AIDA 2020 Italy – WP7

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with contributions from PG, TO, FI, MI

Thanks to Gian Mario Bilei, Daniele Passeri, Nicolo' Cartiglia, Marco Meschini, Gianluca Alimonti for prompt feedback

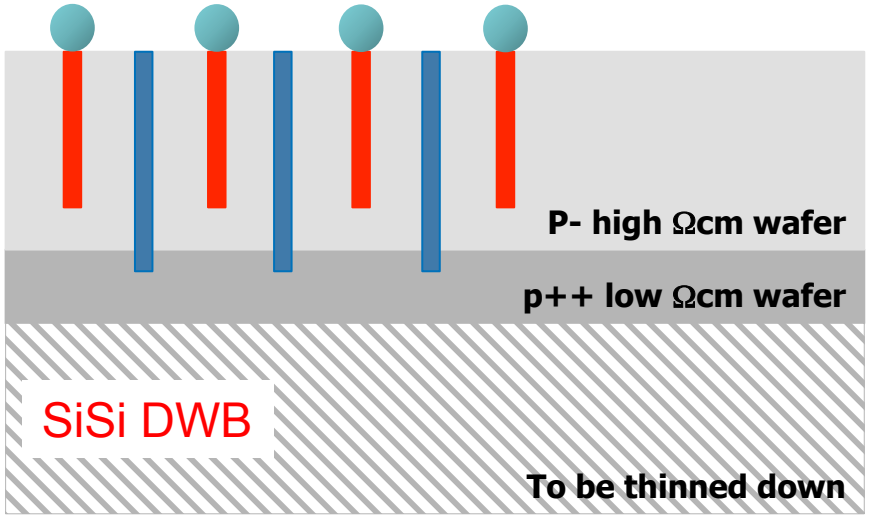
WP7 Task 7.2 (Trento) TCAD simulations

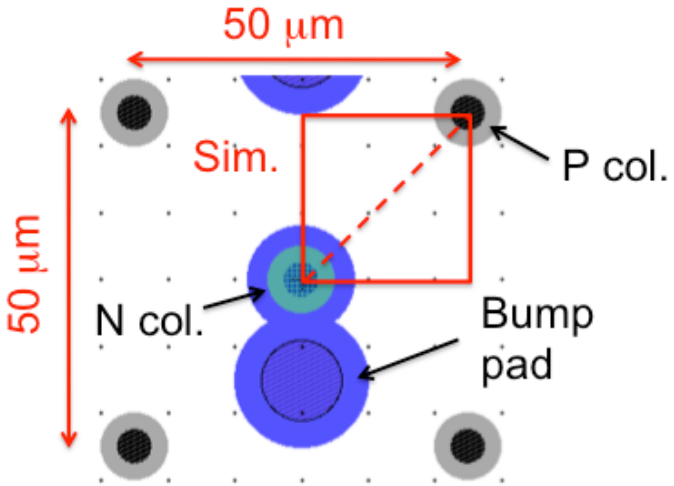
Gian-Franco Dalla Betta (PO): 2 mesi
Roberto Mendicino (Dott): 5 mesi
→ Assegno di Ricerca Junior AIDA2020 da 05/04/16
DMS Sultan (Dott.): 3 mesi

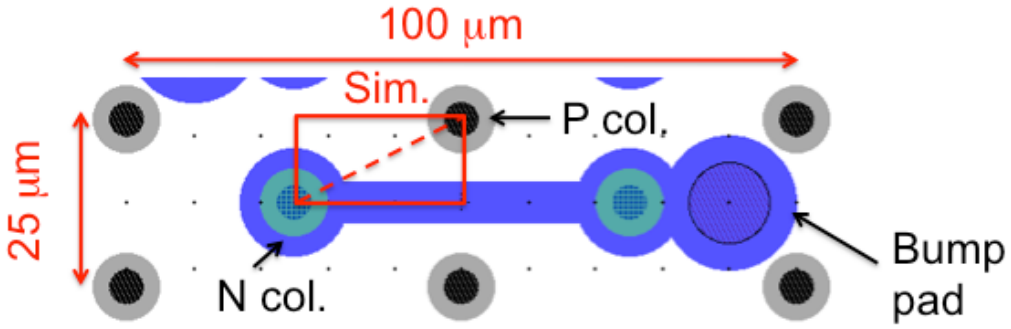
- D7.1 : Simulation of 3D pixel sensor cells [M18] Simulation of new sensor cells for thin 3D sensors with fine pitch, reduced column diameter and inter-column distance. Simulation of charge collection properties of 3D sensors with thinner substrates and determination of optimal thickness for pixel detectors working at HL-LHC.

New thin 3D on 6" @ FBK

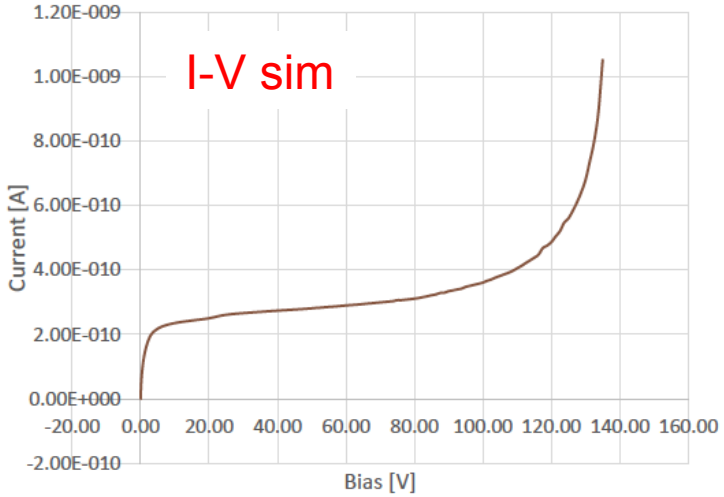
- Single-sided process
- "Thin" active layer: SiSi (or SOI)
- Ohmic columns depth > active layer
- Junction columns depth < active layer
- Reduction of column diameter to 5 um
- Holes partially filled with poly
- Very slim or active edge

