Feasibility study of solar neutrinos with CYGNO

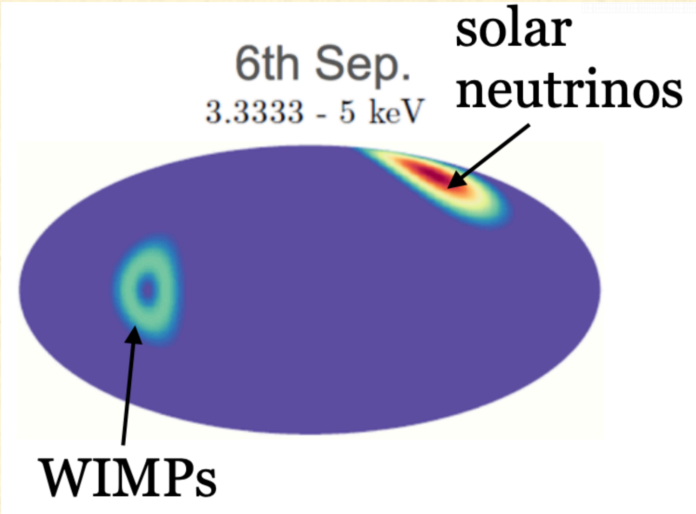
First preliminary results

Samuele Torelli

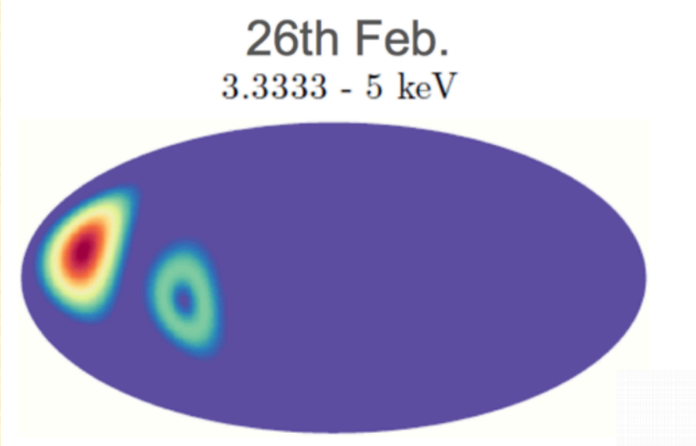
Istituto Nazionale di Fisica Nucleare

GRAN SASSO SCIENCE INSTITUTE
CENTER FOR ADVANCED STUDIES INFN

Physical motivations

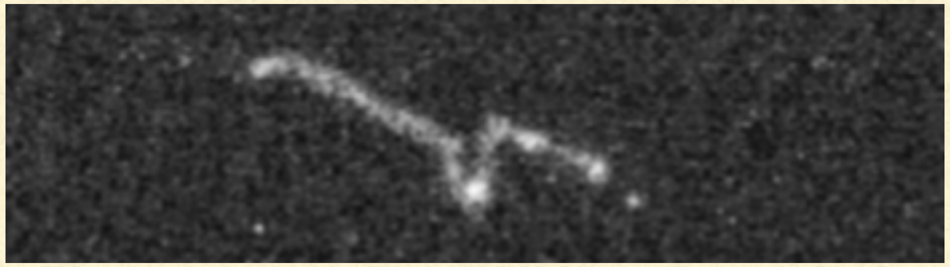


- Directional DM detectors → capability of discriminating particles from different sources through directionality



- Possibility of making solar neutrinos an opportunity to study more than nuisance

- Solar neutrinos from pp cycle can be studied through elastic scattering on electrons



- pp cycle neutrinos can be studied:
  - Low energy threshold (lower than Borexino)
  - Low background (Positive identification by sun direction correlation)

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:

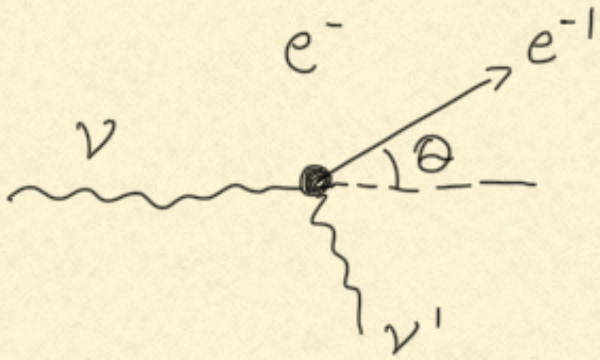
$$R = N_e \sum_i \varphi(E_i)(P_{ee}\sigma_{\nu_e}(E_{\nu,i}) + P_{e\mu}\sigma_{\nu_\mu}(E_{\nu,i}))\Delta E$$

