Honda Flux in GENIE

Wanwei Wu, Robert Hatcher, Tingjun Yang

LArSoft Coordinate Meeting

Tuesday, 11 Sept 2018

Content

I. Overview

- Atmospheric neutrino plays an important role in the science of DUNE Far Detector.
- The previous simulation usually considers a 2D flux (θ-dependent, but not ϕ-dependent).
- Current simulation also has interests in the 3D flux, i.e., Honda Atmospheric flux.
- We need to understand the atmospheric neutrino flux and how to implant it properly in the DUNE FD system.

II. Honda atmospheric neutrino flux file

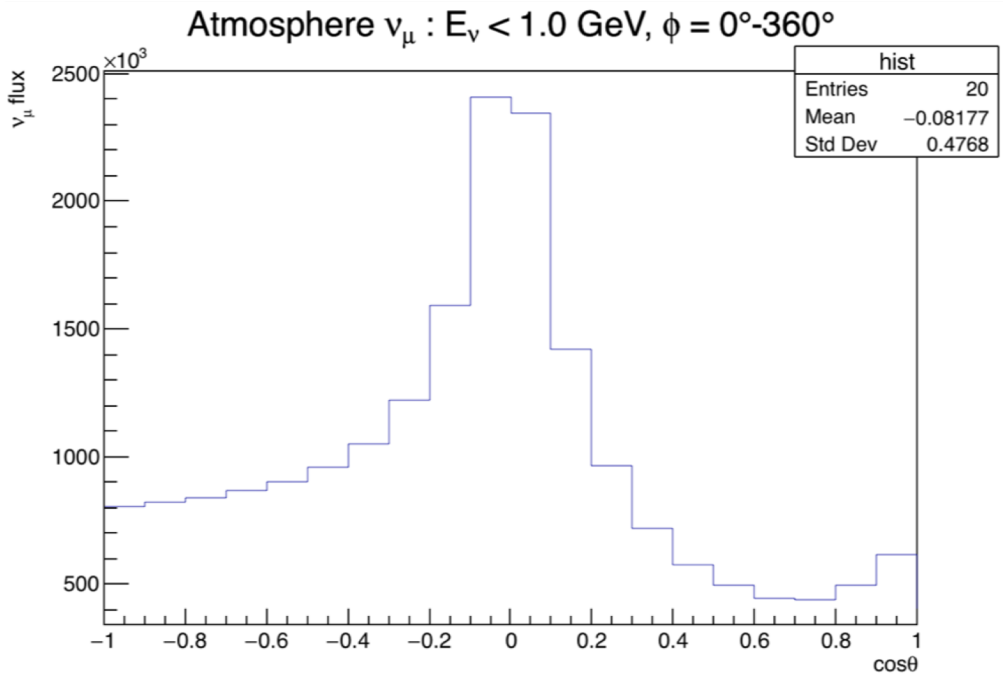
- **Honda flux file location:**
  /pnfs/dune/persistent/TaskForce_ Flux/atmos/Honda
- **Example:**

```
average flux in [cosZ = 0.90 --  1.00, phi_Az =   0 --  30]
 Enu(GeV)   NuMu       NuMubar    NuE        NuEbar  (m^2 sec sr GeV)^-1
 1.0000E-01 9.8672E+03 1.0020E+04 4.8979E+03 4.5842E+03
 1.1220E-01 8.8940E+03 8.9868E+03 4.4193E+03 4.0866E+03
 1.2589E-01 7.9442E+03 8.0068E+03 3.9200E+03 3.5941E+03
 1.4125E-01 7.0265E+03 7.0725E+03 3.4317E+03 3.1152E+03
 1.5849E-01 6.1272E+03 6.1404E+03 2.9803E+03 2.6778E+03
 1.7783E-01 5.2653E+03 5.2489E+03 2.5622E+03 2.2779E+03
 1.9953E-01 4.4671E+03 4.4417E+03 2.1739E+03 1.9119E+03
 2.2387E-01 3.7246E+03 3.7054E+03 1.8265E+03 1.5828E+03
```

- **File format:**
  a. Fluxes for four types of neutrinos
  b. The flux is defined by (E_ν, **cosZ, phi_Az**)
  c. cosZ goes from -1 to 1 with a step of 0.1; phi_Az goes from 0° to 360°, with a step of 30° (20×12 *blocks in total*)

II. Honda atmospheric neutrino flux file

Atmospheric muon neutrino flux zenith angle distribution for E_υ < 1 GeV and ϕ = 0°-360° (cosZ = $cos\theta$, phi_Az=ϕ)

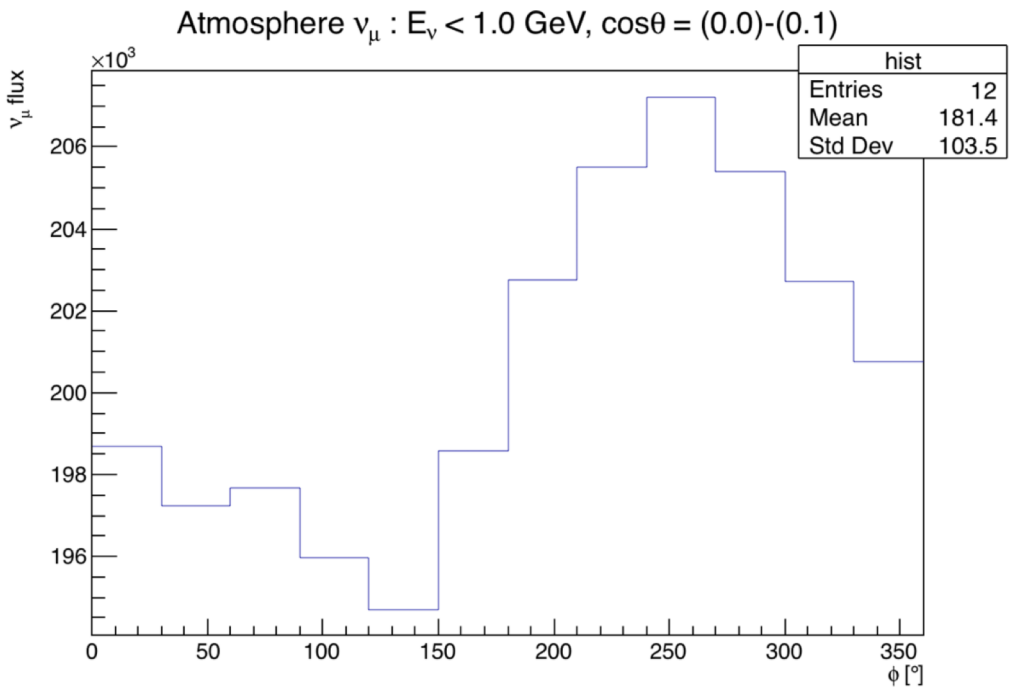


- $cos\theta = 1$ means neutrino moves "Downward". Neutrino's direction is opposite to the flux direction.
- The maximum of atmospheric flux appears in the horizontal direction (around $cos\theta = 0$).

