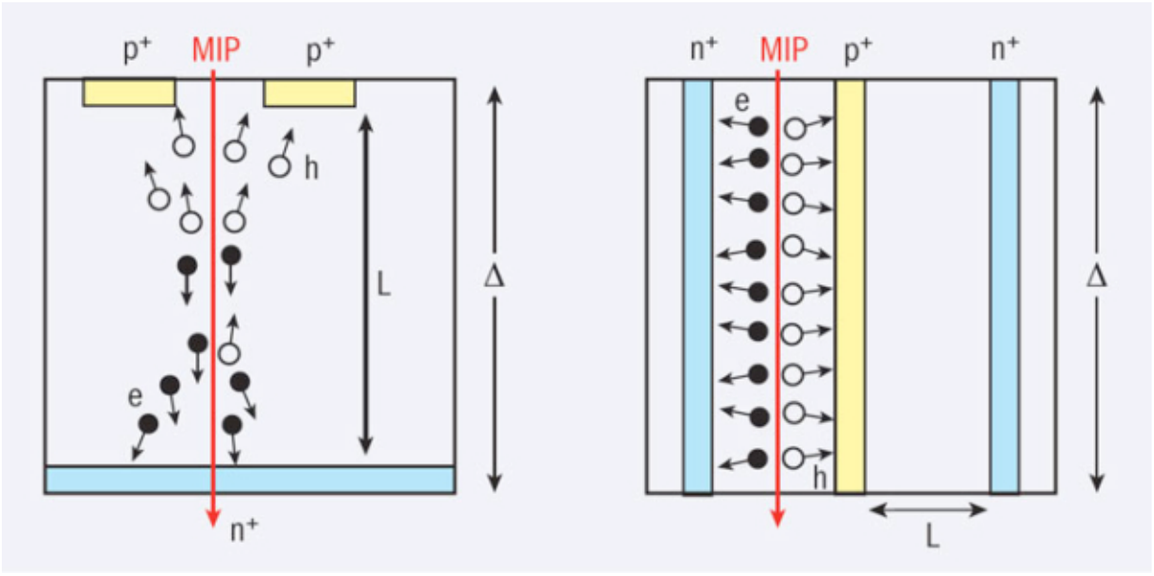
Study of Irradiated CNM 3D Sensors

Susan Dittmer
on behalf of the CMS Tracker Group

17th ‘Trento’ Workshop on Silicon Sensors
3 March 2022

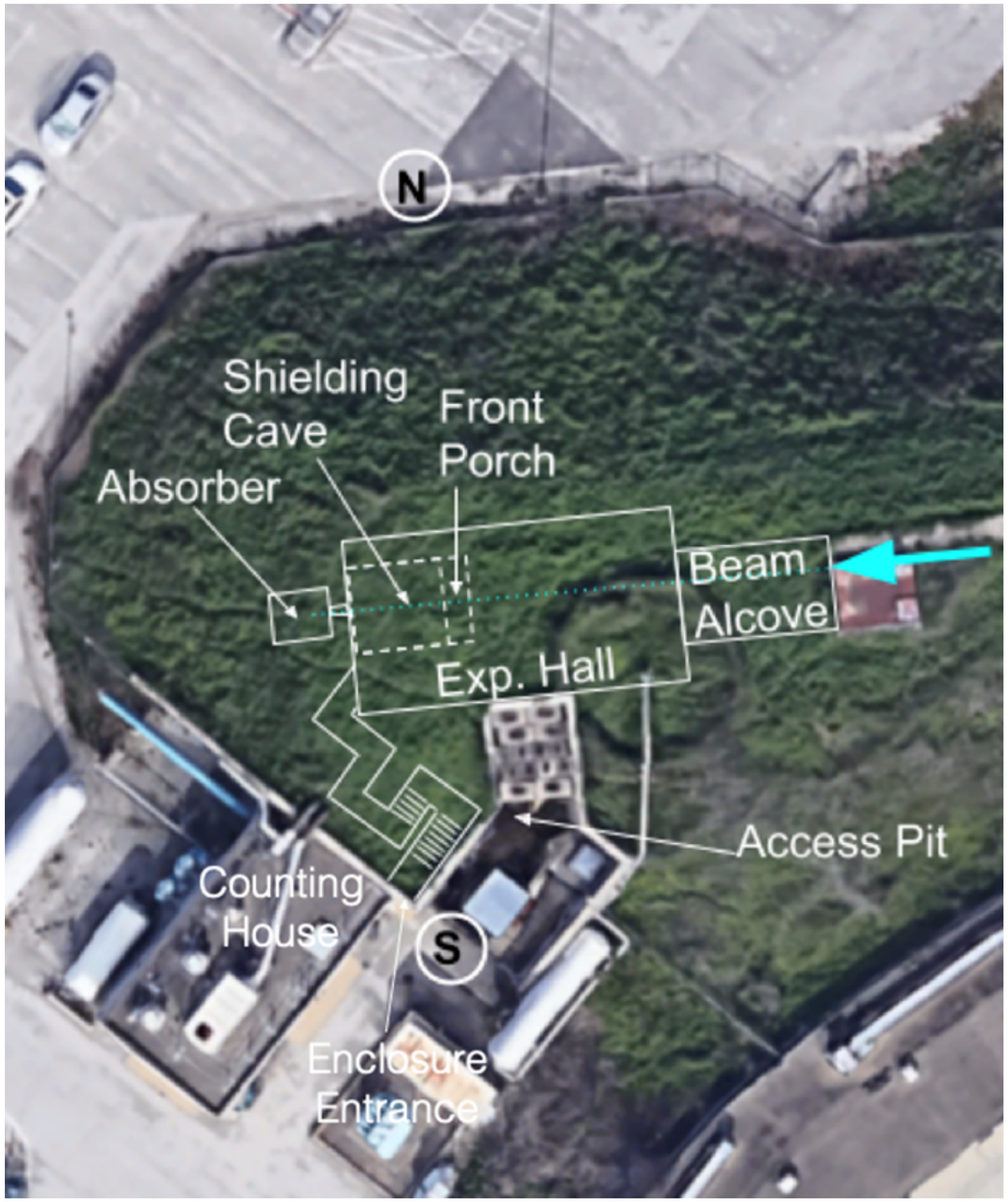
3D Sensors

- HL-LHC necessitates upgrade of ATLAS, CMS pixel detectors
  - High granularity, rad hard, coverage to $|\eta| < 4$
  - Fluence of ~3.5E16 n_{eq}/cm^2 expected in CMS inner layer
- 3D sensors more robust to radiation
  - Decouple sensor thickness and charge drift distance
  - Lower power dissipation to reduce thermal load
- ATLAS to use 3D sensors in inner layer of pixel detector; CMS to decide (mid-April)



Fermilab Irradiation Test Area

- Irradiation Test Area (ITA) operating at Fermilab since Jan. 2020
- 400 MeV Linac protons
- Nominal intensity 2.7E15 protons / hour
- Gaussian beamspot, ~1cm nominal width



