Istituto Nazionale di Fisica Nucleare
SEZIONE DI LECCE

Ideas for GRAIN calibration

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CALIBRATION

In general:

"Calibration = the correlation between a detector (or single device) output signal and a physical quantity that we want to measure by means of the detector".

In our specific context (of a **ν-detector**), the detector signals have to be correlated to the physics processes and properties of the particles produced in the neutrino interaction: momentum and energy, charge, ToF, identity (or variables for PID), …

Such properties and processes will provide the information needed to fully know the **interacting neutrino** features:

- **Energy**
- **Flavor**
- **Interaction type**

GRAIN Detector

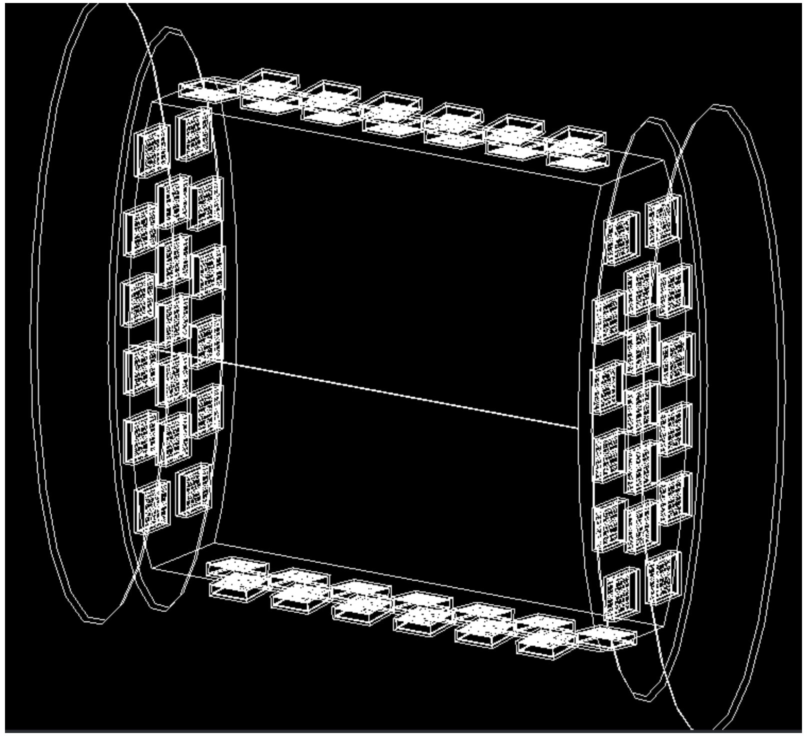
GRAIN case:

Event properties to be reconstructed: **interaction vertex position**, **tracks**, **time**, **energy deposit** (transferred directly to the LAr and/or carried out by the outgoing tracks)

Detector: **SiPM matrices**, imaging the whole sensitive LAr volume through lenses and/or coded masks

Output signal: **charge amplitudes** (ADC) and **times** (TDC) provided by each SiPM as a result of the scintillation light collection

