Hadron production measurements with NA61/SHINE

Town meeting: European Strategy for Neutrino Oscillation physics,

CERN, 14-16 May, 2012

Boris A. Popov (LPNHE, Paris & JINR, Dubna)

for the NA61/SHINE collaboration

- NA61/SHINE detector
- First results for T2K
- Status and plans
- Potential input to the European Strategy

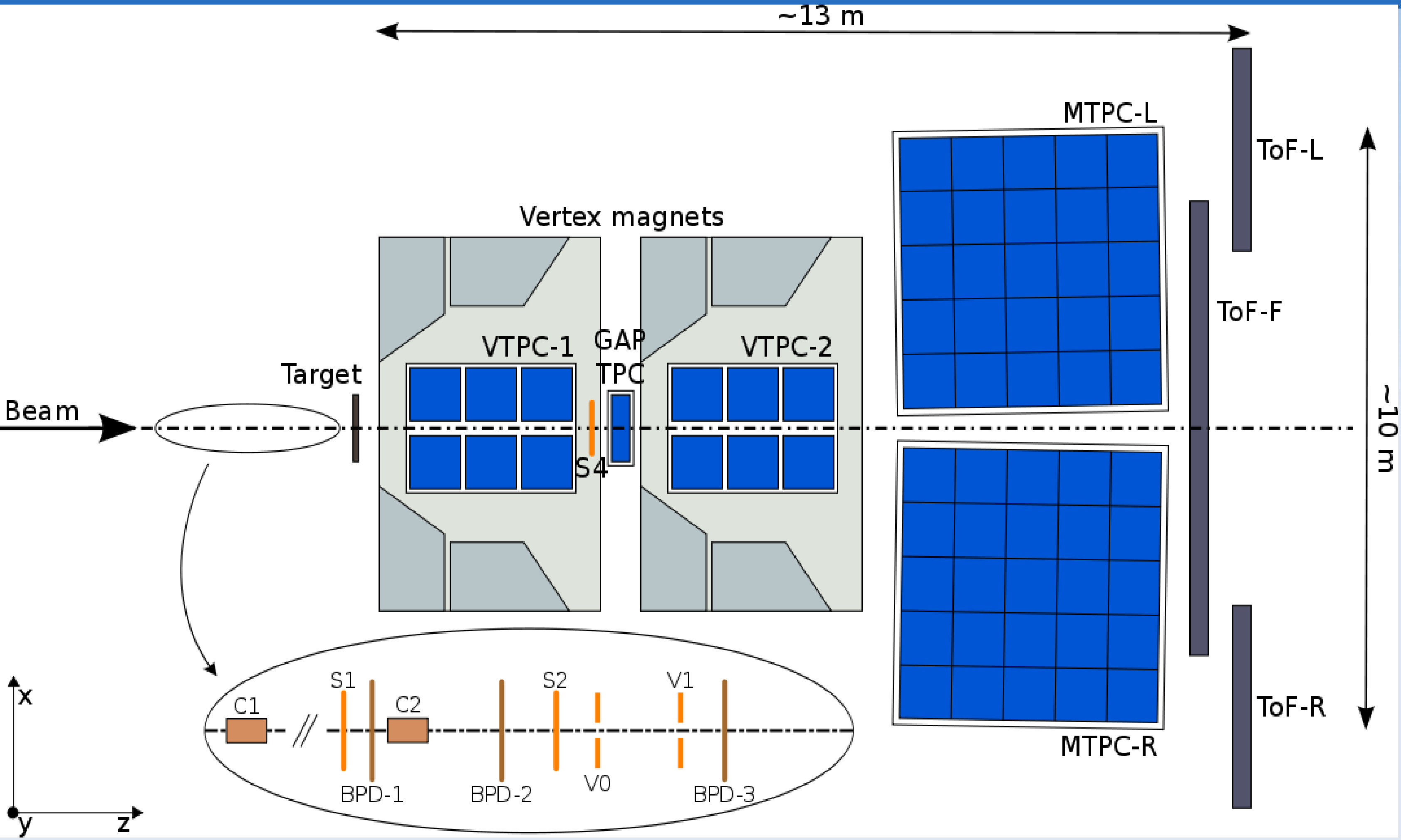
NA61/SHINE physics goals

SHINE = SPS Heavy Ion and Neutrino Experiment

- Hadron production reference measurements for accelerator neutrino (T2K, Fermilab) and cosmic ray (Pierre Auger Observatory, KASCADE) experiments
- Search for the critical point of strongly interacting matter
- Study the properties of the onset of deconfinement in nucleus-nucleus collisions

Not discussed here

NA61/SHINE setup at CERN SPS



TPCs as main tracking devices

2 dipole magnets with max bending power of 9 Tm

New ToF-F array to fully cover T2K acceptance

High momentum resolution

Good particle identification

Beam line instrumentation

Large acceptance spectrometer with excelent capabilities for momentum, charge and mass measurments

NA61/SHINE: recorded data for T2K

- Two different carbon (isotropic graphite) targets were used
- Thin target: 2 cm length, 2.5x2.5 cm cross section, ρ = 1.84 g/cm^3, ~0.04 λ_{int}
- T2K replica target: 90 cm length, 2.6 cm diameter, ρ = 1.83 g/cm^3, ~1.9 λ_{int}
- Data for T2K with incoming 31 GeV/c protons were collected:
- 2007 run (~670k triggers on thin target and ~230k triggers on replica target). Analysis finalized and corresponding results published.
- 2009 run (~6M triggers on thin target and ~2M triggers on replica target). These data are now fully calibrated and analysis is well advanced.
- 2010 run (~10M triggers on replica target). Data being calibrated now. Ultimate data set for most precise neutrino flux predictions.

NA61/SHINE: analysis techniques

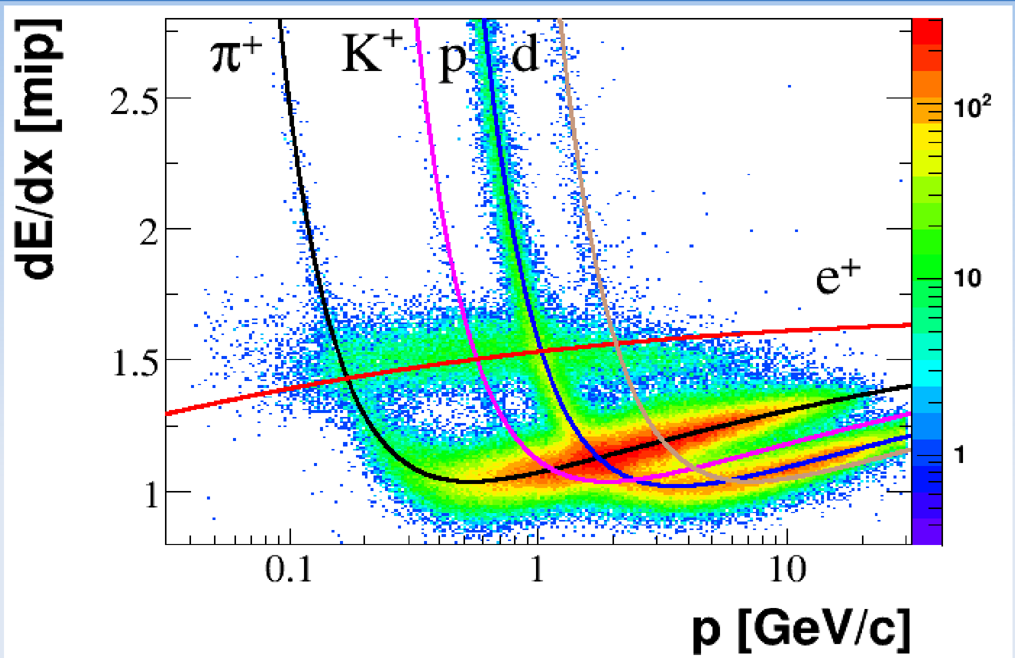
- Three complementary analysis techniques which differ by PID method
- **h^- analysis (π^-):** No PID required; a small non-pion contamination from negatively charged hadrons is corrected for by model-based Monte Carlo

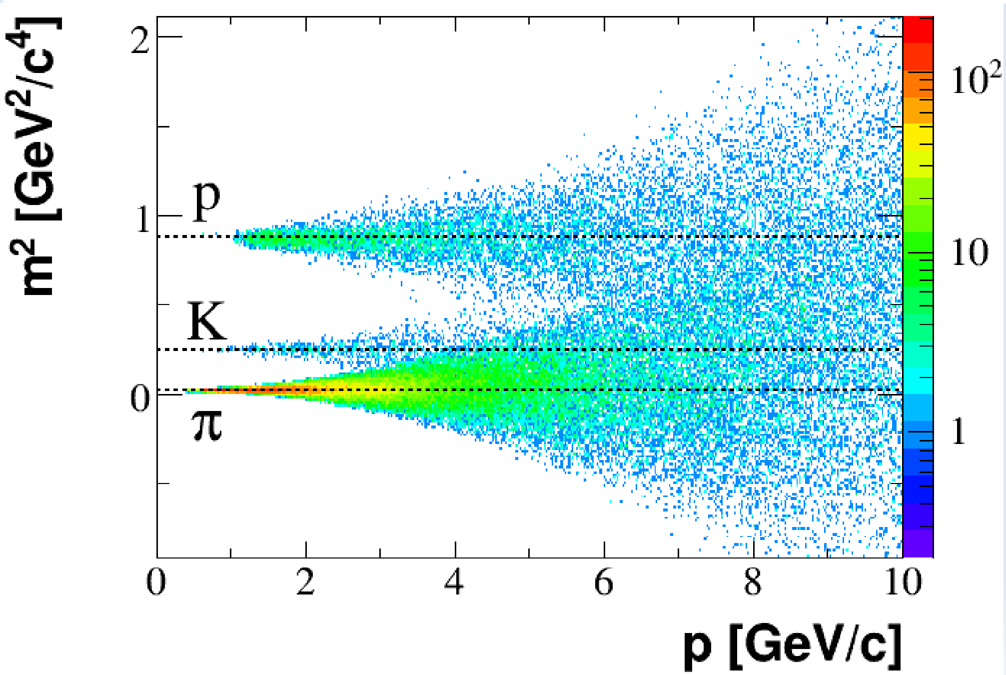
  Corrected π^- spectra in a broad kinematic range.
- **dE/dx analysis at low momenta ($\pi^{\pm}$,p):** yields fitted to dE/dx distributions in the low ($1/\beta^2$) momentum region

  Corrected spectra of π^+/p (π^-) up to 1 GeV/c (3 GeV/c) in momentum.
- **Combined dE/dx + ToF analysis ($\pi^{\pm}$,$K^{\pm}$,p):** yields fitted to 2-dimensional m^2 vs dE/dx distributions.

