Preliminary results of 3D-DDTC pixel detectors for the ATLAS upgrade

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on behalf of

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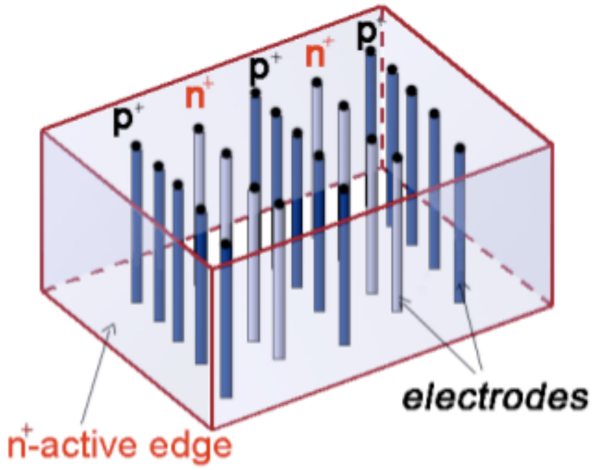
RD09. Sept.30 – Oct.2 , 2009. Firenze, It.

Outline

- 3D-Si sensors overview
- FBK-irst 3D-Si sensors
- Lab characterization
- Beam tests
- Conclusions

3D detectors



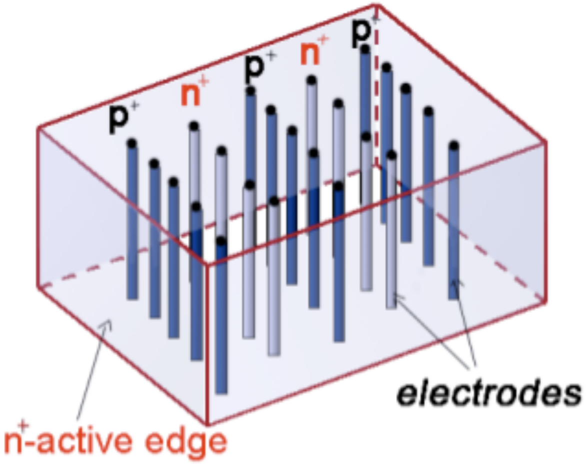
Proposed by S. Parker et al.
NIM A 395 (1997) 328

ADVANTAGE:
-Electron distance
-Low depletion voltage
-Short Collection distance
-Smaller trapping probability after irrad.
    HIGH RADIATION HADRDNESS
- Active edges
    Dead area reduced up to few um
    from the edge

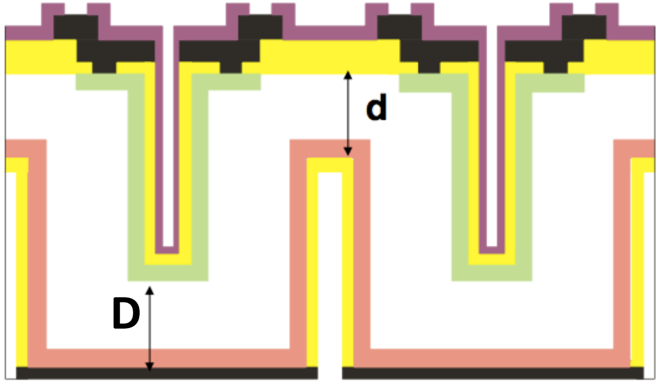
DISAVANTAGE:
-Non uniform response due to electrodes
-Complicated technology
-Higher capacitance with respect to planar

State of the art

Full 3D Active Edge
3D Consortium



Double side Double Type Column
DDTC



3DC Fabricated at Stanford
-tested w/ ATLAS Pixel readout chip (FEI3)
-tested sLHC fluences (NIMA 604 (2009) 504)
-**3DC** SINTEF
-N-in-N bum-bonded w/ FEI3
-N-in-P run advanced (for FEI4)

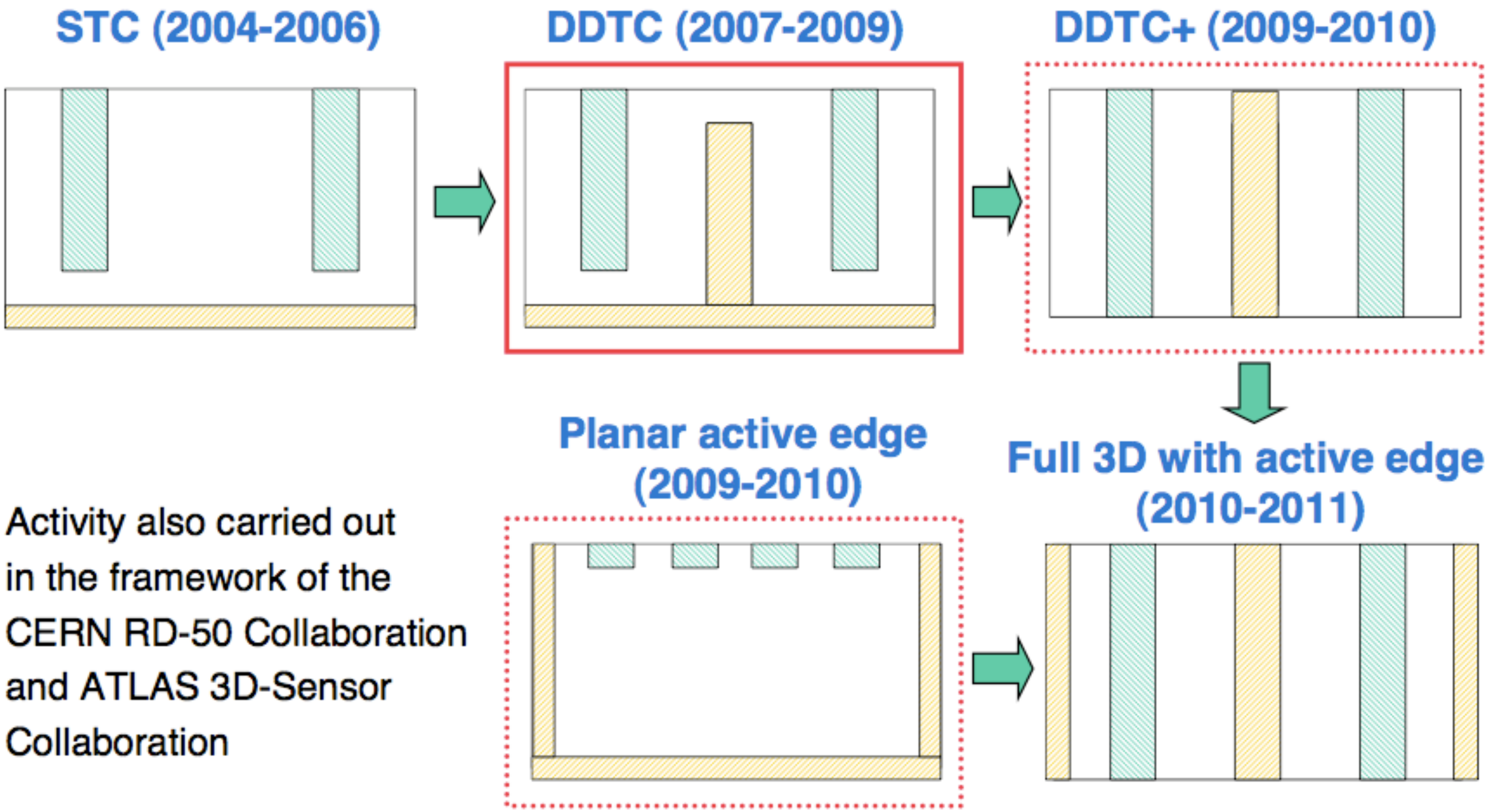
FBK-irst
-tested N-in-P w/ATLAS Pixel readout chip (FEI3)
-Active edge included in the next test runs

CNM
-N-in-P run completed and bump-bonded w/ FEI3

Sensors development / TRENTO

FBK-irst - INFN and University of Trento

FBK/INFN/PAT agreement (since 2004) and CSN5 projects (since 2005)



STC (2004-2006)

DDTC (2007-2009)

DDTC+ (2009-2010)

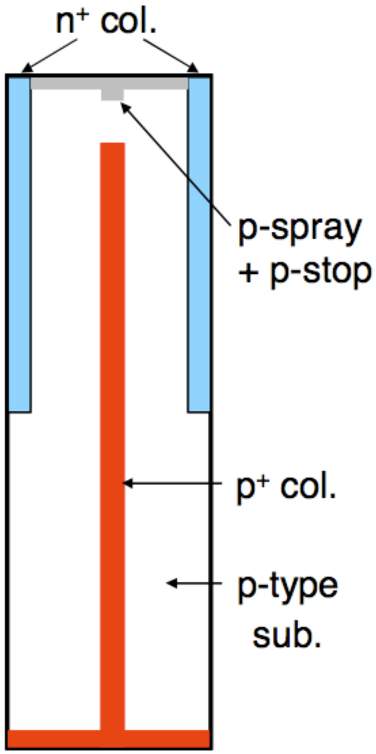
Planar active edge (2009-2010)

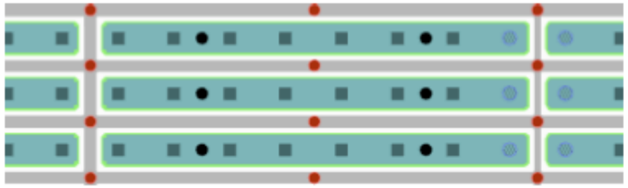
Full 3D with active edge (2010-2011)

Activity also carried out in the framework of the CERN RD-50 Collaboration and ATLAS 3D-Sensor Collaboration

