ECAL FEE: preliminary simulation results and considerations for the choice of FEE

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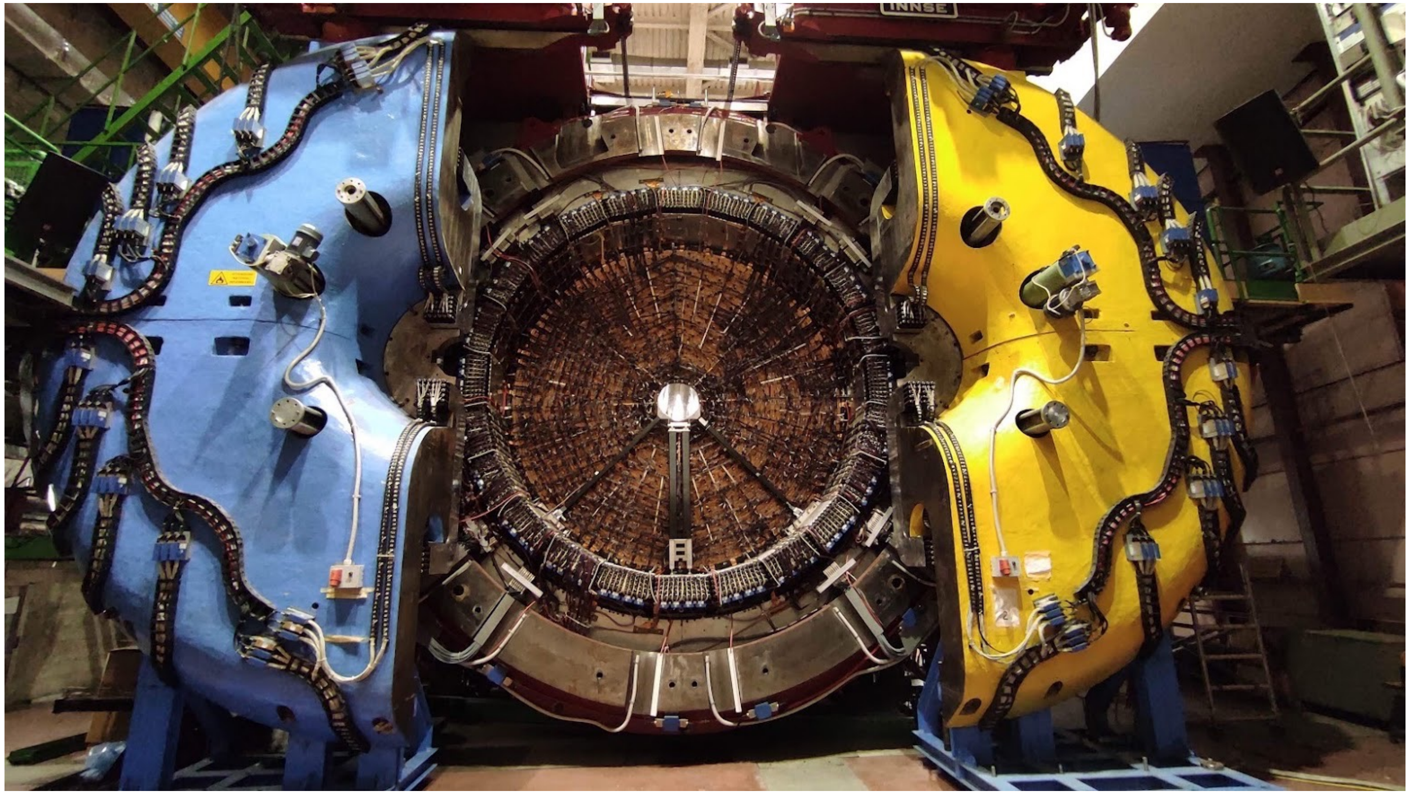


Meeting DUNE-Italia – LNF, 7 November 2022

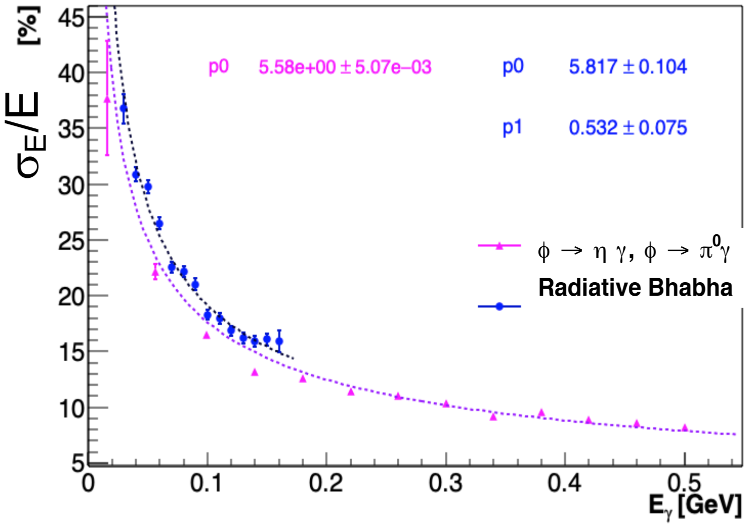
KLOE ECAL performance in KLOE-2 and with neutrons

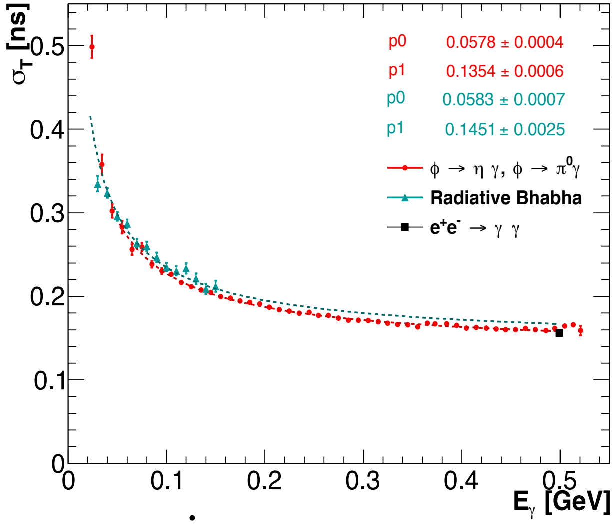
Check e.m. calorimeter performance

during KLOE-2 data taking (2015-2018): compatible with known performance.

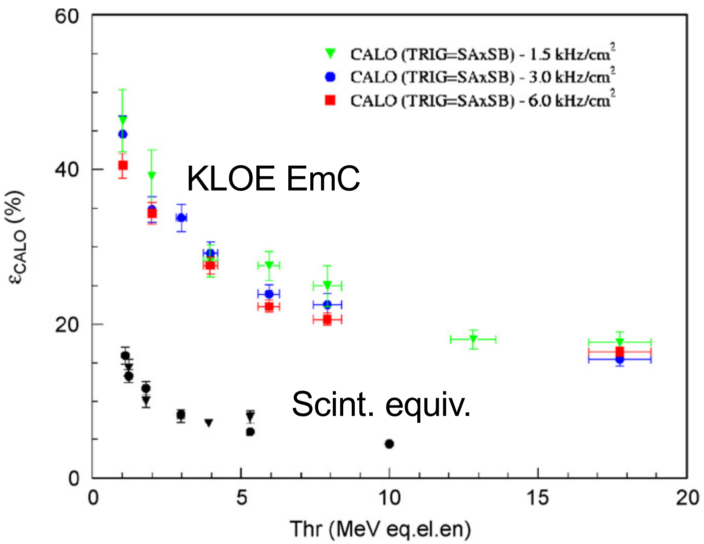
$\sigma_E/E \cong 5.6\% / \sqrt{E(GeV)}$

$\sigma_t \cong 58\ ps / \sqrt{E(GeV)} \oplus 135\ ps$





Thanks to E. Diociauti - LNF



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 (Gauzzi corresponding author)

Maximum Np.e. in a cell (in KLOE)

At KLOE e/γ with max. energy (510 MeV) from Bhabha scattering or γγ production

In practice, this is a quite rare case. Montecarlo simulations show that a particle spreads its energy into several celles and the total energy deposited from a bhabha into one cell extends from 0 MeV to 410 MeV at the 10^{-4} level, as illustrated in fig. 2.

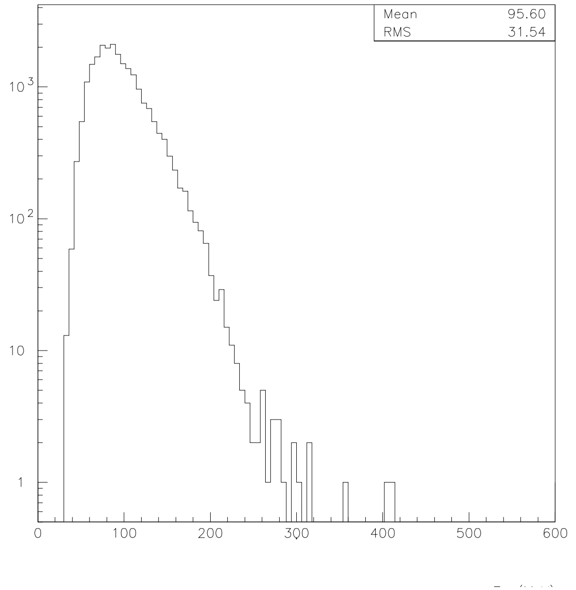


Figure 2: Distribution of the energy deposited by a 510 MeV bhabha in a 4.4×4.4 cm^2 read-out cell.

