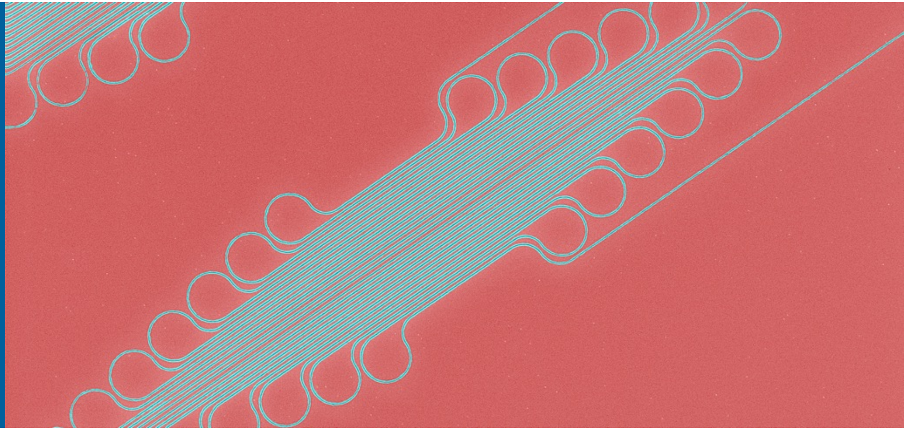
eRD28: SUPERCONDUCTING NANOWIRES FOR THE ELECTRON ION COLLIDER



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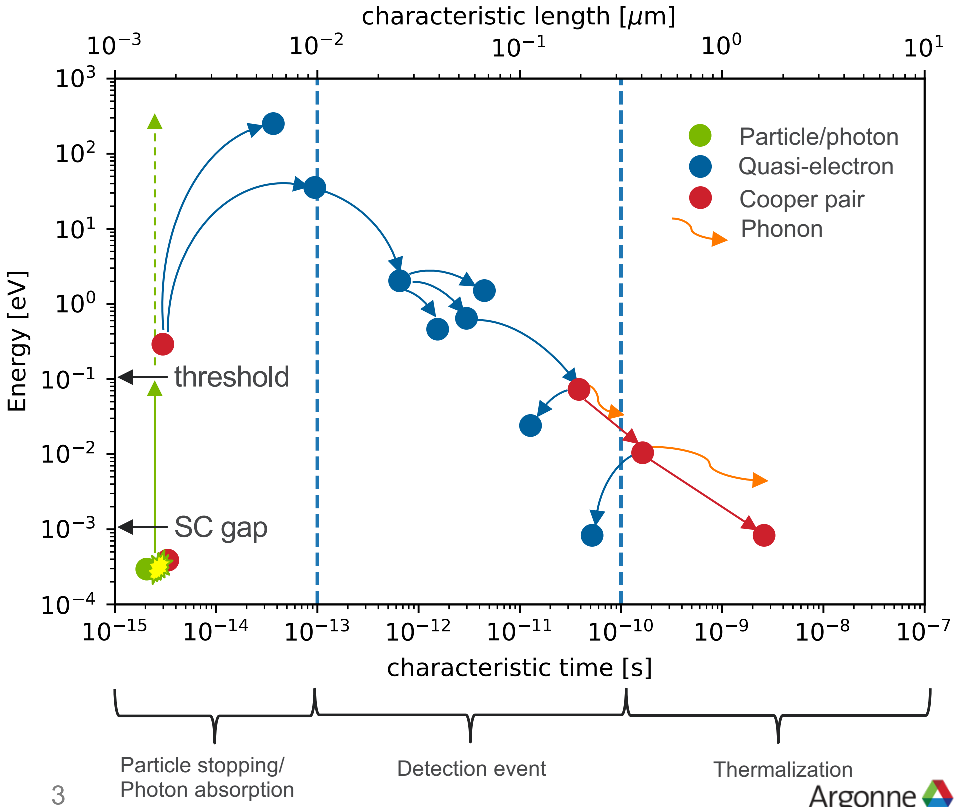
OUTLINE

- Superconducting Nanowire detectors – operation, capabilities
- Superconducting nanowire detectors at EIC – opportunities, goals
- Progress to date – beamline cryogenics integration, sensor design
- Future – eRD28 and beyond

SUPERCONDUCTING NANOWIRE DETECTORS

Principle of operation

- Uses quasi-particle avalanche process inside a current biased superconducting nanowire to detect scattering/absorption of individual quantum excitations
- Much faster and more sensitive than ionization avalanches in semiconductor detectors
- Can be used to detect photons, charged particles (and neutrons, indirectly) [1]



