Measurement of charged pion and kaon production in proton-carbon interaction at 31 GeV/c from NA61

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(on behalf of NA61 collaboration)

EPS HEP2011
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Outline

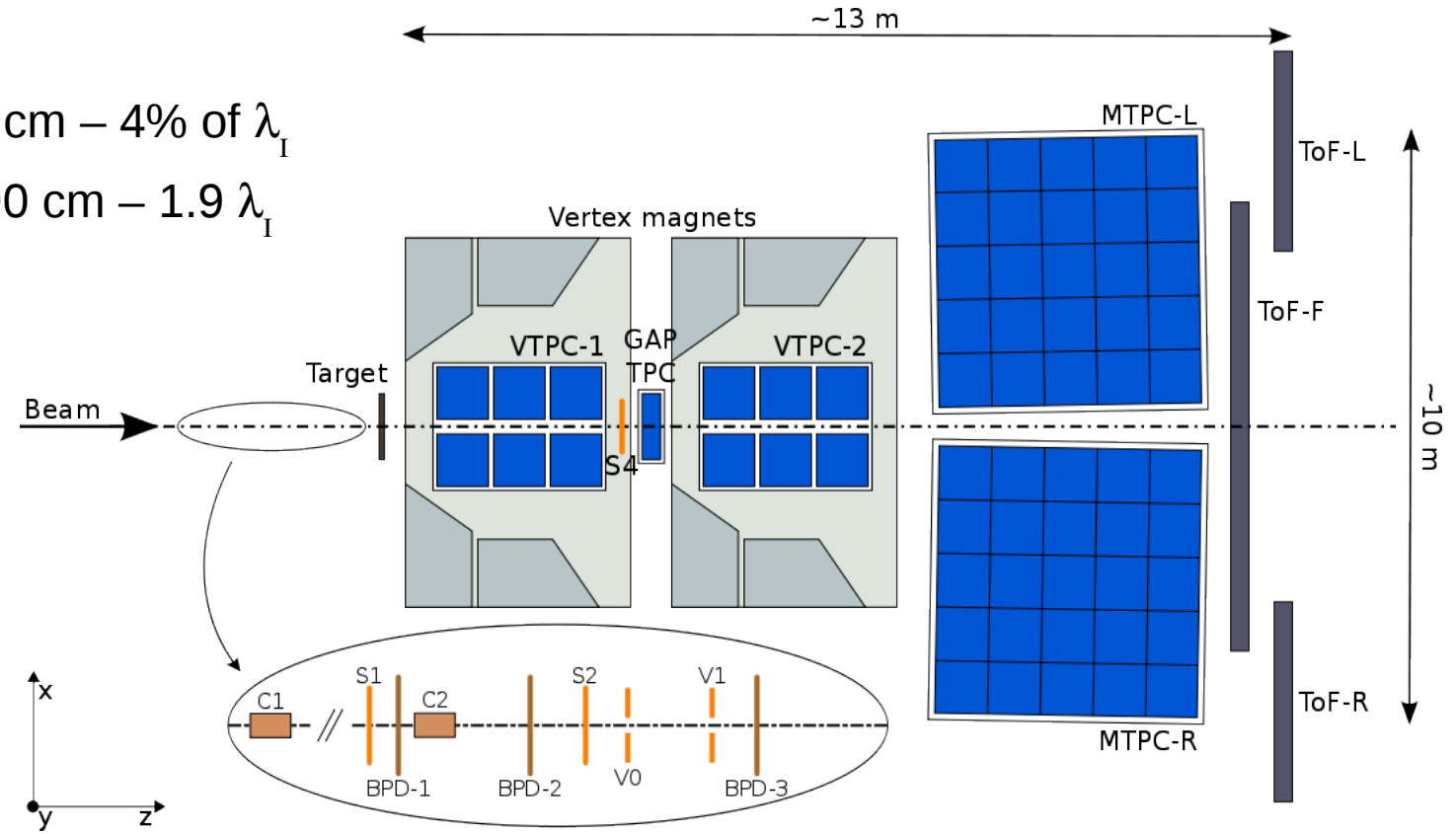
- NA61 experiment
- Analysis of charged pion spectra
- Analysis of positively charged kaon spectra
- Prospect for future results

NA61 experiment in CERN/SPS

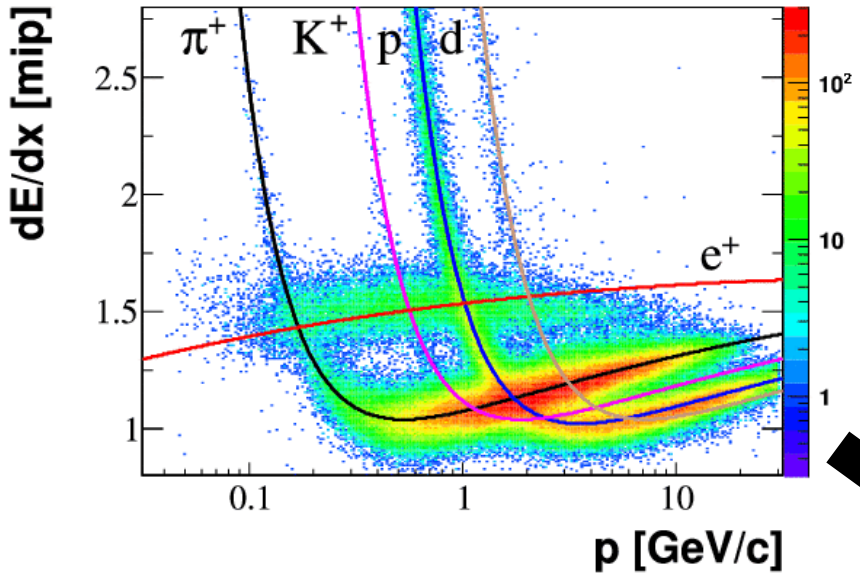
- ~140 physicists from 25 institutes
- One of main goals: Hadron production in p-C interaction to improve the prediction for the neutrino flux in T2K
- 31 GeV/*c* secondary hadron beam
- Tracking detectors: 5 TPCs and 3 MWPCs (beam telescope)
- Particle identification: TPC (*dE/dx*) and TOF

