Istituto Nazionale di Fisica Nucleare
SEZIONE DI LECCE

GRAIN calibration with muons

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GRAIN Detector calibration

Generally for a ν detector

The detector signals have to be correlated to the properties of particles produced in the neutrino interaction: momentum and energy, charge, ToF, particle ID, …

Objective: get full information on the **interacting neutrino** features:

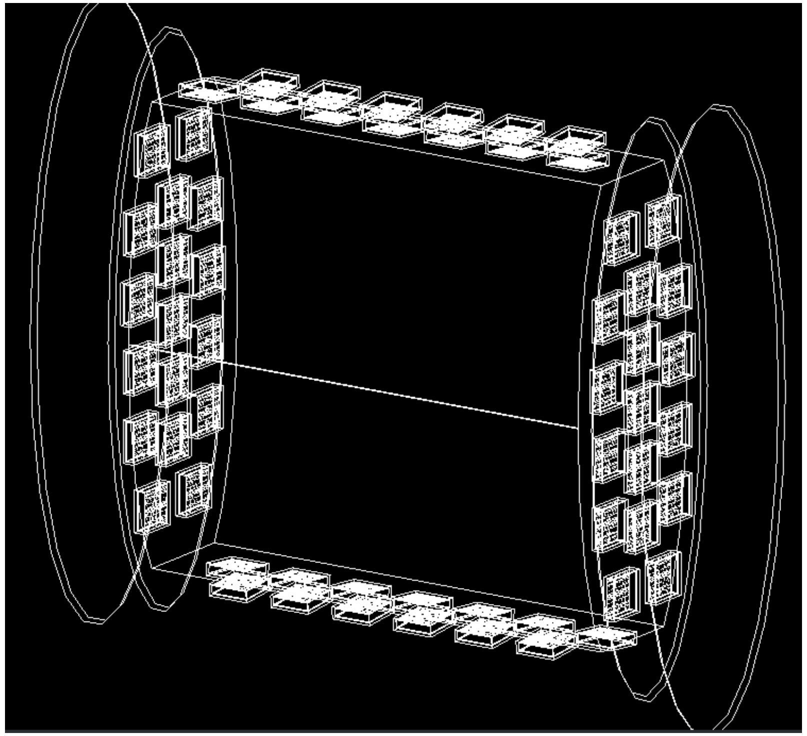
- **Energy, Flavor, Interaction type**

The case of GRAIN

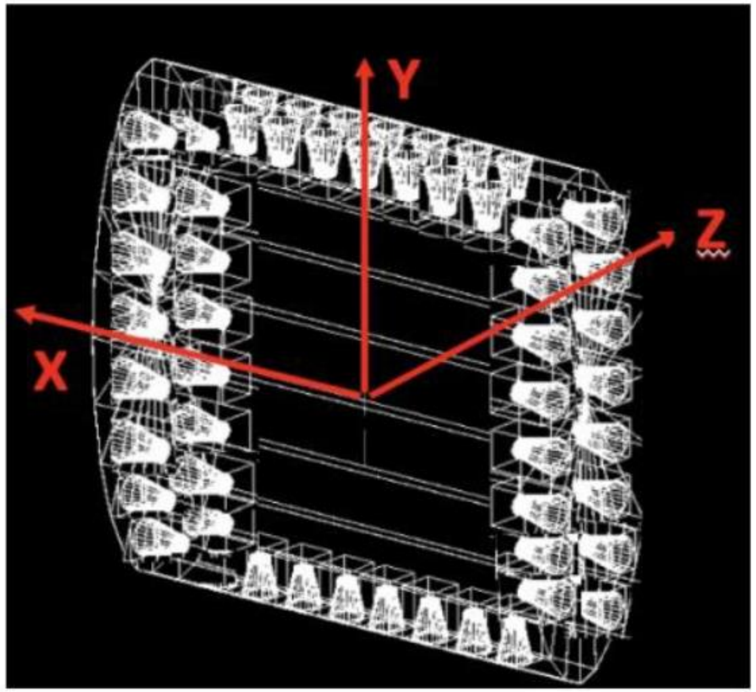
Event features to be reconstructed from detector signals: **interaction vertex**, **tracks**, **time**, **energy deposit** (transferred directly to the LAr and/or carried out by the outgoing tracks)

Detector: **SiPM matrices** collecting the scintillation light photons in the whole sensitive LAr volume through lenses and/or coded masks

GRAIN Detector readout



Coded masks



Lenses

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

- 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.

Energy deposit evaluation

✓ In principle, two possible approaches (probably complementary and interleaved):

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

a) **Track-by-track** energy loss evaluation
   For each reconstructed track, evaluate the associated amount of collected photons

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

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

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

  - π^0

- ✓ Ad hoc calibration sources (?):

  - ~~Radioactive source~~

  - LED

Use of muons for calibration

✓ Most obvious process to be considered: **MIPs crossing the LAr volume**

- muons from the beam interaction outside GRAIN
- cosmic ray muons

✓ 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.

For LAr:

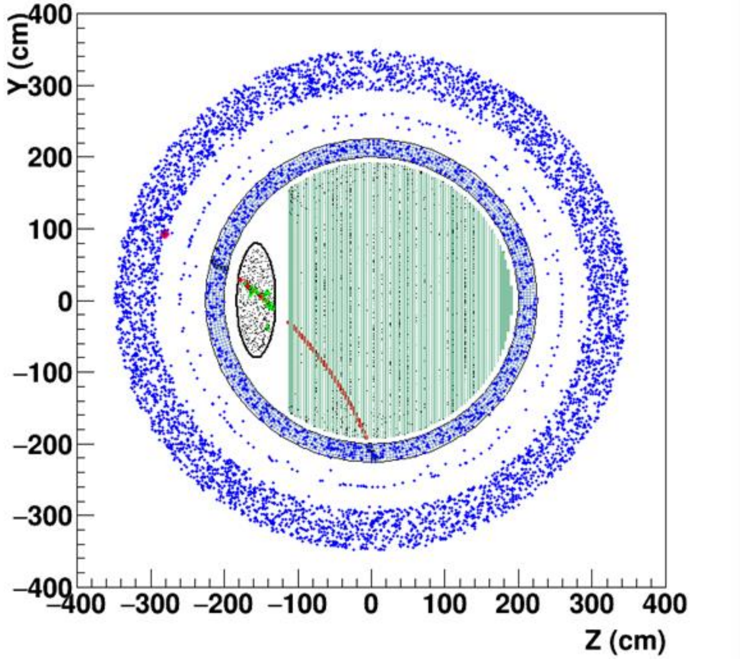
$dE/dL \sim 2.5$ MeV/cm $\Rightarrow N_0 \sim 10^5$ ph /cm   Photon emission per unitary pathlength (assuming $f \sim 4 \cdot 10^4$ ph/MeV)