PMT signal and discriminator threshold in KLOE

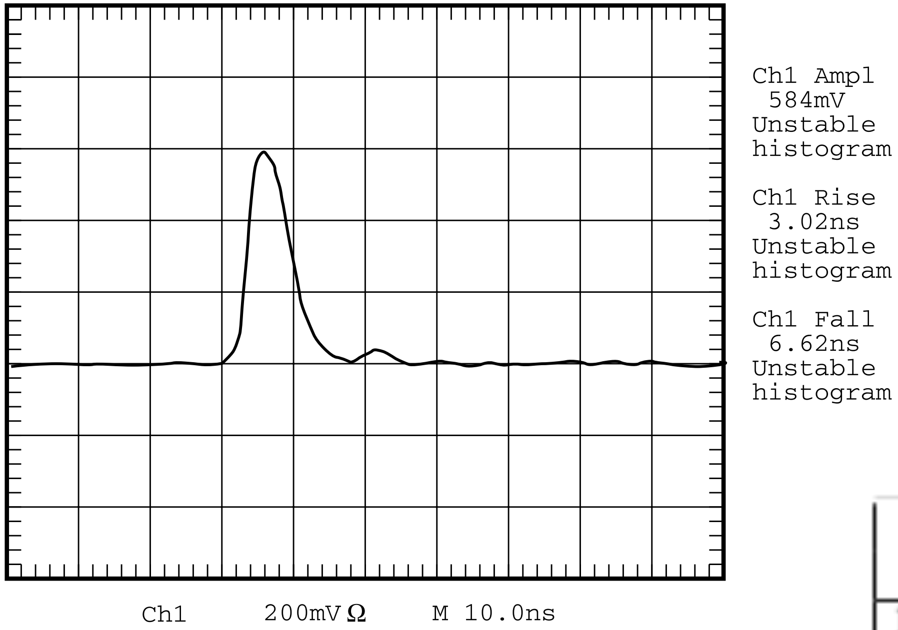


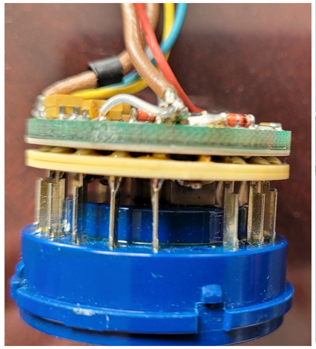
Figure 4: Typical signal from the PM base.

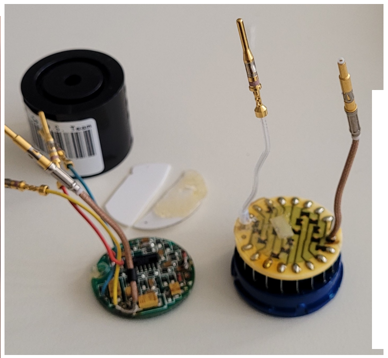
Constant fraction discriminators.
Effective thresholds are in the range 4–5 mV:
They correspond to signals originated by 3–4 photoelectrons or a 3–4 MeV photon at 2 m from PMT

	N_{pe}/MeV (@ center)	N_{pe}/MeV (@ end)	N_{pe}/510 MeV (@ end)
Kuraray	$\sim$ 1.1	$\sim$ 1.8	$\sim$ 909
P.H.T.	$\sim$ 1.1	$\sim$ 1.8	$\sim$ 925

Table 2: N_{pe}/MeV @ center, N_{pe}/MeV @ end and (N_{pe}/510 MeV @ end for a 4.4×4.4 cm^2 calorimeter read-out cell.

Constraints:
- minimum discriminator threshold 4-5 mV
- maximum HV for PMs divider is 2300 V
  typical HV 1700-1800 => G~1-3 x 10^6
- preamplifier linear for signals up to 4.7 V
  (gain preamp ~ 2.5) => ~ 1.8V at discriminator
level after 12-15 m cable





Many thanks to Alessandro Balla and P. Ciambrone to test preamp removal feasibility!!

Neutrino energy spectrum in DUNE

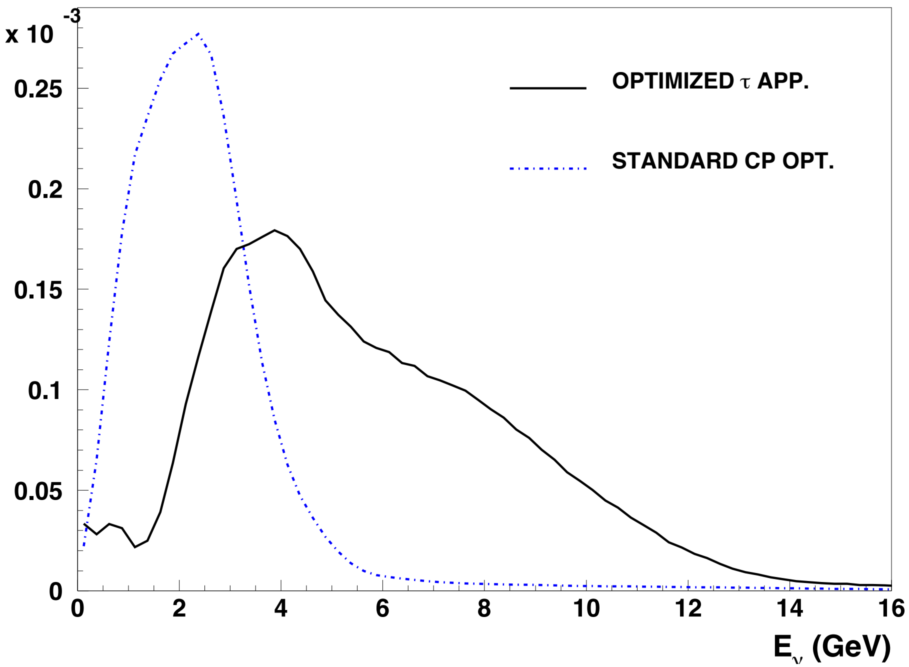


Figure 87: Comparison of LBNF ν_μ fluxes: (a) default 3 horn beam optimized for CP violation (dash-dotted); (b) ν_τ appearance optimized beam (solid).

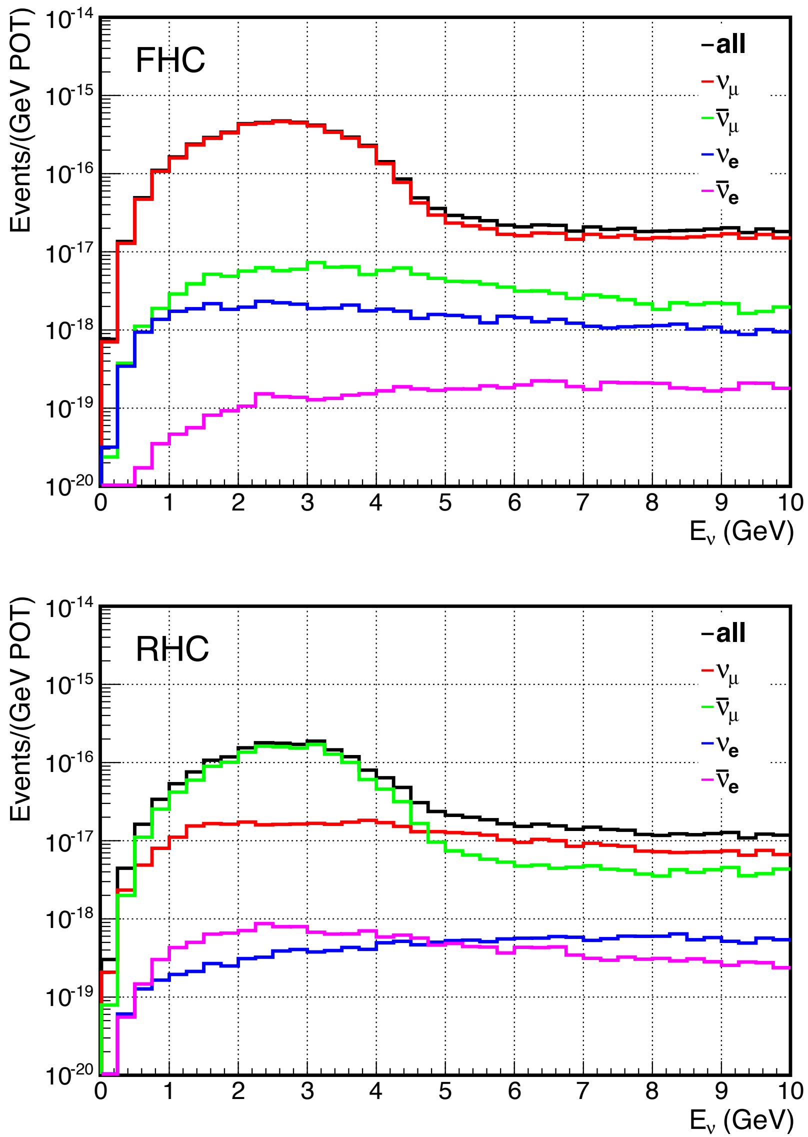
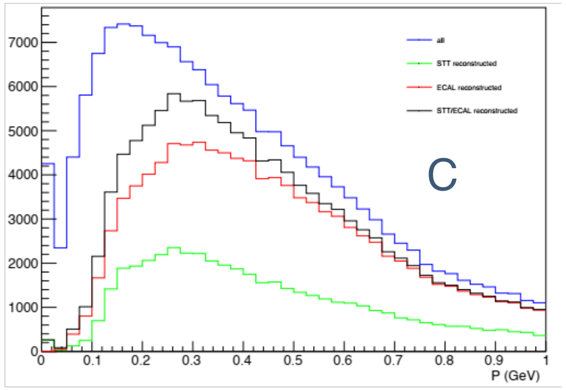


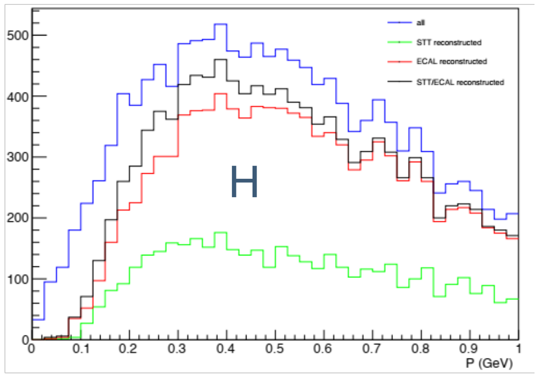
Figure 89: Energy spectra of CC interacting neutrinos in the internal LAr target, having a mass of 1.01 ton, and considering a 120 GeV proton beam in both FHC and RHC modes.

