Measurements of the Cross Sections and Charged Pion Spectra in Proton – Carbon Interactions at 31 GeV/c

Outline:

Only p+C interactions collected during 2007 run on thin carbon target are used. We registered 667 k events. After quality cuts we were left with **521k events** .

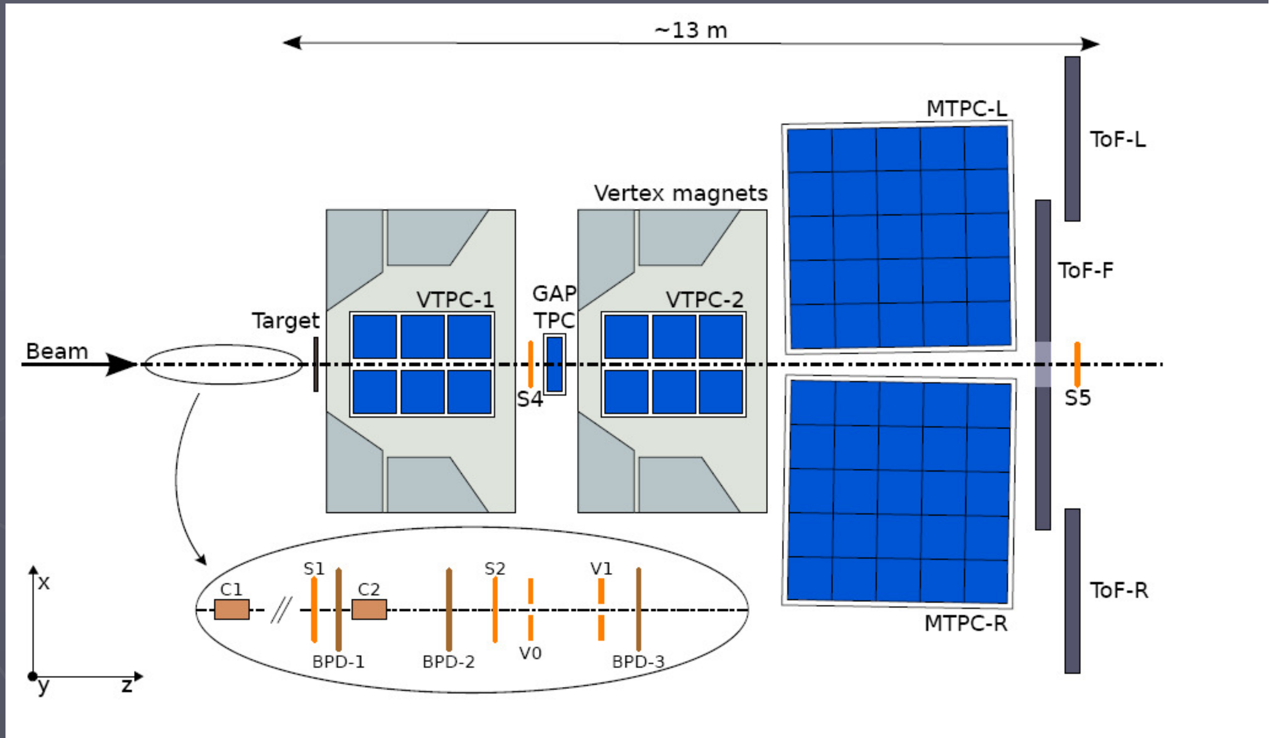
- NA61/SHINE detector performance
- Analyses map
- Normalization of the spectra
- Systematic error studies
- Final spectra of pions compared with FLUKA, URQMD and VENUS predictions
- Status of the 2009 data taking

Magdalena Posiadała
University of Warsaw

NA61/SHINE- detector performance

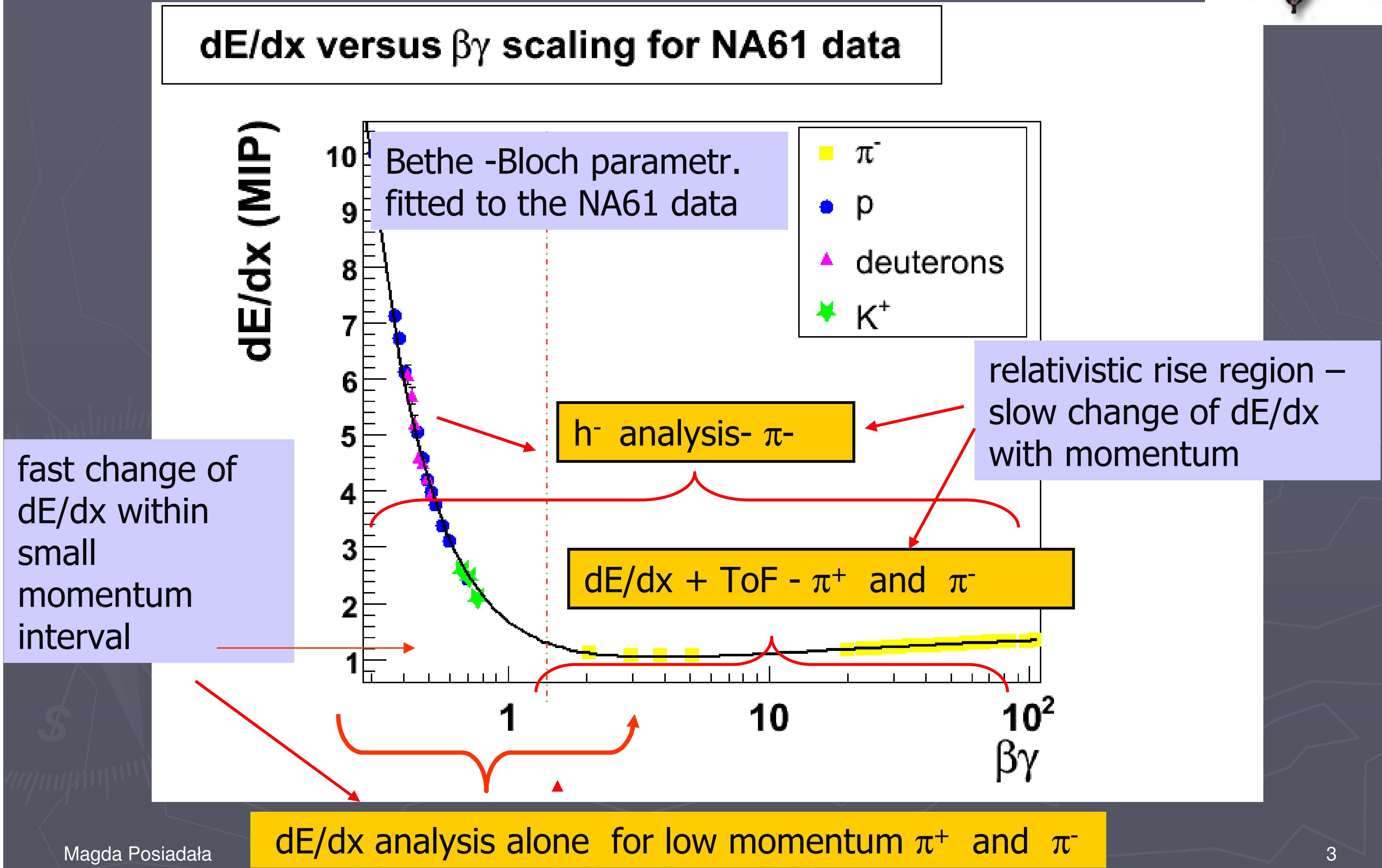
- Large Acceptance NA49 Spectrometer for charged Particles
- **TPC**s as main tracking devices
- 2 dipole magnets with bending power of max 9 Tm over 7m length

(2007 run:1.14Tm)



- New ToF-F to cover T2K acceptance
- High momentum resolution $\sigma_p/p^2 = 10^{-4}\ (GeV/c)^{-1}$
- Good particle identification **(PID) : $\sigma(dE/dx)$~4%**
- Good ToF resolution: **σ(ToF-L/R)=60 ps, σ(ToF-F)<=120 ps**

Analyses map



Cross section measurements

1) **Differential inclusive cross sections** for pion production in small angular intervals have been obtained from π^+ and π^- rates ($\Delta n_{\alpha,}$ where α stands for π^- and π^+) using the following normalization:

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

where the used factors are defined as:

- σ_{trig}**=(298.1±1.9±7.3)mb** is the „trigger" cross section – calculated from the number of interacting protons.
- $N^{I,R}$ is the number of events selected for each analysis with the target inserted and removed, respectively.
- ε**=0.118±0.001** is the ratio of the interaction probabilities for removed and inserted target operation.
- Δp is the bin size of the momentum

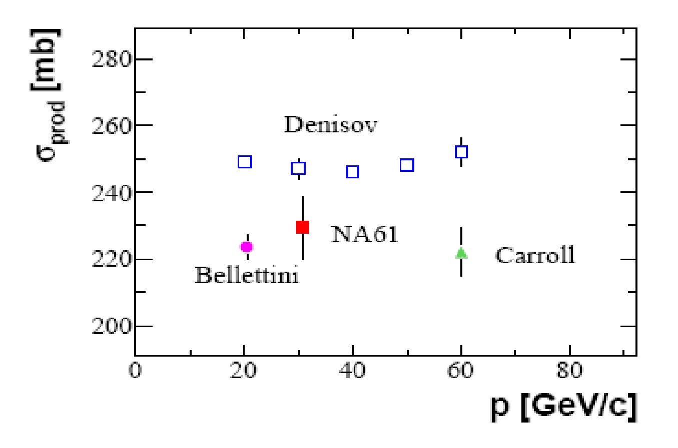
The **total inelastic cross section** was derived from the „trigger" cross section with corrections, calculated by GEANT 4 simulation :

1) the contribution of the coherent elastic scattering (pC) giving trigger signal in the experiment. (47.2±0.2±0.5)mb (subtraction).
2) the loss of inelastic events due to the emitted charged particles hitting S4 veto counter (5.7±0.2±0.5)mb for protons and(0.57±0.02±0.35)mb for pions and kaons (addition)

Finally the **total inelastic cross section** is:

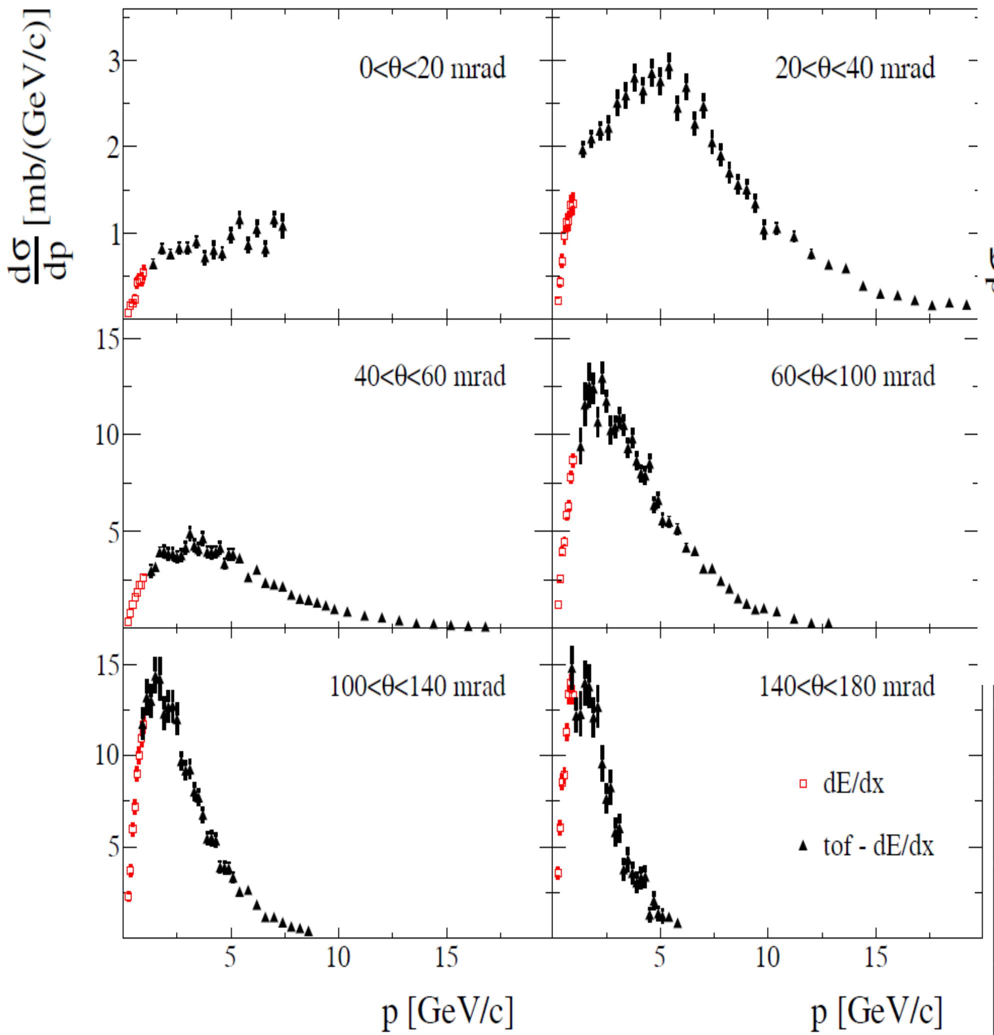
σ_{inel} **= (257.2±1.9±8.9)mb.**

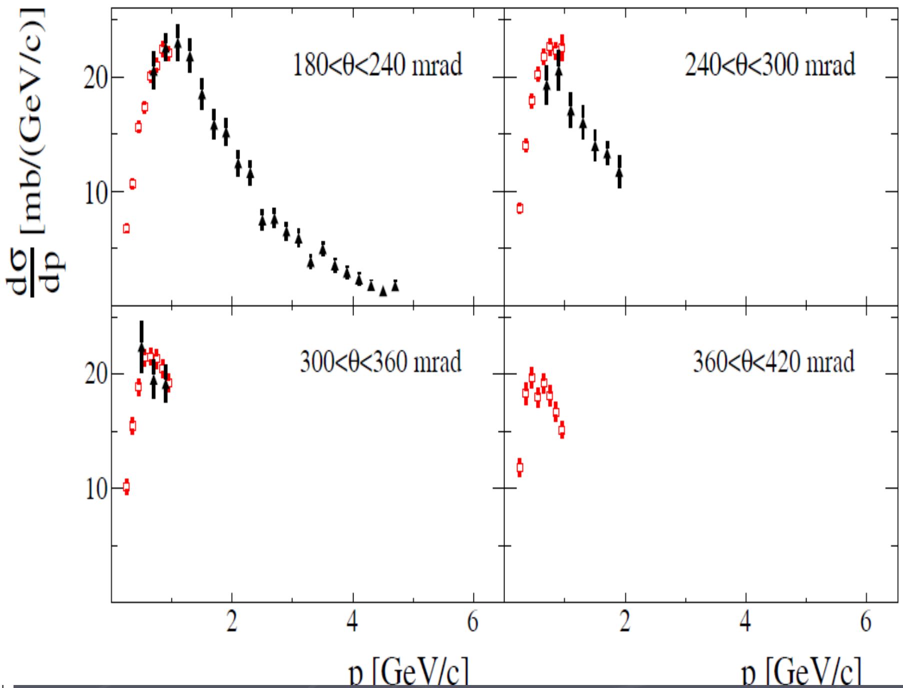
The **production cross section** (σ_{prod}) was calculated from the inelastic cross section by subtracting the quasi-elastic contribution.



The result is: σ_{prod} **= (229.3±1.9±9.0)mb**

Differential cross sections - π^+





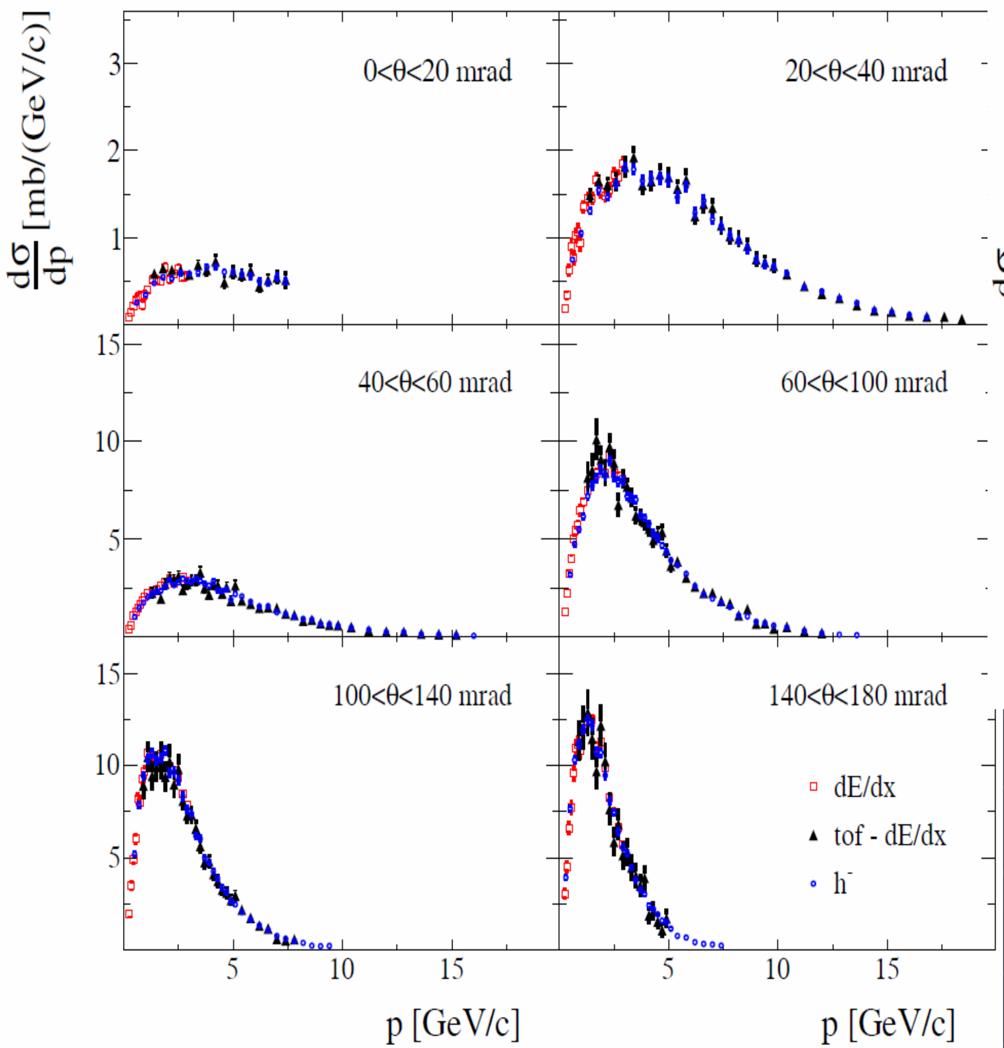
Two methods of analysis are consistent!

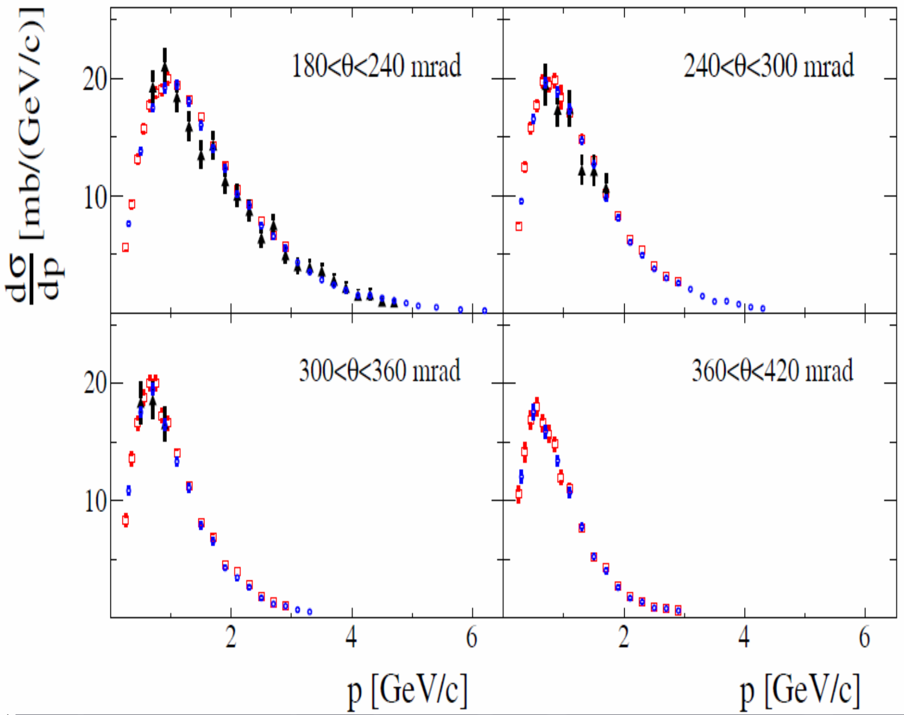
dE/dx +ToF

dE/dx

Statistical errors only

Differential cross sections - π^-





Three methods of analysis are consistent!

