Sampling signal sharing to enable 6D Tracking

Haider Abidi, Gabriele D’Amen (PO/NPP)
Yuhui (Ray) Ren (CSI)
Viviana Cavaliere, Stefania Stucci, Alessandro Tricoli (PO/NPP)

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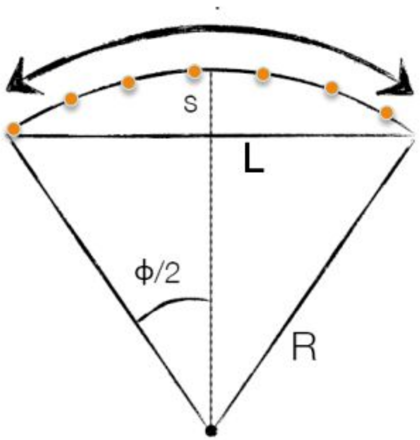
Low mass detector

- Overall tracking resolution of charged particle depends on **track layers & material**

More layers = …

- more measurements → **better resolution at high momentum**
- more scattering → **worse resolution at low momentum**



- Number of layers and material budget needs to be **tailored to physics needs**
- Low mass charged particle trackers **critical** component of future experiments
  - *example:* **ePIC** & **FCCee** detectors

EIC Detector General Requirements

- High precision low mass tracking — Link
  - small (μ-vertex) and large radius tracking

Central and Endcap tracker → High precision low mass tracking

- MAPS – tracking layers in combination with micro pattern gas detectors

Link

$$\frac{\sigma_p}{p} \sim p \cdot \frac{\sigma_s}{BL^2} \sim \text{const} \cdot \left(\frac{p_t}{BL^2}\right)^2 + \text{const} \cdot \left(\frac{1}{B\sqrt{LX_0}}\right)^2$$

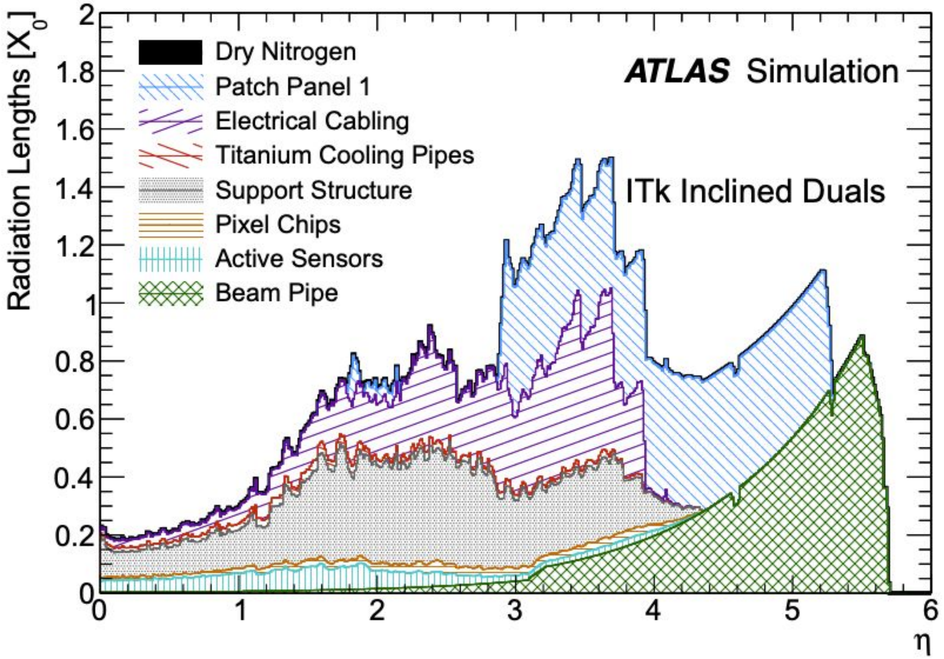
Uncertainty σ_s depends on number and spacing of track point measurements; for equal spacing and large N:

$$\sigma_s = \frac{\sigma_{r\phi}}{8}\sqrt{\frac{720}{N+5}}$$

see: Glückstern, NIM 24 (1963) 381 or Blum & Rolandi, Particle Detection ...

