Measurements of 3D/FBK sensors

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on behalf of

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RD50 Workshop. Nov. 16-18 , 2009. CERN

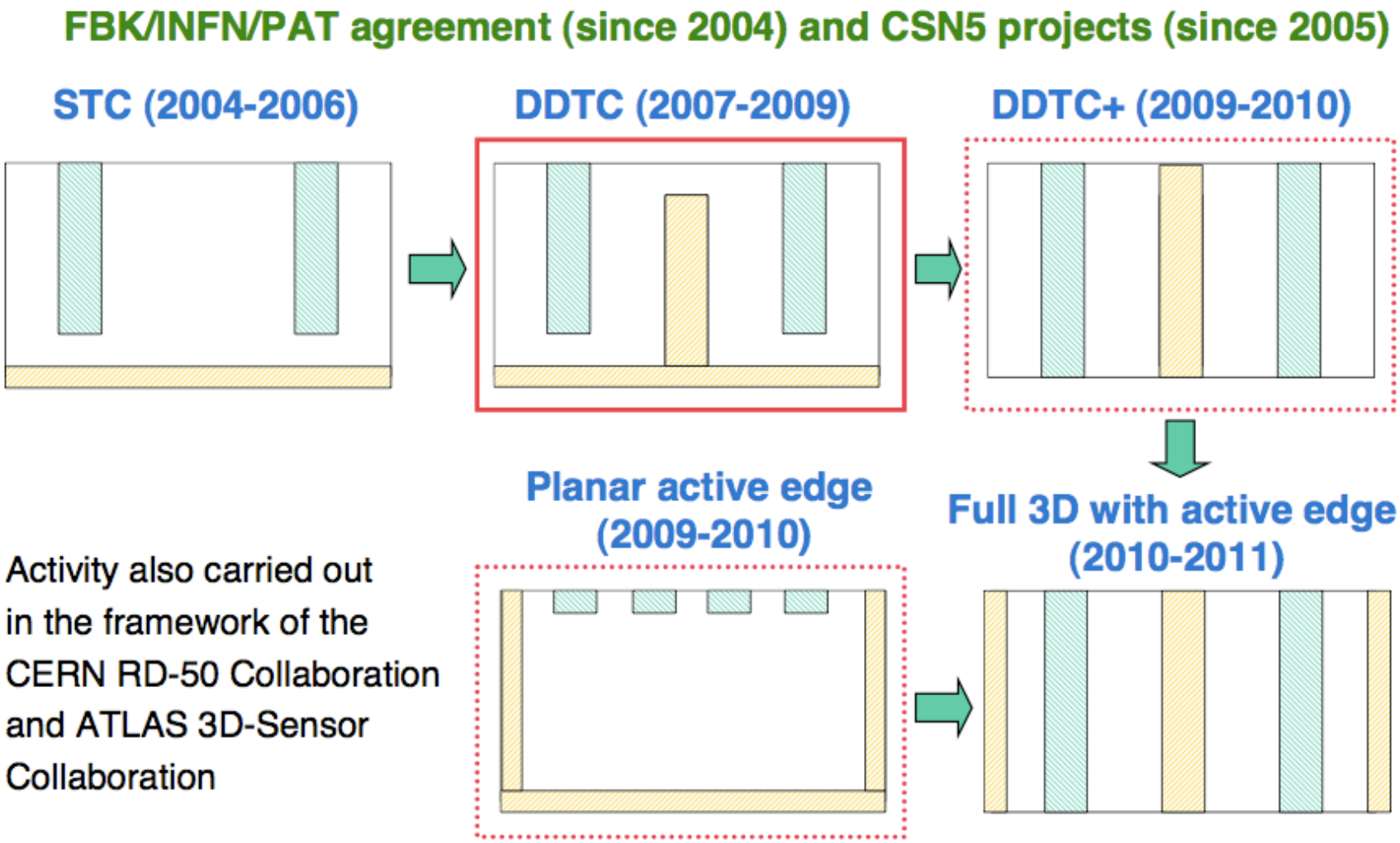
Outline

- FBK-irst 3D-Si sensors
- Lab characterization
- Beam tests (performed with ATLAS 3D Collaboration)
- Irradiation
- Conclusions

Parts of this talk have already been presented at HSTD7 (Hiroshima, Sept. 2009), RD09 (Firenze, Oct. 2009) and ATLAS 3D – Rad. Hard. Studies WG Meeting (CERN, Nov. 2009)

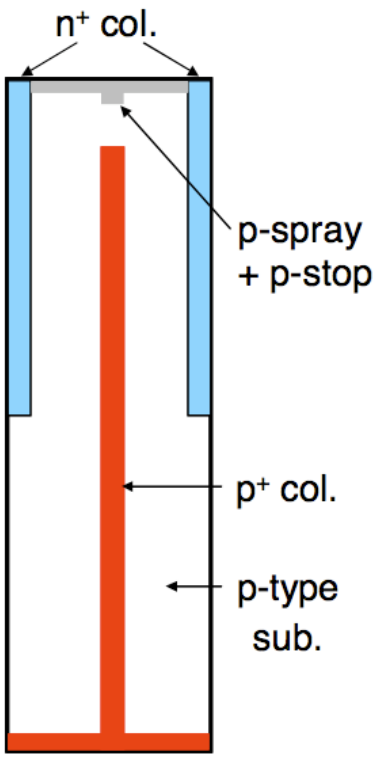
- G-F. Dalla Betta et al. *Development of 3D-DDTC pixel detectors for the ATLAS upgrade.* Submitted in NIM A, available at arXiv:0910.3629
- A. La Rosa et al. *Preliminary results of 3D-DDTC pixel detectors for the ATLAS upgrade.* PoS (RD09)032 available at arXiv:0910.3788
- A. La Rosa. *Irradiation activities at CERN*. Available at https://twiki.cern.ch/twiki/pub/Main/CernAtlasPixelSensorsRD/3D-RadHardWG.pdf

