Results obtained with FBK Pixel Sensor prototypes for the HL-LHC Tracker Upgrade of the CMS experiment

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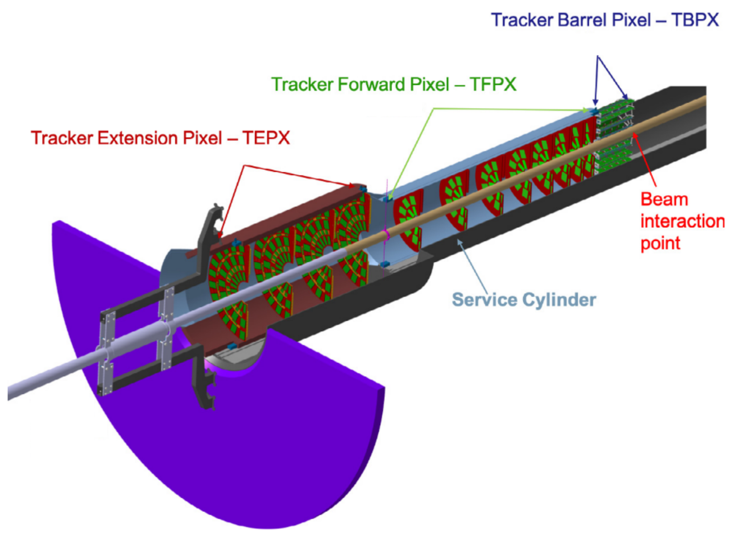
HL-LHC scenario for CMS Tracker



- HL-LHC Scenario:
  - Instantaneous luminosity up to 7.5×10^{34} cm^2/s
  - Collected data up to 4100 fb^{-1} over 10 years
  - Up to 200 collisions per bunch crossing with $\sqrt{s}$ =14 TeV
- CMS Tracker must be replaced to cope with higher luminosity. Main requests are:
  - Higher granularity → 2500 μm^2 area of single pixel to maintain occupancy at per mil level
  - High radiation tolerant sensors to withstand fluences ~ 1.9×10^{16} n_{eq}/cm^2 in the innermost layer.
- Two silicon pixels layouts to equip CMS inner tracker during HL-LHC:
  - Thin Planar pixel
  - 3D pixel

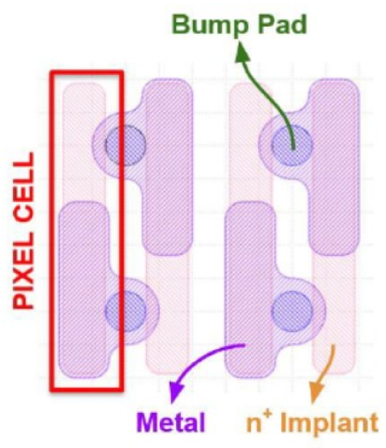
Detailed presentation of CMS inner tracker by Antonio Cassese: *"The CMS Pixel Detector for the High Luminosity LHC"*