Low mass tracker design

Material distribution in a typical detector



Current efforts to reduce material

1. Reduce material in the **support structures**

   (air cooled/reduce data transmission/etc…)

2. Reduce material in the **front-end**

   (MAPS)

Our proposal - Use AI to extract more information from each layer

- Measure **position & direction** of a charged particle from a **single silicon layer**
- Reduce requirements on number of total layers & overall cost to achieve target precision/physics

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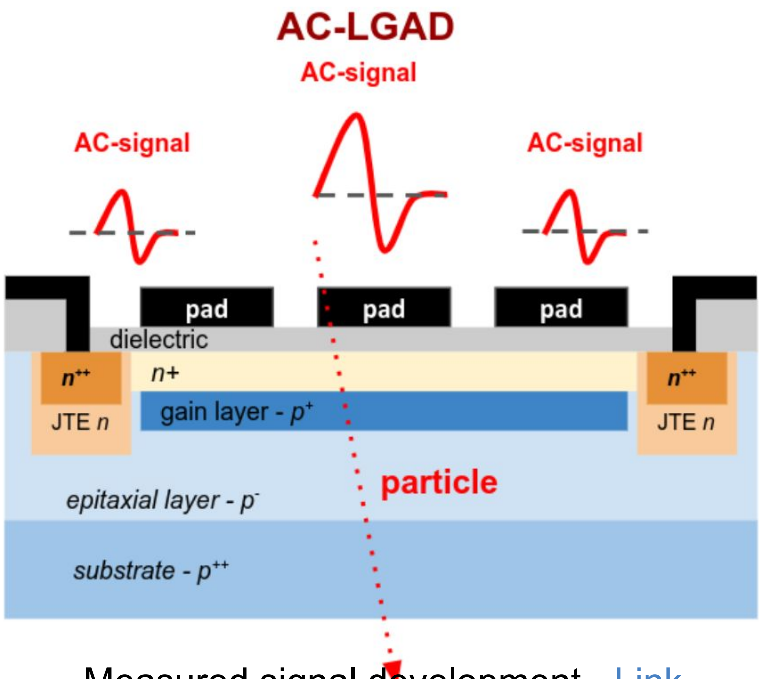
Signal development in RSD/AC-LGAD

- In RSD/AC-LGADs signal generated by passage of a particle is **shared among multiple pads** **(Signal Sharing)**
- Signal development over time is dependent on both **position & direction of the incident charged particle** [SCIPP]
- Difficult to get this information (typically limited by bandwidth requirements/digitalization techniques)

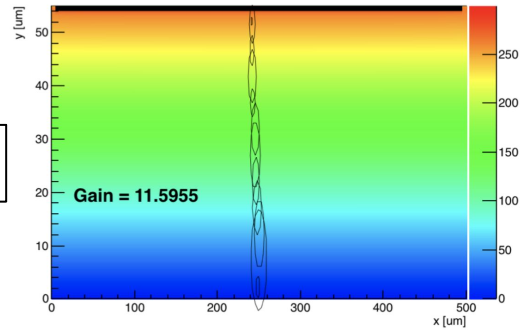


Measured signal development - Link

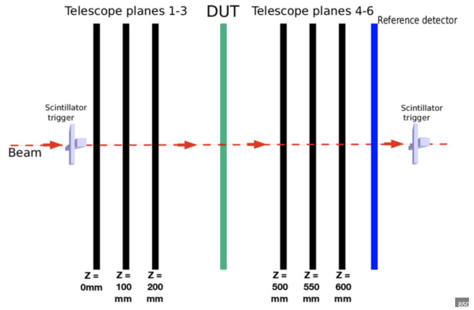
AI measuring position & direction

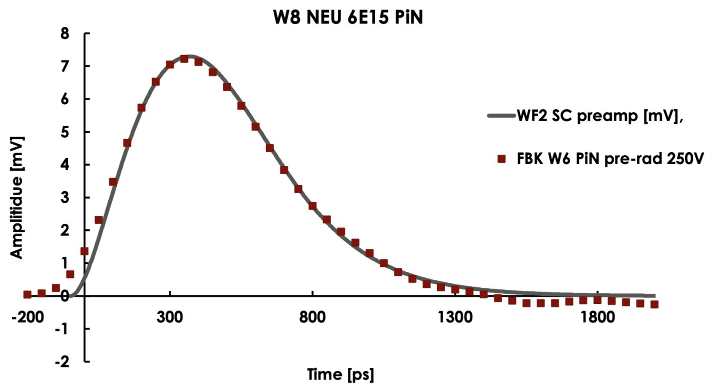
- Feed **signal shape from each pad into a low-latency AI algorithms** to measure **position & direction of particle**
  - **Train** model through **simulations** and **test-beam data**
  - Leverage ideas, skills & collaborations developed at BNL and through LDRDs
- AI system provides the flexibility to **update model as detector conditions vary** and **signal response changes with irradiation**