➢ The relation between muon Pathlength and Energy loss exploited to get knowledge of energy deposit in LAr, to be related to the amount of detected photons

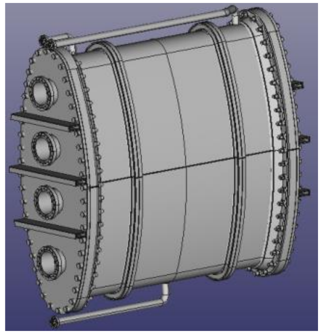
Muons crossing GRAIN

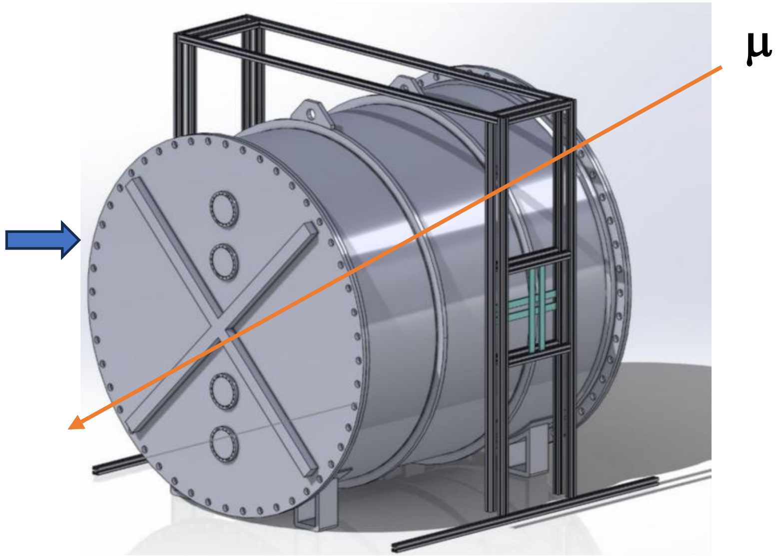
A physics process like a MIP (muon) crossing LAr volume in GRAIN easily available both on the ν **beam** and in **GRAIN prototypes (ARTIC and LNL)**

Muon from ν interaction in the yoke and crossing GRAIN



GRAIN prototypes at LNL





A possible plan

Possible method to be implemented:

- Reconstruct the tracks in the event (“*SandReco*”)
- Select the events with a clean muon track generated outside and crossing GRAIN
- Estimate the track **Pathlength (ΔL)** and the corresponding **Energy Loss (ΔE_{loss})** in LAr
- Correlate the total **collected photons** to the **deposited energy** in Lar, in order to calibrate photo-sensor response

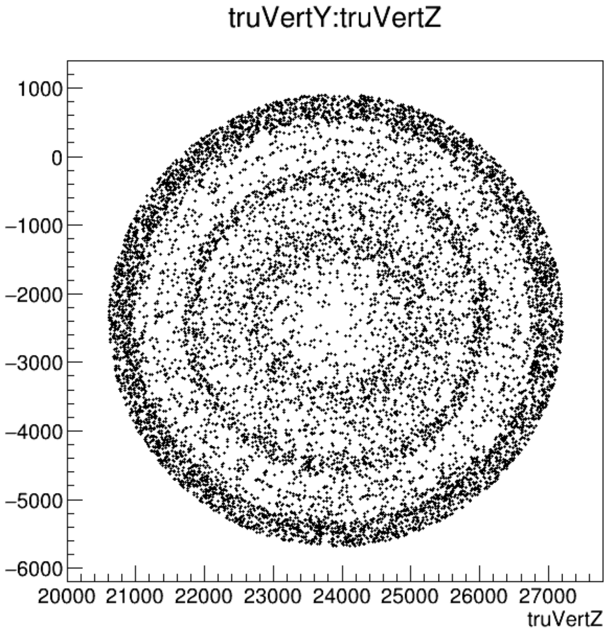
To test this procedure:

- MC samples of nu_mu CC interactions both in ECAL and magnet Yoke were generated
- The events with a muon crossing GRAIN are then selected, and **ΔL** and **ΔE_{loss}** are evaluated from *EdpSim* information related to the muon trajectory
- The subsample of events is considered in which the muon crosses GRAIN not accompanied by other particles
- By using the photo-sensor setup (including layout, efficiencies and electronics), the number of photons collected by all SiPM matrices is finally correlated to ΔE_{loss}

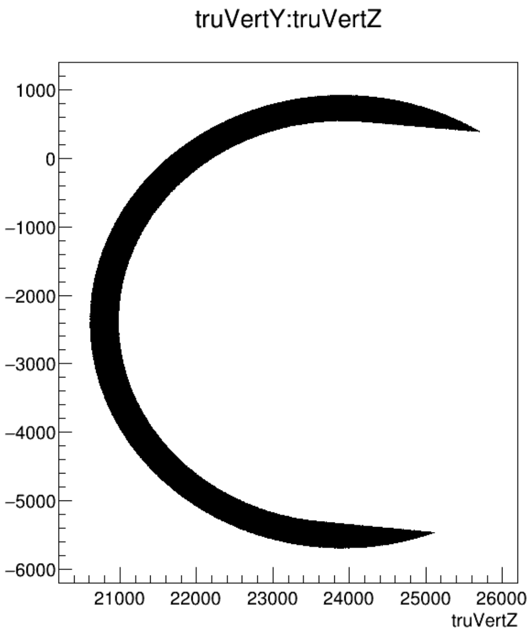
Monte Carlo simulation of ν interactions

