T-992: Rad Hard Sensors for the SLHC

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**SLHC:** Luminosity upgraded to $10^{35} \text{cm}^{-2}\text{s}^{-1}$

→ Integrated luminosity up to 2500 fb$^{-1}$ after 5 years

→ at 5 cm from the interaction point radiation fluence of $10^{16} \text{n}_{eq}/\text{cm}^2$

← High radiation damage

← Less charge collection

← Less efficiency

**Excellent radiation hardness required**
The aim is to study and compare unirradiated and irradiated detectors to check their performance.

Two types tested:
- 3D Silicon sensors
- Diamond sensors

T-992 is a test beam experiment at the Fermilab Test Beam Facility conceived to perform this analysis.

- 120 GeV proton beam
- 8 planes pixel telescope to reconstruct particles tracks
- Several detectors, both irradiated (up to $10^{15} n_{eq}$) and not, available for testing
Several institution collaborated:

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3D Electrodes inserted in the silicon bulk: charge collected laterally along a shorter path

√ Lower depletion voltage
√ Faster charge collection
√ Less carriers trapping
X Higher capacitance → higher noise

**Diamond** Planar sensor with an intrinsic high radiation hardness: high bandgap

√ Faster charge collection
√ No leakage current
X Less charge carriers produced → lower signal
X Trapping due to imperfections in crystalline structure
8 planes of pixel detectors, 4 upstream and 4 downstream, with the DUTs in the middle.

→ 100 × 150 $\mu m^2$ pixels
→ Track reconstruction and plane alignment algorithm
↩ Effective resolution $\approx 6 \mu m$

The telescope and its data software: after each run it was possible to verify the quality of the data.
Many detectors have been analyzed to obtain a large variety of results:

- Various scans to run in different conditions
  - Bias scan
  - Threshold scan
  - Angle scan
- Various types of analysis pursued:
  - Resolution
  - Efficiency
  - Charge collection

- Data were taken in the last two weeks of September
- In the next slides are shown some preliminary results already available for an unirradiated and irradiated \((1 \cdot 10^{15}\text{ neq/cm}^2)\) 3D, and an irradiated \((3.5 \cdot 10^{14}\text{ protons/cm}^2)\) Diamond pixel.
3D Residuals

X residuals for size 1 and 2 clusters

Y residuals for size 1 and 2 clusters

Size 2 clusters are still computed as for planar detectors: a new method must be pursued to improve their resolution!

Diamond Residuals

Same plots
3D Efficiency

Efficiency spatial distribution on detector: mean efficiency = 94.3% (unirradiated)

Diamond Efficiency

Efficiency spatial distribution on detector: mean efficiency = 94% (irradiated)

Distribution on cell: bad values due to bad working pixels, the readout chip was damaged by irradiation.

Distribution on cell if we focus on the center of the detector (blue rectangle): mean efficiency = 99.4%
3D Charge Distributions

Charge overall distribution (Landau):  
M.P.V. = $14.9 \cdot 10^3 \text{ e}^-$

Diamond Charge Distributions

Average charge spatial distribution on cell

Charge overall distribution (Landau):  
M.P.V. = $6.4 \cdot 10^3 \text{ e}^-$ (irradiated!)
**Efficiency**

Efficiency on cell: average efficiency = 93.2%

→ Slightly lower than the unirradiated, as expected!

Alignment not perfect → Must be improved!

**Charge collection**

Overall charge distribution (Landau): M.P.V. = 13.3 \( \times 10^3 \) e\(^-\)

→ Slightly lower than the unirradiated, as expected!

Still working well after a dose of 1 \( \times 10^{15} \) neq/cm\(^2\)
√ Several detectors successfully tested
√ Preliminary results in agreement with predictions so far:
  ↪ Comparison between not irradiated and irradiated sensors
  ↩ Resolution and Charge collection parameters

Work in progress
▷ Improve the analysis to understand behaviour at the boundaries between the pixels and at the edges of the detectors
▷ Improve the size 2 clusters reconstruction

See for example size 2 residuals when the point is "digitalized" (set at the boundary of the pixel) and the charge is set to be below 20 ke$^-$ (to cut $\delta$ rays off)

▷ Analyze the data at angles $> 0^\circ$

Future Goals
▷ Study detectors irradiated at higher doses