The development of a laser system for use in the timing performance measurements of CMS HGCAL silicon modules.

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On behalf of the CMS Collaboration

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TWEPP 2023 talks & poster from HGCAL

1. Performance of H2GCROC3, the readout ASIC of SiPMs for the back hadronic sections of the CMS High Granularity Calorimeter, by Jose David Gonzalez .
2. First test results for ECON-T and ECON-D ASICs for CMS HGCAL, by Cristina Ana Mantilla Suarez.
3. The CMS HGCAL trigger data receiver, by Raghunandan Shukla.
4. CMS HGCAL Electronics Vertical Integration System Tests, Poster by Milos Vojinovic.
5. The development of a laser system for use in the timing performance measurements of CMS HGCAL silicon modules, this talk.

HGCAL : High Granularity Calorimeter

The HGCAL is the 47-layer sampling Calorimeter that will replace the existing ECAL ($PbWO_4$ crystal) & HCAL (plastic scintillator) Endcap *calorimeters in Phase-II upgrades* for High Luminosity Large Hadron Collider (HL-LHC).

Two parts:

CE-E (electromagnetic)

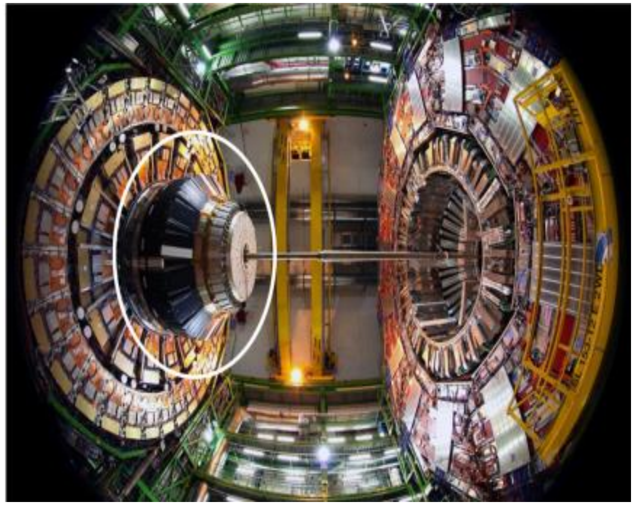
CE-H (hadronic)

Active materials:

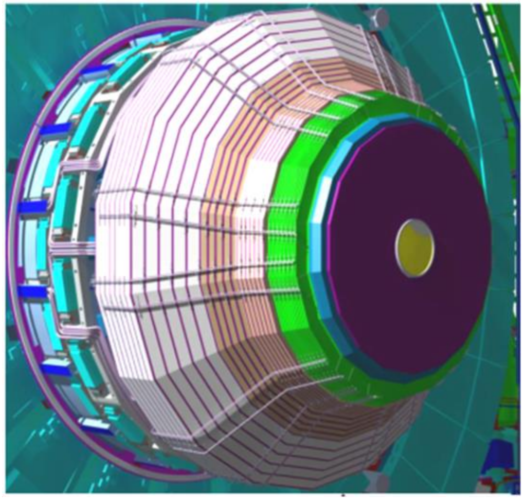
620 m^2 of Silicon in CE-E and high rad. zone of CE-H

370 m^2 of Scintillator tiles with SiPM in low-rad. region

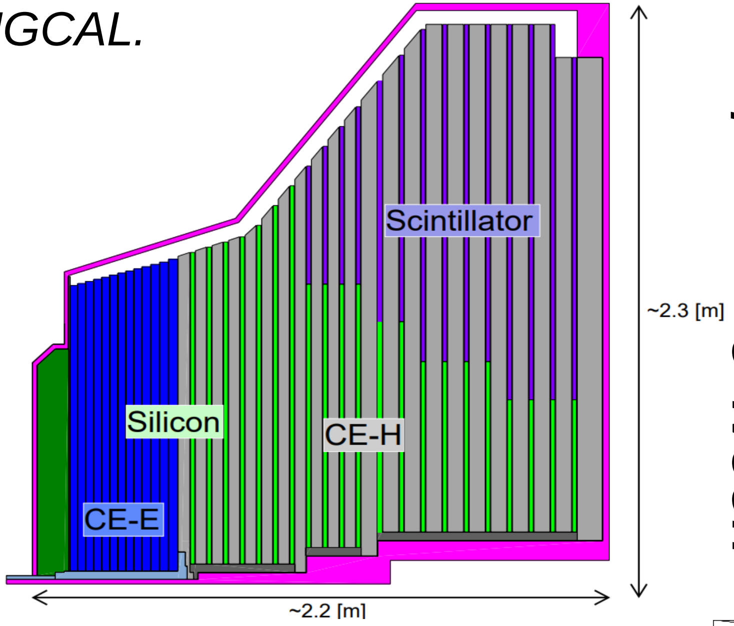
Our work is relevant to the testing of modules for silicon region of HGCAL.



Existing Endcap Calorimeter

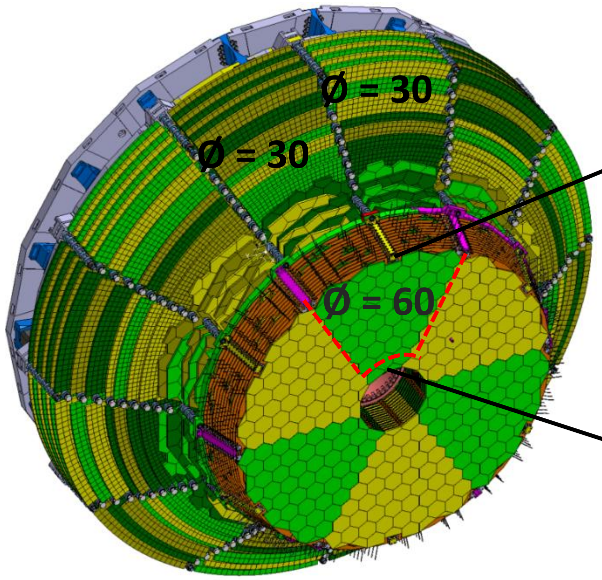


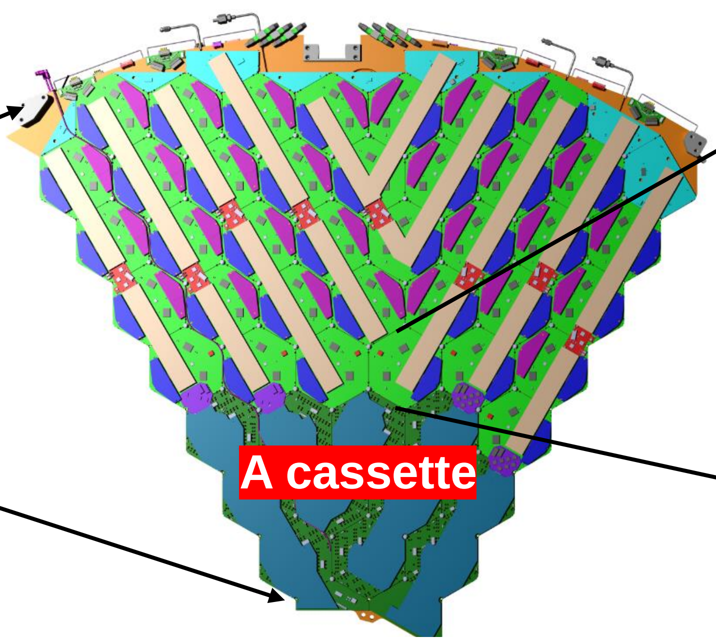
HGCAL model

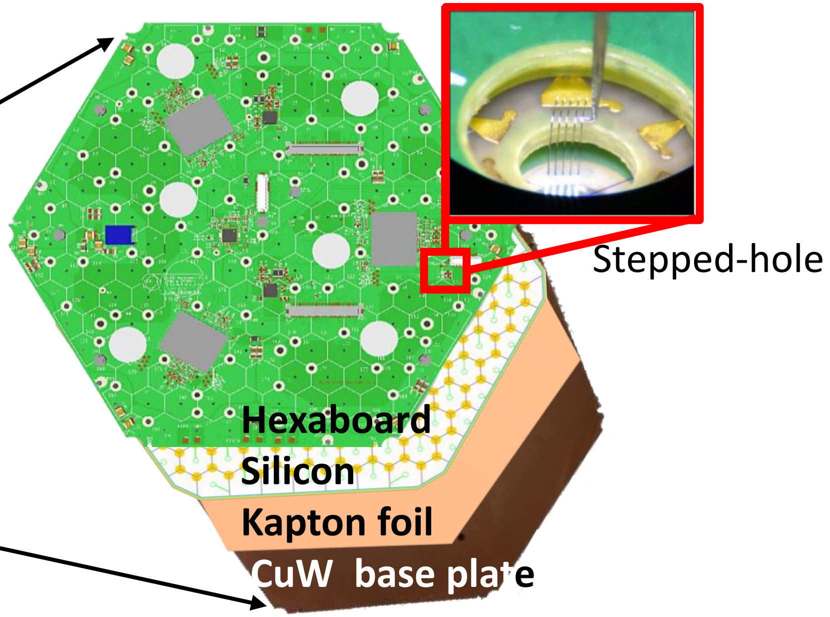


HGCAL Cross-section

HGCAL Front-end electronics chain







Silicon Hex-Module

HGCAL model with electronics view

A cassette is

60⁰ (1/6) in CE-E layer
30⁰ (1/12) of layer CE-H.

- Instrumented with Silicon-Hex- Modules.
- Superimposed by supporting electronics boards.

Silicon Hex-Module (Qty: ~26,000)

- Glued assembly of base-plate, Kapton foil, **Silicon sensor** & **Hexaboard**,
- The bonding pads connected to ASIC are bonded to silicon sensor via stepped holes.

- Hosts upto 06 **HGCROC** ASICs
- Large dynamic range 0.2fC→10 pC
- Trigger Primitive generation

.