Three samples of nu_mu CC interactions in whole SAND, in the Magnet yoke and in ECAL were generated through GENIE

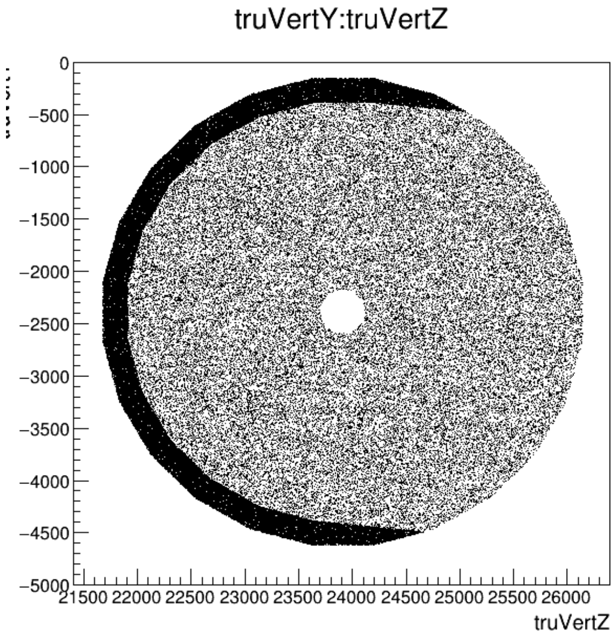
Distribution of interaction vertexes:



SAND



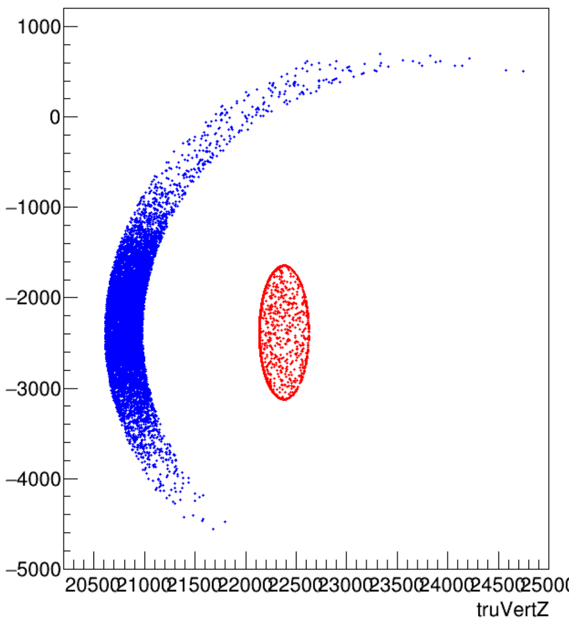
Magnet yoke (no end-caps)



ECAL

Events with the muon entering GRAIN

Vertex in the Magnet yoke

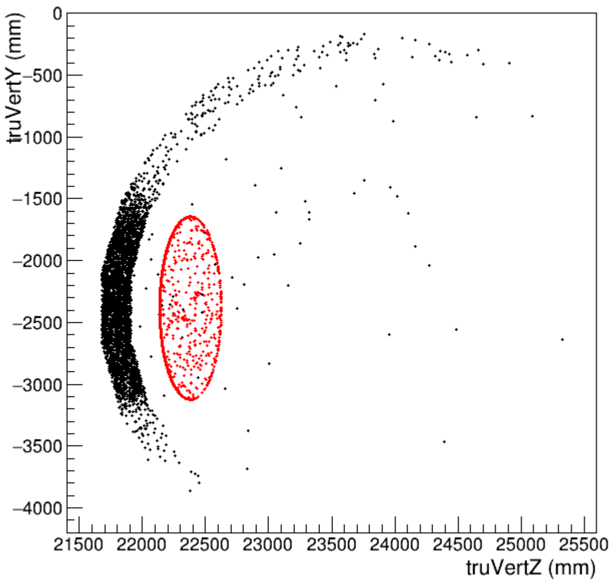


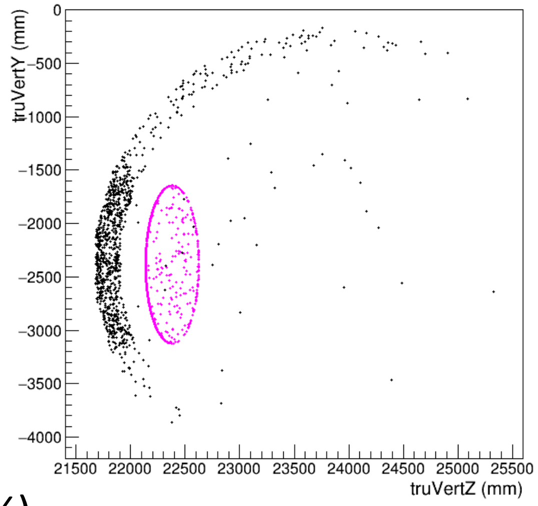
Total interaction events: 441,000

Muons entering GRAIN: ~ 13,000 (3%)

→ Clean muons: ~ 10,000 (2.3%)

Vertex in ECAL





Total interaction events: 200,000

Muons entering GRAIN: ~ 6,000 (3%)

