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Performance analysis of Phase 2 tracker upgrade PS module before and after irradiation

Iqra Sohail[1,2], J. Dickinson[1], L. Dishman[3], O. Gzamouranis[1,4], E. Hagen[3], N .Hinton[5], J. Lawless[3] , L. Lee[3], E. Nibigira[3], J. Peltier[3], F. Ravera[1], N.Salimbeni[6], L. Uplegger[1], P. Wagenknech[5], I. Zoi[1]

1. Fermi National Accelerator Laboratory (FNAL)
2. National Center for Physics , Quaid.e.Azam Uni (NCP)
3. . University of Tennessee
4. Willowbrook High School
5. Brown University
6. University of Padova

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High Luminosity LHC (HL-LHC)

- Increased instantaneous luminosity from 5 to 7.5 x 10^{34} cm^{-2} s^{-1} [1]
- High pile up of 140-200 up to 750 kHz L1 trigger rate

Benefits

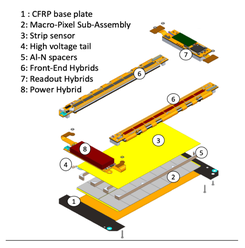
- Improve precision of standard model measurements
- Improve direct searches for new and rare phenomena

Drawbacks

- Increase the collision rate
- Total particle fluence in the outer tracker (OT) is 1.5 x 10^{15} n_{eq} cm^{-2} [2]

Outer tracker phase 2 upgrade [3]

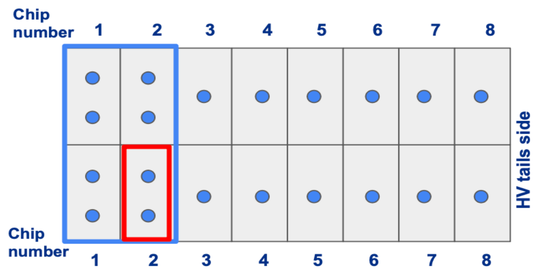
- Silicon PS (pixel-strip) modules and 2S (strip-strip) modules
- On-chip p_T discrimination at 2 GeV
- Trigger information at 40 MHz

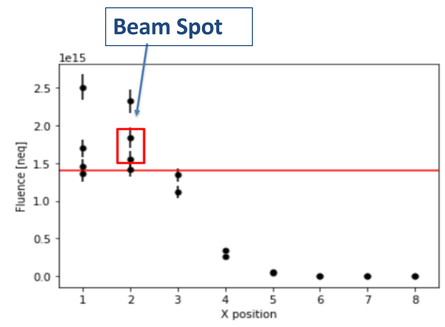


Over view of PS Module

Irradiation of PS Module at Fermilab

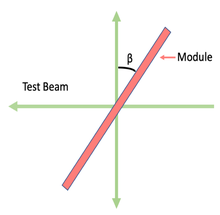
- 400 MeV protons, 8 pulses per minute across the 4 highlighted areas (sandwich of PSs+MaPSA)
- Target radiation fluence 1.4 x 10^{15} n_{eq} cm^{-2}

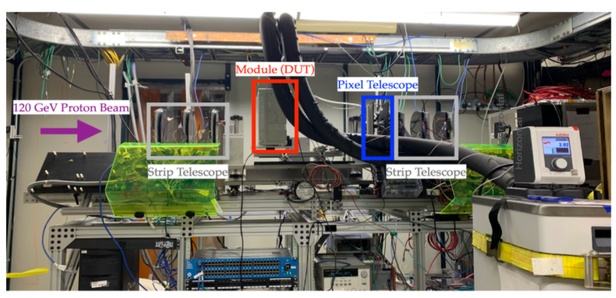




Fermilab Test Beam Facility

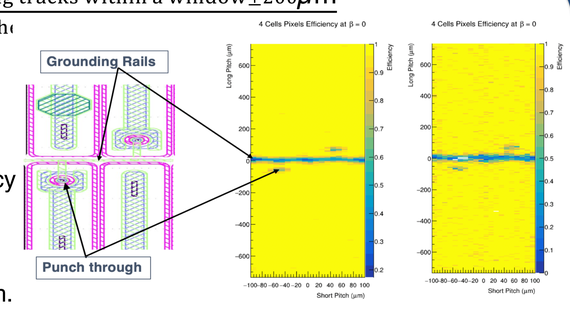
- 120 GeV proton beam [4], ranging from 1 to 300 kHz
- Each spill lasts for 4 seconds every minute
- The telescope [5] consists of 12 strip planes and 4 pixel planes
- Telescope resolution is 7 μm





