Recent results on 3D double sided detectors at IMB-CNM

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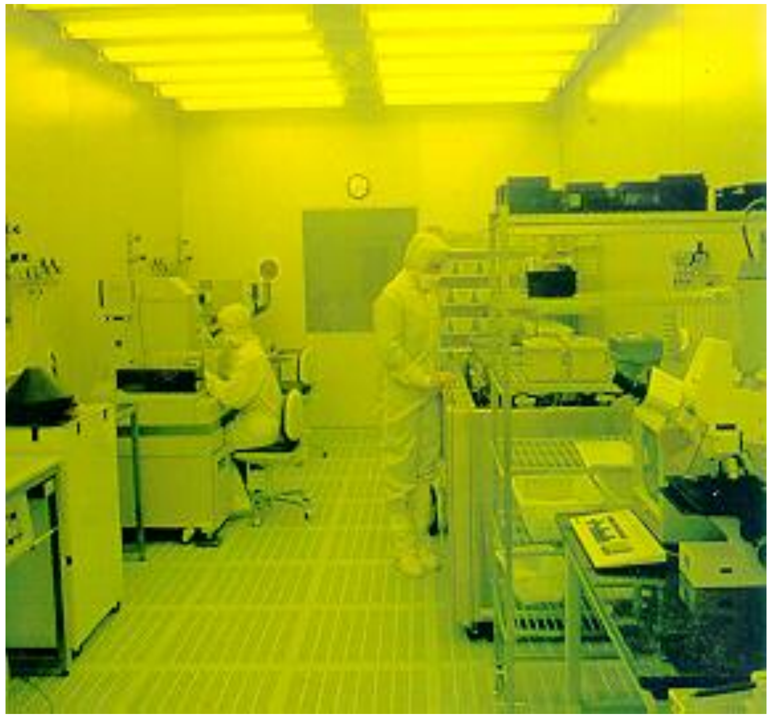
IMB-CNM facilities



Clean Room

- **1.500 m2, class 100 to 10.000**
- **Micro and nano fabrication technologies.**

Processes

- **4'' complete**
- **6'' partial**

Available technologies:

- **CMOS, BiCMOS, MCM-D,MEMS/NEMS,**
- **power devices**
- **Bump bonding packaging**

Silicon micromachining

Laboratories:

Characterization and test

- DC and RF (up to 8 GHz)
- Wafer testing
- Thermography
- Radiation testing

Reverse Engineering

Simulation

CAD

Mechanical Workshop

Chemical sensors

Bio-sensors

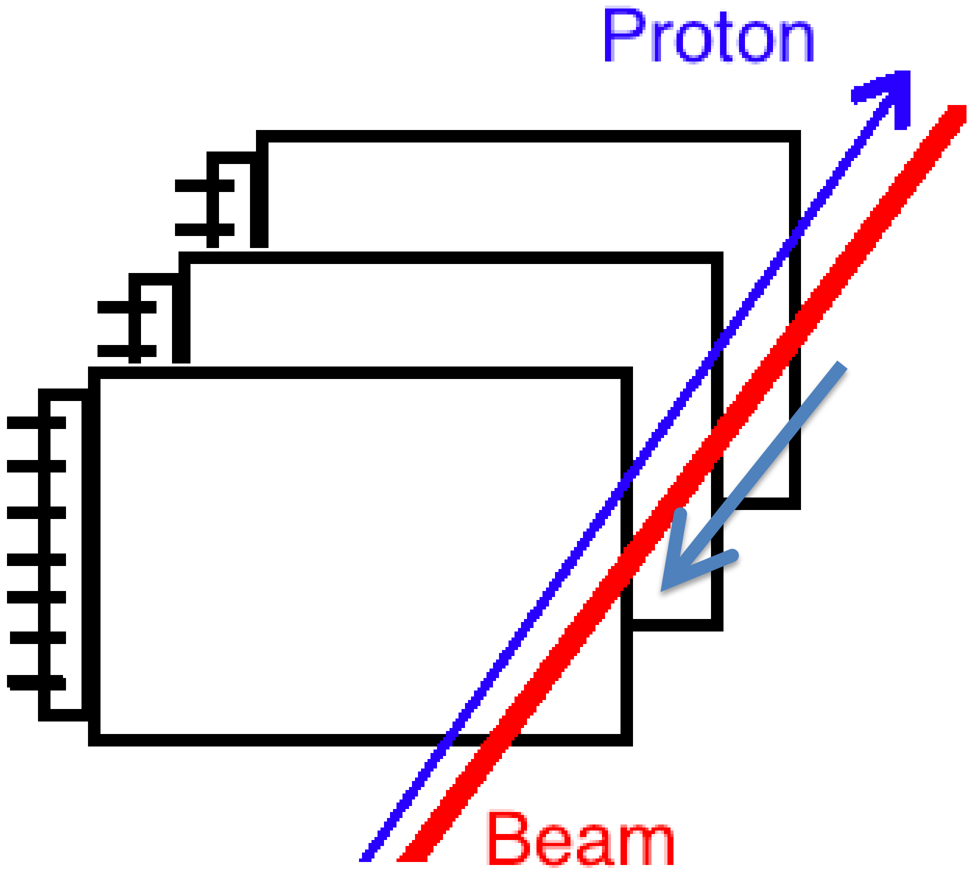
Optical sensors

Radiation sensors

Pixel Status: AFP

Pixel detectors: technology choice in high-energy physics for innermost tracking and vertexing.

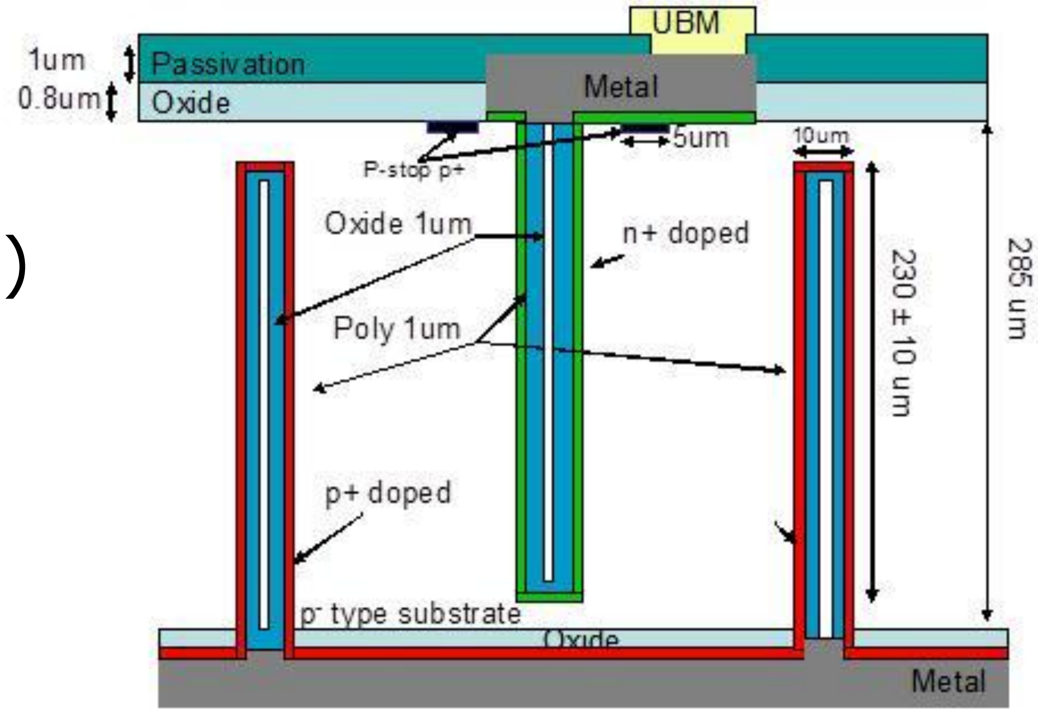
3D detectors: candidates to be installed in new Insertable B-Layer (IBL) of ATLAS experiment. Production already finished.



220m to ATLAS P1

- AFP: detect very forward protons at 220m from IP, with pixel detectors for position resolution and timing detectors for removal of pile up protons.
- Both Si and timing detectors mounted in movable beam pipe
- Silicon detector has to have small dead inactive region on side into beam
- Non-uniform irradiation of the detectors.

3D Technology:

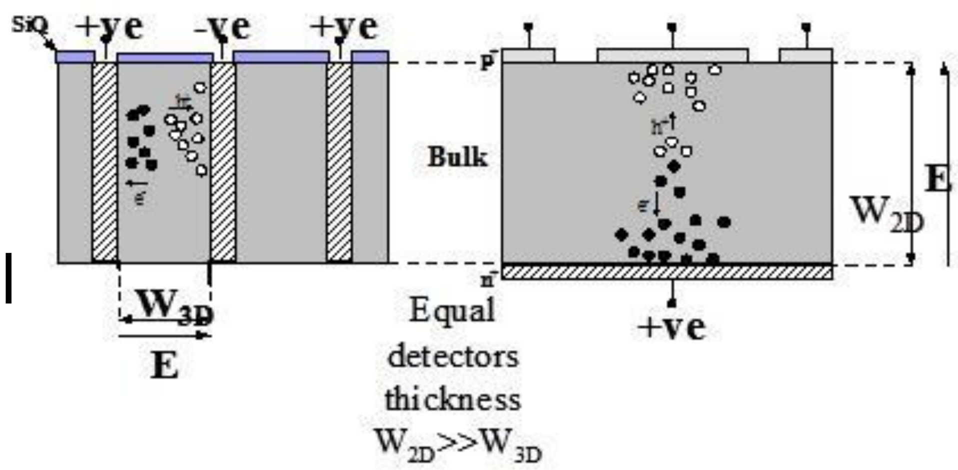


4” silicon wafer
285um FZ high resistivity wafers (n and p- types)
All fabrication done in-house

- ICP etching of the holes: Bosch process, ALCATEL 601-E
- Holes partially filled with LPCVD polysilicon doped with P or B
- P-stop ion implantation

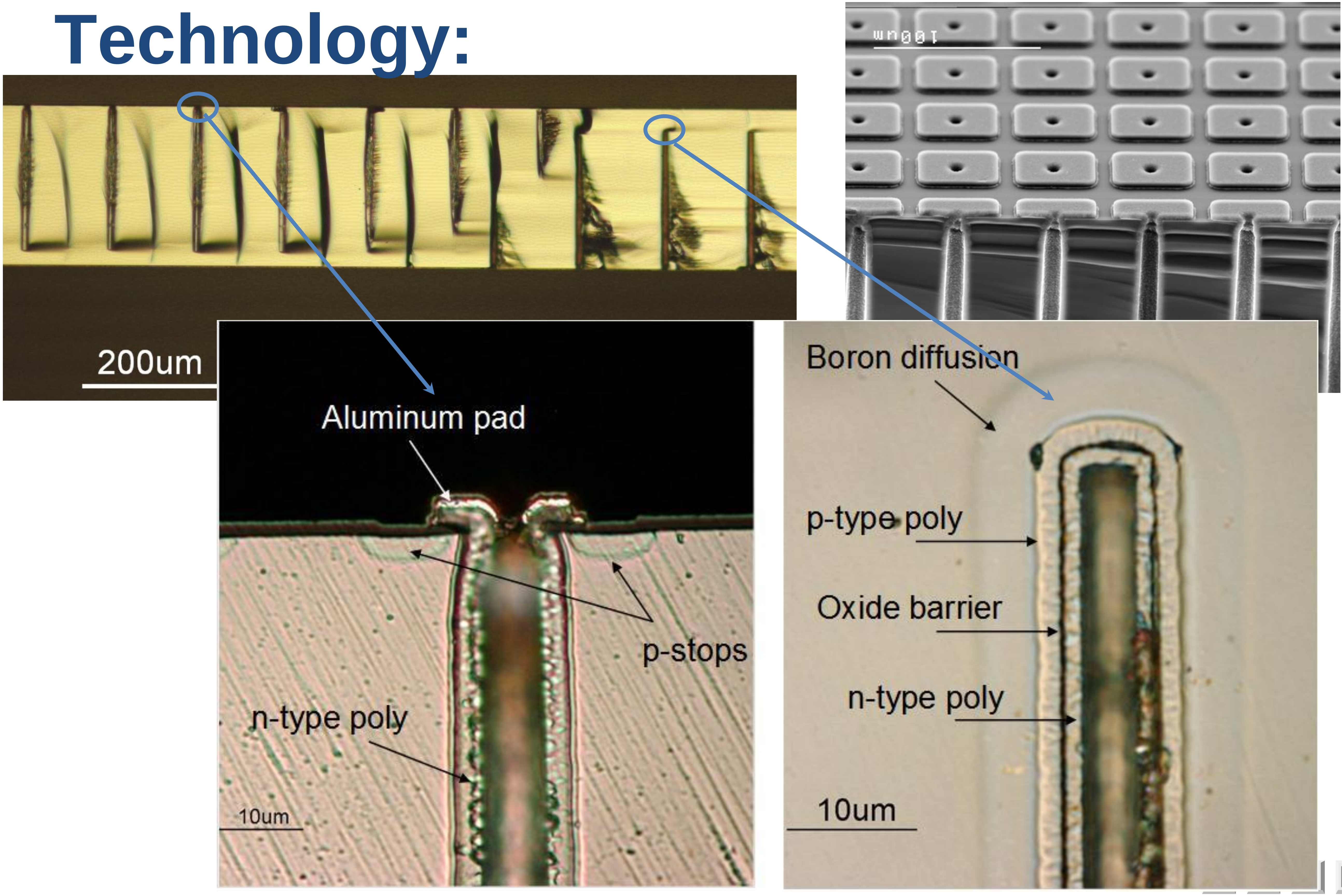
Double side process proposed by CNM in 2006
First fabrication of 3D double sided in 2007.
Since 2007 runs ongoing continuously.
In 2010 CNM started the fabrication on 230um thicl wafers.
Devices tested under extreme radiation fluences.

