Summary of Beam Monitoring Studies with 3DST system.

DUNE ND 3DST Group

Jairo Rodriguez

South Dakota School of Mines and Technology

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Outline

- Motivation
- Neutrino Event Generator and Geometry Simulation
- Results
  - Beam parameters using 3DST modules
  - Neutrino Energy Spectra with beam variations (direction and position)
- Today: We will show preliminary simulation studies focusing to estimate the beam center uncertainty using 3DST modules.
- Finally, we will compare the simulation of the neutrino energy spectra with changes on beam direction and beam position.

- **MOTIVATION OF BEAM MONITORING**

- Given 3DST will be the only detector always on axis at DUNE near detector hall, we could do measurements such as: neutrino spectrum stability, beam center and beam direction on a daily basis.
- DUNE beam monitor goals: <1% flux uncertainty, ~0.2 mrad precession on beam (i.e. ~10.7 cm at 3DST location). DUNE CDR Vol. 4 (page 7-114).

- **NEUTRINO EVENT GENERATOR**

- This preliminary results were done using **GENIE** for generate the neutrino interactions and for this time we only consider muon neutrino charged current events
- The beam used was the DUNE optimized beam (1.2e21 POT/yr). (CDR 2017)

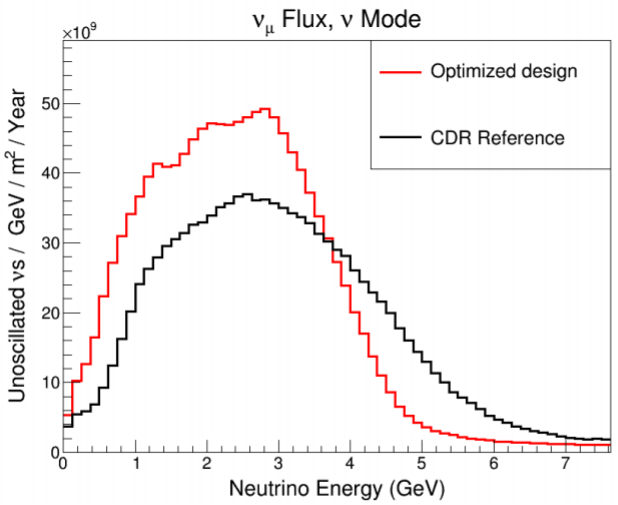
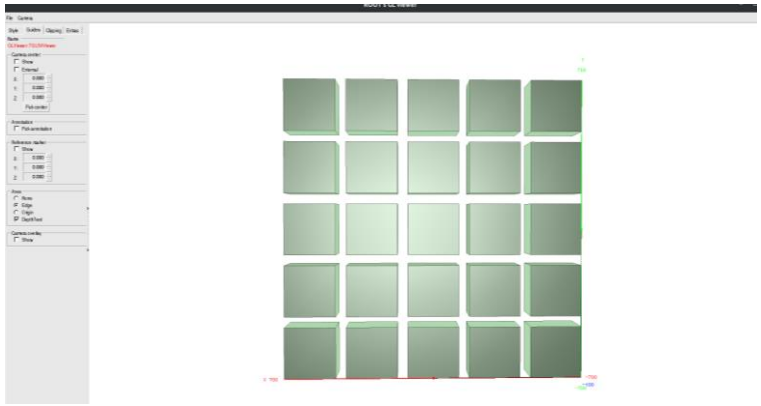


Figure 1-1: Comparison of the neutrino spectrum at the Far Detector for the reference design beam and the optimized design beam.

https://docs.dunescience.org/cgi-bin/private/RetrieveFile?docid=4559&filename=CDR_Optimized_Beam_Oct02.pdf&version=12

