STUDY OF IRRADIATED 3D PIXEL SENSORS FROM CNM

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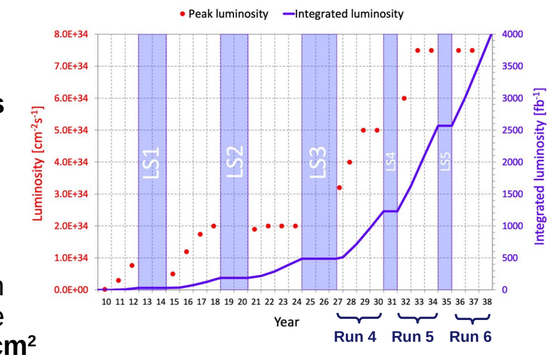
on behalf of the CMS Collaboration

15th Pisa Meeting on Advanced Detectors

High-Luminosity phase of the LHC

More on the CMS IT Upgrade in Antonio Cassese's poster!

- The High-Luminosity LHC environment:
  - Instantaneous luminosity peaks at **7.5x10^{34} cm^2/s**
  - Integrated luminosity of **4000 fb^{-1}**
  - **200** collisions per bunch crossing
- CMS needs an upgrade to cope with it.
  - The tracker will be completely replaced to sustain the foreseen high radiation levels, especially in the innermost layer of the IT: fluence of **1.88x10^{16} n$_{eq}$/cm^2** and dose of **1.03 Grad** for Runs 4+5.

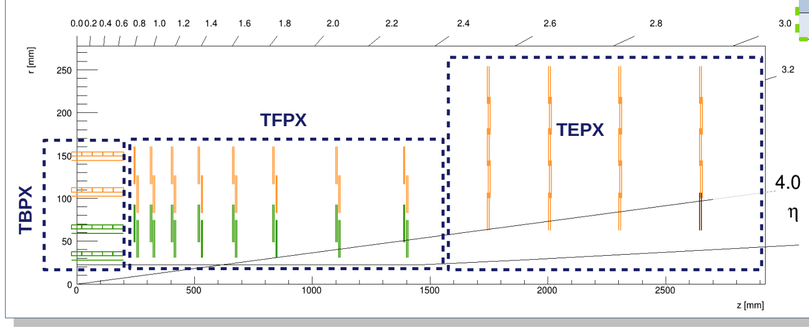


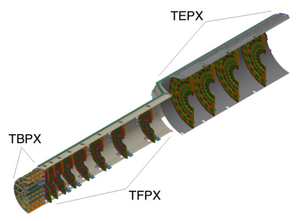
Baseline scenario with replacement in LS5

Sensors cannot sustain the last fluence scenario

Runs 4+5		Runs 4+5+6	
1E16 1MeV neq	Grad	1E16 1MeV neq	Grad
1.88	1.03	3.51	1.91

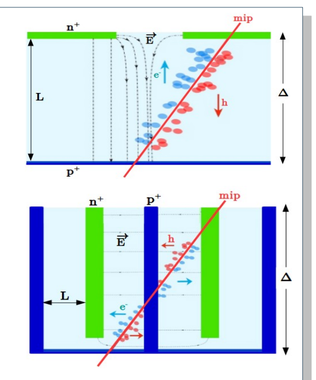
High-Luminosity upgrade of the CMS Inner Tracker layout





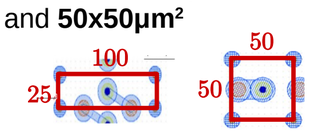
3D pixel sensor technology

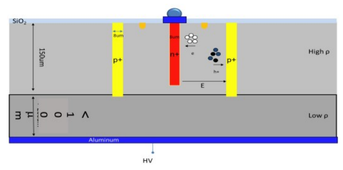
- **Advantages** with respect to planar sensors:
  - **Inter-electrode distance decoupled from the device thickness**
    - Smaller depletion voltage → **lower power dissipation**
    - Shorter path collection → **reduced trapping probability**
- **Drawbacks** with respect to planar sensors:
  - **Less homogeneous electric field + null points**
  - **Efficiency loss in the columns** → reduced sensitivity areas
  - More **complicated production procedure** → lower production yield