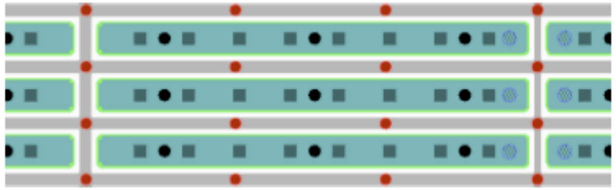
3D-Double side Double Type Column

ATLAS PIXEL SENSORS DESIGN

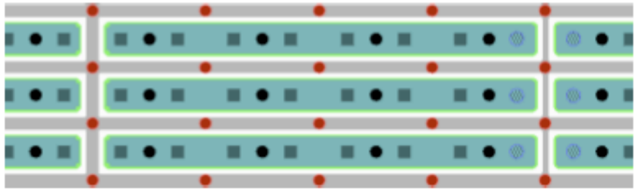




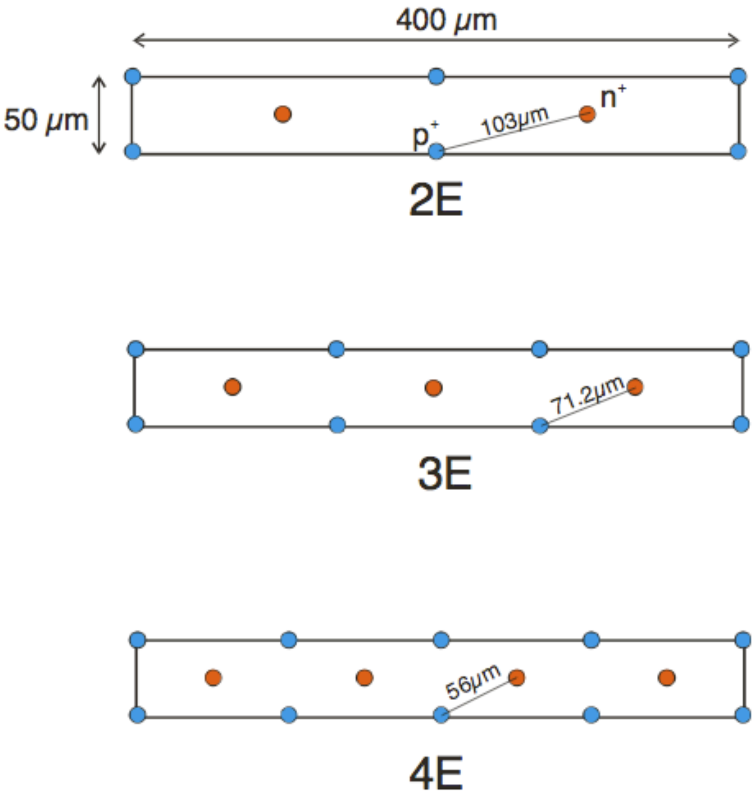
2 junction columns/pixel



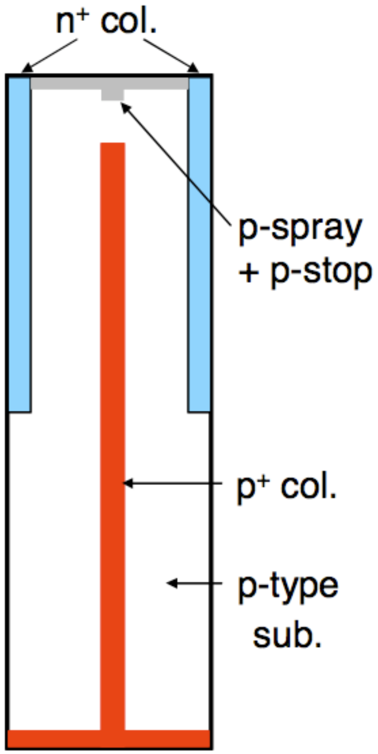
3 junction columns/pixel



4 junction columns/pixel



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)

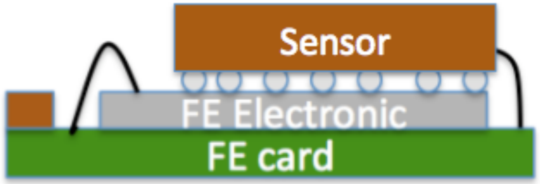
Parameter	**Unit**	**Value**	
		3D-DTC-2	**3D-DTC-2B**
Substrate thickness	μm	200	200
Junction column thickness	μm	100 -110	140 -170
Ohmic column thickness	μm	180 -190	180 – 190
Column overlap	μm	90 - 100	110 -150

Depletion Voltage:

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

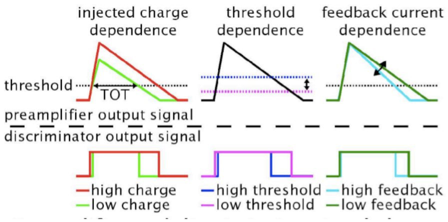
3D-DDTC assemblies with FEI3

- 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



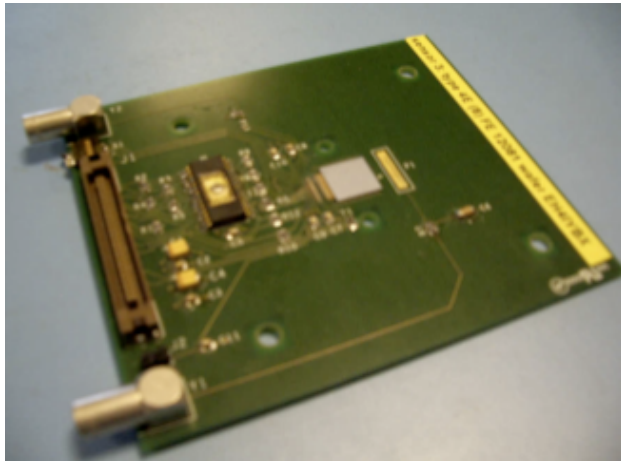
ATLAS readout chip FEI3
-Standard 0.25um CMOS technology
-2880 readout cells of 50um x 400um
-18x160 matrix
-Radiation tolerance up to a total dose of 50Mrad

Each readout cell:
Analog block where the sensor charge is amplified and compared to a programmable threshold by a discriminator;



ToT(length of discriminator signal) depends on:
- deposited charge
- discriminator threshold
- feedback current

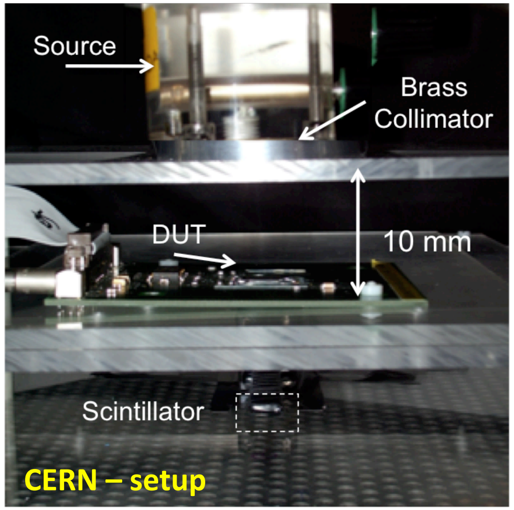
Information of the ToT (in unit of 25 ns) is read out together with the hit information

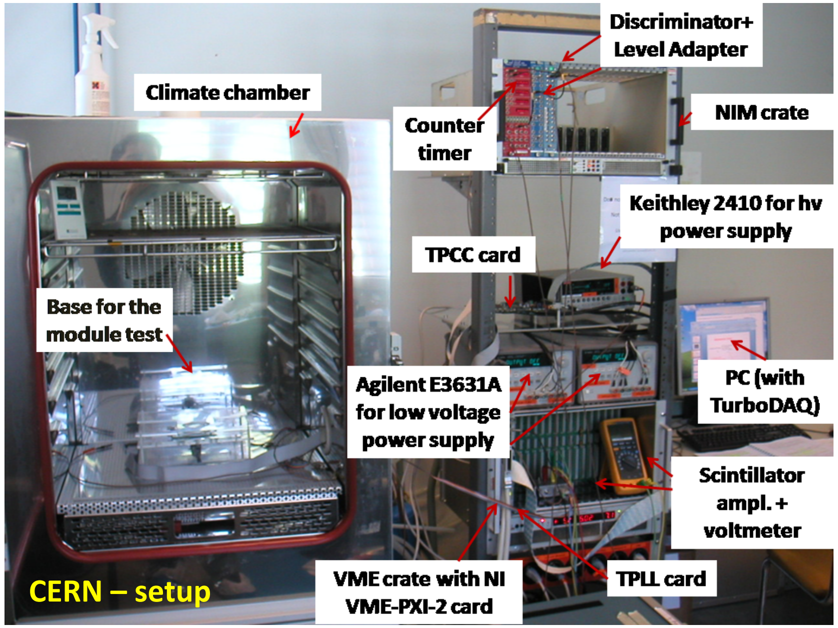


Digital readout part transfers the hit pixel address, a hit time stamp and a digitized amplitude information, the ToT to buffers at the chip periphery.

Experimental setup

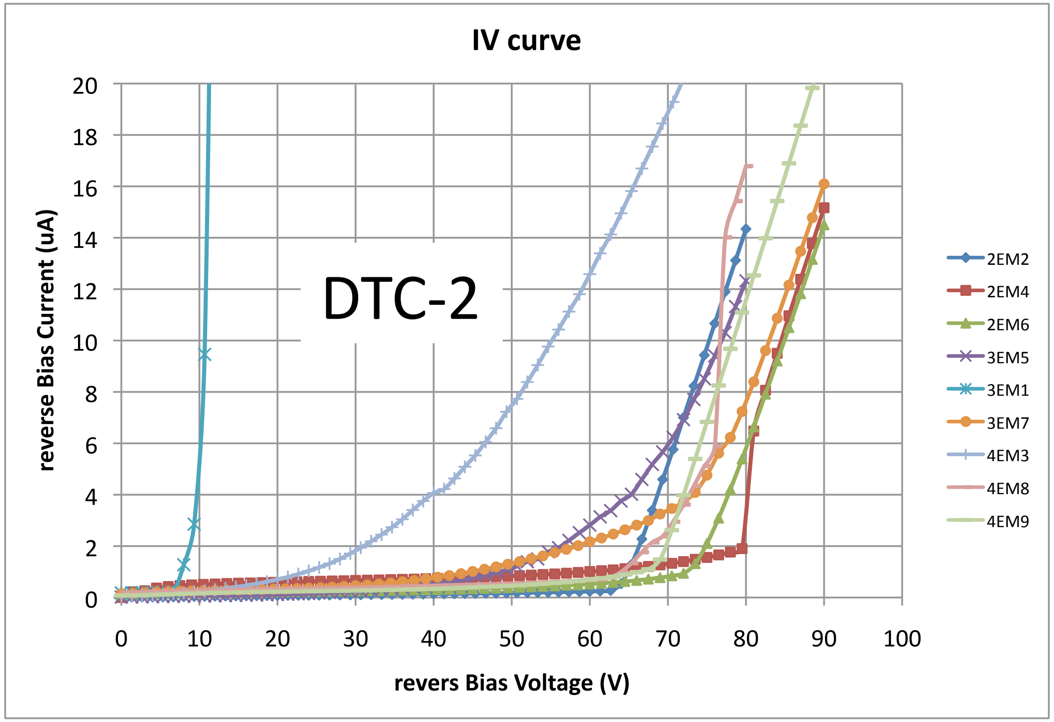
- Tests made at CERN and INFN/Genova
- Pixel test station based on ATLAS TurboDAQ system
- Measurements
  - Electrical and noise tests
  - Response to radioactive sources
    - Gamma: Am241 and Cd 109 →self triggered
    - Beta: Sr90 → triggered by scintillator