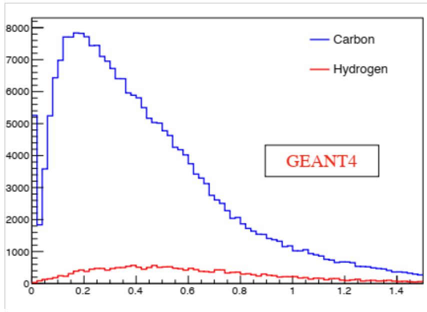
From DUNE docDB note 13262
A proposal to enhance the DUNE near detector complex

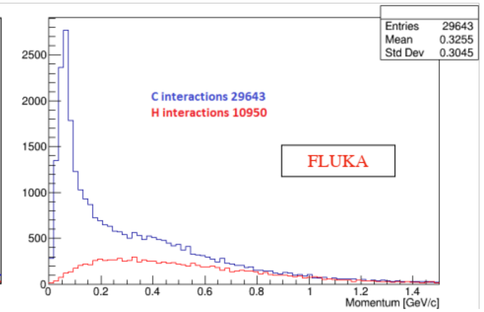
Neutron detection efficiency

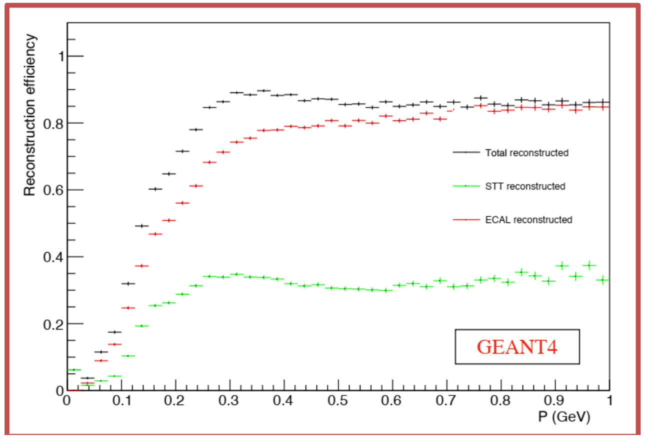
thresholds 250 eV in STT and 1.1 p.e. in ECAL







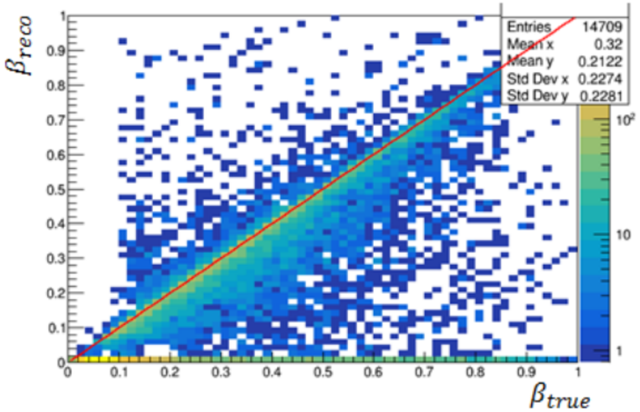


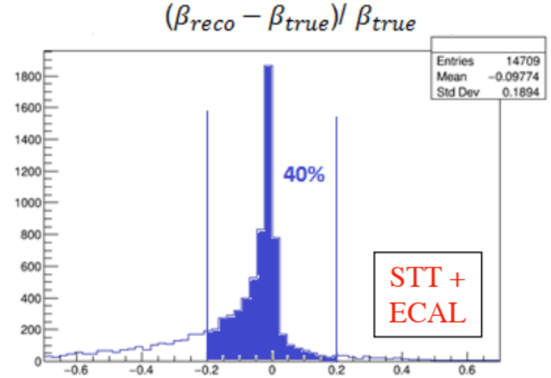


Target	QE	RES	DIS	Total
Carbon	64.8 %	76.5 %	80.1 %	73.6 %
Hydrogen	80.5 %	85.0 %	87.4 %	82.3 %

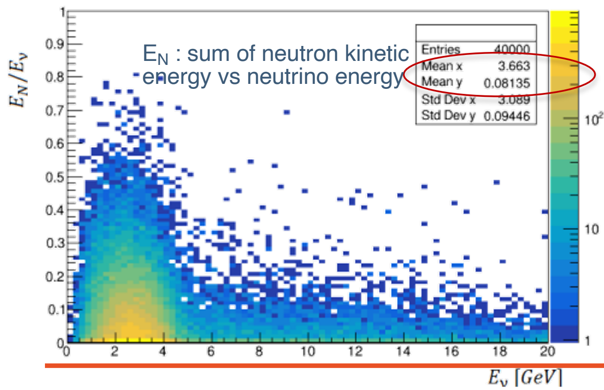
Neutron energy reconstruction

By time of flight in ECAL or in STT





It is influenced by the distance between vertex and interaction point

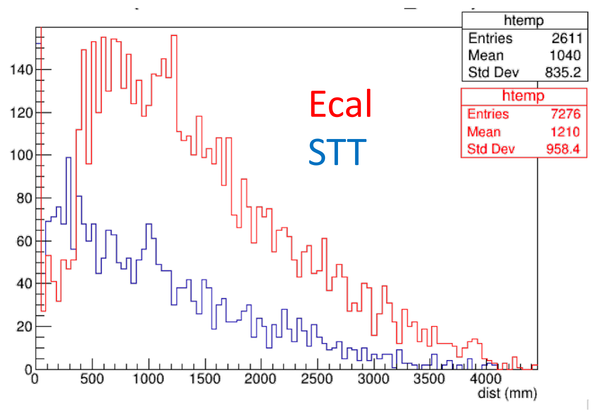


Time resolution:

-- STT: 1ns

- ECAL:

$\sigma_t \cong 58\ ps\ /\sqrt{E(GeV)} \oplus 135\ ps$



11 19th May 2021 L. Di Noto I STT performances in SAND

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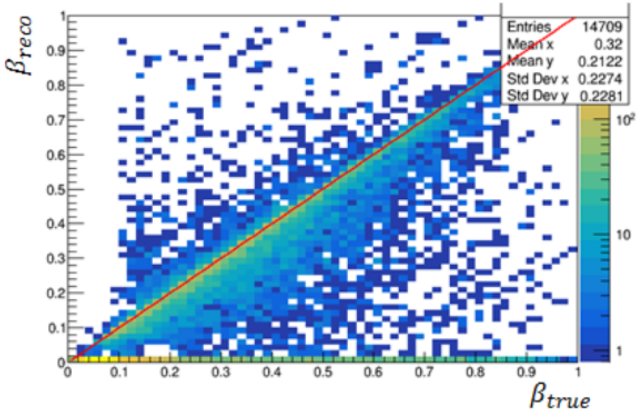
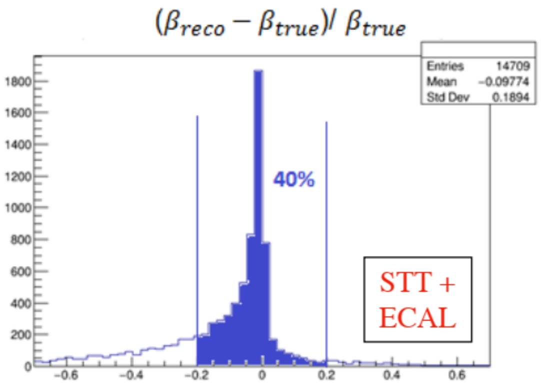
Neutron energy reconstruction

By time of flight in ECAL or in STT





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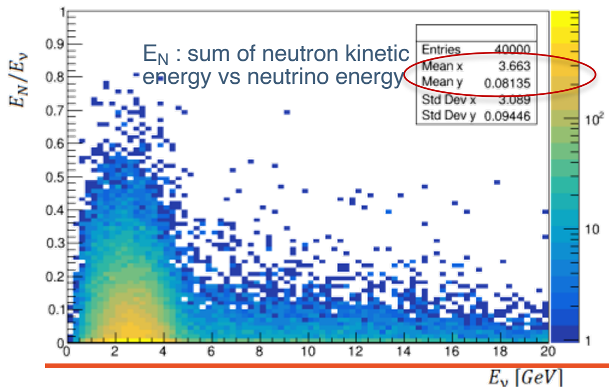

Time resolution:

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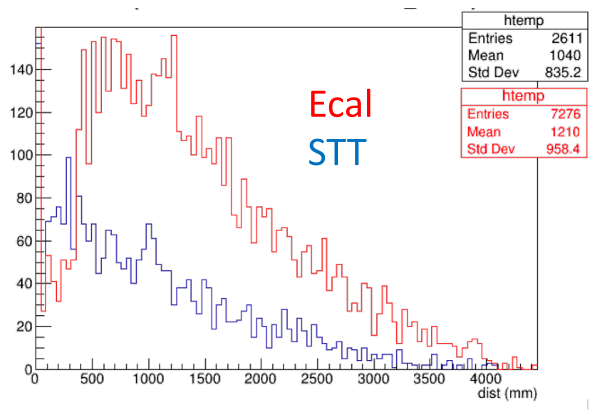
$\sigma_t \cong 58 \text{ ps}/\sqrt{E(\text{GeV})} \oplus 135 \text{ ps}$



