TOF T0 and Calibration “Plans”

personal thoughts on a detector still in the design phase

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LBNL/UIC

TOF Detectors

T0 Determination

TOF Calibration

AC-LGAD Detectors for ePIC

Tracking and Vertexing:

- MAPS
- MPGD

PID:

- AC-LGAD TOF (also for tracking)
- hpDIRC
- pfRICH (also for TOF at e-going)
- dRICH

EMCal:

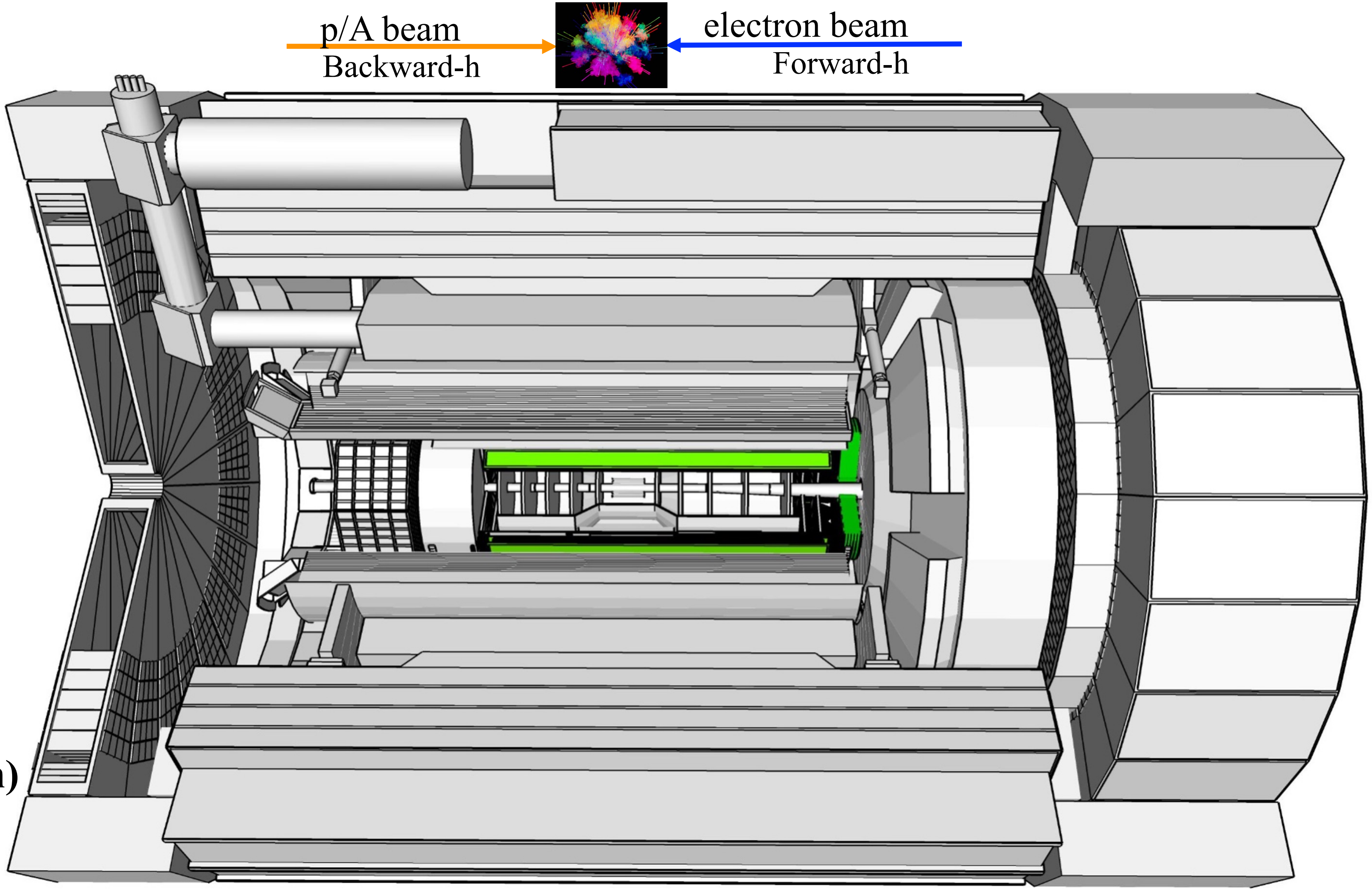
- PbWO EEMCal
- Pb/SciFi Barrel EMCal with Imaging
- W/SciFi FEMC

Hadronic Calorimeter

- Fe/Sc Backward HCAL
- Barrel HCal (sPHENIX re-use)
- Fe/Sc&W/Sc LFHCAL

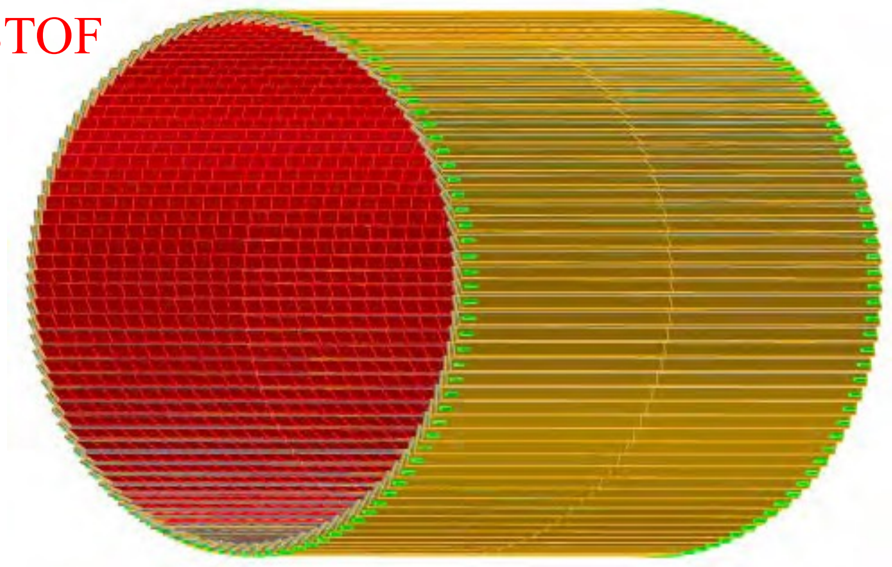
Far-For/Backward (not shown)

- Roman Pots/B0 Tracker/OMD
- Zero Degree Calorimeter
- Luminosity Tracker/Calorimeter
- Low-Q^2 tagger