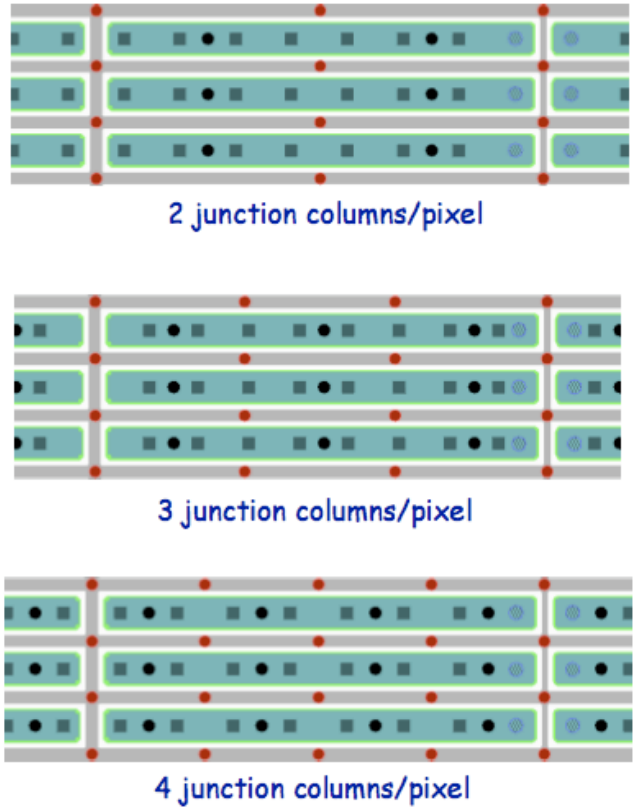
Sensors development / TRENTO

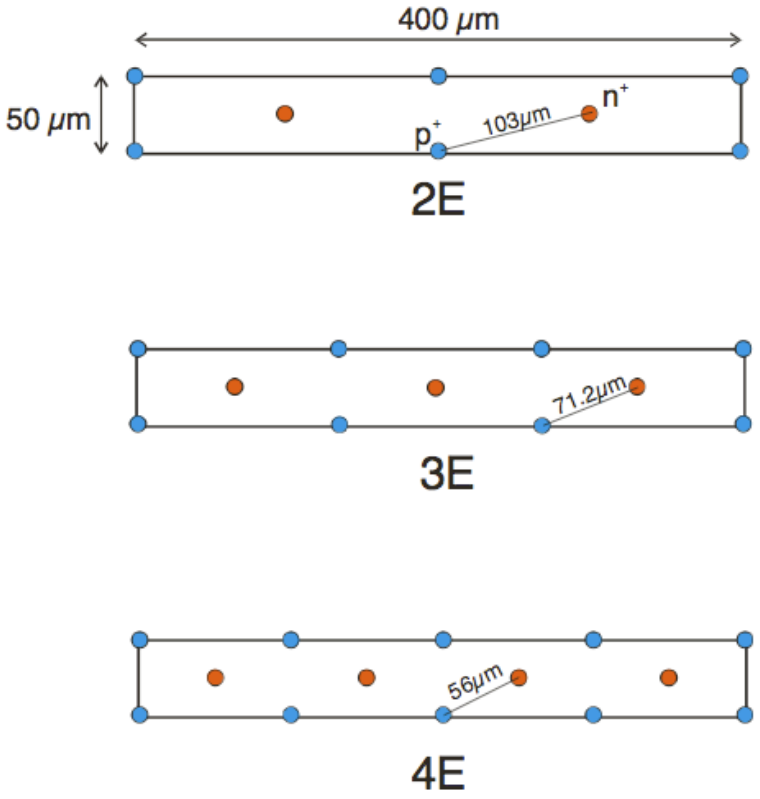


3D-Double side Double Type Column

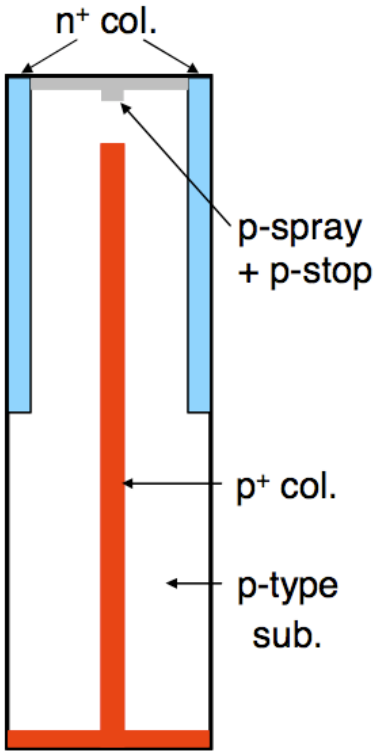
ATLAS PIXEL SENSORS DESIGN







3D-Double side Double Type Column



ATLAS PIXEL SENSORS DESIGN

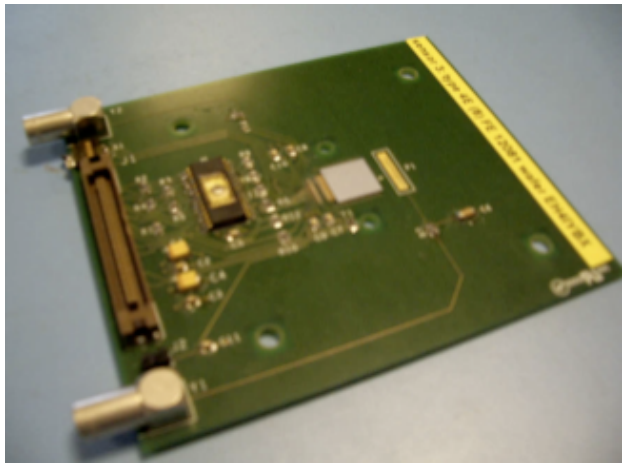
Two batches so far fabricated for ATLAS – FEI3
- 3D-DCT-2 (p-type substrate, 200 um, IBS (Fr) DRIE)
- 3D-DTC-2B (p-type substrate, 200 um, in-house DRIE)

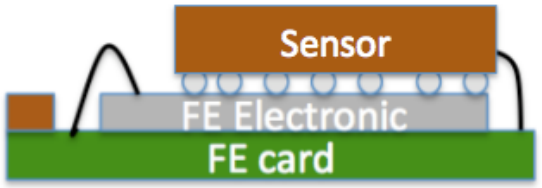
Parameter	Unit	Value	
		3D-DTC-2	3D-DTC-2B
Substrate thickness	μm	200	200
Junction column thickness	μm	100 -110	140 -170
Ohmic column thickness	μm	180 -190	180 – 190
Column overlap	μm	90 - 100	110 -150

Depletion Voltage:
- 3D-DCT-2: -12V
- 3D-DTC-2B : - 4V

3D-DDTC assemblies with FEI3

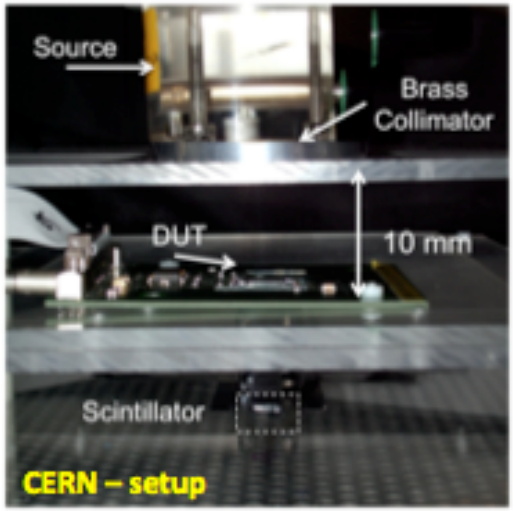
- Bump-bonding at SELEX S.I. (Roma, It.)
  - Indium based technology
  - 22 from batch DTC-2
  - 20 from batch DTC-2B
  - Few of these sensors have been flip-chipped on ATLAS chip FEI3

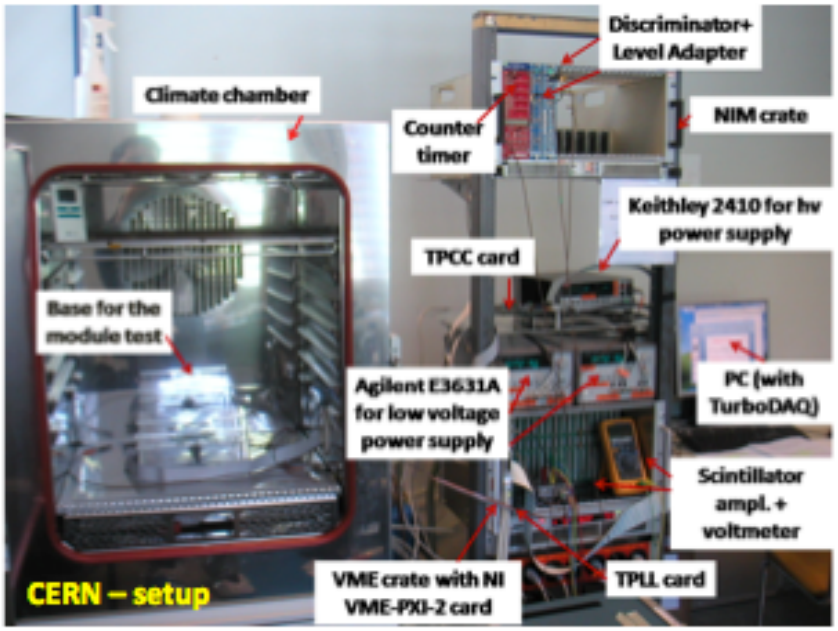




Experimental setup

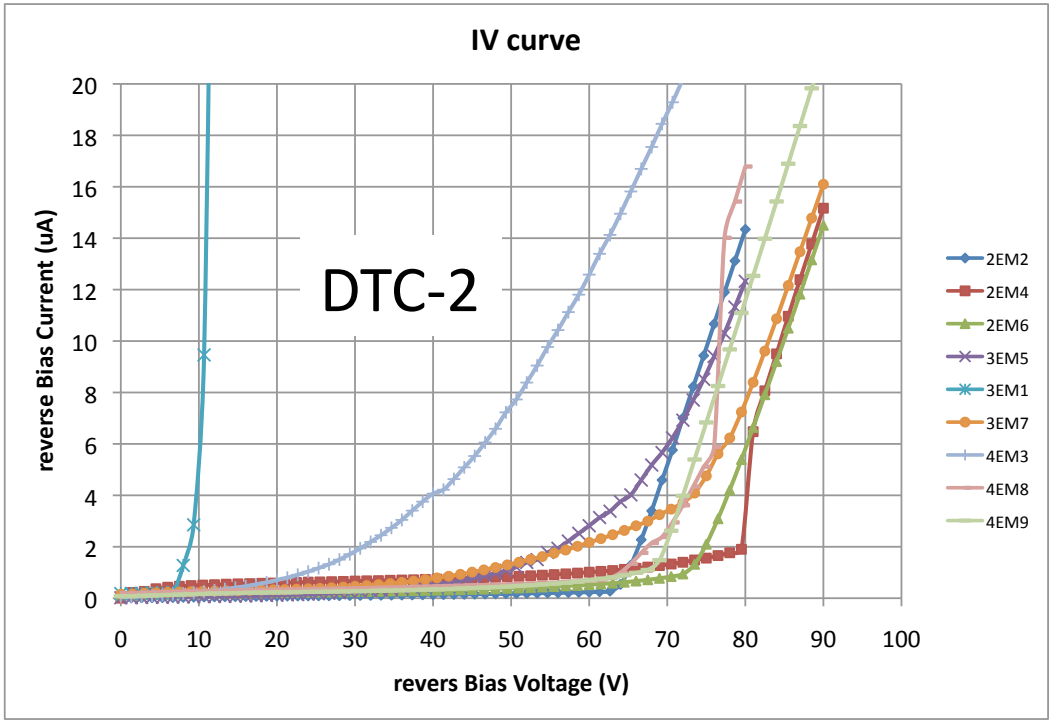
- Tests made at CERN and INFN/Genova
- Pixel test station based on ATLAS TurboDAQ system
- Measurements
  - Electrical and noise tests
  - Response to radioactive sources
    - Gamma: Am241 and Cd 109 →self triggered
    - Beta: Sr90 → triggered by scintillator

