eRD112: AC-LGAD for EIC

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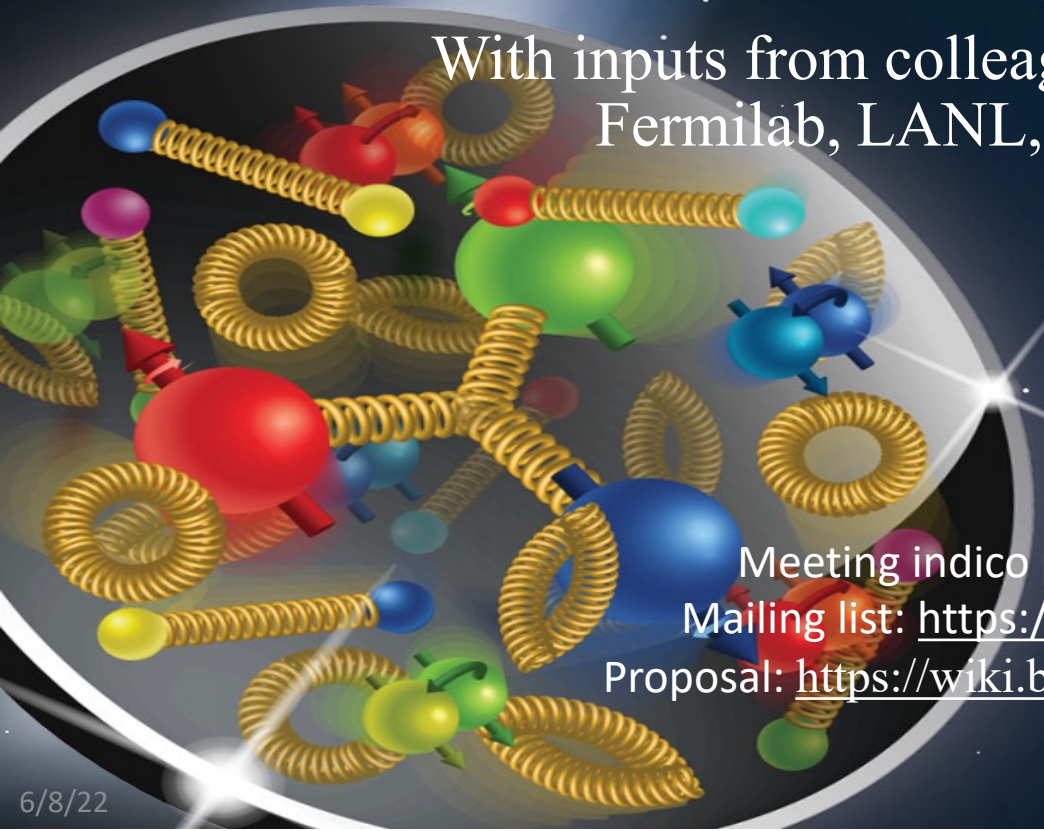
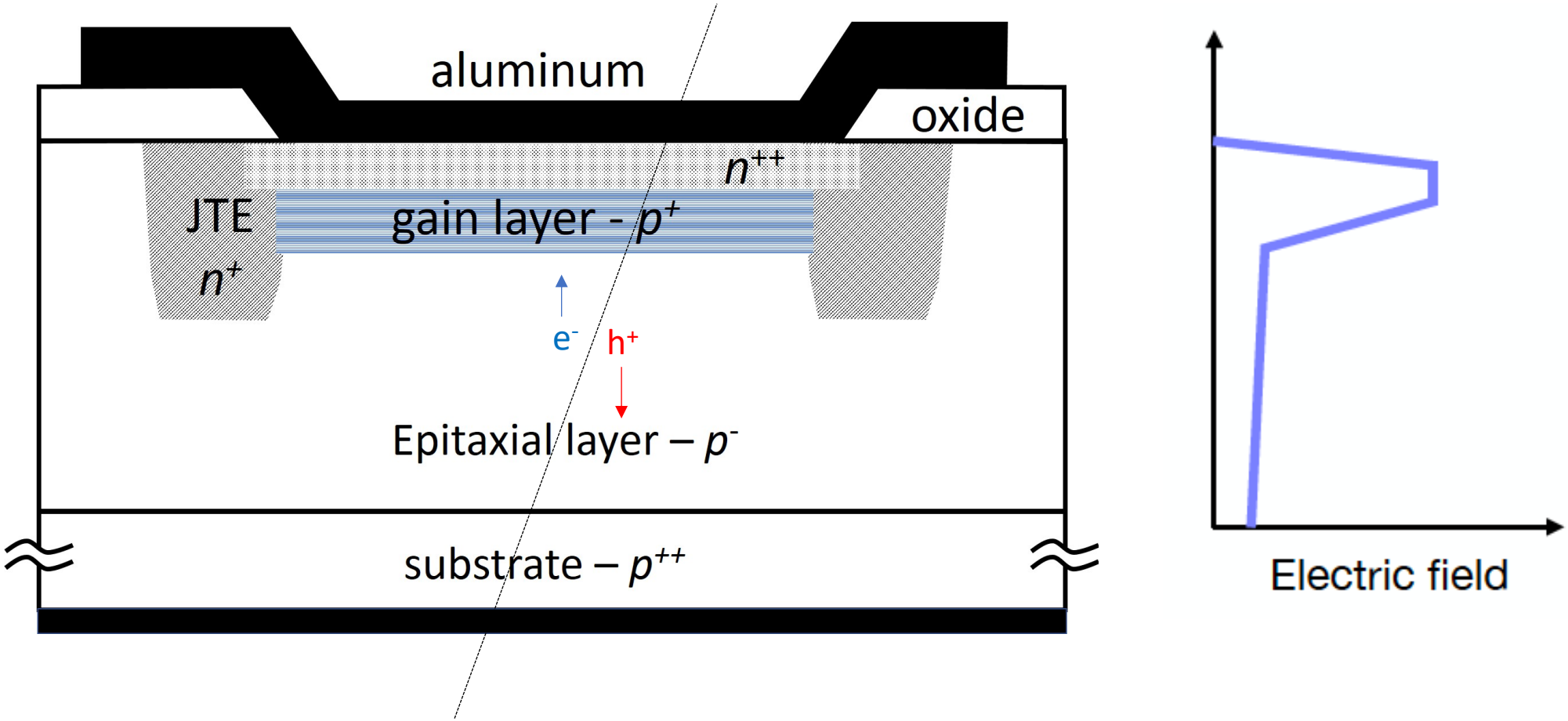
With inputs from colleagues @ BNL, CNRS/IN2P3 IJCLab/Omega, Fermilab, LANL, NCKU, Rice, ORNL, UC Santa Cruz



Meeting indico page: https://indico.bnl.gov/category/323/
Mailing list: https://mailman.rice.edu/mailman/listinfo/lgads-eic
Proposal: https://wiki.bnl.gov/conferences/index.php/ProjectRandDFY22