Thin target: 2 cm – 4% of λ_I

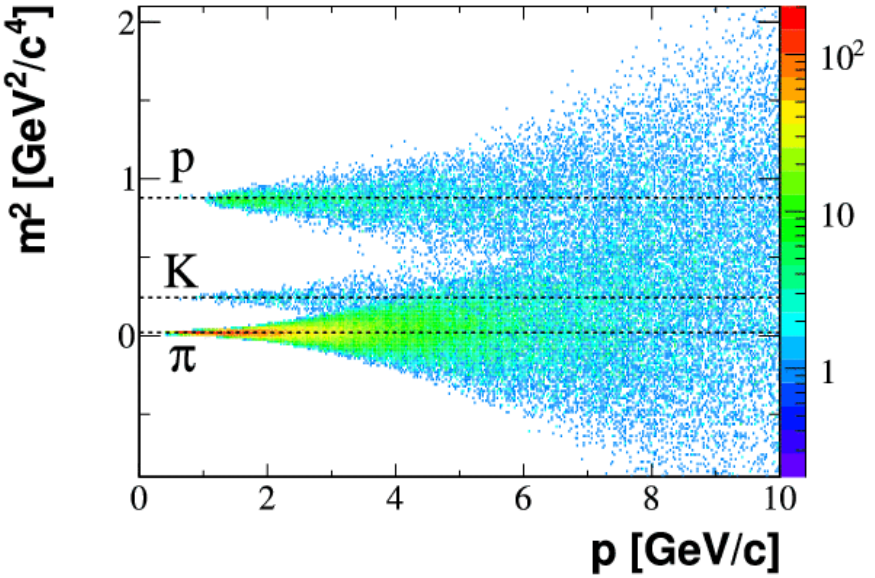
Replica targ: 90 cm – 1.9 λ_I

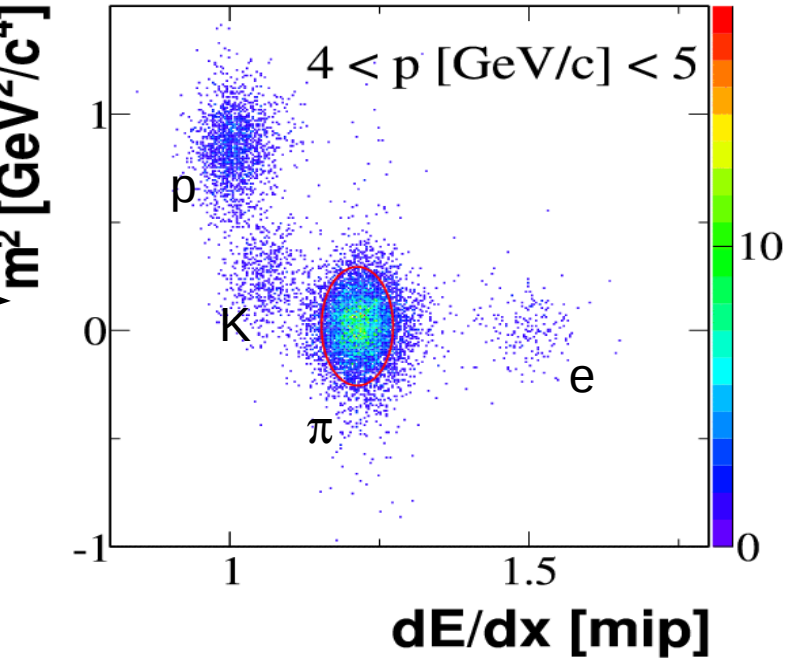


Particle identification



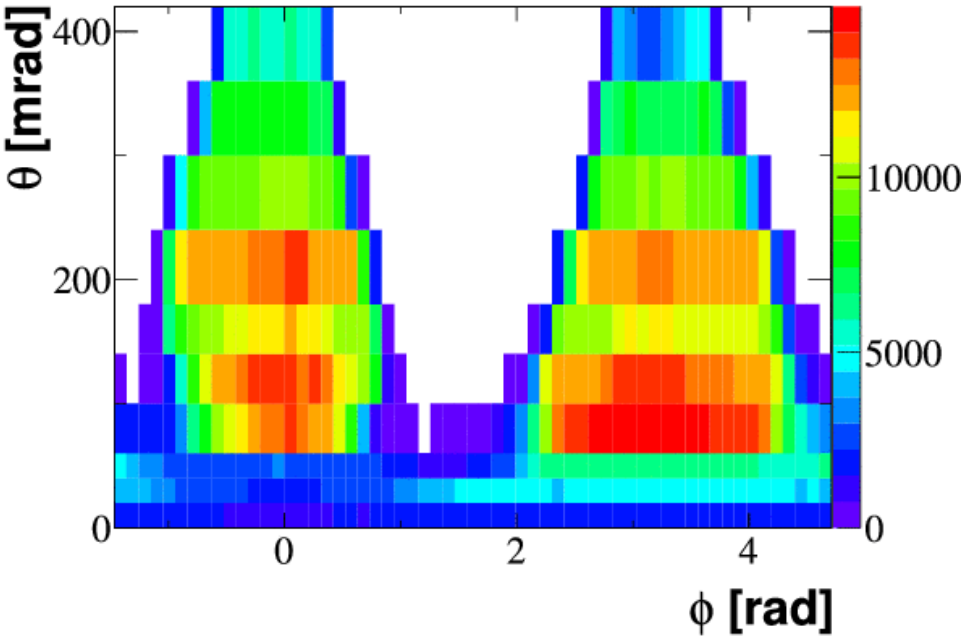
- Energy loss measurement in Ar:CO_2 medium (90:10). Typical resolution 3-5%
- Intrinsic TOF resolution 115 ps. Can be useful up to 10 GeV/*c*
- Combined TOF-*dE/dx* analysis allows efficient identification in cross-over region of BB curves

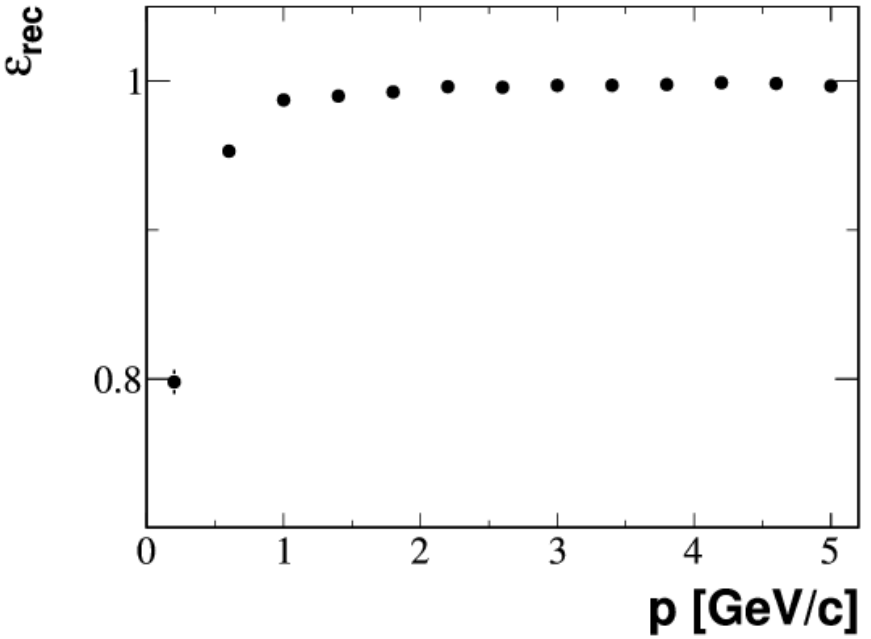




Reconstruction & simulation

- Reconstruction procedure/software essentially inherited from NA49
- In general GEANT 3.21 was used to describe spectrometer and Venus 4.12 for primary interaction
- GEANT 4 was used to calculate parameters of the coherent elastic and quasi-elastic scattering (for production cross section)
- Particles originated from primary vertex and produced in strong and electromagnetic interaction were considered

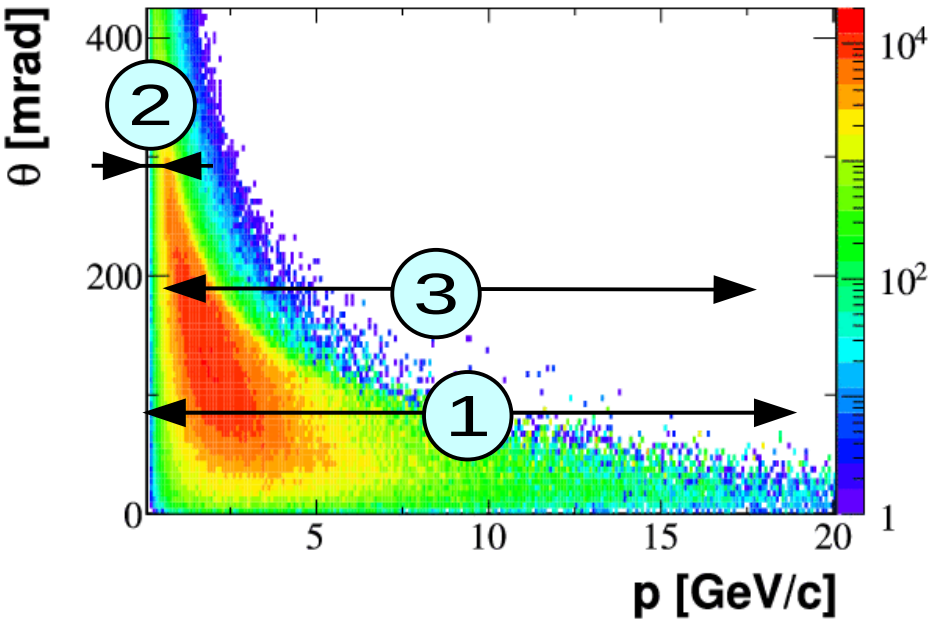




Analysis of charged pion spectra

- Analysis of data collected in the 1-st pilot run in 2007
- arXiv:1102.0983 [hep-ex] accepted for publication in Phys.Rev.C
- Results have been used in 'ν_e appearance' paper of T2K arXiv:1106.2822 [hep-ex]
- 667k proton interaction triggers recoded (+46k for empty target)

