Test Beams with SMSPD

Adi Bornheim

Caltech

29.10.2025

Outline & Context

- This talk discusses the technical needs for testing SMSPDs in particle beams.
- Based on experience from two test beams, 2024 in FNAL M-Test and 2025 in CERN NA.
- 2024 results are published, 2025 results are available as preprint.
- These tests are one facet of a much wider program on quantum technology and quantum networking (INQNET) research.
- On the wider scope of the research program that enables these test beam measurements, see presentation by Cristian Pena later today.

JINST

Published by IOP Publishing for Sissa Medialab

Received: October 1, 2024
Accepted: November 4, 2024
Published: March 4, 2025

High energy particle detection with large area superconducting microwire array

Cristián Peña,[a,*] Christina Wang,[a,b] Si Xie,[a,b] Adolf Bornheim,[b] Matias Barría,[c,d] Claudio San Martín,[c,d] Valentina Vega,[c,d] Artur Apresyan,[a] Emanuel Knehr,[e] Boris Korzh,[e,f] Jamie Luskin,[e,g] Lautaro Narváez,[b] Sahil Patel,[b] Matthew Shaw[e] and Maria Spiropulu[b]

[a] Fermi National Accelerator Laboratory, Batavia, IL 60510, U.S.A.
[b] California Institute of Technology, Pasadena, CA 91125, U.S.A.
[c] Departamento de Física y Astronomía, Universidad Técnica Federico Santa María, Valparaíso 2390123, Chile
[d] Centro Científico Tecnológico de Valparaíso-CCTVal, Universidad Técnica Federico Santa María, Casilla 110-V, Valparaíso, Chile
[e] NASA Jet Propulsion Laboratory, Pasadena, CA 91011, U.S.A.
[f] University of Geneva, 1205 Geneva, Switzerland
[g] University of Maryland, College Park, MD 20742, U.S.A.

E-mail: cmorgoth@fnal.gov

Abstract: We present the first detailed study of an 8-channel $2 \times 2\,\mathrm{mm}^2$ WSi superconducting microwire single photon detector (SMSPD) array exposed to 120 GeV proton beam and 8 GeV electron and pion beam at the Fermilab Test Beam Facility. The SMSPD detection efficiency was measured for the first time for protons, electrons, and pions, enabled by the use of a silicon tracking telescope that provided precise spatial resolution of 30 µm for 120 GeV protons and 130 µm for 8 GeV electrons and pions. The result demonstrated consistent detection efficiency across pixels and at different bias currents. Time resolution of 1.15 ns was measured for the first time for SMSPD with proton, electron, and pions, enabled by the use of an MCP-PMT which provided a ps-level reference time stamp. The results presented is the first step towards developing SMSPD array systems optimized for high energy particle detection and identification for future accelerator-based experiments.

Keywords: Particle tracking detectors; Superconductive detectors (bolometers, tunnel junctions etc); Timing detectors; Cryogenic detectors

*Corresponding author.

https://doi.org/10.1088/1748-0221/20/03/P03001

Prepared for submission to JINST

Towards High-Efficiency Particle Detection Using Superconducting Microwire Arrays

Christina Wang,[a] Cristián Peña,[a] Adolf Bornheim,[b] Shuoxing Wu,[a] Alexander Albert,[b] Thomas Sievert,[b] Artur Apresyan,[a] Emanuel Knehr,[c] Boris Korzh,[c,d] Jamie Luskin,[c] Ludovico Mori,[b] Sahil Patel,[b] Guillermo Reales Gutiérrez,[b] Manish Sahu,[d] Ekkehart Schmidt,[c] Matthew Shaw,[c] Elise Sledge,[b] Maria Spiropulu,[b] Towsif Taher,[d] Si Xie[a,b]

[a] Fermi National Accelerator Laboratory, Batavia, IL 60510, U.S.A.
[b] California Institute of Technology, Pasadena, CA 91125, U.S.A.
[c] NASA Jet Propulsion Laboratory, Pasadena, CA 91011, USA
[d] Group of Applied Physics, University of Geneva, CH-1205, Geneva, Switzerland

