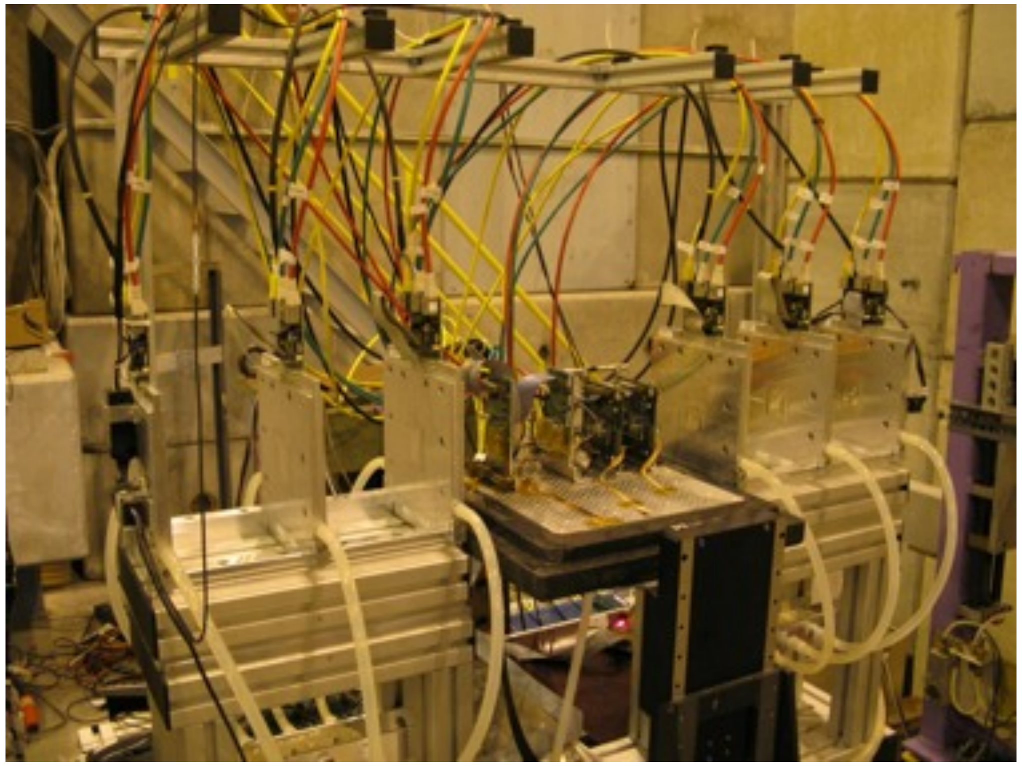
3D-FBK silicon sensors: Test Beam results 2010



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- Test Beam setups
  IBL test Beam at CERN
  Test beam and lab measurements at CERN
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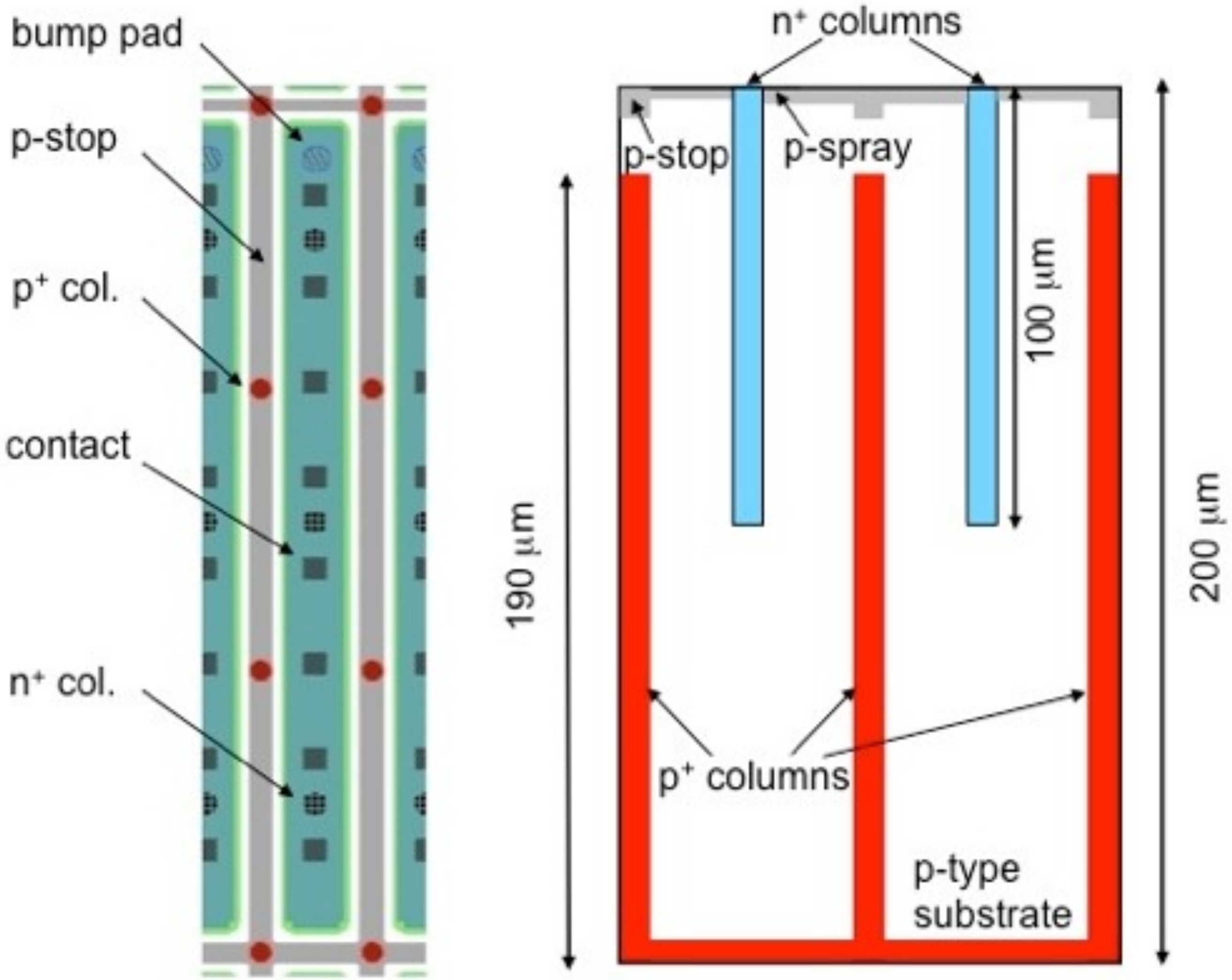
- Summary and Outlook

3D Sensors Design and Technology

Modified 3D sensors



3E cell configuration

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

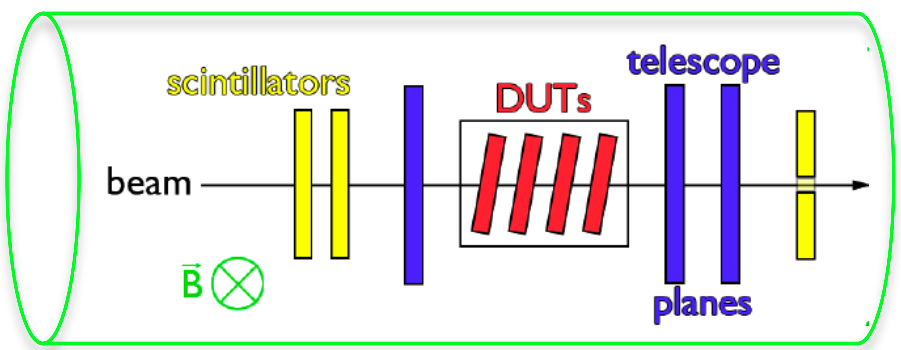
List of characterized devices

ID on Wafer	ID FE-I3	Sensor Type	V_bd	Irrad.	Working?	Comments
3	06051	2E	60	3 10e15	***Dead***	Dead on 25/06/10 during Threshold scan vs HV
17	09051	2E	-	Genova	☺	
18	05051	2E	50	1 10e15	☺	
6	/	2E	70	1 10e15	☺	p
7	07051	3E	65	1 10e15	***Dead***	Dead after Test Beam
9	07052	3E	60	3 10e15	***Dead***	Dead on 22/06/10 during Calibrations scan
13	08052	3E	60	5 10e15	☺	Vbias = 80V
7	/	3E	50	1 10e15	☺	p
12	08051	4E	25	1 10e15	☺	Vbias = 50V
14	09052	4E	60	3 10e15	☺	
16	05052	4E	65	5 10e15	***Dead***	Dead after irradiation
9	/	4E	60	1 10e15	☺	p
2	/	4E	?	2 10e15		p
8	/	4E	?	2 10e15		p

- all fourteen devices from FBK-IRST: tested and qualified in Genoa
- single chip tuned to have:
  - Threshold ~ 3200 e^-, TOT(Q=20ke^-) = 60 BC
- 7 & 14: sensors tested in the test beam (June - no data for 14 since R=1MΩ, usually 20kΩ for others devices), 13 & 14 (Oct-Nov)
- 2 & 8: sensors under test at CERN (plus 6,7,9)

Test Beam Setups

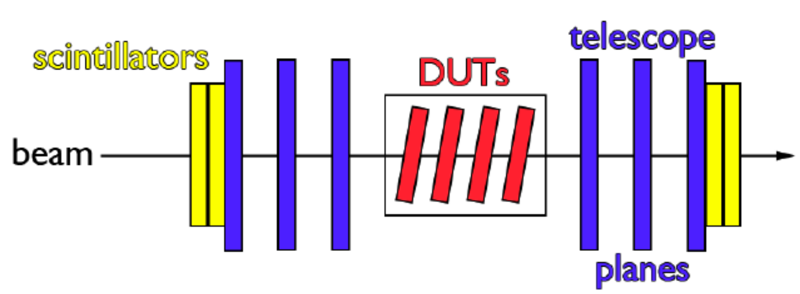
Bonn ATLAS Telescope - Oct 10



- 180 GeV pions from CERN - SPS
- 3 planes: two-sided Si micro-strips (50 μm pitch)
- Trigger: two scintillators (+veto)
- Morpurgo dipole magnet (B~1.57 T)
- DUTs: STA-3E, FBK-3/4E (n-irradiated), Atlas Planar (as reference)

Purpose:
sensors performance after irradiation in B-field at different tilt angles (-30° to 30°):
➡ tracking efficiency, charge sharing, etc.

EU Detector Telescope - June ’10 - Oct, Nov ’10 (IBL)

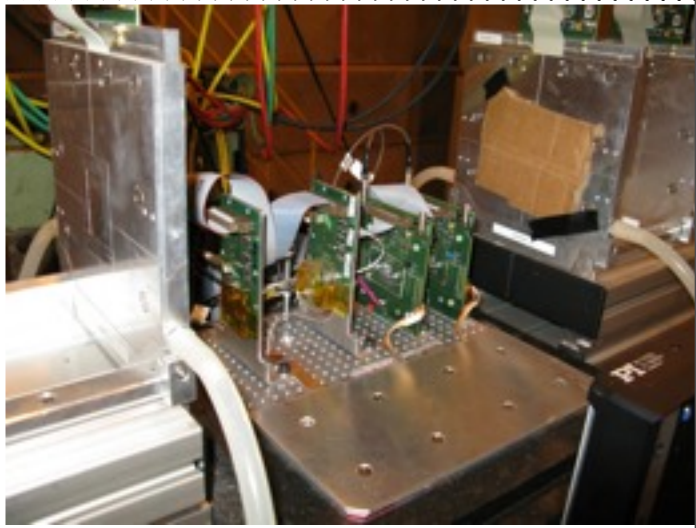


- 120 GeV pions from CERN - SPS
- 6 planes: 660k Si pixels (18.4 μm pitch)
- Trigger: four scintillators
- DUTs: STA-3E, SIN, FBK-3/4E (n-irradiated in June, 7-14M, Oct. 13-14M), Atlas planar (as reference)

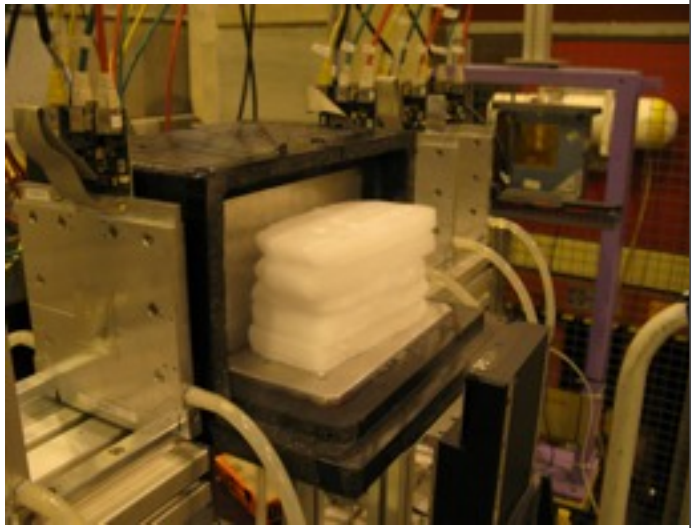
Purpose:
sensors performance after irradiation at different tilted angles (-25° to 25°):
➡ tracking efficiency, charge sharing, electrode efficiency, etc.

