

KLOE-to-SAND: overview

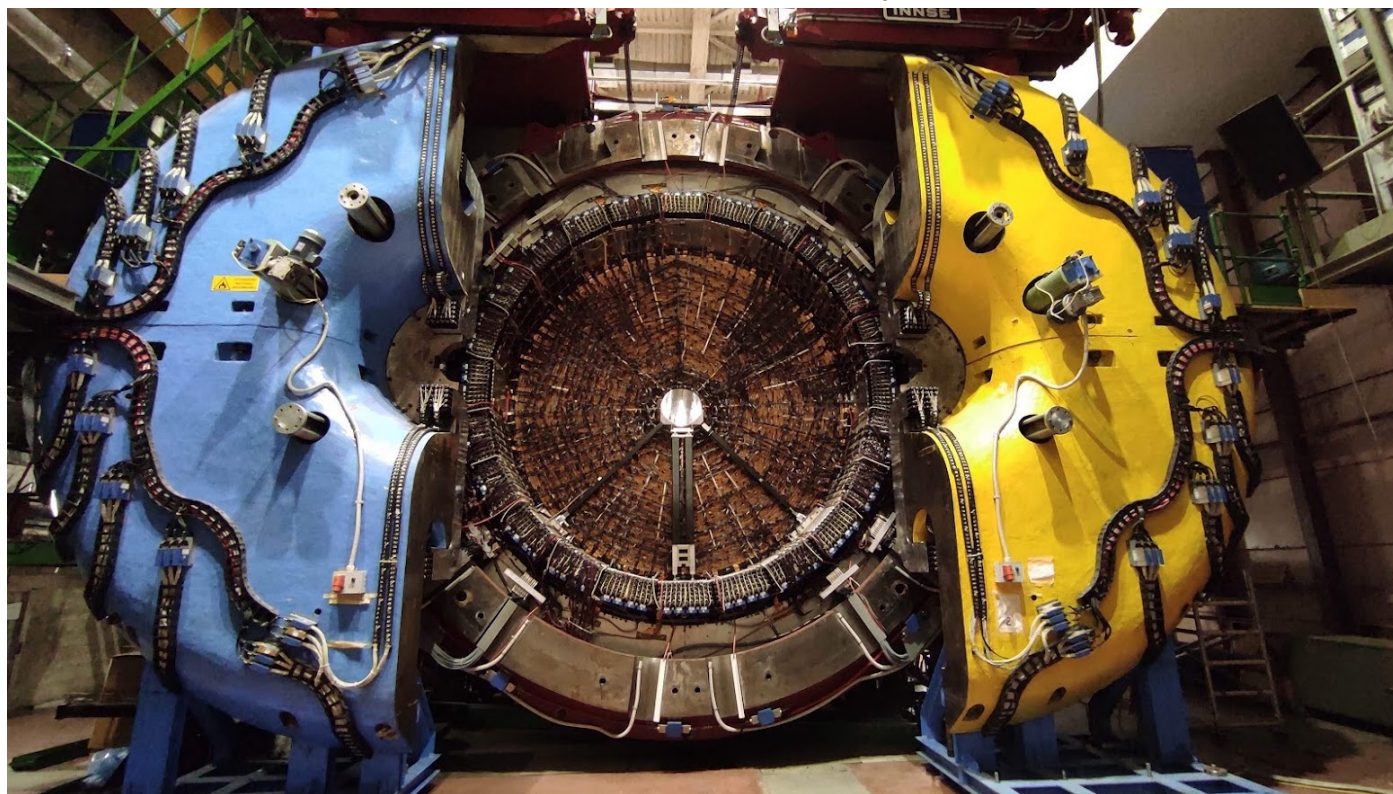
Antonio Di Domenico

Dipartimento di Fisica, Sapienza Università di Roma
and INFN-Roma, Italy



Danilo Domenici

INFN-LNF, Frascati, Italy



Meeting DUNE-Italia – Frascati, 10-12 novembre 2025

Choice of FEE for SAND/ECAL

Several possible solutions investigated with CAEN

Digitizer VX2730



$F_{\text{sampl}} \sim 500 \text{ MS/s} \Rightarrow \sim 3.5 \text{ Meuro}$

Digitizer VX2745B



$F_{\text{sampl}} \sim 125 \text{ MS/s}$
+ shaper 64 ch. $\Rightarrow \sim 1.6 \text{ Meuro}$

DT5203+A5256



PicoTDC + discr. double threshold with ToT $\Rightarrow \sim 790 \text{ keuro}$

A5204 RADIOROC with picoTDC



PicoTDC + discr. single threshold with ToT (for all signals)
+ peak sensing ADC with slow shaper – dead time $20\mu\text{s}$
and good resolution (for rarer signals of large amplitude);
feasibility study in progress $\Rightarrow \sim 520 \text{ keuro}$

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A5204
RADIOROC with
picoTDC

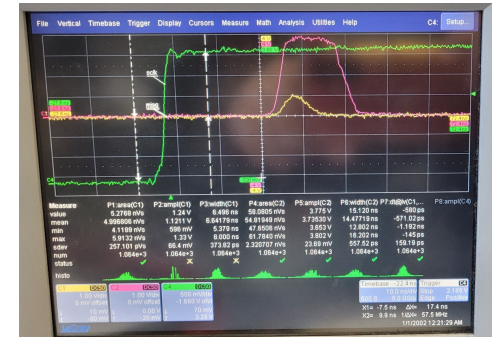


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Optimization and choice of FEE for ECAL

Optimization of PMT working point in SAND

- MC studies of ECAL response to neutrino beam
- expected dynamic range in term of photoelectrons
- experimental study of PMT preamplifier in linear and saturation regimes



~~Two~~ **Three** possible solutions of FEE investigated with CAEN

DT5203+A5256



PicoTDC + double threshold discriminator with ToT

A5204
RADIOROC with
picoTDC

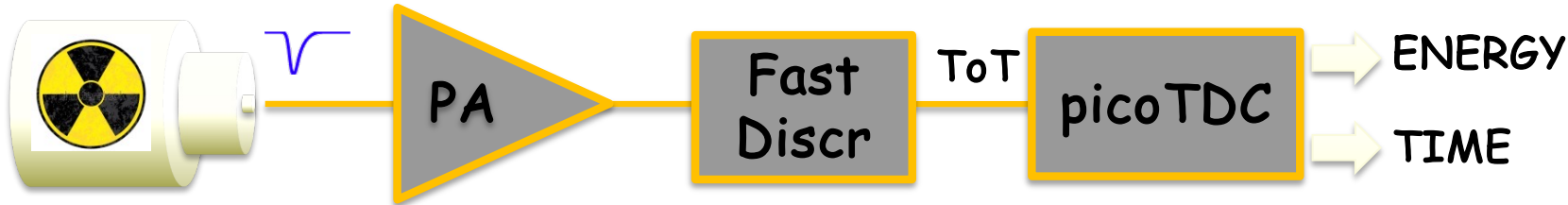


PicoTDC + discr. single threshold with ToT (for all signals)
+ peak sensing ADC with slow shaper – dead time 20 μ s
and good resolution (for rarer signals of large amplitude);

Choice of FEE for ECAL – prototypes (dual thr.+Pico TDC)

read-out scheme: PicoTDC + double threshold discriminator with Time over Threshold (ToT)

Detector



=> energy by ToT
with 2 or more thresholds
not to worsen energy resol.
Time walk correction
needed

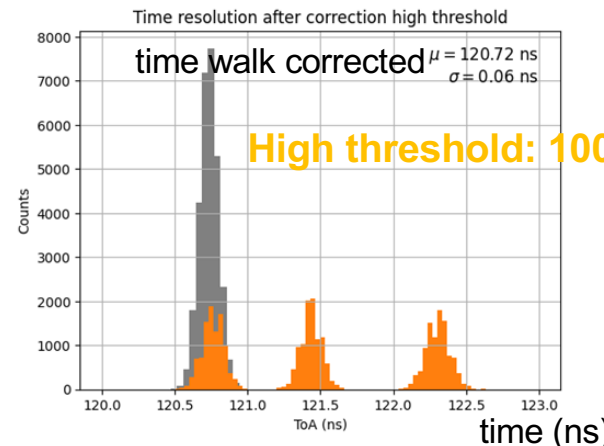
studies on prototypes done in collaboration with



PMTs + Led Driver



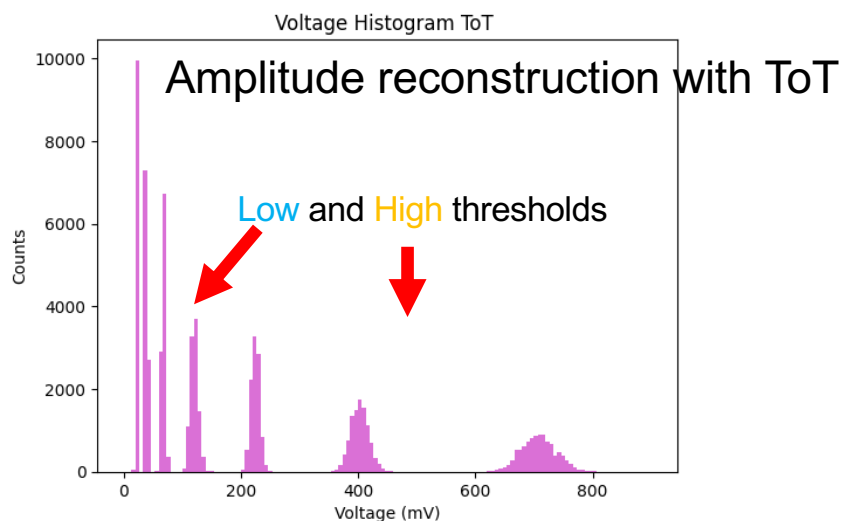
- Led Driver CAEN SP5601 ($\lambda \sim 400$ nm) + fiber splitter
- two KLOE PMTs (test + reference)
- PMT signal => calibrated attenuator => variable amplitude
- DT5203 + A5256 PicoTDC with dual threshold



Time Resolution ~ 60 ps

(ECAL T resol.
 $\sim 54\text{ps}/\sqrt{E(\text{GeV})} \oplus 100\text{ps}$)

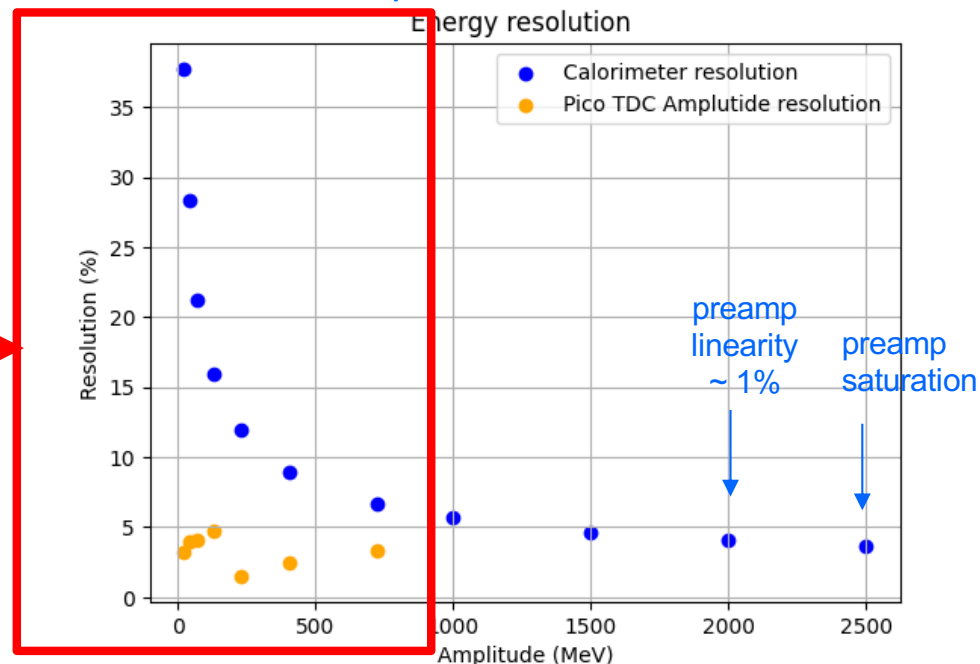
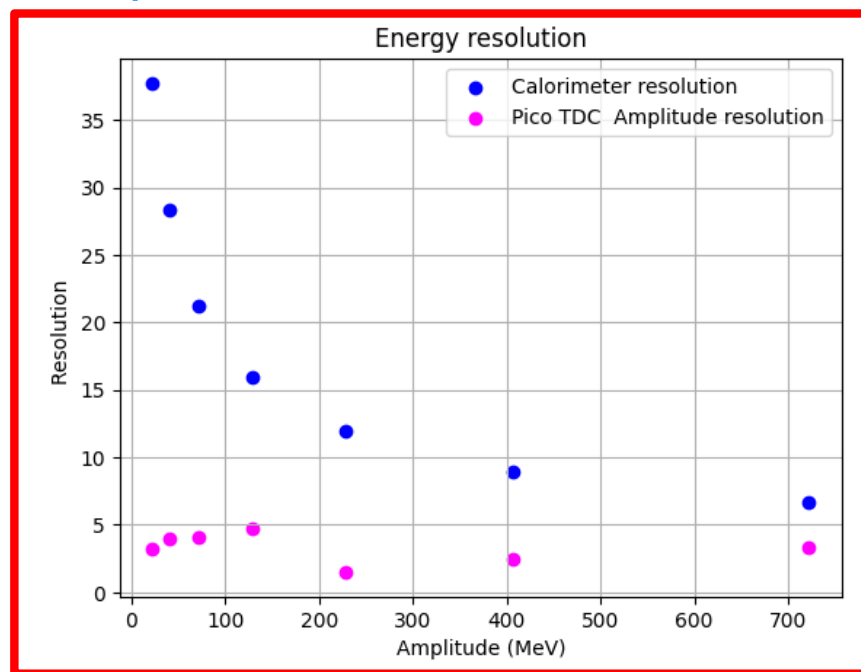
Choice of FEE for ECAL – prototypes (dual thr.+Pico TDC)



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

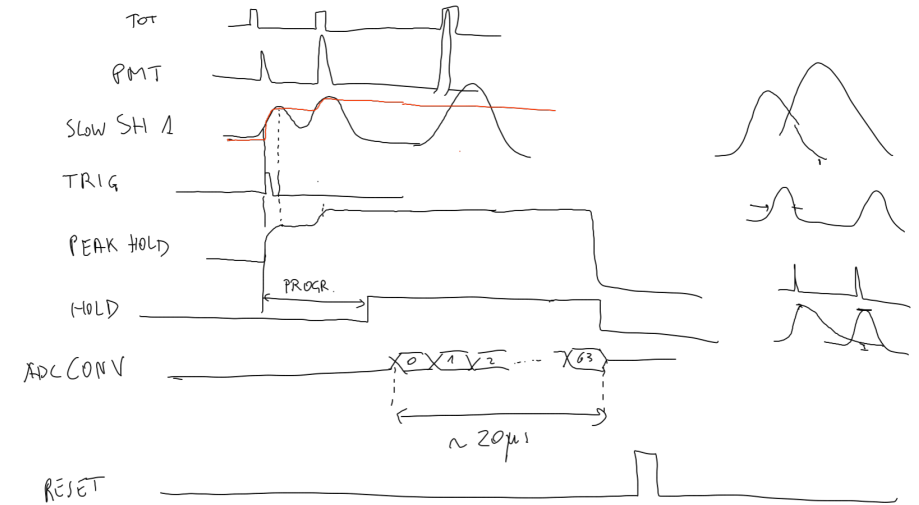
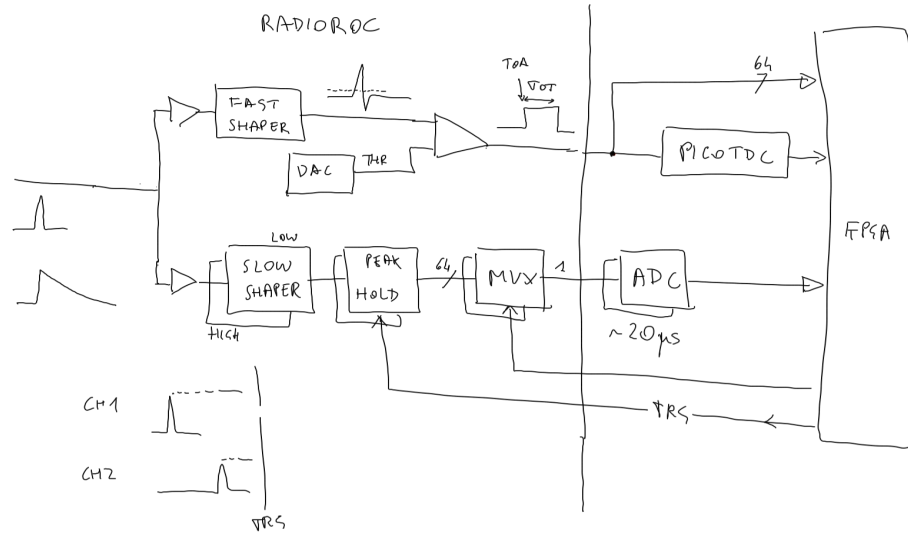
to be done: optimization of the thresholds for the best performance in the whole expected dynamic range (2.5-2000 mV) and in the preamp saturation regime.

comparison with Ecal resolution ($\sigma_E/E \sim 5.7\%/\sqrt{E}$)



Choice of FEE for ECAL – prototypes (Radioroc+Pico TDC)

