Performance of the PS module for particle p_T discrimination in the CMS Phase-2 Outer Tracker

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New Perspectives

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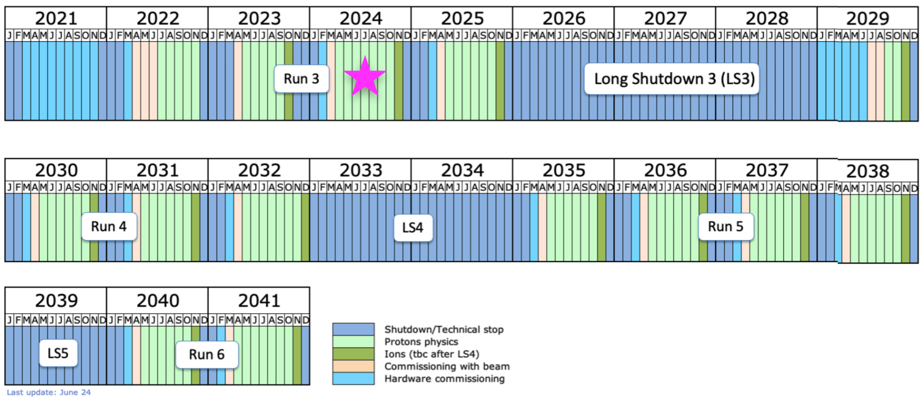
In partnership with:

Phase-2 Outer Tracker Upgrade at the HL-LHC

HL-LHC

- The Large Hadron Collider (LHC) at CERN will be upgraded to the High-Luminosity LHC (HL-LHC) in the late 2020s.
- The upgrade will reach instantaneous peak luminosities of 7.5 x 10^{34} cm^{-2}
- Allows for 10x more data than the what is currently collected
- Will have a center mass of energy of ~14 TeV