- Different test beam successfully carried out on device before and after irradiation at SHLC fluences ($2*10^{16}$ cm^{2} 1 MeV n Eq.).

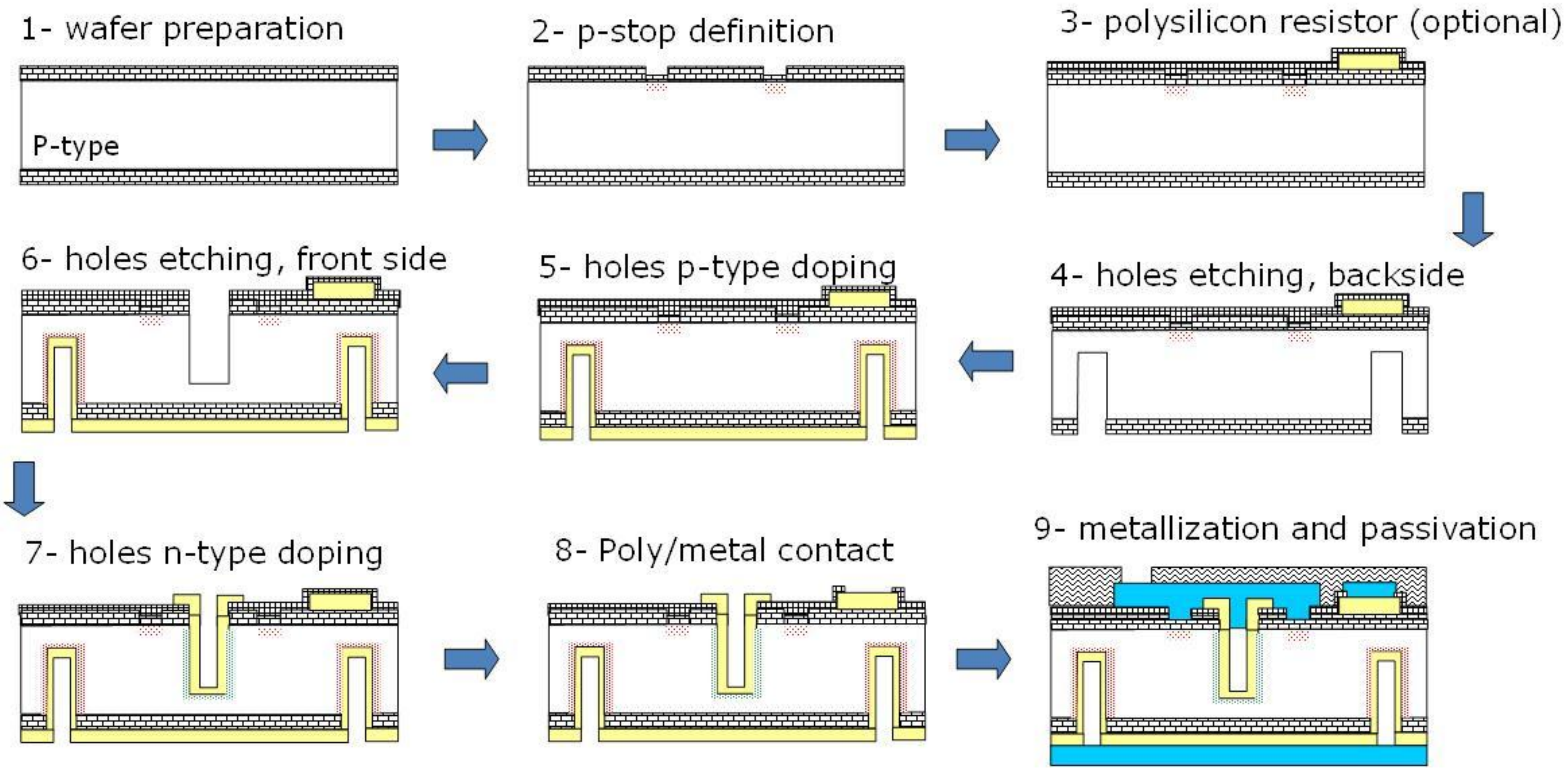


3D Features:
- High electric field
- Short path collection
- Low depletion voltage

Technology:

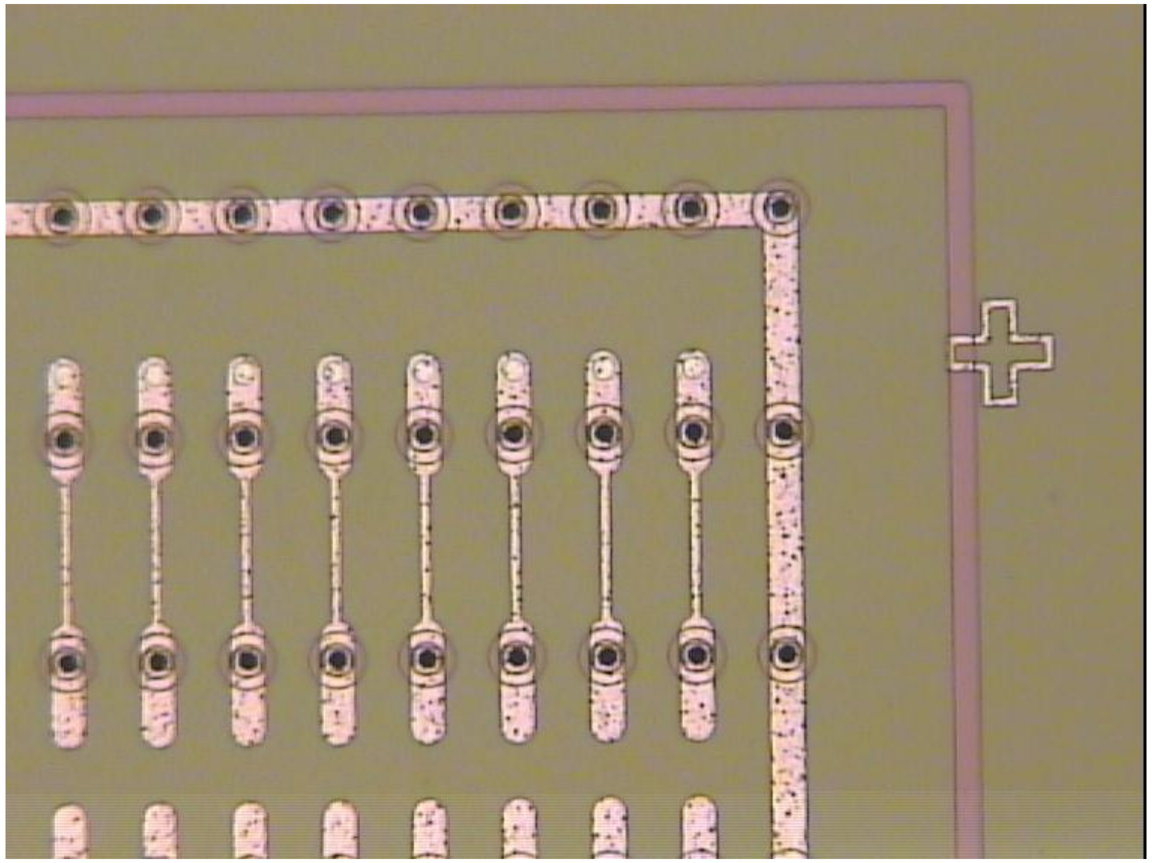

100um
200um
Aluminum pad
p-stops
n-type poly
10um
Boron diffusion
p-type poly
Oxide barrier
n-type poly
10um

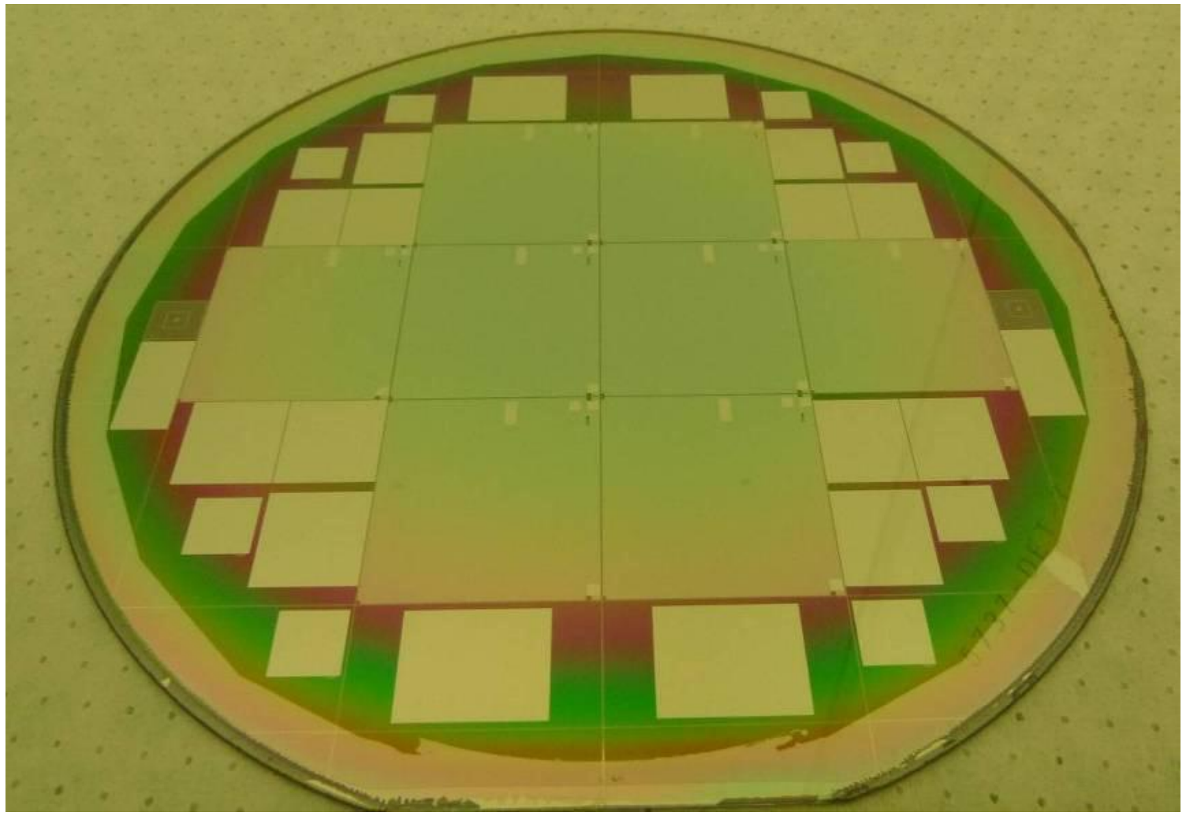
3D process flow



Production

- Part of IBL 3D sensors fabricated at CNM
- Common layout within the Atlas 3D collaboration (http://test-3dsensor.web.cern.ch/test-3dsensor/).
- Sensors produced for the geometry of the FE-I4 chip:
  - 50um x 250um
  - 210um columns in 230um p-bulk
  - 2E configuration (2 readout electrodes/pixel)
- Extensive characterization and testing being done at Barcelona with un-irradiated and irradiated devices up to 5.11x 10^{15} neq/cm^2