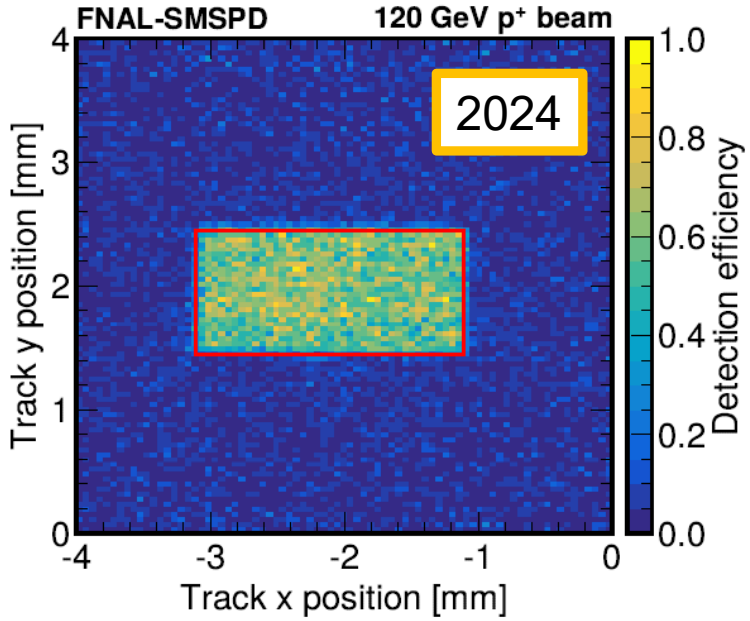
E-mail: christiw@fnal.gov

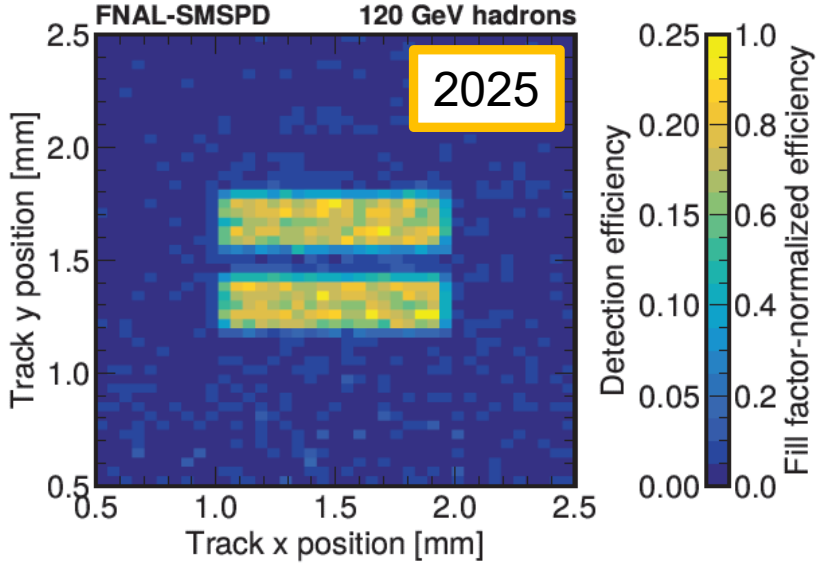
Abstract: We present a detailed study of an 8-channel $1 \times 1\,\mathrm{mm}^2$ WSi superconducting microwire single photon detector (SMSPD) array exposed to 120 GeV hadron beam and 120 GeV muon beam at the CERN Super Proton Synchrotron H6 beamline. Following up on our first detailed characterization of the efficiency and response of an SMSPD fabricated on a 3 nm WSi film, we report measurements of enhanced particle detection efficiency using a sensor fabricated from a thicker 4.7 nm-thick WSi film. We also report the first SMSPD detection efficiency measurement made for muons. Measurements are enabled by a silicon tracking telescope providing 10 µm in-situ spatial resolution. The results show a fill factor-normalized detection efficiency of 75% and a time resolution of about 130 ps across pixels. These findings represent a significant advancement toward developing high-efficiency SMSPD charged particle tracking systems with simultaneous precision timing, with potential applications in future accelerator-based experiments such as the FCC-ee and Muon Collider.

Keywords: Particle detectors, Superconductive detection materials, Cryogenic detectors

Scope of the test beam

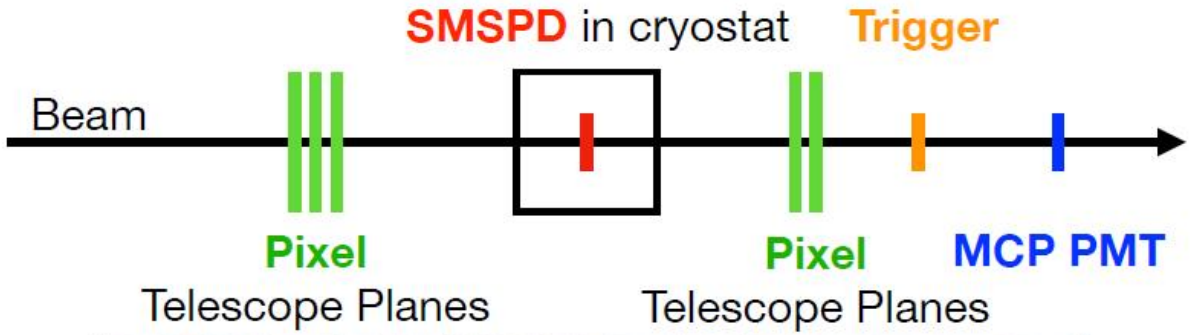
- SMSPDs have a number of features (low noise, high sensitivity, good time resolution) that make them interesting for particle detection.
  - Additional features (radiation resilience, magnetic field tolerance) may turn out to be favorable as well.
- The scope of the 2024 test beam was to explore if SMSPDs can detect high energy particles.
  - The success of this test turned this already into a study of the detection performance.
- The scope of the second test was to study the detection performance (spatial, temporal resolution and efficiency).
  - Conduct tests similar to typical HEP sensor R&D approach.
  - Sensor similar but not identical.

