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The Fermilab Test Beam telescope upgrade

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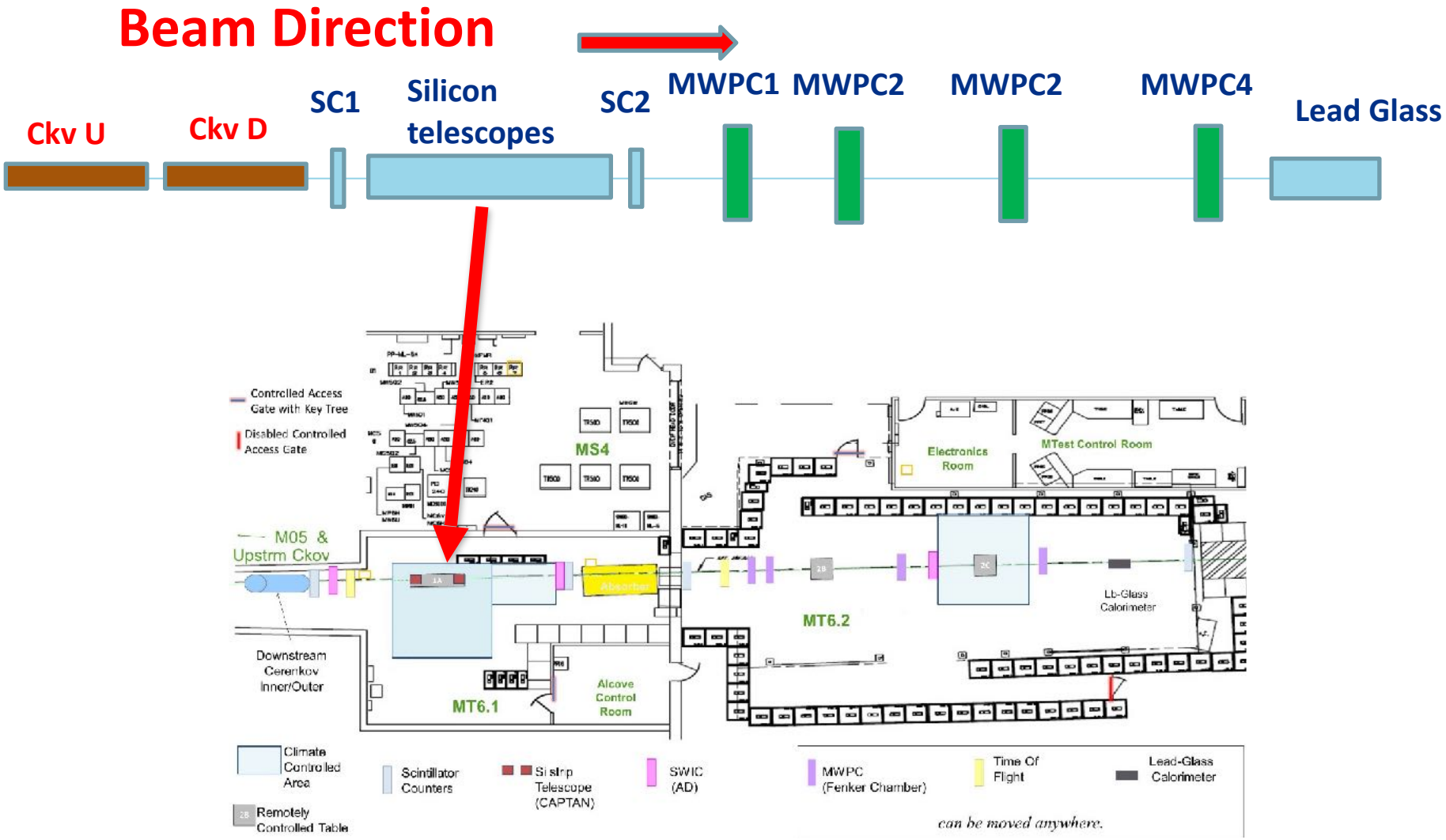
Introduction

- The Fermilab Test Beam Facility has been in operation since 2005
- 2 Beamlines (MTest and MCenter)
  - Energies range from 120 GeV protons in the primary line down to 200 MeV particles in the tertiary line
- MTest offers 2 tracking telescopes:
  - A dedicated ATLAS pixel telescope
  - A CMS based silicon telescope that will be the topic of this talk

