# Tests of Silicon Strip Modules for the Upgrade of the ATLAS Detector at the LHC

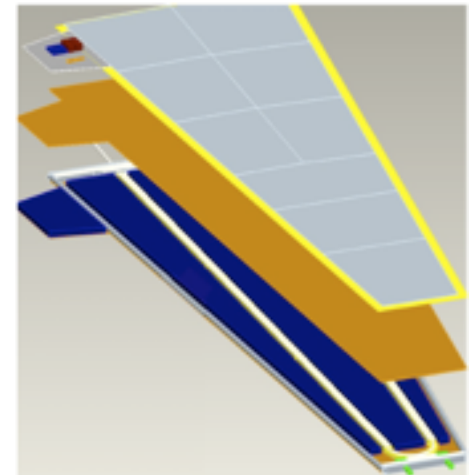
Tai-Hua Lin (林岱樺)

$7^{th}$ Feb 2012 Master Thesis Defense
@ DESY, Zeuthen Site

HELMHOLTZ GEMEINSCHAFT

# Outline

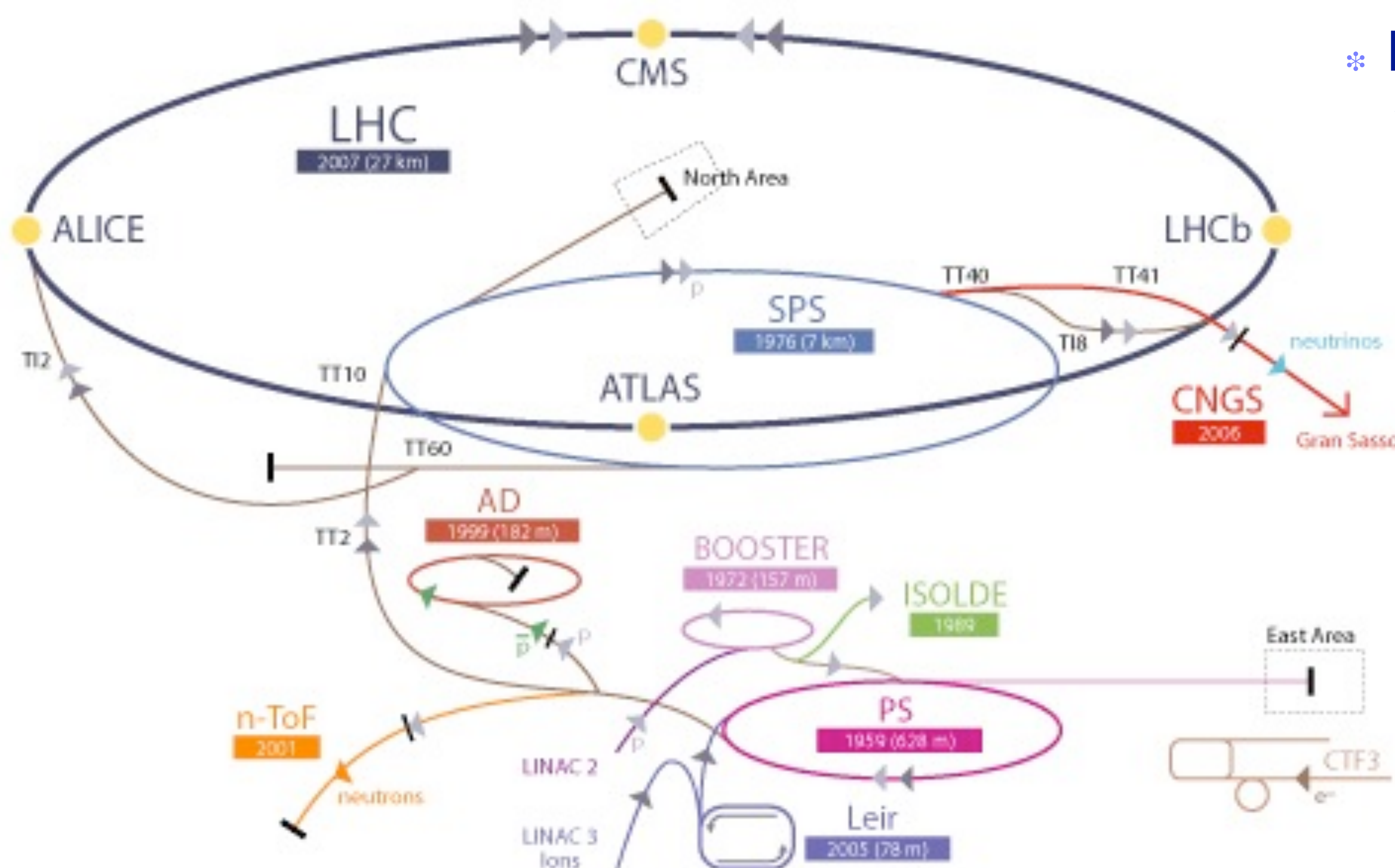
- ATLAS Detector at LHC & Upgrade: HL-LHC and PETAL2014
- Readout System Setup
- Readout Software & Test results
- Database
- Systematic Study of Readout System
- Summary & Conclusion & Outlook