CNM 3D pixel sensor design

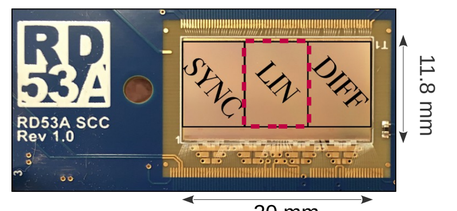
- **Hybrid** pixel detectors: **RD53A readout chip** + **n-in-p sensors**
- Reduced **pixel cell size**: **25x100µm^2** and **50x50µm^2**
- Reduced **active thickness**: **150um**
- **Si-on-Si single-side** processing





The readout chip RD53A

- **Three analog front-ends** for development purpose
- **Serial powering** via on-chip shunt-LDO regulators
- **76800 50x50µm^2 pixels** (26112 in the Linear FE)
- **65 nm CMOS technology**

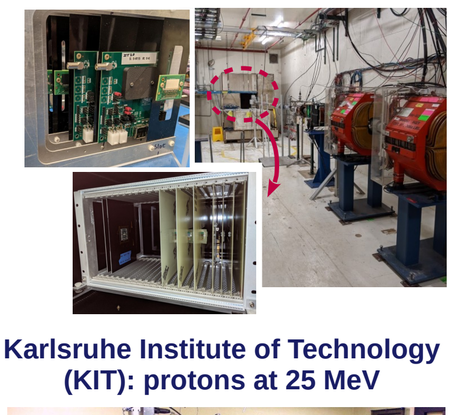


Irradiation & test beam setups

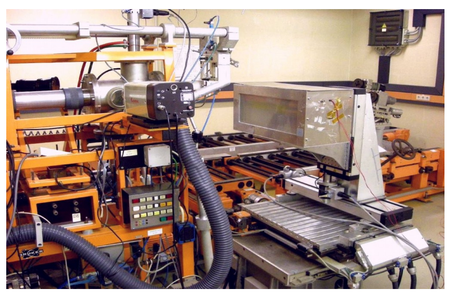
- The **irradiations** of the 3D pixel sensors manufactured by CNM have been carried out at different facilities.
  - The Total Ionizing Dose (TID) in the low-energy irradiation facilities is much higher than the value expected at CMS for the same fluence.
  - Target fluences in the range 1-2x10^{16} n$_{eq}$/cm^2.
  - Currently working on reducing the large systematic uncertainties for ITA fluences. There were some issues with the beam targeting.

Strasbourg: protons at 23 MeV

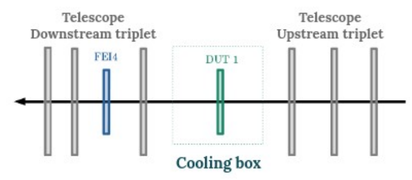
Fermilab Irradiation Test Area (ITA): protons at 400 MeV



Karlsruhe Institute of Technology (KIT): protons at 25 MeV



- The **data taking** has been performed at DESY and CERN SPS test beam areas. The modules have been tested before and after irradiation.
  - **DESY**: electron/positron beam at 5 GeV
  - **Fermilab**: proton beam at 120 GeV
  - **CERN**: pion beam at 120 GeV



Bonn Single Chip Card

RICE Single Chip Card

SPS CERN Test beam setup

- The results in this presentation have been obtained using only the Linear FE of the ROC.
- Telescope resolution around 2-10µm.
- Data Acquisition Systems: BDAQ and Ph2_ACF.

