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The NA61 Hadron Production Measurements for the T2K Neutrino Flux Prediction

Alexis Haesler
University of Geneva
For the NA61 collaboration

T2K off-axis neutrino beam

Long baseline oscillation experiment involving a flux of ν_μ

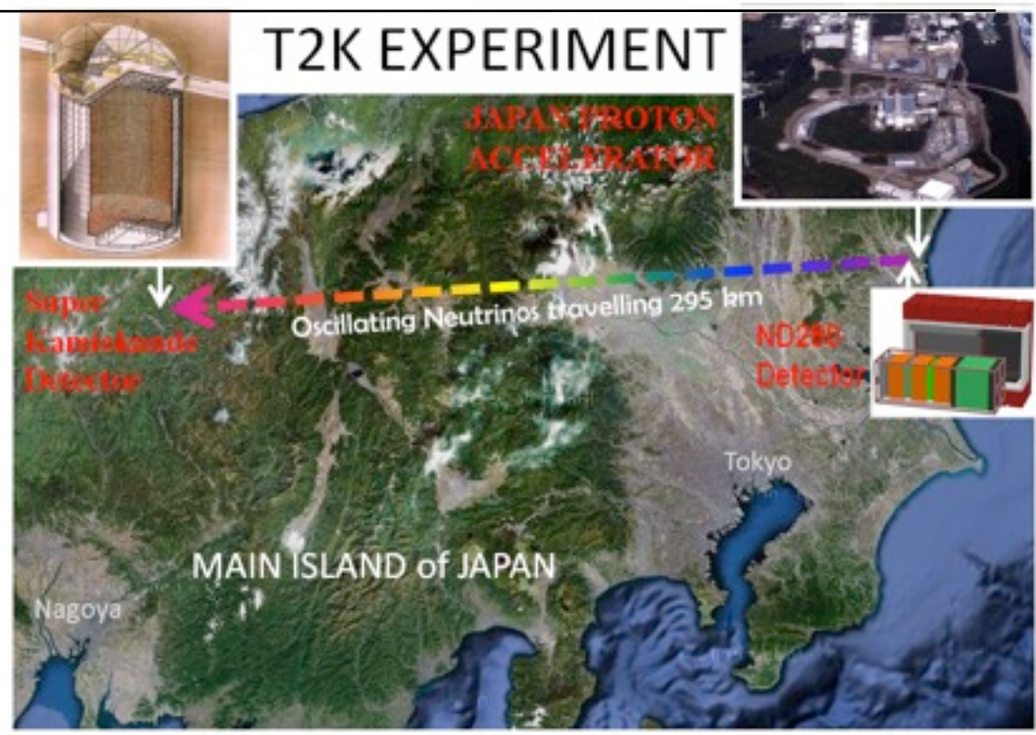
L is set to 290 km (distance between Tokai and Kamioka)

E is the free parameter we can tune ⟶ 600 MeV

The ν_μ beam is produced at J-PARC and pointed almost at SuperK

A near detector is placed 280 m downstream of the target

Comparing the rates in both detectors gives us access to the oscillations parameters