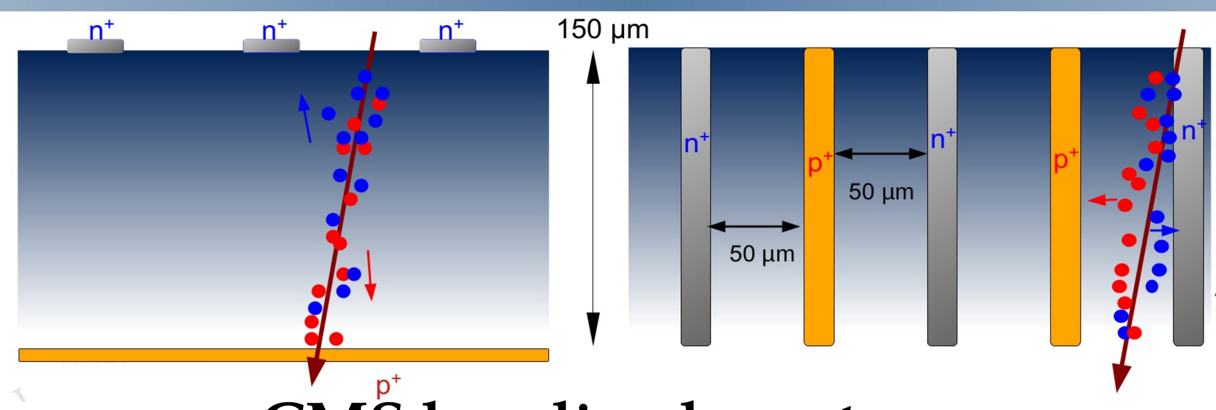
Baseline choice for Barrel-Layer 1

Pixel sensor protoypes

Planar Pixel

- Advantages of planar pixels:
  - Well-known technology widely used in HEP experiments
  - Easy to fabricate
- Large Power dissipation due to large bias voltage and leakage current (after irradiation)
- FBK planar "Mask Aligner" batches:
  - Bitten design
  - No Punch Through option



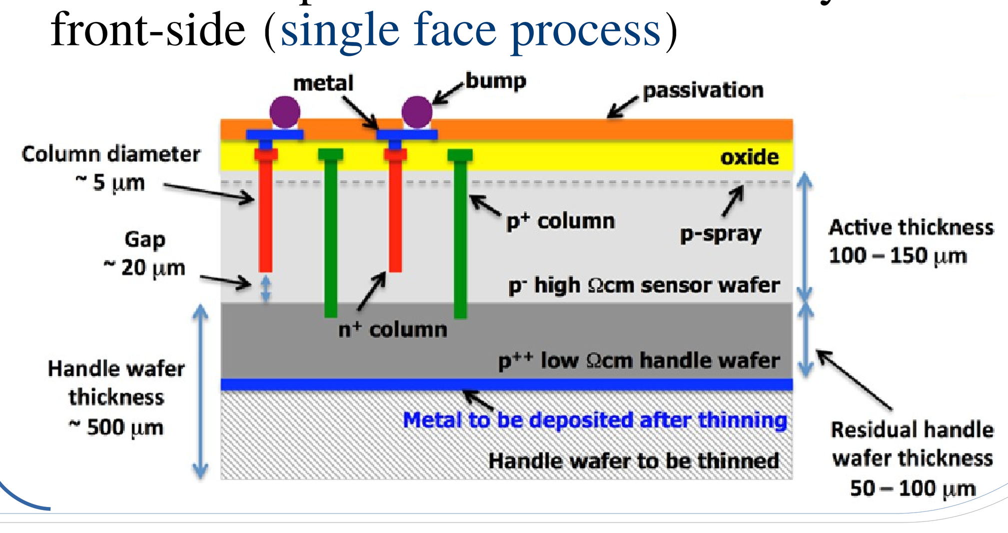


CMS baseline layout

- CMS baseline design for pixel sensors:
  - Sensor type n-in-p
  - Pitch 25×100 μm^2 and active thickness 150 μm
- During R&D, sensor prototypes with prototype chip RD53A via bump-bonding:
  - 65 nm CMOS technology
  - Three front-ends for development purpose
    - CMS → linear FE
- Sensors developed by FBK Trento in collaboration with INFN Firenze
- Sensors irradiated at KIT with low energy protons (23 MeV) up to 2.4×10^{16} n_{eq}/cm^2
- Sensors measured with 6 GeV/c electrons beam at DESY telescope