- **Measure TOA (time of arrival) for charge>12fC**

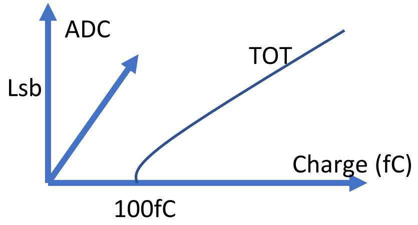
HGCROC, the ASIC used…

See Performance of H2GCROC3, the readout ASIC of SiPMs for the back hadronic sections of the CMS High Granularity Calorimeter.by **Jose David Gonzalez**

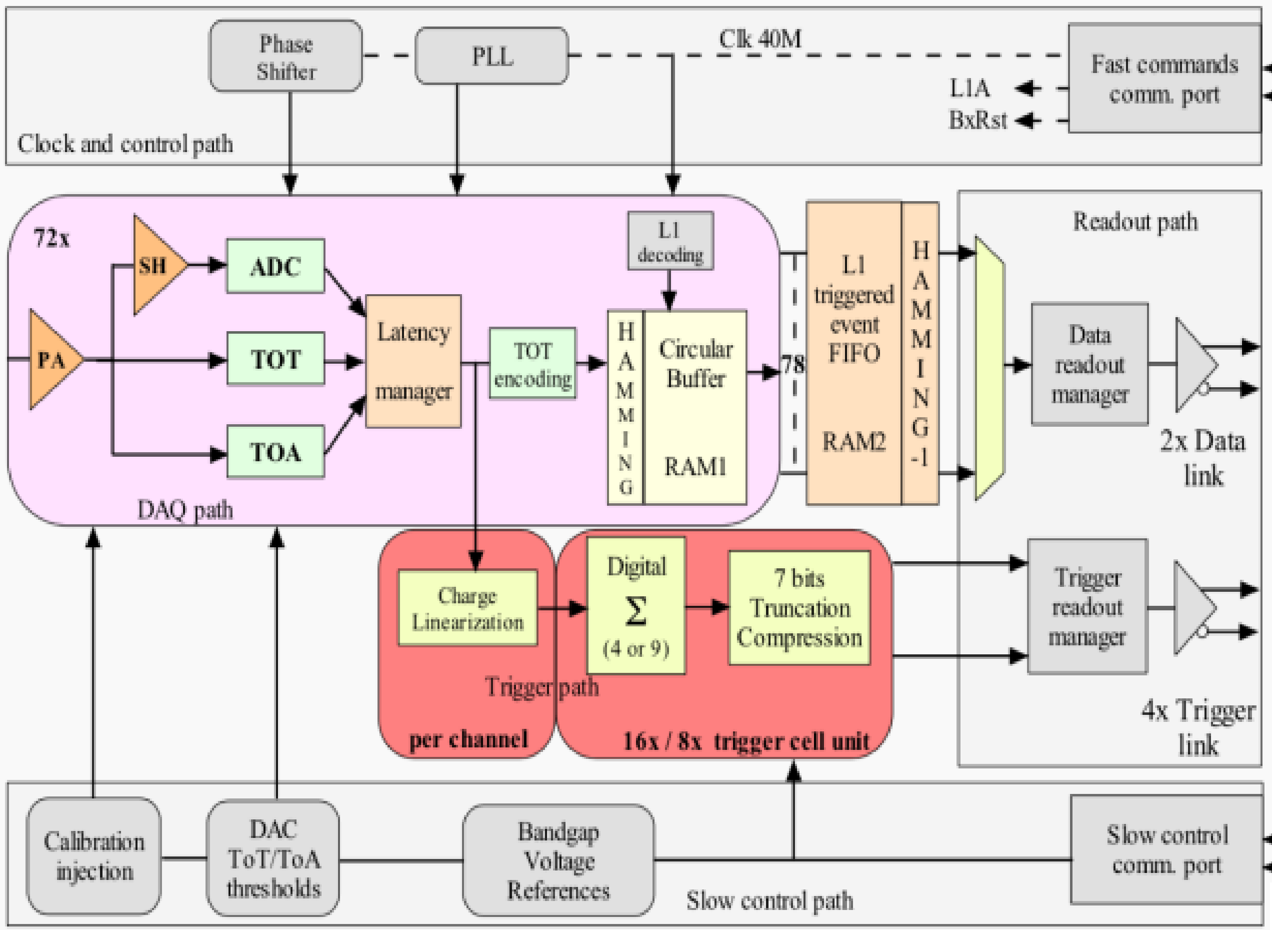
HGCROC is the readout ASICs used on Hexaboard.

Dynamic Range ~0.2fC to 10pC
ENC < 2500e (Cd=65pF)
Shaping Time ~20ns
Linearity <1%
Pos. & Neg input charge

Energy Measurement
ADC 10b SAR
range 0 > 100fC (150fC)
TOT range 100fC > 10pC
TOT bin size 2.5fC



Time Of Arrival (TOA)
10b TDC
lsb <25ps, 25ns full range



HGCROCV3 Block Diagram

- **Comm port**
  - 320MHz clock
  - Reception of fast commands through lpGBT
- **Data Readout Path**
  - Data packets after L1A
  - L1A latency up to 12.5us
  - 2 SLVS outputs @ 1.28Gbps
- **Trigger readout Path**
  - Trigger cells (2x2/3x3)
  - 4 SLVS outputs @ 1.28 Gb/s
- **Slow Control**
  - Programmable registers
  - I2C protocol

HGCROC, the ASIC used…

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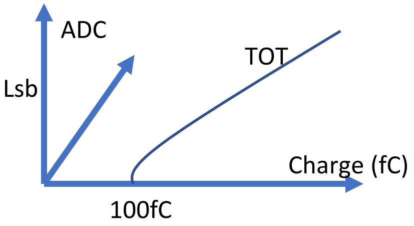

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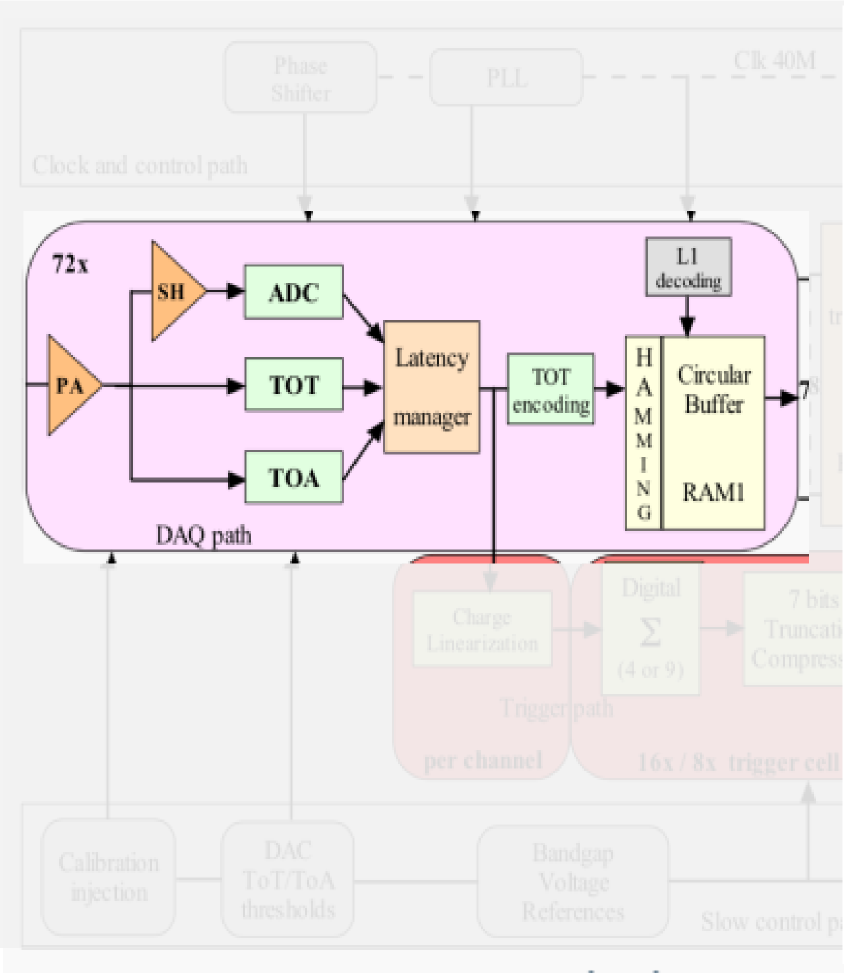
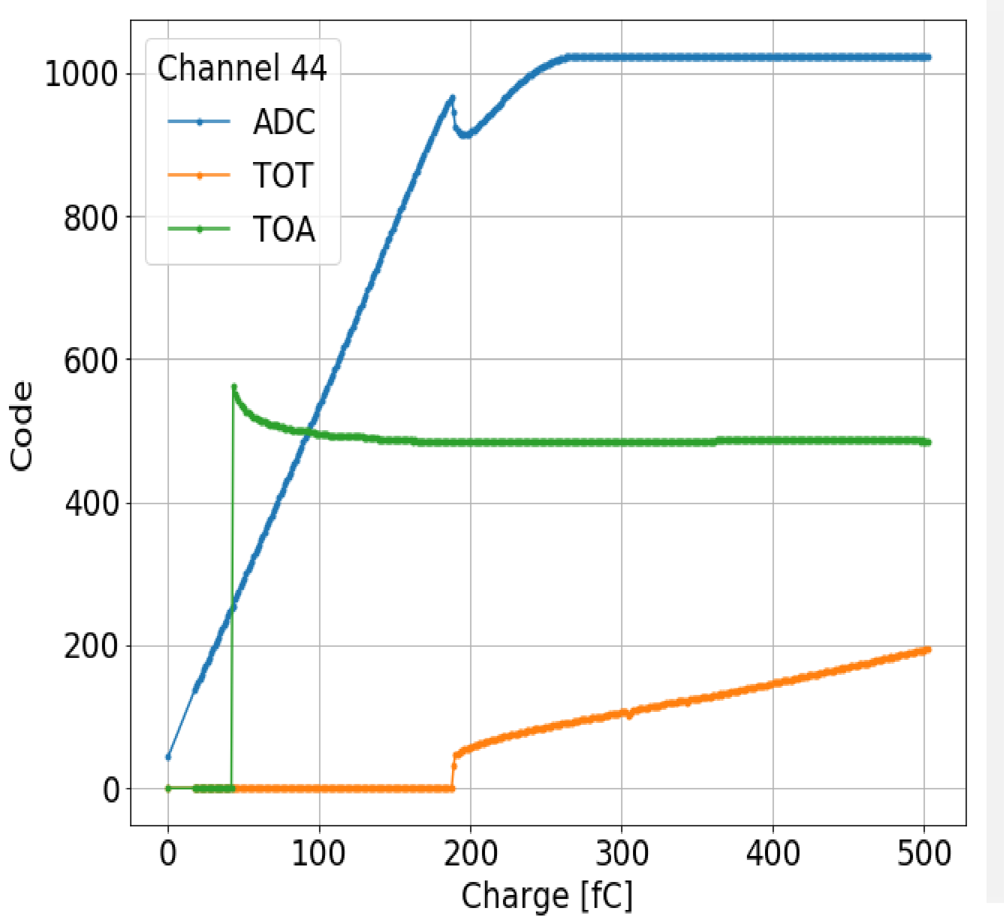




