Tracking the Time: Single cell 3D pixel time resolution and Landau contribution evaluation via test-beam and laboratory measurements

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The proven potential of 3D geometries at higher than 10^{16} neq/cm^2 radiation fluences, in combination with a small cell approach, makes them an excellent choice for a combined precision timing tracker. In this study, the timing resolution of a single 50 x 50 µm 3D pixel cell is presented in various temperatures through charge collection measurements with discrete electronics in a laboratory setting. The series is complemented by an extensive test-beam campaign with 160 GeV SPS pions, using a multi-plane timing telescope with an integrated pixelated matrix. Through a varied incidence angle study, field uniformity, Landau contribution and collected charge are treated at incidence angles of +/- 12º. Using state of the art numerical methods, the choice of instrumentation on signal composition and induced bias on results is also evaluated. Finally, with the help of the EUDET telescope, a detailed timing, field and efficiency map is presented with a 5 µm spatial resolution through MIMOSA CMOS tracking at CERN SPS pion beams.

3D Sensors for timing

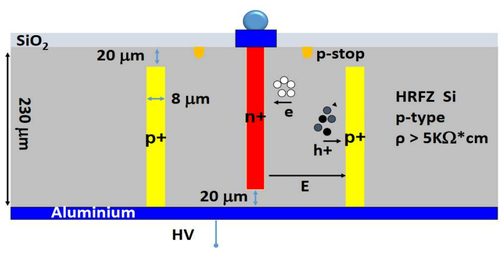


Figure 1: Cross-section of 3D pixel n-on-p, 50 x 50 µm [1]

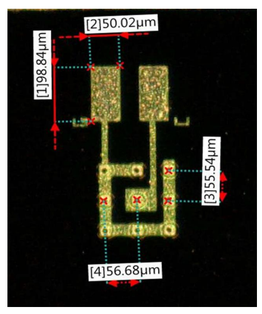


Figure 2: 3D Pixel picture

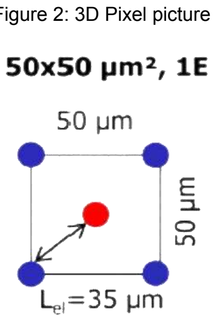


Figure 2: 3D Pixel design

Pros
- High radiation tolerance up to several times 10^{16} neq/cm^2
- Short drift distances with fast rise times
- Reduced Landau fluctuation, practically non-existent for perpendicular tracks

Cons
- Non-uniform field geometry
- High cost
- Increased cell capacitance

Laboratory analysis

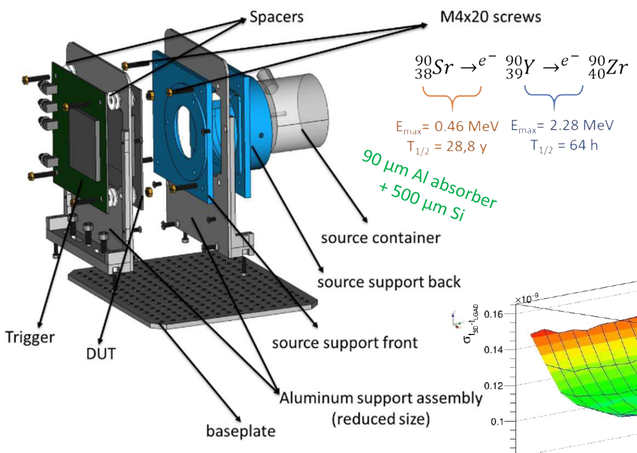


Figure 4: Laboratory setup for β source test

LGADUtils Framework

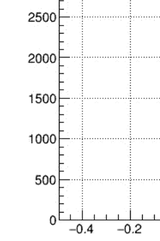


Figure 5: Collected charge and Rise Time (10%-90%), Single Pixel 3D (20V, -20ºC) [2]

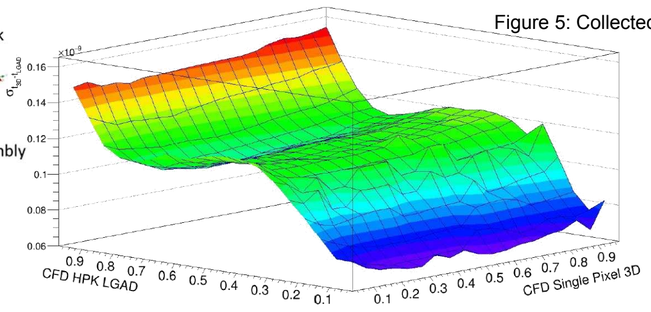


Figure 6: CDF from single 3D pixel against LGAD

β Source Characterization
- High frequency SiGe (~2GHz) amplifier
- Mean sensor + amplifier noise < 1.5 mV
- 5000 recorded events per point