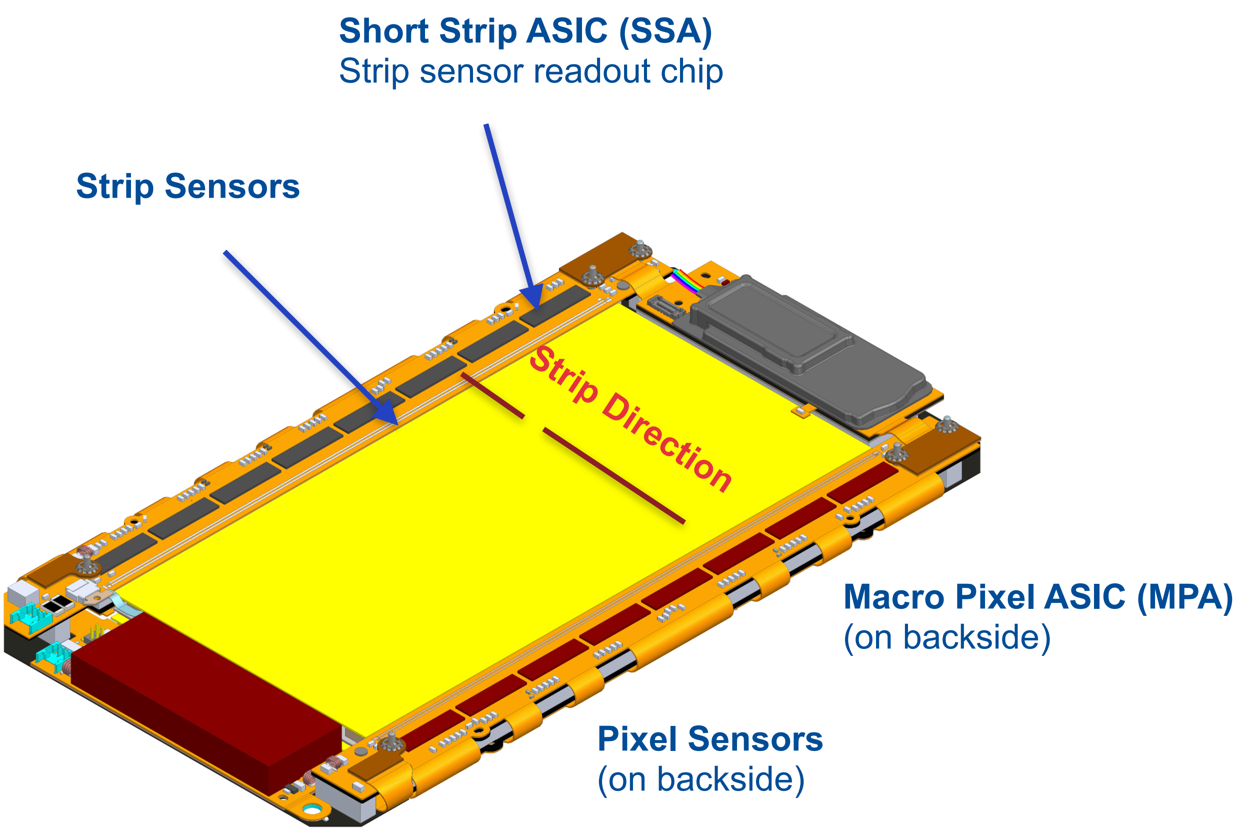


CMS Phase-2

- The upgrade will increase the LHC radiation levels, so new trackers are also required.
- Detector granularity will increase to reduce occupancy
- The tracker will be replaced and the new one will provide track information to the L1 trigger.

The Pixel-Strip (PS) Module

Approx. 6000 PS modules will be manufactured



MPA + Pixel Sensor = MAPSA

$\sim 2 \times 45\ \text{cm}^2$ active area	
2×960 strips:	$\sim 2.4\ \text{cm} \times 100\ \mu\text{m}$
32×960 macro-pixels:	$\sim 1.5\ \text{mm} \times 100\ \mu\text{m}$

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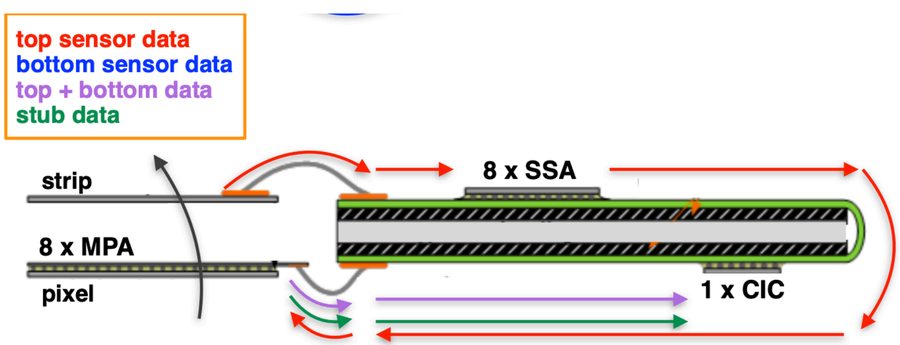
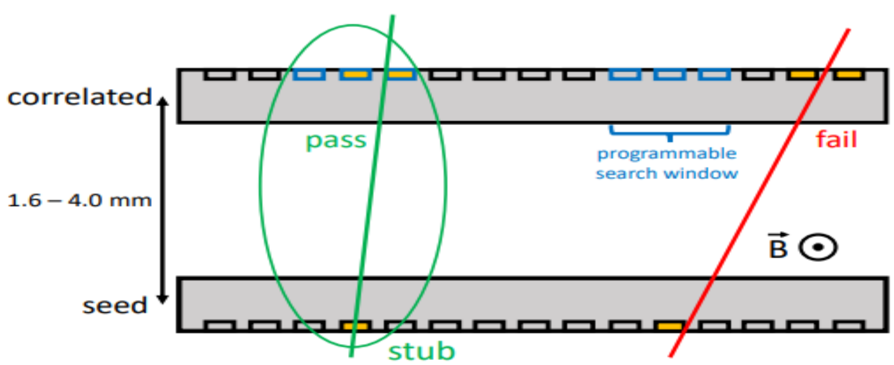
Stubs and Stub Creation

- In order to provide track information to the L1 trigger, not all tracks are able to be reconstructed.
- A selected subset of tracks that correspond to a particle with high p_T will be used.
- It is expected that the most interesting events will contain higher p_T tracks

