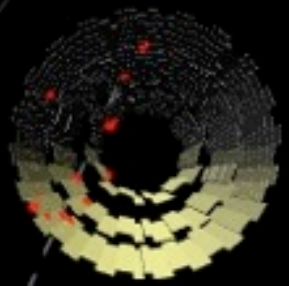
Commissioning the CMS Pixel detector with cosmic ray data



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On behalf of the CMS Pixel group

14th RD50 Workshop

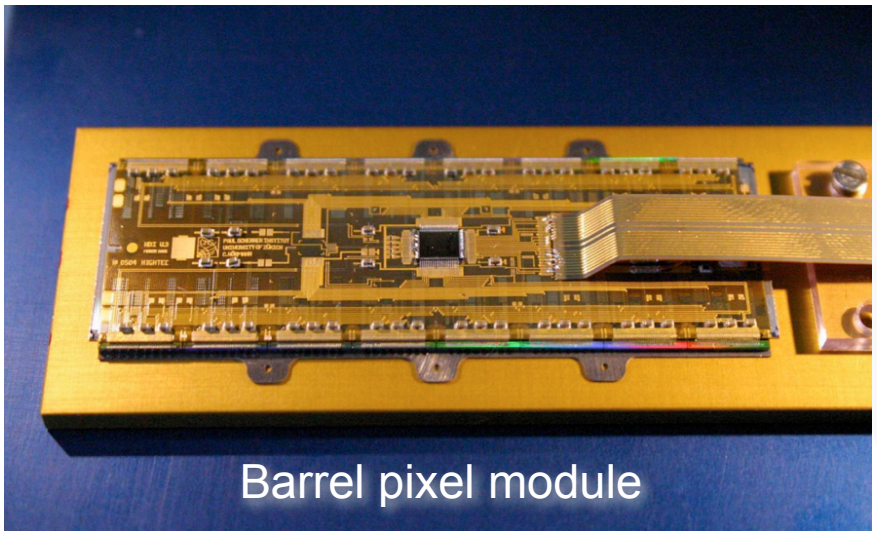
3-5 June, 2009 - Freiburg, Germany

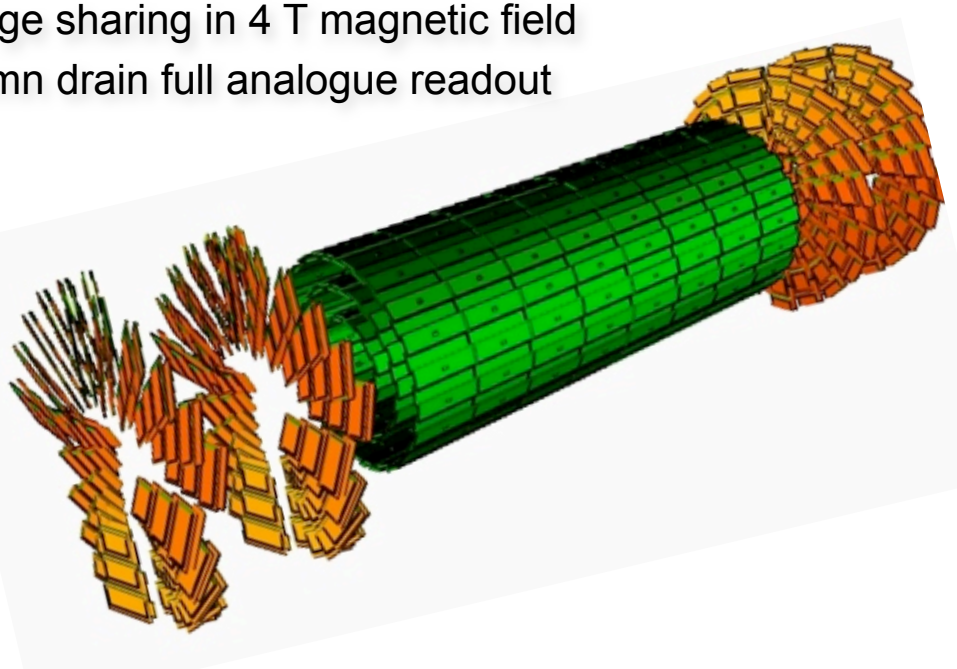
Outline

- Detector layout and installation
- First results from cosmic ray data:
  - Thresholds and charge collection
  - Lorentz angle and position resolution
- Performance after irradiation from test-beam measurements:
  - Charge collection and cluster multiplicity
  - Position resolution