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



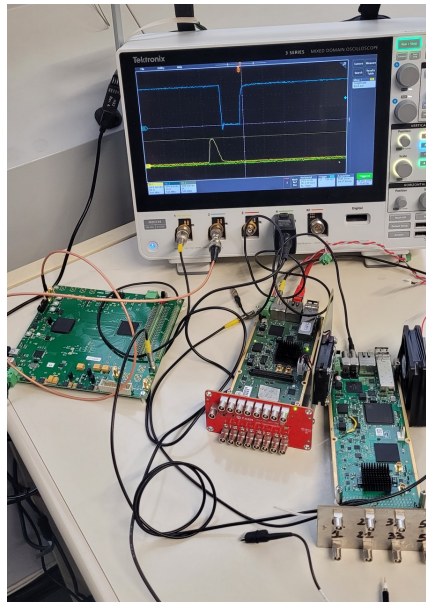
A5204 RADIOROC with picoTDC



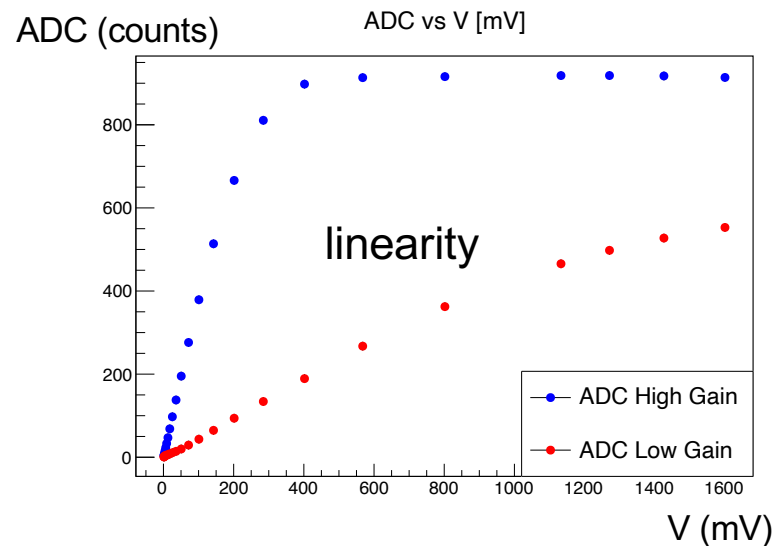
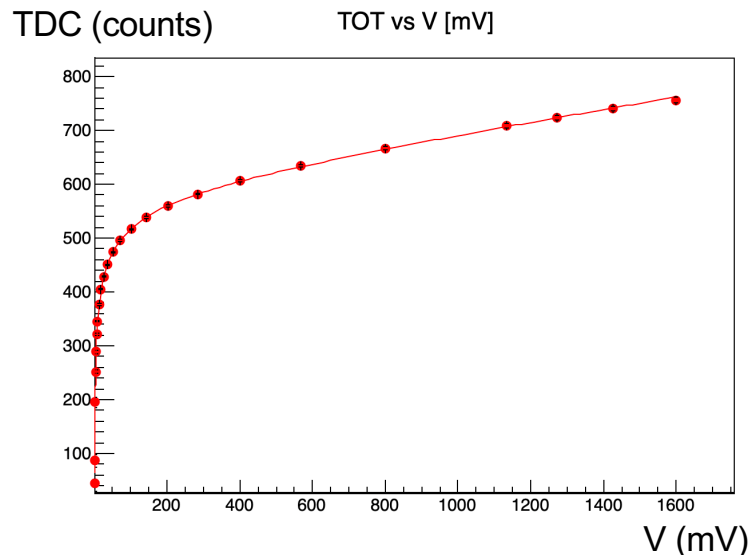
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slow shaper – dead time $20\mu\text{s}$ and good
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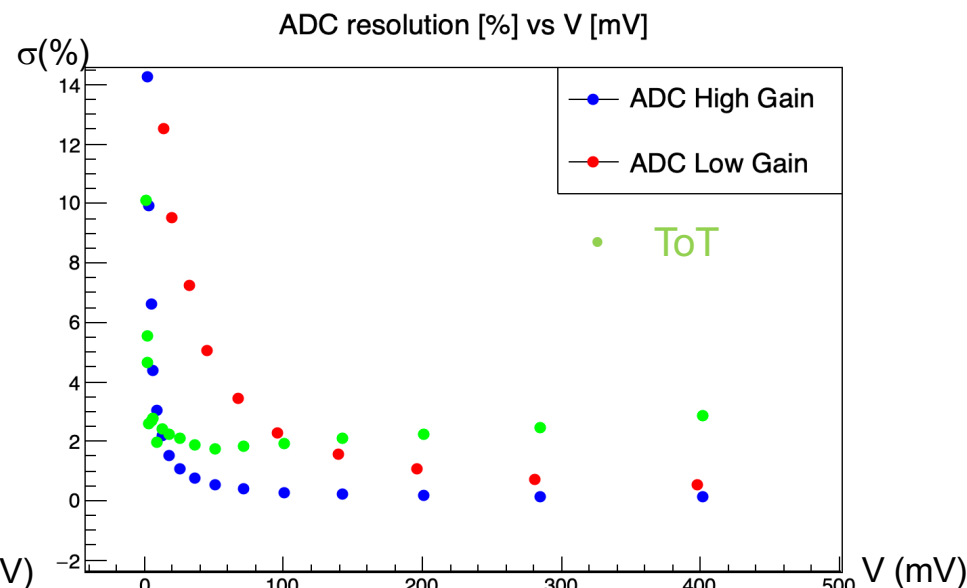
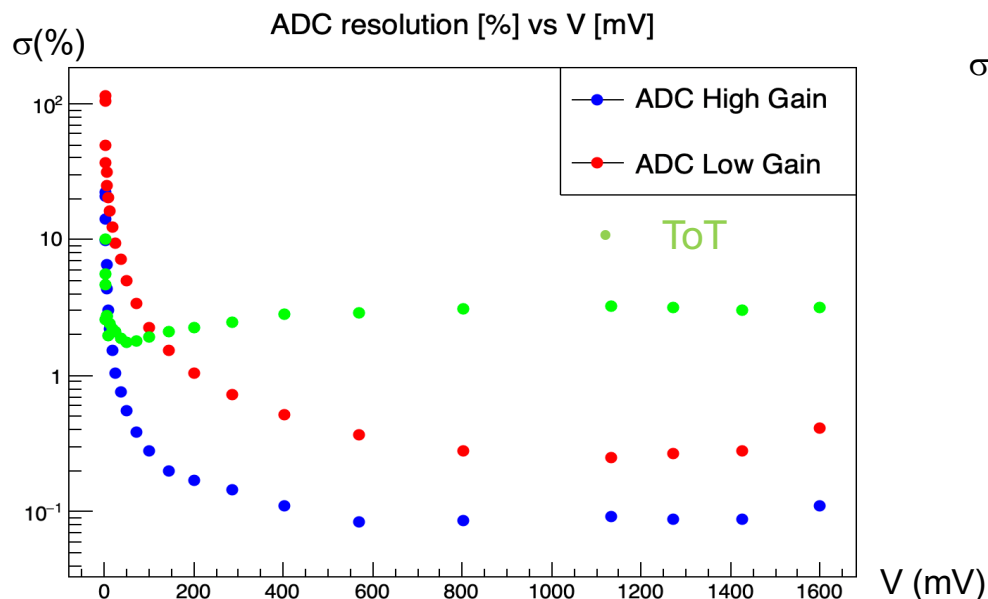


Choice of FEE for ECAL – prototypes (Radioroc+Pico TDC)



Optimal energy resolution:

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



test @ CAEN 7-9 July 2025



Radoroc chip integrated on a FERS board with Pico TDC

- **first test** done on prototype using the **Radoroc evaluation board** with the radoroc chip separated from the FERS A5203 board
- **second test** done on a prototype with the **Radoroc chip integrated on a FERS board with Pico TDC**
- the radoroc chip is primarily designed for low amplitude signals (e.g. from SiPMs)
- non trivial setting of the discriminator threshold
- high sensitive inputs, noise pickup
- signal maximum input voltage 1V
- reduced dynamic range available (safe between 40 and 50 dB, cannot reach 60dB – SAND ECAL requires 60dB)
- important cross-talk for large (~ 1 V amplitude) signals at the discriminator level

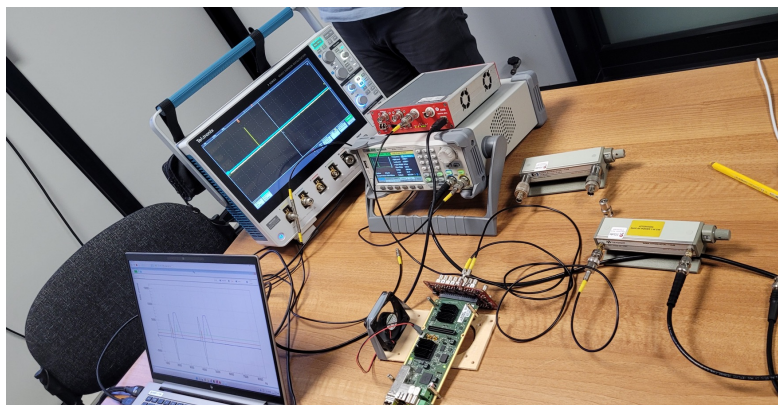
Pros: signal shapers, discriminators and peak hold integrated in the chip; cheapest solution

Cons: noise pickup=> limited signal dynamic, cross-talk

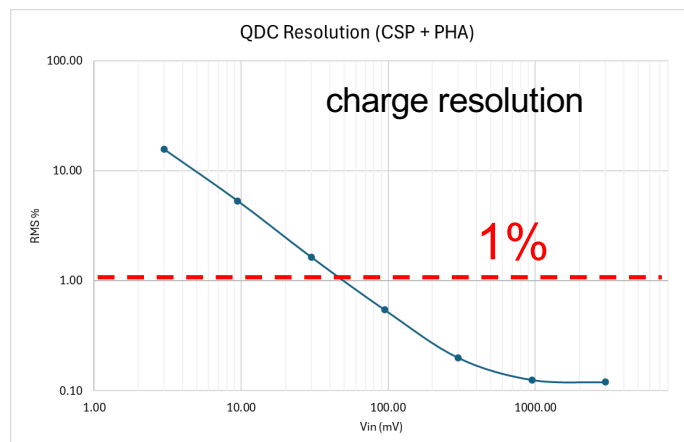
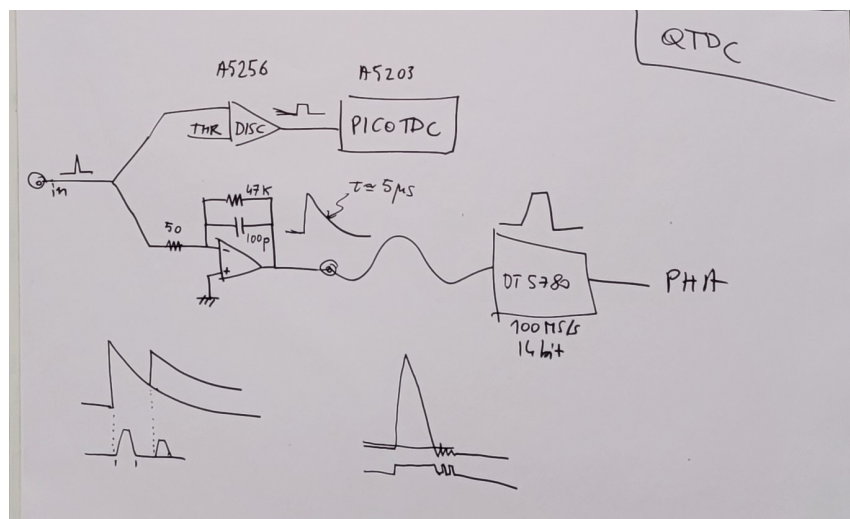
Conclusion: despite promising preliminary results obtained with the first prototype of the Radoroc + Pico TDC, the more advanced studies performed with the Radoroc chip implemented on the FERS board indicate that this solution is not optimal for the SAND/ECAL FEE.

Choice of new FEE for ECAL – prototypes (QTDC)

Third possible solution - CAEN - V9290 - 32ch Multievent Charge & Time Pulse Processor QTDC

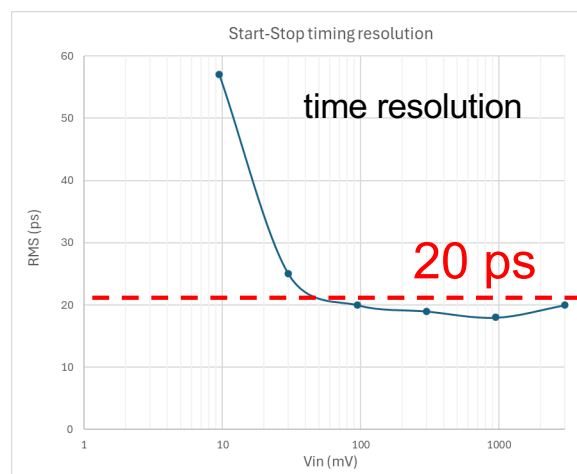


- signal splitted in two branches:
 - (i) a “standard” discr A5256 + A5203 FERS PicoTDC
 - (ii) charge preamp + digital filters + digitizer DT5780 14 bit, 100MS/s
- test on a prototype @ CAEN 7-9 July 2025
- intermediate prototype ready for spring 2026
- final prototype ready fall 2026, full production ~6 months



PROTOTYPE PERFORMANCE

- dynamic range ~60dB
- can accept large signals (~3 V amplitude)
- ADC + TDC info for all signals
- very good time resolution O(20 ps) (and ToT)
- very good charge resolution <1% , ~0.1% at high energy



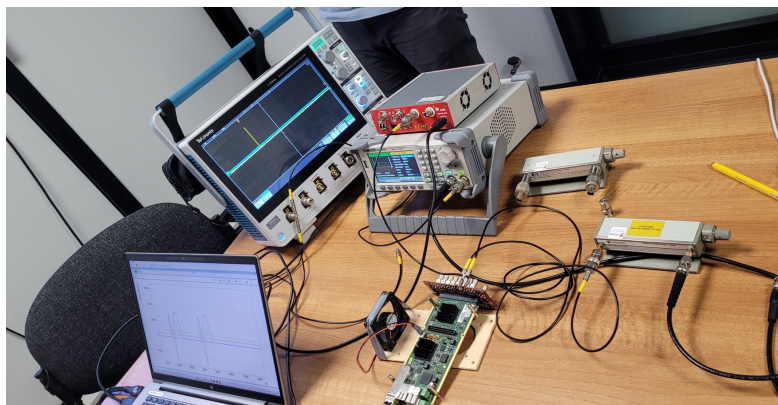
Power consumption of one board (32 ch) ~ 40W
One full crate with 20 boards => ~ 800W.

CAEN OFFER

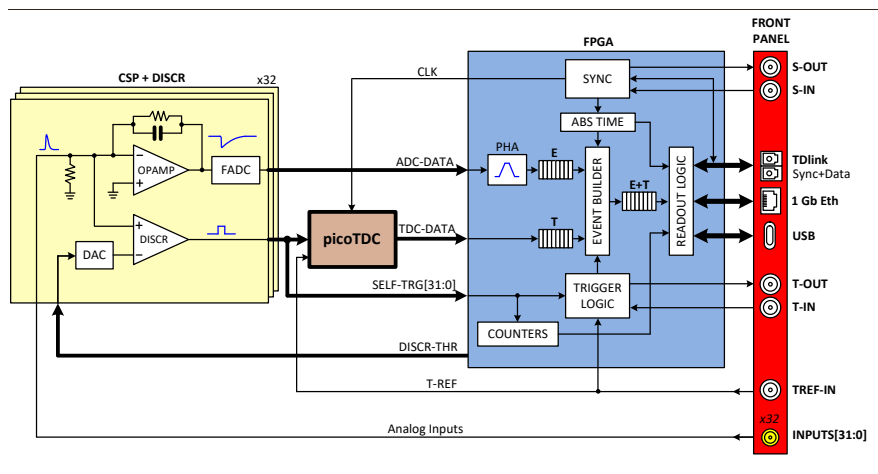
QTDC V9290 (5000 channels) +
n. 4 DT5215 collector board: 1009k
euro (CAEN offer to be refined)
+ 8 VME crates, shipping, tariffs:
TOTAL: 1100k euro

Choice of new FEE for ECAL – prototypes (QTDC)

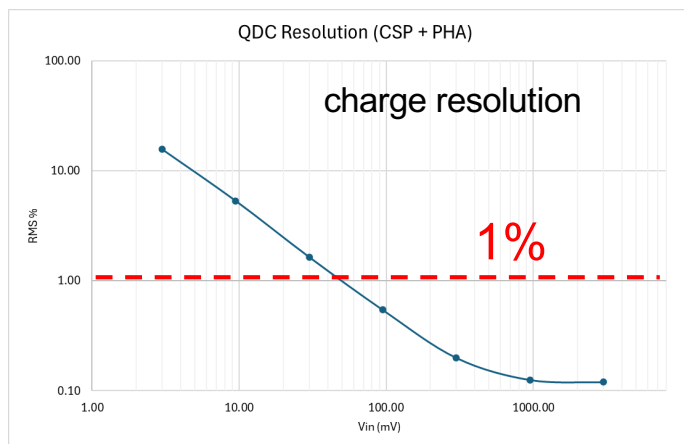
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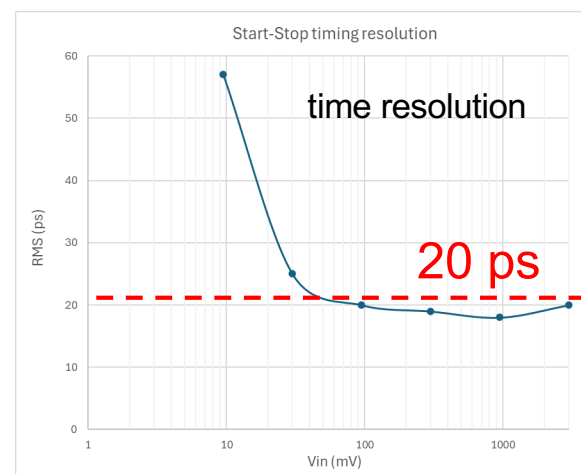


update October 2025:
Intermediate prototype (8ch) ready and under test.
Design of the 32ch board started.



