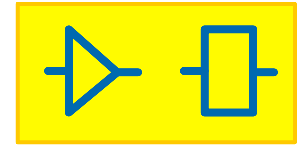
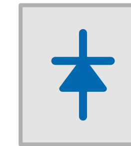
Radiation-hard Active Pixel Sensors for HL-LHC Detector Upgrades based on HV-CMOS Technology

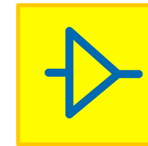
Malte Backhaus – on behalf of the ATLAS Smart CMOS Pixel collaboration

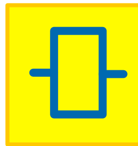
Outline

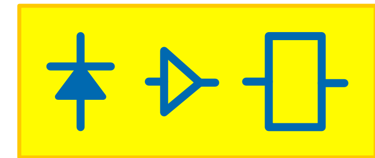
- HV2FEI4 introducton
  - "Sensor"
  - Readout chip
- Lab results
- Test beam results
- Irradiation results
- Outlook
  - Alternative submissions
  - Summary
  - ATLAS Smart CMOS Pixel Collaboration

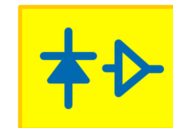


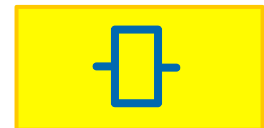






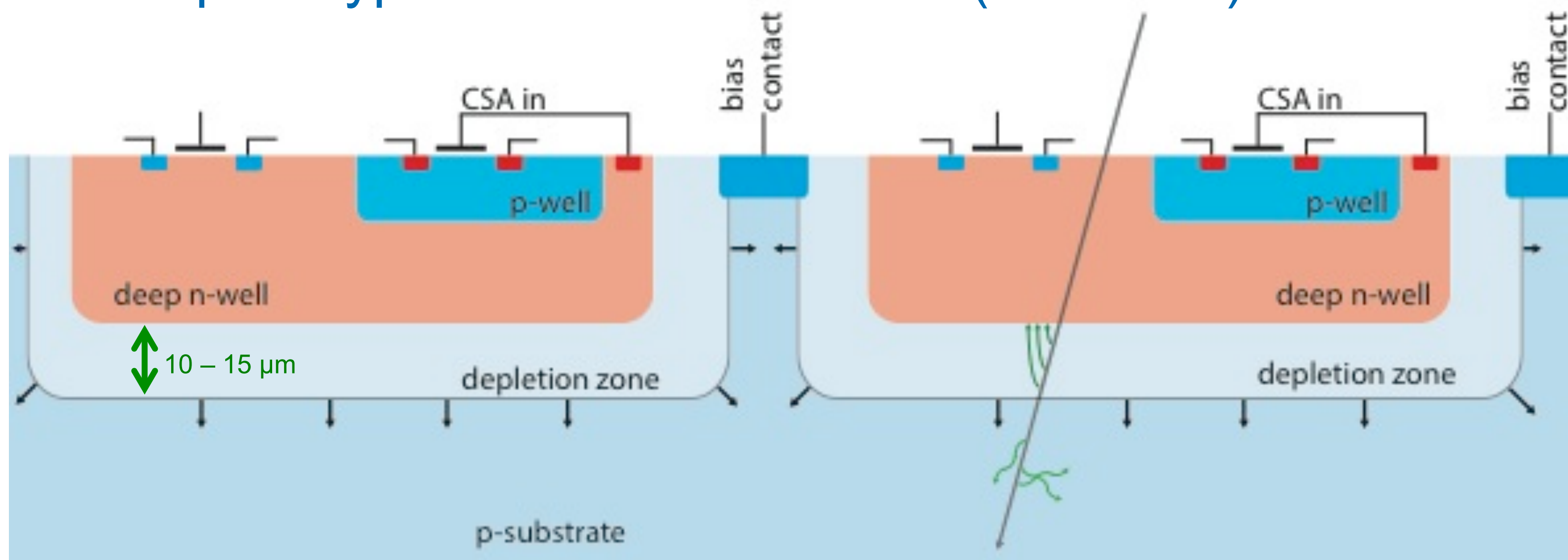






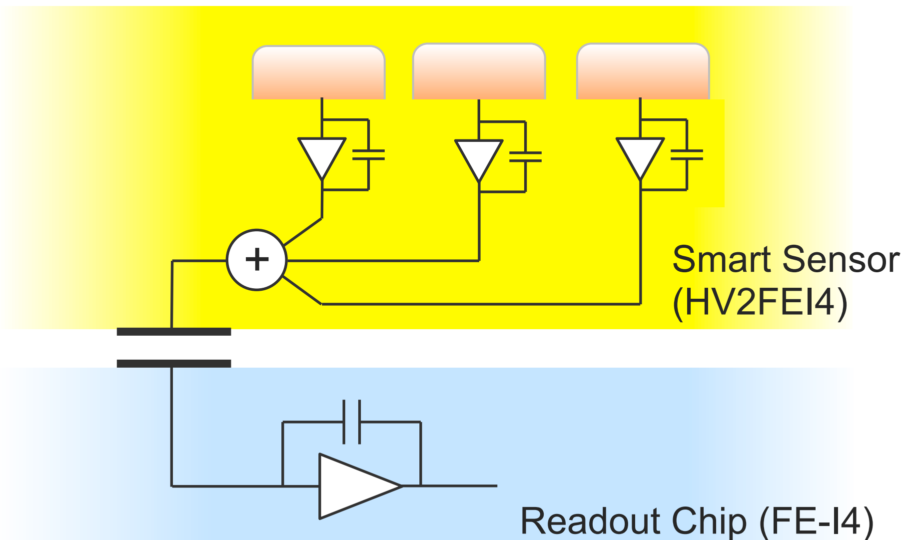
HV2FEI4 Concept

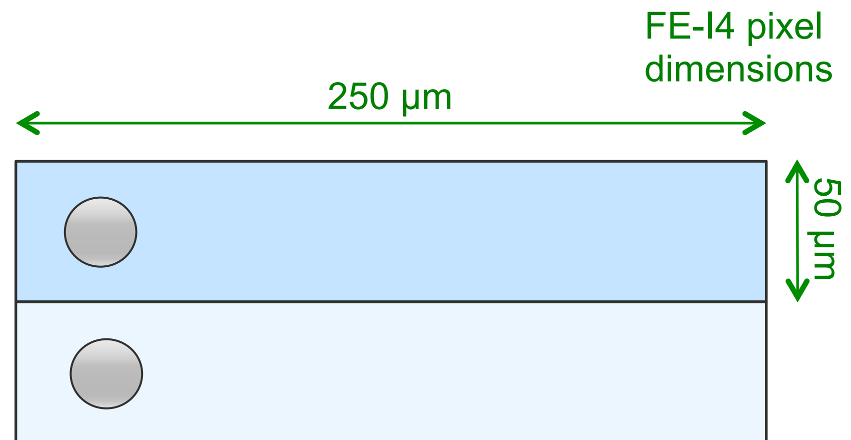
- Use bulk of commercial HV/HR-CMOS process as sensor
- Deep n-well → collection electrode
  - PMOS transistors unshielded from charges → design constraints
  - p-well used for NMOS transistors
- AMS prototypes in characterization (HV2FEI4)



