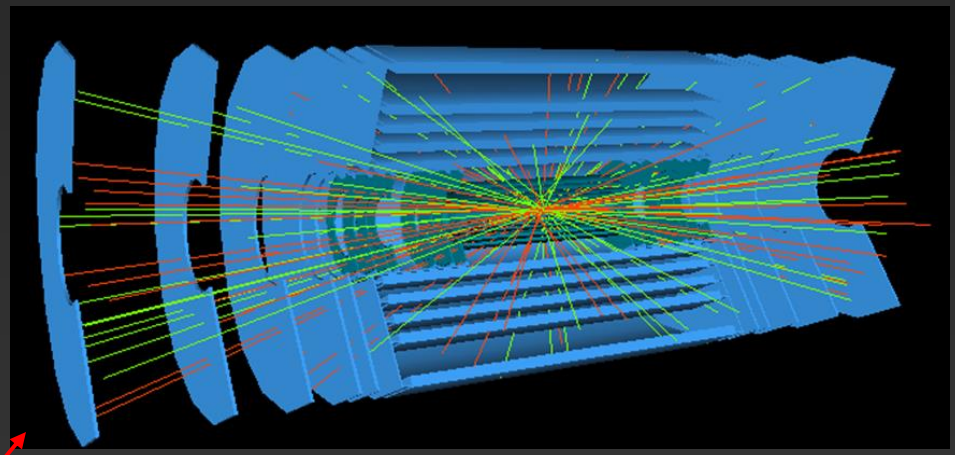
Irradiation tests of LF-CPIX CMOS sensor

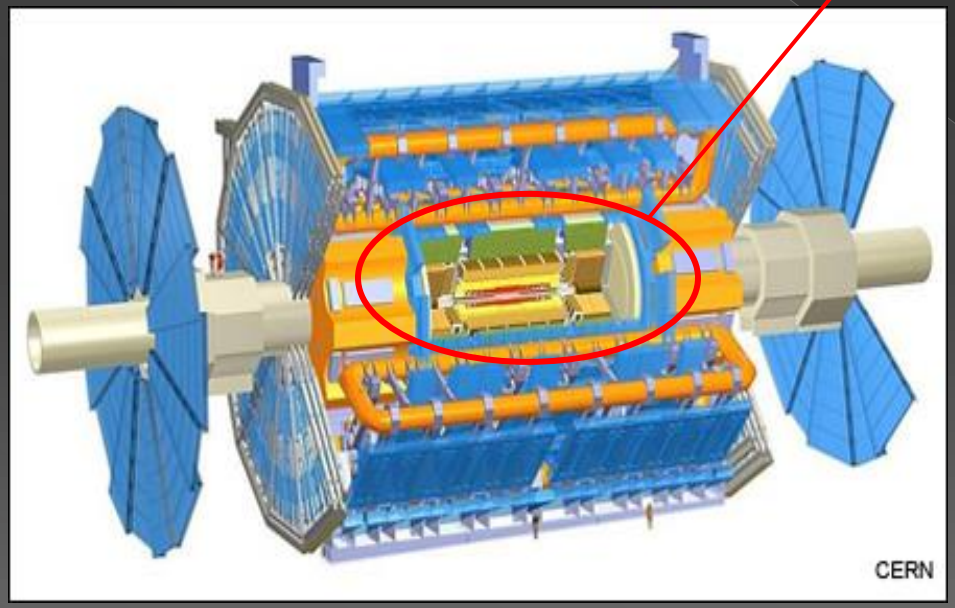
L. Vigani, D. Bortoletto,
L. Ambroz, D. Huang, R. Plackett

31st RD50 collaboration meeting
CERN 22/11/2017

ITk

In 2025 HL-LHC upgrade
Itk will be the ATLAS tracking system
(fully made of Silicon)





Inner tracker: Silicon pixel detectors

Outer tracker: Silicon strip detectors

At the last pixel layer (~30 cm from vertex) expected:

- 80 Mrad Total Ionization Dose
- $1.5 \cdot 10^{15}$ n_{eq}/cm^2 fluence

Bunch crossing: 25 ns

CMOS detectors for HEP

Valid candidate for Itk 5th pixel layer

- Read-out integrated with sensor
- Process used in many applications
  - Solid
  - Cheap

But:

- Charge collected via diffusion
  - Slow
  - Low signal
- Radiation tolerant…?

Can we use them in the harsh HEP environment (HL-LHC)?

CMOS detectors for HEP

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- Read-out integrated with sensor
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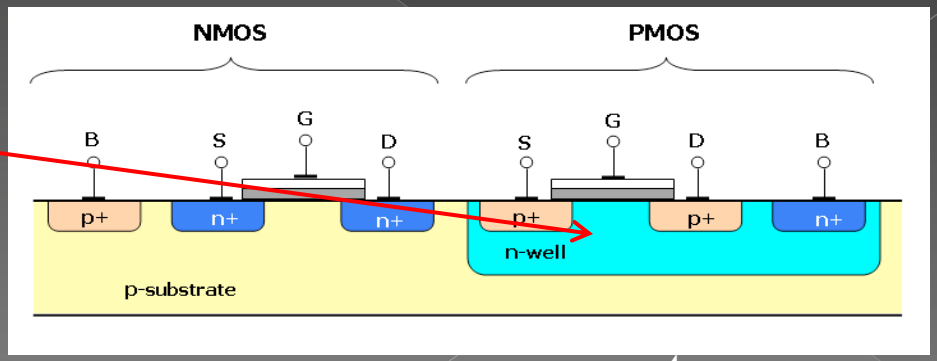
- Radiation tolerant…?

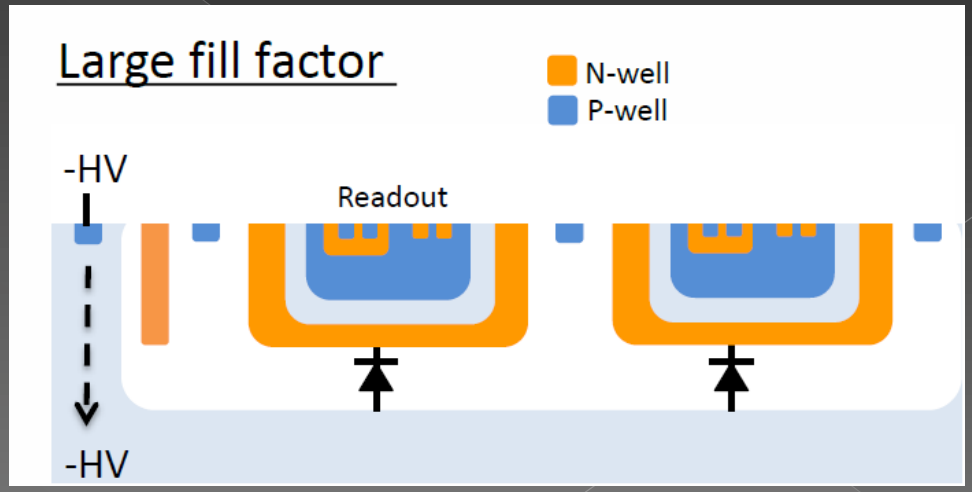
Can we use them in the harsh HEP environment (HL-LHC)?