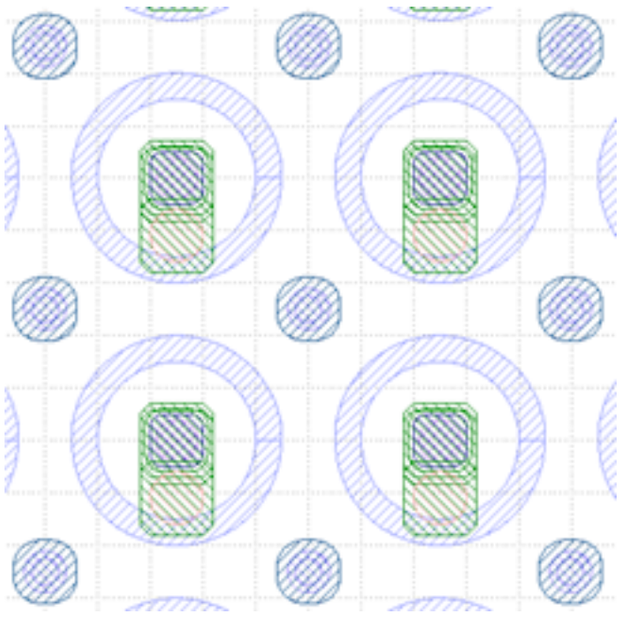
Irradiation of CMS Pixel Sensors

- CMS HL-LHC pixel sensors pilot users of Fermilab ITA
- 3 irradiation campaigns, each targeting 2E16 n_{eq}/cm^2
  - February/April, June, and November 2021
    - Issues with beam targeting, resulting in lower fluences and/or fluence gradients for some sensors
- Mixture of planar and 3D sensors from different foundries including Hamamatsu, CNM, and FBK
  - CNM 3D focus of this talk

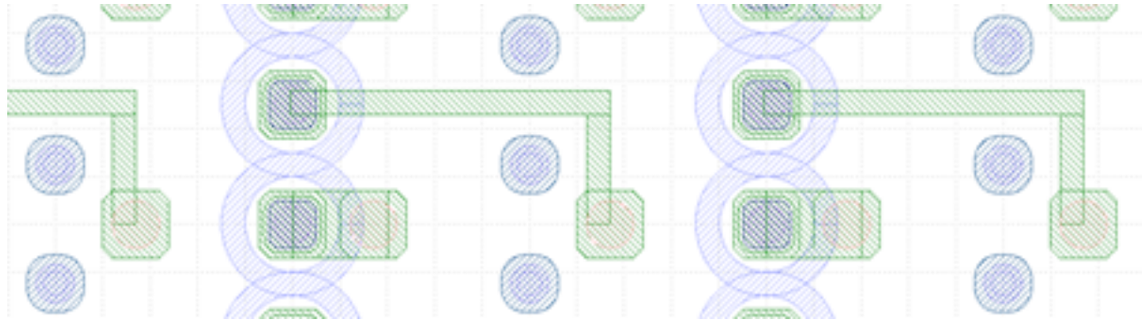
Sensors of Interest

- Focus on measurements of sensors with different fluences and pixel cell geometries
  - 50x50 and 25x100 µm pixel cell
  - 1.3E16, 1.4E16, and >2E16 (exact value TBD) n_{eq}/cm^2 fluence
- This talk shows results for 50x50 and 25x100 µm sensors at 1.3E16 n_{eq}/cm^2 (analysis of other sensors ongoing)

