

# Performance Analysis of Phase 2 Tracker Upgrade PS

## Module before and After Irradiation

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**Abstract :** The Large Hadron Collider will undergo a luminosity upgrade targeting a peak instantaneous luminosity ranging from  $5-7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . The ambitious goal of the High Luminosity LHC is to achieve a total of  $3000-4000 \text{ fb}^{-1}$  of proton-proton collisions at a center-of-mass energy of  $13-14 \text{ TeV}$  by 2029. To cope with such challenging environmental conditions, the outer tracker of the CMS experiment will be upgraded using closely spaced silicon sensors (pixels and strips) to provide tracking information at the Level-1 trigger. A PS module, composed of both a pixel and a strip sensor, was tested at the Fermilab Test-Beam Facility to evaluate its ability to provide accurate tracking information,  $p_T$  discrimination capabilities, and optimal performance at the irradiation levels expected after being exposed to the harsh conditions of the High Luminosity LHC. The results of the test and the comparison of the module performance before and after irradiation will be presented in this poster.

## High Luminosity LHC (HL-LHC)

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

### Benefits

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

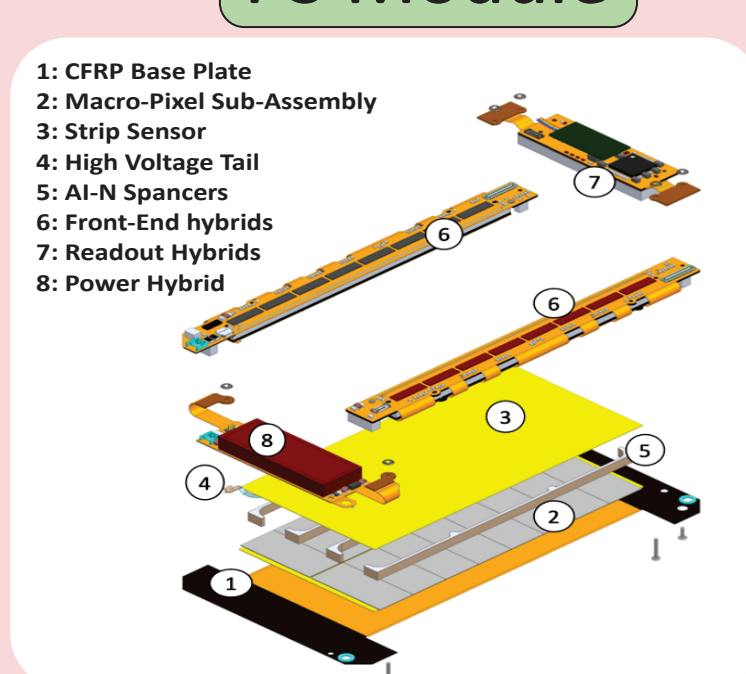
### Drawbacks

- Increase the collision rate
- Radiation induced damage

### Outer tracker phase 2 upgrade

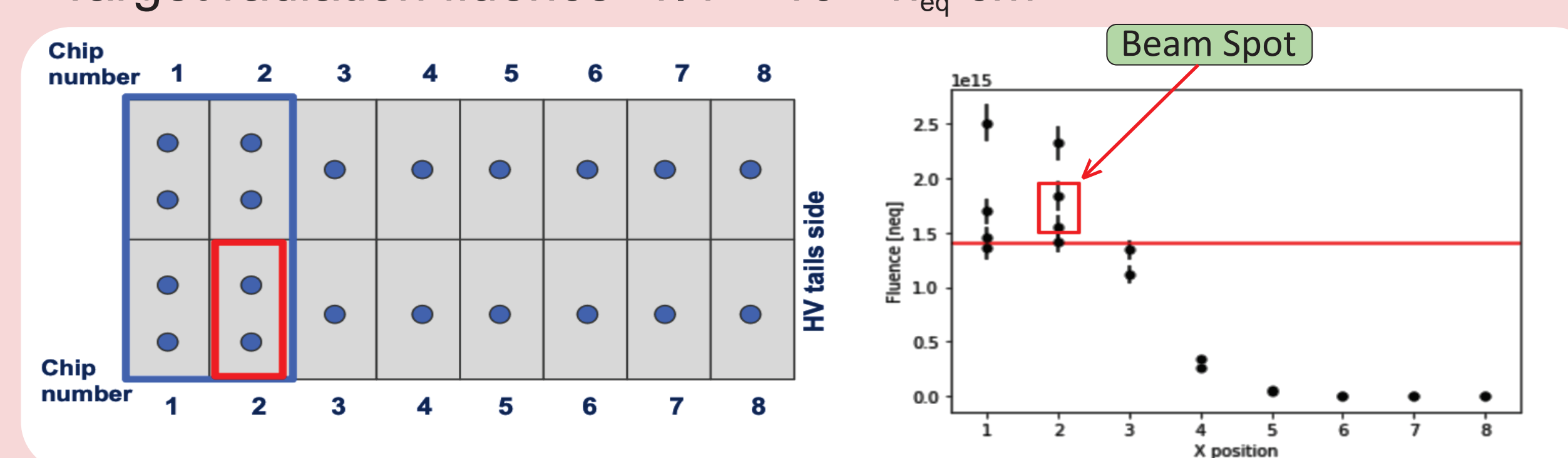
- Silicon PS (pixel-strip) modules and 2S (strip-strip) modules
- On-chip  $p_T$  discrimination at 2 GeV
- Trigger information at 40 MHz

