Fastissimo-Plus: … or the ultimate design for ultra-high speed radiation sensors

G.-F. Dalla Betta[1], C. Da Via[2]

(inspired by S. I. Parker)

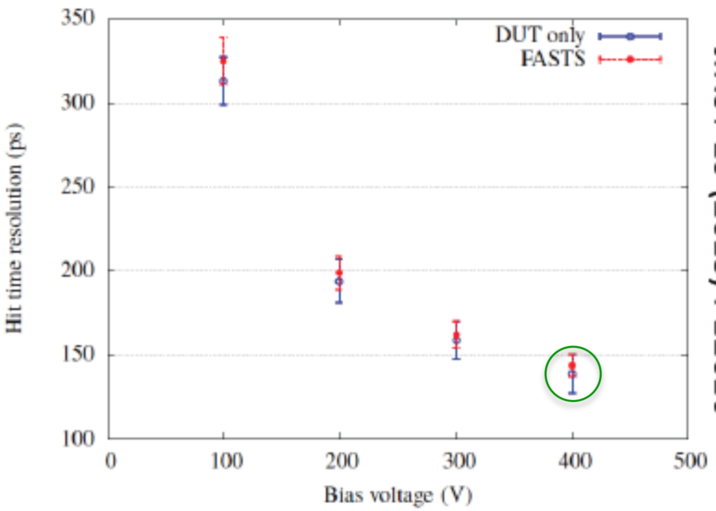
[1] University of Trento and TIFPA INFN, Trento, Italy

[2] University of Manchester, Manchester, UK

2nd ATTRACT TWD Symposium in Detection and Imaging
Strasbourg, 4-5 November, 2016

Ultra Fast Silicon Detectors

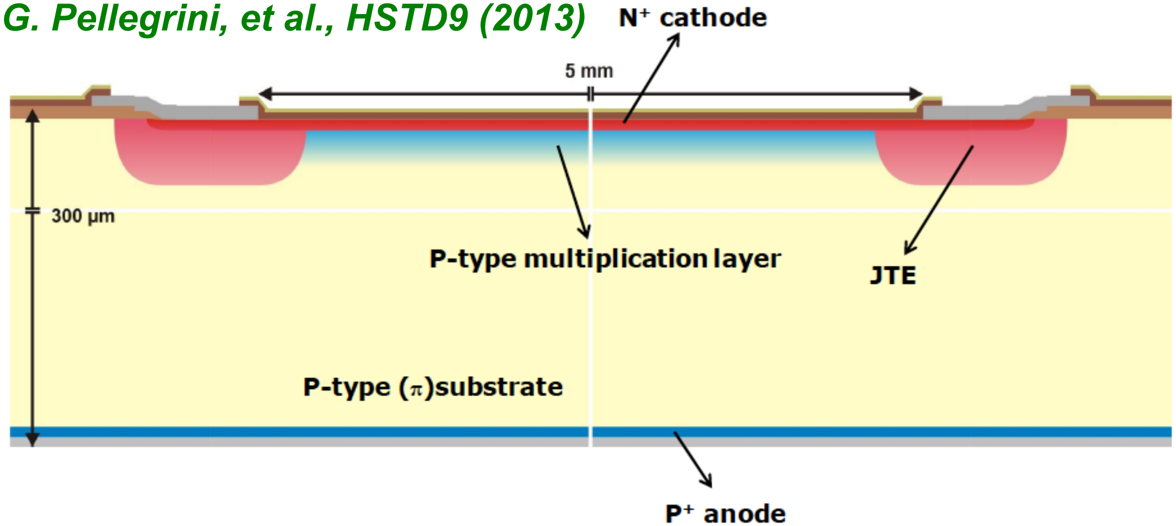
- Ultra Fast Silicon Detectors (UFSD) are a very hot topic …
- There is need for UFSD imaging systems with aggressive spatial resolution for several applications:
  - vertex reconstruction at high energy colliders
  - high intensity synchrotron sources
  - particle beam monitoring (e.g., in hadron therapy)
  - Time of Flight systems (mass spectroscopy, 3D range sensors)
  - …
- Limited performance with planar sensors:
  - Best result with NA62 Gigatracker,
  - 200um thickness, 300um x 300 um pixels
  - Time resolution ~ 140 ps
- Strong improvement with LGAD …

