Feasibility of a directional solar neutrino measurement with CYGNO

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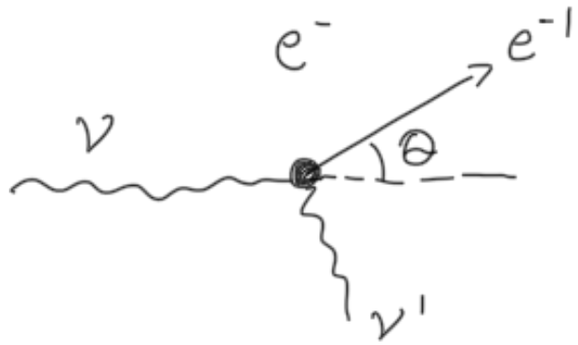
CYGNO Collaboration meeting 2022 - Roma

Solar neutrino with CYGNO/INITIUM



- Neutrino from the sun can be object of study with large TPC through $\nu - e^-$ scattering

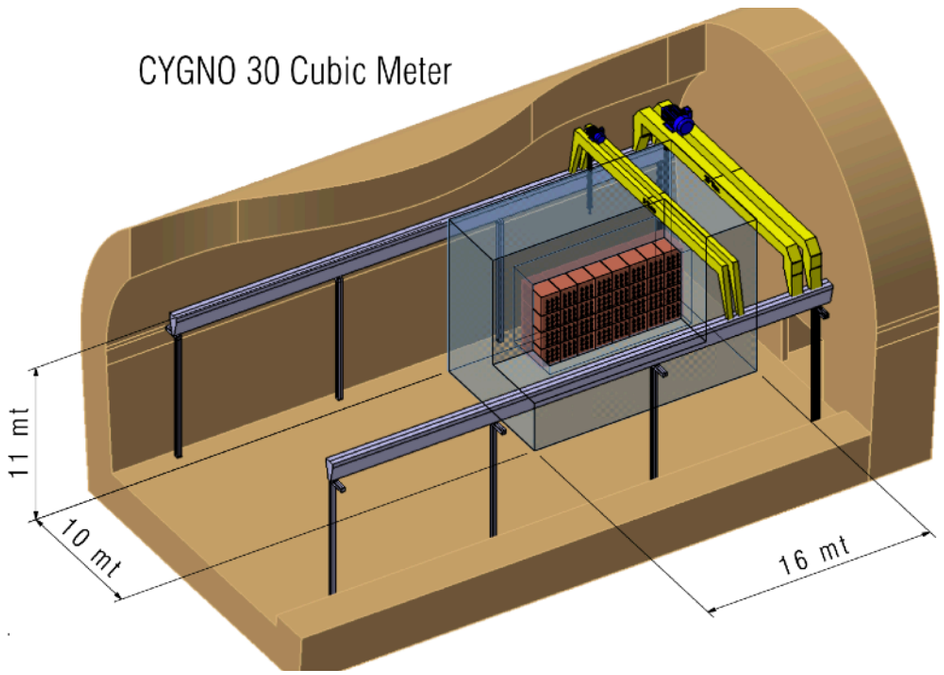
  Seguinot, Jacques & Ypsilantis, Thomas & Zichichi, Antonino. (1992). A high rate solar neutrino detector with energy determination.

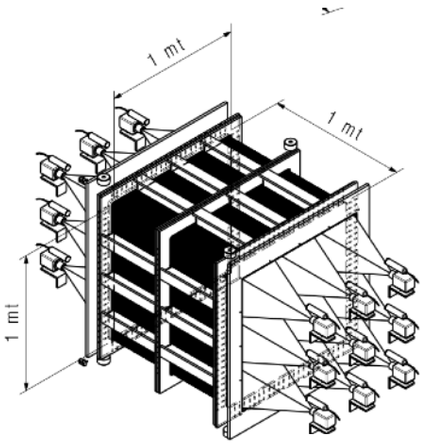
- Directional detection→ capability of discriminating particles from different sources through directionality

Much stronger signature than energy spectrum

Peaked distribution over flat bkg	vs	Exponential Signal over exponential bkg

- With a CYGNO PHASE 2 detector of 30 m^3 active volume we expect: ~ 90 events in 3 y



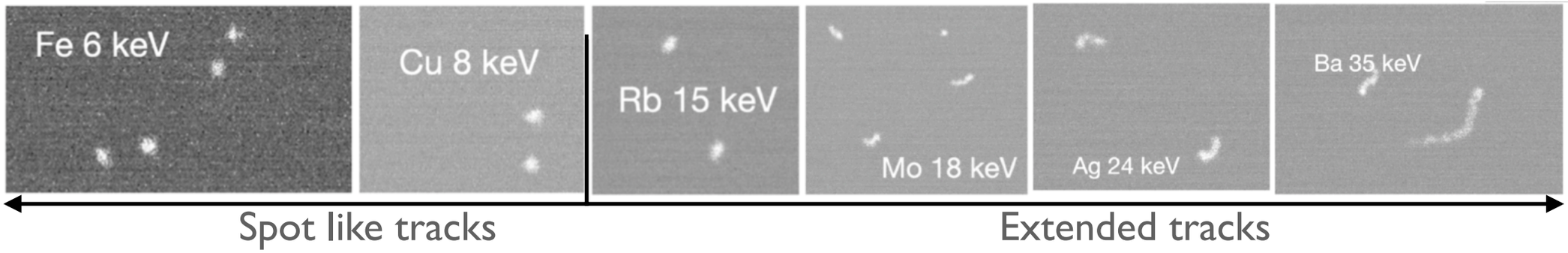


CYGNO 1 Cubic Meter

Energy response and resolution

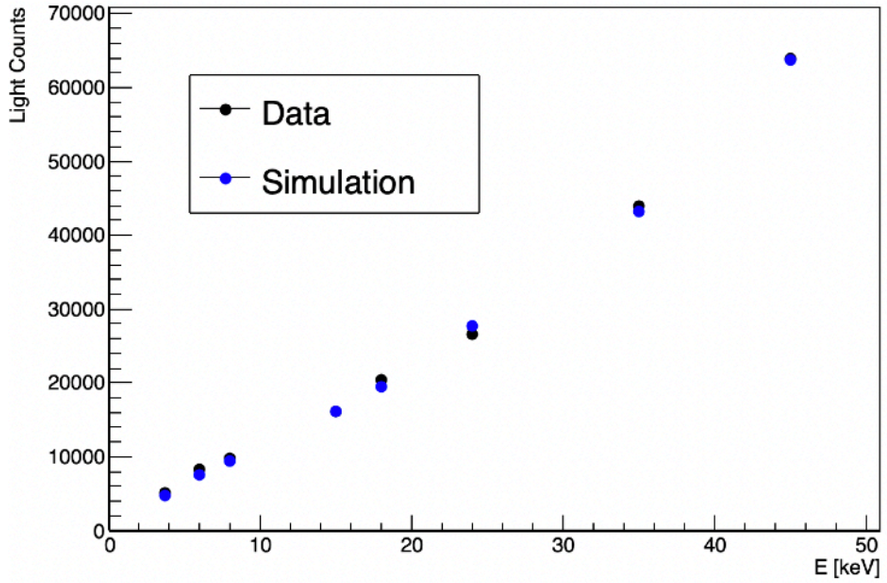
- Study of linearity and energy resolution overground performed with X-Rays at different energies

- How tracks appear in our detector:



- Data shows good linearity in [6-35] keV

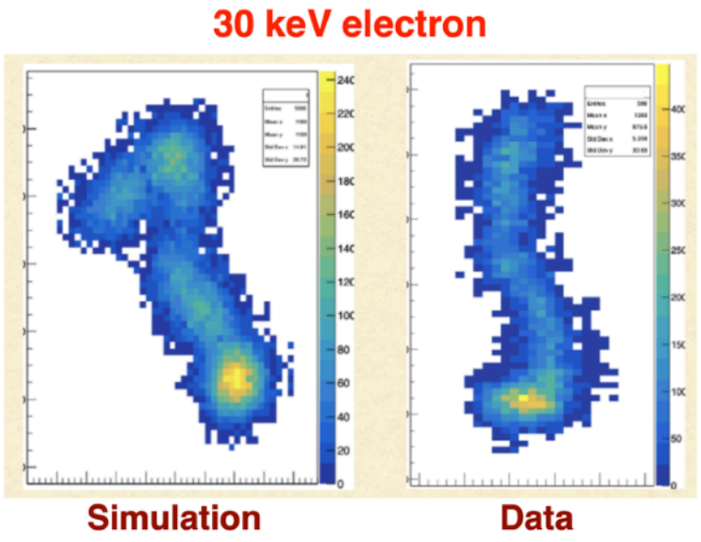
- Energy resolution ~constant at 13% in same range

