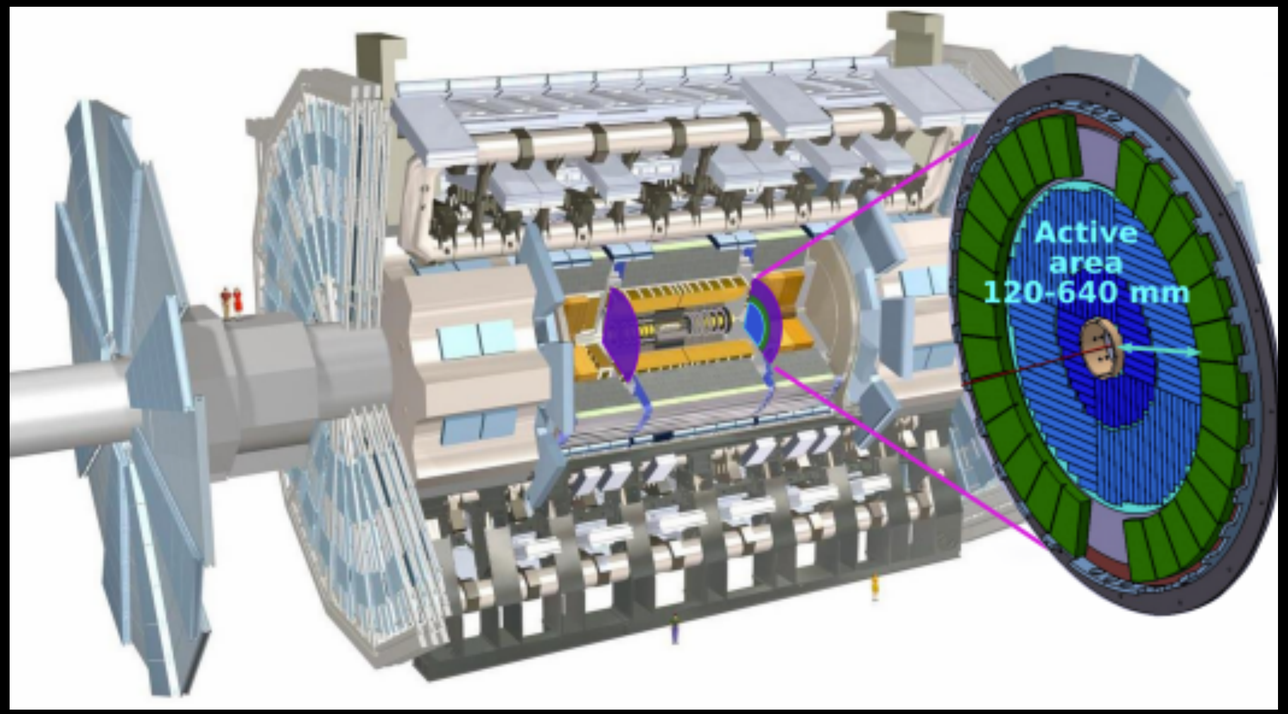
→ Both projects approved by CERN LHCC, to be built by 2026

→Time resolution per track: 30~50 ps

→Granularity: 1.3 × 1.3 mm

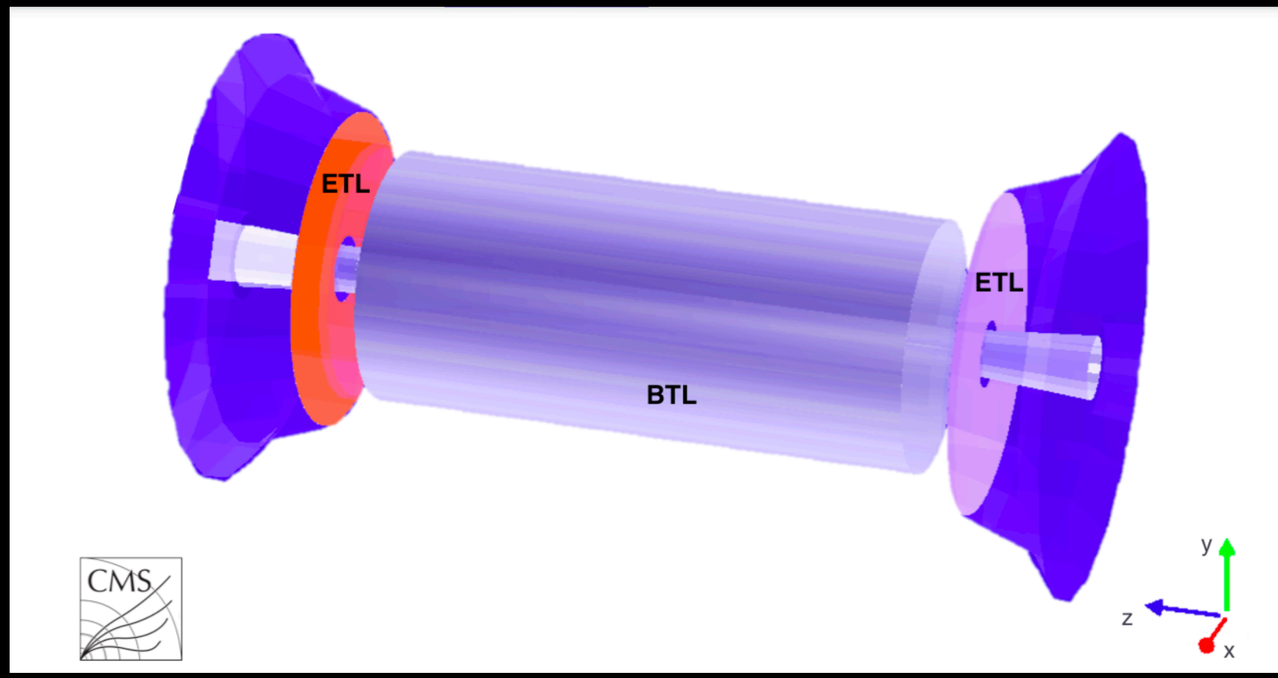
→Radiation hardness: ~fluence: 2.5 × 10^{15} N_{eq}/cm^2 , total ionzation dose: 200 Mrad