Ref.: arXiv: 0203272[hep-ph]

II. Honda atmospheric neutrino flux file

Atmospheric muon neutrino flux azimuth angle distribution for E_υ < 1 GeV and $cos\theta = 0.0 - 0.1$ (cosZ = $cos\theta$, phi_Az=ϕ)

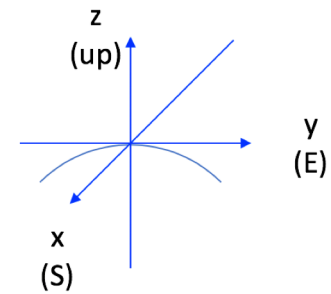


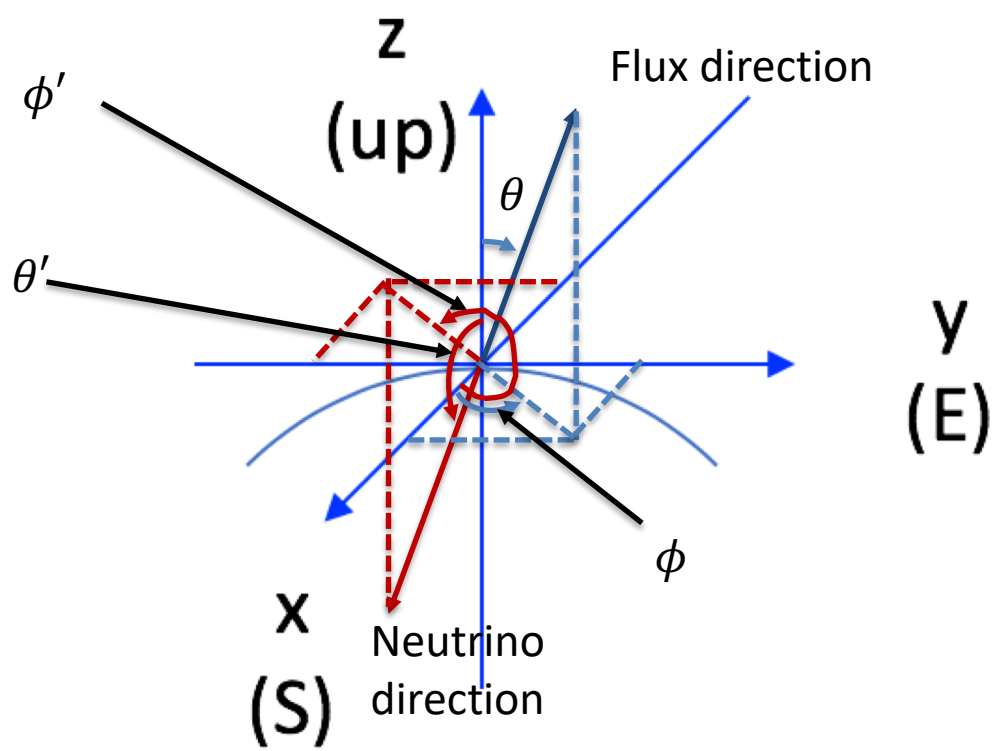
- ϕ is measured from the South, counter-clockwise, i.e., ϕ = 0° means South, ϕ = 90° means East.

Ref.: arXiv: 0203272[hep-ph]

II. Honda atmospheric neutrino flux file

What is the coordinate system here?





- Neutrino's direction is opposite to the flux direction.
- The flux is given by $(E_\upsilon, \theta, \phi)$, therefore, the neutrino moving direction is given by $(E_\upsilon, \theta', \phi')$, with $\boldsymbol{\theta' = 180° - \theta}$ and $\boldsymbol{\phi' = \phi + 180°}$.

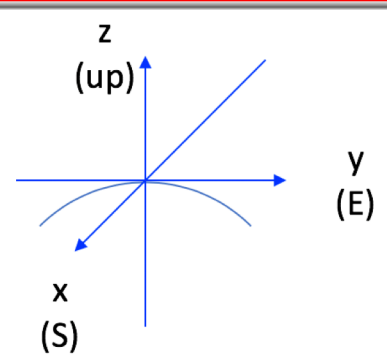
III. GENIE atmospheric flux driver

From the brief in GENIE atmospheric flux driver:

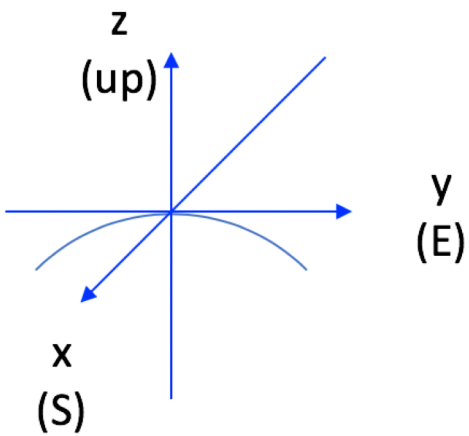
https://genie.hepforge.org/trac/browser/generator/trunk/src/Tools/Flux/GAtmoFlux.h

GENIE_R21210/src/FluxDrivers/GAtmoFlux.h

```
The position of each flux neutrino [going towards a detector centered
at (0,0,0)] is generated uniformly on a plane that is perpendicular
to a sphere of radius Rl at the point that is determined by the
generated neutrino direction (theta,phi). The size of the area of
that plane, where flux neutrinos are generated, is determined by the
transverse radius Rt. You can tweak Rl, Rt to match the size of your
detector.
Initially, neutrino coordinates are generated in a default detector
coordinate system (Topocentric Horizontal Coordinate -THZ-):
   +z: Points towards the local zenith.
   +x: On same plane as local meridian, pointing south.
   +y: As needed to make a right-handed coordinate system.
   origin: detector centre
```



III. GENIE atmospheric flux driver



For the flux given by $(E_\upsilon, \theta, \phi)$, the neutrino direction is given by $(E_\upsilon, \theta', \phi')$.
Here, $\boldsymbol{\theta' = 180° - \theta}$ and $\boldsymbol{\phi' = \phi + 180°}$.

- In this case, the momentum is normally given by:

$$P_z = E_\upsilon * cos\theta' = -E_\upsilon * cos\theta$$
$$P_y = E_\upsilon * sin\theta' * sin\phi' = -E_\upsilon * sin\theta * sin\phi$$
$$P_x = E_\upsilon * sin\theta' * cos\phi' = -E_\upsilon * sin\theta * cos\phi$$

Here, phi is measured from x (to y).

III. GENIE atmospheric flux driver

From source code of GENIE atmospheric flux driver:

https://genie.hepforge.org/trac/browser/generator/trunk/src/Tools/Flux/GAtmoFlux.cxx

GENIE_R21210/src/FluxDrivers/GAtmoFlux.cxx

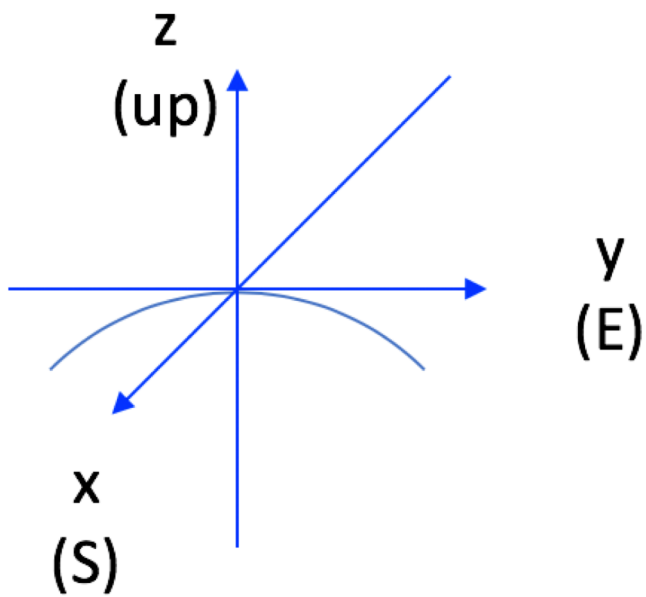
```
// Compute the neutrino momentum
// The `-1' means it is directed towards the detector.
double pz = -1.* Ev * costheta;
double py = -1.* Ev * sintheta * cosphi;
double px = -1.* Ev * sintheta * sinphi;

// Default vertex is at the origin
double z = 0.0;
double y = 0.0;
double x = 0.0;
```

