NEW RESULTS FROM HARP

HARP *A fixed-target experiment at the CERN Proton Synchrotron*
(2000-2002)

Hadron Production Experiment (PS214)
Neutrino Factory
Atmospheric Neutrino Flux
Accelerator Neutrino Beams
Hadron Production Models

Overview of new results

Jaap Panman, CERN, for the HARP collaboration

Venice, 2007

The HARP Collaboration

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Joint Institute for Nuclear Research, JINR Dubna, Russia
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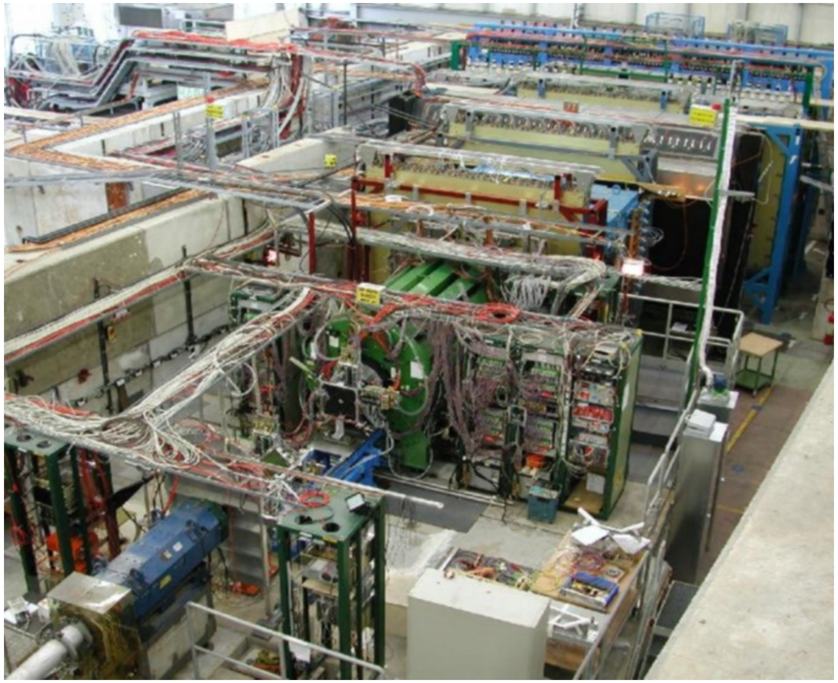
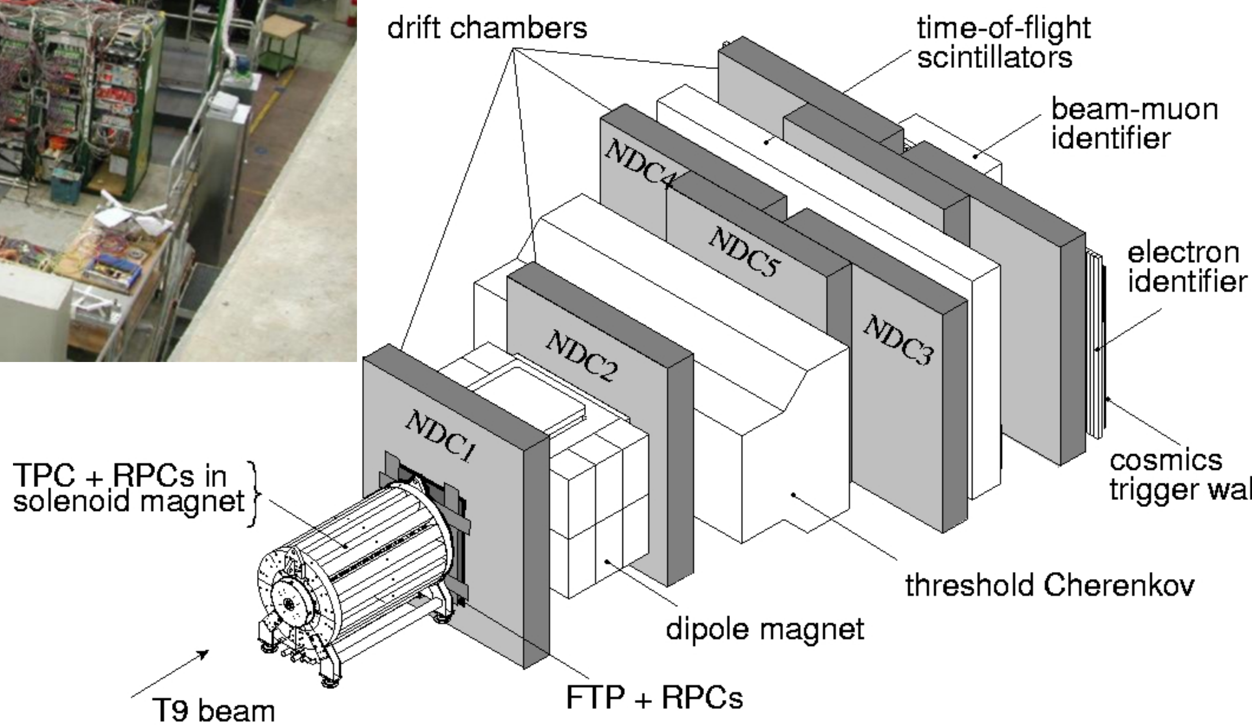
Institute for Nuclear Research and Nuclear Energy, Academy of Sciences, Sofia, Bulgaria
Università di Trieste e Sezione INFN, Trieste, Italy
Univ. de Valencia, Spain

