Development of T2K Beam Simulation with GEANT4

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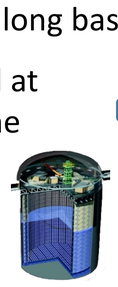
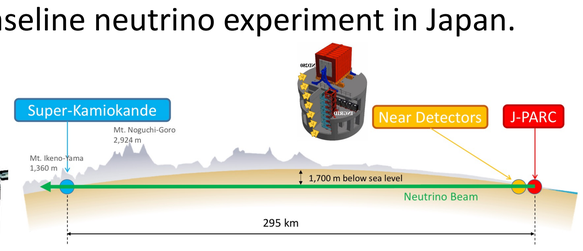
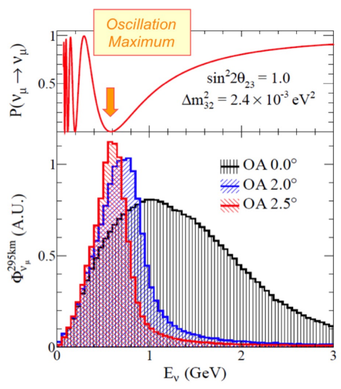
The T2K Experiment

T2K (Tokai-to-Kamioka) is a long baseline neutrino experiment in Japan.

Neutrino beam is produced at the accelerator facility at the Japan Proton Accelerator Research Center (J-PARC).







Neutrino fluxes for off-axis angles 0.0°, 2.0° and 2.5° [1]

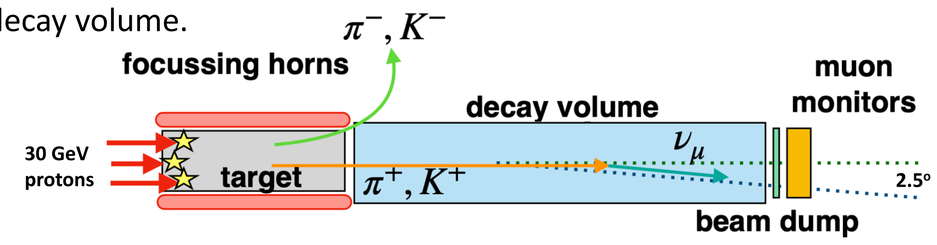
T2K studies the oscillation of neutrinos, observing the disappearance of ν_μ and appearance of ν_e.

Near detector complex (280 m): ND280, INGRID, WAGASCI/BabyMIND.

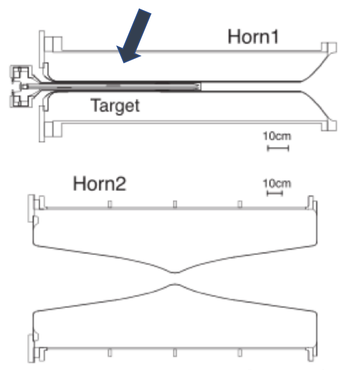
Far detector (295 km): Super-Kamiokande.

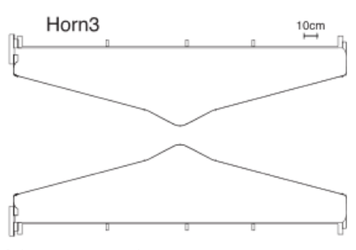
T2K Neutrino Beam

30 GeV proton beam produced in J-PARC impinges on a carbon target producing secondary hadrons, which are focused by three magnetic horns and eventually decay into neutrinos in a decay volume.

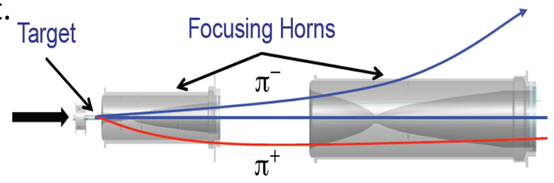


Target: 90 cm long graphite rod inside Horn 1.





Magnetic horns: focus charged particles from interactions of the protons in the target.



Horns generate the magnetic field with a pulsed current of 250/320 kA.

Cross section of three magnetic horns.

T2K Beam Simulations: JNUBEAM

Current T2K Monte Carlo simulation, JNUBEAM [1], is based on a combination of GEANT3 [2] (no-longer maintained) and FLUKA [3].