Far to Near (F/N) ratio

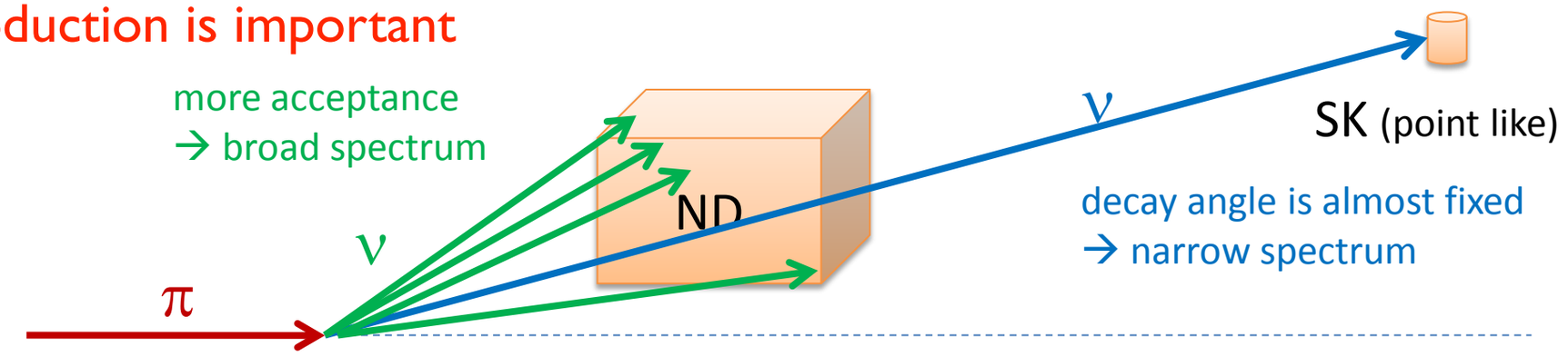
$$\Phi^{SK}_{\mu,e}(E_\upsilon) = R_{\mu,e}(E_\upsilon) \times \Phi^{ND}_{\mu,e}(E_\upsilon)$$

Extrapolated at SK — Measured at ND

because of the acceptance difference, spectrum shape is different between ND280 and SK => has to be taken into account in the F/N ratio

Spectrum shape depends on hadron production =>

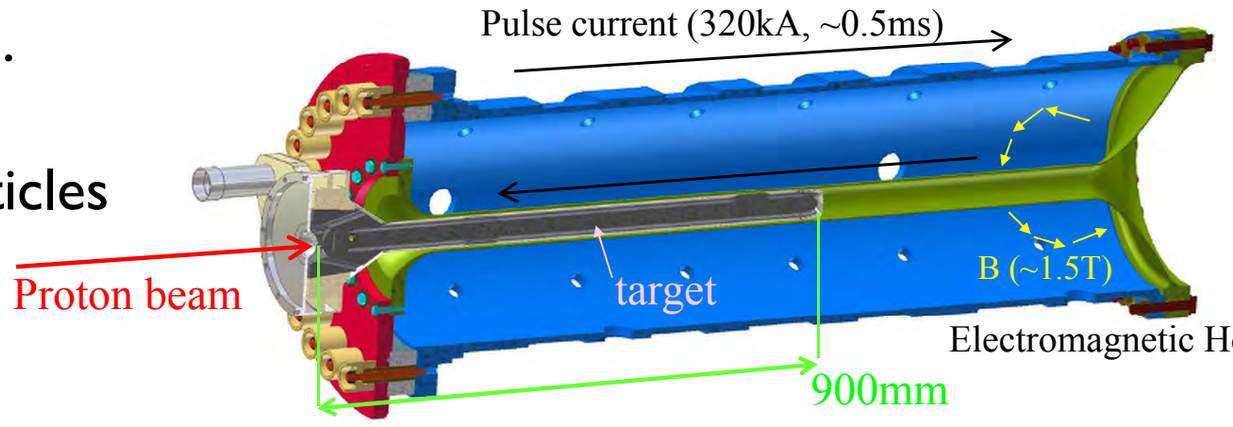
precise knowledge on hadron production is important



Hadron Production

A 31 GeV/c proton beam hits a 90cm long graphite target

Hadron production: $p + N \rightarrow \pi^-, K^-, \pi^+, K^+$ ...



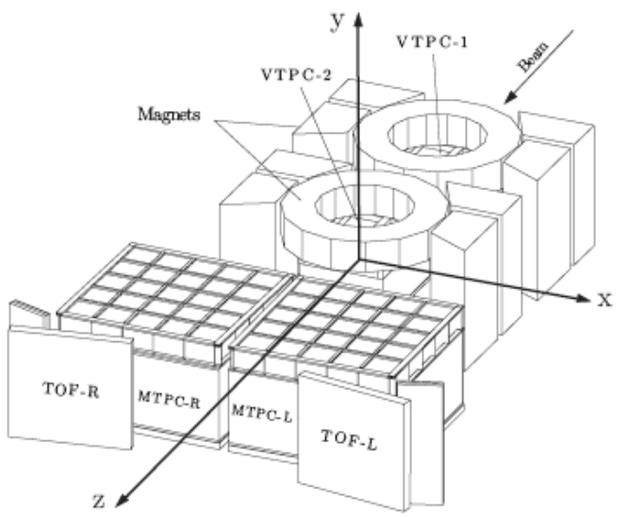
3 electromagnetic horns focus positively charged particles

