SAND SW integration into the ND Production framework

F. Battisti, S. Lanzi, G. Santoni, M. Tenti

INFN, CNAF and University of Bologna

DUNE Italia

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Introduction

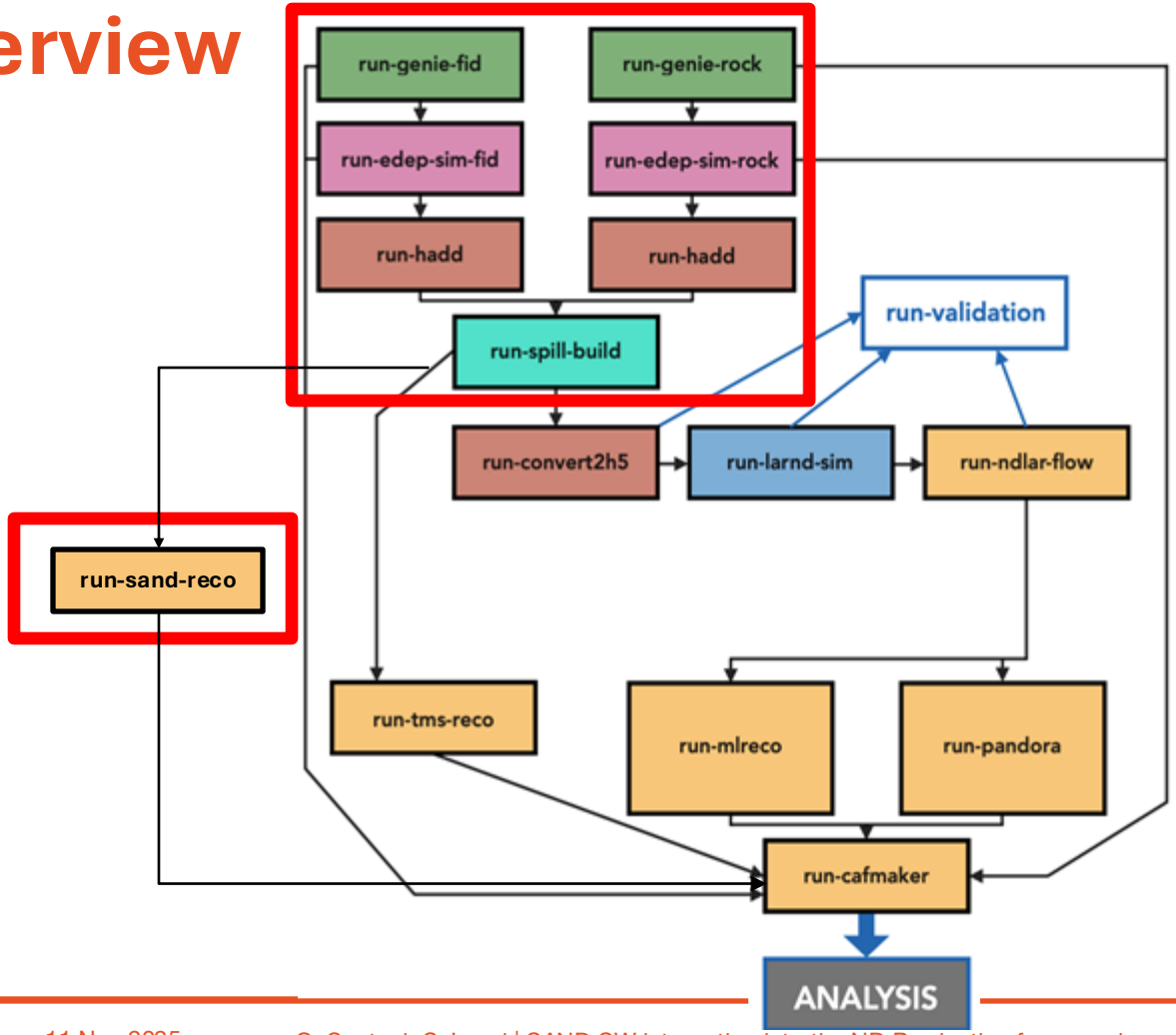
- The Near Detector sim/reco working group set up a workflow to **simulate** the **beam spill**, **reconstruct** the neutrino events and produce **high-level analysis files** (CAF)

- The workflow is **modular**, **containerized** and maintained in a github repository

GOALS of this work:

1. **Reproduce** the ND Production workflow on **CNAF** machines
2. **Include** neutrino interactions in **SAND** into the common production campaigns
3. **Improve** the current version of the **spill simulation**
4. **Port** the SAND reconstruction workflow (**`sand-reco`**) to the ND framework