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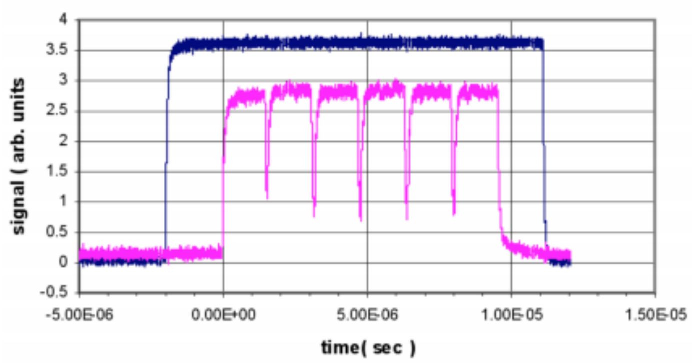
In SAND ECAL is assumed to mantain the same performance as in KLOE

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 (used in MC simulation – see M. Tenti talk)

- 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
$\lesssim$1 interaction/spill in the SAND fiducial volume
$\Rightarrow$ Event rates
O(10 MHz) in the spill
O(100 Hz) global

Choice of FEE for SAND/ECAL

Constraints on signal dynamic range

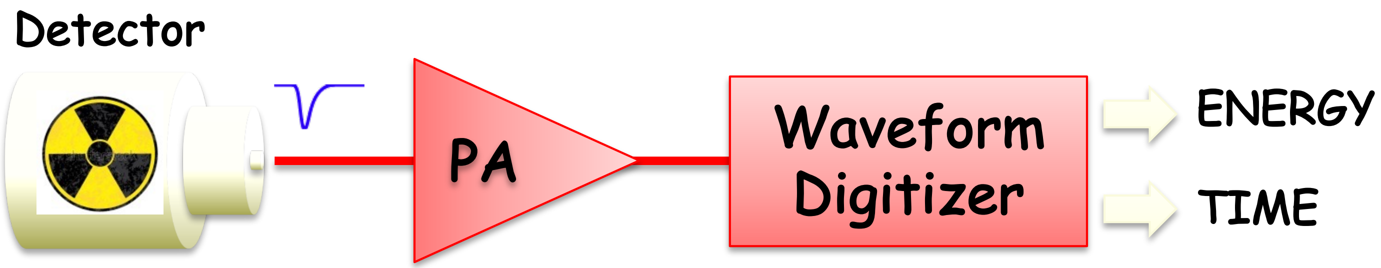
Minimum Np.e. detected: 2

Maximum Np.e. : ~2000 or more (see P. Gauzzi presentation)

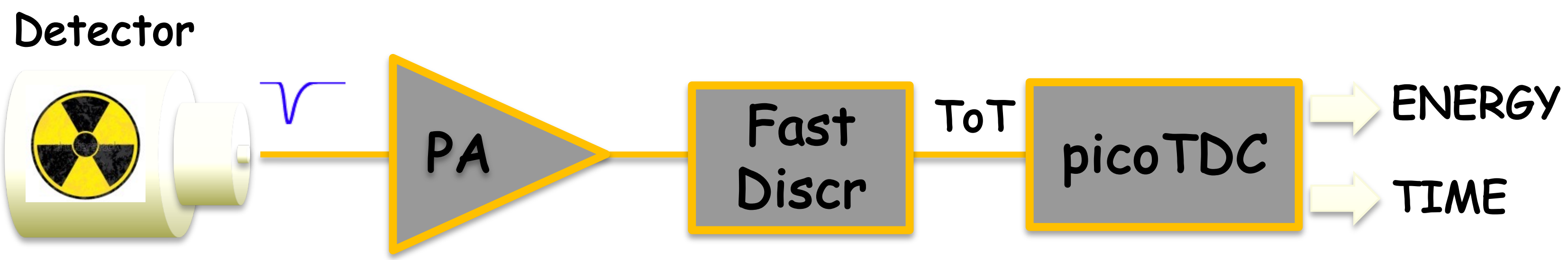
=> not compatible with the preamp in the signal path (saturation at 800-1000 p.e.)

=> 4880 preamps most likely removed from PM bases

Two possible read-out schemes:



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



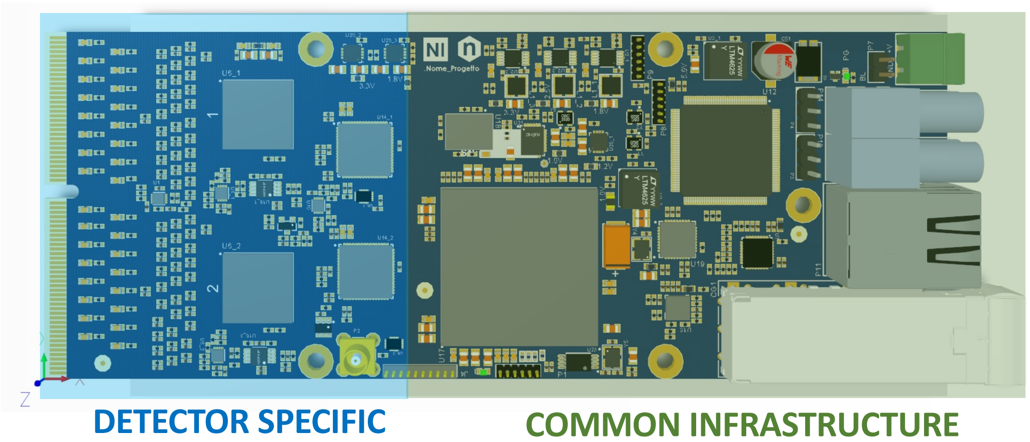
No Flexibility
=>medium cost
energy by ToT
with 1 or 2 thresholds

Meeting with CAEN:

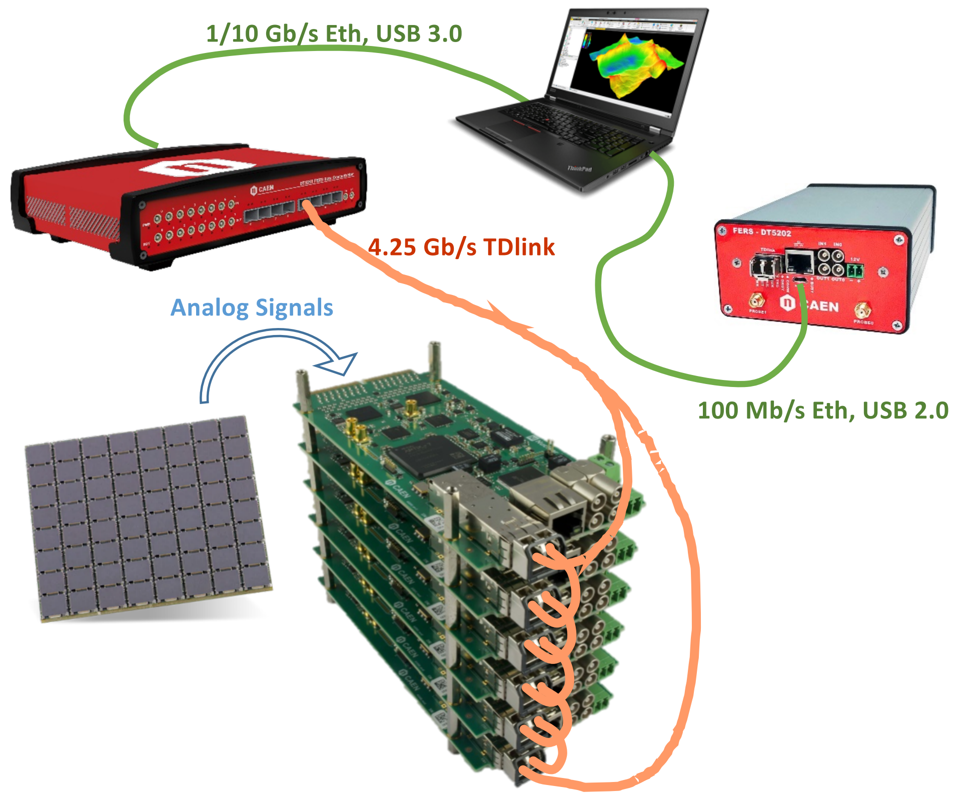
they are studying a possible ready-to-go solution maintaining KLOE energy and time performance

Choice of FEE for SAND/ECAL

FERS: a scalable readout system



- **FERS:** Front End ASIC + ADC/TDC + Scalable Readout Infrastructure
- Easy **integration** of new ASICs
- **Scalability:** from single stand alone version for evaluation, to 10k/100k channels with same electronics
- **TDL:** daisy chainable optical link protocol with **data+sync**
- **Readout Tree:**
  1 link = 16 FERS units
  1 Concentrator = 8 links = 128 FERS = 8k/16k channels
  Multiple Concentrators for unlimited readout…



