# NNN23 22nd International Workshop on Next Generation Nucleon Decay and Neutrino Detectors Procida October 11-13, 2023

## **T2K GEANT4 Beam Simulation**

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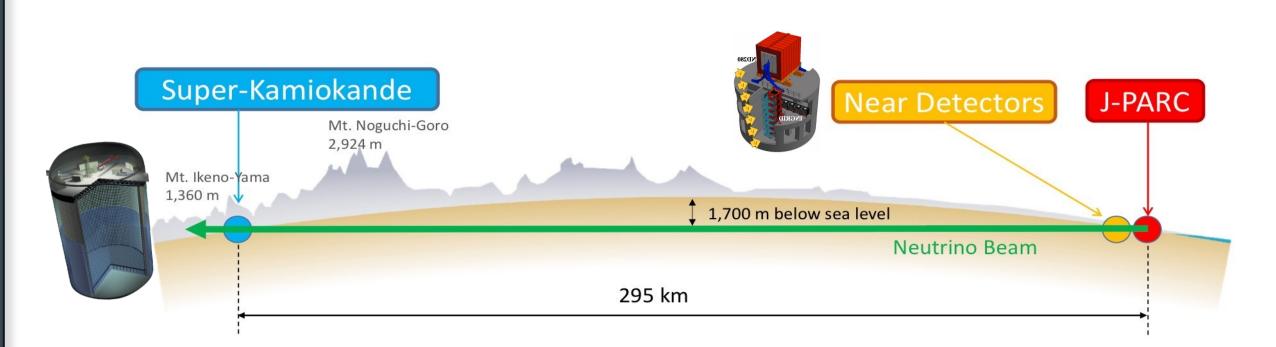
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## The T2K Experiment

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



T2K studies the oscillation of neutrinos, observing the disappearance of  $\nu_{\mu}$  and appearance of  $\nu_{e}$ . The beam is measured in steps:

Near detector complex (280 m): ND280, INGRID, WAGASCI/BabyMIND. Far detector (295 km): Super-Kamiokande.

A 30 GeV proton beam produced at the Japan Proton Accelerator Research Center (J-PARC) impinges on a carbon target producing secondary hadrons.  $\pi^-, K^-$ 

focussing horns  $\frac{\pi}{\text{decay volume}}$   $\frac{\text{decay volume}}{\text{monitors}}$   $\frac{1}{\text{decay volume}}$   $\frac{\pi}{\text{decay volume}}$ 

The charged particles from interactions in the target are focused/defocused by three **magnetic horns**.