50x50

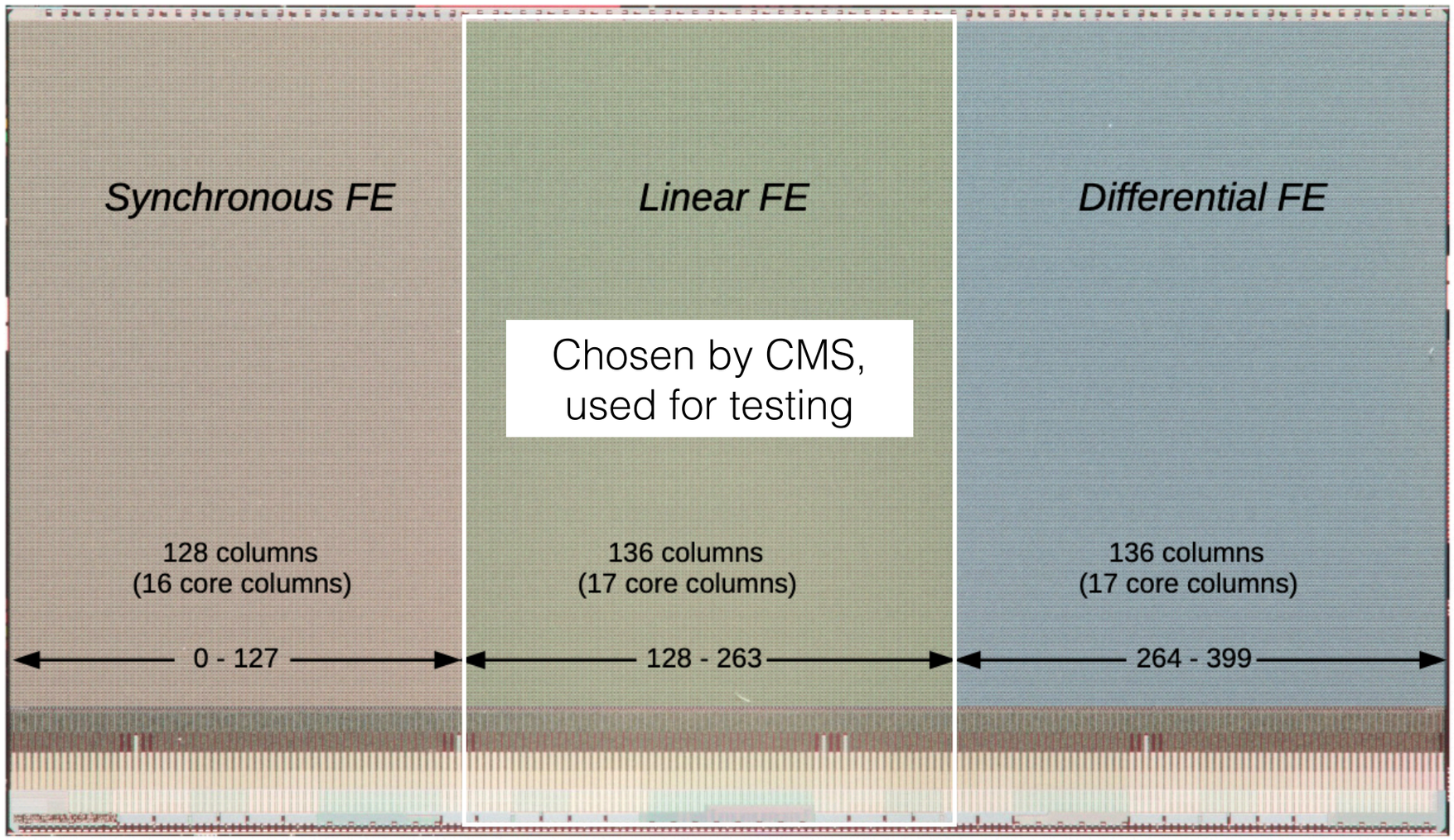


25x100

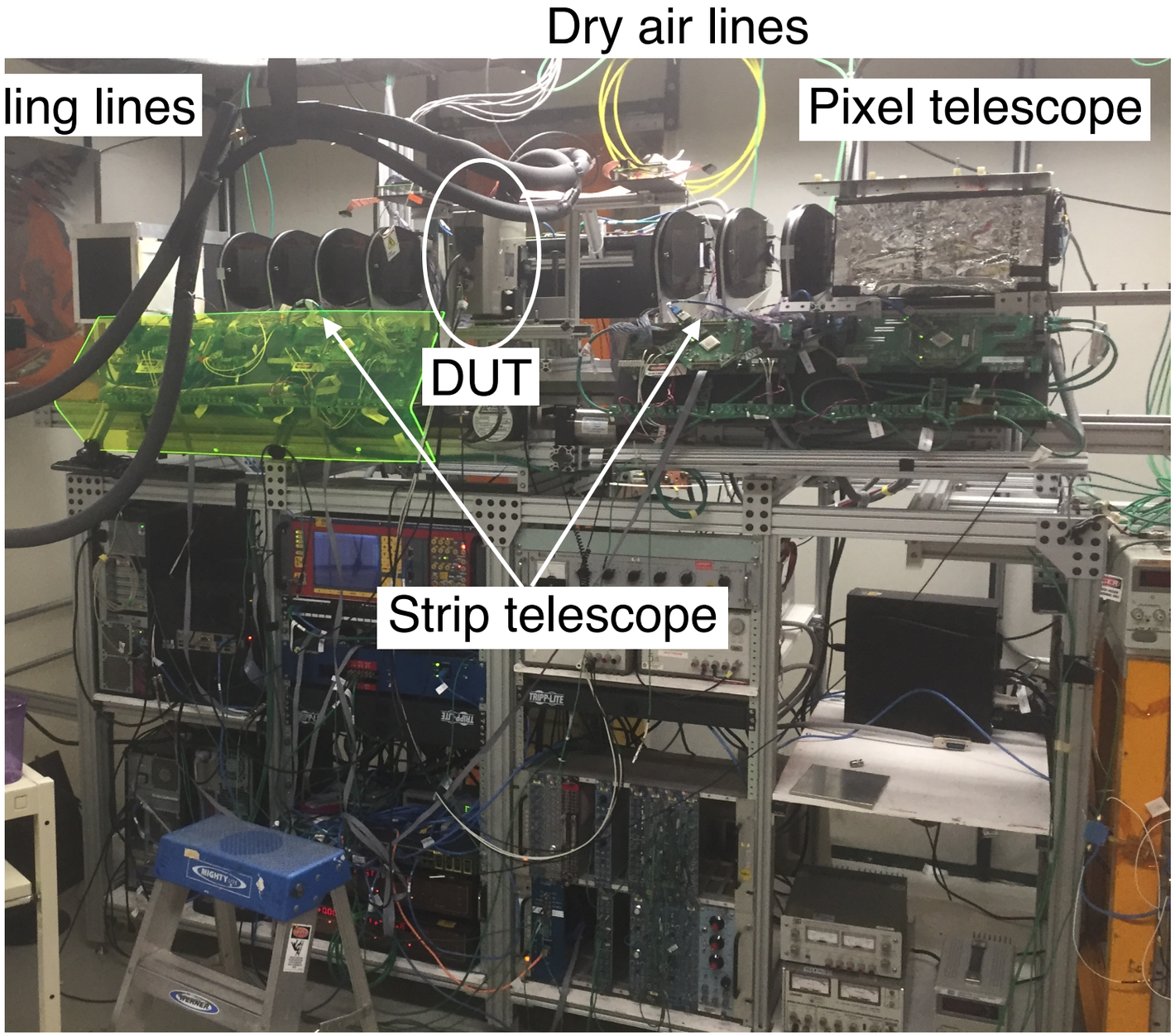


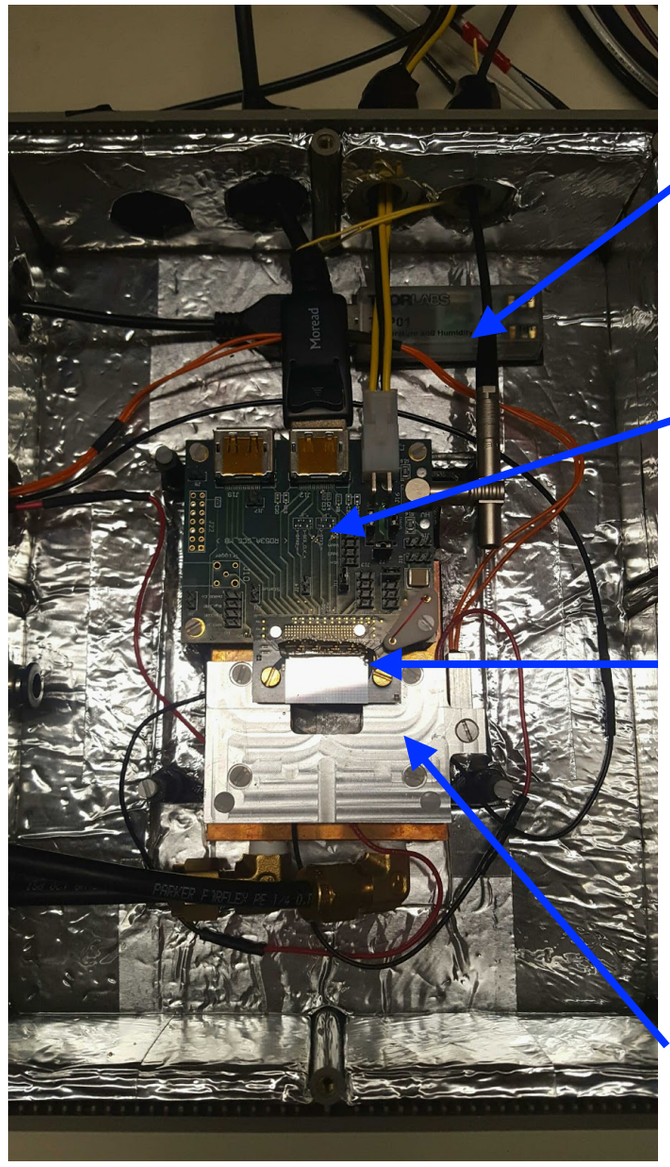
RD53A Readout Chip

- RD53A: common ATLAS+CMS prototype readout chip
  - 65 nm CMOS
  - Three analog front ends



