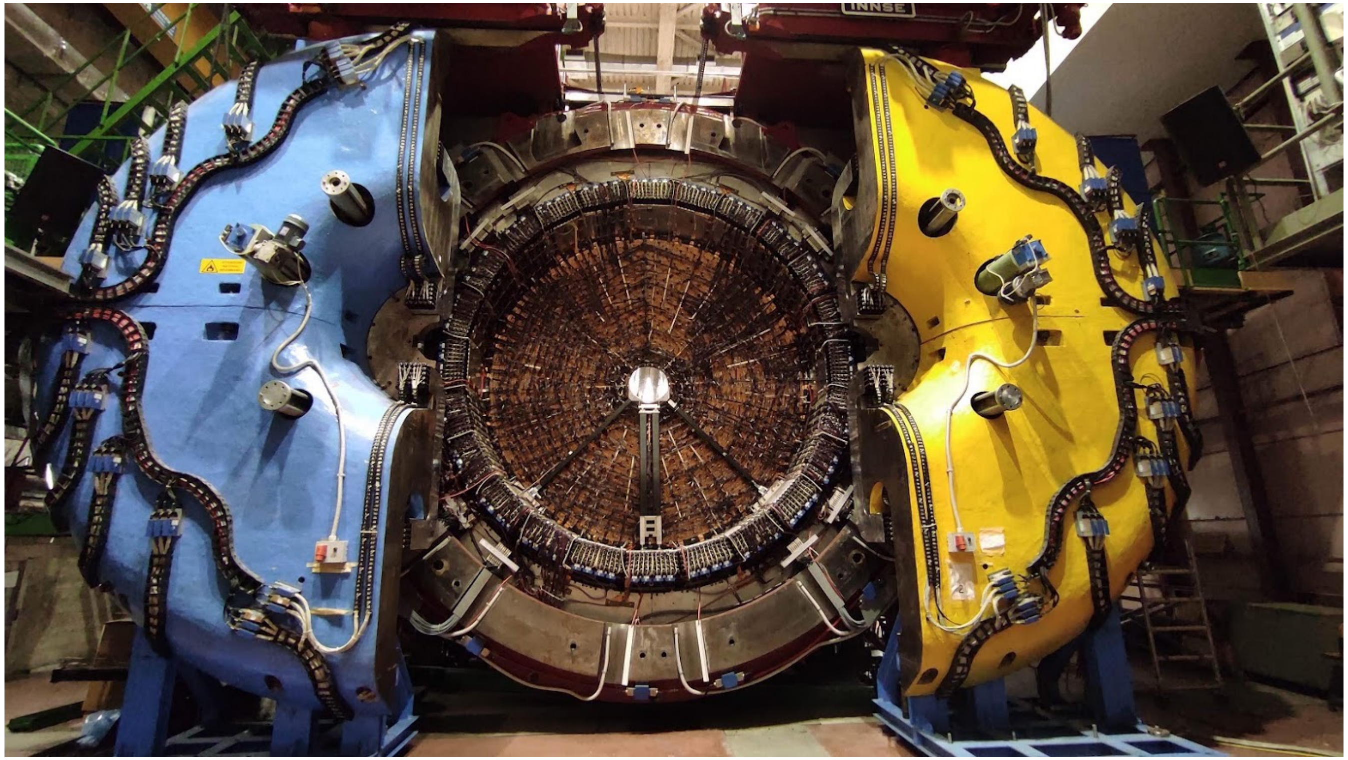
Testing ECAL at LNF and studies for the new FEE

Antonio Di Domenico
Dipartimento di Fisica, Sapienza Università di Roma
and INFN-Roma, Italy

on behalf of the SAND-ECAL WG

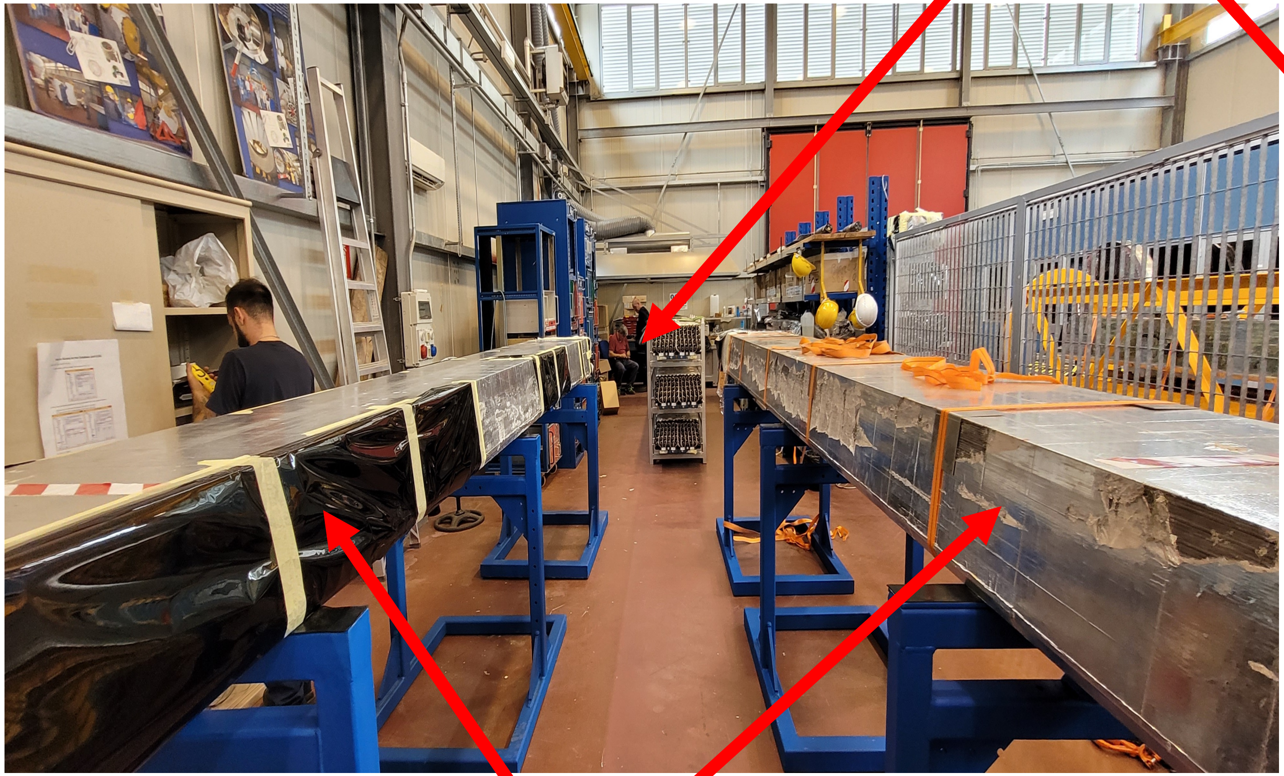


CSN1 Review of SAND – LNF – 11 July 2024

ECAL test at LNF

We plan to test two barrel modules at the same time; (60+60)x2=240 channels

Test area



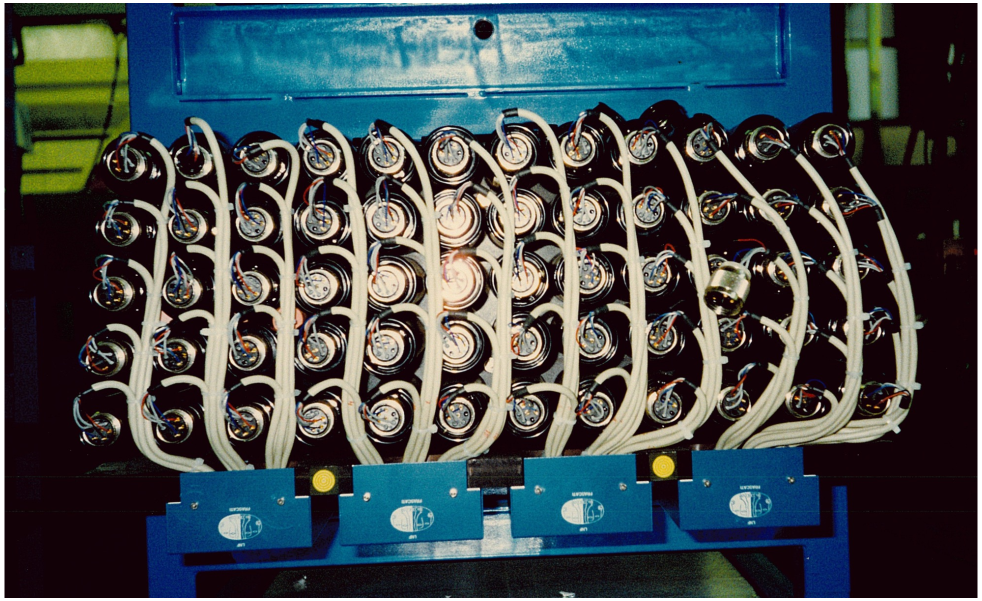
Refurbishment area

(In total test+refurbishment ~85 mq in bld.57)

ECAL test at LNF

PMTs will be dismounted, light guides cleaned, new optical gel applied, and PMT re-mounted.

ECAL module refurbishment and test



Bicron optical gel BC-630

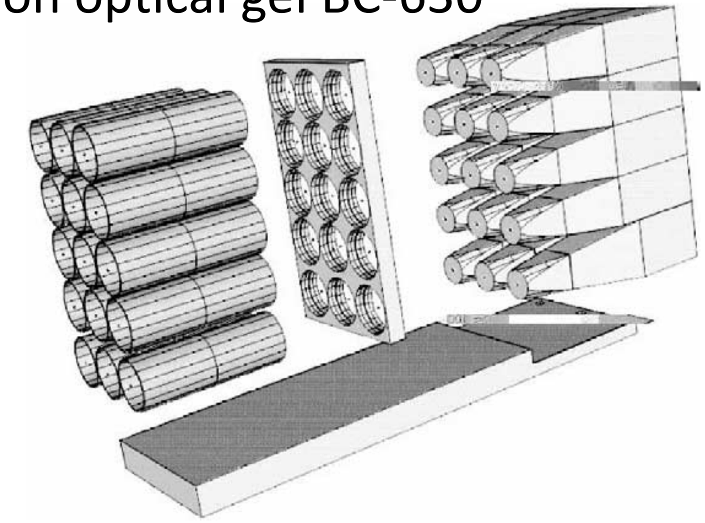


Fig. 4. Exploded view of the PM box.

ECAL test at LNF

For the ECAL module test the KLOE electronics will be reused

VME bridge

trigger distributor
NIM modules for trigger logic

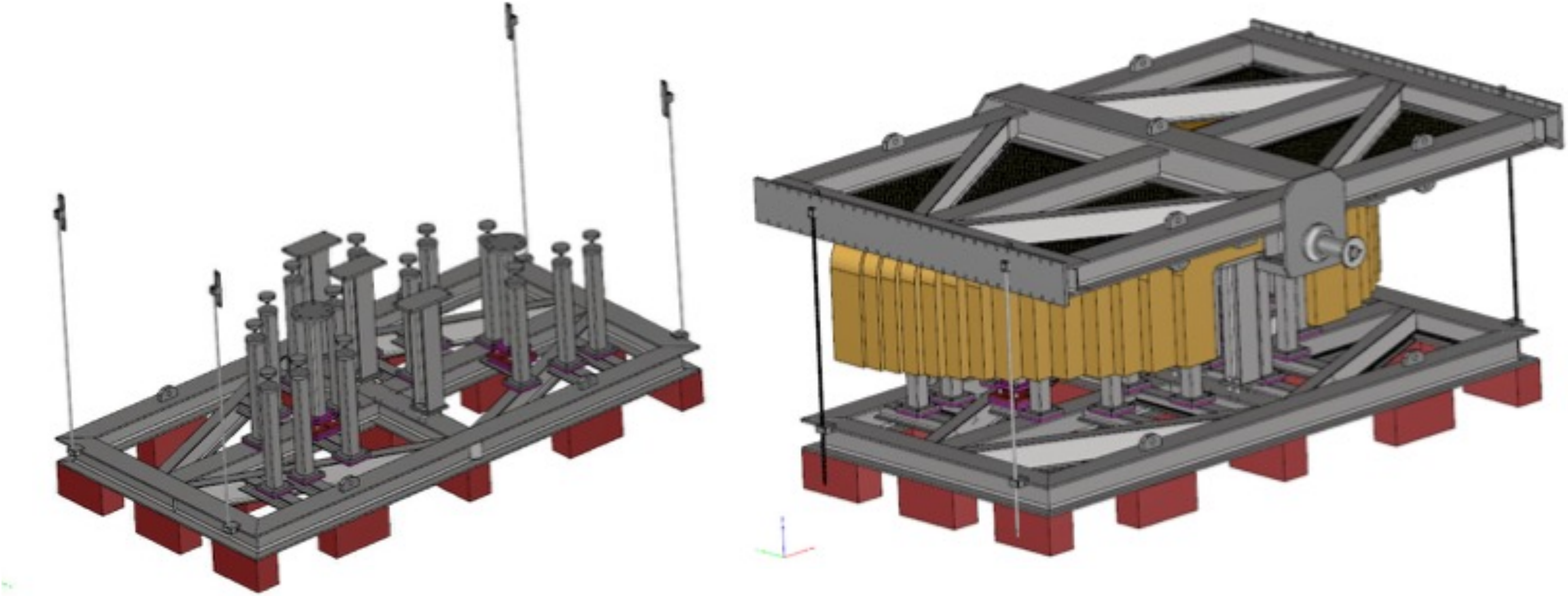
CAEN HV power supply

KLOE ADC CAEN VX559 (30 ch.) 8 boards
KLOE TDC CAEN VX569 (30 ch.) 8 boards

KLOE Low Voltage power supply (380~V)
+/-6V (2x 300W) => PMT preamp, FEE etc.
+/- 5.2 (2x 280W) => digital circuitry

KLOE SDS 8 boards: spllitter +
discriminators on 30 ch./board
common tunable threshold(low+hign thr.)

ECAL test at LNF: End-cap modules



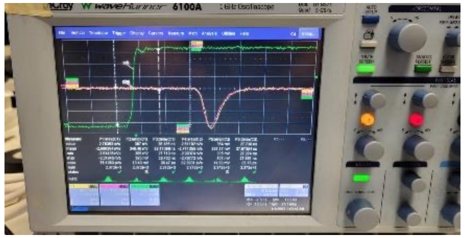
Design of supports for handling and transportation of each half End-cap.

ECAL module refurbishment and test

- After dismounting operation, the special protective adesive tape of all barrel modules has to be replaced; gluing of delaminated modules, etc.
- check light tightness of module and PMT working;
- test basic performance with cosmics rays
- test FEE prototypes
  (comparison with old KLOE electronics)

Shifts of trained technicians and physicists

Test box
for testing
PMTs



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.)~~

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

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)

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

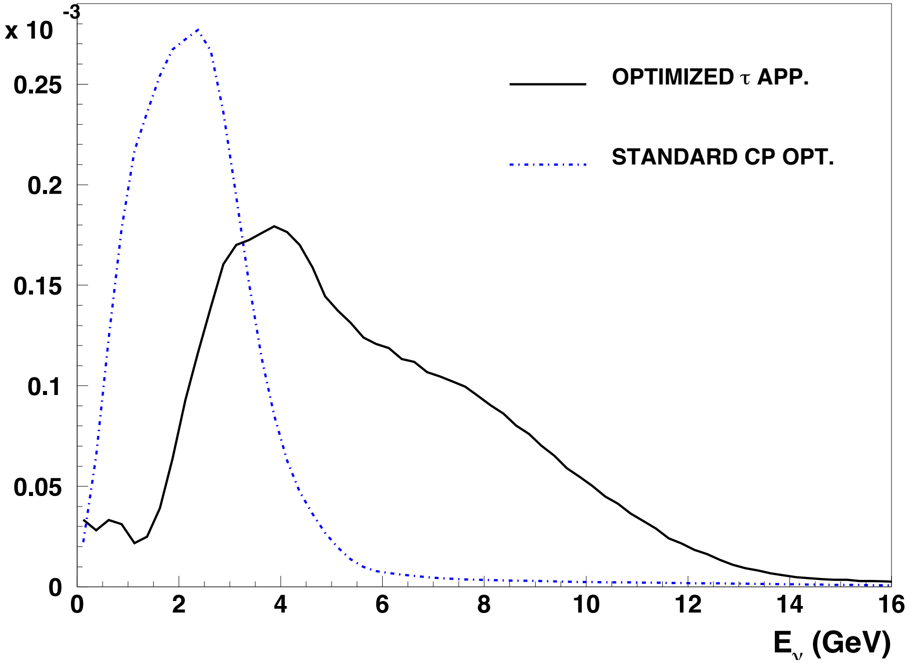


Figure 87: Comparison of LBNF ν_μ fluxes: (a) default 3 horn beam optimized for CP violation (dash-dotted); (b) ν_τ appearance optimized beam (solid).

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

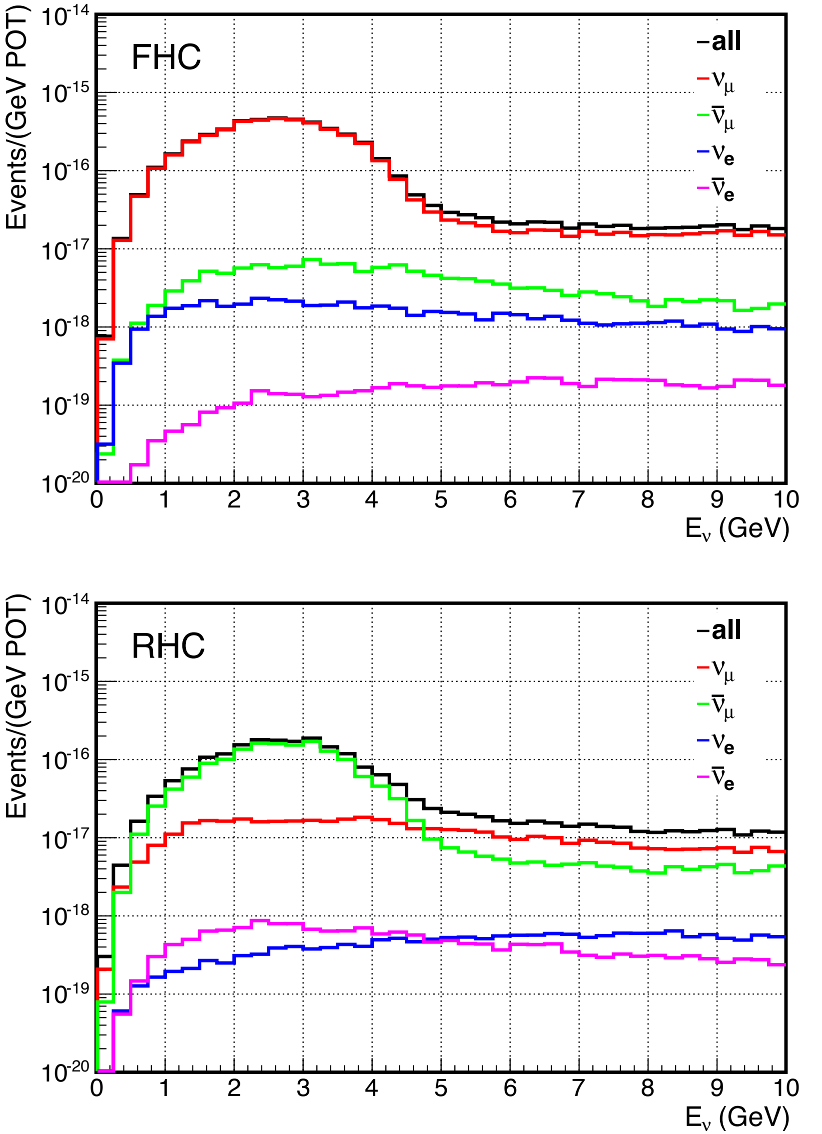


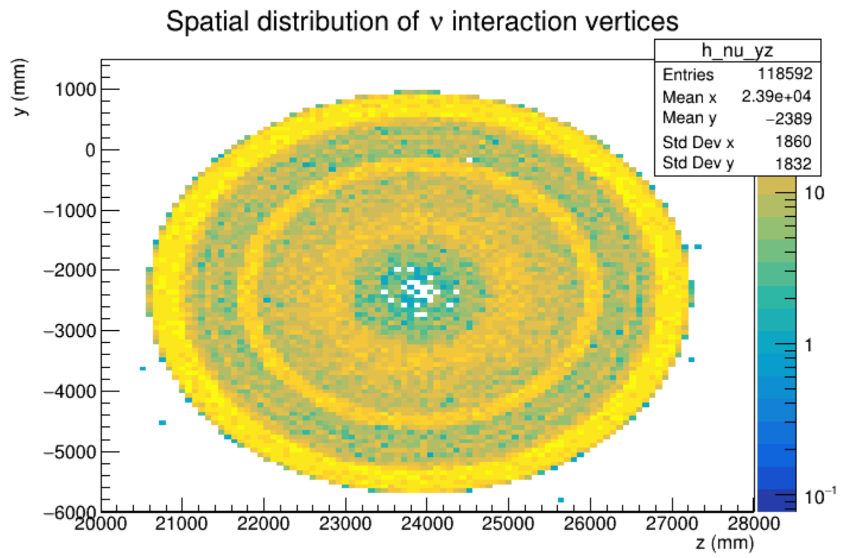
Figure 89: Energy spectra of CC interacting neutrinos in the internal LAr target, having a mass of 1.01 ton, and considering a 120 GeV proton beam in both FHC and RHC modes.