ATLAS: high granularity timing detector



TDR: https://cds.cern.ch/record/2719855/

CMS Mip timing detector



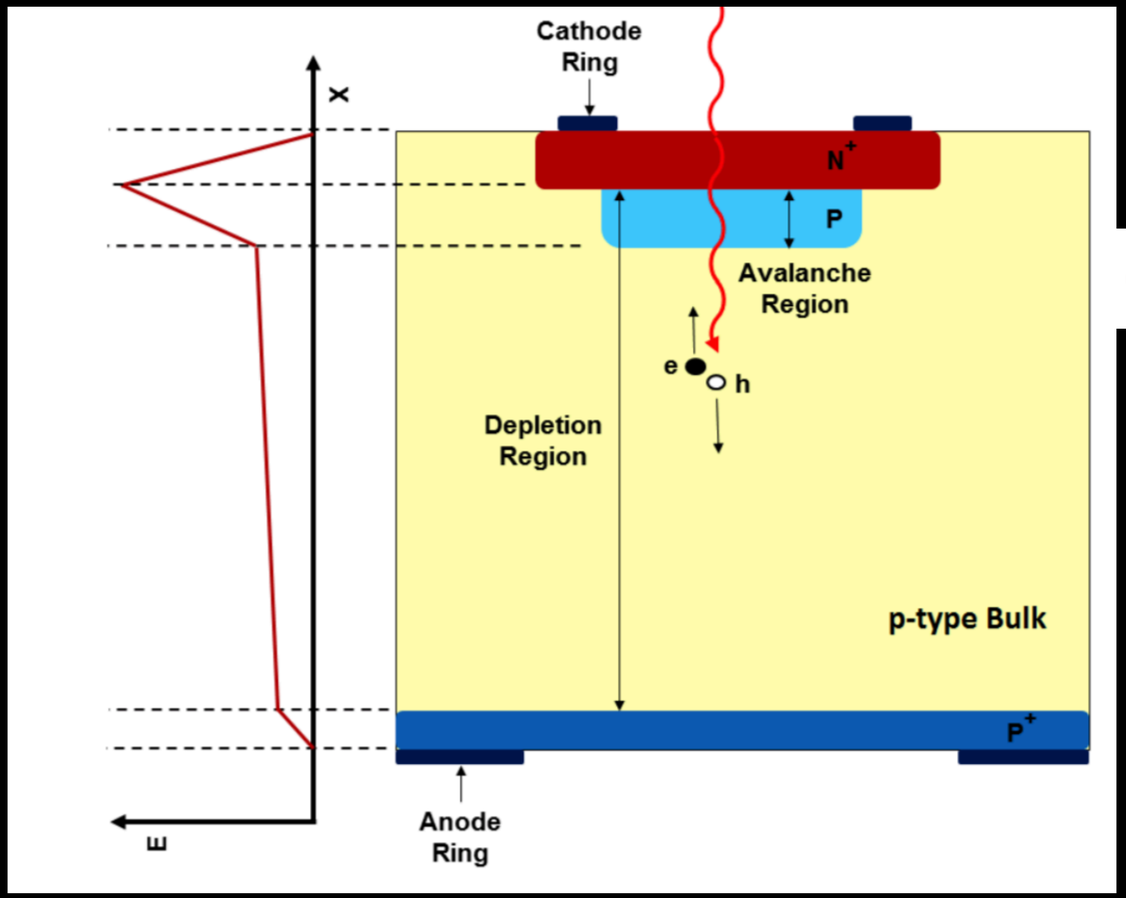
TDR: https://cds.cern.ch/record/2667167

Low-Gain-Avalanche-detector (LGAD)

- LGAD is optimized for charge particle timing measurements
- Add an internal gain layer for charge multiplication
- Compared to SiPM, LGAD has lower gain (20-30)

→ High S/B, no self-triggering, optimized for timing

- high electric field, high drift velocity, thin active layer → fast timing



Manufacturers of LGAD

CNM (Spain), HPK (Japan), FBK (Italy),
BNL (USA), NDL (China), IME (China)

$$\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{Jitter}^2 + \sigma_{TDC}^2$$

$$\sigma_{jitter}^2 = \left(\frac{t_{rise}}{S/N}\right)^2$$

Reduce Jitter term

- Need gain to increase S/N
- Need thin detector to decrease t_{rise}

CEPC silicon timing detector Concept

- Target time resolution:

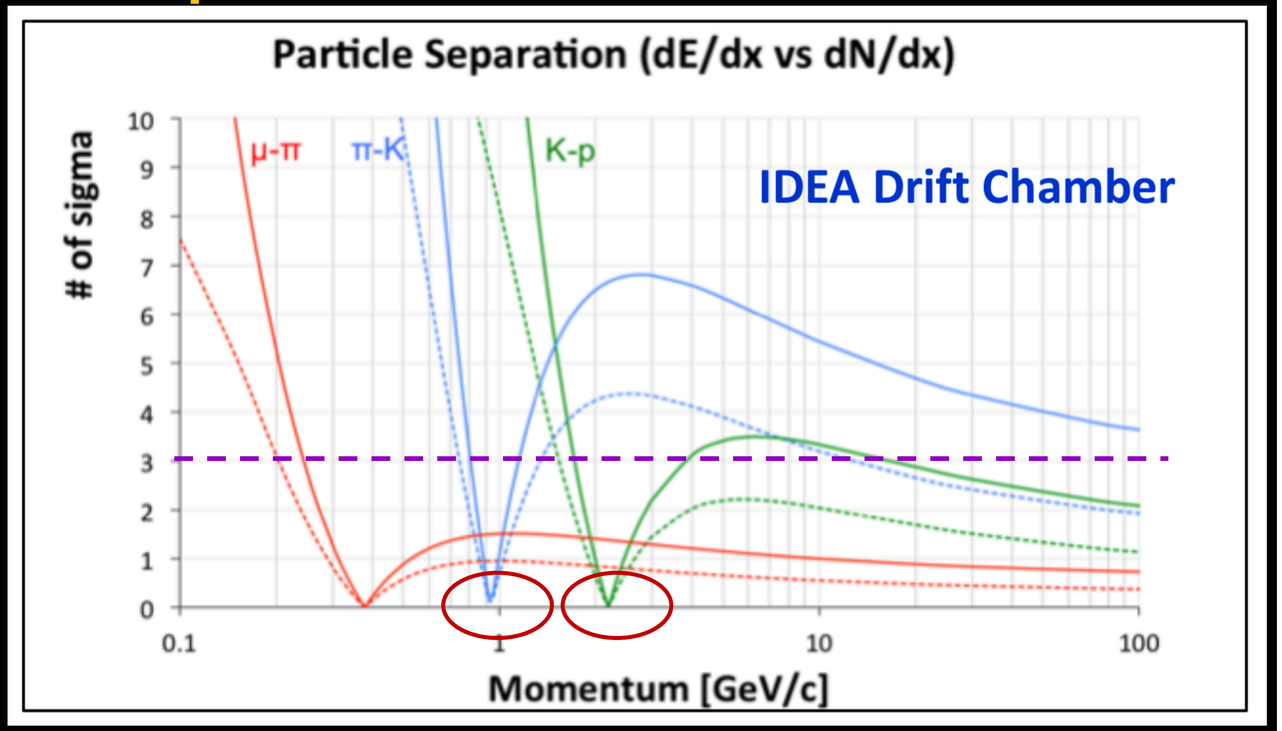
→Aim for 20 pico-second(ps if the cost is under control （ ~10 M CHF ）

- Expected Timing detector performance （assuming 20ps resolution)