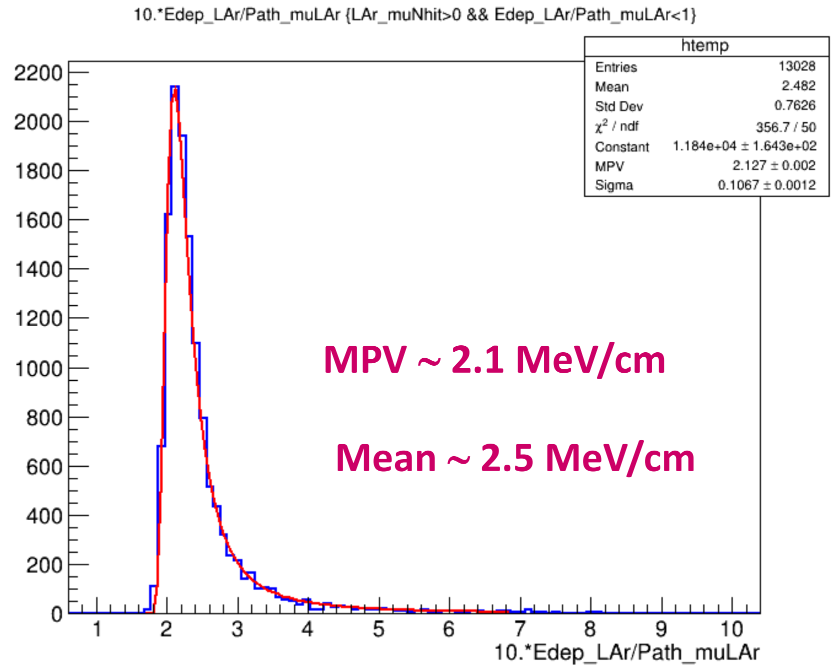
→ Clean muons: ~ 1,500 (0.8%)

Energy deposit evaluation

Selection of events with the muon entering the GRAIN volume:

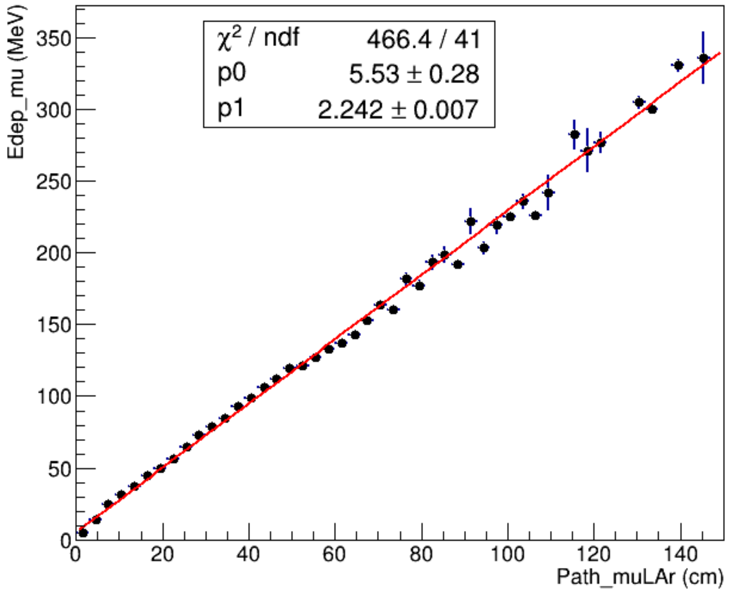
➢ **Precise determination of <dE/dx> by the muons crossing GRAIN**

ΔE/ΔL (MeV/cm)



ΔL: pathlength in GRAIN LAr
ΔE: energy loss by the muon in ΔL

Relation btw ΔL and ΔE

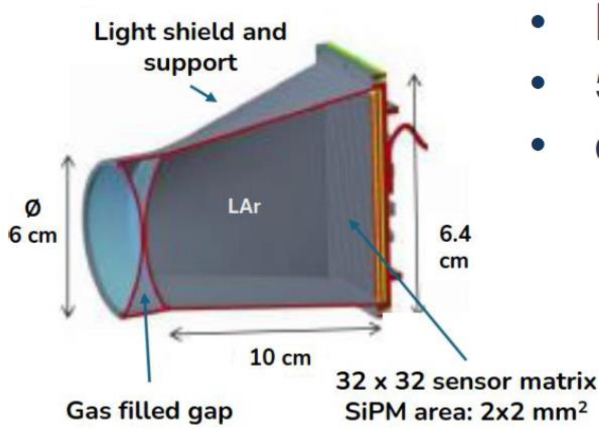


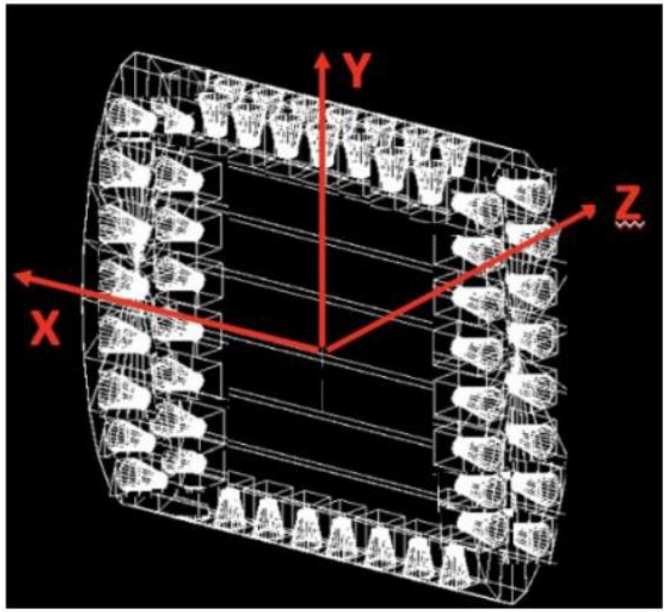
Calibration curve to extract muon energy from Track-length

Simulation of light collection and imaging setup

Scintillation light photons propagated in LAr and collected by the photo-sensor system through *OptMen* code

Simulation of the Lens-camera setup with proper SiPM-PDE and Electronics (also the Coded mask setup could be used)