Fermilab Testbeam Facility

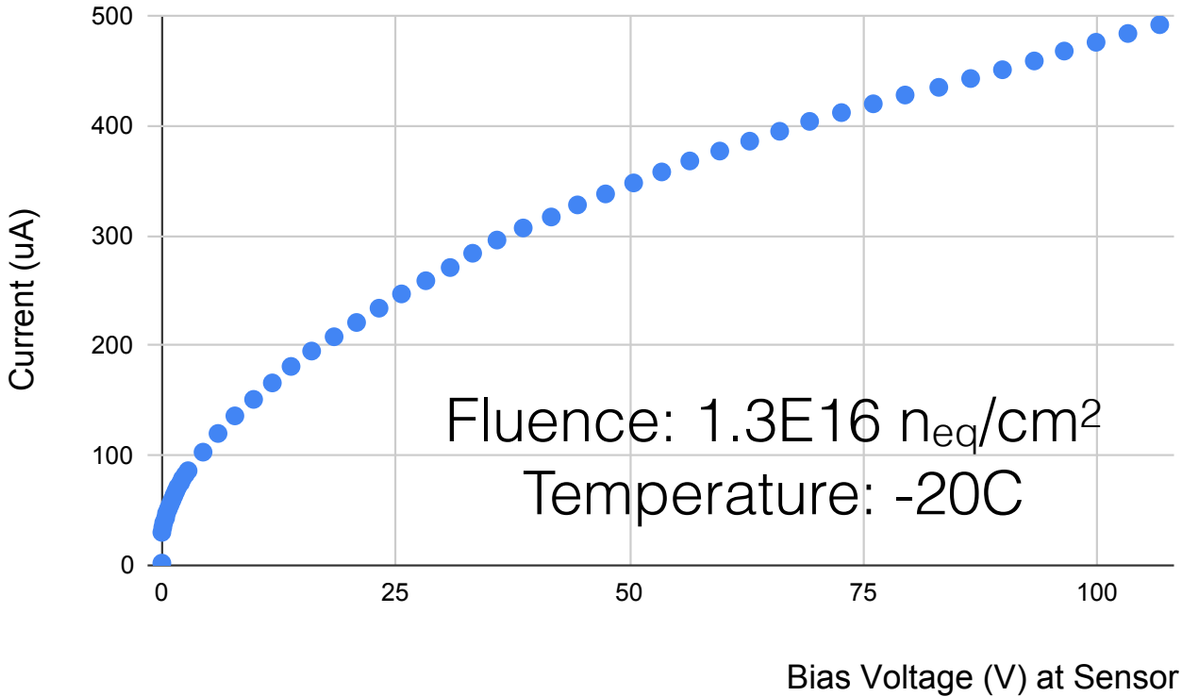


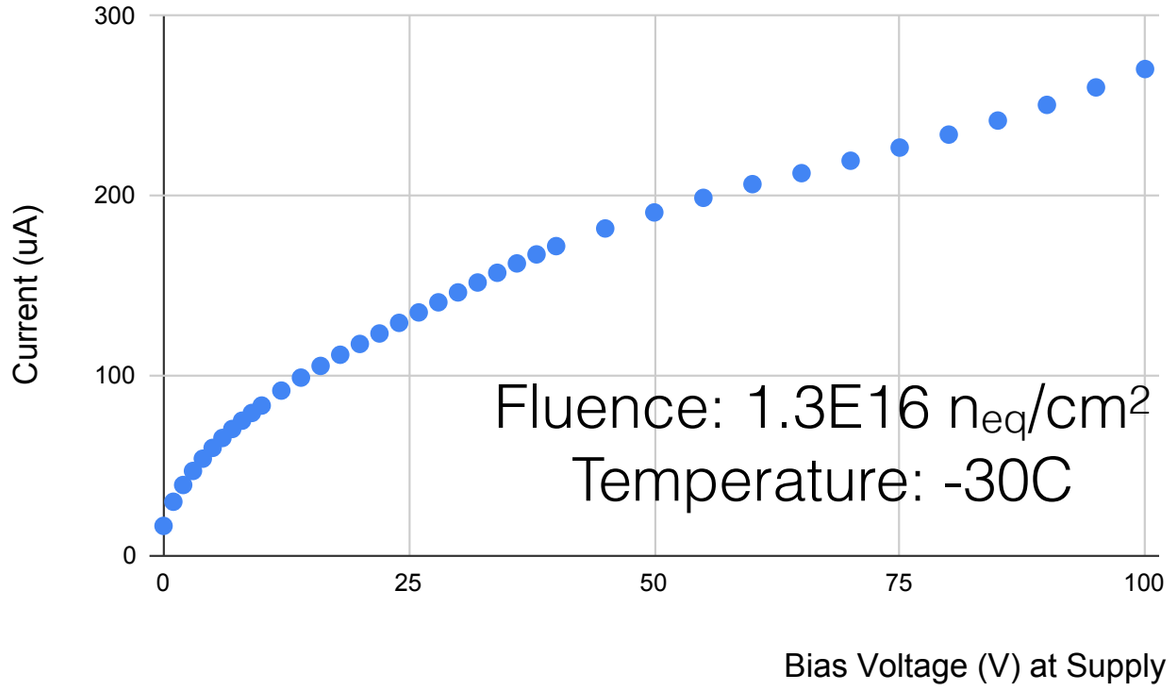


Thanks to INFN Milano for coldbox!

Beam details: 120 GeV protons
4.2s spill with ~80k protons every 60s
53MHz beam frequency

