Development of radiation hard CMOS Active Pixel Sensors for HL-LHC

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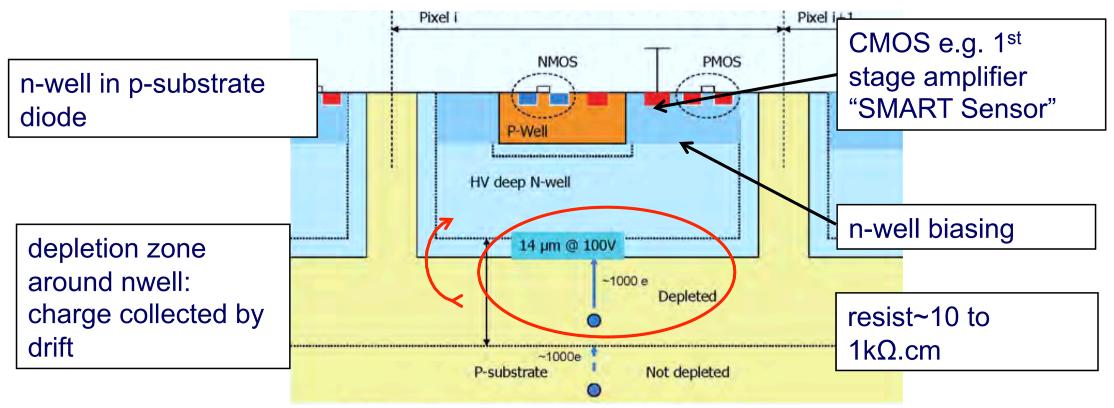
Develop depleted radiation hard CMOS Sensors for ATLAS ITK

- ATLAS ITK upgrade for Phase II Pixel detector requires radiation hard sensors, which present CMOS MAPS cannot do (not radiation hard & too slow)
- Started RD to develop commercial CMOS processes to radiation hard sensors through optimized designs, high voltage processes (>100V on chip) and higher resistivity (100Ohm*cm to kOhm*cm)

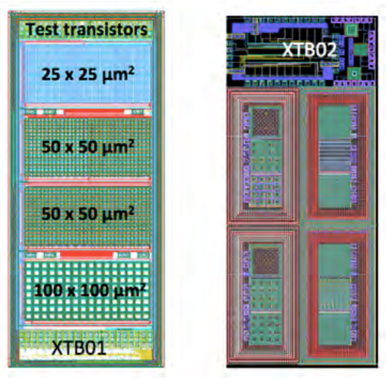


Monolithic solutions benefits:
- Thin & light detector modules
- Simplified assembly and cost advantage for large areas

Hybrid solution benefits
- Fast and complex readout in separate digital chip to cope with highest hit rates at smallest radii
- CMOS sensor + analog stages

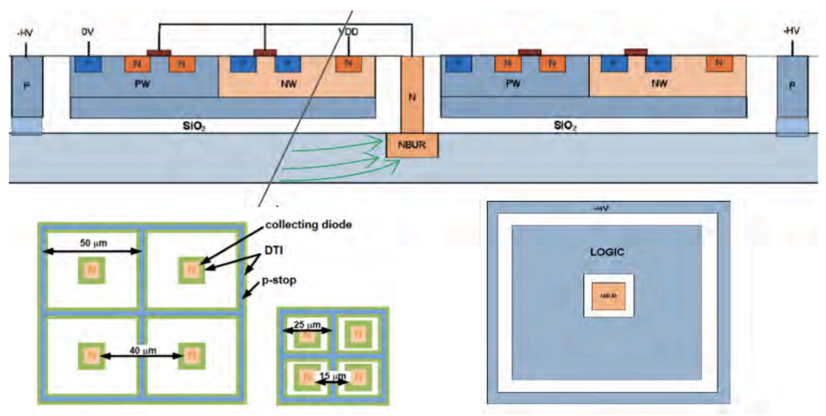
XFAB SOI 180 nm prototype XTB01 & XTB02

- Monolithic test chip to investigate transistor and sensor charge collection performance
- Electronics isolated from substrate through oxide (BOX)
- Small collection well (capacitance!) but no competing wells
- Isolating deep P well between CMOS and BOX to avoid back-gate effect