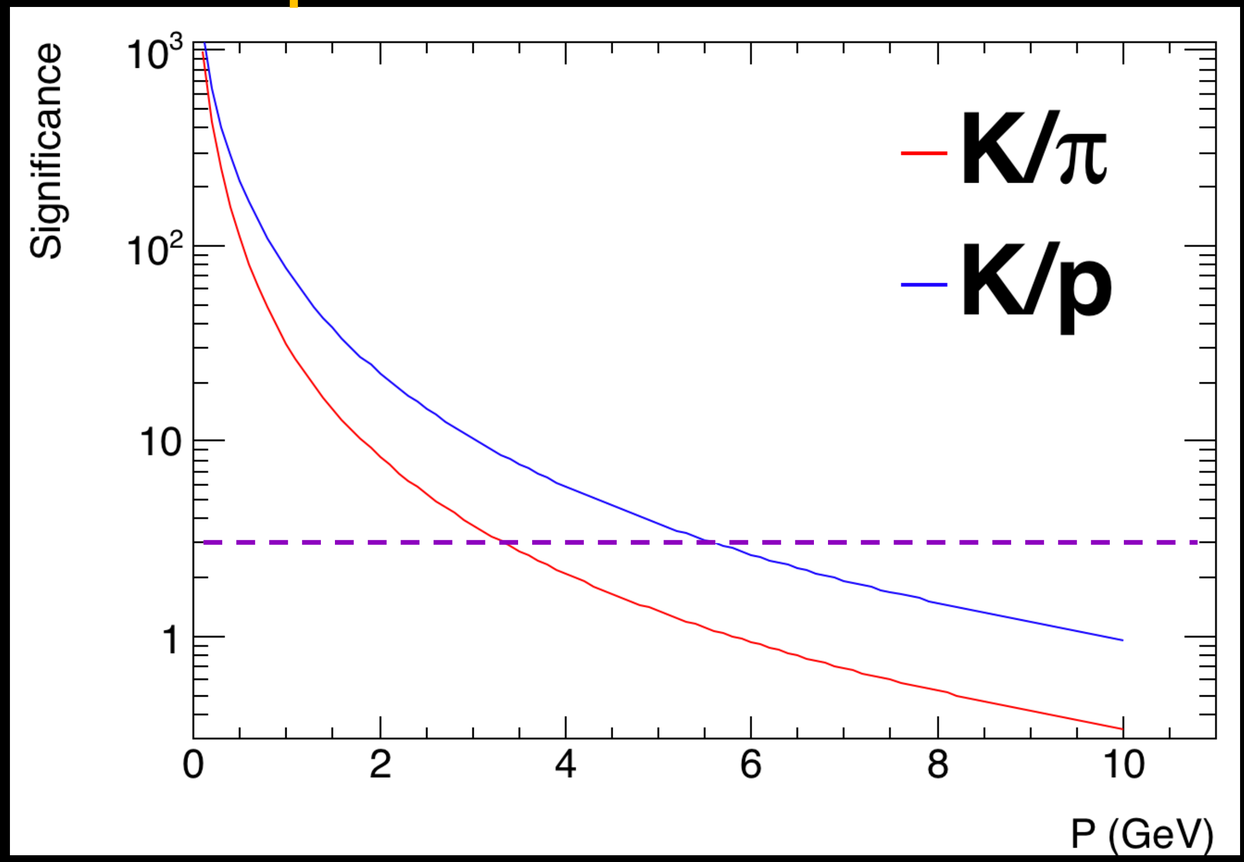
→ More than 3σ K/π separation: 0-3.5GeV

→ More than 3σ K/p separation: 0-5 GeV

PID performance IDEAL drift Chamber



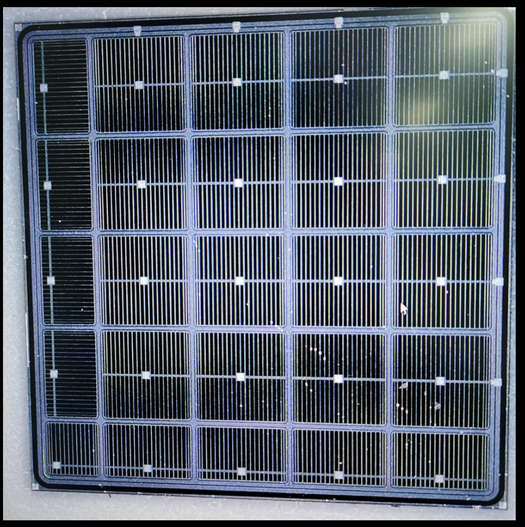
PID performance of CEPC TOF



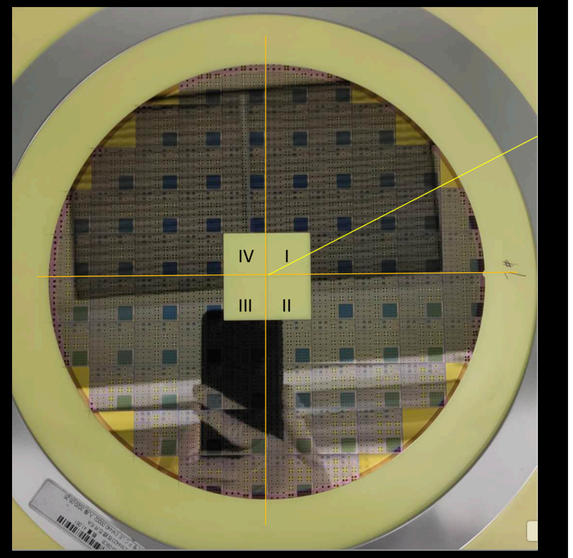
CEPC silicon timing detector : R & D status

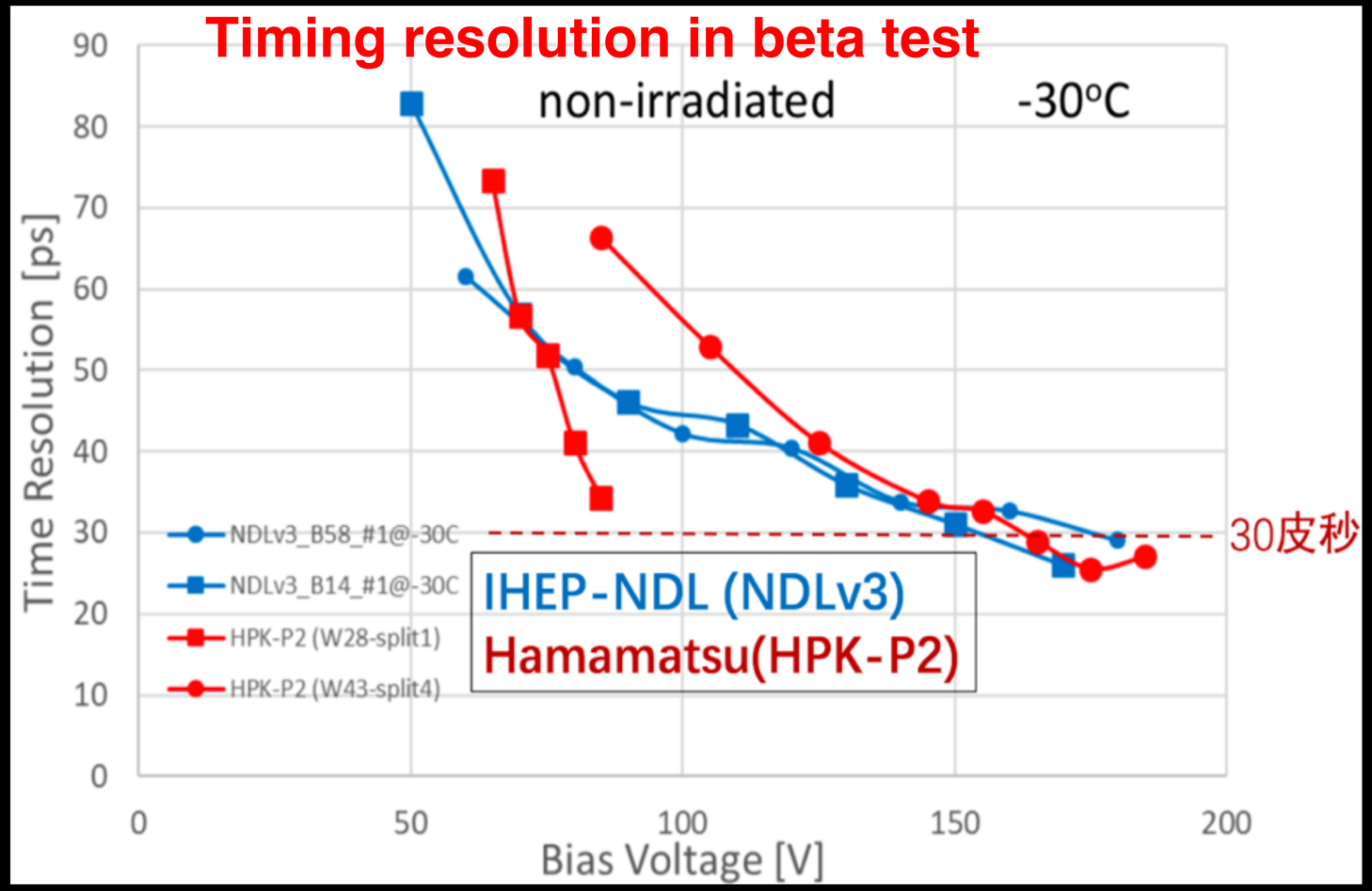
- IHEP and Beijing Normal U. developed IHEP-NDL LGAD sensors
- → Time resolution reach 30 pico-second(ps) per hit
- → Similar performance compared to HPK sensors before radiation
- IHEP and Institute of micro-electronics (IME) developed IHEP-IME sensors
- → IHEP team designed , IME fabricated, ~30ps time resolution