- Necessity of depleting the substrate
- Some modifications to the standard fabrication process:
  - High resistivity substrate
  - High reverse bias add-ons



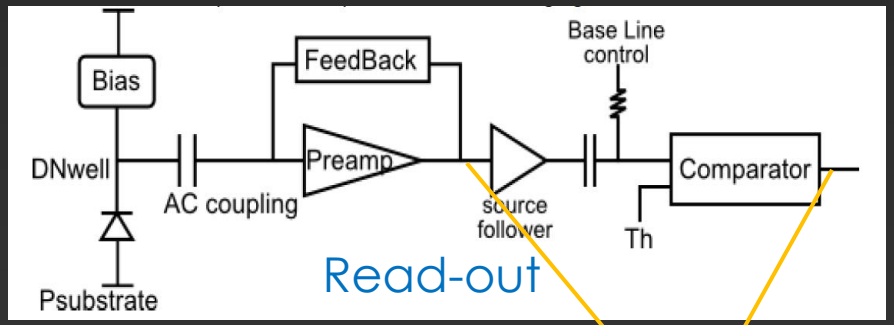
LF-CPIX

- Prototype of active CMOS for ITk
- LFoundry technology
  - High resistivity wafer (3.5÷5 kΩ·cm)
  - High bias voltage provided by multiple (4) nested wells
  - Large fill factor approach
    - Read-out inside N-Well
  - 150 nm technology
    - Radiation tolerant
  - Back-side process
    - Back biased



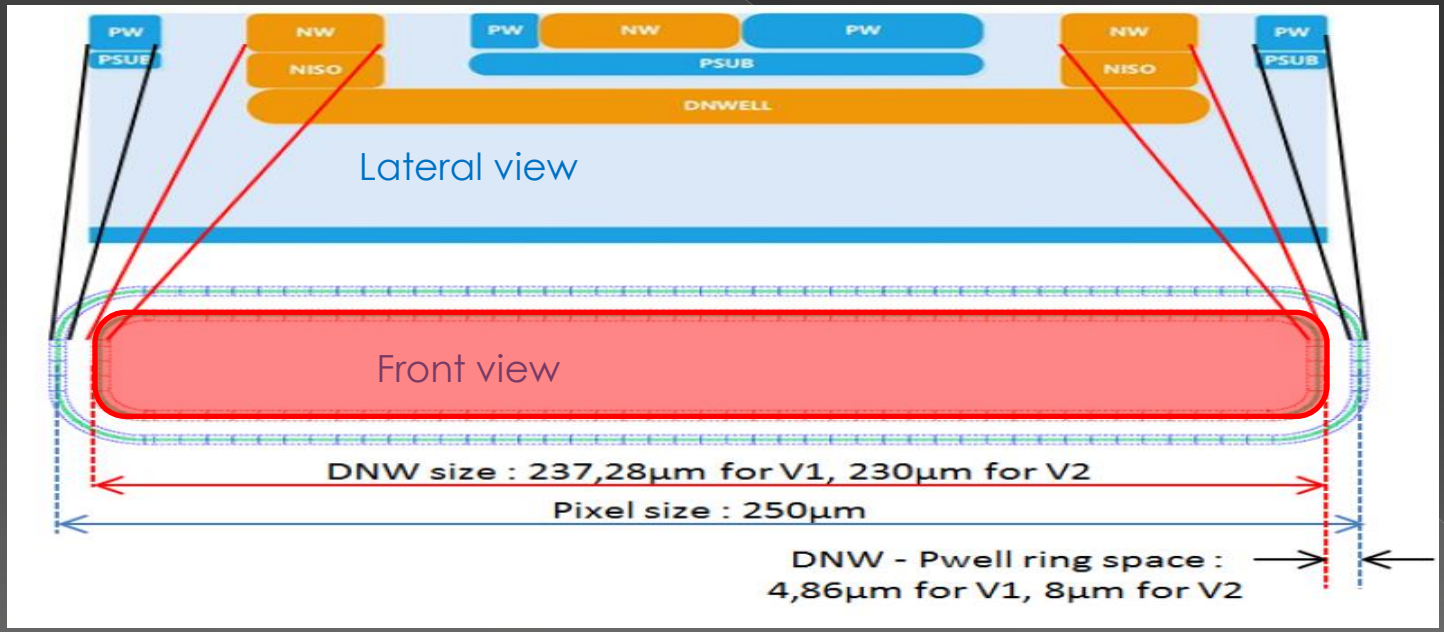
LF-CPIX

Large prototype (9.5x10mm^2)
Standard FE-I4 size (250x50µm^2)
Large (>60%) fill factor
Larger signal and collection area
Larger capacitance (noise)



To external read-out (standalone board)

(Alternatively glued to FE-I4)



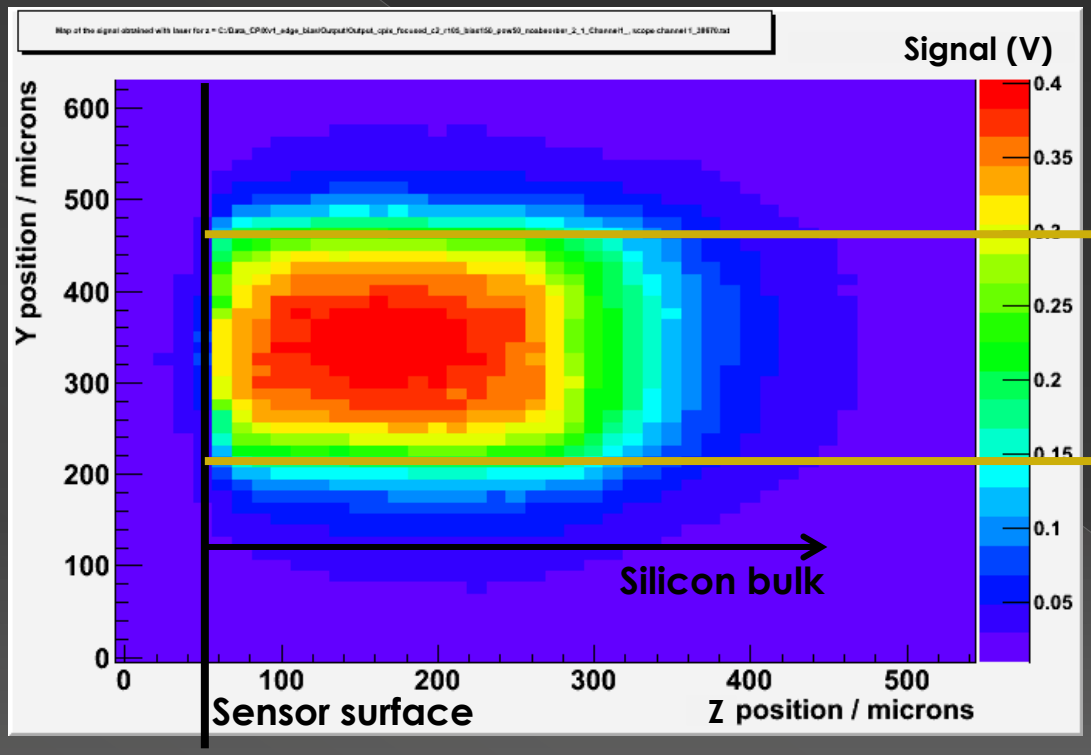
T. Hirono et al, "CMOS pixel sensors on high resistive substrate for high-rate, high-radiation environments", Nuclear Instruments and Methods in Physics Research Section A, Volume 831, 2016

3 "flavours" of Pre-amp implemented:

NMOS PMOS CMOS

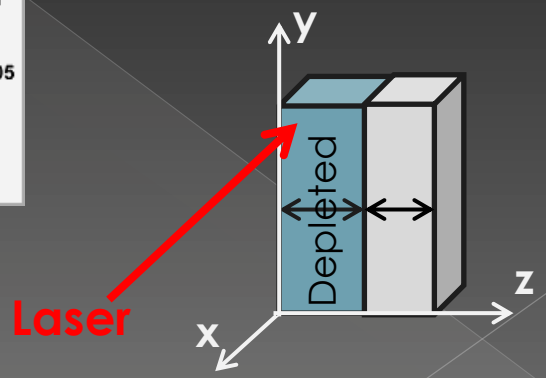
Edge-TCT before irradiation

Col 2, row 105 (NMOS pre-amp)



