Istituto Nazionale di Fisica Nucleare

CYGNO Experiment

Simulation update

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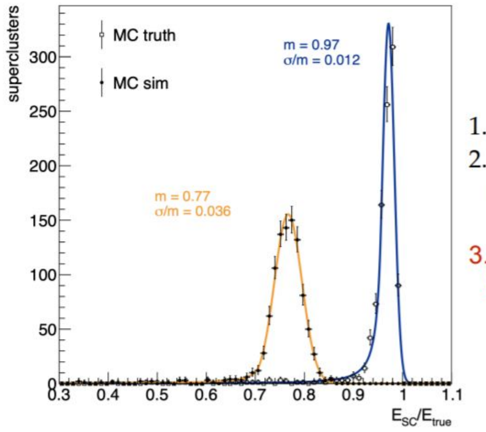
CYGNO general meeting 04/06/20

Reconstruction of simulated images

Energy containment and resolution

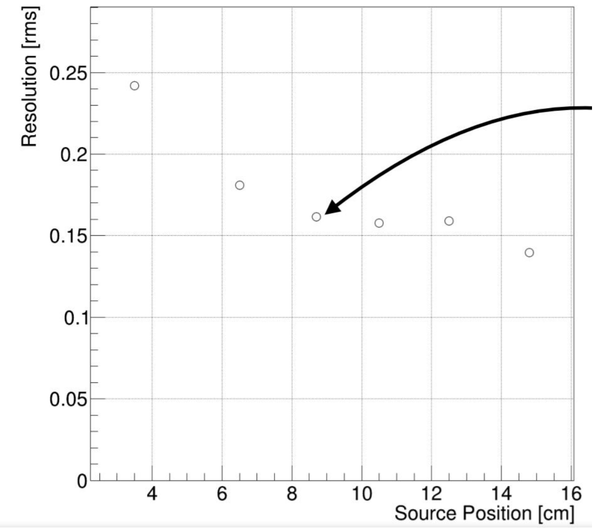
- In the paper on nuclear recoils identification with neutrons we describe the basic- and super-cluster reconstruction
- would be useful to show the energy containment on simulation: mean of E/E_{true} distribution
  - taken from Giulia / Fabrizio a sim of E=6 keV NRs either “pure MC” or with simulation of electronics noise + diffusion



Considerations:

1. w/o noise, containment better than 5%
2. with noise, it decreases to ~80%. Not a problem, since 55Fe calibrates the absolute energy
   1. it could be tuned on simulation
3. *resolution with noise+diffusion (4%) is still much better than in data (~15% on Fe)*
   1. indicates that some more realistic model is needed in sim. 2.1 can be done once we have a better modeling

Measured energy resolution on 55Fe data



Slides by E. Di Marco

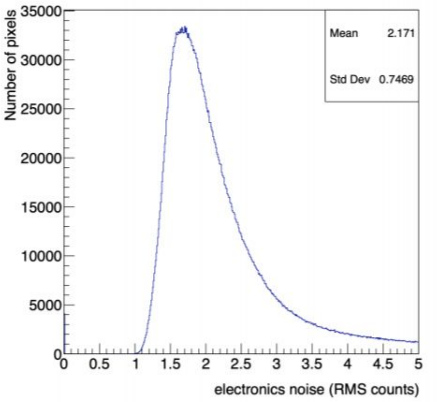
Reconstruction of simulated images

inputs to improve

INFN

- Two items that can impact resolution

1. Noise modeling. Currently a simple Gaussian is used, with σ = 2 photons
   1. the value is OK, but data has a distribution with non Gaussian tails with much larger tail. This should be easy to address: just sample the measured distribution in data to assign the pixel noise

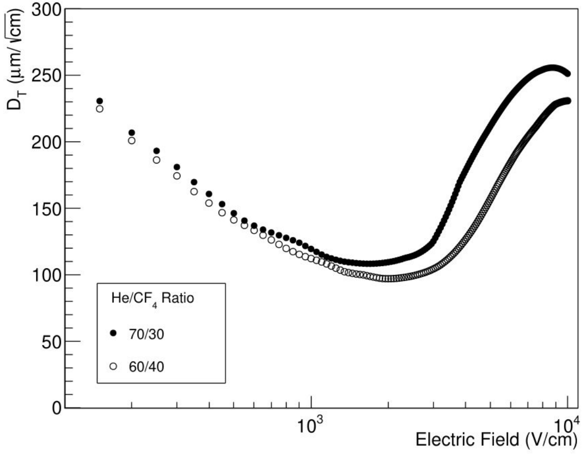


2. Diffusion modeling. The measured diffusion seems larger than the one predicted.
   1. also here, one should try to use the measured one, instead of the simple sqrt(z) model?