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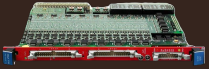
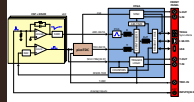


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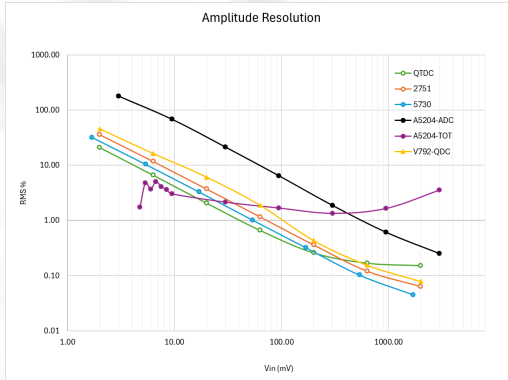
EXPLORED CAEN PRODUCTS

 Analog Readout * (QDC V792 + Discriminator + TDC) ▲ Good performance for both QDC and TDC ▼ Bulky solution (several boards), high dead time, challenging setup, with stability and reproducibility concerns * Only V792 tested	 Digitizer DT5730 (500 MS/s, 14 bits) ▲ Highly versatile, stable, and extensively tested solution. Easily deployable and scalable ▲ Waveform samples recording ▼ Low Sampling for ns pulses leads to poor timing resolution. Cost exceeding the budget	 Digitizer VX2751 (1 GS/s, 14 bits) ▲ Same as DT5730, with better timing performances ▼ Cost exceeding the budget	 FERS-5204 (based on Radioroc + picoTDC ASICs) ▲ Lowest cost per channel, most compact solution ▼ Designed for SiPM, not best suited for PMT. High dead-time in ADC mode. TDC+TOT mode has limited dynamic range and energy resolution	 QTDC (all-in-one QDC + Discriminator + TDC) ▲ Mixed analog+digital readout: high-resolution timing with picoTDC ASIC, good energy resolution with Charge Sensitive Preamplifier (CSP) + Pulse Height Analysis (PHA) ▼ Early prototyping: final performance and cost must be confirmed
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C. Tintori, C. Maggio,
Y. Venturini, A. Mati,
D. Ninci, A. Picchi,
V. Bottiglieri, A. Abba
**CAEN +
Nuclear Instruments**

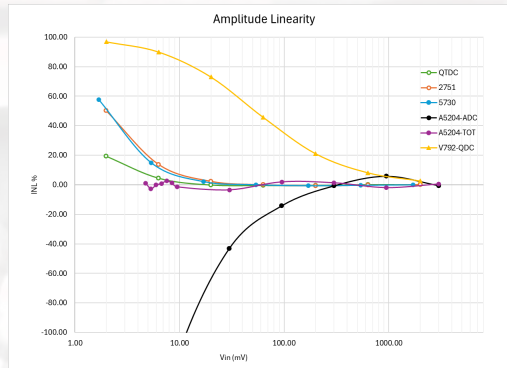
MEASUREMENTS RESULTS & COMPARISON

TEST RESULTS: ADC RESOLUTION



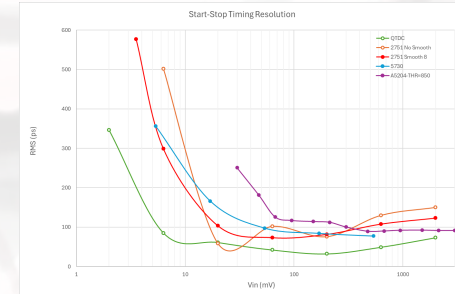
- Charge integration triggered by Tref signal (OUT2)
- Gate Width = 60 ns
- A5204-TOT mode: amplitude reconstruction by TOT curve
- A5204-ADC mode: Preamp + Shaper + Peak sensing ADC

TEST RESULTS: LINEARITY



$$\text{Integral Non-Linearity: } 100 \times \frac{\text{Measured Value} - \text{Linear Fit}}{\text{Measured Value}}$$

TEST RESULTS: TIME RESOLUTION

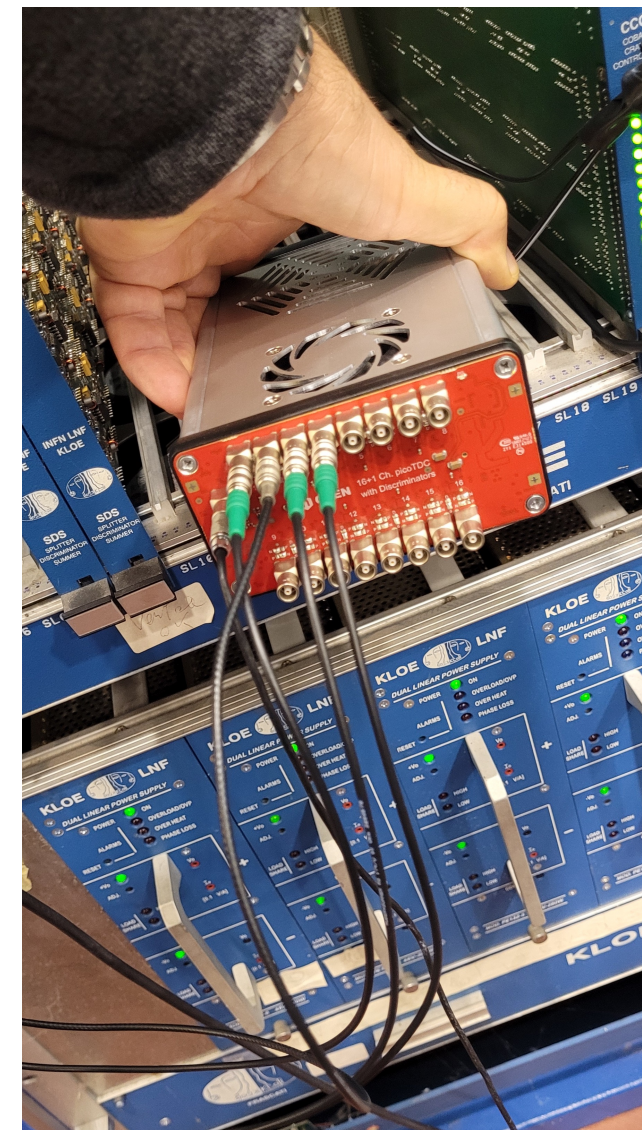


- VX2751: digital smoothing filter applied to suppress high-frequency noise responsible for false triggers. Without filtering, the minimum detectable signal is ≈ 6 mV. Both filtered and unfiltered traces are shown
- (DT)5730: timing spectrum affected by interpolation artifacts due to the limited sampling rate of the acquired pulses. Reported RMS value represents an average between best and worst cases
- A5204: minimum threshold set to ≈ 30 mV to avoid excessive noise-induced triggering

+ A.D.D., P. Gauzzi,
A. Gioiosa

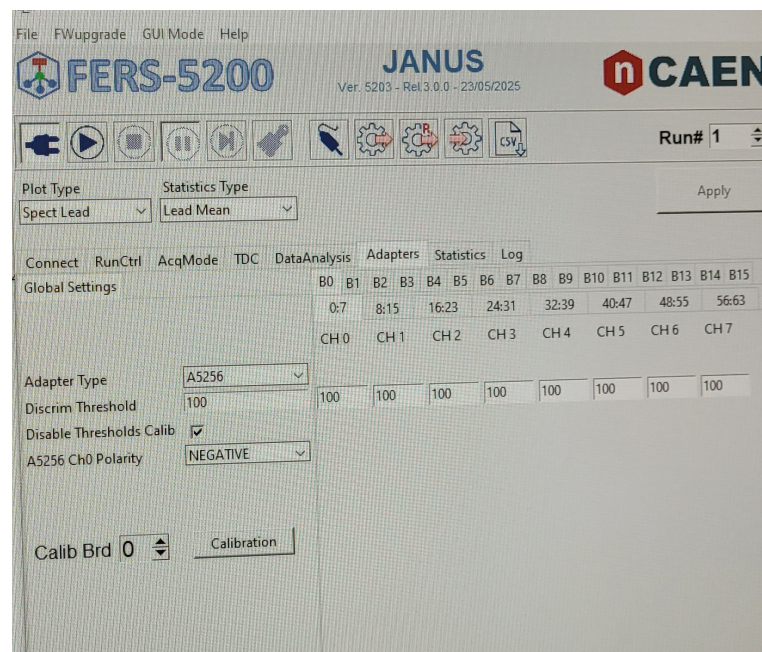
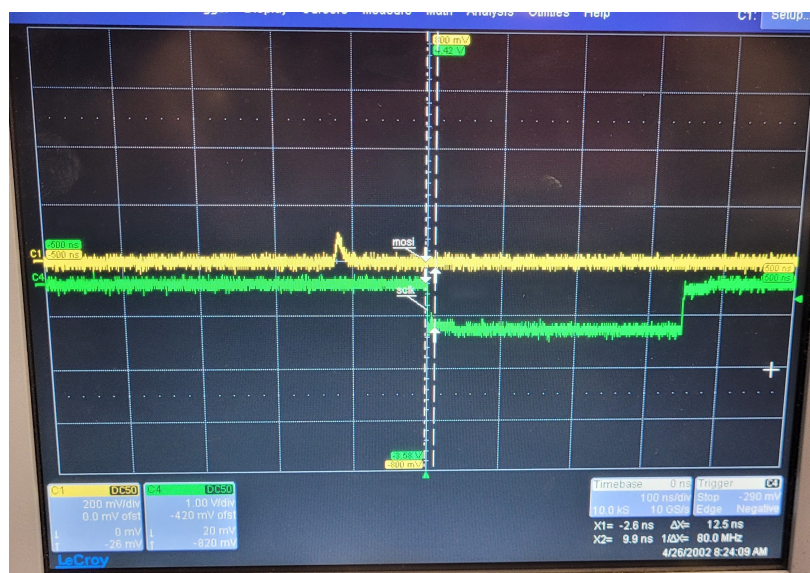
All tested readout systems proved effective for the acquisition of fast PMT signals. Among them, **the QTDC demonstrated the most balanced combination of timing precision, charge measurement accuracy, and system compactness.** Its architecture, integrating QDC, TDC and discriminator functions in a single 6U VME module, allows simultaneous charge, ToA, and ToT acquisition with timing resolutions down to 10 ps RMS and 0.25% resolution in charge. The ongoing tests on the 8-channel prototype confirm stable operation and reproducibility, supporting its suitability for the SAND-ECAL PMT readout and scalability to larger setups. A 32 channel QTDC module is coming soon as a new CAEN catalogue product.

ECAL – preparing the test of new FEE with cosmic rays



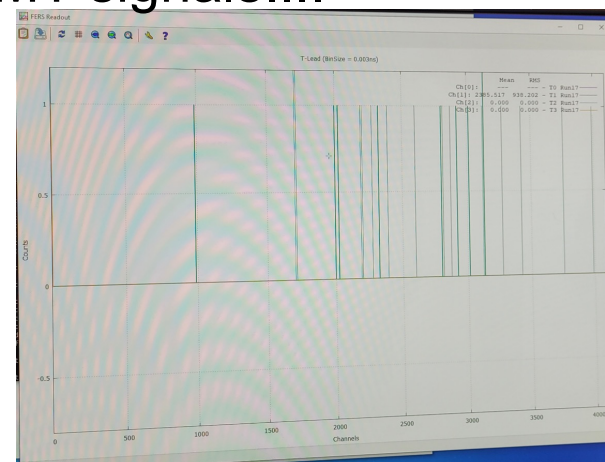
Through the bypass boards, the PMT signals can be sent directly to any new FEE device, in this example to the discriminators CAEN A5256 - 16+1 channels plugged on a CAEN FERS DT5203 64 channels (picoTDC)

ECAL – preparing the test of new FEE with cosmic rays



The test stand at LNF is suitable to study new FEE solutions for SAND/ECAL
First switch on feeding A5256+ DT5203 with PMT signals....

Through the bypass boards, the PMT
signals can be sent directly to any new
FEE device =>
ready to test the new QTDC by CAEN



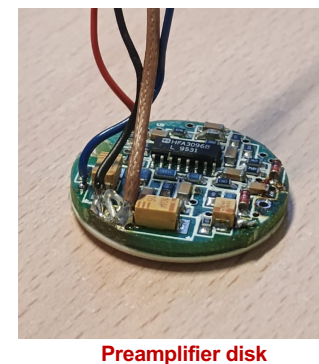
HV divider and preamplifier in KLOE

F. Spinella, E. Pedreschi, P. Falasca, A. Taffara, F. Tramonti (INFN-Pisa)



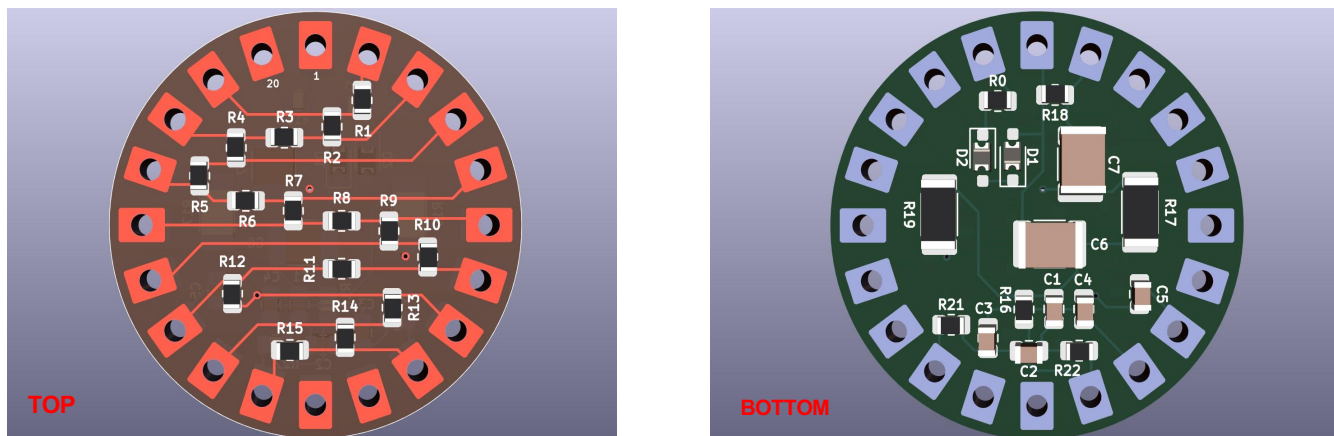
- HV divider and the preamplifier were built as 3 small circuits, assembled directly on the PM base.
- Divider design is more critical. Split in 2 ceramic hybrids circuits: capacitors and resistors disk. Resistors are deposited on ceramic. Each circuit has 2 layers (top and bottom)

Disassembled the original base to analyze component placement on the two ceramic disks



HV divider – PCB design (3D view)

Reverse engineered the original KLOE HV divider and designed the same schematic in KiCAD
Maximum HV for PMs divider is 2300 V. Typical HV 1700-1800.



- Designed a single 4-layer PCB with components distributed both on top and bottom layers, following the KLOE layout:
 - Top layer: divider resistors connected to PMT dynodes
 - Bottom layer: mostly capacitors and other resistors
- Critical high-voltage components (R19, C6) were carefully selected and are available on Digikey. All other components are also available on Digikey
- Investigating sockets availability with Hamamatsu. In April 2025 it was possible to order 1000 sockets with 4000 optionable. Waiting for an update from Hamamatsi-Italia. Requested few for samples for tests.

