Hadron Production Measurements with the T2K Replica Target in NA61/SHINE for the T2K Neutrino Flux Prediction

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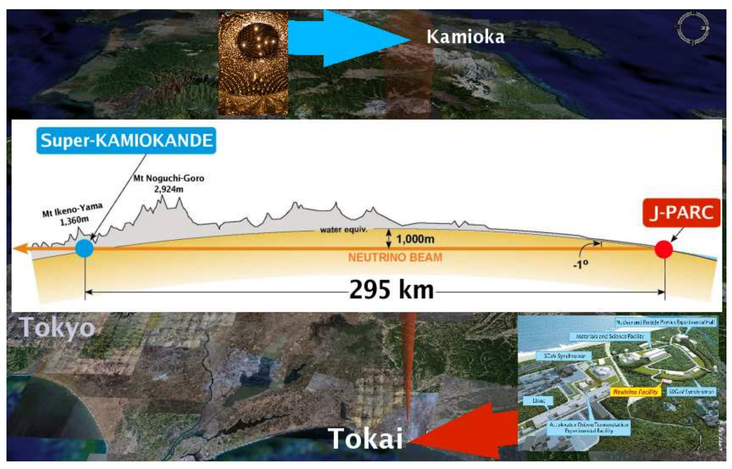
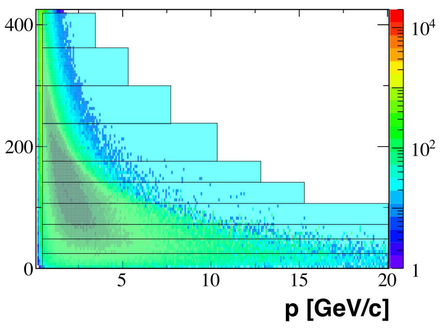
The T2K Neutrino Beamline

In the T2K long baseline neutrino oscillation experiment [2] [3] [1], a high intensity neutrino beam is created by a 30 GeV proton beam impinging on the 90 cm long T2K graphite target. The neutrino flux is measured in a detector (SK) far from the source at 295km and compared with a prediction based on the unoscillated neutrino flux measured with a near detector (ND280) located 280m away from the target.

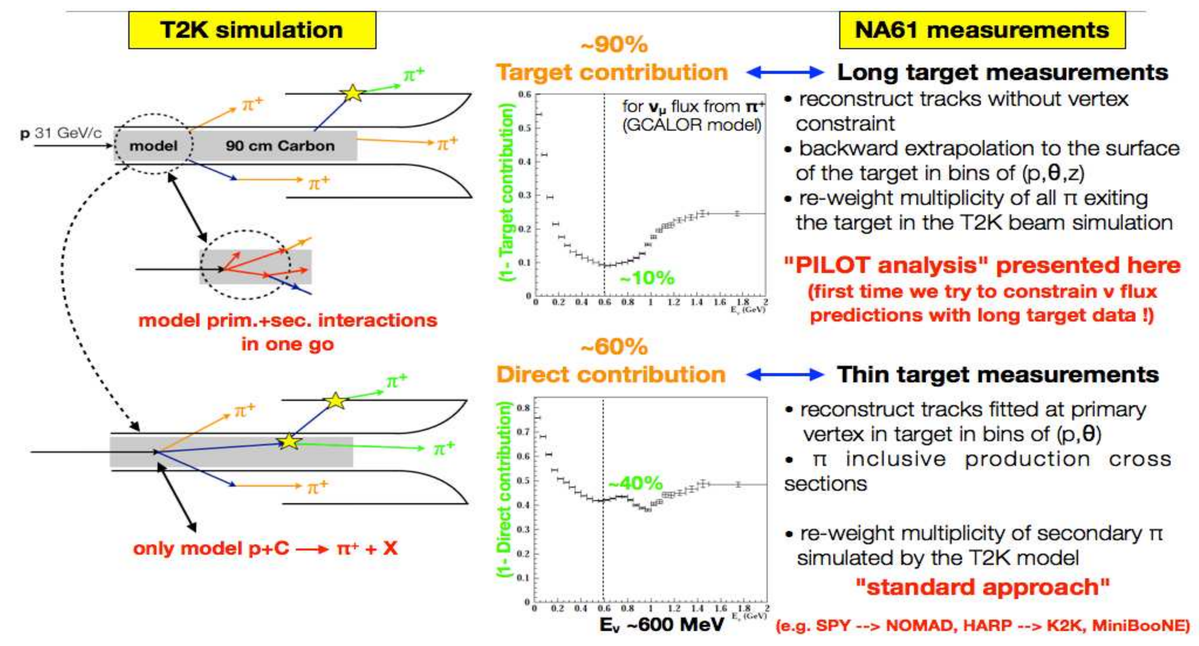




Prediction from the T2K beam simulation: the $\{p, \theta\}$ distribution for positively charged pions weighted by the probability that their decay produces a ν_μ passing through the SK detector. The coverage of NA61 for the T2K replica target 2009 data is super-imposed.

