HV-CMOS Sensor Characterization

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CMOS Strip Collaboration

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Outline

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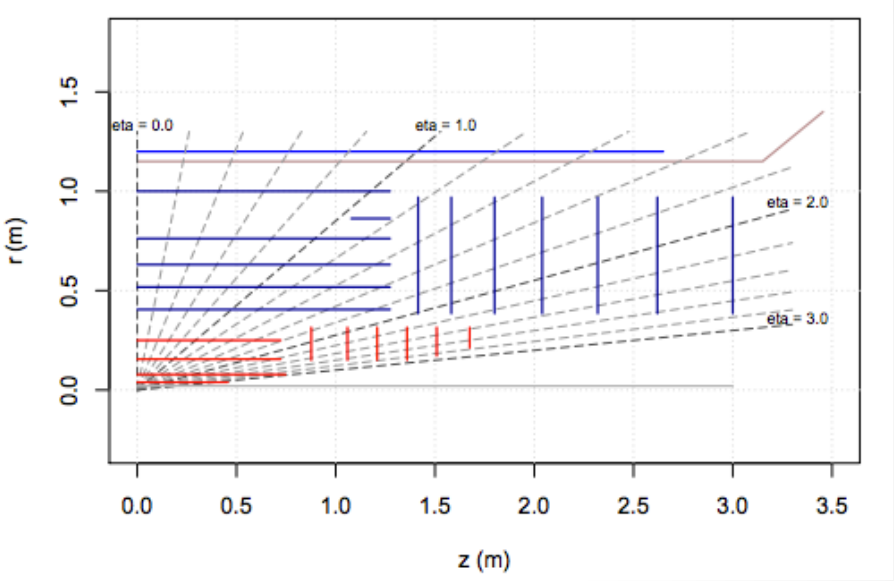
- HVStripV1
  - Testbeam at Diamond
  - Linearity of Response
  - X-Ray Measurements
  - MIPs
- Individual MOSFETs
- Conclusion

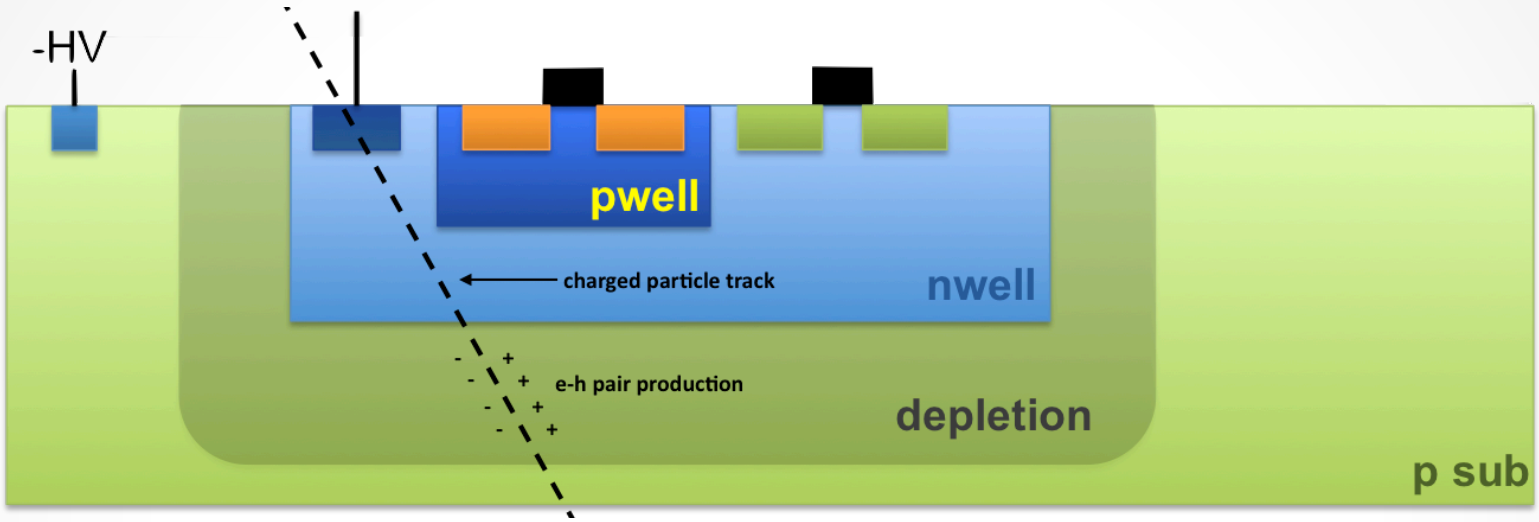
ATLAS Upgrade

- HL-LHC will lead to tenfold increase in luminosity
- New tracker must sustain 10^{14}-$10^{16} n_{eq}/cm^2$ fluence levels
- Fast sensor pulse shaping needed (25ns bunch crossing period)
- Currently well known planar technology being used
- Motivation for alternative
  - ➔ Mass reduction
  - ➔ Production costs
  - ➔ Hit encoding on the sensor