http://dx.doi.org/10.1016/j.nima.2012.07.058

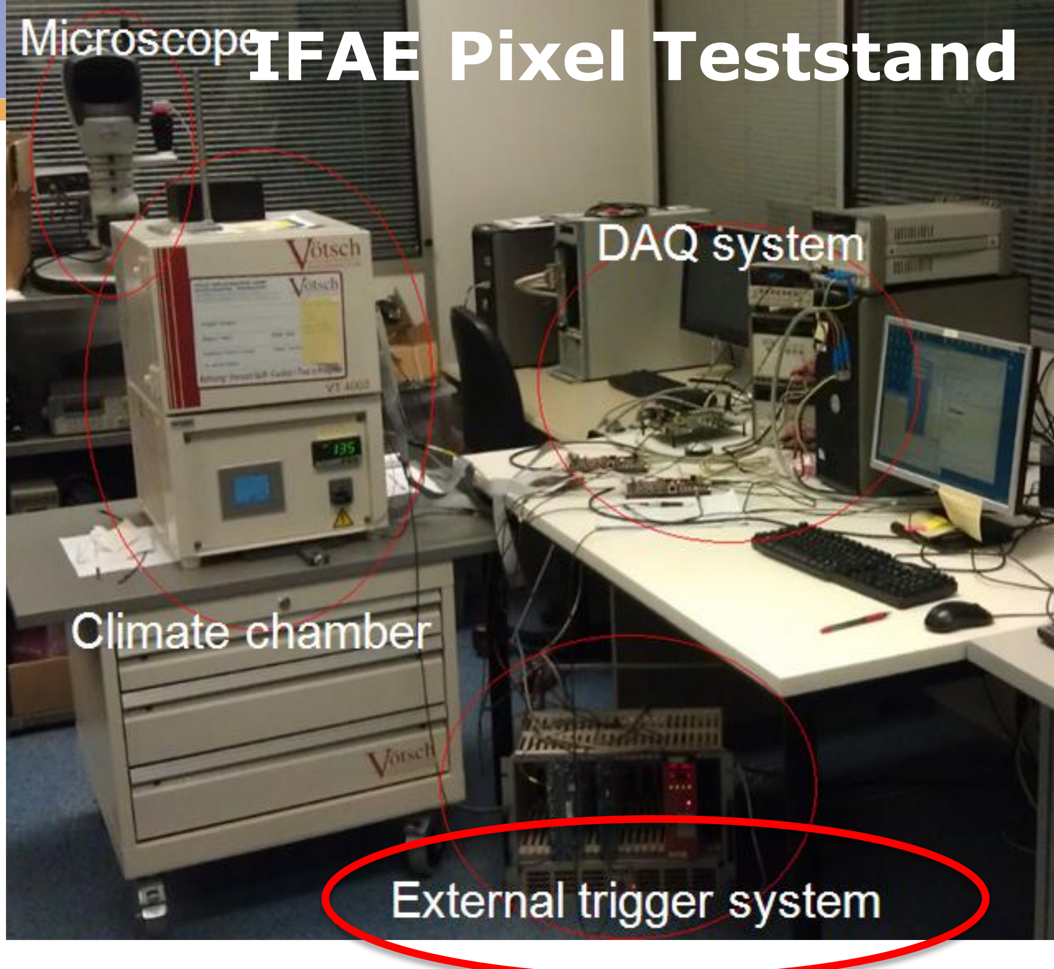
Irradiated IBL Devices

- Several planar and 3D IBL devices irradiated to IBL fluencies (5E15 neq/cm^2)

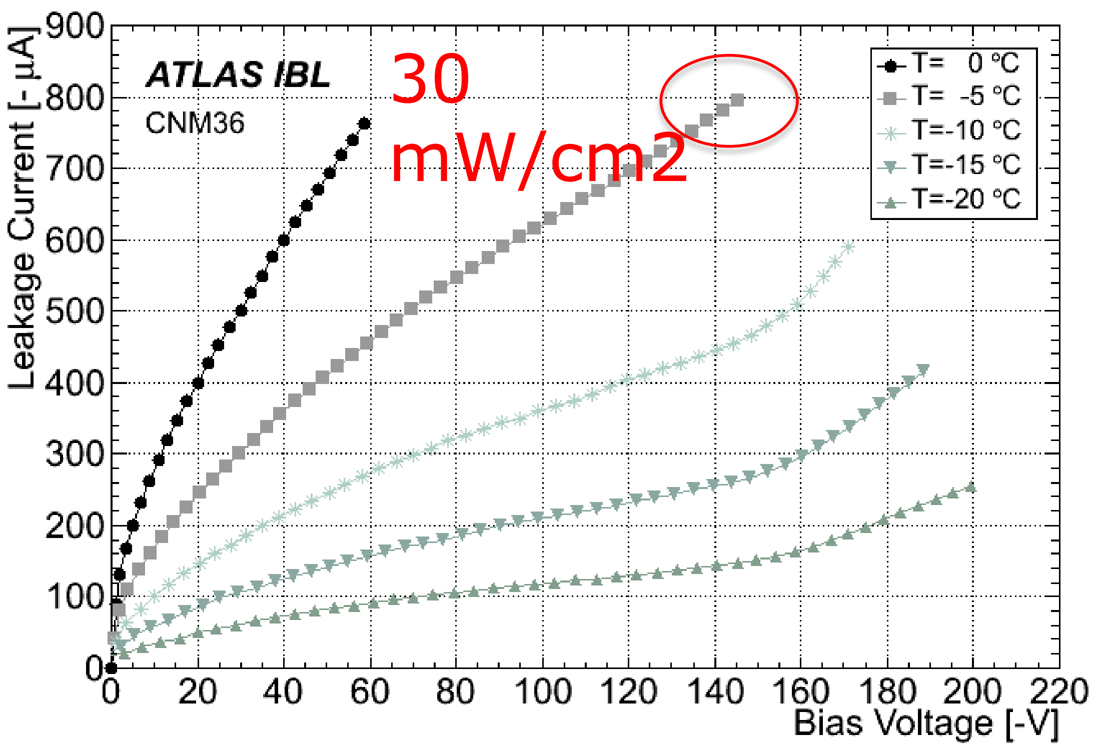
CNM devices irradiated:

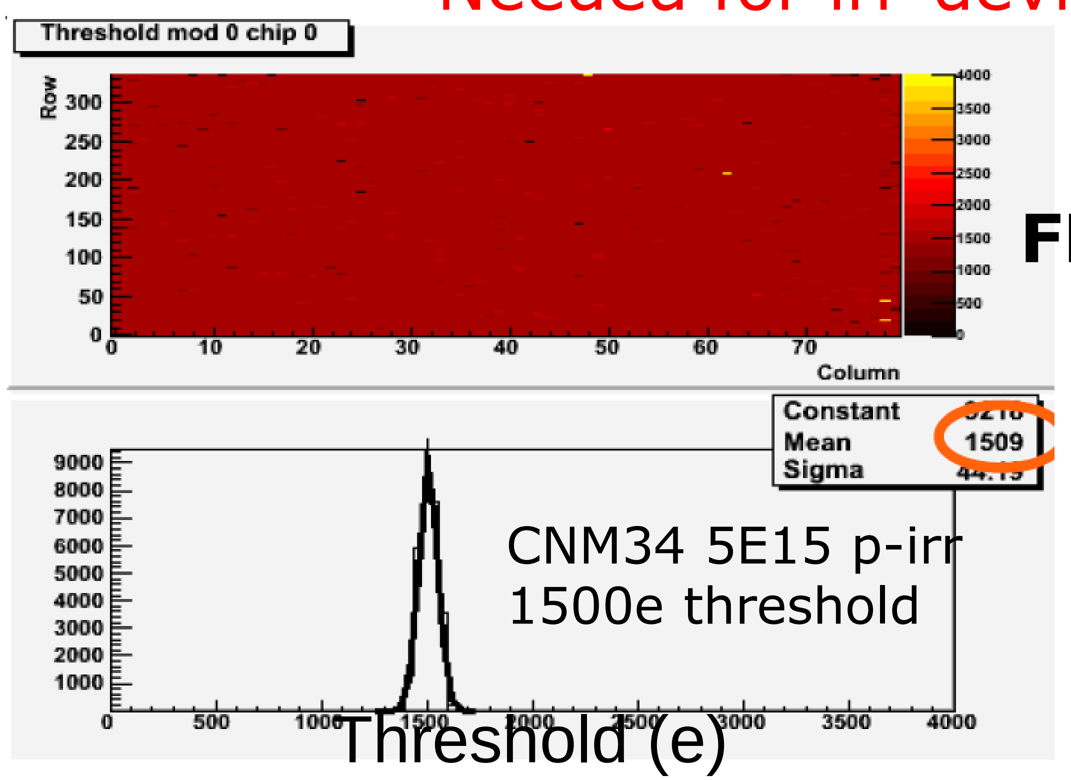
Device	Irradiation $[neq/cm^2]$	Irr Facility
SCC36	p-irrad $6 * 10^{15}$	KIT
SCC34	p-irrad $5 * 10^{15}$	KIT
SCC97	p-irrad $5 * 10^{15}$	KIT
SCC100	p-irrad $2 * 10^{15}$	KIT
SCC82	n-irrad $5 * 10^{15}$	TRIGA
SCC81	n-irrad $5 * 10^{15}$	TRIGA

- Critical to characterize devices before and after irradiation.



Needed for irr-device





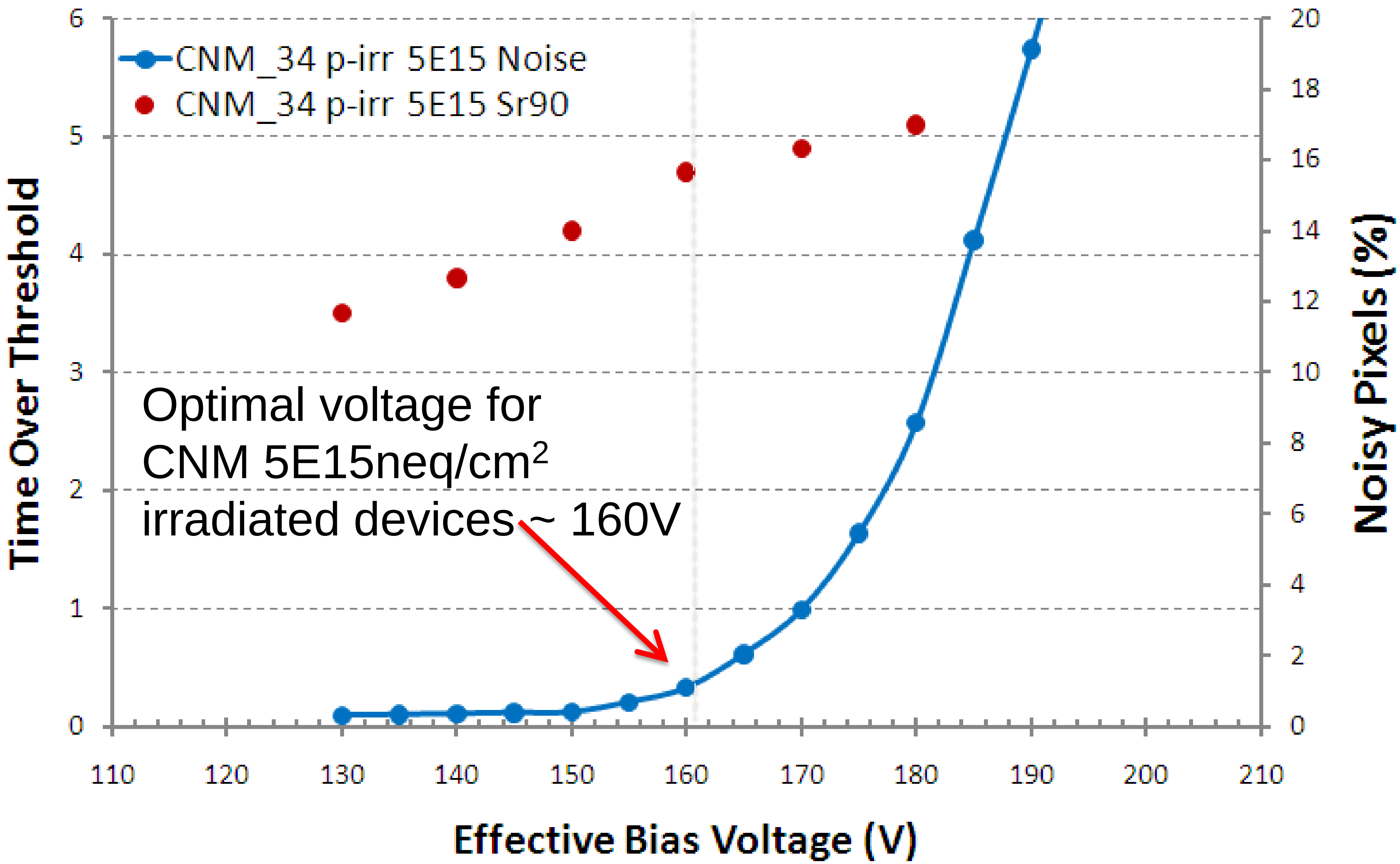
FE-I4

Can tune devices to low thresholds!

