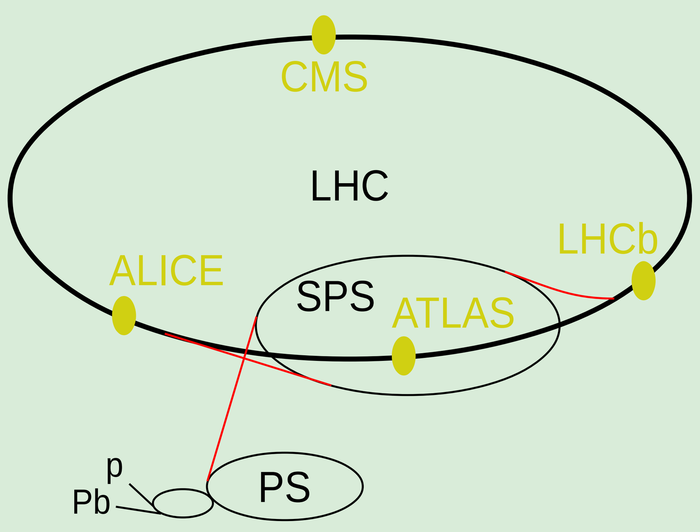
Characterization of thin irradiated epitaxial silicon sensors for the CMS phase II pixel upgrade

The CMS experiment

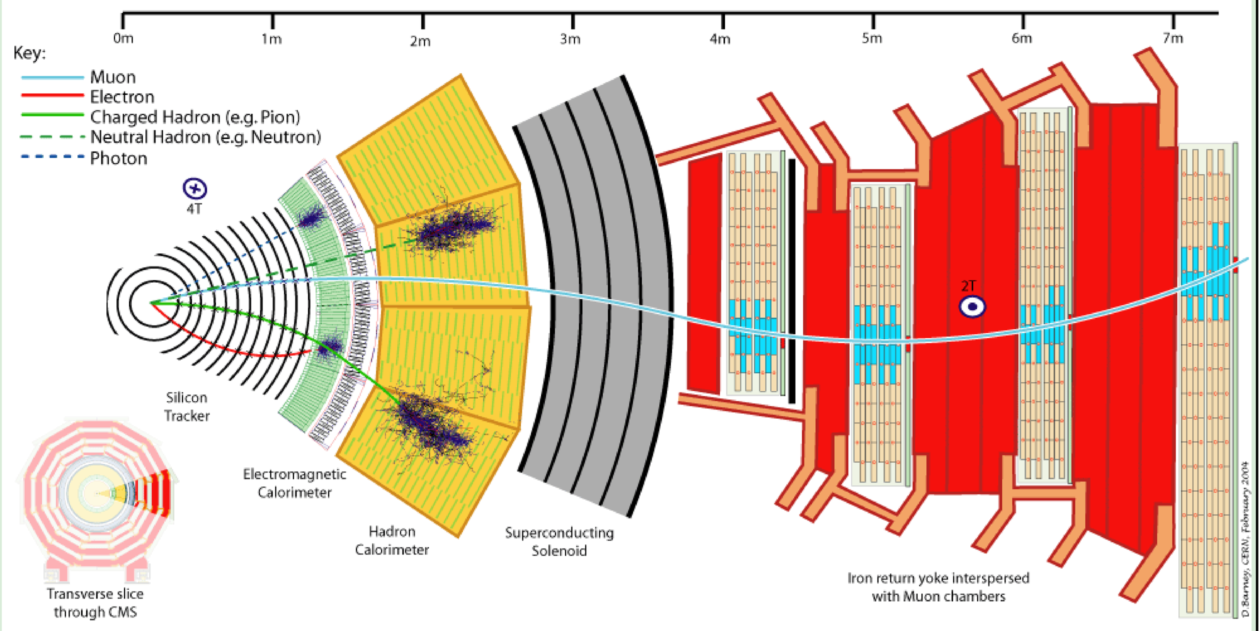


Large Hadron Collider:
- Proton-proton collider
- 27 km circumference
- 4 interaction points

Design parameters:
- CM energy = 14 TeV
- Bunch spacing = 25 ns
- Luminosity = 10^{34} cm^{-2} s^{-1}