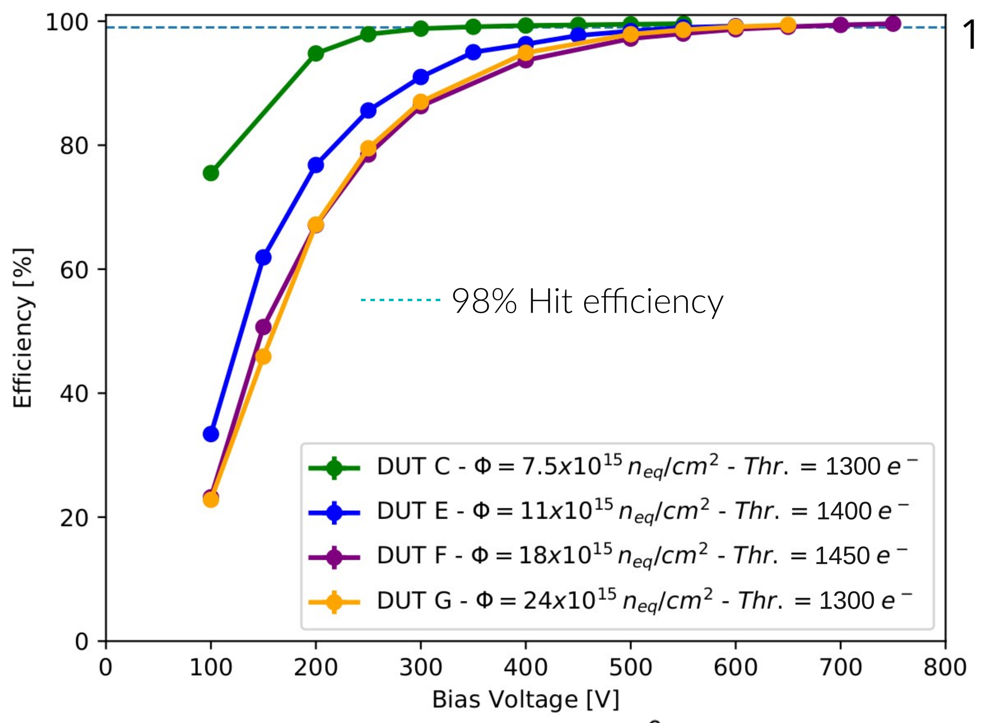
3D Pixel

- Pros and Cons of 3D pixels:
  - Reduced depletion voltage and power consumption
  - Shorter signal collection path for ionization charges
    - reduced trapping probability after irradiation
  - Small inefficiency due to passive material (columns) with orthogonal tracks.
- Two 3D FBK "Step and Repeat" batches, Stepper-1 and Stepper-2:
  - Reduced gap between n$^+$ columns and sensor backside in Stepper-2 batch
- Both n$^+$ and p$^+$ columns are etched only from the front-side (single face process)