Overview



Neutrino Generation

Particle Propagation

File Conversion

Spill Building

Detector Simulation

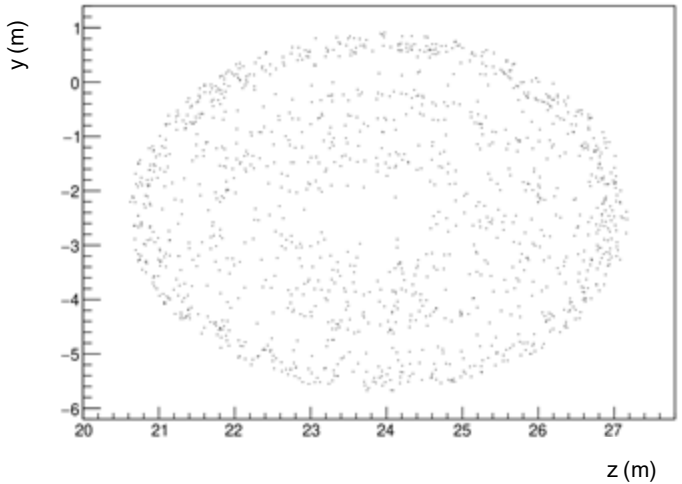
Reconstruction

Event generation and particle propagation

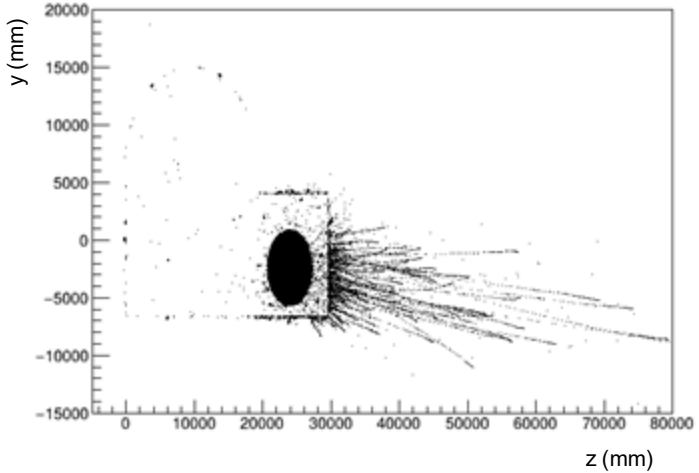
- Neutrino event generation (GENIE software) and particle propagation (Geant4/edep-sim) **successfully run** at **CNAF** after few minor adjustments