IBL Test beam at CERN

IBL TestBeam: from October 25 to November 08, 2010:



- FBK-3E13M:
  - irradiated 5e15 n_{eq}/cm^2
  - tuned before data-taking (after cooling down)
  - HV = -70V (V_{bd} ~ -80V, $I_{leakage} < 4\mu A$)
  - efficiency 84%

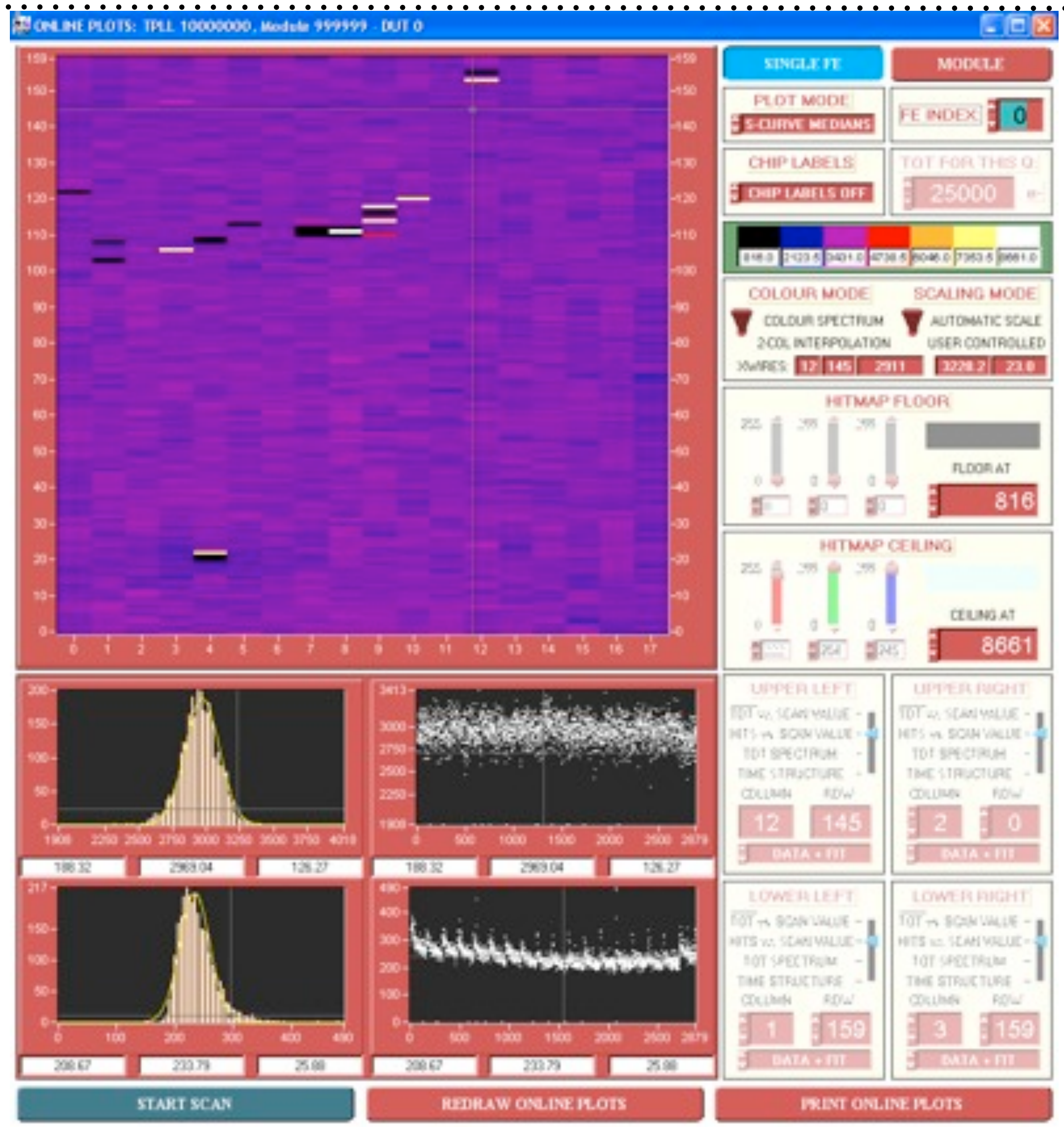


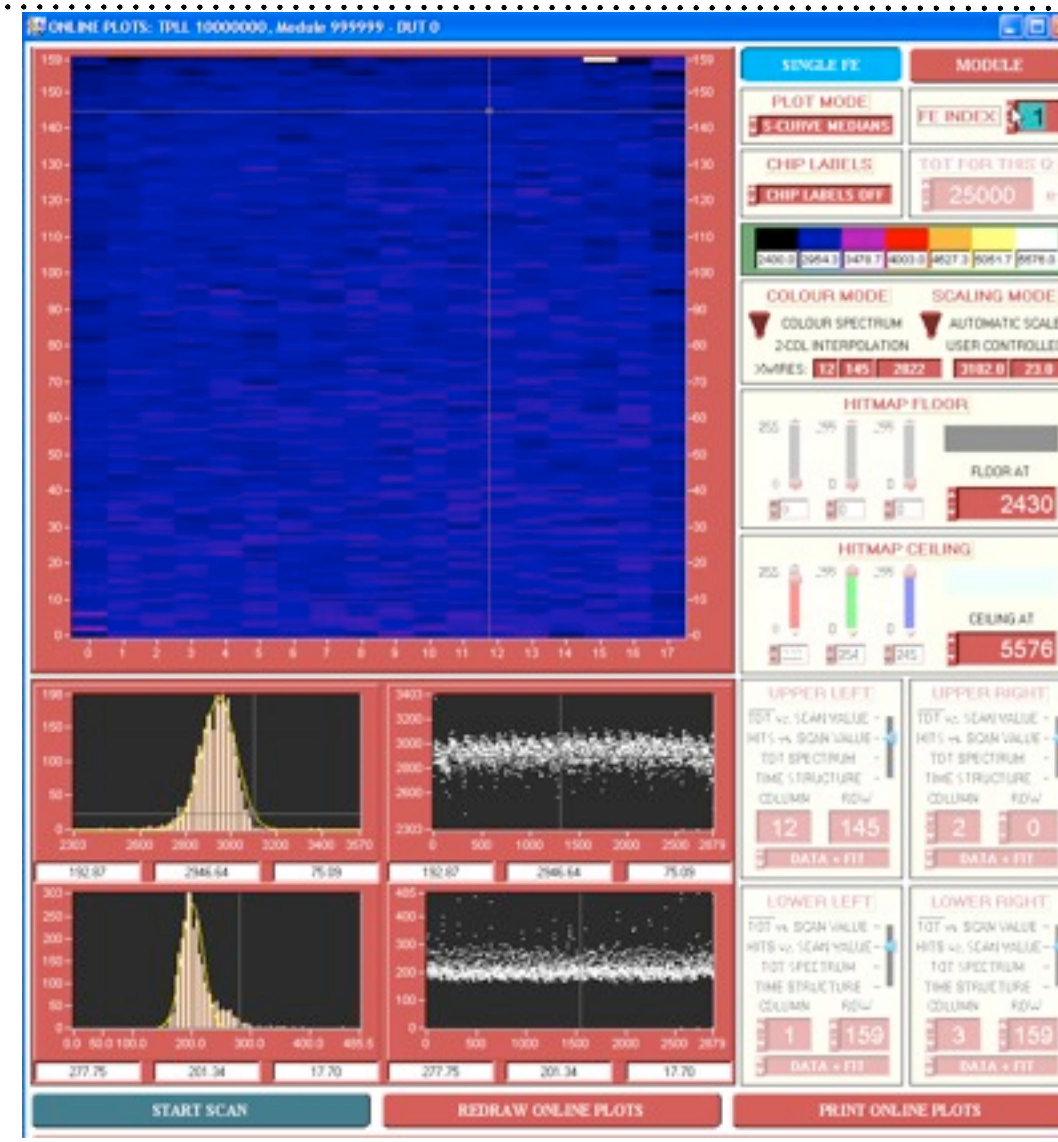
- FBK-4E14M:
  - 3e15 n_{eq}/cm^2
  - same tuning used in Genoa
  - HV = -50V (V_{bd} ~ -60V, $I_{leakage} < 0.1\mu A$)
  - efficiency 46%
  - removed: efficiency was too low

Temperature:
- ~ -50°C (dry ice, Dortmund cooling box)
- non-regulable and value unusually low for FBK (T=-20°) ...

more info: https://twiki.cern.ch/twiki/bin/viewauth/Atlas/IBLTBoct2009

Test beam and lab measurements at CERN



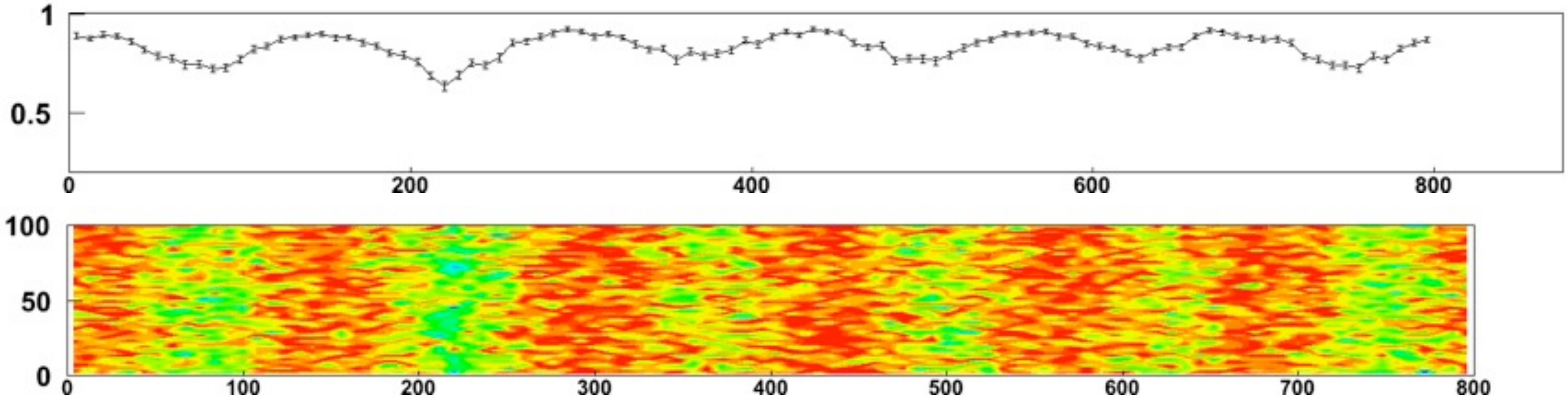


FBK-3E13M (5e15 n_{eq}/cm^2):
- Threshold REAL= 2969,04e^-
- 60 TOT @ 20ke^-

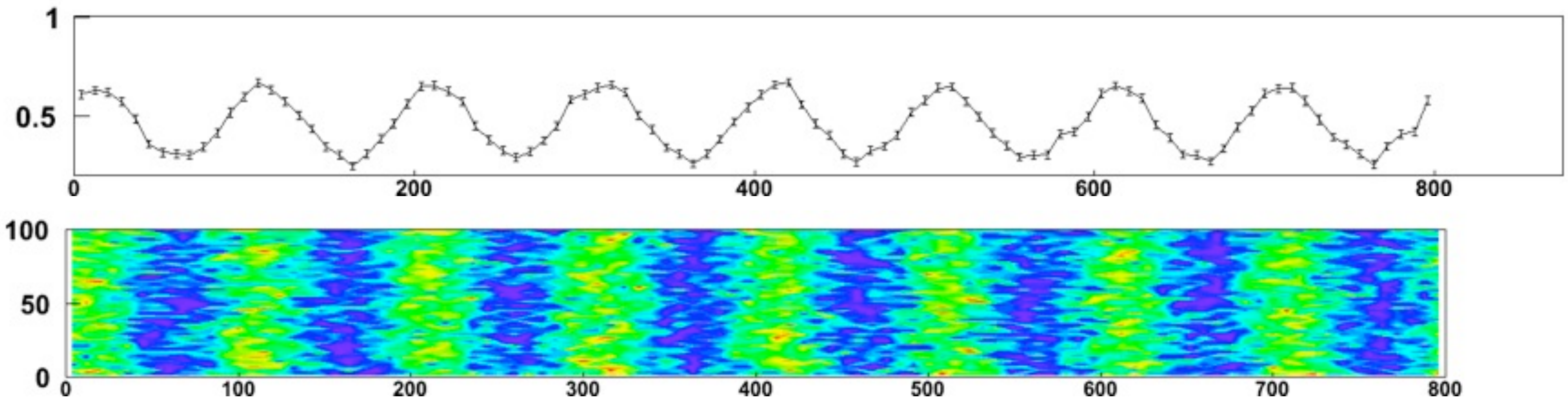
FBK-4E14M (3e15 n_{eq}/cm^2):
- Threshold REAL= 2946,64e^-
- 60 TOT @ 20ke^-

