



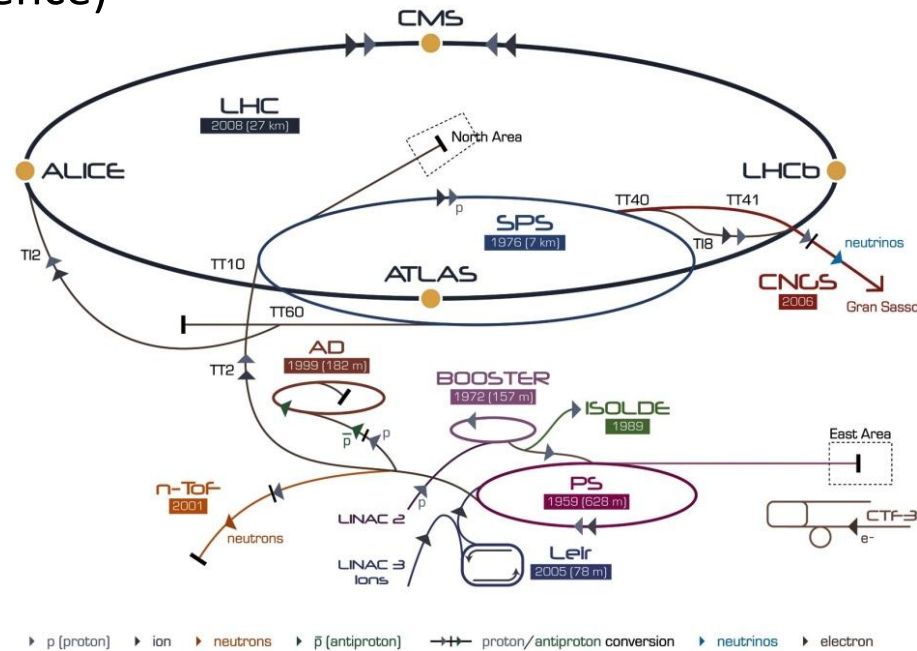
Tests of Semiconductor Detectors for ATLAS Upgrade

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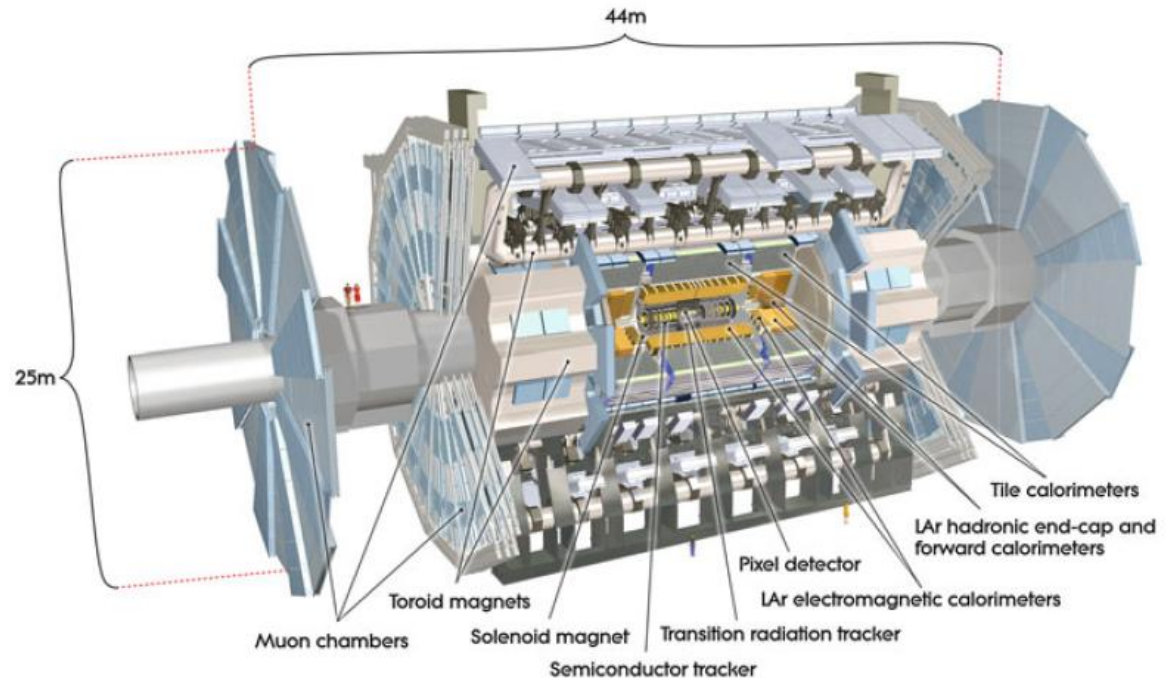
²Institute of Physics, The Czech Academy of Sciences

- the European Organization for Nuclear Research
- world's largest system of accelerators
- Large Hadron Collider (27 km circumference)
 - p-p, Pb-Pb, p-Pb collisions
- Long Shutdown 1 (LS1), 2013 – 2015
 - CMS energy increase (8 TeV -> 13 TeV)
- 7 LHC detector complexes
- leading LHC experiments
 - ATLAS, CMS, ALICE, LHCb

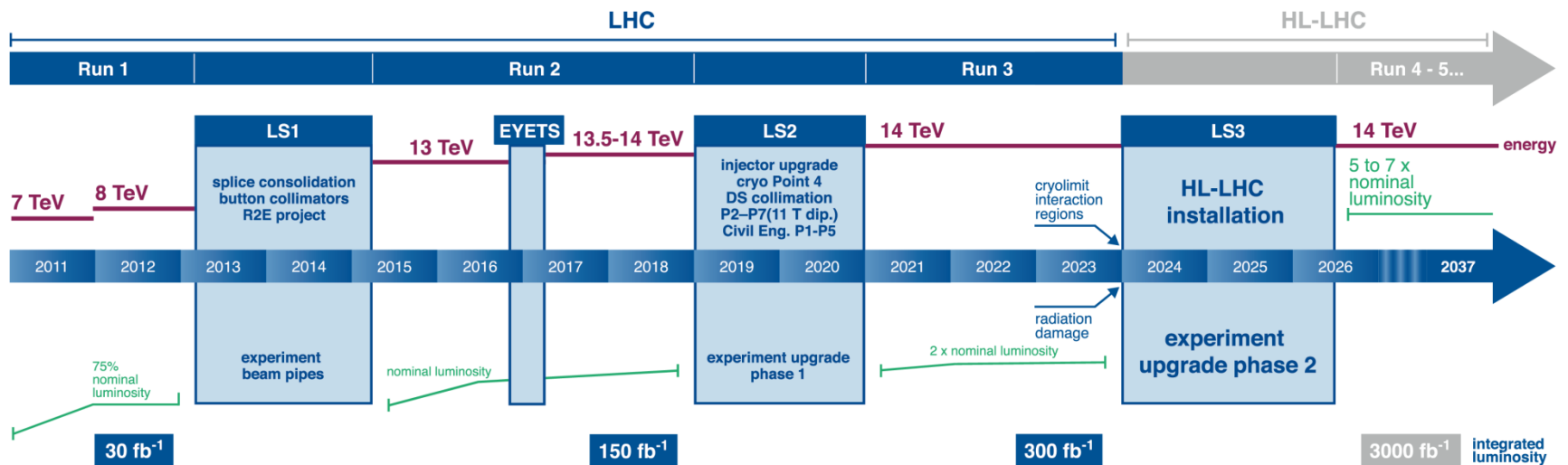


ATLAS Experiment

- general-purpose experiment at the LHC, interaction point
- cylindrical symmetry, several detection subsystems
 - inner detector (ID) – track, vertex, momentum and charge reconstruction
 - calorimeter (LAr, TileCal) - energy reconstruction
 - muon spectrometer (CSC, MDT, RPC, TGC) – muon detection
- magnet system
 - central solenoid (2 T)
 - outer toroid (4 T)

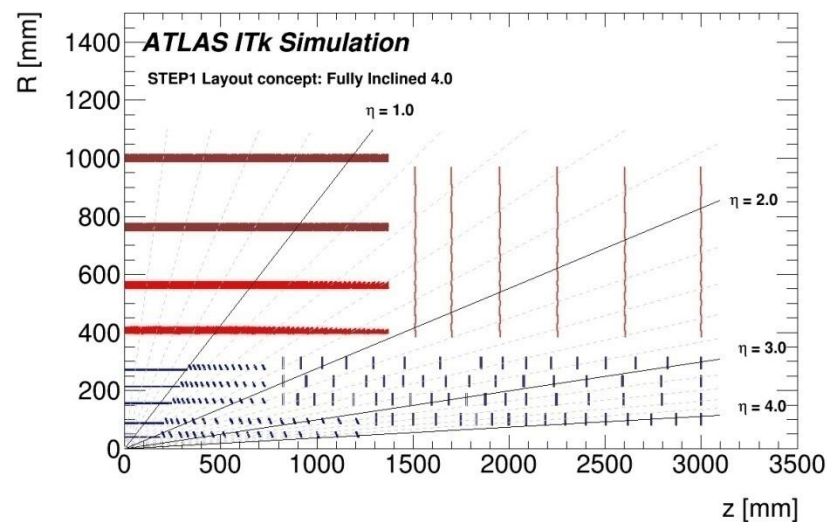
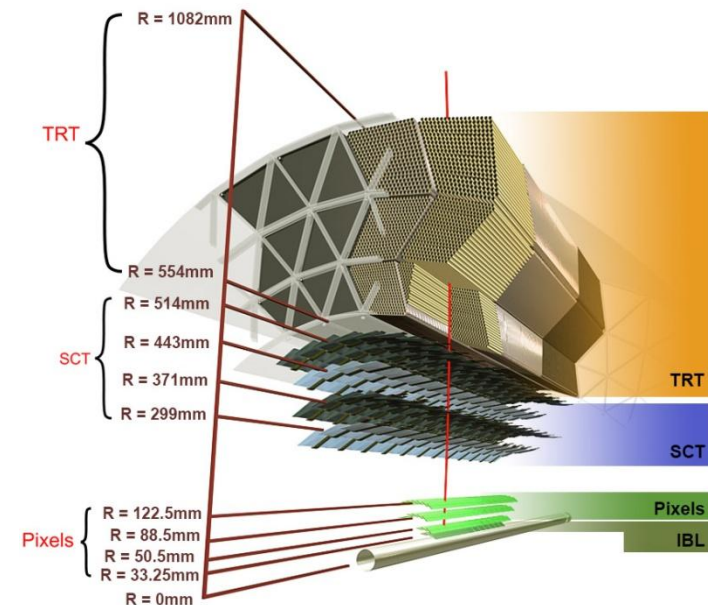