Baseline ITk Layout at HL-LHC

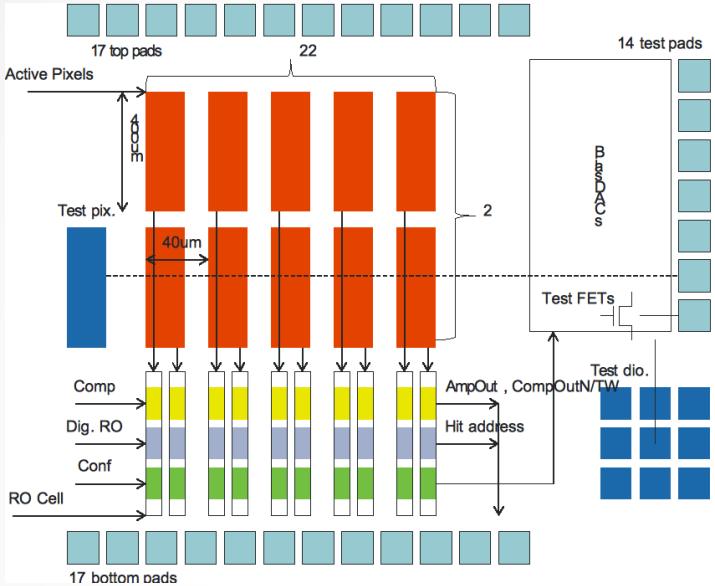


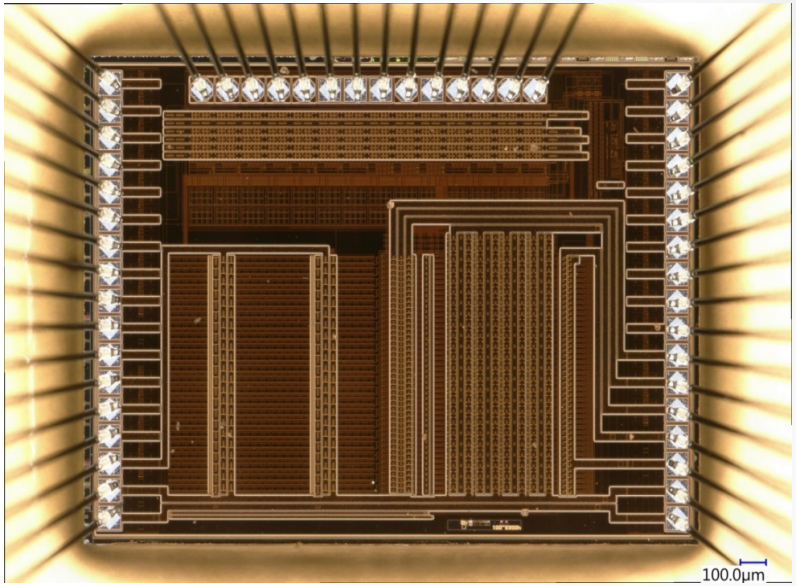
HV-CMOS Overview



- High Voltage-CMOS technology offers integration of pixel circuitry in the same substrate as the sensor
- Potential alternative to widely used planar sensors in HEP experiments
- In-built circuitry and use of commercially available processes
  - ➔ Considerable reduction in production costs
- Noise, radiation hardness, speed of response need to be investigated to determine suitability of the technology

HVStripV1



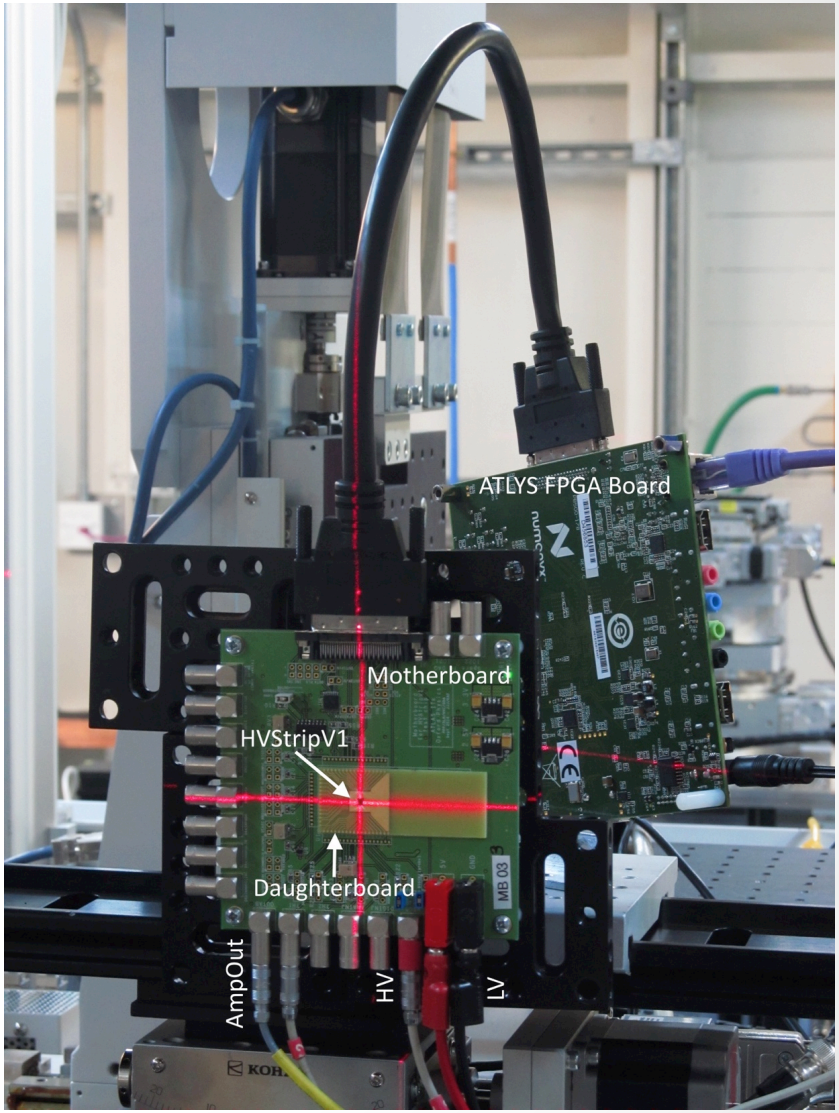


- Test chip designed by Ivan Peric
- Manufactured in AMS HV-CMOS 350nm process
- 22×2 active strip-like pixel matrix, passive structures and MOSFETs
- 40µm x 400µm size pixels with integrated pre-amplifiers
- Implemented digital readout block