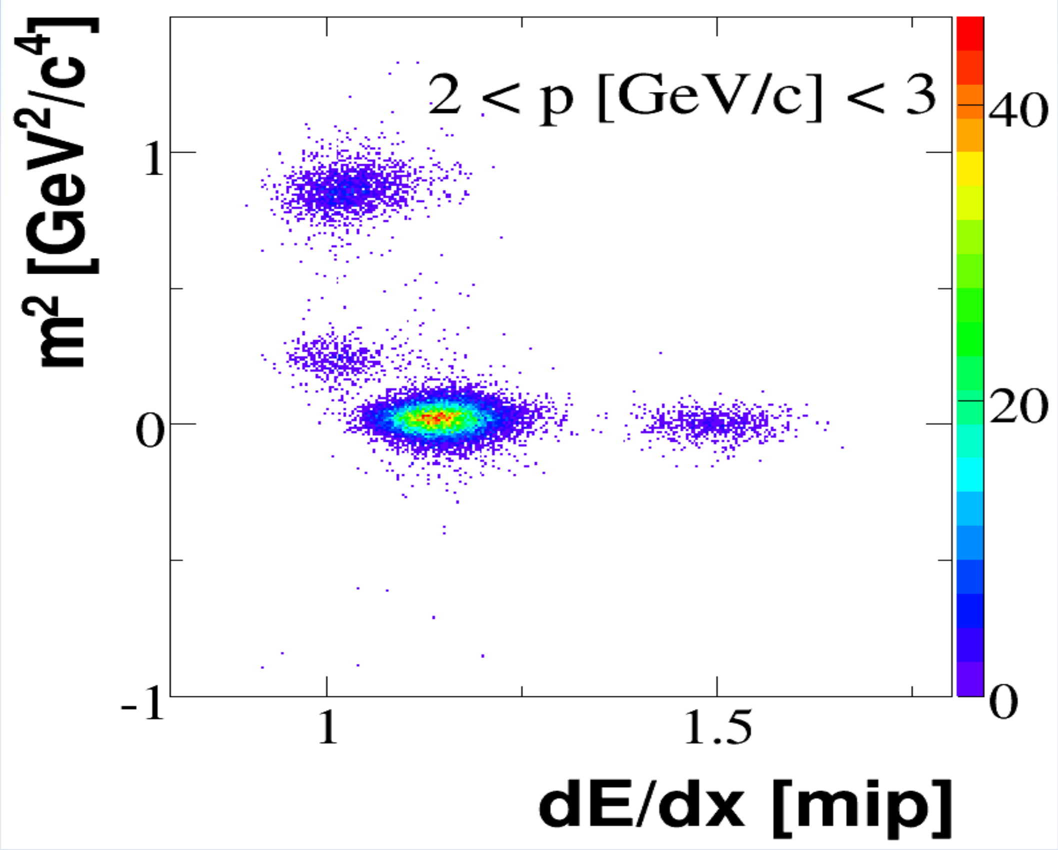
  Corrected spectra above 1 GeV/c in momentum.
- All results are corrected for geometrical acceptance, reconstruction efficiency, contamination of electrons and other particles, secondary interactions and weak decays ("feeddown").

NA61/SHINE PID capabilities

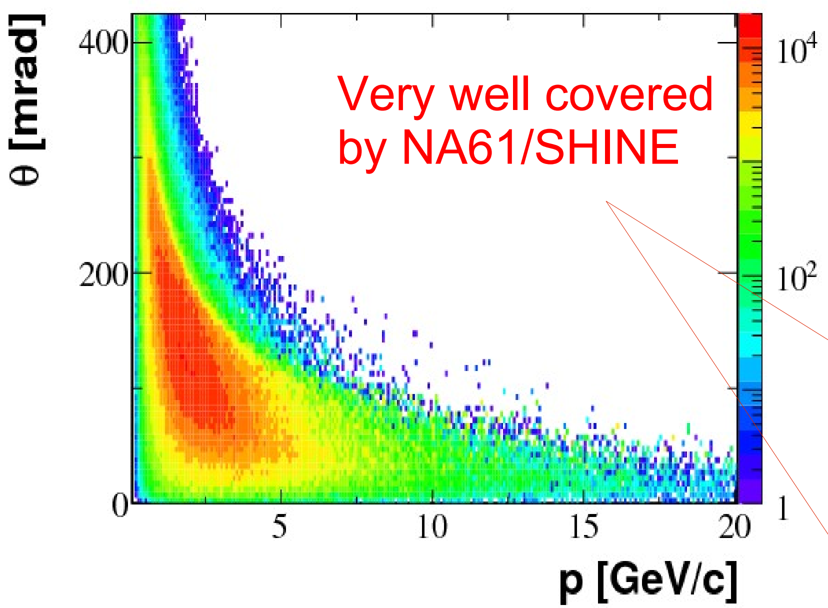




Combined dE/dx + ToF identification



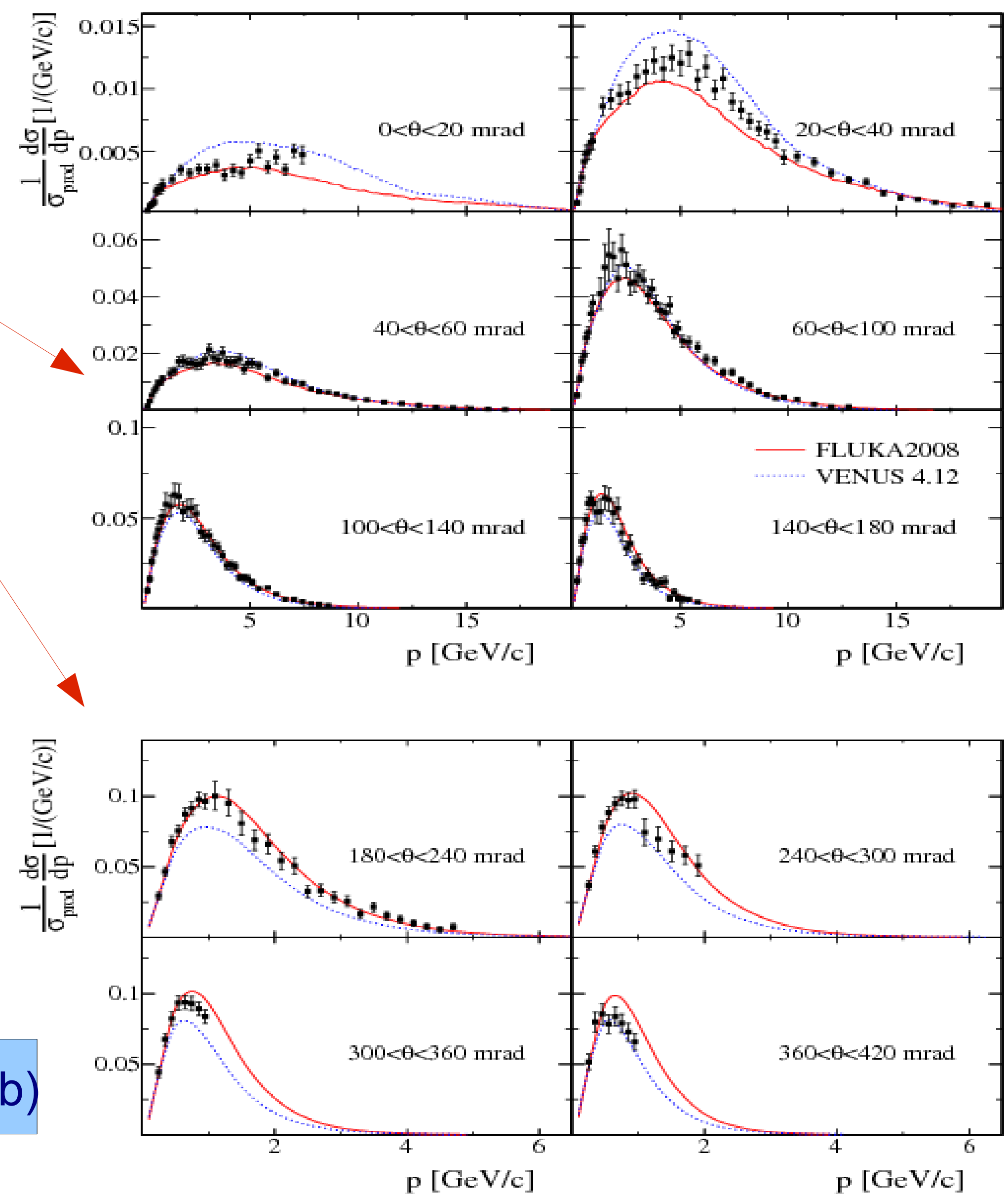
NA61/SHINE pC@31GeV/c: π^+ (& π^-) results



T2K beam simulation: the {p,θ} distribution for π^+ weighted by the probability that their decay produces a ν_μ passing through SK