HL-LHC and ATLAS Upgrade Project

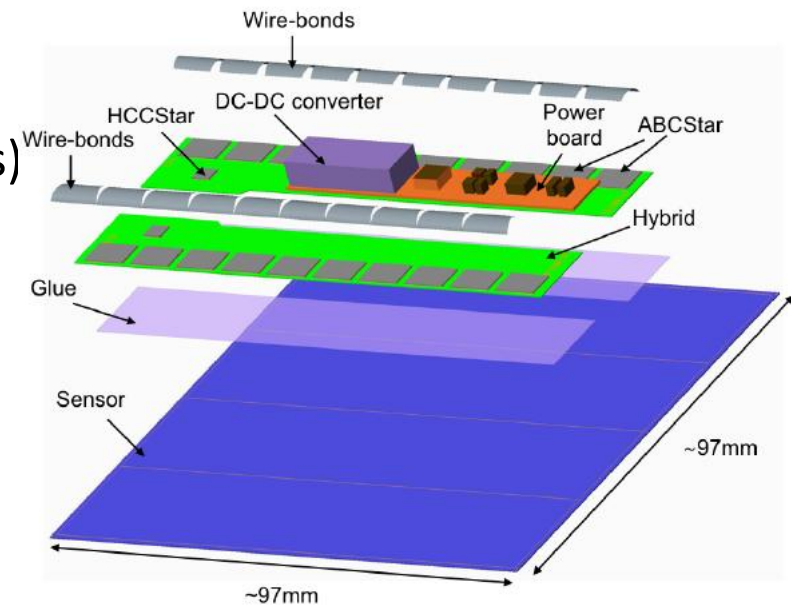
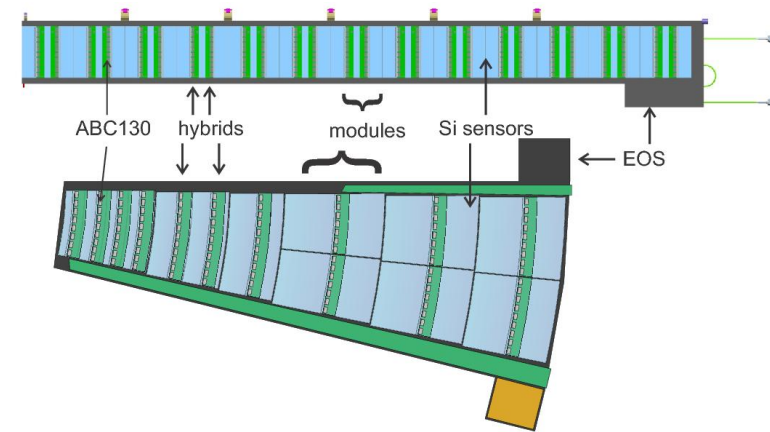


- first beams in 2017 in early May
- LS2: injector upgrade Linac 2 -> Linac 4 – twice higher luminosity
- LS3: new SPL and PS2, upgraded SPS
- ATLAS ID replacement for Inner Tracker (ITk)

- current ID - coverage $|\eta| = 2.5$
 - 4 barrel layers and 6 endcap discs of pixels
 - 4 barrel layers and 18 endcap discs of strips
 - TRT layer with straw tubes
- future ITk - all-silicon tracker, coverage $|\eta| = 4$
 - 5 barrel layers of pixels in inclined layout
 - 32-38 endcap discs in each of 4 pixel layers
 - 4 barrel layers and 12 endcap discs of strips
- motivation - radiation resistance
 - the most resistant layer IBL up to 850 fb^{-1}

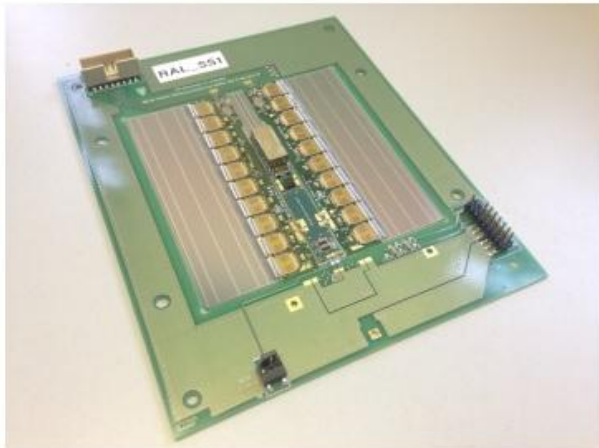
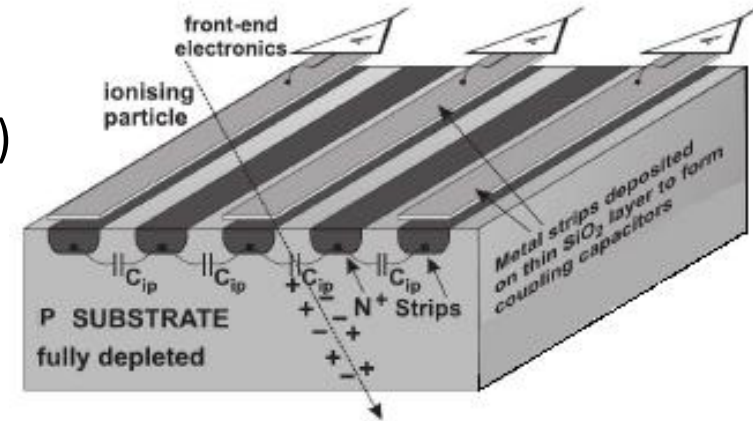


- barrel modules organised in staves and endcap modules in petals
- 6 rings (R0-R5) in petal with different design
- module design:
 - ABC130 readout chips and control chip (HCC) glued on kapton circuits (hybrid)
 - hybrid glued directly on silicon sensor
 - wire bonding (chips on hybrid, strips on chips)
 - End of Structure for powering and readout

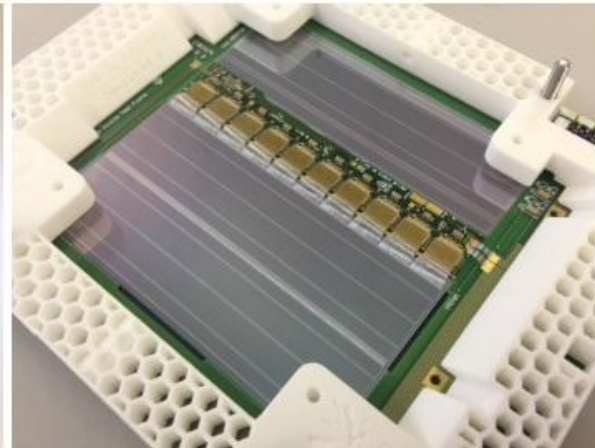


Microstrip Sensors

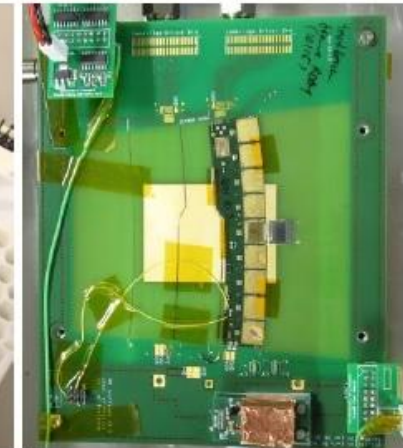
- n^+ strips in p silicon bulk in case of ITk
- larger signal after irradiation than p-in-n (SCT)
- width $320\ \mu\text{m}$, depletion voltage $350\ \text{V}$
- strip pitch $75.5\ \mu\text{m}$ (barrel) and $70\text{-}80\ \mu\text{m}$ (endcap discs)
- pre-production prototypes in tests



Short-Strip Barrel Module



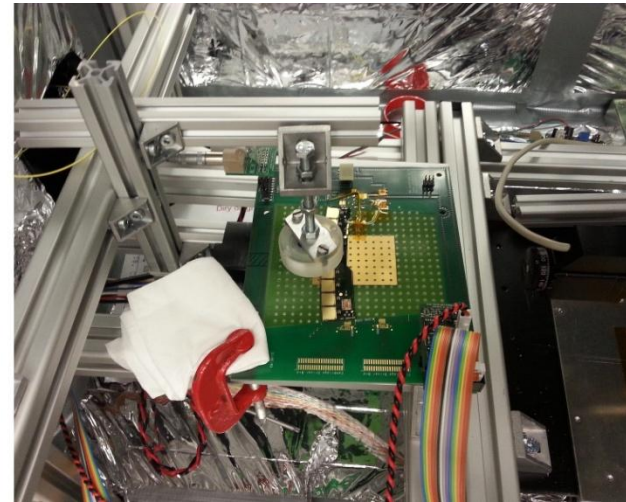
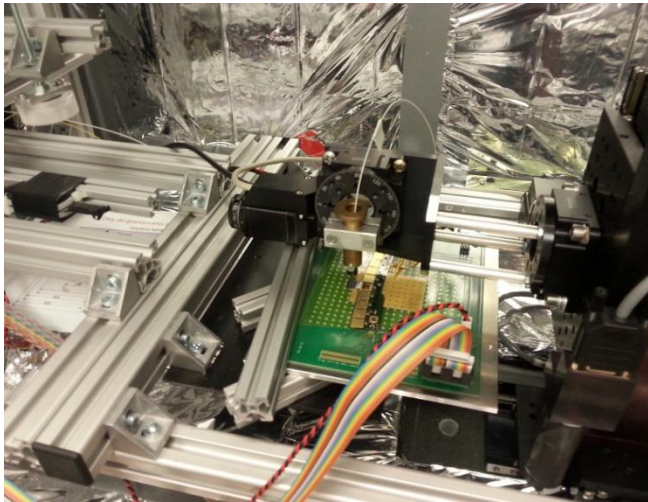
Long-Strip Barrel Module



