SAND Calibration WG

P.Gauzzi
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April 16, 2024

SAND General Meeting

WG meetings

- Two meetings held so far:

Thursday Feb 22, 2024, 3:00 PM → 5:00 PM Europe/Rome

video1601097015....

3:00 PM → 3:10 PM **Calibration WG first meeting**
Speaker: Paolo Gauzzi (Sapienza University of Rome and INFN Rome (Italy)
CalibWGFirstMeetin...

3:10 PM → 3:40 PM **Discussion**

3:40 PM → 4:00 PM **Choice of the co-conveners of the WG**

https://indico.fnal.gov/event/63366/

https://indico.fnal.gov/event/64084/

Friday Apr 5, 2024, 5:00 PM → 7:00 PM Europe/Rome
Paolo Gauzzi (Sapienza University of Rome and INFN Rome (Italy))

Description

Join Zoom Meeting:
https://uniroma1.zoom.us/j/86930763023?pwd=d2x5WkhnZzg5WFIEOWpOZm1YOWZVUT09

ID: 86930763023
Passcode: 283855

Recording of the m...

5:00 PM → 5:05 PM **Communications**
Speaker: Paolo Gauzzi (Sapienza University of Rome and INFN Rome (Italy))

5:05 PM → 5:25 PM **KLOE ECAL Calibration**
Speaker: Paolo Gauzzi (Sapienza University of Rome and INFN Rome (Italy))
CalibEMC.pdf

5:25 PM → 5:45 PM **Ideas for GRAIN calibration**
Speaker: Antonio Surdo (INFN Lecce - Italy)
Calib_WG_GRAIN_A...

5:45 PM → 6:05 PM **Choice of the co-chair of the WG**

- Recording of the meetings and slides of the presentations available
- Next meeting Friday April 19th (t.b.c.)

WG organization

- Since we have (at least) three subdetectors to calibrate, we decided to identify a reference person for each of the subdetectors

  ECAL: P.Gauzzi
  GRAIN: A.Surdo
  STT: ……

- Chair of the WG: P.Gauzzi
  Co-chair: A.Surdo

- Meeting time: Friday at 5:00 p.m. CET (10:00 CT)
  meetings every three weeks (for the moment)

Scope of the Calibration WG

- The information needed to reconstruct the energy of the neutrinos are the properties of the particles produced in the interactions: energy and momenta, ToF, variables for PID, ...

- Calibration means to transform electrical signals from the detectors into physical variables

  - ECAL: energy, time and positions of the particles
  - STT: *r-t* relations, track momentum, dE/dx for PID, ...
  - GRAIN: tracks, time, energy, ...
  - Timing alignment among the subdetectors (for the determination of the interaction time)

Scope of the Calibration WG

- Define a calibration strategy for each subdetector:
  - Sources: cosmics, particles from beam, radioactive sources ?
  - Choose suitable processes (given the expected fluxes of particles in the detector) (*e.g.* for the ECAL: cosmic μ's as MIPs, MIPs from the beam, electrons and photons ....)
  - Set a calibration procedure (at which level of precision ? How much time expected for a calibration ?)

Calibration is strongly related to the reconstruction algorithms (*e.g.* the clustering in case of the ECAL, different algorithms can lead to different energies for the same event ....)

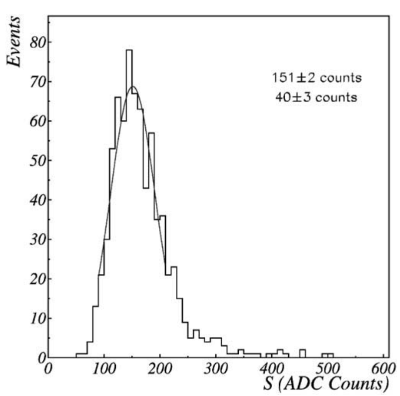
Interplay among subdetectors (*e.g.* for the ECAL to use photons from π^0 decay, need a vertex from the Tracker)

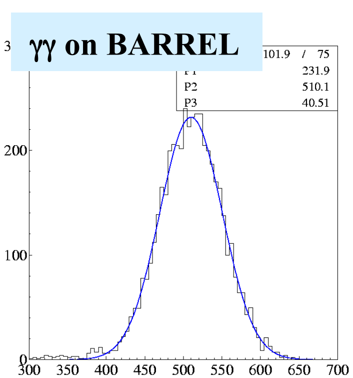
Alignment among subdetectors and among sections/modules of a subdetector