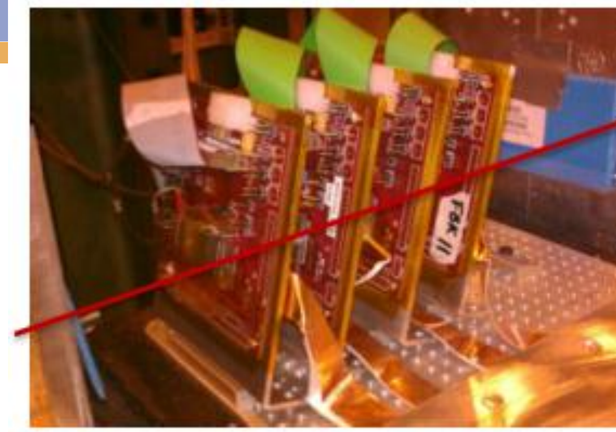
For 3D devices irradiated to IBL fluencies power dissipation is not an issue

Device Performance (laboratory)

Voltage scan for p-irradiated devices shows that 160V is the optimal operating voltage

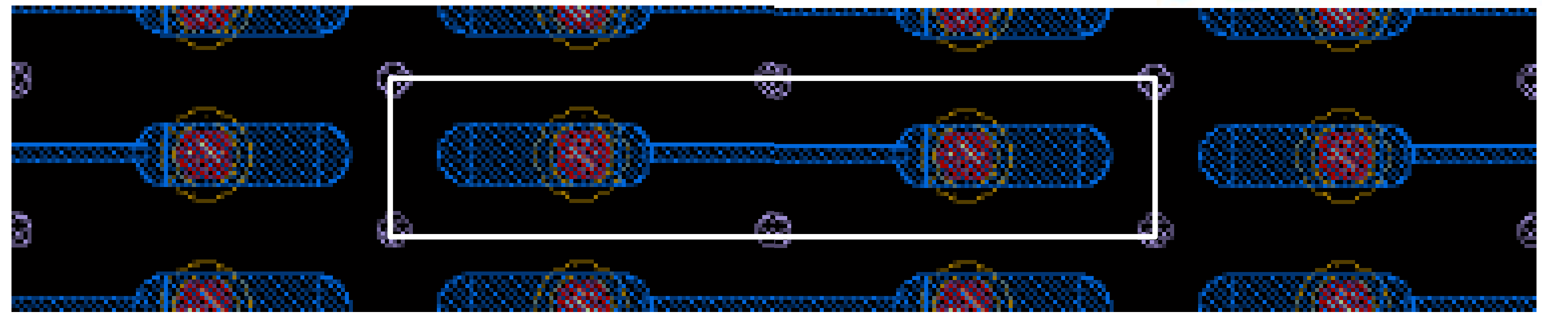


http://dx.doi.org/10.1016/j.nima.2012.03.043



Test-beam Results

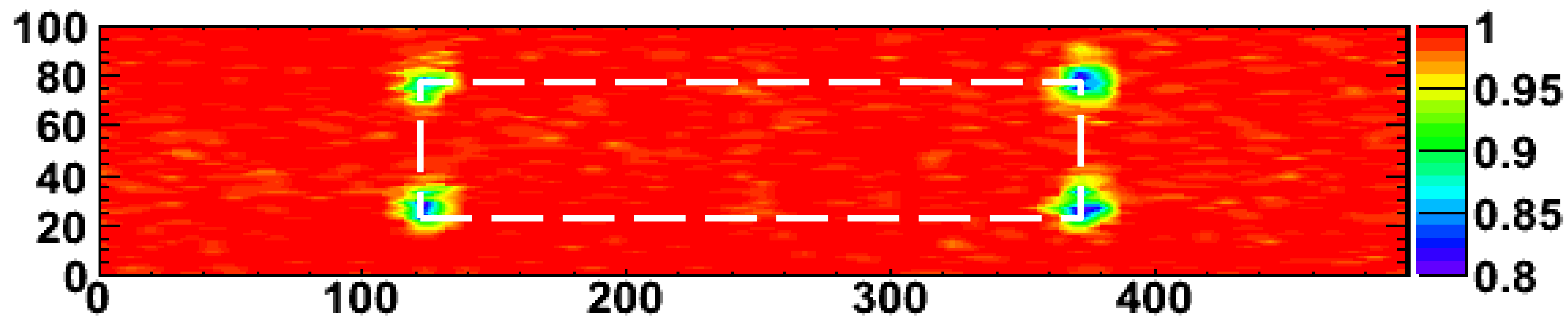
CNM devices have been tested in the CERN testbeam and have shown efficiencies >97% after irradiation (according to IBL specifications)



Pixel efficiency map: fold efficiency to 1 (±0.5) pixel (match track in 3x3pixel window)

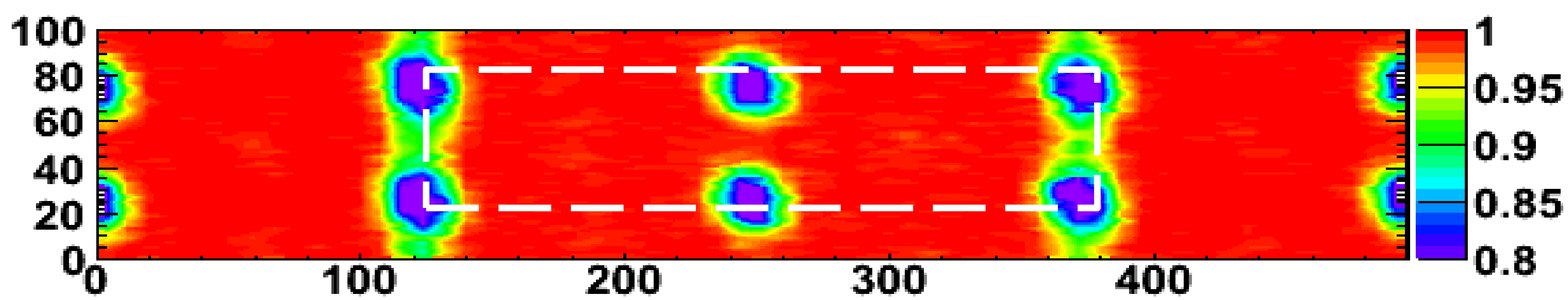
CNM55: un-irradiated
0deg incidence
HV=20V

eff=99.4%



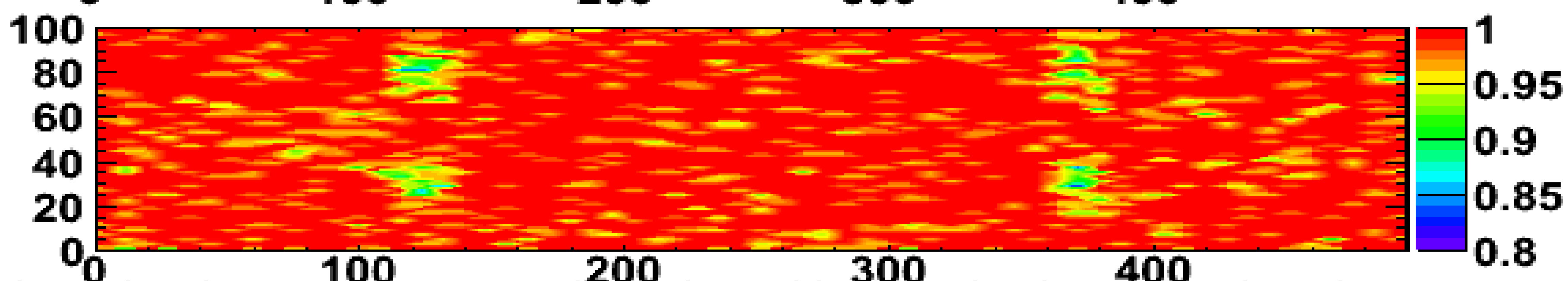
CNM81: n-irradiated
0deg incidence
HV=160V

eff=97.5%



CNM34: p-irradiated
15deg incidence
HV=160V

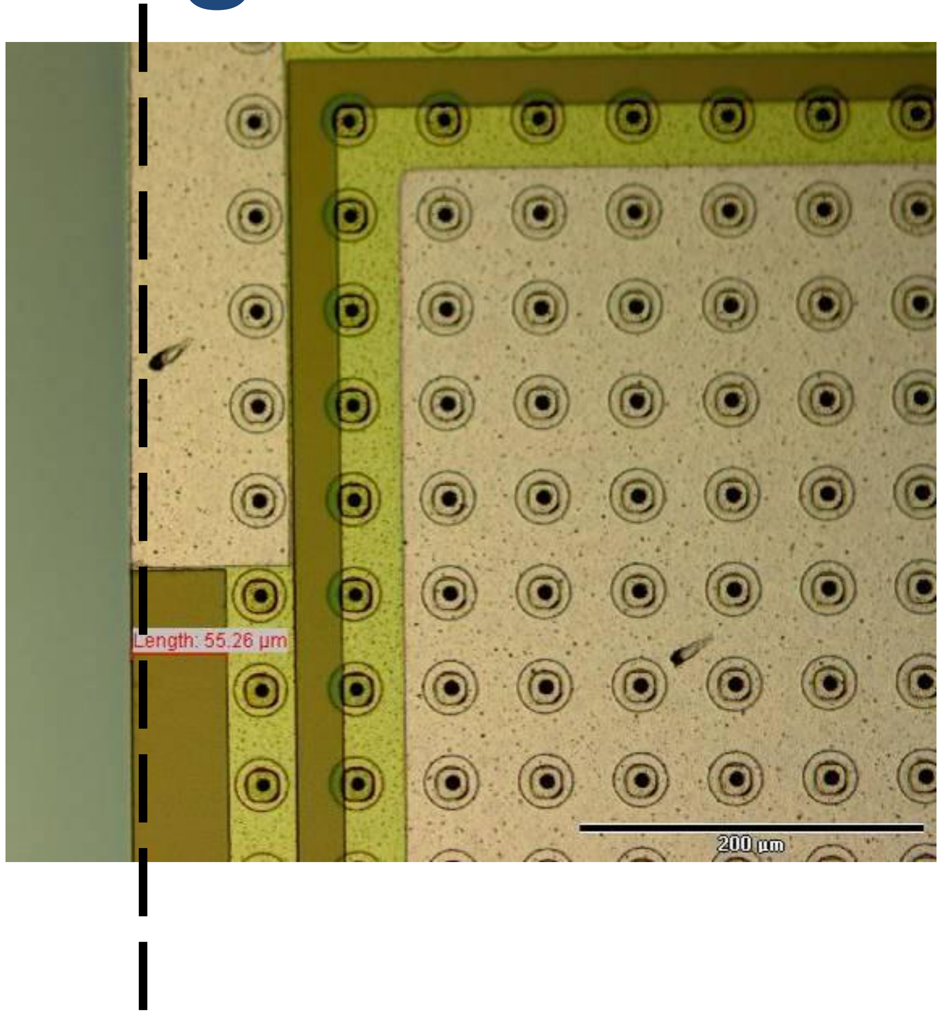
eff=98.9%



Prototype ATLAS IBL Modules using the FE-I4A Front-End Readout Chip, submitted to JINST (2012)

Post processing for slim edges

What can be improved for HEP or other applications?