i-th flux component

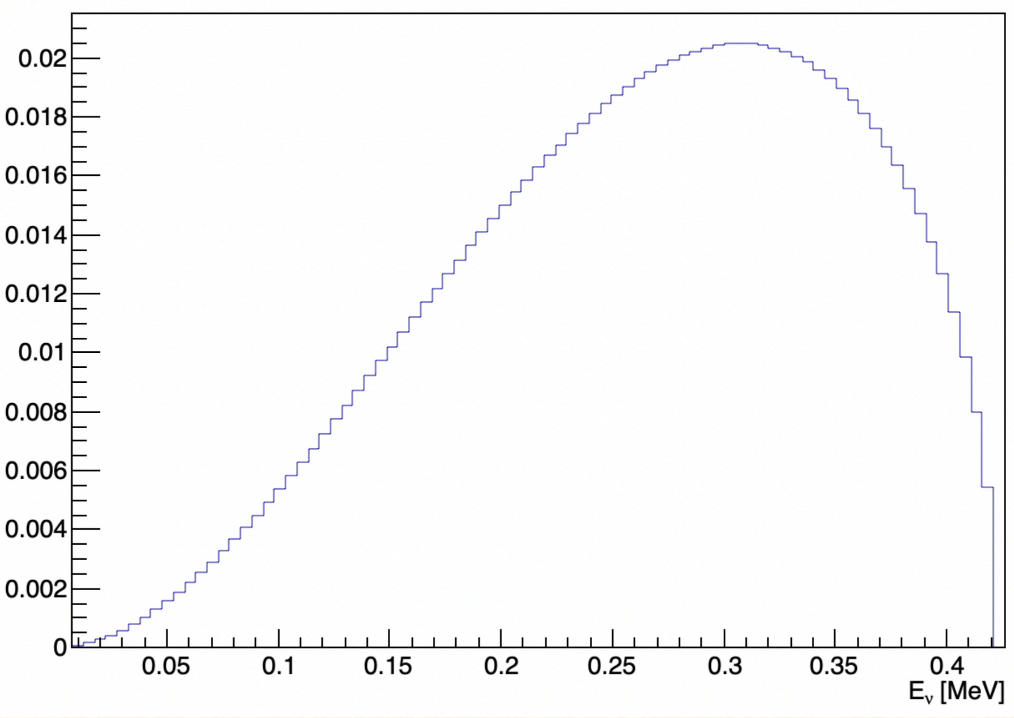
$$R = 2.9\cdot 10^{-8}\ \frac{events}{s\cdot m^3} = 0.9\ \frac{events}{y\cdot m^3}$$

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

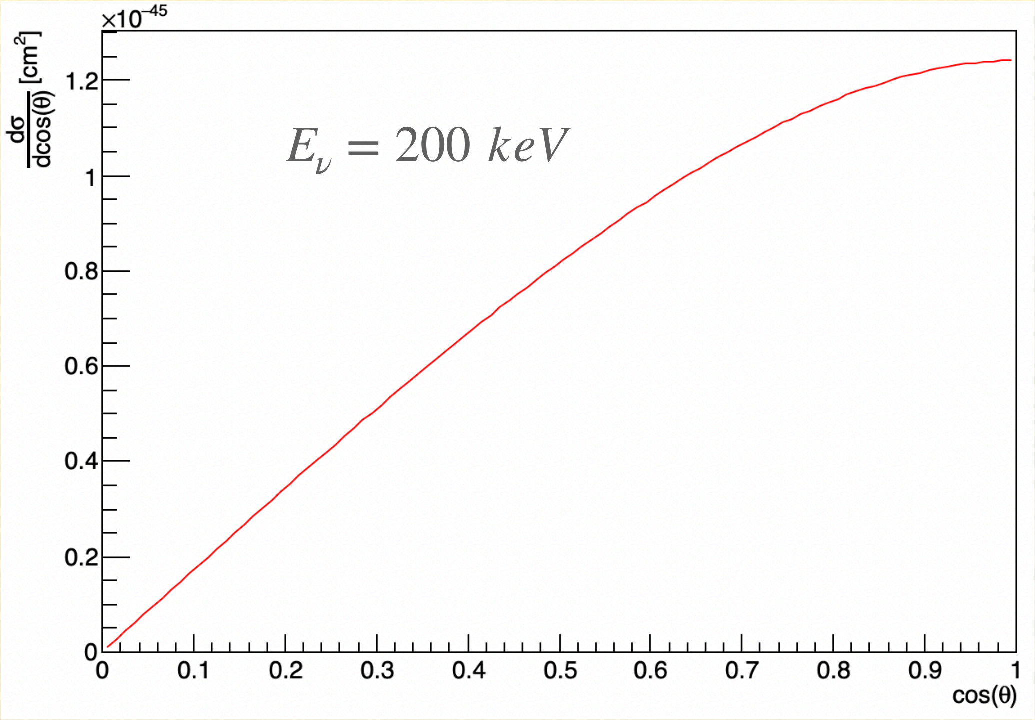
Expected electrons spectrum



- e^- angular distribution + energy spectrum:



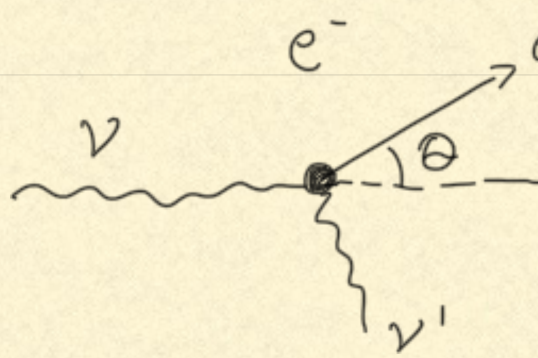
1. Extraction of a random neutrino energy according to the flux



2. Extraction of a random $\cos\theta$ value according to the differential cross section for extracted neutrino energy

The kinematic now is closed

Expected electrons spectrum



3. Calculation of the e^- kinetic energy given E_ν and $\cos(\theta)$

$$T'_e(\theta) = \frac{2E_\nu^2 m_e cos^2(\theta)}{(E_\nu + m_e)^2 - E_\nu^2 cos^2(\theta)}$$

4. Smearing of energy and angle according to the resolutions

$$\frac{\sigma_E}{E} = \sqrt{4.33 + \frac{1890}{E}} \qquad \sigma_\theta = 0.3490 = 20^\circ$$

$E_{Sm} = E + gE$

g: factor extracted from a normalized gaussian with $\mu = 0$ and $\sigma = \sigma_E / E$

