Fermilab

FERMI NATIONAL ACCELERATOR LABORATORY

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High Energy Particle Detection with Large Area Superconducting Microwire Array

Cristián Peña et al.

U.S. DEPARTMENT of ENERGY

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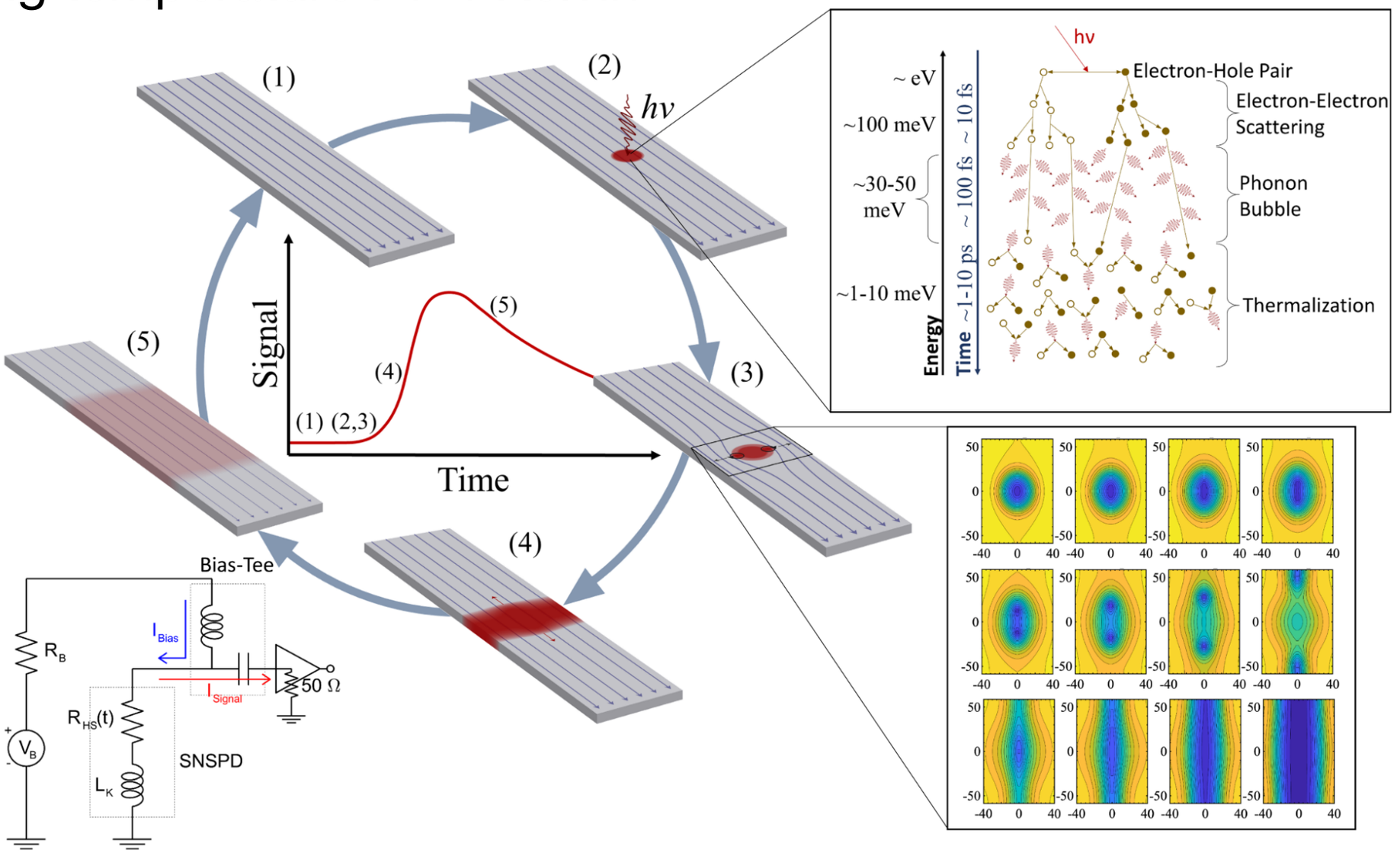
SNSPD Detection

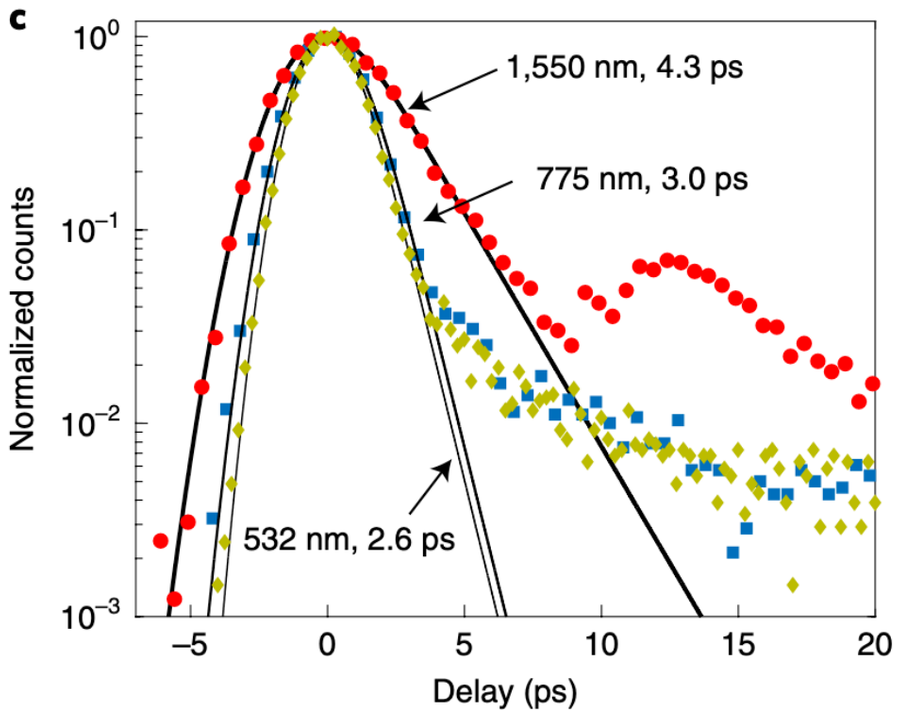
Quantum Sensors: superconducting nanowire single photon detector

- Single photon (heat) triggers detector out of superconductor state
- Resistance quickly (ps) jumps to few kΩ → detector current into readout
- Highest performance single-photon detector, from UV to mid-infrared
- Operating temperature : 1-4 Kelvin



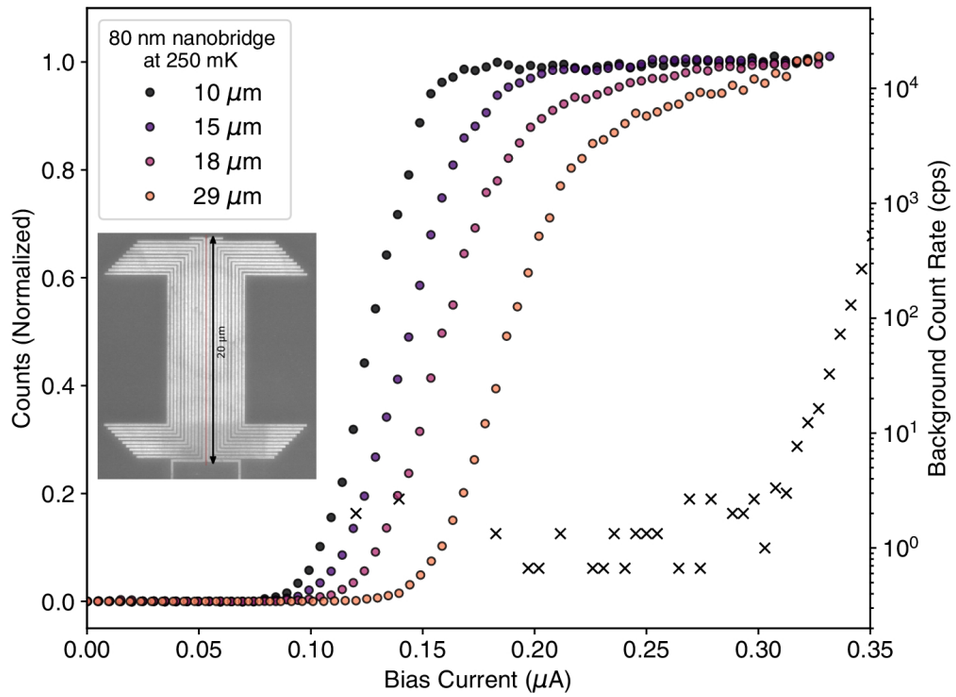
Current SNSPD Best Metrics

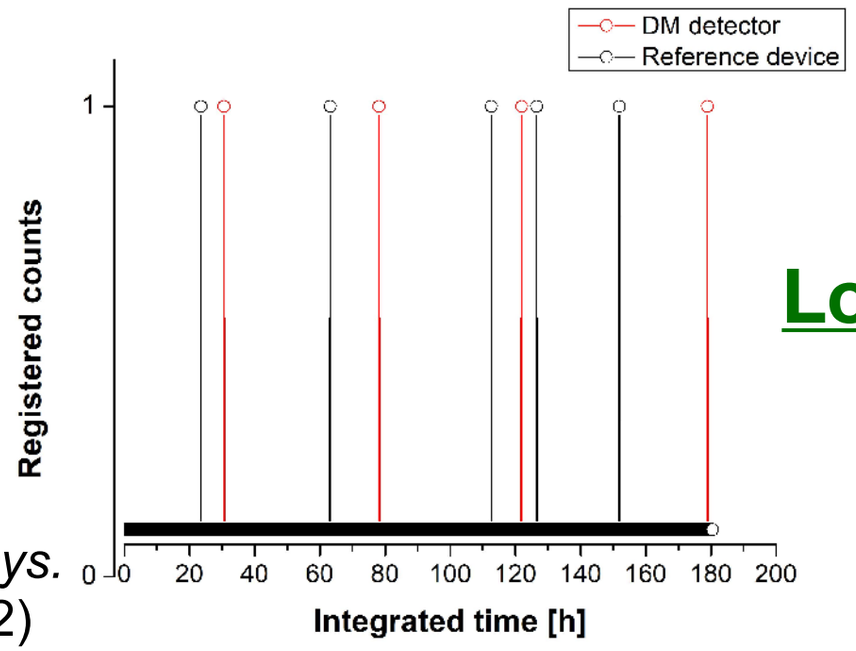
ps-level time resolution



Korzh et al, *Nature Photonics* (2020)

