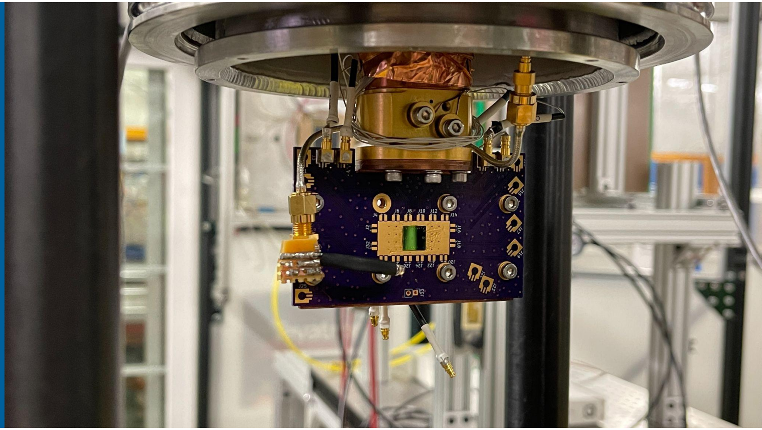
First Detection of 120 GeV Protons with SNSPDs



Sangbaek Lee, Whitney Armstrong
Argonne National Laboratory

11/08/2023, CPAD Workshop 2023 @ SLAC
RDC8: Quantum and Superconducting Sensors

U.S. DEPARTMENT OF ENERGY
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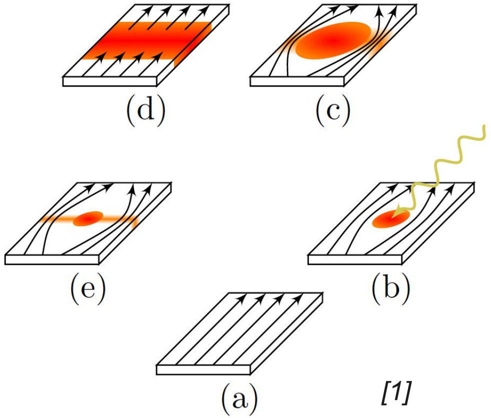
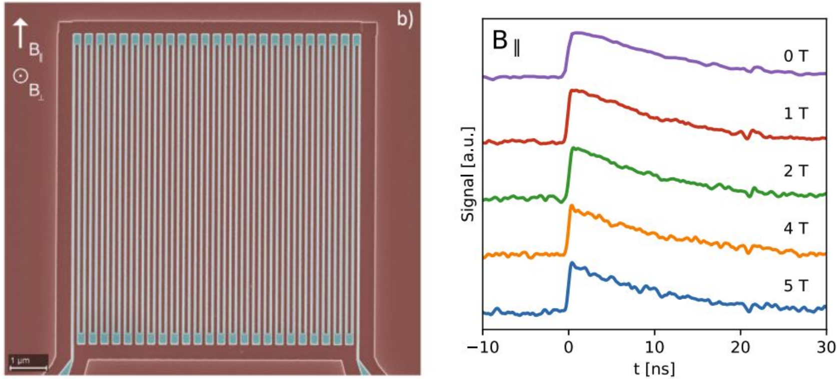
Motivation



[1]

- SNSPD
  - Superconducting Nanowire Single Photon Detector
    - O(10 ps) timing jitter
    - > 90% efficiency

- SNSPD as a charged particle detector
  - $\hbar\omega \gg 2\Delta \approx 2\,\mathrm{meV}$
  - operates under magnetic field
  - Small pixel size, O(10 µm)