• GEOMETRY SIMULATION

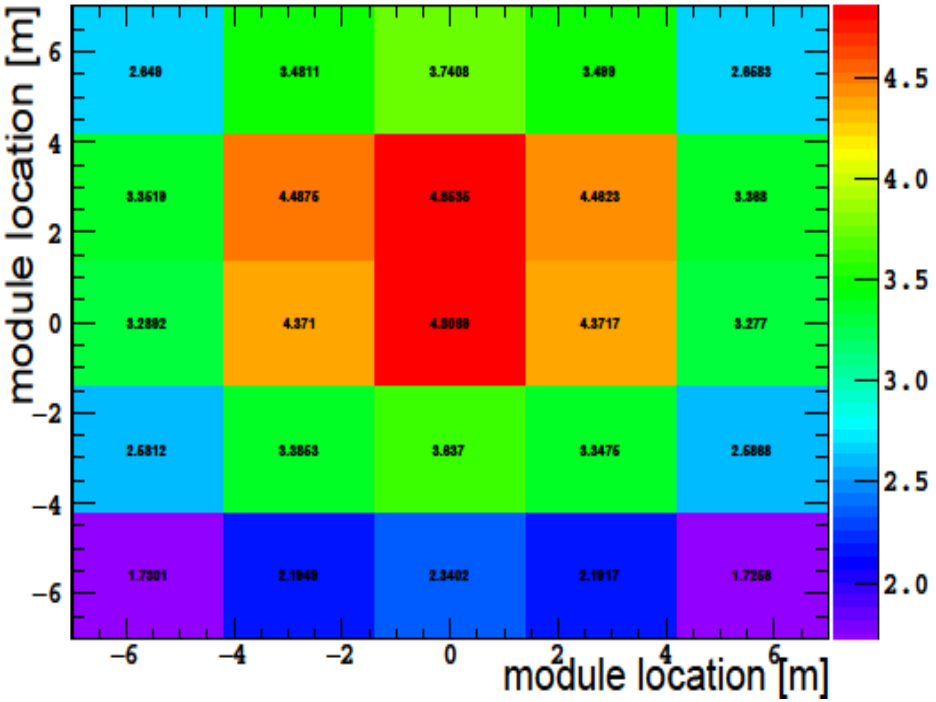
- As a first exercise, we generated a **TEST** geometry of 25 3DST modules.
- 3DST modules were put in a grid with separation between modules of 50 cm. The dimensions of each 3DST module is 2.4m x 2.4m x 2m. All geometries were generated using DUNENDGGD.



- The purpose of this geometry is found a region in where we could expect high statistics of interactions, and then reduce it to a reasonable number of 3DST modules without sacrificing our physics goals.

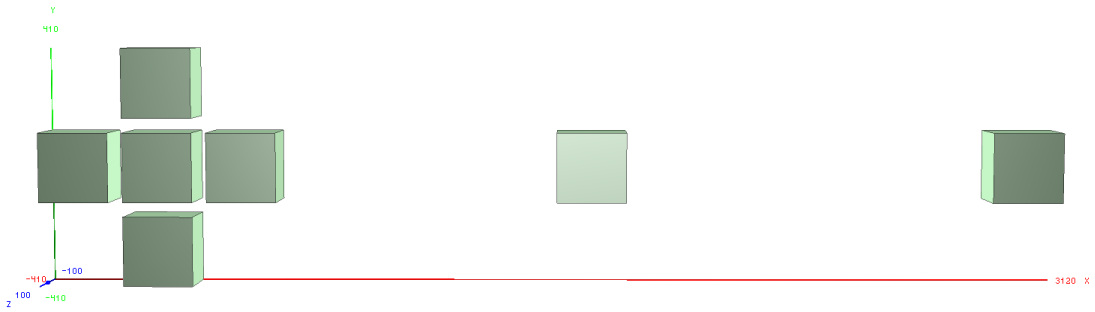
- **GEOMETRY SIMULATION: FIRST TEST**

- The test geometry was exposed to 4.02e18 POT.
- We generated neutrino interactions in test geometry, and we found a region (from -4m to 4m for X and Y direction) around the neutrino beam center where we have a higher statistics.
- Each bin in the figure represents the percentage of detected events in each module. $\left(\frac{\text{events in each module}}{\text{total generated events (4.02e18 POT)}} x100\right)$



- **GEOMETRY SIMULATION: SECOND TEST**

- We updated the configuration to 5 central modules plus two off-axis modules.
- The two off-axis modules will let us analyze the beam shape at different distance from the beam center.