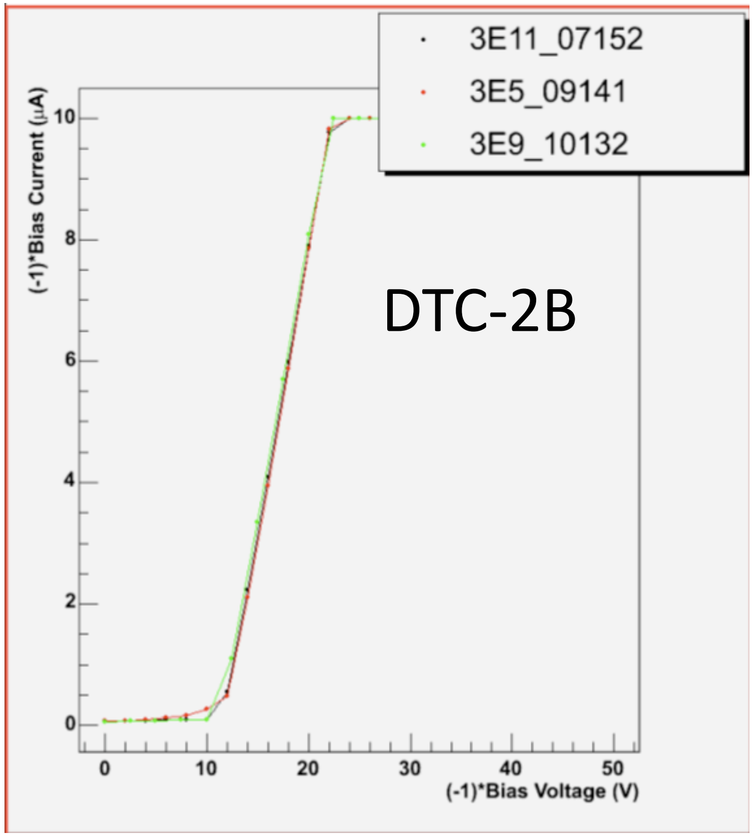




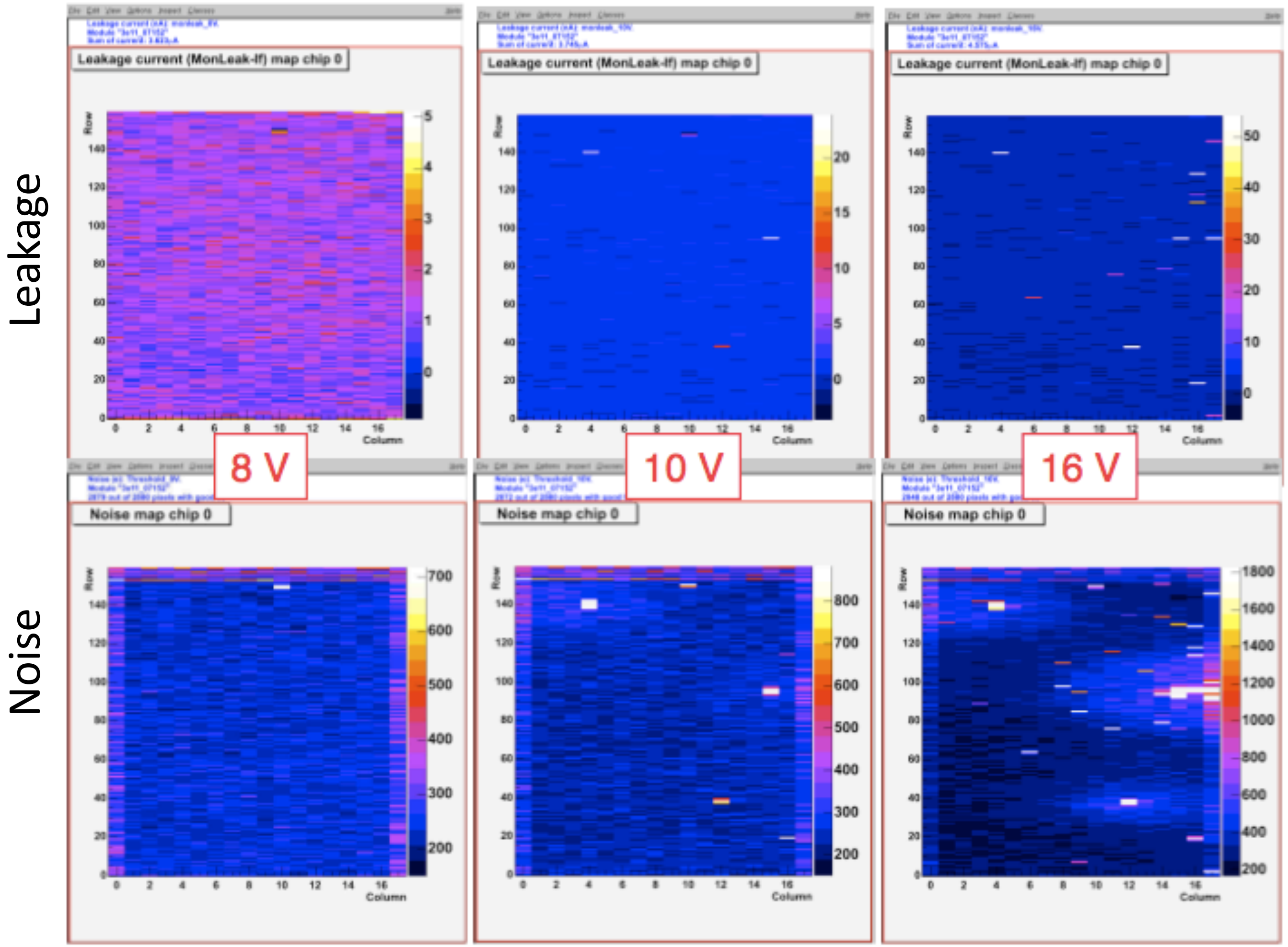
Leakage current

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





DTC-2B: early breakdown problem



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.

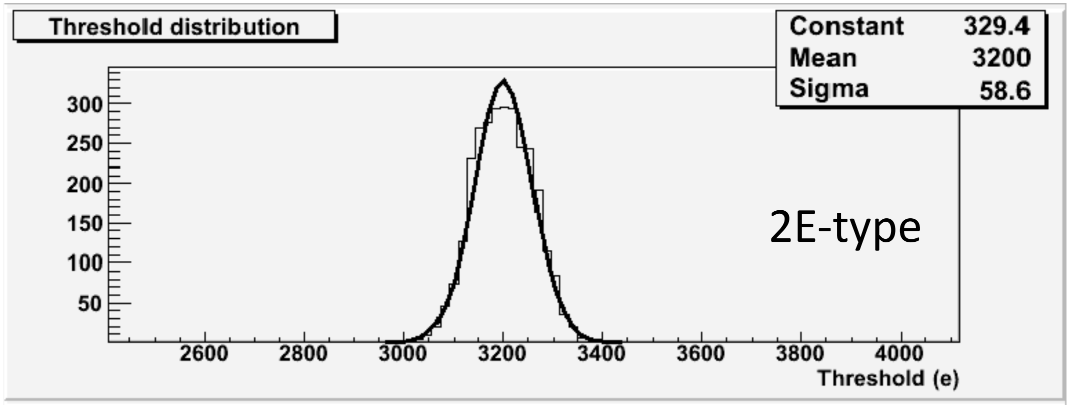
Increasing the bias voltage the number of noisy pixels increases.

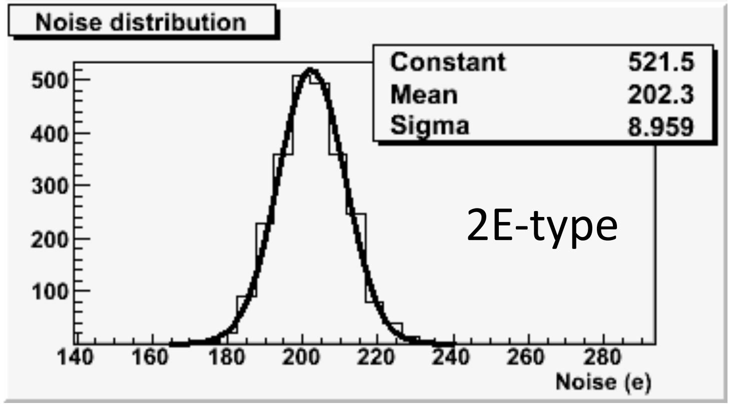
Maybe some damage occurred during the assembly → Still to be understood

Threshold and noise measurements

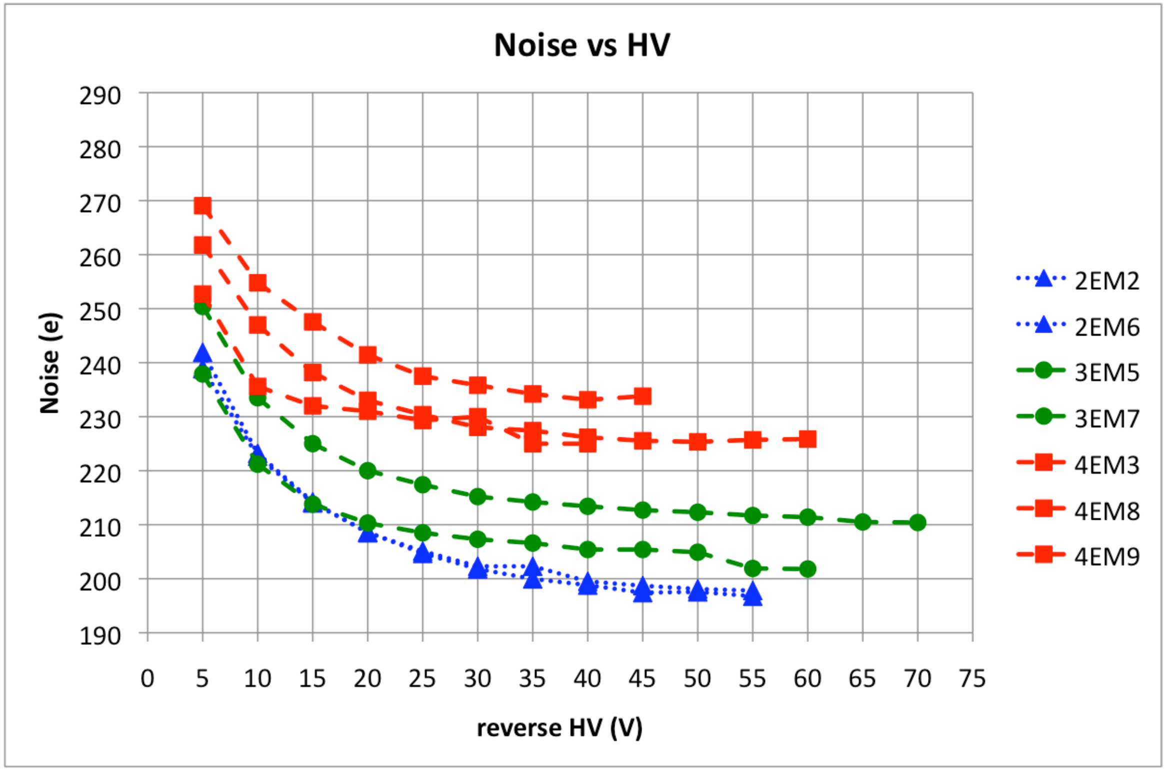
FE Tuned with Th=3k2e- and 60 ToT @ 20ke-

