Pion production in 30 GeV p+C
First results from NA61/SHINE

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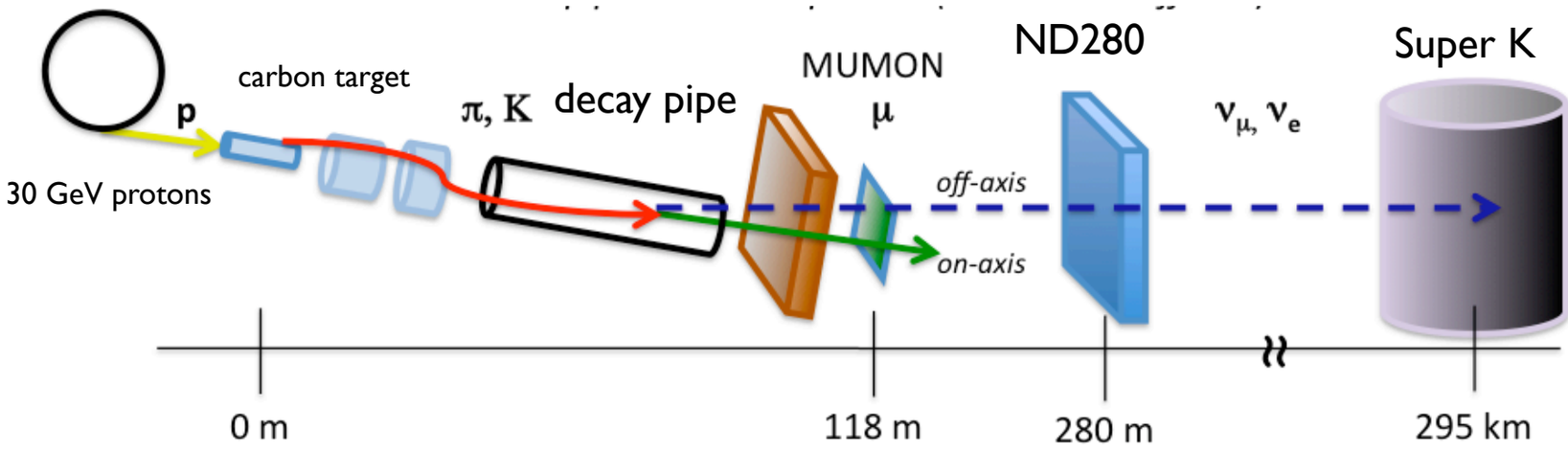
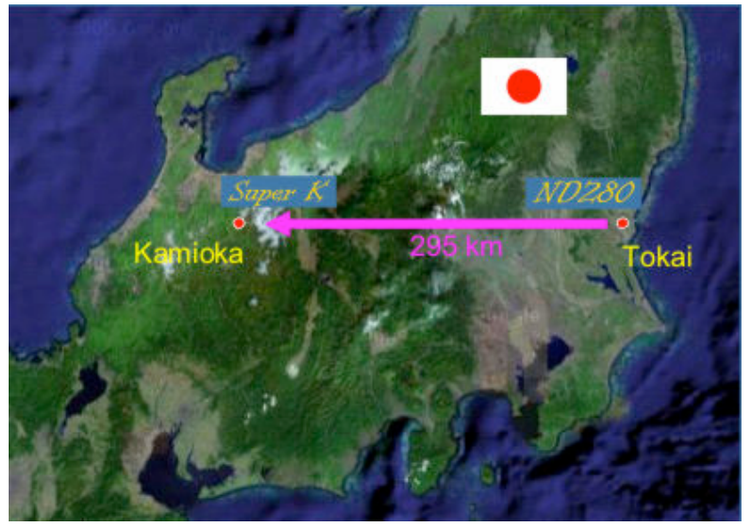
For the NA61/SHINE collaboration

One of the Goals of the NA61/SHINE (SHINE SPS Heavy Ion and Neutrino Experiment) experiment is to provide hadron production reference measurements for the T2K neutrino oscillation experiment. Shown here are results of pion cross sections from pilot data collected in October 2007.

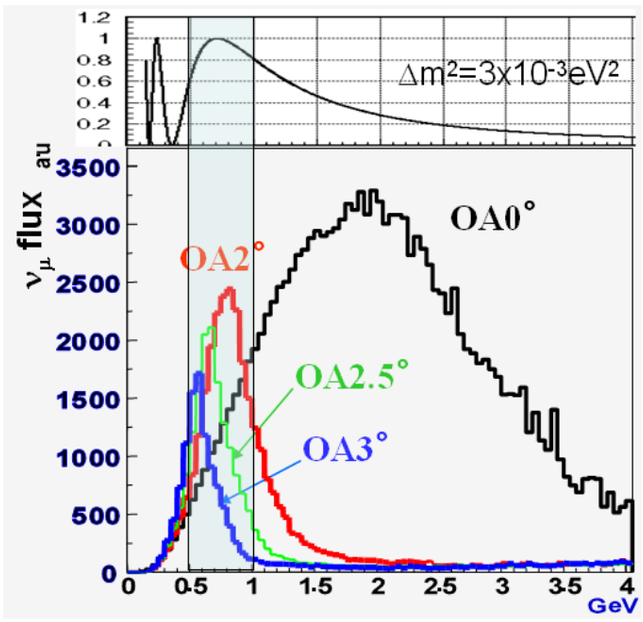
http://na61.web.cern.ch

T2K (Tokai to Kamioka)



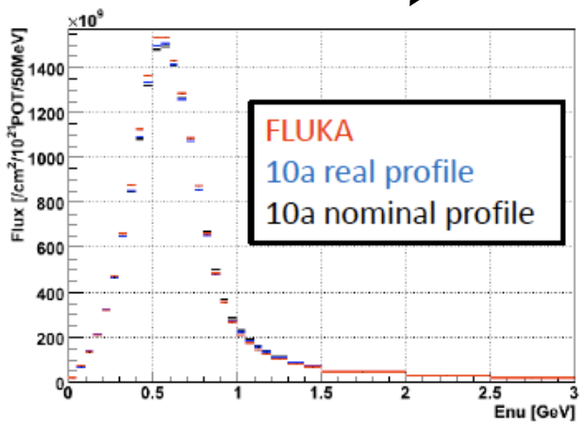


- next generation long-baseline (295 km) neutrino oscillation experiment
- intense ν_μ beam generated by the new JPARC facility in Tokai.
- first off axis neutrino beam:
  - -very narrow neutrino energy spectrum with small high energy tails.
  - -beam energy tuned to neutrino oscillation maximum.
- 2 near detectors one on axis (MUon MONitor) and one off axis at 280 m from the target (ND280).
- Running since January 2010, beam: 50 kW stable operation with trials at 100 kW.
- Goals:
  - $\nu_\mu \rightarrow \nu_x$ for precision results on atmospheric parameters.
  - $\nu_\mu \rightarrow \nu_e$ for Θ_{13} search.

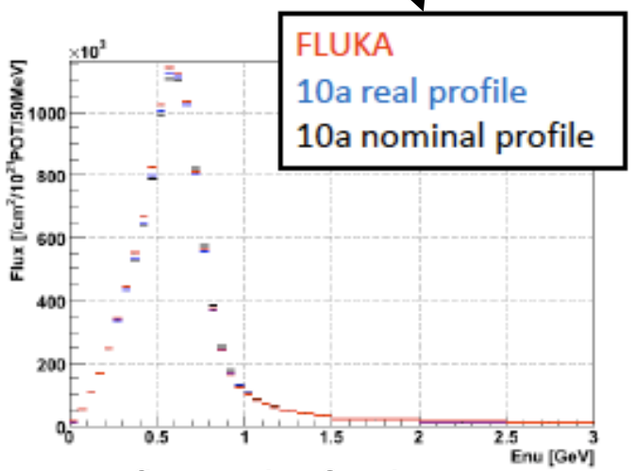


Off-axis ν beam, peak energy at oscillation maximum ~650 MeV

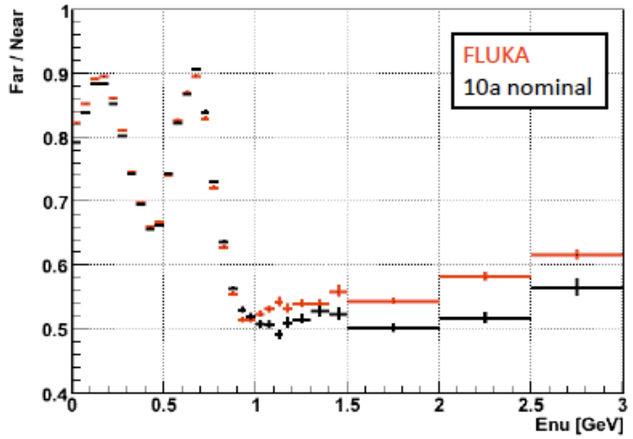
T2K needs for hadron production measurements



ν_μ *flux at the near detector*



ν_μ *flux at the far detector*



Far/Near flux ratio (ν_μ)

- The expected flux at SK is: $\Phi_{SK}^{\exp} = R_{F/N} \times \Phi_{ND}^{obs}$ **Far to near Ratio** (MC): $R_{F/N} = \Phi_{SK} / \Phi_{ND}$

- The neutrino spectrum at far detector different from the one at near site even without oscillation (effect of non-point like source). =>complicated F/N ratio.
- To predict the ν flux ratio correctly we need to know the details of the ν parent hadro-production kinematics.
- No measurement of particle production off carbon with 30 GeV protons over required phase space Difficult to evaluate the validity of existing MC models =>NA61/SHINE

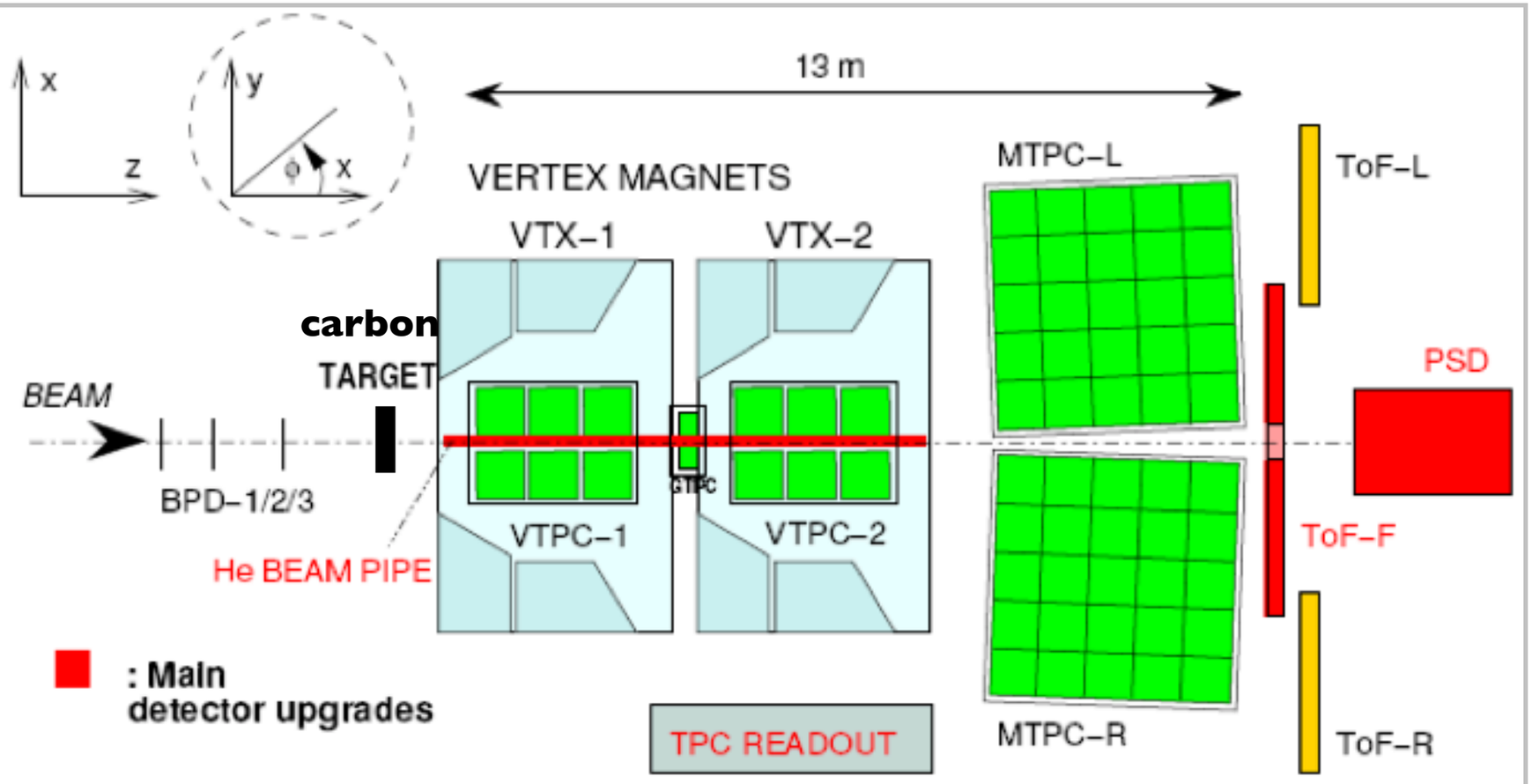
- To achieve the T2K physics goals need to