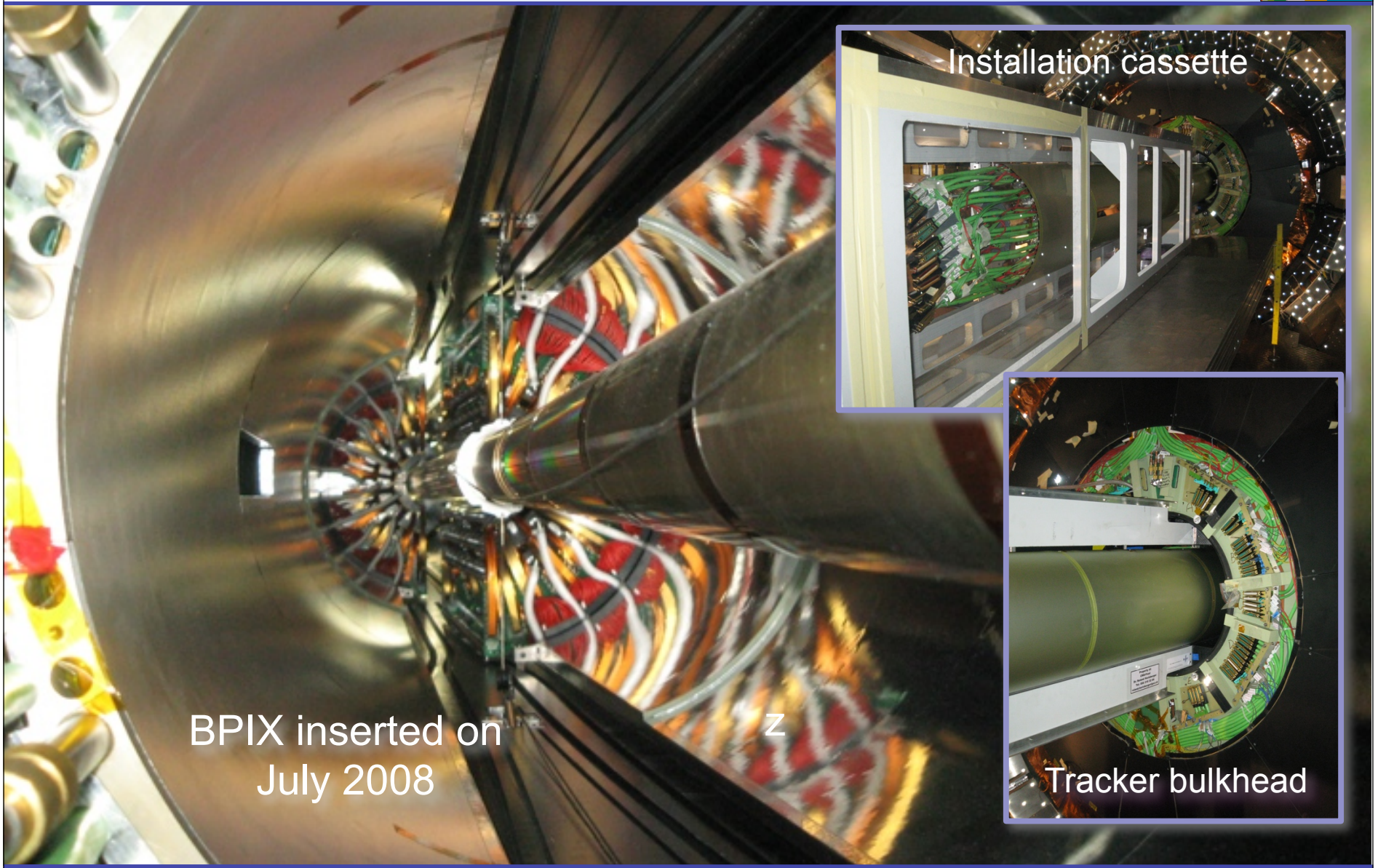
Detector layout

- Three barrel layers and two endcap disks at each barrel end
  - Barrel layers at 4 cm, 7 cm, and 11 cm radius
  - ~700 modules made of 16 chips in barrel region (67k channels/module)
  - Endcap disks: 24 blades made of 7 sensors (4 or 3 per side)
  - About 67×10^6 channels in total, L~1 m, R~30 cm
- Sensors and front-end electronics:
  - *"n-in-n"* design with p-spray (CiS, barrel) and p-stop (Sintef, endcaps) isolation
  - $100(r\phi) \times 150(z)$ μm^2 pixel cell, charge sharing in 4 T magnetic field
  - PSI 0.25 μm CMOS chip with column drain full analogue readout