XTB01: 4 different pixel matrices with 3T readout and transistor test structures

XTB02: Passive diodes to study charge collection ; includes deep p-spray and p-stop structures to intercept accumulation layer

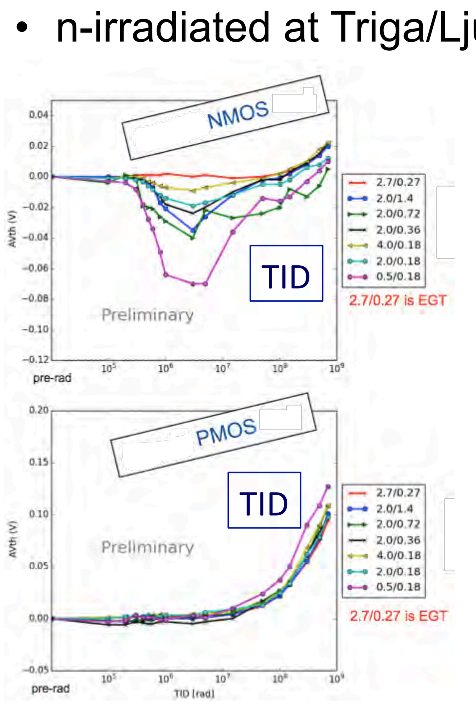


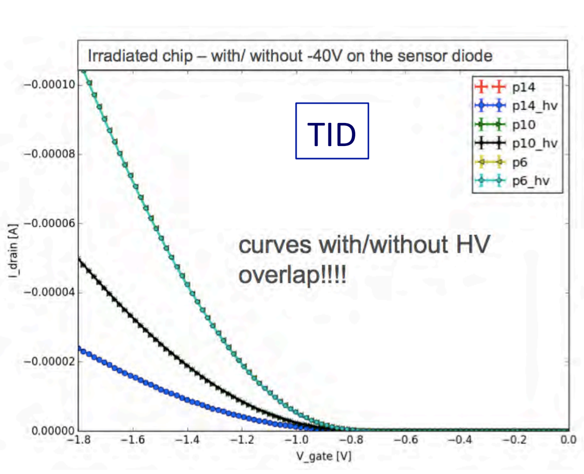
XFAB Trench SOI 0.18 µm CMOS low-power 1.8/5.0V
- P-type bulk, 4 metal layers,
- Prototype size Size: 5 x 2 mm2
- Wafer size: 8" with high handling wafer resistivity:
  - 100 Ω cm CZ
  - 1 kΩ cm possible
- HV applied from front side up to 300V

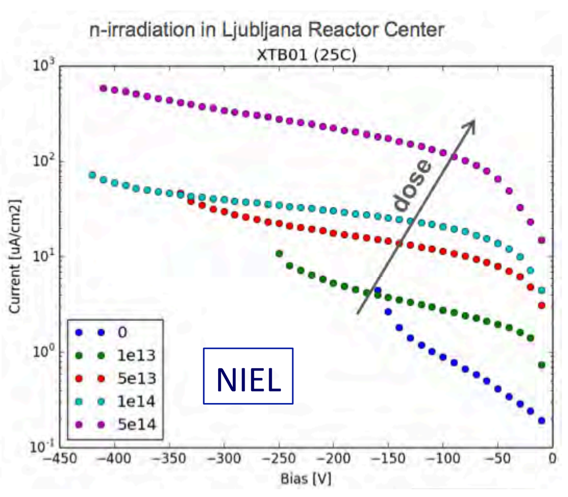
Hemperek, Kishishita, Krüger, NW arxiv 1412.3973, accepted NIM A

Results on XFAB CMOS prototype

- γ-Irradiated up to 700Mrad, annealed after irradiation
- n-irradiated at Triga/Ljubljana up to $5x10^{14}$ n/cm^2

