ND README

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1 Requirements

In order to perform ND diagnostics you should create ND-wall in independent macros. So far there exists some hard-coding which needs to be explained and written down. Wall of neutron detectors is built of individual modules which consist of cylinders inserted in each other. The first cylinder is of stilben. It is put in a bigger cylinder of aluminum shell and then steel cover. This assembly is housed in air box which is essential to simulate neutron scattering in air medium. Further example illustrates setting coordinates of neutron modules.

Air box should be sufficiently big, starting after reaction chamber and containing whole neutron module. Take it 9 m if detector wall is in 8 m from the target. Consider following disposition: center of the reaction chamber is in zero of z-axis, it ends in 40 cm. Then air box starts in 40 cm and ends in 940 cm. Its center is in 490 cm. We want to place stilben module in l cm from the target, see Fig.1.

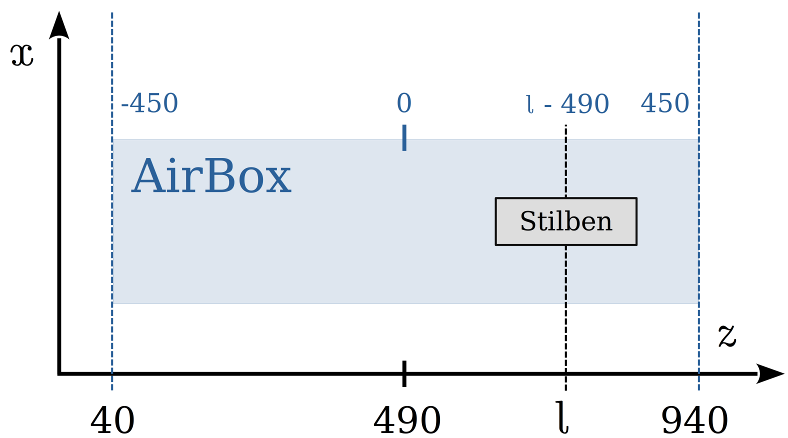

Figure 1: Arrangement of stilben modules. Volume coordinate is coordinate of its center. Air box is positioned in coordinates of experimental setup, stilben · module – in coordinates of air box.

Code lines are to place stilbens into air box. Create shapes:

```
TGeoBBox* PlaneShape = new TGeoBBox("PlaneShape",400./2., 400./2., 900./2.);
TGeoTube* crystalSh = new TGeoTube("crystalSh",
        R_min(crystal), R_max(crystal), HeightZ(crystal)/2.);
TGeoTube* shellSh = new TGeoTube("shellSh",
        R_min(shell), R_max(shell), HeightZ(shell)/2.);
```

```
TGeoTube* housingSh = new TGeoTube("housingSh",
        R_min(housing), R_max(housing), HeightZ(housing)/2.);
```

Set their materials:

```
TGeoVolume* AirBox = new TGeoVolume("NDAirBox", PlaneShape, pAir);
TGeoVolume* crystalVol = new TGeoVolume("crystalVol", crystalSh, pStilbene);
TGeoVolume* shellVol = new TGeoVolume("shellVol", shellSh, paluminium);
TGeoVolume* housingVol = new TGeoVolume("housingVol", housingSh, pSteel);
TGeoVolume* moduleVol = new TGeoVolumeAssembly("moduleVol");
```

Volume arrangement consists in successive inserting of volumes. xyz[i_m]($z = l$ in Fig.1) are coordinates of centers of stilben modules, their z component is offset due to air box z-size (490 cm is half of its z-dimension).

```
shellVol->AddNode(crystalVol, 1,
        new TGeoCombiTrans("A", 0., 0., (Z_Shell-Z_Crystal)/2., rotation));
housingVol->AddNode(shellVol, 1,
        new TGeoCombiTrans("B", 0., 0., (Z_Shell-Z_Crystal)/2., rotation));
moduleVol->AddNode(housingVol, 1,
        new TGeoCombiTrans("C", 0., 0., (Z_Shell-Z_Crystal)/2., rotation));

for (int i_module(0); i_m < 45; i_m++) {
        AirBox->AddNode(moduleVol, i_m, new TGeoCombiTrans("module",
        xyz[i_m][0], xyz[i_m][1], xyz[i_m][2] - 490., rotation));
}
```