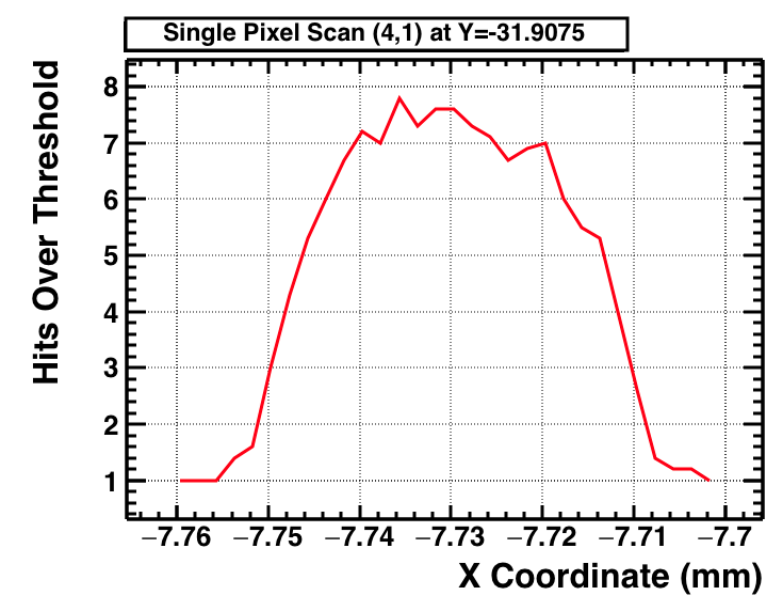
Active Pixel Matrix

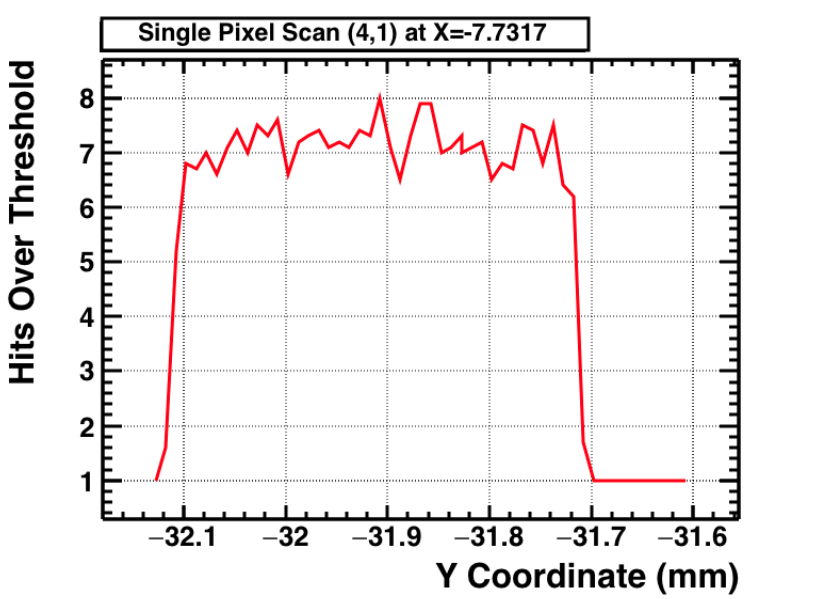
Testbeam at Diamond (1)

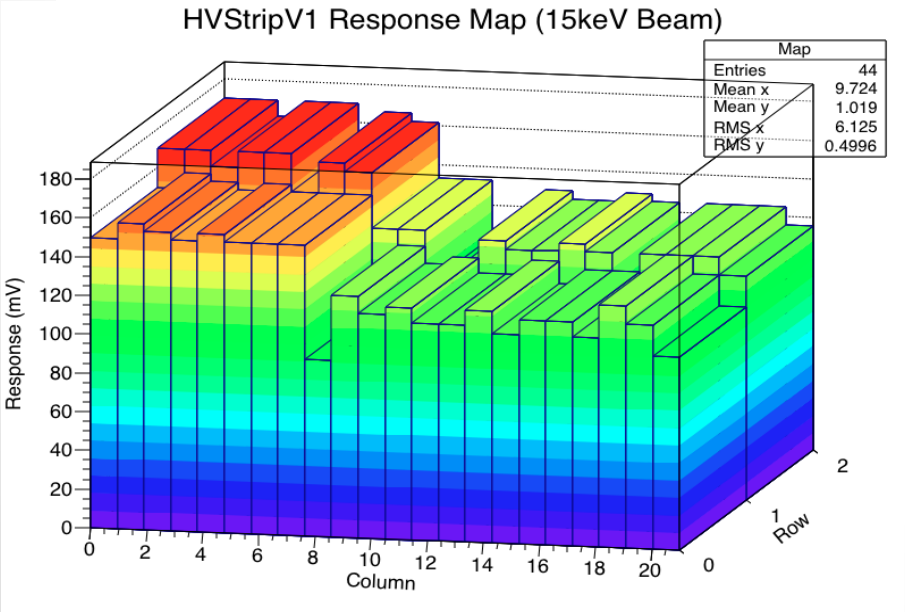
- Testbeam took place at Diamond Light Source facility
- X-Ray beam of 15keV and few μm in width
- ≈4100e^- of deposited charge in sensor
- Analogue pixel signal readout via scope
- Ability to see the output of one pixel at a time
- Substrate biased to -60V



Testbeam at Diamond (2)