3. Other?
   1. Fe data is a good dataset to validate this, since the clustering is trivial

$$\sigma_T = \sqrt{(\sigma_{T0}^2 + D_T^2 \cdot z)}$$

$$\sigma_{T0} = 300\mu m$$



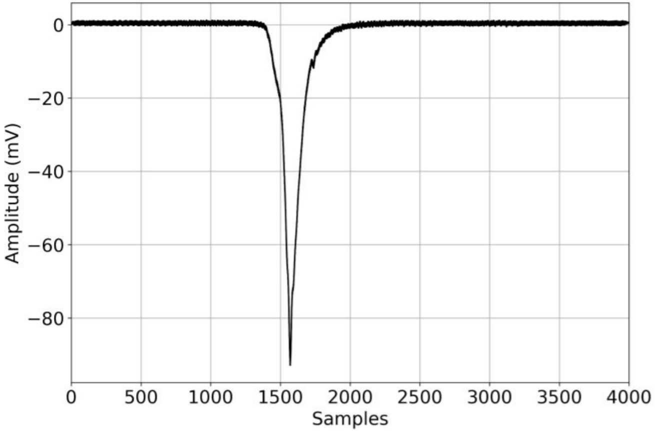
at the moment we are using **500 μm** for every track (corresponds to ~10 cm drift in LEMON)

➜ At this stage we don't include any error on the multiplication process: implement gain distribution

Slides by E. Di Marco

PMT simulation

The idea is to tune the PMT modelized response using 55Fe data



- ❑ Short signals with peak amplitude greater than -120 mV selected;
- ❑ Their peaks were centralized;
- ❑ Mean signal obtained;

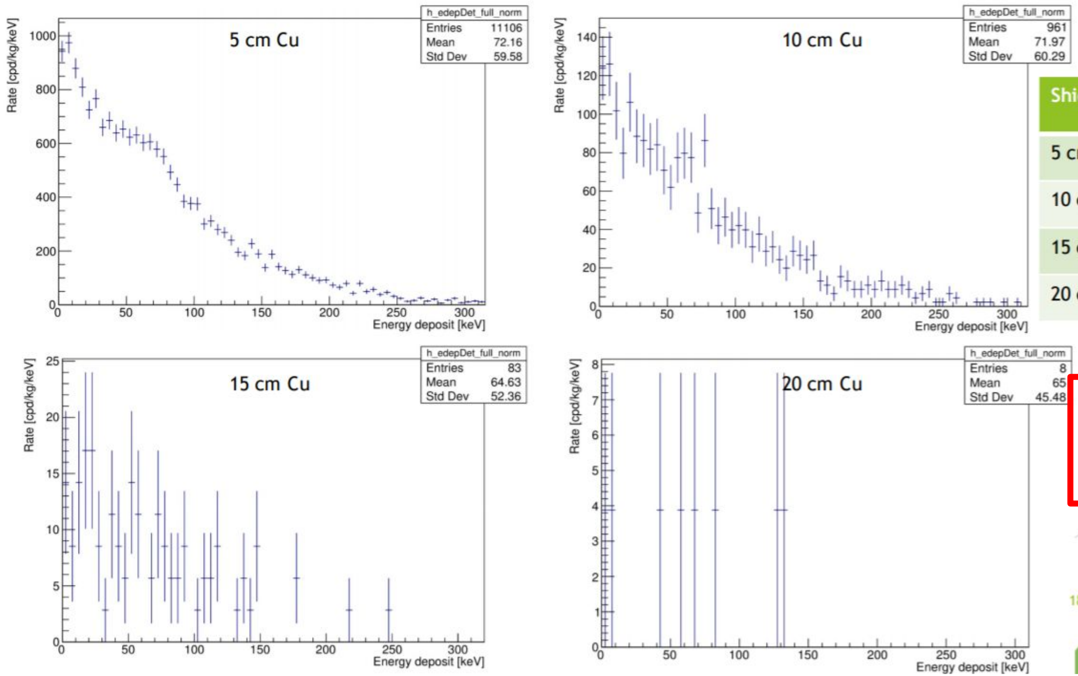
- ❑ Calibration factor for the number of created electrons: 1e-/40eV;
- ❑ Signal amplitude calibration factor: 0.66 mV/e- ;
- ❑ ^{55}Fe event energy: 5.9 keV;
- ❑ Number of electrons created in ^{55}Fe events: around 148 e- ;

Slides by M. Migliorini

LIME background simulations

LIME Simulation Results - Gamma Background

Shielding - 50 cm water plus 5 cm, 10 cm, 15 cm and 20 cm Cu



Shielding	gamma flux [n/cm2/s]	Evts/yr [0-20 keV]
5 cm Cu	6.9e-4	464000
10 cm Cu	-	54100
15 cm Cu	-	6771
20 cm Cu	-	970

For each additional 5 cm Cu the gamma background decreases about a factor of 8.