Published in PRC 84 (2011) 034604

π^+

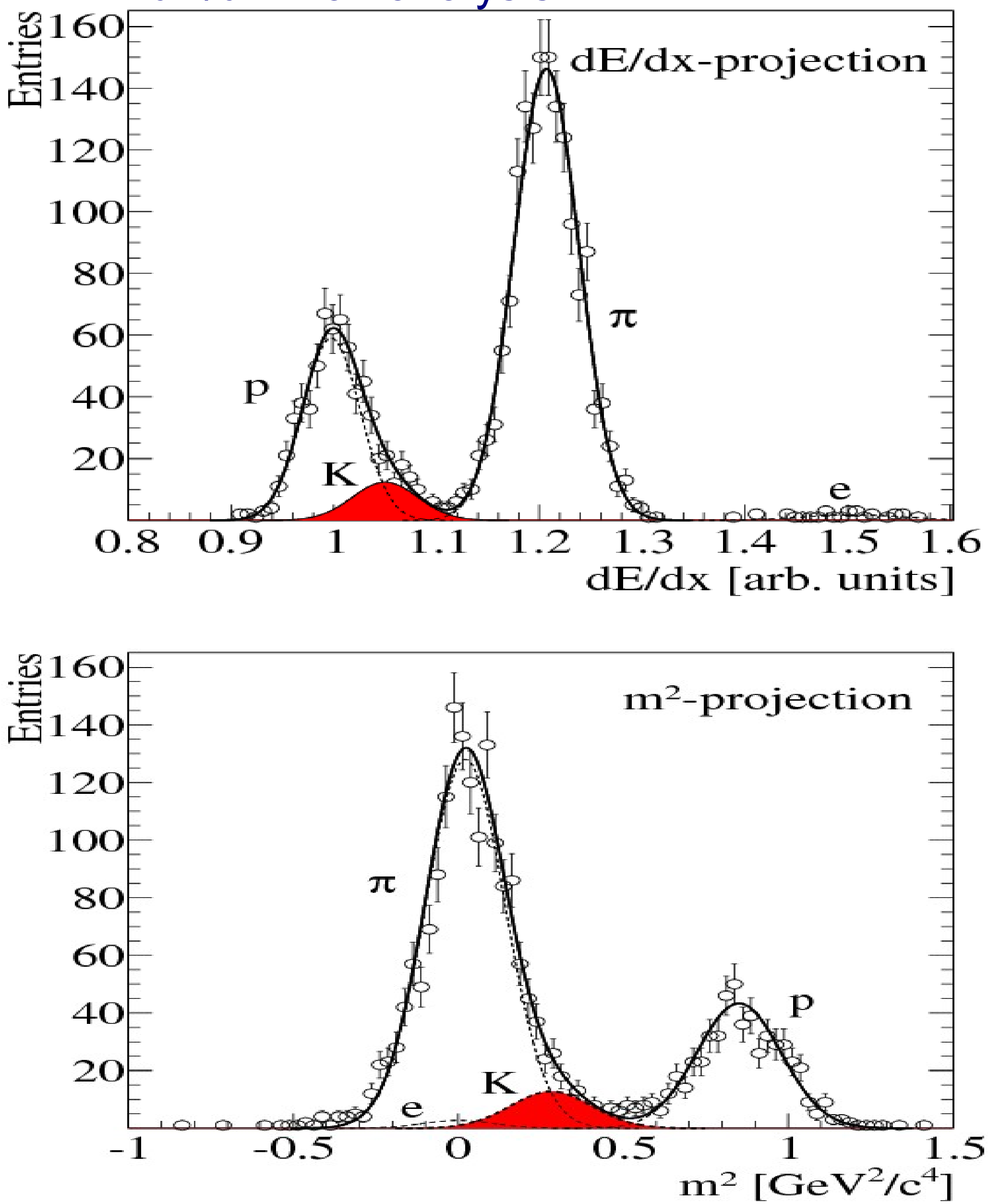


NA61/SHINE measurements

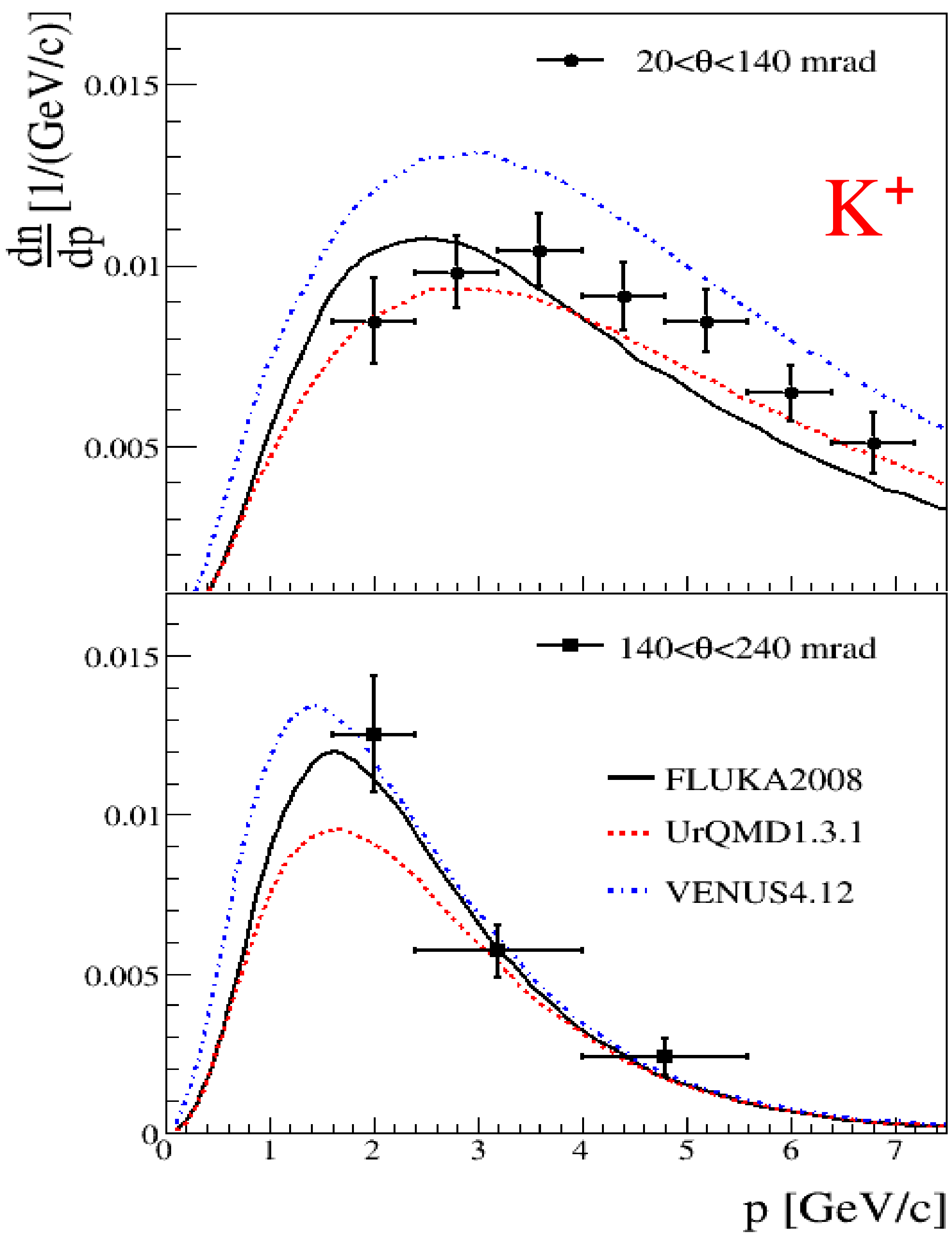
σ_{prod} (pC@31GeV/c)= 229.3 ± 1.9 ± 9.0 (mb)