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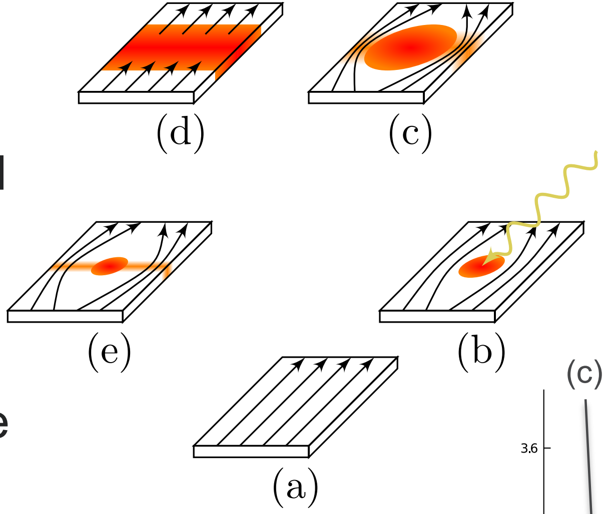
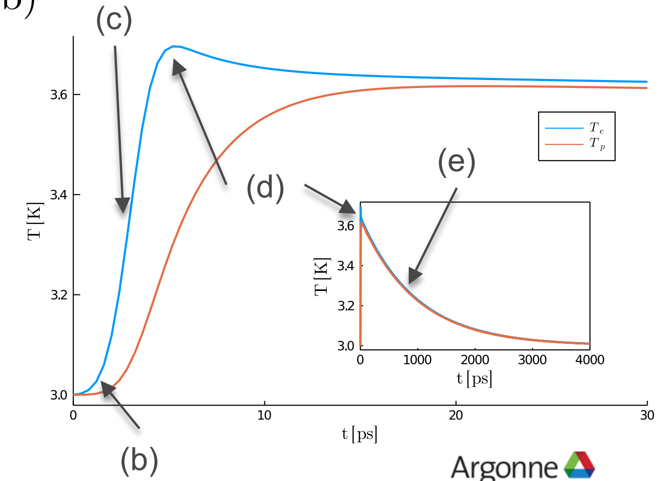




SUPERCONDUCTING NANOWIRE DETECTORS

Capabilities at a glance

- The fastest and most precise "first-gen" quantum detector of individual particles
  - Energy thresholds as low as ~100 meV
  - Timing jitter easily 20-40 ps (current record at 2.7 ps [2])
  - Reset times can be as low as 5-10 ns
  - Conveniently operates at roughly LHe temperatures

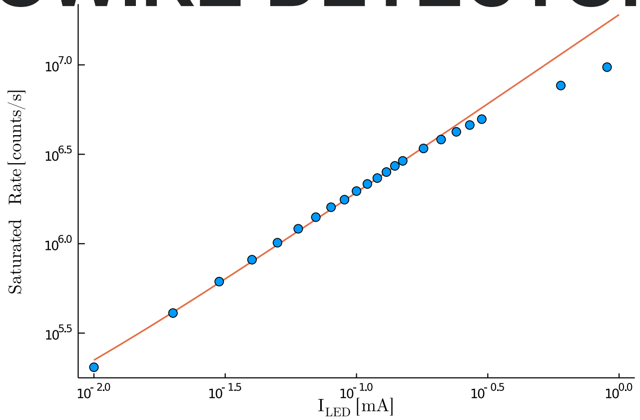
Parameter	SOA 2020	Goal by 2025
Efficiency	98% @ 1550nm	>80 % @10μm
Energy Threshold	0.125 eV (10 μm)	12.5 meV (100 μm)
Timing Jitter	2.7 ps	$<$ 1ps
Active Area	1 mm^2	100 cm^2
Max Count Rate	1.2 Gcps	100 Gcps
Pixel Count	1 kilopixel	16 megapixel
Operating Temperature	4.3K	25 K

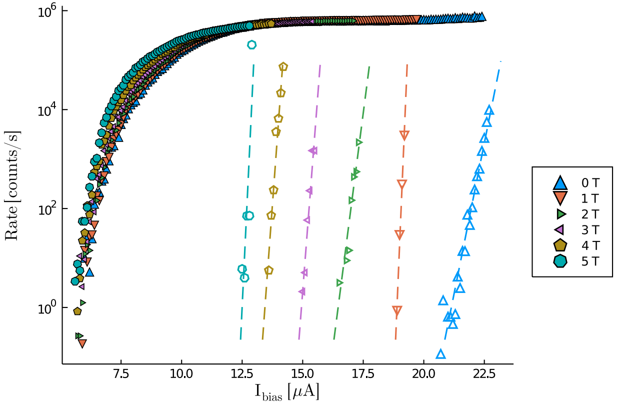
Snowmass2021 SNSPD LOI (2020)