### PS Module



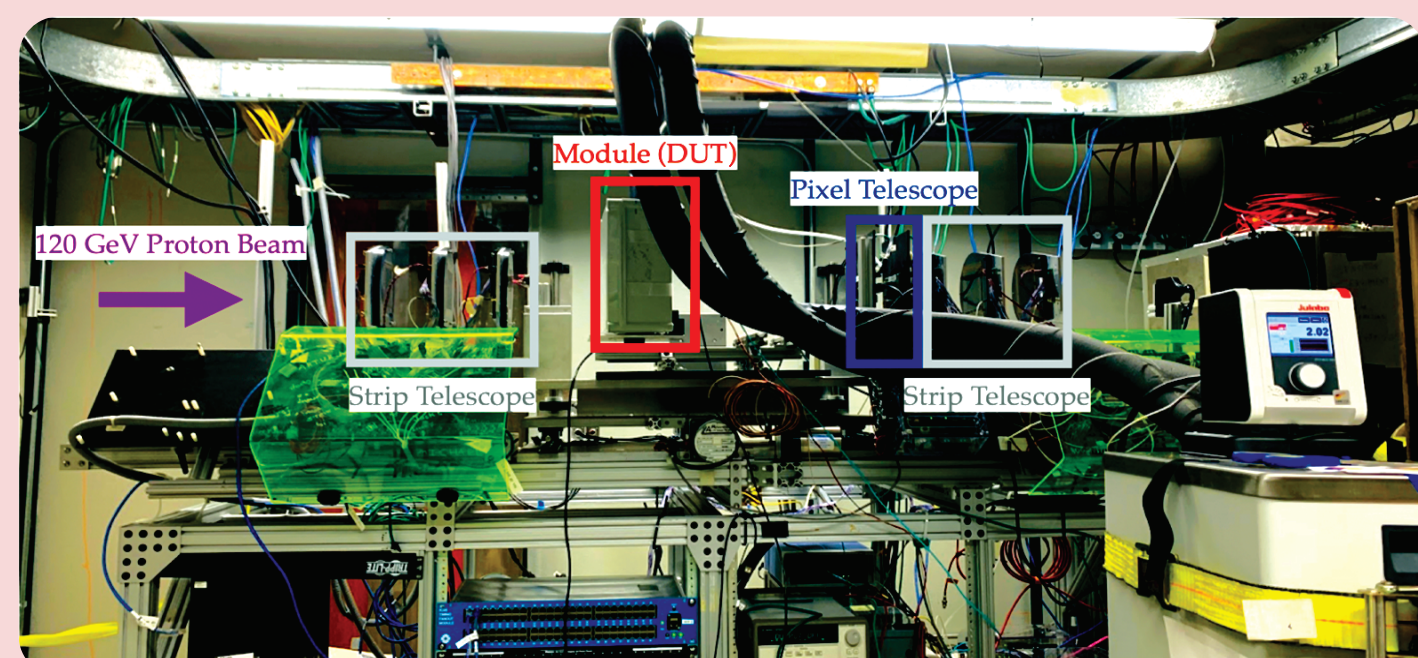
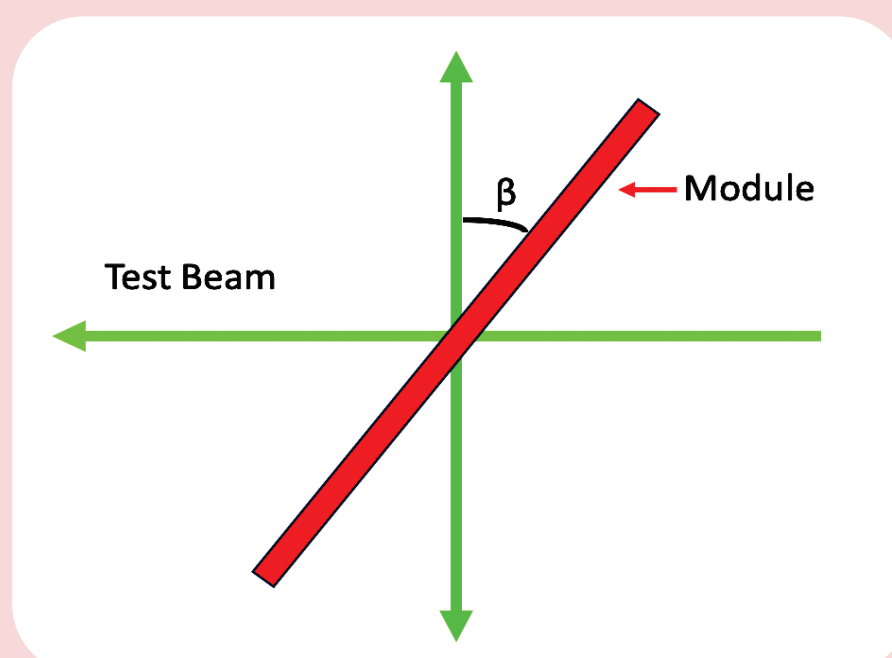
## Irradiation of PS Module at Fermilab