Reduce the dead area at the detector edges. **Laser-Scribing and Al2O3 Sidewall Passivation of P-Type Sensors : (see** Vitaliy Fadeyev´s poster)

Negative charges induced by Al_2O_3 deposited by ALD process, isolate the sidewall surface cut in p-type wafers reducing surface current.

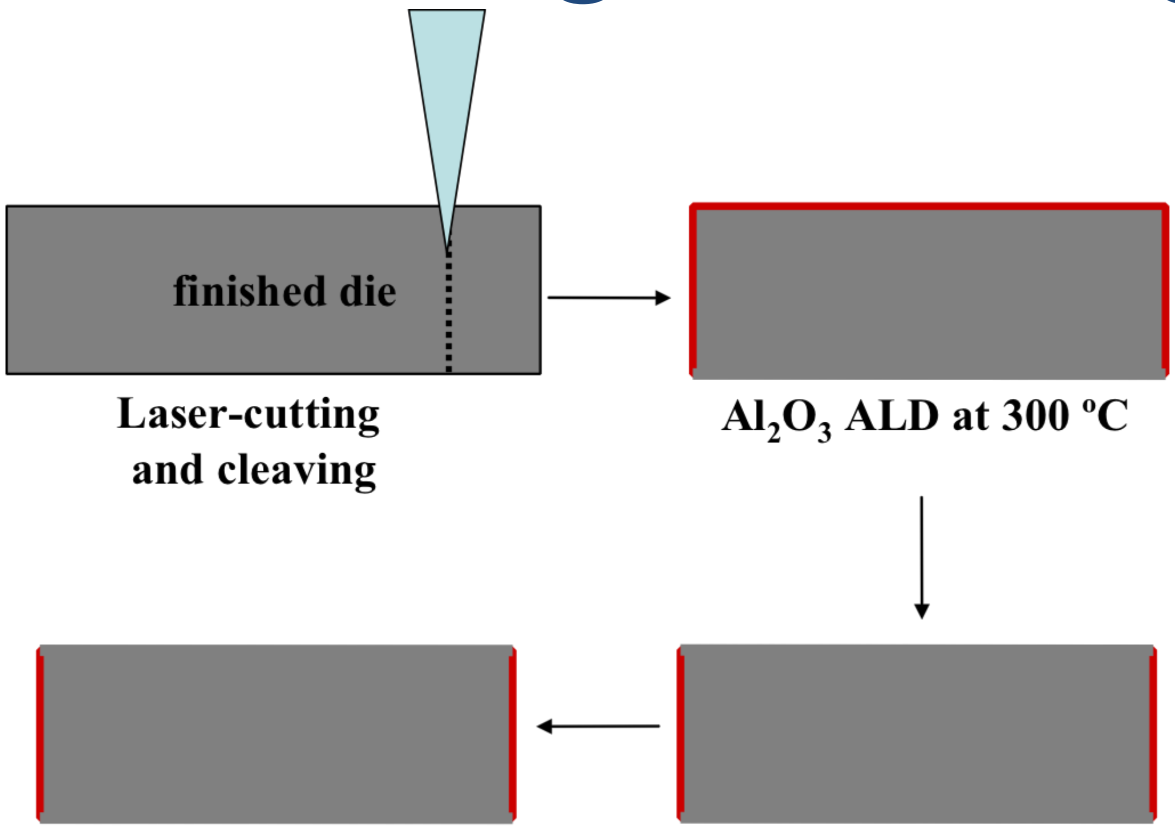
Work done in collaboration with:

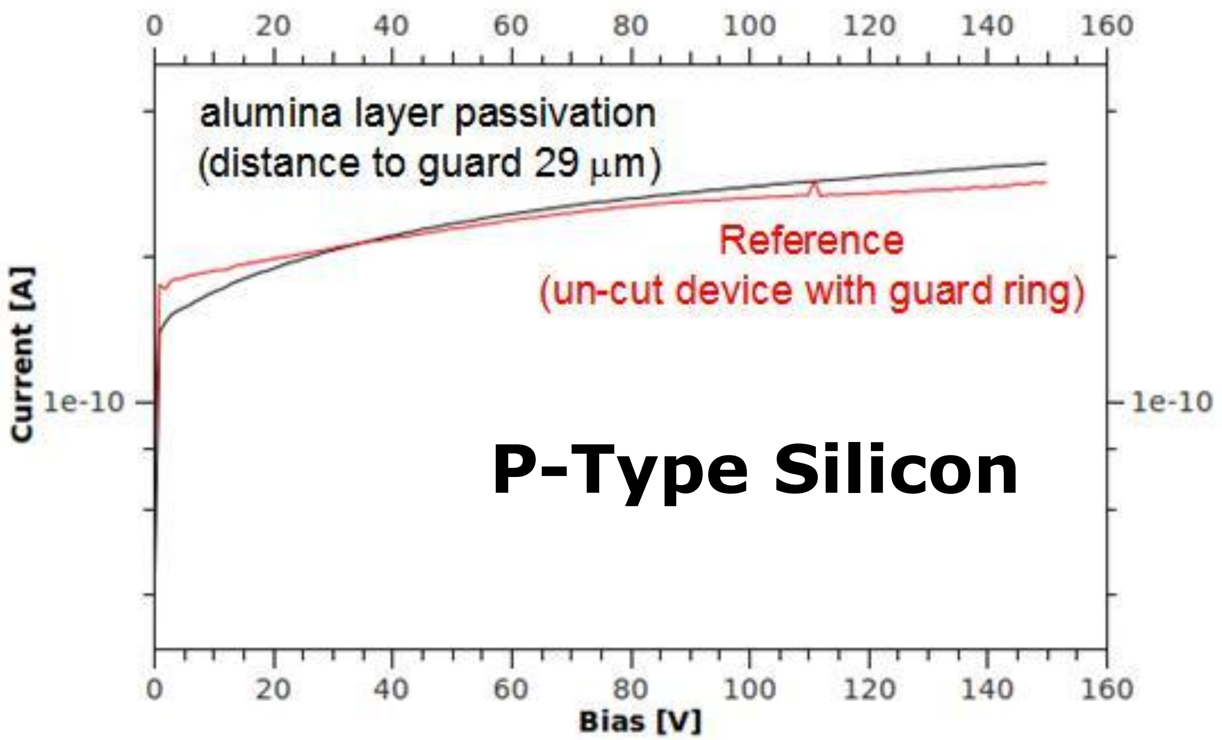
Marc Christophersen, Bernard F. Phlips
(NRL) Naval Research Laboratory U.S.

Vitaliy Fadeyev, Scott Ely, Hartmut F.-W. Sadrozinski
(SCIPP, UCSC) University of California, Santa Cruz U.S.

and within RD50 collaboration (CERN)

Slim edges Dicing process

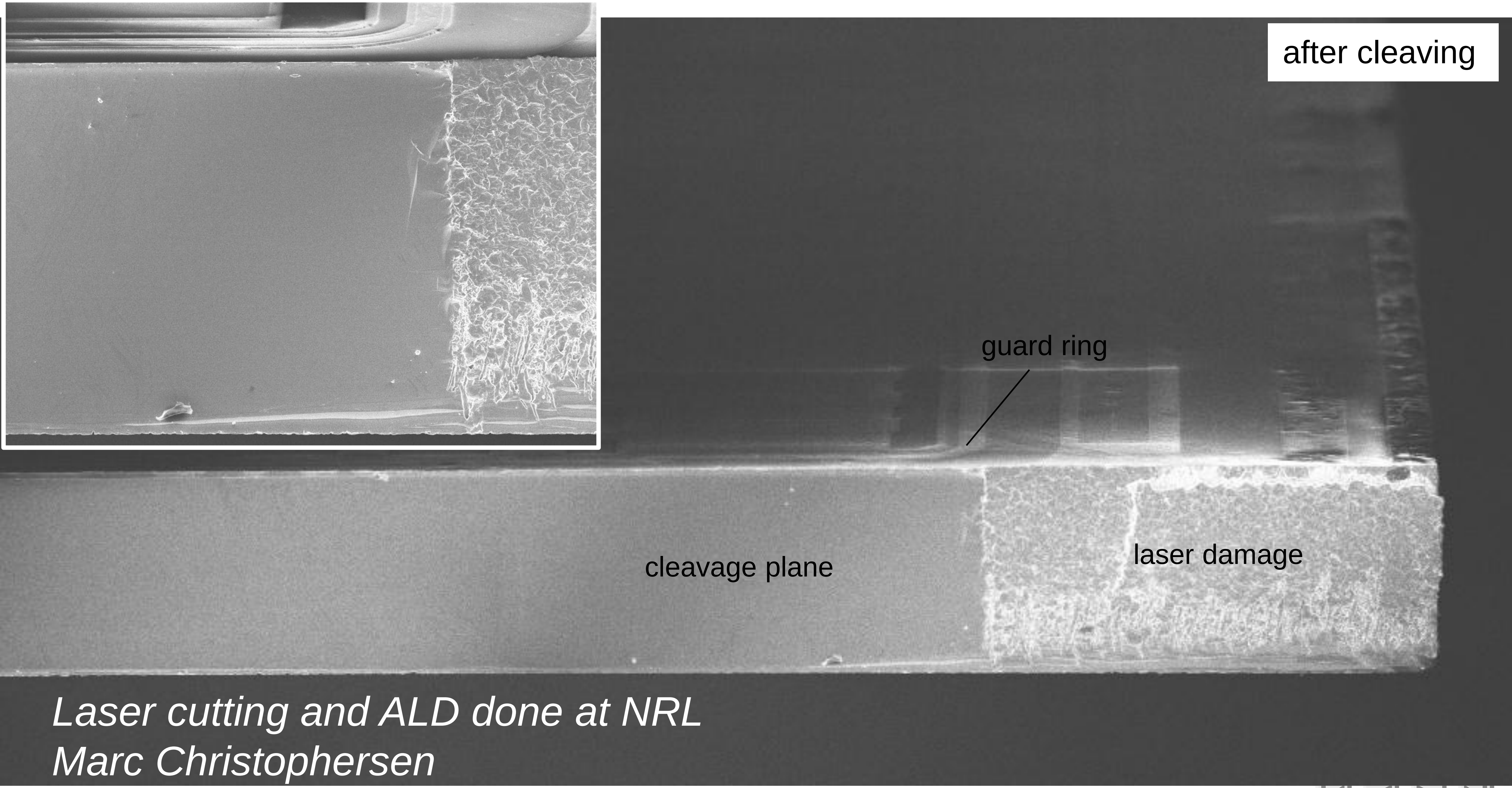




- Annealing of alumina layer reduces leakage current (same effect as seen for solar cells).
- Formation of native oxide (wrong surface charge) ↑ leakage current.
- Native oxide forms rapidly (within seconds/minutes) in air.
- Native oxide: ~ 2 nm thick, high charge trap density.

