Characterization of an ASIC-Based Readout System for the SAND Experiment

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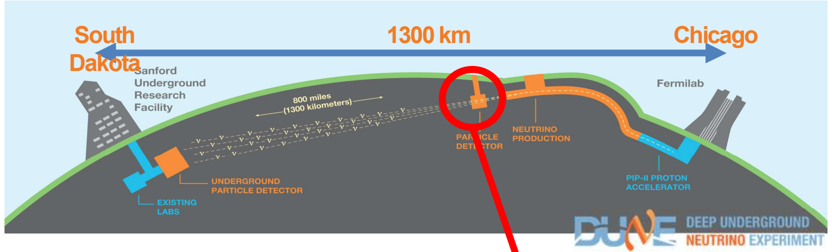
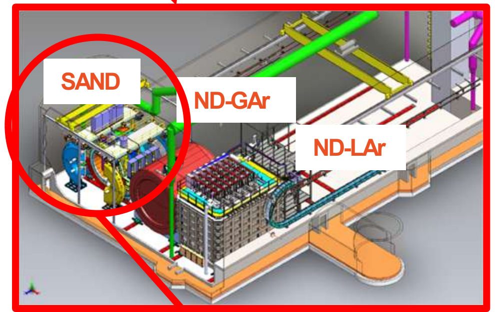
Outline

1. SAND-ECAL PMTs: Description and FEE Requirements
2. Proposed CAEN FEE
3. The CAEN FERS-5200 System
4. A5203:
    - Measurements Setup and Data Acquisition
    - Results
5. A5204:
    - Measurements Setup and Data Acquisition
    - Results
6. Conclusions

SAND calorimeter (and magnet) from KLOE experiment at LNF

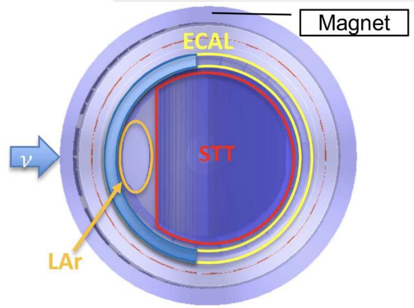


DUNE NEAR DETECTOR COMPLEX (60 m underground)



SAND - System for on-Axis Neutrino Detection

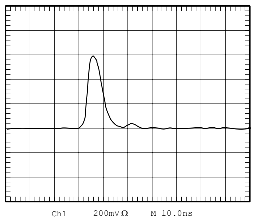
Multipurpose detector with high performance calorimeter (ECAL), light-targeted tracker (STT), LAr target (GRAIN), all in magnetic field, always on beam axis

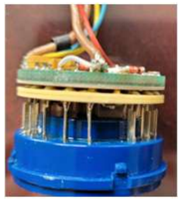


SAND - ECAL

Lead - scintillating fiber calorimeter

In total 4880 PMTs with charge and time readout





Measurement Requirements for SAND-ECAL PMTs

Hamamatsu fine-mesh PMT R5946

- signal: fast rise time ~ 2ns
- PMT base with HV divider and signal preamp.
- typical HV for PMT 1700-1800 V => G ~ 1-3 x 10^6
- gain preamp ~ 2.5

ECAL-PMTs FrontEnd Electronics requirements

- Energy Resolution: → 3-4 % for signals < 400 mV
  → 1-2 % for signals > 400 mV
- Time Resolution: 50 -100 ps
- Data acquisition on a wide dynamic range:
  signal from 2.5 mV to ~ 2 V amplitude
- Compact and scalable
- low-power and low-cost for multi-channel scalability

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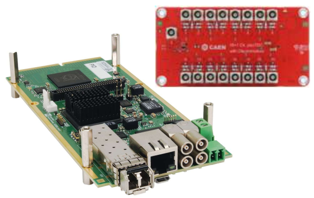
CAEN FrontEnd Electronics Options

ASIC-based front-end boards of FERS-5200 family:
- **A5203** 64-channel front-end for time and ToT-reconstructed amplitude measurements
- **A5204** 64-channel front-end for PHA and picoseconds resolution time measurements optimized for fast pulses (200 MHz counting rate)

1



A5203+A5256:
picoTDC (double threshold discrimination) with ToT

for all SAND-ECAL's PMTs signals

2

A5204:
Radioroc + picoTDC (single threshold discrimination) with ToT

for all SAND-ECAL's PMTs signals

peak sensing ADC with slow shaper – dead time 20 μs and good resolution
→ for rarer signals of large amplitude (to achieve better energy resolution)

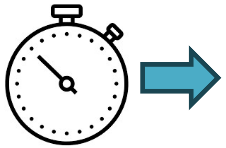
- ASIC integration reduces cost per channel compared to a fully digital front-end solution based on flash ADC
- Trade-off: slightly lower flexibility vs traditional digitizers, but adequate for fixed experimental conditions

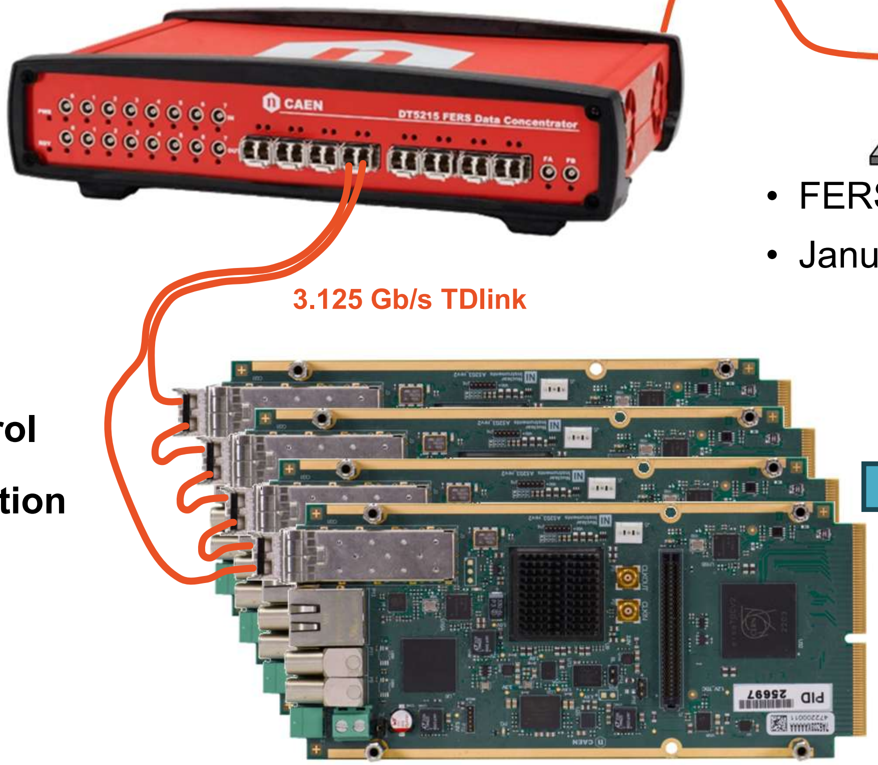
The FERS-5200 Readout System

DT5215 Data Concentrator:

- 1 TDlink => up to 16 FERS
- 1 DT5215 => 128 FERS = 8k/16k ch.

