3D-FBK pixel sensors: overview of recent results with proton and neutron irradiated sensors

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on behalf of

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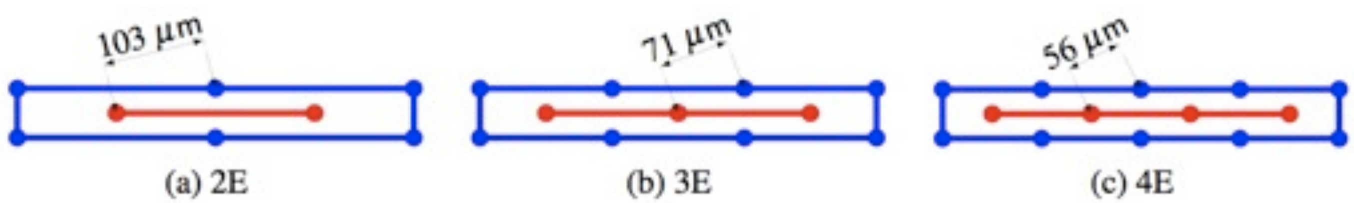
Outline

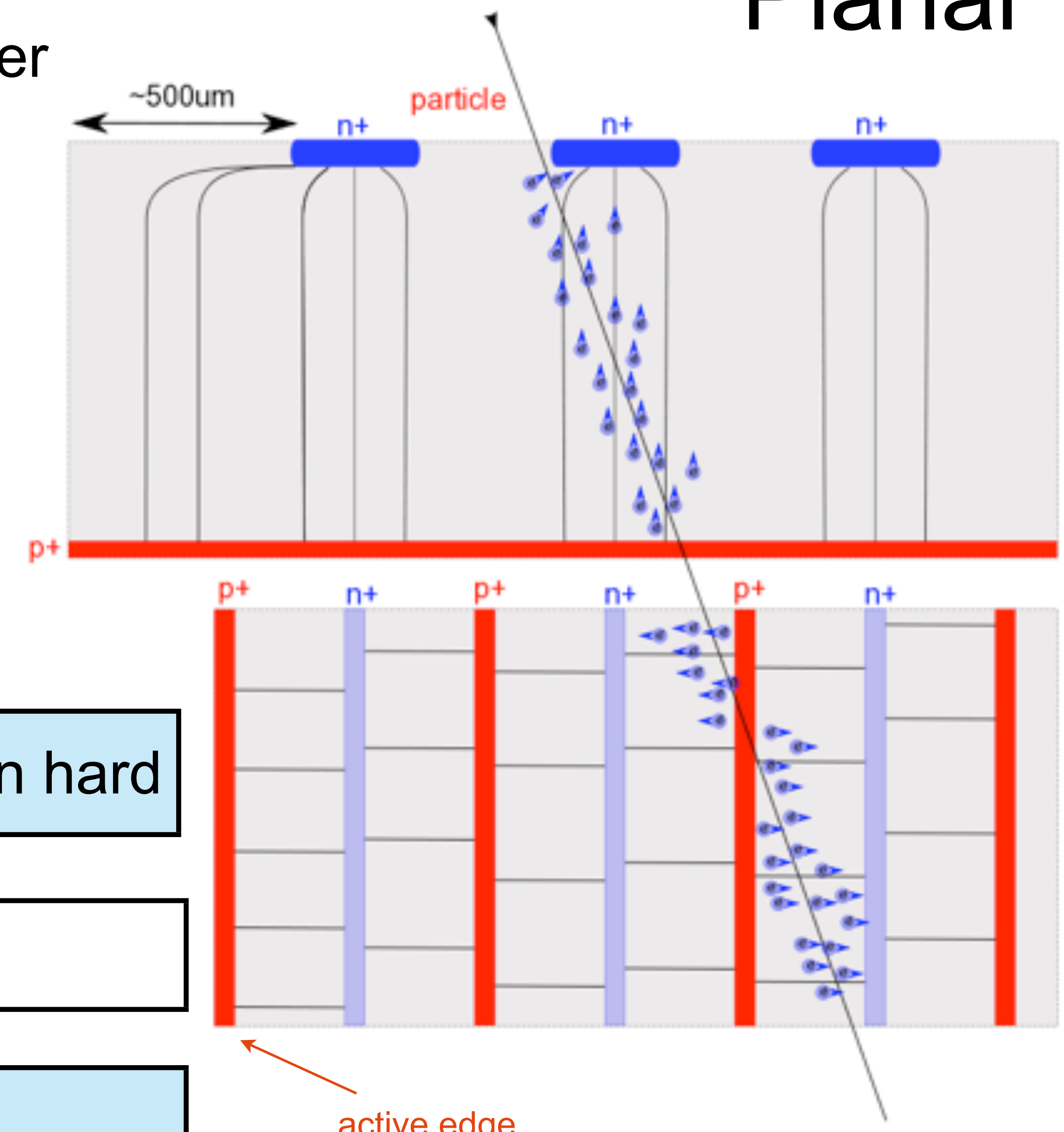
- Introduction
  3D Sensors Design and Technology
  The ATLAS FE readout chip
- List of devices
- Labs Measurements
  I/V, noise, and threshold scans; signal charge with Am^{241}& Sr^{90}
- Summary and Outlook

3D Sensors Design and Technology

- Proposed by Sherwood Parker et al.: NIM A 395 (1997) 328
  - Electrodes (both types) processed inside the wafer bulk - perpendicular to surface
  - Different cell configuration: 2E, 3E or 4E



Planar



3D

Advantages:

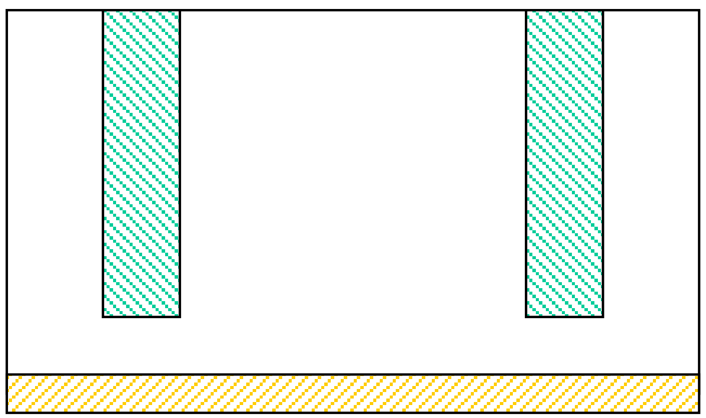
3D Features:

- high electric field → high efficiency / radiation hard
- short collection path → high efficiency / radiation hard; lower depletion voltage; faster charge collection
- sensor edge is an electrode → active edge ~4μm

3D detector technology developments in Trento

FONDAZIONE BRUNO KESSLER

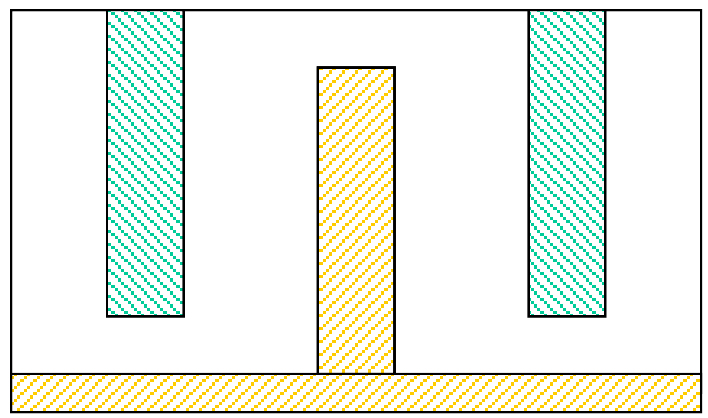
Single-sided **S**ingle **T**ype **C**olumns



(a)

(2004-2006)

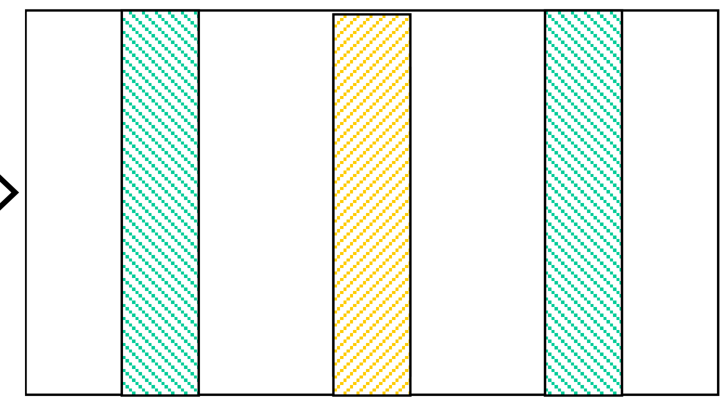
(2007-2009)



(b)

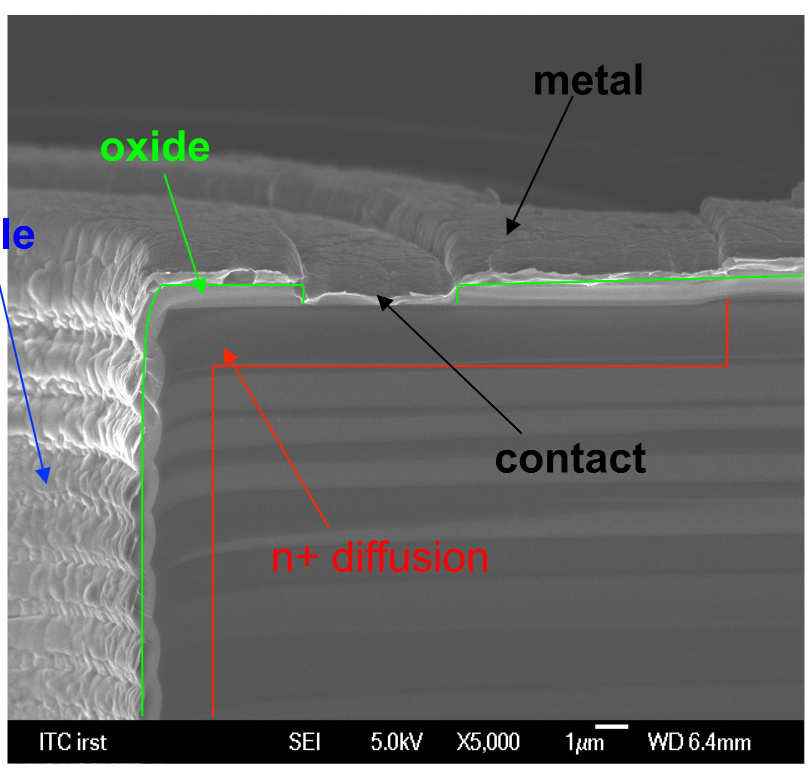
Double-side **D**ouble **T**ype **C**olumns