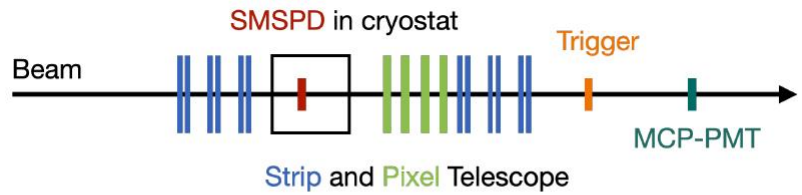


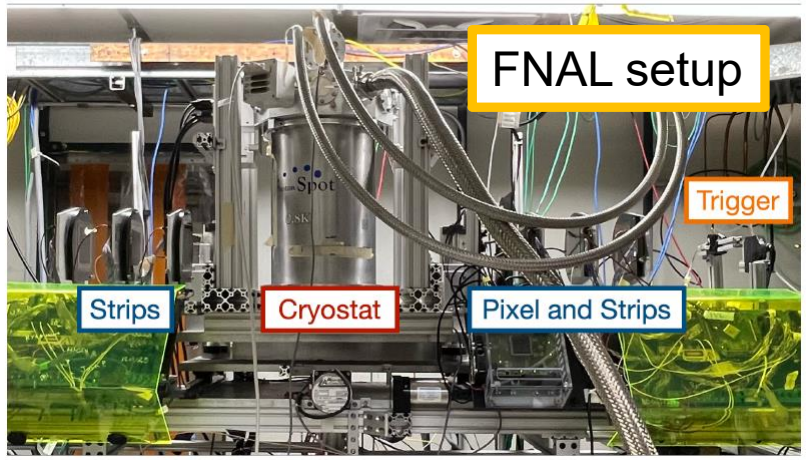


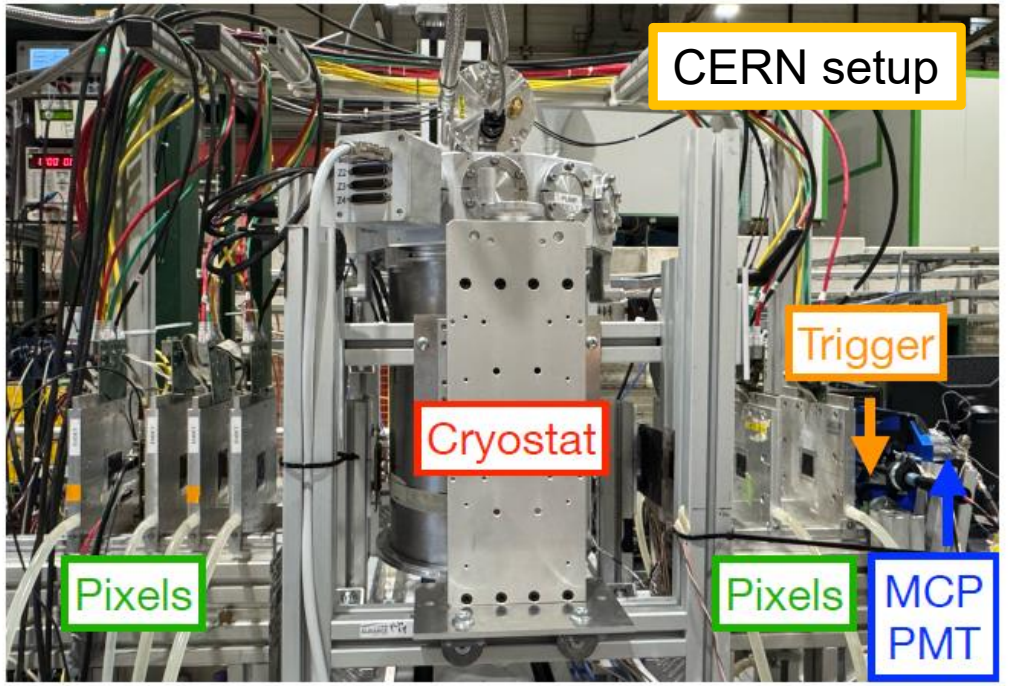
Test beam setup

- Test beam setup similar for FNAL and CERN, focus here on CERN setup.
- Principal components :
  - Cryostate with SMSPD infrastructure
  - Tracking system to measure the impact point of the particle on the SMSPD
  - Trigger system with acceptance slightly larger than and aligned with the SMSPD.
  - Precision timing reference counter to measure time resolution of the SMSPD.