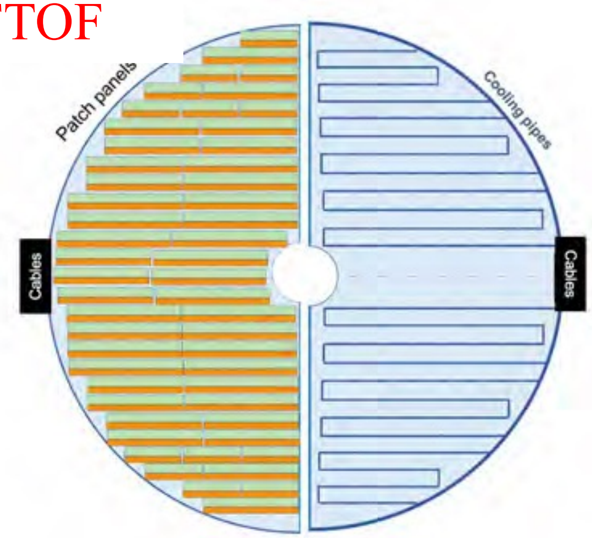


AC-LGAD Detectors for ePIC

BTOF



FTOF

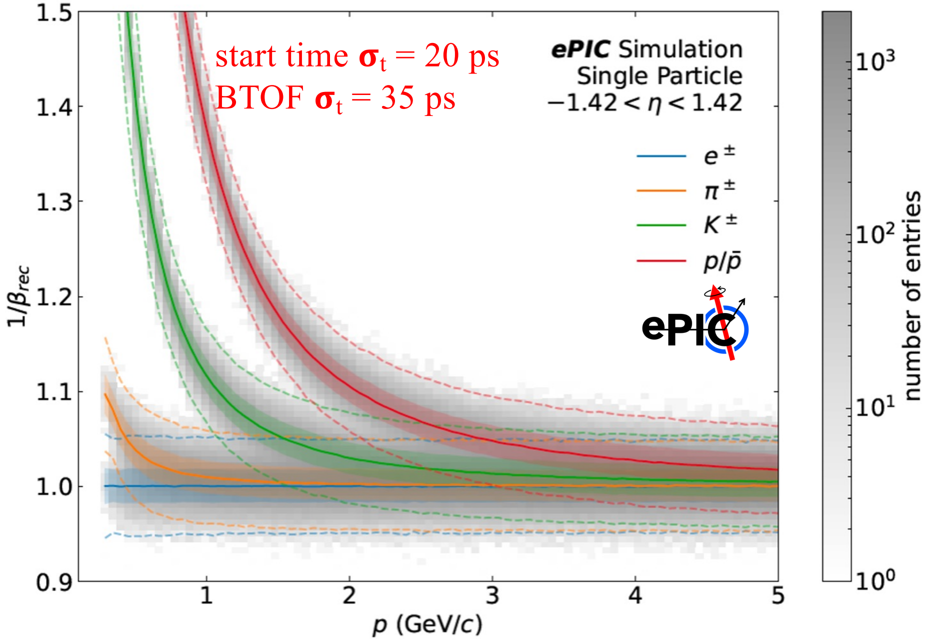


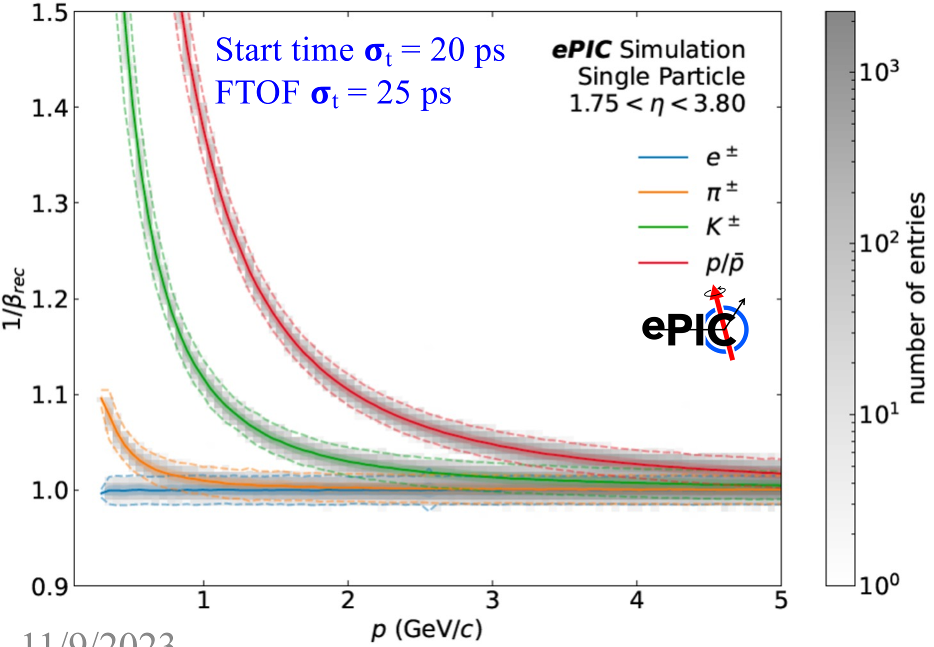
Roman Pots

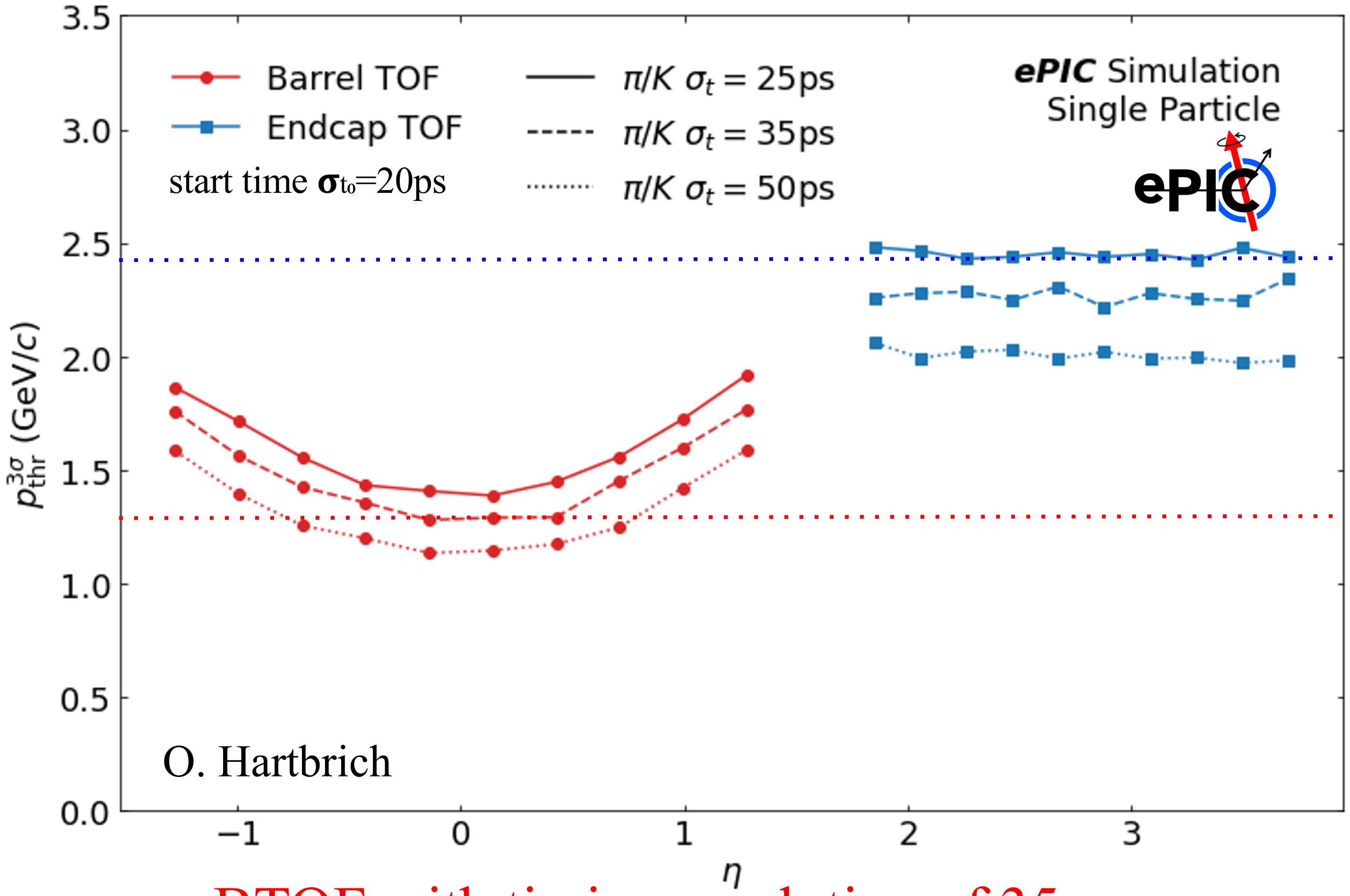
	Area (m^2)	Channel size (mm^2)	# of Channels	Timing Resolution	Spatial resolution	Material budget
Barrel TOF	10	0.5*10	2.4M	35 ps	30 μm in $r \cdot \varphi$	0.01 X_0
Forward TOF	1.4	0.5*0.5	5.6M	25 ps	30 μm in x and y	0.05 X_0
B0 tracker	0.07	0.5*0.5	0.28M	30 ps	20 μm in x and y	0.05 X_0
RPs/OMD	0.14/0.08	0.5*0.5	0.56M/0.32M	30 ps	140 μm in x and y	no strict req.

Requirements on timing and spatial resolutions and material budget are still being evaluated and are subject to change as the design matures, and we will continue to explore common designs for these detectors where possible to reduce cost and risk.

