Update on the TowerJazz CMOS DMAPS development for the ATLAS ITk

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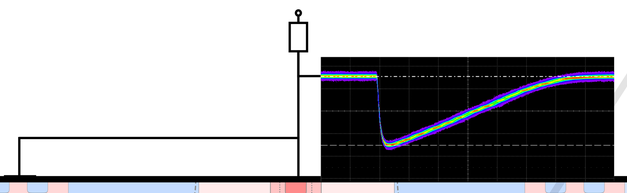
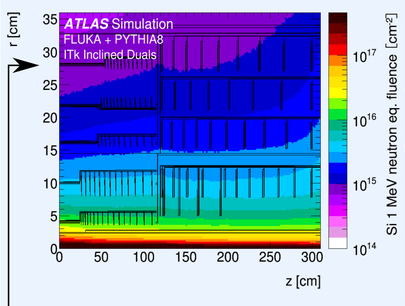
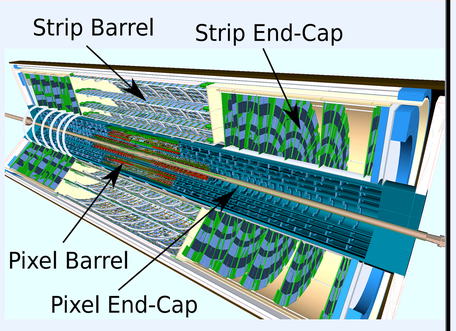
Glossary:
CMOS: Complementary Metal Oxide Semiconductor
DMAPS: Depleted Monolithic Active Pixel Sensor
ITk: Inner Tracker (of the ATLAS experiment)



ATLAS ITk Pixel Detector





5th layer of pixel tracker:

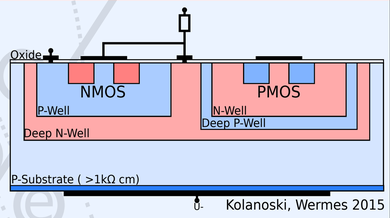
Challenges:
- Occupancy: 1MHz/mm^2
- Expected NIEL: 10^{15} N_{eq}/cm^2
- TID : 50 Mrad
- Active area of 5th layer: 3 m^2

Upgrades and Changes:
- η coverage increased to 4.0
- 5 barrels, 10 pixel rings
- All silicon designs to cope with occupancy and pile up in HL-LHC

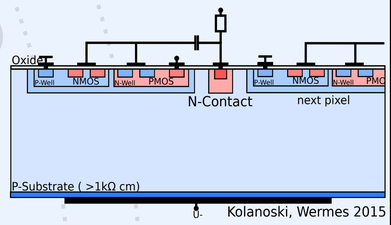
ITk Strip Tech. Design Report,
CERN-LHCC-2017-005. ATLAS-TDR-025

Radiation Resistant CMOS Sensors

Two variants:
- CMOS circuitry inside collection diode
- CMOS circuitry in separate deep p-well



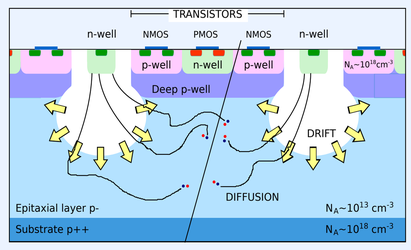
Advantages:
- Complex electronics in active area of pixel matrix
- Very thin at around 100µm
- Cheaper by a factor~3 (no front end no bump bonding)
- Production in large quantities much easier (layer 5 of ITk is largest!)



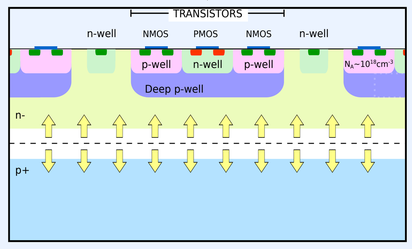
Signal Generation:
- Voltage on collection diode drops when charge from an incident particle is collected and is "slowly" recovered via diode reset
- Initial diode signal is amplified by the in-pixel circuitry and then read out

TJ180nm CMOS Process Modification

Standard Process:
- Depletion only around collection diode
- Charge collection **partially via diffusion** (far from electrode) and **via drift** (close to electrode)