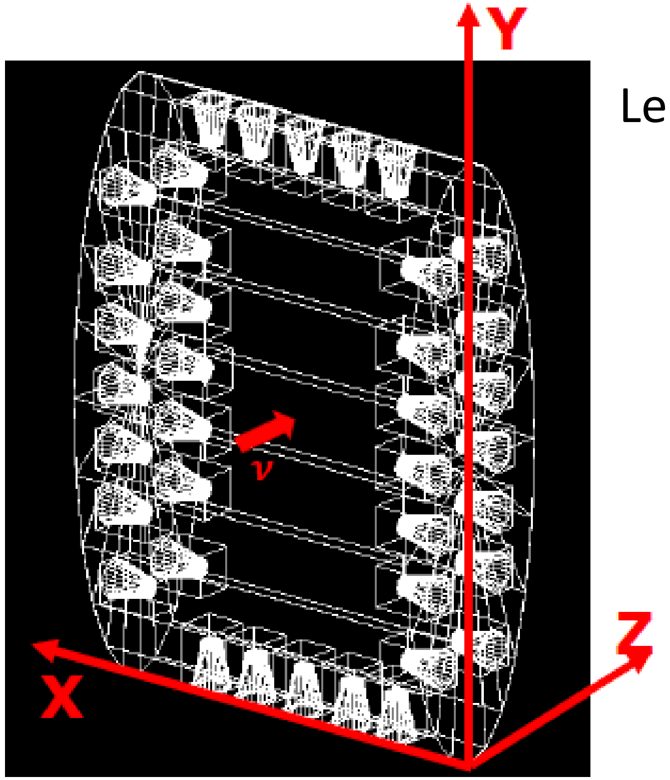
GRAIN Detector readout



Coded masks

- 1024 SiPM matrix
- SiPM 3x3 mm^2 area
- mask same size and hole pitch of SiPM matrix
- 60 cameras inside GRAIN, total 62k channels

GDML:



Lenses

- 38 cameras, for maximum coverage:
  - 14 pairs on the sides (at optimal distance)
  - 5 pairs on top/bottom
- Assuming 32x32 matrix sensors, with 2 mm pixels and 20% QE.

Calibration steps for GRAIN

Two distinct steps for GRAIN calibration

1st step:

The **p.e. peak alignment** (among SiPMs in a single matrix and in different matrices) will ensure to get the same charge-ADC value vs p.e.-multiplicity for all pixels.

Definition of a common $\mathbf{T_0}$ value to which the **time** of the first collected photon, provided by the TDC value for each SiPM, will refer.

Time synchronization with other sub-detectors at O(100ps).

Calibration steps for GRAIN

2nd step:

a) Energy deposit evaluation

The number of collected photons will be a measure of the energy released in GRAIN (transferred to the target nucleus and/or to the interaction products, i.e. tracks and neutral particles).

a) Vertex and tracks determination

Times and (spatial) distributions of collected photons on the SiPM matrices will provide the information useful to reconstruct Vertex position and tracks inside GRAIN.

Calibration steps for GRAIN

➢ Realization of 1st step:

- determination of **Breakdown Voltage** for each device (SiPM)
- ADC/p.e. **peak alignment** (inside the same SiPM matrix and among different matrices) by acting on single channel $\underline{V_{bias}}$ and Gain
- derivation of the (common) **ADC-$N_{p.e.}$ calibration curve**

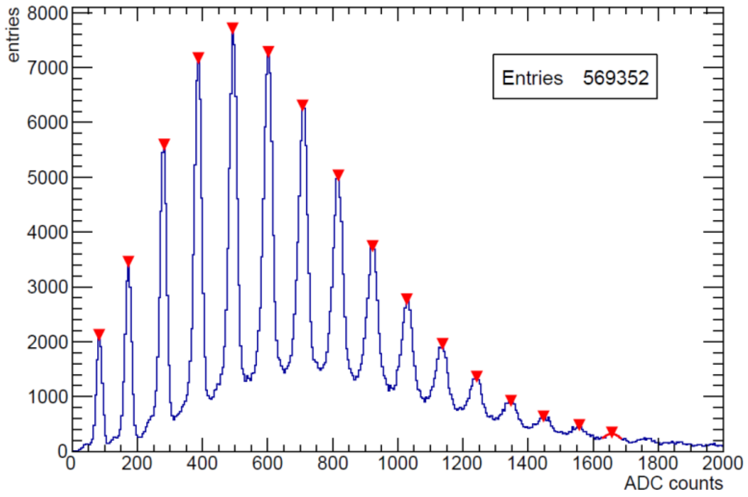
Note: If not possible (number of channels too large),

$\Rightarrow$ a-posteriori correction

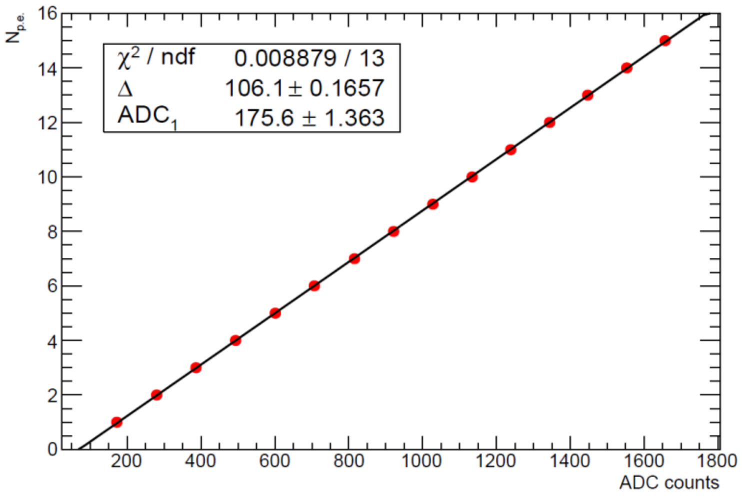
- **T_0 setting** to which all TDC values refer
- **Time synchronization** with other sub-detectors through a physics common process