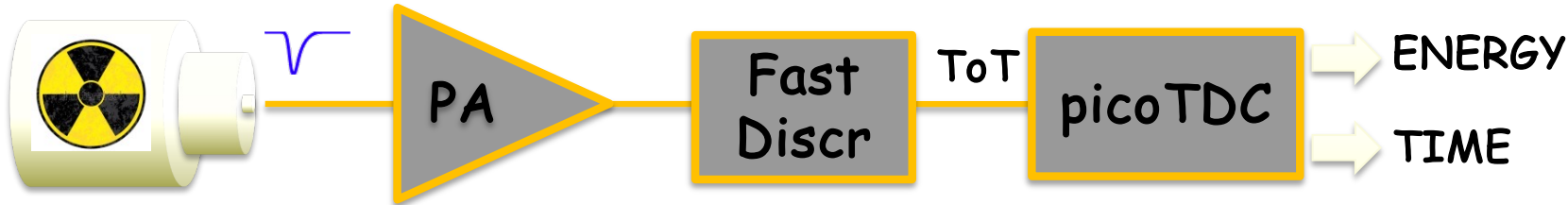
- **Divider:** The adoption of a multilayer PCB structure allows for optimized circuit compactness while maintaining adequate isolation distances between conductors and separation between internal layers, which is essential for high-voltage operation. Building some prototypes is mandatory to validate the new design.
- Circuit operates at voltages up to approximately 1800 V → choice of PCB material critical
- During the prototyping phase, ISOLA FR406 could be used
- For the final implementation ISOLA 370HR is preferred (more suitable for high-voltage applications)
- **Pre-amplifier** design is not critical. All original KLOE components are still available on Digikey. Standard 4 layer PCB, could be easily replicated.
- **KLOE connectors** were custom designed and should be dismantled from existing PMT bases.

spare slides

Choice of FEE for ECAL – prototypes (dual thr.+Pico TDC)

read-out scheme: PicoTDC + double threshold discriminator with Time over Threshold (ToT)

Detector



=> energy by ToT
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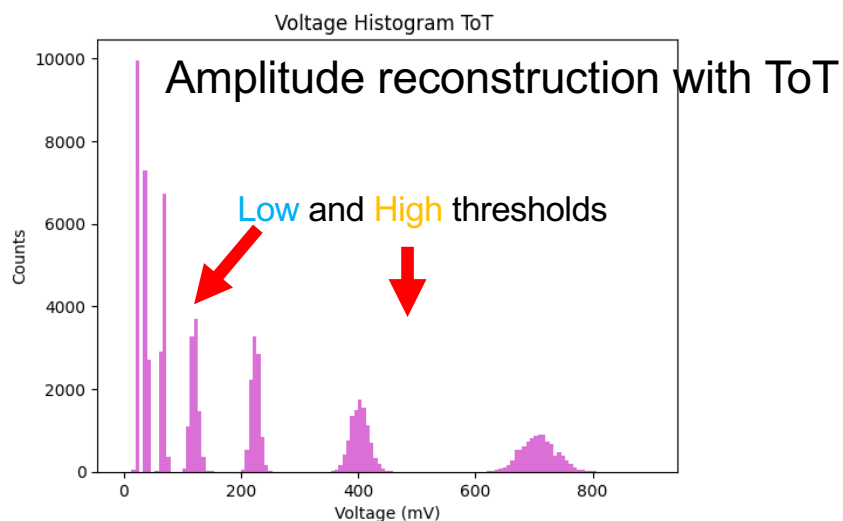
- Led Driver CAEN SP5601 ($\lambda \sim 400$ nm) + fiber splitter
- two KLOE PMTs (test + reference)
- PMT signal => calibrated attenuator => variable amplitude
- DT5203 + A5256 PicoTDC with dual threshold



Time Resolution ~ 60 ps

(ECAL T resol.
 $\sim 54\text{ps}/\sqrt{E(\text{GeV})} \oplus 100\text{ps}$)

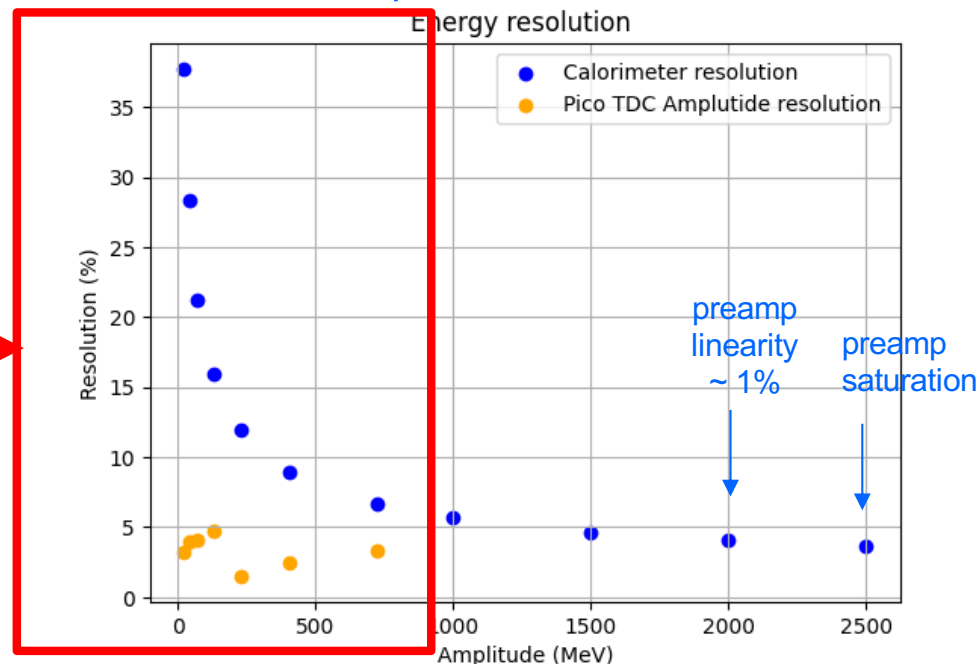
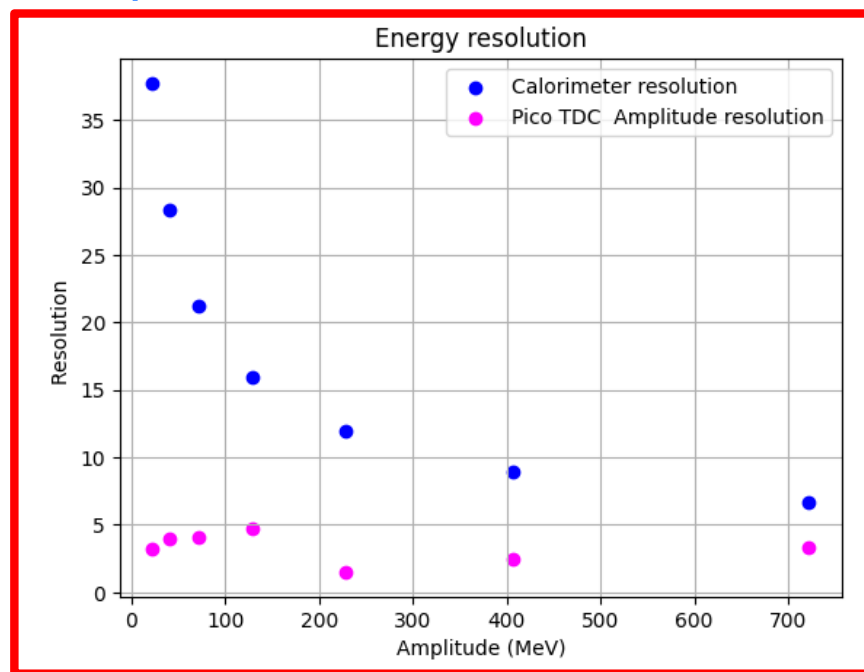
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to be done: optimization of the thresholds for the best performance in the whole expected dynamic range (2.5-2000 mV) and in the preamp saturation regime.

comparison with Ecal resolution ($\sigma_E/E \sim 5.7\%/\sqrt{E}$)



ECAL: procurement of HV and LV power supply



HV



LV



Offer CAEN updated July 2024

n° 102 board A7030P (48 ch.) = 527k euro

n° 7 Sistem SY4527B = 41k euro

n° 7 Power supply booster A4533 = 12k euro

TOTAL: **580k euro** (IVA escl.)

spare: 10 5 A7030P + 2 1 SY4527B + 2 1 A4533 = **67k 34k euro** (IVA escl.)

~~warranty ext. 3 years: = 53k euro (IVA escl.)~~

n° 10+2 spare board A25251 8 full floating channels 8V/12A = **31k euro** (IVA escl.)

Mapping of present HV cables 5x12ch on 48 ch. modularity not trivial (to be studied also for LV)

=> under study to minimize cost (custom connectors or patch panel)

one complete spare
system to be used to test
slow-control software

Studies for the optimization of the ECAL working point and FEE

A. Di Domenico, V. Di Silvestre, P. Gauzzi, D. Truncali - INFN-RM1
A. Balla - INFN-LNF

Neutrino energy spectrum in DUNE

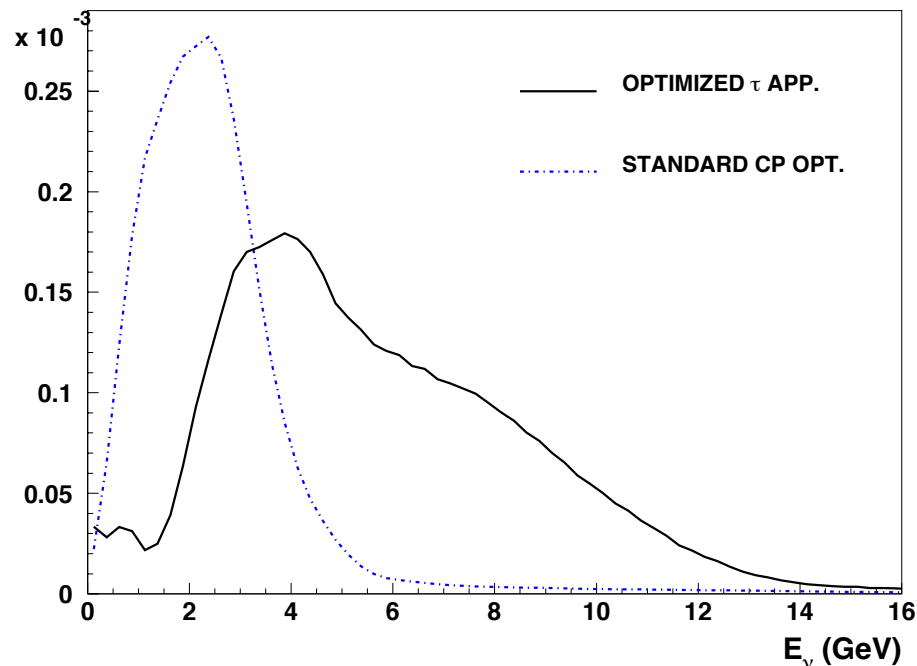


Figure 87: Comparison of LBNF ν_μ fluxes: (a) default 3 horn beam optimized for CP violation (dash-dotted); (b) ν_τ appearance optimized beam (solid).

From DUNE docDB note 13262
A proposal to enhance the DUNE near detector complex

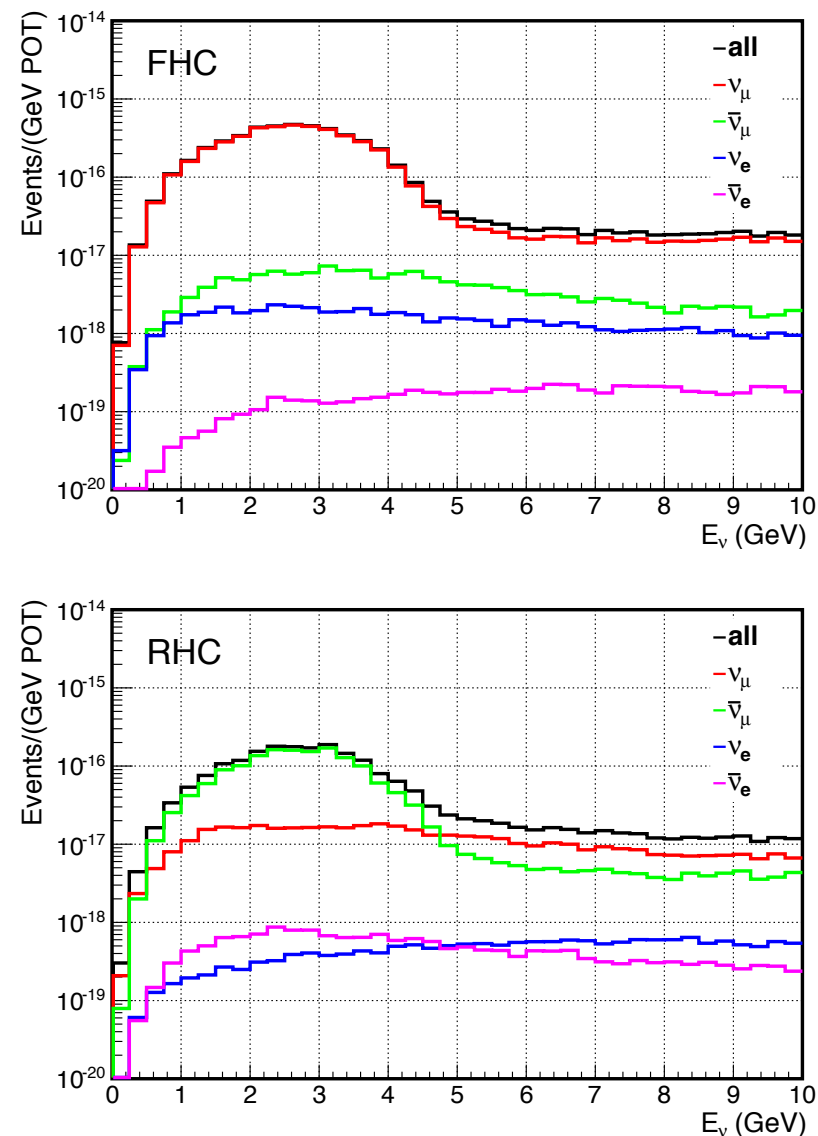
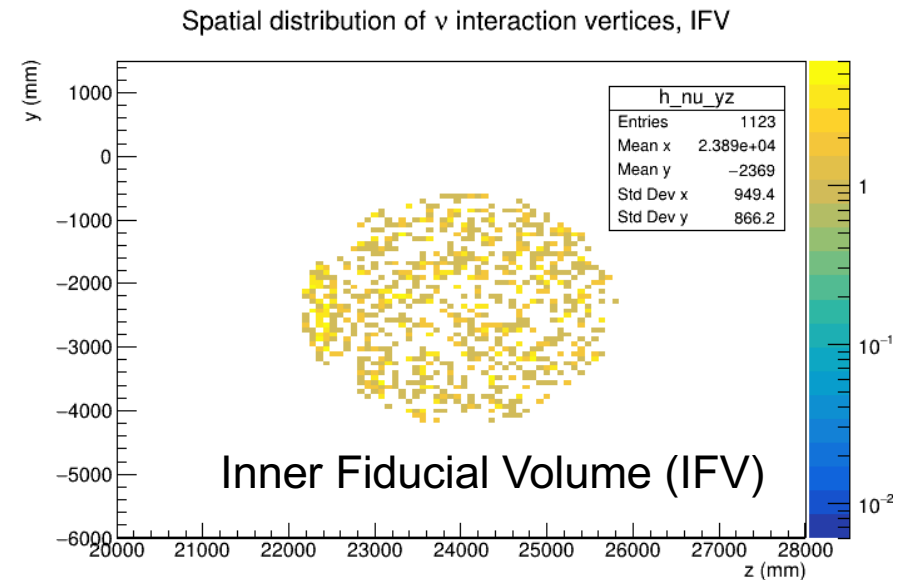
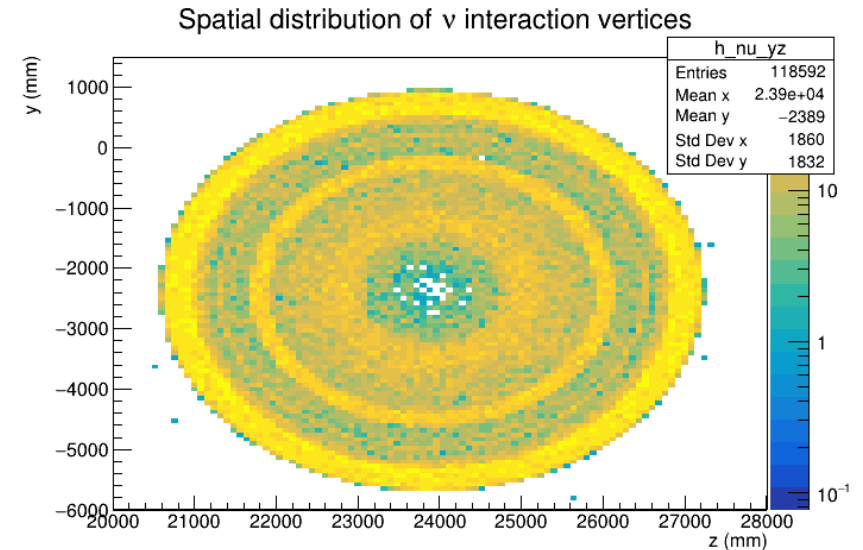


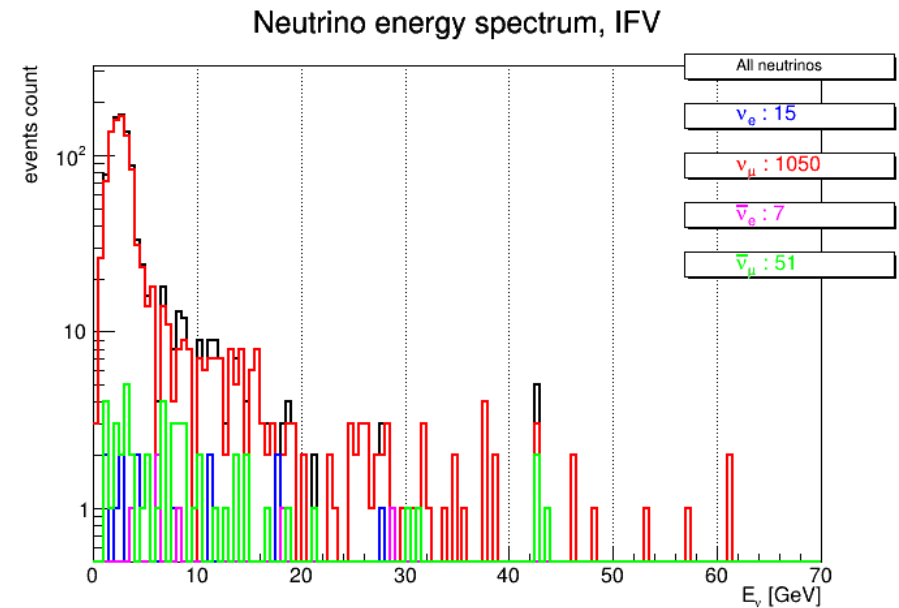
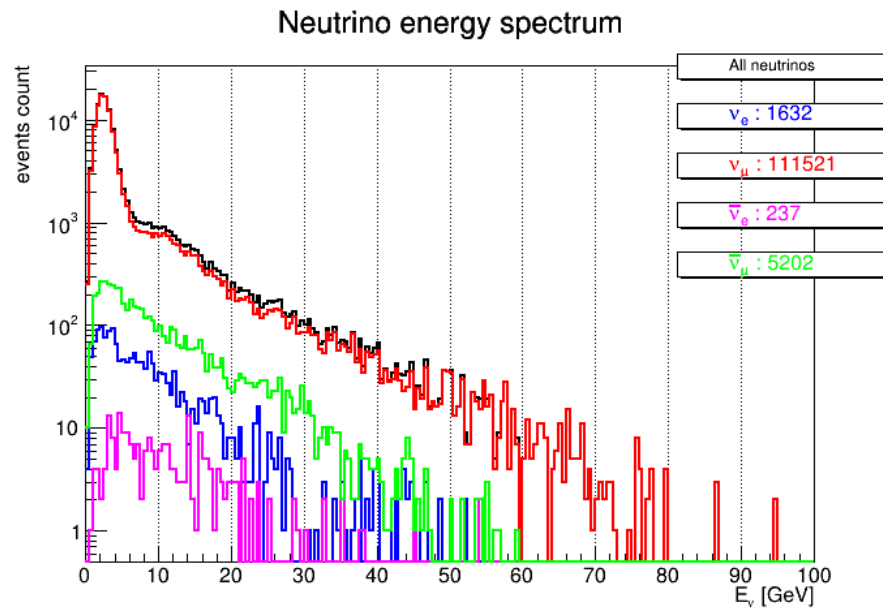
Figure 89: Energy spectra of CC interacting neutrinos in the internal LAr target, having a mass of 1.01 ton, and considering a 120 GeV proton beam in both FHC and RHC modes.