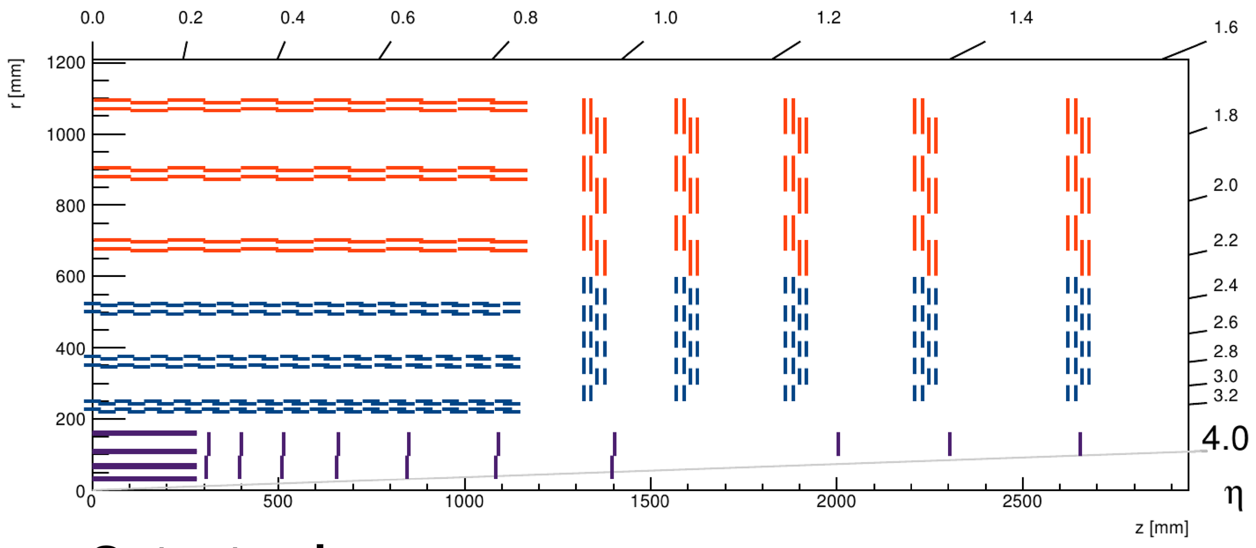
Achievements:
- SM tests
- BSM searches
- Discovery of the Higgs boson

Compact Muon Solenoid:
- General purpose detector
- Cylindrical symmetry



The phase II pixel upgrade

2023: High-Luminosity LHC
- Luminosity of **5 x 10^{34} cm^{-2} s^{-1}**
- Replacement of the tracker



Outer tracker:
- Momentum information for L1 trigger
- 2-strip and pixel-strip modules

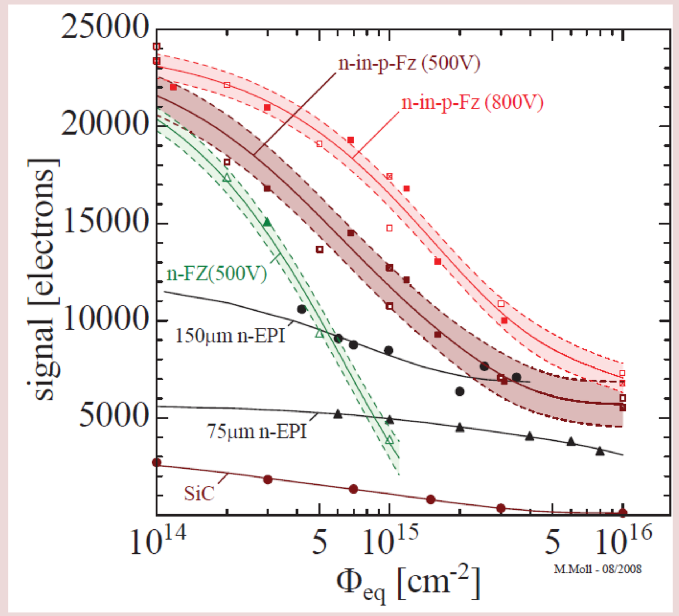
Pixel modules:
- Hybrid configuration
- Pixel area = 2500 µm²
- ~5 m² of pixel sensors

Radiation tolerance

For the innermost pixel layer, after 3000 fb^{-1}
- Φ_{eq} ≈ 10^{16} cm^{-2} } Sensor
- Dose = 5 MGy } Front-end chip
- Hit rate = 1-2 GHz cm^{-2}

