Characterizing InP for Thin-Film Tracking Detectors

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Facilities & Organizations

CLS	- X-ray Active Area
CNM	- Device Fabrication
DIAMOND	- X-ray Active Area
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Ljubljana	- Neutron Irradiation
SCIPP	- 2nd Gen Device Characterization

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HEPCAT

SCIPP SANTA CRUZ INSTITUTE FOR PARTICLE PHYSICS UC SANTA CRUZ

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UIC UNIVERSITY OF ILLINOIS CHICAGO

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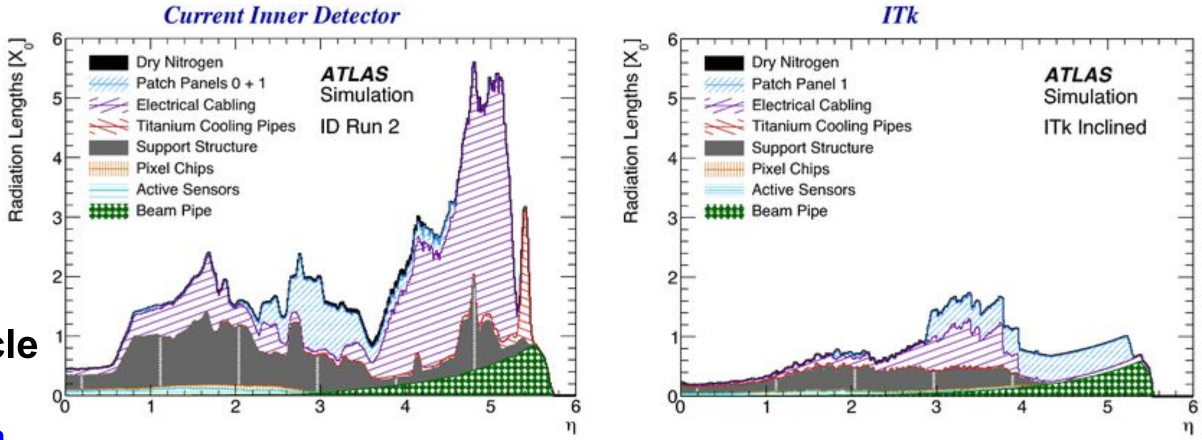
Tracking Detectors

- **Challenges**
  - **Supports and Services**
    - **Cooling**
    - **Structural Support**
    - **Electrical Cabling**
  - **Mass / Radiation Length**
  - **Cost**

- **What Thin-Film Charged Particle Detectors Could Provide**
  - **Room Temperature Operation**
  - **Low Power**
  - **Low Material Use**
  - **Comparable Efficiency and Resolution**
  - **Manufacture at Scale**



Run 2 **Phase-II Upgrade**

[TDR ATLAS Inner Tracker Strip Detector]

Thin Film Detectors

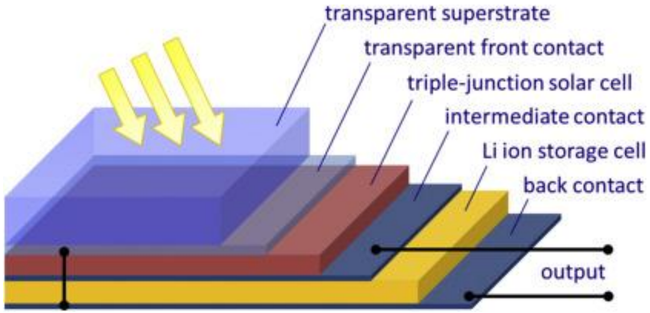
- **Thin layers (nm/µm)**
  of semiconductor/metal/insulator material
  deposited onto substrate

- **Variety of Industrial Applications**
  - High-speed electronics, optoelectronics, photovoltaics, optical sensing, etc
  - Extensive applications in photon response

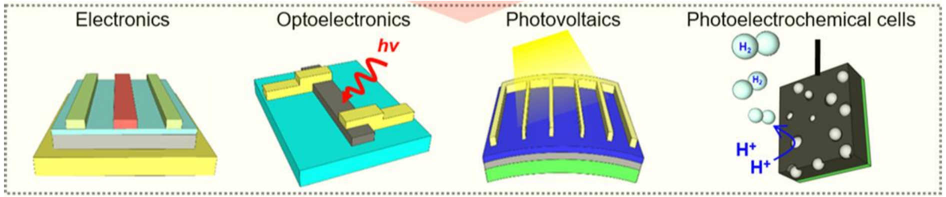
- **We want to target HEP applications**
  - **Charged Particle Detection**

- **Deeper Overview of Thin Film Detectors as a Blue Sky R&D & InP Pilot Study**
  - **9:50 AM on Thursday - Sungjoon Kim**

- **What material is best to demonstrate the promise of Thin Film Tracking Detectors?**



[Journal of Power Sources]

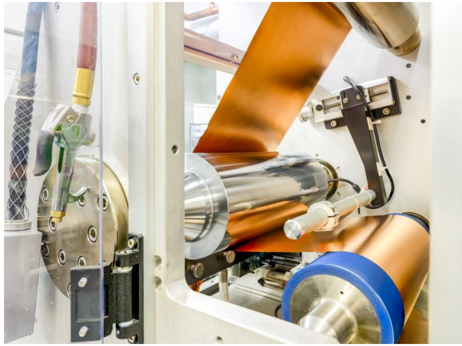


[*ACS Appl. Mater. Interfaces* 2020, 12, 32, 36380–36388]