dE/dx +ToF

dE/dx

h- analysis

Statistical errors only

Systematic error studies

Systematic errors were first of all derived from:

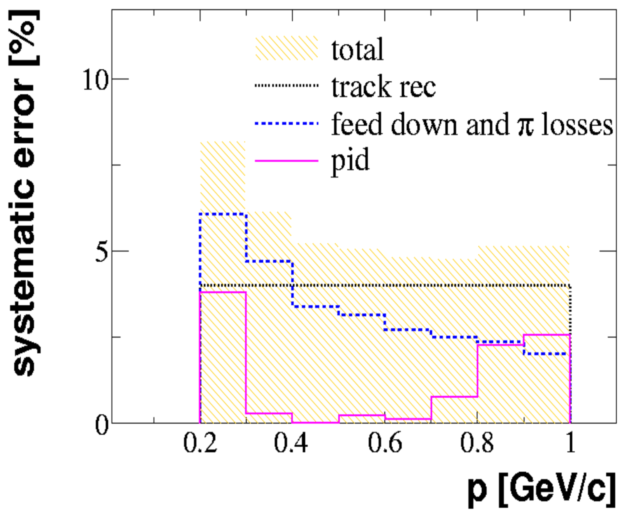
1) Uncertainty of the correction for **weak decays and secondary interactions, referred to as feed down.**
2) Differences of the results obtained from **different track topologies**
3) Uncertainty of **PID** procedure for dE/dx and dE/dx+ToF analyses.

Other contributions to the systematic error studies relevant for dedicated analyses:

1) pion loss correction due to pion decay (dE/dx +ToF) analysis
2) validation of different reconstruction chains used to reconstruct the data
3) knowledge of the ToF efficiency
4) K^- and antiproton contamination and validation of different track cuts for h^- analysis

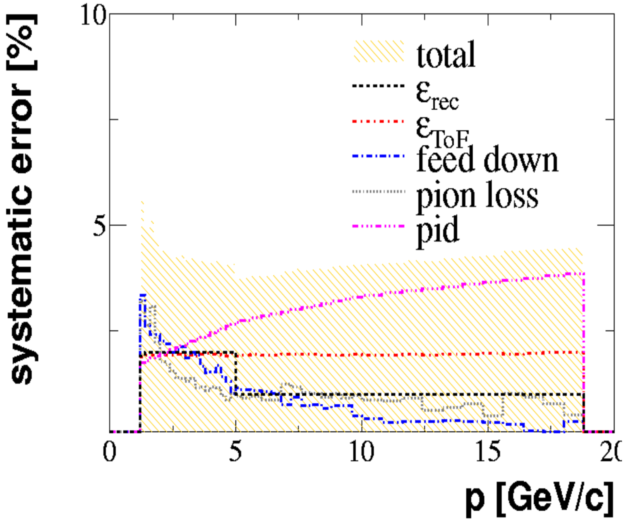
Sources of systematic errors- examples for π^+ and π^-