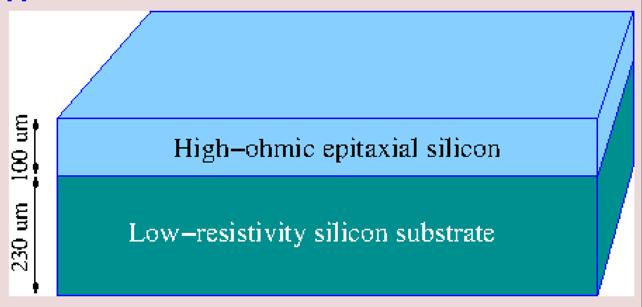
Several materials and configurations under study

Sensors under study

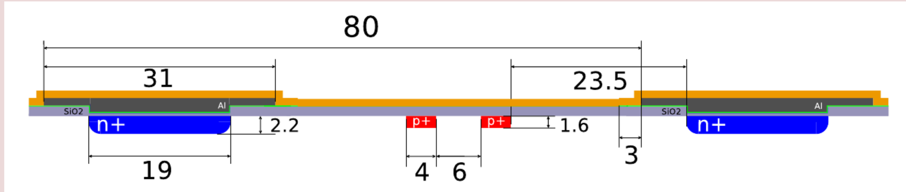


Thin planar sensors (black) compared to thicker ones (300 µm, red and green)
- Before irradiation: smaller signal
- After irradiation: weaker degradation

Diodes and strip detectors:
- High resistivity epitaxial silicon
- n- and p-bulk
- Active thickness = 100 µm
- Total thickness = 330 µm
- Max Φ_{eq} = 1.3 x 10^{16} cm^{-2}
  - 800 MeV and 23 GeV protons
- No annealing

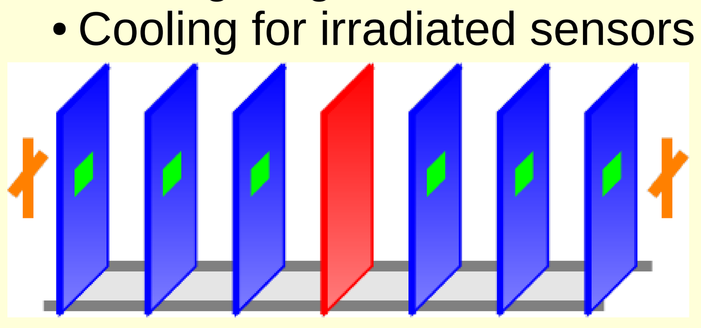


Strip detector with p-stop insulation, pitch = 80 µm



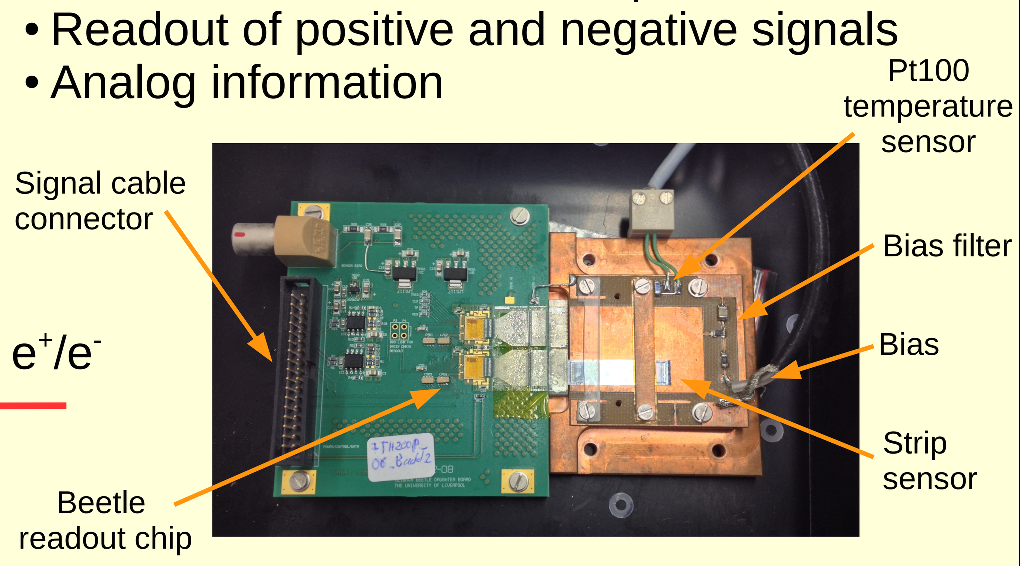
Test beam setup

- **DESY e$^+$/e$^-$ beam**
- AIDA beam telescope
- 4 trigger scintillators
- Sensor housing
  - Moving stage
  - Cooling for irradiated sensors