SAND MC simulation

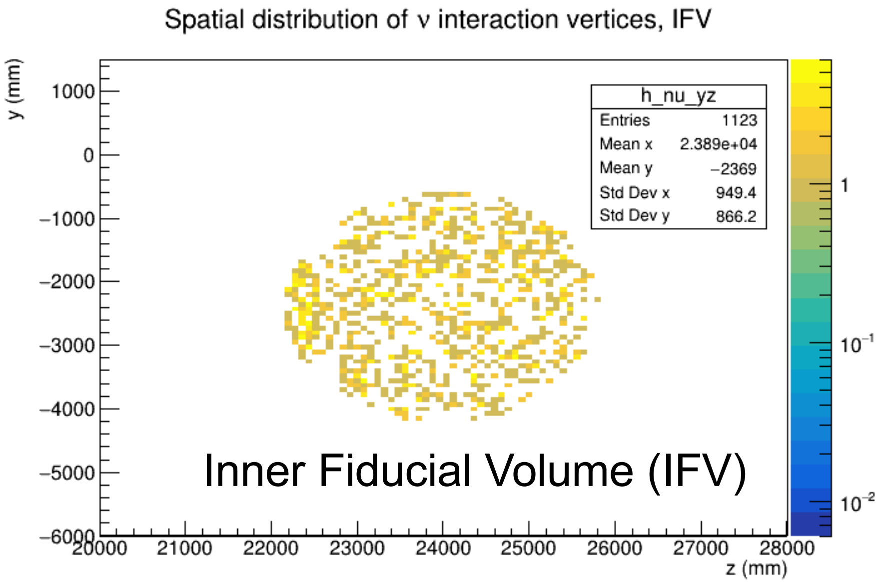
- Analyzed sample: sand-events.*.digi.root and sand-events.*.edep.root

- 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



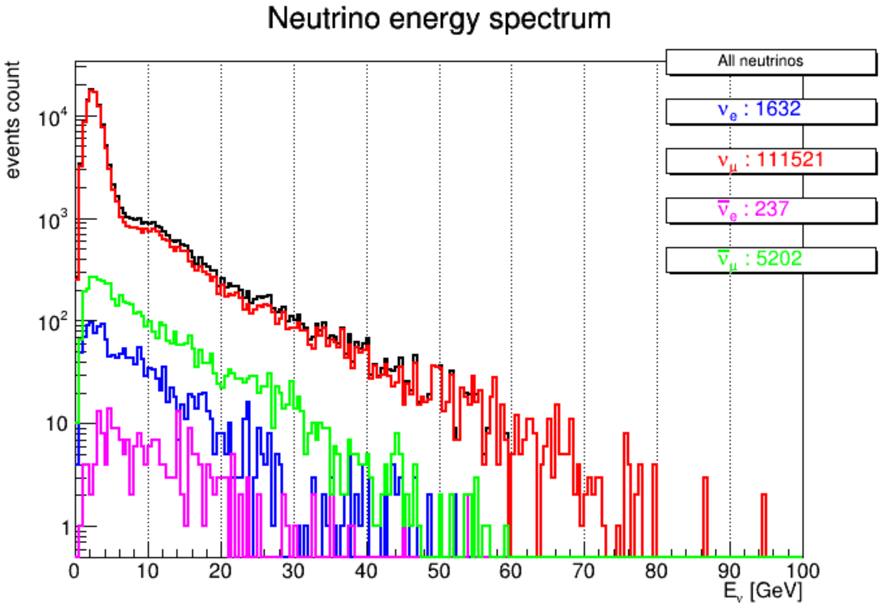
Spatial distribution of ν interaction vertices

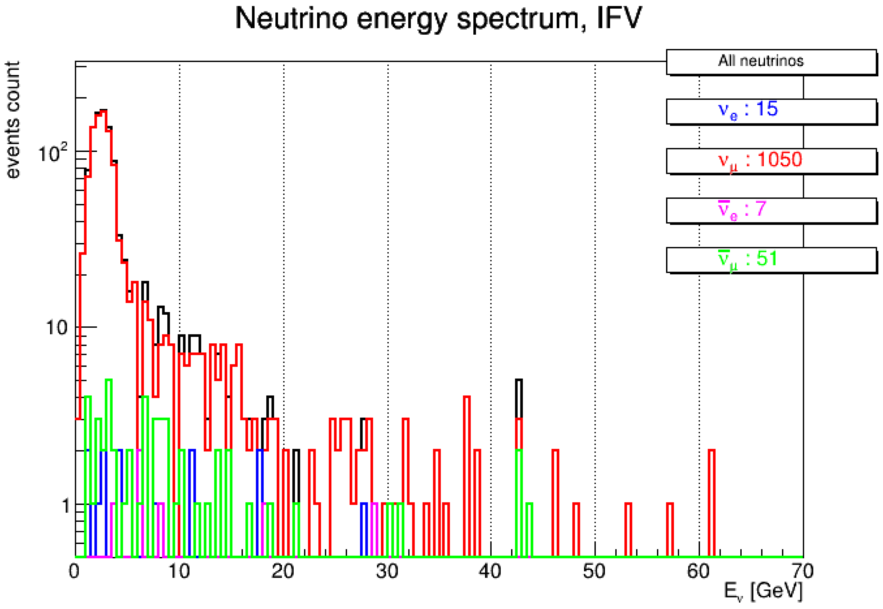


Spatial distribution of ν interaction vertices, IFV

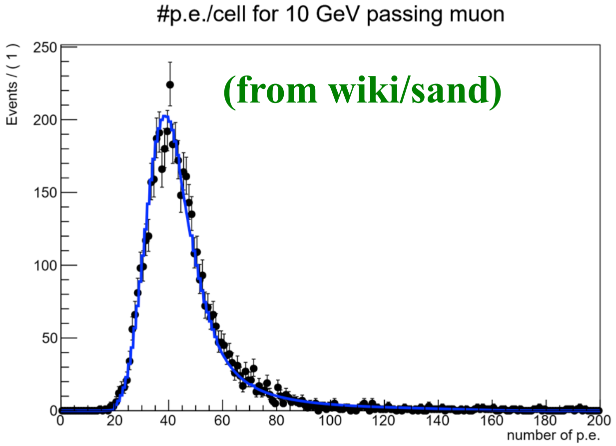
Neutrino energy spectrum in SAND MC

spectrum in the whole energy range





ECAL digitization



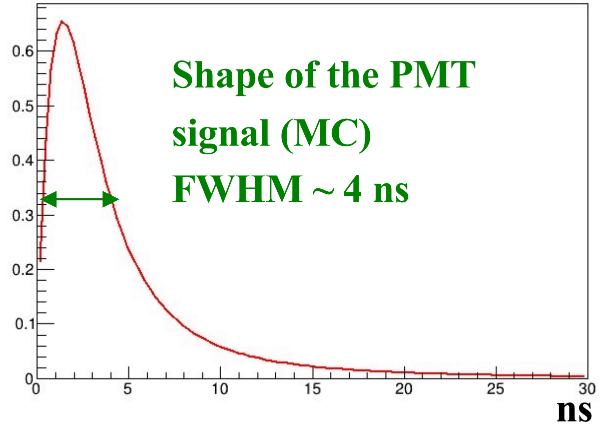
Digitization of ECAL similar to KLOE MC:

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

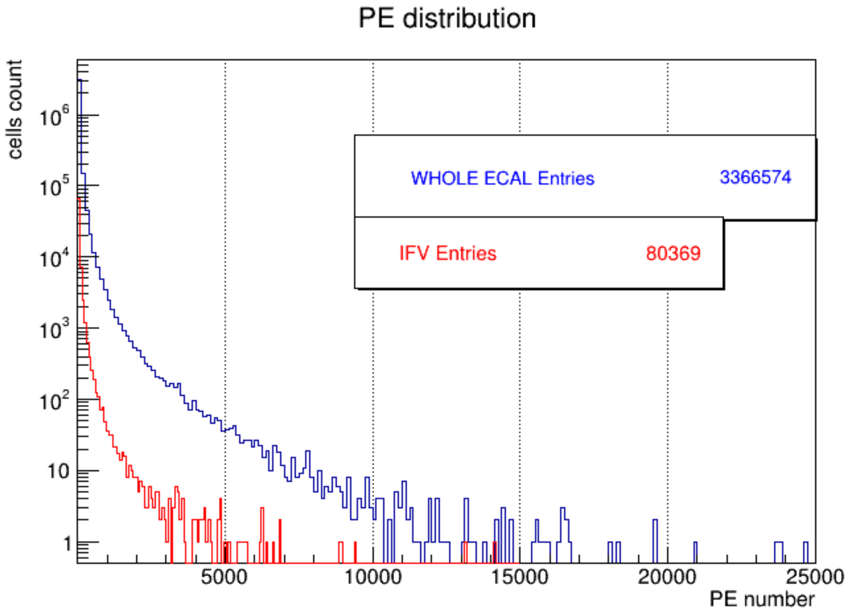
$$f(x) = Ae^{-\frac{x}{\lambda_1}} + (1 - A)e^{-\frac{x}{\lambda_2}}$$

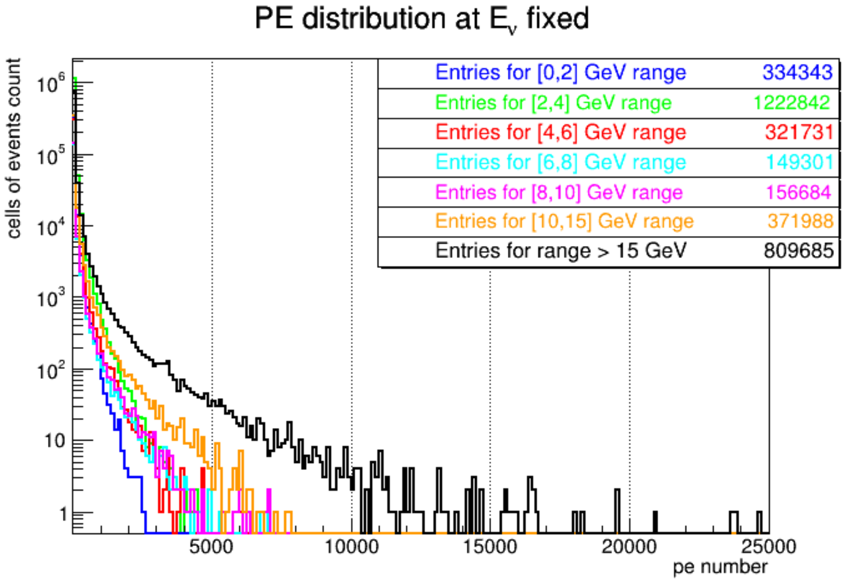
- Converted into p.e. number ⇒ 18.5 p.e./MeV of deposited energy (MIP at the module center ~ 40 p.e.)
- Light yield ~ 1 p.e./MeV of total energy of the particle
- Threshold = 2.5 p.e.

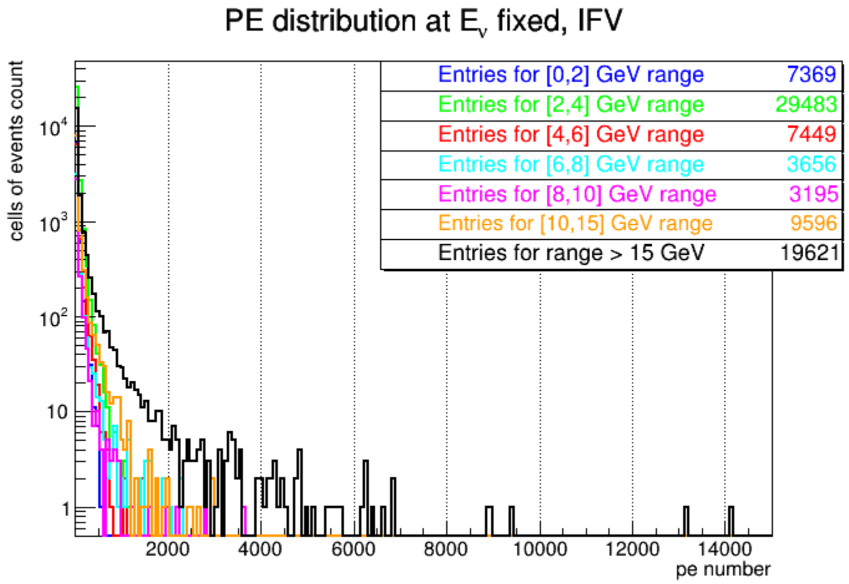
- Constant fraction discriminator at 15% ot fhe signal
- Multihit TDC simulation (30 ns integration time + 50 ns dead time)



Np.e. distributions







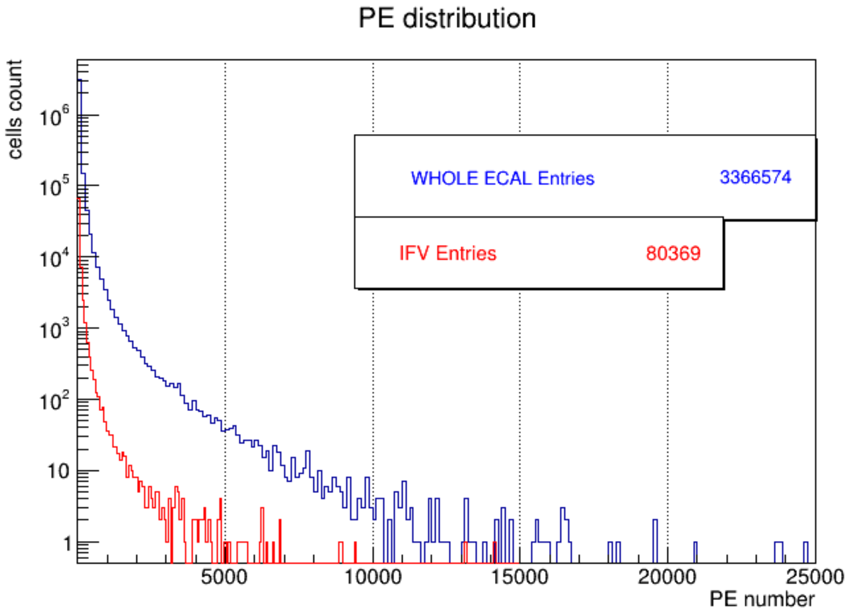
E_ν range = [0,10] GeV

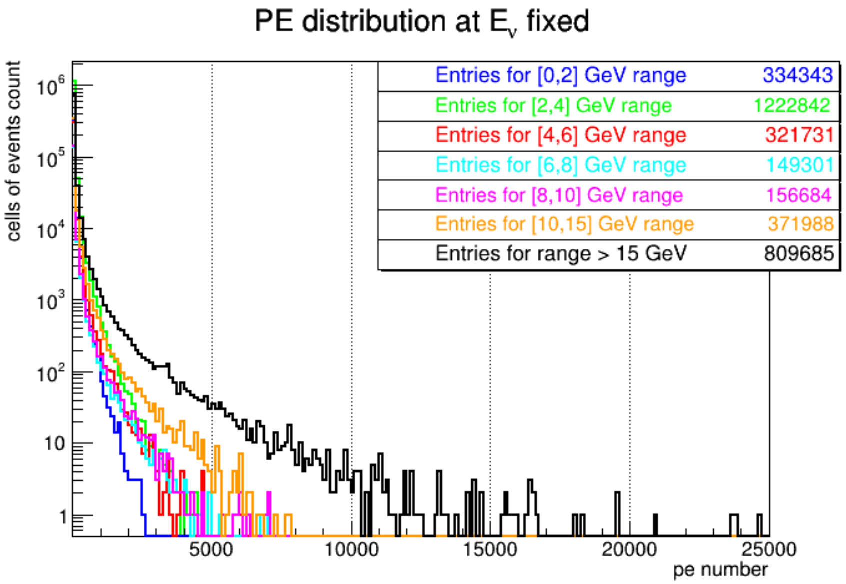
Events number	101,696
Events cells number	2,184,901

