Istituto Nazionale di Fisica Nucleare
SEZIONE DI LECCE

GRAIN calibration with muons

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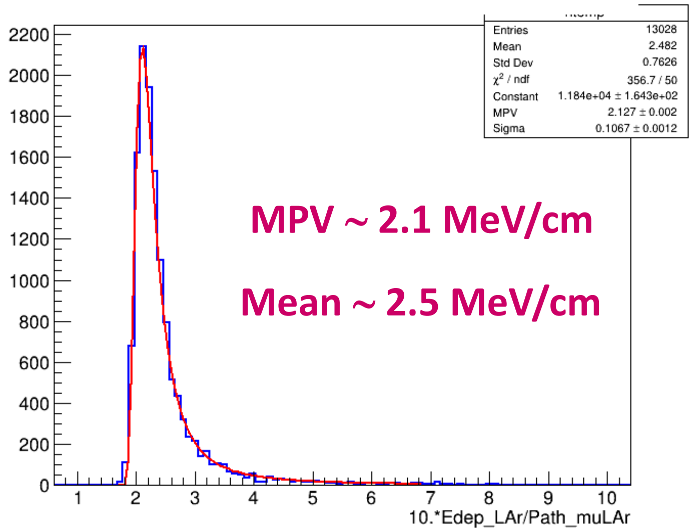
Use of muons for GRAIN calibration

✓ Natural energy calibration probe: **MIPs crossing the LAr volume**

- muons from the beam interactions outside GRAIN (detectors, rock, ..)
- cosmic ray muons

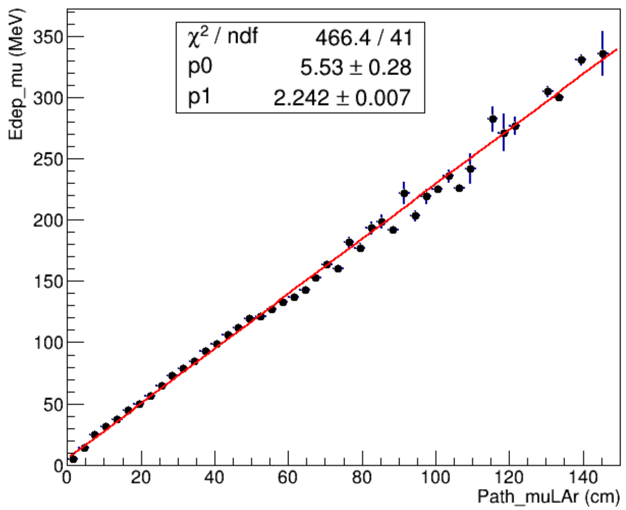
✓ Specific energy loss by muons in LAr

ΔE/ΔL (MeV/cm)



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

Relation btw ΔL and ΔE

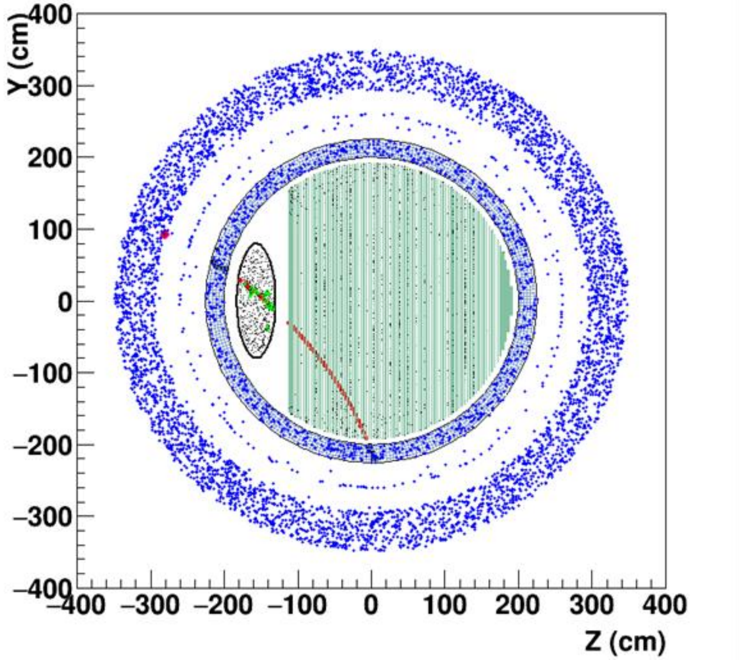


Correlation useful to extract muon energy deposit from Track-length

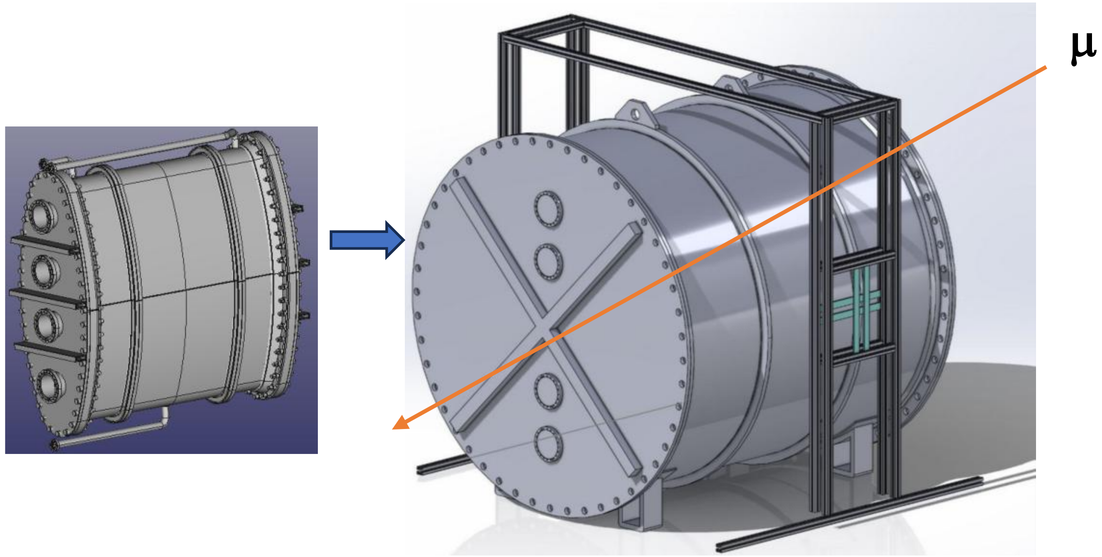
Muons crossing GRAIN

- Muons as MIPs crossing LAr volume in GRAIN are easily available both on the ν **beam** and in **GRAIN prototypes (ARTIC and LNL)**