Double-side **D**ouble **T**ype **C**olumns+

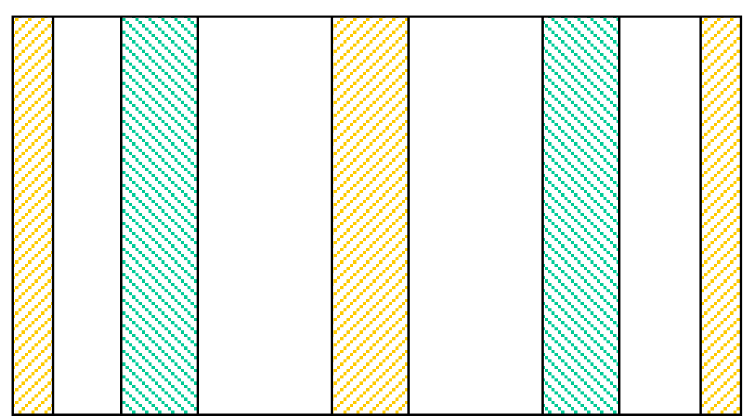


(c)

(2010-2011)



FULL 3D with active edge

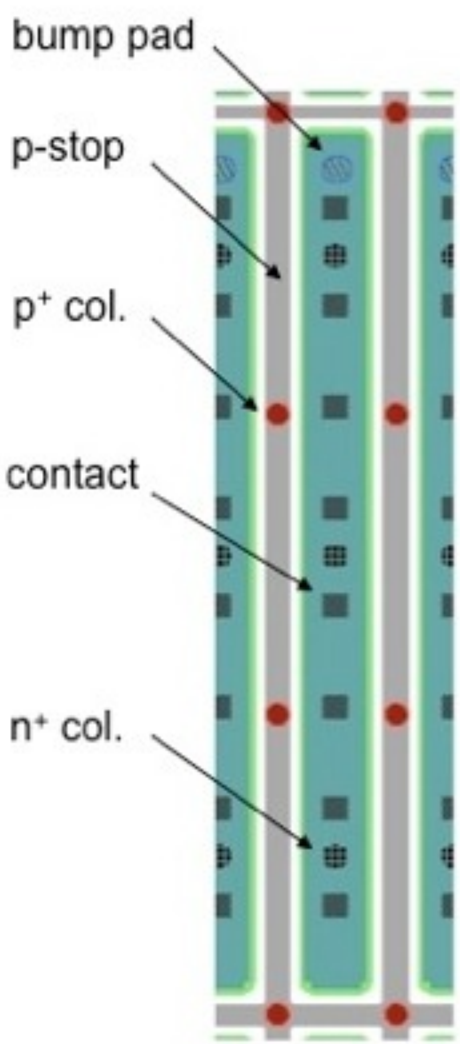


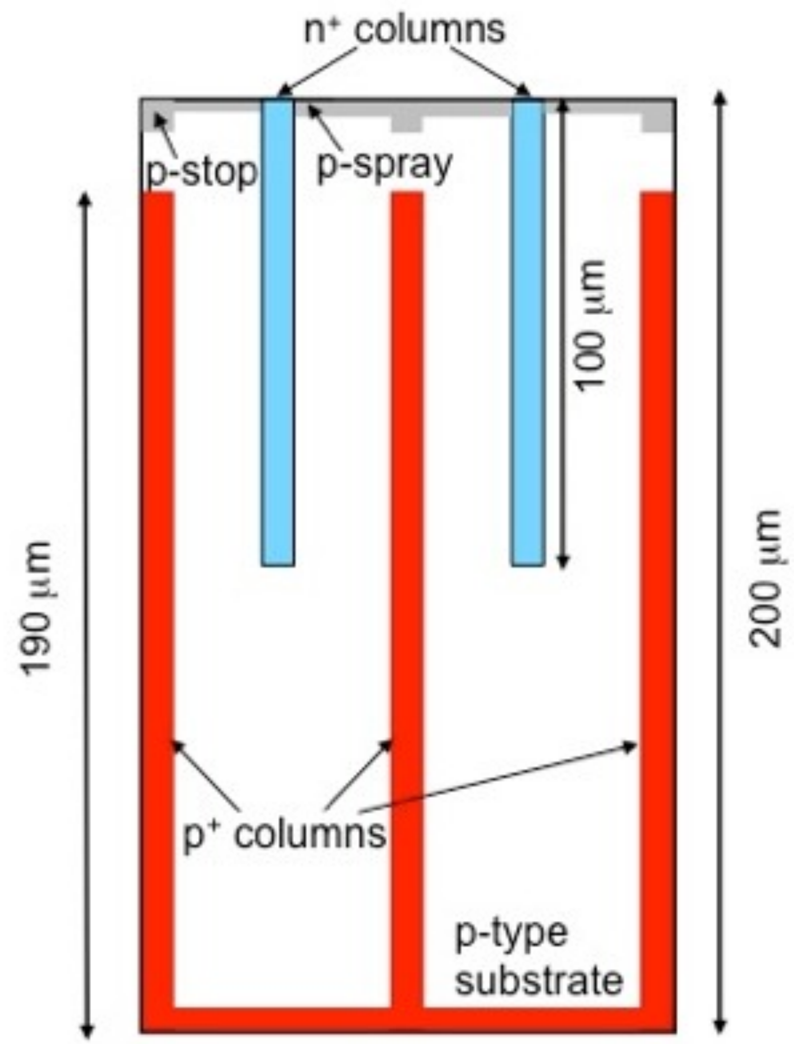
(d)

(2011)

