SuperNEMO collaboration meeting 2026

TARAS SHEVCHENKO NATIONAL UNIVERSITY OF KYIV

Study of 600 – 800 keV plateau in the ^{207}Bi spectrum

Yaroslava Kozina

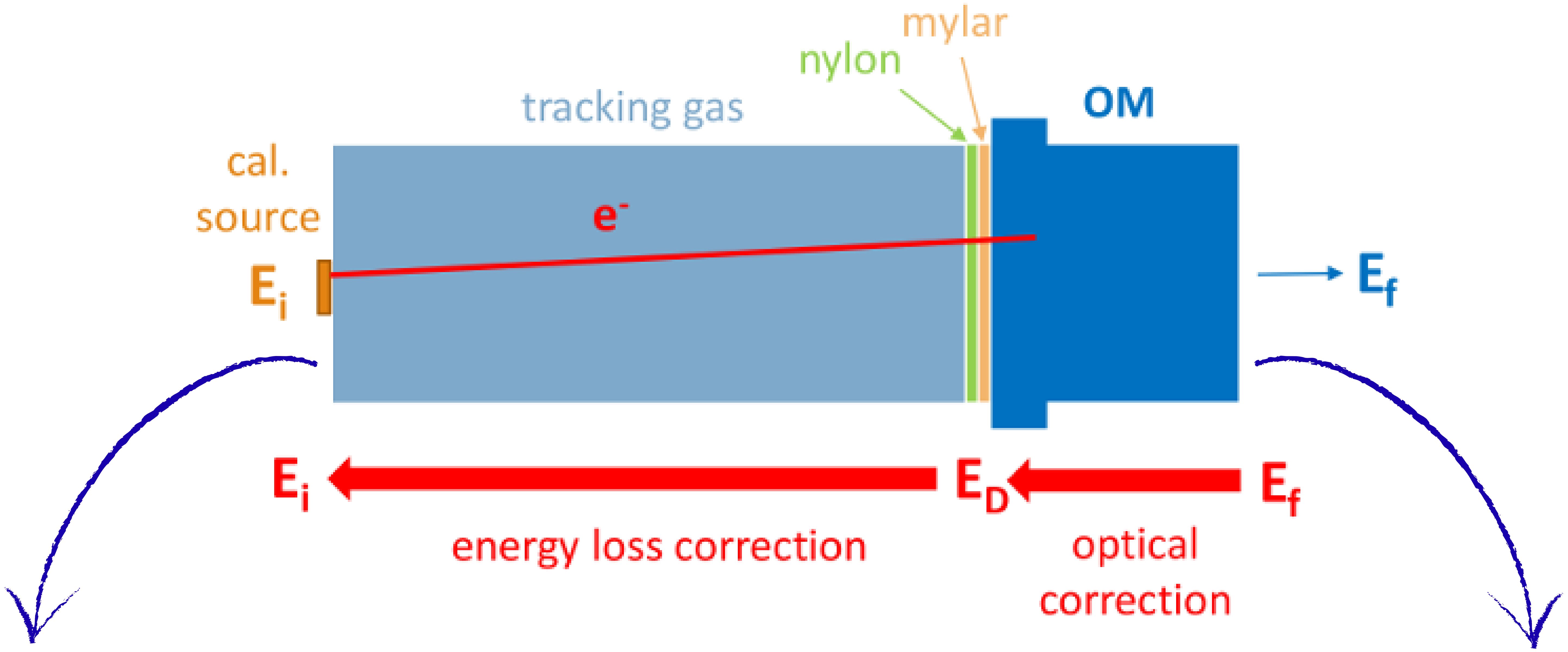
Taras Shevchenko National University of Kyiv, Ukraine

Supervisor: *Miroslav Macko*

Astrocent, Polish Academy of sciences, Poland

Brief description of the calibration model

by F. Koňařík



effects caused by the direct interaction of the electron with the detector

the effects occurring inside the scintillators

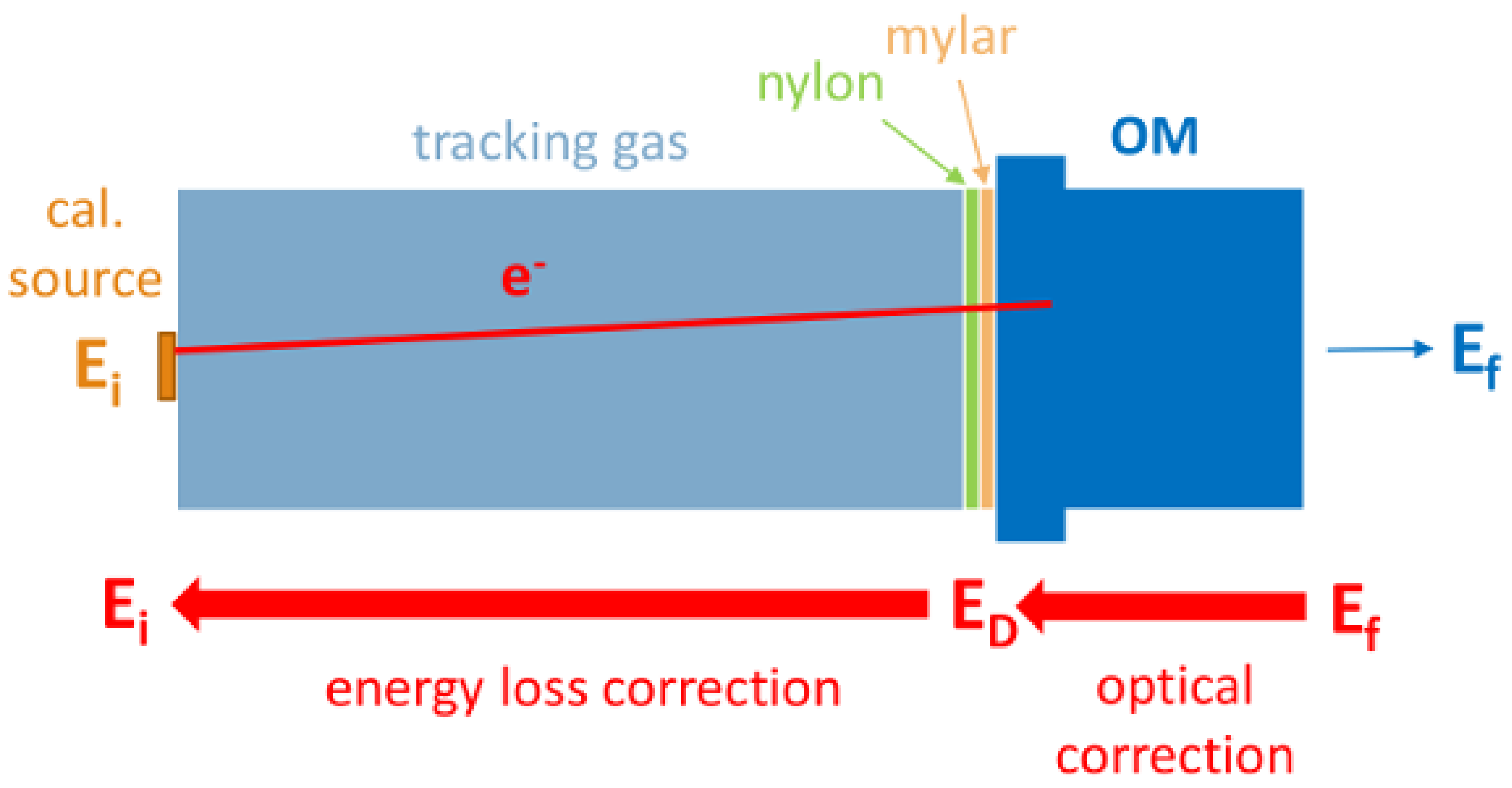
Optical corrections

stand for the effects occurring inside the optical modules

for non-linearity effects:

$$E = a_j Q + b_j$$ *is violated*

- *molecular ionization instead of triggering of the scintillator (Birks' effect)*
- *Cherenkov radiation in the scintillator block*