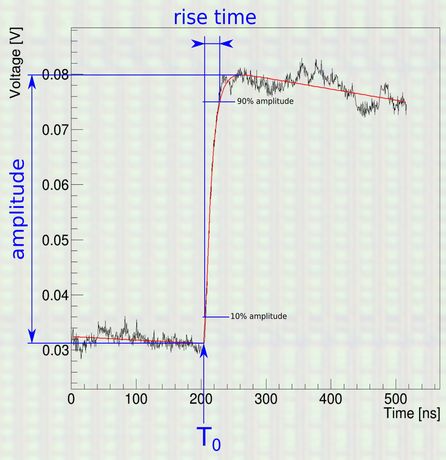


Modified Process:
- Interstitial n-implant ensures homogeneous depletion across whole bulk
- Charge collection **only via drift** thus faster and more radiation tolerant

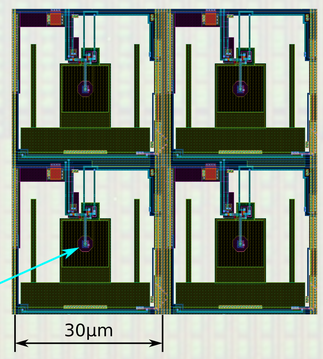


TowerJazz Investigator

Features:
- 134 "mini-matrices" with a great variety of pixel designs
  - pixel pitches range from 20µm to 50µm
  - variable deep p-well coverage
  - variable shape of collection diode
  - analogue output of signal waveform for detailed analysis
  - 3T (3 transistor) readout
  - dedicated reset
  - single pixel readout

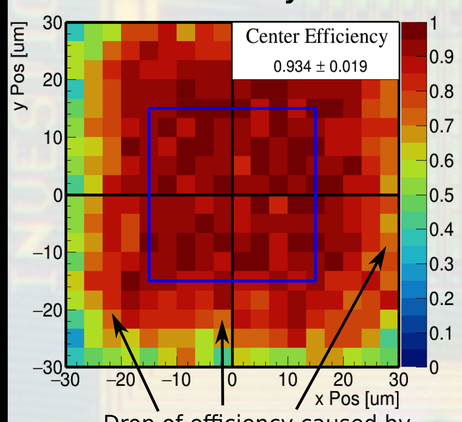


Minimatrix 106:
- Mini-matrix 106 was measured extensively
  - 30µm x 30µm pixel pitch
  - 3µm collection diode
  - large deep p-well extends close to collection diode
  - is close to the design of the pixels for the first full sized digital chip "MALTA"



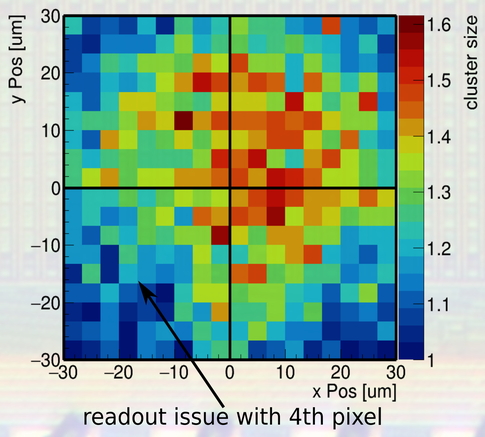
Results:
- **software threshold of 110e$^-$**
- high efficiency maintained after irradiation of 10^{15} N_{eq}/cm^2
- efficency is maintained at pixel borders and edges (see center of efficiency plot)
- cluster size cleary indicates charge sharing even further away from pixel borders