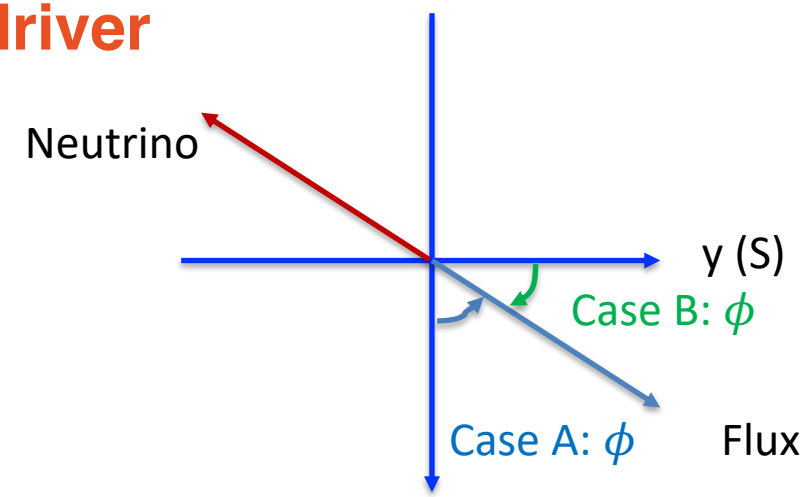
- The above definition does not agree with GENIE coordinate in previous slides.

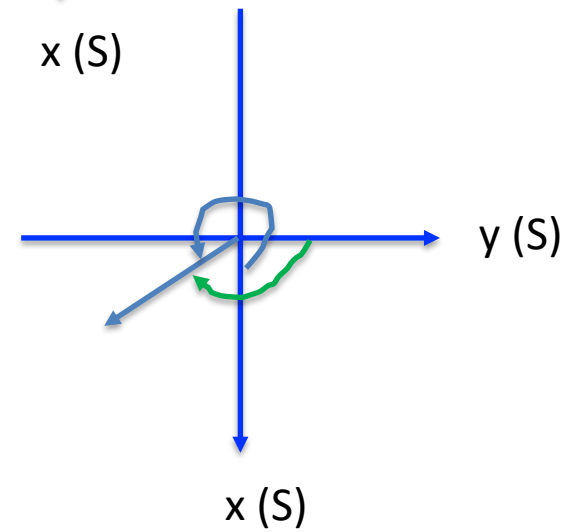
$$P_z = E_v * cos\theta' = -E_v * cos\theta$$
$$P_y = E_v * sin\theta' * sin\phi' = -E_v * sin\theta * sin\phi$$
$$P_x = E_v * sin\theta' * cos\phi' = -E_v * sin\theta * cos\phi$$

Here, phi is measured from y (to x).

III. GENIE atmospheric flux driver







- Case A (customarily and in Honda file):

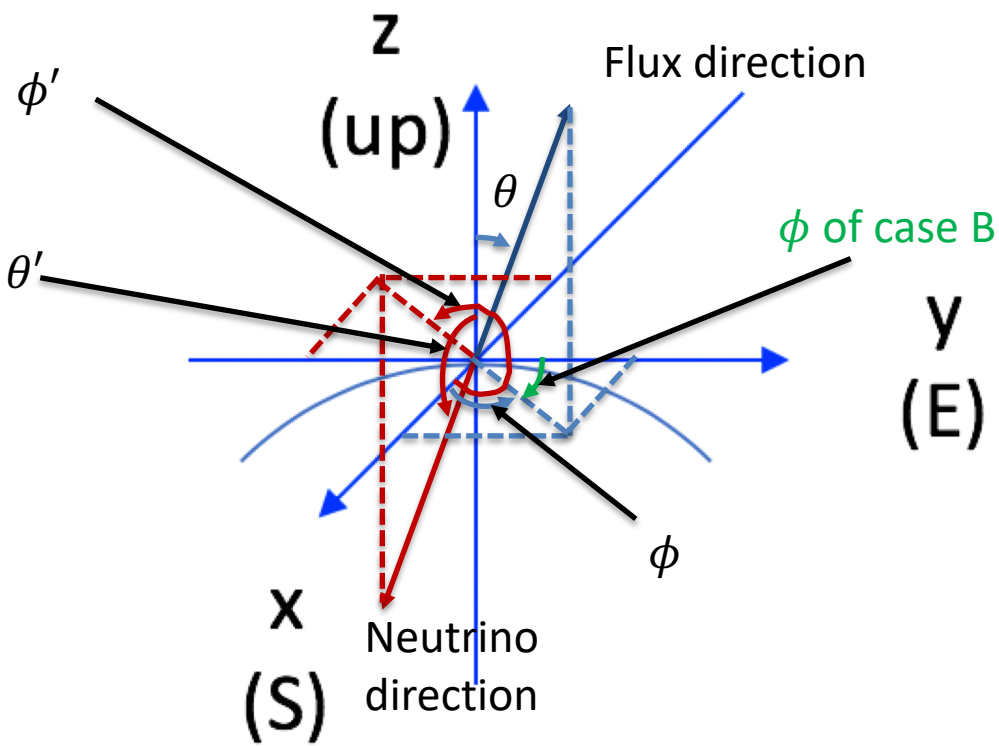
$$P_z = E_v * cos\theta' = -E_v * cos\theta$$
$$P_y = E_v * sin\theta' * sin\phi' = -E_v * sin\theta * sin\phi$$
$$P_x = E_v * sin\theta' * cos\phi' = -E_v * sin\theta * cos\phi$$

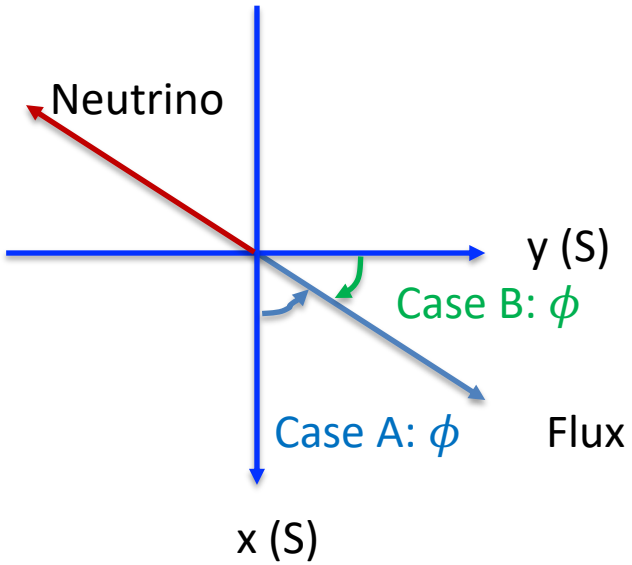
- Case B (GENIE source code):

$$P_z = E_v * cos\theta' = -E_v * cos\theta$$
$$P_y = E_v * sin\theta' * sin\phi' = -E_v * sin\theta * cos\phi$$
$$P_x = E_v * sin\theta' * cos\phi' = -E_v * sin\theta * sin\phi$$