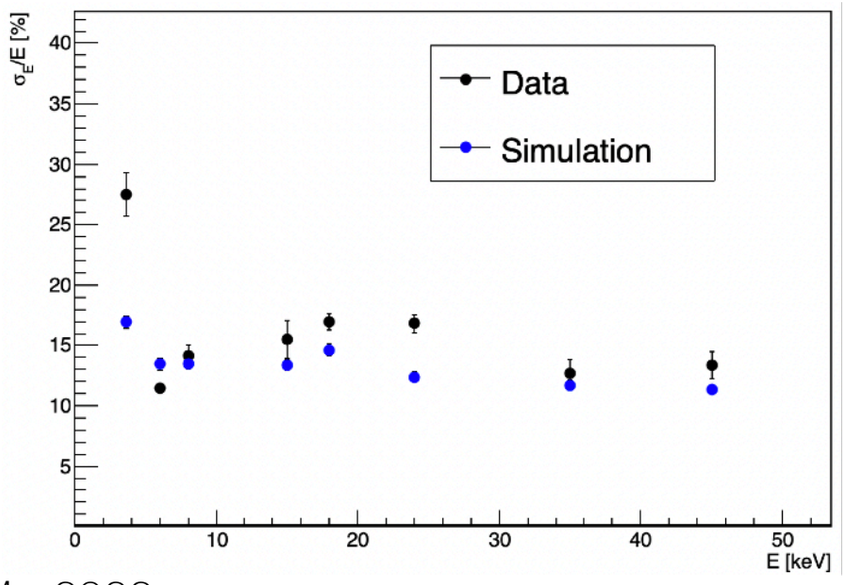


MC developed taking into account detector effect:

- Data in agreement with the simulation for E > 6keV

Tracks shape variables in agreement too!





Directionality of low energy electron recoil

Data sample

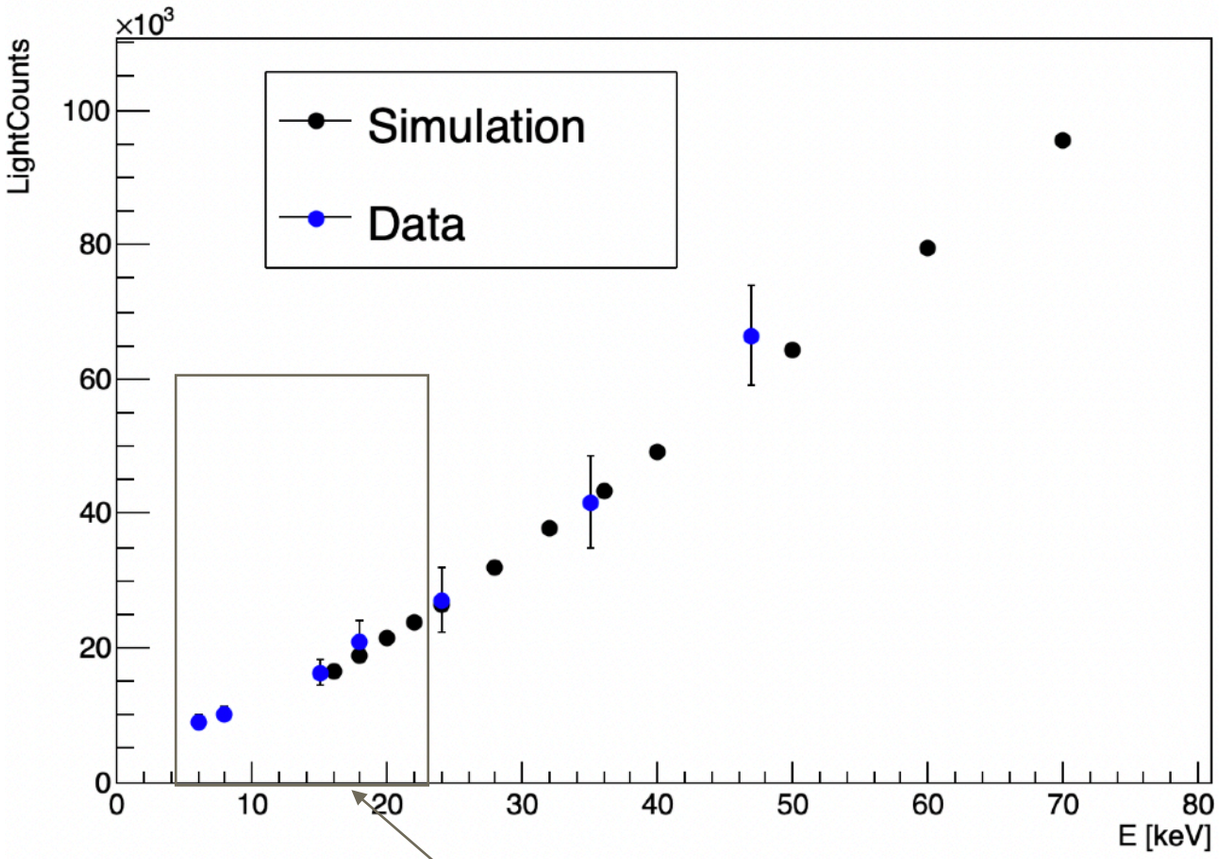
With the new digitization code optimized, I produced samples of:

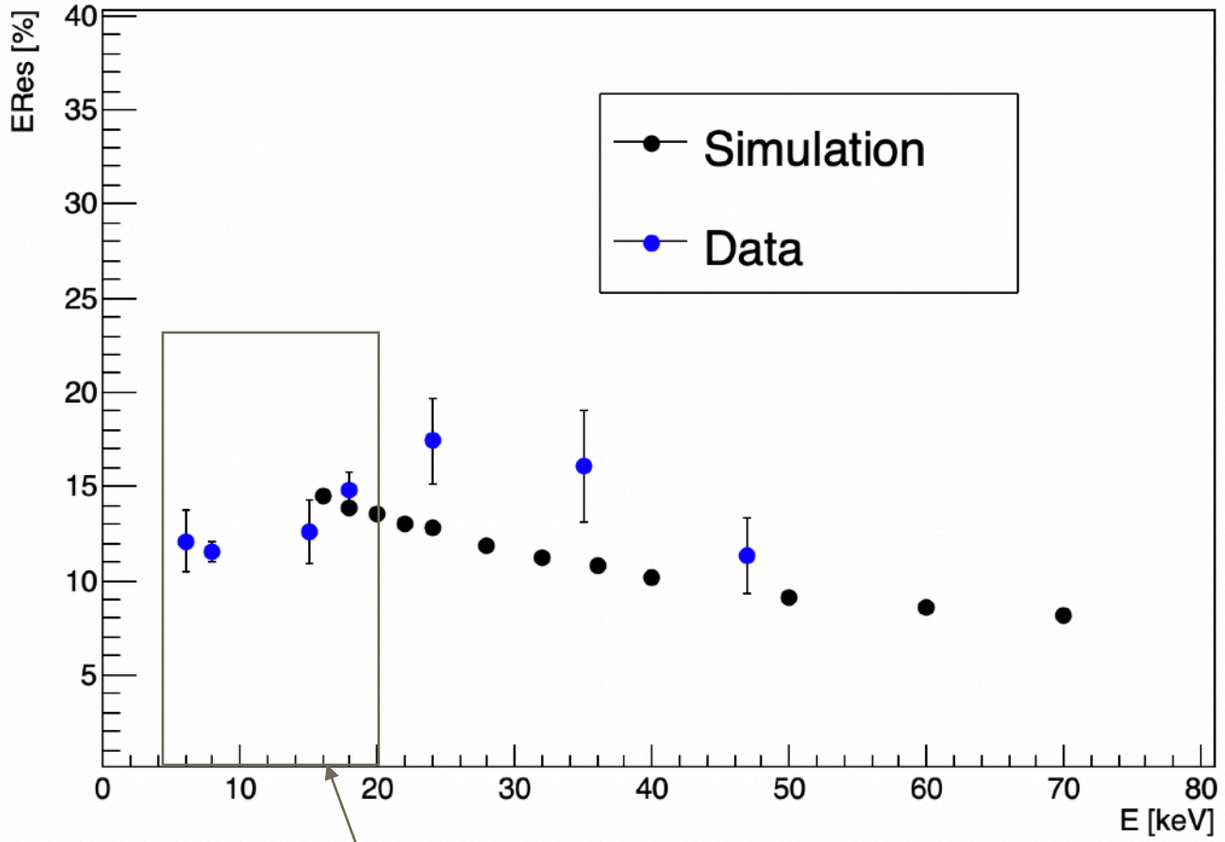
- 10.000 tracks per energy
- Isotropic direction
- Drift distance uniform from 10 to 40 cm
- Random x-y position with vignetting included
- Energies of 16 18 20 22 24 28 32 36 40 50 60 70 keV

N.B. Some optimization of the parameters is needed to reconstruct 100 keV

- Possibility of retrieving the original impact point since the GEANT xyz are saved