Same thing for the angle, but fixed σ_θ

5. Reconstruct the energy of the neutrino with E_{e^-} and $\cos\theta$ smeared

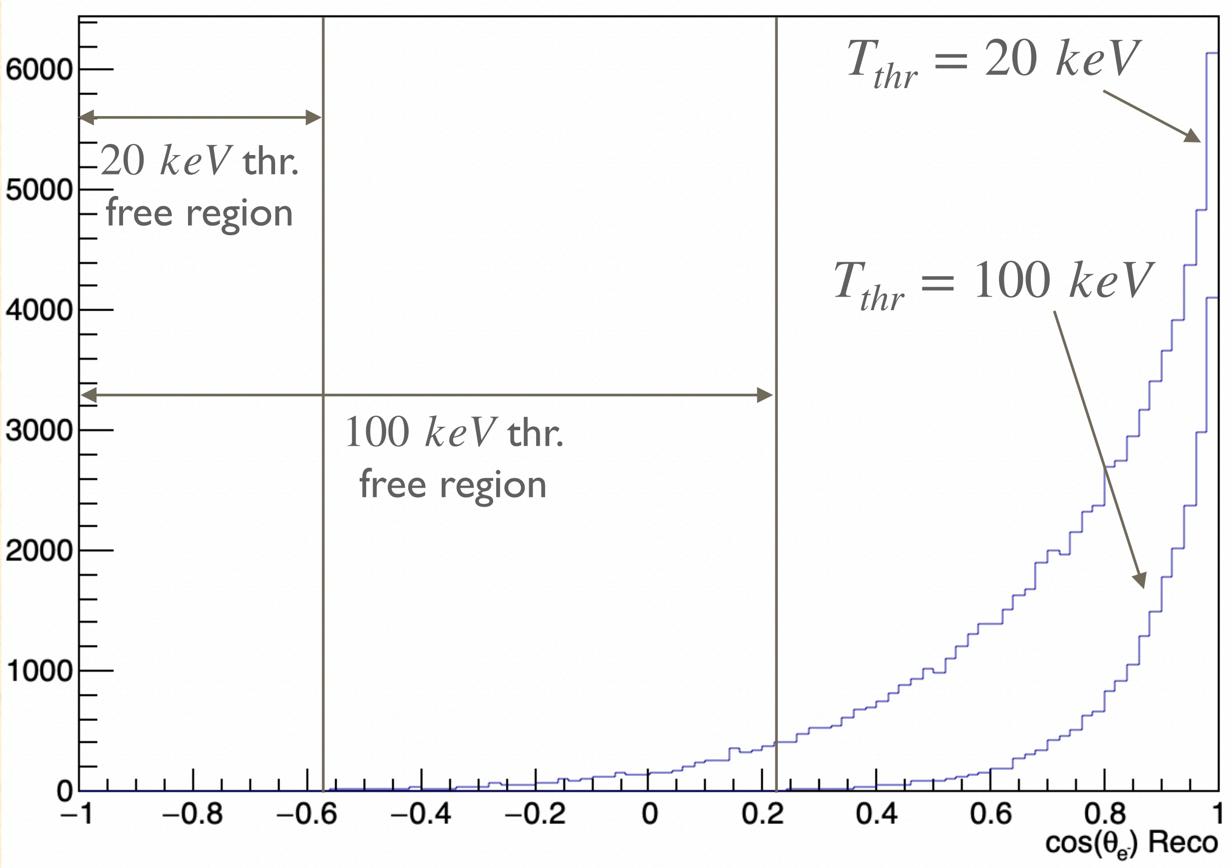
$$E_{\nu,Reco} = \frac{-m_e T_e - \sqrt{T_e^2 m_e^2 \cos(\theta)^2 + 2T_e m_e^3 \cos(\theta)^2}}{(T_e - T_e \cos(\theta)^2 - 2m_e \cos(\theta)^2)}$$

