Simulation update

Giulia D’Imperio for the simulation working group

CYGNO general meeting 15/10/20

Simulation activities and people

Development of simulation/analysis software

1. SRIM ➔ André and Flaminia with Davide coordination
2. Toy MC ➔ Atul and Mariana with Fabrizio and Giulia coordination
3. Analysis ➔ Samuele and Atul with Emanuele coordination

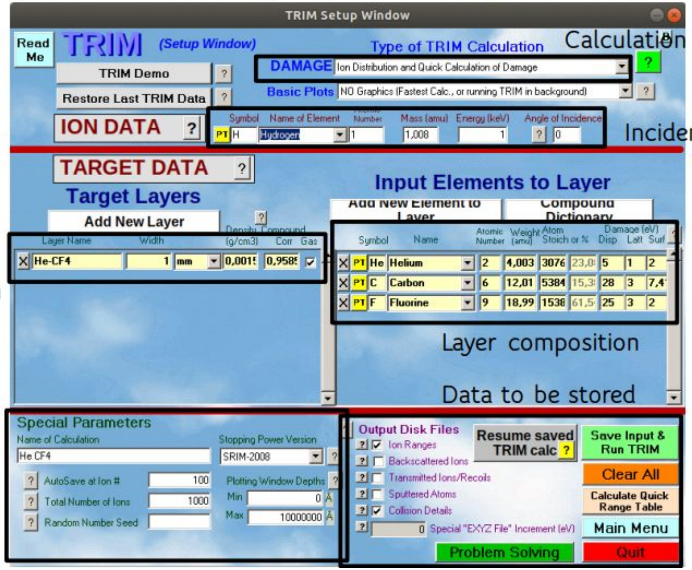
Physics cases

4. Neutrons in LIME ➔ Flaminia with Elisabetta coordination
5. Neutrinos in CYGNO ➔ Samuele and Giorgio with Elisabetta coordination
6. Dark matter in CYGNO ➔ Giorgio with Elisabetta coordination
7. Migdal effect in CYGNO ➔ Stefano with Andrea coordination