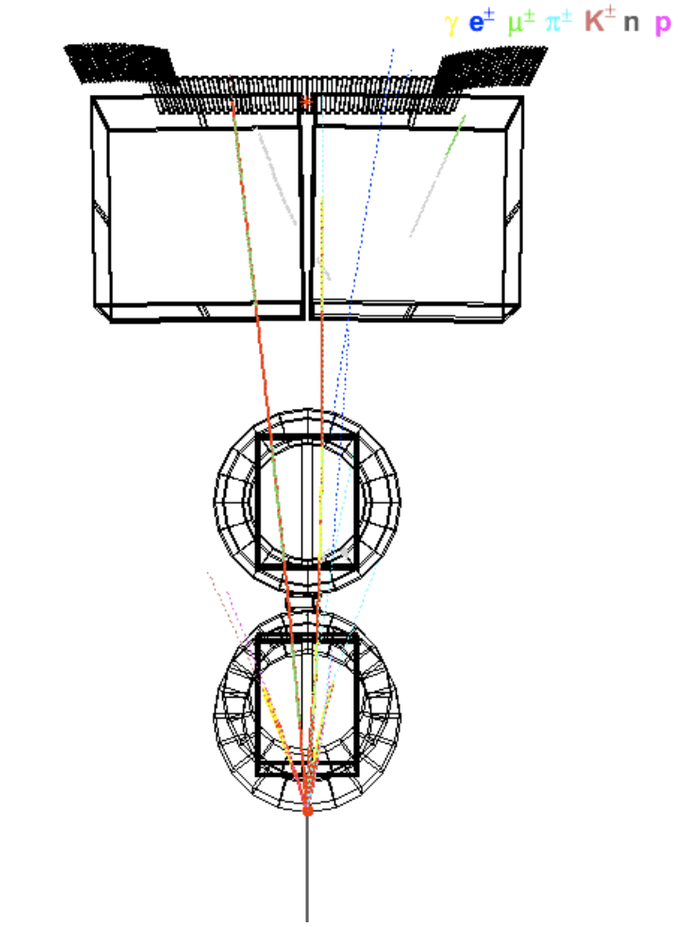
Predict Far / Near neutrino flux ratio to 3%
Predict the absolute neutrino flux to 5%

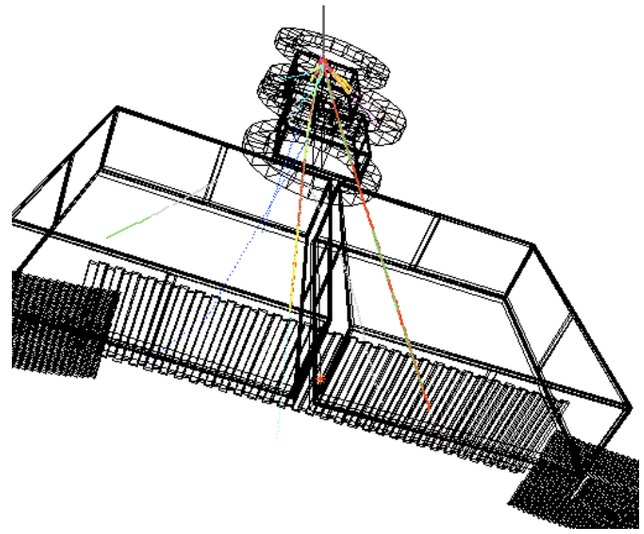
That implies that in NA61 we have to measure π hadro-production cross sections to 5 %

NA61/SHINE

SPS Heavy Ion and Neutrino Experiment







thin target: 2.5x2.5x2 cm^3 int. length ~ 0.04

long target: 90 cm ∅ = 2.6 cm int. length ~ 1.9

3 BPDs (Beam position detectors)

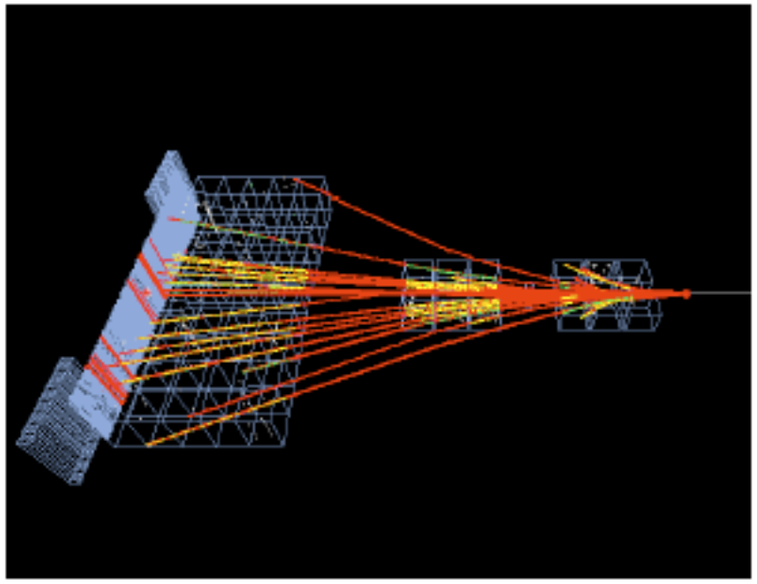
5 TPCs $\sigma(p)/p^2 \sim 10^{-4}$

3 Time of flight: FTOF resolution ~120ps
TOF,L,R resolution ~70 ps

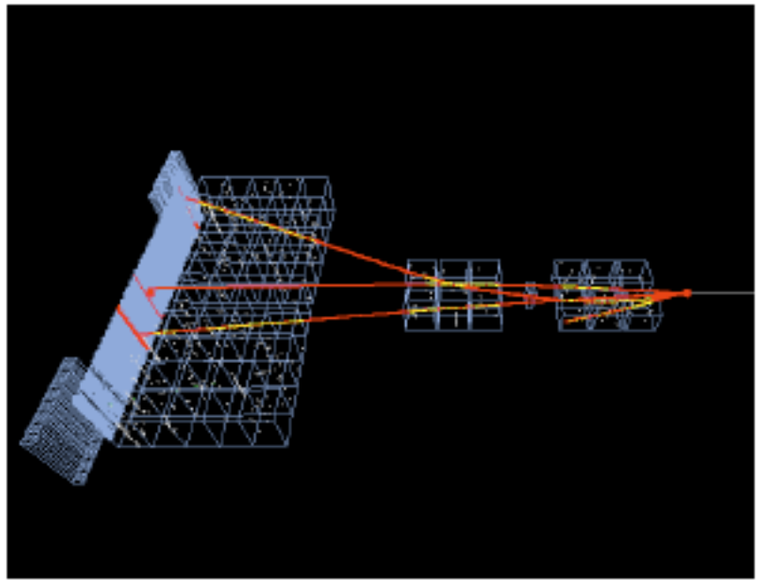
<=Added in 2007 for T2K measurements and extended in 2009

T2K phase space

- High quality of reconstruction:

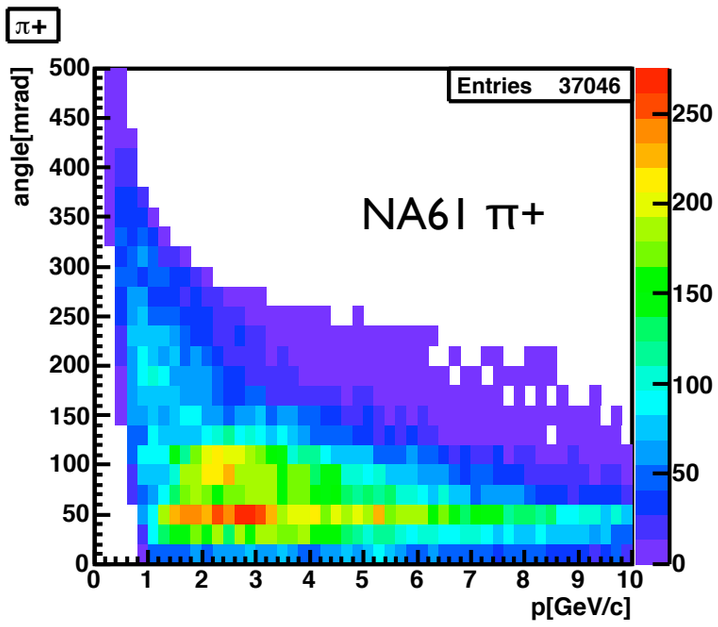


π-+C @ 350 GeV/c

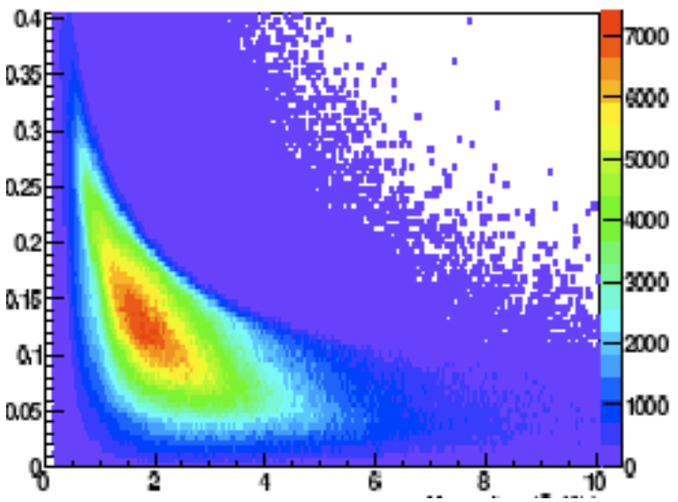


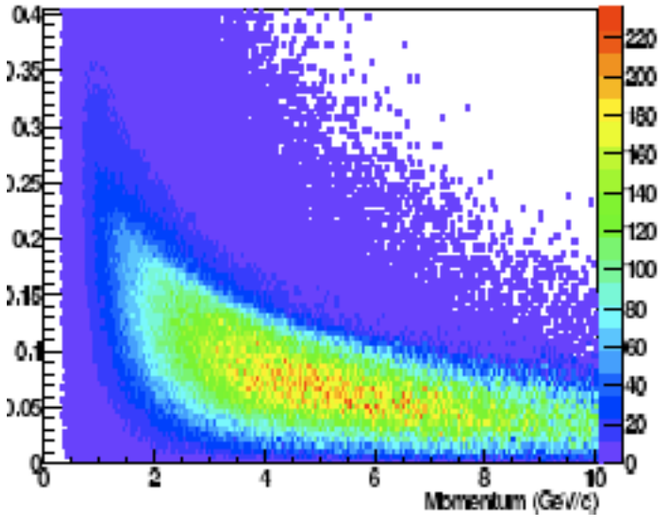
•p+C @ 30 GeV/c

- T2K phase-space entirely covered:



π+ and K+ producing neutrinos at @ SK



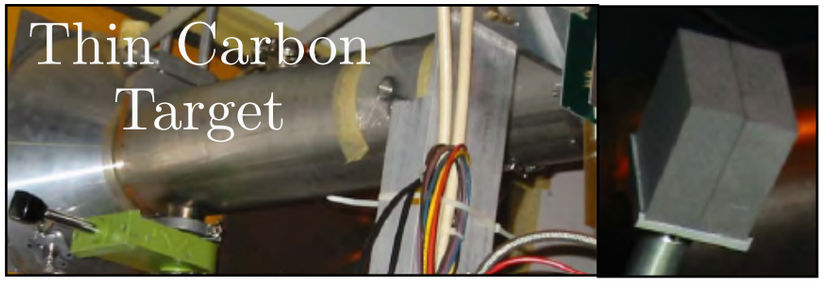


NA61 data taking for T2K

- 2007 pilot run:
  - thin target ~ 660 k triggers
  - replica target ~ 230 k triggers
- 2009 run:
  - thin target ~ 6 M triggers
    - ⇒ 300 k π^+ in T2K phase space
  - replica target ~ 2 M triggers
- 2010 run:
  - complete measurements with replica target
  - ~ 10 M triggers (~ 1 M additional triggers taken with max B in the forward region to predict μ flux in on-axis μ monitors)

Both targets required to understand pC interactions and model reliably of the neutrino flux.

