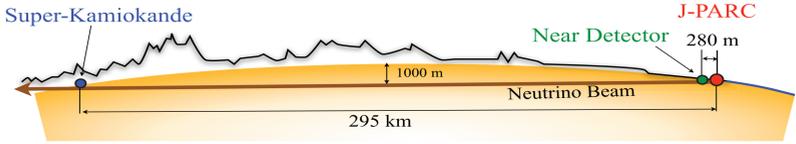


# Constraints on the T2K neutrino flux prediction from hadron production measurements at NA61/SHINE



## The T2K neutrino beam

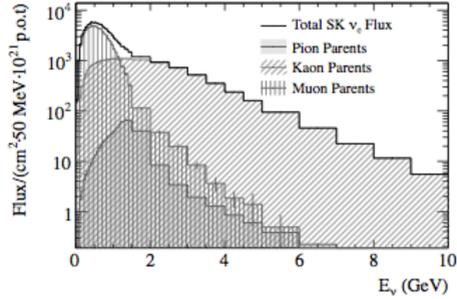
T2K is a long baseline neutrino experiment that aims to precisely measure the PMNS matrix element and to look for first hints of CP violation



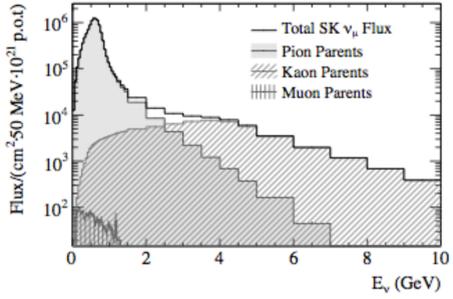
Neutrino beam with peak energy of  $\sim 650$  MeV is created by a 31 GeV/c proton beam impinging on the 90 cm long T2K graphite target

The neutrino flux is measured in a detector far from the source (SK) and compared with a prediction based on the neutrino flux unmodified by oscillations

### $\nu_\mu$ flux @ far detector (MC)



### $\nu_e$ flux @ Far detector (MC)



Beam composed by  $\nu_\mu$  with a  $\nu_e$  contamination of about 1%

T2K requirement is 5% of uncertainty on the flux Large flux systematic uncertainties due to the poor knowledge on the hadronization models

## Measurements of pC interactions at 31 GeV/c with NA61/SHINE experiment

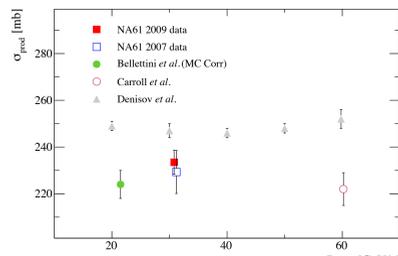
### Hadron production cross section measurements

Needed to normalize the spectra of hadrons produced in the pC interactions

Interactions outside the target estimated with data-set w/o inserted target

Subtract elastic and quasi-elastic contributions estimated with GEANT4

Systematic uncertainty on the model (mod) and detector (det)



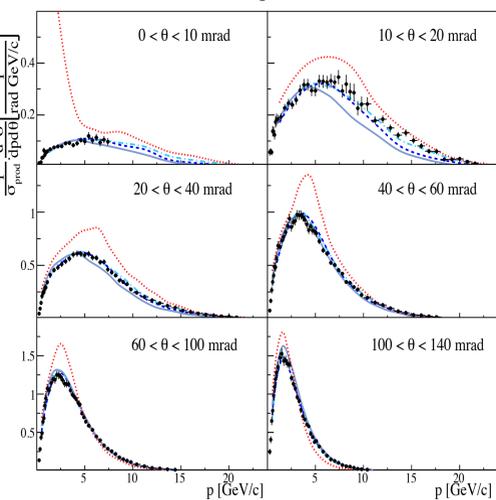
$$\sigma_{prod} = 233.5 \pm 2.8(\text{stat}) \pm 2.4(\text{det}) \pm 3.6(\text{mod}) \text{ mb}$$