Endcap DAQload

Testing of Modules

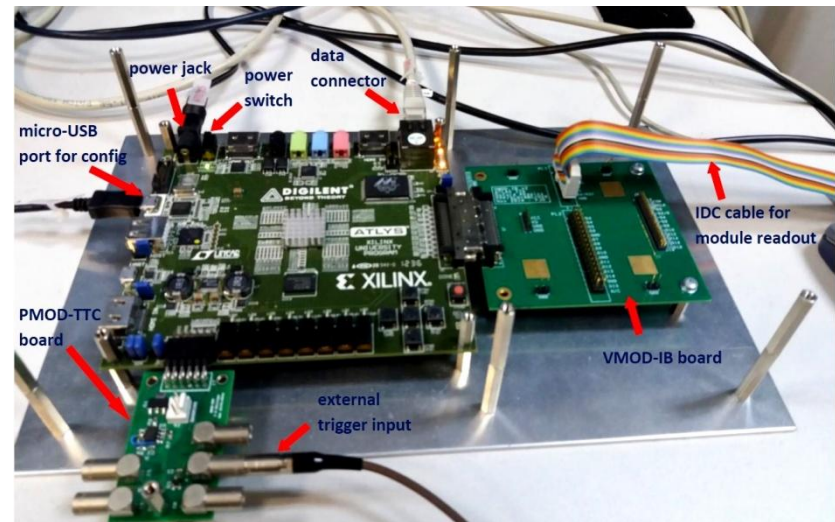
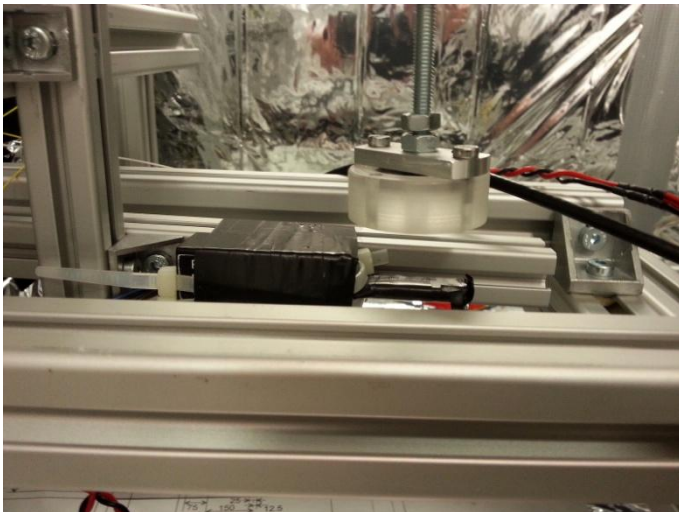
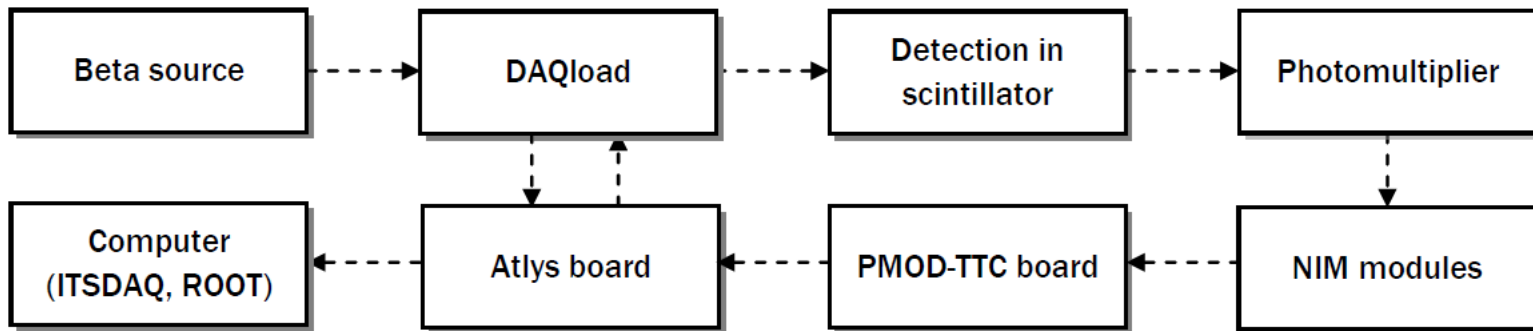
- test beam - accelerated particle beam, expensive, less available, tracking
 - CERN (120 GeV pions), DESY (4 - 4.8 GeV electrons)



- laser tests - available, cheap, good spatial resolution, adjustable intensity
- beta source tests - electrons from beta source, available, cheap, no tracking
 - both setups in operation at IPNP, **newcomers welcome**

Beta Source Test Setup

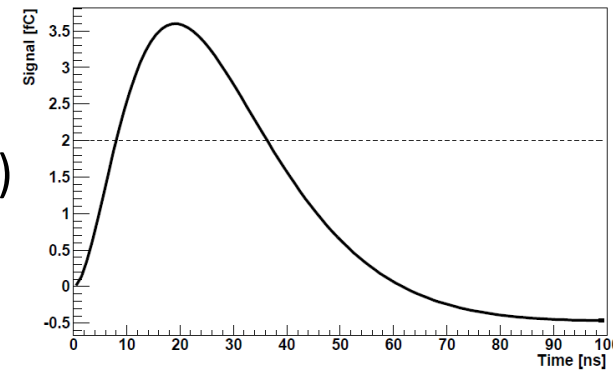
- beta source ^{90}Sr , electrons collimated in plastic collimator, mini sensor ($1 \times 1 \text{ cm}^2$)
- scintillator as an external trigger, Atlys board for readout, software ITSDAQ, ROOT



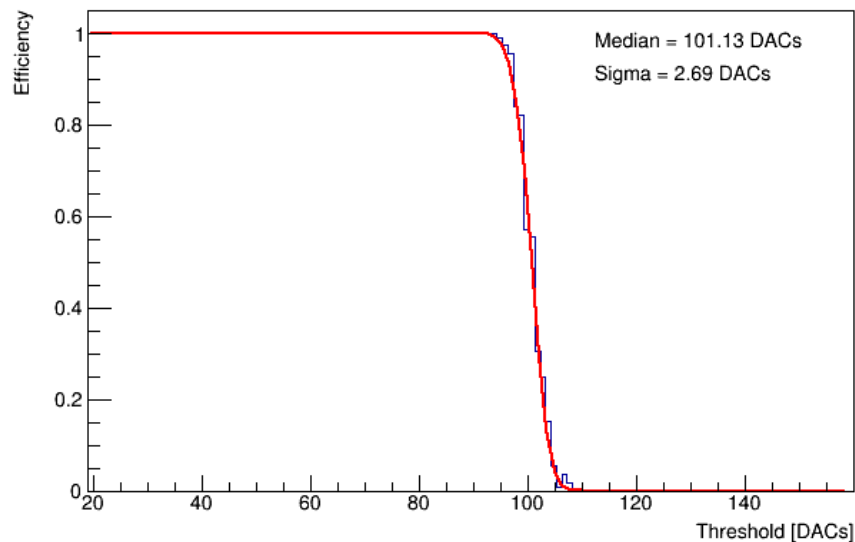
Threshold Scan

- basic ITSDAQ scan, amplitude reconstruction using binary readout
- integral form of convolution of noise and signal distrib.
 - skewed complementary error function (4 parameters)

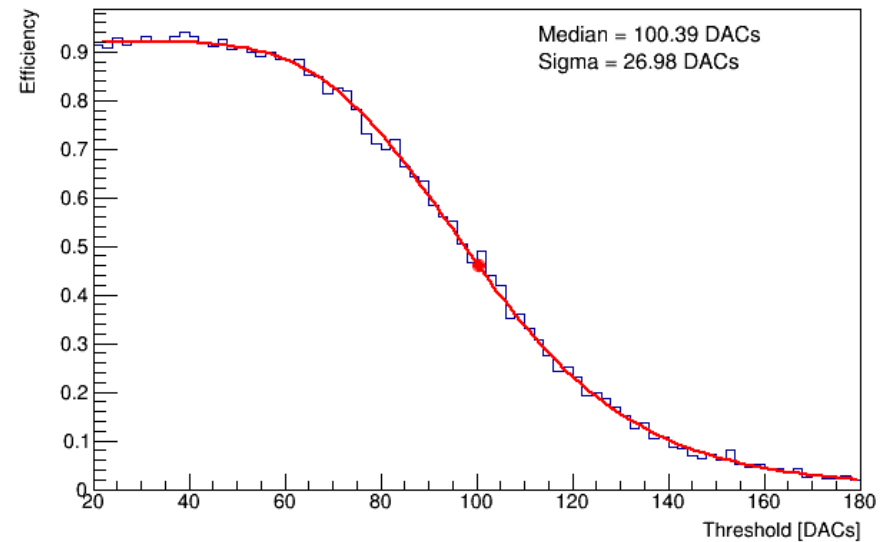
$$f(x) = \epsilon_{max} \text{Erfc} \left[x \left(1 + 0.6 \frac{e^{-\xi x} - e^{\xi x}}{e^{-\xi x} + e^{\xi x}} \right) \right]$$