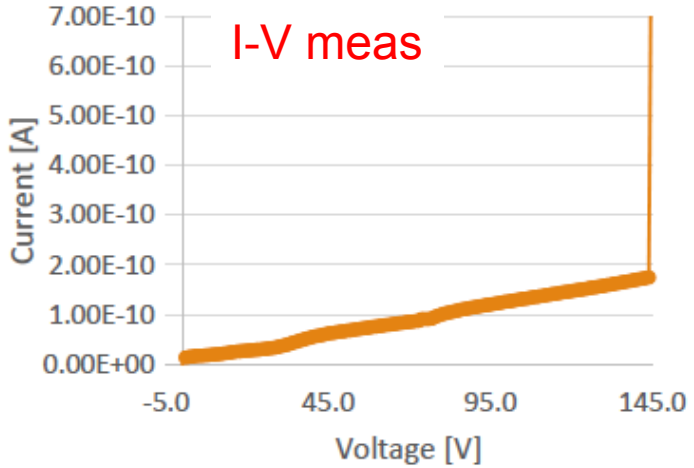


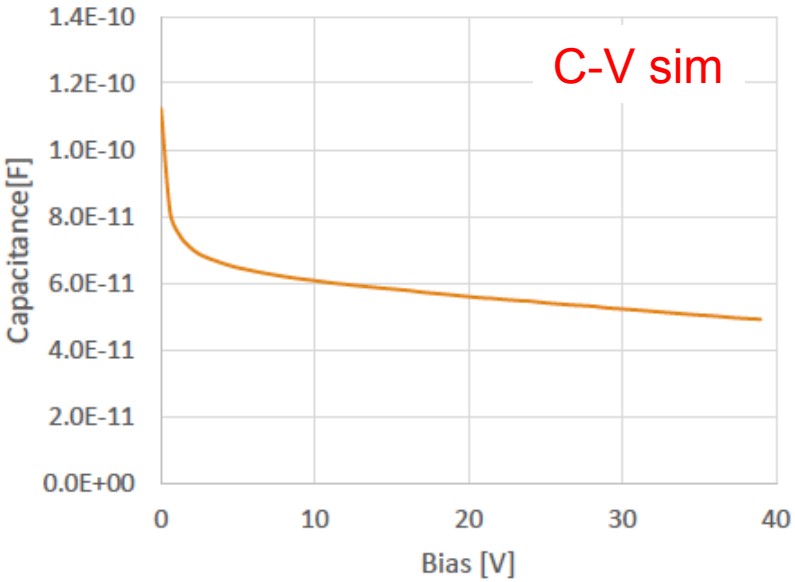


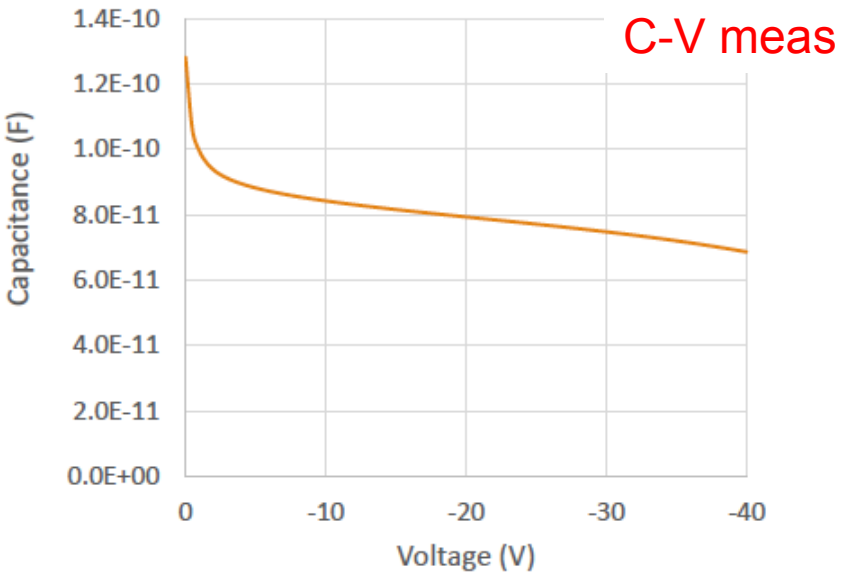


Simulation vs measurements

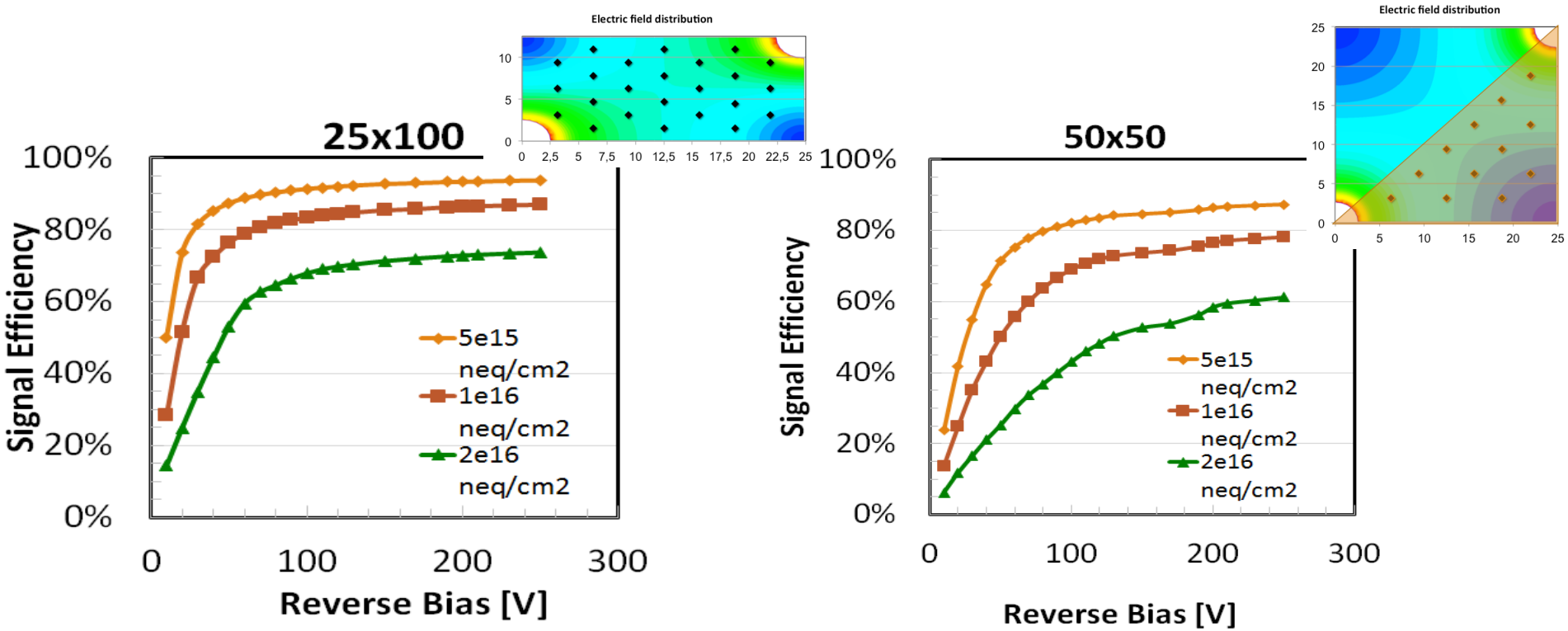








Simulated signal efficiency



- New 3-trap level "Perugia" model, D. Passeri et al. (doi:10.1016/j.nima.2015.08.039)
- 1 μm thick (~2d) slice, with MIP vertical hits at several different points
- 20-ns integration of current signals, average, and normalization to injected charge
- Much better results than with previous trap model !
- Higher Signal Efficiency at lower V_{bias} in 25x100 (2E), as expected due to smaller L

Next steps

- Analysis of simulation results incorporating impact ionization effects
- After tuning the surface model (with PG), full 3D simulations:
  - effects of surface and column tips on capacitance and breakdown voltage
  - inclined tracks, charge sharing
  - comparison with beam test results

WP7 Task 7.2 (Perugia) TCAD simulations

G.M. Bilei (INFN staff)
D. Passeri (UniPG Researcher)
F. Moscatelli (INFN and CNR-IMM staff)
A. Morozzi (UniPG Phd student)

- D7.4 : New TCAD model to reproduce the macroscopic effects of radiation damage in the bulk and at the silicon-oxide interface. Comparison with experimental results on irradiated pixel sensors, comprehensive of those produced within Task 7.3. [M46]

Simulations

- Bulk radiation damage modelling:

  - extension of the three-level UniPG modelling (capture cross sections, charge multiplication, avalanche effects).

- Interface radiation damage modelling:

  - oxide fixed charge and interface trap state @dose;
  - systematic study of acceptor/donor states at different energies.

- Technology (process) dependent effect -> deep level parameterization, oxide charge density, interface trap energy and density, cross sections (e/h), trap type (acceptor or donor) effects.

- Comparison with literature data/dedicated measurements in terms of static behaviour (R, C) and charge collection properties.

- Comprehensive modelling (bulk + interface, 2D/3D).

Work Plan: Measurements

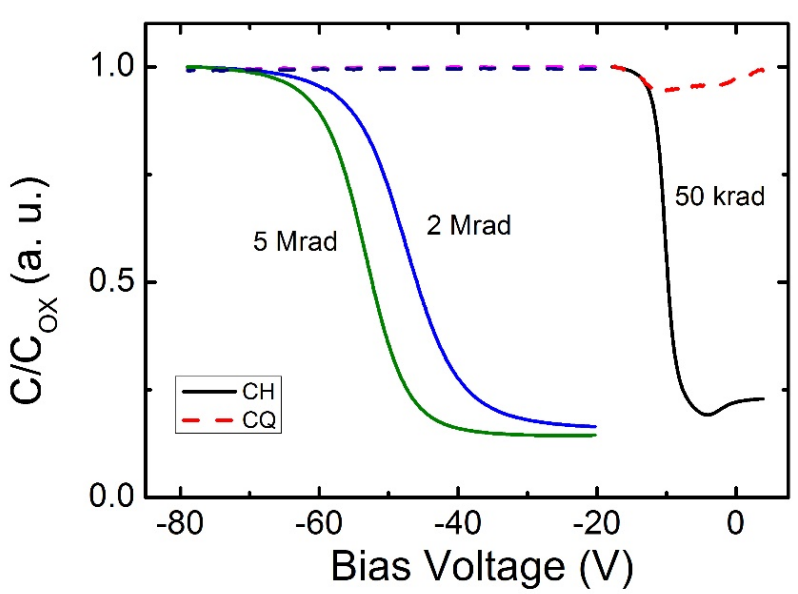
- Measurements on dedicated test structures e.g. gated diodes, MOS capacitors and MOSFETs on p-stop and p-spray/different substrates.
- Different technologies (e.g. FBK, IMM, HPK, …).
- High-Frequency and Quasi-Stationary C, MOSFET V_{FB} and I-V characteristics, …
- Irradiation campaign with gammas, x-rays and neutrons/(protons), protons after x-rays.
- Measurements after irradiation -> trap parameter extraction, TCAD model validation.
- Predictive application of the model -> sensor design and optimization.