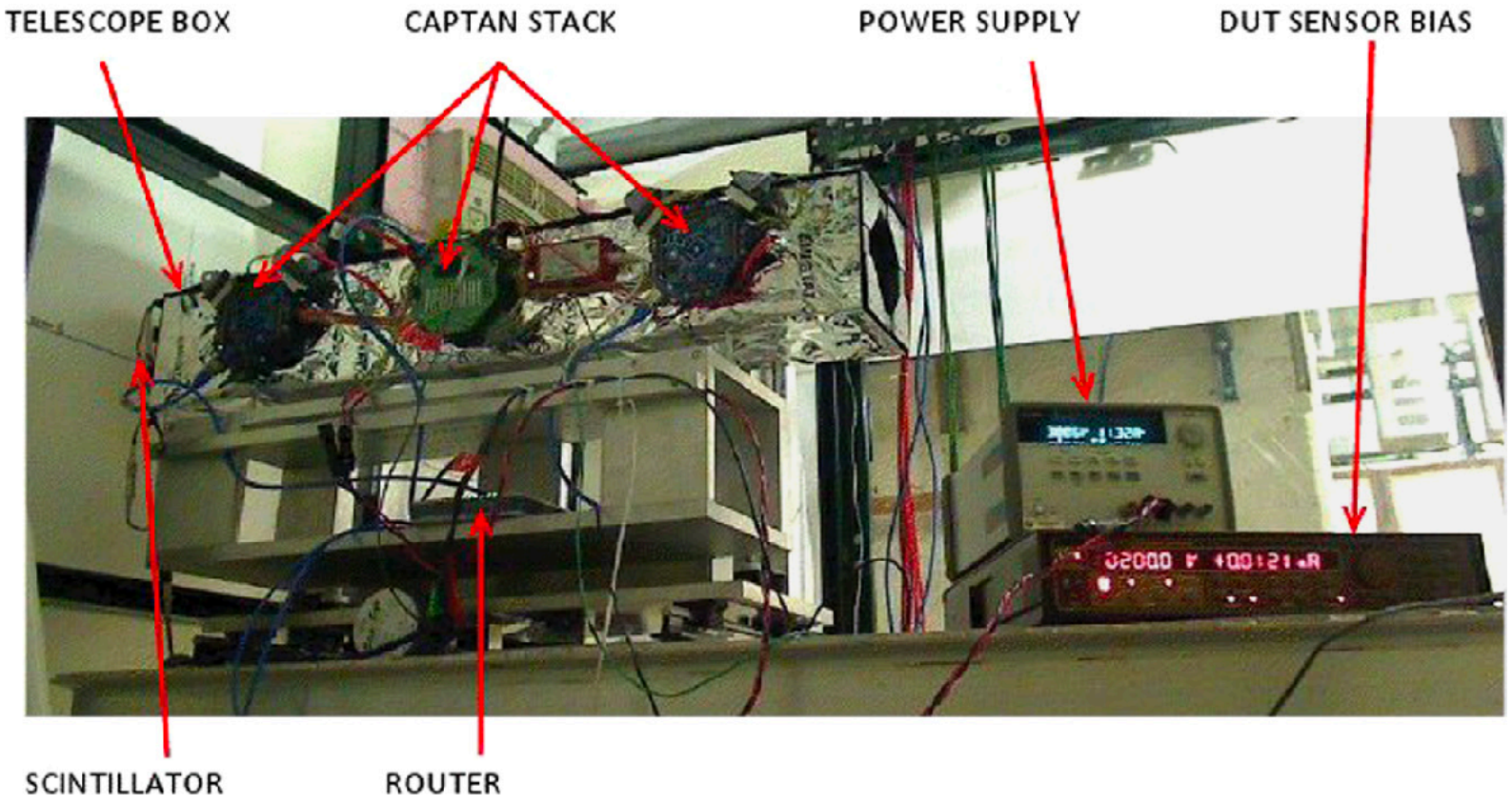
Beam Instrumentation Layout – MTest



Tracking at FTBF

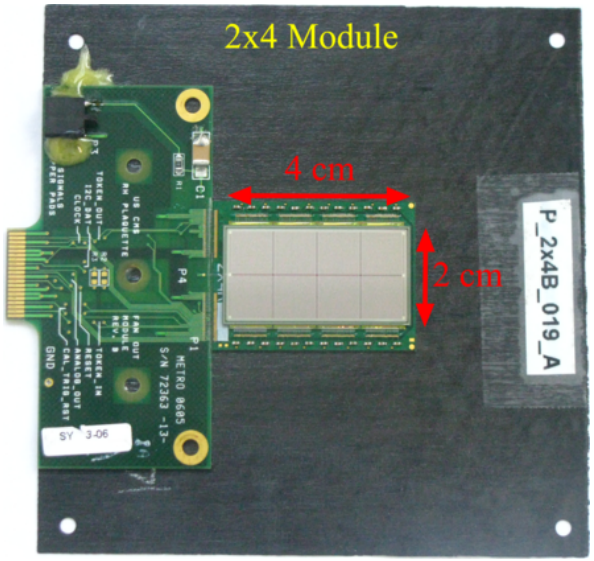
- Since 2009 tracking has been done using a silicon telescope
- The first one was based on pixel detectors used for CMS

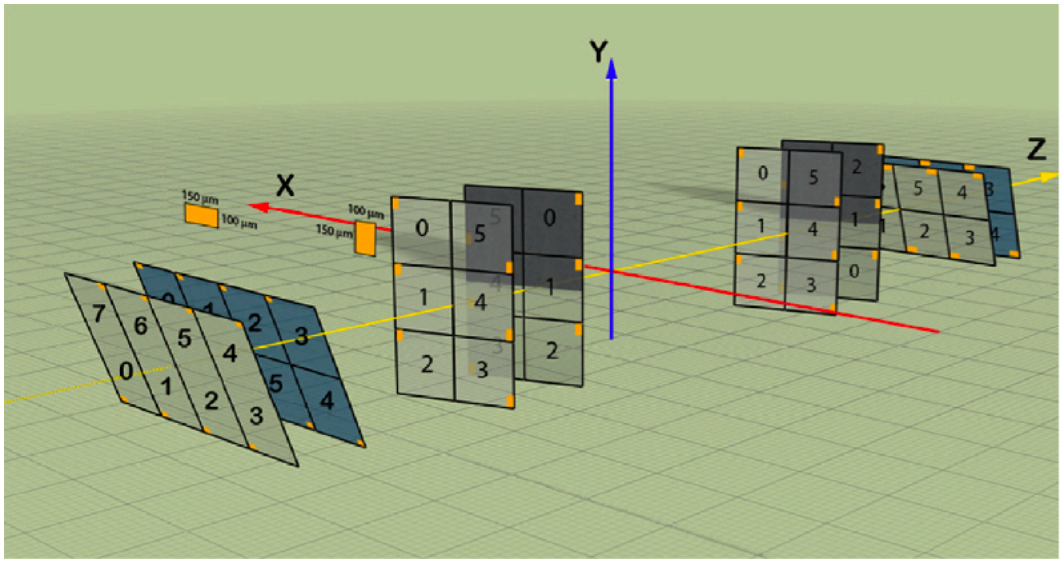
http://www.sciencedirect.com/science/article/pii/S0168900215015521



Telescope 1

- The first telescope installed at FTBF in 2009 was based on the leftover modules from the production of the Phase 0 CMS pixel detector.
- The modules are composed by 2 rows of PSI46 ROCs with 3 or 4 ROCs each row.
- Each ROC has 52 columns and 80 rows for an area of ~0.81x0.81cm^2
- The pixels are 150x100 um^2
- 8 modules were installed. 4 Measuring more precisely Y while other 4 X
- The pixel telescope has a coverage of ~1.6 x 1.6 cm^2
- Minimal material in the path of the beam