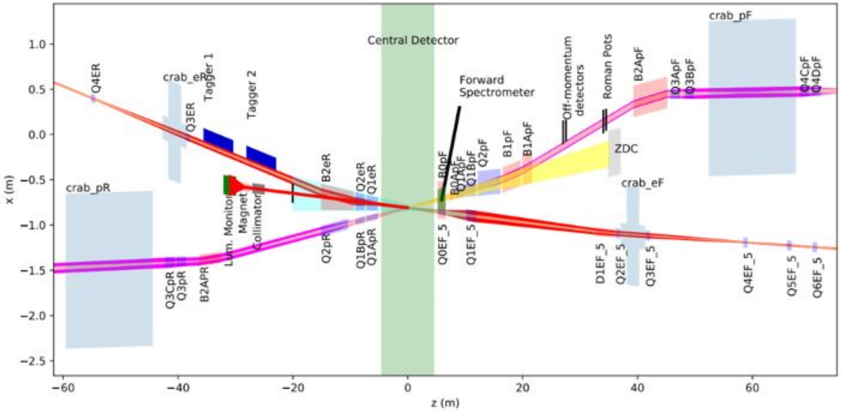


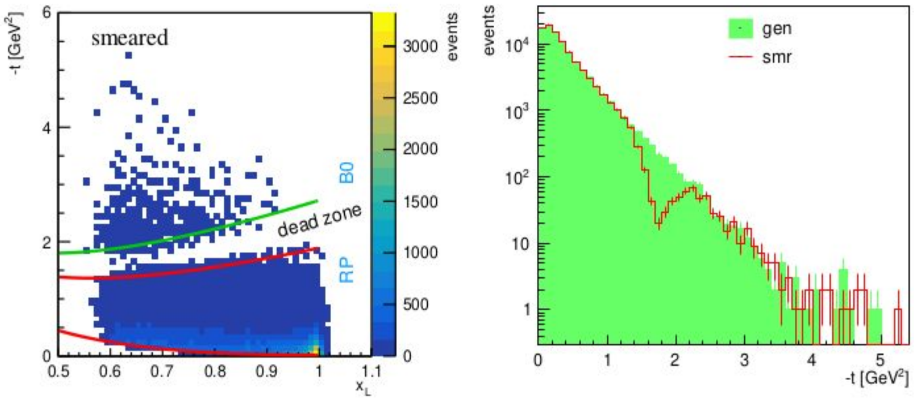
[2]

- Demonstration of detection required for each particle

[1] T. Polakovic, W. Armstrong et al., *Unconventional Applications of Superconducting Nanowire Single Photon Detectors, Nanomaterials* 2020
[2] T. Polakovic, W. Armstrong et al., *Superconducting nanowires as high-rate photon detectors in strong magnetic fields, NIM A* 2020

Motivation





from EIC Yellow Report

Awarded the EIC-related generic detector R&D FY23, 24

And many more ideas!

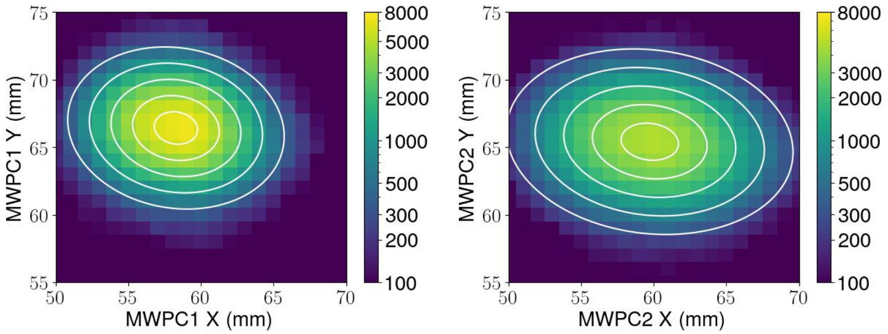
Novel Applications of Superconducting Nanowire Detectors in Nuclear Physics

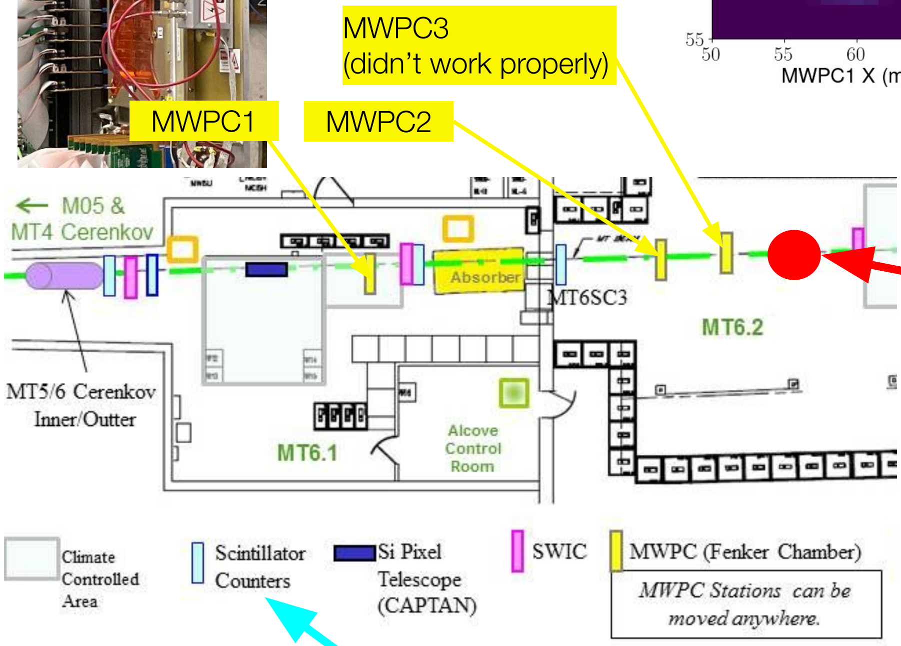
9 Nov 2023, 14:50
20m
53/1-1350-A - Trinity-A (SLAC)