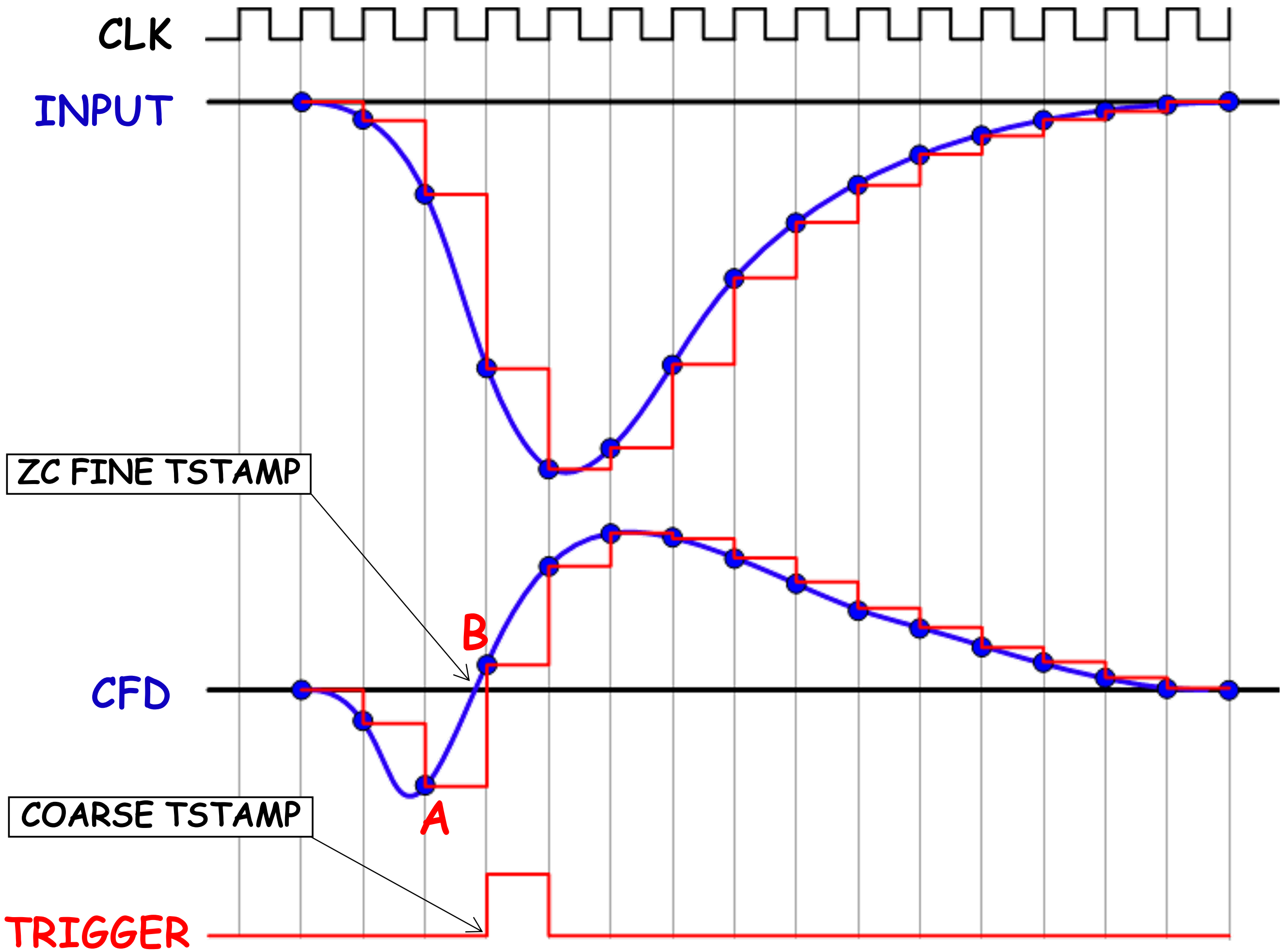
picoTDC (FERS A5203) + ToT solution

Choice of FEE for SAND/ECAL

Digital CFD with interpolation

Digitizer solution

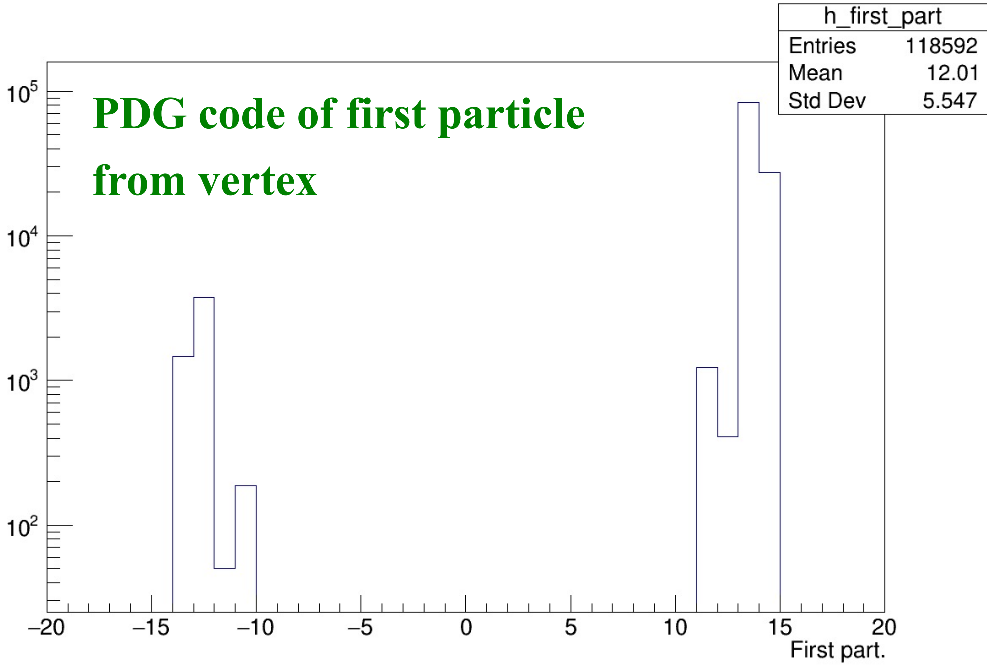
Needs shaper to stretch the signal to use a 125-250 MS/s digitizer
⇒ Lower cost than 1 GS/s digitizer



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}



Ecal digitization

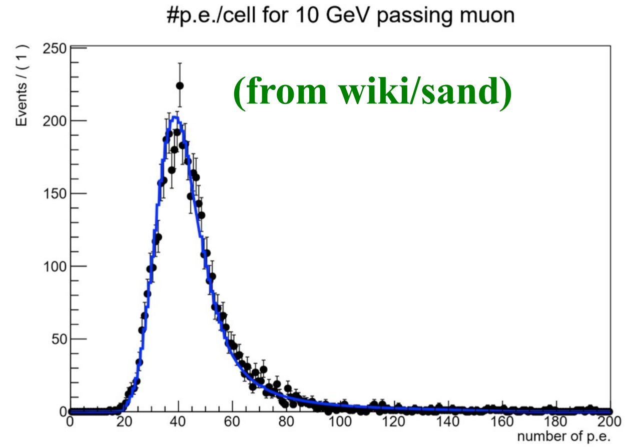
Digitization of ECAL similar to KLOE MC:

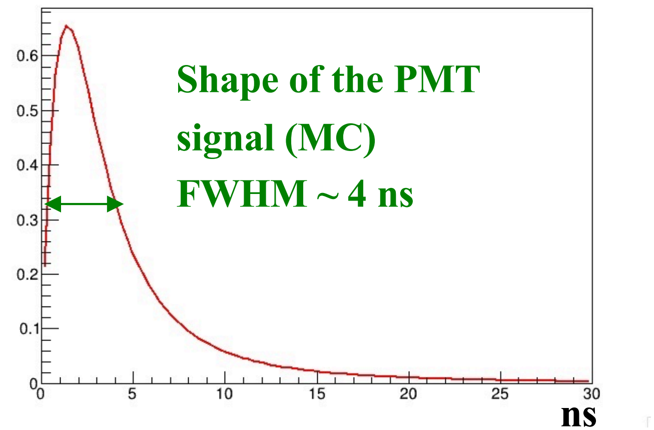
- Deposited energy propagated to PMT's with double exp. attenuation curve

