Status of the development of 3D and active-edge sensors in Trento

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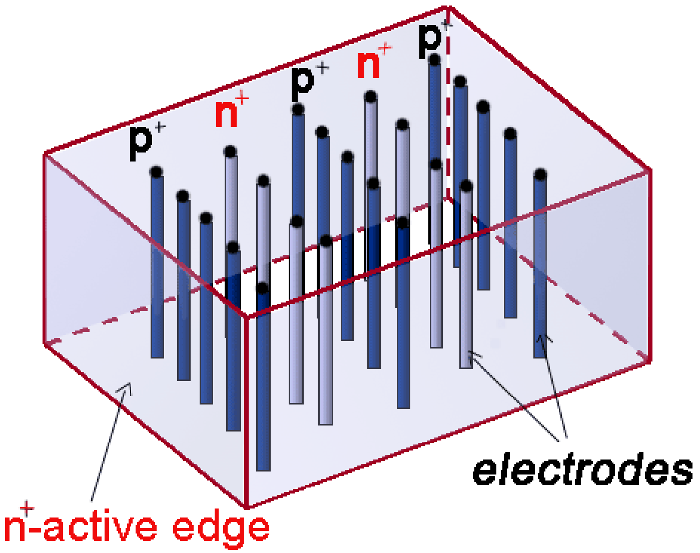
Outline

- Introduction and background
- Highlights from activities in 2009
  - Tests of 3D-DDTC detectors
  - New designs and simulations
- Plans for 2010:
  - Batch schedule

3D detectors - State of the Art

First proposed by S. Parker et. al.
in NIMA 395 (1997), 328



Best result:
66% of the original signal after
8.8×10^{15} cm^{-2} 1-MeV $n_{eq.}$ fluence

Da Via et. al.
NIMA 604 (2009) 504

ADVANTAGES:

- Electrode distance and active substrate thickness decoupled:
  - Low depletion voltage
  - Short Collection distance/time
  - Smaller trapping probability after irradiation

→ **high radiation hardness**

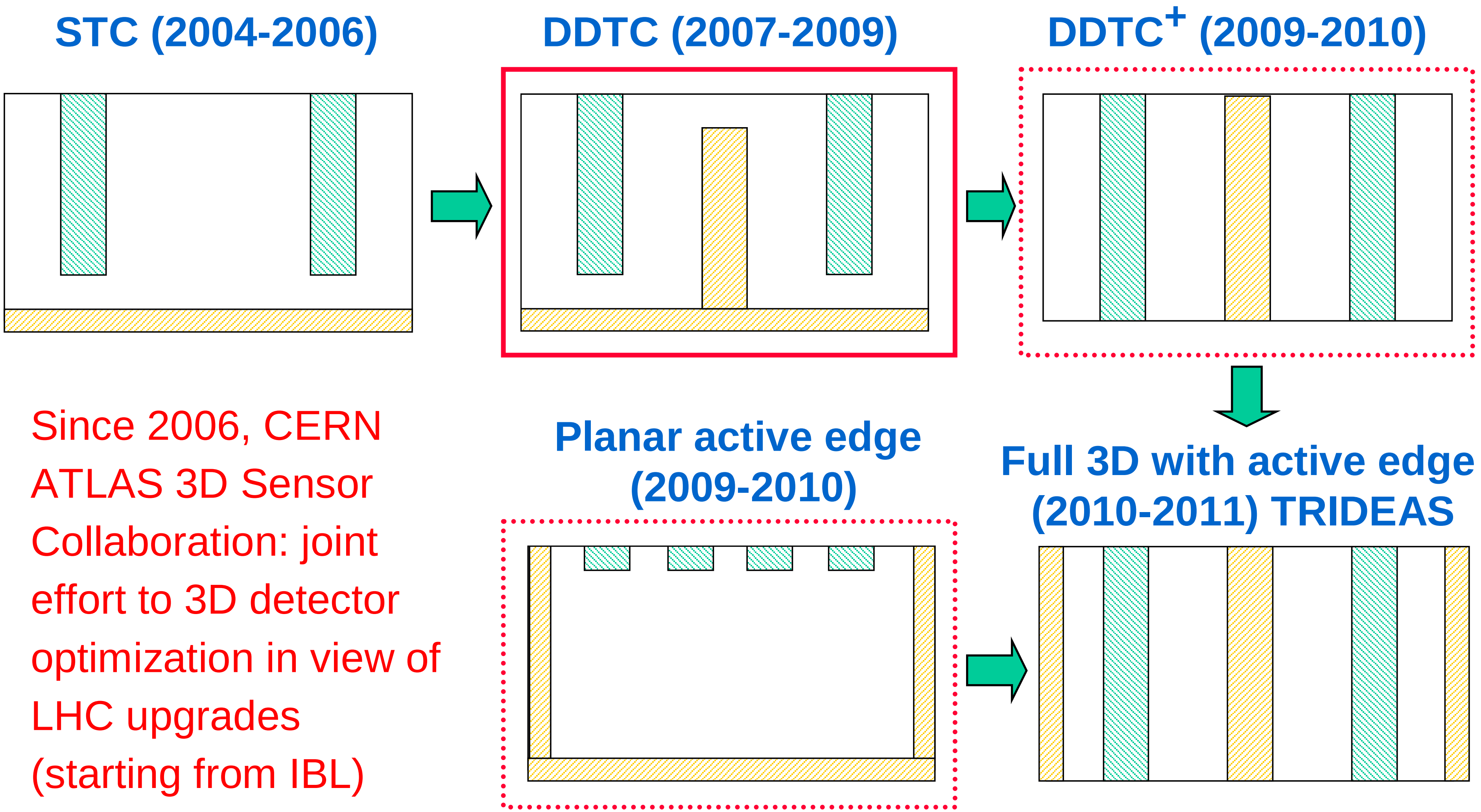
-Active edges:
  - Dead area reduced up to a few microns from the edge

DISADVANTAGES:

- Non uniform response due to electrodes
- Higher capacitance with respect to planar
- Complicated and expensive technology

3D detector developments in Trento

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

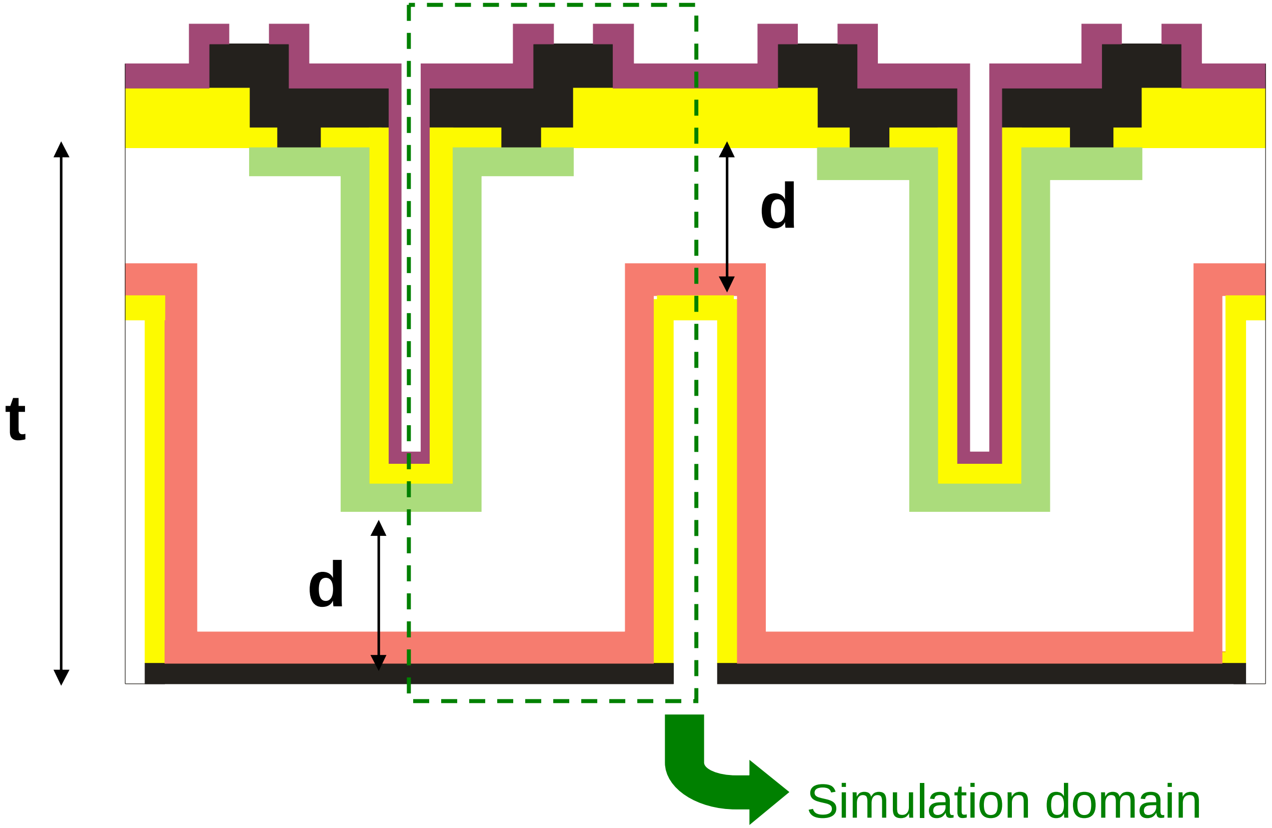


STC (2004-2006) → **DDTC (2007-2009)** → **DDTC$^+$ (2009-2010)** → **Full 3D with active edge (2010-2011) TRIDEAS**

Planar active edge (2009-2010) → **Full 3D with active edge (2010-2011) TRIDEAS**

Since 2006, CERN ATLAS 3D Sensor Collaboration: joint effort to 3D detector optimization in view of LHC upgrades (starting from IBL)

3D-DDTC detectors



Front side as in STC

Back side:
+ litho and DRIE

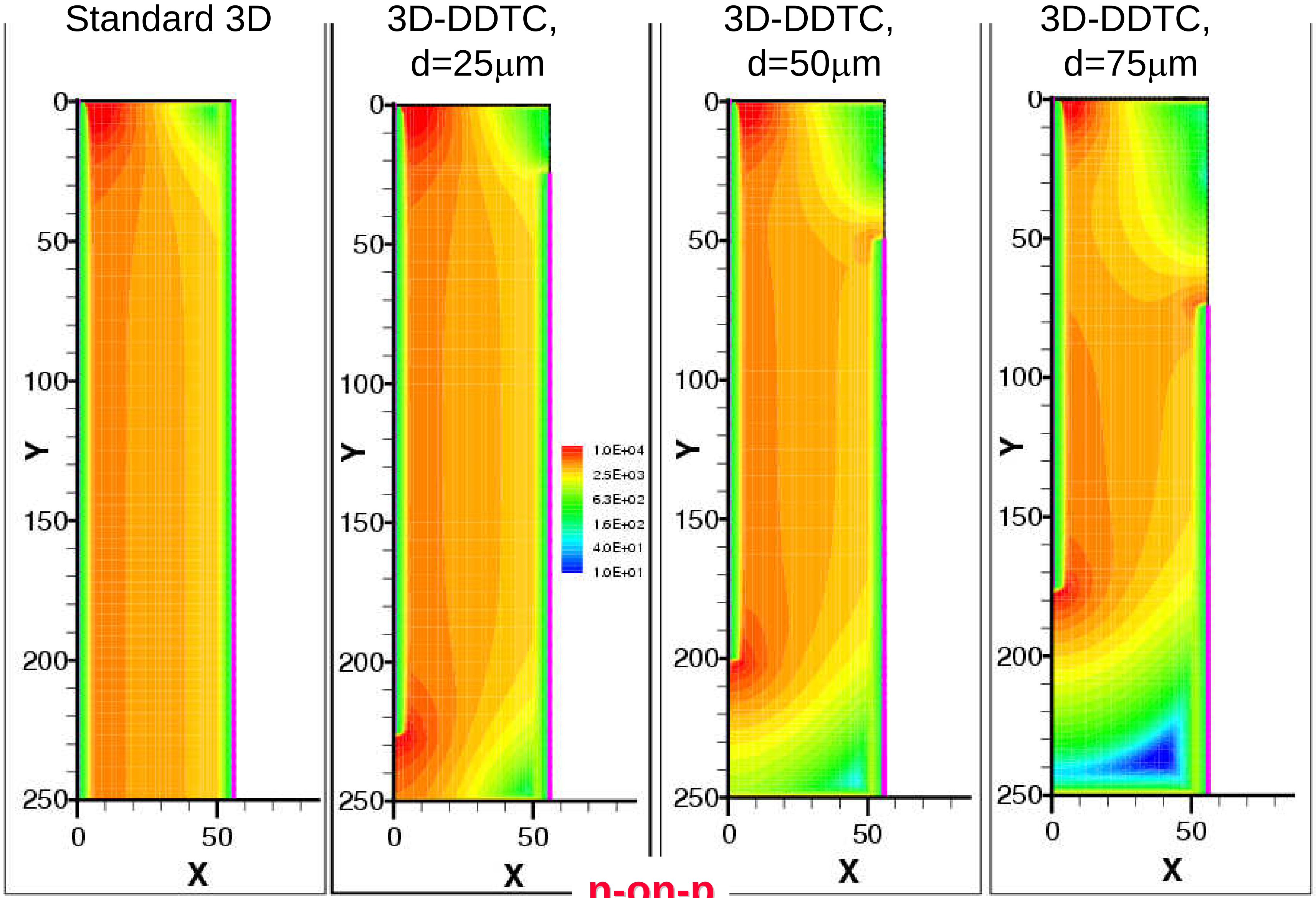
Simulation domain

- Detector concept able to ease the fabrication process
- Expected to have performance comparable to standard 3D detectors

(if **d** is much smaller than **t**)

[G.F. Dalla Betta et al., 2007 IEEE NSS]

Electric field @lateral depletion (16V)