Single photon sensitivity down to 0.04 eV



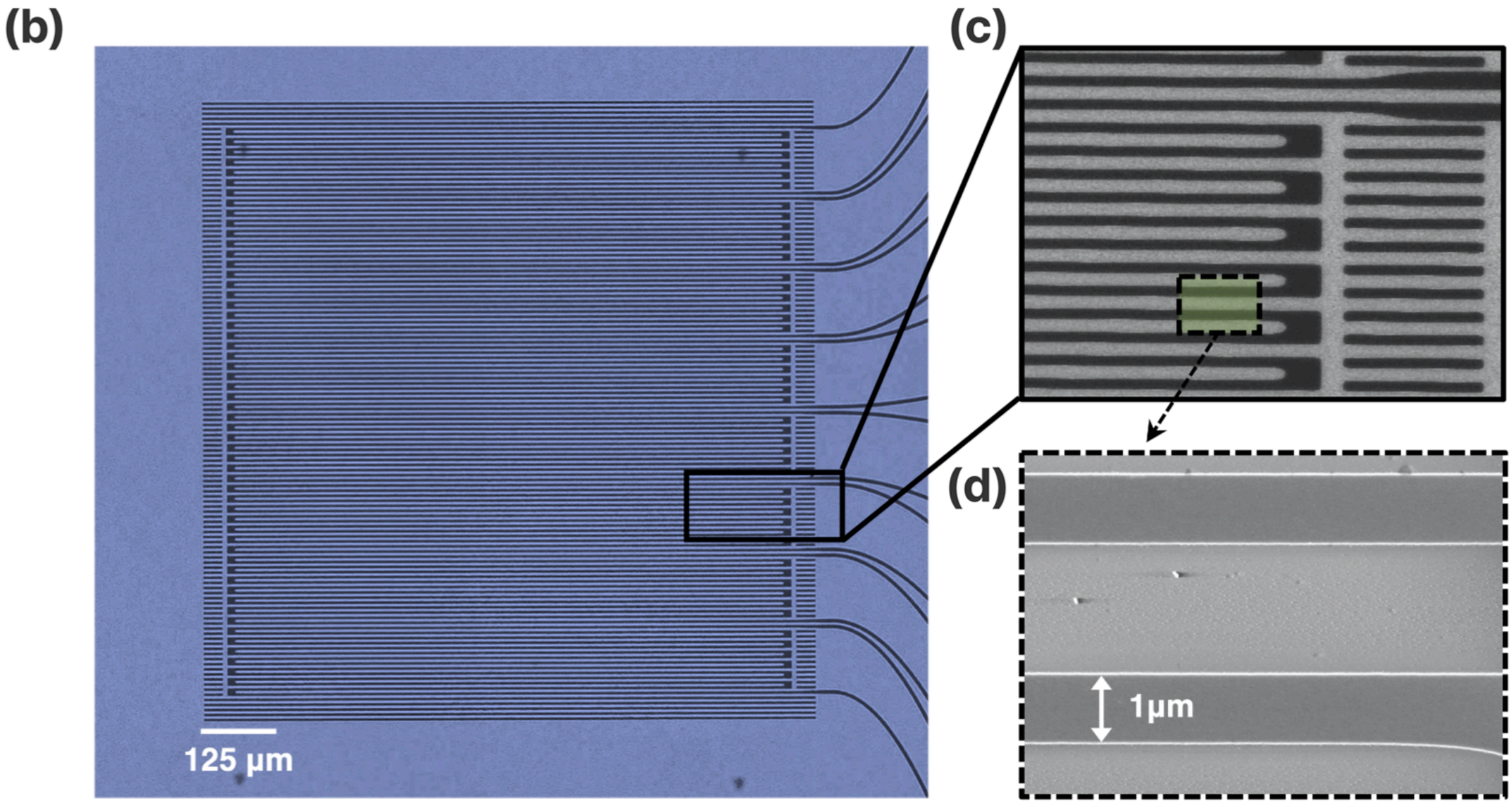


Chiles et al, *Phys. Rev. Lett.* (2022)

Low dark count ~6e-6 Hz

Towards Large Areas (micro wires)

- Traditionally used in QIS for single photon detection
- Large area (mm^2) now possible —
- **enables HEP application** (DM detection)

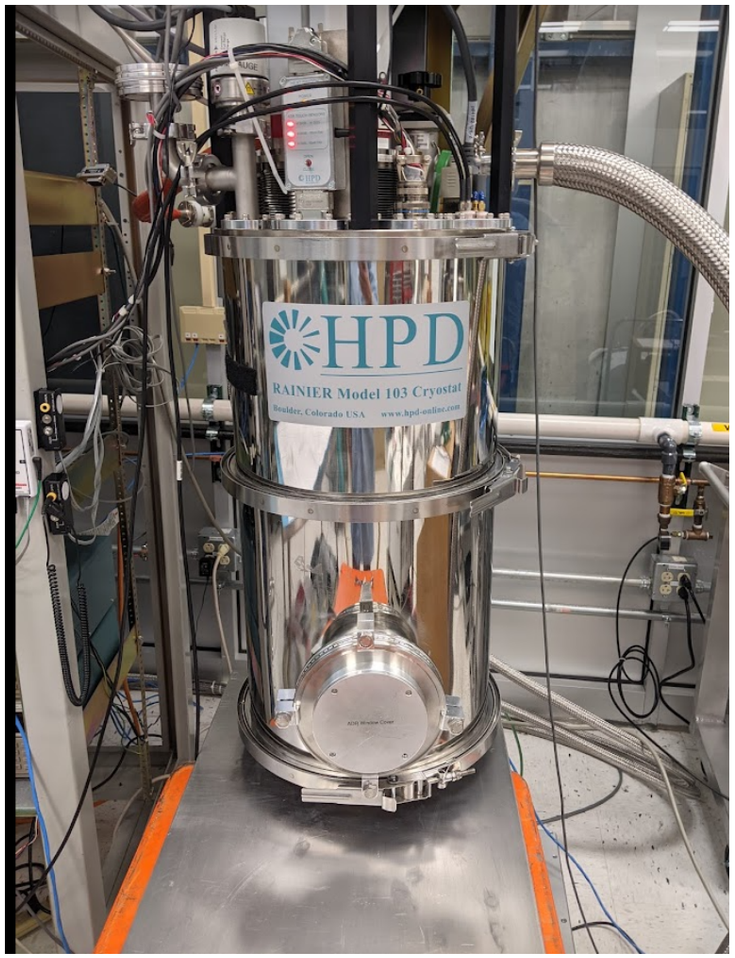


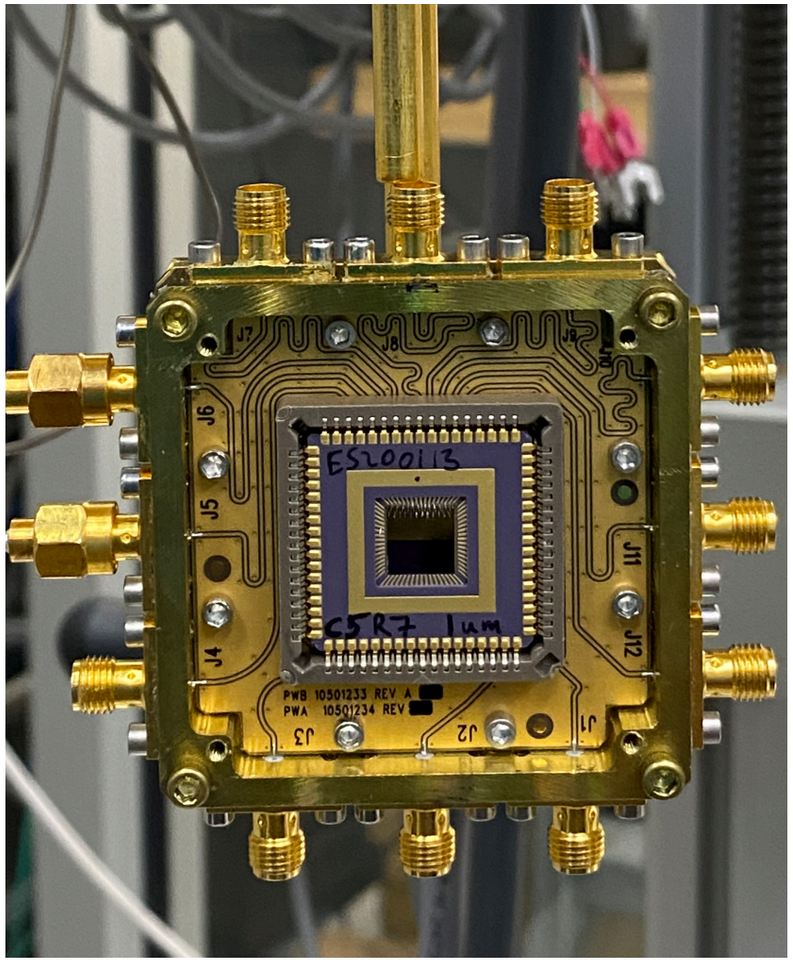
Unique Testing Capabilities at Fermilab

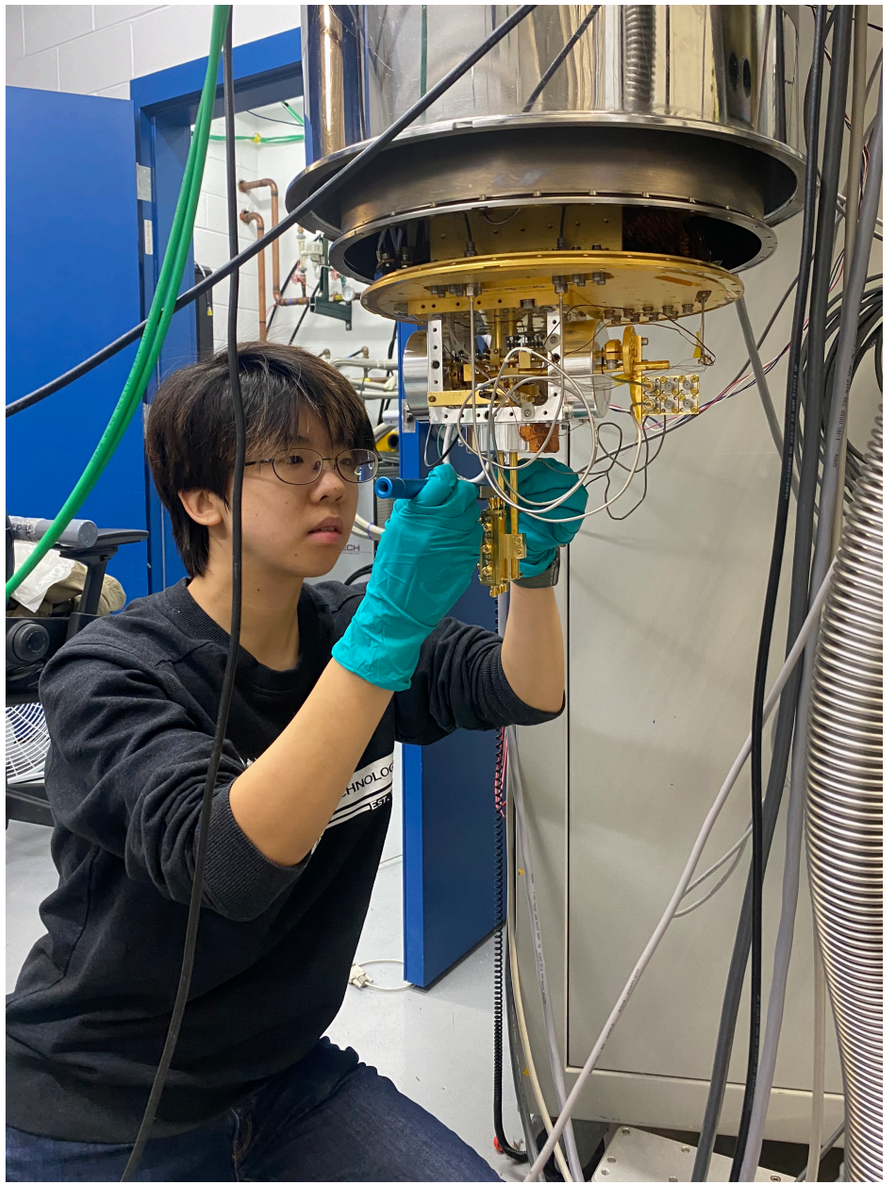
Christina Wang
New Fermilab
Lederman Fellow