Horn3

Horn3

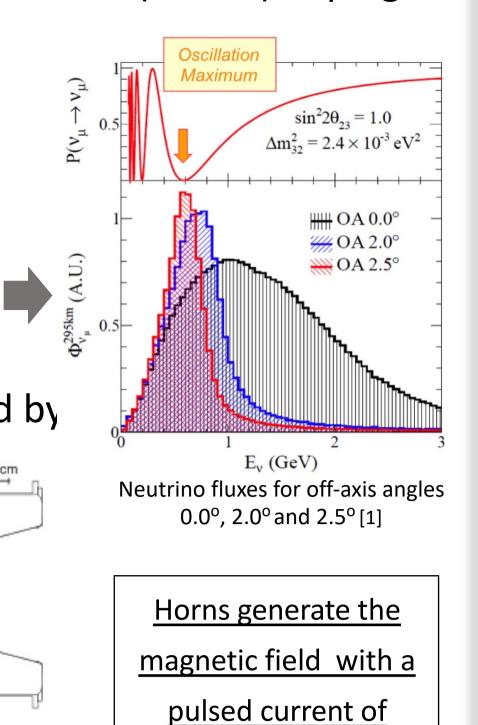
Horn2

Horn3

Farget

Cross section of magnetic horns

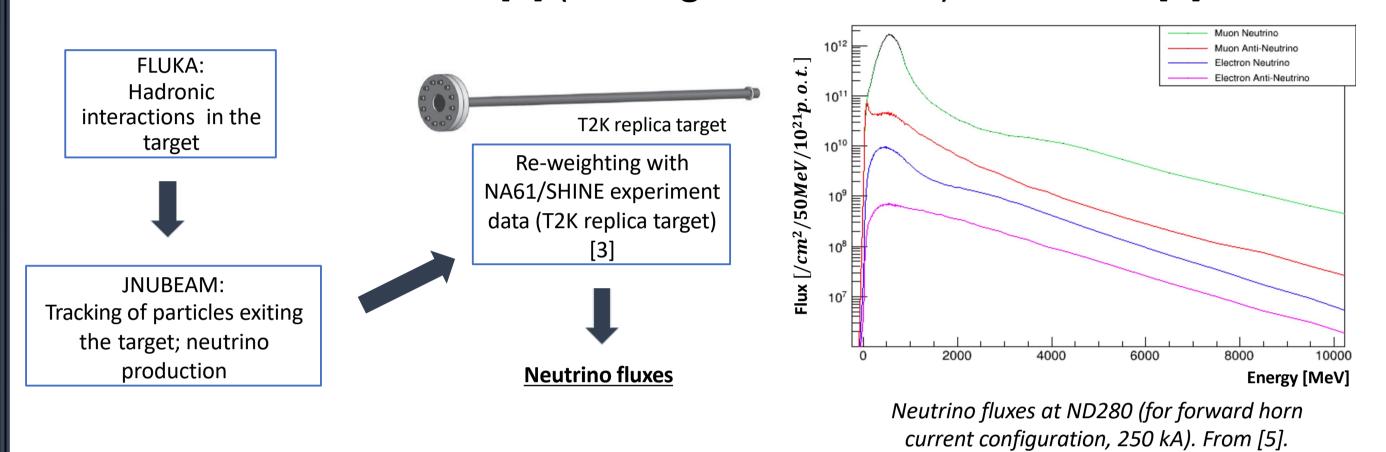
Hadrons eventually decay in a decay volume, producing a neutrino beam.



250/320 kA.

## **T2K Beam Simulations: JNUBEAM**

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



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

# Visualization from G4JNUBEAM Beam dump Decay Volume

Recent improvements to magnetic field (inside conductors, accuracy).

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

### **G4JNUBEAM**

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 – under development.

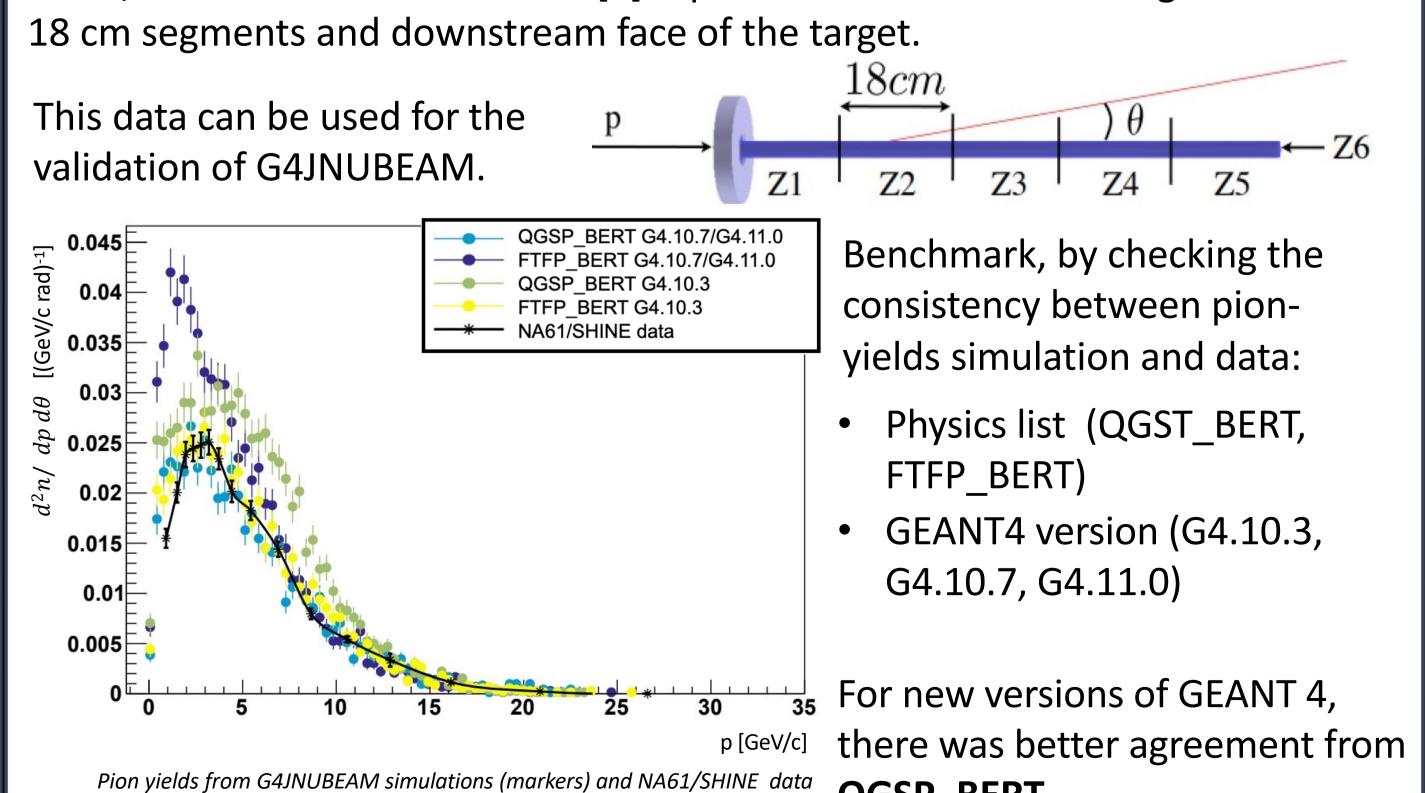
- Successfully converted the JNUBEAM geometry from GEANT3 to GEANT4;
- Pion yield simulations comparison to NA61/SHINE data;
- Framework is almost complete, already available to T2K collaborators;
- Preliminary neutrino flux diagrams in GEANT4.