Analysis techniques



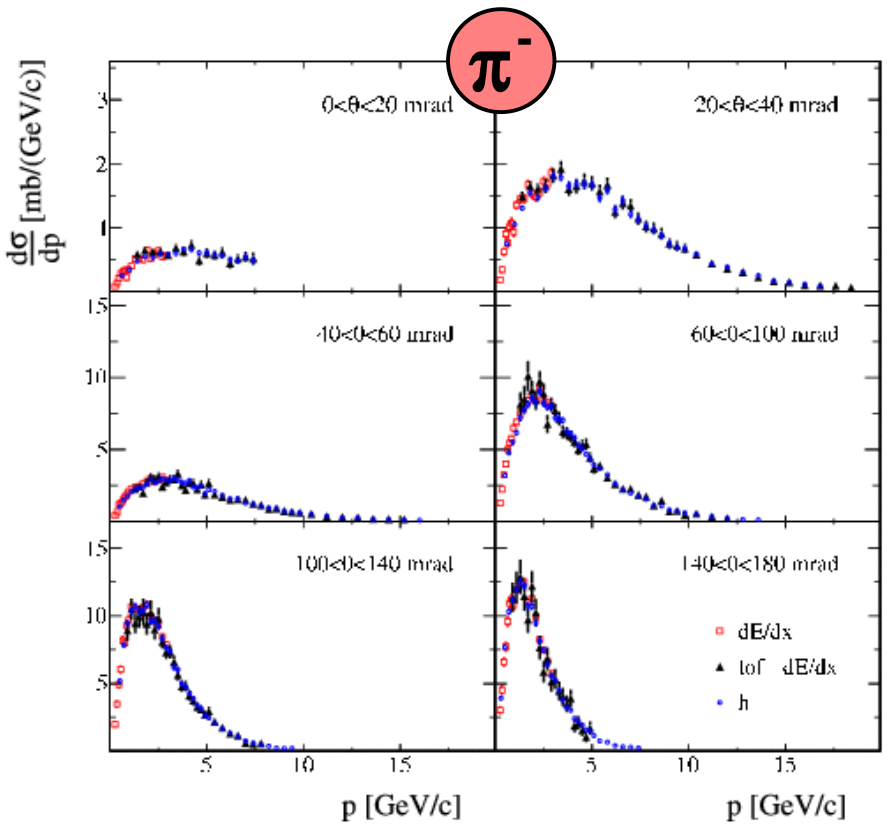
1) h^- analysis: analysis of π^- via measurements of negatively charged particles

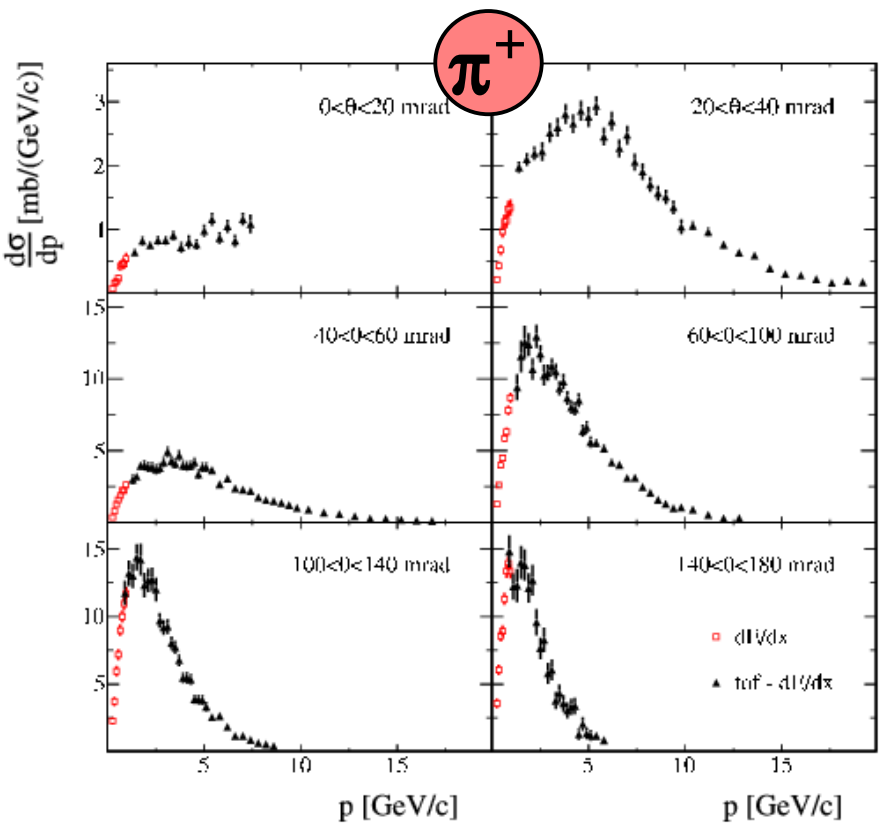
2) *dE/dx* analysis: π^+ and π^- are identified via *dE/dx* measurements in TPCs

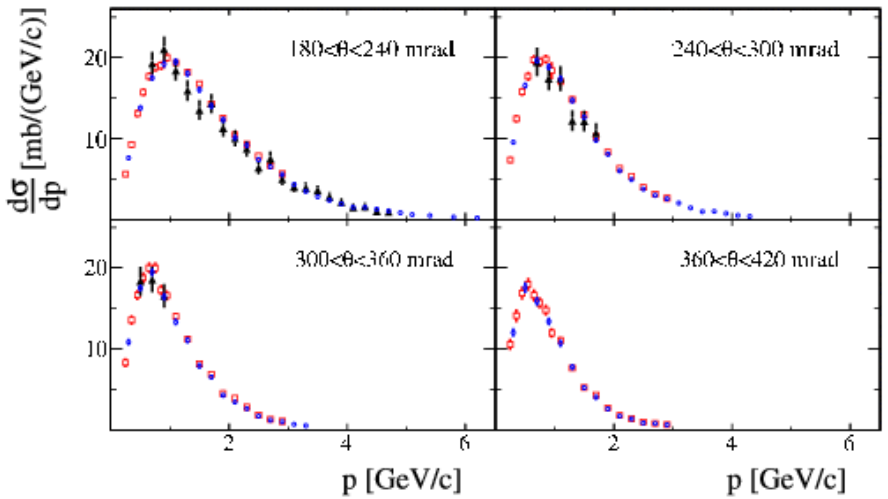
3) *TOF-dE/dx* analysis: π^+ and π^- are identified via *dE/dx* from TPCs and m^2 from TOF-F

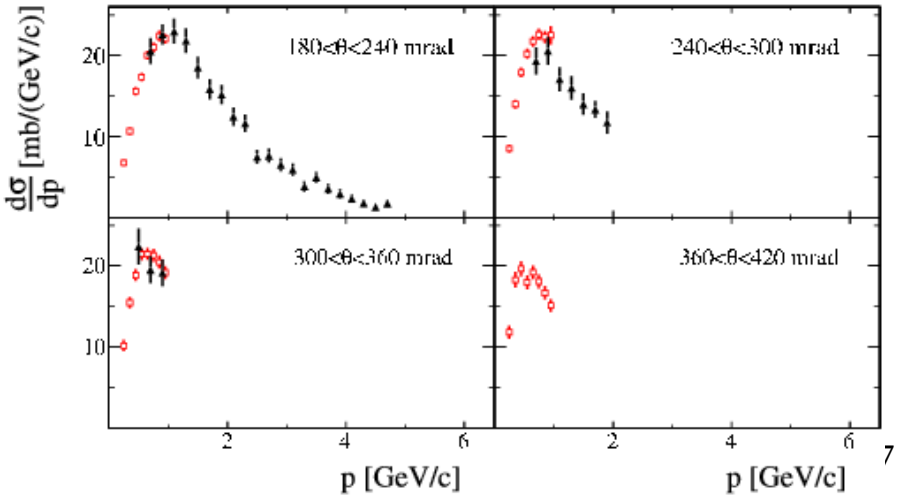
- Independently calculated statistical and systematic errors
- Spectra were compared in overlapping regions to check their consistency
- Complementary domains were combined to reach maximum acceptance