- on-going
- added w.r.t. the original tasks
- to be completed

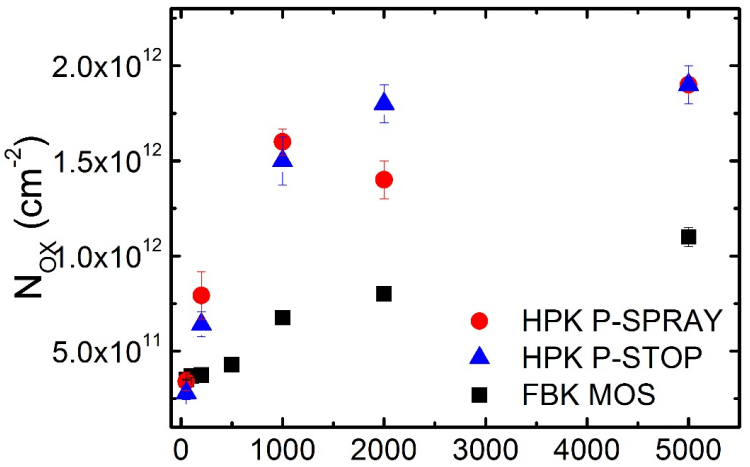
Measurements

- ✓ X-ray doses : 50 krad-10 Mrad
- ✓ Measurements before & after irradiation / annealing 80°C 10 min.

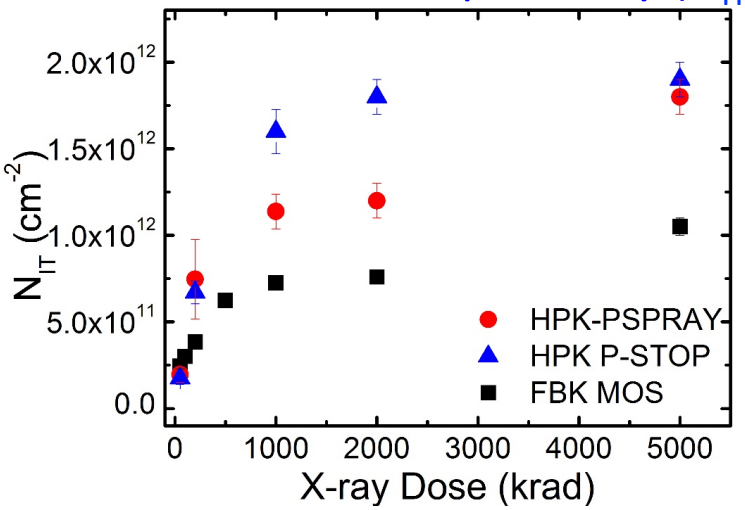
C-V at different frequencies (Hi-Low)



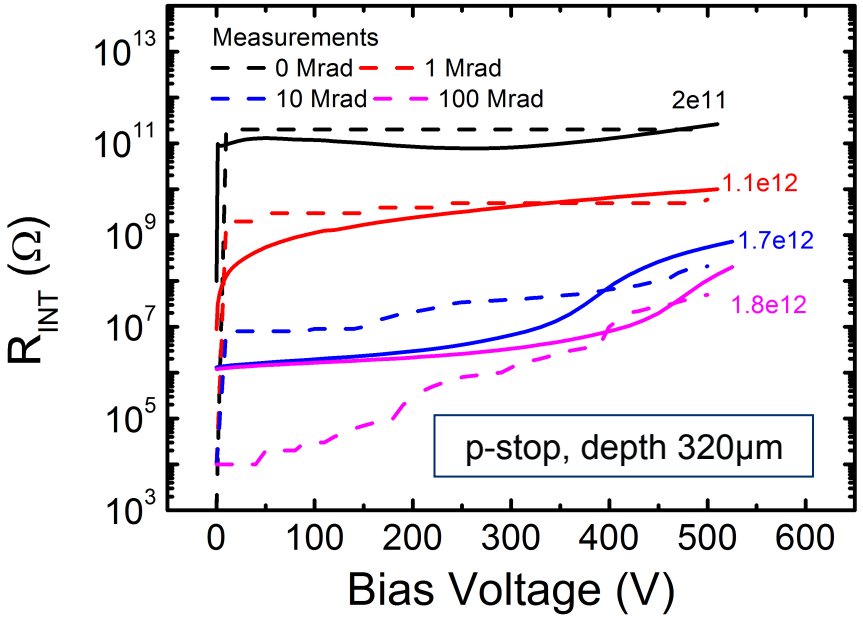
Oxide charge density (N_{OX})



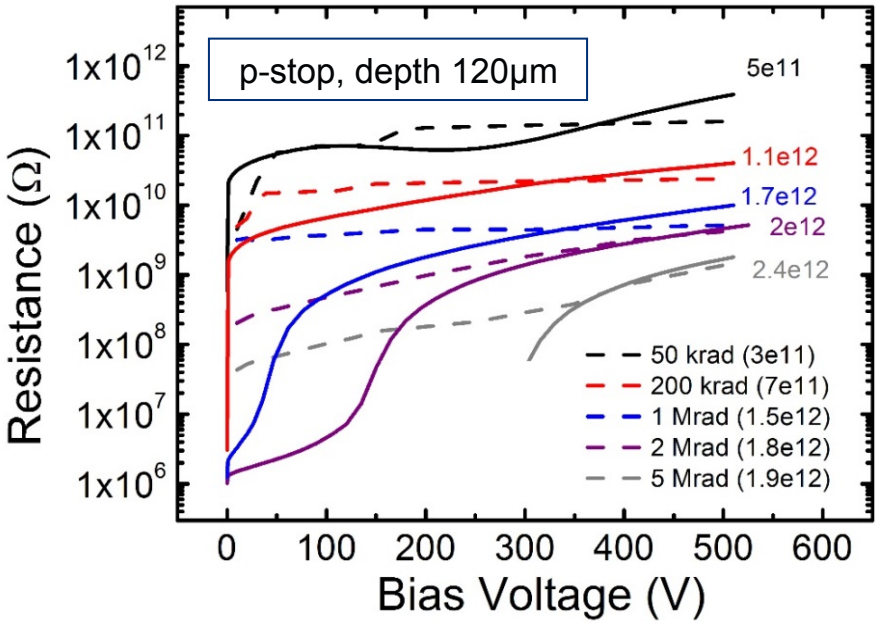
Interface trap density (N_{IT})



Validation of surface damage model



Measurements by A.Peisert and H.Behnamian, CERN (R. Dalal at 25th RD50 meeting)



Measurements by F. Moscatelli 2015/2016, CNR Italy.

With 3 interface trap levels is possible to reproduce the variation of the R_{INT}

- at increasing doses / oxide charge and interface trap states;
- for different devices (e.g. different doping profiles, thickness, ...).

Work Plan: Next Steps

Further validation:

- application of the model to 3D structures simulation (collaboration Trento).
- Comparative analysis with alternative TCAD approach (Sentaurus vs. Silvaco comparative simulations – collaboration LNPHE Paris).
- Comparison with measurements on p-type/n-type structures/devices irradiated at very high fluences.

Comprehensive irradiation plan (γ- , x-rays + neutrons) for global modeling validation (IV, V_{dep}, CCE).

Deliverable D7.4 TCAD model radiation damage (month 46).