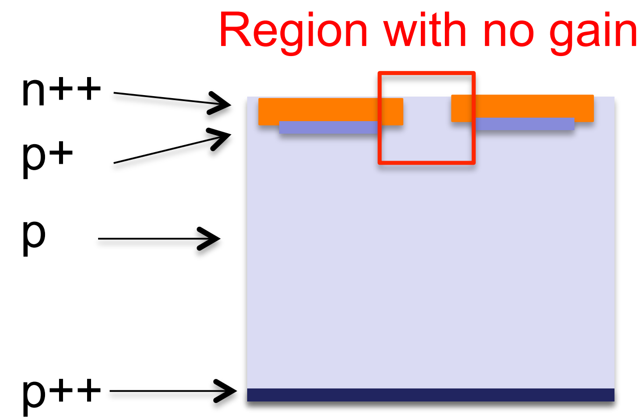


JINST 10 (2015) P12016

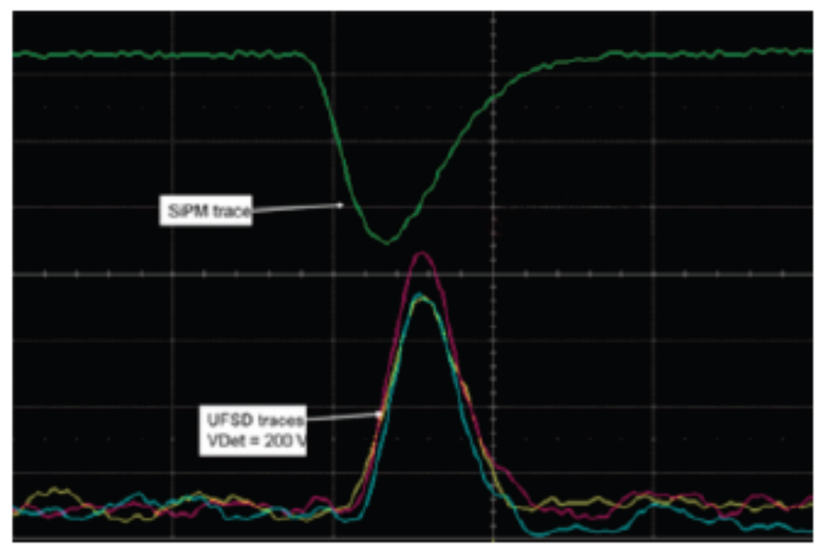
Low Gain Avalanche Detector (LGAD)

G. Pellegrini, et al., HSTD9 (2013)



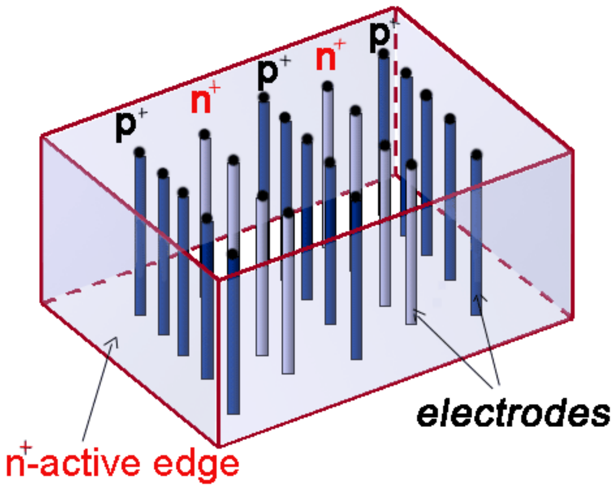


- APDs revisited for ionizing particles
- Gain from units to tens
- Excellent performance for thin (50 um) pad (1.4 mm^2) sensors: ~25 ps time resolution at 200 V bias
- Problems with fine-pitch segmentation and radiation hardness



arXiv:1608.08681

3D sensors



S. Parker et. al. NIMA 395 (1997) 328

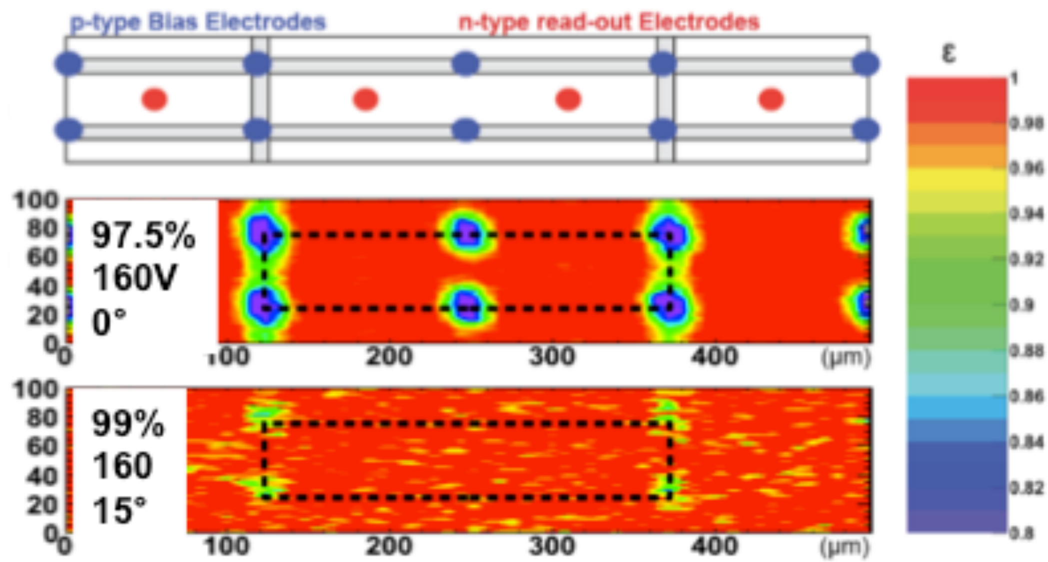
Electrode distance (L) and active substrate thickness (Δ) are decoupled

→ **L<<Δ by layout**

High radiation hardness at relatively low voltage (low power dissipation)