Differential cross section









Slide from the talk of Ken Sakashita in KEK on 15.06.11:
New results from T2K experiment

Summary of ν flux uncertainties on N^{exp}_{SK} for $\sin^2 2\theta_{13}=0$

$$N^{exp}_{SK} = R^{\mu,\,Data}_{ND} \times \frac{N^{MC}_{SK}}{R^{\mu,\,MC}_{ND}}$$

Error source	$R^{\mu,\,MC}_{ND}$	N^{MC}_{SK}	$\frac{N^{MC}_{SK}}{R^{\mu,\,MC}_{ND}}$
Pion production	5.7%	6.2%	2.5%
Kaon production	10.0%	11.1%	7.6%
Nucleon production	5.9%	6.6%	1.4%
Production x-section	7.7%	6.9%	0.7%
Proton beam position/profile	2.2%	0.0%	2.2%
Beam direction measurement	2.7%	2.0%	0.7%
Target alignment	0.3%	0.0%	0.2%
Horn alignment	0.6%	0.5%	0.1%
Horn abs. current	0.5%	0.7%	0.3%
Total	15.4%	16.1%	8.5%

Hadron production & interaction

The uncertainty on N^{exp}_{SK} due to the beam flux uncertainty is **8.5%**

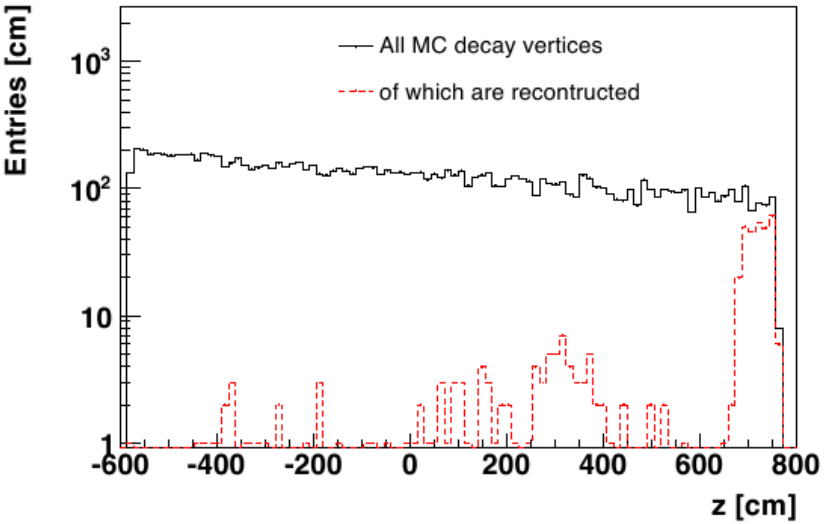
Error cancellation works for some beam uncertainties

Analysis of positive kaon spectra

- Analysis of data collected in the 1-st pilot run in 2007
- In general the fraction of K^+ is by order of magnitude smaller than the fraction of π^+
- Publication is in preparation
- Results have been conveyed to T2K

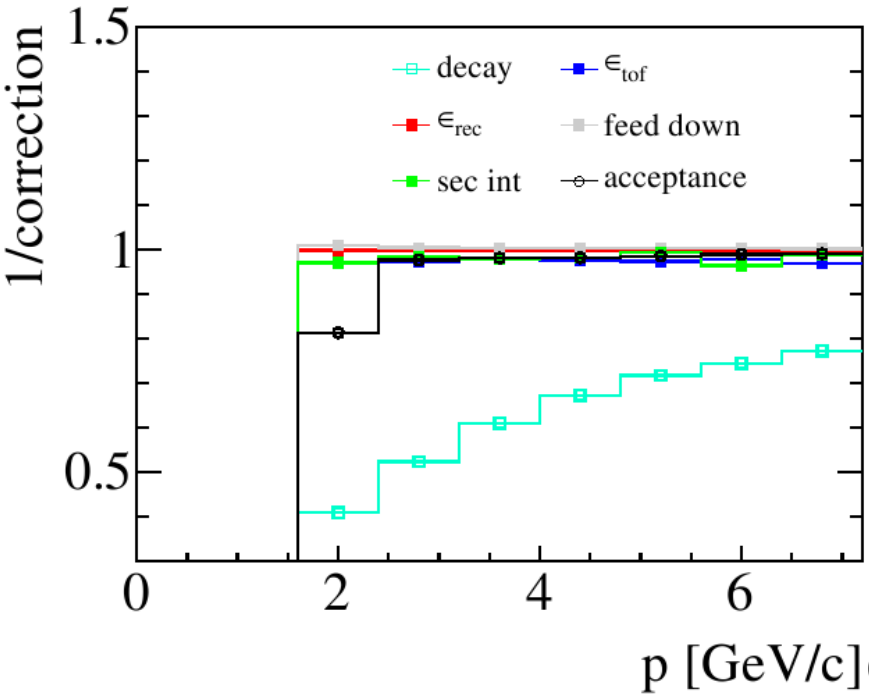
K^+ analysis

- Analysis is almost equivalent to the *TOF-dE/dx* one from the pion section
- Important cut: selection of long tracks to improve the purity of the sample



MC corrections

- Major contribution: correction for the decay in flight of kaons. Others correction are below 10%
- Reconstruction efficiency was maximized at track selection level
- Feed Down (kaons from weak decays) corrections are negligible
- Acceptance below 90% only in the first bin: optimized with track topology selection



Results and comparison to models

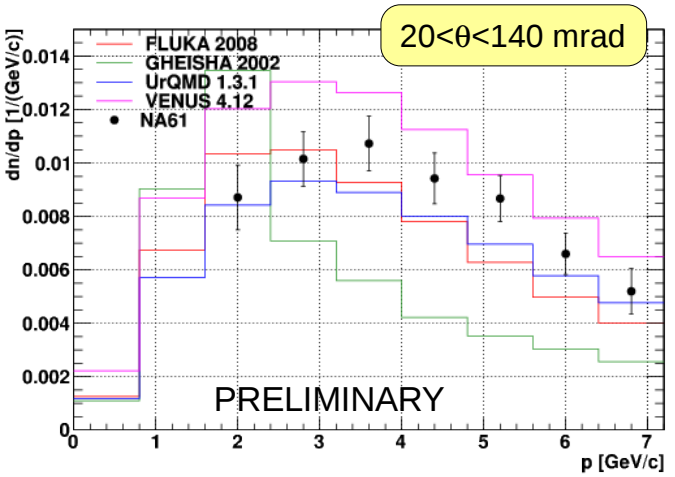
- Only two angular bins were considered:

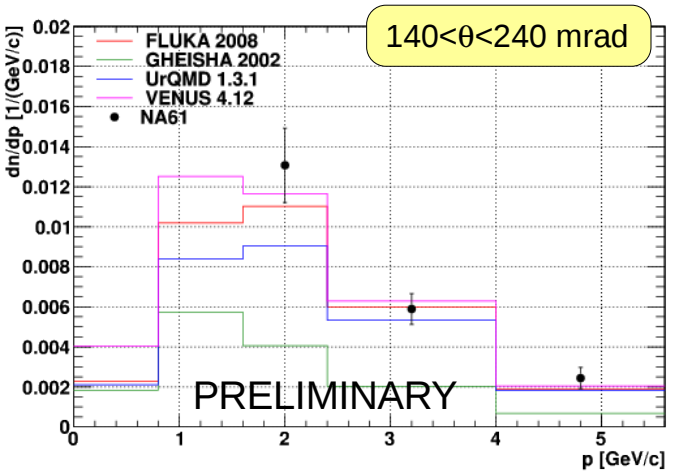
  20<θ<140 mrad

  140<θ<240 mrad

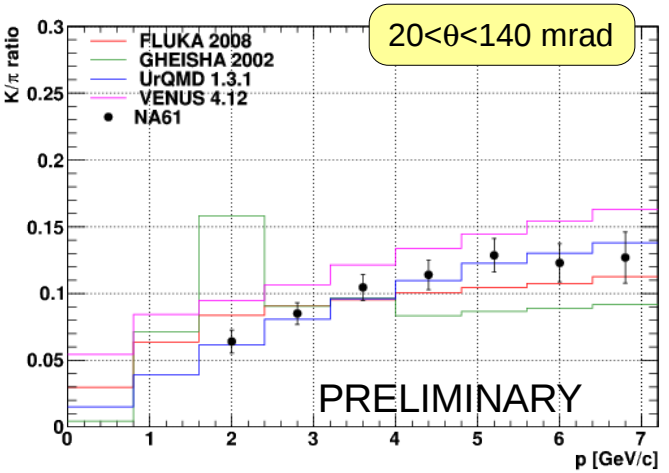
- In general FLUKA 2008 and VENUS 4.12 give a reasonable description to data
- Systematic error is factor 2-3 smaller than statistical one
- Significant improvement with data 2009 is expected

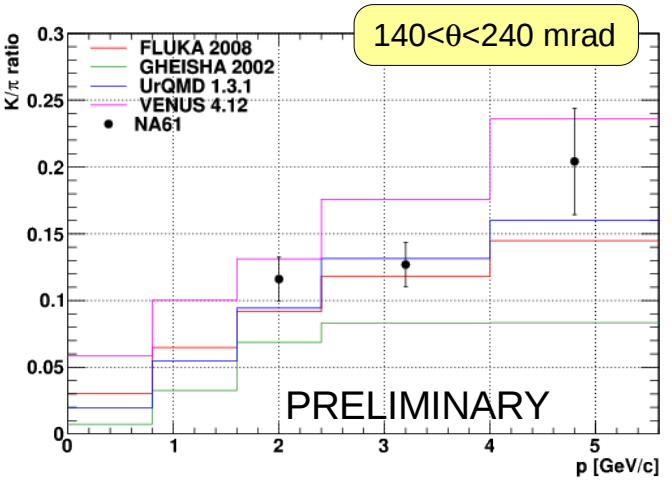
Differential cross section of K^+



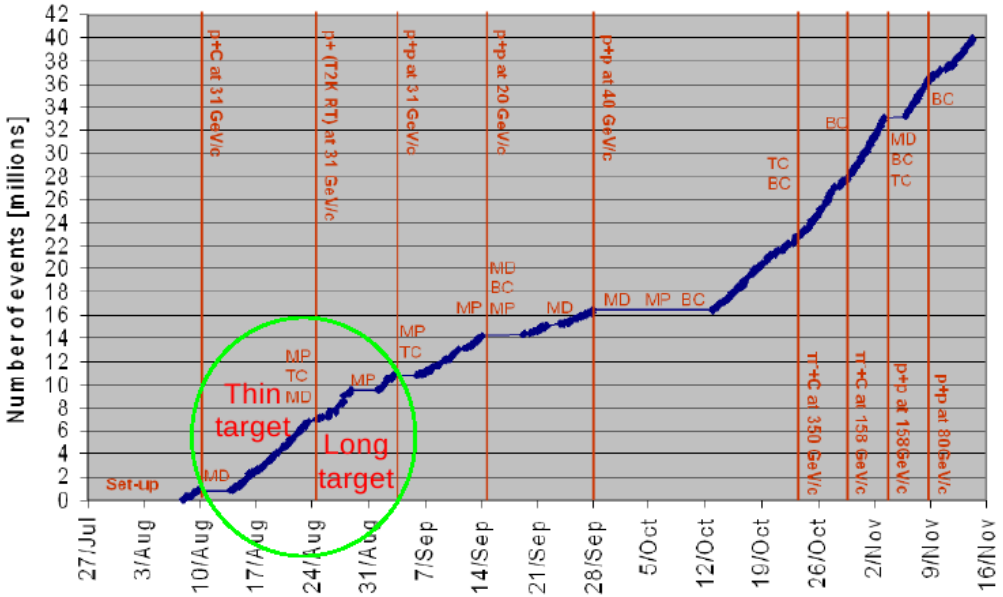


Ratio K^+/π^+



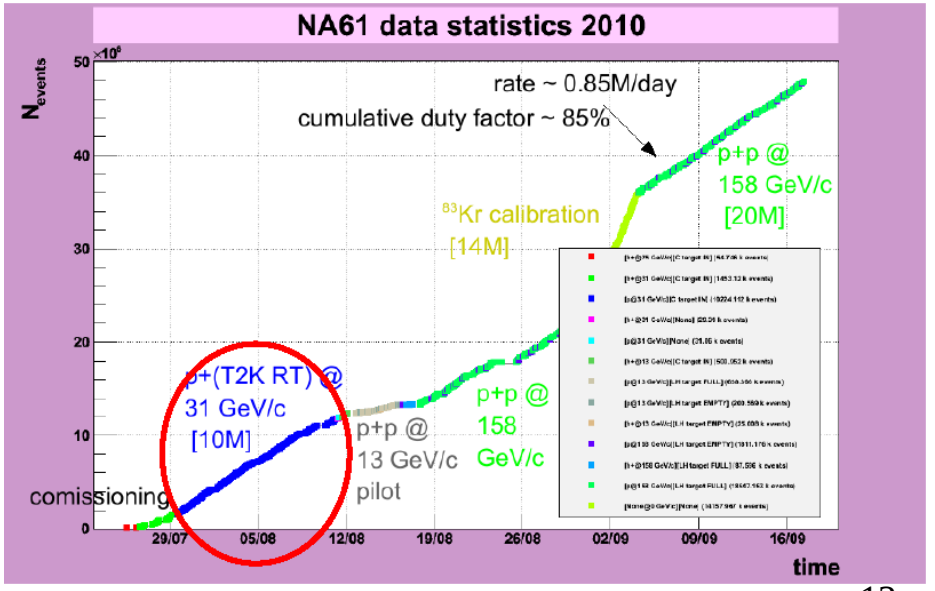


Prospect for forthcoming results



- In year 2009 about 10M events (thin + long target) were collected
- Alignment and calibration are almost completed
- Preliminary results by the end of this year

- In year 2010 about 10M Long Target events were collected
- Should be well enough to get 3% error for the neutrino flux ratio as was requested by T2K



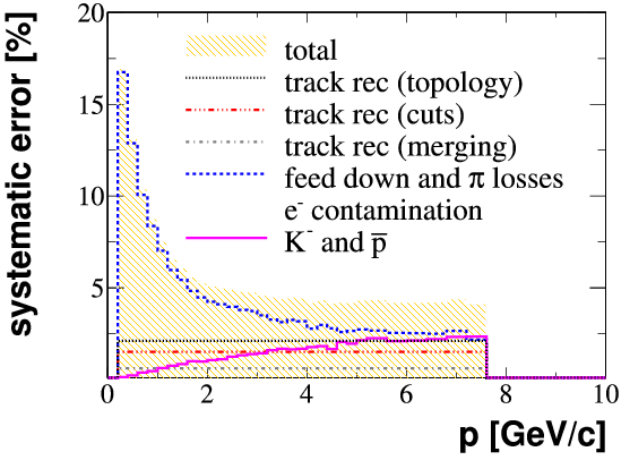
Summary

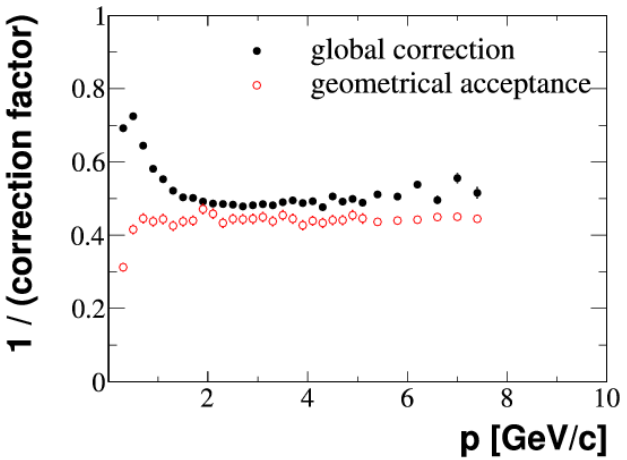
- Pion data from run 2007 have been published (*arXiv:1102.0983*) and presently used by T2K
- Preliminary results for yields of positively charged kaons have been presented (data 2007)
- Data collected in years 2009 and 2010 will increase statistics by an order of magnitude

