CYGNO simulations

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CYGNO meeting 18/10/19

Summary of simulation activities

- **Background simulations** with GEANT4
  - ambient gamma/neutrons and shielding studies(Giulia, Gianluca)
  - internal background, radioactivity of the setup (Flavio, Gianluca)

- **Signal simulations**: nuclear recoils with SRIM (Emanuele M., Davide P.)
- **Drift and detector effect**: simulation of electron drift and diffusion with Garfield (Emanuele M., Davide P.)
- Study of feasibility of **solar neutrino measurements**, electron range in different gas mixtures (Elisabetta, G. Dho, D. Marques)

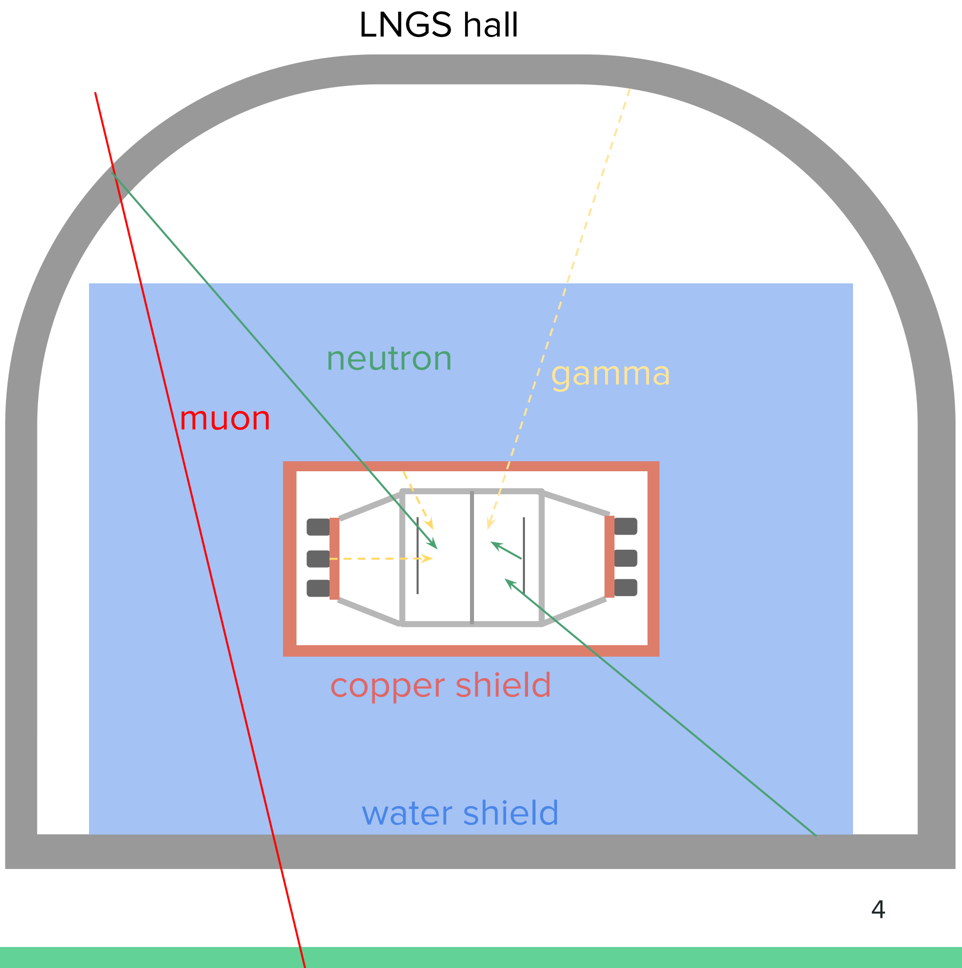
Background simulation with GEANT4

Background components

- Ambient neutrons/gammas
  (origin: outside setup, mostly rock)

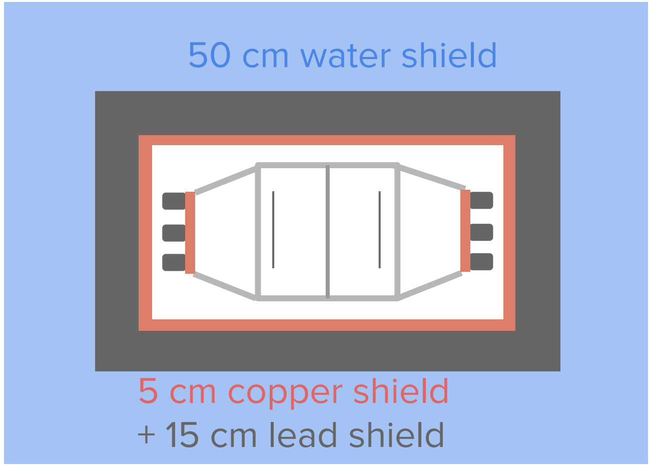
- "Radiogenic" neutrons/gammas
  (origin: materials in setup)