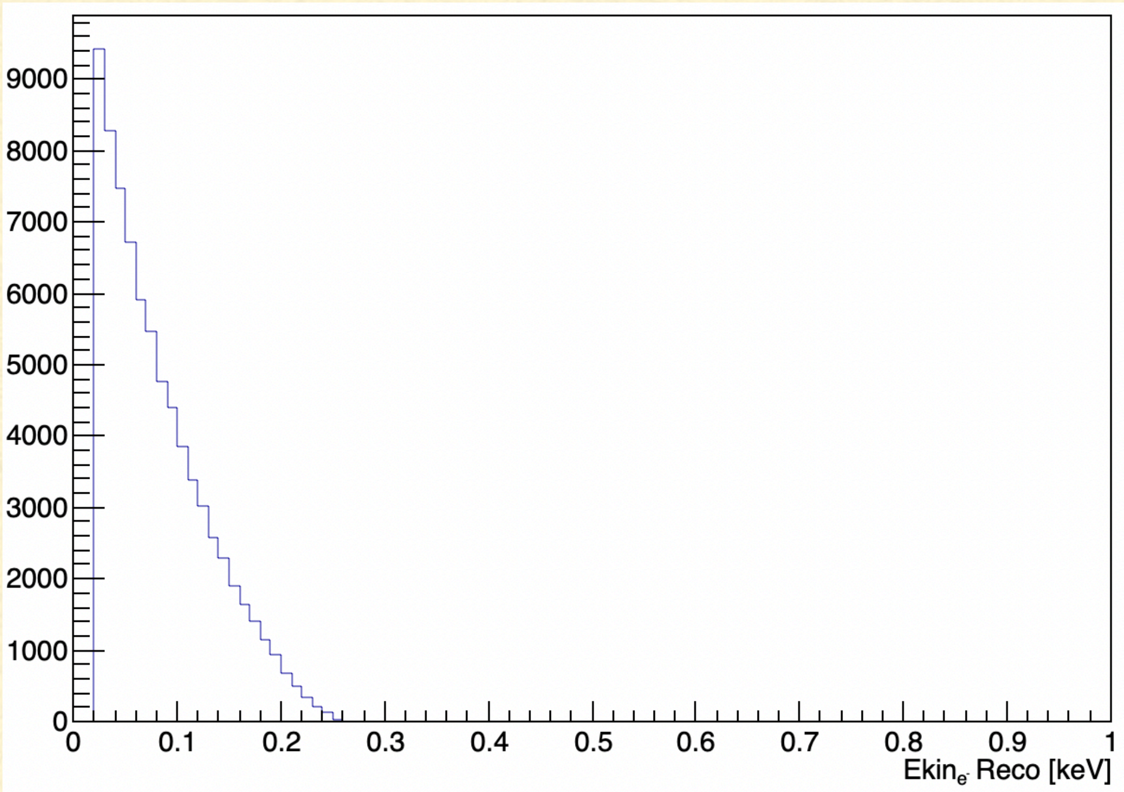
Results

- $\cos(\theta)$ distribution for two different threshold: $20 - 100\ keV$

- Signal free regions available for background measurements

- With higher threshold better signal but $R \sim 0.3ev/(m^3\ y)$



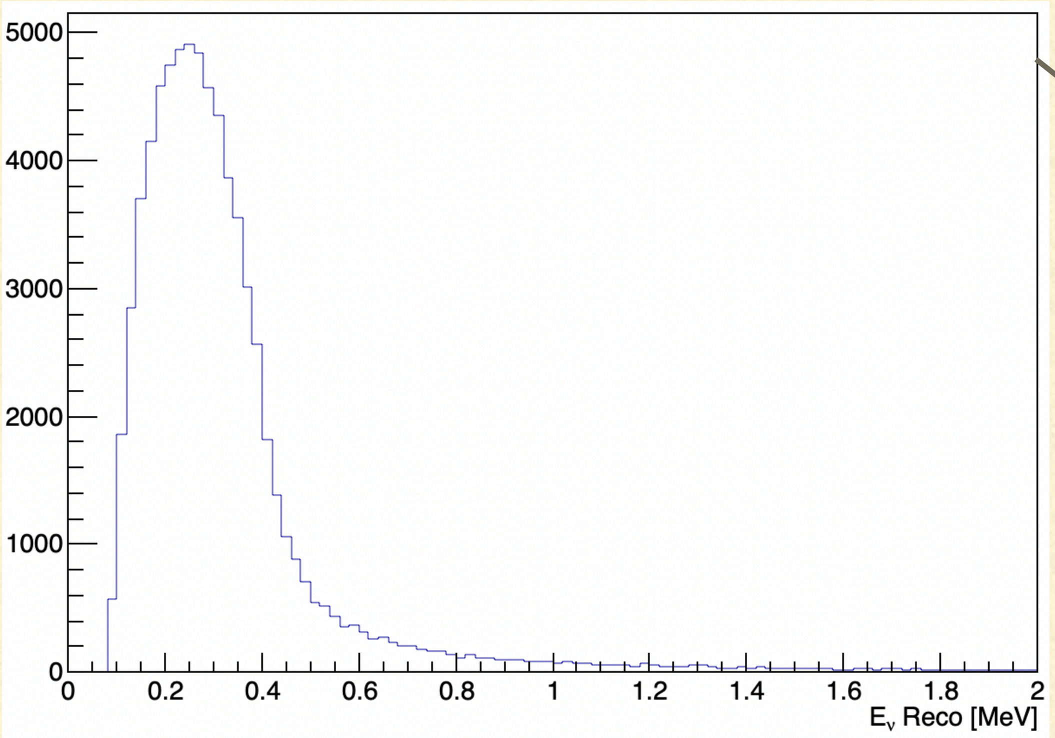


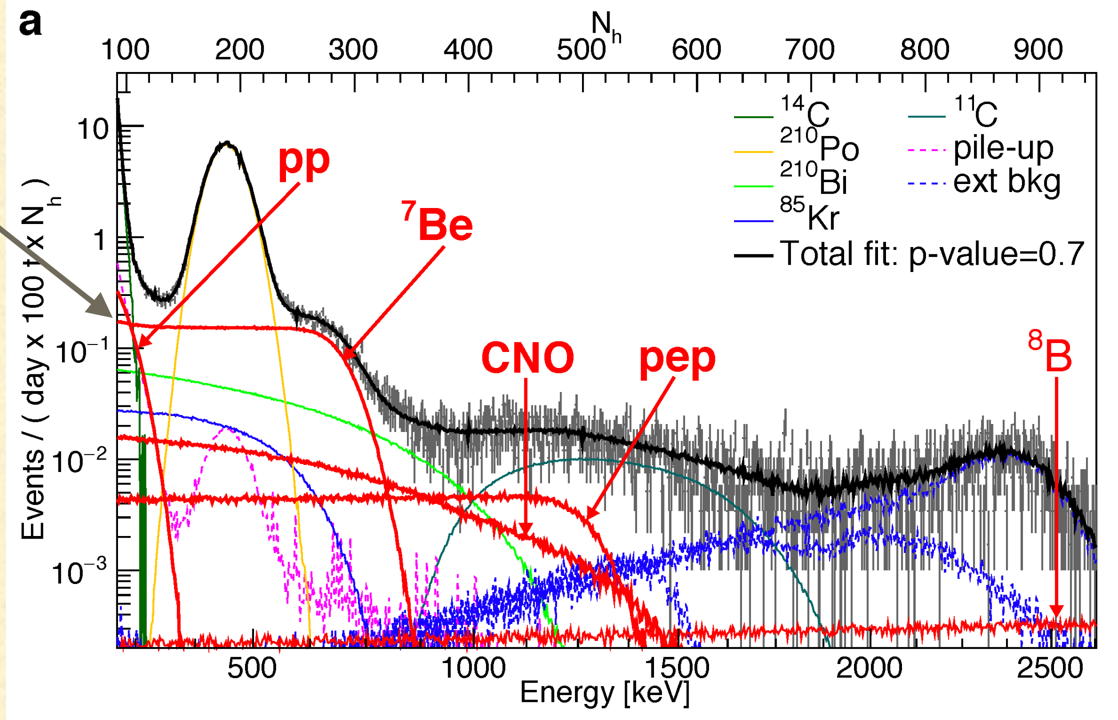
- Electron energy spectrum reconstrucred