2 different graphite (carbon) targets

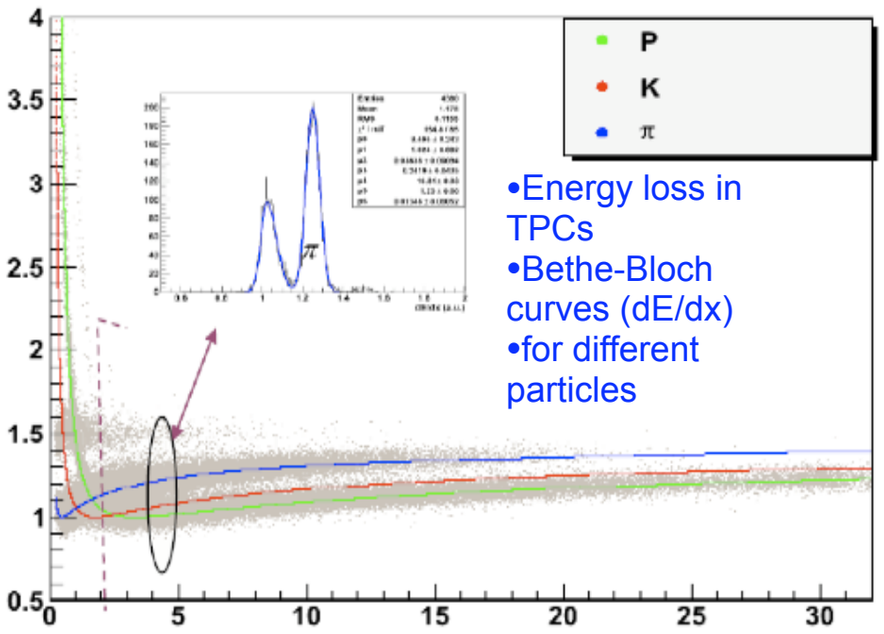


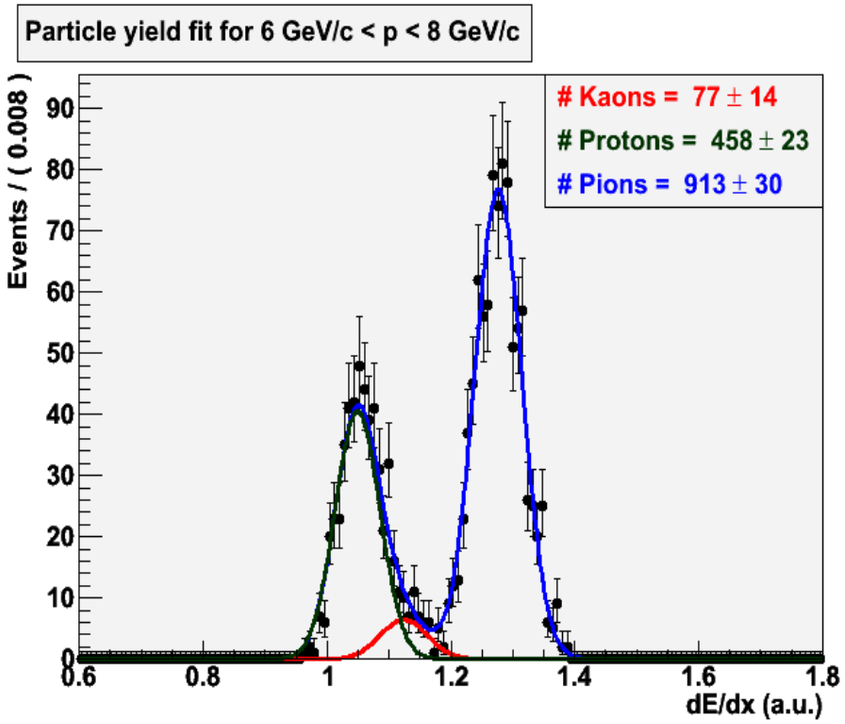
Thin Carbon Target
- **length = 2 cm, 2.5x 2.5 cm²**
- **ρ = 1.84 g/cm³**
- **~0.04 λ_{int}**

T2K replica Target
- **length = 90 cm, Ø=2.6 cm**
- **ρ = 1.83 g/cm³**
- **~1.9 λ_{int}**

Particle identification Methods

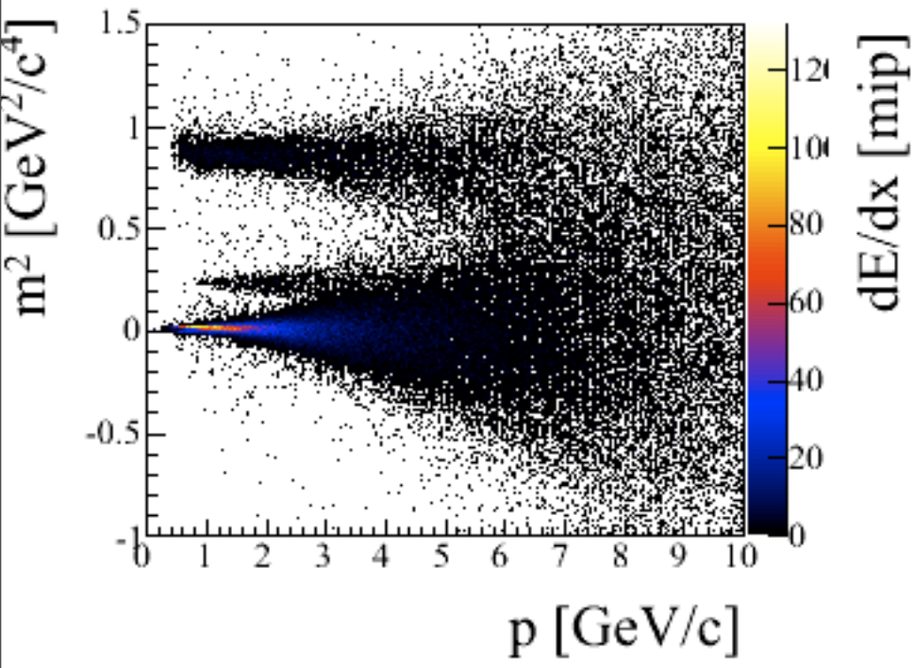
•dE/dx only PID in the relativistic rise region (p ~ above 4 Gev/c)

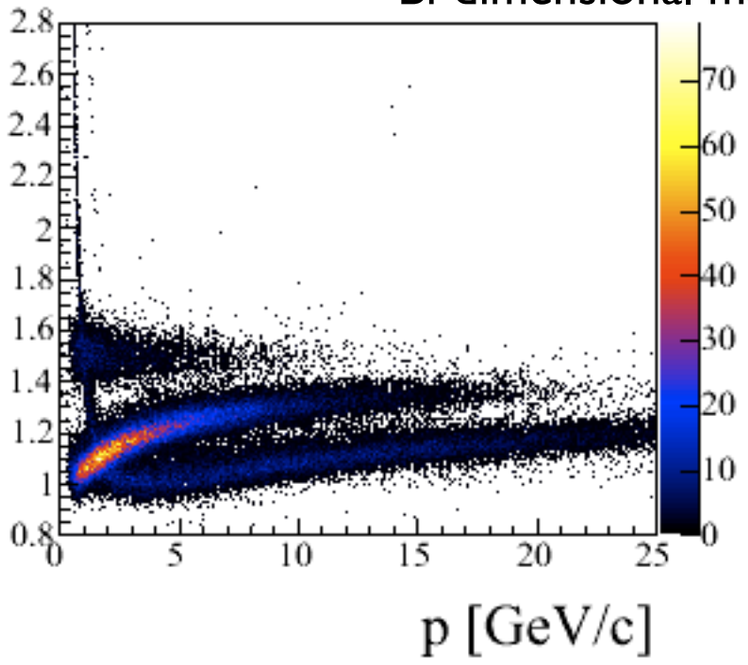




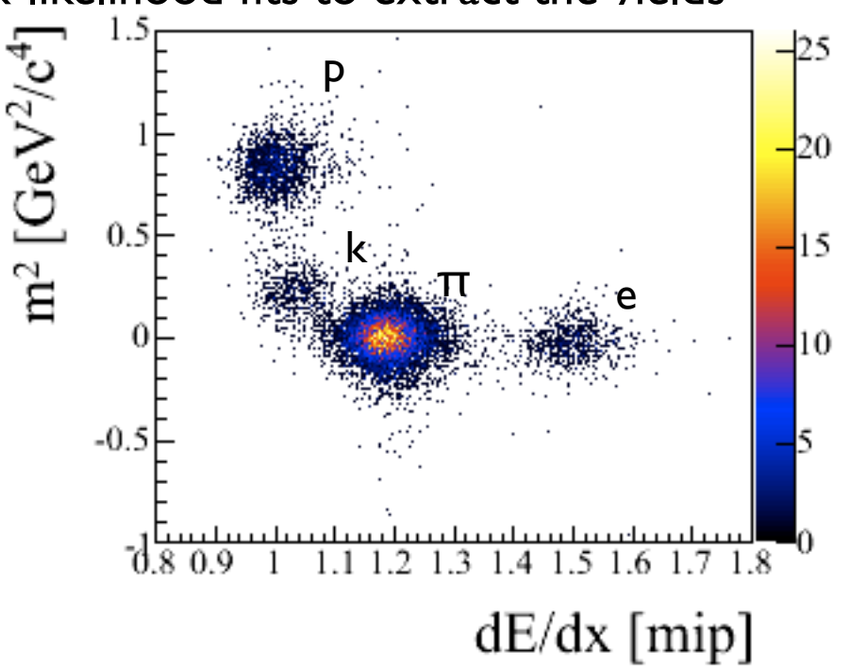
•superposition of 3 gaussians
•maximum likelihood fit
•relative peak positions constrained
•by the expected Bethe-Bloch values
•assume same width for π, K, and p
•(5 free parameters instead of 9)

•Combined ToF-dE/dx PID over the whole momentum range:



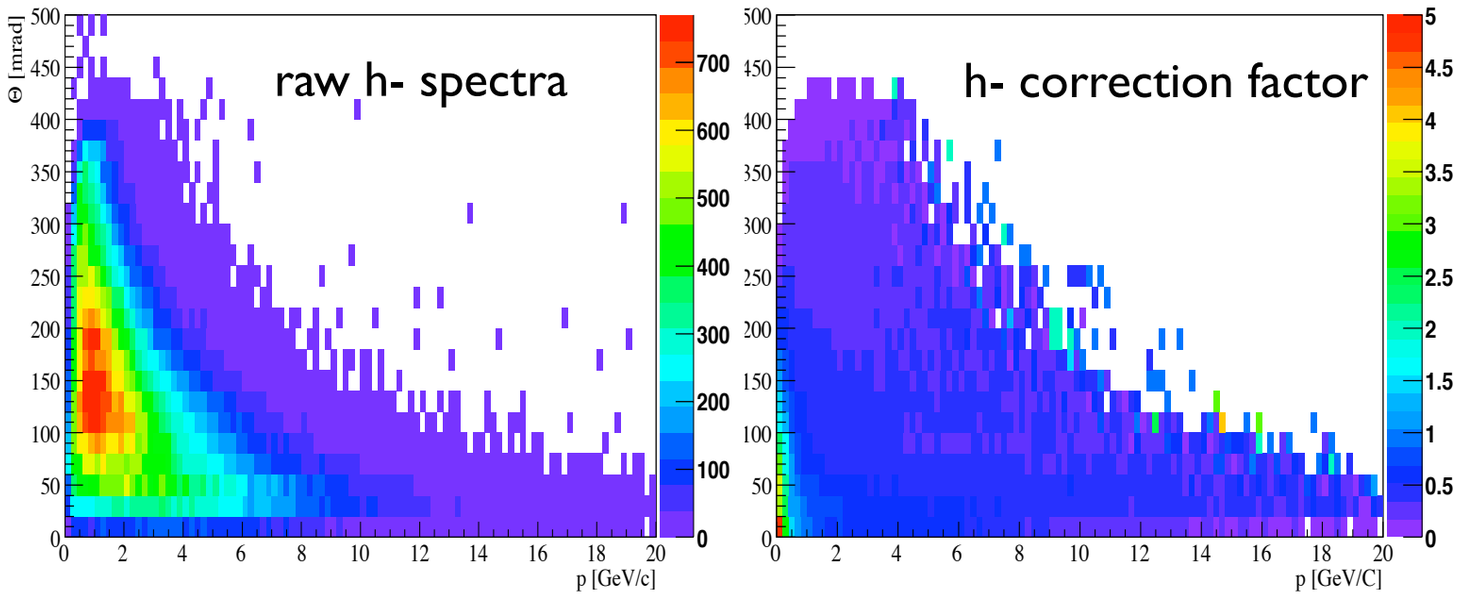


•very high purity pion yields
•Bi-dimensional max-likelihood fits to extract the yields