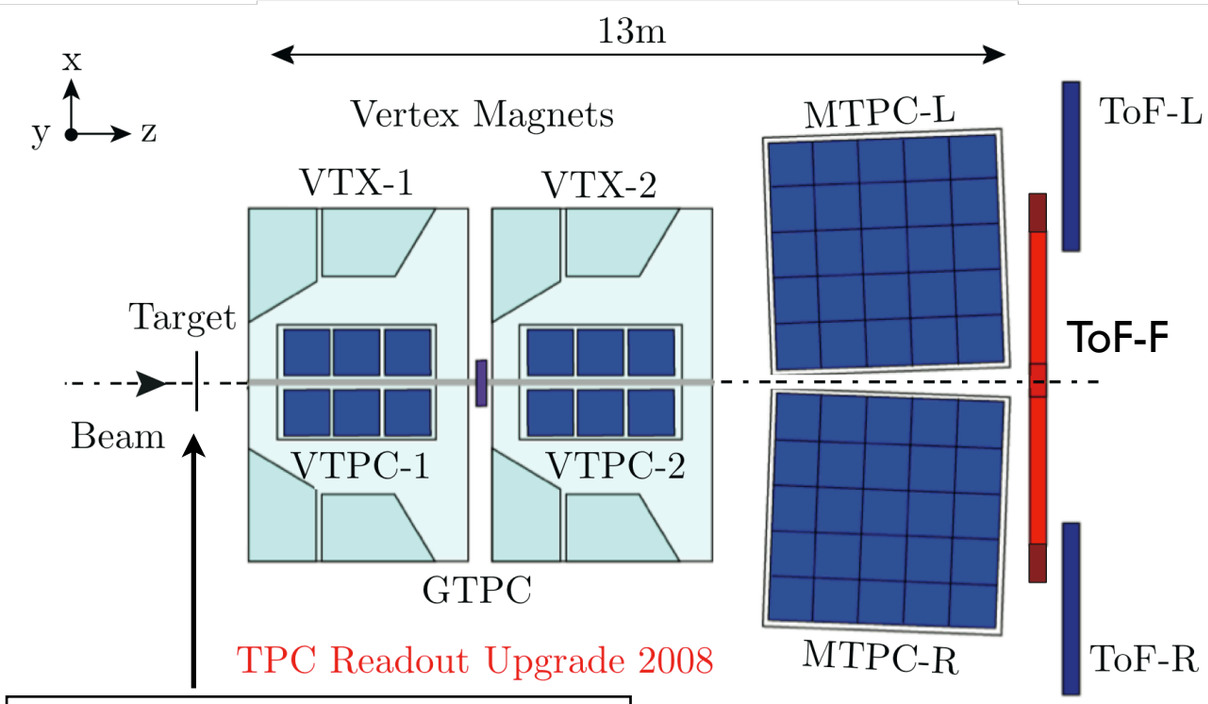
Pion decay :	$\pi^+ \rightarrow \mu^+ + \nu_\mu$	≈100%
Kaon decay :	$K^+ \rightarrow \mu^+ + \nu_\mu$	≈63%
	$K^+ \rightarrow \pi^+ + \pi^0$	≈21%
	$K^+ \rightarrow \pi^+ + \pi^+ + \pi^-$	≈5%
	$K^+ \rightarrow \pi^0 + e^+ + \nu_e$	≈5%
	$K^+ \rightarrow \pi^0 + \mu^+ + \nu_\mu$	≈3%

Precise knowledge of hadron production => precise knowledge of the flux and contamination

The NA61 experiment precisely measures the hadron production for a 31GeV/c proton beam on a graphite target.