1st TestBeam

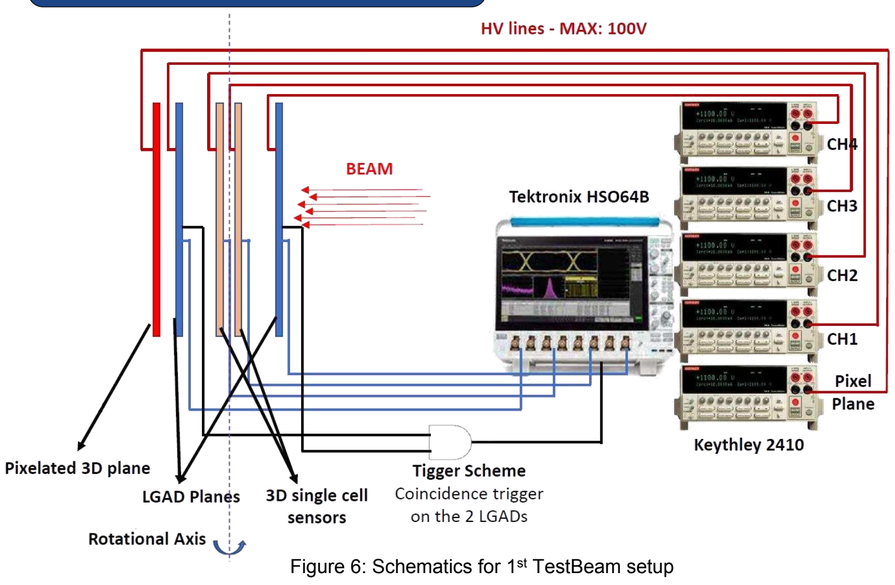


Figure 6: Schematics for 1st TestBeam setup

Data Acquisition
- 2 LGADs → coincidence trigger at 100% efficiency threshold
- Each trigger → Record RAW waveform binary data 4 objects
- Minimum 3M events recorded for each point to ensure adequate statistics (geometric efficiency of 3D ~0.01%)
- Alignment of the 3D cells is verified using the pixelated plane

2nd TestBeam

Aim of the Test-Beam
- Test Single Pixel 50 x 50 µm 3D
- Tracking with 7µm position resolution
- Timing with LGAD telescope
- Study sub-pixel timing map and uniformity

Setup
- Same as 1st TestBeam embedded in EUDET Telescope
- Trigger from scintillators and ROI
- Alignment to improve efficiency