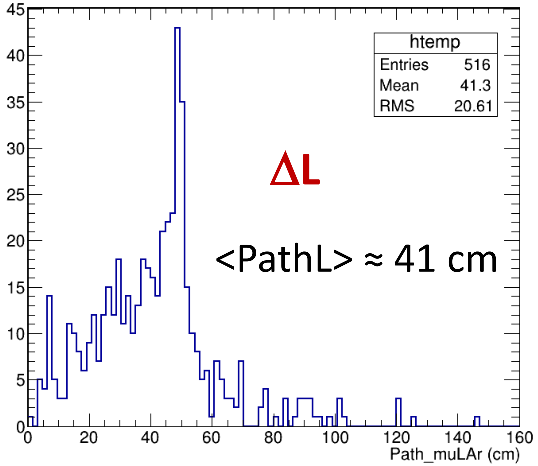




Total # of 53 cameras in GRAIN

PDE ≈ 0.1 - 0.2

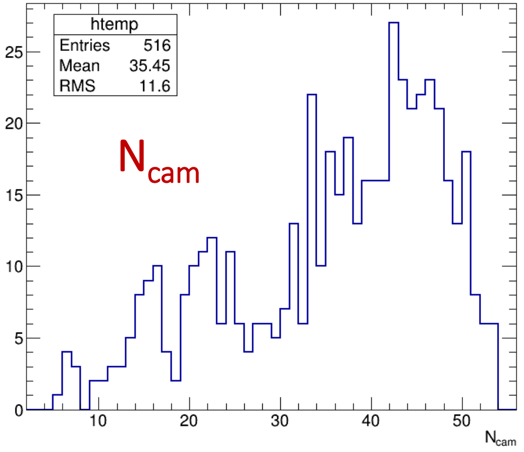
Muon Pathlength in GRAIN and Collected photons

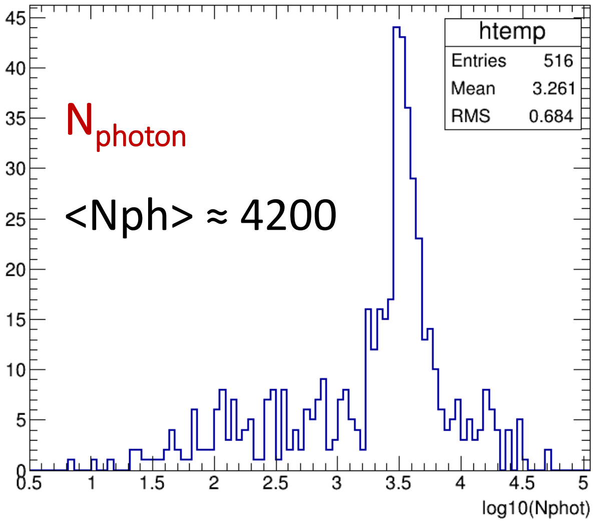


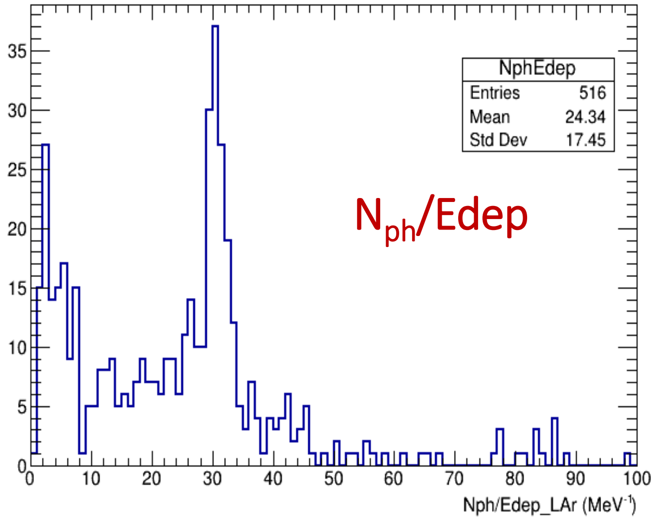
Pathlength of clean μ's in LAr

Photons collected by the 53 cameras in GRAIN

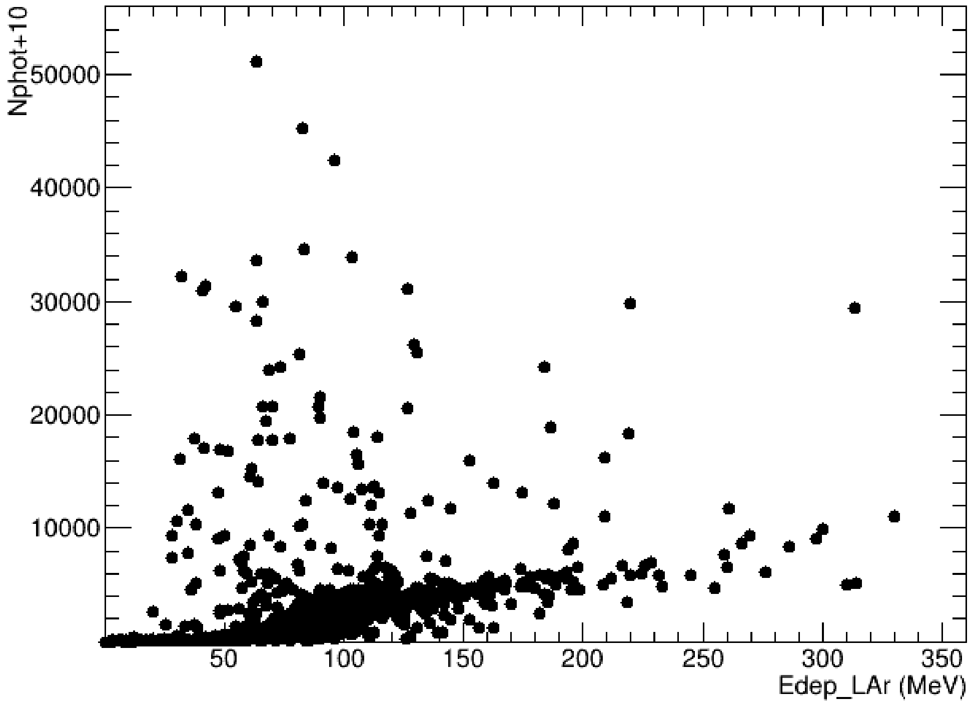
- Average number of fired cameras ≈ 35
- Average number of photons ≈ 4200
- Significant fraction with low number of photons