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

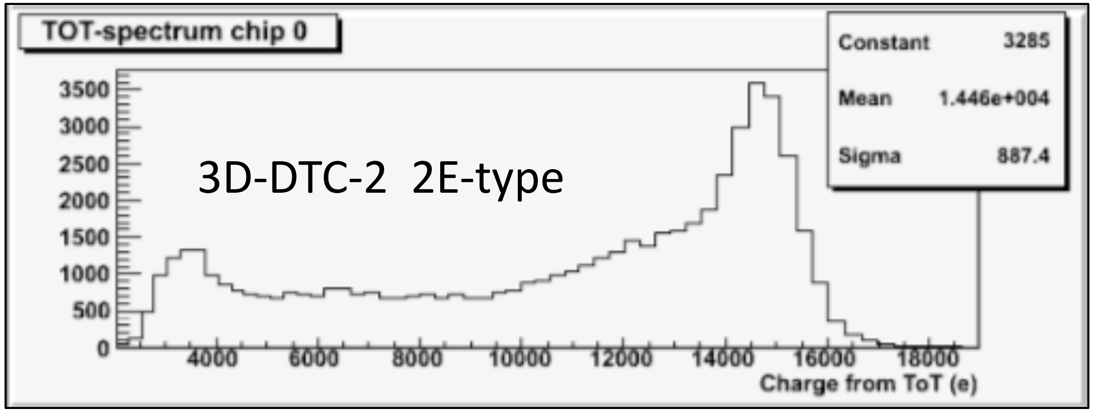
● 3 electrodes per pixel

■ 4 electrodes per pixel

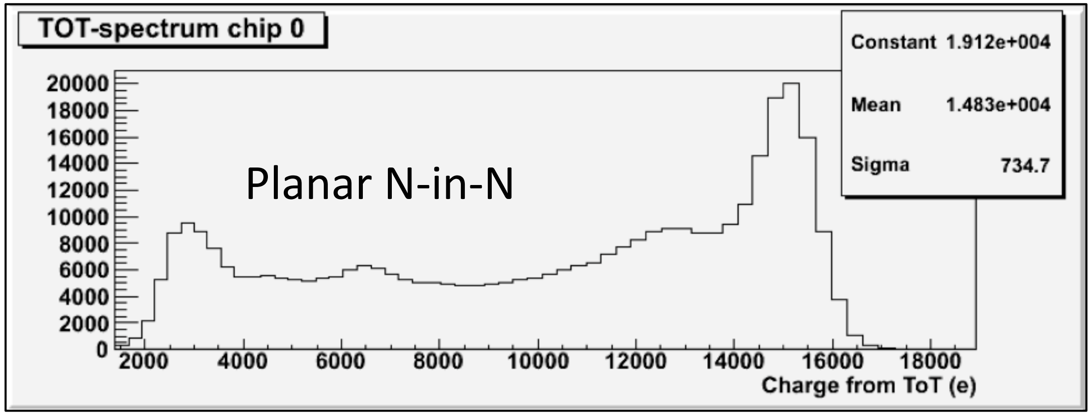
Measurements at climate chamber setup: 20 °C and relative humidity of 12%.

Gamma source test (Am241)

Spectrum as a sum over all pixel without any clustering



3D-DTC-2 2E-type

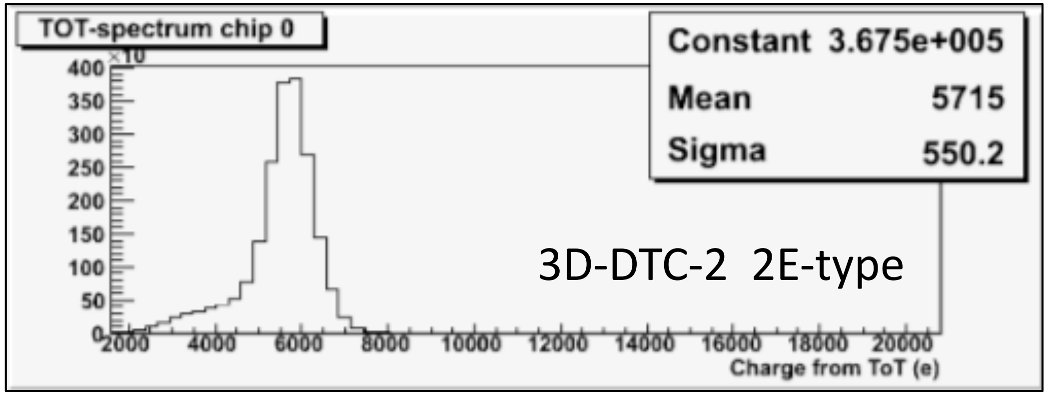


Planar N-in-N

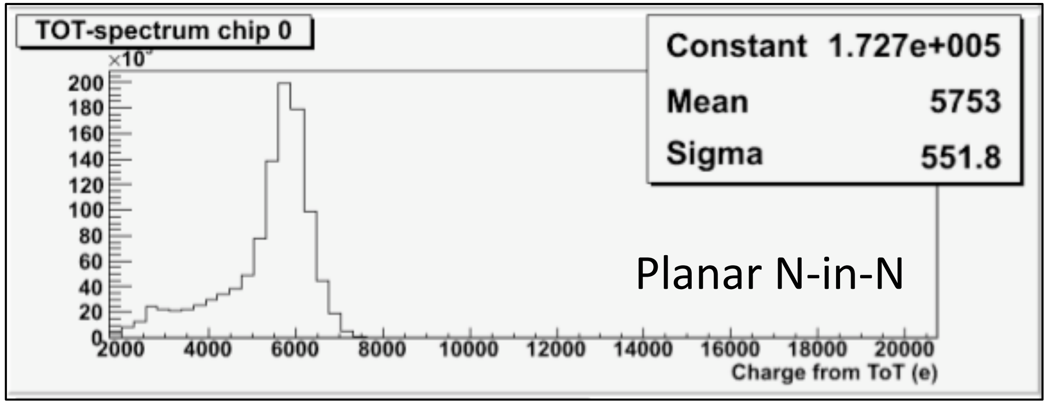
See the expected 60keV peak

Gamma source test (Cd109)

Spectrum as a sum over all pixel without any clustering



3D-DTC-2 2E-type

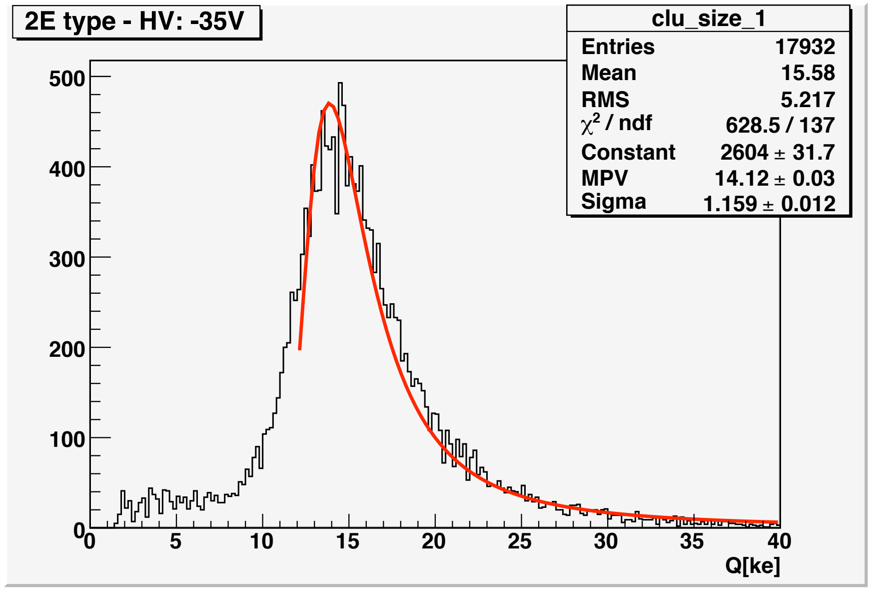


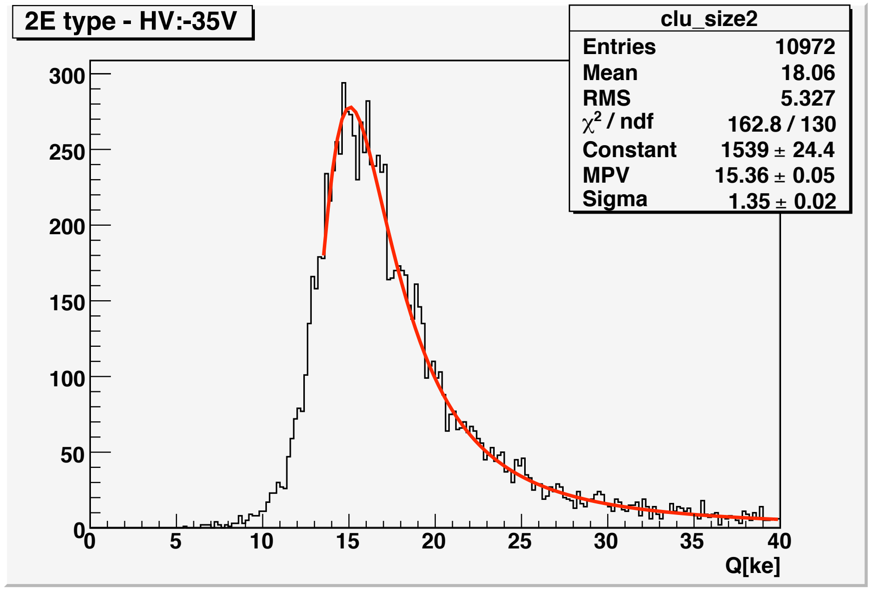
Planar N-in-N

See the expected 23keV peak

Beta source tests (Sr90)

3D-DDTC: 200 μm thickness

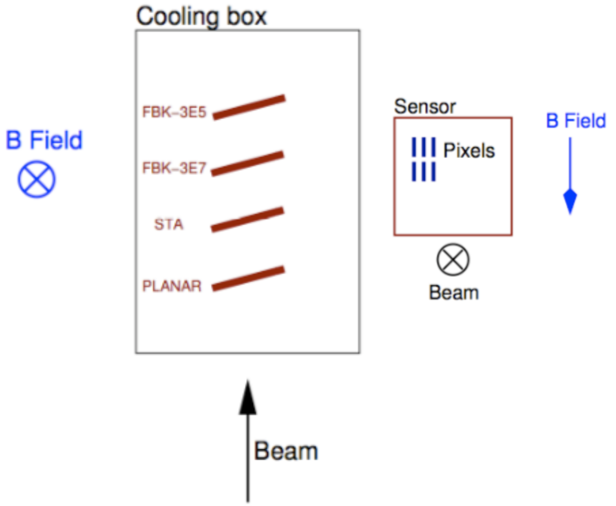




Sensor type	MPV clu.size.1 (ke-)	MPV clu.size 2 (ke-)
3D-2E	14.12 ±0.03	15.36± 0.05
3D-3E	14.07 ± 0.03	15.25± 0.02
3D-4E	14.07± 0.03	15.25± 0.03
Planar (250 μm)	17.19± 0.18	18.52± 0.06

