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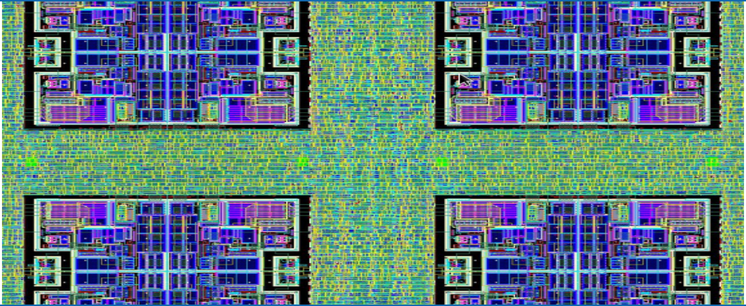

Offline and online calibration algorithms for the RD53A ROC

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IPA

Introduction

- ➜ Comparison between calibration algorithms
- ➜ New feature of the RD53A chip: trickle configuration
- ➜ Development of an online tuning method (in software) following ideas of Timon Heim and Maurice Garcia-Sciveres from LBNL

Offline calibration

The threshold scan algorithm (TSA)

- Binary search for optimal TDAC mask
- At each step: N injections over charge range $\rightarrow$ S-curves are computed
- The mean threshold is calculated and the TDAC shifted for individual pixels to bring their threshold closer to the mean.

The occupancy scan algorithm (OSA)

- Similar structure as TSA but with occupancy scans
- Occupancy scans: N injections at a single charge (not over a range)
- Occupancy higher than $\frac{1}{2} \rightarrow$ threshold is increased (decreased otherwise).
- Much faster than TSA.

Results at high threshold

- ➜ OSA and TSA equivalent at high thresholds ($>$ 1500 electrons): similar σ and tails.
- ➜ OSA is 4 times faster.

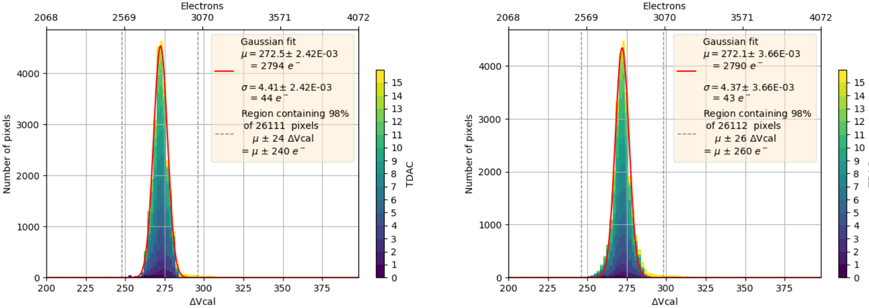


Figure: Threshold distribution for the TSA (left) and the OSA (right)

- ➜ TSA and OSA give gaussian distributions
- ➜ Difference of these distribution should be a gaussian of mean 0 and $\sigma_{diff} = \sqrt{2}\sigma$
- ➜ Figure shows good results from 1500 electrons.

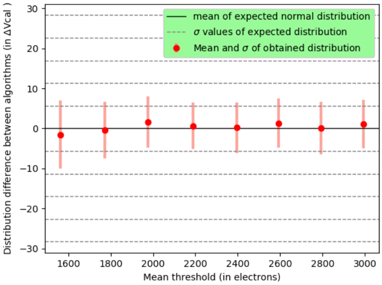


Figure: Mean and σ of the distribution of the pixel by pixel difference in threshold between TSA and OSA outcome as a function of the mean threshold.

- TDAC distribution is very similar for both algorithms
- Correlation plot of TDAC distributions → 77% of pixels have same TDAC values after either one.
- Only 0.4% get significantly different TDAC values (at a threshold of 2500).

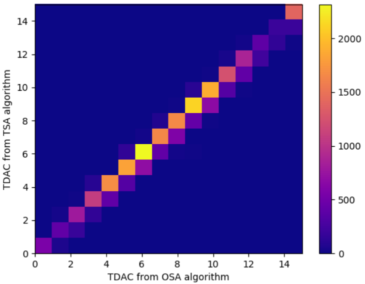


Figure: Scatter plot of individual pixels' TDAC after the TSA against their TDAC after the OSA.