Standard 3D

3D-DDTC, d=25µm

3D-DDTC, d=50µm

3D-DDTC, d=75µm

n-on-p

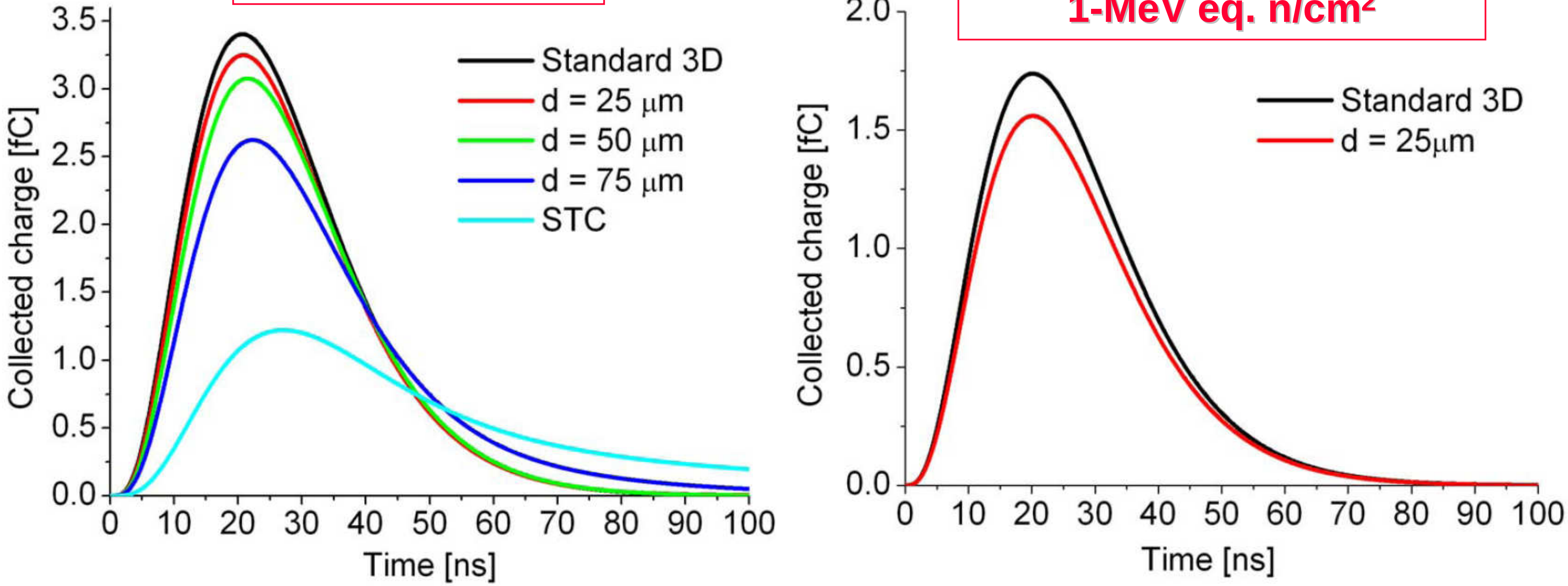
MIP simulations

Transient signals of a 250-μm thick, 3D detector @ lateral full depletion voltage in response to a mip (hitting close to ohmic column) for different column geometries

Output signals with semigaussian CR-(RC)^3 shaper at t_p=20ns

Before irradiation

After irradiation at 1×10^{16} 1-MeV eq. n/cm^2

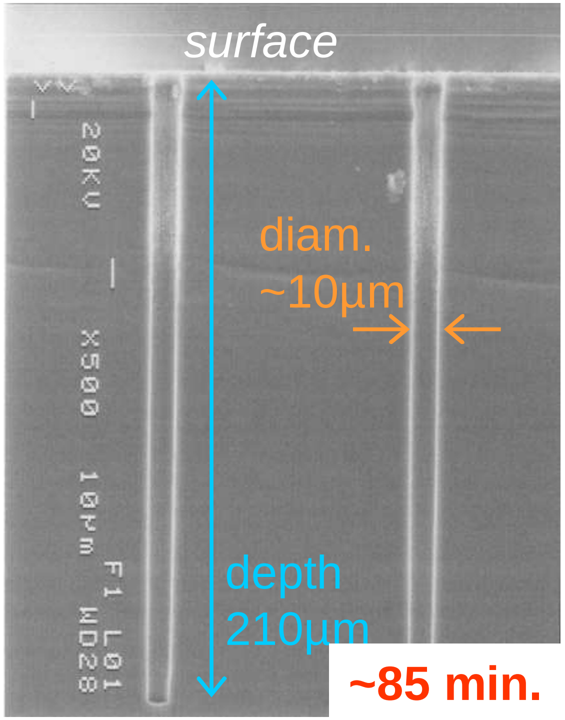


3D-DDTC much better than 3D-STC, and almost as good as standard 3D

3D-DDTC batches

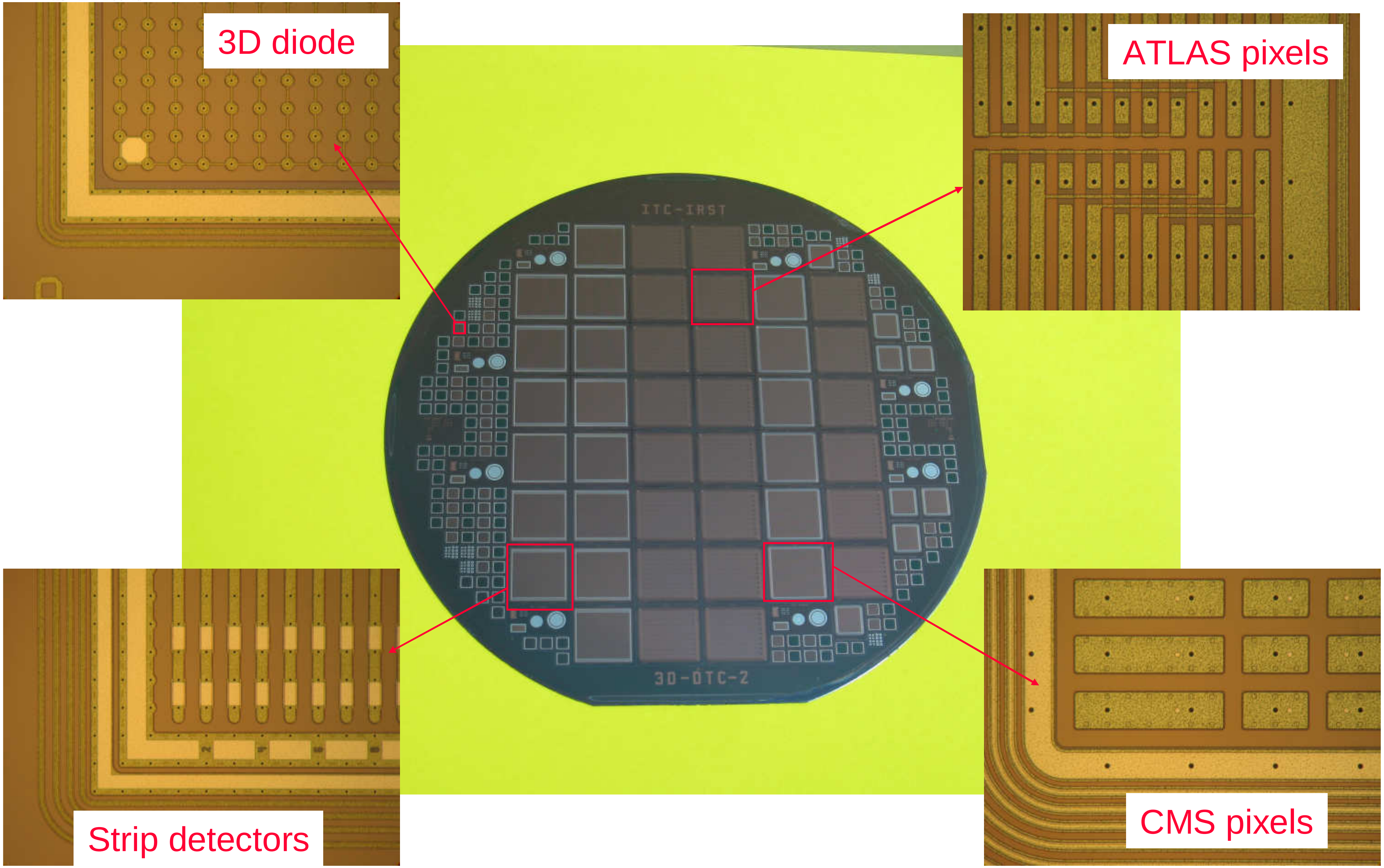
Batch	3D-DTC-1	3D-DTC-2	3D-DTC-2b
Substrate type	n-type	p-type	p-type
Substrate thickness (µm)	300	200	200
Junction column depth (µm)	190	110	160-170
Ohmic column depth (µm)	160	190	190
Completed by	October 2007	July 2008	April 2009

- For 3D-DTC-1 and 3D-DTC-2, DRIE etching performed as an external service @ IBS, France
- For 3D-DTC-3, process completely performed in house at FBK

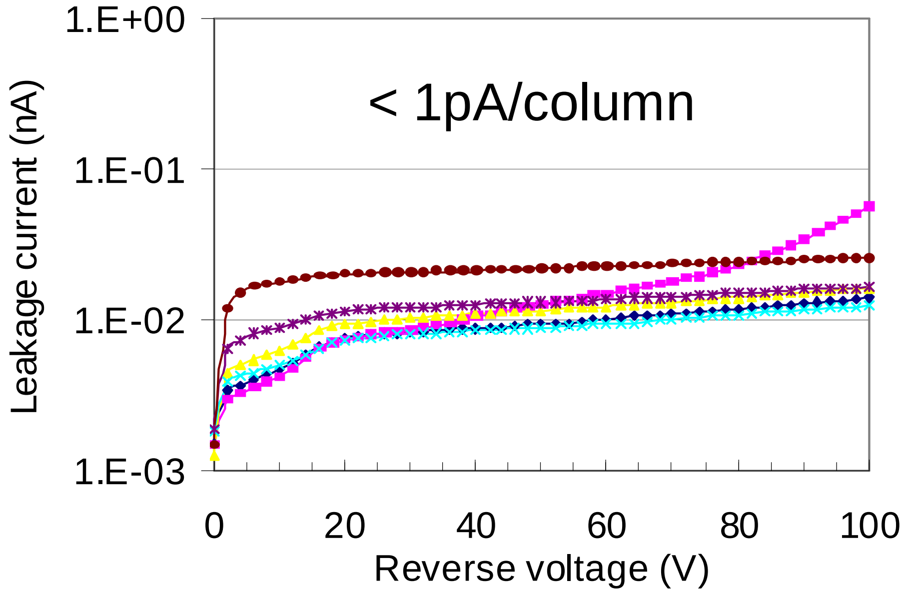


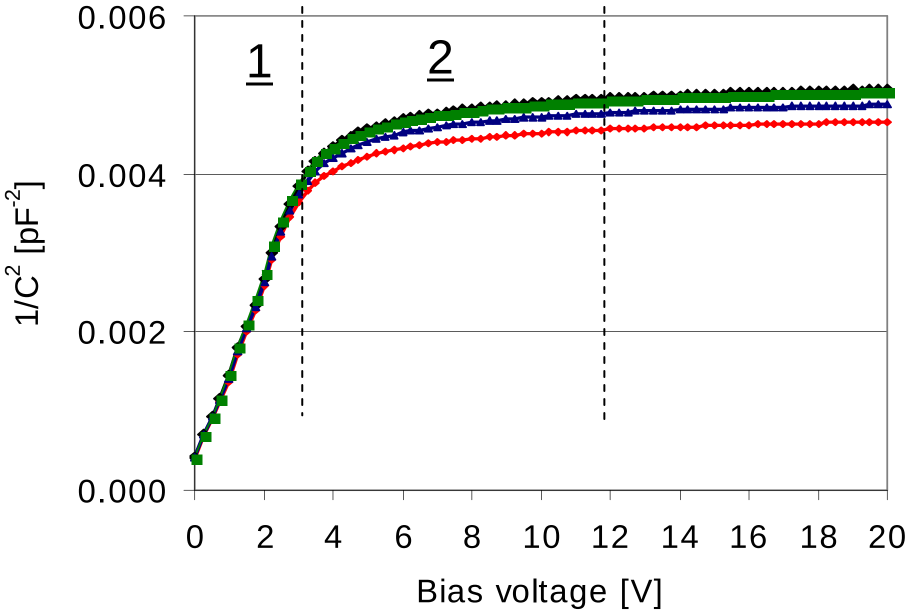
~85 min.

3D-DTC-2: some pictures



3D diodes: I-V and C-V curves

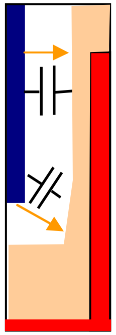




1

Depletion first proceeds first sideways, parallel to surface.

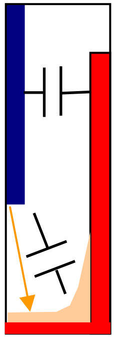
Lateral depletion ~ 3V



2

After lateral depletion an extra voltage is required to deplete the volume below the column

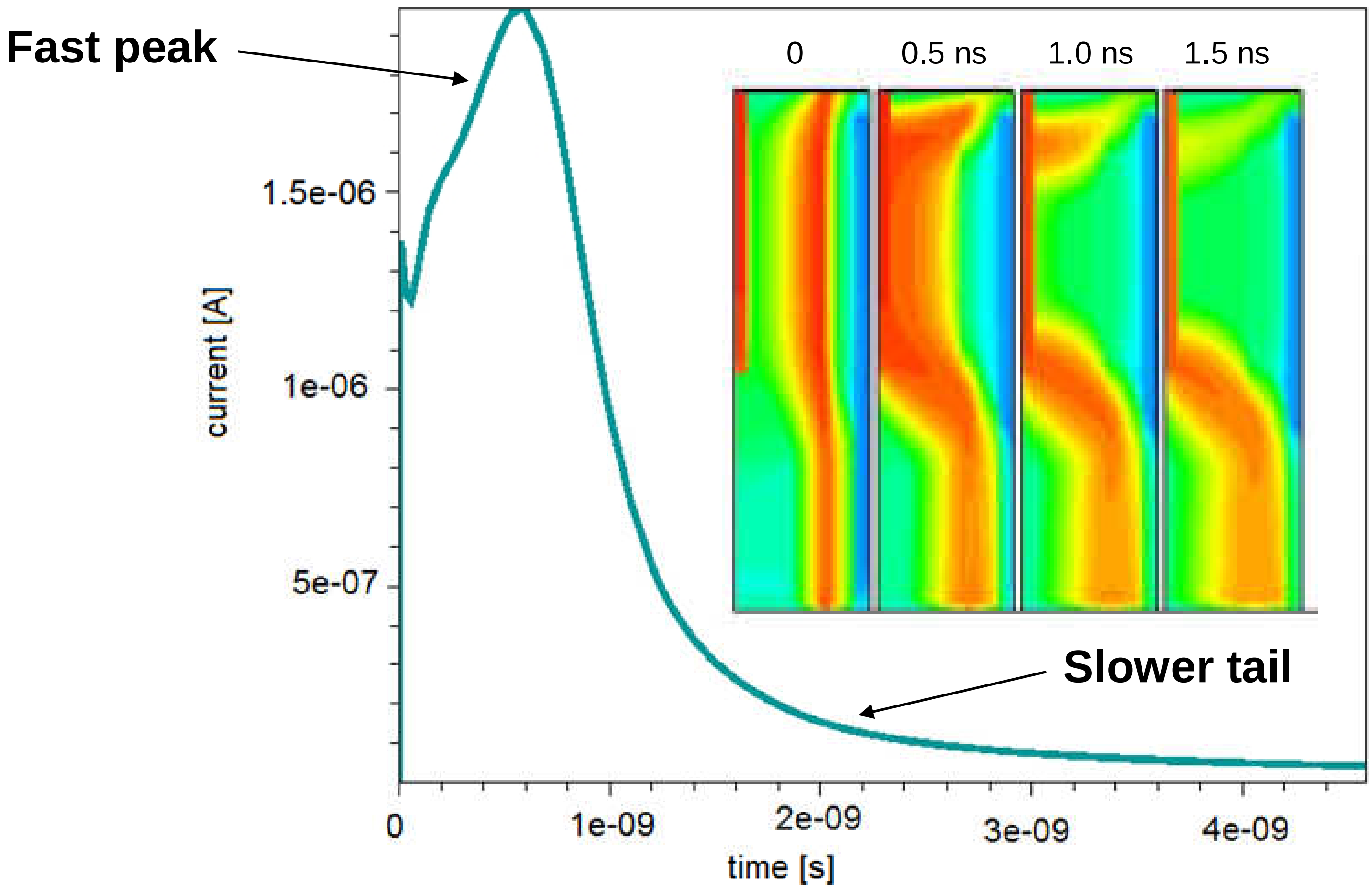
Full depletion not abrupt



Signal dynamics: simulations

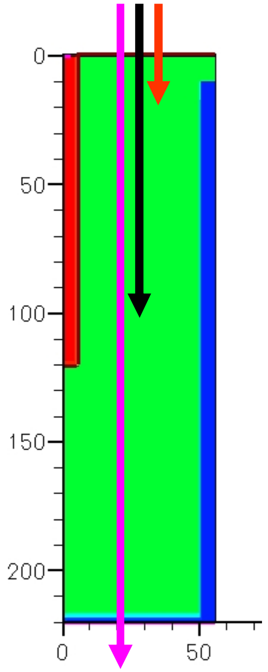
Simulated transient current signal of 3D detector from batch 3D-DTC-2 @ 16V in response to a mip (hitting close to ohmic column).