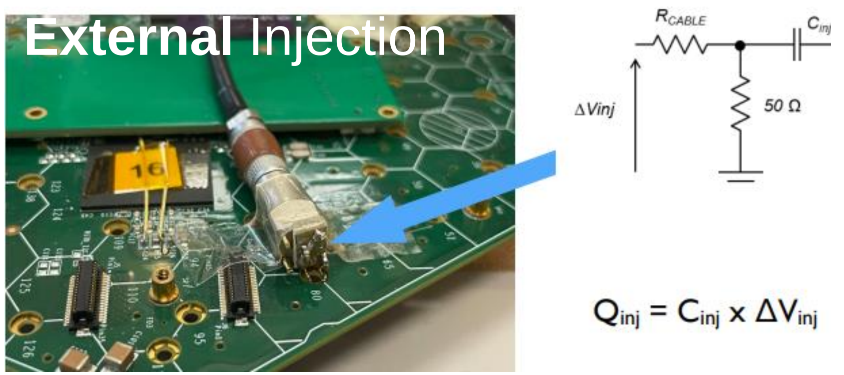
HGCROCV3 Block Diagram

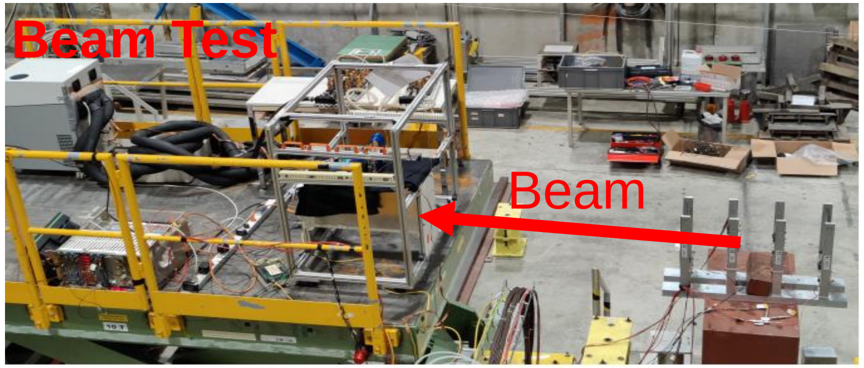
Three complementary setups (methods) for the module tests

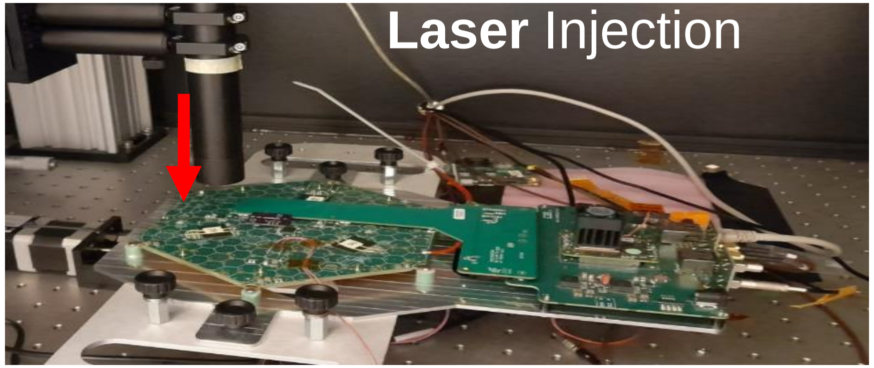
1: Charge Injection by External Capacitor:
- For test board level characterization.
- Fixed hardware, possible inconsistency of impedance

2: Beam Test:- (The realistic environment)
- Real charge distribution in the Si sensor by known particles.
- Limited time, Needs a lot of logistic and person power

3: Charge Injection by Laser:
Injecting Laser in silicon cell includes
- whole path (sensor+ readout circuitry)
- repeatable, easy access in the lab, easy DAQ system.
- In <100 ps accurate test system is not simple.

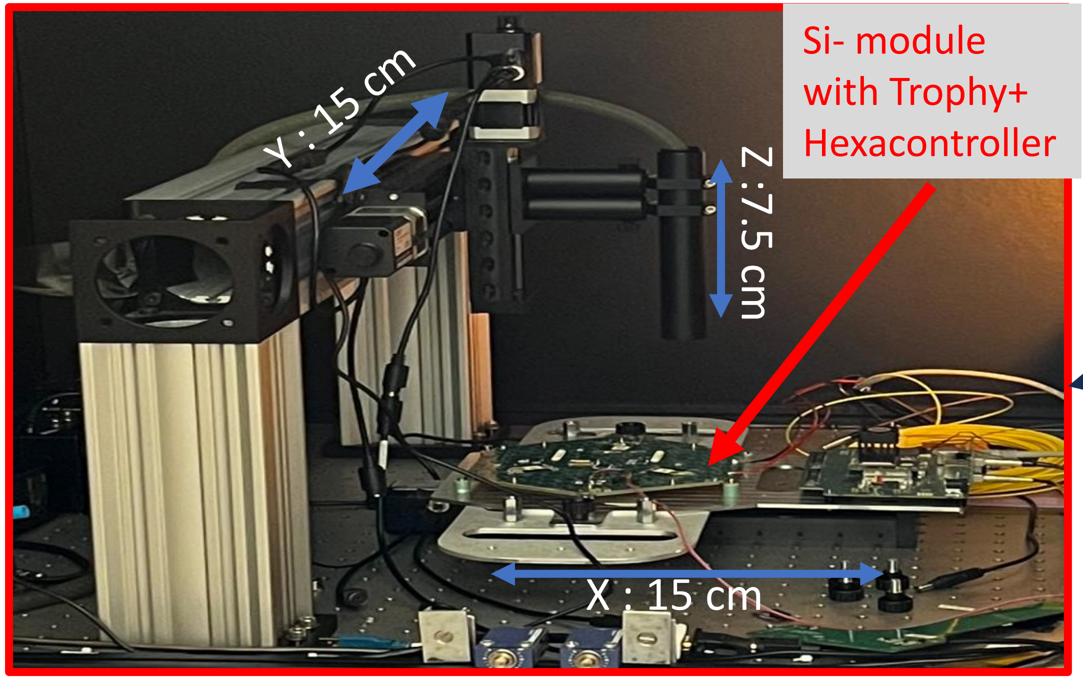






Laser test system for Si-module characterization

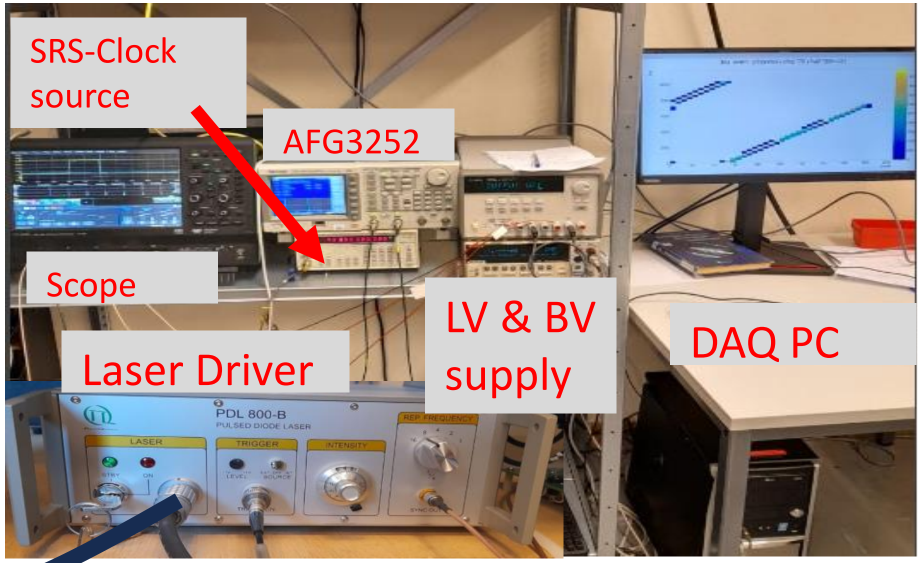
- ❑ ~26,000 module in 11 variants..
- ❑ < 100 ps resolution,
- ❑ Large dynamic range (0.2fC → 10 pC)
- ❑ A test system with precise control over time & charge injection is required.



For safety purpose: All optical components & Interconnects are inside dark room type cabin

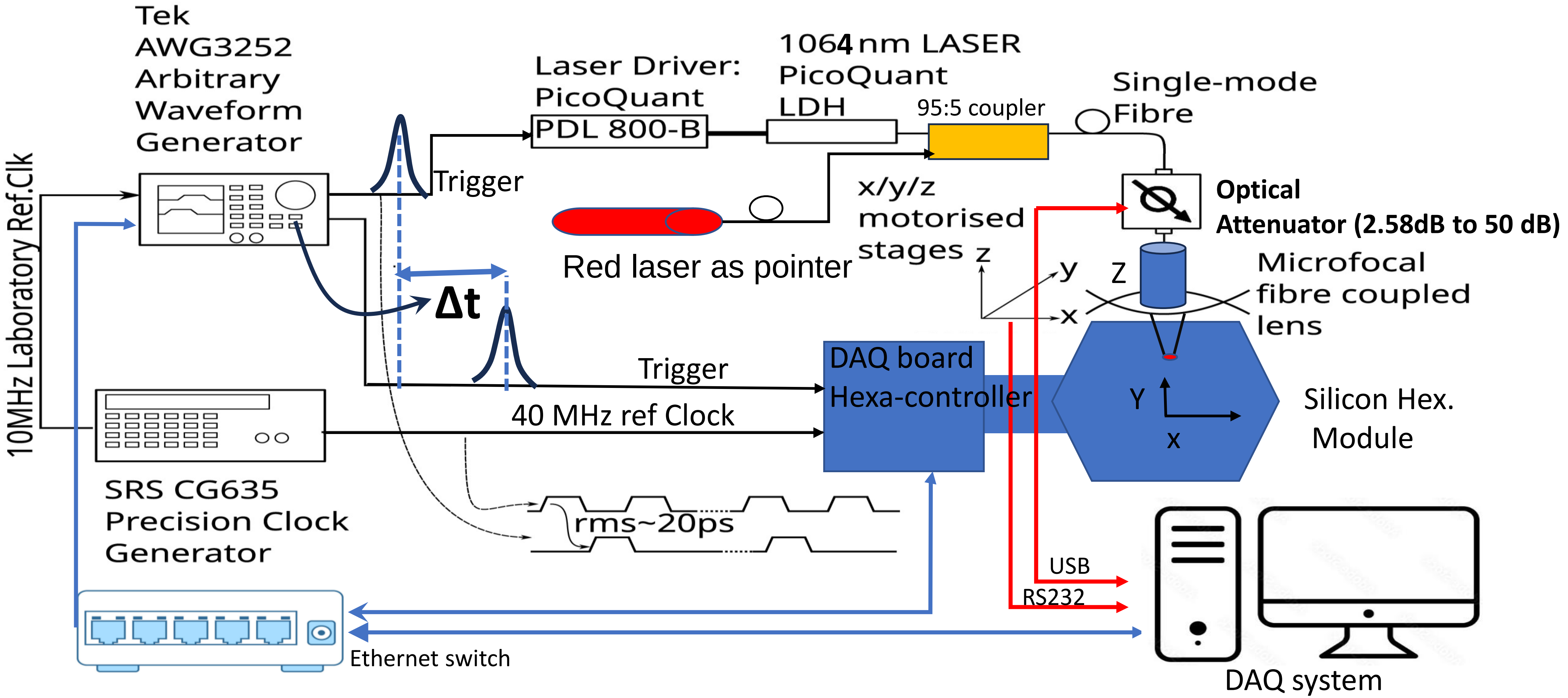
- ❑ We developed a laser system for the Silicon Modules characterization(legacy of NA62, we modified it for HGCAL setup)