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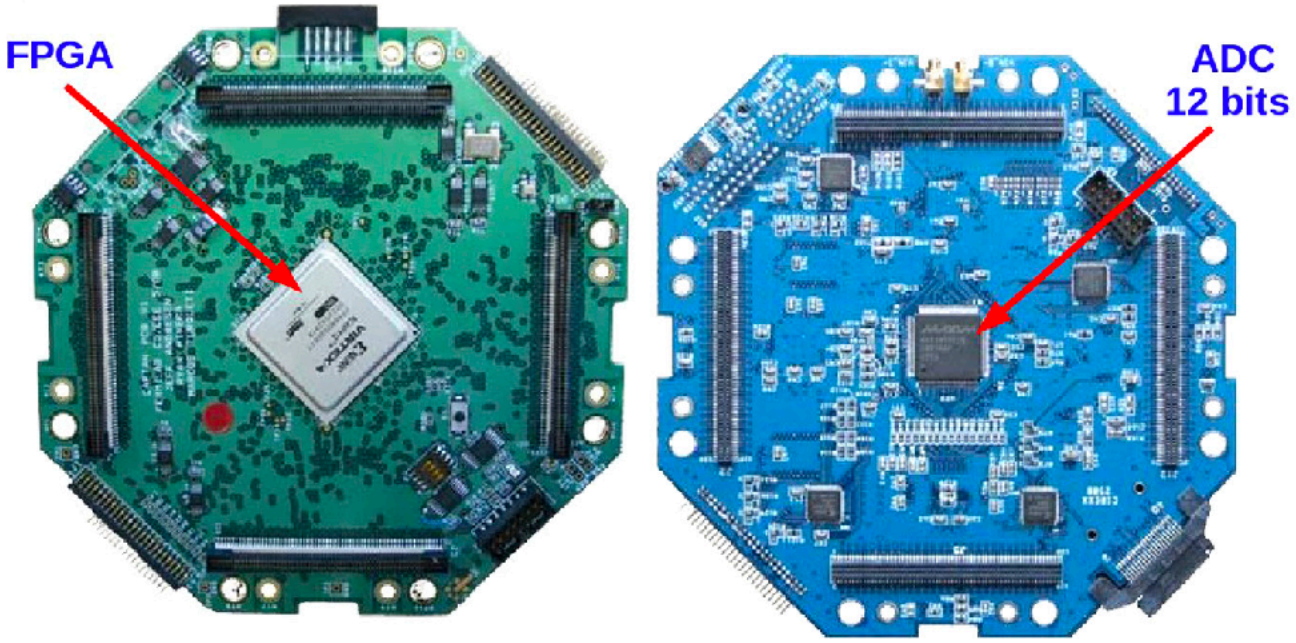
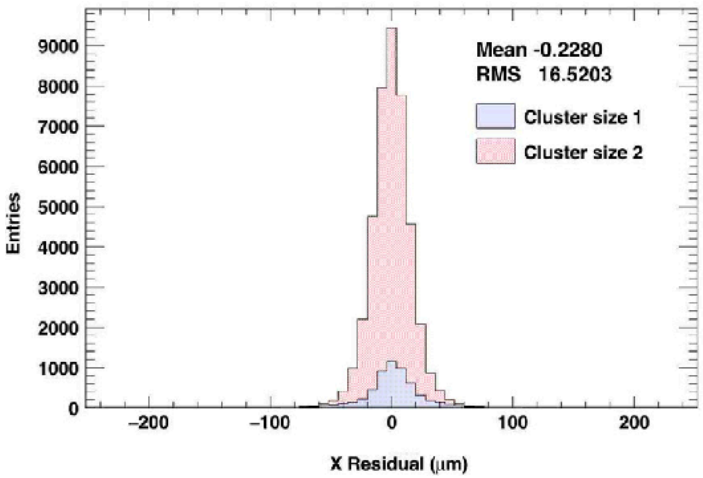
Telescope 1 DAQ

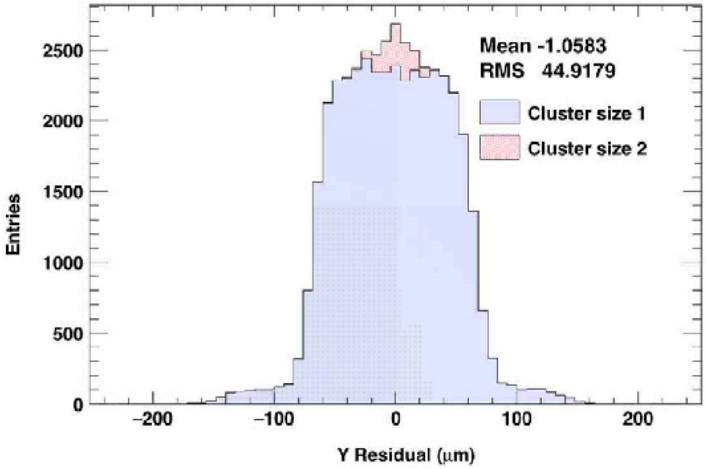
- The DAQ is based on the CAPTAN board developed at Fermilab featuring a Virtex 4 FPGA which can transfer data at 1Gb/s
- We also develop a 12 bit ADC card to readout the fully analog charge and readout the levels of the PSI46 CMS pixel chip



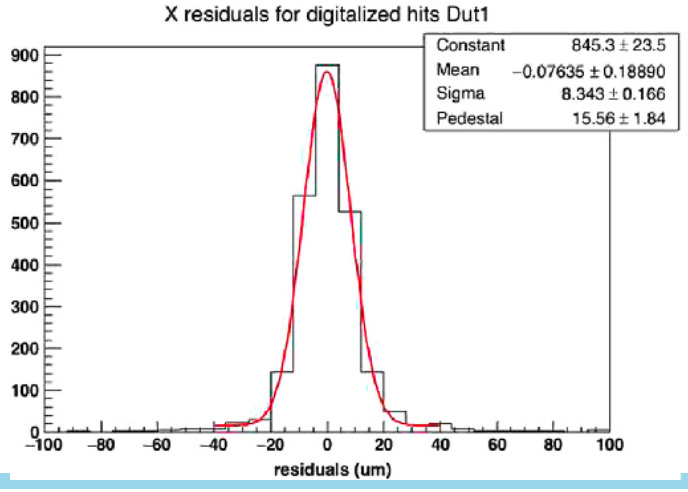
Resolution Telescope 1

- With the 20^0 tilt and the fully analog readout, we exploited charge sharing to measure a resolution of about 16um in one direction and ~45um in the other





- The projected resolution on the DUT is about 8um, measured on a 3D pixel detector.



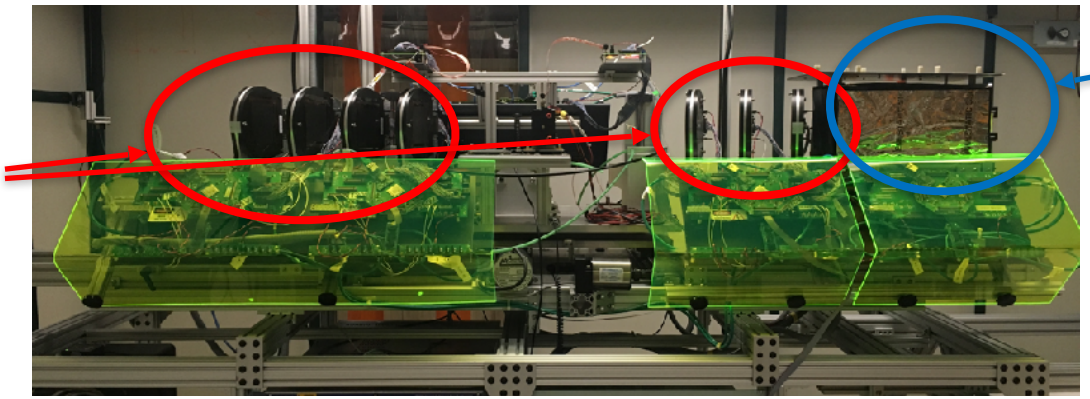
Telescope 2

- In 2013 the facility, in collaboration with Purdue university, decided to upgrade the telescope for few reasons:
  1. In the previous years we had many users with large detectors that they had to move around to be able to scan the whole area. With a coverage of only 1.6x1.6 cm^2 the scan was time consuming.