- 400 MeV protons, 8 pulses per minute across the 4 highlighted areas (sandwich of PSs + MPAs)
- Target radiation fluence  $1.4 \times 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$



## Fermilab Test Beam Facility

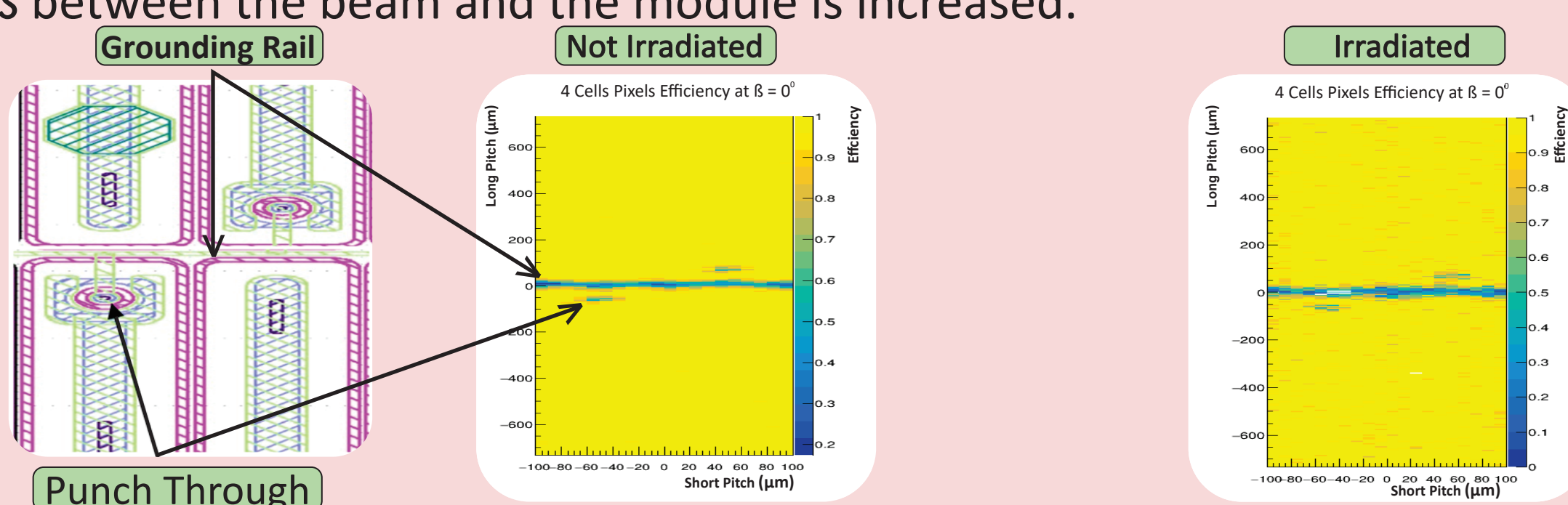
- 120 GeV proton beam [2], ranging from 1 to 300KHz
- Each spill lasts for 4 seconds every minute and delivers  $\sim 40\text{k}$  protons
- The telescope [3] consists of 12 strip planes and 4 pixel planes
- Telescope resolution is  $7 \mu\text{m}$