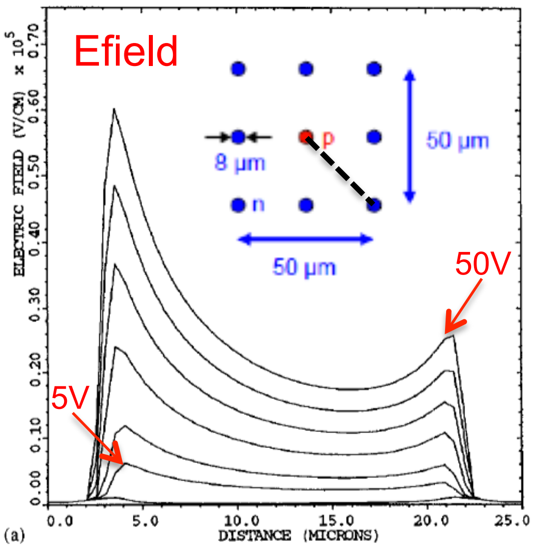
State of the art: ATLAS IBL 3D pixels

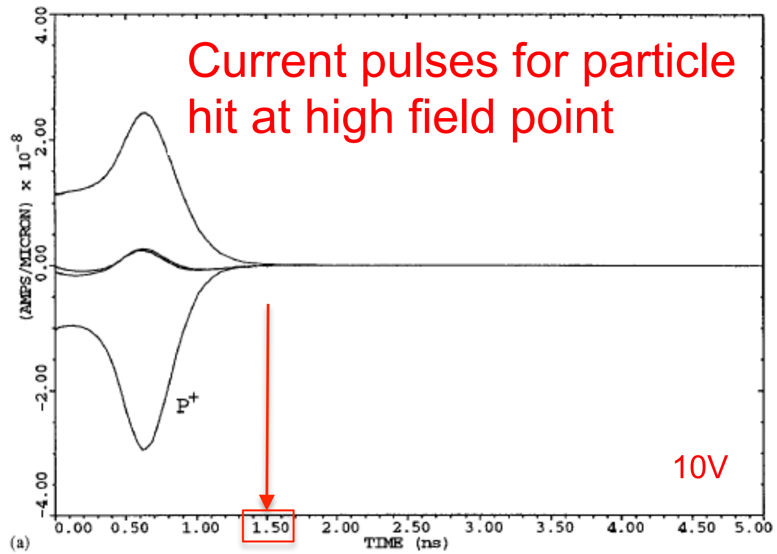
- Double-sided 3D, produced by CNM and FBK
- Excellent performance up to 5×10^{15} n_{eq} cm^{-2}: 99% hit reconstruction efficiency at 15° tilt and -15°C temp. (~10 mW/cm^2 power dissipation)
- Also pushed to ~1×10^{16} n_{eq} cm^{-2} in AFP tests and being further increased for HL-LHC

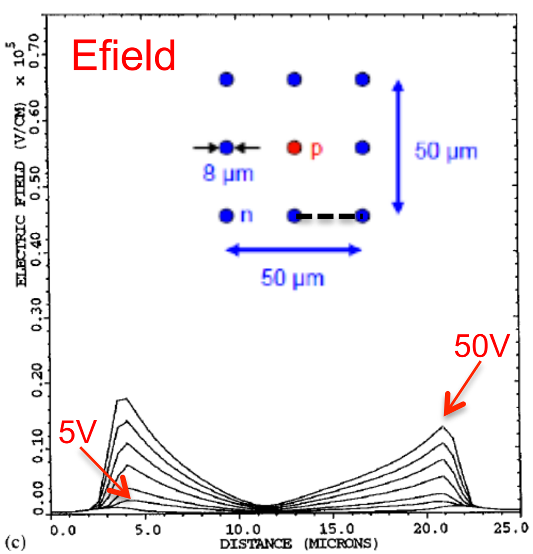


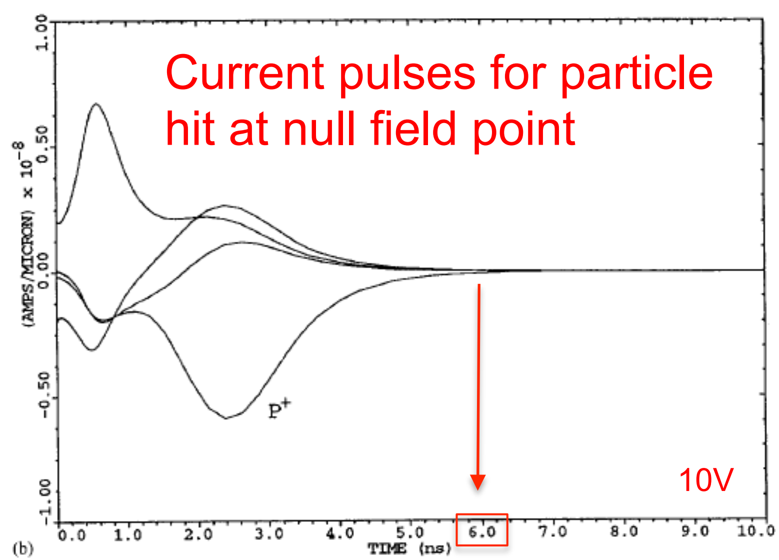
ATLAS IBL, JINST 7 (2012) P11010

Potential 3D features





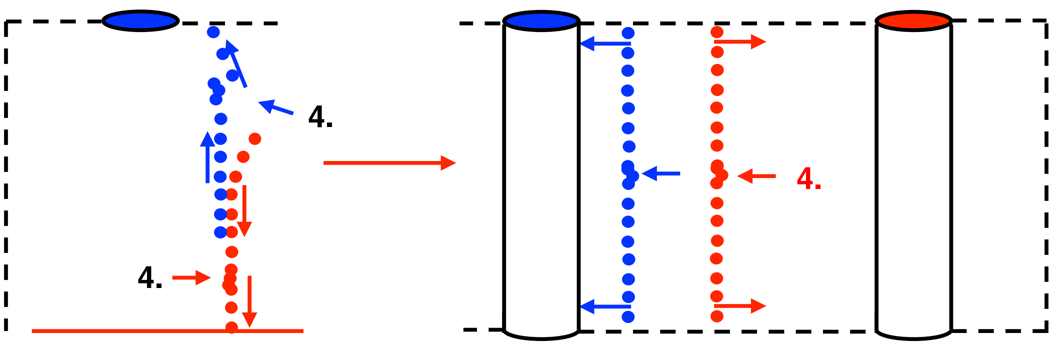




S. Parker et al. NIMA395 (1997) 328

- 3D structure can potentially yield very fast signals of the order of 1 ns
- But electric field is not uniform, and null field points are present: signals are delayed due to initial diffusion
- Moreover, electrodes are (almost) dead regions
- These aspects can be improved with dedicated designs