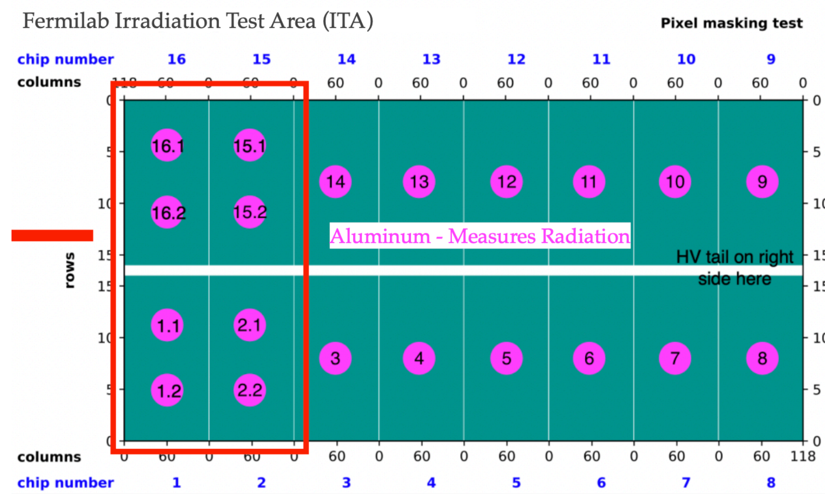
- A stub is a pair of coordinated hits on both the pixel and strip sensors in the module.
- Particles with a momentum > 2GeV are what we are looking for!
- The stub creation conditions can be changed by altering the window of strip sensors that can create a stub for each pixel hit.
- Stubs are then sent to the L1 trigger for selection

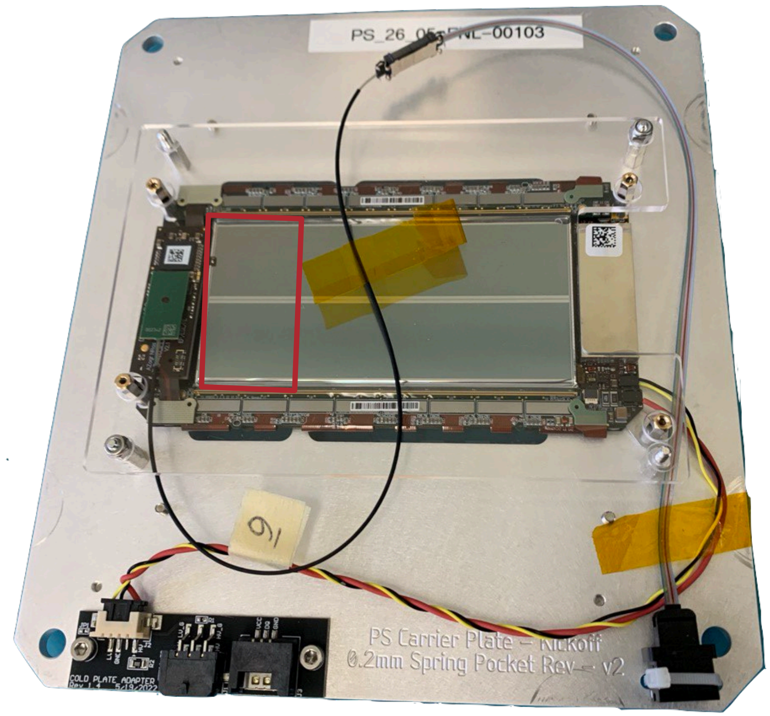




The PS Module Irradiation

- To mimic the environment of the HL-LHC, the module was irradiated.
- Comparing the irradiated and non-irradiated data allows us to see how the sensors will function in the HL-LHC
- A 5 x 2 cm portion of the MAPSA and strip-sensor sandwich was irradiated to target fluence of $1.4 \times 10^{15} n_{eq}$ per cm^2