Beam Tests at CERN

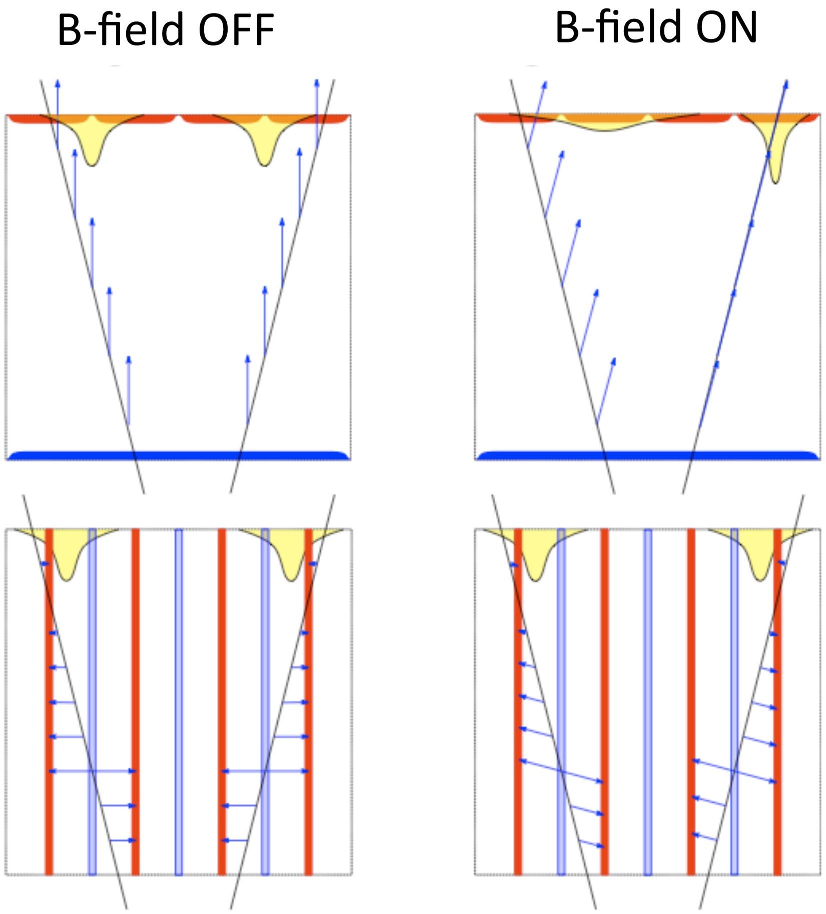
- In the framework of ATLAS 3D Collaboration
  - Study the ATLAS 3DSi pixels in the operational conditions of ATLAS Inner Detector
- The beam line (CERN North Area – H8)
  - 180 GeV π^+ from SPS
  - *Morpurgo* magnet: Vertical field, max strength: (1.35±0.10)T, large bore dipole: 4m x 1.6mϕ
  - Used 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

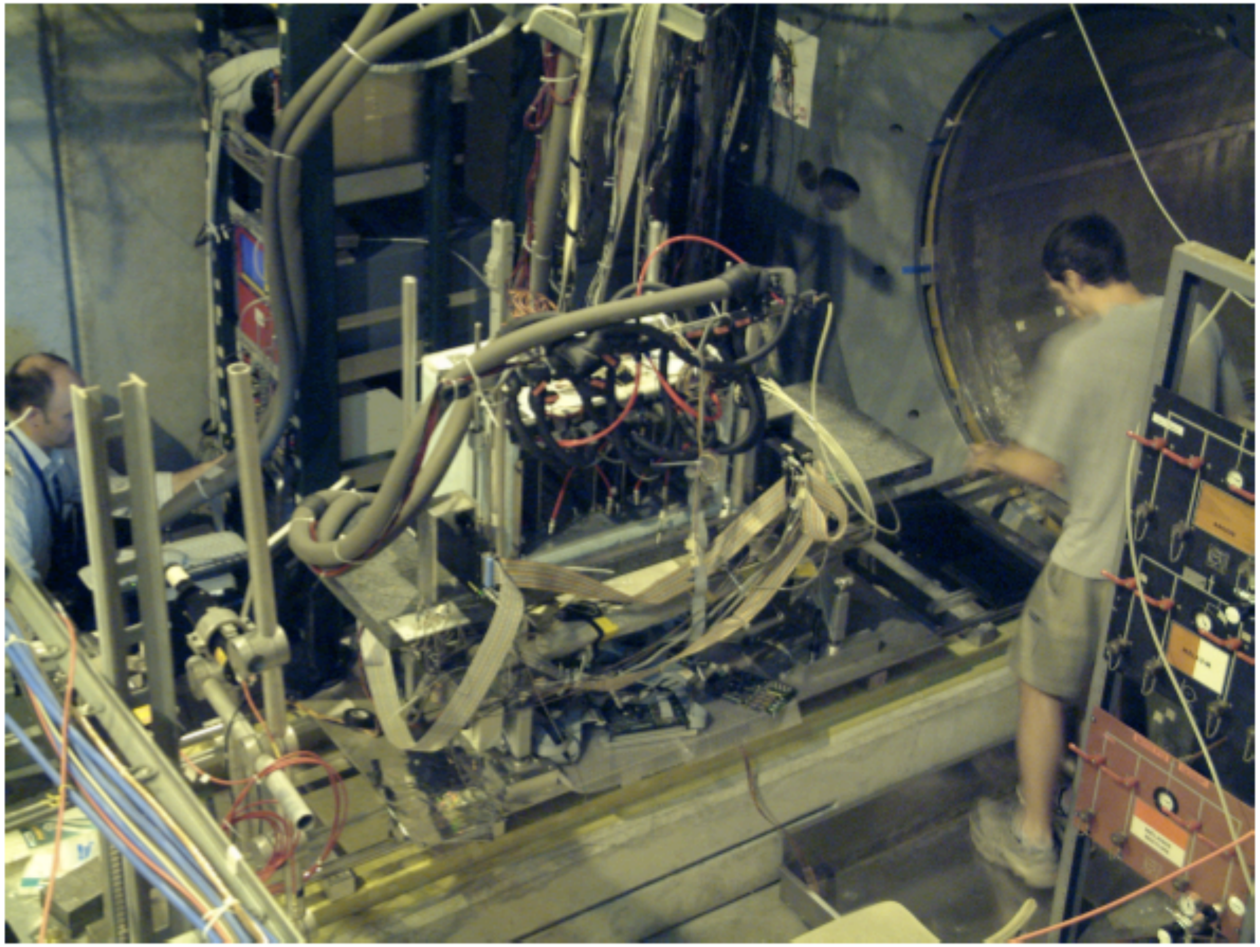
- Planar sensors
  - E and B fields are orthogonal
  - Lorentz force orthogonal to drift
  - Focus or de-focus charge cloud
  - Cluster size minim. at Lorentz angle

- 3D sensors
  - E and B fields are coplanar (lateral)
  - Lorenz force act out of the lateral plane
  - Minimal effect on charge could



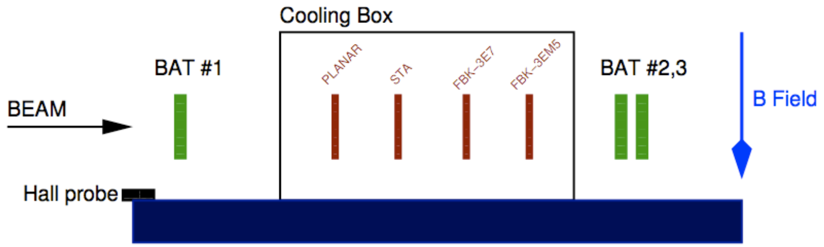
→ Expect small effect for 3D sensors

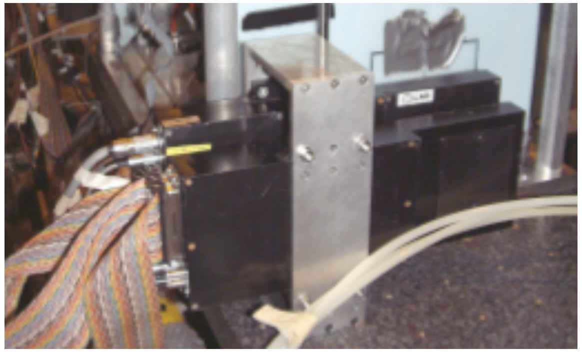
Experimental area



Beam Telescope and Tracking

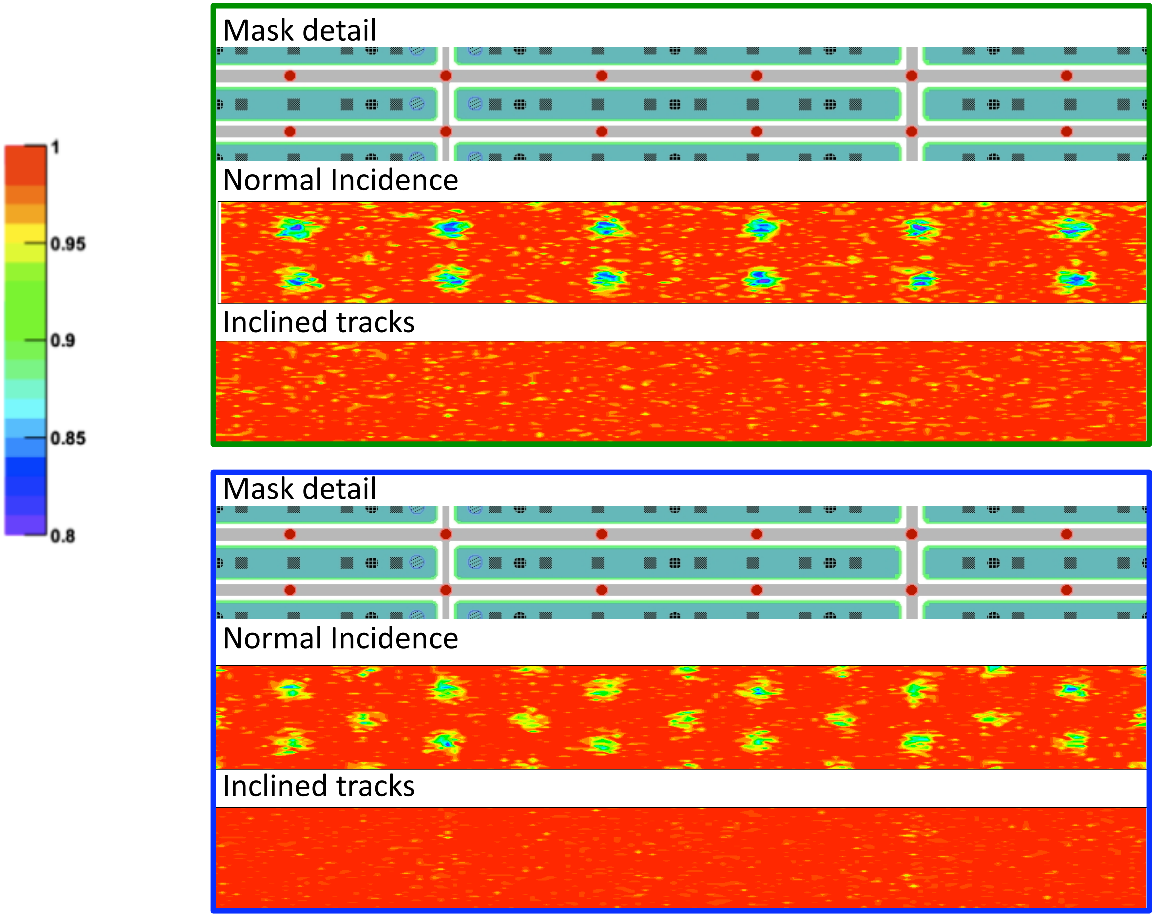
- Bonn ATLAS Telescope
  - Two-sided Si micro-strip sensors
  - Strip pitch: 50 um
  - Analog read-out
  - Integrated DAQ and on-line DQ system
  - Position resolution ~ 5um
  - Masked noisy strips
- Trigger system
  - Two scintillators in coincidence
  - Trigger Veto – anti coincidence
  - Trigger phase measurements (TDC)
- Magnetic field tracking
  - Using 3 telescope planes
  - Approximate field as homogeneous