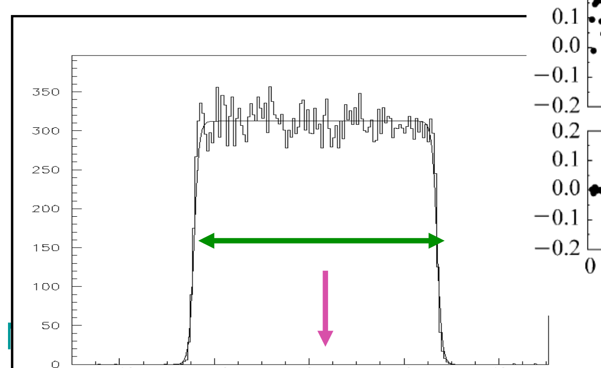
Summary of KLOE ECAL calibration at DAΦNE

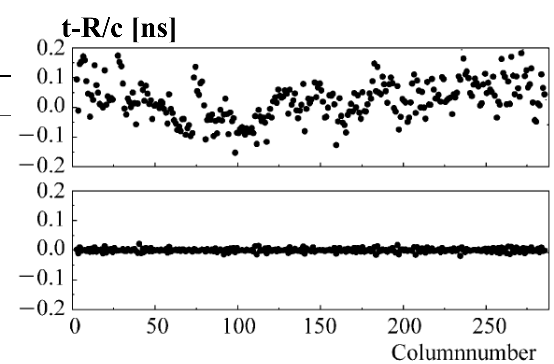
From P.G. presentation at April 5 meeting

	Frequency	Duration	# of events
MIP runs (cell-by-cell calibration)	every few months (2-3 times/year)	~ 24 hrs	10^3 evts/cell ("golden MIP" selection)
Cosmics (MIPs) for timing (Cell time-offset determination)	once per day	10 min	10^6 evts
Bhabha's, $e^{\pm}$ of 510 MeV (relative cell calib. with e.m. showers)	each run from normal data-taking	1 – 2 hrs	~ 10^4 evts Barrel ~ 10^5 evts EndCap
$e^+e^- \rightarrow \gamma\gamma$, photons of 510 MeV (absolute energy scale and fine timing calib., at cluster level)	each run from normal data-taking	1 – 2 hrs	10^3 – 10^4 evts









ECAL Calibration in SAND

MIPs from cosmic rays:

- muon flux at surface ~ 0.02 μ/(s cm^2) + underground reduction of ~ 100
- effective cross-section of the ECAL for vertical muons of ~ 5×10^5 cm^2

  ⇒ ~ 100 μ/s on ECAL (without any selection)
- Rough estimate by rescaling the KLOE numbers

  1 day (24 hrs): ~ 10 evts/cell
- By relaxing the “golden mip” selection: in few days ~ 10^3 evts/cell

MIPs from beam (rock, magnet and Fe yoke, upstream ECAL modules)

- ~ 1.5×10^3 μ/spill (1 spill = 9.6 μs every 1.2 s) without any selection

(DUNE-doc-13262, A Near Detector for DUNE)

- Can we use also charged π’s as MIPs ?
- A MC study could be useful
- Could be useful a calibration with cosmics of all the modules with the final FE electronics before re-assembling the ECAL

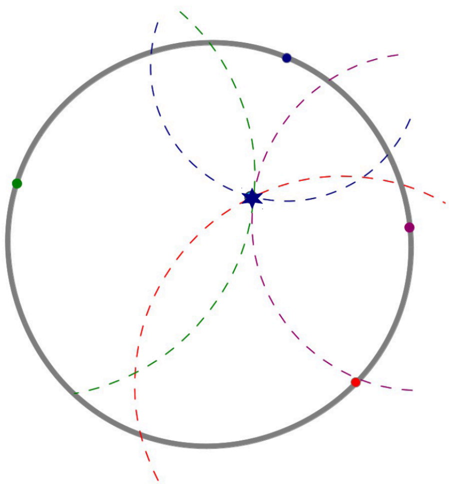
Energy scale calibration

- γ's from π^0 decays, invariant mass reconstruction (need a vertex from the STT)
- γ + electrons: ~ 30% of photons from π^0 convert in the STT
  $\Rightarrow$ ~ 50% of π^0 have at least one $\gamma \rightarrow e^+e^-$