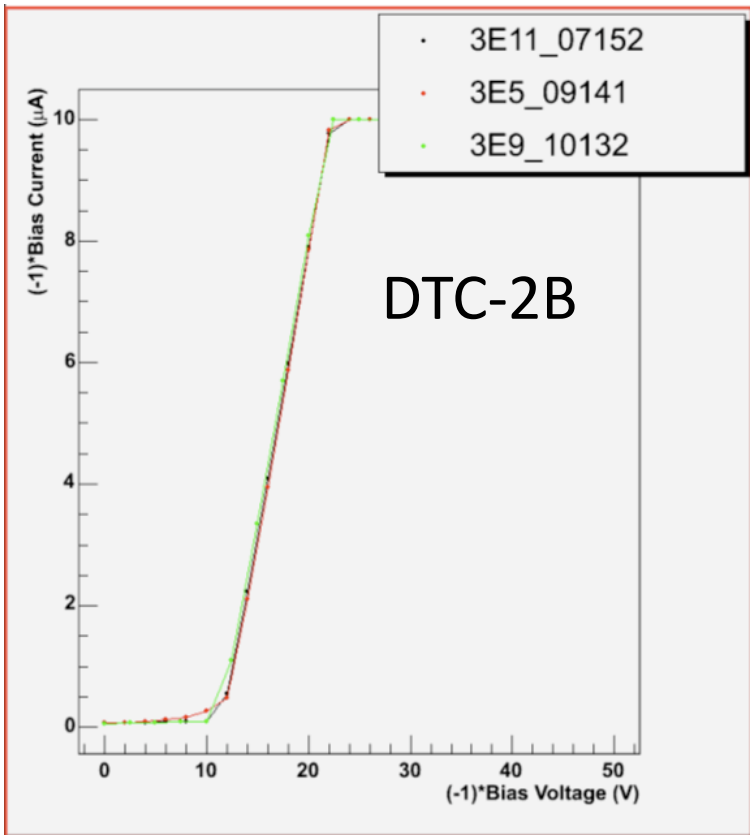




Leakage current

- DTC-2
- DTC-2B systematically early breakdown

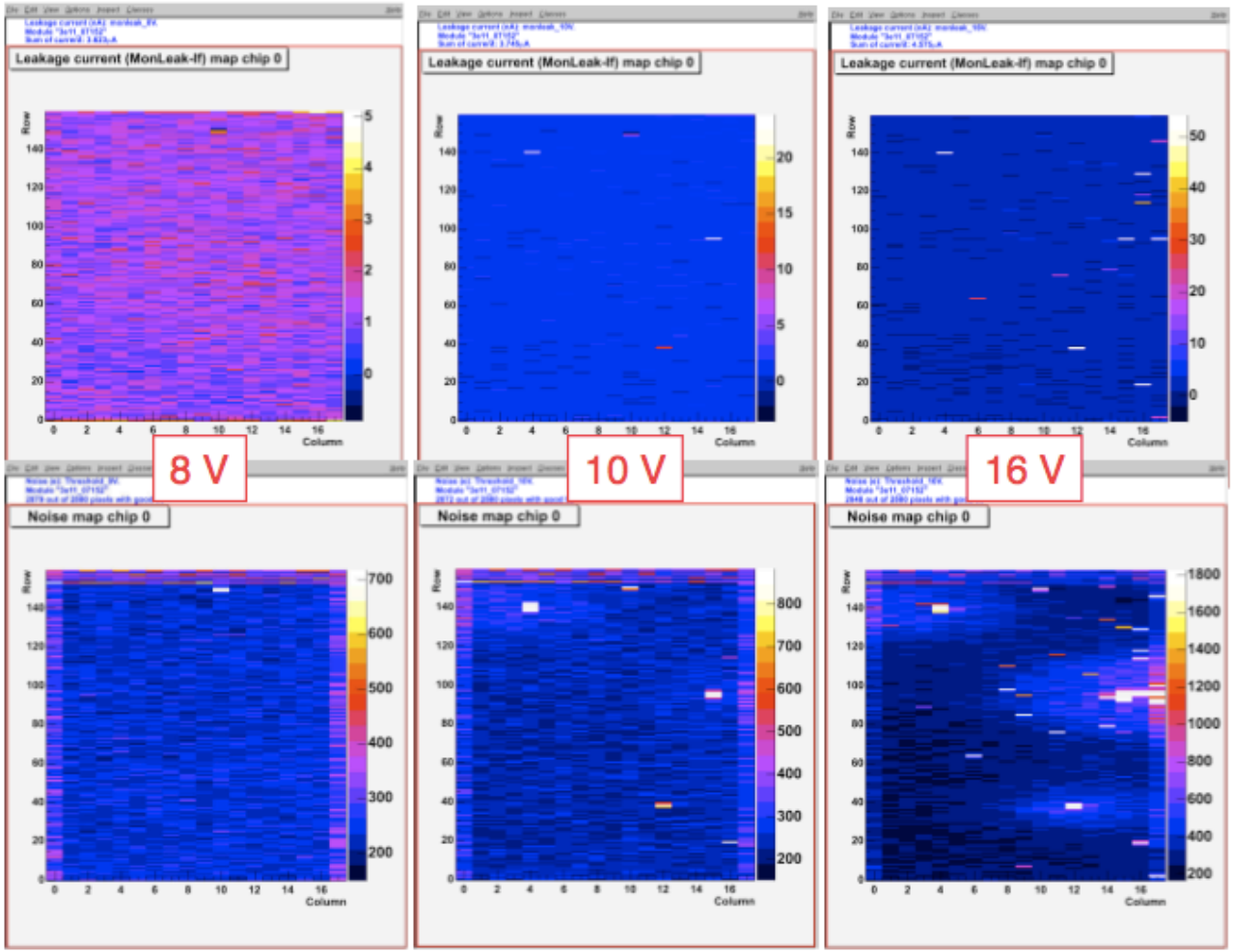




DTC-2B: early breakdown problem

Leakage

Noise



Early breakdown related to presence of local effects

At about -10V the leakage current starts to rise and a few pixels become very noisy compared to the others.

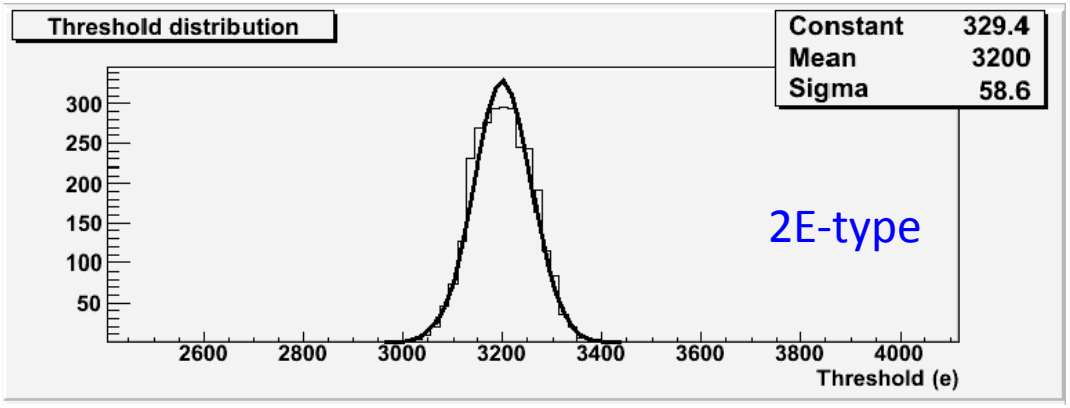
Increasing the bias voltage the number of noisy pixels increases.

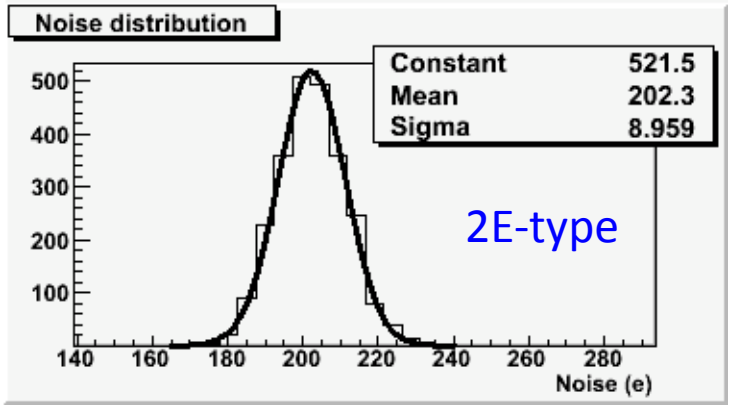
Maybe some damage occurred during the assembly → Still to be understood

Threshold and noise measurements

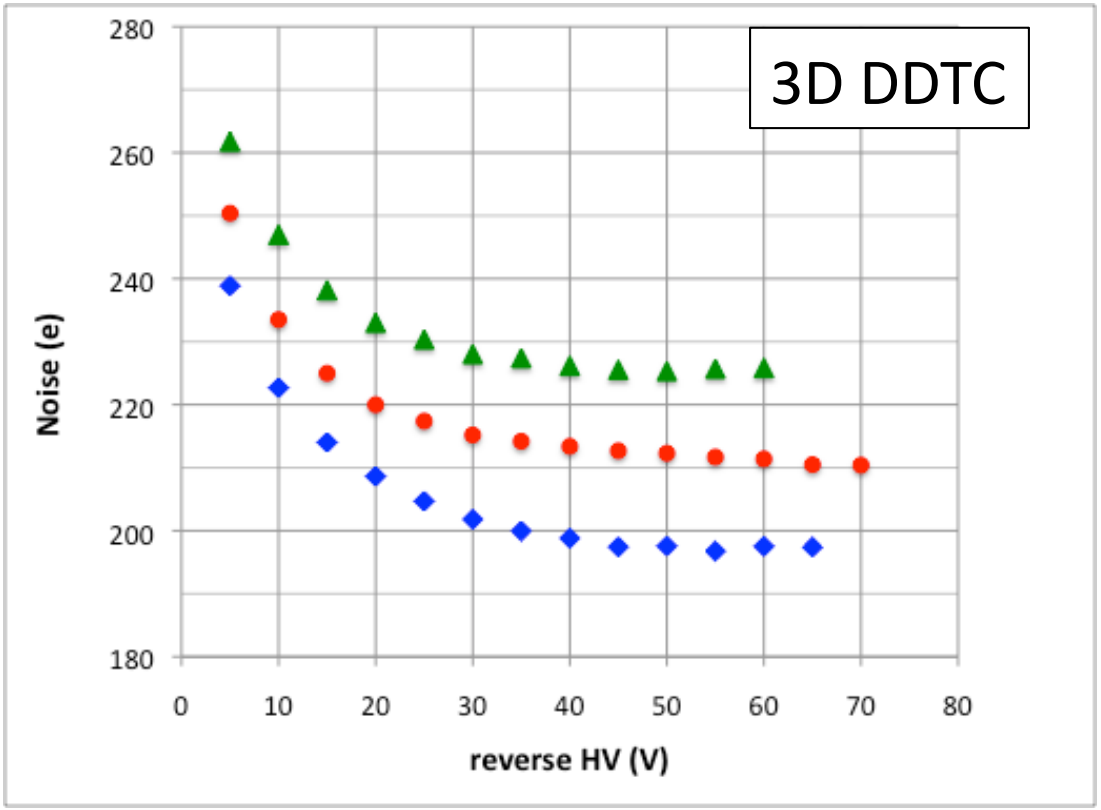
FE Tuned with Th=3k2e- and 60 ToT @ 20ke-