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

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

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

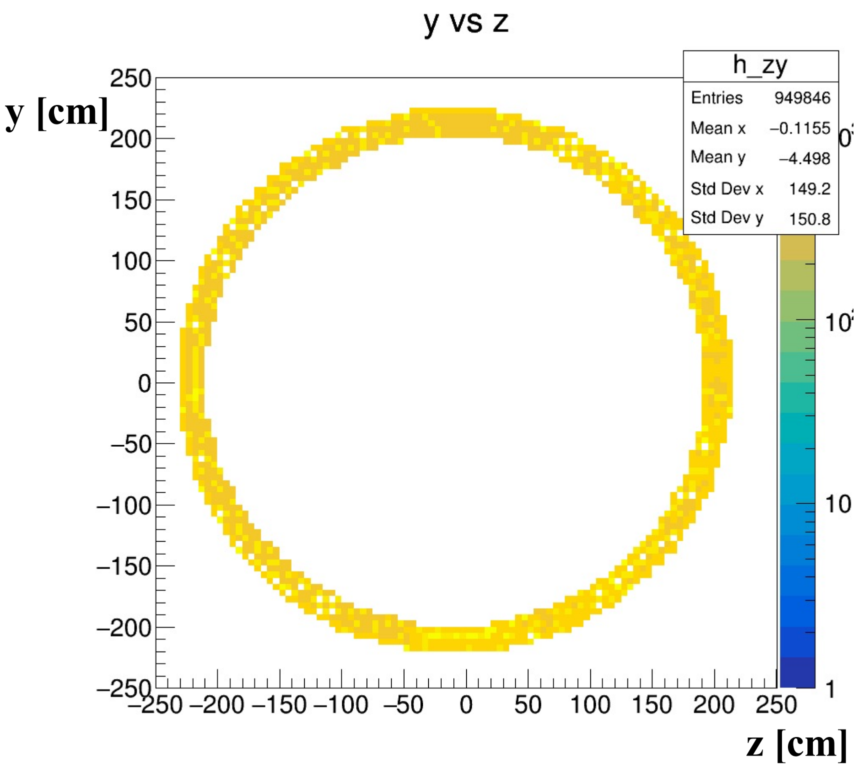


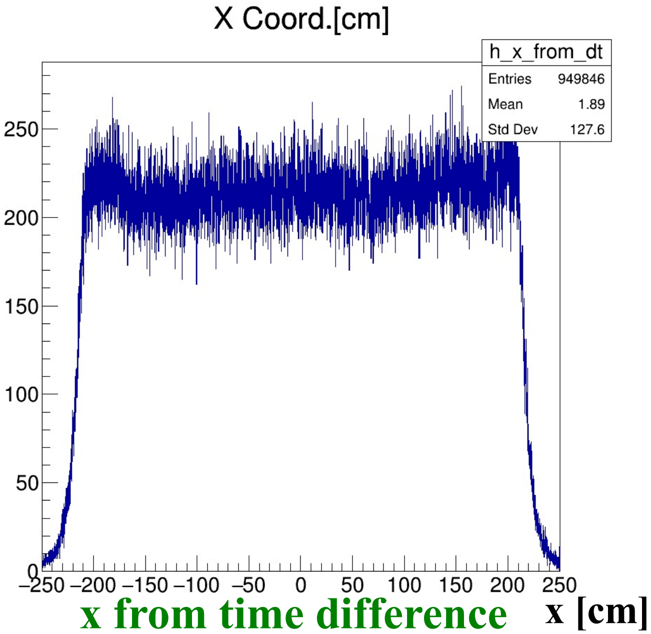


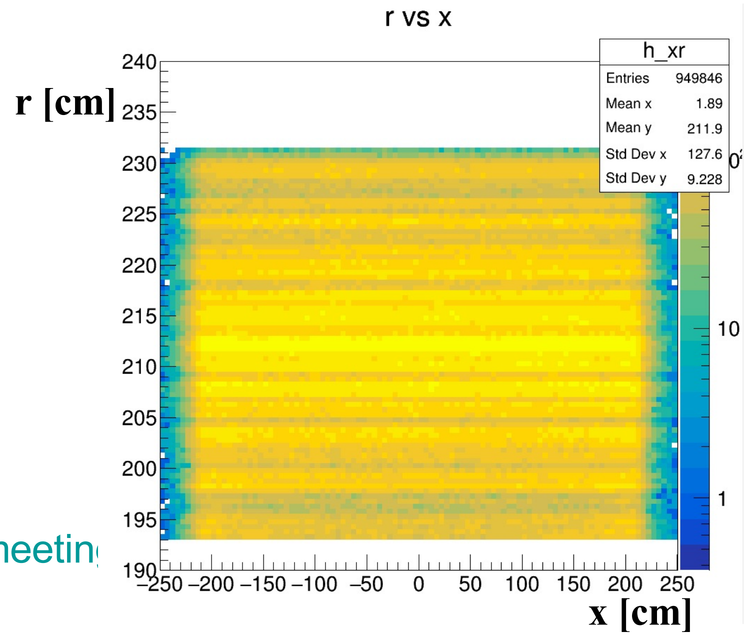
Event distributions: hit cells

- **Select only Barrel cells**

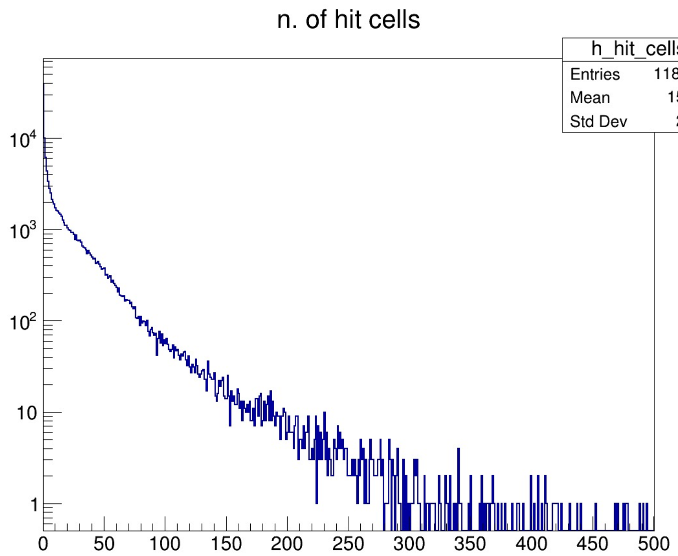
(ECAL center coord. = 0., 0., 0.)

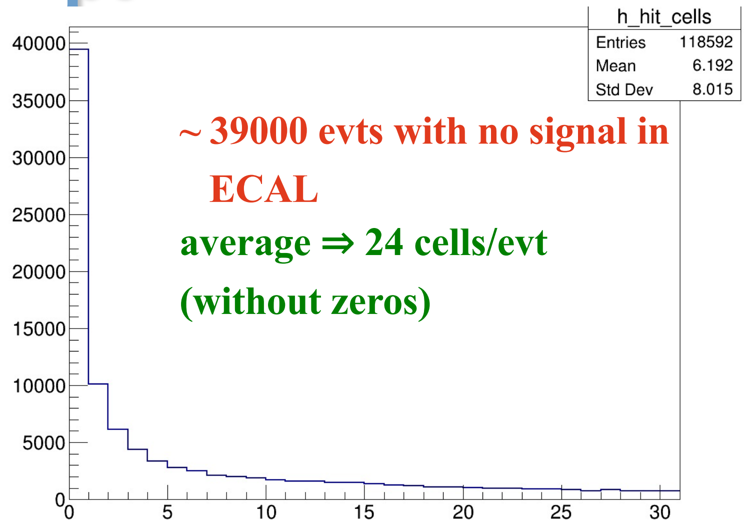


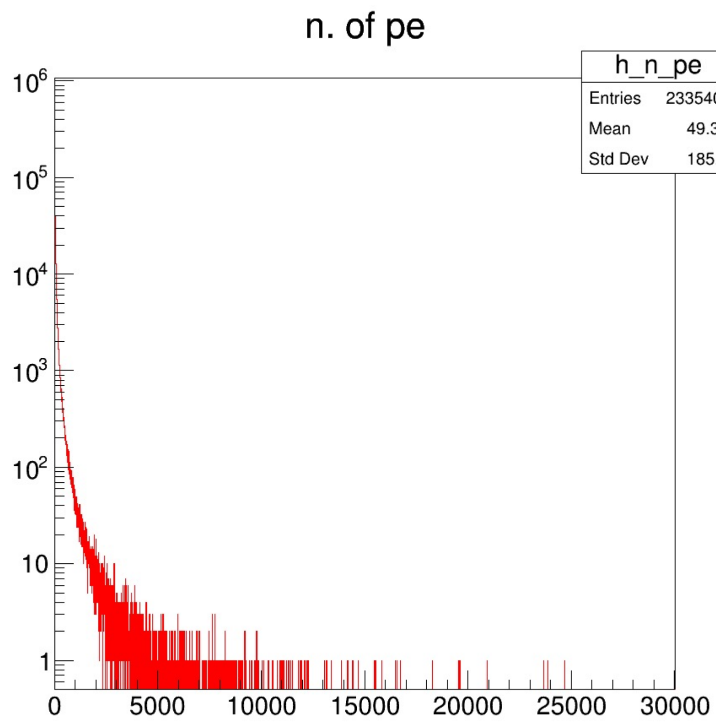


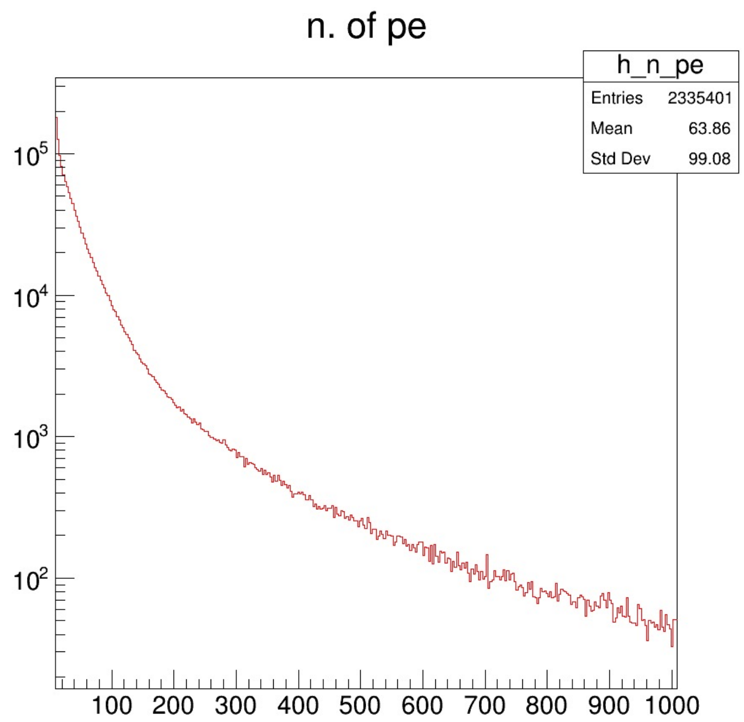


Hit cells – N_{pe}/cell









Event with ~ 25000 pe/cell

- N_{pe} max = 24674, cell: 10 2 01
- ν_μ on H: DIS

$$\nu_\mu p(quark\ d) \rightarrow \mu^-\pi^+\pi^0\pi^0 n\pi^+$$

Primary vertex in the Ecal (r = 223 cm):

0)	μ^-	$2.1\ GeV$
1)	π^+	$40.9\ GeV$
2)	π^0	$10.9\ GeV$
3)	π^0	$204\ MeV$
4)	n	$1.2\ GeV$
5)	π^+	$431\ MeV$