Here,
ϕ (case A) + ϕ (case B)
= 90° or 90°+360°

III. GENIE atmospheric flux driver

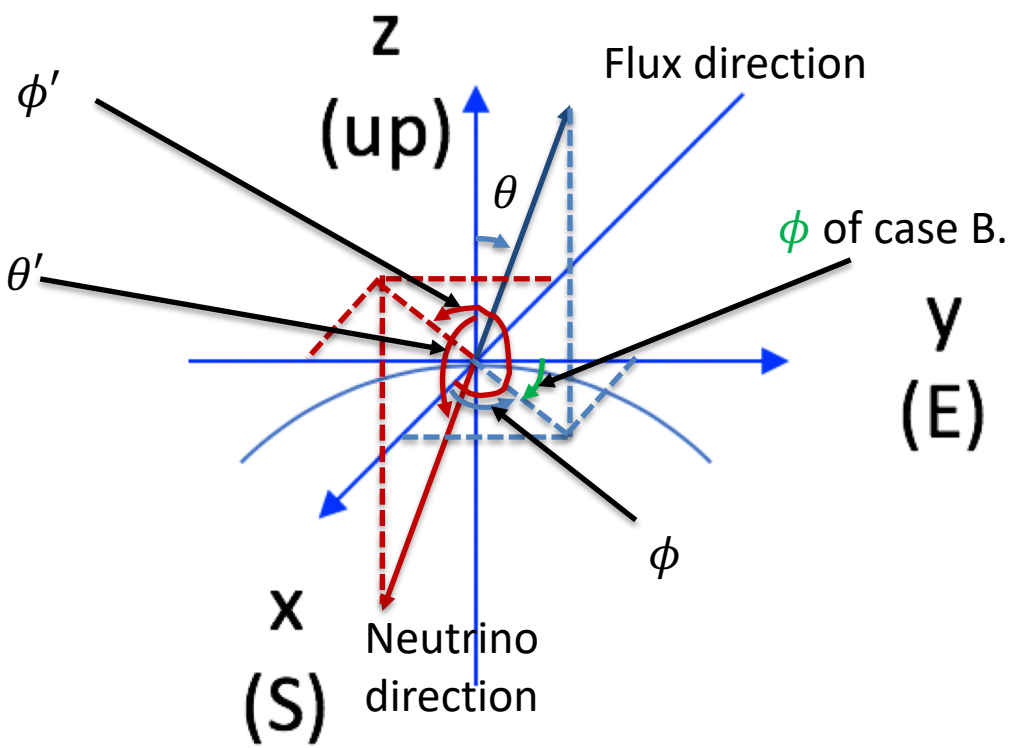


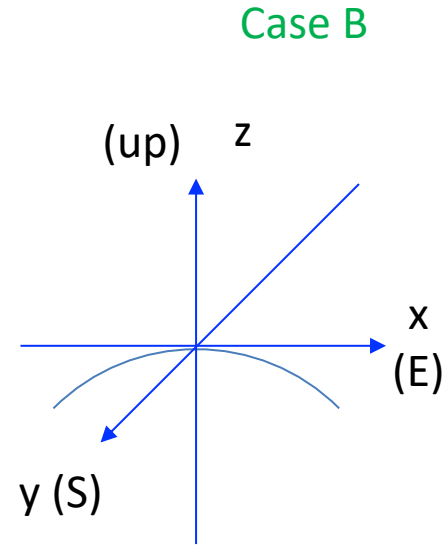


Note:

- Honda flux in it's own system (Case A): (θ, ϕ)
- Honda flux in Case B: $(\theta, 90°- \phi)$
- Neutrino direction in case A: $(\theta' = 180° - \theta, \phi' = \phi + 180°)$
- Neutrino direction in Case B: (GENIE source code):
  $(\theta'' = 180° - \theta, \phi'' = -90° - \phi)$

III. GENIE atmospheric flux driver





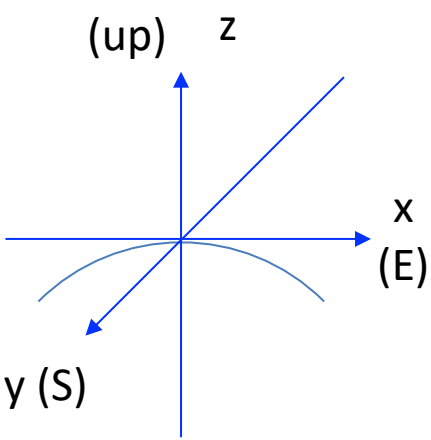
A left-handed system

Case B (GENIE source code):

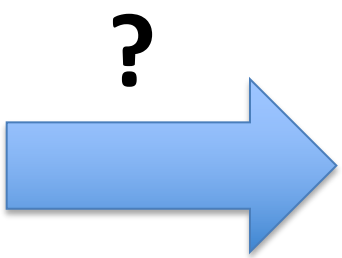
- In fact, this is a left-handed coordinate system, with its azimuth angle defined from x (East) to y (South), clockwise.
- This left-handed feature comes from the definition of phi in the source code.

IV. Rotation and transformation for DUNE FD coordinate system

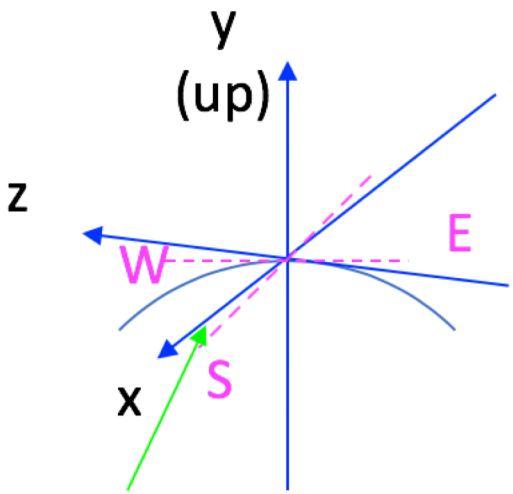
Note:
- Honda flux in it's own system: (θ, ϕ)
- Honda flux in GENIE initialization: $(\theta, 90°- \phi)$
- Neutrino direction in GENIE initialization:
  $(\theta'' = 180° - \theta, \phi'' = -90° - \phi)$



GENIE initialization:
A left-handed system



Rotation itself cannot change a left-handed system to a right-handed system.



~ 7.176° (from +x to S)

DUNE FD coordinate system
(Right-handed)

IV. Rotation and transformation for DUNE FD coordinate system

- R. Hatcher added the rotation parts in the recent release (v06_84_00). The key configuration is given by:

```
physics.producers.generator.FluxRotCfg: "verbose series
rotXdeg rotZdeg rotZdeg"
physics.producers.generator.FluxRotValues: [90,-90,0]
```

- Rotations are done by the a rotation series.
- Here, rotXdeg, rotYdeg, rotZdeg are rotations in the left-handed system.
- One has the freedom to define his/her own rotation series: i.e, [rotYdeg, rotXdeg, rotZdeg, rotXdeg].