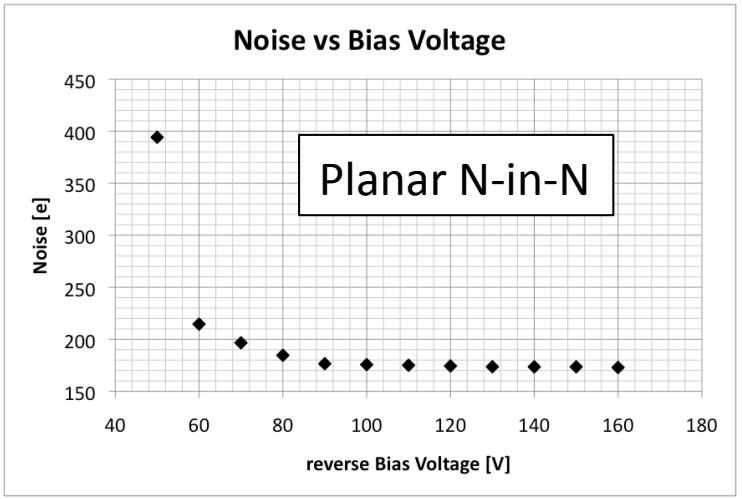
sensor	Threshold (e)	Noise (e)	HV
FBK-2E	3200 ± 58.6	202.3 ± 8.96	-35
FBK-3E	3318 ± 42.02	206.6 ± 8.29	-35
FBK-4E	3284 ± 41.27	229.8 ± 9.87	-35
N-in-N	3259 ± 42.96	181.1 ± 9.367	-150





Noise vs Bias Voltage





▲ 2 electrodes per pixel

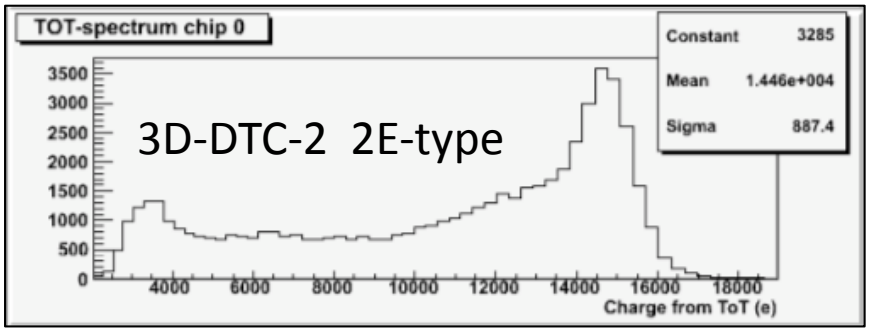
■ 3 electrodes per pixel

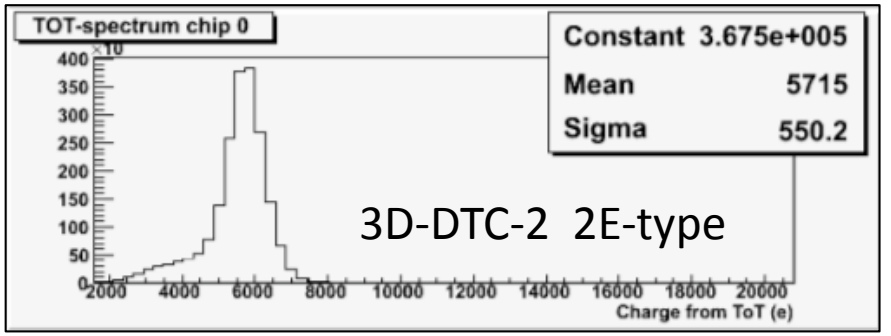
● 4 electrodes per pixel

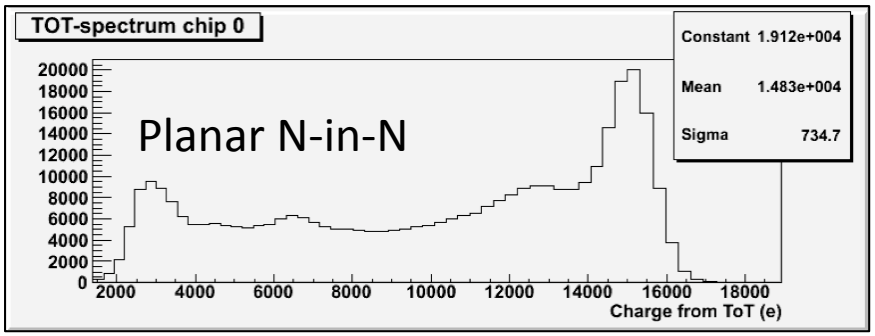
Measurements at climate chamber setup: 20 °C and relative humidity of 12%.

Gamma source test

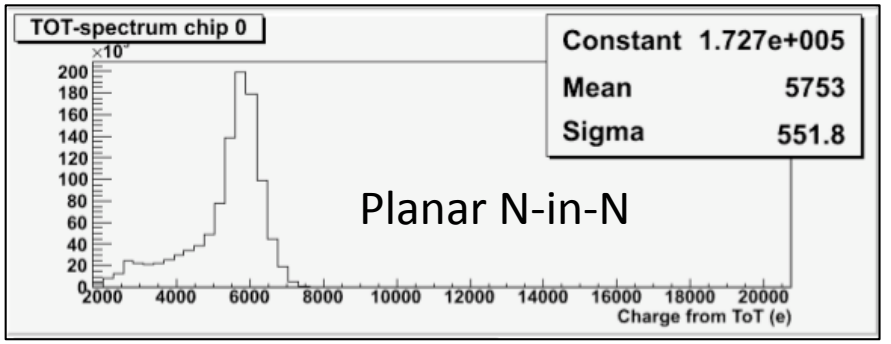
Spectrum as a sum over all pixel without any clustering







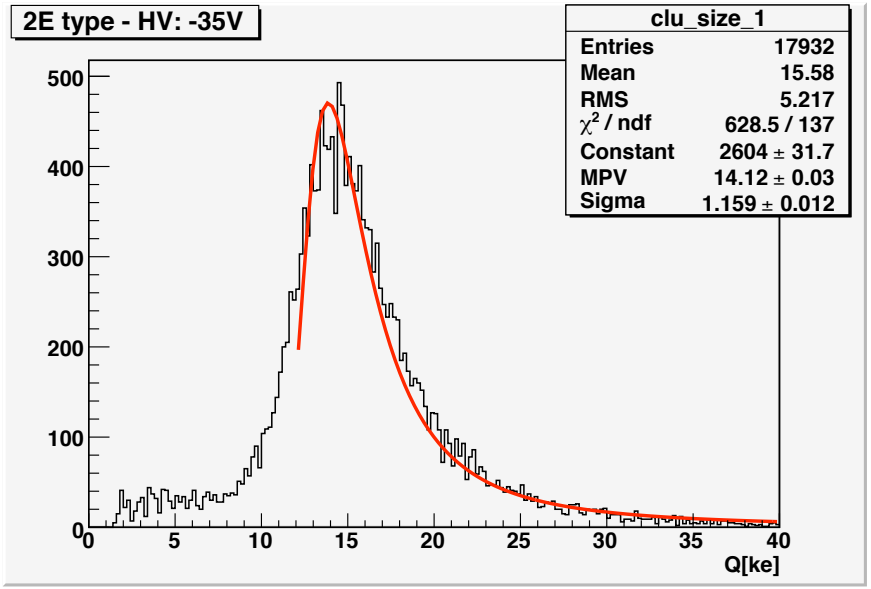
Am241
See the expected 60keV peak

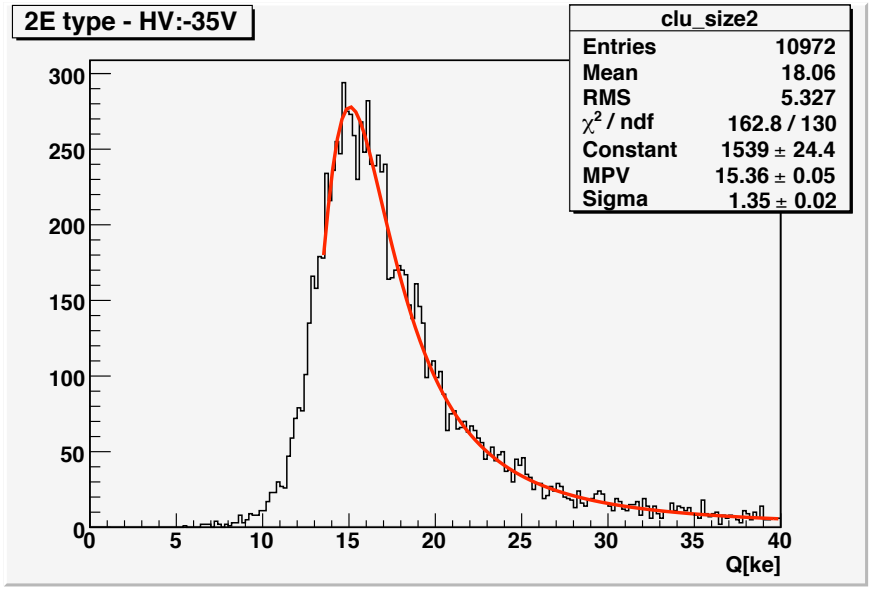


Cd109
See the expected 23keV peak

Beta source tests (Sr90)

3D-DDTC: 200 μm thickness

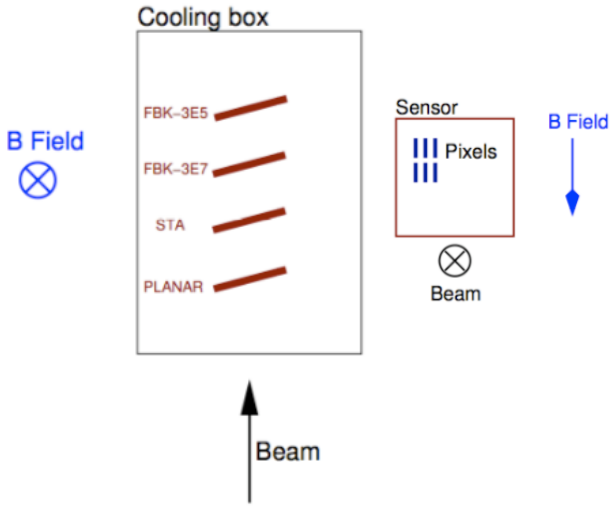




Sensor type	MPV clu.size.1 (ke-)	MPV clu.size 2 (ke-)
3D-2E	14.12 ±0.03	15.36± 0.05
3D-3E	14.07 ± 0.03	15.25± 0.02
3D-4E	14.07± 0.03	15.25± 0.03
Planar (250 μm)	17.19± 0.18	18.52± 0.06