AC-LGAD Detectors for TOF PID

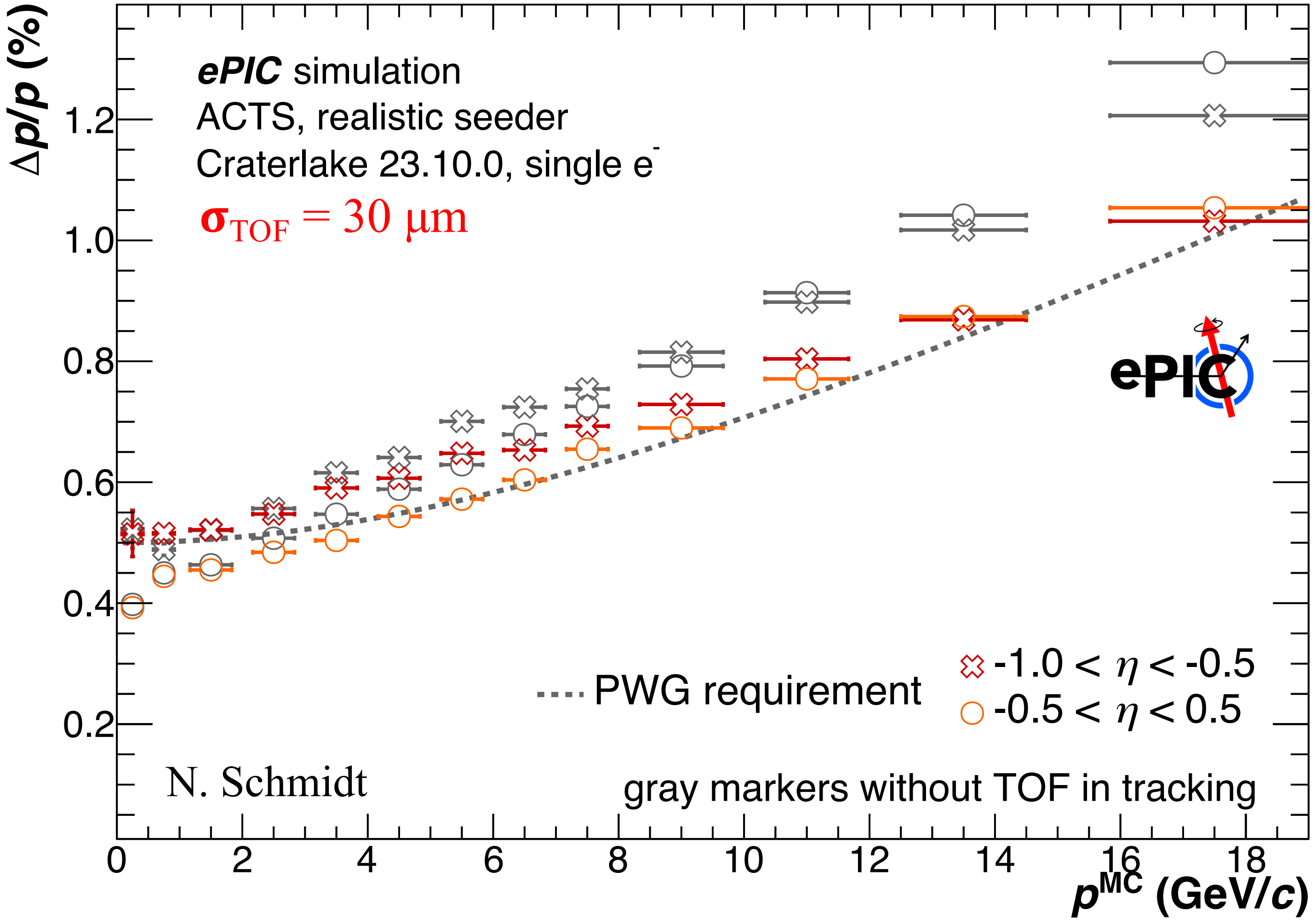






- BTOF with timing resolution of 35 ps can provide 3$\boldsymbol{\sigma}$ $\boldsymbol{\pi}$/K separation upto ~1.3 GeV/c
- FTOF with timing resolution of 25 ps can provide 3$\boldsymbol{\sigma}$ $\boldsymbol{\pi}$/K separation upto ~2.4 GeV/c

AC-LGAD Detectors for Tracking



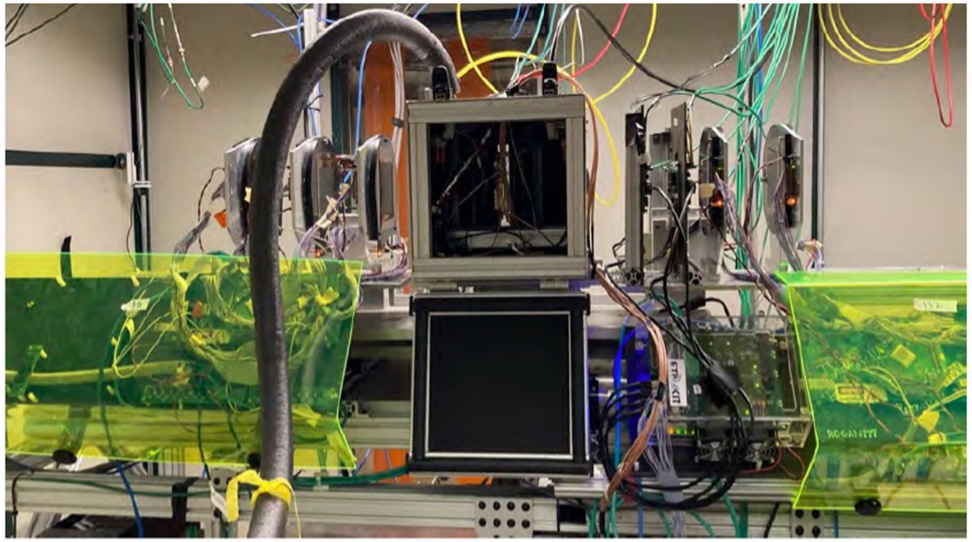
- BTOF with a spatial resolution of 30 μm improves momentum resolution at high p
- TOF helps track reconstruction by rejecting beam background and pileup hits in Si-MAPSs

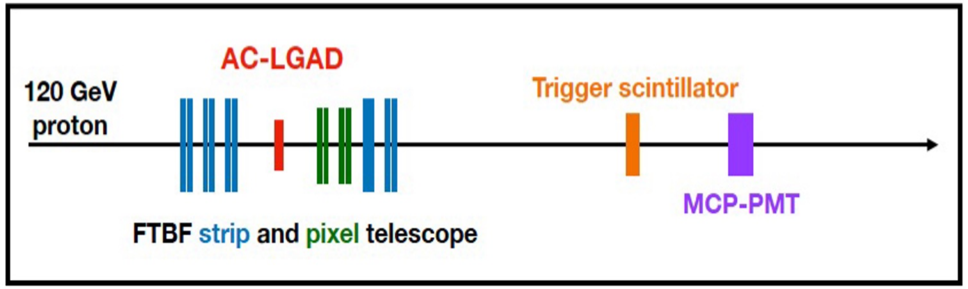
AC-LGAD Sensor

- Sensors with different configurations produced by BNL-IO and HPK, and tested with 120GeV protons
- Prototype strip sensors with ~35 ps time resolution and <15 um spatial resolution.
- Prototype pixel sensors with ~20 ps time resolution and ~20* um spatial resolution.

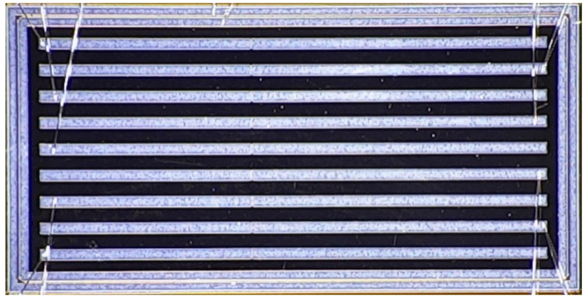
* ~50 um under metal electrodes. To be improved

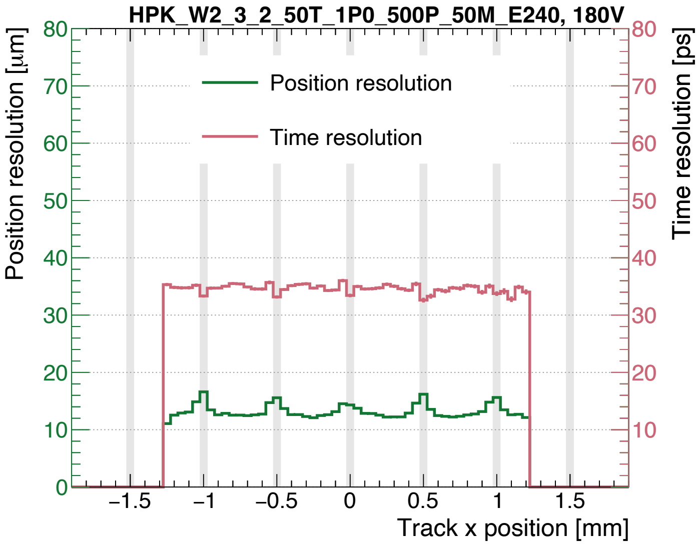
Fermilab Test Beam Setup



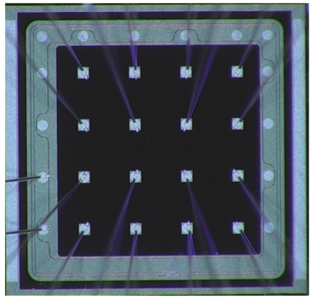


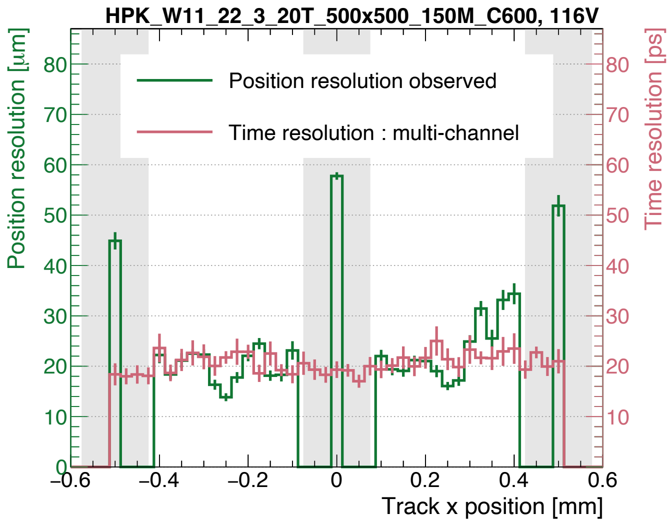
HPK Strip Sensor (4.5x10 mm^2)