Back up slides

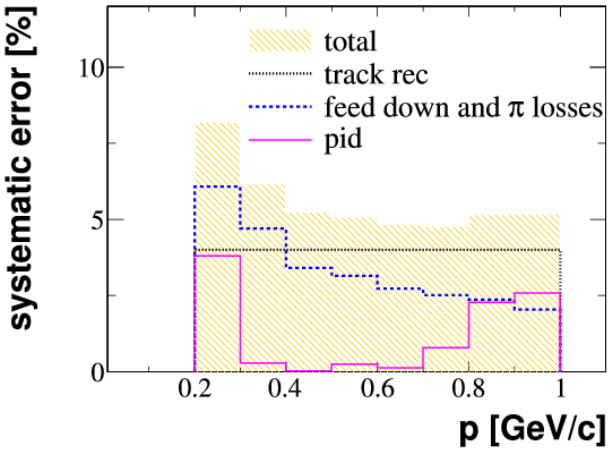
Systematic error and correction factors

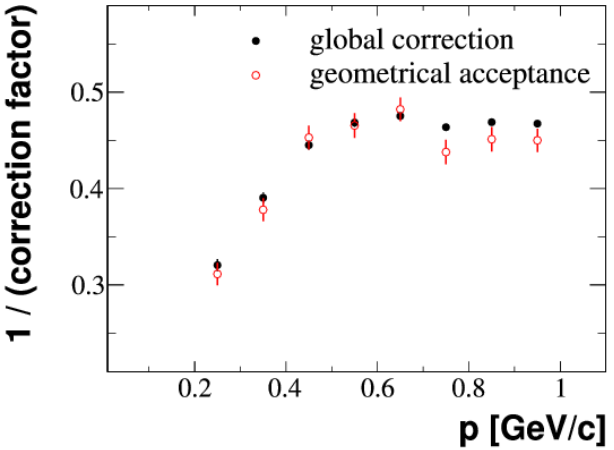
h^- analysis



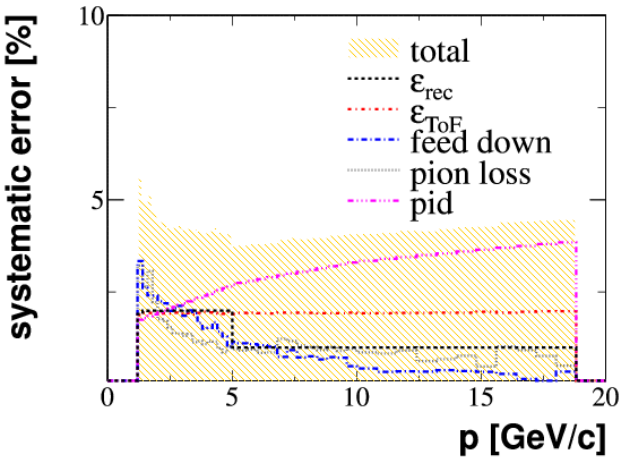


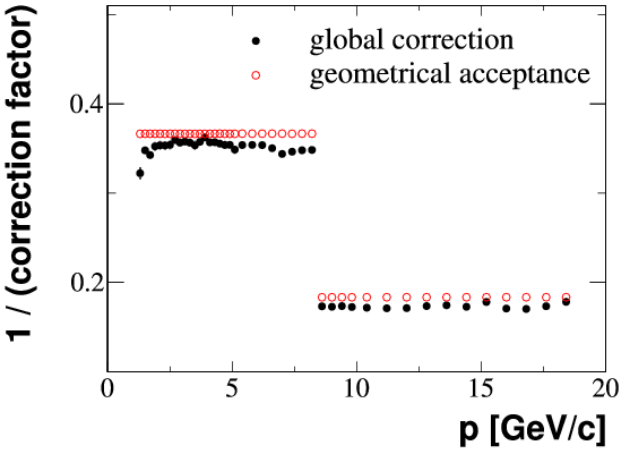
dE/dx analysis



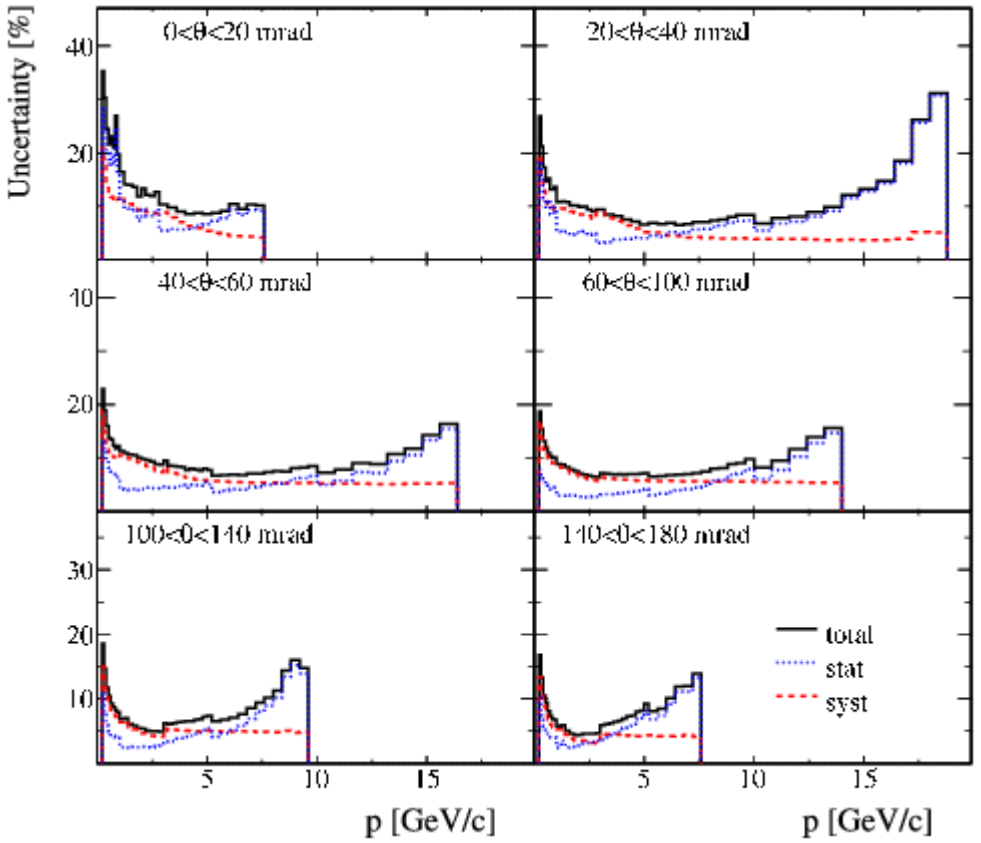


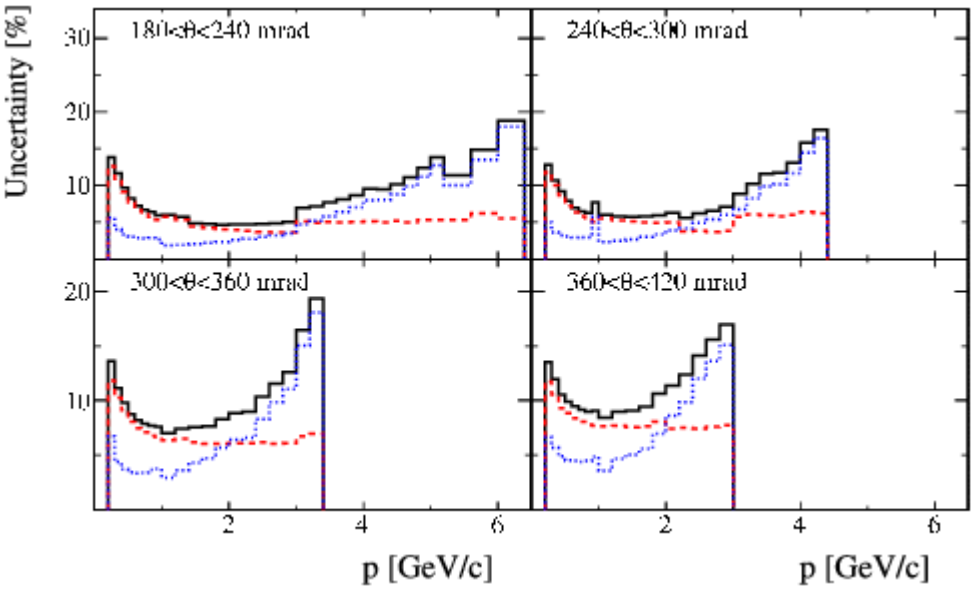
TOF-dE/dx analysis