  2. To study the next generation of pixel detectors for the CMS phase 2 upgrade the resolution started to become an issue and a more precise telescope was needed.

- The decision was to upgrade the system to a hybrid of pixels and strips

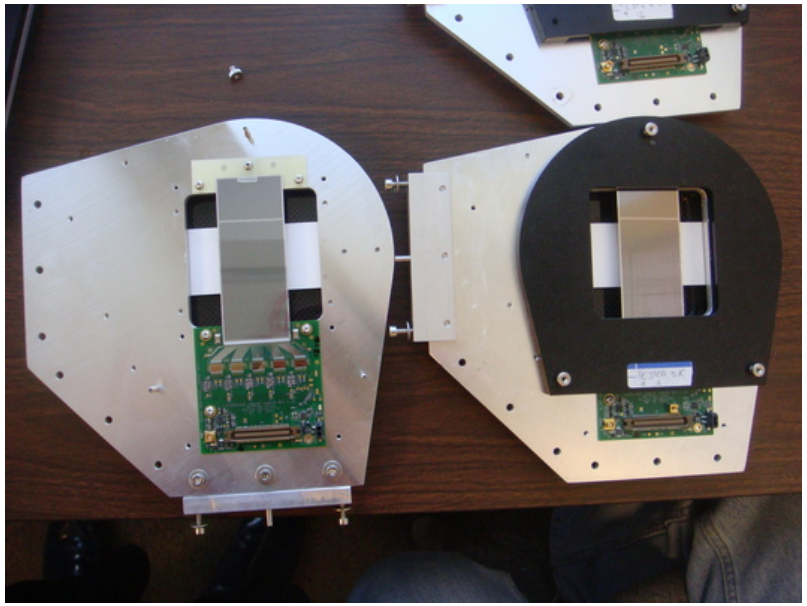
Strip telescope (2 movable arms can leave enough space for any device to be mounted on a remotely controlled moving table)



Pixel planes for hit confirmation

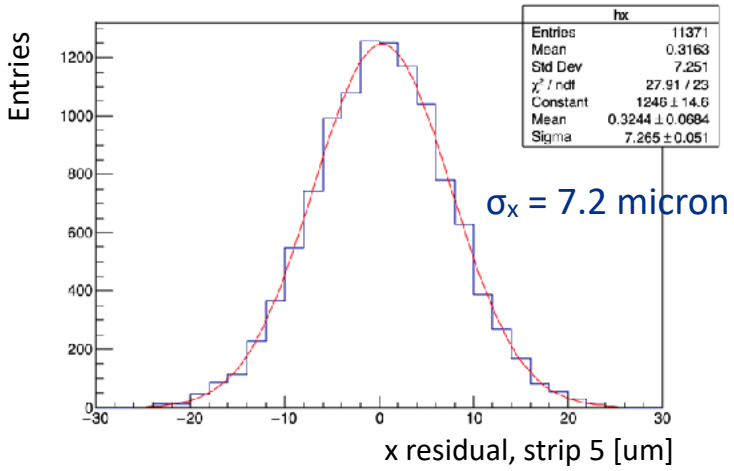
Telescope 2

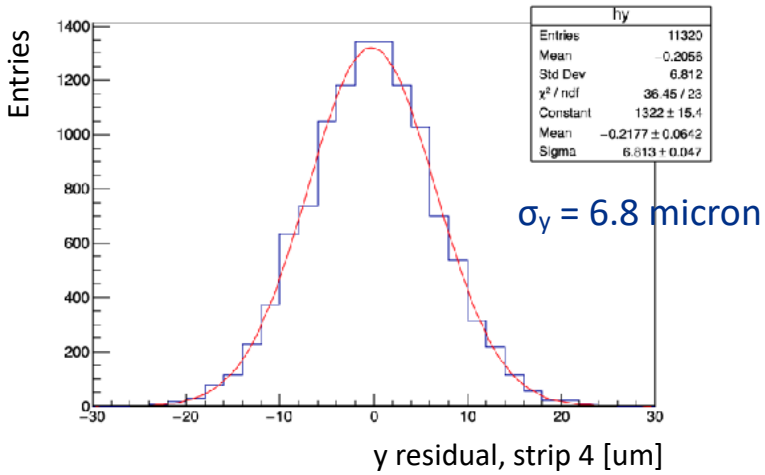
- The strip detectors are leftover production of the cancelled D0 run IIb, while the readout chip is the FSSR2 chip leftover of the cancelled BTeV experiment
- Each station is composed by two sensors mounted on a support, rotated by 90^{o} relative to each other
  - ✓ a 2D hit position can be reconstructed from each pair of sensors
- Each sensor has 640 (1280) strips and a thickness of 320 μm
- The overlap area of the two sensors is 3.8 x 3.8 cm^{2}
- Strip pitch is 30 μm while the readout pitch is 60 μm, exploiting the capacitive charge-division