Bias -150V

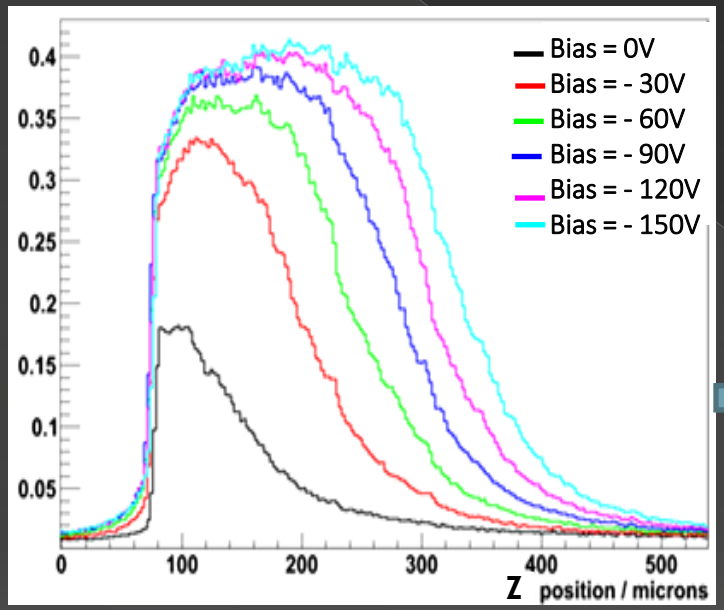
250 µm



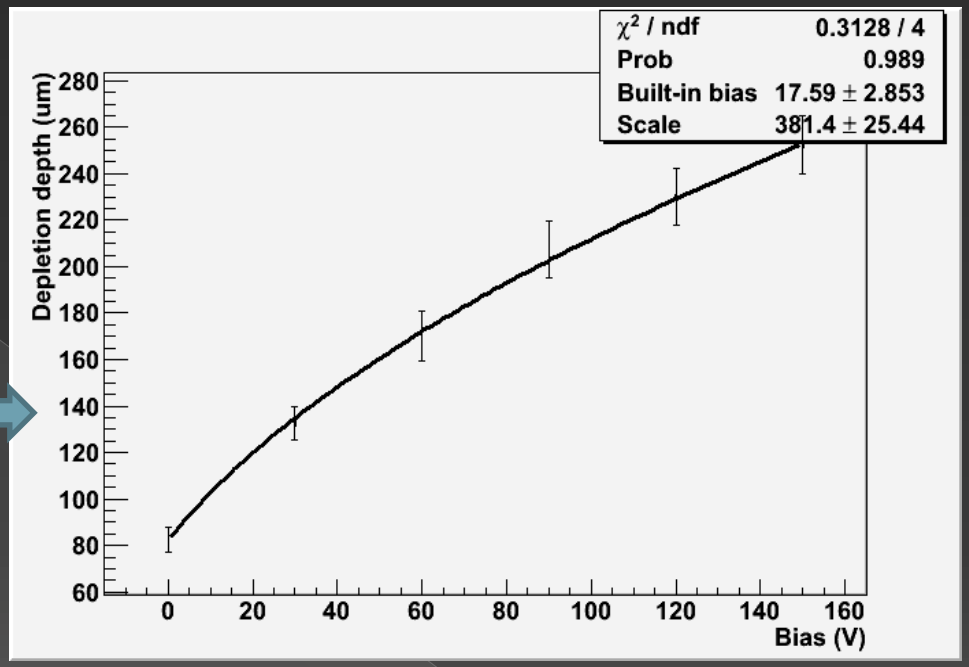
Output from pre-amplifier
One channel only
Signal region larger than 250 um due to charge sharing

Edge-TCT before irradiation

Bias scan



Signal vs depth
(1D profile along centre of the pixel)