Planar vs 3D



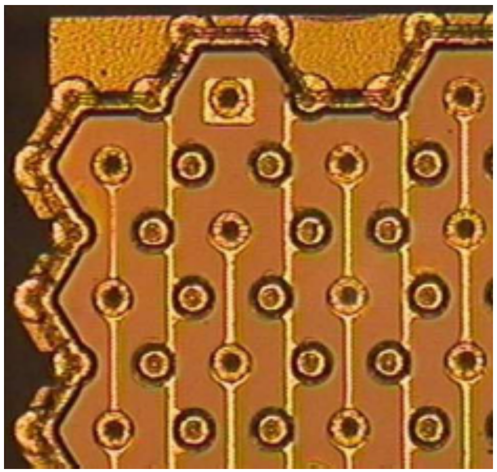
1. 3D lateral cell size can be smaller than wafer thickness, so
2. in 3D, field lines end on electrodes of larger area, so
3. most of the signal is induced when the charge is close to the electrode, so planar signals are spread out in time as the charge arrives, and
4. Landau fluctuations along track arrive sequentially and may cause secondary peaks

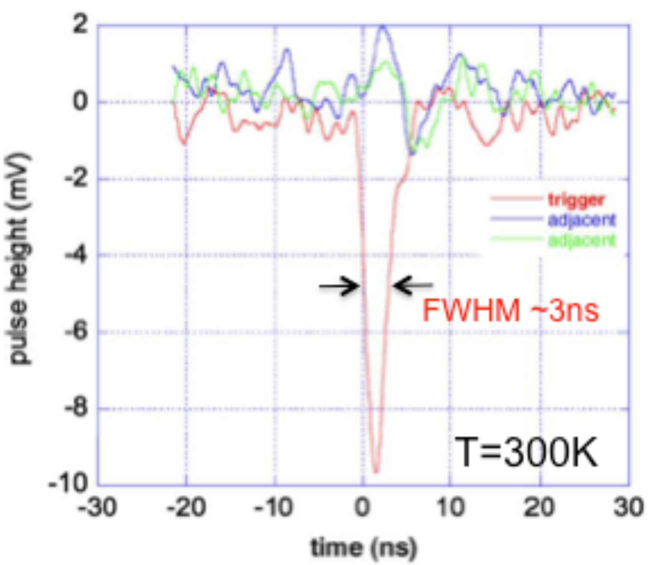
1. shorter collection distance
2. higher average fields for any given maximum field (price: larger electrode capacitance)
3. 3D signals are concentrated in time as the track arrives
4. Landau fluctuations (delta ray ionization) arrive nearly simultaneously