PhotoElectron peak alignment

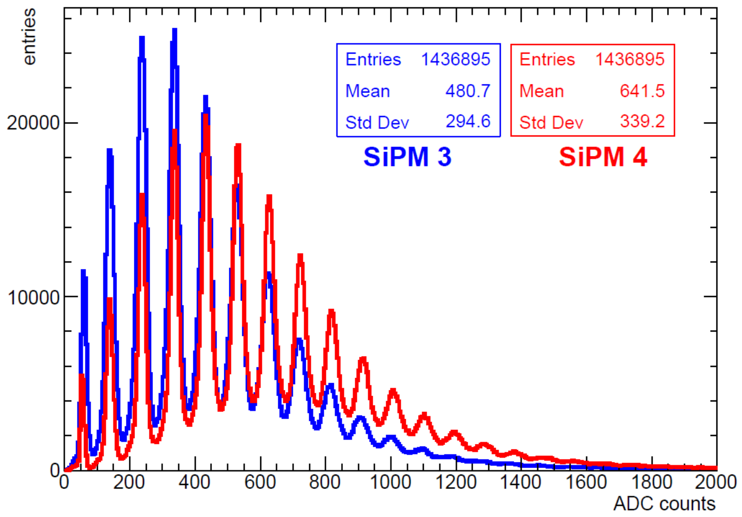
An example from tests of ECAL prototype read-out in Lecce.
Peak alignment and calibration curve for SiPM matrices (3 mm pixels):



Result of alignment of the 16-channels peaks of a 4x4 Hamamatsu SiPM matrix (3mm pixels)



ADC-$N_{p.e.}$ calibration curve



Result of peak alignment of two 4x4 SiPM matrices (with different photon collection efficiency)

Energy deposit evaluation

- Realization of 2nd step:

Energy deposit

In principle, two possible approaches:

a) **Calorimetric** measurement of total released energy
b) **Track-by-track** energy loss evaluation

a) Extract the whole energy released in GRAIN from the total number of collected photons by all SiPM matrices

b) For each reconstructed track, evaluate the associated amount of collected photons

Energy deposit evaluation

✓ Probably, both approaches are needed (because complementary and interleaved)…

For instance:

- the energy not deposited just near the interaction point, but generally spread-out in a (large) volume → different distances from the same detecting matrix
- the reconstructed tracks not enough to account for the total released energy

✓ In both cases, several factors must be taken into accounts:

- positions of interaction vertex and track propagation through the volume (geometrical acceptance, absorption of photons, ..)
- SiPM photon detection efficiency
- relation between energy deposit and scintillation light emission

Energy deposit evaluation

For a given track (or interaction event) in GRAIN, the photon content in the i-th image (i.e. in the i-th SiPM matrix) can be written as:

$$N^{\mathrm{i}}_{photons} = \alpha^{i}_{QE} \cdot \alpha^{i}_{GEOM} \cdot N_0 , \qquad N_0 = \mathrm{f} \cdot \Delta \mathrm{E}$$

α^{i}_{QE}: SiPM Photon Detection Efficiency in i-th matrix *(known)*

α^{i}_{GEOM}: geometric acceptance factor, depending on the distance and position of the pixels in i-th matrix, and (for coded masks) on the mask layout

(from MC simulations and comparison of different matrices)

f: factor relating deposited energy and scintillation light emission in LAr

(≈ known or estimated from experimental data ... ARTIC?)

Typical value for (UV) light emission: **$\mathrm{f} \sim 4 \cdot 10^4$ ph/MeV**

Physics processes useful for calibration

- ✓ Most obvious (or simple) physics process to be considered:

  MIP crossing the LAr volume.