Unique infrastructure to test new SNSPDs

- Absolute efficiency characterization
- Dark count rate dependence on T
- Cosmic ray response
- New underground facilities

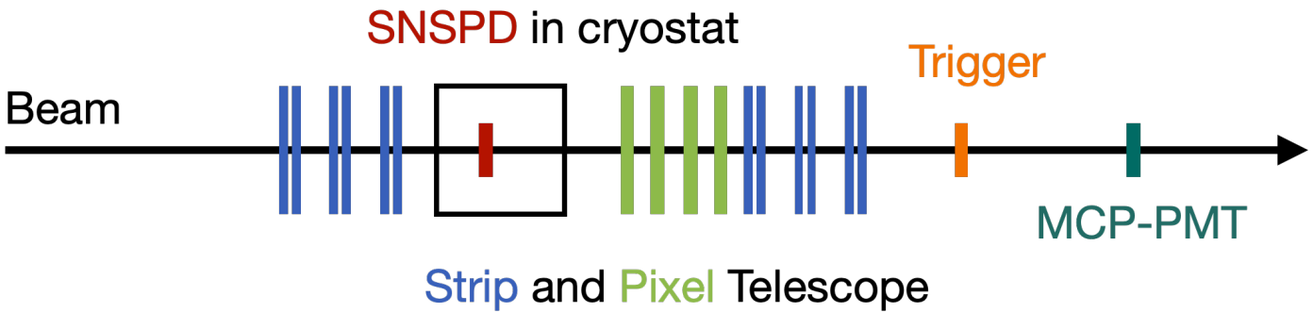


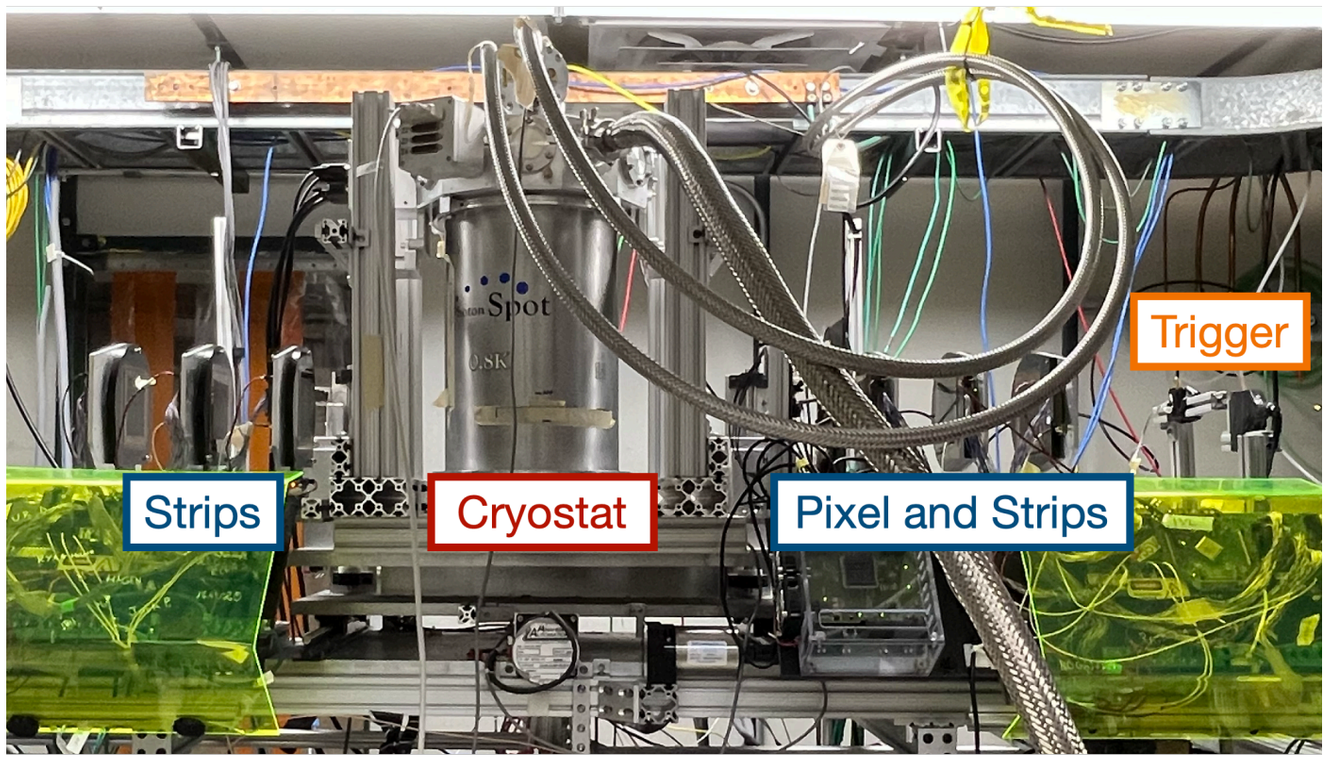




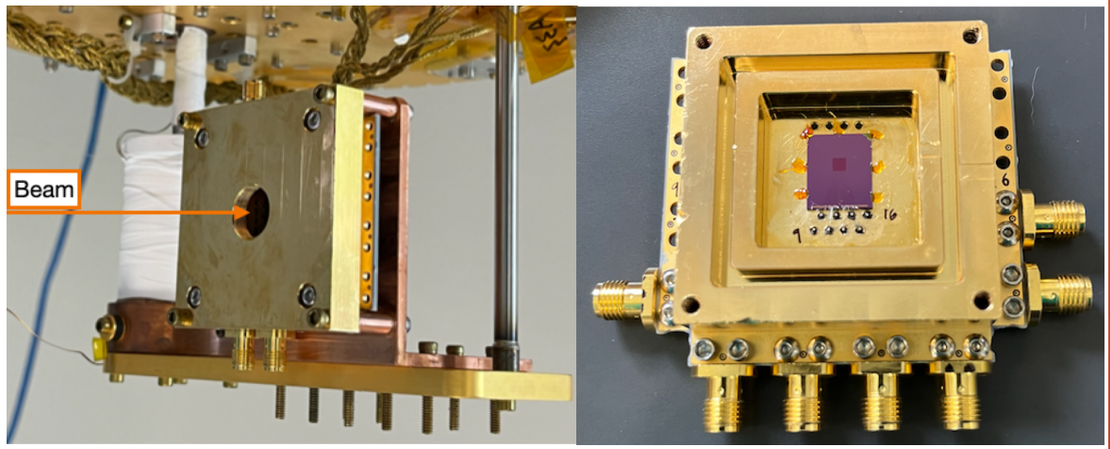
Superconducting Nanowire Single ~~Photon~~ Detector (SNSPD)

Particle





- New R&D program for SNSPD to detect high energy particle with the Fermilab Test Beam Facility
- **First test beam** to detect 120 GeV proton and 8 GeV electrons and pions with **large-area** (2×2 mm^2) **multi-pixel** (8-pixel) SNSPD



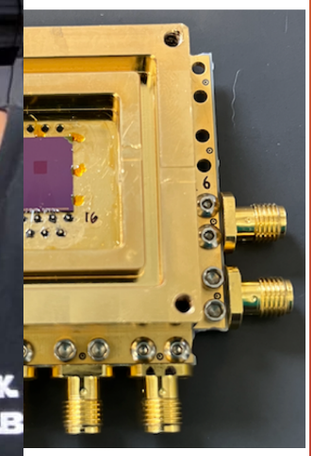
New thrust towards sub-eV charged particle tracking with picosecond level time resolution

Superconducting Nanowire Single ~~Photon~~ Detector (SNSPD)

Particle

PD to
with the

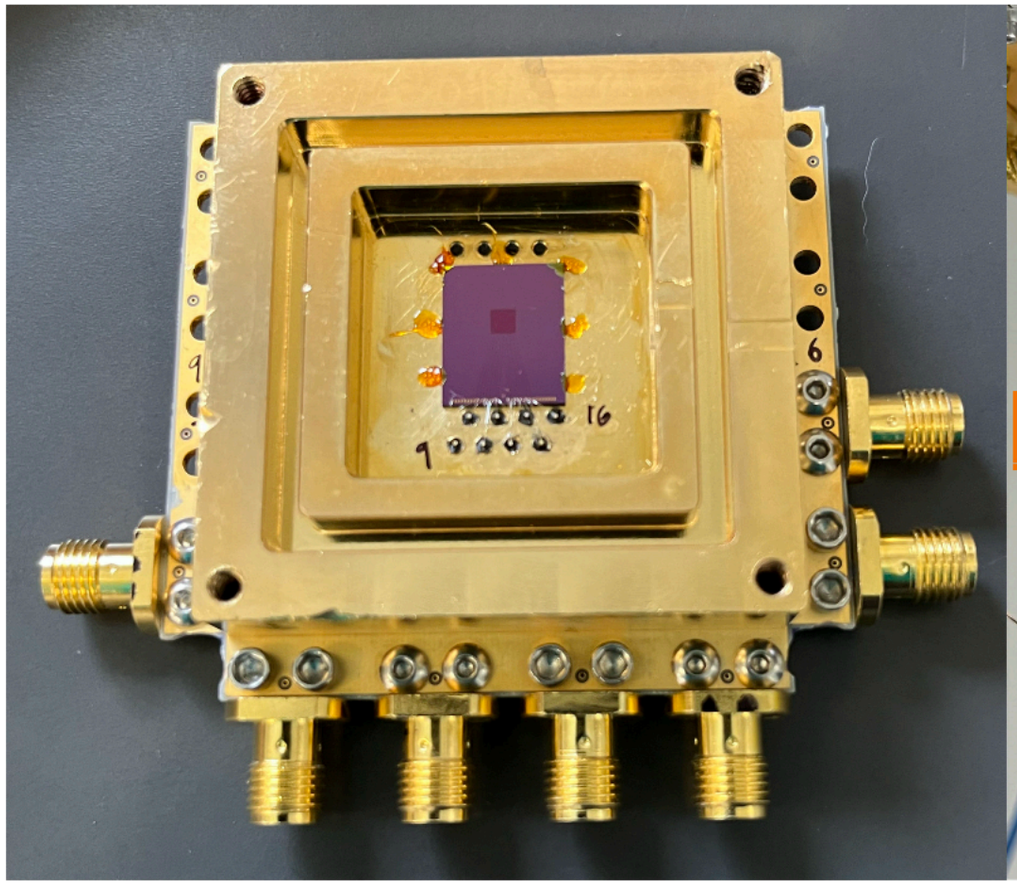
20 GeV
and
mm²)