(DUNE-doc-13262, A Near Detector for DUNE)

- Electrons from ν_e interactions
  $\Rightarrow$ need the momentum measurement in the STT

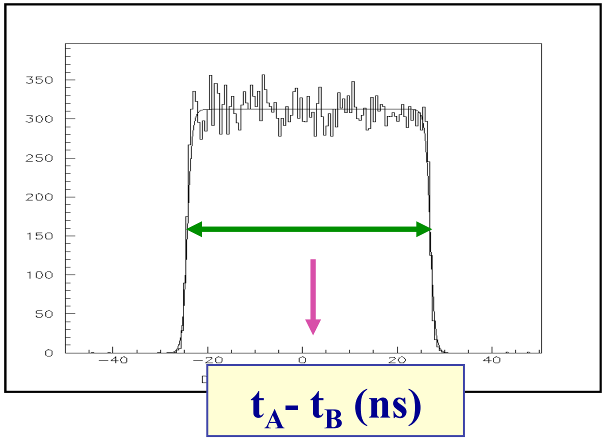
- Exploit $K^0 \rightarrow \pi^0\pi^0 \rightarrow 4\gamma$? (From a naive rescaling of $K^0 \rightarrow \pi^+\pi^-$
  $\Rightarrow$ $O(10^5)$ evts in 5 years of FHC data-taking)

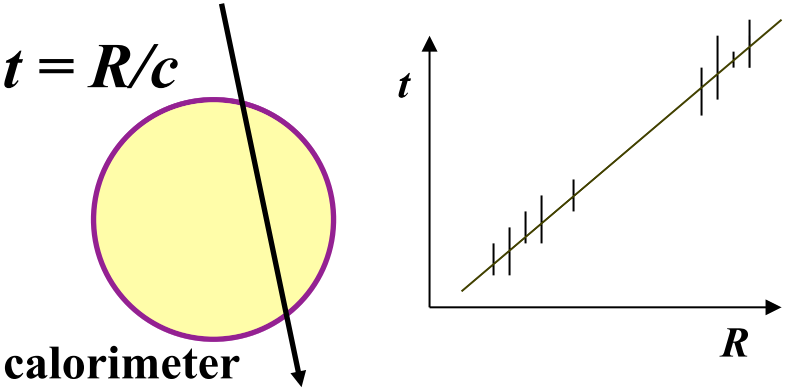


Reconstruct a vertex with the ECAL only
Back propagate each of the 4 photons
Times of the ECAL cells must be very well aligned

Time Calibration

- Alignment of the t_0's: MIPs from cosmics and other beam particles





- Fine calibration of t_0's non-trivial: we need events connecting different parts of the ECAL
- Maybe events with π^0 decaying into γ (and $e^{\pm}$) could be used, with the information of the vertex in the STT

Calibration steps for GRAIN

From A.Surdo's presentation at April 5 meeting

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.

Alignment probably not possible pixel by pixel (huge number)

⇒ a-posteriori correction?

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

- **Calorimetric** measurement of total released energy
- **Track-by-track** energy loss evaluation (geometric acceptance factor from MC, …)

b) 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.

Several reconstruction algorithms (MC, analytical, ..) under development

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

Conclusions

- **Preliminary discussion on first ideas on GRAIN and ECAL calibration**
  - **Cosmic muons**
  - **Particles from beam / events from collected data**
  - **Ad hoc sources, like radioactive sources, LED, ...**

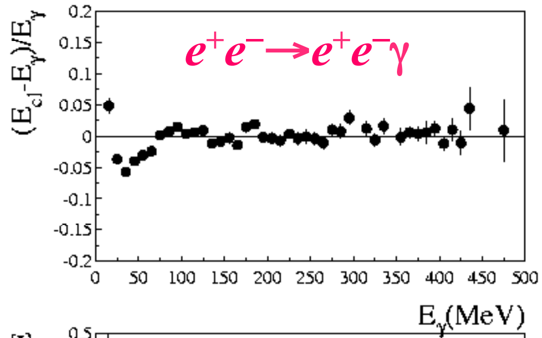
- **MC studies needed to quantify the rates of possible processes to be used**