NA61 experiment at CERN





Large acceptance spectrometer:

5 TPCs
2 dipole magnets
$\sigma(p)/p^2 \approx 10^{-4}$ (GeV/c)$^{-1}$
$\sigma(dE/dx)/\langle dE/dx\rangle \approx 0.04$

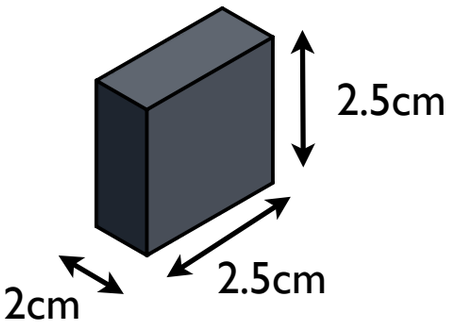
3 ToFs
σ(ToF-F) ≈ 120 ps
σ(ToF-L/R) ≈ 60 ps

Full Coverage of T2K phase space

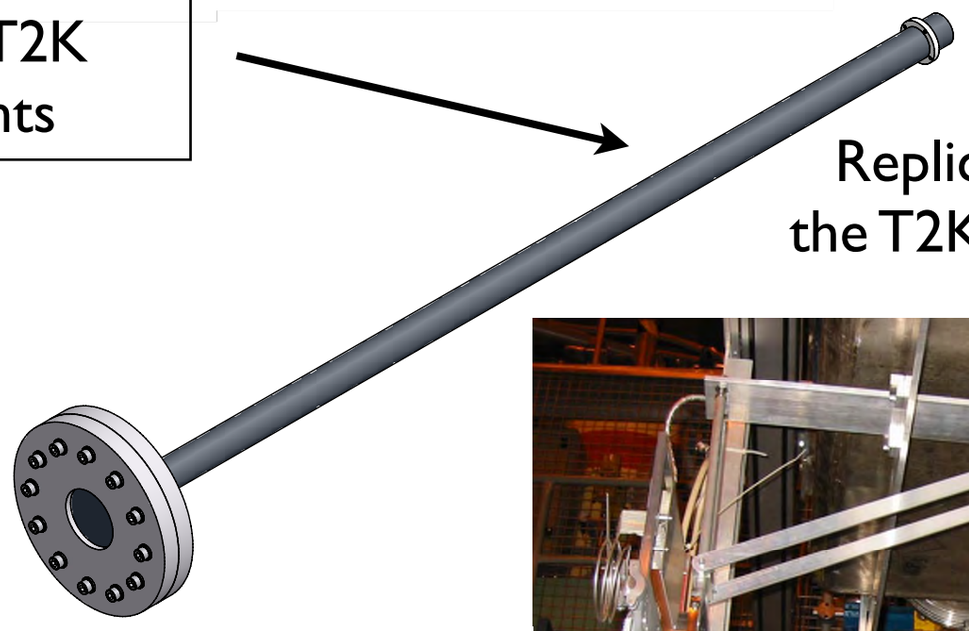
2 targets for T2K measurements

Thin Target

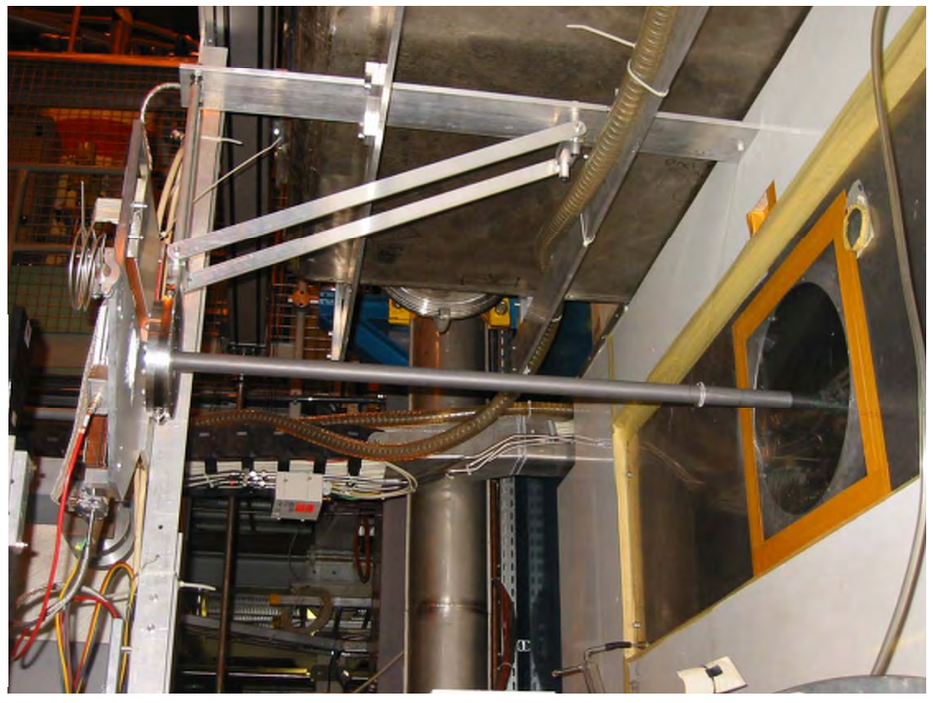
cross section and production measurements for p+C at 31 GeV/c