dE/dx



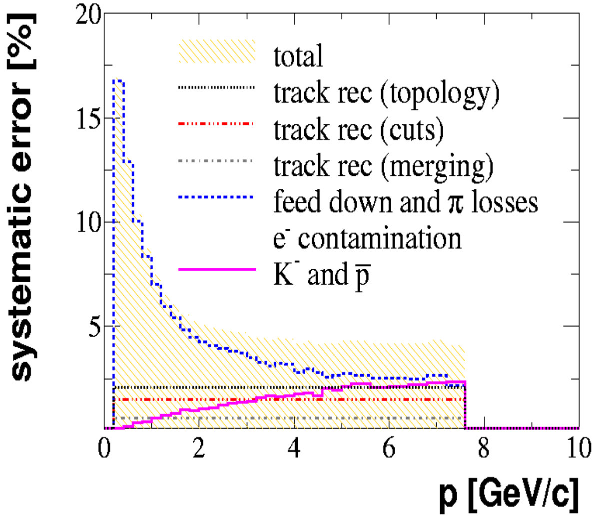
π^+ and θ=[140,180]mrad

dE/dx +ToF



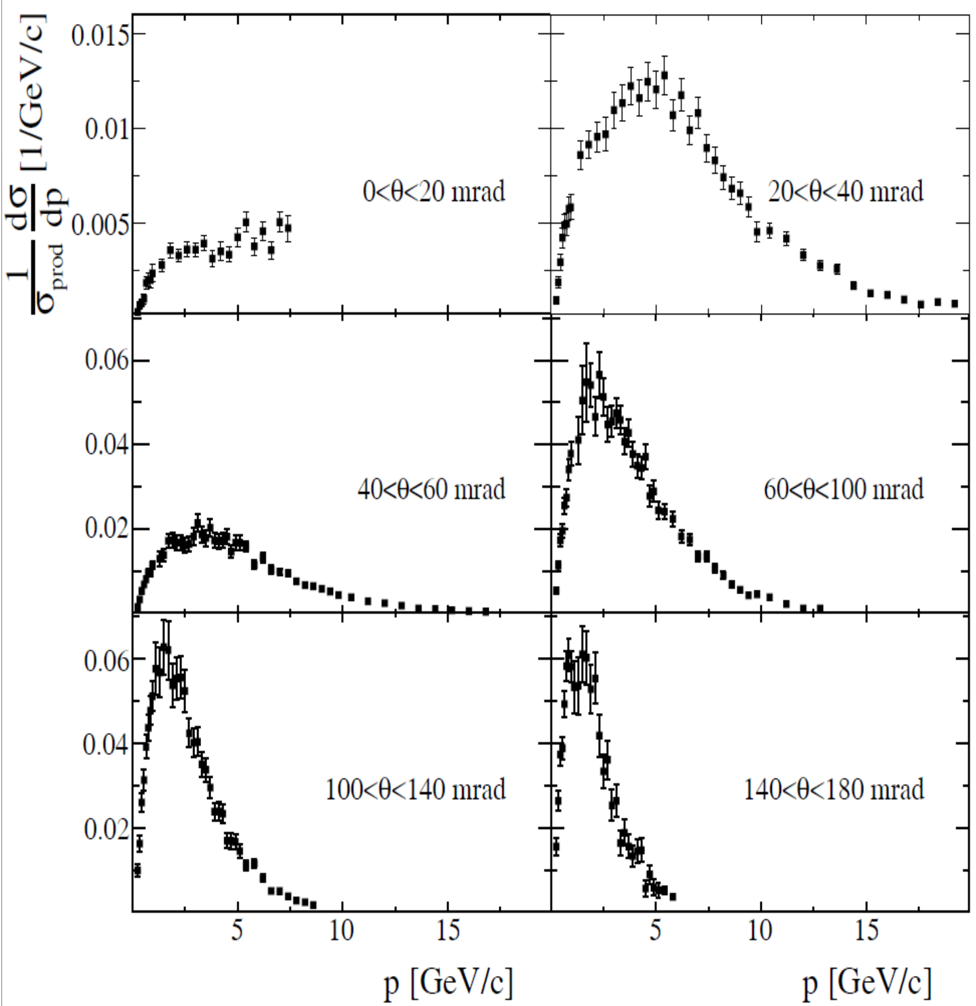
π^+ and θ=[40,60]mrad

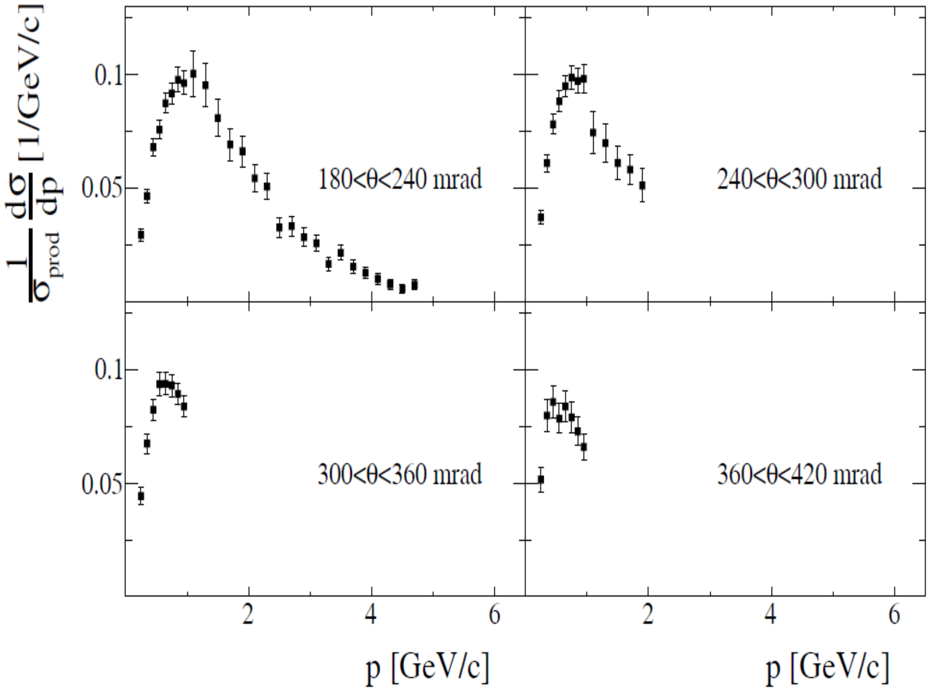
h^-



π^- and θ=[140,180]mrad

Spectra normalized to the mean π^+ multiplicity in production interactions

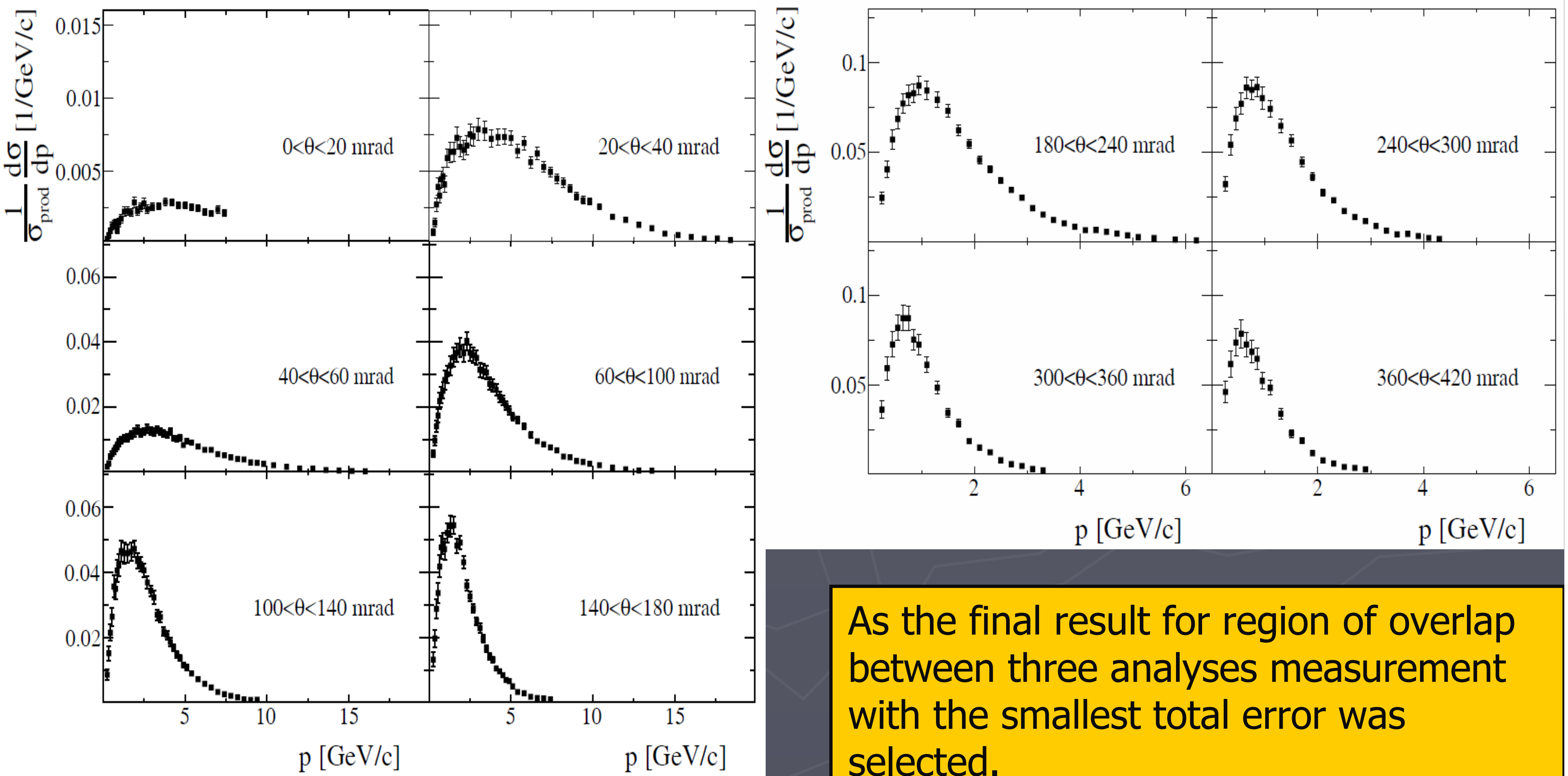




As the final result for region of overlap between two analyses measurement with the smallest total error was selected.

For each point total error is plotted . In addition the total normalization uncertainty is 2.3%.

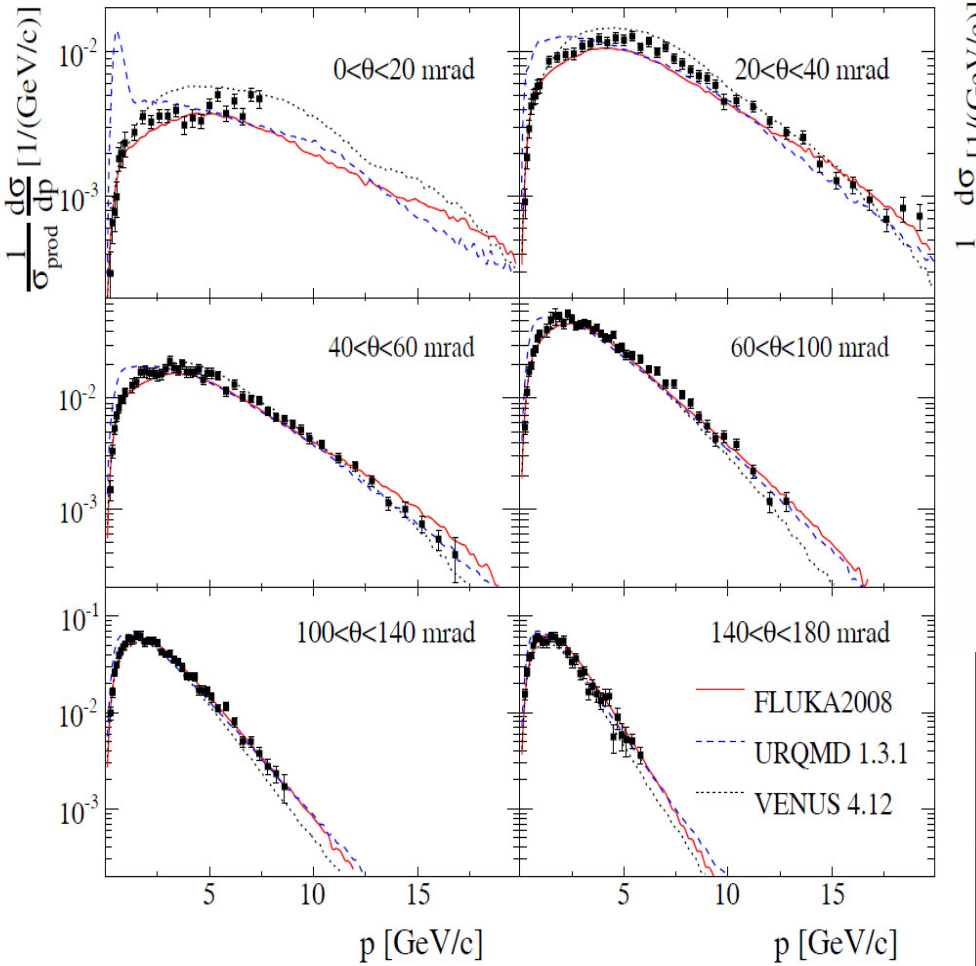
Spectra normalized to the mean π^- multiplicity in production interactions

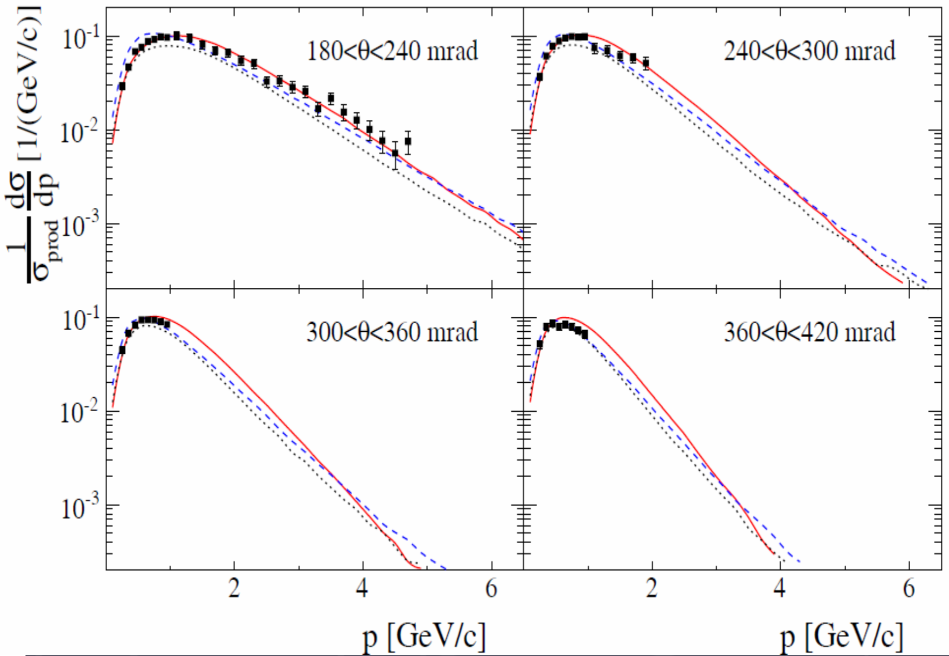


As the final result for region of overlap between three analyses measurement with the smallest total error was selected.

For each point total error is plotted . In addition the total normalization uncertainty is 2.3%.

Spectra normalized to the mean π^+ multiplicity in production interactions - comparison with models