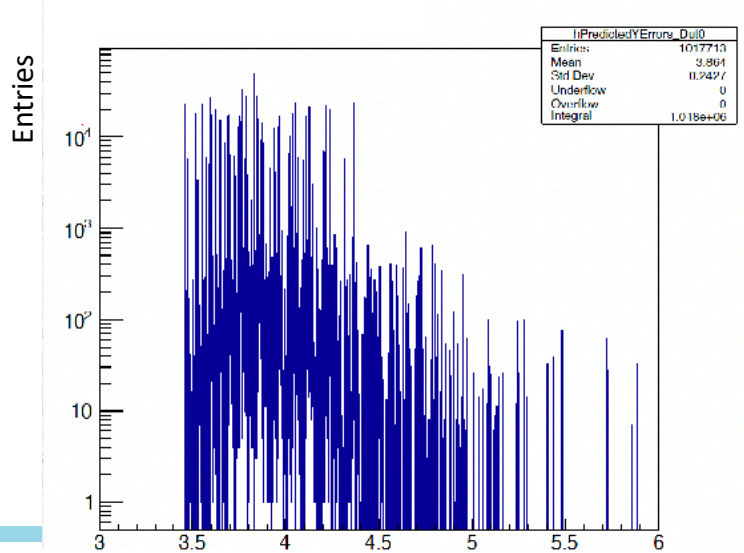
Resolution Telescope 2

- The observed residuals in the strips indicate per hit resolution of 7 microns





- The mean projected resolution on the DUT is about 4um



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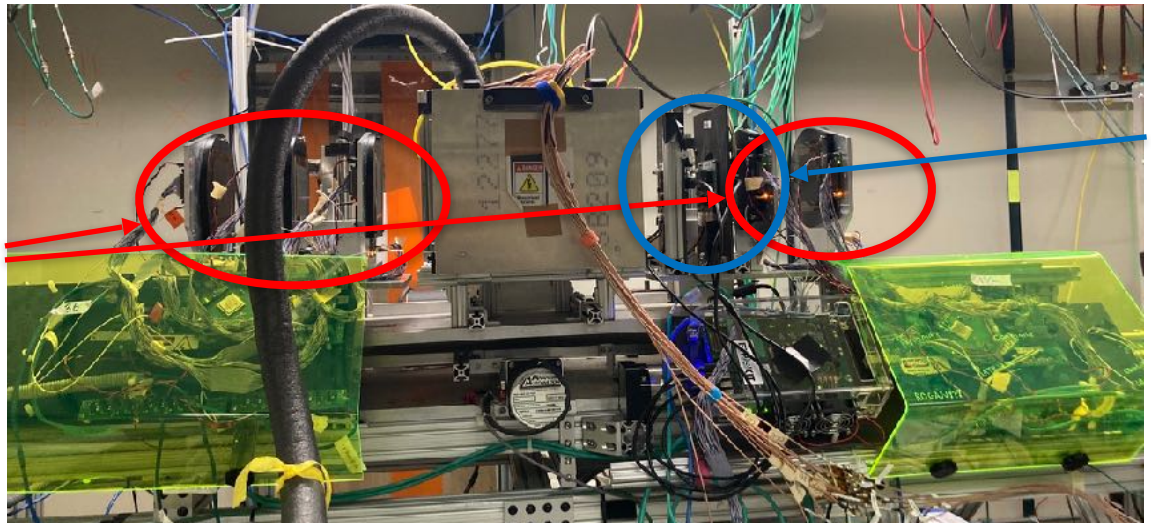
Telescope 3

- In 2022 the facility, in collaboration with INFN Milan and Firenze, decided to upgrade the telescope for few reasons:
  1. The pixel part of the telescope is based on an old DAQ written on Windows that required a lot of maintenance and could not be integrated in OTSDAQ while the RD53A is
  2. Adding more precise pixel detectors will improve the resolution on the DUT

- The new pixels are based on the RD53A chip and are mixed with the strips detectors in a configuration similar to the previous one but with the pixels now close to the DUT for better resolution

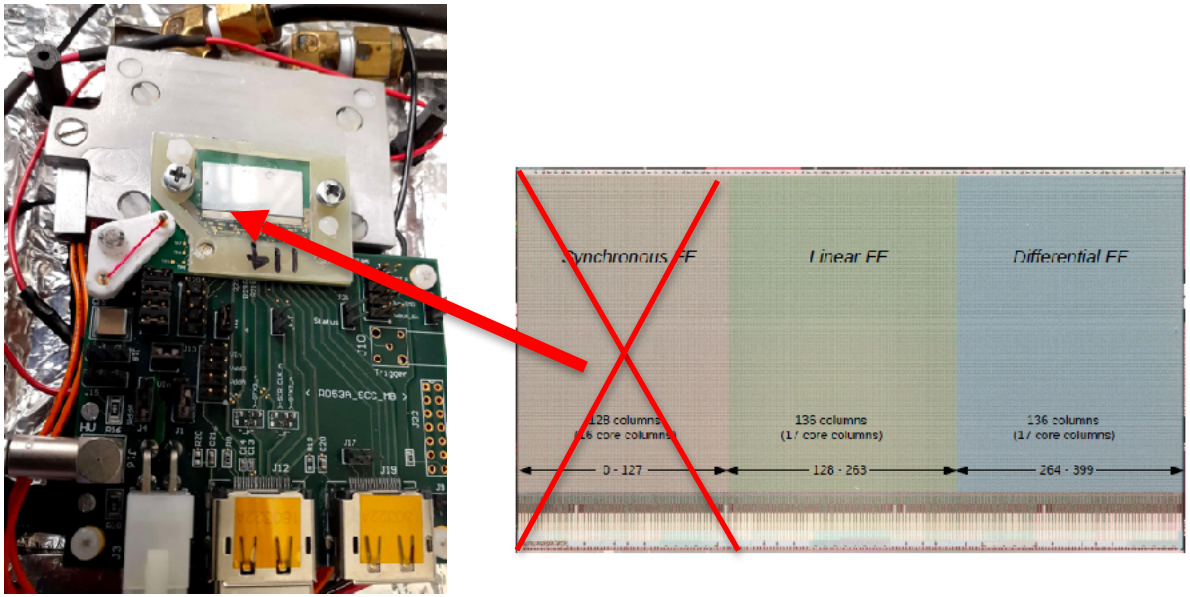
Strip telescope (2 movable arms can leave enough space for any device to be mounted on a remotely controlled moving table)