Barrel pixel module

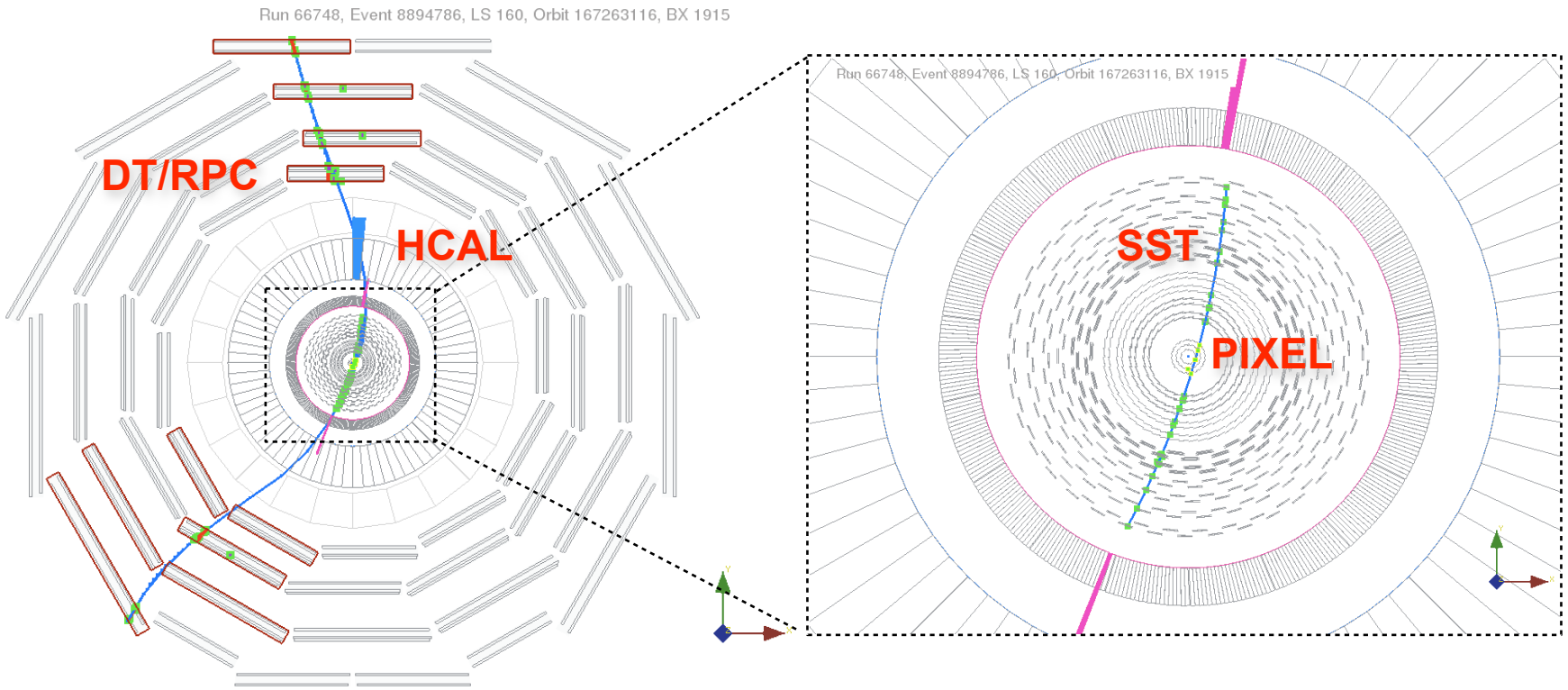


Detector installation

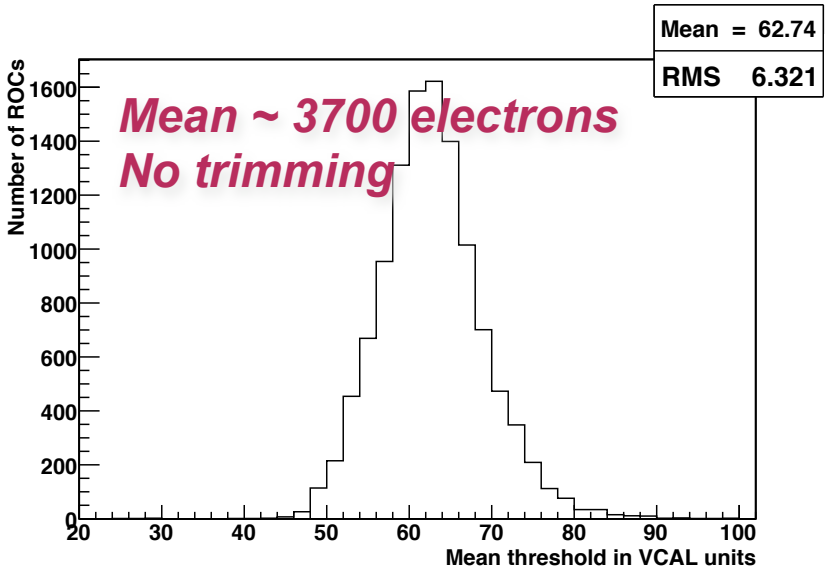


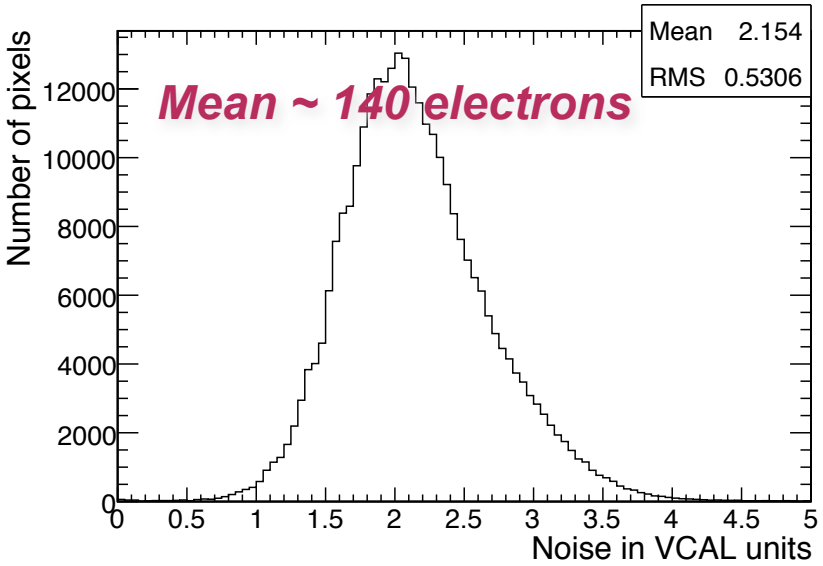
2008 CMS run with cosmic rays

- ~300M cosmic triggers collected in Oct-Nov 2008 with full CMS experiment
  - CMS solenoid at 3.8 T
- ~85‘000 tracks crossing the pixel detector
  - About 250‘000 pixel clusters associated to a track