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	$2.11 \cdot 10^{-3}$

Np.e. distributions





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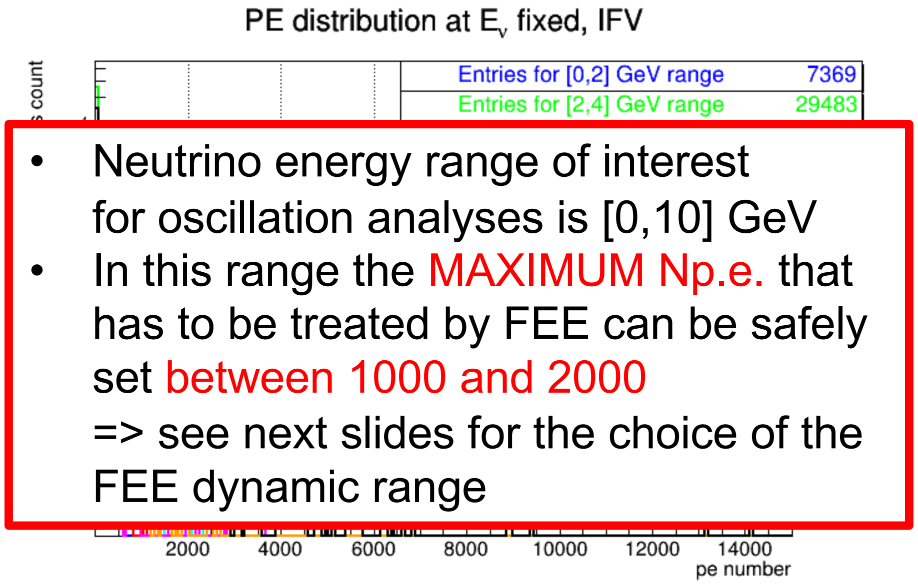
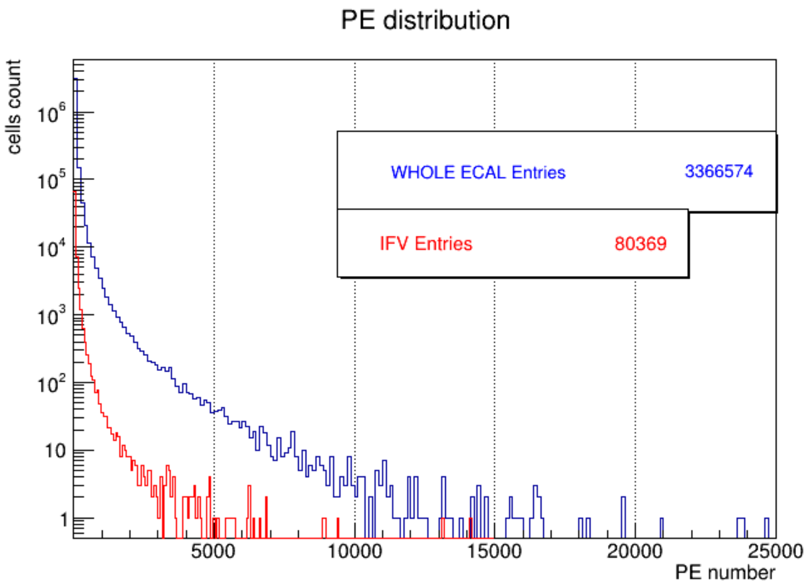
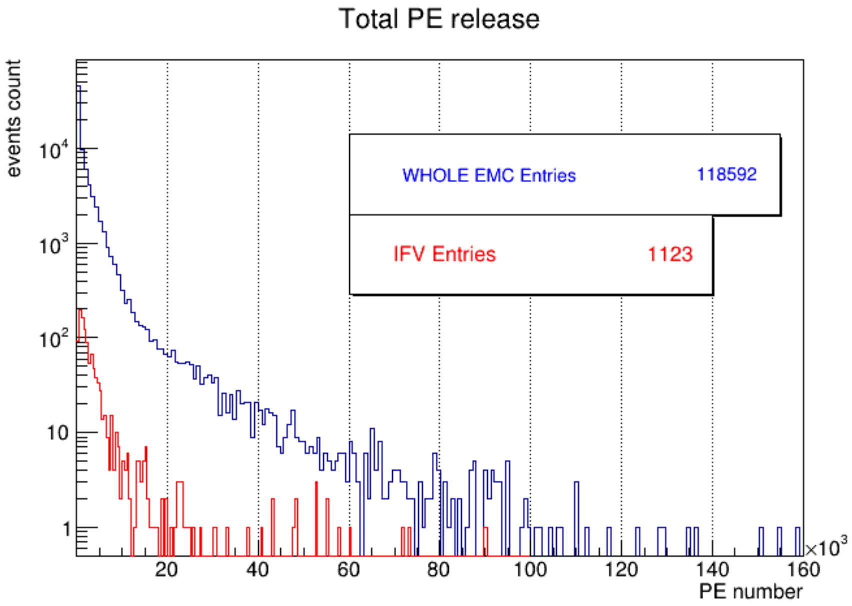
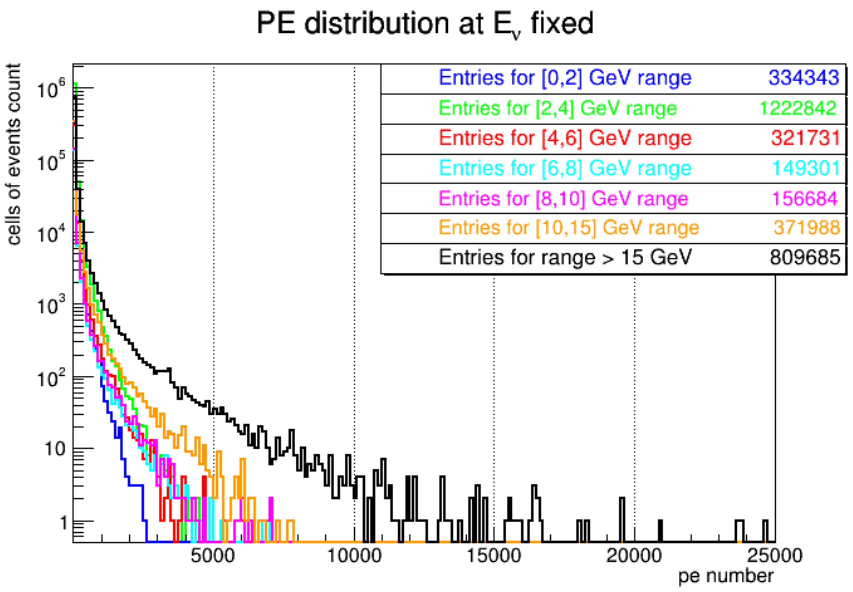


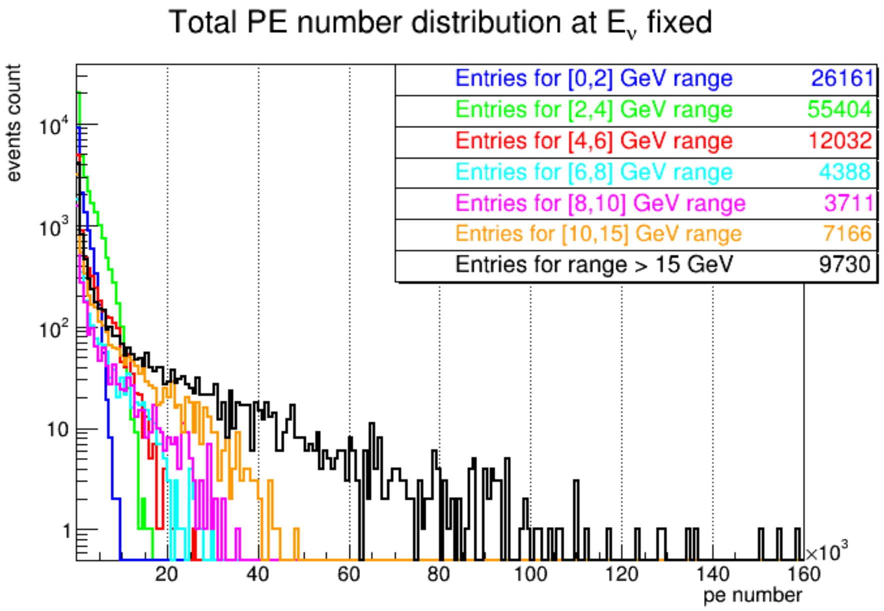
- Neutrino energy range of interest for oscillation analyses is [0,10] GeV
- In this range the MAXIMUM Np.e. that has to be treated by FEE can be safely set between 1000 and 2000
  => see next slides for the choice of the FEE dynamic range

Np.e. distributions

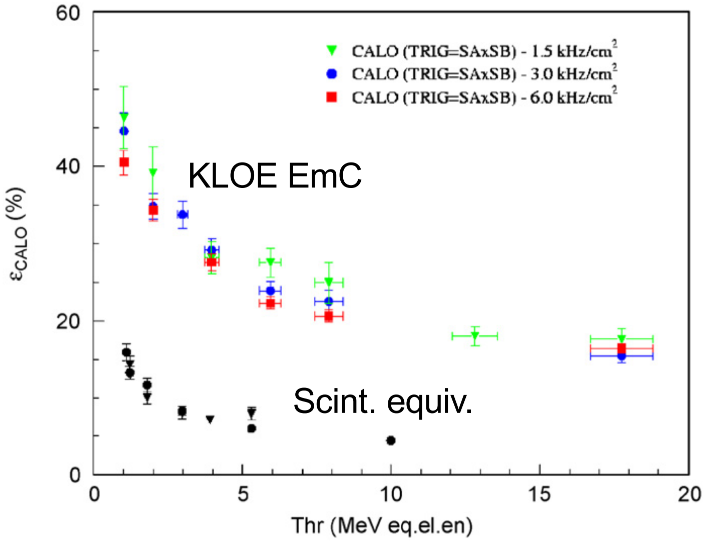

PE distribution


Total PE release


PE distribution at E_ν fixed


Total PE number distribution at E_ν fixed

Np.e. distributions

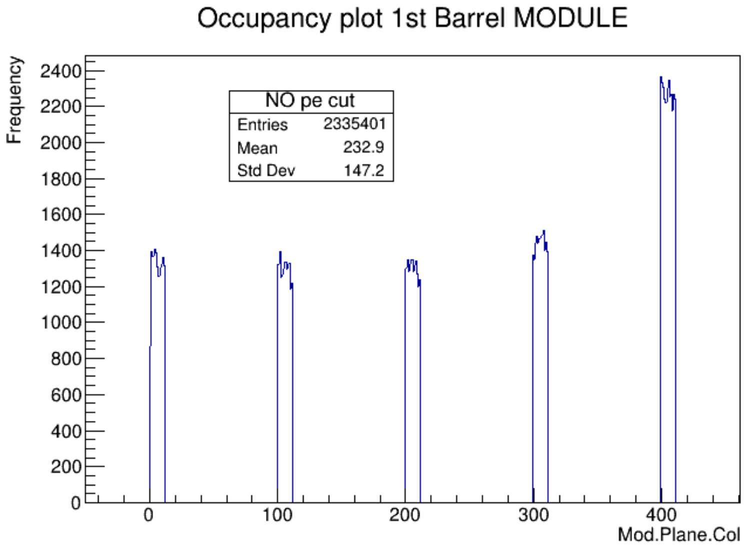


Measurement of the neutron response of the KLOE EmC

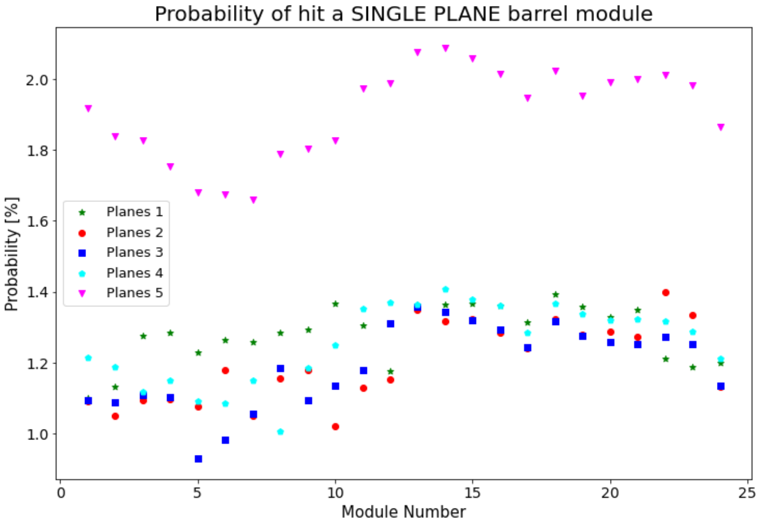
- M. Anelli et al., *"Measurement and simulation of the neutron response and detection efficiency of a Pb-scintillating fiber calorimeter "*, NIM **A581** (2007) 368
-
- M. Anelli et al., *"Measurement of the neutron detection efficiency of a 80% absorber–20% scintillating fibers calorimeter "*, NIM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

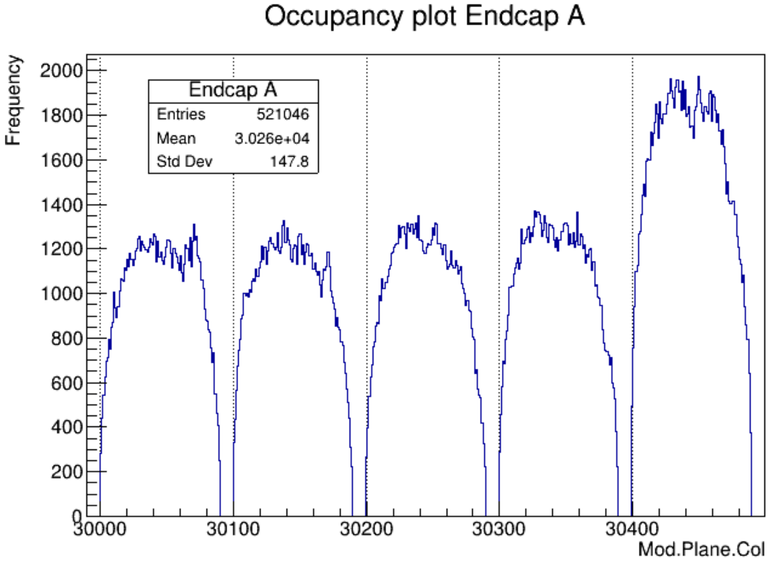
Cell occupancy plots and hit probability



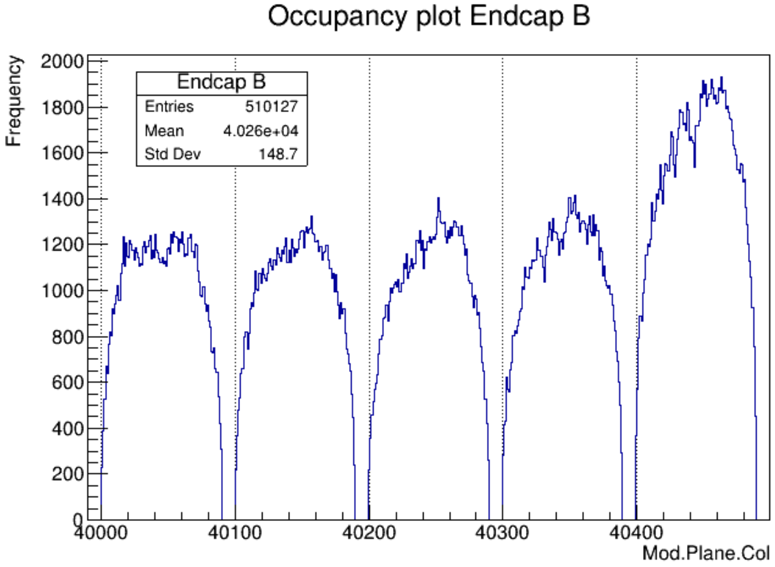
Barrel



Ecap A



Ecap B



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

P_{barrel} = 1.37%
P_{ecapA} = 0.88%
P_{ecapB} = 0.86%

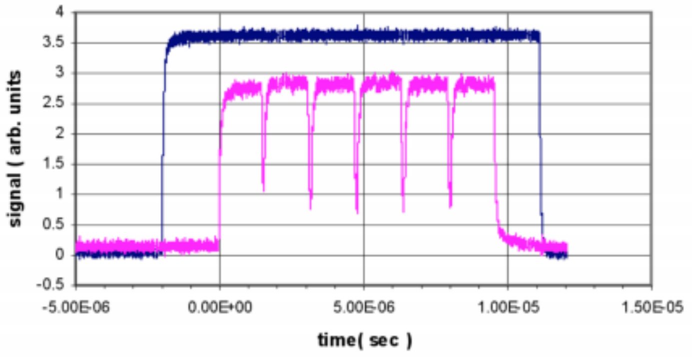
P_{cell} = 1.16%

Beam, spill structure, and event rates in SAND

Beam power 1.2 MW
7.5 x 10^{13} protons extracted every 1.2 s at 120 GeV
1.1 x 10^{21} pot/year

Spill time structure

- 9.6 μs per spill
- 6 batches, 84 bunches/batch
- 2 empty bunches
- 1 bunch: Gaus(σ = 1.5 ns)
- Δt bunches = 19 ns



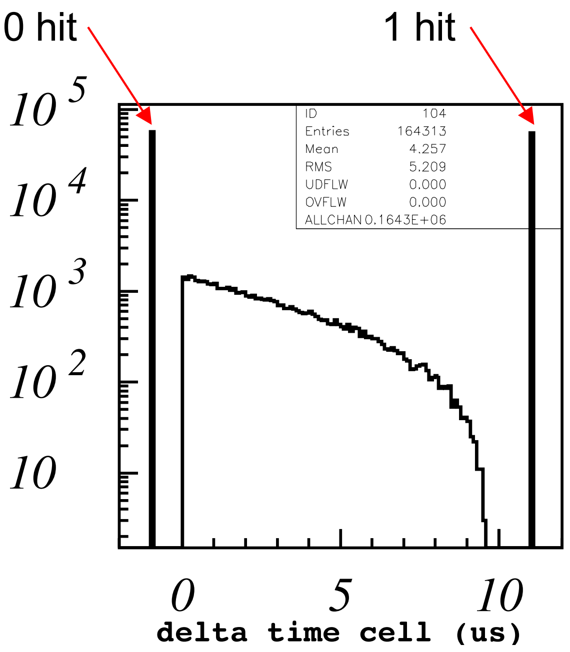
Event rates expected in SAND

~ 84 interactions/spill

≲1 interaction/spill in the SAND fiducial volume

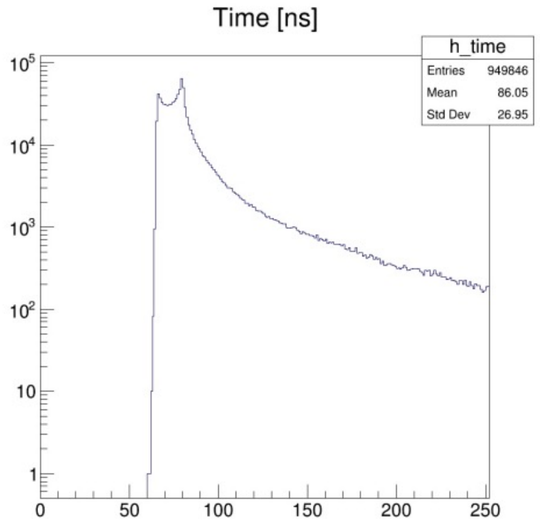
Pile-up probability

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 μs. 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_{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



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

Pile-up probability

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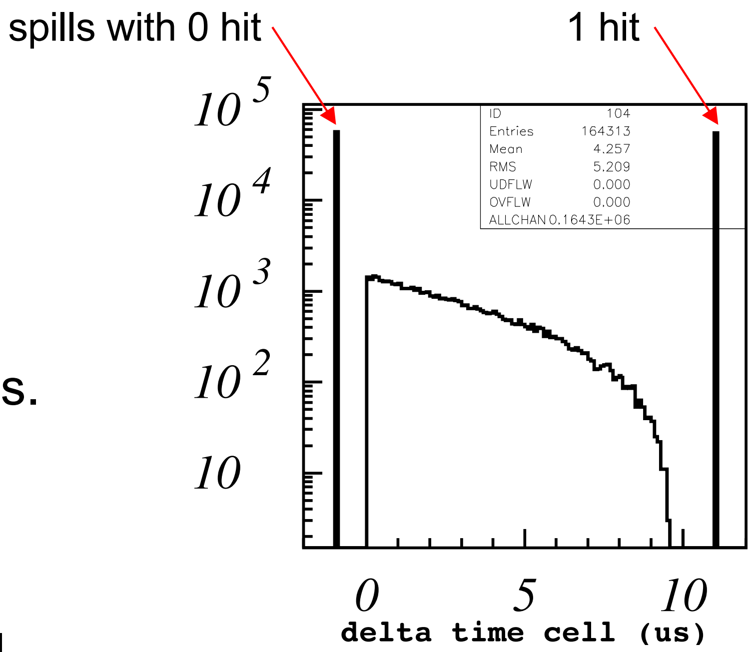
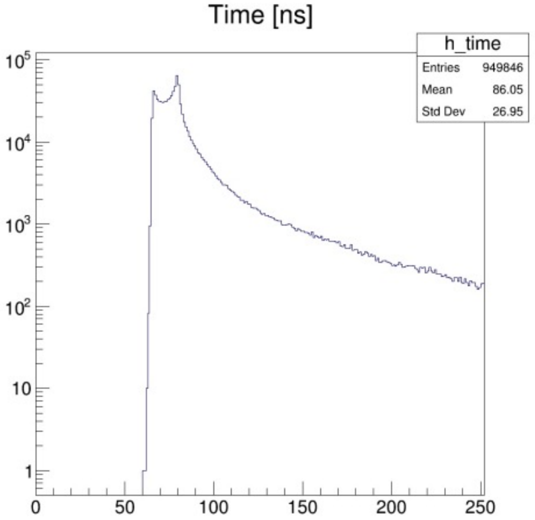




Time propagation/smearing of hits in a single neutrino interaction event.