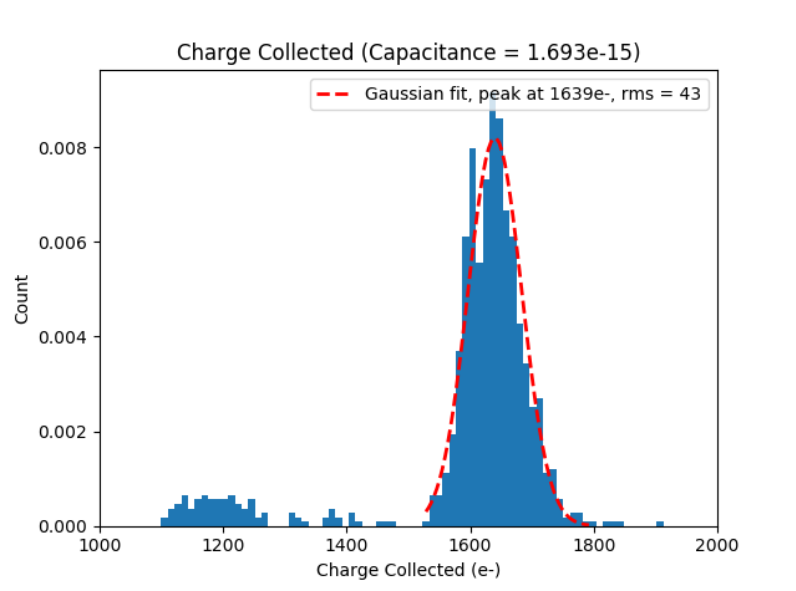


FWHM (=depletion depth) as a function of bias

From fit: resistivity = 4.2 kΩ·cm

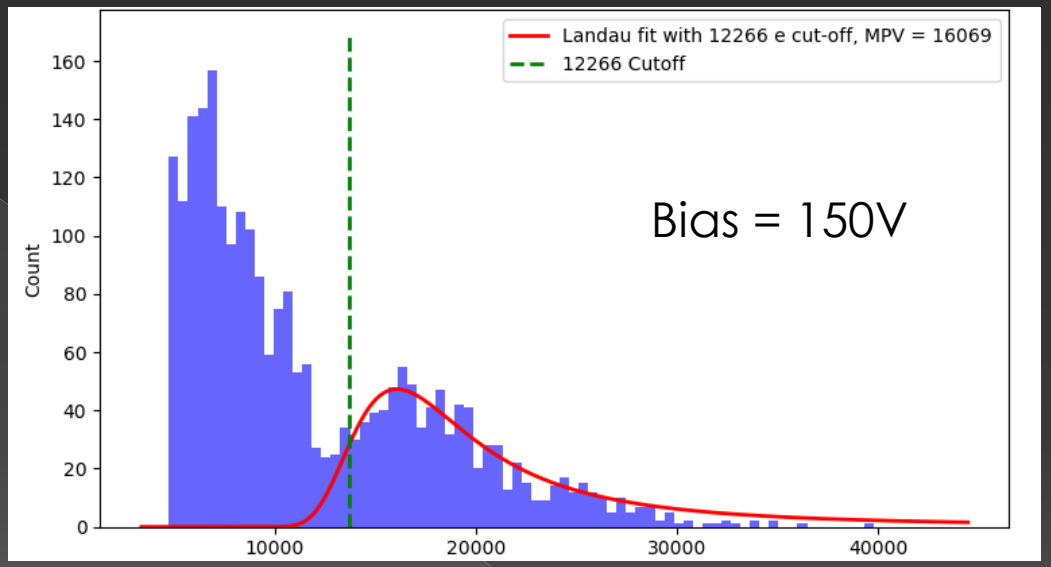
Radioactive sources before irradiation

Fe^{55}



X-ray spectrum:
full absorption peak detected

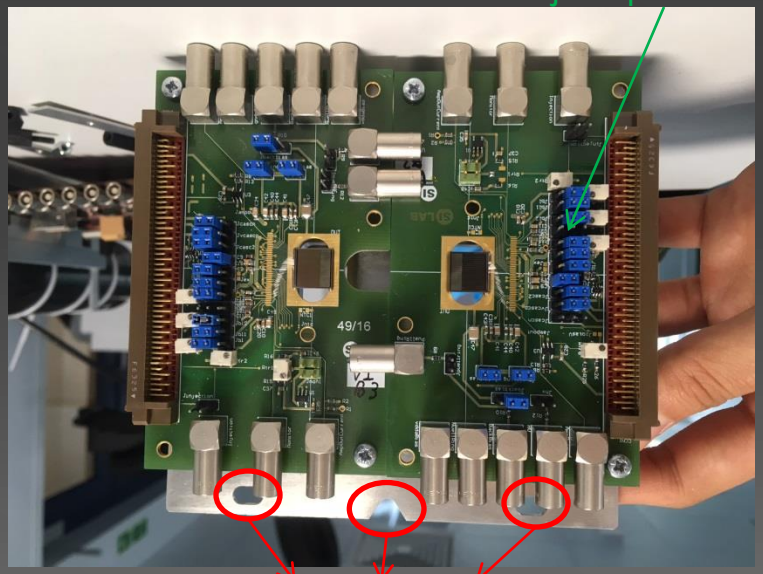
Sr^{90}

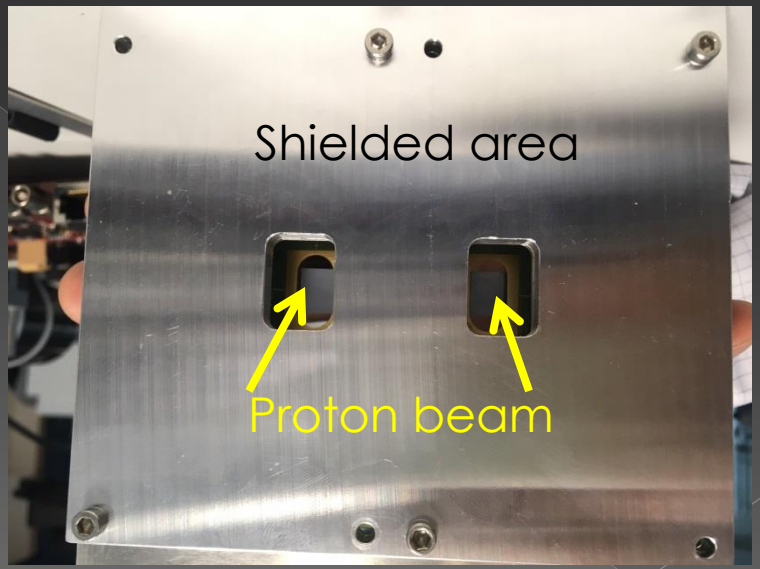


MIP spectrum: Landau fit compatible with depletion depth of 211 μm (expected 250 μm from edge-TCT, agreement within errors)
S/N ≈ 100

Irradiation at Birmingham

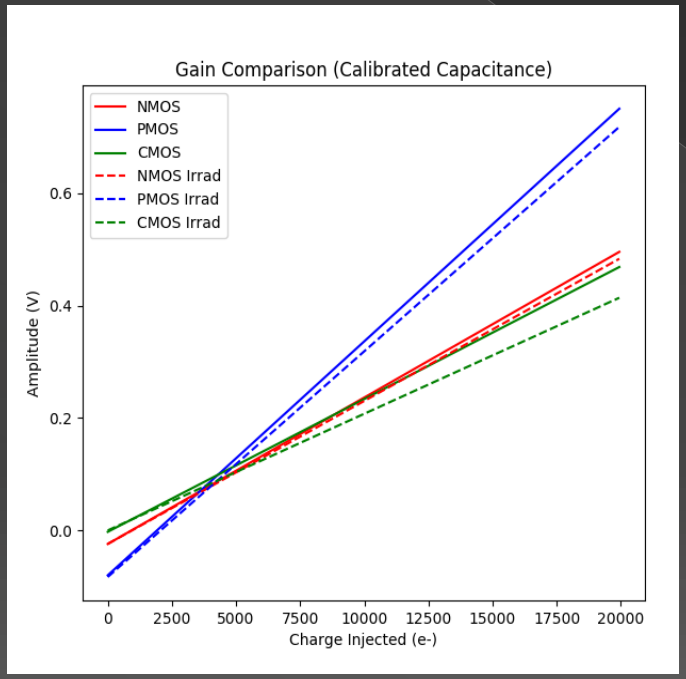
- Birmingham MC40 Cyclotron (AIDA2020 facility)
- 27 MeV protons
- 2 samples, 90 minutes exposure each
- Both to $1.0 \cdot 10^{15}$ n_{eq}/cm^2 (133 MRad TID)