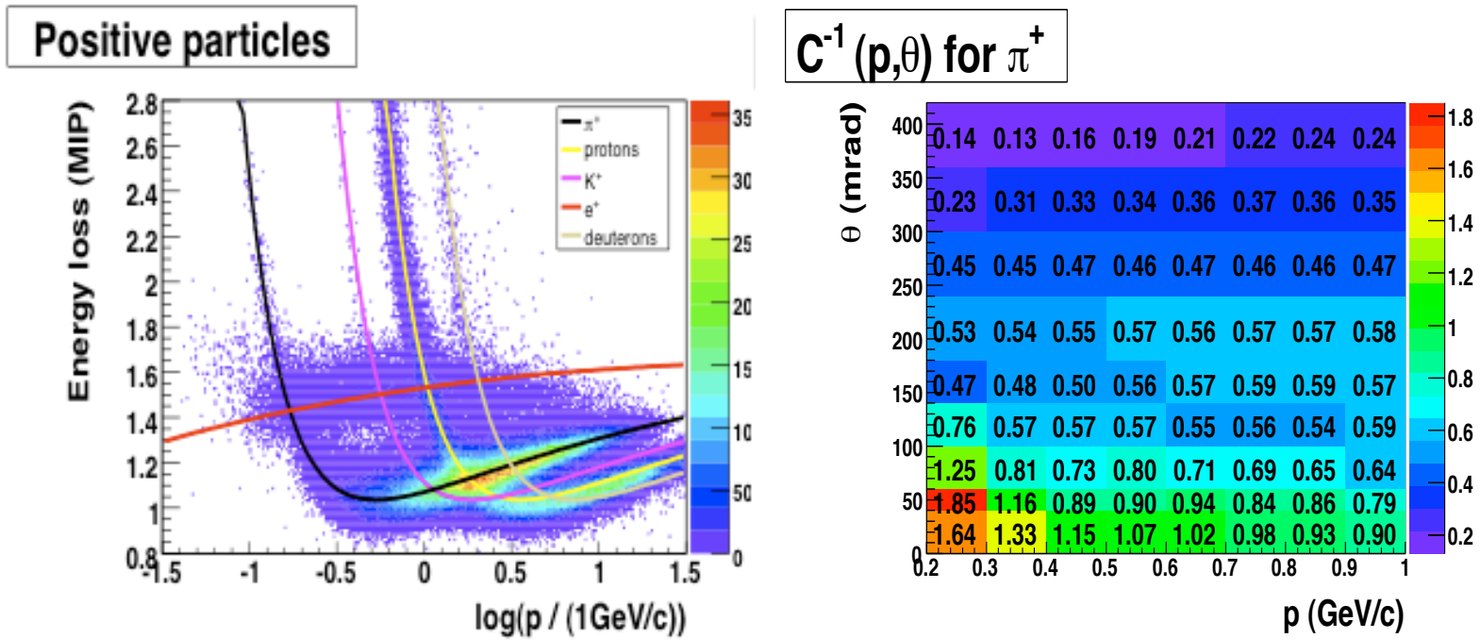


Analysis methods

- **h minus analysis**:
  - only for π-.
  - pure tracking with no pid- large acceptance.
  - consider all negative tracks and remove electrons and k- with a global Monte Carlo correction.



- **Dedicated dE/dx only below 800 MeV/c**:
  - Fast change of energy loss with momentum.
  - π+ and π- large acceptance
  - PID based only on dE/dx.
  - Global MC correction (takes into account reconstruction efficiency, acceptance of the NA61 detector, smearing between neighboring bins, pion decays)
  - relativistic rise region in preparation.

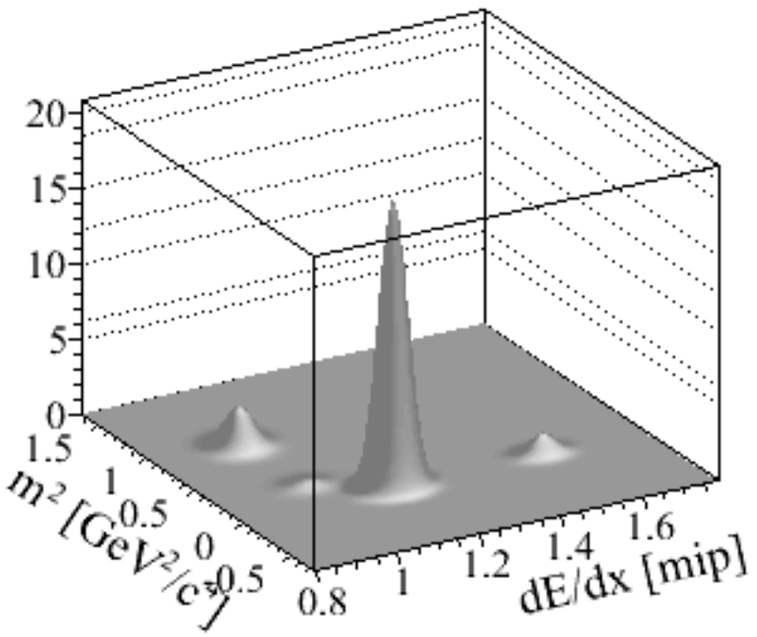


- **Analysis based on combined ToF+dE/dx PID:**
  - π+ and π-
  - Request particles in ToF ->High purity PID over whole momentum range, but reduced acceptance.
  - Step by step MC corrections
  - **See next slides**

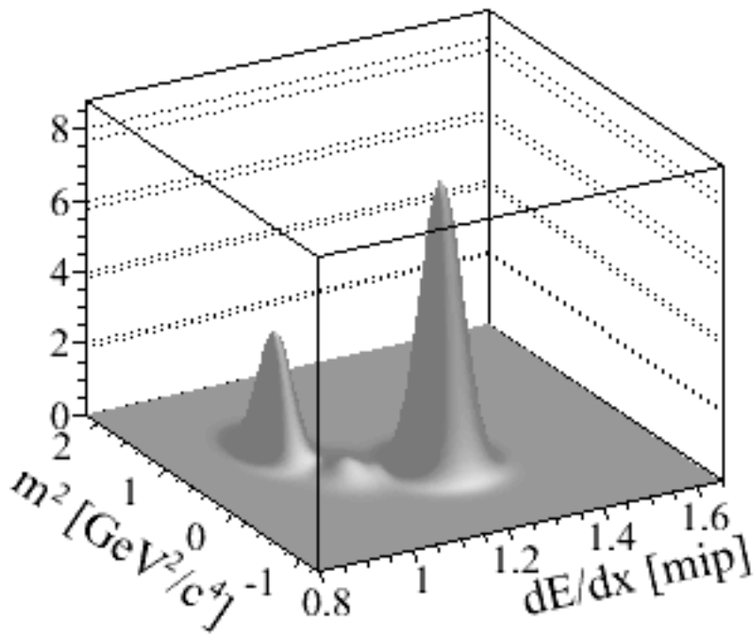
Analysis based on combined ToF-dE/dx PID

- Examples of 2D Fits in the mass-squared-dE/dx plane:
- Fit with a sum of 4 Normalized 2D Gaussians (20 parameters):

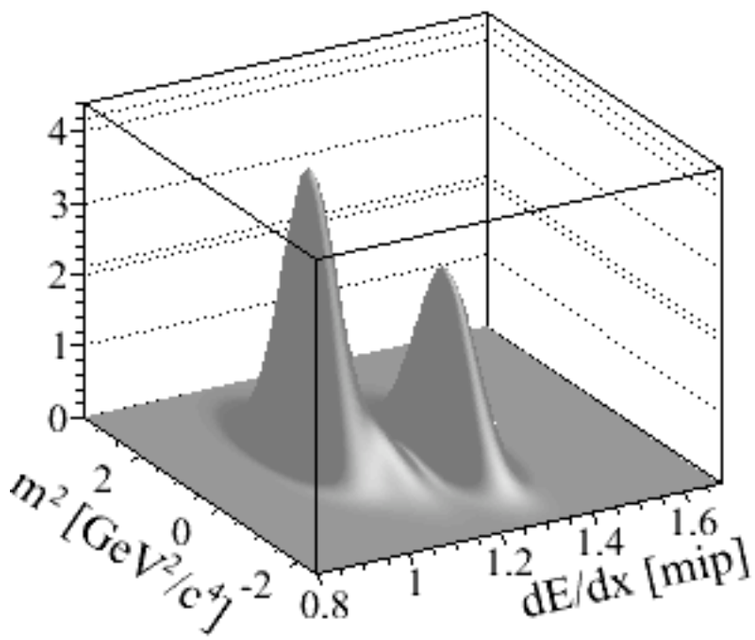
- 3-3.2 GeV/c



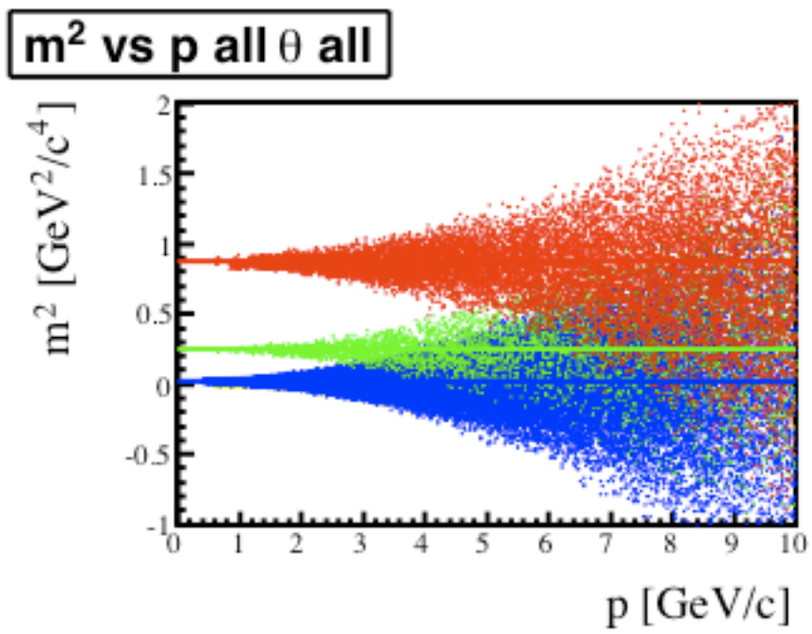
- 5-5.2 GeV/c

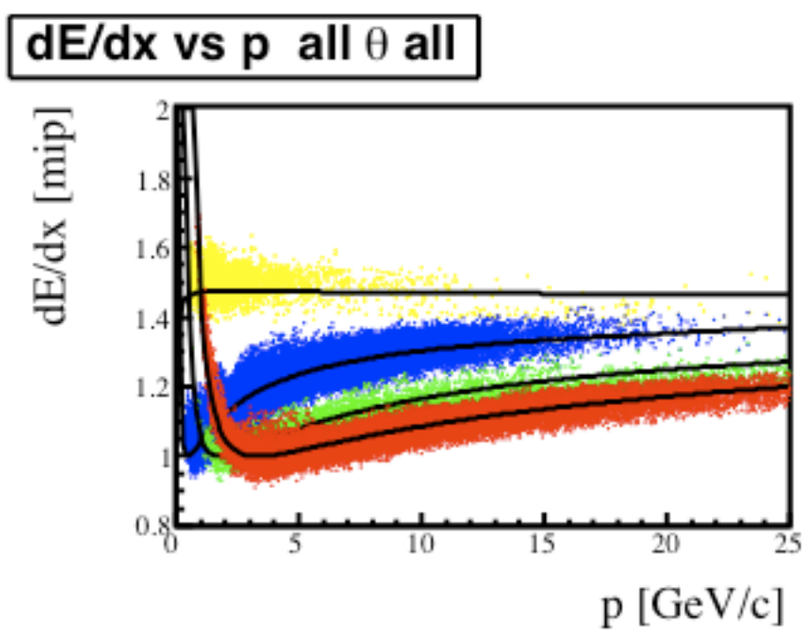


- 9.6-10 GeV/c



- identified particles





List of Monte Carlo corrections

The following effects are corrected for bin by bin:

- geometrical acceptance of the detector.
- Efficiency of the reconstruction chain.
- Efficiency of the time of flight detector.
- pions decaying before reaching the ToF.
- pion lost to secondary hadronic interactions.
- pions from weak decays reconstructed as a primary track

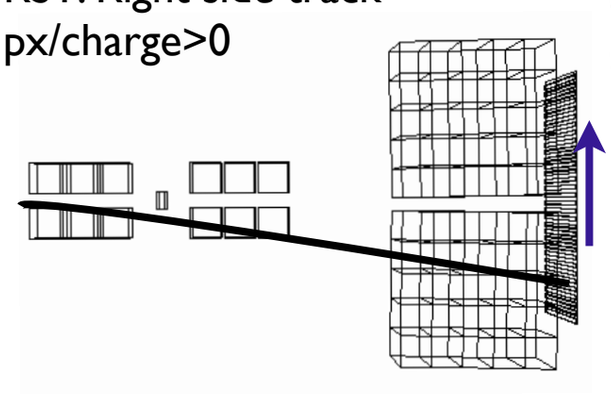
  (important correction for π^- from lambda decay).