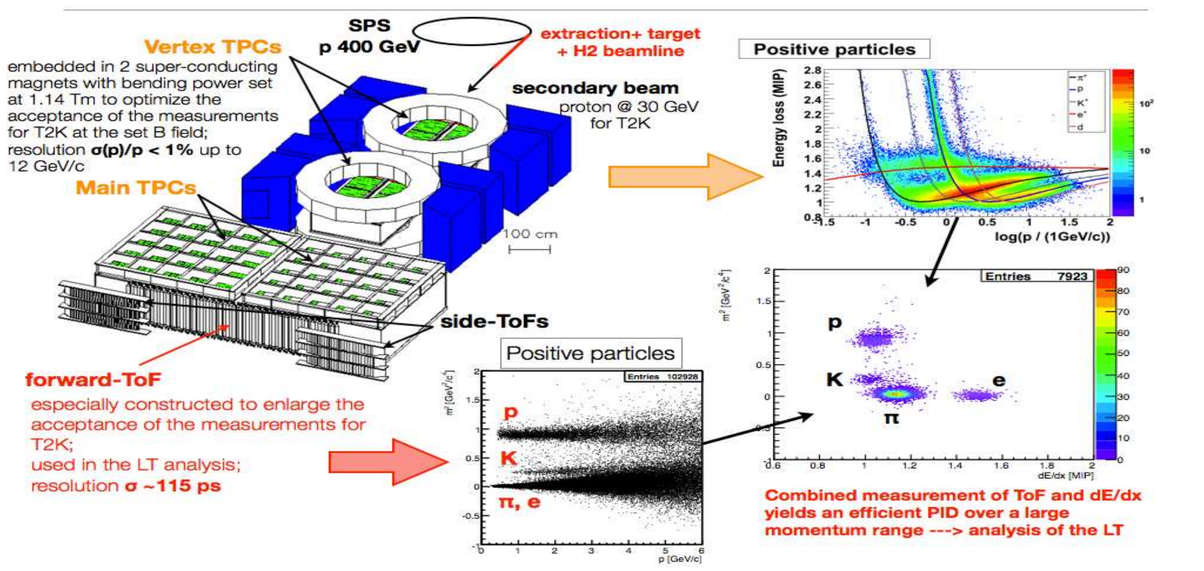
T2K Replica Target Pilot Analysis

$\sim 95\%$ of the ν_μ flux at SK comes from π^+ decays. Need to look at different sources to understand which fraction could be constrained by auxiliary hadron production measurements. $\sim 50\%$ of the ν_e flux from μ^+ decay produced in the same π^+ decays $\rightarrow \nu_e$ flux partly constrained by the same data !