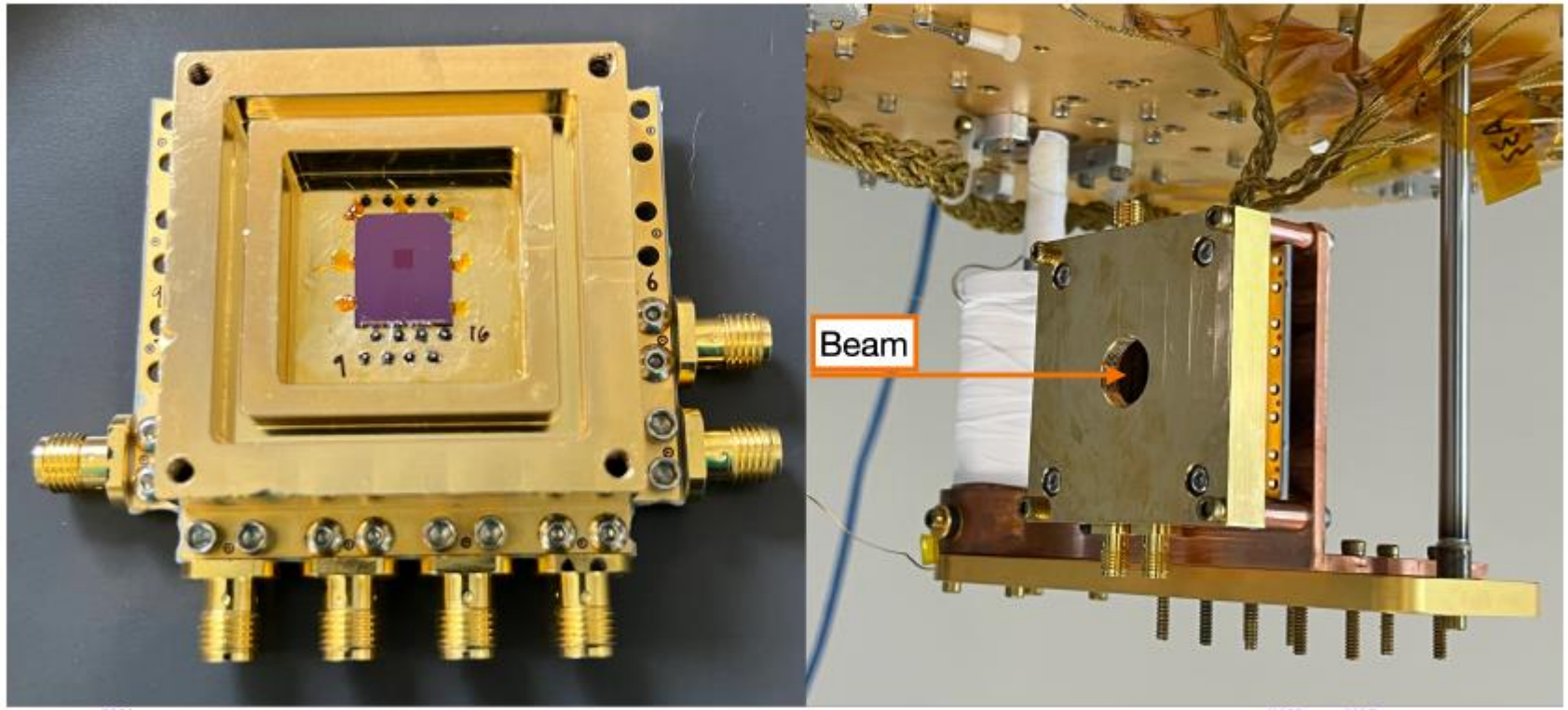
Cryostat & Beam mounting

- Commercial cryostat :
  - Our sensor (Wsi) requires operation at 0.8 K.
  - Takes several hours to pump down vacuum, about ~24 hours to reach the target temperature from room temperature.
  - Cooling cycle from ~few K to 0.8 K takes few hours, has to be repeated every ~24 hours.
  - Size and weight of the cryostat allow to ship and handle it «manually», though typically requires two people.
  - Size compatible with tracking device in PPE156, with tight margins.
  - Accessing the sensor requires to remove the cryostat from beam.
  - Same sensor was tested and calibrated in the same cryostat extensively, the cryostat has been used extensively since years.

- Mounted on a manually operated, custom XZ motion frame.
  - Cryostat mounted in the frame and both together in the beam.
  - Aligning the SMSPD and correcting beam position on the scale of ~1 mm was sufficient at this stage.
  - The alignment of the SMSPD inside the cryostat is fixed.
  - Beam spot in CERN is larger than sensor.
  - Relevant measurements rely on the tracking device only.