HV2FEI4 Sensor

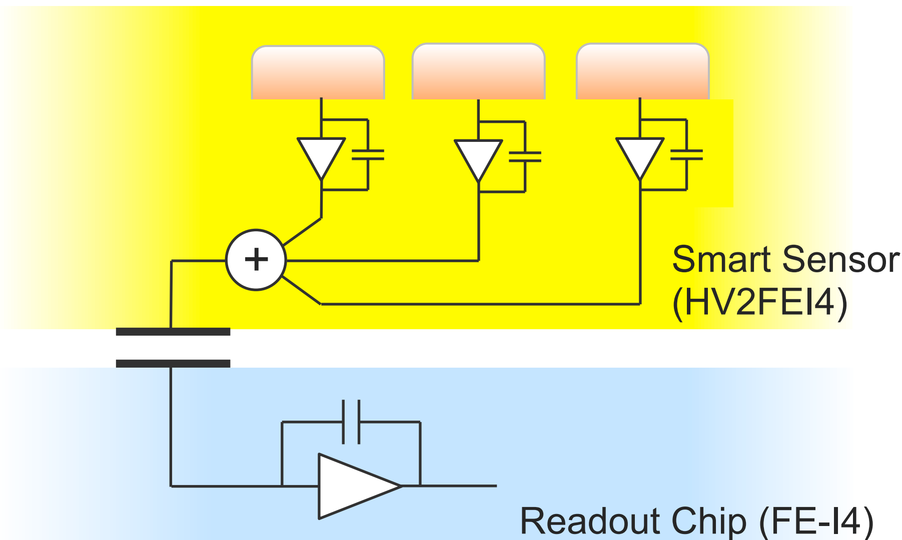
- Limited logic implementation in sensor:
  - CSA + Discriminator
  - Adjustable sub-pixel output pulse (for AC coupled signal to FE)
  - Adding of sub-pixel pulses

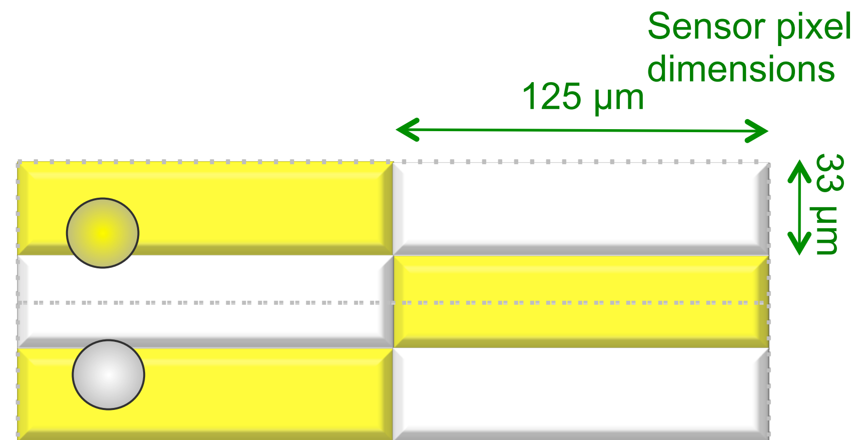




HV2FEI4 Sensor

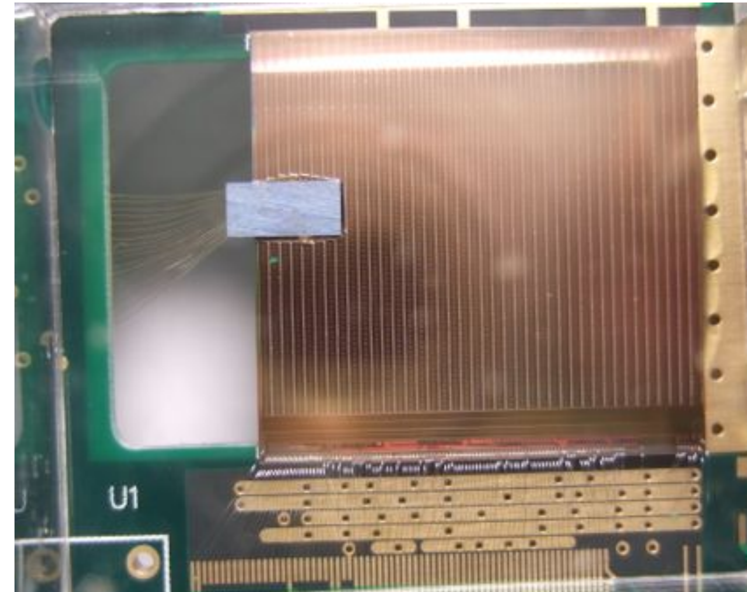
- Limited logic implementation in sensor:
  - CSA + Discriminator
  - Adjustable sub-pixel output pulse (for AC coupled signal to FE)
  - Adding of sub-pixel pulses
- Six sub-pixels connect to two FE pixels