Simulation



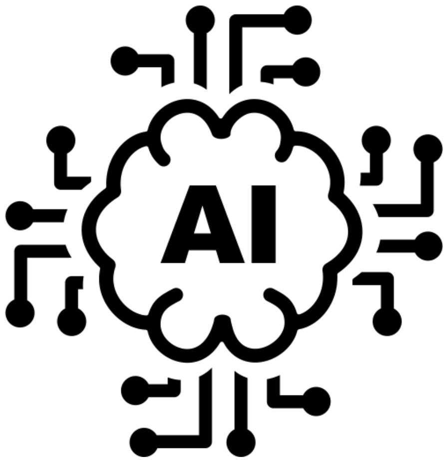
Test-beam





Signal pulse shape

TRAINING

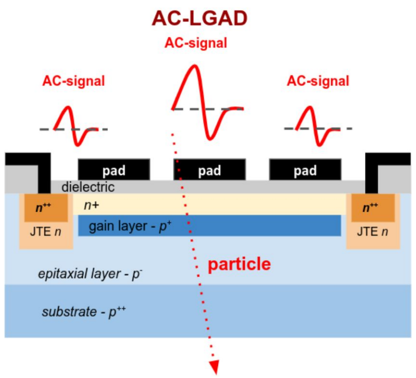


Train AI model

Overall AI system design

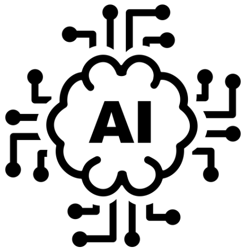
- AI system **extracts the underlying information & compress data** that needs to be read from detector
  - Perform this step in **readout chain** to extract critical data to fit within bandwidth
- AI **inference at high clock rate on dedicated hardware limits** increase on cooling requirements
  - Leverage ideas that are developed through LDRD

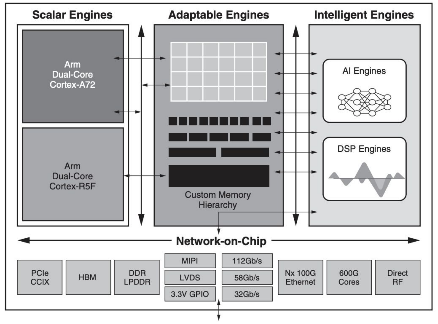
INFERENCE



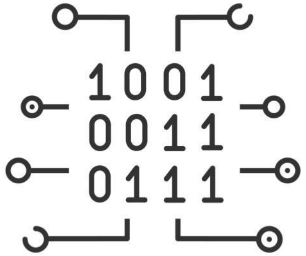
AC-LGAD sensor

High-frequency readout ex. Nalu system





Trained AI model running on low-latency heterogeneous hardware



Measured position & direction information

Rest of detector readout & trigger chain

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Team & Budget

- **AI/ML:** Haider Abidi (PO/NPP), Yuhui (Ray) Ren (CSI), Viviana Cavaliere (PO/NPP)
  - Exploring collaborations with Department of Electrical and Computer Engineering at *Stony Brook* and *University of Rutgers*
- **Silicon sensor & simulation:** Gabriele D’Amen, Stefania Stucci, Alessandro Tricoli (PO/NPP)
  - Exploring collaborations with *Stony Brook* and *UC Santa Cruz* (MSI)

- **Budget/per year (Personnel) ~ 875k + 25k for travel:**
  - ~ 1 FTE for AI/ML ~ 275k
  - ~ 1 FTE for Si ~ 275k
  - ~ 2 postdocs ~ 275k
- **Budget once (Equipment) ~ 60k + 25k for travel:**
  - Readout boards (10k), AI inference board (50k)
  - Travel for test-beam
- Sensors available at BNL

Timeline & Deliverables

- **Year 1:**
  - **AI:** System setup, exploration of low-latency models, training of first simulation-only models
  - **Si:** Layout study, simulation setup + dataset generation for training

- **Year 2:**
  - **AI:** Validation of model with real-data, augmentation of training with real-data
  - **Si:** Test-beam/testing campaign to measure signal shape development

- **Year 3:**
  - **AI:** Low-latency optimization, integration into overall AI system
  - **Si:** Testing of end-to-end sensor <-> readout chain

- Write up & publishing of results

Summary

- Project:

  Develop AI system to measure position & direction of particle in readout chain

- Physics outcome:

  Increase data extracted from each silicon tracking layer to overall improve charge particle reconstruction. This will lower active layer requirements enabling lower cost low mass tracking systems

- Personnel:

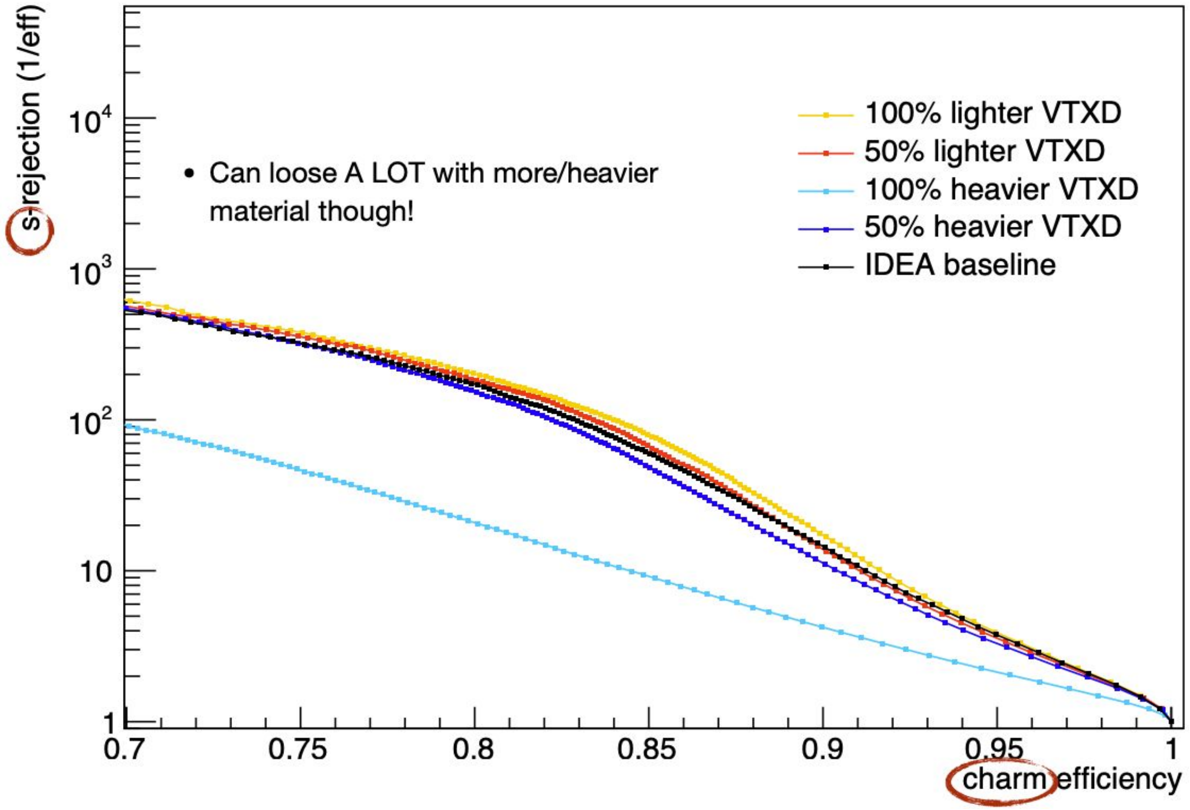
  Builds on our amazing collaboration developed through various BNL and ATLAS projecteds

- Budget: $900k/year

Backup

Impact on physics

- **Extra material** in the detector **can have extremely detrimental impact** on the final experiment goal
  - *example:* Jet tagging is critical for measuring Higgs to charm/strange coupling at FCCee