PMT signal and discriminator threshold in KLOE

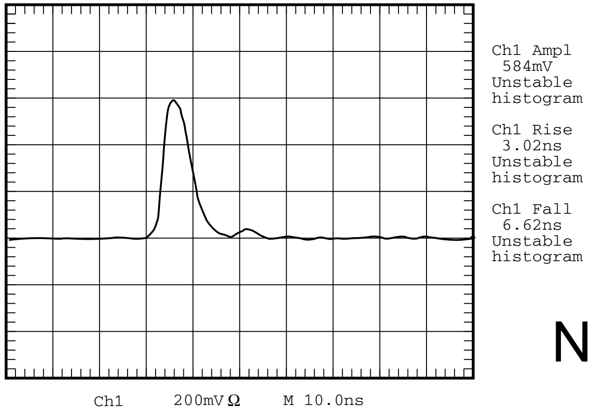
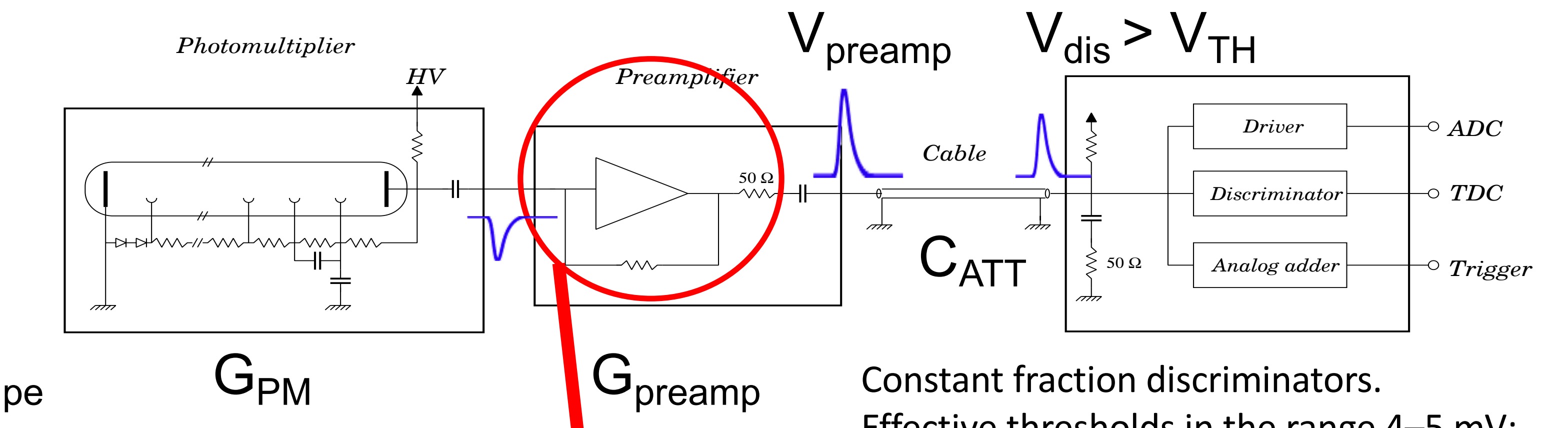
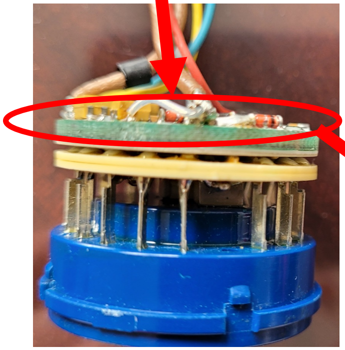


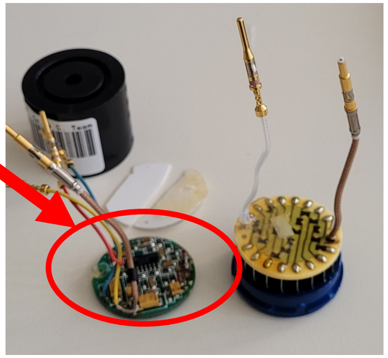
Figure 4: Typical signal from the PM base.

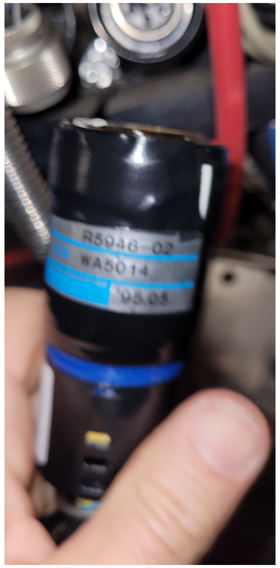


Constant fraction discriminators.
Effective thresholds in the range 4–5 mV:
correspond to signals originated
by 3–4 p.e. or a 3–4 MeV photon
at 2 m from PMT

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







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 mV**
- Preamplifier linearity (within 0.2%) range = [0, 4.7] V => V_{preamp}(max) = 4.7 V
- preamp transimpedance gain G= 250 V/A => I_{peak}(max)=19 mA => max signal charge Q(max)=133 pC (triangle approx.); from Q = e N_{pe} G_{PM} => (N_{pe} G_{PM})(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}(max) = V_{preamp}(max) • 0.5 • C_{ATT}= **1.74 V**
- signal ampl = V_{dis}(max)/N_{pe}(max)
- N_{pe}(min)=V_{TH}/(signal ampl) => N_{pe}(max)/N_{pe}(min) = V_{dis}(max)/V_{TH}

G_{PM} $(\times 10^5)$	G_{tot} $(\times 10^6)$	$N_{pe}(\max)$	signal amplitude (mV/pe)	$N_{pe}(\min)$ $V_{TH} = 5$ 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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- signal ampl = V_{dis}(max)/N_{pe}(max)
- N_{pe}(min)=V_{TH}/(signal ampl) => N_{pe}(max)/N_{pe}(min) = V_{dis}(max)/V_{TH}

G_{PM} ($\times10^5$)	G_{tot} ($\times10^6$)	N_{pe}(max)	signal amplitude (mV/pe)	N_{pe}(min) $V_{TH} = 5$ mV	MeV at module center
4.2	1.04	$\sim$ 2000	0.87	$\sim$ 6	6.0
5.5	1.38	$\sim$ 1500	1.16	$\sim$ 4	4.0
8.3	2.1	$\sim$ 1000	1.74	$\sim$ 3	3.0
10	2.5	$\sim$ 800	2.18	$\sim$ 2	2.0

KLOE choice →

Extending dynamic range in SAND

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

Measure	P1:area(C1)	P2:ampl(C1)	P3:delay(C1)	P4:area(C2)	P5:ampl(C2)	P6:delay(C2)	P7:---	P8:---
value	46.9877 nVs	3.538 V	27.602 ns	193.57 pVs	31 mV	0		
mean	18.62874 nVs	2.5356 V	28.22170 ns	179.0622 pVs	28.19 mV	—		
min	4.6581 nVs	935 mV	27.472 ns	87.51 pVs	22 mV	—		
max	48.4638 nVs	3.59 V	28.967 ns	259.88 pVs	40 mV	—		
sdev	12.42187 nVs	817.5 mV	264.18 ps	30.4737 pVs	3.58 mV	—		
num	518	518	518	519	519	0		
status	✓	✓	✓	✓	✗	⚠		
histo								

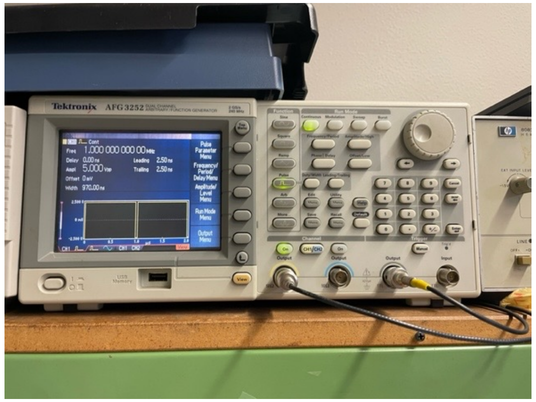
2.7 V

2.35 V

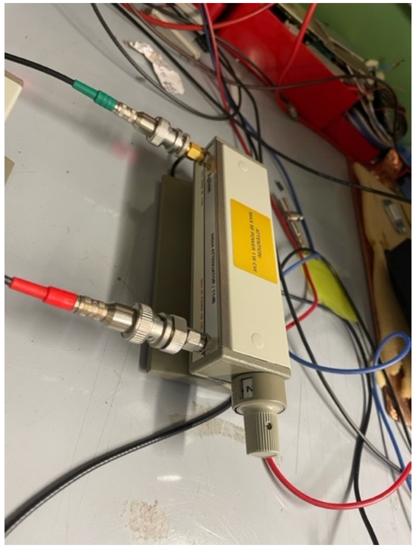
Preliminary considerations:
there is margin to increase the dynamic range by slightly releasing the stringent requirements for linearity in KLOE (e.g. from 0.2% to 1%) .
In fact, in the specific case of the above picture at the oscilloscope (negligible cable length C_{ATT} = 1) we expect linearity at **0.2%** level for V_{dis}(max) = V_{preamp}(max) • 0.5 = **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) • 0.5 = **2.7 V** **=> increase dynamic range**

Preamp linearity test (1) using pulse generator

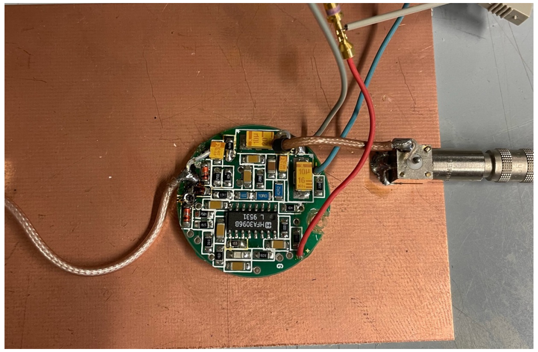
Test set-up



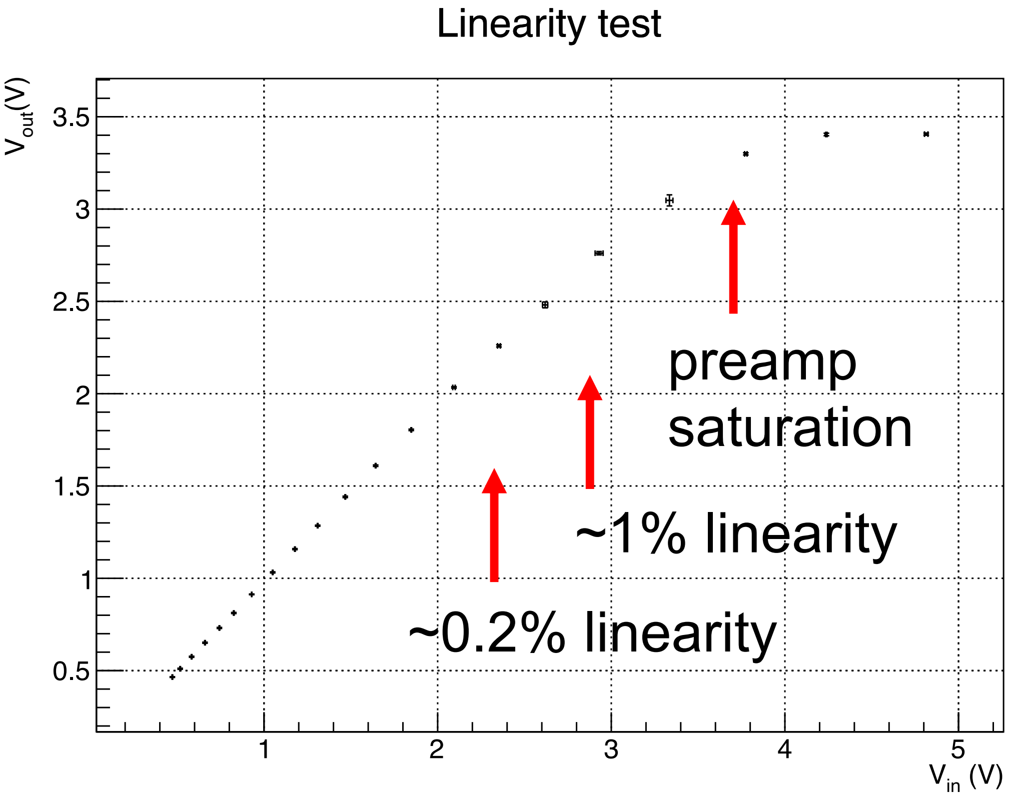
Signal amplitude varied
with calibrated attenuators
(pulse width ~ 30 ns)



Signal at a modified
test input: preamp
gain ~1



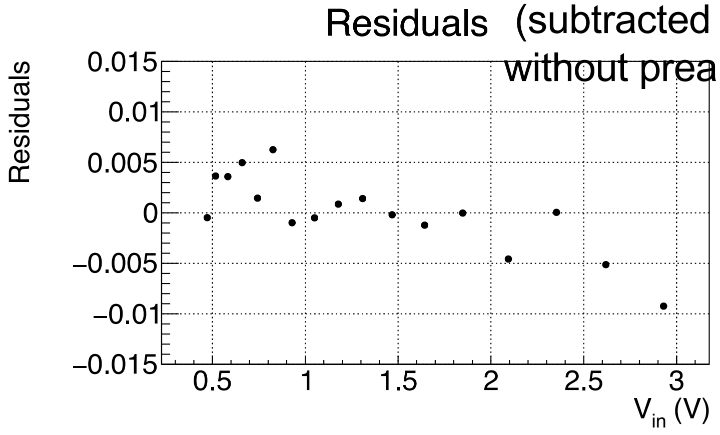
Preamp linearity test (1): linear and saturation regimes



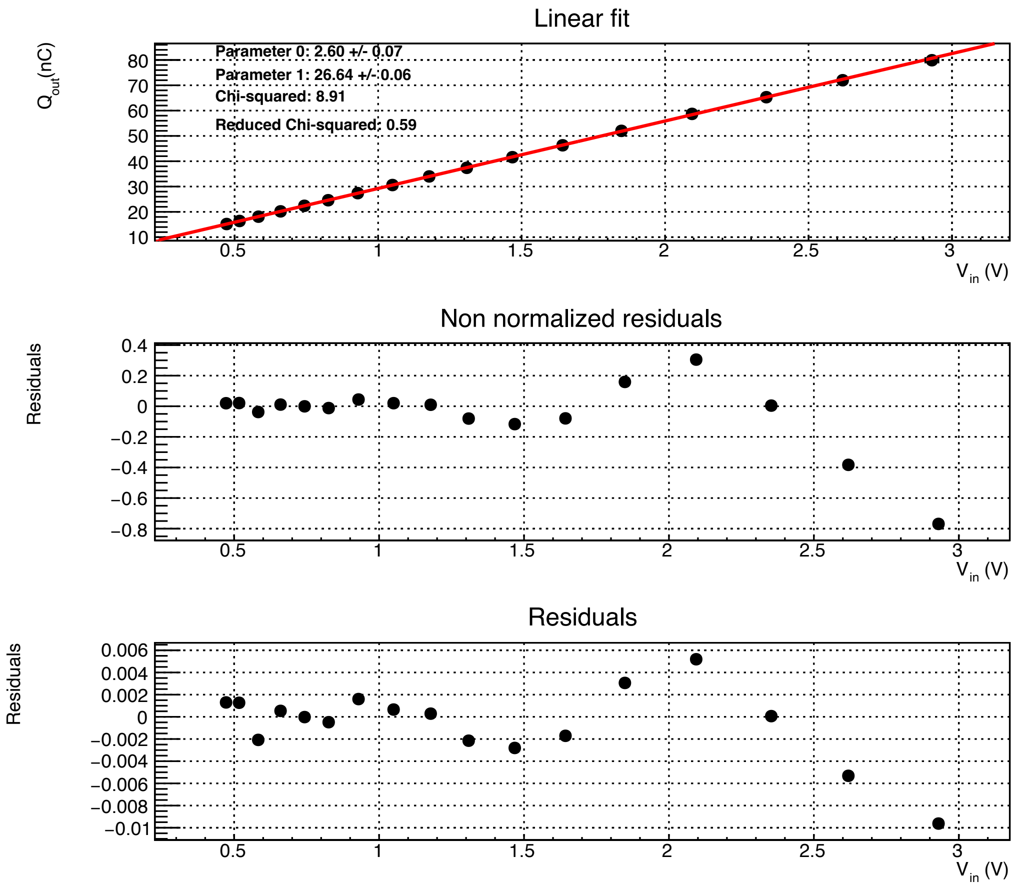
preamp saturation

~1% linearity

~0.2% linearity



(subtracted system response without preamp)



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:

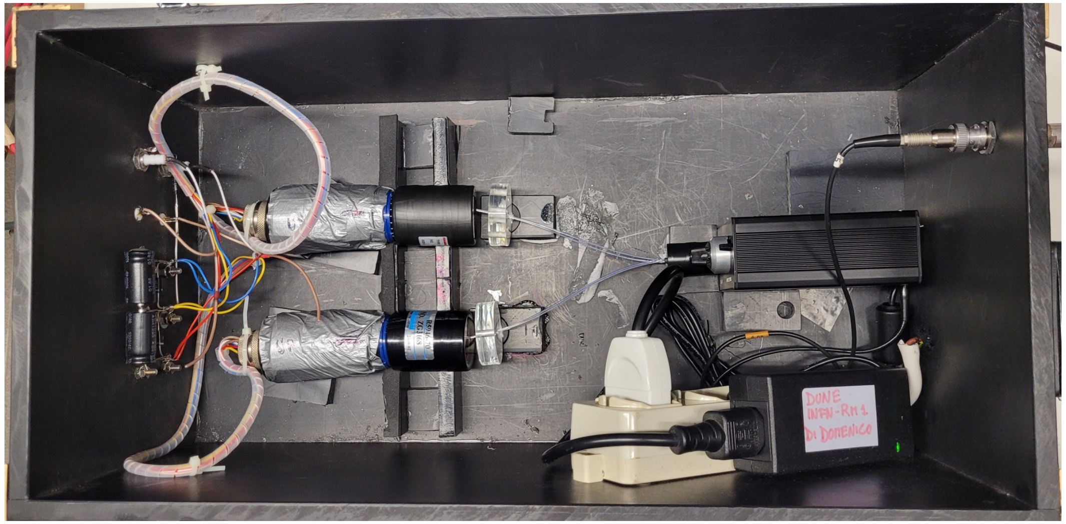
- to increase V_{preamp}(max) by 15% => V_{preamp}(max) = 5.4 V
  (linearity from 0.2% to 1%)
- (N_{pe} G_{PM})(max) = $95 \cdot 10^7$
- V_{dis}(max) = V_{preamp}(max) • 0.5 • C_{ATT}= 2.0 V (12m long cable attenuation: C_{ATT} = 0.74)
- to have a very low noise environment as in KLOE => lowering (halving)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

G_{PM} $(\times 10^5)$	G_{tot} $(\times 10^6)$	N_{pe}(max)	signal amplitude (mV/pe)	N_{pe}(min) $V_{TH} = 2.5$ 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

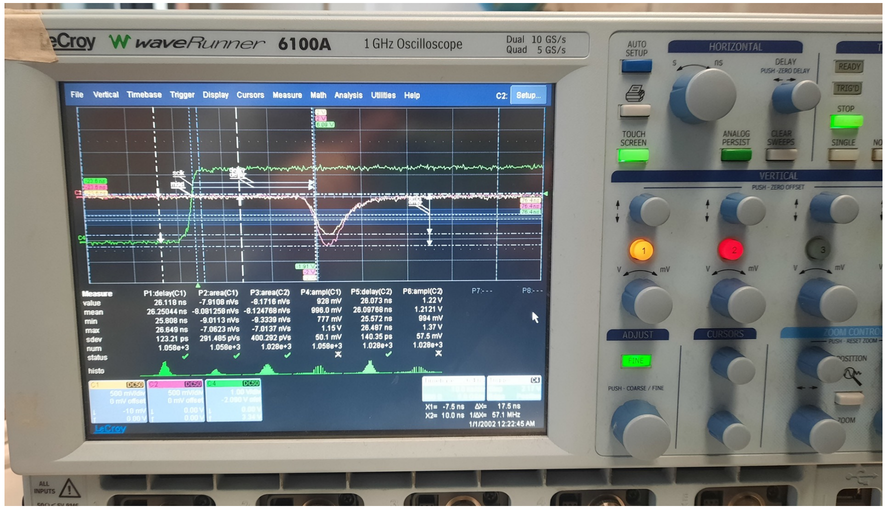
- Different dynamic ranges can be implemented changing G_{PM} =>
  the final choice should be a compromise between an affordable level of events with energy saturated cells, depending on N_{pe}(max), and an acceptable neutron detection efficiency, depending on N_{pe}(min).

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.)