Replica Target of the T2K experiment

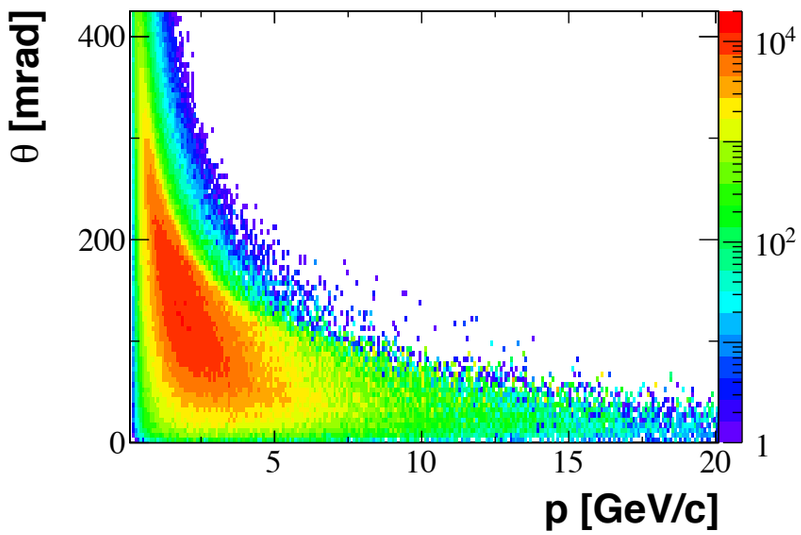


with (90cm) long target one can correct models for secondary interactions

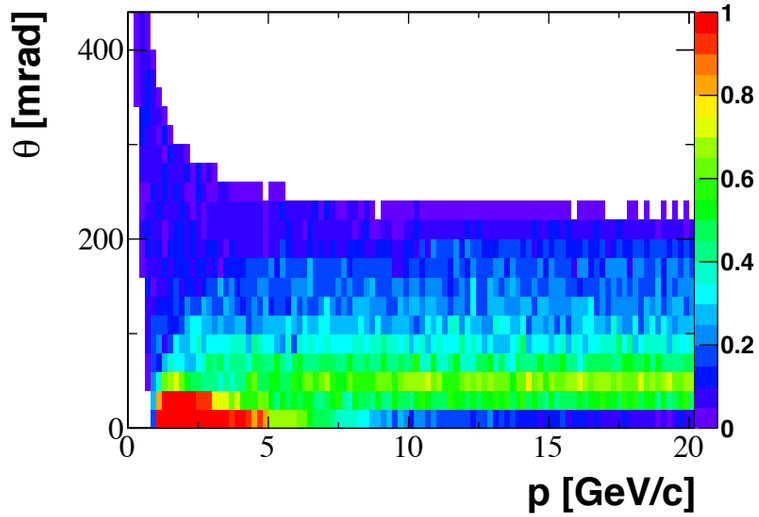


NA61 coverage and PID

Full coverage of T2K phase space



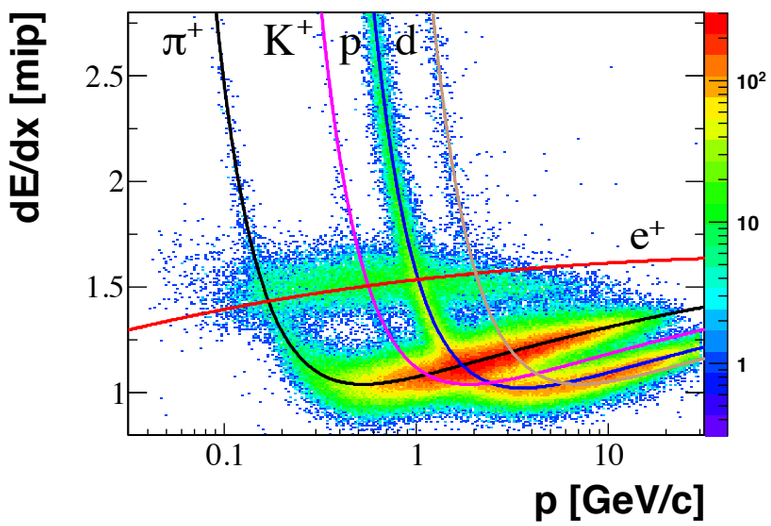
Prediction from the T2K beam simulation : {p, θ} distribution for