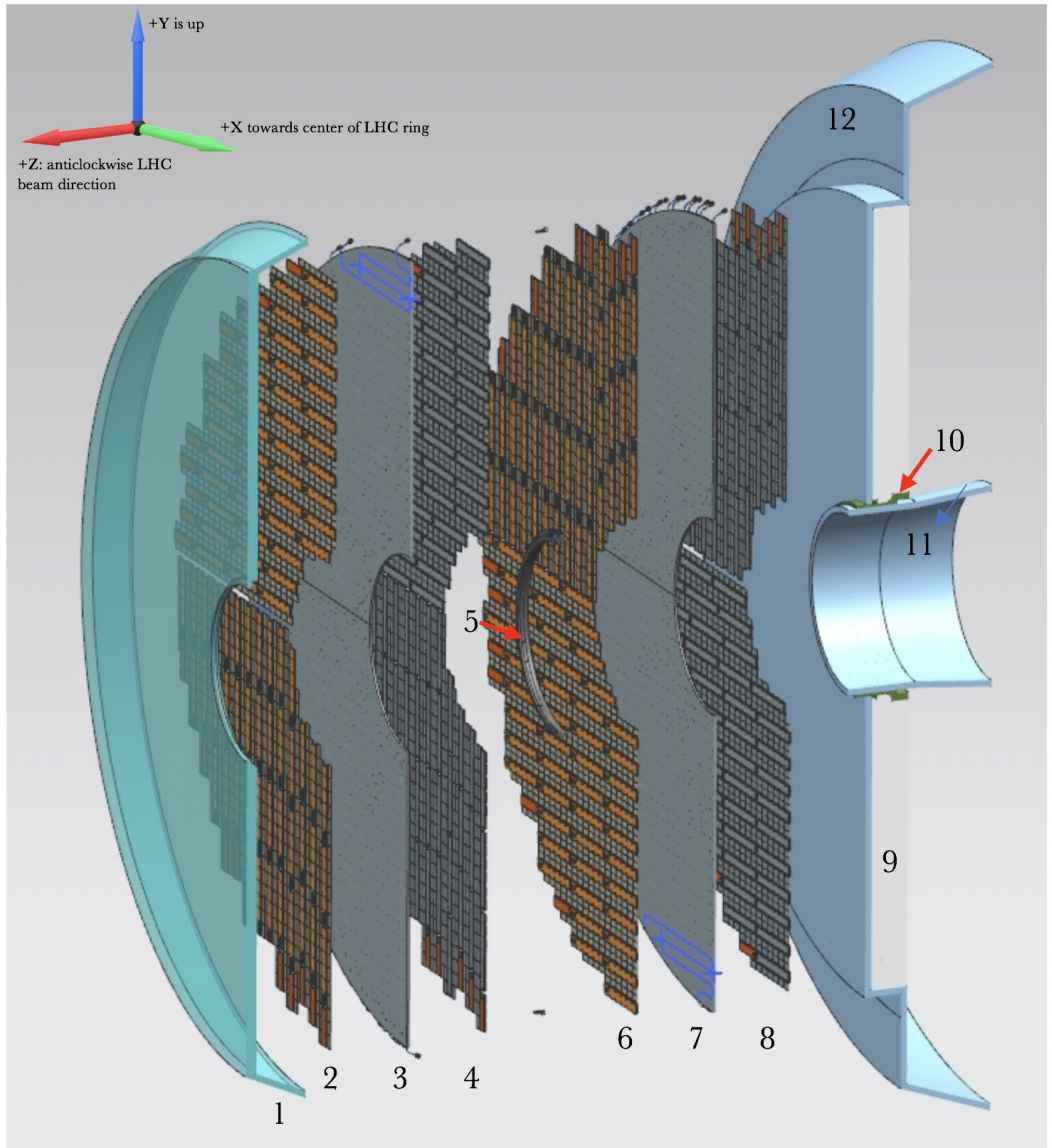
Low Gain Avalanche Detector



Ultra-fast silicon detectors with a highly doped p+ gain layer

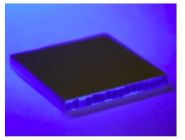
Moderate internal gain : 10-30

CMS Endcap Timing Layer

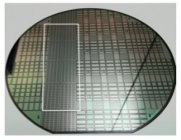


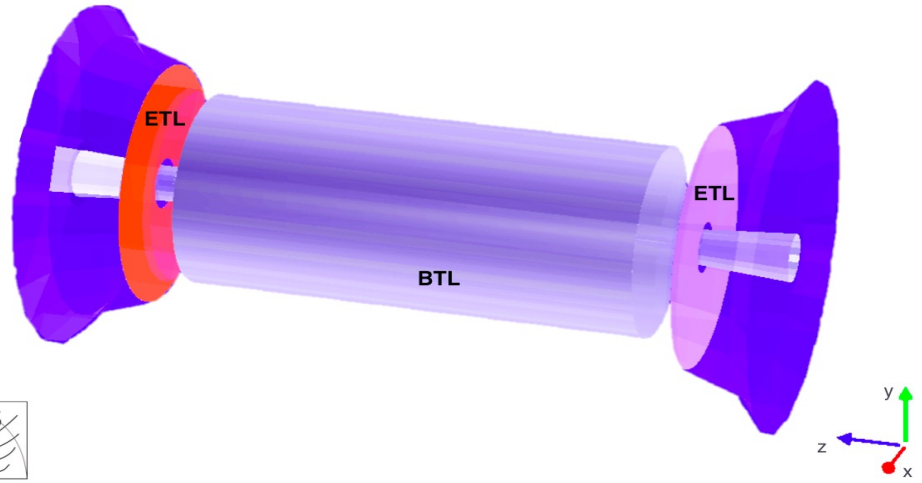
1: ETL Thermal Screen
2: Disk 1, Face 1
3: Disk 1 Support Plate
4: Disk 1, Face 2
5: ETL Mounting Bracket
6: Disk 2, Face 1
7: Disk 2 Support Plate
8: Disk 2, Face 2
9: HGCal Neutron Moderator
10: ETL Support Cone
11: Support cone insulation
12: HGCal Thermal Screen

BTL: LYSO bars + SiPM readout:
- TK/ ECAL interface: $|\eta| < 1.45$
- Inner radius: 1148 mm (40 mm thick)
- Length: ±2.6 m along z
- Surface ~38 m^2; 332k channels
- Fluence at 4 ab^{-1}: 2×10^{14} n_{eq}/cm^2



ETL: Si with internal gain (LGAD):
- On the HGC nose: $1.6 < |\eta| < 3.0$
- Radius: 315 < R < 1200 mm
- Position in z: ±3.0 m (45 mm thick)
- Surface ~15.8 m^2; ~6M channels
- Fluence at 4 ab-1: up to 2×10^{15} n_{eq}/cm^2