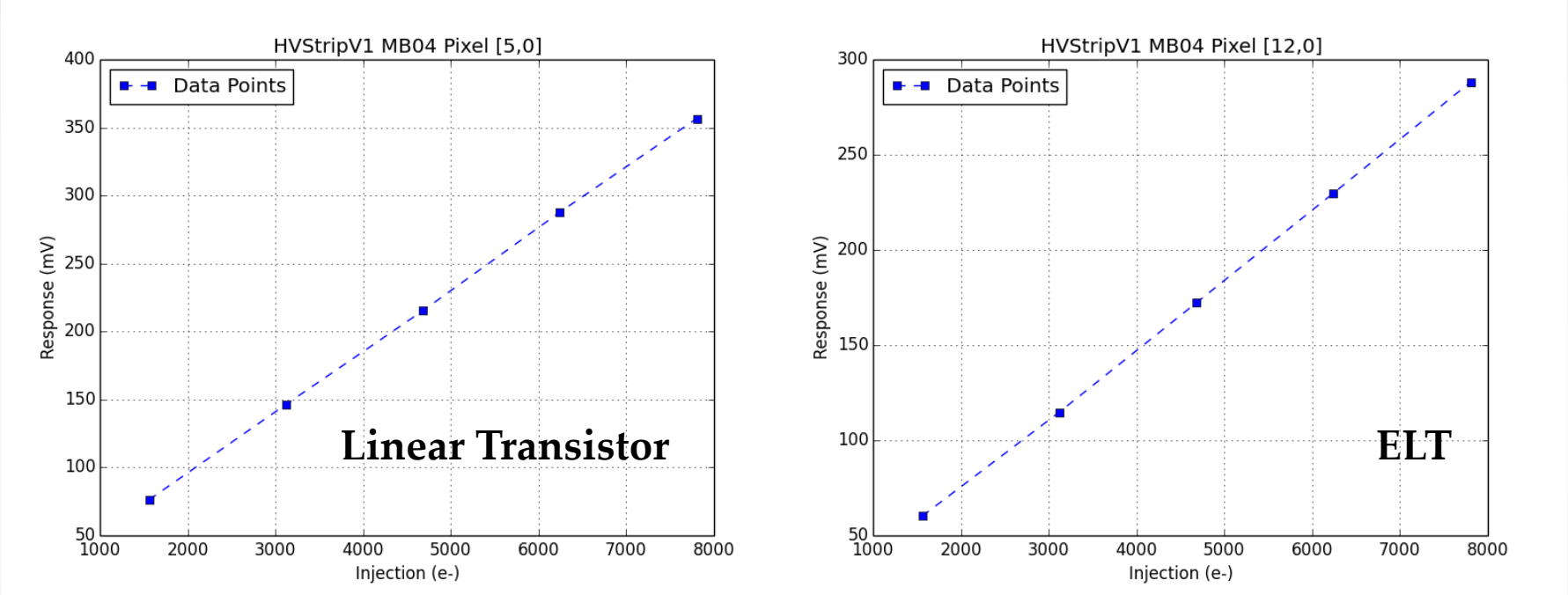






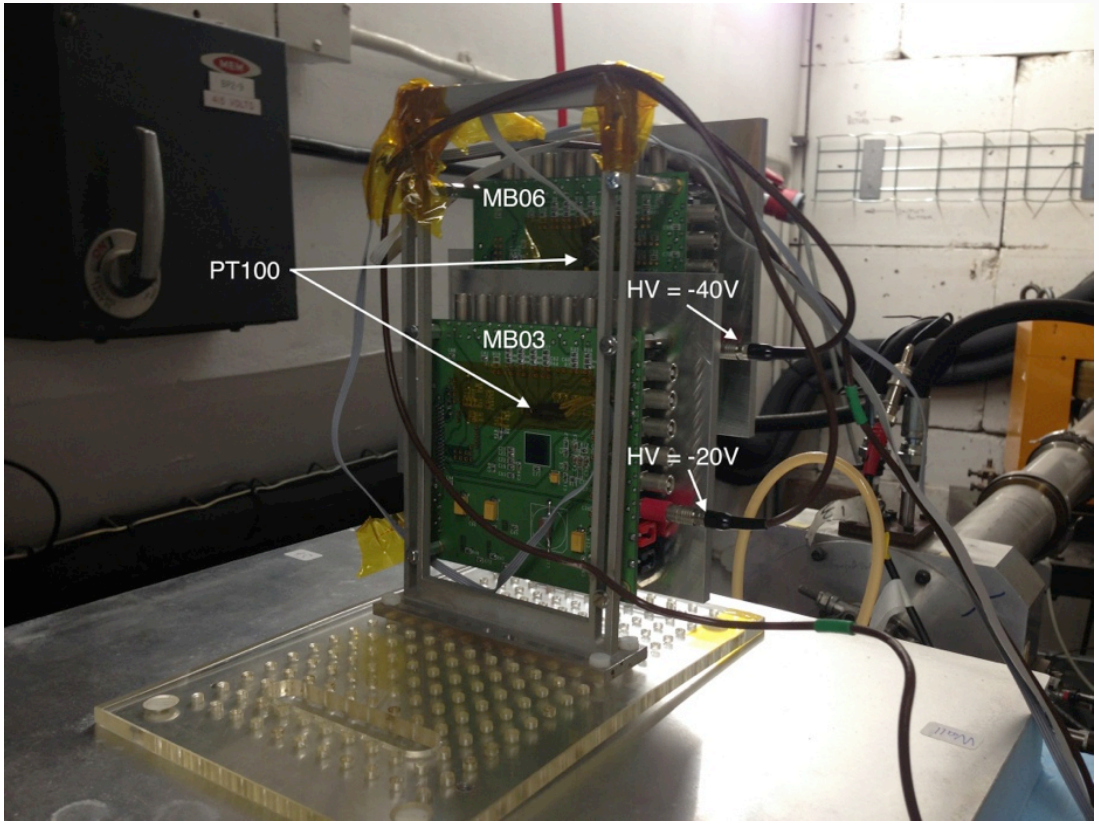
- Results of single pixel scan matches specified pixel dimensions
- Scan performed over all pixel centers
- Two distinct regions in the signal map seen due to different types of transistors used in pre-amplifier feedback circuit design (linear and ELT)

Linearity of Response



- The pre-amplifier response can be tested by injecting external pulses
- The injection done via dedicated ≈0.5fF capacitor (1V pulses ≈ 3100e^-)
- All the pixels tested demonstrate linear behavior