24 institutes
~120 collaborators

HARP Detector Layout

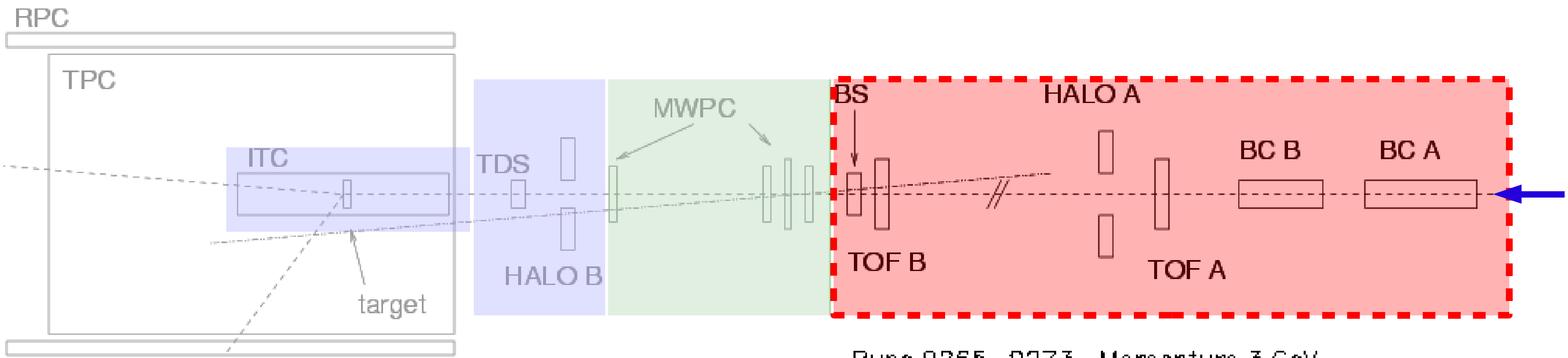


Large range of
beam momenta (3 – 15 GeV/c)
target materials (H – Pb)



HARP: barrel spectrometer (TPC) + forward spectrometer (DCs) to cover the full solid angle, complemented by particle-id detectors