WP7 Task 7.4 (Firenze)

Detector validation for tracking devices

M. Meschini (INFN staff)

On going activities in Florence

- New hybrid pixel modules order
- Preparation for next planar active edge at FBK
- Serial Powering studies on FEI4 and RD53
- Test Beam 2016: irradiated Planar, new modules from first FBK planar batch, new 3D modules

Planar Batch Layout

Active Device 6" Float Zone Si-Si DWB (Direct Wafer Bond, Icemos), P type, FZ Sensor resistivity > 3kOhm cm, 100µm and 130µm thick. CZ Handle wafer, 0.1-1 Ohm cm resistivity, 500µm thick

FBK production completed Dec 2014
10 wafers: 6 x 130µm + 3 x 100µm DWB and one 275µm standard FZ

ATLAS Double (G. Calderini)

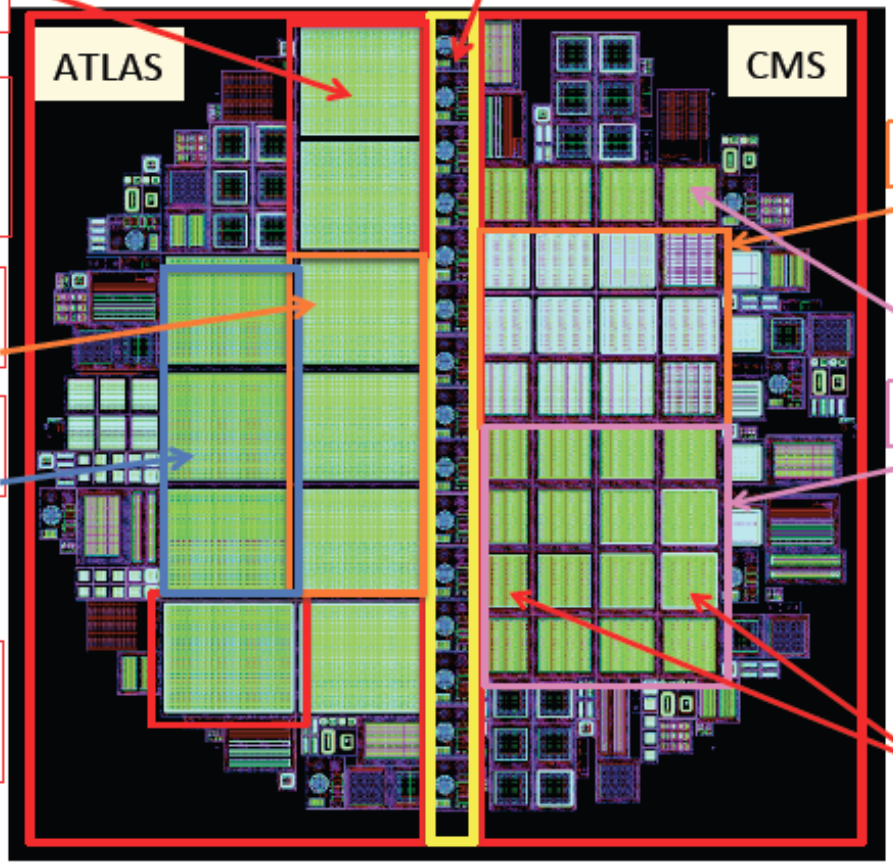
Increasing number of Guard Rings from row 4 to 1

Standard Punch Through

New Punch Through

8 ATLAS single sensors (FE-I4) total

FBK QA test structures



Pixels with P_stop

32 CMS sensors (PSI46dig) total

Pixels without P_stop

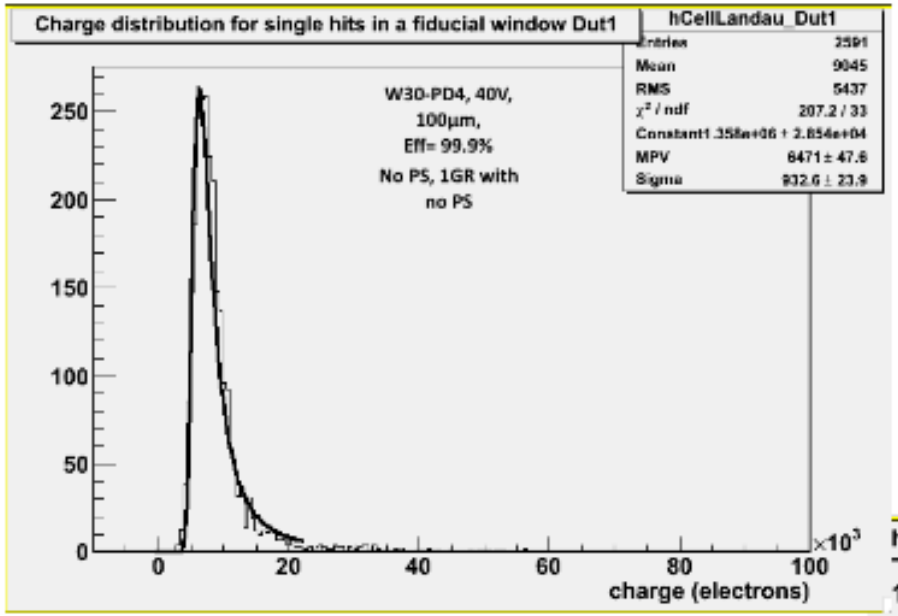
Increasing number of Guard Rings from col. 1 to 4

P-spray in 3 doses (Low-Med-Hi)

Layout finalization at FBK: G. Giacomini, M. Boscardin, N. Zorzi

Test beam at FNAL Dec. 2015

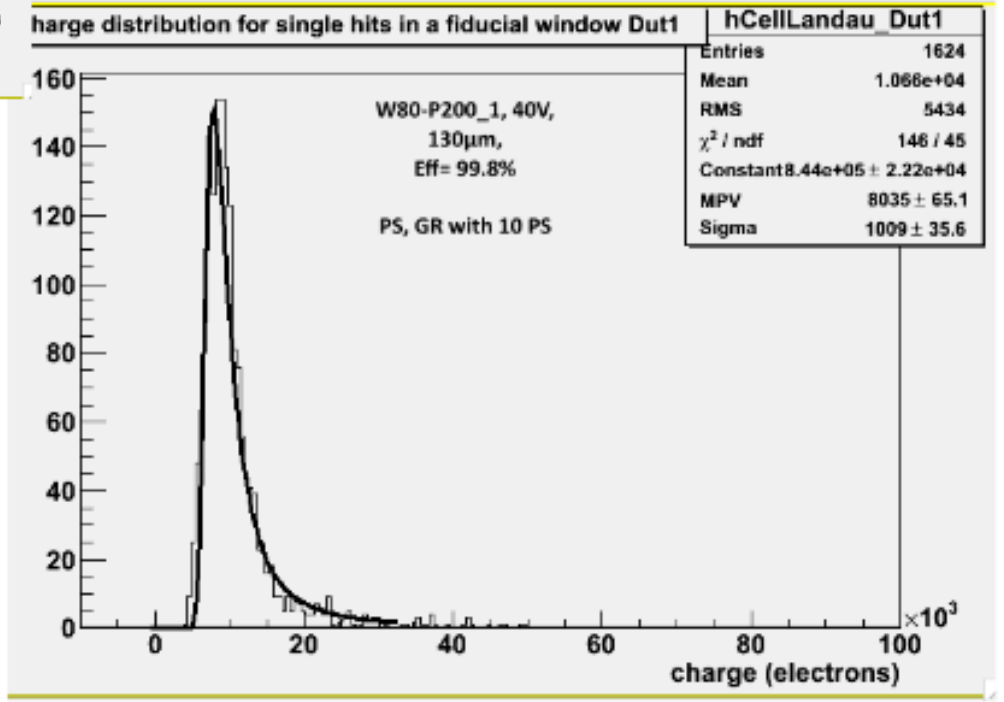
Spettri di Carica



MPV 100µ → 6400e⁻
MPV 130µ → 8000e⁻

Carica media 100µ → 9000e⁻
Carica media 130µ → 10600e⁻

Efficienze >99.8% sul volume fiduciale, ottenuto escludendo tutti i pixel non funzionanti e richiedendo 8 pixel attivi intorno al pixel attraversato dalla traccia



BCB on PSI46dig ROC Wafer

- **Wafermap and layer definition**

Gds-Layers# IZM:

20 – BCB (drawn structures will be BCB-free)
21 – UBM

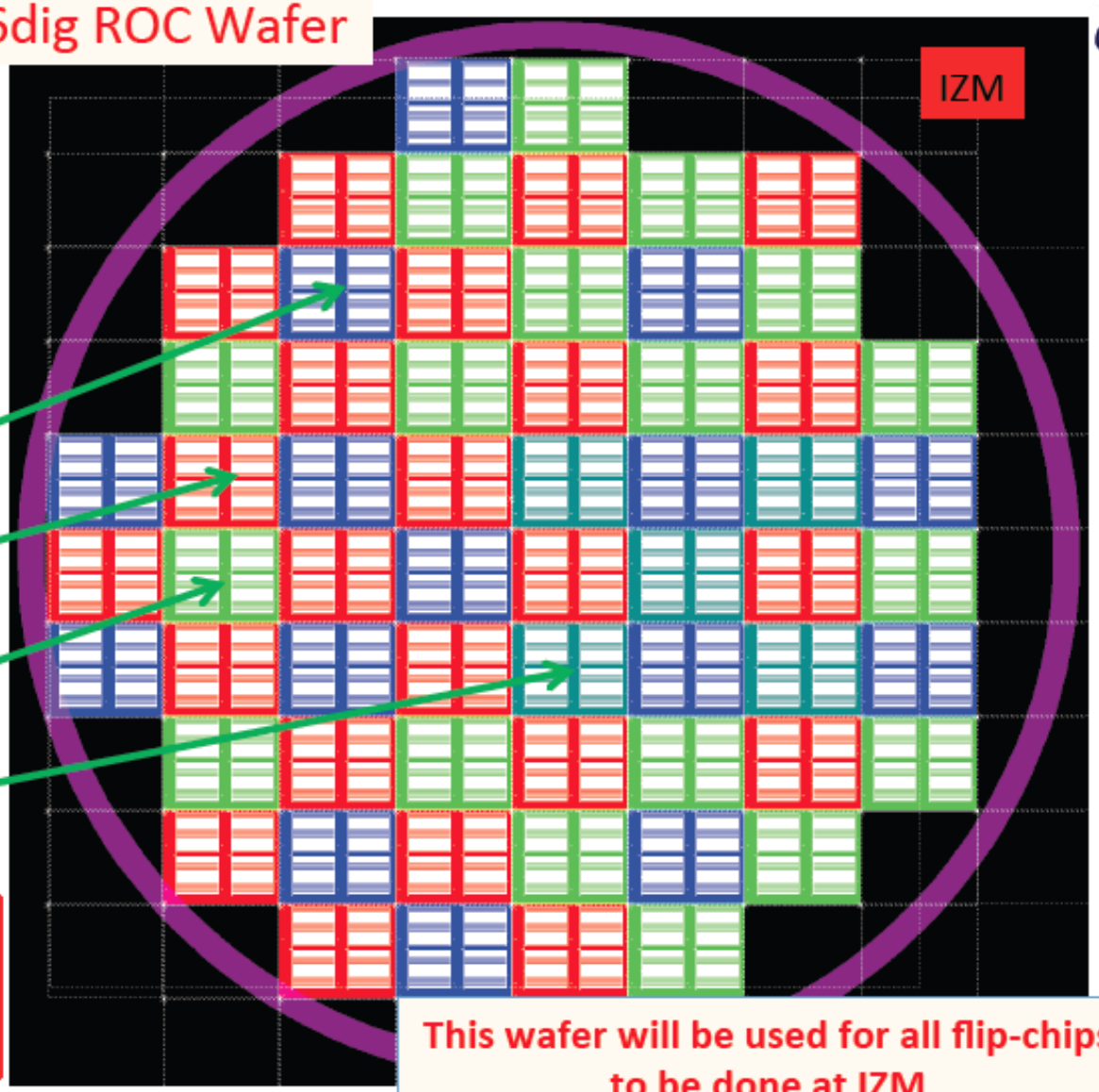
Reticle variants:

15x BCB-free (with GR-bumps)

23x frame mask (without GR-bumps)

18x full mask (without GR-Bumps)

5x full mask (with GR-bumps)



BCB around bumps can help in reducing the mechanical stress on ROCs during wire-bonding and handling

This wafer will be used for all flip-chips to be done at IZM

Planar Active/Slim Edge Batch (PAE)

To be submitted

- The overall philosophy is to have
  - standard "well known" sensors (from the point of view of pixel behaviour and readout electronics): on those ones change the periphery design with slim and active edges in different flavours
  - new small pitch sensors with more conservative periphery design to be tested with new readout chips
- The readout chips to be included in the layout:
  - PSI46dig
  - FEI4b
  - ROC4sens (R. Horisberger et al)
  - RD53A
  - other possible options:
    - FCP130 (FNAL design, 30x100µm2)
    - RD53 mini prototypes (FE65-P2 Bonn? Chipix65 Italy?)
- The pixel sizes to be included (µm2):
  - 25x100, 50x50, 30x100, plus the standard ATLAS 50x250 and CMS 100x150

It will be extremely complex to test other than PSIdig and FEI4.

Activities in sharing with other INFN groups

WP7 Task 7.4 (Milano)