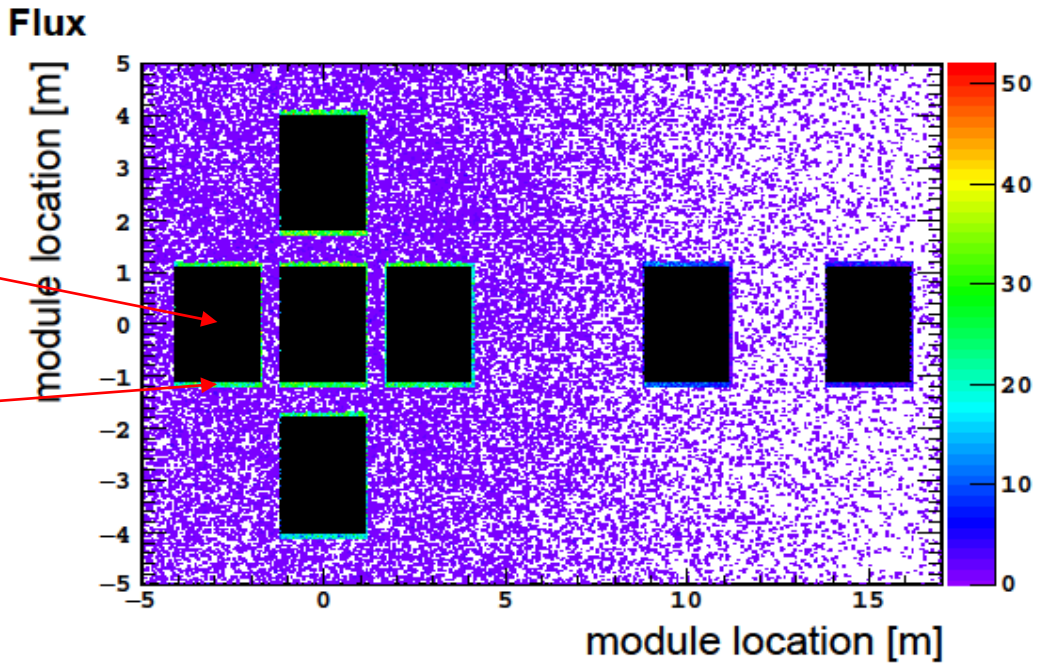


- **GEOMETRY SIMULATION: SECOND TEST**

- The 5 central modules were separated 50cm one each other, and the two off-axis modules are at the distance of 10m and 15m (see figure below).
- The 3DST modules in this configuration has 10cm of veto region.
- The geometry was exposed to 4.02e18 POT (~1.3 days).

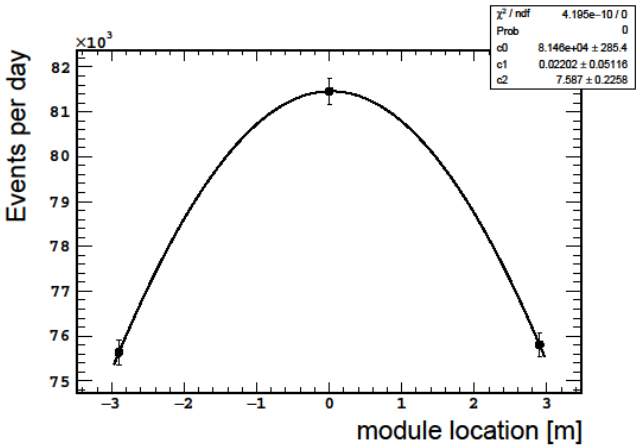
Black boxes :
Active region.

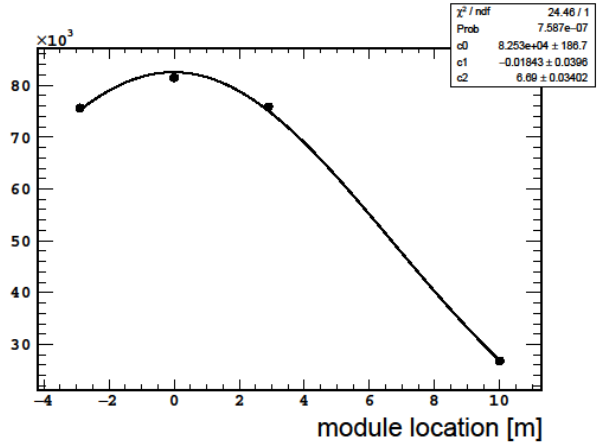
Color side :
Veto region.