- Cosmogenic neutrons
  (origin: muon interactions)

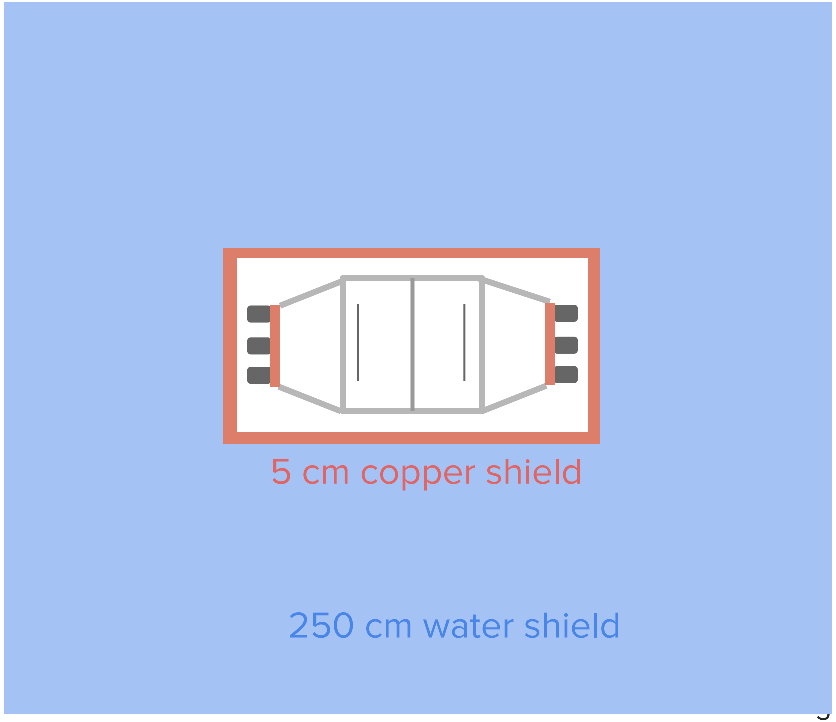


Shielding options

1) 50 cm water + 15 cm Pb + 5 cm Cu



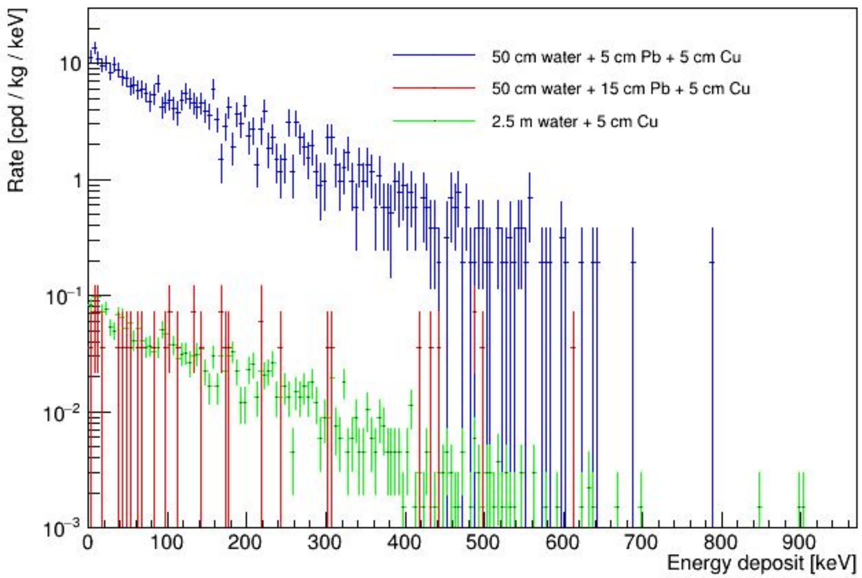
2) 250 cm water + 5 cm Cu



Background from ambient gammas

- Goal total background < 10^4 evt/yr

➜ both options (1 and 2) **~10^3 evt/yr**



Pro's option 1:

- good gamma rejection
- compact shielding
- Pb shields gammas produced by neutron capture in water

Con's option 1:

- expensive
- OPERA Pb is too radioactive, need archaeological lead

Pro's option 2:

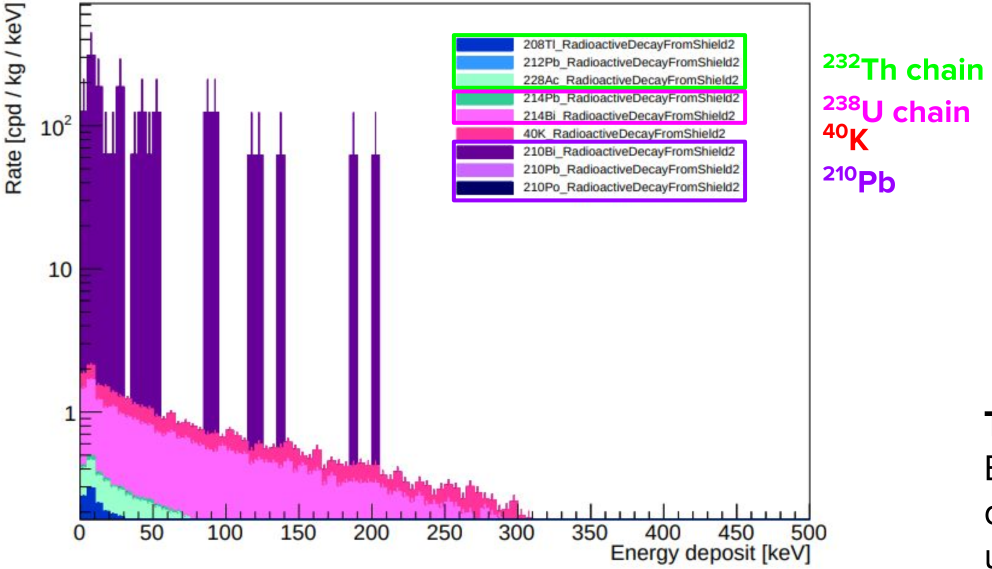
- good gamma rejection
- negligible cost of primary material (water)
- only cost of infrastructure (tanks, etc.)
- water is radio-pure

Con's option 2:

- large size
- need to verify the effect of secondary gammas from neutron interactions (wip)

Radioactivity background of lead shield (OPERA)

- Energy deposit in CYGNO detector from lead shield radioactivity
- assume ^{210}Pb of OPERA lead
- U, Th, K activities from T-REX paper (arxiv 1812.04519)
- shielding option 1 (50 cm water + 5 cm Pb + 5 cm Cu)



	Activity [mBq/kg]	**Rate** [cts/yr]
^{238}U	0.33	11.2 10^3
^{210}Pb	10^5	1.97 10^6
^{232}Th	0.10	4.51 10^3
^{40}K	1.2	4.6 10^3

Total rate 2 10^6 cts/yr

Even a 5 cm-thick shield of lead for 1 m^3 detector gives a large background, unless using archaeological lead.

Status shielding & to do

- Shielding with 15 cm lead is a reasonable option only if we use archaeological lead (expensive), otherwise too radioactive
- Water + copper shielding is good for ambient gammas and for radioactivity but need to evaluate the effect of secondary gammas from neutron capture in water
- To do: Neutron background + secondary gammas (work in progress..)

Camera radioactivity

Measured with HPGE at LNGS
High content of U, Th and K in the camera body, mostly K in the camera lens

Camera body

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sample:          camera, Hamamatsu, orca-flash4.0, 2.1275 kg, CYGNO
number:          1
live time:       83383 s
detector:        GeMPI

radionuclide concentrations:

Th-232:
Ra-228:          (2.1 +- 0.2) Bq/pc
Th-228:          (2.1 +- 0.1) Bq/pc

U-238:
Ra-226           (1.8 +- 0.1) Bq/pc
Pa-234m          (7 +- 2) Bq/pc

U-235:           (0.4 +- 0.1) Bq/pc

K-40:            (1.9 +- 0.3) Bq/pc

Cs-137:          (0.09 +- 0.03) Bq/pc

Co-60:           < 0.012 Bq/pc    @ start of measurement: 12-JUL-2018
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Camera lens

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==========================================================================

sample:          objective of Hamamatsu orcaflash4.0, 213.5 g (with plastic cap), CYGNO
number:          1
live time:       504104 s
detector:        GePaolo

radionuclide concentrations:

Th-232:
Ra-228:          (0.077 +- 0.009) Bq/pc
Th-228:          (0.078 +- 0.006) Bq/pc