Muon from ν interaction in the yoke and crossing GRAIN



Full-scale GRAIN prototype at LNL



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 $\times$ 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

	Magnet Yoke		ECAL		Yoke + ECAL		GRAIN	
Total/spill	**69**		**14**		**83**		**0.14**	
CC + (NC)	**51**	(18)	**10**	(4)	**61**	(22)	**0.1**	(0.04)
Evts in **ECAL**	**12** (24%)		**10** (100%)		**22** (36%)			
Evts in **GRAIN**	**2.2** (4,4%)		**2.0** (19%)		**4.2** (6,9%)		**0.1**	
μ's from rock	**~1.7/spill in GRAIN (*)**							

- 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 $\times$ 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 …

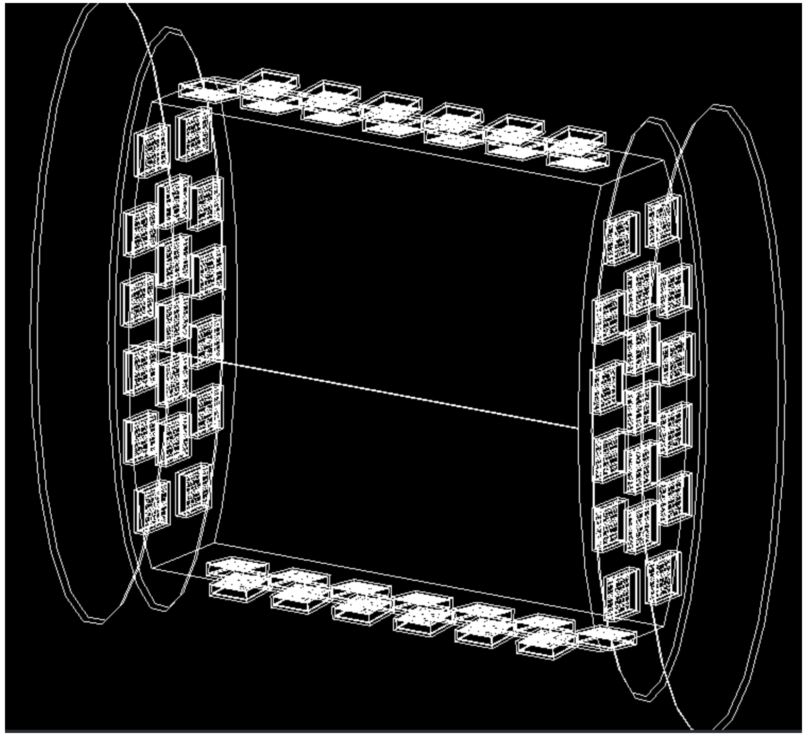
CR Muon flux at surface ~ 0.01 μ/(s cm^2) + underground reduction of ~ 100

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

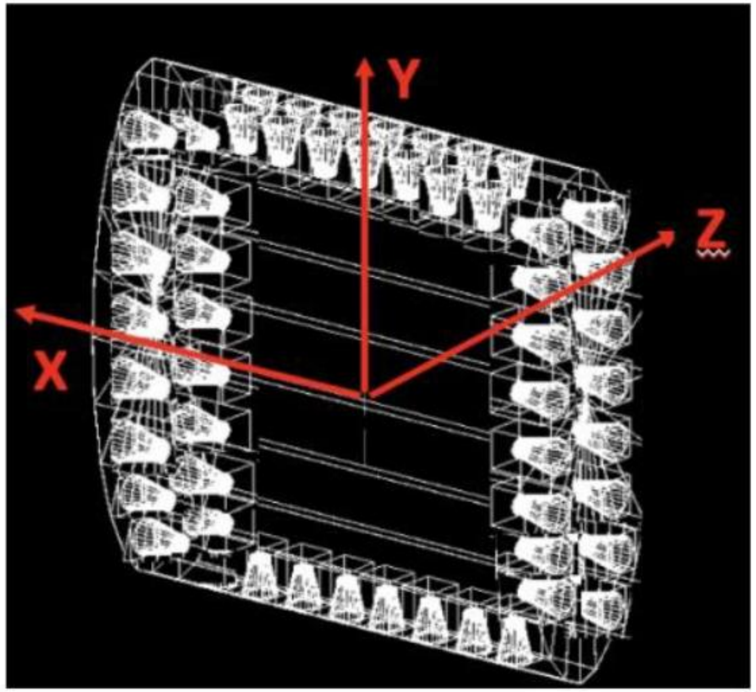
Drawback: smaller acceptance by the tracker for a precise track reconstruction

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

GRAIN Detector readout by photosensors



Coded masks



Lenses

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

- 53 cameras for maximum coverage:
  - 16 pairs on the sides (at optimal distance)
  - 7 pairs on top
  - 7 single cameras on bottom
- 32 x 32 SiPM matrix, with 2 mm pixels and 20% PED