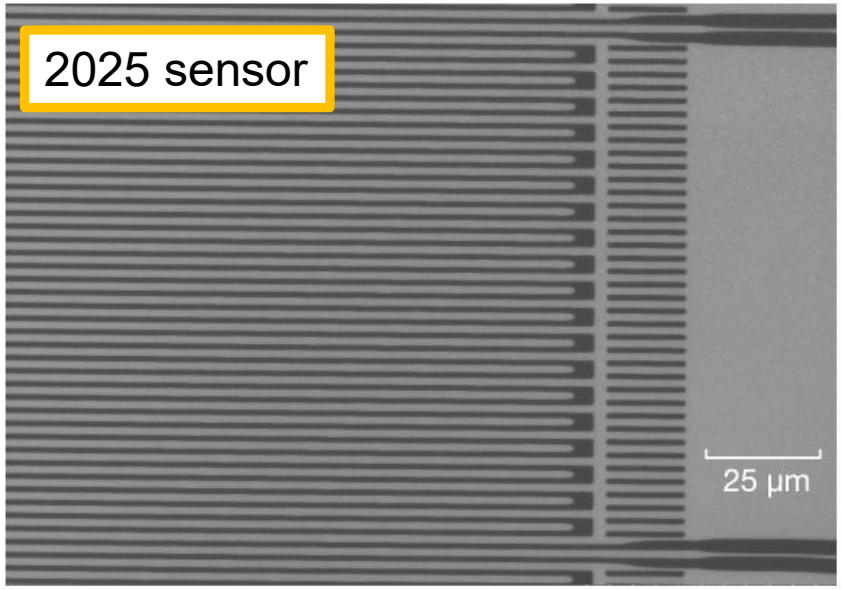
SMSPD Infrastructure

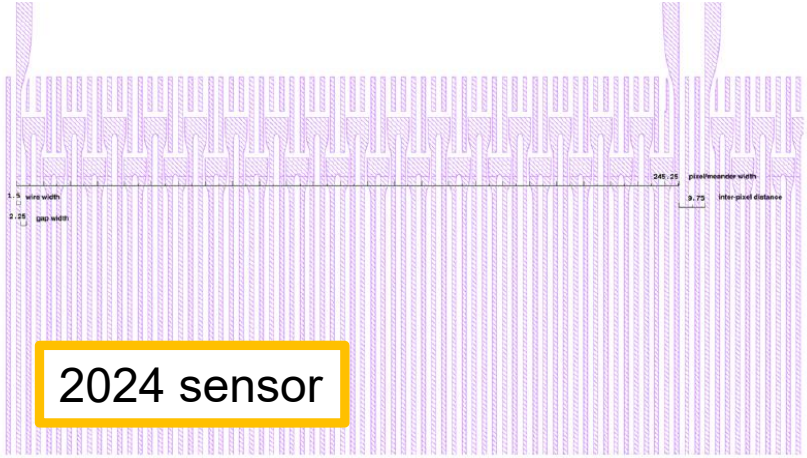
- SMSPD holder is one used for SMSPD research, not particularly customized for beam tests.
- 1 K cold stage has sensor, sensor holder and cable connections.
- We do not require a clean room to handle the sensor.
- Sensor holder dominates the material budget around the sensor.
- This sensor holder may be extended up to 16 channels. For more complex sensor, additional development work needed.



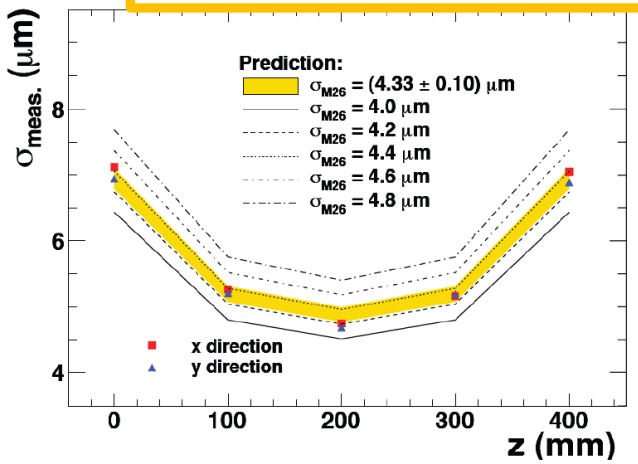
Tracking device

- We find high efficiency detection upon impact of the particle on the sensor area - within the resolution of the tracking device.
- The feature size of the SMSPD used at CERN is 1 mμ wire width and 3 mμ wire distance (1.5/2.25 at FNAL).
- We used the AIDA telescope available at PPE156.
- Using the edge of a thin trigger counter we meaured the «edge detection» resolution of the tracker to be around 10 mμ.
  - 5 out of 6 layers of the tracking device were working.
  - Close, but not quite good enough to resolve features of the SMSPD.
- A resoution of a few might be achievable.