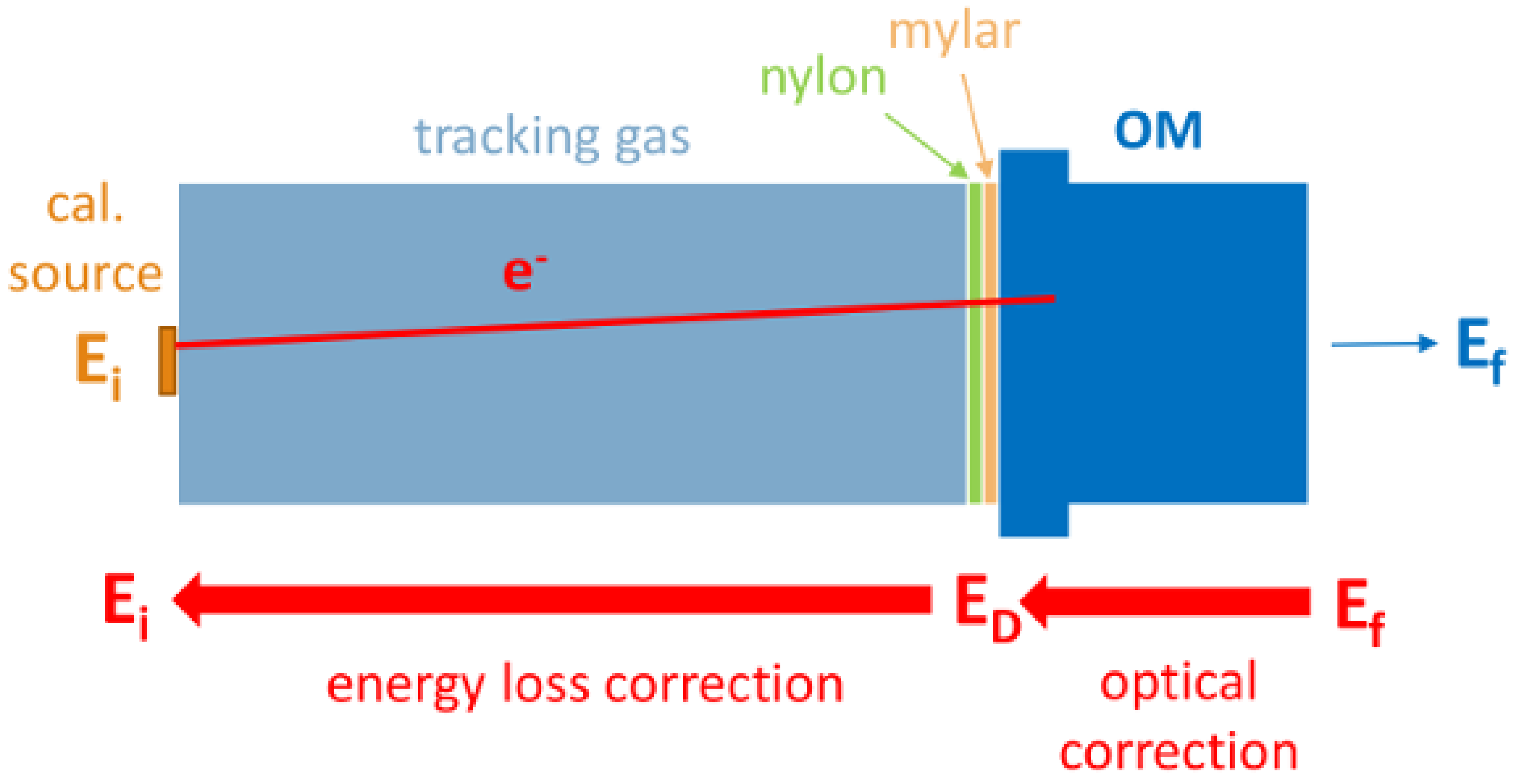


for geometrical non-uniformity effects:

- *fraction of the photons which reach the PMT depends on the position where the electron hits the scintillator (internal light scattering in the scintillator)*

Energy loss corrections

represent energy loss effects caused by the direct interaction of the electron with the medium on its way from the calibration source to the calorimeter

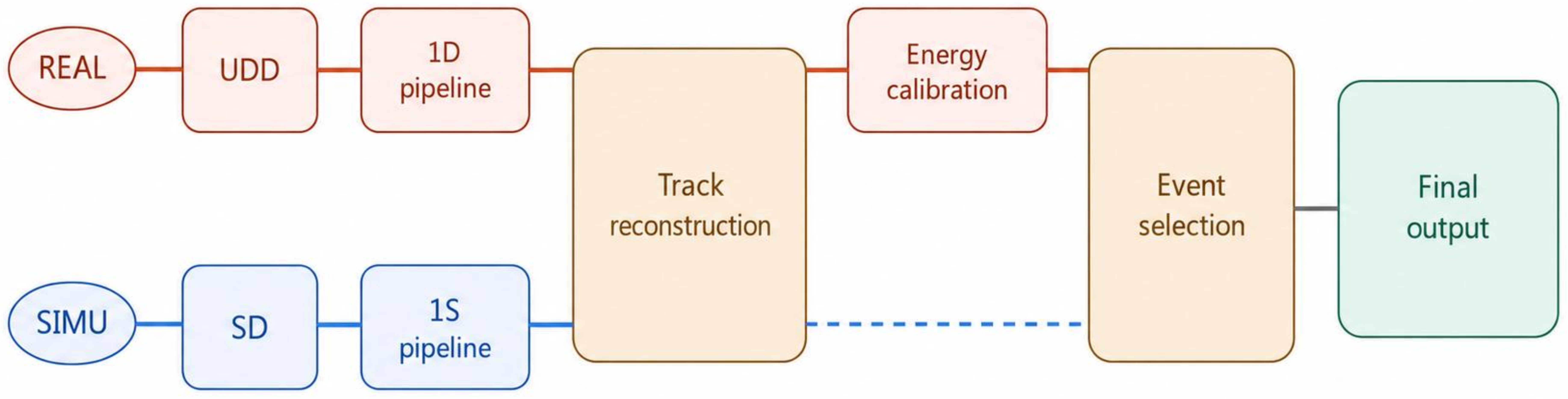


Bete-Bloch formula

$$\frac{dE}{dx} = \frac{2\pi N_A \langle Z/A \rangle}{m_e c^2} \left(\frac{e^2}{4\pi\varepsilon_0} \right)^2 \frac{\rho}{\beta^2} \Phi(E)$$

$$\Delta E \ll E \longrightarrow \Delta E(d,\, E) = \frac{dE}{dx}(E) \cdot d$$

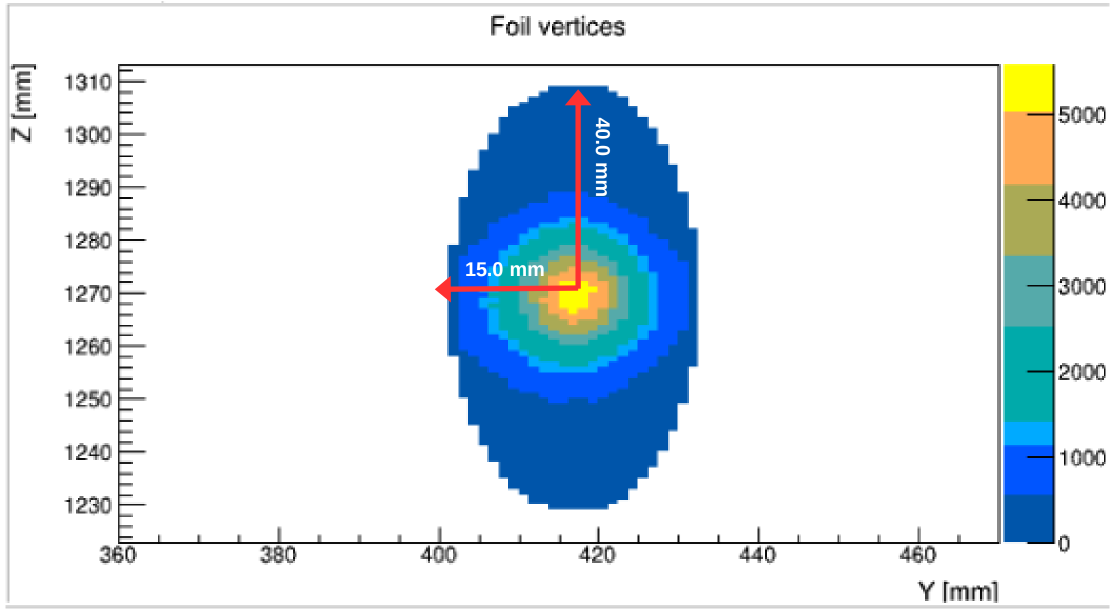
Software: the unified pipeline scheme (simplified)