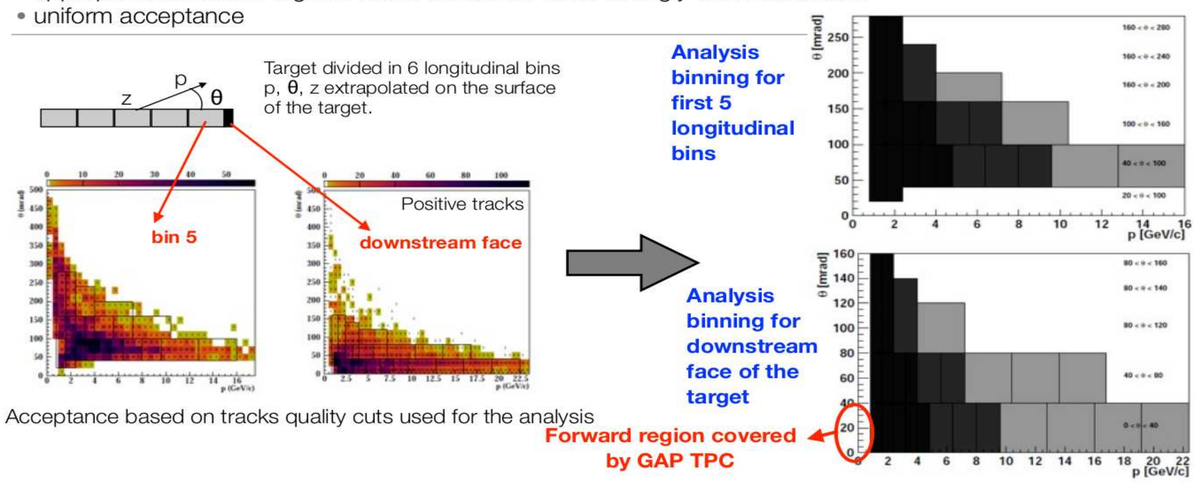
NA61/SHINE Setup and PID Capabilities

NA61 is a large acceptance hadron spectrometer at CERN. Particle identification in NA61 is based on both dE/dx and Time-Of-Flight measurements [4] [5].



The **analysis binning in {p,θ,z}** is based on:

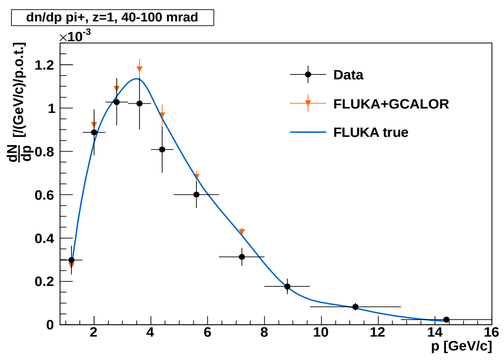
- coverage after track quality cuts that maximize the resolution of the track parameters on target
- appropriate bin size in regions where the dE/dx varies strongly with momentum
- uniform acceptance



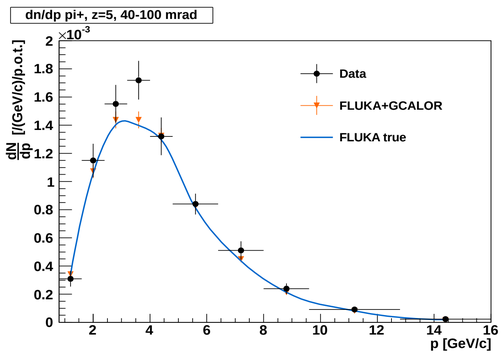
Acceptance based on tracks quality cuts used for the analysis

Reconstructed π^+ Yields from the T2K Replica Target

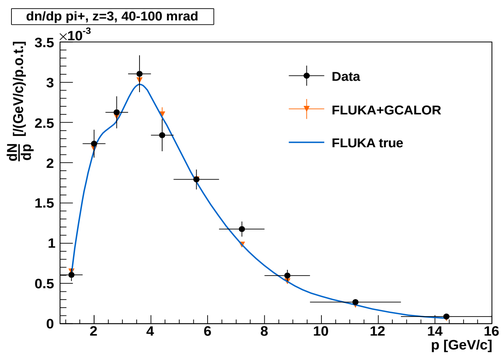
Comparison of π^+ yields extracted from the 2007 NA61 data and the Monte Carlo (FLUKA 2011.2) simulation for different longitudinal bins along the target.



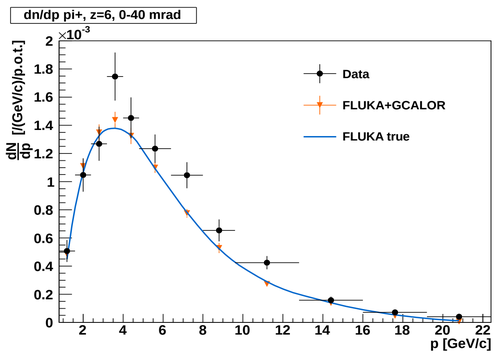
π^+ spectra for the first (most upstream) longitudinal bin along the target surface.



π^+ spectra for the third longitudinal bin along the target surface.



π^+ spectra for the fifth longitudinal bin along the target surface.