Next step is to add ND parts in ascending order of Z-coordinate of part in sim_digi.C:

```
ERND* nd= new ERND("ERND", kTRUE,verbose);
nd->SetGeometryFileName(ndGeoFileName);
run->AddModule(nd);

ERNDDigitizer* ndDigitizer = new ERNDDigitizer(1);
ndDigitizer->SetEdepError(0.0,0.04,0.02);
run->AddTask(ndDigitizer);
```

Function $SetEdepError(ErrorA, ErrorB, ErrorC)$ determines coefficients to calculate σ of energy deposite E_{dep} in stilben:

$$\sigma(E_{dep}) = \sqrt{ErrorA^2 + (ErrorB \cdot \sqrt{E_{dep}})^2 + (ErrorC \cdot E_{dep})^2}, \quad (1)$$

where σ [MeV], ErrorA [MeV], ErrorB [$\sqrt{MeV}$], ErrorC [dimensionless].

In reco.C:

```
ERNDTrackFinder* trackFinderND = new ERNDTrackFinder();
run->AddTask(trackFinderND);
ERNDPID* pid = new ERNDPID();
run->AddTask(pid);
```

2 ND diagnostics

Run sim_digi.C and reco.C to obtain sim_digi.root and reco.root. Run nd_precision.C. In this example stilben wall consists of 45 modules placed in 8 meters from the target in semicircle (z-coordinate is from 7.865 to 7.945 meters). Front sight of their arrangement is shown in Fig.2. Further changes were made to increase registration efficiency: modules are put close together, the module at the beam line was not excluded. Stilben parameters are: $R_{crystal} = 4$ cm, $h_{crystal} = 5$ cm. Crystals are covered with aluminum (2 mm thick) and steel (6 mm thick).

Neutrons are born in ^{10}He decay:

$$
\begin{aligned}
{}^{8}He + {}^{3}H &\longrightarrow {}^{10}He + {}^{1}H, && (2)\\
{}^{10}He &\longrightarrow {}^{8}He + n + n, && (3)
\end{aligned}
$$

where vectors of decay products in center-of-mass system are obtained from Monte-Carlo Event Generator (by Irina Egorova [here should be reference to the paper]). Further they are converted into laboratory system and guided through the set-up.

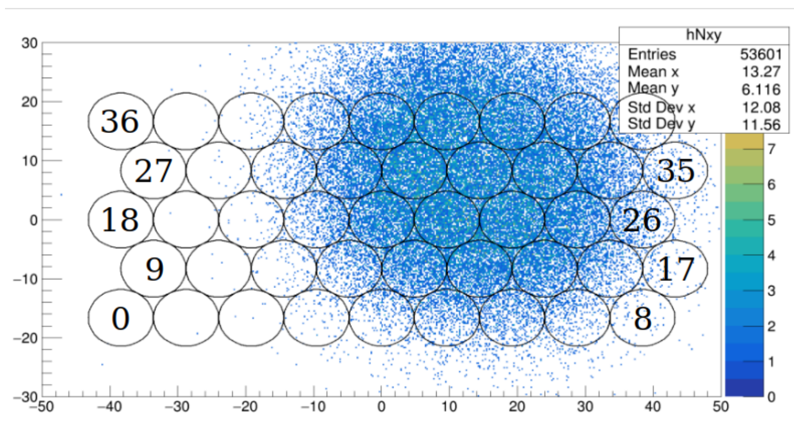

Figure 2: Wall of neutron detectors, front view. Blue dots are neutron coordinates (cm) when the wall is in 8 meters from the target.