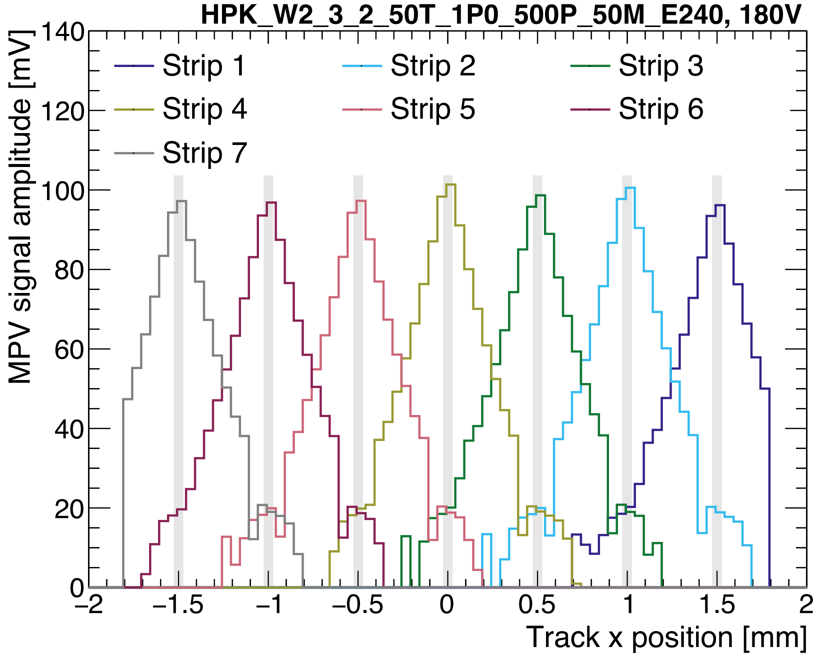
HPK Pixel Sensor (2x2 mm^2)

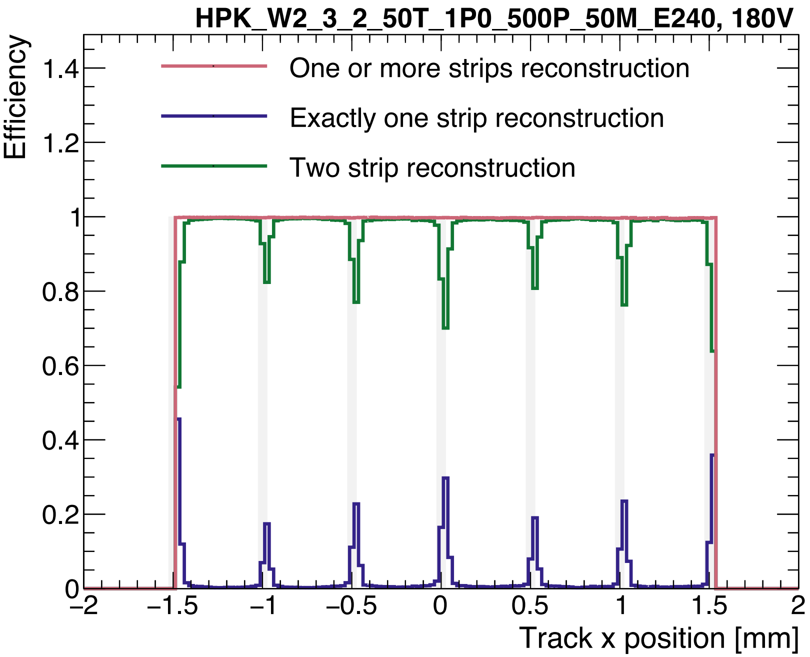


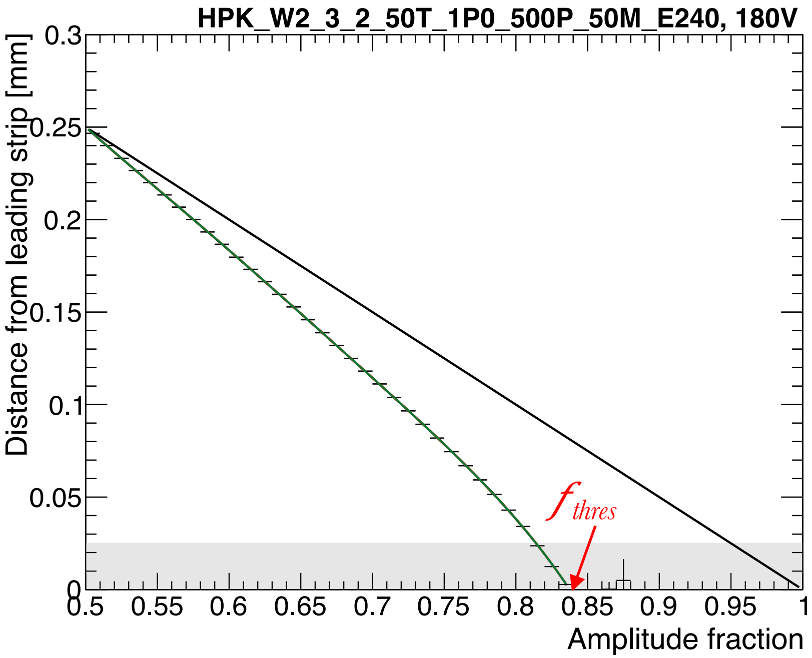


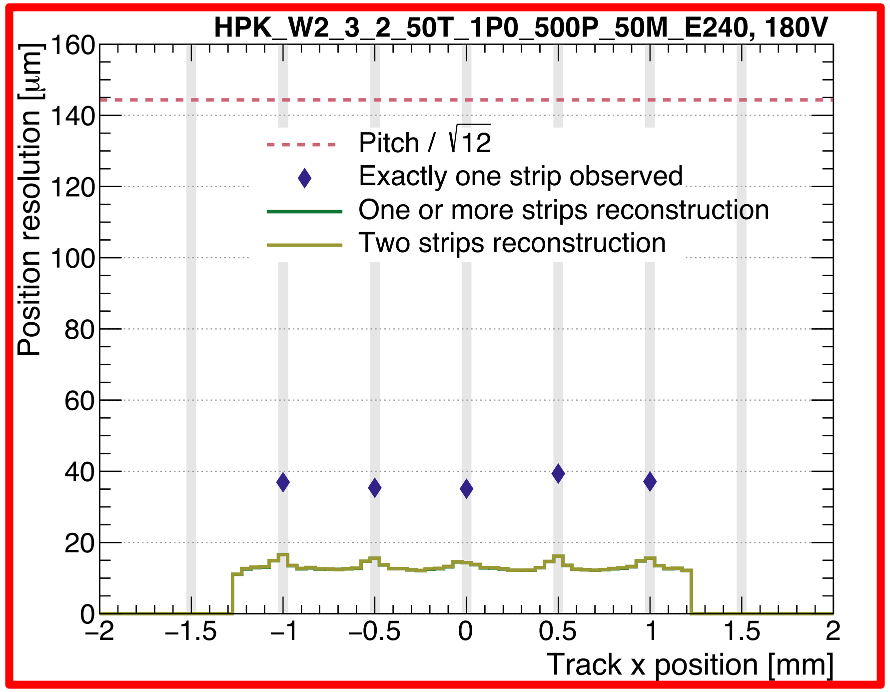
Position Measurement

- Sensor efficiency to have a signal in at least one strip is ~100% with most of the hits having signals from two strips.
- Hit position perpendicular to strip (x) is reconstructed from leading strip signal fraction $f=a_1/(a_1+a_2)$
  - Two strip ($0.5<f<f_{thres}$): leading strip center ± $x(f)$
  - One strip ($f>f_{thres}$): leading strip center
- **Spatial resolution in x: 12-16 um**