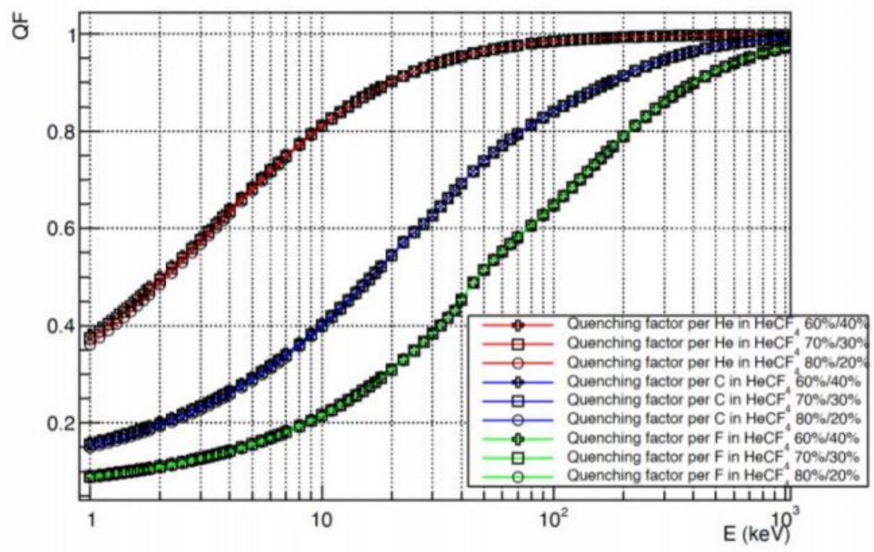
Updates from last simulation meeting

Quenching Factor assessment

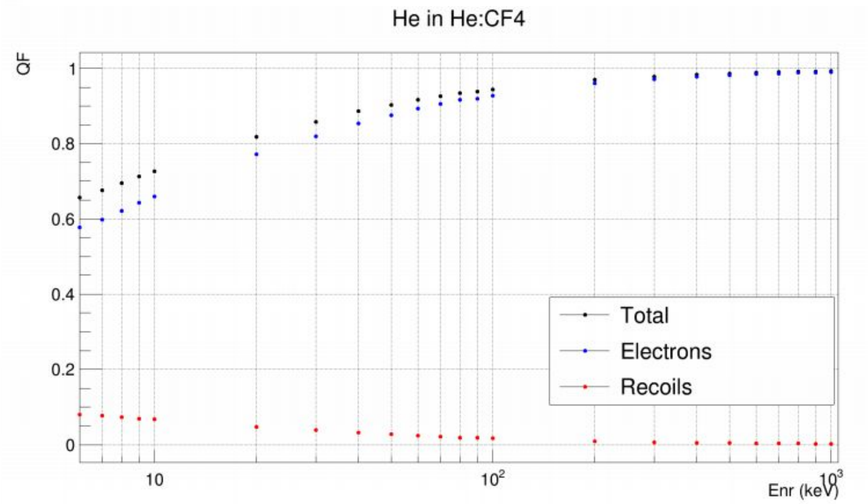
- Simplified approach to QF analysis already performed for H, He, C, F for different energies (from 1 keV up to 1 MeV);
- In this approach we used the "quick calculation" of SRIM;
- Parameters used:
  - Gas density: 0.00156 g/cm3;
  - Atomic percent (He-23.1%, C-15.4% and F-61,5%);
  - Target width (depends on the energy and was conceived to optimize the bin to particle range);
  - Number of ions simulated: 1000 per run;



Preliminary QF results



He QF = 0.8 for 10 keV
C QF = 0.4
F QF = 0.2
(Previous calculation by
E. Marconato)



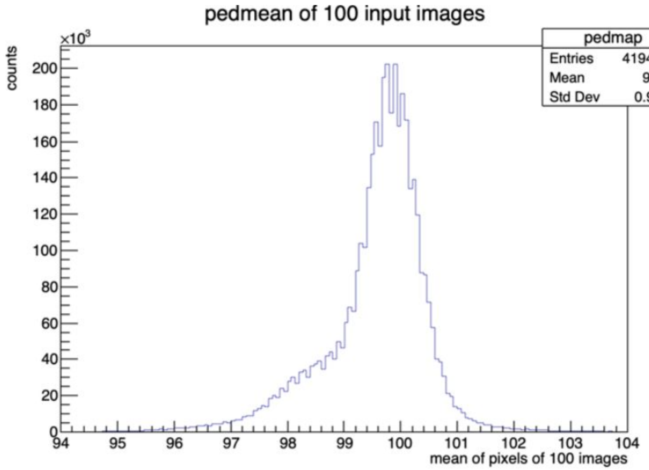
He QF = 0.73 for 10 keV
C QF = 0.46
F QF = 0.37
(New calculations)

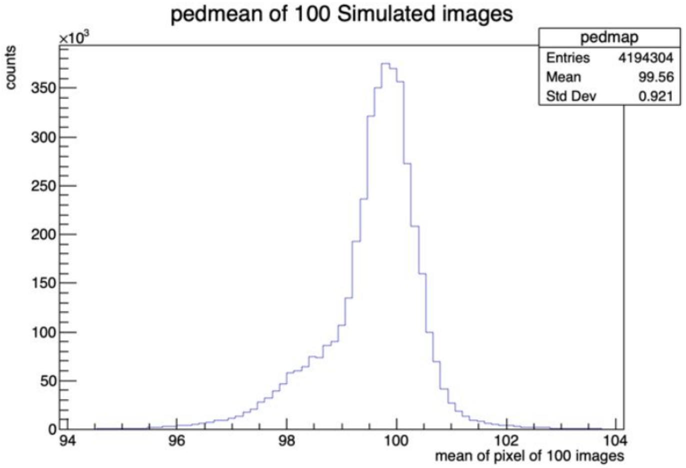
A.Cortez, F. Di Giambattista, D. Pinci

Noise simulation of CMOS

- Using method developed by Rafael and brazilian group
- Atul managed to run on his laptop, plan to move on LNGS cluster

  ➡ software setup almost done thanks to Emanuele and Stefano Stalio (calcolo at LNGS)