π^+ spectra for last longitudinal bin, which corresponds to the target downstream face

T2K Replica Target Re-Weighting and its Effects on the ν_μ Flux

By considering ratios between Data and Monte Carlo reconstructed with the same procedure, most of the correction factors (and hence systematic uncertainties) related to geometrical acceptance, particle losses, etc. cancel out (only the TOF efficiency has to be taken into account as the efficiency is artificially at 100% in the NA61 simulation). Hence, re-weighting factors are calculated as:

$$w(p,\theta,z) = \frac{1}{\epsilon_{TOF}^{NA61}(p,\theta)} \times \frac{N_\pi^{NA61}}{N_\pi^{FLUKA}}(p,\theta,z) \times \frac{N_{POT}^{FLUKA}}{N_{POT}^{NA61}}$$

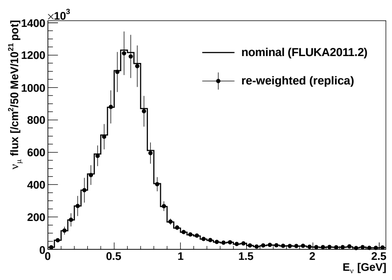
Sources of systematic uncertainties are:

- Particle Identification: $\sim 1-5\%$
- Normalization to protons on target: $\sim 1.4\%$
- TOF efficiency: $\sim 3\%$
- Target alignement: 3%
- Target density: $< 3\%$
- Beam momentum: $< 3\%$

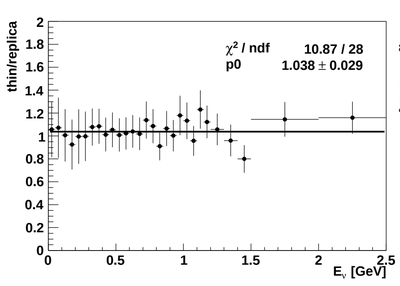
Target alignment, target density and beam momentum are not exactly the same in NA61 and T2K. Related systematic uncertainties on the re-weighting factors have been estimated to be $< 3\%$ with dedicated MC studies.

Due to restricted amount of data taken in 2007, the statistical errors for this data set is typically $10-15\%$. It will significantly decrease with the 2009 data set, as the amount of recorded events is one order of magnitude larger.

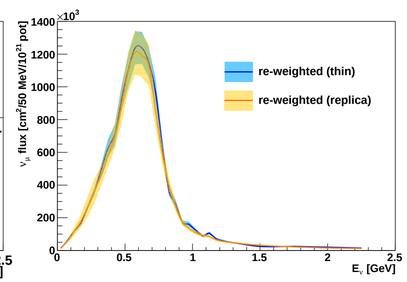
The re-weighting factors calculated with the replica target data can be directly used to tune the particle emission from the target in the T2K beam simulation. The obtained prediction is compared to that based on the NA61 thin target data bellow. Both methods, the thin target tuning and the T2K replica target tuning are consistent within the current uncertainties.



Prediction of the ν_μ flux at SK detector normalized to 10^{21} protons on target. The thin target tuning and T2K replica target tuning. A first order polynomial fit is overweighted prediction based on the replica target data is superimposed.



Ratio of the ν_μ flux predictions with the laid on top of the ratio.



Weighted ν_μ flux predictions at the far detector of T2K based on the NA61 thin target and T2K replica target data. In both caes, error bands correspond to the error associated to the weighting.

The actual large uncertainty over the replica target re-weighting factors can be significantly reduced by the high statistics data that were taken in 2009-2010 and currently being analyzed. The Full set of replica target data from the NA61/SHINE experiment will allow to reach the 3% uncertainty over the far to near flux ratio, as required to reach T2K physics goals.

References

[1] T2K Collaboration K. Abe et al. Indication of electron neutrino appearance from an accelerator-produced off-axis muon neutrino beam. *Phys. Rev. Lett.*, 107:041801, Jul 2011.

[2] T2K Collaboration K. Abe et al. The t2k experiment. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 659(1):106 – 135, 2011.

[3] T2K Collaboration K. Abe et al. First muon-neutrino disappearance study with an off-axis beam. *Phys. Rev. D*, 85:031103, Feb 2012.

[4] N. Abgrall et al. (NA61/SHINE collabration). Measurements of cross sections and charged pion spectra in proton-carbon interactions at 31 gev/c. *Phys. Rev. C*, 84:034604, Sep 2011.

[5] N. Abgrall et al. (NA61/SHINE collabration). Measurement of production properties of positively charged kaons in proton-carbon interactions at 31 gev/c. *Phys. Rev. C*, 85:035210, Mar 2012.