NA61/SHINE pC@31GeV/c: K^+ results

dE/dx+ToF analysis

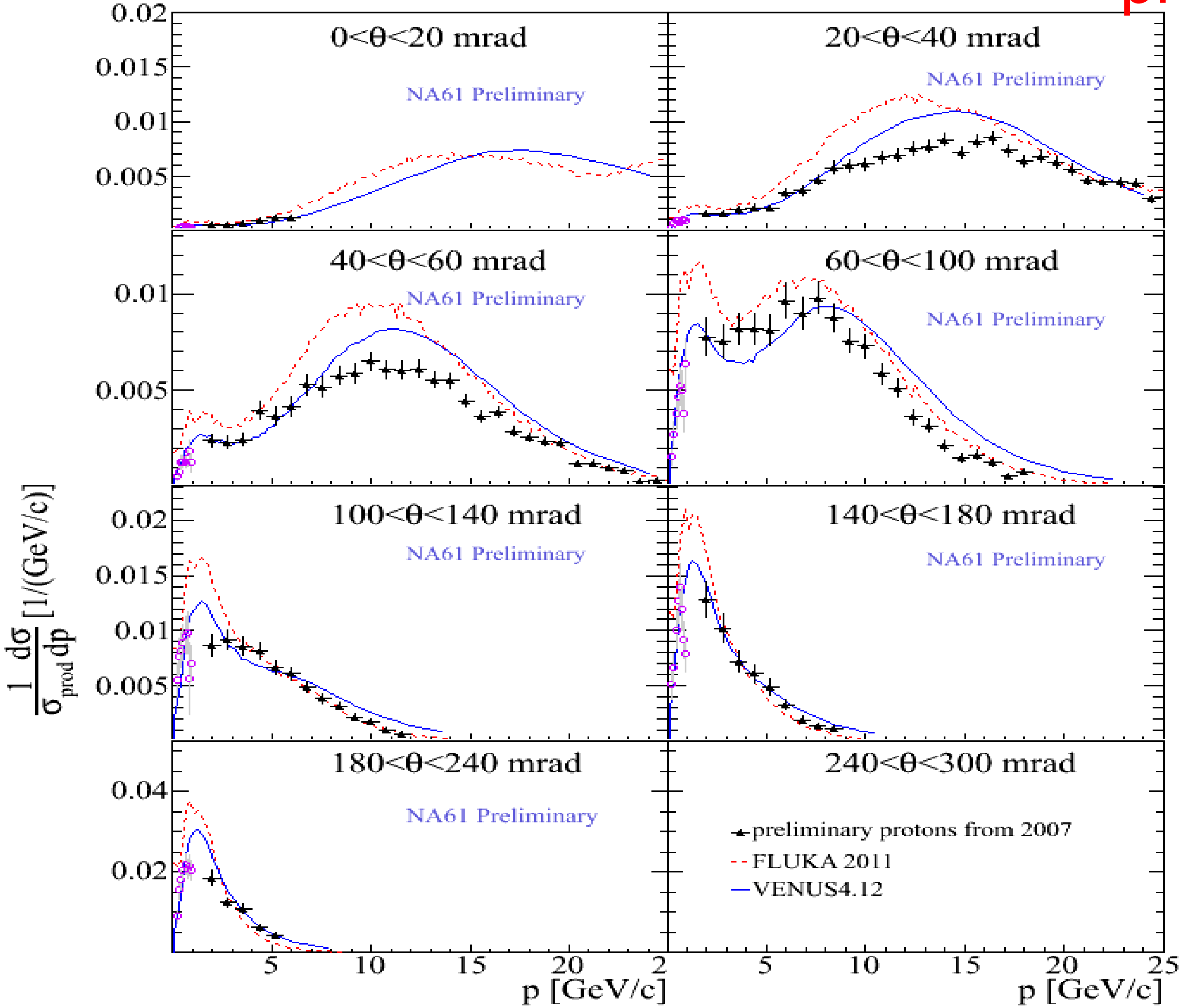


Published in PRC 85 (2012) 035210



NA61/SHINE pC@31GeV/c: proton results

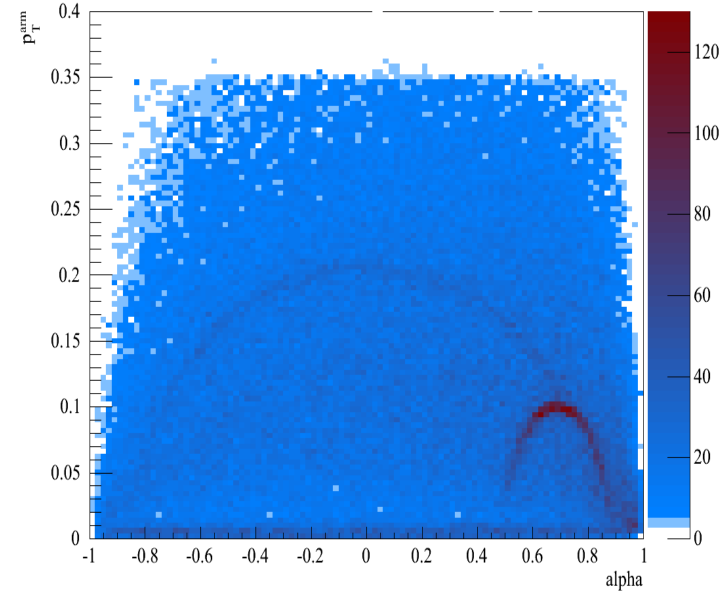
protons

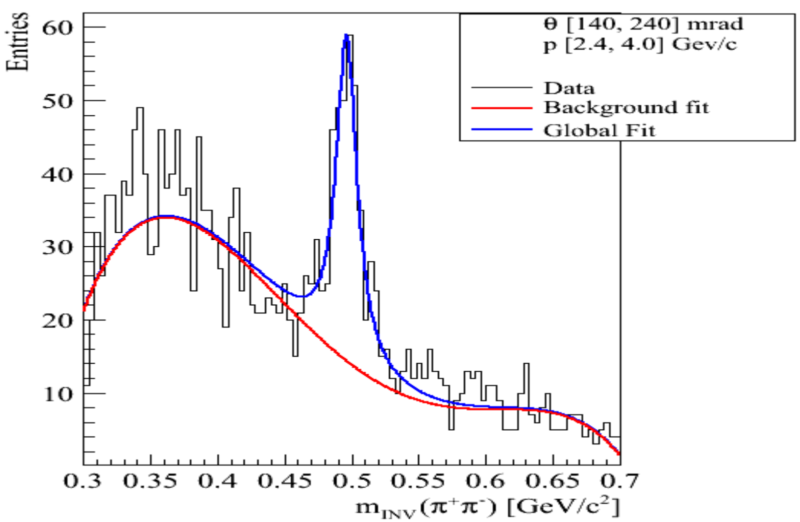


Preliminary results from 2007 data

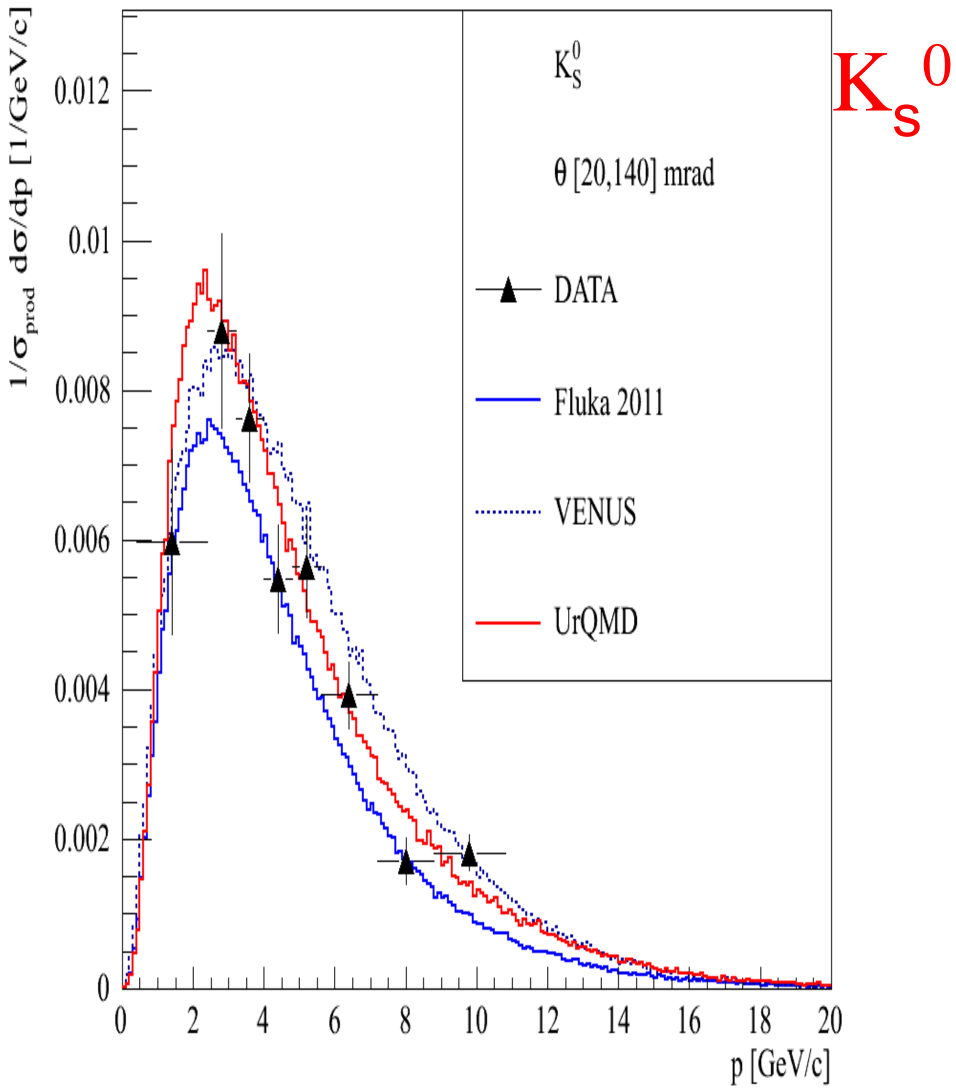
M.Posiadala, PhD thesis, Univ. of Warsaw, 2012; S.Murphy, PhD thesis, Univ. of Geneva, 2012

NA61/SHINE pC@31GeV/c: V0 analysis



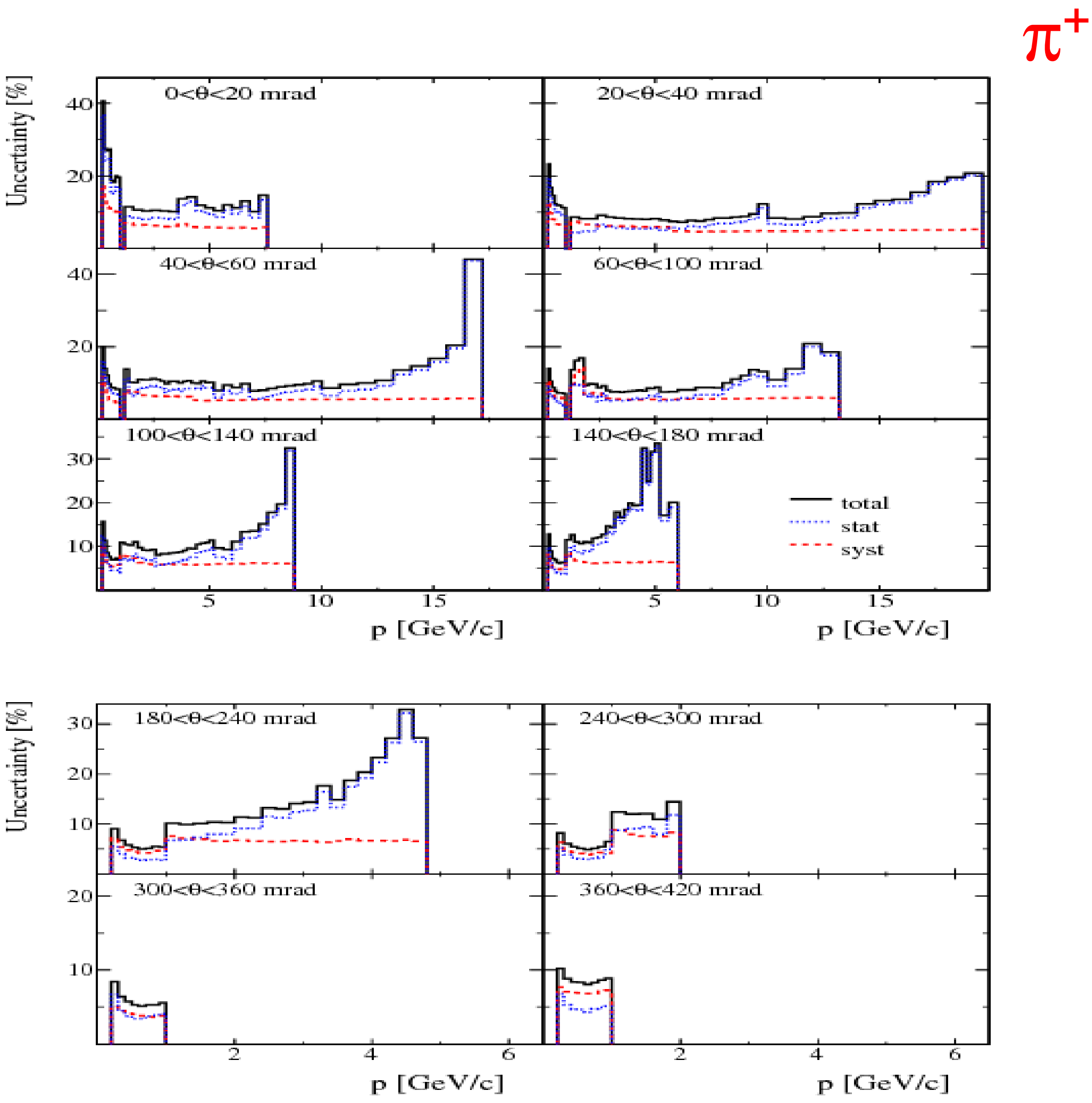


Preliminary results from 2007 data



T.Palczewski, PhD thesis, National Centre for Nuclear Research, Warsaw, 2012

NA61/SHINE pC@31GeV/c: stat vs syst errors



In 2007 data analysis statistical errors dominate.

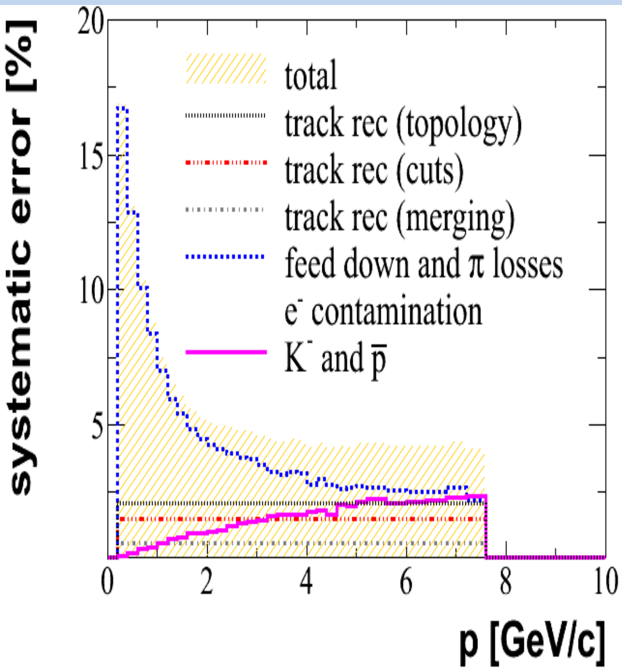
With 2009 data we hope to reduce statistical errors by a factor of 3.

