Imperial College London

CERN

R&D on EXPERIMENTAL TECHNOLOGIES

13th International workshop on position sensitive detectors

Oxford, 6th September 2023

# Time resolution of single pixel irradiated 3D devices up to $10^{17}$ $n_{eq}/cm^2$ at 120 GeV SPS pion beams

Evangelos –Leonidas Gkougkousis

# •3D Sensors

## Timing at Extreme Fluences

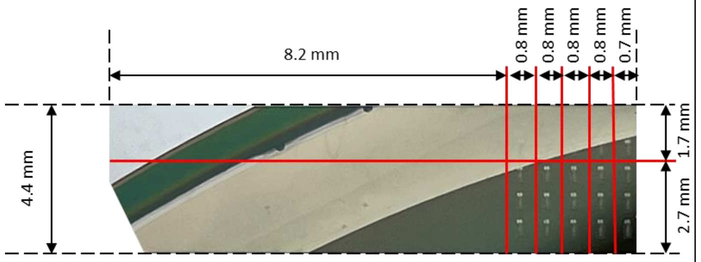
**3D Sensors:** Decoupling of charge generation and drift volume (*Standard columns, TimeSpot, Hex geometries* ect.)

**Pros**

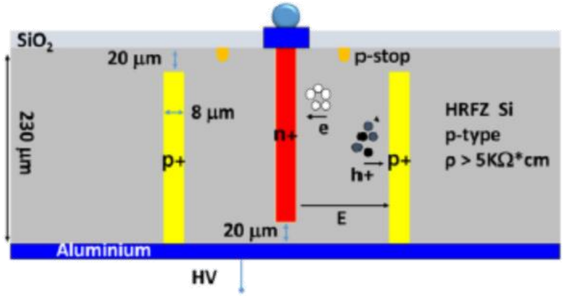
- High radiation tolerance up to several times $10^{16}$ $n_{eq}/cm^2$
- Short drift distances with fast rise times
- Reduced Landau fluctuation, practically non-existent for perpendicular tracks

**Cons**

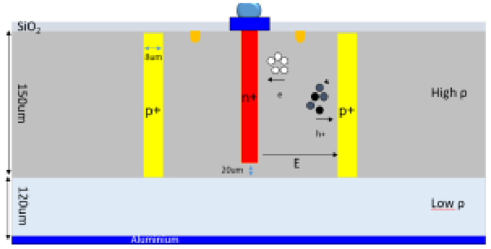
- Non-uniform field geometry
- High cost
- Increased cell capacitance




***Double Sided***
*(thicker, more expensive)*

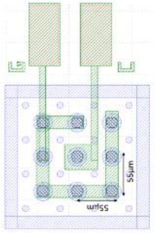



***Single Sided***
*(thinner, simpler process)*



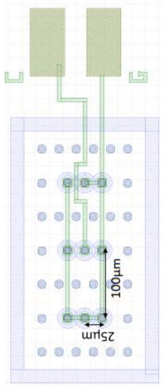

### *Pixel Size vs Field Uniformity*

*ATLAS IBL Type*

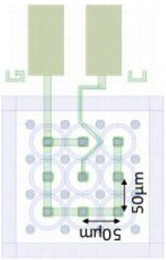



- ✓ Double sided n-on-p process
- ✓ Pixel Size 55 × 55 $\mu m^2$
- ✓ Active thickness 230 µm
- ✓ High Resistivity (> 2 kΩm × cm) Fz silicon

*ATLeS Pre-Production type*




- ✓ Single sided n-on-p process
- ✓ Pixel Size 25 × 100 $\mu m^2$
- ✓ Active thickness 150 µm
- ✓ High Resistivity (> 2 kΩm × cm) Fz silicon

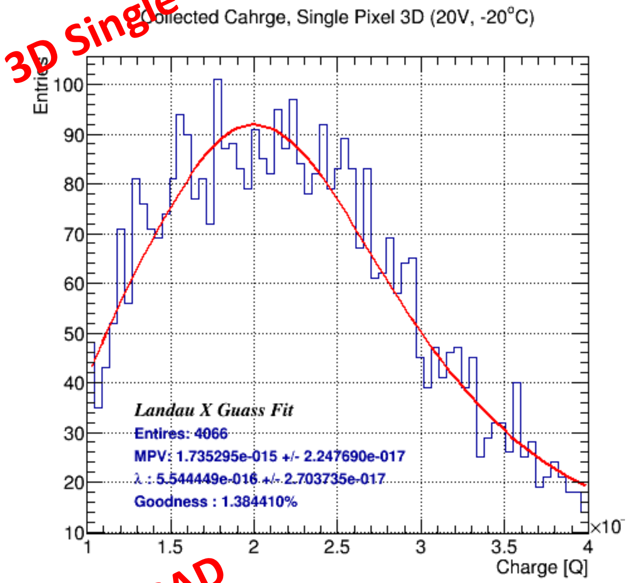


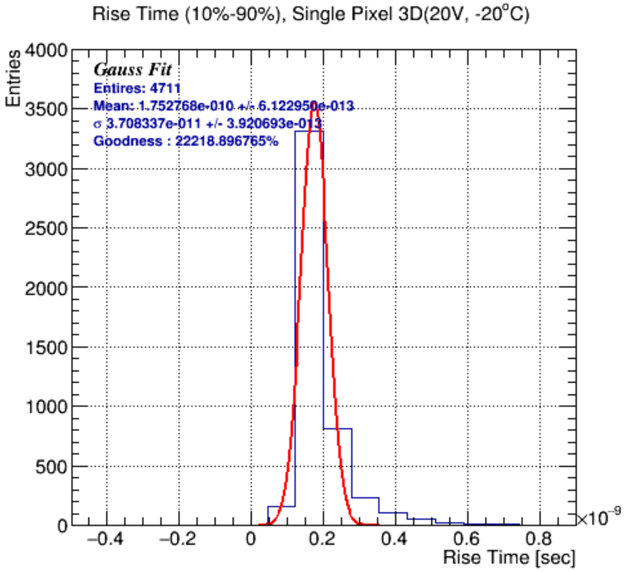

- ✓ Single sided n-on-p process
- ✓ Pixel Size 50 × 50 $\mu m^2$
- ✓ Active thickness 150 µm
- ✓ High Resistivity (> 2 kΩm × cm) Fz silicon

# •3D Sensors - Timing

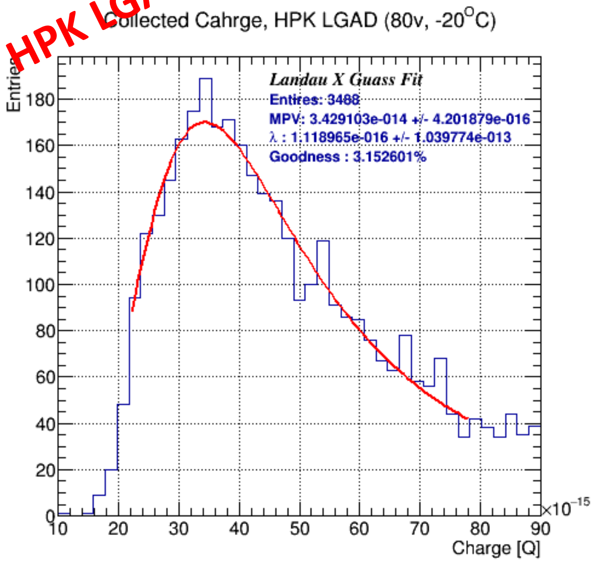
**V. Gkougkousis,** 17th Trento workshop on advanced radiation silicon detectors
"Single cell 3D timing: Time resolution assessment and Landau contribution evaluation via test-beam and laboratory measurements"

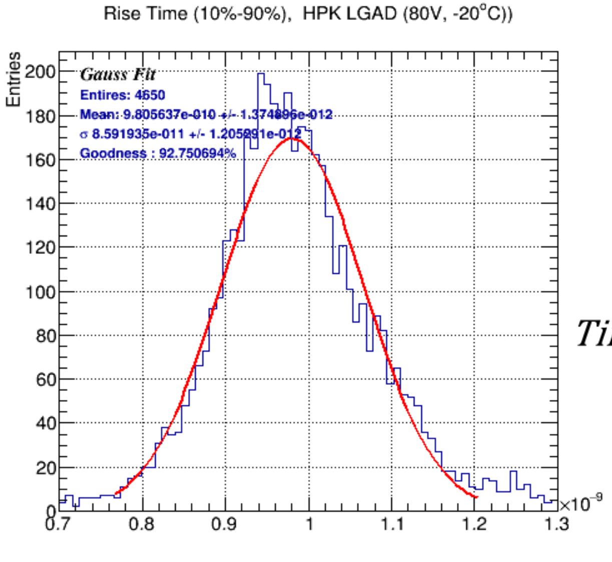
3D Single Cell




HPK LGAD

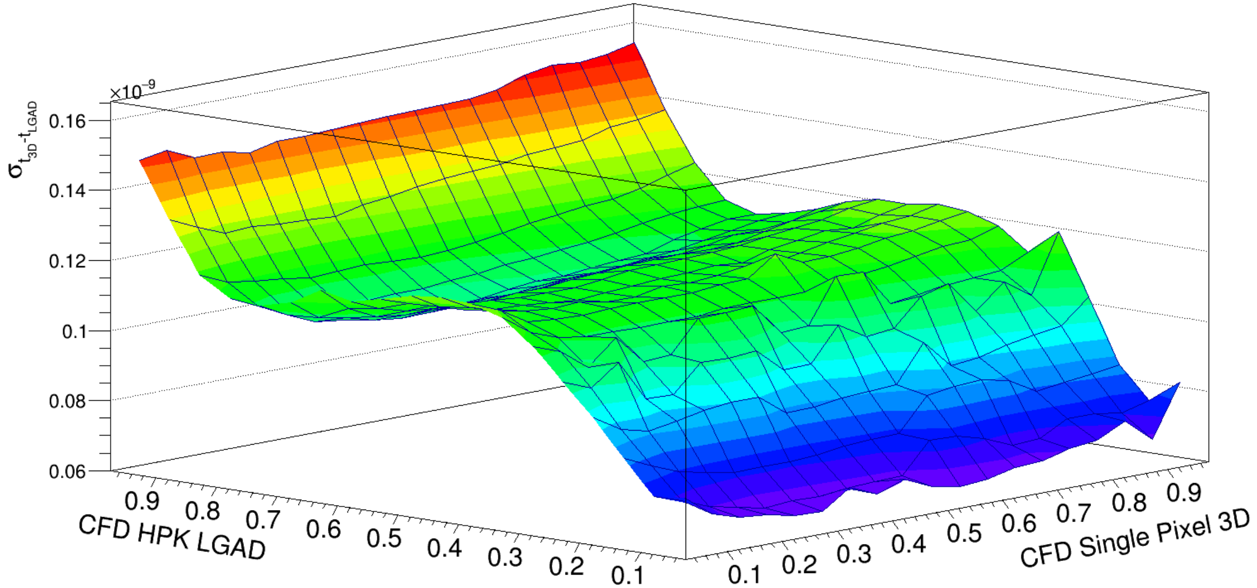



- **Extremely fast rising edge (< 180 psec)**
- **Linear stable behavior with CFD, good SNR control**

$$(\sigma_{\text{Dut}})_{CFD_{ij}} = \sqrt{(\sigma^2_{\text{Tot}})_{CFD_{ij}} - (\sigma^2_{\text{Ref}})_{CFD_i}}$$

CFD Map, LGAD - Single Pixel 3D (-20°C, 20V)




2D optimization plot – 0.5% binning

*Time Resolution:* $\sigma^2_{tot} = \underbrace{\sigma^2_{timewalk}}_{\sigma^2_{Dist.} + \sigma^2_{Landau}} + \underbrace{\sigma^2_{jitter}}_{\left(\frac{t_{rise}}{S/N}\right)^2} + \underbrace{\sigma^2_{conversion}}_{\left(\frac{TDC_{bin}}{\sqrt{12}}\right)^2} + \underbrace{\sigma^2_{Clock}}_{\text{Fixed Term} \sim 5\text{-}7\ psec}$

# •3D Sensors – Signal Integrity

- Frequency of radioactive decay events follows Poisson law
- Record trigger time and convert to event frequency

***Poisson Distribution:*** $f(n) = \mu^{n} * \frac{e^{-\mu}}{n!}$

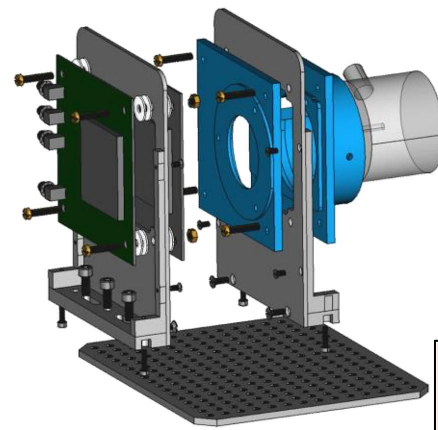
**Variable change**: $n' = n * C$, $\mu = B/C$

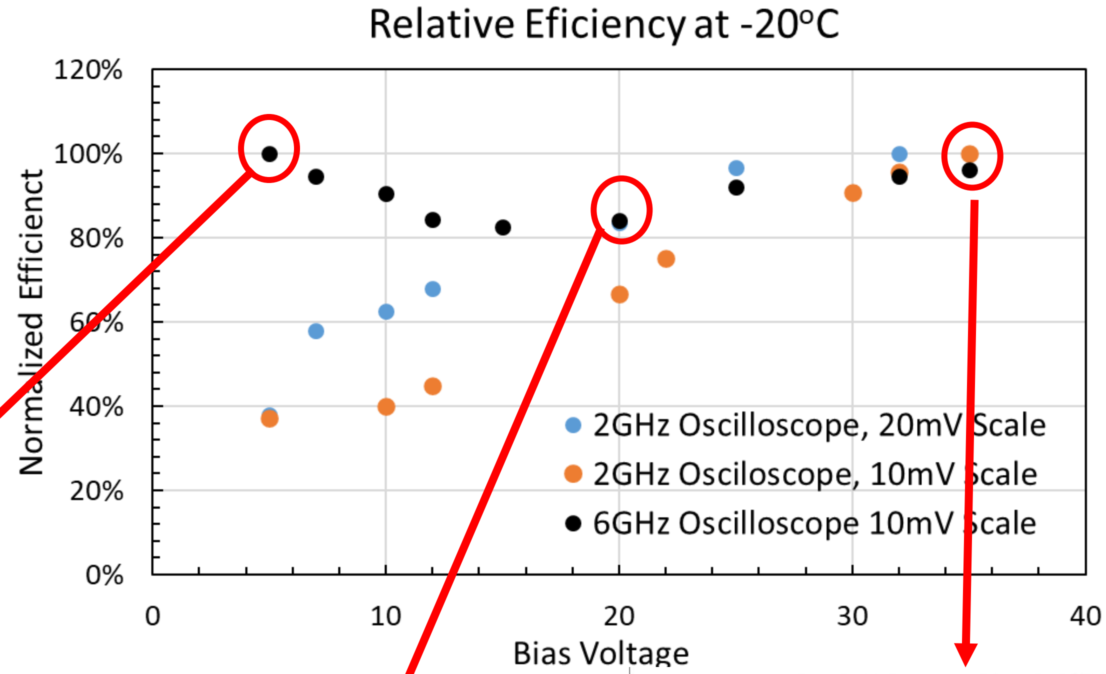
$f(n') = A * \left(\frac{n'}{C}\right)^{B/C} * \frac{e^{-B/C}}{\Gamma\left(\frac{n'}{C}+1\right)}$

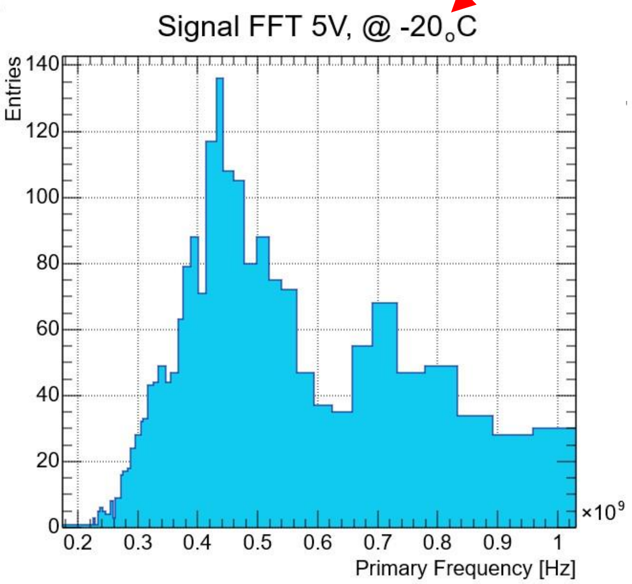
*Where:* $n$ number of events in interval, $\mu$ *mean*, $f(n)$ *frequency*

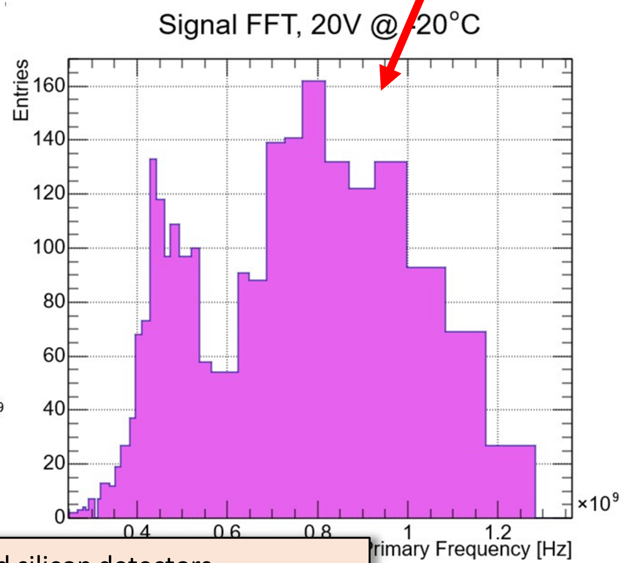
*Where:* $A$ Normalization parameter, $B/C$ *mean*, $f(n')$ *Scaled frequency*

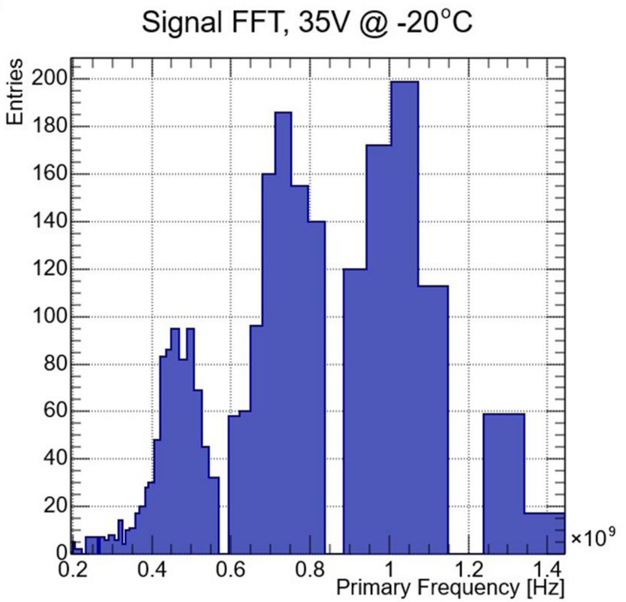
- Efficiency dependent on bandwidth
- Signal distribution in the Fourier domain highly depends on bias
- Minimum time over threshold effect for trigger latching of instrument affect efficiency