Temperature on the NTC : ~ -55/57°C

Test beam and lab measurements at CERN

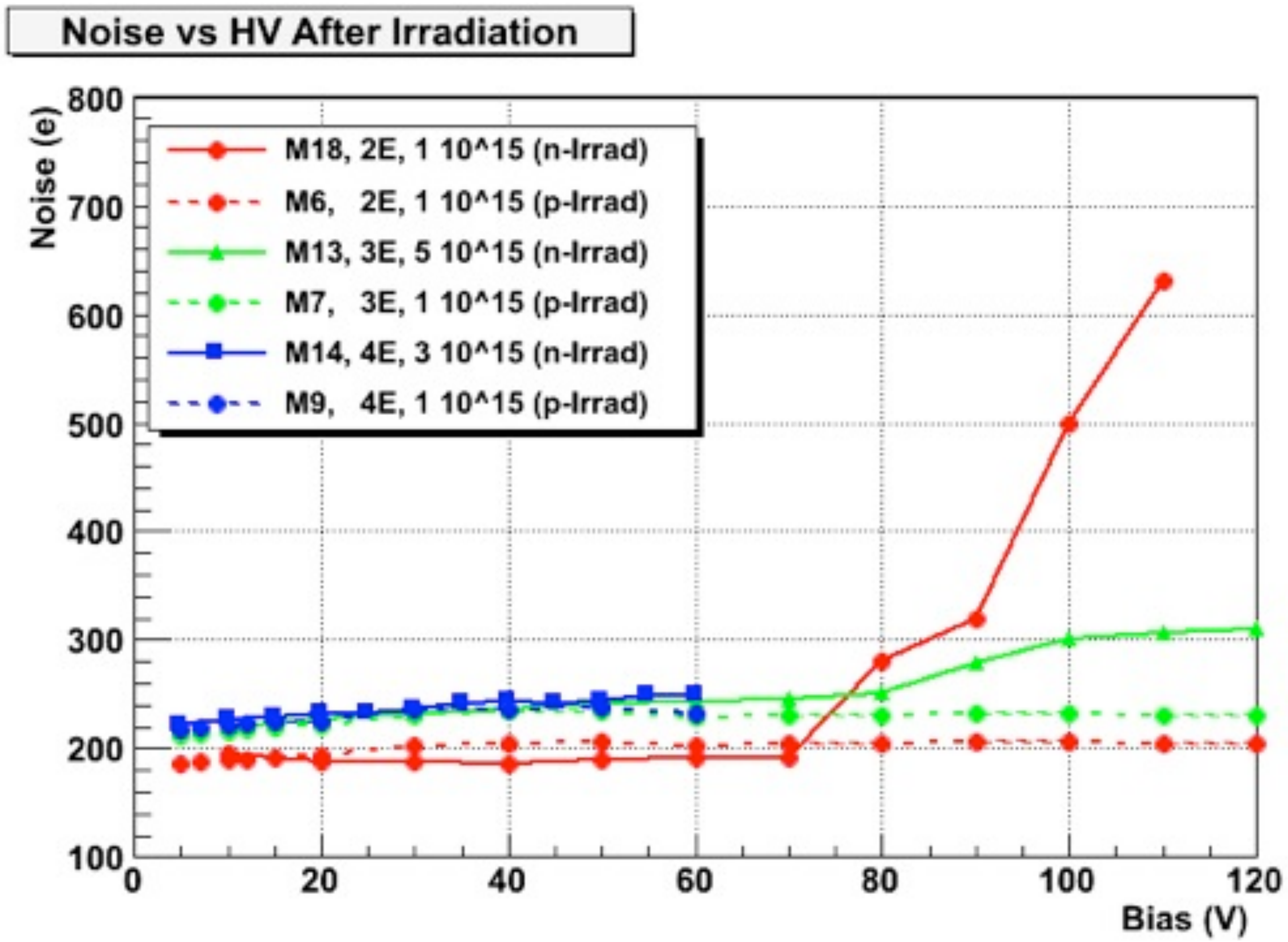


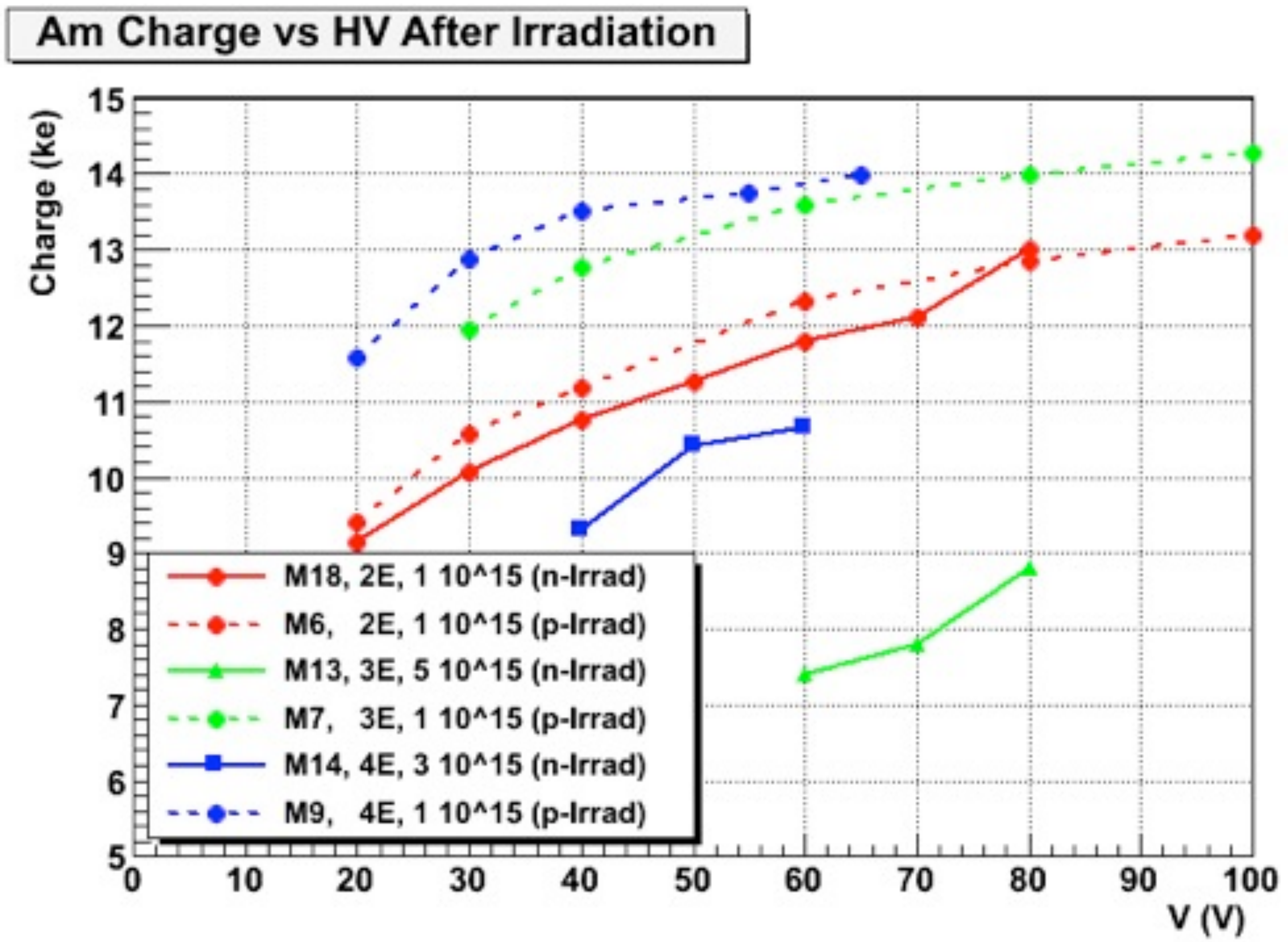
FBK-3E13M (5e15 n_{eq}/cm^2) eff = 84%



FBK-4E14M (3e15 n_{eq}/cm^2) eff = 46%

in Genoa, after-irradiation Lab measurements





- Few examples: see module FBK-4E 14M
  - temperature of scans T~ -20°C
- Behavior looks very similar for the same type of devices
- Am^{241} scans to measure charge collection vs bias after irradiation (ToT calibration repeated at every voltage)
- proton irradiated devices collect more charge

Summary and Outlook

- 3D-DDTC FBK sensors: status and plans
  - FBK-4E 14M low efficiency (~46%) first time tested at very low temperature. Before was working properly (lab measurements in Genoa)
  - Future: test beam at Desy (16 Feb to March 2) and at CERN
    - we could think to test again FBK-4E14M at Temp = -20°
  - development of passing-through column detector is ongoing (first wafer completed at FBK, more wafers to come in a few weeks)

- For more details:
  - A. Micelli *et. al* - “3D-FBK Pixel sensors: recent beam tests results with irradiated devices”, in press (http://dx.doi.org/10.1016/j.nima.2010.12.209)
  - A. Micelli, “3D-FBK pixel sensors: overview of recent results with proton and neutron irradiated sensors”, RD50: 17th RD50 Workshop on Radiation hard semiconductor devices for very high luminosity colliders, CERN, Switzerland, Nov 17-19, 2010

Backup

Quick look at data from Oct. 2010 BAT test beam

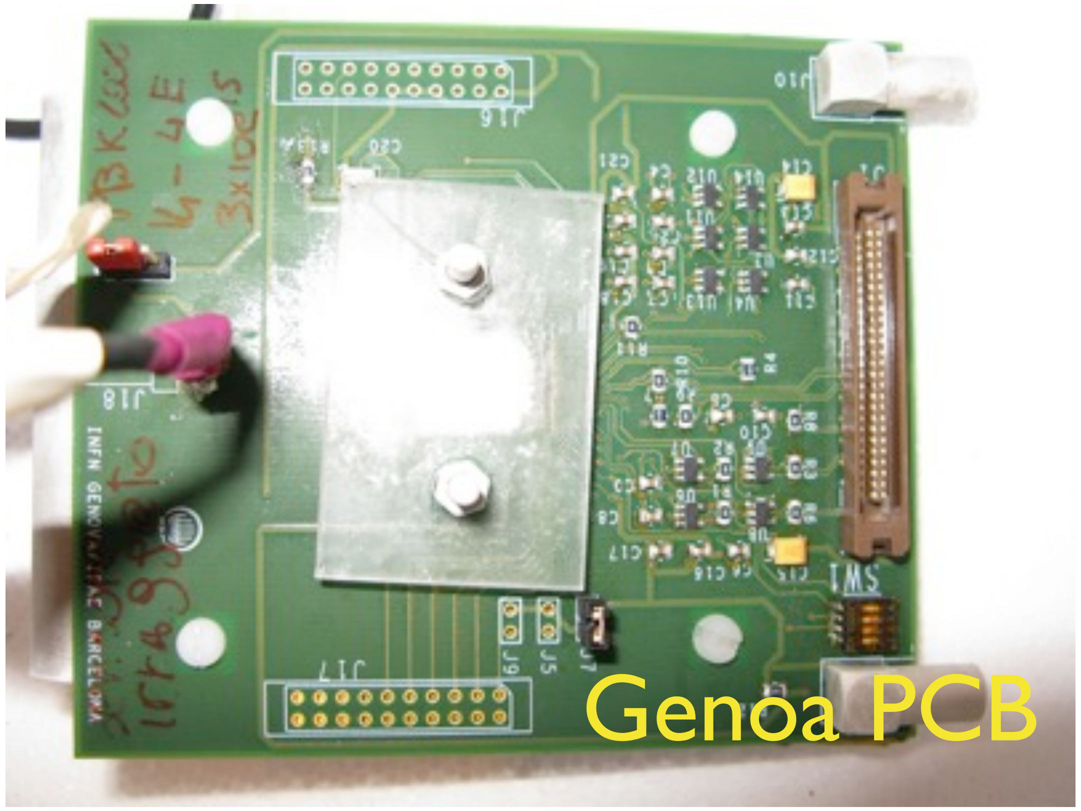
Device	ID	Bias voltage	Comment
STA-3E	160	35	Most upstream device
FBK-3E-5E15 (M13)	161	80	Irradiated to $5 \cdot 10^{15} n_{eq.}$
FBK-4E-3E15 (M14)	162	60	Irradiated to $3 \cdot 10^{15} n_{eq.}$
PLANAR	163	150	Most downstream device