Why InP is Promising

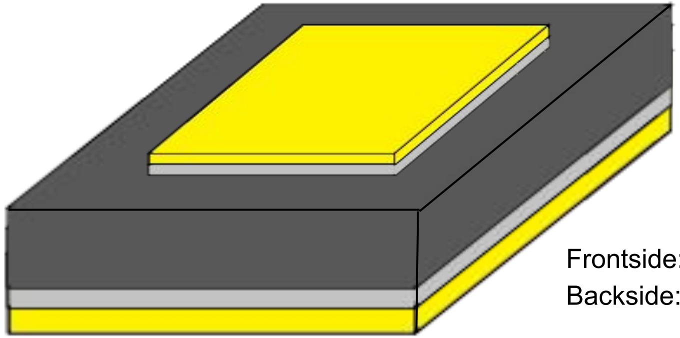
- **High Carrier Mobility**
- **Abundance of e-h pairs**
- **High Resistivity**
- **Doped Wafers Commercially Available**
- **Thin Film Roll-to-Roll Production**
    - InP may be amenable to roll-to-roll thin film production

	InP	Silicon
e^- Mobility (μ)	4600	1400
$N_{e\text{-}h}$ pairs in 10 μm from MIP	4.8k	1.1k
Bulk Resistivity (ρ in Ω cm)	10^7	10^4



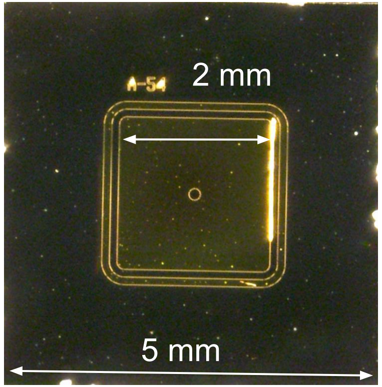
Dopant	Conduction Type
Undoped	N-type
Sulphur	N-type
Zinc	P-type
Iron	SI-type

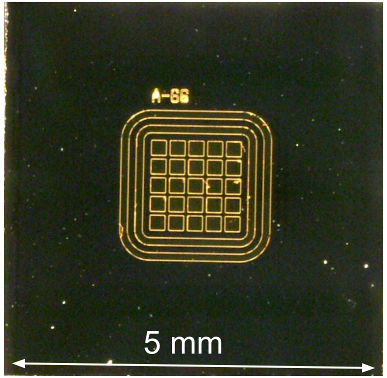
Fabricated Device Structure



Gold (100 nm)
Chromium (10 nm)
InP:Fe (350 µm)
Chromium (10nm)
Gold (100 nm)

Frontside: e-beam metal deposition
Backside: sputter





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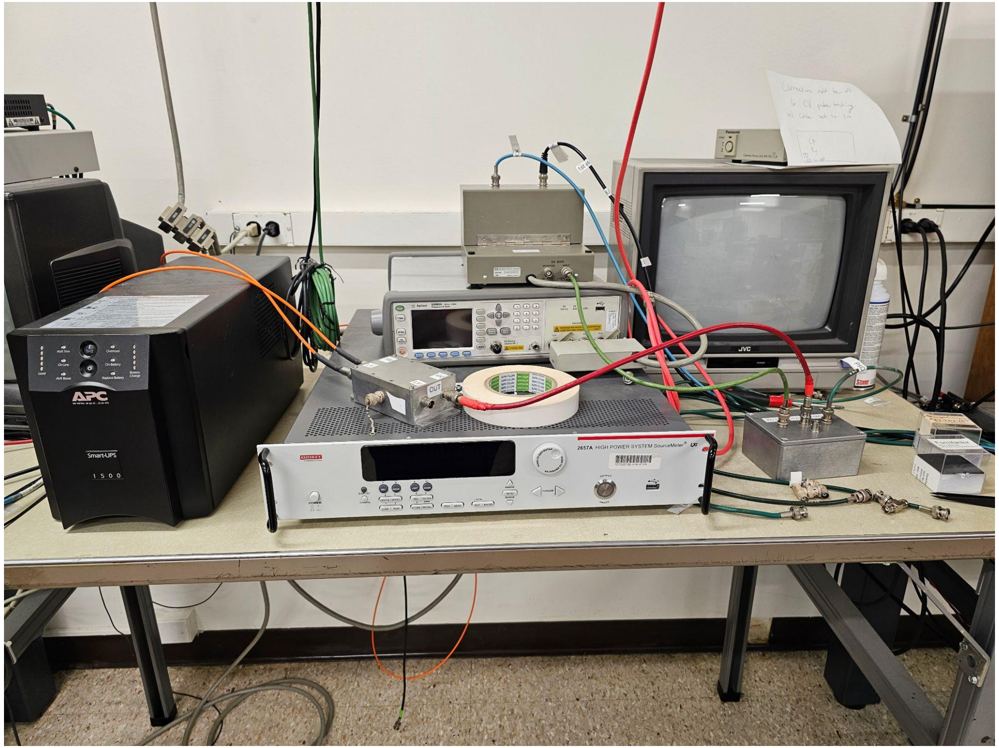
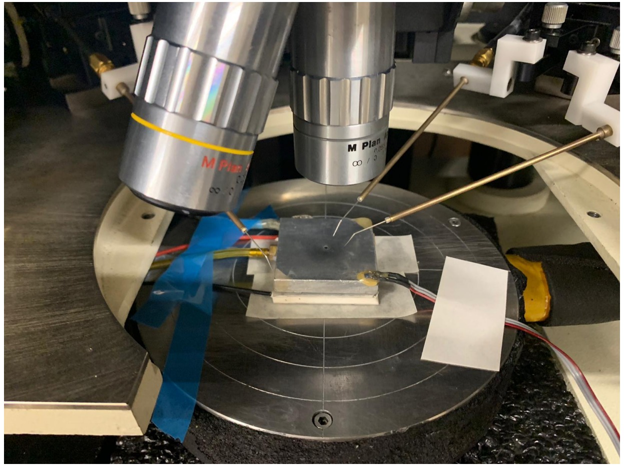
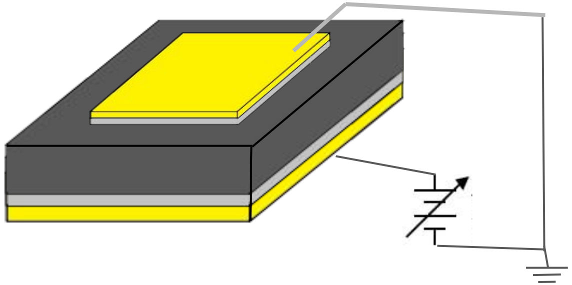
- 2nd iteration of devices
- Check properties with Crystalline InP
  - Commercially Available
  - Baseline before Thin Film production