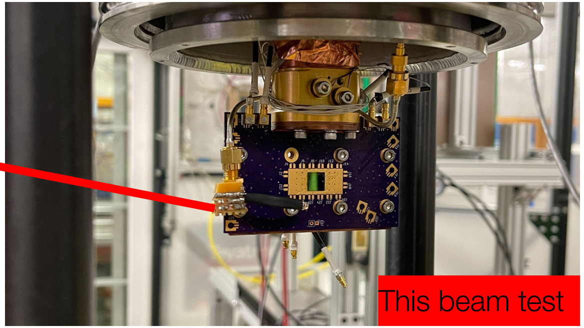
Oral Cross-Cutting: RDCs 1, 2, and 7 RDC1+2+7

Speaker
Sangbaek Lee (Argonne National Laboratory)

Experiment



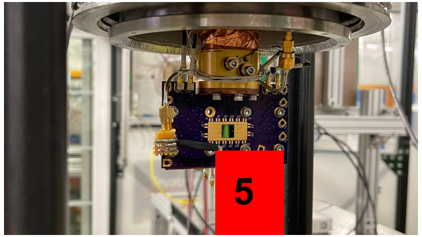




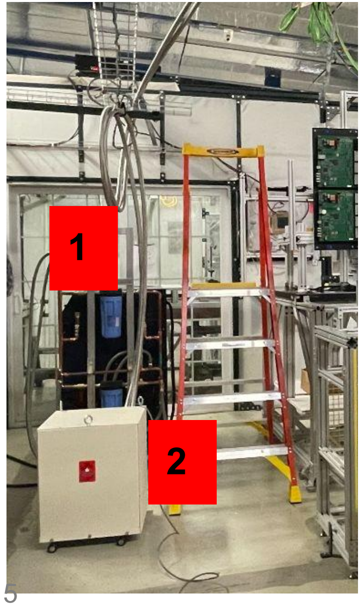
provides total number of protons coming to the beam enclosure per spill

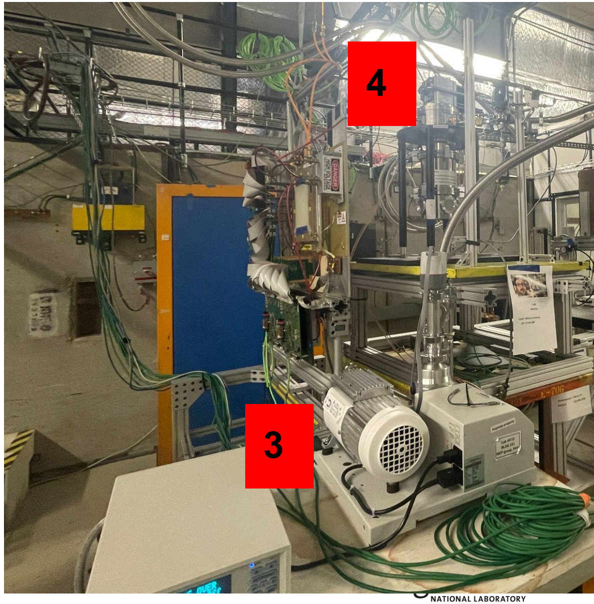
Experiment

The G-M Cryocooler to maintain the operating temperature (< 4 K)
The entire setup was installed in the beam enclosure of MT6.2.