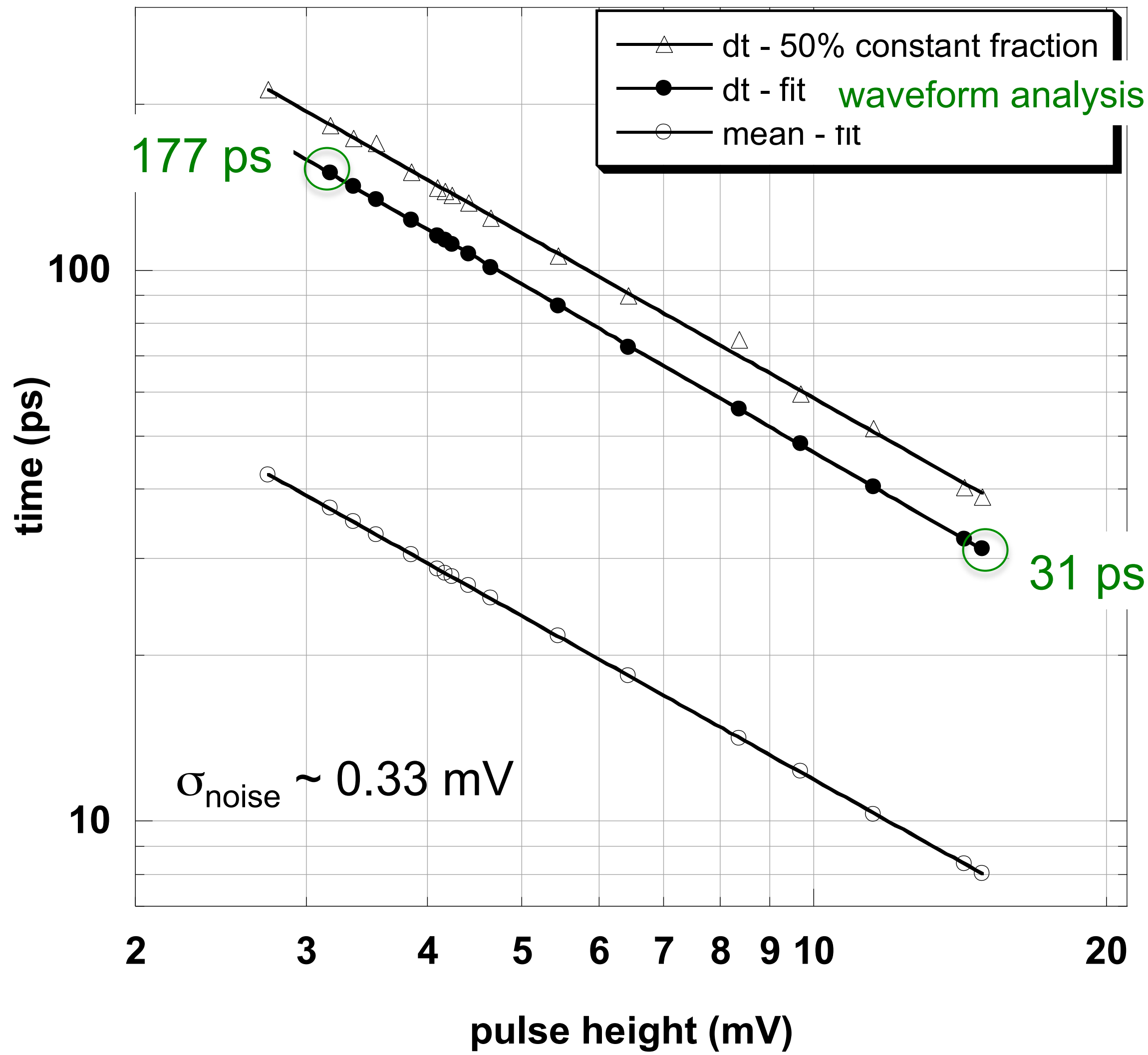
Speed with 3D

S. Parker et al. IEEE TNS 58(2) (2011) 404

So far tested with hex-cell 3D's ($L=50\mu m$) & fast current amplifier

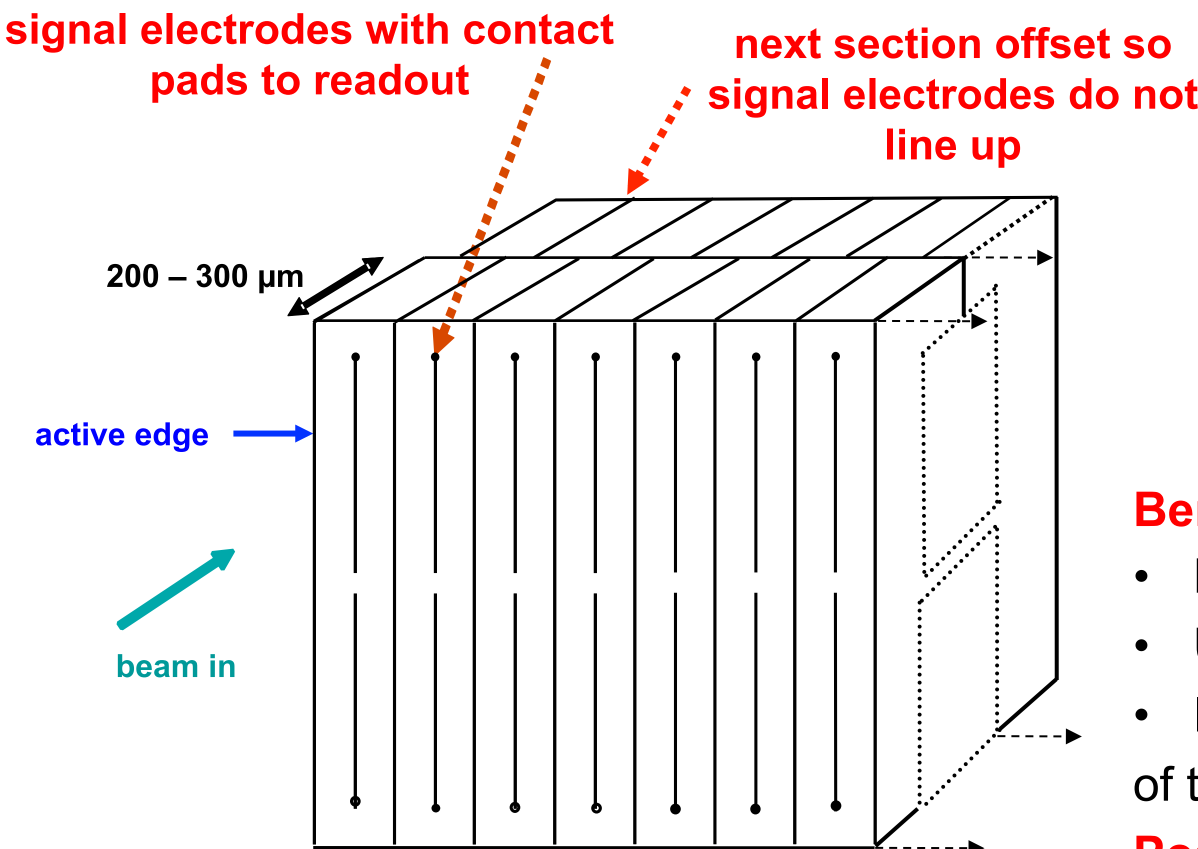




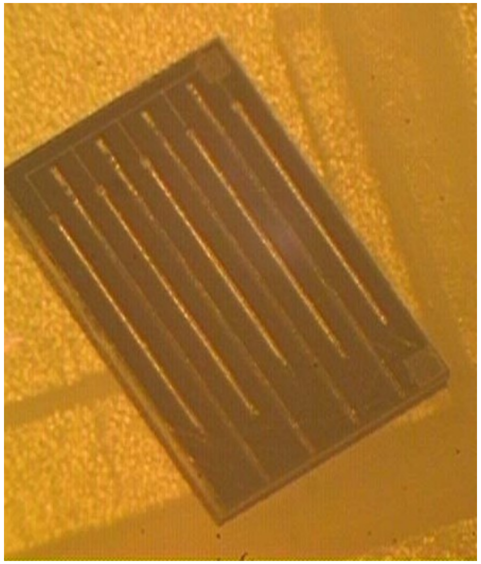


Trench-electrode sensors

S. Parker et al. IEEE TNS 58(2) (2011) 404



Schematic diagram of multiple plane arrangement in an active-edge 3D trench-electrode detector. Other offsets (⅓, ⅔, 0, ⅓, ⅔ ..etc.) may also be used.