Total > 11000 particles

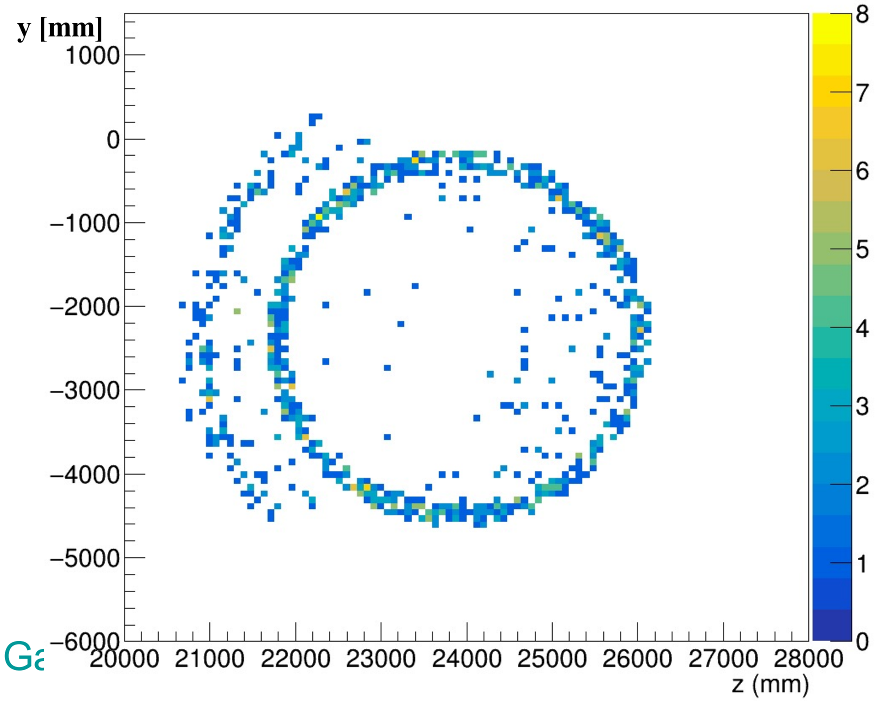
Contributions to cell 10 2 01

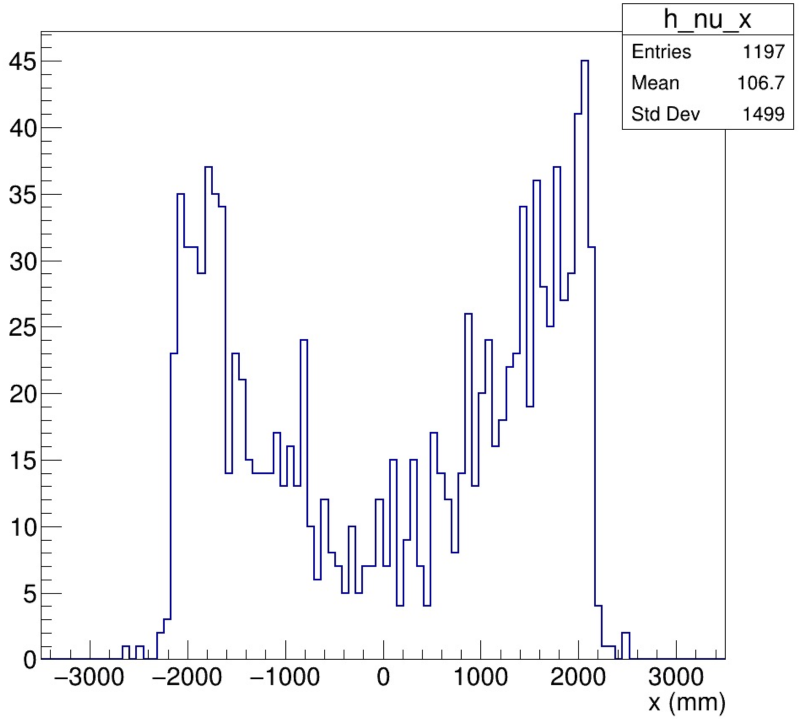
1) π^+			
5) π^+			
101) γ	$198\ MeV$	$parent$	$=$ 3) π^0
180) γ	$6.1\ GeV$	$parent$	$=$ 2) π^0
181) γ	$4.8\ MeV$	$parent$	$=$ 2) π^0
3514) π^-	$3.0\ GeV$	$parent$	$=$ 1) π^+
3515) π^+	$467\ MeV$	$parent$	$=$ 1) π^+
3516) γ	$162\ MeV$	$parent$	$=$ 1) π^+
4179) γ	$1.8\ GeV$	$parent$	$=$ 1) π^+
4180) γ	$4.0\ GeV$	$parent$	$=$ 1) π^+
6344) π^+	$241\ MeV$	$parent$	$=$ 1) π^+
6345) π^-	$395\ MeV$	$parent$	$=$ 1) π^+
6347) γ	$770\ MeV$	$parent$	$=$ 6346) η 929 MeV
		$parent$	$=$ 1)π^+
6744) γ	$10.2\ GeV$	$parent$	$=$ 1) π^+
6745) γ	$66\ MeV$	$parent$	$=$ 1) π^+
10334) π^+	$704\ MeV$	$parent$	$=$ 1) π^+
10335) π^-	$1.1\ GeV$	$parent$	$=$ 1) π^+
10337) γ	$116\ MeV$	$parent$	$=$ 10336) π^0 1.6 GeV
10338) γ	$1.5\ GeV$	$parent$	$=$ 10336) π^0 1.6 GeV
		$parent$	$=$ 1) π^+

Events with high N_{pe}/cell

Tot. events	118592	
Evts with signal in Ecal	79112	
N_{pe}/cell > 2000	1674	(2.1%)
N_{pe}/cell > 5000	317	(0.4%)

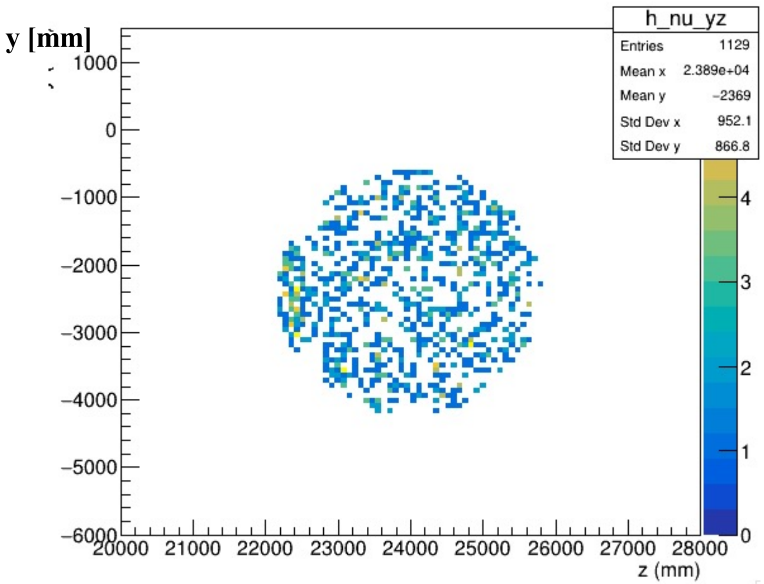
Primary vertex (N_{pe} > 2000)

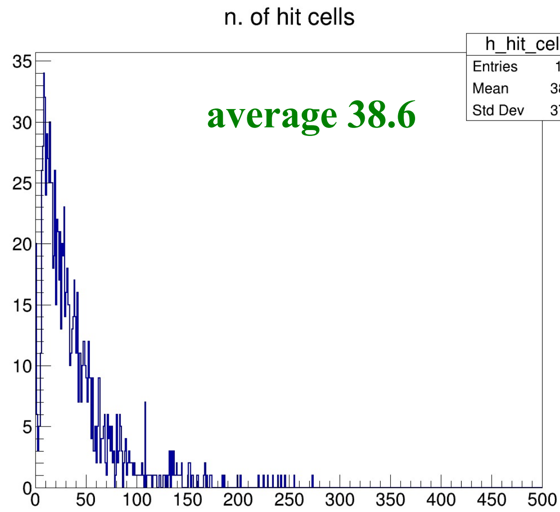


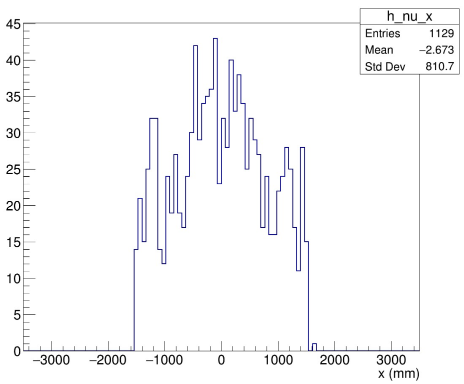


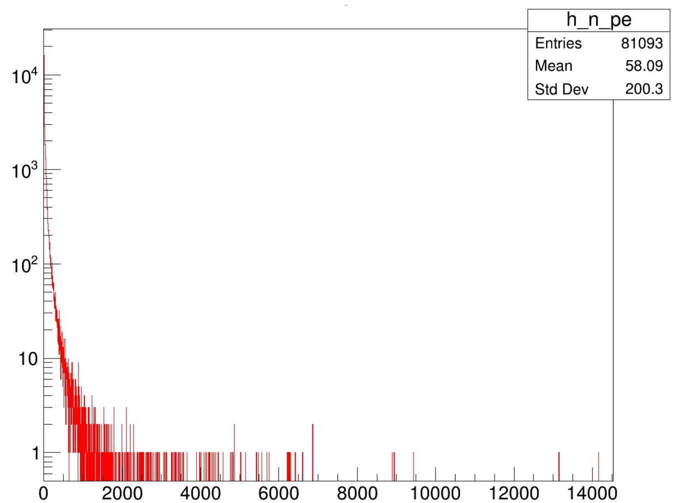
Vertices in the fiducial volume

- Select events with the primary vertex in a fiducial volume 20 cm inside the inner surface of the Ecal
- 1129 events / 79112 total (1.4%)