### Charged hadrons multiplicities

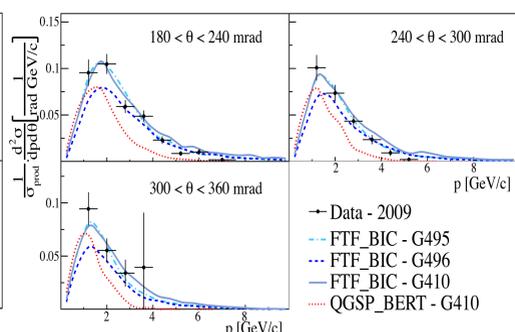
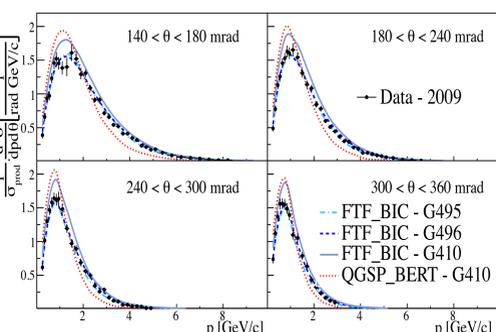
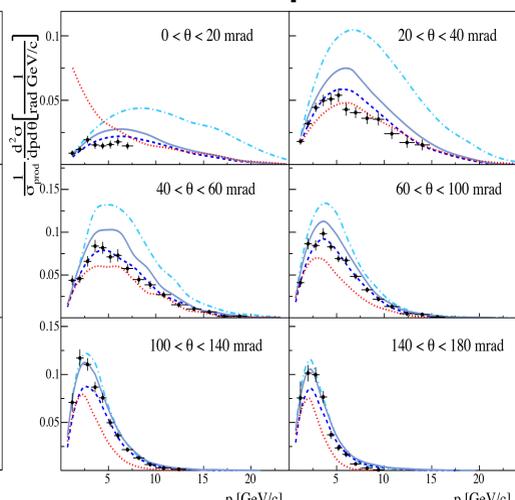
Combine dE/dx and ToF informations to identify  $\pi^\pm$ ,  $K^\pm$ , p for  $p > 1$  GeV/c

Comparison with recommended GEANT4 physics lists

#### $\pi^\pm$ multiplicities



#### $K^+$ multiplicities



## The NA61/SHINE experiment

NA61/SHINE is a fixed target experiment at CERN SPS

Pilot run in 2007 to test the method

Hadron production measurements of pC@31 GeV/c

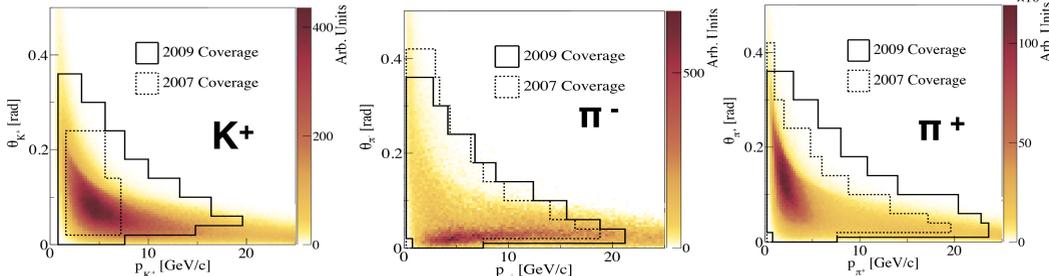
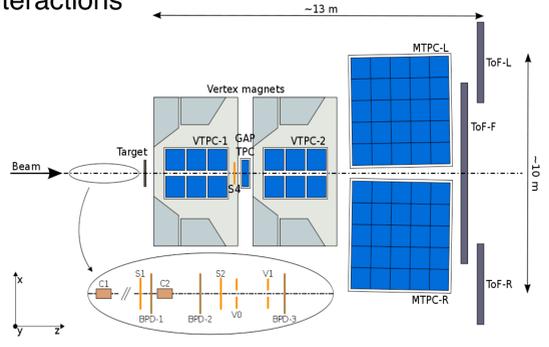
- Thin target ( $4\% \lambda_I$ ) for primary interactions
- T2K replica long target ( $1.9 \lambda_I$ ) for secondary interactions

New results with the high statistic data-set taken with the thin target 2009 run

- 3 BPDs (Beam position detectors)
- 5 TPCs  $\sigma(p)/p^2 \sim 10^{-4}$
- 3 Time of Flight (ToF)

### Particle Identification:

- Time of Flight (3 walls) + dE/dx in TPCs
- ToF resolution:  $< 120$  ps;
- $\sigma(dE/dx) / \langle dE/dx \rangle \sim 4\%$