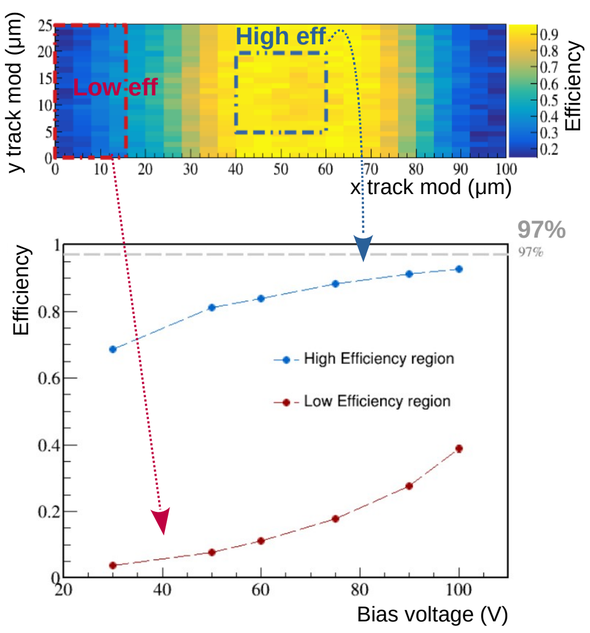
Irradiated sensor characterization

Results from the FBK foundry in Rudy Ceccarelli's poster!

Fluence estimation possibly affected by **large systematic uncertainties**: efficiencies higher than the expected values for the given bias voltages at such fluences.

25x100 3D CNM irradiated to 2x10^{16} n$_{eq}$/cm^2 at KIT

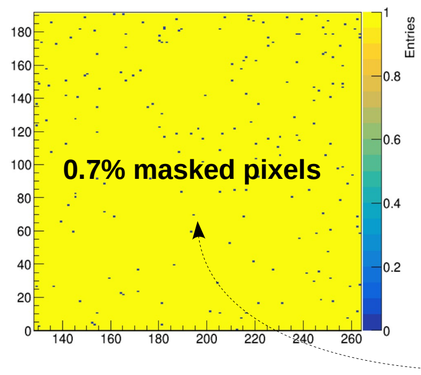
Sensor broke before reaching full depletion → looking at **two different efficiency regions** within the pixel cell



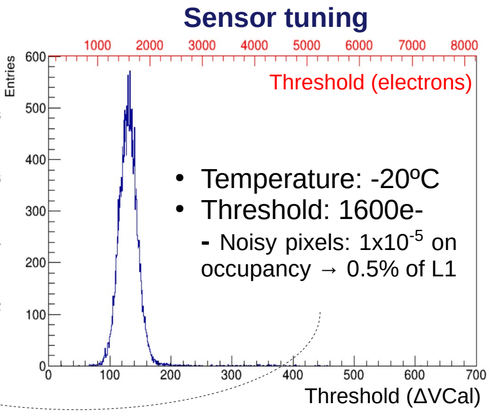
Full efficiency obtained at voltages much higher than 100V. Plateau expected at around 160-170V