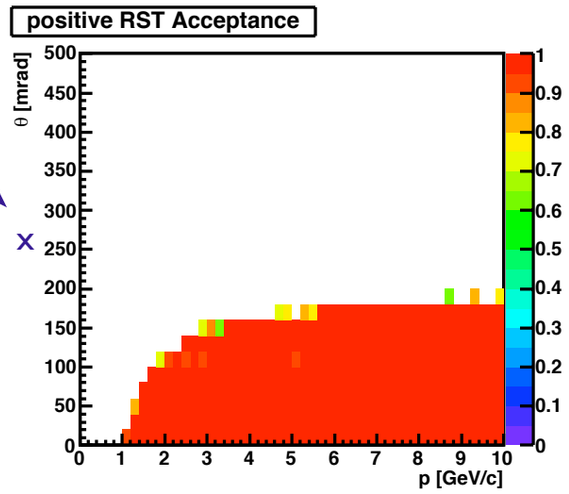
Monte Carlo corrections

Example of correction: geometrical acceptance

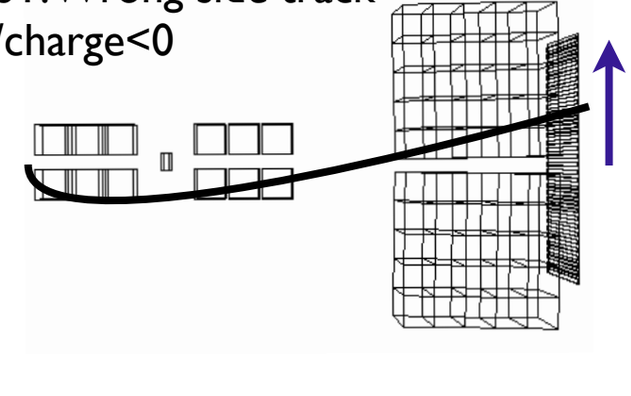
Two track topologies called Right Side Tracks (RST) and Wrong Side Tracks (WST) populate different areas of the detector phase space. Bins with a lower than 40% acceptance are not considered to avoid sharp fluctuations on the detector side.

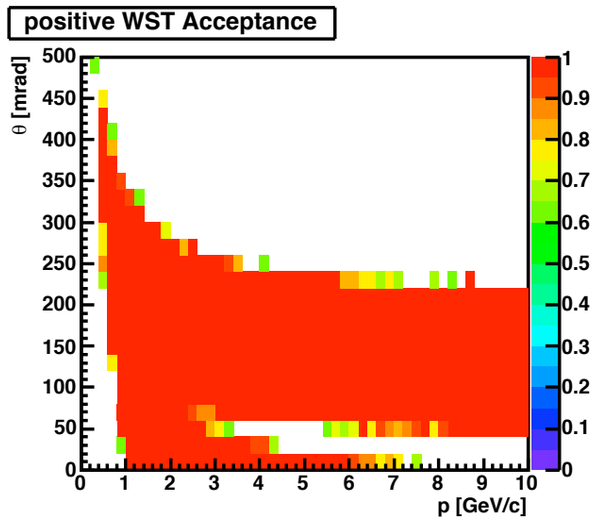
RST: Right side track
px/charge>0



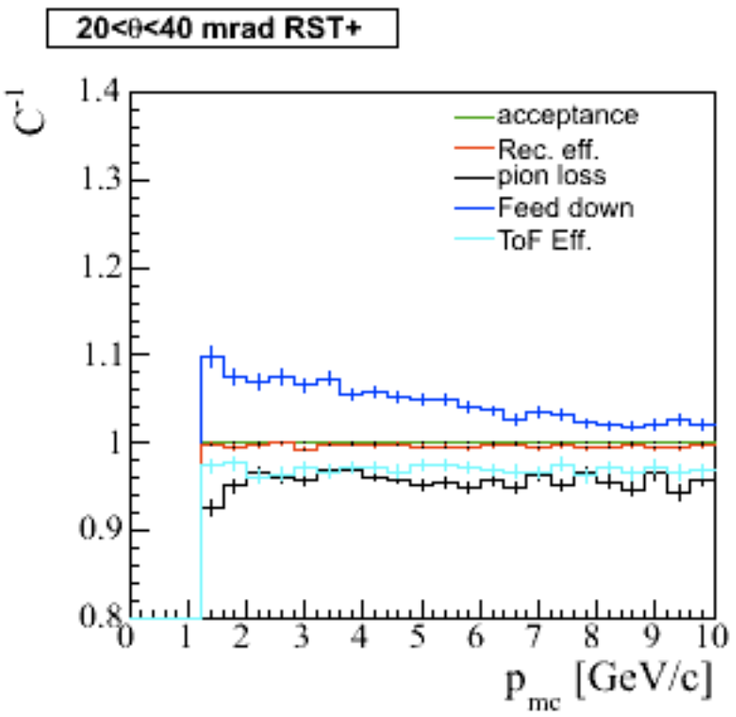


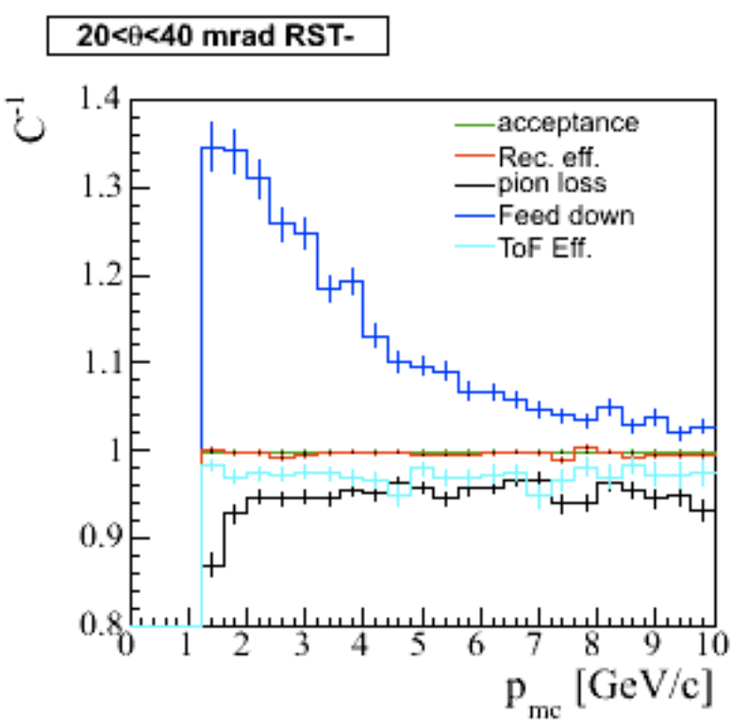
WST: Wrong side track
px/charge<0





All corrections

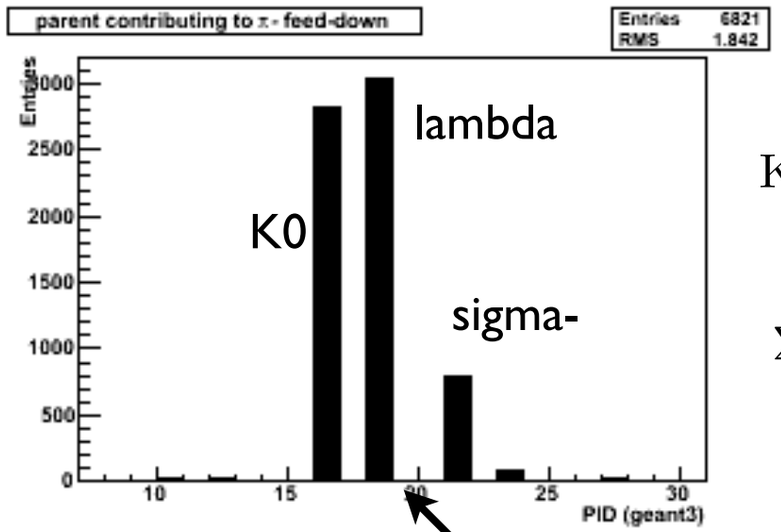




- Select only regions with high acceptance => low correction factors.
- Except for π- where the Feed down correction reaches ~40% in a few areas (because of lambdas)

particles leading to feed down

particles leading to π- feed down

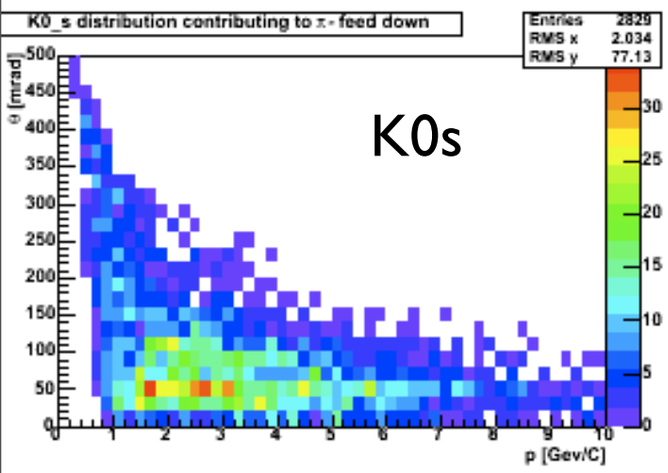


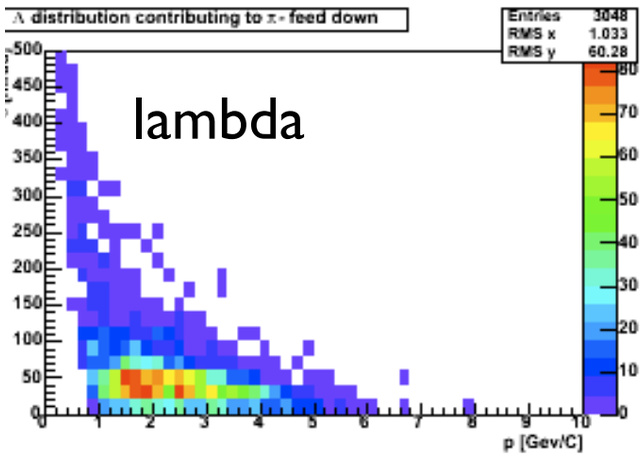
main source:

$$K_s^0 \rightarrow \pi^+ + \pi^-$$

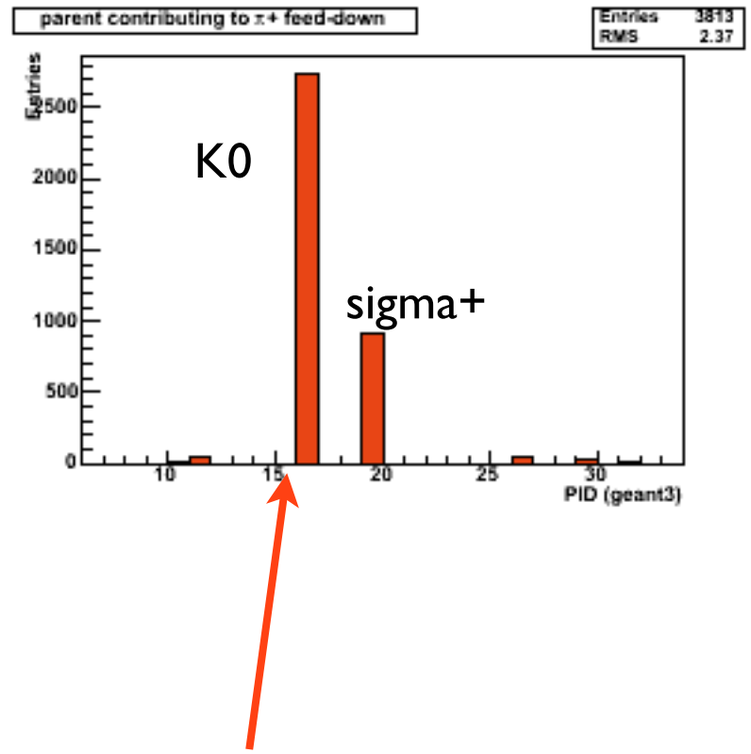
$$\Lambda \rightarrow p + \pi^-$$

$$\Sigma^- \rightarrow n + \pi^-$$





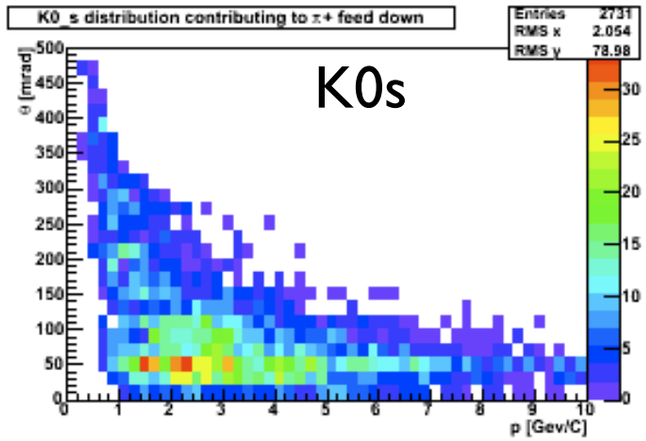
particles leading to π+ feed down



main source:

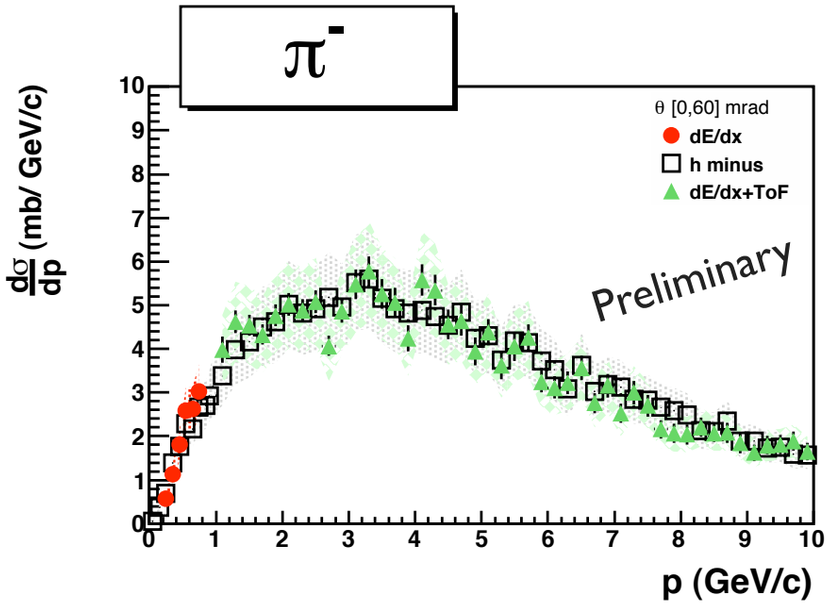
$$K_s^0 \rightarrow \pi^+ + \pi^-$$

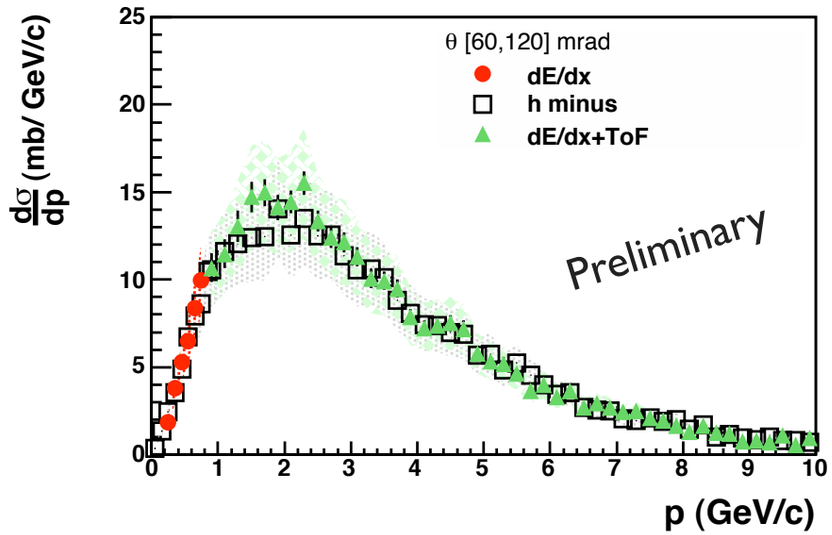
$$\Sigma^+ \rightarrow n + \pi^+$$

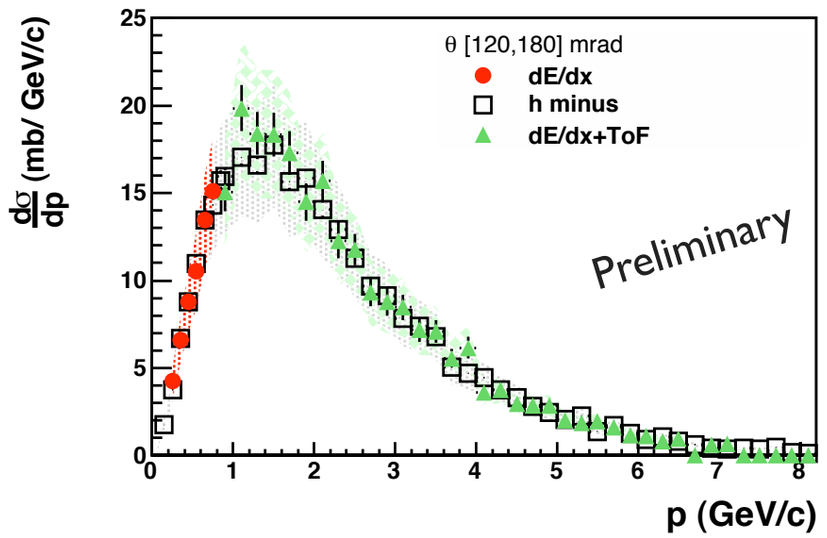


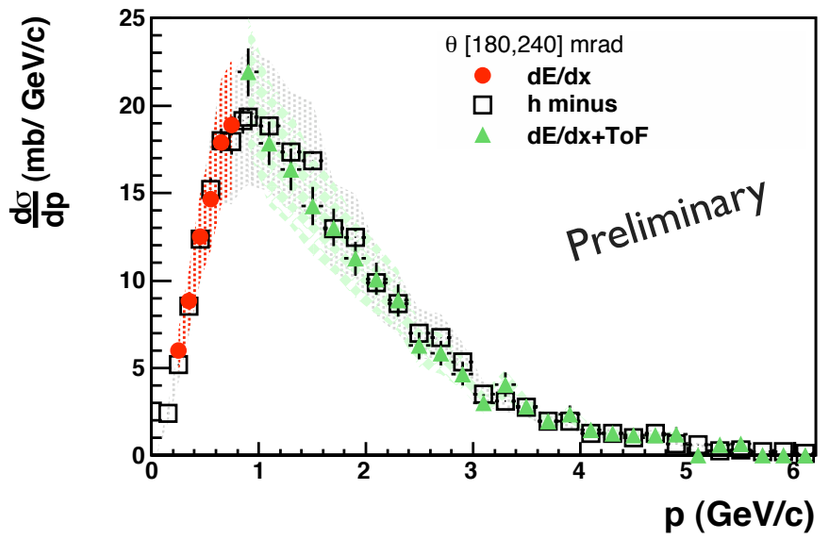
All results π-

Comparisons between preliminary results show good agreement except for a few momentum bins in the 60-120 mrad region (up to 20% difference). **->20% systematic error on the spectra.**