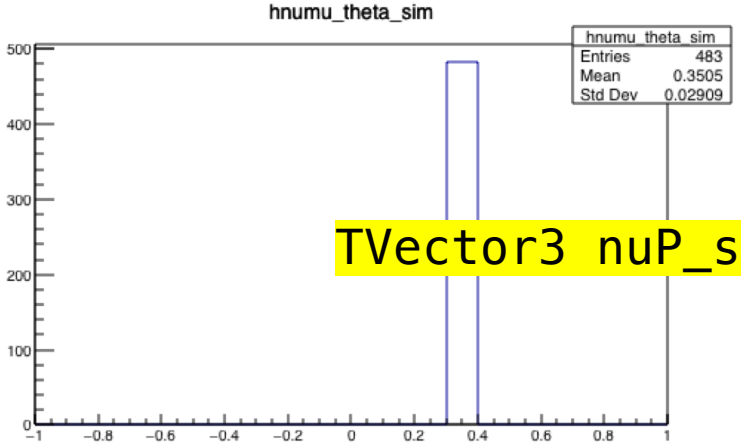
- To test the conversion, we used neutrino flux with $\cos\theta = (-0.4) - (-0.3)$ and $\phi = 0 - 30^\circ$ from Honda flux file and set all the other neutrino flux to be 0.
- We use TVector3 to get a vector's cosTheta and Phi (-180°, 180°). For a vector (x1,x2,x3), phi is measured from x1 to x2 in the system (x1,x2,x3), cosTheta is measured to x3.
- For each rotation, we always look at what GENIE tells us, i.e., TVector3 nuP_sim(nuPx,nuPy,nuPz); it is left-handed.
- We also define a new vector (or right-hand system), i.e., TVector3 nuP_atm(-nuPx,nuPy,nuPz).

IV. Rotation and transformation for DUNE FD coordinate system

Honda flux only for cosθ = (–0.4) – (–0.3) and ϕ = 0 – 30°

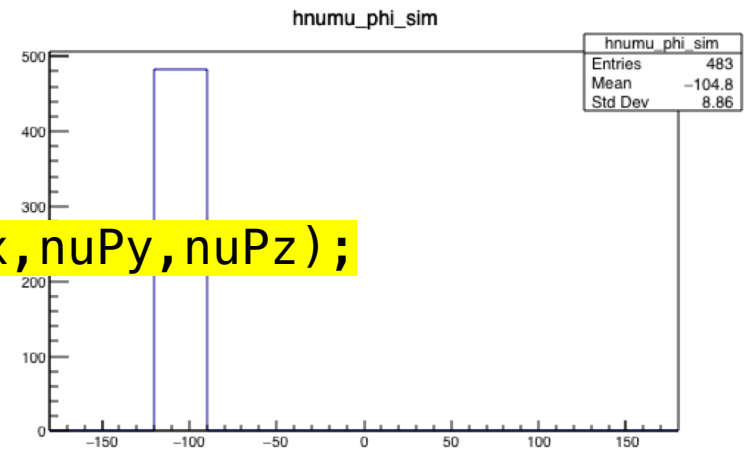
Test A:

```
[rotXdeg, rotZdeg, rotZdeg] = [0,0,0]
```

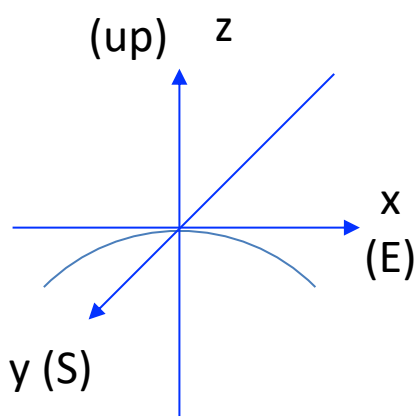


$cosTheta$

```
TVector3 nuP_sim(nuPx,nuPy,nuPz);
```



phi



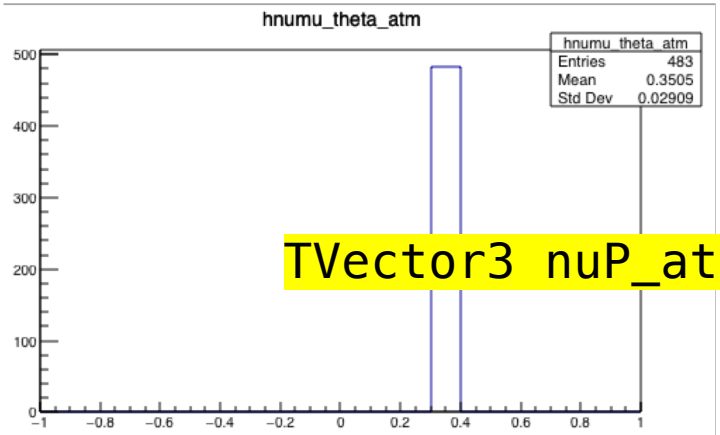
- Honda flux in it's own system: (θ, ϕ)
- Neutrino direction in GENIE initialization: $(\theta'' = 180° - \theta, \phi'' = -90° - \phi)$

IV. Rotation and transformation for DUNE FD coordinate system

Honda flux only for cosθ = (–0.4) – (–0.3) and ϕ = 0 – 30°

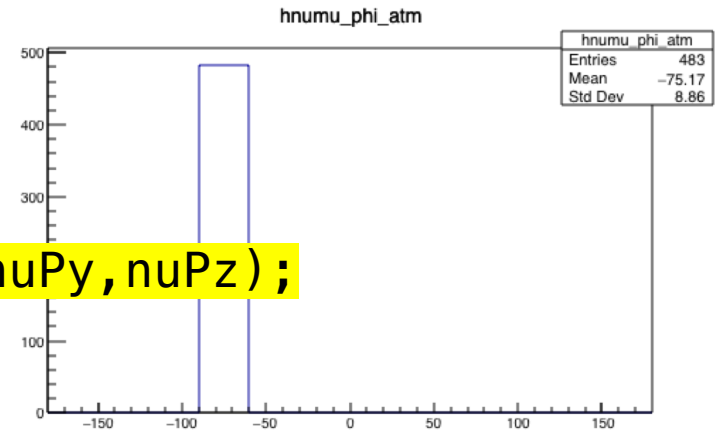
Test A:

```
[rotXdeg, rotZdeg, rotZdeg] = [0,0,0]
```

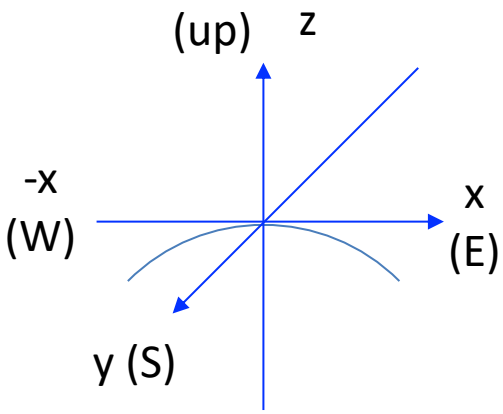


$cosTheta$

```
TVector3 nuP_atm(-nuPx,nuPy,nuPz);
```



phi



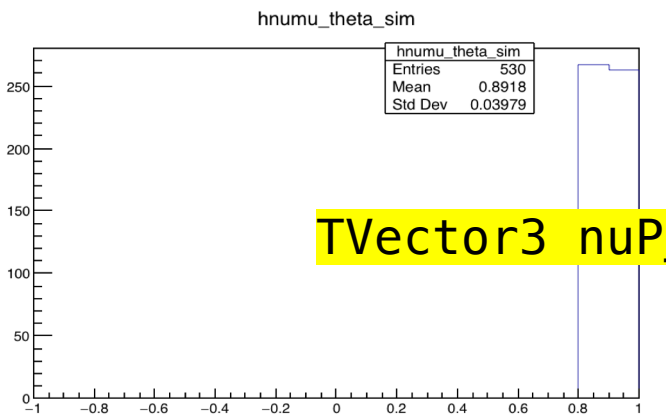
- Honda flux in it's own system: (θ, ϕ)
- Neutrino direction in GENIE initialization: $(\theta'' = 180° - \theta, \phi'' = -90° - \phi)$