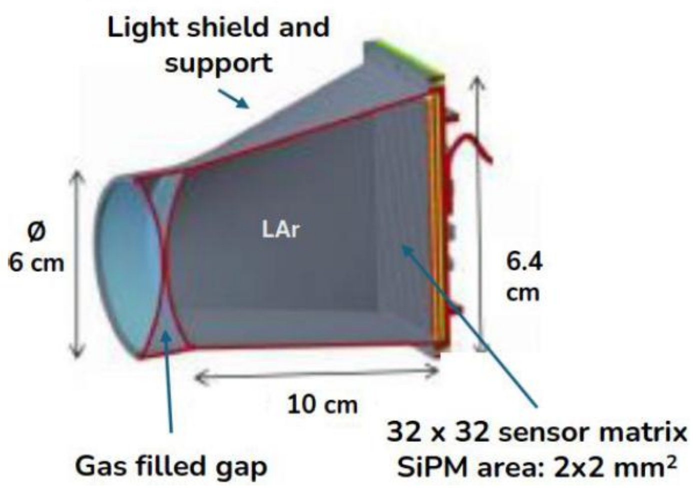
Imaging setup: Lens-camera system

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

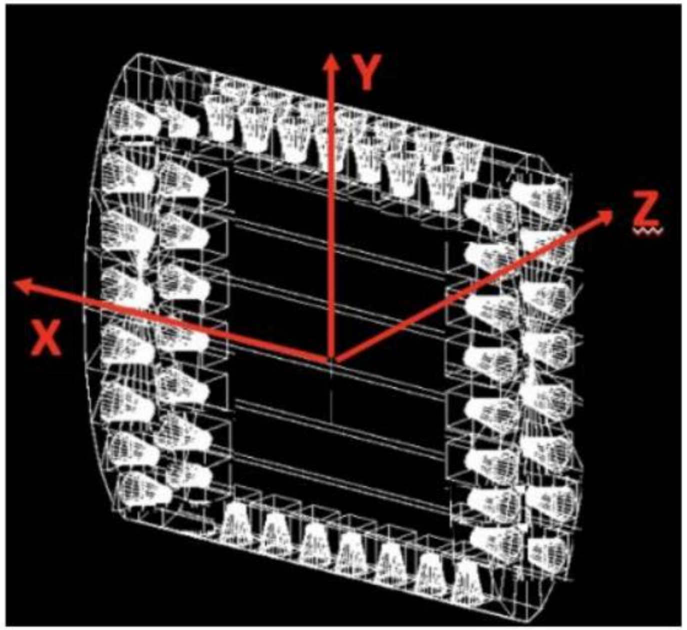
Simulation of the Lens-camera setup with proper SiPM-PDE and Electronics

- **Sensor matrix:**
  - 32 x 32 Silicon Photomultipliers (SiPM)
  - SiPM active area: 2x2 mm^2

  PDE ≈ 0.1 - 0.2



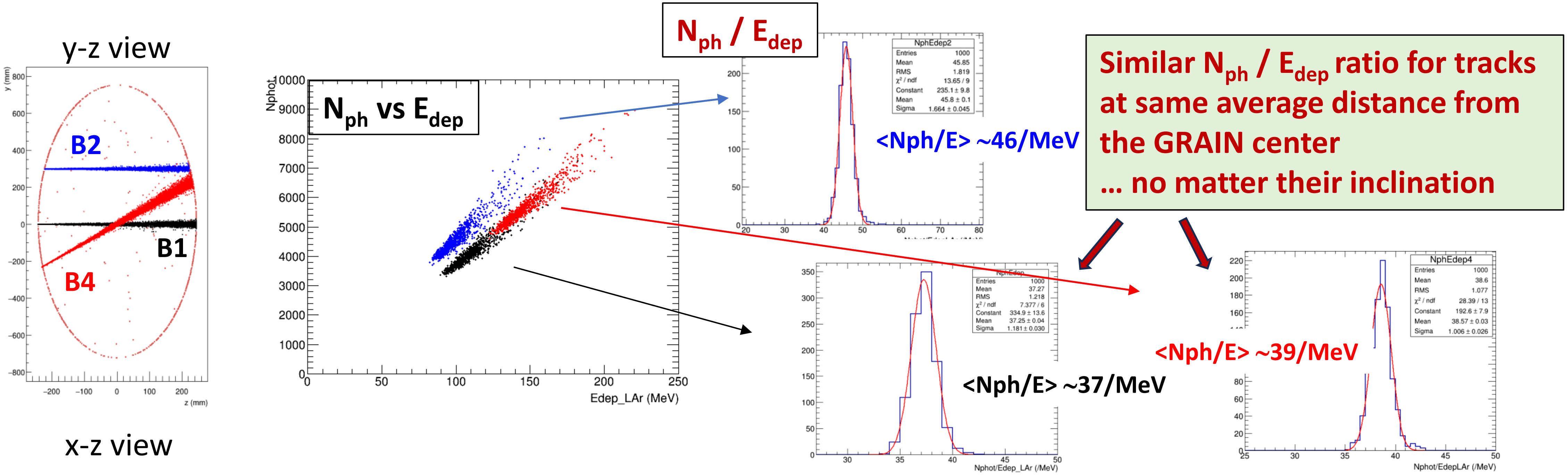
Total # of 53 cameras in GRAIN



Simulation of muon beams crossing GRAIN

- Scintillation photon emission $f \sim 4 \cdot 10^4$ ph/MeV
- The photon collection depends on the energy deposit location inside GRAIN, according to the camera layout

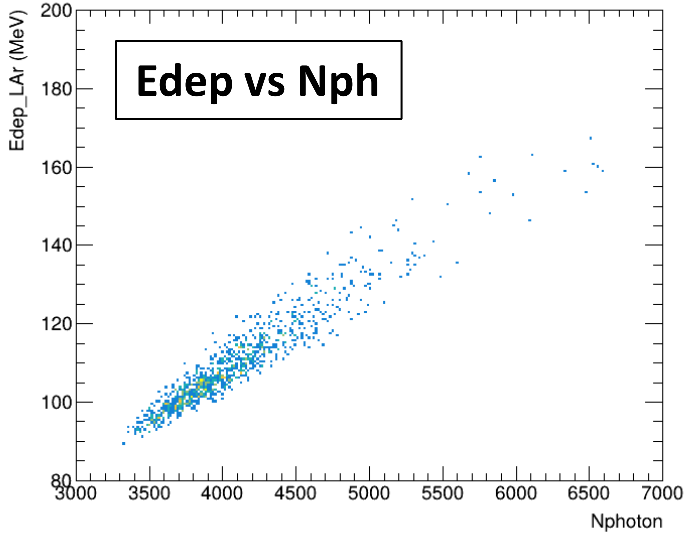
  $\Rightarrow$ The calibration constants are functions of the position and orientation of the track related to the scintillation light emission