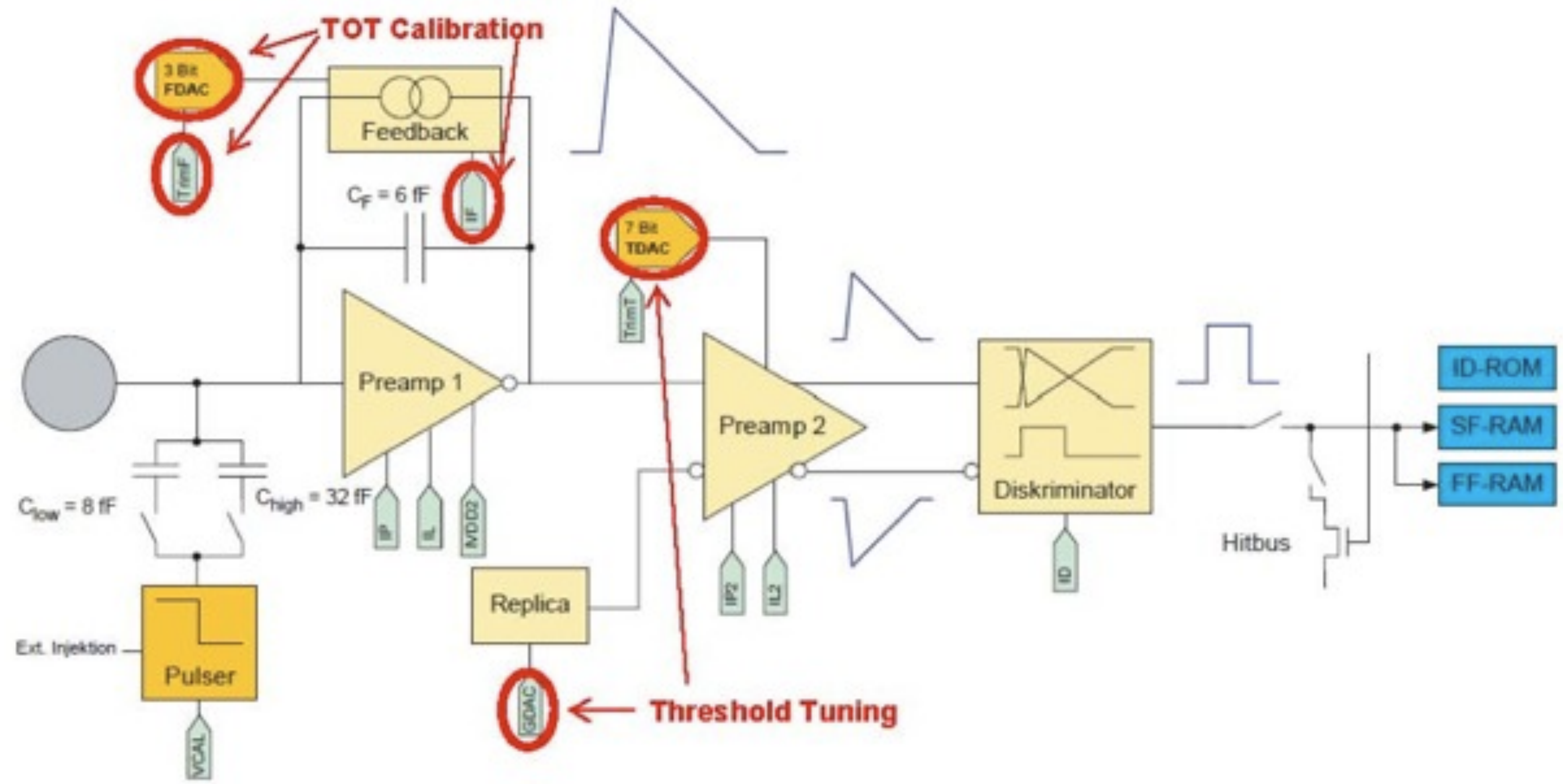
	STA-3E	FBK-3E-5E15	FBK-4E-3E15	PLANAR	Triggers
B=off, 0°	94.64	77.35	43.38	98.74	196'2917
B=on, 0°	93.59	66.25	42.84	97.46	150'6560
B=off, 15°	95.39	72.57	36.53	99.71	150'6560
B=on, 15°	NOT ENOUGH DATA				626

- analysis done by Kyrre Ness Sjøbæk (December 2010)
- more info:

https://twiki.cern.ch/twiki/pub/Atlas/PixelUpgrade3DTestBeam/tb2010-10.pdf

The ATLAS FE readout chip

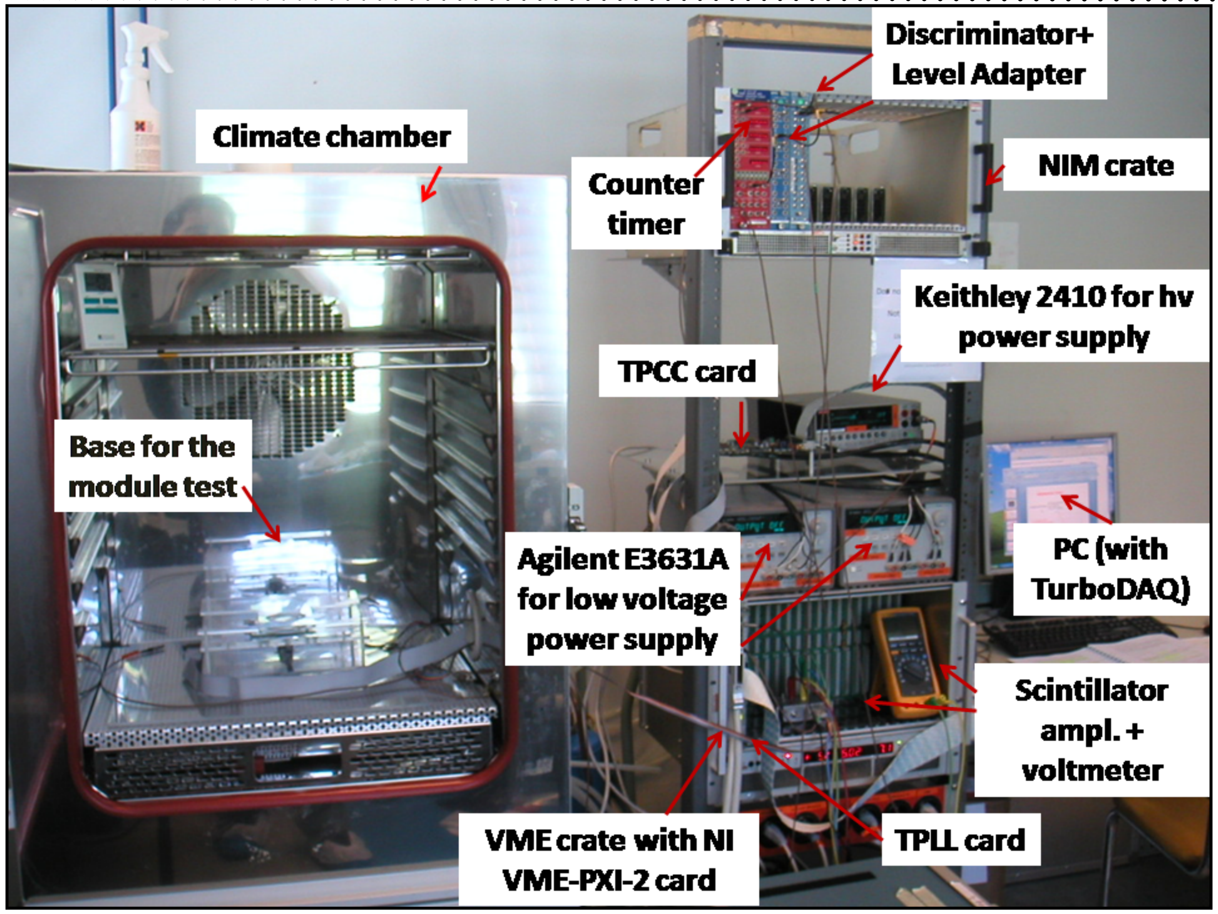


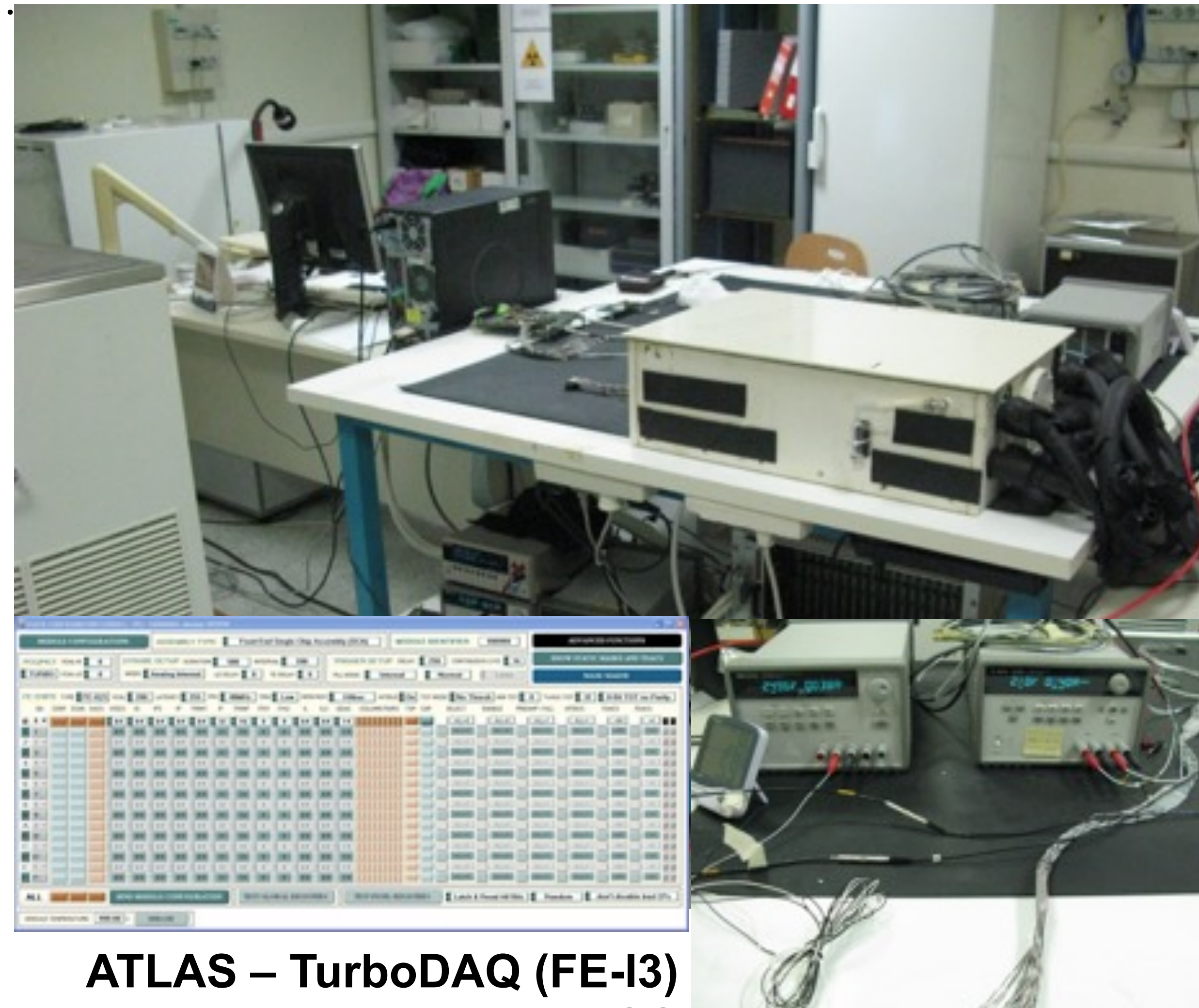


Single Chip Assembly (SCA):