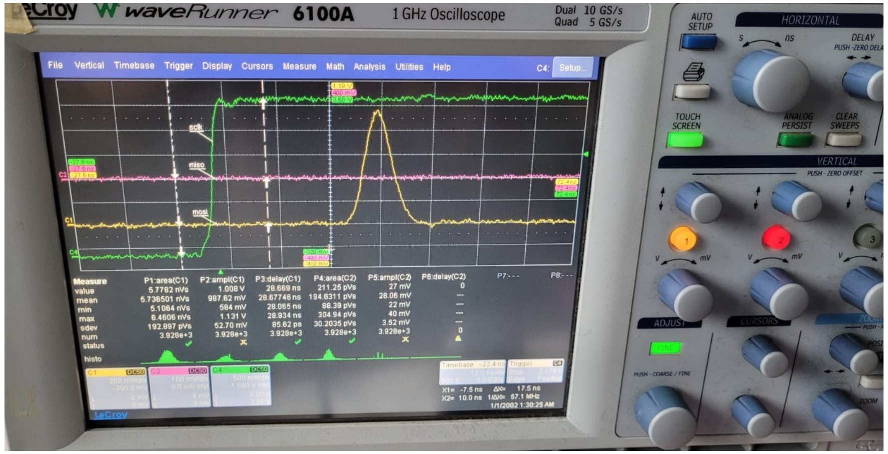


no preamplifier



Measure	P1:delay(C1)	P2:area(C1)	P3:area(C2)	P4:ampl(C1)	P5:delay(C2)	P6:ampl(C2)	P7:---	P8:---
value	26.118 ns	-7.9108 nVs	-8.1716 nVs	928 mV	26.073 ns	1.22 V		
mean	26.25044 ns	-8.081258 nVs	-8.124768 nVs	996.0 mV	26.09768 ns	1.2121 V		
min	25.808 ns	-9.0113 nVs	-9.3339 nVs	777 mV	25.572 ns	994 mV		
max	26.649 ns	-7.0623 nVs	-7.0137 nVs	1.15 V	26.487 ns	1.37 V		
sdev	123.21 ps	291.485 pVs	400.292 pVs	50.1 mV	140.35 ps	57.5 mV		
num	1.058e+3	1.058e+3	1.028e+3	1.058e+3	1.028e+3	1.028e+3		
status	✓	✓	✓	✗	✓	✗		

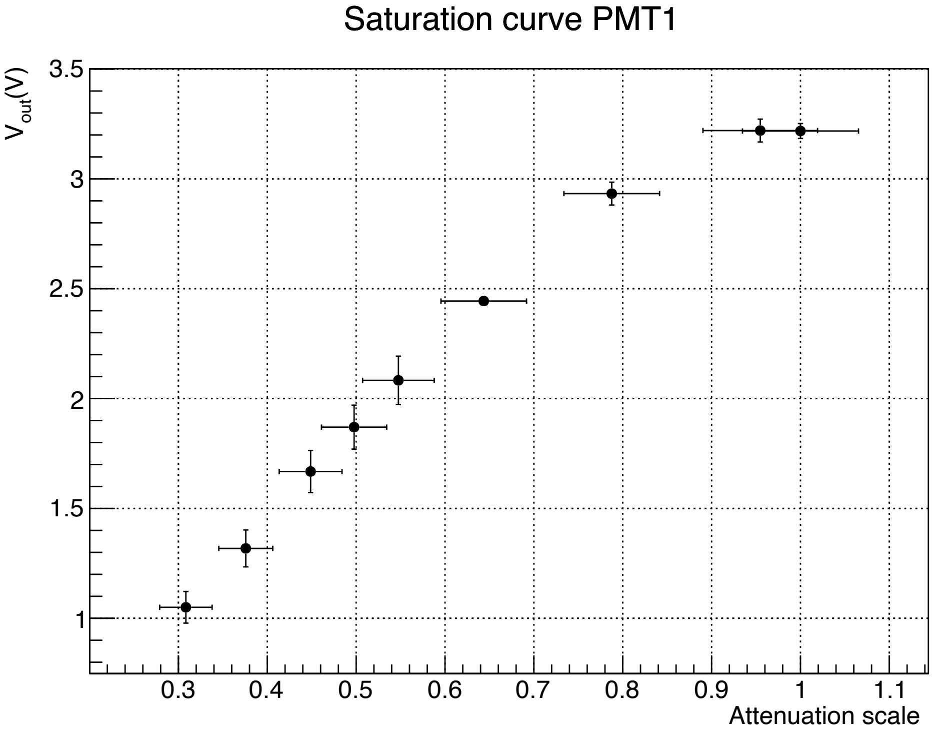
with preamplifier

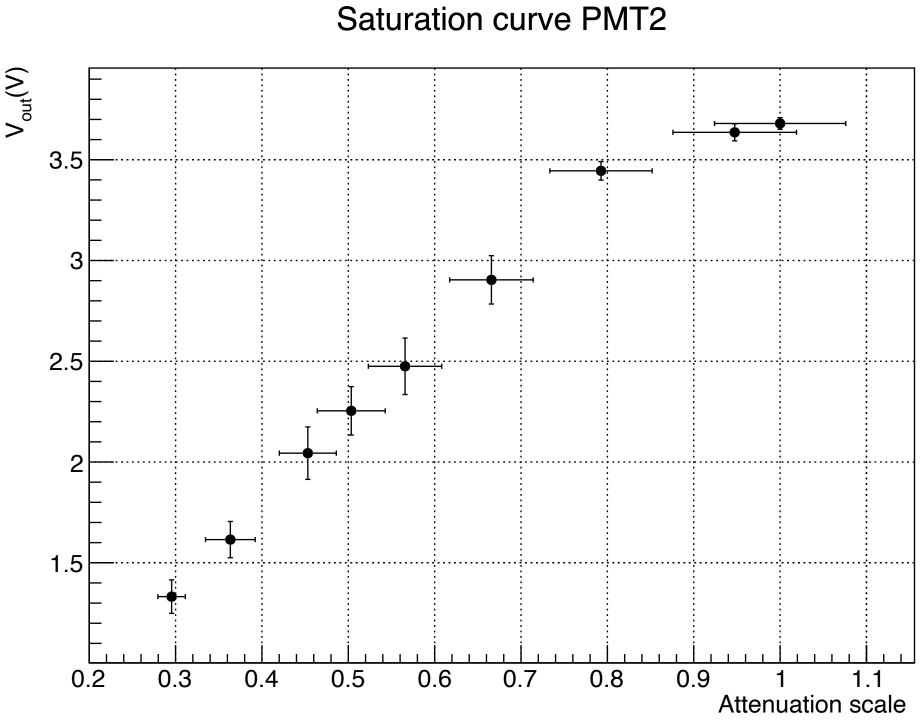


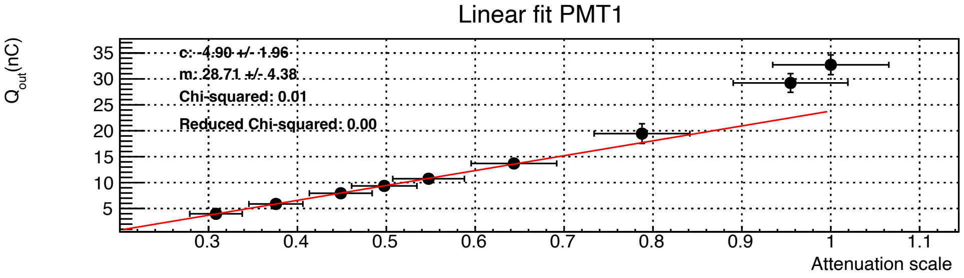
Measure	P1:area(C1)	P2:ampl(C1)	P3:delay(C1)	P4:area(C2)	P5:ampl(C2)	P6:delay(C2)	P7:---	P8:---
value	5.7782 nVs	1.008 V	28.669 ns	211.25 pVs	27 mV	0		
mean	5.736501 nVs	987.62 mV	28.67746 ns	194.6311 pVs	28.06 mV	---		
min	5.1064 nVs	584 mV	28.065 ns	88.39 pVs	22 mV	---		
max	6.4606 nVs	1.131 V	28.934 ns	304.94 pVs	40 mV	---		
sdev	192.897 pVs	52.70 mV	85.62 ps	30.2035 pVs	3.52 mV	---		
num	3.928e+3	3.928e+3	3.928e+3	3.928e+3	3.928e+3	0		
status	✓	✗	✓	✓	✗	⚠		

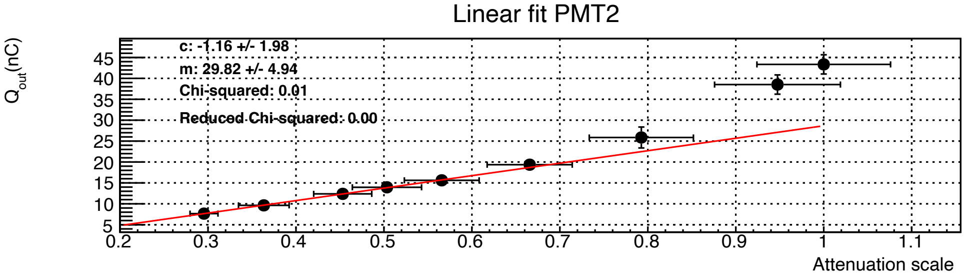
Preamp linearity test (2): results (i)

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









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

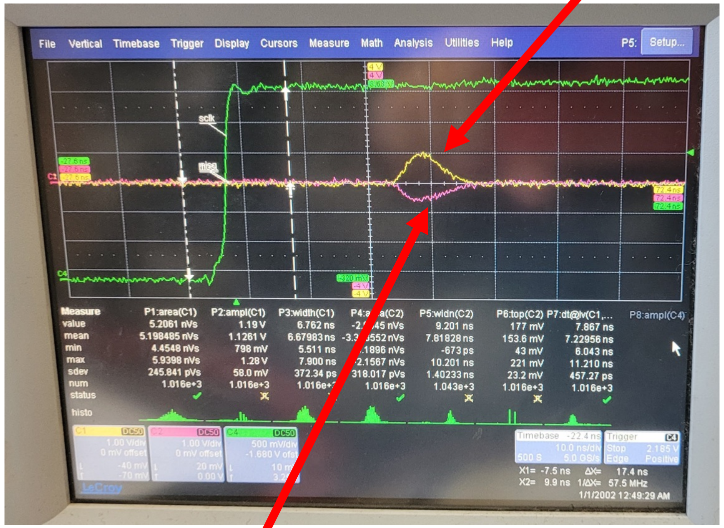
PMT2 HV=1700 V

REF PMT1

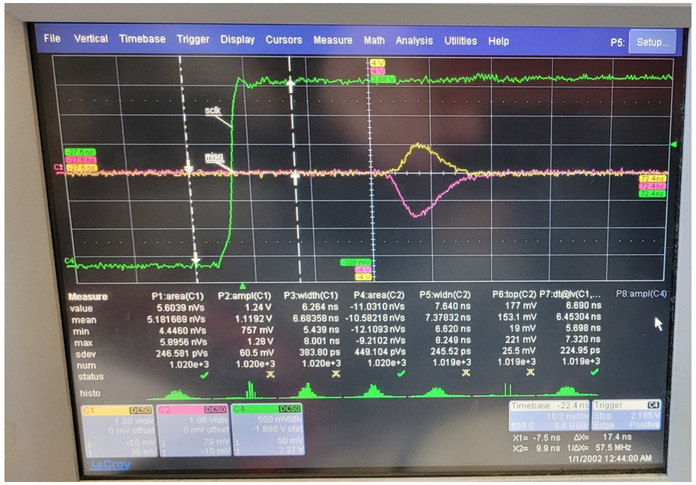
HV=1900 V

fixed LED
intensity (full)

HV=2100 V



Measure	P1:area(C1)	P2:ampl(C1)	P3:width(C1)	P4:area(C2)	P5:widn(C2)	P6:top(C2)	P7:dt@lv(C1,...	P8:ampl(C4)
value	5.2061 nVs	1.19 V	6.762 ns	[illegible]	9.201 ns	177 mV	7.867 ns	
mean	5.198485 nVs	1.1261 V	6.67983 ns	[illegible]	7.81828 ns	153.6 mV	7.22956 ns	
min	4.4548 nVs	798 mV	5.511 ns	[illegible]	-673 ps	43 mV	6.043 ns	
max	5.9398 nVs	1.28 V	7.900 ns	[illegible]	10.201 ns	221 mV	11.210 ns	
sdev	245.841 pVs	58.0 mV	372.34 ps	318.017 pVs	1.40233 ns	23.2 mV	457.27 ps	
num	1.016e+3	1.016e+3	1.016e+	1.016e+3	1.043e+3	1.016e+3	1.016e+3	
status	✓	✗		✓	✗	✗	✓	
histo								



Measure	P1:area(C1)	P2:ampl(C1)	P3:width(C1)	P4:area(C2)	P5:widn(C2)	P6:top(C2)	P7:dt@lv(C1,...	P8:ampl(C4)
value	5.6039 nVs	1.24 V	6.264 ns	-11.0310 nVs	7.640 ns	177 mV	6.690 ns	
mean	5.181669 nVs	1.1192 V	6.68358 ns	-10.58218 nVs	7.37832 ns	153.1 mV	6.45304 ns	
min	4.4460 nVs	757 mV	5.439 ns	-12.1093 nVs	6.620 ns	19 mV	5.698 ns	
max	5.8956 nVs	1.28 V	8.001 ns	-9.2102 nVs	8.249 ns	221 mV	7.320 ns	
sdev	246.581 pVs	60.5 mV	383.80 ps	449.104 pVs	245.52 ps	25.5 mV	224.95 ps	
num	1.020e+3	1.020e+3	1.020e+3	1.020e+3	1.019e+3	1.019e+3	1.019e+3	
status	✓	✗	✗	✓	✗	✗	✓	
histo								

Measure	P1:area(C1)	P2:ampl(C1)	P3:width(C1)	P4:area(C2)	P5:widn(C2)	P6:top(C2)	P7:dt@lv(C1,...	P8:ampl(C4)
value	5.0293 nVs	863 mV	6.713 ns	-25.0672 nVs	7.222 ns	133 mV	5.793 ns	
mean	5.345805 nVs	1.1419 V	6.66539 ns	-25.73820 nVs	7.23661 ns	147.1 mV	5.99559 ns	
min	4.3753 nVs	730 mV	5.600 ns	-28.4348 nVs	6.782 ns	23 mV	5.441 ns	
max	6.1077 nVs	1.33 V	7.915 ns	-23.6971 nVs	7.658 ns	221 mV	6.556 ns	
sdev	249.343 pVs	63.1 mV	357.36 ps	813.913 pVs	137.71 ps	34.2 mV	183.04 ps	
num	1.066e+3	1.066e+3	1.066e+3	1.066e+3	1.066e+3	1.066e+3	1.066e+3	
status	✓	✓	✗	✓	✗	✗	✓	
histo								

no preamp PMT2

with preamp PMT2

preamp recovery time from saturation
depends on input amplitude signal

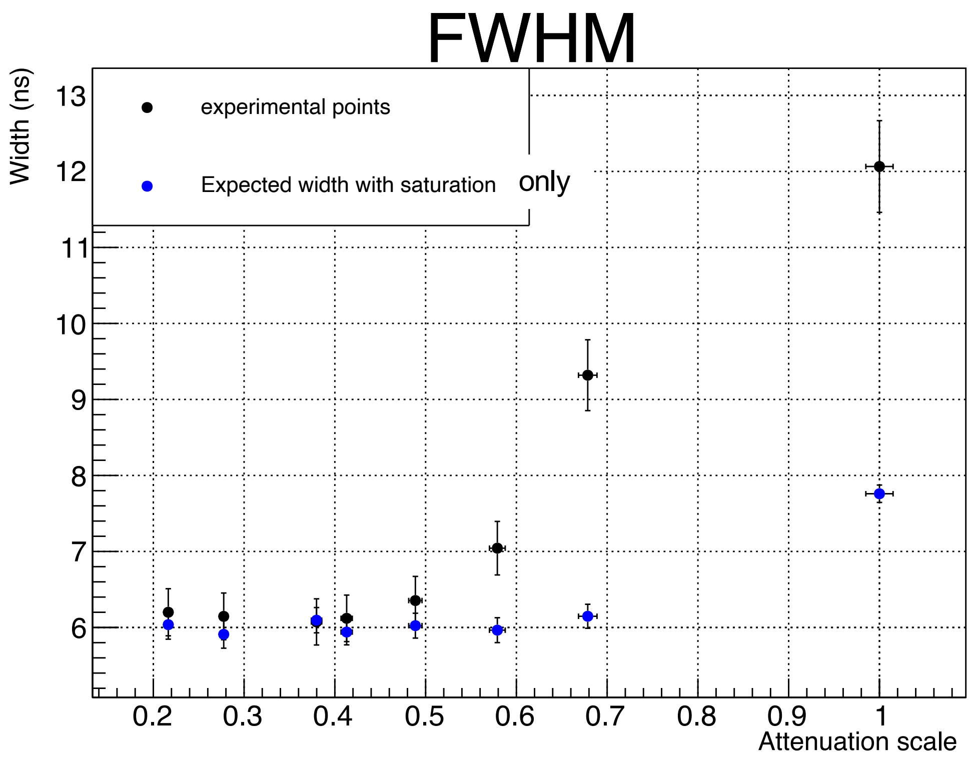
Measure	P1:area(C1)	P2:ampl(C1)	P3:width(C1)	P4:area(C2)	P5:ampl(C2)	P6:width(C2)	P7:dt@lv(C1,...	P8:ampl(C4)
value	5.5155 nVs	1.19 V	6.543 ns	14.7875 nVs	2.34 V	6.141 ns	575 ps	
mean	5.812773 nVs	1.2240 V	6.64347 ns	14.72286 nVs	2.2540 V	6.29800 ns	320.40 ps	
min	4.9321 nVs	772 mV	5.740 ns	13.0551 nVs	1.50 V	5.694 ns	-157 ps	
max	6.5762 nVs	1.37 V	7.854 ns	16.3078 nVs	2.47 V	7.381 ns	807 ps	
sdev	257.201 pVs	61.4 mV	325.10 ps	492.065 pVs	101.0 mV	177.02 ps	154.73 ps	
num	1.079e+3	1.079e+3	1.079e+3	1.079e+3	1.079e+3	1.079e+3	1.079e+3	
status	✓	✗	✗	✓	✗	✗	✓	
histo								

Measure	P1:area(C1)	P2:ampl(C1)	P3:width(C1)	P4:area(C2)	P5:ampl(C2)	P6:width(C2)	P7:dt@lv(C1,...	P8:ampl(C4)
value	5.2768 nVs	1.24 V	6.496 ns	58.0805 nVs	3.775 V	15.120 ns	-580 ps	
mean	4.996806 nVs	1.1211 V	6.64179 ns	54.81949 nVs	3.73530 V	14.47719 ns	-571.02 ps	
min	4.1189 nVs	596 mV	5.379 ns	47.6506 nVs	3.653 V	12.802 ns	-1.192 ns	
max	5.9132 nVs	1.33 V	8.000 ns	61.7840 nVs	3.802 V	16.202 ns	-145 ps	
sdev	257.101 pVs	66.4 mV	373.82 ps	2.320707 nVs	23.69 mV	557.52 ps	159.19 ps	
num	1.064e+3	1.064e+3	1.064e+3	1.064e+3	1.064e+3	1.064e+3	1.064e+3	
status	✓	✗	✗	✓	✓	✓	✓	
histo								

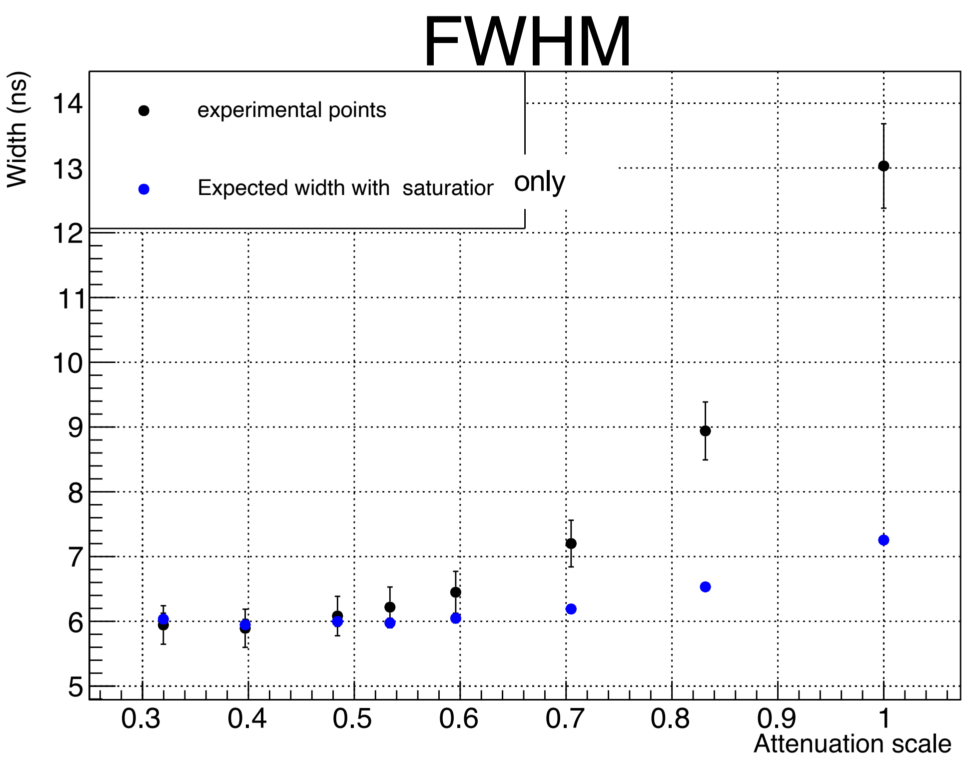
Measure	P1:area(C1)	P2:ampl(C1)	P3:width(C1)	P4:area(C2)	P5:ampl(C2)	P6:width(C2)	P7:dt@lv(C1,...	P8:ampl(C4)
value	5.3652 nVs	1.19 V	6.770 ns	111.7505 nVs	3.944 V	28.143 ns	-1.657 ns	
mean	5.797903 nVs	1.2149 V	6.64817 ns	109.2025 nVs	3.90436 V	27.44828 ns	-1.65764 ns	
min	4.8879 nVs	948 mV	5.600 ns	104.0694 nVs	3.848 V	26.155 ns	-2.110 ns	
max	6.5673 nVs	1.37 V	8.200 ns	115.3302 nVs	3.953 V	28.699 ns	-1.280 ns	
sdev	246.325 pVs	61.0 mV	334.60 ps	1.753481 nVs	16.26 mV	422.72 ps	139.94 ps	
num	537	536	536	536	536	536	536	
status	✓	✗	✗	✓	✓	✓	✓	
histo								

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

PMT1



PMT2



- The time baseline is distorted during saturation. The recovery time from saturation to linear regime depends on the input signal amplitude.