Synopsys TCAD

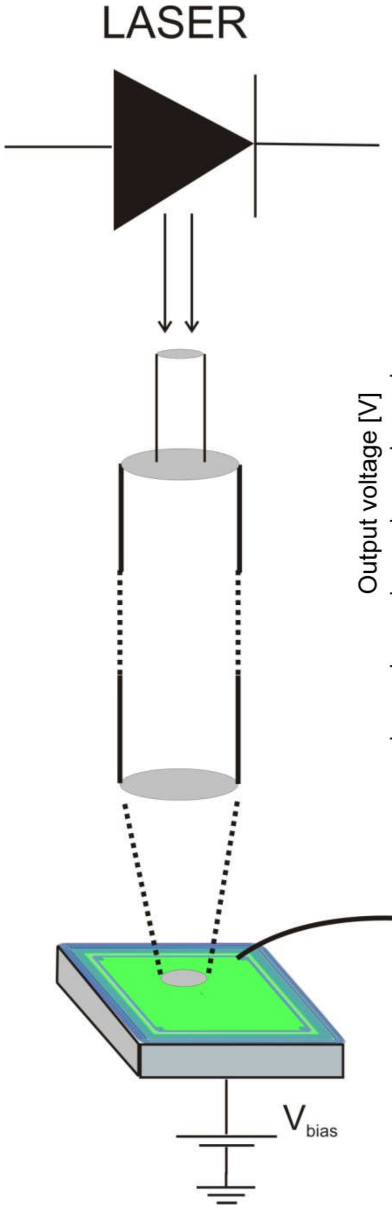


Pulsed laser tests on 3D diodes

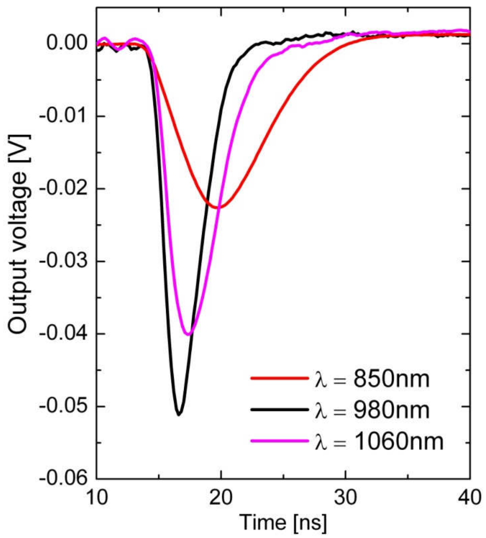
LASER
wavelengths:
850nm
980nm
1060nm



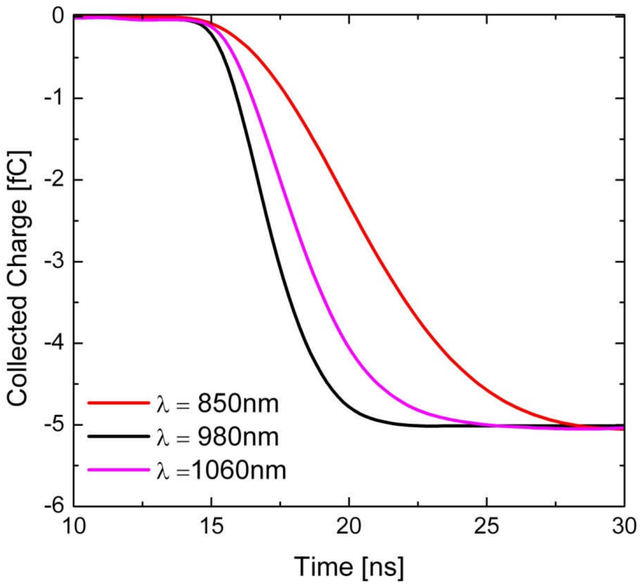
For MIP like charge deposition (λ=1060nm) the collection time is **only 8ns.**

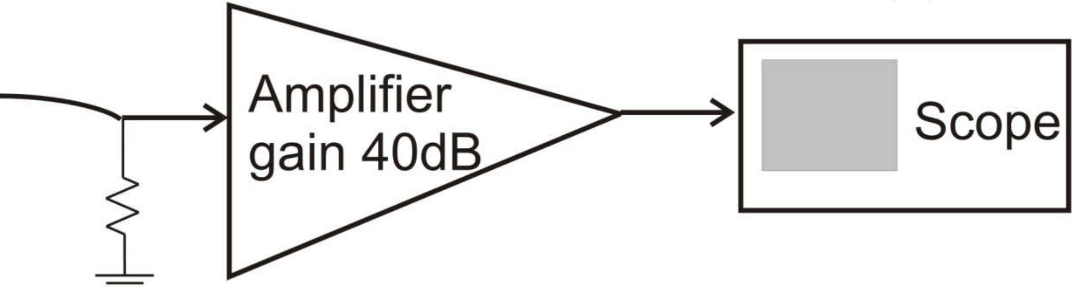


Induced signal



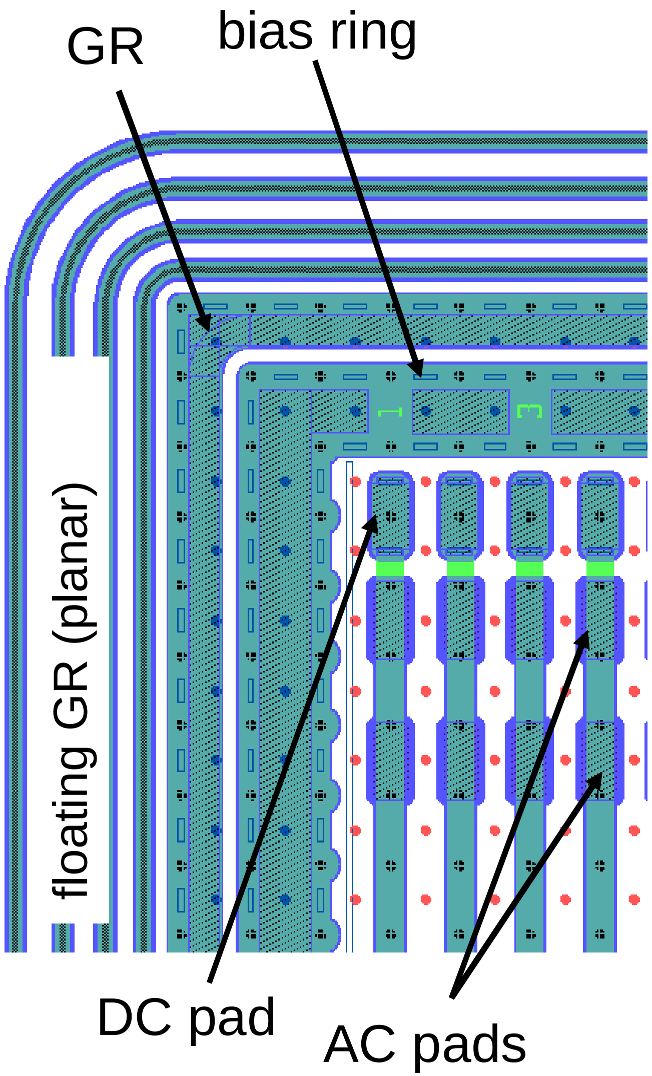
Integrated charge

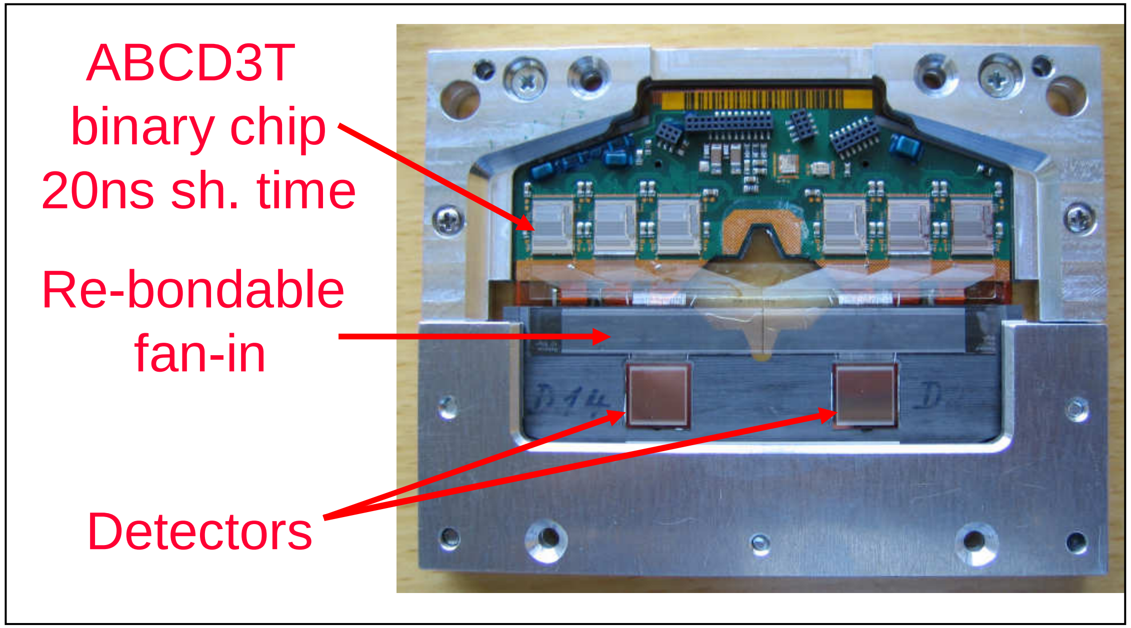




Functional tests on Strip detectors

(University of Freiburg)

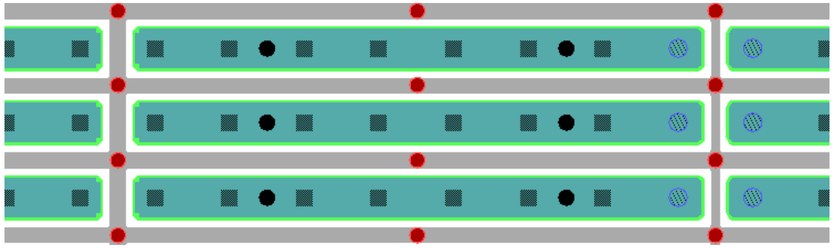




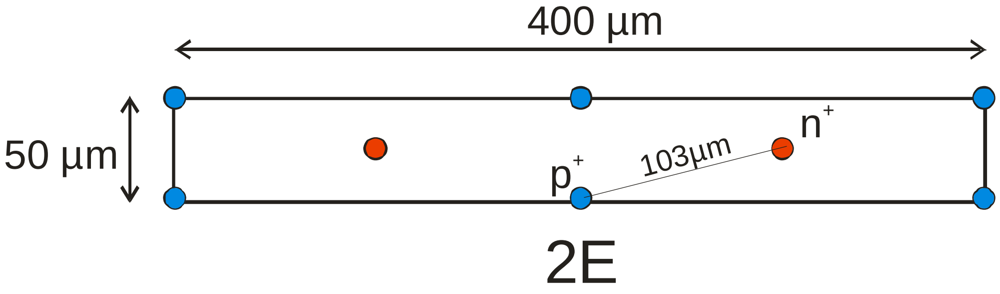
- Noise measurements
- Charge collection uniformity
- Charge collection efficiency

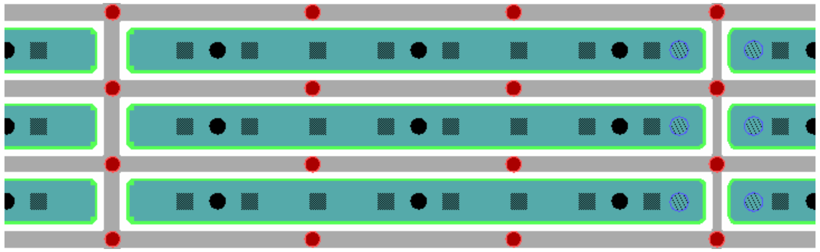
[G.F. Dalla Betta et al., 2009 ESSD Wildbad Kreuth]