Systematic errors will become more important

NA61/SHINE pC@31GeV/c: systematic errors

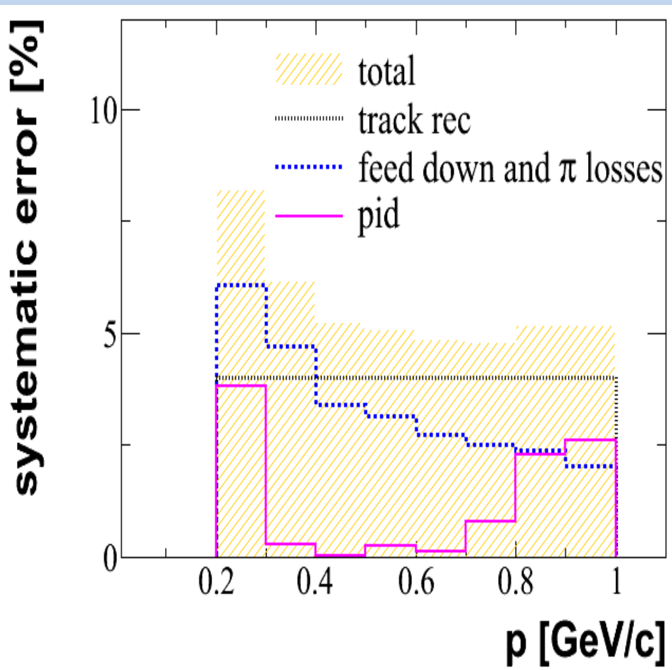
h- analysis

π^- θ=[140,180] mrad



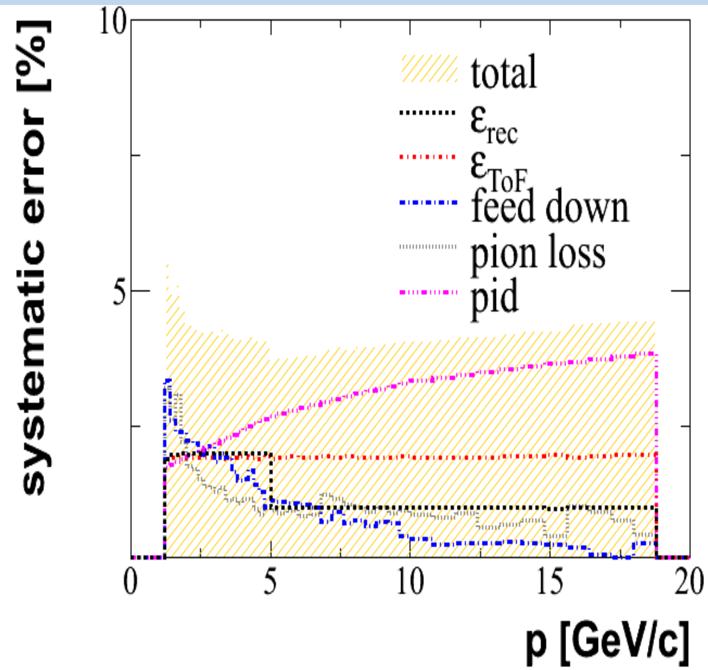
dE/dx analysis

π^+ θ=[140,180] mrad



dE/dx+ToF analysis

π^+ θ=[40,60] mrad



Typical value 6%
Hope to reduce down to 3-4%

Systematic error due to uncertainty of the feeddown correction is larger for π^- than for π^+ due to contribution from Λ hyperon decays. NA61/SHINE measurements of neutral strange particle production will allow to reduce this systematic error.

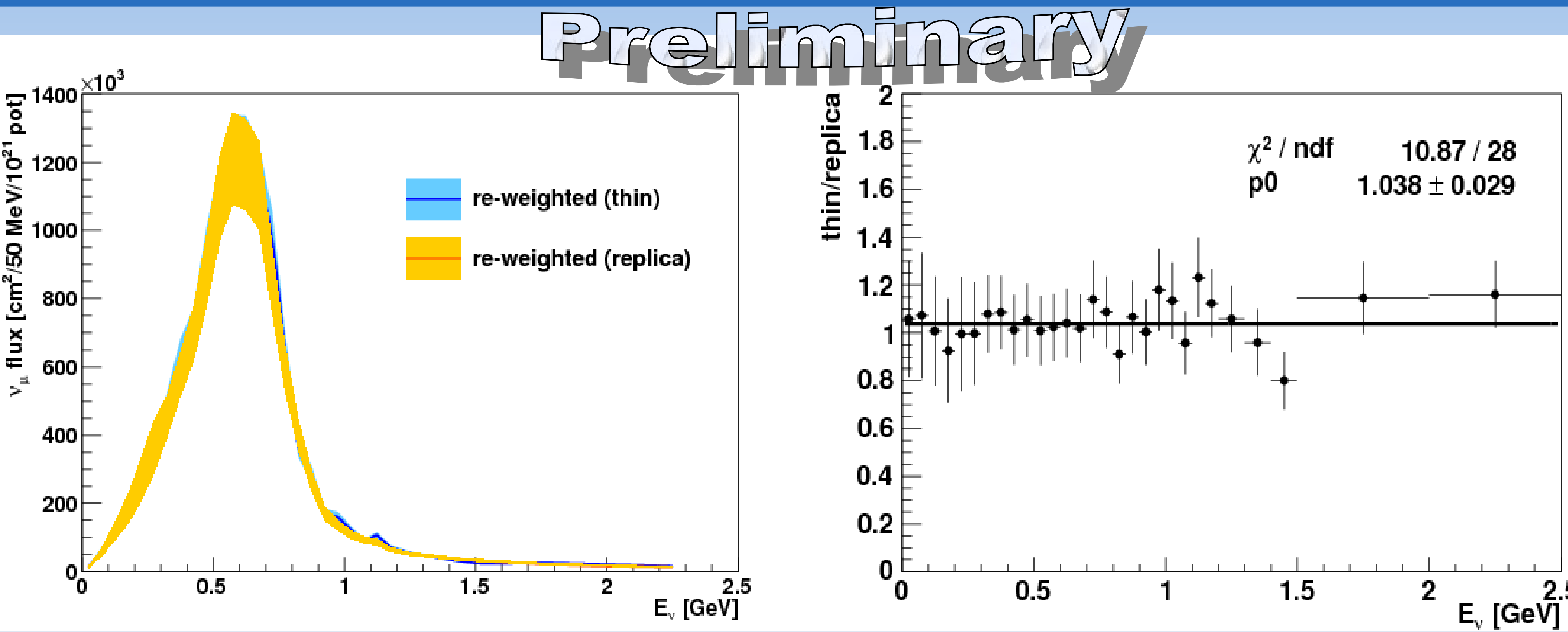
NA61/SHINE: replica target analysis

- Special reconstruction and analysis techniques developed for the replica target (RT)
- Pilot analysis on π^+ emission from the RT surface performed on 2007 data with 5 longitudinal bins along the target and target downstream face
- RT hadron production measurements allow to constrain up to 90% of neutrino flux in T2K
- Proof-of-principal neutrino flux re-weighting performed with NA61/SHINE RT data
- Results consistent with the thin target tuning

More details in the poster by Alexis Haesler

[N.Abgrall, PhD thesis, Univ. of Geneva, 2011; NA61/SHINE paper in preparation]

NA61/SHINE: replica target analysis



Replica target data are used for the first time for neutrino flux predictions.

Combination of thin and replica target measurements would allow to better understand effects of reinteractions in the long target.

Ultimate precision on T2K neutrino flux will be achieved with replica target re-weighting, once 2010 NA61/SHINE data are analyzed.

N.Abgrall, PhD thesis, Univ. of Geneva, 2011; NA61/SHINE paper in preparation

NA61/SHINE: prospects

- NA61/SHINE 2009 & 2010 pC@31GeV/c and pRT@31GeV/c data provide even a better coverage of phase space of interest for T2K and will allow to reach T2K requirements on neutrino flux predictions: 5% error on absolute neutrino fluxes in the near and far detectors as well as 3% error on the far-to-near ratio
- US groups involved in Fermilab neutrino experiments plan to join NA61 in order to perform required hadron production measurements
- Future accelerator neutrino experiments (in Europe!) could definitely profit from the NA61/SHINE know-how (if proton momentum and target material are known)

US Interest in NA61/SHINE

- **Institutions:** FNAL, LANL. University of Texas at Austin, TX, University of Colorado, Boulder, CO, Northwestern, IL, University of Pittsburgh, PA, University of Rochester, NY, William and Mary, VA
- These institutions listed are interested in precise neutrino flux constraints for NuMI experiments (MINOS, NOvA, Minerva) and the future (LBNE).
  - Neutrino oscillation experiments require an understanding of the unoscillated neutrino spectrum. For cross-section experiments the hadron production uncertainties directly impact the final answer.
  - Both redundancy and over-constraining hadronic production modeling through measurements will be useful in reducing all sorts of backgrounds and systematics
  - Using NA61 is an opportunity to do it relatively fast and in a cost effective way and mutually beneficial.

Valid for any future project

- On May 2 US funding adgencies (DOE and NSF) have been informed of our plans: Submitted Letter of Intent (LOI) – Detailed full proposal to be submitted later this summer
- On May 3 the NA61 Collaboration Board and Spokesperson accepted the limited membership of the US groups in NA61.
- Thin target 120 GeV/c run planned for this summer using the T2K thin target and holder is important both to demostrate feasibitly of full plan and for US groups to gain experience with the NA61 detector → Hoping for several weeks of running during 2014

NA61/SHINE: Conclusions

- NA61/SHINE has already performed important hadron production measurements relevant for neutrino physics (these data have been used for neutrino flux predictions in the T2K experiment)
- Further analysis of data collected for T2K with both thin and replica targets is on-going
- Strong interest from our US colleagues to perform hadron production measurements for Fermilab neutrino experiments
- Hadron production studies is a MUST for next generation accelerator neutrino experiments
- Existing NA61/SHINE spectrometer can be used for precision hadron production measurements relevant for future neutrino experiments

Backup slides

NA61/SHINE: derivation of spectra

- The corrected number of particles α in p bins and θ intervals with the target inserted (Δn_α^I) and the target removed (Δn_α^R) are used to compute inclusive differential cross-sections:

$$\frac{d\sigma_\alpha}{dp} = \frac{\sigma_{trig}}{1-\varepsilon} \cdot \left(\frac{1}{N^I} \frac{\Delta n_\alpha^I}{\Delta p} - \frac{\varepsilon}{N^R} \frac{\Delta n_\alpha^R}{\Delta p} \right)$$

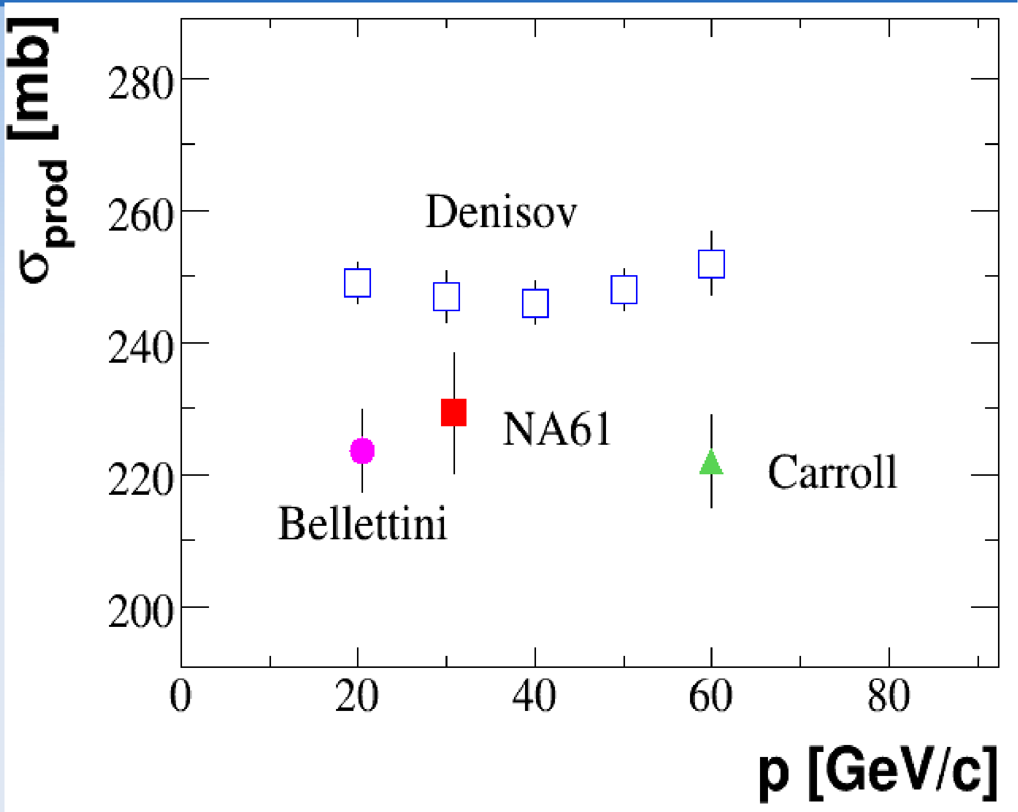
- $\sigma_{trig}=298.1\pm1.9\pm7.3$ (mb) is the "trigger" cross-section calculated from the number of interacting protons
- N^I and N^R are the numbers of events with the target inserted and removed
- $\varepsilon=0.118\pm0.001$ is the ratio of the interaction probabilities for removed and inserted target operation
- Δp is the bin size in momentum

NA61/SHINE pC@31GeV/c: cross-sections

- To obtain inelastic cross-section, the "trigger" cross-section was corrected for:

  1) the contribution of the coherent elastic pC scattering giving trigger signal in the experiment. Simulated by GEANT4-QGSP_BERT (47.2±0.2±0.5) mb [subtraction]

  2) the loss of inelastic events due to the emitted charged particles hitting S4 trigger counter (5.7±0.2±0.5) mb for protons and (0.57±0.02±0.35) mb for pions and kaons [addition]



The inelastic processes include the production processes and in addition interactions which result only in the desintegration of the target nucleus (quasi-elastic interactions).