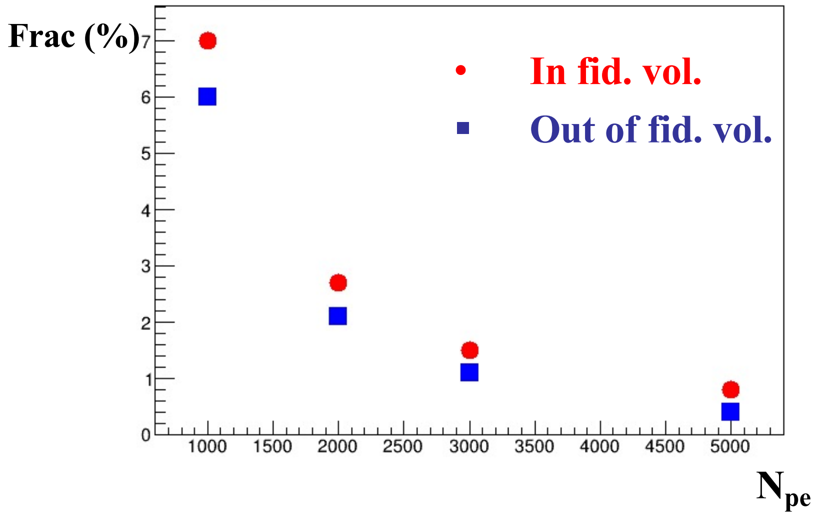




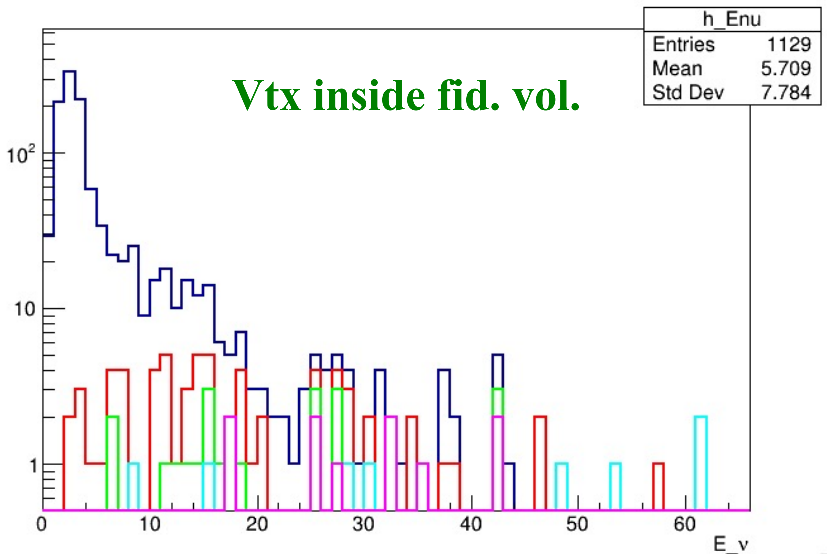


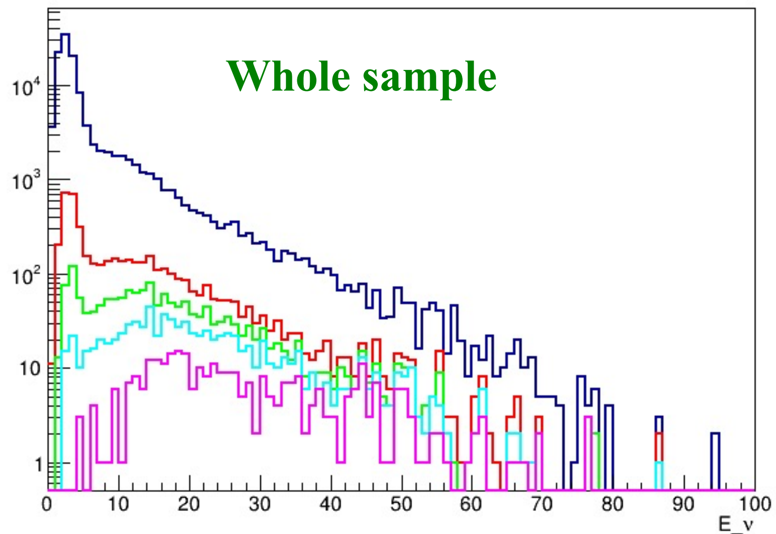
Evts with high N_{pe}/cell

Evts. in fid. vol.	1129	
N_{pe}/cell > 1000	79	(7.0%)
N_{pe}/cell > 2000	31	(2.7%)
N_{pe}/cell > 3000	17	(1.5%)
N_{pe}/cell > 5000	9	(0.8%)



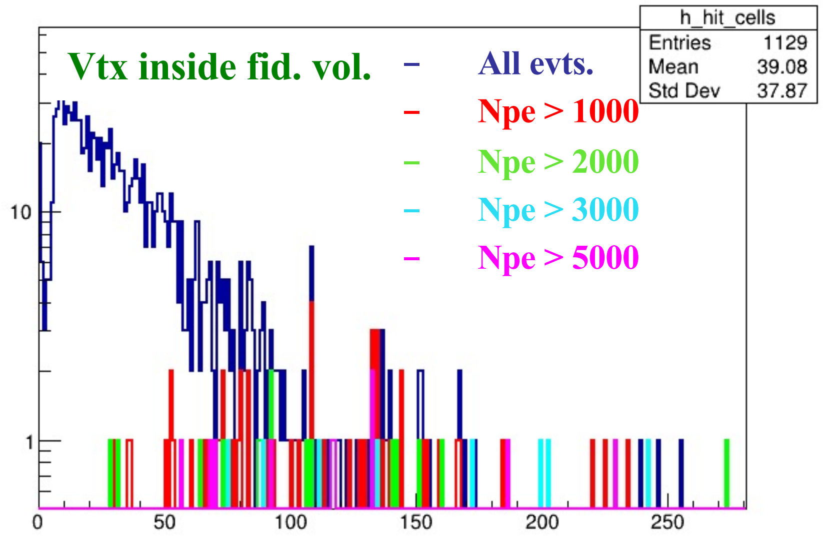
- Neutrino energy [GeV]:

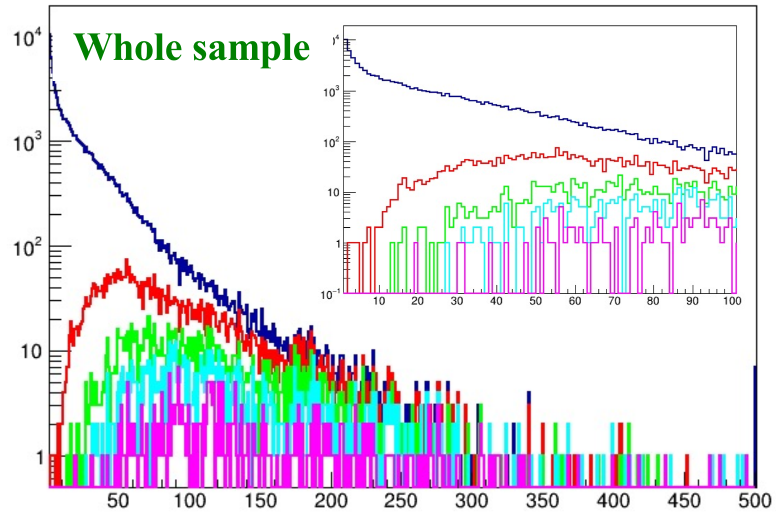




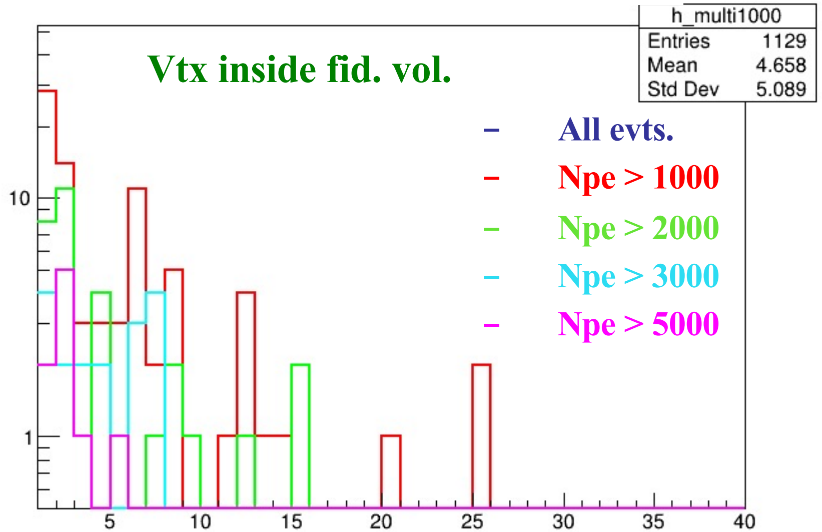
Evts with high N_{pe}/cell

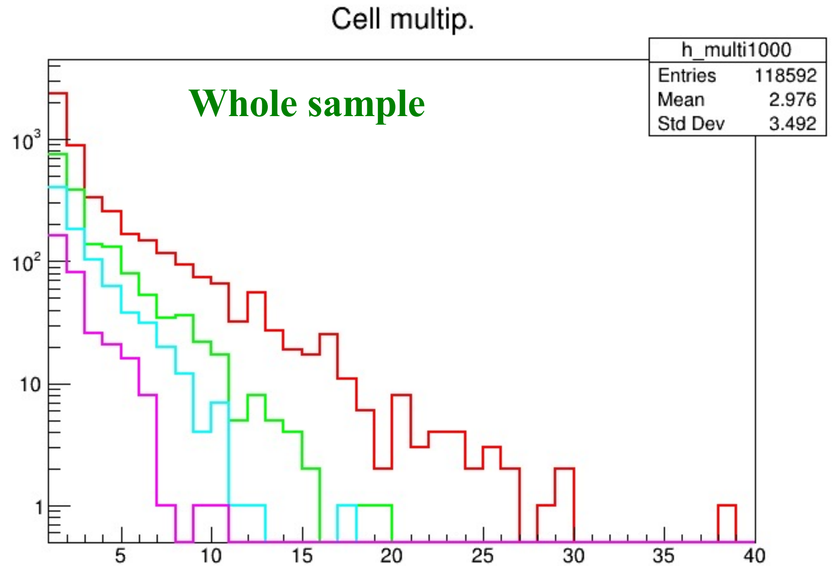
- **Total number of cells**





- **Number of cells above cut**





Conclusions

Studies with MC simulation of ECAL digitized response and signal dynamic range for the FEE choice are at an advanced stage.

Most likely 4880 preamps will be removed from PMT bases

Meeting with CAEN in October:
two possible read-out scheme are being studied by CAEN in realistic KLOE/SAND conditions (scintillating light + PMT base w/wo preamp) with the aim of proposing a ready-to-go solution to mantain KLOE energy and time resolution performance at an "affordable cost".

Spare

Time simulation

- **TDC Multihit simulation: integration time 30 ns (starting from first p.e. time) 50 ns dead time**
- **Constant fraction simulation: 15% of the total p.e. number**