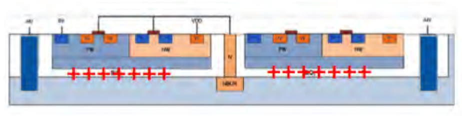




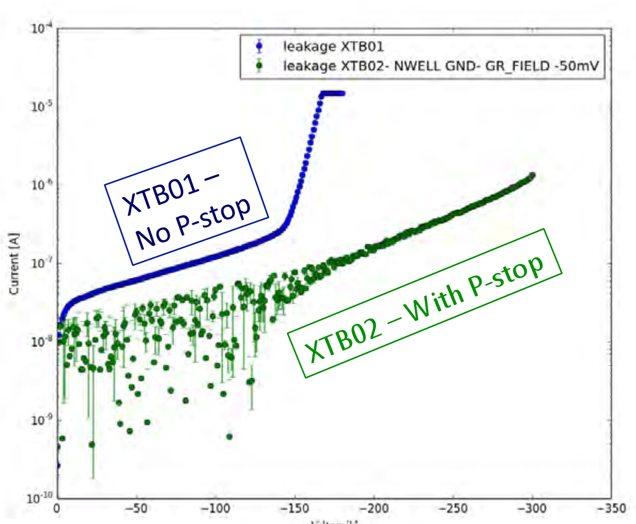


→ **No back-gate effect observed & Electronics shielded from field of sensor diode**

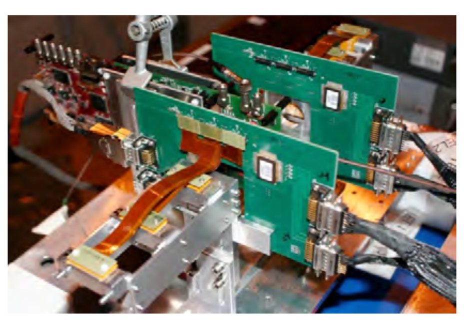
- TID leads to BOX charge-up, which creates an accumulation layer in the substrate between DNW and bias-DPW
  - Increased leakage
  - Reduced max bias voltage
- Implemented p-stop (DPW) to intercept accumulation layer in XTB02