ifh.de https://www.ifh.de/asdb/

# The Large Hadron Collider (LHC)

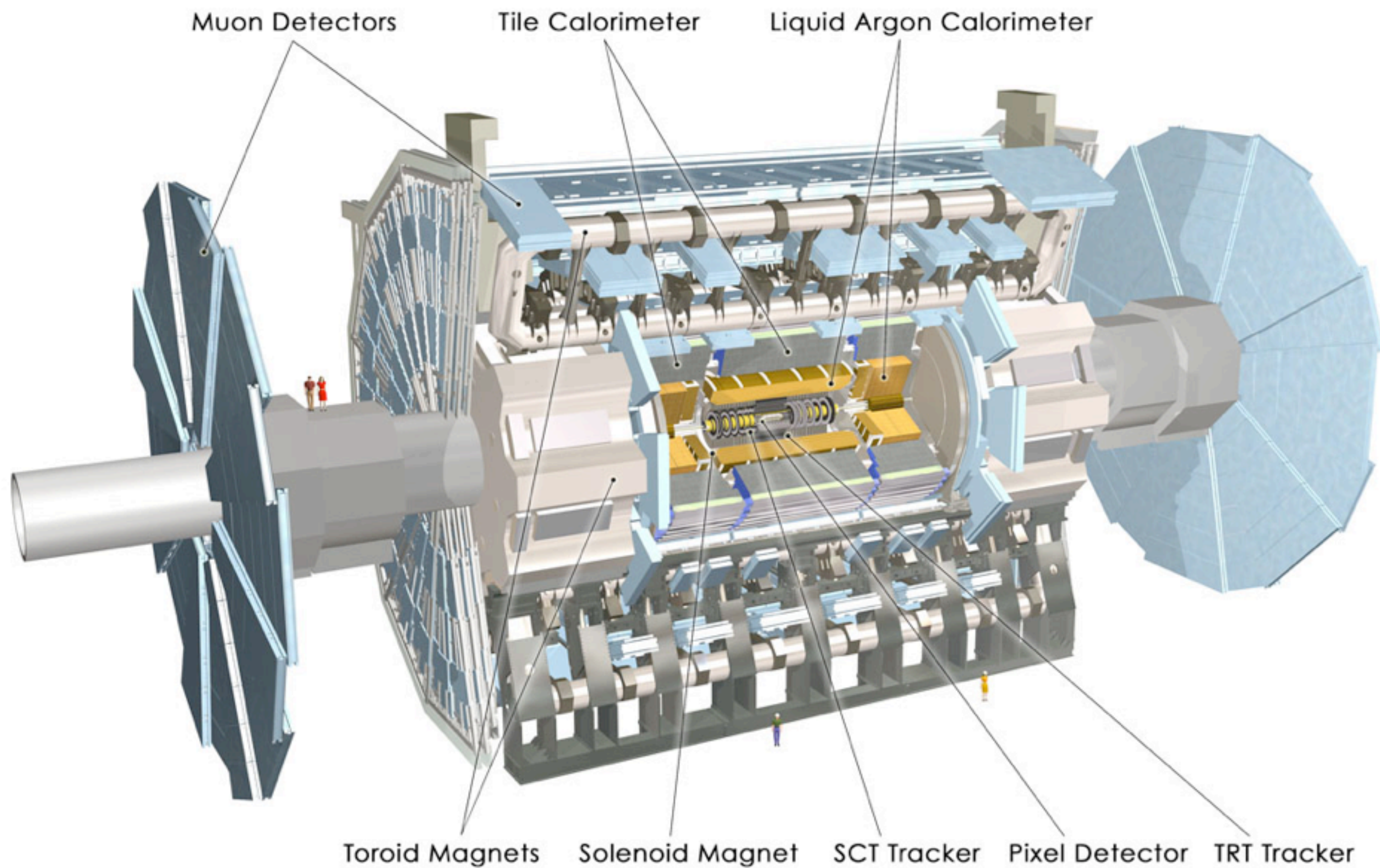





- Proton- Proton Collider with bunch crossing rate 25 ns

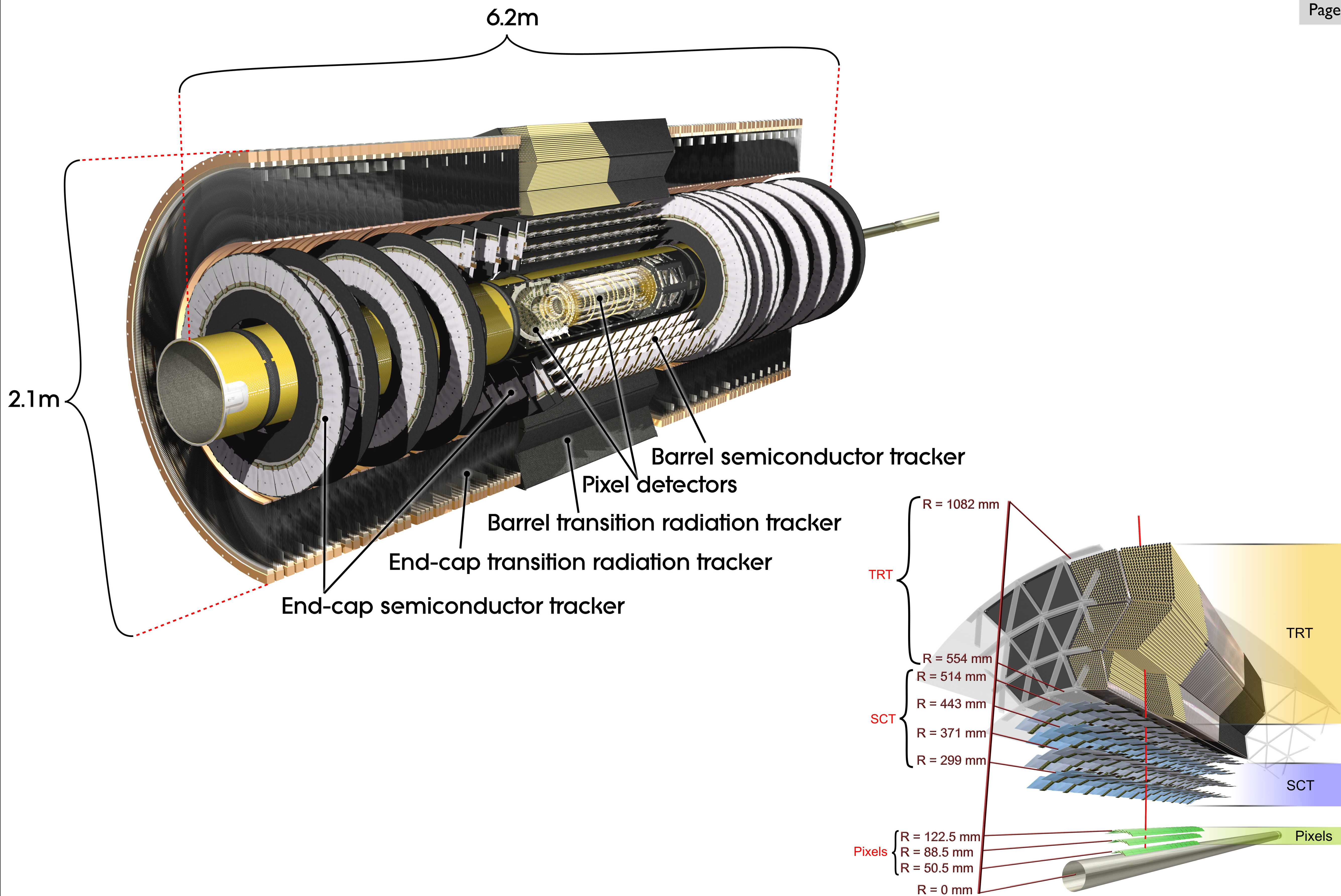
# The Current ATLAS Detector





# Inner Detector





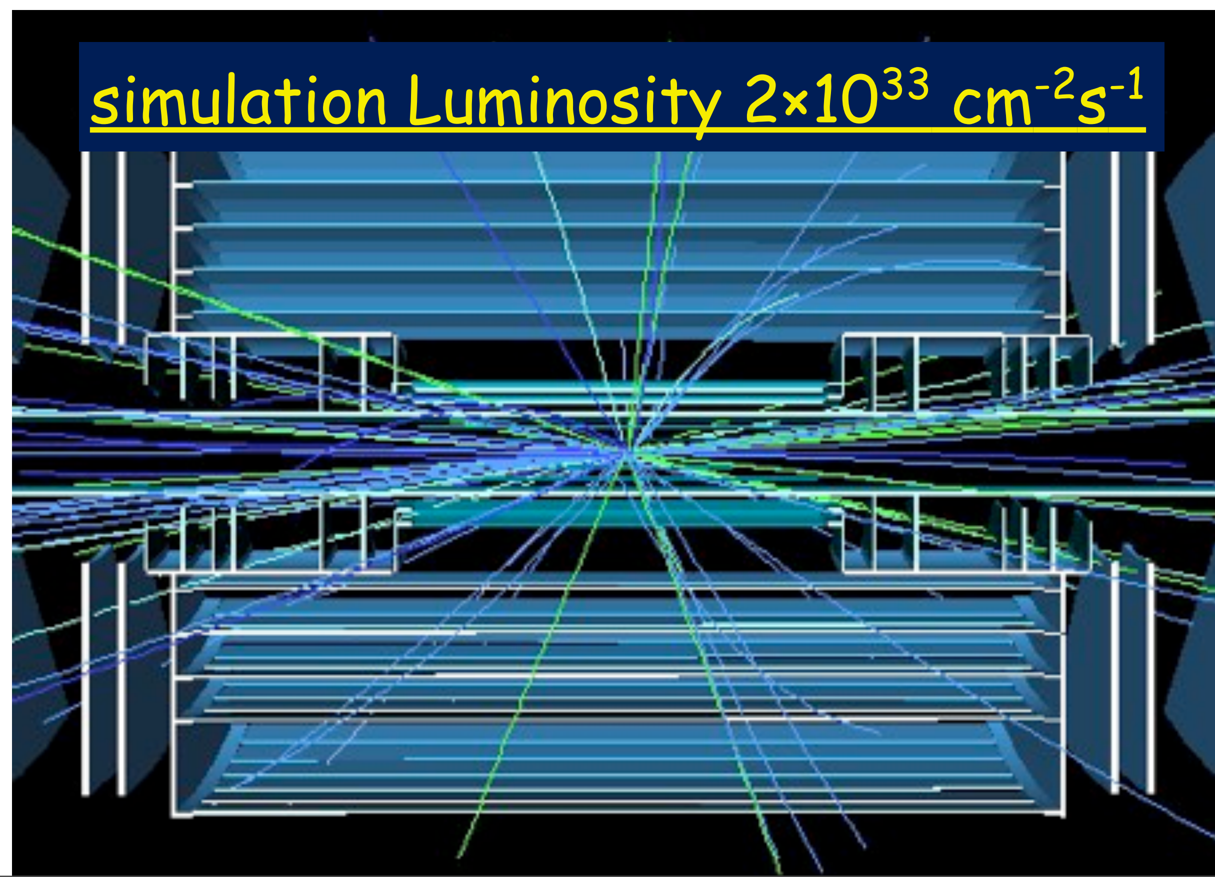
# Upgrade of LHC

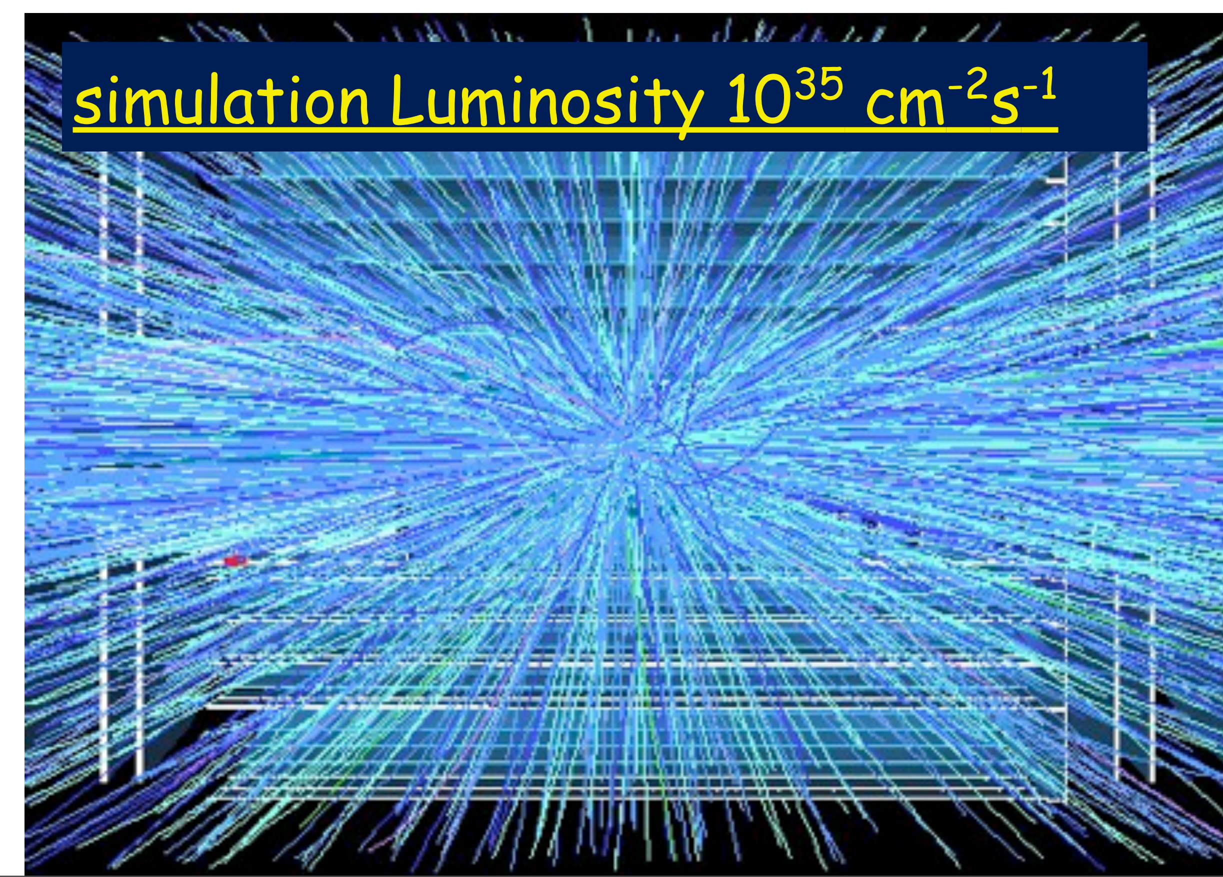


## HL-LHC (High Luminosity Large Hadron Collider)

- Upgrade of LHC & ATLAS Detector
  - to reduce the statistical uncertainties for measurements
- the expected luminosity after upgrade in 2020: $5\times10^{34}$ $cm^{-2}s^{-1}$
- effects of higher luminosity for the detector: higher occupancy, higher radiation
- upgrade:
  higher granularity, increased electronic channels, radiation hardness,
  new powering schemes

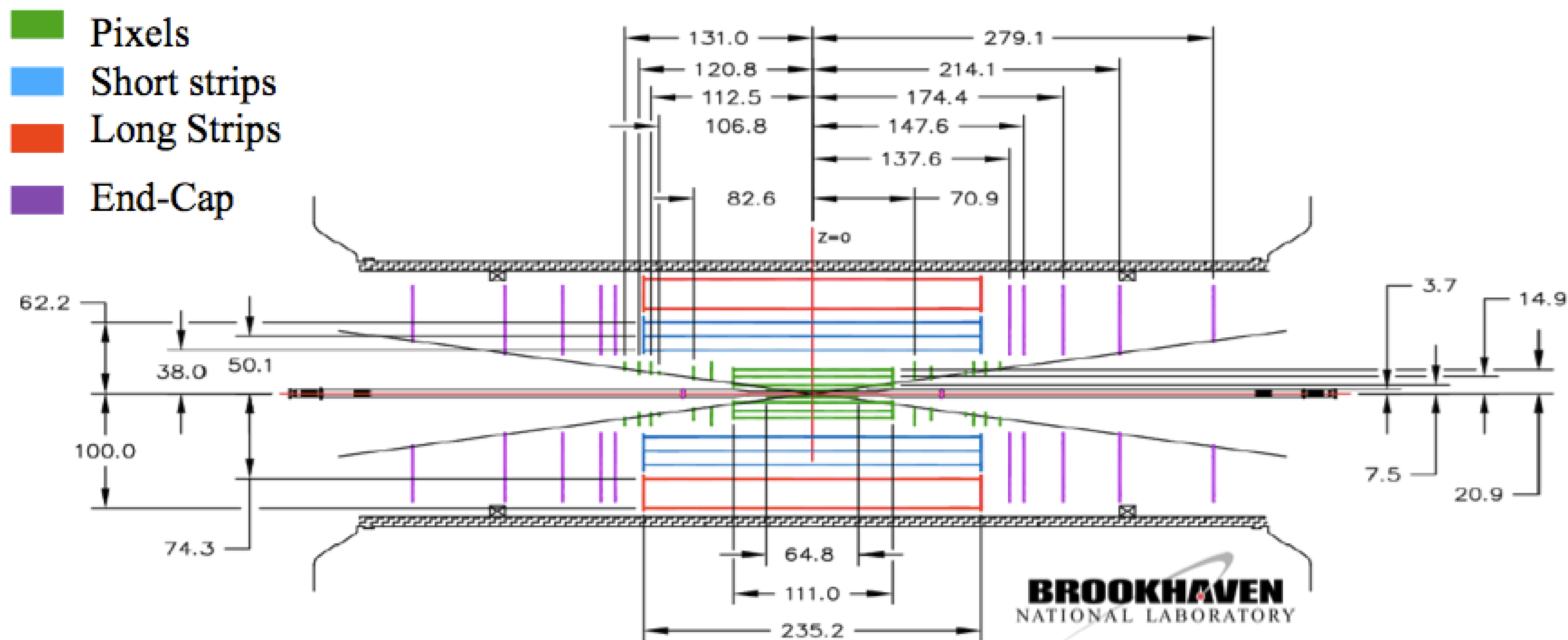
Plots of tracks Simulation of ATLAS detector



# Proposed Layout of the Inner Detector





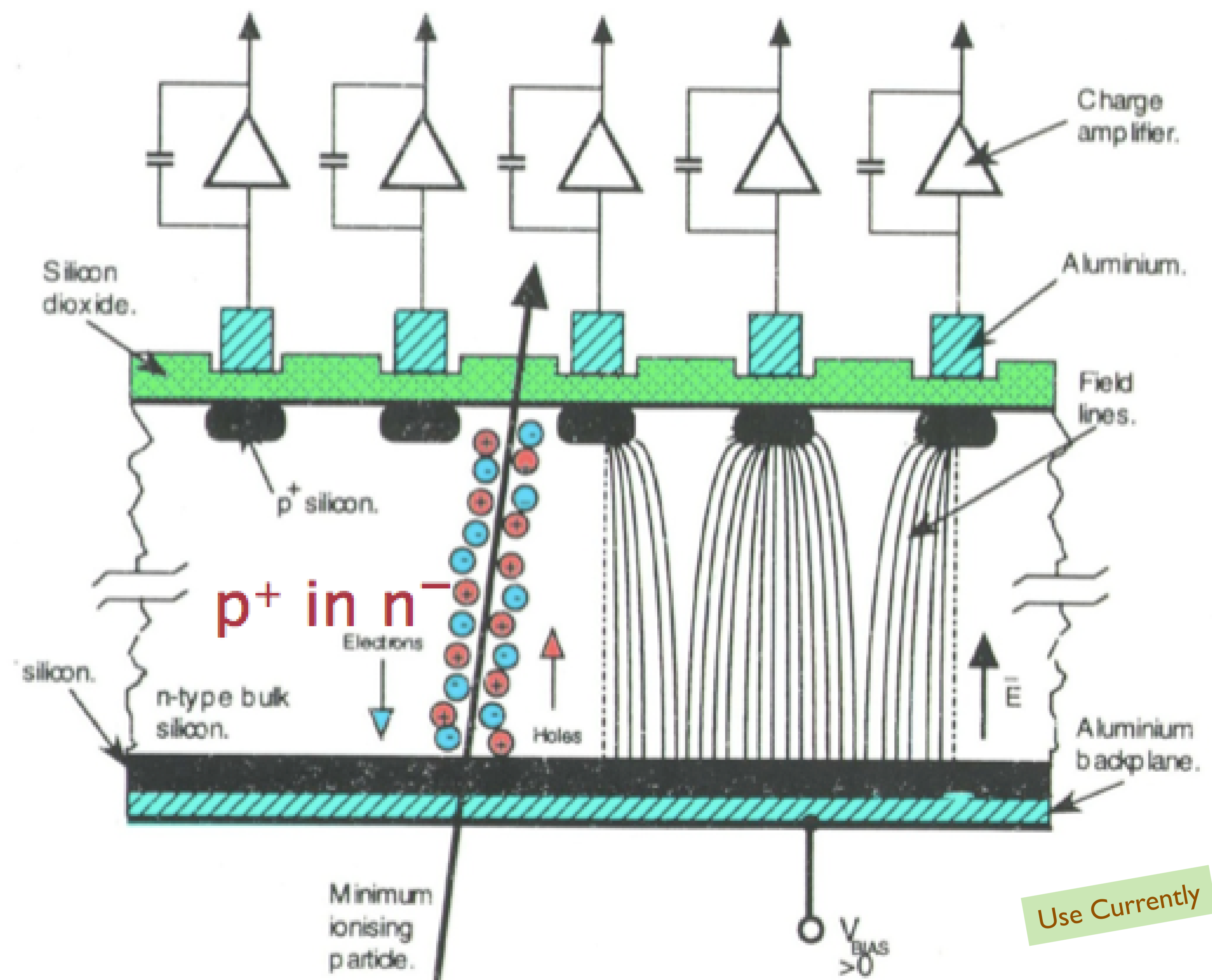
# Silicon Strip Detector



- Charge deposition in 300µm thick silicon ~22000 e (3.5 fC)
- Electrons collected within ~10 ns, holes collected within ~25ns, for 300µm thick silicon

Currently use (SCT):
p in n sensor,
holes collected

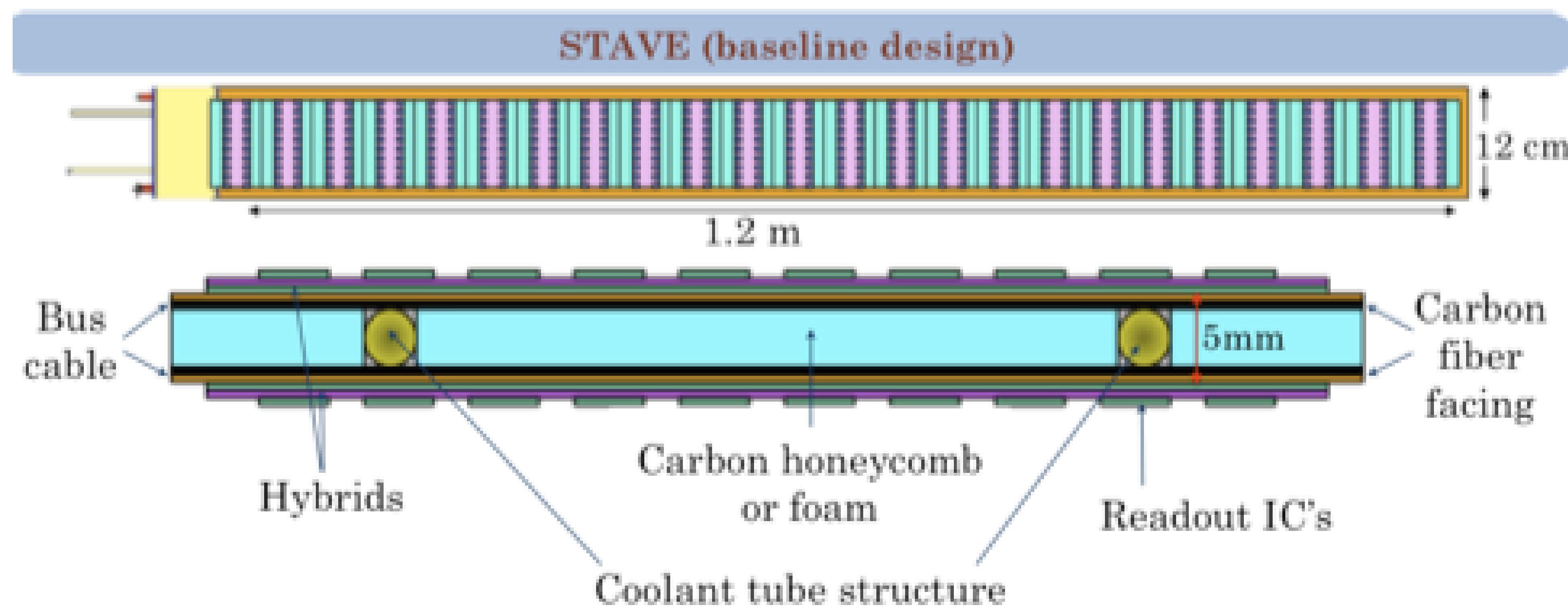
Upgrade (Silicon Strip Detector):
n in p sensor,
electrons collected