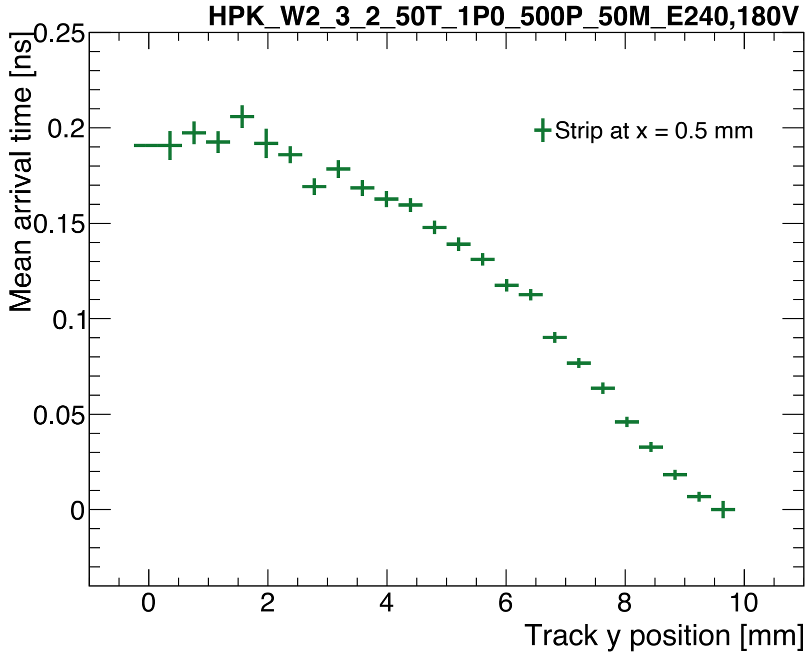




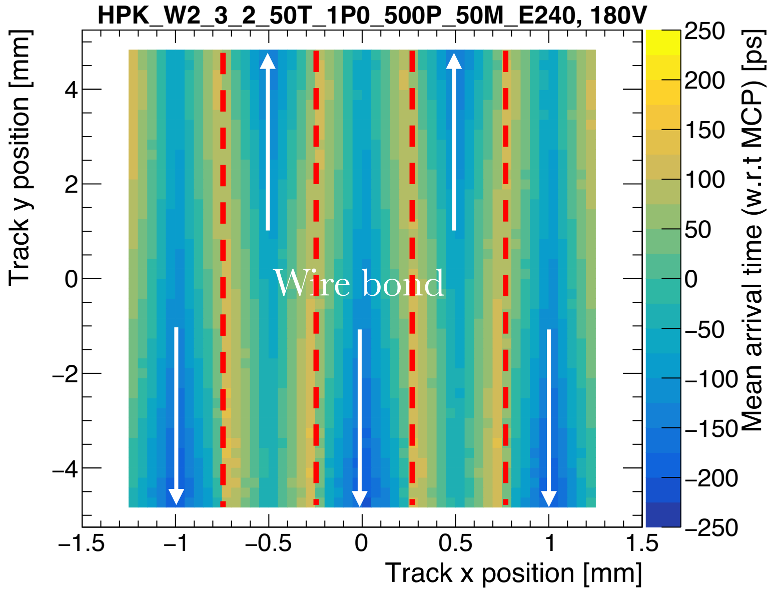
Timing Measurement

- Signal arrival time at wire-bonds depends on the hit distance to the wire bond due to finite signal propagation speed along electrode: ~5 cm/ns
- This effect can be corrected using the hit position from external tracker.
- For hits with signals in two strips, TOAs are combined $t_{\text{reco}} = \frac{a_1^2 t_1 + a_2^2 t_2}{a_1^2 + a_2^2}$

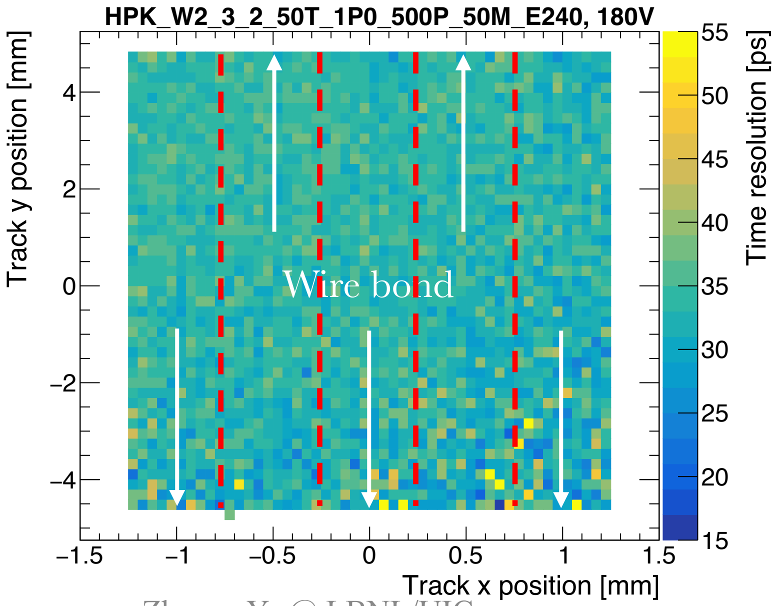
Before delay correction: 45 - 55 ps
After delay correction: 35 - 44 ps
After combining TOAs: 34 - 35 ps

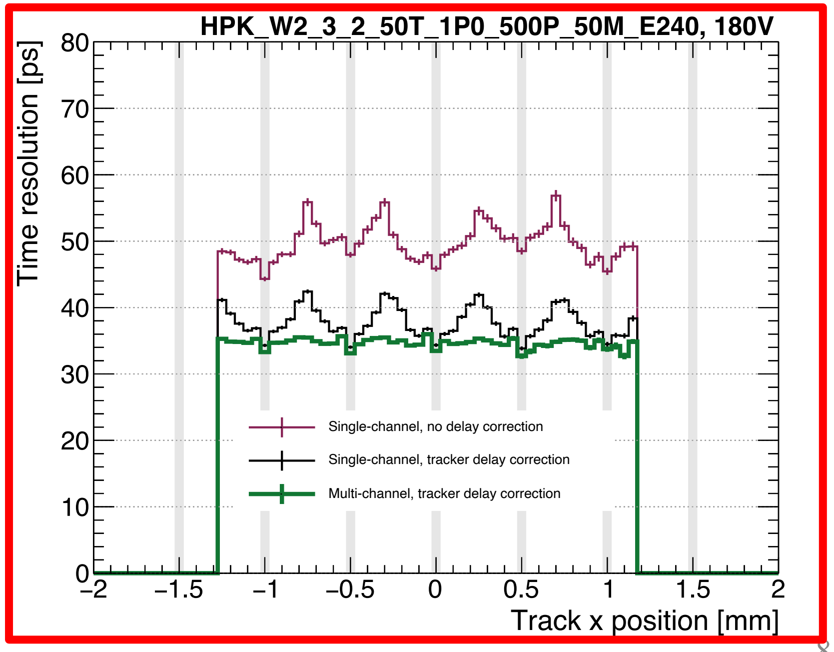


Single-channel, before delay correction



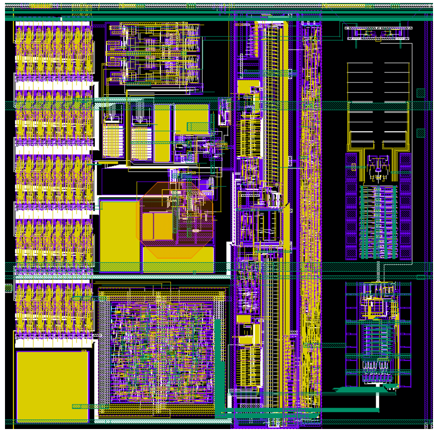
Multi-channel, after delay correction

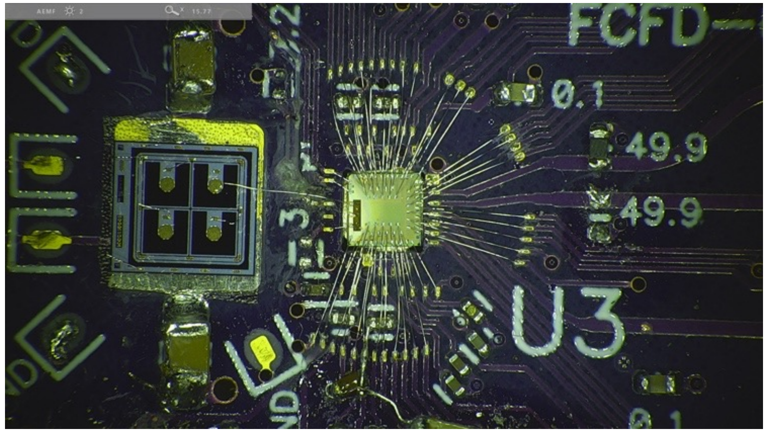




Frontend Readout ASIC

- **R&D Goals**
  - 15-20 ps jitter with minimal (1-2 mW/ch) power consumption, match AC LGAD sensors for ePIC.
- **Plan**
  - Utilize the design and experience in ASICs for fast-timing detectors from ATLAS and CMS, and investigate common ASIC design and development for TOF and FF.