ATLAS pixel sensor design

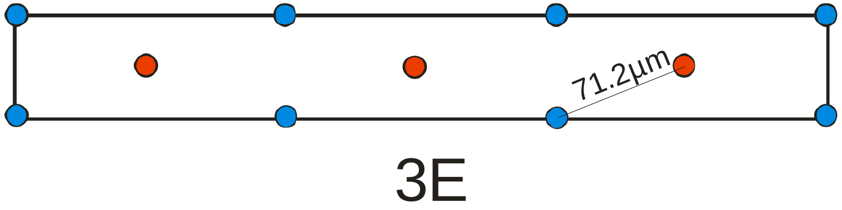


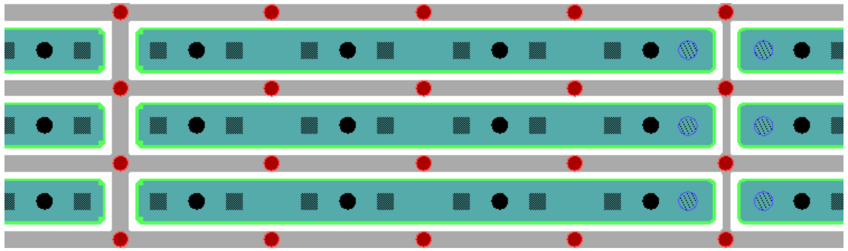
2 junction columns/pixel



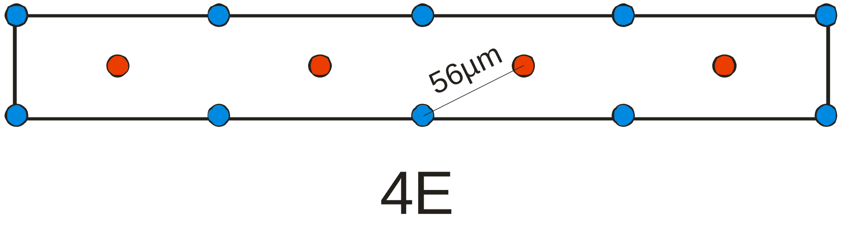


3 junction columns/pixel

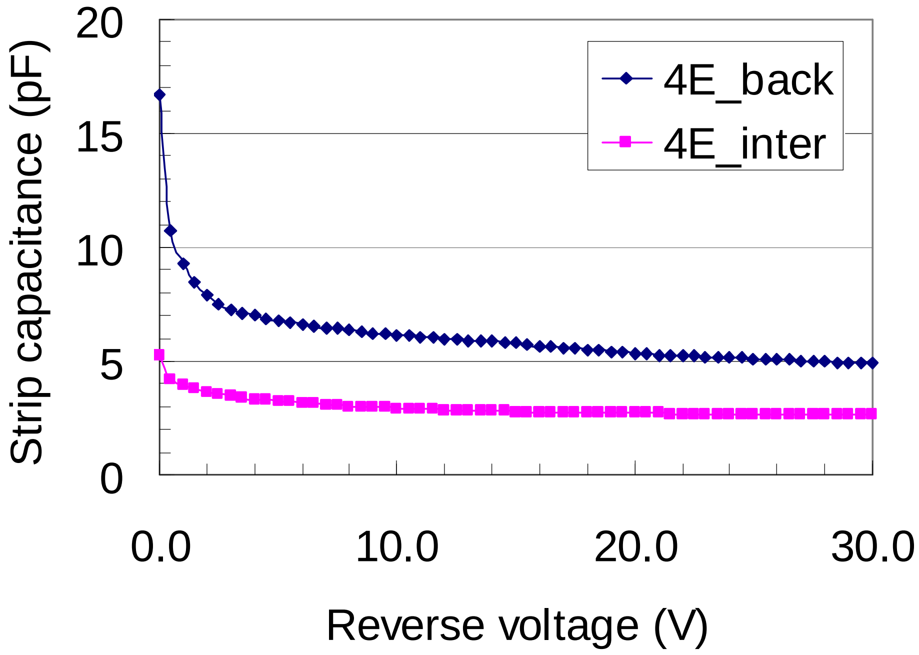




4 junction columns/pixel

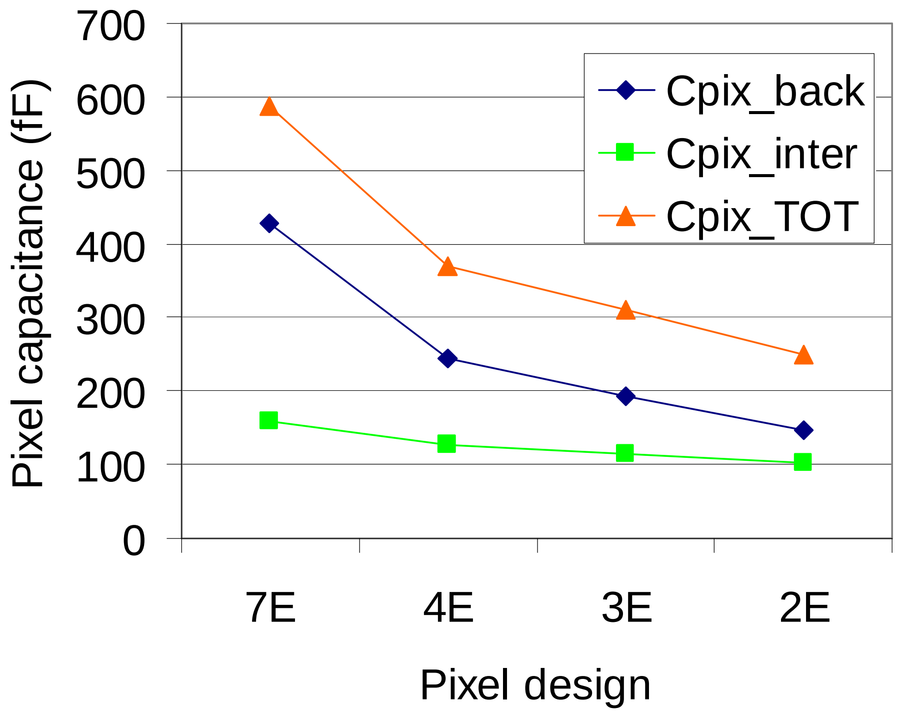


ATLAS pixel capacitance



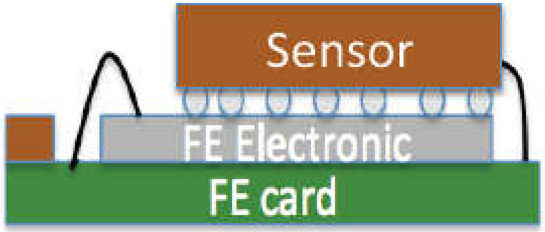
Measurements performed on strip-like test structure featuring same layout options as ATLAS pixels.

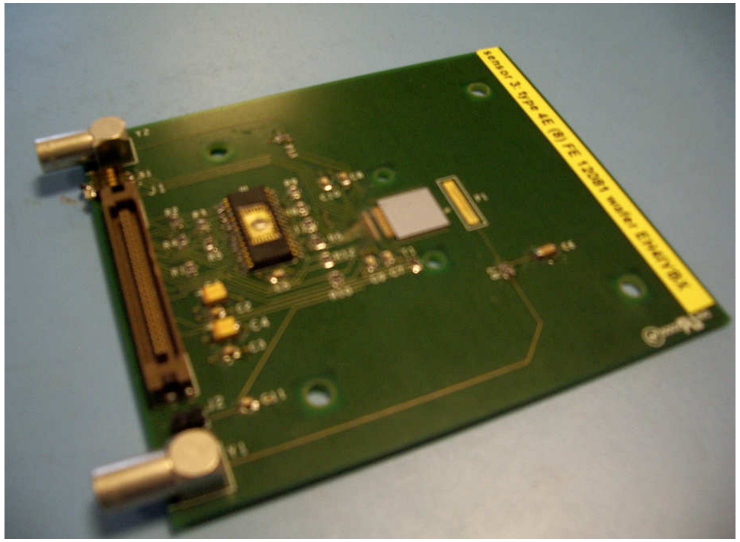
- Experimental values normalized to number of columns in ATLAS pixel designs
- The observed trend is very similar to what expected from TCAD simulations

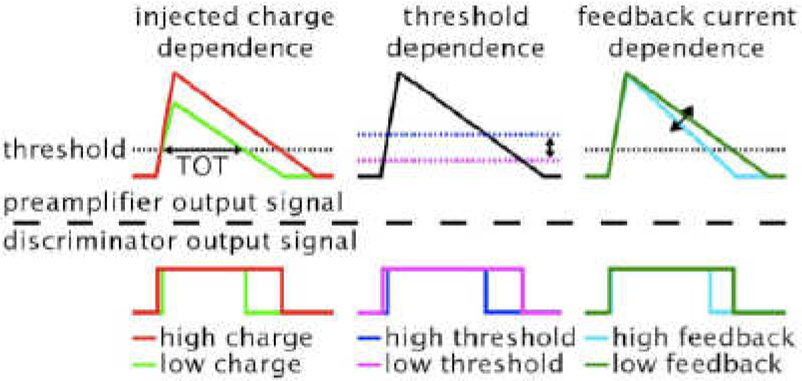


ATLAS pixel assemblies with FEI3

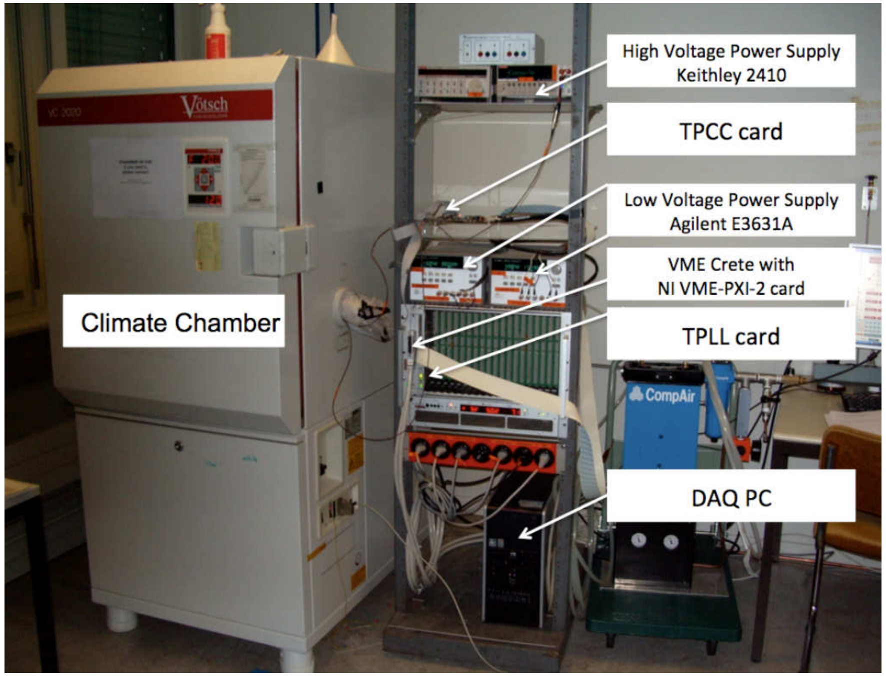
- Bump-bonding @ SELEX S.I. (Rome), Indium based technology
- Single Chips (18x160 pixels):
  - 22 from batch 3D-DTC-2
  - 20 from batch 3D-DTC-2B
- A subset of these sensors have been flip-chipped on ATLAS FEI3.



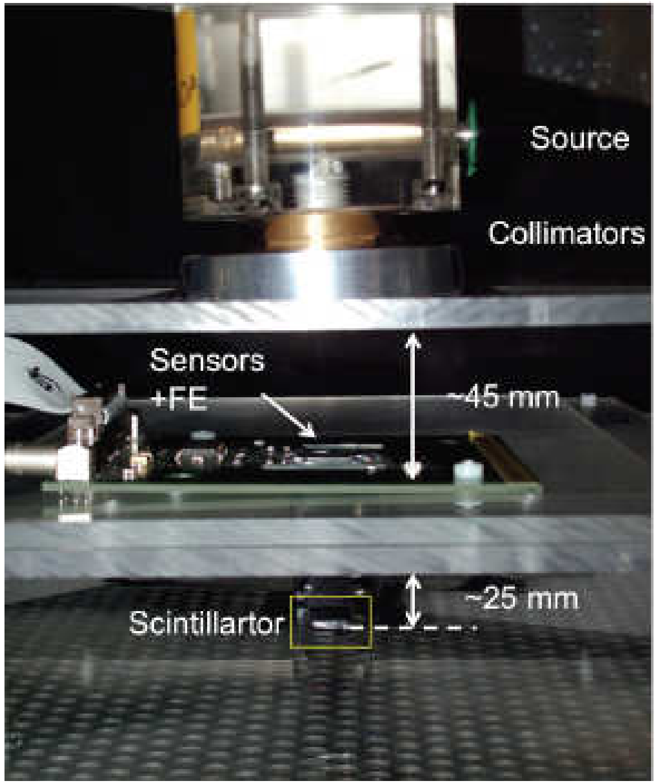




Experimental setup



- Lab. Tests made at INFN Genova and CERN
- Pixel test station based on ATLAS TurboDAQ system

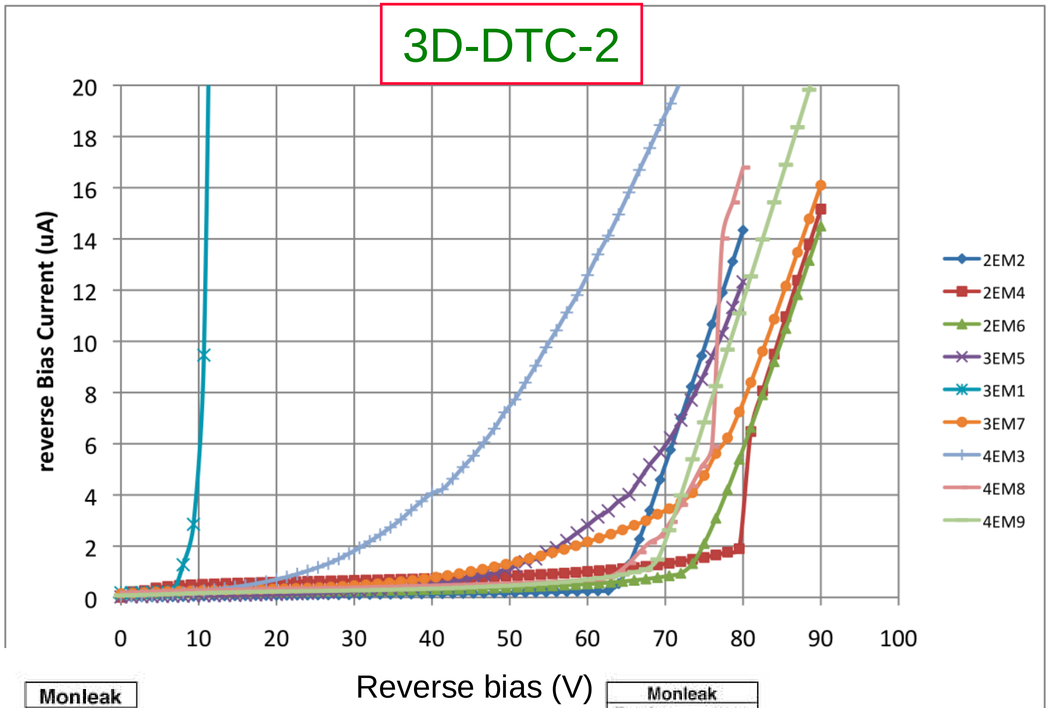


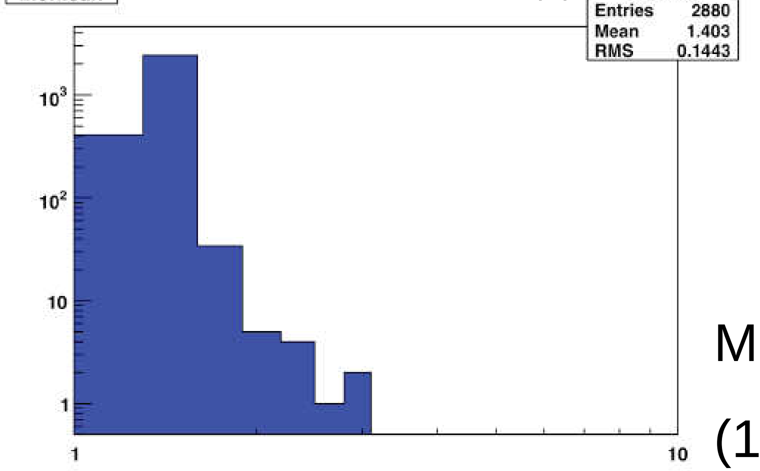
- Electrical and noise tests
- Response to radioactive sources