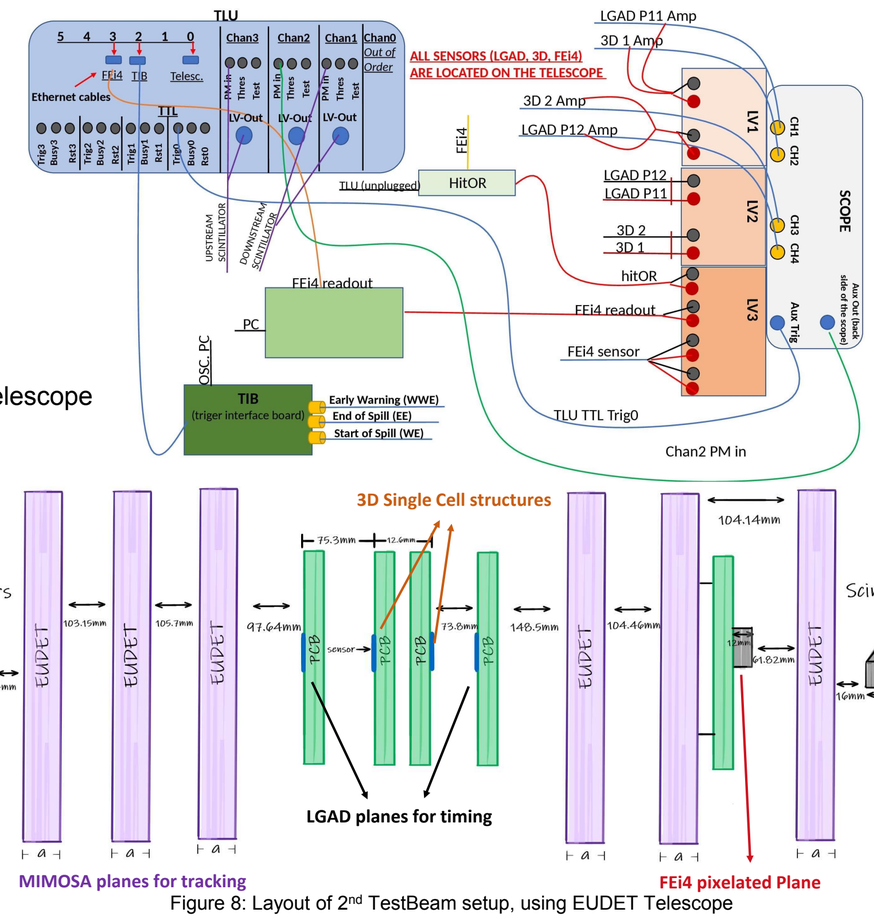


Figure 8: Layout of 2nd TestBeam setup, using EUDET Telescope

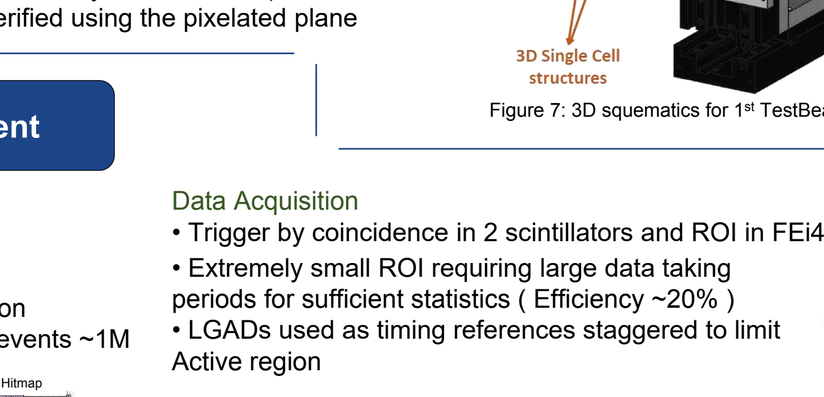


Figure 7: 3D squematics for 1st TestBeam sensor setup

Tracking & alignment

Telescope Planes
- 6 MIMOSA planes for tracking
- Plane no. 5 known to be bad
- Expected 5µm tracking resolution
- Estimated acquired number of events ~1M

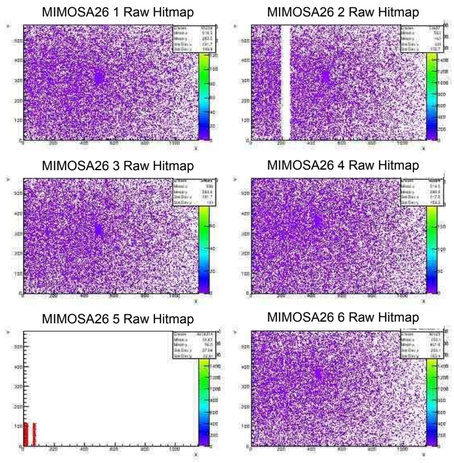


Figure 9: Mimosa planes data example, one broken plane

Data Acquisition
- Trigger by coincidence in 2 scintillators and ROI in FEi4 board
- Extremely small ROI requiring large data taking periods for sufficient statistics (Efficiency ~20%)
- LGADs used as timing references staggered to limit Active region