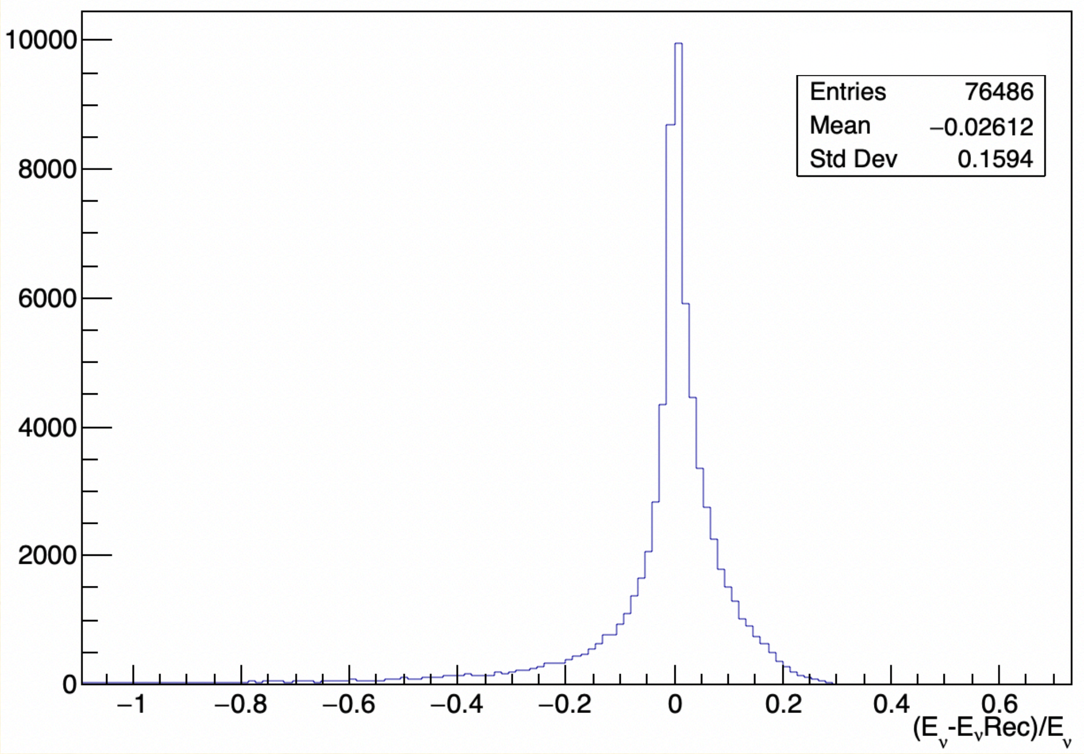
- Typical falling exponential signal

Results

pp spectrum reconstructed (in agreement with the Borexino one)