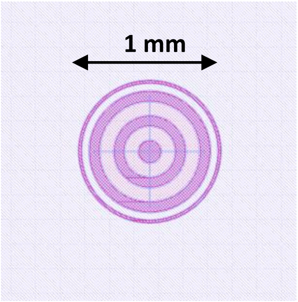



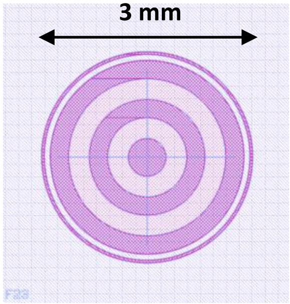

**V. Gkougkousis,** 35th RD50 workshop on radiation hard silicon detectors
"Efficiency estimation on irradiated LGAD with respect to sensor stability"

# •Planar Sensors

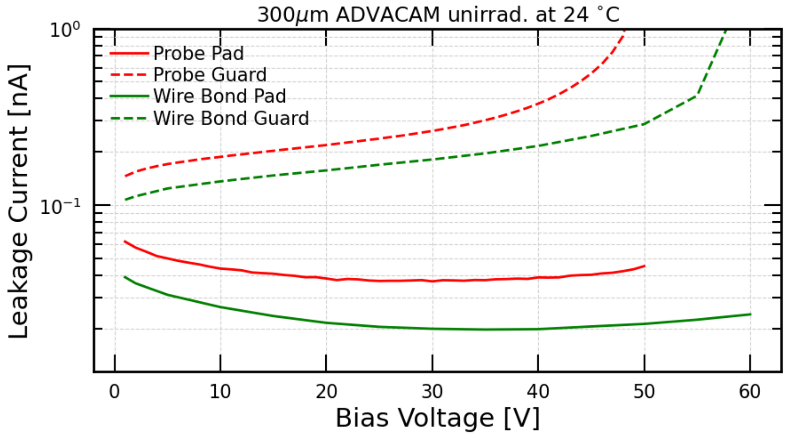
**Sensors:** CERN EP-R&D n-on-p planar sensor run with ADVACAM at 50, 100, 200 and 300 μm active thickness

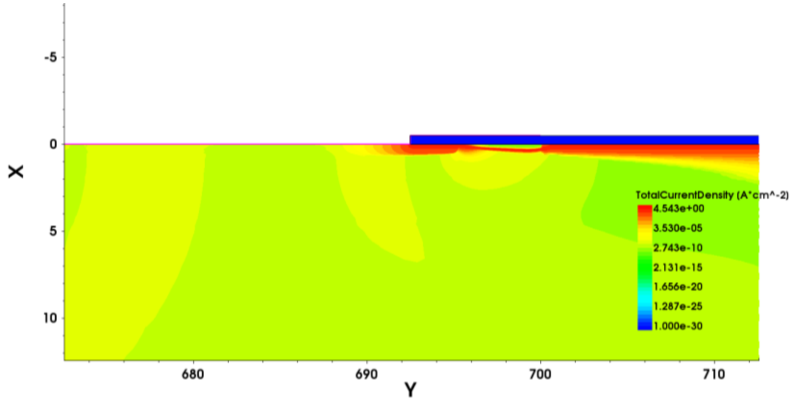


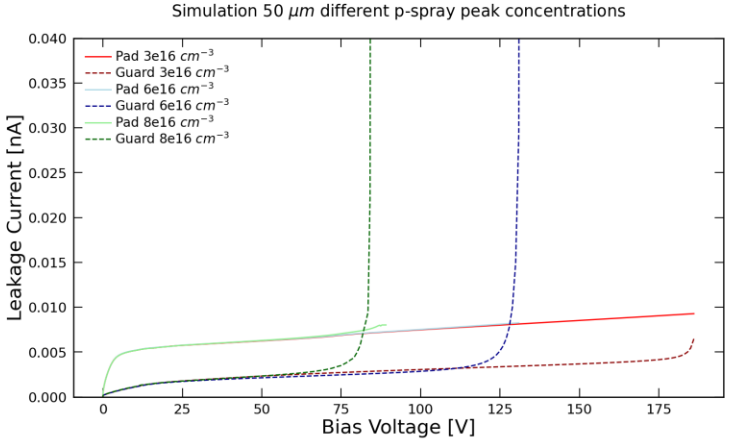
Small Diode



Big Diode




## Test Structures

- Small diodes (3.14 mm2 active area) Circular diodes for timing studies due to lower capacitance
- Big diodes (28.27 mm2 active area) Circular diodes for radiation damage studies
- 5x5 Pixel matrix (0.003 mm2 active area) for charge sharing and interpixel efficiency – timing studies

## Issues

- Early breakdown due to high p-spray concentration leading to impact ionisation at the interface between p-spray and electrode implant
- Breakdown first visible in guard ring due to bigger interface region compared to pad

*Irradiations*

**(both 3D and planar)**

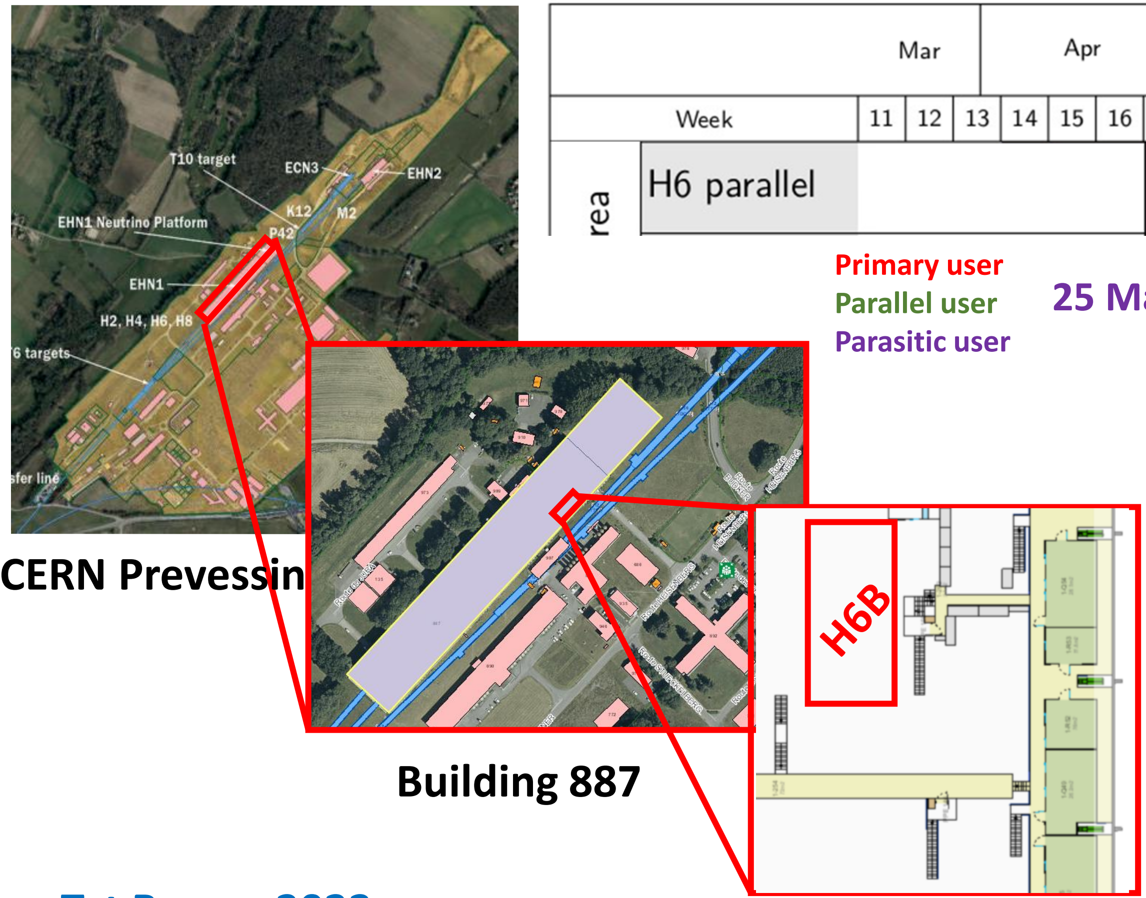
**Neutron** @ JSI (Ljubljana)

- ✓ $1 \times 10^{15}\ n_{eq}/cm^2$
- ✓ $8 \times 10^{15}\ n_{eq}/cm^2$
- ✓ $6 \times 10^{16}\ n_{eq}/cm^2$
- ✓ $1 \times 10^{17}\ n_{eq}/cm^2$

**Proton** @ PS

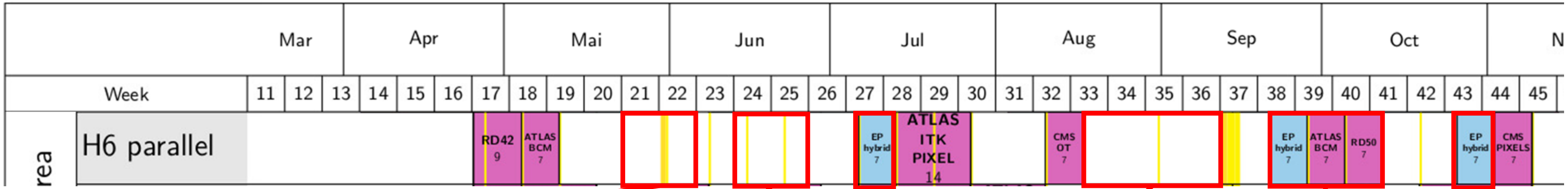
- ✓ $1 \times 10^{15}\ n_{eq}/cm^2$
- ✓ $8 \times 10^{15}\ n_{eq}/cm^2$
- ✓ $6 \times 10^{16}\ n_{eq}/cm^2$
- ✓ $1 \times 10^{17}\ n_{eq}/cm^2$

# •Part I - Test Beams




CERN Prevessin

Building 887




Primary user
Parallel user
Parasitic user

25 May – 8 June

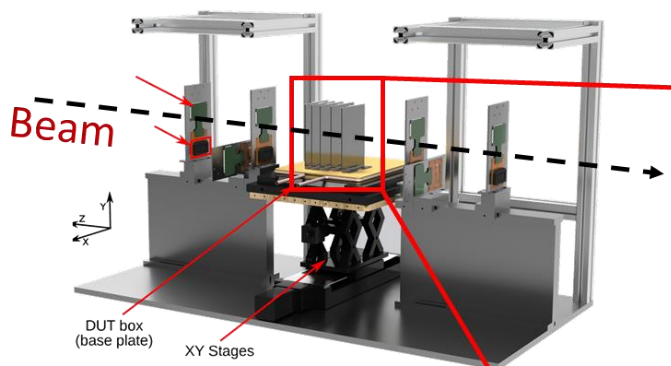
15 – 29 June

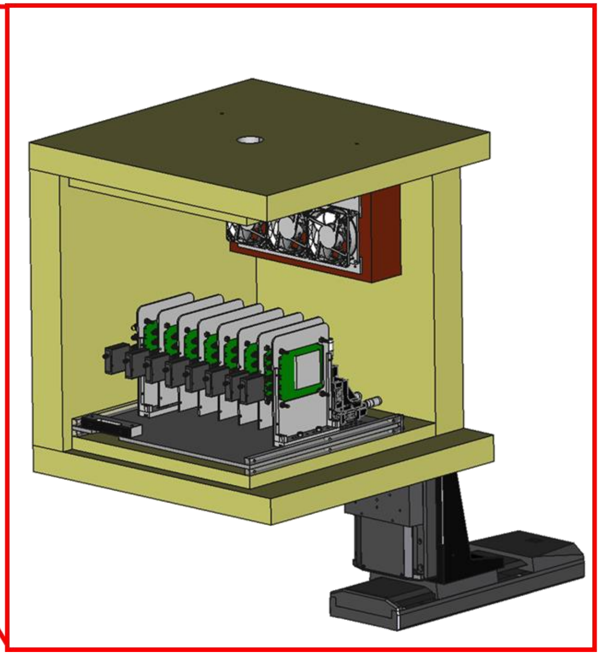
6 July – 13 July

17 August - 14 September

21 September - 12 October

26 October – 2 November



## Tet Beams 2022

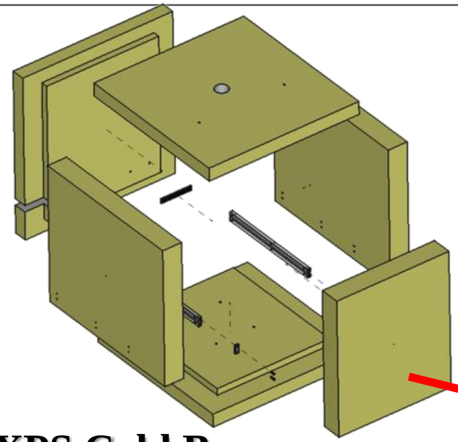
- Several periods but only two as primary user
- Main target irradiated Planar / 3D sensors
- No / Limited possibility of extension
- Extensive infrastructure developments

## The Setup

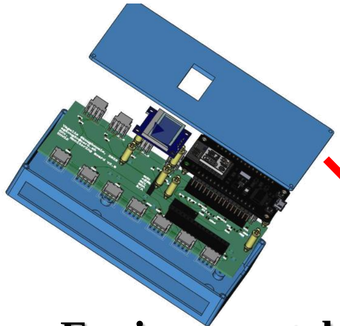
- AIDA Telescope
- Custom Cold Box
- DUTs on individual motorized individual stages
- Pixelated alignment & ROI plane

# •Setup @ SPS

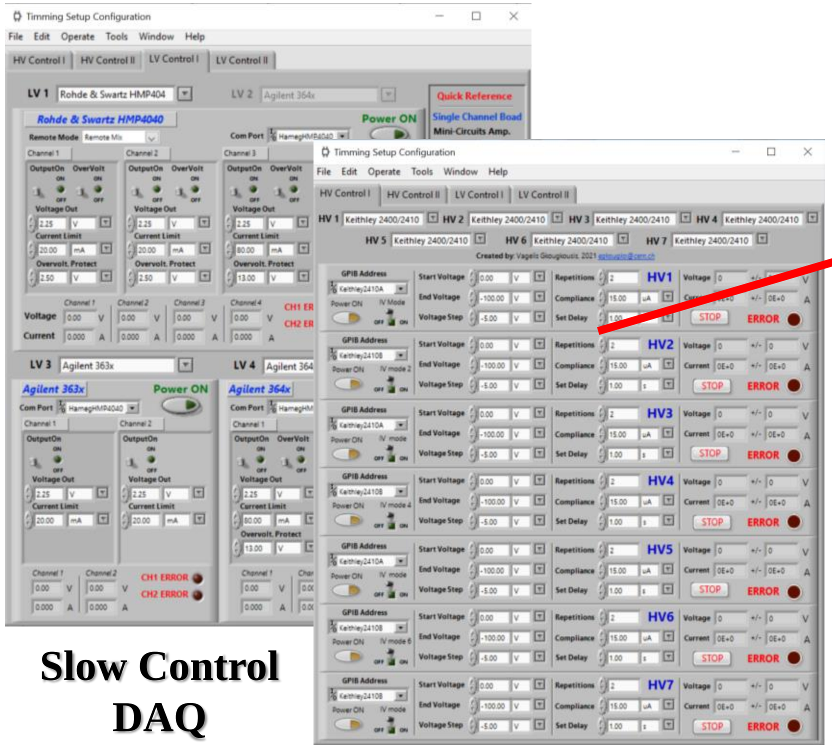
**V. Gkougkousis,** 10th Beam Telescopes and Test Beams Workshop
"[Tracking the time: Single pixel 50μm pitch 3D cell time resolution map]"