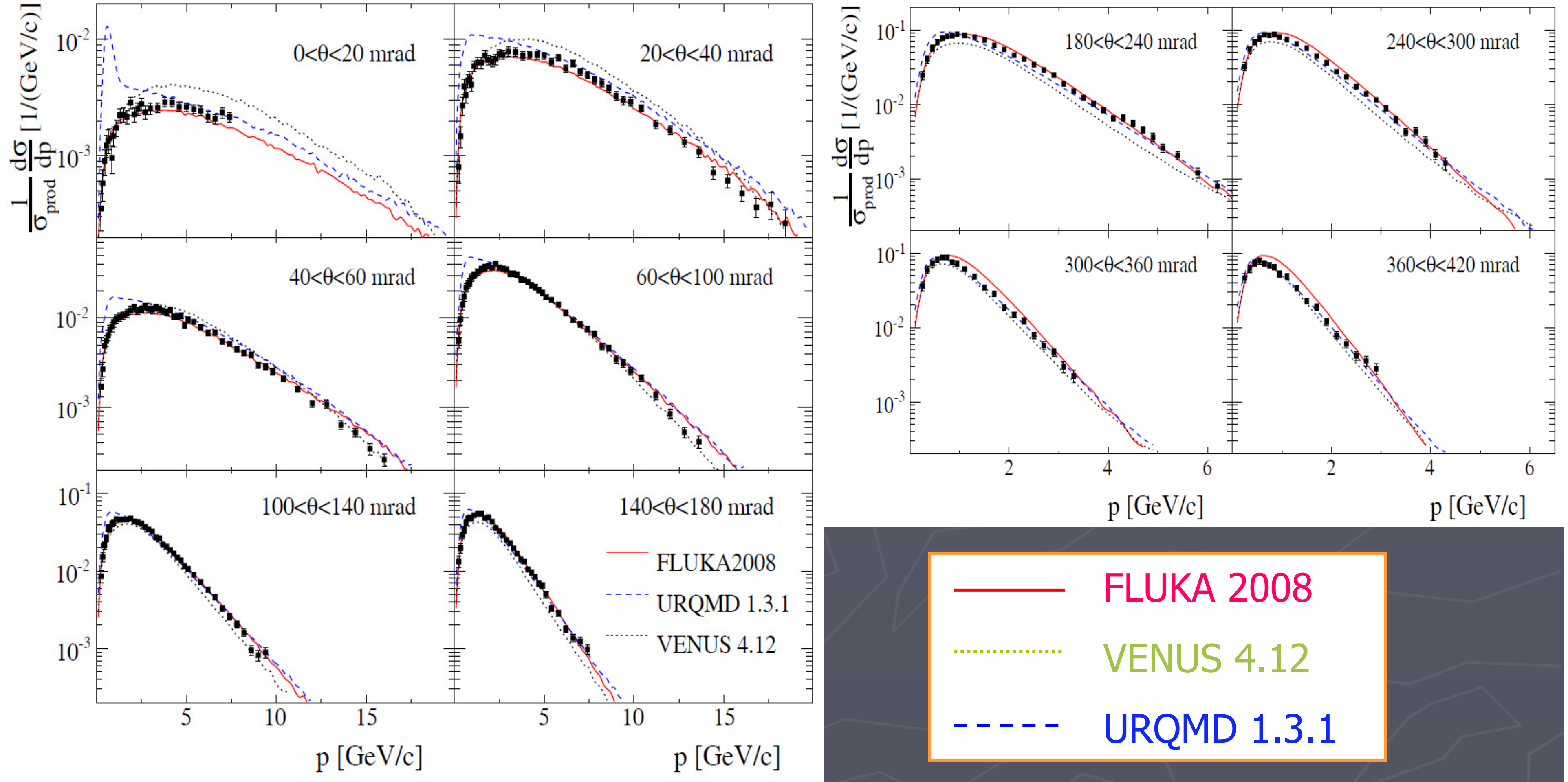


FLUKA 2008

VENUS 4.12

URQMD 1.3.1

Spectra normalized to the mean π^- multiplicity in production interactions - comparison with models



FLUKA 2008

VENUS 4.12

URQMD 1.3.1

Conclusions

- We presented pion spectra obtained from 2007 data on interactions of 30 GeV protons on thin Carbon target.
- The **spectra of π^+ and π^- mesons in 10 angular bins up to 420 mrad** were obtained using 3 different analyses and compared with Venus, Fluka 2008 and URQMD models. These data have been used for T2K analysis presented in: „***Indication of Electron Neutrino Appearance from an Accelerator-produced Off-axis Muon Neutrino Beam***"
- The numerical values of the final charged pion spectra as well as details concerning analyses, cross section normalization, systematic errors, model comparisons may be found in the publication: ***Measurements of Cross Sections and Charged Pion Spectra in Proton-Carbon Interactions at 31 GeV/c,*** (arXiv:1102.0983 , CERN-PH-EP-2011-005, to be published in Phys. Rev. C, 2011).
- **In 2009 year** three weeks were dedicated for T2K measurements. We registered **6 million** interaction triggers for the **thin target**. Collected data are currently being calibrated and will be used to increase the limited statistics from 2007 pilot run.
- We have also measured **kaon spectra** from 2007 data. These results will be discussed next by **Silvestro Di Luise.**
- Status of the **T2K replica target** analysis will be presented by **Nicolas Abgrall**

Back up

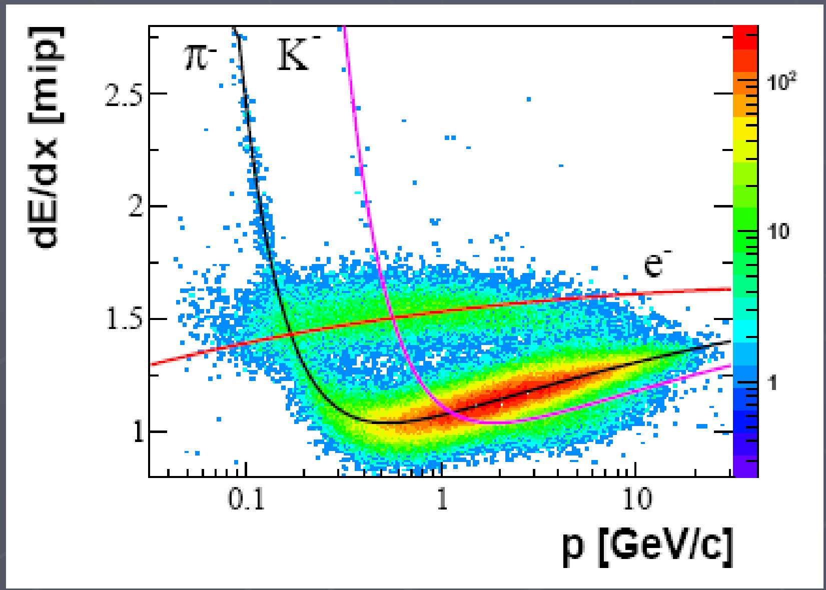
Analysis of π^- mesons based on MC corrections: „h^- analysis”

1) **NO PID**

Assumes that π^- mesons are dominant

2) GLOBAL MC corrections are applied to correct for a :

- contribution of electrons and other particles (like K^-), model dependent,
- geometrical acceptance,
- reconstruction efficiency,
- secondary interactions or weak decays („feed down”)



3) Corrected spectra of π^- mesons **in broad momentum range** are obtained. (**the largest statistics !)**

Analysis of π^+ and π^- mesons using energy loss measurements in TPCs

1) **PID**

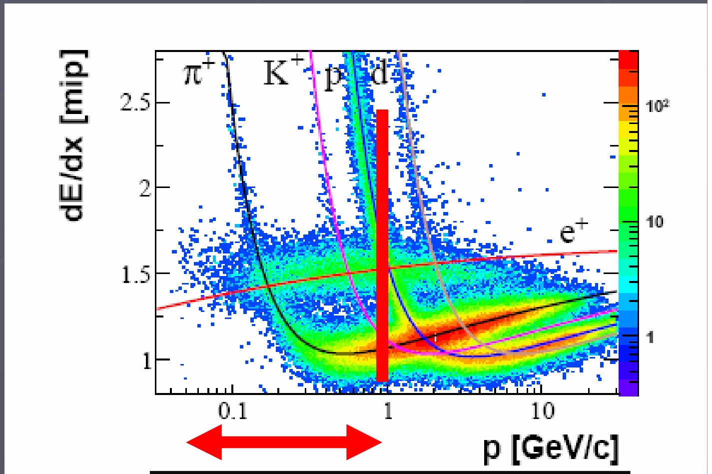
dE/dx analysis

For each (p,θ) bin **maximum likelihood fit** was applied. Probability density functions, calculated track-by-track, were assumed to be Gaussian distributions with the momentum dependent mean given by the fitted to the data BB parametrisation and dE/dx variance.

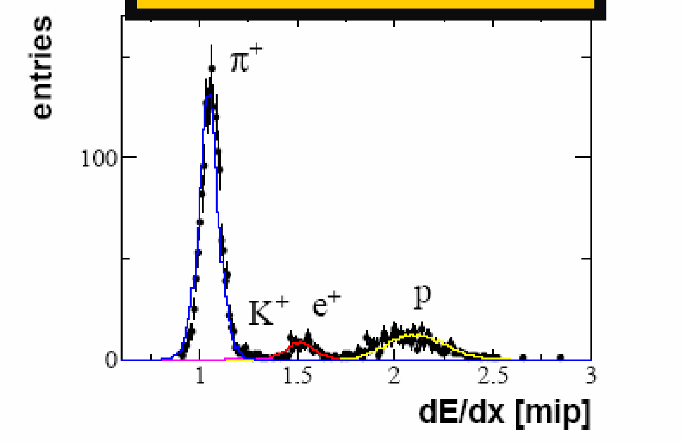
2) GLOBAL MC corrections are used for

- geometrical acceptance,
- reconstruction efficiency,
- secondary interactions or weak decays („feed down")

3) Corrected spectra of π^+ mesons till 1GeV/c and π^- till 3 GeV/c.



p=[0.7,0.8] GeV/c
θ=[180,240]mrad



Analysis of π^+ and π^- mesons using time-of-flight and dE/dx measurements

1) PID

dE/dx +ToF analysis

For each (p,θ) bin-by-bin maximum likelihood method was applied to the m^2 and dE/dx distributions. Pion yields were calculated summing all particles within 2σ around the fitted pion peak.

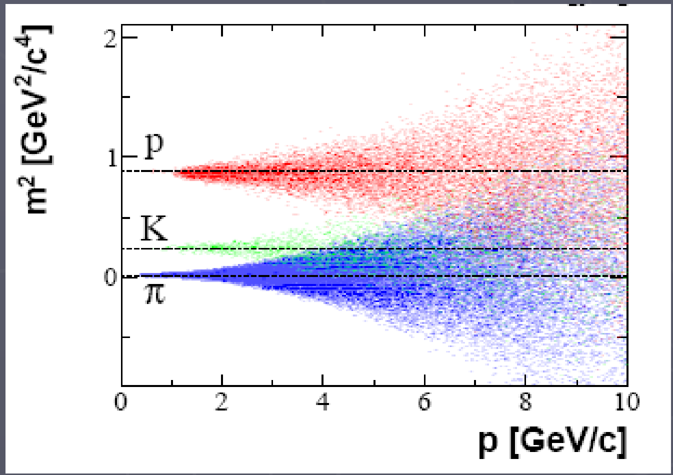
2) FACTORIZED MC corrections for

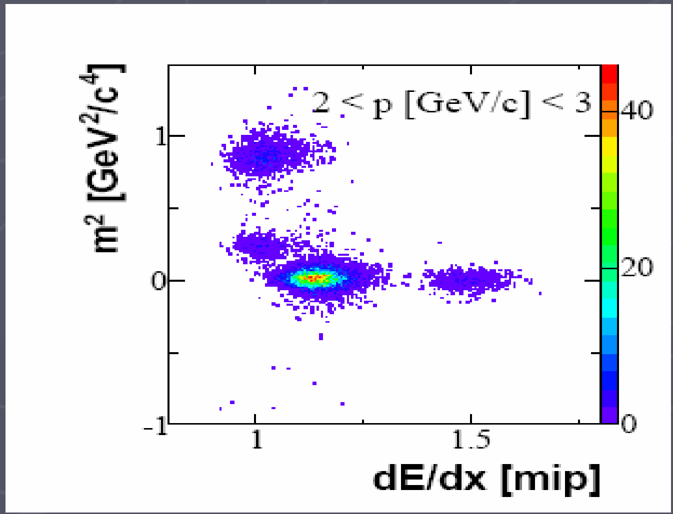
- pions from weak decays („feed down”),
- track reconstruction efficiency,
- losses due to pion decays,
- geometrical acceptance of the detector,
- ToF-F detection efficiency

were applied to the data.