3-5 GeV e$^+$/e$^-$

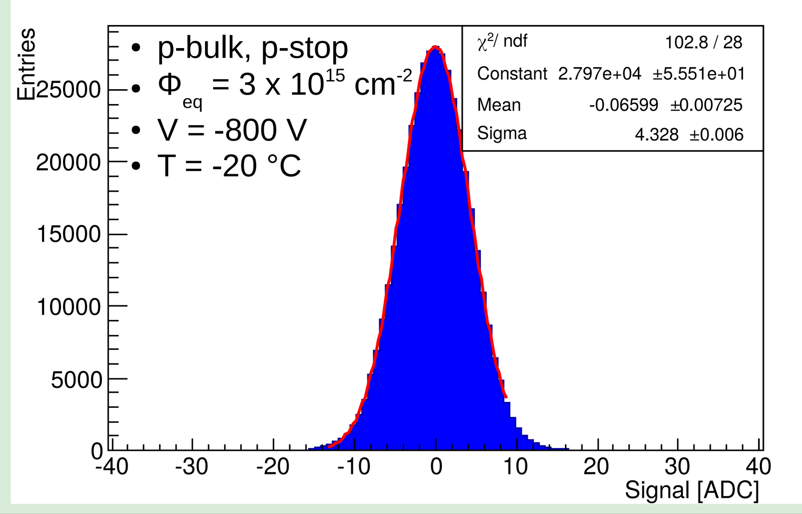
ALiBaVa readout system
- Based on LHCb readout chip
- Readout of positive and negative signals
- Analog information