- Both steps worked using **SAND** geometry

Event Vertices from GENIE

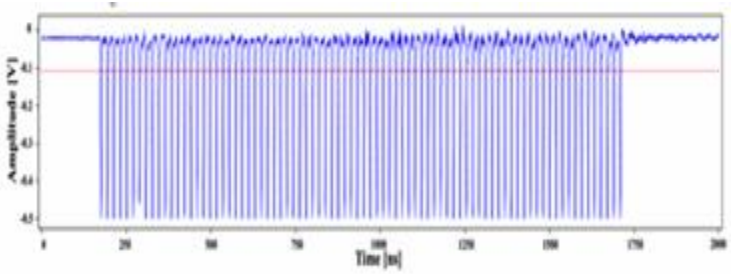


Trajectories from EDEPSIM



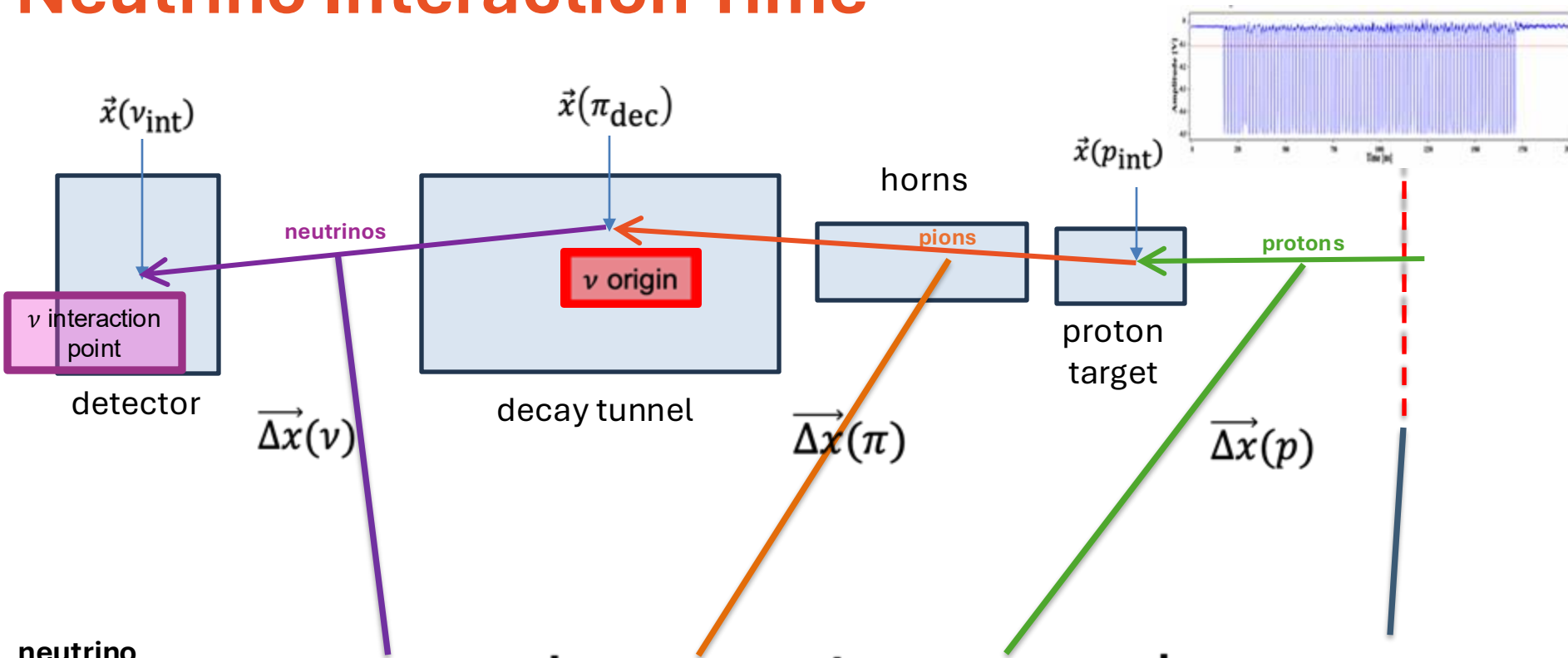
Spill building

- Spill building step **successfully tested** at **CNAF** with **SAND** geometry
- The current version shifts the interaction time according to the **beam spill microstructure**

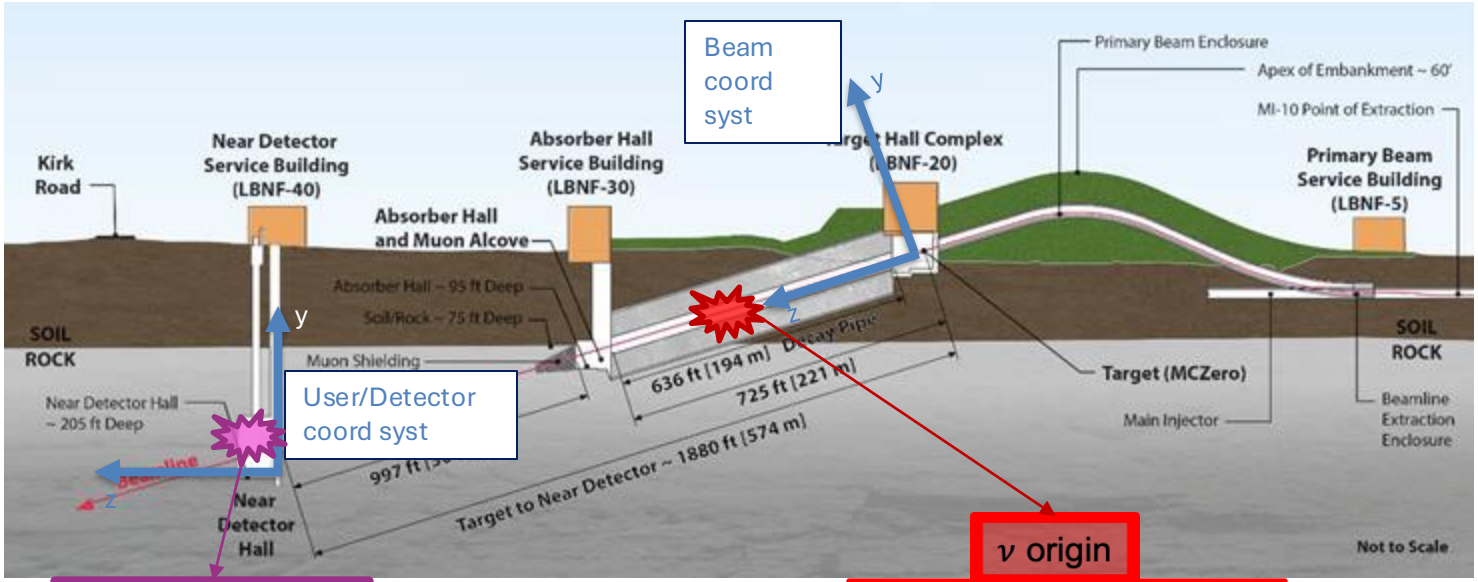


- We fixed the neutrino interaction time by taking into account all the contributions from the **proton production** up to the **interaction** (see next slide)