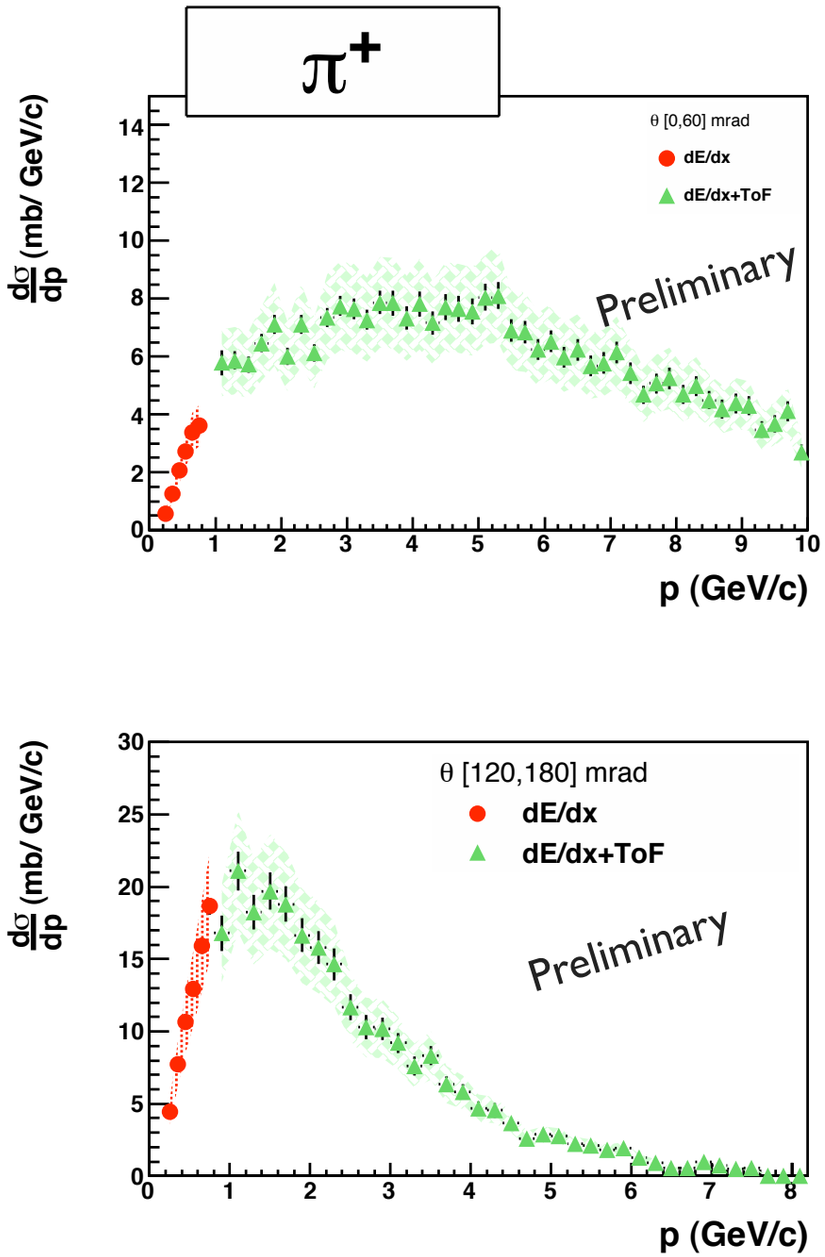


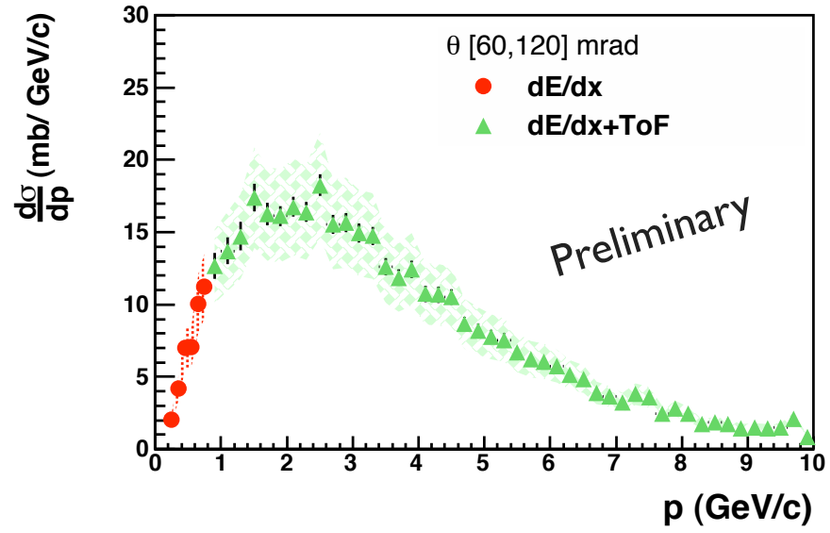


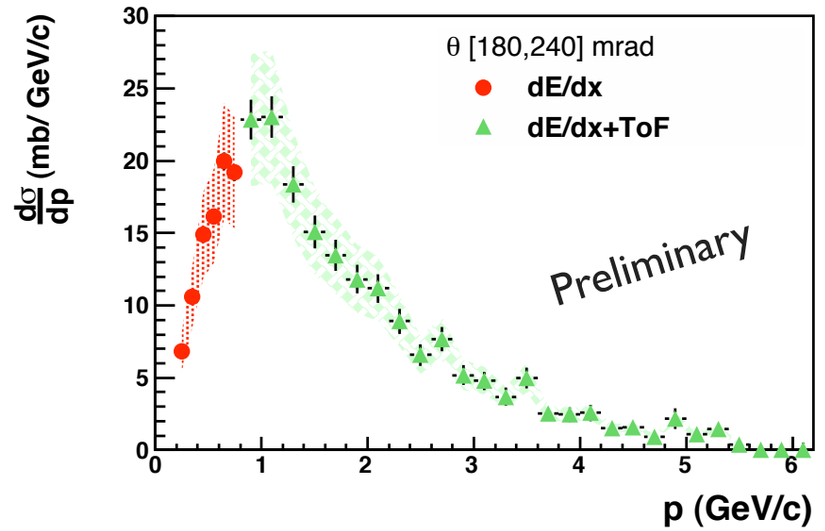


All results π+

Comparisons between ToF+dE/dx and dE/dx only analysis. No overlap due to TOF acceptance. But results can be checked for continuity.

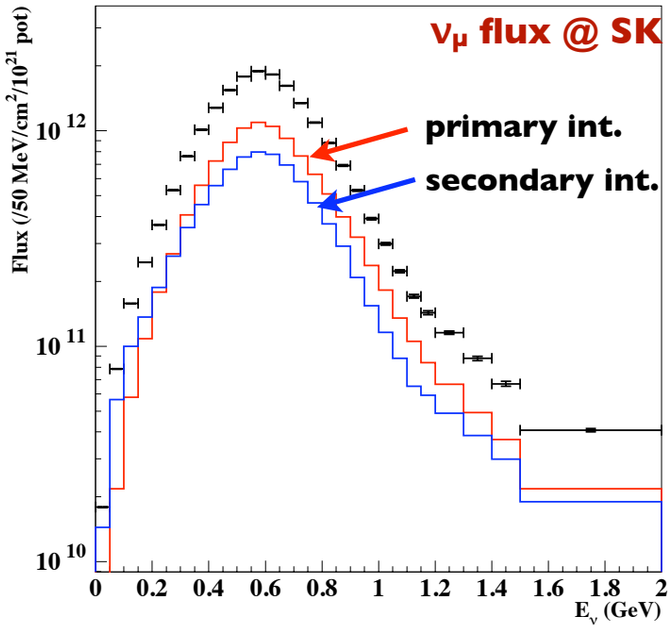


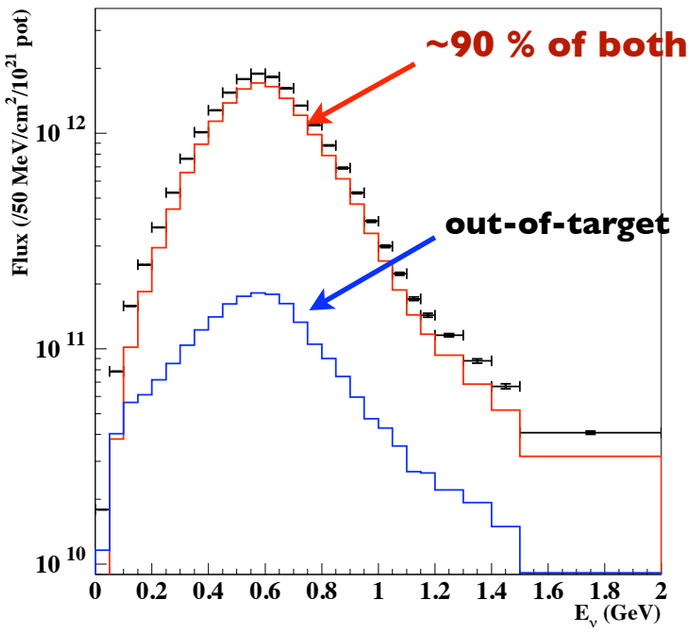




T2K replica target analysis

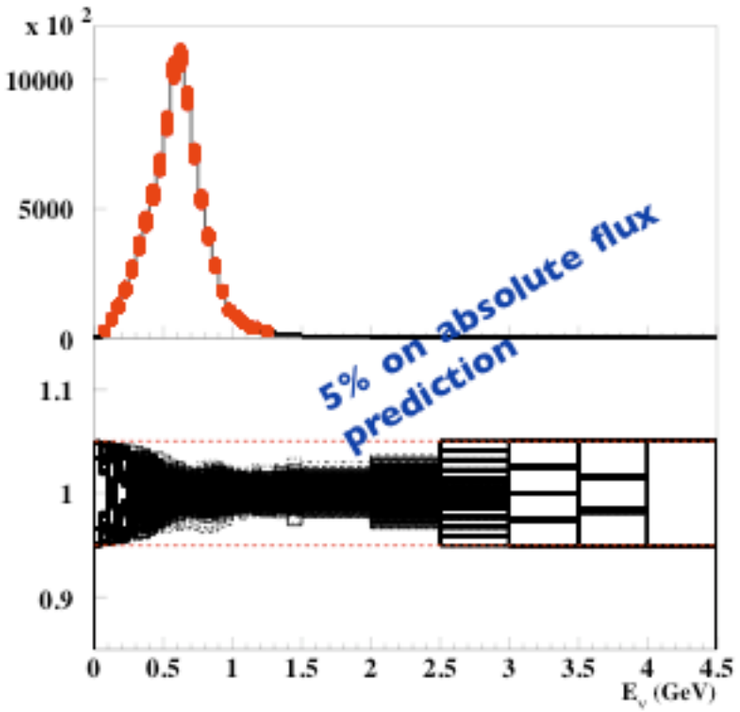
- Importance of long target measurements

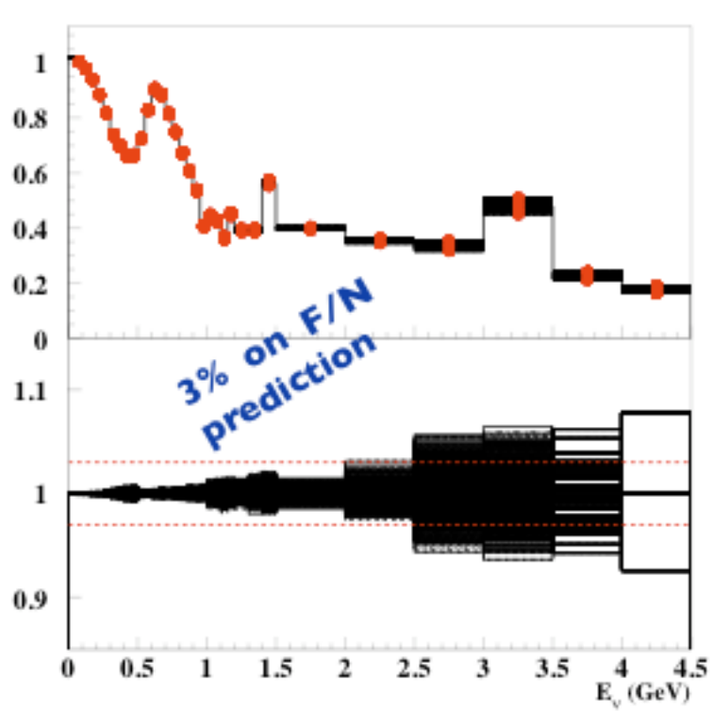




- ~40% of ν flux is coming from secondary interactions (thin target alone not enough)
- ~90 % of ν_μ and ν_e fluxes at peak energy are coming from parents produced in the target: =>measure production from replica target directly.

- NA61 Required statistics to fulfill the T2K goals

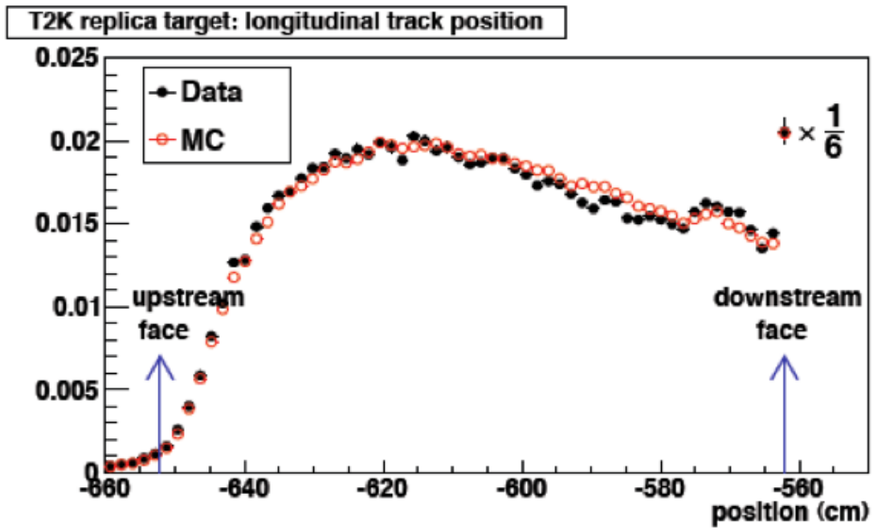


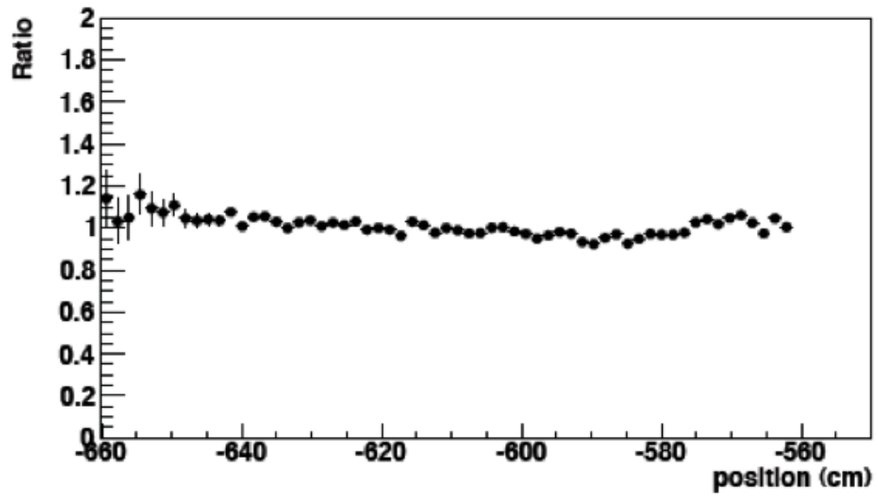


- assuming 5 % uncertainty on hadro-production measurements.
- need 7M triggers ->got 10 M triggers in 2010 (200 k in 2007).