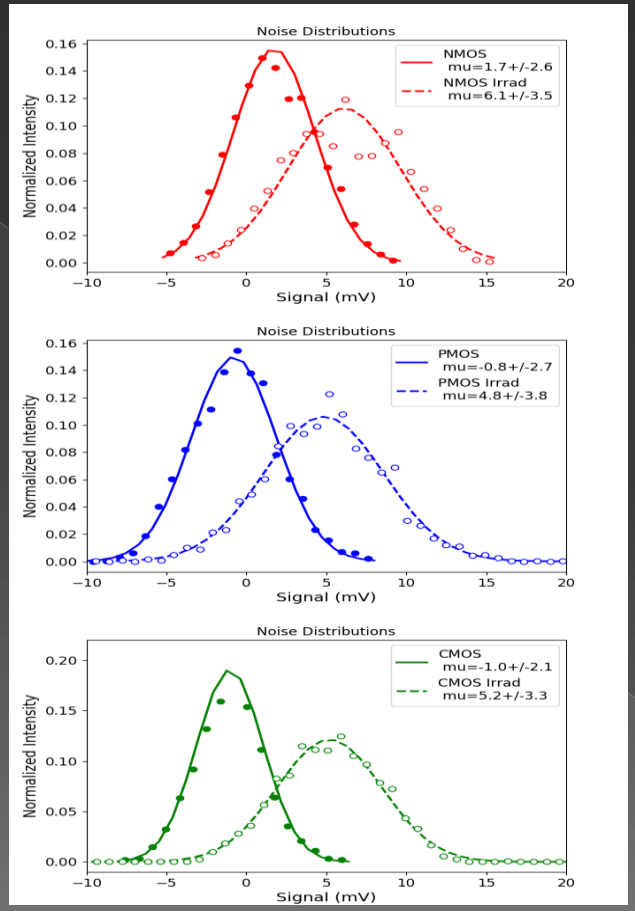


This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

Pre-amp performance after irradiation



Gain decreases by less than 10% for all pre-amp flavours



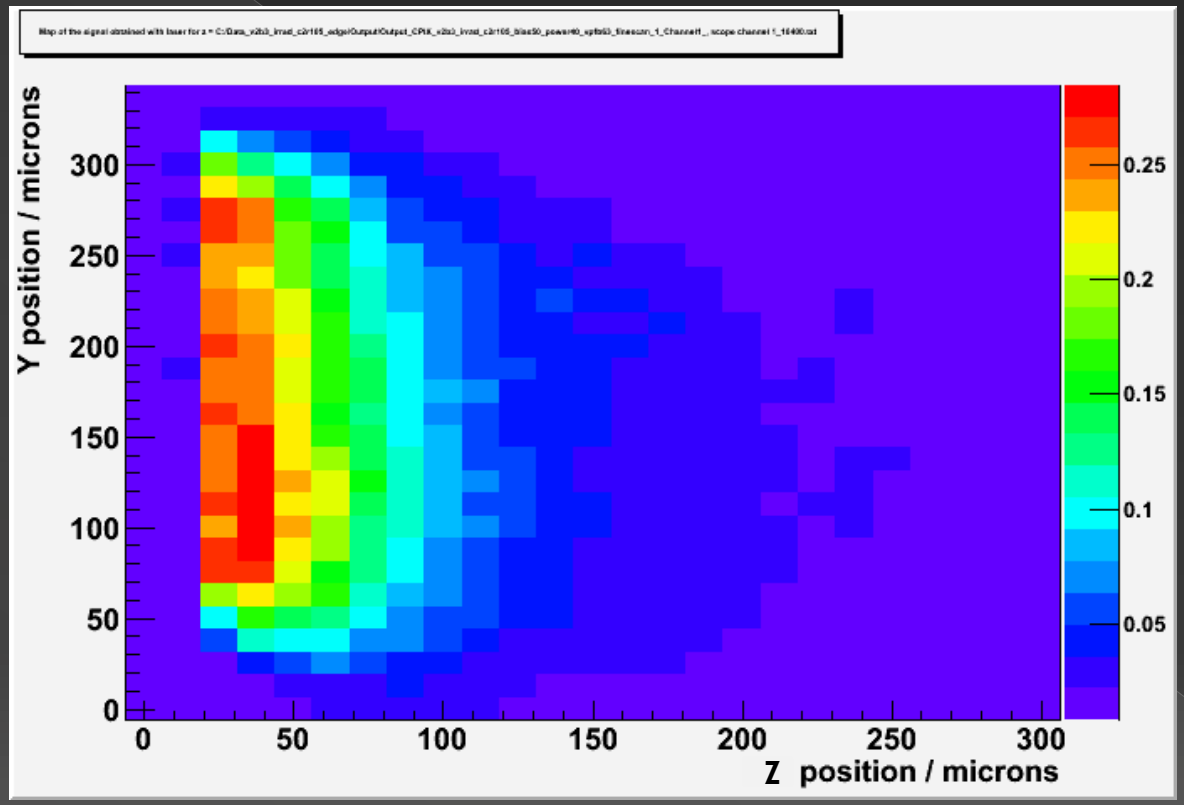
NMOS noise: +34%

PMOS noise: +40%

CMOS noise: +50%

Noise as fluctuation on the baseline

Edge-TCT after irradiation

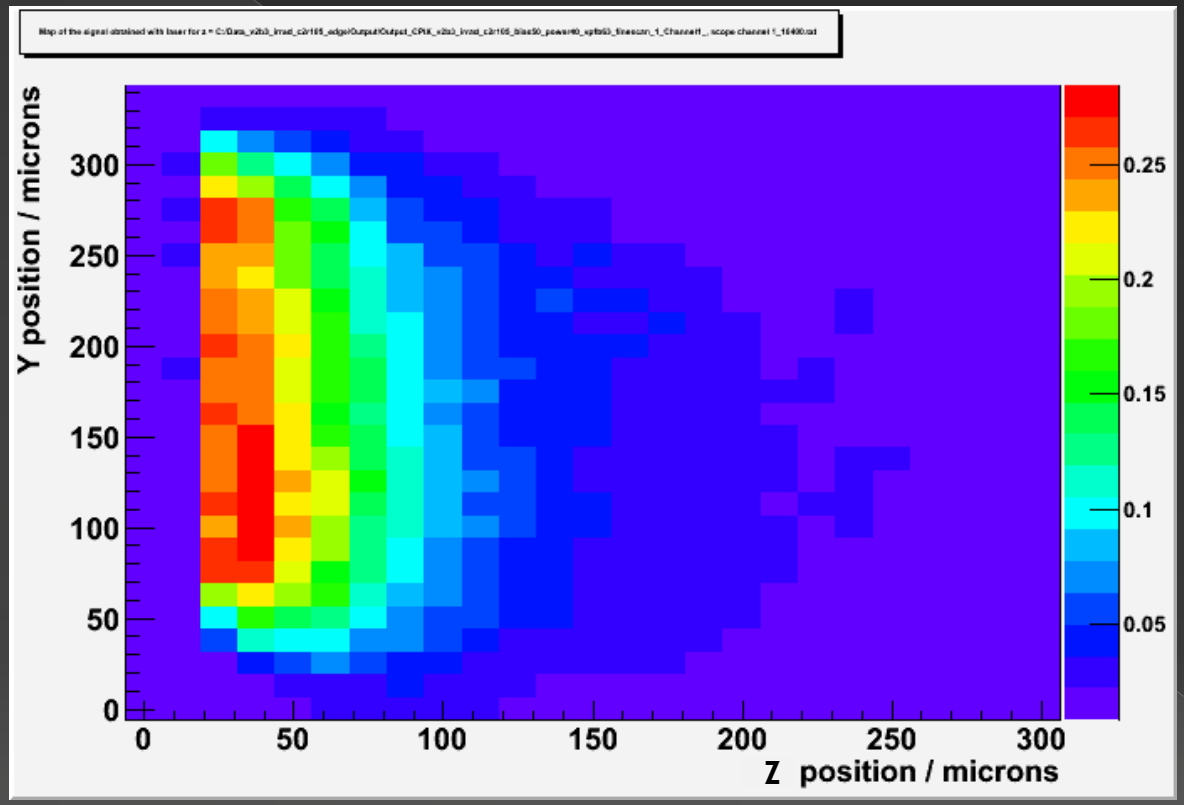


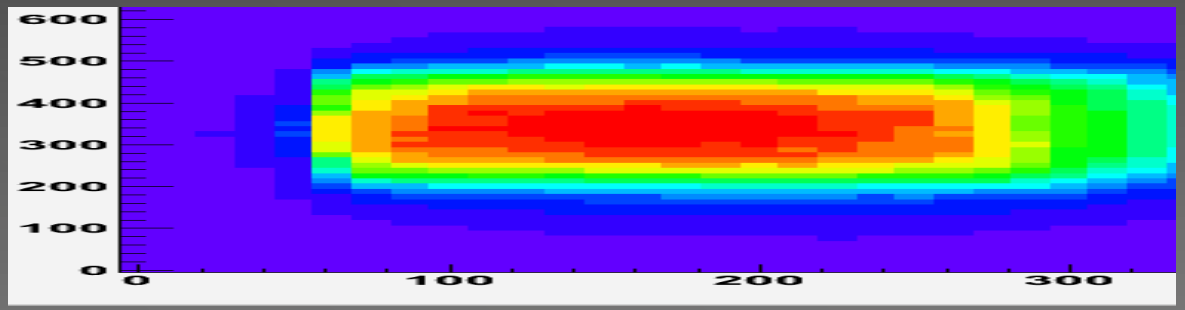
Bias -120 V

Temperature -3C

Signal region not symmetric: charge trapping?