IHEP-NDL sensor



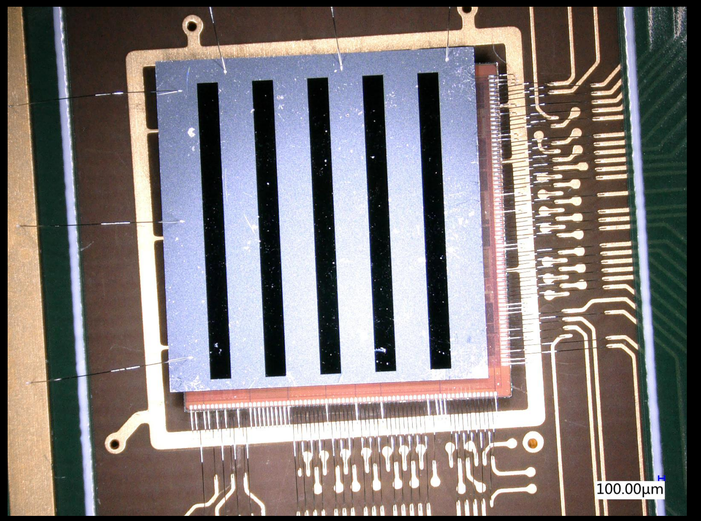
IHEP-IME sensors 8 inch wafer



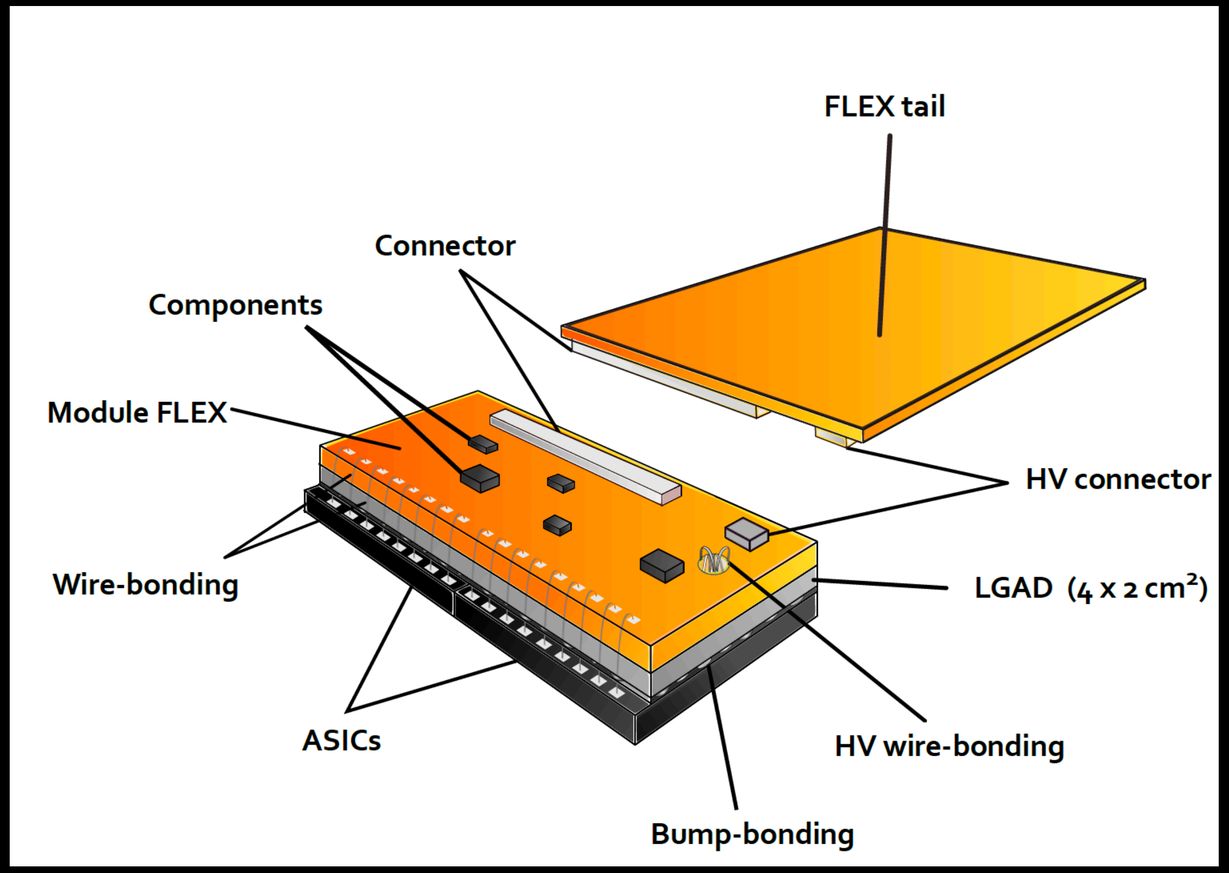


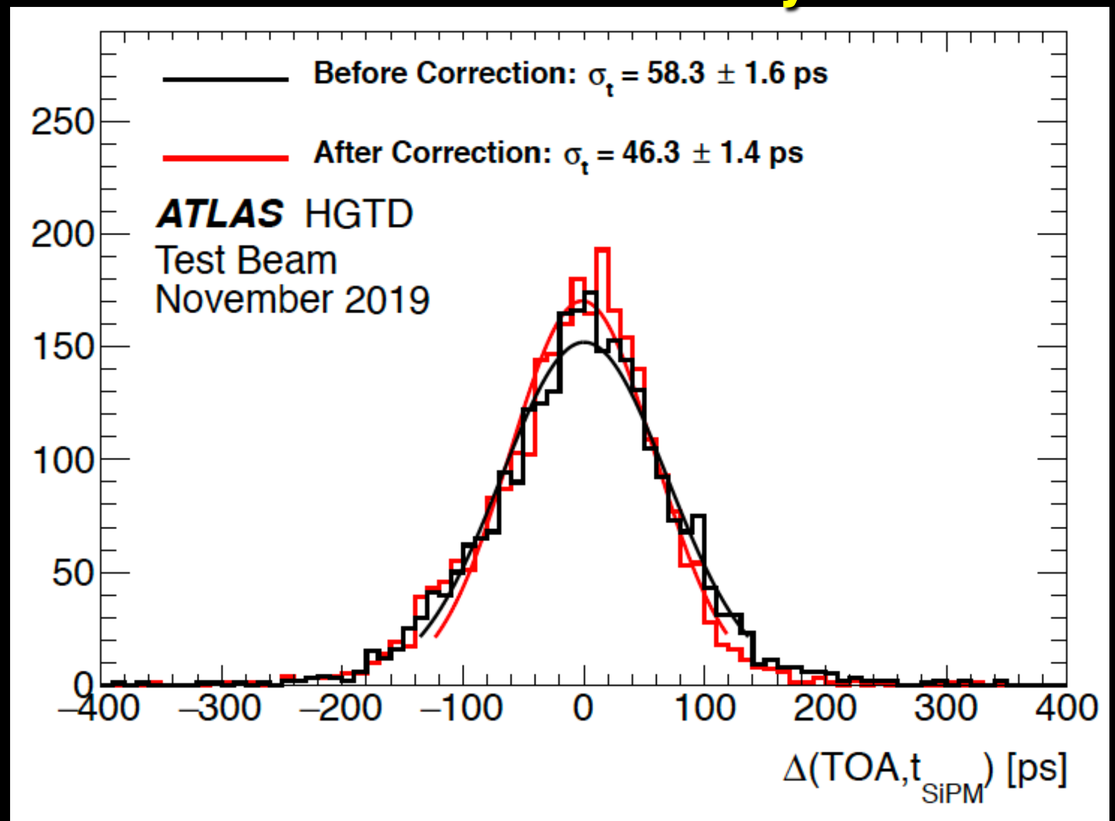
R & D status of ATLAS HGTD detector

- **Mini-Detector modules prototyped**
- **LGAD bonded bumped with fast readout ASIC**
- **Time resolution : 45ps (from test beam)**
- **Area : 6.5mm × 6.5mm (mini-modules)**
  → 2cm × 4cm (full size modules, to be built in 2021)