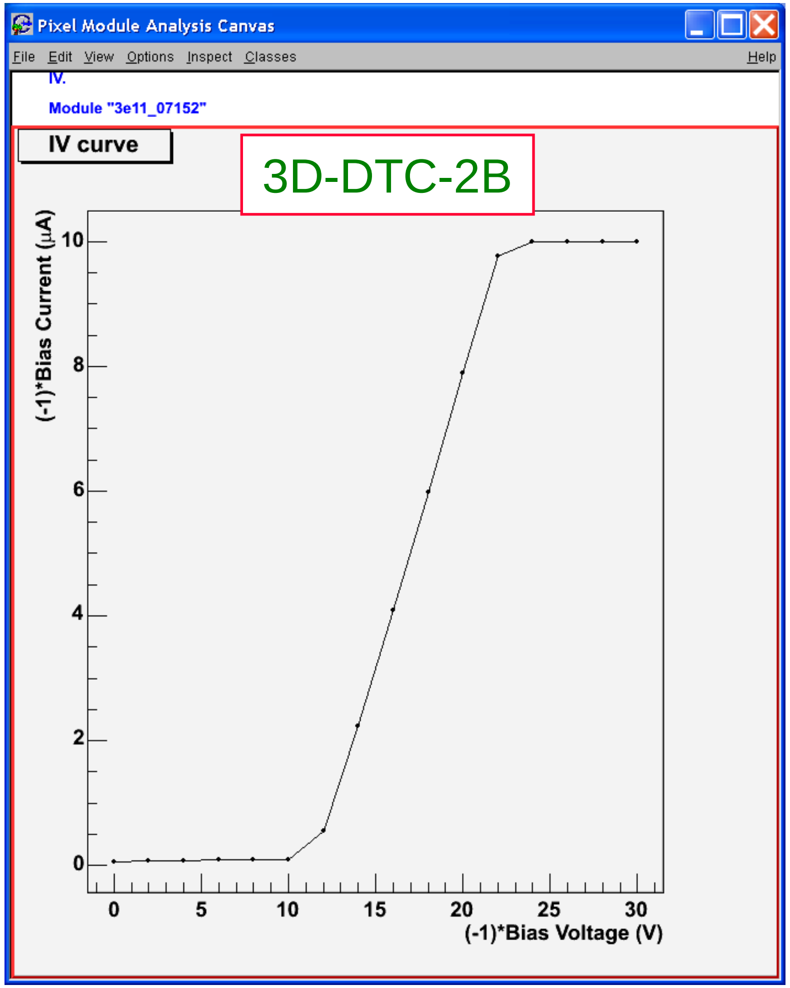
  γ : Am^{241}, Cd^{109} (self triggered)

  β : Sr^{90} (triggered by scintillator)

Leakage current







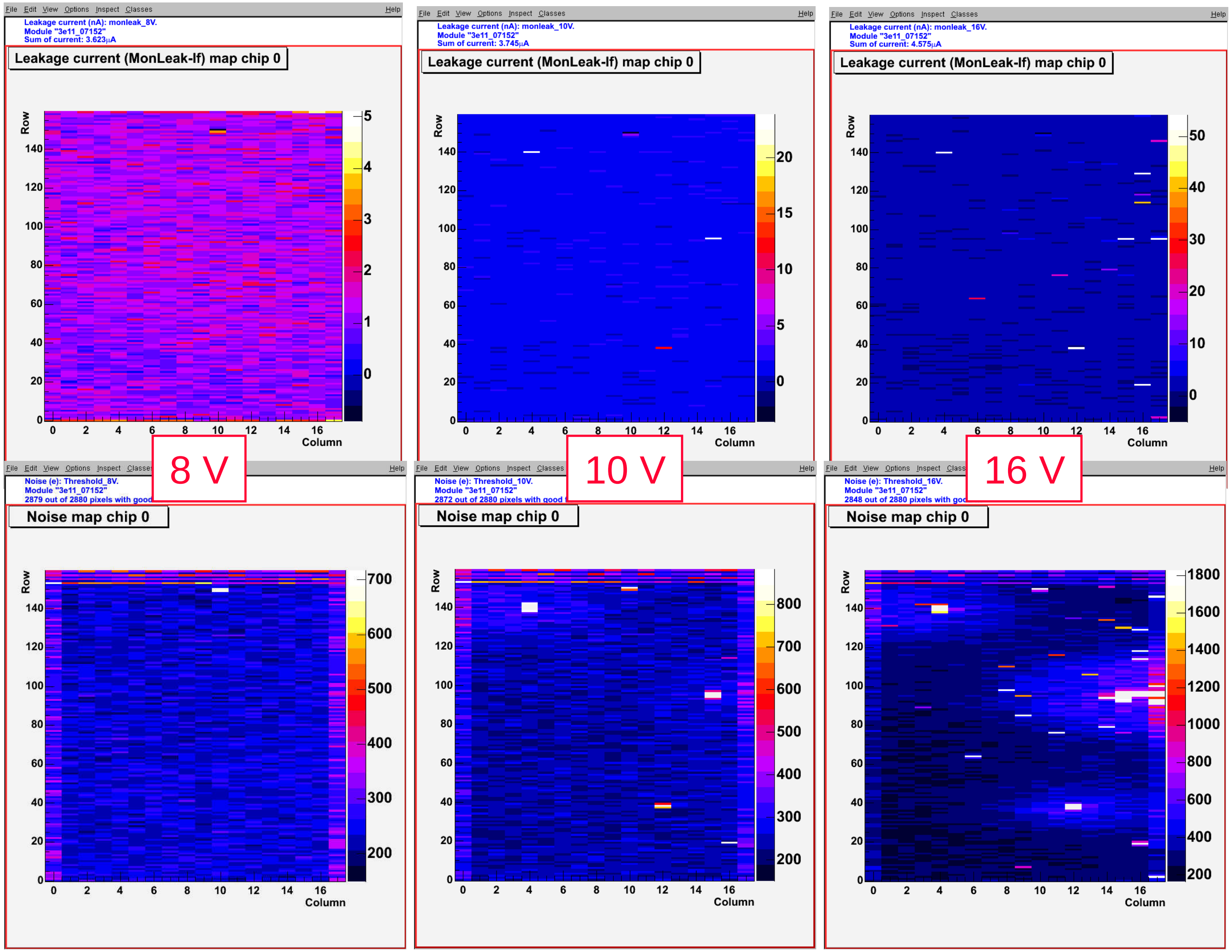
Monleak: pixel leakage current in DAC unit

(1 DAC = 125pA) → <Ileak> ~ 179 pA

Early breakdown problem in 3D-DTC-2B

Leakage

Noise



8 V

10 V

16 V

Leakage current (nA): monleak_8V.
Module "3e11_07152"
Sum of current: 3.623μA

Leakage current (MonLeak-If) map chip 0

Leakage current (nA): monleak_10V.
Module "3e11_07152"
Sum of current: 3.745μA

Leakage current (MonLeak-If) map chip 0

Leakage current (nA): monleak_16V.
Module "3e11_07152"
Sum of current: 4.575μA

Leakage current (MonLeak-If) map chip 0

Noise (e): Threshold_8V.
Module "3e11_07152"
2879 out of 2880 pixels with good

Noise map chip 0

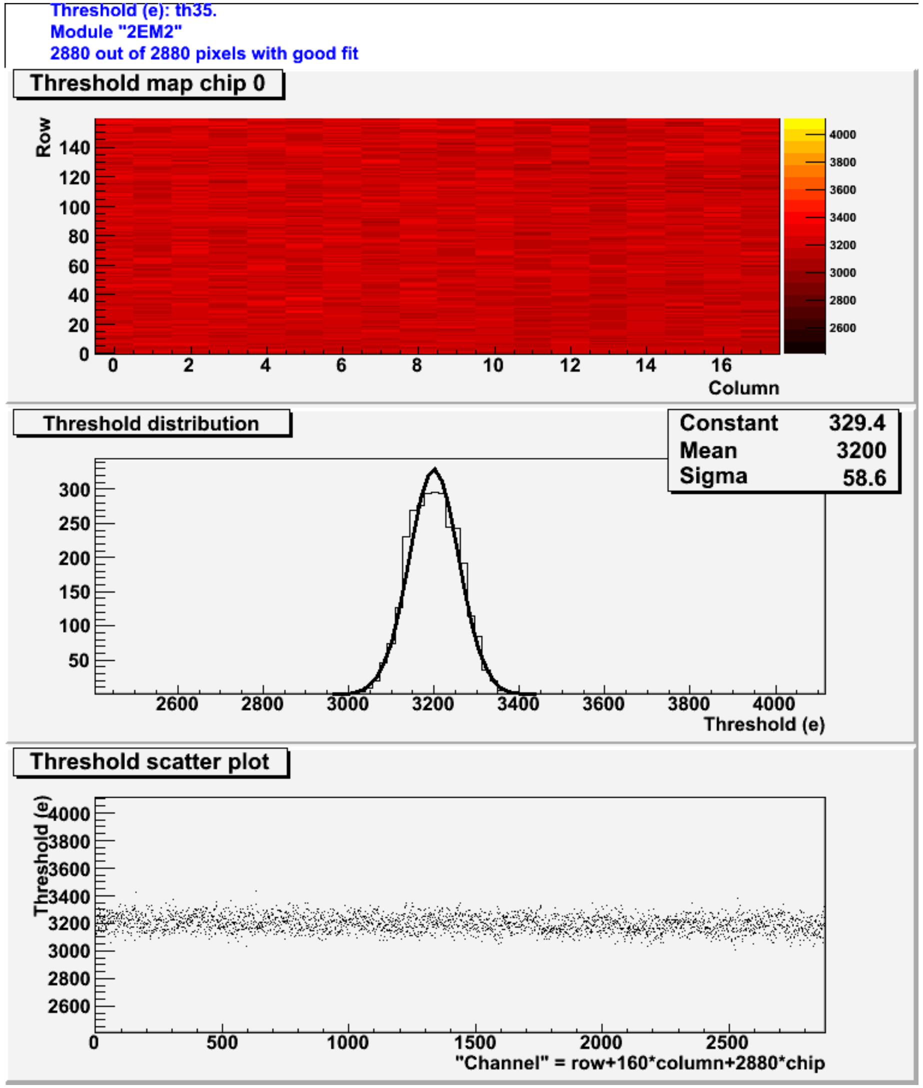
Noise (e): Threshold_10V.
Module "3e11_07152"
2872 out of 2880 pixels with good