Specific energy loss for a generic material: $\langle dE/dx \rangle \sim 2\ \mathrm{MeV/g \cdot cm^{-2}}$

Can be estimated from MC simulation or measured from experimental data.

Specifically, for LAr ($\rho \sim 1.4$ g/cm^3):

$dE/dL \sim 2.8$ MeV/cm $\Rightarrow N_0 \sim 1.1 \cdot 10^5$ ph /cm Photon emission per unitary pathlength

- ➢ From measured $N^{i}_{photons}$ for each i-th SiPM matrix (and different distances):

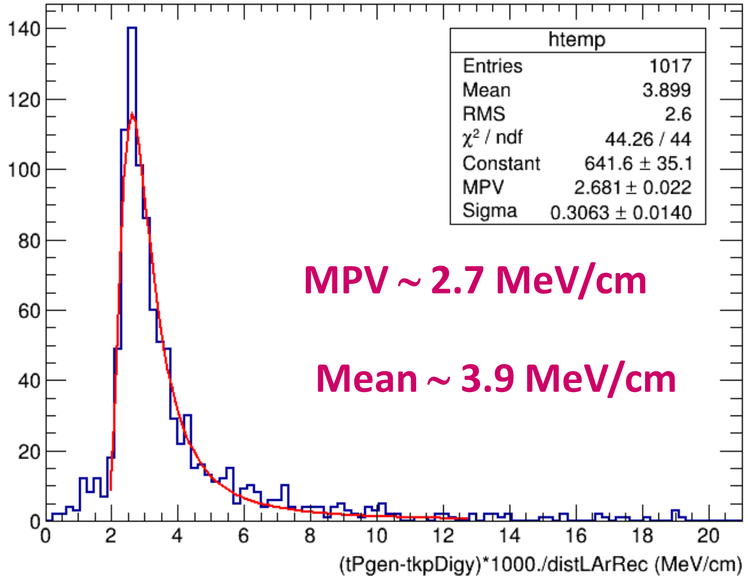
  $\Rightarrow$ experimental estimate of α^{i}_{GEOM} and comparison with MC simulation

Muons crossing LAr volume

- **Precise determination of <dE/dx>**

  From MC simulation (FLUKA) of SAND, for a μ crossing GRAIN (cryostat walls included):

ΔE/ΔL (MeV/cm)