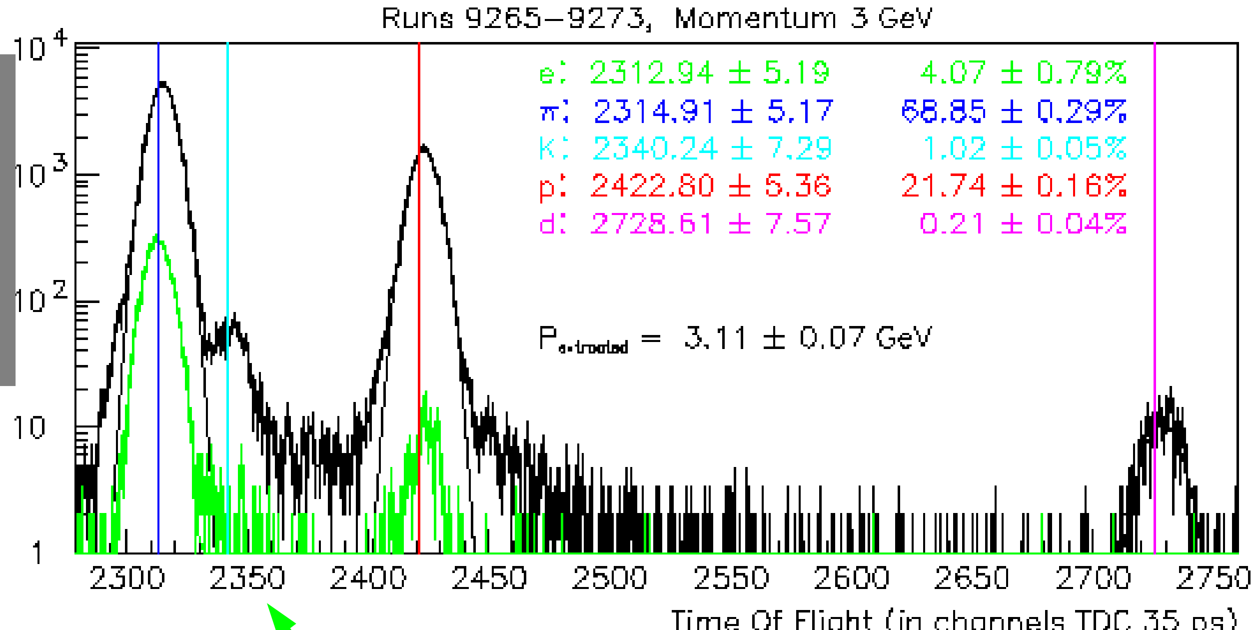
Beam Particle-ID



identification performed by:

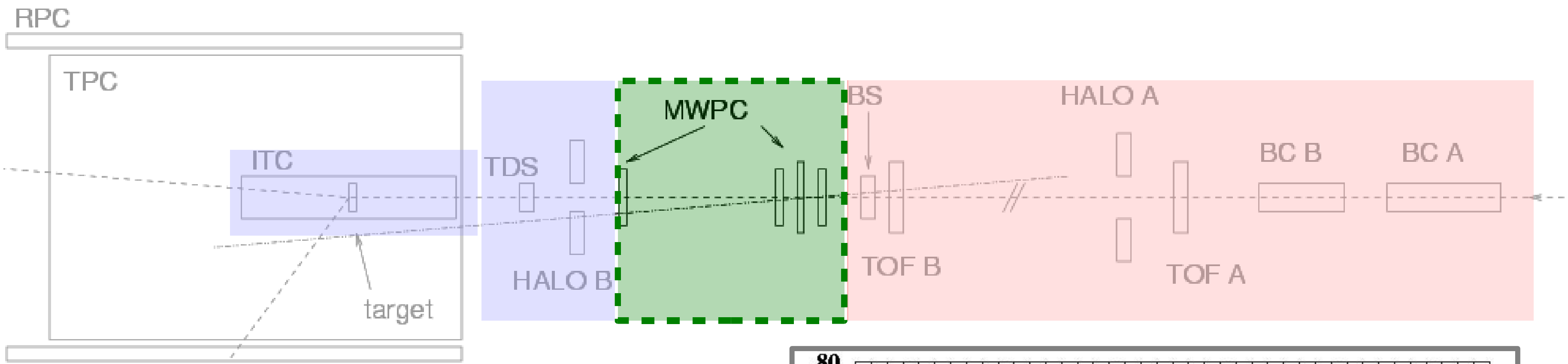
- two gas Cherenkovs
- TOF system (21 m base)