Neutrino Interaction Time



neutrino interaction time = neutrino time of flight + pion time of flight + proton time of flight + proton beam time structure



This info is in the **detector** coordinate system

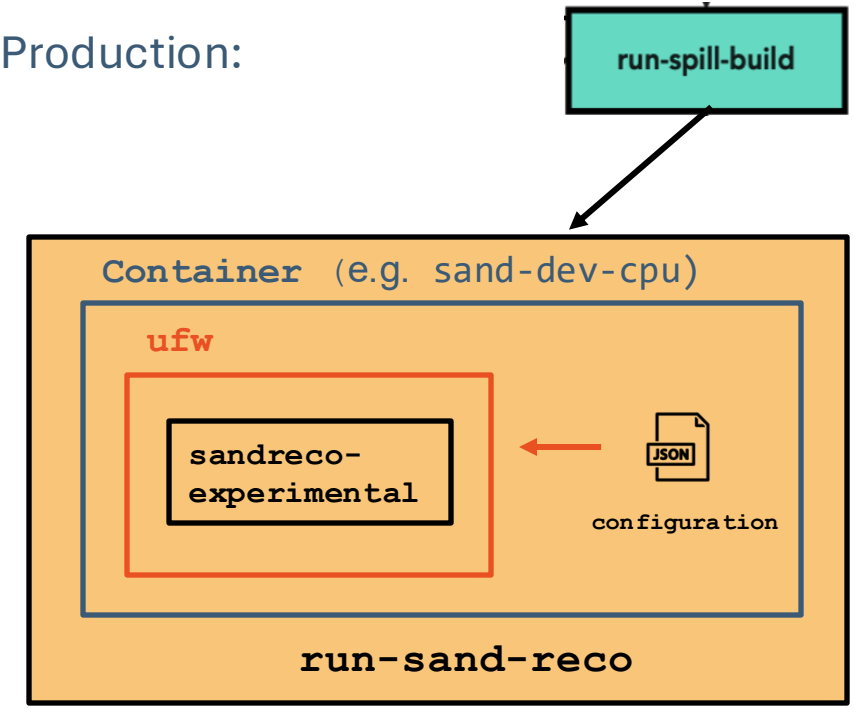
This info is in the **beam** coordinate system

We need to have these info in the **same** system, so we imported the **coordinate transformation** already present in the generator software into the spill building script

sand-reco

Strategy for sand-reco integration into ND Production:

- Deploy in **Docker container**
- Usage of the **micro-framework (ufw)**
- Configuration via **.json file**
- **Modular** execution of algorithms



Conclusions and next steps

Coming back to the goals of this work:

1. Reproduce the ND Production workflow on CNAF machines ✓
2. Include events in the SAND geometry in the general common productions ✓
3. Improve the current version of the spill simulation: **currently** the **modifications** are **implemented** and they are **being reviewed**, and we are dealing with neutrino interactions in rock ⏳
4. Include SAND reconstruction workflow (`sand-reco`) in this common framework: currently testing algorithms present in the experimental version of `sand-reco` ⏳

Thanks for your attention

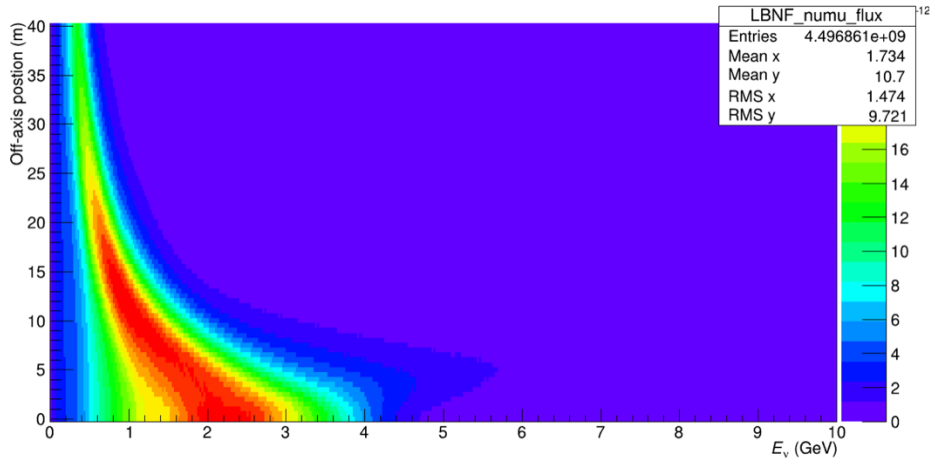
Backup

Beam structure

Beam temporal structure:

- Cycle (spill) time: 1.2 s
- Proton per cycle: 7.5 x 10^13
- Batches per cycle: 6 (+1 empty)
- Time between batches: 170 ms
- Batch (pulse) duration: 9.6 μs
- Buckets per batch: 84
- Time between buckets : 18.9 ns (53.1 MHz)
- Bucket duration: ~1 ns (RMS)

Beam spatial structure:



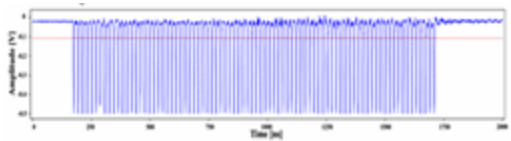
Flux as a function of the off-axis position

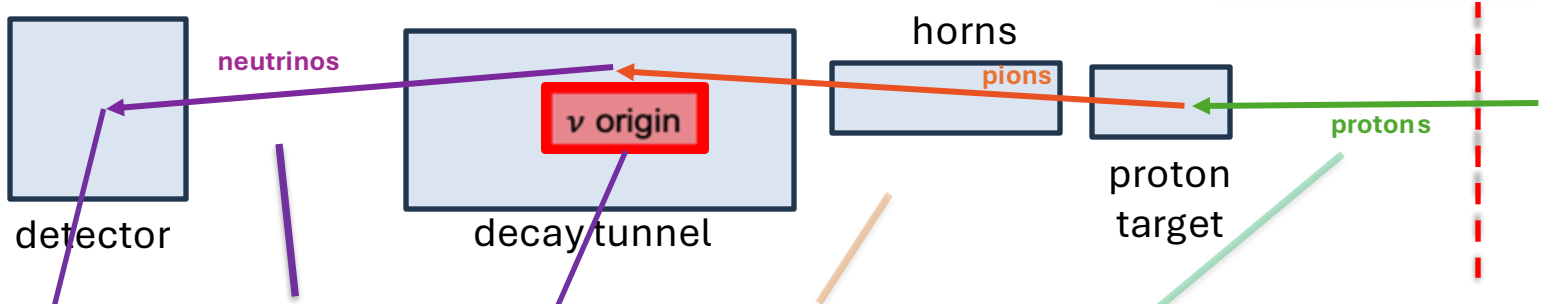
Coordinate Transformation

```
void GDk2NuFlux::Beam2UserPos(const TLorentzVector& beamxyz,
                              TLorentzVector& usrxyz) const
{
  usrxyz = fLengthScaleB2U*(fBeamRot*beamxyz) + fBeamZero;
  // above assumed T=0
  usrxyz.SetT(beamxyz.T()*fTimeScaleB2U);
}
```

- Implemented a script that converts the neutrino origin from the beam to the user coordinate system
- For the moment, the needed info (i.e., **neutrino origin**) is stored in a TTree, but it's still to be figured out if this is the best way to do

Neutrino Interaction Time





Neutrino interaction point position in **GTRAC** files in the ND hall coordinate system

Neutrino origin in the **user** coordinate system (the output of the conversion)

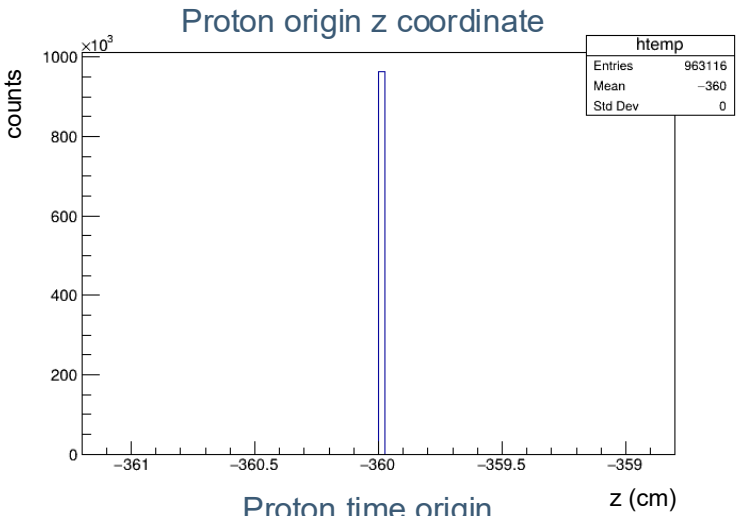
They are taken into account in **neutrino origin time**, for which t=0 is when protons are generated (see next slide)