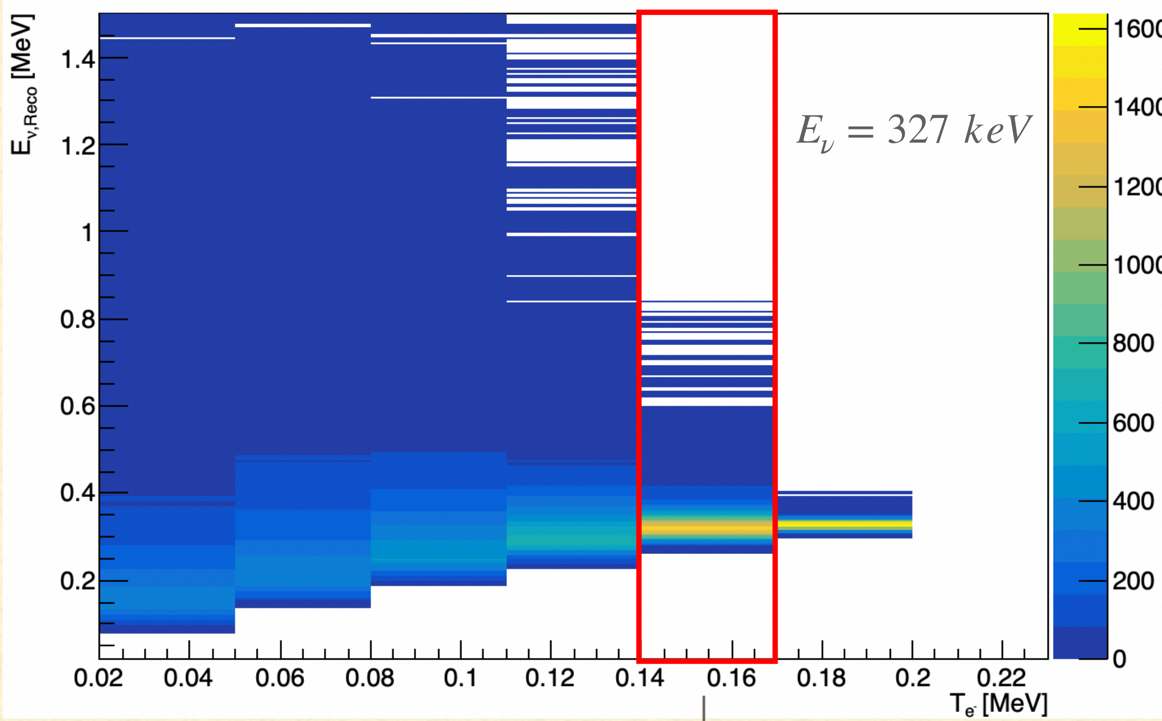




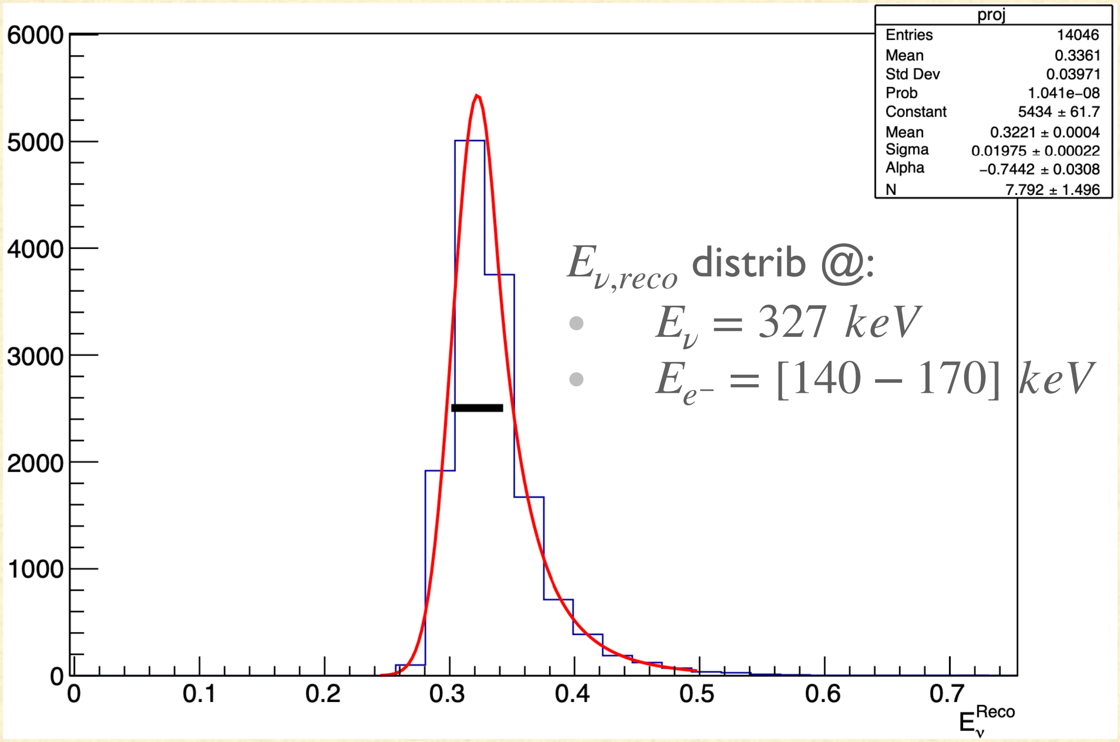
- Residual distribution
- Histogram std. dev. $0.16E_\nu$

Energy resolution

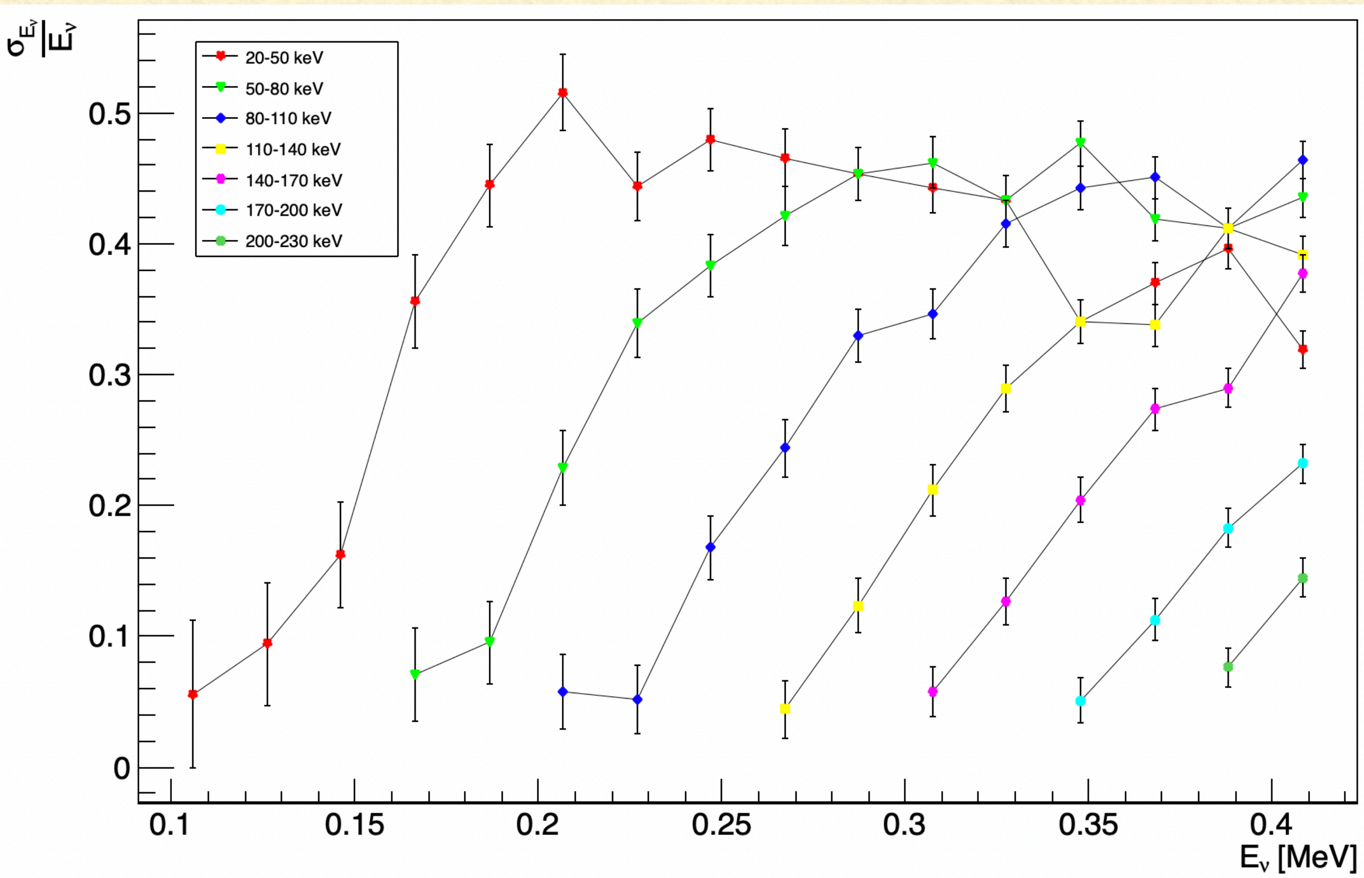
- σ_{E_ν}/E_ν vs E_ν @ fixed e^- kinetic energy
- Same angular and Energy resolution of before