Global Time

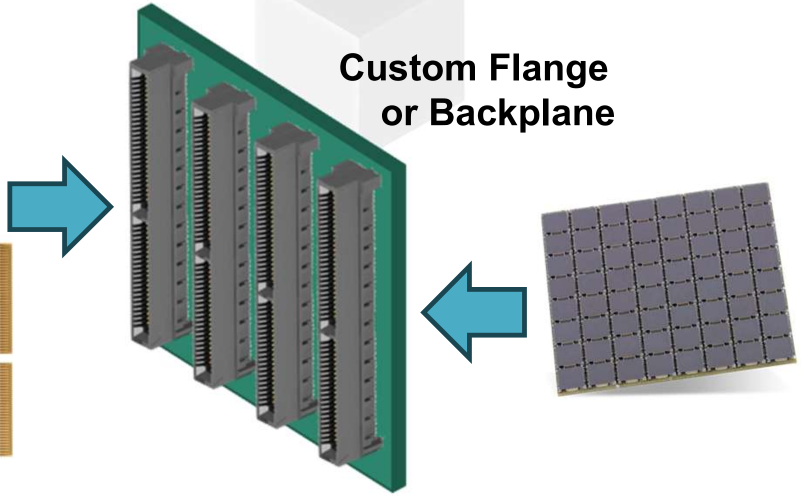




- FERSlib library (SDK coming soon)
- Janus 520X software

Desktop Evaluation Setup: Low Cost, Plug & Play

Readout + Slow Control + Synchronization

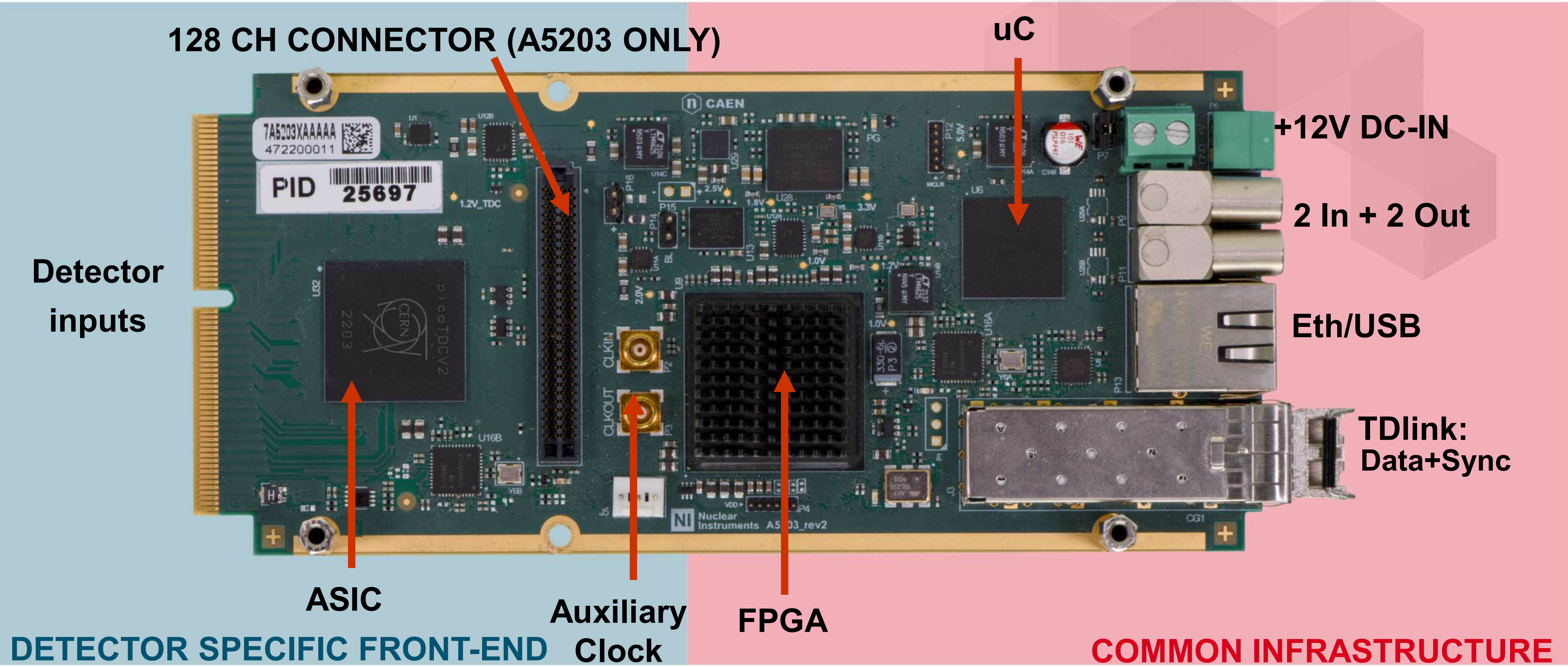


Custom Flange or Backplane

Easy ASIC integration on FERS

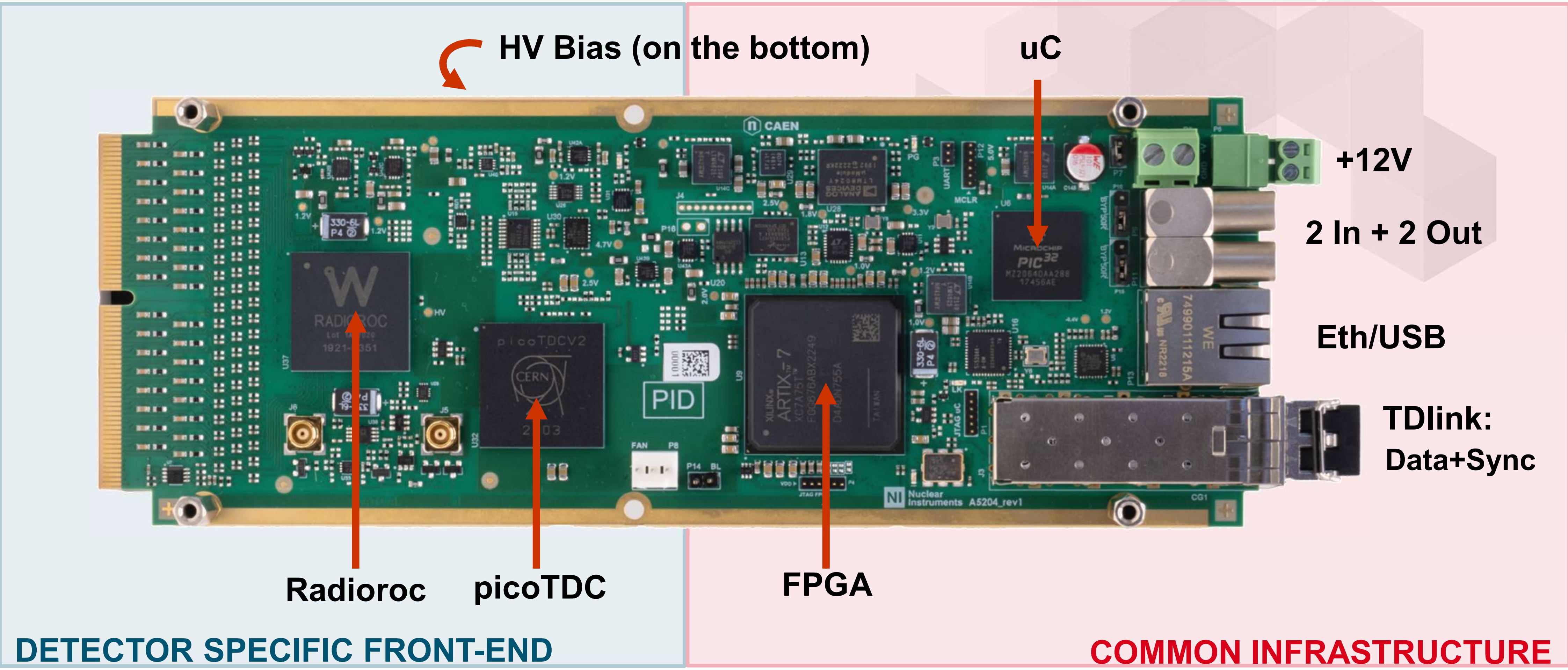
FERS-5200 Units

A5203 Example



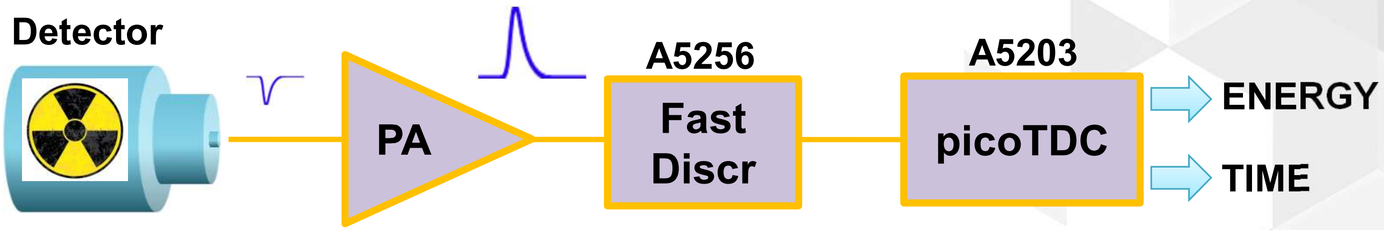
FERS-5200 Units

A5204 Example



Measurements with A5203 Only

1 **Read-out scheme:** picoTDC + double threshold discriminator with Time over Threshold (ToT)