Solar neutrinos in CYGNO

Expected rate

Threshold on e^- E set at $20\ keV$

- Total cross section calculated with quantum field theory

  Differential cross section integrated form threshold to maximum electron energy

$$\sigma_{\nu_e}(E_\nu) = \frac{G_F^2 m_e}{2\pi}\left\{(g_V+g_A+2)^2\left[\frac{2E_\nu^2}{(m_e+2E_\nu)} - T'_{e,Thr}\right] + \right.$$
$$- (g_V-g_A)^2\frac{E_\nu}{3}\left[\left(1-\frac{2E_\nu}{m_e+2E_\nu}\right)^3 - \left(1-\frac{T'_{e,Thr}}{E_\nu}\right)^3\right] +$$
$$\left. - (g_V-g_A)(g_V+g_A+2)\frac{m_e}{2}\left[\frac{4E_\nu^2}{(m_e+2E_\nu)^2} - \frac{T'^{2}_{e,Thr}}{E_\nu^2}\right]\right\}$$

- Expected rate calculated on 60:40 He/CF_4 gas mixture @ 1atm 25°C

- Oscillation taken into account

$$P(\nu_e \to \nu_\mu) = P_{e\mu} = \frac{1}{2}\sin^2(2\theta_{12}) \quad P(\nu_e \to \nu_e) = P_{ee} = 1 - \frac{1}{2}\sin^2(2\theta_{12})$$

- pp flux tabulated taken from Bahcall

q [MeV]	P(q)	q [MeV]	P(q)	q [MeV]
0.00504	0.0035	0.11089	1.2477	0.21675
0.01008	0.0138	0.11593	1.3417	0.22179
0.01512	0.0307	0.12097	1.4370	0.22683
0.02016	0.0538	0.12601	1.5335	0.23187
0.02520	0.0830	0.13106	1.6310	0.23691
0.03024	0.1179	0.13610	1.7291	0.24195
0.03528	0.1582	0.14114	1.8278	0.24699
0.04032	0.2038	0.14618	1.9267	0.25203
0.04537	0.2543	0.15122	2.0258	0.25707

- Resulted rate:

$$R = N_e \sum_i \varphi(E_i)(P_{ee}\sigma_{\nu_e}(E_{\nu,i}) + P_{e\mu}\sigma_{\nu_\mu}(E_{\nu,i}))\Delta E$$

i-th flux component

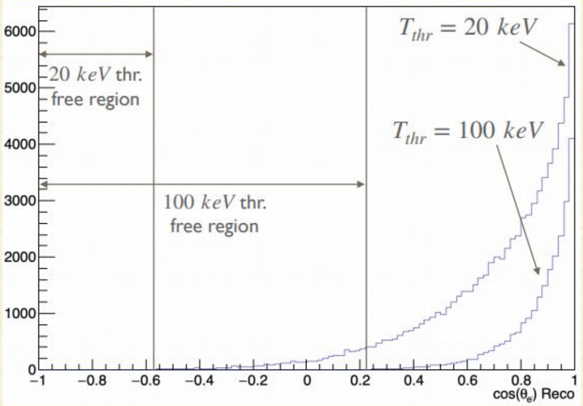
$$R = 2.9 \cdot 10^{-8}\frac{events}{s \cdot m^3} = 0.9\frac{events}{y \cdot m^3}$$

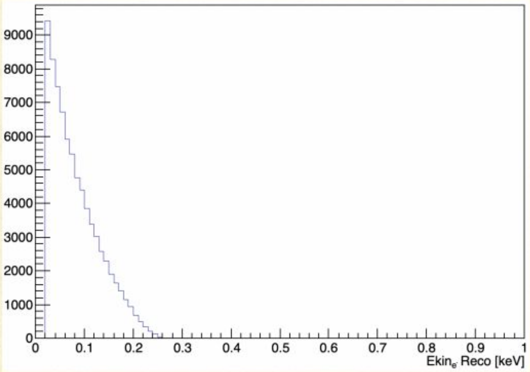
Not so bad for a $1000\ m^3$ detector

Simulated electrons spectrum

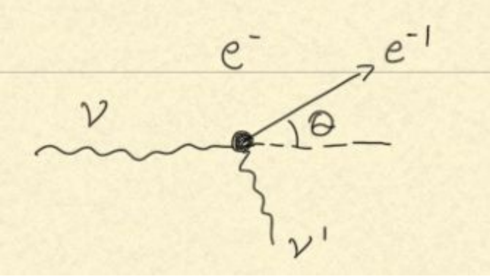
Results

- $\cos(\theta)$ distribution for two different threshold: $20 - 100\ keV$
- Signal free regions available for background measurements
- With higher threshold better signal but $R \sim 0.3 ev/(m^3\ y)$