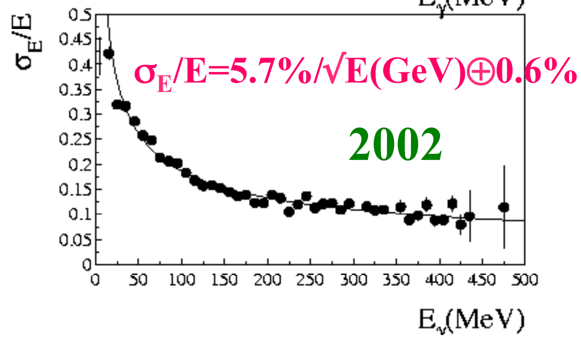
- **Tracker part still missing, participation to the WG of interested people from STT would be important**

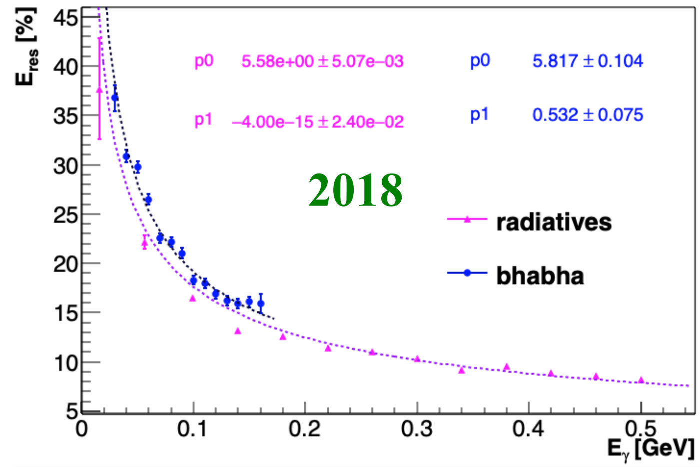
Spare

Resolutions in KLOE

- **Energy resolution (linearity within 1% for E > 70 MeV)**





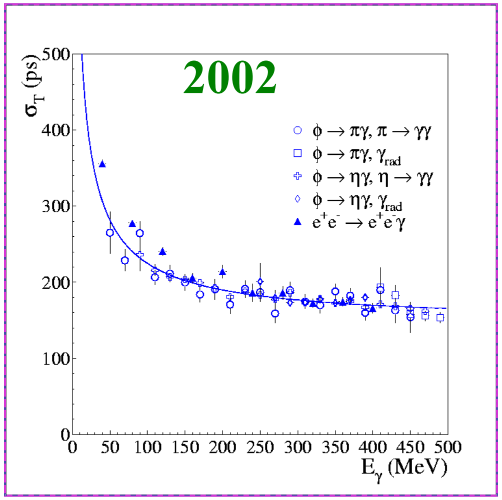


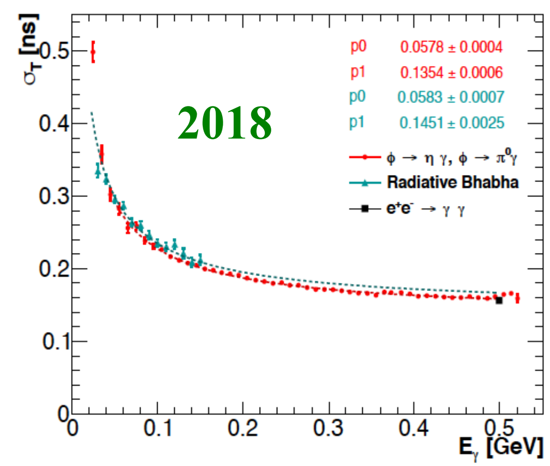
- **Time resolution**

$$\sigma_t = \frac{57 \text{ ps}}{\sqrt{E\ [\text{GeV}]}} \oplus 140 \text{ ps}$$