Device Size	=	5 x 5 mm^2
Pads	=	2 x 2 mm^2
Guard Rings	=	100 µm
GR Spacing	=	100 µm
Hole Diameter	=	150 µm
Multipad Pads	=	200 x 200 $µm^2$

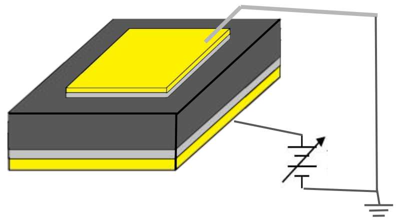
IV-CV Measurement Station Setup

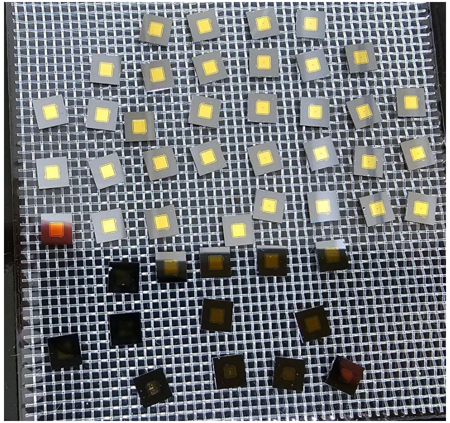


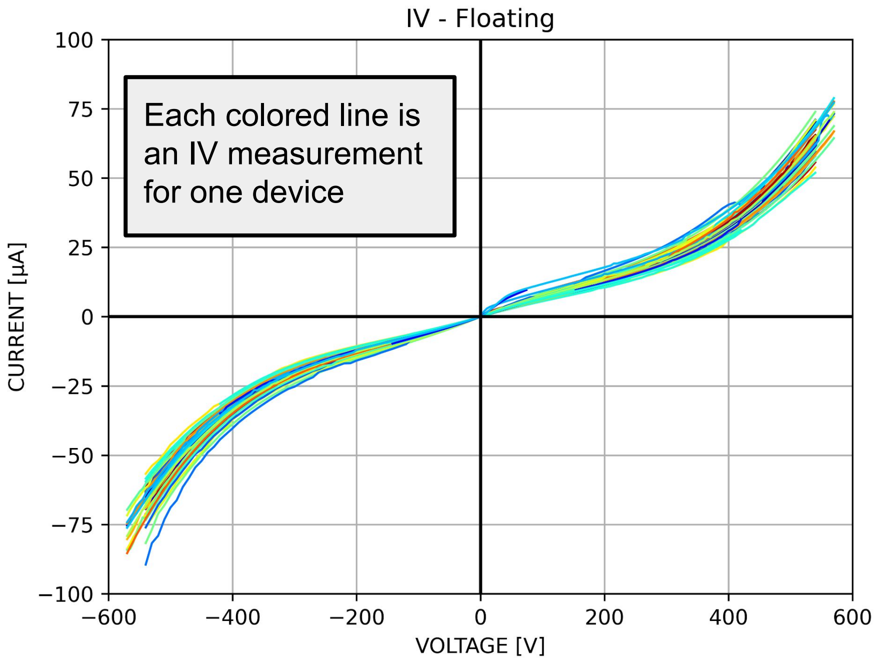




Current - Voltage Characterization







IV Measurement Results:

- Symmetric IV & Device IV Homogeneity
  - Homogeneous Doping Confirmed
- No breakdown observed
- I(600V) = 100 μA
  - ρ_600V = $5 \cdot 10^6$ Ω cm
- **I(350V) = 30 μA**
  - **ρ_350V ~ 10^7 Ω cm**