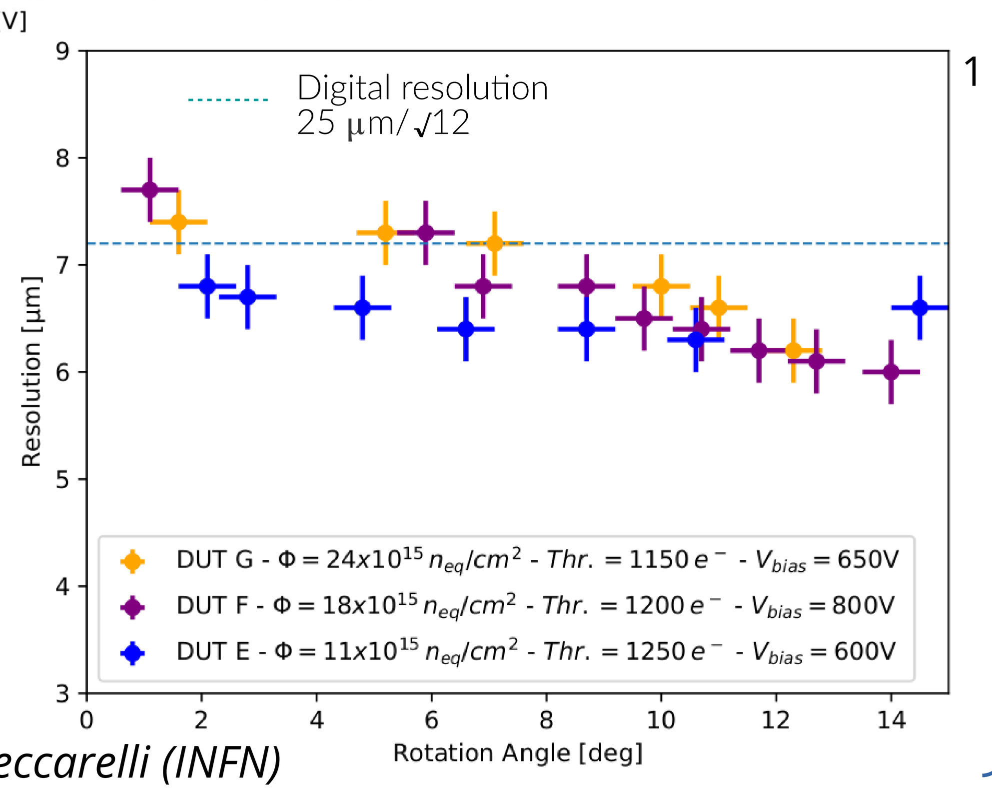
Results for highly irradiated samples

Planar Pixel



- 98% hit efficiency for all the sensors
  - 200 V for sensor irradiated @7.5×10^{15} n_{eq}/cm^2
  - 500 V for sensor irradiated @24×10^{15} n_{eq}/cm^2
- Planar pixel modules can withstand the high fluence foreseen in HL-LHC

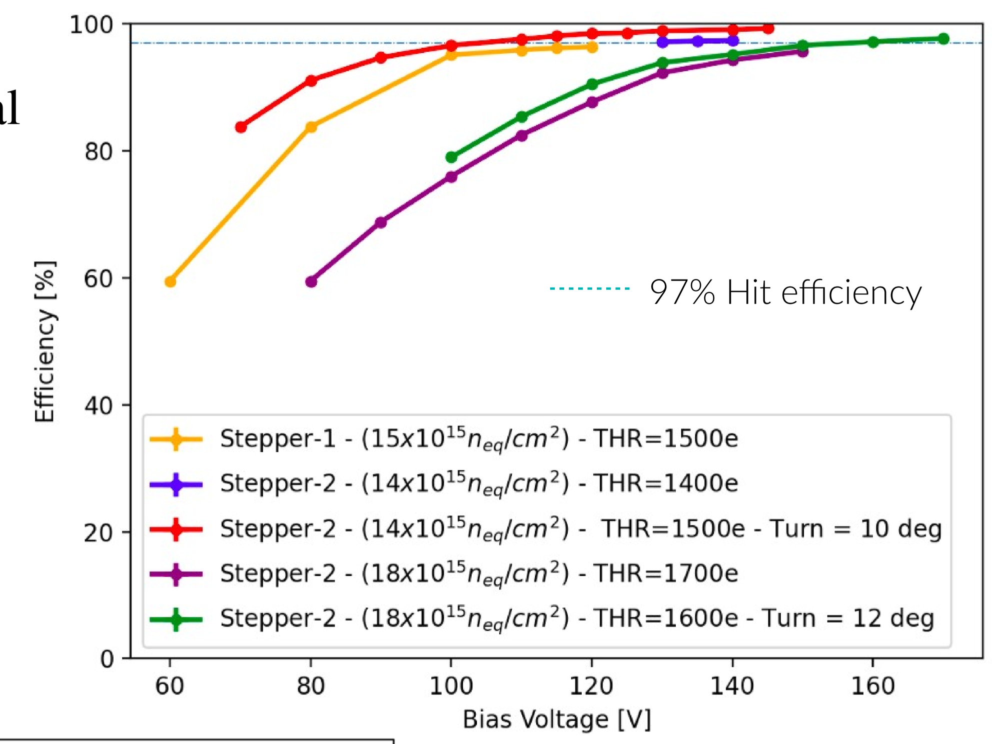
- Spatial resolution measured with the first three planes of DESY telescope
  - Second triplet unusable due to multiple scattering with cooling box material
- Minimum spatial resolution below digital resolution $25/\sqrt{12}$ μm