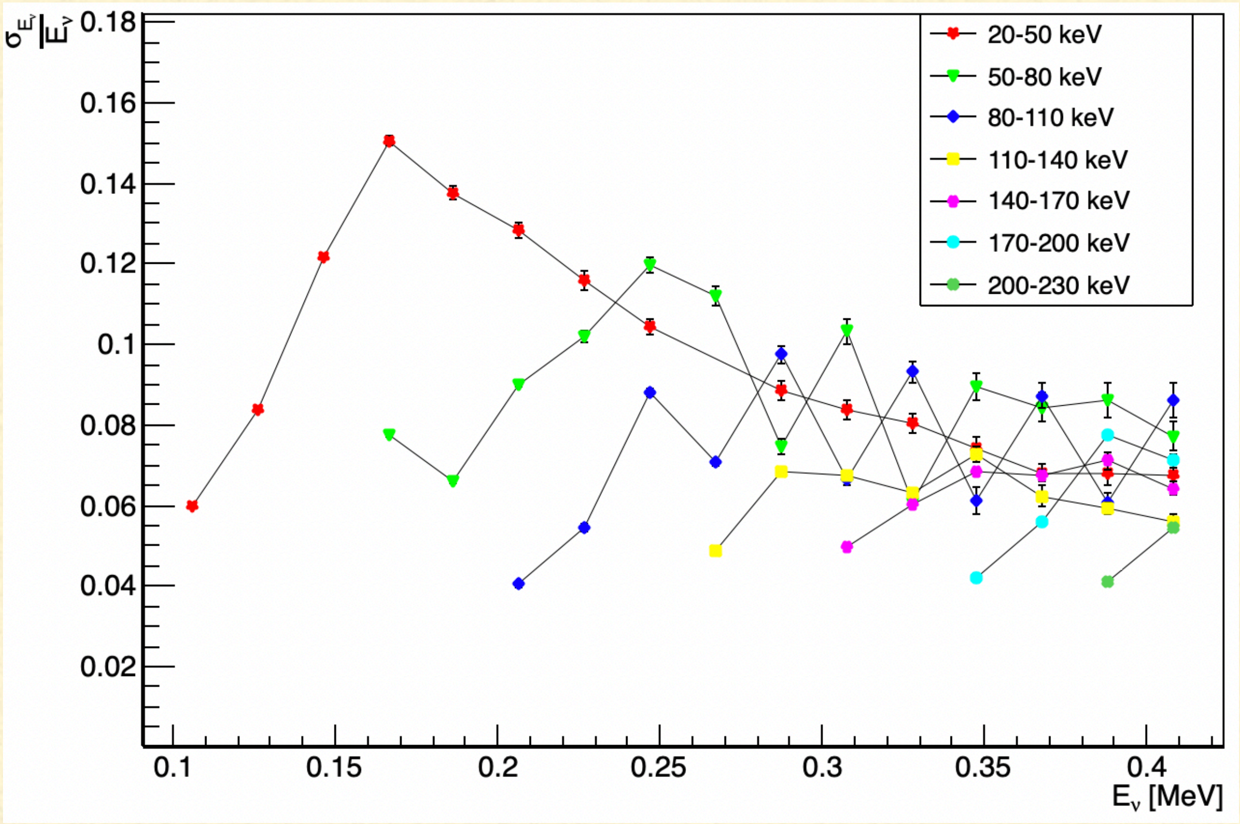
1. Fix a neutrino Energy
2. Simulate the interaction (e^- Energy and $\cos(\theta)$)
3. In bins of electron energy build the $E_{\nu,Reco}$ distrib.
4. Fit each projection (Crystal ball) for any E_ν
5. Build the σ_{E_ν}/E_ν vs E_ν for different e^- energy



Results in neutrinos E resolution



Resolution as FWHM (Hellaz like)



Resolution as CB standard deviation

The first has more sense?