FLUKA: Hadronic interactions in the target

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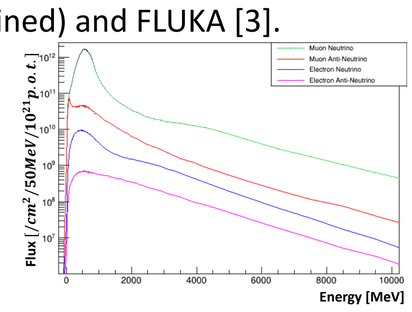
JNUBEAM: Tracking of particles exiting the target; neutrino production

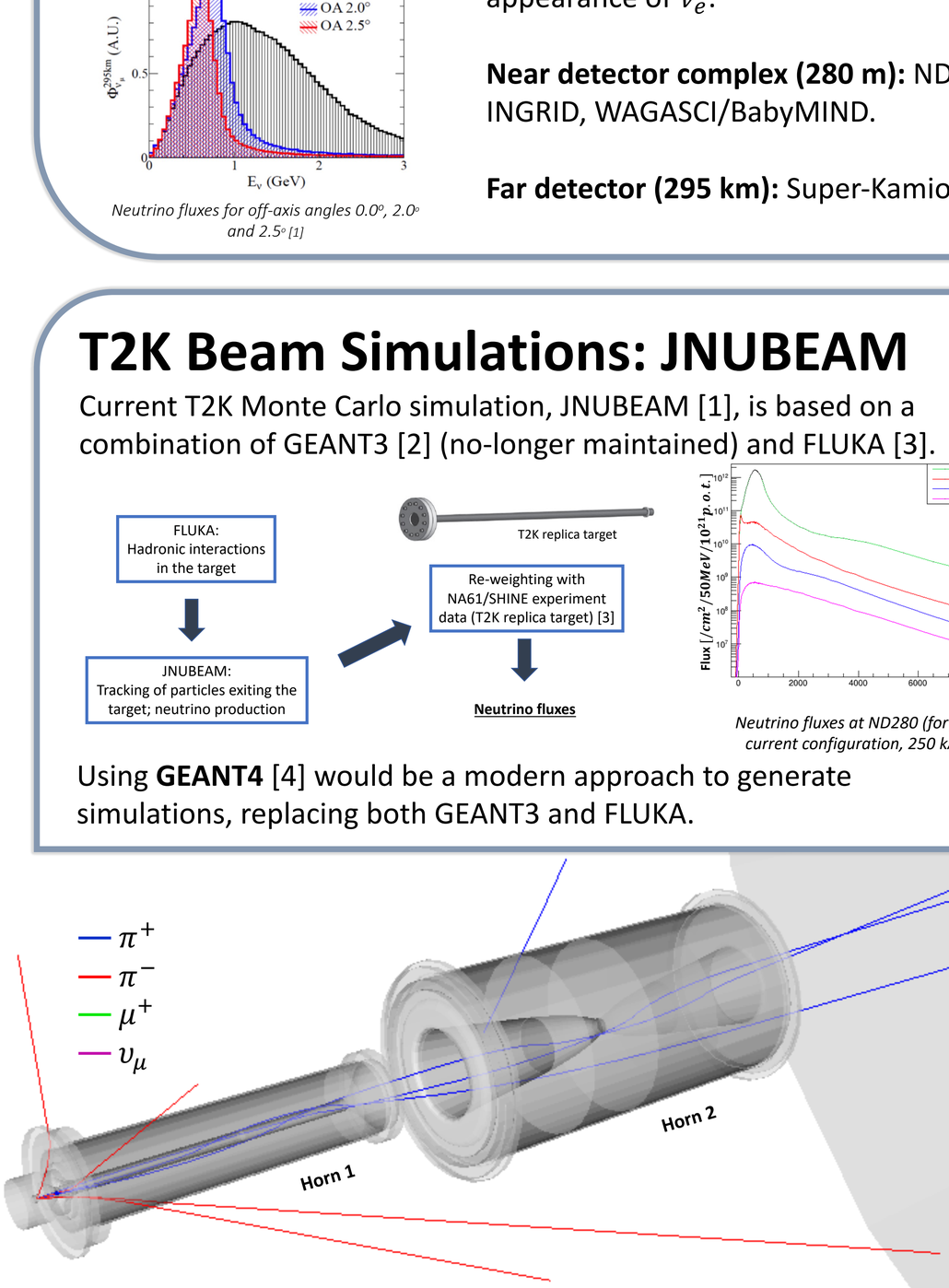
→ Re-weighting with NA61/SHINE experiment data (T2K replica target) [3] → **Neutrino fluxes**



Neutrino fluxes at ND280 (for forward horn current configuration, 250 kA). From [5].

Using **GEANT4** [4] would be a modern approach to generate simulations, replacing both GEANT3 and FLUKA.

Visualization from G4JNUBEAM



The geometry is stored in GDML (Geometry Description Markup Language) format.

GEANT4 Framework - G4JNUBEAM

Under development: Monte Carlo simulation based on GEANT4, aiming to describe the physical processes from proton interactions in the target to the decay of hadrons and muons producing neutrinos.