See talk at this meeting:
"3D Detector status at FBK"
G. Giacomini & E. Vianello

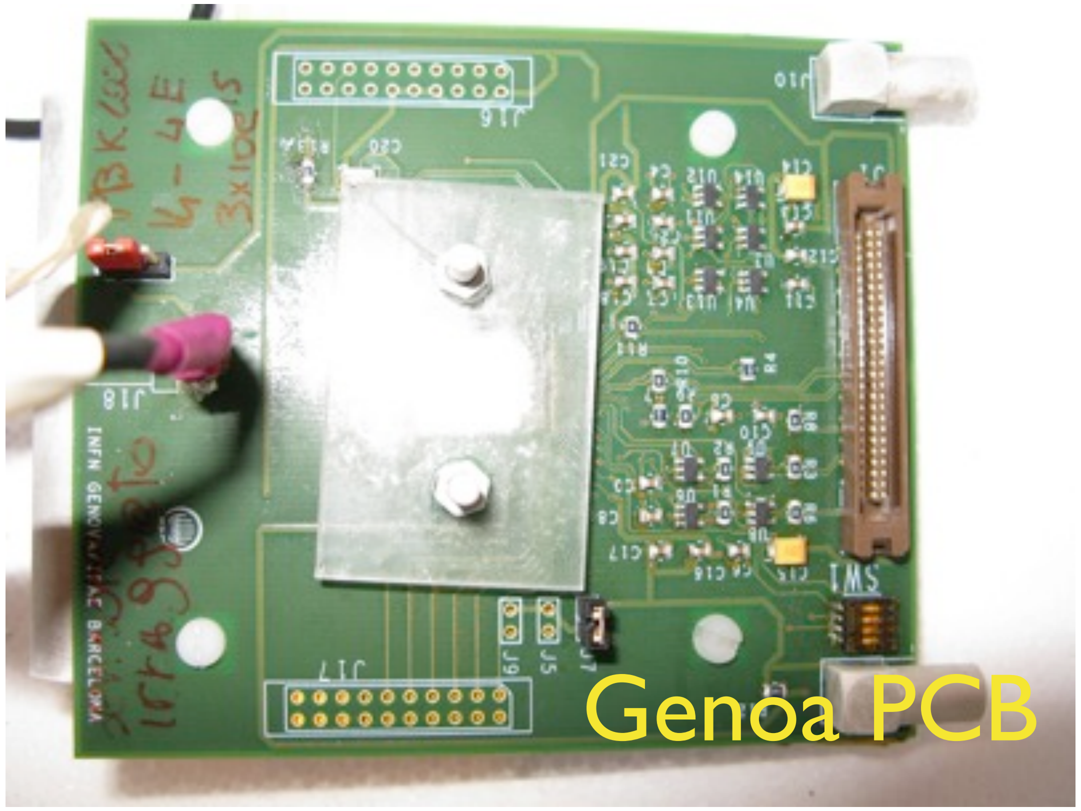
Modified 3D sensors

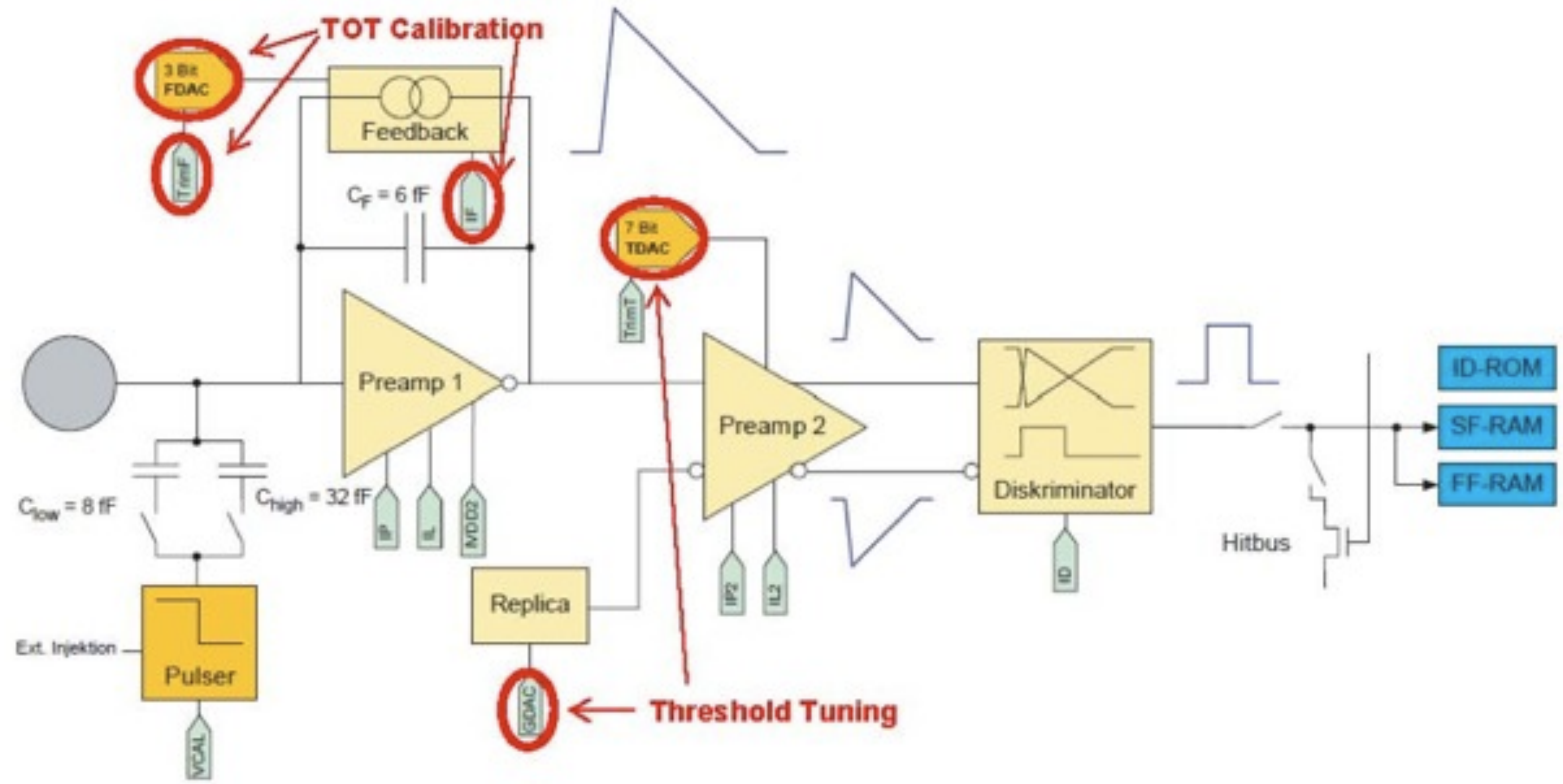




Parameter	Unit	Value
		3D-DTC-2
Substrate thickness	µm	200
Junction column thickness	µm	100 -110
Ohmic column thickness	µm	180 -190
Column overlap	µm	90 - 100
Substrate doping concentration	cm^{-3}	1×10^{12}
Lateral depletion voltage	V	3
Full depletion voltage	V	12
Capacitance vs backplane	fF/column	35
Leakage current @ Full depletion	pA/column	< 1
Breakdown voltage	V	> 70

The ATLAS FE readout chip





Single Chip Assembly (SCA):

- Sensor bump-bonded to the FE-I3 Chip
- Bump-bonded at Selex (thermo-compression with indium bumps processes)
- 2880 readout cells, 160×18 pixels, each 50×400 μm^2 size
- provides pixel charge measurement through digital-time-over-threshold (TOT)
  - measured in units of LHC bunch crossing rate (40 MHz)
- the conversion have been tuned to each individual pixel to respectively:
  - 3200 threshold e$^-$ and 60 ToT for a deposited charge of 20 ke$^-$
- 3D SCA pixels: threshold tuned and TOT calibrated with "TurboDAQ" software

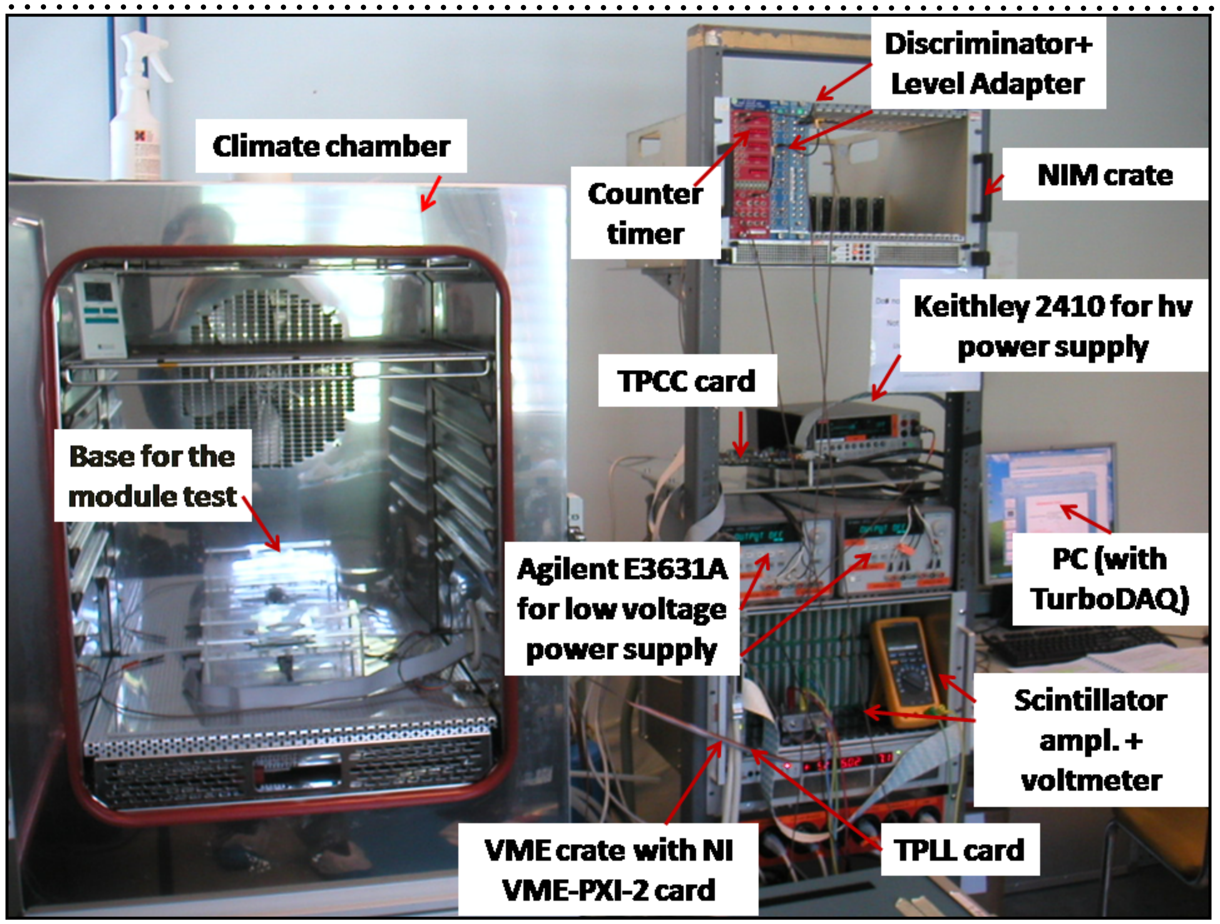
List of devices

- DUTs have been irradiated at difference fluence Nx10^{15} n_{eq}/cm^2 with neutrons (18,13,14) and protons (6,7,9 - 2,8), respectively:

- proton-irrad.:
  - *Karlsruhe* facility, 27-MeV
  - modules 6, 7, 9
  - proton-irrad at 5.4 10^{14} p/cm^2 ≈ 1 10^{15} n_{eq}/cm^2
- proton-irrad.:
  - *CERN* facility *(M. Glaser)*, 24-GeV proton beam
  - module 2, 8
  - 2E,4E @ 3 $10^{15}$$p/cm^2$ ≈ 2 10^{15} n_{eq}/cm^2
  - waiting for wire bonding @ CERN
- neutron-irrad.:
  - JSI neutron reactor in *Ljubljana (V.Cindro, G. Kramberger)*
  - modules 18, 13, 14
  - neutron-irrad. at 1,3,5 10^{15} n_{eq}/cm^2

ID on Wafer	Sensor Type	Fluence [n_{eq}/cm^2]	Irrad. Type
18	2E	1 10^{15}	n
6	2E	1 10^{15}	p
13	3E	5 10^{15}	n
7	3E	1 10^{15}	p
14	4E	3 10^{15}	n
9	4E	1 10^{15}	p
2	2E	2 10^{15}	p
8	4E	2 10^{15}	p