Edge-TCT after irradiation





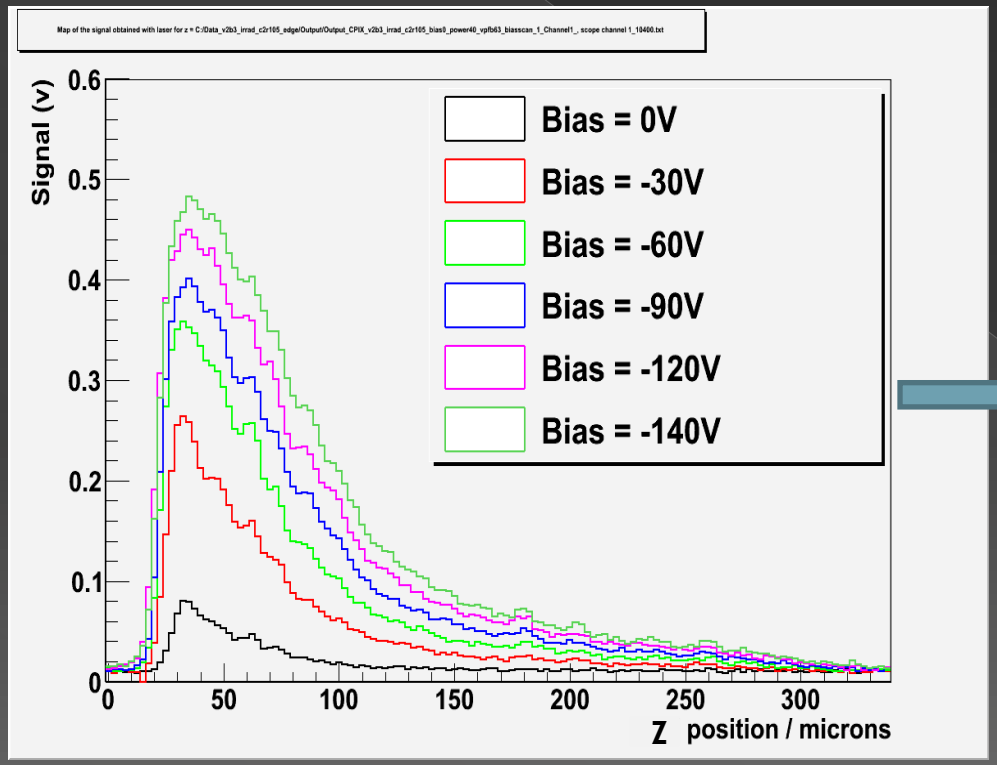
Bias -120 V

Temperature -3C

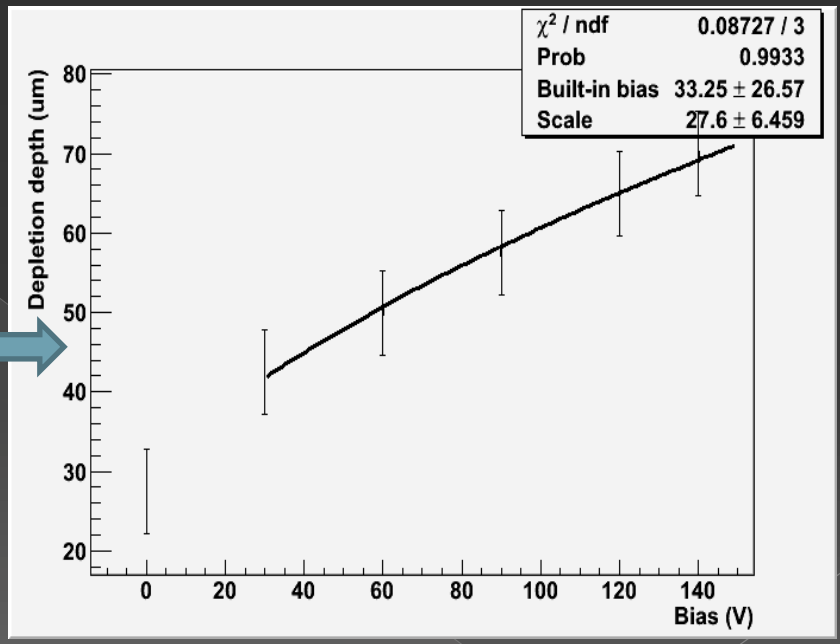
Signal region not symmetric: charge trapping?