Detector validation for tracking devices

G. Alimonti (INFN staff)

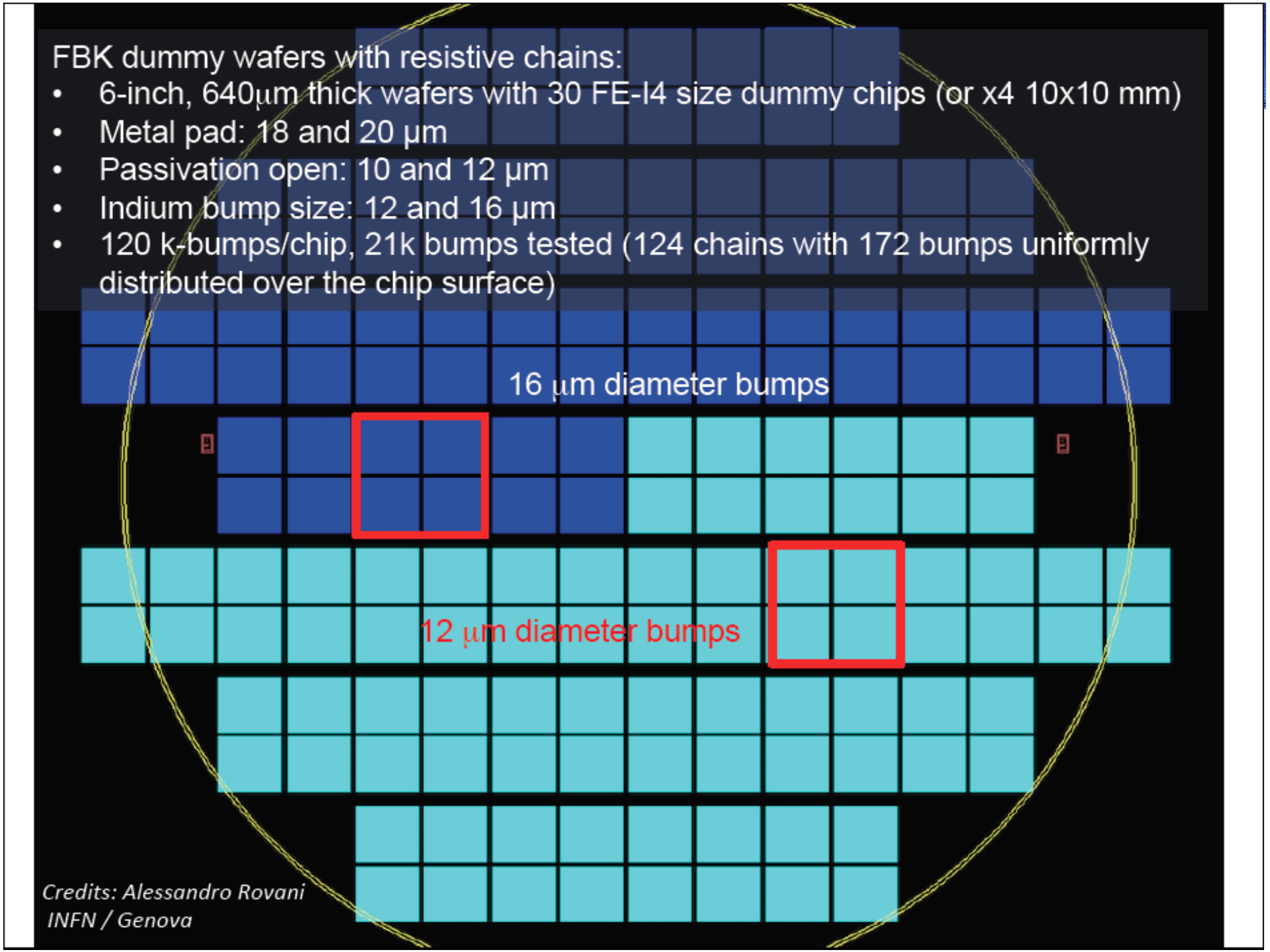
Current R&D with FBK/Selex

High density – High number of bumps

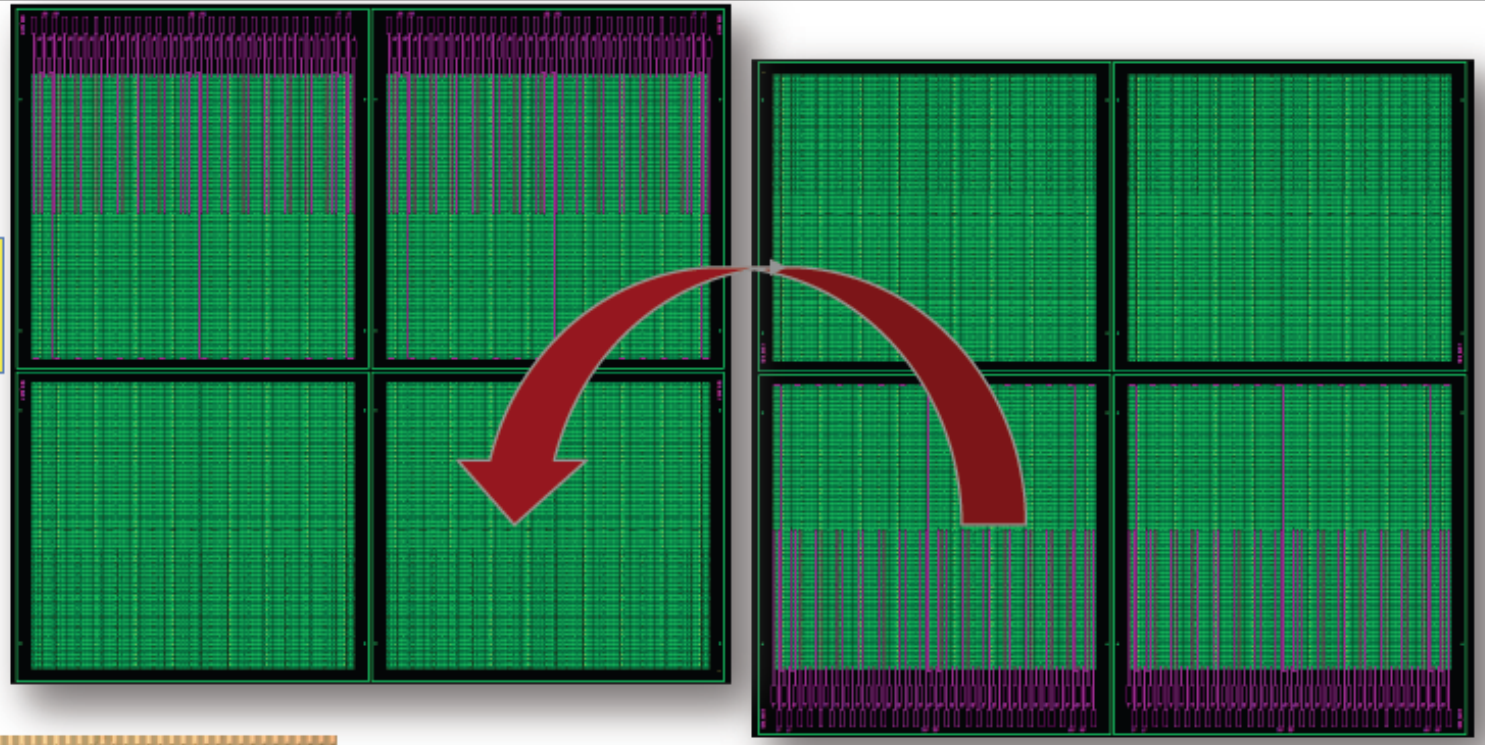
- **5x bump number of FE-I4 → 120 k-bumps/chip FE-I4 size**
- **Optimize process on dummies:** bump height, bump size, pad and overglass opening geometry, temperature and pressure with resistive chains.
- Mechanical / electrical test on assemblies

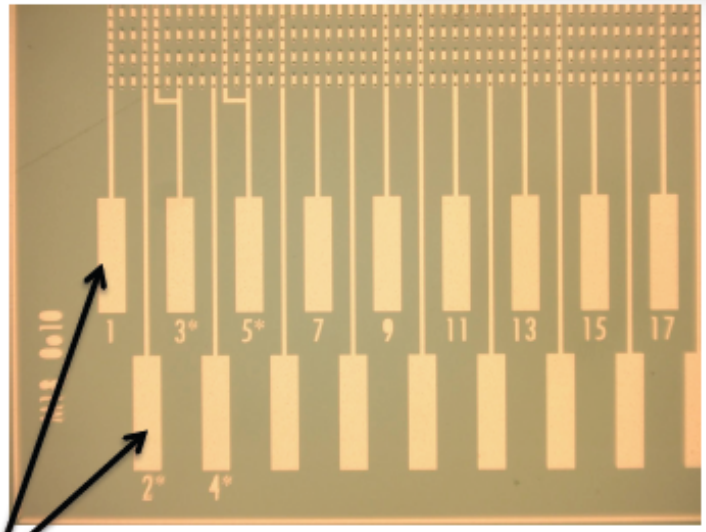
Bump deposition on 12-inch wafers

- wafers & deposition mask already procured
- test uniformity of vacuum deposition of bumps


FBK dummy wafers with resistive chains:
• 6-inch, 640μm thick wafers with 30 FE-I4 size dummy chips (or x4 10x10 mm)
• Metal pad: 18 and 20 μm
• Passivation open: 10 and 12 μm
• Indium bump size: 12 and 16 μm
• 120 k-bumps/chip, 21k bumps tested (124 chains with 172 bumps uniformly distributed over the chip surface)
16 μm diameter bumps
12 μm diameter bumps
Credits: Alessandro Rovani
INFN / Genova

Front view before flipping





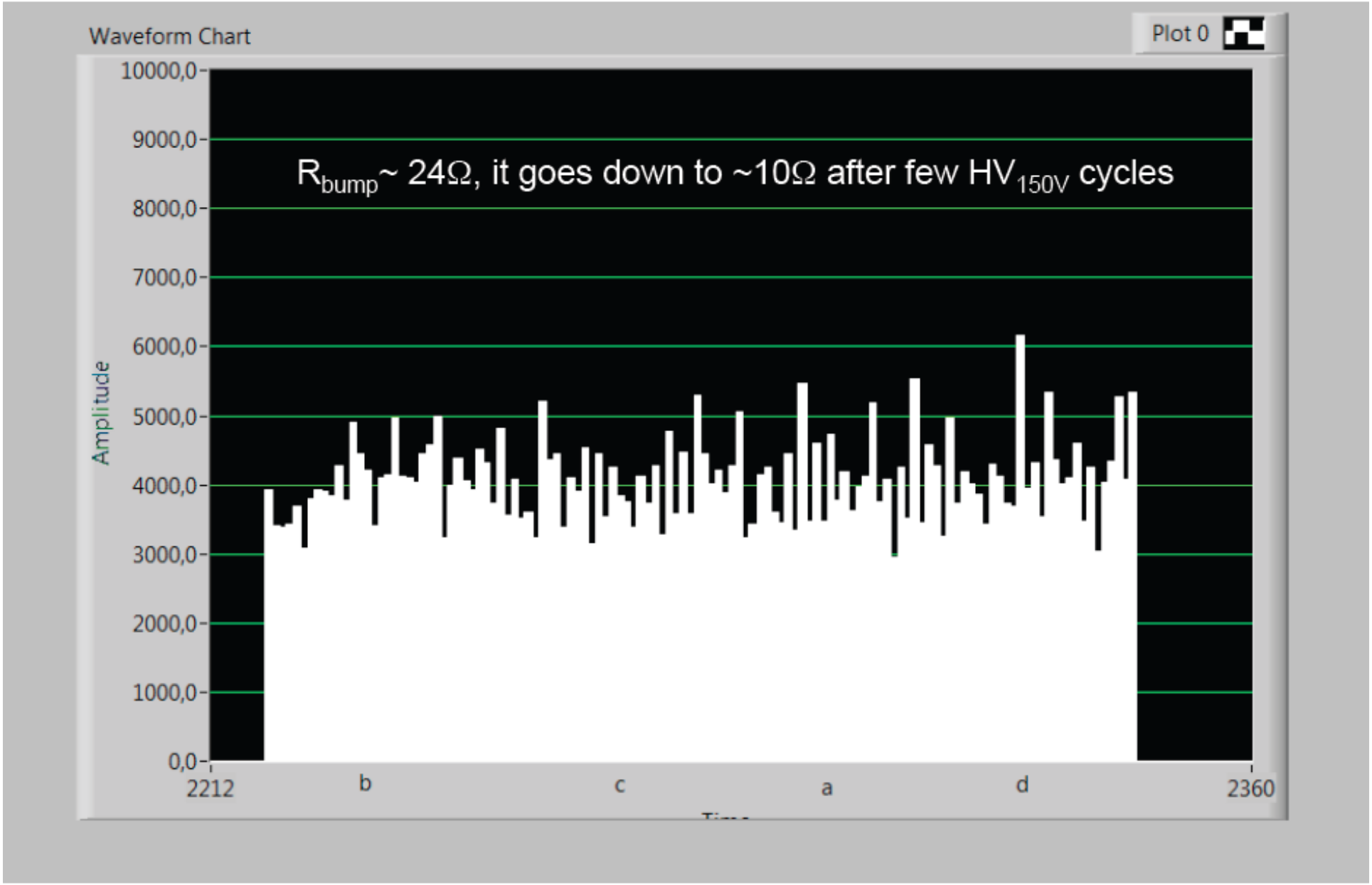
R-measurement

- Test 124 chains with 172 bumps in series.
- Must apply 150V (I_{max}=100μA) to break Indium oxide before R-measurement