3) Corrected spectra of π mesons with p>1GeV/c

(the smallest statistics !)



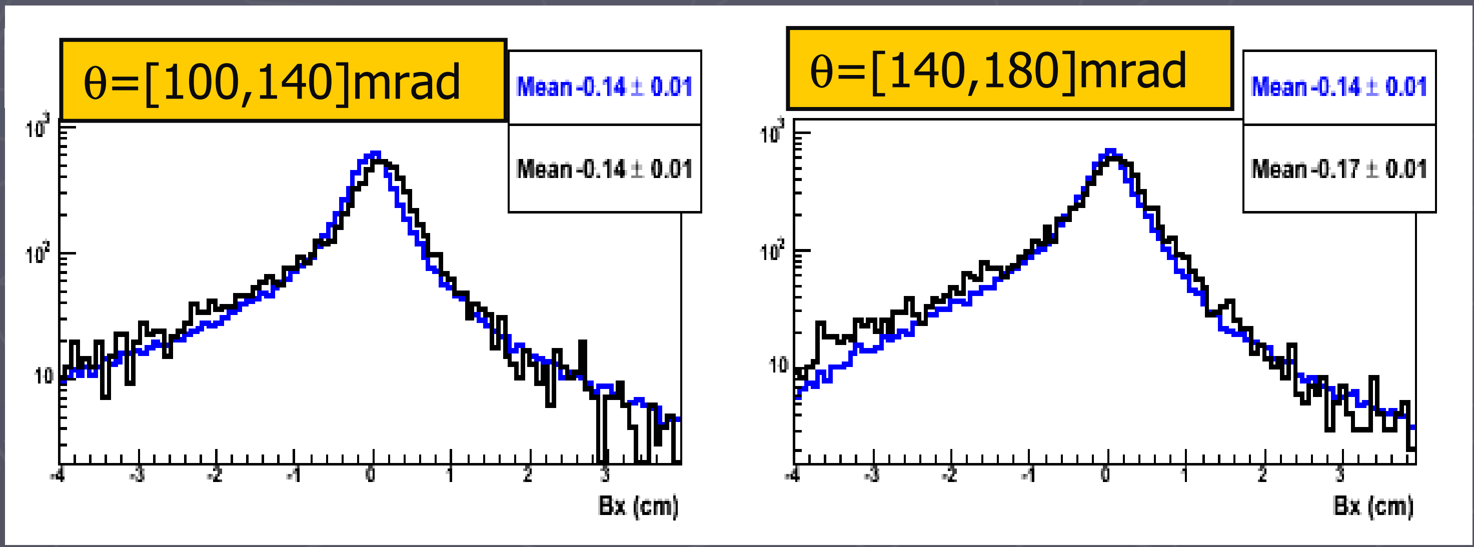


Data sample

- A total 667 k of registered events.
- **521k events** passed Beam Position Detectors cuts
  a) Signals in all 3 Beam Position Detectors
  b) Impact parameter cut of 4 cm (tracks within 4 cm from interaction point)

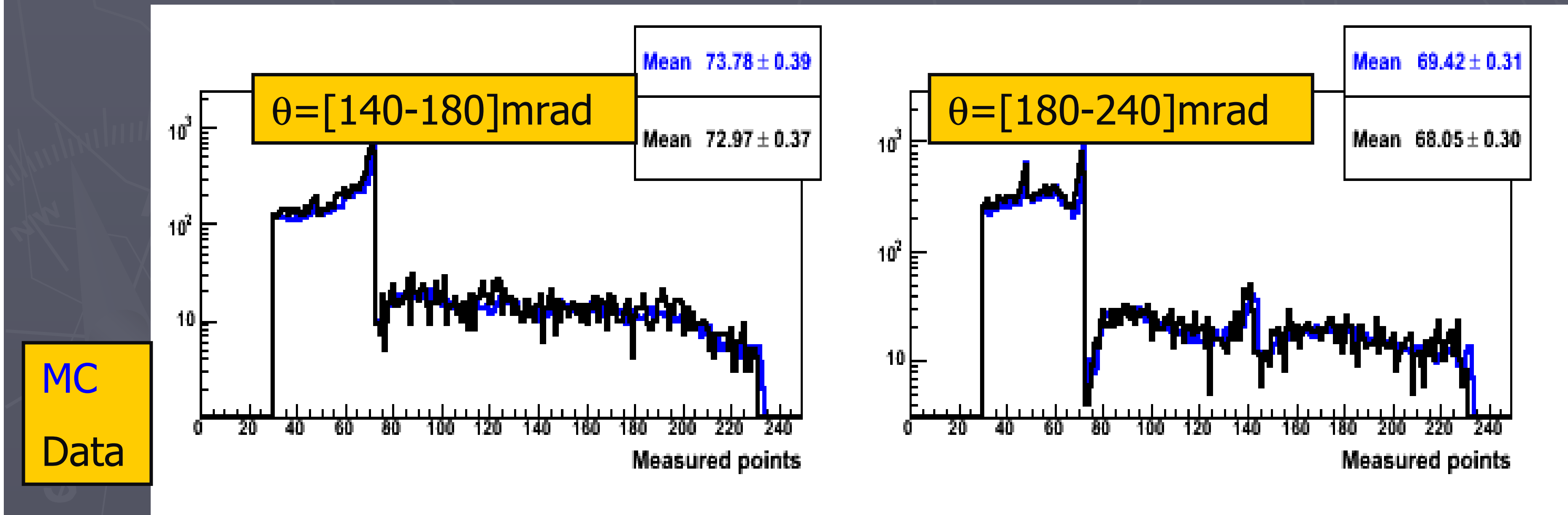
MC

Data



Track selection based on the number of points

- Total # of reconstructed points on a track should be N>=30
- Sum of # of reconstructed points in Vertex TPC1 & Vertex TPC2 >= 11



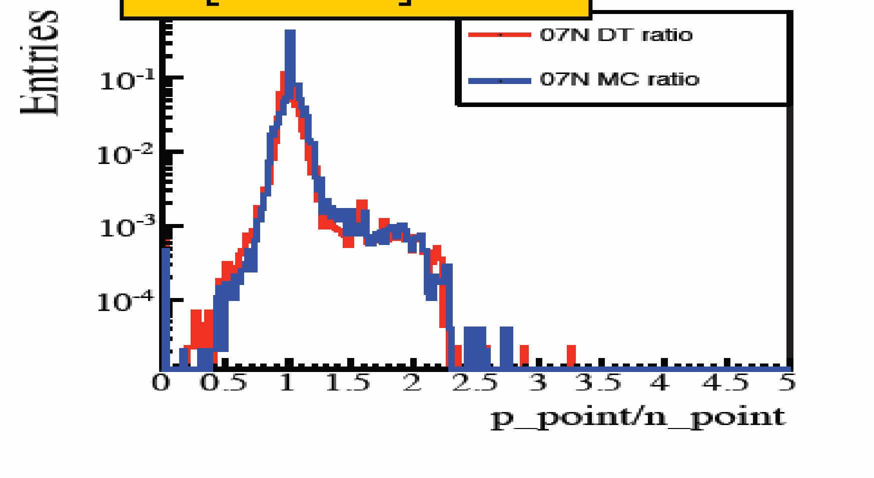
Positive particles with p<1GeV/c

Track selection based on the potential points

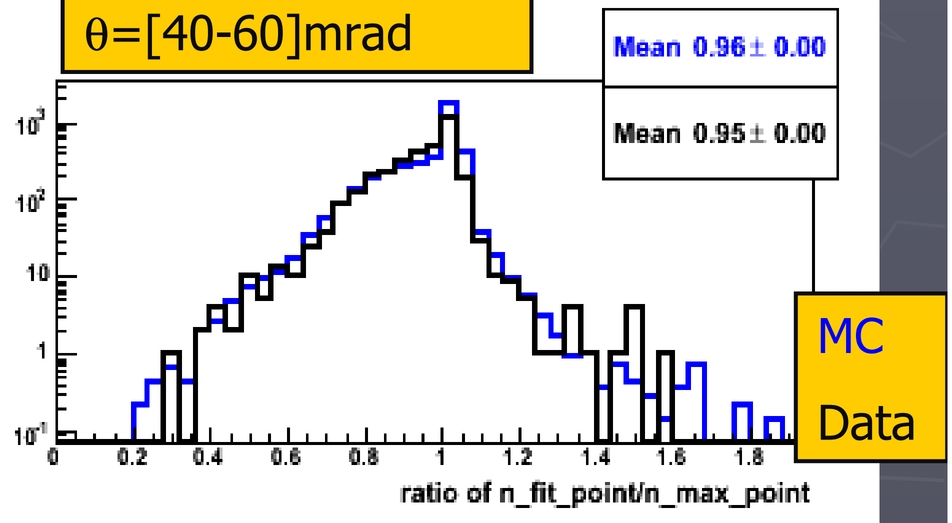
$$Ratio = \frac{\text{total \# of points}}{\text{potential \# of points}} > 0.5$$

Potential # of points is the max # of points expected for the trajectory.