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

# Validation 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.

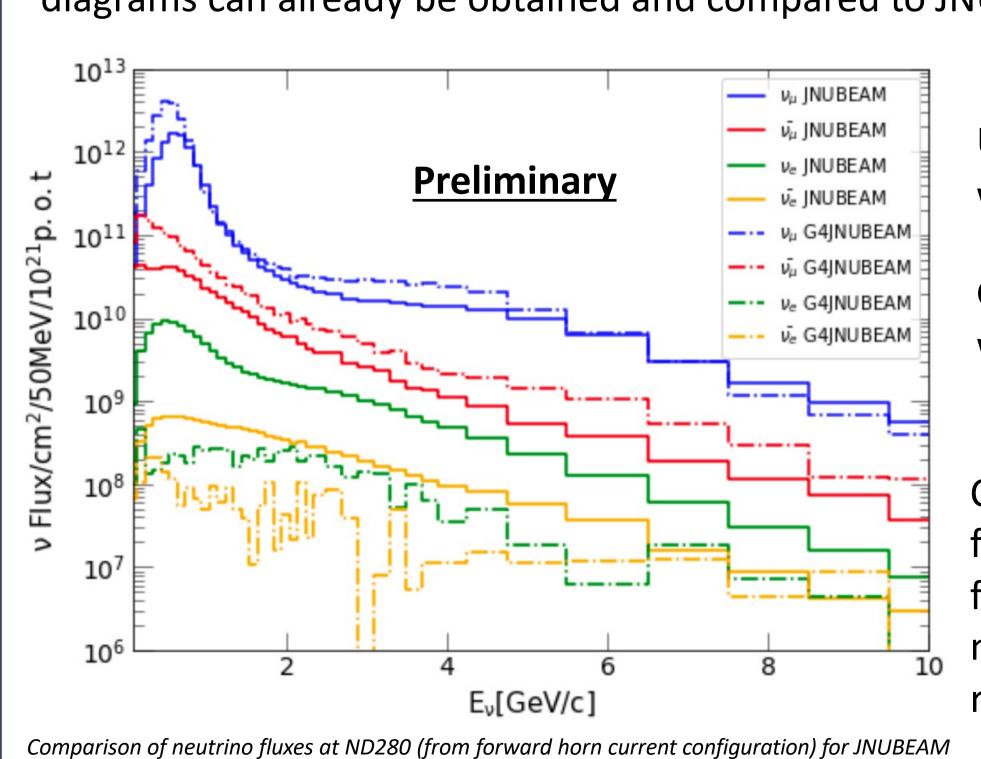
QGSP\_BERT.



(solid line) for last 18 cm downstream of the target. (20-40 mRad).

# **Preliminary Results**

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



(solid lines/tuned for NA61/SHINE) and G4JNUBEAM (dashed lines/untuned for NA61/SHINE).

Using **GEANT 4.11.0**, with QGSP\_BERT model.

Good overall agreement with JNUBEAM.

Currently improving the framework to reduce time for simulation and to make it compatible to reweighting procedure.

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.