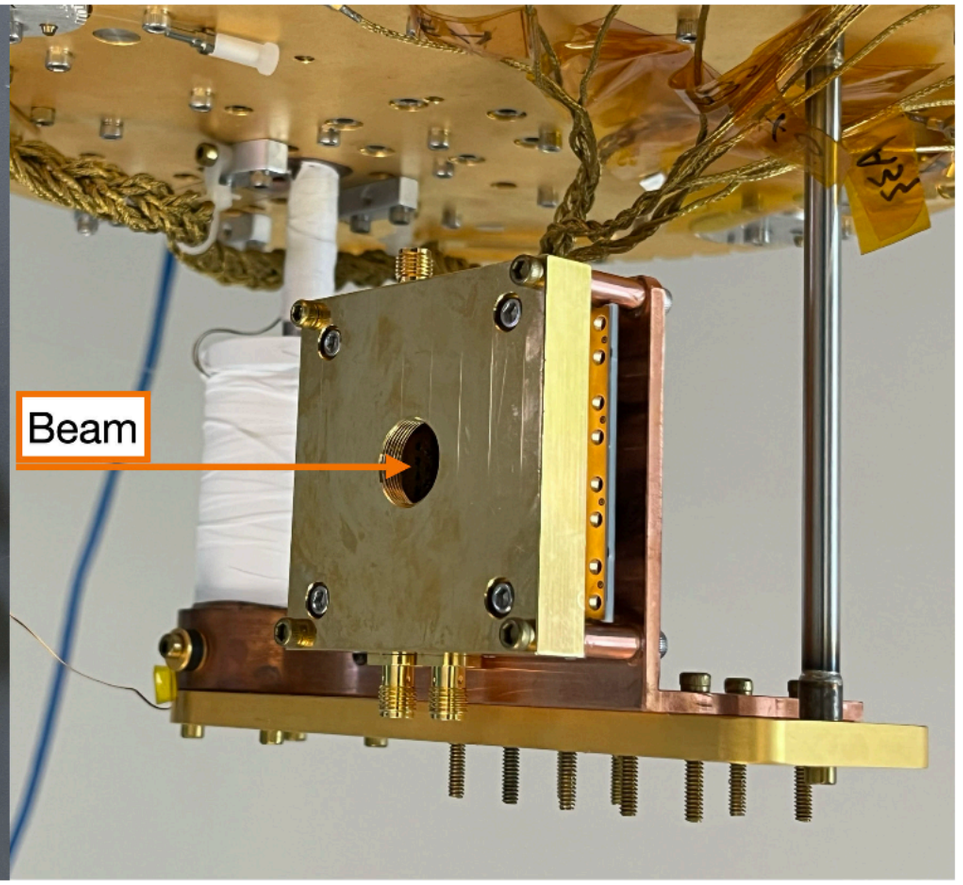


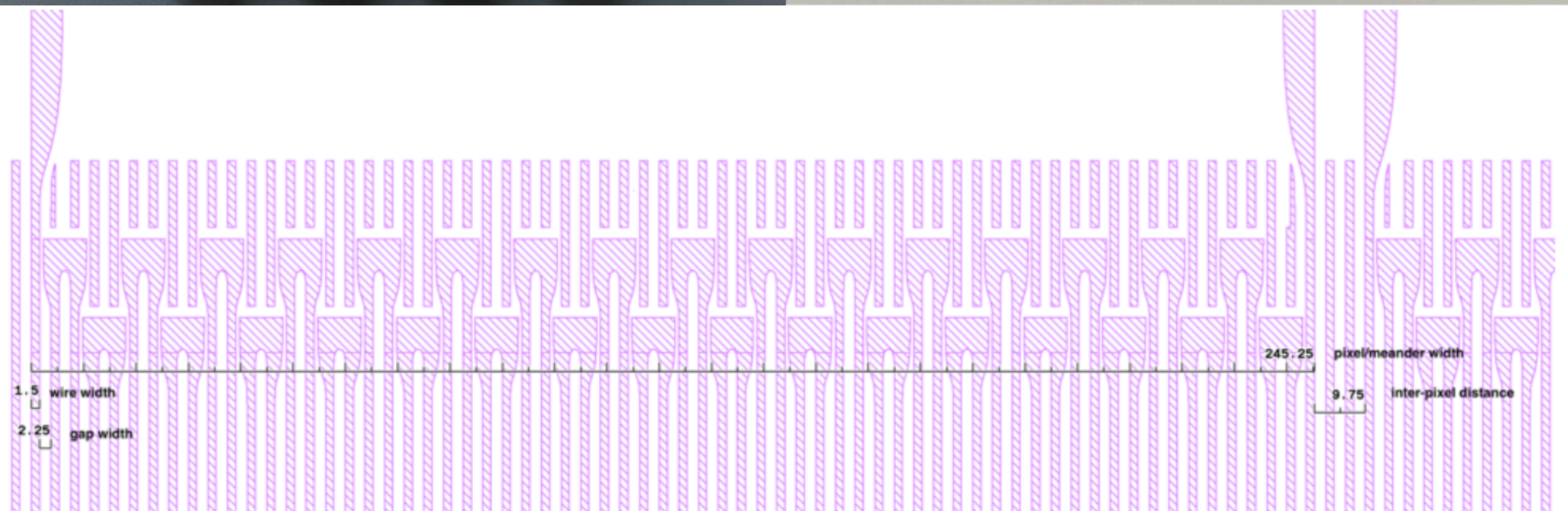
New **cle tracking with picosecond level time resolution**