Threshold scan at 3.01 fC

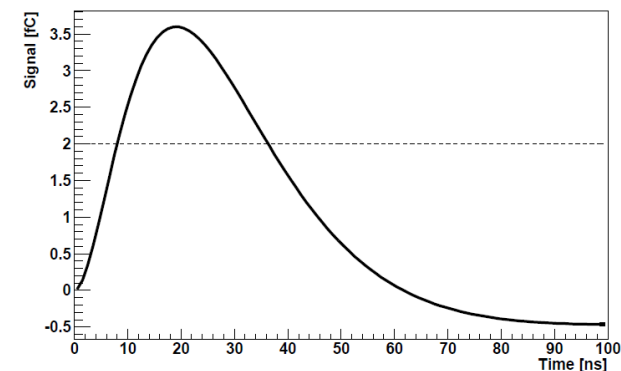


Threshold scan for bias_400V_1000trg_latency_10

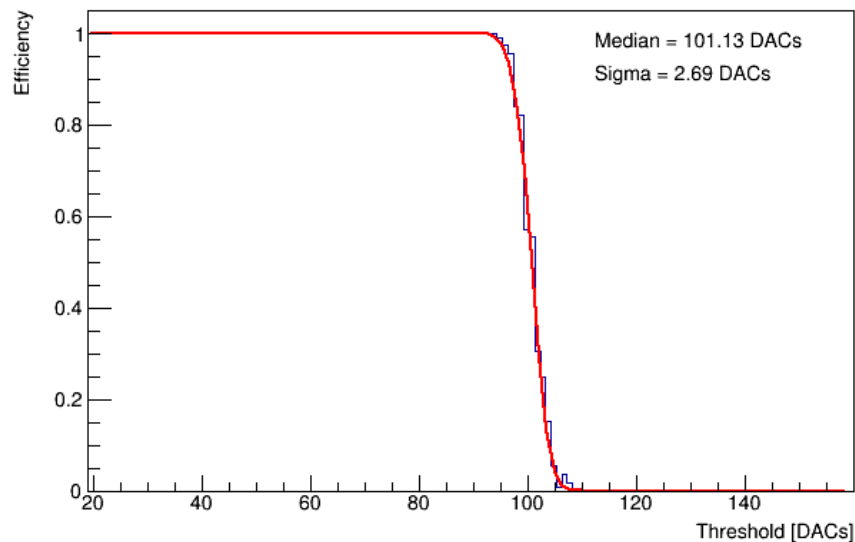


Threshold Scan

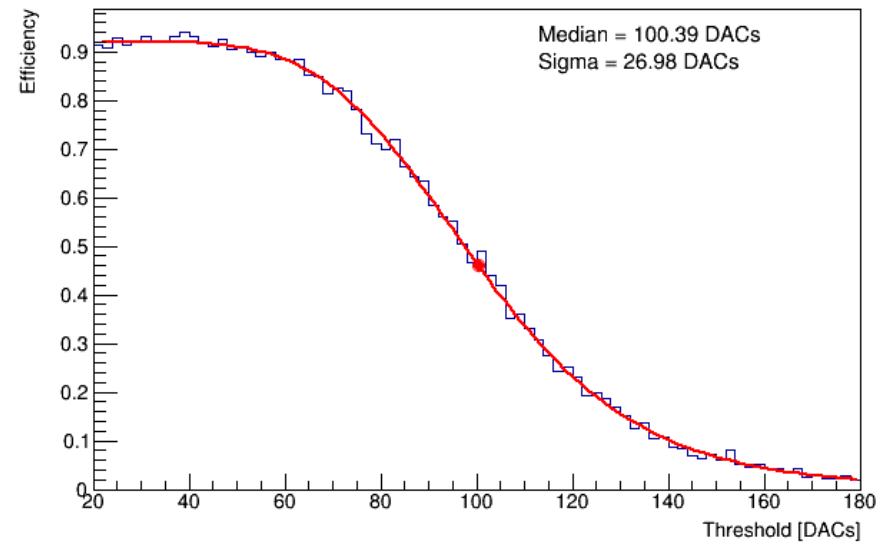
- basic ITSDAQ scan, amplitude reconstruction using binary readout
- critical parameters
 - collected charge, noise, hit efficiency, gain, S/N
- calibration scan (gain, ENC)
- beta source scan (50% point = V_{t50})



