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Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

Precision single hit resolution measurements for the CMS Inner Tracker Phase-2 upgrade

Irene Zoi for the CMS Tracker Group
irene.zoi@cern.ch

HL-LHC

Instantaneous peak luminosity: 5-7.5x10^{34} $cm^{-2}s^{-1}$

Increase Standard Model measurements precision
Increase discovery potential

✗ **Up to 200 pileup interactions**
✗ **Radiation fluence up to ϕ_{eq} = 2.3×10^{16} cm^{-2}**

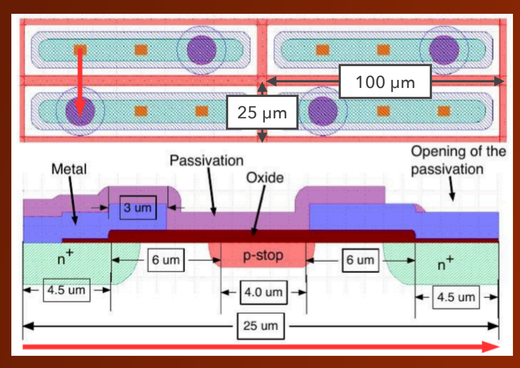
Discriminate interesting events from background
Maintain detector performance

The Phase-2 Inner Tracker

- Radiation hard → **Thin n⁺p sensors**
- Increased granularity → **6 times smaller pixels**
- Increased pseudo-rapidity coverage

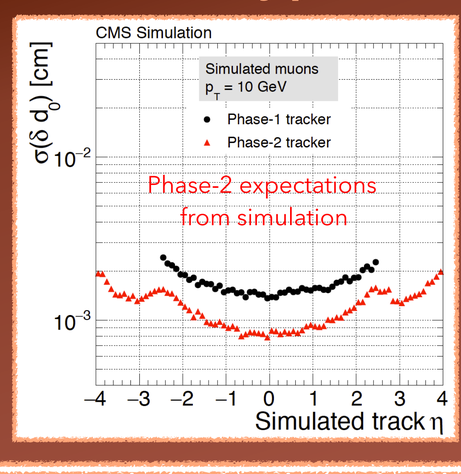
Tested HPK planar pixel sensors

- 150 µm thickness & 100 x 25 $µm^2$
- Bump bonded to PSI ROC4SENS analog ROC



- Irradiated sensors:
  - CERN PS @ 3.3x10^{15} p/cm^2 (ϕ_{eq} = 2.1x10^{15} cm^{-2}) → Layer 3
  - Ljubljana TRIGA reactor (ϕ_{eq} = 4x10^{15} cm^{-2}) → Layer 3 < ϕ_{eq} < Layer 2

Why precision resolution measurements?



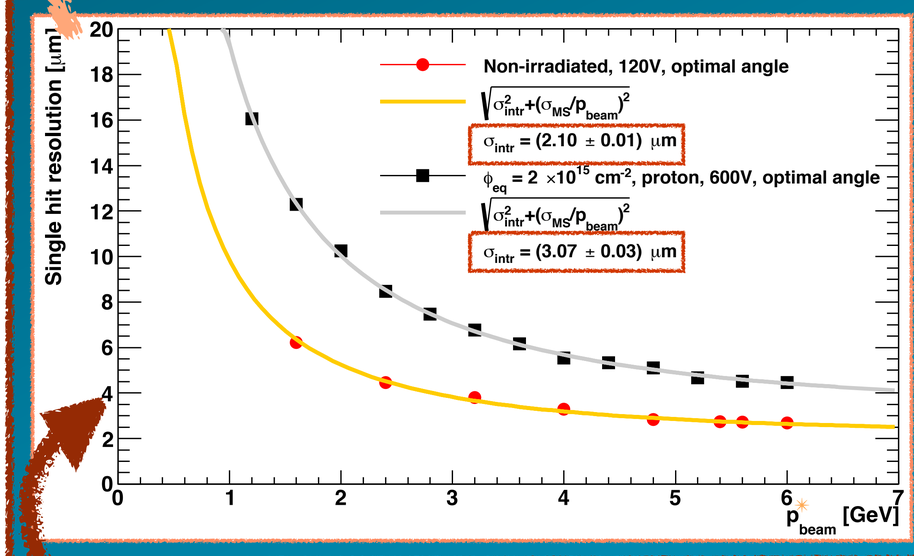
- What is the resolution of the small pitch pixel sensors?
- Does resolution degrade with radiation damage?
- How to measure the spatial resolution with 25 µm pitch?