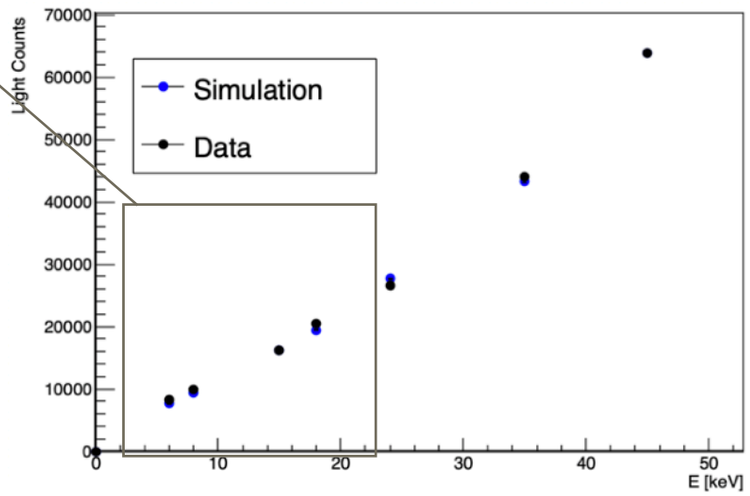
Linearity and energy resolution

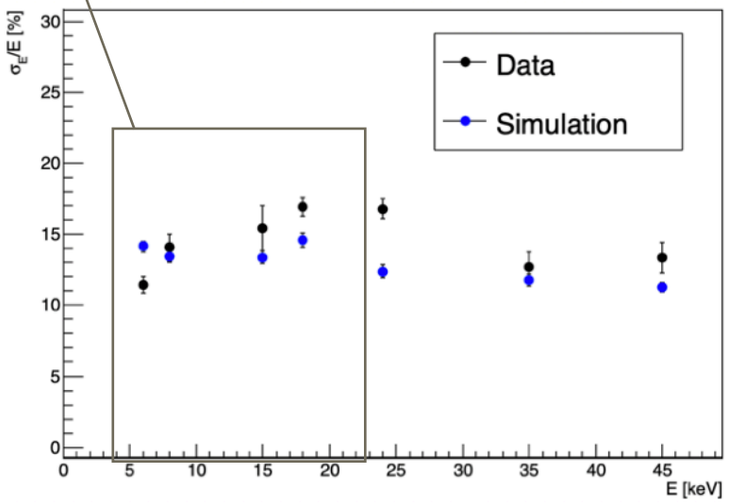




From previous results simulation points expected to follow the trend of data at lower energies (0-20keV)

Blue and black points

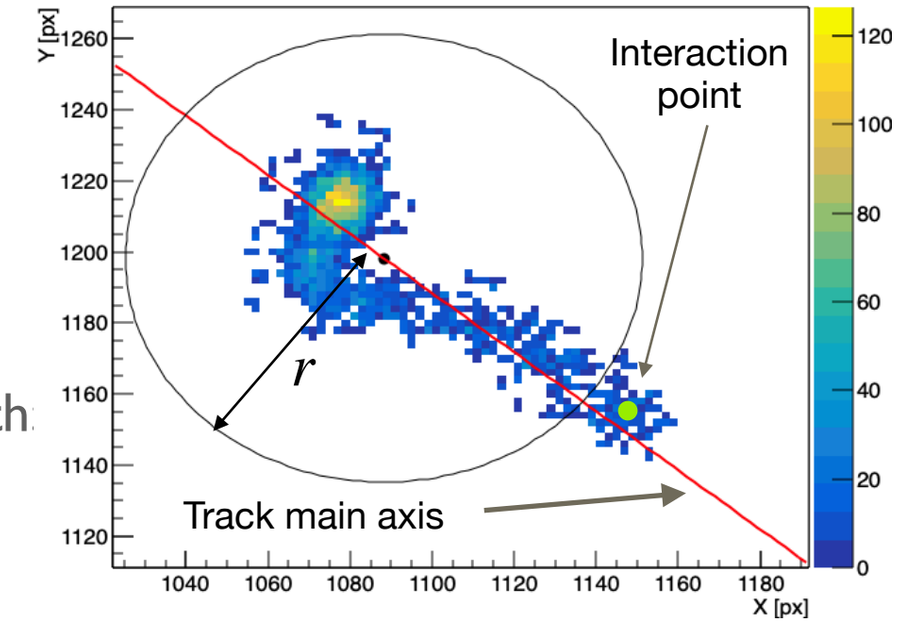




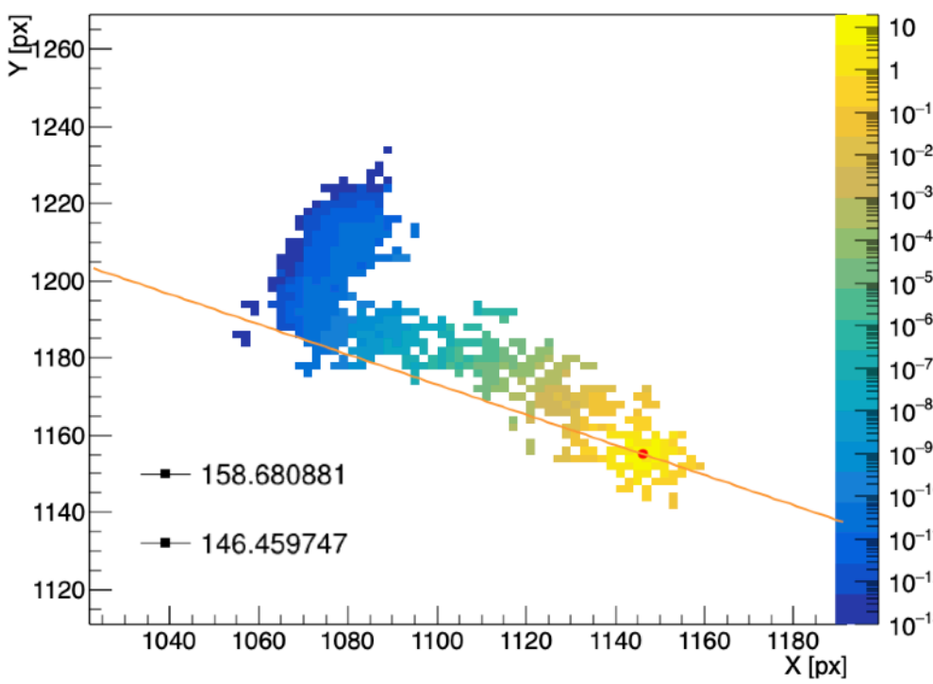
Directionality algorithm in a nutshell

- Algorithm adapted from X-ray polarimetry:

"Measurement of the position resolution of the Gas Pixel Detector"
Nuclear Instruments and Methods in Physics Research Section A, Volume 700, 1 February 2013, Pages 99-105



- First part of the algorithm: searching for the beginning of the track with:
  - Skewness
  - Distance of pixels from barycenter (farthest pixels)
  - Selection of a region with fixed number of points N_{pt}

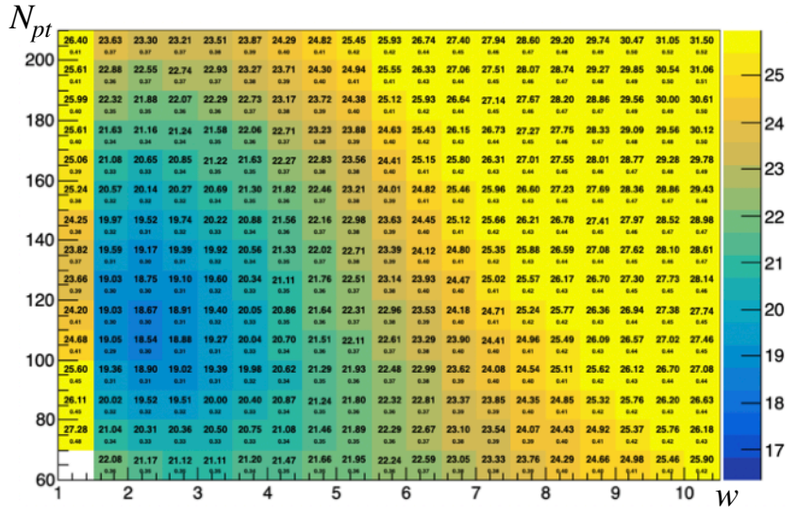


- Second part of the algorithm aims to find the direction:
  - Track point intensity rescaled with the distance from the interaction point: $W(d_{ip}) = exp(-d_{ip}/w)$
  - Direction taken as the main axis of the rescaled track passing from the interaction Point
  - Orientation given following the light in the Pixels