For each additional 25 cm water the gamma background decreases about a factor of 4.

Note: The gamma flux is not provided in this study because of the computer time that would be required. It will be important to further increase the statistics

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Goal <10^4 cpy (ER) for E< 20 keV

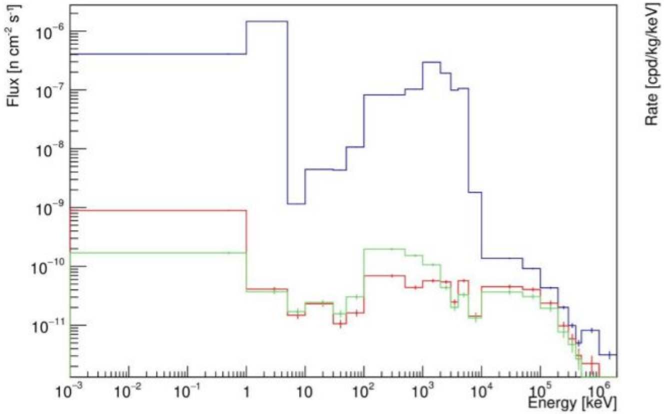
50 cm water + 20 cm copper
or
100 cm water + 10 cm copper
→ O(10^3) cpy

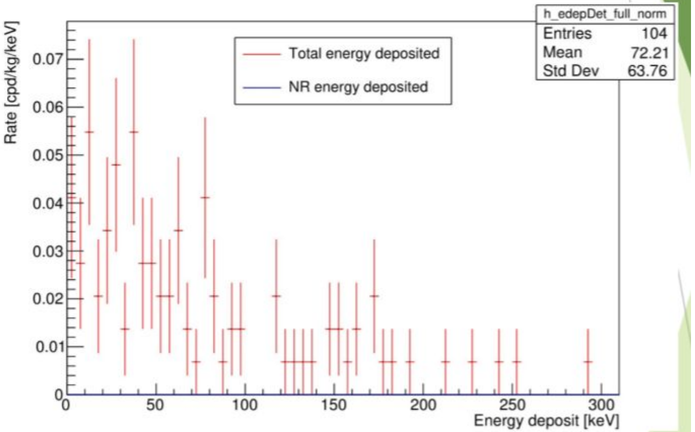
Slides by A. Cortez

LIME background simulations

LIME Simulation Results - Neutron Background

Shielding - 50 cm water plus 5 cm Cu





Number of events in [0-20] keV: 0.0359634±0.00784786 cpd/kg/keV
Resuting in about 18.0445±3.93764 events/year

Number of NR in [0-20] keV: 0.0±0.0 cpd/kg/keV
Resuting in about 0.0±0.0 NR/year

A.F.V. Cortez, CYGNO Simulation Meeting, 28th May, 2020

Flux (n/cm2/s)	Neutron	Secondary Gamma
@LNGS	2.76e-6	-
After 50 cm Water	1.45e-9	1.66e-7
After 5 cm Cu	9.64e-10	2.09e-8

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Goal <1 cpy (NR) for E< 20 keV

50 cm water +
5 cm copper
➔ sufficient to have
0 NR evts/yr
(Equivalent time of simulation ~1 year)

Secondary gammas are negligible

Slides by A. Cortez

Summary and next steps

- Reconstruction efficiency studies on MC (Fabrizio, Giulia, Emanuele)
  - **improve inputs to the digitization** and re-digitize some MC samples
  - compare with data and see if with MC we r**eproduce resolution measured on data**
  - once this is fixed ➔ systematic **efficiency and bkg rejection study on MC**
- PMT (Rafael, Mariana)
  - tuning simulation on LEMON ^{55}Fe data
- LIME background simulations (Andrè, Giulia)
  - **external background: 1 m water + 10 cm copper** gives **0 NR/year** and **O(10^3) ER/year**
    ➔ compatible with space available in currently assigned site for LIME @LNGS
  - **camera background:** work in progress, we expect to be the dominant background
- Sensitivity study (Giorgio, Elisabetta)
  - **Sensitivity** curves with different **background** and **energy threshold**
  - Very important input to discussion on optimization of shielding, gas mixture, etc.
- Solar neutrino with CYGNO (Elisabetta)
  - look promising, some preliminary studies ongoing ➔ could be a publication *per se*