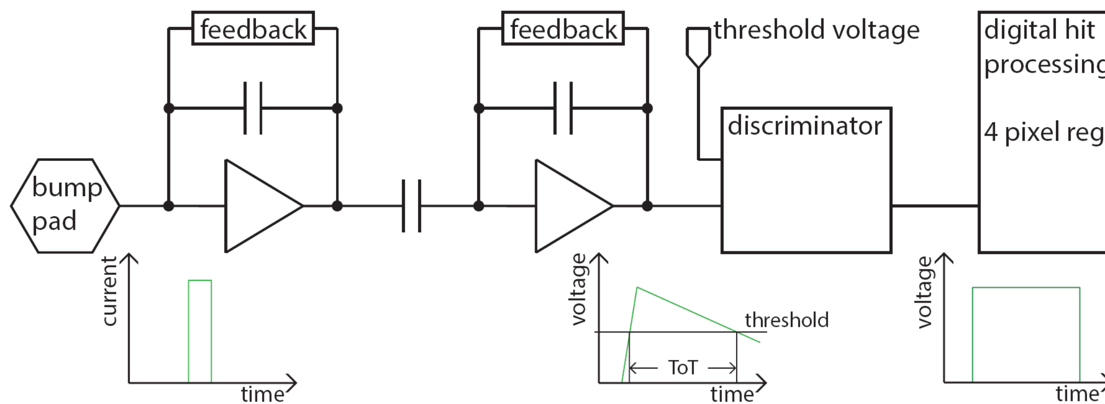




Readout Chip – FE-I4

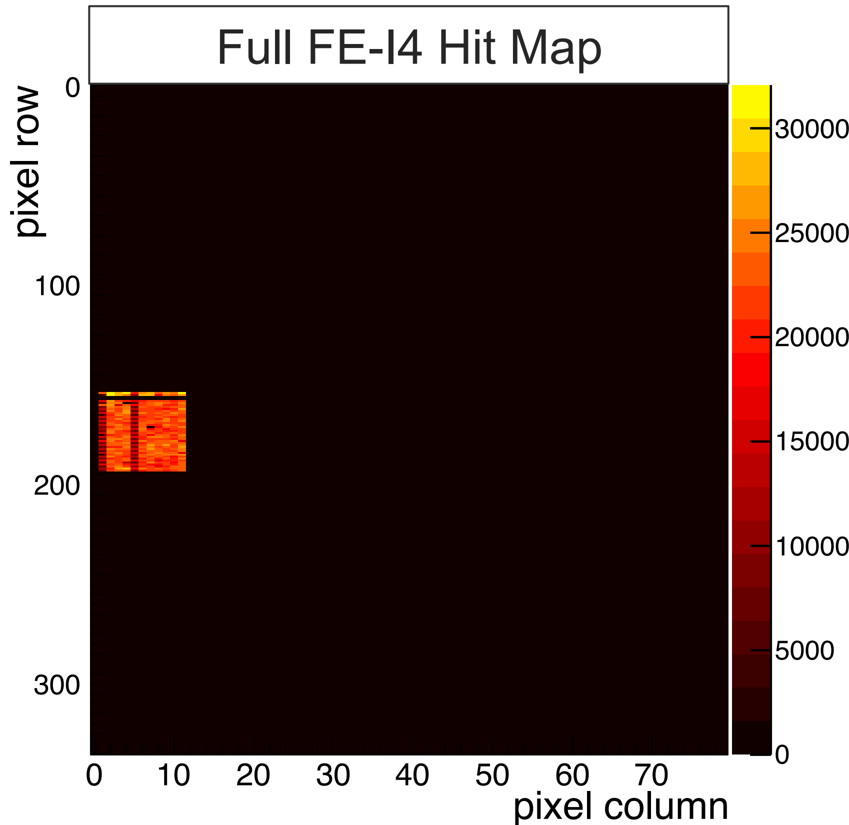
- Use IBL readout chip: FE-I4
- Huge complexity
- Designed for passive sensor
- Pixel size 50 x 250 µm
  → area of 3 „sensor“ chips
- „Smart sensor“ glued to FE-I4
- Analog information (TOT)
  → Can be used for sub-pixel decoding