The production processes are defined as those in which new hadrons are produced.

$$\sigma_{prod} = \sigma_{inel} - \sigma_{qel}$$

(229.3 ± 1.9 ± 9.0) mb = (257.2 ± 1.9 ± 8.9) mb - (27.9 ± 1.5) mb

from Glauber model calculations

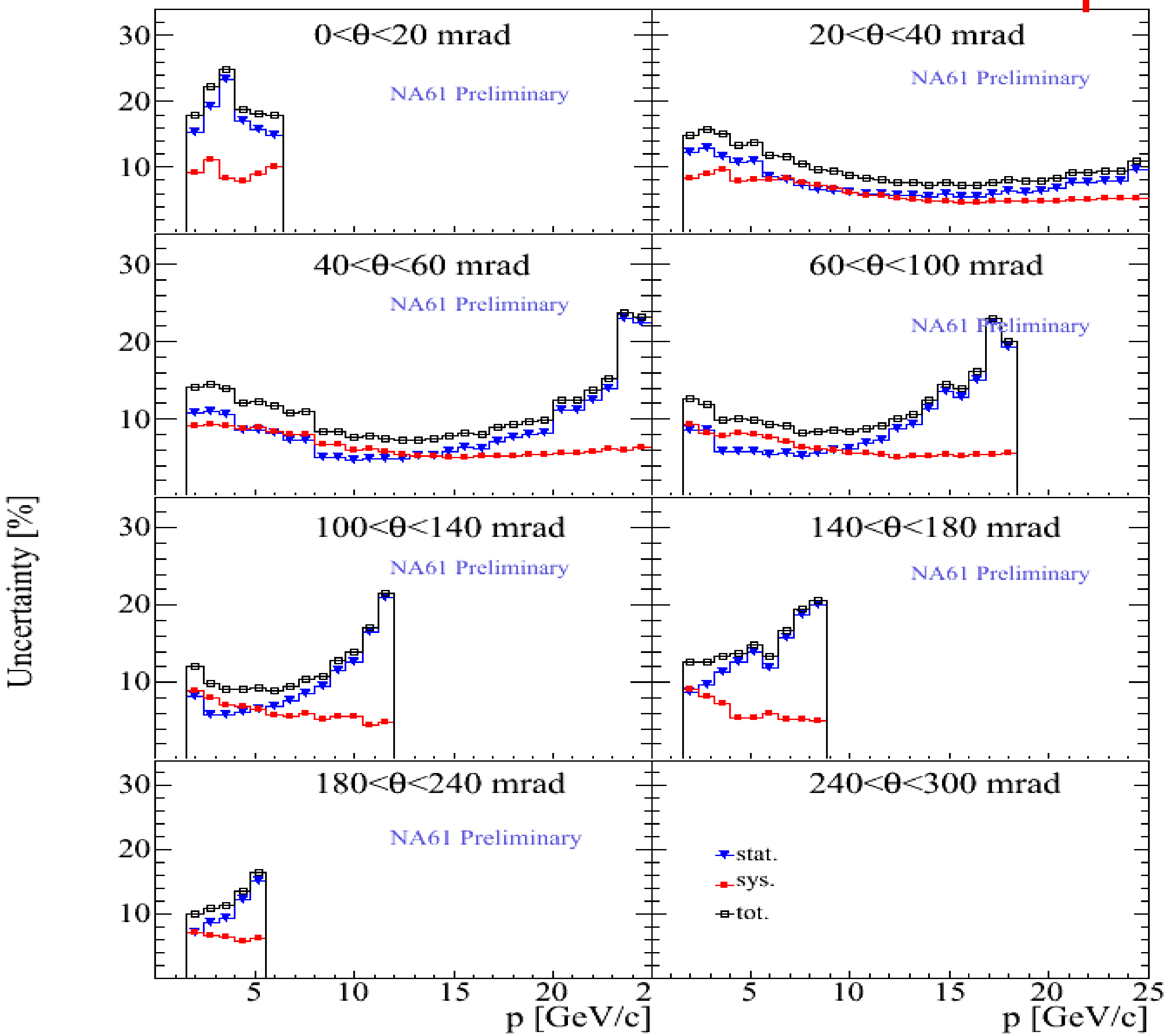
C.Strabel, PhD thesis, ETHZ, 2011

NA61/SHINE: systematic errors

- Considered systematic errors
- Uncertainty of PID procedure for dE/dx and dE/dx+ToF analyses
- Feeddown: pions from weak decays and secondary interactions reconstructed at primary vertex
- Track topology
- Track cuts (number of points, azimuthal angle, impact parameter)
- Track merging algorithm
- Reconstructed efficiency
- ToF detection efficiency
- Electron, K- and antiproton contamination in the h- analysis
- Pion/kaon loss correction due to pion/kaon decay

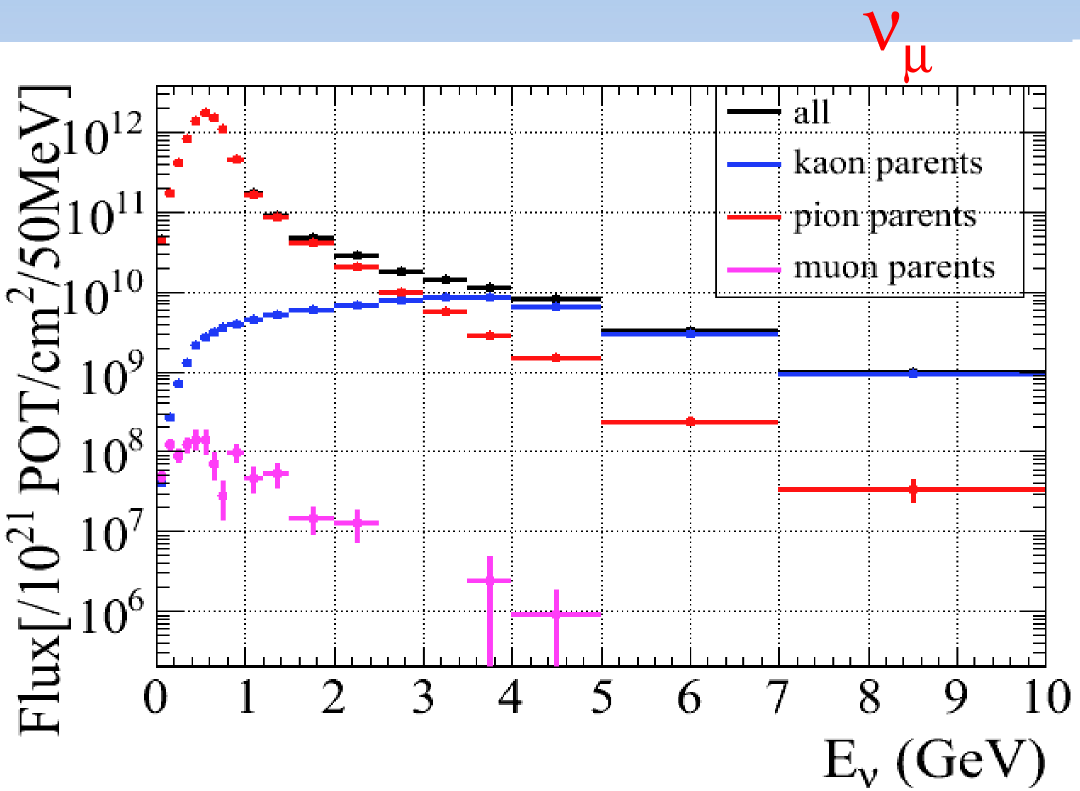
NA61/SHINE pC@31GeV/c: stat vs syst errors