3D-DDTC - Preliminary results

- Hit Efficiency



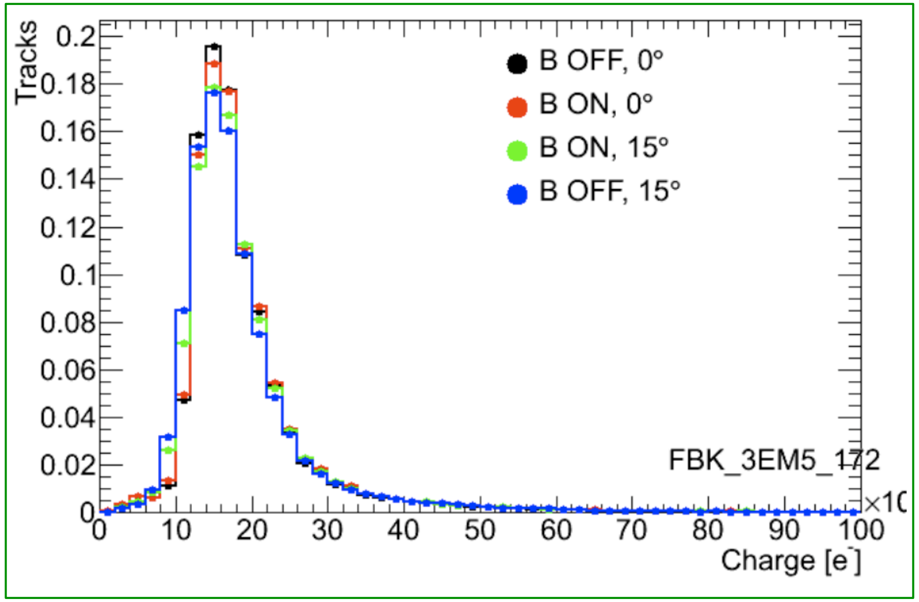
DTC-2
90-100 Column Overlap

DTC-2B
110-150 Column Overlap

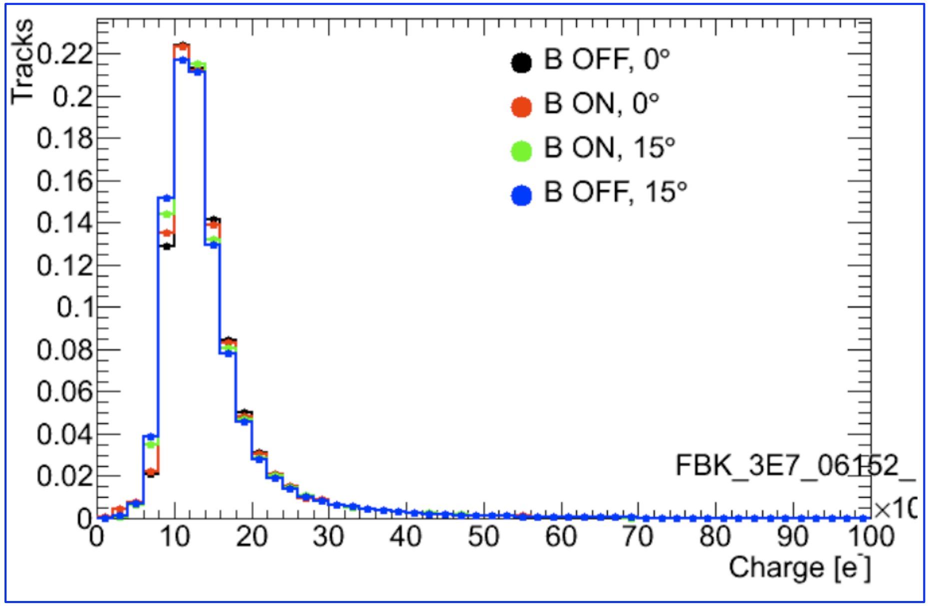
3D-DDTC - Preliminary results

- Most probable charge distribution (200um of thickness)

DTC-2 3E-type

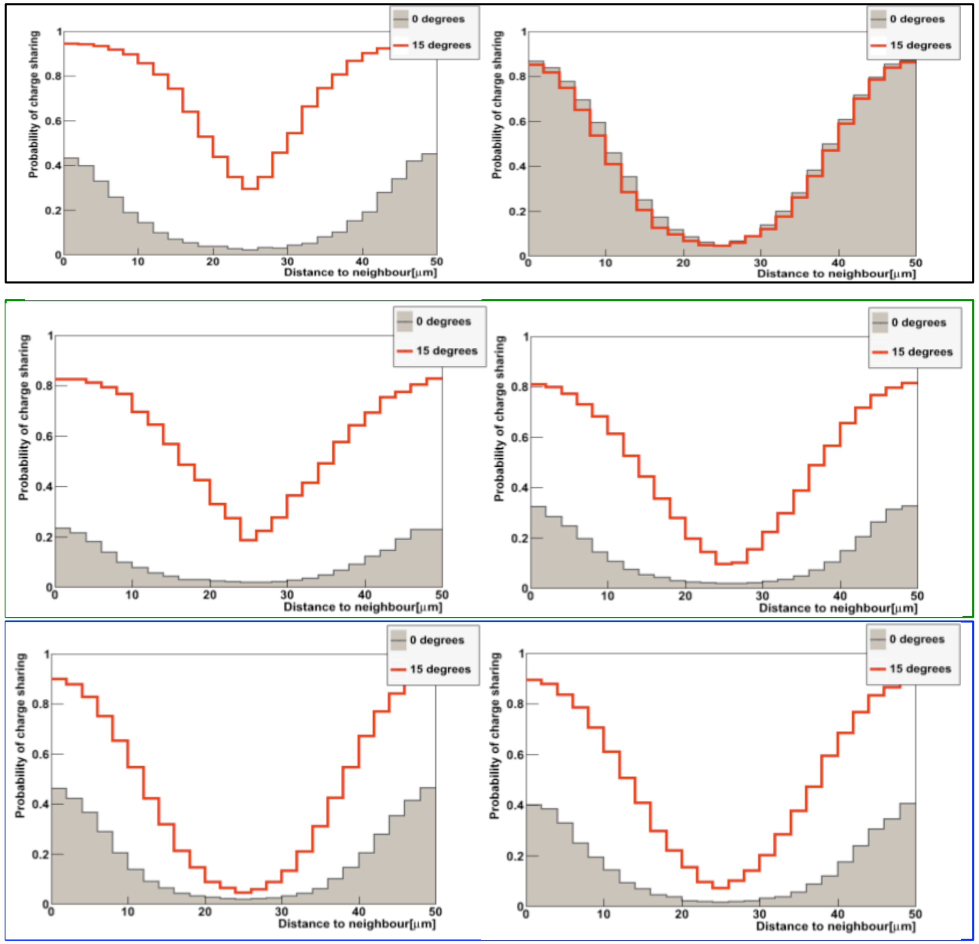


DTC-2B 3E-type



3D-DDTC - Preliminary results

- Charge sharing probability (50 um direction)