positively charged pions weighted by the probability that their decay produces a muon neutrino passing through SK



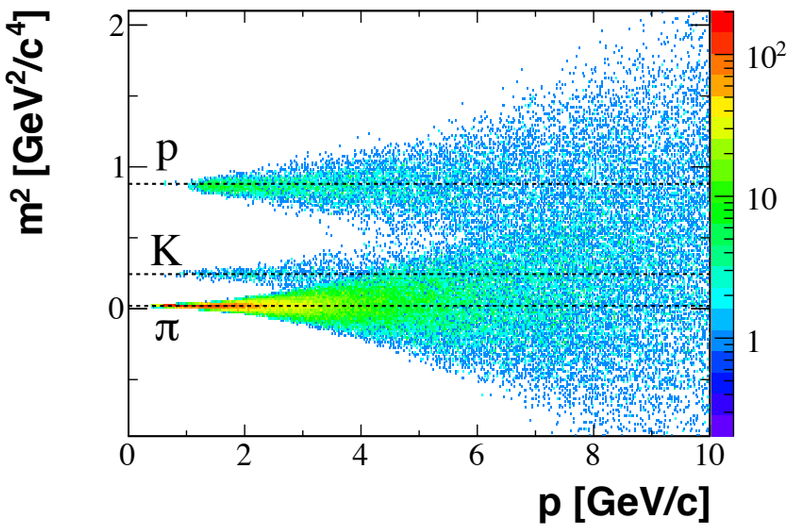
NA61 fraction of accepted particles as a function of momentum and polar angle after the track reconstruction cuts (for thin target analysis)

Particle ID

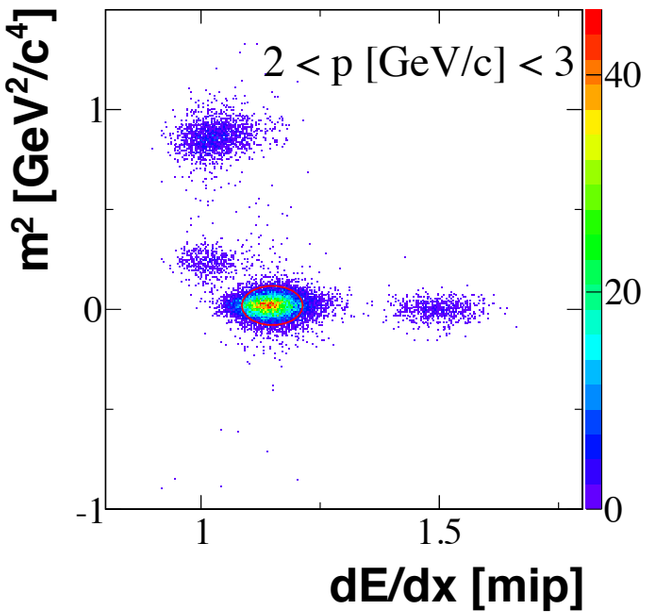
(Thin target data)