Threshold scan at 3.01 fC

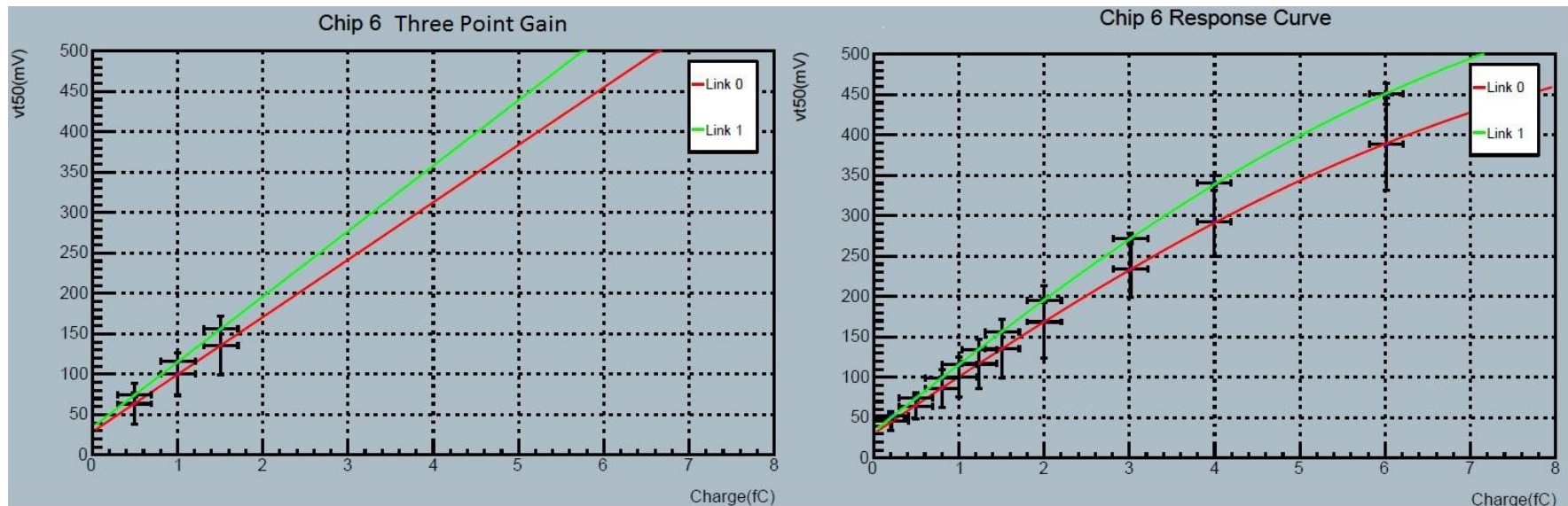


Threshold scan for bias_400V_1000trg_latency_10

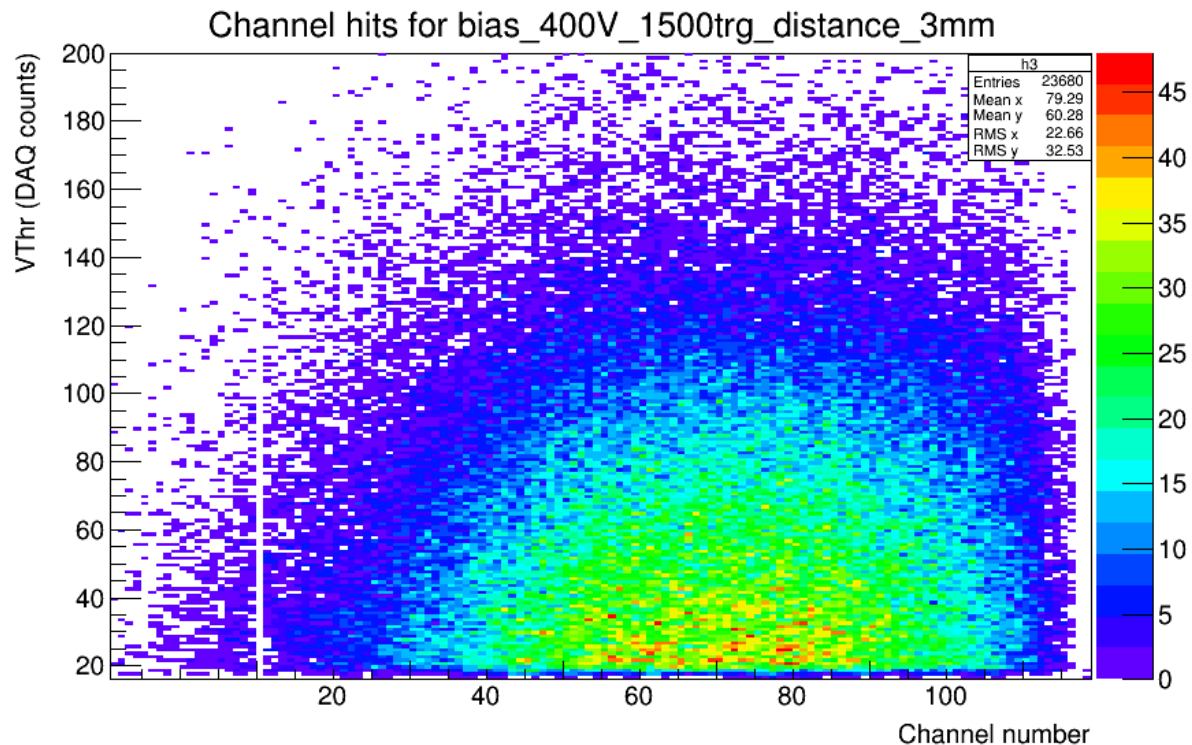


Calibration

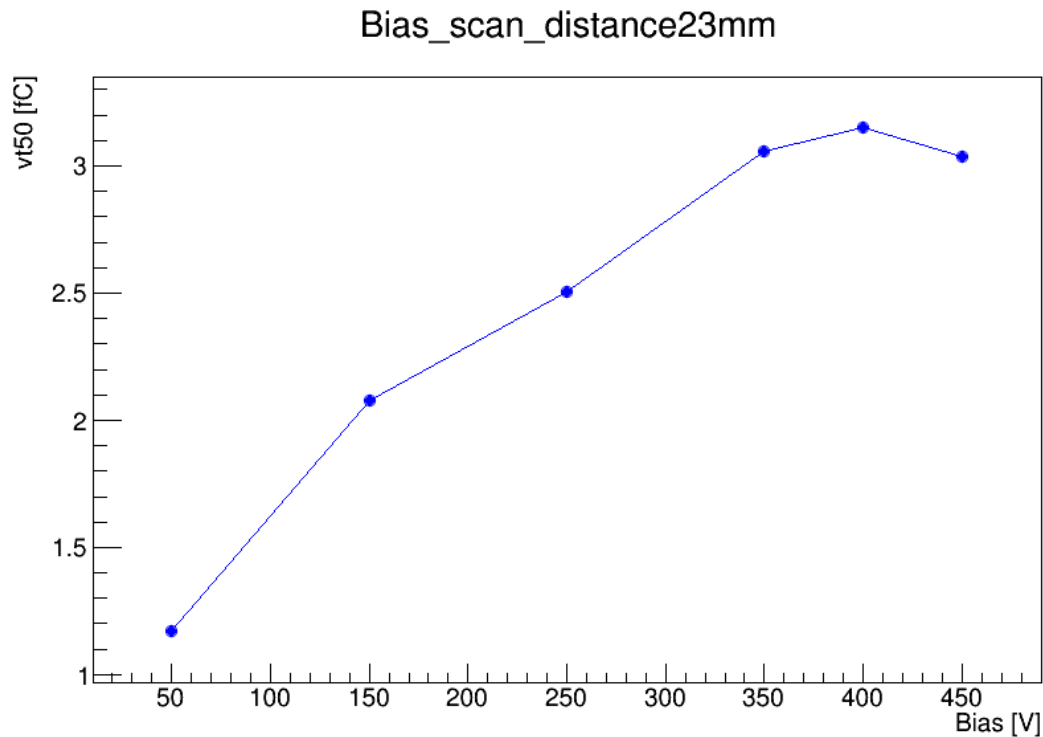
- internal ITSDAQ units DACs, conversion to fC required
- DACs-to-mV conversion using ABC130 chip simulation
- mV-to-fC conversion using injected charge through calibration circuit
- Three Point Gain (linear, gain + offset), Response Curve (non-linear, 3 parameters)



- bias scan, angular scan, temperature scan, FE parameters scan, latency scan
- hit map for 128 bonded channels (Link 1)
- $U_{\text{bias}} = 400 \text{ V}$ (fully depleted), 1500 triggers (events) per threshold
- cut-off rules for analysis: 1 cluster/event, cluster size < 6

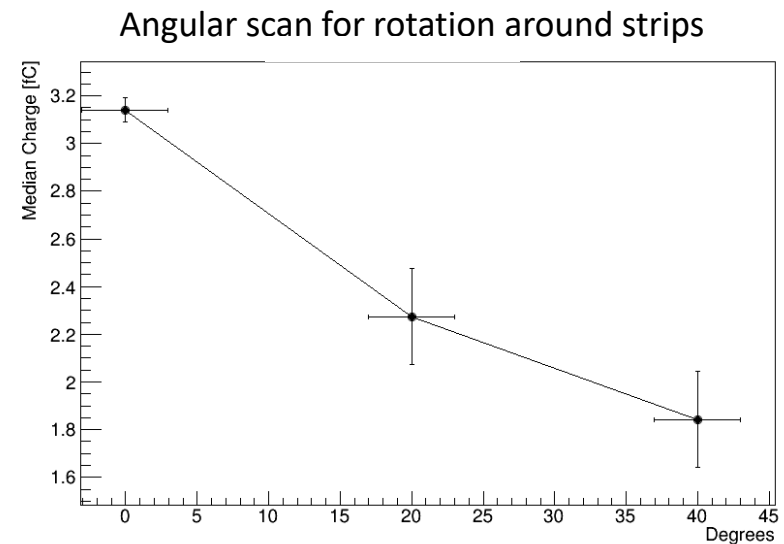
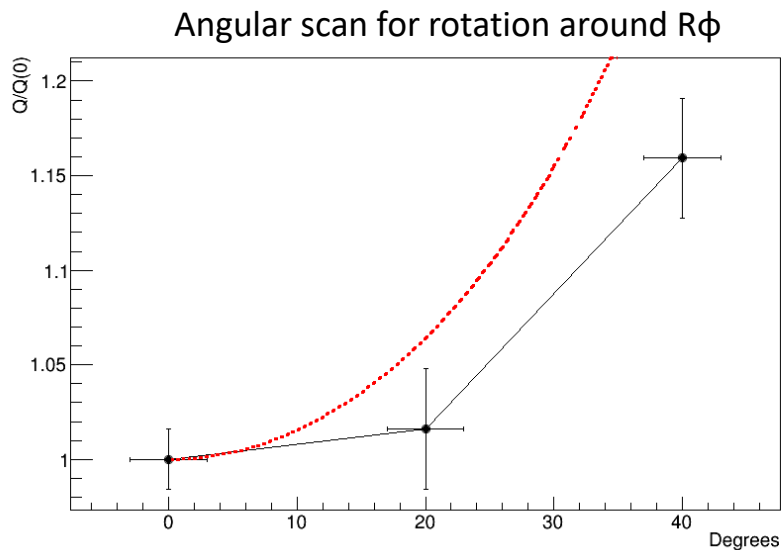


- idea: decrease of collected charge (V_{t50}), when sensor is not fully depleted
- specification - 320-380 V, source tests - around 350 V
- collected charge (3.1 ± 0.1) fC , noise (ENC) $550 e^-$, S/N 35



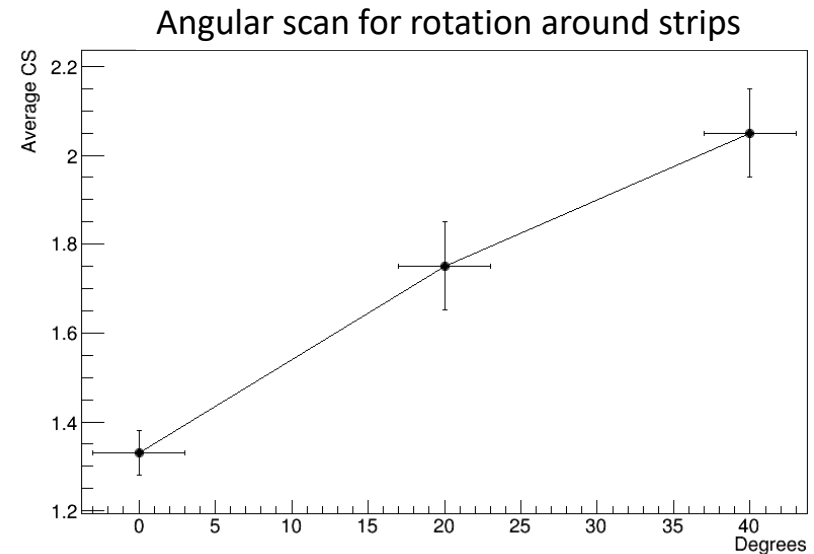
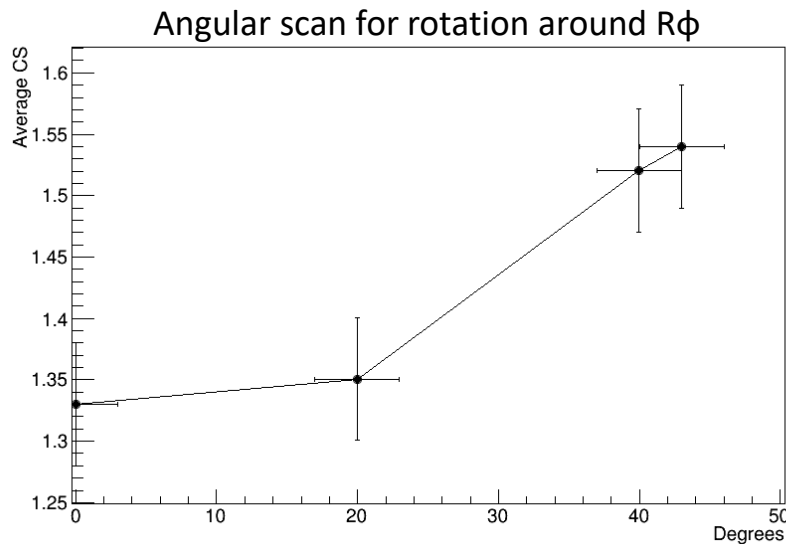
Angular Scan

- source rotation around axis perpendicular to strips in the sensor plane
 - decrease of V_{t50} and increase of cluster size
 - comparison with geometric relation $1/\cos(\alpha)$ (red dotted line)
- source rotation around axis parallel to strips
 - increase of V_{t50} and cluster size