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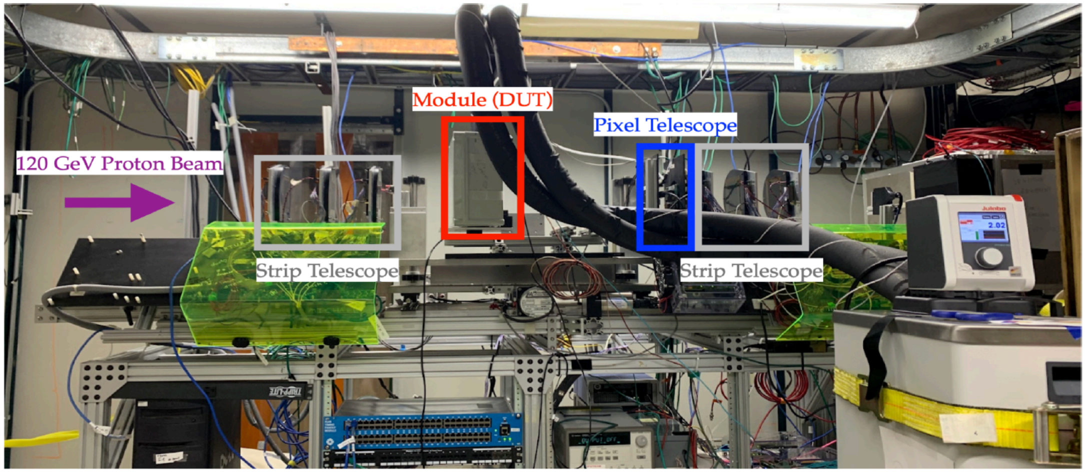
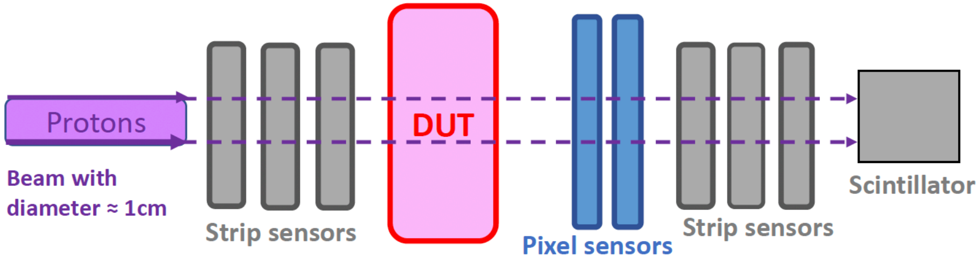
2023 Test Beam at Fermilab Test Beam Facility

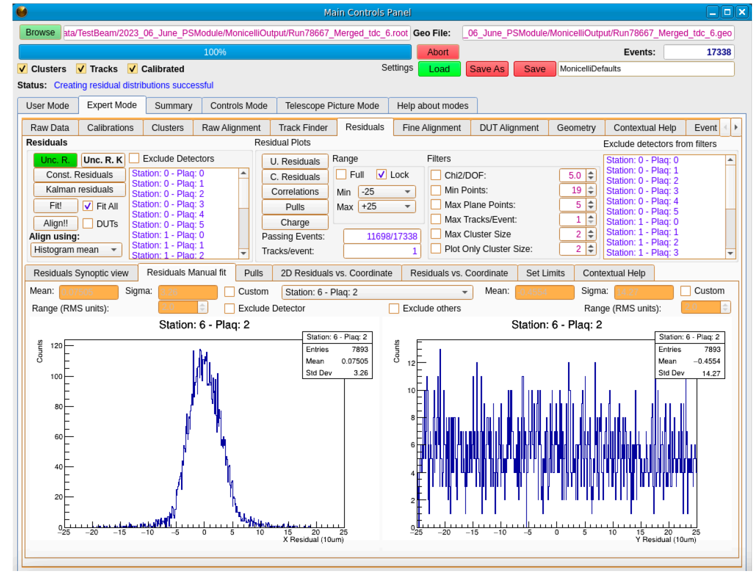
- Proton beam with momentum of 120 GeV
- Telescope operates with spatial resolution of 7μm in x and y
- Telescope consists of 12 strip plane and 4 pixel planes
- Rotation of the module was required to study the stubs.