Results from BNL Higgs factory LDRD-A research

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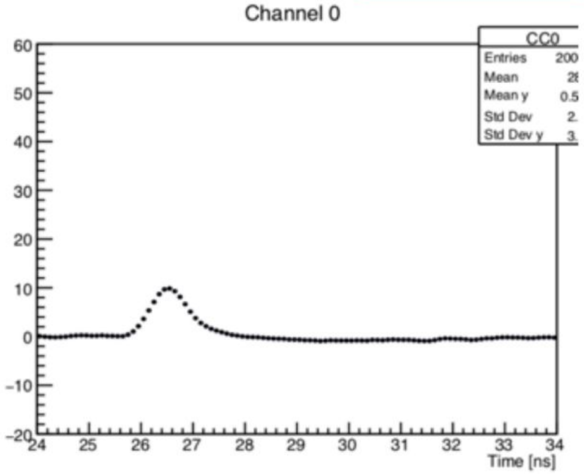
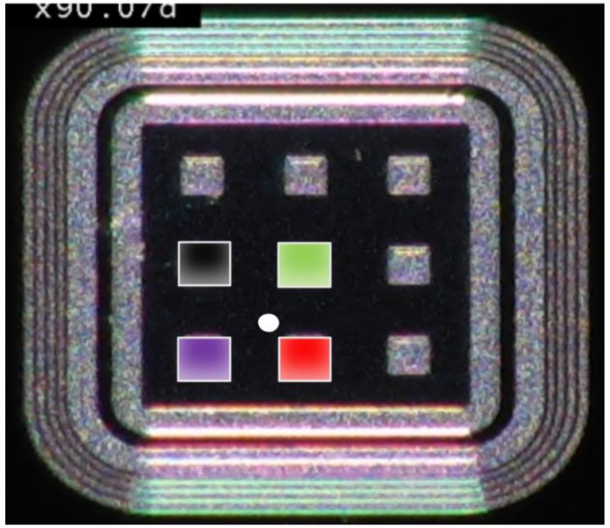
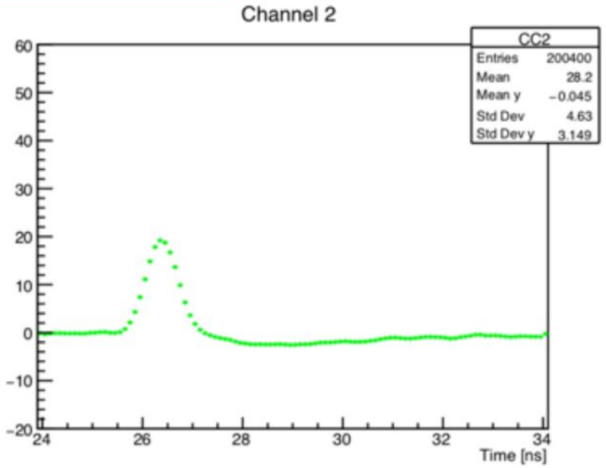
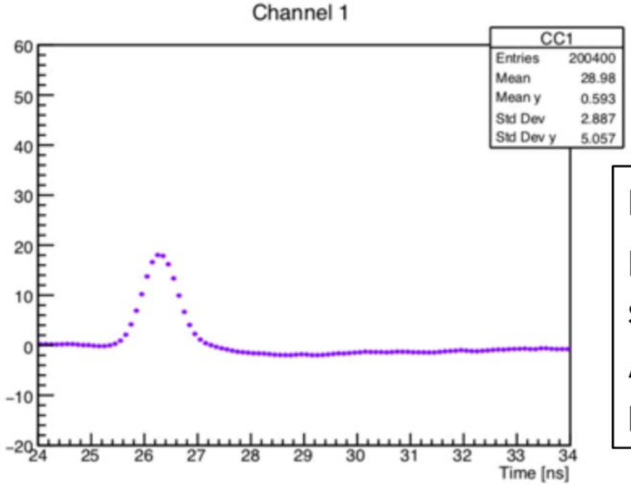
Signal development in AC-LGAD



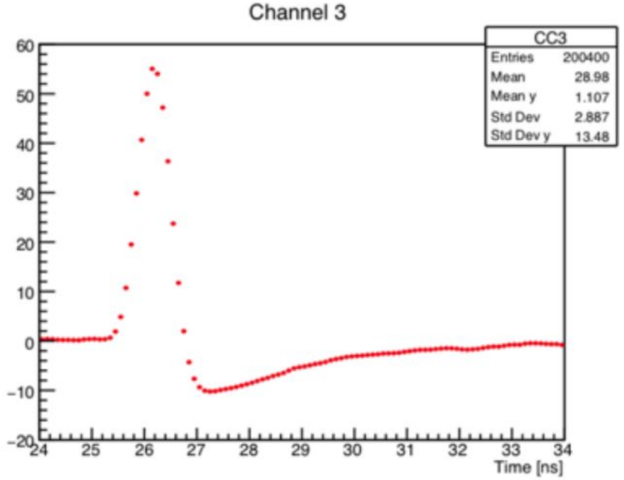
Each hit position is characterized by a specific set of amplitudes in the pads







It is possible to associate to each x-y point the relative importance of the signal in each pad: **A[0]/Atot, A[1]/Atot, A[2]/Atot,A[3]/Atot,**
In this case (0.09, 0.18, 0.18, 0.55)



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Measured signal development - Link