Noise map chip 0

Noise (e): Threshold_16V.
Module "3e11_07152"
2848 out of 2880 pixels with goo

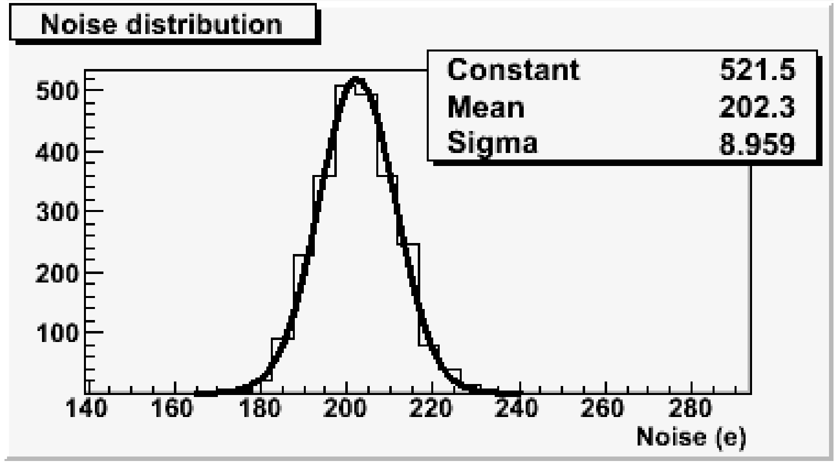
Noise map chip 0

Threshold and Noise



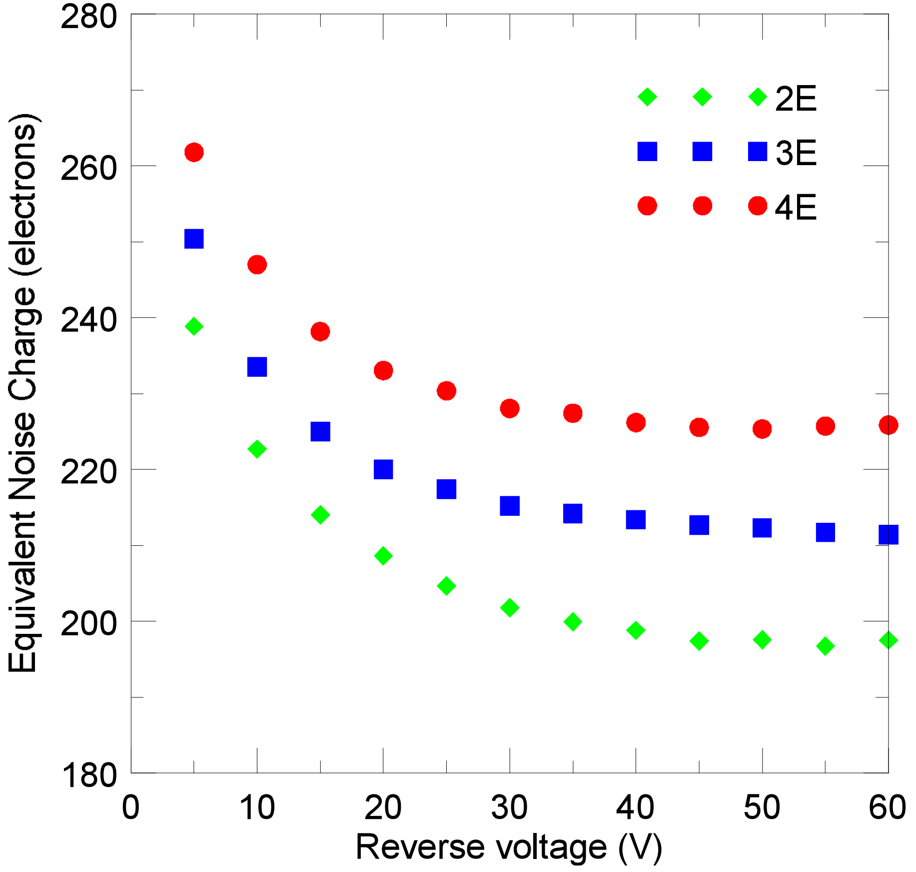
FE Tuned with Th=3.2ke- and

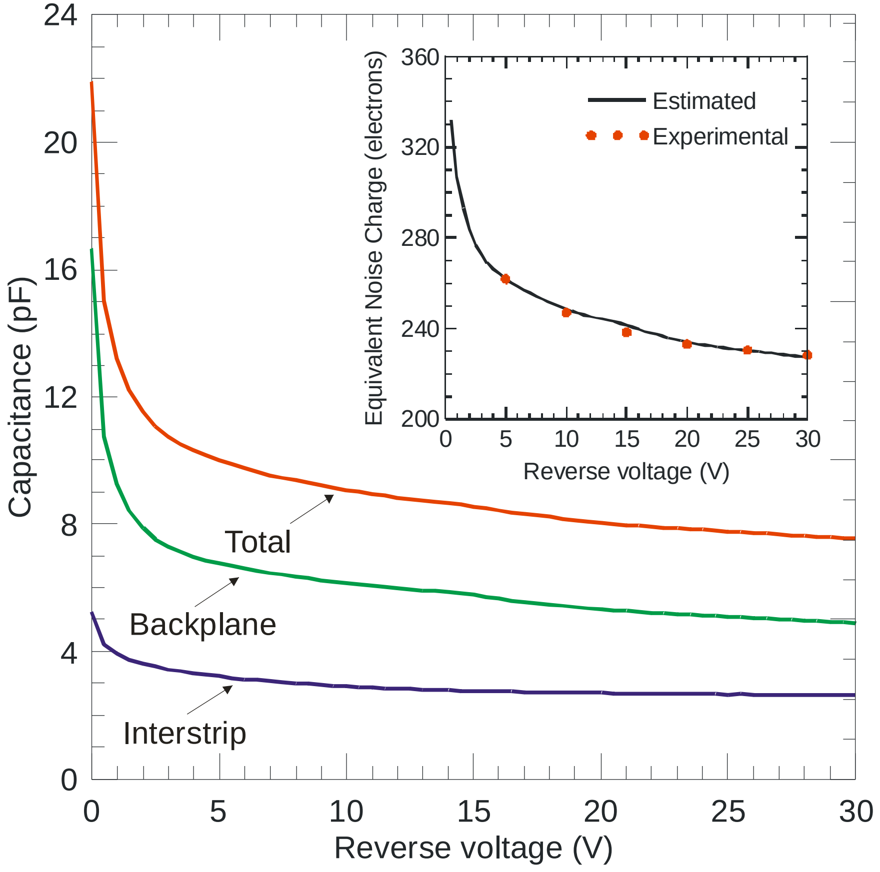
60 ToT @ 20ke-



Sensor type	Threshold (e-)	Noise (e-)
3D-2E	3200 ± 58.60	202.3 ± 8.96
3D-3E	3318 ± 42.02	206.6 ± 8.29
3D-4E	3284 ± 41.27	229.8 ± 9.87
Planar	3259 ± 42.96	181.1 ± 9.37

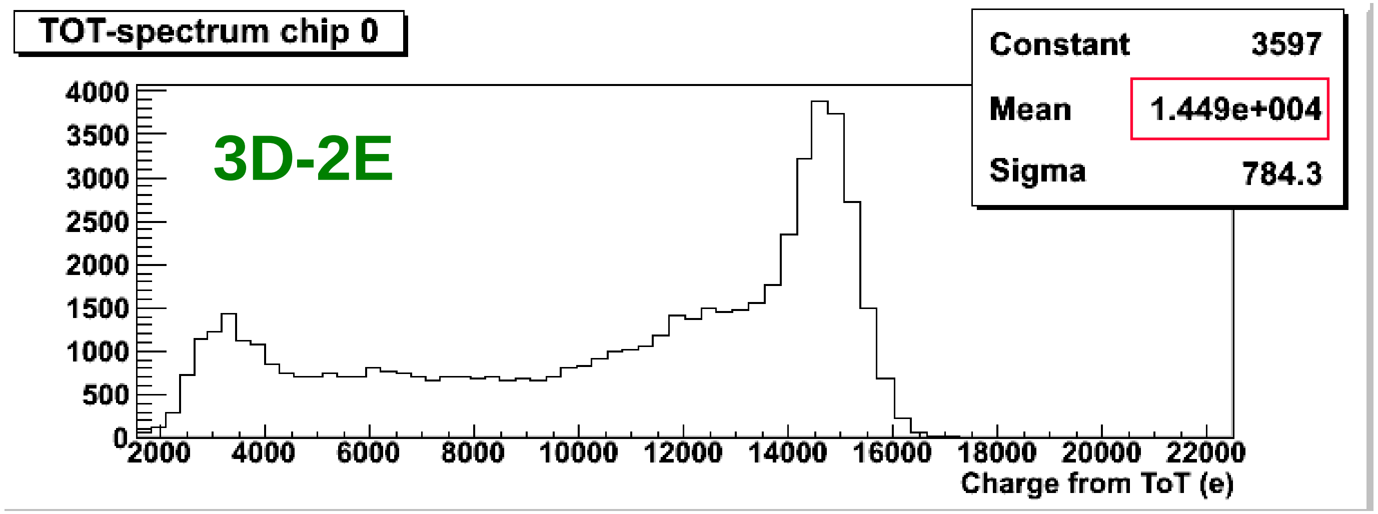
Noise and Capacitance



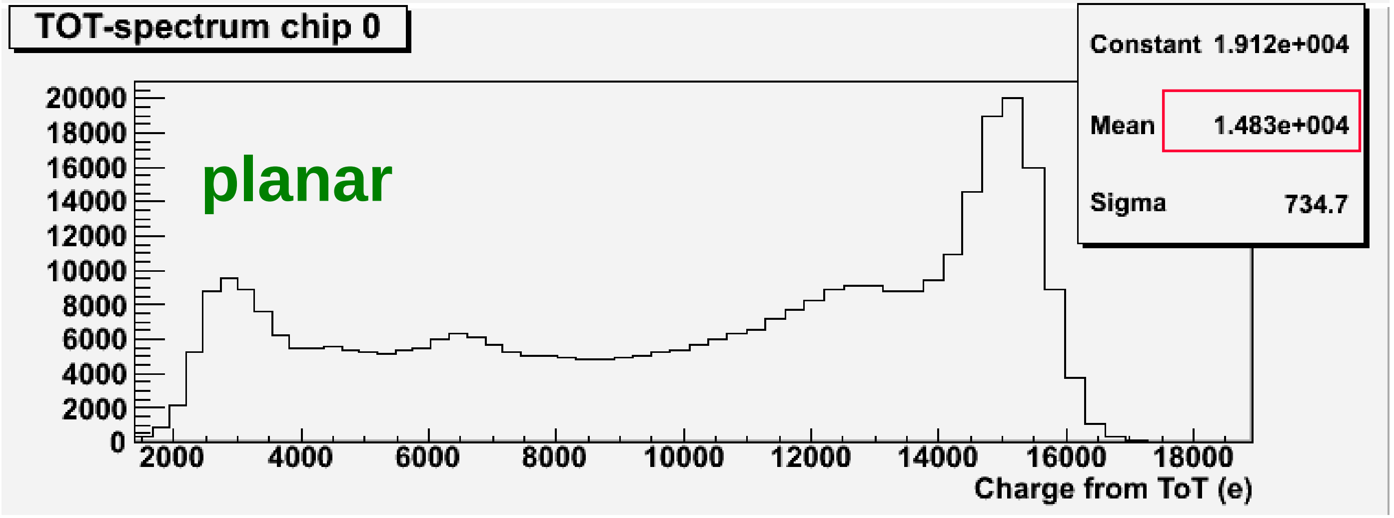


[G.F. Dalla Betta et al., 2009 IEEE NSS]

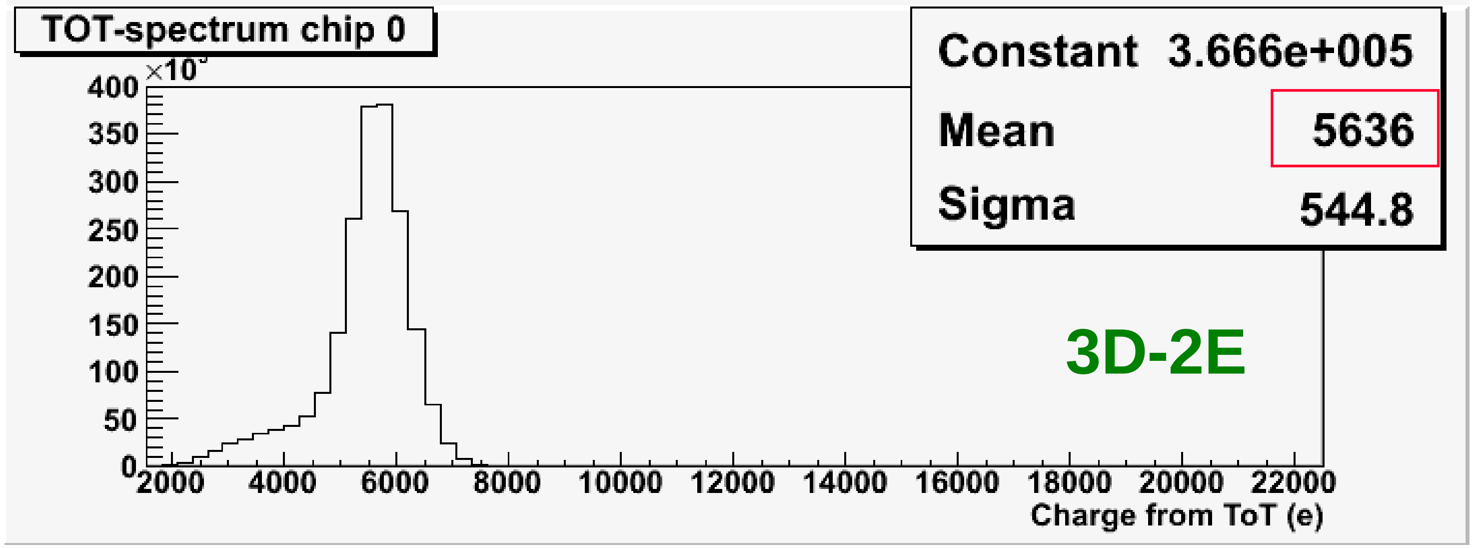
Gamma source tests: Am^{241}



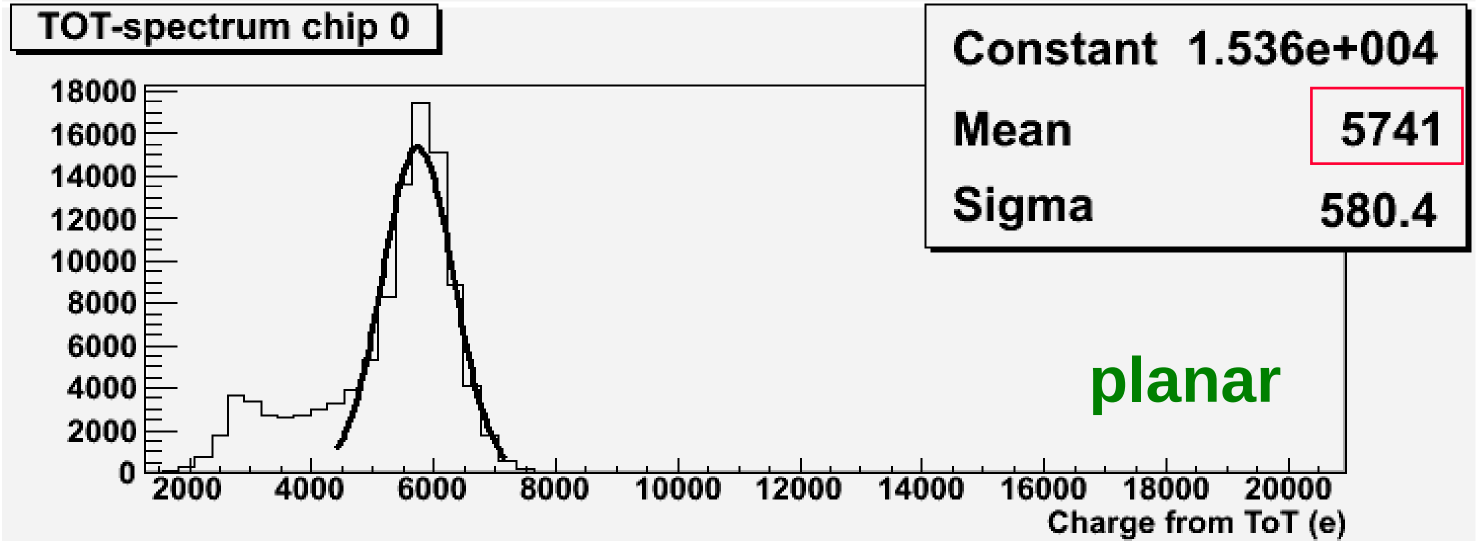
Spectrum as a sum over all pixel without any clustering