- Analyzed sample: sand-events.*.digi.root and sand-events.*.edep.root
- 100 files
- Total evts = 118592
- Total p.o.t = 1.011×10^{17}
- p.o.t./spill = 7.5×10^{13} at 1.2 MW beam power
- corresponding to ~ 30 minutes of data taking in FHC mode (or equivalently to ~ 15 min at 2.4 MW)
- Inner Fiducial Volume (IFV) defined at a distance of 20 cm from ECAL internal surface



Neutrino energy spectrum in SAND MC

spectrum in the whole energy range

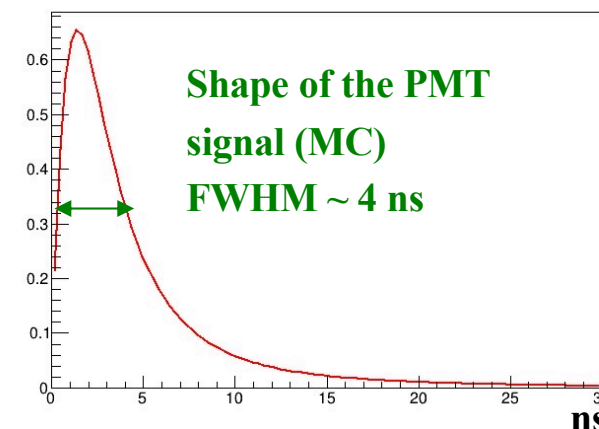
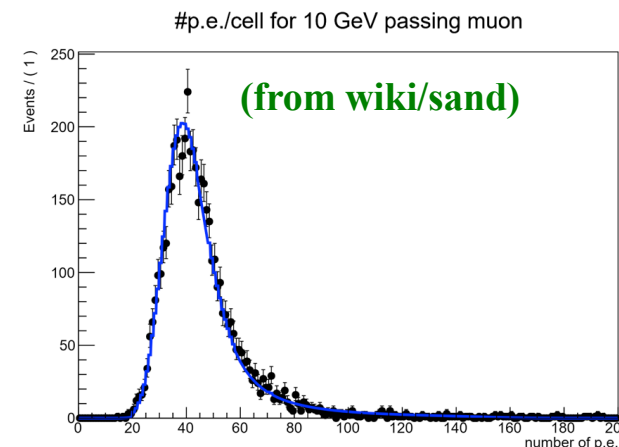


Digitization of ECAL similar to KLOE MC:

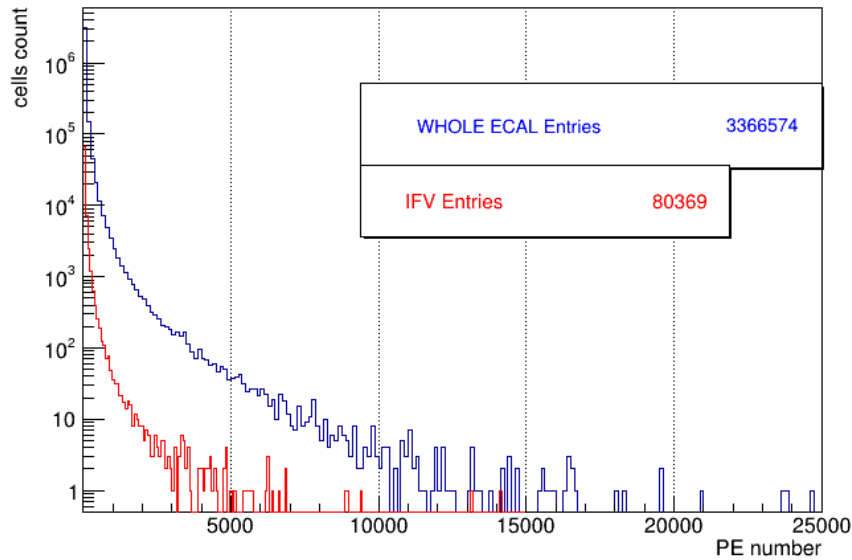
- Deposited energy in the cells propagated to PMTs with double exp. attenuation curve

$$f(x) = Ae^{-\frac{x}{\lambda_1}} + (1 - A)e^{-\frac{x}{\lambda_2}}$$

- Converted into p.e. number $\Rightarrow$ 18.5 p.e./MeV of deposited energy (MIP at the module center $\sim$ 40 p.e.)
- Light yield $\sim$ 1 p.e./MeV of total energy of the particle
- Threshold = 2.5 p.e.
- Constant fraction discriminator at 15% of the signal
- Multihit TDC simulation (30 ns integration time + 50 ns dead time)



PE distribution



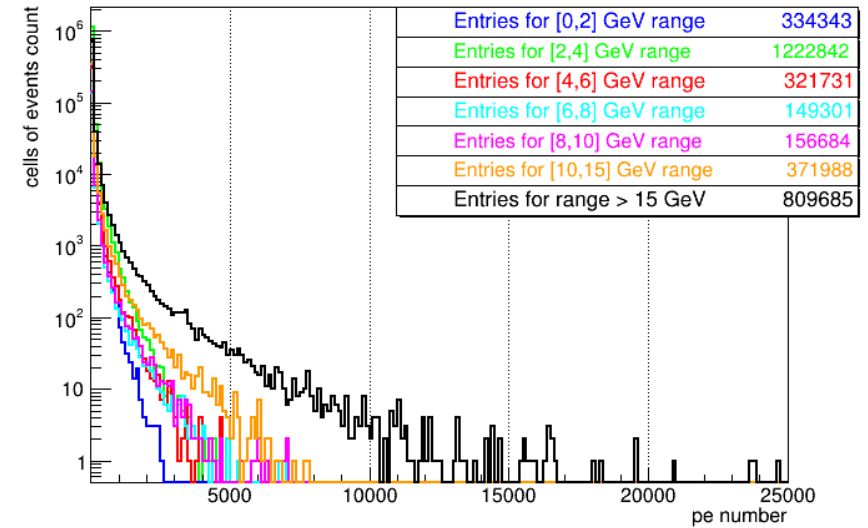
E_ν range = [0,10] GeV

Events number 101,696

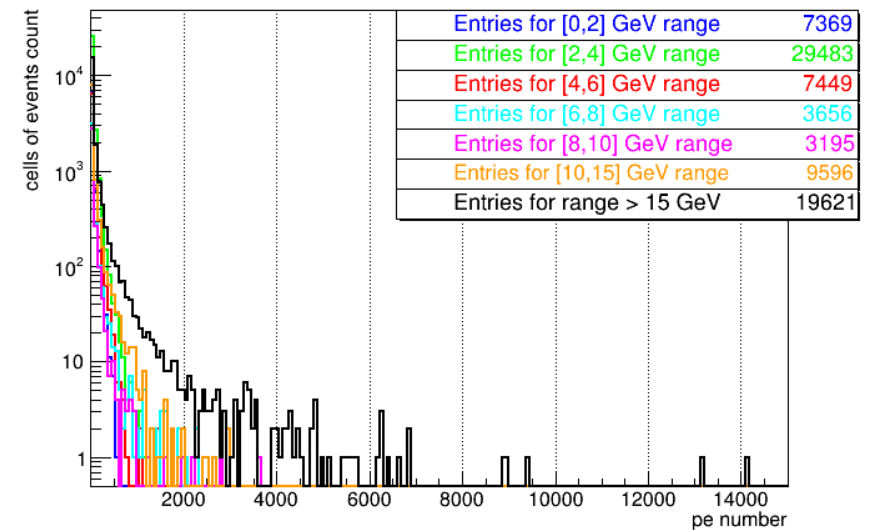
Events cells number 2,184,901

Fraction of events with at least one cell above PE threshold	[%]
1000 PE threshold	2.58
2000 PE threshold	0.49
3000 PE threshold	0.13
4000 PE threshold	$3.64 \cdot 10^{-2}$
Fraction of hit cells above PE threshold	[%]
1000 PE threshold	0.19
2000 PE threshold	$3.03 \cdot 10^{-2}$
3000 PE threshold	$7.19 \cdot 10^{-3}$
4000 PE threshold	$2.11 \cdot 10^{-3}$

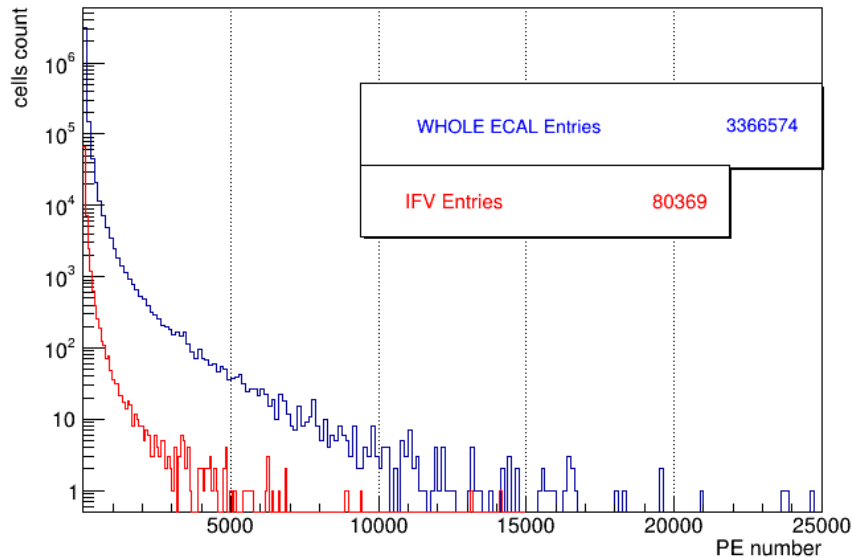
PE distribution at E_ν fixed



PE distribution at E_ν fixed, IFV



PE distribution



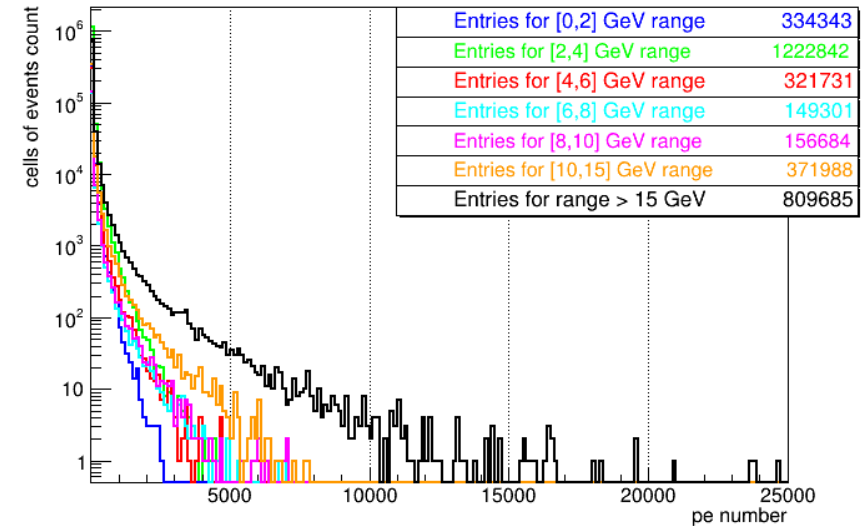
E_ν range = [0,10] GeV

Events number 101,696

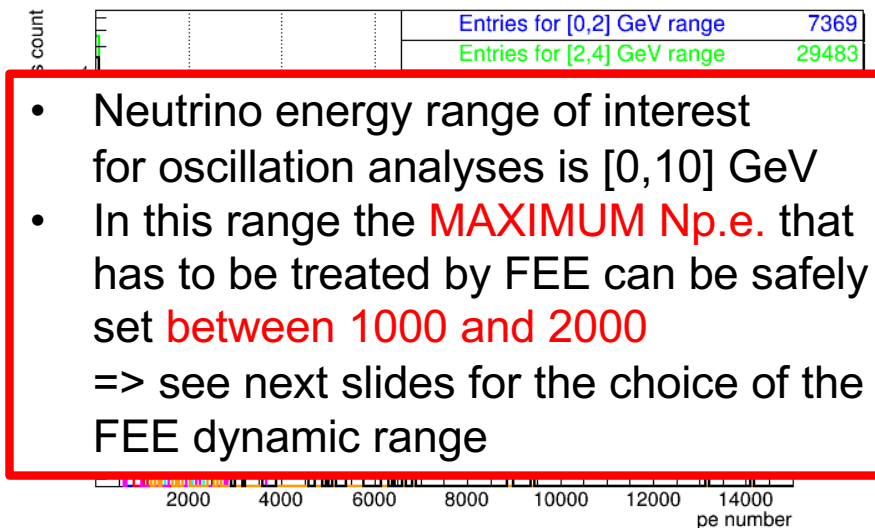
Events cells number 2,184,901

Fraction of events with at least one cell above PE threshold	[%]
1000 PE threshold	2.58
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4000 PE threshold	$2.11 \cdot 10^{-3}$

PE distribution at E_ν fixed

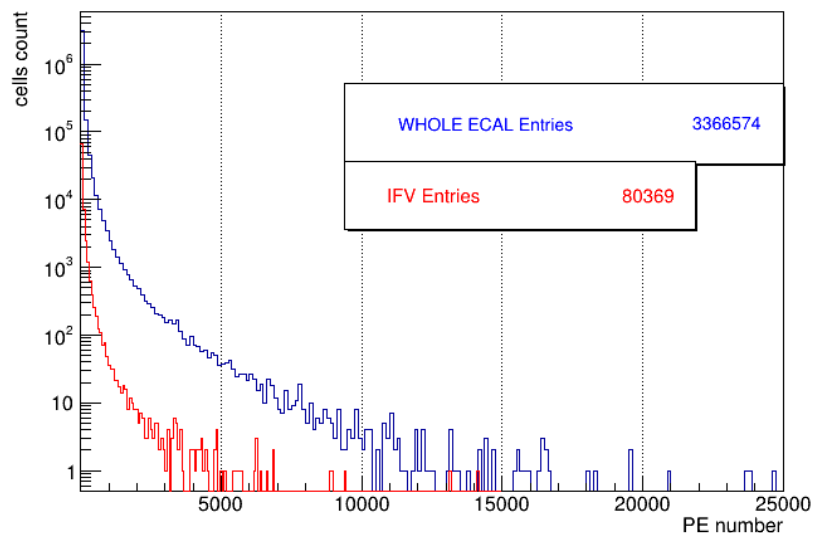


PE distribution at E_ν fixed, IFV

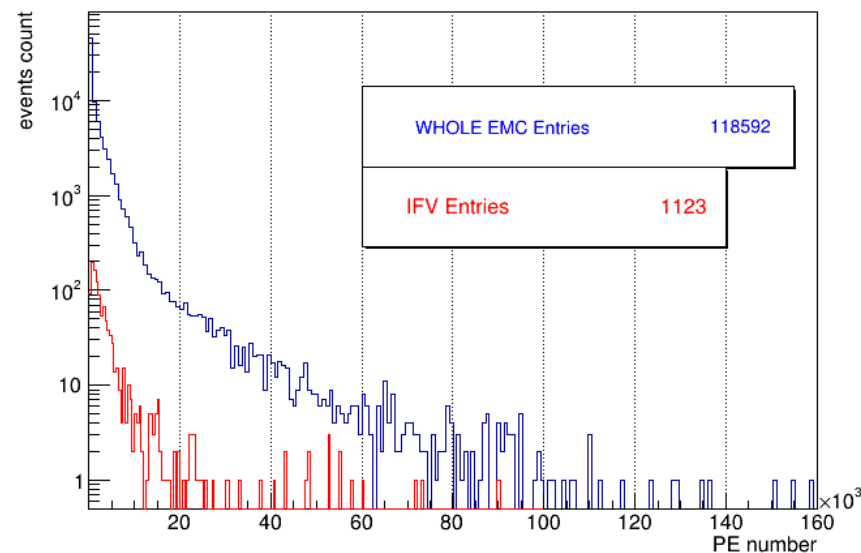


- Neutrino energy range of interest for oscillation analyses is [0,10] GeV
- In this range the **MAXIMUM Np.e.** that has to be treated by FEE can be safely set **between 1000 and 2000**
=> see next slides for the choice of the FEE dynamic range