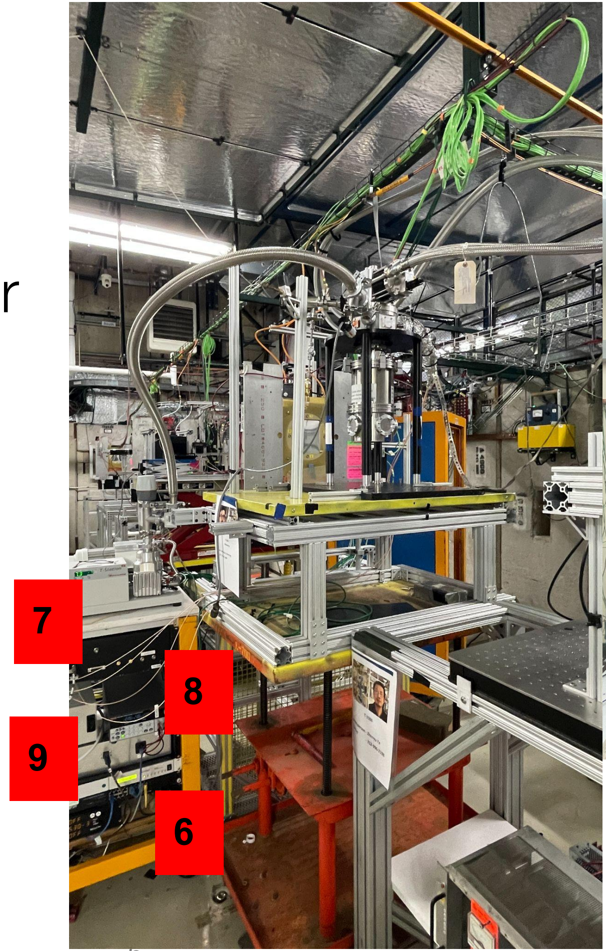
- **1** Water chiller
- **2** Compressor
- **3** Turbomolecular pump
- **4** Cryostat
- **5** Nanowire Sensor