Pixel thresholds & noise

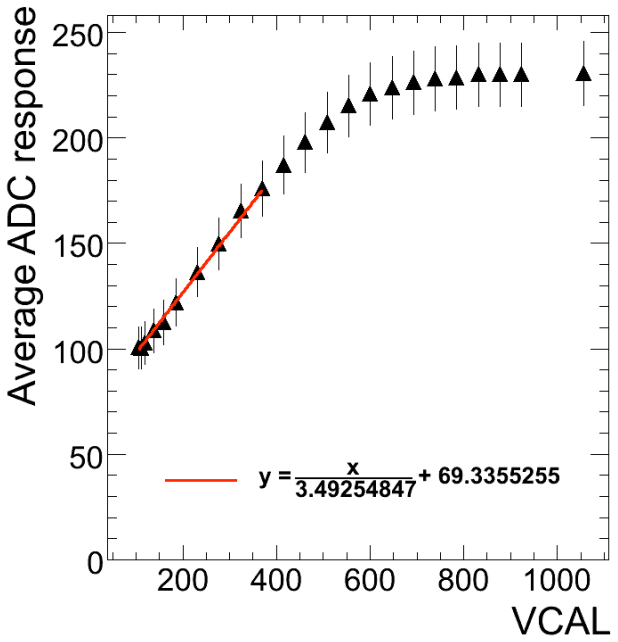


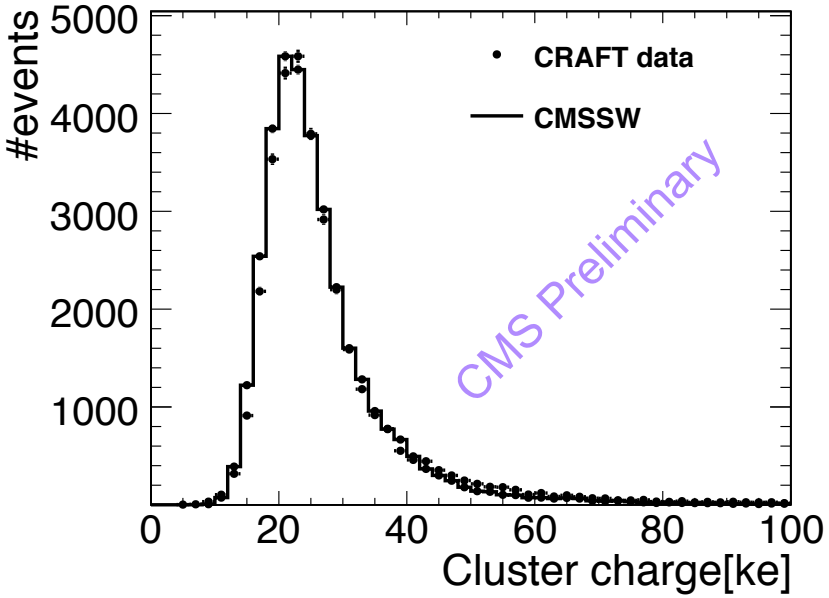


- Absolute readout threshold measured with pulser scans
  - Not enough time to perform fine trimming before cosmic data taking
  - In-time threshold due to time-walk effect ~5000 electrons
  - Front-end chip noise from threshold fluctuation ~140 electrons
    - Other sources of electronic noise (e.g. optical transceivers) ~300 electrons

Charge collection

- Pixel charge calibrated with pulser signal:
  - Converts ADC counts into electrons
  - Low charge part fitted with straight line
  - 1 VCAL unit ~ 65 electrons

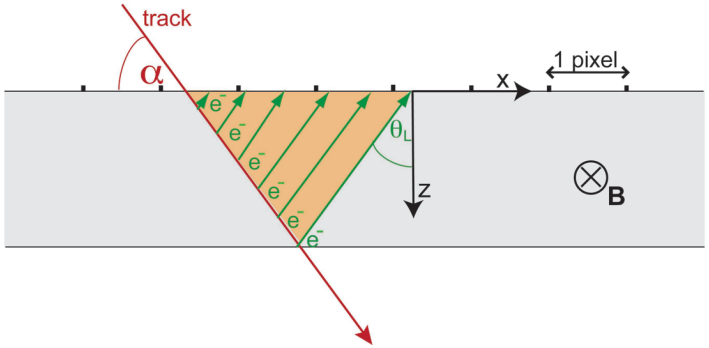




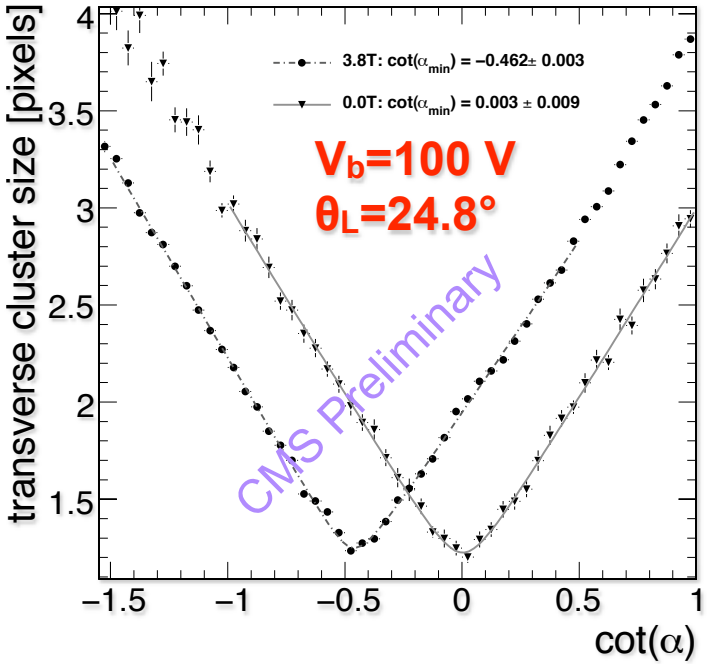
- Cluster charge after calibration
  - Only clusters with charge sharing
  - Most probable value ~21‘000 electrons
  - In agreement with simulation within 5%