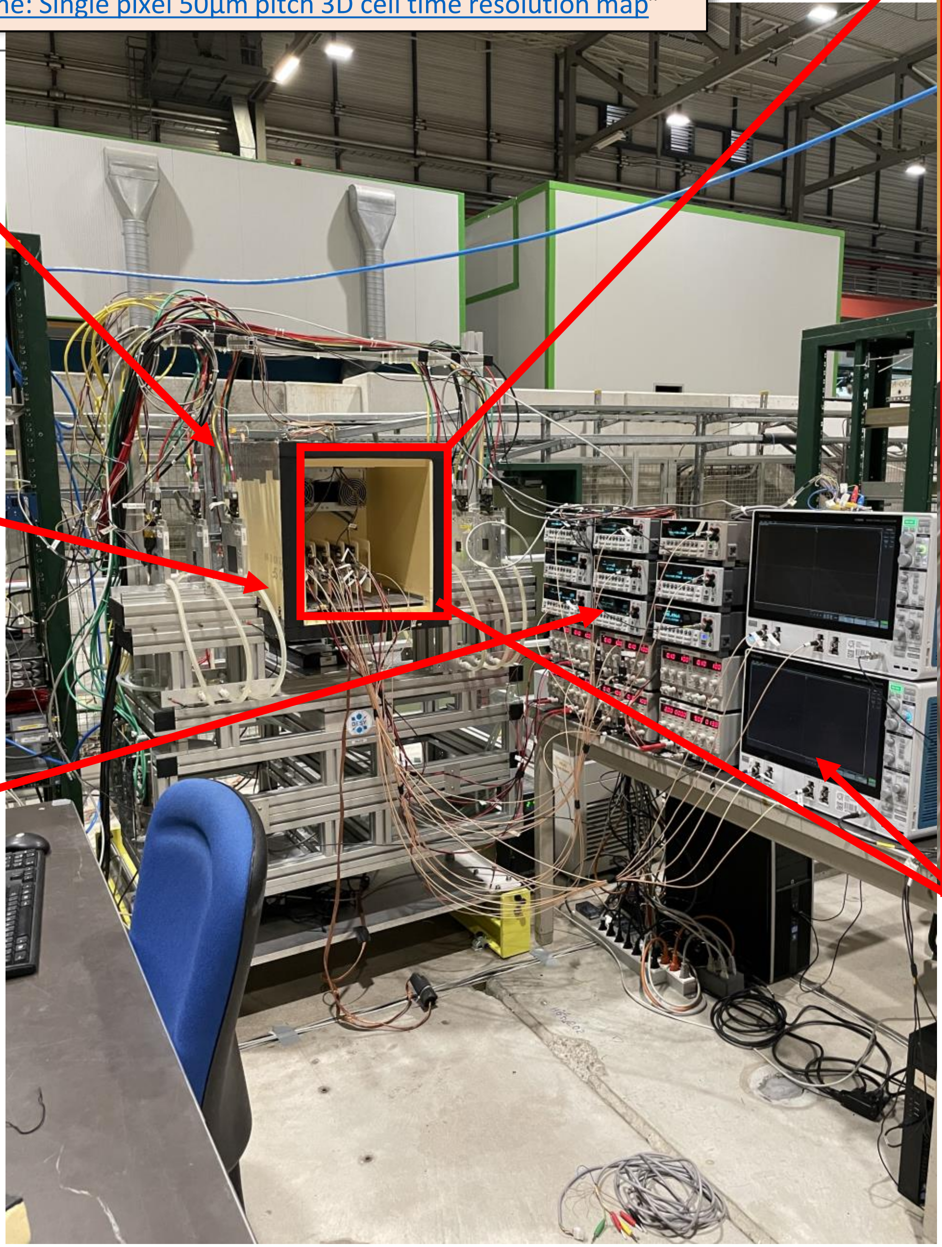
**XPS Cold Box**

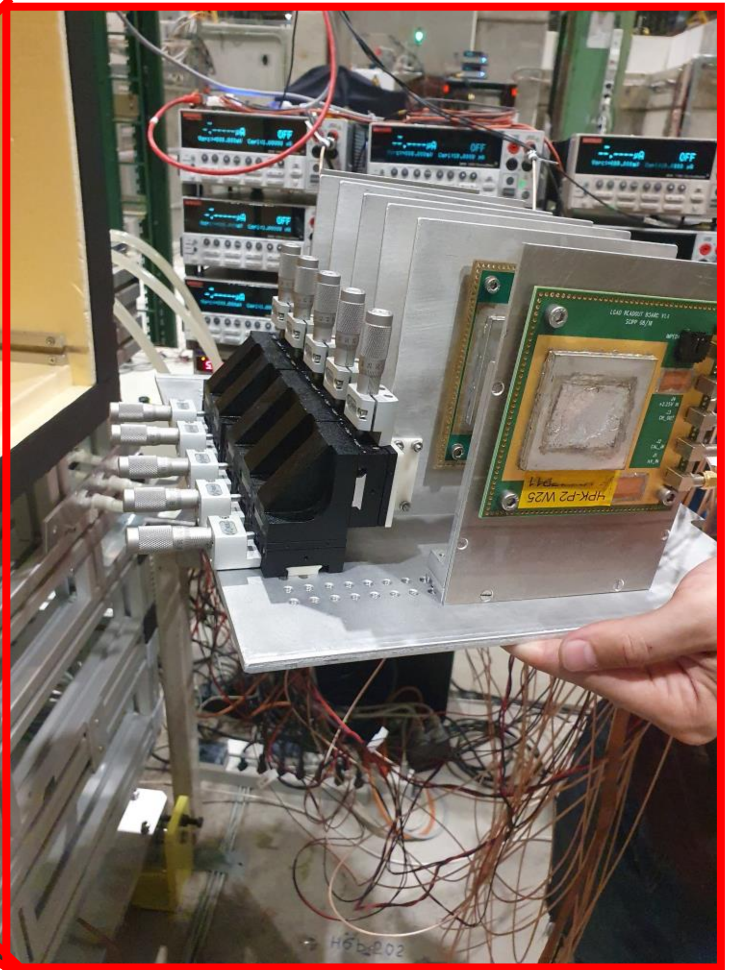


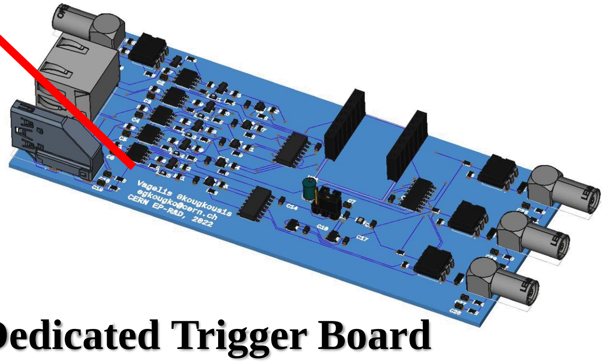
**Environmental Control**




**Slow Control DAQ**



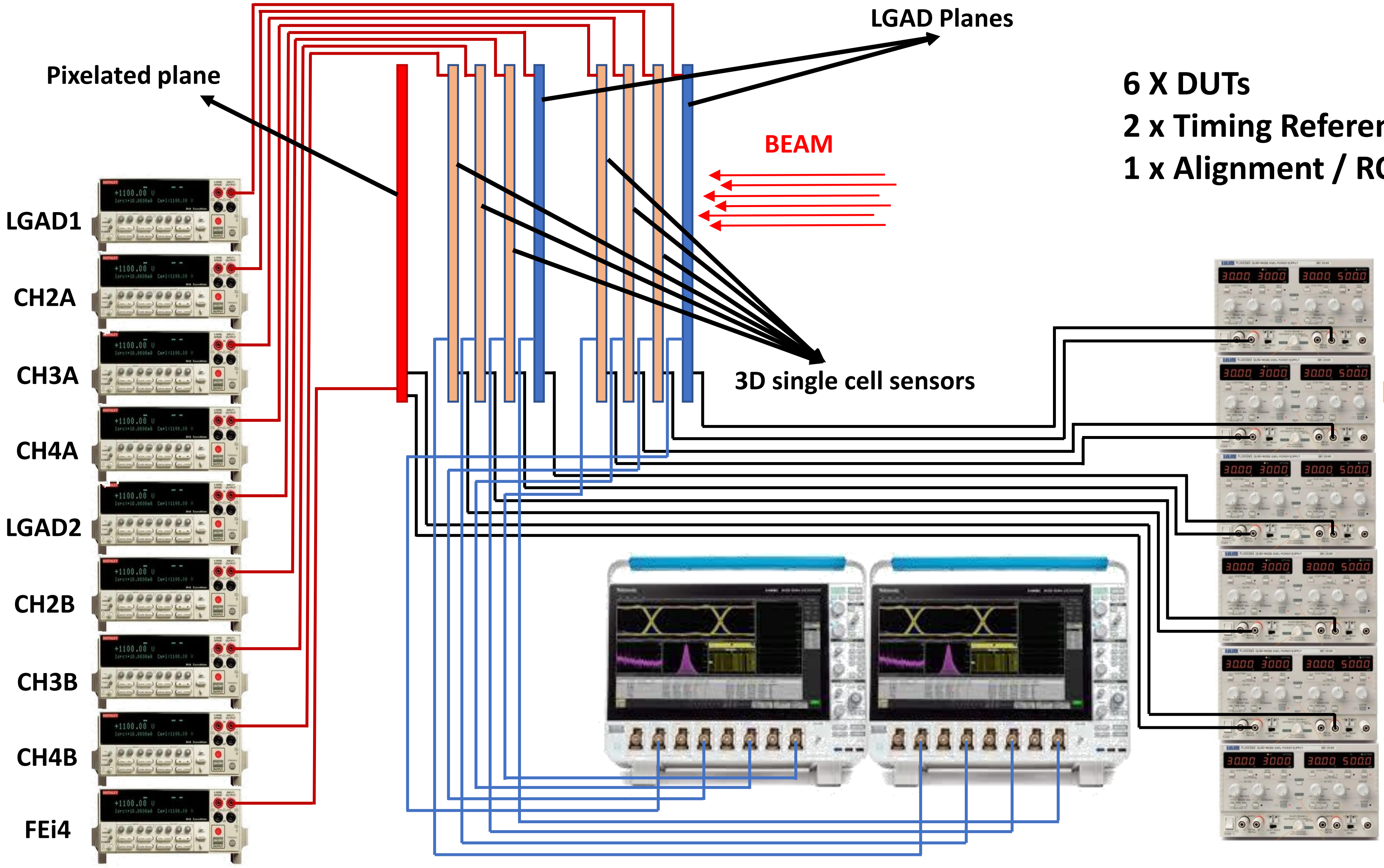




**Dedicated Trigger Board**

# •Test Beam Configuration

**V. Gkougkousis,** 40th RD50 Workshop on Radiation hard semiconductor devices for very high luminosity colliders
"Time resolution of single cell 3D devices on SPS pion beams"



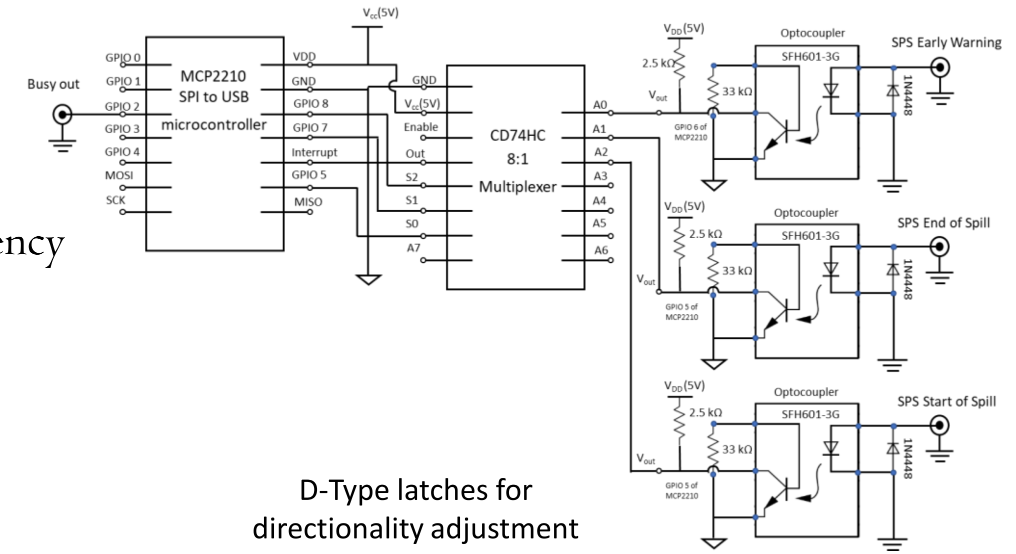

**6 X DUTs**
**2 x Timing References (HPK LGADs)**
**1 x Alignment / ROI matrix (FEi4B planar)**

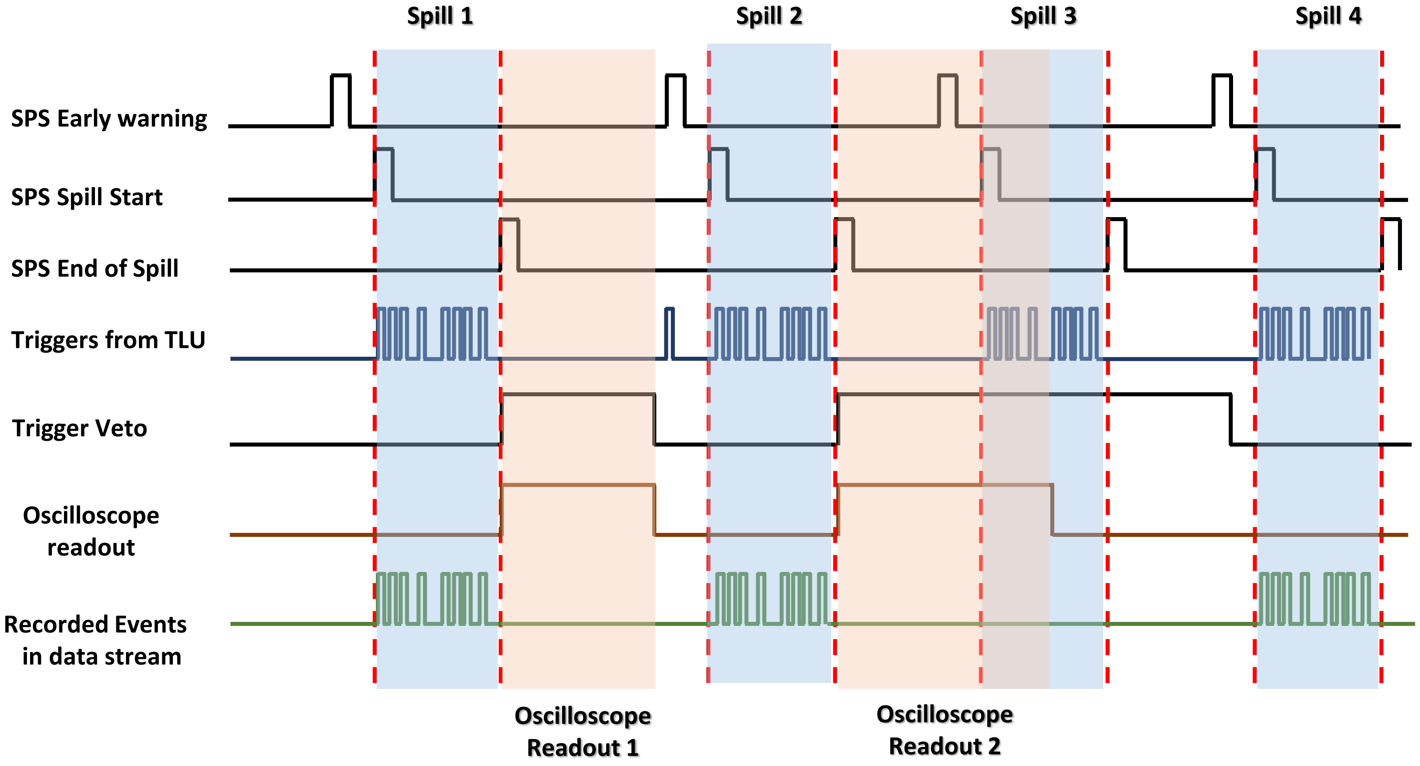
## Equipment List

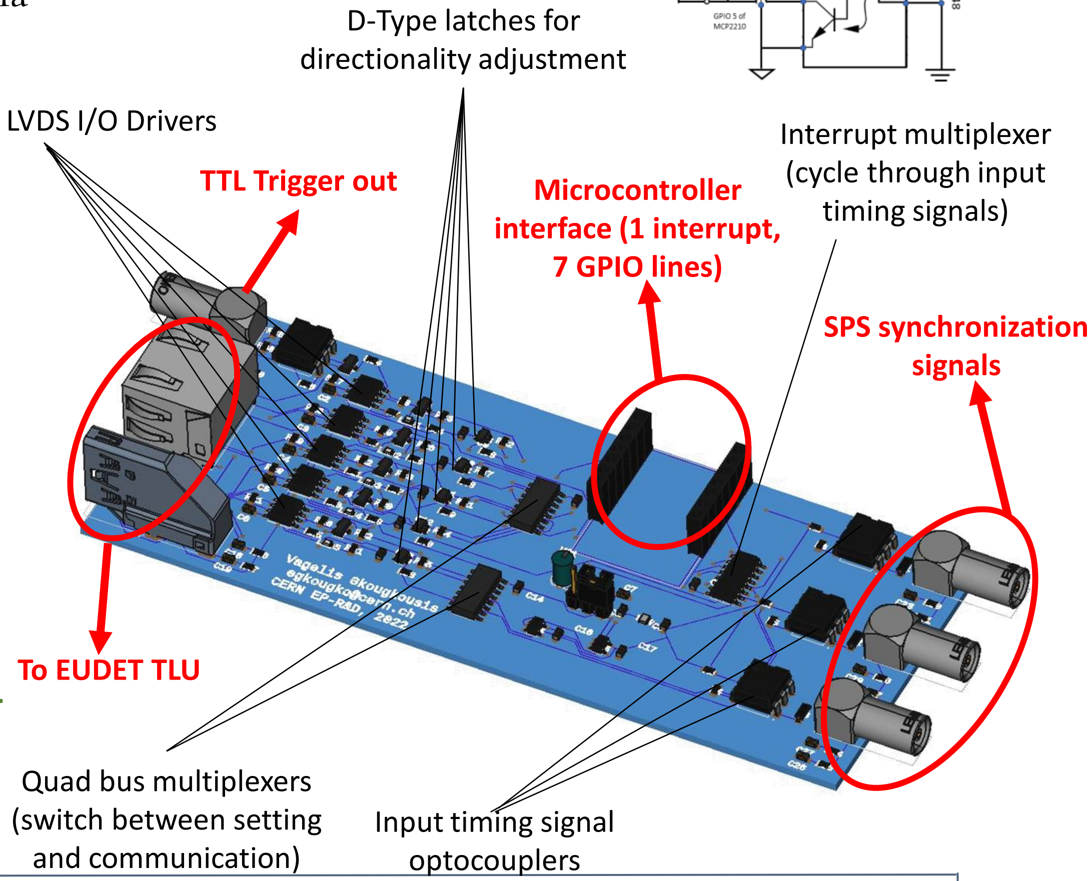
- 2 x Oscilloscopes
- 9 x Keithley 2410
- 6 x TTi PL303
- 8 Second stage amplifiers
- 6 micro-positioning stages
- Humidity – Temperature monitoring system (EnViE)
- Cold Box for -20°C operation
- Trigger Interface Board V2.0
- SMA Cables

# •Trigger Interface Board (TiB)

- Oscilloscope in fast readout mode with binary format
- Event readout only between SPS-spills or when event buffer full ti increase efficiency
- TLU Synchronization by vetoing data taking during read-out
- RJ-45 or HDMI for EUDET TLU communication (EUDET 2 compatible)
- **Versatile design**, I/Os **Reconfigurable** and microcontroller **Reprogrammable** via USB