Other comparison

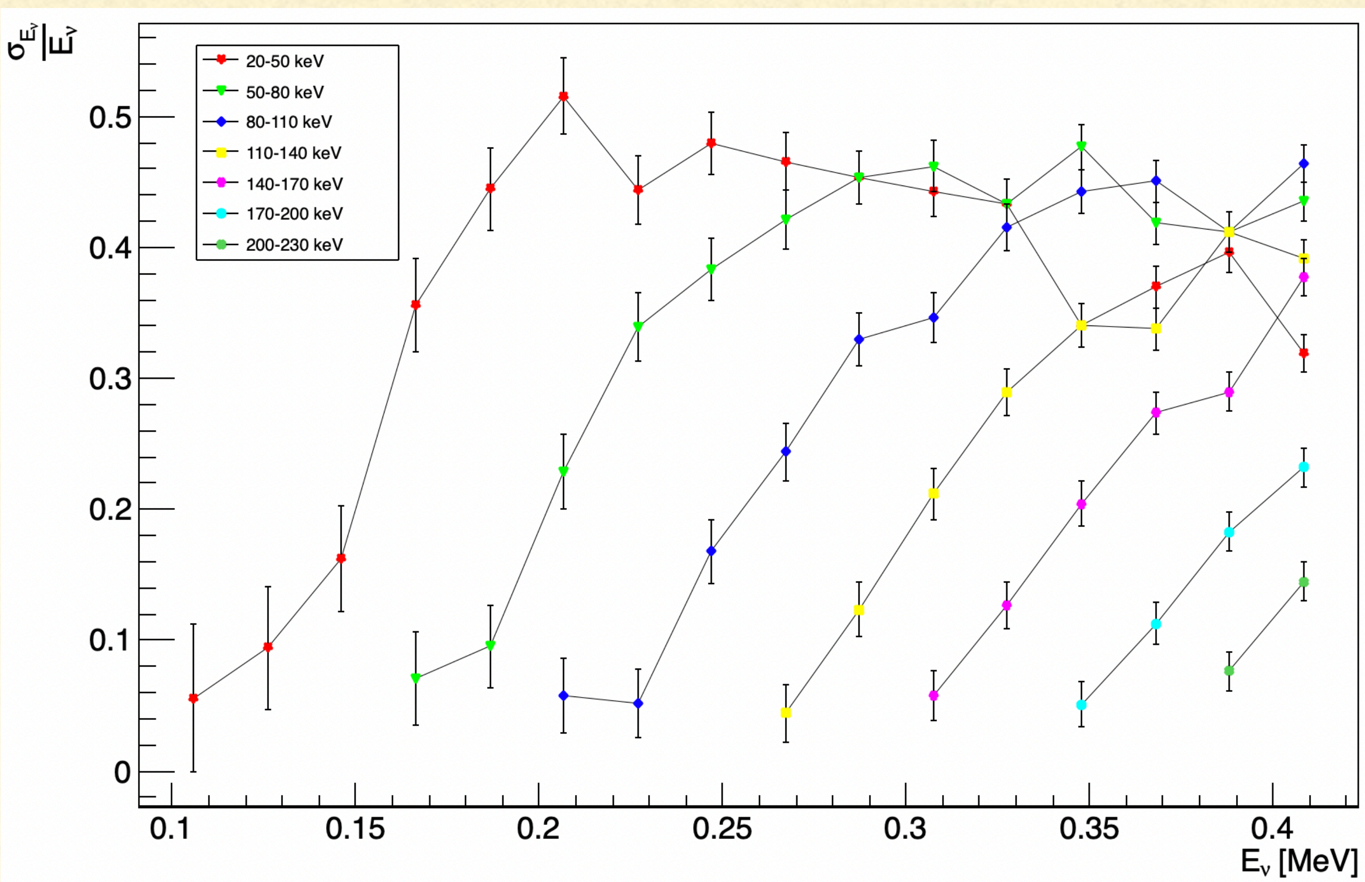
Comparison with Elisabetta's analytical result

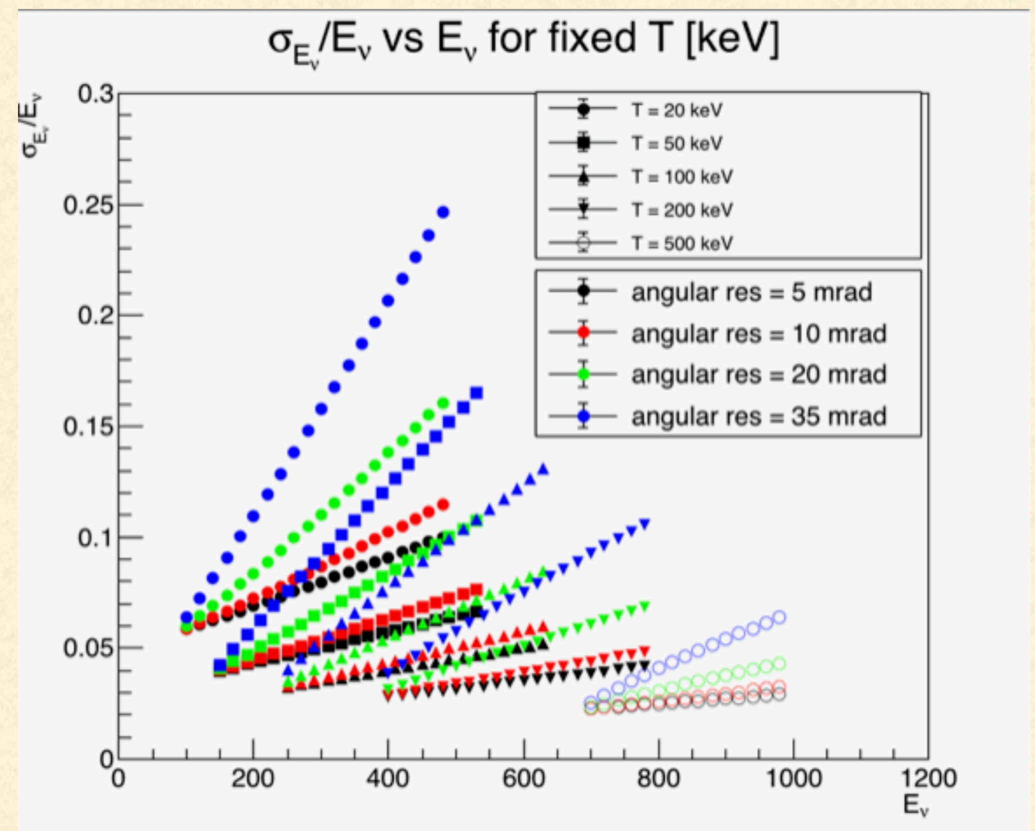
The neutrino energy resolution $\sigma_{E\nu}/E_\nu$ is obtained from the derivatives of eq. (2) i.e.

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

where the dimensionless logarithmic derivatives

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





Remember: $FWHM = 2.355\ \sigma_{Gaussian}$

Backup

Hellaz comparison