## Pixel Efficiency

$$\epsilon = \frac{\text{\# of hits on the detector matched to the pointing track within a window } \pm 200 \mu\text{m}}{\text{\# of tracks pointing to the detector}}$$

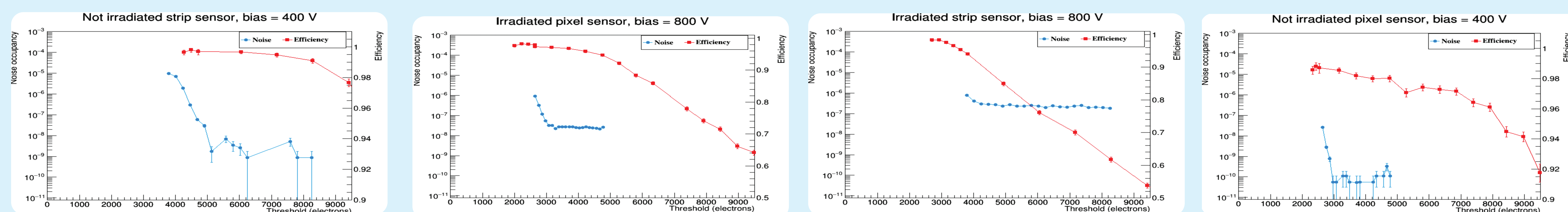
- Pixel cell pitch =  $100 \mu\text{m} \times 1467 \mu\text{m}$
- Punch through and grounding rails are part of the pixel structure and the cause of the lower efficiency in the corresponding areas [4].
- These plots are made with data collected when the module was perpendicular to the beam. The inefficient areas are reduced when the angle  $\beta$  between the beam and the module is increased.