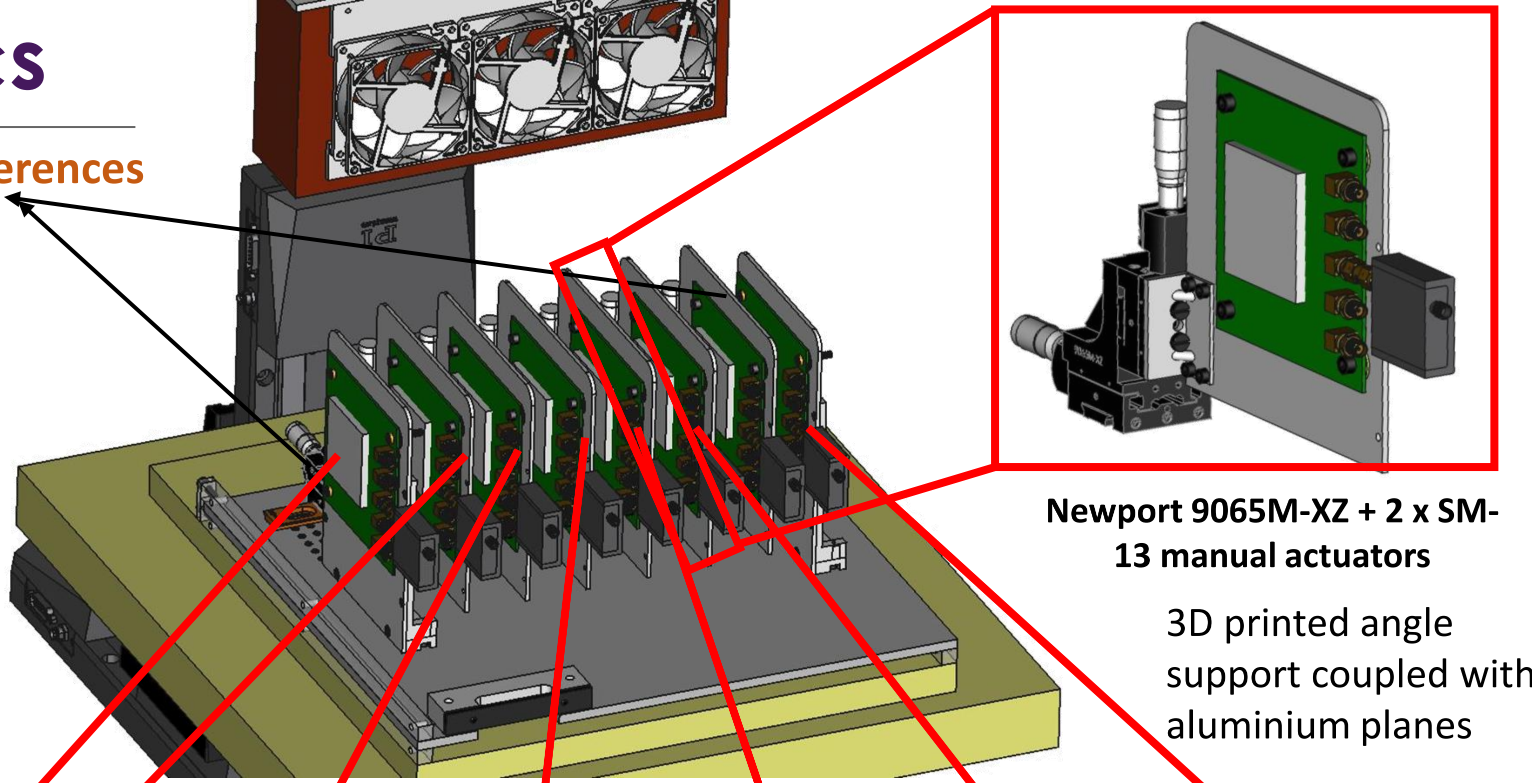


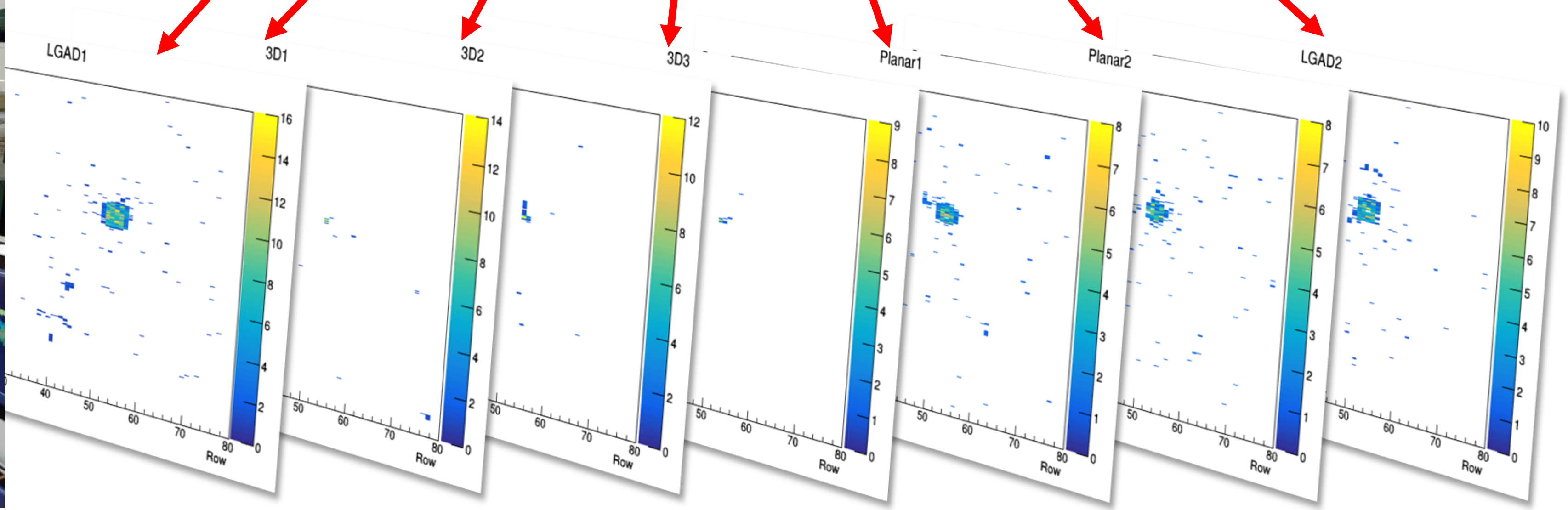



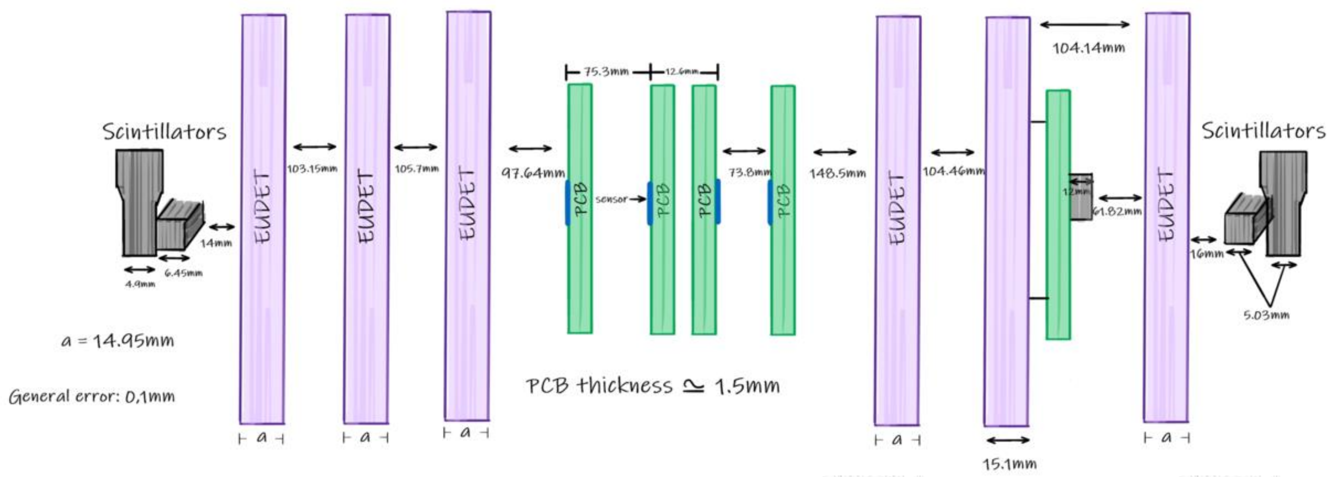
# •Alignment & Mechanics

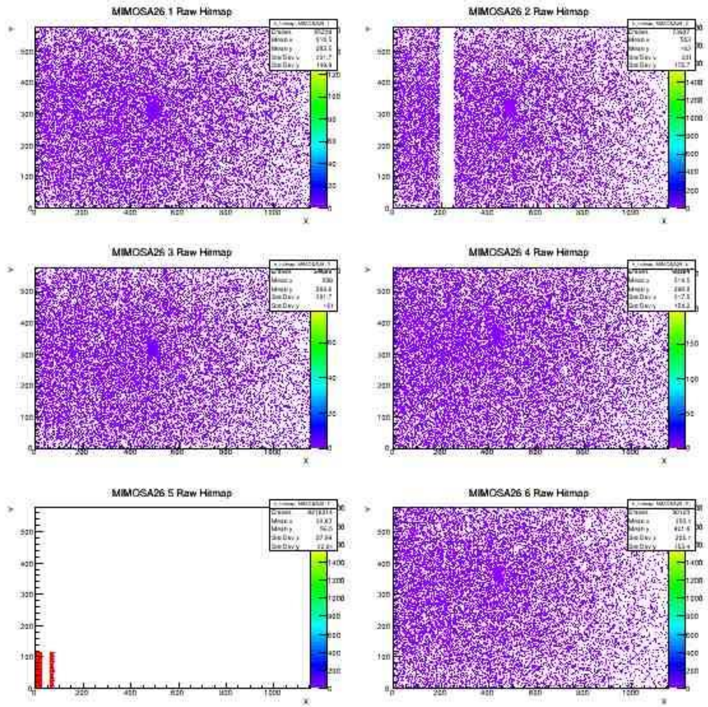
- Coincidences between DUTs and LGADs required for timing
- Alignment crucial to increase data efficiency
- Efficiency defined by largest overlapping region
- Micrometric on-line alignment using projections on FEi4 matrix
- ROI defined in addition to other trigger conditions

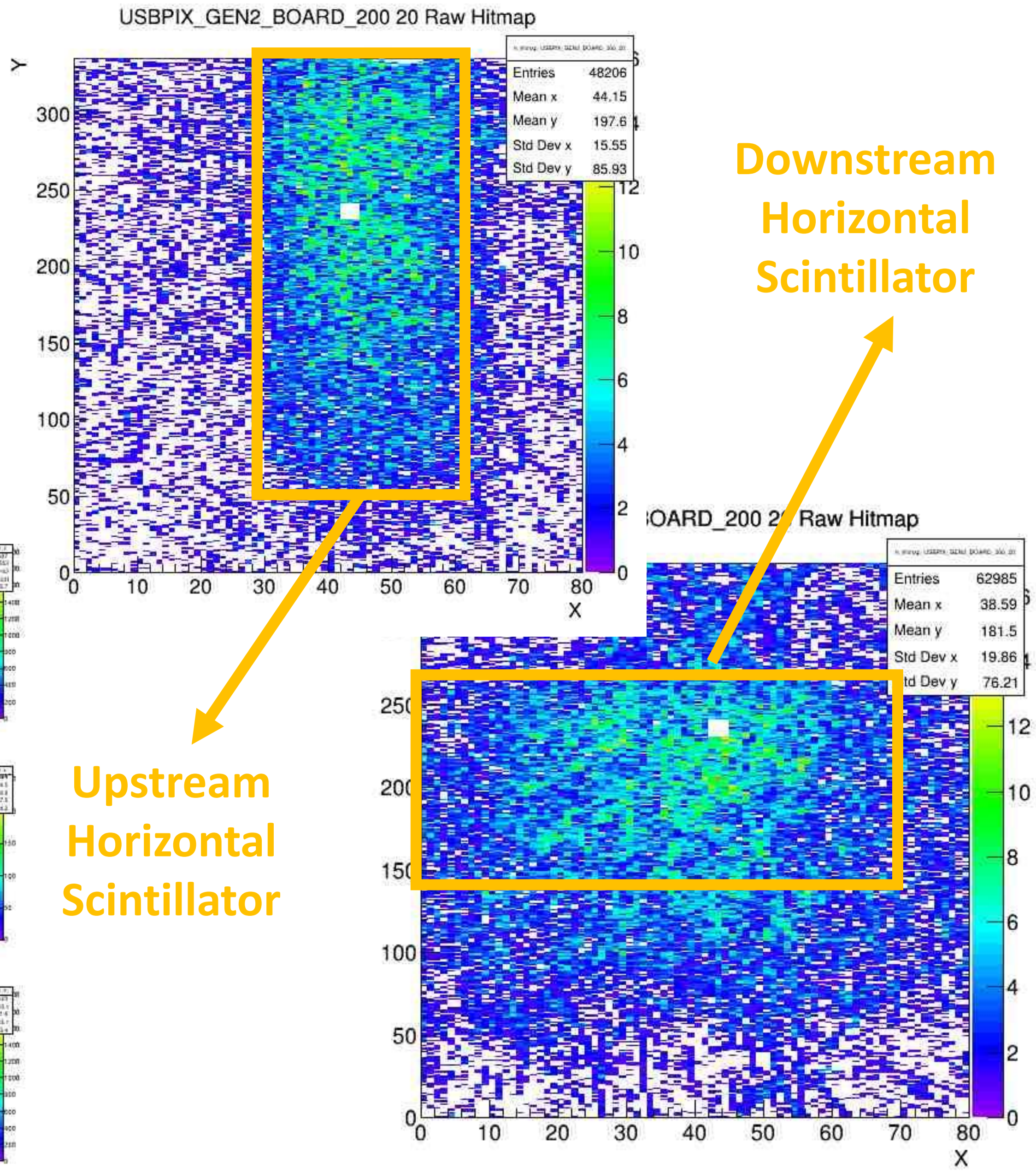


# •Tracking and ROI




## Telescope Planes

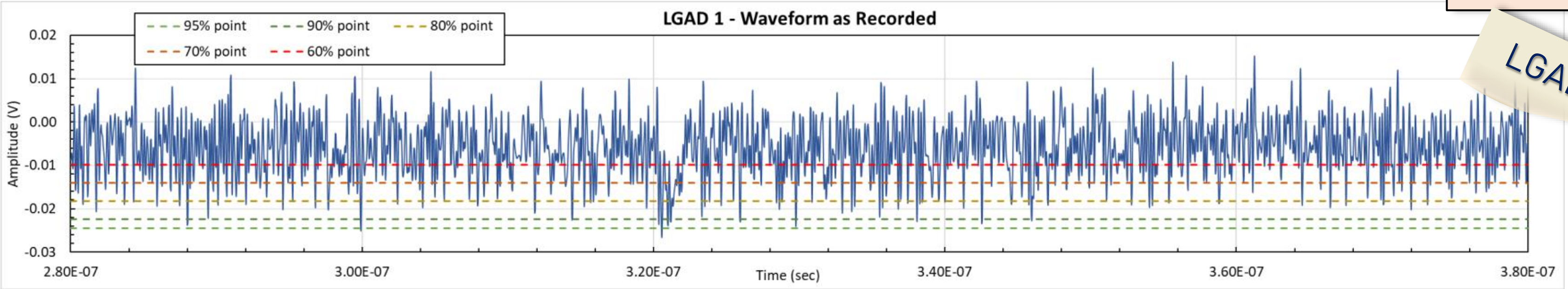
- **6 MIMOSA planes for tracking**
- **Plane no. 5 known to be bad**
- **Expected 5μm tracking resolution**
- **Estimated acquired number of events ~1M**

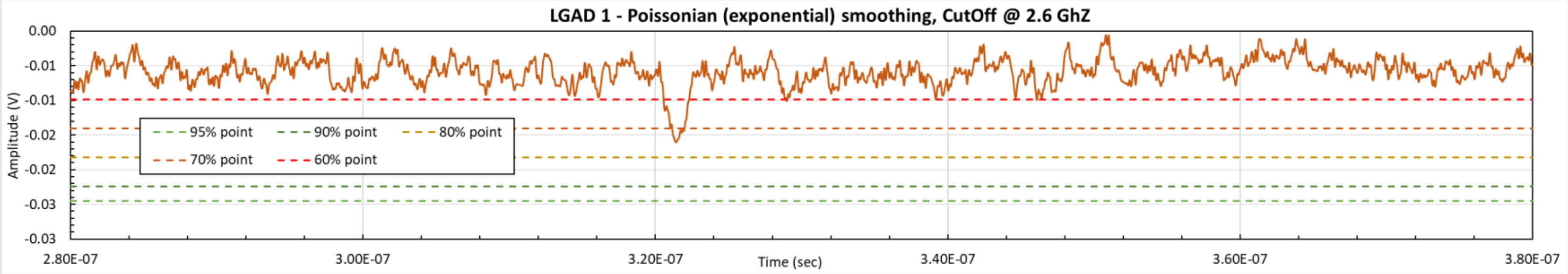
- Limited beam control as parasitic user
- Suffer from low intensity and low data rates of EUDAQ

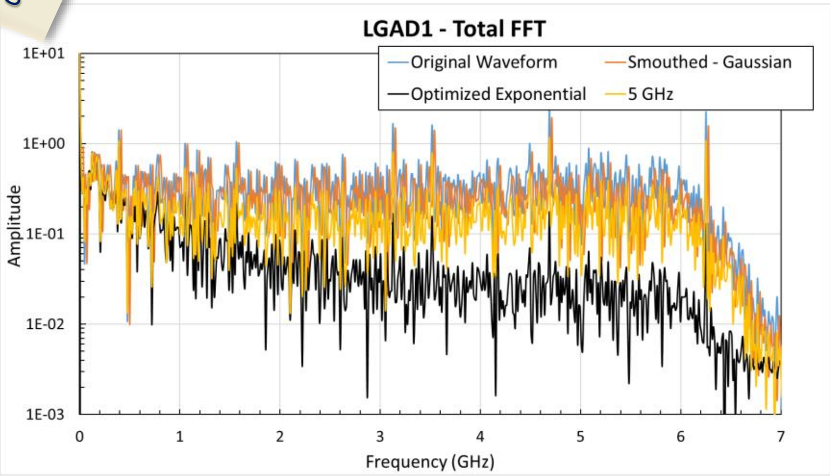
# •The importance of bandwidth

**V. Gkougkousis,** Ultrafast imaging and tracking Instrumentation, Methods and Applications Conference - ULITIMA 2023
"Radiation damage effects overview on Low Gain Avalanche Diodes"