⇒ *Energy by ToT with 2 thresholds not to worsen energy resolution*
⇒ *Time walk correction needed*

Test Setup:

PMTs + LED Driver

⇒ *Two KLOE PMTs (test + reference)*
⇒ *Led Driver CAEN SP5601 (λ~400 nm) + fiber splitter*

Step Attenuator

⇒ *Calibrated attenuator*
⇒ *Variable amplitude*

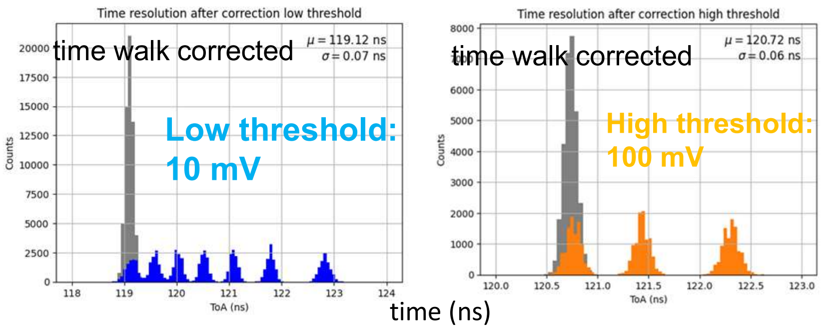
DT5203+A5256

⇒ *Dual threshold*
⇒ *ToT acquisition*

⇒ *Walk correction*
⇒ *Energy estimation using ToT*

Characterization Results #1:

Time and Energy Resolutions



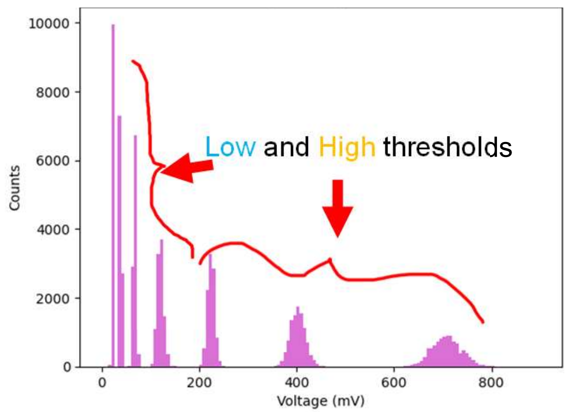
Time Resolution ~ 60 ps
(ECAL T resol. ~ 54ps/√E(GeV) ⊕ 100ps)