25x100 3D CNM Irradiated to 1.3 x10^{16} n$_{eq}$/cm^2 at ITA

Masked pixels

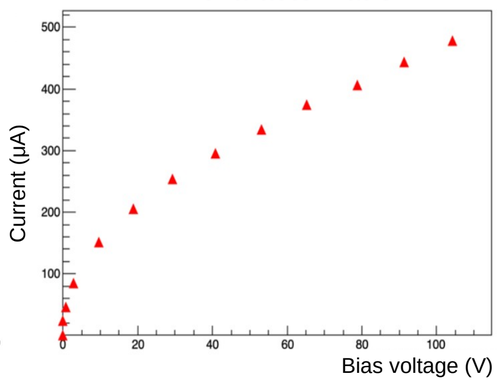


Sensor tuning

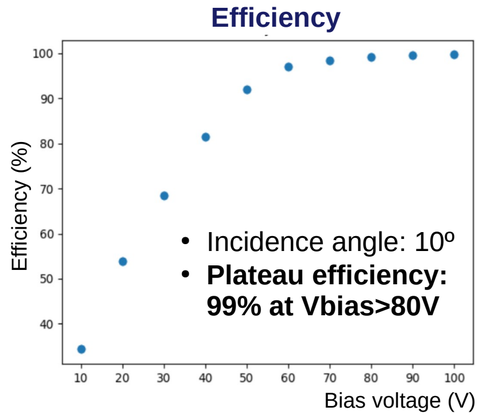


- Temperature: -20ºC
- Threshold: 1600e-
  - Noisy pixels: 1x10^{-5} on occupancy → 0.5% of L1

IV characterization

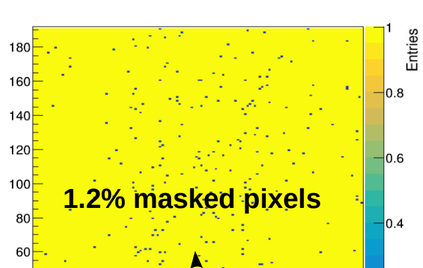


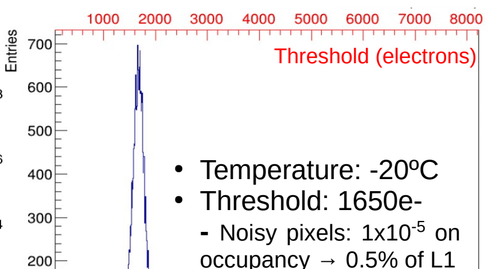
Efficiency



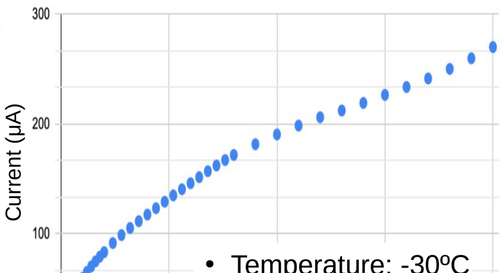
- Incidence angle: 10º
- **Plateau efficiency: 99% at Vbias>80V**

50x50 3D CNM Irradiated to 1.3 x10^{16} n$_{eq}$/cm^2 at ITA

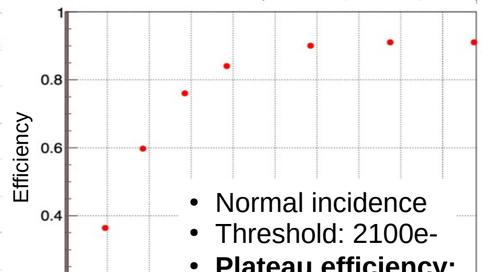




- Temperature: -20ºC
- Threshold: 1650e-
  - Noisy pixels: 1x10^{-5} on occupancy → 0.5% of L1



- Temperature: -30ºC



- Normal incidence
- Threshold: 2100e-
- **Plateau efficiency: 91% at Vbias>60V**

Summary

- **CNM 3D sensors have been irradiated up to a fluence of 2x10^{16}** n$_{eq}$/cm^2 and measured in test beams.
- Several samples got damaged during handling and transportation resulting in **limited data for CNM 3D sensors.** The large uncertainties in the ITA fluence estimation are under investigation.
- **Further irradiation programmes as well as test beam analysis are currently on-going.**

REFERENCES

[1] CMS Collaboration. "The Phase-2 Upgradeof the CMS Tracker". CERN-LHCC-2017-009. CMS-TDR-014. Geneva: CERN, June 2017.
[2] Garcia-Sciveres,Maurice; RD53A Collaboration. "The RD53A Integrated Circuit". CERN-RD53-PUB-17-001. Geneva: CERN, Oct 2017.
[3] M. Daas, Y. Dieter et al. "BDAQ53, a versatile pixel detector readout and test system for the ATLAS and CMS HL-LHC upgrades". Jan 2021.

ACKNOWLEDGMENTS

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