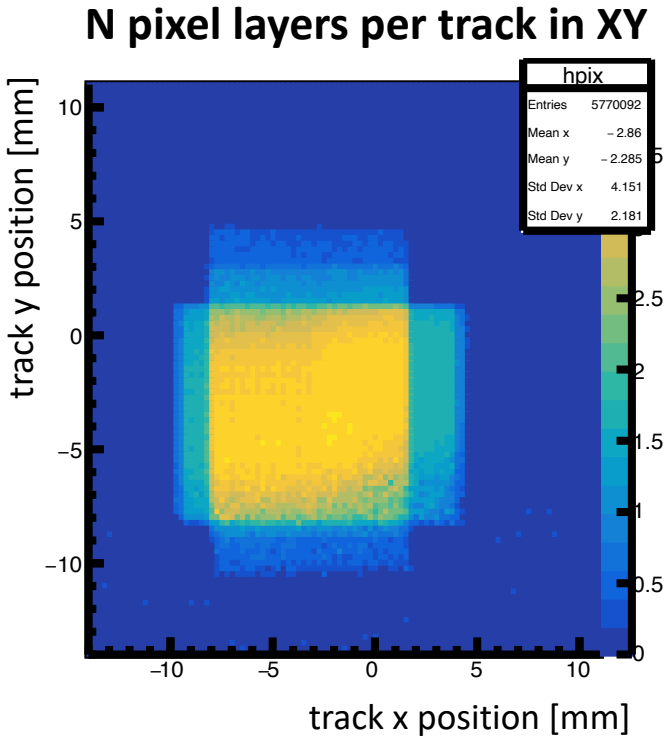


RD53A Pixel planes

Telescope 3

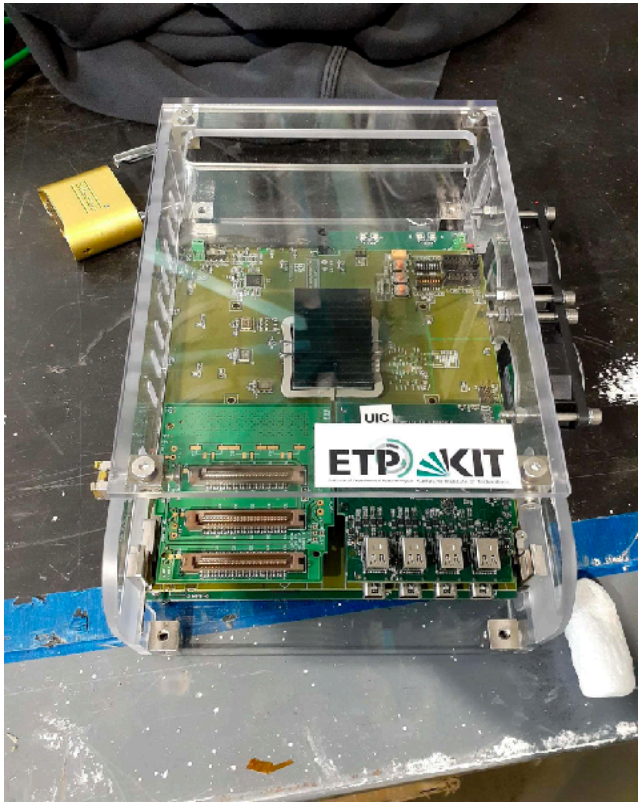
- 4 pixel detectors from the R&D of the CMS phase II upgrade have been installed
- Each sensor has 200 columns and 384 rows and a thickness of 120 µm. The chip readout has instead 400 columns and 192 rows but the first 128 columns are unused.
- The sensor pitch is 25x100 um^2
- Each station is composed by two sensors mounted on a support, rotated by 90^o relative to each other give the best resolution both in X and Y
- The overlap area of the 4 layers is 1 x 1 cm^2





Telescope 3 DAQ

- The pixel DAQ is based on the FC7 board developed at CERN.
- It is used by many systems in CMS (Inner Tracker, Outer Tracker and more)
- It features a Kintex 7 FPGA and 2 FMC connectors
- The software is the Ph2_ACF designed for the phase 2 upgrade of the CMS inner and outer tracker.

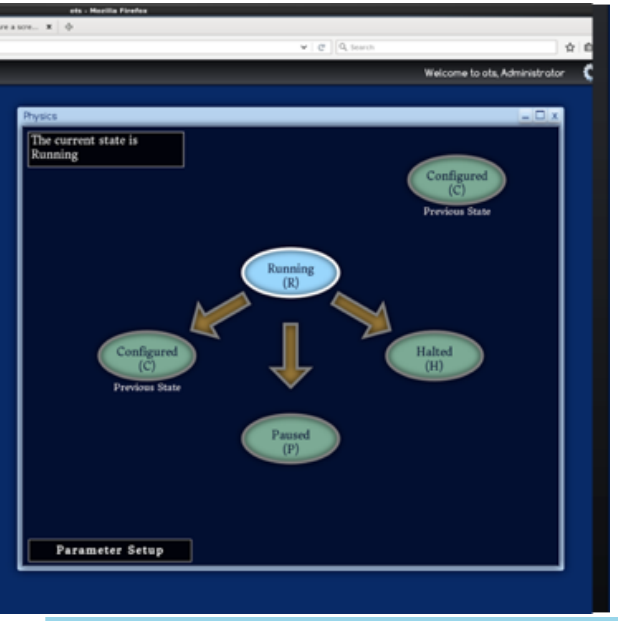


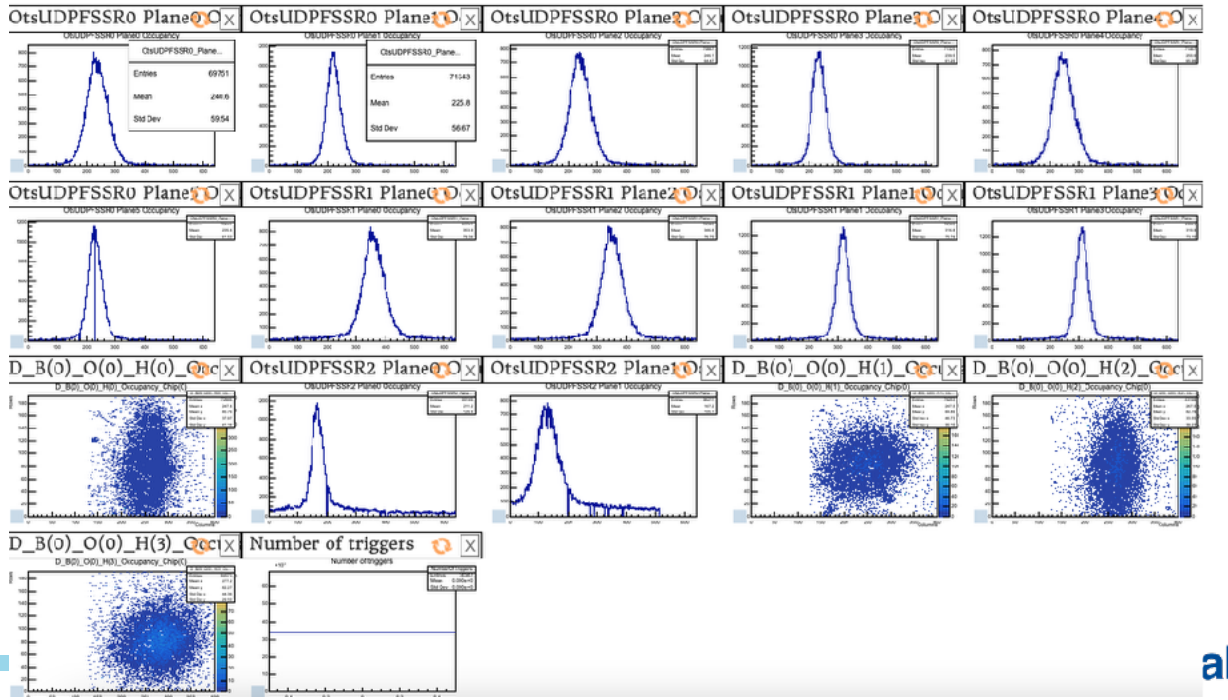
OTSDAQ DAQ

- The Fermilab computing division is developing an Off The Shelf Data Acquisition (OTSDAQ), based on XDAQ (CMS) and ArtDAQ (Fermilab)
- The silicon strip telescope is fully integrated in OTSDAQ, while pixels run ~separately on windows
- Few experimenters, CMS Outer Tracker, CMS Timing and RD53 chip, have been fully integrated in OTSDAQ and took data synchronized with the strip telescope

http://otsdaq.fnal.gov/

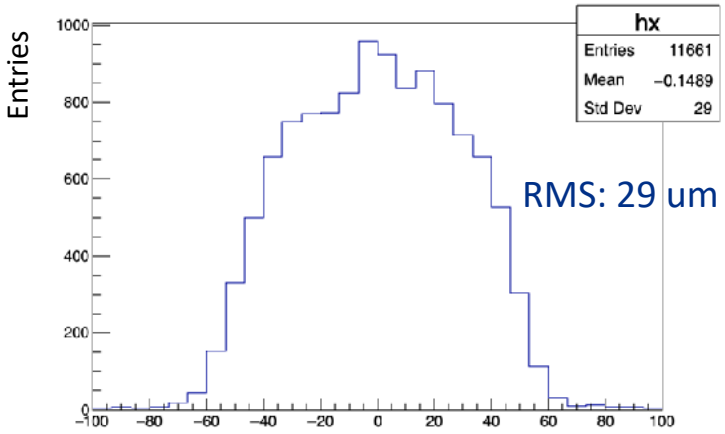
https://cdcvs.fnal.gov/redmine/projects/otsdaq/wiki