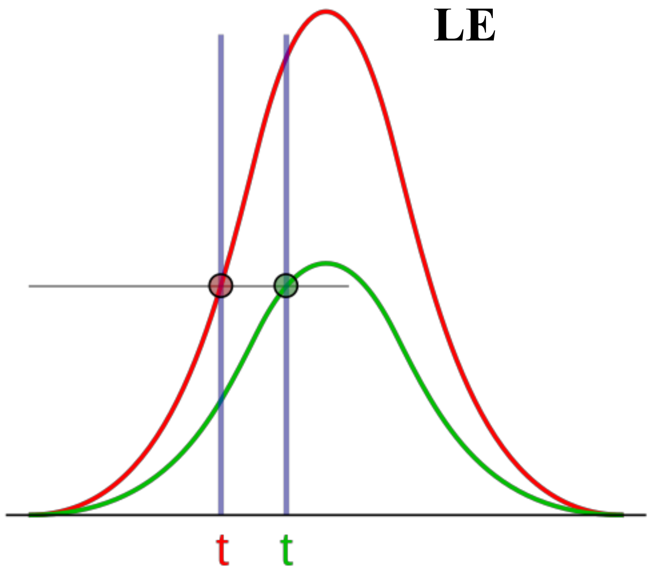


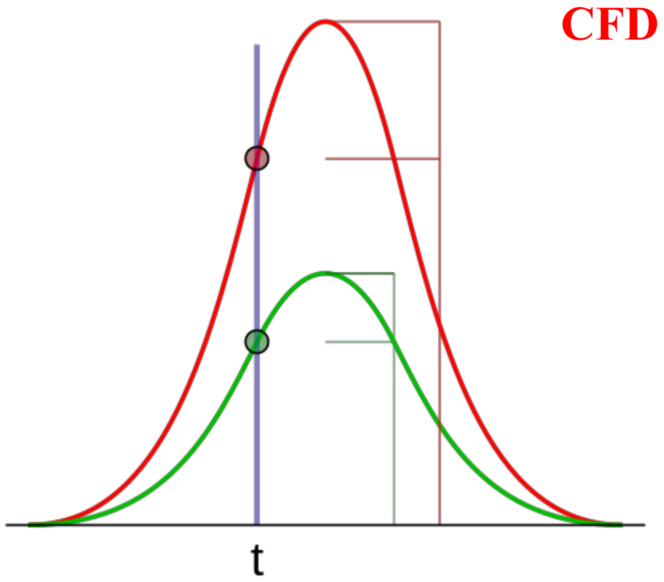
EICROC by Omega/IJCLab/Irfu/AGH (in Alessandro's talk)
- Preamp, discri. taken from ATLAS ALTIROC
- I2C slow control taken from CMS HGCROC
- TOA TDC adapted by IRFU Saclay
- ADC adapted to 8bits by AGH Krakow
- Digital readout: FIFO depth8 (200 ns)

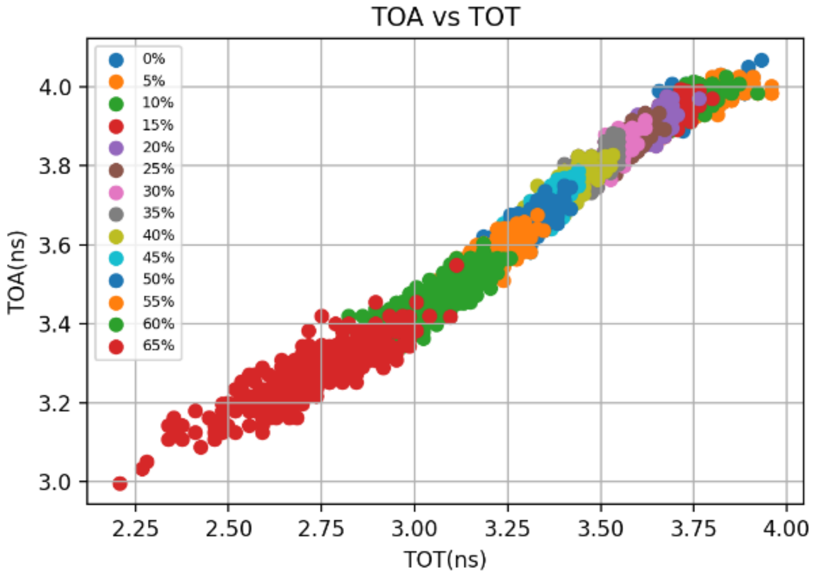
FCFD by Fermilab (this talk)
- Adapt the Constant Fraction Discriminator (CFD) principle in a pixel paired with a TDC, one time measurement gives the final answer.
- Charge injection consistent with simulations: ~30 ps at 5 fC, and <10 ps at 30 fC
- Tested with laser, beta source and beam

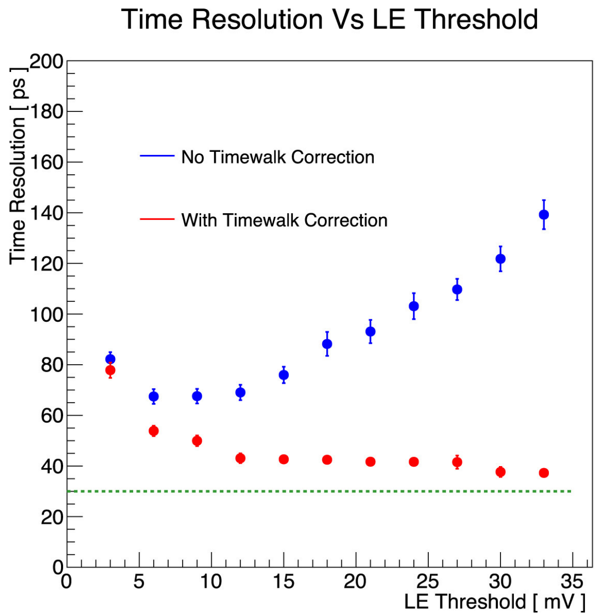
Time Walk Correction

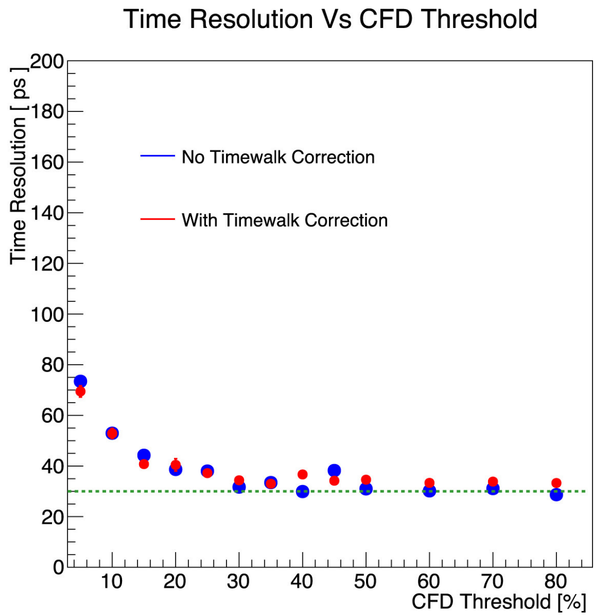
- Time cross the threshold of a LE discriminator dependent on signal amplitude
- Time cross the threshold of a CFD independent on signal amplitude with same signal shape











AC-LGAD TOF Calibration

- **AC-LGAD sensor**
  - bias voltage: determine optimal voltage of each sensor to achieve best S/N and stability
- **Frontend readout ASIC**
  - Baseline: determine the pedestal and noise of each readout channel
  - Threshold: set effectively same threshold across all readout channels
  - Gain: determine the gain of each readout channel
  - TDC bin width: determine the TDC bin width of each readout channel
- **Clock distribution**
  - Synchronize clock signals and correct for residual variation across all readout channels
- **Time walk**
  - Correct for the dependence of time of arrival on signal amplitude
- **Position dependence**
  - Correct for intrinsic position dependence for strip sensor due to signal propagation
  - Correct for residual channel-by-channel variation
- **Time dependence**
  - Monitor and correct for possible short-term environment (e.g. temperature) variation
  - Monitor and correct for possible long-term variations (e.g. radiation damage)

operation (bias voltage, baseline, threshold)

calibration (gain, TDC bin width)

both operation and calibration (clock distribution)

operation and/or calibration (time walk)