Influence of noise

- ➜ Failing pixels → S-curve cannot be computed because of noise hits.
- ➜ Calibration before decreasing the mean threshold is needed.

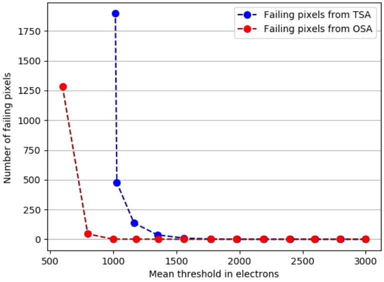


Figure: Number of failing pixels as a function of the final mean threshold for the TSA and OSA.

Online calibration

Software implementation based on the ideas of T. Heim's and M. Garcia-Sciveres paper [1]

[1] T. Heim and M. Garcia-Sciveres. Self-adjusting threshold mechanism for pixel detectors. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 867:209–214, 2017

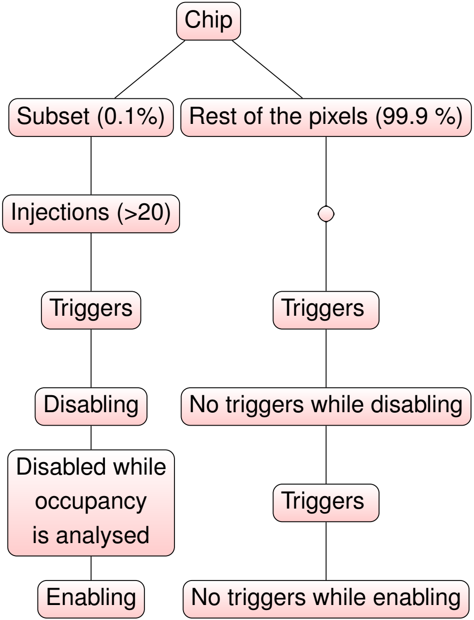
Motivation

- SEU negating the spatial calibration
- Trickle configuration: chip receives its settings regularly to mitigate SEU. New feature of RD53A.
- TID $\rightarrow$ threshold shift even with trickle configuration
- Solution: calibrate the chip during data taking (trickle tuning)

- Principle of the method: regularly inject a specific charge into a small subset of the pixels and update their TDAC according to their occupancy
- How can it work?
  - Occupancy calibration works
  - Low occupancy ($\approx$ 0.1 %) for the pixels at CMS $\rightarrow$ low probability of physics hit while analysing occupancy

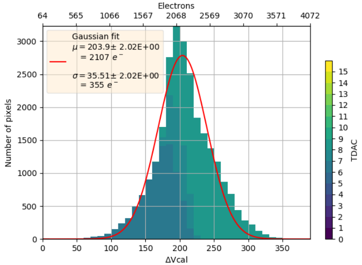
A BDAQ53 feature

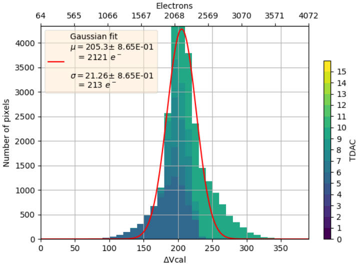
- Version 0.11 of BDAQ: functionality for quick online data retrieval.
- Threading process $\rightarrow$ adds raw data to a queue for occupancy histogramming.
- Can be called during data taking.