Mesurement pads here

Side view after flipping

Resistance across each chain of 172 bumps (124 chains)



Conclusions and next steps

Very promising results from first resistive chain tests on 6":

- No open among 64k bumps (3 chips)
- No indication of shorts (either by X-rays or R meas.)
- Flip-chip planarity needs to be improved

More studies on:

- More modules planned with adjusted planarity
- Mechanical stress tests (FEI4 dummy glued on IBL stave with flex circuit, -40C to 40C thermal cycles, 3 hours each state, preliminary results are positive)
- Bump deposition on 12" wafer ongoing now (preliminary results on bump height uniformity very good ~10 um, but problems with width uniformity below 16 um)
- Resistive chains on 12" wafer dummy modules

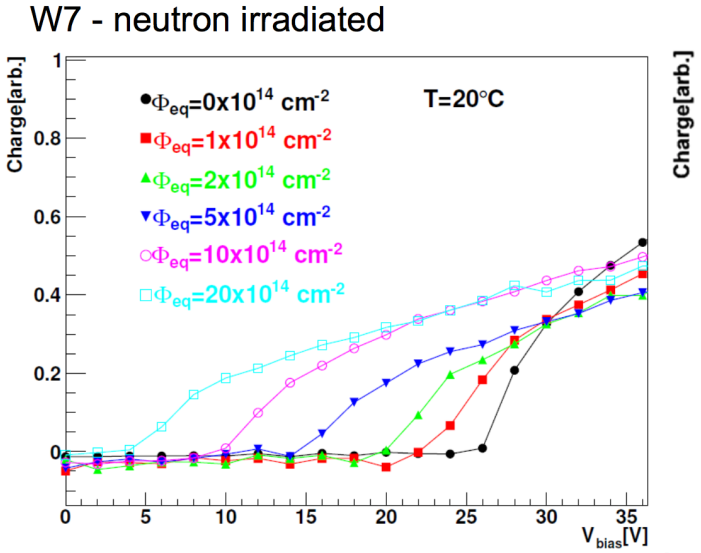
WP7 Tasks 7.2 e 7.5 (Torino)
TCAD simulations
Detector validation for LGAD sensors

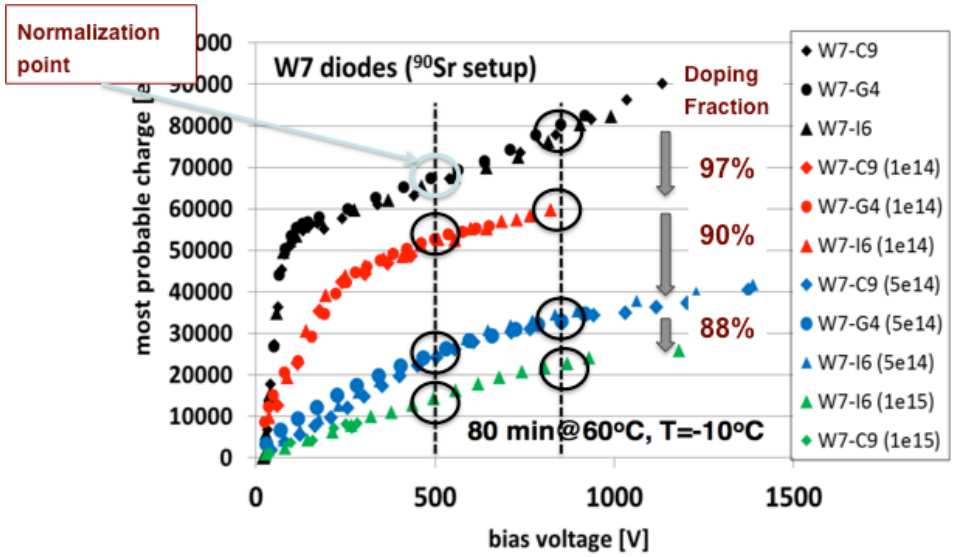
- Sensor design
- Sensor testing
- Design read-out electronics
- Preparation for beam - tests

- D7.3 : Results of LGAD simulation with choice of doping profile and position of the gain layer for pads and pixelated detectors. Identification of optimal dopant as alternative to boron for best radiation resistance. Choice of design between electron initiated or hole initiated avalanche. [M18]

Sensor design

- **Study of radiation damage data: simulation of measured results, interpretations with and without strong initial acceptor removal**





- Development of 50 um geometry, including the optimization of the trade offs between dead area vs signal quality
- Study of optimum thickness and gain for best matching with electronics, including the effect of radiation damage up to 5 *10^{15} n/cm^2

Inconclusive conclusions

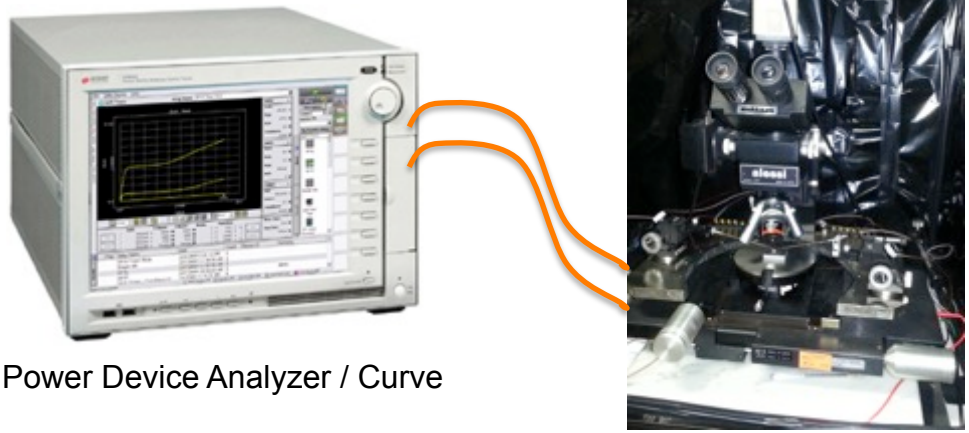
The data from the foot and the gain are difficult to reconcile in TCAD

- **If we trust the foot**, we have a strong acceptor removal, and the collected charge according to TCAD/WF2 should be much smaller.
- **If we trust the collected charge**, then there is a reduced acceptor removal, but the foot measurement is difficult to explain.
- The difference in collected charges for LGAD and PiN diode above 2-3 10^{14} n/cm^2 suggests the presence of the gain layer?
- Is the increase in the signal from 500V to 800V an indicator of the gain mechanism at work?
- Data on SiPM and APD does not show strong gain reduction.

How do we reconcile these information?