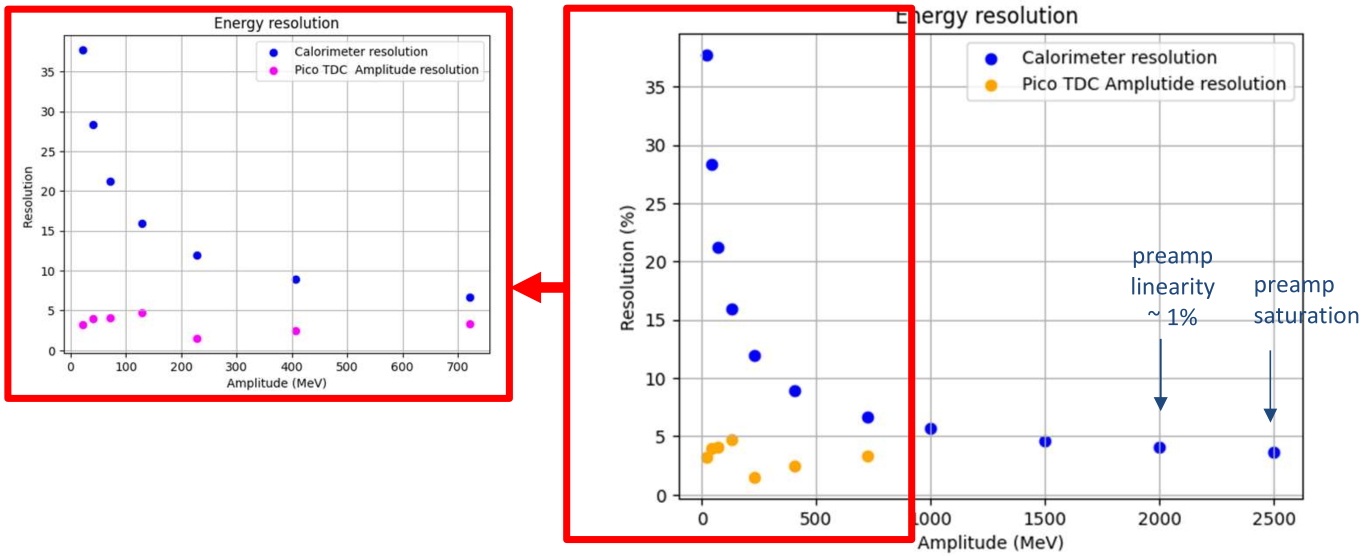
Amplitude resolution obtained from ToT is compared with the intrinsic calorimeter resolution (assuming PMT gain 1 mV = 1 p.e. = 1 MeV => 1 V = 1 GeV)

To be done: optimization of the thresholds for the best performance in the whole expected dynamic range (2.5-2000 mV)

comparison with Ecal resolution **(σ_E/E ~ 5.7%/√E(GeV))**

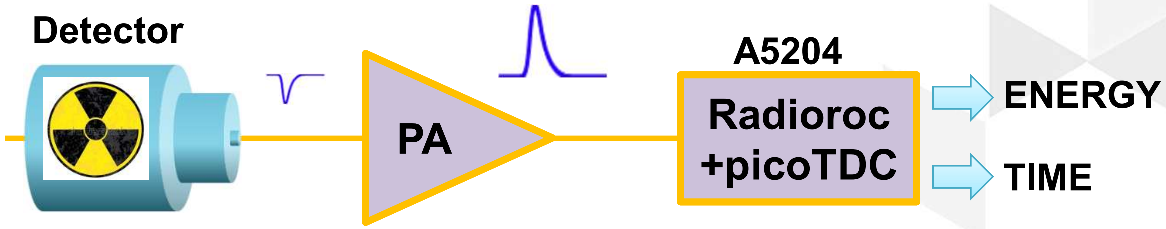
Amplitude reconstruction from ToT





Measurements with A5204

2 **Read-out scheme:** Radioroc chip + PicoTDC single threshold discriminator with Time over Threshold (ToT)



⇒ *Energy&Time:Single threshold with ToT acquisition (for all signals)*

⇒ *Energy: Peak sensing ADC with slow shaper – dead time 20 μs and good resolution (for rarer signals of large amplitude)*

Test Setup:

AFG 3252

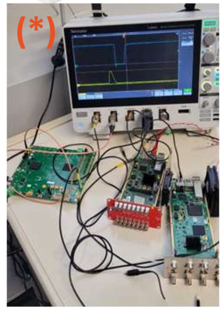
Step Attenuator

- ⇒ *No calibration needed (done with ADC)*
- ⇒ *variable amplitude*

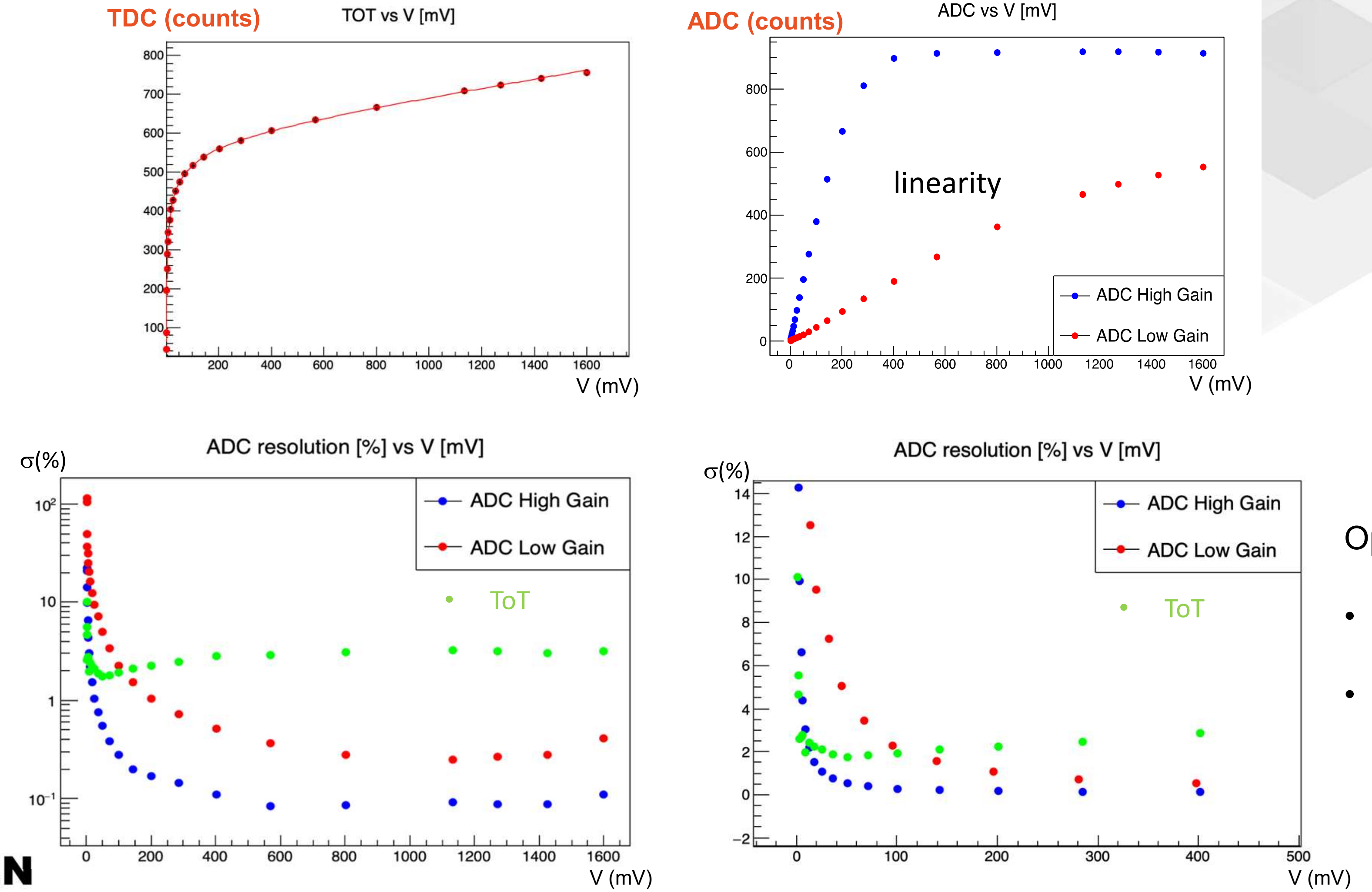
A5204 (*)