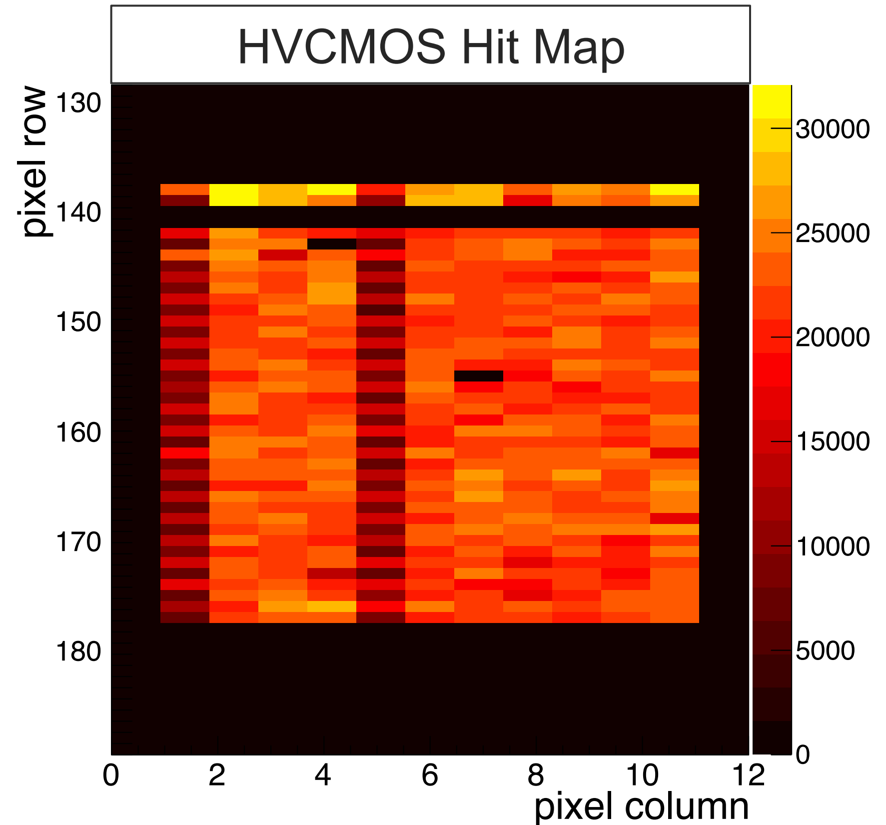




Source Scan Occupancy

^{90}Sr



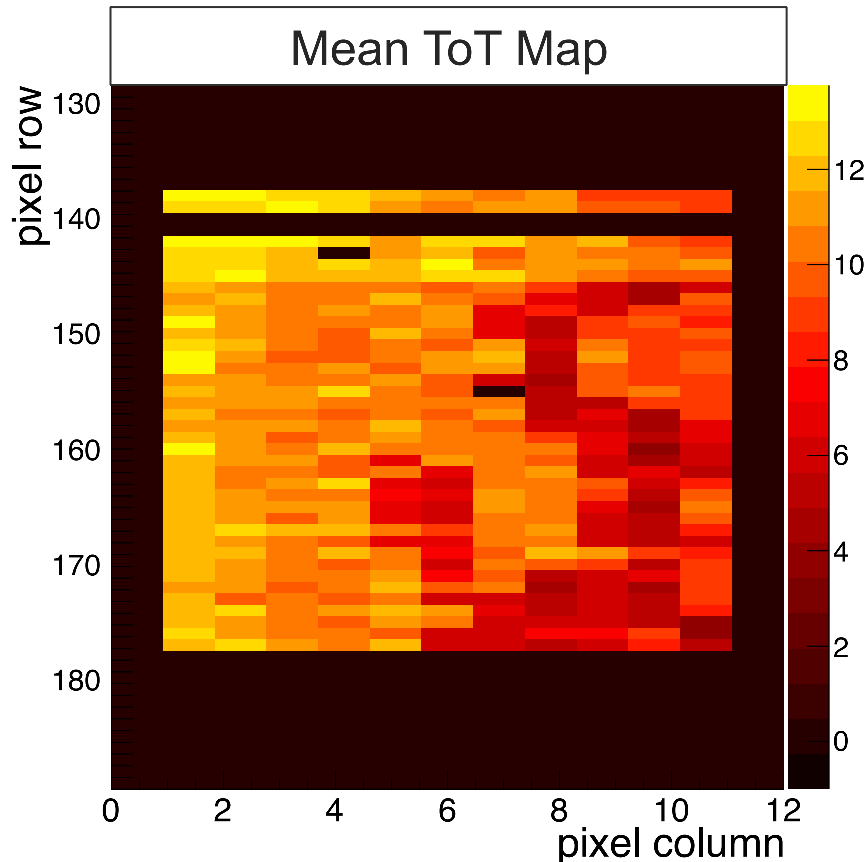


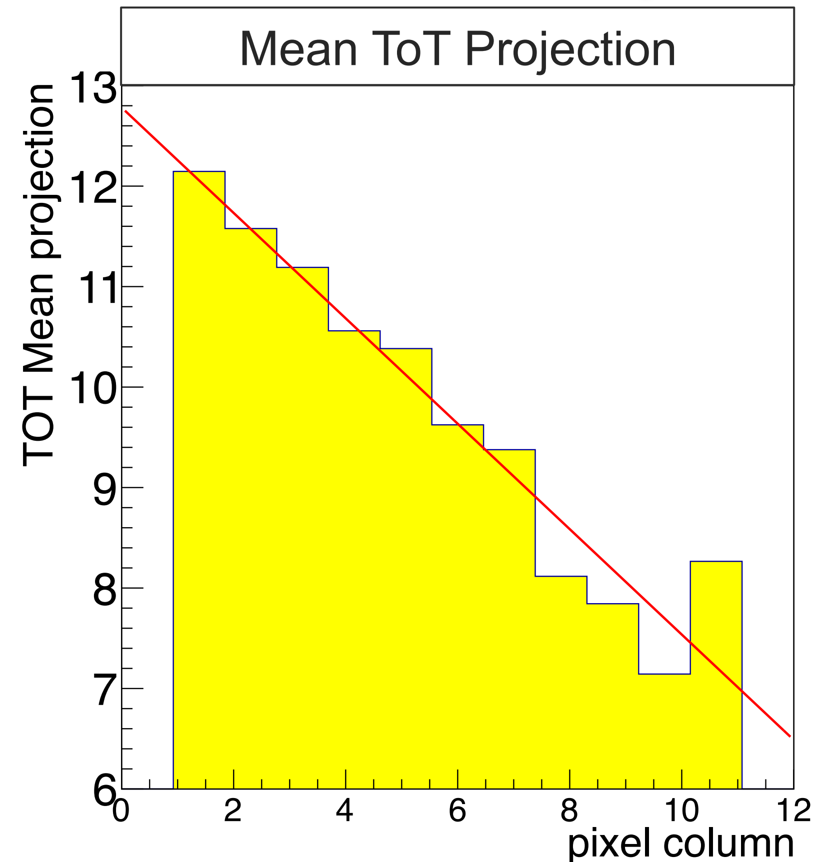
→ Full FE-I4 pixel matrix active

→ Charges generated in sensor transmitted to FE-I4 (AC coupled)

AC Coupled Signal Transmission

^{90}Sr



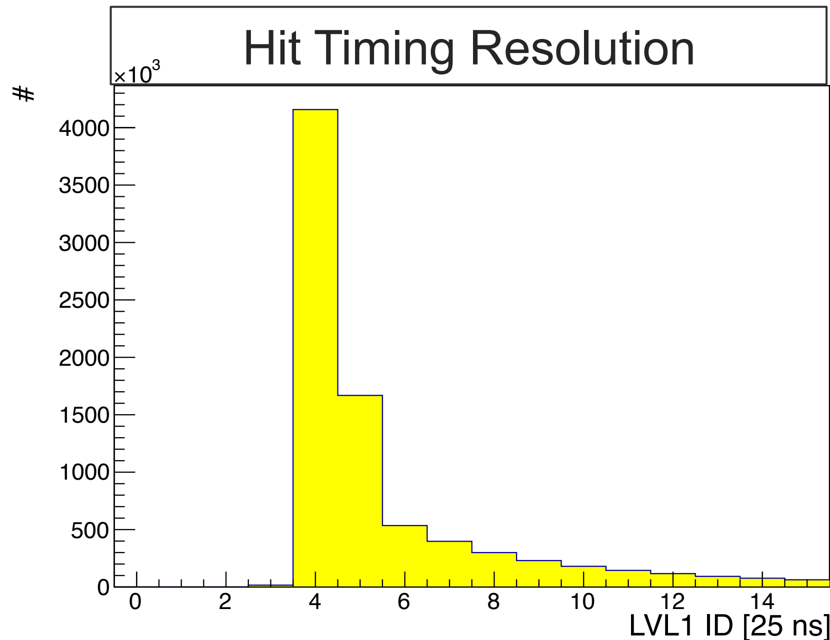


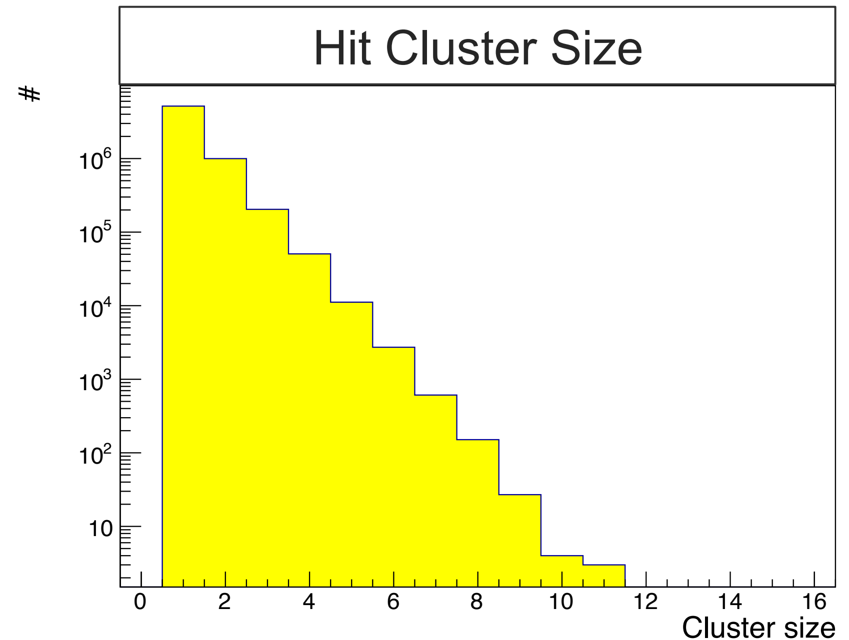
→ ToT indicator for AC coupling strength