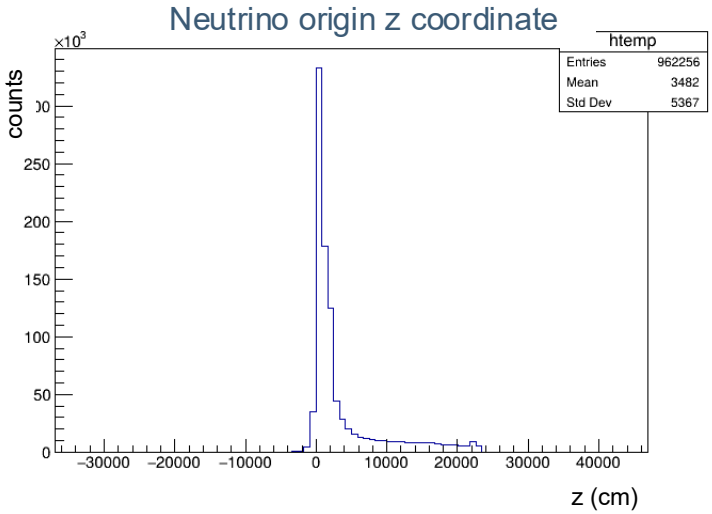
Proton production time (the script generates this time according to beam spill time structure)

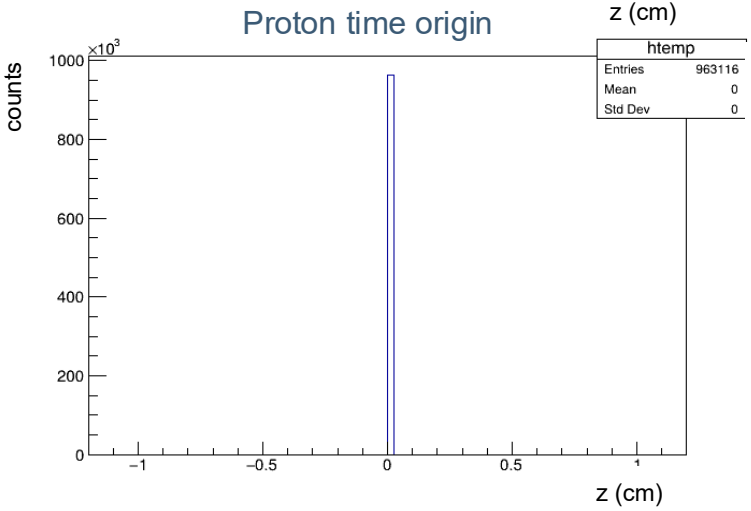
Neutrino TOF = (Distance neutrino origin - neutrino interaction point) / c

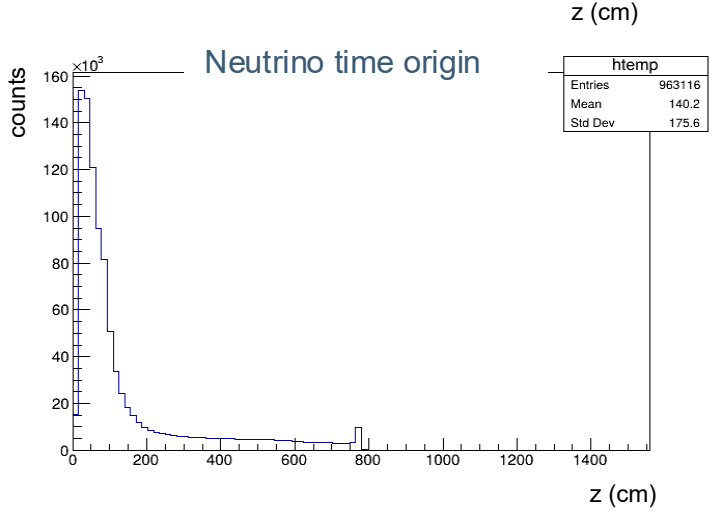
Neutrino time origin

- In dk2nu files, the time reference frame t = 0 is the time when protons cross the surface at z = -360 cm.
- The origin time of the particles is computed starting from this, as we can see in these plots.