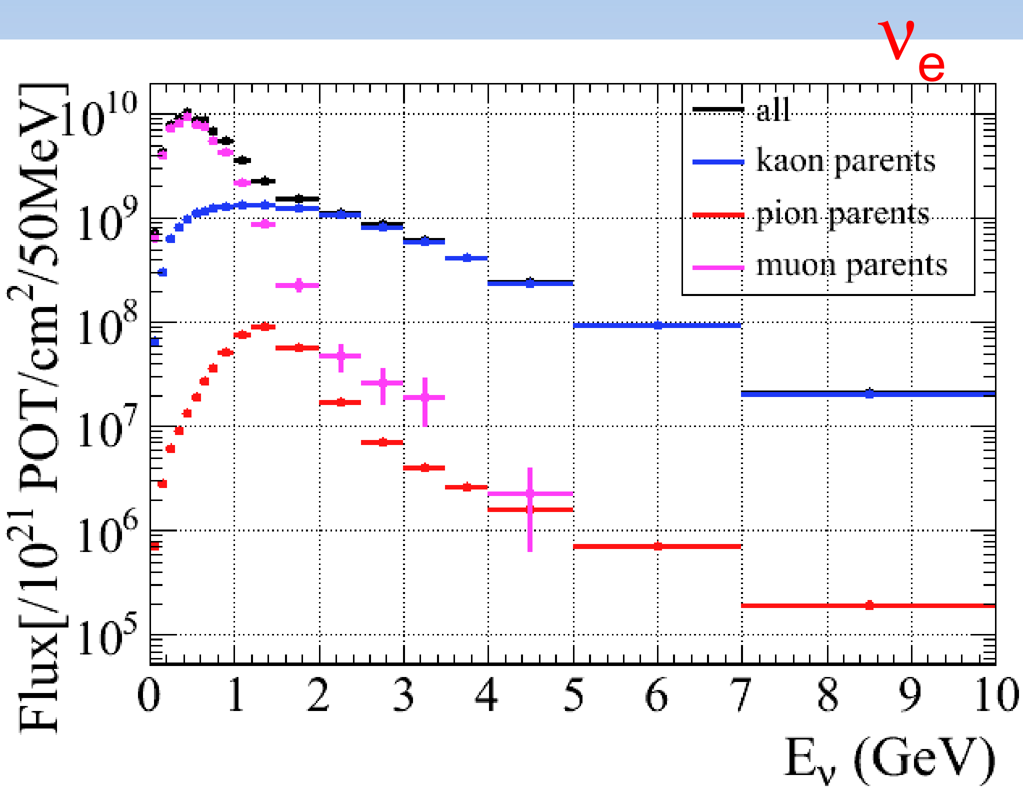
protons



Preliminary results from 2007 data

T2K neutrino fluxes

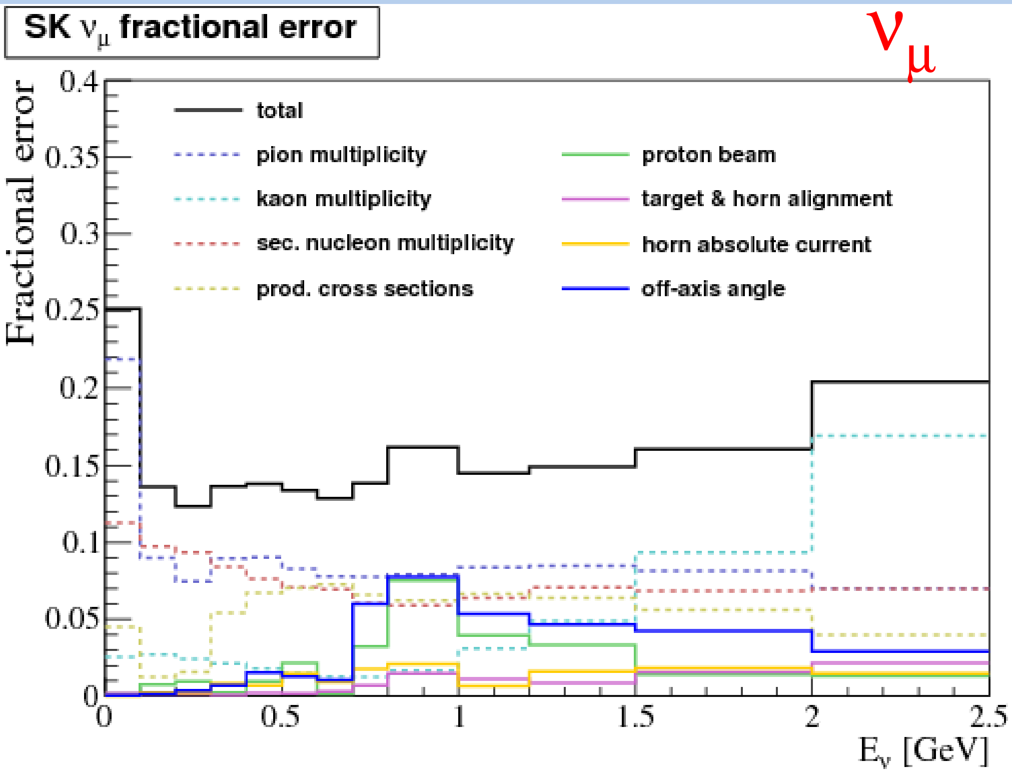


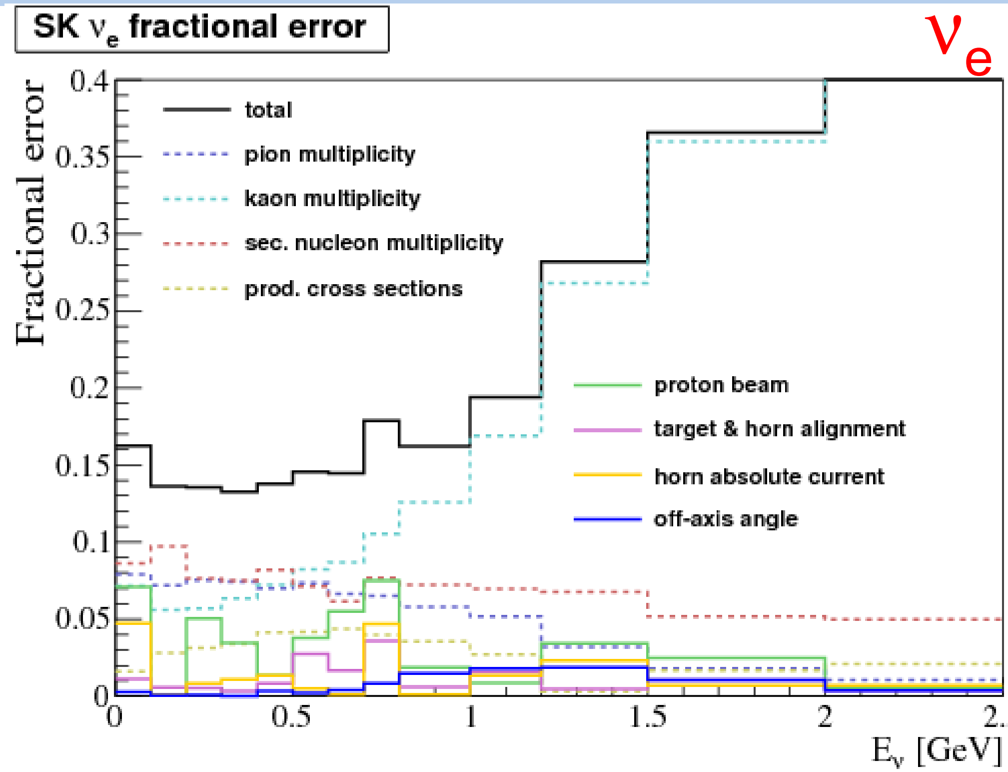


Predictions of the ν_μ and ν_e fluxes at the T2K near detector:

Based on FLUKA2008 and weighted by the NA61/SHINE thin target pion data

T2K neutrino flux uncertainties



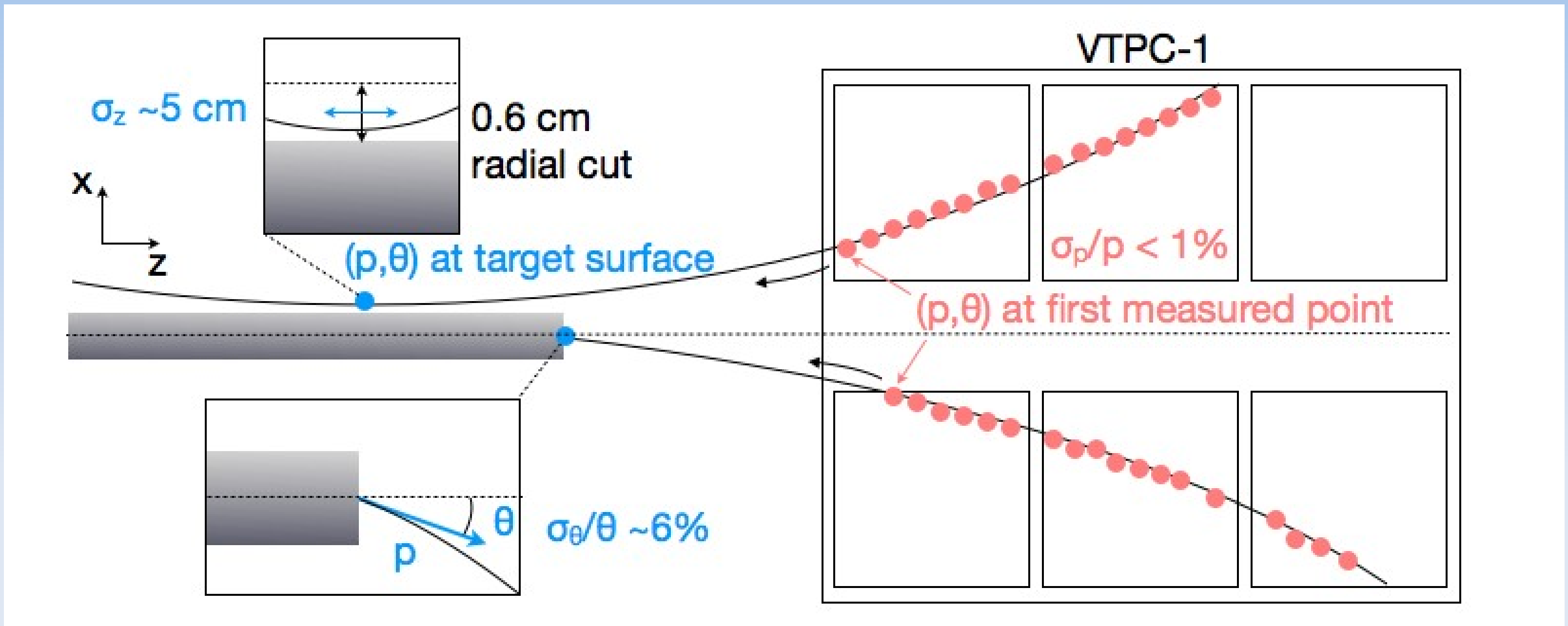


Fractional errors on the ν_μ and ν_e fluxes at the T2K far detector in the first published T2K analysis

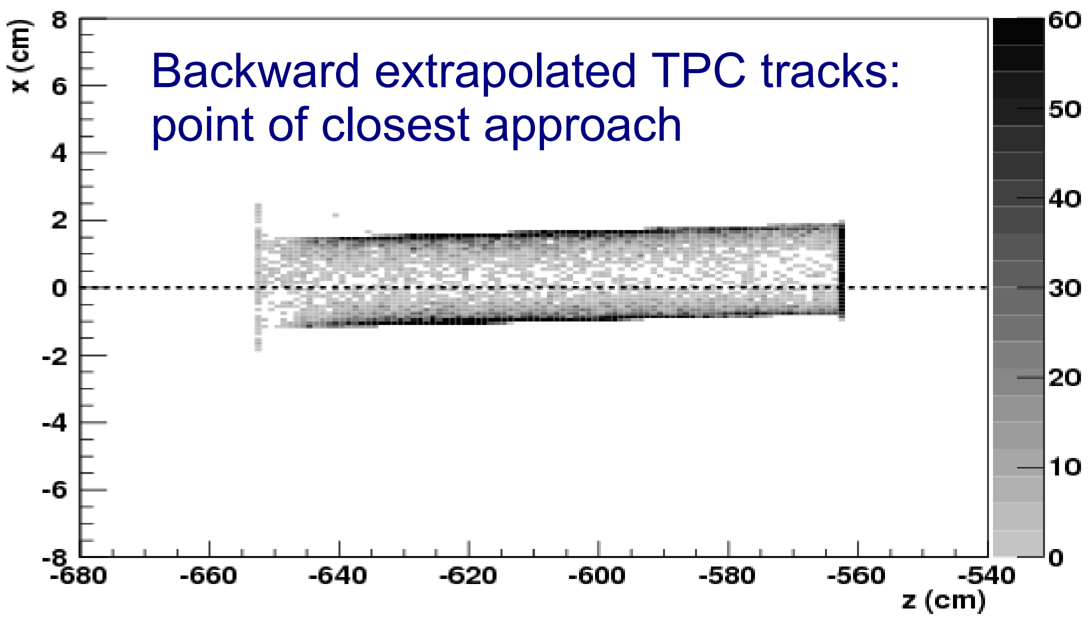
[PRL 107 (2011) 041801; PRD 85 (2012) 031103]