Labs Measurements

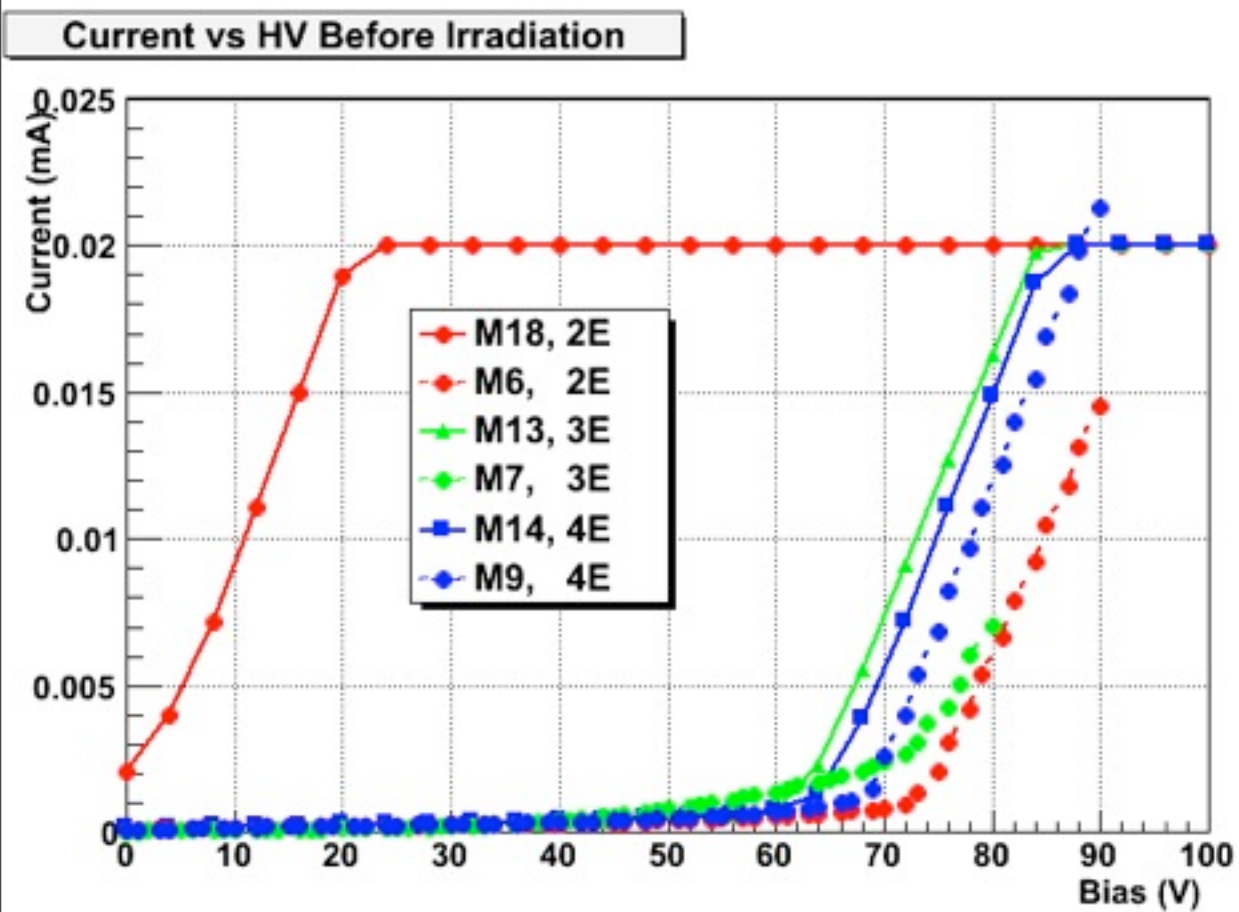


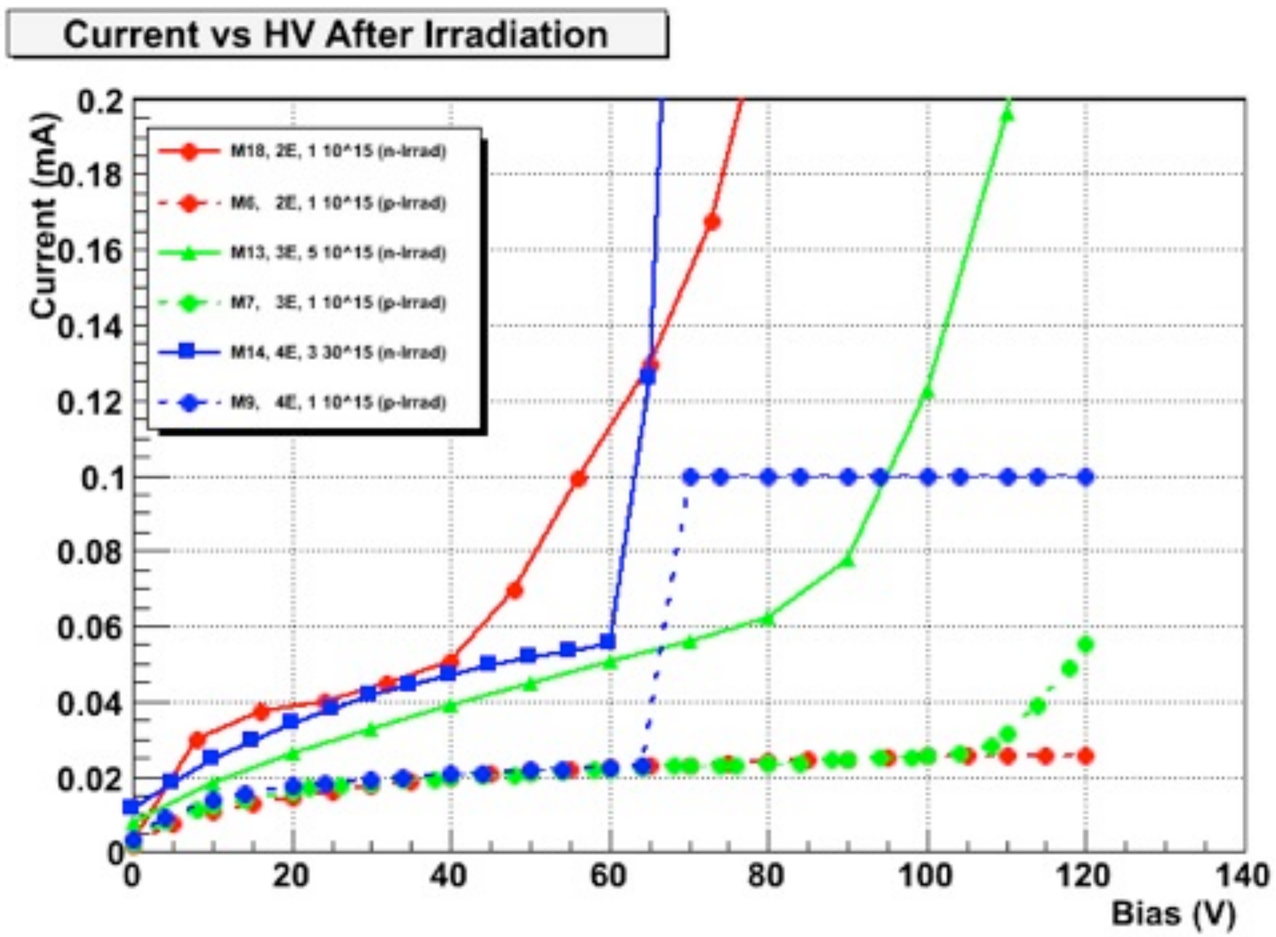
ATLAS – TurboDAQ (FE-I3)
TPLL and TPCC
VME based

Measurements:

- Electrical and noise tests:
  - IV scan
  - Standard calibration at $V_{nominal}$: Threshold, ToT calib
  - Standard calibration repeated for different voltage and temp. settings
  - Noise scan vs HV
- Response to radioactive source (γ-source Am^{241} (at Genova/Cern) - ß-source Sr^{90} (Cern)):
  - The results shown here are still preliminary