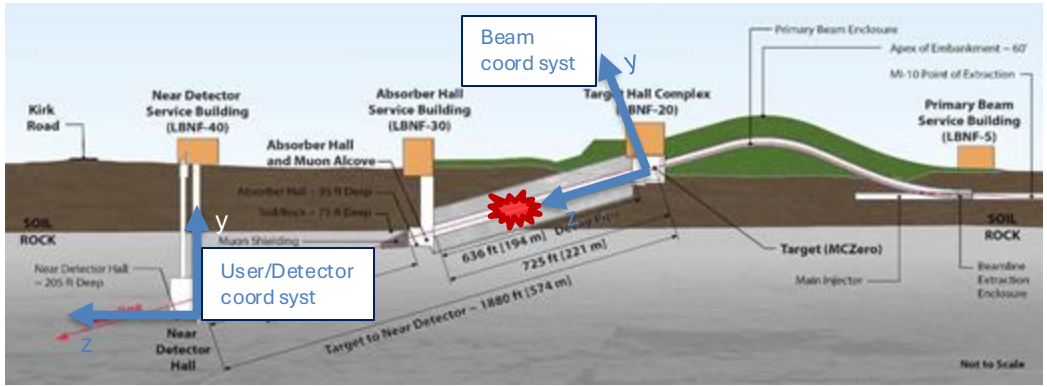


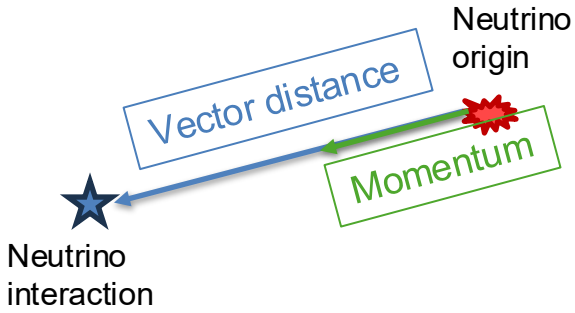






Validation of the Beam2User conversion



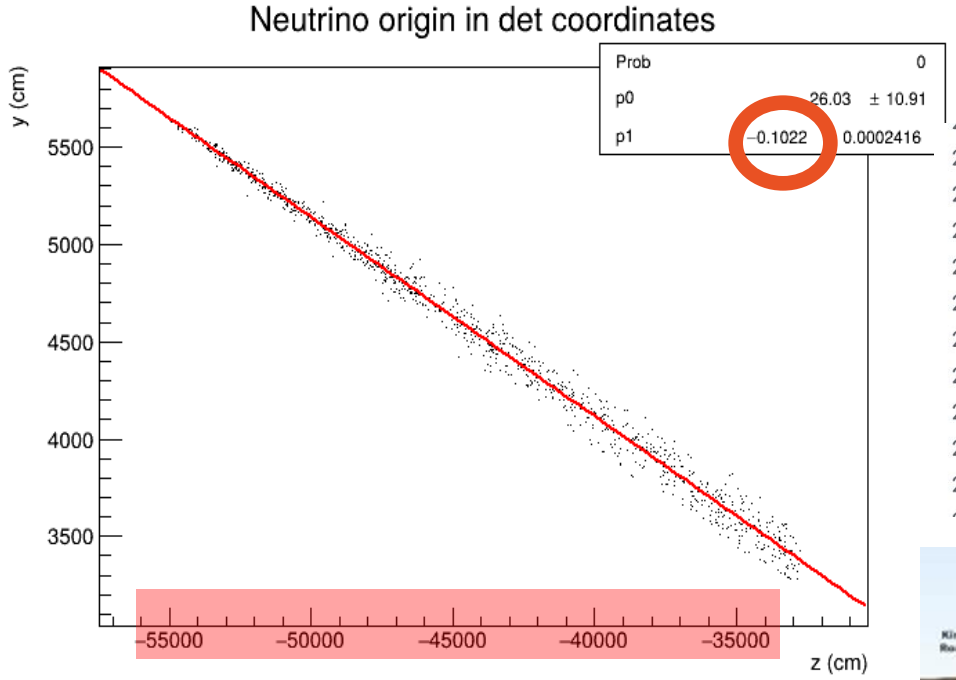


Two validation criteria:

1. Check if by plotting the neutrino origin points in the user and the beam coordinate systems, we see a **rotation** and a **translation**