SNSPD Under Testing

- WSi: 1.5μm, 40% fill factor, T_c = 2.8 K; pixel size is 0.25x2 mm²

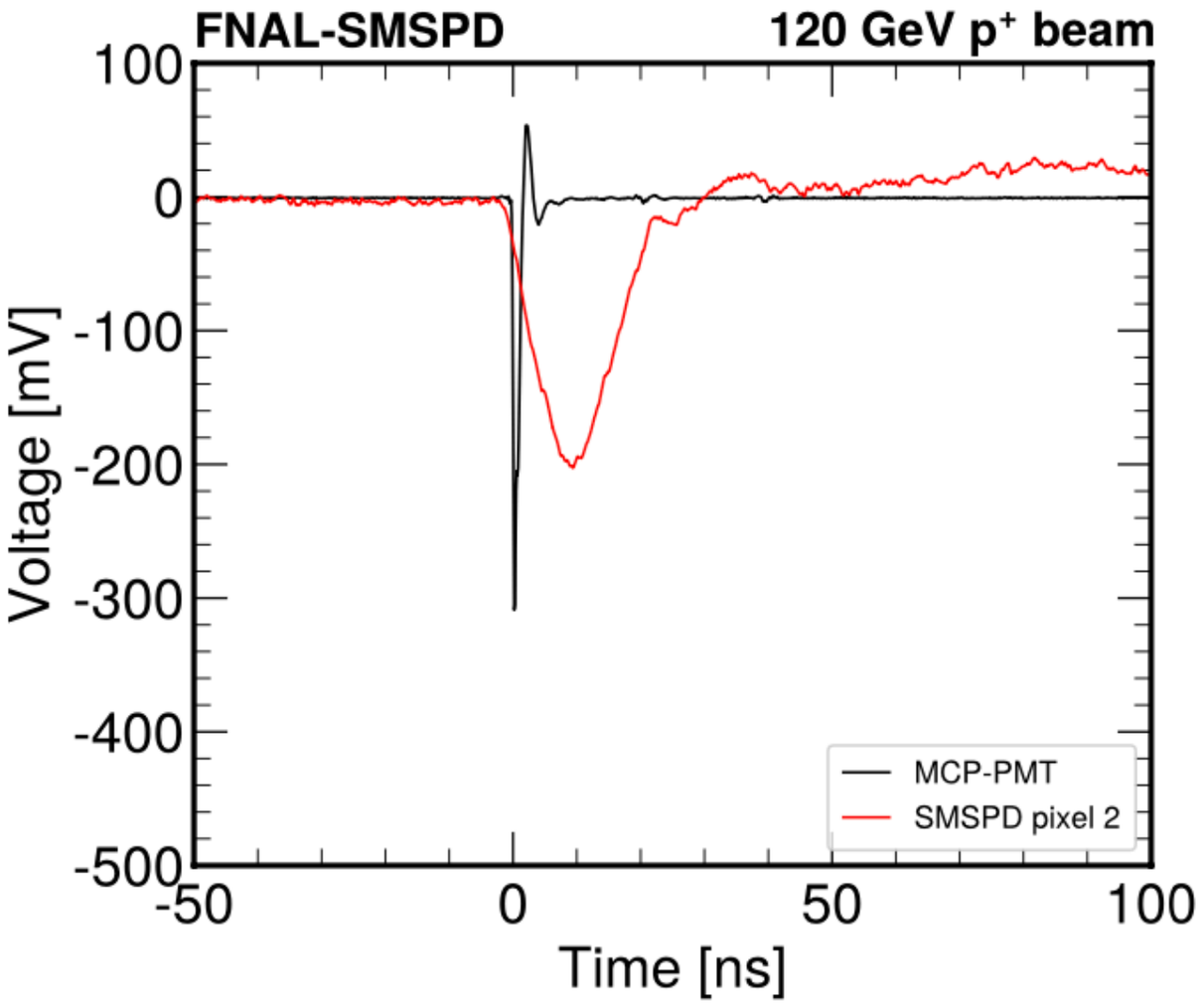


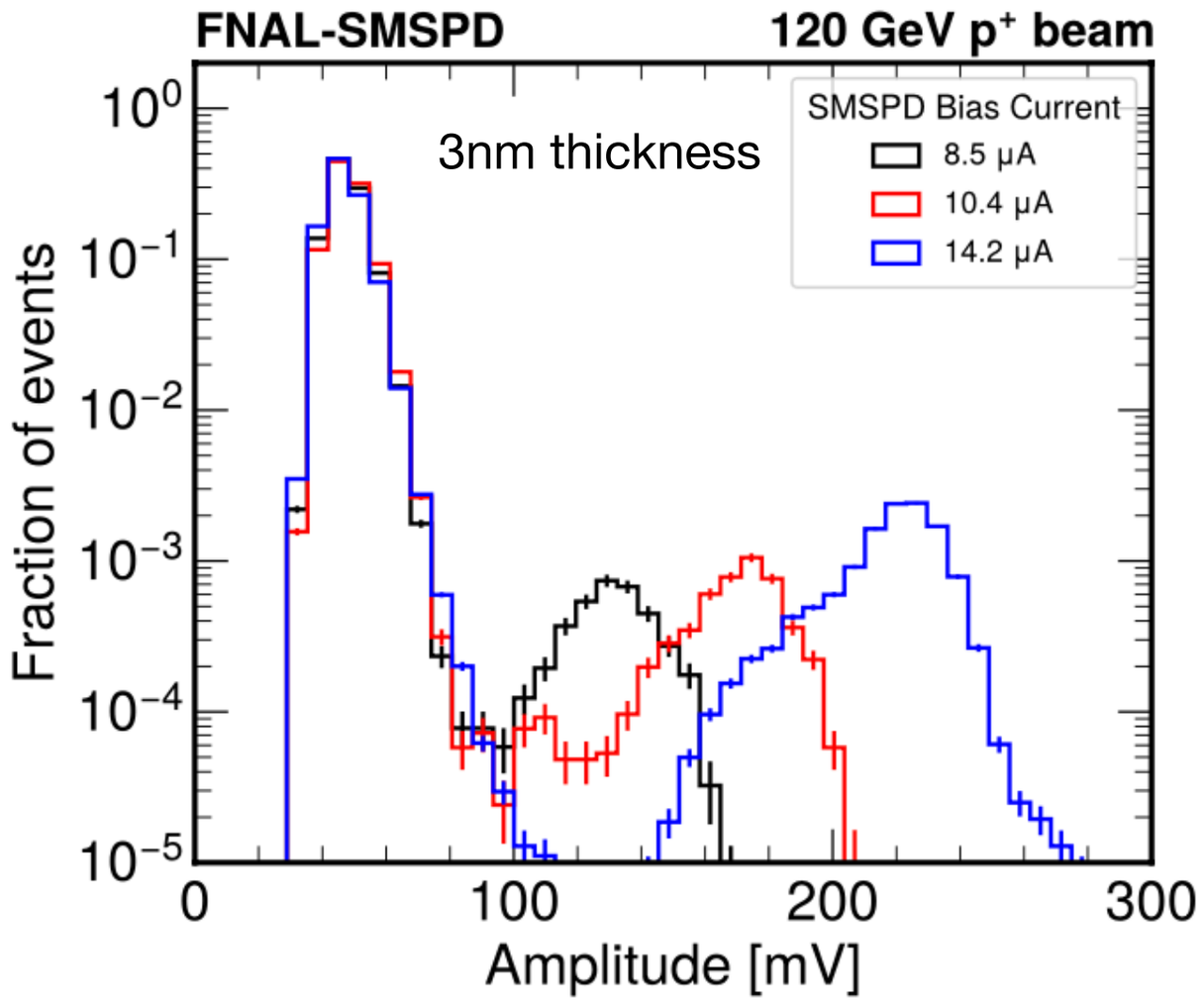




SNSPD Under Testing

New: JINST 20 P03001



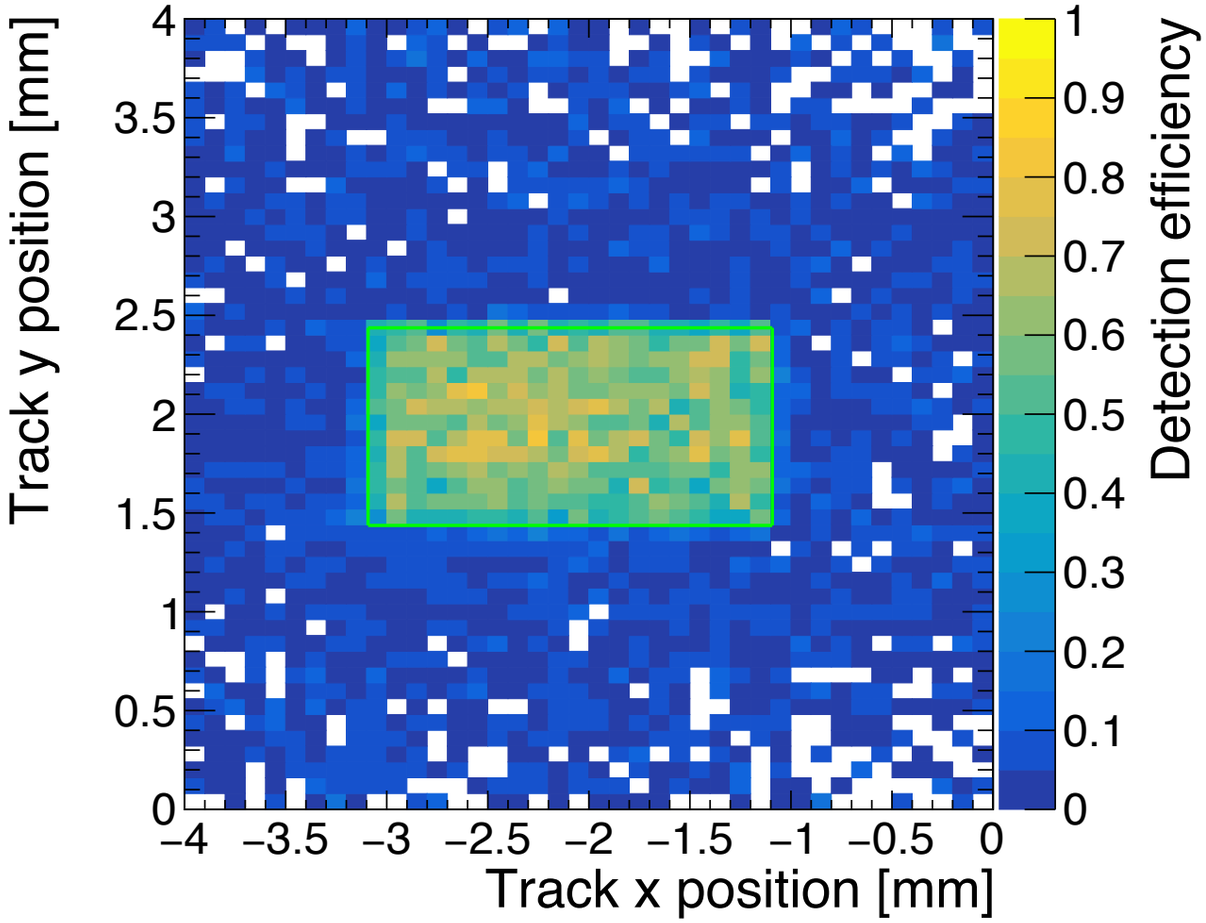


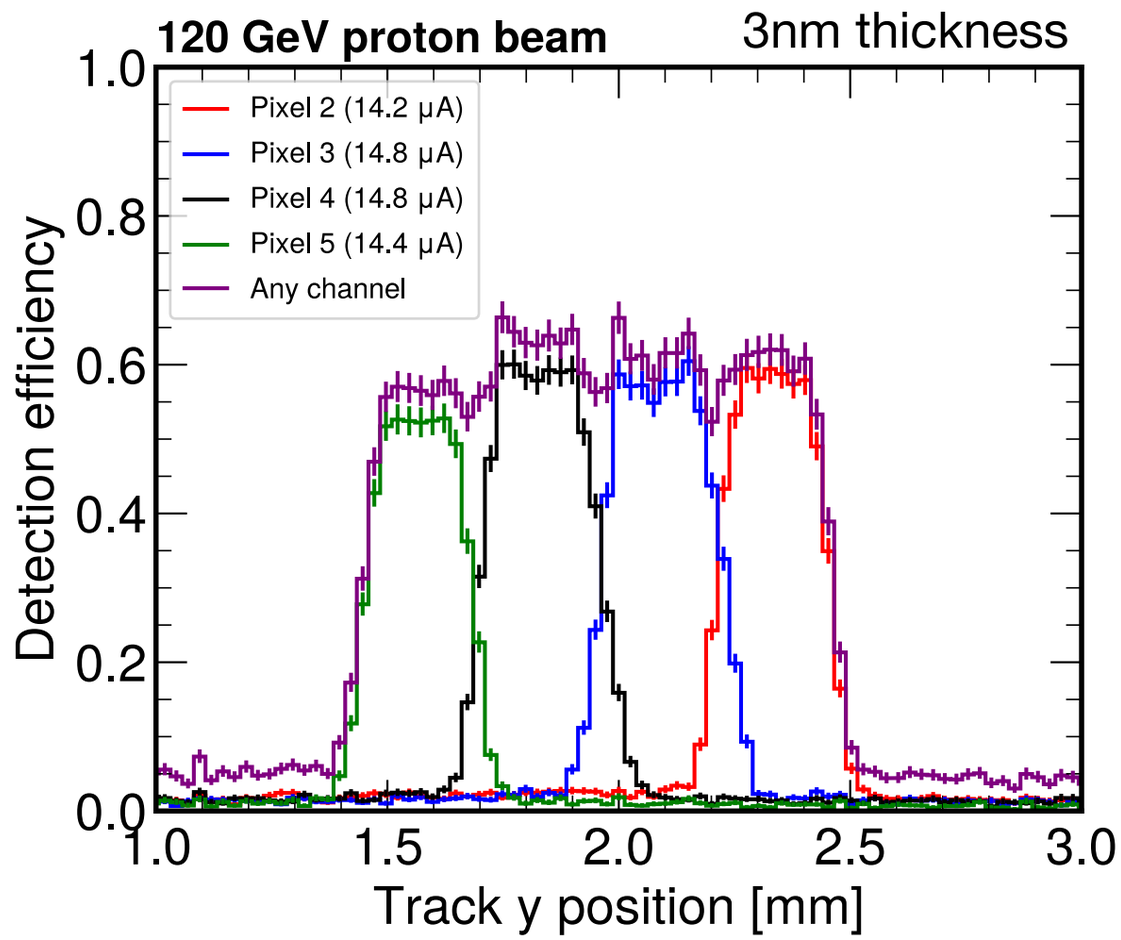
Clear coincidence with reference MCP-PMT and signal clearly above noise for all currents

SNSPD Particle Detection Efficiency

New: JINST 20 P03001

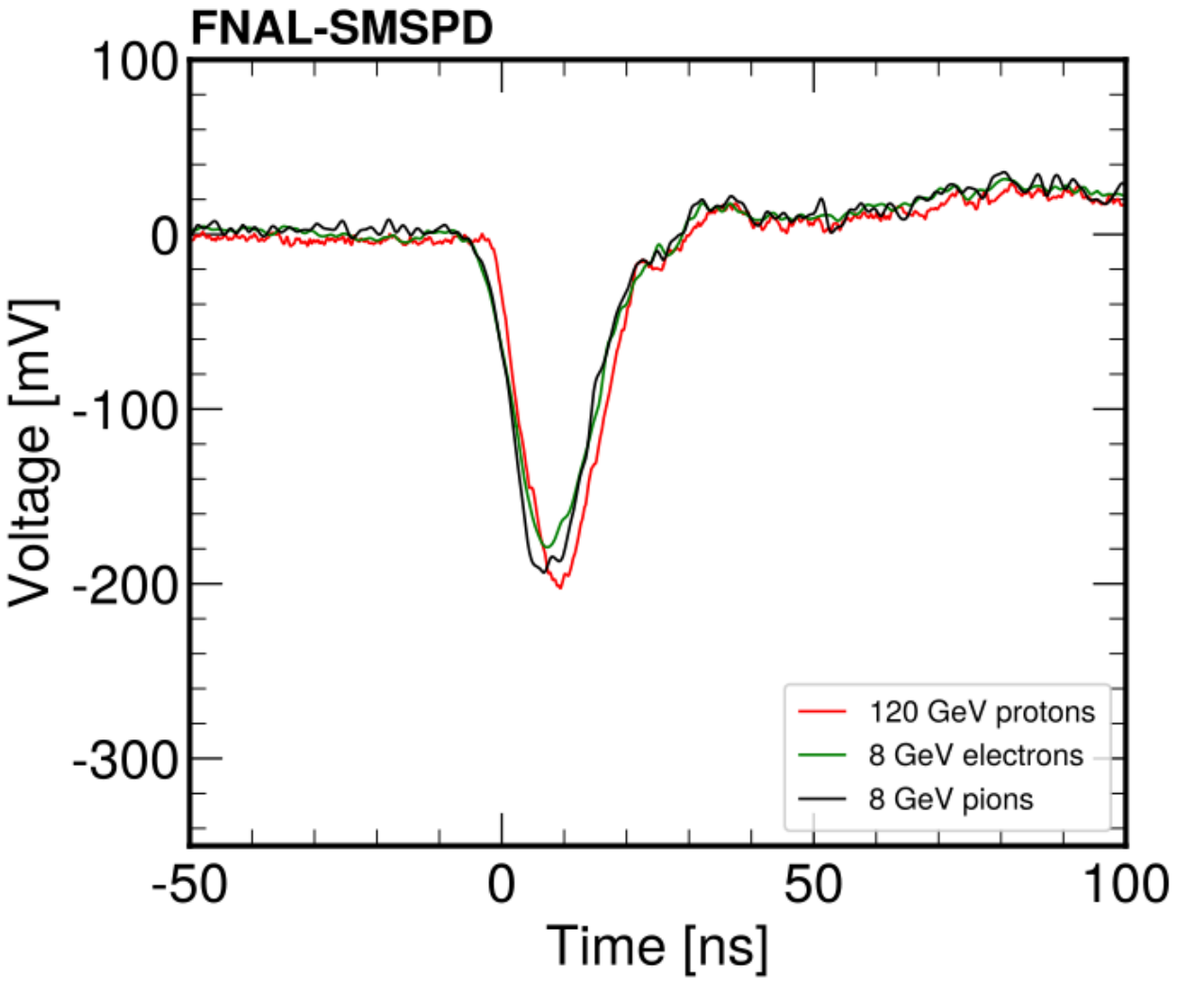
- Readout 4 channels
- Precise tracking telescope (30um spatial resolution) to measure absolute efficiency and response uniformity for the first time