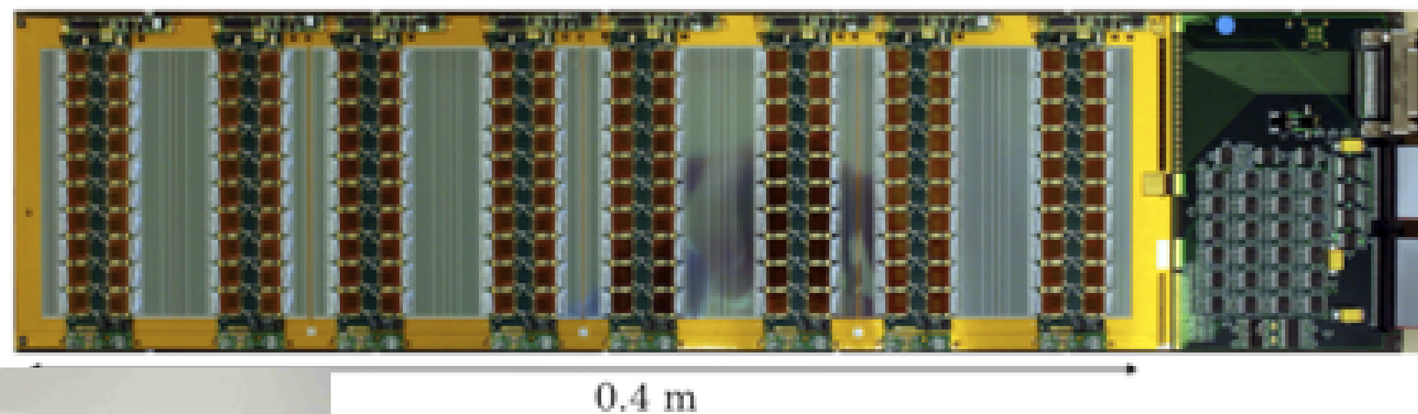
# Upgrade of Silicon Strip Detector

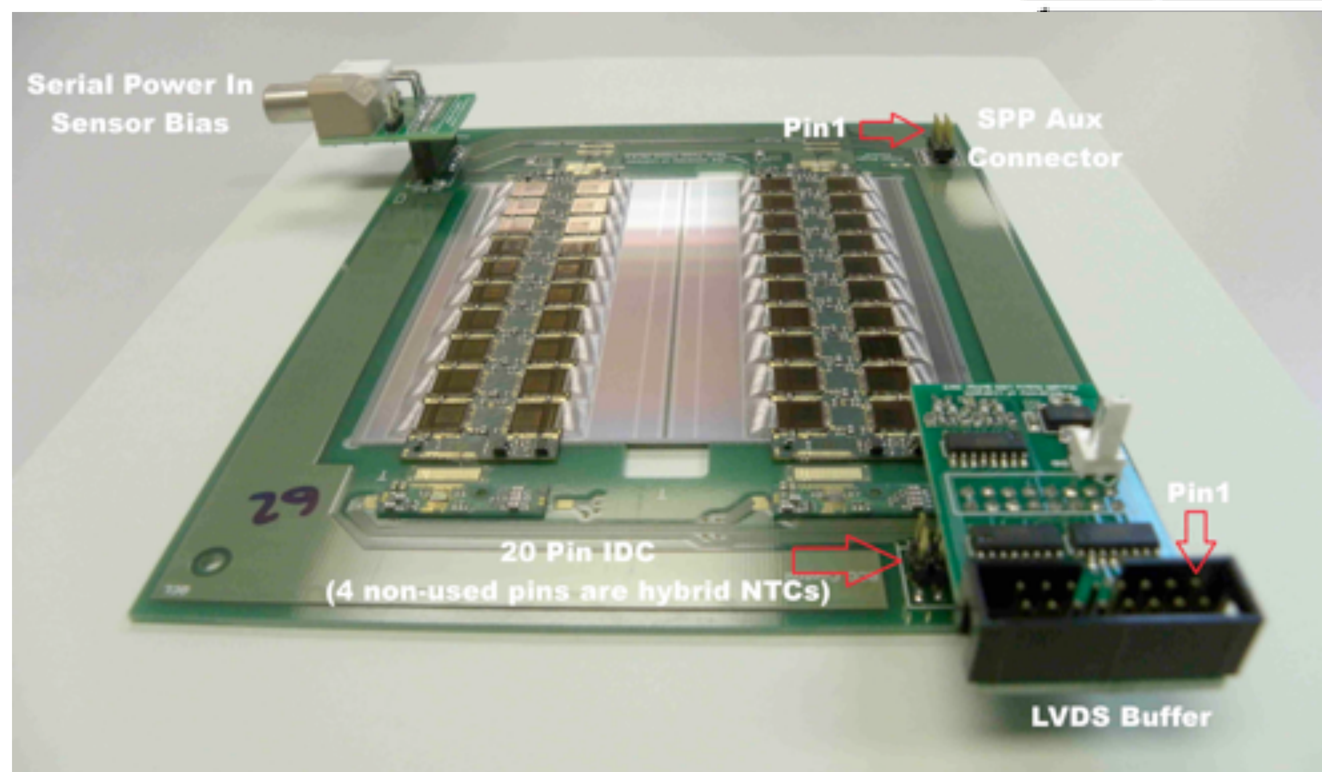


Stave --->




Stavelet --->



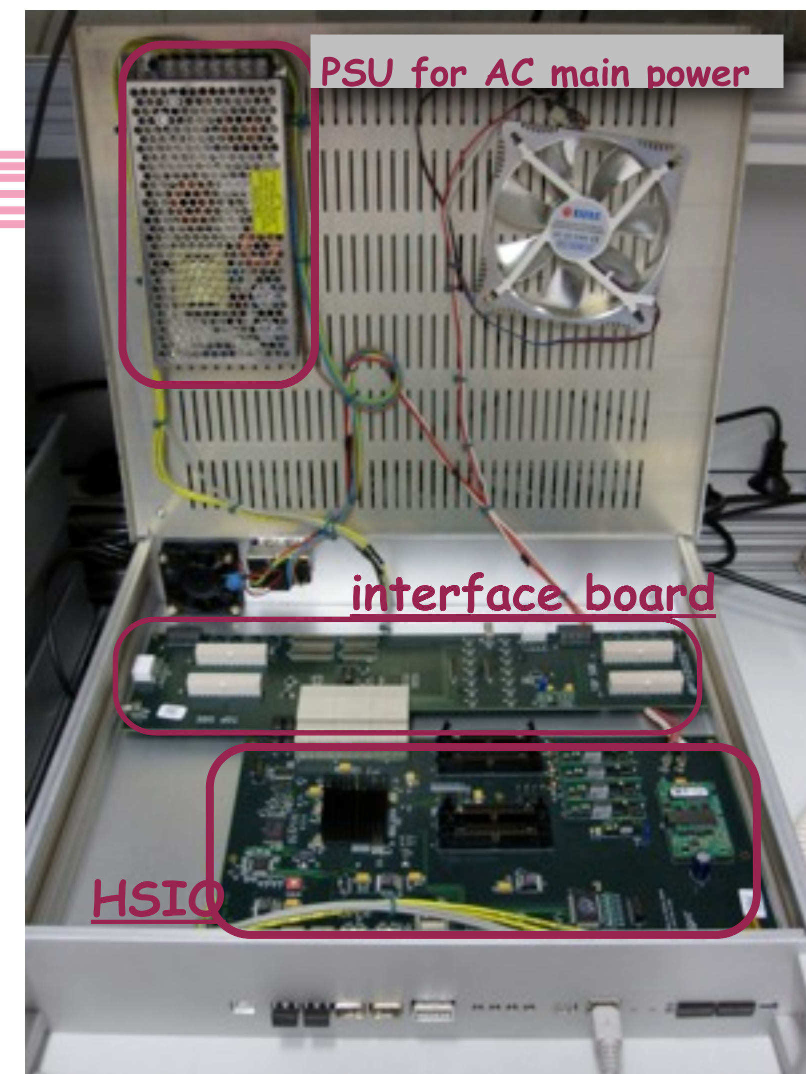




<------ Testing Module

# HSIO (High-Speed Input/Output) Readout System

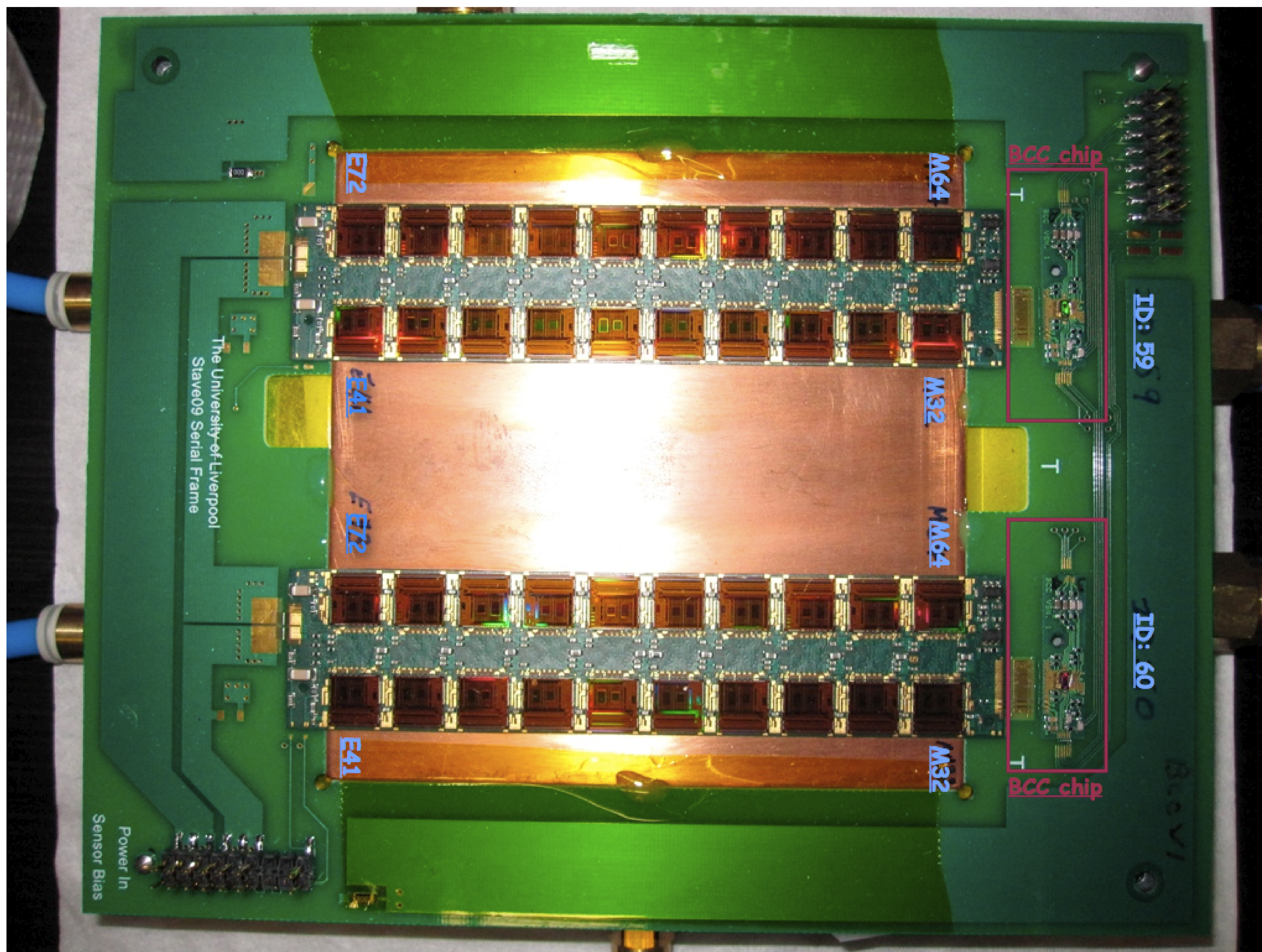


LVDS
Dummy
Power
Chiller
TTi Power
LSP Power Supply
Vacuum Pump



# Dummy Module





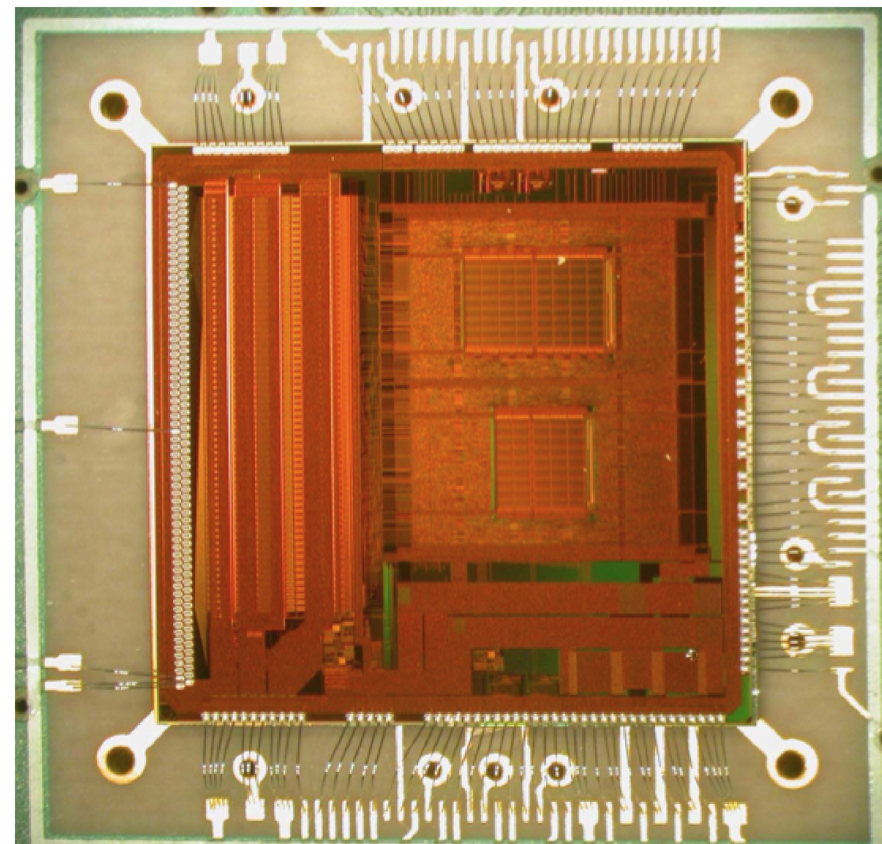
# Readout Concept

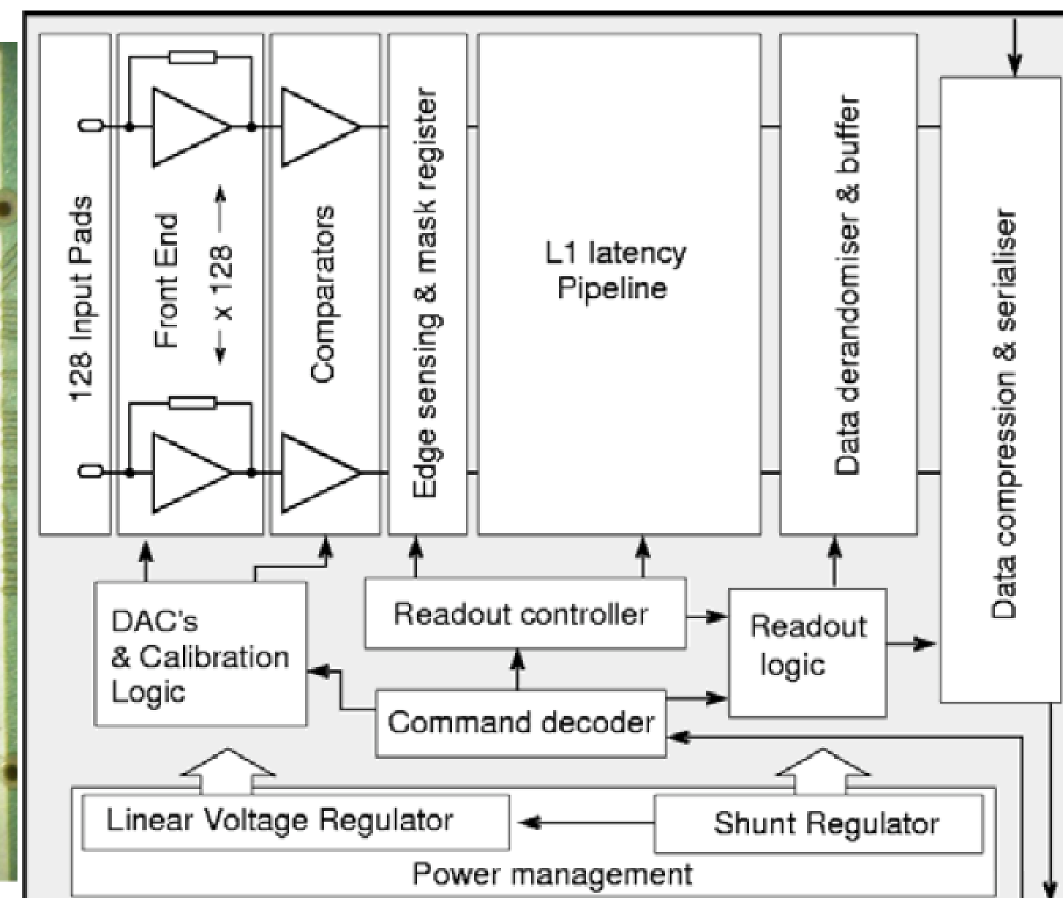


- Binary readout architecture

1. Charge injection (to simulate a particle passing through the detector)
2. Amplitude above the threshold : a hit "1",
   below the threshold : no hit "0"
3. Trigger is sent to readout the hits

readout chip ----->
ATLAS Binary Chip- Next (ABCN 25)





# Structure of Redout System (Current)

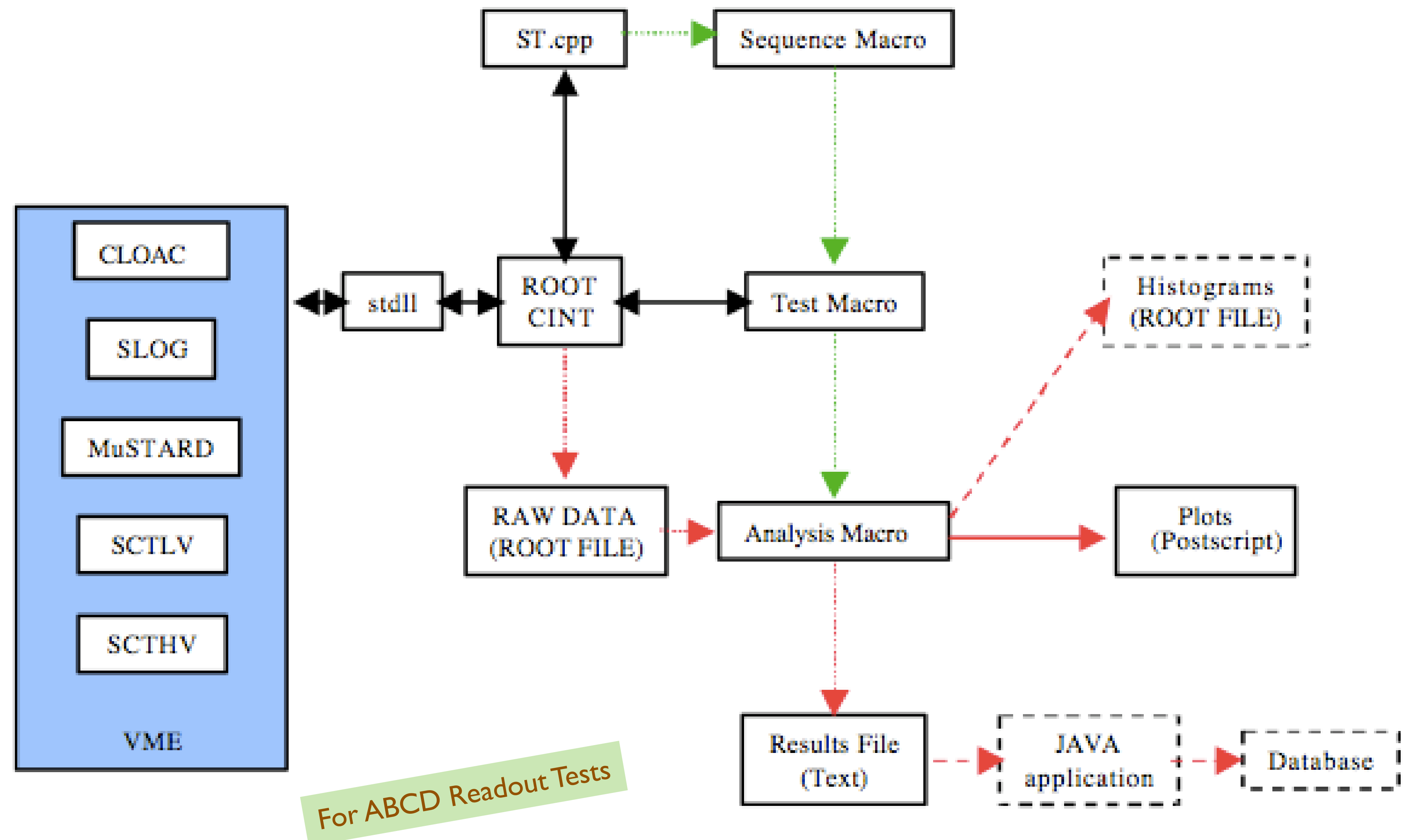


- Offline-Detector Readout Devices : VME units (CLOAC, SLOG, MuSTARD) are replaced by HSIO for the upgrade