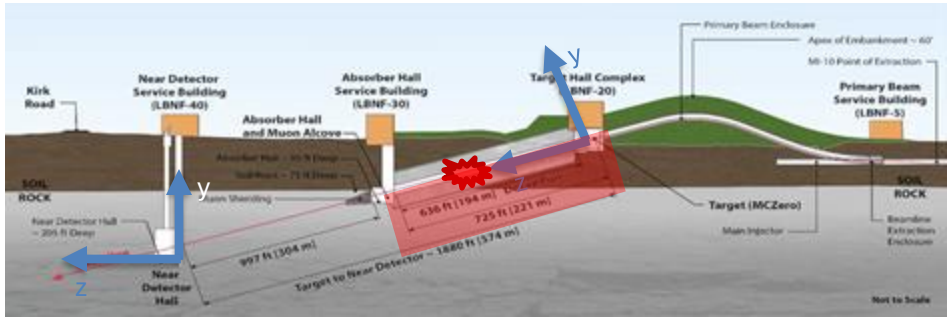
2. Check if the **direction** of the **vector distance** from the neutrino origin – neutrino interaction is the same as the **momentum** vector

Validation check #1



arctan(-0.1022) = -0.101 rad

```
233     <param_set name="DUNEND">
234       <!-- setting user units should be first -->
235       <units> m </units>
236
237       <!-- beamdir must come before beam zero position -->
238       <!-- rotation matrix created by sequence of rotations -->
239
240       <beamdir type="series">
241         <rotation axis="x" units="rad"> -0.101 </rotation>
242       </beamdir>
```



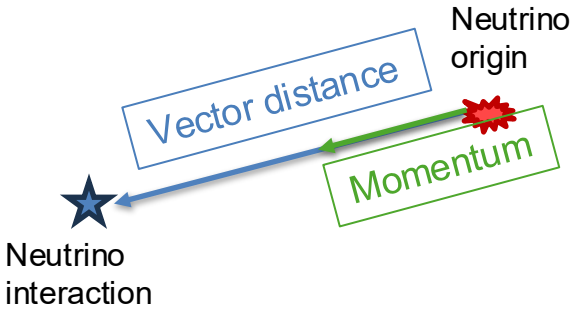
Neutrino origins in user coordinate system are reasonably **inside** the decay pipe

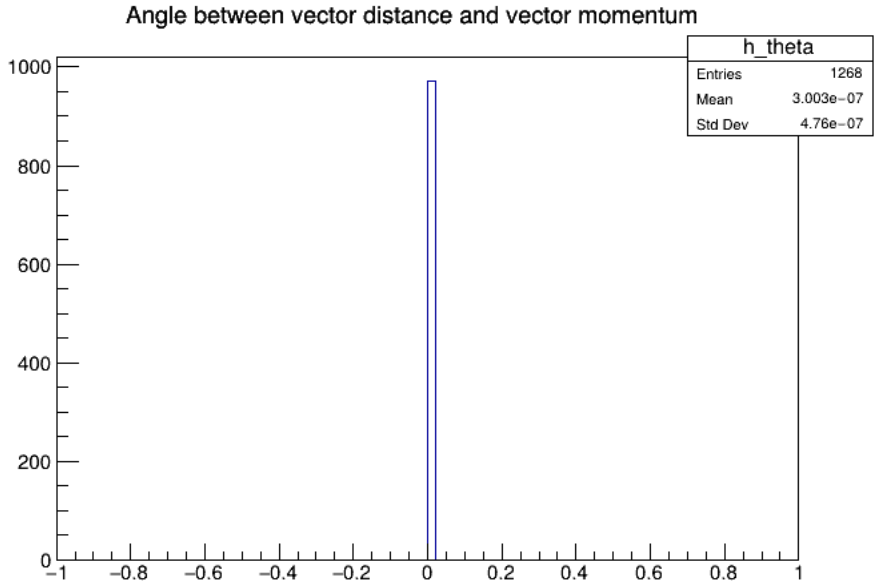
Validation check #2

Check if the **direction** of the **vector distance** from the neutrino origin – neutrino interaction is the same as the **momentum** vector

Plotting the angle between the **direction** and the **momentum**, I get that this angle is always 0 as it should be.

These two checks confirm that the conversion is good





Modification proposals to run-spill-build

1.

GHEP files, for neutrino origin info

GNuMIFlux.xml for coordinate system conversion

N.B. in **run-hadd**, edepsim files are grouped by a factor of 10 (usually), so in the further steps we have no 1-1 correspondence between GHEP files and edepsim ones

Modification proposals to run-spill-build

2. Implementation of a function that computes the **neutrino interaction time** by taking into account all the time contributions.

   `getInteractionTime` should return the sum of:

   - Proton production time according to the beam spill structure
   - Neutrino time origin, from ancestor variable in dk2nu
   - Neutrino TOF

     → Implement another function **`getNuTOF`**:

INPUT
- Neutrino origin in **beam** coordinates
- Neutrino interaction point in **user** coordinates

→ getNuTOF
- Converts the neutrino origin in user coordinates
- Computes the distance and the **TOF**

→ OUTPUT
Returns the neutrino TOF