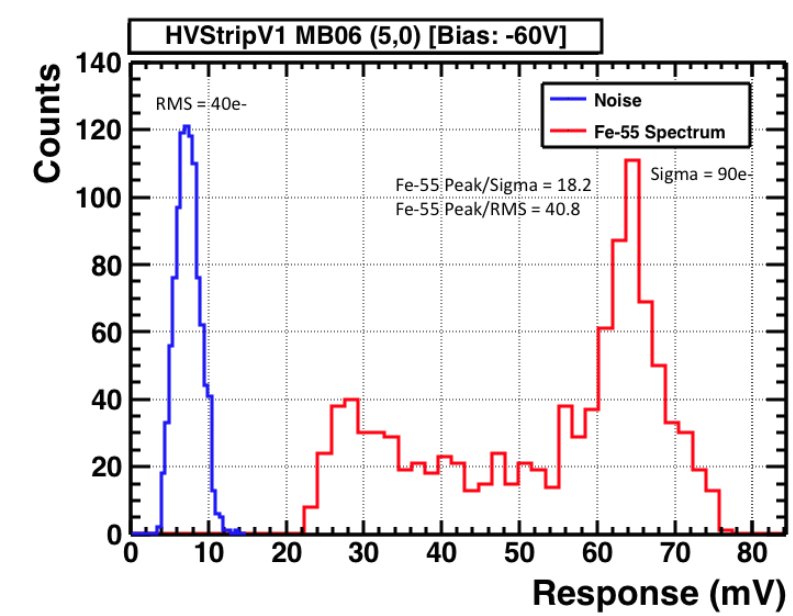
Irradiation Campaign



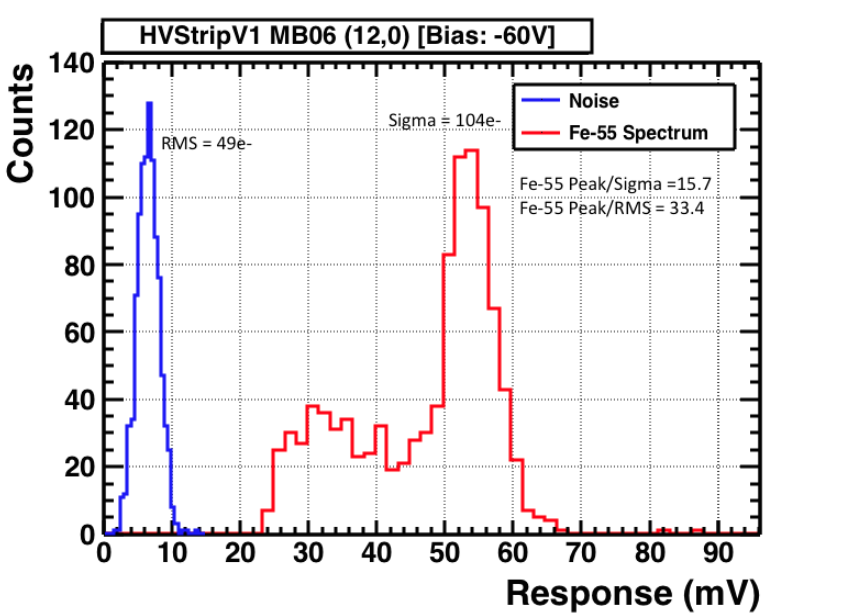
- Two HVStripV1 samples irradiated to HL-LHC fluence levels at MC40 cyclotron facility at the University of Birmingham
- 27MeV protons used for irradiation
- Devices kept at -50°C using nitrogen supply
- Actual fluences received: MB03 - $0.99\times10^{15} n_{eq}/cm^2$, MB06 - $1.23\times10^{15} n_{eq}/cm^2$

X-Ray Measurements (1)

Linear Transistor



ELT

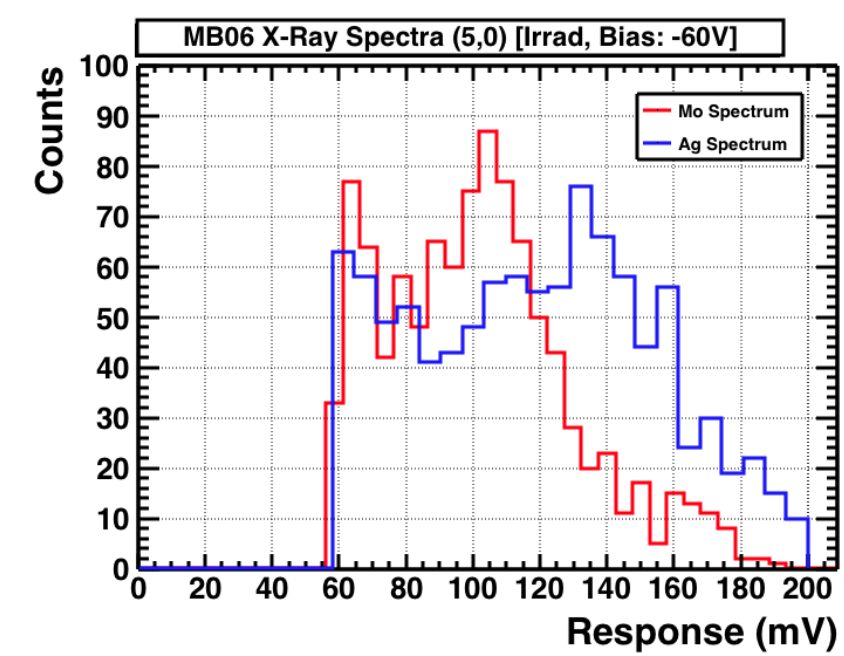


- Before irradiation Fe-55 spectra acquired for selected pixels
- The conservative SNR calculations give values from ≈16 to ≈18
- Increase in noise level after irradiation
  - ➔ Fe-55 measurements could not be repeated
- A variable X-Ray source with different metal targets used instead

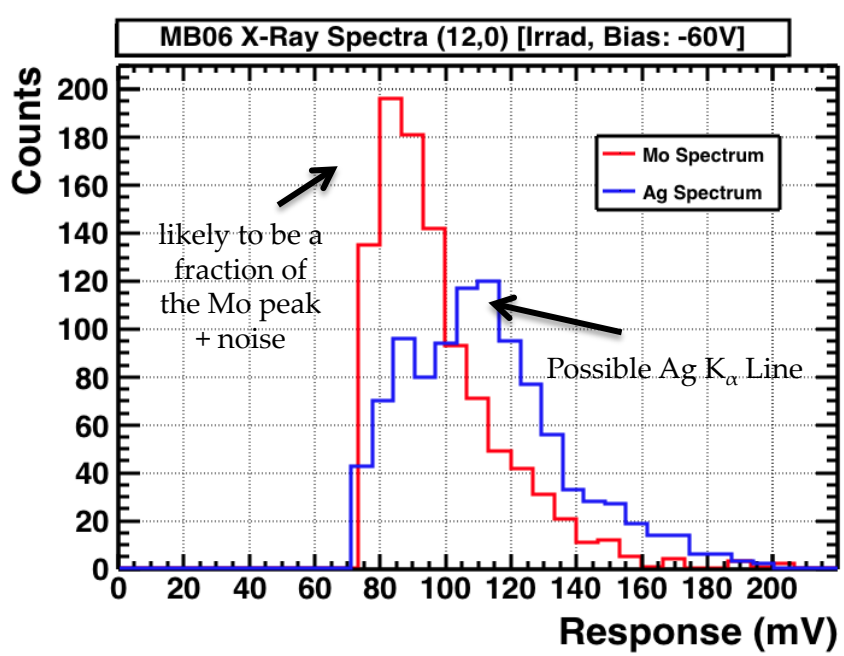
X-Ray Measurements (2)

After Irradiation

Linear Transistor



ELT



- Initially no reasonable analogue signal from pixels
- Global DAC tuning was necessary
  - ➔ Adjustment done for VNFB – feedback resistance DAC
- Proper AmpOut signal seen again
- Ag (22keV) and Mo (17keV) X-ray spectra acquired