The T2K neutrino parent phase space is fully covered

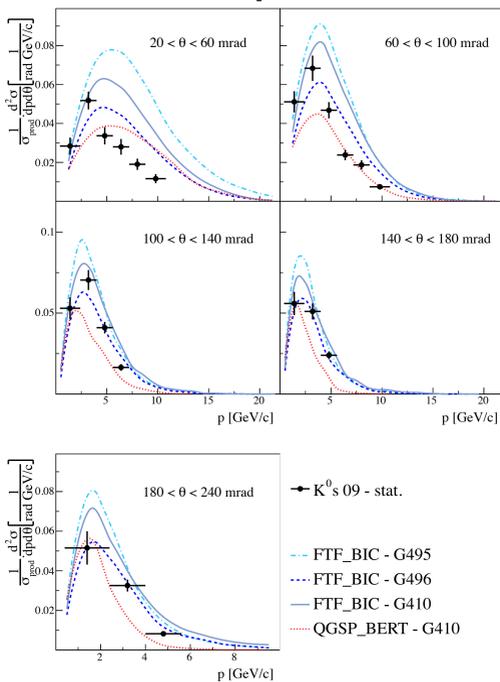
## $V^0$ multiplicities from thin target data

$K^0 \rightarrow \pi^+ \pi^-$  and  $\Lambda \rightarrow p \pi^-$  are the main source of systematic for  $\pi^\pm$  and p multiplicities

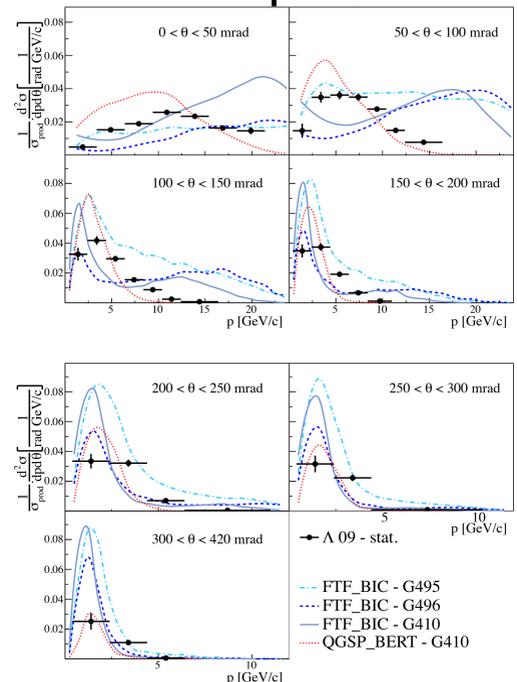
$K^0 \rightarrow \pi^- \nu_e e^+$  is the main source of high energy  $\nu_e$  at T2K

Invariant mass fit

### $K^0$ multiplicities

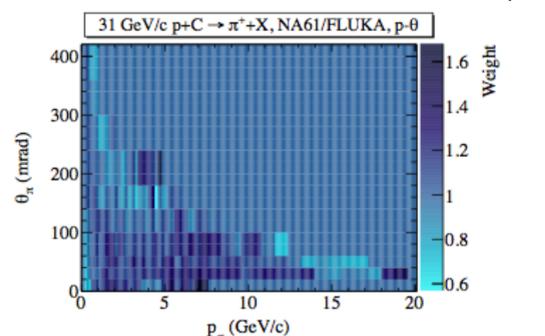


### $\Lambda$ multiplicities



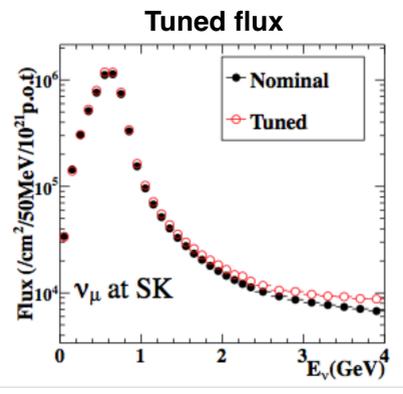
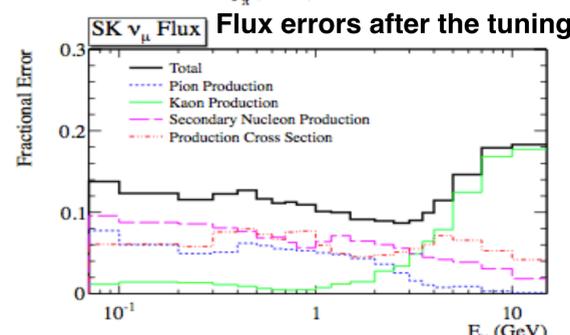
## Tuning of the T2K neutrino flux

Simulation of the T2K secondary beam-line: p interactions in the target simulated with Fluka. Geant3+CALOR used for the propagation in the beam-line



Phys. Rev. D 87 (2013), 012001  
arXiv: 1211.0469

Weights computed with external data (priority to NA61/SHINE) are applied to the simulated flux



Procedure successfully tested using the multiplicities of the 2007 pilot run  
Multiplicities measured with 2009 run data will be used in 2014 T2K analyses