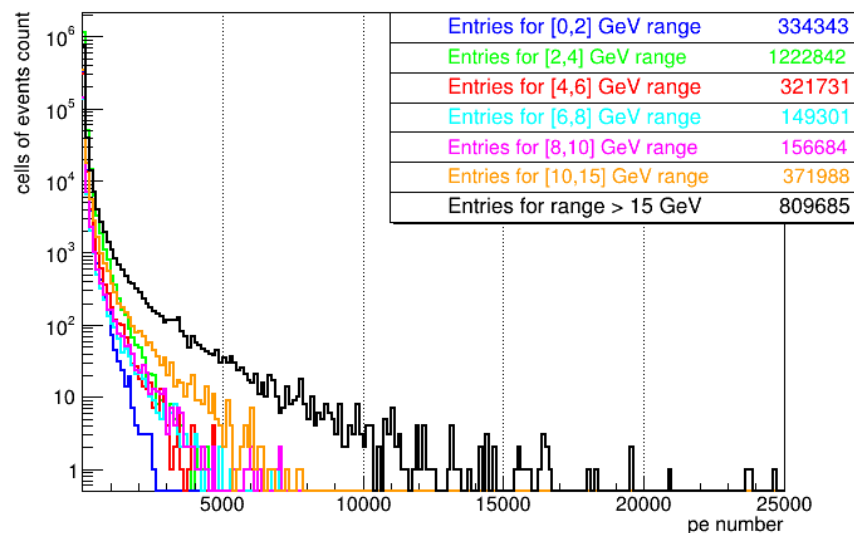
PE distribution



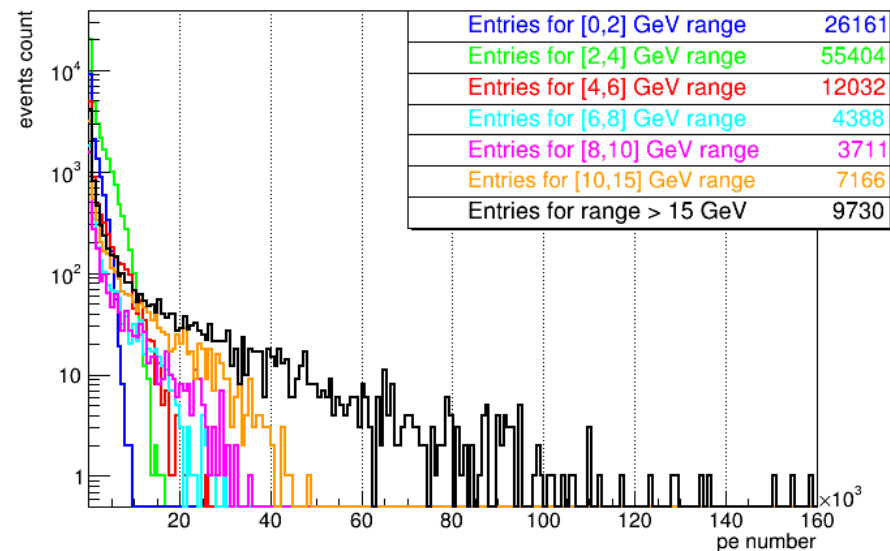
Total PE release

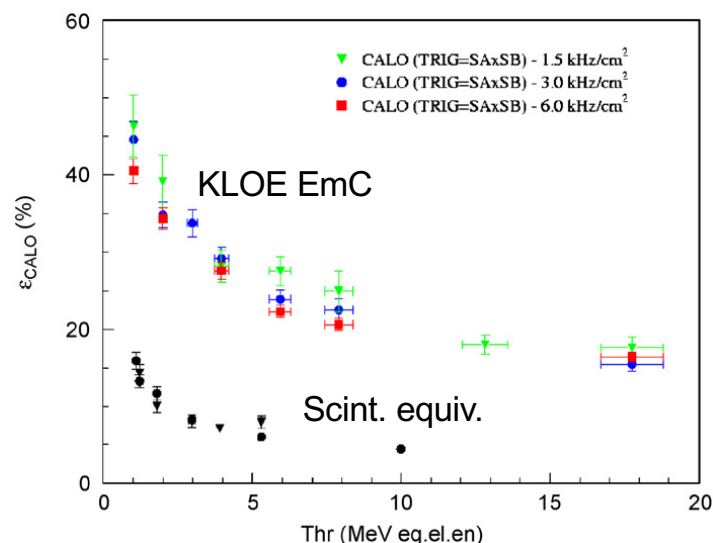


PE distribution at E_ν fixed



Total PE number distribution at E_ν fixed





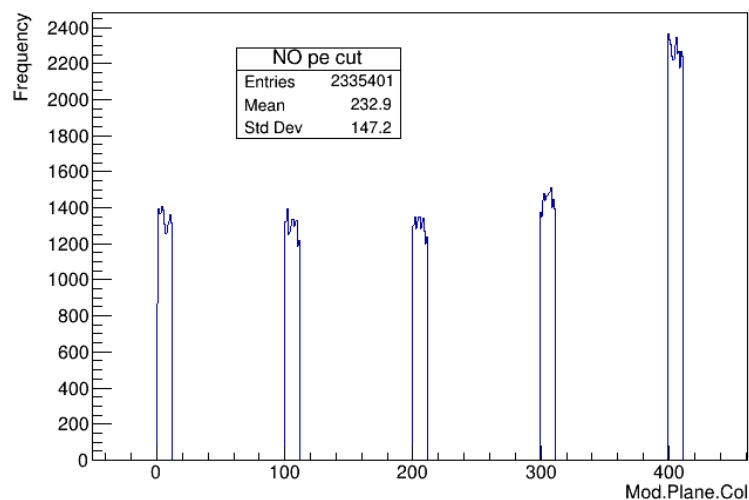
Measurement of the neutron response of the KLOE EmC

- M. Anelli et al., "Measurement and simulation of the neutron response and detection efficiency of a Pb-scintillating fiber calorimeter ", NIM **A581** (2007) 368
-
- M. Anelli et al., "Measurement of the neutron detection efficiency of a 80% absorber–20% scintillating fibers calorimeter ", NIM **A626** (2011) 67

- to maximize the neutron detection efficiency by ECAL the **MINIMUM Np.e.** that has to be treated by FEE is the **lowest possible, ideally 1-3 Np.e.**

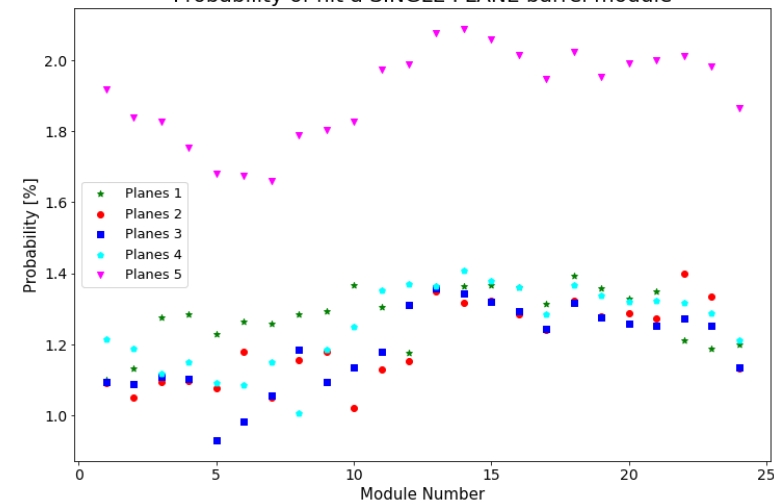
Cell occupancy plots and hit probability

Occupancy plot 1st Barrel MODULE



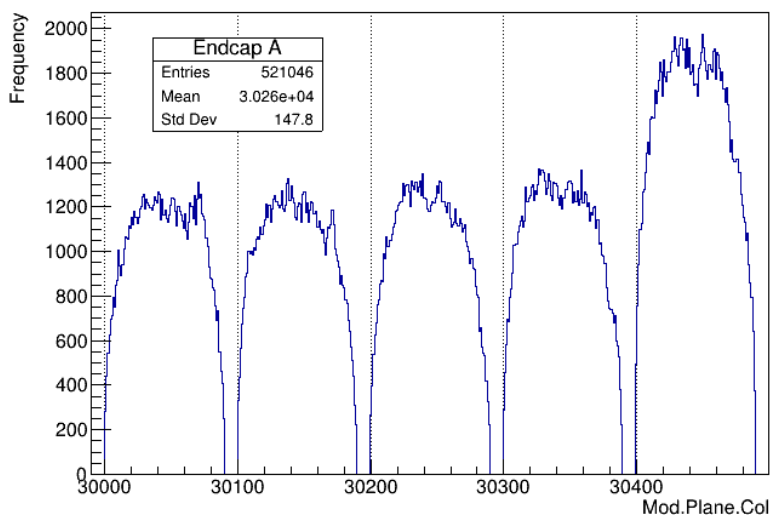
Barrel

Probability of hit a SINGLE PLANE barrel module



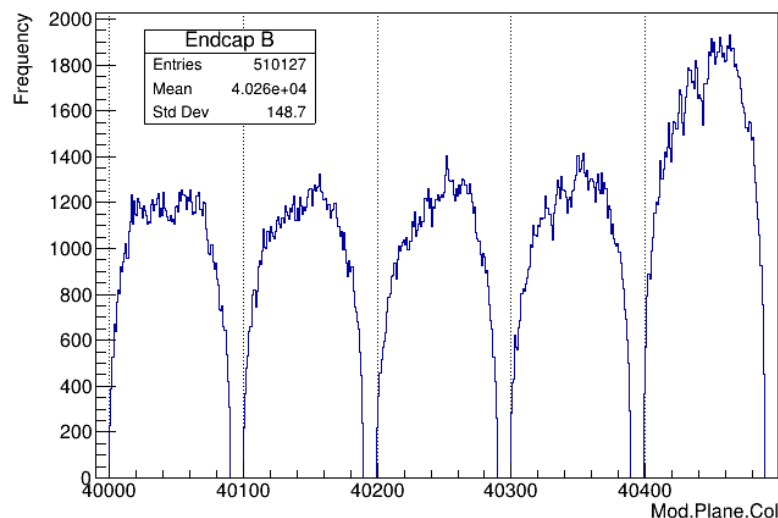
Ecap A

Occupancy plot Endcap A



Ecap B

Occupancy plot Endcap B



Average probability
that a cell is fired/hit in
a neutrino interaction
event:

$$P_{\text{barrel}} = 1.37\%$$

$$P_{\text{ecapA}} = 0.88\%$$

$$P_{\text{ecapB}} = 0.86\%$$

$$P_{\text{cell}} = 1.16\%$$

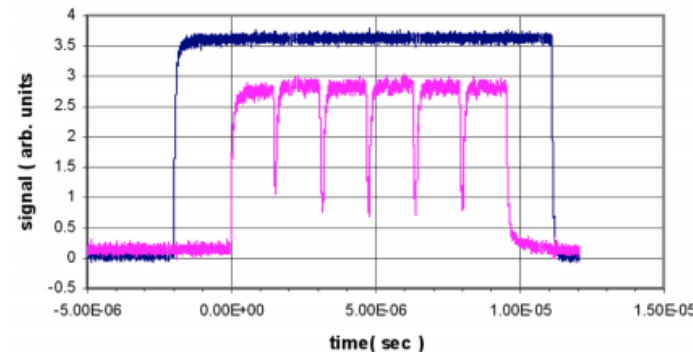
Beam power 1.2 MW

7.5×10^{13} protons extracted every 1.2 s at 120 GeV

1.1×10^{21} pot/year

Spill time structure

- 9.6 μ s per spill
- 6 batches, 84 bunches/batch
- 2 empty bunches
- 1 bunch: Gaus($\sigma = 1.5$ ns)
- Δt bunches = 19 ns



Event rates expected in SAND

~ 84 interactions/spill

$\lesssim 1$ interaction/spill in the SAND fiducial volume

Pile-up probability

The beam time structure is reconstructed to simulate the time of the neutrino interaction event and calculate the pile-up probability that, given a PMT signal, a second signal arrives within a fixed time window (TW) after the first signal.

The times of N interactions per spill (in average **N=84** with 1.2 MW beam) are extracted uniformly between 0 and 9.6 μ s. The time difference between two consecutive interactions is calculated for all spills, following an exponential distribution with $\tau_{\text{spill}} \simeq 114$ ns. From this, the distribution of time differences for a single cell with a probability to be hit of $P_{\text{cell}} = 1.16\%$ is evaluated, and then the pile-up probabilities for different time windows are also evaluated, TW = 50, 100, 150, 200 ns.

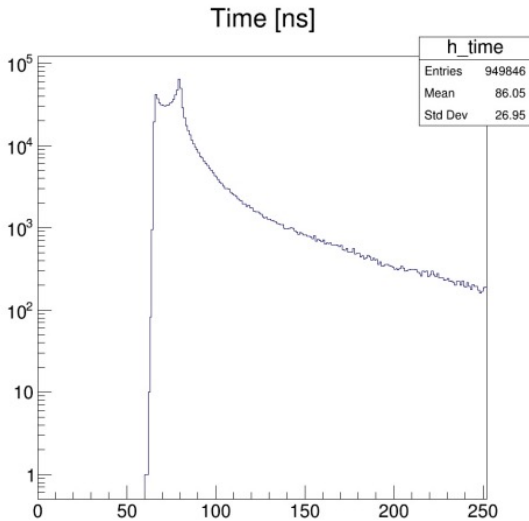
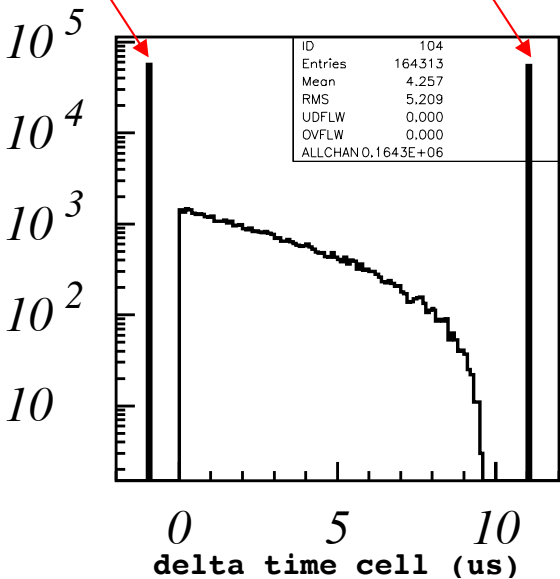
before smearing

after smearing

$P_{\text{CELL}} [\%]$	1.16	1.5	2.0	1.16	1.5	2.0
Time window [ns]	pile-up probability (%)					
50	0.67	0.90	1.28	0.64	0.86	1.36
100	1.33	1.81	2.52	1.32	1.71	2.56
150	1.95	2.71	3.72	1.91	2.60	3.78
200	2.59	3.58	4.87	2.52	3.48	4.93

spills with 0 hit

1 hit



Time propagation/smearing of hits in a single neutrino interaction event.

Pile-up probability

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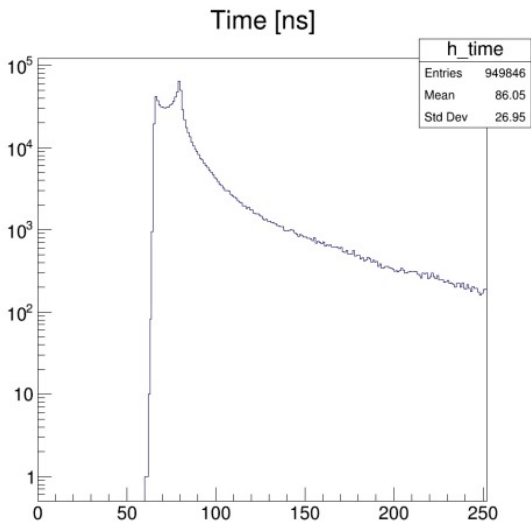
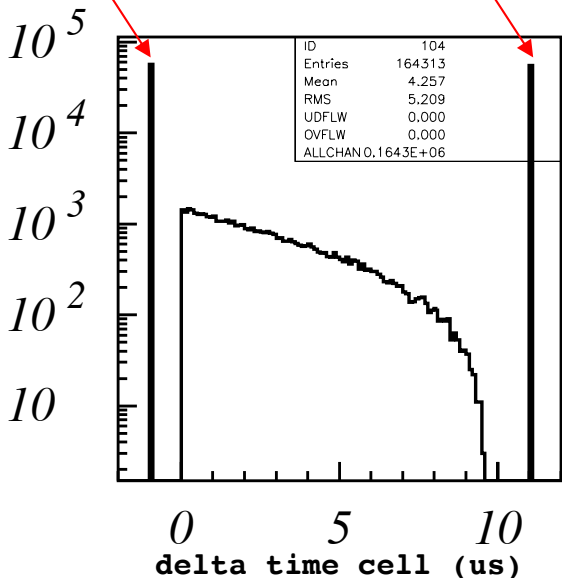
before smearing

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spills with 0 hit

1 hit



Time propagation/smearing of hits in a single neutrino interaction event.