Comparison of simulated and reconstructed coordinates of the neutron on target is shown in Fig.3. They are obtained from BeamDetTrack reconstruction.

Comparison of simulated and reconstructed unit vector coordinates of the neutron on target is shown in Fig.4

Comparison of simulated and reconstructed neutron energy on target is shown in Fig.5.

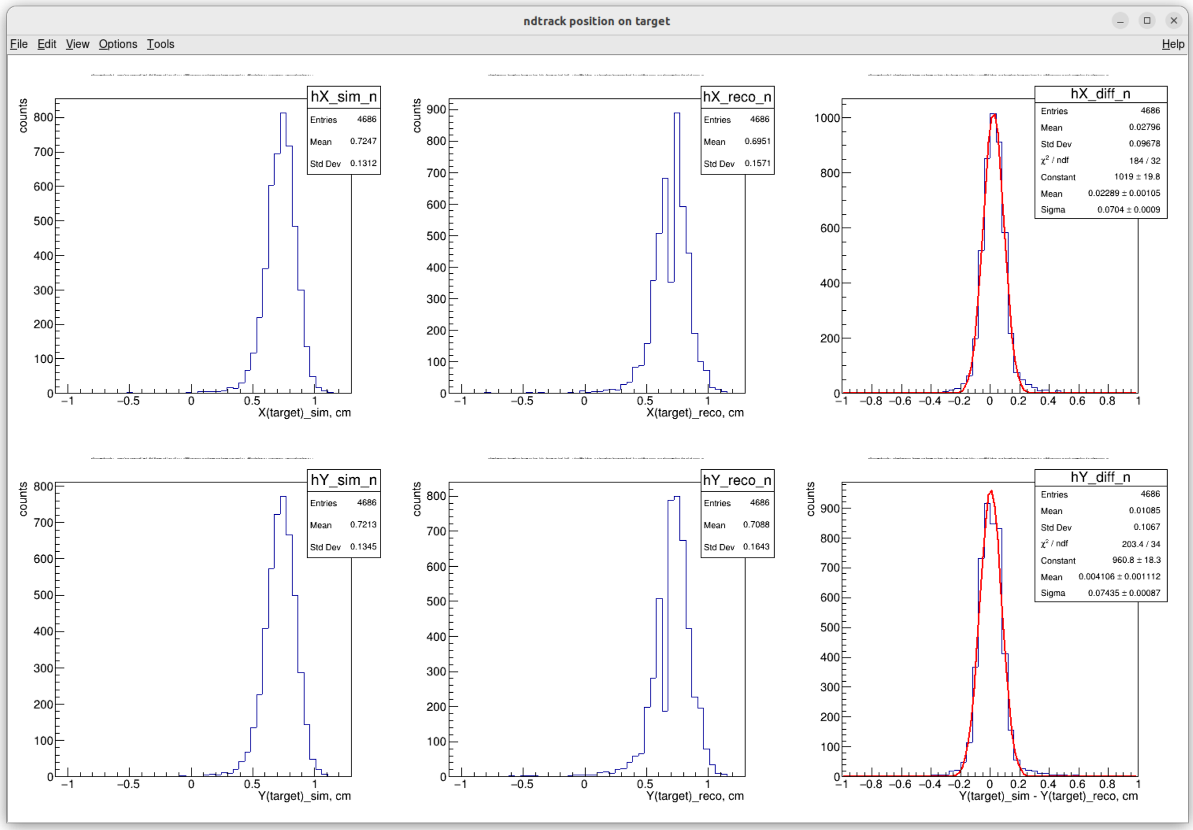

Figure 3: Difference between simulated (EventHeader) and reconstructed (NDTrack) coordinates of neutron on target. First row is x-coordinate, second row is y-coordinate. From left to right: simulated coordinate, reconstructed coordinate, their difference. Reconstruction accuracy: mean bias is $\langle \Delta x \rangle = 0.02289$ cm, $\langle \Delta y \rangle = 0.004106$ cm; standard deviation is $\sigma(\Delta x) = 0.0704$ cm, $\sigma(\Delta y) = 0.07435$ cm.