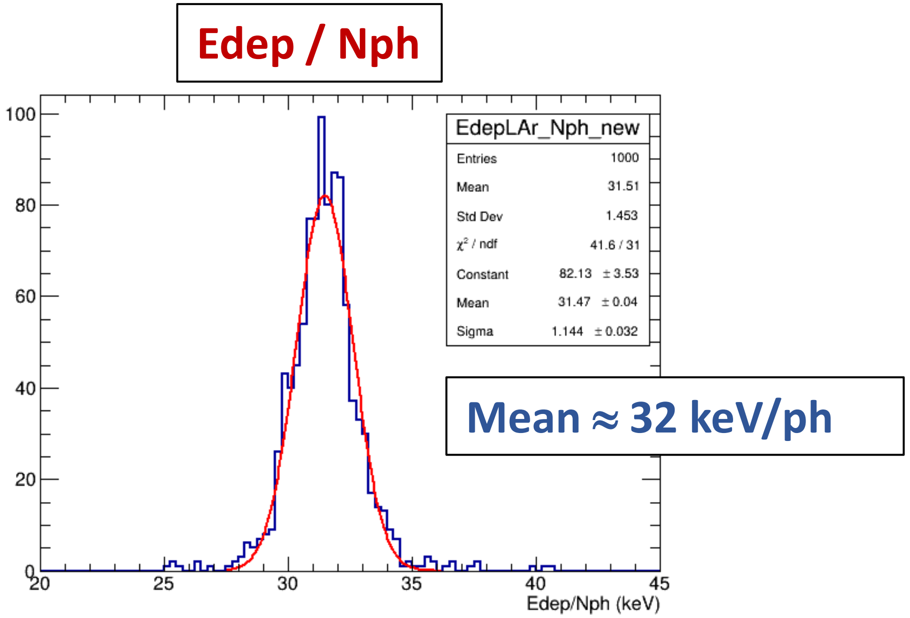


Calibration constants for energy estimate

Mean of the distribution of **(Edep_LAr / Nphoton)** taken as **calibration constant** for a given position inside GRAIN

Random beam





The "constants" are parametrized with the distance from GRAIN center, to account for dependence on the average position of deposited energy (the track) on X and Y axes

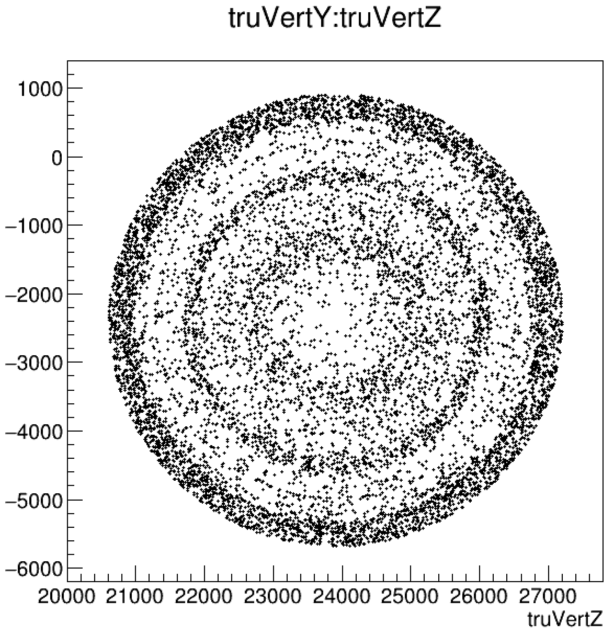
- **Assumption: track position and length reconstructed in GRAIN**

(by combining information also from Tracker and Ecal)

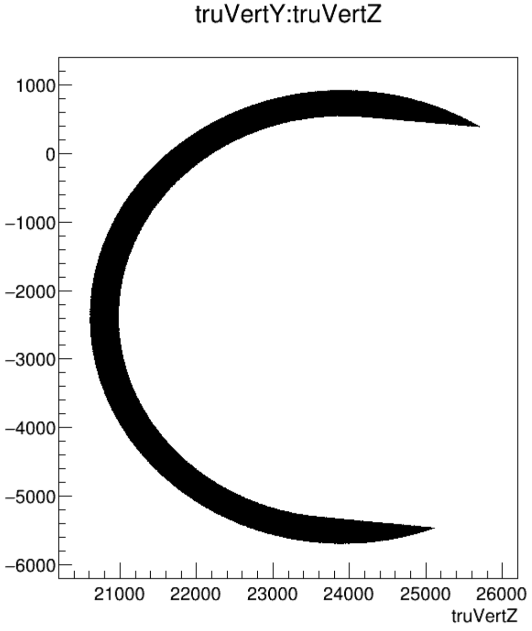
Monte Carlo simulation of ν interactions

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

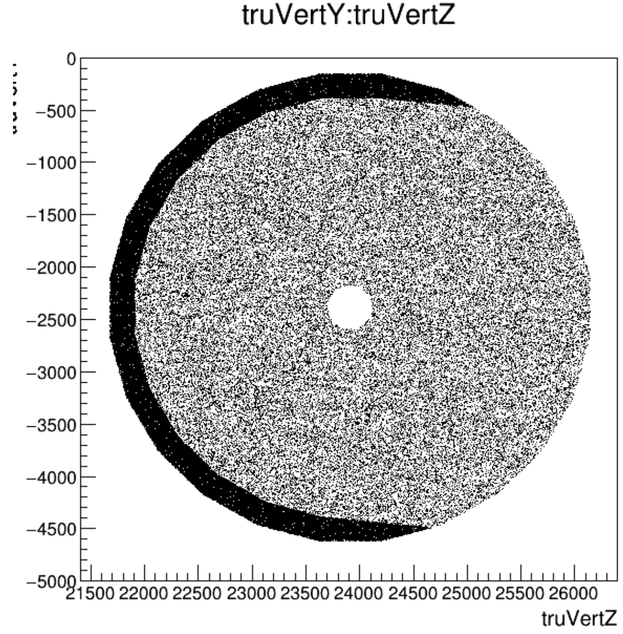
Distribution of interaction vertexes:



SAND



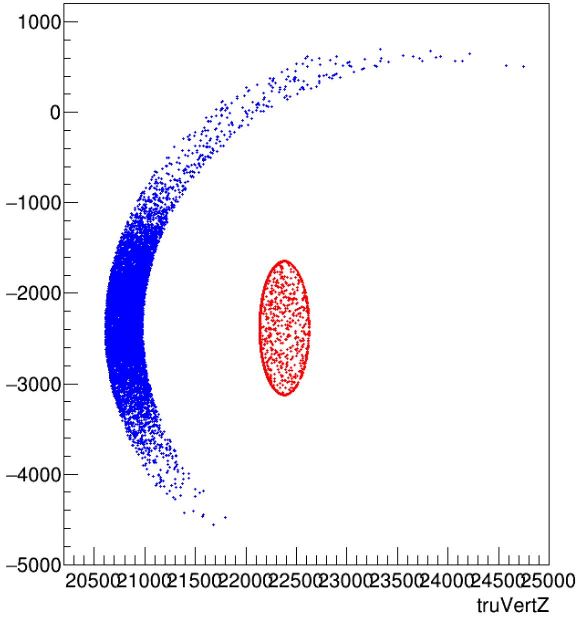
Magnet yoke (no end-caps)