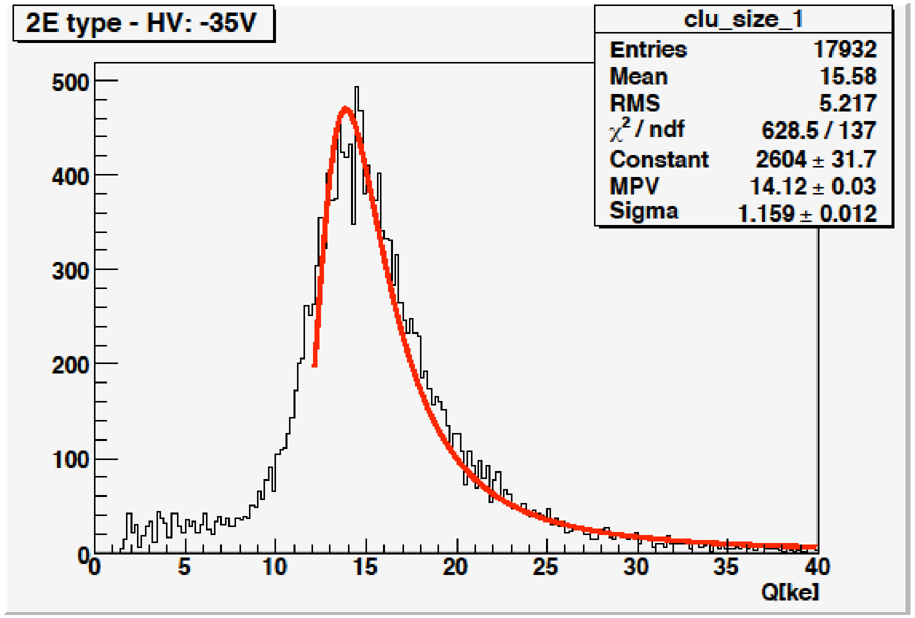
Gamma source tests: Cd^{109}

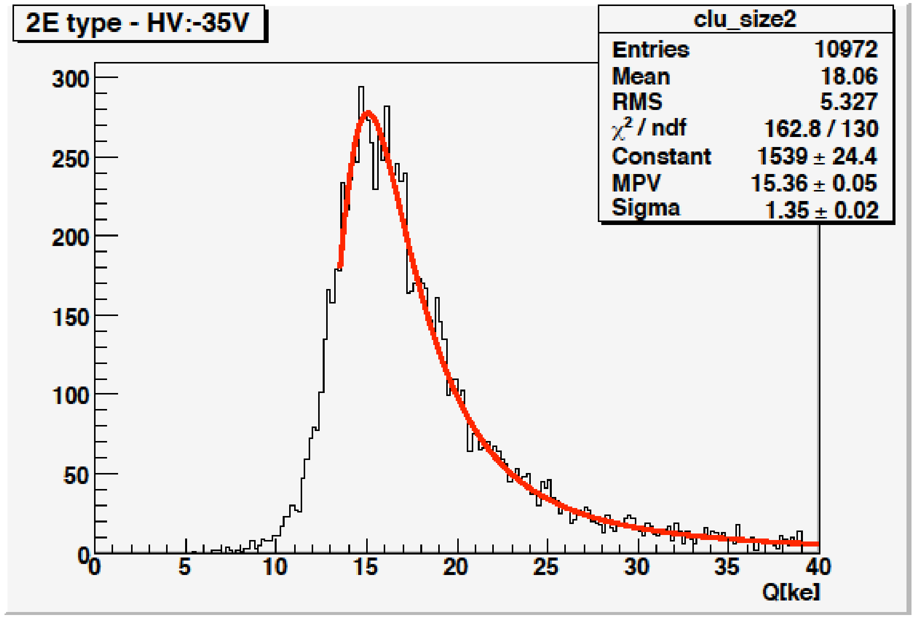


Spectrum as a sum over all pixel without any clustering



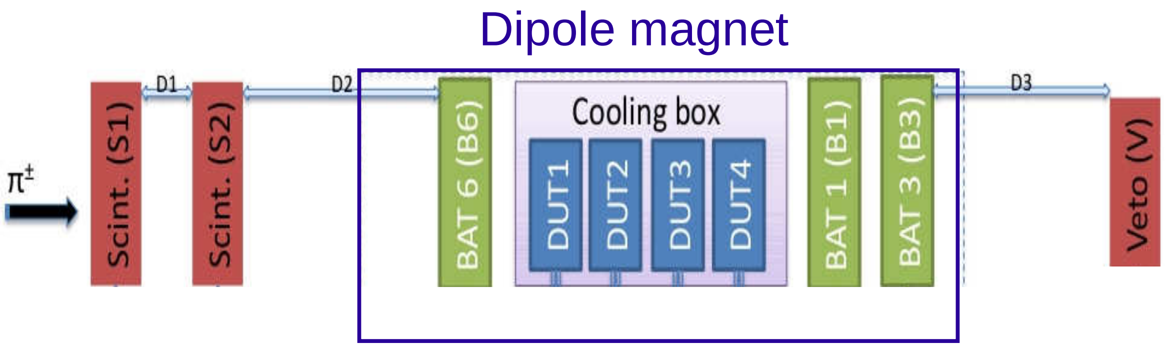
Beta source tests



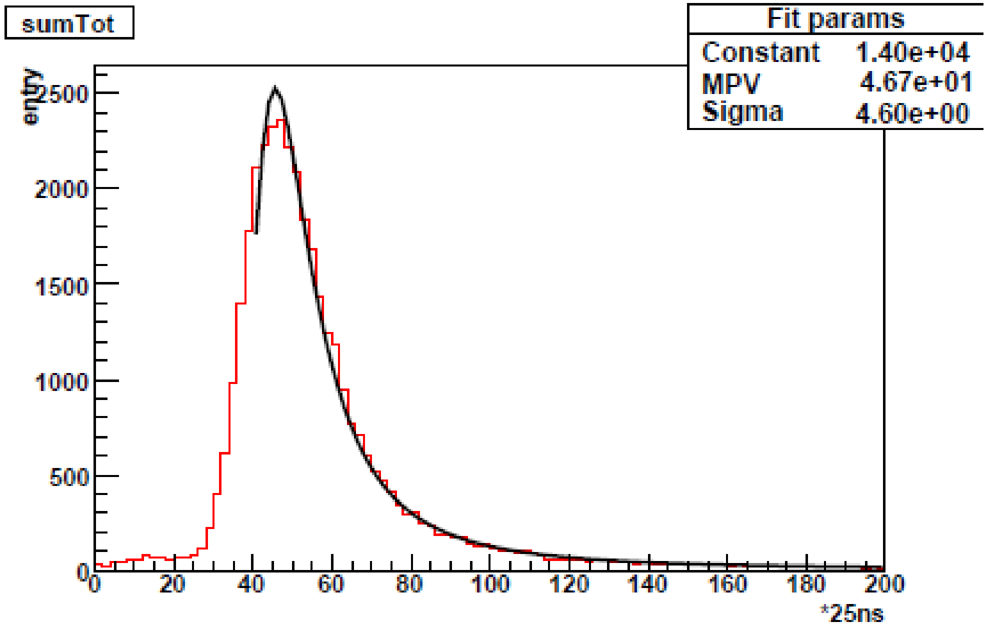


Sensor type	MPV clu.size.1 (ke-)	MPV clu.size 2 (ke-)
3D-2E (200 μm)	14.12 ±0.03	15.36± 0.05
3D-3E (200 μm)	14.07 ± 0.03	15.25± 0.02
3D-4E (200 μm)	14.07± 0.03	15.25± 0.03
Planar (250 μm)	17.19± 0.18	18.52± 0.06

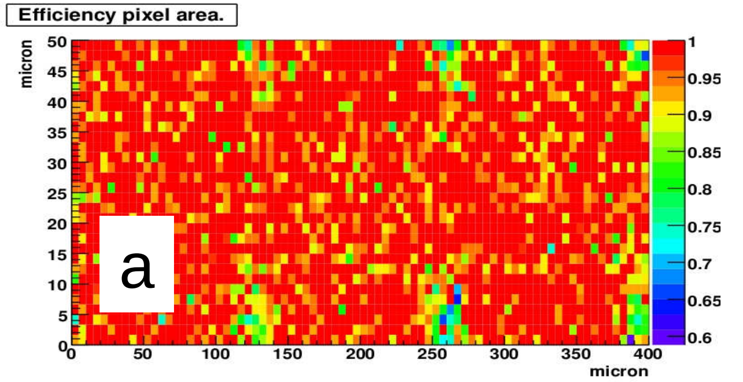
May 2009 beam test at CERN

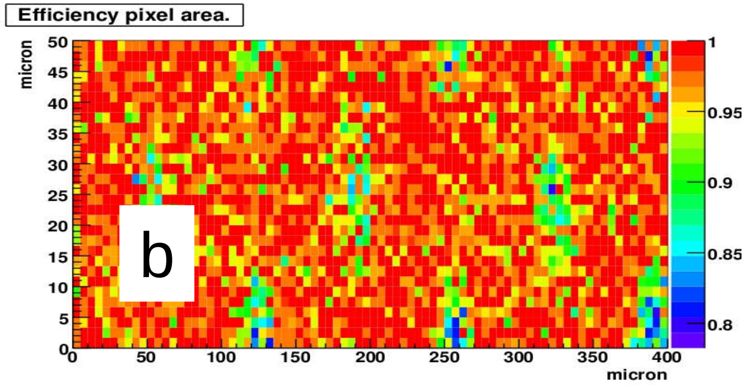


Two 3D-DDTC sensors tested:
a) 3D-DTC-2 @ 35 V
b) 3D-DTC-2B @ 8 V



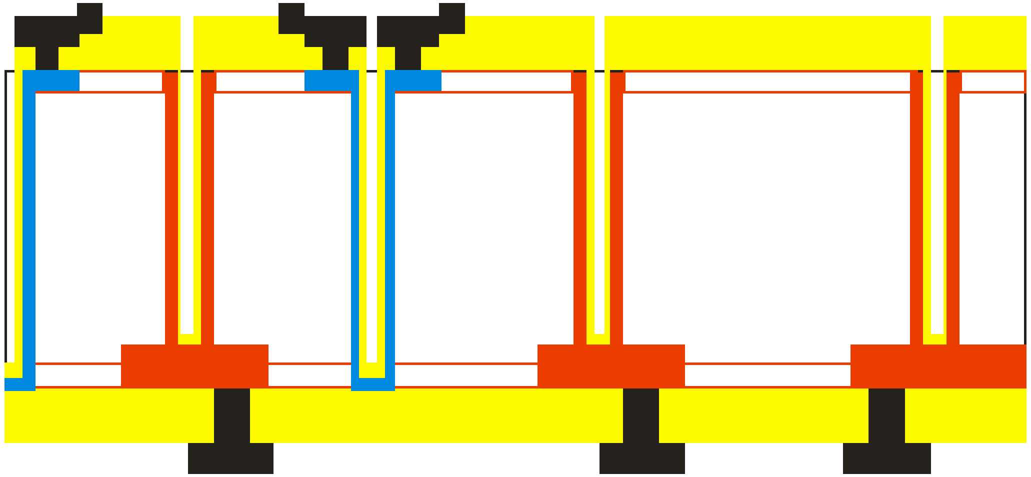
Data from M. Borri, S. Fazio

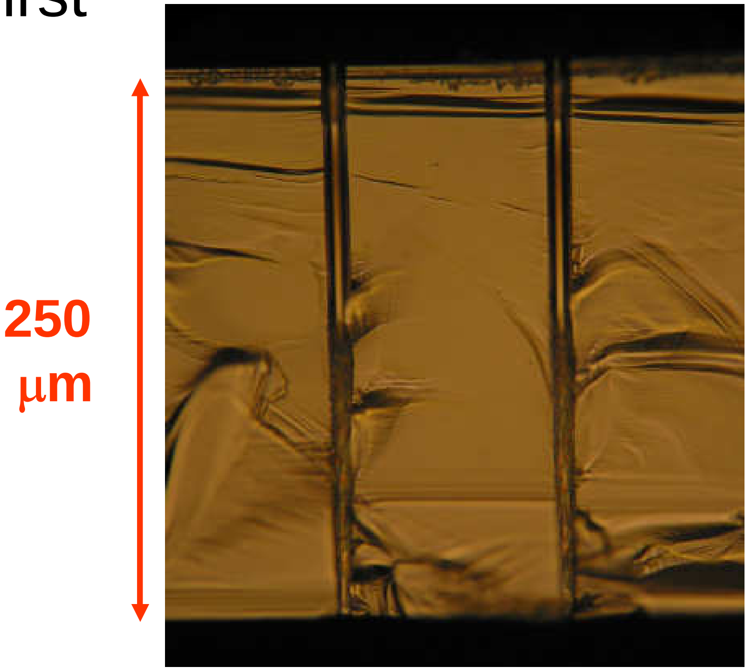




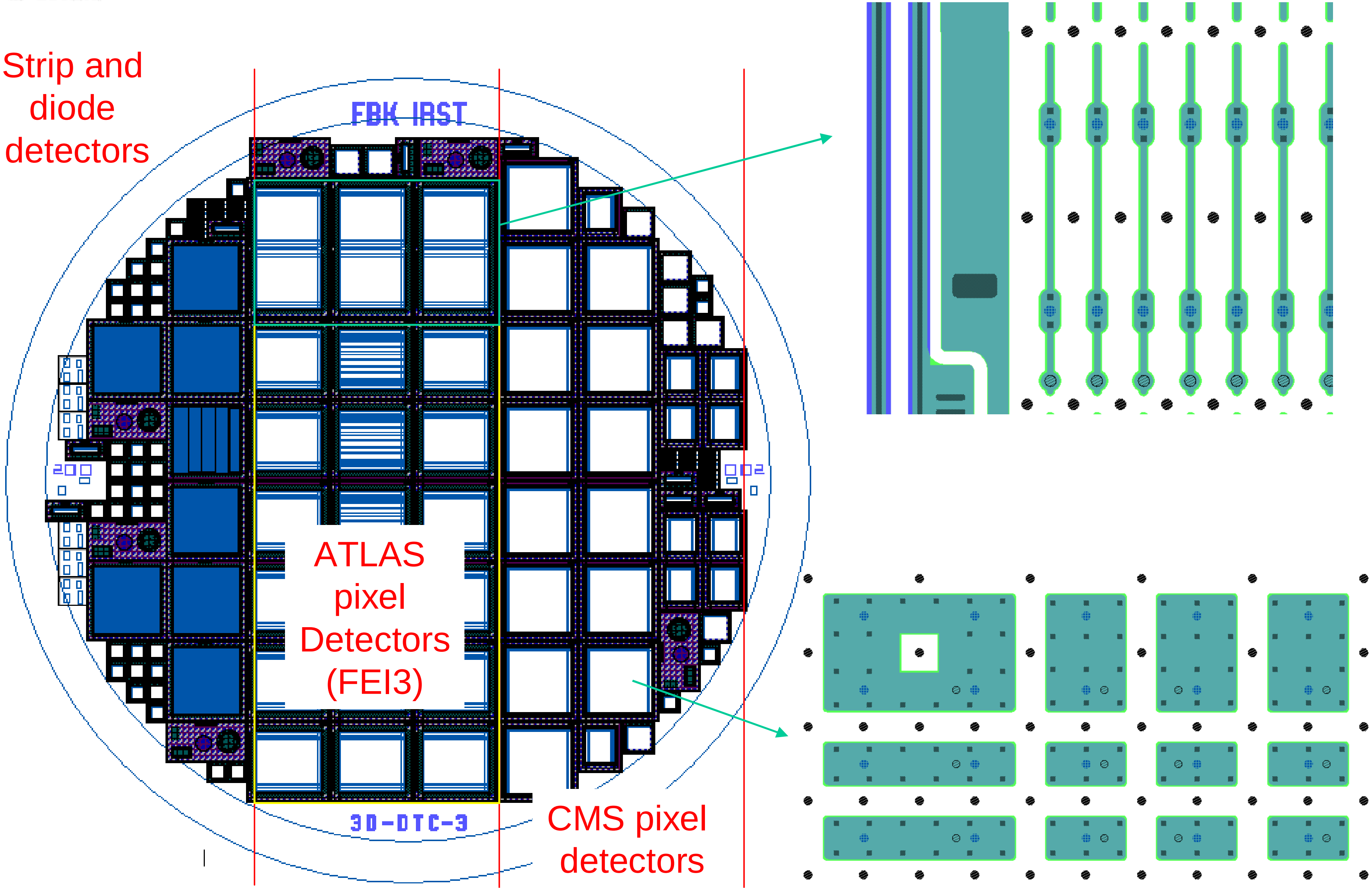
Next steps (1):
3D-DDTC$^+$ “passing through columns”

- Modified 3D-DDTC technology approach, already proved on test structures of 250 μm thickness.
- No support wafer, allows for dual-readout pixel/strip sensors
- Allows for “slim-edge” detectors (ohmic fence termination)
- One batch under fabrication at FBK-irst