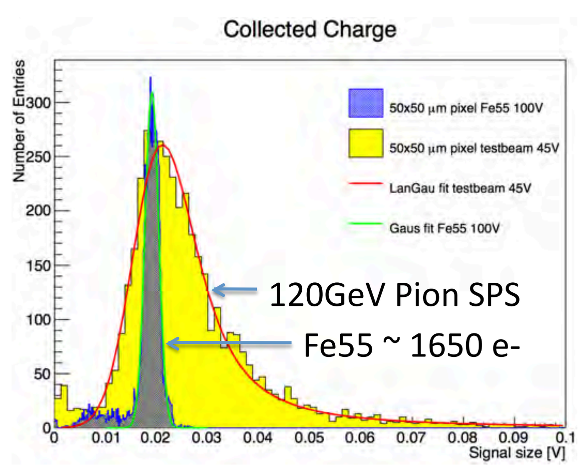


→ **DPW (P-Stop) reduces leakage and leads to high breakdown voltage**

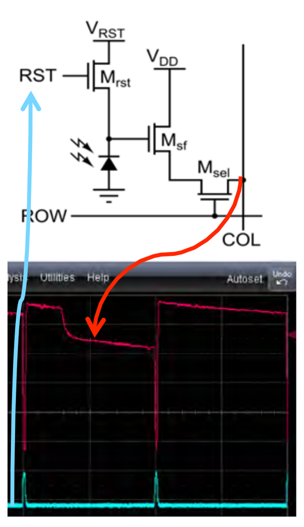


Signals in Source & Beam tests XFAB XTB01





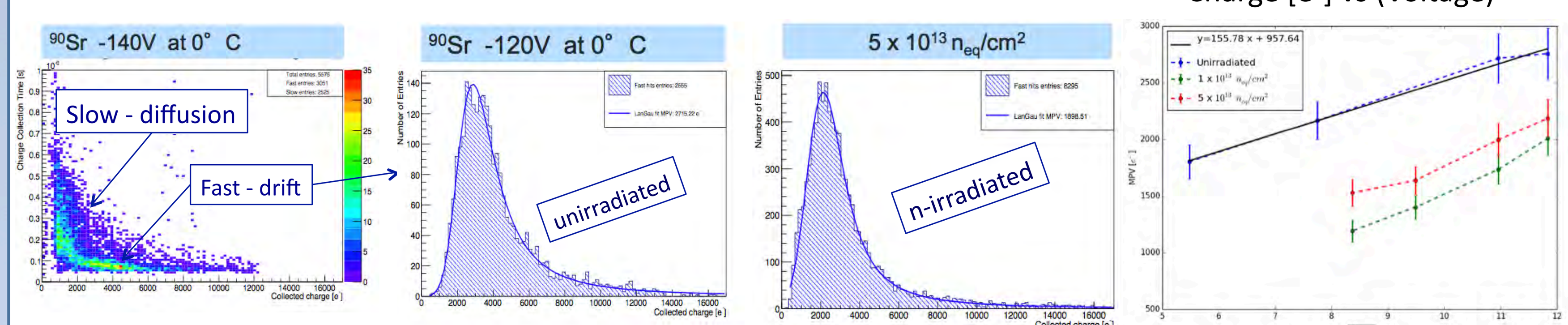
- XFAB readout with 3T structure
- 50x50 µm pixels



→Observe depletion of ~ 31µm (calculated ~ 36µm)

→Observe faster (high field region) and slower signals (lower field regions

Charge [e-] vs (Voltage)$^{1/2}$



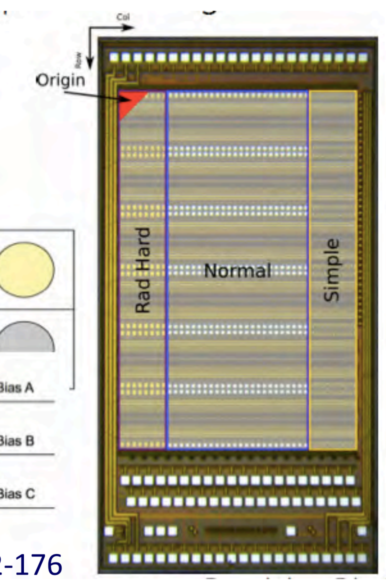
AMS H18 180nm HV2FEI4 Version 2 & 4

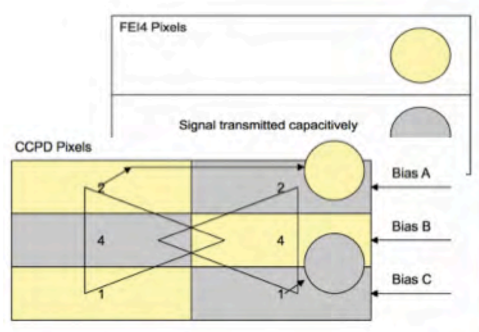
- Matched to ATLAS FEI4 readout chip (50x250µm pixel size) and includes sub-pixel encoding
- Sub-pixel (size 33x125µm) includes Preamp + Shaper + Discriminator

Produced in AMS H18 process:
- ρ=10Ωcm with bias 60–100V
- Depletion depth ~10 µm
- Q (theoretical) ~1000 e- by drift
- capacitively coupled to FEI4

HV2FEI4 CCPD Version 2:
- Three pixel types
- Voltage based sub pixel encoding
- First to work after 850 Mrad

HV2FEI4 CCPD Version 4:
- Lower noise
- Pulse length or voltage based sub-pixel encoding