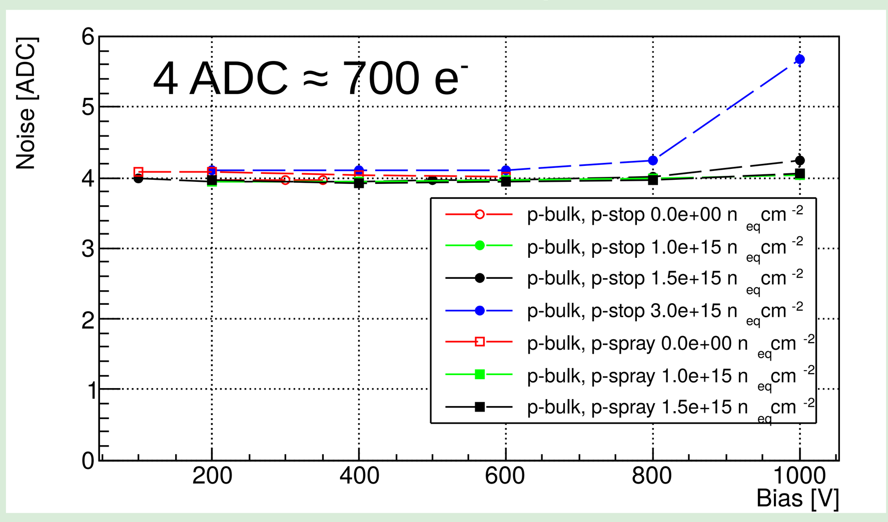
Noise

Noise dominated by readout electronics and sensor capacitance for bias < 800 V

Single channel noise

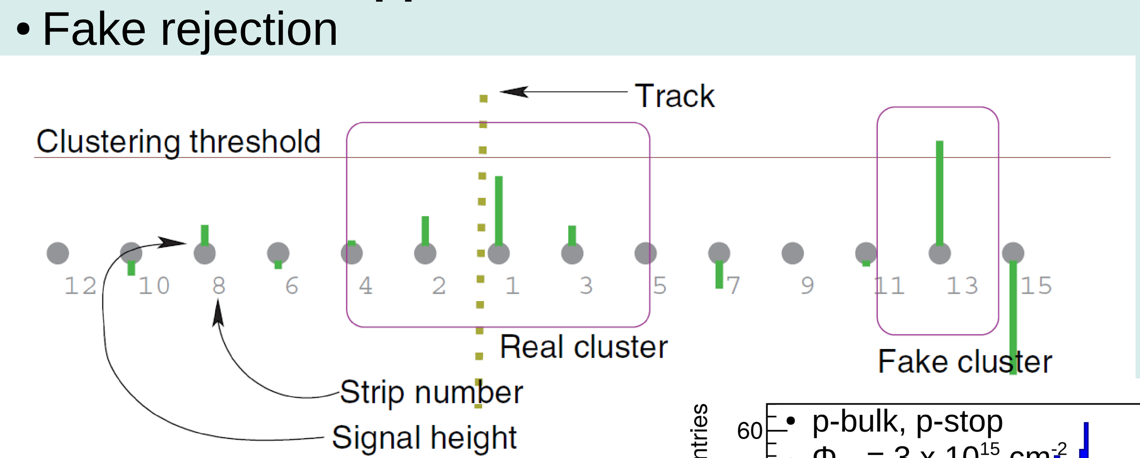


Mean noise amplitude

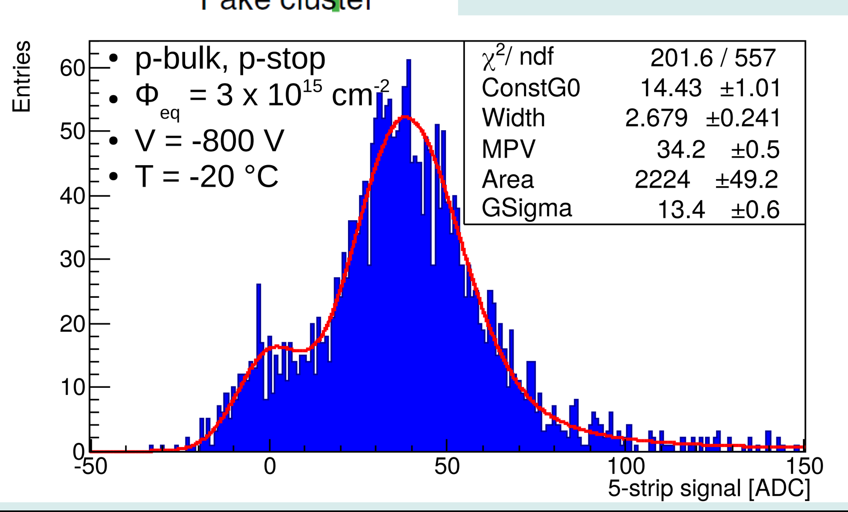


Charge Collection Efficiency

Charge definition based on telescope tracks:
- Charge := sum of the signal over 5 strips, centered on the telescope prediction
- **No threshold applied**
- Fake rejection