HGTD mini-module by IHEP



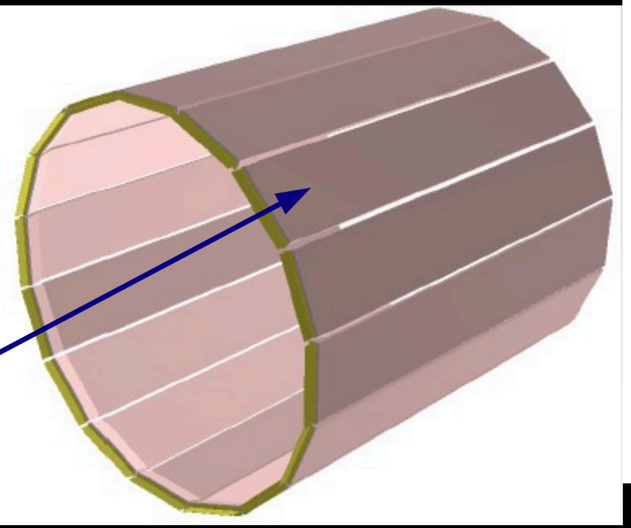


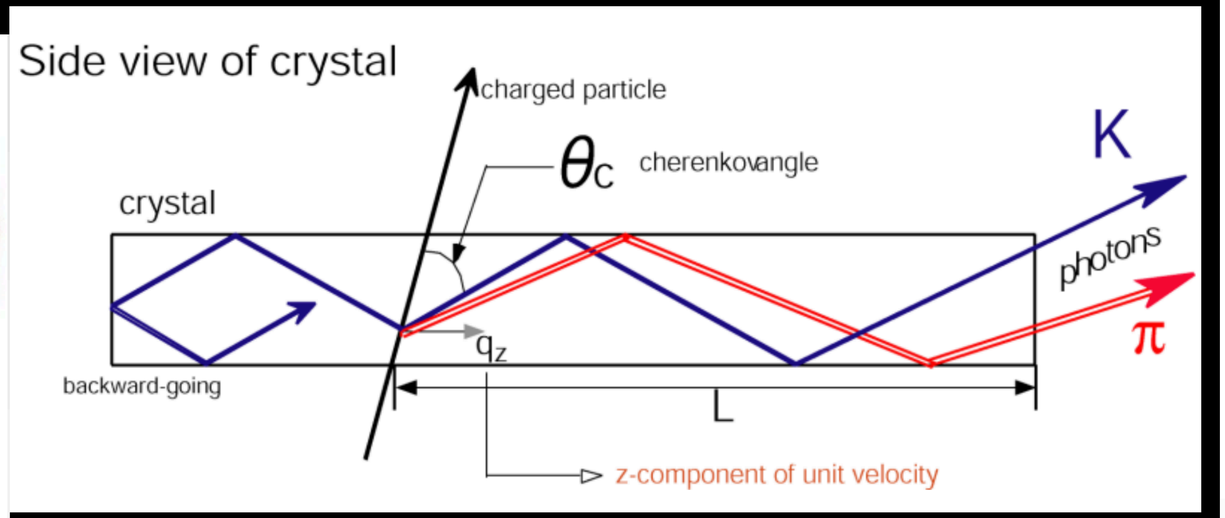
Belle II time of flight detector : TOP

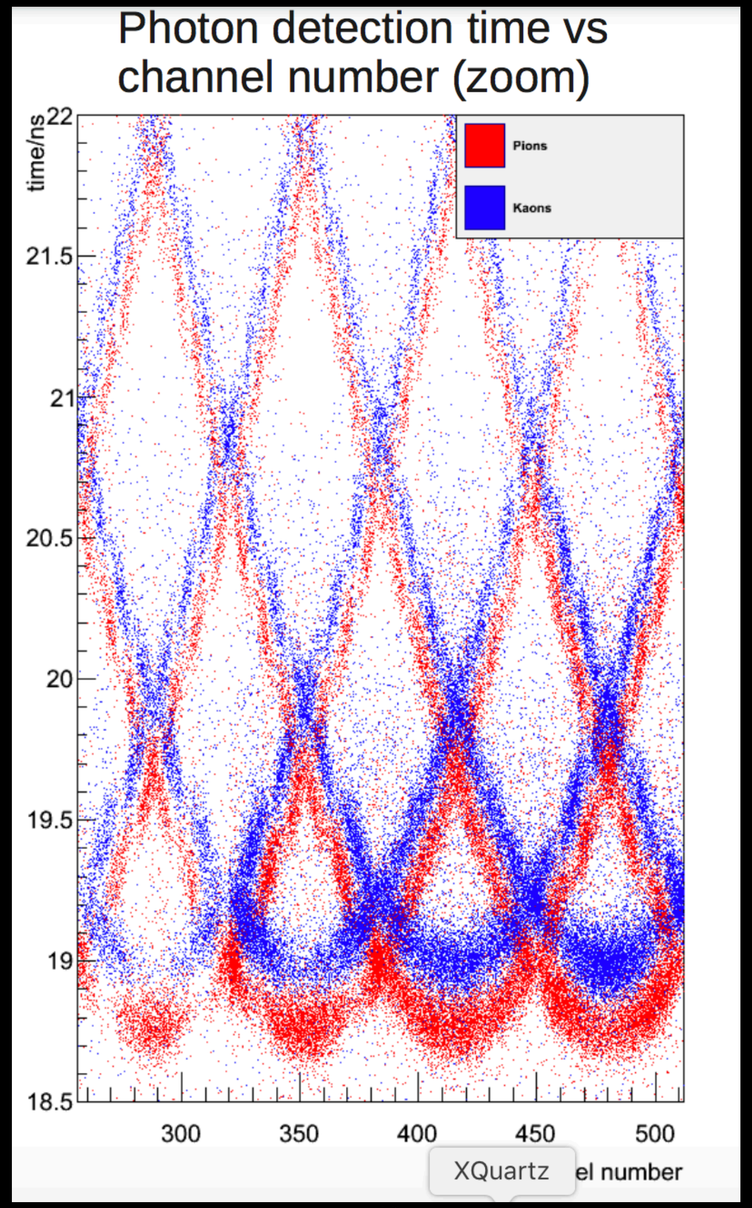
- **Time of Propagation subdetector can be used for PID**
- **New MCP-PMTs for sub-50ps photon detection**

- **A 2-dimensional PDF can be constructed based on detection time and detection position of Cherenkov photons.**

- **The different Cherenkov angle for photons from kaons leads to a later arrival time than for photons from pions.**



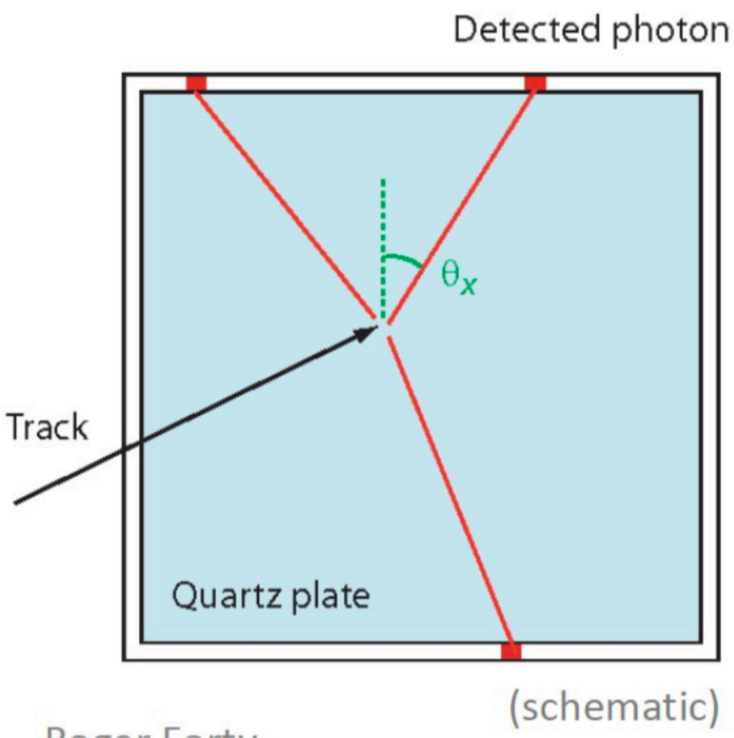




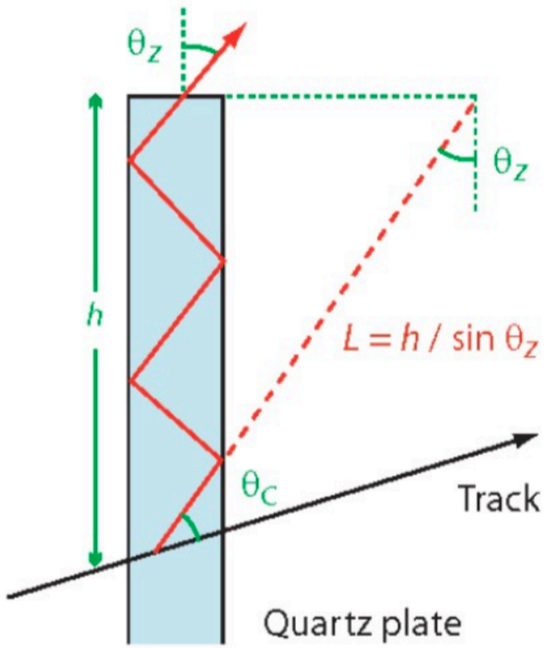
TORCH: a novel concept for PID

- **LHCb proposed TORCH(Time Of internally Reflected Cherenkov light)**
- **Cherenkov light produced in a thin quartz plate propagates to the edge by total internal reflection focused via cylindrical lens to fast photon detectors.**
- **Photon detection requires to have angular resolution of ~1 mrad with timing resolution of 70 ps/photon and 10-15 ps/track with 30 photons.**