$$(140 \text{ ps} = 92 \text{ ps} \oplus 105 \text{ ps})$$

Common term **Uncorrelated term**

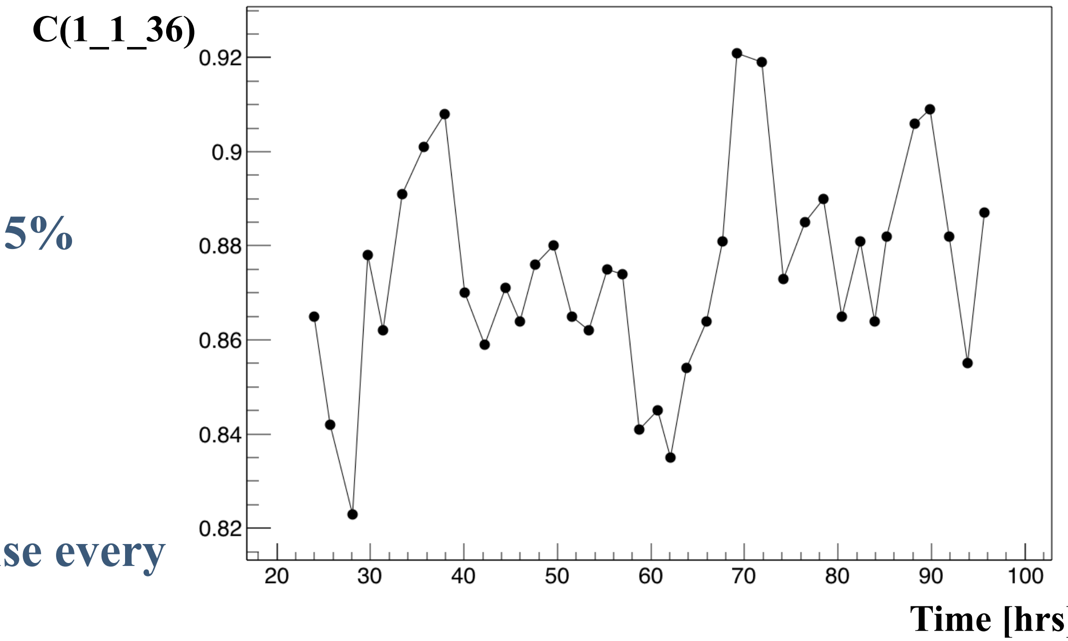




P.Gauzzi

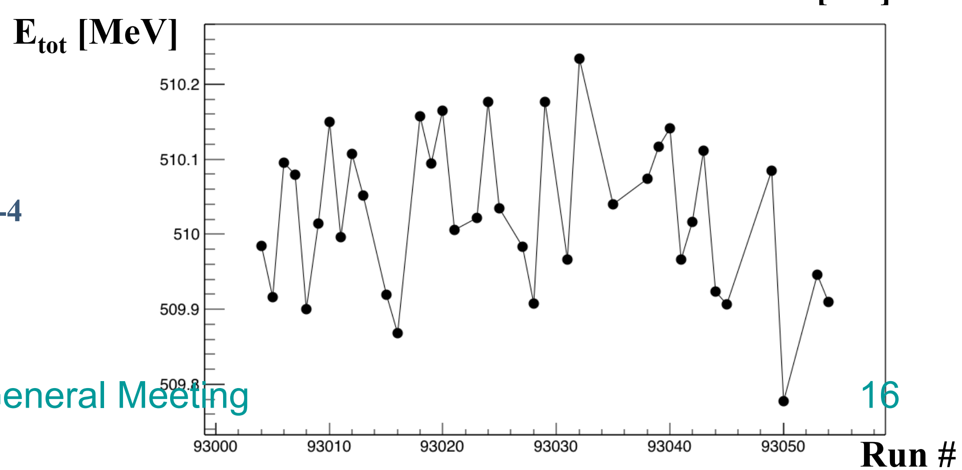
Energy calibration

- Typical calibration constant variations (1 barrel channel)