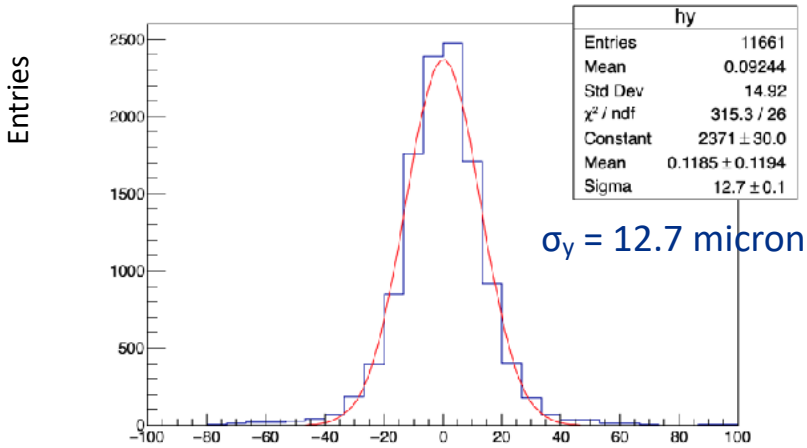


Resolution Telescope 3

- The observed residuals in the pixles indicate per hit resolution of 29 microns and 12 microns along long/short axes

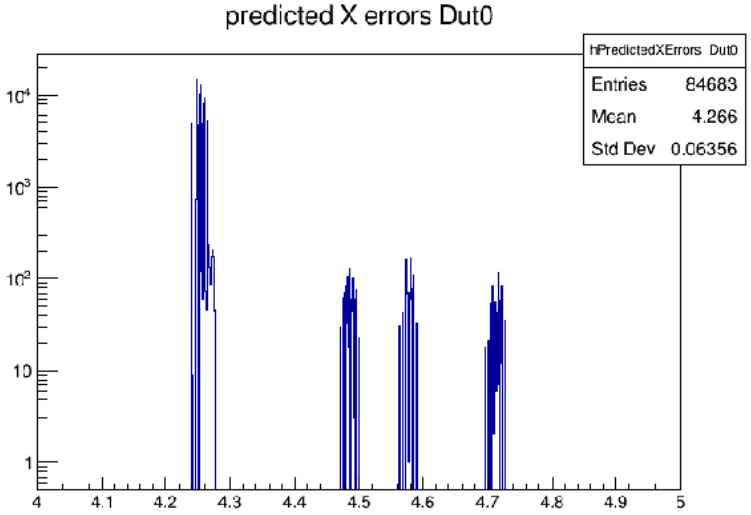


x residual, pixel long axis [um]



y residual, pixel short axis[um]

- The mean projected resolution on the DUT is about 4um



Projected xuncertainty at DUT location [um]

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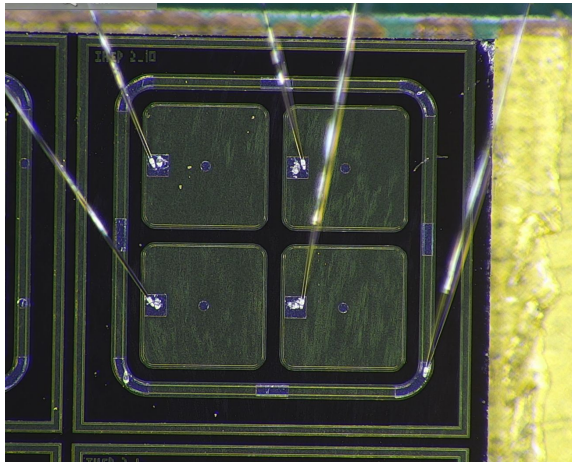
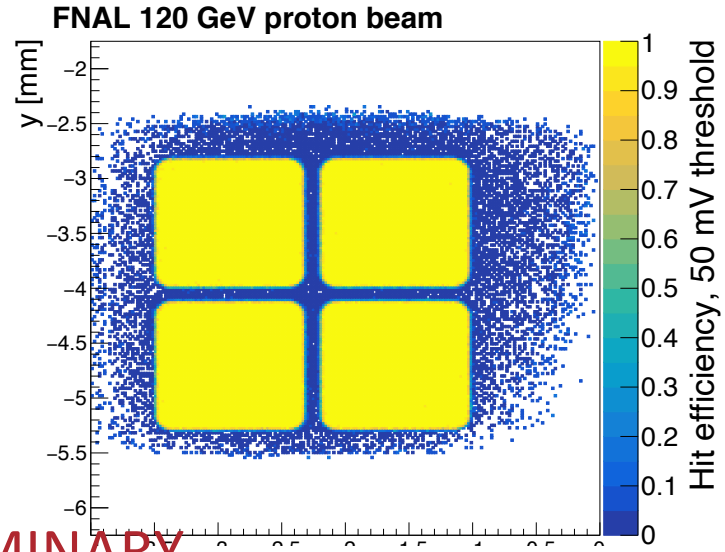
Example results with CMS Timing sensors

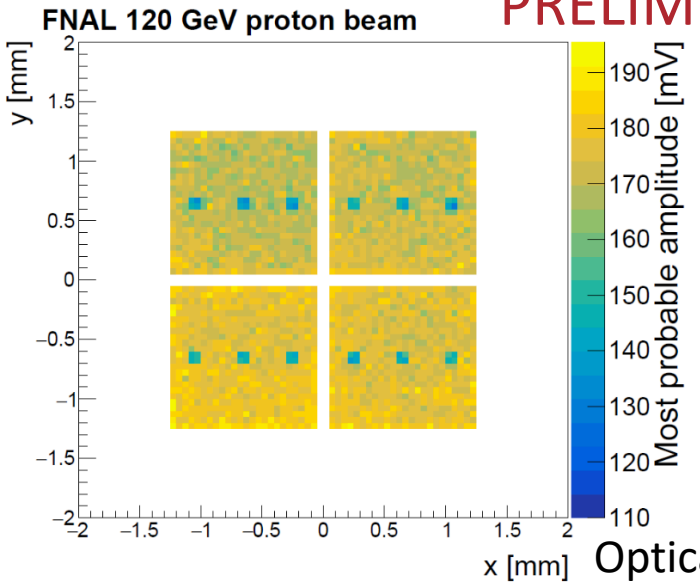
- Low Gain Avalanche Detectors (LGADs) with 30 ps resolution for CMS Phase II Endcap Timing Layer