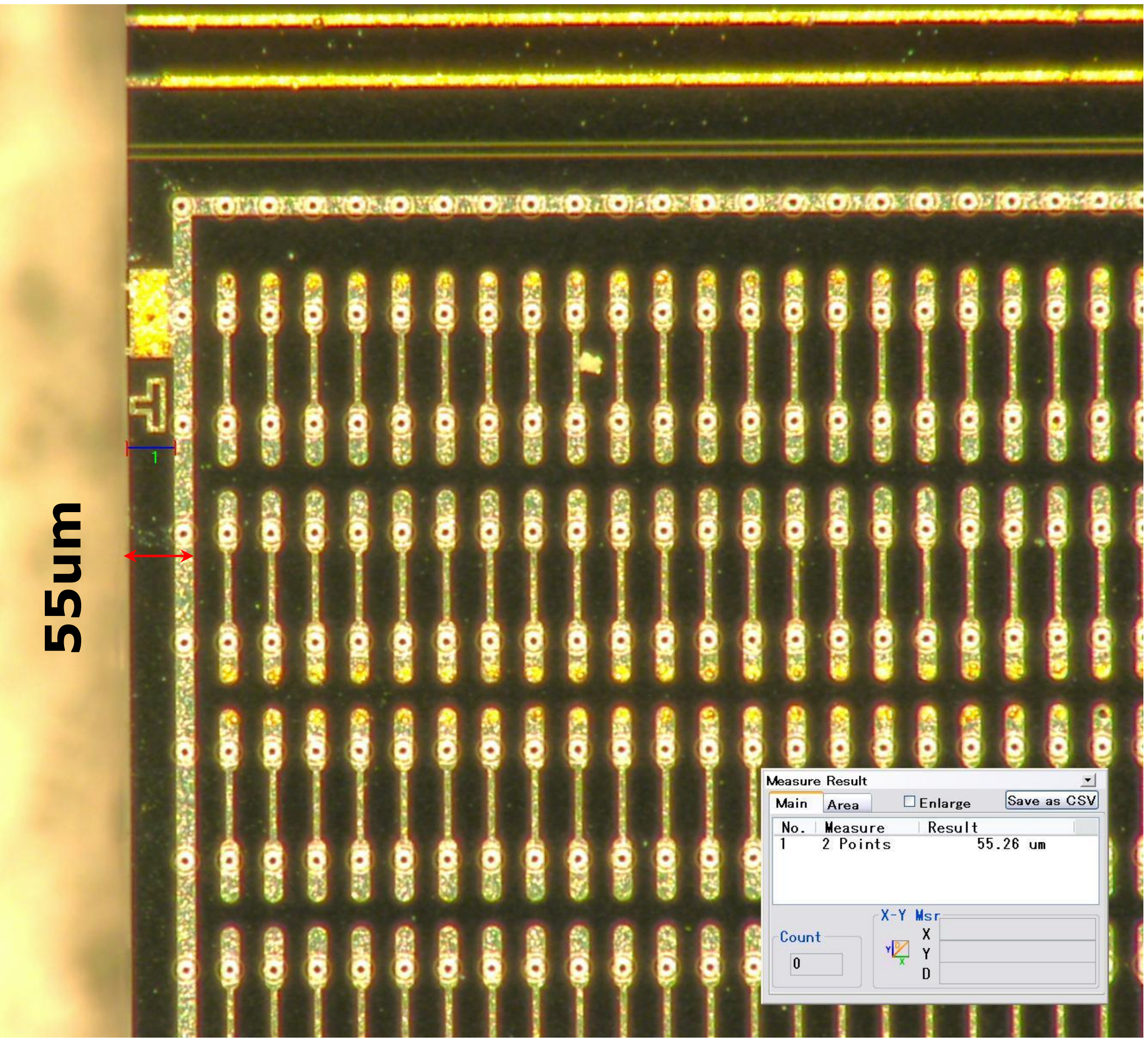
- Laser-scribing and cleaving common in LED industry
- Automated tools for scribing and breaking of devices on wafer-scale

$XeFe_2$ etching and cleaving

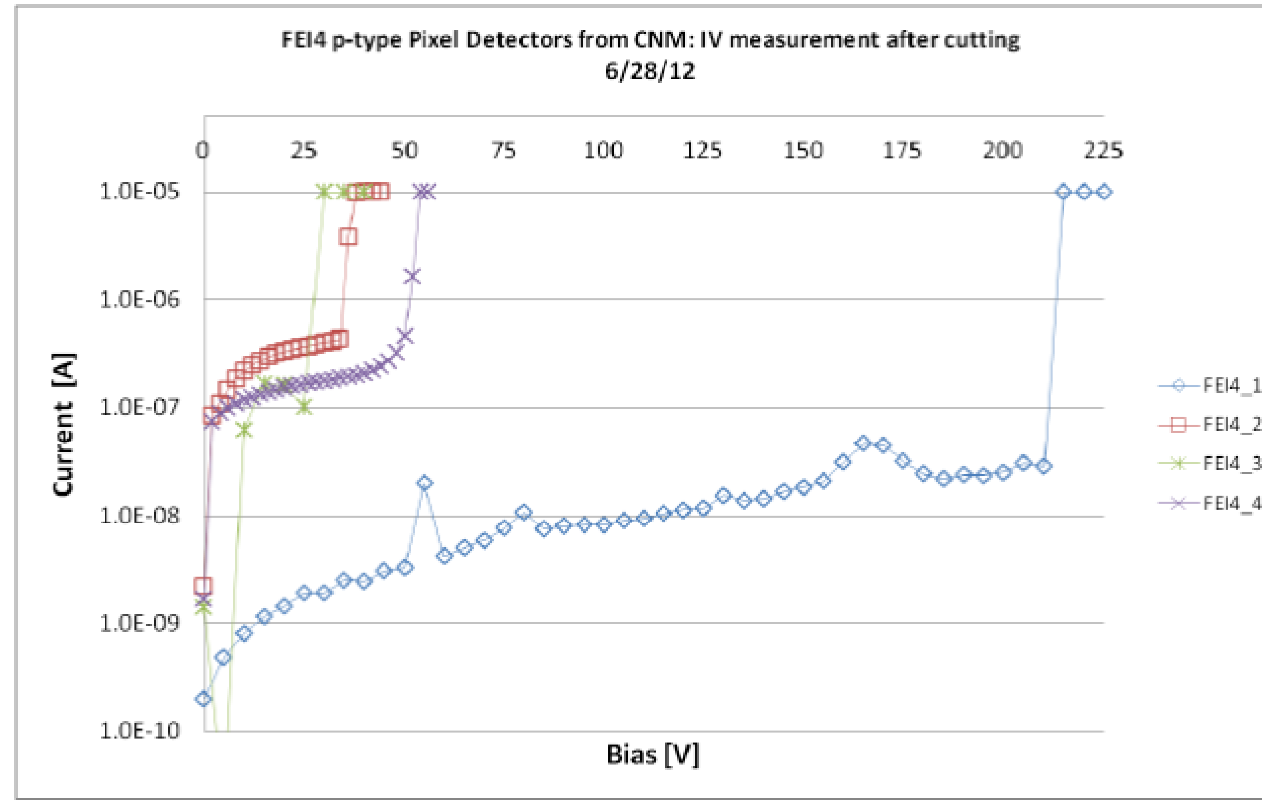


SEM micrographs (bird's-eye view)

New samples with slim edges (Atlas FE-I4 pixels)



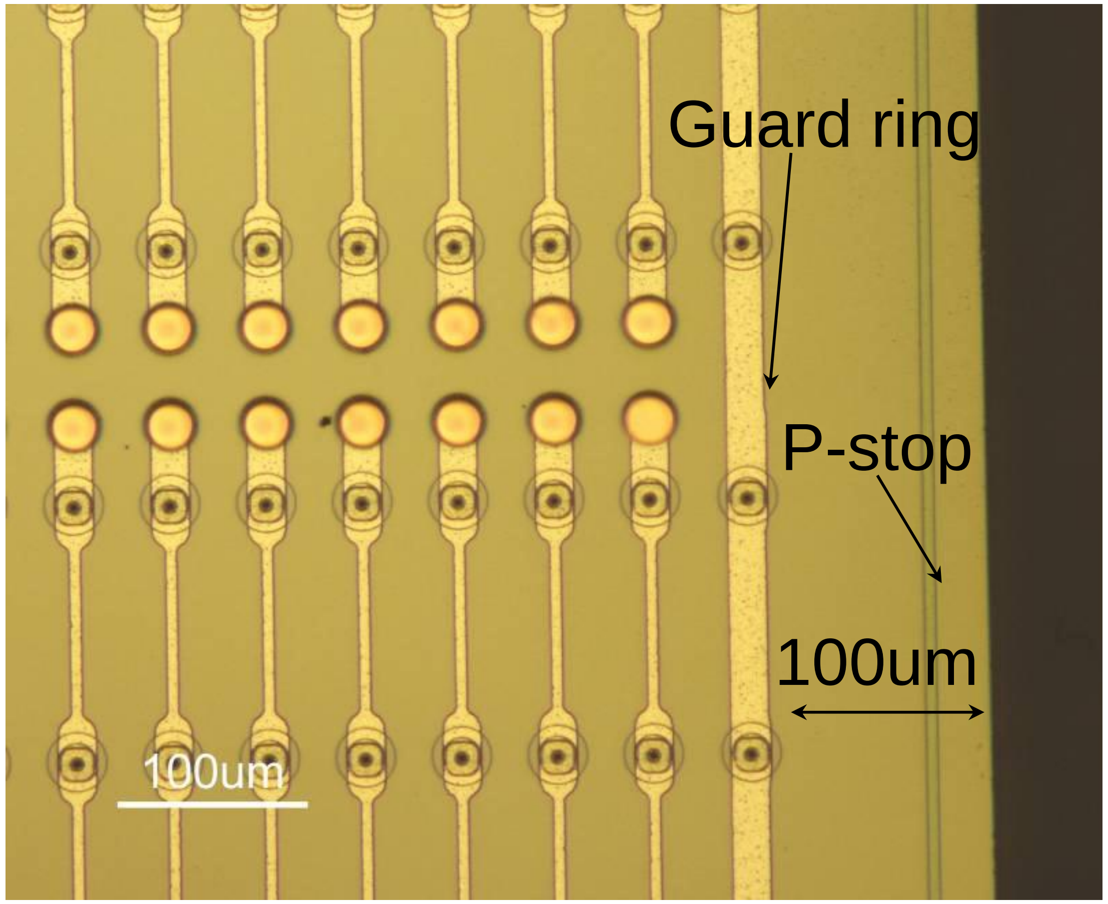
FE-I4 IV measurements

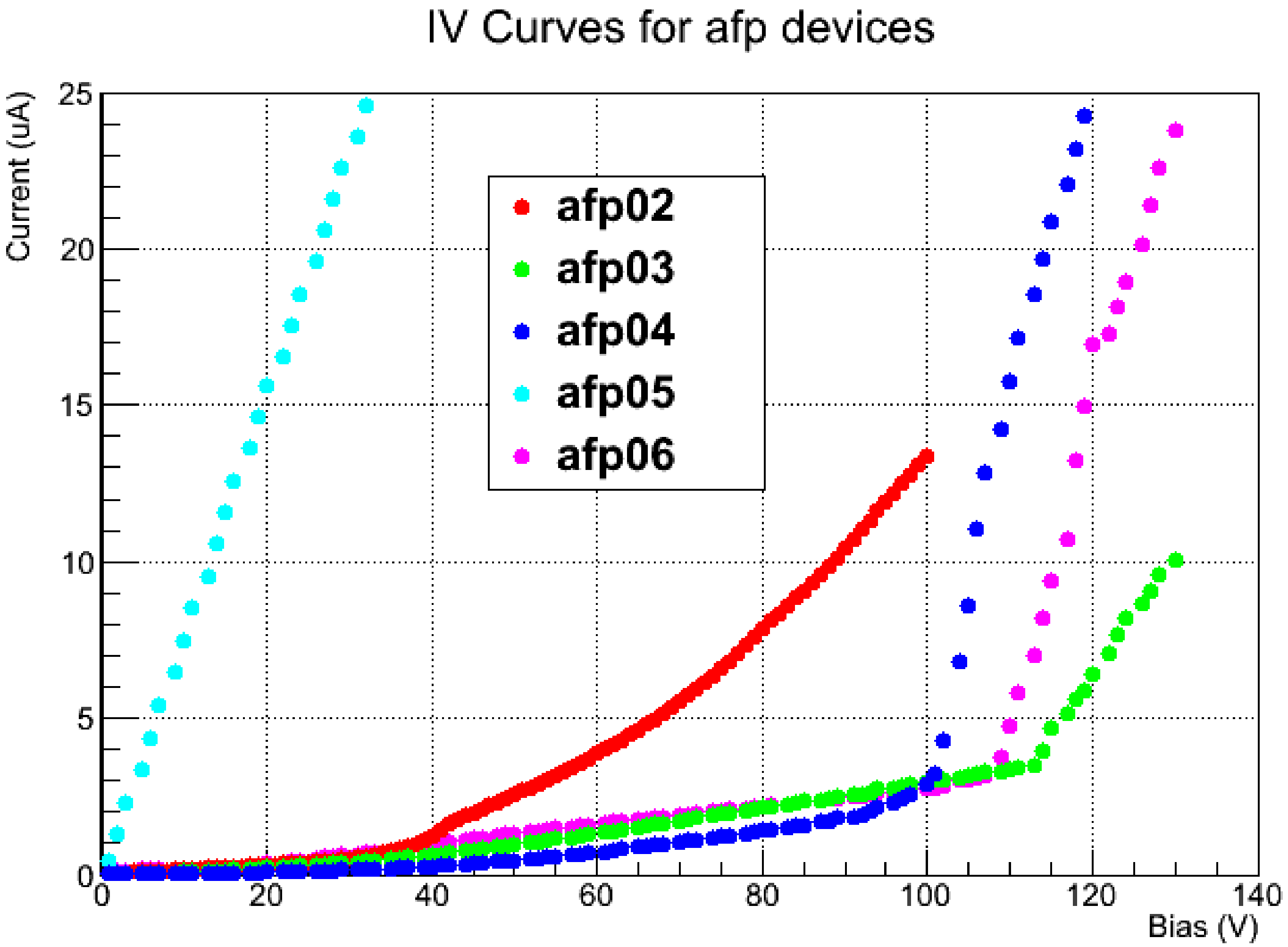


Detectors ready for flip chip.