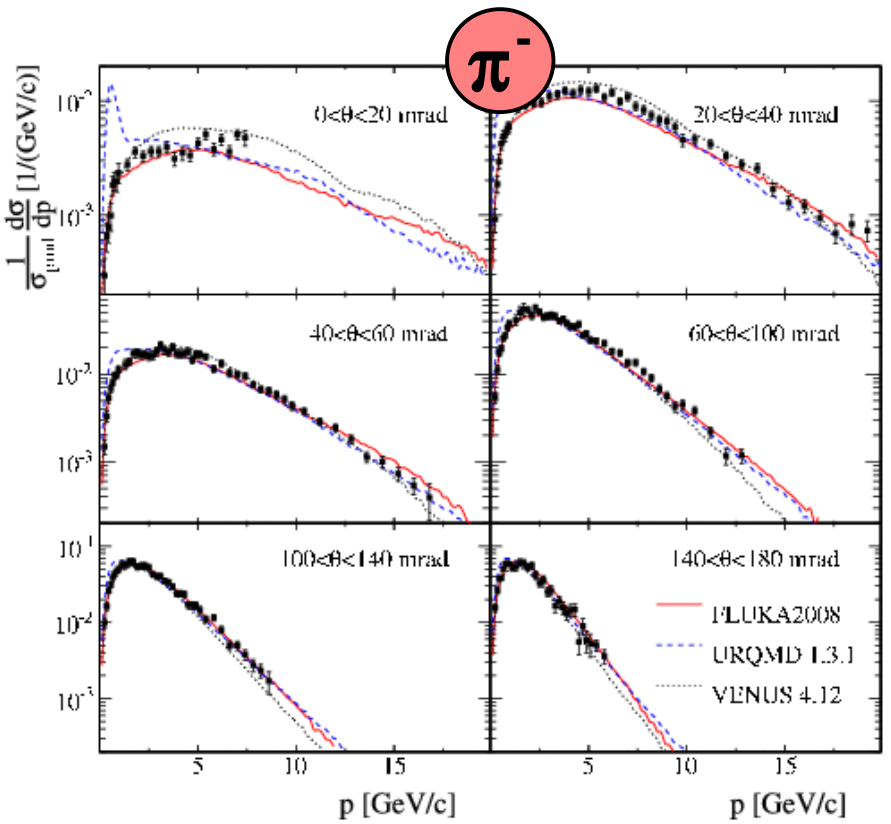
Relative uncertainties for π^-

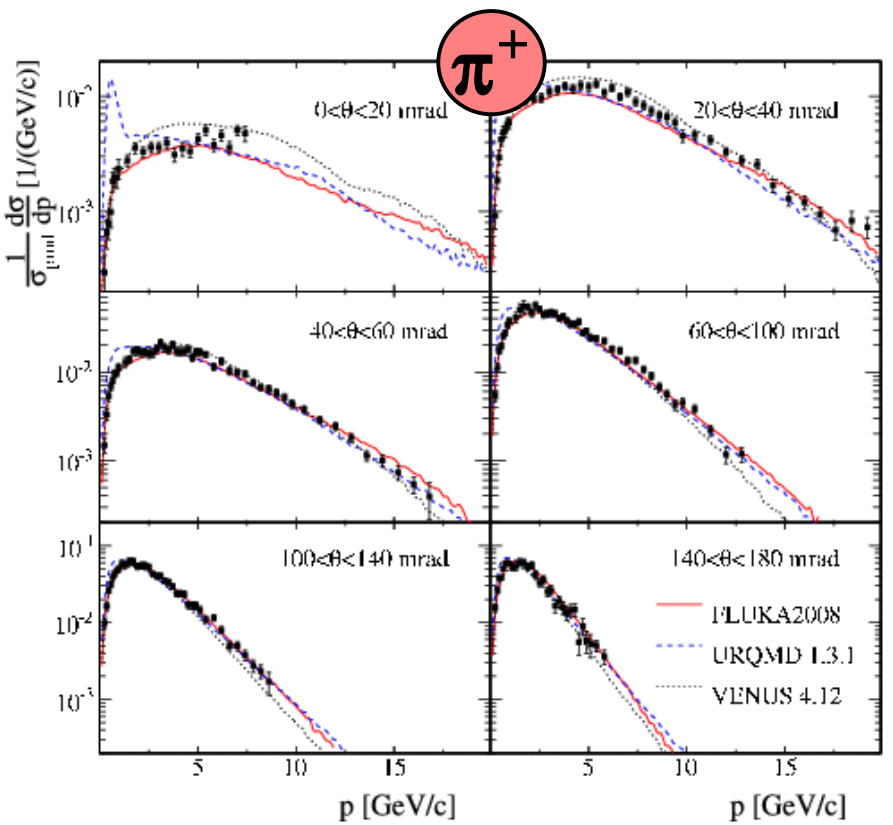


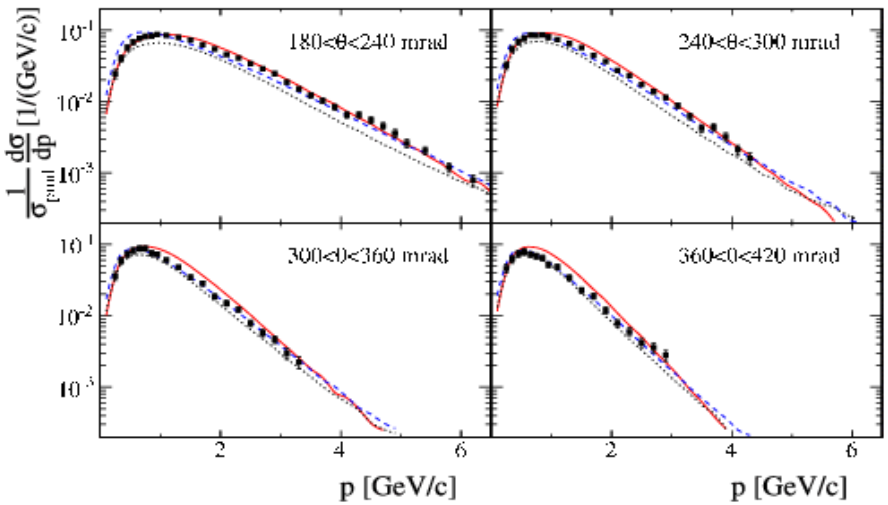


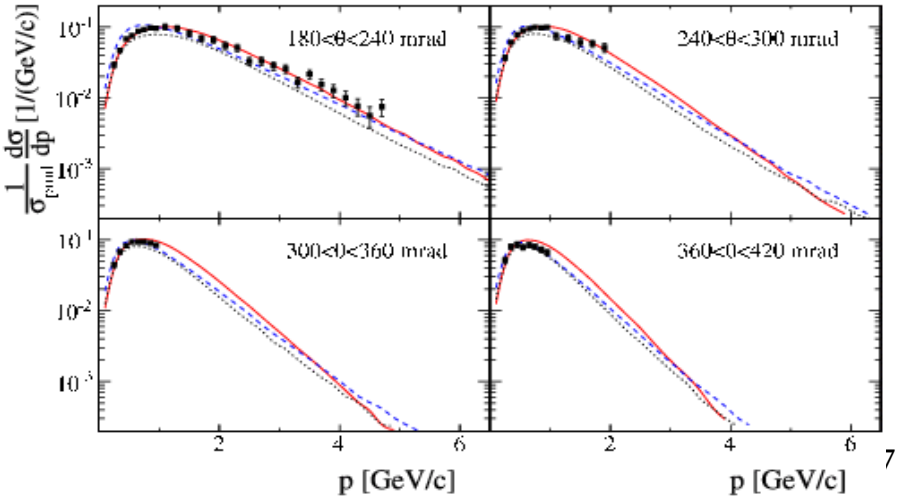
- Among 3 analyzes the one with smaller total error was selected
- Systematic error dominates at lower momenta. At higher momenta stat. error is larger