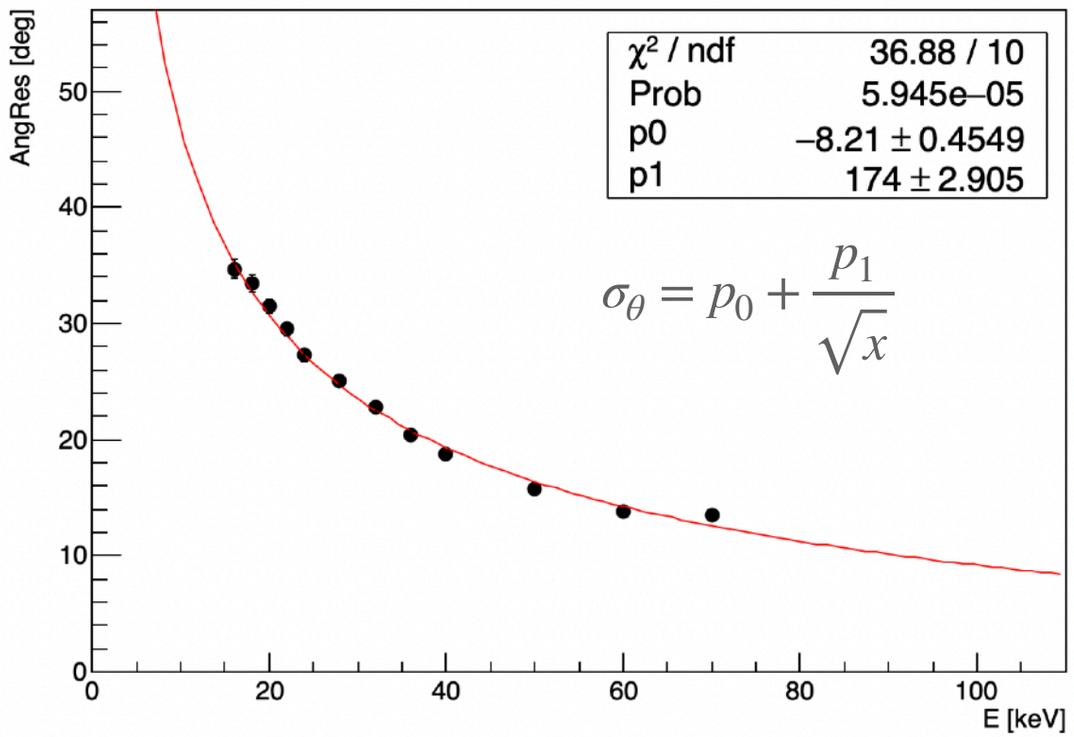
- Two parameters of the algorithm: N_{pt} and w

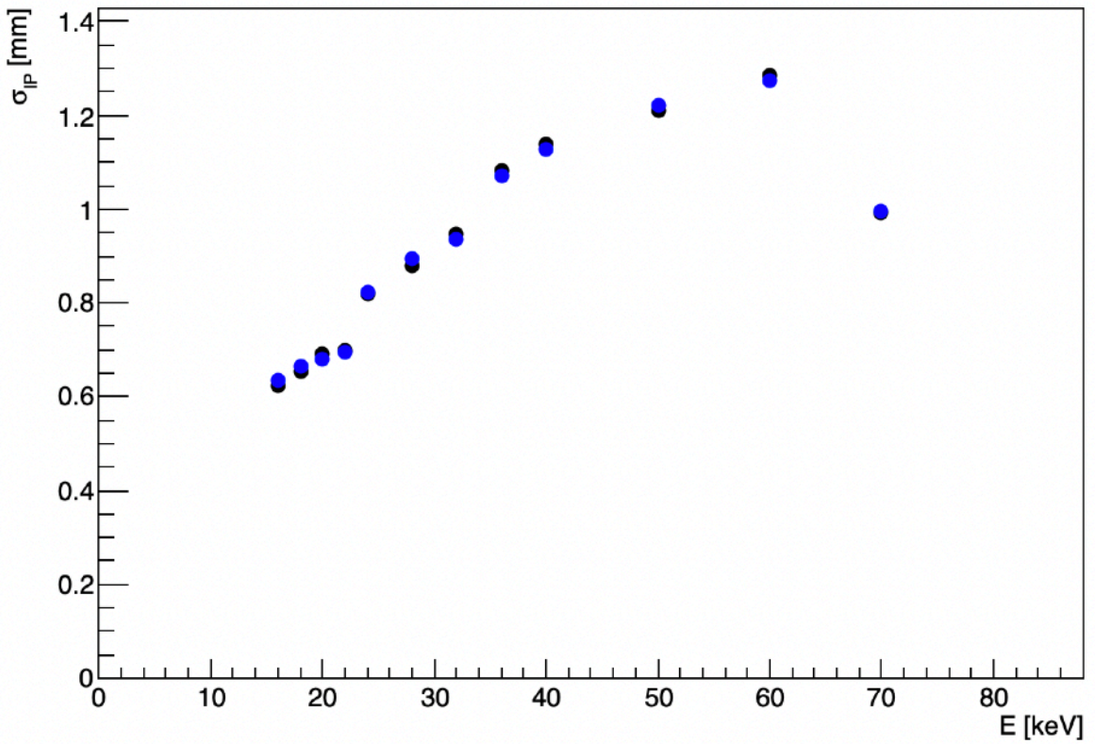
Results on angular and impact point resolution

- Parameters of the algorithm N_{pt} and w not known a priori → optimized with a scan of ang res vs them



- Parameters for which the angular resolution is on minimum used





- Angular resolution defined as the sigma of the distribution $\theta_{meas} - \theta_{true}$ (same for IP)

Solar neutrino sensitivity

Bayesian framework

- Sensitivity studies performed with the Bayesian framework:

Posterior probability

Likelihood

Prior probabilities

$$p(\mu_s, \mu_b \,|\, D) = \frac{p(D \,|\, \mu_s, \mu_b) \cdot \pi(\mu_s) \cdot \pi(\mu_b)}{p(D)}$$

Normalization factor

- Prior probability: a priori knowledge of the signal and background probability distribution, it will be assumed possoanian for the background and flat for the signal

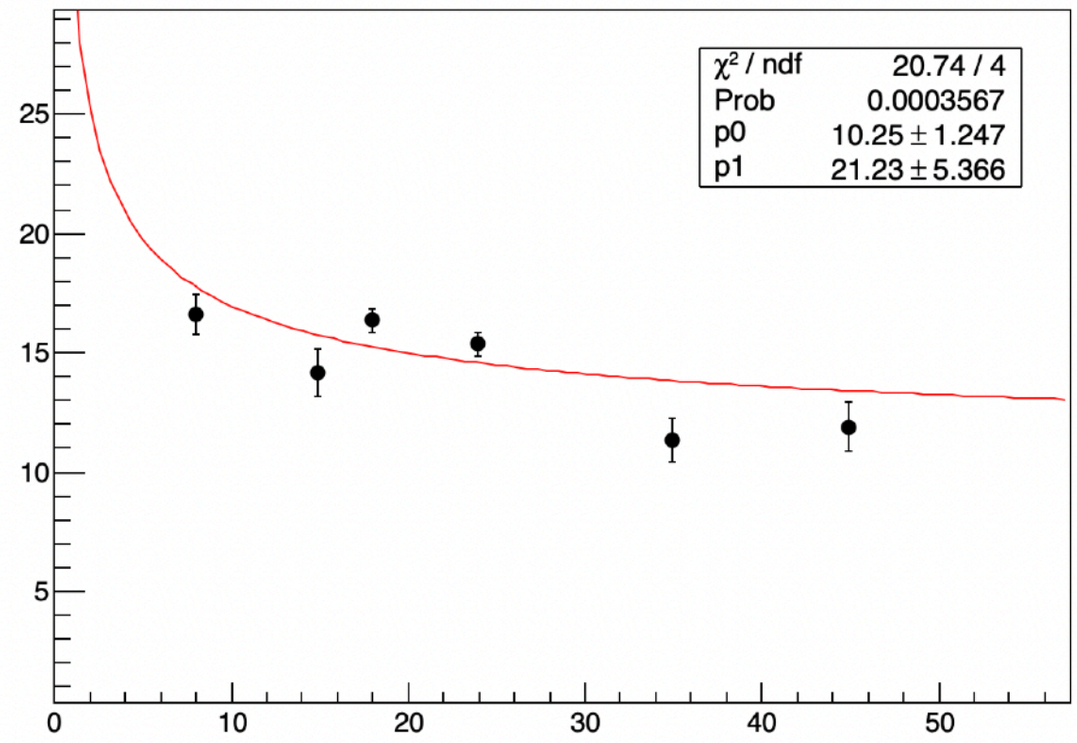
- Likelihood: probability of observing the data given μ_s and μ_b, calculated as the product of the probability of $n_{i,j}$ events in the i, j bin with expected value $\lambda_{i,j}$