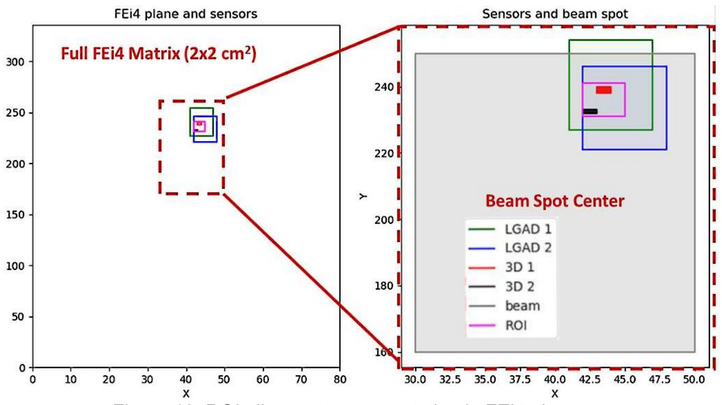


Figure 10: ROI alignment representation in FEi4 plane

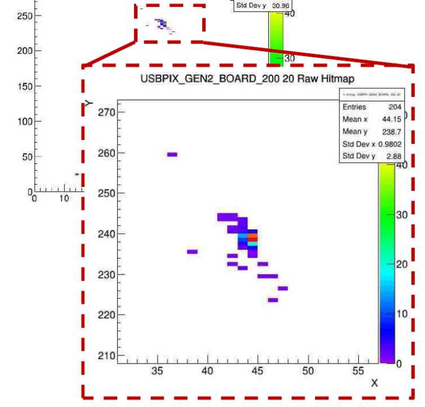
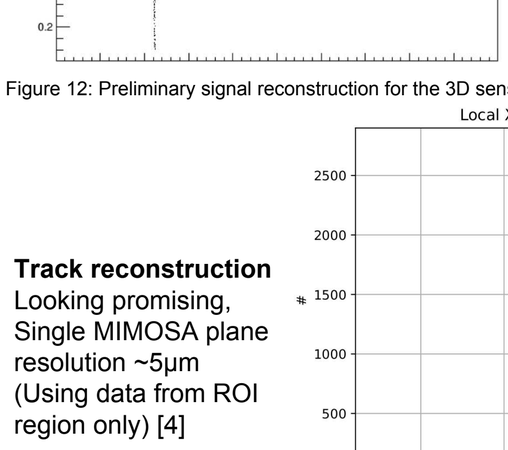


Figure 11: Single 3D pixel effect on FEi4 board

Preliminary results



Signal Reconstruction for 3D sensors
Acquisition frame from oscilloscope (~850.000 ROI events)

Figure 12: Preliminary signal reconstruction for the 3D sensors

Track reconstruction
Looking promising, Single MIMOSA plane resolution ~5µm (Using data from ROI region only) [4]

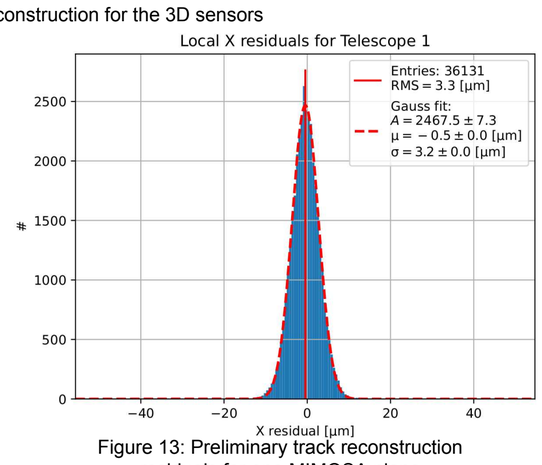


Figure 13: Preliminary track reconstruction residuals for one MIMOSA plane

Timeline

- 1st Lab timing measurements presented and look extremely promising
- 2 Testbeam campaigns completed with tracking and results soon to be published
- A new multi-channel (x16) versatile board has been developed and is at the final stages of testing, suitable for 3D and planar timing applications
- 3 more test beam campaigns planned for 2022 with EUDET – We are open to partnerships!!
- Non-irradiated 3D studies are completed, sensors are being currently irradiated up to 1e17 with protons and neutrons
- New production planned for mid-2022, tender will be out soon and we invite ALL producer to participate

[1] G.Kramberger et al., "Timing performance of small cell 3D silicon detectors" https://arxiv.org/abs/1901.02538
[2] Gkougkousis E. - L., "Single cell 3D timing: Time resolution assessment and Landau contribution evaluation via test-beam and laboratory measurement", 17th "Trento" Workshop on Advanced Silicon Radiation Detectors, https://indico.cern.ch/event/1096847/contributions/4743685/
[3] P. Ahlburg et al., "EUDAQ—a data acquisition software framework for common beam telescopes", 2020 JINST 15 P01038
[4] Beam Telescope Analysis Framework (BTA), https://github.com/SiLab-Bonn/beam_telescope_analysis

Research project: -PID2019-110378GB-I00. Studying Lepton Flavour Universality and the Nuclear Structure with the Upgraded LHCb Experiment