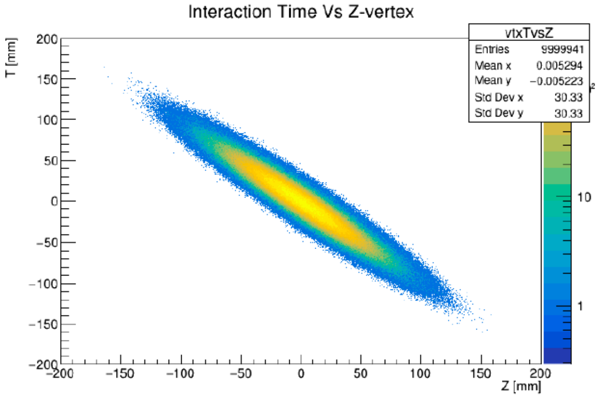
timing calibration after alignment (position dependence)

both operation and calibration (time dependence)

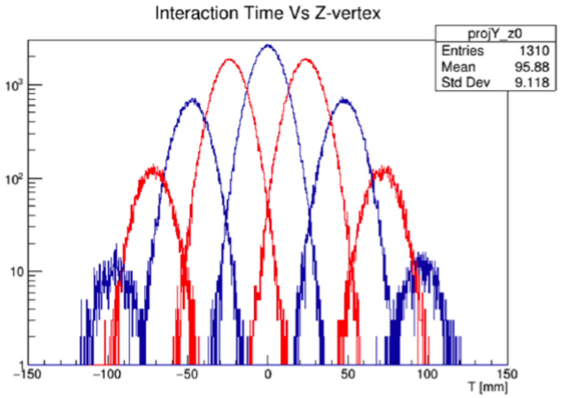
T0 Determination from Vertex – Brian Page (BNL)

https://indico.bnl.gov/event/17534

Z-Vertex – T0 Correlations: 18x275



❑ Z-Vertex and T0 of the collision are tightly correlated due to the relative size differences of the hadron and electron bunches (6 vs 0.9 cm) – practically, determined by size of electron bunch



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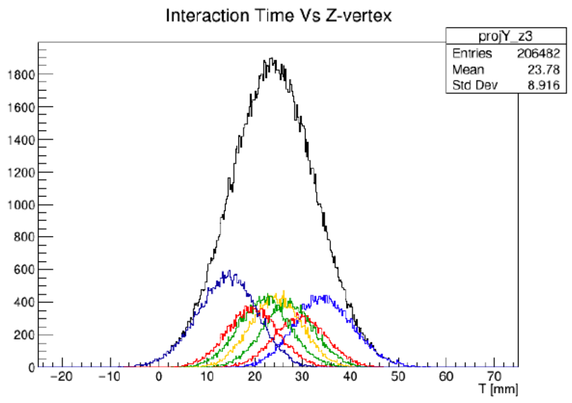
Adding X-Vertex Information: 18x275



❑ Choose the Z-vertex bin at -25 mm and look at T0 distributions for various X-vertex bins

❑ X and Z binned T0 distributions have much better resolution than Z binned alone (~18 vs ~30 ps)

X Bin	Mean [mm]	Sigma [mm]
0	34.6	6.14
1	29.5	5.4
2	27.0	5.36
3	24.5	5.39
4	22.0	5.44
5	19.5	5.38
6	14.1	6.24

❑ Basically, X-Vertex position is telling where within the electron bunch the colliding particle comes

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- Bunch sizes and beam crossing configuration provide opportunity to derive the time of the collision from the position of the primary vertex
- Based on the model used to simulate beam effects in MC, T0 resolutions on the order of 20 to 25 picoseconds should be achievable by measuring the X and Z positions of the primary vertex within reasonable tolerances

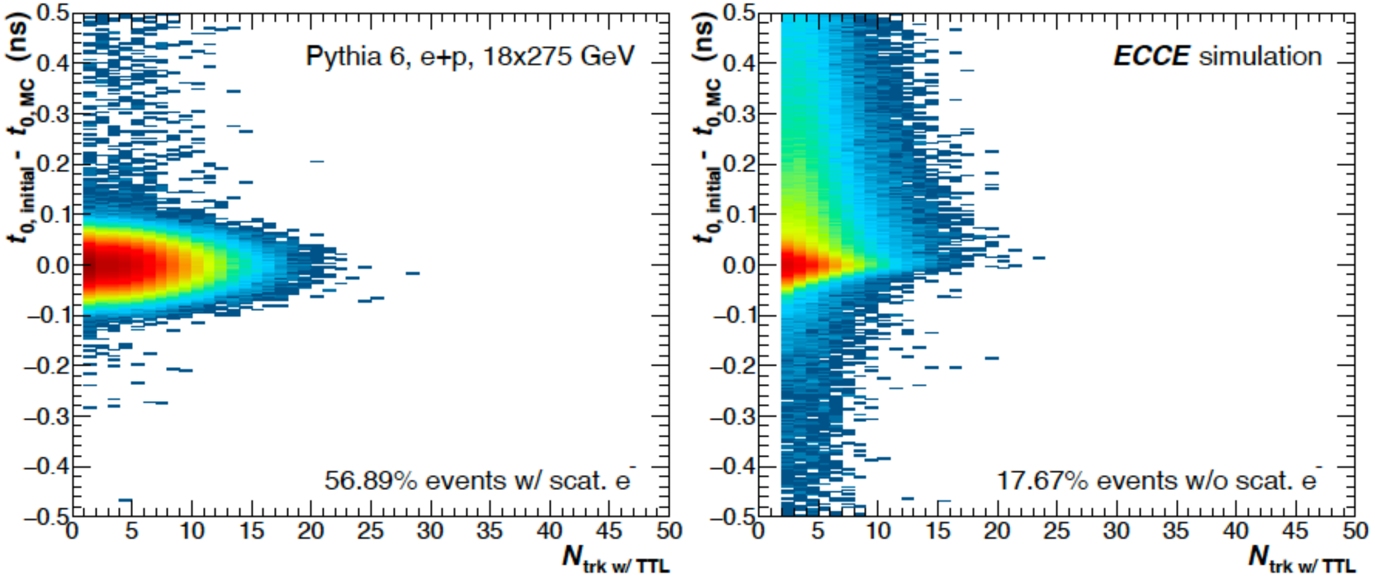
T0 Determination from TOF – Friederike Bock (ORNL)

https://indico.bnl.gov/event/17534

OAK RIDGE National Laboratory

Initial start time determination

EIC



a) scattered electron found

- Scattered electron found if: $p_{e^-} > 3$ GeV/c, $\eta < 0.5$ in calo/ cherenkov detector acceptance
- Assuming calo & cherenkov detectors together can identify electron w/o losses

⇒ initial t_0 determined based on scattered electron

b) scattered not electron found

- Assume all particles in event charged pions
- All orginінate from common vertex
- Needs at least 2 tracks with TTL hits

⇒ initial t_0 determined based pion assumption

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T0 Determination from TOF – Friederike Bock (ORNL)

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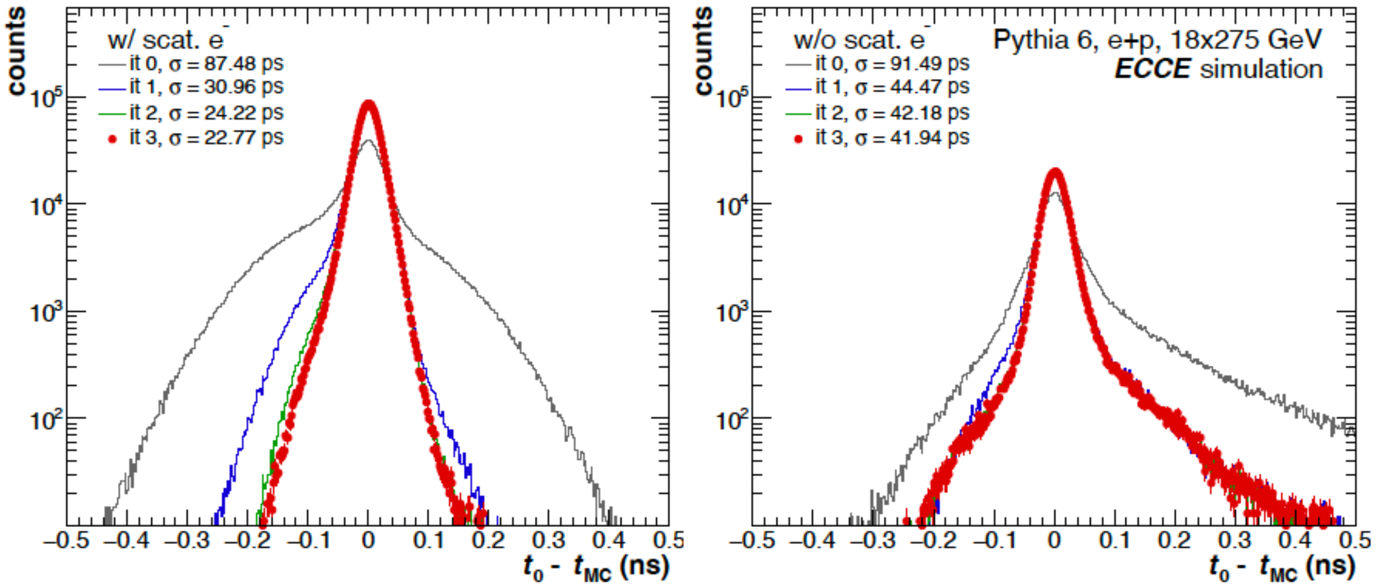
Iterative Improvements to t_0