CLOck And Control module (CLOAC)

SLOw command Generator (SLOG)

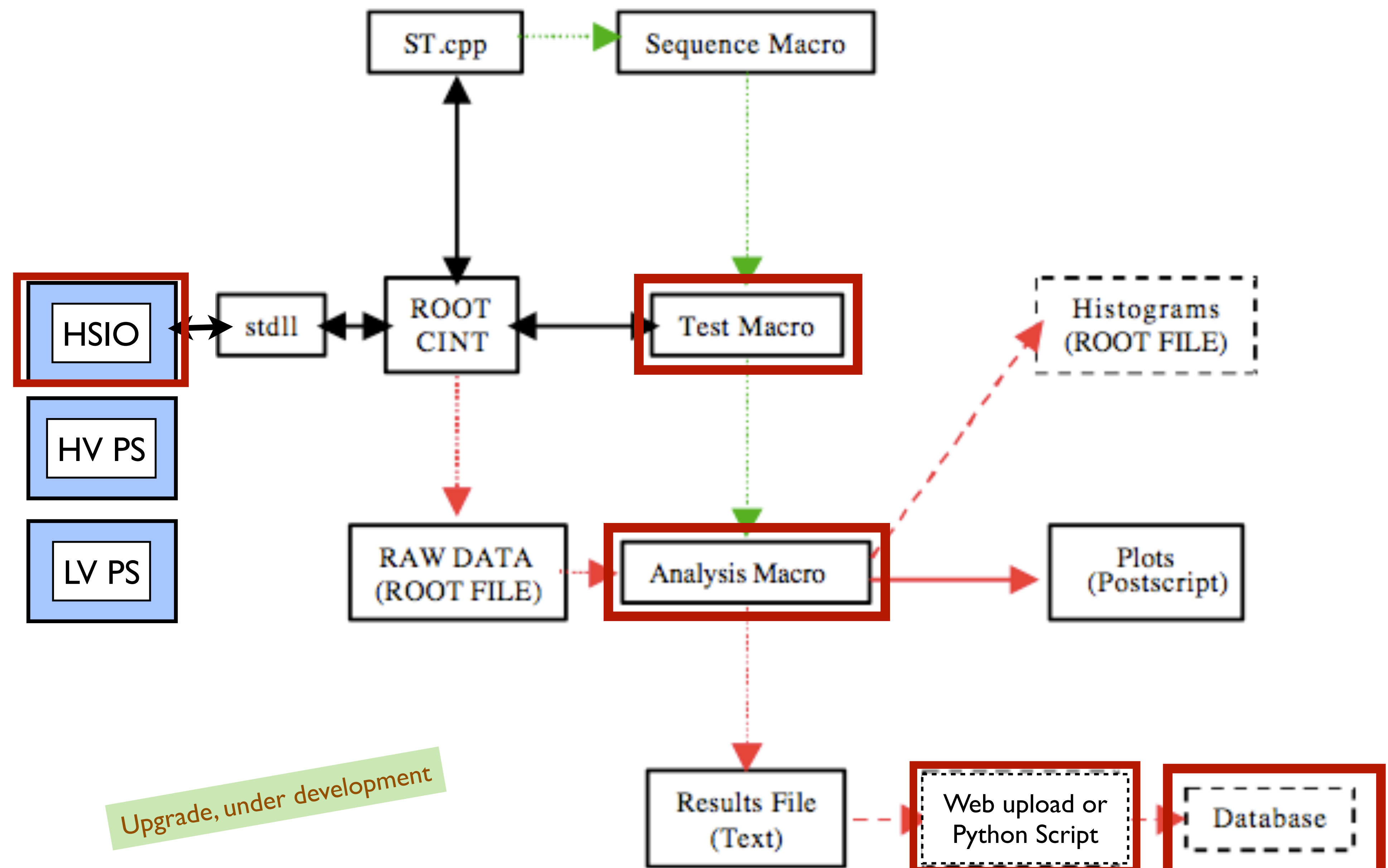
Multi-channel Semiconductor Tracker ABCD Readout Device (MuSTARD)



# Structure of Redout System (Upgrade)



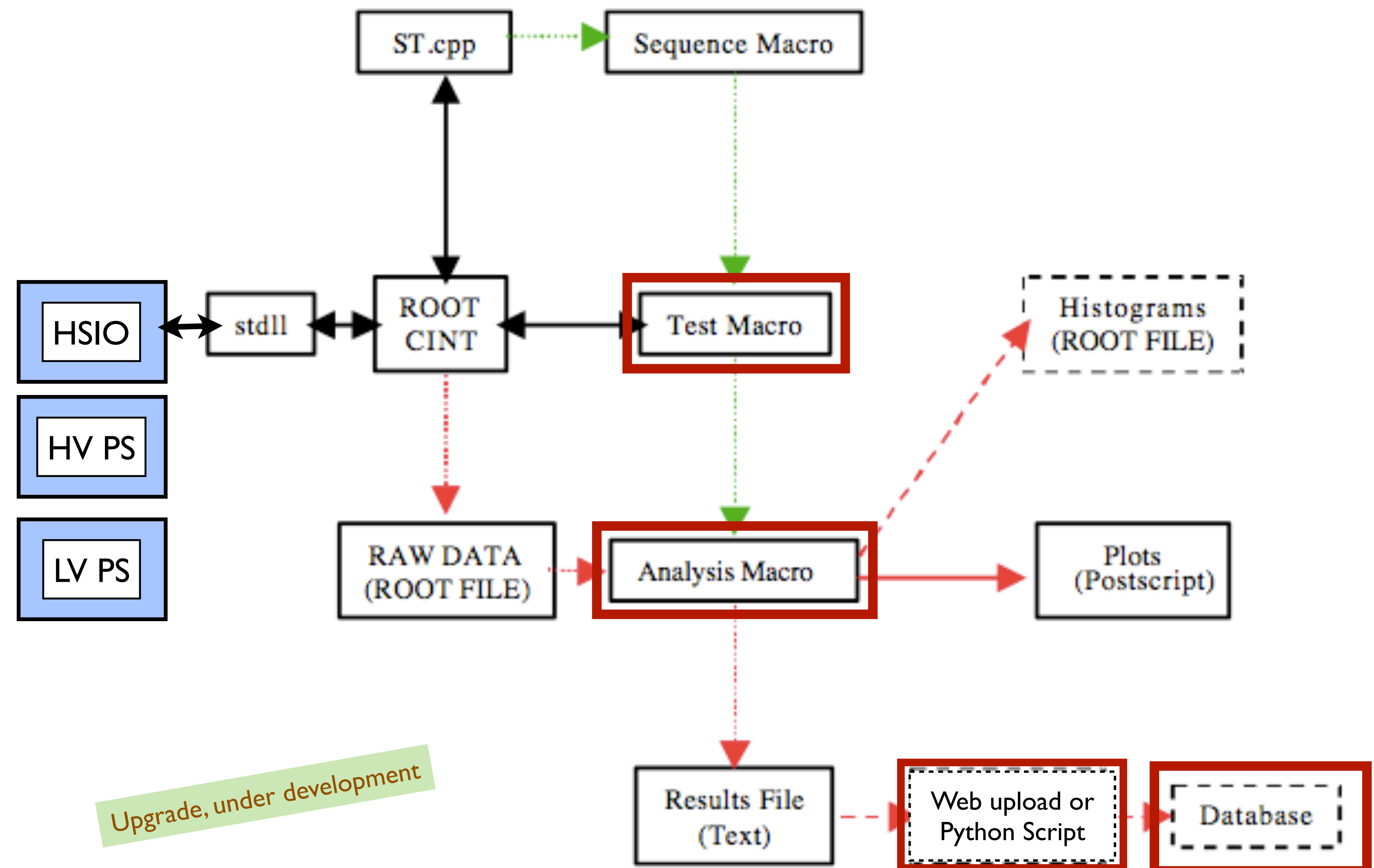
- Offline-Detector Readout Devices :
  VME units (CLOAC, SLOG, MuSTARD)
  are replaced by HSIO for the upgrade



# Redout Software - SCTupDAQ



- Top level routine : in C++ & ROOT
- Lower level routine : in C



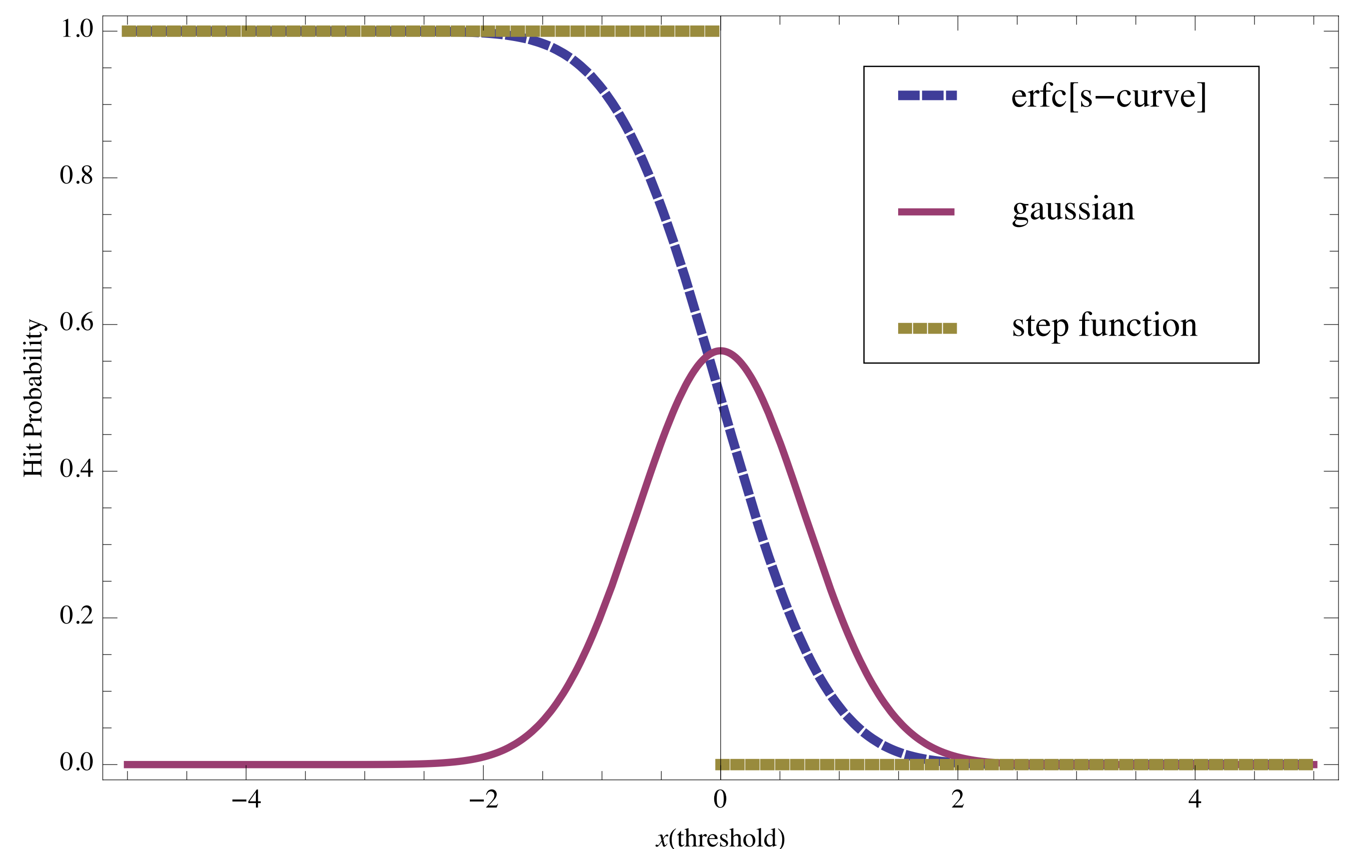
# Threshold Scan - basic concept of readout



- SCTupDAQ is the threshold scan based examinations
- Scan through thresholds with a fixed value of injected charge

- Hit Probability w.r.t threshold
  ideal: Step Function
  reality: S-Curve (in the present of noise)

- S-Curve can be fitted with complementary error function
  Vt50: threshold voltage at 50% hit prob.
  noise: $\sigma_s$ of the Gaussian function




$$S(x) = \frac{1}{2}\mathrm{erfc}(x) = \frac{1}{2}(1 - \mathrm{erf}(x)) = \frac{1}{2} - \frac{1}{\sqrt{\pi}}\int e^{-x^2}\,\mathrm{d}x = \frac{1}{2} - \frac{1}{\sqrt{\pi}}\int G(x)\,\mathrm{d}x$$

$$x = \frac{\mathrm{Vt50} - \mu_s}{\sqrt{2}\sigma_s}$$

# Readout Tests



Goal:

characterization and confirmation of the module performance during the module production

Main Tests:

**Strobe Delay** : optimize the timing of the injected charge *calibration*

**Gain Tests** (3 Point Gain & Response Curve) : Vt50, response, and noise performance

**Trim Range** : minimise the channel to channel variations of the threshold *calibration*

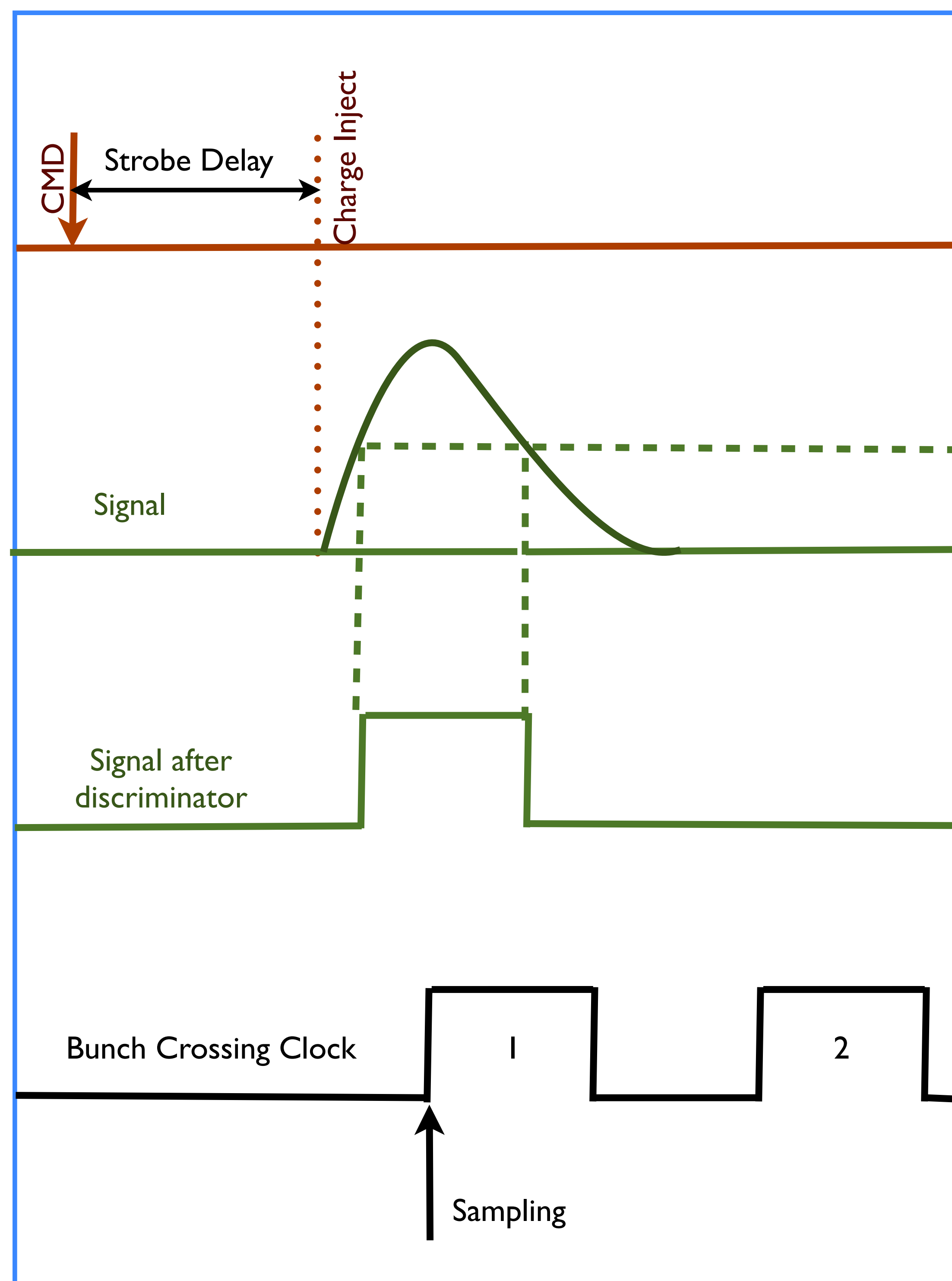
**Noise Occupancy** : direct measure of the noise present in a channel