3D-DTC-3: wafer layout

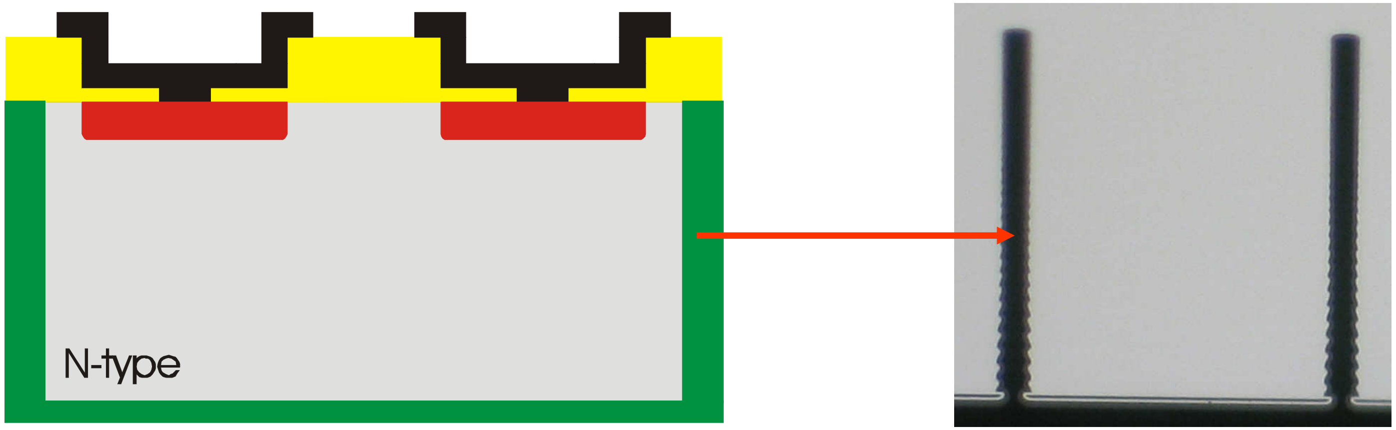


Strip and diode detectors

ATLAS pixel Detectors (FEI3)

CMS pixel detectors

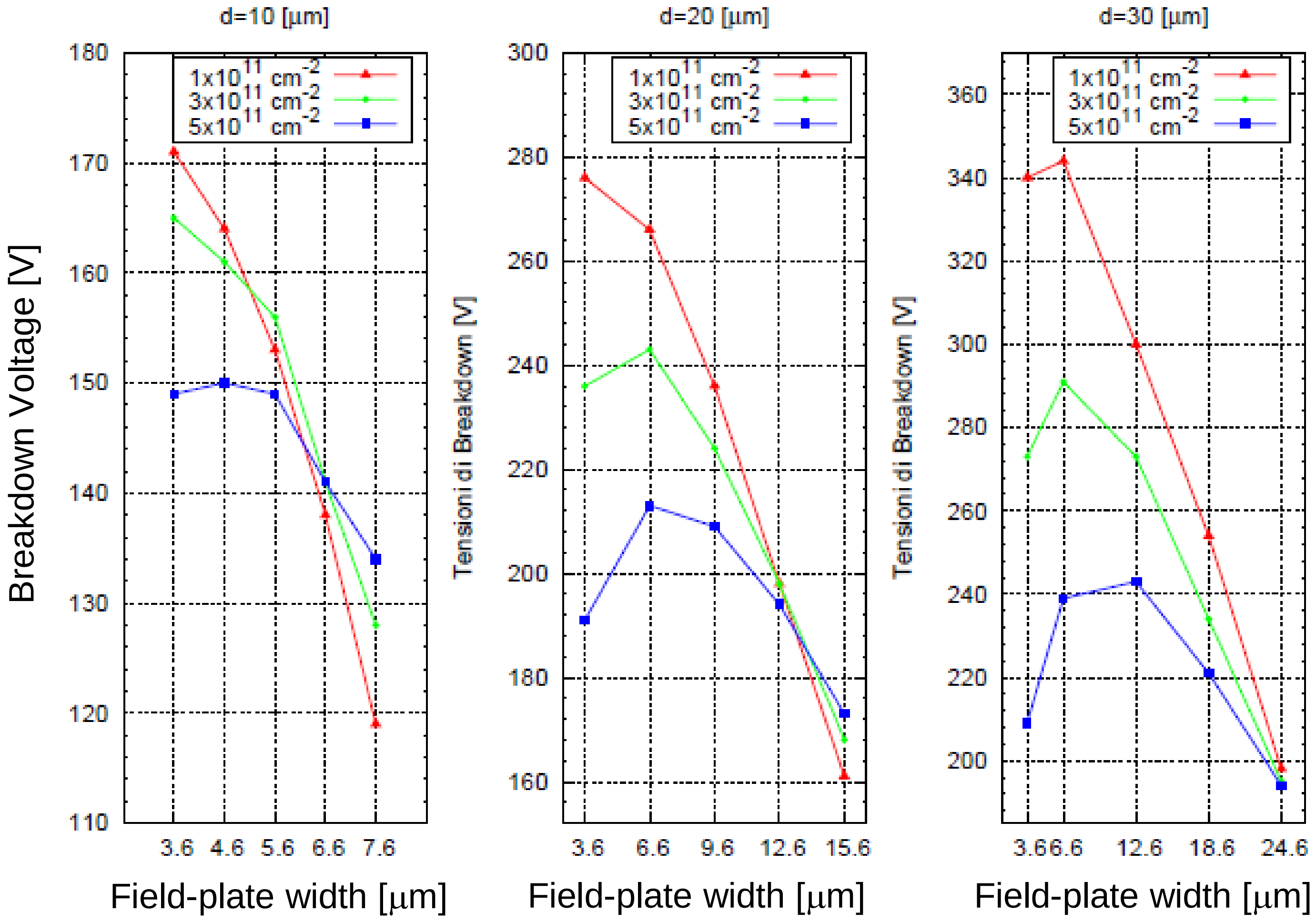
Next steps (2): Planar detectors with active edge

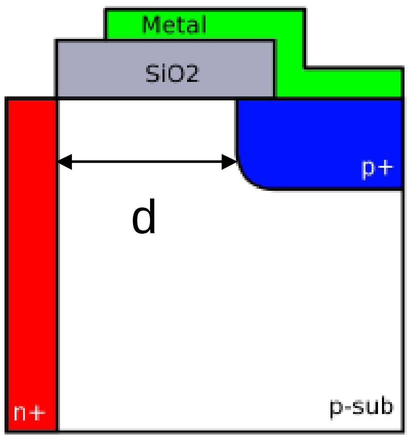


- Trench etching steps investigated on test wafers
- TCAD simulations for breakdown prediction
- Layout complete (p-on-n, mainly strips)
- External service at SINTEF for wafer bonding
- Ready to start …

Simulations: breakdown voltage

- Sensors can be safely operated well above full depletion voltage
- Field-plate largely enhances breakdown voltage performance

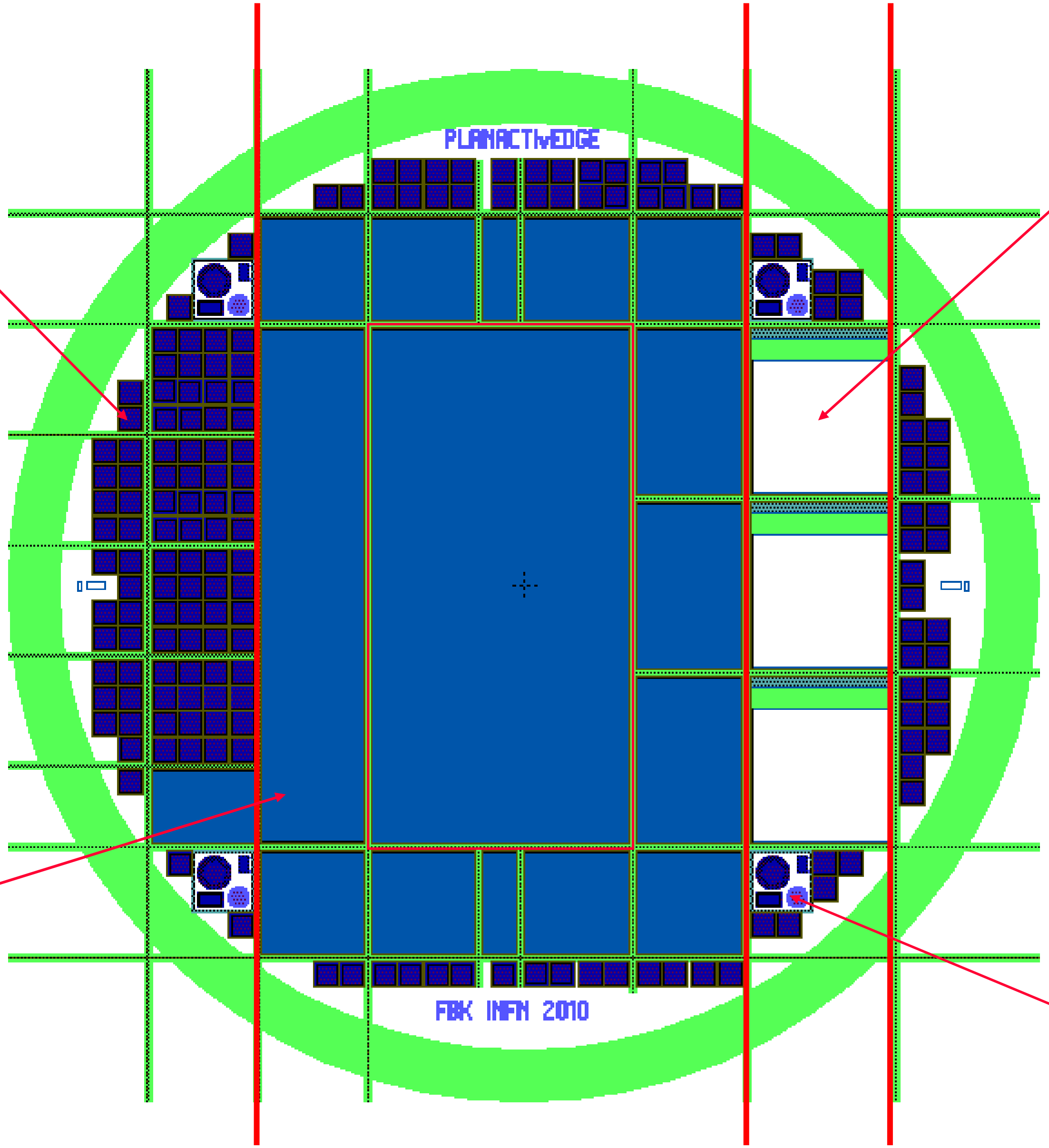




V_{bd} @N_{ox}=1x10^{11}cm^{-2}

d (µm)	w/FP 3.6µm	wo/FP
10	171 V	127 V
20	276 V	183 V
30	340 V	219 V

PAE: wafer layout



Diode detectors with different edge configuration

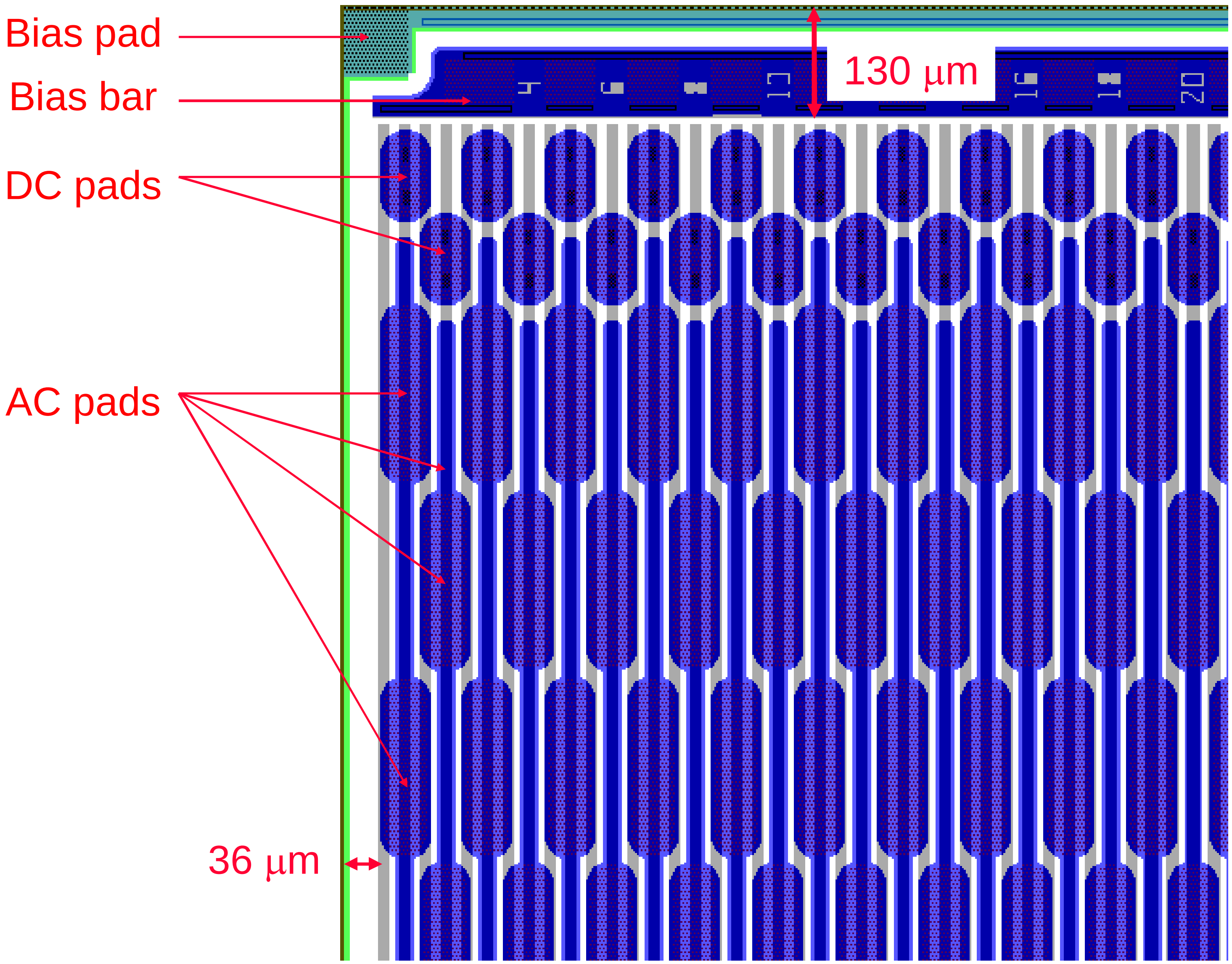
ALICE pixel sensors

Strip detectors

Test structures

PAE strip sensor

(2.5x5.0 cm^2, 498 read-out strips, pitch 50 μm, with floating strips)



2010: batch schedule at FBK

1) 3D-DTC-3: n-on-p, 250-μm thick substrate, full 3D detectors (passing-through) columns.

Under way, to be completed by April 2010

2) Planar – active edge.

Started, 18 wafers with bonded support (made at SINTEF), to be completed by March 2010

3) 3D - ATLAS – IBL1 (full 3D with slim edge) and
3D - ATLAS – IBL2 (full 3D with active edge)

To start in February 2010, due by June/September 2010

Conclusions

- The development of 3D detector technologies at FBK-irst is proceeding with encouraging results.

- In 2009he first prototypes of ATLAS pixel sensors made with the 3D-DDTC approach and assembled with FEI3 read-out chips have shown good performance in terms of charge collection (to be validated after irradiation)
- Early breakdown problems have been observed after bump-bonding (still to be fully understood)
- 3D detectors with “passing through” columns and planar detectors with active edge are also being developed and will be available soon.