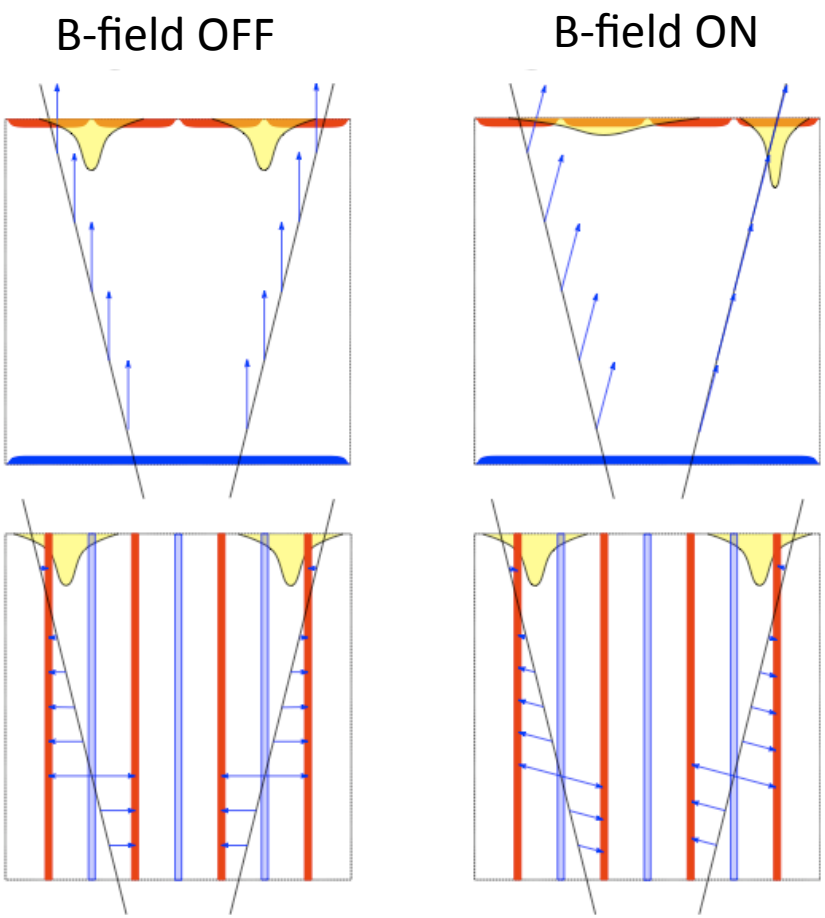
Beam Tests at CERN

- In the framework of ATLAS 3D Collaboration
  - Study the ATLAS 3DSi pixels in the operational conditions of ATLAS Inner Detector
- The beam line (CERN North Area – H8)
  - 180 GeV π^+ from SPS
  - *Morpurgo* magnet: Vertical field, max strength: (1.35±0.10)T, large bore dipole: 4m x 1.6mϕ
  - Used for ATLAS Inner Tracker characterization
- The Detectors Under test
  - N-in-N Planar Pixel sensor (reference sensor) -*HV= -150V* -
  - Stanford full 3D sensor (3E-type) -*HV= -35V* -
  - FBK – DTC-2 (3E-type) -*HV= -35V* -
  - FBK – DTC-2B (3E-type) -*HV= -8V* -
- Configuration
  - DUTs with no tilt, magnetic field ON and OFF
  - DUTs with 15° nominal tilt, magnetic field ON and OFF



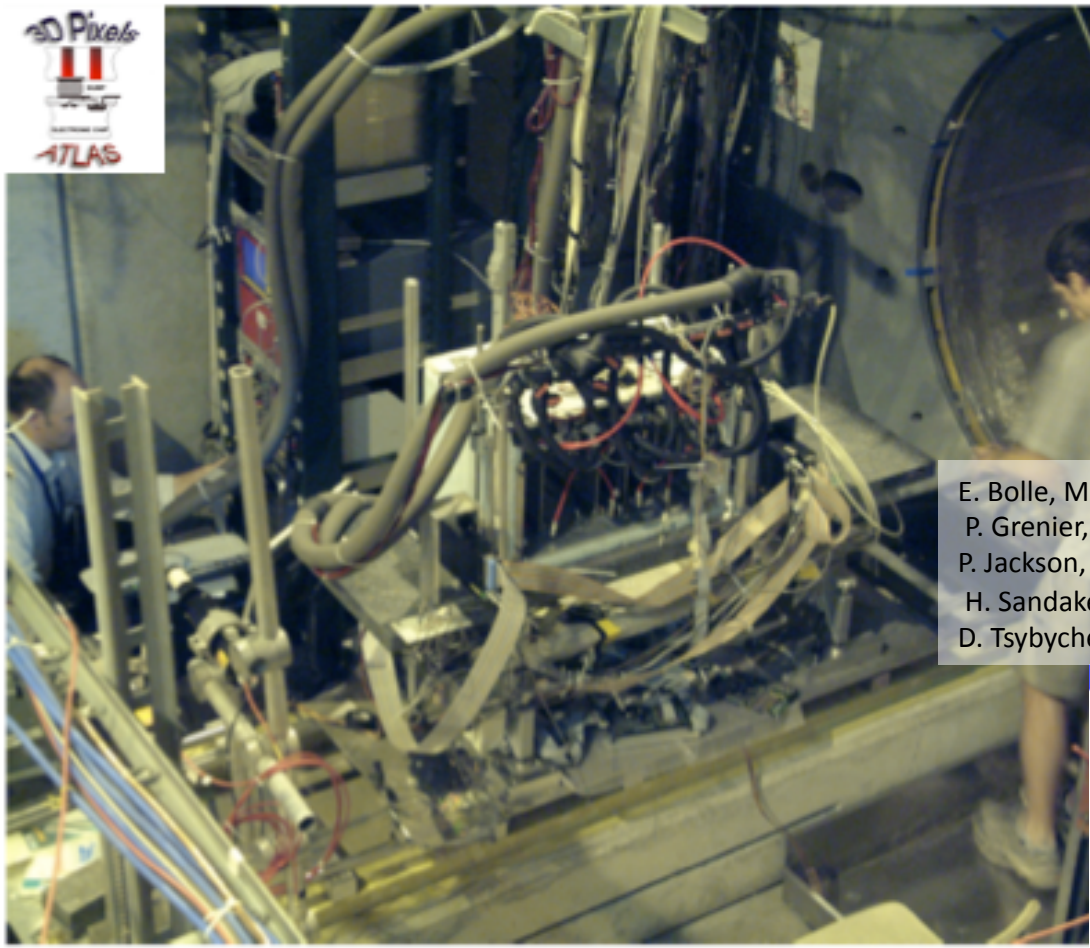
Effect of Magnetic Field

- Planar sensors
  - E and B fields are orthogonal
  - Lorentz force orthogonal to drift
  - Focus or de-focus charge cloud
  - Cluster size minim. at Lorentz angle
- 3D sensors
  - E and B fields are coplanar (lateral)
  - Lorenz force act out of the lateral plane
  - Minimal effect on charge could



→ Expect small effect for 3D sensors

Experimental area



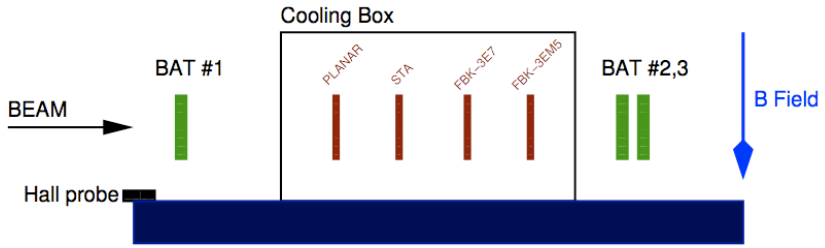
E. Bolle, M. Borri, C. Da Via, S. Dong, S. Fazio, P. Grenier, S. Grinstein, H. Gjersdal, P. Hansson, P. Jackson, M. Kocian, A. La rosa, F. Rivero, O. Rohne, H. Sandaker, K. Sjobak, T. Slavicek, J.-W. Tsung, D. Tsybychev, C. Young