- ⇒ *Energy with ADC and by ToT with 1 threshold*
- ⇒ *Time with 1 threshold*

- ⇒ *Energy measurement and calibration with ADC*
- ⇒ *Walk correction*
- ⇒ *Energy estimation using ToT*



Characterization Results #2:
Linearity and Energy Resolution



Optimal energy resolution:

- for signals < 100 mV 1-2% with fast ToT
- for signals > 100 mV <1% with ADC (low gain)

Conclusions

SAND-ECAL PMTs FEE -> A5203 and A5204 ASIC-based boards proposed by CAEN SpA

A5203:

- Characterized up to 700 mV signal amplitudes, due to fixed pulser light intensity. Needs further characterization
- External 64 ch. double threshold discriminator needed, now only 8+1 ch.
- Double discrimination thresholds to be further optimized
- Meets time resolution requirements, meets energy resolution requirements just for low energy signals

A5204:

- Characterized Radioroc evaluation board+A5203, aim to test again with the final A5204 version
- No need for external discriminator, improved ToT linearity for high signals amplitudes (no need for double threshold)
- meets both energy and timing SAND requirements

A5204, thanks to Radioroc+picoTDC, offers very good energy resolution at both low (ToT- reconstructed amplitude) and high energies (ADC-converted amplitude), and very good time resolution

-> SAND-ECAL's requirements met

-> Future work: measurement optimization and test under beam conditions

Thank you

Back Up Slides

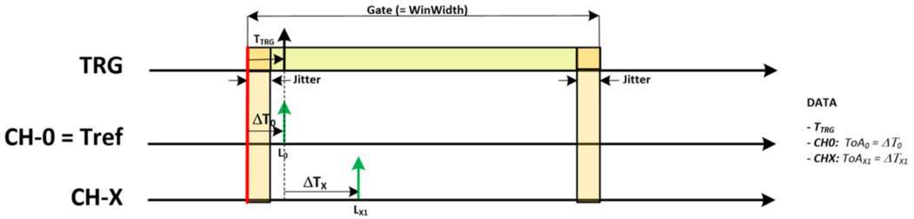
Comparison Table

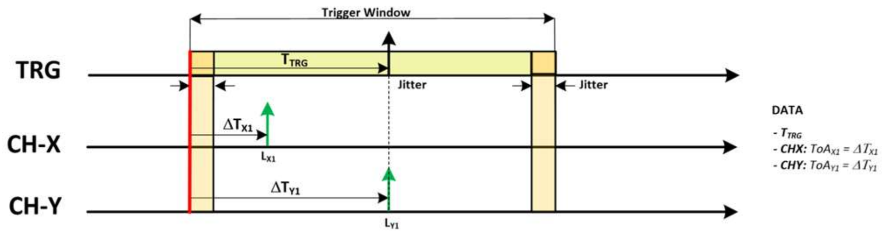
A5203 vs A5204

Feature	A5203 (B)	A5204
No. of Channels	64/128	64
Input signals	LVDS	Analog
Mounted Chip	picoTDC	Radioroc+picoTDC
PHA (ADC conversion)	No – pulse amplitude estimated via ToT	Yes
Energy Resolution	see slide n. 10	see slide n. 12
Time Resolution	5 ps RMS	55 ps RMS
Principal Application	Timing	PHA, Counting, Timing
Best suited for	---	SiPM

X5203 Specifications

- **TDC**: 64/128 channels (1 picoTDC = 64 ch), LSB = 3.125 ps, dynamic range = 56 bit (extended by FPGA)
- **Inputs:** digital, LVDS ⟶ Front-End needed
- **Output Data:** Time of Arrival (ToA), Time over Threshold (ToT)
- **Data throughput:** up to ~**64 Mcps/board** (without filters)
- **Acquisition modes**: Common Start/Stop (Tref=Ch0), Trigger Matching, Streaming





- **DeltaT Resolution (*)** :
  - Same board: **typ 5 ps RMS**
  - Board to board: **~20 ps RMS**
    synchronized by DT5215 Concentrator Board via TDlink
  - Board to board: **~8 ps RMS**
    synchronized by DT5215 Concentrator Board via TDlink , with auxiliary daisy chain/fan out clock cables

(*) Tested with A5256 discriminator. Pulse: 0.5 Vpp, 0.8 ns rise time

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X5203 Specifications

x5203 Pros	x5203 Cons
• high timing resolution (~ 5 ps), high channel density, almost no dead time • provides ToA and ToT in one word	• ToA affected by walk effect • No energy information (PHA) acquired -> need for a separate ADC readout chain

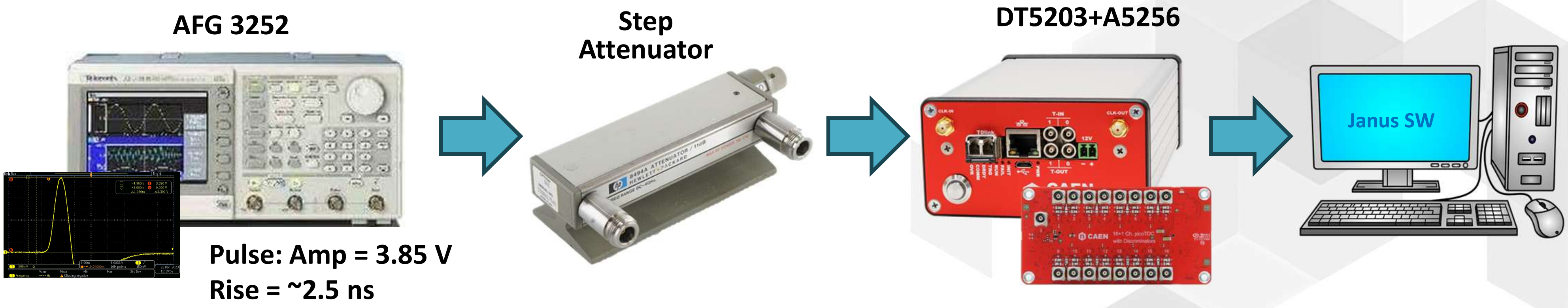
-> ToT-Based Analysis: Walk correction and PHA