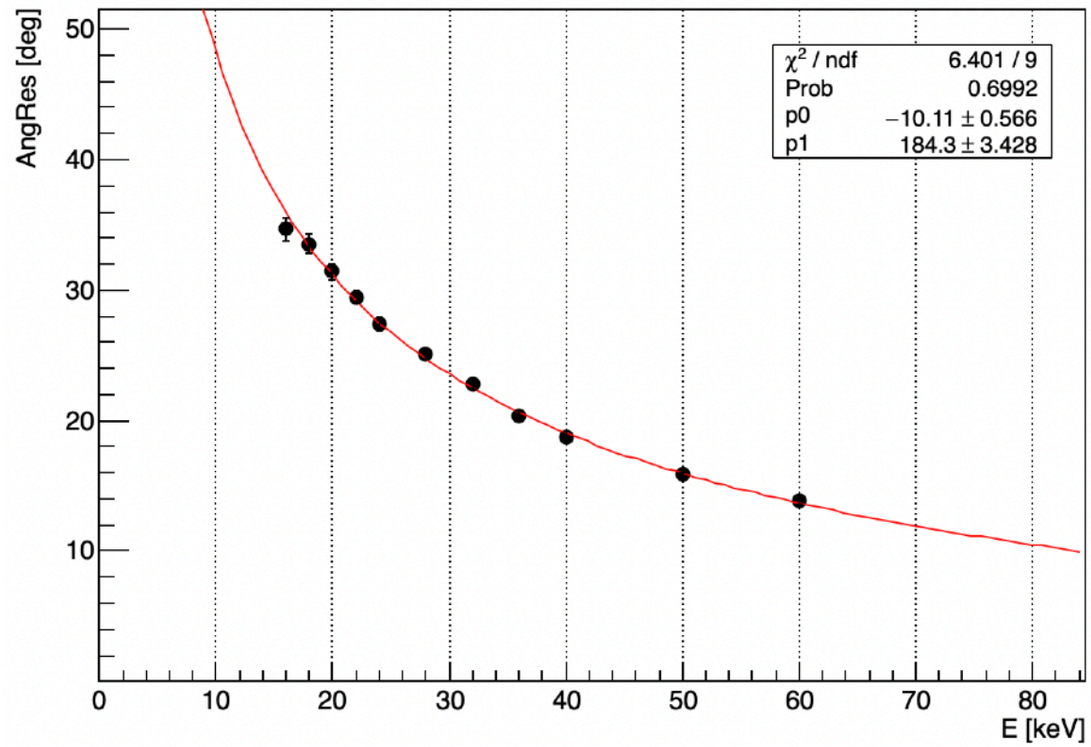
$$L = \prod_{i,j} \frac{\lambda_{i,j}^{n_{i,j}} e^{-\lambda_{i,j}}}{n_{i,j}!}$$

- Normalization factor: difficult to estimate a priori, it will be calculated by integrating the numerator distribution with a Markov-Chain Montecarlo based algorithm (posterior must be nomalized to 1)

Resolution used and assuptions

- For the templates generation ($\lambda_{i,j}$ information) the energy resolutions from the data and the angular resolution from the MC have been used

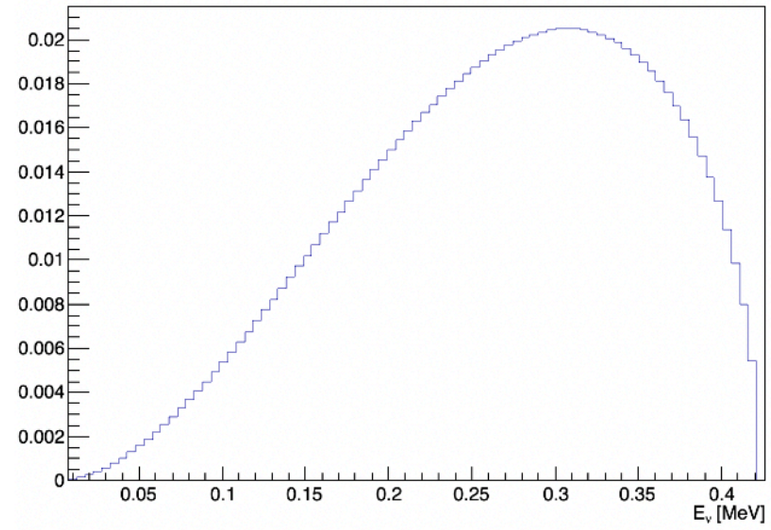




- Assumptions:
  - Same resolution in both theta (on the GEM plane) and phi (respect to the perpendicular to the GEM plane)
  - Isotropic gamma background

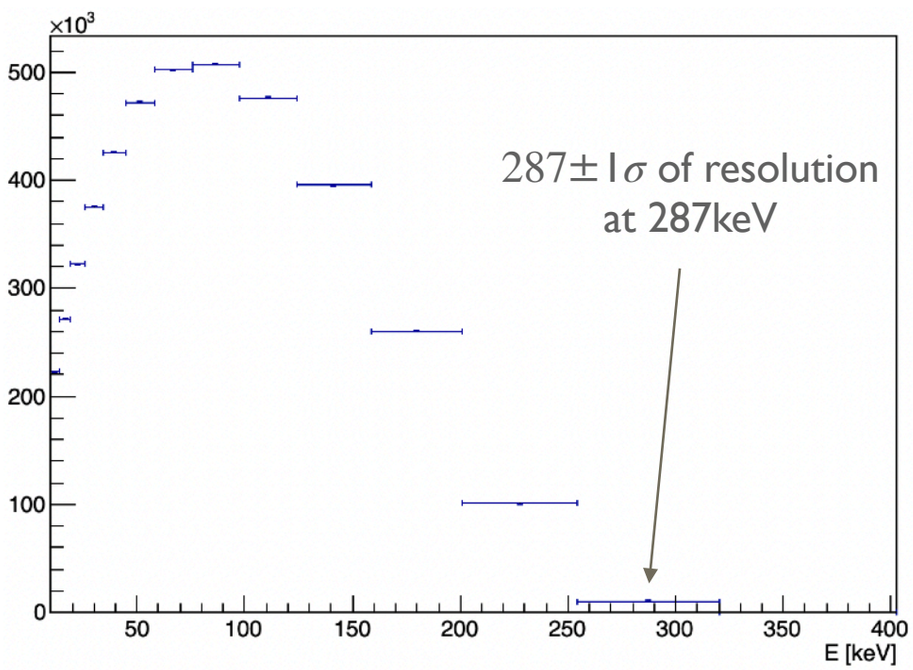
Signal templates production

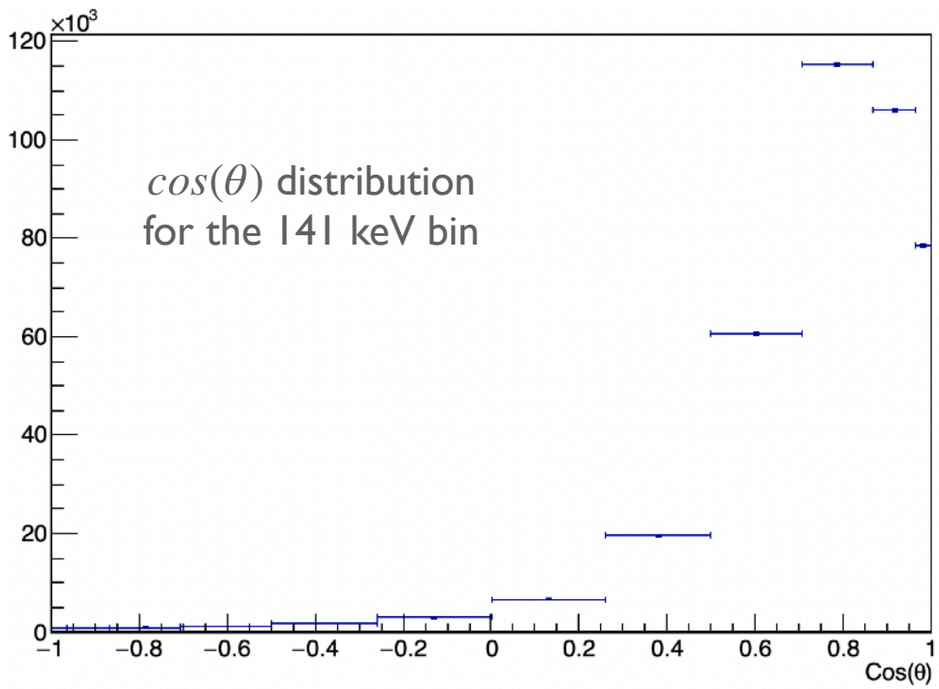
- Random neutrino energy according to the pp solar flux
- $\cos\theta$ value according to the differential cross section
- Calculation of the electron energy