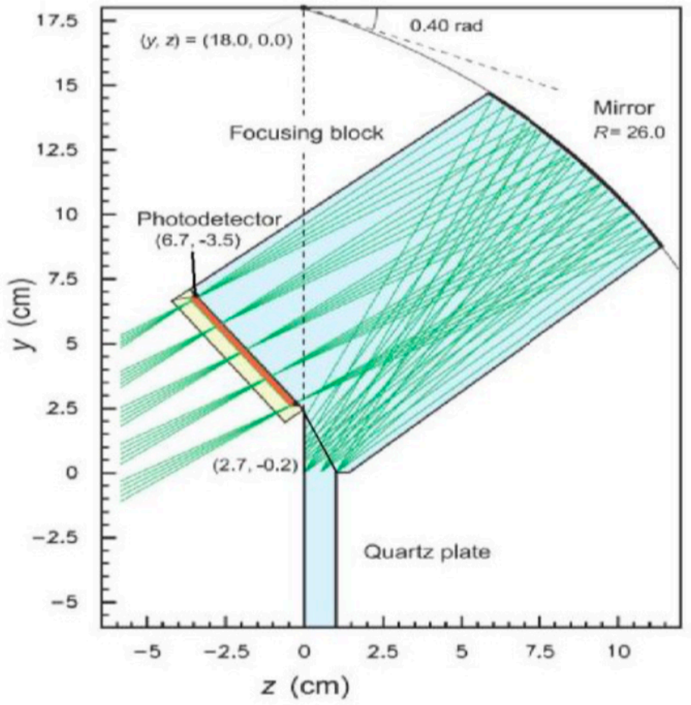
Front and side views of radiator plate



(schematic)

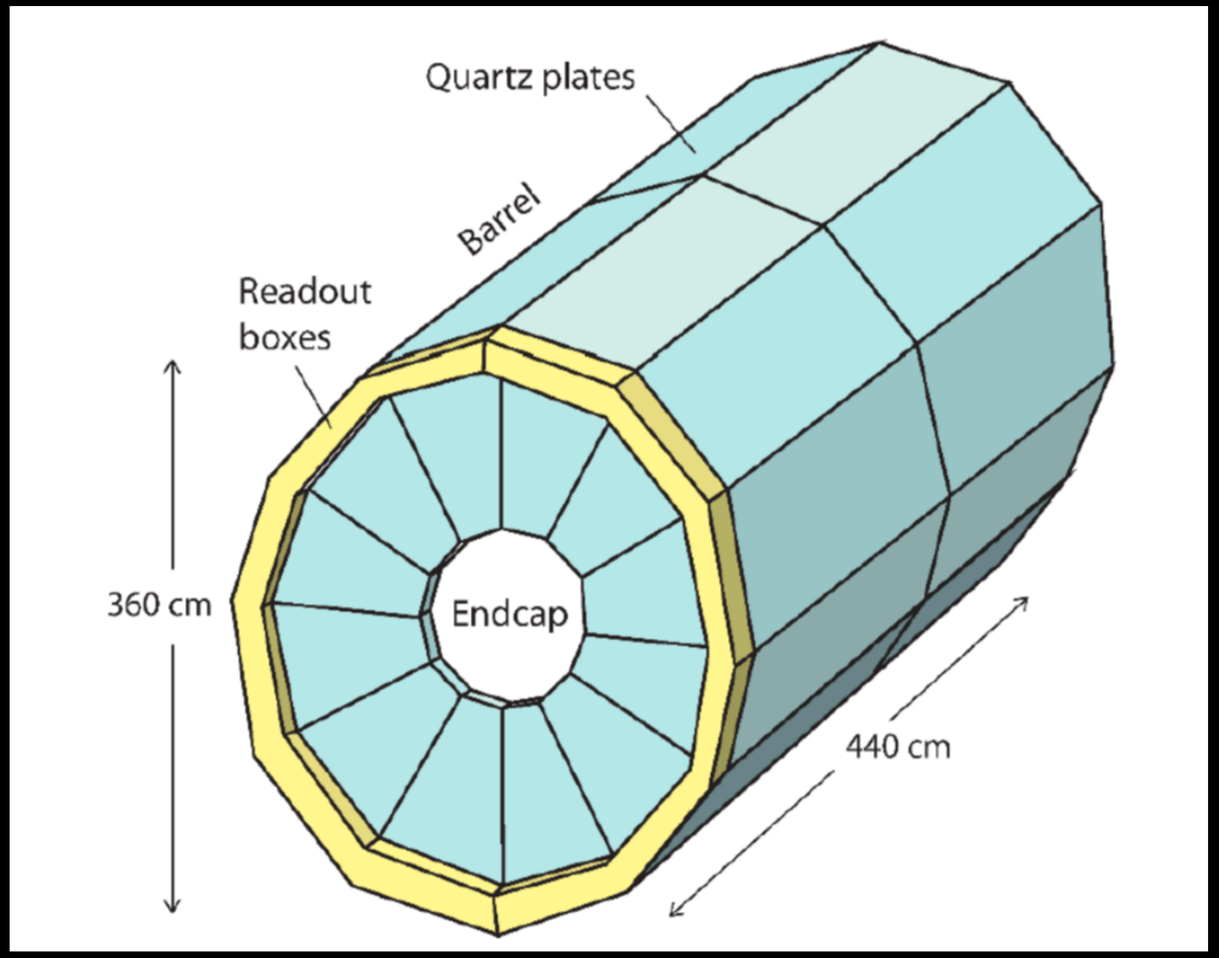


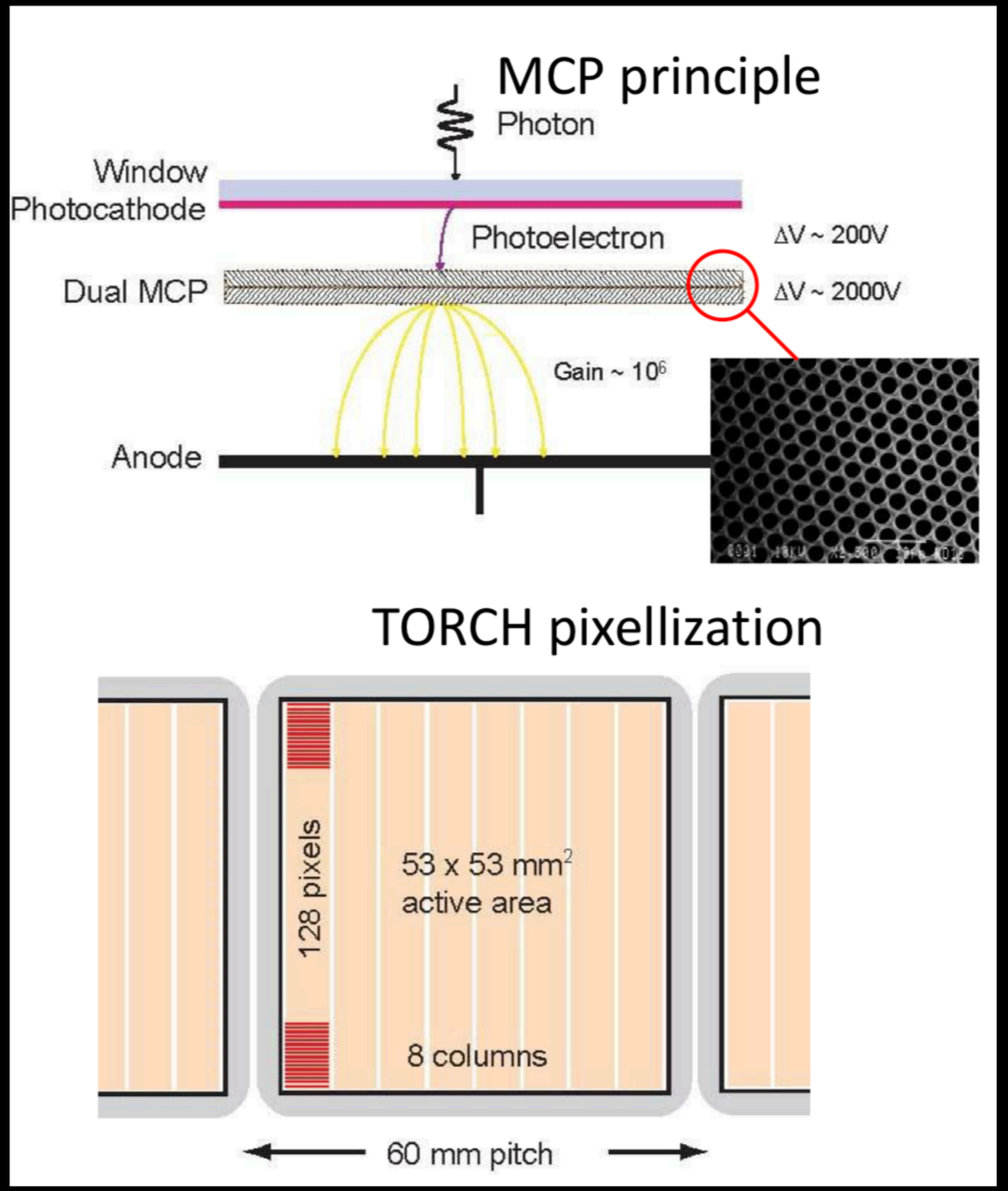
Focusing at edge of plate



TORCH (2)