Magnetic field OFF

Magnetic field ON

Planar
N-in-N

DTC-2
3E-type

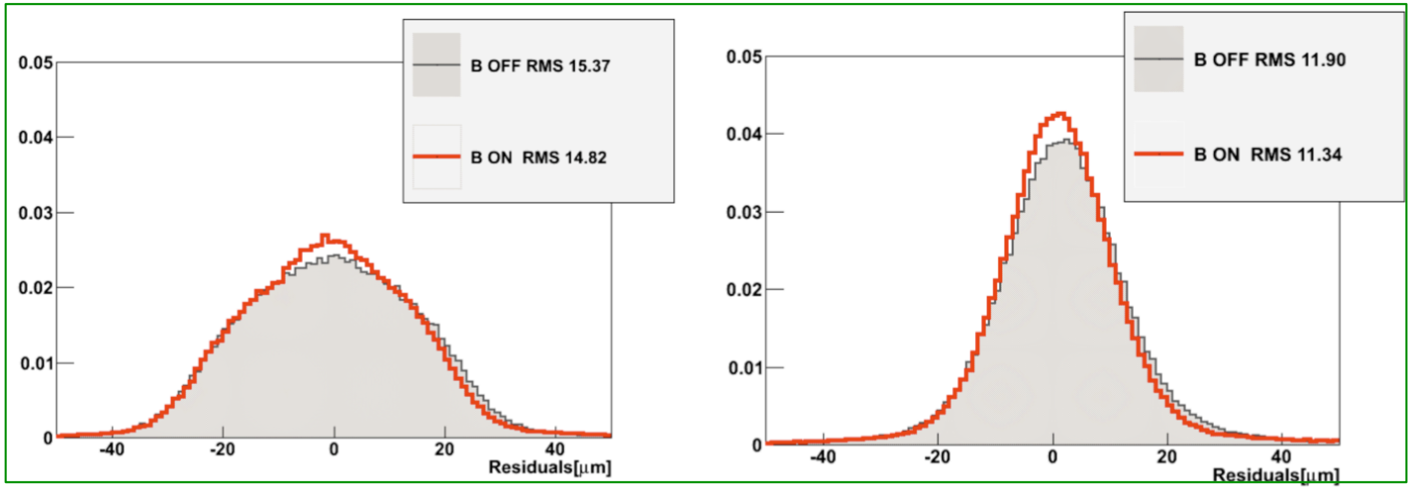
DTC-2B
3E-type

3D-DDTC - Preliminary results

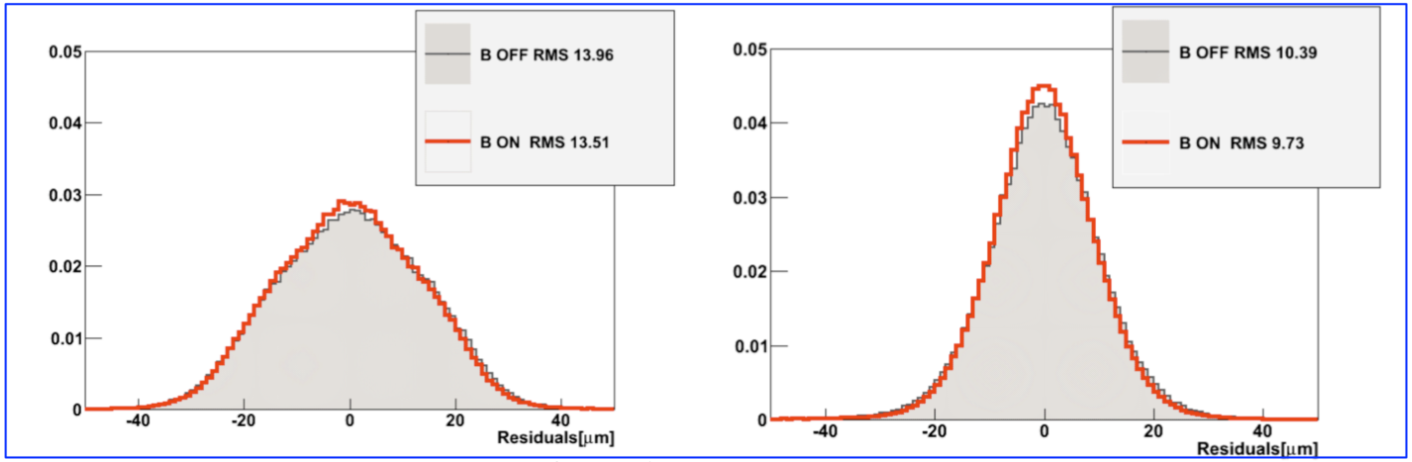
- Track residual distribution (50 um direction)

Perpendicular tracks *Inclined tracks*

DTC-2
3E-type



DTC-2B
3E-type

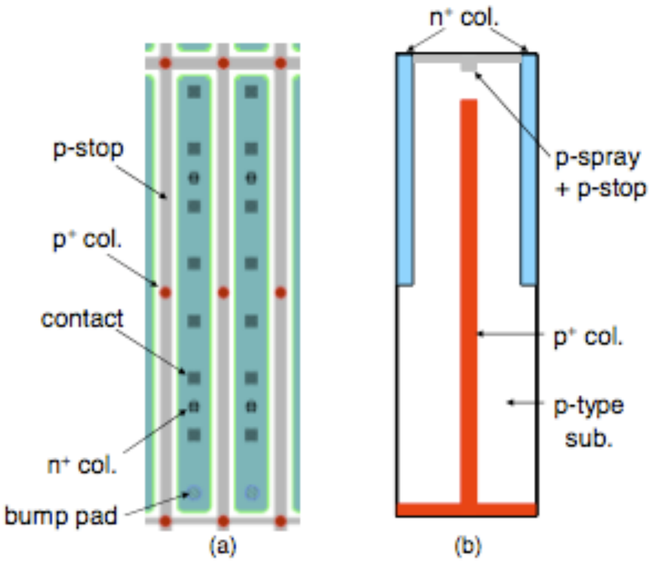


Conclusions

- 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 !
  - near future: CERN PS 24 GeV/c, Oct. - Nov. 2009
- Development of “passing-though column” detectors is on going.
- Possible Detector technology for ATLAS-IBL and SLHC projects

Back-up

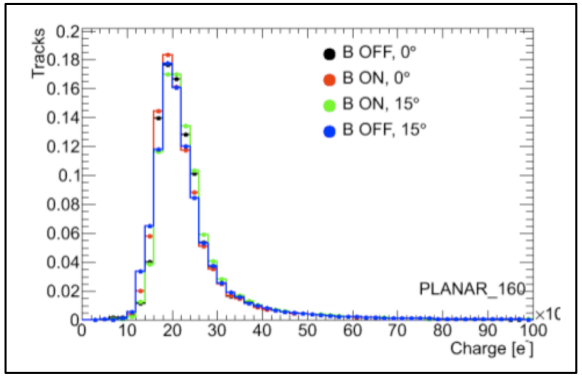
3D-Double side Double Type Column



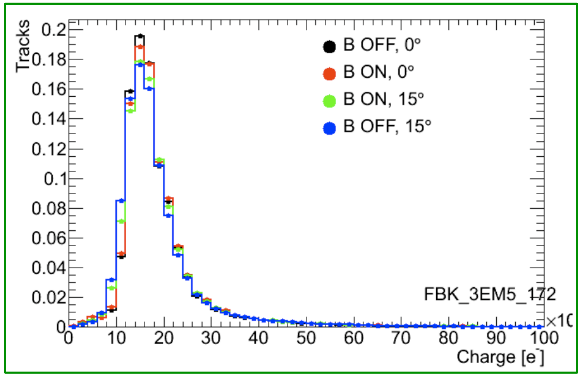
Parameter	**Unit**	**Value**	
		3D-DTC-2	**3D-DTC-2B**
Substrate thickness	μm	200	200
Junction column thickness	μm	100 -110	140 -170
Ohmic column thickness	μm	180 -190	180 – 190
Column overlap	μm	90 - 100	110 -150
Substrate doping concentration	cm^{-3}	1×10^{12}	7×10^{11}
Lateral depletion voltage	V	3	1 - 2
Full depletion voltage	V	12	3 - 4
Capacitance vs backplane	fF/column	35	45 - 50
Leakage current @ Full depletion	pA/column	< 1	< 1
Breakdown voltage	V	> 70	> 70

3D-DDTC - Preliminary results

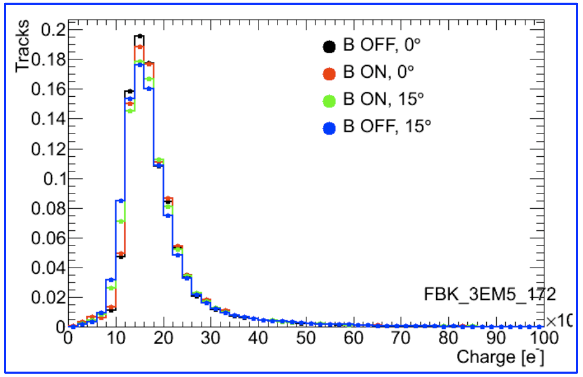
- Most probable charge distribution



Planar N-in-N
250 um



DTC-2 3E-type
200 um



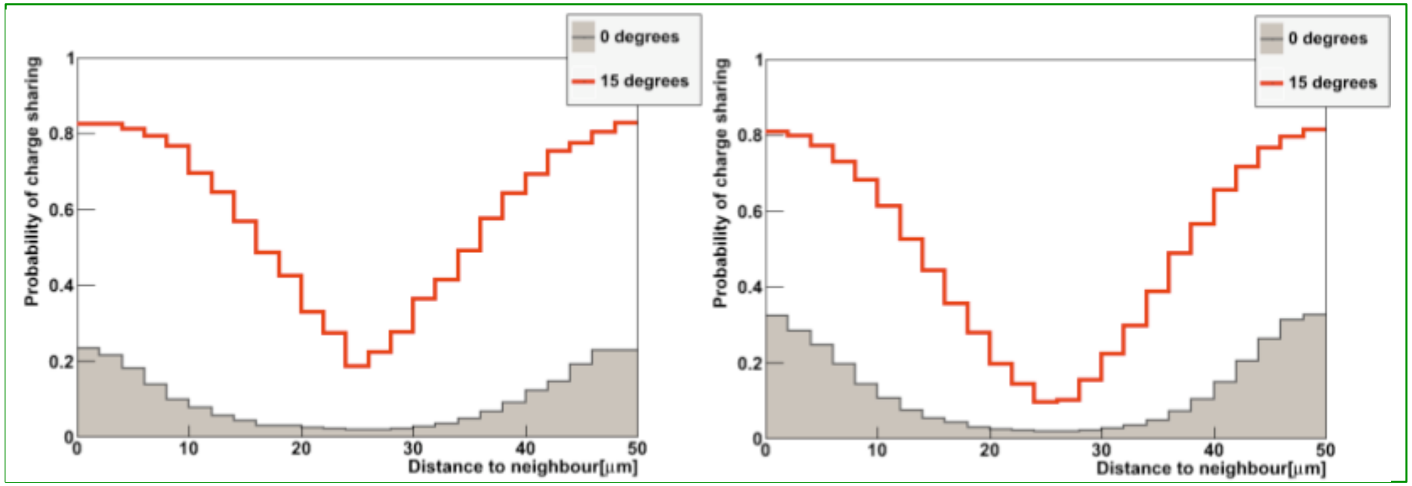
DTC-2B 3E-type
200 um

3D-DDTC - Preliminary results

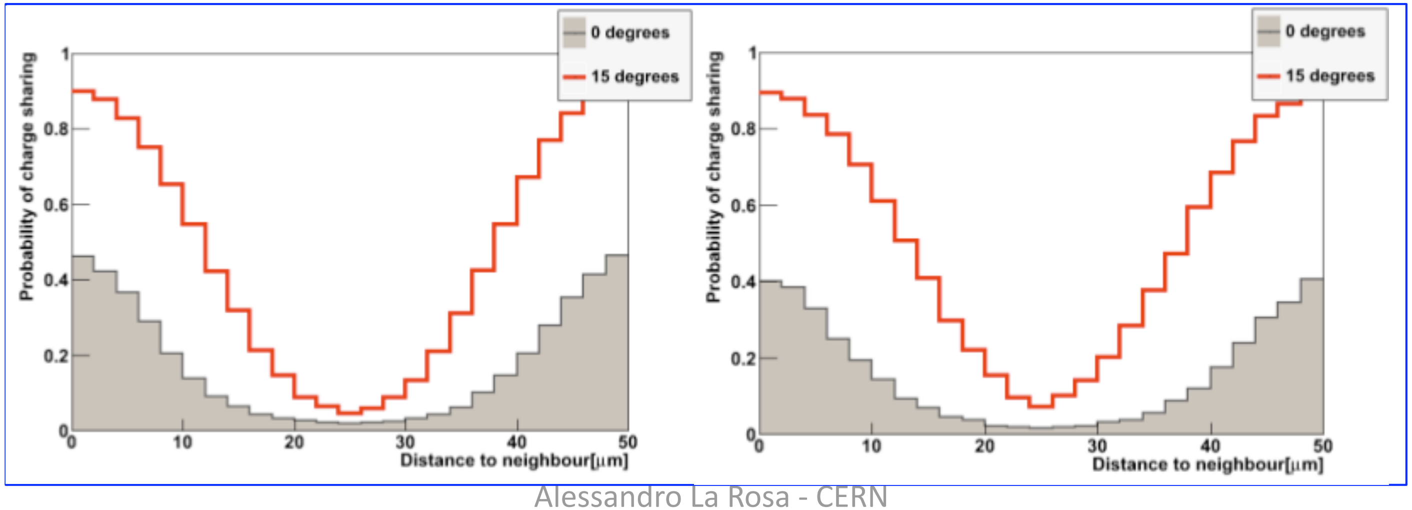
- Charge sharing probability (50 um direction)