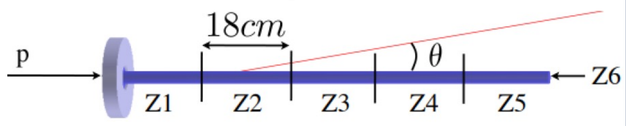
- Successfully converted the JNUBEAM geometry from GEANT3 to GEANT4;
- Framework is almost complete, already available to T2K collaborators;
- Pion yield simulations from G4JNUBEAM are compared to NA61/SHINE data;
- Preliminary neutrino flux diagrams in GEANT4.

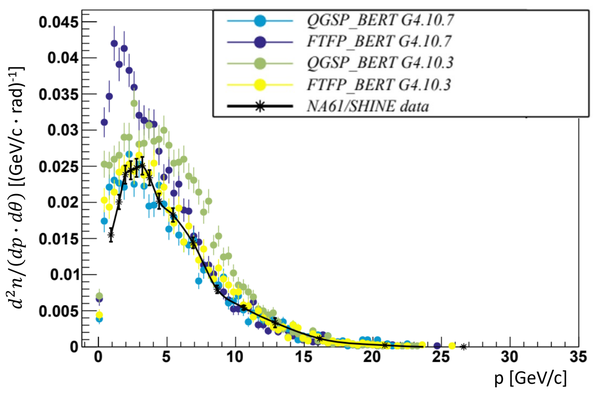
Currently testing in the T2K flux tuning code (for NA61/SHINE reweighting).

Benchmarking with NA61/SHINE data

NA61/SHINE data from 2010 run [6] is provided for six different segments: five 18 cm segments and downstream face of the target.

This data can be used for the validation of G4JNUBEAM.





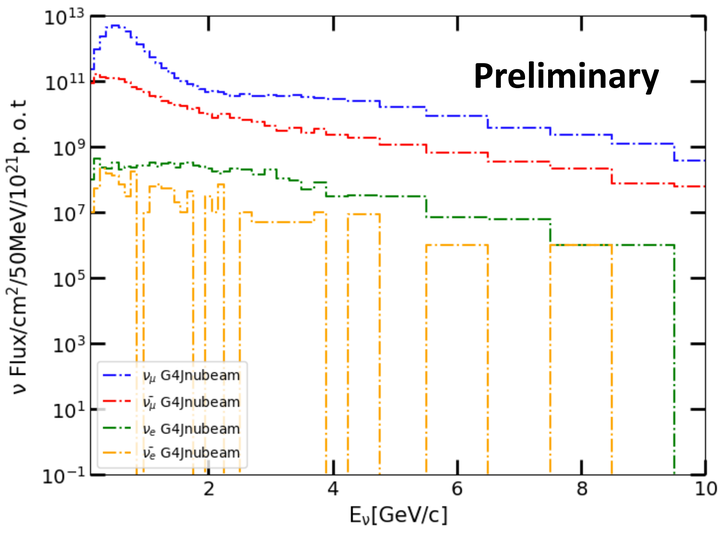
Pion yields from G4JNUBEAM simulations (markers) and NA61/SHINE data (solid line) for last 18 cm downstream of the target. (20-40 mRad).

Consistency between pion-yields simulation (using T2K replica target and NA61/SHINE proton beam profile) and data:

Benchmark physics list (QGST_BERT or FTFP_BERT) and GEANT4 version to be used for the neutrino flux predictions.

Preliminary Results

G4JNUBEAM is still under development, but some preliminary neutrino flux diagrams can already be obtained and compared to JNUBEAM:



Neutrino fluxes at ND280 (from forward horn current configuration)

GEANT4.11.0.3, with QGSP_BERT model.

Good overall agreement with JNUBEAM.

G4JNUBEAM fluxes are still not tuned with NA61/SHINE data. The software is currently being optimized to be compatible with the T2K flux tuning.

References: **[1]** K. Abe et al., "T2K neutrino flux prediction," Phys. Rev. D 87, 012001 (2013), **[2]** R. Brun et al., "GEANT3," CERN-DD-EE-84-1, **[3]** G. Battistoni et al., "Overview of the FLUKA code," Annals of Nuclear Energy 82, 10-18 (2015) **[4]** S. Agostinelli et al., "Geant4 - A Simulation Toolkit," Nucl. Instrum. Meth. A 506 (2003) 250-303, **[5]** Webpage: https://t2k-experiment.org/result category/flux, **[6]** N. Abgrall et al., "Measurements of π±, K± and proton yields from the surface of the T2K replica target for incoming 31 GeV/c protons with the NA61/SHINE spectrometer at the CERN SPS," Eur.Phys.J. C79 (2019) no.2, 100.