3 Long stilbens

In order to obtain better statistics in the first steps of analysis stilbens were prolonged up to 50 cm in length. As soon as neutron energy is calculated from its time of flight, the greater spread of distances causes larger energy dispersion. This results in worsening of energy resolution, see Fig.6.

Spread of distances is shown in Fig.7.

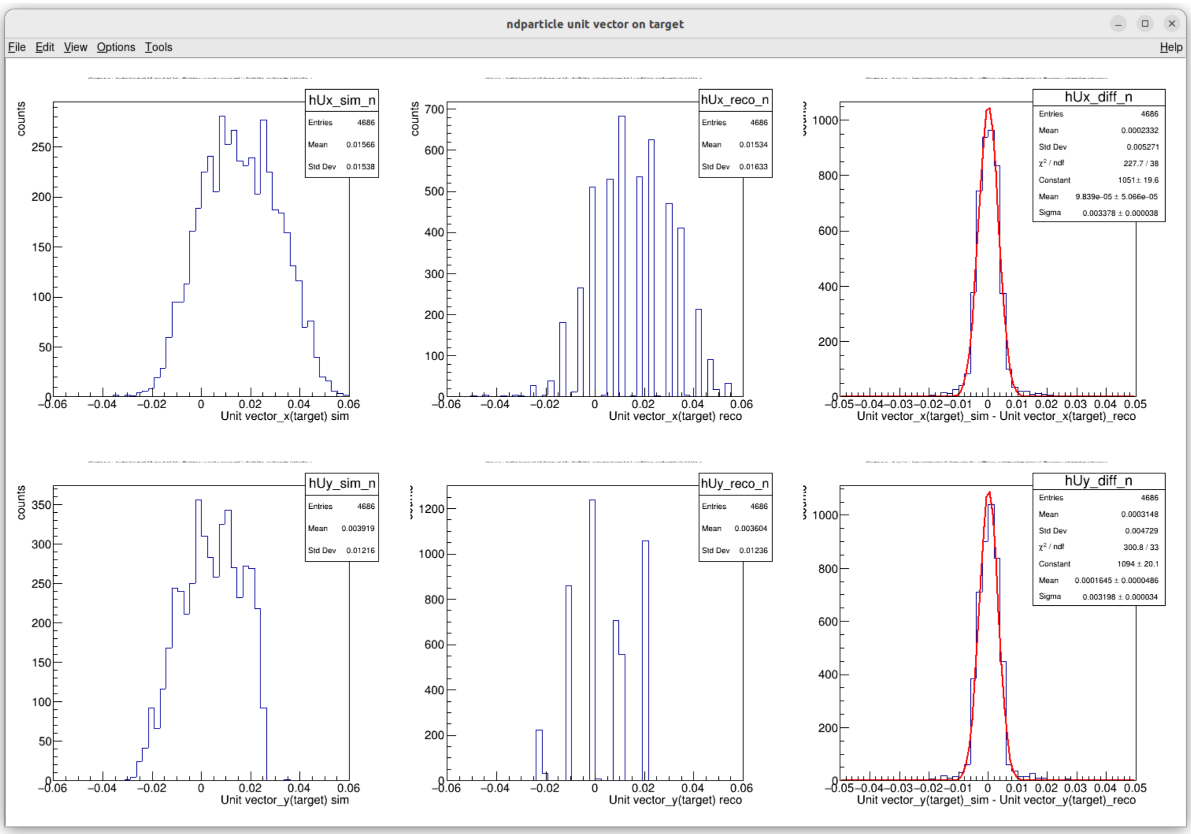

Figure 4: Difference between simulated (EventHeader) and reconstructed (NDTrack) components of unit vector of the neutron direction. First row is x component, second row is y component. From left to right: simulated component, reconstructed component, their difference. Reconstruction accuracy: mean bias is $\langle \Delta x \rangle = 9.839 \cdot 10^{-5}$, $\langle \Delta y \rangle = 1.645 \cdot 10^{-4}$; standard deviation is $\sigma(\Delta x) = 0.007294$, $\sigma(\Delta y) = 0.005857$.