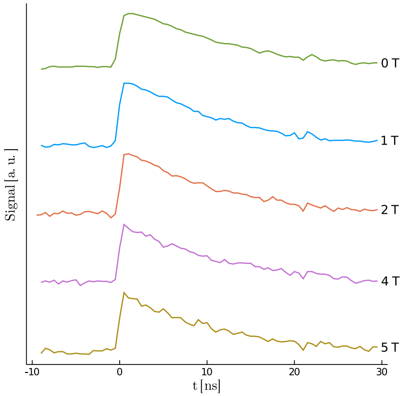
SUPERCONDUCTING NANOWIRE DETECTORS

Capabilities at a glance, continued

- Operates in magnetic fields of >5 T [3]
- Zero dark counts
- Can be made rad hard





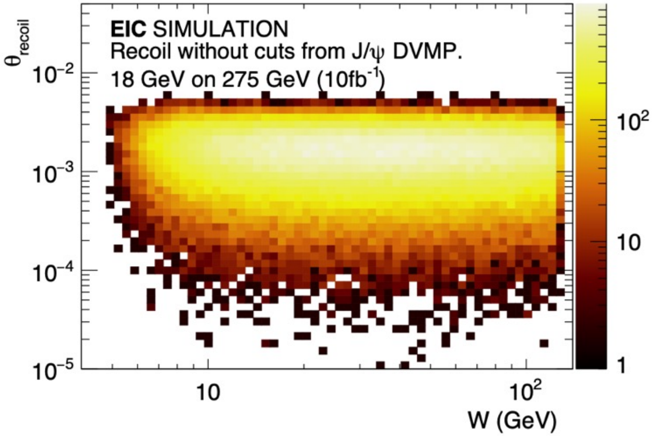


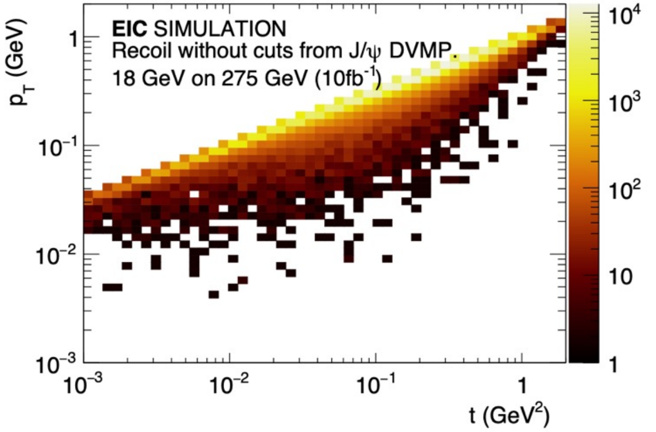
SUPERCONDUCTING NANOWIRE DETECTORS AT EIC

Motivation

- Good far-forward recoil acceptance critical for tagging the proton/nucleus in exclusive electro- and photo-production J/ψ and Υ, especially at threshold
  - Conventional detectors of this type covered by eRD24
- High position resolution, radiation hardness necessary for the Compton polarimeter
  - See also eRD26
- Coverage of currently empty regions (cold bore of superconducting magnets, front of ZDC, etc.) potentially enhances performance of detector(s)

- Goal of eRD28: Demonstrate that these are a possibility, not necessarily build a complete system