- 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

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

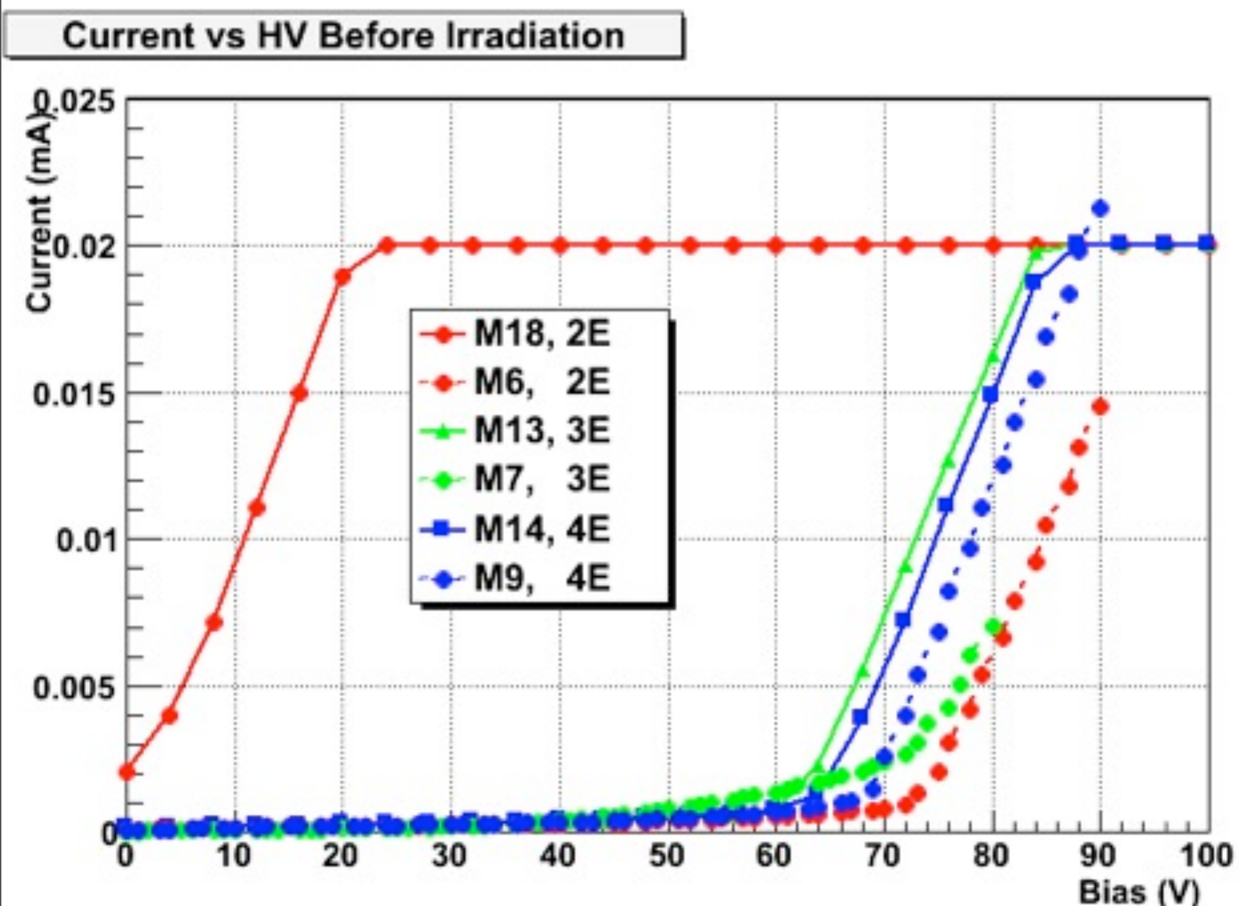
List of devices

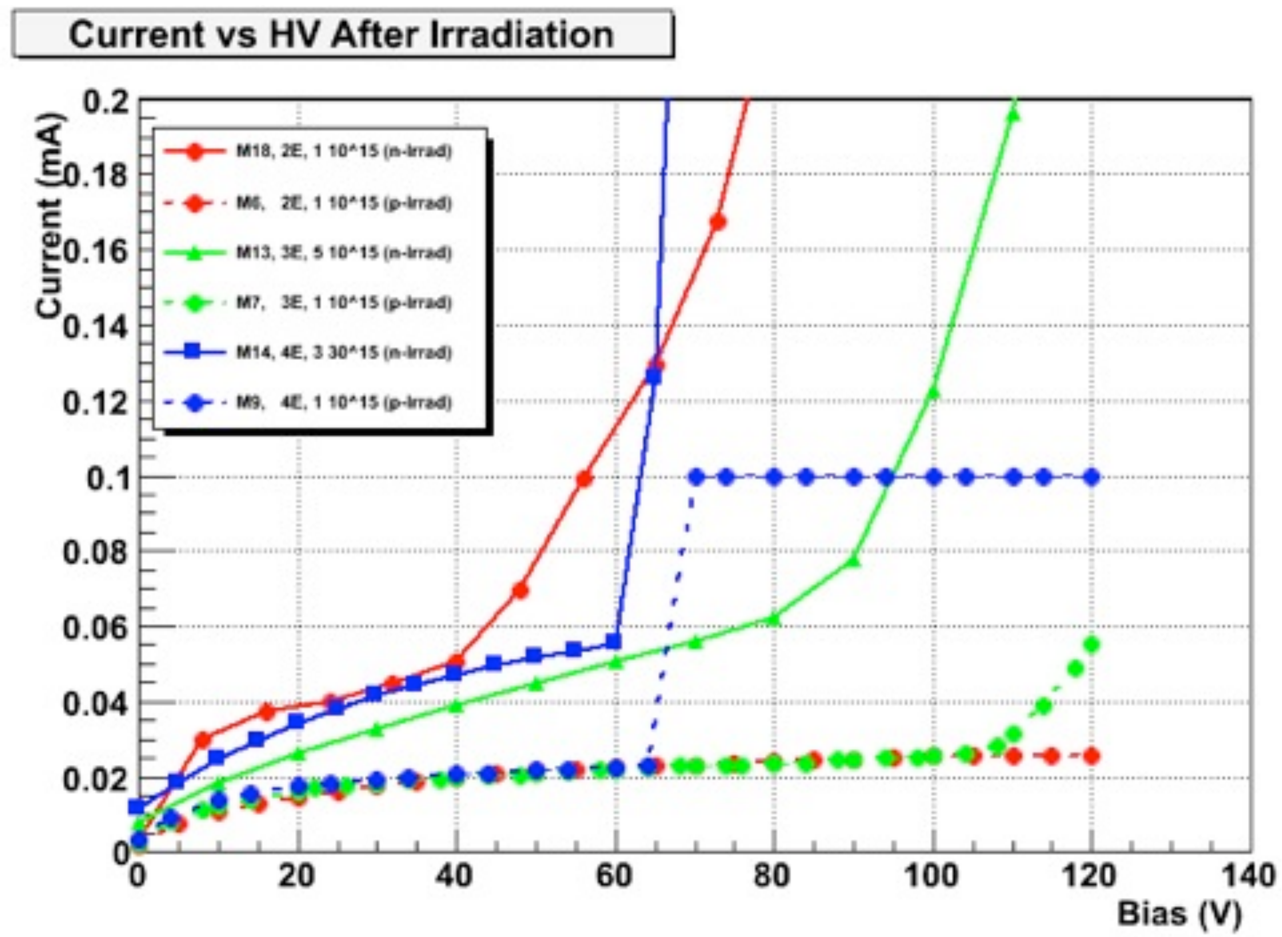
- DUTs have been irradiated at difference fluence Nx10^{15} n_{eq}/cm^2 with neutrons (18,13,14) and protons (6,7,9 - 2,8), respectively:

- 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, 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*
  - 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

IV SCAN before/after irradiation





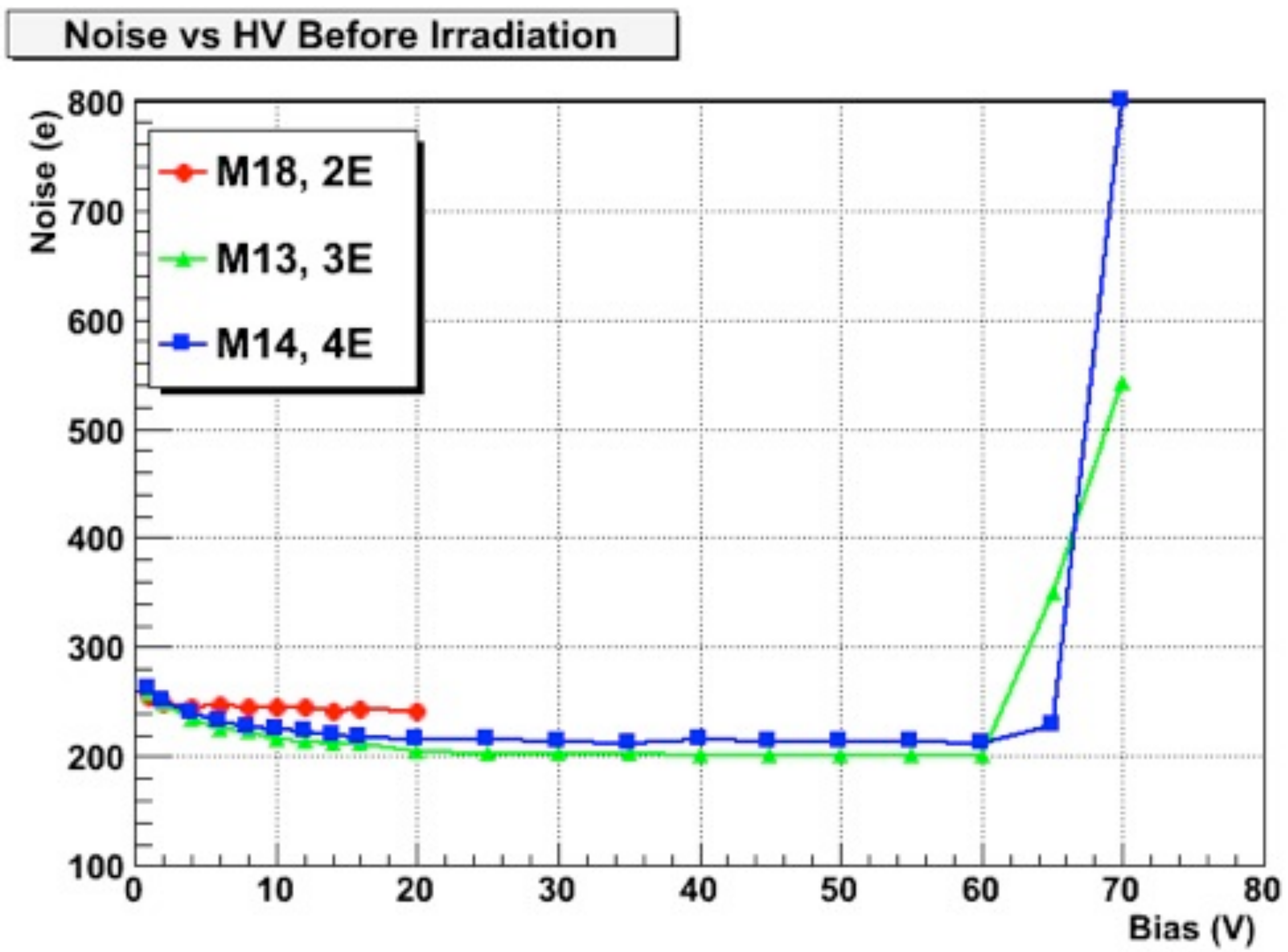
ID on Wafer	Sensor Type	Fluence [n_{eq}/cm^2]	Irrad. Type	V_{bd} [V]	V_{bd} [V]	α [10^{-17} A/cm]
18	2E	1 10^{15}	n	0	10	
6	2E	1 10^{15}	p	70	>120	5.40
13	3E	5 10^{15}	n	60	60	
7	3E	1 10^{15}	p	50	100	5.39
14	4E	3 10^{15}	p	60	60	
9	4E	1 10^{15}	p	60	65	5.28