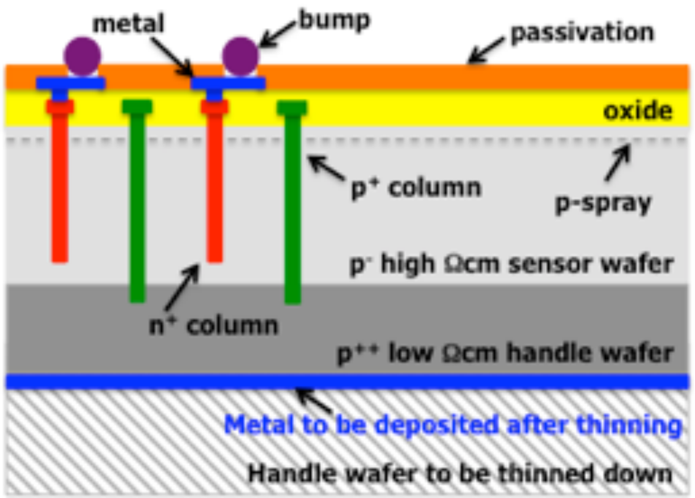
Benefits from trench electrodes

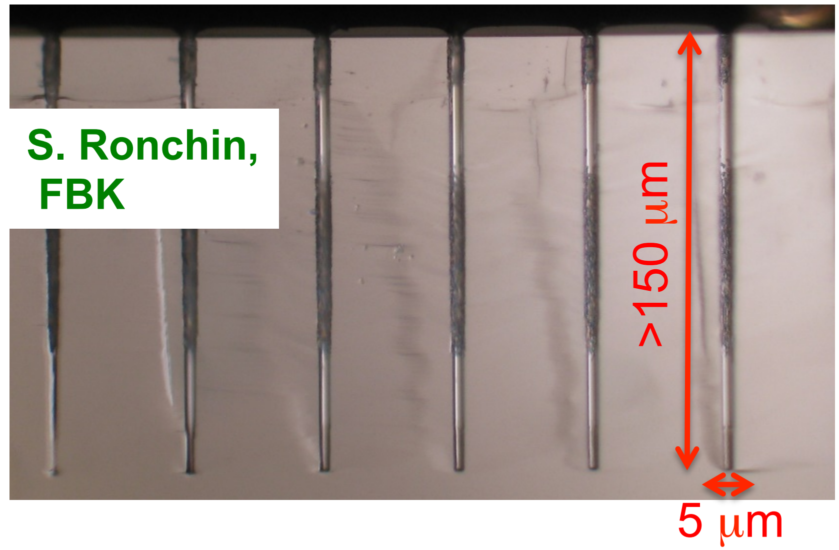
- High average field / peak field
- Uniform Ramo weighting field
- Initial pulse time independent of the track position