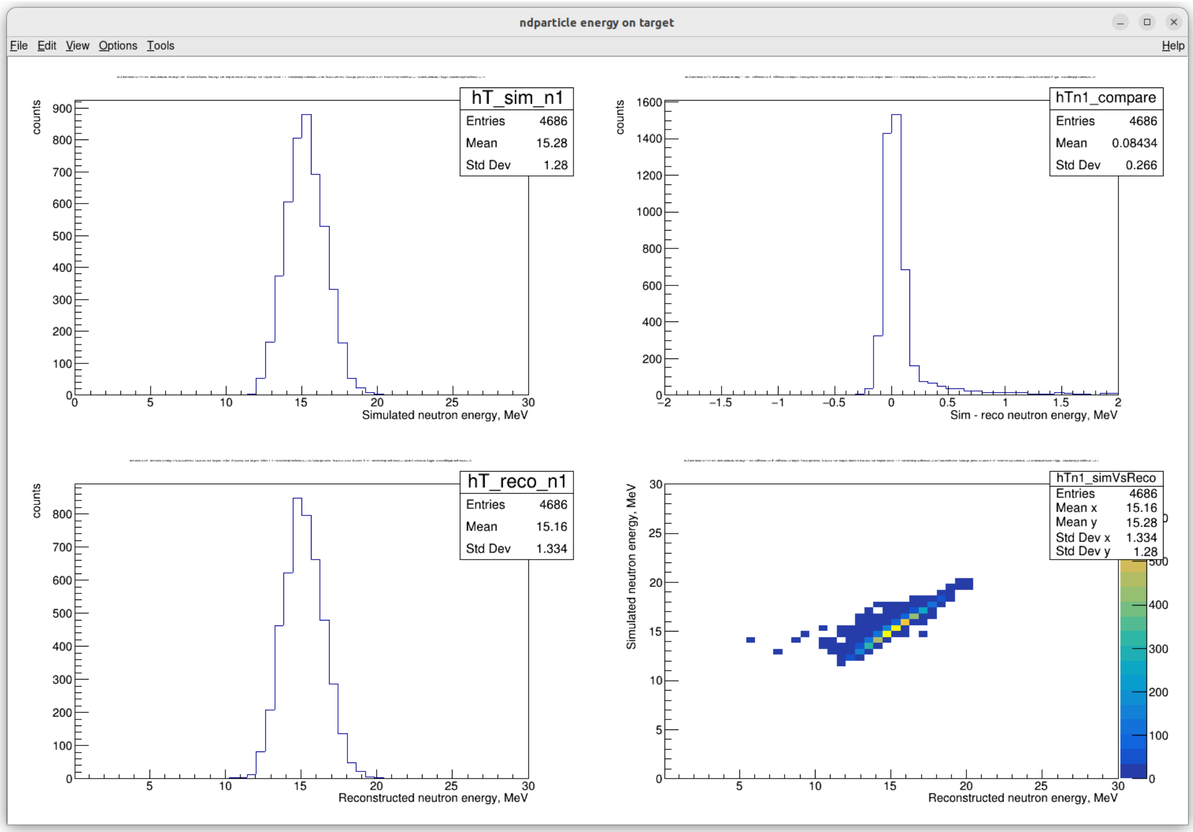

Figure 5: Difference between simulated (EventHeader) and reconstructed (NDParticle) energy of the neutron on target. First column up is simulated energy of the beam, down - reconstructed energy. Second column up is difference between simulated and reconstructed energy of the beam, down - is two-dimensional chart with reconstructed energy on the x-axis and simulated energy on the y-axis. Reconstruction accuracy: mean bias is $\langle \Delta E \rangle = 0.08434$ MeV, standard deviation is $\sigma(\Delta E) = 0.266$ MeV.