IV SCAN before/after irradiation



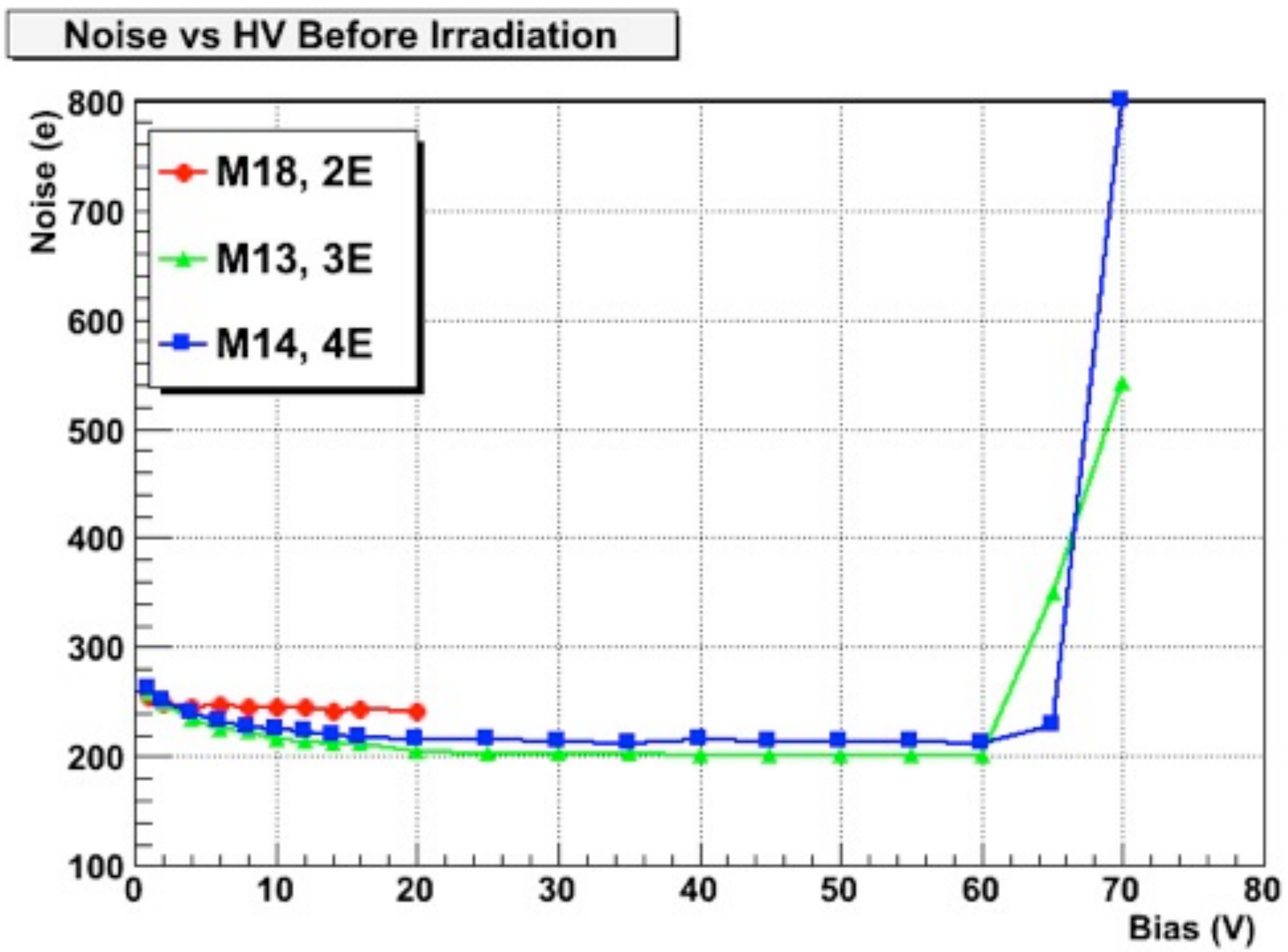


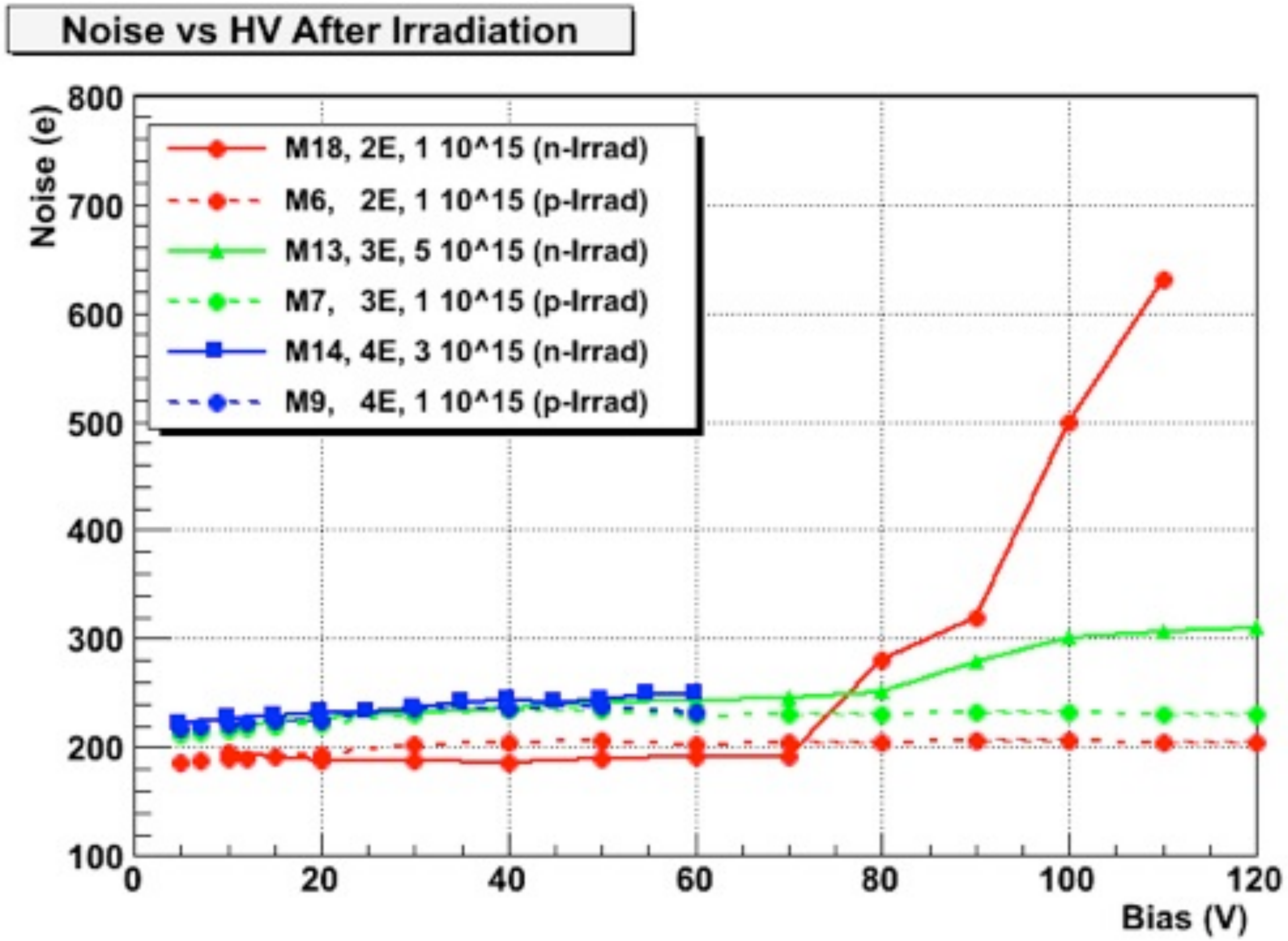
ID on Wafer	Sensor Type	Fluence [n_{eq}/cm^2]	Irrad. Type	V_{bd} [V]	V_{bd} [V]	α [10^{-17} A/cm]
18	2E	1 10^{15}	n	0	10	
6	2E	1 10^{15}	p	70	>120	5.40
13	3E	5 10^{15}	n	60	60	
7	3E	1 10^{15}	p	50	100	5.39
14	4E	3 10^{15}	p	60	60	
9	4E	1 10^{15}	p	60	65	5.28
					After IRRAD	

- p-irrad. devices:
  fluence 5.4 10^{14} p/cm^2 ≈ 1 10^{15} n_{eq}. /cm^2
- Damage rate:

$$\alpha = \frac{1}{\phi} \cdot \left(\frac{I_{vol} - I_{vol,\phi=0}}{Vol} \right)$$

Noise SCAN before/after irradiation



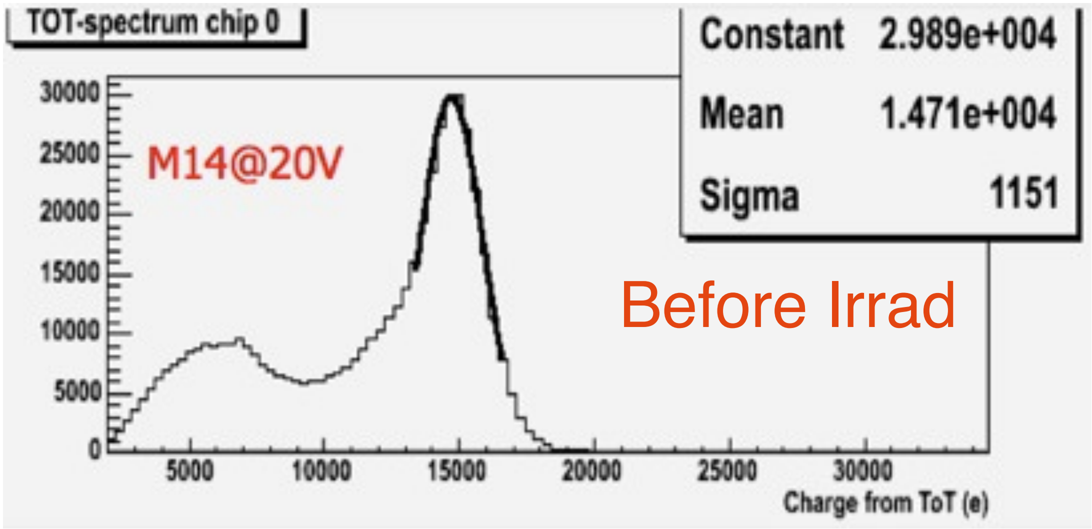


- Behavior looks very similar for the same type of devices
- After irradiation the noise of the neutron irradiated sensors increase faster
- Temperature of scans T~ -20°C