- Common procedure after intial t_0 determination
- For all particles the velocity estimate is based on $t_{part,rec} - t_{0,it-1}$
- In iterations $1/\beta$ is calculated and compared to expectation value for π,K,p and e
  $\rightarrow$ assumed to be corresponding particle if within 1% of expectation value & $p < 6$ GeV/c
  $\rightarrow$ $p > 15$ GeV/c pion mass assumed, except for scattered electron candidates
- Latest after 4 iterations no significant change observed any more

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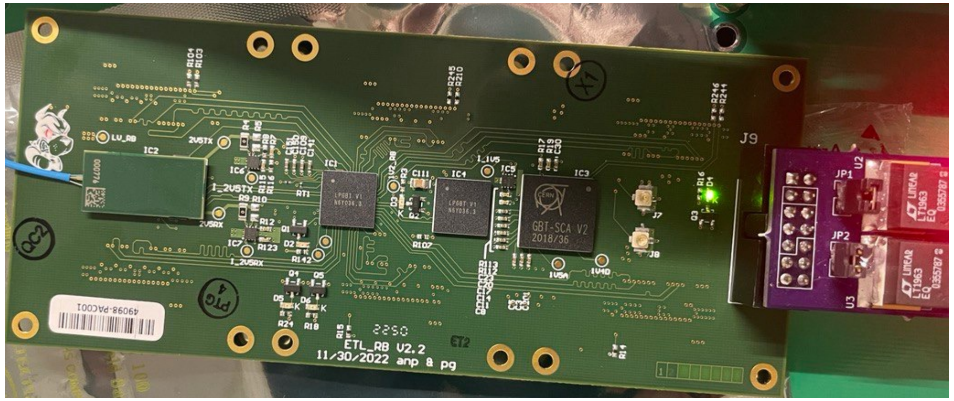
Summary and Outlook

AC-LGAD TOFs can provide both precise timing and spatial measurements. To do so, there are a number of effects that need to be well understood, characterized and corrected for. In terms of calibrations:

- **If there is external data you need?** Yes, track impact Z-position on BTOF from tracking for TOA, vertex position from vertexing for T0, electron TOA from pfRICH for T0
- **if you need specific beam conditions?** Probably not, or least not critical
- **if you need other detectors to be calibrated before you start?** Yes, tracking, vertexing, pfRICH
- **what the time scales you need (does the calibration go continuously, getting better every day, or do you take n-events and call it done!)** Some calibrations will be done at the beginning and end of a running period, some at every fill, some continuously
- **how much data you need to finish the calibration?** Hard to tell now
- **Do you need human intervention, or can it be done automatically?** Some yes, some no
- **If you do need human intervention, is there support from the SRO group that can make this human intervention easy (and fast)?** Yes
- **What are the results of the calibration (do they have to be put into the early DAQ process before data files are finished being constructed, or are they applied during reconstruction, or applied during analysis)?** Mix of all
- **Do you need external storage or DBs, and if so do they need to store multiple data versions of calibrations applying to the same time periods?** Yes

Readout and Power Boards (for CMS LGAD Detector)

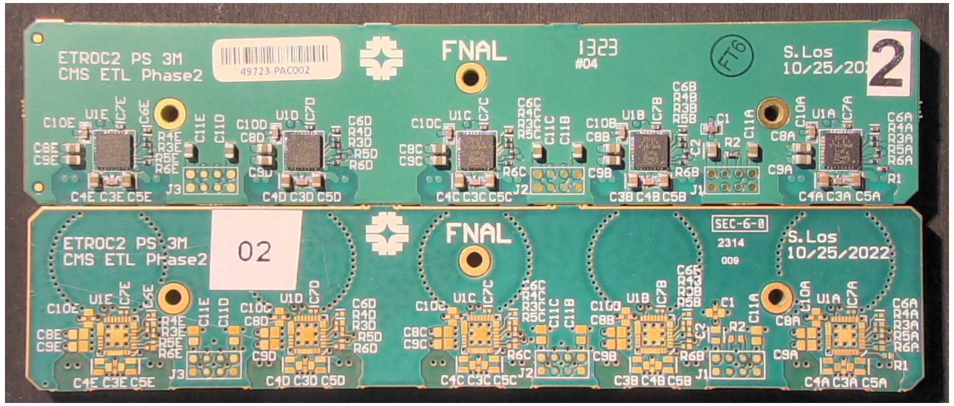
- Prototype V2 readout board
  - LpGBTv1+VTRX



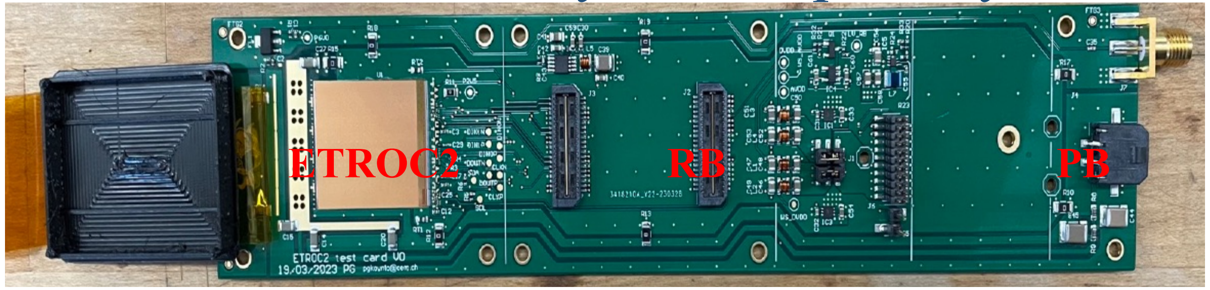
- Prototype V2 power board
  - Efficiencies ~ 65-67%

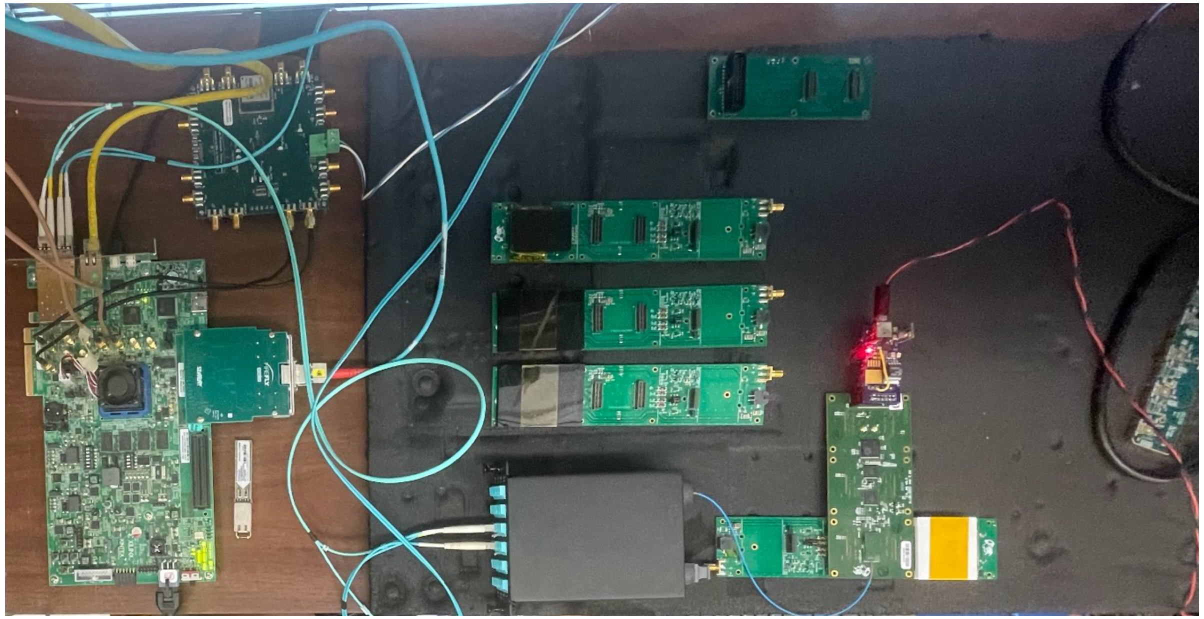
Pactron

Saturn



- First system test with bare ETROC2 on the first functional module PCB successful;
- Full demonstration rely on complete system test





ePIC TOF service hybrid R&D supported by eRD109 FY24