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

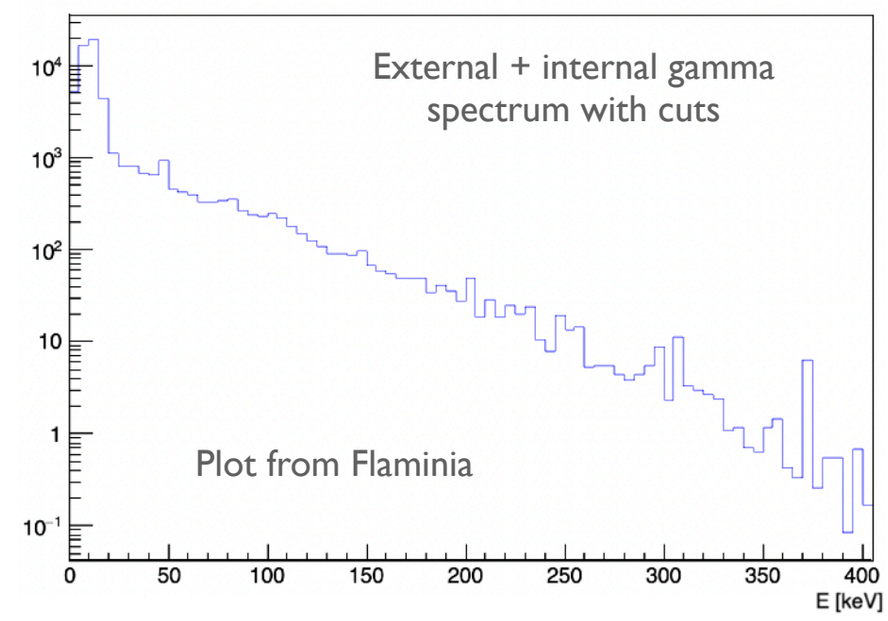
- Smearing of the energy and angle

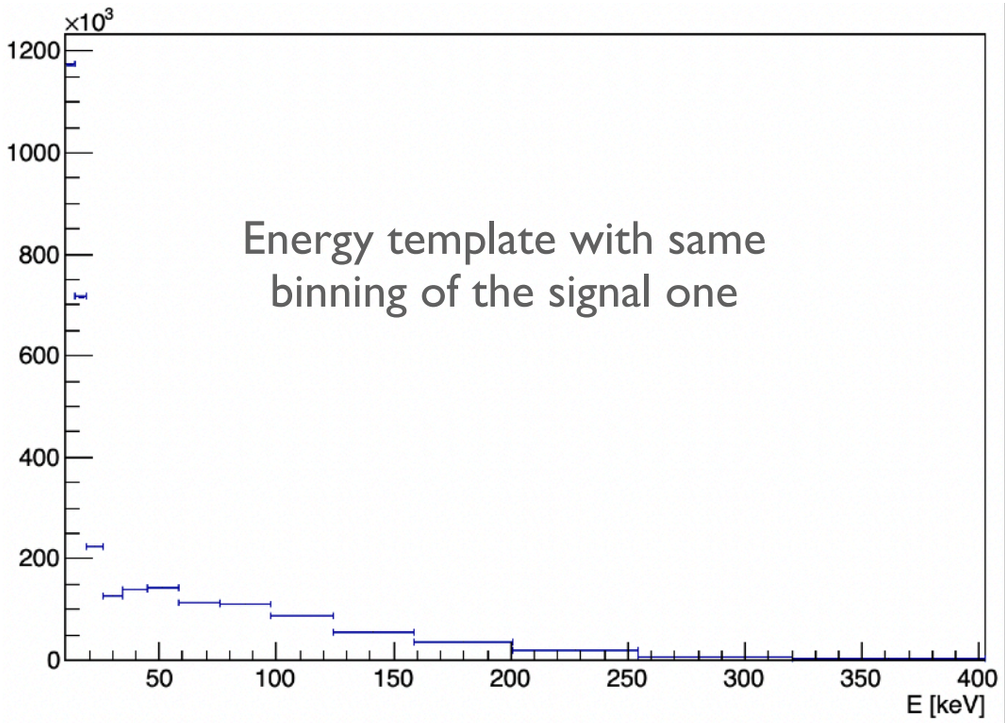


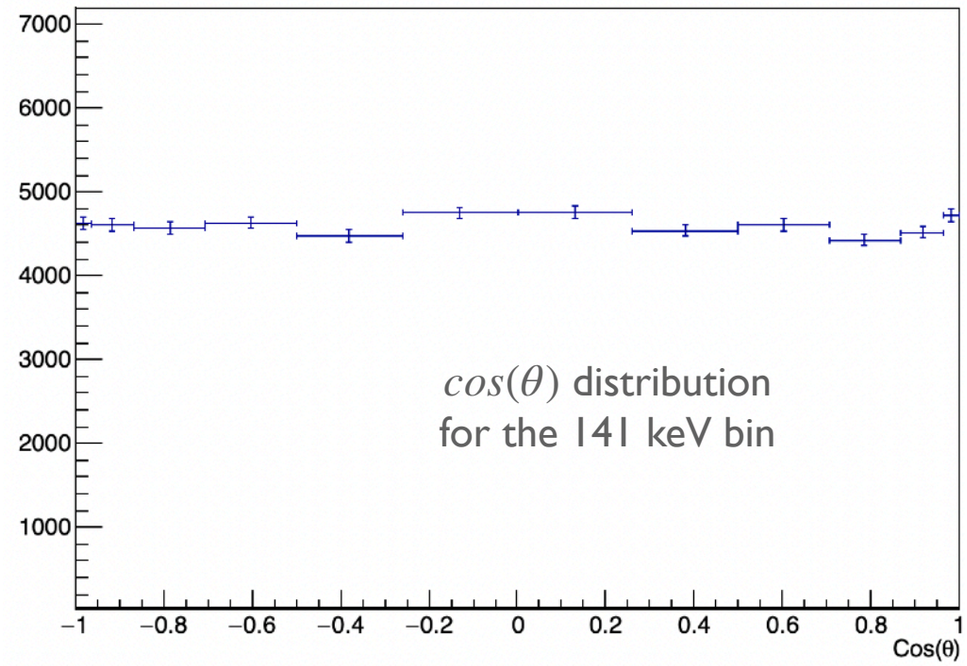


Background templates production

- Preliminarly the LIME bkg spectrum is used
- Random electron energy according to the bkg spectra
- θ value extracted from a random distribution
- Smearing of the energy and angle

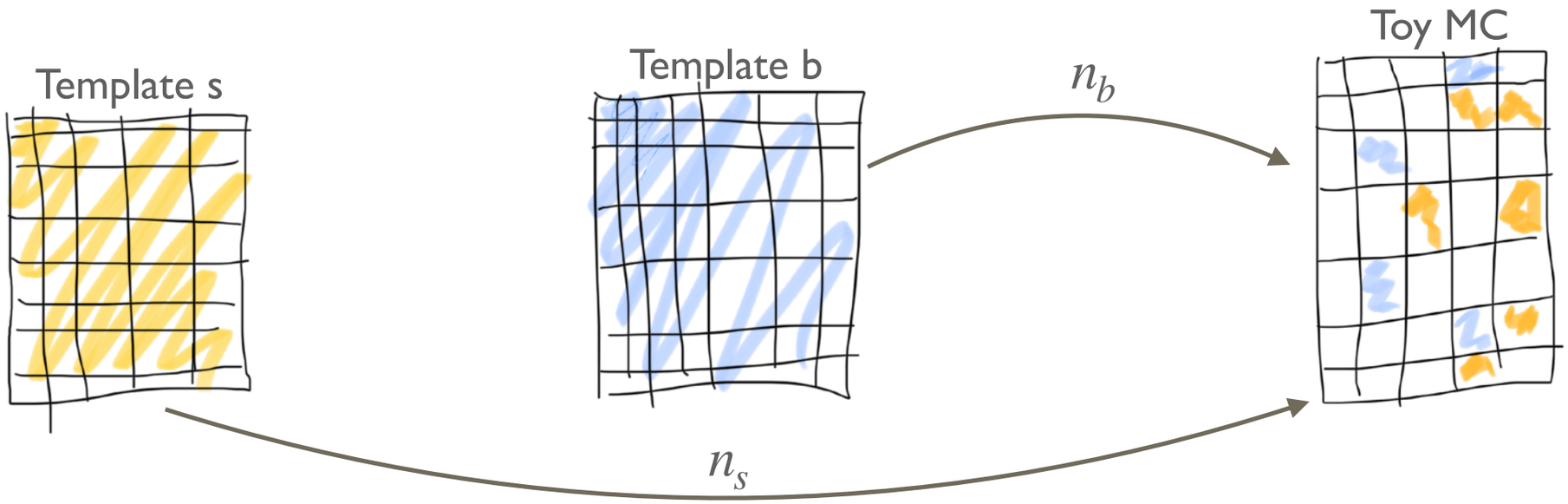






Toy-MC production

- Toy-MC generated by:
  - Choosing an hypothesis of signal and background $\bar{N}_s, \bar{N}_b$
  - Extracting the actual values from a poissonian distribution n_s, n_b
  - Injecting n_s, n_b events, respectively from the signal and background templates, into an E-cos(θ) histogram