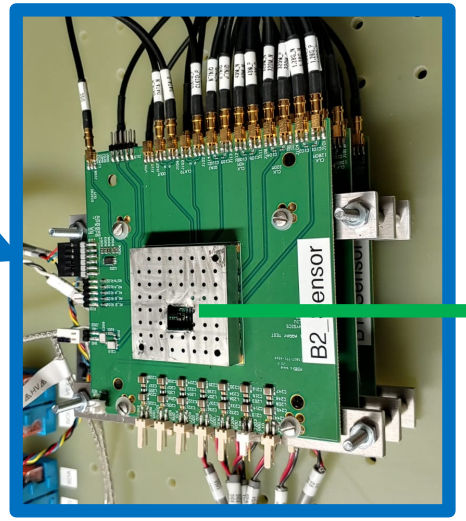


- On the CE nose: $1.6 < |\eta| < 3.0$
- Radius: $315 < R < 1200\ mm$
- Position in Z: $\pm 3.0\ m$ (45 mm thick)
- Surface $\sim 15.8\ m^2$; ~8.6M channels
- Weight 282 kg/side; Power: 26kW/side

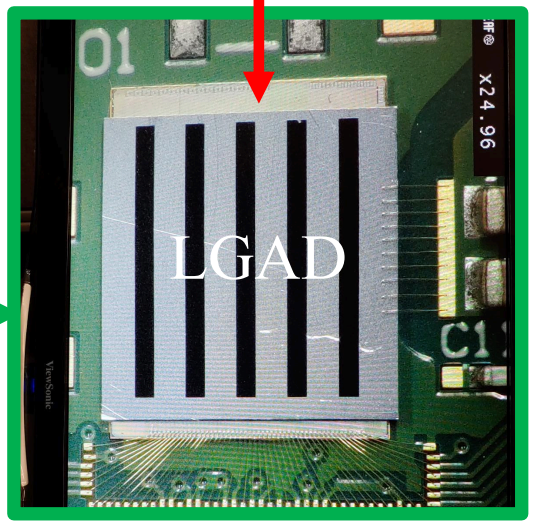
- **Two disks on each side allowing up to two measurements per track**
  - **50 ps per hit → 35 ps per track**

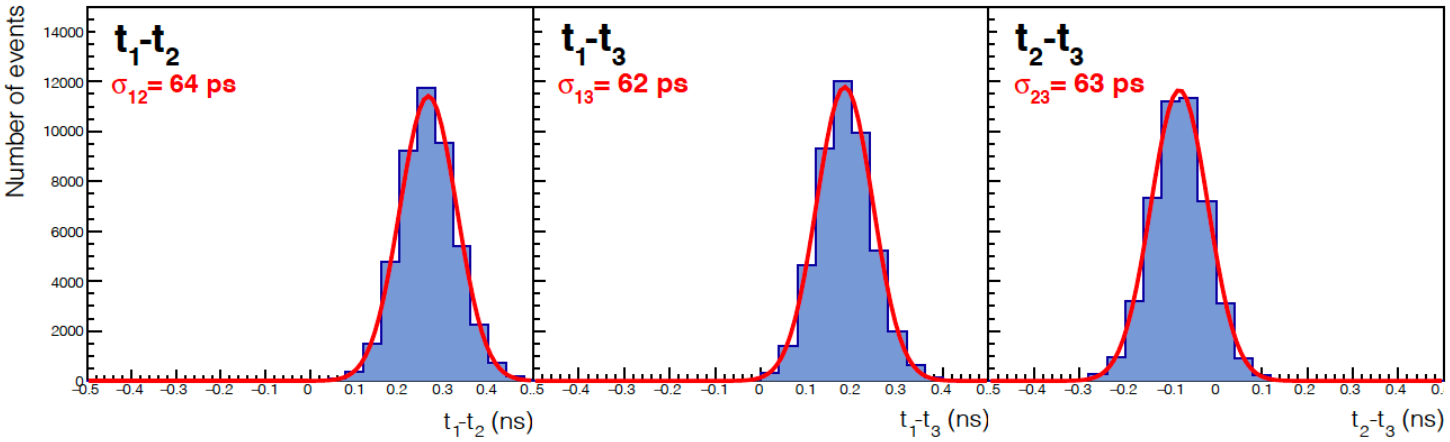
ETROC1+LGAD – Test Beam Results

ETROC1 Test Board



ETROC1



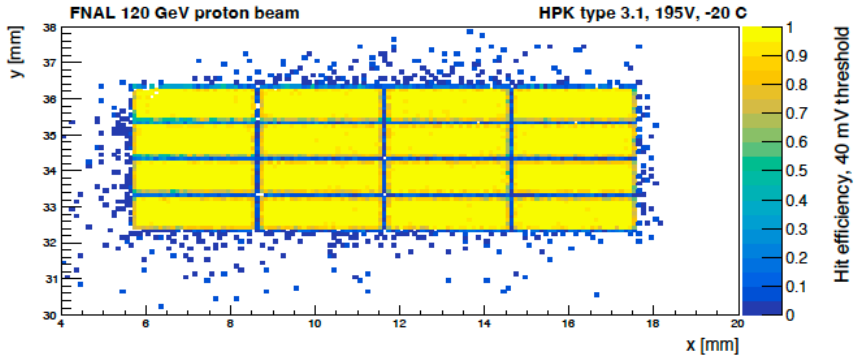


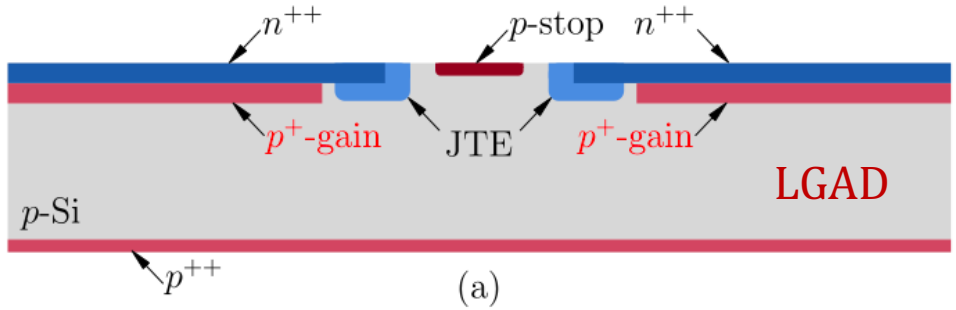
From preliminary analysis of the data from ongoing beam test at FNAL, the resolution of single LGAD+ETROC1 devices with large signal amplitude is 42-46 ps.

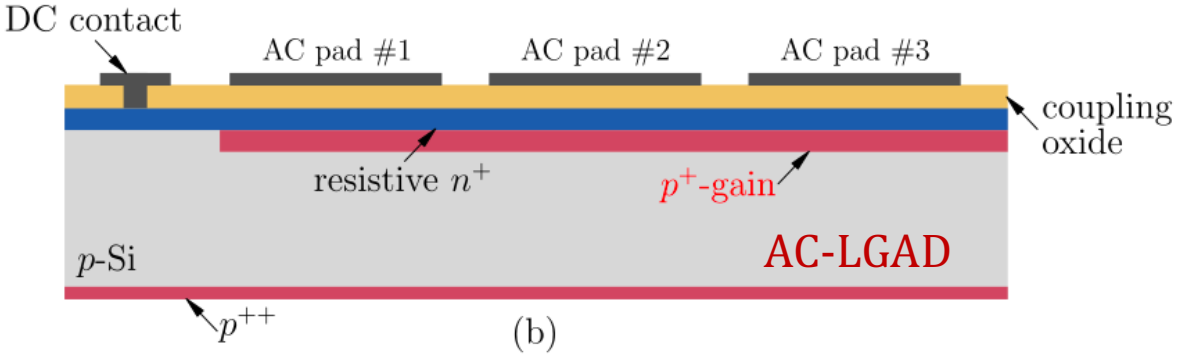
$$\sigma_i = \sqrt{0.5 \cdot \left(\sigma_{ij}^2 + \sigma_{ik}^2 - \sigma_{jk}^2\right)}$$

AC-Coupled LGAD

- Due to the presence of JTE and the gap between LGAD cells, 100% fill factor can not be achieved in LGAD. The position resolution is limited to be $\sqrt{1/12}$ of cell size.