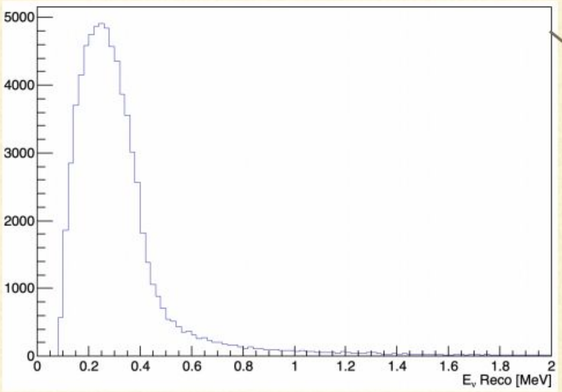


- Electron energy spectrum reconstrucred
- Typical falling exponential signal

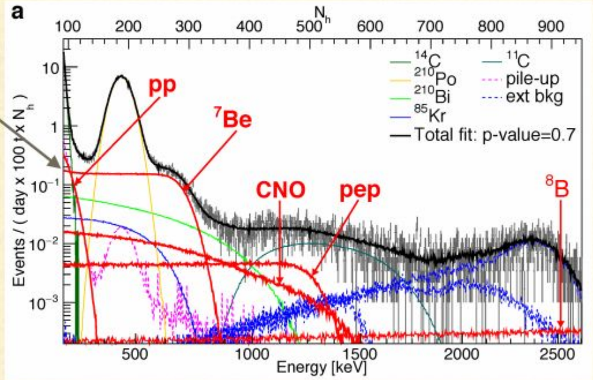


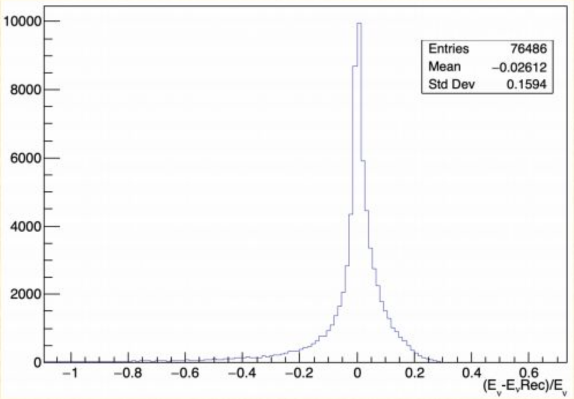
S. Torelli, E. Baracchini

“Reconstructed” neutrino spectrum



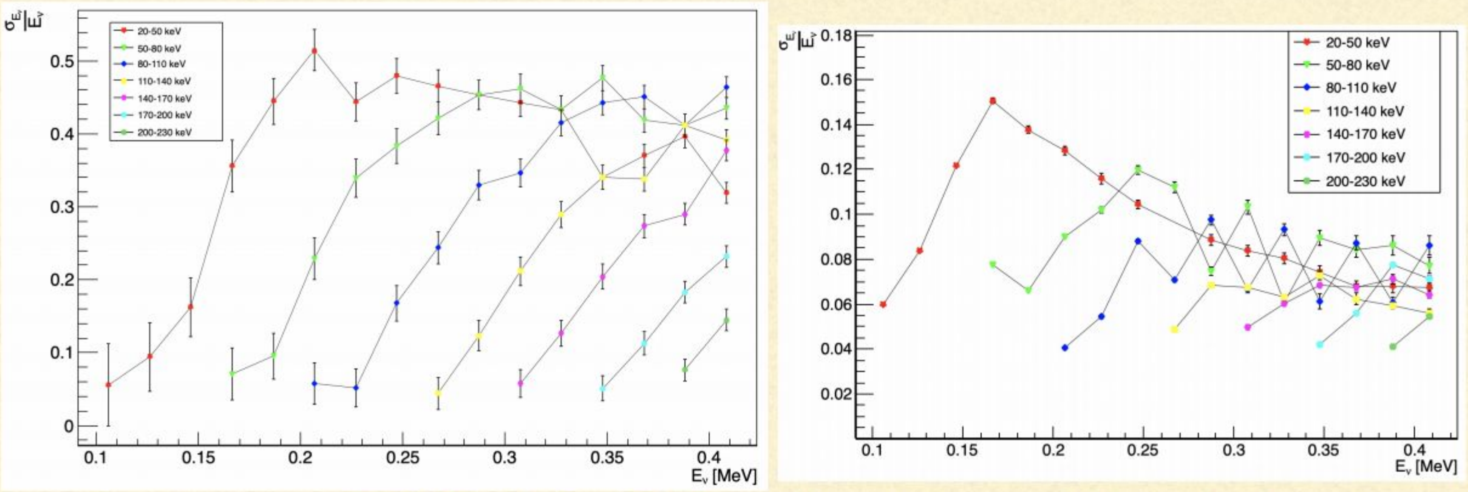
pp spectrum reconstructed (in agreement with the Borexino one)





- Residual distribution
- Histogram std. dev. $0.16E_\nu$

Neutrino energy resolution



Resolution as FWHM (Hellaz like) Resolution as CB standard deviation

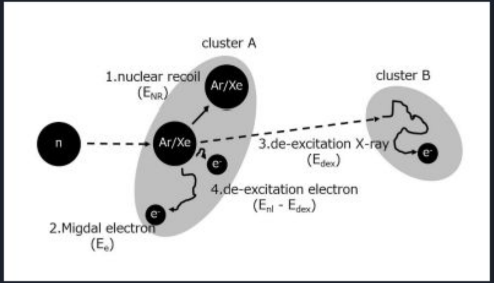
- To be compared to similar calculations for other TPC detectors
- This is still all-analytic calculation, need to add detector effects (diffusion, noise, etc)

Migdal effect feasibility study

- More details in Andrea's presentation https://agenda.infn.it/event/24078/contributions/122382/attachments/75775/97181/cygnoMC-2020.09.28.pdf
- Interesting for low mass dark matter search (< GeV)
- Signature is a NR with an ER @3 keV separated by O(cm)
- Investigate use of Ar:CF4 in one of our prototypes
- Neutron source to characterize detector