U-238:
Ra-226           (0.41 +- 0.02) Bq/pc
Pa-234m          (0.9 +- 0.3) Bq/pc

U-235:           (0.031 +- 0.008) Bq/pc

K-40:            (11 +- 1) Bq/pc

Cs-137:          < 0.0057 Bq/pc

Co-60:           < 0.0099 Bq/pc  @ start of measurement: 10-JUL-2018

La-138:          (0.52 +- 0.04) Bq/pc
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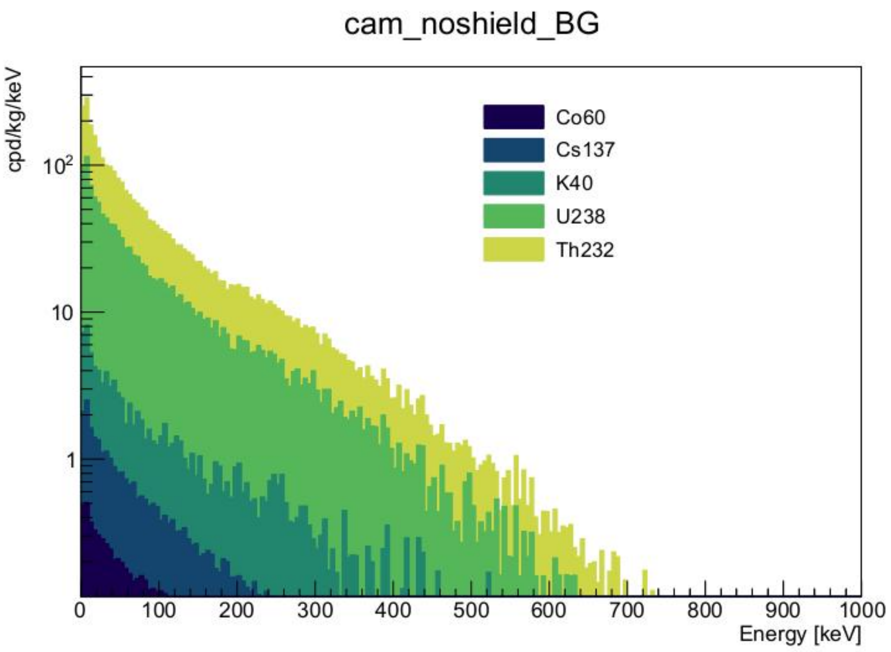
Background from cameras (body + lens)

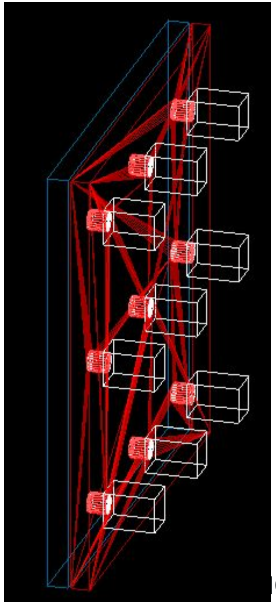


Energy deposit in CYGNO detector:

- Events in [0-20] keV: **2.05 x 10^7 cpy**

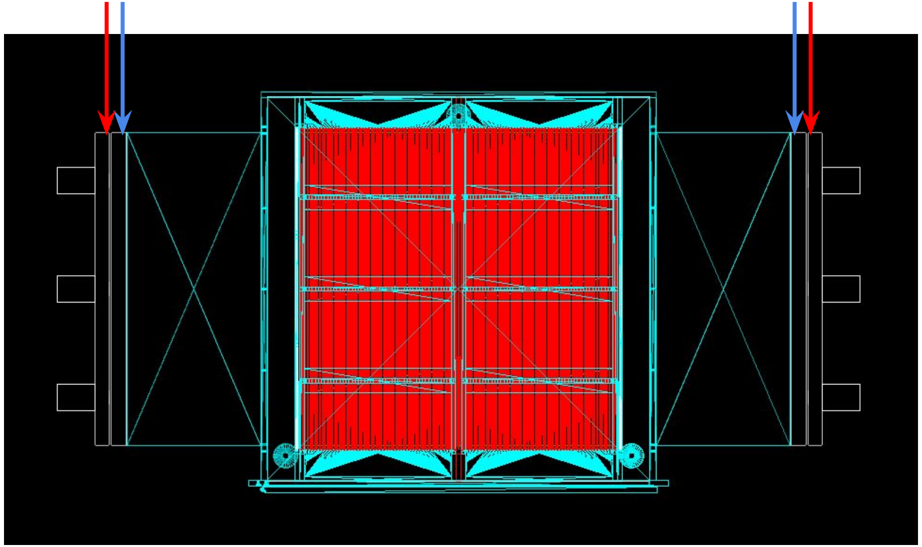
We investigated the effect of a copper shielding to the camera body and a fused silica layer between lens and acrylic box