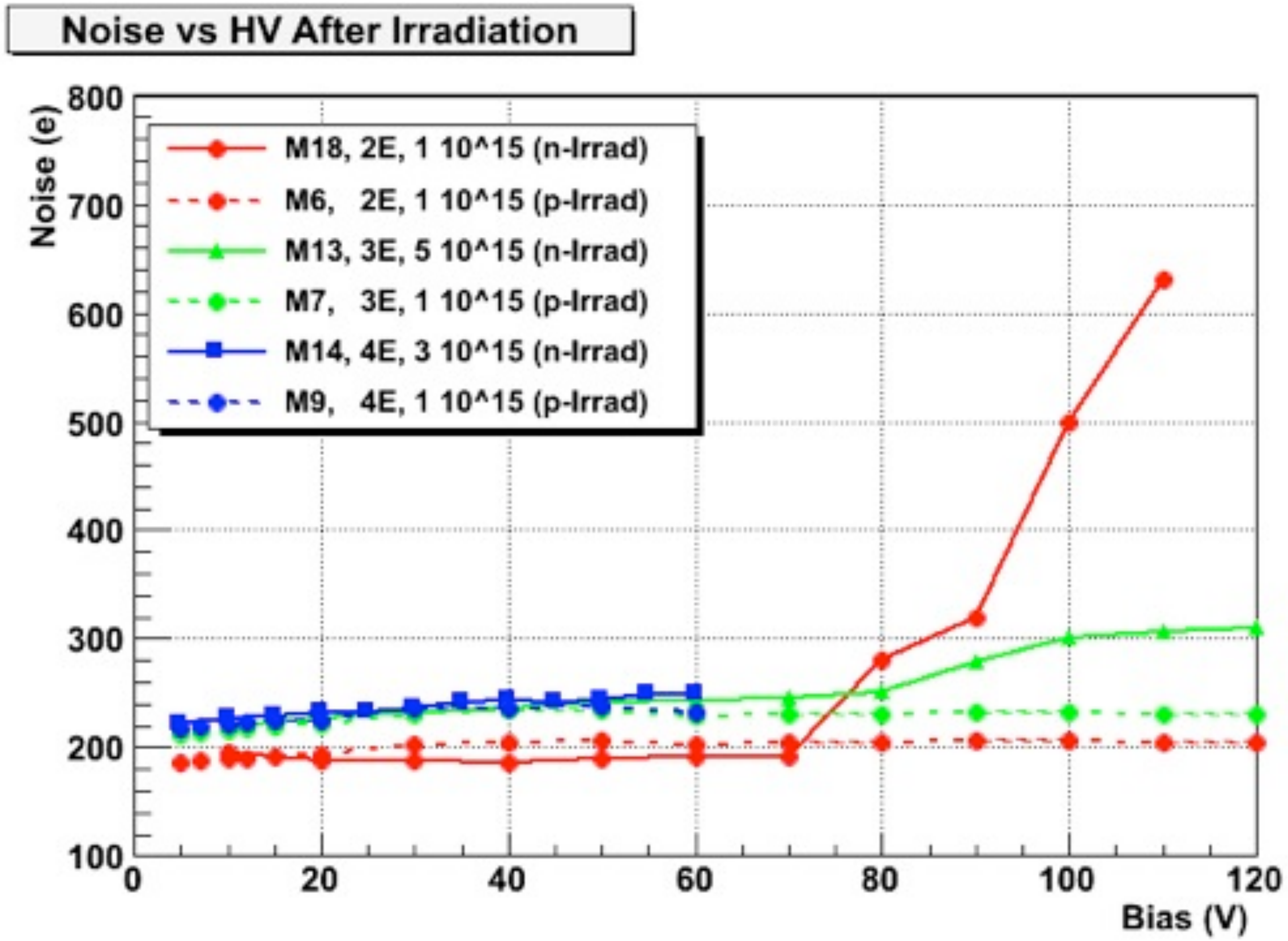
After IRRAD

- 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



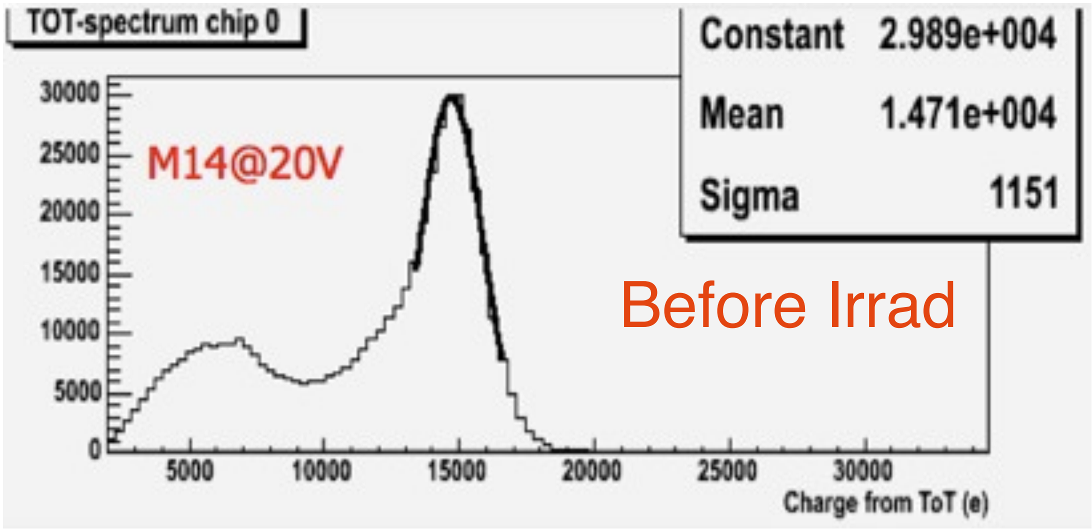


- Behavior looks very similar for the same type of devices
- After irradiation the noise of the neutron irradiated sensors increase faster
- Temperature of scans T~ -20°C

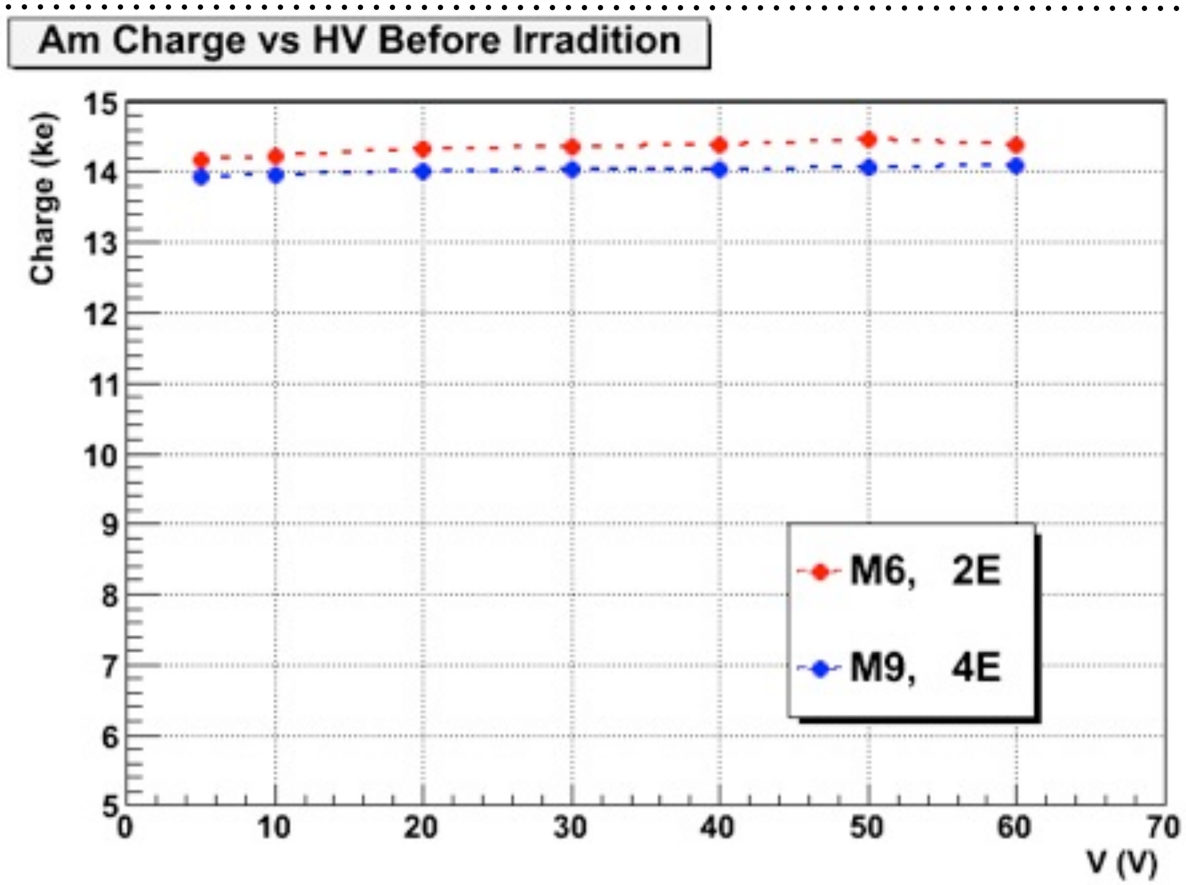
Charge collection before irradiation

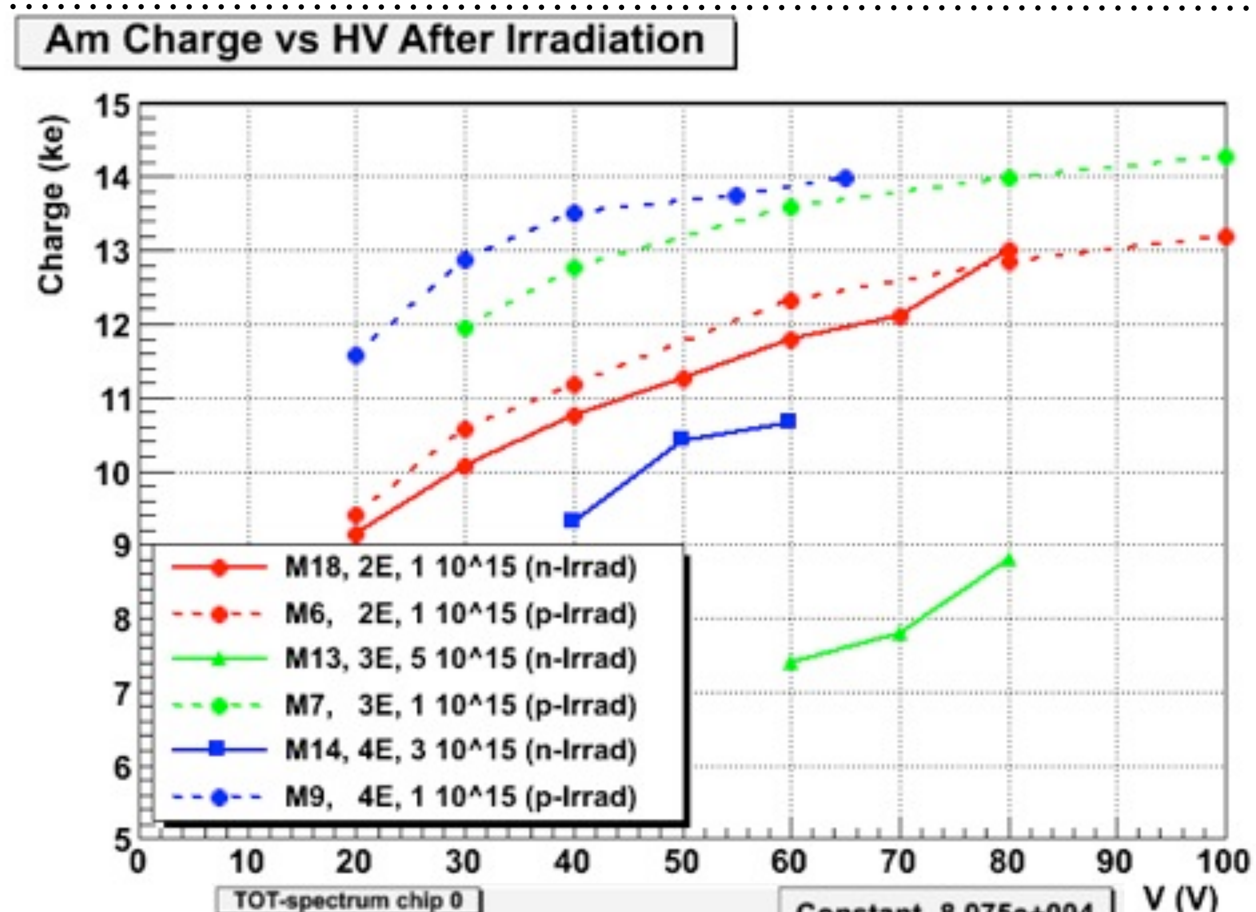
- Charge collection measured with Am^{241} source

