A further look into electron directionality

24/02/21

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Outline

• Comments and consideration on the angular resolution assumed in the HELLAZ proposal for solar neutrino measurements presented at last meeting

• Intrinsic limit to angular resolution for He:CF$_4$ at 1 bar

• Overview of CYGNO MC simulation & reconstruction analysis to introduce S. Torelli talk on directionality of low energy electrons in CYGNO
For low energy electrons, there is a large contribution coming from the scattering with atom’s electrons that is not taken into account here. Such scattering can be very large and with significant change of the low energy electron direction.
There are tracks ending their path BEHIND the starting point here.
Goal: try to evaluate the intrinsic change of direction of the track fitting with a straight line the real MC true track hits (no diffusion, no readout effect) for the first XX mm

Work for the moment only the 2D projection as seen by CYGNO CMOS-camera
Constraint on starting point at (0,0) to better related to S. Torelli work (see later)
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30 keV - 4 mm

Constraint on starting point at (0,0) to better related to S. Torelli work (see later)
30 keV fit to first 1, 2, 3, 4, 5, 10, 15 mm with constraint on IP at (0,0)
60 keV examples

1 mm

\[
\chi^2 / \text{ndf} = 11.71 / 8 \\
\text{Prob} = 0.1647 \\
p0 = 0 \pm 1.21 \\
p1 = -0.02123 \pm 0.6888
\]

2 mm

\[
\chi^2 / \text{ndf} = 12.39 / 36 \\
\text{Prob} = 0.9999 \\
p0 = 0 \pm 0.5867 \\
p1 = -0.2064 \pm 0.03454
\]

10 mm

\[
\chi^2 / \text{ndf} = 23.28 / 83 \\
\text{Prob} = 1 \\
p0 = 0 \pm 0.5296 \\
p1 = -0.3672 \pm 0.000886
\]

15 mm

\[
\chi^2 / \text{ndf} = 40.84 / 126 \\
\text{Prob} = 1 \\
p0 = 0 \pm 0.5693 \\
p1 = -0.4295 \pm 0.005814
\]
60 keV fit to first 1,2,3,4,5 mm with constraint on IP at (0,0)
100 keV examples

Graph 1 mm

\[ \chi^2 / \text{ndf} = 0.01236 / 6 \]

Prob = 1

\[ p0 = 0 \pm 0.04538 \]

\[ p1 = 0.03786 \pm 0.009811 \]

Graph 10 mm

\[ \chi^2 / \text{ndf} = 0.607 / 31 \]

Prob = 1

\[ p0 = 0 \pm 0.1399 \]

\[ p1 = 0.1484 \pm 0.003817 \]

Graph 15 mm

\[ \chi^2 / \text{ndf} = 9.062 / 51 \]

Prob = 1

\[ p0 = 0 \pm 0.4215 \]

\[ p1 = 0.2079 \pm 0.006231 \]
100 keV fit to first 1, 2, 3, 4, 5 mm with constraint on IP at (0,0)
“Intrinsic” low energy electrons angular dispersion in He:CF$_4$ 60:40 @ 1 bar

HELLOAZ claims 2° for 100 keV in pure He @ 10 bar for 12 mm track sampling
Overview of CYGNO simulation and reconstruction

Geant4/SRIM simulation

- ER simulated with Geant4
- He NR simulated with SRIM
- 1000 events starting from the center
- Energies 1, 3, 6, 10, 30 keV
- Initial direction (1,0,0)

![6 keV electrons](image1)

![60 keV electrons](image2)
Digitization parameters

- Transverse diffusion from [https://arxiv.org/abs/2007.00608](https://arxiv.org/abs/2007.00608) for an electric field of 0.93 kV/cm
  \[
  \sigma_T = \sqrt{\sigma_{T0}^2 + D_T^2} \cdot \tau \quad D_T^{60/40} = 115 \quad \frac{\mu m}{\sqrt{cm}} \quad \sigma_{T0}^{60/40} = (280 \pm 60) \mu m
  \]
- Active area: 35 cm x 35 cm
- ORCA Fusion:
  - 2304 x 2304 pixels (1 pixel 6.5 um x 6.5 um)
  - Camera aperture 0.95
  - Sensor size 14.976 mm Orca Fusion
- Ionization potential: 46.2 eV (Garfield simulations 42-49 eV)
- Single GEM gain: 123 (see IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 65, NO. 1, JANUARY 2018)
- Light yield: 0.07 photons/electrons
- Sensor calibration: 1 photon = 0.5 sensor counts
- Distance from the GEM: 30 cm
inserting gain fluctuations