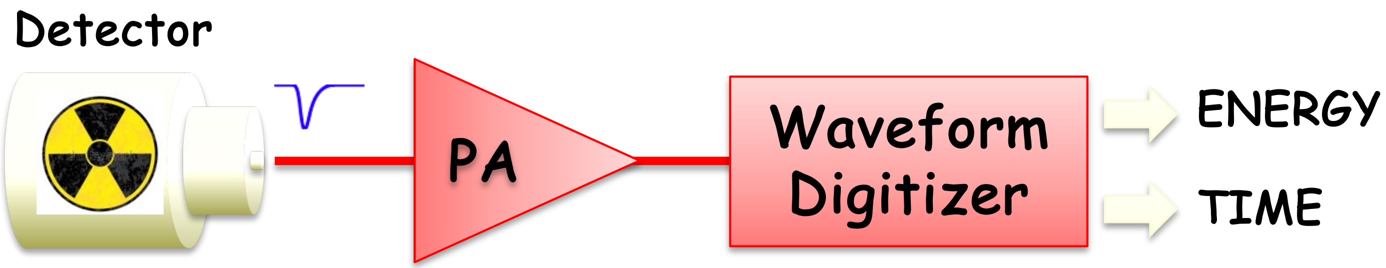
- The input information is not fully lost during the saturation regime. The "over-linearity" of the integrated charge, or the signal width increase vs the input signal amplitude could be exploited to characterize signals beyond the preamp saturation regime.

Studies and tests for FEE choice in collaboration with CAEN

A. Di Domenico, V. Di Silvestre - INFN-RM1
C. Tintori, C. Maggio, L. Colombini – CAEN, Viareggio

Choice of FEE for SAND/ECAL

Three possible read-out schemes:



Detector

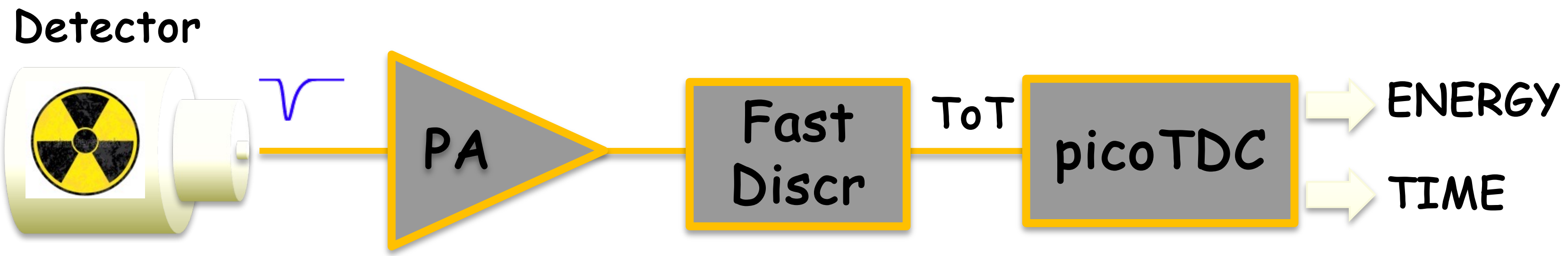
PA

Waveform Digitizer

ENERGY

TIME

Highest Flexibility
=>
Fsampl ~ 1 GS/s =>High Cost or
Fsampl ~ 125-250 MS/s
+ signal shaper



Detector

PA

Fast Discr

ToT

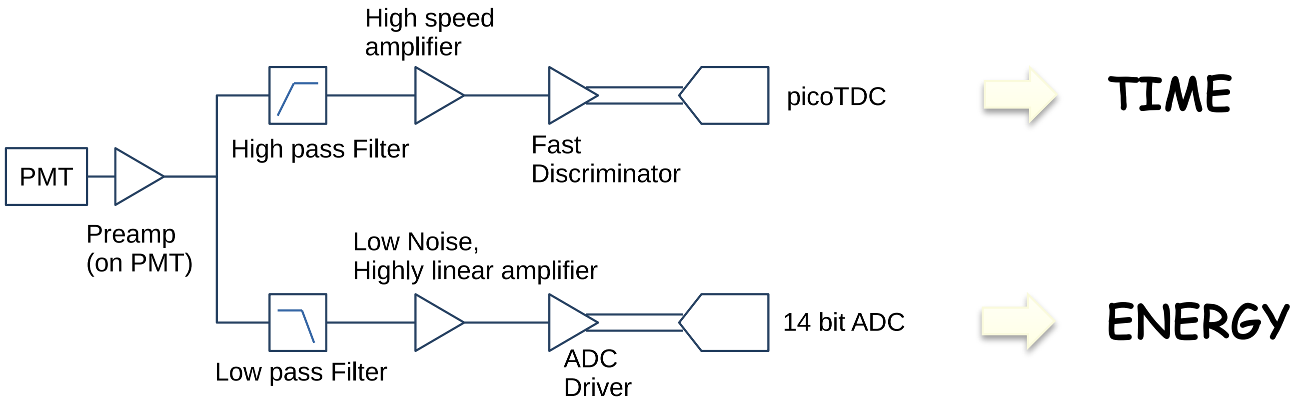
picoTDC

ENERGY

TIME

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

a more conventional approach



PMT

Preamp
(on PMT)

High pass Filter

High speed
amplifier

Fast
Discriminator

picoTDC

TIME

Low pass Filter

Low Noise,
Highly linear amplifier

ADC
Driver

14 bit ADC

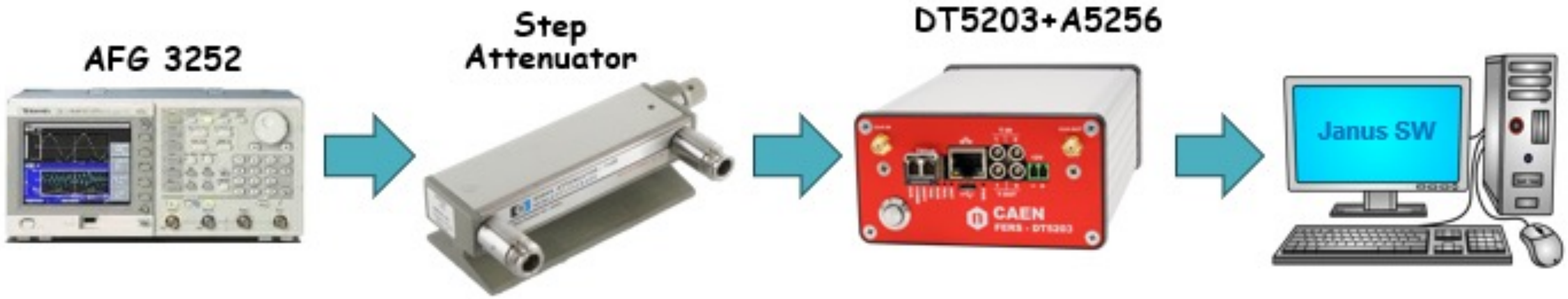
ENERGY

CAEN:

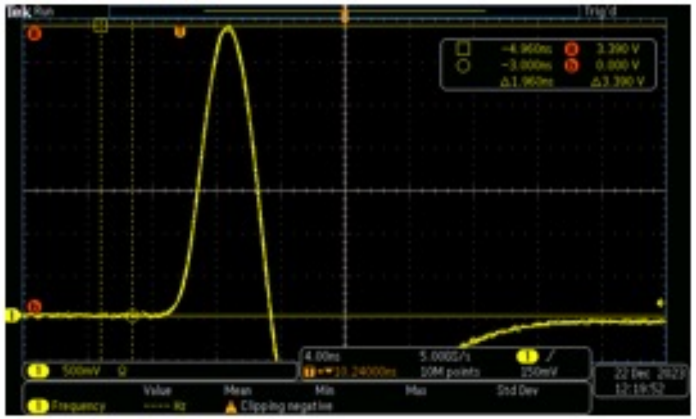
collaboration for a commercial (partly customized) solution keeping KLOE energy and time performance

Pico TDC test I (CAEN)

Test setup:



Pulse: Amp = 3.85 V, Rise = ~2.5 ns



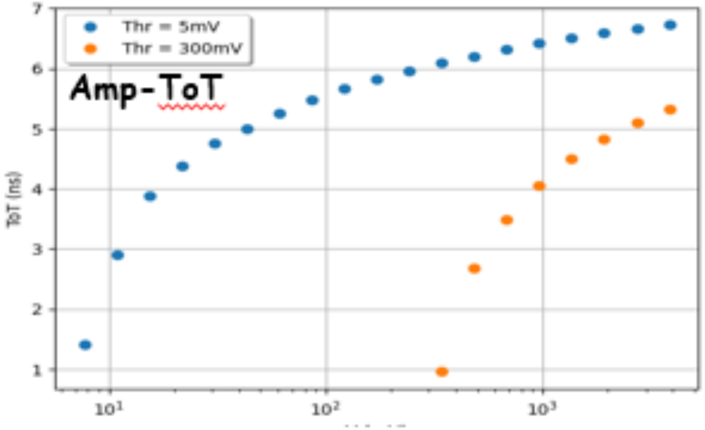
- Start on Ch0 with fixed amplitude. Stop on Ch1 and Ch2 (dual threshold) with variable amplitude (max = 3.85 V). Delay = 13 ns.
- Acquire **ToT** (ToT= Time Over Threshold) and **ΔT** (ΔT = walk) at different amplitudes (from 0 to 52 dB, 3 dB step)
- Fit points and build **ToT-Walk** and **ToT-Ampl** curves
- Use curves to correct Walk from ToT (replace CFD)
- Use curves to get Amplitude from ToT (make ADC from TDC)

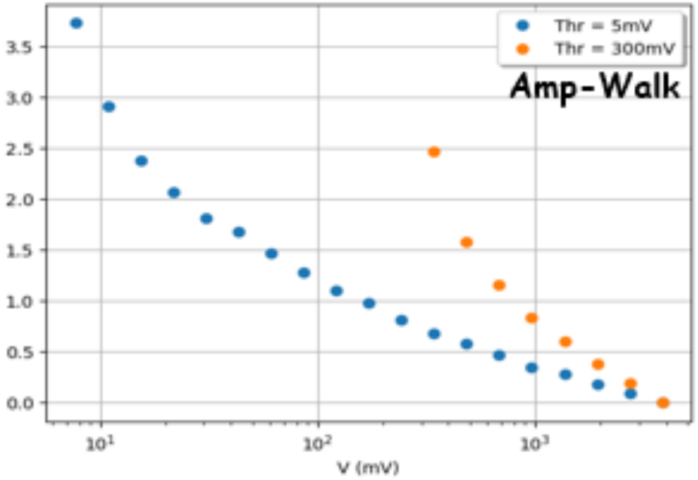
Pico TDC test I (CAEN)

Calibration Curves:

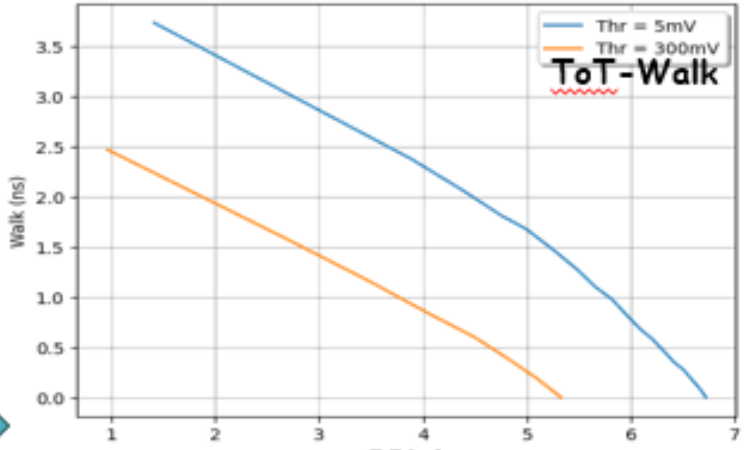
Low threshold: 5mV

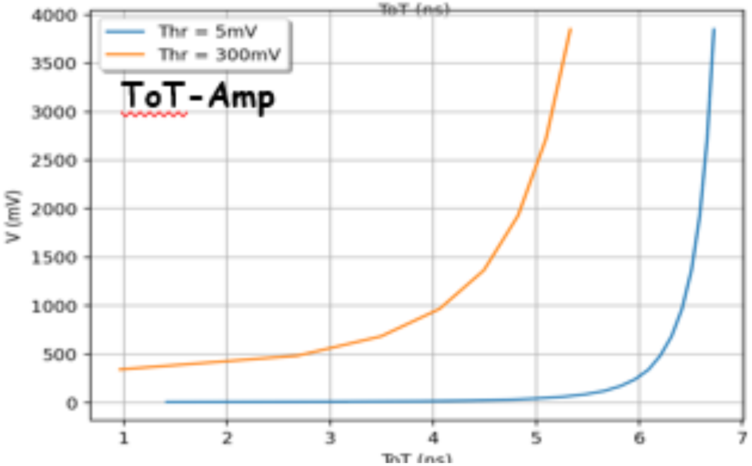
High threshold: 300mV





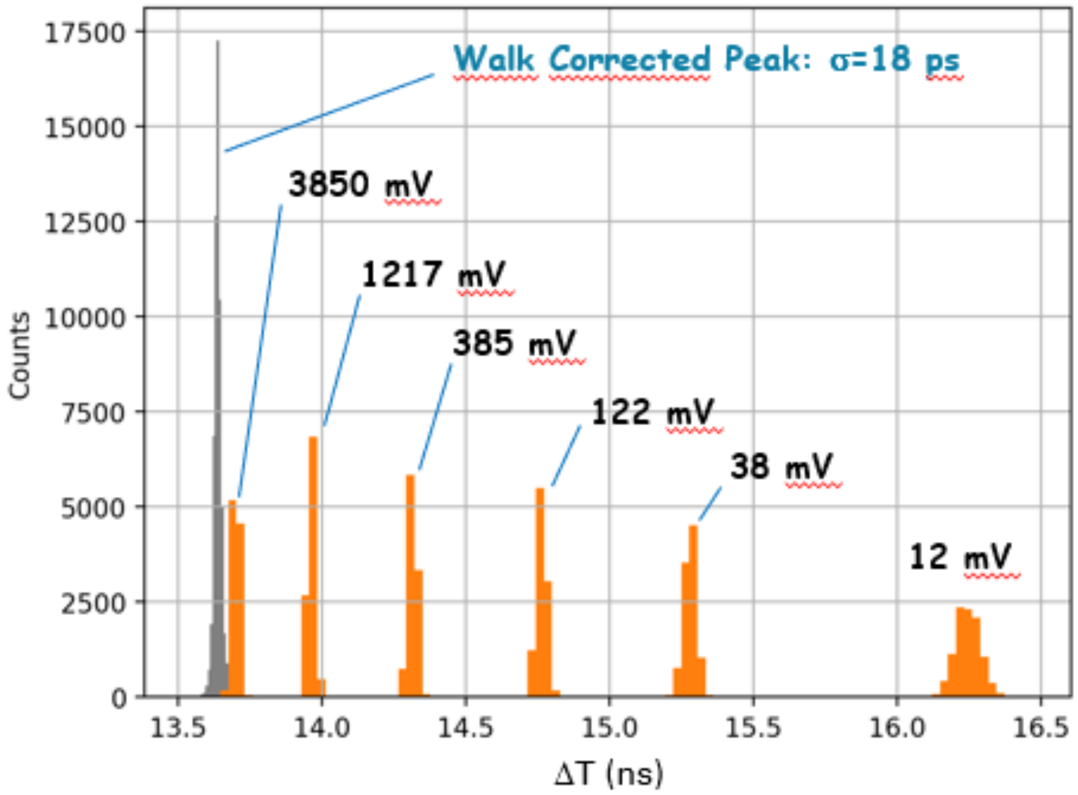
Poly-Fit





Pico TDC test I (CAEN)

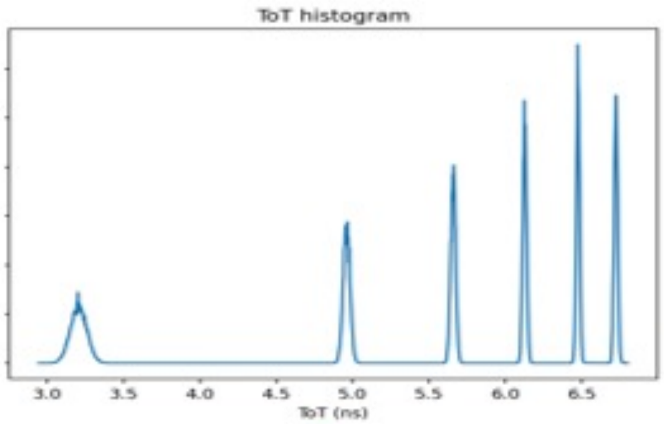
Time Reconstruction (using ToT-Walk correction)