- Treats **real** data from the detector and **simulated** data **equally**
- **Modular**, thus flexible
- **Number** of modules is as **reduced** as possible

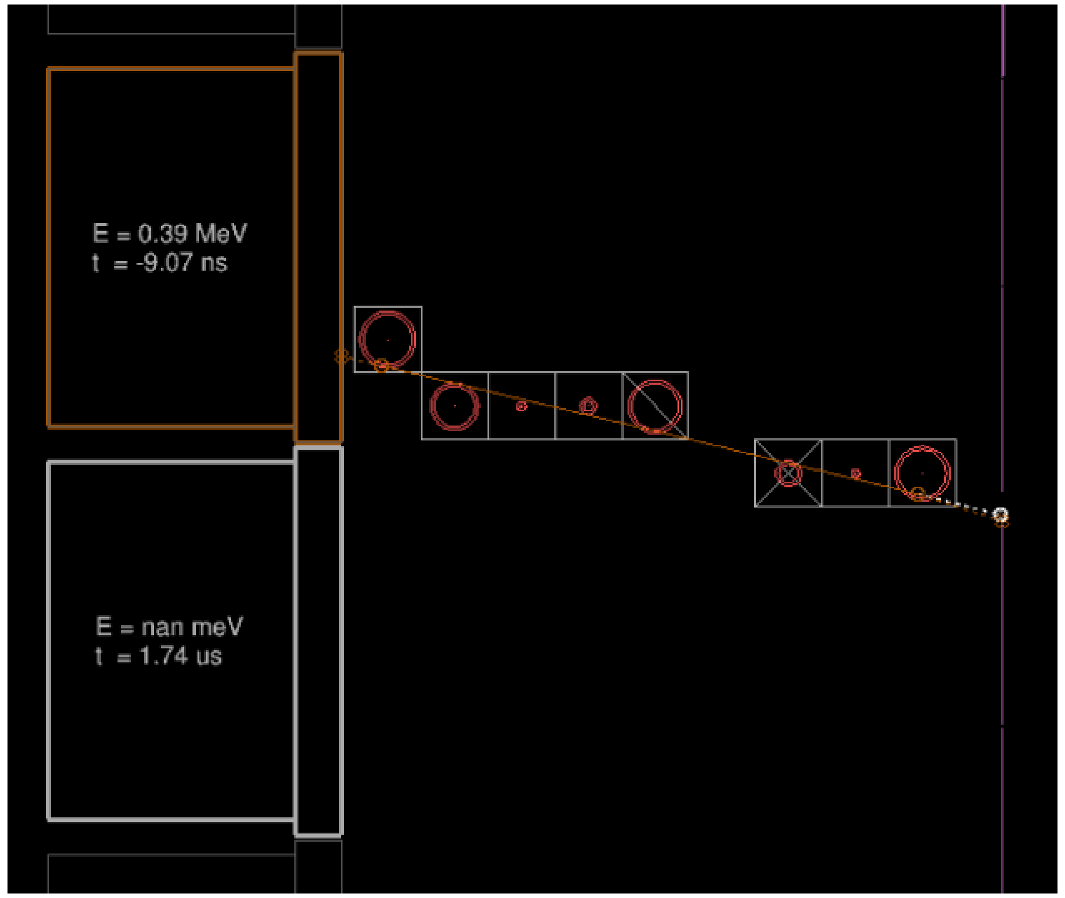
Criteria for data selection for ^{207}Bi events

- The decay **TPP is inside the ellipse** (15.0 mm, 40.0 mm) surrounding the center of the calibration source



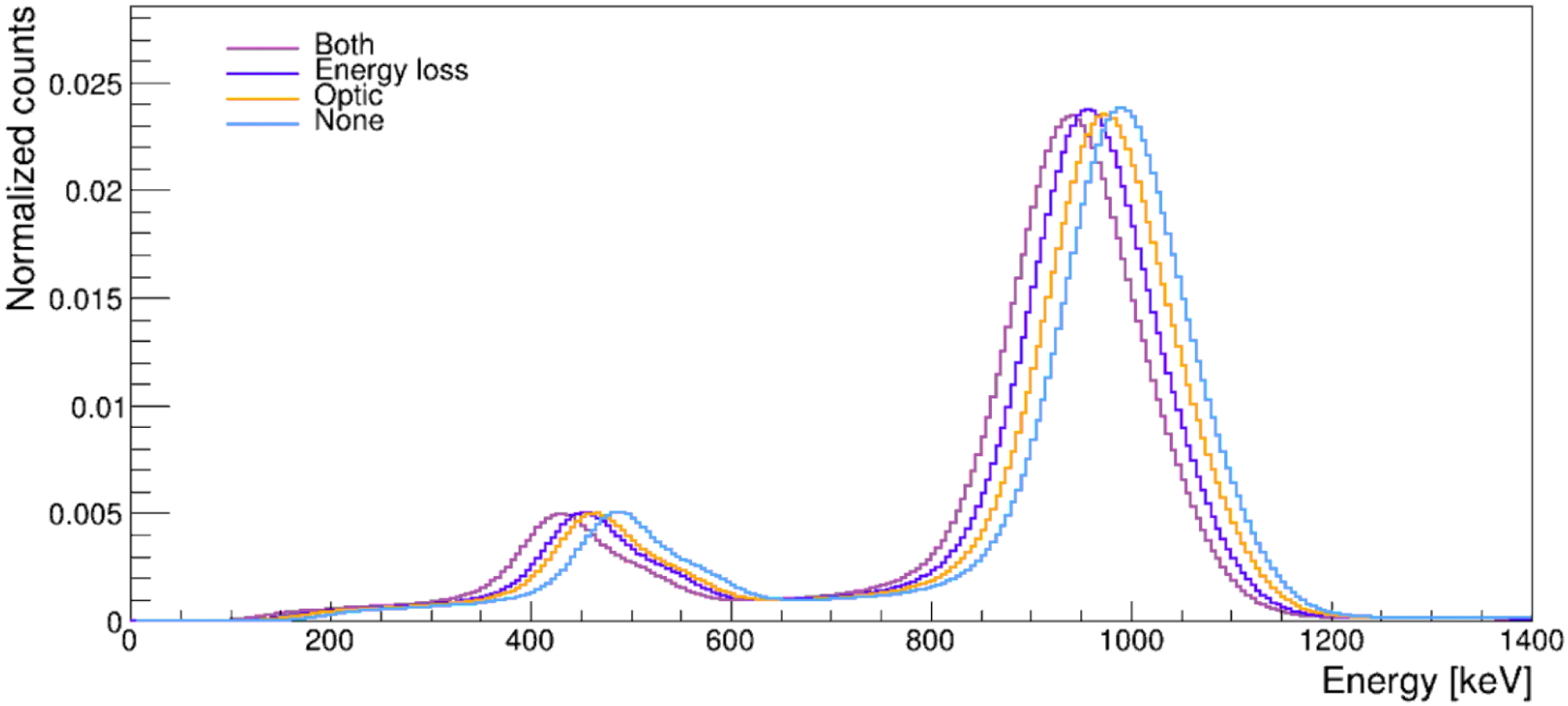
- There is **only one straight track** with no kinks