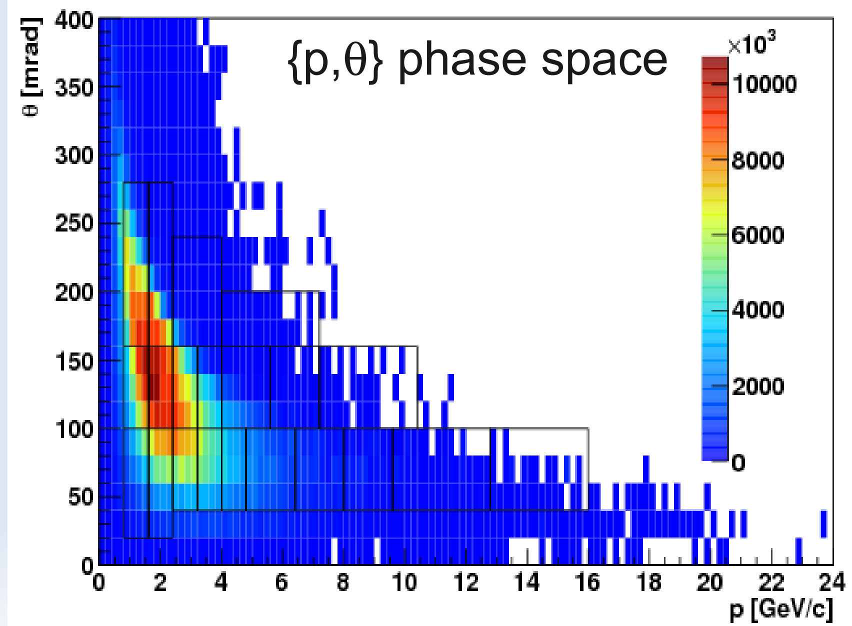
Have recently been improved with the inclusion of the new NA61/SHINE K^+ measurements

NA61/SHINE: replica target analysis

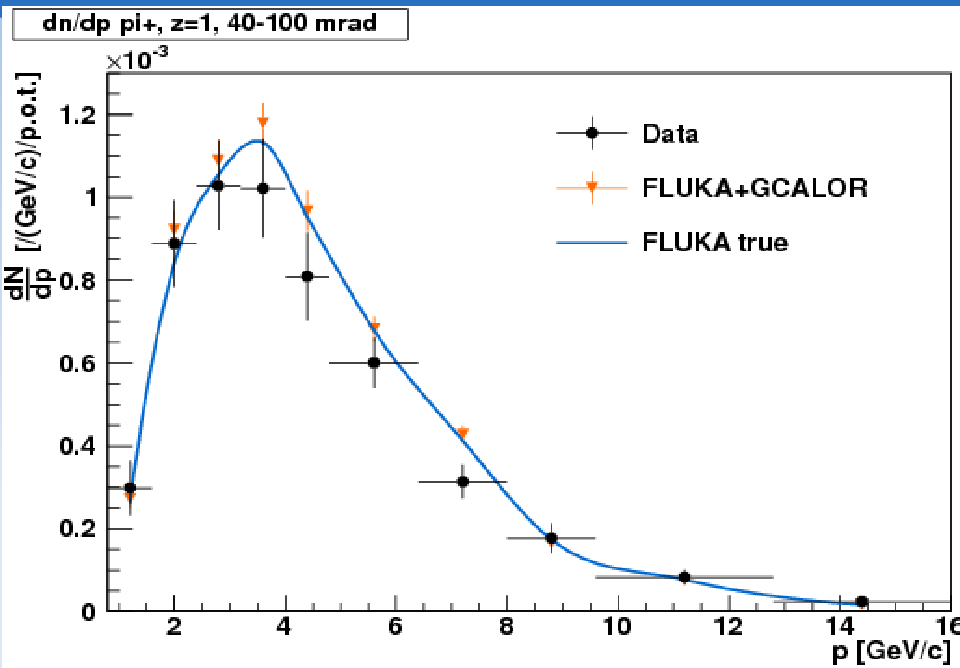


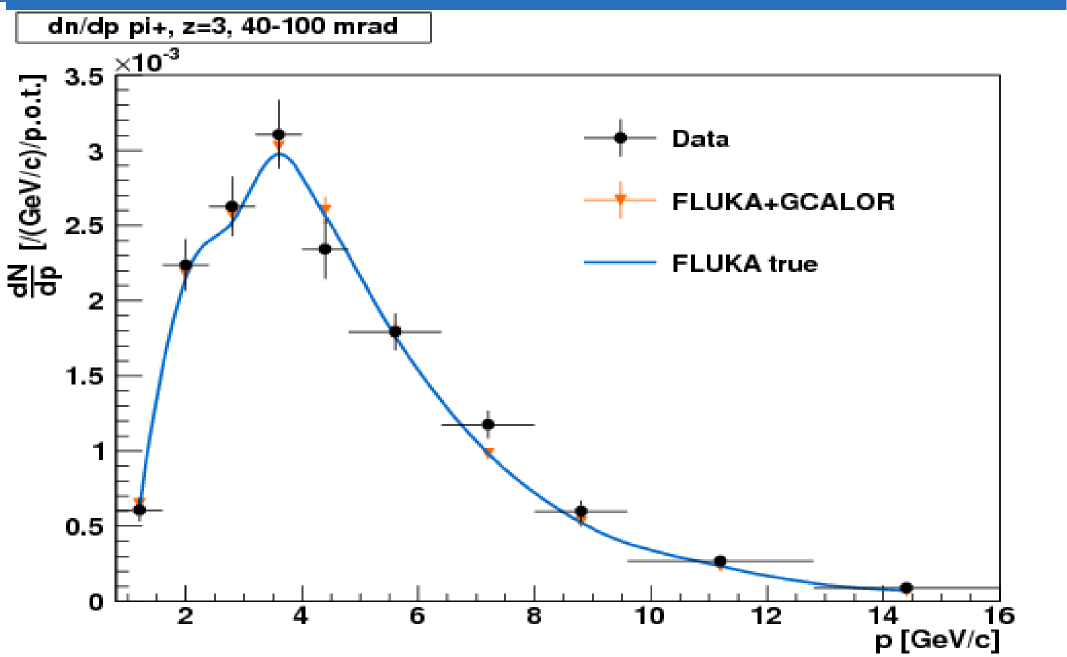
5 longitudinal bins of 18 cm each + target downstream face

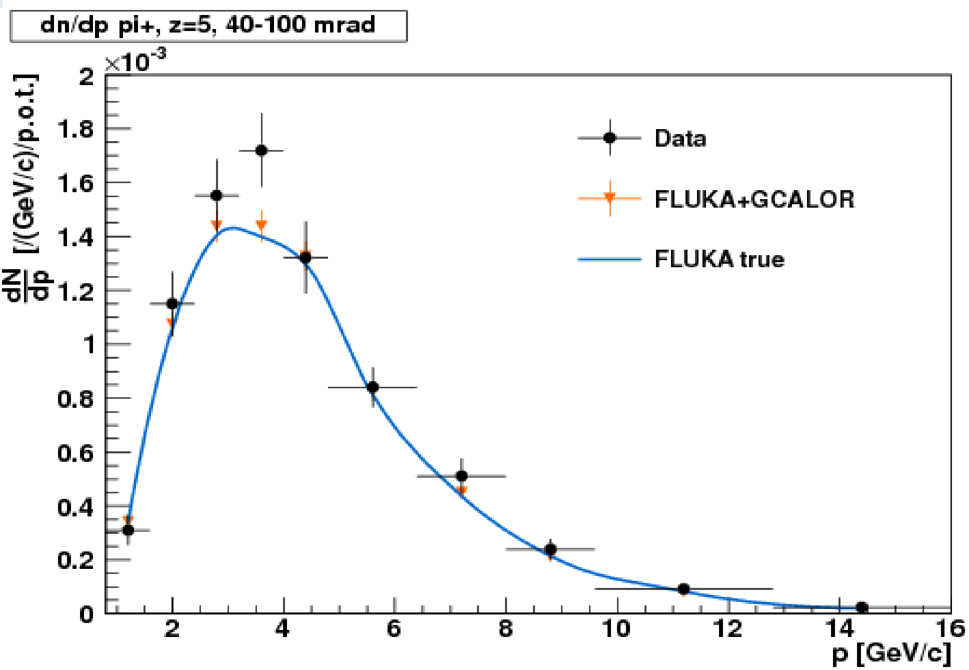


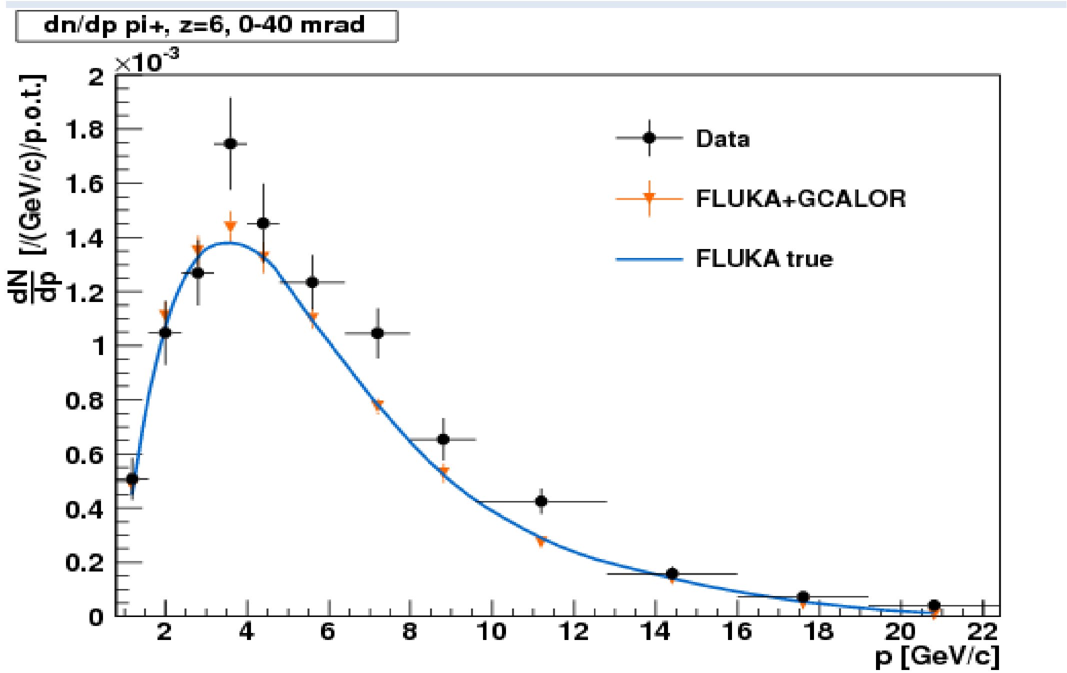


NA61/SHINE: RT measurements









NA61/SHINE: RT re-weighting