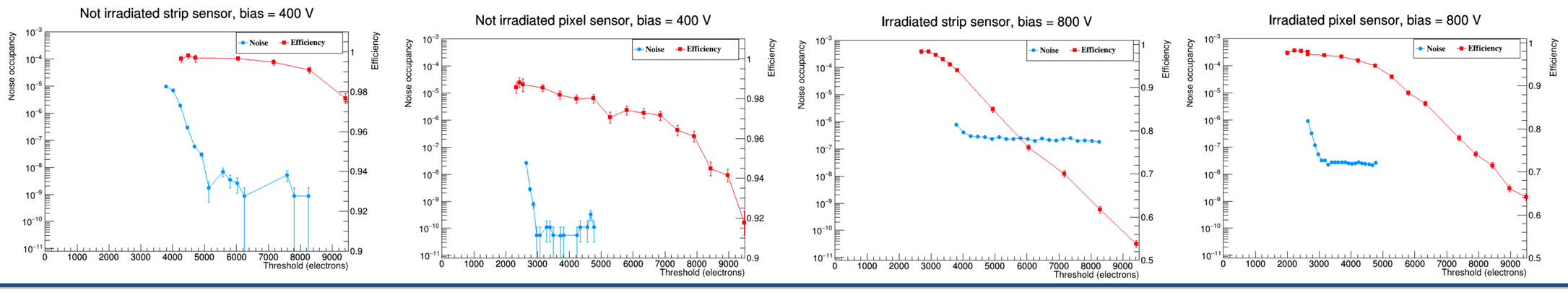
Pixel Efficiency

- $\varepsilon = \frac{\#\text{ of hits on the detector matched to the pointing tracks within a window} \pm 200\mu m}{\#\text{ of tracks pointing to th}}$
- Pixel cell pitch = 100 μm x 1467 μm
- Punch through and grounding rails are part of the pixel structure and cause of the lower efficiency in the corresponding areas [6]
- These plots are made with data collected when the module was perpendicular to the beam. The inefficiency areas are reduced when the module is positioned at an angle β with respect to the beam



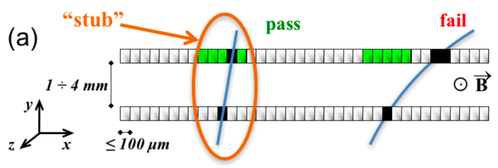
Efficiency and Noise Occupancy as Function of Threshold

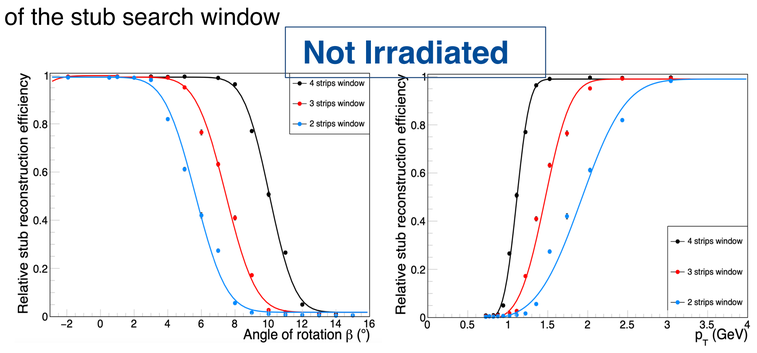
- Noise Occupancy = $\frac{\text{Number of hits in one cell}}{\text{Number of trigger}}$
- After the irradiation, it is expected that the noise occupancy should increase due to damage in the silicon bulk
- According to the requirements, the noise occupancy should be ~ < 10^{-5}

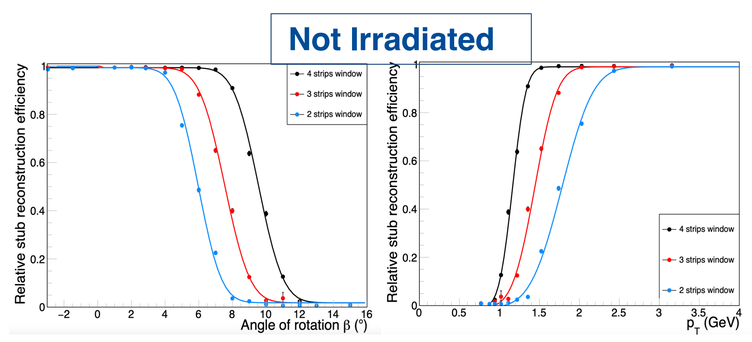


Stub Efficiency

- A hit from the bottom sensor is matched with a hit from the top sensor within a programmable search window. If they align within this window, they form a short track segment called a stub
- The relative stub efficiency is calculated with respect to having a cluster in both the pixel and the strip sensors
- The rotation can mimic the performance of a module with sensor spacing 1.6 mm and placed at distance R = 0.372 m inside the 3.8 T magnetic field of the CMS experiment
- The efficiency was measured for three different widths of the stub search window







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Summary

- Preliminary studies of PS module efficiencies:
  Not Irrad : pixels ≈ 98.7% and strips ≈ 99.6%
  Irrad @ 1.4 x 10^{15} n_{eq} cm^{-2} : pixels ≈ 98.5% and strips ≈ 98.6%
- Stub efficiencies with respect to angle and p_T are consistent with geometrical window cut

iqra.Sohail@cern.ch

References

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[6] D. Schell and A. Dierlamm,"Optimization of bias rail implementations for segmented silicon sensors", NIM A 924 (2019) 19-22