Comparison to different models predictions

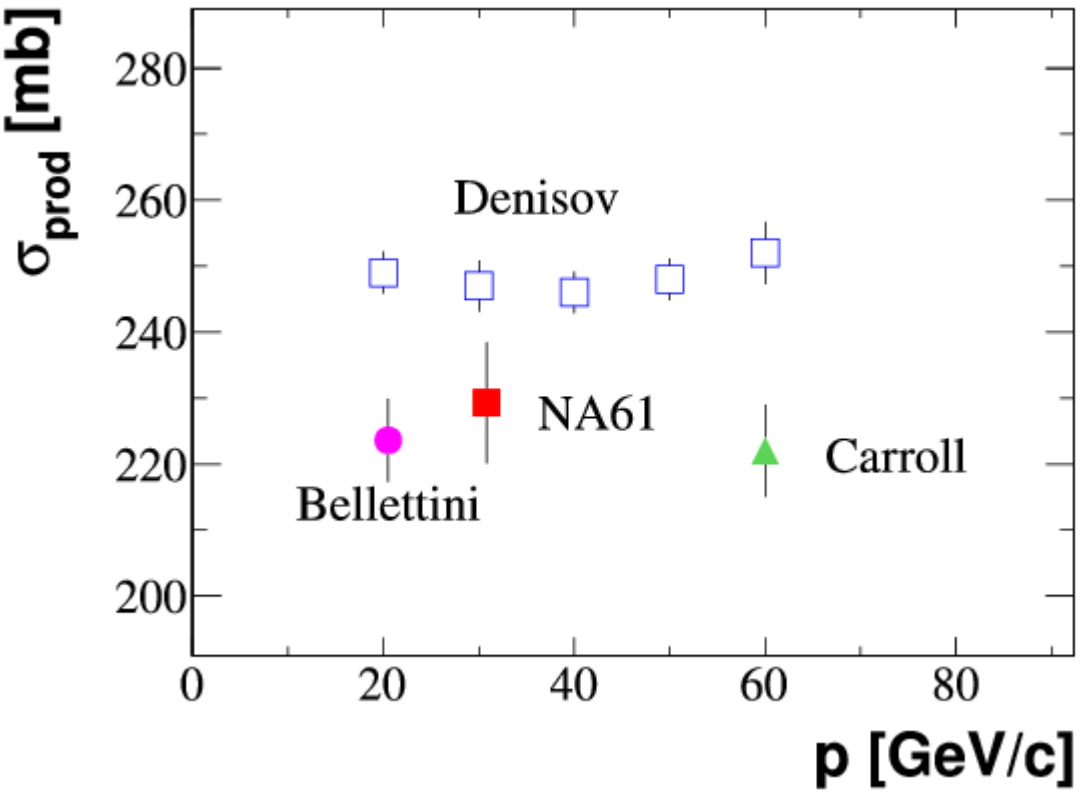








Production cross section



- Inelastic cross section

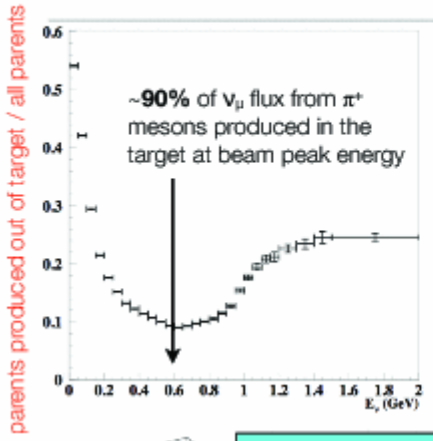
  $\sigma_{inel}=\sigma_{tot} - \sigma_{el}=257.2\pm1.9\pm8.9$ mb

- Production cross section

  $\sigma_{prod}=\sigma_{inel} - \sigma_{qe}=229.3\pm1.9\pm9.0$ mb

G. Bellettini, Nucl. Phys. 79 (1966) 609 : $\sigma_{inel} = \sigma_{tot} - \sigma_{elastic}$ at 20 GeV
S.P. Denisov, Nucl. Phys. B61 (1973) 62: σ_{meas} at 20/30/40/50/60 GeV
A. Carroll, Phys. Lett. B80 (1979) 319: $\sigma_{meas} = \sigma_{tot} - \sigma_{elastic} - \sigma_{qe}$ at 60 GeV

NA61 long target measurements for T2K



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

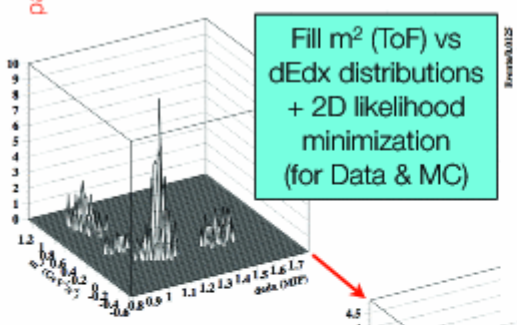
NA61 thin target data: π^+ production cross sections in p+C at 31 GeV/c

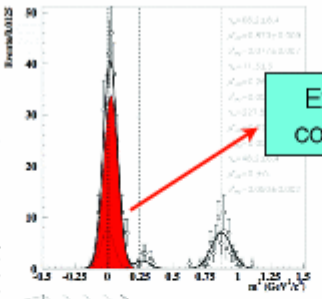
re-weight π^+ production from primary interaction in the FLUKA based T2K beam simulation

NA61 long target data: all π^+ exiting the target

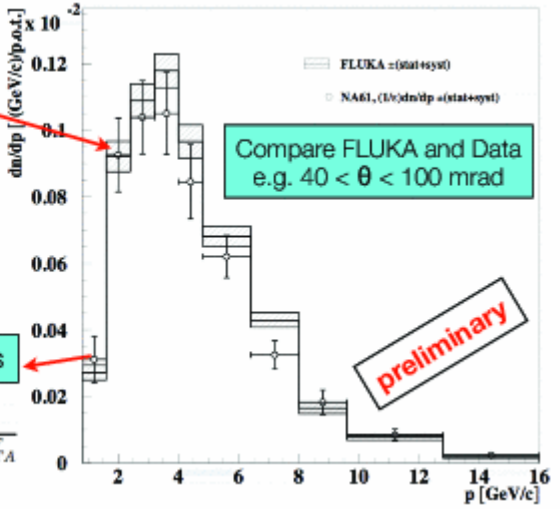
re-weight the whole π^+ production from the target in the FLUKA based T2K beam simulation

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



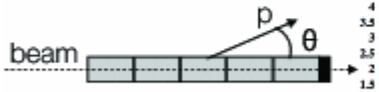


Extract π^+ component

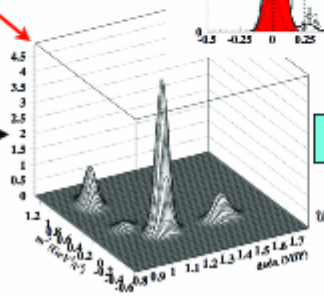


Compare FLUKA and Data e.g. 40 < θ < 100 mrad

preliminary



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



Compute re-weighting factors

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