- There **exists an associated vertex** on the OM of the main wall



- Electron energy is between i and j keV (i, j values depend on the goal of the study)

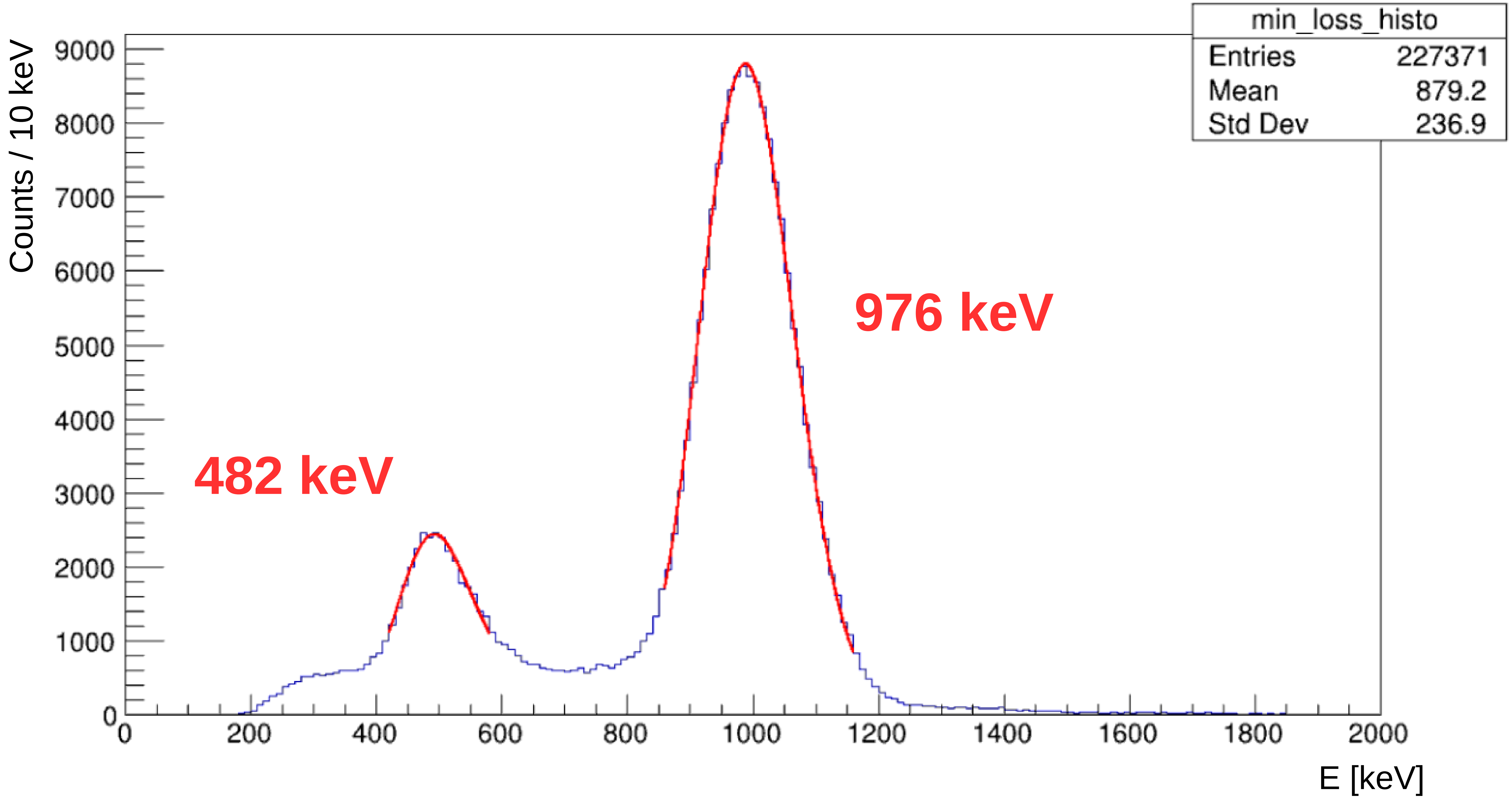
Comparison of the spectra for all types of corrections



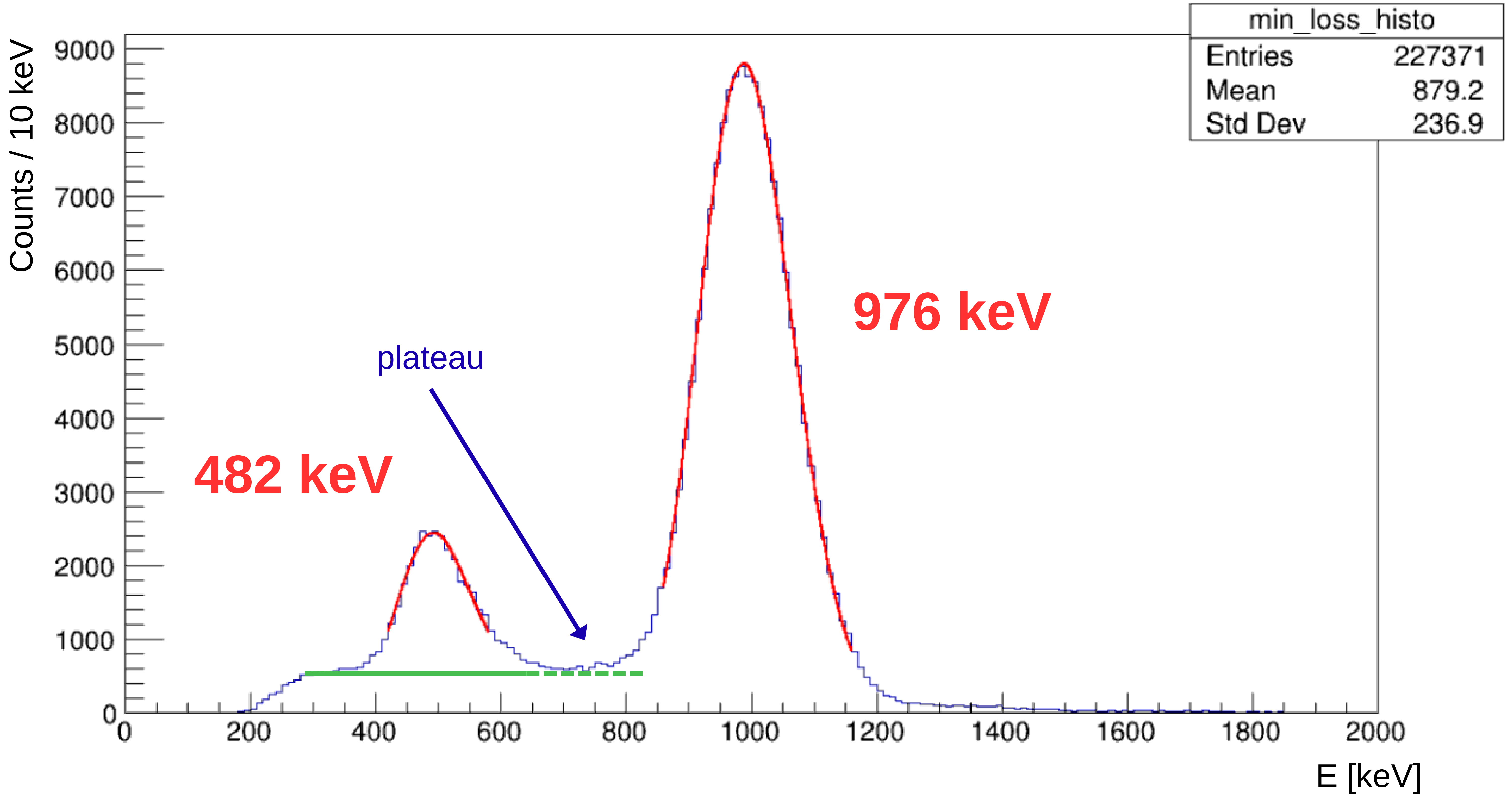
Spectra obtained from real data of ^{207}Bi decay (data from 285 data sets with ~ 180 000 events in each)