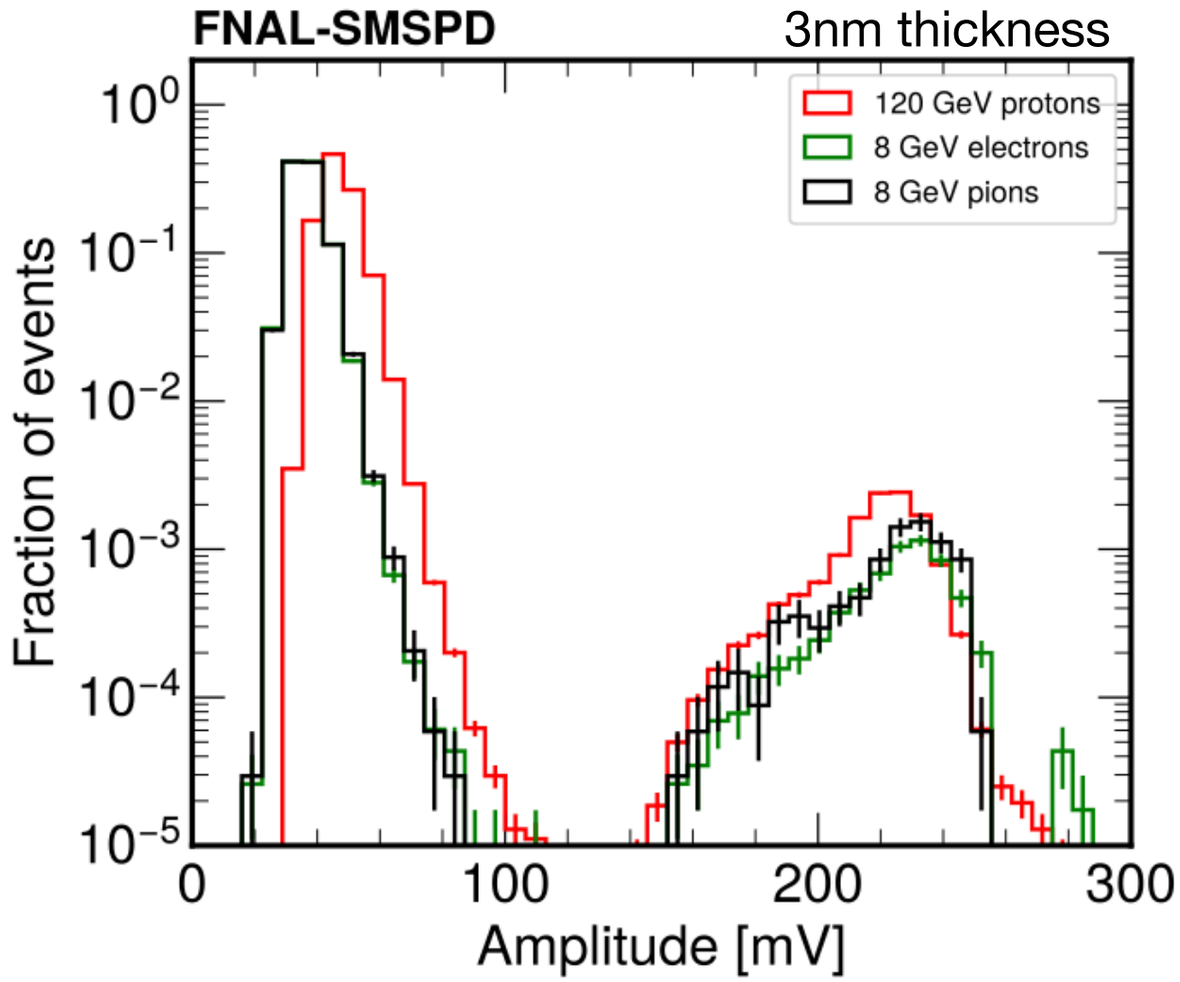




SNSPD response for protons, electrons, and pions

New: JINST 20 P03001



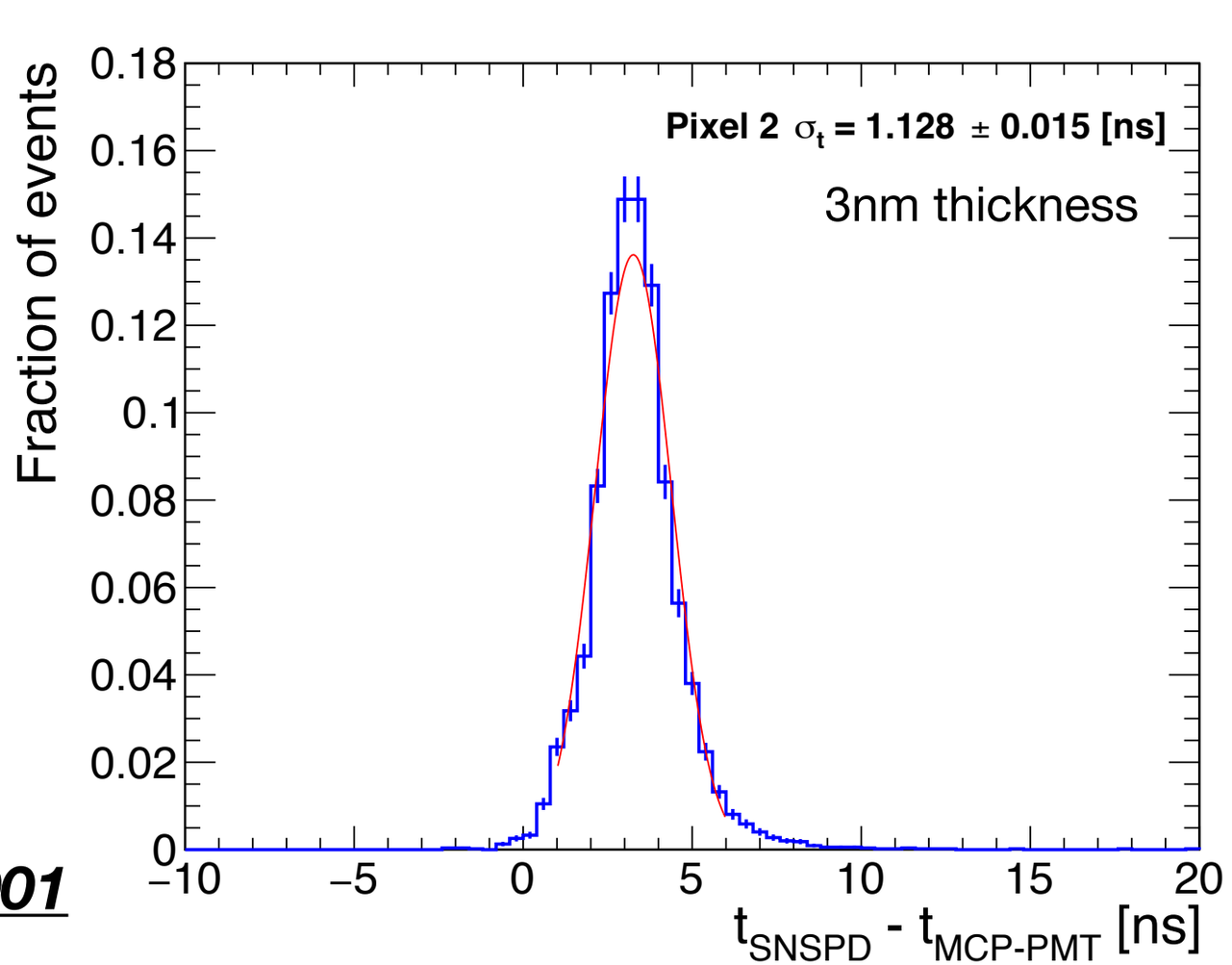


Very similar behavior among the 3 particle types

SNSPD Time Resolution

- MCP-PMT (<10 ps time resolution) provides a precise reference time stamp to measure the time resolution of SNSPD of 1 ns for the first time

- Next step: optimize SNSPD to measure intrinsic nanowire time resolution. **Possibility to tackle the sub-ps and sub-micron 4D-tracking challenge!**