- TORCH proposed for Fcc-ee by R. Forty.
- → between TPC and calorimeter
- 24 barrel modules 96 x 220 cm^2 = 50 m^2
- 12 modules for each endcap ~ 10 m^2

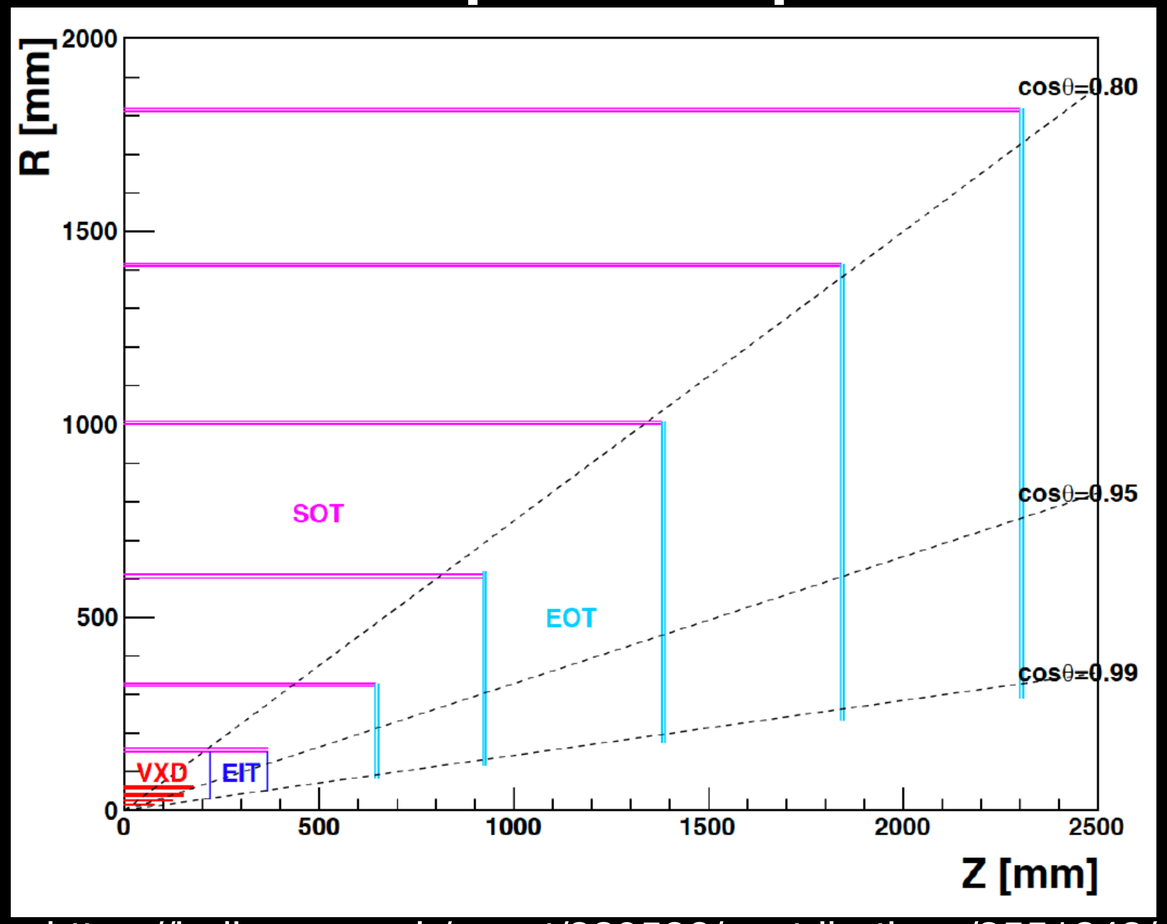


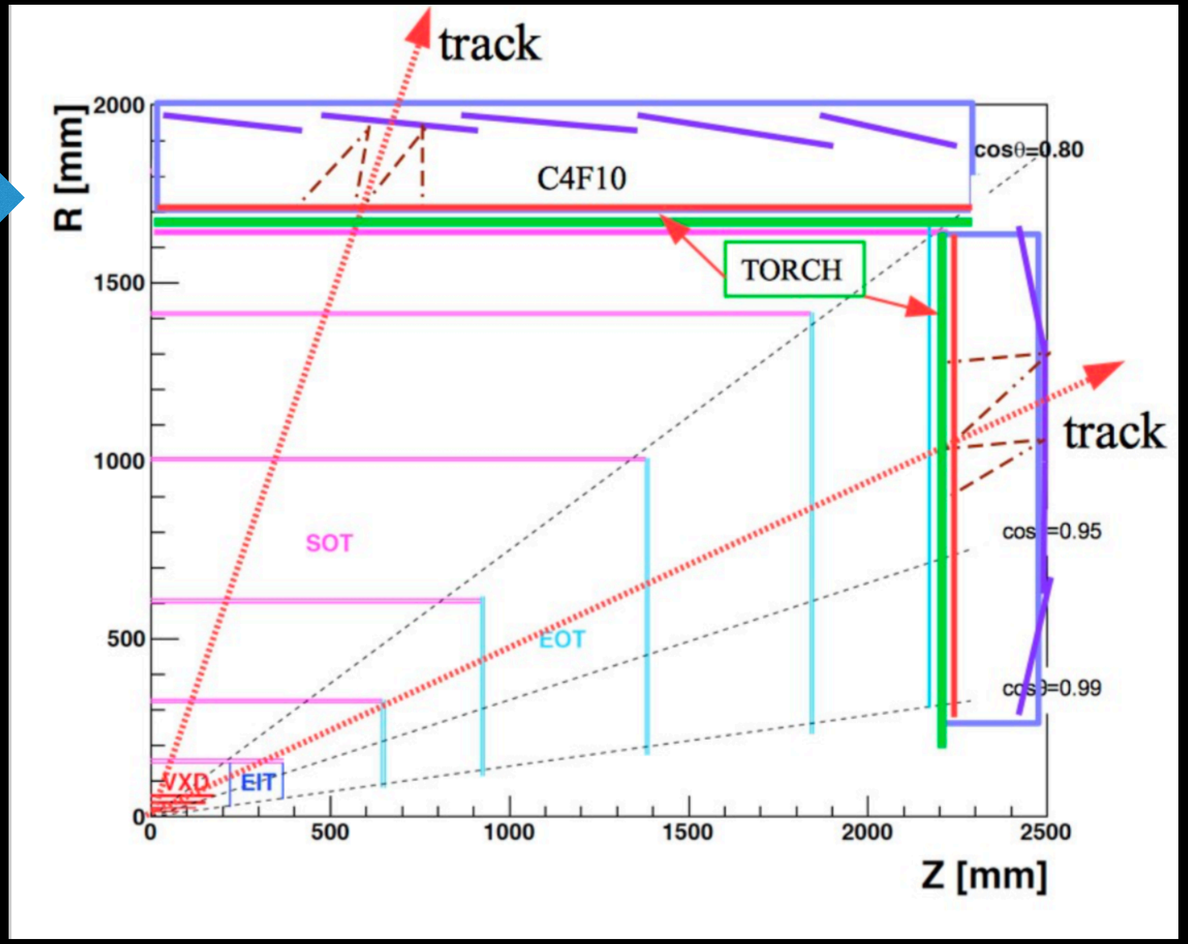


https://indico.cern.ch/event/766859/contributions/3255803/attachments/1776523/2888463/FCC-ee-TORCH.pdf