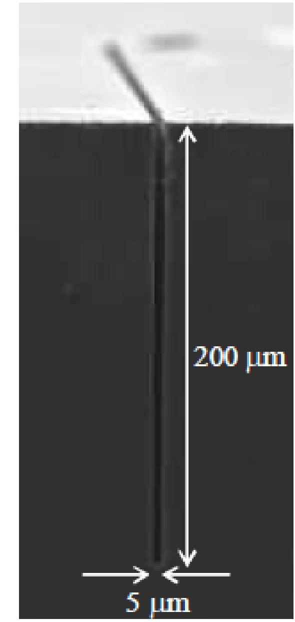
Possible issues

- Fabrication complexity
- Capacitance

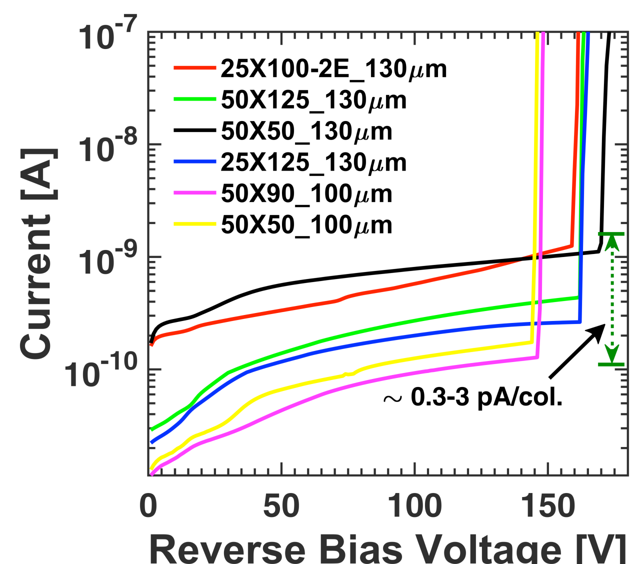
3D technology today





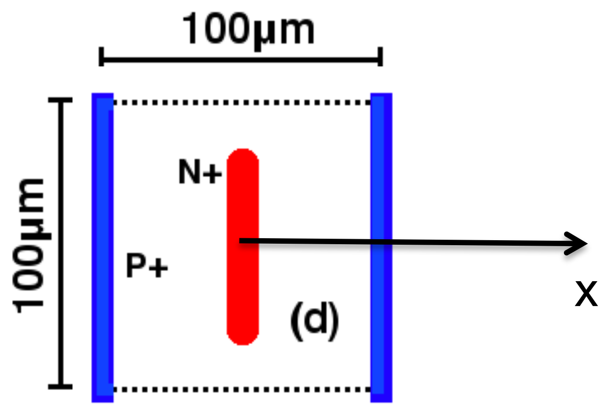


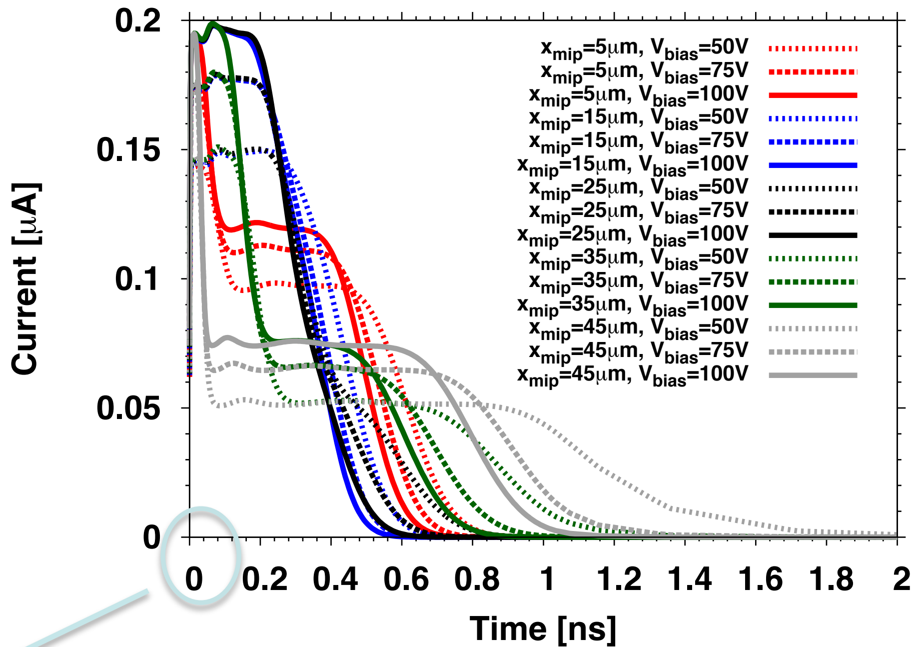
- Very impressive progress made in the past few years
- High aspect ratio (depth/width) DRIE feasible: up to 30:1 and beyond for columnar electrodes, even better for trenches (> 40:1)
- Flexibility in the choice of active thickness and inter-electrode distance
- High breakdown voltage can be achieved also before irradiation, allowing for large V_{bias} range

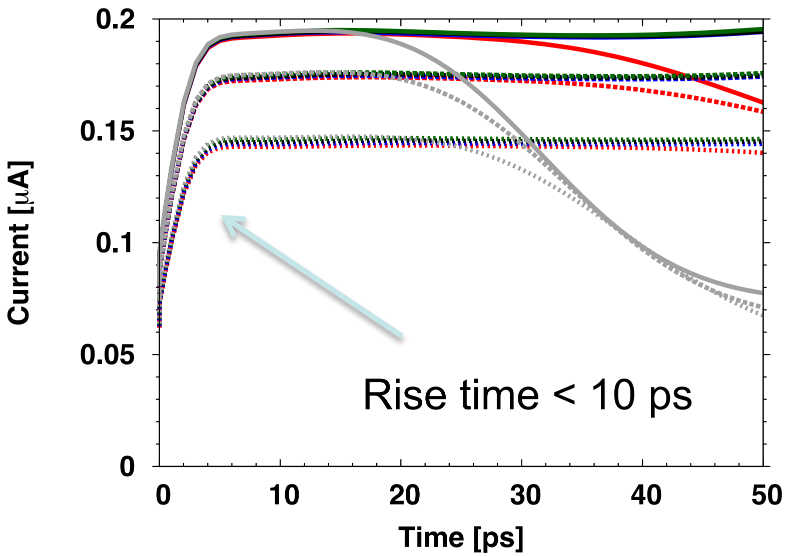


Trench-electrode simulations (1)