ECAL (including end-caps)

Events with the muon entering GRAIN

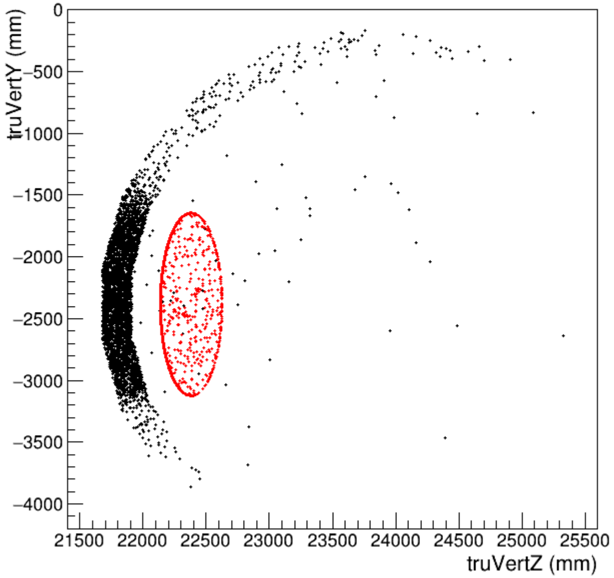
Vertex in the Magnet yoke

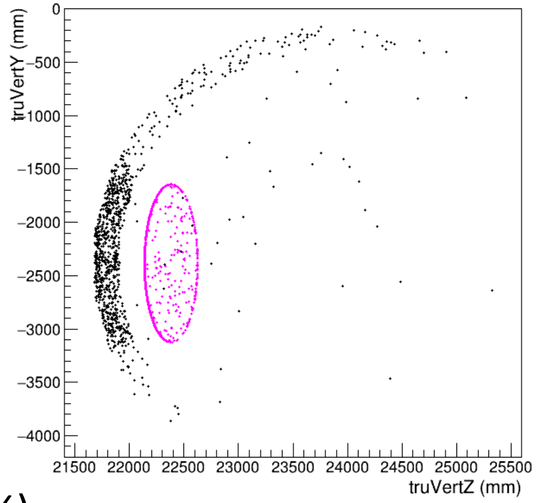


Total interaction events: 441,000
Muons entering GRAIN: ~ 13,000 (3%)

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%)

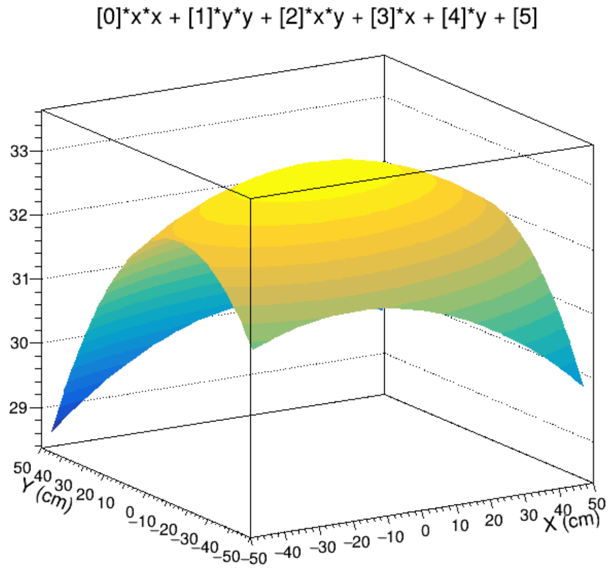
Calibration constants for any position in X-Y plane

The GRAIN surface ΔX = (-50cm,50cm) and ΔY = (-50cm,50cm) was subdivided into 100 cells (10cm x 10cm) and the sample of Yoke muons spread-out on the whole area was used

The average calibration constant was estimated in each cell from the Gaussian fit of the distribution of (Edep/Nphot) ratio for the muons crossing the cell

Fit of the most probable values of (Edep/Nphot) ratios in the grid with a 2D function of X and Y coord

$\rightarrow$ quadratic function used as a calibration function: $F_{cal}(x,y) = a \cdot x^2 + b \cdot y^2 + c \cdot xy + d \cdot x + e \cdot y + f$



- Muons from ν interaction in Yoke
- $\rightarrow$ Realistic muon distribution in GRAIN from ν beam

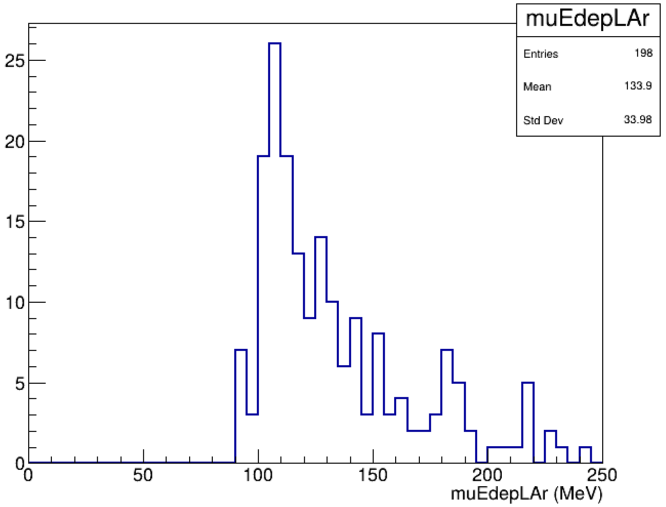
- Event statistics not huge, anyway enough to obtain the parametric function fitting the grid points

```
a = -3.9e-04
b = -1.0e-03
c =  2.7e-04
d = -1.44e-04
e = -1.4e-04
f = 33.1
```

Test of the Calibration function on ECAL μ's

- **Calibration function tested on the sample of isolated muons from ν interactions in ECAL, as an independent muon sample**