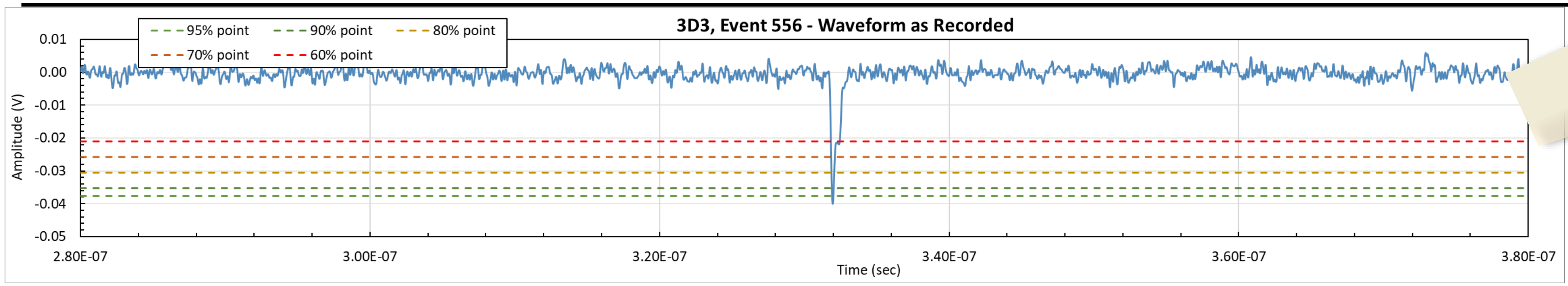
LGADs

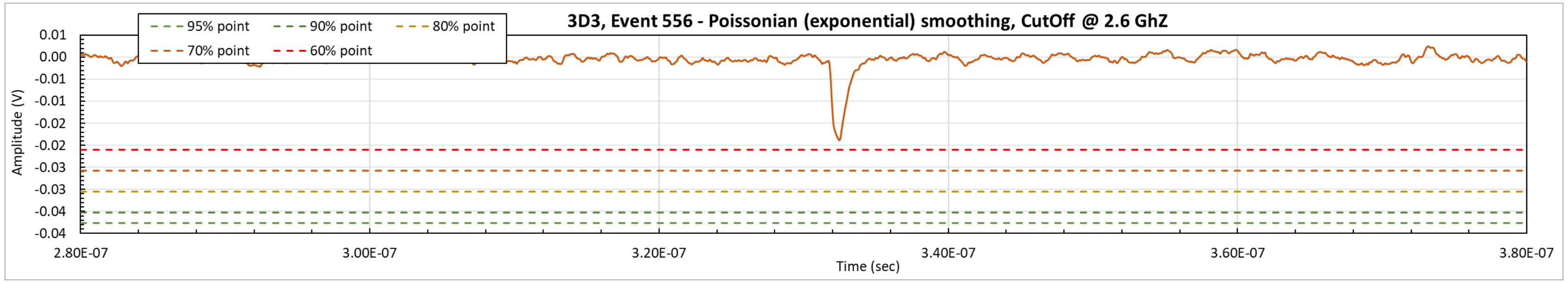


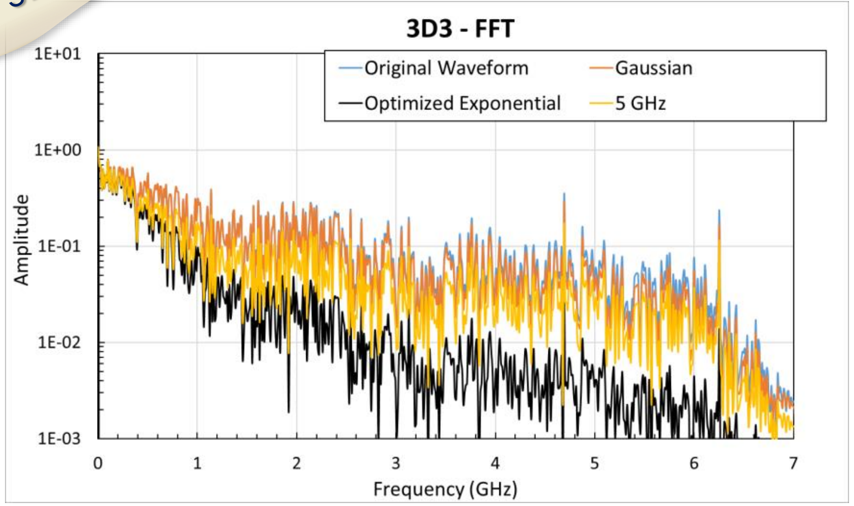



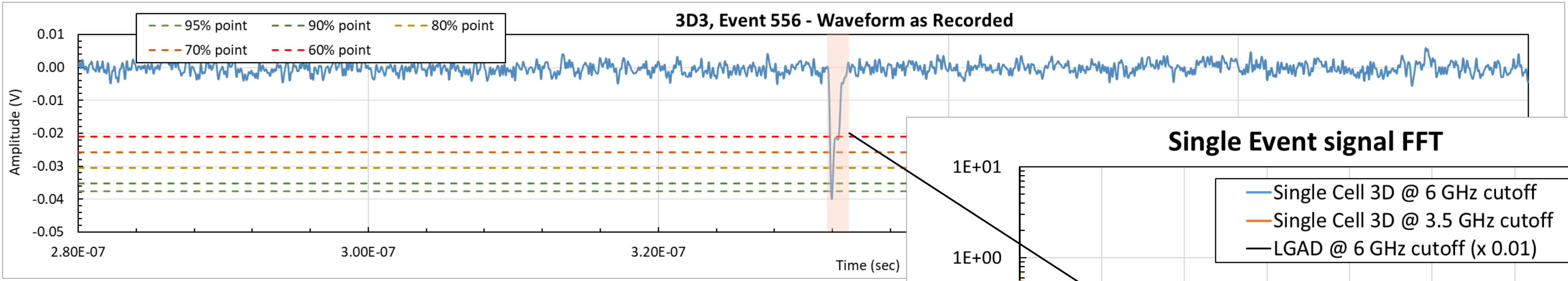

3Ds

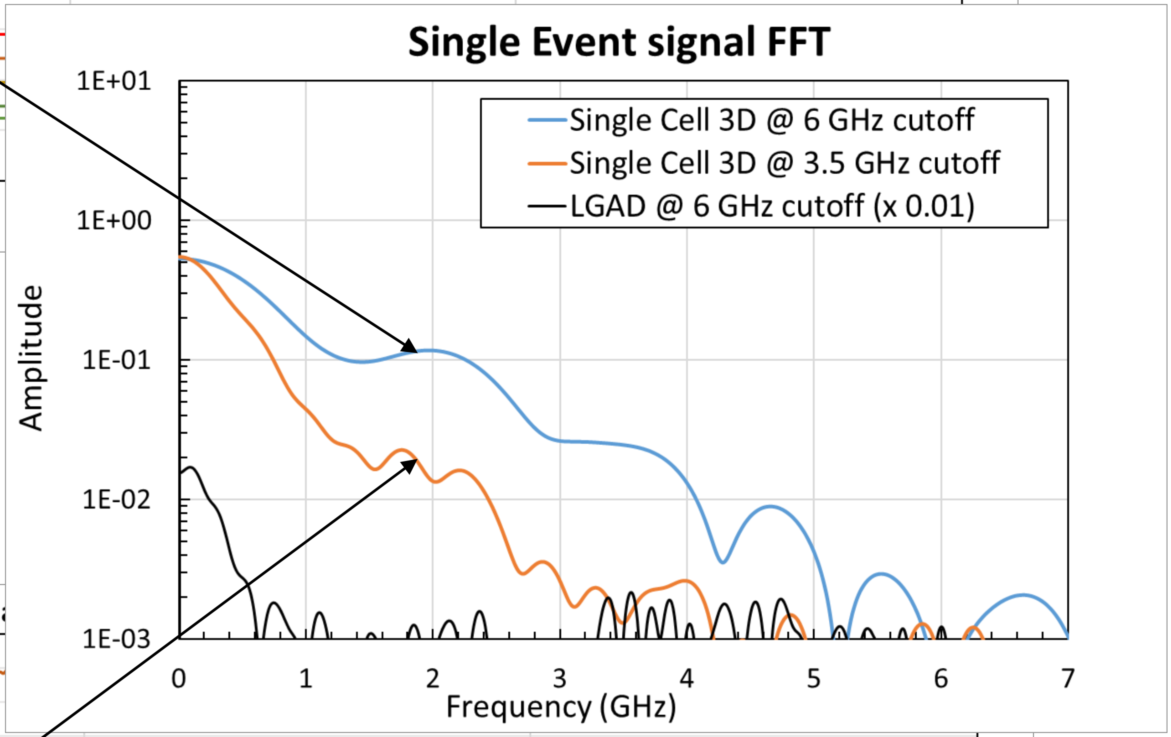


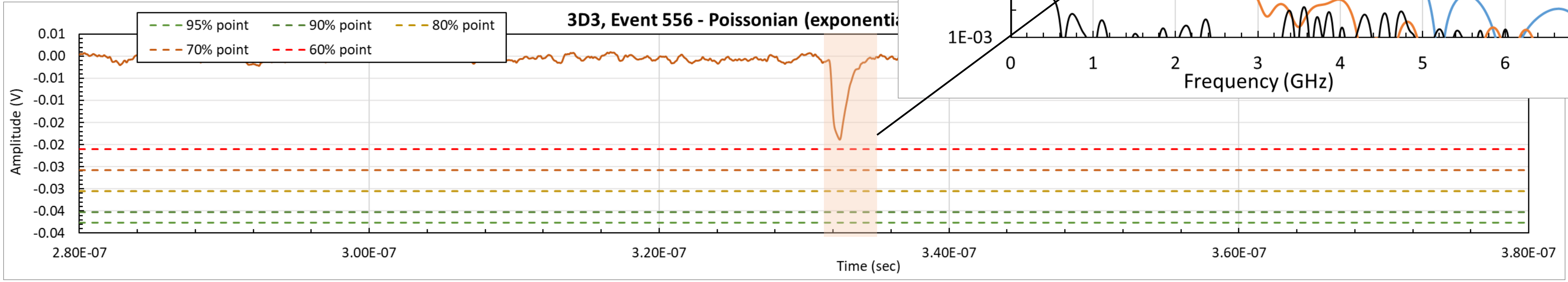



# •The importance of bandwidth




- **60 % less amplitude**
- **20 % more charge**
- **If bandwidth not correct, we are probing electronics transfer function**



# •Event by Event Strategy

File: WaveForm.cxx

- A four sequential step analysis approach
- Analysis escalates in a pyramid structure

Five preliminary sequential steps before we even start looking at the waveform

**Step 1**

Set Waveform values → Determine polarity → Find max, min point → Find start, stop point → Determine if noise → Determine if pulse within window

**Step 2**

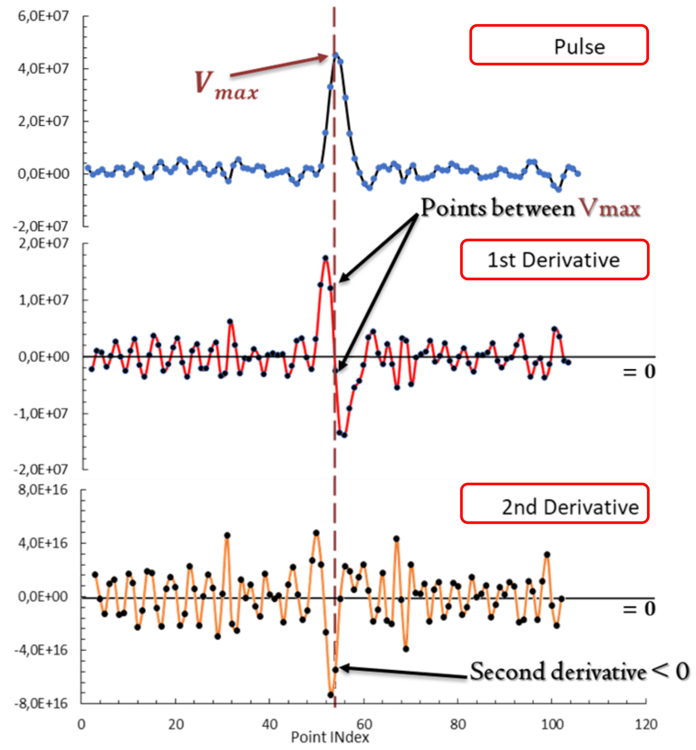
Define noise points → Use Gaussian fit for noise/Pedestal → Pedestal subtraction/ inversion → Recalculate start, stop points, min, max

**Step 3**

Compute charge → Determine rise time → Determine CFD Time → Compute dV/dT → Determine Trigger Time → Estimate Trigger & CFD ToT

**Step 4**

Perform CFD time to voltage Correction (Time Walk) → Signal FFT → Noise FFT




- If $SD_{maxima} > SD_{minima}$
  $D_m(max) > D_m(min)$
  
  or $SD_{maxima} < 1.05*SD_{minima}$
  $D_m(max) > D_m(min)$

Positive polarity

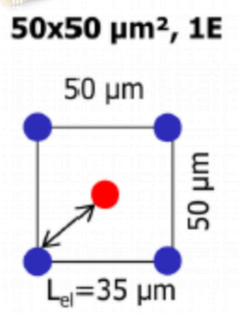
IsNoise Algorithm

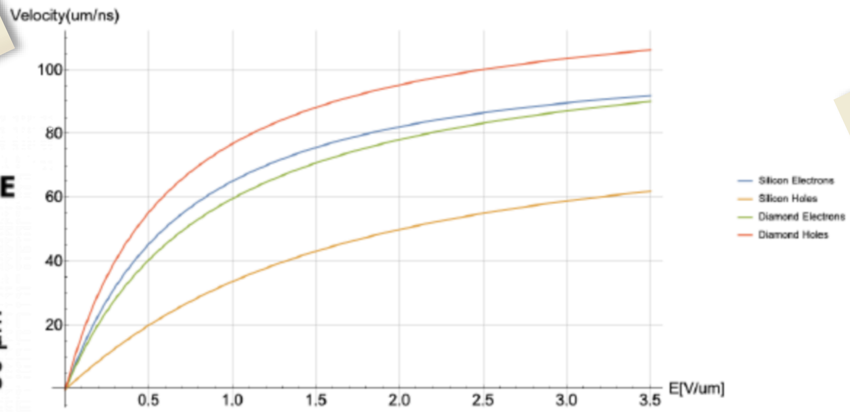
Number of points with $0.8 \bullet V_{max}$

- If $N_{points} > 2$ test 0.7 , 0.6 & $0.5 \bullet V_{max}$ to account for wavy waveforms
- If $N_{points} > 2$ then require $dN_{points} < 8/12/16/20$

# •16 Channel Board

The issue....




- Assuming a linear filed dependence and a -15 V operation point at 35 µm column distance:

$$|E| \cong 0.43\ V/\mu m$$

- Estimating drift velocity for electrons:

$$v^{e}_{drift} = \frac{\mu_{0,e} \times E}{\left[1 + \left(\frac{\mu_{0,e} \times E}{v^{e}_{sat.}}\right)^{\beta_e}\right]^{1/\beta_e}}$$

with $v^{e}_{sat.} = 107\ \mu m/ns, \mu_{0,e} = 1417 \frac{cm^2}{Vs}, \beta_e = 1.109$

$$\boldsymbol{v^{e}_{drift} \approx 41.4\ \mu m/ns}$$

- Extrapolated Rise time and Frequency:

$$t_{Rise} \approx \frac{1}{3} \times t_s = \frac{1}{3} \times \frac{d/2}{v^{e}_{drift}} \approx 140\ psec \Rightarrow \boxed{\mathbf{2.3\ GHz}}$$

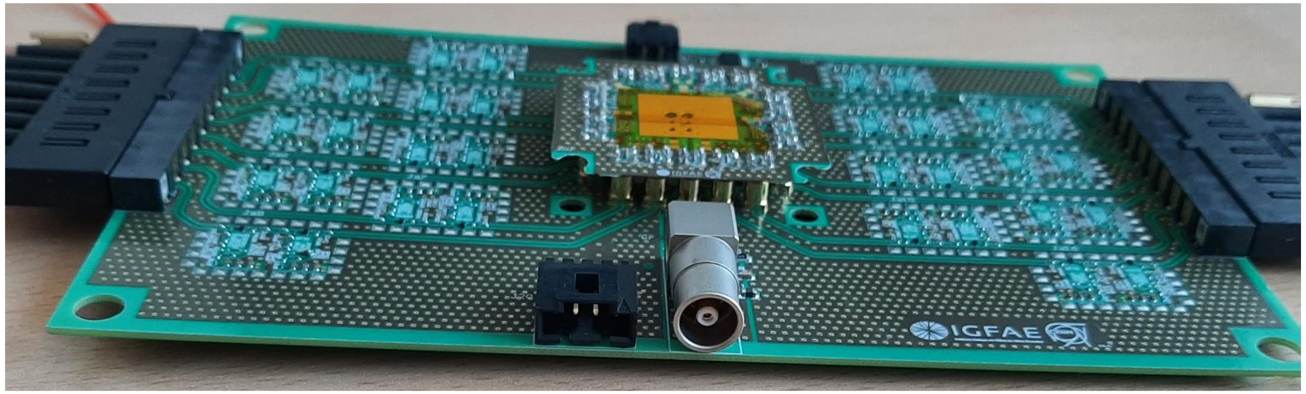
The solution

| July 2021 | October 2021 | April 2022 | June 2023 |
|---|---|---|---|
| Design submission | Initial tests | 2nd Mezzanine iteration | Test beam measurement with planar matrix |

Timeline

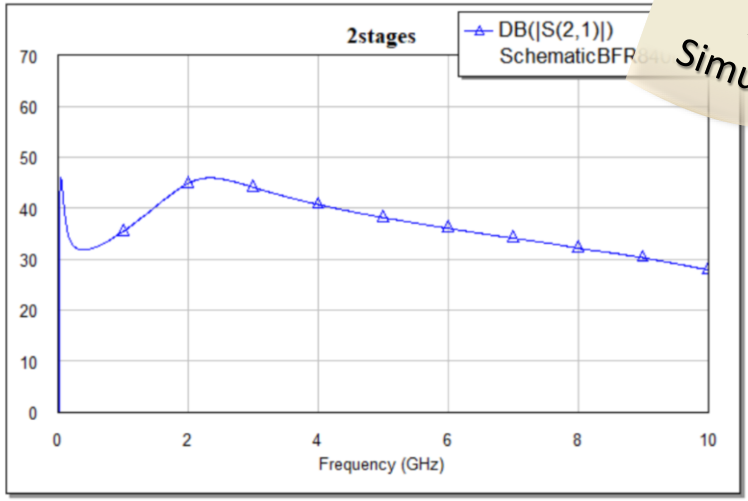
- High frequency multichannel versatile board
- Mezzanine design for fast sensor interchangeability
- Suitable for matrices (AC-LGAD applications) but also for single pad devices

- High Frequency SiGe discreate electronics @ 12 GHz bandwidth
- 2 Stage configuration with a transimpedance followed by a voltage stage
- Low max current (~10mA) with well behaved gain linearity vs $V_{DD}$
- Ruggers 3000 High Frequency substrate
- Pre-assembled miniaturized coaxial edge connectors with panel-mounted SMA plugs (1m cable length)
- 140 x140 mm outer dimensions



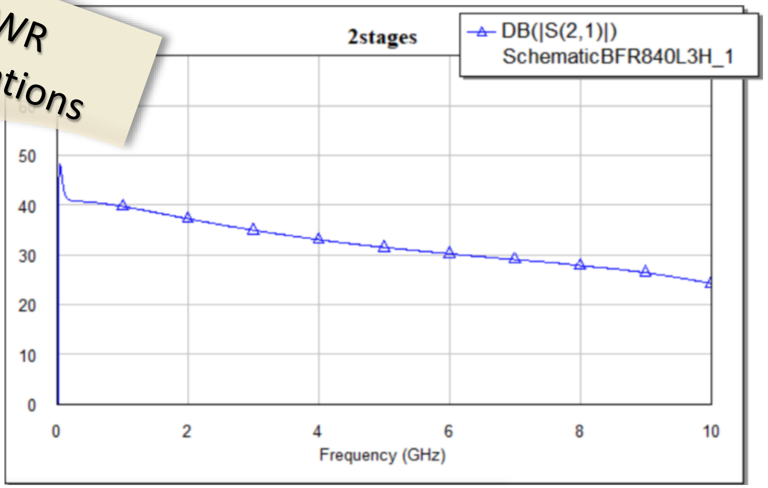
# •Simulations and performance I

**Initial design**



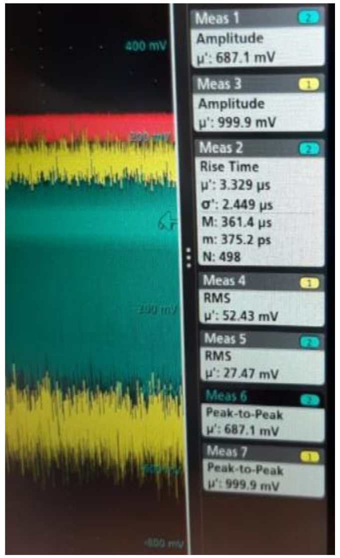

AWR Simulations

**Modified –Uniform design**

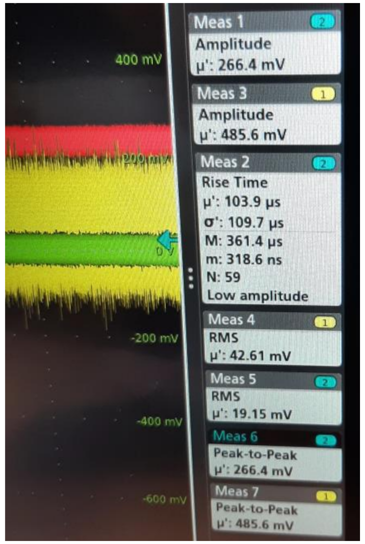



- Optimized design for uniform response with frequency
- No sharp gain change discontinuities
- No undershoot/overshoot observed
- Gain moderated to ~70 for a two-stage configuration
- 20% Higher SNR than UCSC board (with both stages)
- 2 x SNR with respect to UCSC board + niniCircuits second stage amplifier
- On going energy and transimpedance simulation