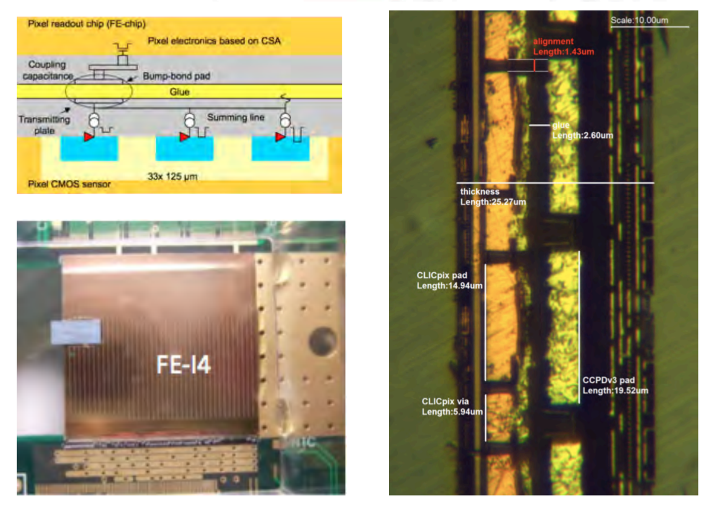




I. Peric et al., NIM A765 (2014) 172-176

Capacitive coupling to FEI4

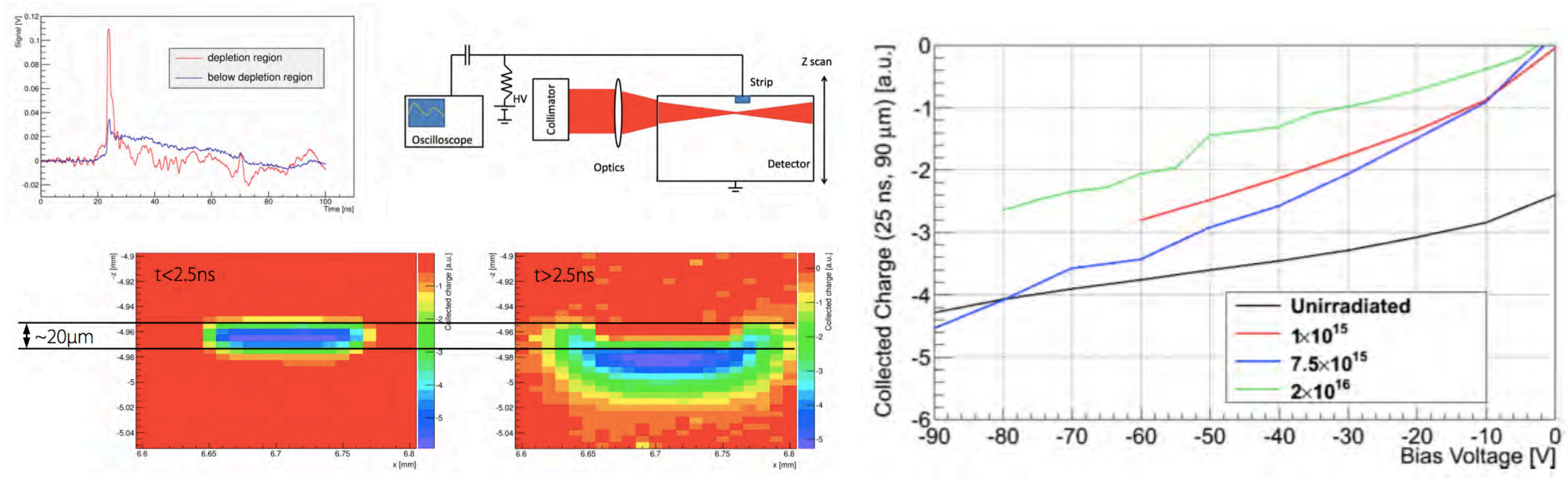
- Capacitive readout AMS CMOS sensor to input of ATLAS FEI4 pixel readout chip
- "Capacitive Coupled Pixel Detector" (CCPD)
- Flip chip on SET FC150
- Achieved glue layer thickness of 3µm
- Alignment of 1-1.5µm
- Also demonstrated planarity and thickness on full size FEI4 assemblies (21x18mm) using planar sensors