Laser   λ=1064 nm, FWHM = 100 ps
Automated: X, Y, Z stage with 0.5um step & Optical Attenuator (2.58 → 50 dB)

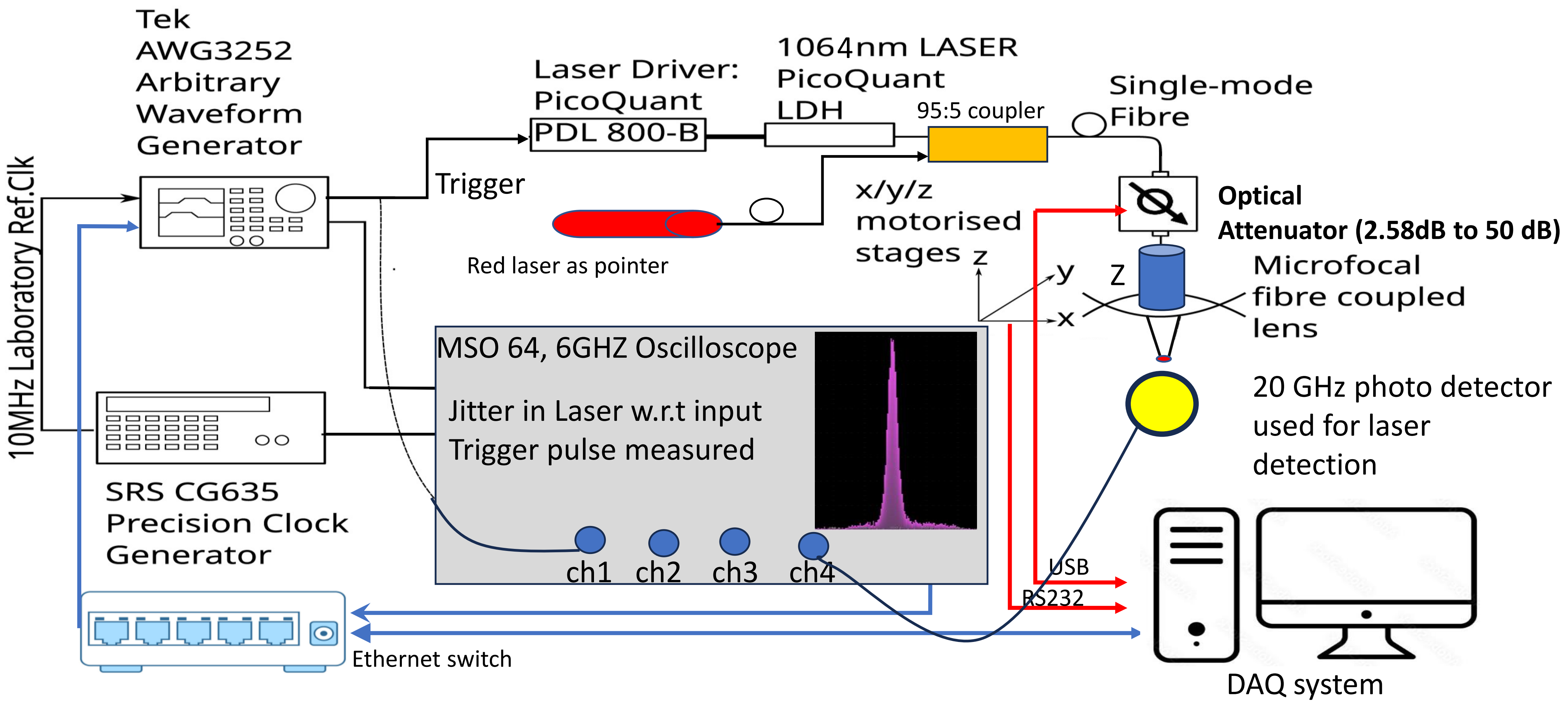


Laser-setup's parts out of the dark room (cabin)

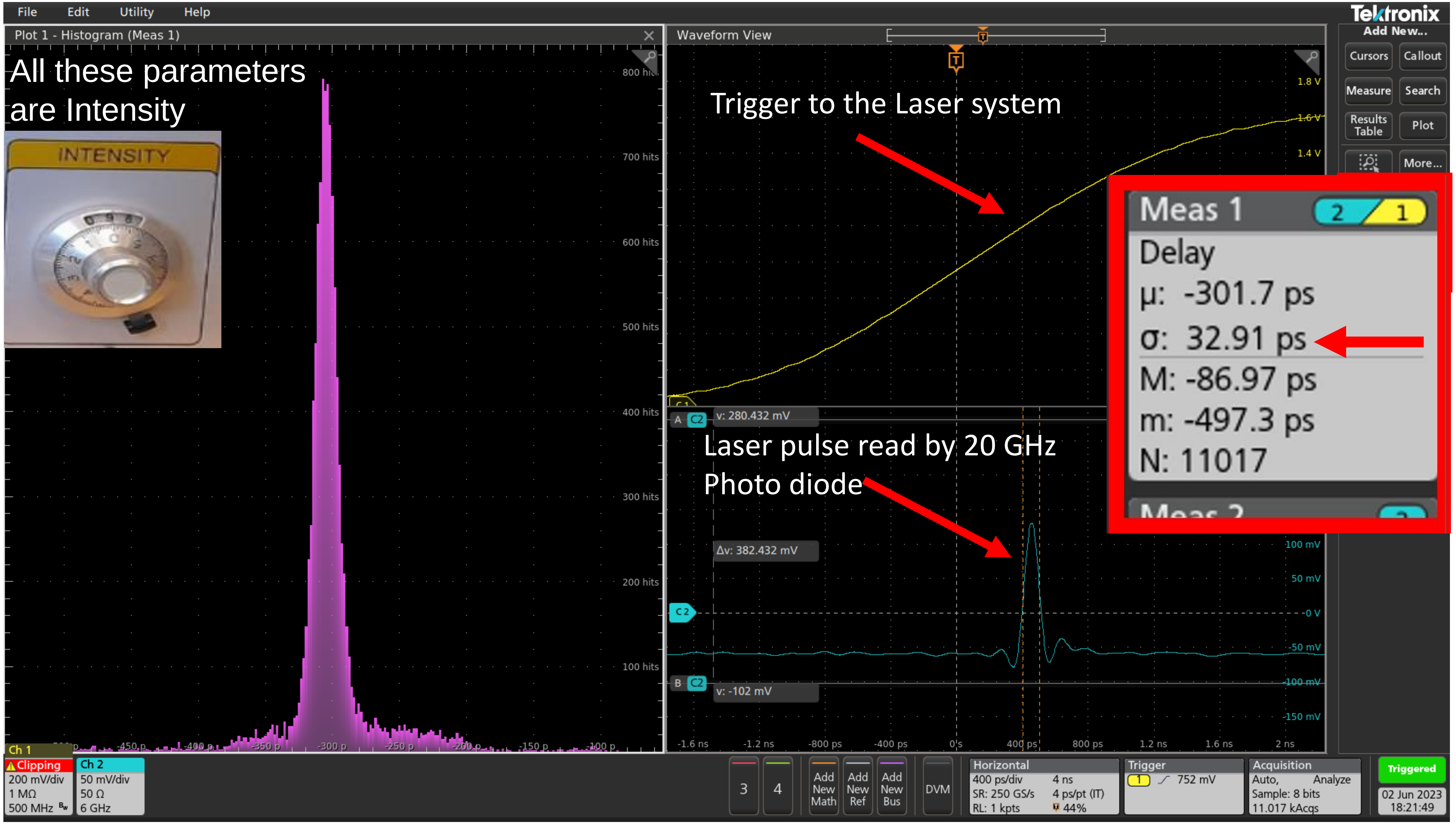
Laser test system for Si-module characterization
Block diagram