Efficiency



Drop of efficiency caused by limited telescope resolution

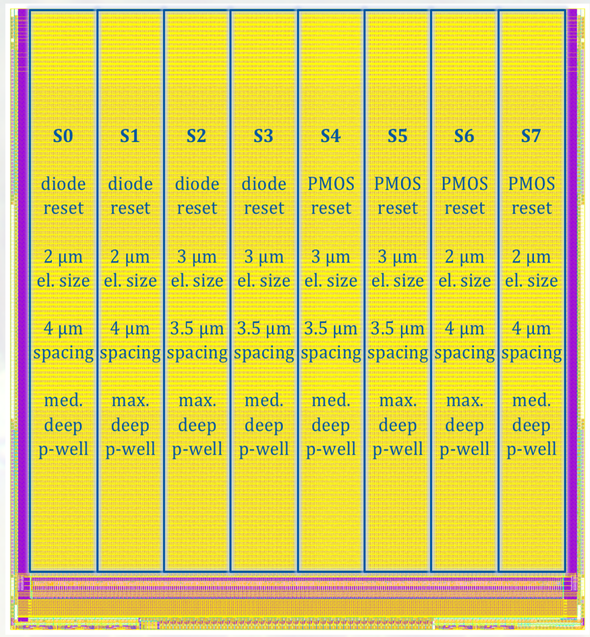
Cluster Size

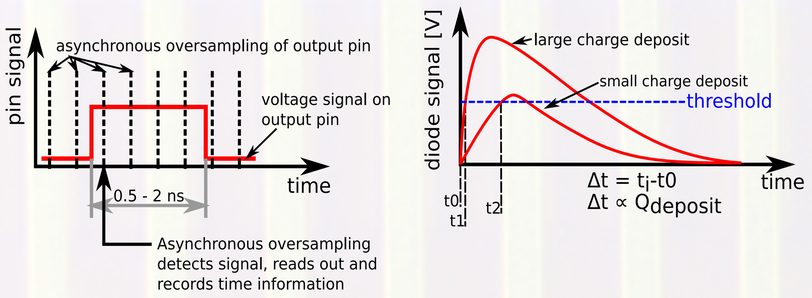


readout issue with 4th pixel

MALTA

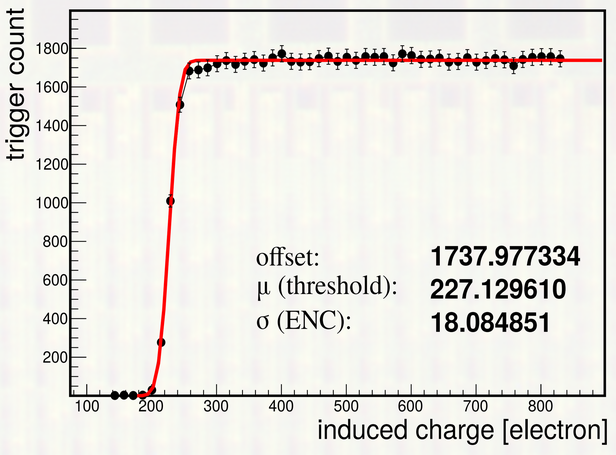
General Information:
- full sized digital chip
- 25µm epil layer, fully depleted
- 512 x 512 pixels with a 36.4 x 36.4 µm^2 pitch
- 8 sectors of 64 columns with different pixel flavours
- **fully asynchronous operation**
  - readout via asynchronous oversampling



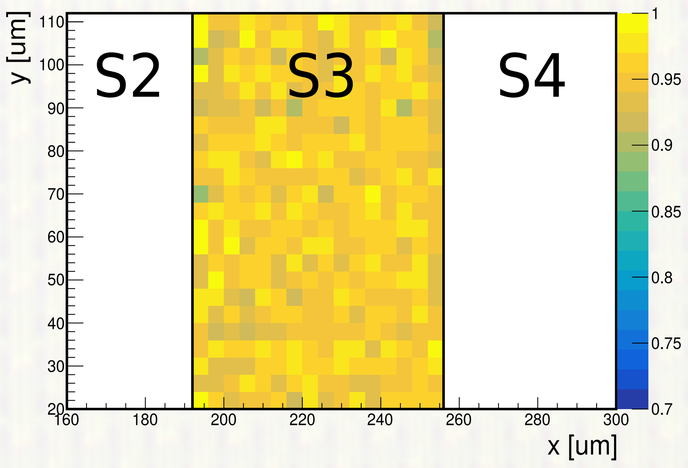


Special Features:
- very small collection diode with low capacitance of <5pF
- low capacitance greatly reduces noise
- low noise allows for operation at very low thresholds
  - ENC of only ~15-20e$^-$ possible!
- low thresholds are needed for thin epi layers of 25µm thickness which can be fully depleted
- full depletion of epi layer means charge is only collected via drift
  - chip is faster and more tolerant to radiation damages
- charge deposition is inferred from time walk of signal
- 500nA/pixel or <70mW/cm^2

Threshold scan



MALTA Efficiency, unirradiated, Q_{TH} = 250e$^-$



Time walk for Sr^{90}, unirradiated, Q_{TH} = 210e$^-$