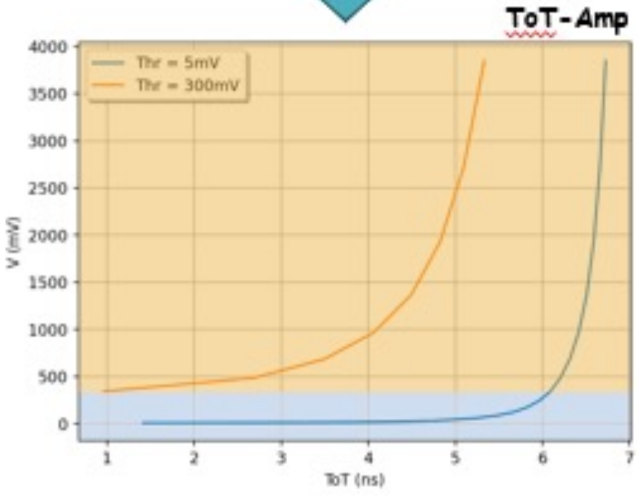


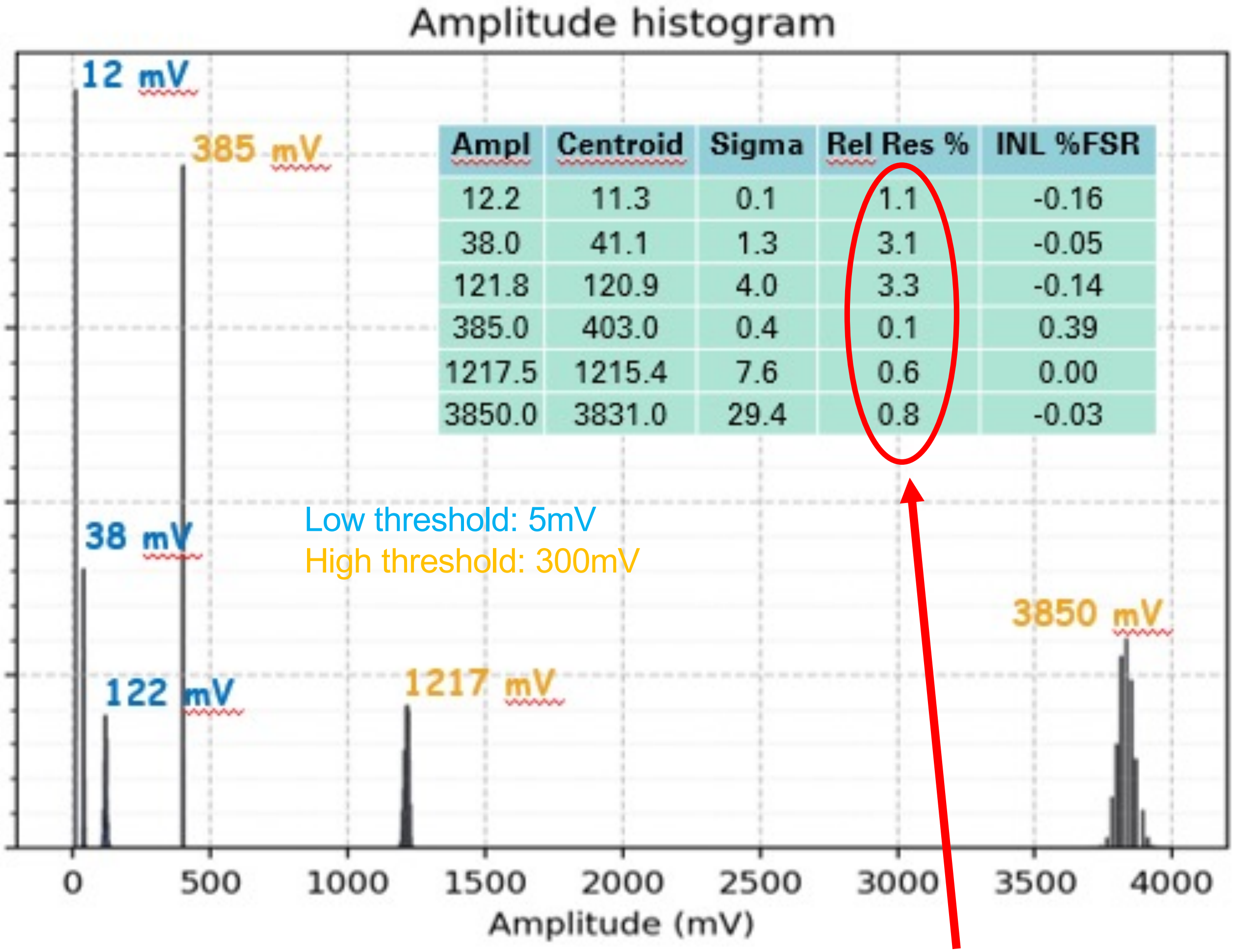
- Acquired pulses at 6 different amplitudes over a 50 dB dynamic range, the walk causes ~2 ns spread on ΔT: 6 separate peaks appear on the histogram
  (sample independent from calibration sample)
- ΔT corrected by ToT using calibration data with a 5th order polynomial fit of the **ToT-Walk** points taken at lower threshold (5 mV)
- Corrected ΔT histogram presents one single peak:
- **Time resolution ~18 ps**
  over 50 dB dynamic range

Pico TDC test I (CAEN)

Amplitude Reconstruction (using ToT-Amp correction)







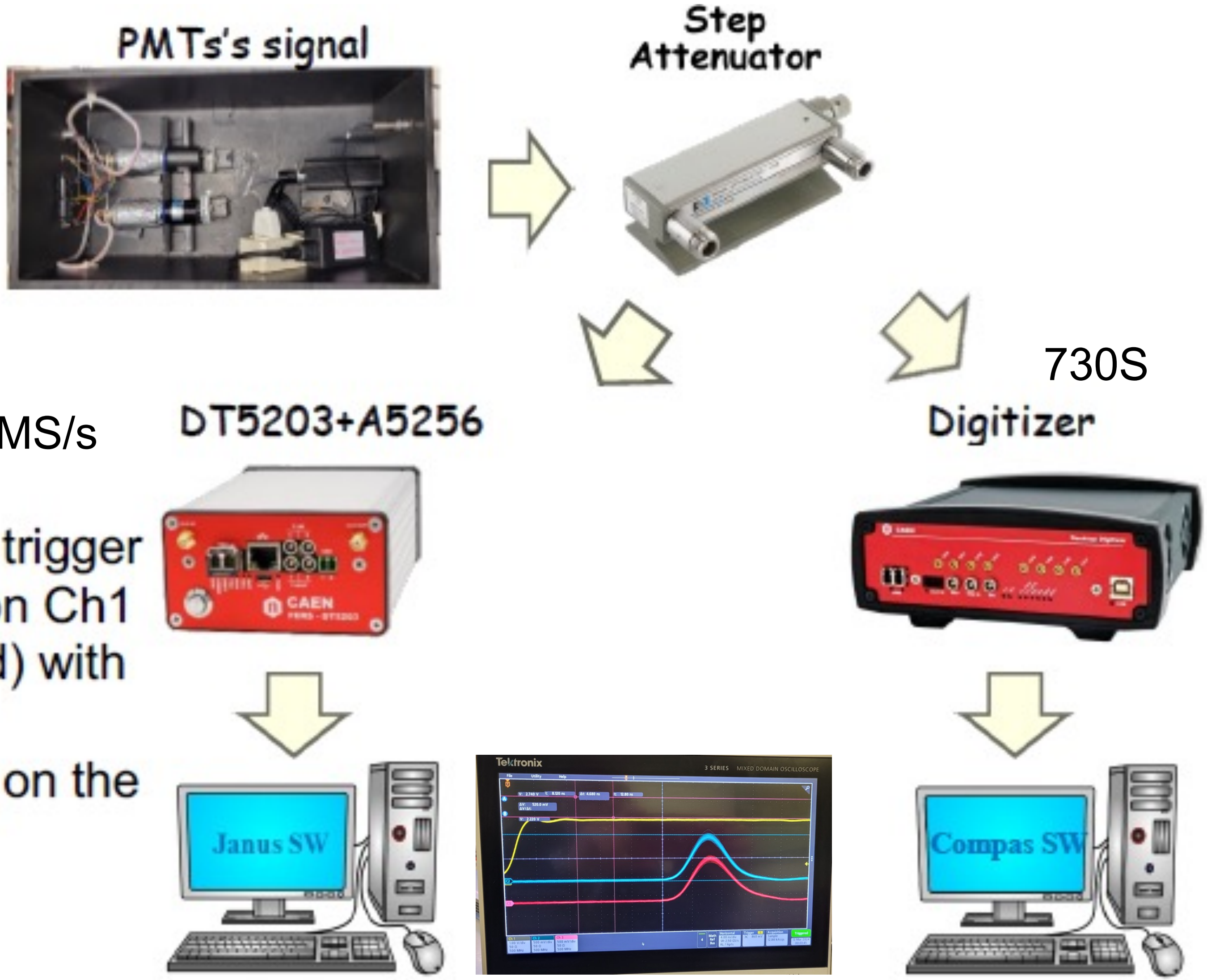
Ampl	Centroid	Sigma	Rel Res %	INL %FSR
12.2	11.3	0.1	1.1	-0.16
38.0	41.1	1.3	3.1	-0.05
121.8	120.9	4.0	3.3	-0.14
385.0	403.0	0.4	0.1	0.39
1217.5	1215.4	7.6	0.6	0.00
3850.0	3831.0	29.4	0.8	-0.03

Amplitude resolution <1% at large values
(well below ECAL resol. ~ 5.7%/√E in the whole range)

Pico TDC test II (CAEN+INFN)

Test setup:
2.

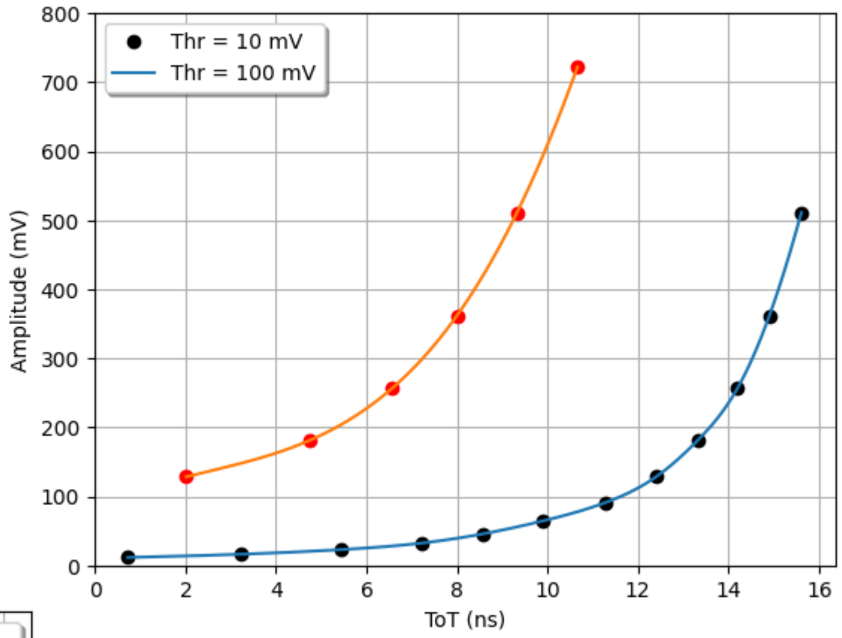
- PMT WA5656
- PMT WA8792
- Signal splitted:
  i. Pico TDC
  ii. Digitizer 14 bit @ 500 MS/s
- Resolution comparison
- TDC: Start on Ch0 with trigger from LED Driver. Stop on Ch1 and Ch2 (dual threshold) with variable amplitude.
- Digitizer: autotriggering on the Ch0.

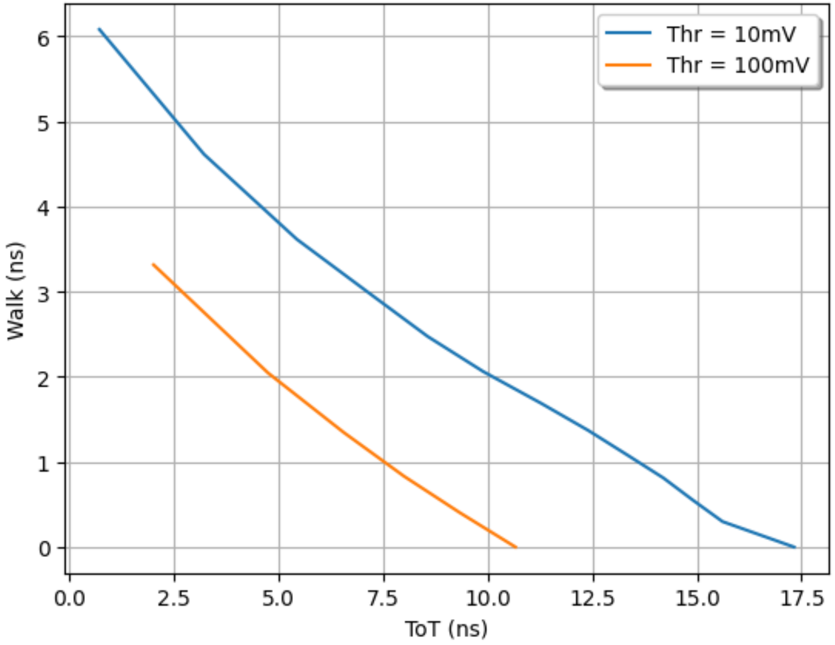


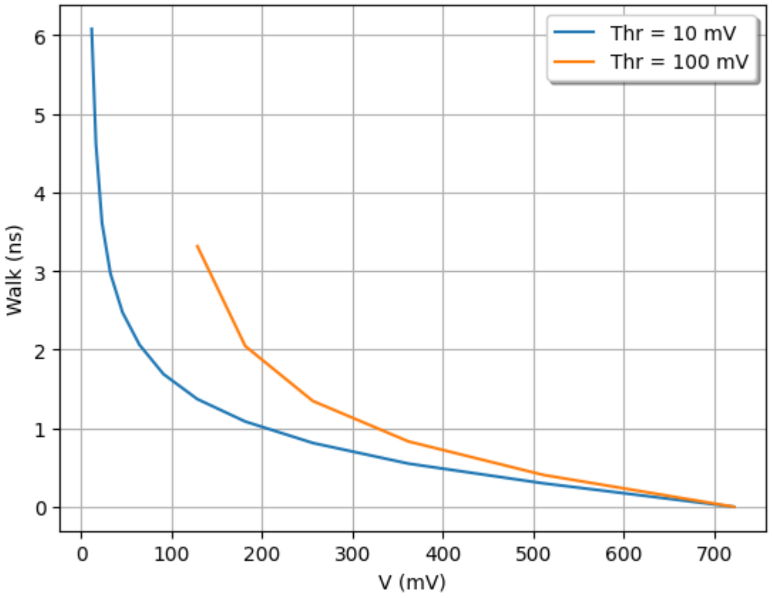
Pico TDC test II (CAEN+INFN)

Calibration Curve:

- Acquire **ToT** and **ΔT** at different amplitudes (from 0 to 39 dB, 3 dB step)
- Low threshold: 10 mV
- High Threshold: 100mV

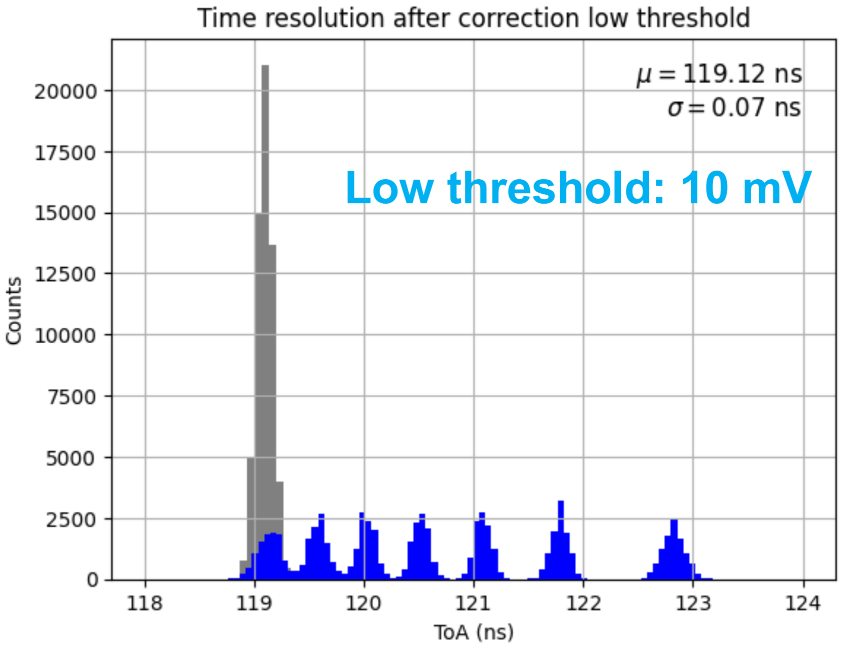






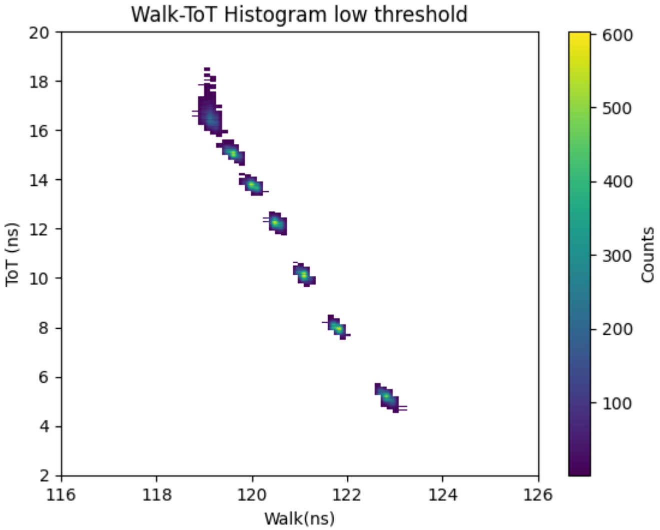
Pico TDC test II (CAEN+INFN)

Time Reconstruction (using ToT-Walk correction)



(peak at 119.1 ns at limit)

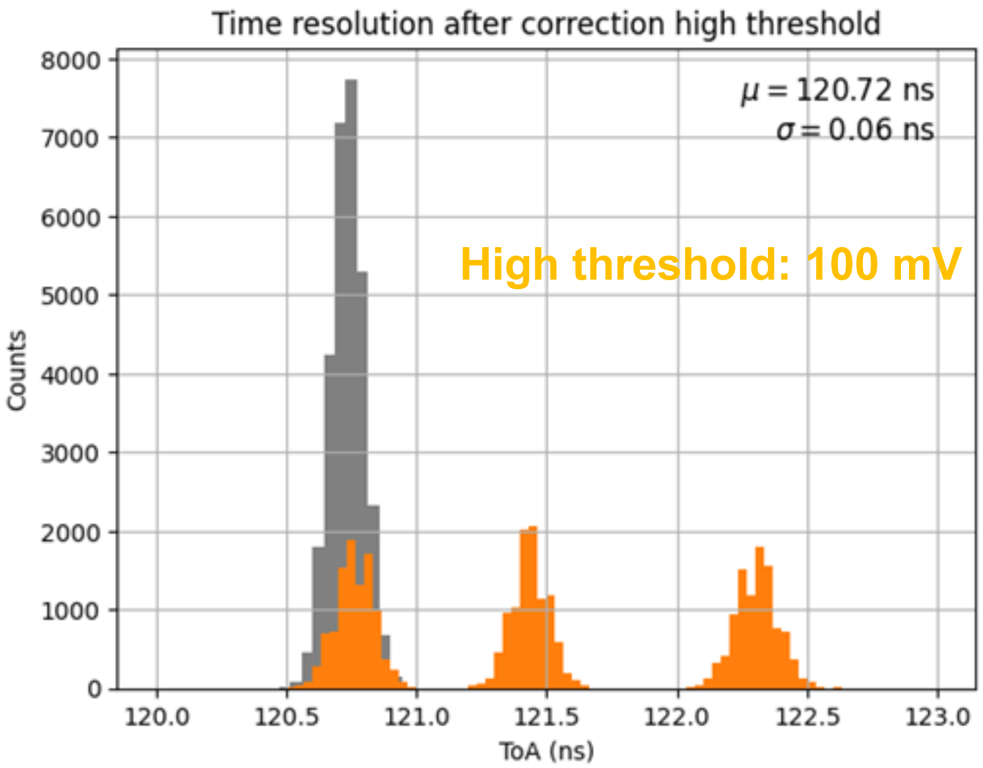
- Acquired pulses at 7 different amplitudes over a 40 dB dynamic range, the walk causes ~3-4 ns spread on ΔT: 7 separate peaks appear on the histogram.
  (sample independent from calibration sample)
- ΔT corrected by ToT using calibration data with a 5th order polynomial fit of the **ToT-Walk** points taken at the lower threshold (10 mV)
- Corrected ΔT histogram presents one single peak:
- **Time Resolution ~ 70 ps**