PMT signal and discriminator threshold in KLOE

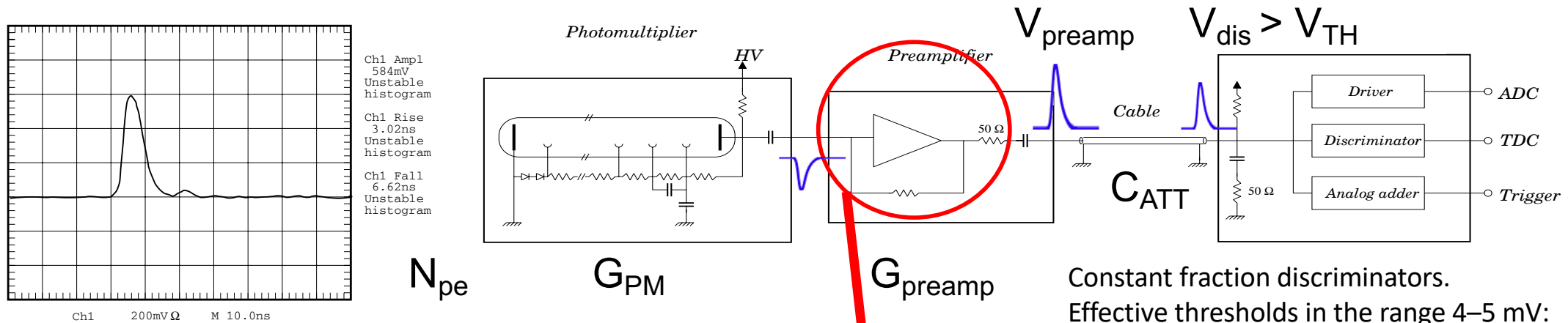
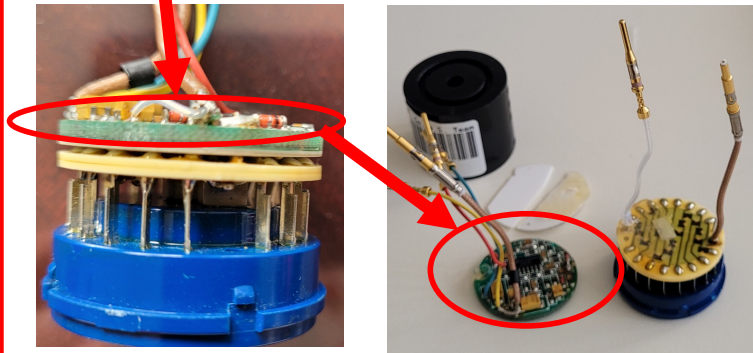


Figure 4: Typical signal from the PM base.

Constraints:

- minimum discriminator threshold 4-5 mV
- max energy release in one cell: 410 MeV
 $\Rightarrow$ 1.p.e./MeV at cell center $\sim$ 1.8 p.e. at end.
- maximum HV for PMs divider is 2300 V
typical HV 1700-1800 $\Rightarrow$ $G \sim 1-3 \times 10^6$
- preamplifier linear (**within 0.2%**) for signals up to 4.7 V (gain preamp $\sim$ 2.5)
 $\Rightarrow$ 1.74 V at discriminator level after 12-15 m long cables and termination

Constant fraction discriminators.
Effective thresholds in the range 4–5 mV:
correspond to signals originated
by 3–4 p.e. or a 3–4 MeV photon
at 2 m from PMT



thanks to A. Balla and P. Ciambrone



Choice of the dynamic range in KLOE

The dynamic range in terms of N_{pe} and the PMT gain G_{PM} can be evaluated using the following constraints for the FEE after the PMT:

- Minimum discriminator threshold $V_{TH} = 5 \text{ mV}$
- Preamplifier linearity (within 0.2%) range = $[0, 4.7] \text{ V} \Rightarrow V_{preamp}(\text{max}) = 4.7 \text{ V}$
- preamp transimpedance gain $G = 250 \text{ V/A} \Rightarrow I_{peak}(\text{max}) = 19 \text{ mA} \Rightarrow \text{max signal charge } Q(\text{max}) = 133 \text{ pC}$ (triangle approx.); from $Q = e N_{pe} G_{PM} \Rightarrow (N_{pe} G_{PM})(\text{max}) = 83 \cdot 10^7$
- $G_{TOT} = G_{PM} G_{preamp}$ with $G_{preamp} \simeq 2.5$
- 12m long cable attenuation: $C_{ATT} = 0.74$
- MAX single pulse amplitude at the discriminator/digitizer input is:
 $V_{dis}(\text{max}) = V_{preamp}(\text{max}) \cdot 0.5 \cdot C_{ATT} = 1.74 \text{ V}$
- signal ampl = $V_{dis}(\text{max})/N_{pe}(\text{max})$
- $N_{pe}(\text{min}) = V_{TH}/(\text{signal ampl}) \Rightarrow N_{pe}(\text{max})/N_{pe}(\text{min}) = V_{dis}(\text{max})/V_{TH}$

G_{PM} ($\times 10^5$)	G_{tot} ($\times 10^6$)	$N_{pe}(\text{max})$	signal amplitude (mV/pe)	$N_{pe}(\text{min})$ $V_{TH} = 5 \text{ mV}$	MeV at module center
4.2	1.04	~ 2000	0.87	~ 6	6.0
5.5	1.38	~ 1500	1.16	~ 4	4.0
8.3	2.1	~ 1000	1.74	~ 3	3.0
10	2.5	~ 800	2.18	~ 2	2.0

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- $N_{pe}(\text{min}) = V_{TH}/(\text{signal ampl}) \Rightarrow N_{pe}(\text{max})/N_{pe}(\text{min}) = V_{dis}(\text{max})/V_{TH}$

G_{PM} ($\times 10^5$)	G_{tot} ($\times 10^6$)	$N_{pe}(\text{max})$	signal amplitude (mV/pe)	$N_{pe}(\text{min})$ $V_{TH} = 5 \text{ mV}$	MeV at module center
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8.3	2.1	~ 1000	1.74	~ 3	3.0
10	2.5	~ 800	2.18	~ 2	2.0

KLOE
choice



Extending dynamic range in SAND

At oscilloscope:
preamplifier saturation
well visible over **3.2 V**



Preliminary considerations:

there is margin to increase the dynamic range by slightly releasing the stringent requirements for linearity in KLOE (e.g. from 0.2% to 1%) .

In fact, in the specific case of the above picture at the oscilloscope (negligible cable length $C_{ATT} = 1$) we expect linearity at **0.2%** level for $V_{dis}(\max) = V_{preamp}(\max) \cdot 0.5 = \mathbf{2.35\ V}$

Assuming to increase $V_{preamp}(\max)$ by 15% while keeping linearity at an acceptable level, e.g. **1%** (feasible - see next slide), we get: $V_{preamp}(\max) = 5.4\ V$

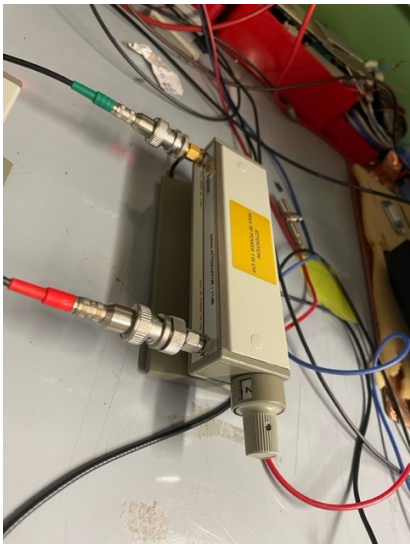
$V_{dis}(\max) = V_{preamp}(\max) \cdot 0.5 = \mathbf{2.7\ V} \Rightarrow \text{increase dynamic range}$

Preamp linearity test (1) using pulse generator

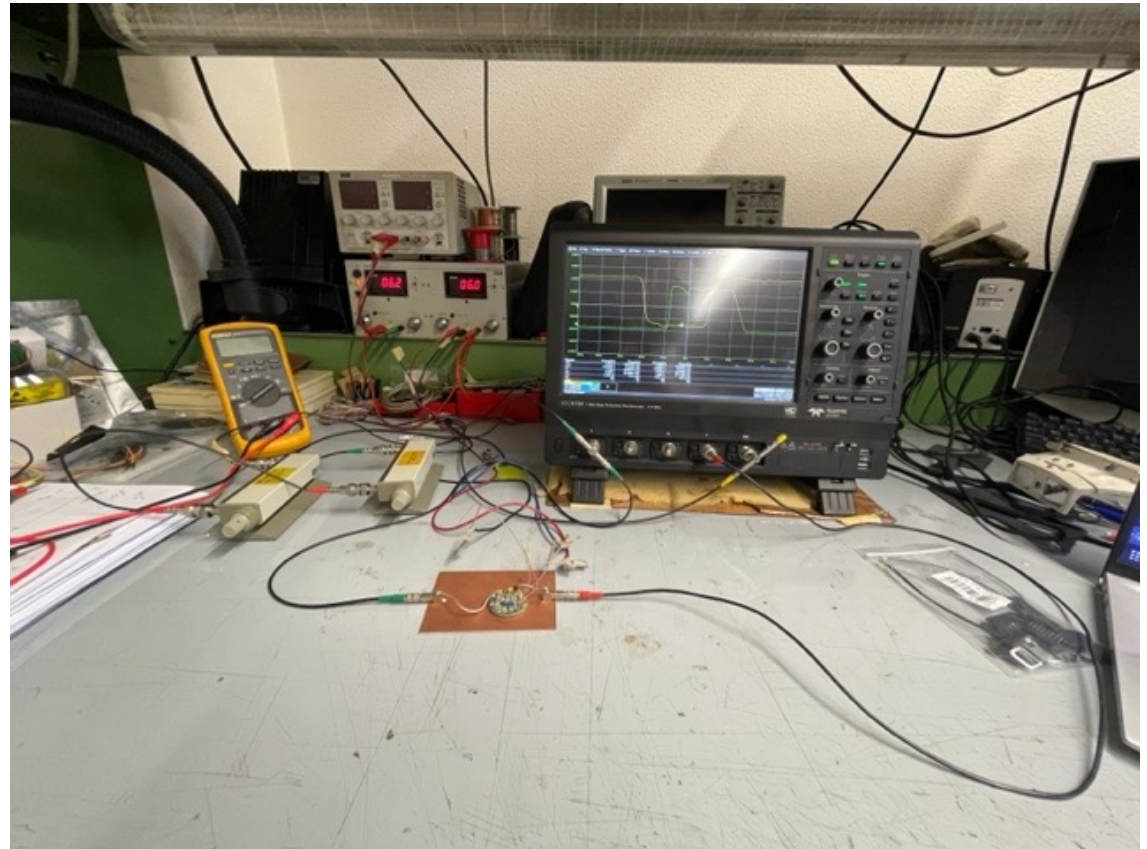
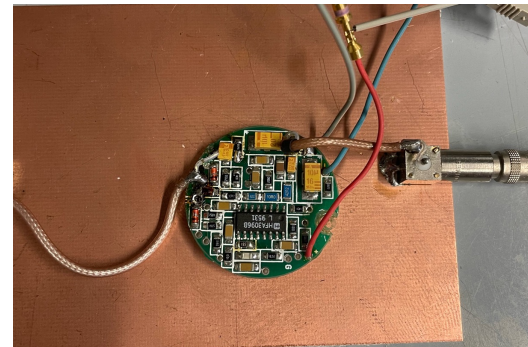
Test set-up



Signal amplitude varied
with calibrated attenuators
(pulse width ~ 30 ns)

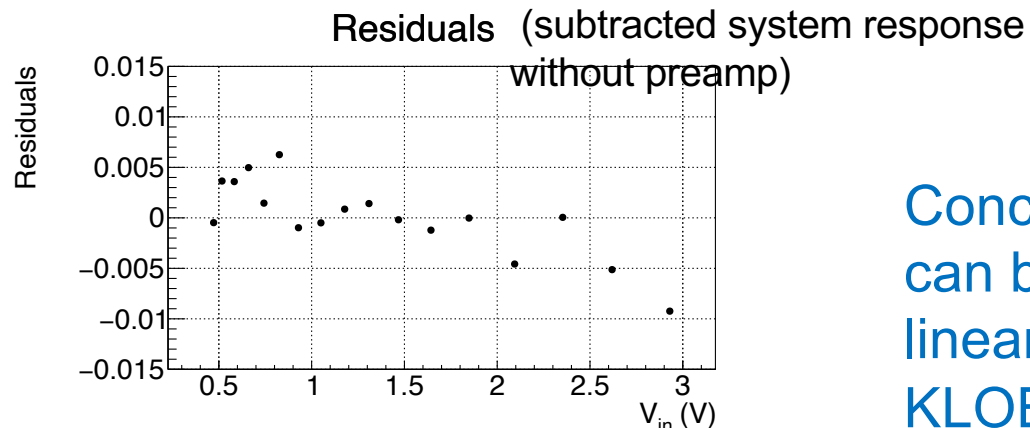
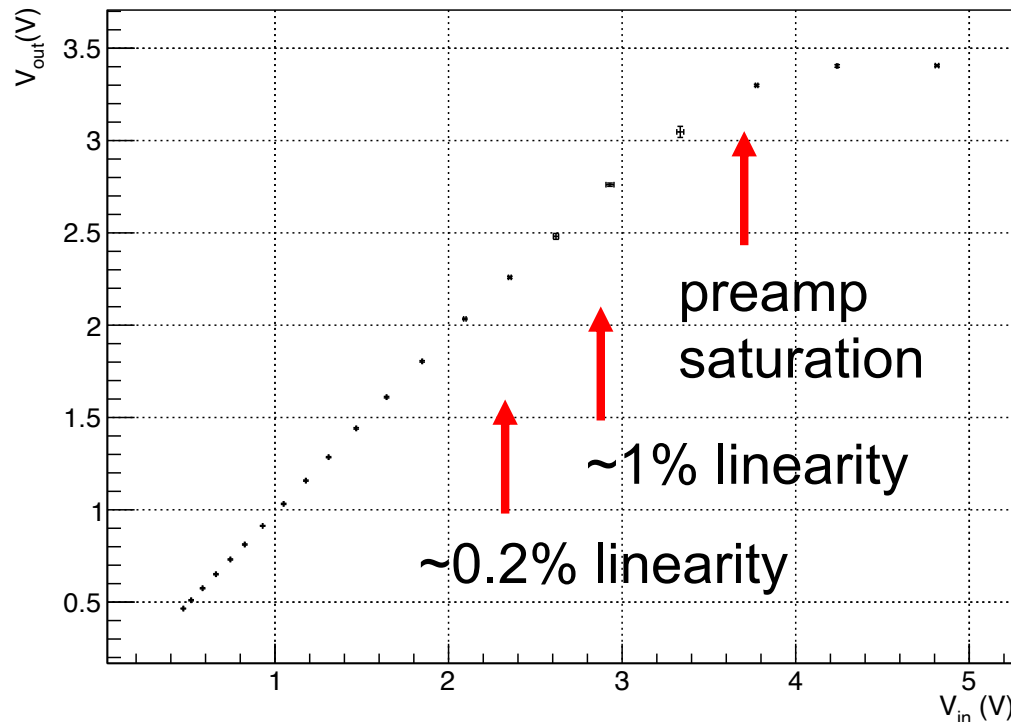


Signal at a modified
test input: preamp
gain ~ 1

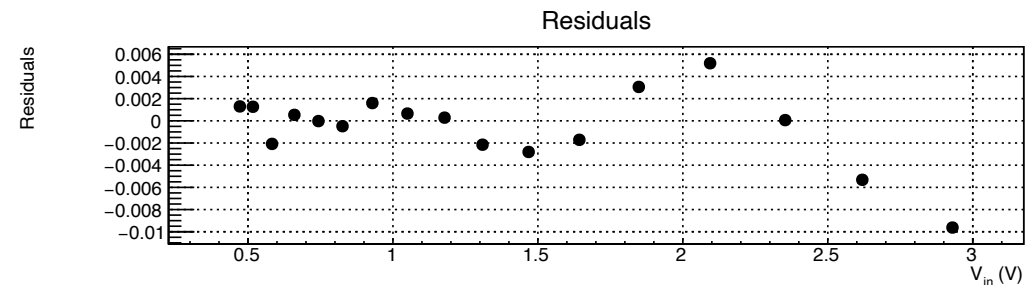
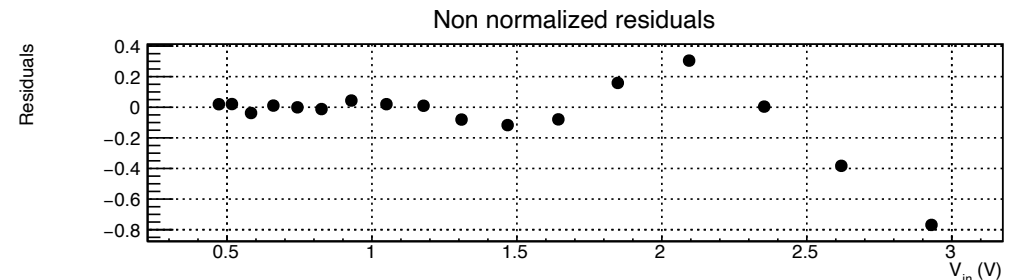
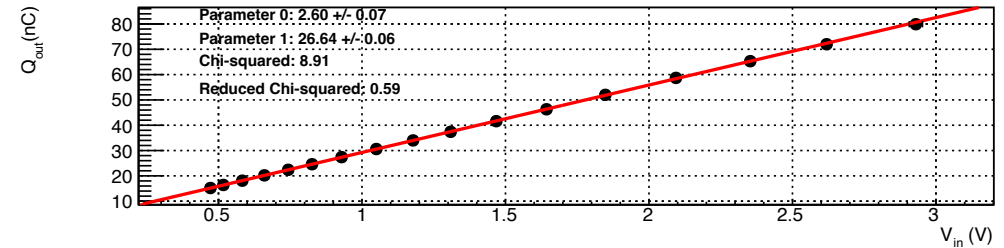