    - Am-Be source
    - neutron/ion beams
- Plan to start from a simple simulation of neutrons + electrons in LIME
    - compare with expected background
    - estimate source rate needed to characterize the detector for this measurement
    - study analysis performance on MC

Migdal effect in CYGNO

Neutron source: FNG?



Neutron spectrum (~ isotropic):
- 14 MeV - 10^{11} n / s
- 2.5 MeV - 10^{8} n / s

Minimal distance from the center of interaction: 4 mm

Useful numbers:

AmBe spectrum:	1-10 MeV - 2.2×10^5 n / s
Migdal BR for Argon:	$f(E_n) * 7.2 \times 10^{-5}$
Fluorescence yield (K shell, Ar):	0.14
Solid Angle/4π @ 50 cm for 20x20 cm^2 TPC:	1.27 %
Solid Angle/4π @ 10 cm for 20x20 cm^2 TPC:	31.8 %

arXiv:1707.07258
arXiv:2009.05939

$$f(E_n) = \left(\frac{q_e}{511\,\mathrm{eV}}\right)^2 = \left(\frac{1}{511\,\mathrm{eV}}\right)^2 \frac{2m_e^2 E_R^{max}}{m_T} = \left(\frac{1}{511\,\mathrm{eV}}\right)^2 \frac{2m_e^2}{m_T}\frac{4m_n m_T}{(m_n+m_T)^2}E_n$$

Google sheet with more infos here.

$f(E_n = 14$ MeV$) = 72.4$

$f(E_n = 2.5$ MeV$) = 12.9$ → O(3000 ev/day) @ 265 cm

S. Piacentini, A. Messina