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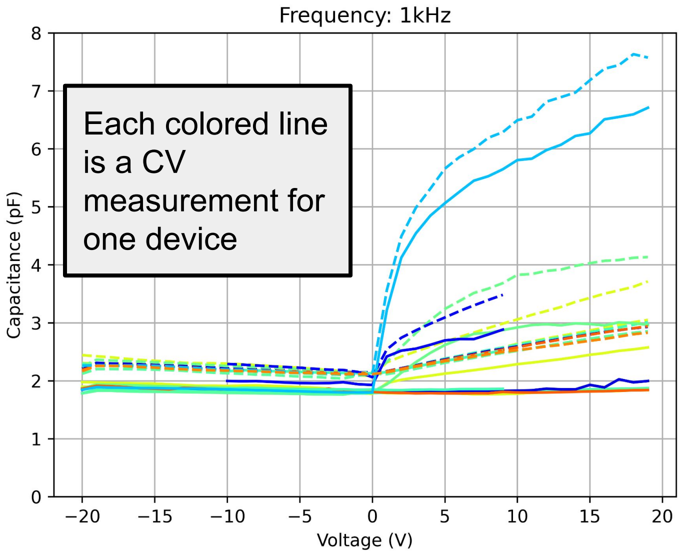
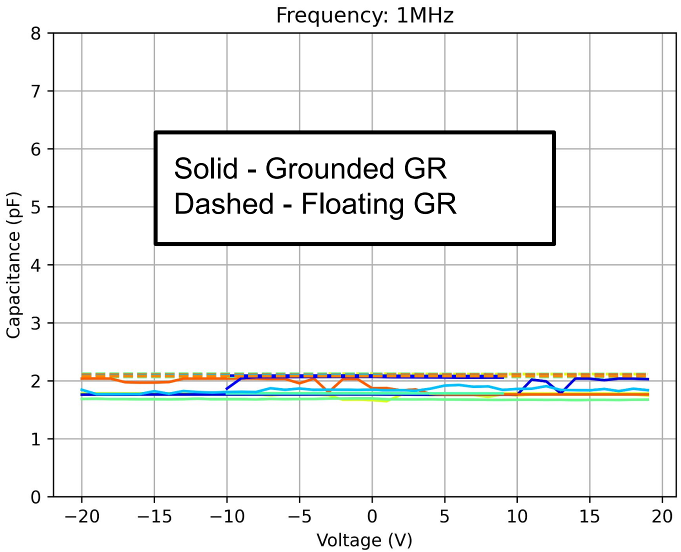
Capacitance - Voltage Characterization





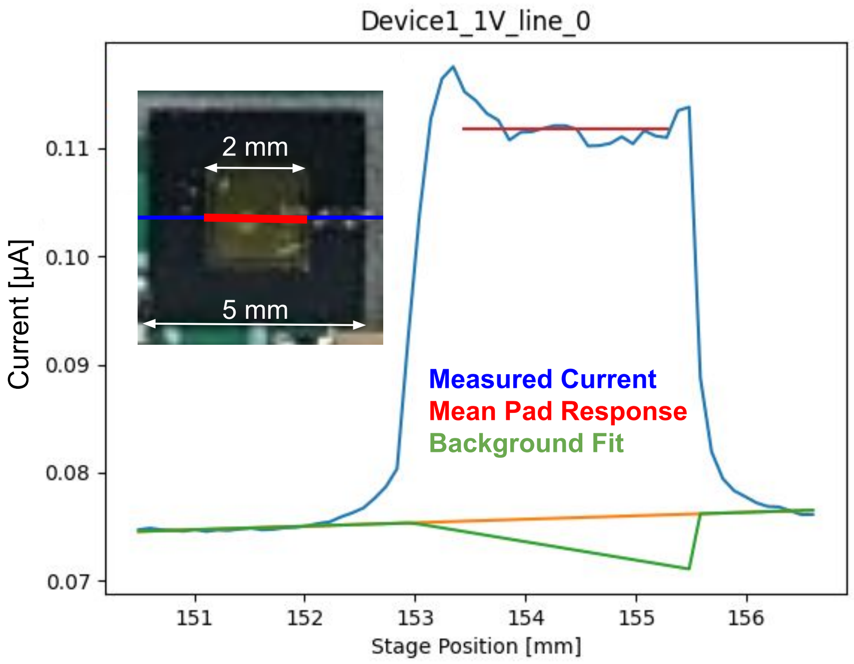
Polarization of semi-insulating InP dependent on both frequency and carrier mobility

- Capacitance is frequency and carrier-mobility dependent

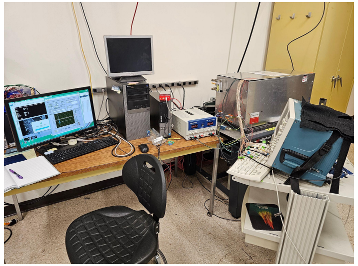
High-f Capacitance: 2 pF with floating GR, bias independent

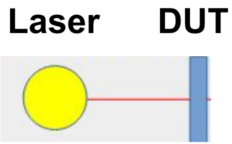
Active Area Uniformity from Focused X-Ray Responses