Spectrum with both types of corrections applied

obtained from **real** data for one of the OMs



The “second-order” effects: the plateau

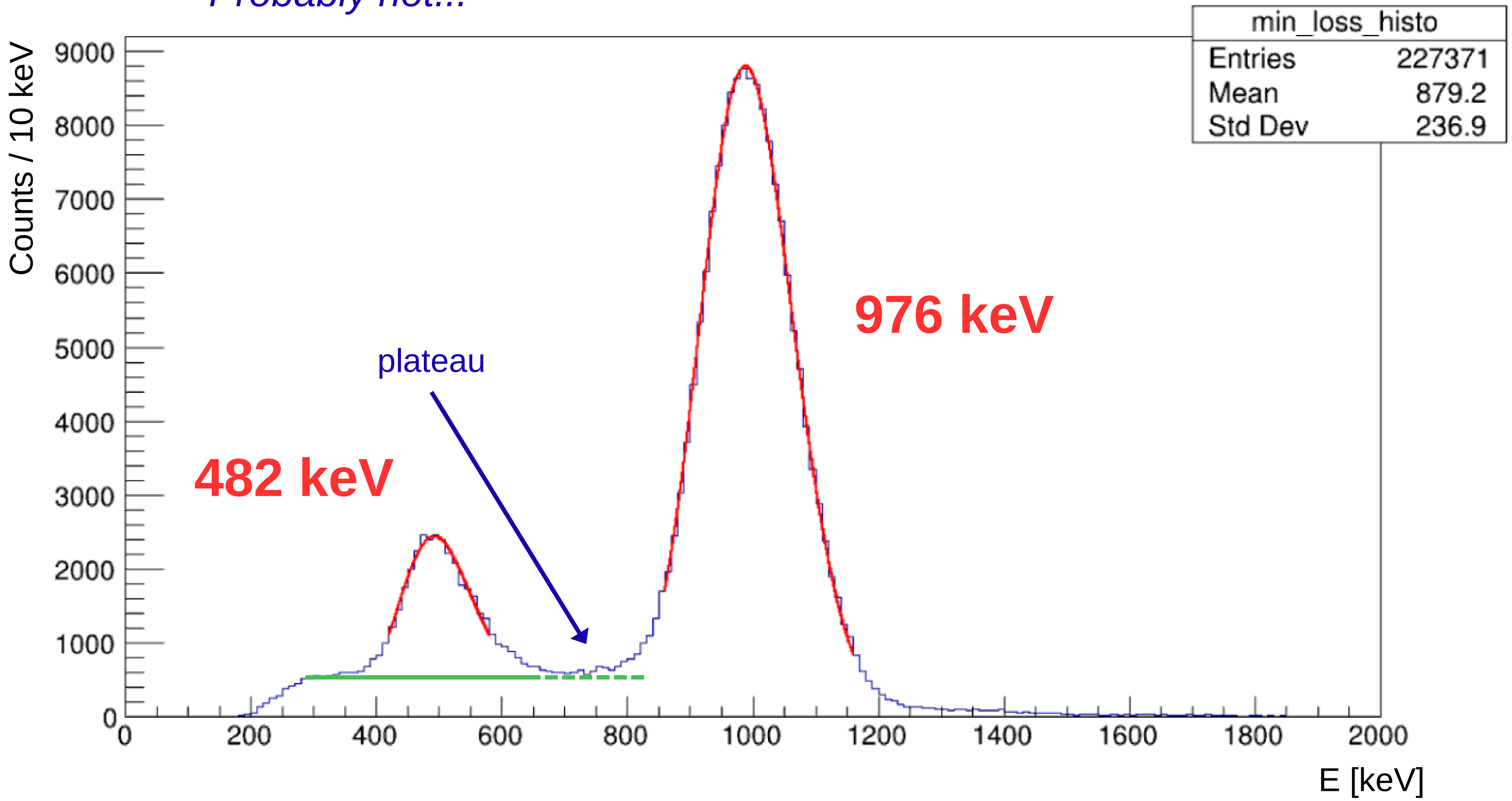


The “second-order” effects: the plateau

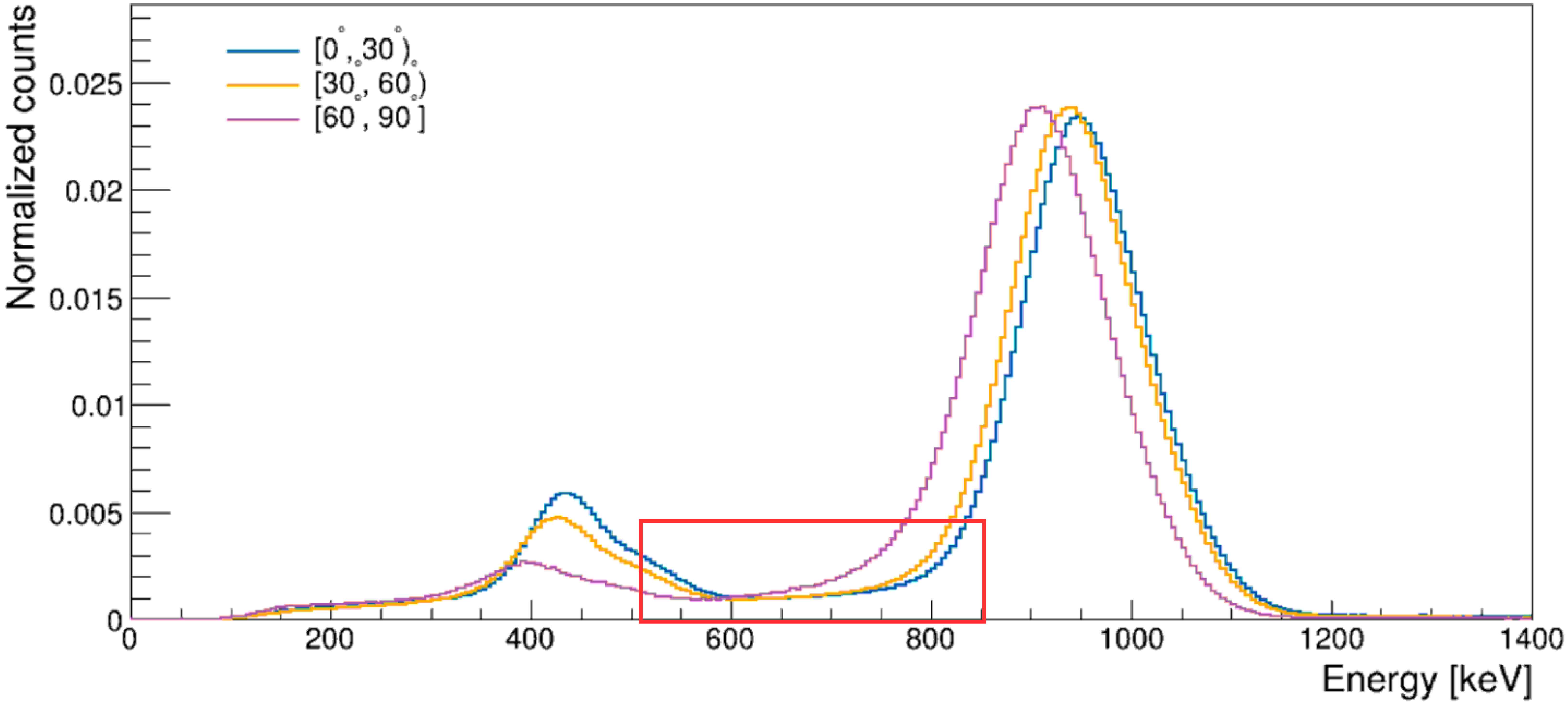
Tracker-gas energy losses?