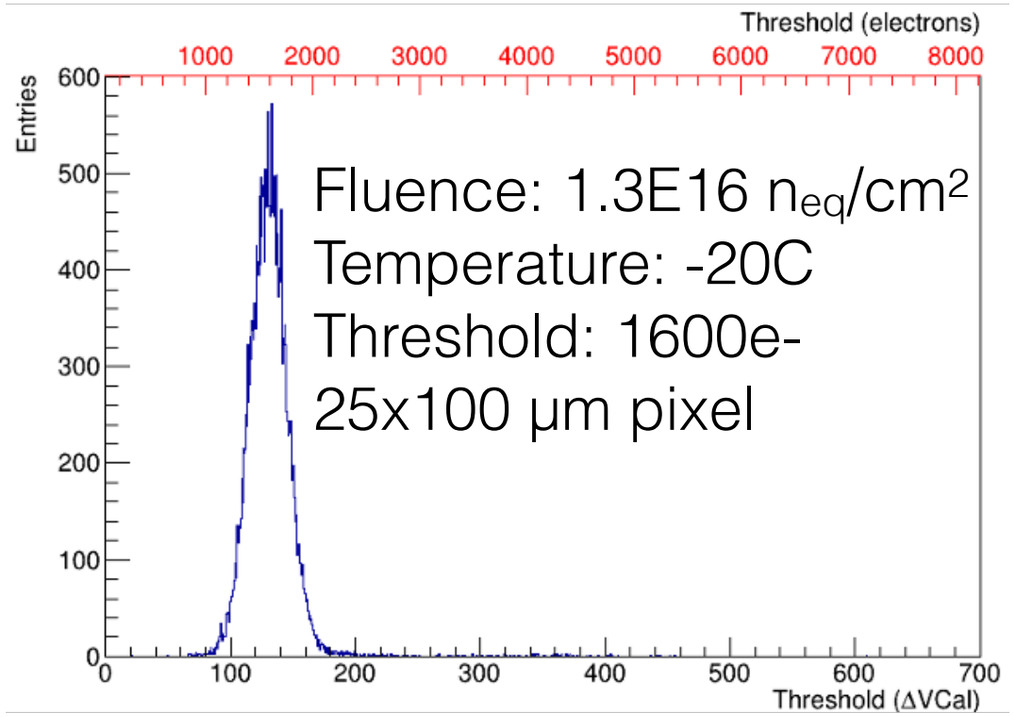
Sensor IV Characterization

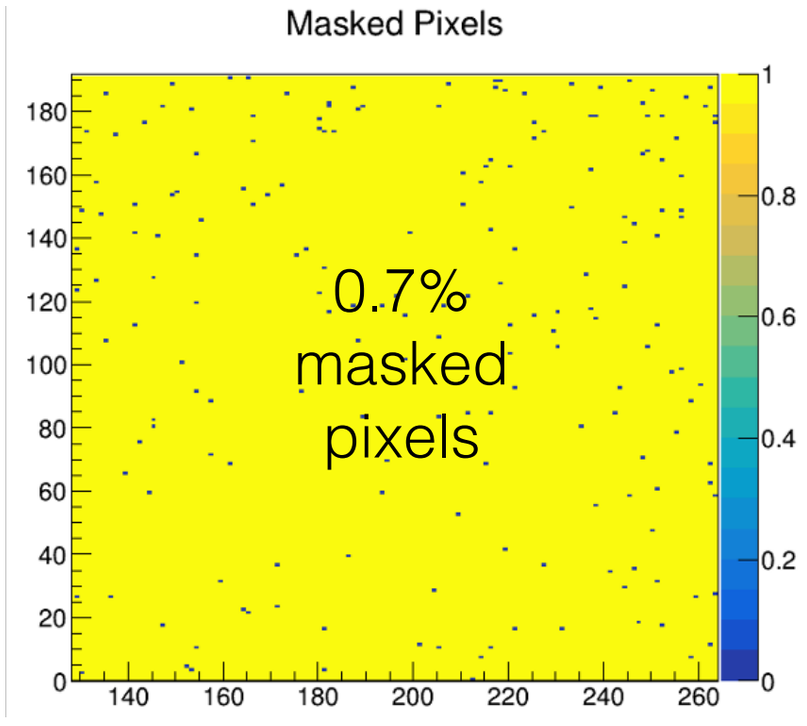




Sensor Tuning

- Threshold adjustment
  - Target ~1% noisy pixels (~1600e-)
  - Noisy pixels = noise rate 1E-05
- Mask remaining noisy pixels
- Extract charge calibration (digitized value vs injected charge) to use in cluster reconstruction