Procedure:

# Readout Tests- Strobe Delay

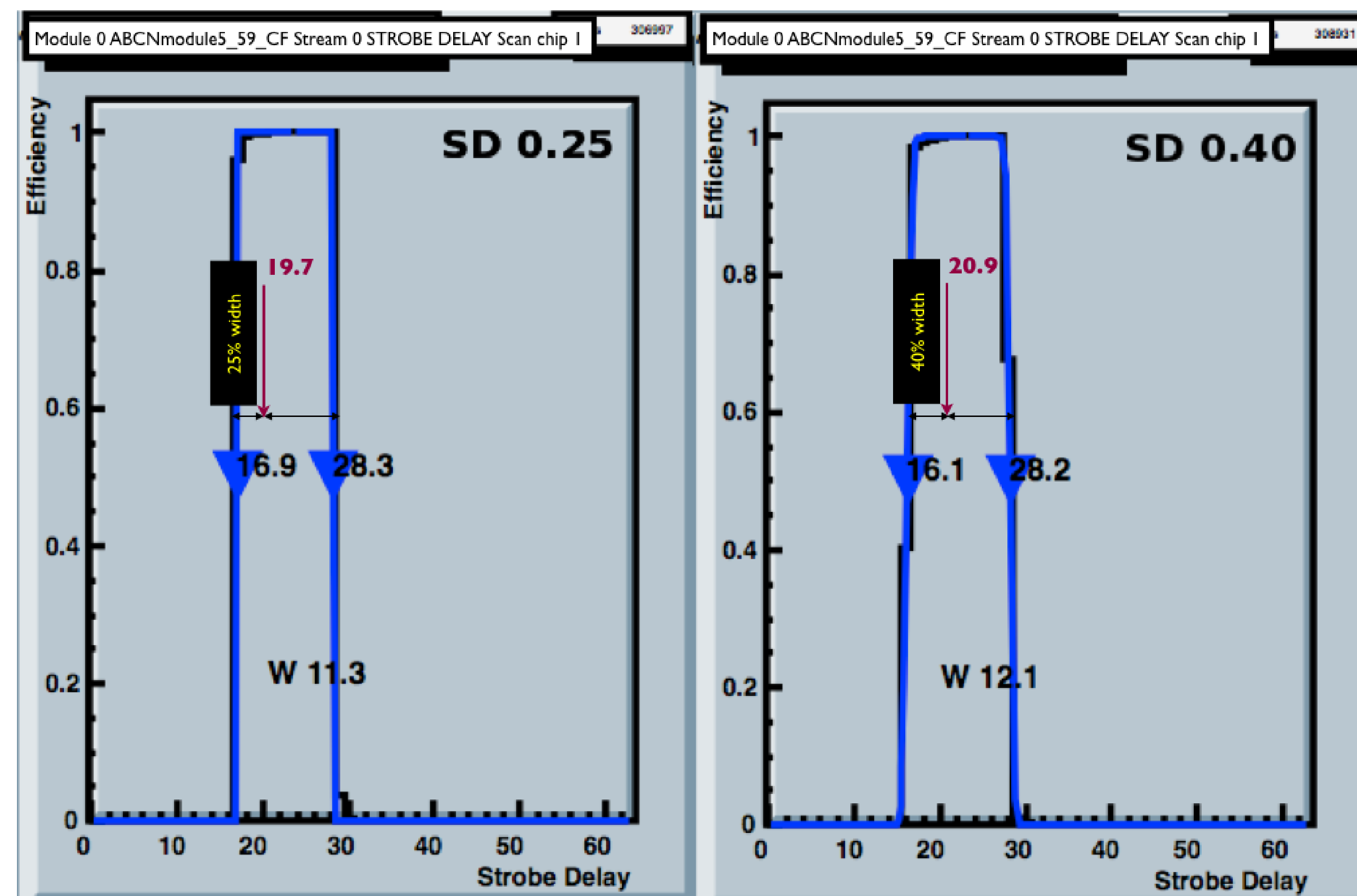







Delay the charge injection to sample signal in the correct phase of bunch crossing

Set at 25% (or 40%) of the working range as the timing to inject charge

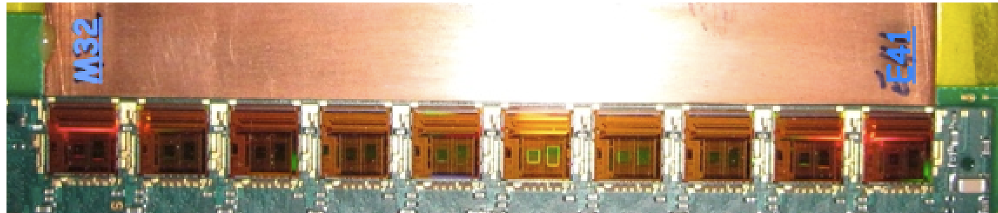



Result of Dummy Module M59 strun 661 @Zeuthen

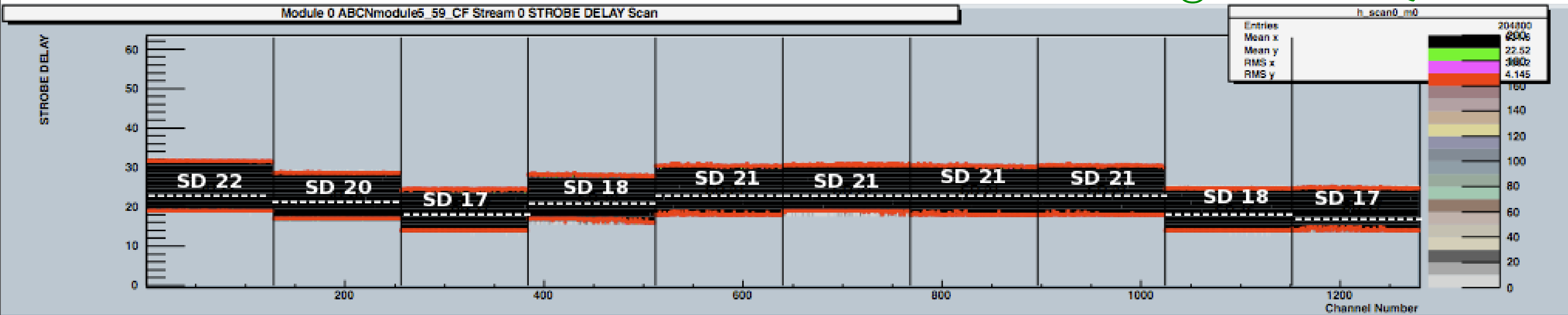
# Readout Tests- Strobe Delay





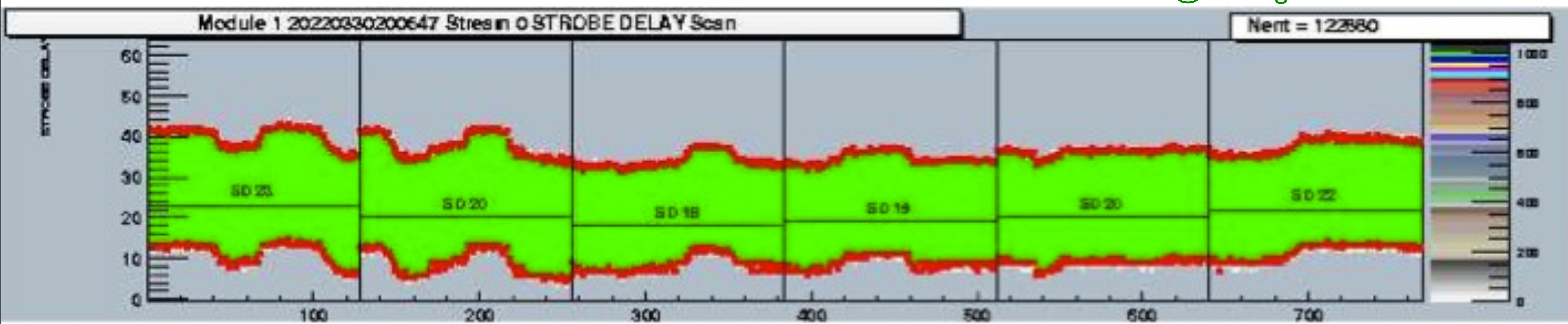



Result of Dummy Module M59 stream 0
strun 661 @Zeuthen SCTDAQ.trunk 1768




SD 0.40 is used in the situation of large channel to channel variation

Result of Barrel_Hybrid stream 0
strun 393 @Birmingham



# Gain Tests



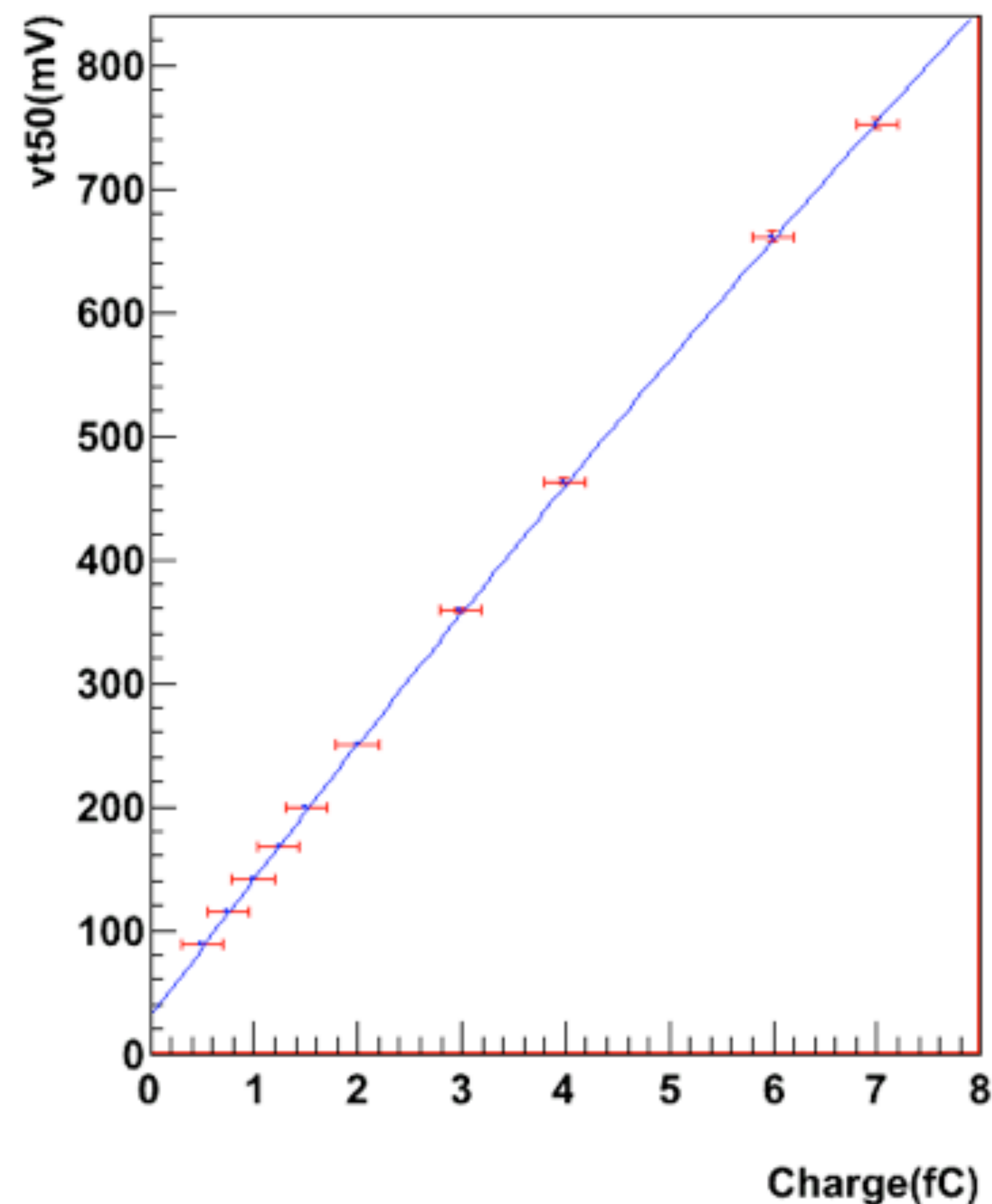
## Threshold scan with different injected charge

Response Curve shows linear behavior for lower injected charge

| Linear Fit | $g = \frac{Vt50_2 - Vt50_1}{q_2 - q_2} = p_1$ |
|---|---|
| Exponential Fit | $g = \frac{p_0 e^{-\frac{q}{p_1}}}{p_1 \left(1+e^{-\frac{q}{p_1}}\right)^2}$ |
| Grillo Function Fit | $g = \frac{p_1}{\left(1+\frac{p_1^2 q^2}{p_2^2}\right)^{\frac{3}{2}}}$ |
| Polynomial Fit | $g = p_1 + 2p_2 q$ |

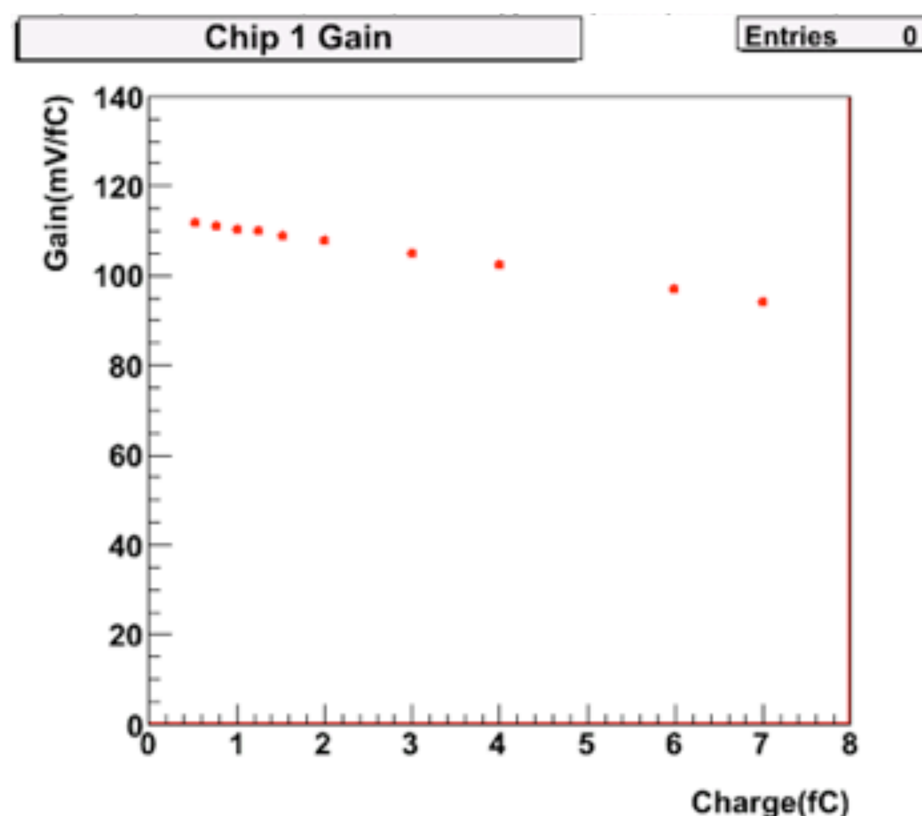
$g$, Gain (mV/fC)
$q$, Injected Charge (fC)
$p_0$, Offset (mV)
$p_1$, Small Signal Gain
$p_2$, measurement of the non-linearity