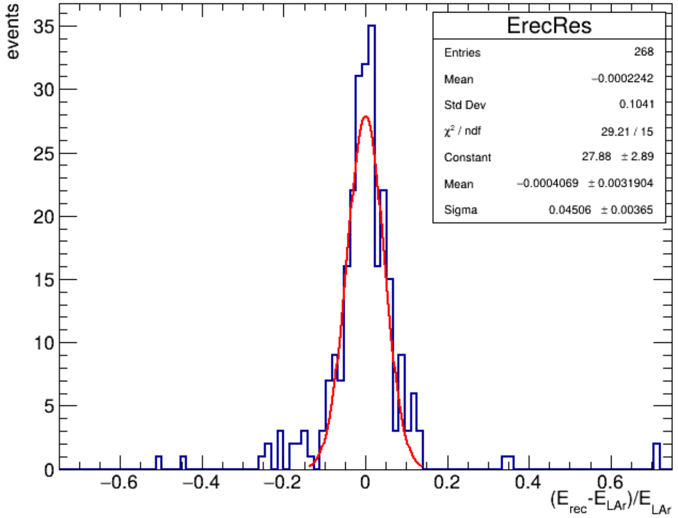
E_{dep} by ECAL muons in LAr



applying the above calibration function

- **Reconstruction of deposited energy in GRAIN for the ECAL muons**

$(E_{rec}-E_{dep})/E_{dep}$



Mean ≈ 0
σ ≈ 4.5 %

Cut: muons entering GRAIN with E_{μ}>300MeV and within 35cm from Z axis are selected

Muons useful for GRAIN calibration

Requirements for muons to calibration purposes:

- produced outside GRAIN (from ν interactions in ECAL, in the Yoke, in front detectors, in the rock, from cosmic rays, ..)

- with enough energy to reach and cross GRAIN as isolated particles

- with a minimum track length in the SAND Tracker, to ensure a precise measurement of the pathlength inside GRAIN LAr volume (combining the information from ECAL, GRAIN, Tracker)

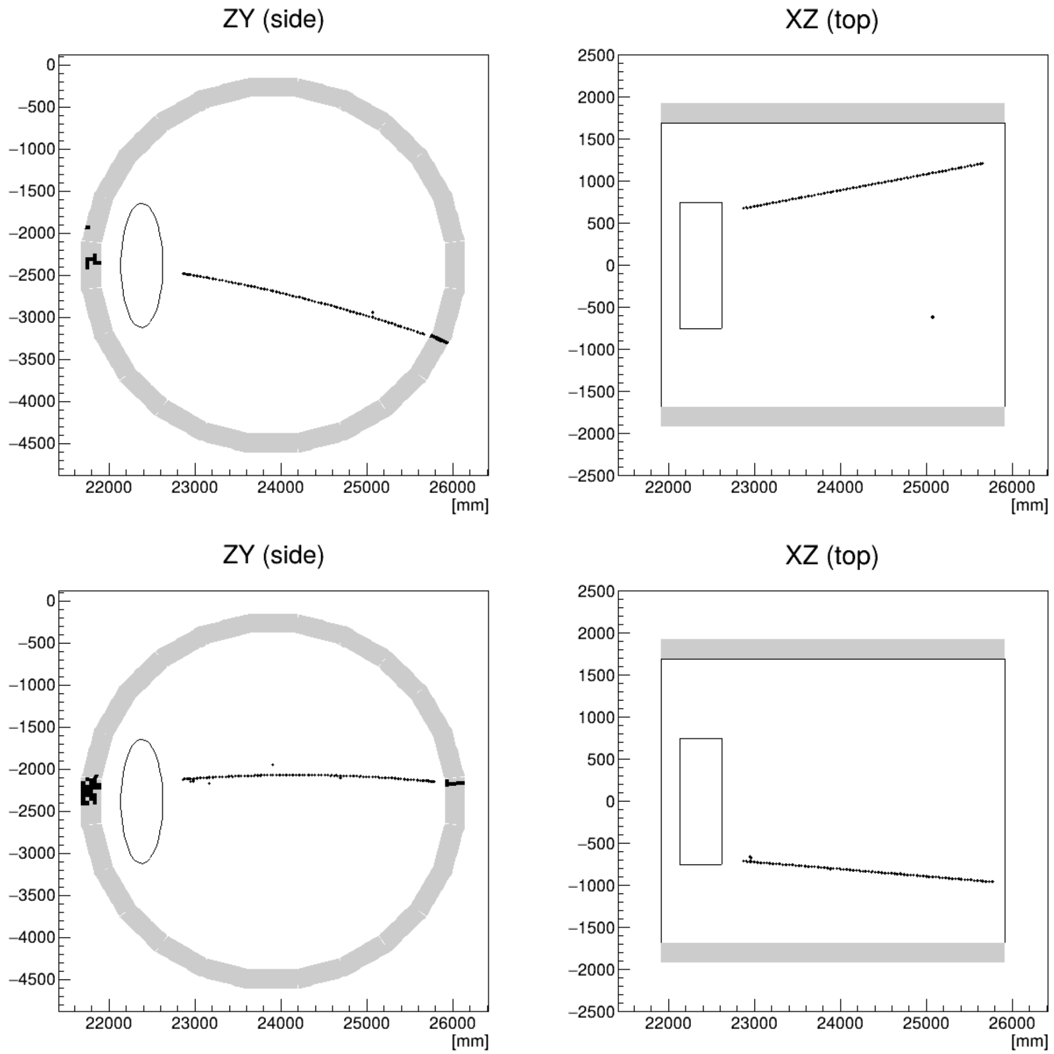
Selection of "calibration muons"

✓ In the real experiment, a proper selection of events with muons useful for GRAIN calibration will be needed, both for ν beam muons and cosmic muons

✓ Possible selection criteria for ν beam muons (without use of MC info):

- events with at most 1 cluster (with no more than 3 nearly contiguous cells) in the innermost layer of the upward ECAL
- energy deposit occurring in GRAIN
- a single track reconstructed in the Tracker, such that:
  - length > L_min = 15 (or 30) hits
  - geometrically crosses the GRAIN volume
  - matches the cluster in ECAL