→ Tilt of sensor or output pulse amplitude

Source Hit Timing and Cluster

^{90}Sr

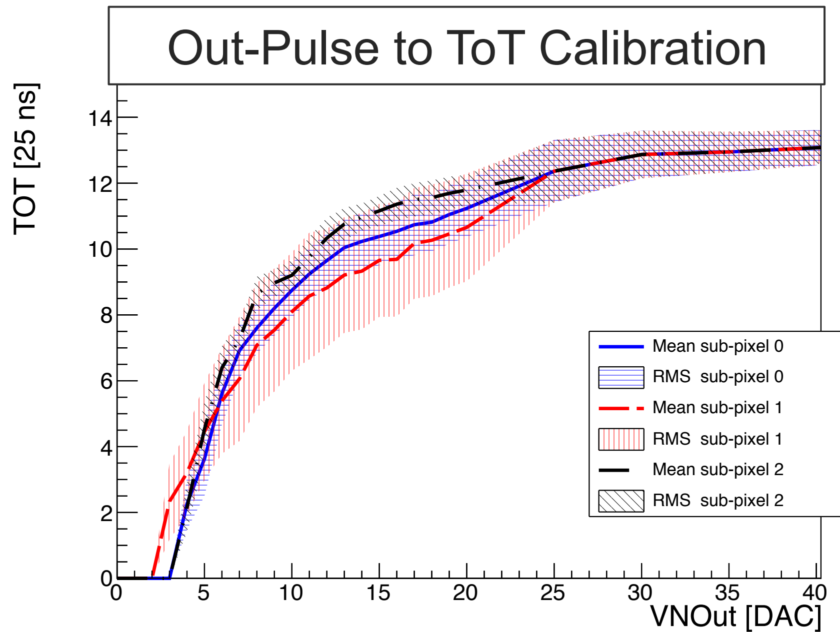


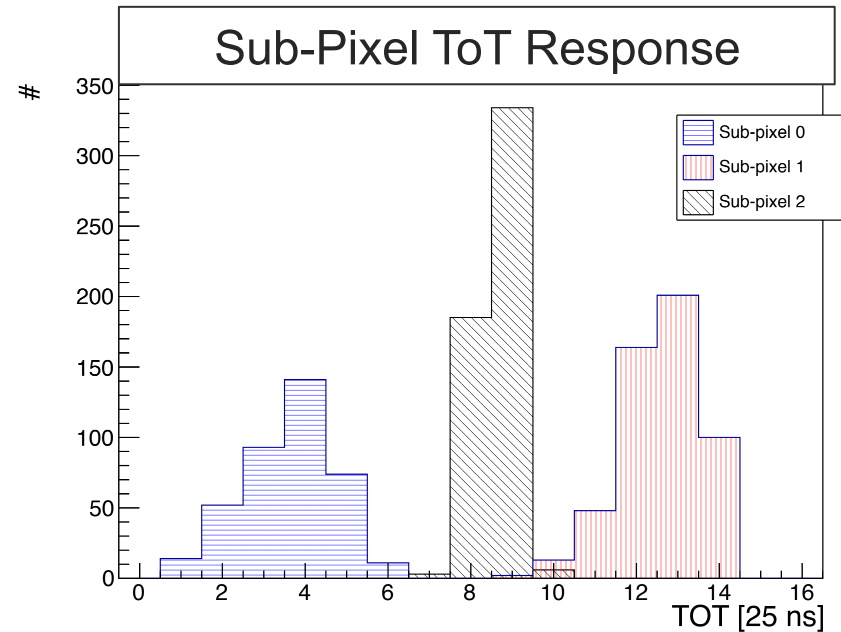


→ Hits with significant delay recorded, time-walk sources present twice
→ Sub-pixel resolution + dedicated algorithm mandatory for investigation
→ Large hit clusters present

Sub-Pixel Resolution

→ Convoluted scans possible with new HVCMOS support in USBpix
→ Puls adding disabled, test charge injections





→ Distinct ToT peaks → sub-pixel resolution demonstrated
→ Tuning algorithm and test beam necessary for spatial resolution measurement

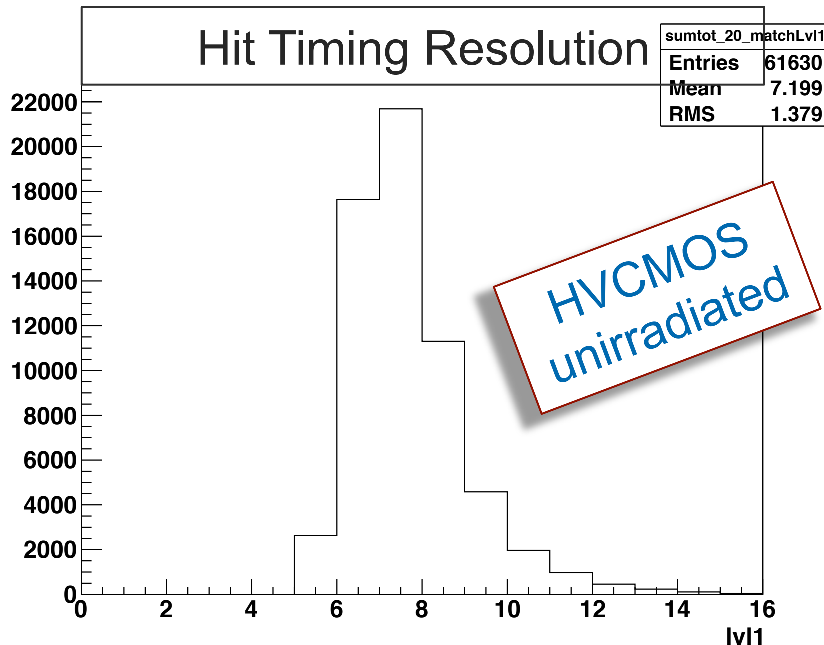
Test Beam Results – Introduction

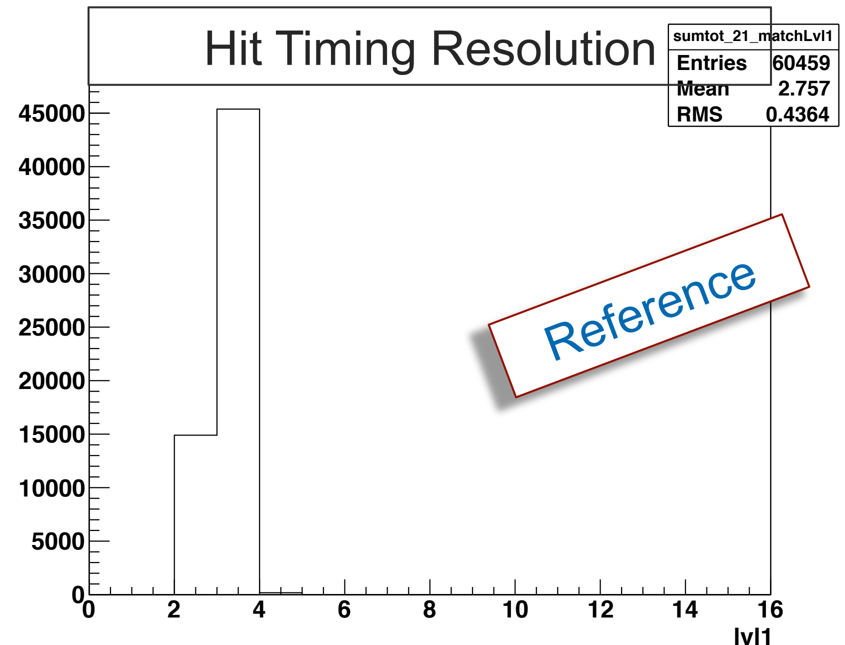
- Tuning algorithm for “full matrix sub-pixel reconstruction” under development
  → Sinlge test system for “smart sensor + FE-4” mandatory
    → USBpix integration
- No sub-pixel reconstruction serious challenge for test beam measurements (temporally):
  → Alternating pixel connection pattern → challenging alignment
  → Sub-pixel resolution mandatory for in-pixel efficiency measurements

