T-992: Radiation-Hard Sensors at FTBF for the SLHC

Jennifer Ngadiuba
INFN, Milano

ALL EXPERIMENTERS' MEETING

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Test Beam Goal

- test the candidate pixel sensors for the SLHC Pixel upgrade before and after irradiation to compare the performances to understand if we have a technology capable of withstanding the enormous fluences
- efforts have been focused on the two most promising sensor types:
  - 3D Silicon sensors
  - Diamond sensors
- this talk will present the preliminary analysis and results from last week's run
3D Silicon & Diamond Sensors

3D Sensors

- first proposed by Sherwood Parker of the University of Hawaii and colleagues in 1995
- $p^+$ and $n^+$ electrodes are arrays of columns that penetrate through the silicon bulk
- Lateral depletion: good for rad-hard
  - shorter collection path
  - lower full-depletion voltage
  - less carrier trapping
  - faster charge collection

Diamond sensors - intrinsically rad-hard

- high bandgap and high displacement energy
- fast charge collection
- absence of thermally generated leakage current
Setup

- Telescope with 8 silicon planar pixel sensors (4 upstream and 4 downstream) with 2 Detectors Under Test (DUTs) in the middle
- The projected track resolution on the DUT is 6 - 10μm
- Data acquisition with CAPTAN system

Our software allows us to check immediately the data quality!
Collaboration

Many different institutions and collaborators for the CMS pixel upgrade:

- Femilab
- Purdue
  E. Alagoz, O. Koybasi, G. Bolla, D. Bortoletto, M. Bubna, A. Krzywda
- Colorado
  M. Dinardo, S. Wagner, J. Cumalat
- Texas A&M
  I. Osipenkov
- Milano
  L. Moroni, D. Menasce, S. Terzo, J. Ngadiuba
- Torino
  M. Obertino, A. Solano
- Mississippi
  L. Perera
- Buffalo
  A. Kumar, R. Brosius
- IHPC Strasbourg
  J. M. Brom
1x10^{14} \text{n-eq/cm}^2 \text{ irradiated 3Ds}

Beam spots

3D 1E sensor

3D 4E sensor
Irradiated 3Ds resolution

X Residuals Cluster Size 1
\( \sigma = 31.18 \mu m \)

Y Residuals Cluster Size 1
\( \sigma = 46.46 \mu m \)

X Residuals Cluster Size 2
\( \sigma = 27.52 \mu m \)

Y Residuals Cluster Size 2
\( \sigma = 30.21 \mu m \)
Irradiated 3D 1E efficiency

Efficiency distribution across a part of the detector

Efficiency distribution across the single pixel cell

Result very similar to not-irradiated 3D detector presented at the November 14th AEM meeting

Efficiency ~ 96.6%

Inefficiency mainly due to particles passing through the p+ and n+ electrodes!

Not-irradiated 3D detector

Efficiency ~ 97.6%
Irradiated 3D 4E efficiency

Efficiency distribution across a part of the detector

Efficiency distribution the single pixel cell

Efficiency ~ 71.9%

Inefficiency mainly due to particles passing through the p+ and n+ electrodes!

4E 3D detectors never worked as good as 1E or 2E 3D design!
Irradiated 3Ds charge

Charge distribution 3D 1E

MPV ~ 14.3k electrons

Charge distribution 3D 4E

MPV ~ 17k electrons

In agreement with the expected charge released in a 200/235 μm thick silicon
Diamond sensors

Beam spots

**LC500**
non irradiated 500μm thick polycrystal diamond sensor

**E6-DDL-M1**
500μm thick monocrystal diamond sensor irradiated to $3.6 \times 10^{14}$ n-eq/cm$^2$
Diamond sensors

Beam spots

**FBP-1**
non irradiated 750μm thick
2x3 polycrystal diamond sensors

First time we acquired data with a module sized diamond detector!
LC500 resolution

X Residuals Cluster Size 1
\( \sigma = 36.91 \, \mu m \)

Y Residuals Cluster Size 1
\( \sigma = 53.52 \, \mu m \)

X Residuals Cluster Size 2
\( \sigma = 45.27 \, \mu m \)

Y Residuals Cluster Size 2
\( \sigma = 52.96 \, \mu m \)
Irradiated Diamond resolution

X Residuals Cluster Size 1
\( \sigma = 36.71 \, \mu m \)

Y Residuals Cluster Size 1
\( \sigma = 50.01 \, \mu m \)

X Residuals Cluster Size 2
\( \sigma = 38.81 \, \mu m \)

Y Residuals Cluster Size 2
\( \sigma = 40.23 \, \mu m \)
Efficiency distribution across a part of the detector

Due to the high bandgap the charge released by particles is low

Inefficiency mainly due to events that don't pass the threshold

Efficiency distribution the single pixel cell

Efficiency ~ 62.3%

Unable to operate the detector with a lower threshold

It's important to modify the future electronics to make this possible
The longer Charge Collection Distance of the monocrystal relative to the polycrystal makes this detector more efficient even after irradiation.

Charge calibration has not been done because the detector was damaged when we tried to operate it at -700V bias voltage.
Conclusions

- We achieved our goal of thoroughly testing 6 sensors in a compact one week schedule – many thanks to the Test Beam Facility!

- 2 types of detectors tested, 3D Silicon and Diamond:
  - irradiated 1E and 4E 3D Silicon
  - irradiated monocrystal and non-irradiated polycrystal Diamond, single chip and multichip

- these are the main candidates to replace existing planar technology Si sensors in LHC phase 2 run and for the first time we tested a 2x3 diamond sensor

- the results of this preliminary (a few days) analysis already show the main characteristics/performance of the detectors and highlight sensor issues that still need to be fixed/understood

- for Diamond the need for a new electronics with much lower threshold is clearly emerging and furthermore, charge-sharing in Diamond must be better studied and understood

- 3D Silicon presents an efficiency which is intrinsically limited by the cross section of the column implants

- next we have to refine the analysis and extend it to the full data sample to investigate the still outstanding issues in order to finally better tune the plan for the next test beam campaign in late March