IV. Rotation and transformation for DUNE FD coordinate system

Honda flux only for cosθ = (–0.4) – (–0.3) and ϕ = 0 – 30°

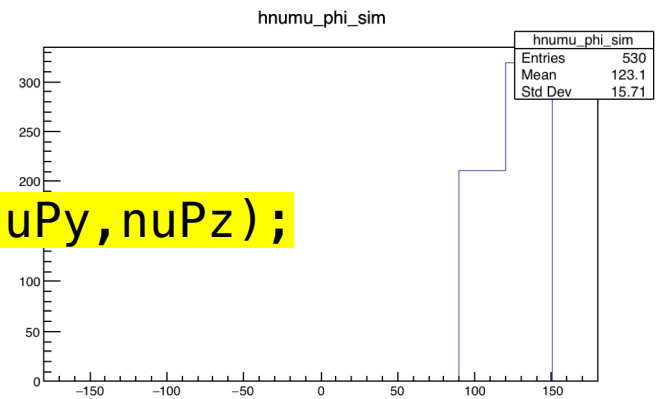
Test B:

```
[rotXdeg, rotZdeg, rotZdeg] = [90,0,0]
```

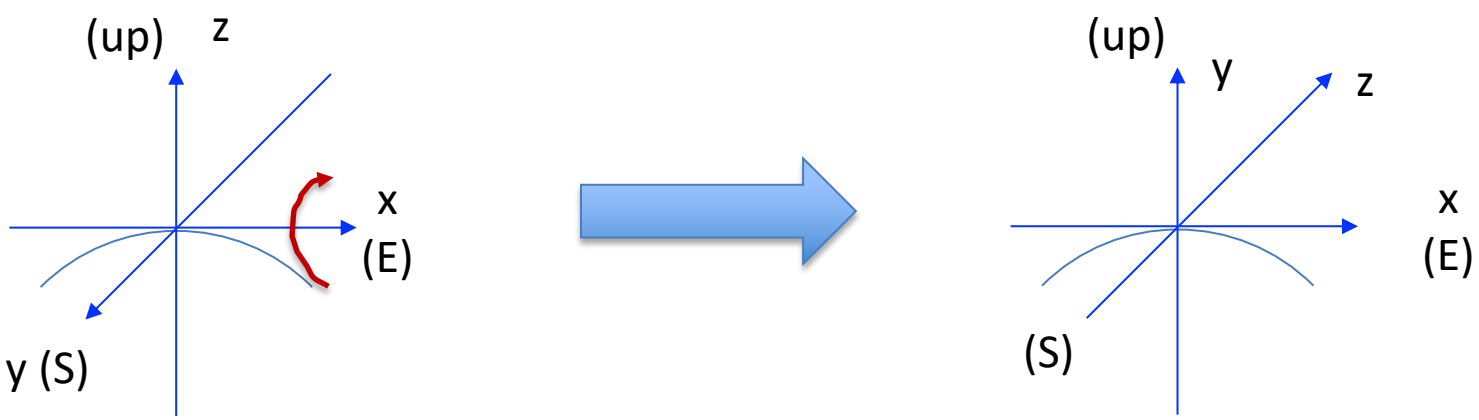


cosTheta

```
TVector3 nuP_sim(nuPx,nuPy,nuPz);
```



phi

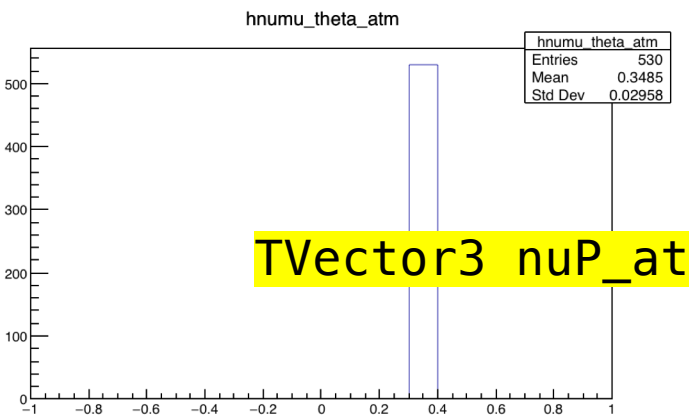


IV. Rotation and transformation for DUNE FD coordinate system

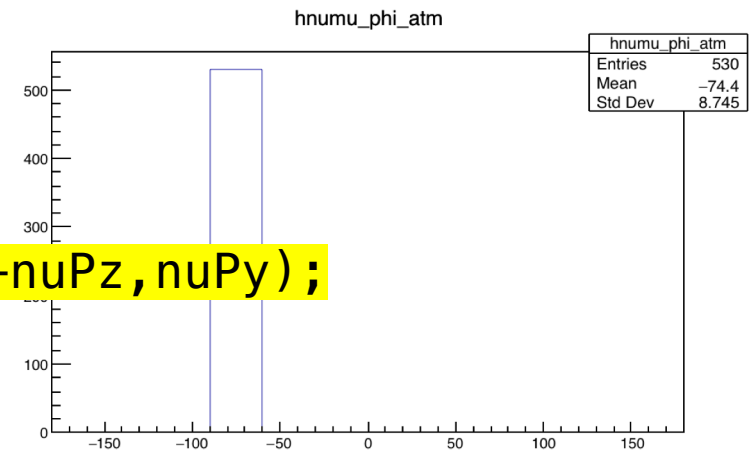
Honda flux only for cosθ = (–0.4) – (–0.3) and ϕ = 0 – 30°