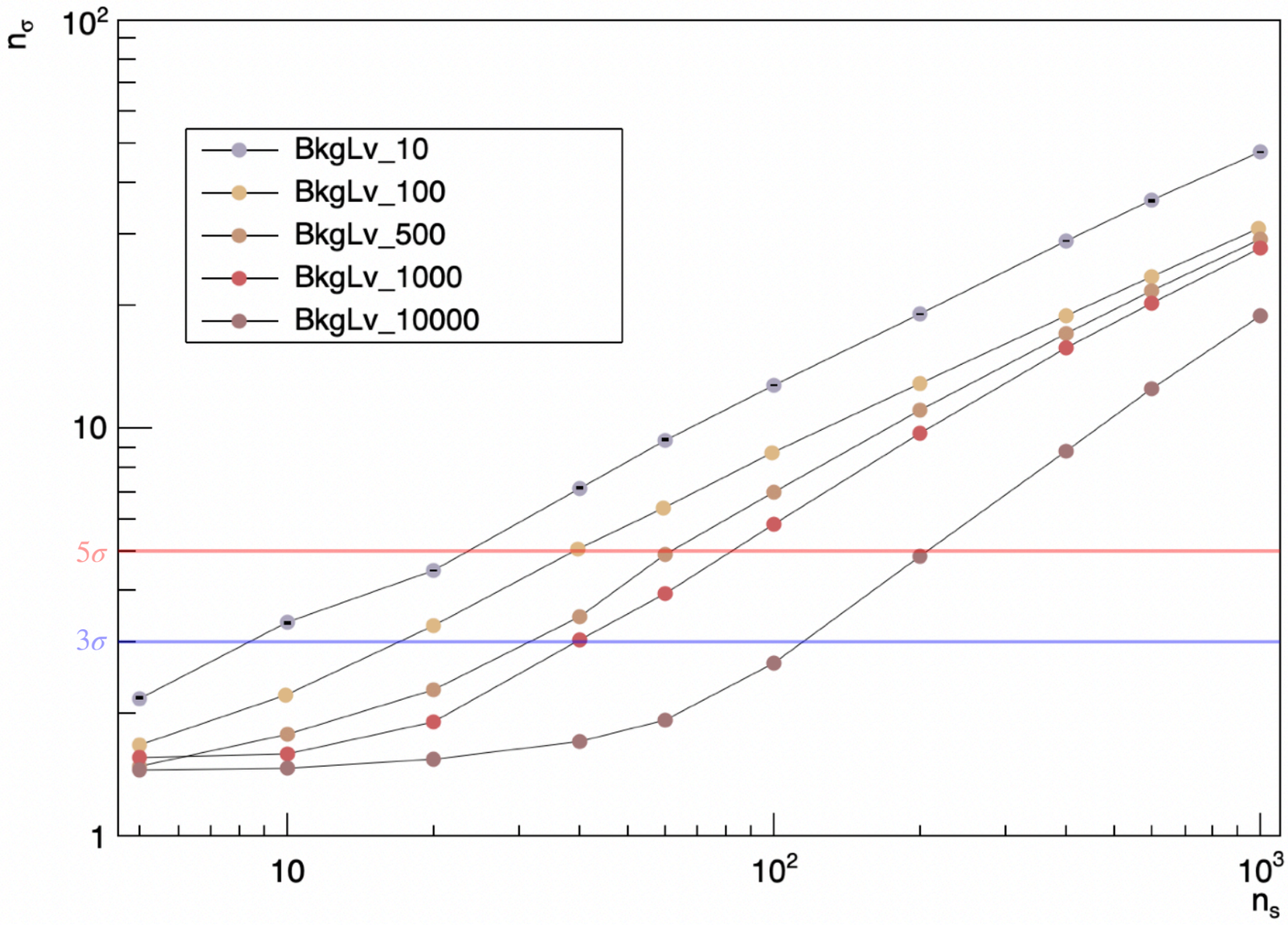


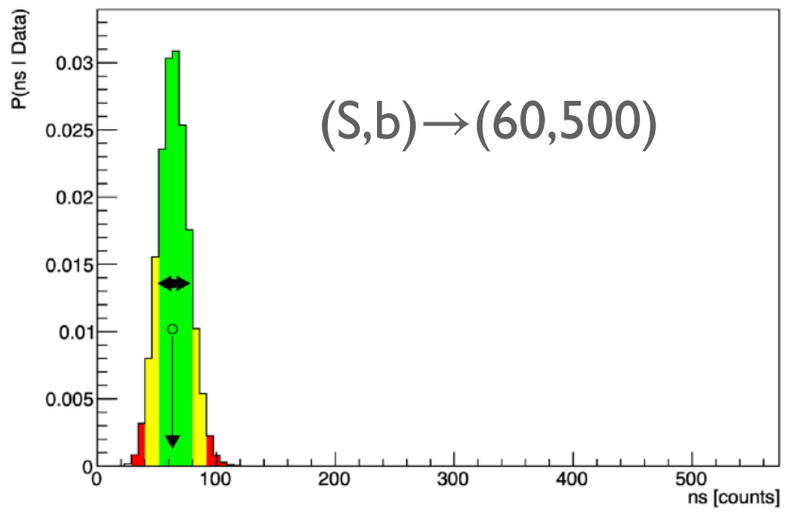
N.B. all the histograms have the same binning

- 50 toy MC for every combination of $\bar{N}_s$ and $\bar{N}_b$ have been generated:
  - $\bar{N}_b$ = 10,100,500,1000,10000
  - $\bar{N}_s$ = 5, 10, 20, 40, 60, 100, 200, 400, 600, 1000

N_σ sensitivity

- Plot of $\frac{\bar{n}_s - 0}{\sigma}$ as a function of n_s under different background hypotheses
- Each point is the mean of the 50 MC generated and analyzed