Max variations ~ ± 5%

- Not a problem in KLOE because every run was calibrated



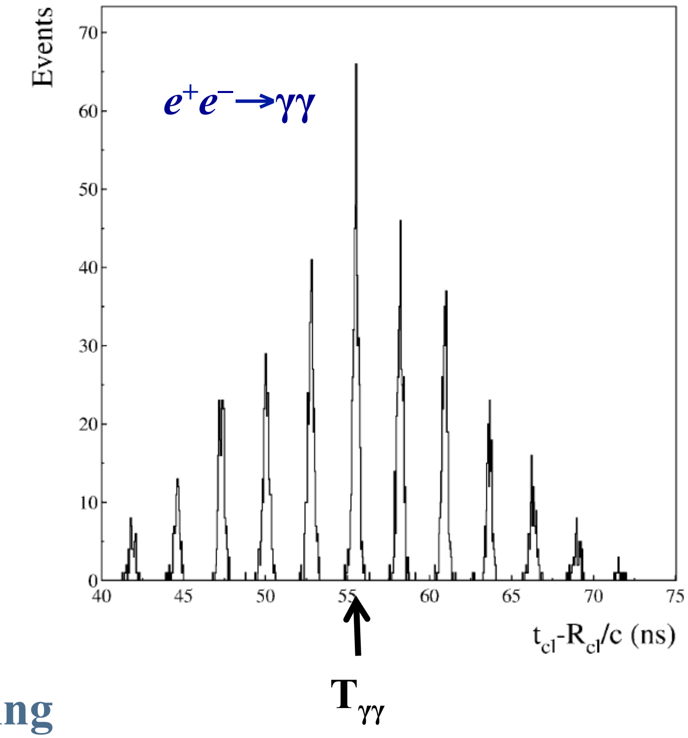
Max variations $< 4 \times 10^{-4}$

Global t_0 determination

- The trigger signal is synchronized with a clock from the radiofrequency of DAΦNE of 2.7 ns period (T_{RF})
- Typical multipeak time distribution of the events

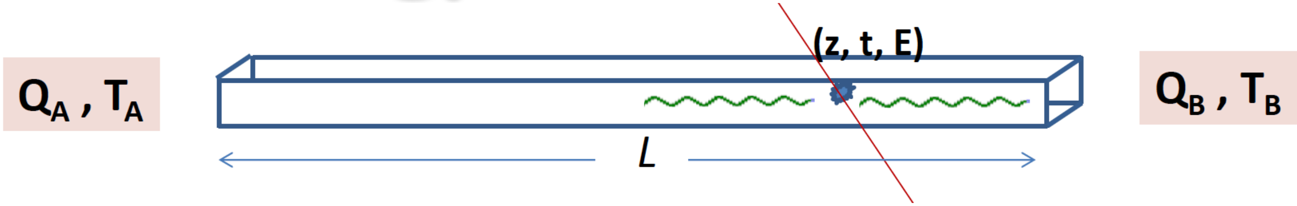
$$t = \frac{1}{2}(t_A + t_B) - \frac{L}{2v} - t_0 - t_G^0$$

- Time needed to a photon from the interaction point to reach the calorimeter: 6 − 9 ns
- Time needed to Kaons (or the decay products) to reach the calorimeter can be as high as 30 − 40 ns
- How to associate the event to the correct beam crossing ?
  - First, choose (arbitrarily) one of the peaks ($T_{\gamma\gamma}$)
  - For each event assume that the first particle arriving at the calorimeter is a prompt photon (coming from the Interaction Point), and determine the integer *k* by imposing:



$$t - \frac{R}{c} = 0 \Rightarrow t_G^0 = T_{\gamma\gamma} + kT_{RF}$$

Energy reconstruction



$$E_i^{(A,B)}[\text{MeV}] = \frac{(Q_i^{(A,B)} - P_i^{(A,B)})[\text{ADC counts}]}{C_i[\text{ADC counts/MIP}]} K \times f_{MIP2MeV}[\text{MeV/MIP}]$$

- **Each cell readout at both ends (A, B): Q = collected charge, P = pedestal, C_i = calibration constant, K = absolute energy scale factor**

$$E_i = \frac{1}{2}\left(\frac{E_i^{(A)}}{w_A(z)} + \frac{E_i^{(B)}}{w_B(z)}\right)$$

Cell energy, corrected for the attenuation along the fibers

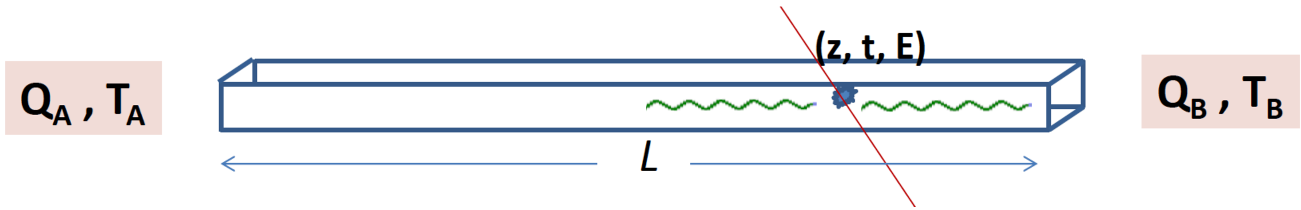
$$w(z) = Ae^{-\frac{z}{\lambda_1}} + (1-A)e^{-\frac{z}{\lambda_2}}$$