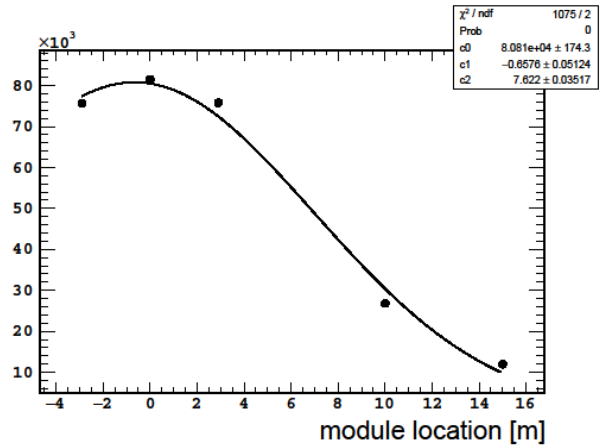


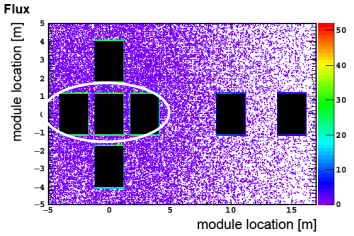
- **RESULTS: BEAM PARAMETERS**

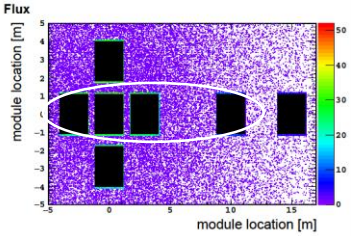
- We calculated the number of events per module. We fitted the results '**assuming**' the beam shape follows a gaussian function.
- C_o is the height of the curve's peak, C_1 is the beam center and C_2 is the beam width.

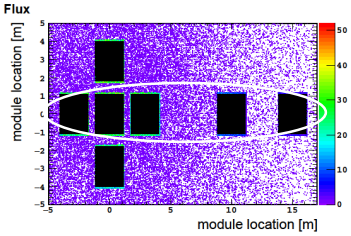








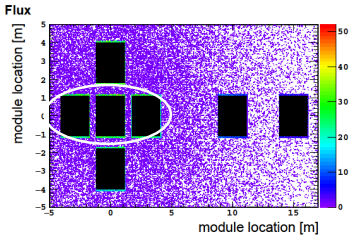


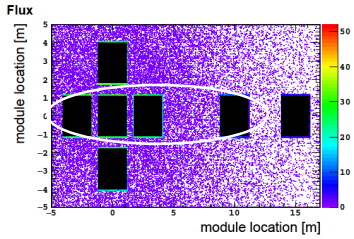


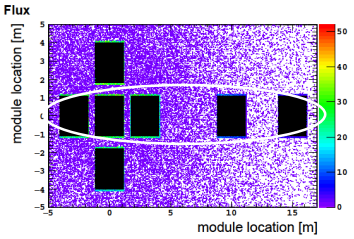
• RESULTS: BEAM PARAMETERS

- We obtained the Gaussian fit parameter values for 4.02e18 POT (~1.3 days).
- The table below summarizes the results for 3, 4 and 5 3DST modules.