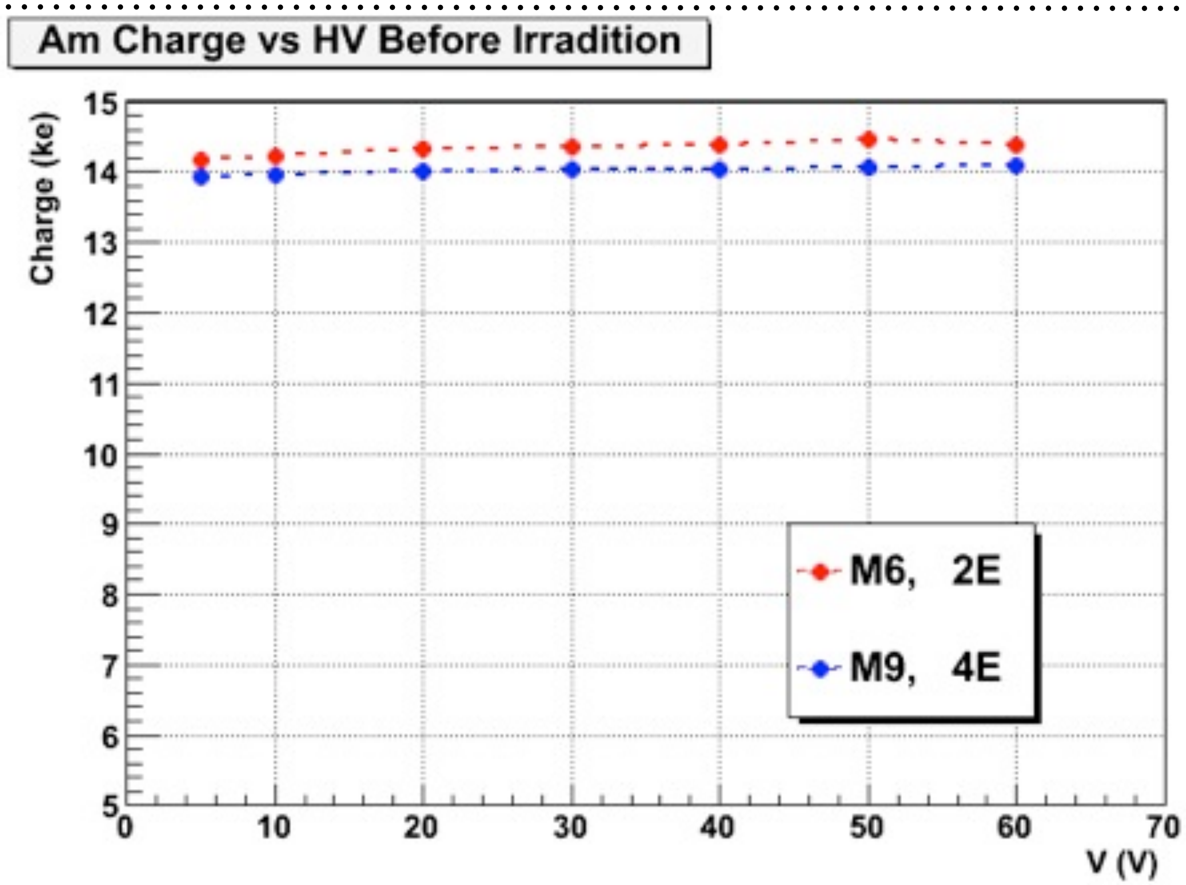
Charge collection before irradiation

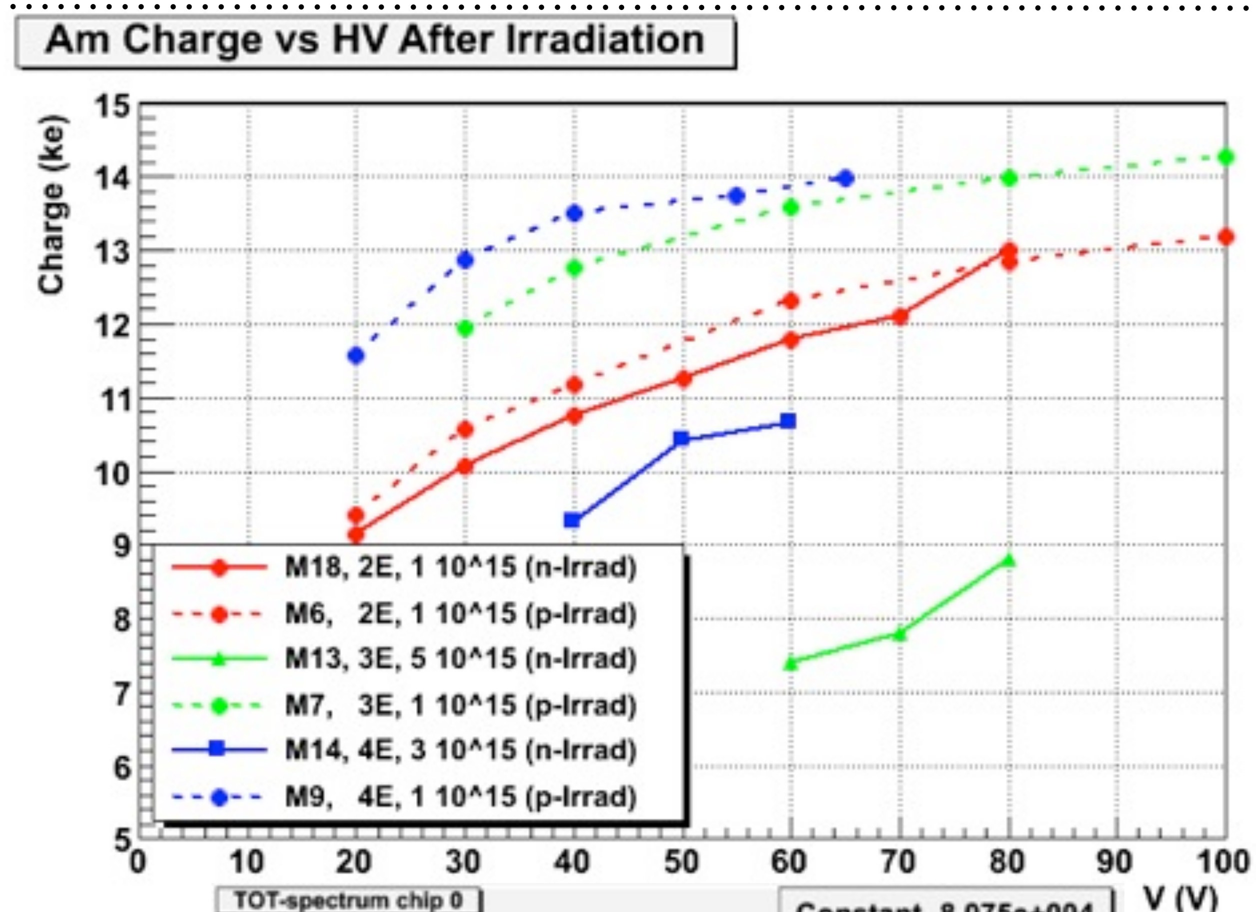
- Charge collection measured with Am^{241} source

ID on Wafer	Sensor Type	Fluence [n_{eq}/cm^2]	Irrad. Type	V_{bd} BEFORE [V]	V_{bd} AFTER [V]	α [10^{-17} A/cm]	Am^{241} mean peak before irrad. [ke]
18	2E	$1\ 10^{15}$	n	0	10		14.2@20V
6	2E	$1\ 10^{15}$	p	70		5.40	14.5@50V
13	3E	$5\ 10^{15}$	n	60	60		14.4
7	3E	$1\ 10^{15}$	p	50	100	5.39	
14	4E	$3\ 10^{15}$	p	60	60		14.7@20V
9	4E	$1\ 10^{15}$	p	60	65	5.28	14.09@50V