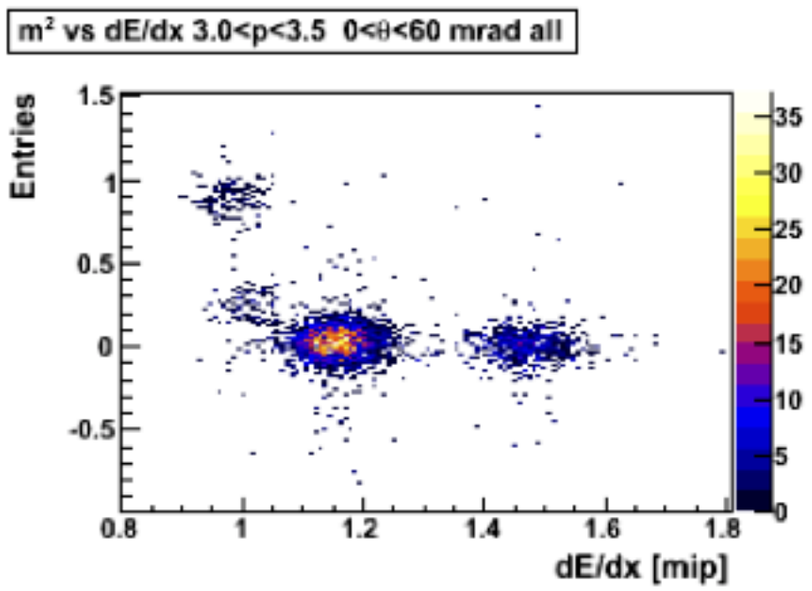
T2K replica target analysis

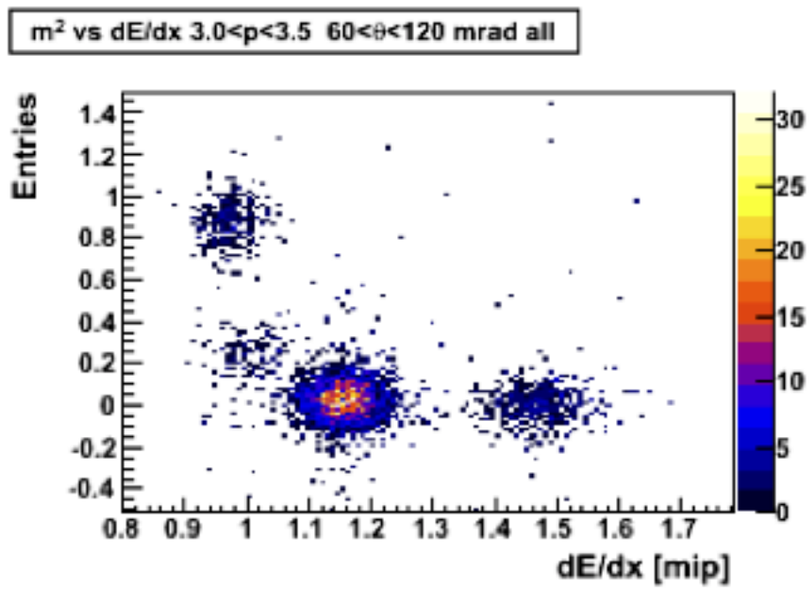
- Dedicated reconstruction procedure:
  - no vertex constraint
  - tracks reconstructed in the TPCs are back-propagated to the target skin (closest approach)

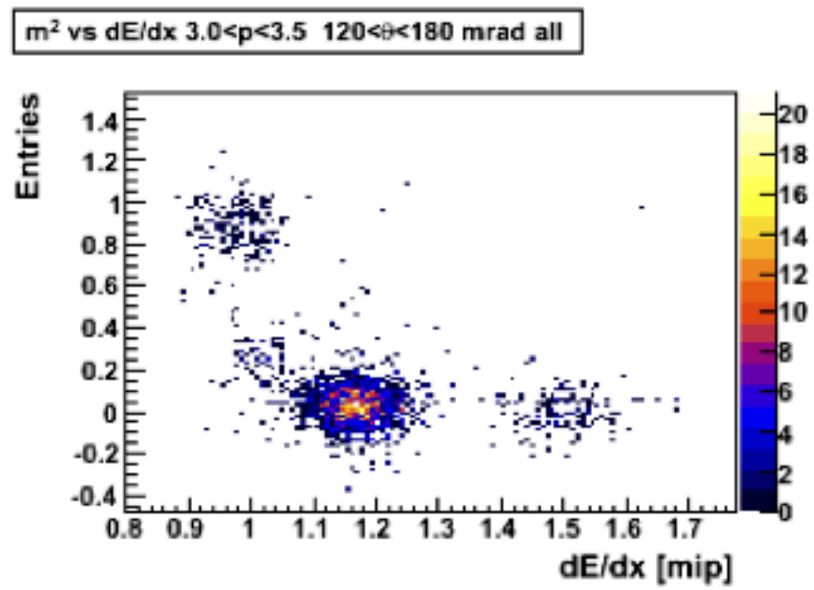




- First PID results:
  - track length computed from back-propagation to the middle of the target.
  - first combined ToF-dEdx plots.
  - same performance as with thin target

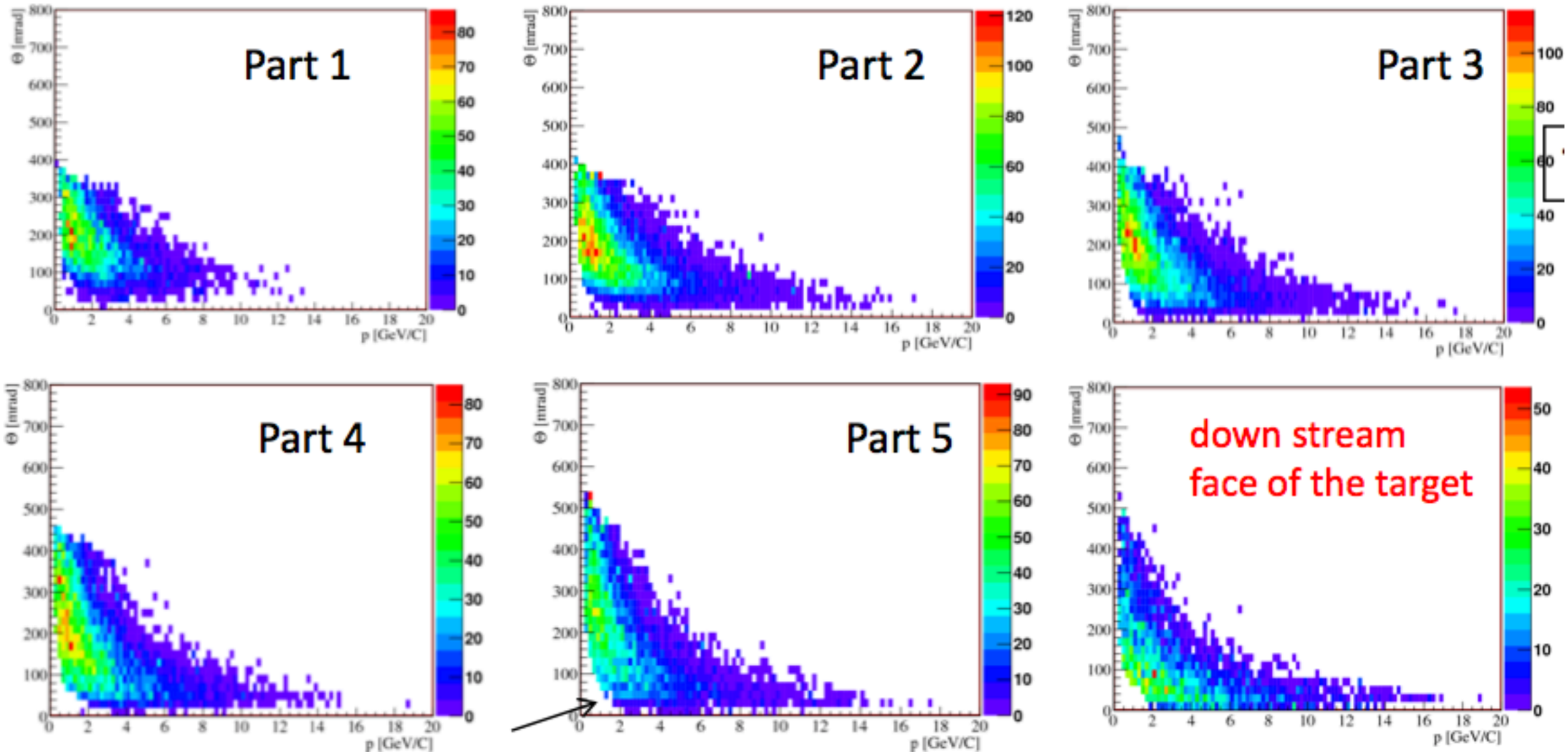






T2K replica target analysis

•h^- distributions for 5 longitudinal bins & target downstream face measured at target skin with correction procedures similar to the thin target h^- analysis.



summary and plans

•First results on pi+ spectra in p+C interactions at 31 GeV/c in momentum range 1-10 GeV/c have been obtained using different analyses methods.

-working on identifying and reducing systematics Goal: <10% (NA49 managed ~ 4%).

-work also ongoing to extend analysis at higher momenta and definition of a new binning.

-Paper preparation on the 2007 data started.

•Those results are currently used and provide useful input for the T2K beam simulation.

• ~10 times larger set of data in 2009 currently in the calibration phase, which has yet to be analyzed.

•Data from long target is currently been analyzed ->crucial because an important part of the neutrino flux in T2K comes from target re-interactions. PID capabilities similar to short target. Preliminary results soon!

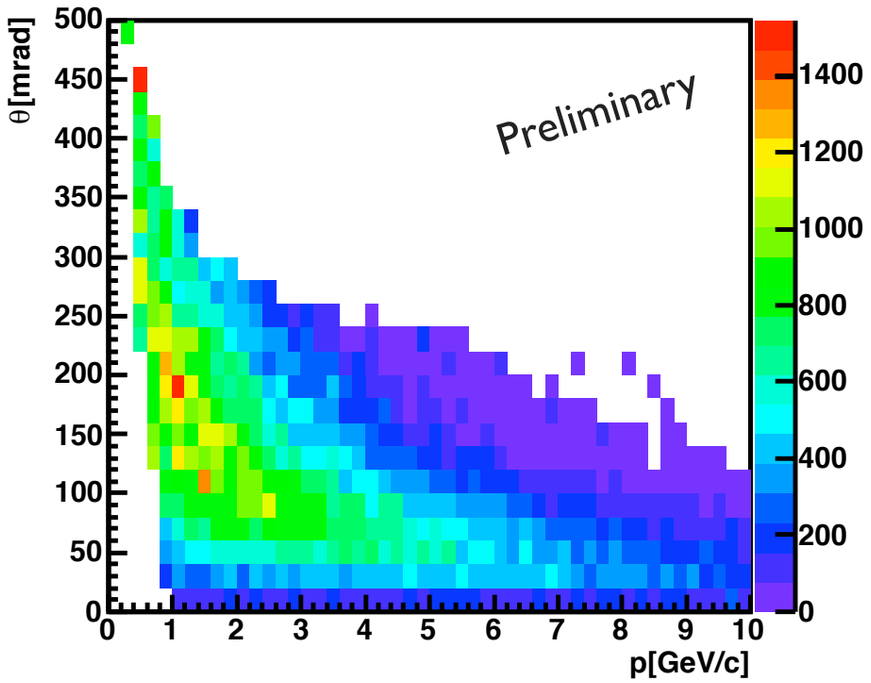
THANK YOU!

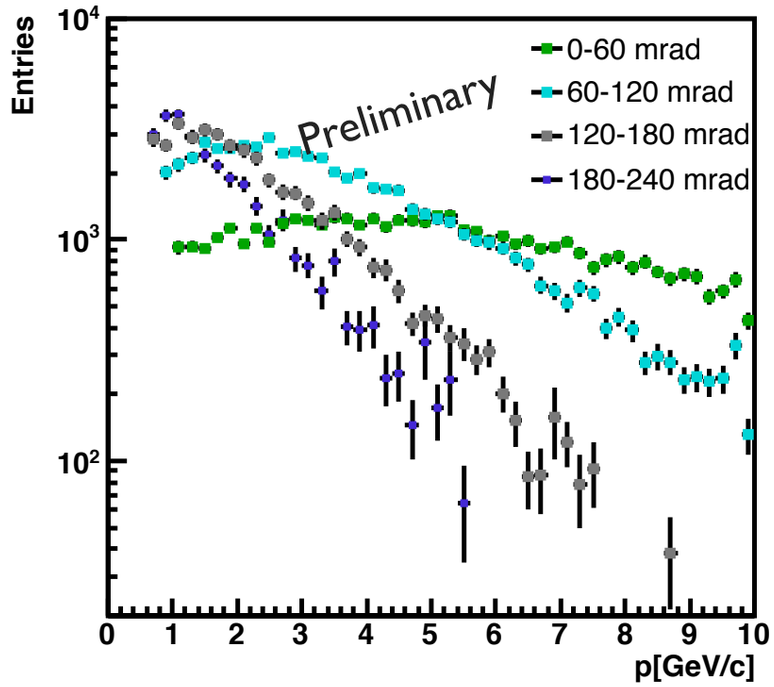
Results

- Results obtained with the combined ToF+dE/dx PID

π+

systematic error <20%





π-

systematic error <20%