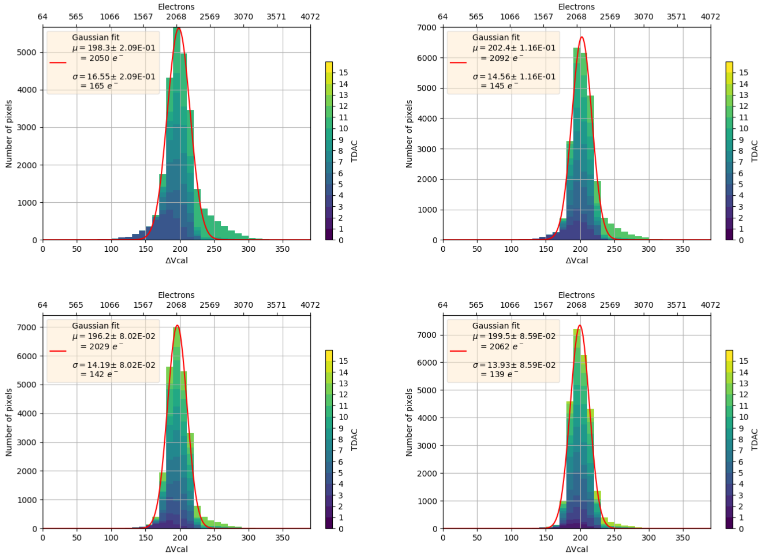

Chip
Subset (0.1%)
Rest of the pixels (99.9 %)
Injections (>20)
Triggers
Triggers
Disabling
No triggers while disabling
Disabled while occupancy is analysed
Triggers
Enabling
No triggers while enabling

Calibration results

- Online method applied to the whole LFE.
- 0.25% of the 26112 pixels injected at each calibration step.
- 15 calibration steps. *n*-th calibration step corresponds to
  - *n* updates of the TDAC of each pixel
  - $400 \times 31000 \times n$ triggers sent to every pixel







Electrons
64 565 1066 1567 2068 2569 3070 3571 4072
Gaussian fit
μ = 198.3± 2.09E-01
= 2050 e⁻
σ = 16.55± 2.09E-01
= 165 e⁻
Number of pixels
ΔVcal
TDAC
Gaussian fit
μ = 202.4± 1.16E-01
= 2092 e⁻
σ = 14.56± 1.16E-01
= 145 e⁻
Gaussian fit
μ = 196.2± 8.02E-02
= 2029 e⁻
σ = 14.19± 8.02E-02
= 142 e⁻
Gaussian fit
μ = 199.5± 8.59E-02
= 2062 e⁻
σ = 13.93± 8.59E-02
= 139 e⁻

➜ Convergence in 7 whole matrix iterations and stable.

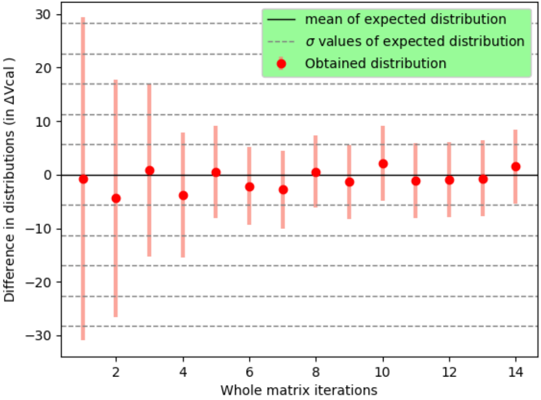


Figure: Mean and σ of the pixel by pixel difference in threshold between ideal and obtained distributions.

➜ $|\text{TDAC}_{\text{ideal}} - \text{TDAC}_{\text{obtained}}| > 0$ (orange) and
$|\text{TDAC}_{\text{ideal}} - \text{TDAC}_{\text{obtained}}| > 1$ (blue)

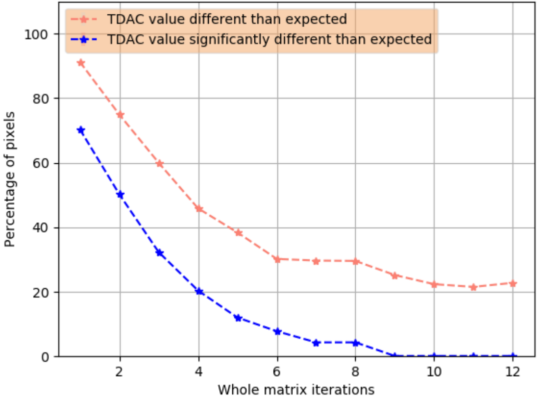


Figure: TDAC convergence w.r.t whole matrix iterations

Averaging

- After optimal calibration is reached, pixels in tails of threshold distribution still have high occupancies $\rightarrow$ continously get shifted.
- To measure this: $N = 150$ updates of the TDAC of each pixel starting from a calibrated distribution.
- Plot of $u + d$ as a function of the distance to the mean threshold of the pixels (u (resp. d) = number of times the TDAC of a pixel has been shifted upward (resp. downward)).