Spare 3D FE-I4 detectors from IBL production done at CNM. Normally from damaged wafers.

New samples with slim edges (Atlas FE-I3 pixels)

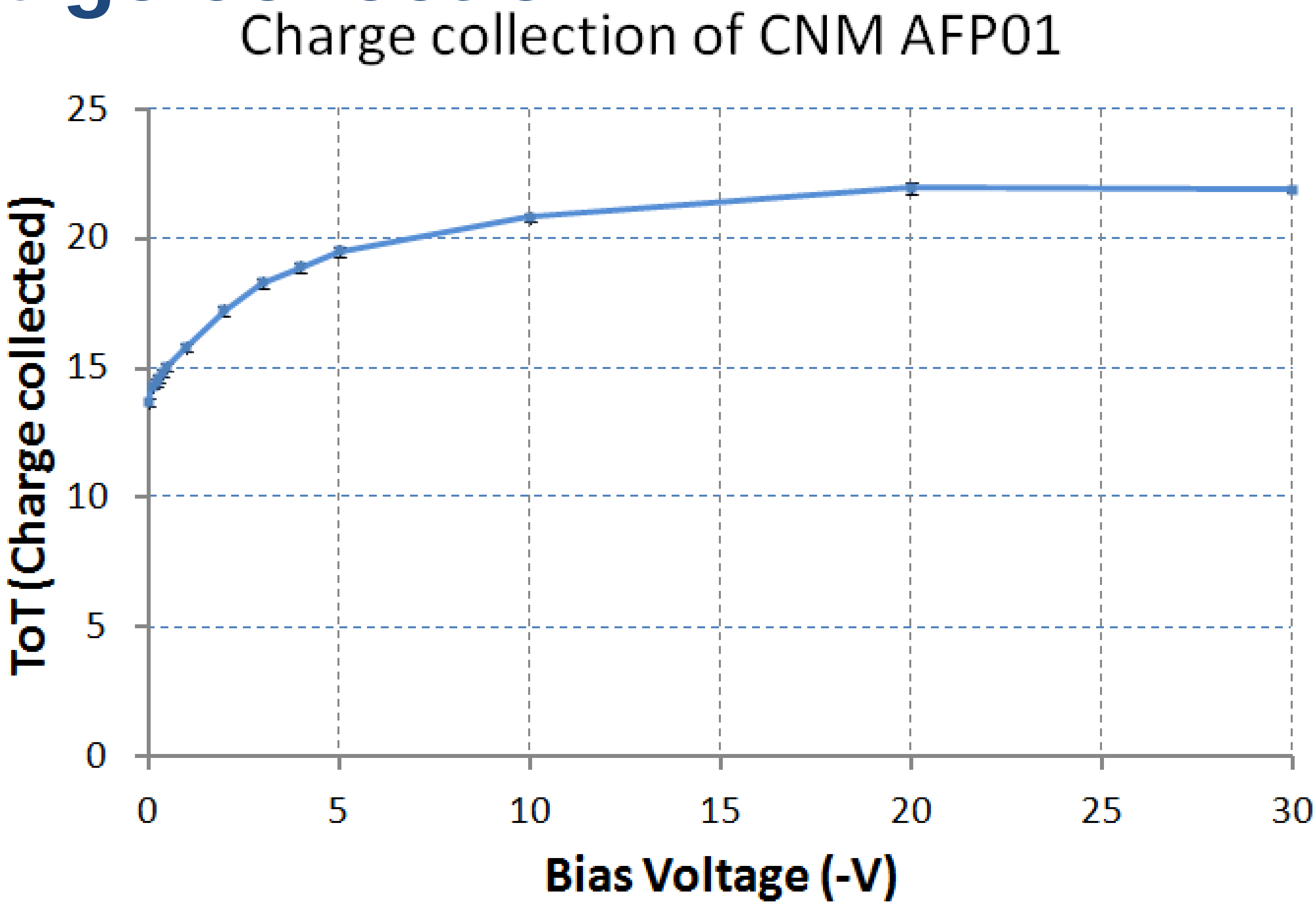




Full current after flip chip, measured through FE.

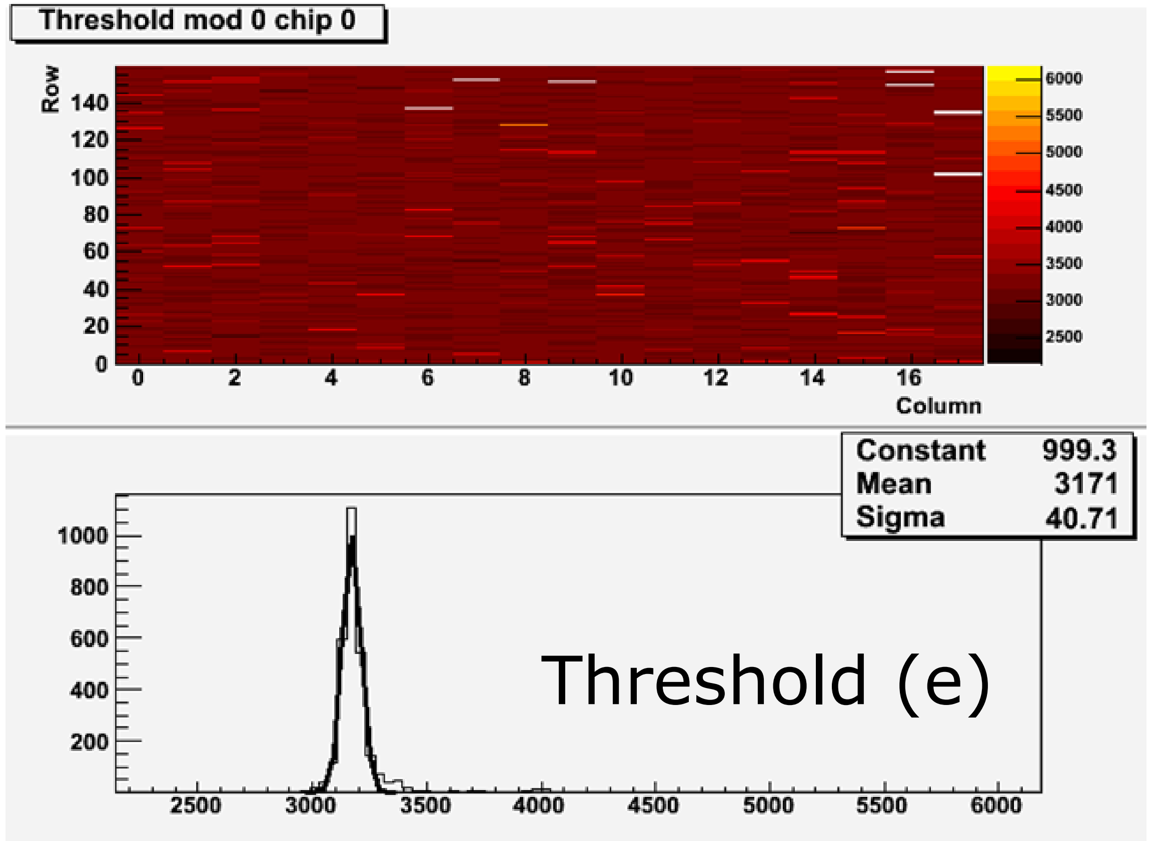
- Flip-chipped by IFAE (to 700um-thick old FE)
- Wirebonded by CNM