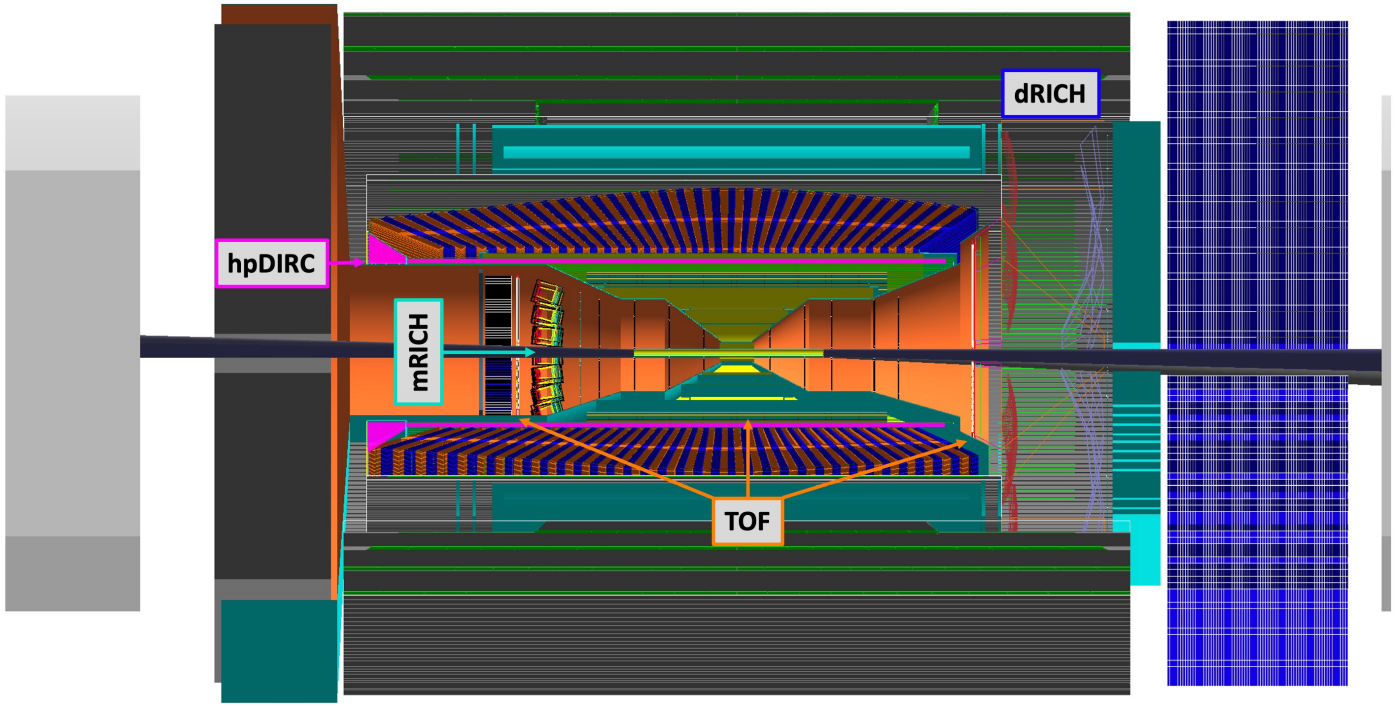
- AC-LGAD: replacement of the segmented n^{++} layer by a less doped but continuous n^+ layer. Electrical signals in the n^+ layer are AC-coupled to neighboring metal electrodes that are separated from the n^+ layer by a thin insulator layer.

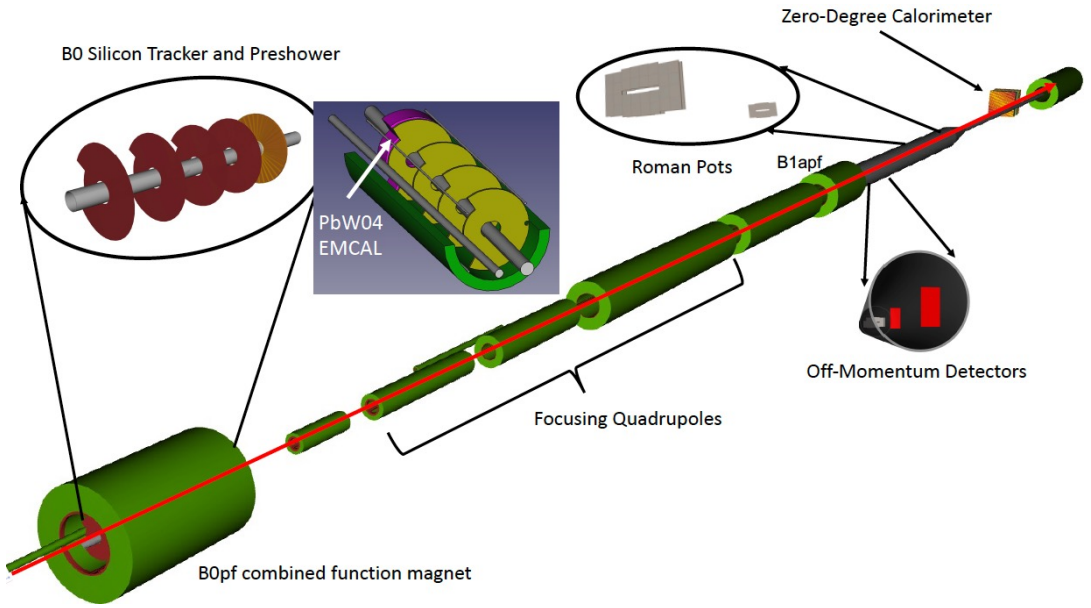
- AC-LGAD not only provides a timing resolution of a few tens of picoseconds, but also 100% fill factor and a spatial resolution that are orders of magnitude smaller than the cell size. Therefore, it is a good candidate for 4D detectors at future high energy experiments.