Fit Parameters	3 Modules	4 Modules	5 Modules
C0	8.146e+04 ± 285.4	8.253e+04 ± 186.7	8.081e+04 ± 174.3
Beam Center (m)	0.022 ± 0.051	-0.018 ± 0.039	-0.658 ± 0.051
Beam Width (m)	7.587 ± 0.226	6.69 ± 0.03	7.622 ± 0.035

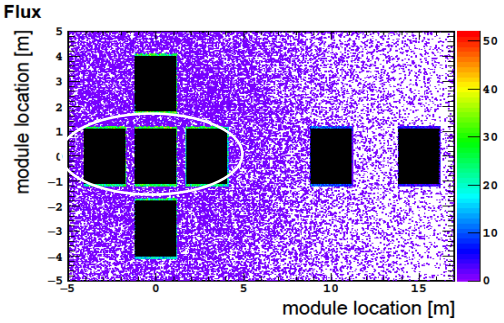






• RESULTS: BEAM PARAMETERS

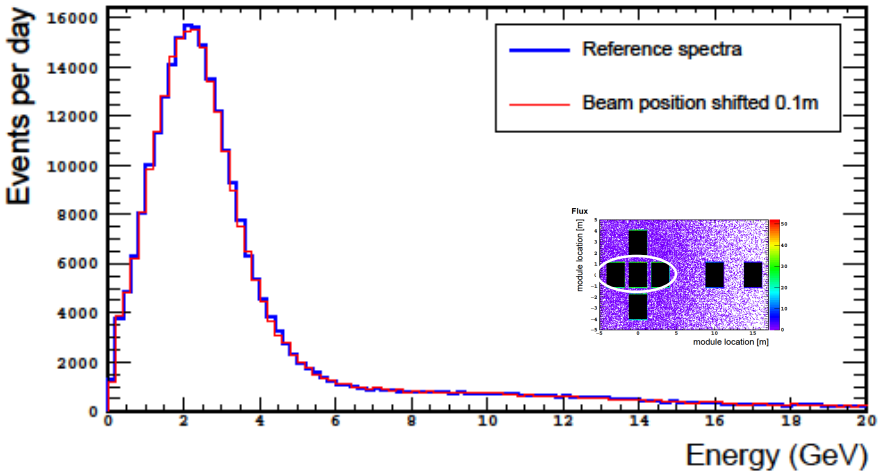
- All configurations show an uncertainty on the beam center better than 10cm (CDR requirement).
- Gaussian fit of the flux shape seems to be a good enough approximation for this feasibility study, though the fit of 5 modules shows some tension.
- Preliminary results showed that 3 central modules may be enough for the CDR requirements.

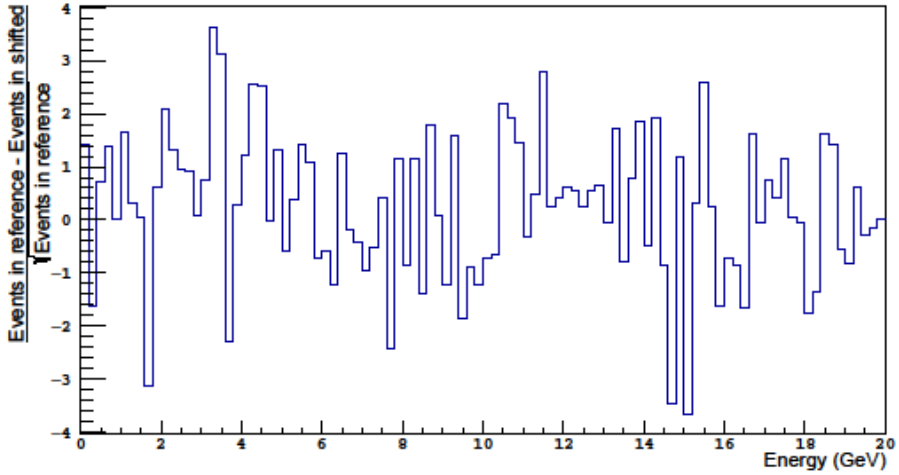


- We could reduce the number of 3DST modules to a single large module covering few meters along X and Y directions without sacrifice the physics needs of beam monitoring. More tests will be done
- Currently we only consider the X-direction, we assume Y-direction will have similar result.