θ=[180-240]mrad



θ=[40-60]mrad



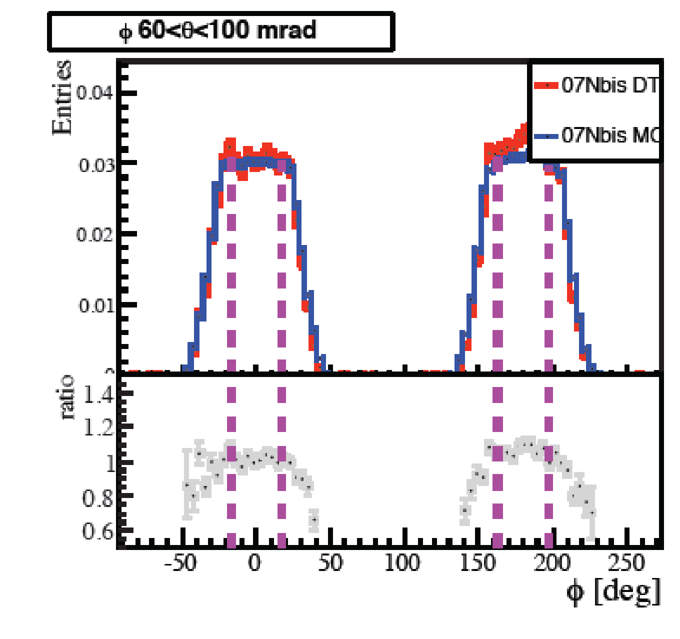
Positive tracks reaching the ToF detector

Positive tracks with p<1 GeV/c

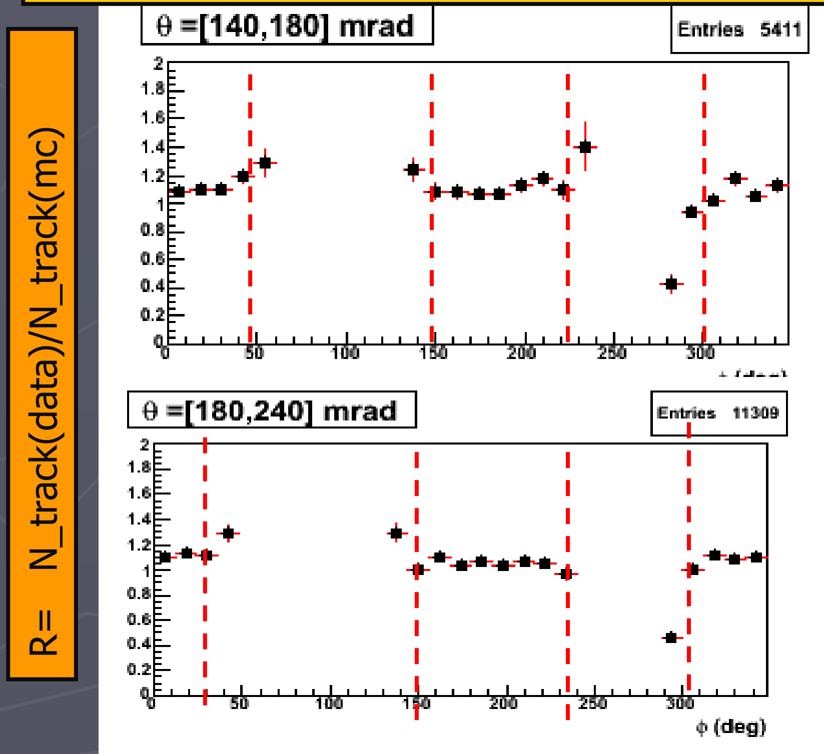
Track selection based on the azimuthal angle

- should be within a wedge around horizontal plane.
- wedge size depends on polar angle and momentum.

Positive tracks reaching the ToF detector



Positive tracks with p<1 GeV/c



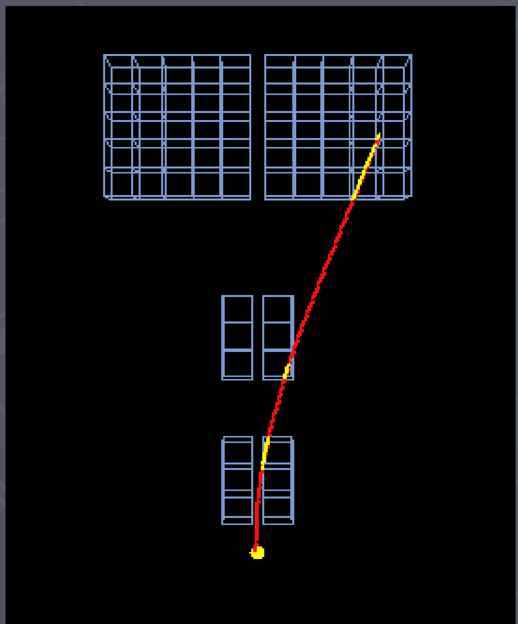
RST and WST results

- NA61 approach :
  - Fit function to the |rst- wst|/2 and take into account statistical errors of the rst and wst $\sigma = \sqrt{\sigma_{RST}^{2} + \sigma_{WST}^{2}}$

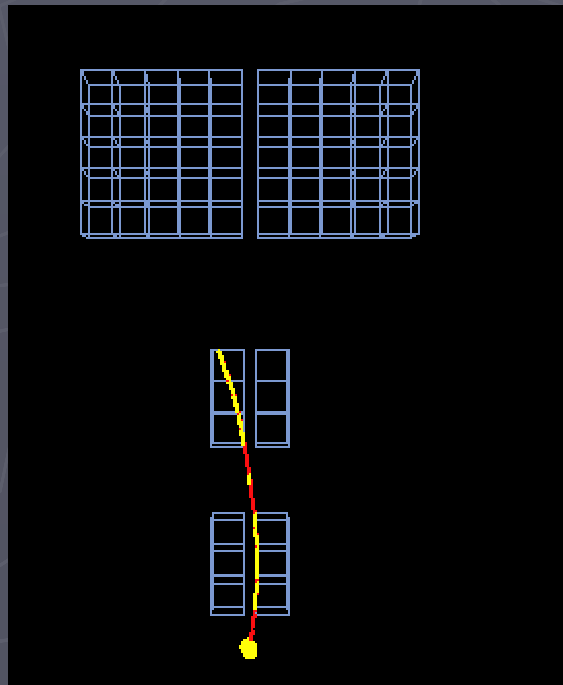
(Right Side Tracks
by def. **charge*p_x>0**)

(Wrong Side Tracks
charge*p_x<0).

RST
charge==-1



WST
charge==1



RST and WST results-example

π+ from

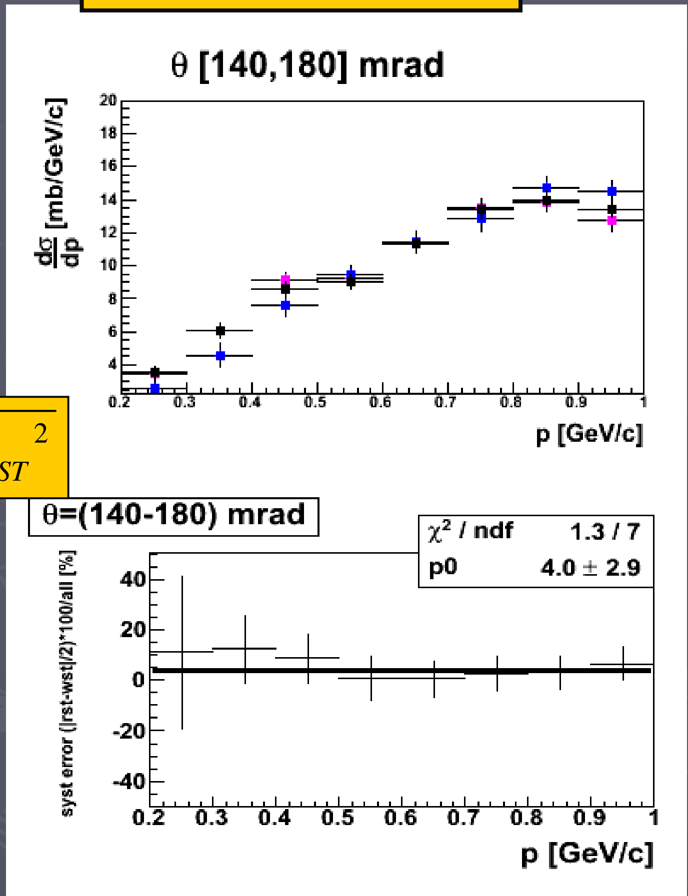
RST

WST

ALL

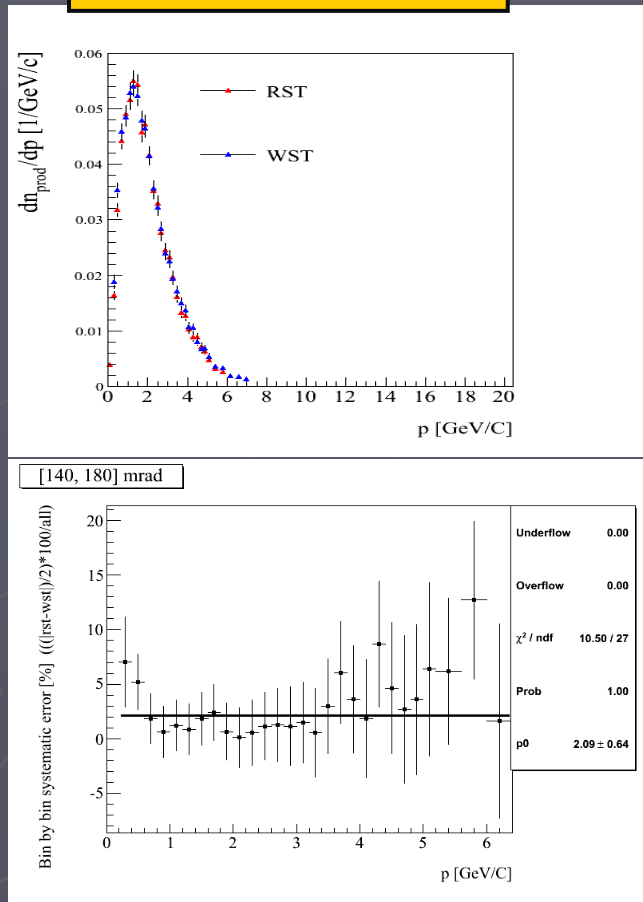
$$\sigma = \sqrt{\sigma_{RST}^{2} + \sigma_{WST}^{2}}$$