Laser system jitter measurements

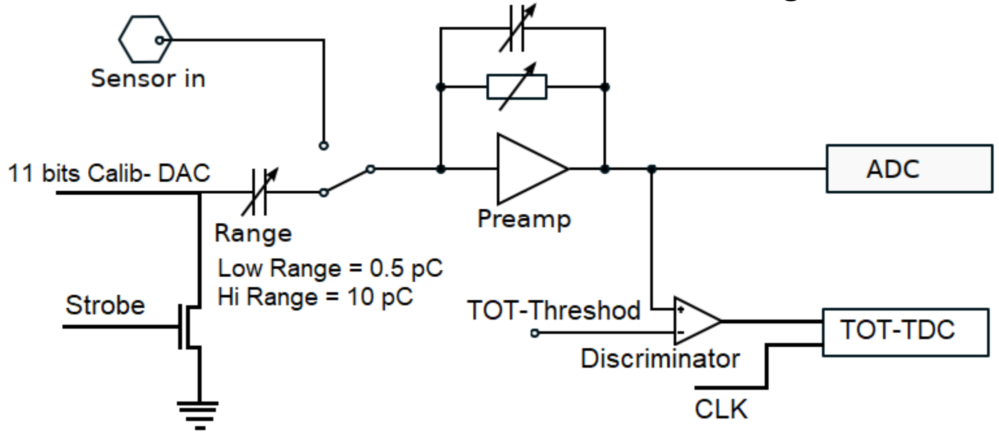


Laser has ~ 33 ps jitter w.r.t Laser Trigger

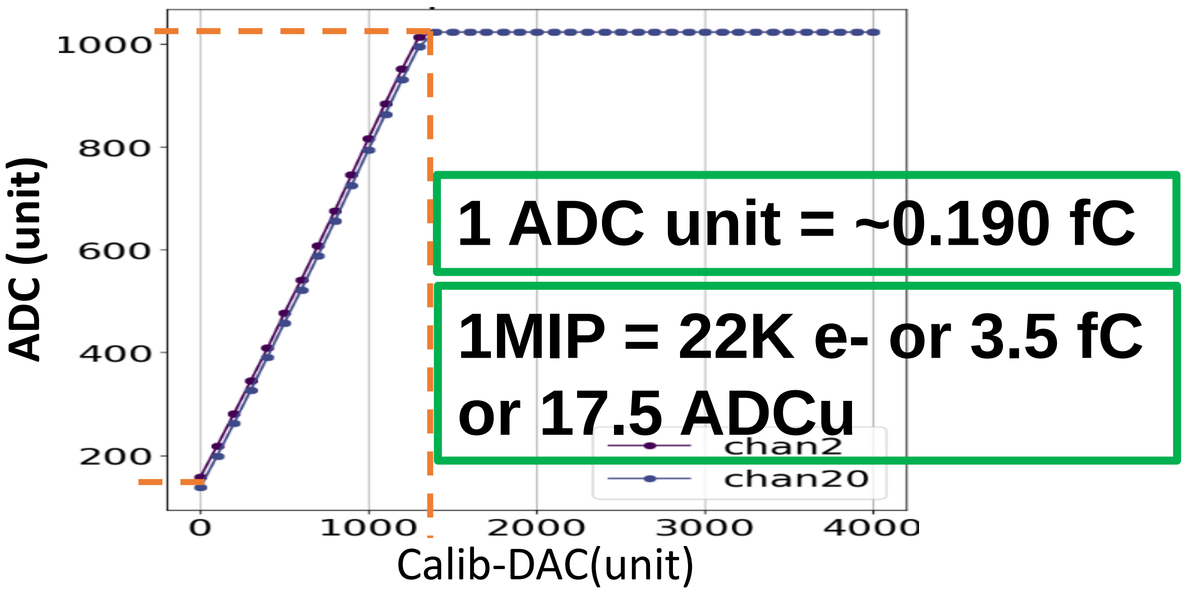


Charge Calibration of HGCROC channel

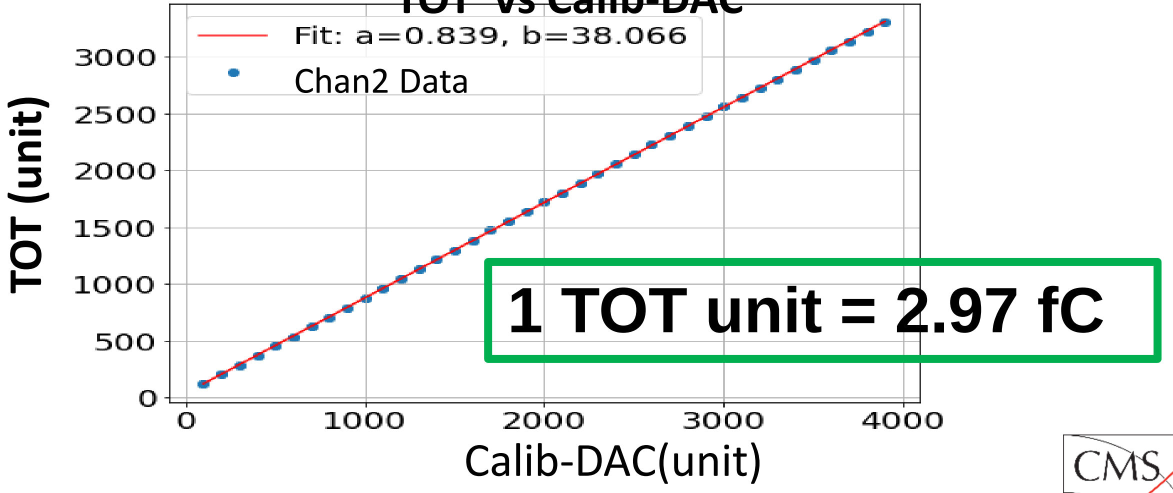
Internal calibration block diagram



ADC vs Calib-DAC



TOT vs Calib-DAC



Two modes

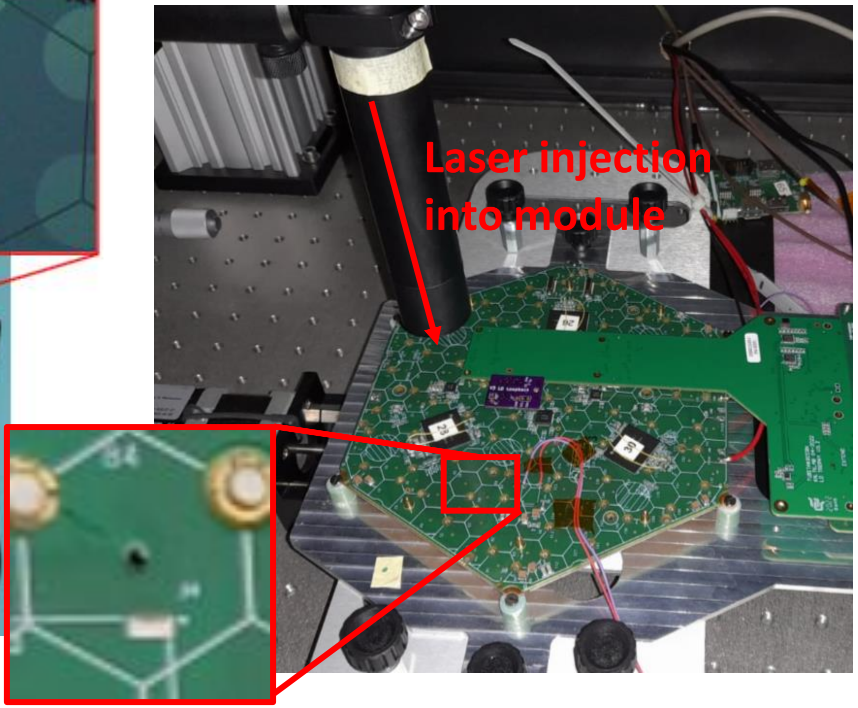
1) ADC calibration:
500 fF Cap used to inject 500fC charge .

2) TOT (Time over Threshold) region:
10 pC charge injected via 10 pF Cap.

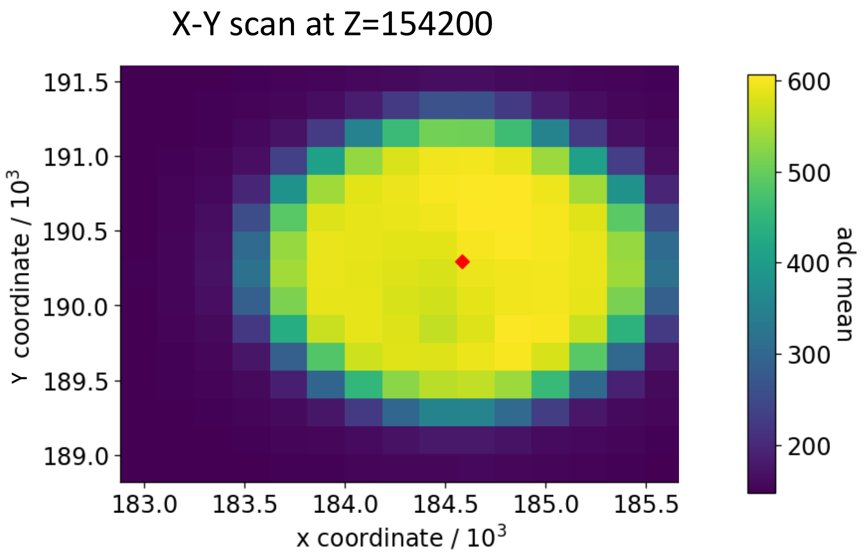
Charge Injection into Si-module by Laser

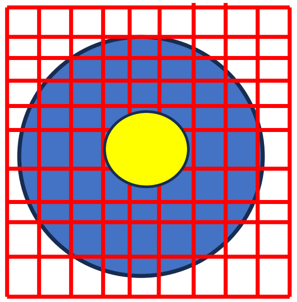
Laser light is injected into the silicon module by holes in the center of cell of the Hexaboard

Silicon sensor with metallization opening(hole) in center of each cell, where laser can be injected



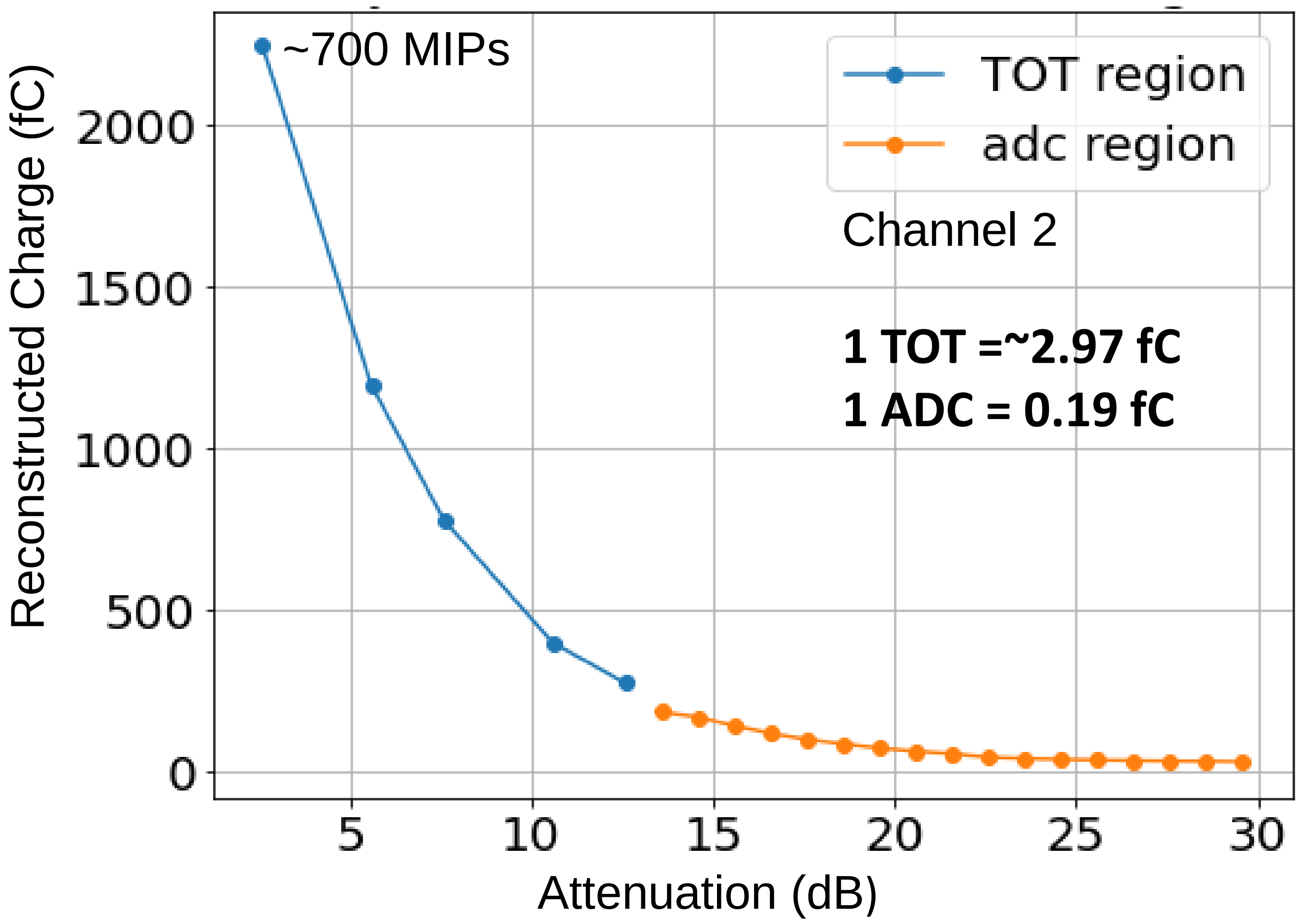
Hole in Hexaboard align to hole in Si are used for injection.