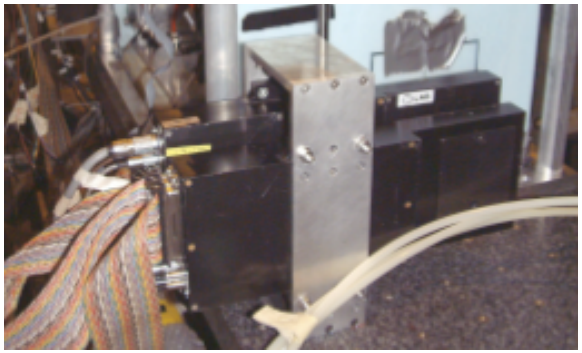
October 3DSi TestBeam Shift List

	Mon. 05	Tues. 06	Wed. 07	Thur. 08	Frid. 09	Sat. 10	Sun. 11
00:00-08:00	-	-	O. Rohne	O. Rohne D. Silverstein	O. Rohne D. Silverstein	I. Troyano D. Silverstein	I. Troyano
08:00-16:00	-	-	P. Hansson H. Gjersdal	P. Hansson M. Giordani	P. Hansson H. Gjersdal	P. Grenier H. Gjersdal	P. Grenier M. Giordani
16:00-24:00	-	-	I. Troyano P. Grenier	A. La Rosa P. Grenier	A. La Rosa M. Giordani	A. La Rosa M. Giordani	H. Gjersdal C. Nellist
	Mon. 12	**Tues. 13**	**Wed. 14**	**Thur. 15**	**Frid. 16**	**Sat. 17**	**Sun. 18**
00:00-08:00	I. Troyano	I. Troyano	O. Rohne	O. Rohne	K. Sjobaek	S. Grinstein K. Sjobaek	I. Troyano K. Sjobaek
08:00-16:00	P. Hansson P. Jackson	P. Hansson P. Jackson	M. Borri P. Jackson	C. Barrera A. La Rosa	C. Da Via A. La Rosa	M.Chmeissani P. Grenier	M.Chmeissani J. Balbuena
16:00-24:00	H. Gjersdal C. Nellist	P. Grenier C. Nellist	I. Troyano P. Grenier	S. Grinstein M. Borri	C. Barrera M. Borri	C. Barrera C. Da Via	C. Barrera M. Borri
	Mon. 19	**Tues. 20**	**Wed. 21**	**Thur. 22**	**Frid. 23**	**Sat. 24**	**Sun. 25**
00:00-08:00		O. Rohne S. Grinstein	O. Rohne S. Grinstein	O. Rohne K. Helle	O. Rohne K. Helle	K. Helle	
08:00-16:00	Installation in H8	C. Fleta	C. Fleta A. La Rosa	C. Fleta A. La Rosa	M. Giordani C. Da Via	M. Giordani C. Da Via	M. Giordani J. Stupak
16:00-24:00	M.Chmeissani J. Balbuena	I. Troyano J. Balbuena	I. Troyano I. Korolkov	J. Balbuena I. Korolkov	H. Gjersdal I. Korolkov	H. Gjersdal A. Micelli	A. Micelli
	Mon. 26	**Tues. 27**	**Wed. 28**	**Thur. 29**	**Frid. 30**	**Sat. 31**	**Sun. 01**
00:00-08:00							
08:00-16:00	J. Stupak	J. Stupak P. Hansson	J. Stupak P. Grenier	P. Grenier B. DeWilde	D. Silverstein P. Grenier	D. Silverstein P. Grenier	P. Grenier
16:00-24:00	A. Micelli H. Gjersdal	B. DeWilde H. Gjersdal	P. Hansson H. Gjersdal	H. Gjersdal			

Beam Telescope and Tracking

- Bonn ATLAS Telescope
  - Two-sided Si micro-strip sensors
  - Strip pitch: 50 um
  - Analog read-out
  - Integrated DAQ and on-line DQ system
  - Position resolution ~ 5um
  - Masked noisy strips
- Trigger system
  - Two scintillators in coincidence
  - Trigger Veto – anti coincidence
  - Trigger phase measurements (TDC)
- Magnetic field tracking
  - Using 3 telescope planes
  - Approximate field as homogeneous
- <u>Data Analysis performed with:</u>
  - **H. Gjersdal** and **O. Rohne** / **Oslo**
  - **P. Hansson** and **P. Grenier** / **SLAC**

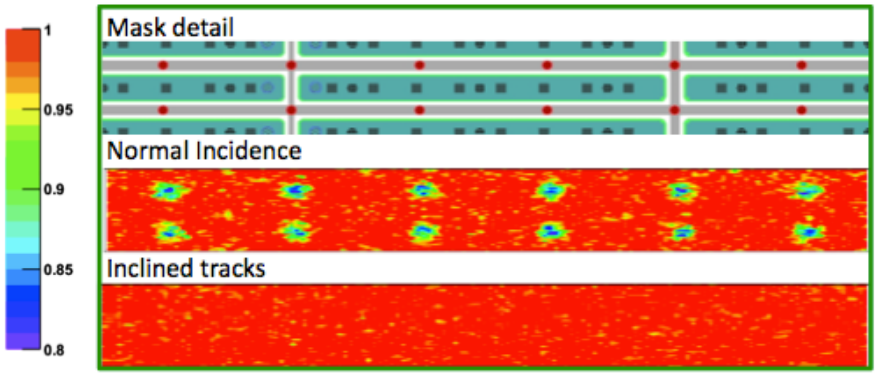




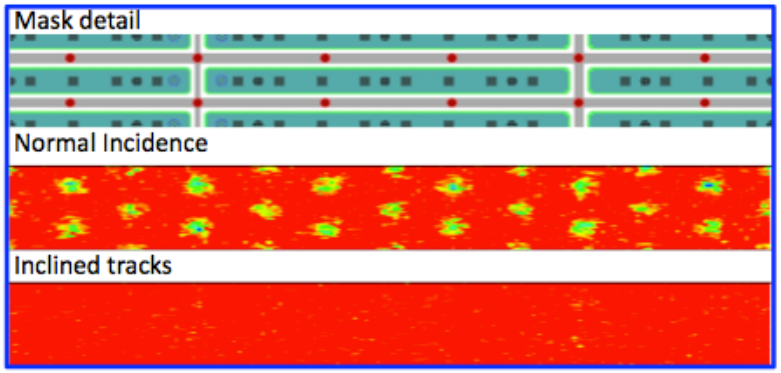
3D-DDTC - Preliminary results

- Hit Efficiency

To show the hit efficiency as function of the track position all tracks have been studied and the track position has been folded into a 2x2 cell (800µ*m x* 100*µm).*



DTC-2: 90-100um Column Overlap

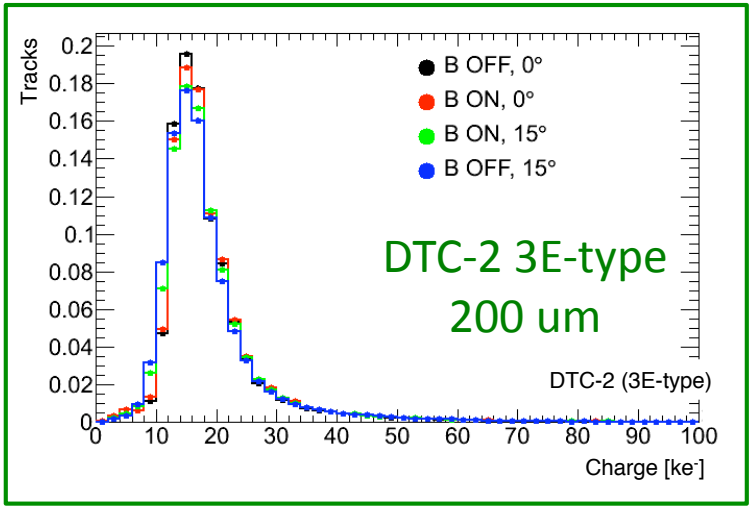


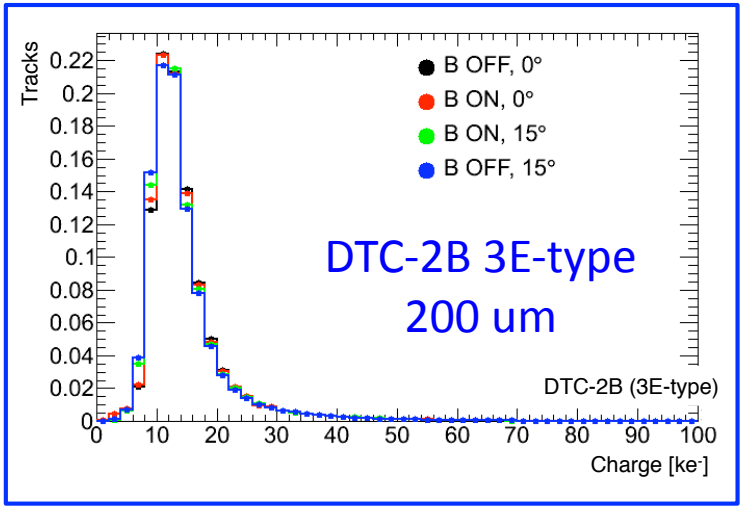
DTC-2B: 110-150um Column Overlap

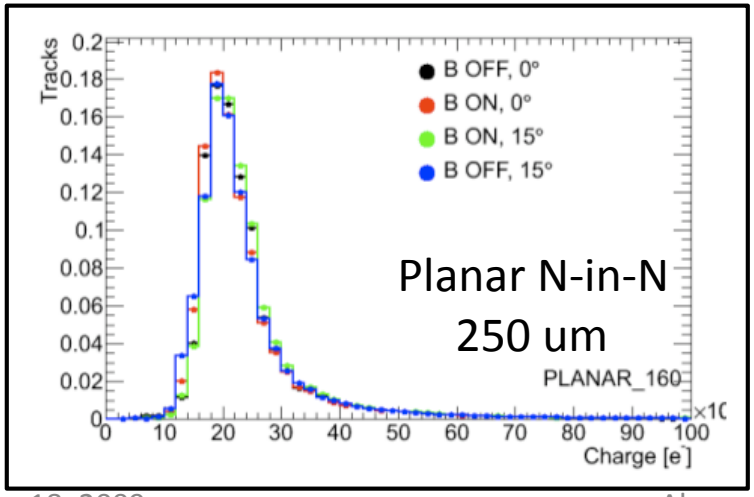
DUTs	B off		B on	
	ϕ = 0°	ϕ = 15°	ϕ = 0°	ϕ = 15°
DTC-2 (3E-type)	98.38±0.03	99.82±0.01	98.34±0.03	99.49±0.01
DTC-2B (3E-type)	99.21±0.02	99.82±0.004	99.14±0.02	99.945±0.004