Lorentz angle

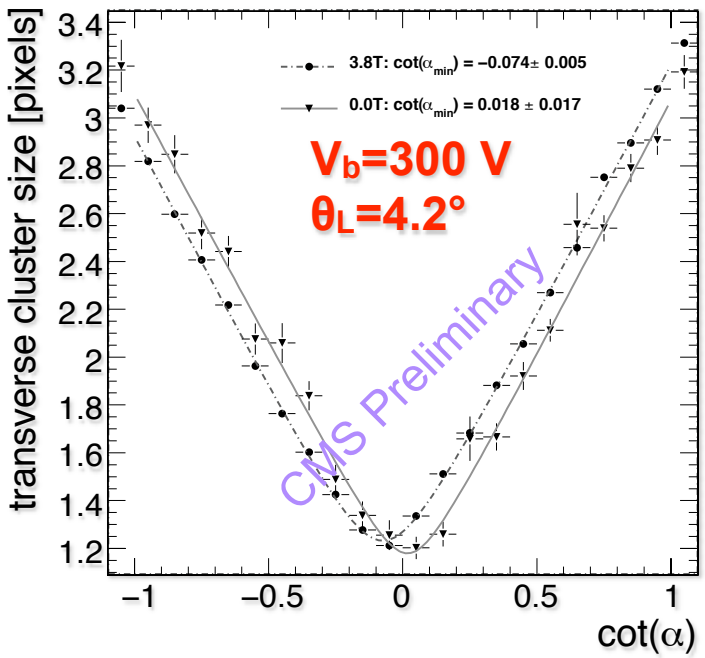
- Measured from the minimum of the cluster size vs. impact angle
- Bias=100V, 300V - Temp.=20°C
- Compatible with the expectations