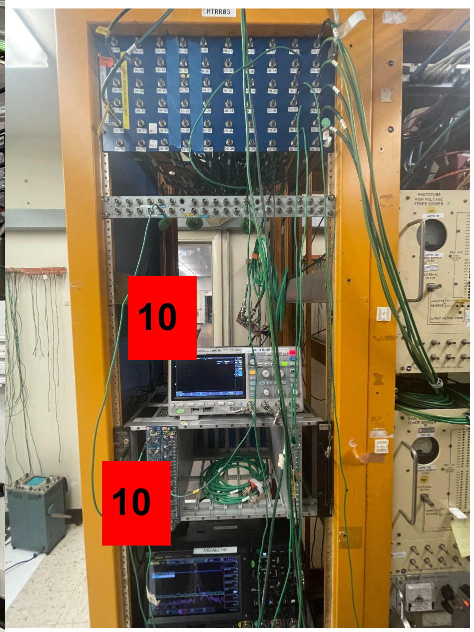




Experiment

6	Vacuum Gauge Controller
7	LNA and Bias Tee box
8	Power Supply
9	Raspberry Pi
10	Oscilloscopes

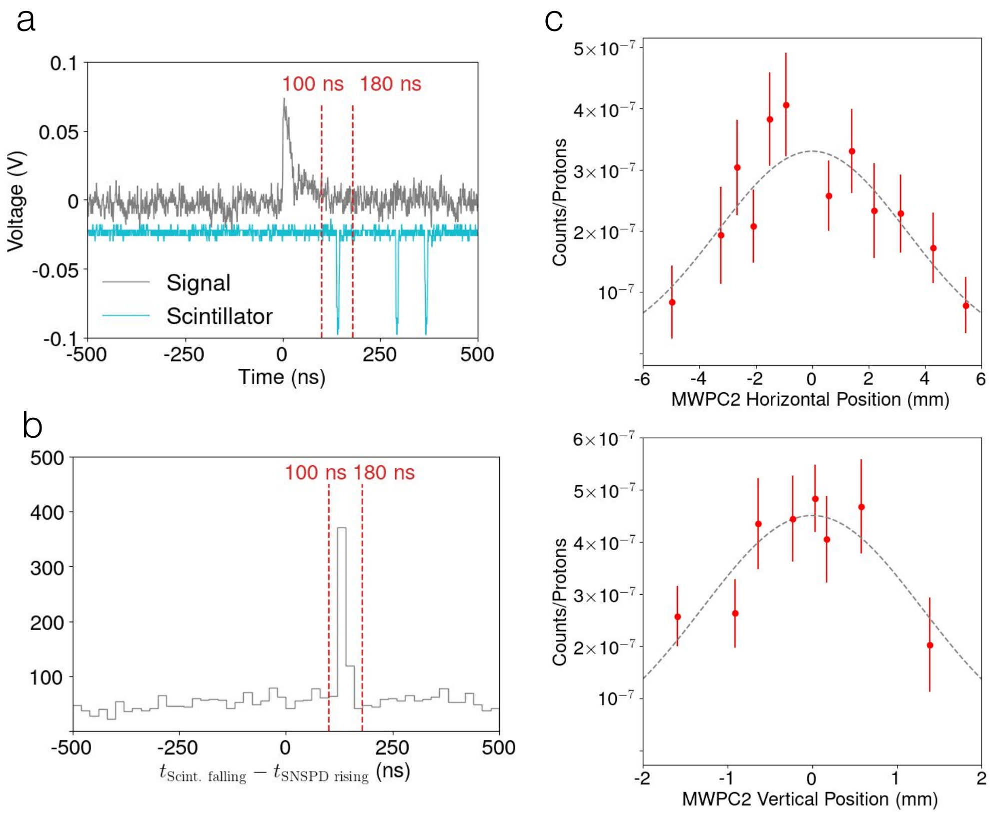




Results — Calibration Runs

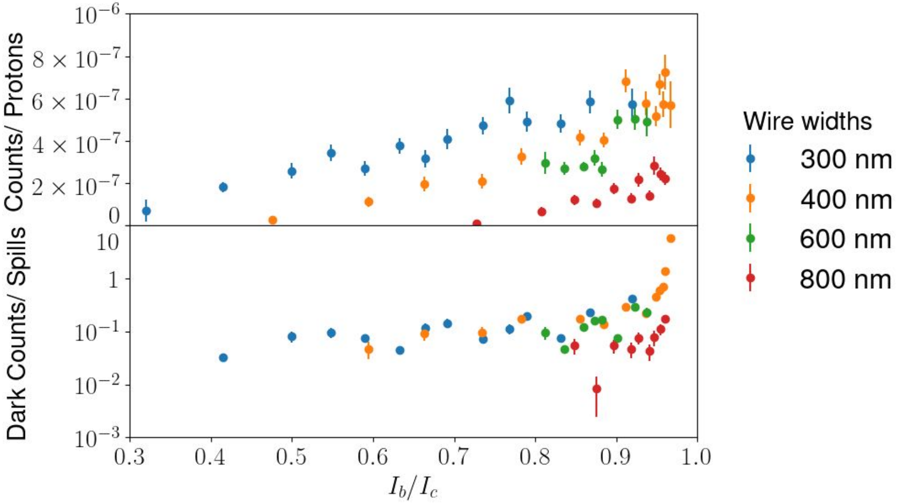
- During the calibration runs,
  a. A ‘Hit’ was identified
  b. Timing differences between the plastic scintillators and the nanowire
  c. Optimal *position* was determined using the MWPC2 and SNSPD (+plastic scintillator). FOM is the hit counts normalized to incident protons to the beam enclosure

- Limitations
  – No motion table access. The position was set by the magnet currents
  – Horizontal position was measured when vertical position was off-center and vice versa
  – No event-by-event coincidence



Results — Relative Efficiencies

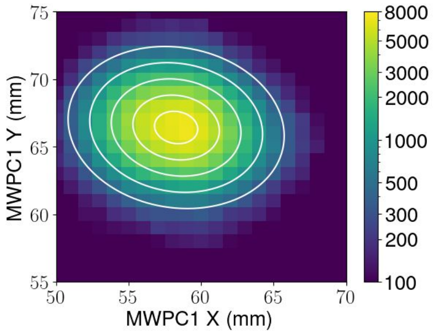
- We performed the bias current (I_b) scan with the nanowire sensors of various widths.
- Triggered on SNSPDs and looked at coincidence window with the plastic scintillators.
- FOM is the hit counts normalized to the incident protons
  - the relative efficiencies.
  - statistical uncertainties only.
- Takeaways
  - First measurements w/ 120 GeV protons
  - Devices w/ smaller wires (~200 nm) will give the best performance and bias operating range

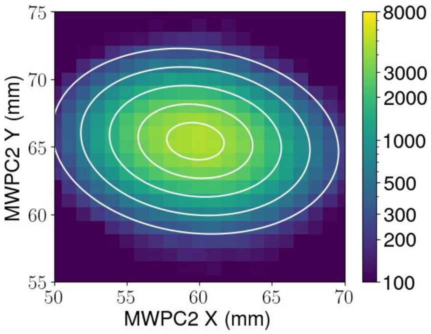


Widths (nm)	300	400	600	800
Critical currents I_c (μA)	12.5	25.2	48	55

Results — Relative Efficiencies

- Beam
  - Typically, 1M proton per spill (maximum) requested and delivered.
  - Fermilab pulsed beam's spill is 4.2s long, and has 1 minute period.
- Acceptance
  - We used MWPCs that has $1/\sqrt{12}$ mm resolution in x and y, but the sampling rate of the device is too low to perform coincidence measurement.
  - The center of the beam was not controlled well enough to measure the absolute efficiency.
  - Unfortunately, MWPC3, closest to our cryostat, didn't work properly.