3D-DDTC - Preliminary results

- Most probable charge distribution







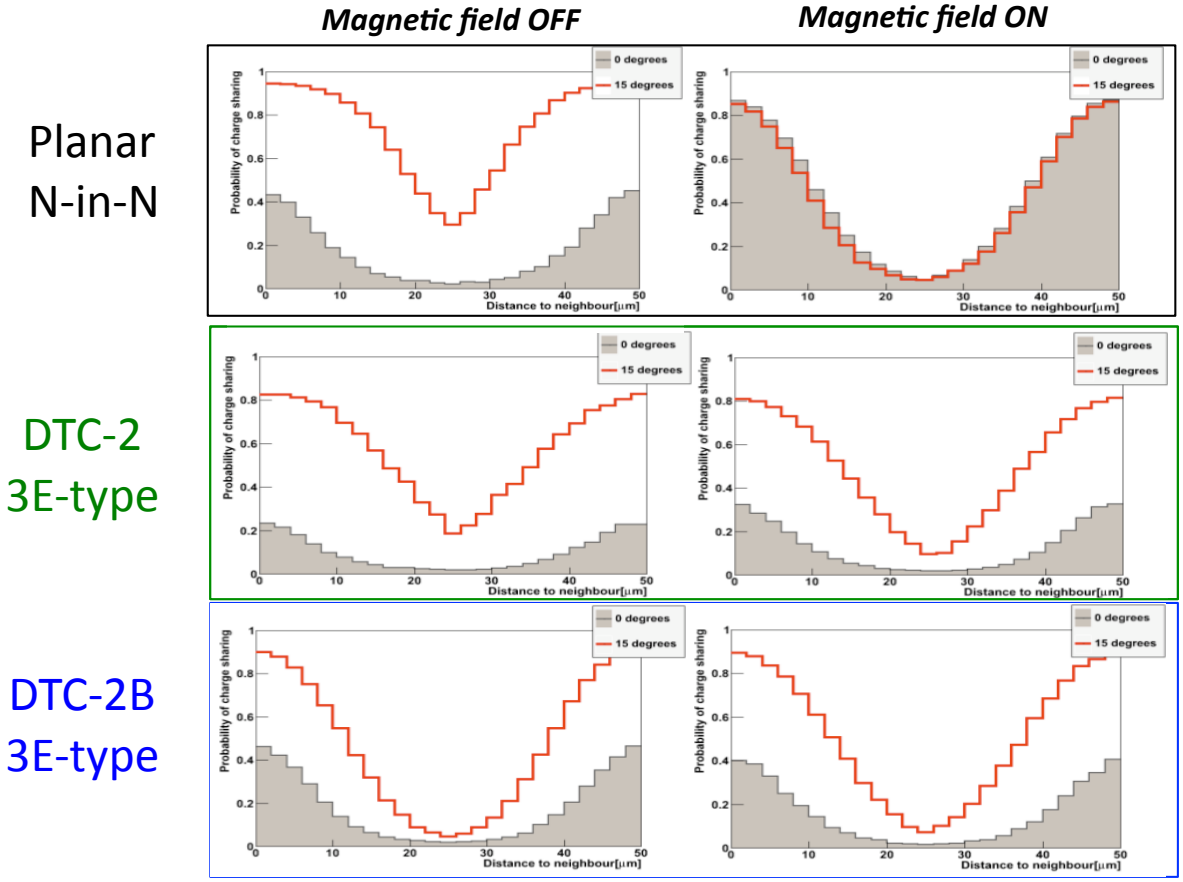
DTC-2B *lower charge than* ***DTC-2*** *!!!!!*
Operated with a lower bias voltage (-8 V) due to its early breakdown problems

DTC-2 *and* ***Planar N-in-N*** *…*
different charge collected in according to different sensors thickness !!

3D-DDTC - Preliminary results

- Charge sharing probability (50 um direction)

Defined as as the probability that one of the relative neighbors of the pixel cell the track passes through has gone above threshold, given that the pixel cell where the track passes through has gone above threshold

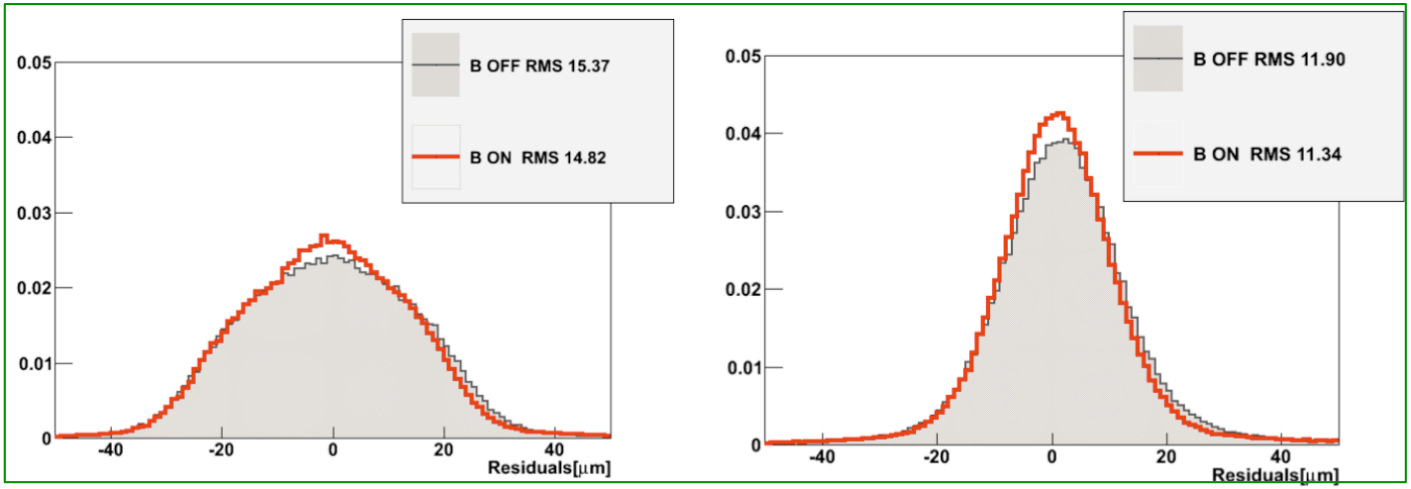


3D-DDTC - Preliminary results

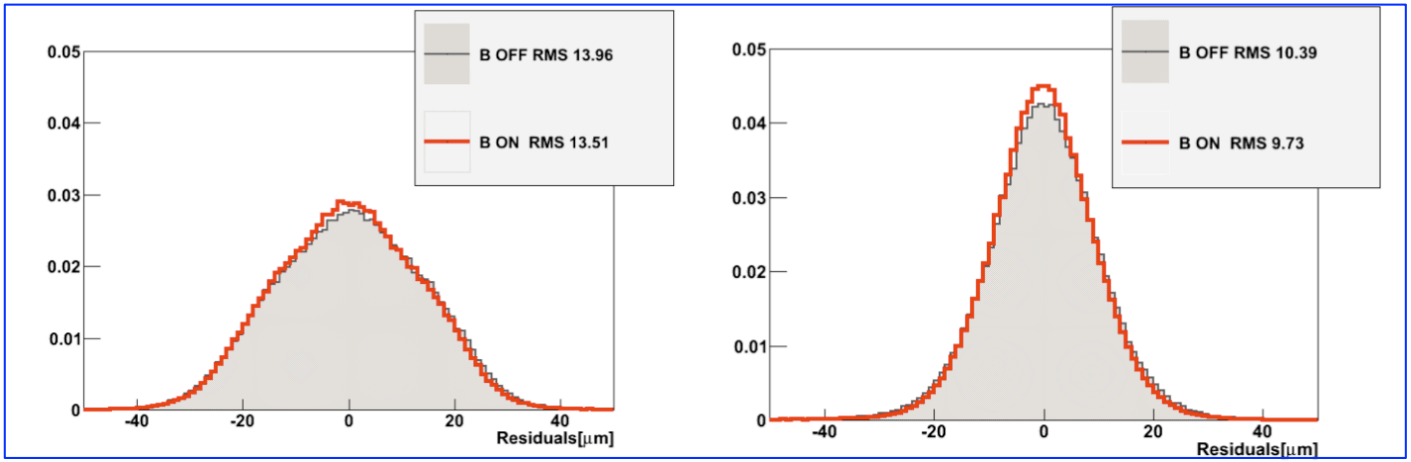
- Track residual distribution (50 um direction)

Perpendicular tracks *Inclined tracks*

DTC-2
3E-type



DTC-2B
3E-type



CERN Irradiation plans

- **Pre-Irradiation tests**
  - For DUTs : IV scan, Monleak scan, Threshold&Noise, ToT Calib, Source tests: Am241 and Cd109 (self-triggered) and Sr90 (external triggered)

- **Front-end electronics irrad tests (CERN – IRRAD-1)**
  - We know the FEI3 should work after a tot fluences irrad of ~ 4 E15 p/cm2
  - Study its behavior at different higher fluences (~5-6 E15 p/cm2) in several steps.
    - Already tested up to 3.78 E15 p/cm2 at IRRAD-3.

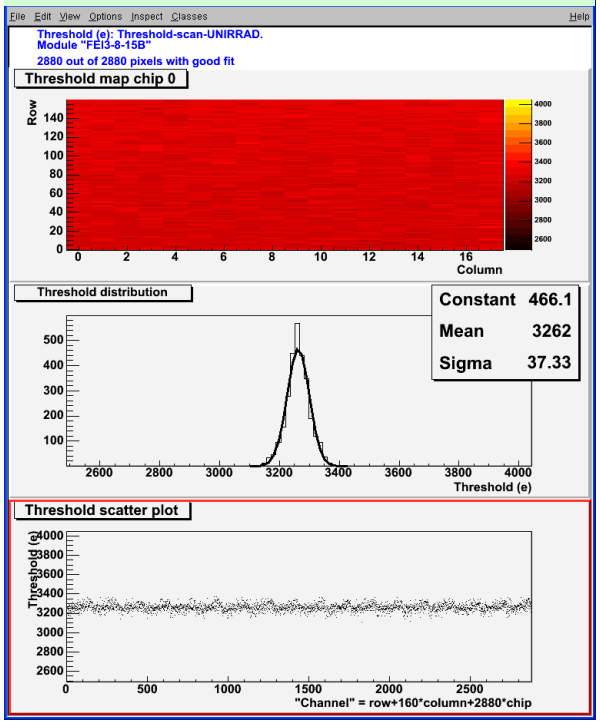
- **Detectors (FE+sensor) irrad tests (CERN – IRRAD-3)**
  - Silicon 3D (FBK-dtc2) and planar Silicon sensors (N-in-N).
  - Study their behavior at different fluences (up to 4 E15 p/cm2)

- **Post-Irradiation tests**
  - For DUTs : IV scan, Monleak scan, Threshold&Noise, ToT Calib, Source tests: Am^{241} and Cd^{109} (self-triggered) and Sr^{90} (external triggered).
  - ATLAS 3D and PPS beam tests (2010) at CERN SPS.