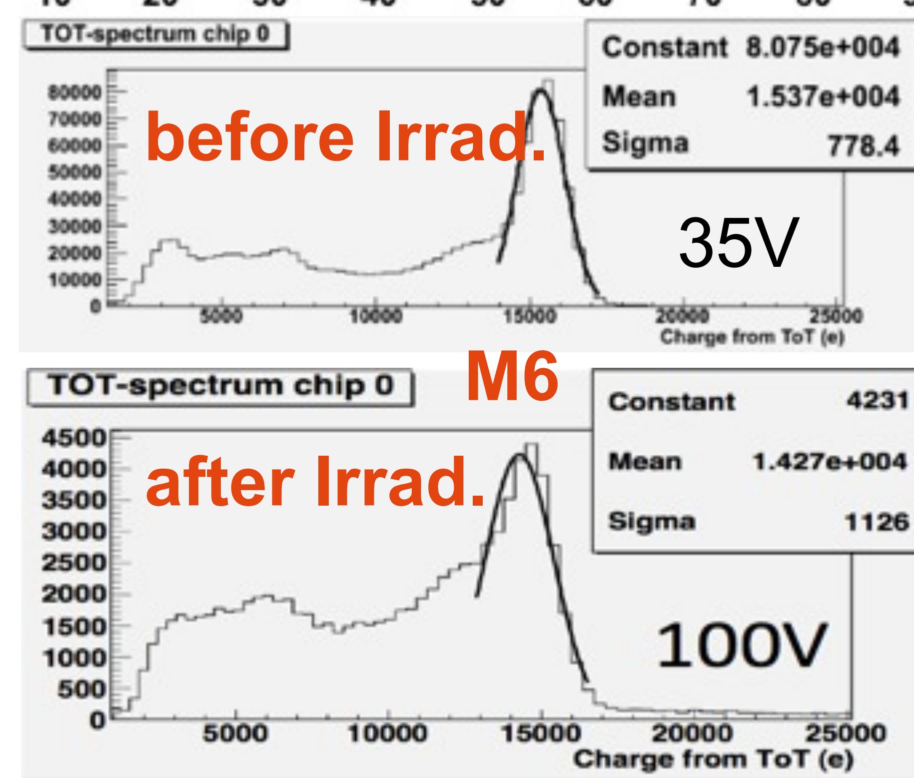


Am^{241} SCAN before/after irradiation

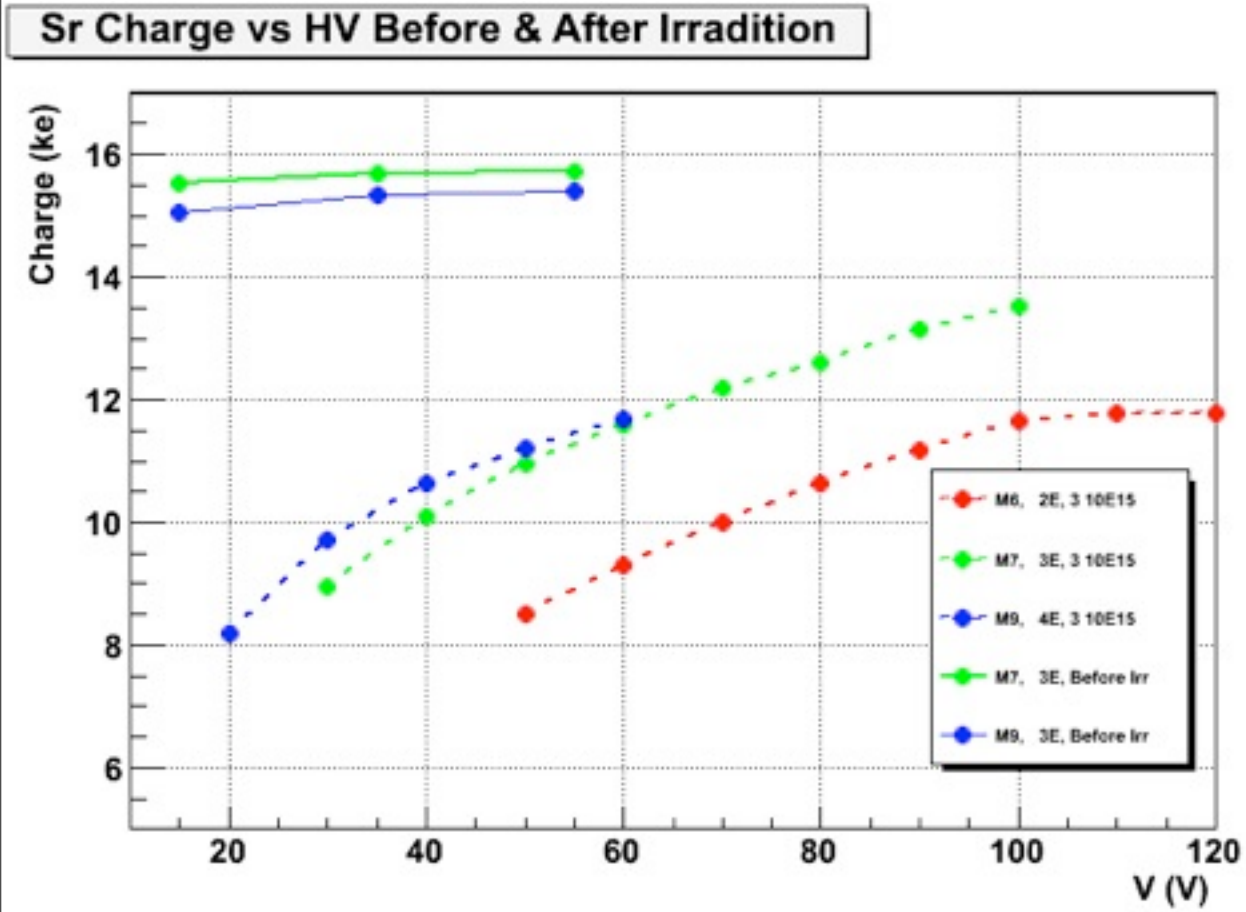


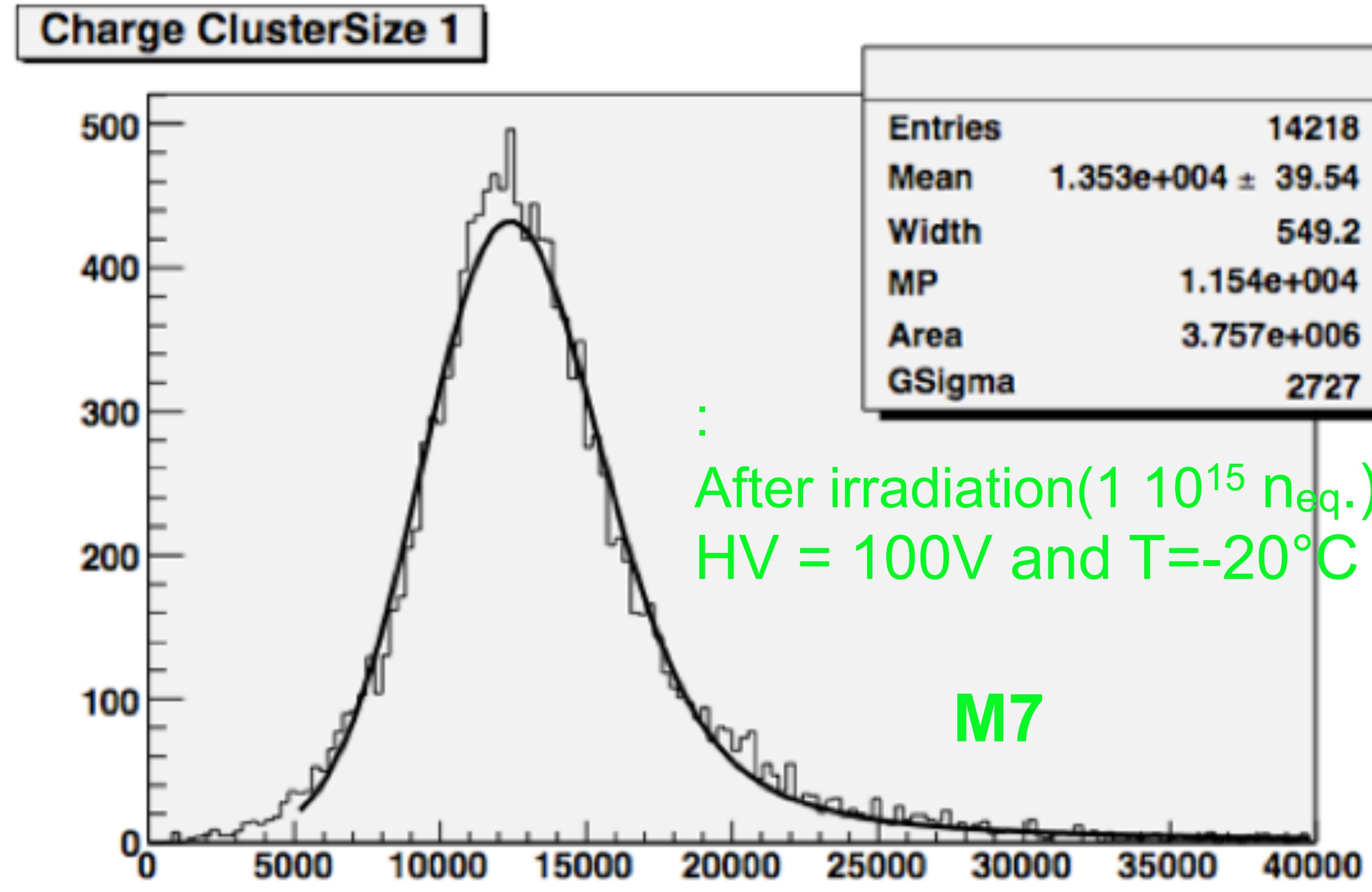


- Before irradiation Am^{241} peak is ~ 14.5 ke^-
- Am^{241} scans to measure charge collection vs bias after irradiation (ToT calibration repeated at any voltage)
- the proton irradiated devices collect more charge
- plots with one cluster size
- temperature of scans T~ -20°C



Sr^{90} SCAN before/after irradiation





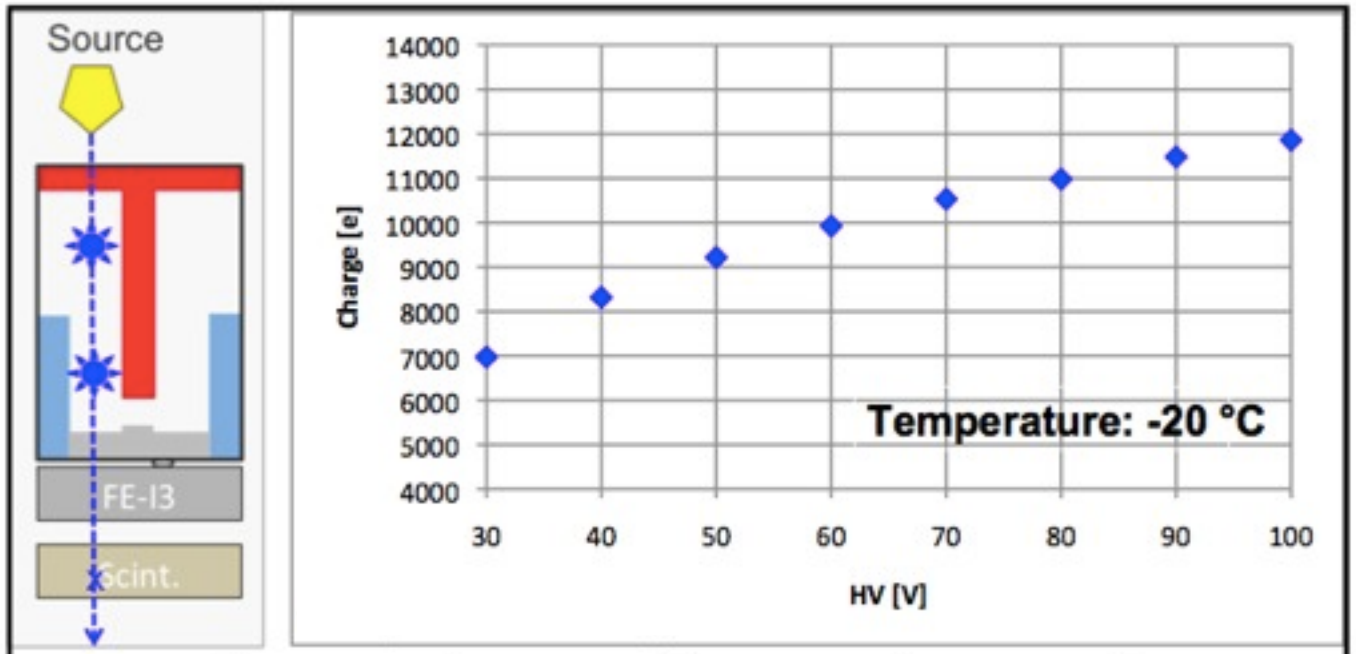
- Before irradiation Sr^{90} peak is ~15.71 ke^{-}
- Sr^{90} scans to measure charge collection vs bias after irradiation (ToT calibration repeated at any voltage)
- plots with one cluster size
- temperature of scans T~ -20°C

Summary and Outlook

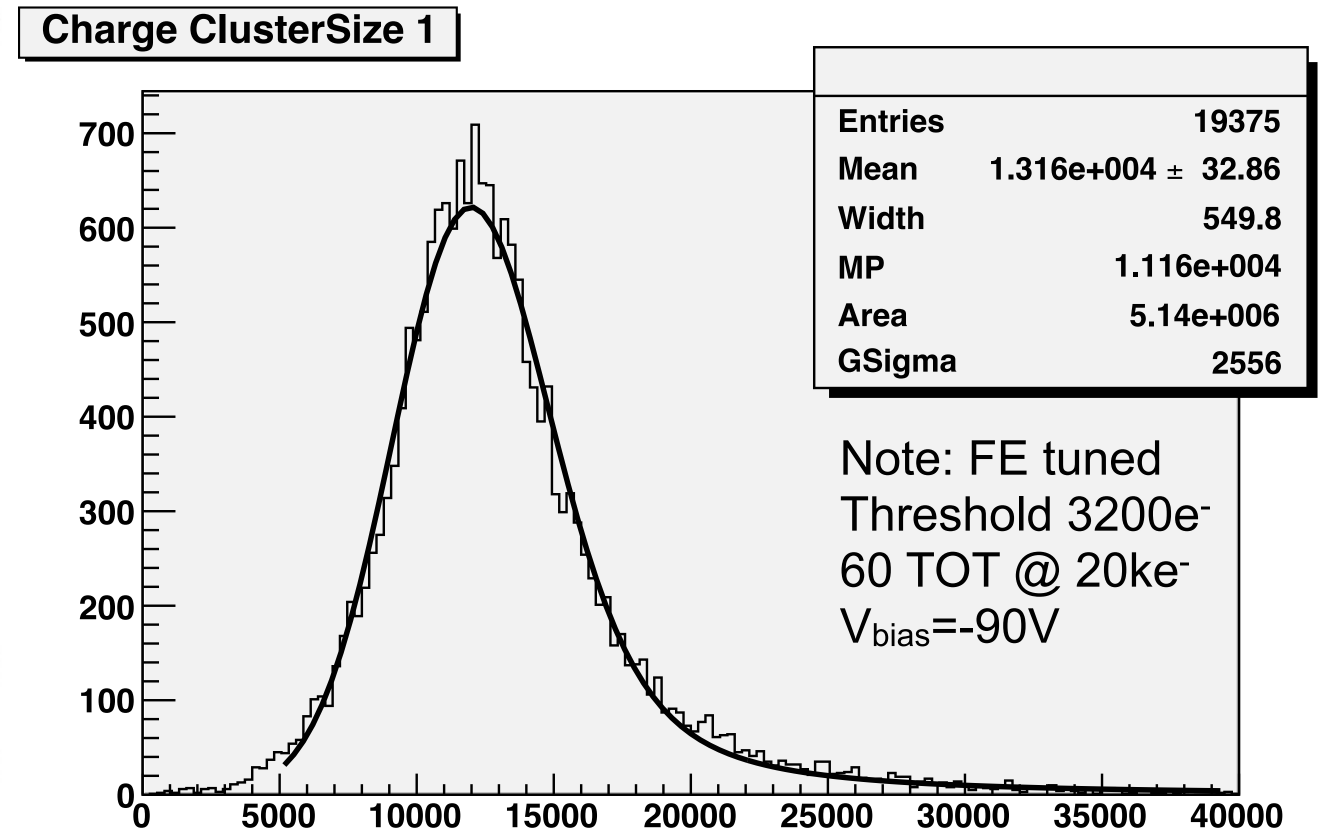
- 3D-DDTC FBK sensors
  - six devices of different flavours assembled and irradiated (3 p-irrad., 3 n-irrad.) here reported, two sensors waiting for measurements
  - the behavior looks very similar
- Lab measurements before & after irradiation
  - electrical,
  - noise tests
  - response to radioactive sources (Am^{241}, Sr^{90})
- Test beam plans
  - p-irradiated sensors tested at CERN (Oct 2009 - Eudet telescope) and the same for the n-irradiated sensors (June 2010 - Eudet telescope)
    see A. Micelli *et. all* - “3D-FBK Pixel sensors: recent beam tests results with irradiated devices” (http://cdsweb.cern.ch/record/1304583)
  - n-irradiated sensors tested in magnetic field (Oct 2010 - Bat telescope)
  - IBL test beam RD (Oct/Nov) analysis on going (thanks to the 3D ATLAS collaboration)
- 3D good candidate for ATLAS IBL
  - development of passing-through column detector is on going
    (first wafer completed at FBK, more wafer to come in a few weeks)