Magnetic field OFF *Magnetic field ON*

DTC-2
3E-type



DTC-2B
3E-type



3D-DDTC - Preliminary results

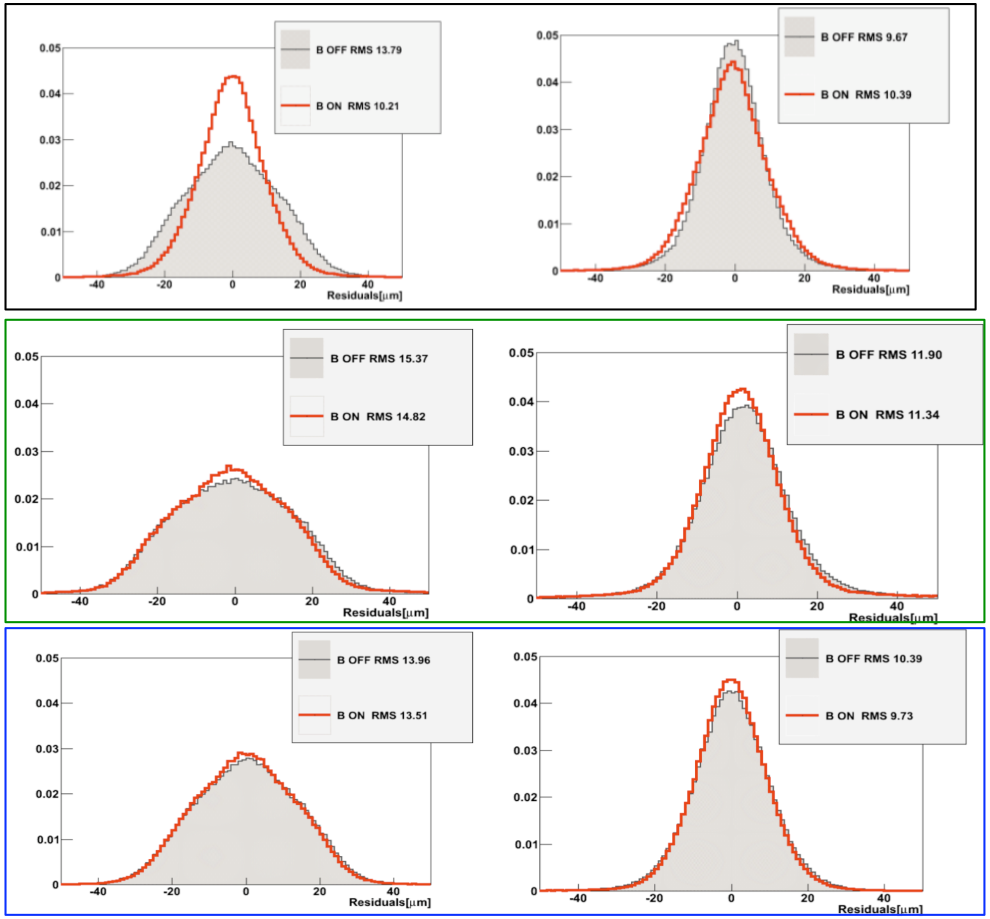
- Track residual distribution (50 um direction)

Perpendicular tracks *Inclined tracks*

Planar
N-in-N

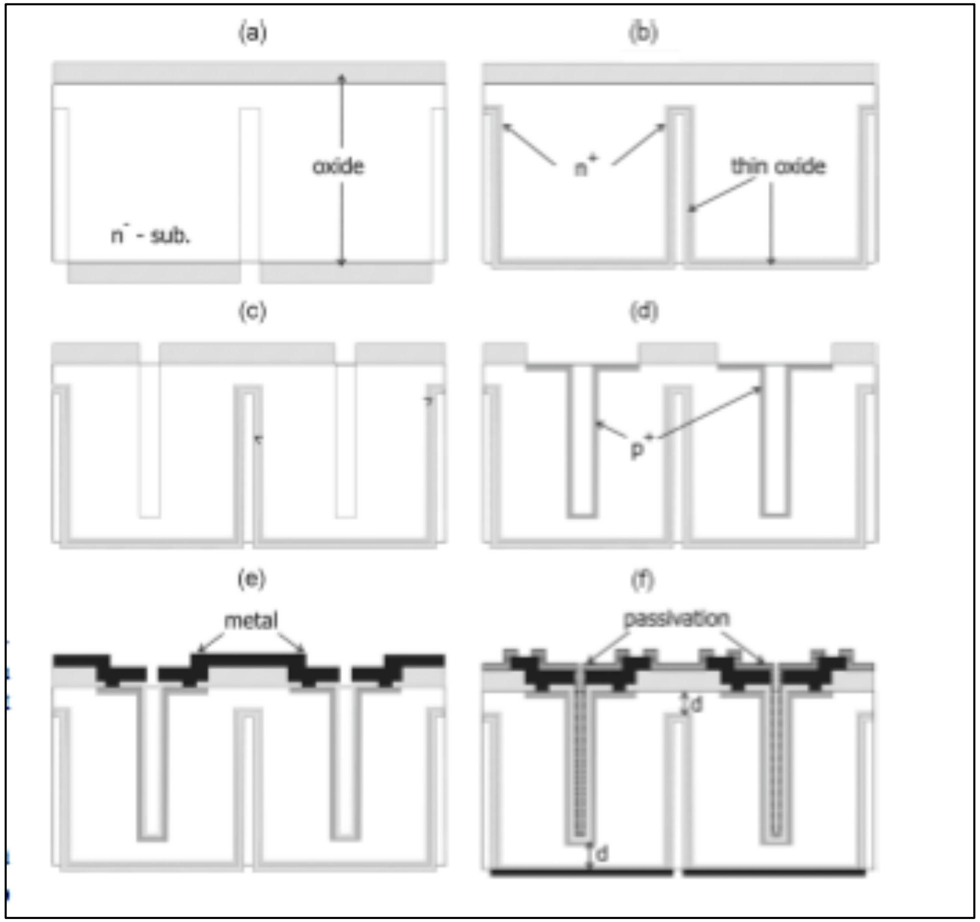
DTC-2
3E-type

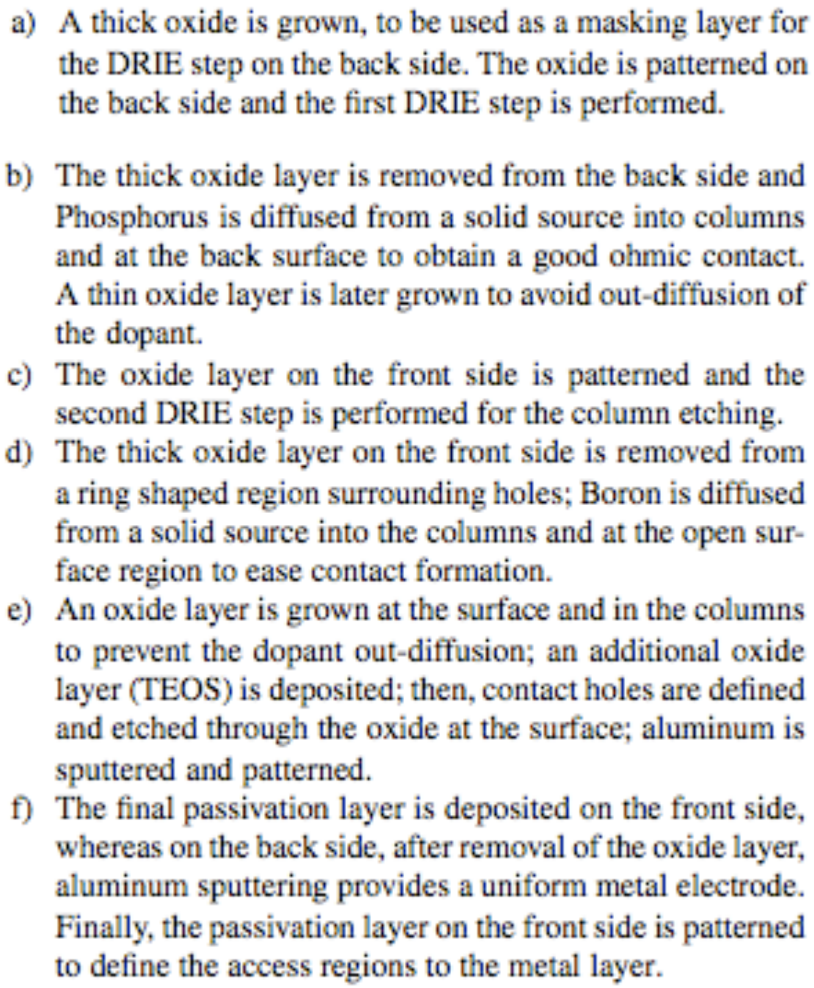
DTC-2B
3E-type



Main steps of 3D-DDTC fabrication process on n-type substrate

[Zoboli et. al. IEEE Trans. Nucl. Sci. NS-55(5) (2008) 2275.





a) A thick oxide is grown, to be used as a masking layer for the DRIE step on the back side. The oxide is patterned on the back side and the first DRIE step is performed.

b) The thick oxide layer is removed from the back side and Phosphorus is diffused from a solid source into columns and at the back surface to obtain a good ohmic contact. A thin oxide layer is later grown to avoid out-diffusion of the dopant.

c) The oxide layer on the front side is patterned and the second DRIE step is performed for the column etching.

d) The thick oxide layer on the front side is removed from a ring shaped region surrounding holes; Boron is diffused from a solid source into the columns and at the open surface region to ease contact formation.

e) An oxide layer is grown at the surface and in the columns to prevent the dopant out-diffusion; an additional oxide layer (TEOS) is deposited; then, contact holes are defined and etched through the oxide at the surface; aluminum is sputtered and patterned.

f) The final passivation layer is deposited on the front side, whereas on the back side, after removal of the oxide layer, aluminum sputtering provides a uniform metal electrode. Finally, the passivation layer on the front side is patterned to define the access regions to the metal layer.

For 3D-DDTC (p-type): a) inverted doping of the columns and related surfaces;
b) additional steps for p-spray/p-stop implantations on the front side.