Test B:

```
[rotXdeg, rotZdeg, rotZdeg] = [90,0,0]
```

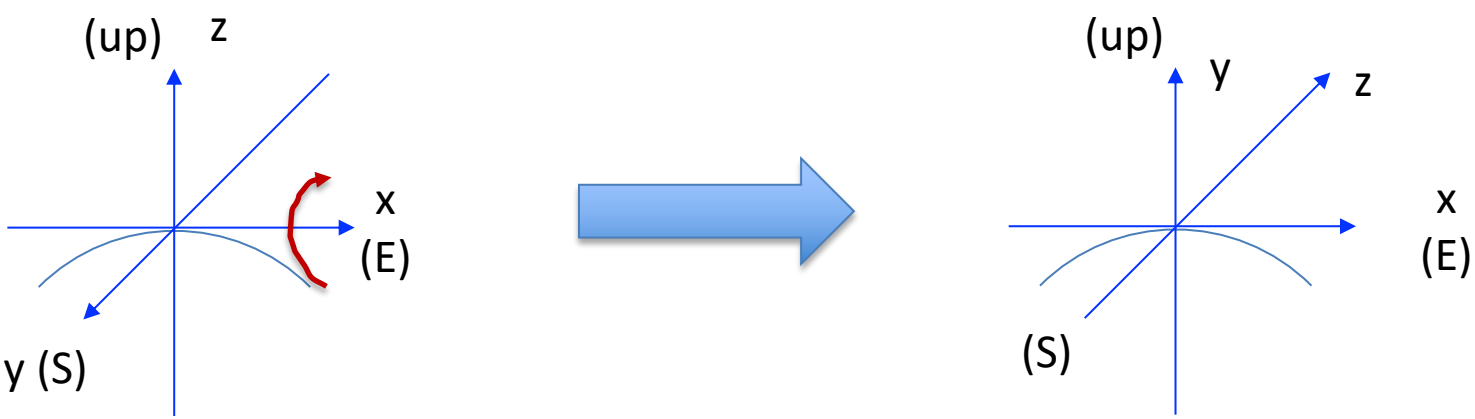


$cosTheta$



phi

```
TVector3 nuP_atm(-nuPx,-nuPz,nuPy);
```

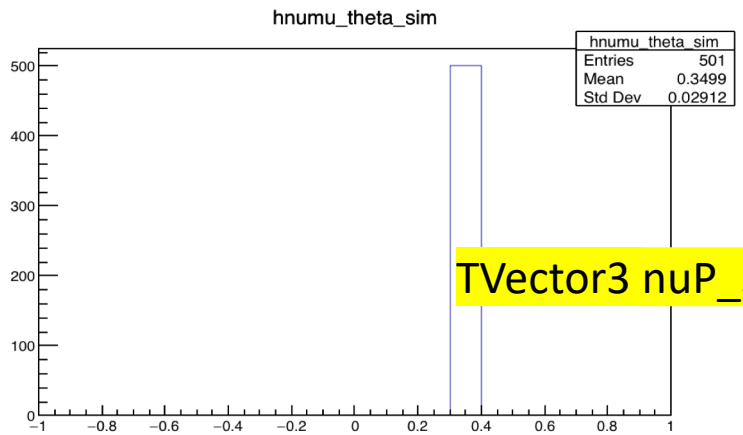


IV. Rotation and transformation for DUNE FD coordinate system

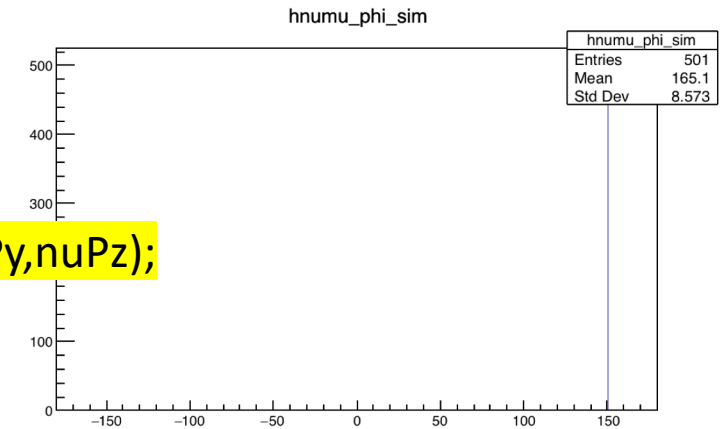
Honda flux only for cosθ = (–0.4) – (–0.3) and ϕ = 0 – 30°

Test C:

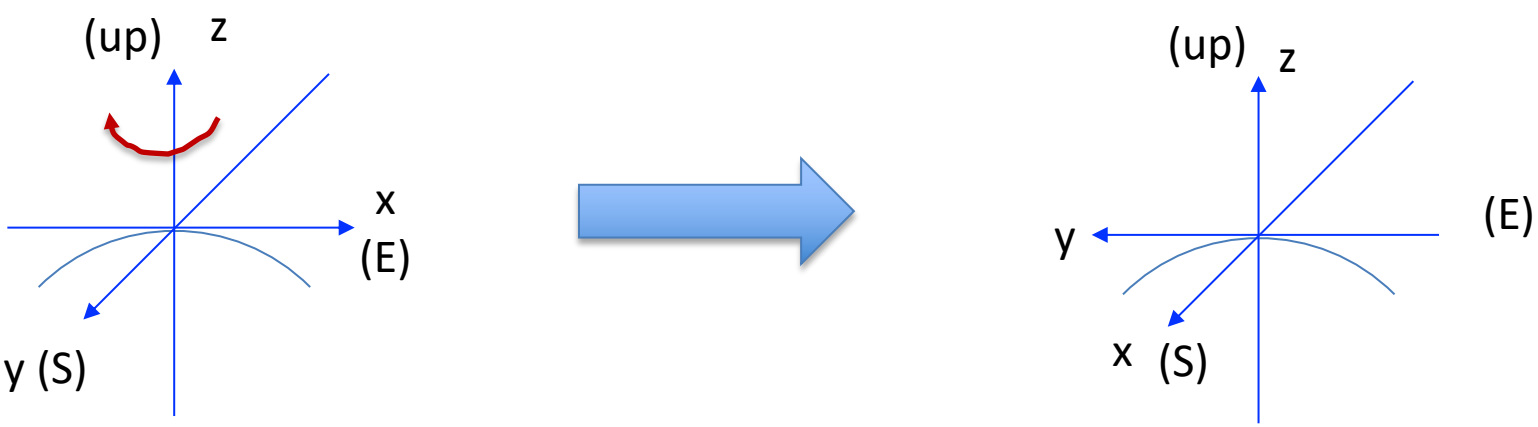
```
[rotXdeg, rotZdeg, rotZdeg] = [0,90,0]
```



TVector3 nuP_sim(nuPx,nuPy,nuPz);



$cosTheta$ phi

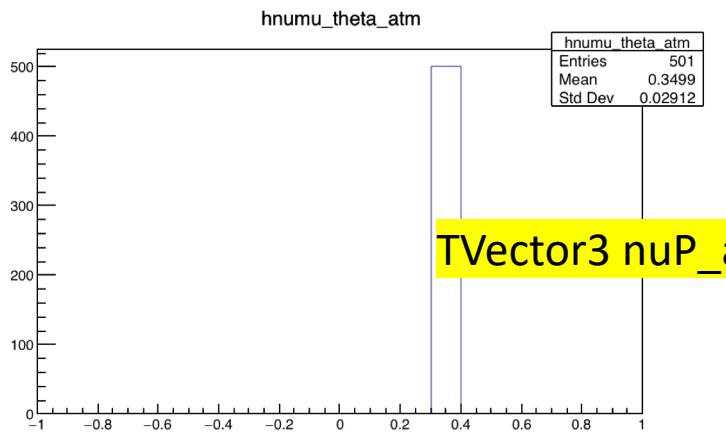


IV. Rotation and transformation for DUNE FD coordinate system

Honda flux only for cosθ = (–0.4) – (–0.3) and ϕ = 0 – 30°

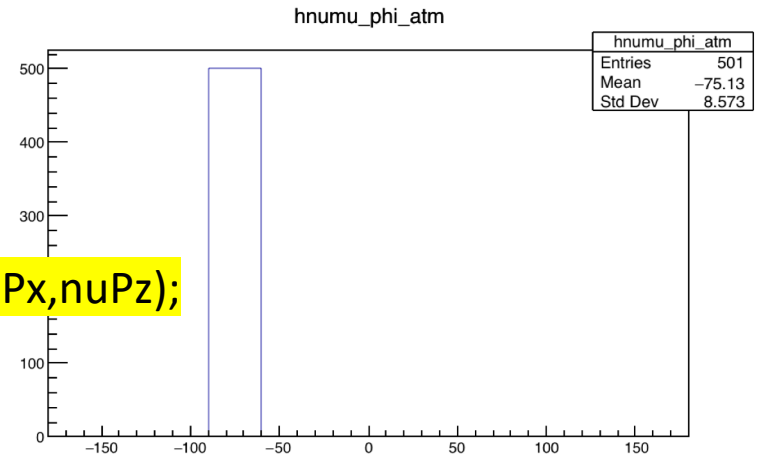
Test C:

```
[rotXdeg, rotZdeg, rotZdeg] = [0,90,0]
```