TORCH for full-silicon detector concept

- Challenge to perform particle identification in full silicon concept
  - → Silicon timing detector alone can be cover medium/high energy range
- Torch for CEPC in full silicon concept proposed by Weimin Yao
- →Replacing outer strip layers with TORCH
- →Good K/π separation up to 30GeV





https://indico.cern.ch/event/820586/contributions/3551243/attachments/1908931/3154693/cepc_tracking_chicago2019.pdf

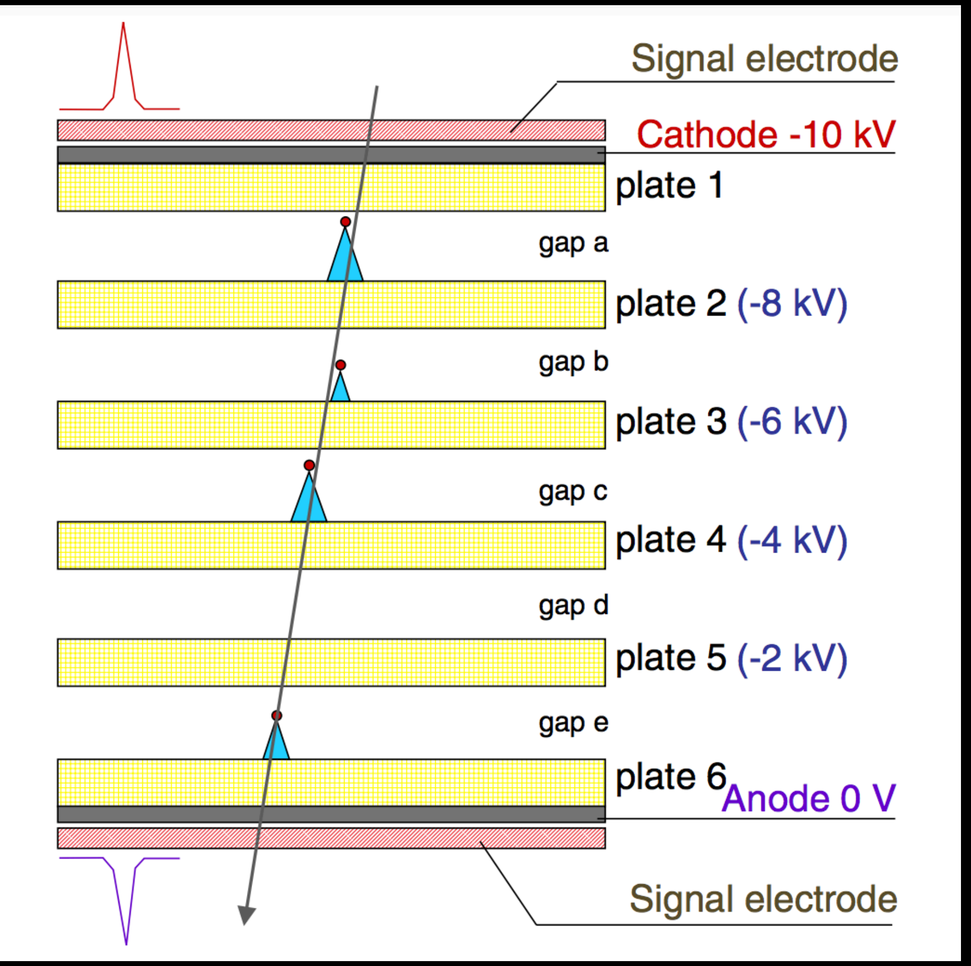
Multi-gap RPC at ALICE

- **Multigap resistive plate chamber (mRPC)**

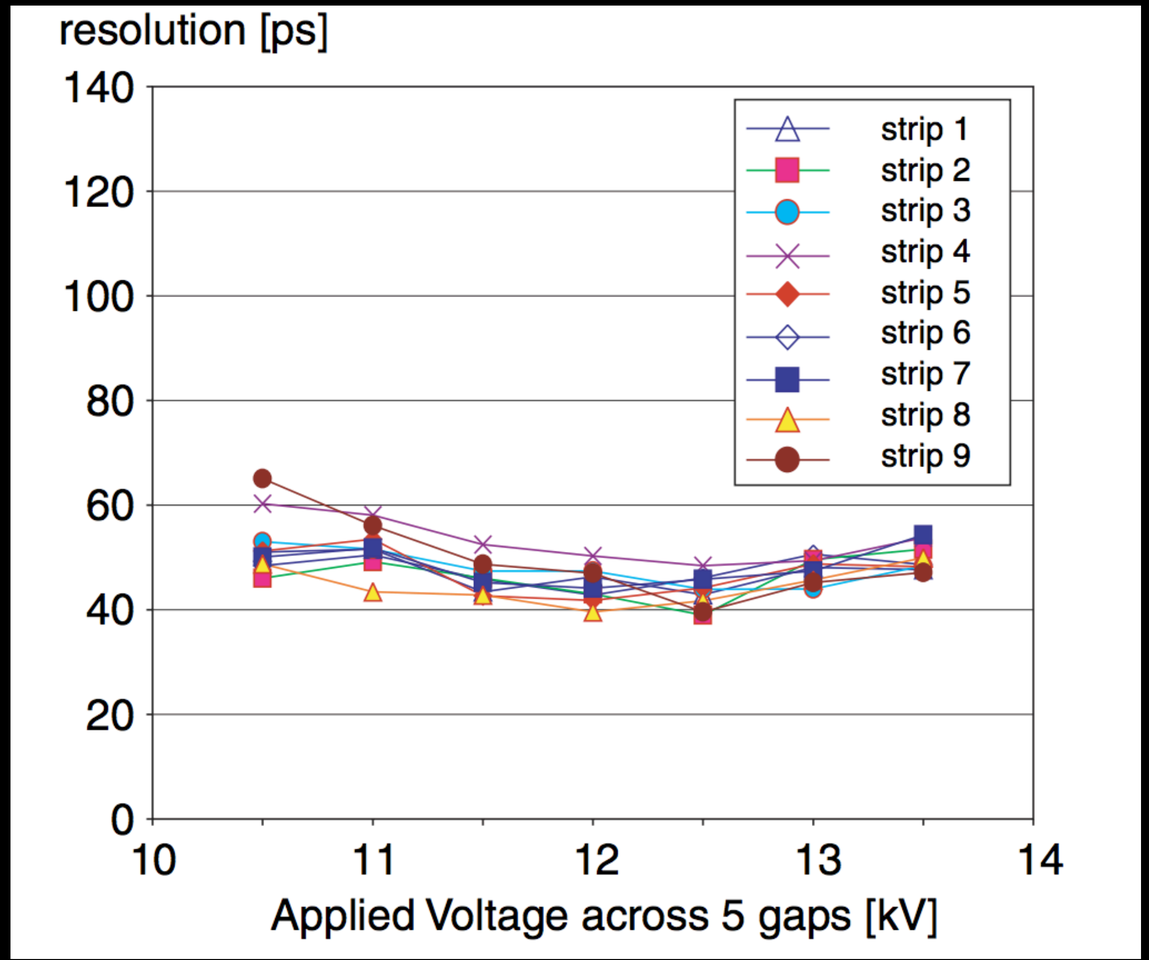
→Easy to build, easily segmented

→Adding more gaps in RPC → improve time resolution (~**50ps** for ALICE mRPC)

→**Challenge**: to handle High continuous flux



Performance of the ALICE TOF MRPC strips



Summary

- Timing detector is essential to PID in flavor physics Fcc-ee/CEPC
- Especially at low energy range around **1GeV**

- Silicon timing detector is making progress very rapidly
- **Expect to have the first implementation in ATLAS/CMS in 2026.**

- TORCH proposed in Fcc-ee/CEPC
- **Can be integrated in many detector concepts**
- **Extremely important for for full silicon concept**

- mRPC have proven their validity in several systems.
- **Can provide with the required resolution (50 ps)**

- Time of propagation of Cherenkov light represent a alternative to mRPC.