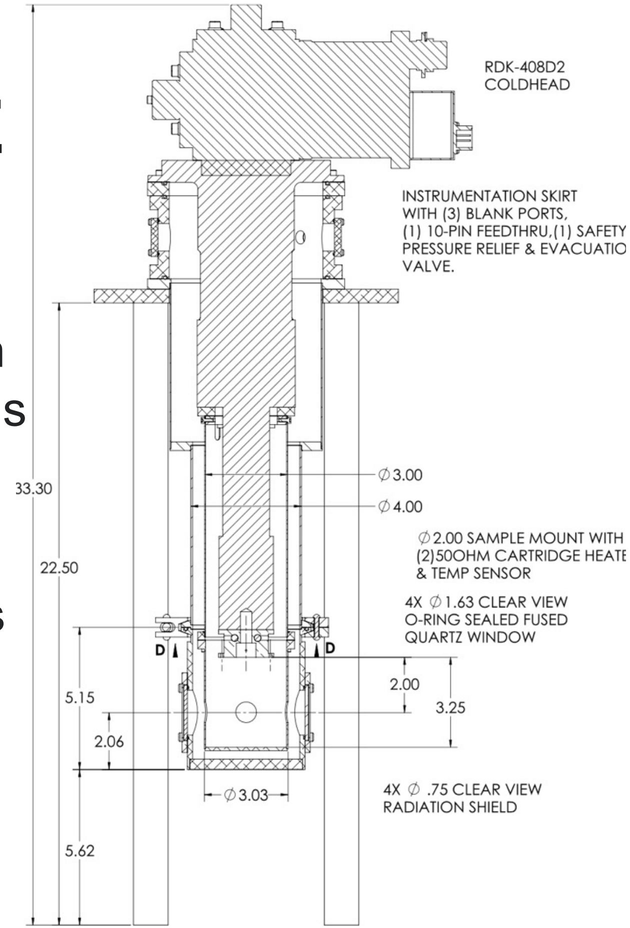


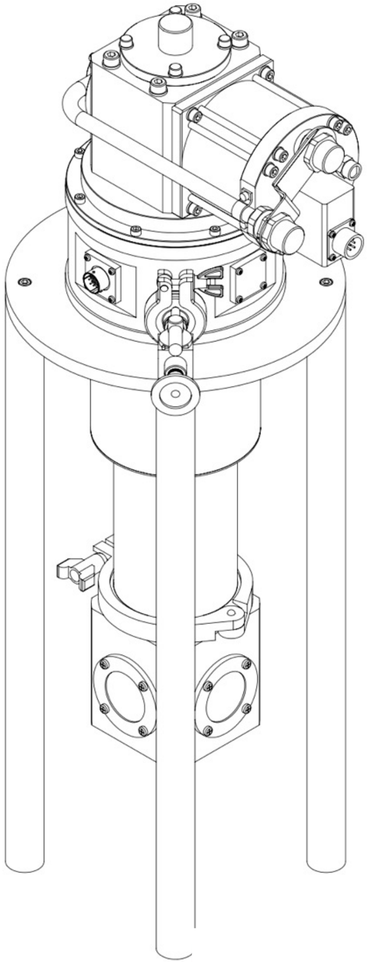


PROGRESS TO DATE

Portable beamline cryostat

- Cryostat capable of dry (no liquid helium) operation, independent on beamline facility cryogenic systems
  - Base temperature of 3 K
- 8 RF channels (can add more)
- 26 low frequency AC/DC channels
- Initial testing currently in progress





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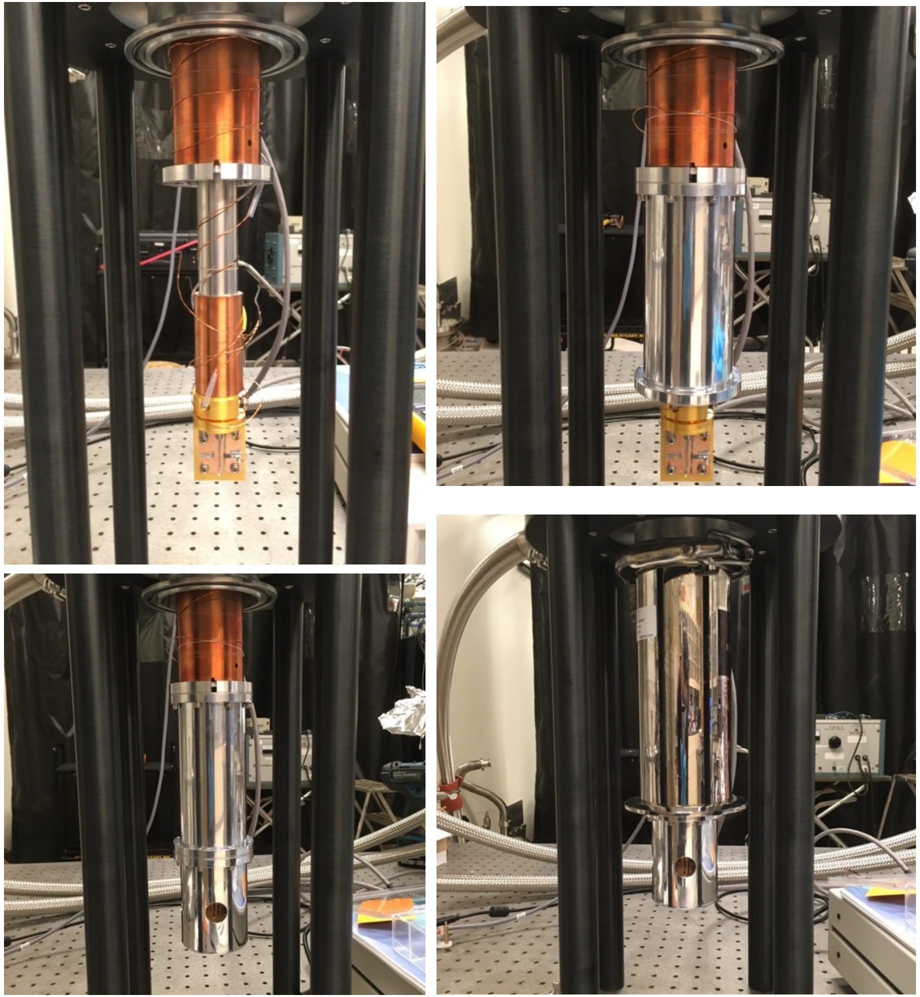
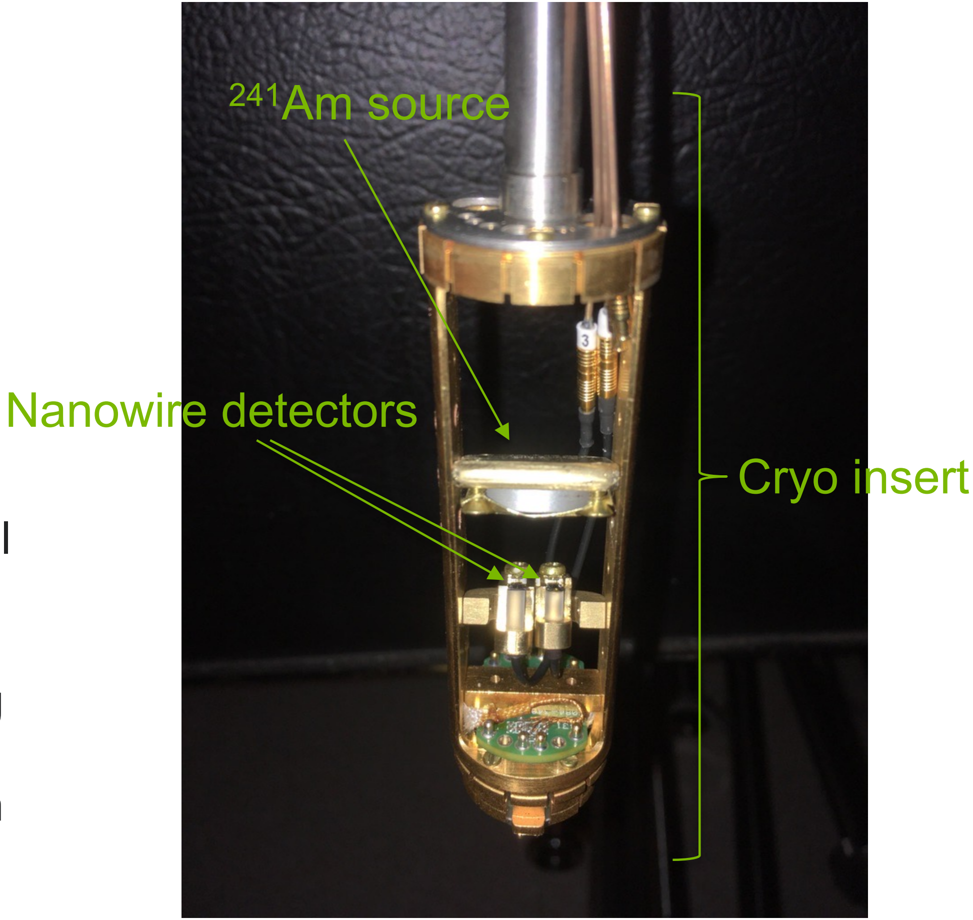