With X & Z stages, Laser Scanning the module cell in the form of a mesh and find out exact center

Laser System's Charge Calibration



- The values of charge injected by Laser are calibrated with ADC and TOT conversion values we got by internal calibration.
- Provide charge variation with 0.01 dB step, ranging from 2.58 db to 50 dB.
- The Max. charge value at 2.58 dB corresponds to ~700 MIPs
- **Precise control on injected charge (0.01 dB) and laser timing (~30 ps) makes it clean environment for silicon modules characterization.**

Time-Walk study of Silicon Module

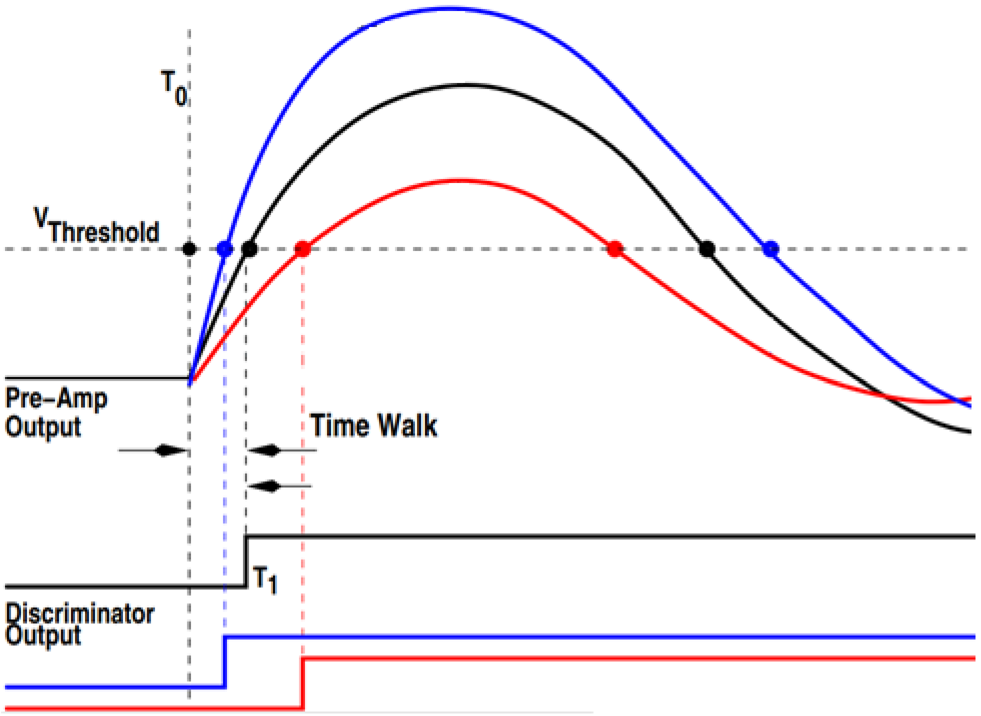
Time-walk:

The dependence of measured time intervals (or time differences) of incoming signal or events on the amplitudes or shapes of the input signals.

Effect in HGCROC:

Time-walk systematically shifts the time of arrival discriminator signal earlier as the signal charge increases.

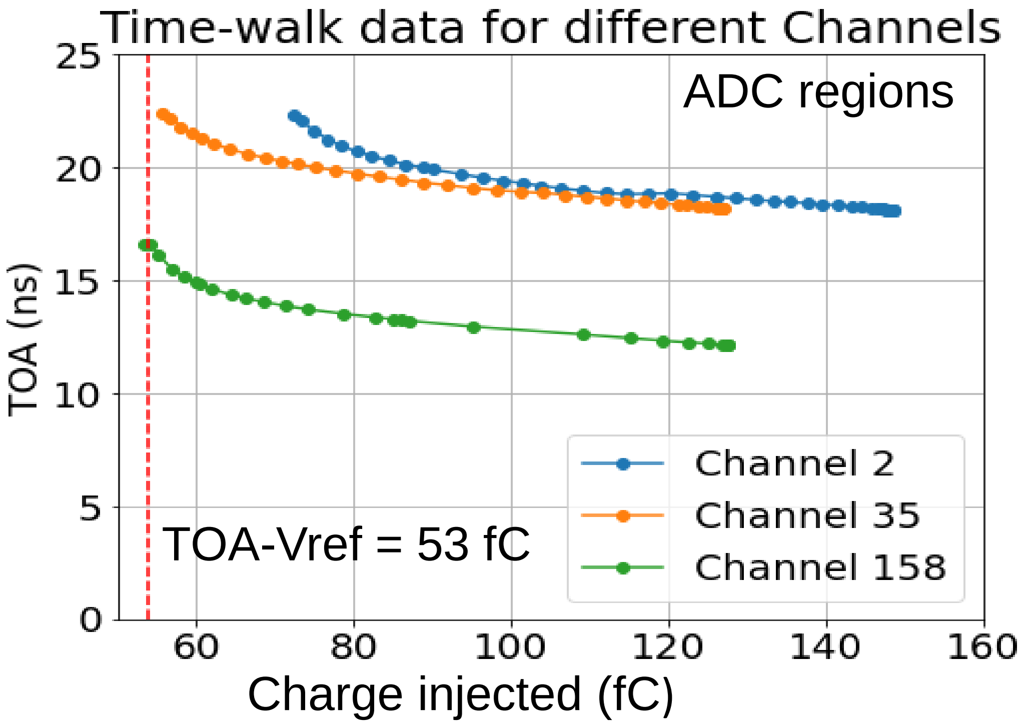
This is due to the signal increased slew rate.

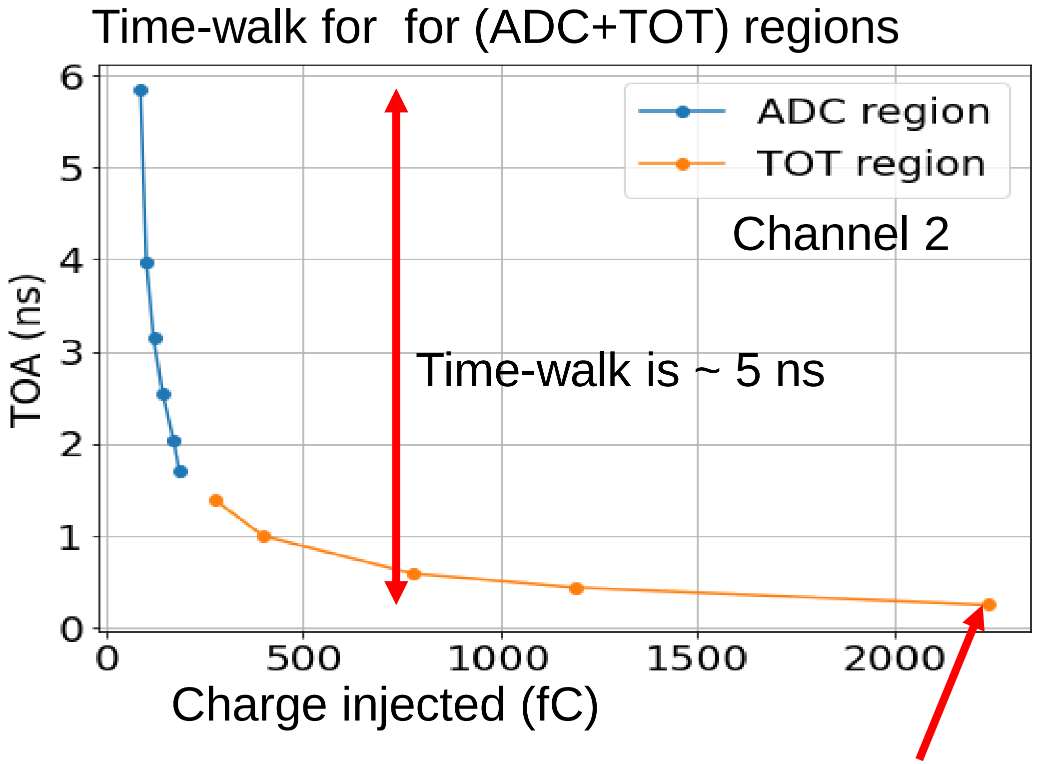


Three signals with different amplitudes crossed same threshold, give three different Time of arrivals at discriminator

Time-Walk study of Silicon Module

Time-walk curves can be produced by injected laser light and varying its intensity by attenuator.





Max Q-injected by Laser @2.58 dB **~700 MIPs**

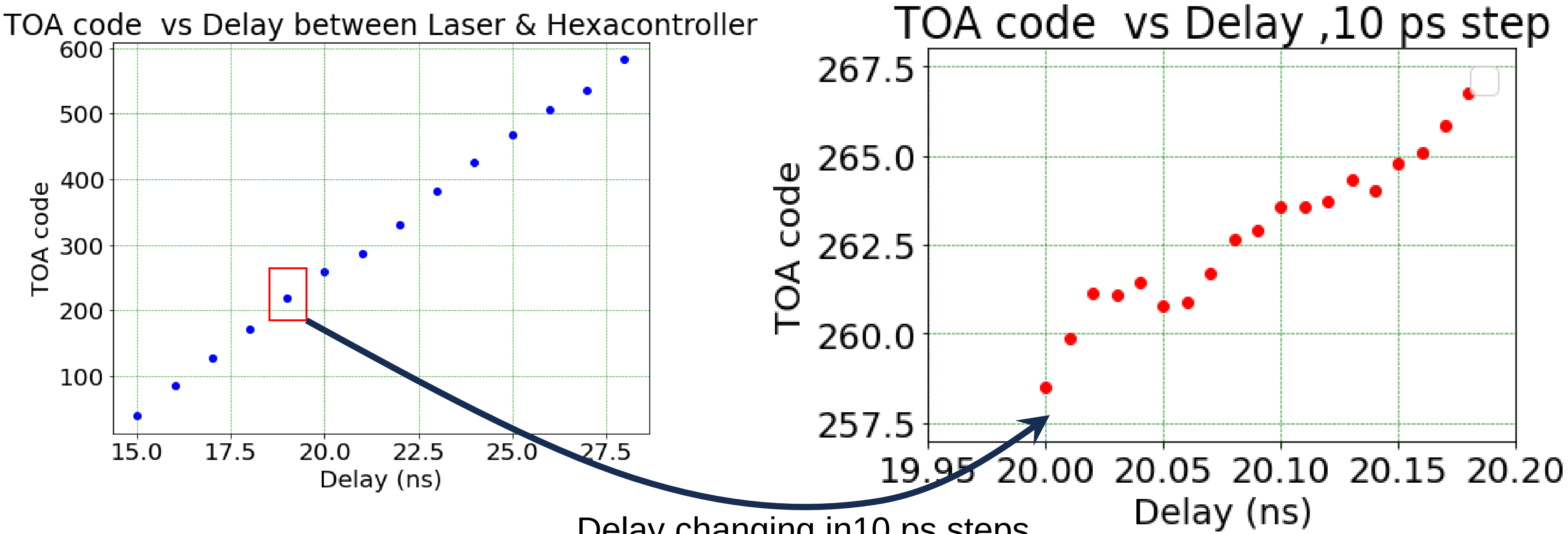
- ❑ **Pk-Pk shift approx. 5ns**
  → we must correct for it using the charge measurement.
- ❑ Time-walk curve be produced for any cell (within the mechanical limits of X-Y stage) of the silicon module.