A POSSIBLE 3D PIXEL LAYOUT



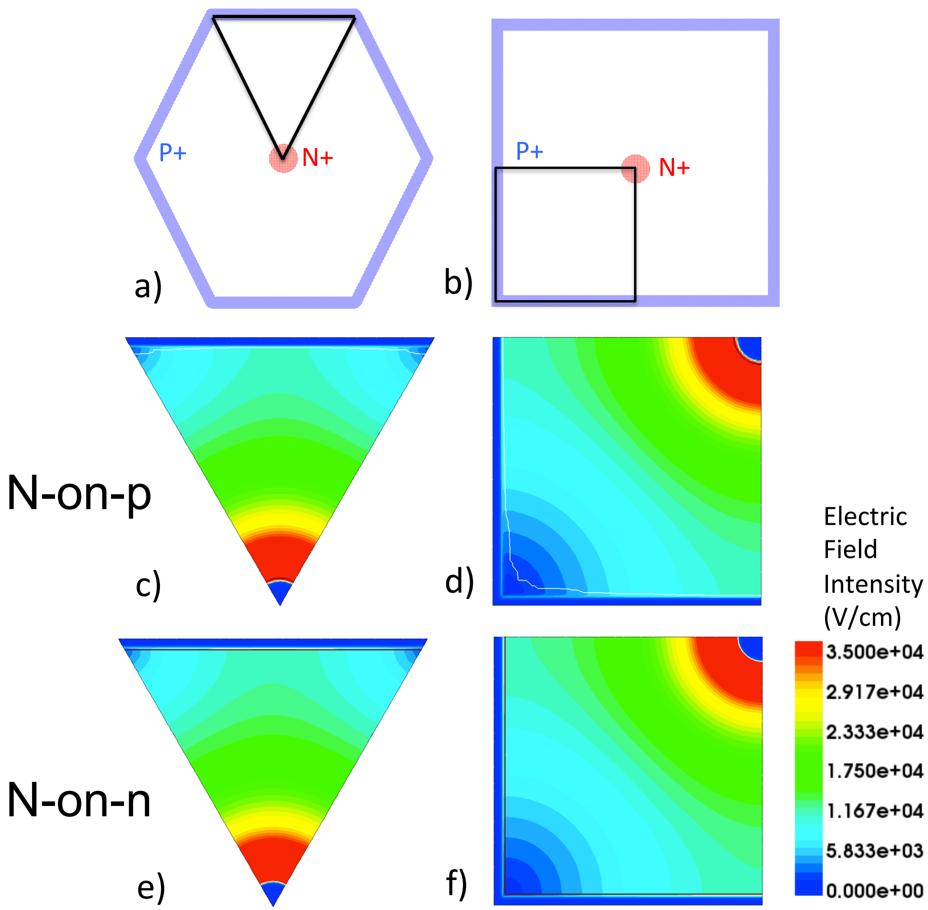




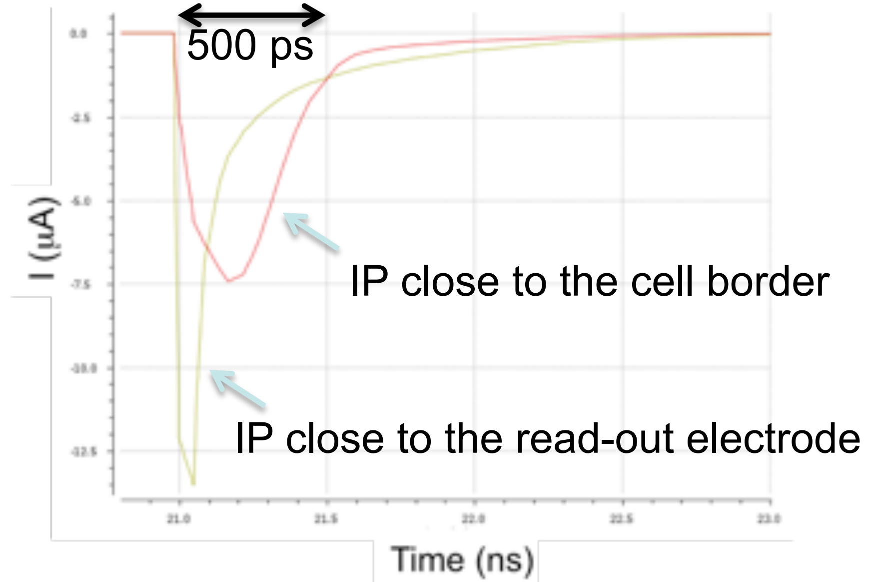
READOUT ELECTRODE CURRENT IN RESPONSE TO A MIP CROSSING THE PIXEL AT DIFFERENT POINTS

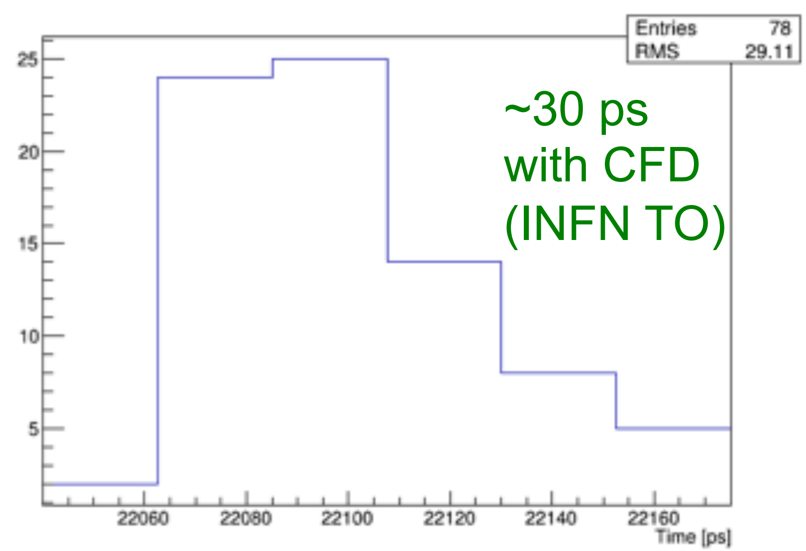
Trench-electrode simulations (2)

Other possible layouts



Simulated Efield at V_{bias} = 100 V





Implementation

Phase 1 (short term):

- Design and Fabricate Trench-Electrode sensors of different geometries
- Test their time response with:
  - Fast commercial single-channel readout circuits

    AND

  - Multi channel front-ends designed for the CERN-NA62 Giga Tracker experiment

  (300 um pixel → ~ 100 um 3D cell)
- At different operating conditions (T)
- Before and after irradiation

Phase 2 (mid term):

- Extended R&D Collaboration to develop the entire detector system:
- concurrent optimization of sensors and front-end electronics
- fast data processing (track pattern recognition)
- mechanical integration (multiple layers)
- extensive characterization

Fastissimo