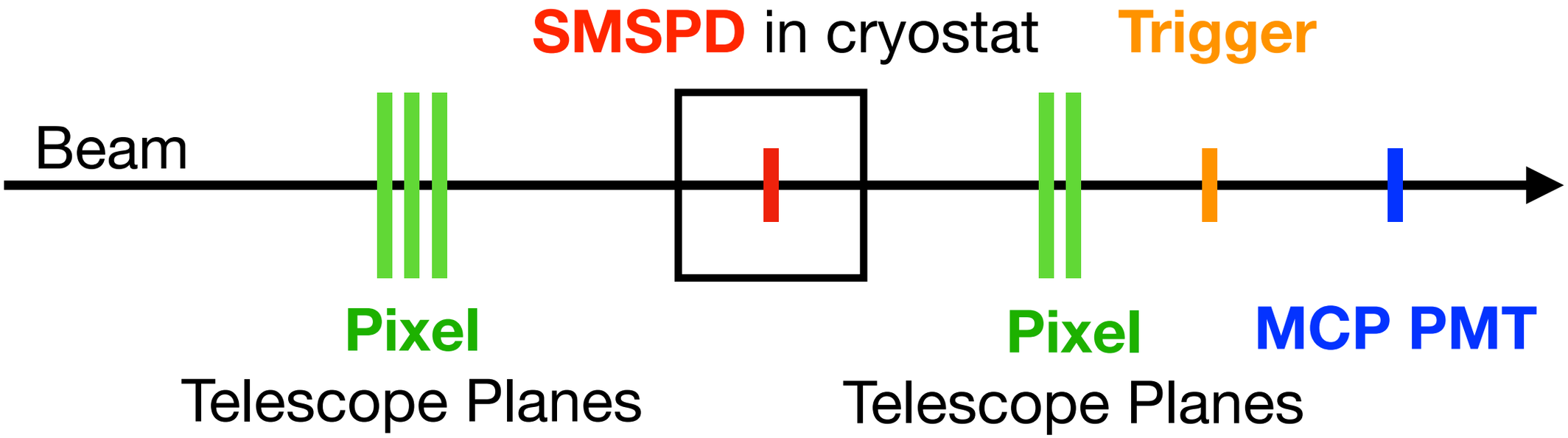
New: JINST 20 P03001

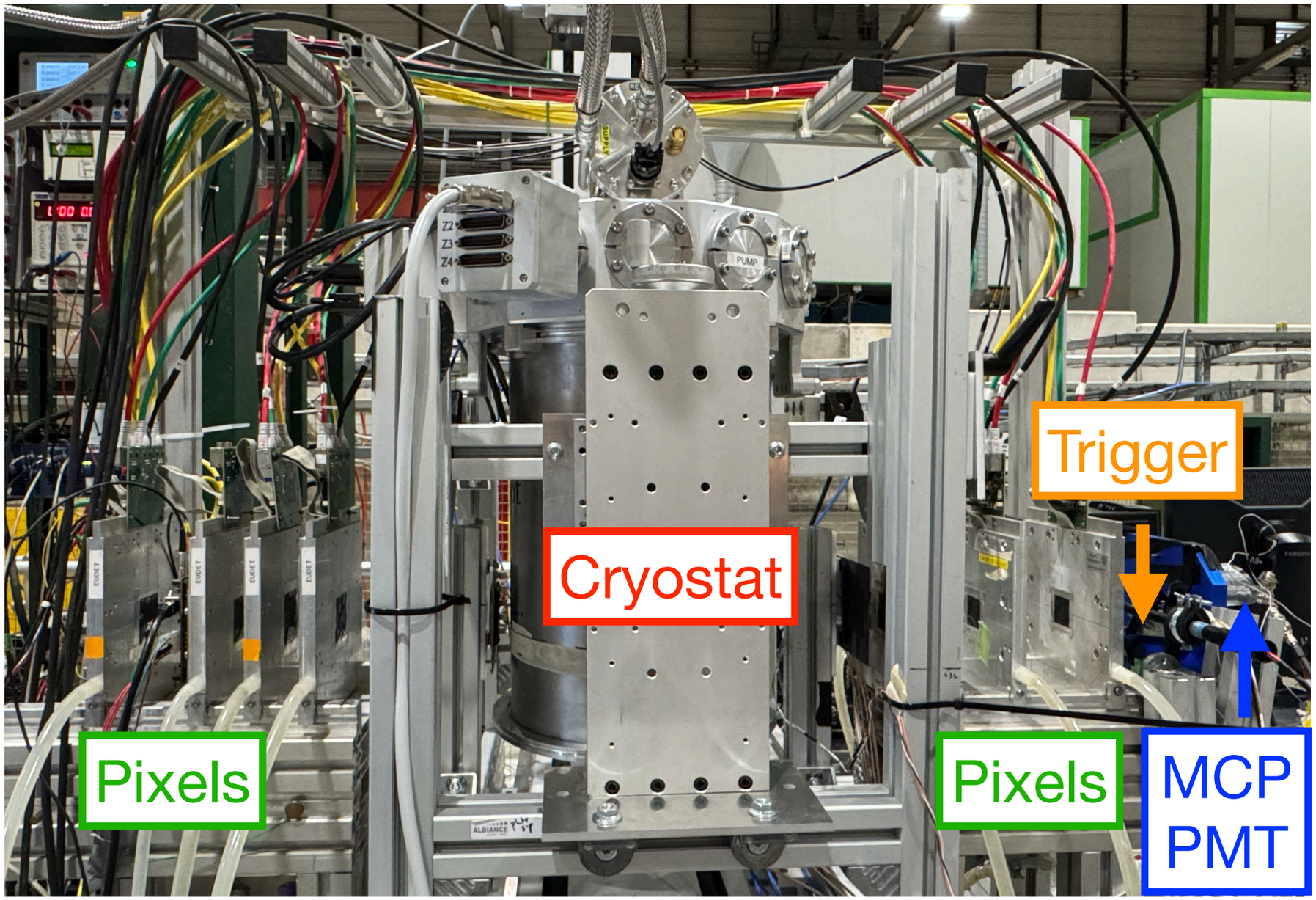
Towards fully efficient SMSPDs

Second test beam campaign at CERN tested a very similar SMSPD

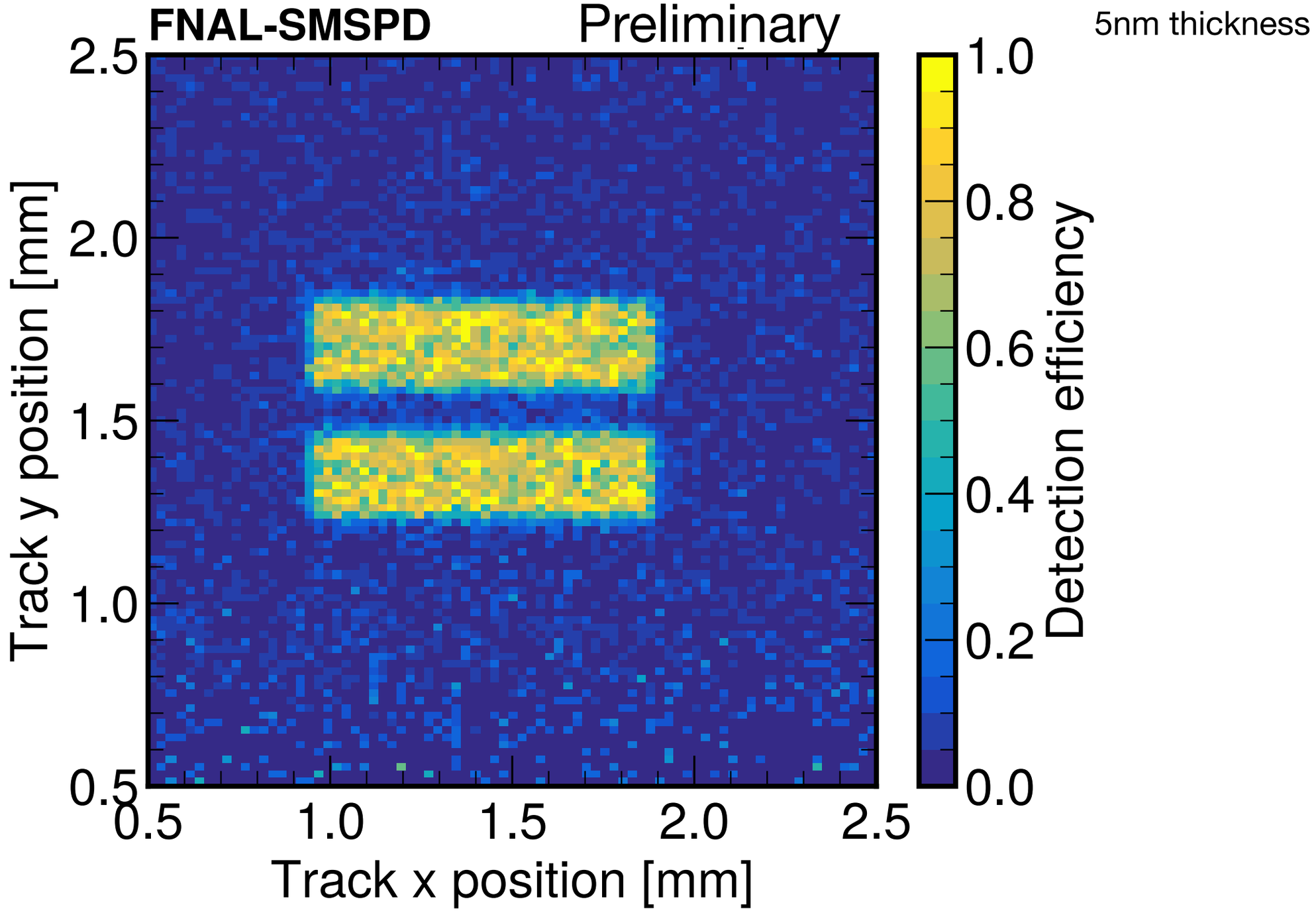
Towards fully efficient SMSPDs

Main objective: validate Fermilab results and check the effect of thicker superconducting films


SMSPD in cryostat
Trigger
Beam
Pixel
Pixel
MCP PMT
Telescope Planes
Telescope Planes