- Facilities
  - CLS in Canada
  - DIAMOND in UK
- Procedure
  - Scan Focused X-ray Beam Across Device
  - Measure Current Response
  - Subtract Background
- Purpose
  - New Material
    - Active Area Response Uniformity
    - Active Area Size
    - Baseline Comparison with Amorphous InP
  - Active Area Definition
    - Area of sensor that gives a response greater than 50% of the average photocurrent under the pad



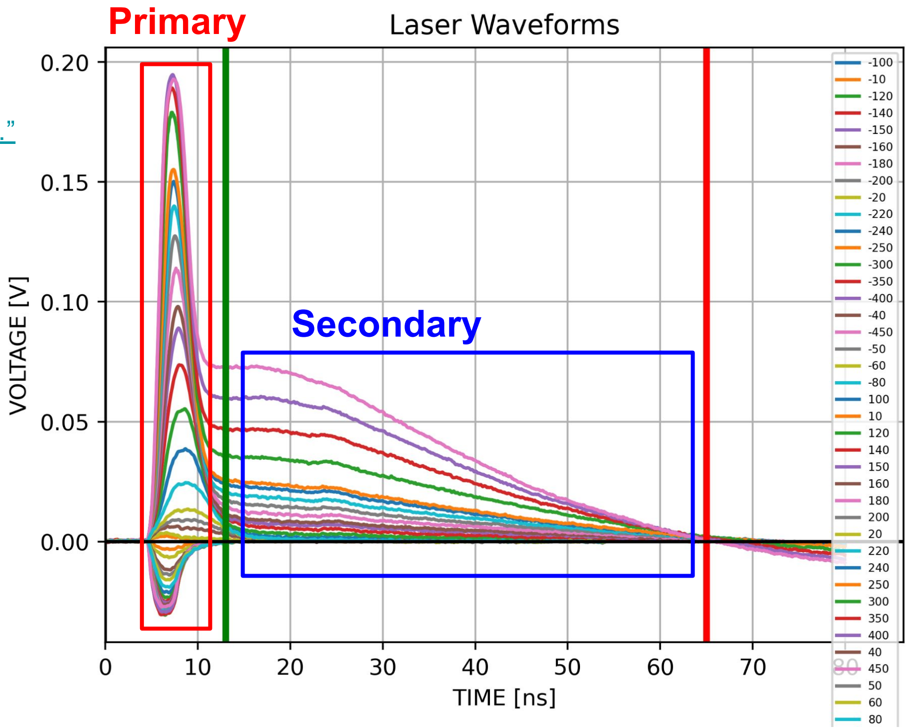
Red Laser - Charge Injection Near Surface



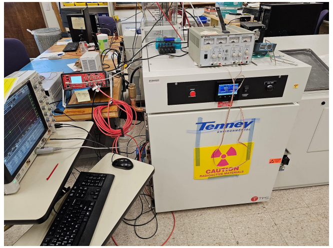


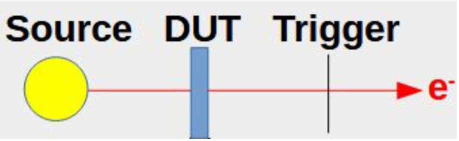
[Böll, Julian et al “Sr-90 Beta Setup…”](#)
Image Source

- Investigate Signal Formation and Charged Particle Transport
- Electron Response
  - **High Pulse Height**
    - e^- mobility: 4600 $cm^2/(Vs)$
  - **Secondary Wave Observed**
    - Ongoing Investigation
- Hole Response
  - Lower Pulse Height