Backup

Lab Measurements



Bias	-30V	-40V	-60V	-80V	-100V
Charge Lost	49%	40%	30%	21%	15%



Preliminary results

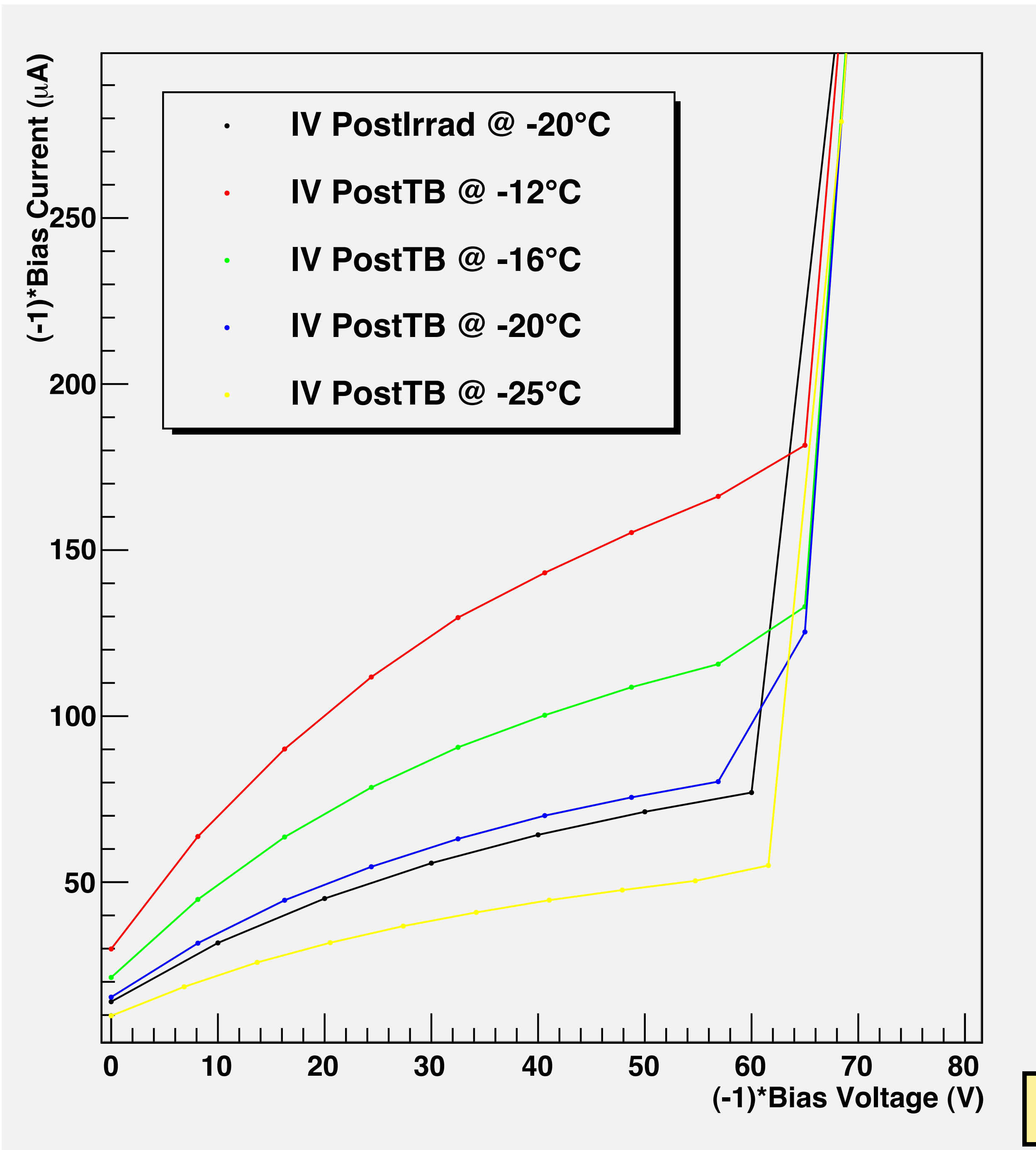
3D-FBK-3E proton-irradiated to 1×10^{15} n_{eq}/cm^{-2} (thickness 200μm)

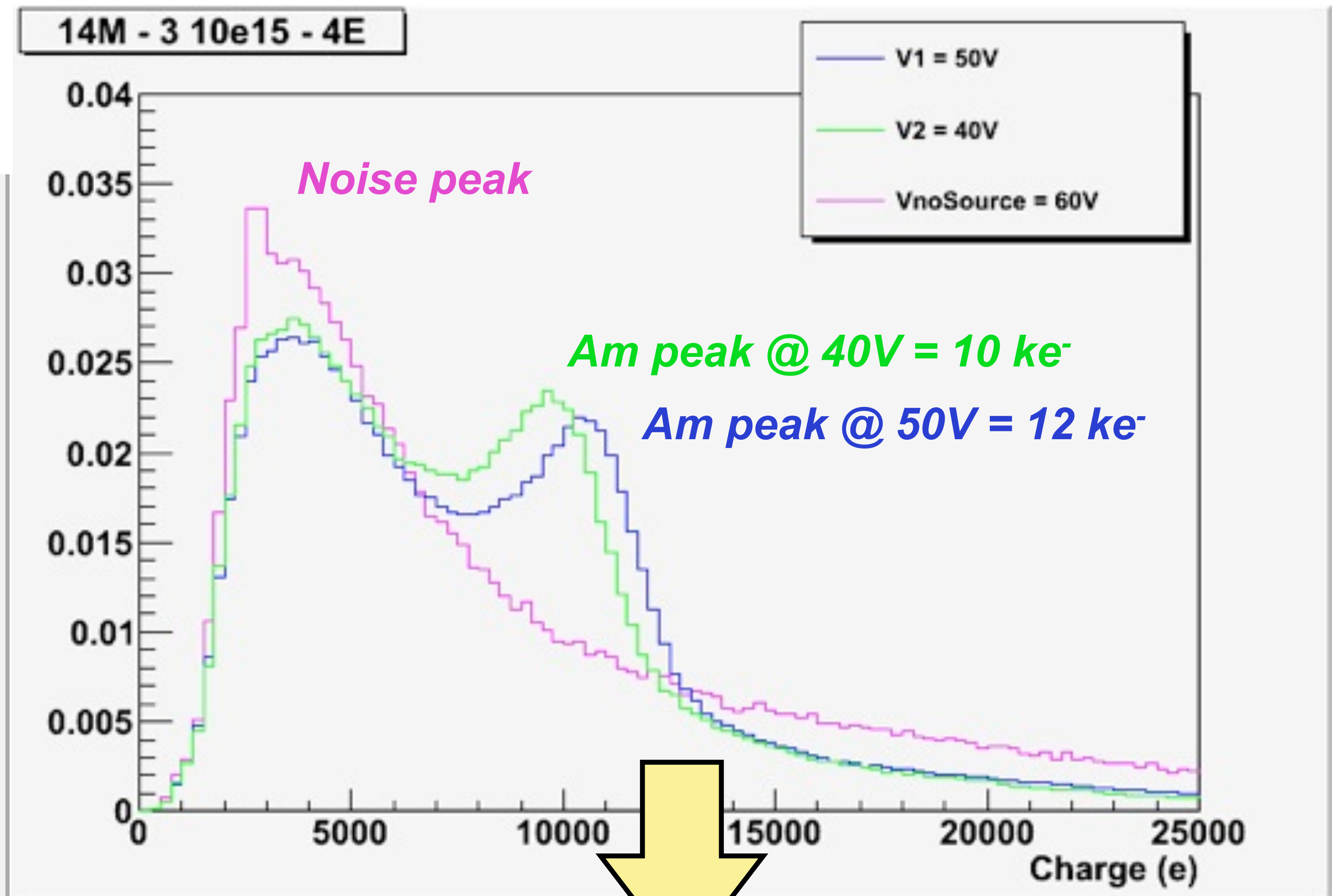
- radiation damage: run with bias voltage -80 V
  - ~ -20% signal loss
    - ➡ in agreement with lab tests made with β source Sr^{90}
  - sensor was not fully depleted
- overall efficiency still high (~99%)

Lab Measurements

Preliminary results

3D-FBK-4E
irradiated to 3×10^{15} n/cm^2





Source scan with γ source (Am^{241}): to verify TOT tuning (0.5 Mhits, ~250 entries per pixel)

IV curve at different temperatures $V_{\text{break down}}$ ~ -60V