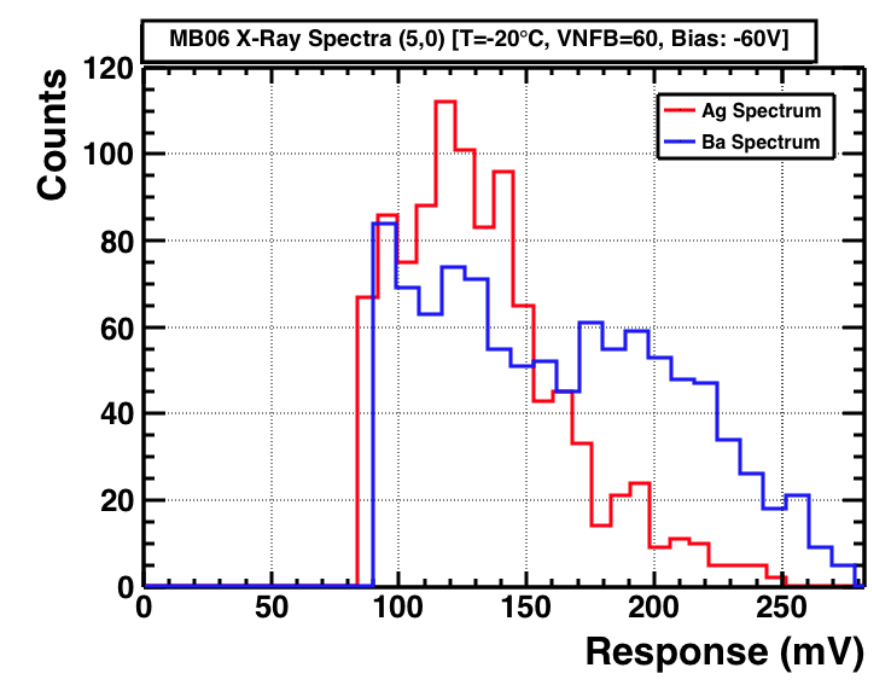
X-Ray Measurements (3)

Change in gain after irradiation (before annealing)

Pixel (c, r)	Before* (mV/fC)	After (mV/fC)	Change (%)
(5,0)	147.40	132.65	-10.01
(12,0)	150.56	112.05	-25.57

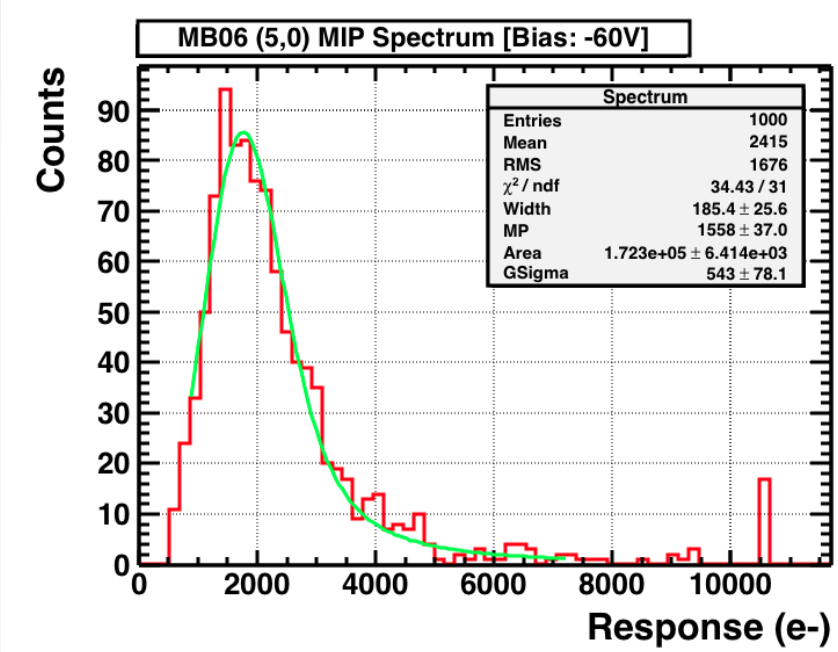
* Estimated gain at VNFB = 60 using non-irradiated MB12 Fe-55 data.

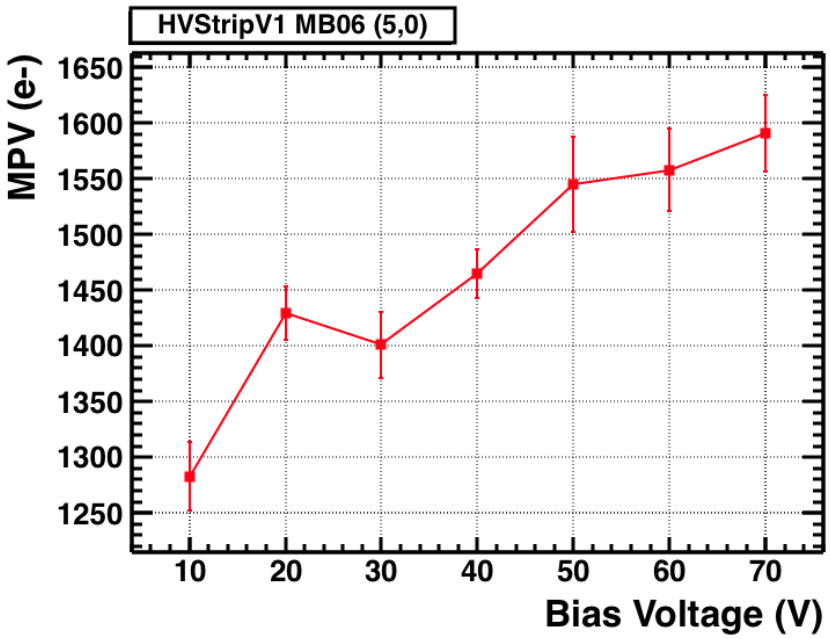
After Annealing



- Annealing of irradiated samples done for 80min at 60°C
- Further increase in noise level
- Ag and Ba (32keV) spectra acquired for linear pixel
- K_α lines could not be identified as clearly