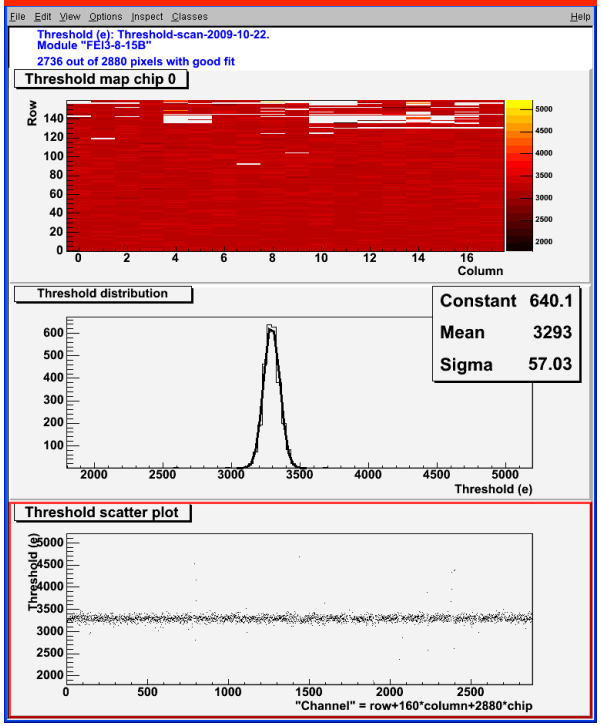
FEI3 irradiation: preliminary results

FE Tuned at 60 ToT @ 20ke- with a Threshold of 3k2-

Before irradiation



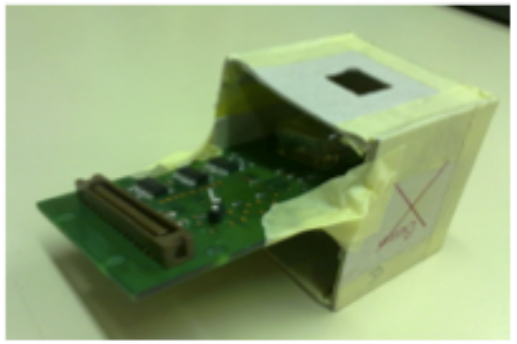
After irrad: 3.78 E15 p/cm^2



CERN – IRRAD 1

FE No biased

FE retuned
after irradiation

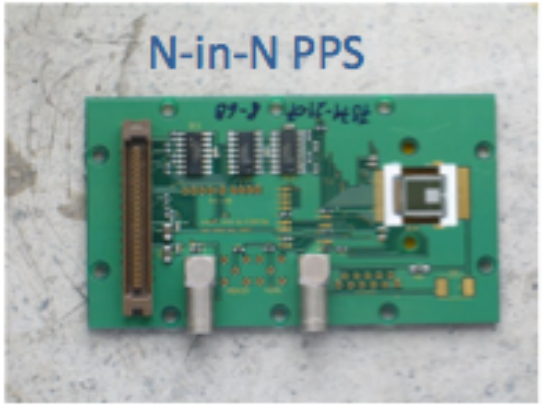


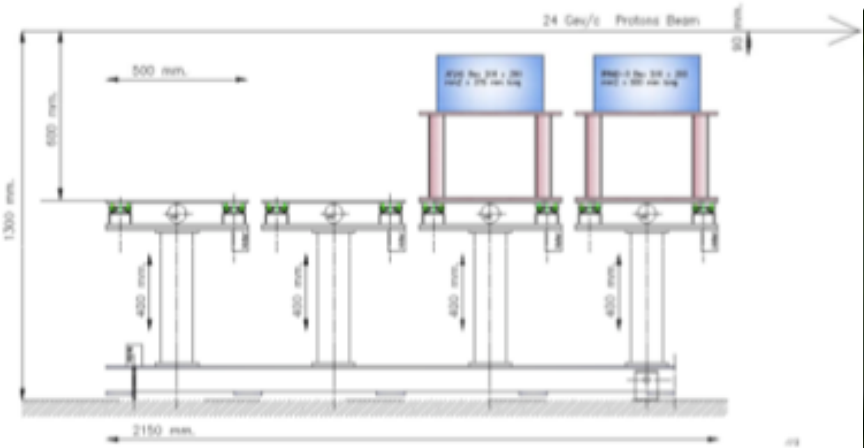
	BEFORE IRRAD	AFTER IRRAD (3.78 E15 p/cm2)
Threshold (e)	3262 ± 37.33	3293 ± 57.03
Noise (e)	101.8 ± 8.3	105.5 ± 8.12
ToT (e)	61.67 ± 1.84	59.85 ± 2.42

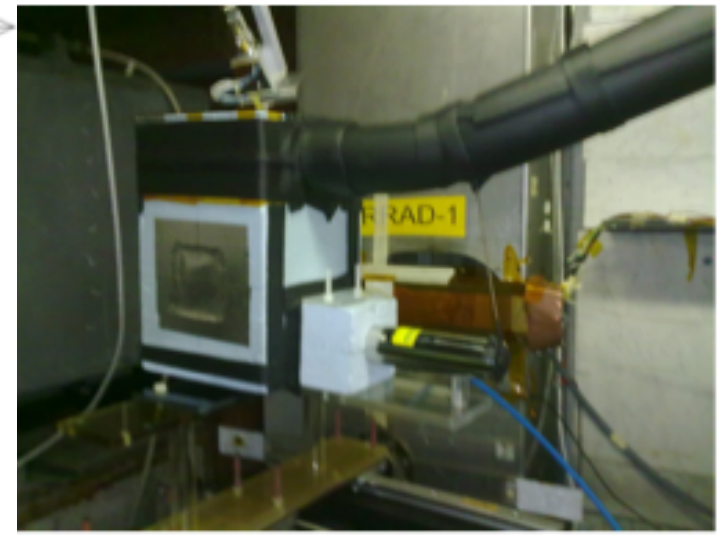
Thanks to:
N. Wermes and F. Hugging for FE-I3 availability and M. Gleser and F. Rivero for irradiation support

SCA Irradiation

- DUTS: Planar (n-in-n) pixel sensor and 3D-DDTC (FBK)
- DUTs biased
- Low temperature (-14C)
- Fluence up to 4 E15 p/cm2





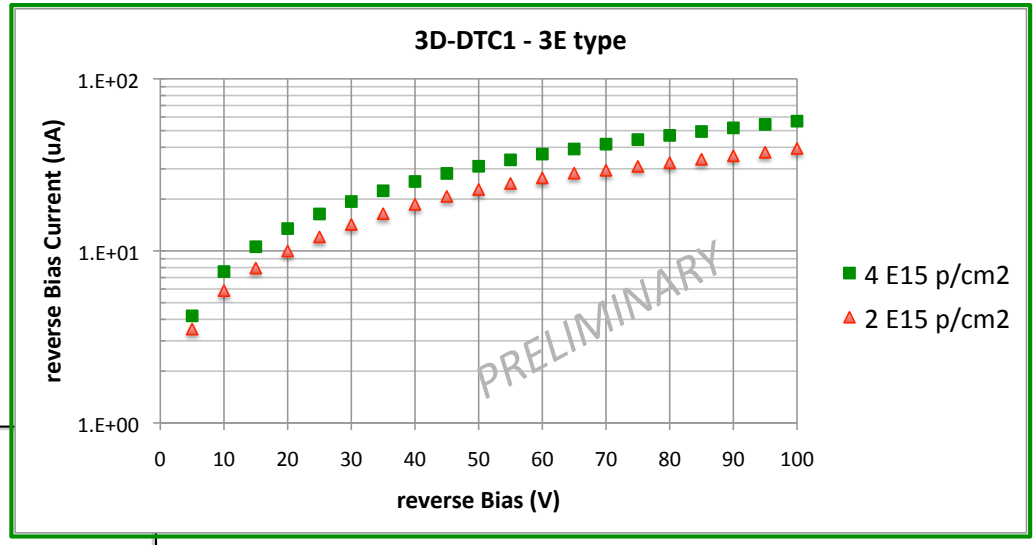


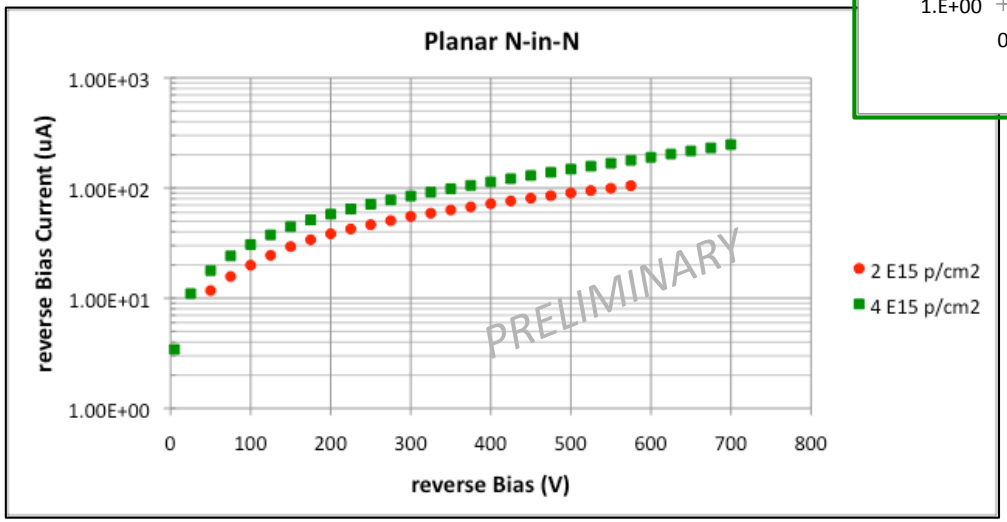
Thanks to M. Gleser and F. Rivero for irrad. supporter

Very preliminary results from irrad SCA

- IV characteristic of irrad sensors flip-chipped to FE-I3 (sensor&FE irradiated at the same time)
  - 24 GeV proton beam
  - T = -14C

Tot. fluences to be confirmed with Al dosimetry





Contribution to measurement:
F. Rivero / CERN & UniTo

Conclusions

- Development 3D-Si sensor technologies is proceeding with encouraging results at FBK-irst.
- First prototypes (ATLAS 3D-DDTC) have shown good performance
  - Lab and beam tests characterization
- ATLAS 3D-DDTC to be validated after irradiation !
  - CERN PS (24 GeV proton beam) Oct. - Nov. 2009
  - post irrad. test.: work in progress …….
- Development of “passing-though column” detectors is on going.
- Possible Detector technology for ATLAS-IBL and SLHC projects