**With signal injection**

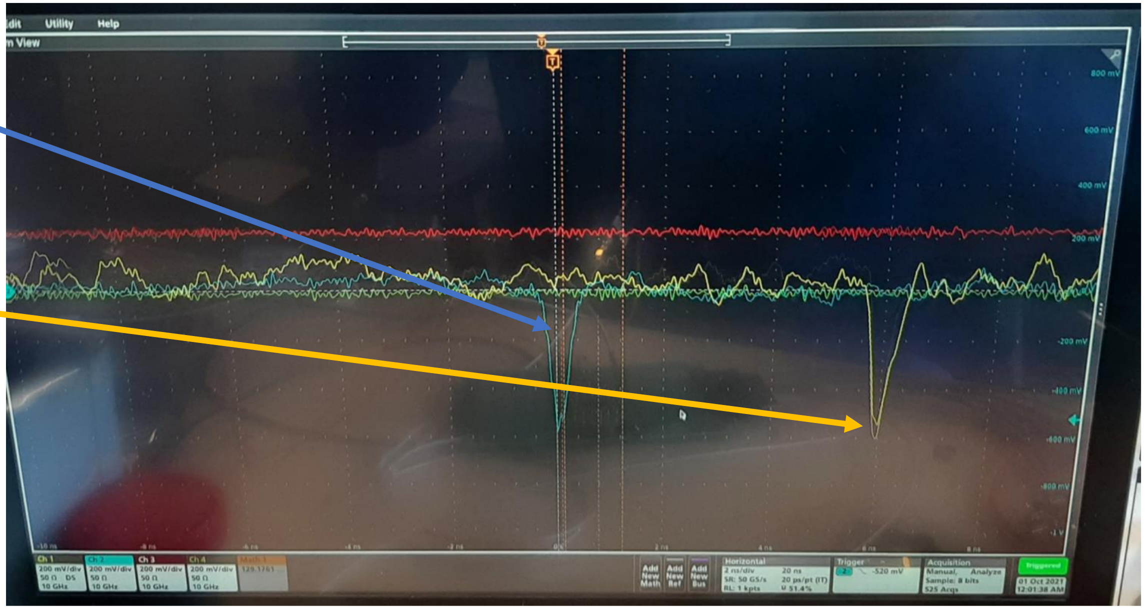



**Without signal injection**



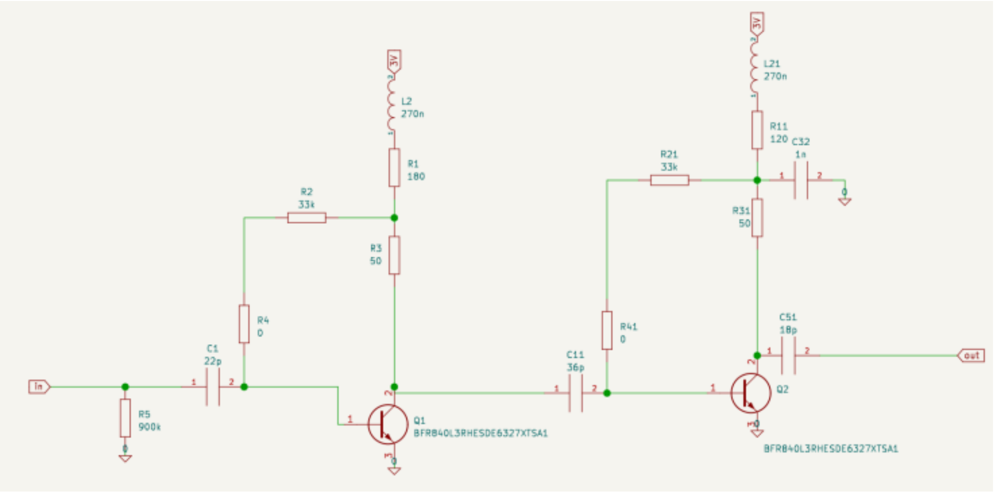

Blue: 16 channel board

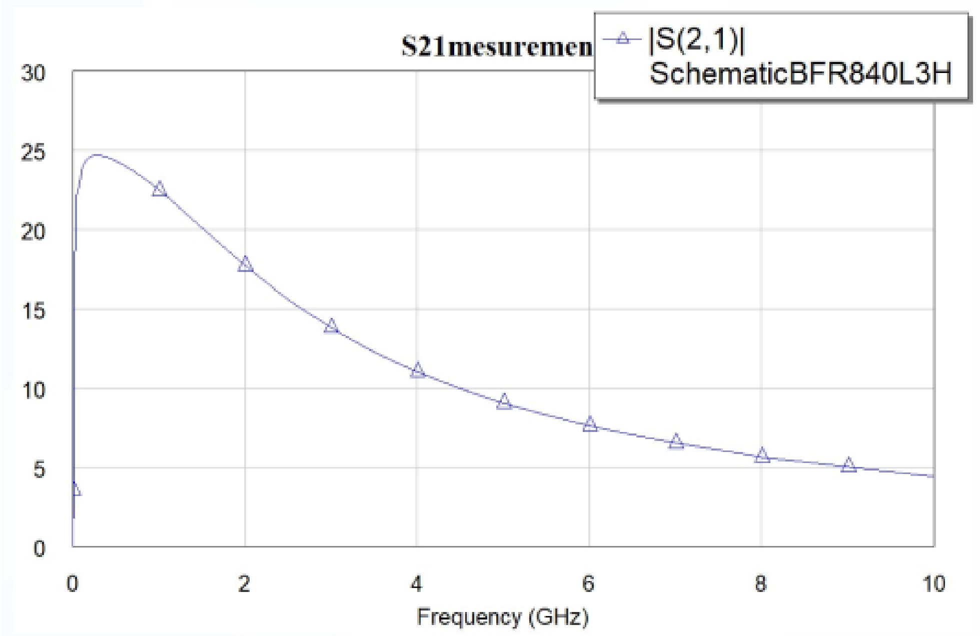
Yellow: UCSC board (only one stage)

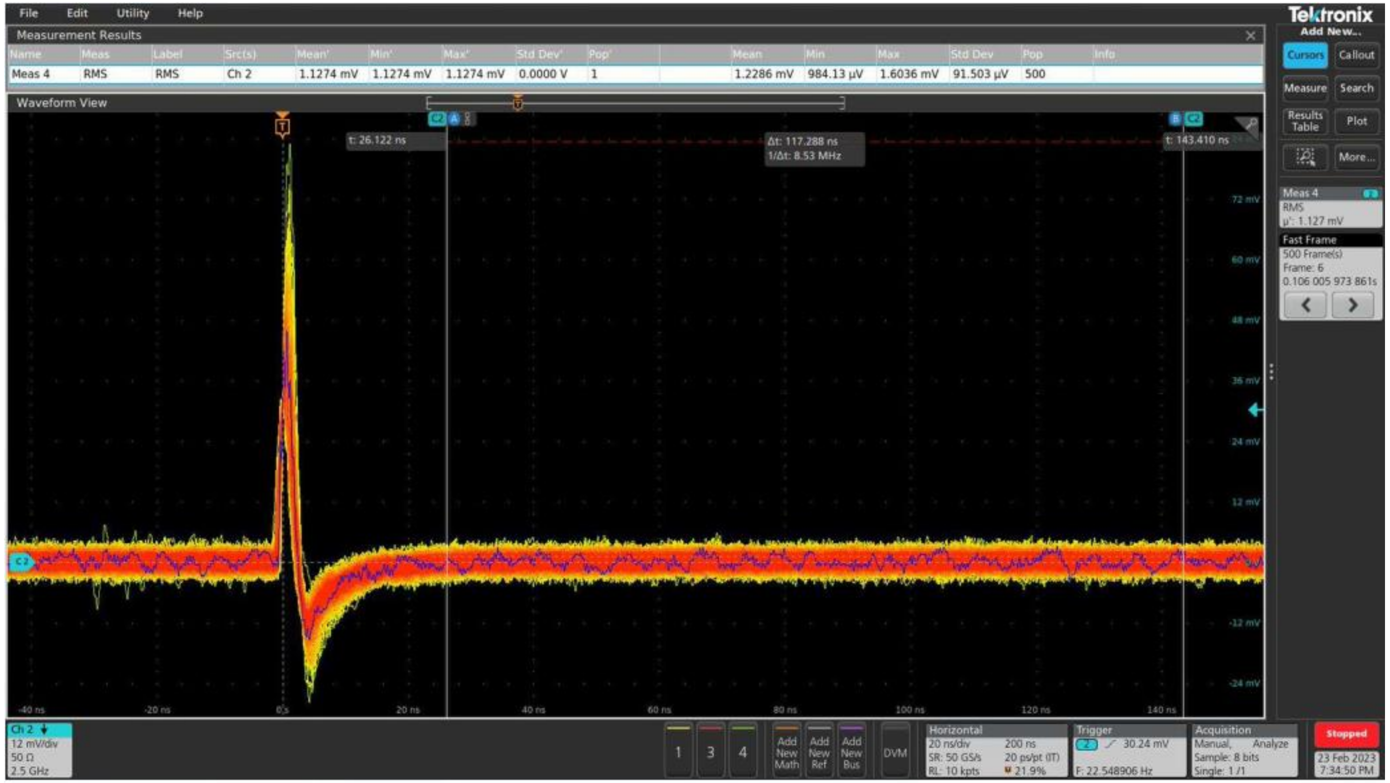


# •Simulations and performance II

**Edgar Lemos Cid ,** 18th Trento Workshop on Advanced Silicon Radiation Detectors
"[Multichannel board for picosecond timing measurements of silicon sensors]"





- Mean noise (~RMS) of 1.2 mV for a gain of ~ 70
- Tested with a 55 x 55 μm 3D double sided sensor of 230 μm
- Not frequency optimized for this sensor geometry with fast dropout at lower scale
- Leads to bipolar signal due to the increased trans-impedance at lower frequencies

# •Conclusions

## 3D Pixels - Planar measurement campaign

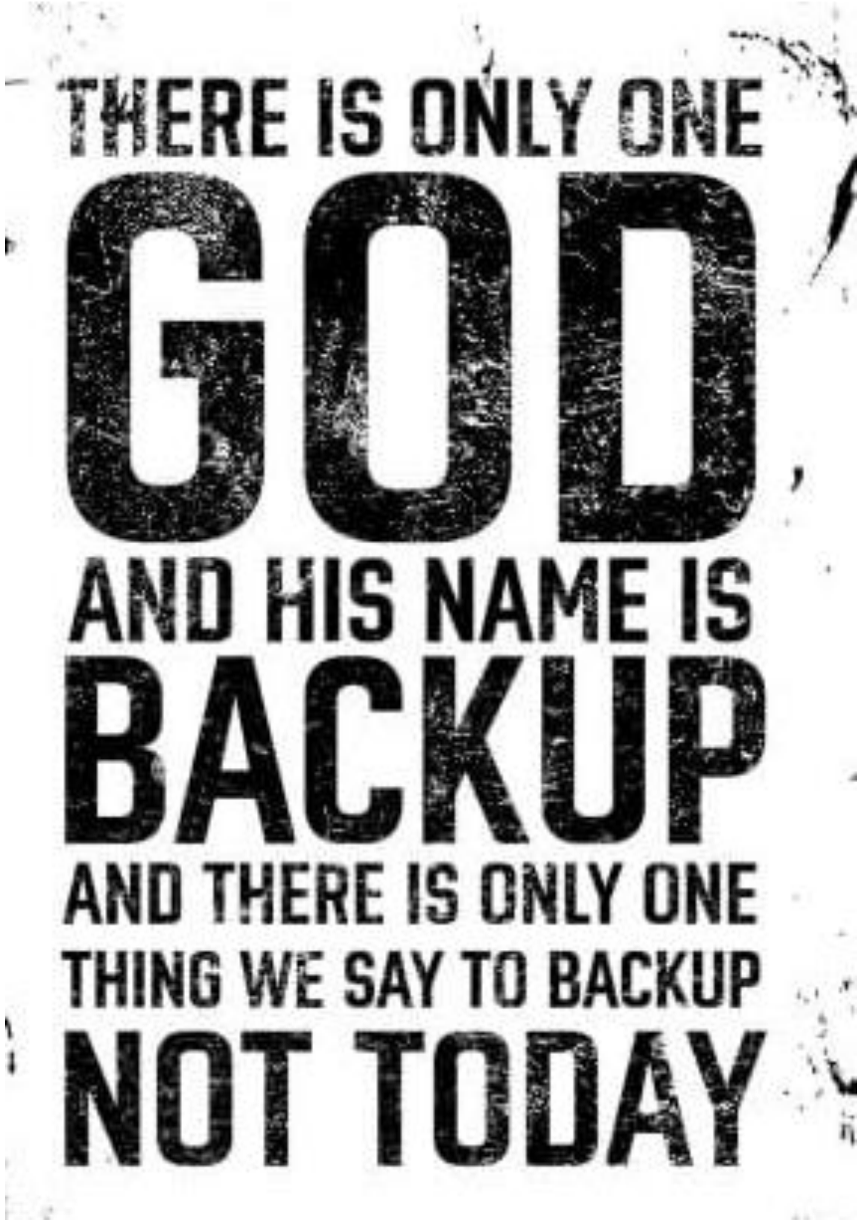
- Several productions under investigation of different pixel size and thickness
- ***Estimate filed non-uniformity impact on time resolution vs pixel size***
- ***Determine minimal acceptable thickness for time resolution applications (SNR)***
- ***Investigate effects after irradiation up to 1e17 $n_{eq}/cm^2$ in protons and neutrons***

} **Primary Goals**

## Test-Beam Setup

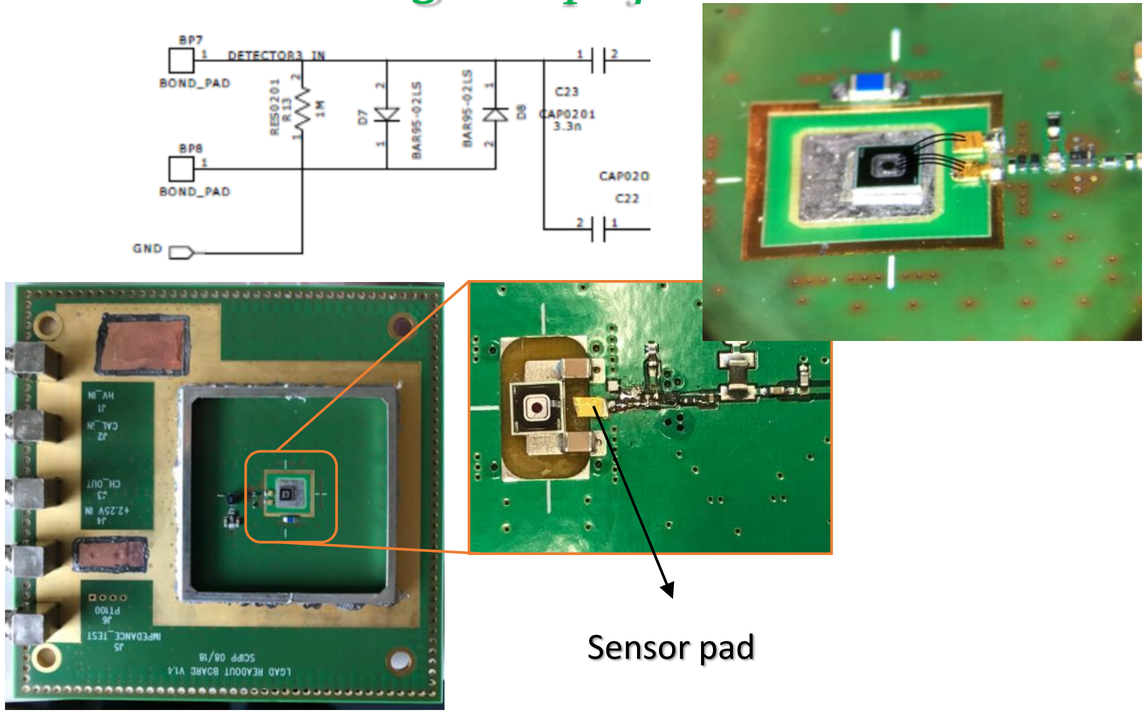
- ***Trigger Interface board:*** Versatile, allows interfacing any acquisition instrument with EUDET
- ***Control Software:*** Polymorphic UI with seeming-less multi-instrument support
- ***Cooling:*** XPS cold box with web interface temperature controllable system @ -18°C
- ***Mechanics:*** Micrometric alignment with individual DUT stages
- ***Analysis Framework:*** Advanced framework with signal shapes, iterative re-fitting and shape-based noise rejection

- Backup


THERE IS ONLY ONE
GOD
AND HIS NAME IS
BACKUP
AND THERE IS ONLY ONE
THING WE SAY TO BACKUP
NOT TODAY

# •Readout Electronics

## *First Stage amplifier*




- High frequency SiGe (~12 GHz) common emitter first stage charge amplifier (470Ω trans-impedance)
- Fully enclosed faraday cage surrounding sensor
- Mean sensor + amplifier noise < 1.8 mV
- Use of identical sensors for calibration and comparison

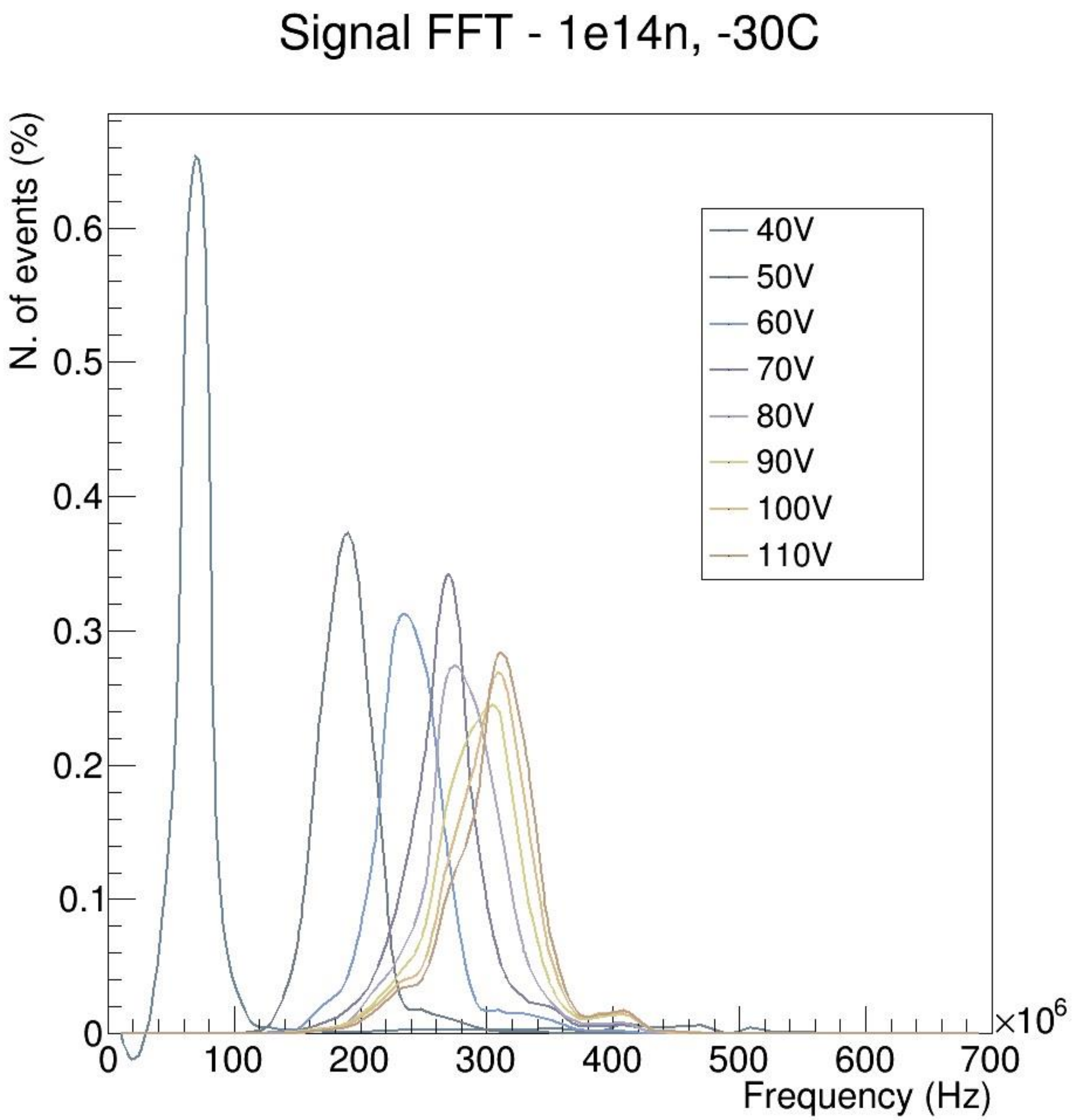
## *Second Stage amplifier*

- Mini-circuits (Gali 52+) Gallium arsenate voltage amplifier with a 2 GHz bandwidth for LGADs
- Mini-circuits (ZX60-V63+) 6 GHz microwave voltage amplifier for 3D and planar planes
- Amplification factor of ~ 10 at 12 and 5 V respectively
- Amplifiers mounted directly on the boards and placed inside the cold box