- **ToT** can be used **to correct for time walk** => no need of Constant Fraction Discriminator in hardware
- **ToT** can be used **to reconstruct pulse amplitude**: ToT – PHA curve is not linear => need calibration (pulse shape dependent)
- **FPGA ToT filter**: rejects pulses if **ToT < LowCut** or **ToT > HighCut** (remove noise, DCR, saturation…)

Ongoing feasibility study of the ToT technique for the readout of 5000 PMTs in SAND (DUNE)

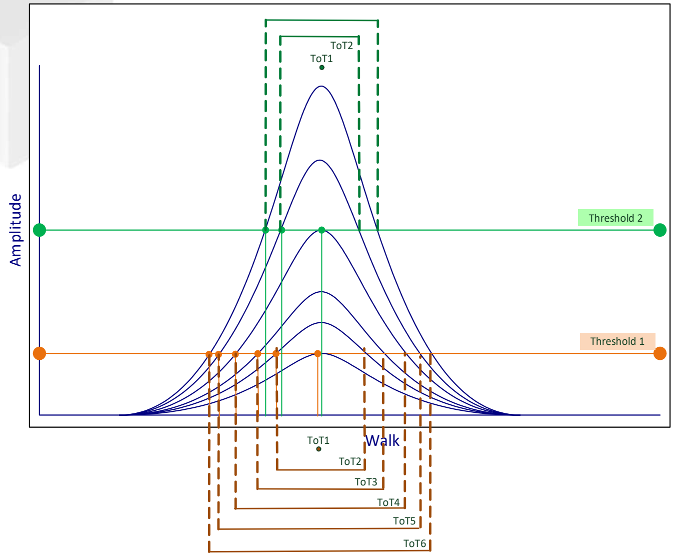
SEE NEXT

ToT Analysis Setup



Common Start Acquisition: start on Ch0 with fixed amplitude, stop on Ch1 and Ch2 (dual threshold) with variable amplitude (max = 3.85 V). Delay = 13 ns

1. **Sweep**: acquire **ToT** and **ΔT (ToA)** at different amplitudes (from 0 to 54 dB, 3 dB step)
2. Fit points and build **ToT-Walk (ToA)** and **ToT-Ampl** curves
3. Use curves to **correct Walk** from ToT (replace CFD)
4. Use curves to **get Amplitude** from ToT (make ADC from TDC)



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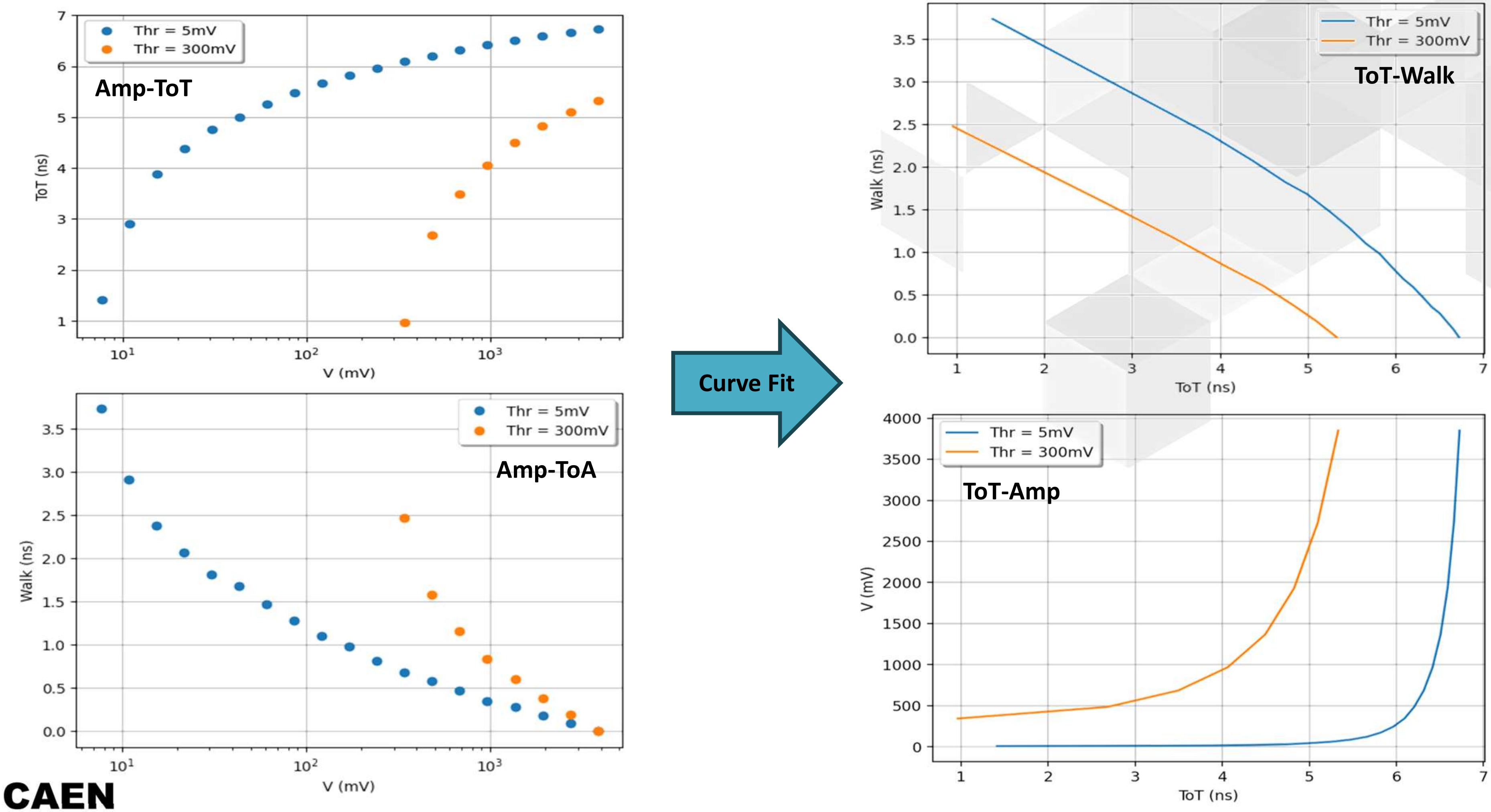
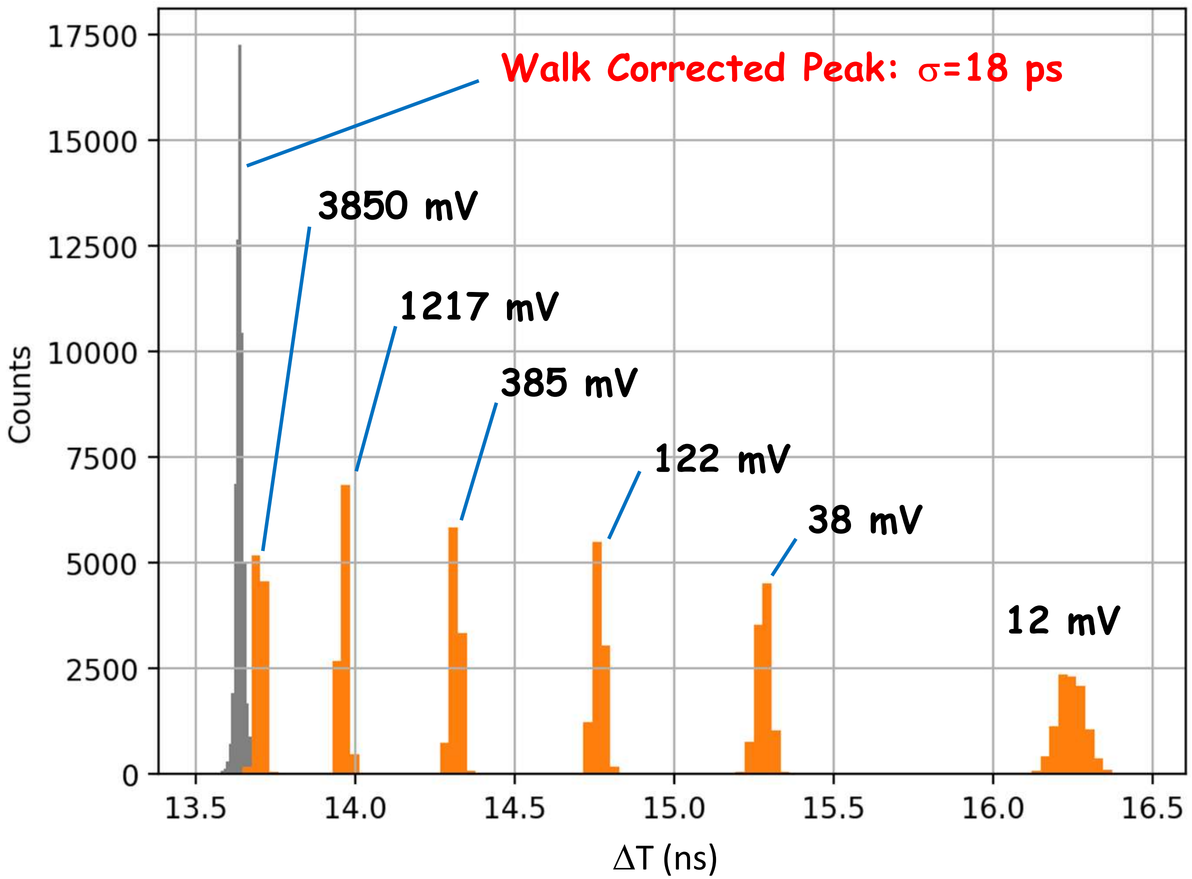
ToT Calibration Curves