Result of Dummy Module M59 strun 661 @Zeuthen SCTDAQ.trunk 1768



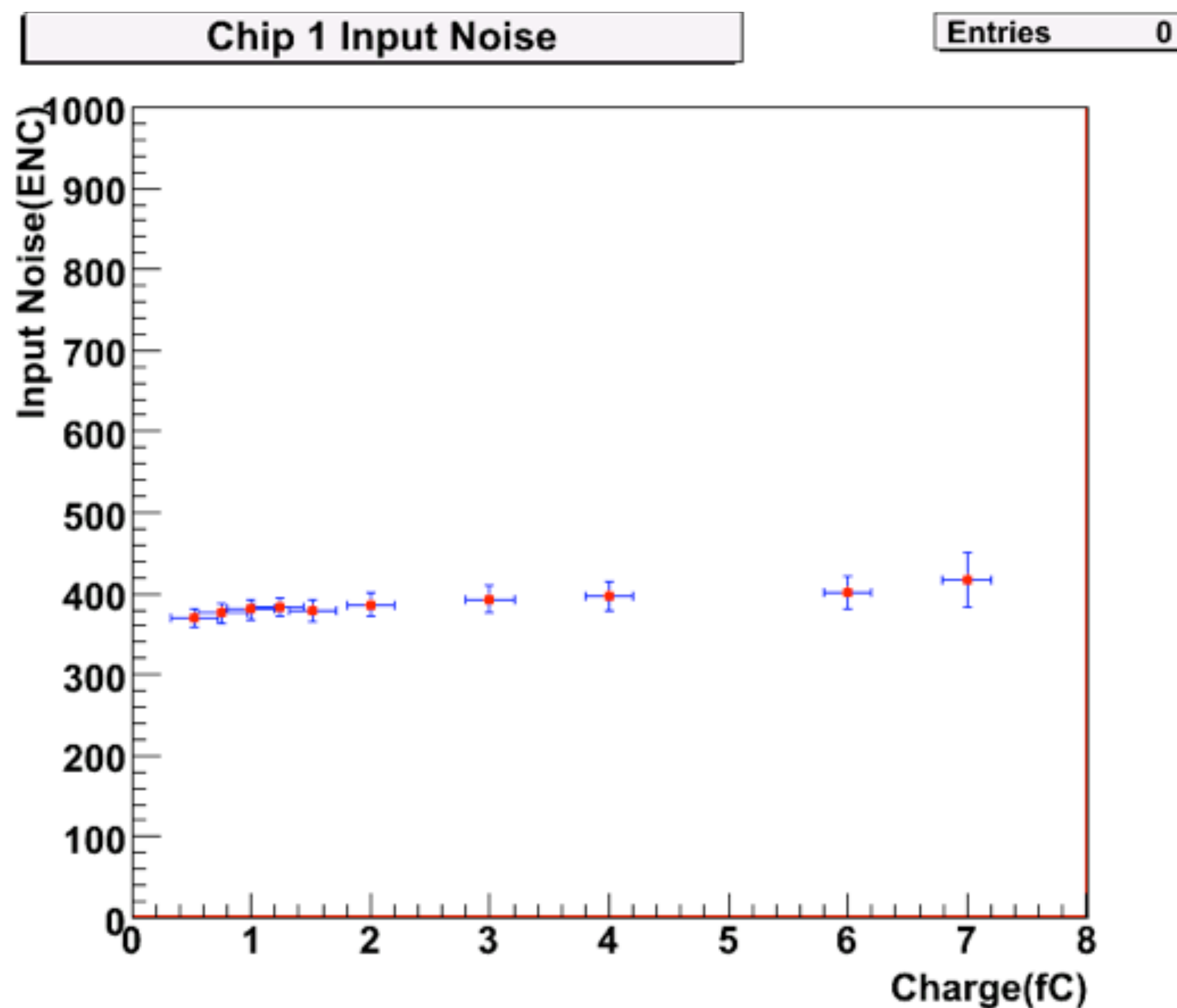
# Readout Tests- Gain Tests

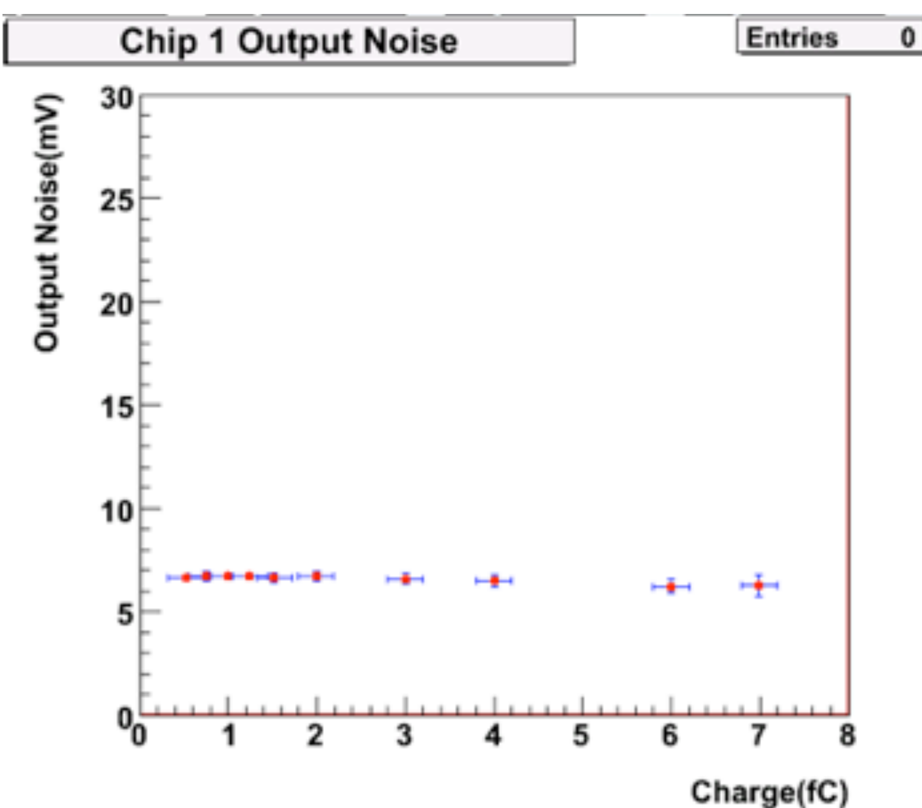





$$\text{Input Noise} = 6250 \times \frac{\sigma_s}{\text{gain}}$$

ENC (Equivalent Noise Charge) 1 fC : 6250 e




Result of Dummy Module M59 strun 661 @Zeuthen SCTDAQ.trunk 1768

# Readout Tests- Gain Tests



| | Injected Charge (fC) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3PT 1fC | 0.52 | – | 1.00 | – | 1.48 | – | – | – | – | – |
| 3PT 2fC | – | – | – | – | 1.52 | 2.00 | 2.48 | – | – | – |
| RC | 0.52 | 0.76 | 1.00 | 1.24 | 1.52 | 2.00 | 3.00 | 4.00 | 6.00 | 7.00 |

| | m59 (ENC) | m60 (ENC) |
|---|---|---|
| 3PointGain 1fC | $365 \pm 20$ | $373 \pm 21$ |
| 3PointGain 2fC | $367 \pm 21$ | $378 \pm 22$ |
| Response Curve | $371 \pm 18$ | $383 \pm 18$ |

Input Noise Values

3PT (1fC) ~ 3PT (2fC) < RC

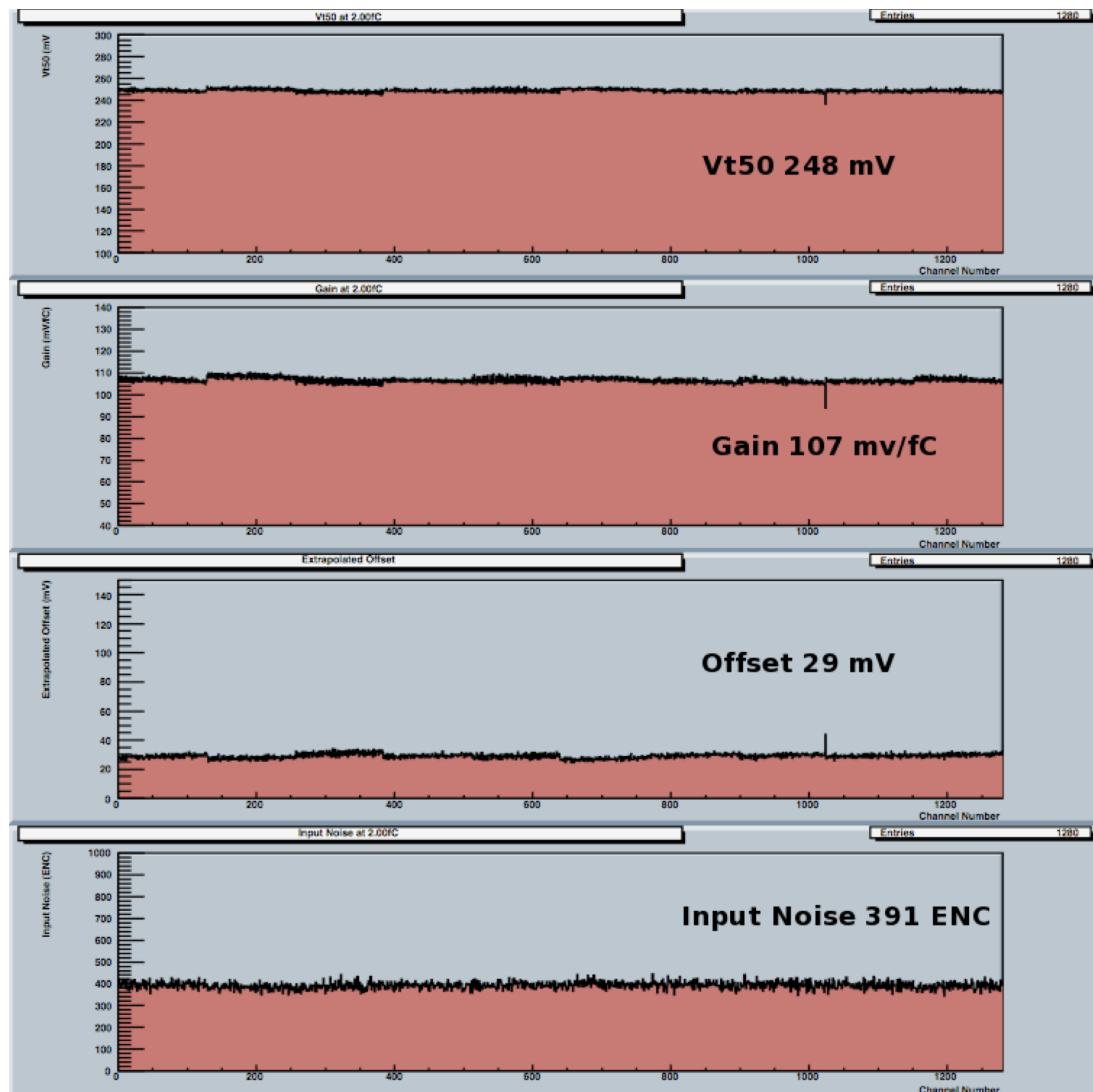
Output Noise values are at the same level, it might be due to the lower gain for higher injected charge

# Readout Tests- Gain Tests





- Gain Test result of all 1280 channels (10 chips)
- Vt50 at injected charge of 2fC
- Input Noise
  The main index now commonly used in SCT community to determine the performance of the module or system



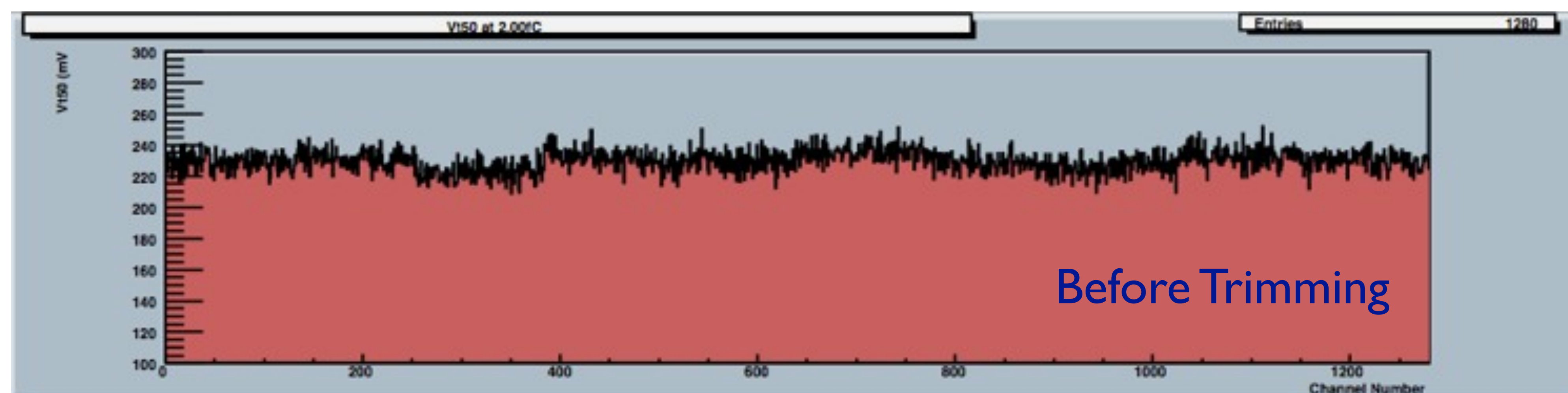

Result of Dummy Module M59 stream 0
strun 661 @Zeuthen SCTDAQ.trunk 1768

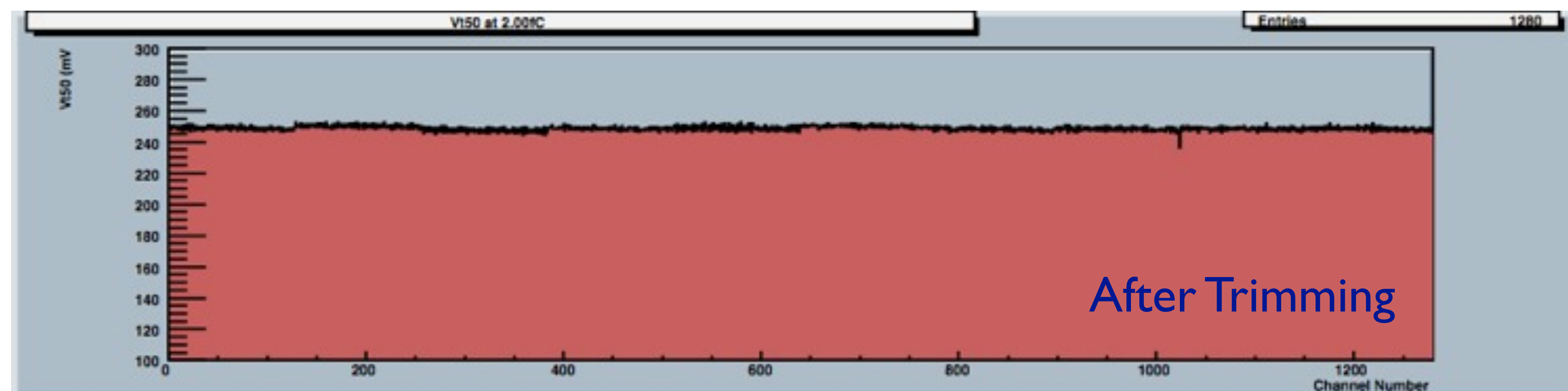
# Readout Tests- Trim Range





- To keep the homegeneity of performance across all channels, Threshold for each channel has to be tuned
- 8 target thresholds are acuqired to be trimmed (with 8 different trim steps and ranges),
- The channels are not able to be trimmed, they are masked




Result of Dummy Module strun 661 @Zeuthen SCTDAQ.trunk 1768

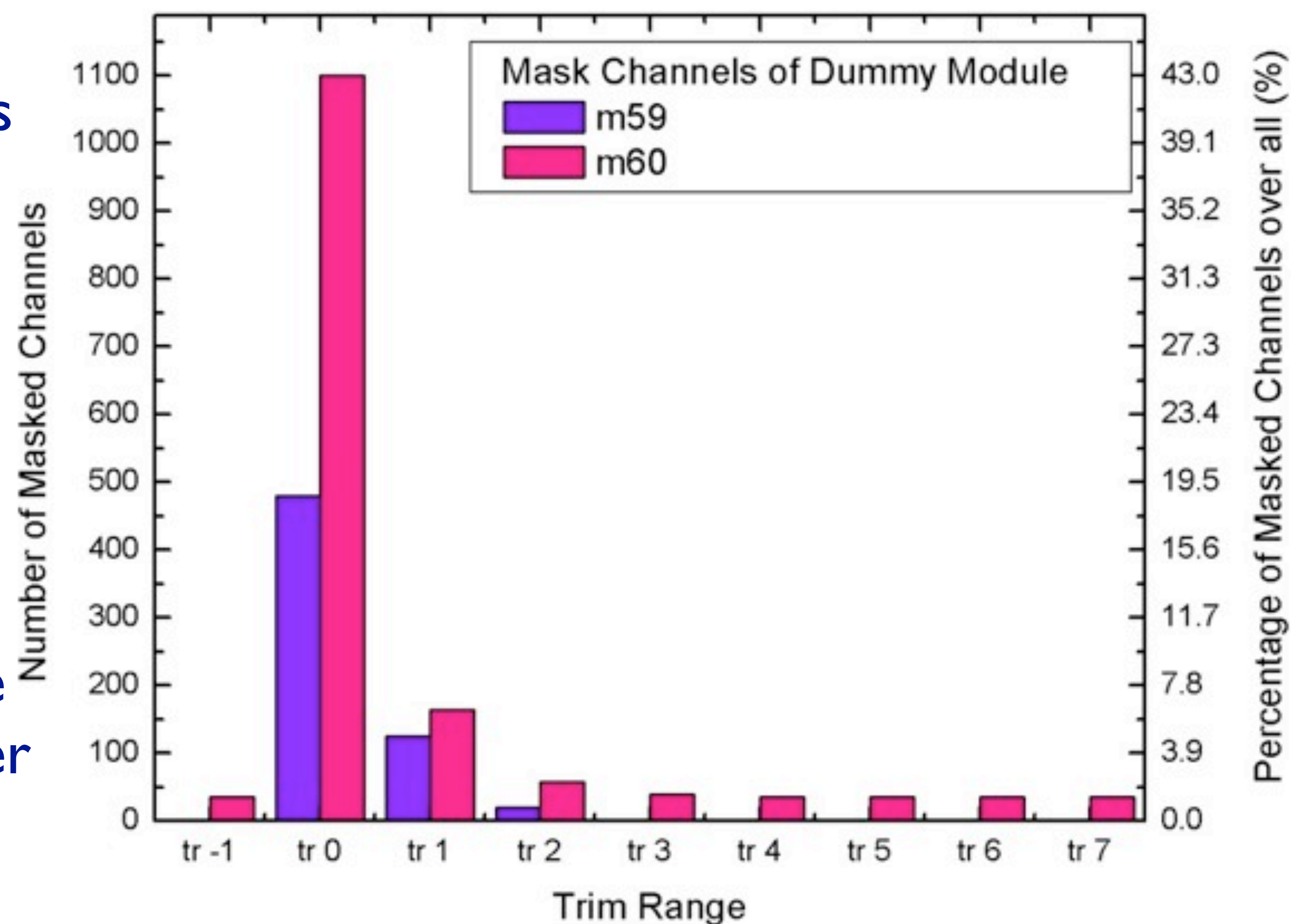
# Readout Tests- Trim Range





- 8+1 different trim and mask results
- the optimize one:
  1. less masked channels
  2. smaller trim ranges