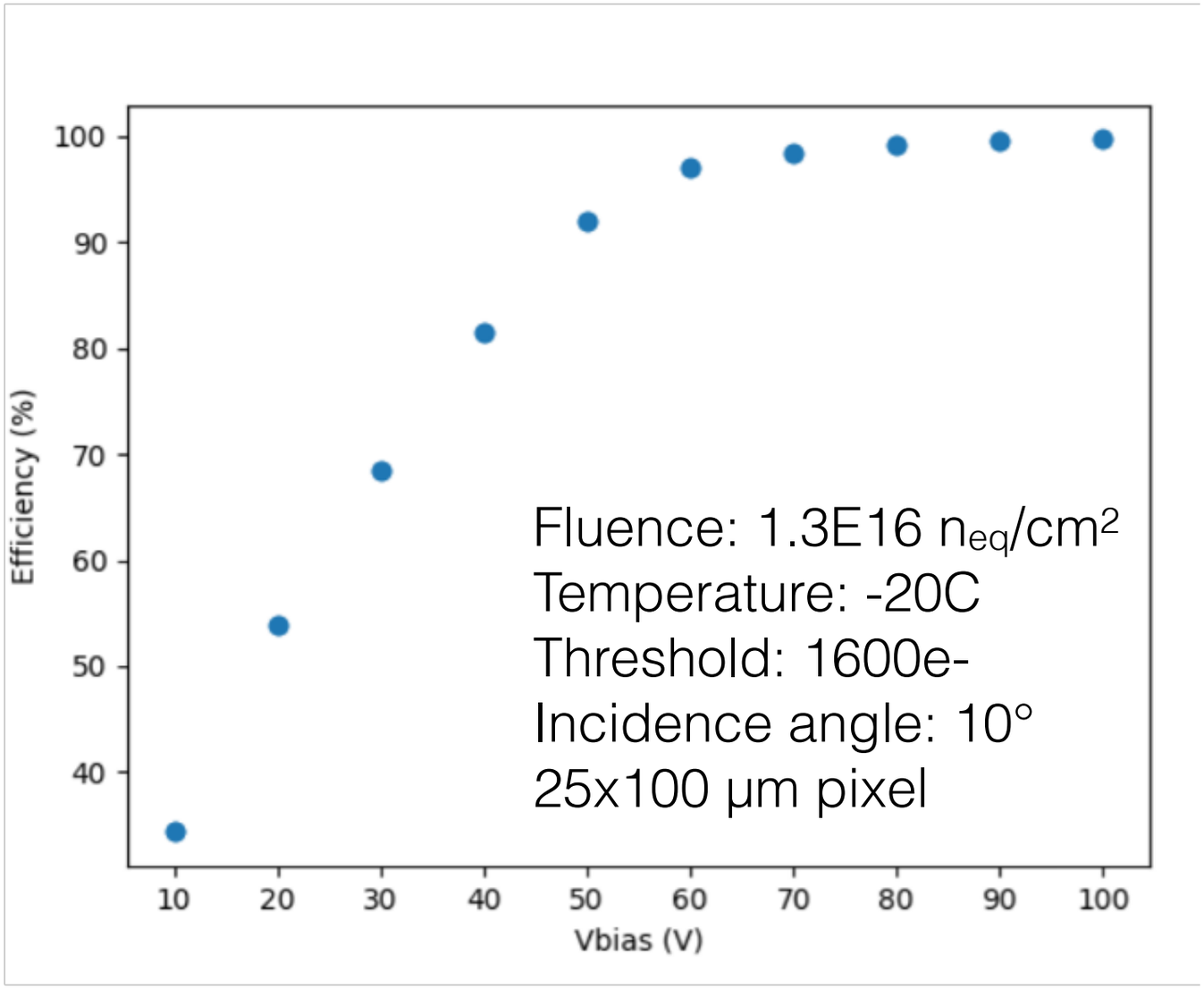


Testbeam Data Analysis

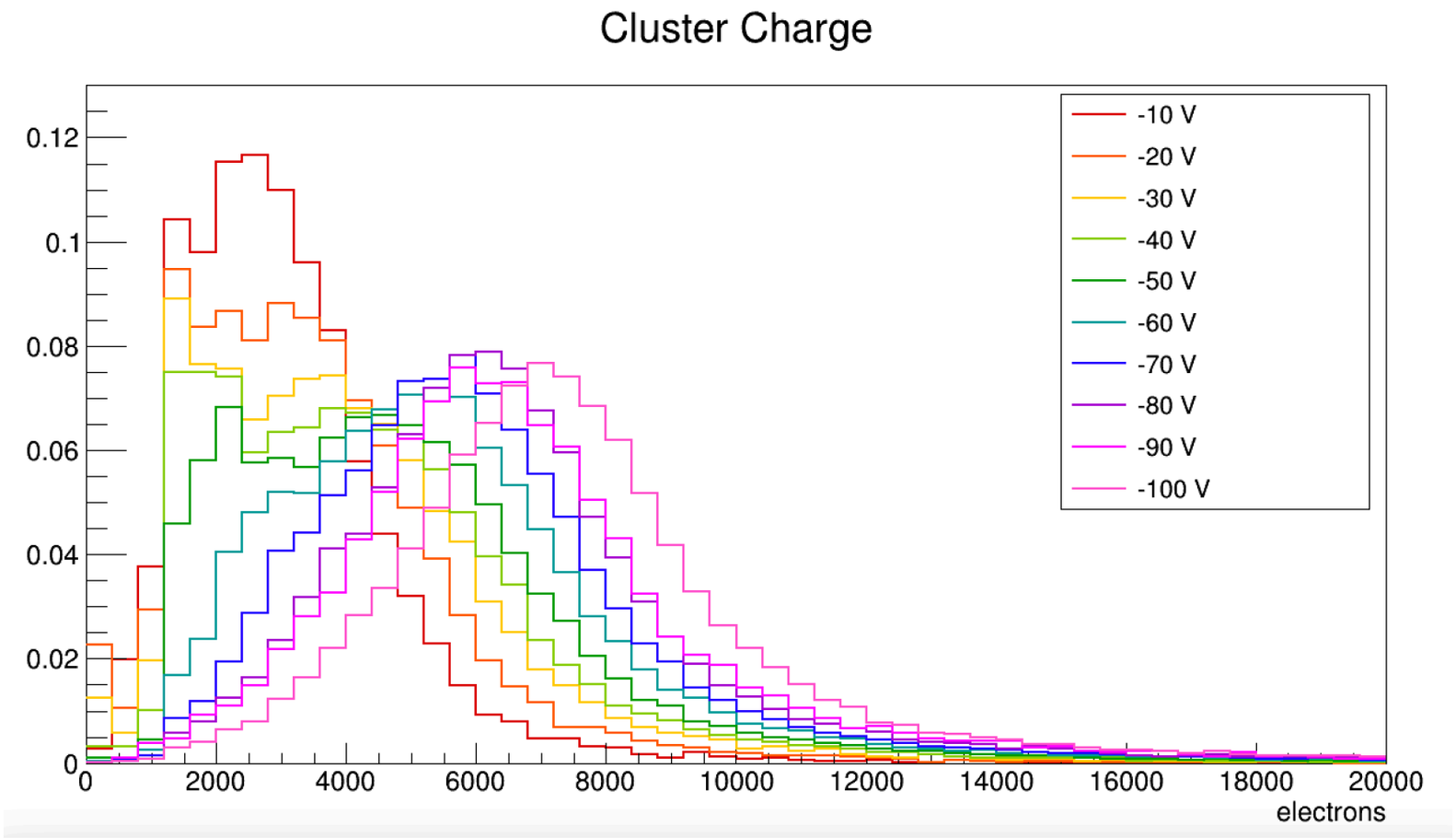
- Sensor calibration and readout performed using FC7 DAQ
  - Interfaced with testbeam OTSDAQ for data synchronization
- Track reconstruction and alignment performed with Monicelli
  - Kalman filter tracks
  - Pixel geometry, charge calibration provided as inputs