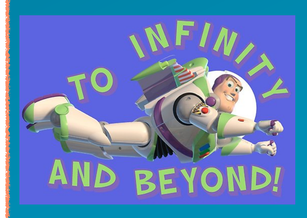
Summary

- **Excellent resolution for the 25 µm pixels:**
  σ_{intr} (ϕ_0) = 2 µm
- **Maintained after full layer 3 lifetime fluence:**
  σ_{intr} (ϕ_{eq} = 2 x10^{15} cm^{-2}) = 3 µm

Dependence of optimal angle from fluence and bias voltage needs to be taken into account

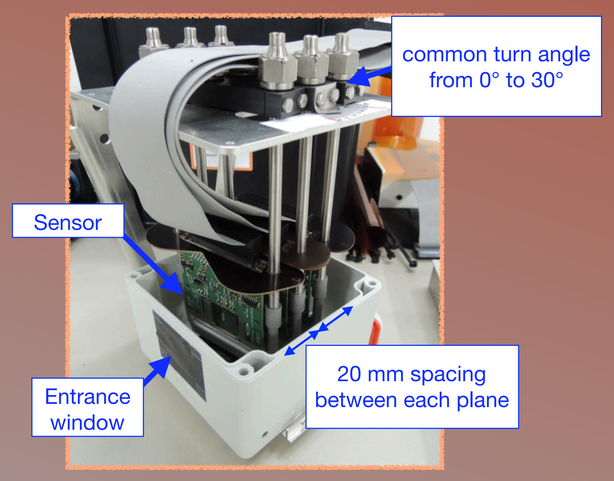
Intrinsic resolution

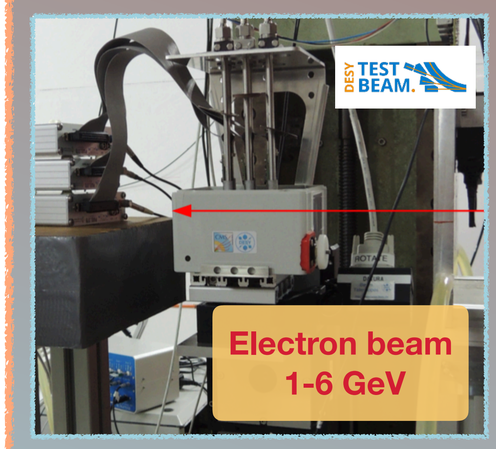




✶ Uncertainty on beam momentum spread not taken into account

"The DREIMASTER"