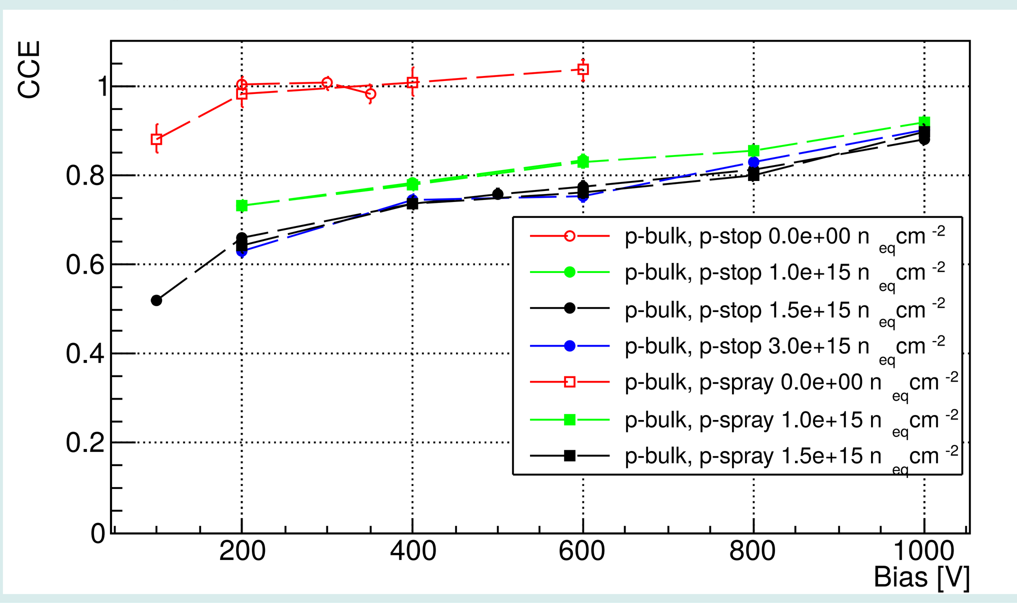


Charge distribution fit:
- Gauss function constrained to the noise
- Landau-Gauss convolution

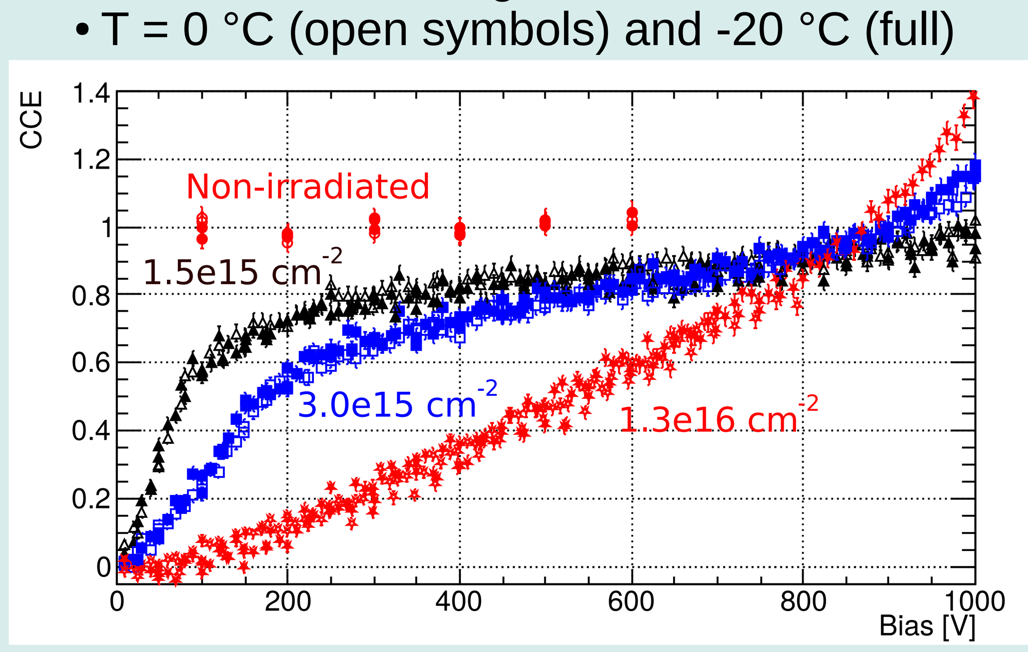


- **CCE of n-in-p strip sensors 90% after Φ_{eq} = 3 x 10^{15} cm^{-2}**
- **Diodes show better CCE than strip sensors**
- **Charge multiplication is present in diodes, to be investigated in strip detectors**

CCE of **strip detectors** from **test beam**:
- Landau MPV from fit
- Normalization using non-irradiated sensors in range 200-400 V
- Only statistical errors taken into account



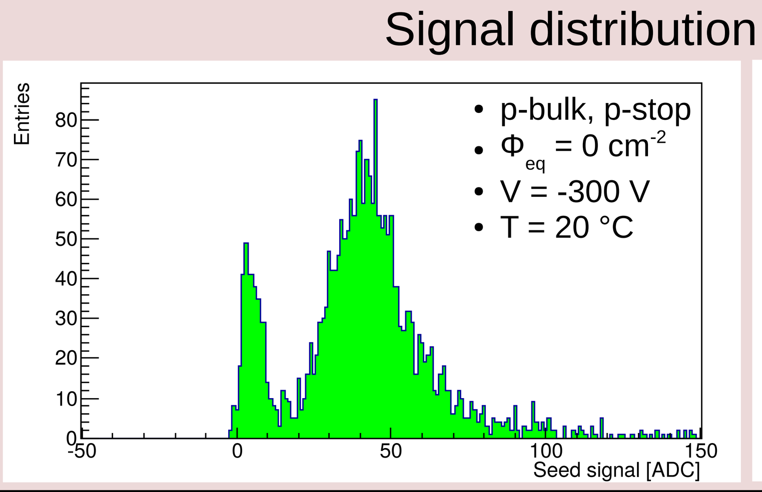
CCE of **diodes** using **TCT**:
- p-bulk, p-spray
- Infrared laser
- Normalization using non-irradiated sensors
- T = 0 °C (open symbols) and -20 °C (full)