PROGRESS TO DATE

Sensor design

- Experimental work and device fabrication on hold due to COVID-19
  - Project restart currently ongoing
  - Device patterning (lipography and etching) back online
  - Thin film deposition being worked on
  - Cryogenic device testbed operational as of this week

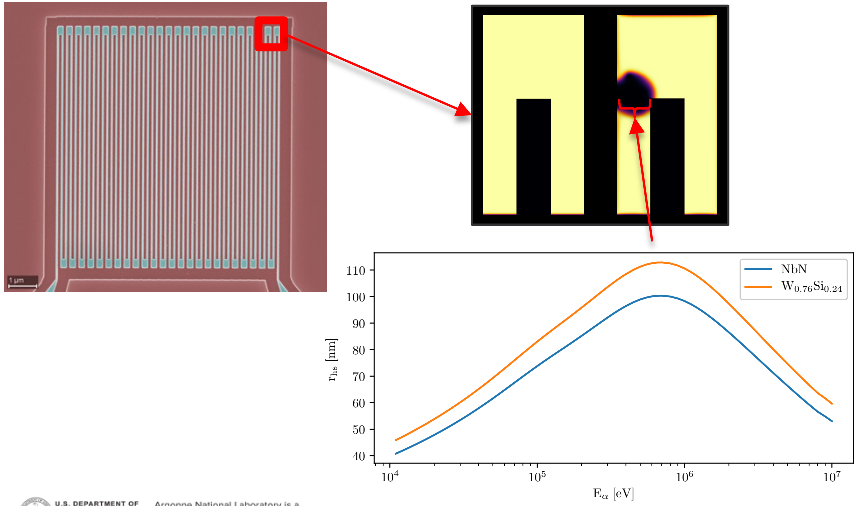
- Detailed simulations of particle stopping inside sensor stack
- Development of open-source simulation software [4] to aid future detector development