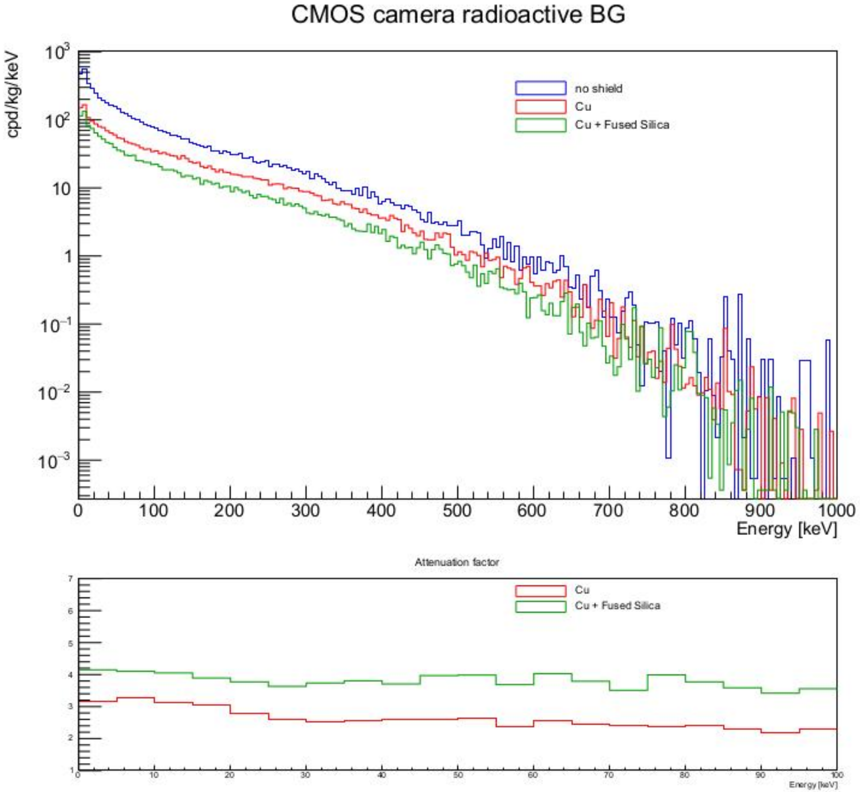
4.5 cm copper
5 cm fused silica



Shielding for cameras

4.5 cm copper
5 cm fused silica





Energy deposit in CYGNO detector:

- Events in [0-20] keV: **6.60×10^6 cpy**

Status background study & to do

- Cameras (body+lens) are the most radioactive element of the setup
- Large background in CYGNO gas, even with copper + fused silica shielding
- Possible solutions:
  - understand what part of the camera body is most radioactive, R&D of the camera assembly (measure separate pieces of a broken camera from Hamamatsu)
  - investigate use of fused silica lens (low radioactivity)
  - use mirrors, and place the cameras far from the detector, with some thick shielding
  - other...?

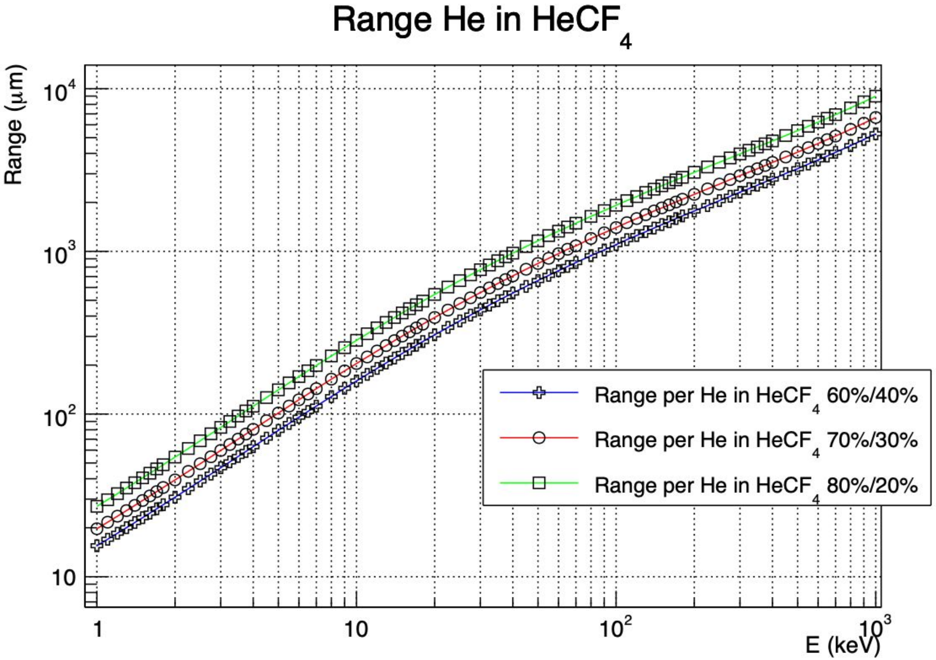
- To do: systematic studies of internal background, starting from the parts close to the sensitive region (GEM, field cage, etc..)