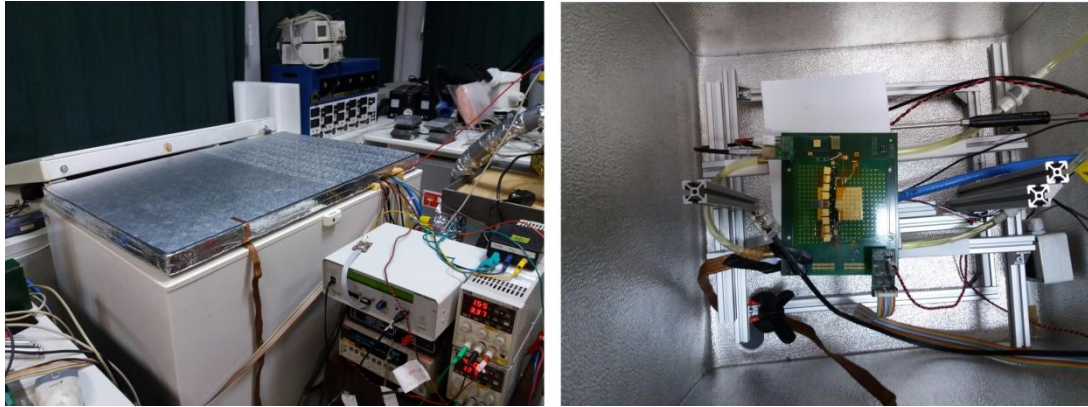
Angular Scan

- source rotation around axis perpendicular to strips in the sensor plane
 - decrease of $Vt50$ and increase of cluster size
- source rotation around axis parallel to strips
 - increase of $Vt50$ and cluster size
- cluster size = number of neighboring strips with hit

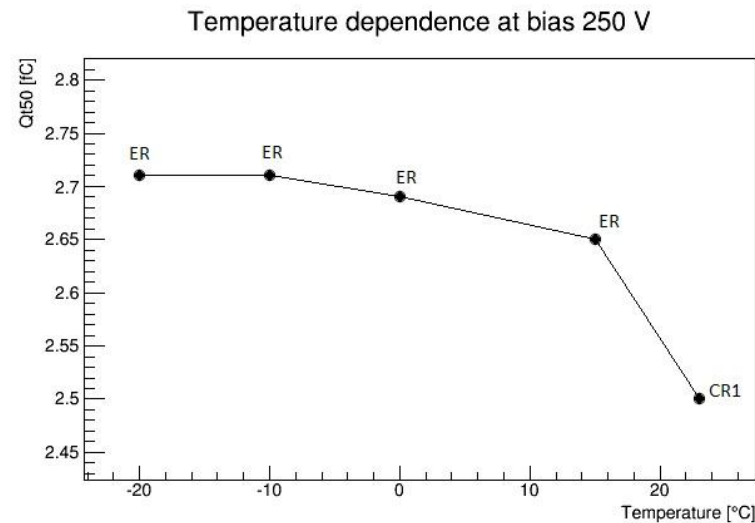


Temperature Scan

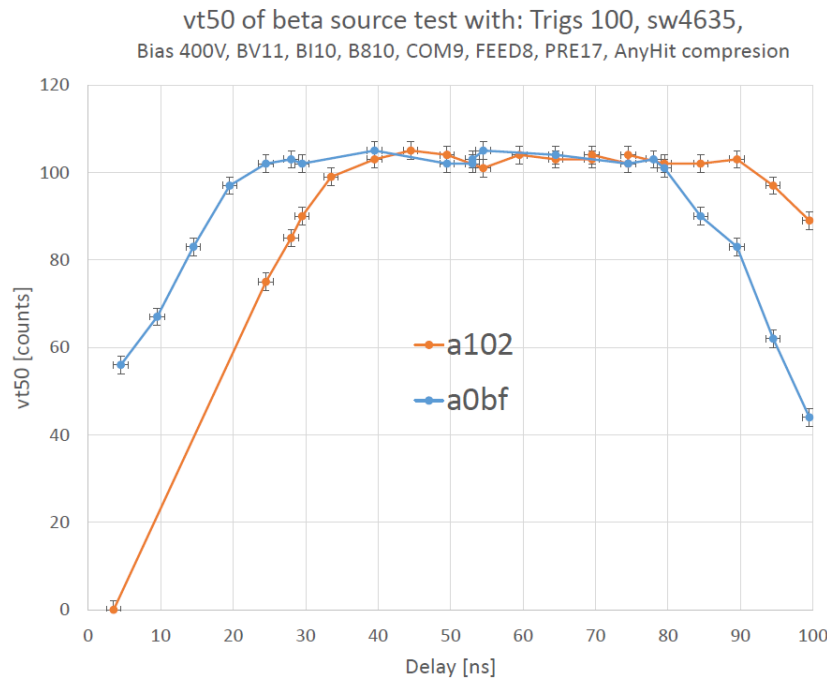
- measurement at 250 V, setup moved to the freezer in Electronic Room (ER)



- up to -20°C , small discrepancy between ER and CR1 in collected charge



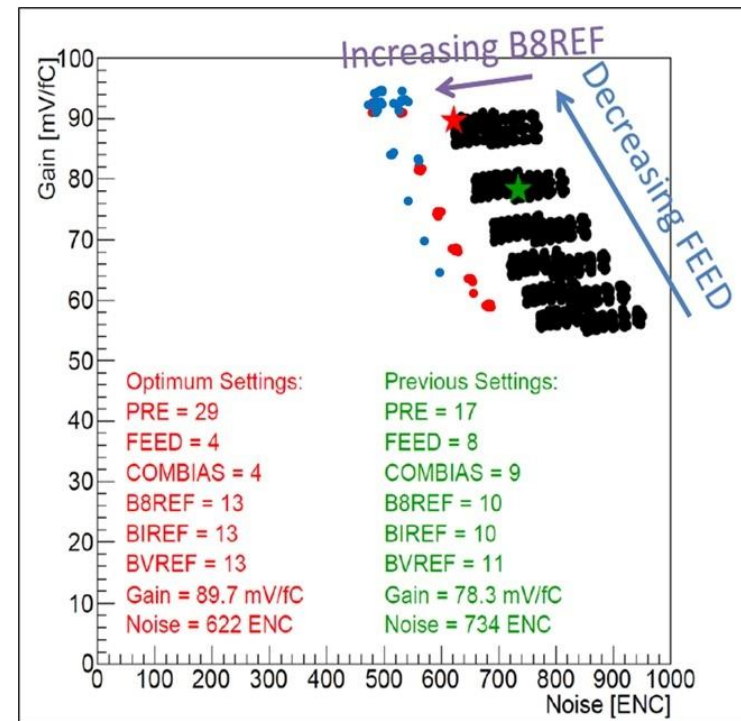
- possible explanation: shorter cabling in CR1
=> larger delay between external trigger signal and readout signal
- integer ITSDAQ variable latency (step 25 ns), finer latency scan with delay unit
- Atlys firmware version problem, preset latency value 10 changed to 11



FE Parameters Scan

- 6 internal parameters of front-end electronics of ABC130 chip
- to adjust control currents and voltages, possible change of pulse shape
- search for best setting (high gain, low noise)

- new recommended setting
- collected charge 3.1 fC \rightarrow 2.8 fC
- noise 550 e^- \rightarrow 500 e^-

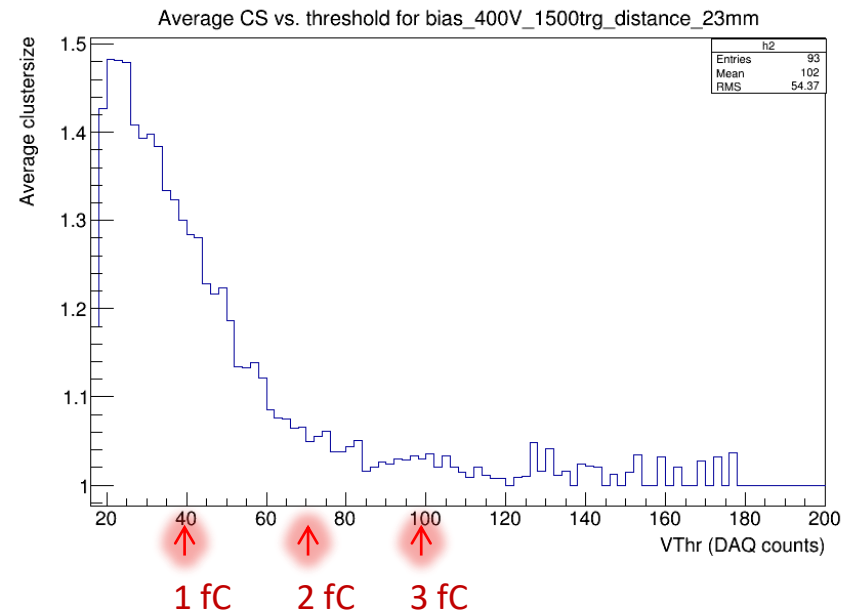
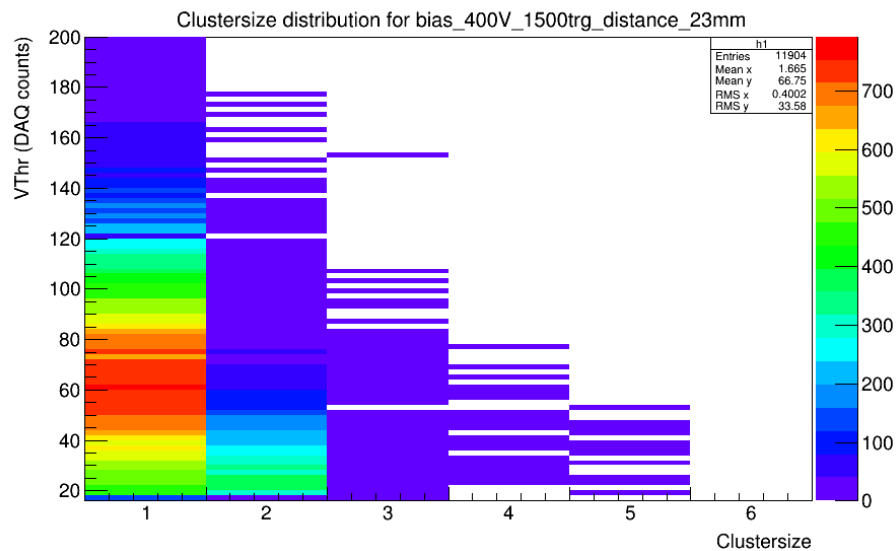