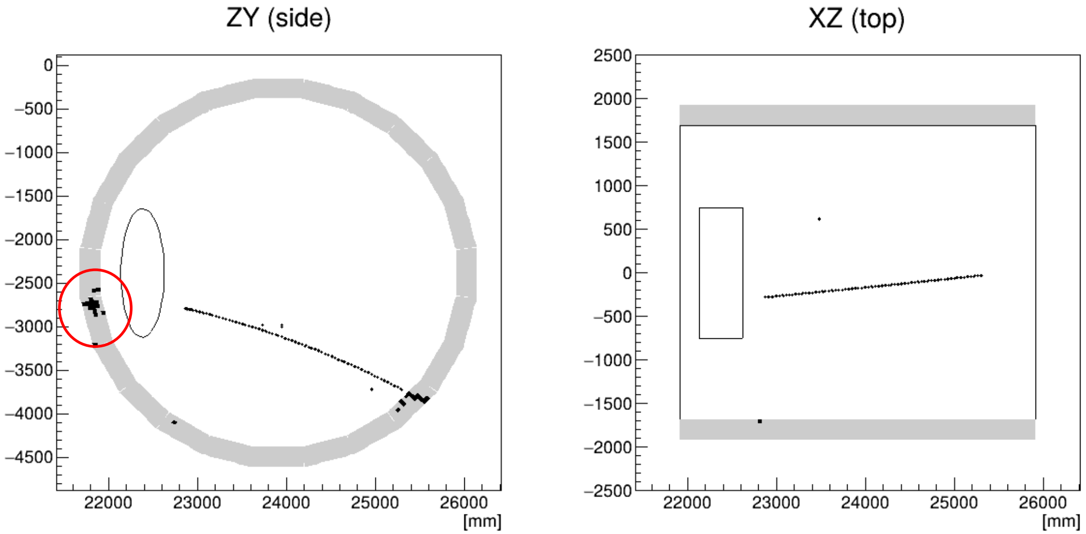
Events with ν interaction in ECAL



Accepted events

Rejected event

(> 1 cluster in innermost ECAL layer)



Events selection tests

✓ The above selection criteria were tested on the MC sample of ν interactions in the Yoke and ECAL

➢ Results:

- Efficiency:

  - Events with ν interactions in Yoke: **≈ 72 %**

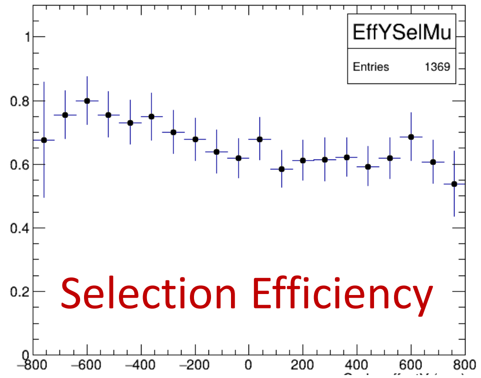
  - Events with ν interactions in ECAL: **≈ 54 %**

- Purity of selected sample:

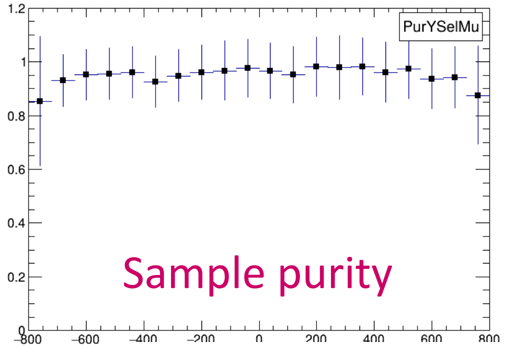
  - Events with ν interactions in Yoke: **≈ 94 %**

  - Events with ν interactions in ECAL: **≈ 68 %**

Yoke muons



Grain Y position (mm)



Grain Y position (mm)

Events selection tests

✓ Additional selection cut in order to increase purity for <u>ECAL sample</u>:

- events with at least 1 cluster in the 4th layer of the upward ECAL, matching the track (to ensure the muon production occurred up to that layer)

➢ Updated results:

- Efficiency:

  - Events with ν interactions in Yoke: $\approx$ 72 %

  - Events with ν interactions in ECAL: **$\approx$ 35 %**

- Purity of selected sample:

  - Events with ν interactions in Yoke: $\approx$ 95 %

  - Events with ν interactions in ECAL: **$\approx$ 72 %**

Conclusions

✓ What presented:

- Muons (from beam or cosmic rays) as natural probes for GRAIN calibration
- A possible calibration procedure investigated and tested, using simulated muons from beam ν interactions in the Yoke and ECAL
- Definition of the basic requirements for calibration muons
- Possible event selection criteria for calibration muons from netrino beam

✓ Nest steps:

- evaluation of track-length inside GRAIN for selected events
- estimate of energy deposit from Edep vs Pathlength relation

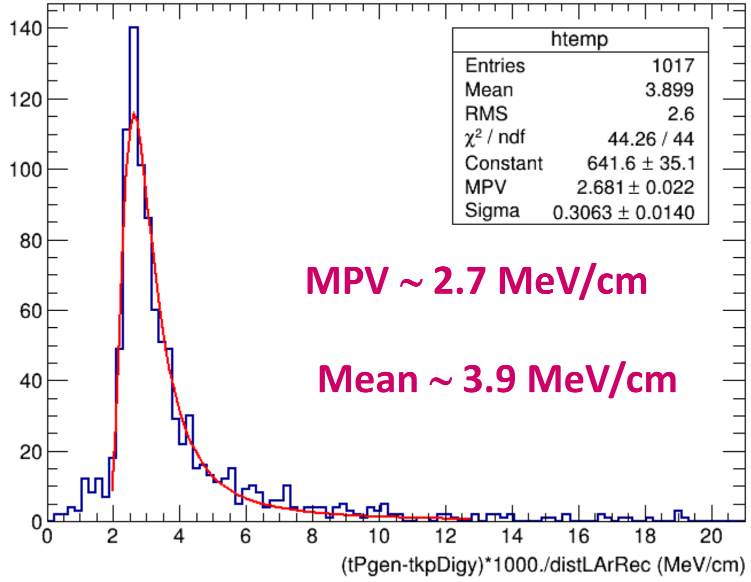
BACKUP

Muons crossing LAr volume

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

From MC simulation of SAND, for a μ crossing GRAIN:

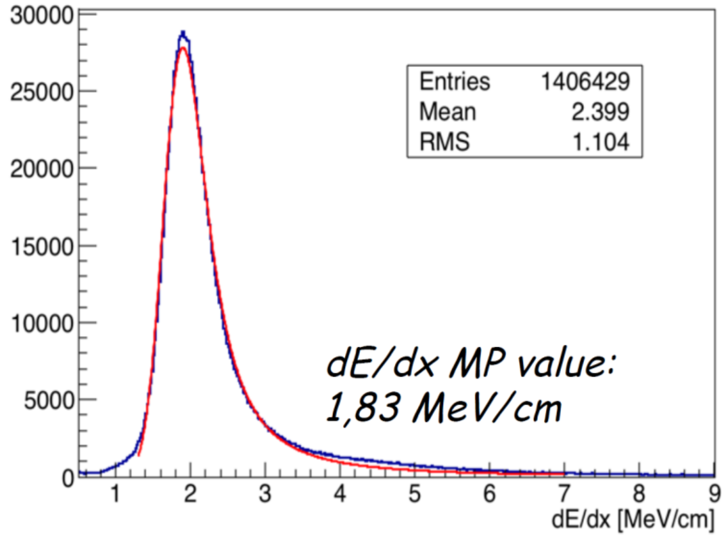
$\Delta E/\Delta L$ (MeV/cm)