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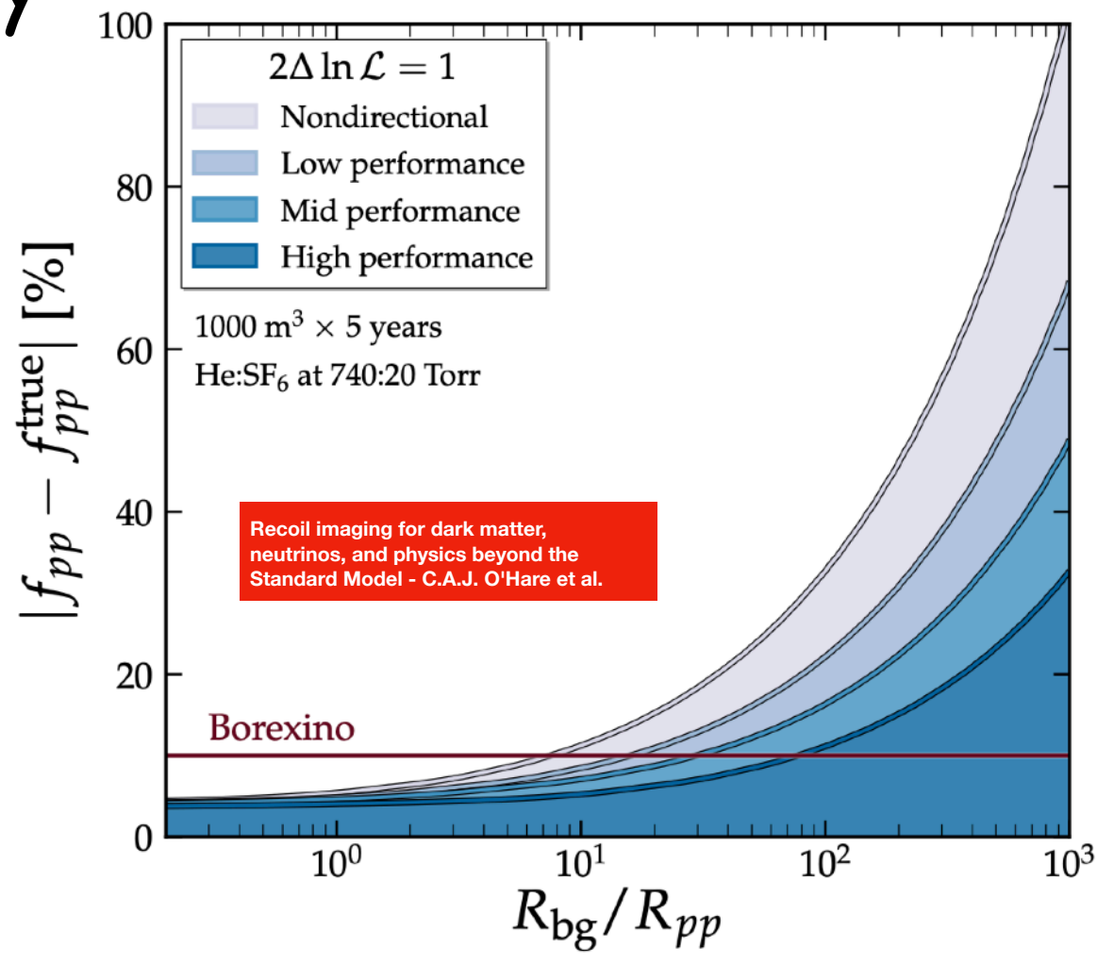
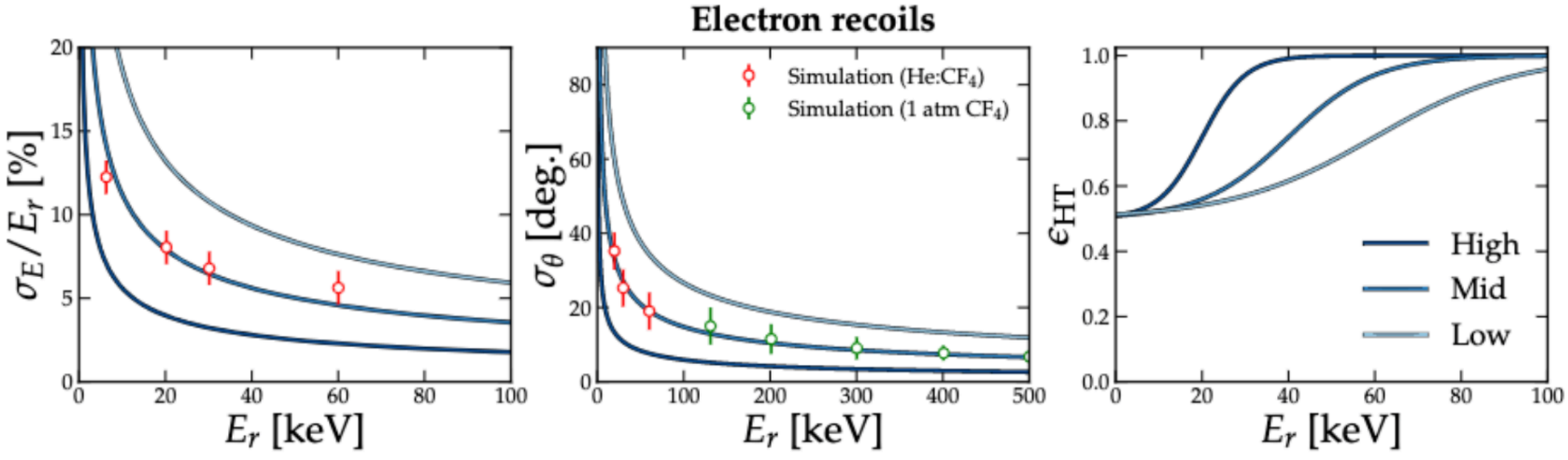
Parameter "ns" :
Mean +- sqrt(Variance):          +64.362 +- 12.766
Median +- central 68% interval: +64.068 + 13.263 - 12.459
```

$$n_\sigma = 64{,}3/12{,}7 = 5{,}1$$

The power of the directionality

- Plot showing the relative uncertainty on the pp flux as a function of the bkg/signal rate
- Higher level of background can be tolerated with good directionality performances
- Same of Borexino with 14x bkg more

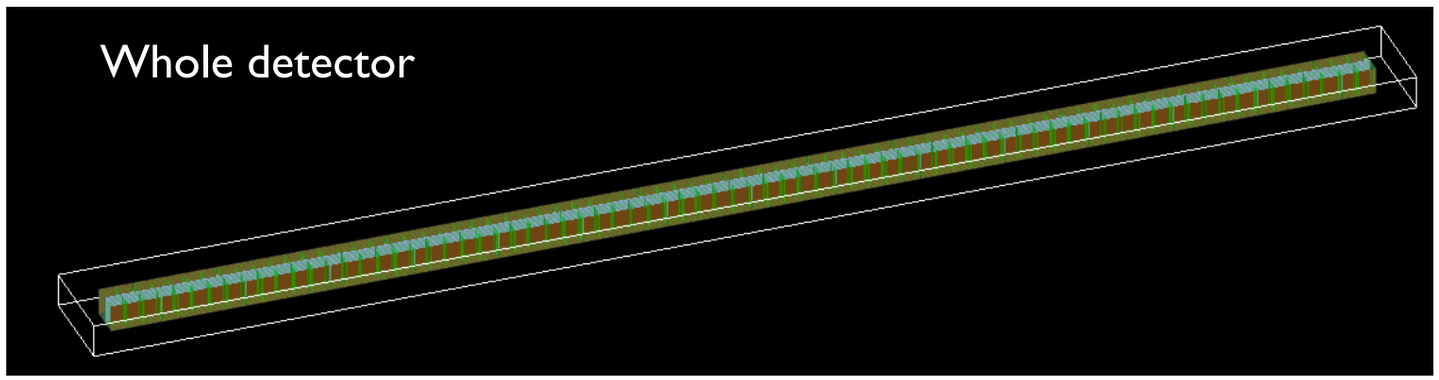


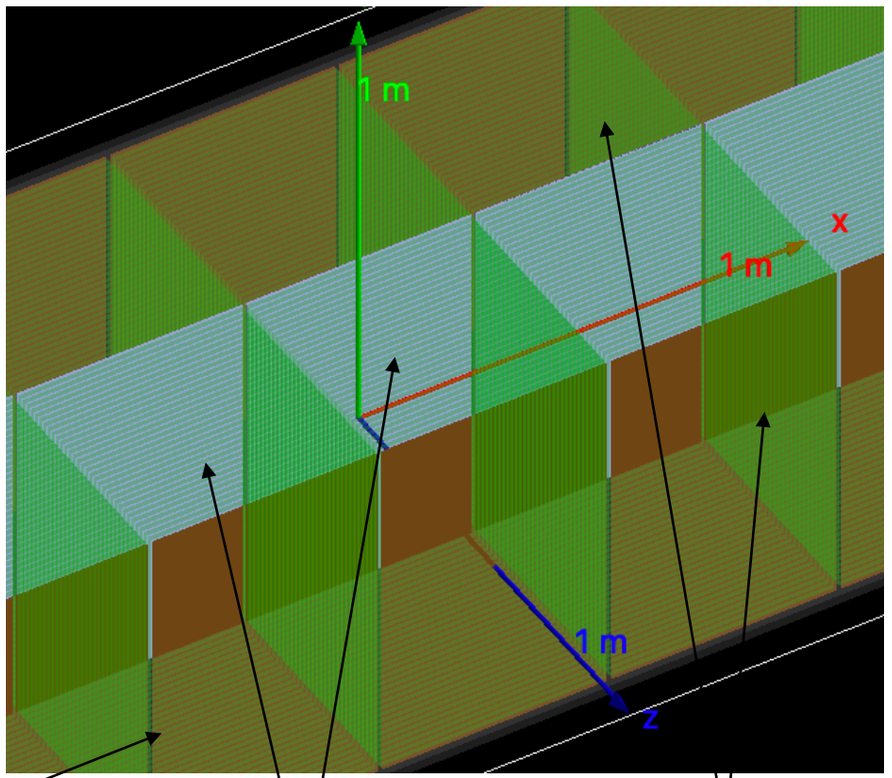


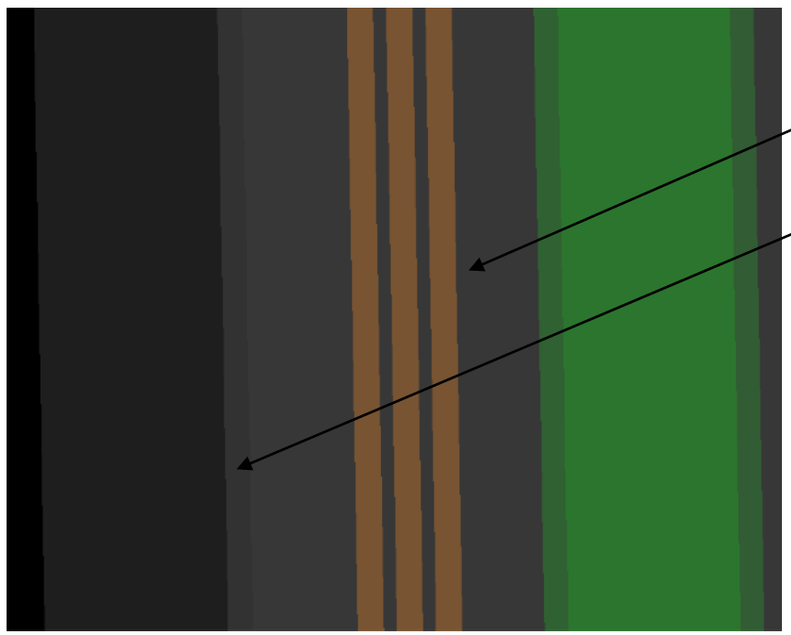
Bkg studies for CYGNO_30

CYGNO_30 background

- Geant4 simulation of the main components of CYGNO_30 ongoing (75x CYGNO_04)
- Will be used to produce the bkg spectra for the sensitivity study
- The expected radioactivity values will be used
- Geometry is almost ready







- Lens and sensors not yet added
- Trying now to make interact particles with matter

Conclusions

- Neutrinos from the Sun can be studied with the optical TPC approach
- Linearity and E resolution on low energy electron recoils measured
- Simulation able to reproduce the electron data above 6 keV developed
- Angular resolution capability measured from the simulation
- Preliminary sensitivity study on solar pp neutrino shows feasible results
- Simulation of the background expected on CYGNO_30 in progress