- experimental setup of beta source test built
- testing and analysis macros in C prepared and ready for further use
- fully automated readout and analysis from ROOT framework
- several specialized scans performed (bias, angular, temperature, latency, FE par.)
- total collected charge 3.1 fC (2.8 fC), ENC 550 e⁻ (500 e⁻), S/N 35
- updated results continuously presented at regular meetings

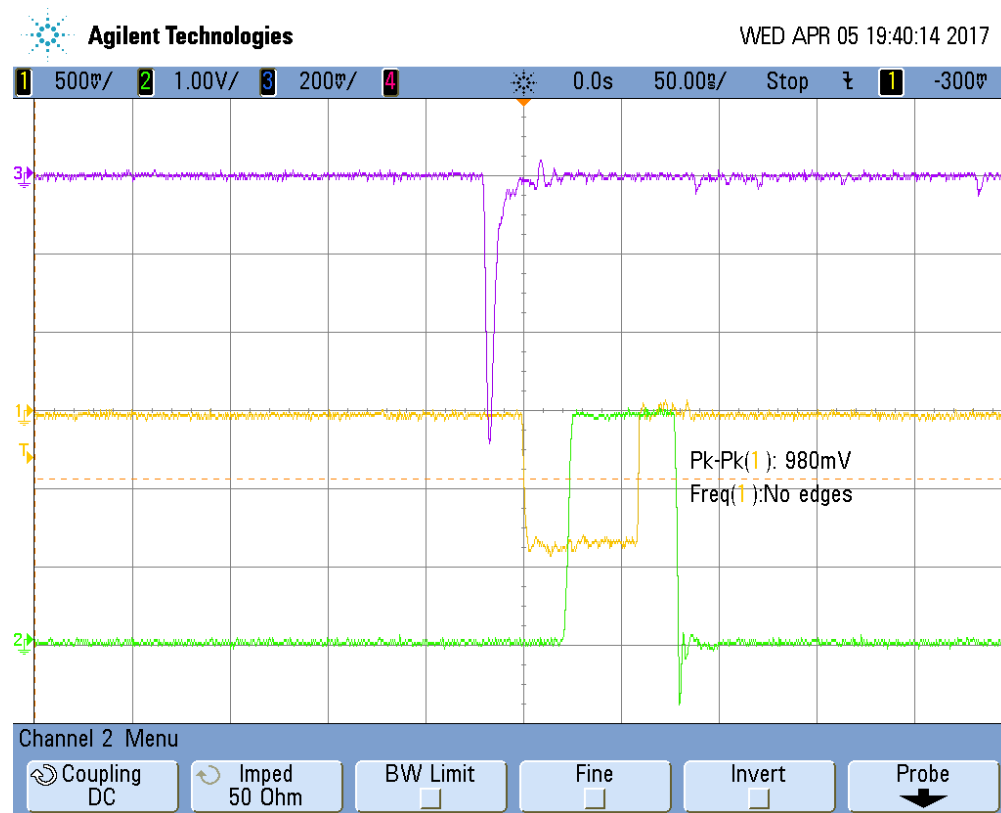
BACKUPS

Cluster Analysis

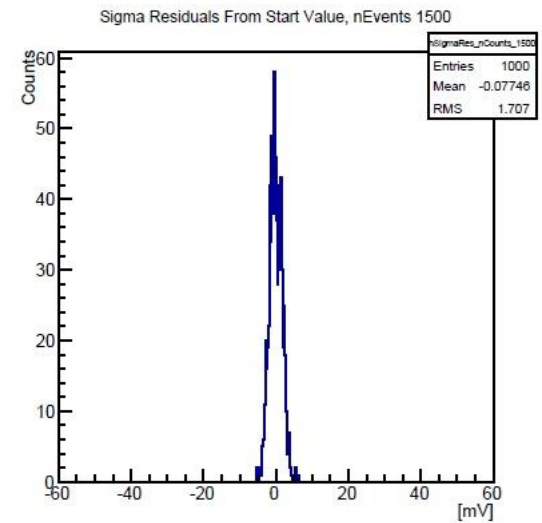
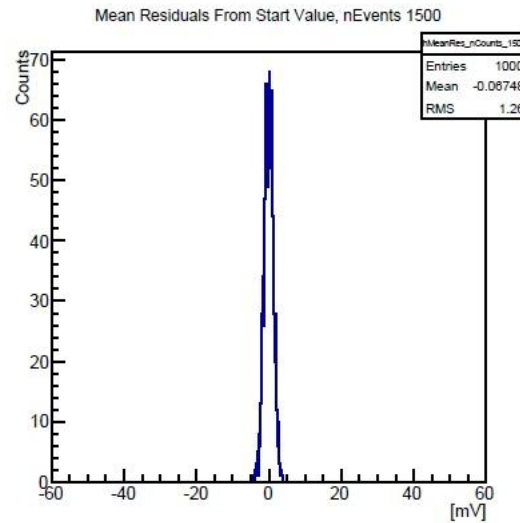
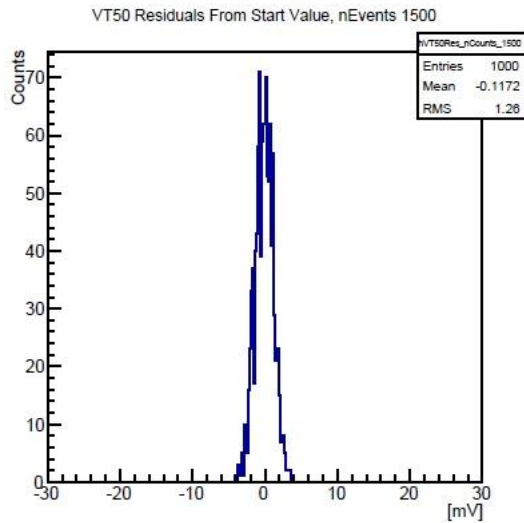
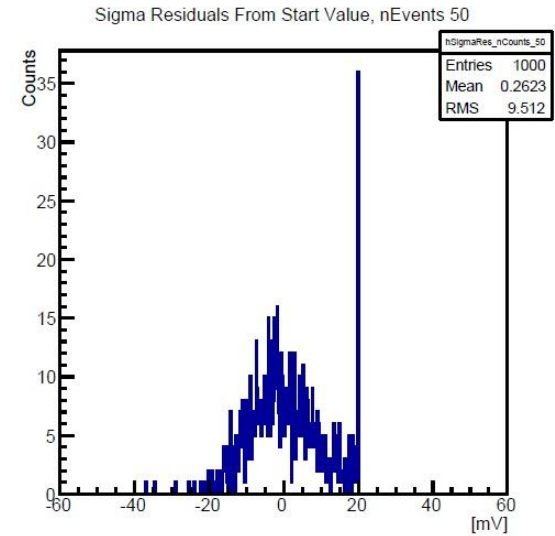
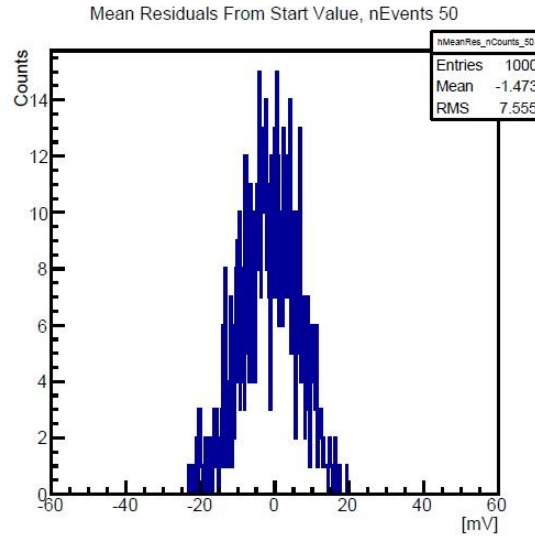
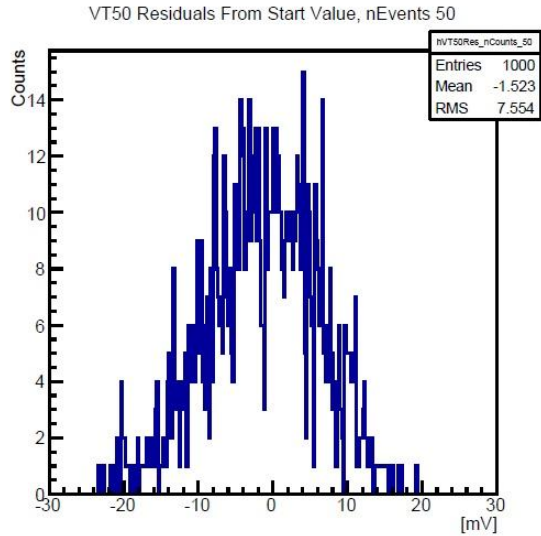
- cluster reconstruction from event lists
- sum of clusters for every cluster size gives S-curve
- average CS at 1 fC: 1.33 (fully depleted, perpendicular scan)