Barrel

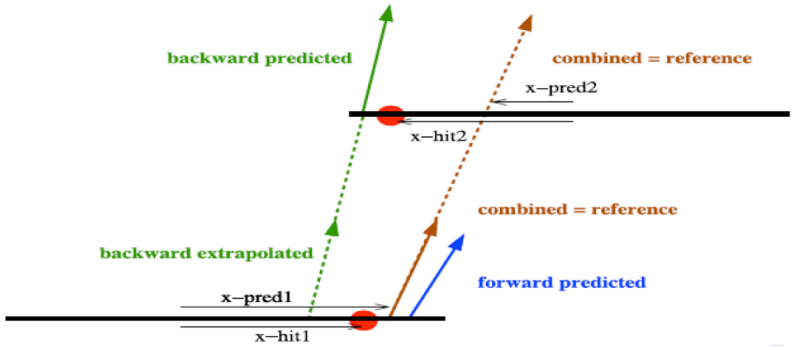


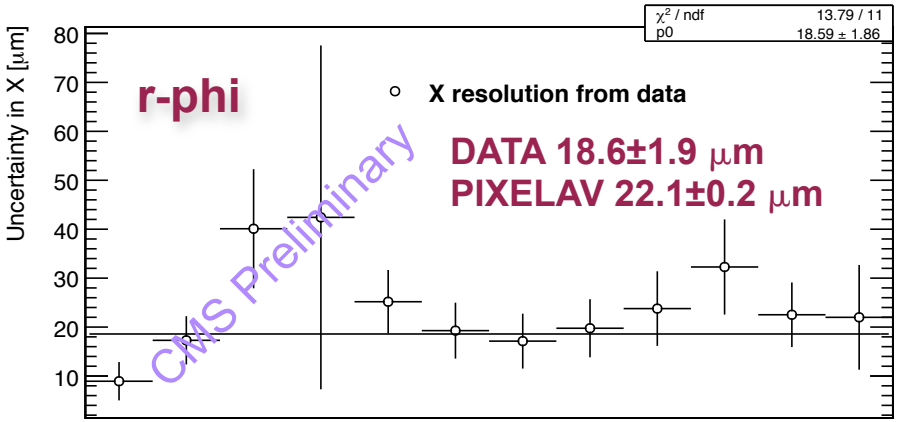
Endcap



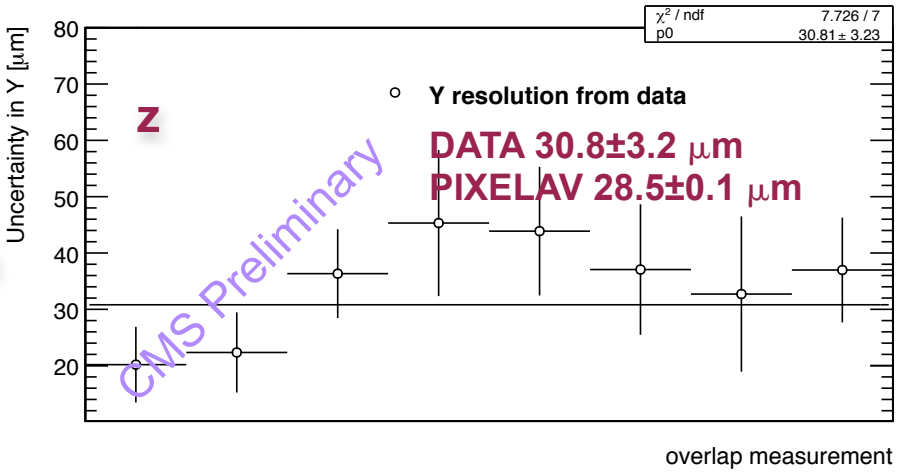
Position resolution

3.8T field, In-time threshold~5000 electrons



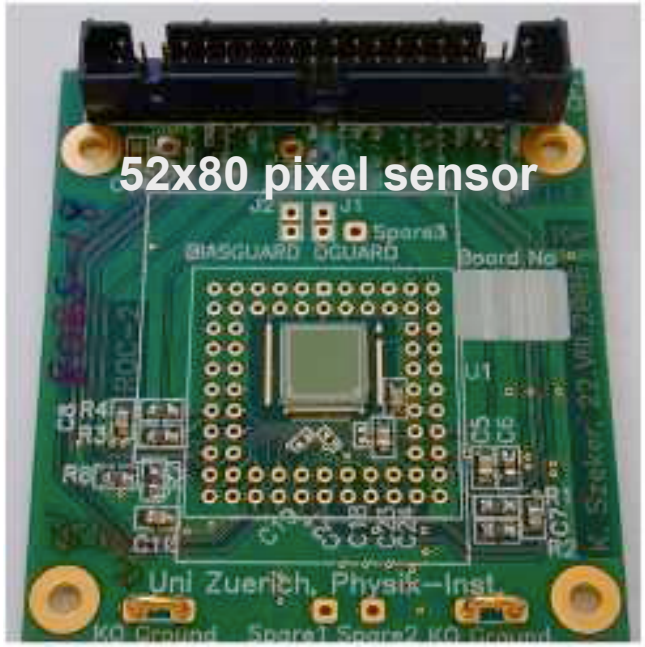


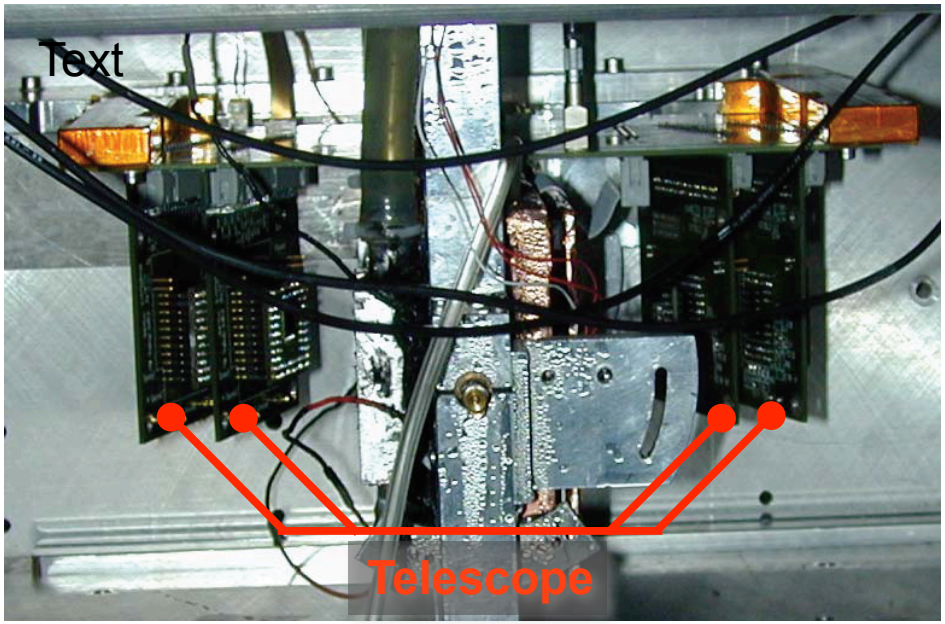
- Position resolution measured from overlapping sensors in a given layer
- Less sensitive to misalignment and multiple scattering
- Measured values are compatible with the PIXELAV simulation