Signal simulation

Range of ions

Dark matter expected signal is a nuclear recoil (NR)

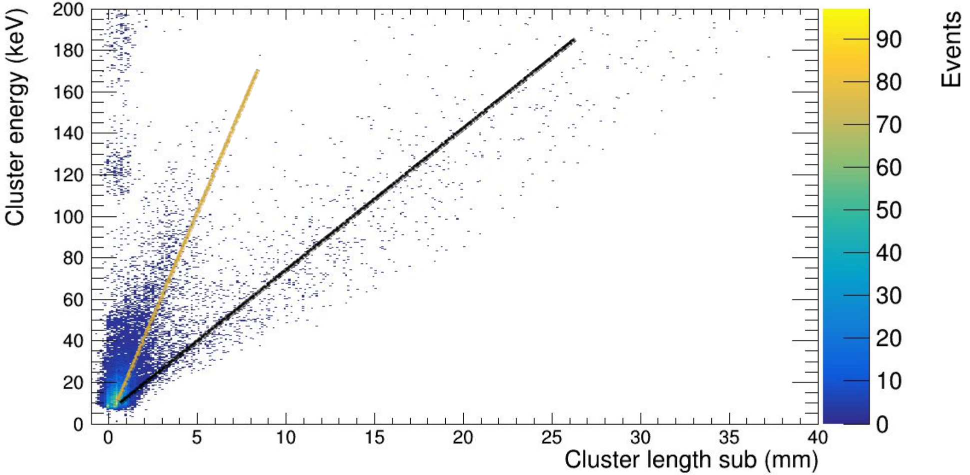
SRIM used to calculate the range of nuclei (p, He, C, F) in different gas mixtures

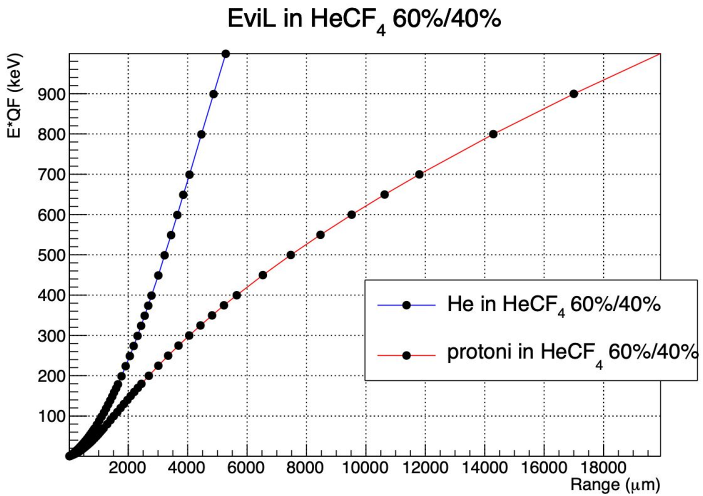


He nuclei energy in 60/40 (almost double in 80/20)
10 keV ➔ 170 μm
20 keV ➔ 300 μm
100 keV ➔ 1.1 mm

- Comparison between SRIM and GEANT for 0.5 MeV He in 60/40 shows that results are compatible: 3 mm in SRIM and 2 mm in GEANT
- SRIM can't simulate electrons