Sensor testing

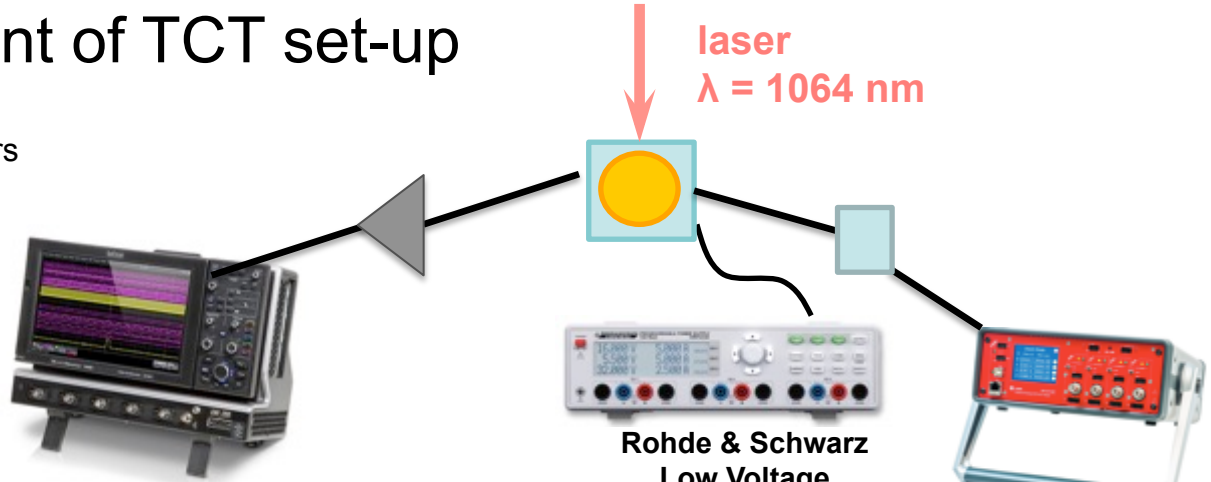
- Set-up of new semiconductor analyzer stand



Keysight B1505A Power Device Analyzer / Curve Tracer

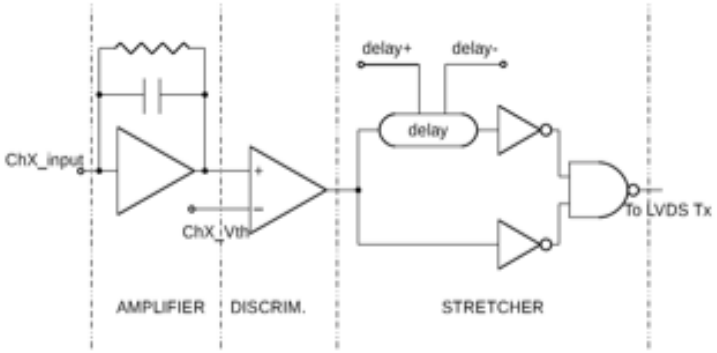
- Improvement of TCT set-up

Many types of pre-amplifiers and read-out options

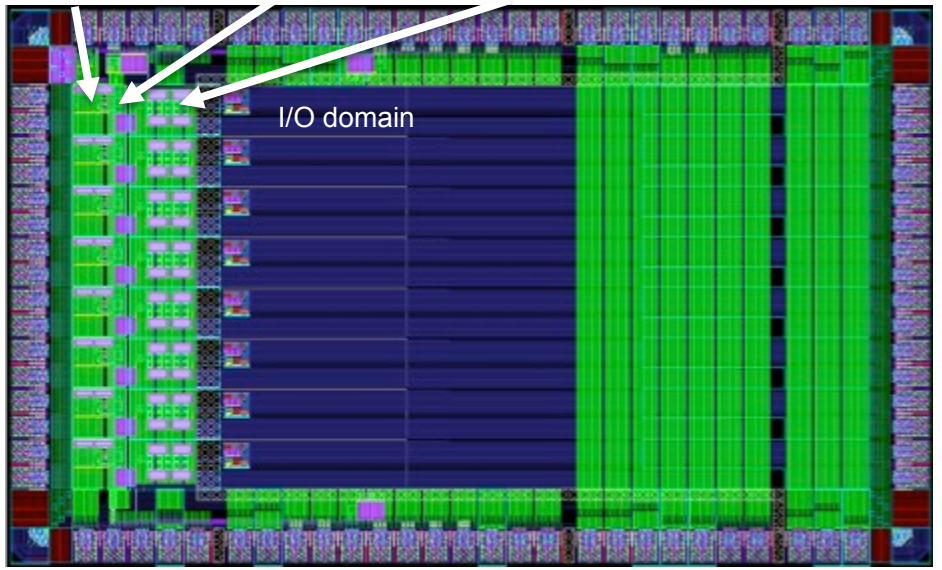


Read-out electronics

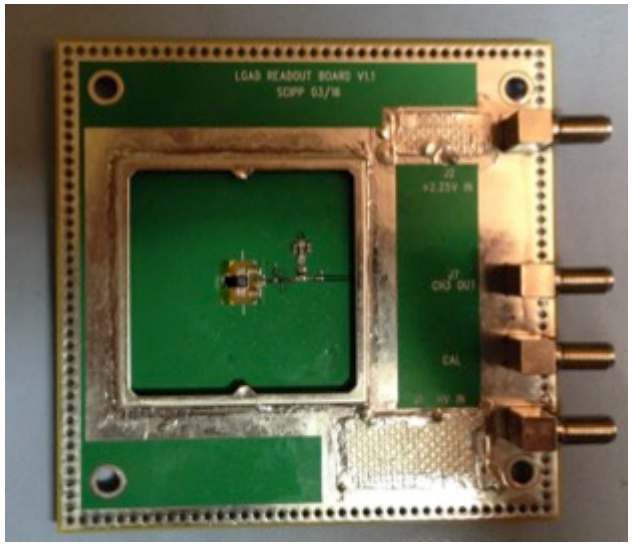
Full custom chip for LGAD read-out



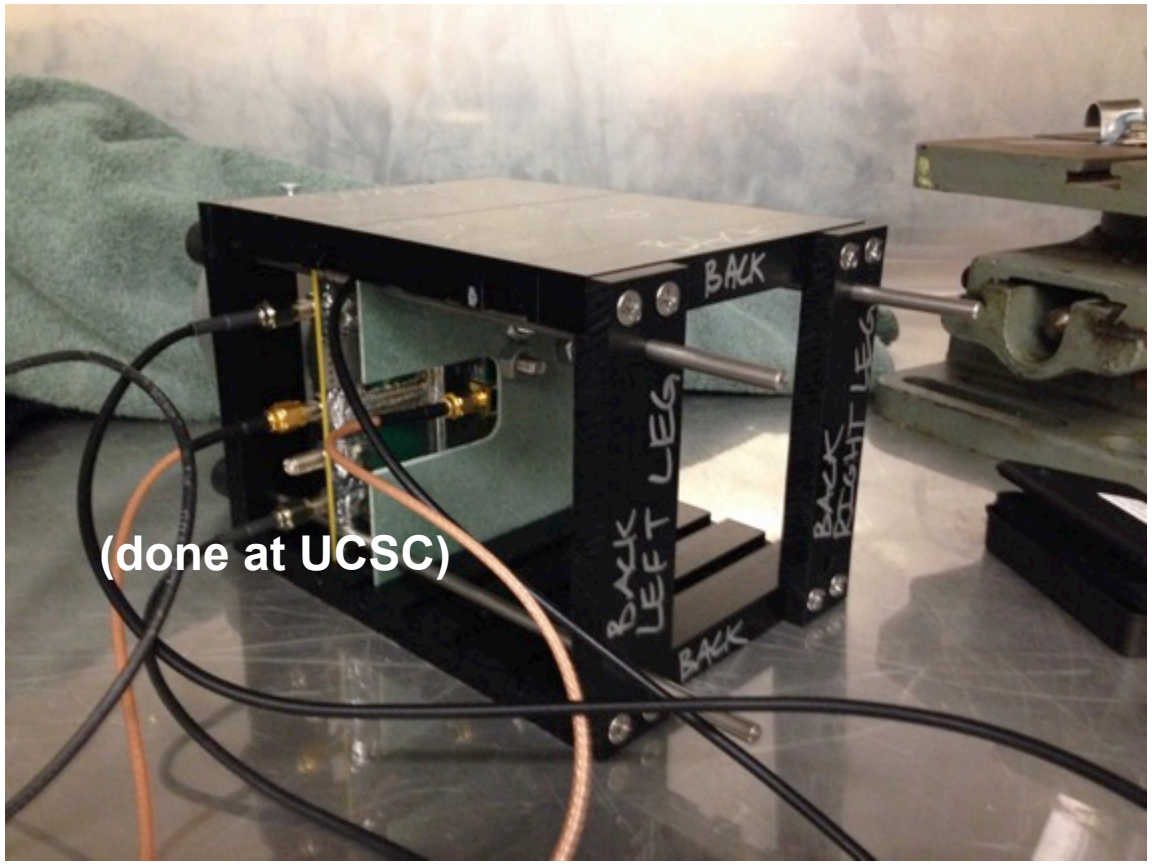
A0 domain: amplifier A1 domain: buffer + disc1 A2 domain: disc2 + delay line



Full custom read-out board for beam test (with UCSC)



Beam test telescope with 30 ps SiPM trigger



Ready for beam test in the first week of June