($A \approx 35\%$, $\lambda_1 \approx 50$ cm, $\lambda_2 \approx 4$ m)

- **Clustering algorithm to join contiguous cells in position and time,**

$$E_{cl} = \sum_i E_i \qquad t_{cl} = \frac{\sum_i t_i E_i}{\sum_i E_i} \qquad \vec{r}_{cl} = \frac{\sum_i \vec{r}_i E_i}{\sum_i E_i}$$

Time reconstruction



$$t_{A,B}[ns] = (T_{A,B} - T^0_{A,B})[\text{TDC counts}] \times c_{A,B}[\text{ns/TDC count}]$$

$T_{A,B}$ = arrival time at the PMTs

$c_{A,B}$ = 53 ps/TDC count (measured in lab. before the installation)

$$t_A = t + \frac{z}{v} + t^0_A + t^0_G$$

$$t_B = t + \frac{L - z}{v} + t^0_B + t^0_G$$

t = Time-of-Flight

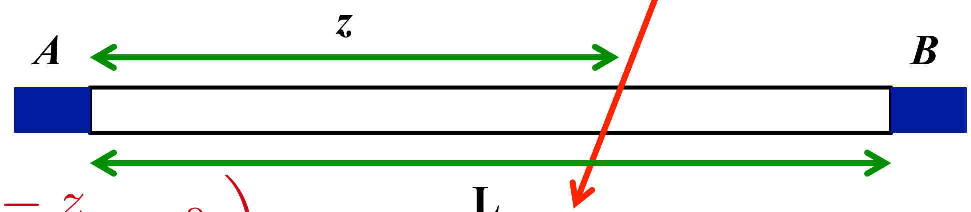
$t^0_{A,B}$ = time offsets

v = effective light velocity in the scintillating fibers

t^0_G = global time offset to be determined event by event

Z-coordinate reconstruction

- Time difference

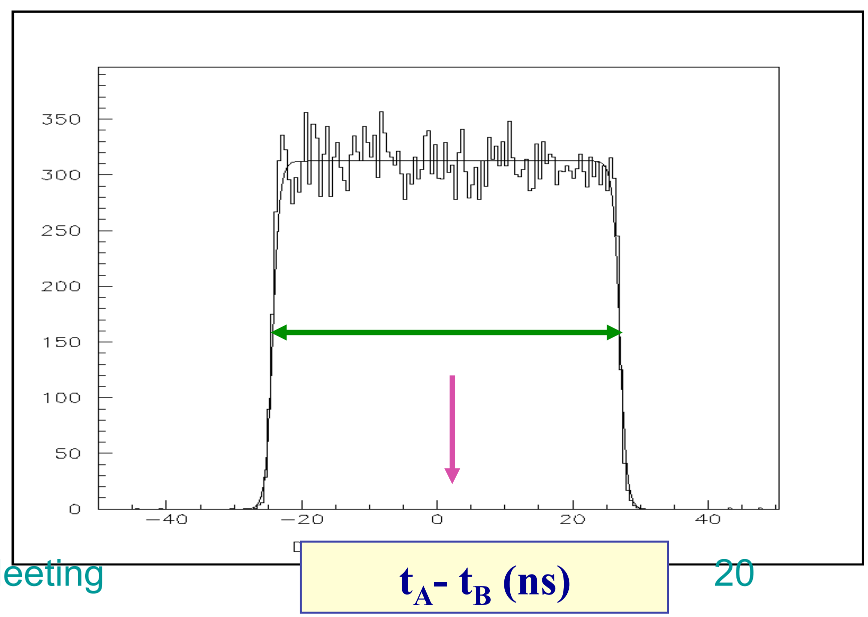


$$\frac{1}{2}(t_A - t_B) = \frac{1}{2}\left(t + \frac{z}{v} + t_A^0 - t - \frac{L-z}{v} - t_B^0\right)$$