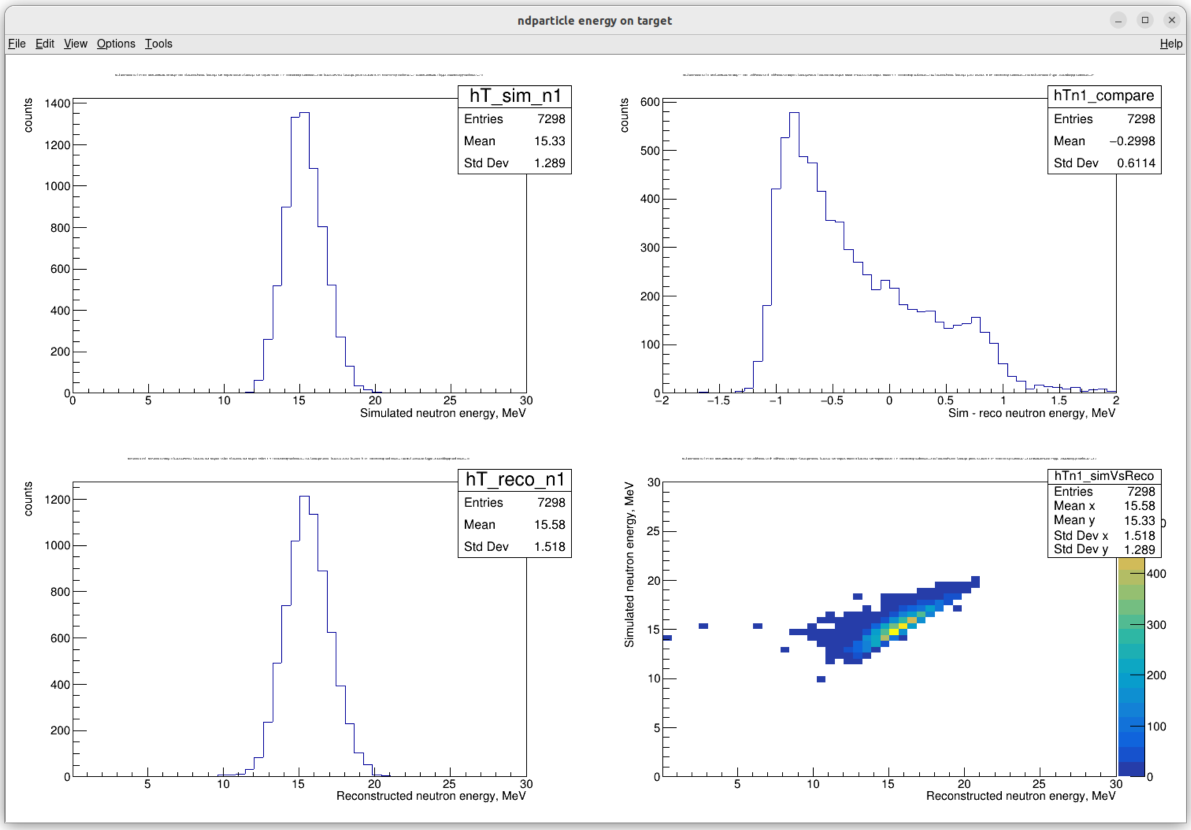

Figure 6: Difference between simulated (EventHeader) and reconstructed (NDParticle) energy of the neutron on target in case of long (50 cm) stilbens. First column up is simulated energy of the beam, down - reconstructed energy. Second column up is difference between simulated and reconstructed energy of the beam, down - is two-dimensional chart with reconstructed energy on the x-axis and simulated energy on the y-axis. Reconstruction accuracy: mean bias is $\langle \Delta E \rangle = -0.2998$ MeV, standard deviation is $\sigma(\Delta E) = 0.6114$ MeV.