Double Threshold



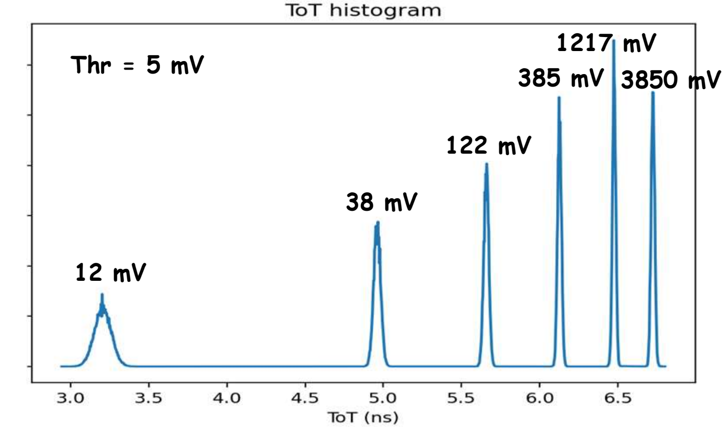
Walk Correction

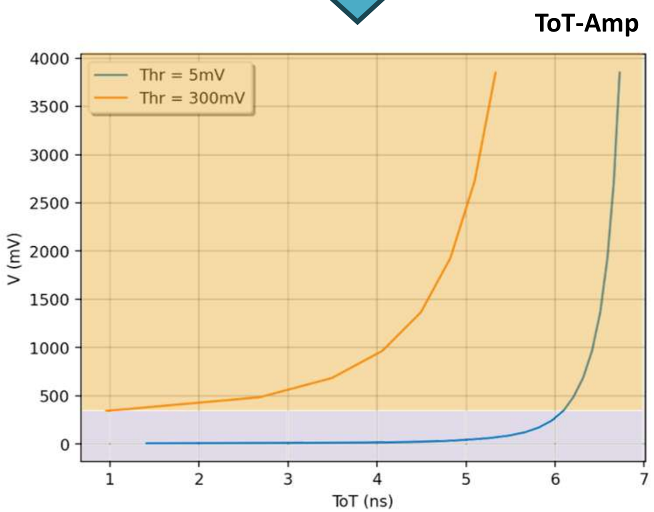


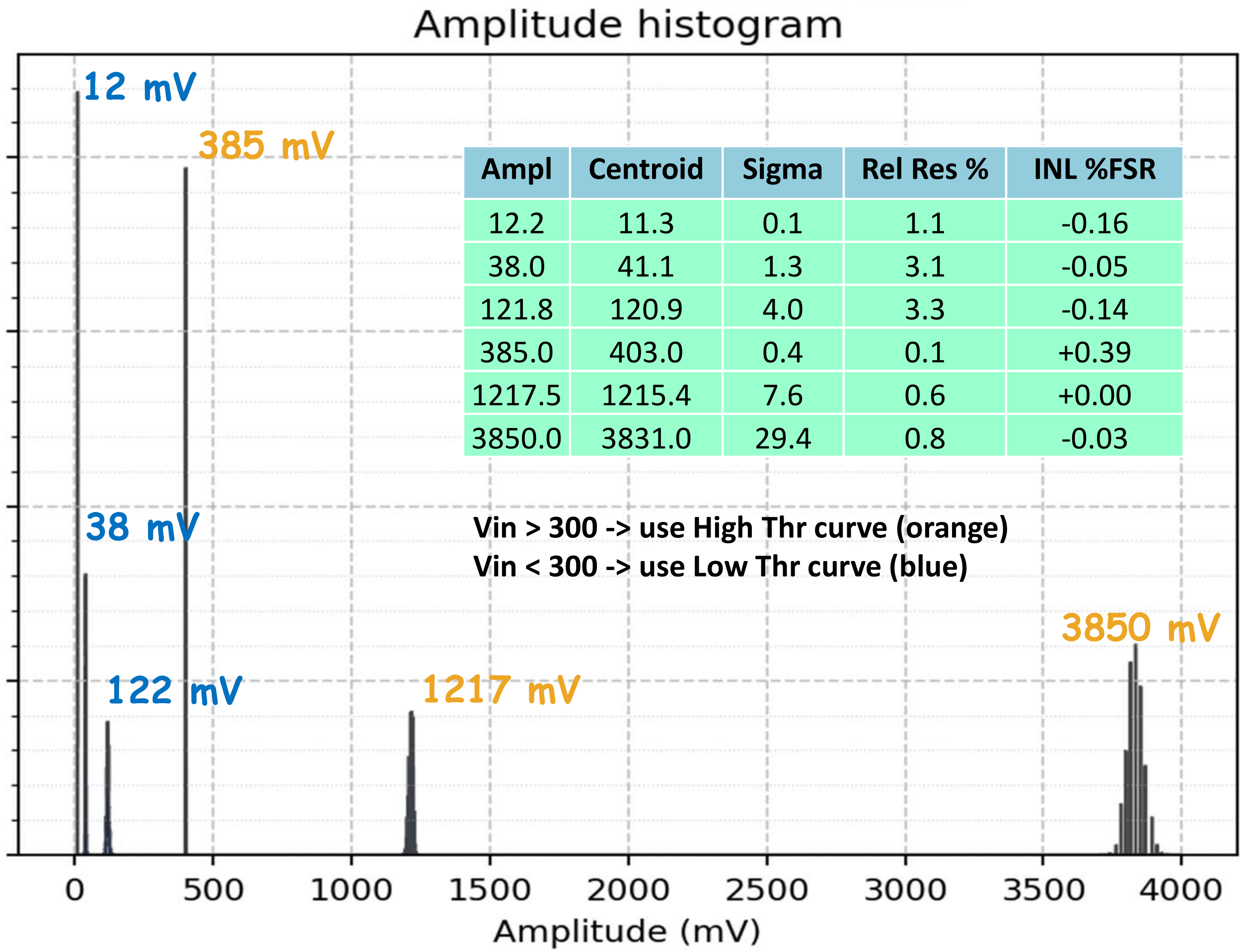
- Pulses at 6 different amplitudes over a 50 dB dynamic range
- ~2 ns spread on ΔT (ToA) caused by the walk effect: 6 separate peaks !!
  - ➔ timing resolution totally destroyed
- ΔT corrected by ToT using a 5th order polynomial fit of the **ToT-Walk** points taken at threshold = 5 mV
- Corrected ΔT histogram presents one single peak:

  18 ps RMS over 50 dB dynamic range