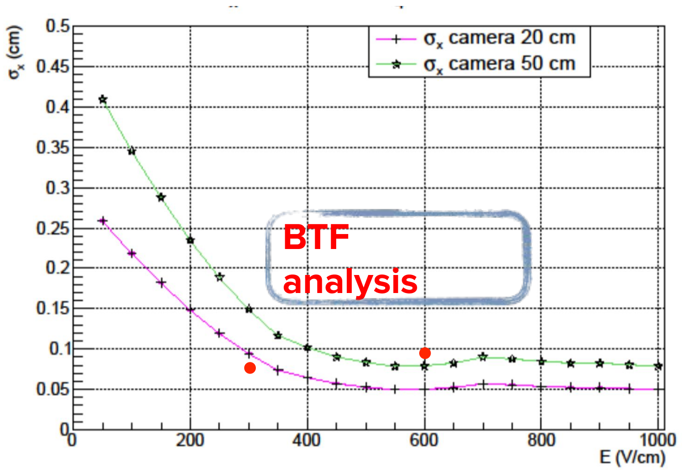
Energy vs track length for p and He



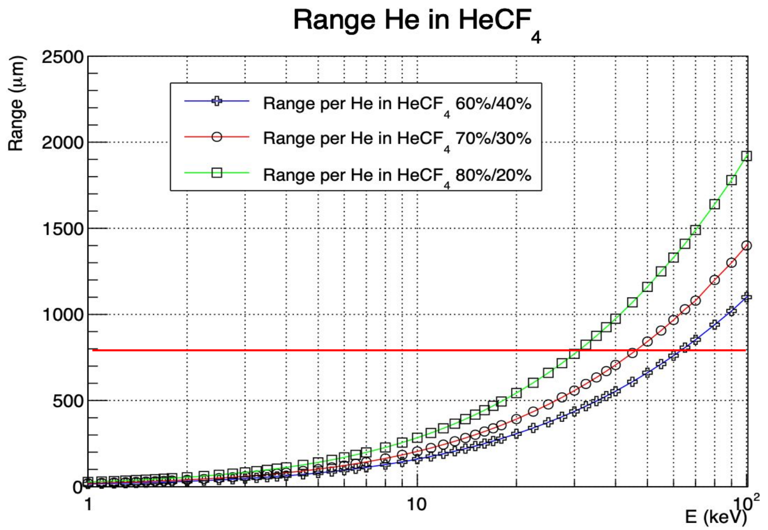


Manual fit to data in Ev[i]L plot provided by Emanuele & Igor:
- He slope: 80/4 = 20 keV/mm
- proton slope: 25/4 = 6.2 keV/mm

Diffusion in 60:40 He:CF_4 mixture



- Diffusion effects were also simulated with Garfield
- Agreement with experimental data
- Diffusion effect does not decrease for drift field > 500 V/cm



This corresponds to directionality thresholds in energy of:

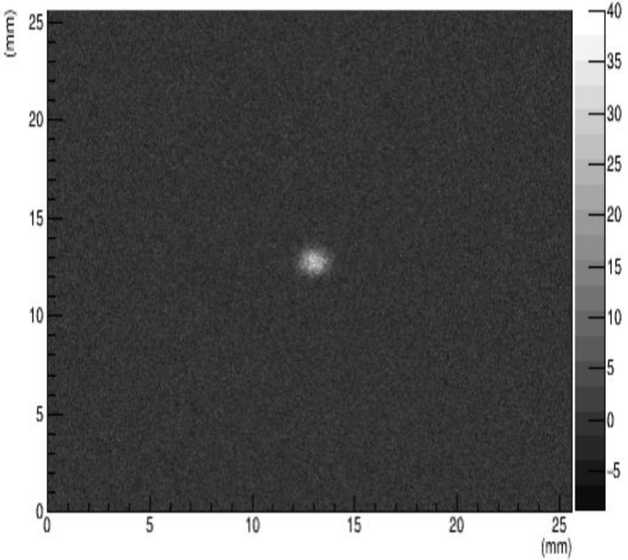
- 60 keV (60/40)
- 45 keV (70/30)
- 30 keV (80/20)

Simulation of the detector

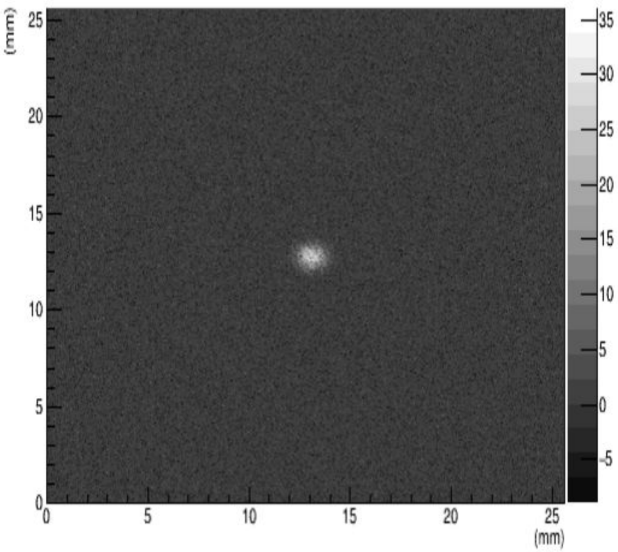
He 60 keV in $HeCF_4$ 60%/40% simulated with SRIM and GEANT

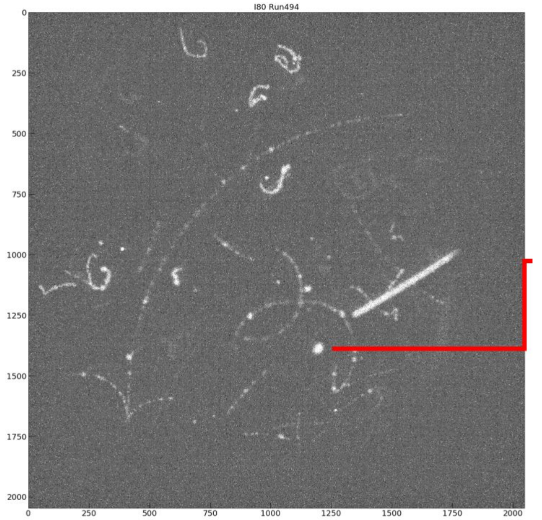
➡ applied diffusion in 10 cm depth camera

SRIM + diffusion



GEANT + diffusion





SRIM and GEANT are in agreement, also agreement with data

(No equivalent comparison for electrons because SRIM can't simulate electron recoils)