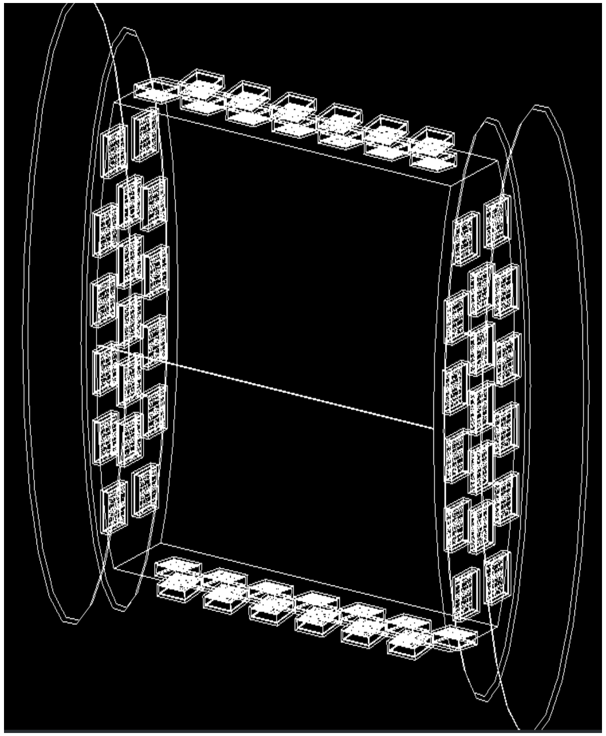
$$z = \frac{1}{2}v(t_A - t_B) - \Delta t_0 \qquad \left[\Delta t_0 = \frac{1}{2}\left(t_A^0 - t_B^0 - \frac{L}{v}\right)\right]$$

- Calibration with cosmic rays
  ⇒ uniform illumination of the calorimeter
- Δt_0 is the center of the distribution
- v is obtained from the width of the distribution
- 10^6 cosmics, 10 min run (once per day)

⇒ v = 16.7 cm/ns

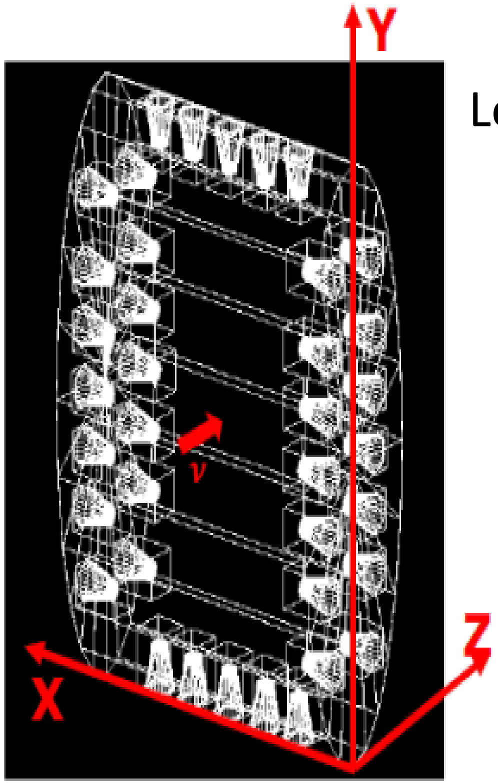


GRAIN Detector readout



Coded masks

GDML:



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

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?)

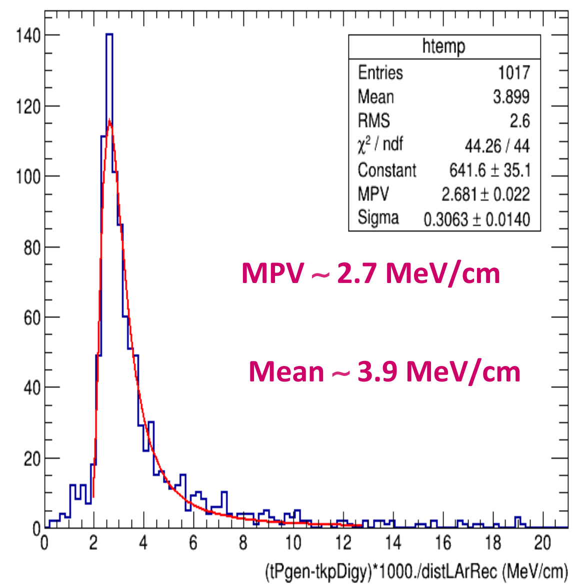
Typical value for (UV) light emission: $f \sim$ **4 ·10[4] ph/MeV**

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 DL

From ICARUS

Full 3D reconstruction on selected muon tracks crossing LAr volume