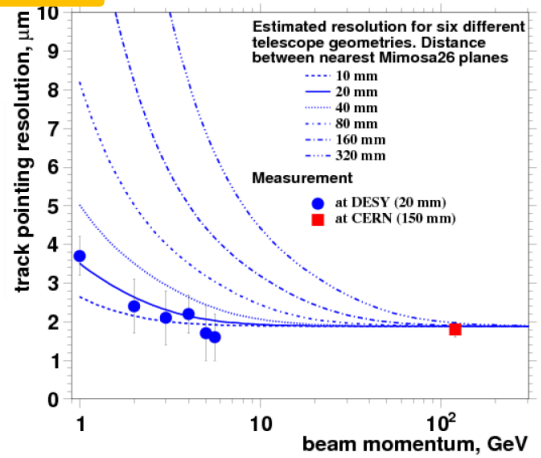




AIDA telescope performance

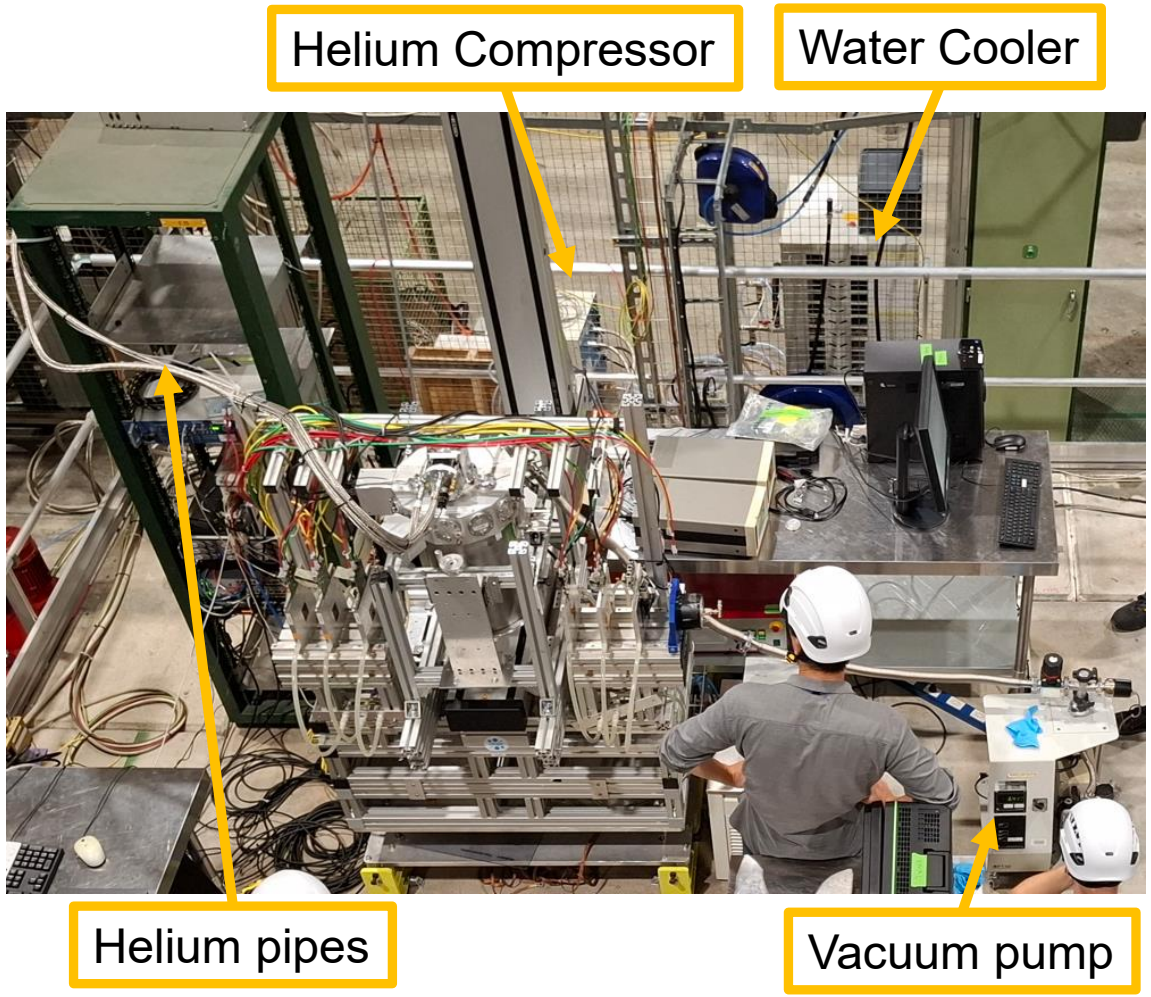


Estimated and measured resolution for equidistant setup with 6 planes



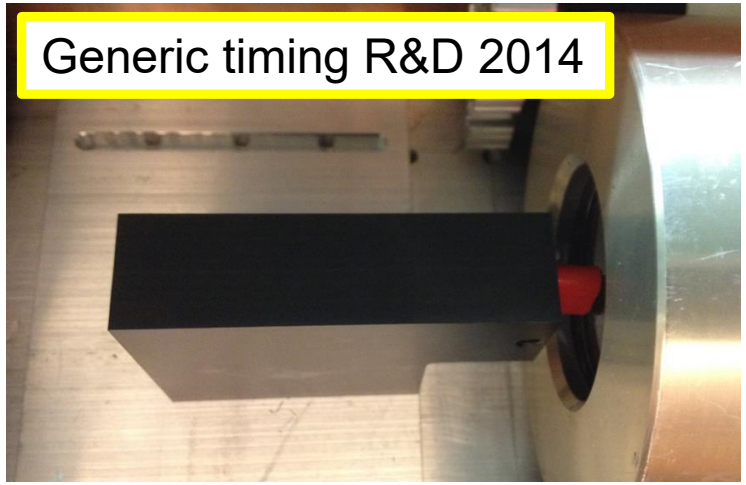
Test beam infrastructure

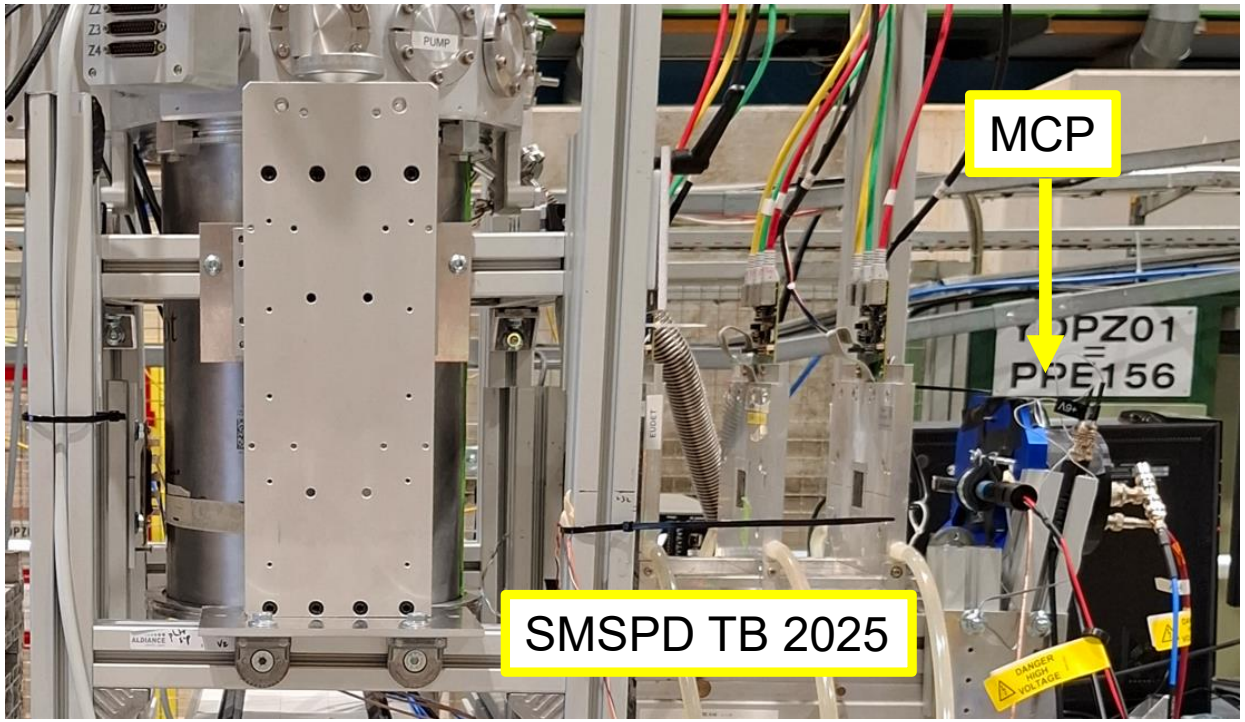
- Setup requires Helium compressor, water cooler to cool Helium compressor, vacuum pump, DAQ and powering.
- Helium compressor, vacuum pump from Uni Geneva (including some PS and controls), water cooler from CERN.
  - Components similar but not identical to the setup used at FNAL for SMSPD R&D.
- Complete setup was tested at Uni Geneva before moving to CERN.
  - Crucial validation step that allowed swift installation in test beam zone.
- Sensor calibrated with laser light at Uni Geneva and CERN before moving to beam.
  - Ideally would ultimately do this fully in situ as displacing the cryostat may affect exact working point. Require more (and better) services into cryostat.
  - PPE156 equipment set up in ~12 hours. Ready for beam after cooldown.