Backup

Neutrinos with CYGNO

Goal: reproduce plot & verify expected number of events

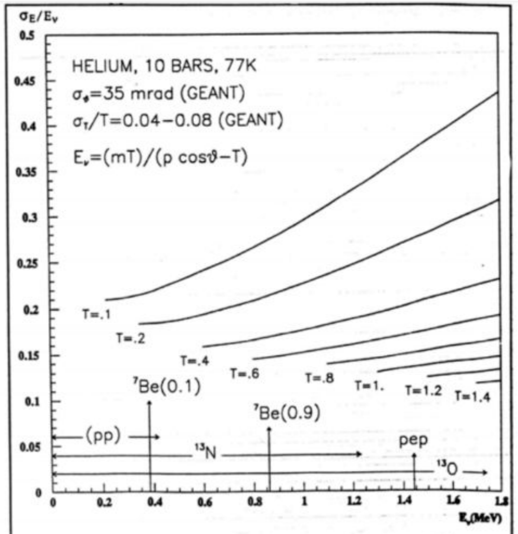
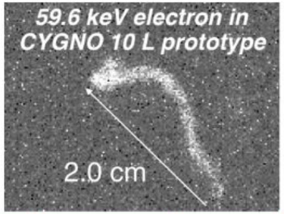


Fig. 12. The neutrino fractional energy error σ_E/E_ν vs neutrino energy E_ν for various fixed values of the electron energy T (MeV).

HELLAZ: He @ 5 bar, 10 m drift, 1 mm x,y,z strips

Electron energy threshold: 100 keV

HELLAZ: A HIGH RATE SOLAR NEUTRINO DETECTOR WITH NEUTRINO ENERGY DETERMINATION



CYGNO PHASE-2 can detect order 50 events/year

	Diffusion	Target density	Electron energy threshold	Expected yield from pp
HELLAZ	0.2 sqrt(cm)	3 kg/m³	100	0.5-1 m^{-3} y^{-1}
CYGNO	0.01 sqrt(cm)	1-1.5 kg/m³	10-20	1-2 m^{-3} y^{-1}

back of the envelope evaluation

with He:CF4 60:40 and 20 keV threshold

➙ also confirmed with a complete calculation by Samuele Torelli (PhD student @GSSI)

Slides by E. Baracchini

Neutrinos with CYGNO

Goal ➔ reproduce this plot for our experiment

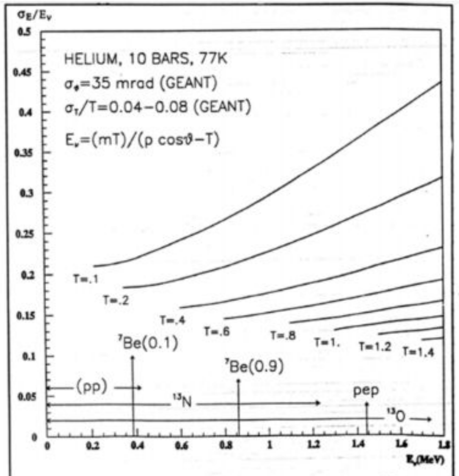


Fig. 12. The neutrino fractional energy error σ_E/E_ν vs neutrino energy E_ν for various fixed values of the electron energy T (MeV).

Energy resolution of proportional ionisation counter

$$R = 2.35\sqrt{\frac{F}{N} + \frac{1}{N}\left(\frac{\sigma_q}{G_q}\right)^2} = 2.35\sqrt{\frac{F}{N} + \frac{f}{N}}$$

The neutrino energy resolution $\sigma_{E\nu}/E_\nu$ is obtained from the derivatives of eq. (2) i.e.

$$\sigma_{E\nu}/E_\nu = \sqrt{\{D_\theta^2\sigma_\theta^2 + D_T^2(\sigma_T/T)^2\}} \qquad (11)$$

where the dimensionless logarithmic derivatives

$$D_\theta = (1/E_\nu)(\partial E_\nu/\partial\theta) = (E_\nu/m_e)\sqrt{\{1+(2m_e/T)-[1+(m_e/E_\nu)]^2\}} \qquad (12)$$
$$D_T = (T/E_\nu)(\partial E_\nu/\partial T) = (E_\nu+m_e)/(T+2m_e)$$

Inputs ➔ energy and angular resolution

Angular resolution

Try to measure on MC

Giulia provided me MC sample (both MC truth & digitised hits)

Parameterise from pixel size, diffusion and multiple scattering

where $g=1+\varepsilon\log_{10}(\langle z\rangle/X_0)$ and (S_2=14.1 MeV, ε=1/9). The recoil angle error $\sigma_\theta=\sigma_\psi$ since the unit vector from the sun to the track start point is well determined. This error is shown in fig.5 for

Hellaz problem:
several version of this plot, even using the same parameters
➔ need to understand which one is the right to compare with…

Preliminary study promising ➔ could be a publication *per se*

Slides by E. Baracchini