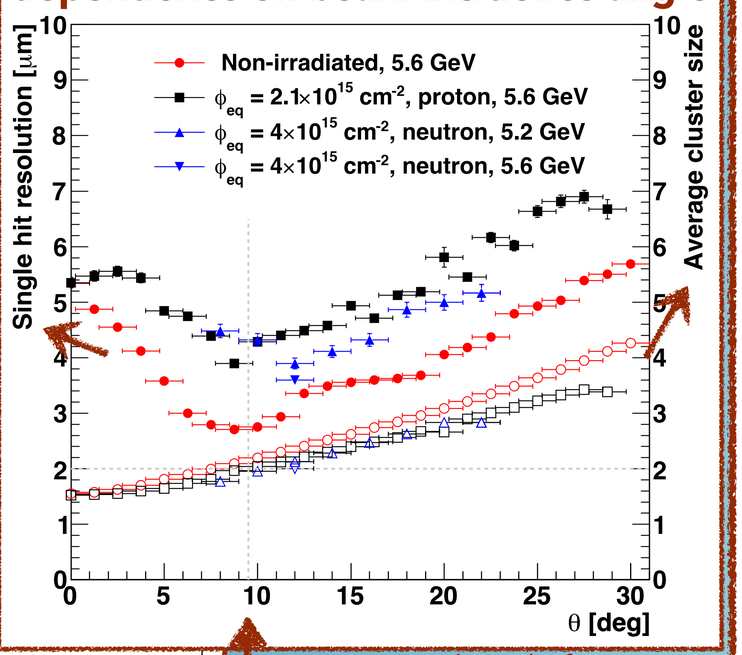
- **3 parallel** planes of **sensors**
- **Does not rely on an external reference tracking detector → intrinsic resolution**
- **Resolution** measurement by the **triplet method**
- **Measurements @ DESY II** test beam facility → **electron beam @ 1-6 GeV**

Single hit resolution

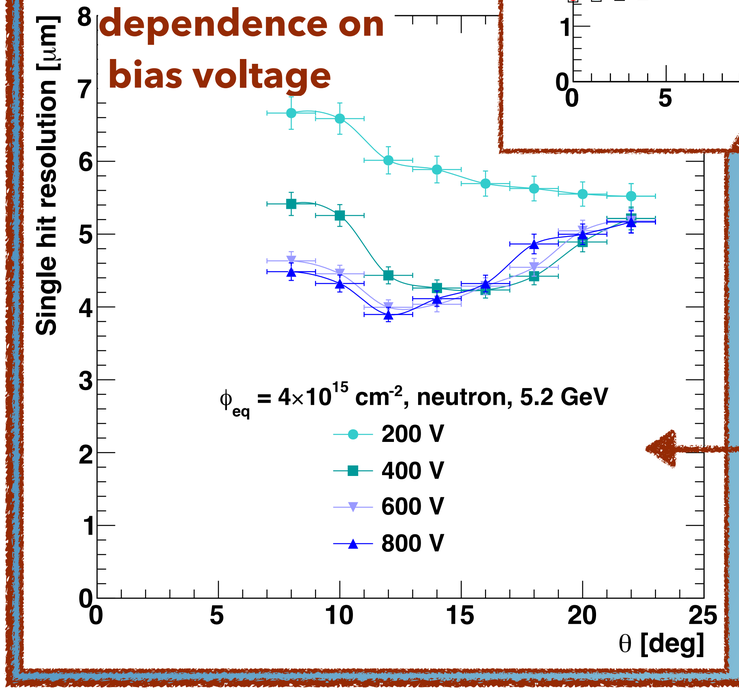
- Non-Irradiated @ 120 V, room temperature
- Irradiated @ 800V, cooled @ ~ -24°C

✦ Foreseen Lorentz angle in CMS: 11° @ 300V before irradiation

dependence on beam incidence angle



dependence on bias voltage



Optimal angle for charge sharing = $\arctan \frac{pitch(25\mu m)}{thickness(150\mu m)} = 9.5°$

Optimal angle depends also on **bias voltage**

Single hit resolution extraction

$$residual = x_B - \frac{x_A + x_C}{2}$$

- From the uncertainty propagation:
  - Uncertainty on single hit Δ_{XB} independent from Δ_{XC} and Δ_{XA}
  - For non irradiated sensors $\Delta_{XB} = \Delta_{XC} = \Delta_{XA} = \Delta_X$
  - For irradiated sensors Δ_{XB} != $\Delta_{XC} = \Delta_{XA} = \Delta_X$

$$\Delta_X = \sqrt{\frac{2}{3}}\Delta_{res}$$

$$\Delta_{XB} = \sqrt{\Delta_{res}^2 - \frac{1}{2}\Delta_X^2}$$