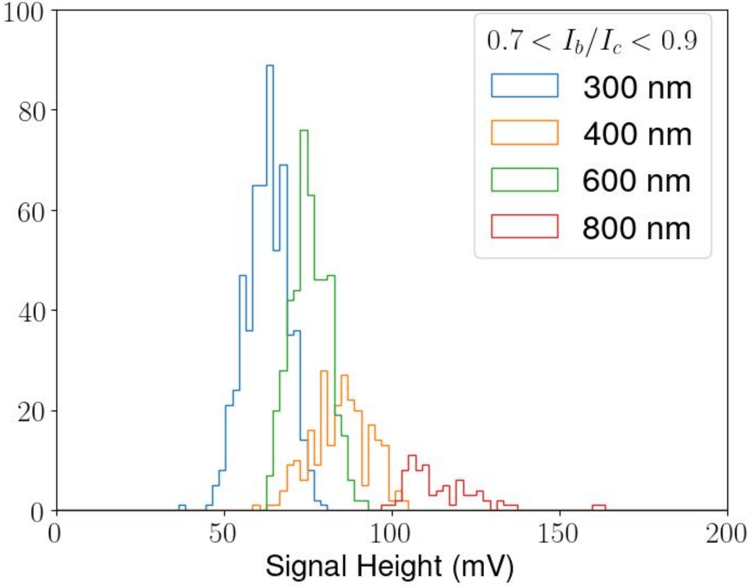


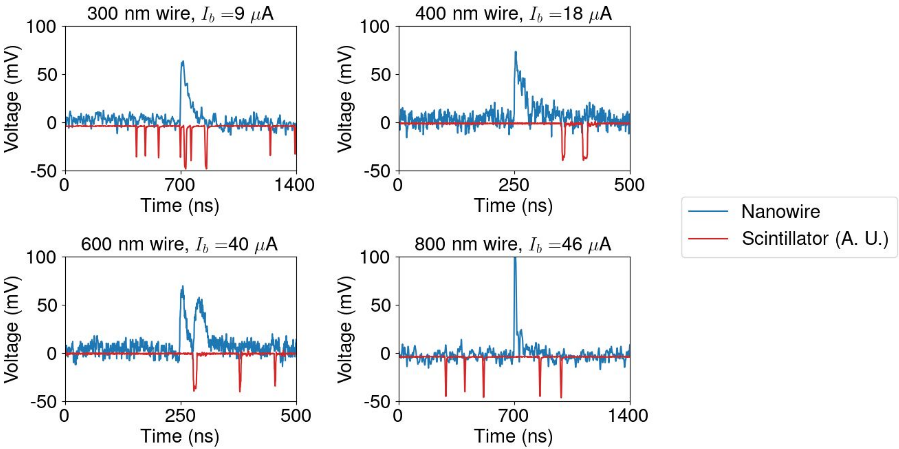


- Active region is 30μmX30μm.
- Beam radius ~ 5.5 mm in X, 4 mm in Y.
- Rate ~ 1.6 Hz during the spill @ center
  ~ 0.5 Hz if off by 5 mm
  ~ 0.013 Hz if off by 10 mm.

Results — Signal Heights

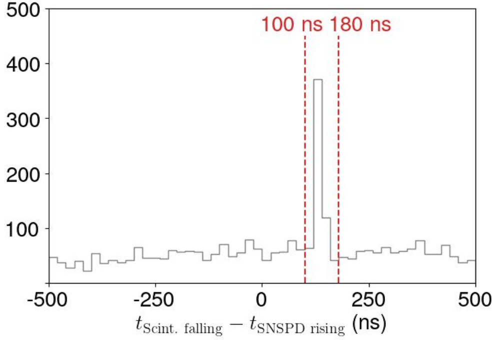
- The signal height depends on the wire size and the bias current.
- Left: histograms of signal heights for the same I_b/I_c range
- Right: An example of waveforms for each nanowire