Significant reduction when compared with pre-irradiation

Edge-TCT after irradiation

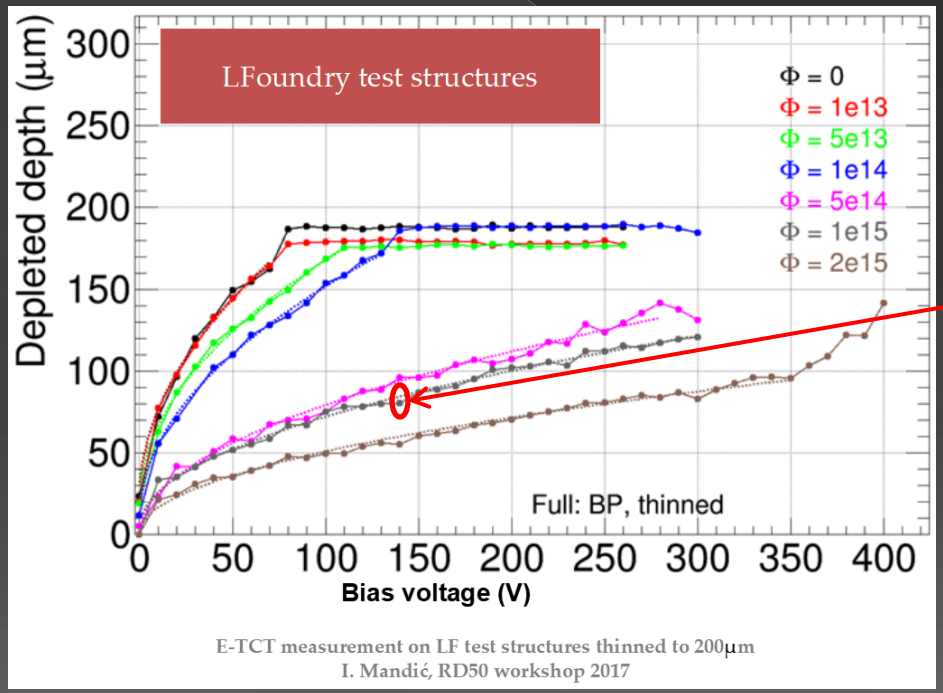


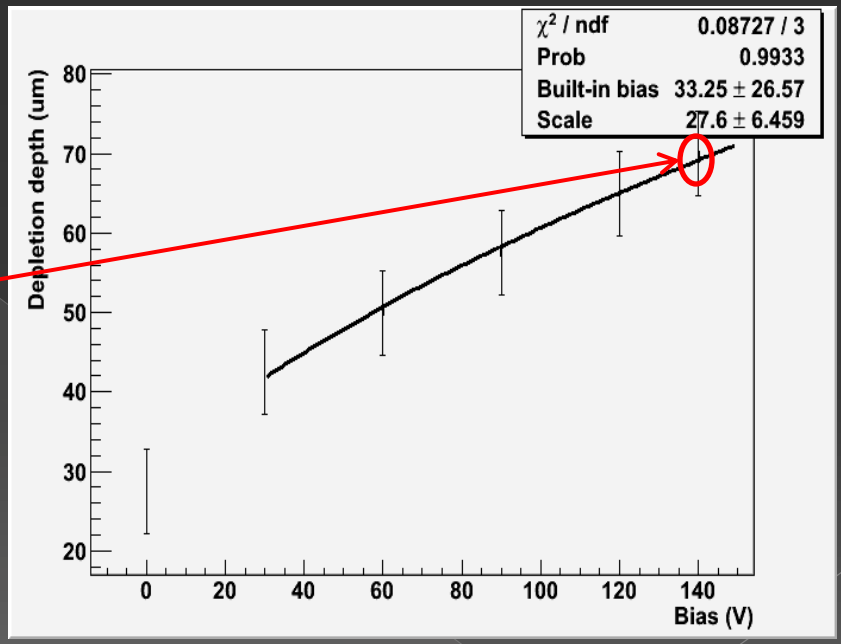
Signal vs depth



~70 μm depletion depth
at -140V bias

Edge-TCT after irradiation



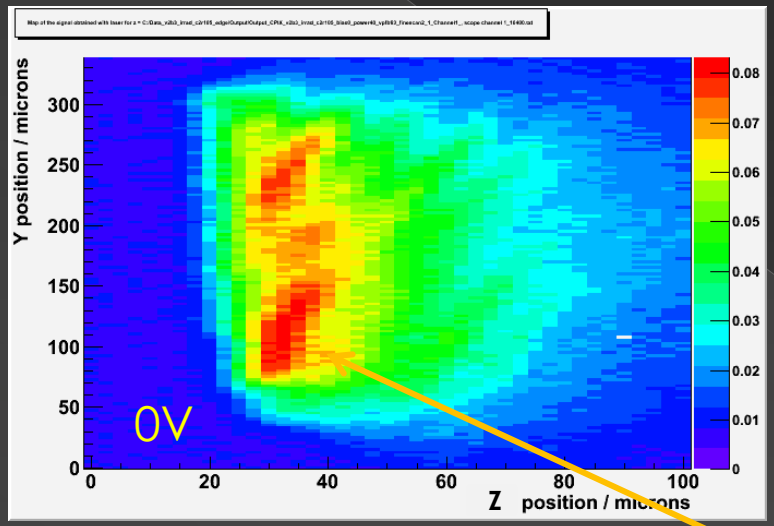


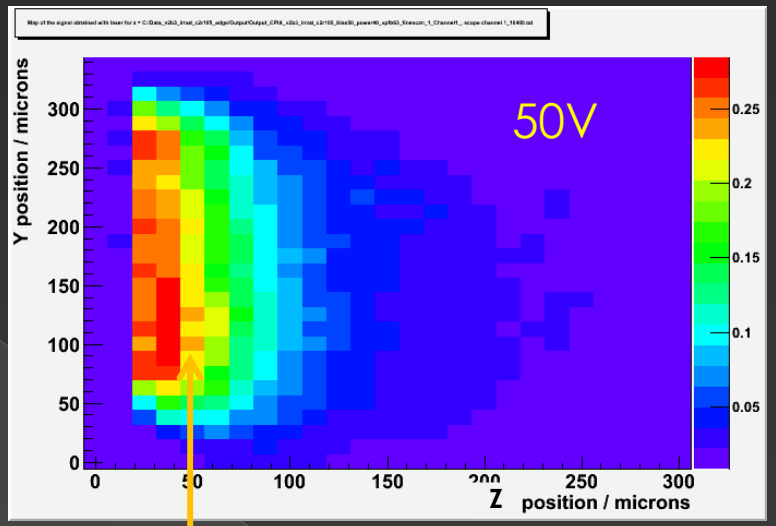
I. Mandic

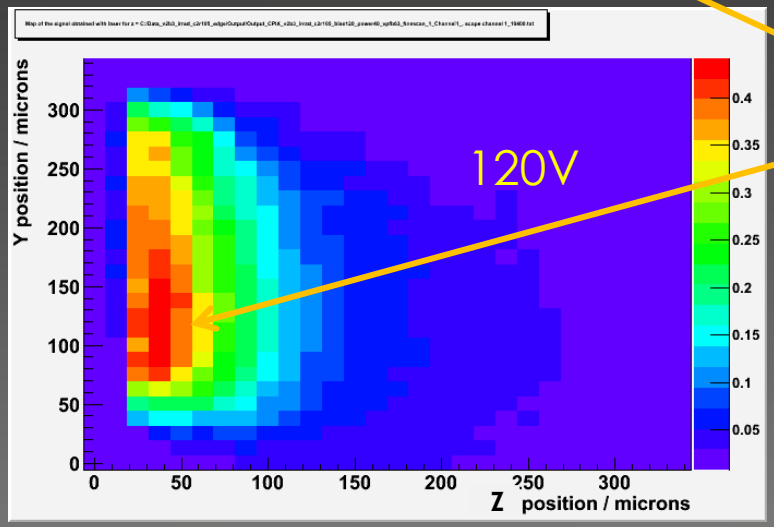
Compatible with neutron irradiation

Edge-TCT after irradiation

2D scans at different bias voltages



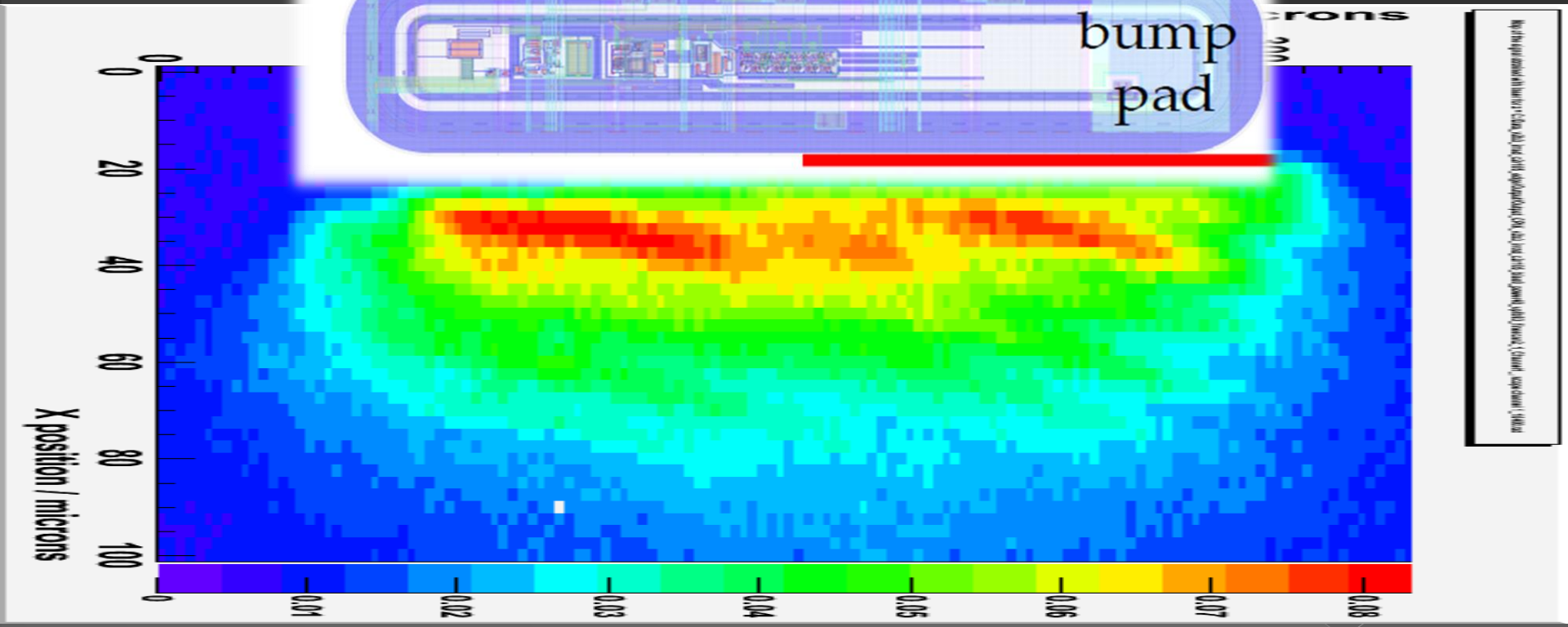




Collecting diodes? The further from the diodes, the more charge is trapped. Better visible at 0V as charge is slower and is not collected in the depletion region.

Edge-TCT after irradiation

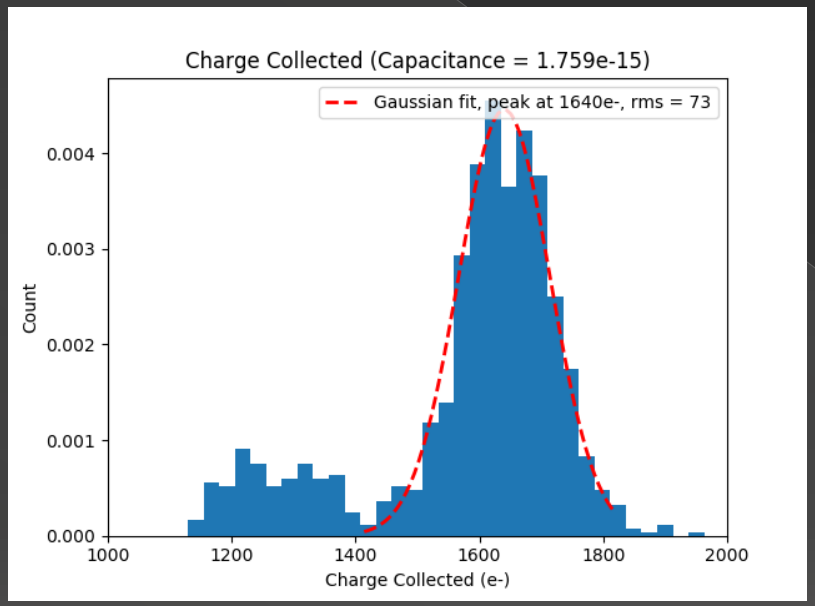
Comparison with design



Some structures could be matching.