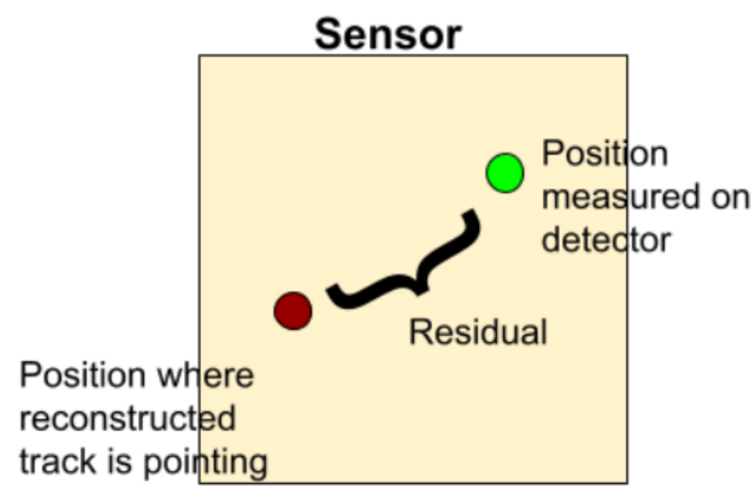




Alignment

- In order to analyze the test beam data, the exact position of each detector had to be reconstructed.
- By using a program called Monicelli, we were able to determine the geometric location of the detectors and reconstruct the tracks of particles passing through.
- Optimize residual distribution
- Requires the precision of a few microns





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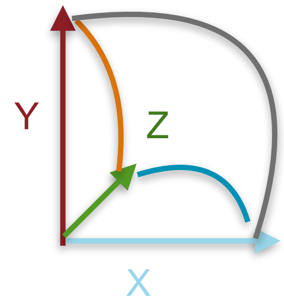
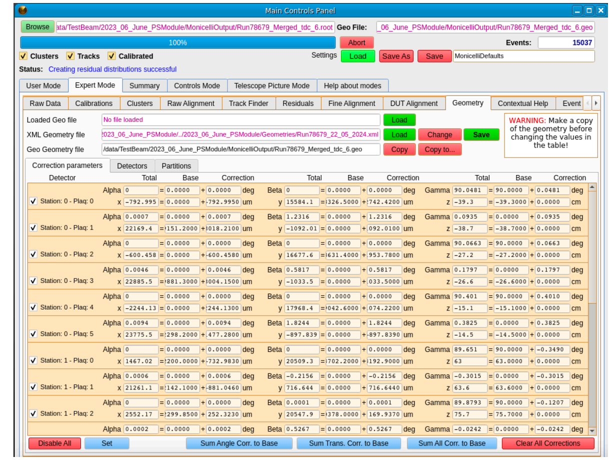
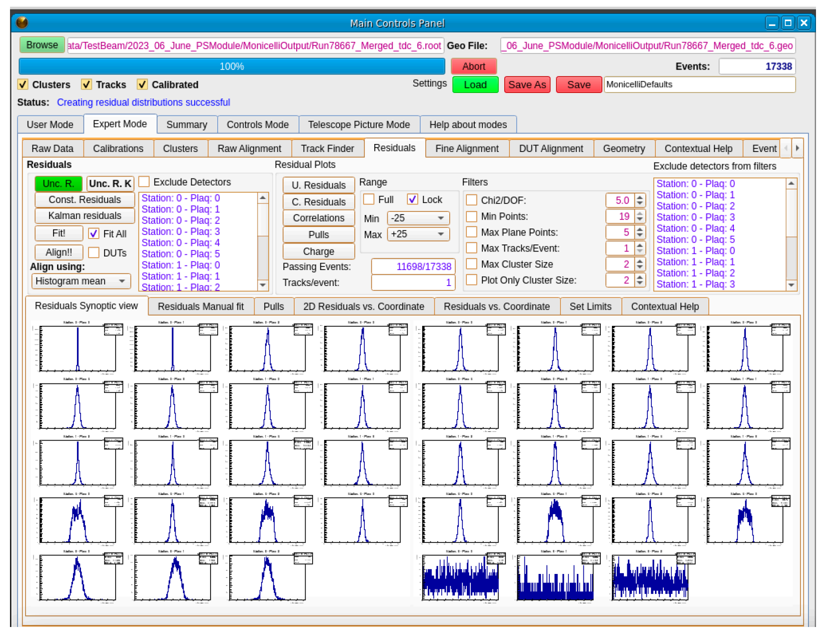
Alignment

- During the alignment process, a subset of the particle tracks are reconstructed and used to find geometry parameters.
- The alignment returns the angles and translations at which the detector has been placed
- Once alignment is done, we use the alignment parameters to reconstruct all tracks.