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

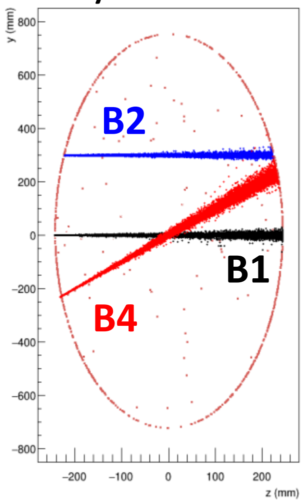
From ICARUS

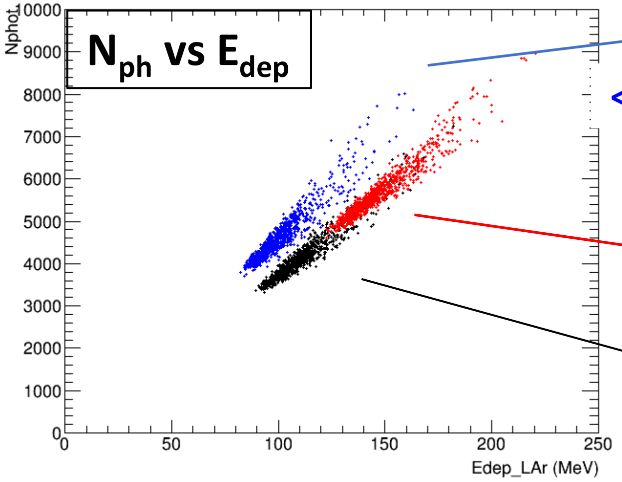
Full 3D reconstruction on selected muon tracks crossing LAr volume

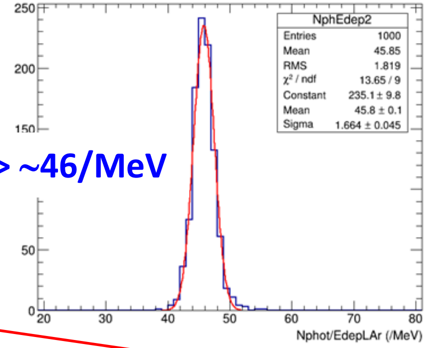


Muon beams with different positions and inclinations

y-z view

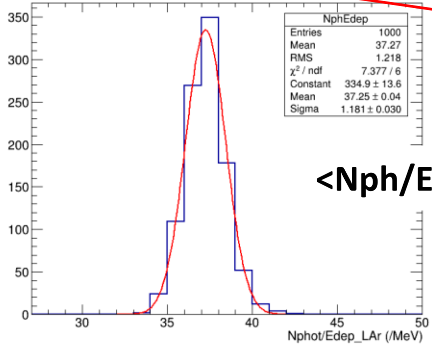




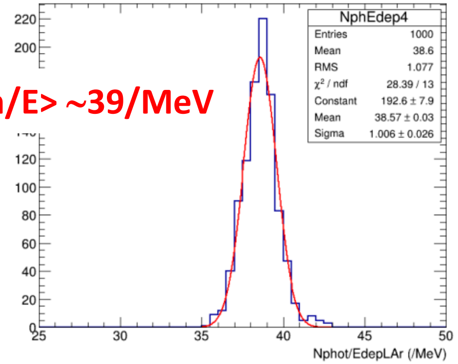


<Nph/E> ~46/MeV

Similar calibration constants for beams at same average distance from GRAIN center … no matter their inclination

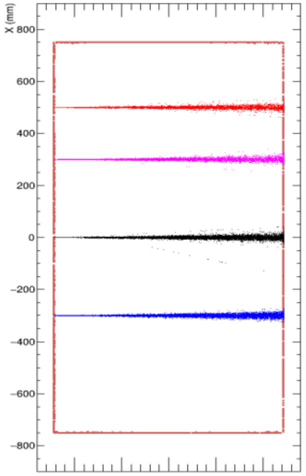


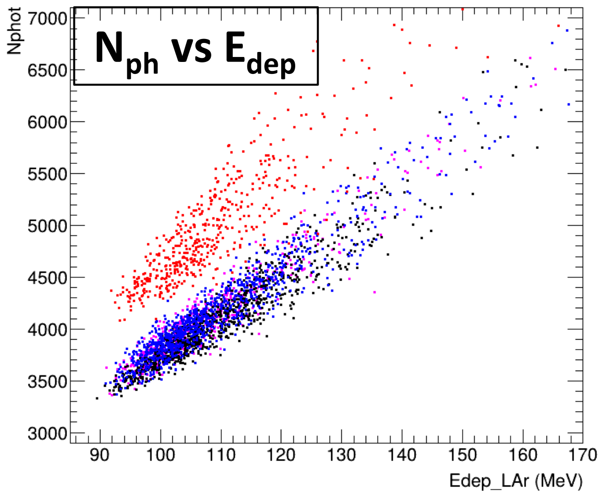
<Nph/E> ~37/MeV



<Nph/E> ~39/MeV

x-z view



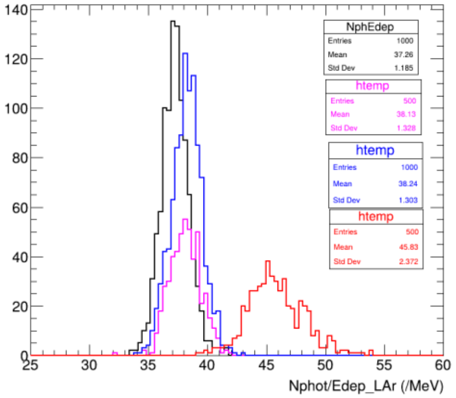


<Nph/E> ~37/MeV

<Nph/E> ~38/MeV

<Nph/E> ~38/MeV

<Nph/E> ~46/MeV



Events selection tests

✓ Preliminary event selection for calibration muons: pure purity for <u>ECAL sample</u> due to interactions in ECAL internal layers with particles entering GRAIN but not tracked …