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

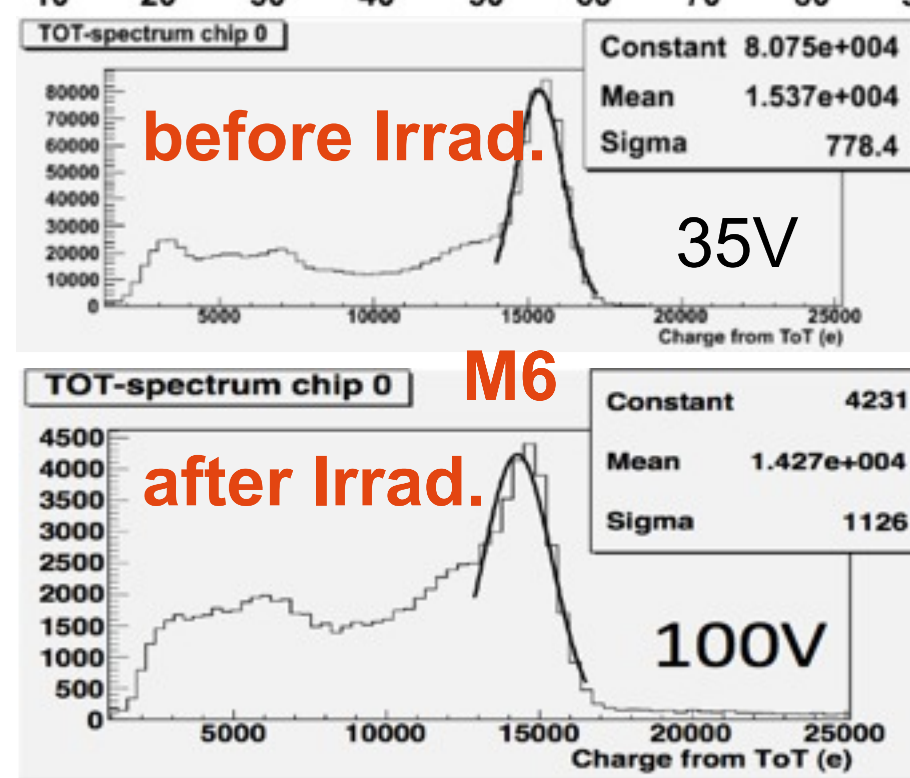


Am^{241} SCAN before/after irradiation

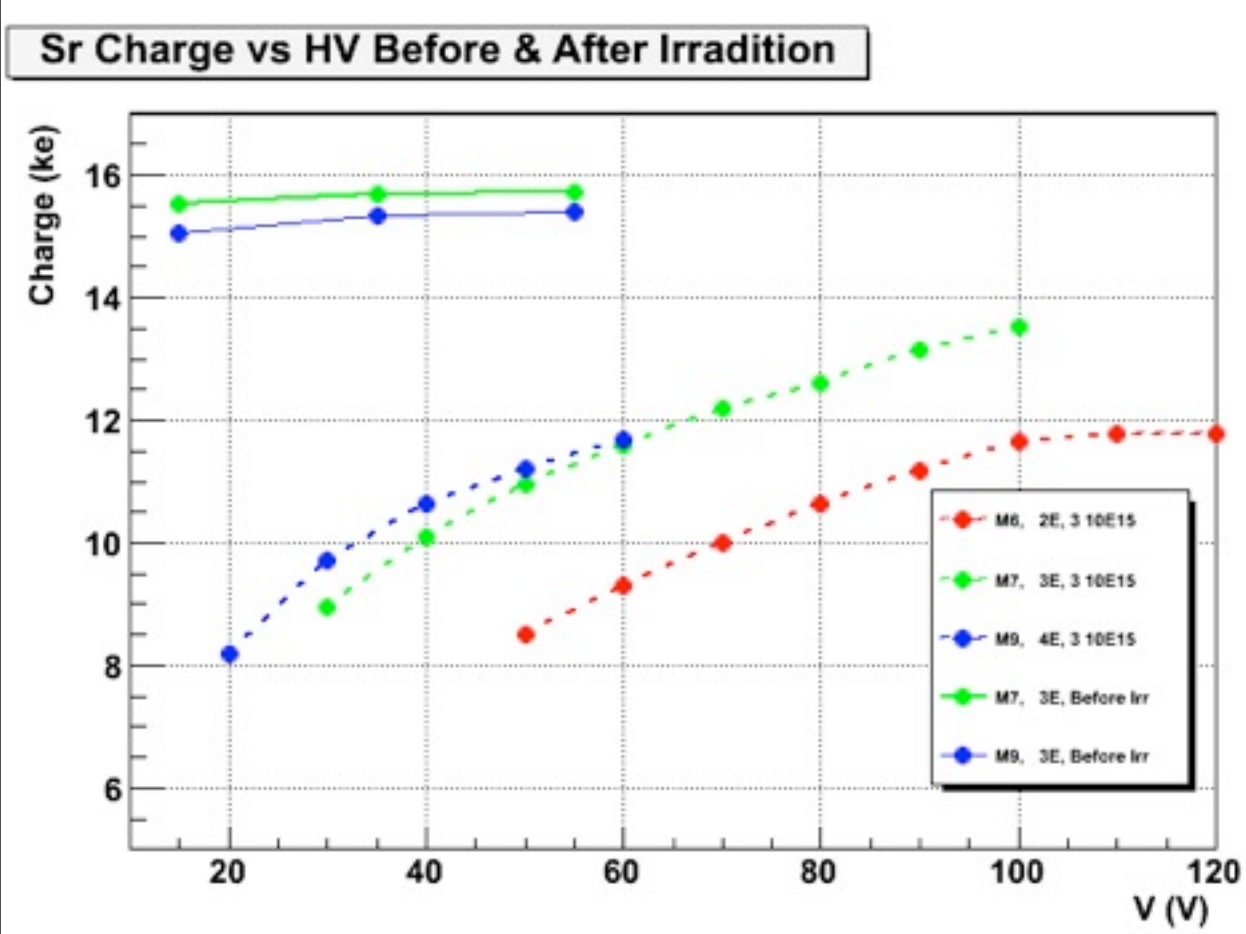


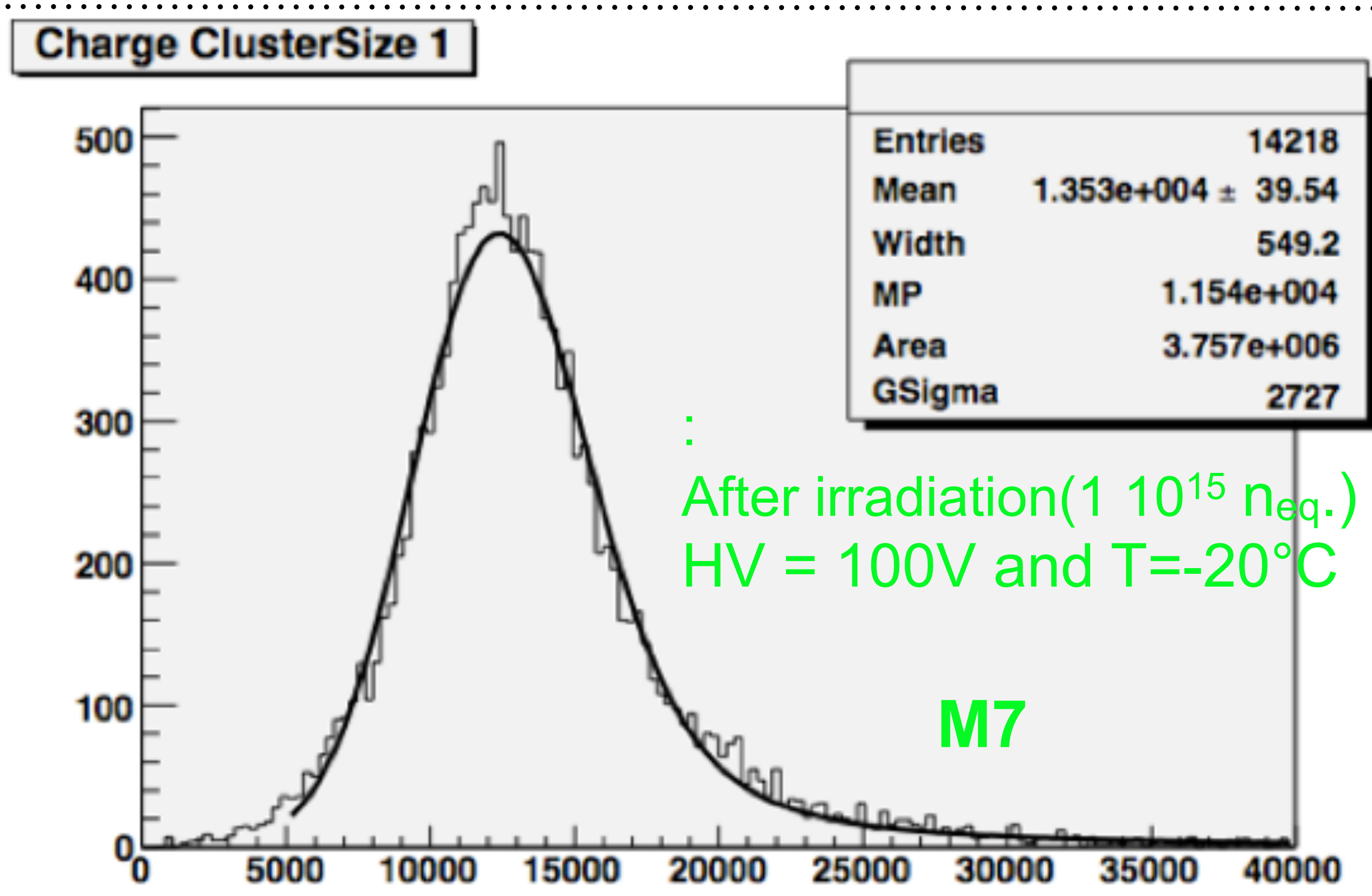


- Before irradiation Am^{241} peak is ~ 14.5 ke^-
- Am^{241} scans to measure charge collection vs bias after irradiation (ToT calibration repeated at any voltage)
- the proton irradiated devices collect more charge
- plots with one cluster size
- temperature of scans T~ -20°C