Results on AMS 180nm CCPD

Charge Collection Studies

- Lab characterization before and after irradiation : Edge Transient Current Technique



- Drift and diffusion are distinguished by timing cut at 2.5ns

→**In-time signal fraction increases with irradiation**

→Acceptor removal due to irradiation may lead to increased substrate resistivity & depleted area

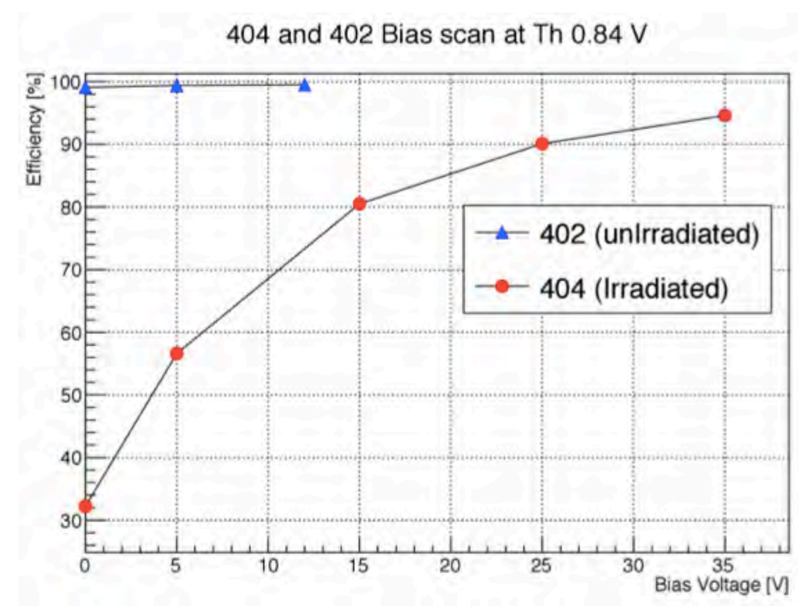
Beam test results on AMS 180nm

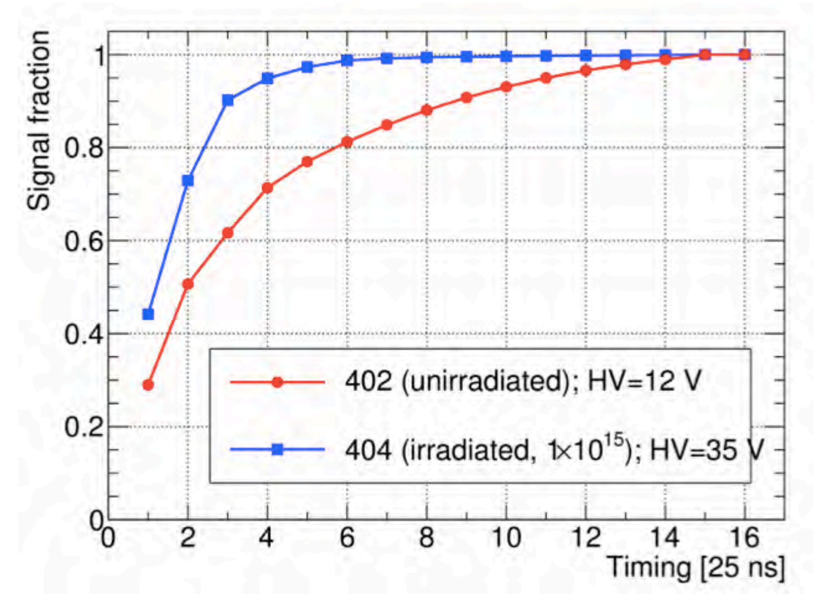
- Unirradiated and irradiated HV2FEI4 CCPD Version 4 (neutrons $1x10^{15}$ neq/cm^2)

Overall efficiency (time-integrated):

→ **Unirradiated 99.7% at -12V bias, irradiated 96.2% at -30V**

- Signal after irradiation ~ 1500 e- (SNR ~25) but in-time efficiency not yet met





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