Sr-90 - Beta Source - Charged MIP Response





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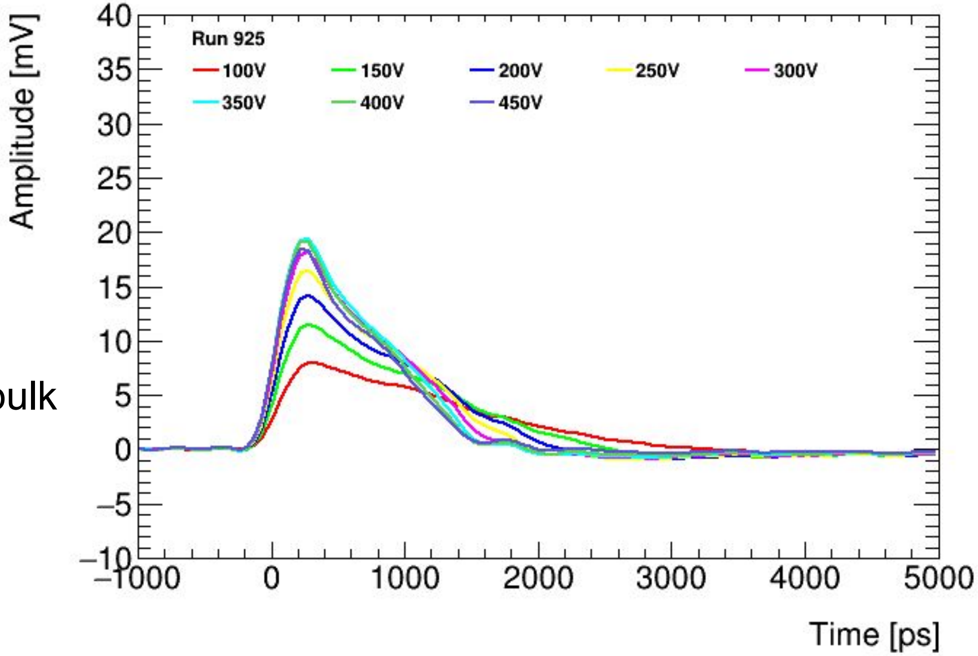
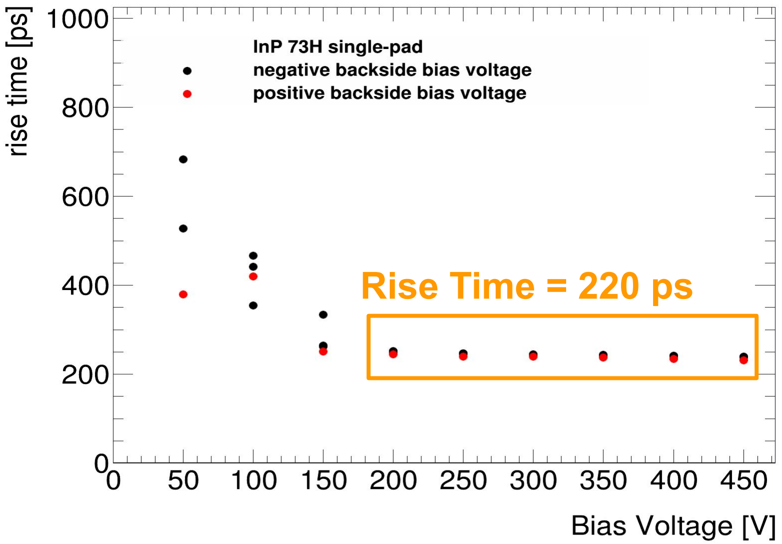
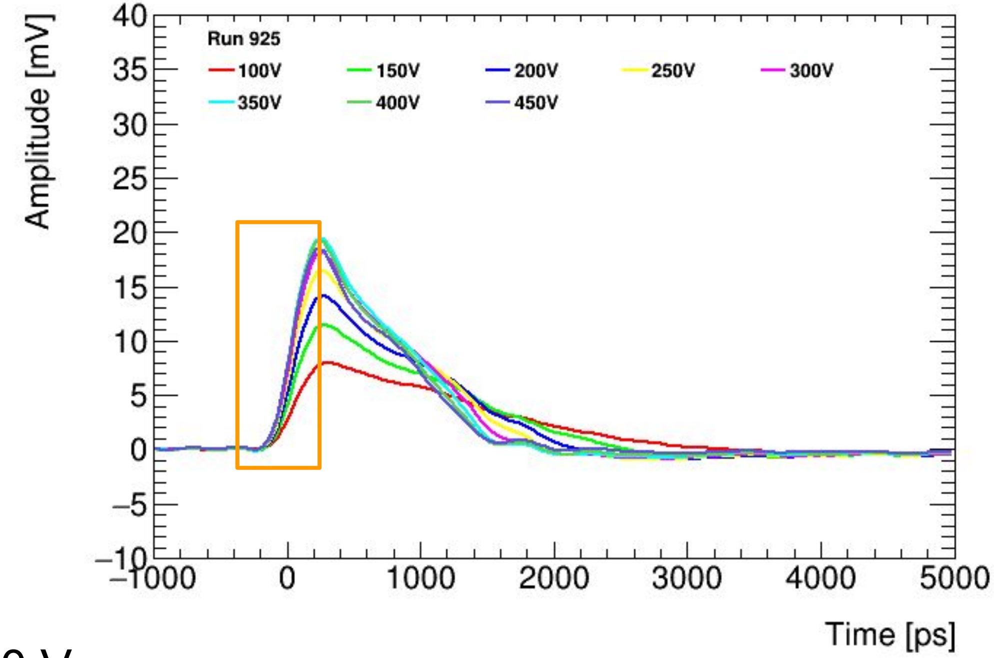


- Fundamental test of MIP Charged Particle Response
  - Charge deposited evenly throughout bulk
  - Primary peak is less pronounced compared to Red Laser