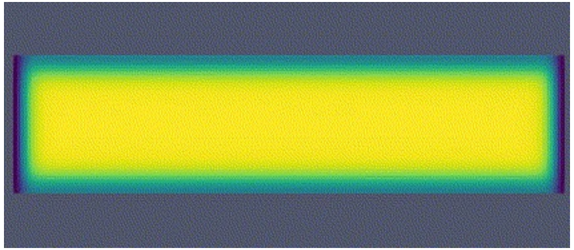
PROGRESS TO DATE

Sensor design

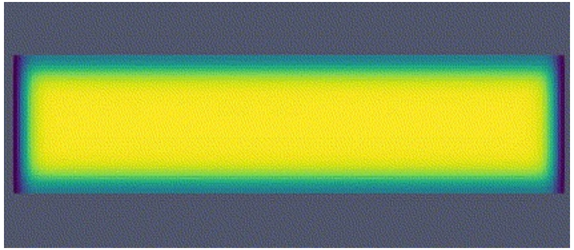
- Development of open-source simulation software [4] to aid future detector development
  - Massively parallel, multi-XPU
  - High-level interface
  - Possibility of interactive use
  - Potential for tighter integration with EIC simulations
  - Useful also outside of nanowire detector simulations



$E/(C_e * t_{e\text{-}p} * \xi^3) = 20$ (~1 eV photon)



Cooper pair density

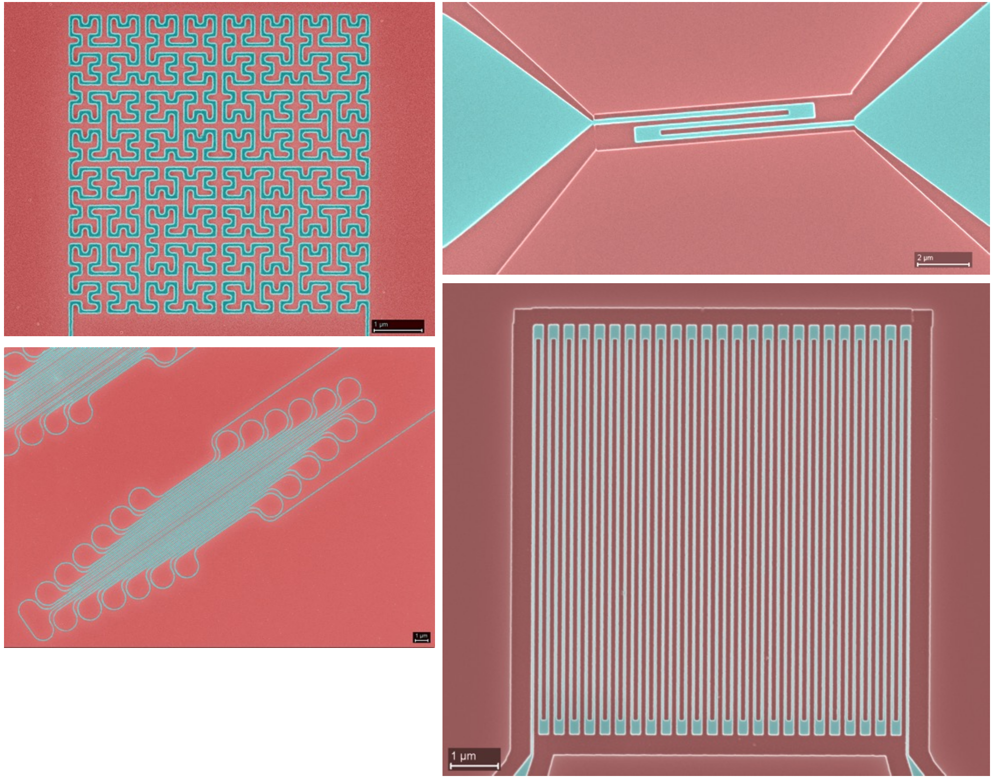


$E/(C_e * t_{e\text{-}p} * \xi^3) = 200$ (~1 MeV α)