→ **Careful** conclusions on radiation hardness from test beam / lab results, although very promising (Samples “alive” after up to 10^{16} n_{eq} cm^{-2})

Test Beam Results – Timing Resolution

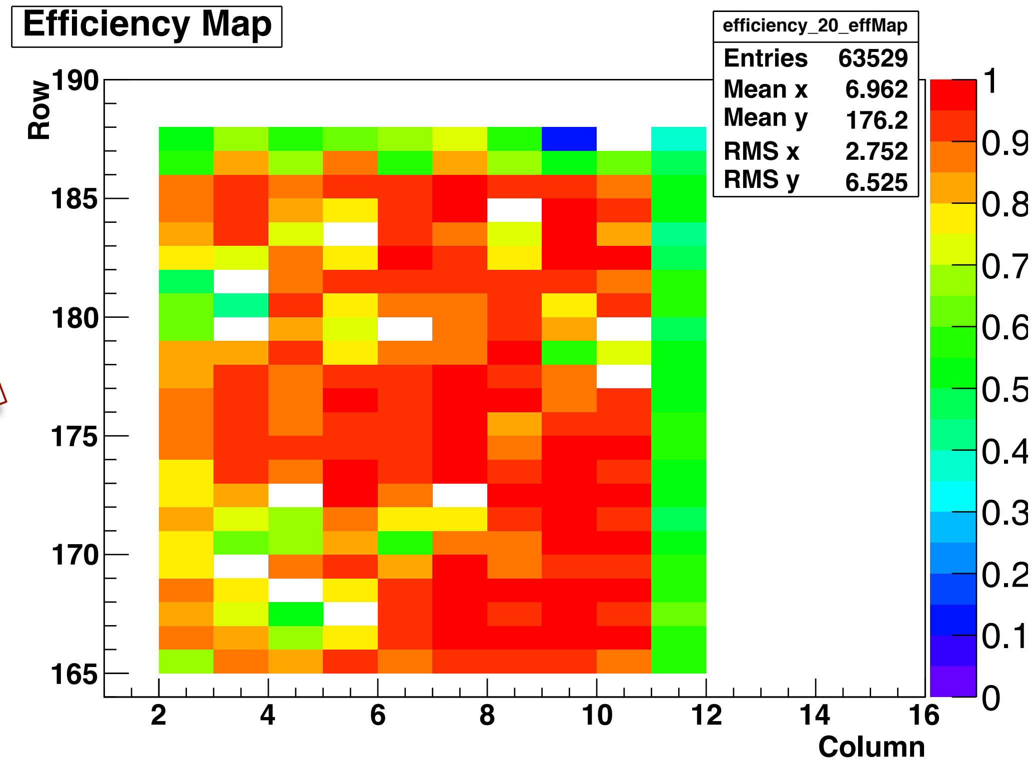
→ DESY test beam, 4 GeV e





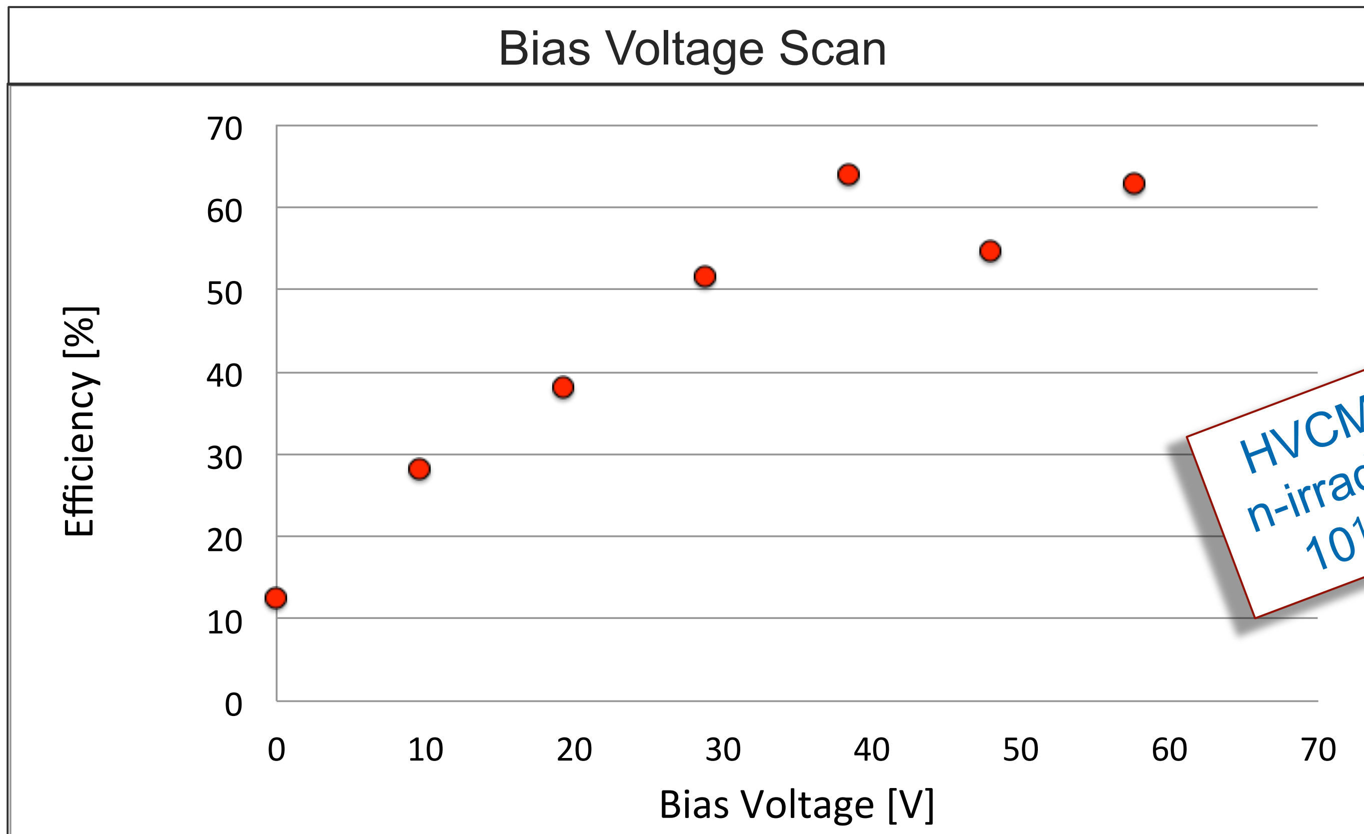
→ Hits with delayed detection

Test Beam Results – Mean Efficiency



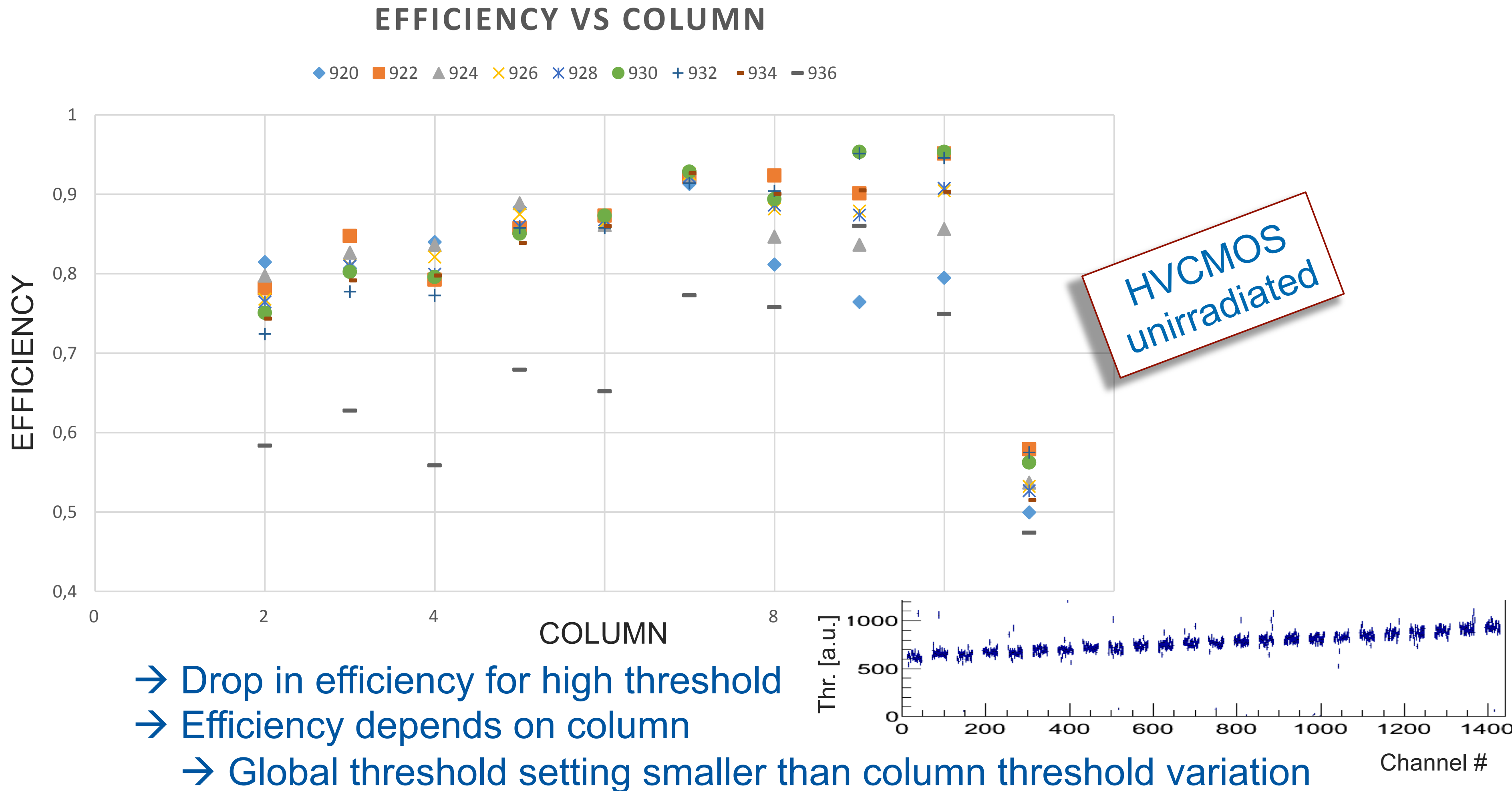