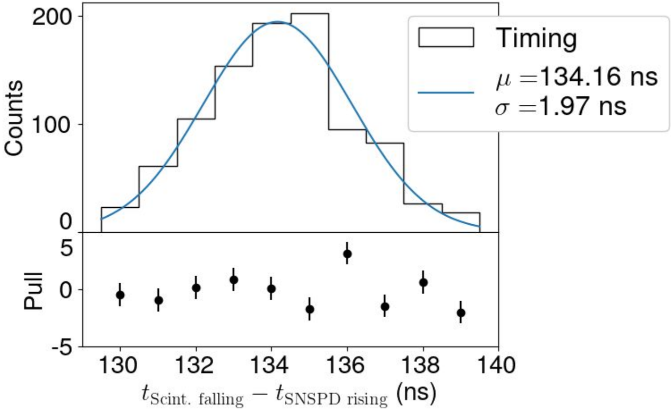


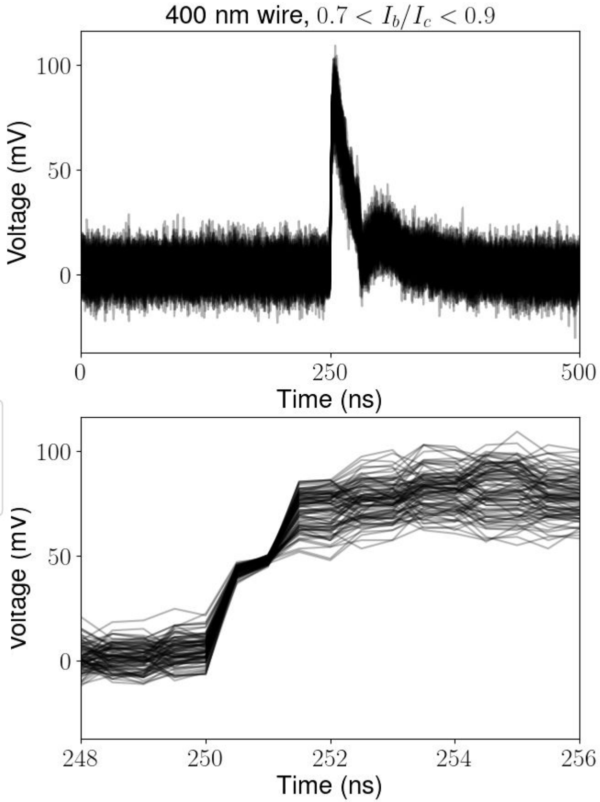


Results — Time Resolutions

- Timing is not the primary purpose of the test but the time scale is consistent with low timing jitter and fast detector response up to the measurement limitation.







Summary and Outlook

- First 120 GeV proton direct detection using the SNSPDs was performed, driven by strong nuclear & particle physics motivations.
- The nanowire is an advanced technology that is supported by the ANL PHY, MSD division, the HYDRA microelectronics co-design project, and the EIC-related generic R&D.
- We are continuing our efforts toward further demonstrations and co-design of the full-size detector.

Argonne NATIONAL LABORATORY

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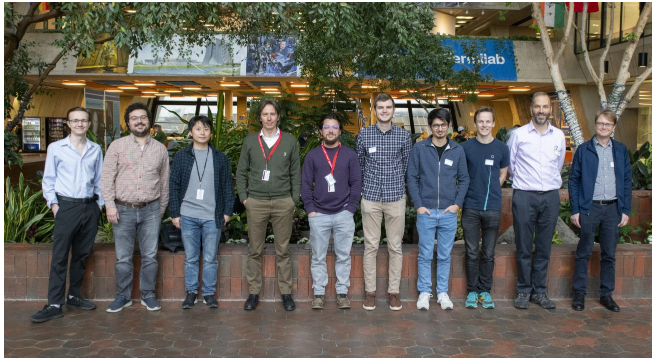
Valentine Novosad