**Gali 52+**
**GaAs , <2Ghz, 50Ω**


ZX60-V63+
**50 - 6000 MHz, 50Ω**

# •Signal Evolution with bias in LGADs

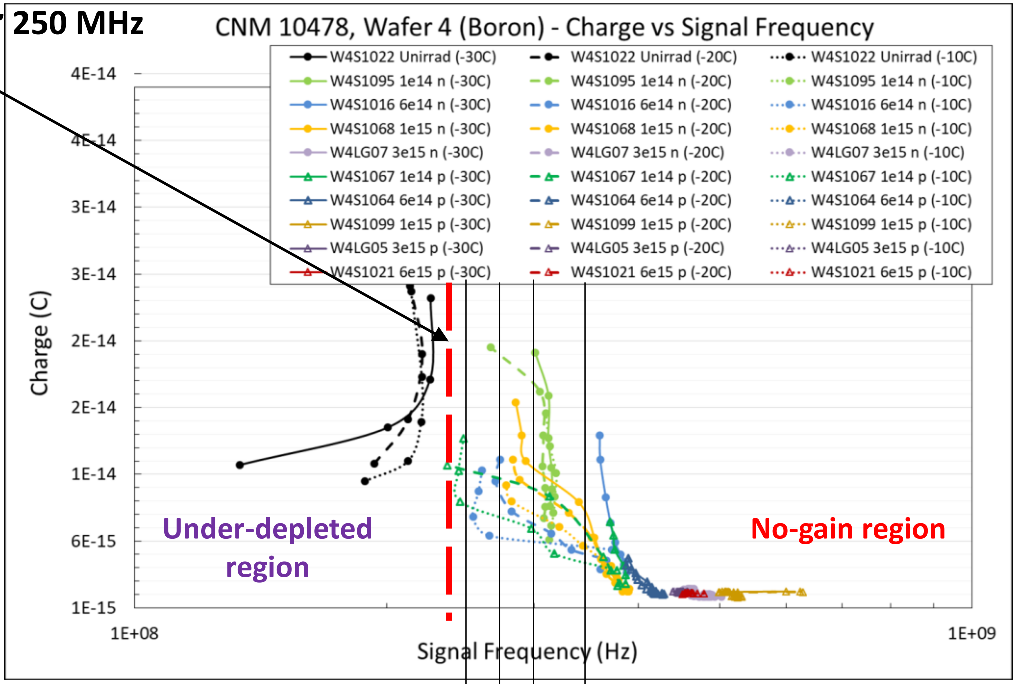


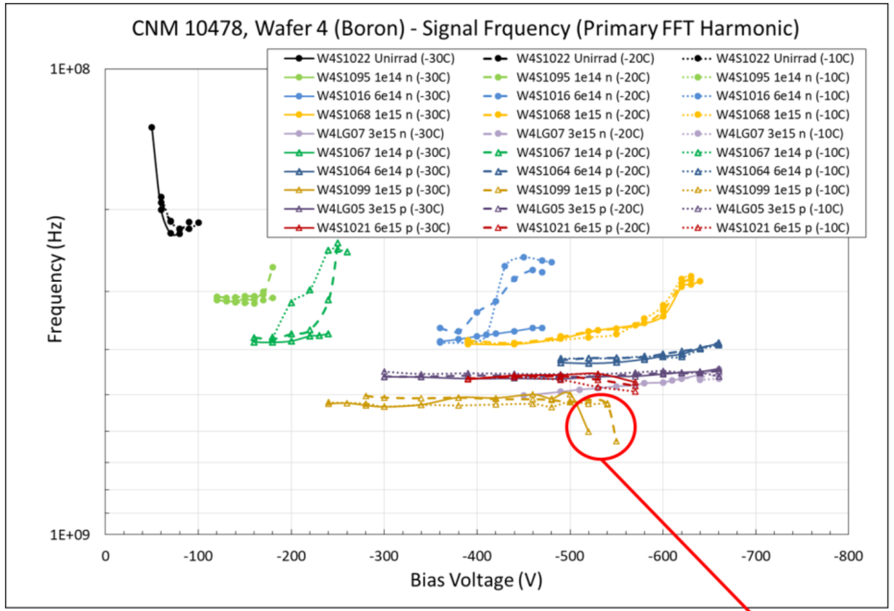
# •Signal Analysis LGADs

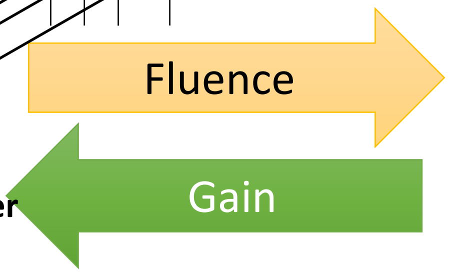
## FFT

- ✓ FFT vs Voltage presents an asymptotic behavior towards a frequency
- ✓ Asymptotic frequency depends on fluence and remaining gain
- ✓ Signal frequency increases with voltage and decreases on the onset of multiplication

**Asymptotic point ~ 250 MHz**




**Asymptotic move to higher and higher frequencies as gain decreases and fluence increases**

**High Frequency noise, sensor in breakdown**

# •Towards the Future: Sampic

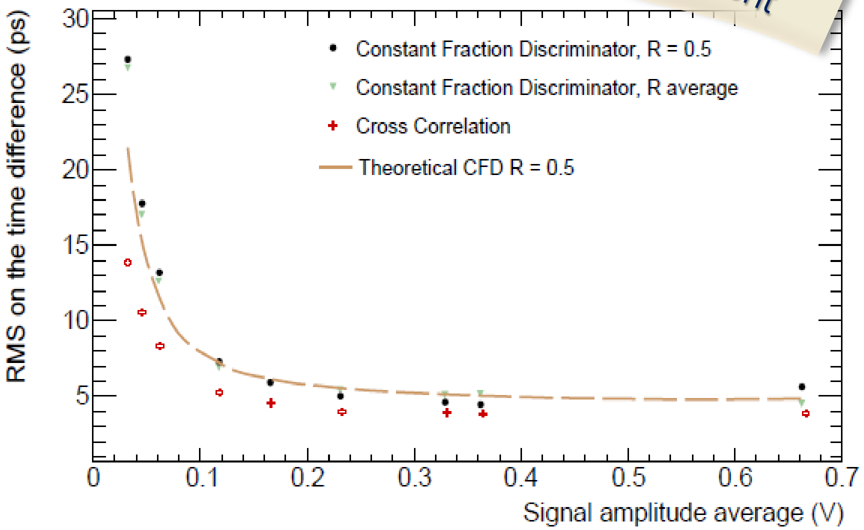
## *The ASIC (SAMPIC)*

- Technology: AMS 0.18µm
- Sampling: between 3 and 8.4 GS/sec on 16 channels (depends on DAC setting)
- 16 channels per chip
- Signal Bandwidth of 1.6GHz
- Discrimination noise 2 mV, chip noise < 1.3 mV RMS
- Max input Signal: 1V unipolar (0.1V to 1.1V)

## *ADC*

- 8 to 11 bit Wilkinson ADC at 1.3GHz
- Upon triggering 64 samples digitalized in parallel per channel
- Resolution adjustment possible to improve timing by reducing bit count
- Time resolution between 5 ps (calibrated) and 15ps (uncalibrated)

No minimum ToT Requirement




## *Calibration*

- Calibration files provided for all operational points of the ADC
- Channel by channel calibration to be performed by user
- 64 channels x 4 operation points = 256 calibration runs

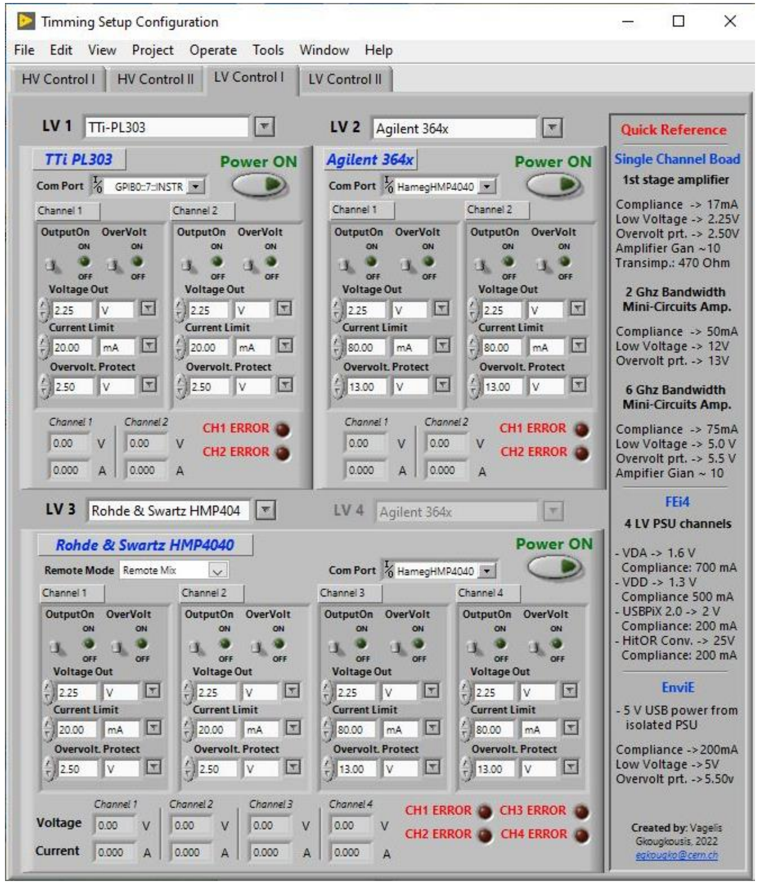
## *Connectivity*

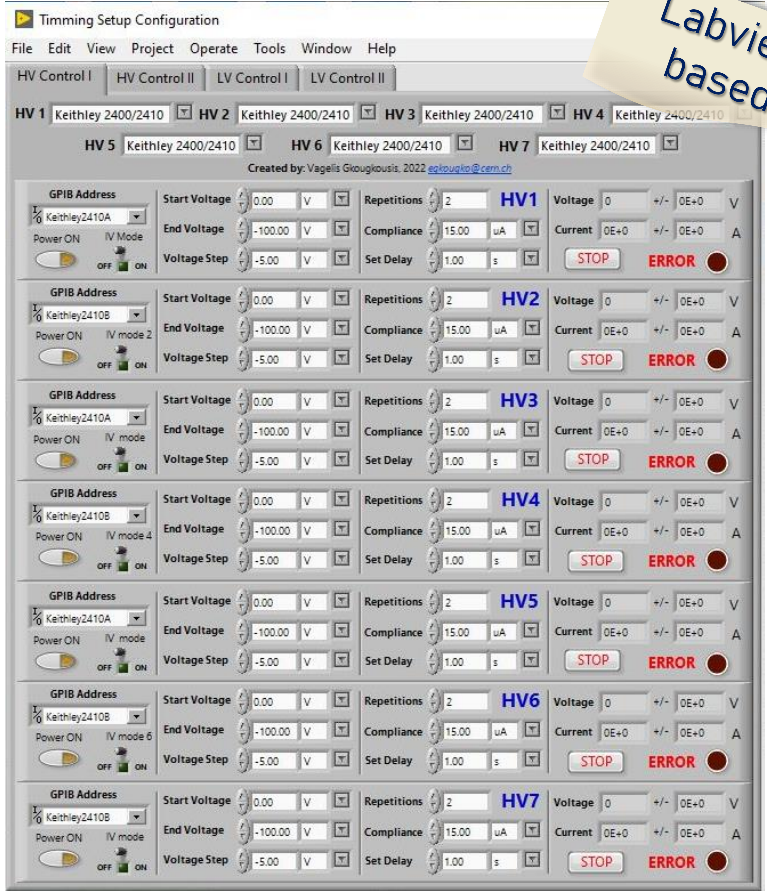
- USB2.0 + LabWindows based software (provided)
- UDP Based Ethernet, direct PC connection – no router support

# •HV & LV Control/monitoring

➢ Precompiled executable available on GitLab: here

Labview based

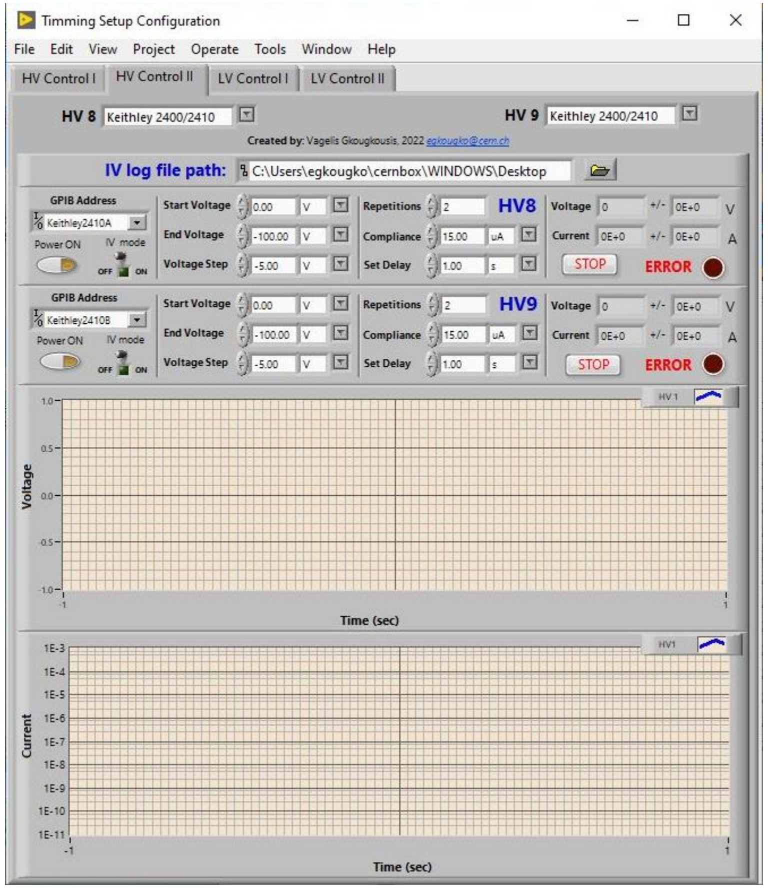



High voltage

KEITHLEY

2400/2410 series




**Multi-model Support with Polymorphic UI**

Agilent Technologies

363X series

KEYSIGHT TECHNOLOGIES

364X series

ROHDE&SCHWARZ

HMP4040

Aim TTi

PL330DP

Aim TTi

PL303QMD

- 9x HV channels
- 16x LV channels
- Constant monitoring & logging
- Live protection

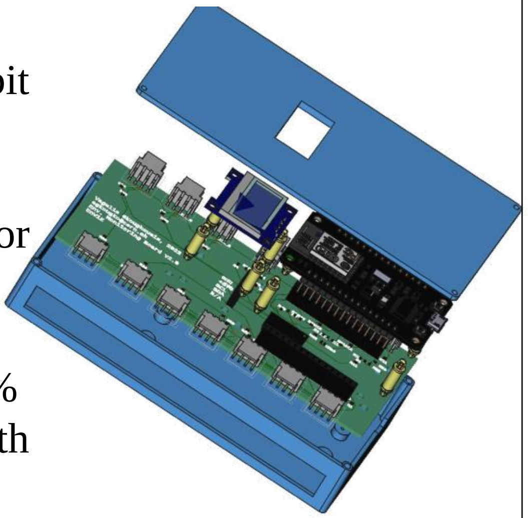
# •Temperature Regulation

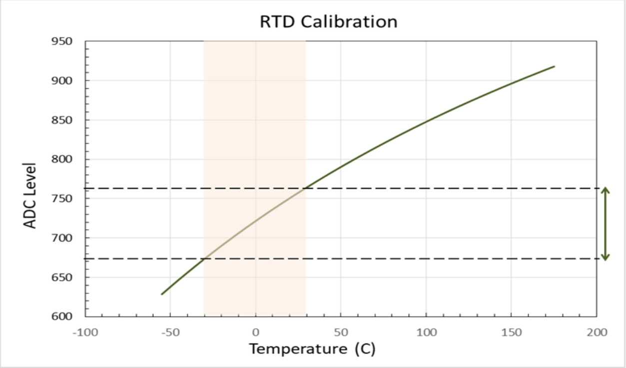
- ➢ Running at a crisp **-18 °C**
- ➢ Glycol cooling with temperature feedback - Labview control
- ➢ Humidity regulation though $N_2$ feeds

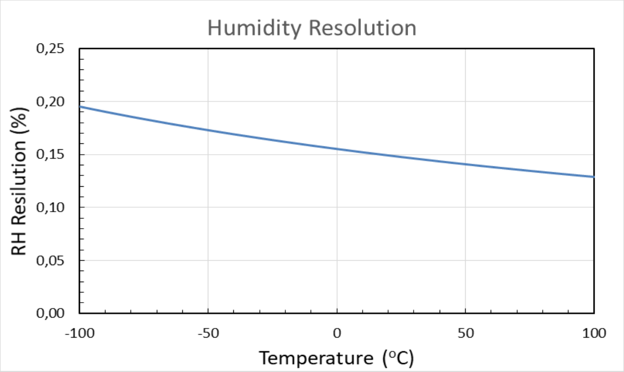
➢ EnviE GitLab with schematics: [here]