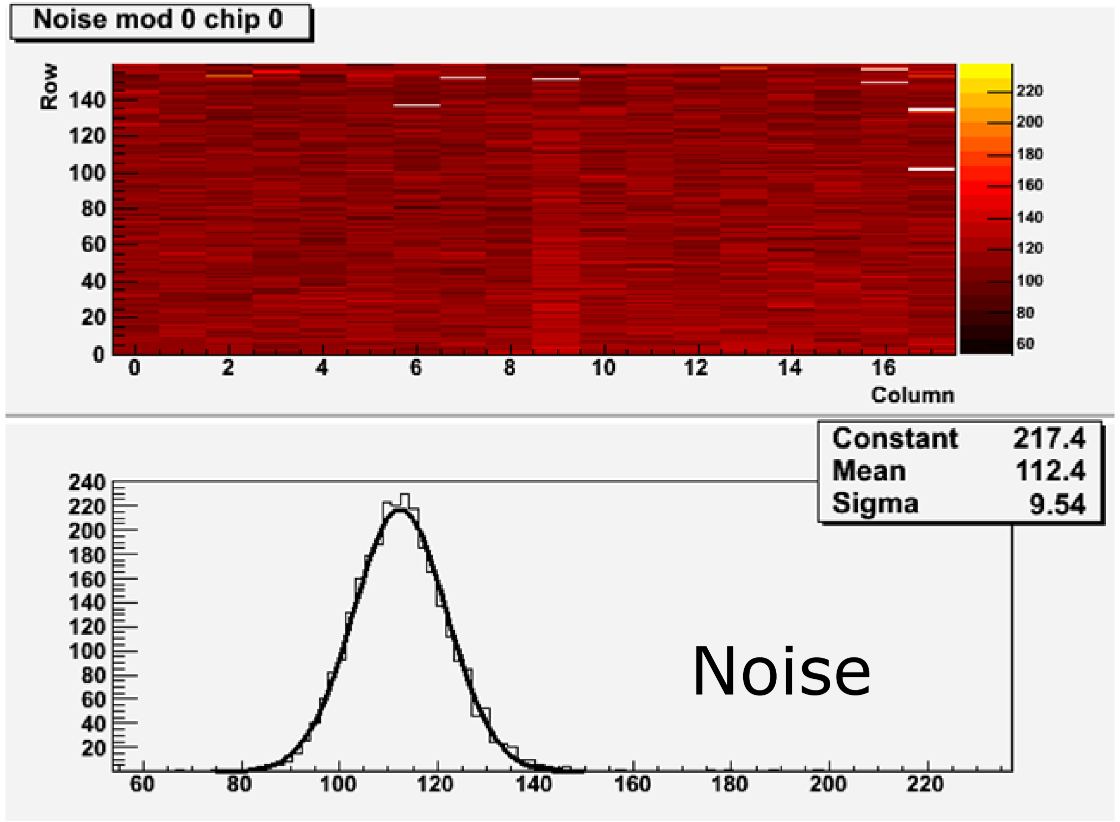
Charge collection



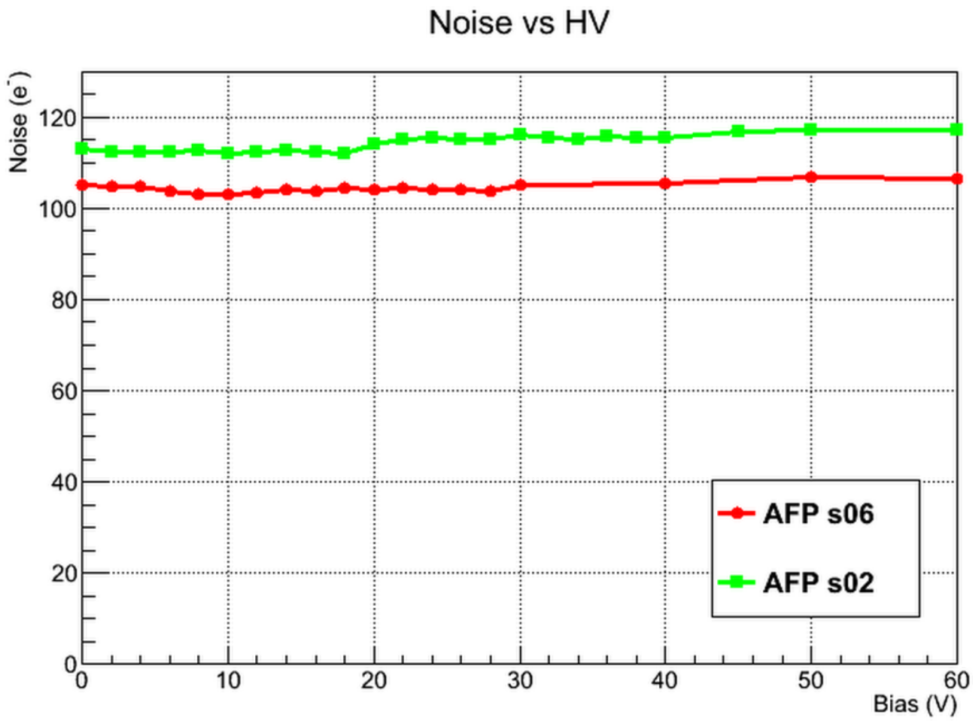
- Sr 90 charge collection vs HV
- ToT: time over threshold in 25ns units
- Full depletion at 20V for these devices

Atlas FE-I3 Geometry





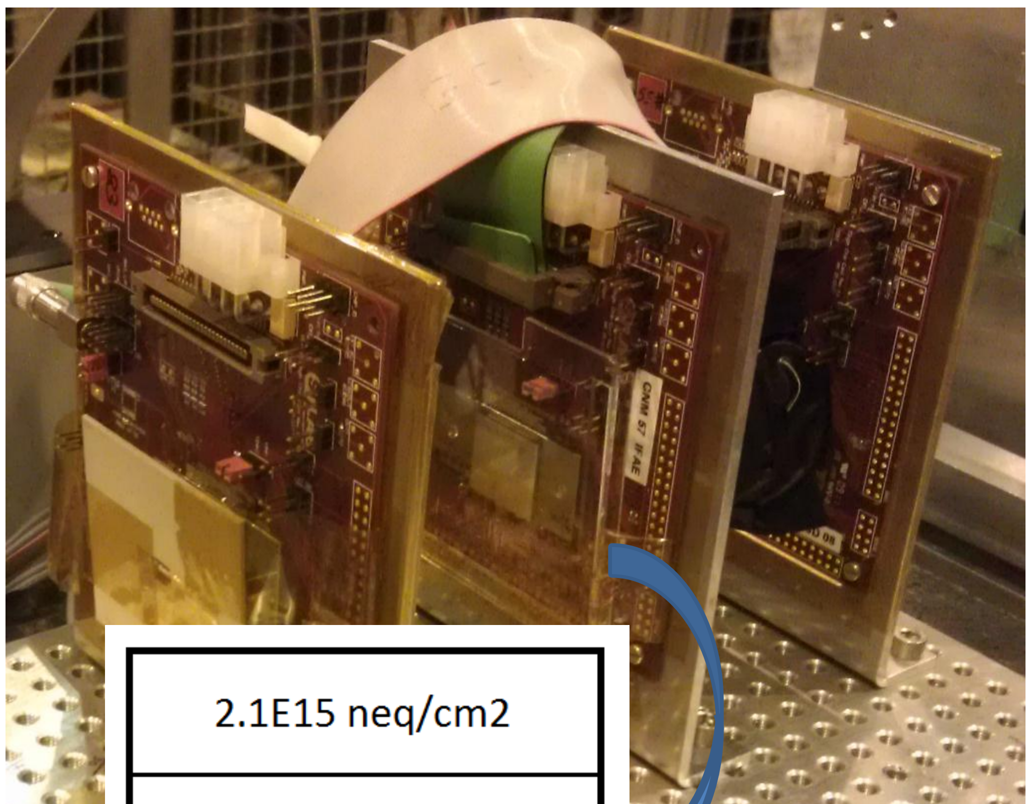
- Threshold set to 3200e (same as current ATLAS Pixel detector – FEI3)
- Noise of the order of 100e (un-irradiated)
- Noise stable vs bias voltage



In-Homogeneous Irradiation and Test-beam Results

- AFP devices will receive an in-homogeneous irr dose (up to 2E15 neq/cm2)
  - Irradiation done at CERN (24 GeV protons)
- IBL-sensors were irradiated 'a la-AFP' and their performance evaluated with beam
- Work done with the ATLAS IBL, 3D and AFP groups

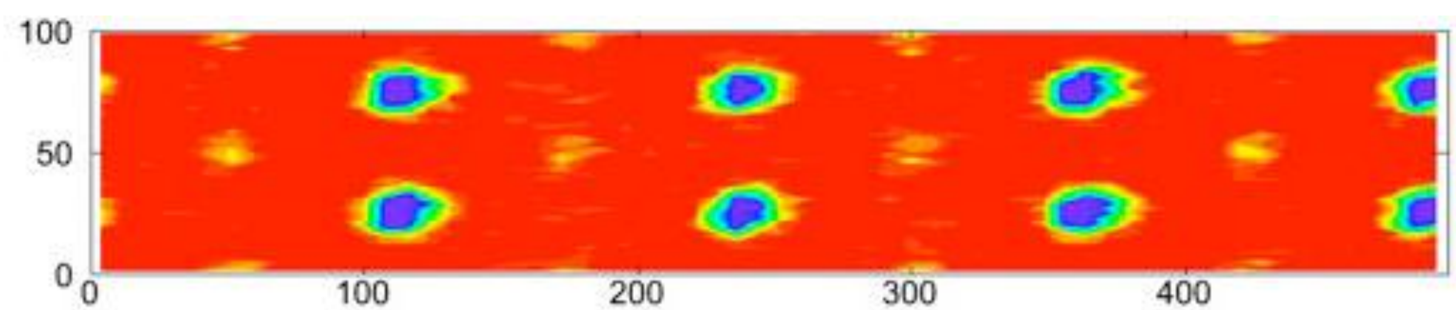
CERN 3D Testbeam



2.1E15 neq/cm2
0.8E15 neq/cm2
0.1E15 neq/cm2
0.2E14 neq/cm2

Preliminary results for CNM(57) device:

- Operated at 130V
- Beam pointing to "irradiated side"
- Cooled with dry-ice (-30C)



Preliminary efficiency: 98.3%

Conclusions

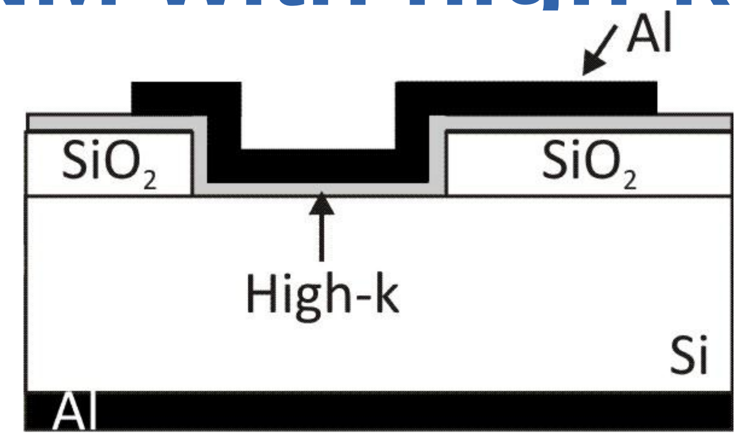
- At Barcelona we have the full chain for sensor production, assembly and testing available.
- The CNM sensors for the Atlas-IBL perform as specified after being irradiated
- The first tests of the proposed cleavage procedure have been shown
- For AFP, even a small yield can guarantee the procurement of the needed sensors for the first installation
- A production of special sensors for AFP can be started at CNM once the IBL production is finished
- If technological issues are solved we might have them ready for the first installation opportunity of AFP

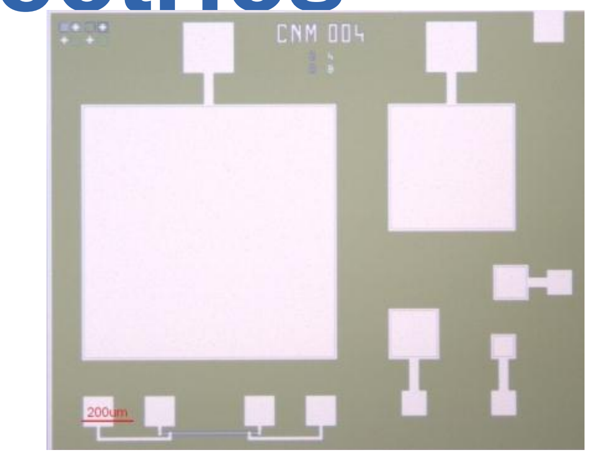
Future Work

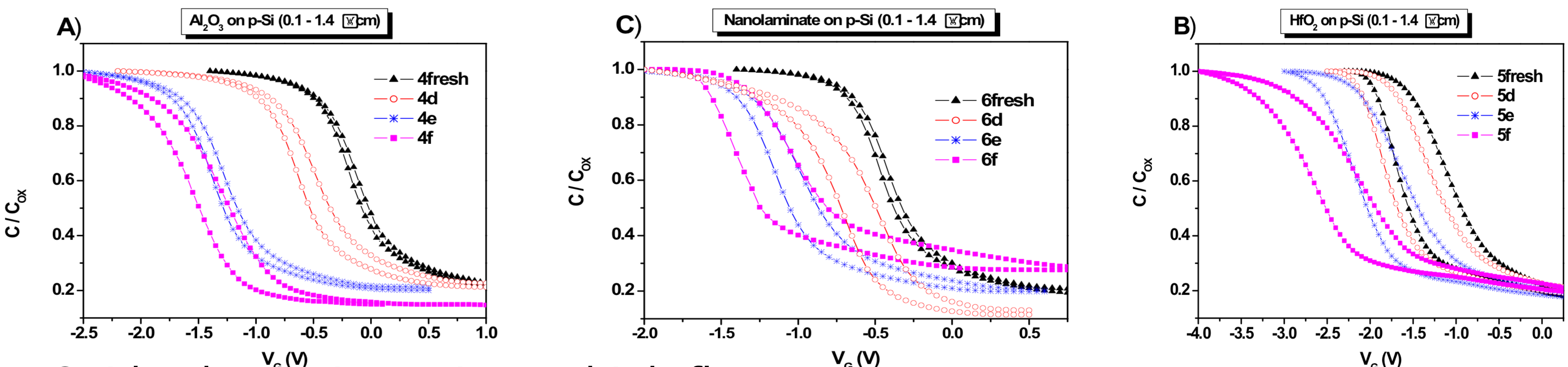
- Test beam data under analysis.
- Some detectors have been sent for irradiation.
- Flip chip to FE-I4 electronics (when FE available to CNM-IFAE).
- Next test beam in October 2012 at CERN.

Back up slides

Previous work at CNM with high-k dielectrics







Oxide charge inversion at high fluences

H. Garcia et al., 220th ECS Meeting ***Physics and Technology of High-k Materials 9*** *- October 9 - October 14, 2011 , Boston, MA*
ECS Transactions, v. 41, no. 3, 2010, pp. 349-359

Irradiations were performed at Takasaki-JAERI in Japan
2 MeV electrons for three different fluences: $\phi = 1\times10^{14}$ e/cm^2, 1×10^{15} e/cm^2 and 1×10^{16} e/cm^2
The total ionizing doses were about 2.5 Mrad-Si, 25 Mrad-Si and 250 Mrad-Si
Irradiation was performed at room temperature and capacitors not biased.