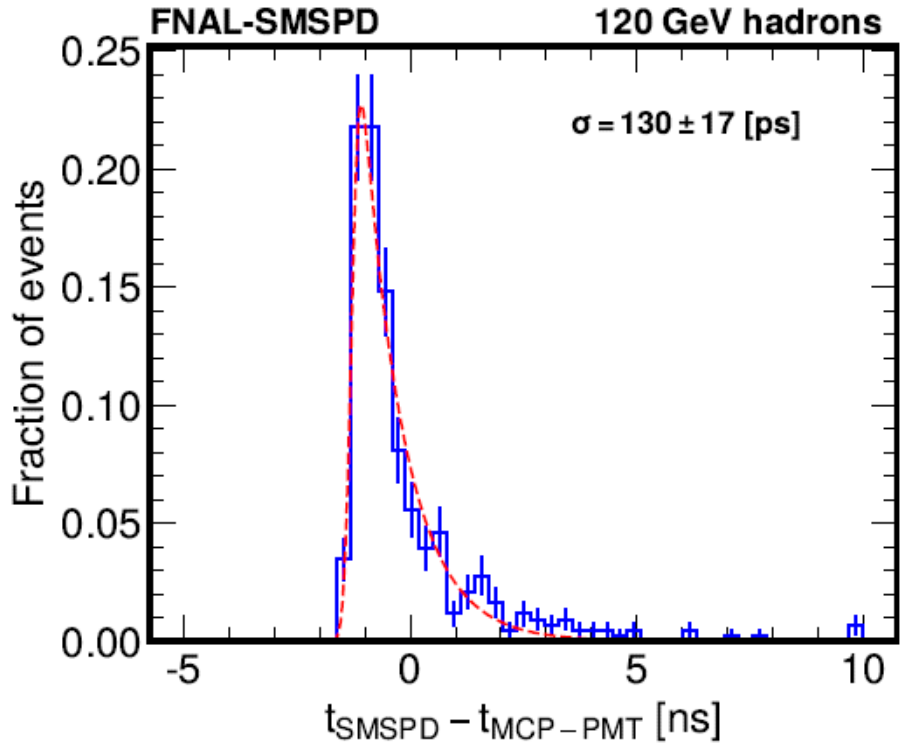


Time reference

- The timing performance is referenced agains a Photek MCP.
- Readout using fast scope.
- This technique is derived from the many years of timing work on generic R&D and CMS MTD. Good down to ~10 ps.
- CERN sensor and electronics achieved 130 ps. Some geometric jitter observed. Ultimate performance will require very good time reference and patial resolution.







Operation and logistics

- The test beam at CERN relied heavily on the previous experience at FNAL.
  - Dedicated prep time for the CERN test was several weeks excluding actual SMSPD R&D.
  - Prep time for the initial FNAL test was rather months with repeated beam time slots.
- Extensive experience with the SMSPD technology and generally quatum technology in the team conducting the tests.
- The infrastructure available at Uni Geneva was crucial for a successfull test.
- Curiosity driven team enjoying the process !

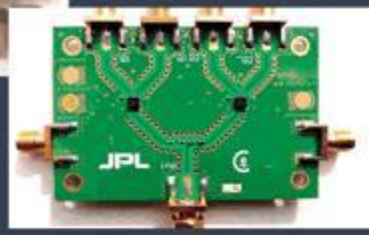
Summary

- Test beams with SMSPDs were conducted successfully with the particle beam infrastructure at CERN and FNAL.
- SMSPD specific infrastructure and auxilliary equipment requirements are substantial.
- Tests we conducted are with small size, few channel sensors and testing one configurations only per test capaign.
- Future test will require a more versatile and spatious cold platform.





inqnet
ALLIANCE FOR QUANTUM TECHNOLOGIES



Caltech | Fermilab U.S. DEPARTMENT OF ENERGY | Office of Science | NASA JPL

- Founder: M. Spiropulu w/ AT&T/Caltech/JPL/FNAL (est 2017 inqnet.Caltech.edu)
- W/ LABS: USER BASE, SCALING, SYSTEMS INTEGRATION, ENGINEERING, HYBRID SYSTEMS
- w/ ACADEMIA: WORKFORCE DEVELOPMENT, STUDENTS/POSTDOCS, inspired PI'S, cross-disciplinary intersections HEP
- w/Industry: PRODUCTS cross-BENCHMARKING, supply chain, Tech transfer
- POCs: Caltech (Adi Bornheim) FNAL (Cristian Pena) JPL (Matt Shaw/Boris Korzh now U Geneva) DRD5 (Si Xie)

AQT

inqnet

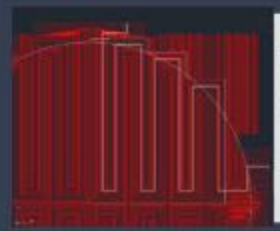
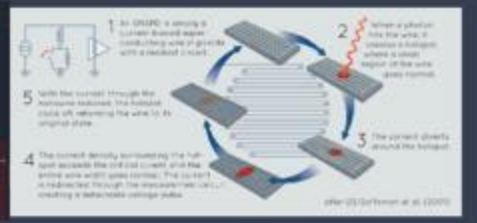
q-Net

FQNET
IEQNET
CQNET
AQNET
WCQNET
...
USQNET

q-AI

QAML optimization
quantum
algos/simulation

q-tech

q-fun