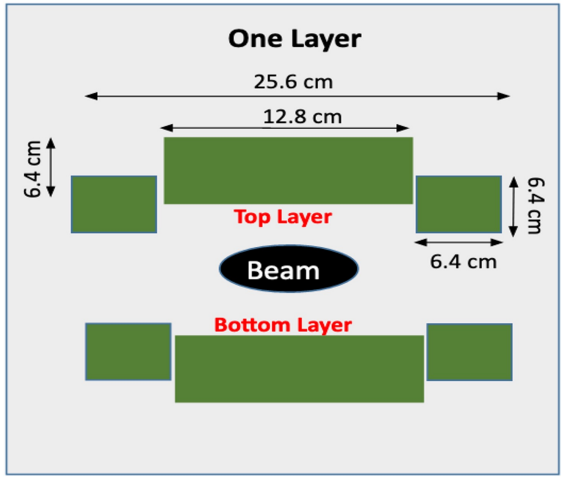
AC-LGAD at EIC

AC-LGAD for TOF/Tracking (G. Kalicy)

- Timing resolution: ~25 ps per hit
- Position resolution: ~30 μm with 500 μm pitch
- Total area: ~ 15 m^2





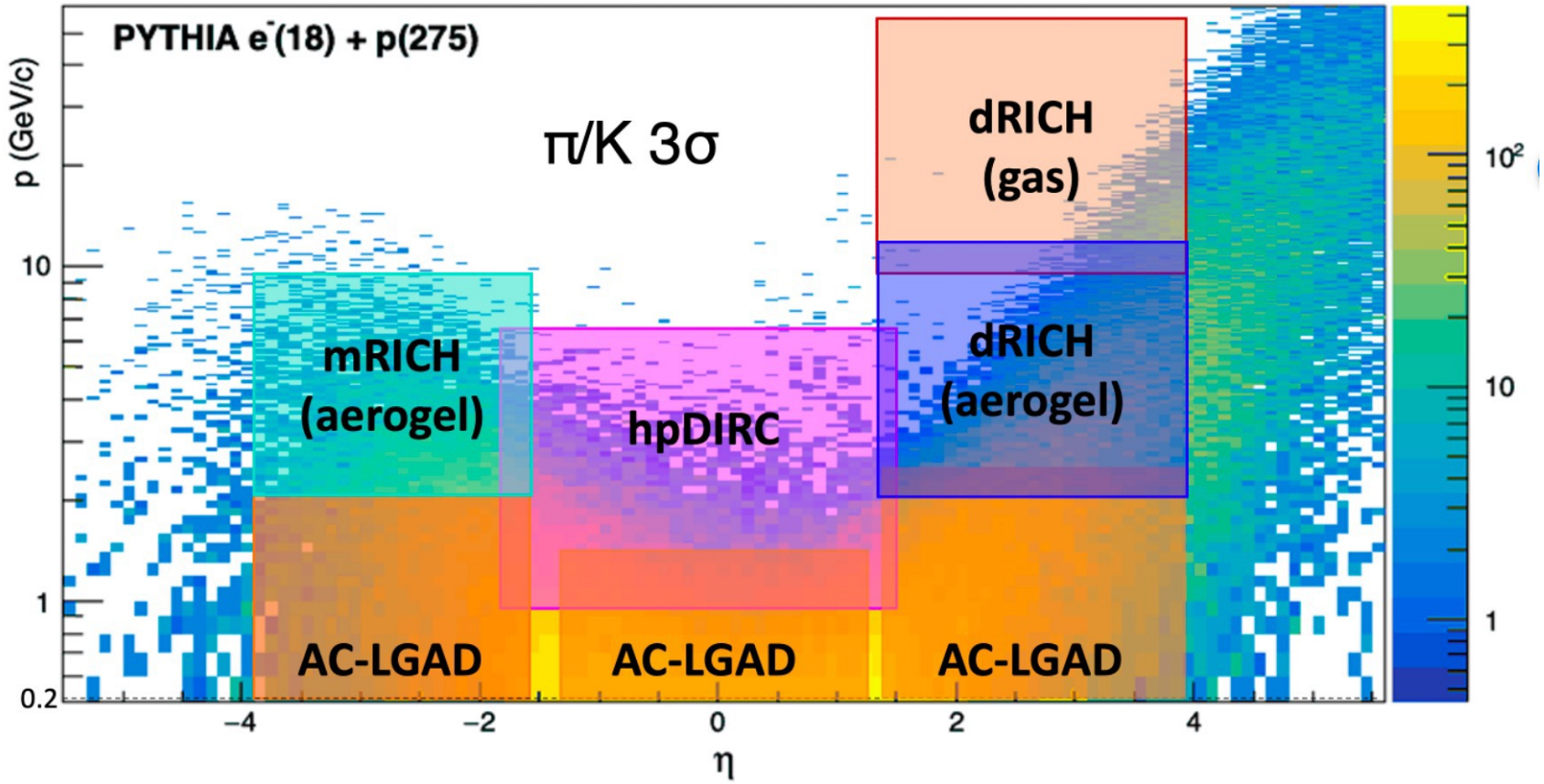


Option for Roman Pots (A. Jentsch):

- AC-LGAD with both fine pixilation (~140 um spatial resolution), and fast timing (~35 ps)
- MAPS + LYSO timing layer

TOF PID for EIC Detector-1

- A nearly 4π TOF coverage for e/π/K/p PID at low-to-intermediate p range that sufficiently overlaps with RICH-based PID detectors to cover the interesting phase space at EIC.
- Explore novel technology (AC-LGADs, benefit the tracking) and leverage established designs (DC-LGADs for CMS/ATLAS) to minimize the cost.