Timothy Draher

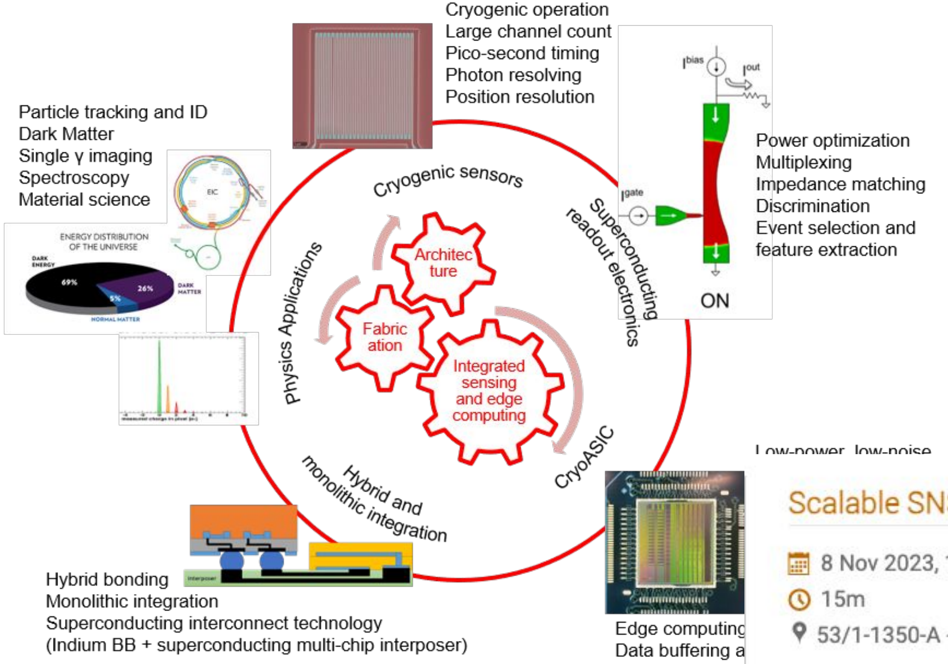
HYDRA Microelectronics Co-design Collaboration



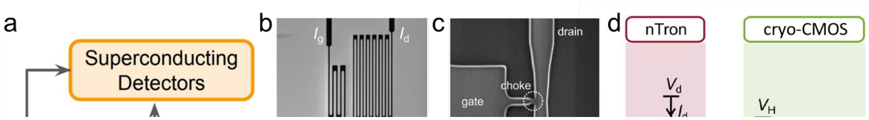
Backup

HYDRA: Hybrid Cryogenic Detector Architectures for Sensing and Edge Computing enabled by new Fabrication Processes (LAB 21-2491).

A microelectronics co-design project



- Timely microelectronics R&D focused on cryogenic sensors and readout
- Project will produce first Cryo-CMOS ASIC for high channel count detectors at the EIC
- Fermilab is developing a cryo-CMOS ASIC architecture
- MIT is leading the development of superconducting electronics
- Argonne is leading the particle detector thrust
- JPL is investigating new interfacing technologies



Scalable SNSPD cryogenic readout

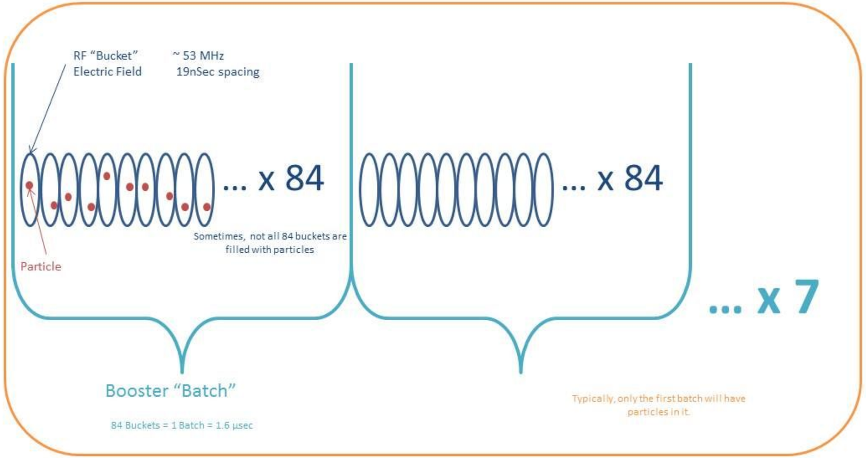
8 Nov 2023, 16:35
15m
53/1-1350-A - Trinity-A (SLAC)

Oral | RDC4: Readout and ... | RDC4

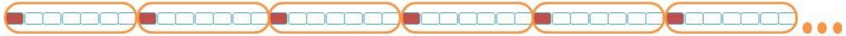
Speaker

Davide Braga (Fermilab)

FTBF Proton Beam Overview

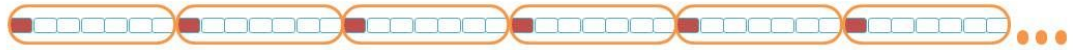


7 Batches = 1 MI Cycle = 11.2 microSec



Beam is resonantly extracted over 375,000 MI Cycles, to create a 4.2 second Spill.

If beam were smoothly extracted, 100 kHz or less would imply 1 particle per MI rotation (1 particle every 11.2 microsec) would occur.
Beam extraction is not smooth, resulting in up to 35% double occupancy per MI rotation



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From https://ftbf.fnal.gov/beam-delivery-path/