- Greater Applied Bias
  → Faster / Less Smeared Signal

Sr-90 - Beta Source - Rise Time





Identifying the characteristic rise time

- 220 ps consistent past bias of 200 V

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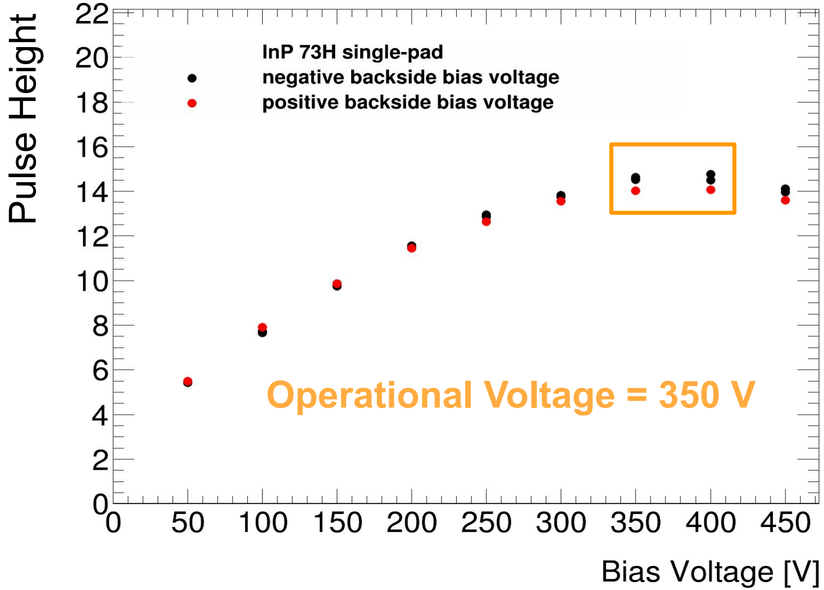
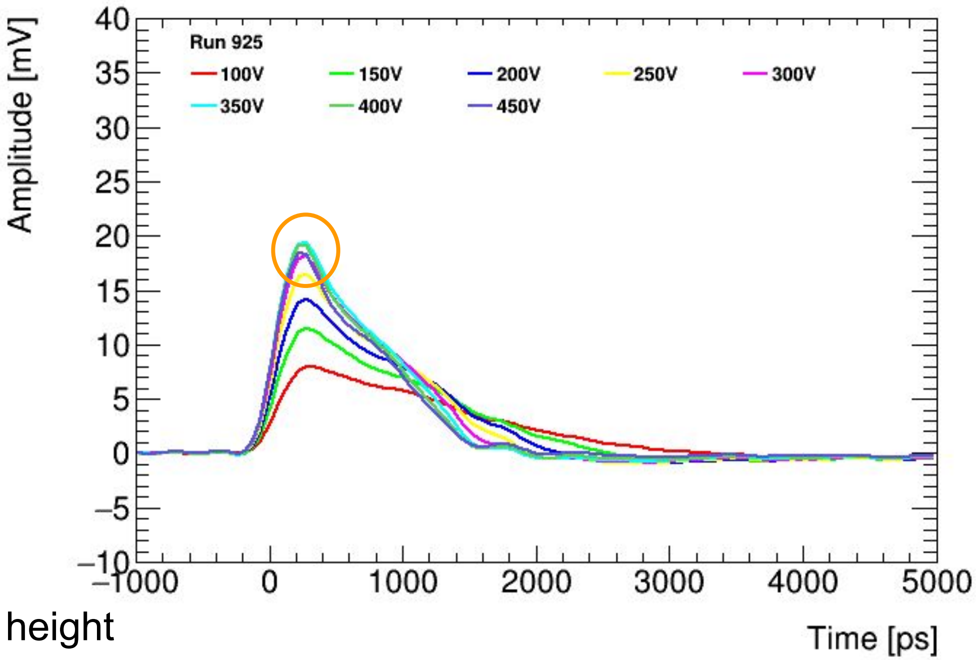
Sr-90 - Beta Source - Pulse Height