Hit Efficiency vs Bias

- Max efficiency >99%
  - For Vbias > 80V



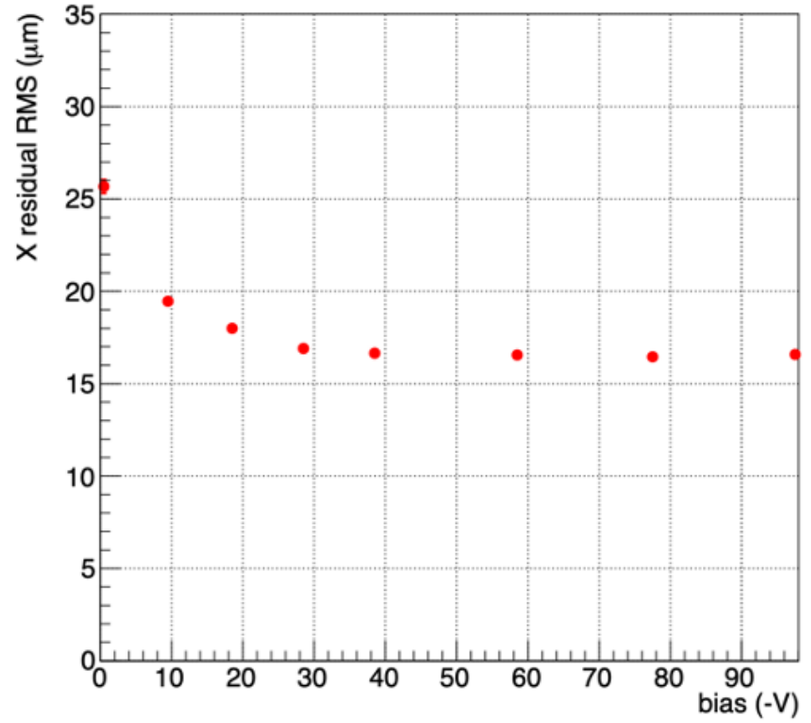
Cluster Charge vs Bias

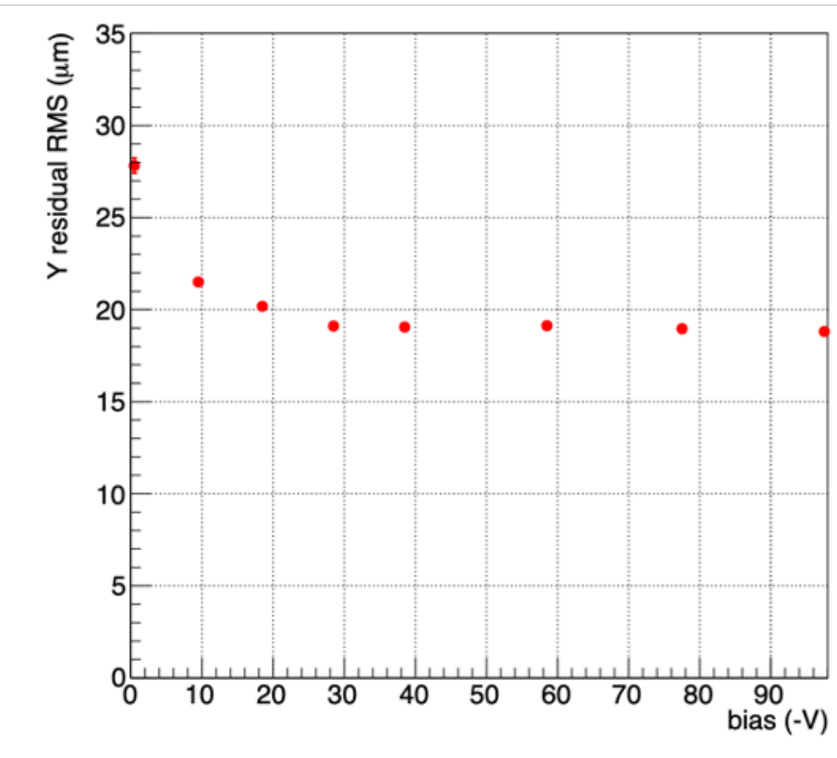


- Fluence 1.3E16 n_{eq}/cm^2, temperature -20C, incidence angle 10°, threshold 1600 e-, 25x100 µm pixels
- Charge increases with bias up to 100V —> not yet fully depleted

Residuals vs Bias

- Fluence 1.3E16 n_{eq}/cm^2
- Temperature -30C
- 50x50 μm pixel cell, normal incidence
- Threshold 2100 e-
- Residuals at full efficiency: 16 μm X, 19 μm Y
  - Consistent with pixel geometry
  - Telescope resolution ~5 μm





Summary

- 3D sensors potentially improve rad hardness of CMS HL-LHC tracker inner layer
  - Sensor decision to be made in ~April
- Irradiation program at Fermilab ITA supports CMS HL-LHC sensor testing
  - Paired with testing program at Fermilab Test Beam Facility
- Large set of data on irradiated CNM 3D sensors accumulated in past year
  - Testbeam measurements at various angles and bias voltages, plus lab bench testing
  - Analysis of full dataset ongoing

US Testbeam Group

Corrinne Mills, Titas Roy, Joaquin Siado Castaneda, Joey Reichert, Jason Thieman, Scarlet Norberg, Atanu Pathak, Christine McLean, Susan Dittmer, Sofia Lasky-Headrick, Hugo Becerril, Sahithi Rudrabhatla, Samuel Bright-Thonney, Liam Foster, Edgar Albelo Ortiz, Mauricio Matta Seclen, Jahid Hossein, Jesse Harris, Hsin-Wei Hsia, Gail Hanson, Jieun Yoo, Abbas Hassani, John Cumalat, Stefan Spanier, Matthew Jones, Julia Thom-Levy, Stephen Wagner, Karl Ecklund

FC7, telescope, cold box, & essential advice: Lorenzo Uplegger, Luigi Moroni, Mauro Dinardo, Davide Zuolo, Ioannis Kazas

ITA & FTBF: Mandy Kiburg, Evan Niner, Jason St. John, Petra Merkel, Erik Ramberg, with support from the particle physics (PPD) and accelerator (AD) divisions

BACKUP