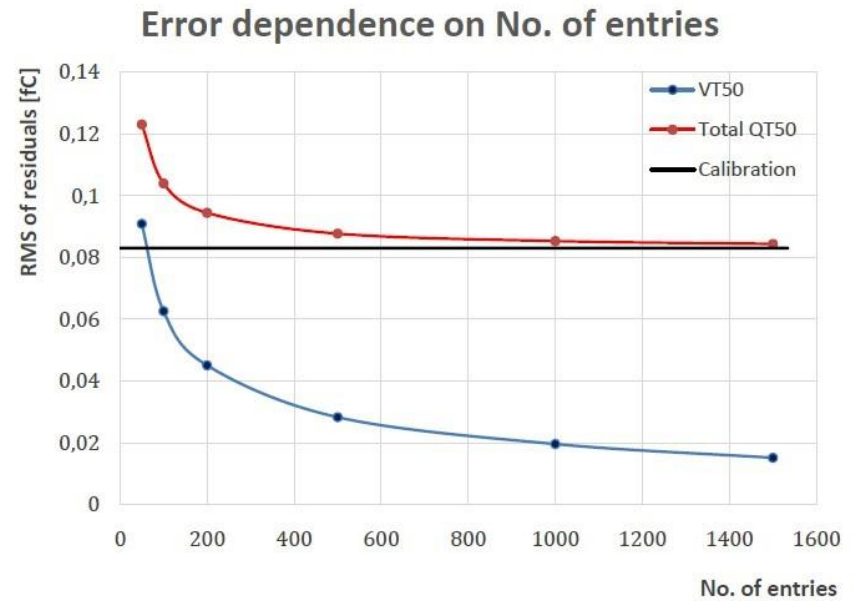
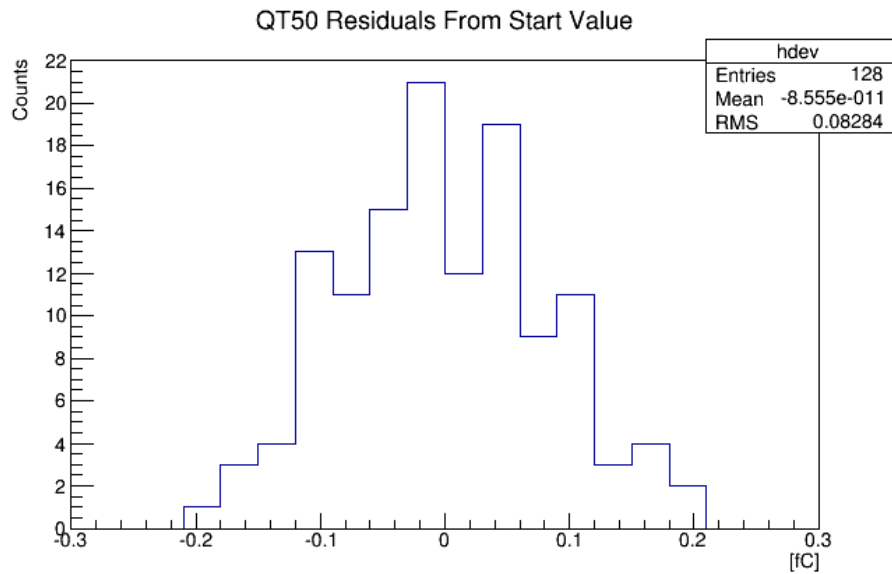
- negative analogue signal from scintillator does not meet Atlys requirements
=> signal modulation using NIM crate (Discriminator, Level Adapter modules)



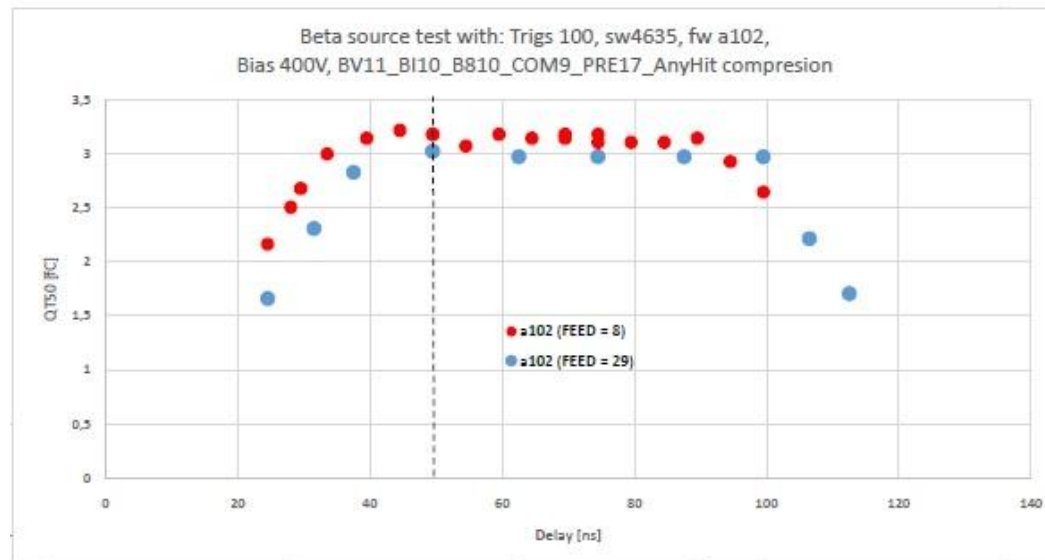
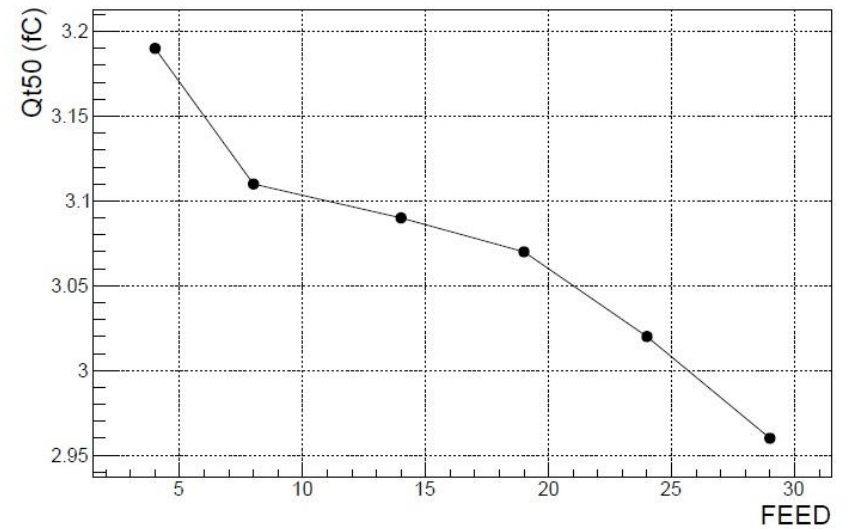
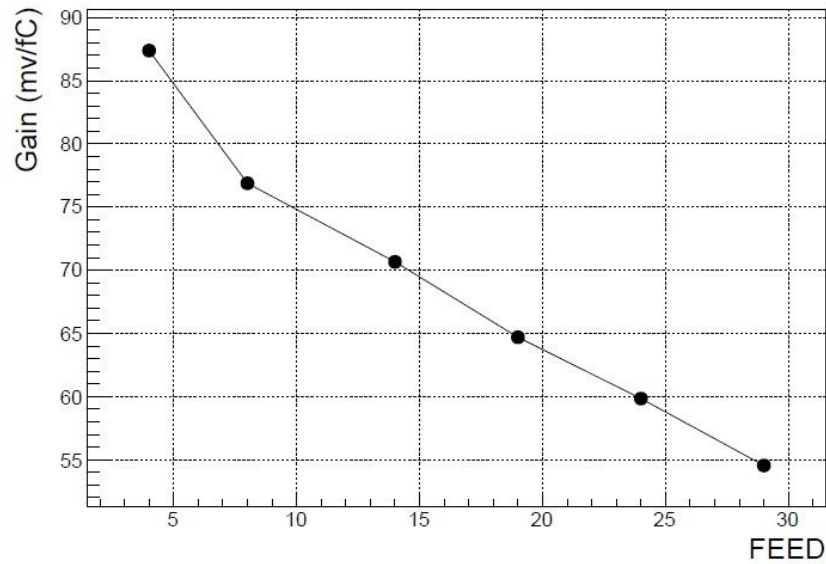
Error Estimation



Error Estimation



FE Parameters



Module Type	Fluence $10^{14} n_{eq} cm^{-2}$	Charge ke^- 500 V	Charge ke^- 700 V	Noise e^-	S/N 500 V	S/N 700 V
SS	8.1	13.7	16.1	630	21.8	25.6
LS	4.1	17.3	19.5	750	23.1	26.0
R0	12.3	11.5	14.0	650	17.7	21.5
R1	10.1	12.5	15.0	640	19.6	23.4
R2	8.7	13.3	15.7	660	20.3	23.9
R3	8.0	13.8	16.2	640	21.4	25.1
R4	6.8	14.6	17.0	800	18.4	21.3
R5	6.0	15.3	17.6	840	18.3	21.1

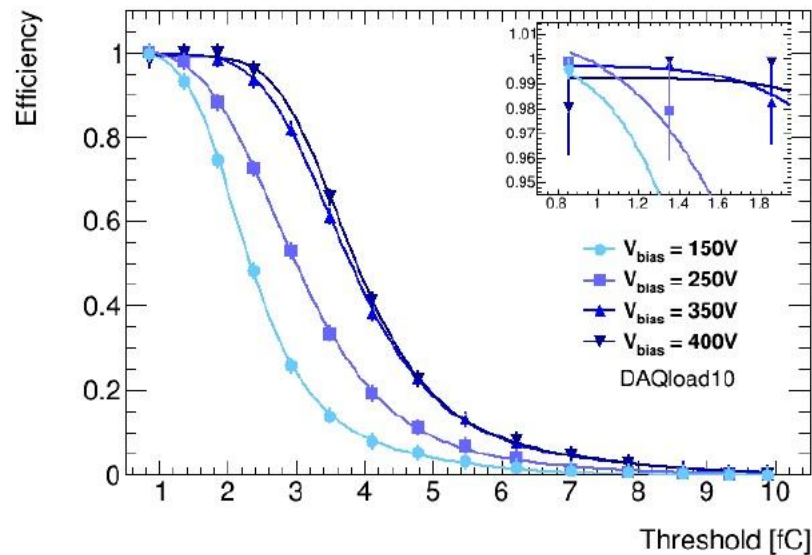


Figure 8.12: Efficiency versus threshold for one sensor on DAQload10, at four different bias voltages.