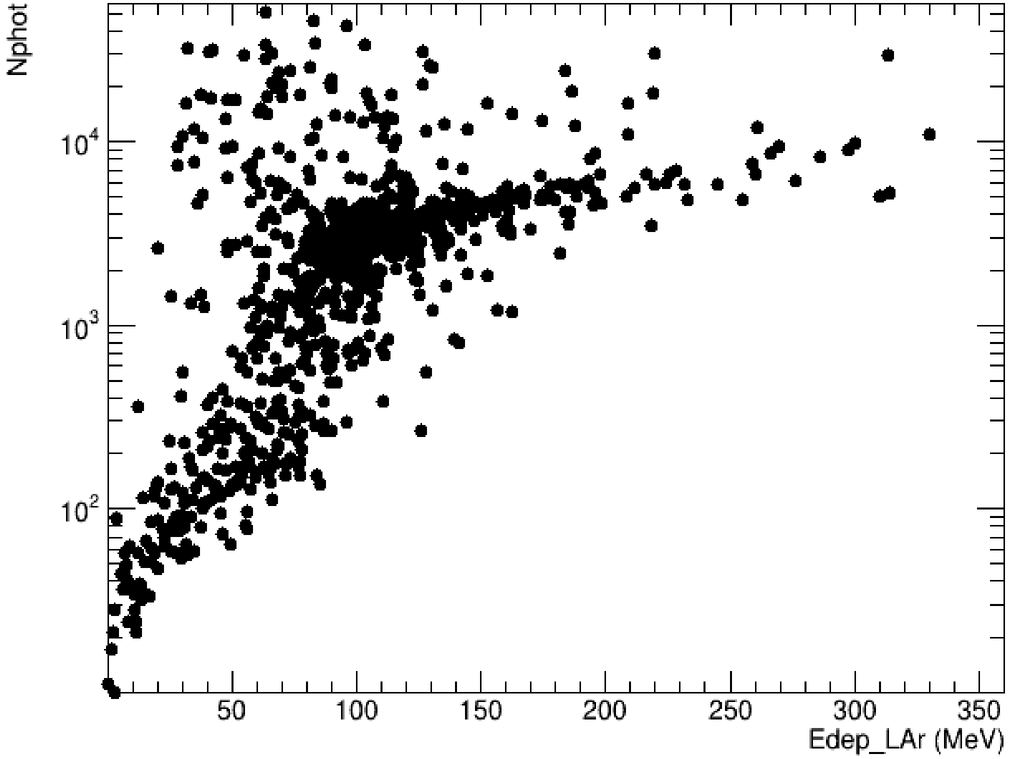


Correlation btw detected photons and deposited energy



- Not a so narrow correlation
- Possible effects from track position vs geometrical acceptance