FUTURE

Sensor design and testing

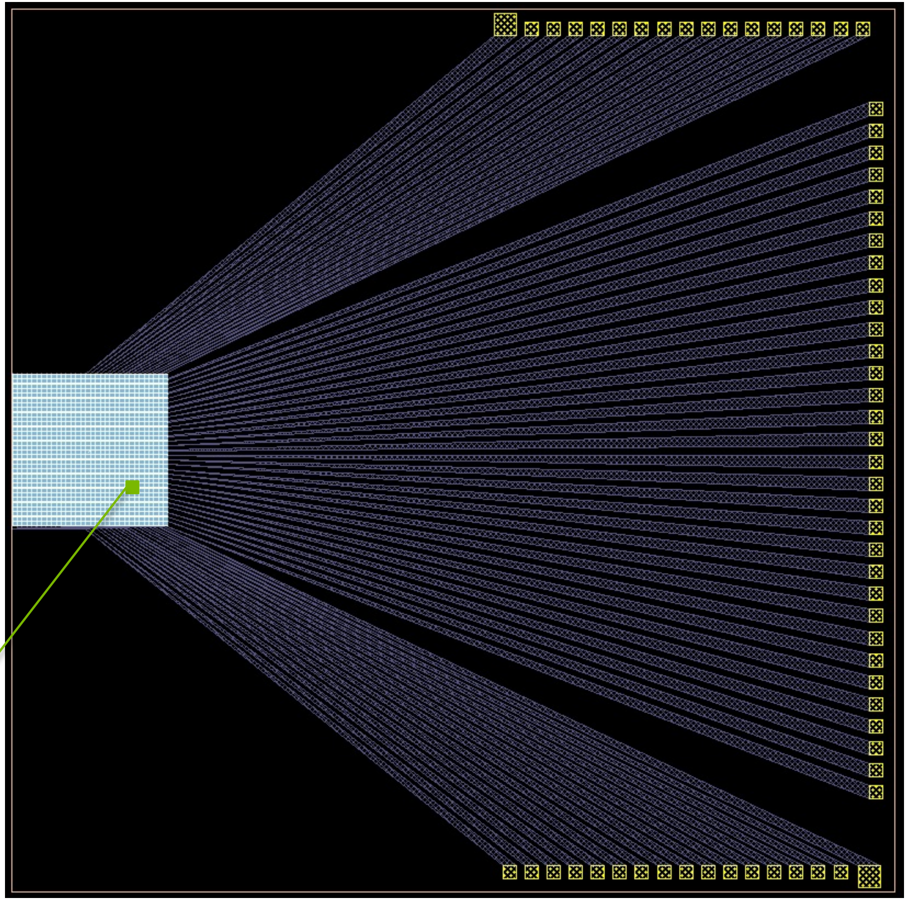
- Design individual pixels for optimal performance for particle detection, beamline conditions:
- High magnetic field
  – Done
- High count rate
  – Can be increased by implementation of sub-pixels, larger wires,…
- Larger single-pixel area
  – Easier for particle detection because of wider wires
- Radiation hardness
  – Currently in progress, outlook positive
- Discuss and cater to needs of other auxiliary detectors

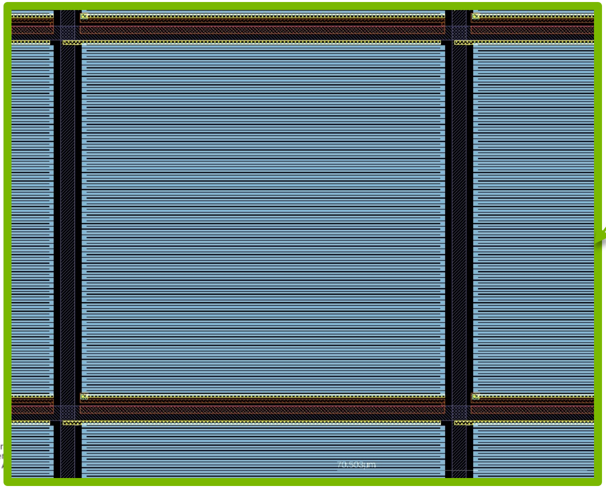


FUTURE

Detector design

- Design a multi-pixel, multiplexed readout array
- For purposes of eRD28, only small number of channels (8-16)
- Perform detector tests with protons at Fermilab test beam