Probably not...

...then maybe ***backscattering?***

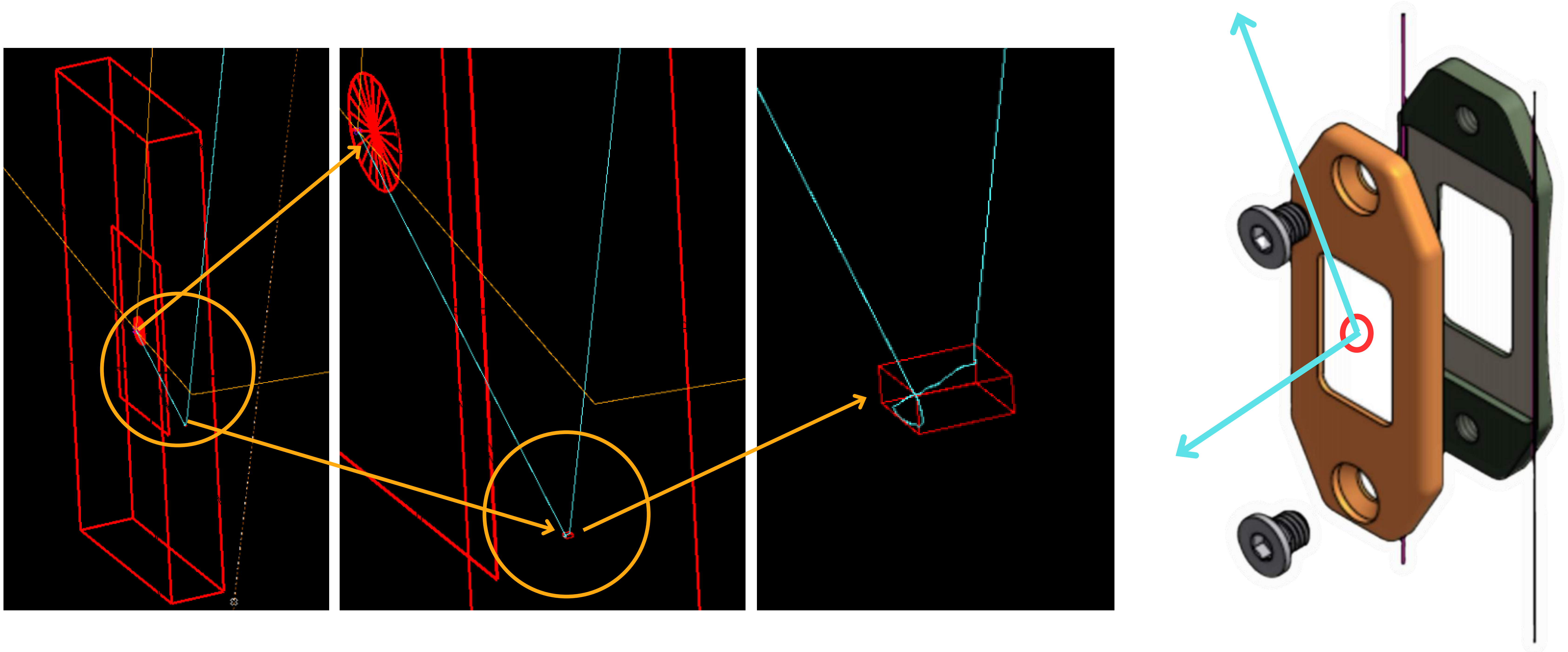


The “second-order” effects: angular dependency



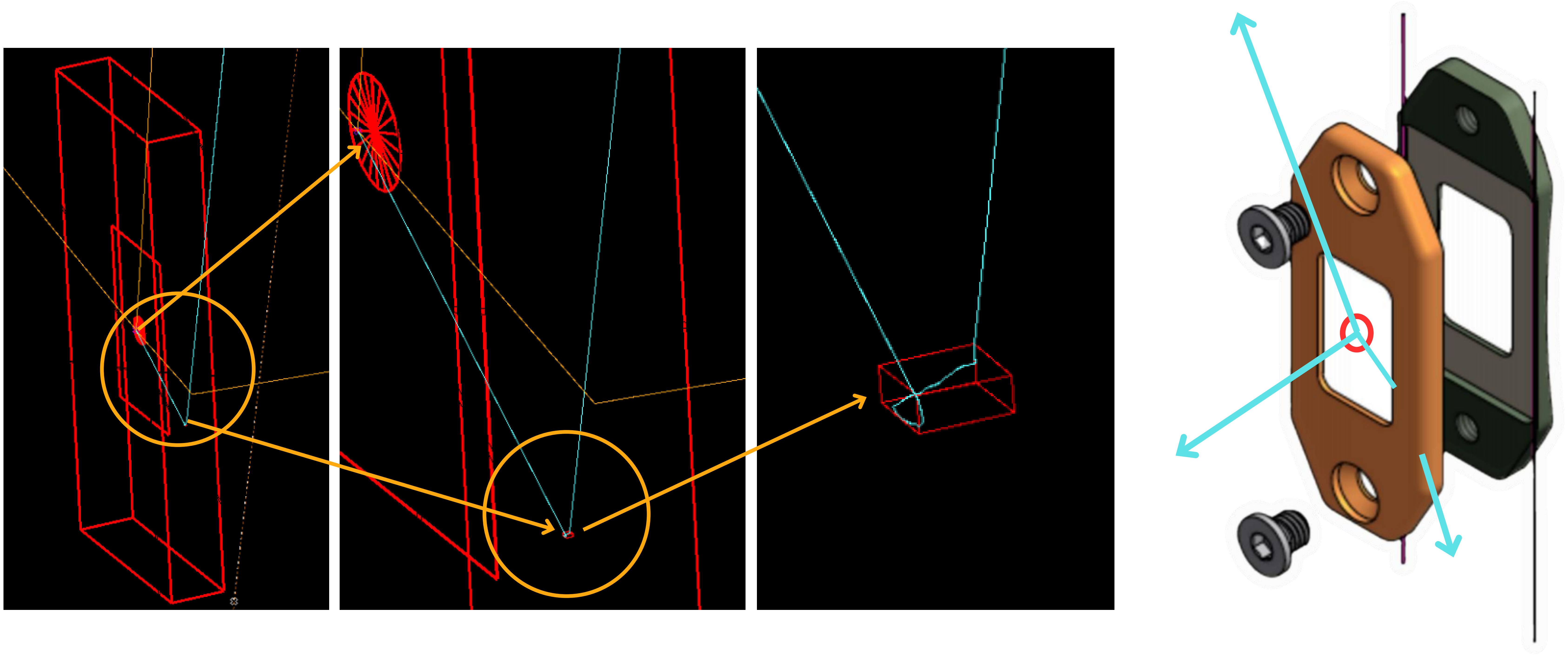
Spectra obtained from real data of ^{207}Bi decay (data from 285 data sets with ~ 180 000 events in each)

The “second-order” effects: not backscattering?