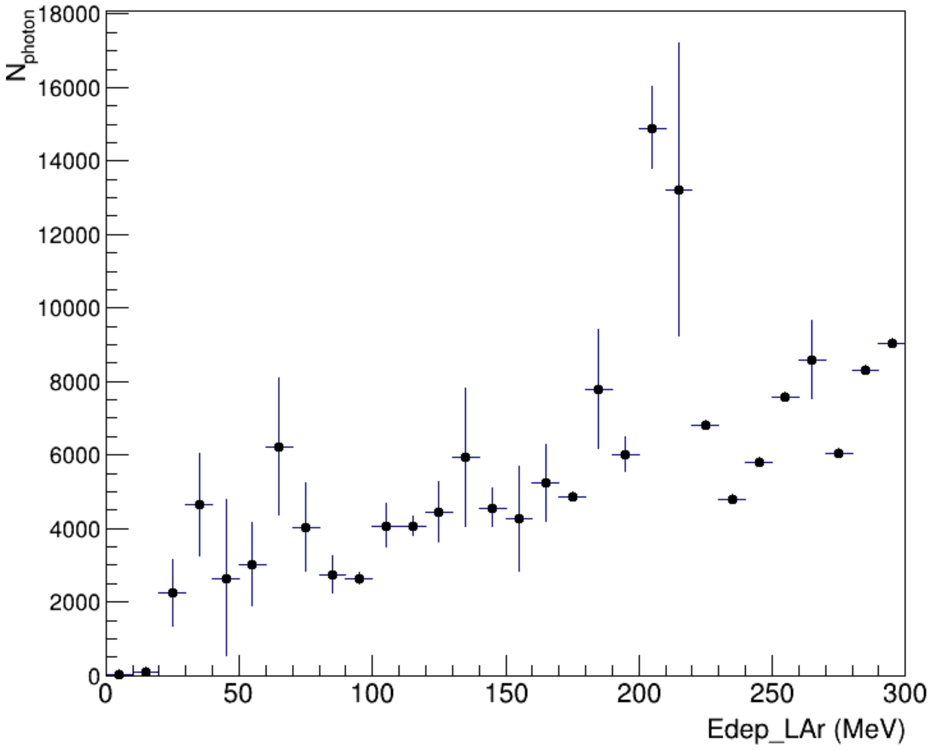
Log scale for N $_{phot}$



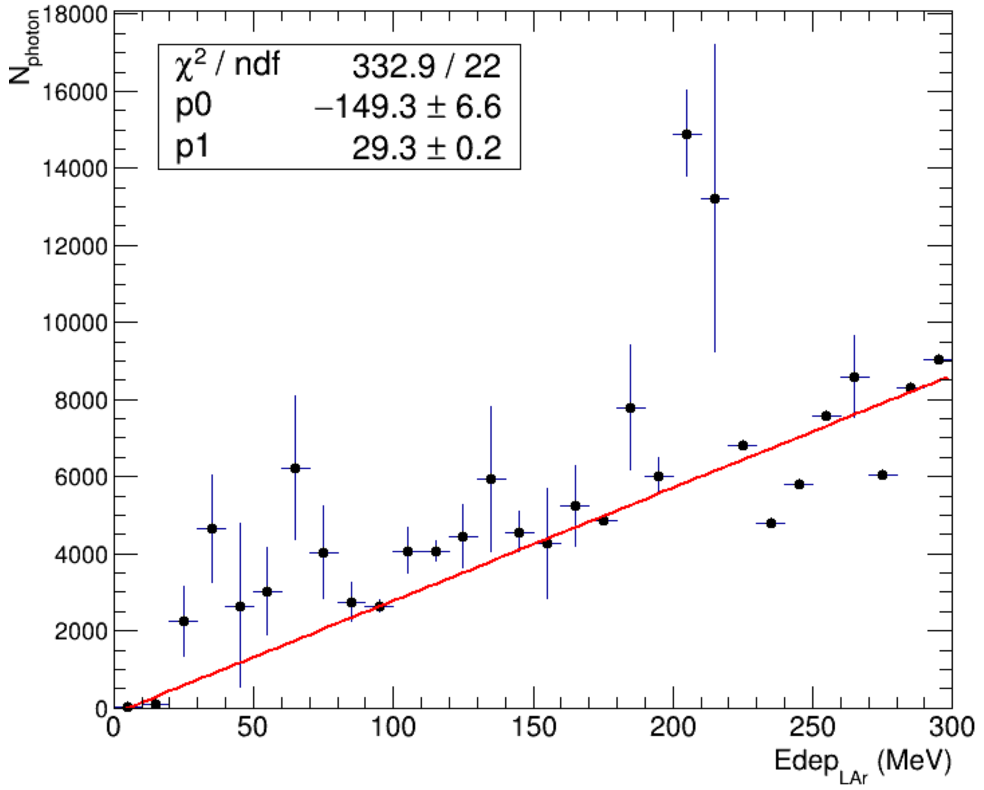
Apparently, different behaviours ?

Calibration curve from muons

Correlation using the profile



Calibration curve from the fit



Expected muon flux from the beam and CRs

✓ Different contributions of the target masses in SAND for beam neutrinos

Table 1.29: Total number of $(\nu_\mu + \bar{\nu}_\mu + \nu_e + \bar{\nu}_e)$ CC+NC events expected within a single beam spill (9.6 μs, 7.5×10^{13} POT) in the various detector components for both the FHC and RHC beam modes.

Detector element	Mass	FHC	RHC
Magnet	511 t	68.9	36.6
ECAL	100 t	13.5	7.2
LAr+STT	8.2 t	1.1	0.59
STT fiducial volume	5.5 t	0.74	0.39
Total	619.2	83.5	44.39

- From the interaction rate /spill in Magnet yoke and ECAL, a quite low number of clean muons are expected to cross GRAIN per spill (≲ 1 / spill)

Table 1.34: Number of events per spill (9.6 μs, 7.5×10^{13} POT) and selection efficiency for the signal from ν_μ CC in the front barrel ECAL and the backgrounds from rock muons and magnet events.

	ECAL		Rock muons		Magnet events	
Cut	Events	ε (%)	Events	ε (%)	Events	ε (%)
No cut	2.23	100.0	1447.26	100.000	50.82	100.000
μ in ECAL FV	2.23	100.0	12.73	0.880	18.92	37.229
STT & ECAL hits	1.63	72.9	6.05	0.420	3.443	6.775
NN cut	1.56	95.5	0.10	0.007	0.07	0.136

- Further contribution from rock μ's (~ 1.7/spill) …

✓ **Contribution from Cosmic Rays …**

CR Muon flux at surface ~ 0.01 μ/(s cm^2) + underground reduction of ~ 100

Effective area of GRAIN for <60^o CR muons: ~3×10^4 cm^2 ⇒ ~ 3 μ/s are expected to cross GRAIN

Drawback: smaller acceptance by the tracker for a precise track reconstruction

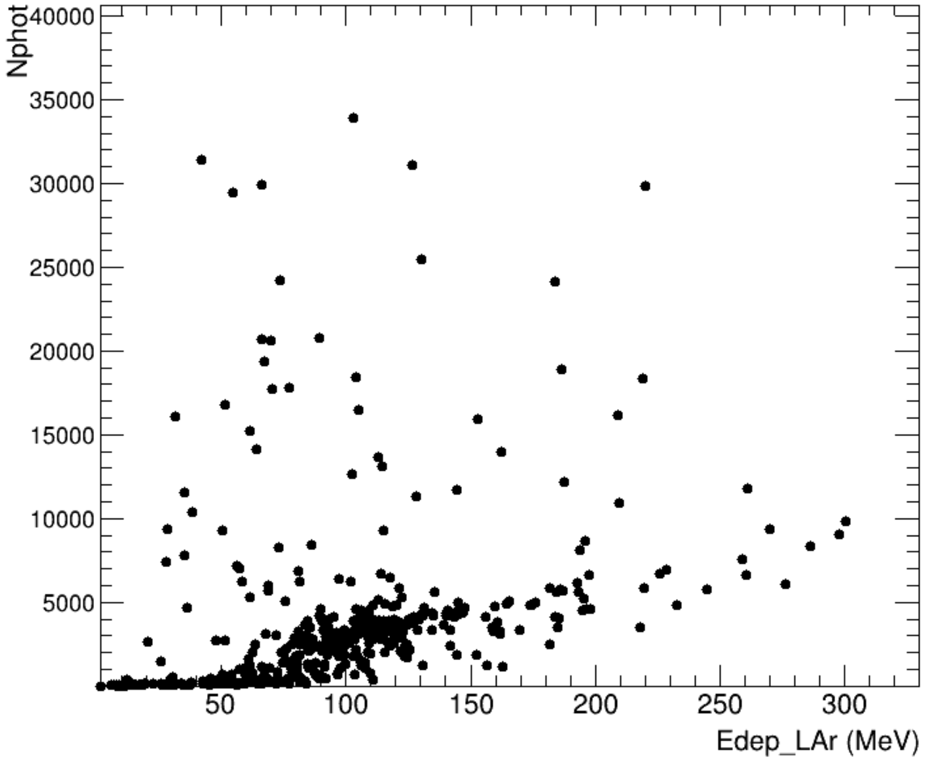
- **Main contribution only if inter-spill DAQ were ON**