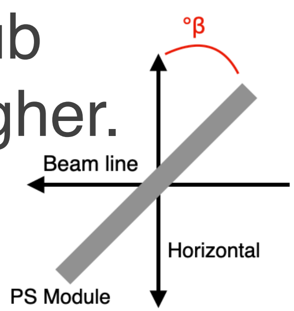


The parameters measured in Monicelli are three spatial rotations and three translations

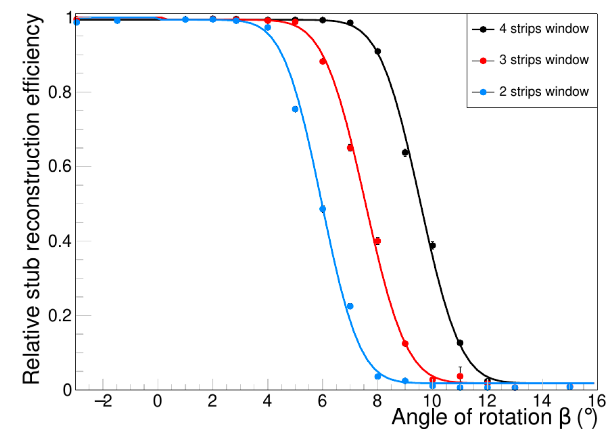


Module Placement

- In CMS, there is a magnetic field of 3.8T that bends the trajectory of the charged particles.
- In order to mimic the effects of this magnetic field at the Fermilab test beam, the module started orthogonally to the beam was rotated with respect to the beam direction.
- For small angles beta (small bending =high momentum particle) stub reconstruction efficiency is higher.



Stub Reconstruction Efficiency v.s. Angle of Rotation (Not Irradiated)



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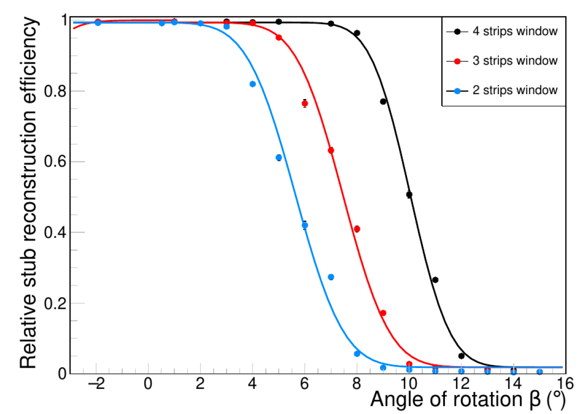

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Transverse Momentum

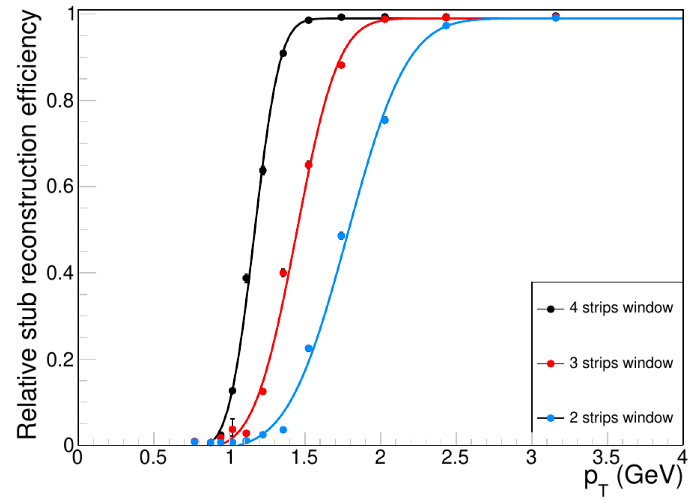
The transverse p_T values were calculated using the equation:

$$P_T[GeV] \approx (0.57 \cdot R[m])/(\sin\beta)$$

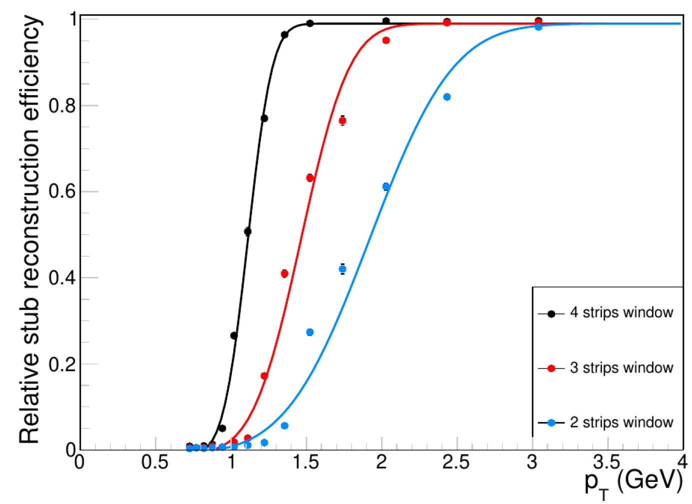
R=0.372m is the radial position of the module inside the tracker in the first layer, and **β** is the angle at which the module was placed in relation to the beam.