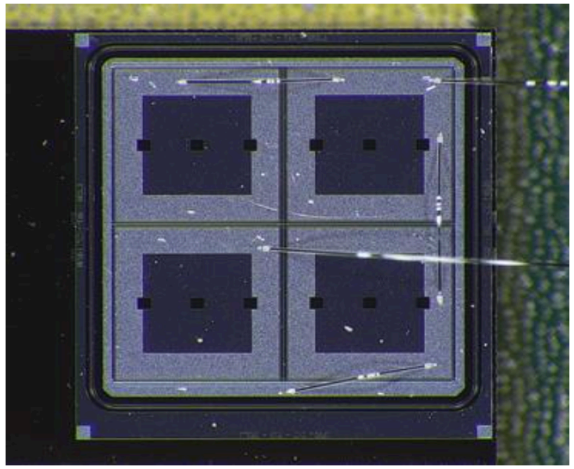
2x2 prototype array from IHEP-IME





PRELIMINARY





Irradiated 2x2 prototype array from FBK.
1e15 neq/cm^2

Optical windows reduce rad hardness—see very sharply with telescope!

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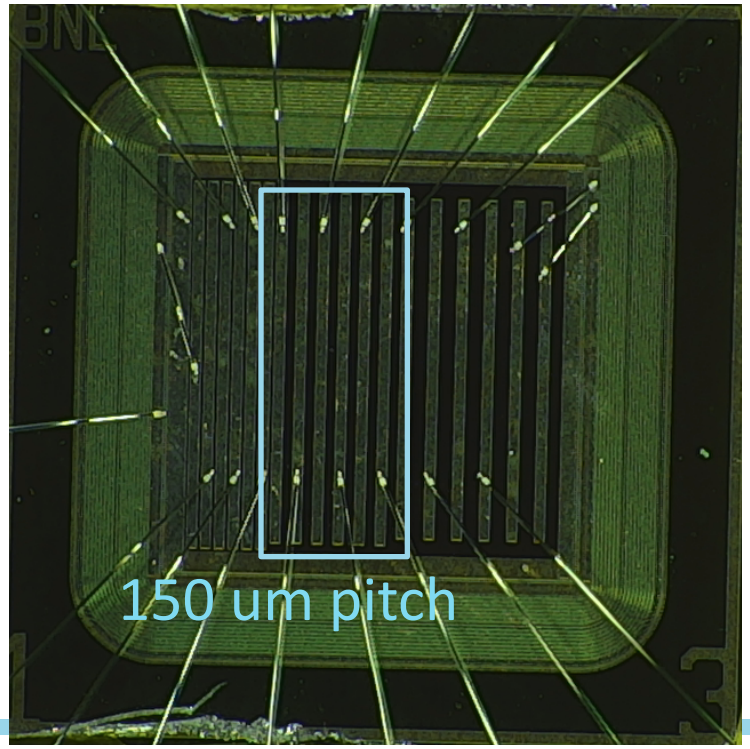
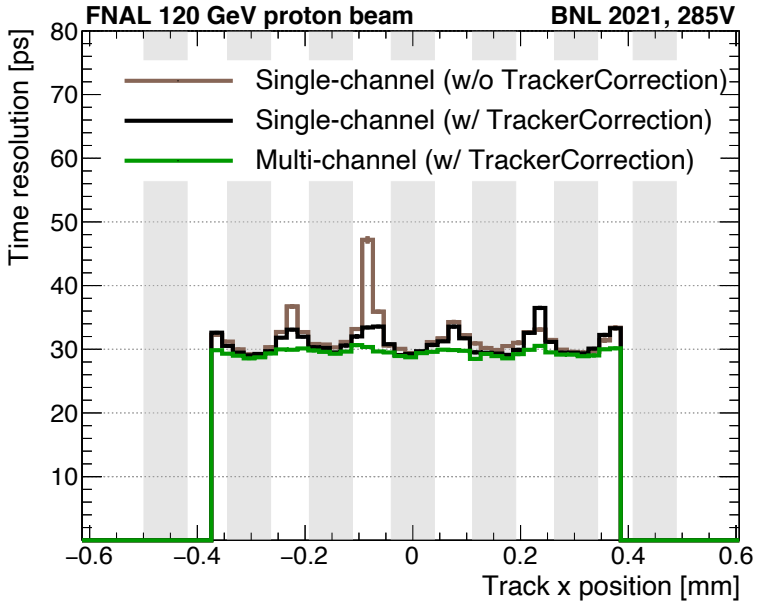
Example results with AC-LGAD sensor

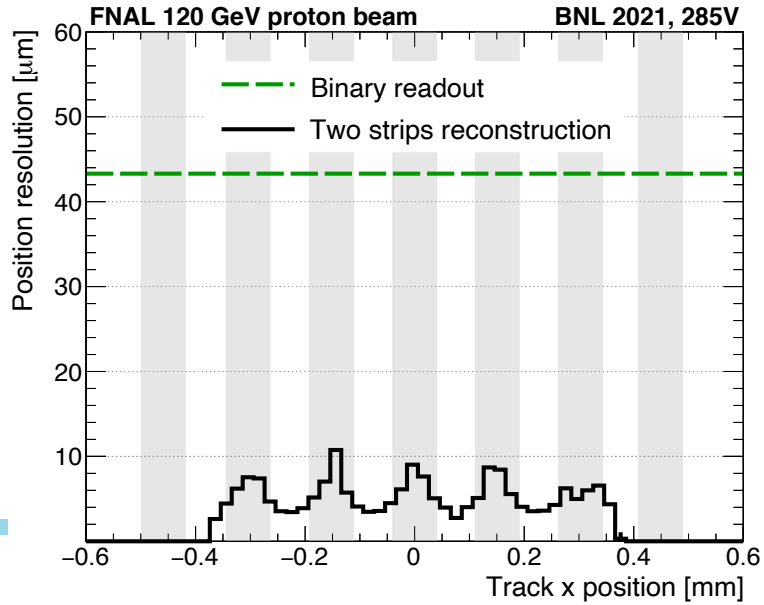
- Segmented AC-coupled LGAD strips for 4D tracking
- Telescope was used to demonstrate 30 ps & 5-10 um resolution with 150 um strips

BNL AC-LGAD strips with 3 pitches: 100, 150, 200 um





PRELIMINARY



2022 JINST 17 P05001

Conclusions

- The Fermilab Test Beam facility upgraded the silicon telescope over the years and now it is a hybrid of strips from D0 Run IIb and pixels based on the RD53A chip
- The preliminary impact parameter resolution is about 4 um
- People pile up n the control room to use it!