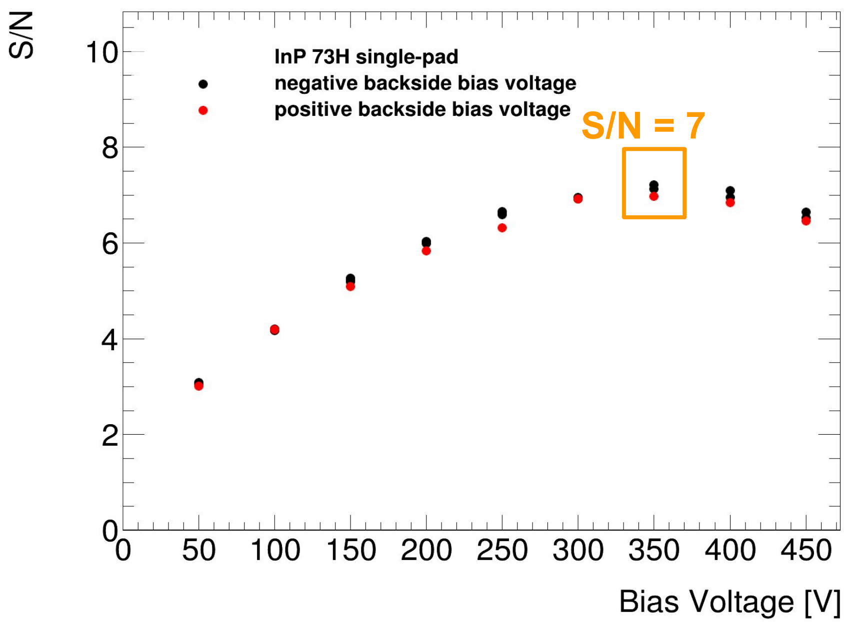


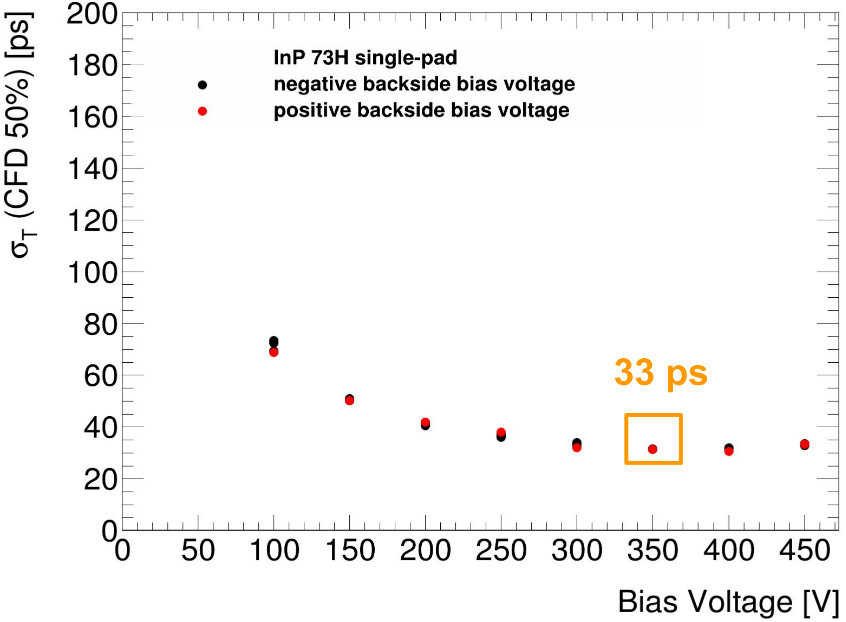
Identifying **operating voltage** through max pulse height

Carrier **velocity plateaus at high field**

→ **Pulse height plateaus at high field**

Sr-90 Beta - S/N & σ_T





S/N peaks at operating voltage

Unoptimized setup

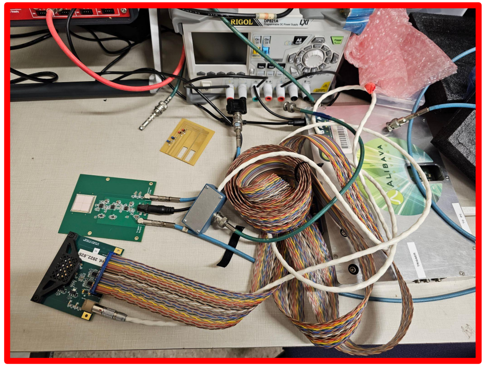
- Could be vastly improved

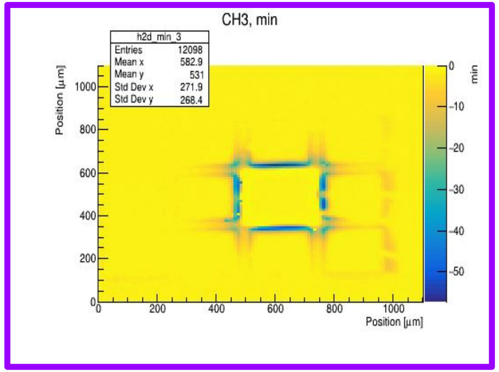
Time uncertainty minimized at operating voltage

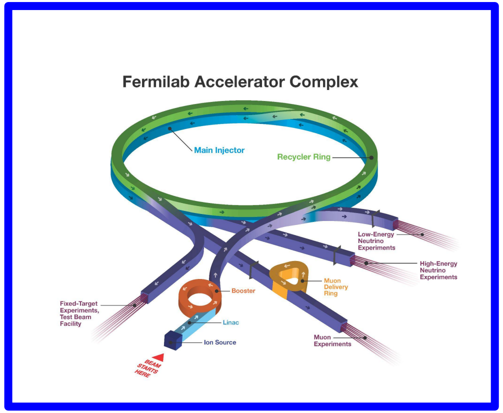
Unoptimized device architecture

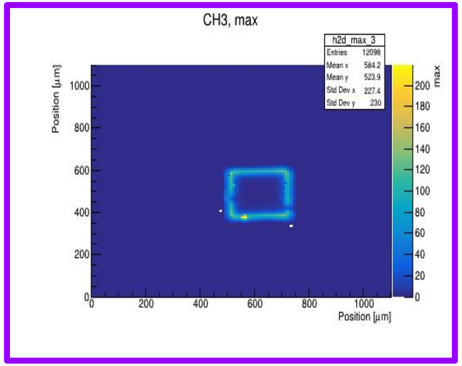
Next Steps

- CCE with Alibava
  - Radiation Hardness
- Testing True Amorphous Samples
  - Crystalline vs Amorphous InP
- Fermilab Proton Beam
  - High Energy Charged Particle Response
- Multipad Device Tests
  - Detector Geometry and Cross Talk









Why InP is Promising

- **Simple Design**
  - No dedicated architecture to aid signal
  - Uniform Bulk Semi-Insulator due to Fe doping
  - Results taken at **Room Temperature**
- Setting Bias to 350 V
  - **Good Device Uniformity**
  - **Bulk Resistivity: 10^7 Ω cm**
  - **High-f Capacitance: 2 pF**
  - **Rise Time = 220 ps**
  - **σ_T = 33 ps**
  - **S/N = 7 (Unoptimized Setup)**
- **InP:Fe - A Low Noise Fast Novel Material**

Promising for Charged Particle Detection

	InP	Silicon
e^- Mobility (μ)	4600	1400
$N_{e\text{-}h}$ pairs in 10 μm from MIP	4.8k	1.1k
Bulk Resistivity (ρ in Ω cm)	10^7	10^4