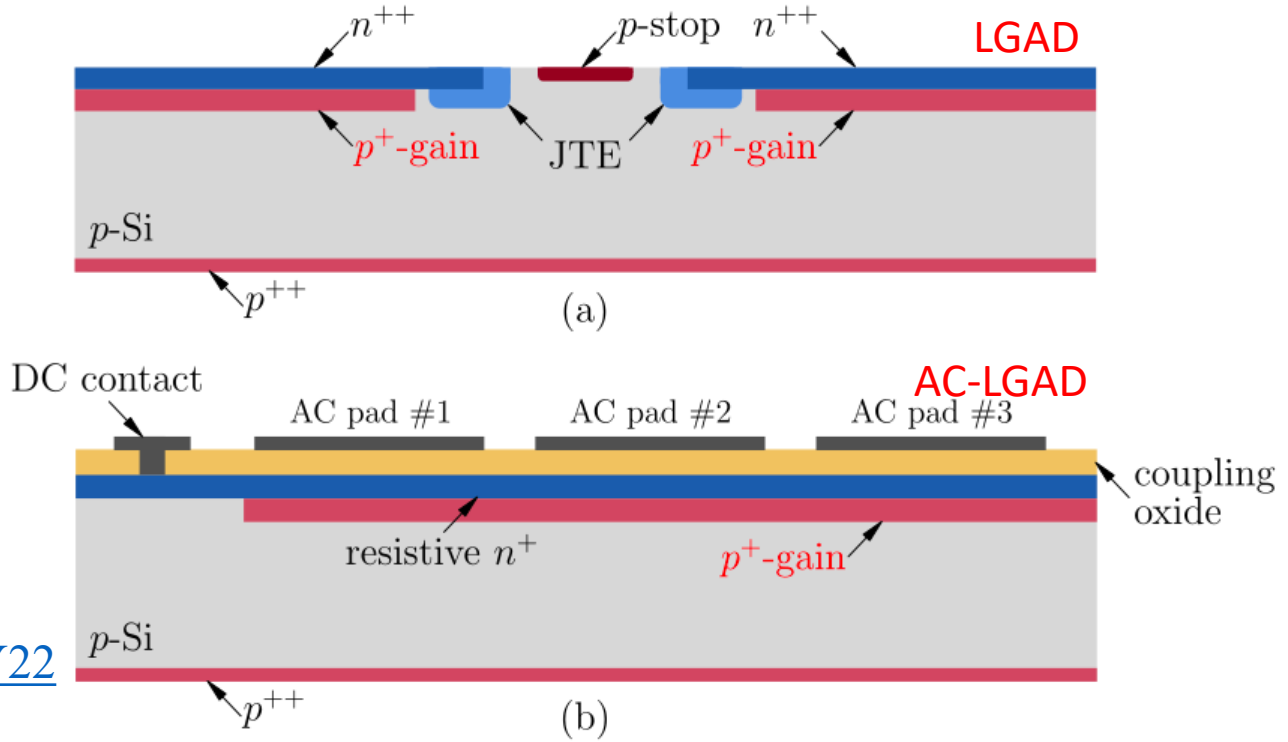


- FTTL: 1.5<η<3.5
  0.15 < p < 2 GeV
- CTTL: |η|<1.4
  0.15 < p_T < 1.5 GeV
- ETTL: -3.7<η<-1.74
  0.15 < p < 2.5 GeV

eRD112: AC-LGAD for EIC

- AC LGAD detectors proposed for EIC
  - Roman Pots and B0
  - TOF for PID (and tracking)

- Have common designs in sensor, ASIC etc. when possible, combine R&D efforts [1]

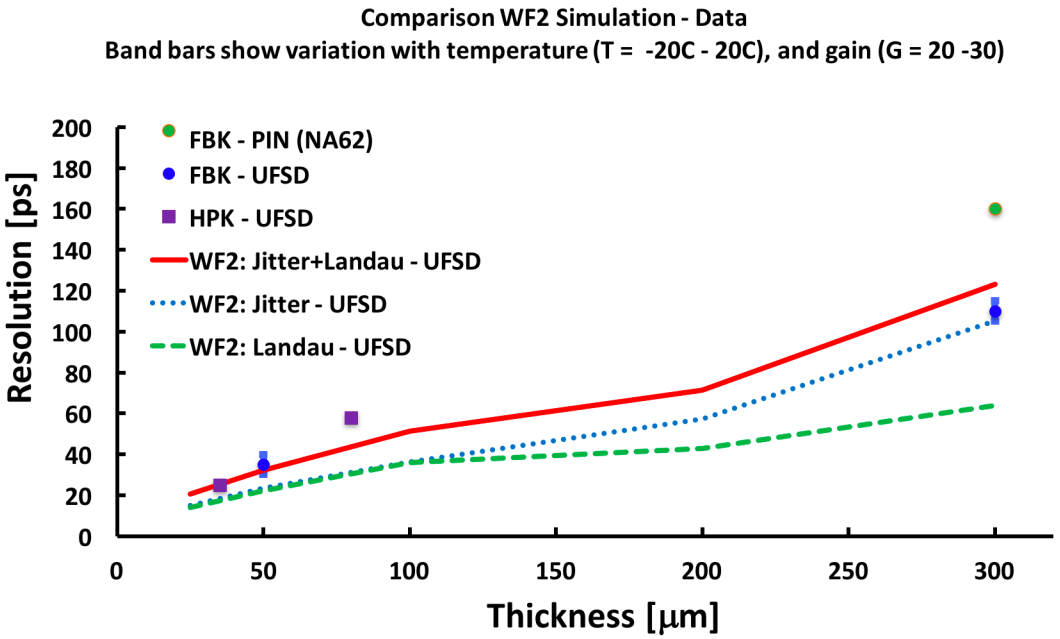


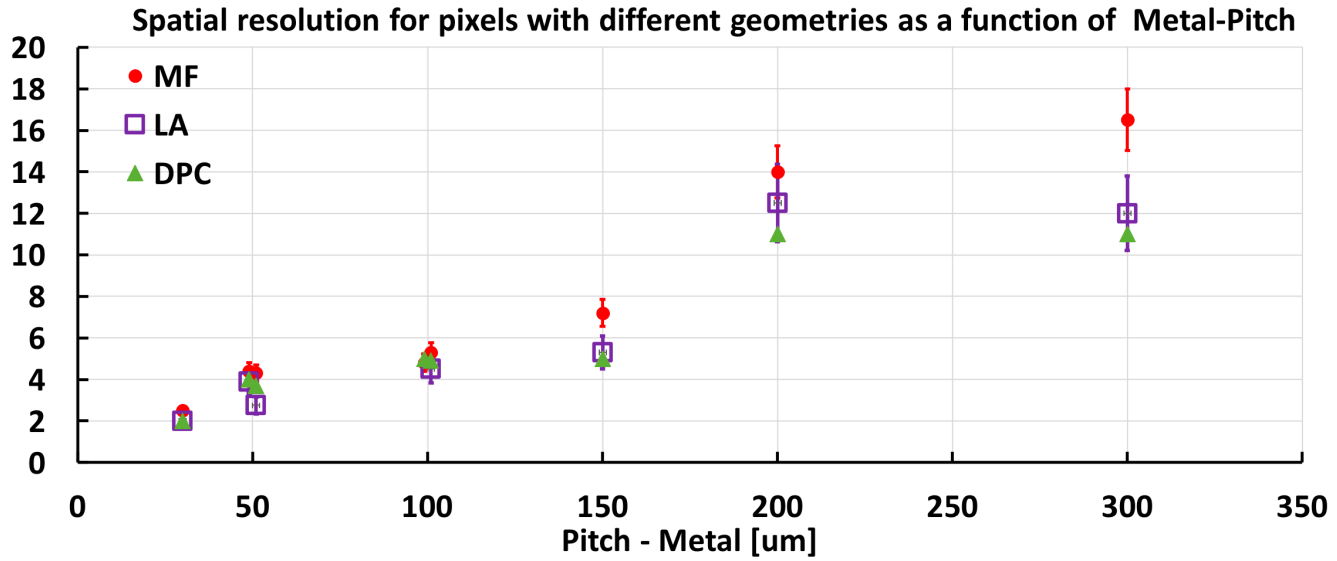
[1] https://wiki.bnl.gov/conferences/index.php/ProjectRandDFY22