→ Reduced efficiency at edges and around dead pixels to be investigated
→ Again column dependency → Powering of HVCMOS columns

Test Beam Results - Scans



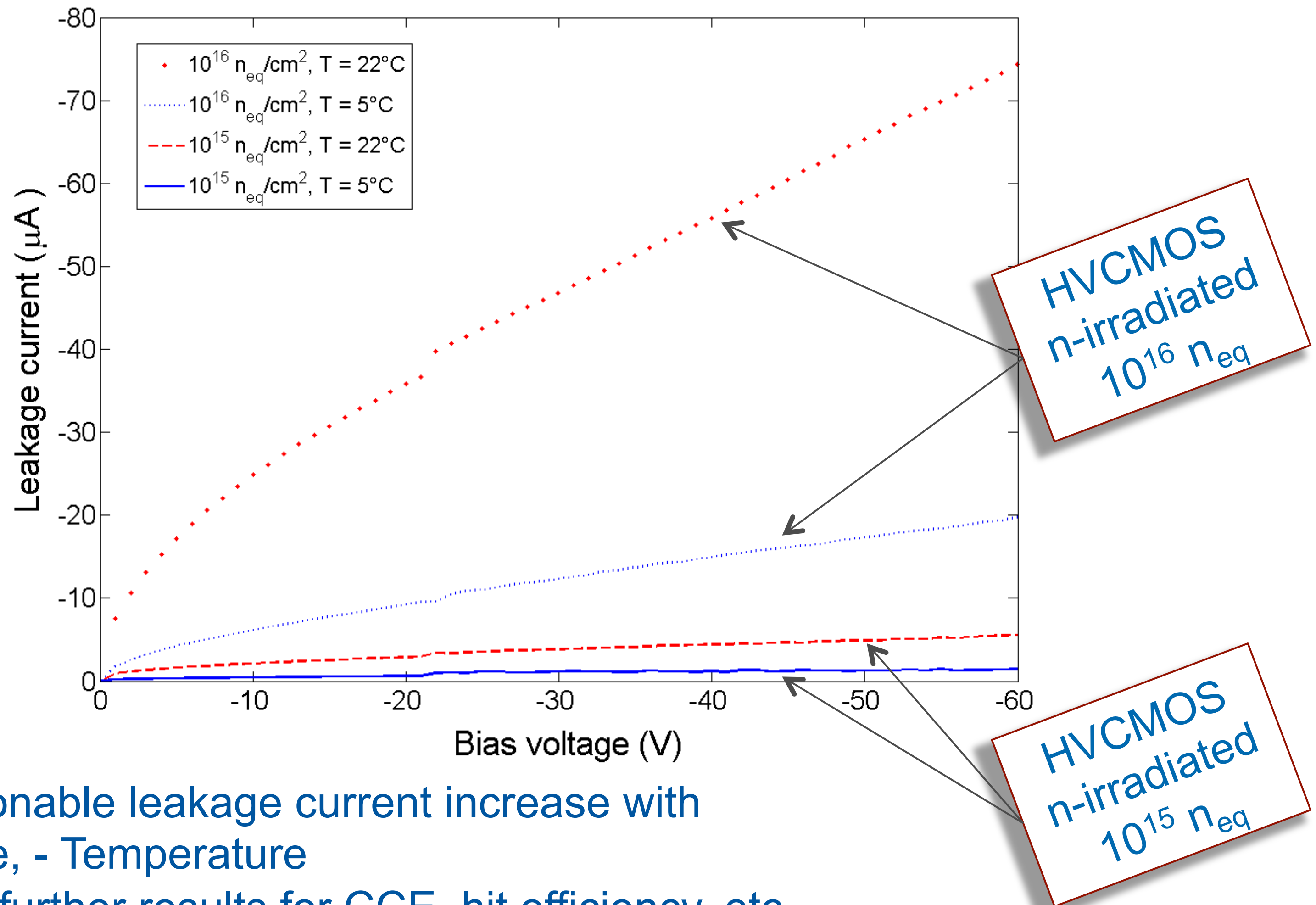
→ Bias voltage increases efficiency

Test Beam Results – Column Efficiency



→ Drop in efficiency for high threshold
→ Efficiency depends on column
→ Global threshold setting smaller than column threshold variation