TOA Calibration's validation(automation is in progress)

Waveform Generator (AFG3252) has minimum delay step of 10 ps, that will be used for TOA calibration confirmation.

Delay (AFG3252) ←linear→ TOA code value.

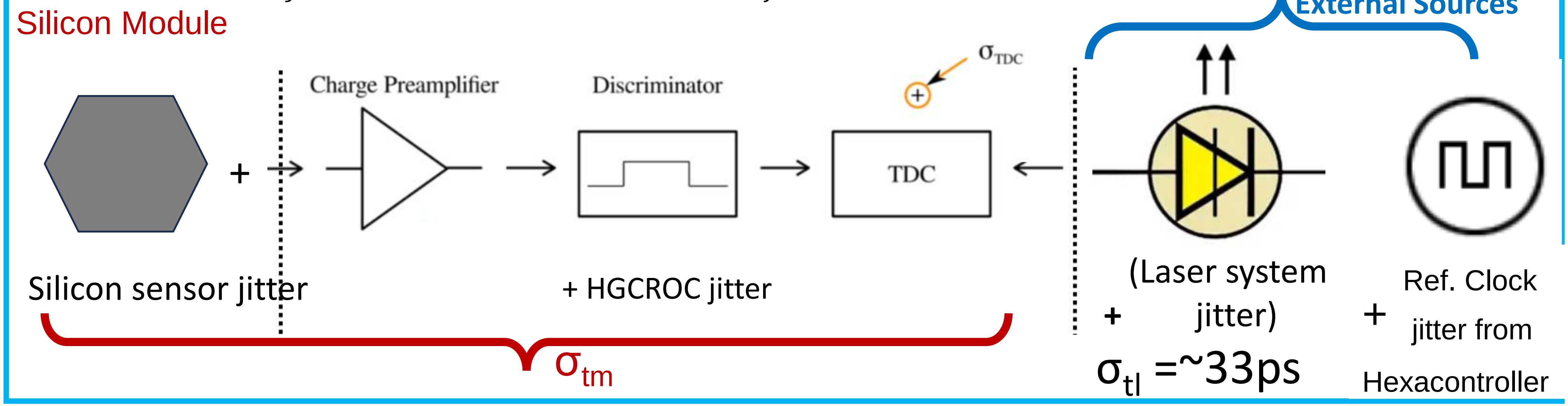
Note:-Currently we did it manually just to show the method, for full range of BX to scan with 10 ps step, we need 2500 value, automation is in progress. The plot showed for un-calibrated TOA



Delay changing in10 ps steps around this point

Next steps for module time resolution

Module measured jitter has included contribution from



Next steps are

- ❑ TOA calibration has to be implemented
- ❑ Ref. Clock jitter to be measured.

$$\textbf{Module Jitter } (\boldsymbol{\sigma}_{\mathbf{tm}}) = \sqrt{(\boldsymbol{module\ measured\ jitter})^2 - (\boldsymbol{Laser\ system\ jitter})^2 - (\boldsymbol{Module\ ref.clock\ jitter})^2}$$

Summary and outlook

- HGCAL is 47-layer sampling Calorimeter that will be installed in LS3.
- ~26,000 silicon module will be produced for Silicon region of HGCAL
- Stringent specifications, many variants, huge production volume demands to have a reliable and precise module characterization system.
- The Laser system developed, with low jitter (30 ps) and control energy 0.01 dB energy steps and upto ~2 pC charge, capable to scan Silicon module (by x, y, z stages), will be used for silicon module characterization.
- The wide energy range (2 pC) gives us provision to use optical coupler or beam splitter to transform this to multichannel setup.

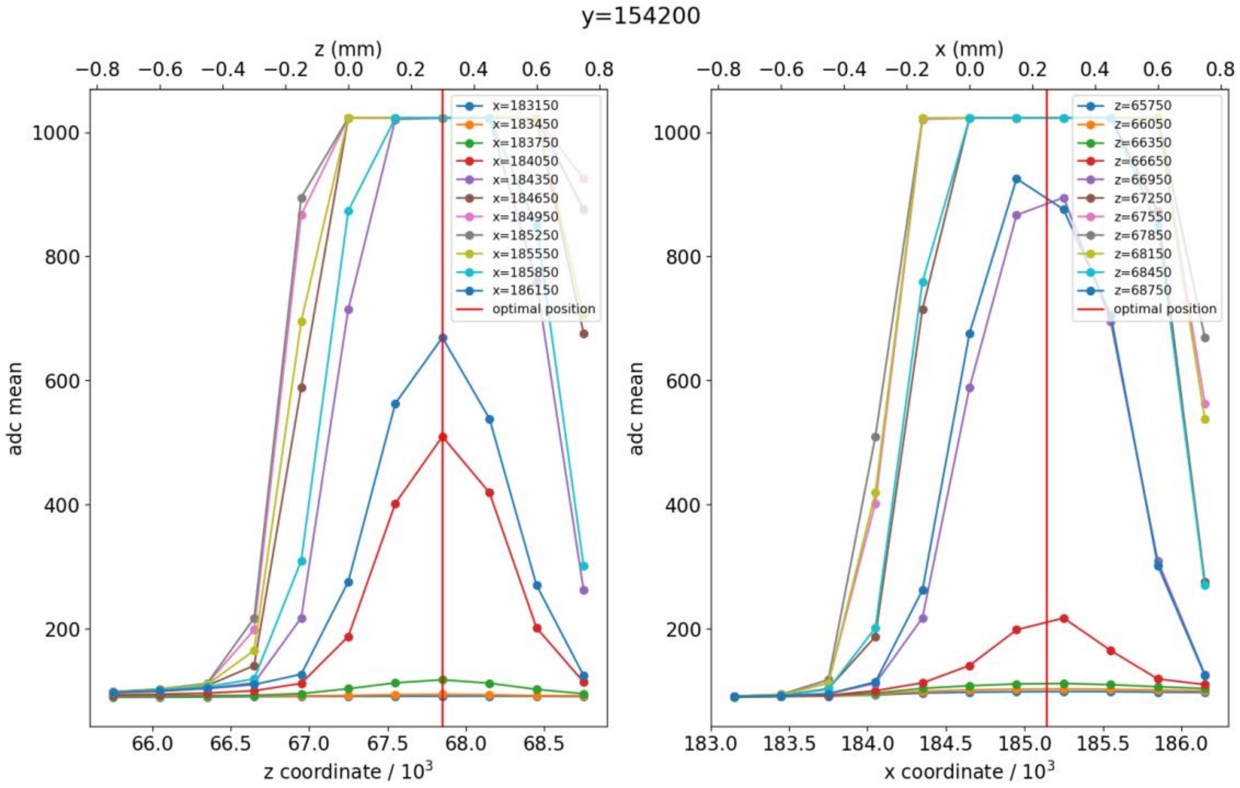
THANKS

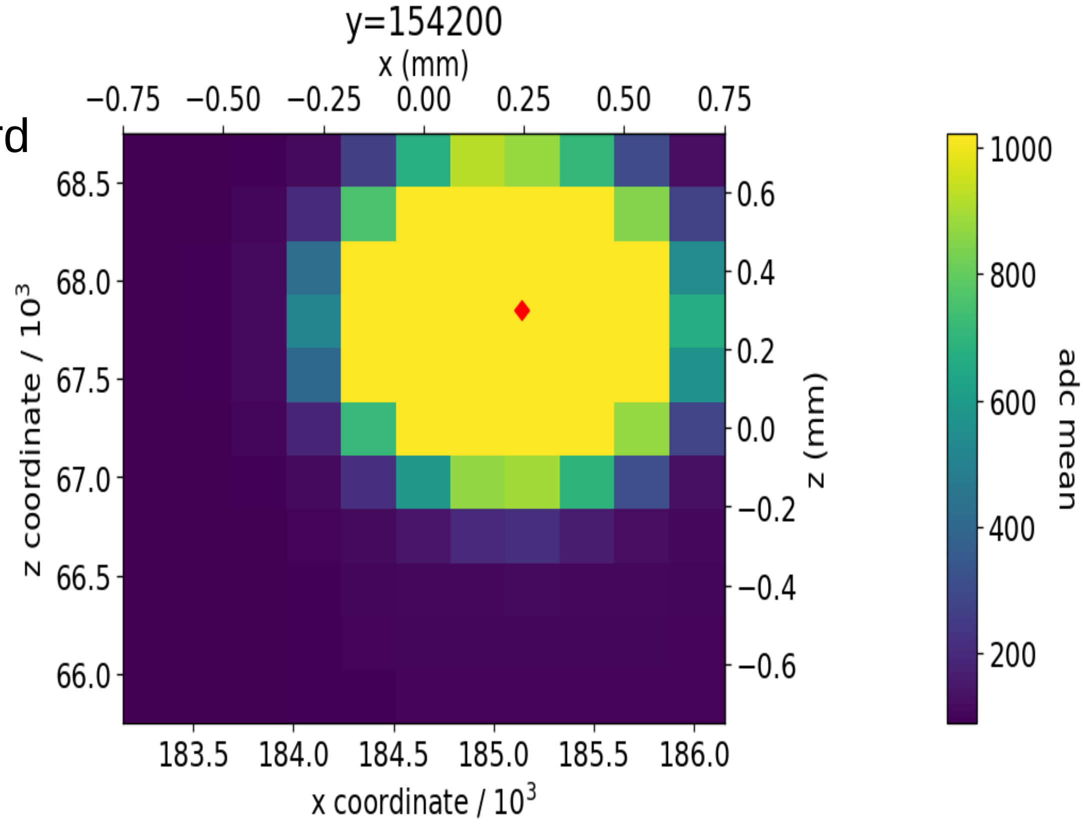
for your attention

Backup

Table Calibration, finding exact center of cell

We scan the opening in si- cell through the hole in Hexaboard using Laser X,Z stage.(Y is the collimation axis, it is fixed to closest position to silicon module Y=154200)
We start with an approximate location and the Laser system scan the area in the vicinity to final exact enter of the si- cell