	Time resolution / hit	Position resolution / hit	Material budget / layer
Barrel ToF (Tracker)	<30 ps	(3-30 μm for Tracker)	$< 0.01\ X_0$
Endcap ToF (Tracker)	<25 ps	(30-50 μm for Tracker)	e-direction $< 0.05 X_0$ h-direction $< 0.15 X_0$
Roman Pots	<50 ps	$< 500/\sqrt{12}\ \mu m$	N/A
B0	<50 ps	$O(50)\ \mu m$	$< 0.01\ X_0$

eRD112: AC-LGAD Sensor R&D

Nicolo Cartiglia

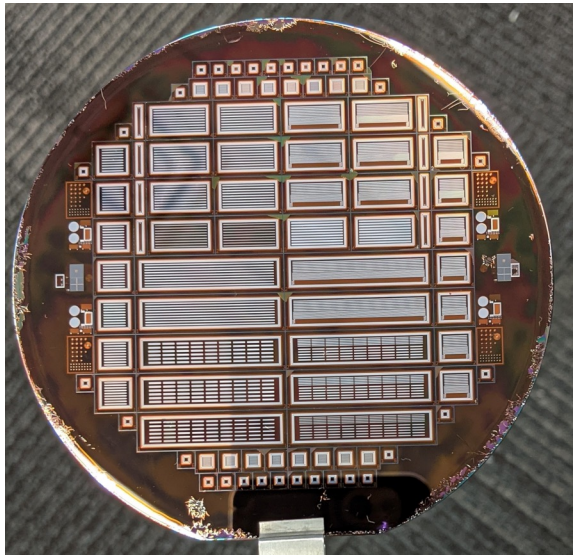




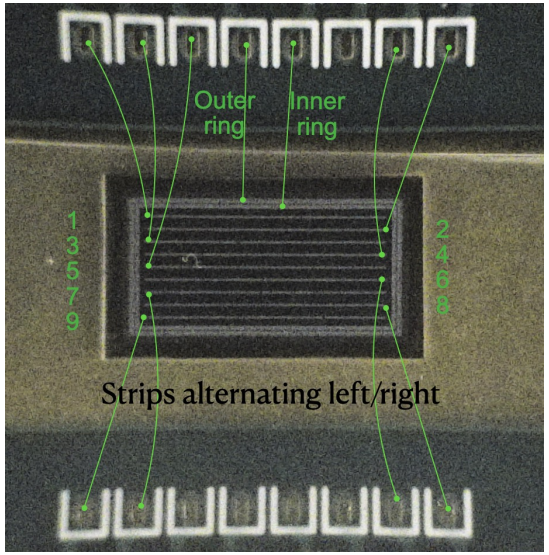
- **R&D Goals**
  - 15-20 ps timing resolution, O(3-50μm) position resolution where needed
  - Minimal readout channel density (long strip, rectangular pixel) for reduced power, material and cost
- **Plan**
  - Produce and test sensors with thinner active volume to achieve the desired timing resolution
  - Optimize implantation parameters and AC-pad segmentation through simulation and real device studies
  - Engage commercial vendors to improve fabrication process and yield

eRD112: AC-LGAD Sensor R&D

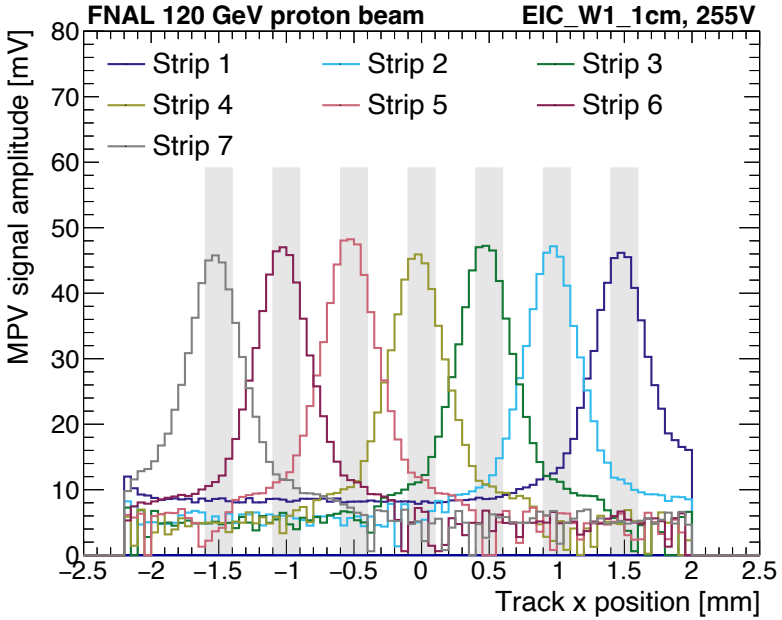
- **FY22**:
  - Production of thin (20 and 30 um) sensors for ToF application with time resolution ~20 ps by BNL IO.
  - Production of medium/large-area sensors with different doping concentration, pitch, and gap sizes between electrodes to optimize performance by BNL IO and HPK.
- **FY23 Q3**: Design and submission for fabrication of advanced sensor prototypes with <20 ps time resolution and space resolution that matches RPs, ToF, and Tracker requirements. This will be baseline for CD2/3A.
- **FY24 Q2**: Sensor batch submission with optimized sensor layouts and performance, based on laboratory and test-beam results. This sensor design will be used as baseline for the CD3 review.
- **FY25**: Module-size sensor fabrication with target time and space performance.