Conclusions

- ✓ Primary aim of GRAIN calibration: measure of deposited enery
- ✓ Available «standard candle» processes (selected directly in the collected data) useful for this purpose: MIP, stopping muons, muon decay e-, π^0, …
  Ad hoc sources: ~~radioactive source~~, LED, .. ?
- ✓ Most obvious available process: muons crossing the LAr volume, from beam interactions outside GRAIN (other detector volumes, rock) and cosmic rays
- ✓ A possible procedure for energy calibration proposed and preliminarly tested, based on the Monte Carlo simulation of ν_μ interactions in ECAL and Yoke, and the Lens-camera system response (including geometrical layout, PDE, electronics, ..)
- ✓ Results too preliminary to get conclusions on the method validity

BACKUP

Correlation btw photons and deposited energy



- Not a so narrow correlation
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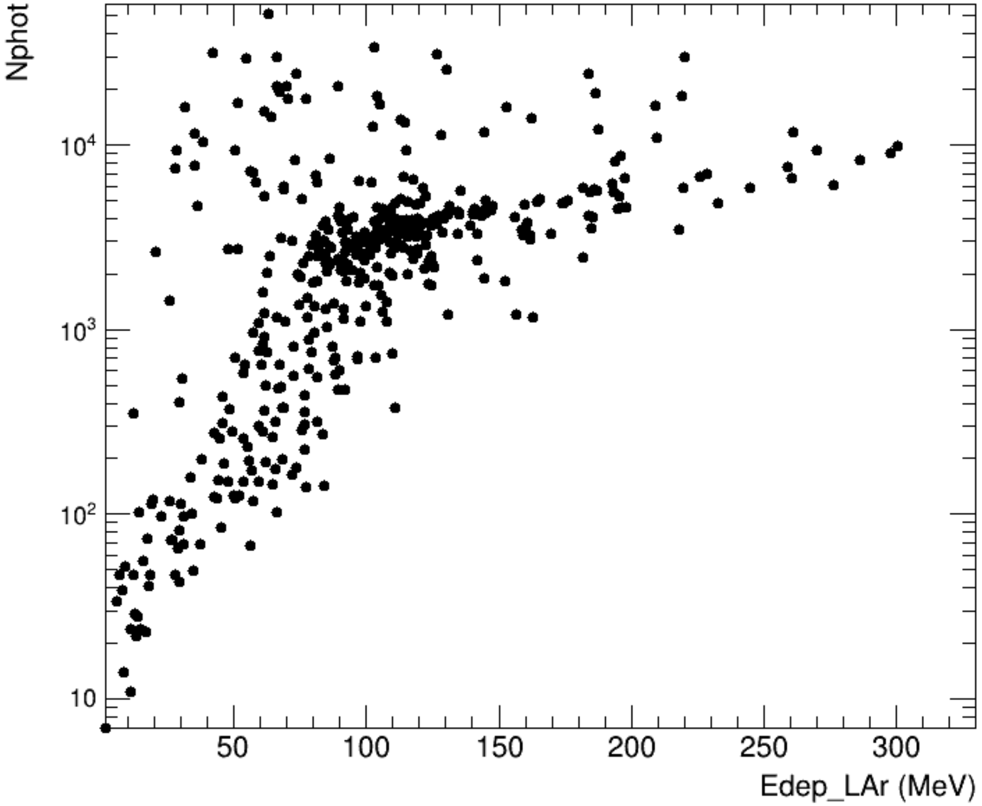
Log scale for N $_{phot}$



Apparently, different behaviours ?

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:

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

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?)

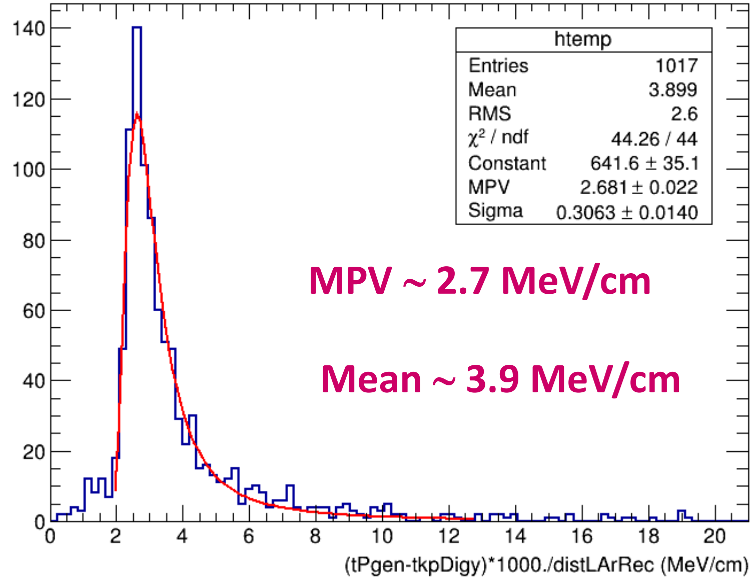
Typical value for (UV) light emission: $\mathbf{f \sim 4 \cdot 10^4}$ **ph/MeV**

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