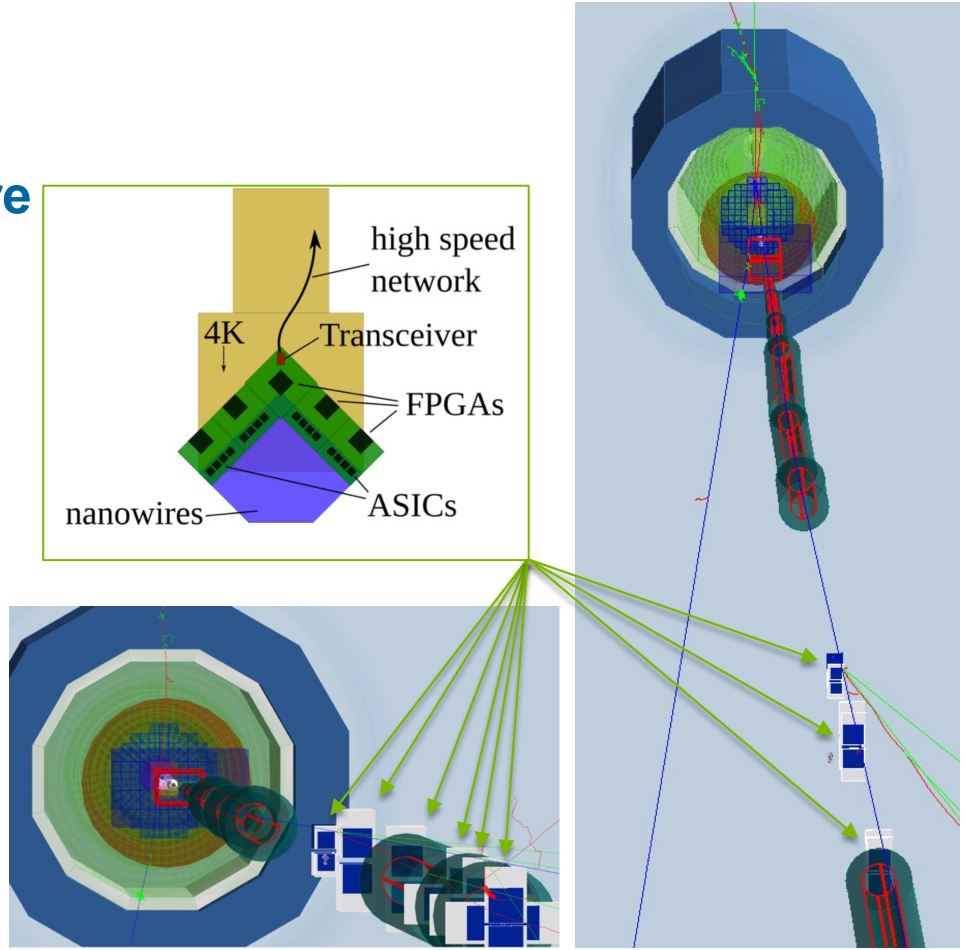




FUTURE

Beyond current eRD28 - hardware

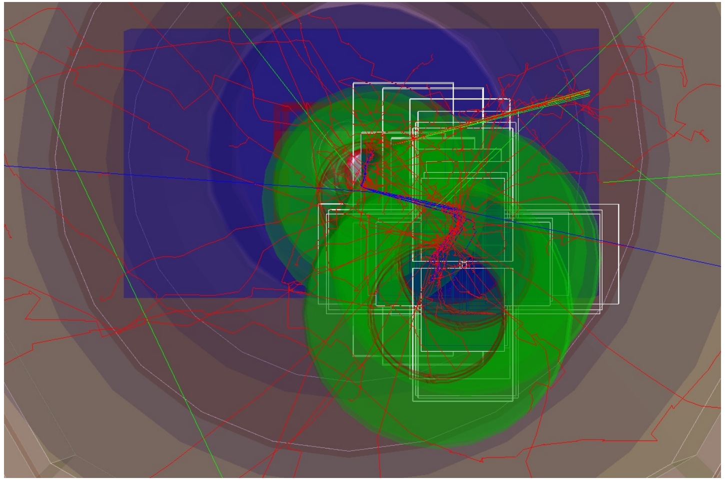
- Design and construct a Roman Pot-style superconducting nanowire detector in the (extreme) far forward region of the hadron beam
  - Truly zero-edge (~1 um from chip edge) sensor design, field and cryo-tolerance allow for greater flexibility in positioning along the accelerator lattice
- Explore possibilities of integration in other parts of EIC
  - Tracking inside the cold bore of the superconducting magnets
  - Neutral particle tracker in front of ZDC

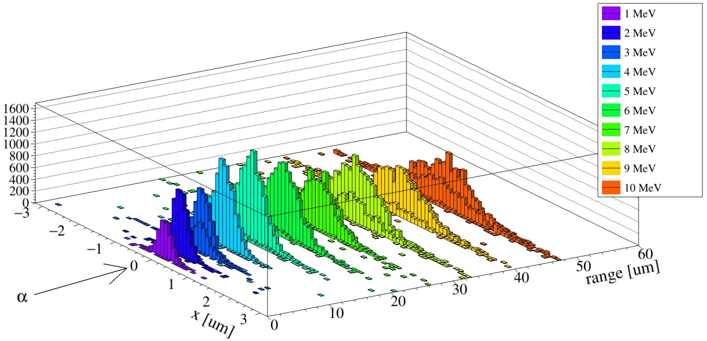


FUTURE

Beyond current eRD28 - Software

- Continue development of software for simulation of sensor response in close collaborations with detector simulation developers
- Allows for optimization of parts of the detector at a much lower level than with other technologies





Physics requirements → Detector simulation → Sensor requirements → Sensor simulation → Fabrication requirements → Fabrication process → Finalized detector

THANK YOU FOR YOUR ATTENTION!

REFERENCES

- [1] Polakovic, T., et al. "Unconventional applications of superconducting nanowire single photon detectors." *Nanomaterials* 10.6 (2020): 1198.
- [2] Korzh, B., et al. "Demonstration of sub-3 ps temporal resolution with a superconducting nanowire single-photon detector." *Nature Photonics* 14.4 (2020): 250-255.
- [3] Polakovic, T., et al. "Superconducting nanowires as high-rate photon detectors in strong magnetic fields." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 959 (2020): 163543.
- [4] ”FastWires: A library for numerical simulations of superconducting nanowires.” https://eicweb.phy.anl.gov/nanowire/simulations/fastwires