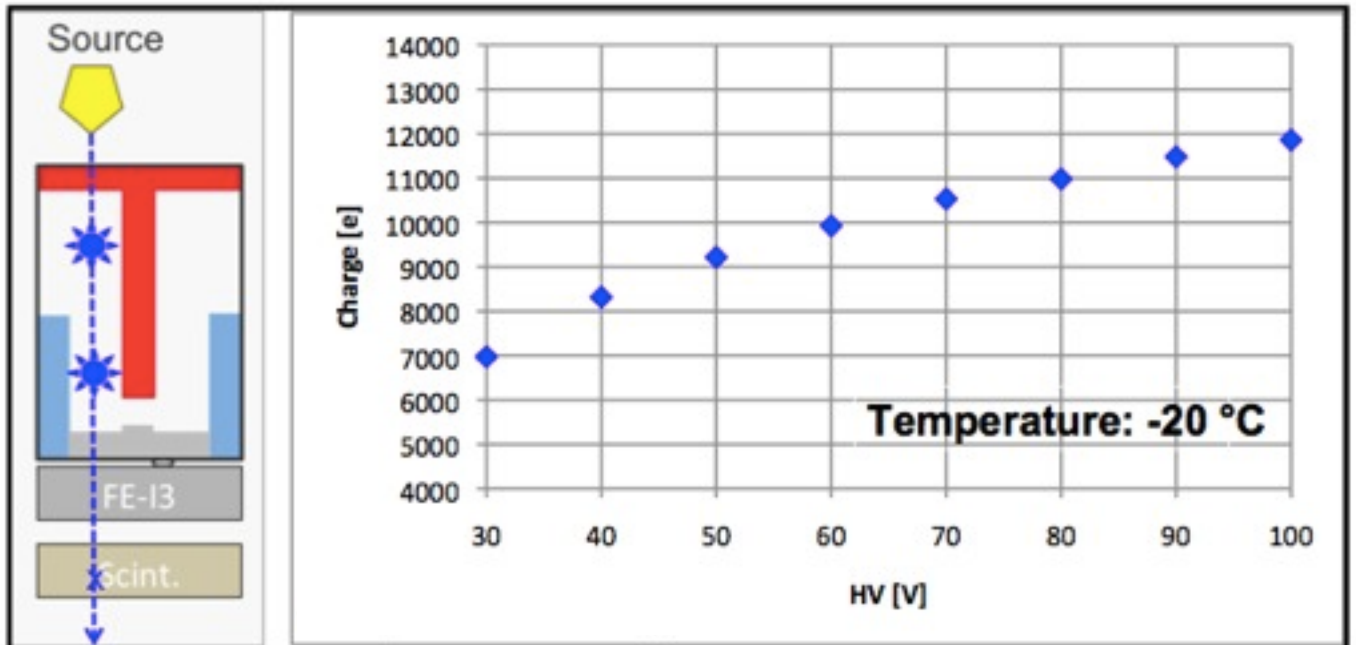
Sr^{90} SCAN before/after irradiation



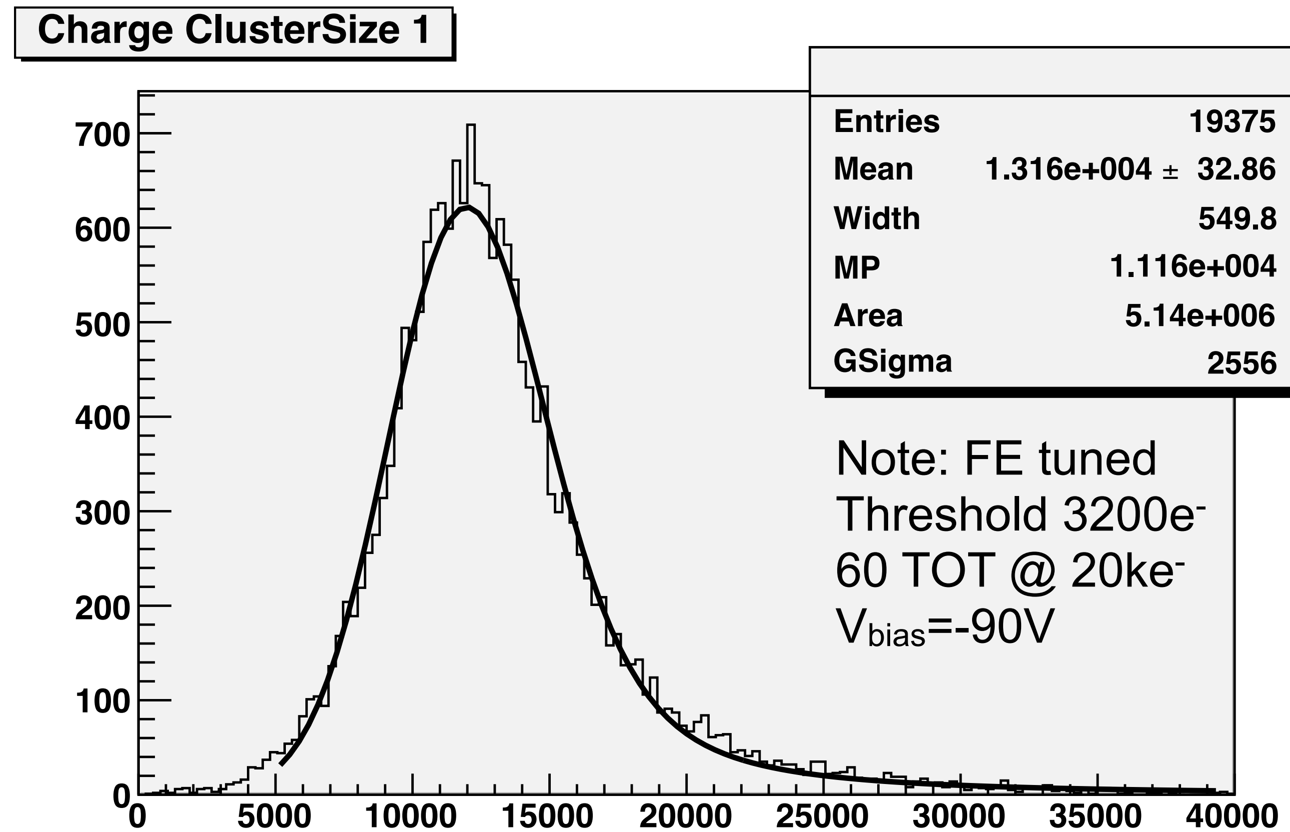


- Before irradiation Sr^{90} peak is ~15.71 ke^-
- Sr^{90} scans to measure charge collection vs bias after irradiation (ToT calibration repeated at any voltage)
- plots with one cluster size
- temperature of scans T~ -20°C

Lab Measurements



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



Preliminary results

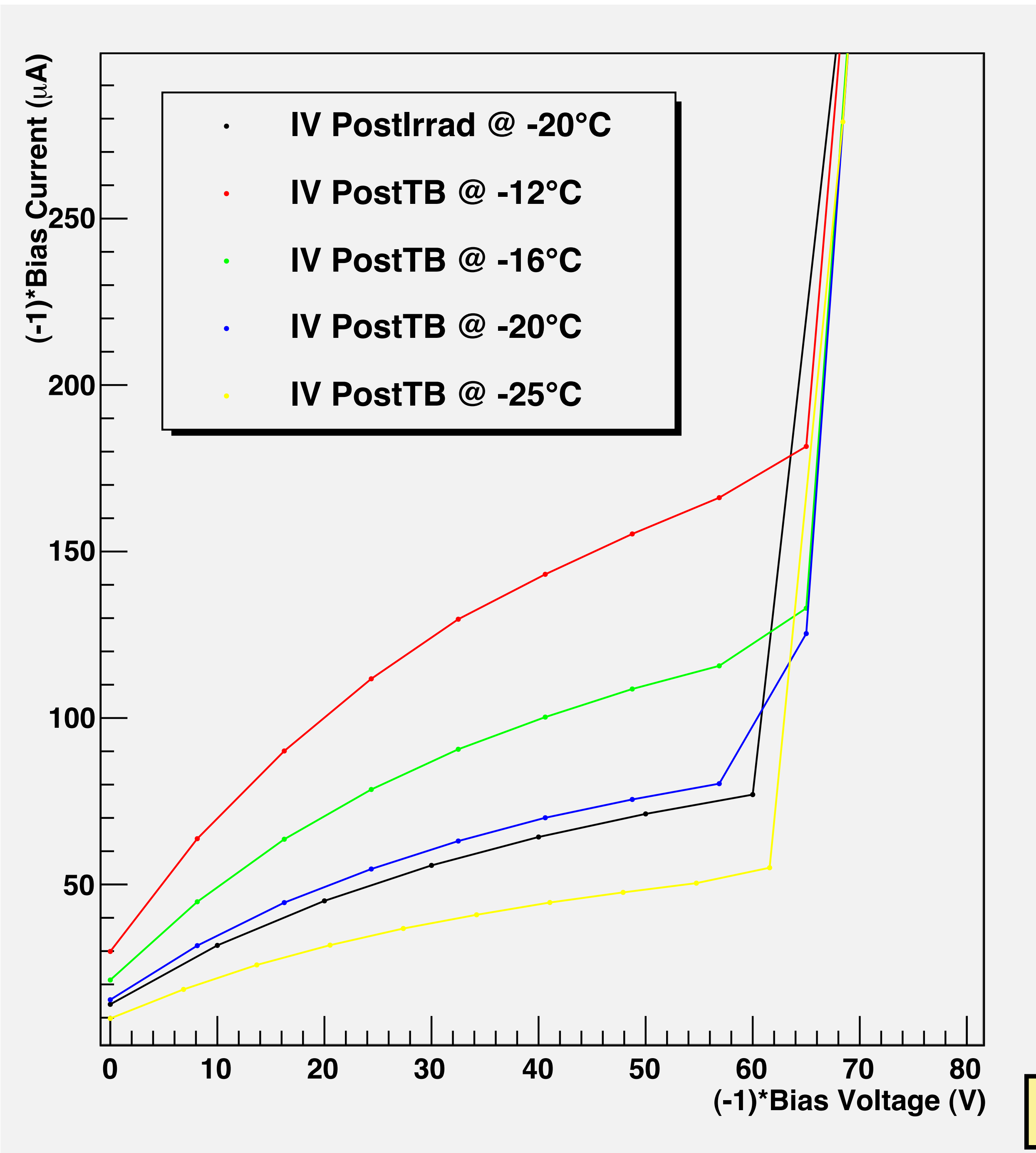
3D-FBK-3E proton-irradiated to 1×10^{15} n_{eq}/cm^{-2} (thickness 200μm)

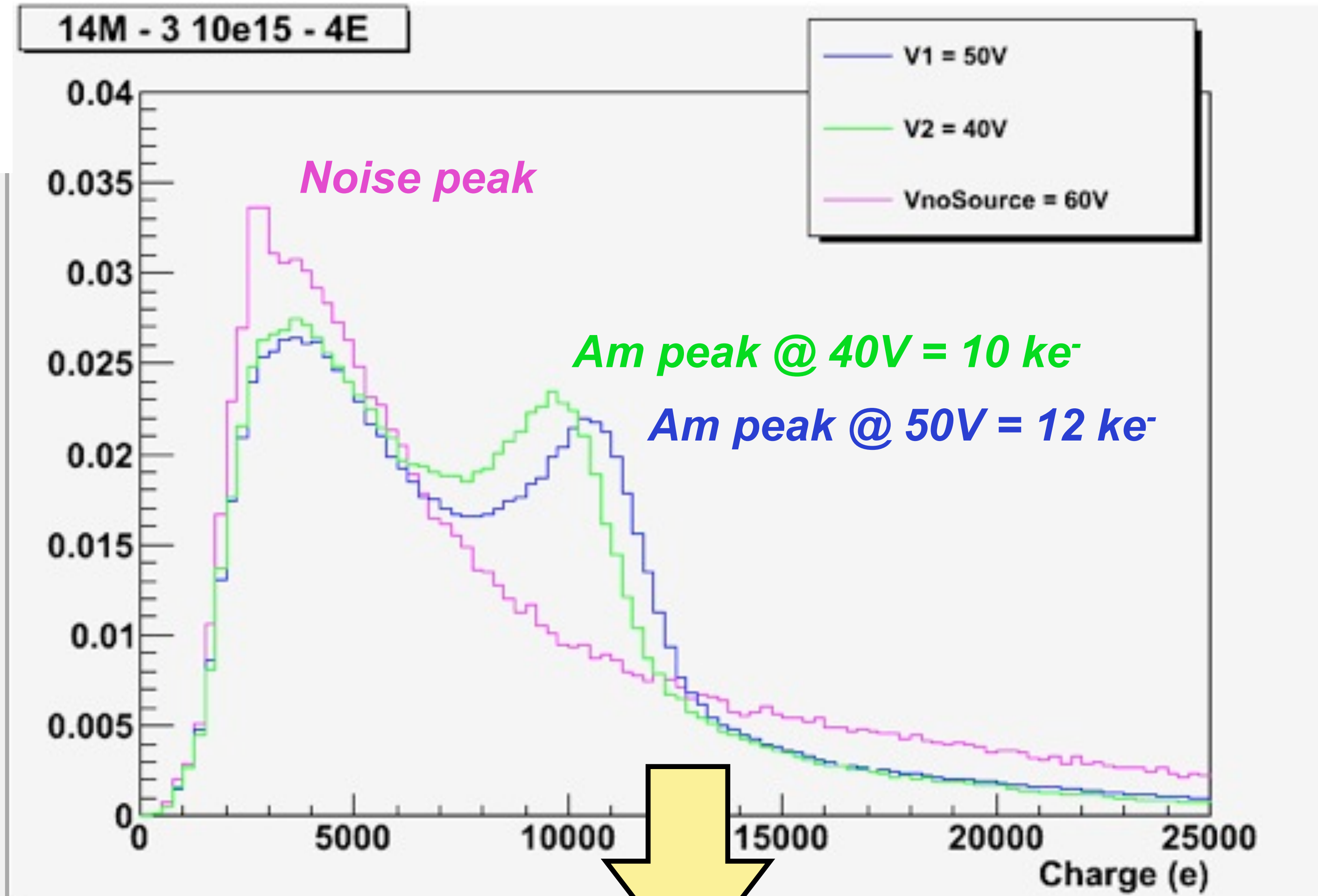
- radiation damage: run with bias voltage -80 V
  - ~ -20% signal loss
    - ➡ in agreement with lab tests made with β source Sr^{90}
  - sensor was not fully depleted
- overall efficiency still high (~99%)

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
$V_{break\ down}$ ~ -60V