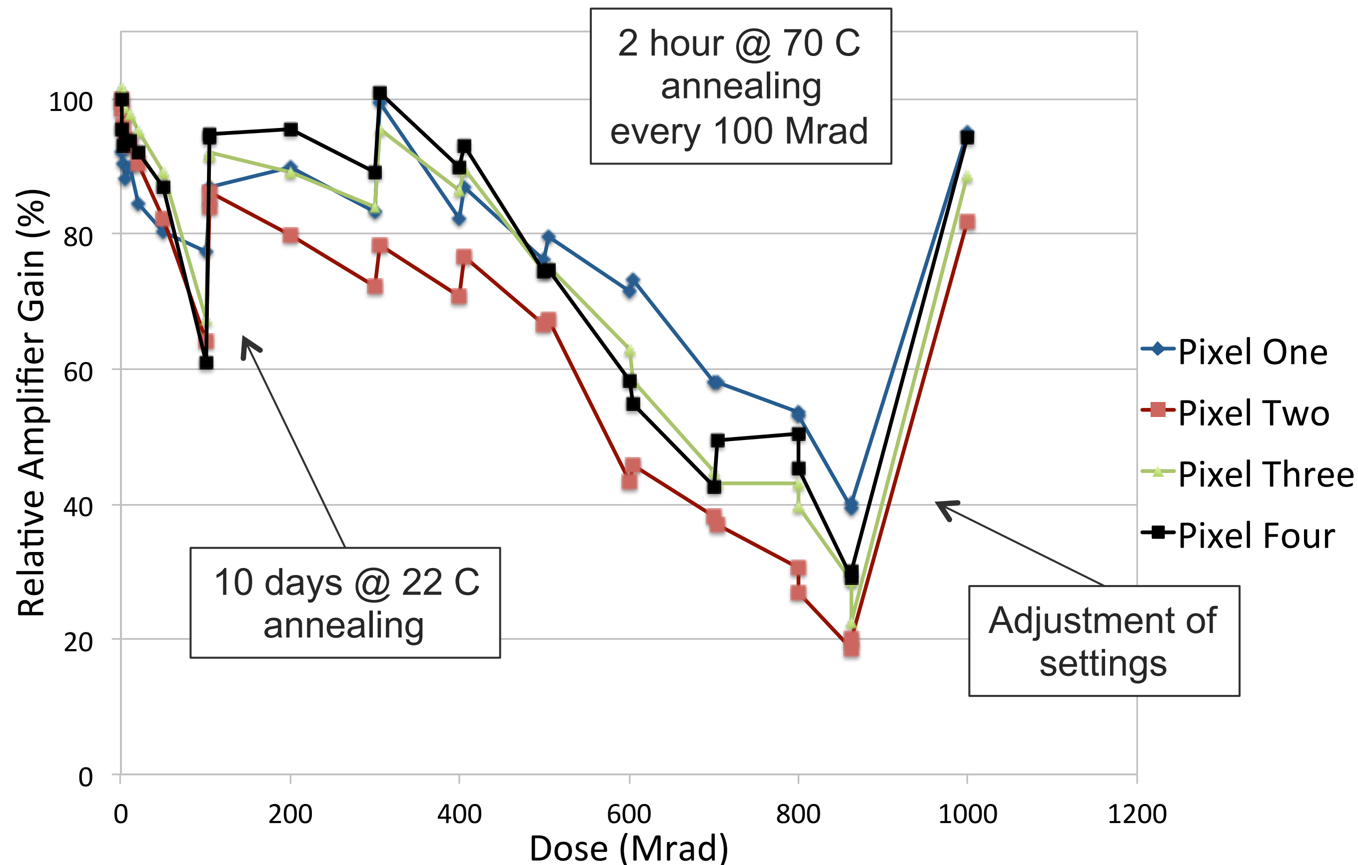
Irradiation Studies – Bulk Damage



→ Reasonable leakage current increase with
- Dose, - Temperature

→ Need further results for CCE, hit efficiency, etc.

Irradiation Studies – Electronics



→ Decrease of Preamplifier gain with irradiation
→ Annealing periods observable
→ Parameter tuning recovers to 90 % gain after ~ 900 Mrad

Smart CMOS Pixel Submissions Overview

Submissions targeting R&D with FE-I4 readout

HVCMOS:

• AMS 180 nm – V1:	First prototype	In test
• AMS 180 nm – V2:	Radiation hard electr. design	In test

HRCMOS:

• GF 130 nm:	First prototype	In test
• LFoundry 150 nm:	First prototype	In design (→ march/april 2014)

Conclusions

- Promising **HVCMOS and HRCMOS** prototypes submitted and in hand
- Large step towards **on sensor analog signal processing + digital FE**
- AC coupled signal transmission demonstrated
  → Research on gluing techniques started
- Sub-pixel resolution possible
  → Detailed characterization to come
  → Complicated tuning and reconstruction
  algorithms under development
- Radiation hardness of process very promising
  → Physics hits detected after several
  hundred Mrad (not shown here)
  → Radiation hard electronics for LHC environment
  feasible

- **A lot achieved – more work ahead!**

ATLAS Smart CMOS Pixel Collaboration

- **University of Bonn:**
  L. Gonella, T. Hemperek, T. Hirono, F. Hügging, J. Janssen, H. Krüger, T. Obermann, N. Wermes
- **LBNL:**
  M. Garcia-Sciveres
- **CERN:**
  M. Backhaus, M. Capeans, S. Feigl, S. Fernandez-Perez, M. Nessi, H. Pernegger, B. Ristic
- **University of Geneva:**
  S. Gonzales-Sevilla, D. Ferrere, G. Iacobucci, A. La Rosa, A. Miucci, D. Muenstermann
- **University of Göttingen:**
  M. George, J. Grosse-Knetter, A. Quadt, J. Rieger, J. Weingarten
- **University of Glasgow:**
  R. Bates, A. Blue, C. Buttar, D. Hynds
- **University of Heidelberg:**
  C. Kreidl, I. Peric
- **CPPM:**
  P. Breugnon, P. Pangeaud, S. Godiot-Basolo, D. Fougeron, F. Bompard, J.C. Clemens, J. Liu, M. Barbero, A. Rozanov