1. For each hit, a mean of $N_{\text{mean}} e^{\text{ion}}$ ionization electrons are produced:
   $$N_{\text{mean}} e^{\text{ion}} = \Delta E / W_i \quad (W_i = 46.2 \text{ eV/pair in He/CF}_4 \ 60/40)$$

2. The actual number $N_e^{\text{ion}}$ of ionization electrons is obtained from a Poisson distribution with a mean of $N_{\text{mean}} e^{\text{ion}}$

3. Ionization electrons diffuse in the drift region: $\sigma_D = D_T^2 \cdot z$
   (diffusion is considered only at the end...)

4. Ionization electrons arrive at the GEM stack;
   - gain fluctuations of the first foil only are relevant:
   - For each ionization electron $\rightarrow N_e^{G1,k}$ multiplication electrons
     in the first GEM ($k=1$, $N_e^{\text{ion}}$) extracted using an exponential distribution with mean=$G_{\text{GEM}}$
     ($G_{\text{GEM}}$ is the gain of a single GEM foil, see next)
     - Total number of multiplication electron for the first foil: $N_e^{G1} = \sum N_e^{G1,k}$

5. The total number of multiplication electrons is computed considering the gain in the other two foils: $N_e^{\text{tot}} = N_e^{G1} \cdot (G_{\text{GEM}})^2$

6. Electrons diffuse in the GEM stack: $\sigma_{T_0}$

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inserting gain fluctuations (II)

7. The mean total number of photons is obtained using 0.07 γ/e:
   \[ N_{γ}^{\text{mean,tot}} = N_{e}^{\text{tot}} \cdot 0.07 \frac{γ}{e} \]

8. The actual number of total photons \( N_{γ}^{\text{tot}} \) is obtained from a Poisson distribution with mean value \( N_{γ}^{\text{mean,tot}} \)

9. The number of photons hitting the sensor depends on the solid angle ratio \( Ω \):
   \[ N_{γ} = N_{γ}^{\text{tot}} \cdot Ω \]
   \[ \text{where: } Ω = \frac{1}{(4(δ+1)a)^2}; \]
   \[ δ = \left( \frac{\text{object dimension}}{\text{image dimension}} \right) = \frac{25\text{cm}}{1.33\text{cm}} \left( \text{for LEMON, } \frac{35}{1.33} \text{ for LIME} \right); \]
   \[ a = 0.95 \text{ aperture} \]

10. \( γ \)'s positions are obtained with random extractions of \( N_{γ} \) positions from a gaussian around the initial hit position, with
    \[ σ_T = \sqrt{σ_{T0}^2 + σ_D^2} \]
inserting gain fluctuations (III)

- the GEM gain $G$ varies according to operating conditions and detector configuration
  $\Rightarrow$ we fix it to obtain the correct light yield;
- we can fix it to obtain (on average) the same number of photons as in the “old” version of the digitization:

$$N_\gamma = \Delta E \cdot C_F \quad \text{(in the “old” digitization)}$$

$$\bar{N}_\gamma = \frac{\Delta E}{W_i} \cdot G \cdot 0.07 \cdot \Omega \quad \text{(in the new approach)}$$

$$G = \frac{C_F \cdot W_i}{0.07 \cdot \Omega} = 1.8 \cdot 10^6 \quad \text{(for LEMON where $C_F = 500 \ \gamma/\text{keV}$)}$$

$$G = (G_{GEM})^3 \Rightarrow G_{GEM} = 123 \quad \text{single GEM gain (to be used in the exponential extraction)}$$
Response to neutrons & gammas:
low energy nuclear recoil & discrimination from $^{55}\text{Fe}$

AmBe source, Pb shield


Multiple DBSCAN iteration to select different ionisation patterns

Morphological geodesic active contours (GAC) to connect long tracks

Iterative morphological thinning for actual track length

5.2 keV$_{\text{ee}}$ nuclear recoil candidate

Can spot direction and sense!