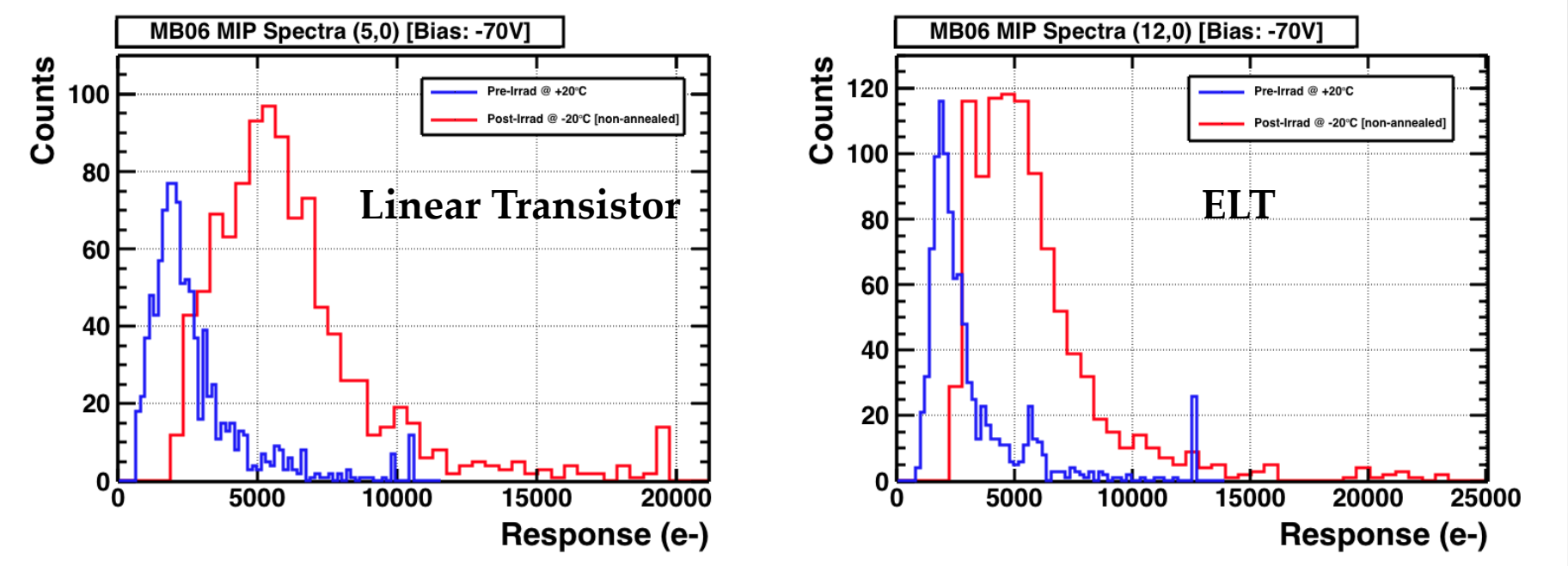
MIPs (1)





- MIP measurements done using Sr-90 (190MBq) beta source
- Scintillator placed below DUT and used as a trigger
- MIP spectra acquired within [-70,-10] bias voltage range
  - ➔ Data acquisition for both pixel types
- Results indicate variation of depletion depth with bias voltage

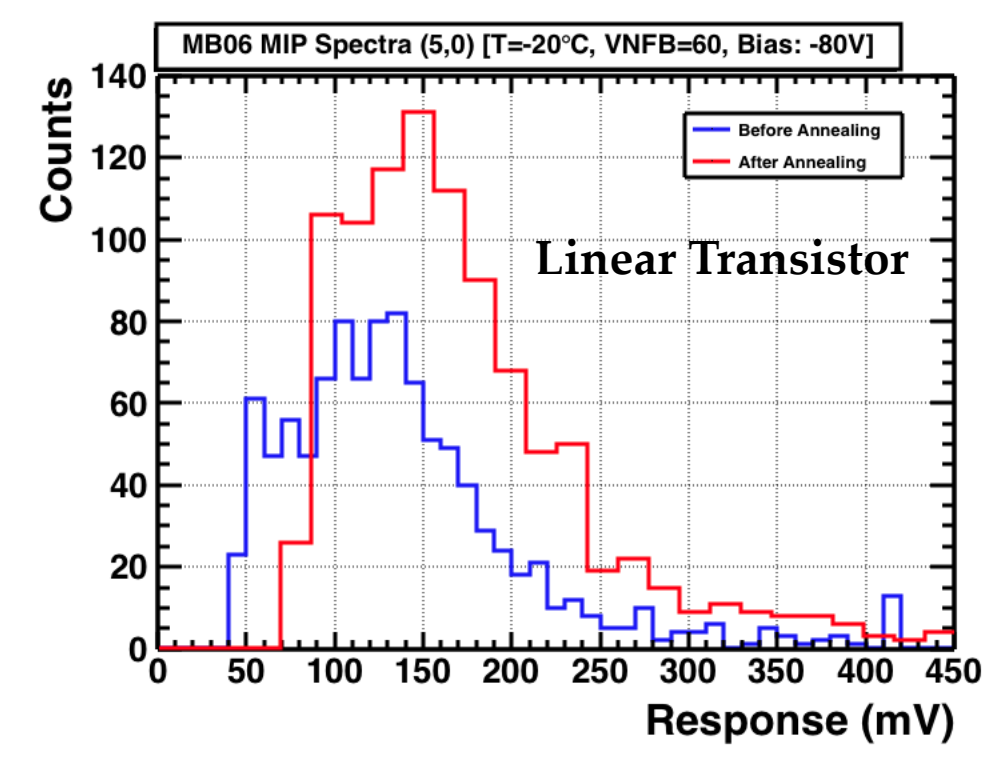
MIPs (2)



- MIP signal still observed after irradiation for both pixel types
- Signal conversion to e^-
  - ➔ Done using X-Ray data taken before and after irradiation
- Substantial increase in MIP signal (depletion depth)
  - ➔ ≈2.6x increase for both pixels
- Similar results seen for HV-CMOS AMS-Chess1 chip at Ljubljana

MIPs (3)