dE/dx



Syst error [%] =4.0 %

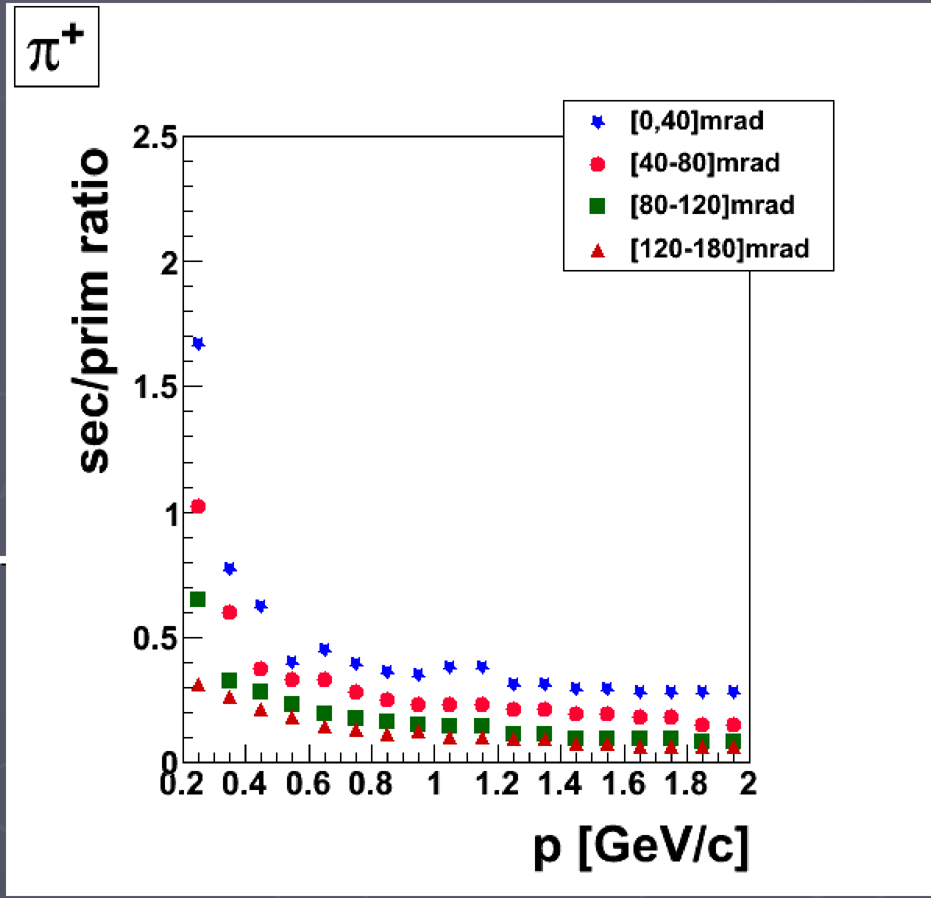
h⁻ analysis



Syst error [%] =2.1 %

Systematic errors resulting from corrections for weak decays and secondary interactions

- For all 3 methods 30% uncertainty of the correction value was taken.
- This comes from 30% uncertainty estimated on modeling of strange particle production in the relevant momentum range.
- The same uncertainty was assumed for secondary interactions.
- In addition 20% uncertainty of the correction value was assumed for electrons in h- analysis



Normalization of Particle Spectra

1a)

Normalization to inclusive cross section

$$\frac{\Delta\sigma_{\alpha}}{\Delta p} = \frac{1}{1-\varepsilon}\frac{\sigma_{trig}}{N'_{trig}}\frac{\Delta n_{\alpha}}{\Delta p}$$

$$\left[mb / {}^{GeV}\!/_{c}\right]$$

1b)

Normalization to mean multiplicity in inelastic interactions

$$\frac{\Delta n_{inel,\alpha}}{\Delta p} = \frac{1}{\sigma_{inel}} \cdot \frac{\Delta\sigma_{inel,\alpha}}{\Delta p}$$

$$\left[1 / {}^{GeV}\!/_{c}\right]$$

1c)

Normalization to mean multiplicity in production interactions

$$\frac{\Delta n_{prod,\alpha}}{\Delta p} = \frac{1}{\sigma_{prod}} \cdot \frac{\Delta\sigma_{inel,\alpha}}{\Delta p}$$

$$\left[1 / {}^{GeV}\!/_{c}\right]$$

$\sigma_{trig}= (298.1 \pm 1.9 \pm 7.3)$mb

$\sigma_{inel}= (257.2 \pm 1.9 \pm 8.9)$mb

$\sigma_{prod}= (229.3 \pm 1.9 \pm 9.0)$mb using $\sigma_{qe} = (27.9 \pm 1.5)$mb

1a) σ_{trig}: $(298.1 \pm 1.9\ (0.6\%) \pm 7.3\ (2.4\%))$mb

1b) $\sigma_{trig}/\sigma_{inel}$: $1.159 \pm 0.002\ (0.2\%) \pm 0.023\ (2.0\%)$

1c) $\sigma_{trig}/\sigma_{prod}$: $1.300 \pm 0.002\ (0.2\%) \pm 0.030\ (2.3\%)$

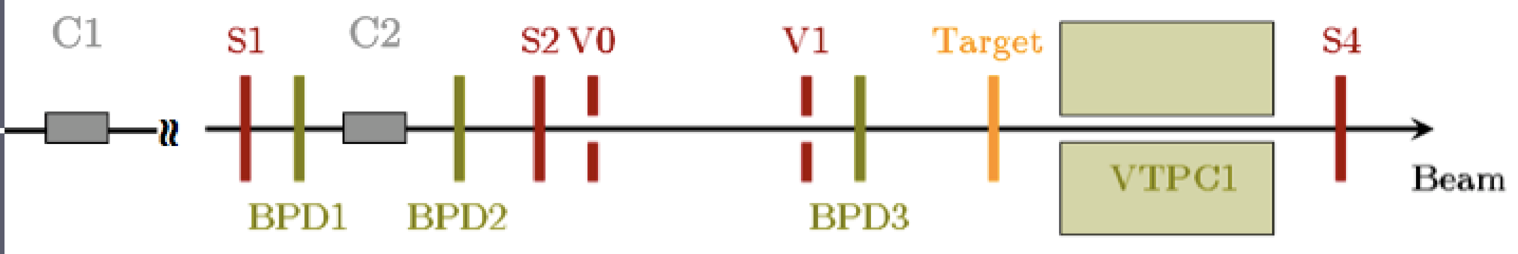
2) Number of events used for analysis (N'_{trig})

3) Bin size ($1/\Delta p$)

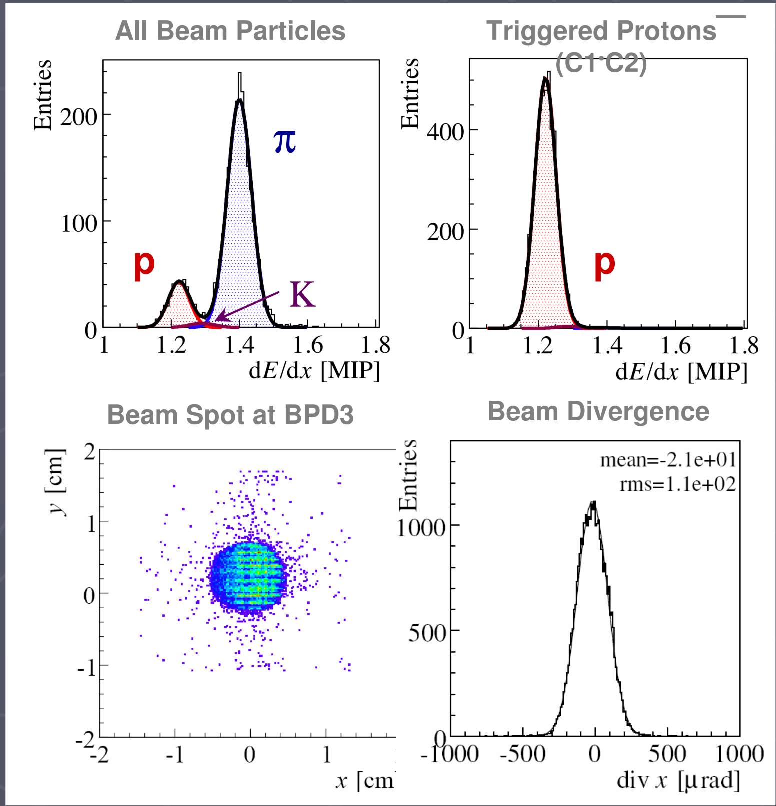
4) Correct for Empty Target Contribution by $1/(1-\varepsilon)$ (use ε according to the cut)

For the standard BPD Cut (I+II): $1/(1-\varepsilon) = 1.134 \pm 0.001$

Setup of Beam Line



- **Secondary** hadron beam composed of 83.7% π^+, 14.7% p and 1.6% K^+
- Proton beam particles identified by CEDAR (C1) and threshold Cerenkov counters (C2)
- Incoming p then selected by several scintillator counters (S1, S2, V0, V1)
  - → beam defined as $B = S1 \cdot S2 \cdot \overline{V} \cdot C1 \cdot \overline{C2}$
- Trajectory of beam particles measured by the beam position detectors (BPD-1/-2/-3)
- Interactions in the target selected by anti-coincidence of the beam particle with a small scintillator S4 ($B \cdot \overline{S4}$)



Inelastic and Trigger Cross Section

- For the thin target data the goal is to present data in terms of yields and inclusive cross sections
- Experimentally, the differential inelastic cross section can be expressed in the following way

$$\frac{\Delta\sigma^{meas}_{inel,\alpha}}{\Delta p \Delta\theta} \approx \frac{1}{n N_{Beam}} \frac{\Delta n_\alpha}{\Delta p \Delta\theta} = \frac{\sigma_{trig}}{N_{trig}} \frac{\Delta n_\alpha}{\Delta p \Delta\theta} \quad \text{with} \quad \sigma_{trig} = \frac{1}{n} \frac{N_{trig}}{N_{beam}} \quad n = \rho L N_A / A$$

ρ: density, L: length, N_A: Avogadro const., A: Atomic number, N_{beam}: # of incoming beam particles, N_{trig}: # of triggered evts coming from the target

- Several steps for normalization and correction needed

1) Correct σ_{trig} for distortions due to events outside of the carbon target

$$\sigma_{trig} = \frac{1}{\rho L_{eff} N_A / A} P_{int} \quad \text{with } P_{int} \text{ calculated from} \quad P_{T_{in}} = \left(\frac{N_{trig}}{N_{beam}}\right)^{T_{in}} \text{ and } P_{T_{out}} = \left(\frac{N_{trig}}{N_{beam}}\right)^{T_{out}}$$

2) Correct σ_{trig} for the exponential beam attenuation in the target

$$L_{eff} = \lambda_{abs}(1 - e^{-L/\lambda_{abs}}) \quad \text{with} \quad \lambda_{abs} = \frac{A}{\rho N_A \sigma_{trig}}$$

L_{eff}: effective length

λ_{abs}: abs. length

3) Correct the particle yield $\Delta n/N_{trig}$ for distortions due to events outside of the carbon target

$$\left(\frac{\Delta n_\alpha}{N_{trig}}\right)^{C} - \frac{1}{1-\varepsilon}\left(\left(\frac{\Delta n_\alpha}{N_{trig}}\right)^{T_{in}} - \varepsilon\left(\frac{\Delta n_\alpha}{N_{trig}}\right)^{T_{out}}\right) \quad \text{with} \quad \varepsilon = P_{T_{out}} / P_{T_{in}}$$