Status signal simulation & to do

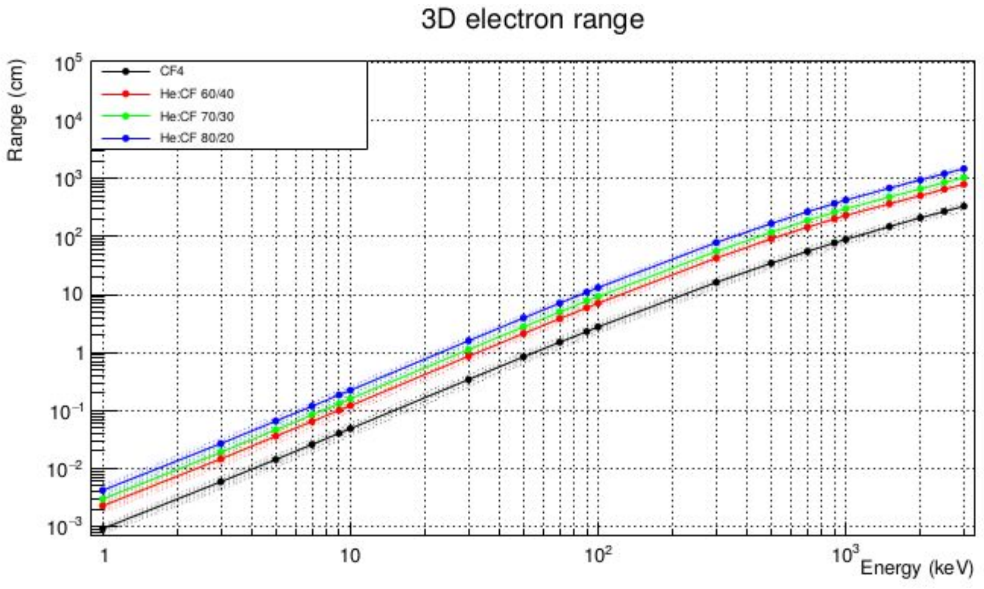
Results of simulation eventually should be used as input to the
Analysis & Reconstruction in order to study ER rejection and NR efficiency

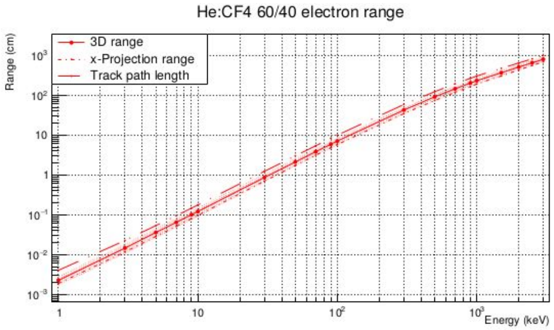
- Systematic analysis of NR MC pictures (SRIM + diffusion)
- Validation GEANT4 vs SRIM (in progress)
- Systematic analysis of NR and ER MC pictures (GEANT4 + diffusion)
- Comparison data-MC and interpretation of data

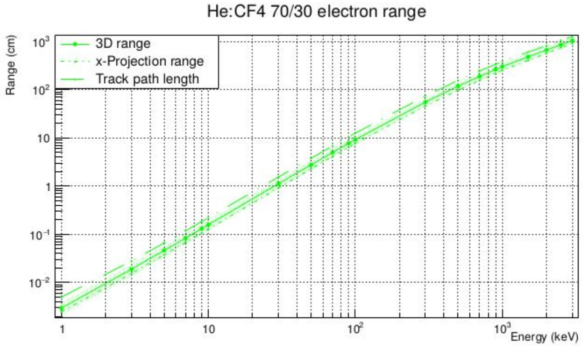
Electron recoils and solar neutrinos

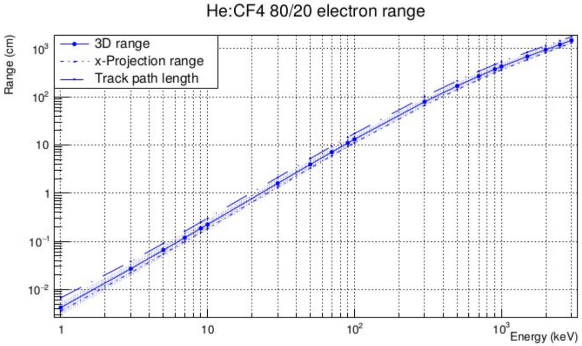
Range of electrons

- Exploring the possibility to use CYGNO as a detector for **solar neutrinos**
- Neutrino scattering produces electron recoils
- Study of the electron range in different gas mixtures









Status & to do

- Simulate diffusion with Garfield
- Apply detector effect and produce MC pictures of the tracks
- Study energy and angular resolution of the tracks
- Study threshold for directionality