Amplitude Reconstruction



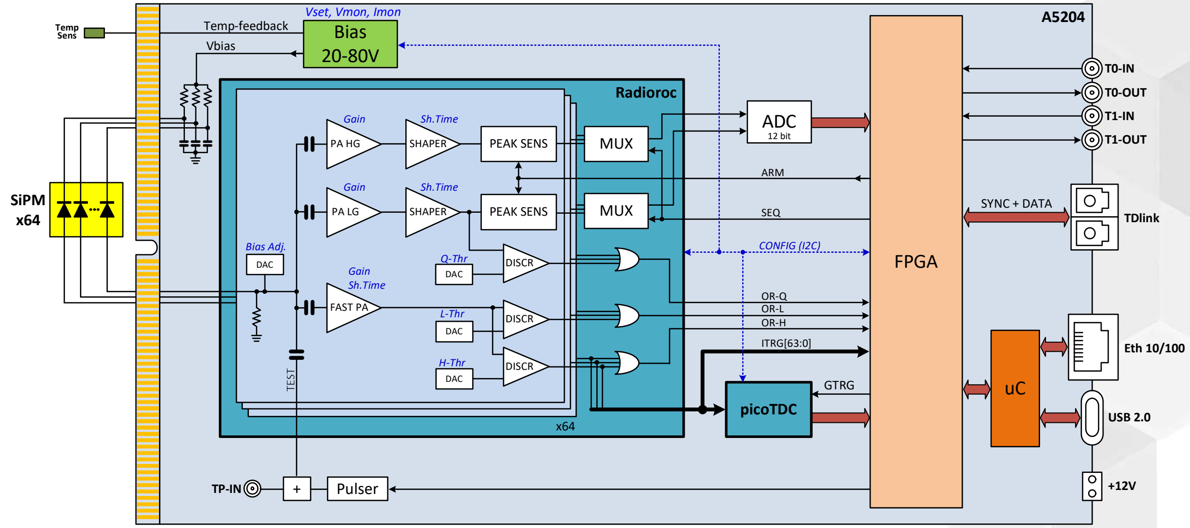


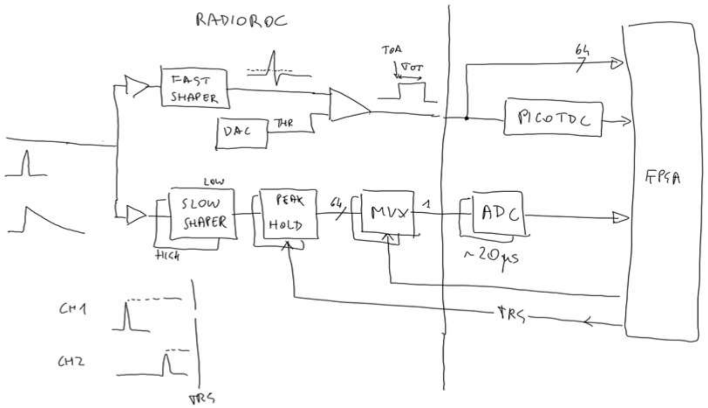


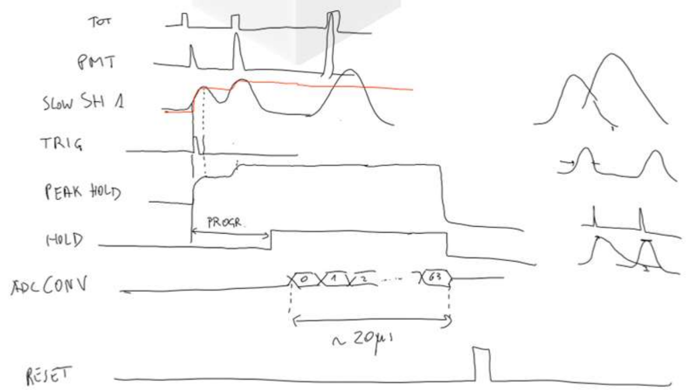
Ampl	Centroid	Sigma	Rel Res %	INL %FSR
12.2	11.3	0.1	1.1	-0.16
38.0	41.1	1.3	3.1	-0.05
121.8	120.9	4.0	3.3	-0.14
385.0	403.0	0.4	0.1	+0.39
1217.5	1215.4	7.6	0.6	+0.00
3850.0	3831.0	29.4	0.8	-0.03

Vin > 300 -> use High Thr curve (orange)
Vin < 300 -> use Low Thr curve (blue)

A5204 Block Diagram







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