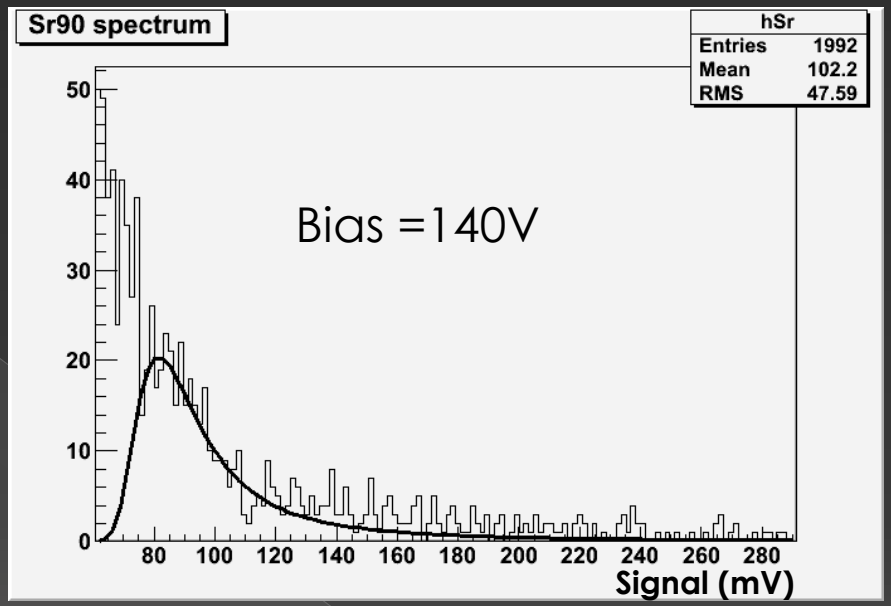
Radioactive sources after irradiation

Fe^{55}



X-ray spectrum:
full absorption peak detected
RMS larger (noise increase)

Sr^{90}

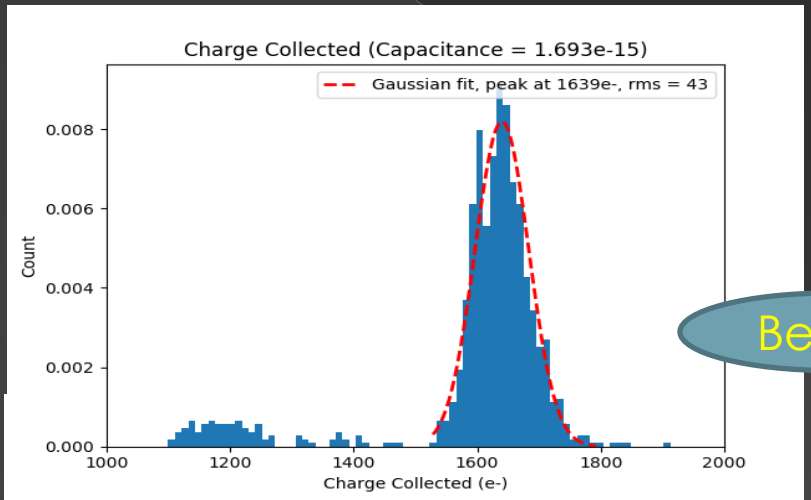


MIP spectrum: Landau fit compatible with depletion depth of 69µm
(In agreement with 70µm measured with edge-TCT)

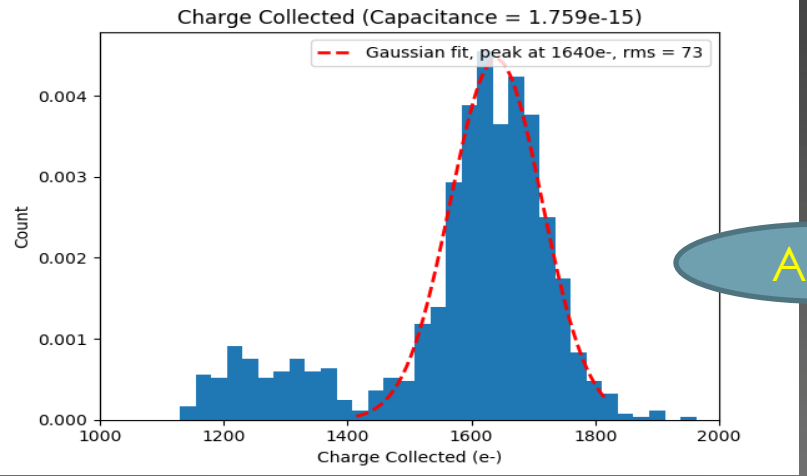
Note: signal 80mV, noise 4mV (slide 11)

Radioactive sources irradiation comparison

Fe^{55}

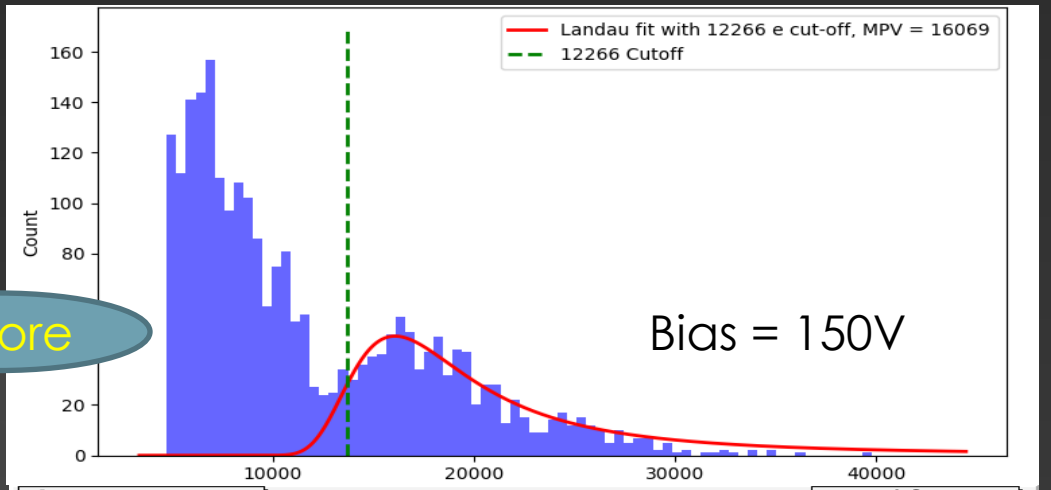


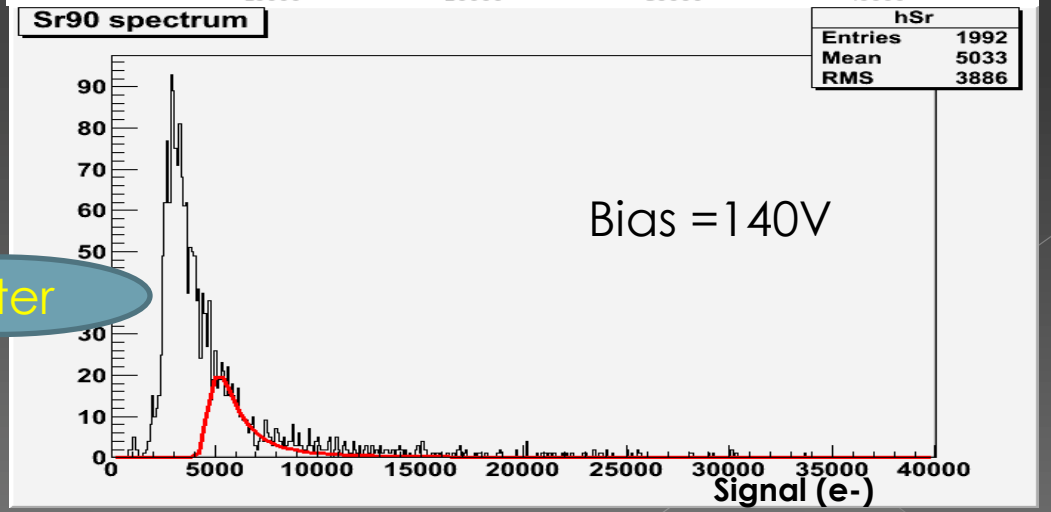
Before



After

Sr^{90}





Conclusions

- LF-CPIX successfully tested before and after irradiation
- Good performances after 10^{15} n_{eq}/cm^2 and 133 MRad
  - S/N ≈ 20
  - Non-uniformities in depletion region
    - Negligible