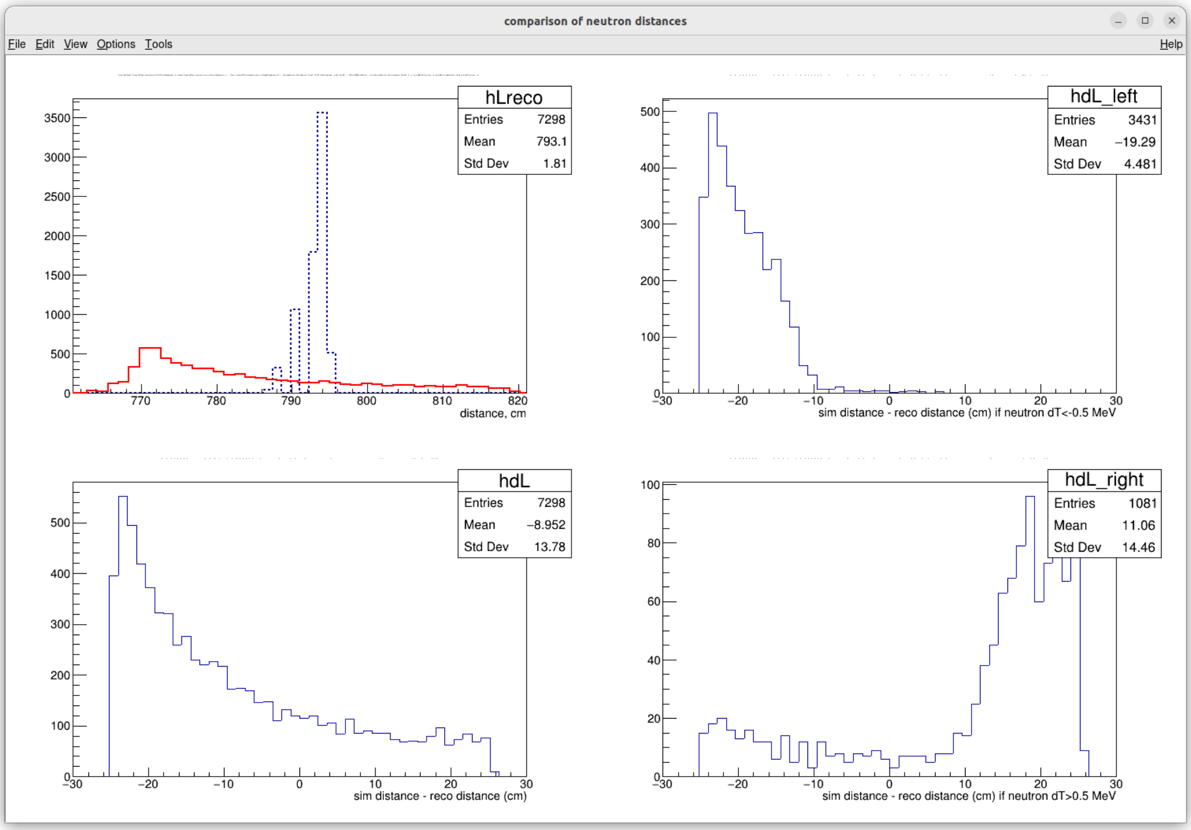

Figure 7: Difference between simulated (EventHeader and NDDigi) and reconstructed (NDTrack) distances which neutrons pass from their birth in the target to the moment of proton knocking-out in scintillator in case of long (50 cm) stilbens. First column up is distribution of neutron distances: red solid line is simulated, blue dotted – reconstructed. First column down is their difference. Second column up is difference of simulated and reconstructed distances when energy difference (see Fig.6) is less than -0.5 MeV. Second column down – when energy difference is more than 0.5 MeV.