Strip AC-LGAD Sensor Wafer for EIC by BNL

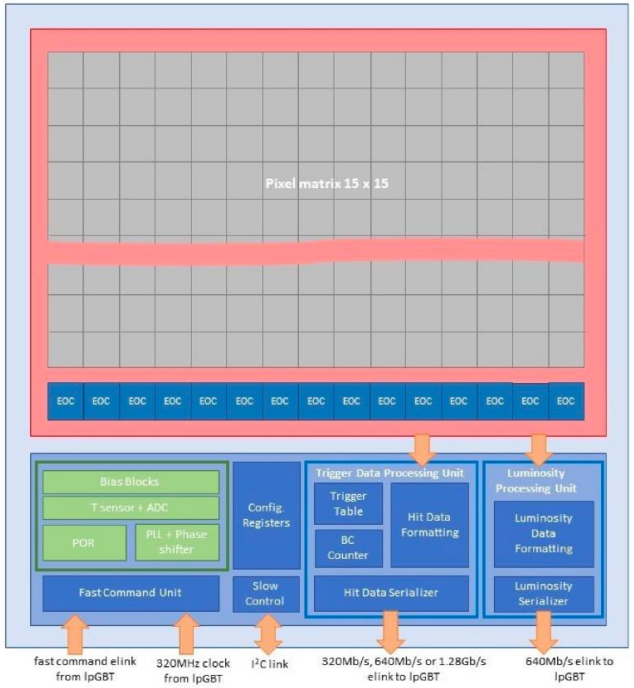


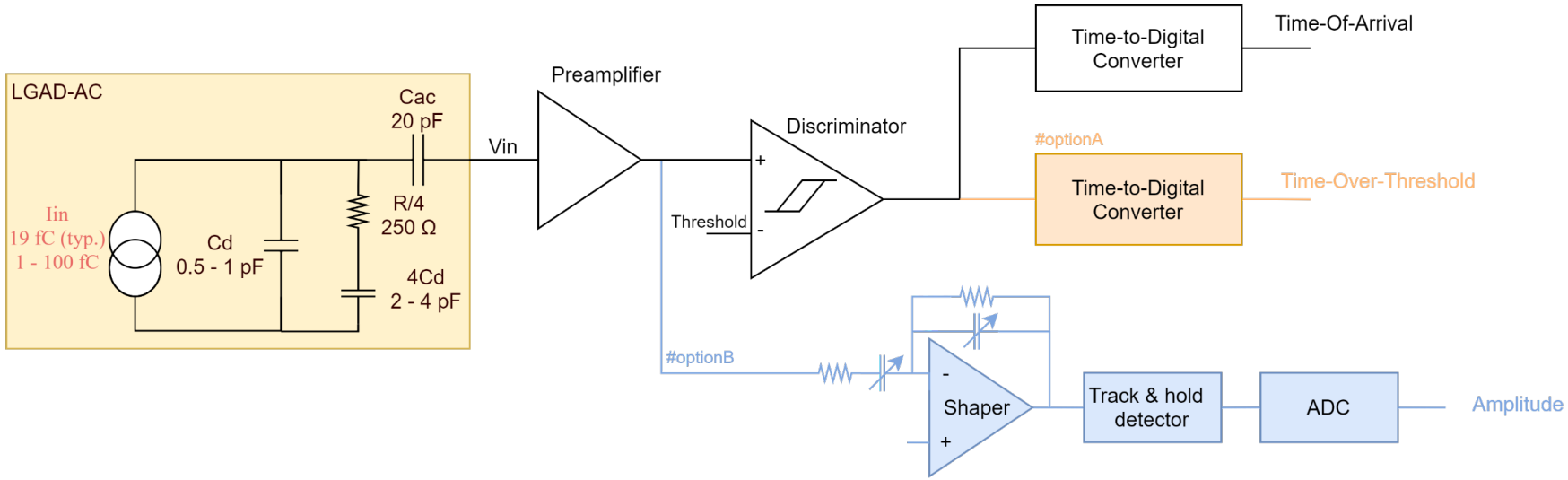
500 um*1cm strip AC-LGAD sensor mounted on test board



Signal amplitude vs x position at 2022 Fermilab test beam

eRD112: ASIC R&D





- **R&D Goals**
  - 15-20 ps jitter with minimal (1-2 mW/ch) power consumption, match AC LGAD sensors for EIC
- **Plan**
  - Continue the ASIC prototyping effort for RPs by IJCLAB/Omega (1st submission in FY22 funded externally)
  - Utilize the design and experience in ASICs for fast-timing detectors from ATLAS and CMS, and investigate common ASIC design and development for RP/B0 and ToF

eRD112: ASIC R&D

EICROC0 (submitted in 3/2022) by Omega/Irfu/AGH

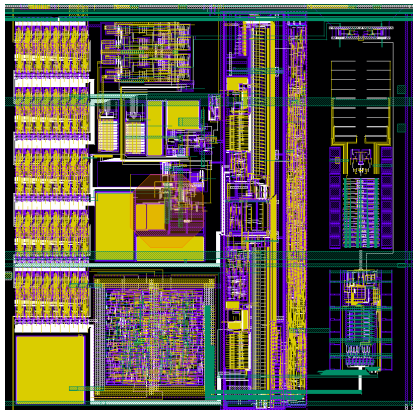
- Preamp, discri. taken from ATLAS ALTIROC
- I2C slow control taken from CMS HGCROC
- TOA TDC adapted by IRFU Saclay
- ADC adapted to 8bits by AGH Krakow
- Digital readout: FIFO depth8 (200 ns)

FCFD0 (submitted in 2021) at Fermilab

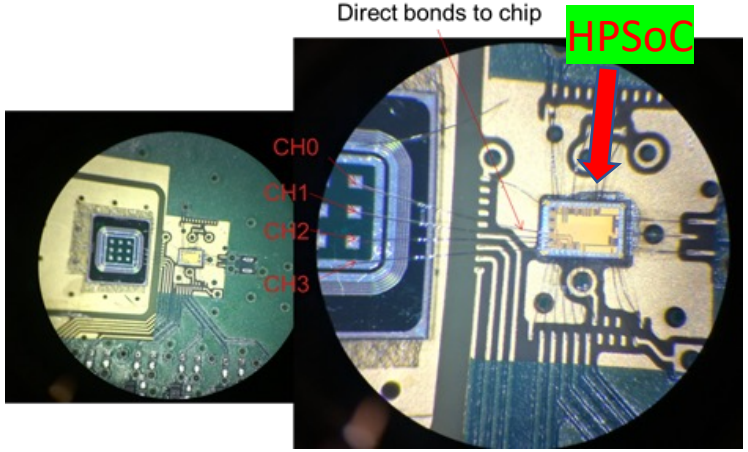
- Adapt the Constant Fraction Discriminator (CFD) principle in a pixel when a CFD is paired with a TDC, one time measurement gives the final answer.
- Charge injection consistent with simulations: ~30 ps at 5fC, and <10 ps at 30 fC, with LGAD like pulses
- Tests with beta sources and beam are planned

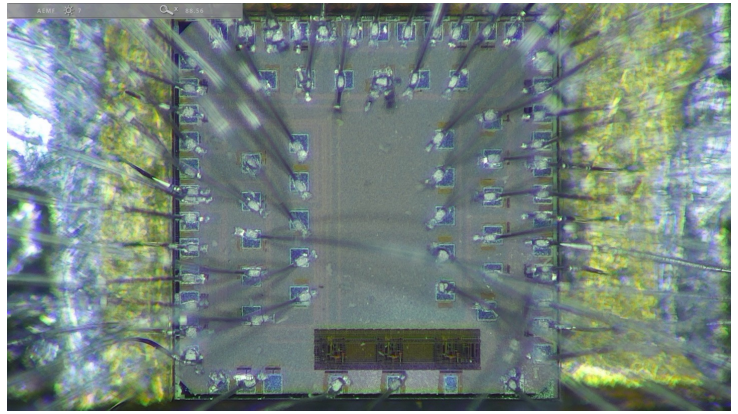
ASIC Efforts at UC Santa Cruz

Institution		Technology	Output	# of Chan	Funding	Specific Goals	Status
INFN Torino	FAST	110 nm CMOS	Discrim. & TDC	20	INFN	Large Capacitance TDC	Testing
NALU Scientific	HPSoC	65 nm CMOS	Waveform	5 (Prototype) > 81 (Final)	DoE SBIR	Digital back-end	Testing
Anadyne Inc	ASROC	Si-Ge BiCMOS	Discrim.	16	DoE SBIR	Low Power	Simulations, final Layout, Board design



EICROC0





FCFD0

Summary and Outlook

- AC-LGAD is a very promising technology for 4D detectors at future high energy experiments
- In order to meet the EIC project timeline, eRD112 plan to
  - FY22
    - Finalize the requirements by EIC Detector-1 through simulation
    - Funds for AC-LGAD sensor R&D: sensor fabrication through BNL IO and HPK, build up expertise
    - Externally funded front-end ASICs: submission and testing
    - Start looking into other detector system components: mechanical, cooling, on and off-detector electronics
  - FY23
    - Continue sensor R&D, ramp up efforts on ASIC, realistic design of other detector system components
    - Come up with preliminary system designs of AC-LGAD detectors for **CD2/3A review (Oct 2023)**
- Please join us if you are interested
  - Indico page: https://indico.bnl.gov/category/323/
  - Mailing list: https://mailman.rice.edu/mailman/listinfo/lgads-eic
  - FY22 Proposal: https://wiki.bnl.gov/conferences/index.php/ProjectRandDFY22