- **RESULTS: NEUTRINO ENERGY SPECTRA**

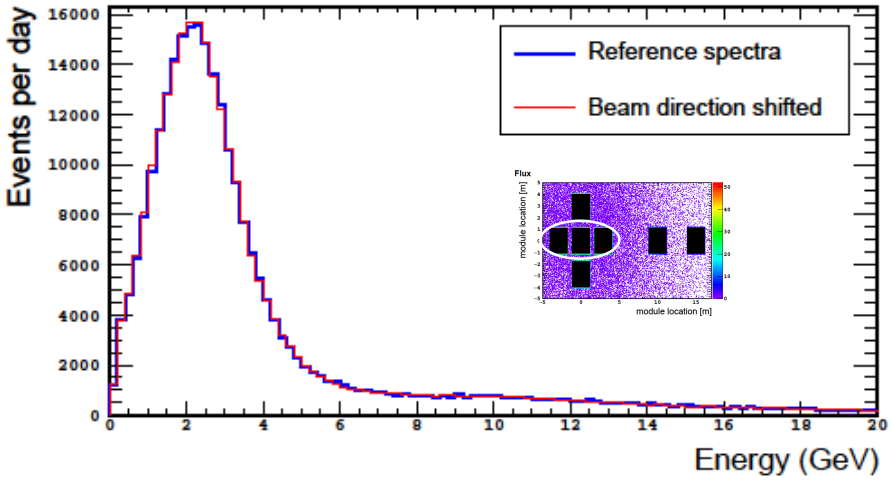
- The plot show the neutrino energy spectra distribution in the **3 central modules** only considering X direction.
- We generated a reference neutrino energy spectra and then we compared it with an energy spectra shifted in the beam position along X direction.
- Reference position: (0,0,0)m
- Shifted position: (0.1,0,0)m

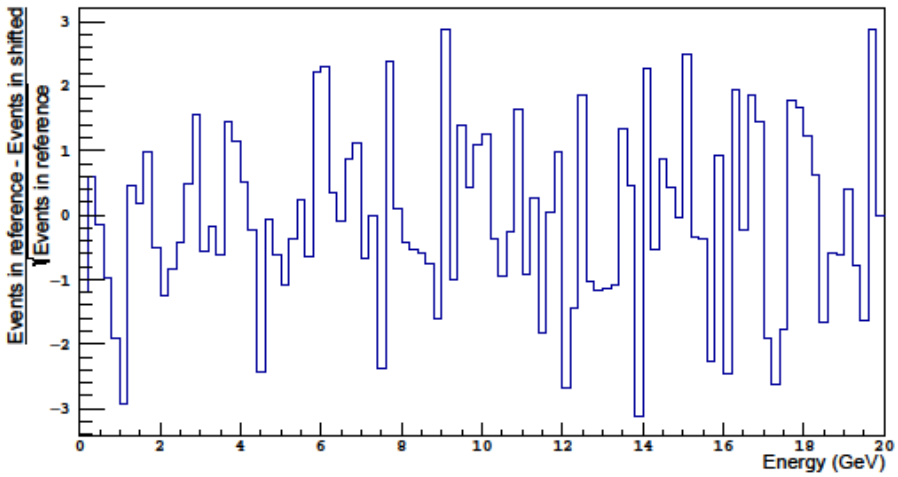




- **RESULTS: NEUTRINO ENERGY SPECTRA**

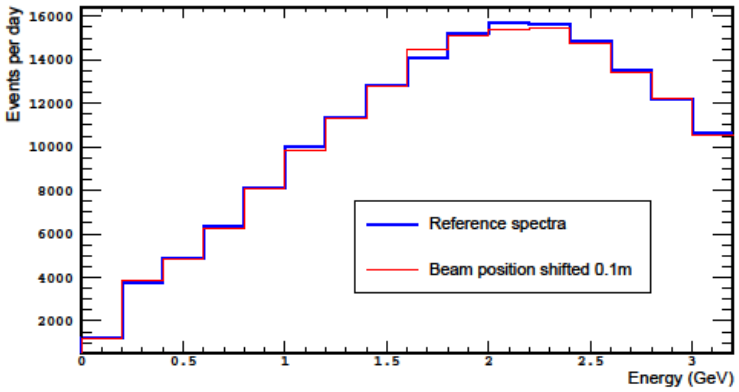
- Then, we compared the reference neutrino energy spectra with an energy spectra shifted in the beam direction.
- Reference direction:-0.101rad.
- Shifted direction: -0.103rad.