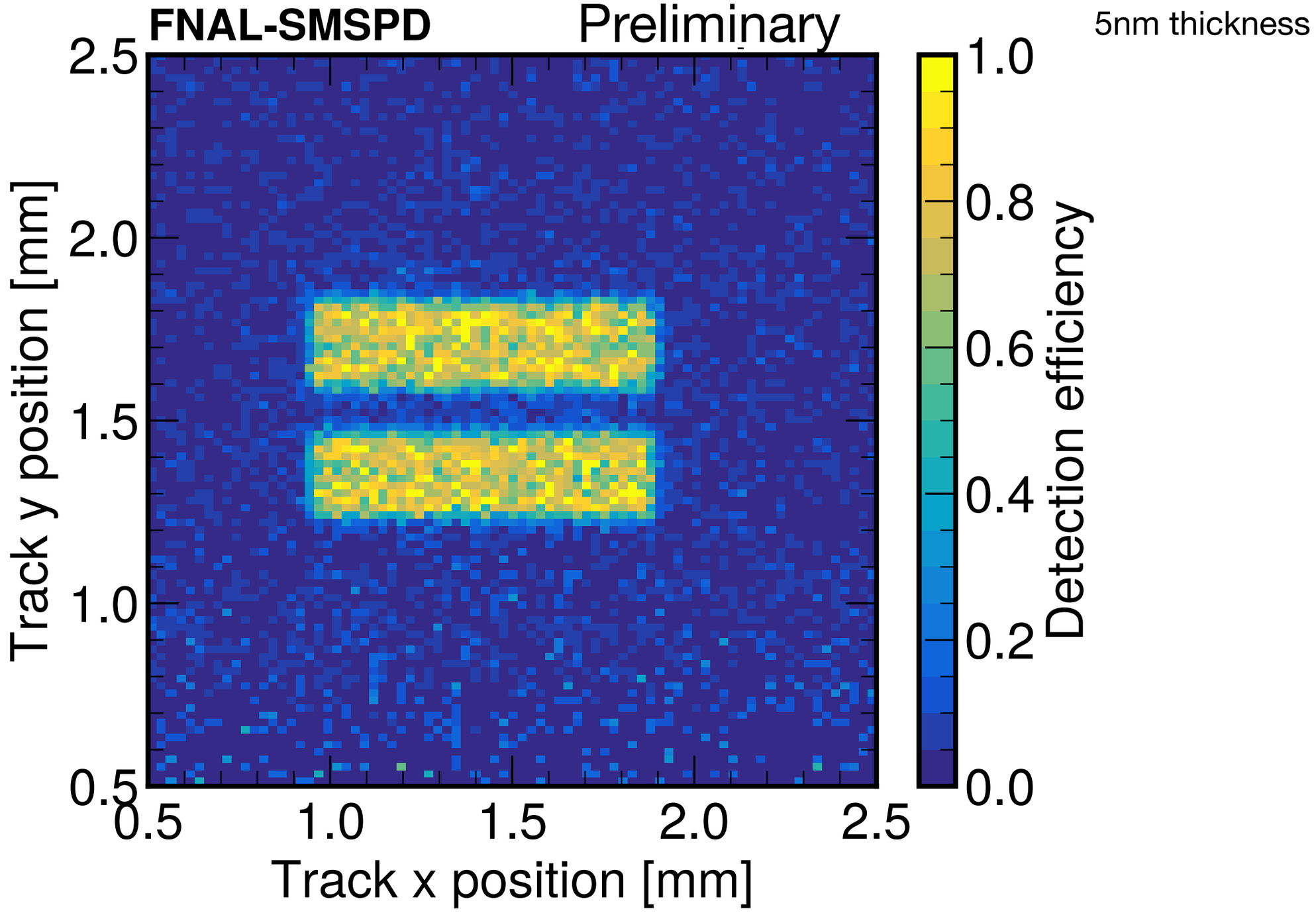

Pixels
Cryostat
Trigger
Pixels
MCP
PMT

SMSPD Efficiency



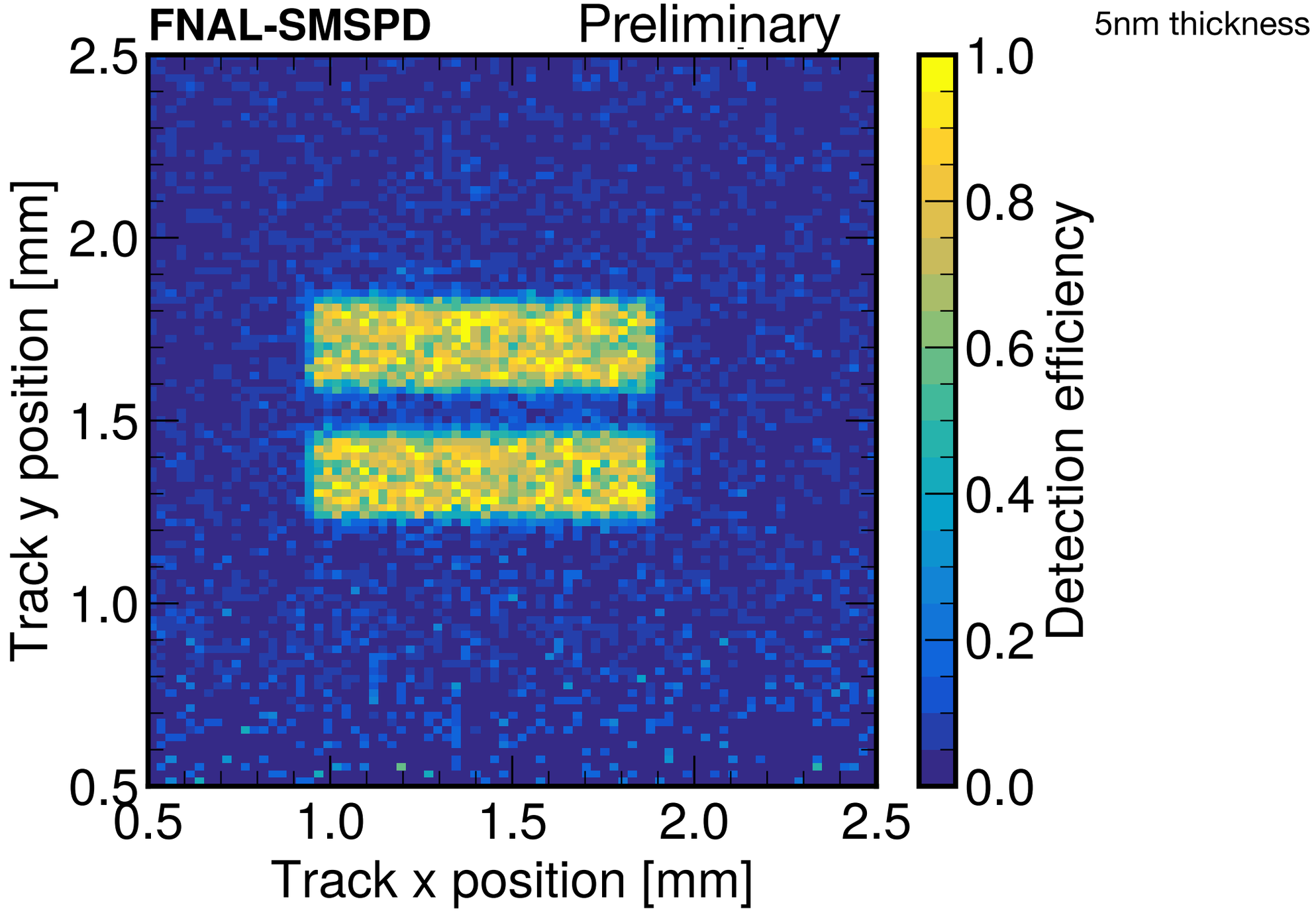
Clear response to charged pions

SMSPD Efficiency



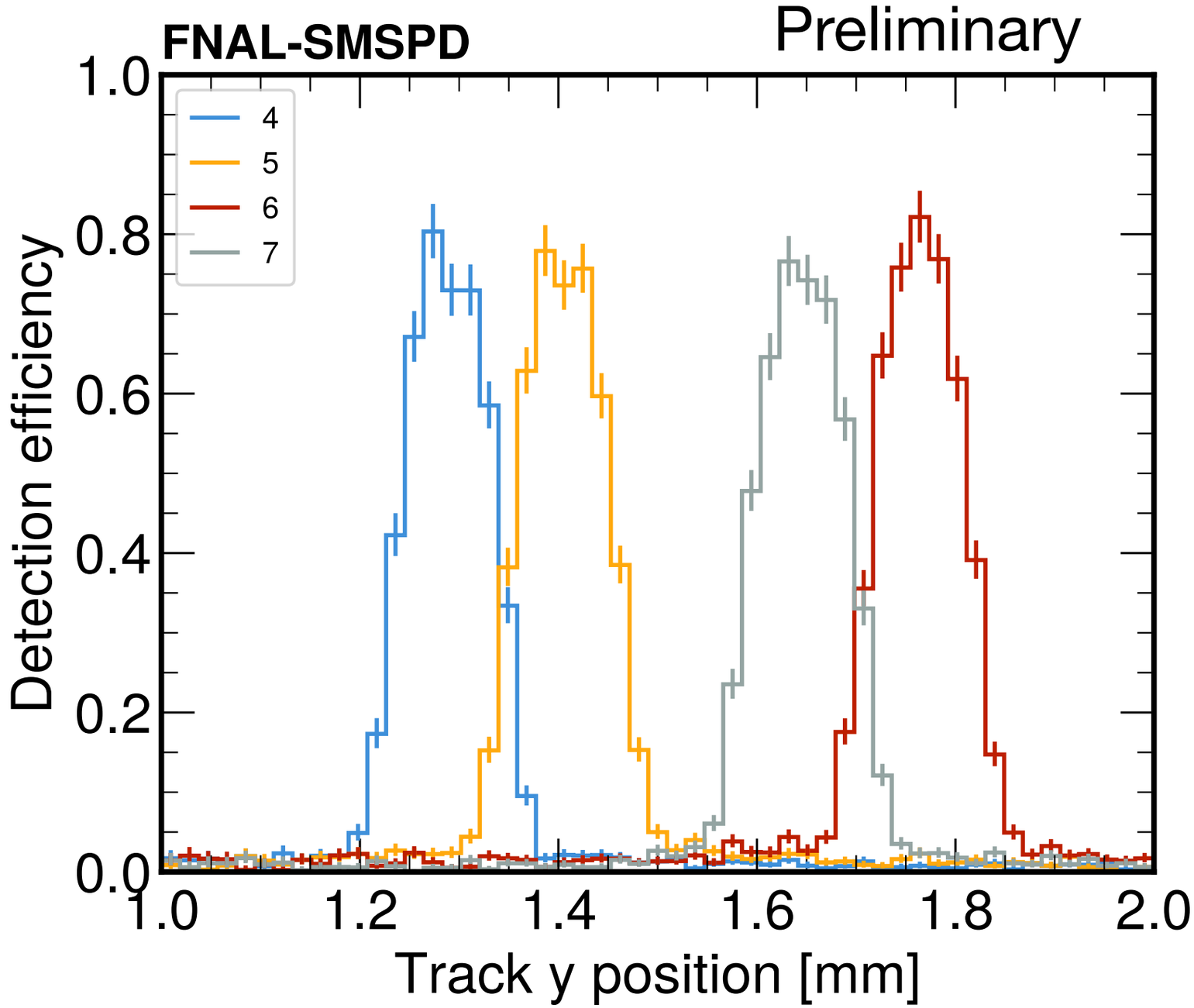
Detection efficiency is increased to ~80%

SMSPD Efficiency



Very exciting results — More studies to come!

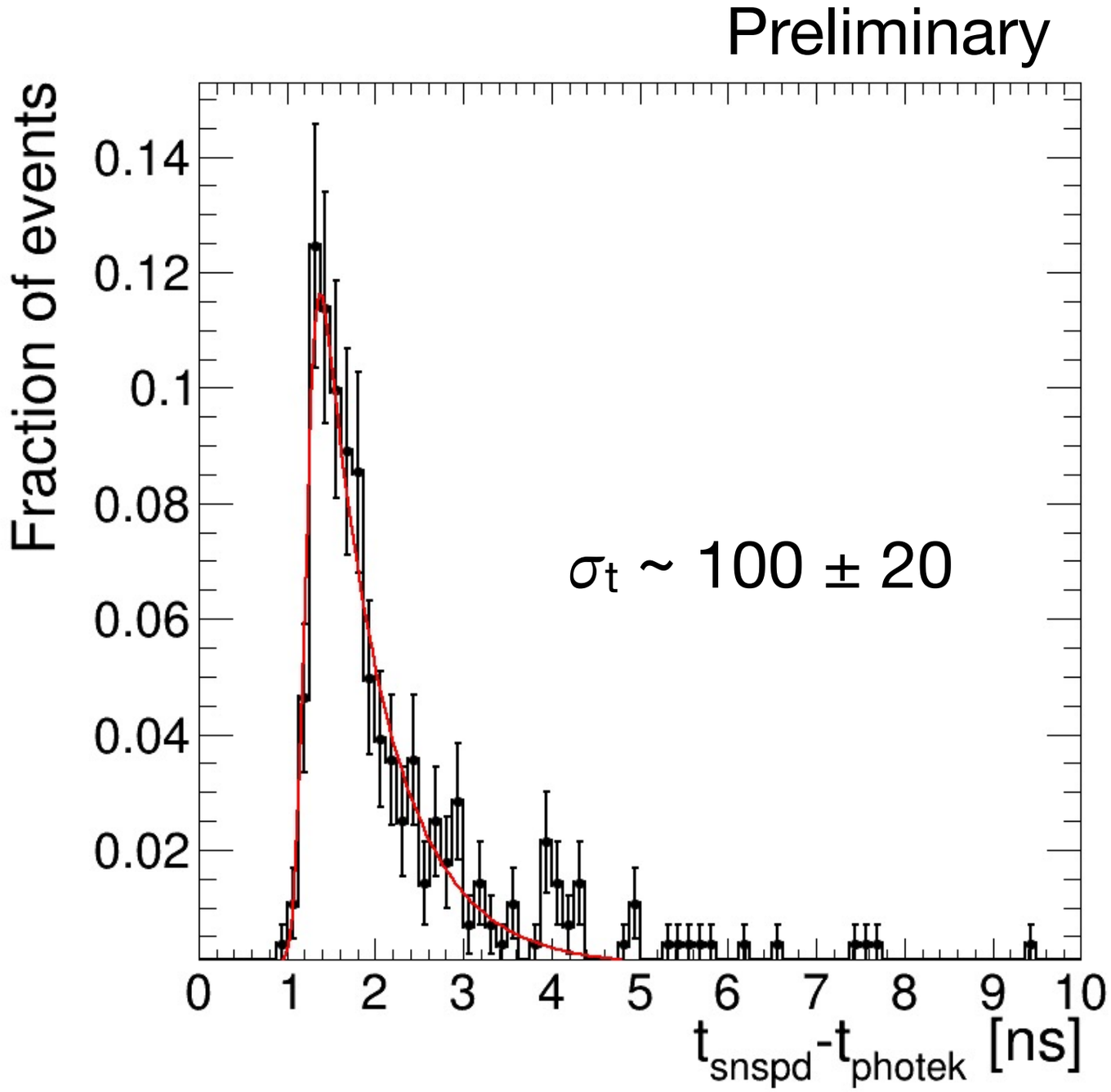
SMSPD Efficiency



5nm thickness

Individual pixel behavior consisten among themselves

SMSPD Time Resolution



5nm thickness

Significant improvement in time resolution by optimized readout

Outlook

- Measured for the first-time SMSPD detection efficiency
- Successfully validated results with a second successful test beam campaign
- Large improvements in detection efficiency and time resolution observed
- Exciting new thrust for superconducting single particle detection
- **Many new results to come!**

Thank You!