Preamp linearity test (1): linear and saturation regimes

Linearity test



Linear fit



Conclusion: the dynamic range of signals can be increased in SAND by accepting linearity at 1% level (instead of 0.2% as in KLOE)

Choice of the dynamic range

Assuming:

- to increase $V_{\text{preamp}}(\text{max})$ by 15% $\Rightarrow V_{\text{preamp}}(\text{max}) = 5.4 \text{ V}$
(linearity from 0.2% to 1%)
- $(N_{\text{pe}} G_{\text{PM}})(\text{max}) = 95 \cdot 10^7$
- $V_{\text{dis}}(\text{max}) = V_{\text{preamp}}(\text{max}) \cdot 0.5 \cdot C_{\text{ATT}} = 2.0 \text{ V}$ (12m long cable attenuation: $C_{\text{ATT}} = 0.74$)
- to have a very low noise environment as in KLOE $\Rightarrow$ lowering (halving) the minimum discriminator/digitizer threshold to $V_{\text{TH}} = 2.5 \text{ mV}$

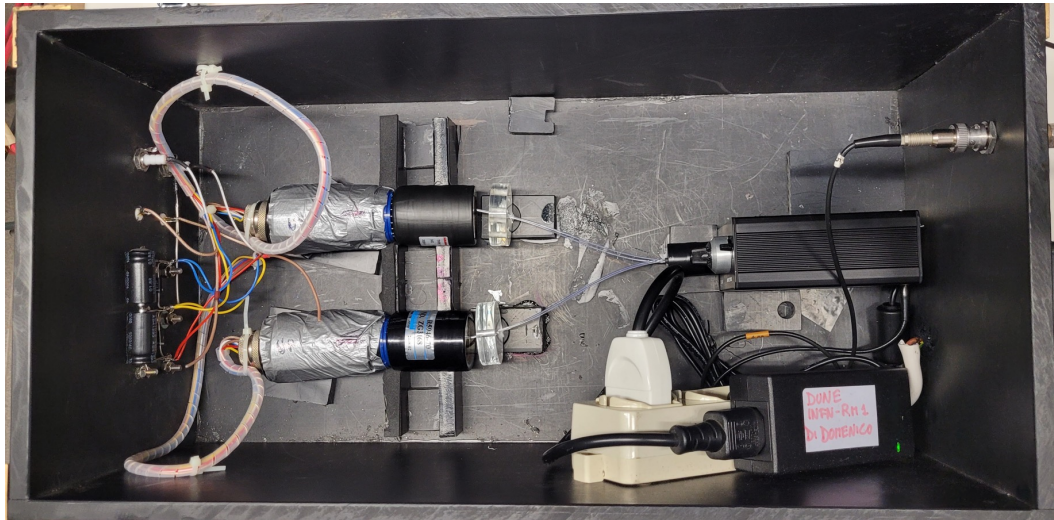
G_{PM} ($\times 10^5$)	G_{tot} ($\times 10^6$)	$N_{\text{pe}}(\text{max})$	signal amplitude (mV/pe)	$N_{\text{pe}}(\text{min})$ $V_{\text{TH}} = 2.5 \text{ mV}$	MeV at module center
4.8	1.2	~ 2000	1.0	~ 3	3.0
6.4	1.6	~ 1500	1.3	~ 2	2.0
9.5	2.4	~ 1000	2.0	~ 1	1.0

- Different dynamic ranges can be implemented changing $G_{\text{PM}} \Rightarrow$
the final choice should be a compromise between an affordable level of events with energy saturated cells, depending on $N_{\text{pe}}(\text{max})$, and an acceptable neutron detection efficiency, depending on $N_{\text{pe}}(\text{min})$.

Preamp linearity test (2) with PMT system test

PMT system test at LNF with

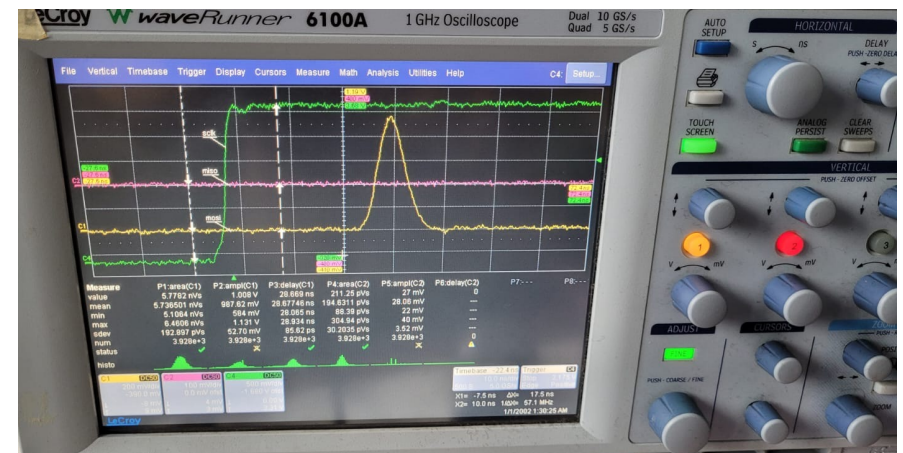
- CAEN LED driver SP5601 (wavelength ~ 400 nm) with fine tunable LED intensity
- scint. fiber splitter
- two PMTs (for relative QE meas.)



no preamplifier



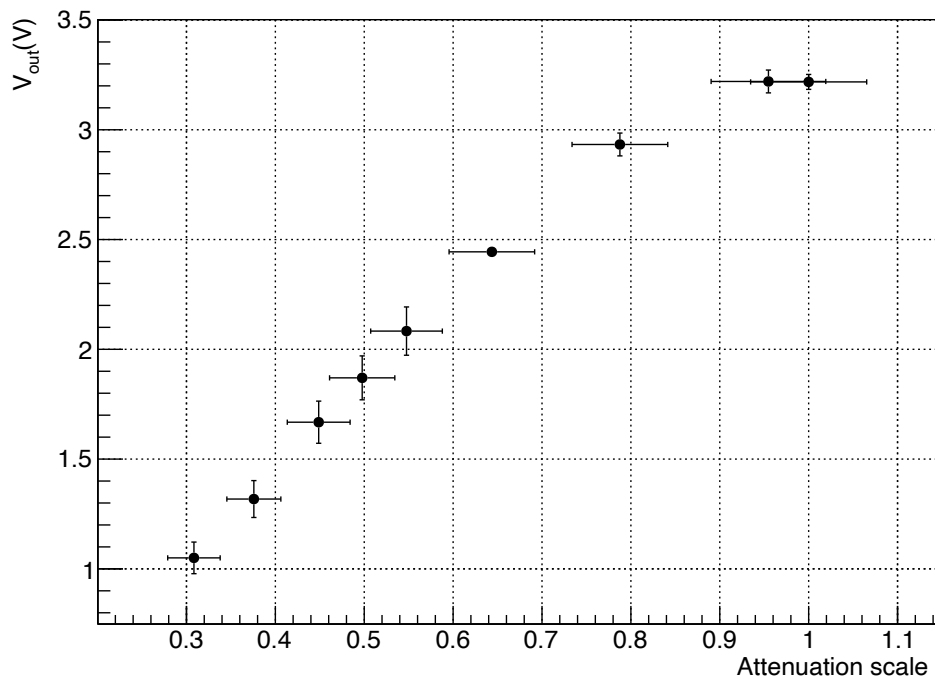
with preamplifier



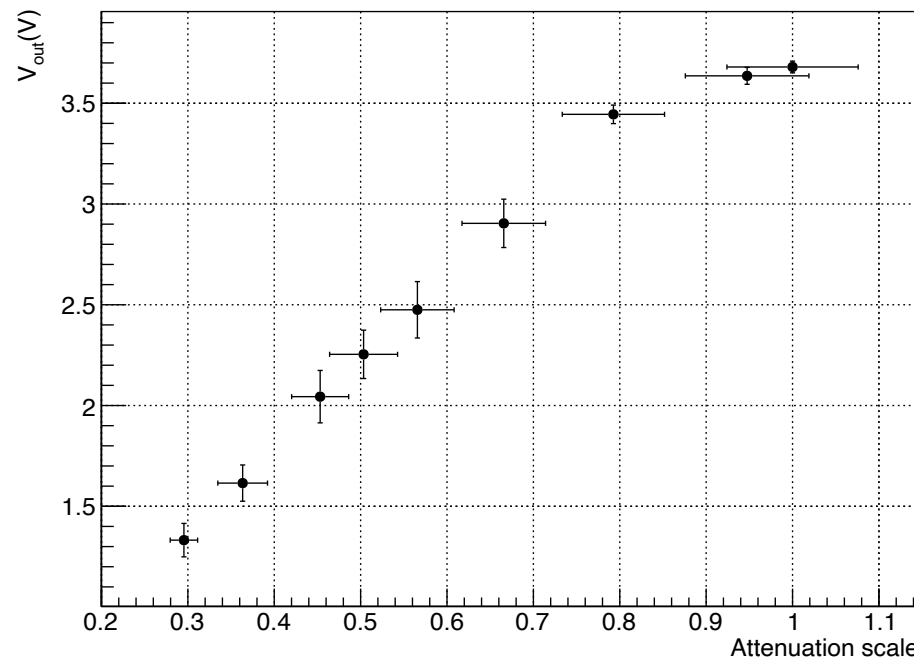
Preamp linearity test (2): results (i)

LED driver attenuation scale checked and calibrated with PMT response in linear region

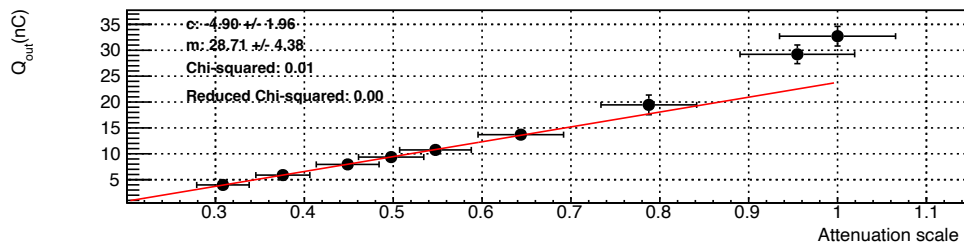
Saturation curve PMT1



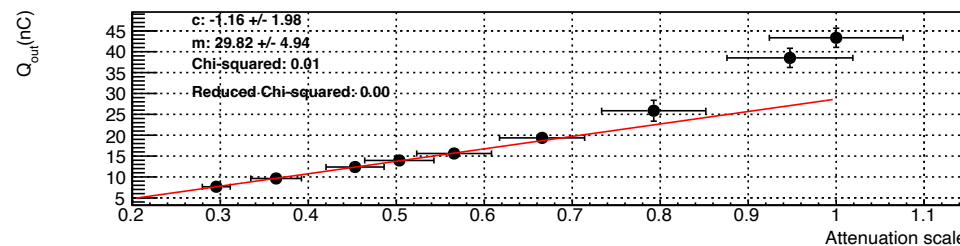
Saturation curve PMT2



Linear fit PMT1



Linear fit PMT2



Preamp linearity test (2): results (ii) => saturation

PMT2 HV=1700 V

REF PMT1

HV=1900 V

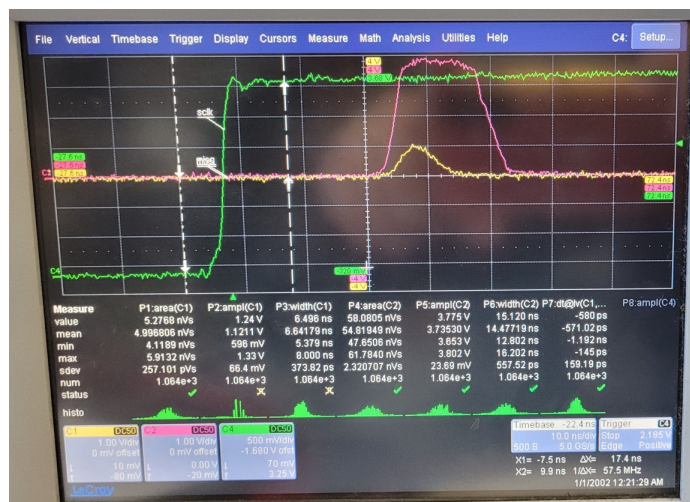
fixed LED
intensity (full)

HV=2100 V



no preamp PMT2
with preamp PMT2

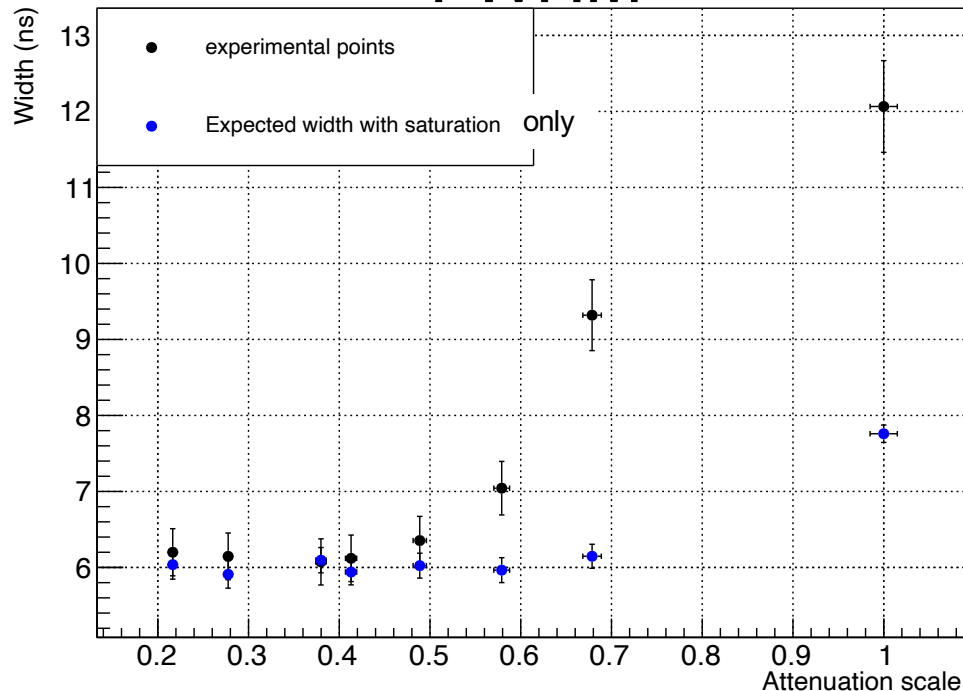
preamp recovery time from saturation
depends on input amplitude signal



Preamp linearity test (2): results (iii) => saturation

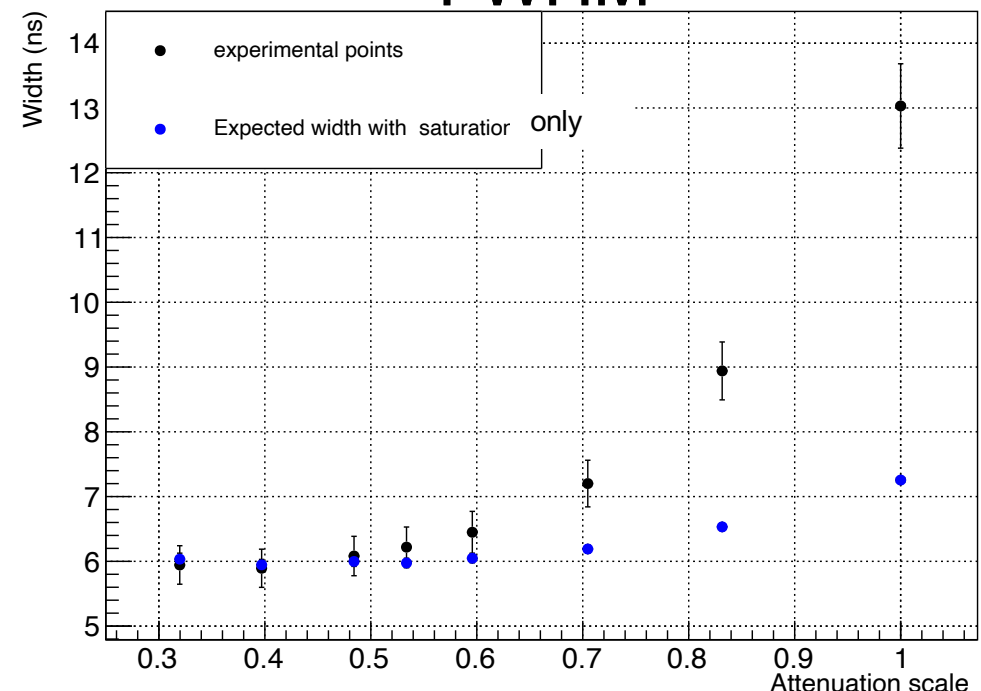
PMT1

FWHM



PMT2

FWHM



- The time baseline is distorted during saturation. The recovery time from saturation to linear regime depends on the input signal amplitude.
- The input information is not fully lost during the saturation regime. The “over-linearity” of the integrated charge, or the signal width increase vs the input signal amplitude could be exploited to characterize signals beyond the preamp saturation regime.