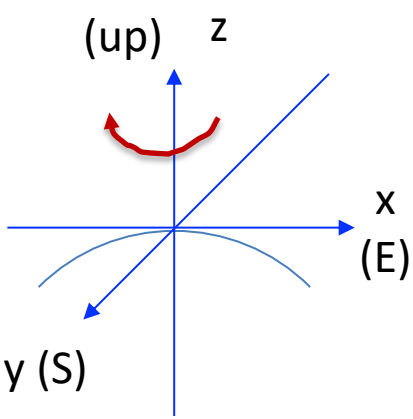


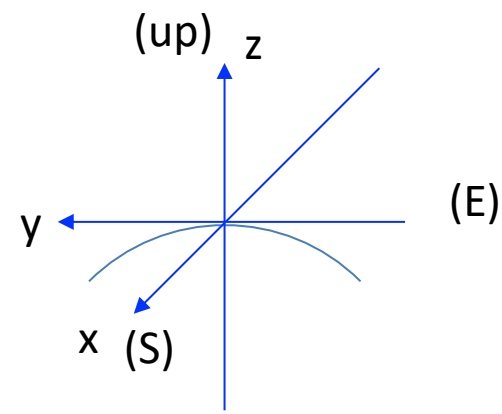
$cosTheta$

TVector3 nuP_atm(nuPy,nuPx,nuPz);



phi

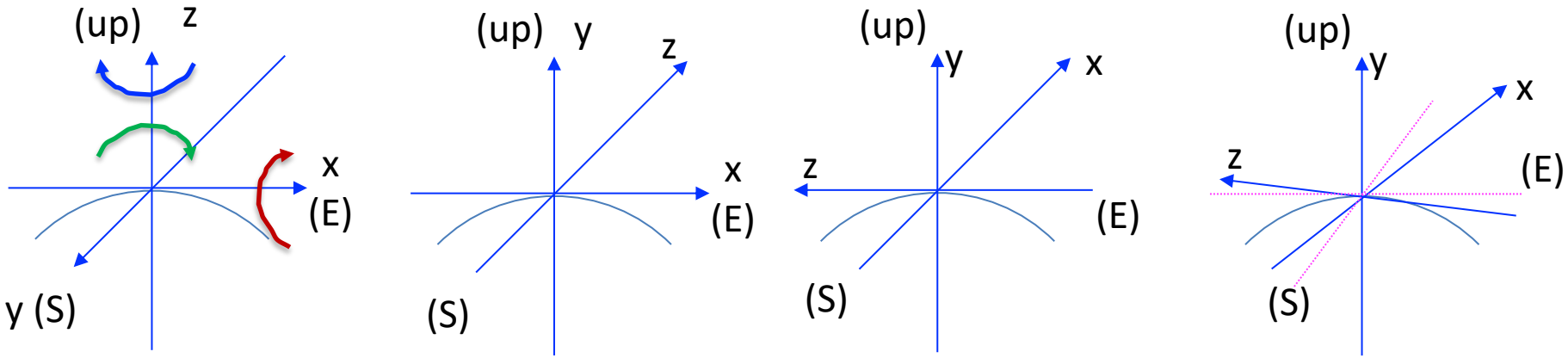




IV. Rotation and transformation for DUNE FD coordinate system

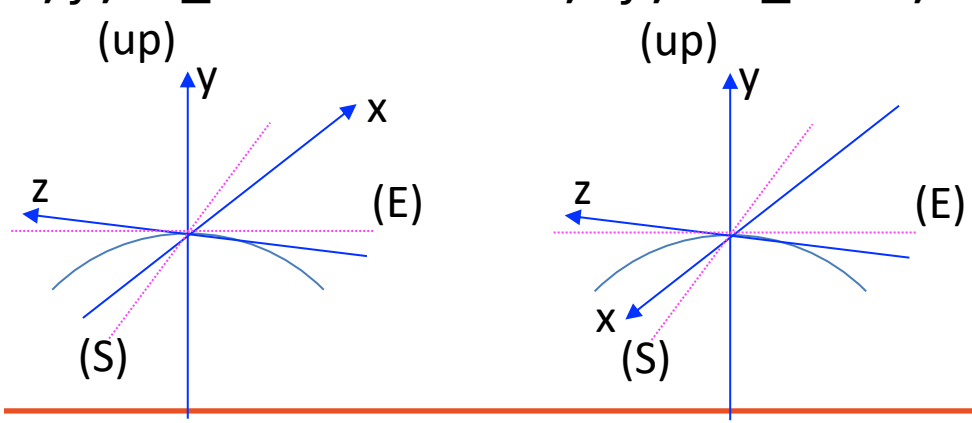
1. Rotation First

```
physics.producers.generator.FluxRotCfg: "verbose series
rotXdeg rotZdeg rotZdeg"
physics.producers.generator.FluxRotValues: [90,-90,7.175588]
```



2. LH to RH. (x->-x)

```
(x,y,z)_{LH}. -> {-x, y, z}_{RH}, same for (px,py,pz)
```



One has to set x=-x (px =-px) to convert the coordinate system after rotation in GENIE to obtain the DUNE FD coordinate system.

V. Conclusion

- The definition of phi in GENIE source code is measured from y:

```
// Compute the neutrino momentum
// The `-1' means it is directed towards the detector.
double pz = -1.* Ev * costheta;
double py = -1.* Ev * sintheta * cosphi;
double px = -1.* Ev * sintheta * sinphi;

// Default vertex is at the origin
double z = 0.0;
double y = 0.0;
double x = 0.0;
```

- If we follow the above definition, we have to do some rotations on a left-handed system and flip x to obtain the DUNE FD coordinate system.
- However, a left-handed system makes a lot of people uncomfortable. We'd better change the GENIE code, then just apply the rotations.

V. Conclusion

Solution:

```
191    double py = -1.* Ev * sintheta * cosphi;
192    double px = -1.* Ev * sintheta * sinphi;
```

```
191    double py = -1.* Ev * sintheta * sinphi;
192    double px = -1.* Ev * sintheta * cosphi;
```

```
204    y += fRl * sintheta * cosphi;
205    x += fRl * sintheta * sinphi;
```

```
204    y += fRl * sintheta * sinphi;
205    x += fRl * sintheta * cosphi;
```

Yes, I think this can be fixed in v3.0.0. Other experiments are probably using this - The Honda flux was contributed from INO and IceCUBE folks so they should be using it in some way or another. Not sure if this made it to any of their publications. We can fix this / document the change, and then we will also notify all known users of that flux.

--Costas (GENIE Collaboration)