If the target threshold can not be trimmed by small trim step, there are more channels masked than the larger trim range



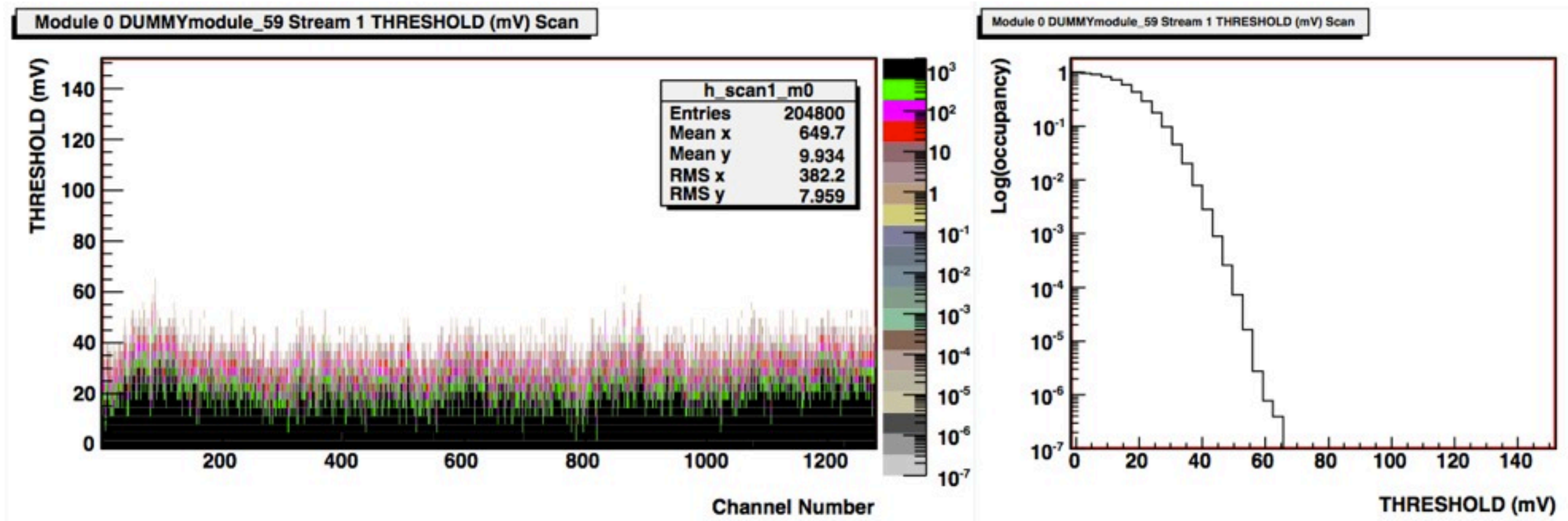

Result of Dummy Module strun 661 @Zeuthen SCTDAQ.Windows version

# Readout Tests- Noise Occupancy





- Measured without injecting charge
- Send 2000 triggers to readout the signal
- Reduce the statistical error by sending more triggers



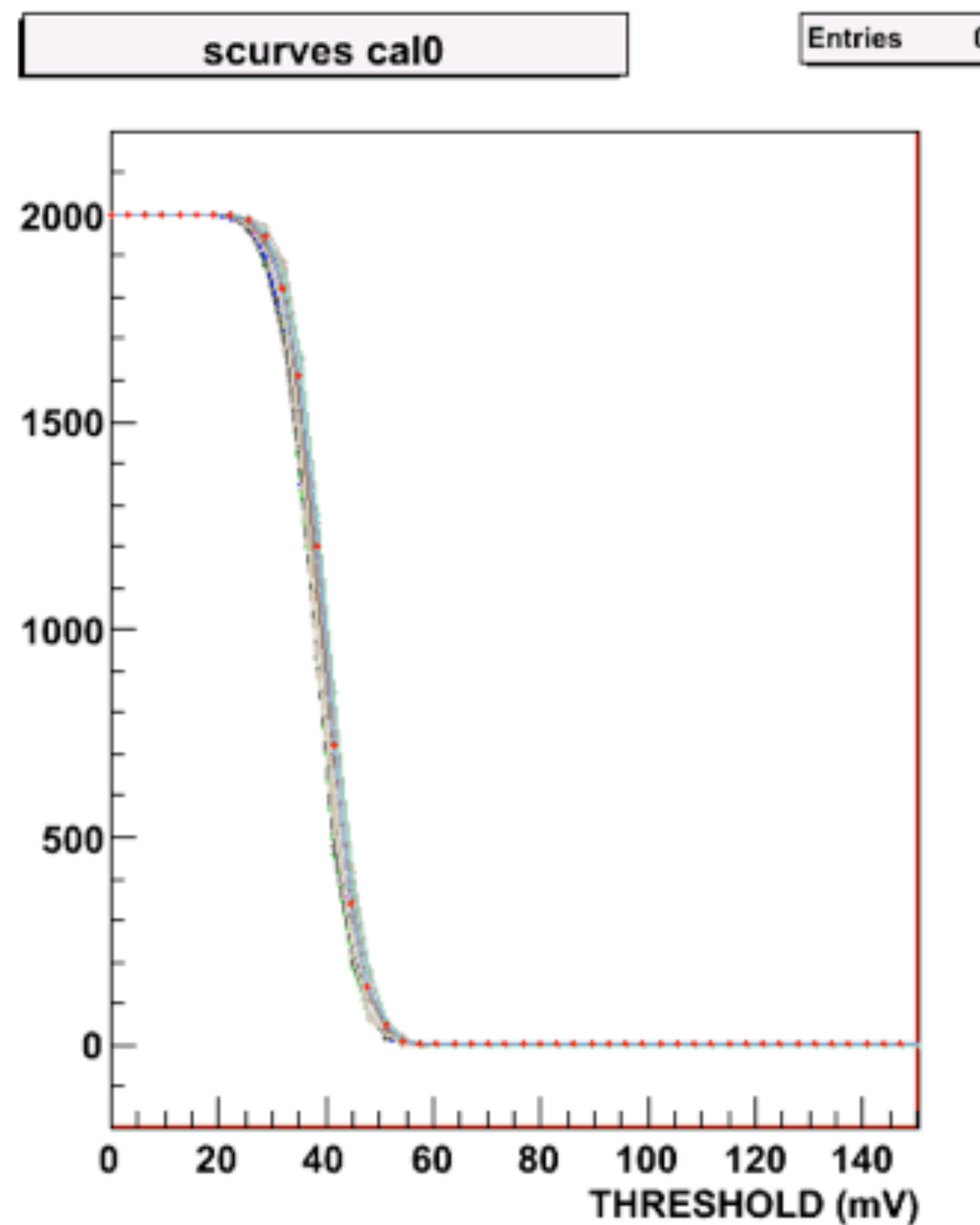

Result of Dummy Module strun 570 @Zeuthen Modified Version

# Readout Tests- Noise Occupancy





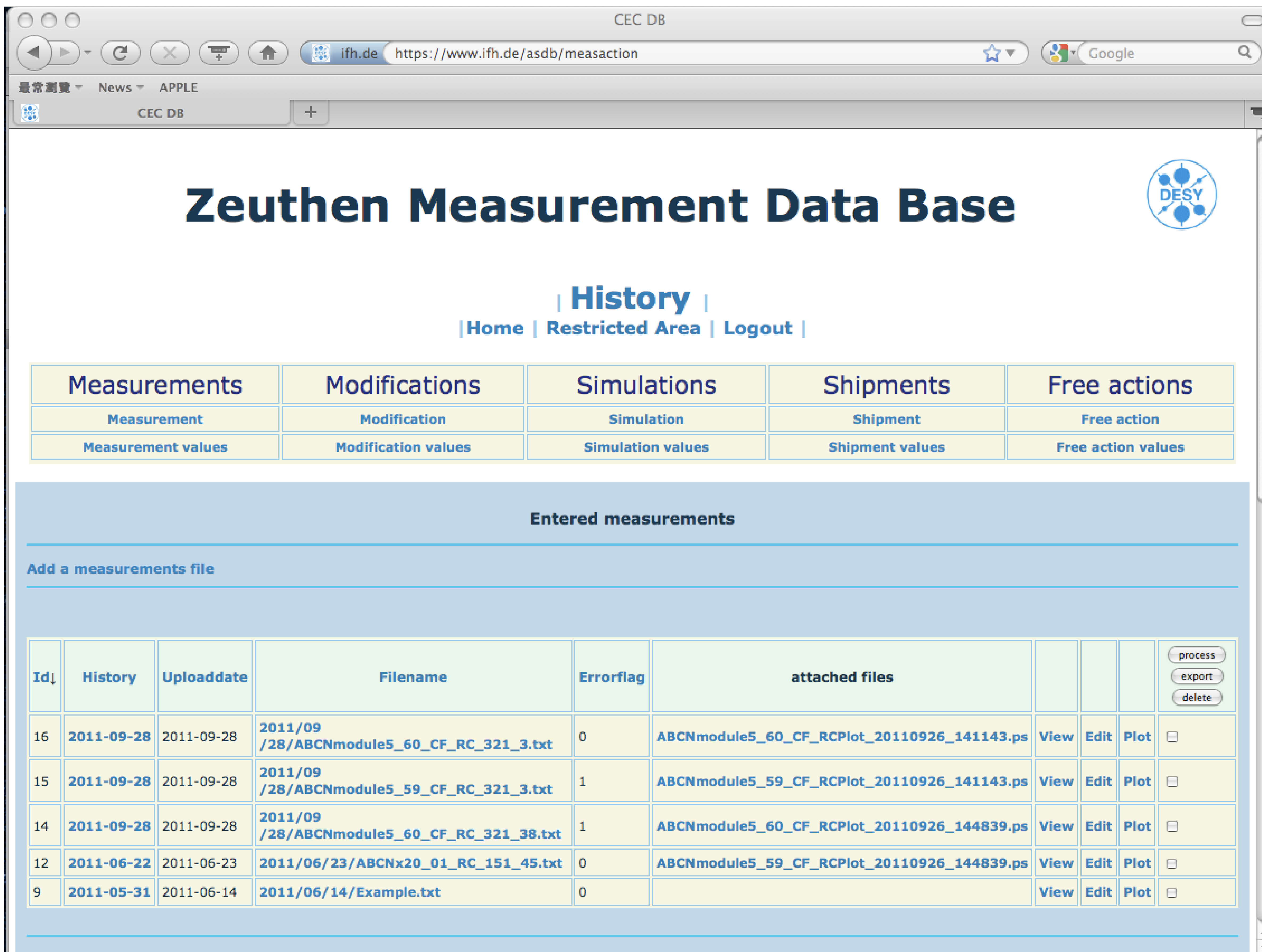
- S-Curve from Noise Occupancy
- Vt50 can be converted from mV to fC by result from Gain Tests




Result of Dummy Module strun 570 @Zeuthen
Modified Version

# Local Database System



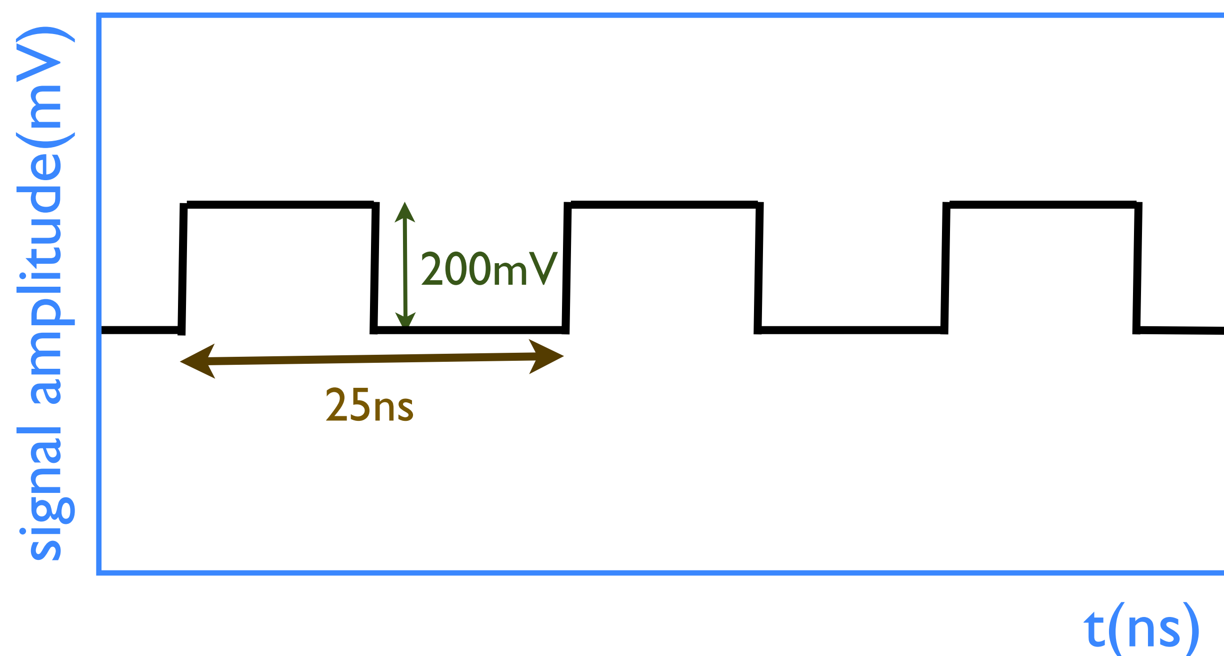


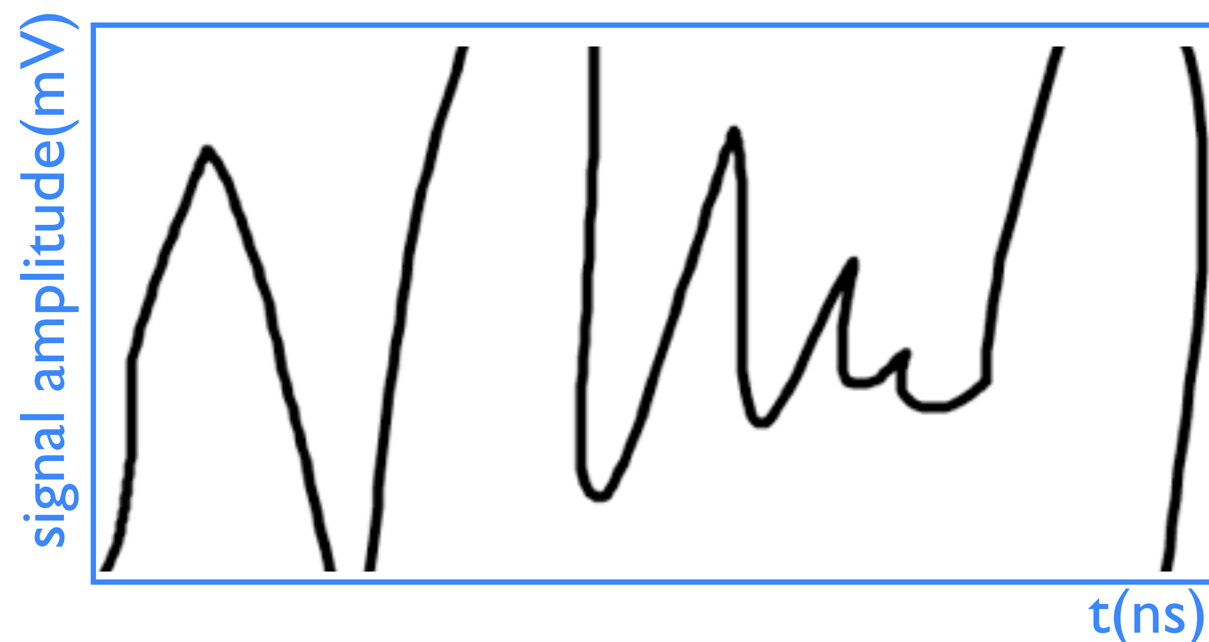
# System Stability - Electromagnetic Interference