dE/dx identification



ToF identification



combined ToF dE/dx identification

NA61 long target measurements

At the T2K far detector:
~95% of ν_μ from π^+ mesons

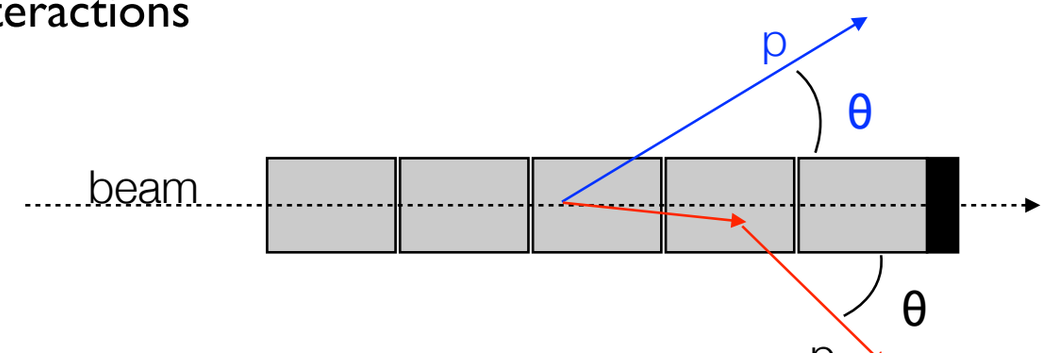
Among these π^+ mesons:
~60% from the primary interaction

~90% produced in the target coming from primary + secondary interactions

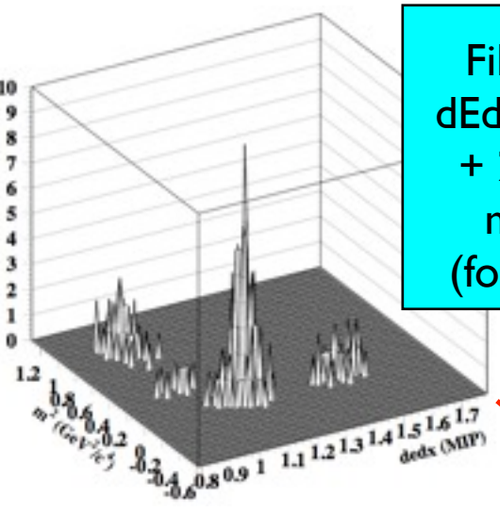
NA61 thin target data: π^+ production cross sections in p+C at 31 GeV/c → re-weight π^+ production from primary interaction in the FLUKA based T2K beam simulation

NA61 long target data: all π^+ exiting the target → re-weight the whole π^+ production from the target in the FLUKA based T2K beam simulation

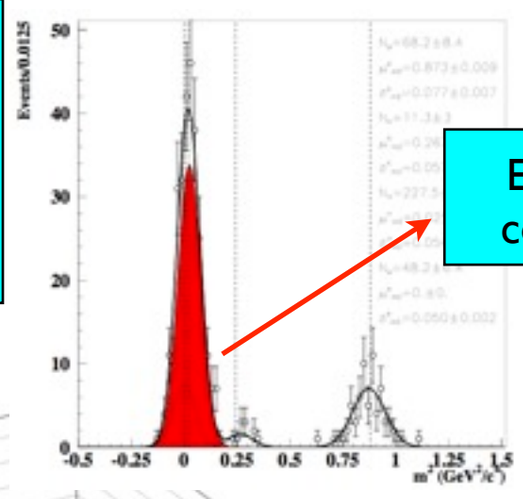
Target binning in (p,θ,z)
5 longitudinal bins + 1 for the downstream face