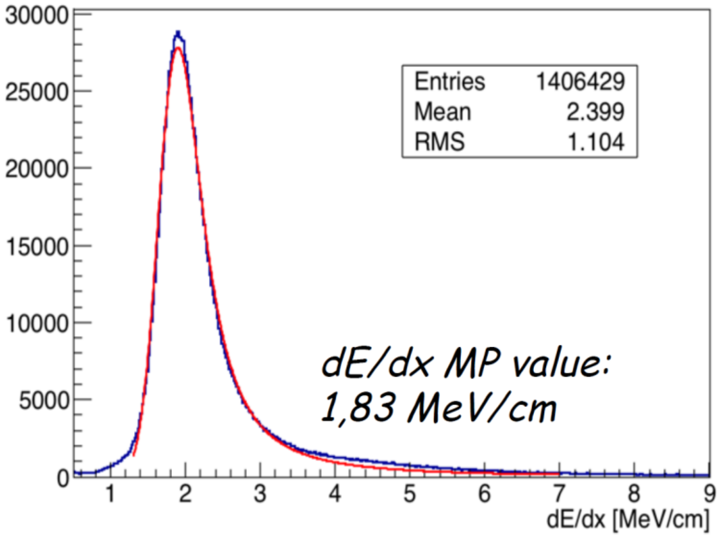


ΔL: distance between interaction Vertex in GRAIN and first hit in STT

ΔE: muon energy loss in ΔL

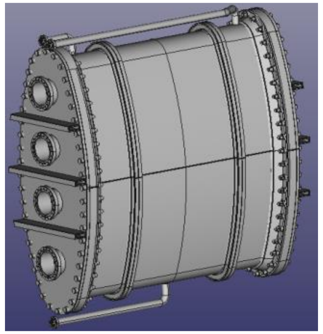
From ICARUS

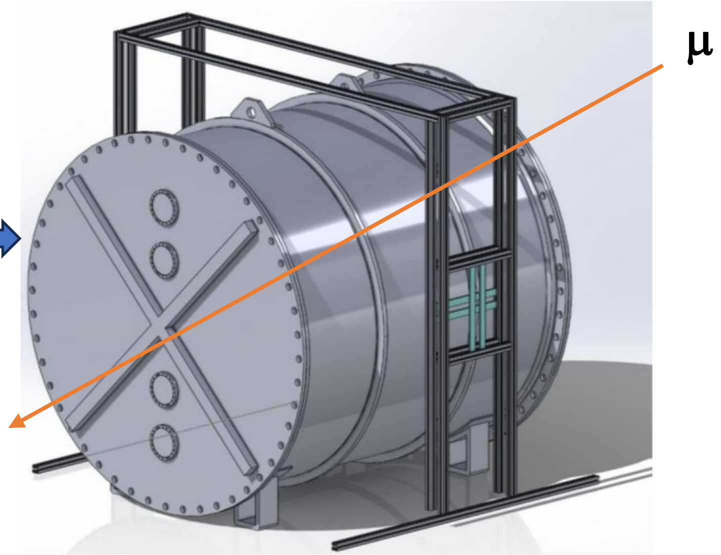
Full 3D reconstruction on selected muon tracks crossing LAr volume



Muons crossing GRAIN

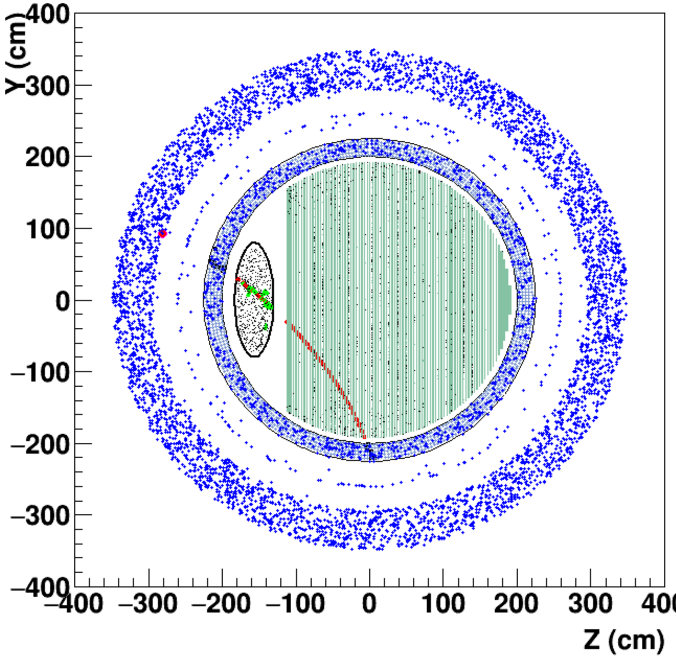
A physics process like a MIP (muon) crossing LAr volume in GRAIN easily available both in **GRAIN prototype at LNL** and on the **ν beam**





GRAIN prototype at LNL

Muon from ν interaction in the yoke and crossing GRAIN



Physics processes useful for calibration

- ✓ Calibration obtained from selected processes in GRAIN, using directly the experimentally collected events (in prototype or on the ν beam)

  Other “standard candle” processes:

  - **MIP**
  - **muon decay electrons**
  - **stopping muons**
  - $\boldsymbol{\pi^0}$

- ✓ Ad hoc calibration sources (?):

  - Radioactive source
  - LED

Full event reconstruction in GRAIN

Vertex and tracks

The use of several algorithms, like:

- Voxel pattern through coded masks
- Multidimensional geometric projections, through lenses and coded masks
- …

should allow to reconstruct Vertex position and Tracks from the spatial distributions (i.e. images) and (possibly) times of collected photons by the SiPM matrices.

Conclusions

- ✓ Some preliminary ideas for GRAIN calibration

- ✓ Calibration in 2 steps

  1° step: equalization of the SiPM channel responses

  2nd step: estimate of physical quantities: energy deposit, vertex position (for internal interactions), tracks, ..

- ✓ Use of «standard candle» processes (selected directly in the collected data): MIP, stopping muons, muon decay e-, π^0, …

- ✓ Ad hoc sources: radioactive source, LED, .. ?