After Annealing

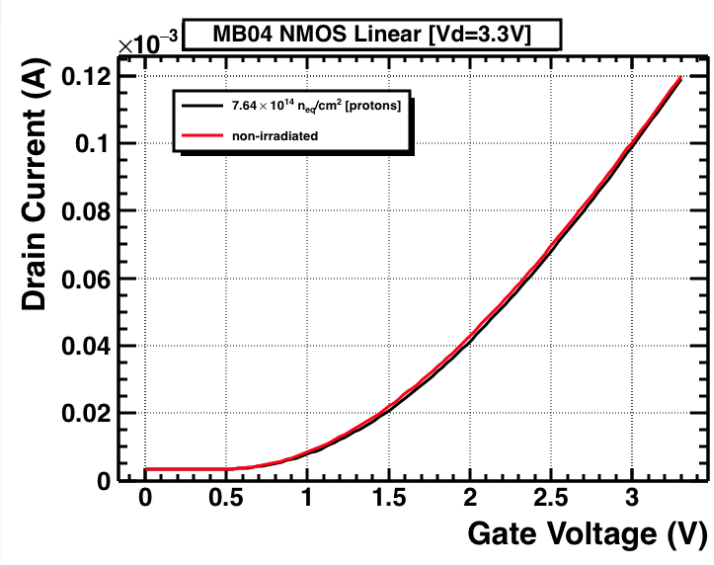


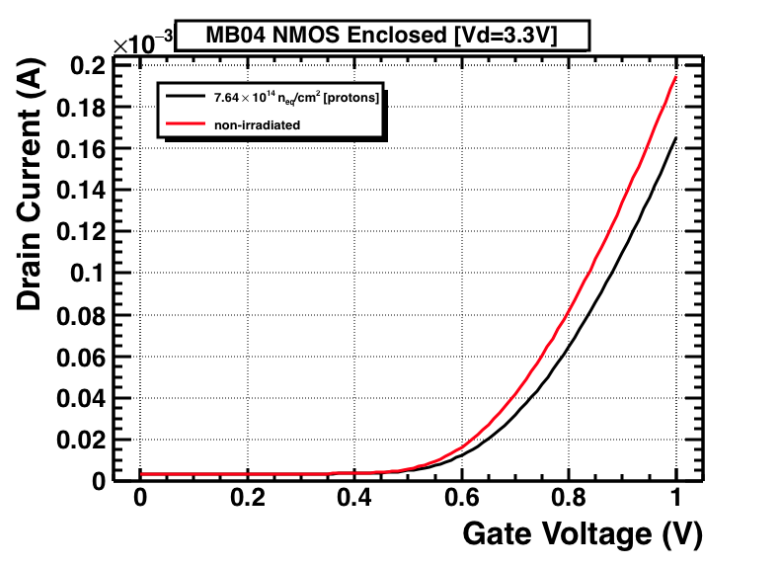
- MIP signal also observed after annealing for linear pixel
- Further increase in noise is evident
- The MIP peak appears to be close to pre-annealing level
- Note that direct comparison can not be done
  - ➔ Lack of reliable calibration

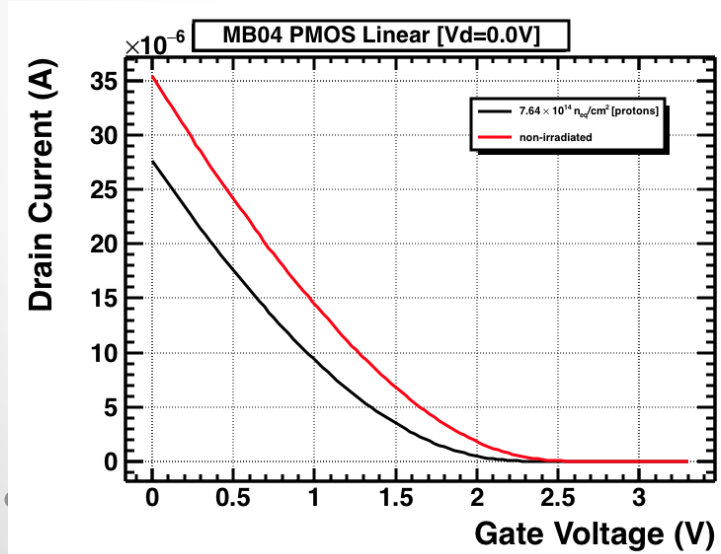
- Noise level too high for ELT pixel after annealing
- Perhaps higher voltages needed to observe the full MIP spectrum

Individual MOSFETs

MOSFETs (1)





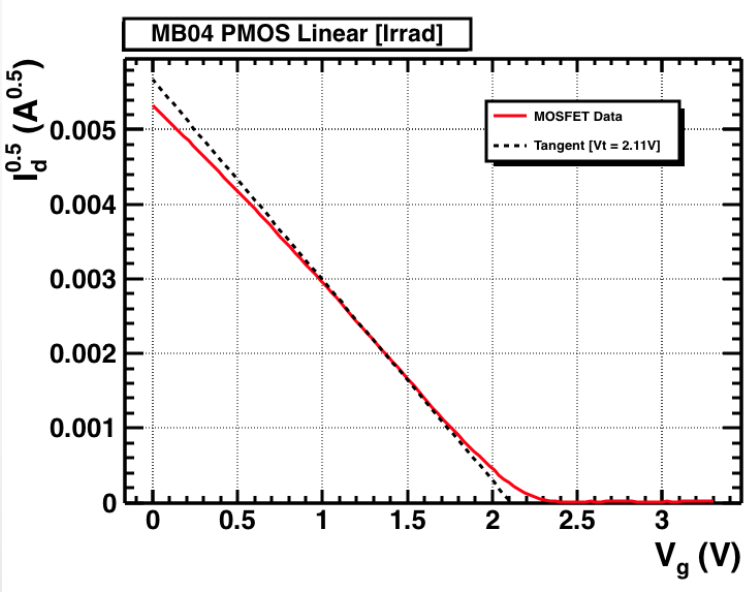


- Three different test MOSFETs available on HVStripV1
- Measurements done on MB04 sample (proton irradiation to $7.64\times10^{14} n_{eq}/cm^2$)
- Transistors operated in saturation mode
- V_{th} extracted before and after irradiation

MOSFETs (2)

Table of Threshold Voltage Change

	NMOS Lin	NMOS Enc	PMOS Lin
$\lvert\Delta V_{th}\rvert$	0.00V	0.00V	0.23V



- Both sets of MOSFET measurements done at room temperature
- No significant change in V_{th} observed for NMOS transistors
- Substantial change occurred for p-channel MOSFET

Conclusions

- MIP spectrum seen after irradiation to fluence levels expected at HL-LHC
- Significant increase in MIP signal after $\approx 1\times10^{15} n_{eq}/cm^2$
- Promising results, although need to evaluate
  - ➔ Signal timing and increase in noise
  - ➔ Radiation hardness from different devices
- Further results to be obtained from similar HV-CMOS test chip characterization (ex. AMS-Chess1)

Thank you for your attention!