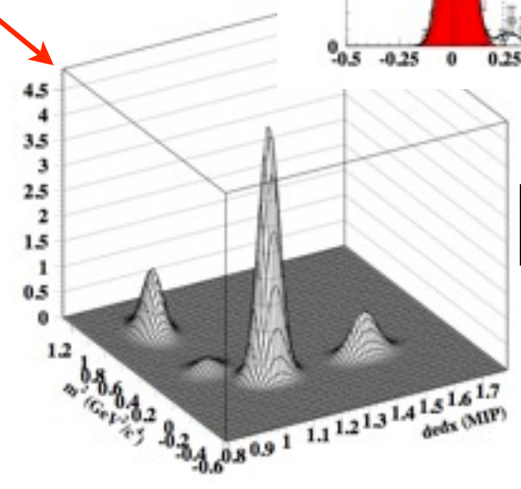
$$w(p,\theta,z) = \frac{N_\pi^{DATA}}{N_\pi^{FLUKA}} \times \frac{N_{pot}^{FLUKA}}{N_{pot}^{DATA}}$$



Fill m^2 (ToF) vs dEdx distributions + 2D likelihood minimization (for Data & MC)

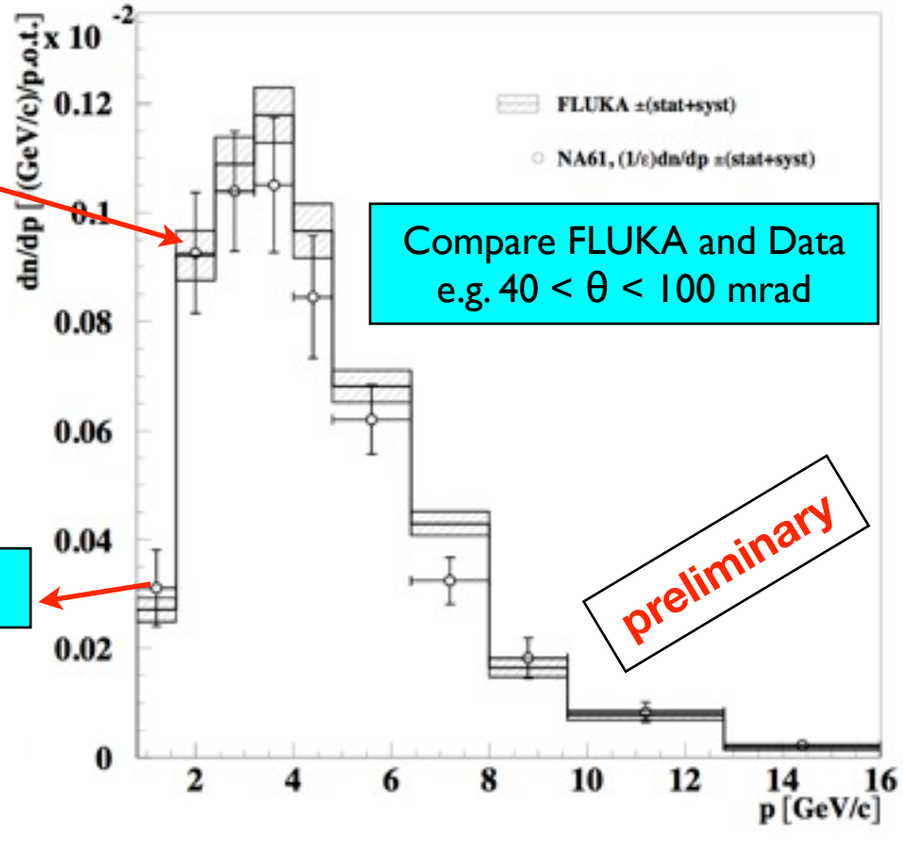


Extract π^+ component



Compute re-weighting factors

$$w(p,\theta,z) = \frac{N_\pi^{DATA}}{N_\pi^{FLUKA}} \times \frac{N_{pot}^{FLUKA}}{N_{pot}^{DATA}}$$



Compare FLUKA and Data
e.g. 40 < θ < 100 mrad

preliminary