Performance after irradiation

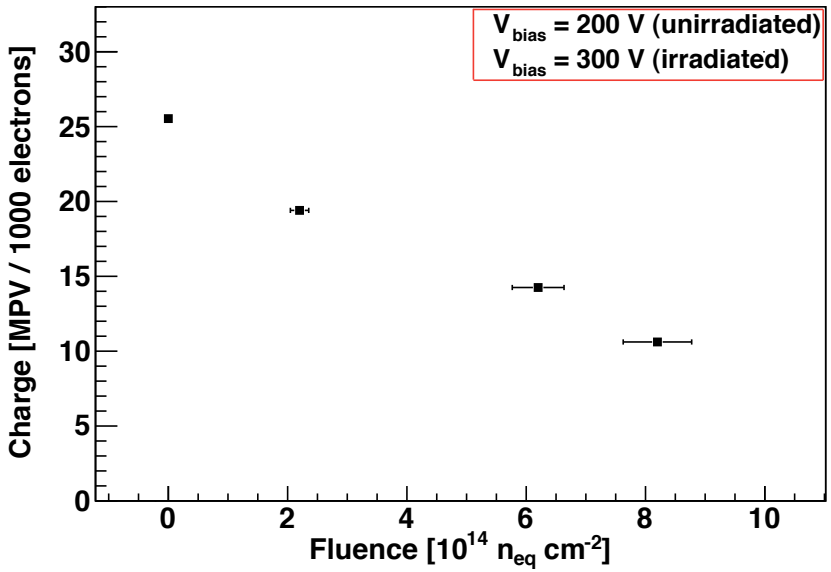
- Sensor performance measured at the CERN H2 beam line with 150 GeV pions
  - Fully pixel-based telescope with four planes.
  - Final sensor layout (p-spray, 100×150 μm^2) and front-end electronics
  - Setup installed in the H2 3T superconducting solenoid
  - Sensors irradiated up to 8×10^{14} n/cm^2, standard annealing
- Fluence expected after first four years at 4 cm layer = 6×10^{14} n/cm^2