## Efficiency and Noise Occupancy as function of threshold

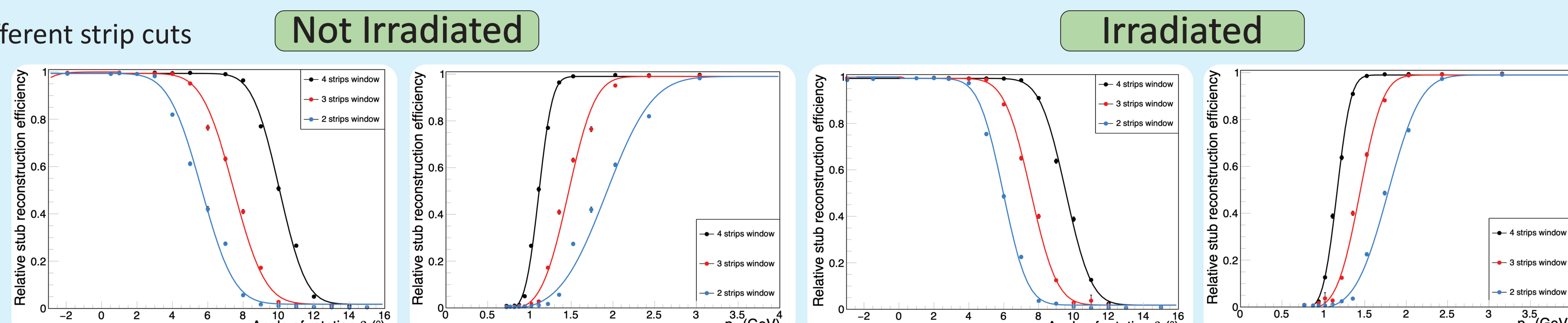
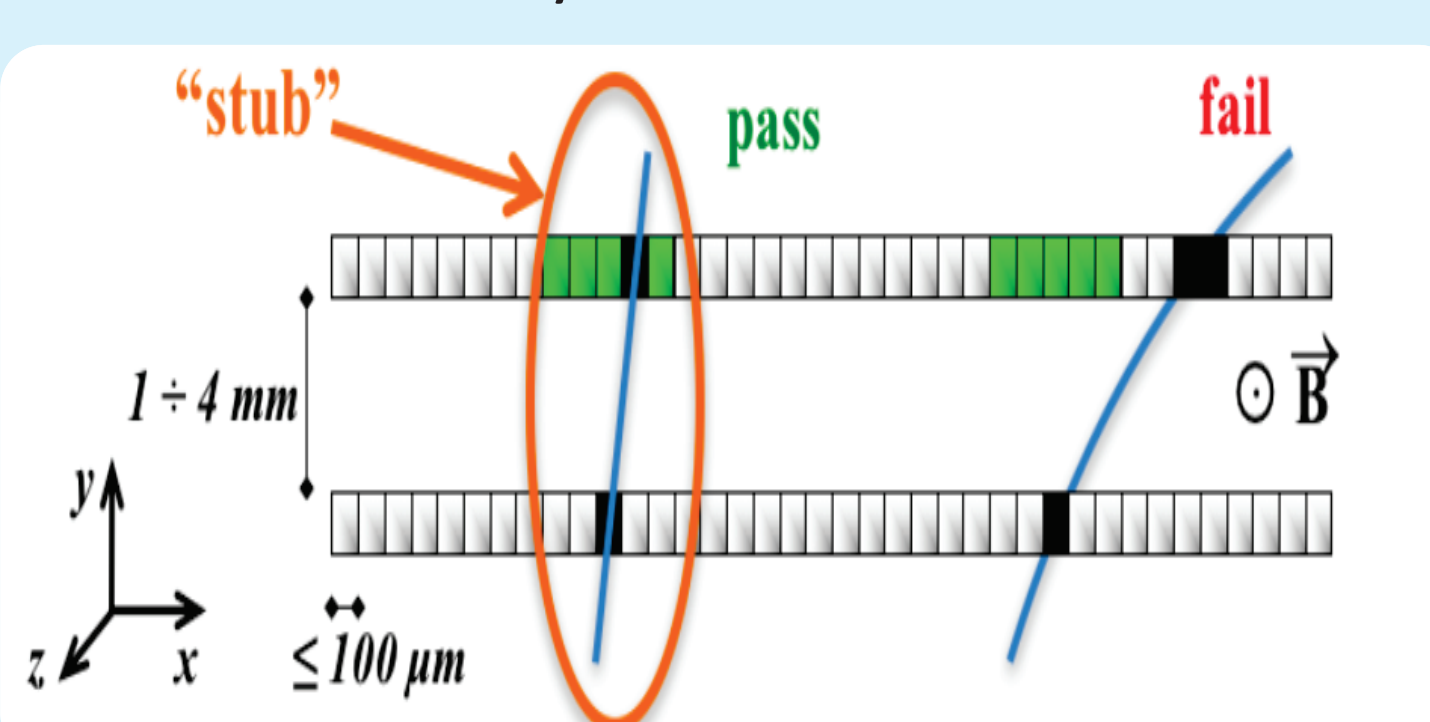
- Noise Occupancy =  $\frac{\text{Number of hits in one cell}}{\text{Number of triggers}}$
- After the irradiation, it is expected that the noise occupancy should increase due to damage in the silicon bulk
- According to the requirements, the noise occupancy should be  $\sim 10^{-5}$
- The conversion between digital threshold DAC (V<sub>th</sub>) units to electrons has been obtained with a linear fit of the measured average V<sub>th</sub> as a function of the injected V<sub>cal</sub>

MPA :  $1\text{V}_{\text{cth}} = 106 \text{ e}^-$  (94 e<sup>-</sup> expected)  
SSA :  $1\text{V}_{\text{cth}} = 223 \text{ e}^-$  (250 e<sup>-</sup> expected)



## Stub Efficiency

- 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 1.6mm and placed at distance  $R = 0.372 \text{ m}$  inside the 3.8T magnetic field of CMS experiment as shown below in the  $p_T$  plots
- The efficiency was measured for three different strip cuts



## Summary

- Preliminary studies of PS module efficiencies
  - Not Irrad : pixels  $\approx 99\%$  and strips  $\approx 99.6\%$
  - Irrad @  $1.4 \times 10^{15} \text{ n}_{\text{eq}} \text{ cm}^{-2}$  fluence : pixels  $\approx 98.5\%$  and strips  $\approx 98.6\%$
- Stub efficiencies w.r.t angle and  $p_T$  are consistent with geometrical window cut

## References

- CMS Collaboration, "Technical proposal for the Phase-II upgrade of the Compact Muon Solenoid", CMS-TDR-15-02
- Fermilab, Fermilab test beam facility, <http://ftbf.fnal.gov>, 2019
- S. Kwan et al., "The Pixel Tracking Telescope at the Fermilab Test Beam Facility", NIM A 811 (2016) 162
- D. Schell and A. Dierlamm, "Optimization of bias rail implementations for segmented silicon sensors", NIM A 924 (2019) 19-22