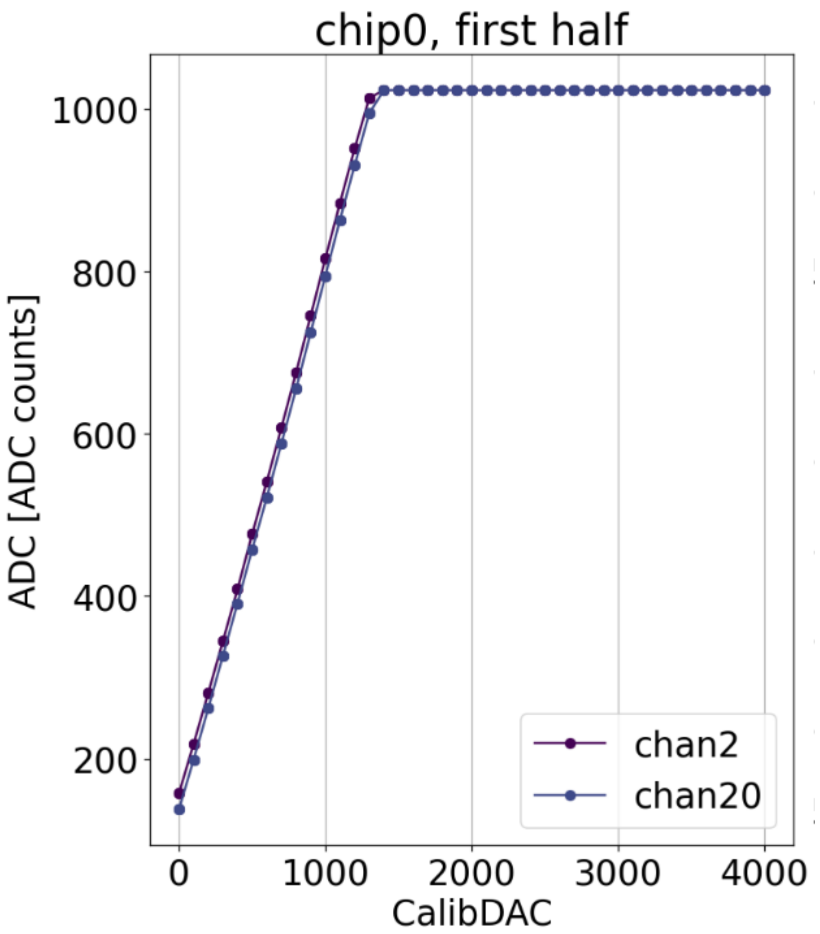
Fields

Column type:

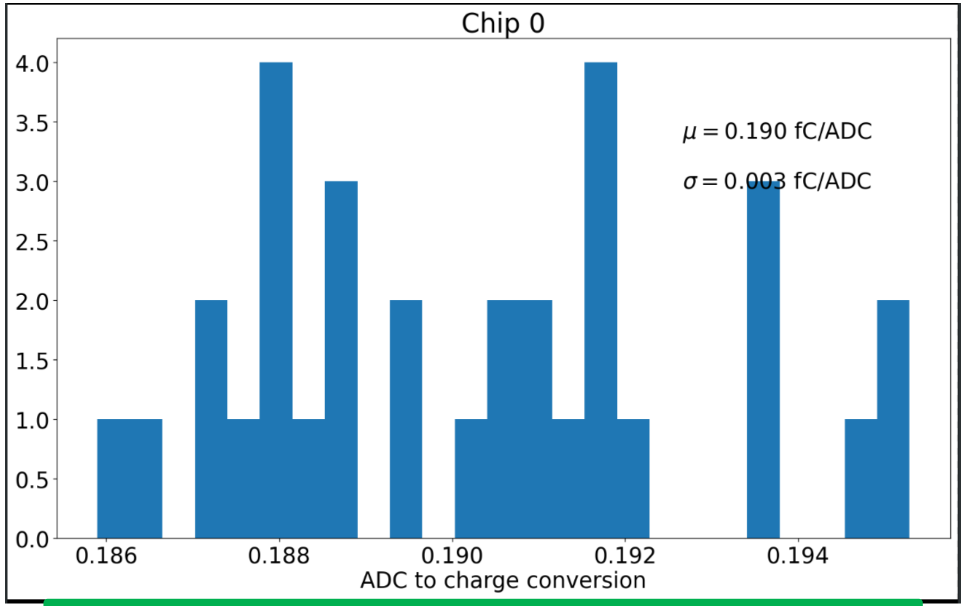
	Standard	Standard	Standard	Standard	Standard	Standard	Standard
1	chan_id	chip	channel	half	x	y	z
2	35	0	35	0	185141	154200	67849

Charge calibration (ADC region)

For typical gain of 160 fC 1ADC unit = 0.190 fC



Internal Injection with 500 fC capacitor
12 bits DAC: 4096 : 500fC
1 Calib DAC: 0.122fC
1023-pedestal = 848 : 1340 Calib DAC & pedestal = 175
848 ADC: 1340*0.122= ~0.190 fC



1 ADC unit = ~0.190 fC

Phase-II upgrades

The Large Hadron Collider (LHC) will see a second phase of high-luminosity operation that is expected to start in 2029.

The **High Luminosity Large Hadron Collider (HL-LHC)** will bring major challenges :

Pile-up : ~50 → 140 – 200

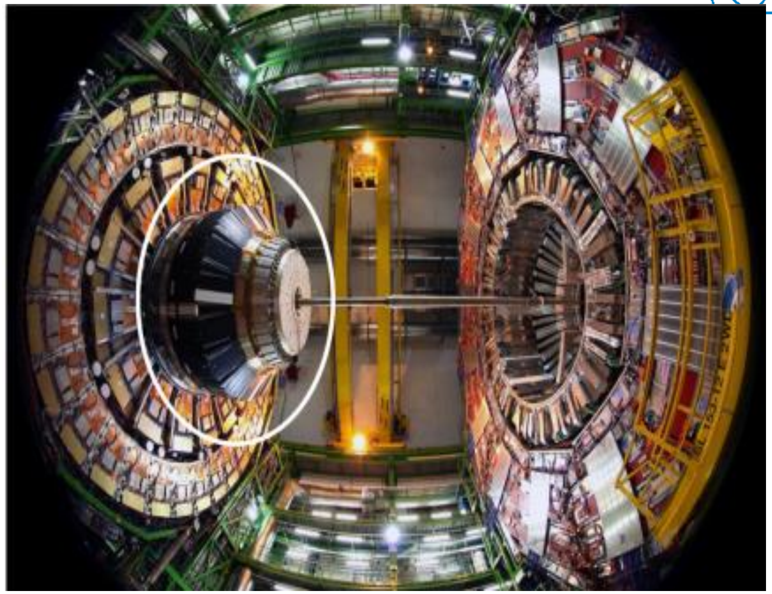
Luminosity: ~ 2× 10^{34} → ~ 5 - 7 × 10^{34} cm^{-2} s^{-1} .

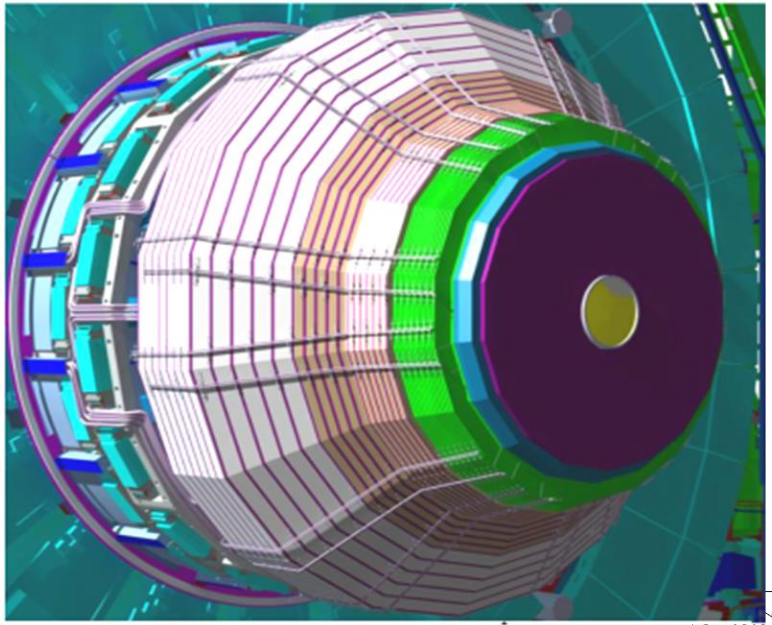
Fluence: ~10^{16} 1 MeV neq cm^{-2} & ~2 MGy @end 3000fb^{-1}

To cope with these challenges

Significant detector upgrades are planned…

- **One very important and major upgrade is HGCAL**
- To replace Endcap Calorimeters ECAL ($PbWO_4$ crystal) & HCAL (plastic scintillator) completely with new calorimeter, the **High-Granularity Calorimeter (HGCAL).**
  - **silicon and plastic scintillator mix**





Introduction to HGCAL

The HGCAL is a 47-layer, sampling Calorimeter that will give 5D information (E,X,Y,Z, time) of incident particles

Key parameters:-

Weight ~250 ton., coverage $1.5 < \eta < 3.0$, operating Temp : -30 C^0.

Two parts: **CE-E** (electromagnetic) & **CE-H** (hadronic)

*Radiation environment: **2** MGy & **8 x 10^{15}** n/cm^2*

Active materials:

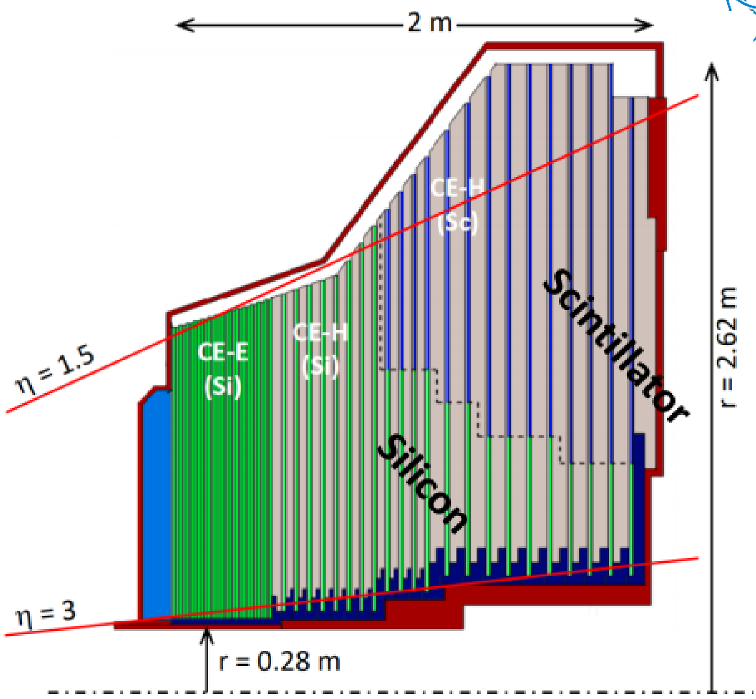
~620 m^2 of Si in CE-E and high rad. zone of CE-H .

~400 m^2 *of* Scintillator tiles with SiPM in low-rad. region.

Very granular

~6M Si-channels to be read out by ~28K Si-Hex modules.

Use the Front-end ASIC HGCROC for readout (designed by OMEGA) .



HGCAL cross sectional view