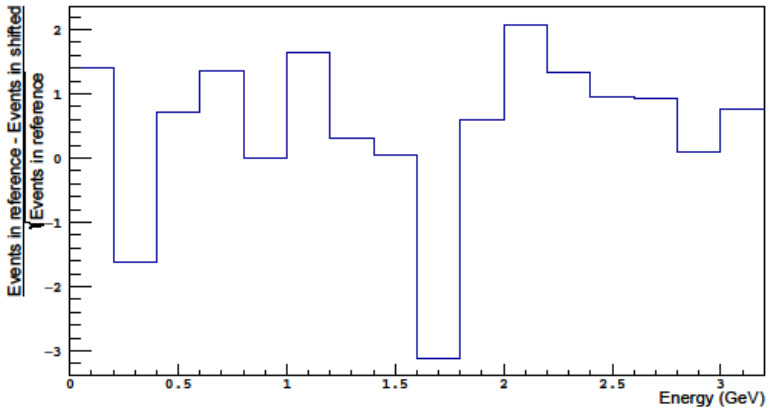


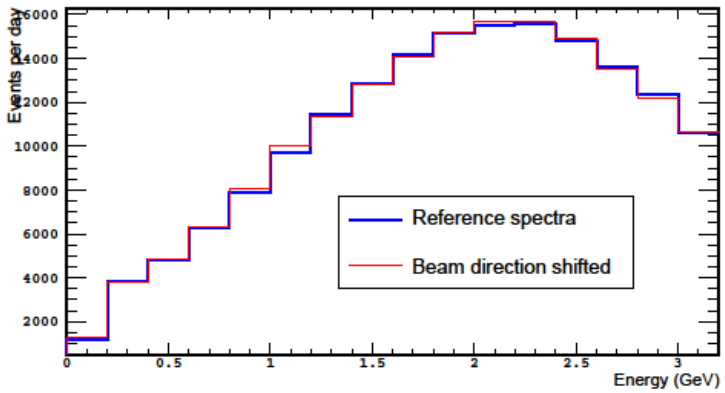


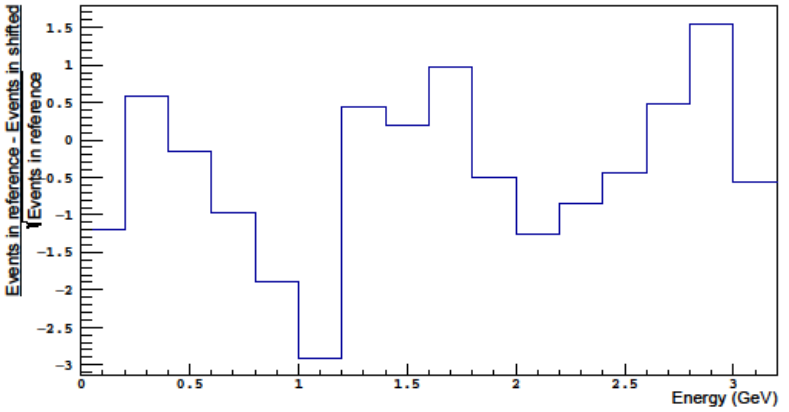
- **RESULTS: NEUTRINO ENERGY SPECTRA**

- We had deviations in the energy spectra up to 2-3 sigmas (stat error) in some bins and 1 sigma in several bins around the peakcan be observed.









- **SUMMARY**

- Using the **TEST** geometry, we found a region with higher statistics of charged current events.
- The geometry with two off-axis modules was exposed to 4.02e18 POT (~1.3 days). Assuming a gaussian fit function, we obtained the parameters for beam center and beam position for 3 different cases only considering x direction: 3 central modules, 3 + 1 off-axis and 3 + 2 off-axis. In all cases we found that the CDR requirement to be able to reach a beam center uncertainty of ~0.1 m is fulfilled.
- We obtained the energy spectra for muon neutrinos for two different cases
  - When the beam center is shifted 0.1m from its initial position
  - When the beam direction is shifted 2 mrad from its initial position.
- All suggestions and comments are more than welcome!!!