- 90 % of the pixels satisfy $|u - d| \leq 1$, only those are considered.
- Clear increase with distance to mean threshold.

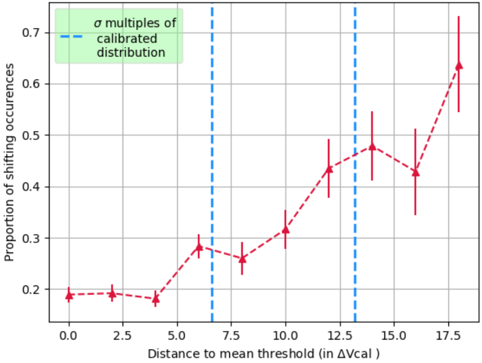
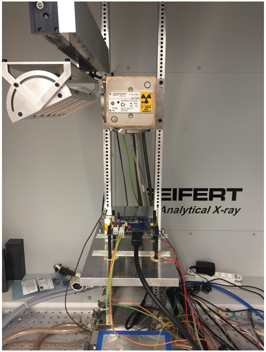
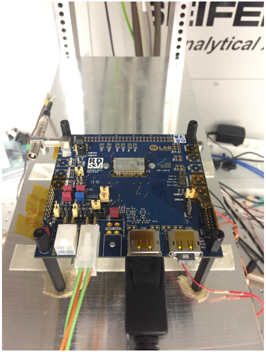


Figure: Mean of $\frac{u+d}{N}$ as a function of the distance to the mean threshold of the pixels

Testing in X-ray chamber

➜ X-ray tube with Cr anode operated at 10 kV and 18 mA: mean hit probability per trigger of a pixel $\approx 2 \times 10^{-4}$





- ➜ From a calibrated distribution: same measurement with and without trickle tuning.
- ➜ Same number of triggers: 62×10^6 over 2800 seconds, 0.4% of the pixels injected.

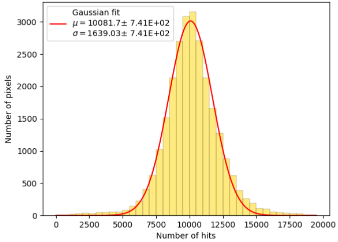


Figure: Detected hits for the regular scheme (left) and the online method (right)

- ➜ Consistent means (p-value of 14% to Student's test)
- ➜ Averaging phenomenon leads to a thinner effective distribution (Levene's and Bartlett's test for statistical decision)

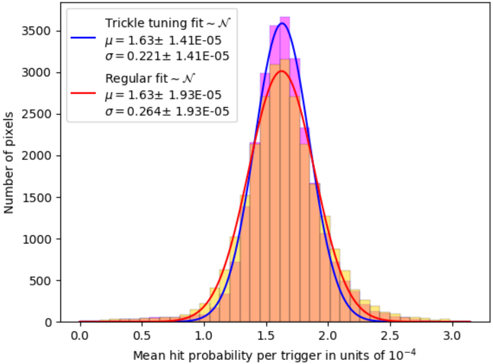


Figure: Hit probability per trigger with (purple) and without (orange) trickle tuning

Summary and conclusions

- Implementation of a new offline calibration algorithm:
  - Fast and efficient at high threshold ($>$ 1500 electrons)
  - Slight modification to obtain usable TD at low threshold ($<$ 1000 electrons)
- Software implementation of a method for trickle tuning:
  - Using occupancy analysis of chosen pixels
  - Quick convergence towards calibrated distribution
  - Stable over many iterations
  - Leads to averaging phenomenon
- Code available on this git: Link
- Work in progress!!