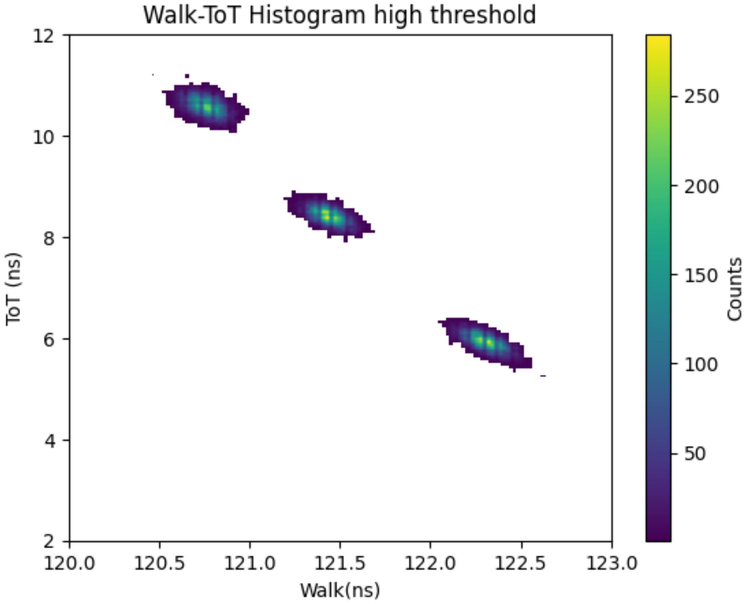


Walk (ns)	Sigma before (ps)	Sigma after (ps)
119.1	-	-
119.6	89	72
120.0	81	71
120.5	75	70
121.1	74	65
121.8	77	63
122.8	100	71

Pico TDC test II (CAEN+INFN)

Time Reconstruction (using ToT-Walk correction)





Walk (ns)	Sigma before (ps)	Sigma after (ps)
120.8	74	69
121.4	72	61
122.3	82	62

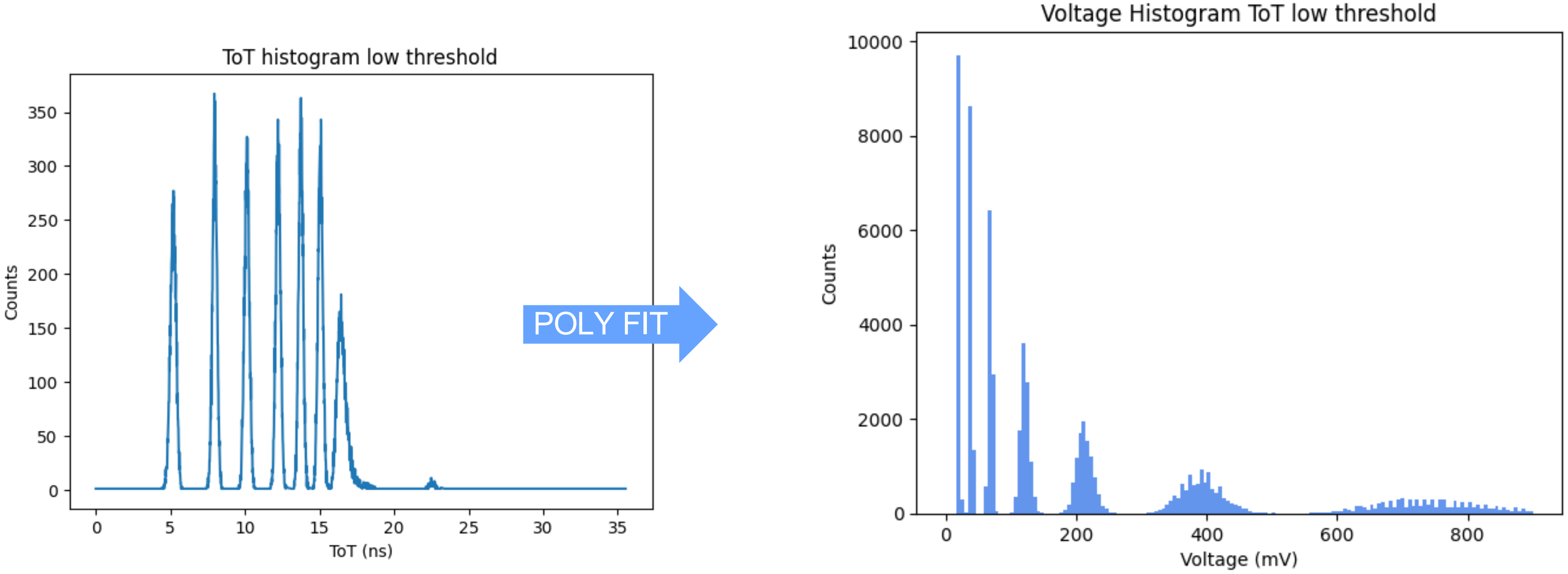
Time Resolution ~ 60 ps

(ECAL resol. ~ 54ps/√E + 100 ps)

Pico TDC test II (CAEN+INFN)

Amplitude Reconstruction (using ToT-Amp correction)

Low threshold: 10 mV



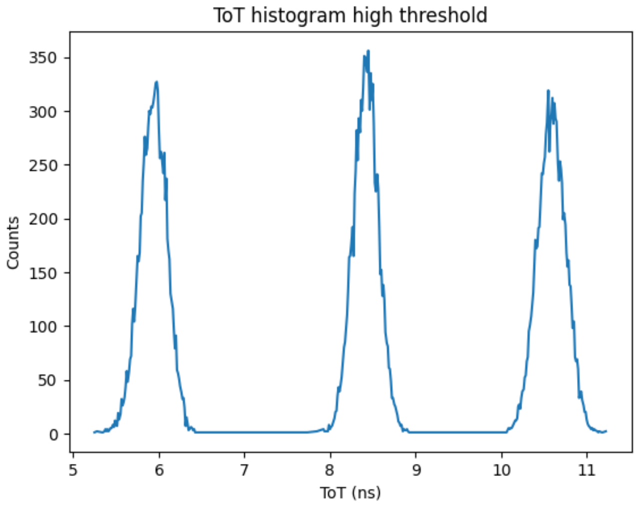
Amplitude (mV)	Sigma (%)
722.0	-
406.0	8.0
228.3	5.9
128.4	5.4
72.2	4.0
40.6	4.0
22.8	3.2

Amplitude resolution from 3 to 6 % in the low/medium range
(well below ECAL resol. ~ 5.7%/√E in this range – see next slides)

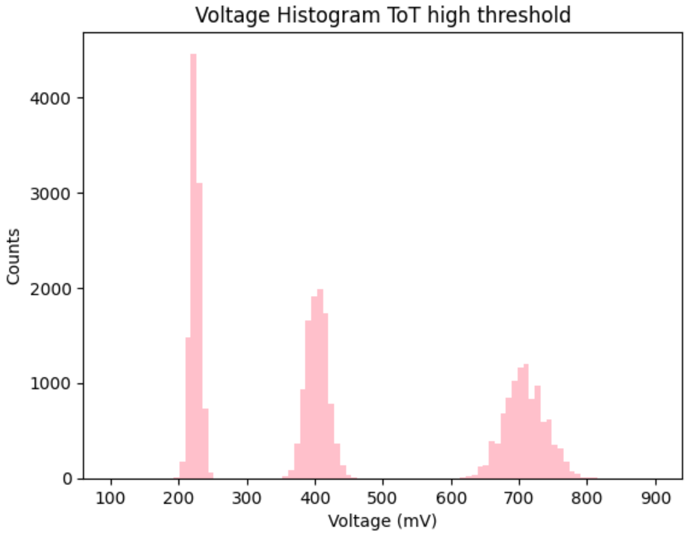
Pico TDC test II (CAEN+INFN)

Amplitude Reconstruction (using ToT-Amp correction)

High threshold: 100 mV



POLY FIT



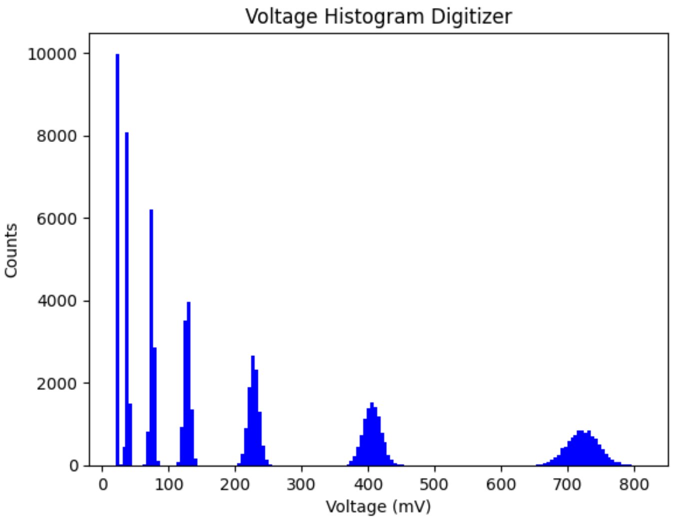
Amplitude (mV)	sigma (%)
722.0	4.2
406.0	3.8
228.3	3.2

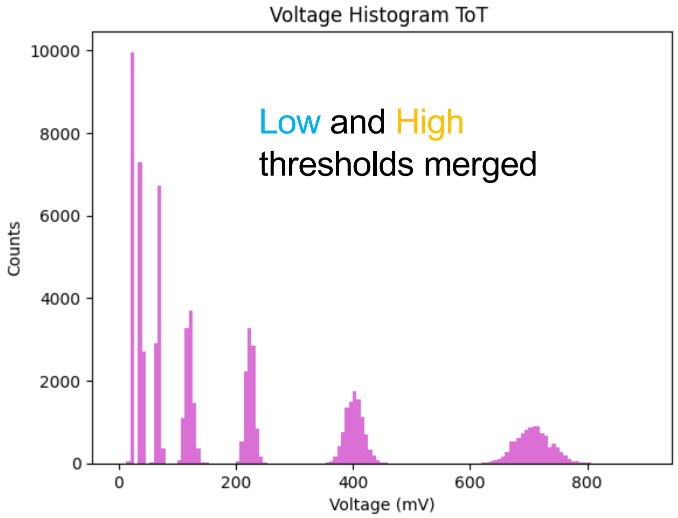
Amplitude resolution ~ 3-4 % in the higher range

(below ECAL resol. ~ 5.7%/√E – see next slides)

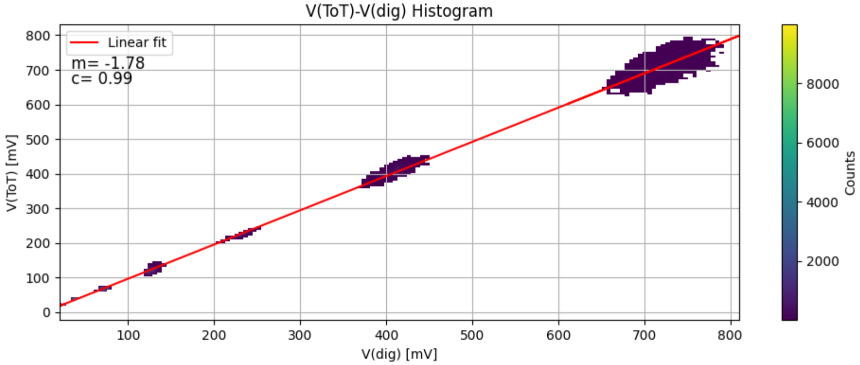
Pico TDC test II (CAEN+INFN)

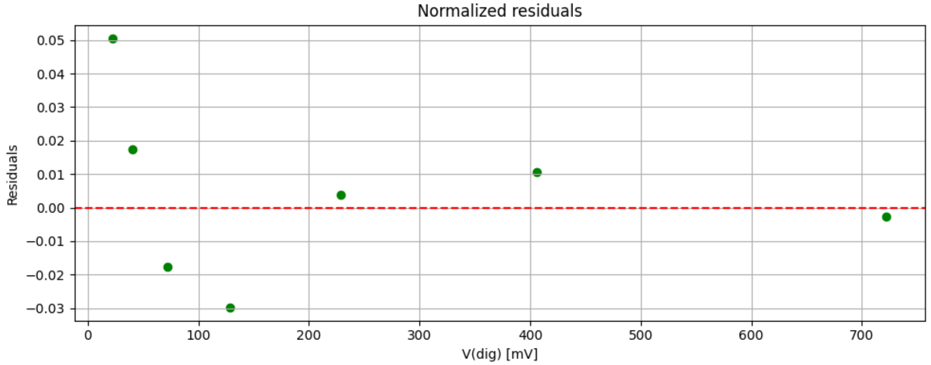
Amplitude reconstruction: comparison with Digitizer





Low and High
thresholds merged





Amplitude (mV)	sigma digit. (%)	sigma ToT (%)	sigma Diff (%)
722.0	3.2	4.2	3.3
406.0	3.2	3.8	2.4
228.3	3.3	3.2	1.5
128.4	3.6	5.4	4.7
72.2	4.2	4.0	4.3
40.6	5.3	4.0	5.2
22.8	10.8	3.2	-

Pico TDC test II (CAEN+INFN)

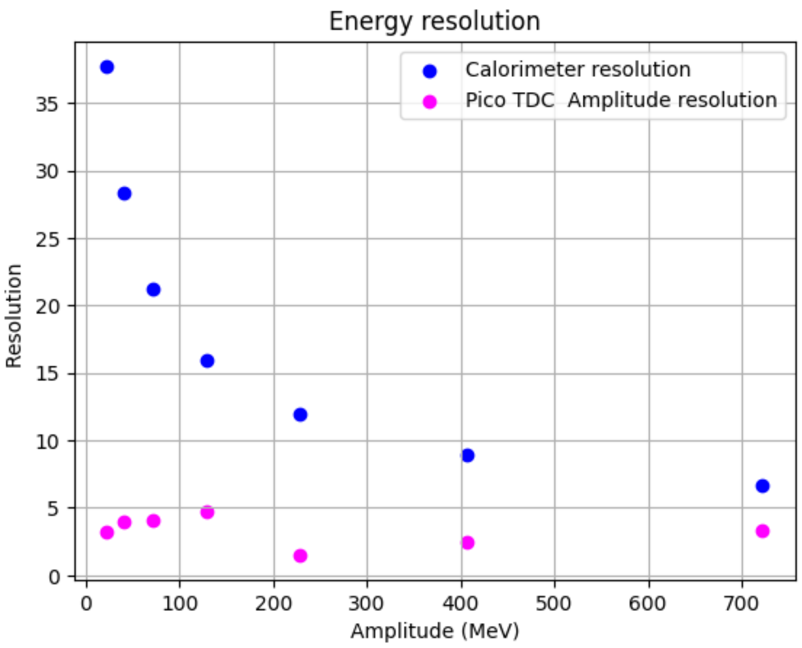
comparison with Ecal resolution

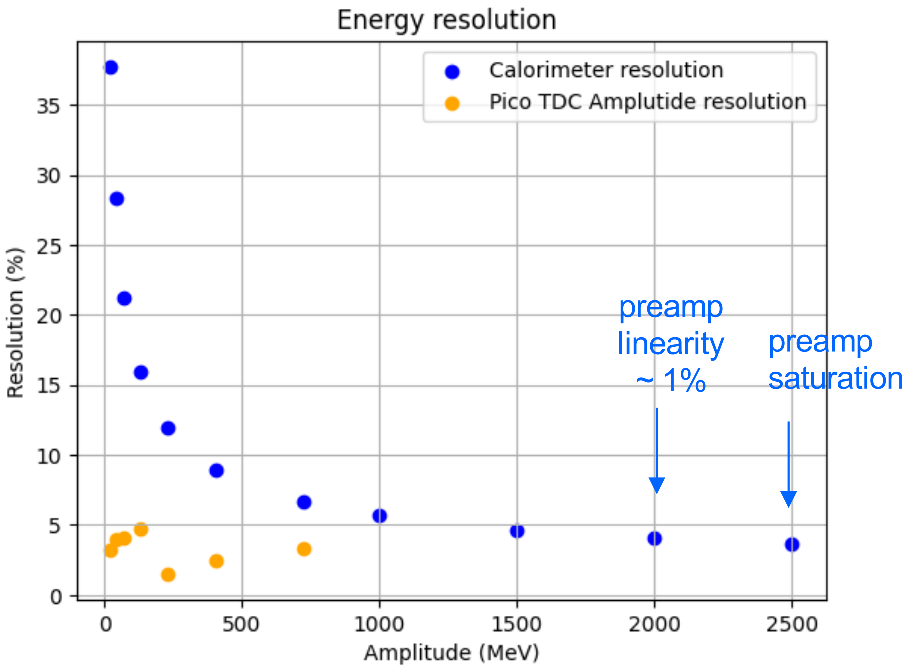
From previous studies on dynamic range:

- V_{dis}(max) = V_{preamp}(max) • 0.5 • C_{ATT}= 2.0 V
- minimum discriminator threshold possible V_{TH}= 2.5 mV

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

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





Choice of FEE for SAND/ECAL

Four possible solutions investigated with CAEN

Digitizer VX2730

Fsampl ~ 500 MS/s => **~ 3.5 Meuro**

Digitizer VX2745B

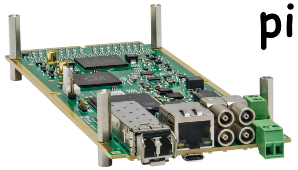
Fsampl ~ 125 MS/s

+ shaper 64 ch. => **~ 1.6 Meuro**

DT5203+A5256

PicoTDC + discr. double threshold with ToT => **~ 790 keuro**

A5204 RADIOROC with picoTDC



PicoTDC + discr. single threshold with ToT (for all signals)
+ peak sensing ADC with slow shaper – dead time 20μs
and good resolution (for rarer signals of large amplitude);
feasibility study in progress => **~ 520 keuro**

Conclusions (I)

ECAL testing is being to start at LNF in a dedicated area

Studies for the optimization of the working point of the SAND calorimeter read-out electronics have been performed.
The dynamic range and pile-up of the signals have been studied with MC.
PMT preamplifiers have been tested for linearity and are well compatible with needed dynamic range and proposed FEE solutions, with the additional advantage of a lower gain and HV level, beneficial for PMTs lifetime.
The features of preamp saturation could be exploited to partially recover input signal information during saturation regime.

Possible solutions for the FEE that could constitute a good compromise between cost and performance are being investigated in collaboration with CAEN.

In general, any solution must be integrated in the SAND DAQ scheme, with possible synergies with other detector electronics.

Conclusions (II)

PicoTDC tests:

- The time resolution with the signal generator is 18 ps, while for the PMTs signal is 60/70 ps on a 39 dB dynamic range;
- Amplitude resolution from ToT with two thresholds is ~3-5 % in the range 20-700 mV (with no specific threshold optimization)
- In this range the resolution from ToT is well below the intrinsic calorimeter resolution $\sigma/E=5.7\%/\sqrt{E}$

- Next steps:
  1. Optimization of the thresholds for the best perfomance in the whole expected dynamic range (2.5-2000 mV) and in the preamp saturation regime.
  2. Improve simulation of the PMT signal and FEE electronics in the official SAND MC simulation; implementation of Walk-ToT correction, ToT amplitude reconstruction, preamp saturation etc..
  3. Test of PicoTDC and ToT with KLOE modules at test stand in Frascati.
  4. Other solutions based on PicoTDC + amplitude meas. (RADIOROC chip) are being investigated in collaboration with CAEN and appear very promising.