- Example :
  The bunch crossing clock signal during the test of single hybrid

Electromagnetic impose noise on the bunch crossing clock signal
in extreme case, can crash the readout software



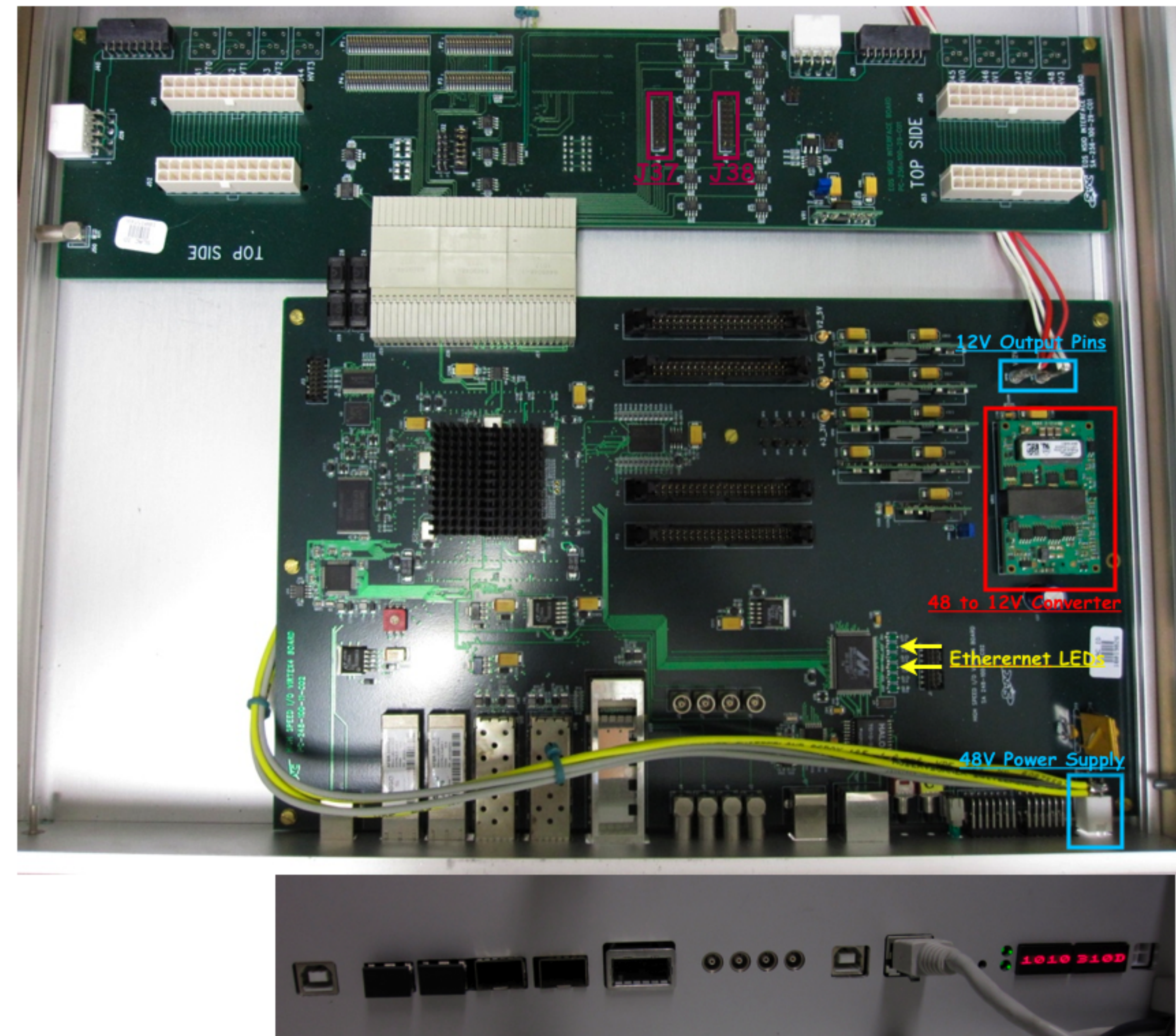



# Noise Hunting - Different Way to Power HSIO



Powering the HSIO without large DC-DC converters (noisy)

Other group observe different behavior (under investigation)

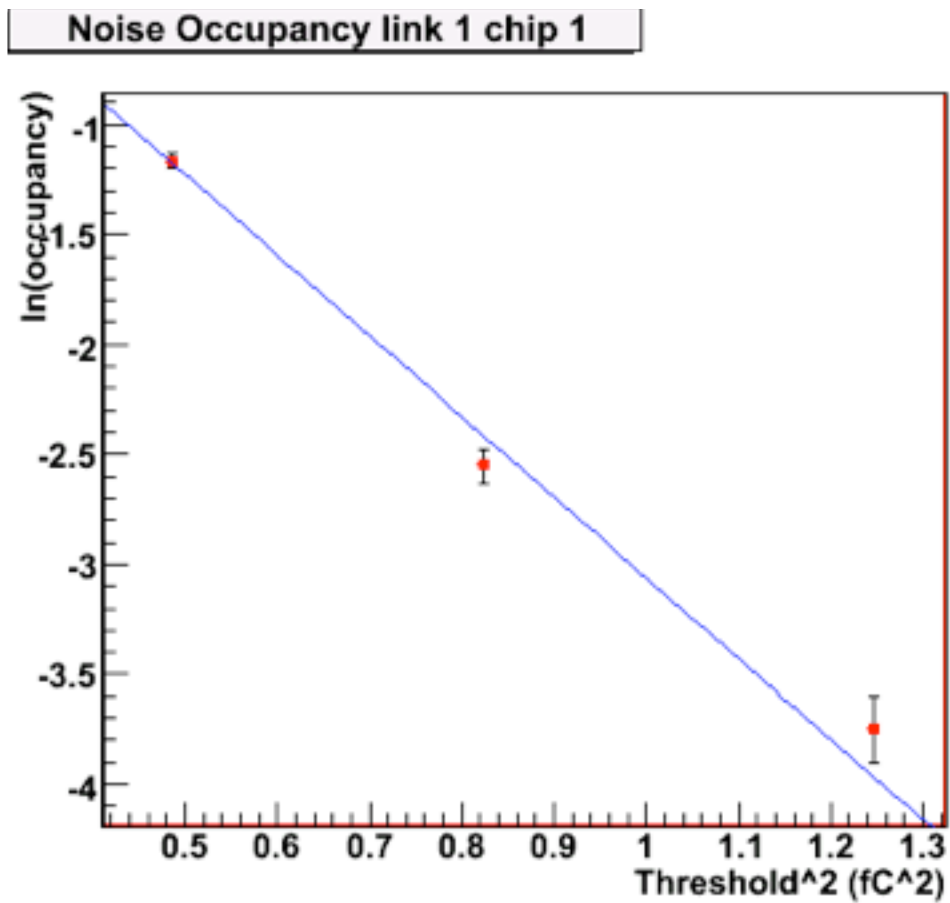



| | m59 (3PT 1fC) | m59 (3PT 2fC) | m60 (3PT 1fC) | m60 (3PT 2fC) |
|---|---|---|---|---|
| 48 V | $401 \pm 21$ | $449 \pm 27$ | $403 \pm 29$ | $453 \pm 33$ |
| 12 V | $412 \pm 25$ | $464 \pm 29$ | $409 \pm 29$ | $464 \pm 67$ |

# Summary & Conclusion & Outlook

- Upgrade of LHC & ATLAS Detector
- DESY focus on module production and testing
- HSIO based readout system and the SCTupDAQ software set up (further debugging is still on going)
  - ready for the future module production & testing
- Test results of dummy module
  - Strobe Delay, Gain tests, Trim Range, Noise Occupancy
- The Zeuthen Database
  - Modified the interface to local database
- Stability and Noise hunting of the readout system
  - The sources of system instability identified, noise hunting season has not yet ended

- the behaviour of ln(O) should be linear as the theory predicted

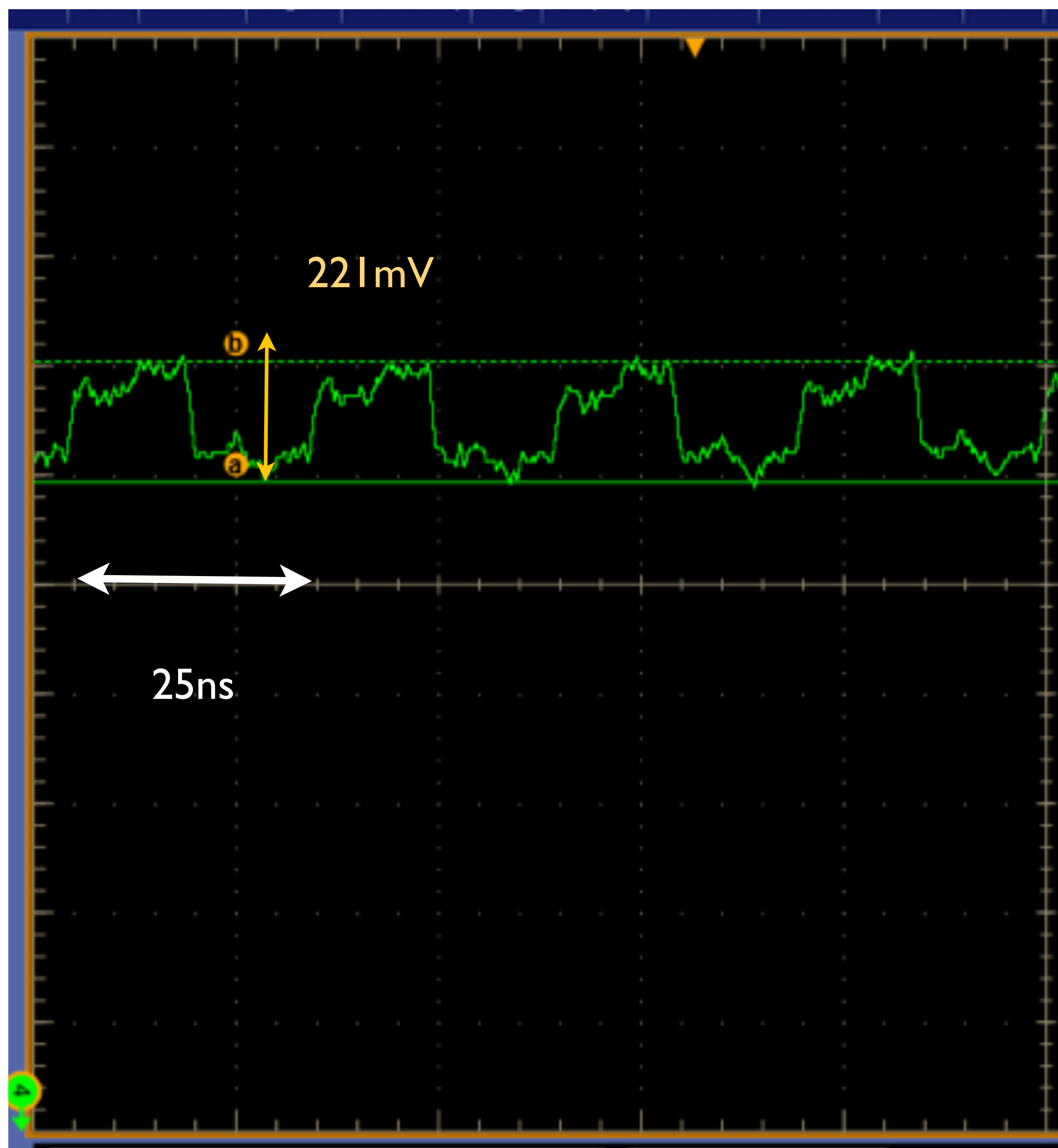


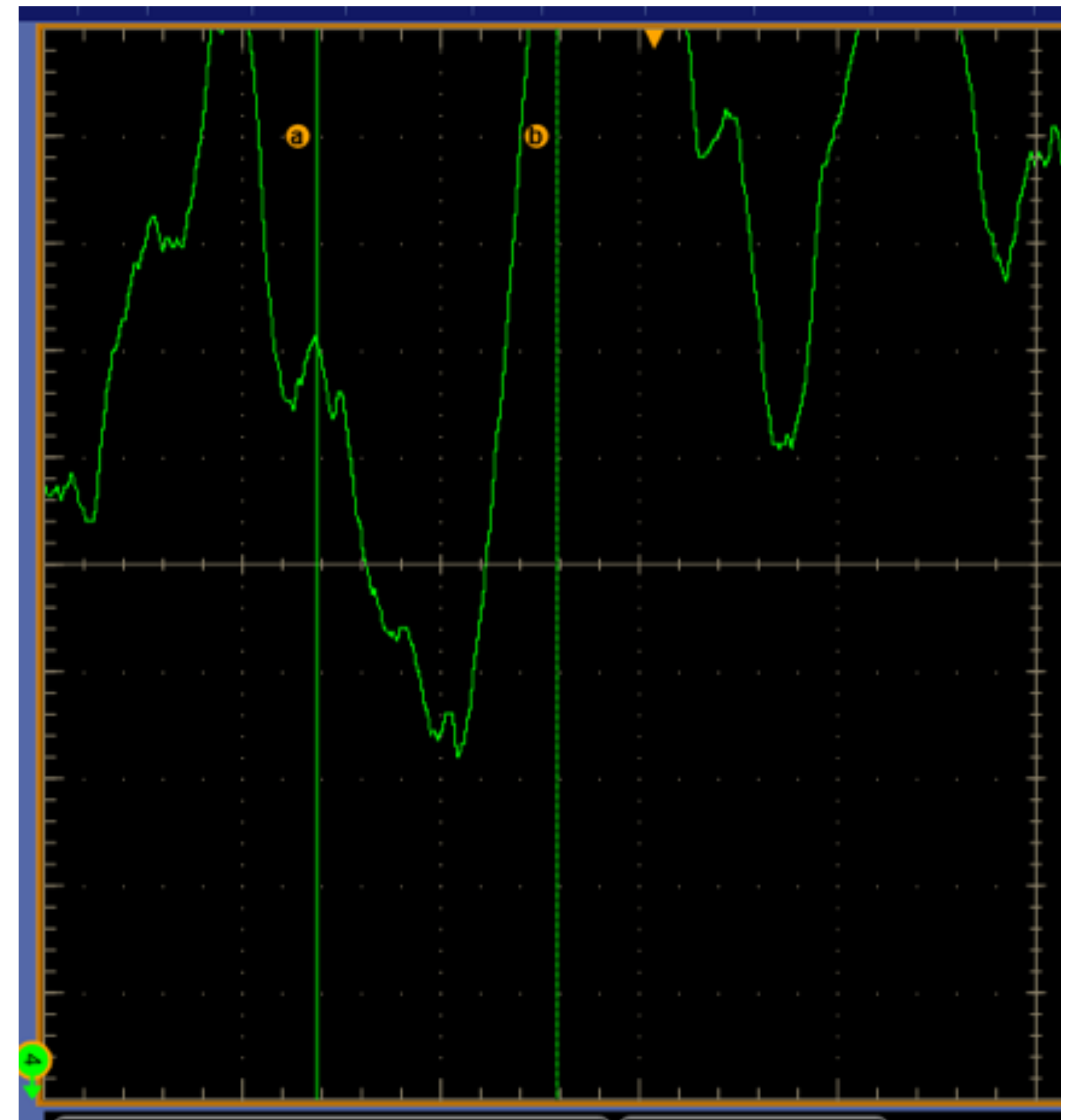

$$\ln(O) \approx -\frac{1}{2}\mathrm{V}_{\mathrm{thr}}^2 - \ln\left(\sqrt{2\pi}\mathrm{V}_{\mathrm{thr}}\right)$$

# Electromagnetic Interference

- The bunch crossing clock signal during the test of signal hybrid

- The signal from electromagnetic interference superpositon the bunch crossing clock signal and make the readout terminated



| Trim DAC Code (bit2 bit1 bit0) | Trim DAC range | Trim DAC step |
|---|---|---|
| 0 0 0 | 0 mV – 14.88 mV | 0.48 mV |
| 0 0 1 | 0 mV – 22.32 mV | 0.72 mV |
| 0 1 0 | 0 mV – 29.76 mV | 0.96 mV |
| 0 1 1 | 0 mV – 37.20 mV | 1.20 mV |
| 1 0 0 | 0 mV – 44.64 mV | 1.44 mV |
| 1 0 1 | 0 mV – 59.52 mV | 1.92 mV |
| 1 1 0 | 0 mV – 74.40 mV | 2.40 mV |
| 1 1 1 | 0 mV – 89.28 mV | 2.88 mV |