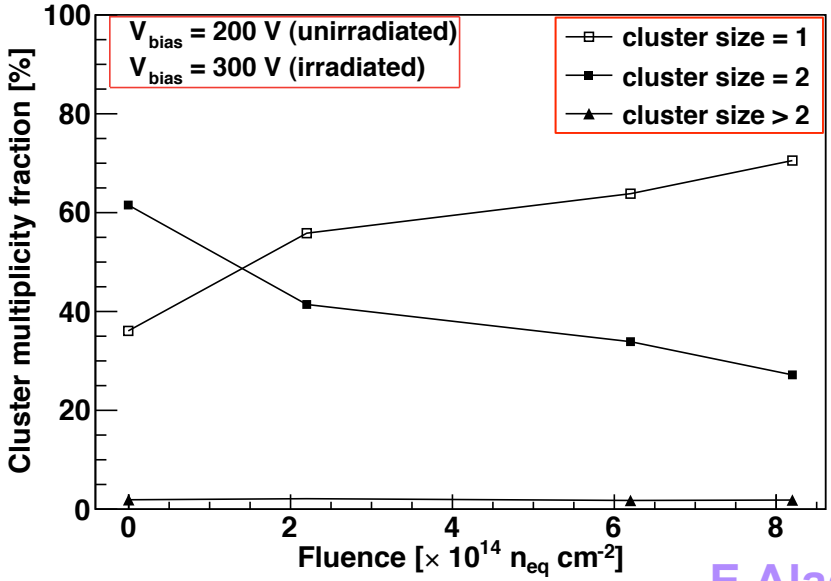




Charge and cluster size

Straight tracks, 3T field, Readout threshold ~ 2850 electrons



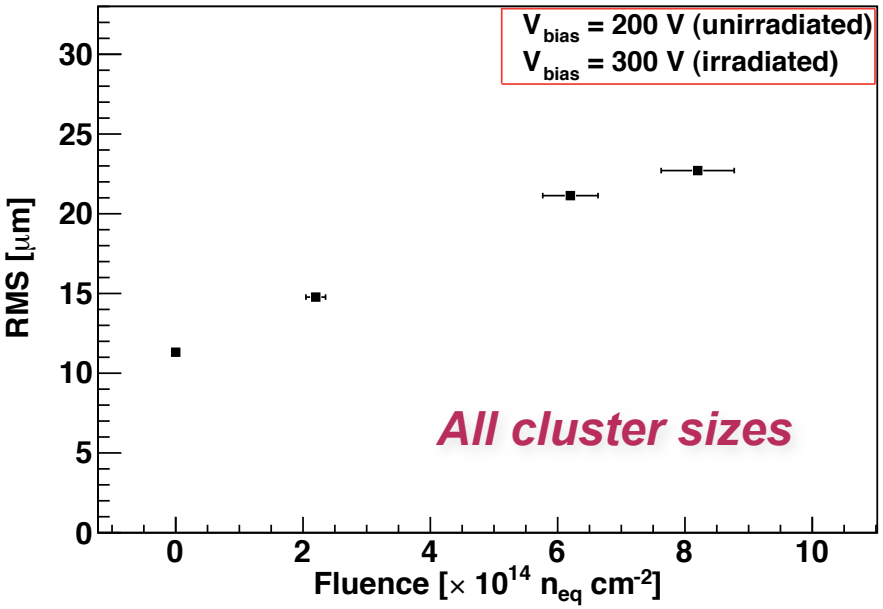


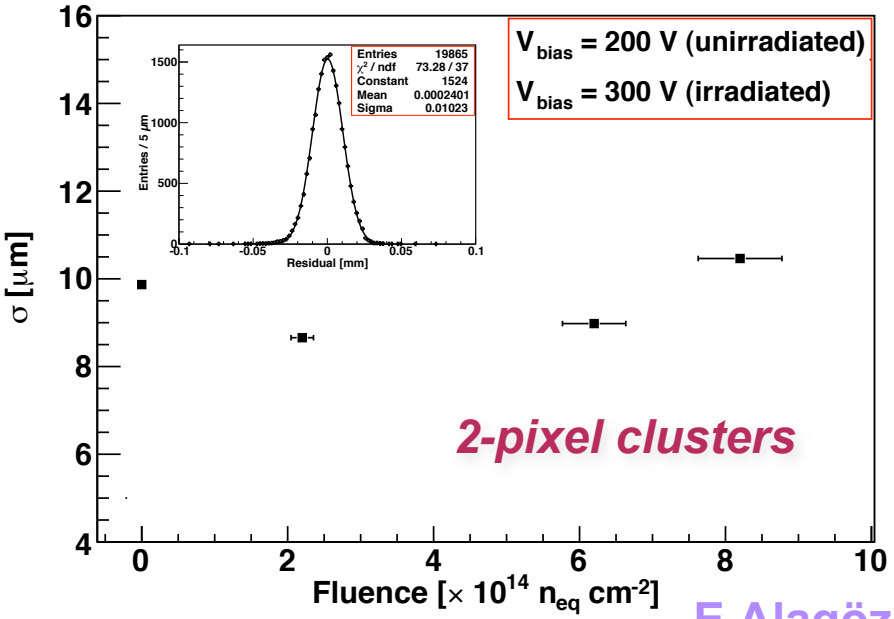
E.Alagöz

- Cluster charge at 6×10^{14} n/cm^2 about 50% of startup value
  - Expect decrease of hit detection efficiency
- Clusters of single pixels become dominant at 2×10^{14} cm^2
  - Expect degradation of position resolution due to reduced charge sharing

Position resolution

Straight tracks, 3T field, Readout threshold ~ 2850 electrons





E.Alagöz

- Position resolution degrades by almost a factor 2 at $\Phi_{eq}=6\times10^{14}$ n/cm^2
  - Dominated by increase of single-pixel clusters
- Resolution of 2-pixel clusters almost flat vs. Φ_{eq}

Summary

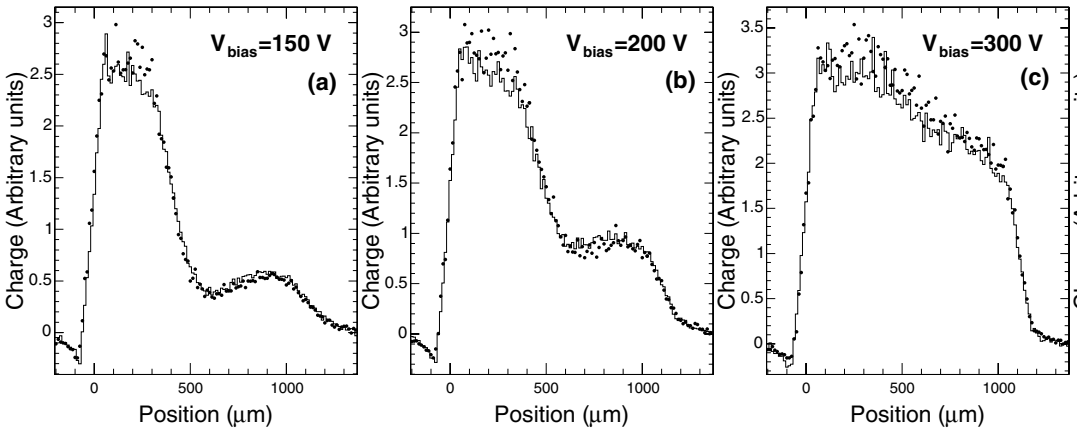
- CMS pixel detector installed in summer 2008 has been tested with cosmic ray events
  - Charge collection behaves as expected
  - Lorentz angle in barrel section ~25° at (100V, 20°C, 3.8T). To be remeasured this year at 150V and 10°C
  - Position resolution is well described by PIXELAV simulation
- Performance after irradiation were measured at the H2 beam line with a 3T magnetic field, final sensor, final front-end chip
  - 10 ke$^-$ cluster charge at $\Phi=8\times10^{14}$ n_{eq}/cm^2, 300V
  - Single pixel clusters become dominant around $\Phi=2\times10^{14}$ n_{eq}/cm^2
  - RMS of residuals at $\Phi=8\times10^{14}$ n_{eq}/cm^2 is ~23 μm. Unirradiated ~12 μm.

BACKUP

PIXELAV: a sensor simulation

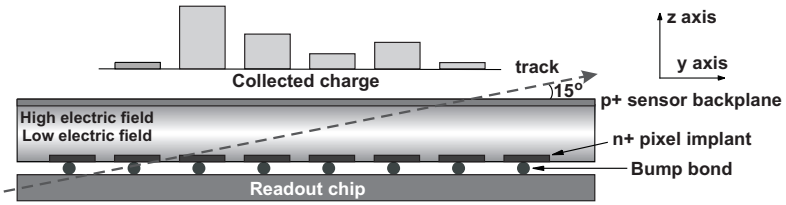
- In addition to the standard CMSSW full detector simulation a dedicated pixel sensor and front-end simulation was developed
- Electrostatic simulation based on TCAD plus charge creation, drift and signal induction based on custom program PIXELAV.
- Incorporates double-trap effective model of radiation damage. Describes cluster shapes from beam tests in a wide fluence range Φ_{eq}=(0.5-6)x10^{14} n/cm^2
- The simulation is used to extract average cluster shapes, called *templates*

Sensor irradiation: Φ=6x10^{14} n/cm^2



Full line: PIXELAV simulation
Full dots: test beam measurements

Grazing angle technique



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Nucl.Instrum.Meth.A565:212-220,2006
Nucl.Instrum.Meth.A568:51-55,2006
IEEE Trans.Nucl.Sci.52:1067-1075,2005