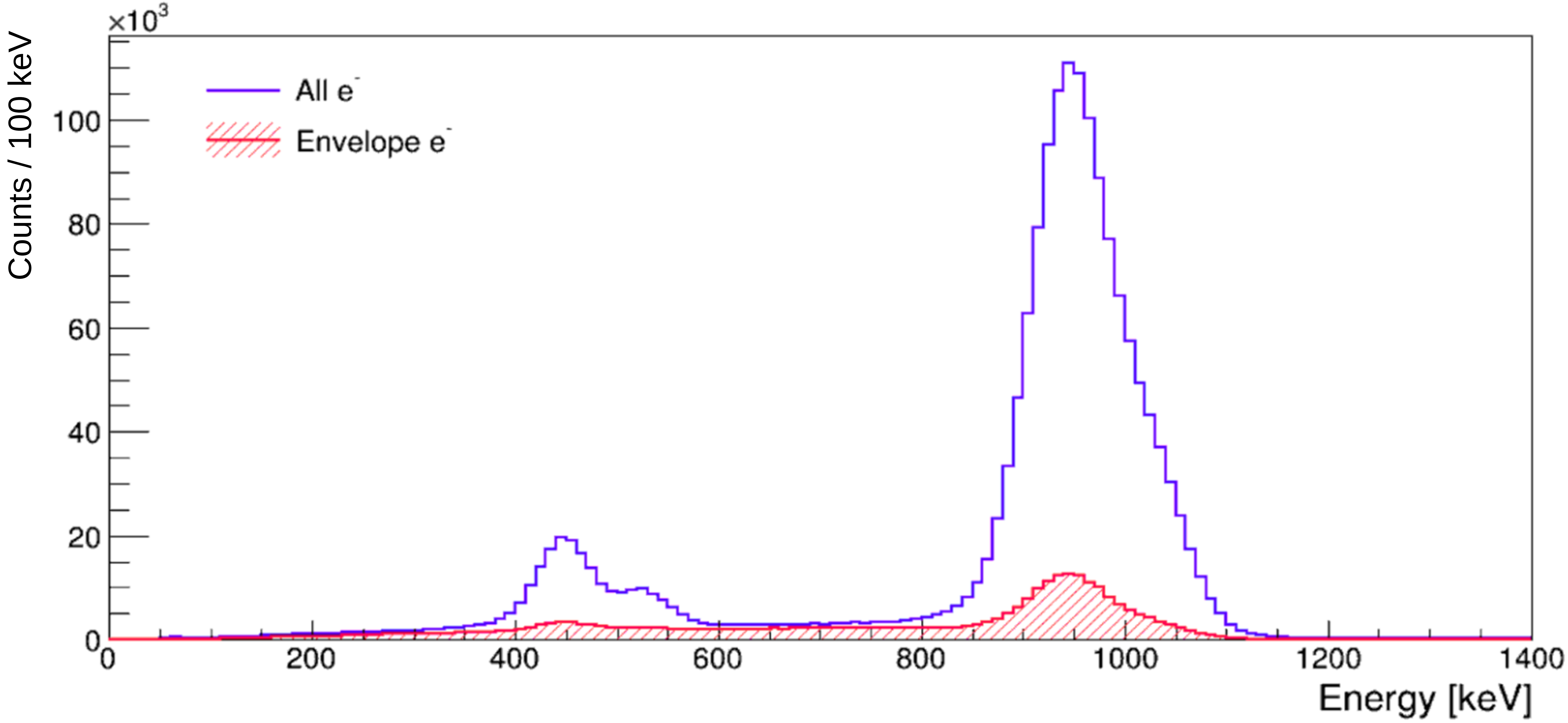
Simulated event of ^{207}Bi decay with electron energy between 600 and 800 keV

The “second-order” effects: not backscattering?



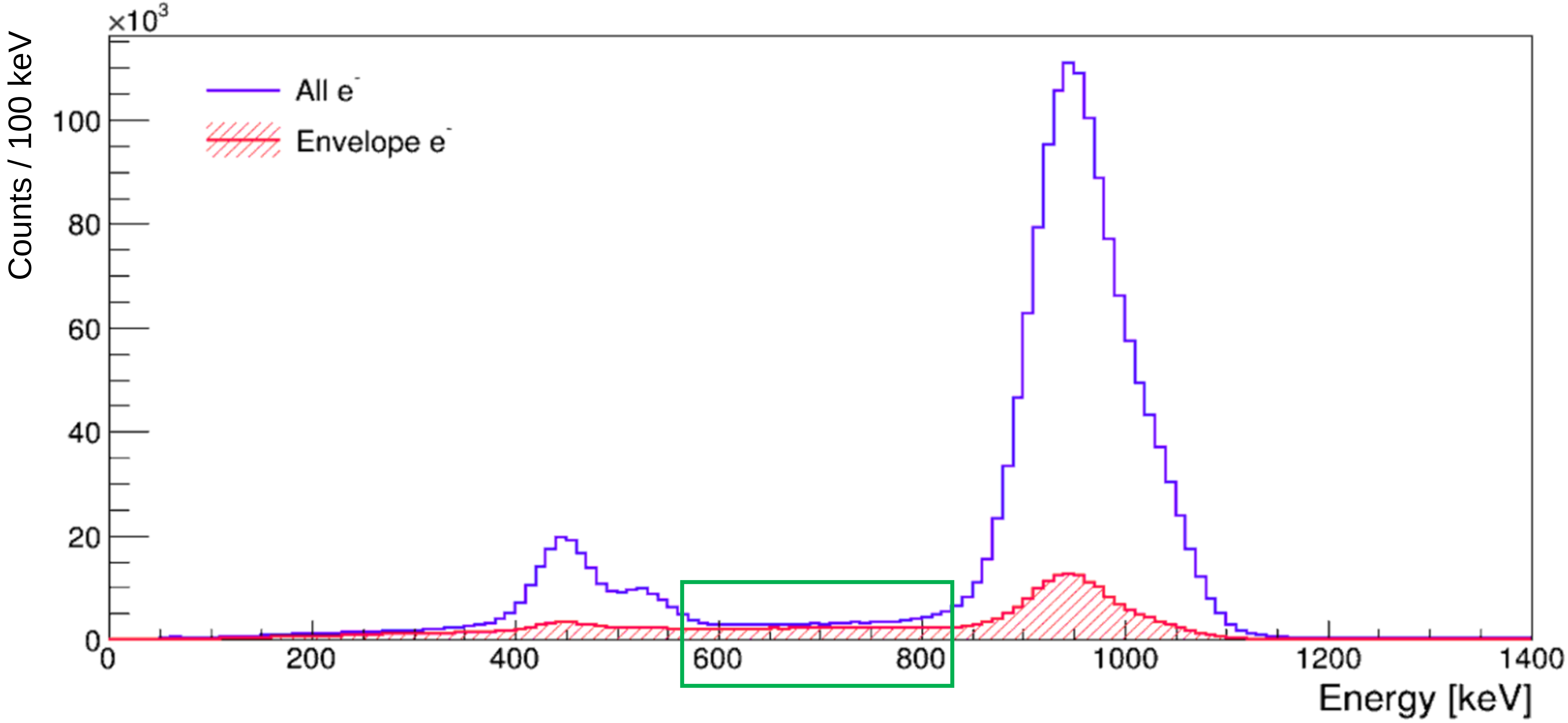
Simulated event of ^{207}Bi decay with electron energy between 600 and 800 keV

The “second-order” effects: not backscattering!



Spectra obtained from simulated data of ^{207}Bi decay (combined 100 data sets with ~ 17 000 events in each)

The "second-order" effects: not backscattering!



Spectra obtained from simulated data of ^{207}Bi decay (combined 100 data sets with ~ 17 000 events in each)

Conclusion

- The **unified** data processing pipeline, compatible with **both** experimental and simulated data for the SuperNEMO framework, developed

- The origin of the **inter-peak plateau** explained

- A potential path toward a unified fitting function describing the full calibration spectrum outlined

Thank you for attention!