- Can see how accurate the module is in creating stubs from high momentum events
- Strip windows of 3 and 4 are fully efficient for 2 GeV tracks

Stub Reconstruction Efficiency v.s. p_T (Not Irradiated)

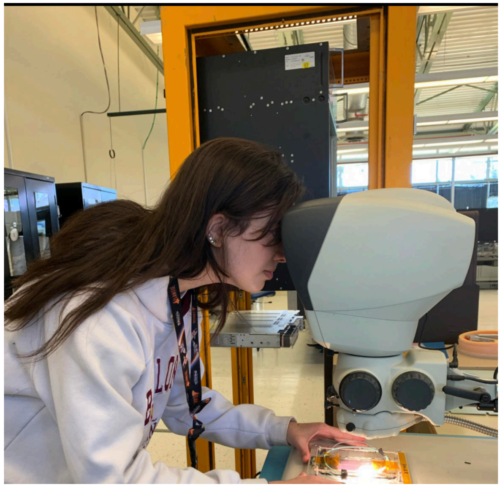


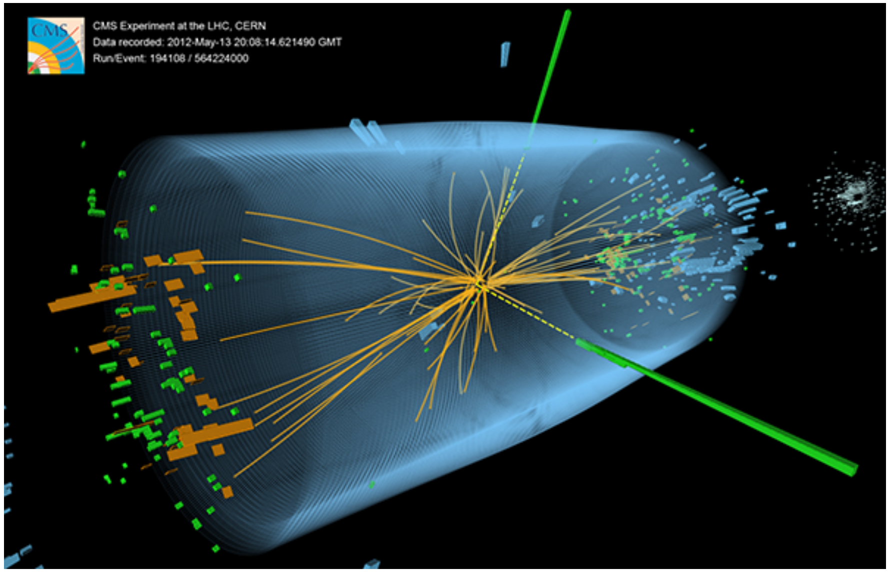
Stub Reconstruction Efficiency v.s. p_T (Irradiated)



Summary

- Due to the upgrade to the LHC, new detectors will be required to track particle momentum
- These detectors will be able to provide stubs to the L1 triggers, allowing it to do online track reconstruction
- The PS module was built, irradiated and tested at Fermilab
- Analysis showed that the module works as expected





Thank you for your attention

Plotting

- Plots were fit with an inverse error function, allowing effective p_T threshold and resolution to be calculated.
- These values allow
- The reconstructed tracks from Monicelli were used to plot the stub reconstruction efficiency for each angle the module was placed at, as well as for the transverse momentum.

Strip # and level of irradiation	Effective p_T	Resolution	Sigma Value
2 Strip (Not Irradiated)	1.55	24.1%	0.374
2 Strip (Irradiated)	1.65	31.7%	0.523
3 Strip (Not Irradiated)	1.2	21.9%	0.162
3 Strip (Irradiated)	1.3	24.2%	0.302
4 Strip (Not Irradiated)	1.55	16.2%	0.162
4 Strip (Irradiated)	0.95	16.2%	0.154