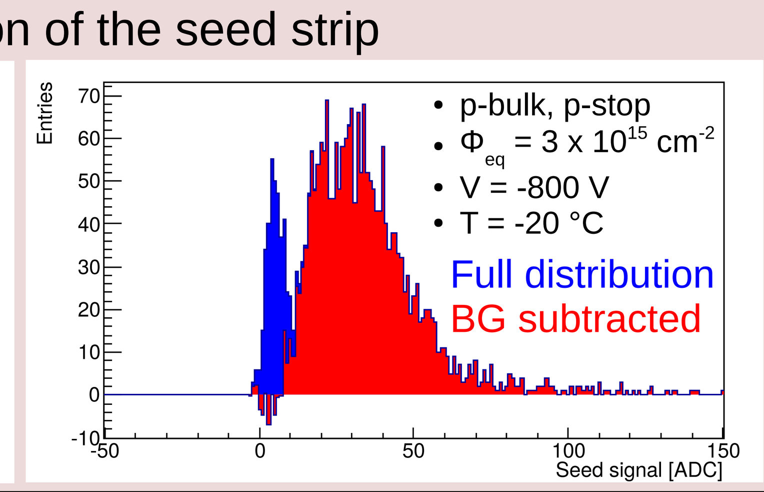


Detection efficiency estimation

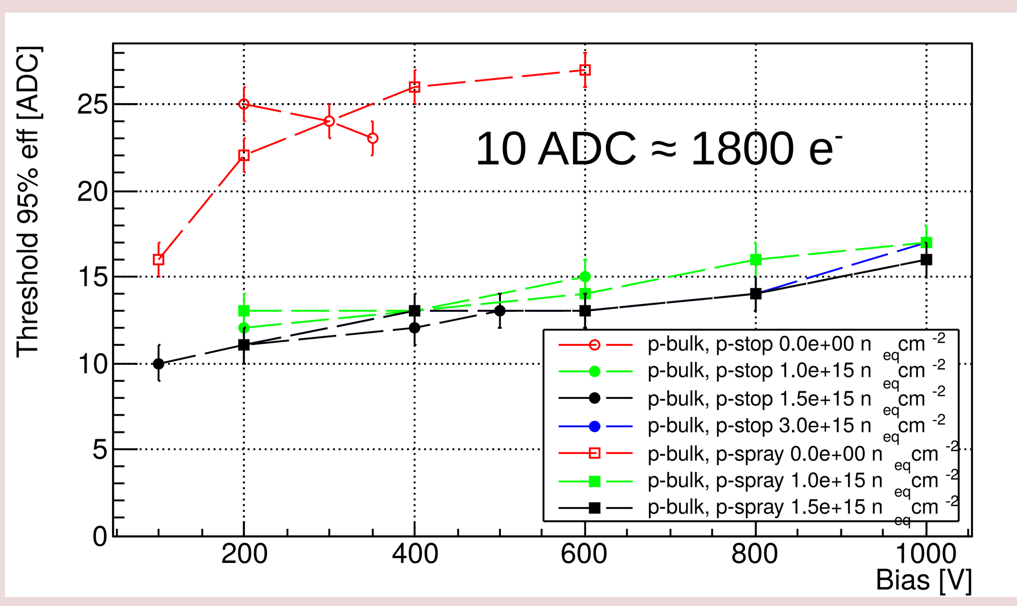
The irradiation produces a smearing of the distribution (charge sharing)

Signal distribution of the seed strip





Seed threshold to have 95% efficiency



Conclusions & Outlook

- The CCE of thin epitaxial silicon diodes and strip sensors has been measured
- **Thin epitaxial silicon is a promising material for the CMS pixel phase II upgrade**
- Extend the test beam analysis to different sensors and higher fluences
- Choice of material and thickness: end of 2016
- Prototype test sensors in 2017

Bibliography

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