Backup

Optical corrections

$$E = a_j Q + b_j$$

E *is the deposited energy of the electron,* ***Q*** *is the collected charge of the electron, and constants* ***a*** *and* ***b*** *refer to each individual optical module (OM) j*

for non-linearity effects

$$E_f = \alpha E_{BC} + \beta \left(E_{BC}\right)^{\gamma}$$

for geometrical non-uniformity effects

$$E_D = \frac{E_{BC}}{G(y,z)}$$

E_f *final electron energy which is detected directly by the OM*

E_{BC} *electron energy accounting for non-linearity effects (obtained numerically)*

E_D *deposited energy accounting for the space non-uniformity of the OMs and the non-linearity effects*

$G(y,z)$ *OM 2D space non-unnoformity factor*

Energy loss corrections

Bete-Bloch formula

$$\frac{dE}{dx} = \frac{2\pi N_A \langle Z/A \rangle}{m_e c^2} \left(\frac{e^2}{4\pi\varepsilon_0} \right)^2 \frac{\rho}{\beta^2} \Phi(E)$$

$$\Delta E \ll E \longrightarrow \Delta E(d,\, E) = \frac{dE}{dx}(E) \cdot d, \qquad d = \frac{L}{\cos\theta}$$

for solid-state components (Mylar and nylon)

$$\Delta E_M(d_M,\, E_D)\,,\ \Delta E_n(d_n,\, E_D + \Delta E_M)$$

for tracker gas

$$\Delta E_g(d_g,\, E_D + \Delta E_M + \Delta E_n;\, p)$$

- d *final electron energy which is detected directly by the OM*
- l *thickness of a given material layer*
- θ *angle between the electron's track and the source foil plan*
- p *operating pressure*

Energy loss corrections for tracker gas

$$\Delta E \ll E$$

$$\Delta E(d,\ E) = \frac{dE}{dx}(E)\cdot d, \qquad d = \frac{L}{\cos\theta}$$

Bete-Bloch formula

$$\frac{dE}{dx} = \frac{2\pi N_A \langle Z/A\rangle}{m_e c^2}\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \frac{\rho}{\beta^2}\,\Phi(E)$$

$$\Phi(E) = \ln\frac{m_e c^2\beta^2 E}{2I^2(1-\beta^2)} - \left(2\sqrt{1-\beta^2} - 1 + \beta^2\right)\ln 2 + 1 - \beta^2 + \frac{1}{8}\left(1-\sqrt{1-\beta^2}\right)^2$$

$$\langle Z/A\rangle = \sum_i \frac{w_i Z_i}{A_i} \qquad I = \exp\frac{\sum_i w_i \frac{Z_i}{A_i}\ln I_i}{\langle Z/A\rangle}$$

$$\rho = \frac{M_m\, p}{RT}; \quad M_m = \omega_{He}M_{He} + \omega_{Ar}M_{Ar} + \omega_{Et}M_{Et}$$

$$T \approx 298\,\mathrm{K}$$

The operating pressure ***p*** is an independent parameter, as it is not fixed in the detector. Hence, p is the only free parameter of the following calibration model.

Combining all the corrections…

$$
\begin{aligned}
E_i(E_D, d_M, d_n, d_g; p) = E_D & \quad \text{(deposited energy)} \\
+ \Delta E_M(d_M,\, E_D) & \quad \text{(loss in Mylar)} \\
+ \Delta E_n(d_n,\, E_D + \Delta E_M) & \quad \text{(loss in nylon)} \\
+ \Delta E_g(d_g,\, E_D + \Delta E_M + \Delta E_n; p) & \quad \text{(loss in the gas)}
\end{aligned}
$$

Calibrating algorithm

by F. Koňařík

$$E = a_j Q + b_j$$

E *is the deposited energy of the electron,* ***Q*** *is the collected charge of the electron, and constants* ***a*** *and* ***b*** *refer to each individual optical module (OM) j*

1. Choose arbitrary a_j and b_j.
2. Calculate $E_f = a_j Q + b_j$ for each electron detected by given OM.
3. Apply energy corrections to calculate E_i for each electron detected by given OM (equation (4.16) from chapter 4).
4. Fit the E_i energy spectrum using functions from the equation 4.18 to find positions μ_1 and μ_2 of the first and the second peak.
5. Calculate $L(a_j, b_j) = (\mu_1 - E_1)^2 + (\mu_2 - E_2)^2$, where $E_1 = 482$ keV and $E_2 = 976$ keV.

The plateau

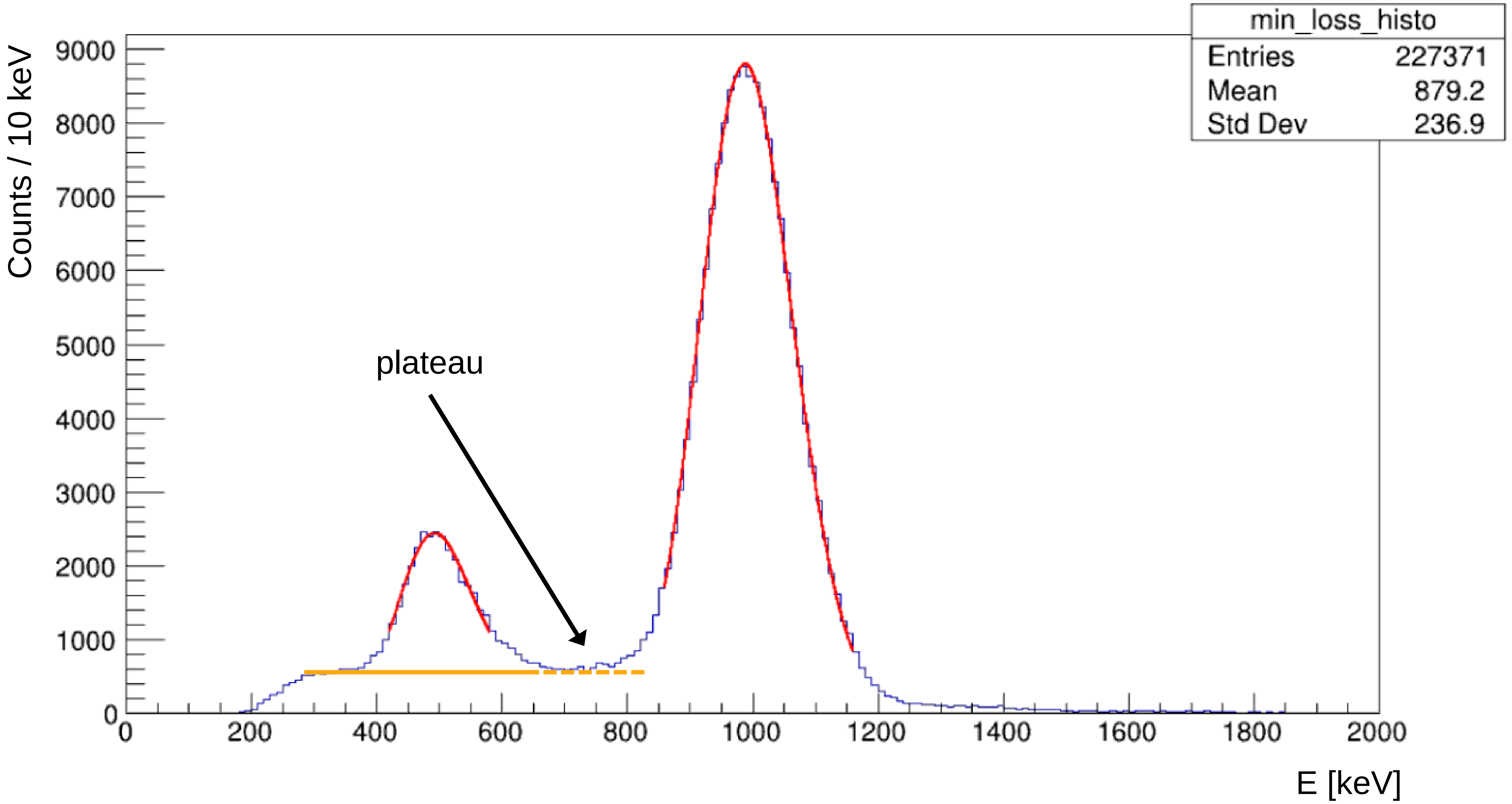
Tracker-gas energy losses?

Probably not...

$$f_{\text{measured}}(E) = f_{\text{Landau}}(E) \otimes f_{\text{Gauss}}(E)$$

↓

$$f_{\text{measured}}(E) \approx \underbrace{f_{\text{Landau}}}_{\approx\,\delta\text{-function}} \otimes f_{\text{Gauss (broad)}} = f_{\text{Gauss}}$$



...then maybe backscattering?