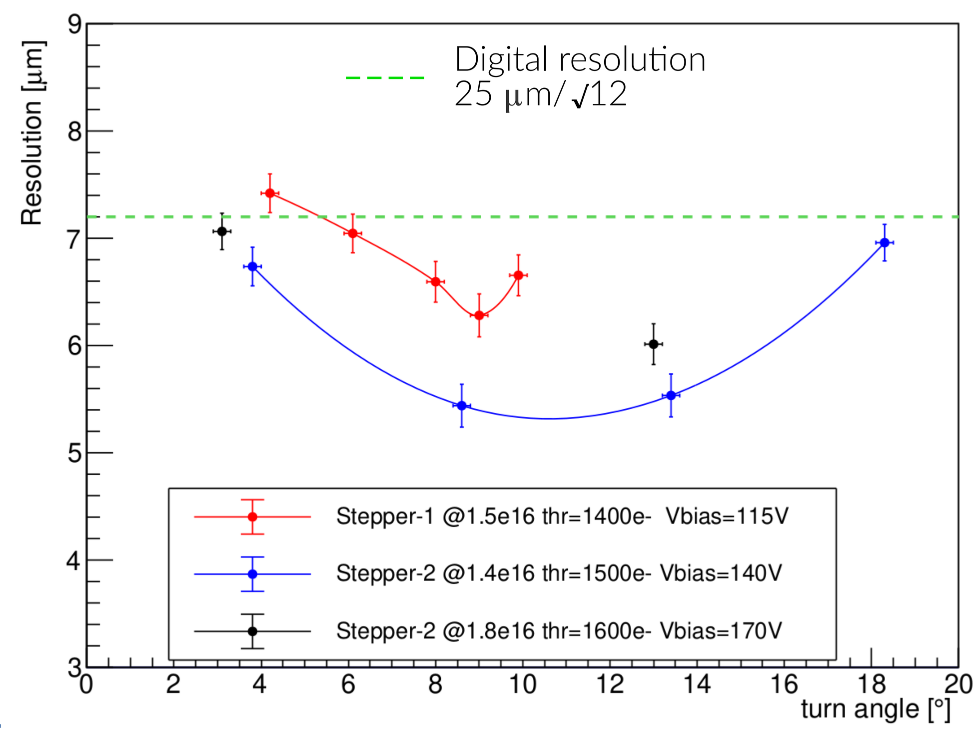


1 *Courtesy from Rudy Ceccarelli (INFN)*

3D Pixel

- 97% hit efficiency for all the sensors with orthogonal tracks
  - Hit efficiency plateau from 110 V up to 140 V
- 99% hit efficiency with tilted DUT
- Quick increase in the number of noisy channels for Stepper-1 modules at high Voltage
  - Better with Stepper-2 sensors

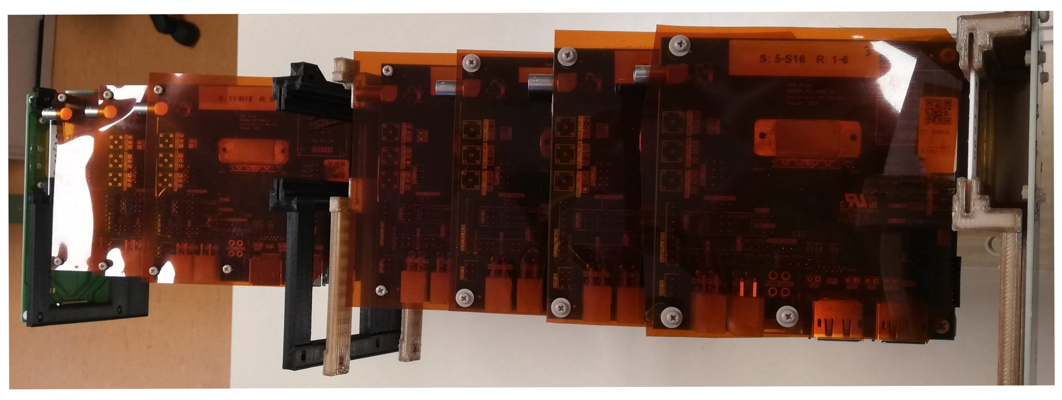




- Angle scan with respect to 25 μm side
- Minimum of spatial resolution around 9° turn angle
  - Reached 5 μm for Stepper-2 module
- Minimum of spatial resolution below than digital resolution $25/\sqrt{12}$ μm

Outlook and future perspectives

- Further investigation for irradiated 3D pixel
  - Irradiation at CERN-IRRAD with 24 GeV/c protons
  - Lower TID with respect to low energy protons
  - Expected fluence from 1.5×10^{16} n_{eq}/cm^2 up to 1.8×10^{16} n_{eq}/cm^2



- First 3D and Planar sensors assembled with CROC-v1 (CMS-ReadOut Chip prototype version 1)
  - Final Chip prototype
  - Only linear Front-End
  - 145142 Channels