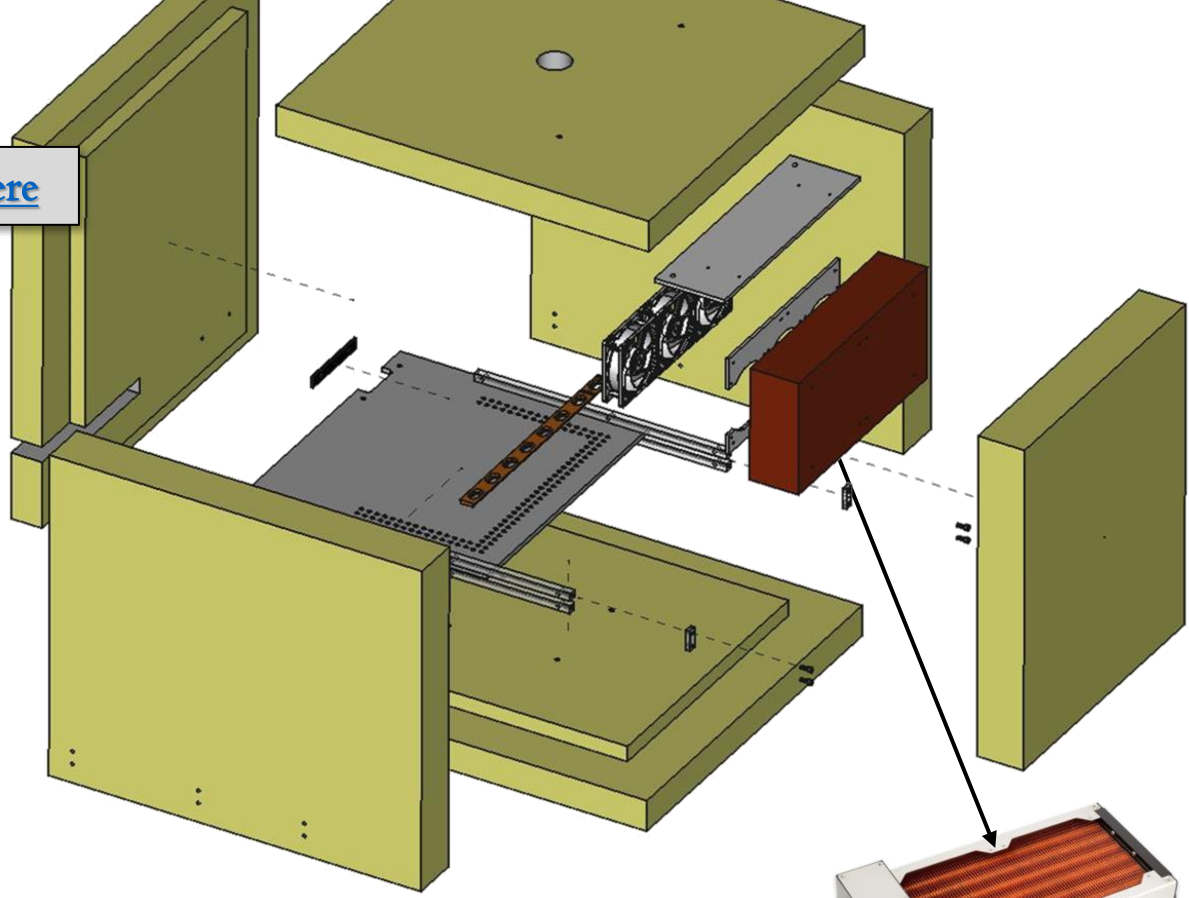
## Environmental Expander V2.0 (EnviE)

- ESP8266 based with integrated 10-bit ADC, I2C and WiFi 802.11b
- Integrated OLED 128X64 pixel screen
- High precision voltage dividers and sensor decoupling
- ARDUINO / LoUA core web interface
- Temperature resolution of 0.8 °C ± 0.06 %
- Humidity resolution 0.1 % with temperature compensation





**Water cooling block**

- ➢ 6 c.m. thick XPS foam insulation
- ➢ Outer dimensions of 50 x 48 x 48 $cm^3$
- ➢ Use of commercial water-cooling block ([link])
- ➢ 3 x Axial Fan DC 80x80x25mm 24V 111.6m³/h – low remperature tested to -20°C ([link])
- ➢ Total cost ~ 400 CHF

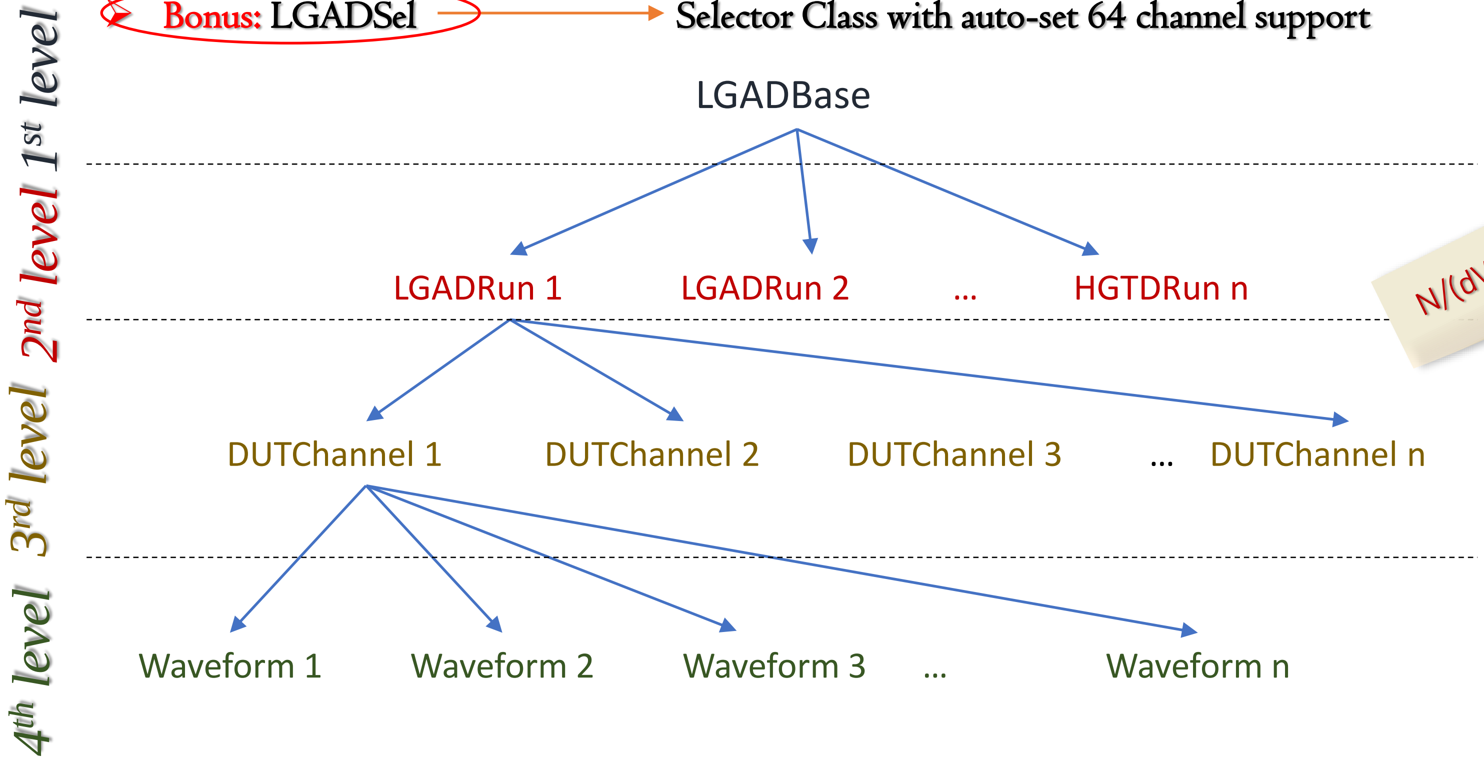
# •Analysis Framework

➢ Code available on git: https://gitlab.cern.ch/egkougko/lgadutils

➢ Four main classes with dedicated header and implementation files, one wrapper class handling user interaction

C++ 11

- LGADUtils → Wrapper to handle user I/O and pass arguments
- ➢ LGADBase → Basic framework function and infastructure
- ➢ LGADRun → Timing resolution, CFD maps, multi DUT operations
- ➢ LGADChannel → Mean pulse shape, mean pulse properties form entire run
- ➢ WaveForm → Single Waveform properties and time walk corrections
- ➢ Bonus: LGADSel → **Selector Class with auto-set 64 channel support**




- Iterative re-fitting and re-binning algorithm
- Fitting of discrete and variable binning quantities
- Bayesian uncertainties at efficiency level
- Event by event FFT transimpedance correction

$N/(dV/dt)$ , $T_{Rise}/SNR$

| *Quantity* | *Applied Fit type* |
|---|---|
| Min, Max voltage : | Gauss, Gauss x Landau fit |
| Start, stop, min, max indices : | Gauss, Gaussian fit |
| Noise / pedestal : | Gaussian fit |
| Min, Max, Rise, Trigger time : | Gaussian fit |
| Charge, dV/dT, Jitter, ToT: | Gauss x Landau fit |
| FFT: | Variable bin Gaussian |

# •Iterative Re-fitter & signal templates

File: LGADFits.cxx

- Centralized fitter engine for all fits
- Fully automated, including limits, method and Minuit minimization
- 36 Iterations per fit with limits and bin size variation to determine best combination
- Over-binning protection, automatic variable discreetness test
- Variable binning for FFT, frequency histograms
- Supported ROOFit, Standalone Minuit, Integral optimization or Shape

| Dataset Type | Statistic Categorization | Bin Selection Criteria | | |
|---|---|---|---|---|
| | | Lower 3 bin number variations | Optimum Bin number | Higher 3 bin number variations |
| Discrete Datasets | $\frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma} < \sqrt{N_{elements}} < N_{bins\_max}$ | $\left\lceil \lceil \sqrt{N_{elements}} \rceil - n \times \left\lceil \frac{\sqrt{N_{elements}} - \frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma}}{3} \right\rceil \right\rceil$ with 1 < n < 3 | $\lceil \sqrt{N_{elements}} \rceil$ | $\left\lceil \lceil \sqrt{N_{elements}} \rceil + n \times \left\lceil \frac{N_{bins\_max} - \sqrt{N_{elements}}}{3} \right\rceil \right\rceil$ with 1 < n < 3 ** |
| | | Lowest bin number | Rest of the bin number array | |
| | $\sqrt{N_{elements}} \leq \frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma} < N_{bins\_max}$ | $\lfloor \sqrt{N_{elements}} \rfloor$ | $\lfloor \sqrt{N_{elements}} \rfloor + n \times \left\lceil \lvert N_{bins\_max} - \sqrt{N_{elements}} \rvert / 6 \right\rceil$ with 1 < n < 6 ** | |
| | $\sqrt{N_{elements}} \leq N_{bins\_max} < \frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma}$ | | | |
| | $N_{bins\_max} \leq \sqrt{N_{elements}}$ | $n \times \lfloor N_{bins\_max} / 7 \rceil$ with 1 < n < 7 | | |
| | | Lower 3 bin number variations | Optimum Bin number | Higher 3 bin number variations |
| Continuous Datasets | $\frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma} < \sqrt{N_{elements}}$ | $\left\lceil \lceil \sqrt{N_{elements}} \rceil - n \times \left\lceil \frac{\sqrt{N_{elements}} - \frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma}}{3} \right\rceil \right\rceil$ with 1 < n < 3 | $\lceil \sqrt{N_{elements}} \rceil$ | $\left\lceil \lceil \sqrt{N_{elements}} \rceil + n \times \left\lceil \frac{\frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma}}{3} \right\rceil \right\rceil$ with 1 < n < 3 |
| | $\sqrt{N_{elements}} \leq \frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma}$ | $\left\lceil \left\lceil \frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma} \right\rceil - n \times \left\lceil \frac{\frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma} - \sqrt{N_{elements}}}{3} \right\rceil \right\rceil$ with 1 < n < 3 | $\left\lceil \frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma} \right\rceil$ | $\left\lceil \frac{\lvert \lim_{fit} High - \lim_{fit} Low \rvert}{\sigma} + n \times \left\lceil \frac{\sqrt{N_{elements}}}{3} \right\rceil \right\rceil$ with 1 < n < 3 |

## *Template Method*

- Point by Point projection of all time-walk corrected (though CFD) signal pulses
- Landau X Gauss fit on projected point by point distribution
- Extraction of a "characteristic" signal composed of the MPVs of the Point by point projection fits
- RooKeyPdf for analytical description of signal
- Re-iteration on all events and fit of each waveform with the extrapolated analytical signal description
- Re-caclculate all quantities

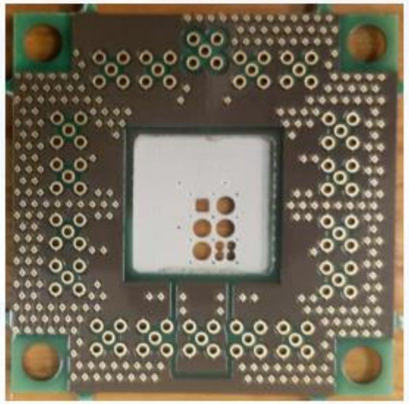
# •Sensor Daughterboard

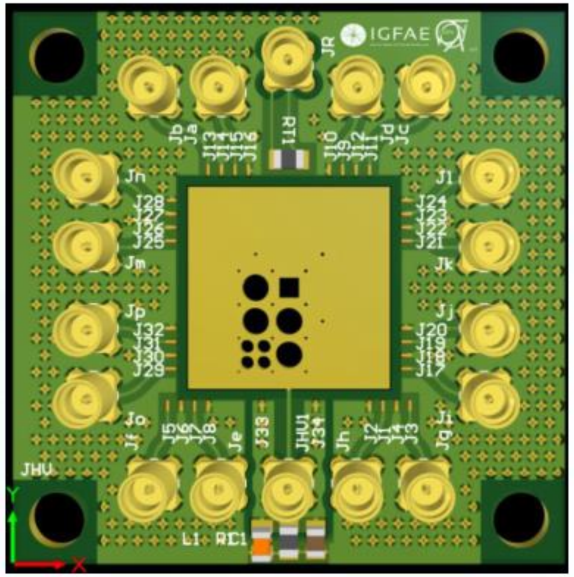
**Edgar Lemos Cid ,** 18th Trento Workshop on Advanced Silicon Radiation Detectors
"Multichannel board for picosecond timing measurements of silicon sensors"

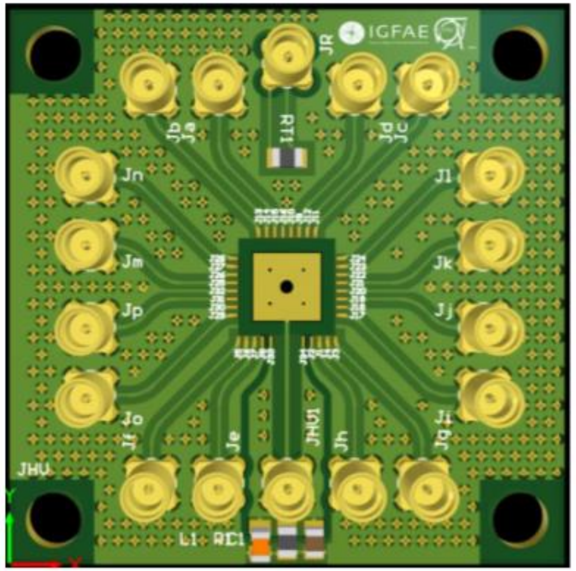
## Sensor board

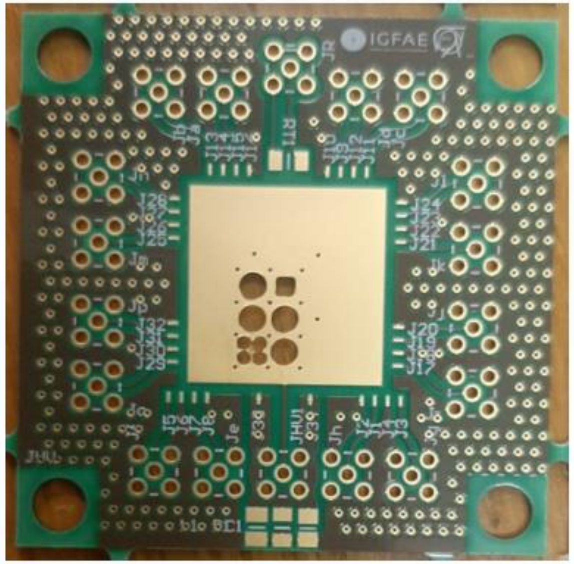
- Two types of designs. (15x15 mm and 5x5 mm central pad).
- 41 x 41 mm square shape.
- Rogers 4350B for the high speed signals.
- Connector area reinforce with 0.3 µm FR4.
- Under sensor pad thickness of 100 µm.
- Multiple drills design on the central pad to place different types and sensors sizes.
- 140 boards produced at Gacem.

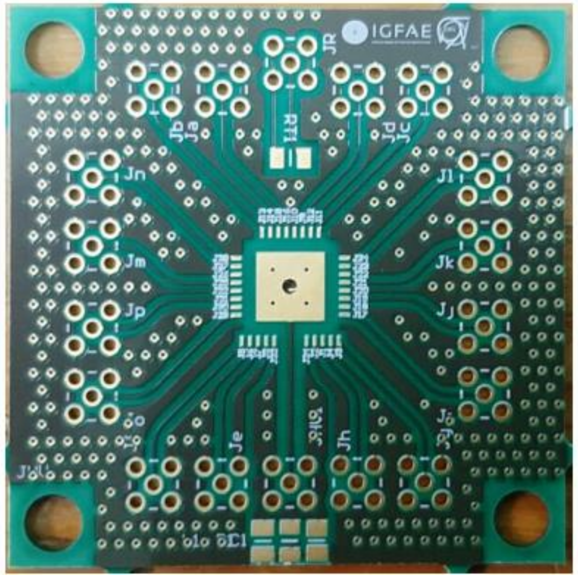
Back side





# •H/W and S/W developed

| Category | Function | Description | Github Project Link |
|---|---|---|---|
| Electronics | **TiB Board** | Interface and synchronize oscilloscope with AIDA TLU | Trigger Interface Board - TiB |
| | **FEi4 HitOr Converter** | Convert CMOS level output to TTL level necessary for ROI trigger | HitOr Converter |
| | **Environmental Expander (EnviE)** | Monitor Temperature / Humidity at DUT level | Environemental Monitoring Expander - EnviE |
| | **Front-End readout board** | 12 GHz fast transimpedance amplifier with integrated faraday cage | Single Channel Board |
| Mechanics | **Cold-Box and DUT Support** | XPS foam enclosure for -20C operation and individual DUT alignment | Test beam Mechanics |
| Software | **Oscilloscope Fast DAQ** | SCPI layer DAQ program for oscilloscope readout | Oscilloscope DAQ |
| | **Power/ Temp Control Software** | Labview based Low Voltage and HV control software with integrated single event burnout protection | TiCAS - Timing Control Automation Software |
| | **Trimming analysis Software** | LGADUtils timing analysis framework | LGADUtils |