--> Proton selection purity > 98.7%



electrons tagged by threshold Cherenkov

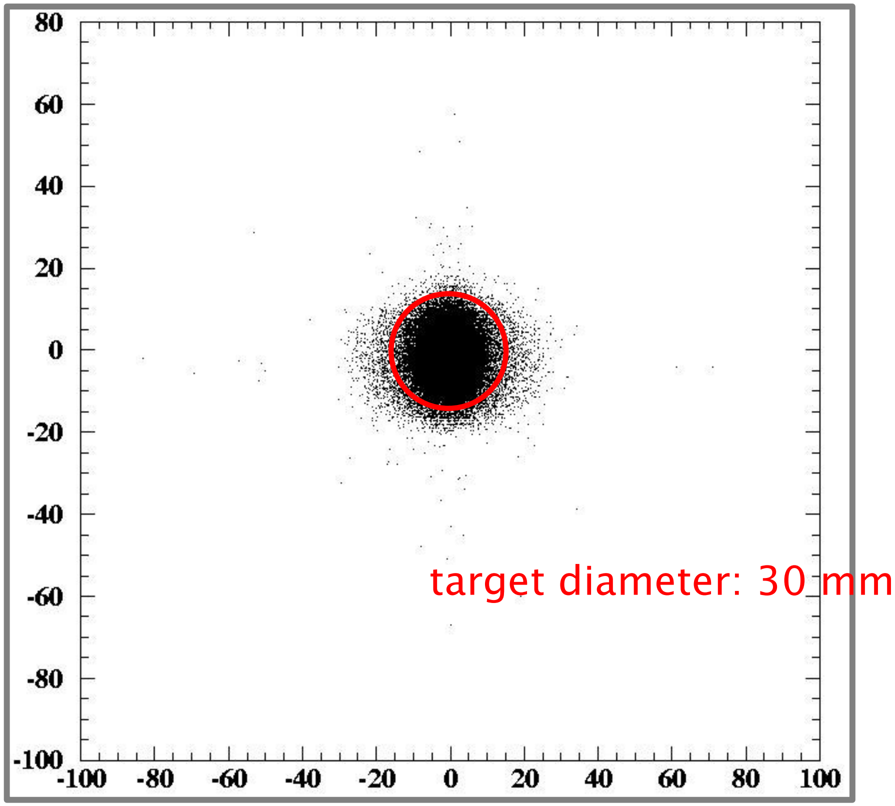
Beam Tracking



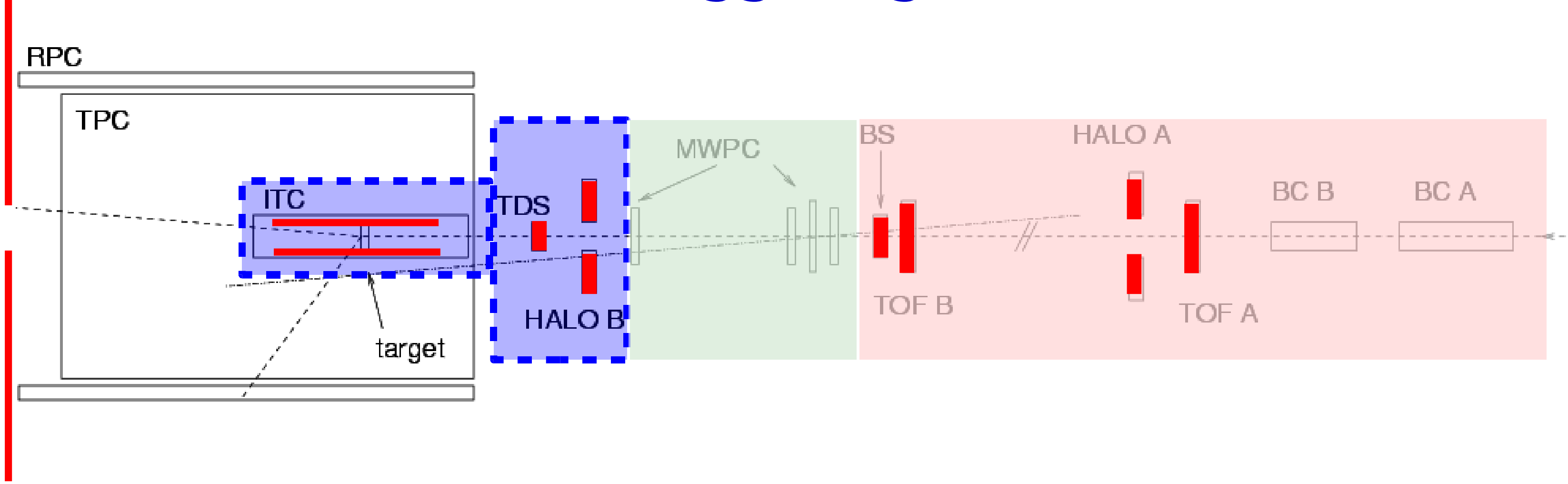
tracking provided by 4 Multi-Wire-Proportional-Chambers

accuracy: < 1mm

Beam particle extrapolated to the target
-> elliptic beam profile



Triggering



main triggers:

- BEAM x (ITC+FTP) (thin targets)
- BEAM (thick targets)

efficiency: > 99% (single-track)
purity: 15-50 % (thin targets)
event rate: 200-500 per 400ms spill

Additional triggers:

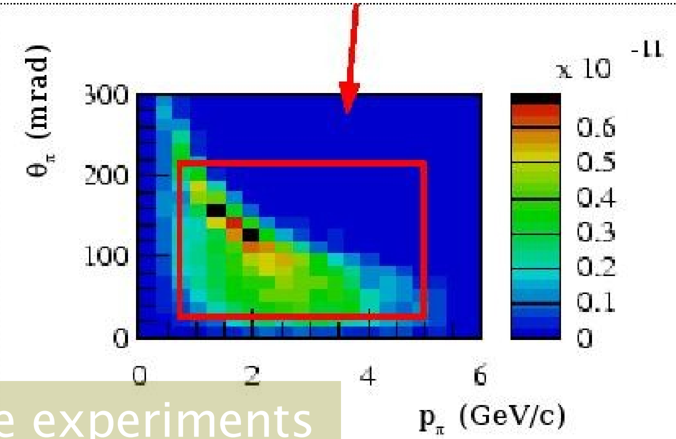
- Forward (Cherenkov)
- Minimum-biased: down-scaled beam (**<u>normalization</u>**, calibration)
- Inter-spill cosmics (TPC and NDC calibration and alignment)
- Pedestal/Pulser triggers for all PMTs

Neutrino Oscillation Experiments

Neutrino flux of conventional neutrino beams *not known accurately.*

pion and kaon production and use relevant targets and momenta:

- *K2K:* Al target, 12.9 GeV/c
- *MiniBooNE:* Be target, 8.9 GeV/c
- *SciBooNE:*



Momentum and Angular distribution of pions decaying to a neutrino that passes through the MB detector.

Removes *major* source of uncertainties for the experiments (in collaboration with *K2K* and *MiniBooNE*)

HARP p-AL data 12.9 GeV/c:
M. G. Catanesi et al., HARP, Nucl. Phys. **B732** (2006) 1

K2K results, with detailed discussion of relevance of production measurement:
M. H. Ahn et al., K2K, Phys. Rev. **D74** (2006) 072003. [arXiv:hep-ex/0606032]

Cross-Section determination for neutrino beams: **Forward Dipole Spectrometer Data**

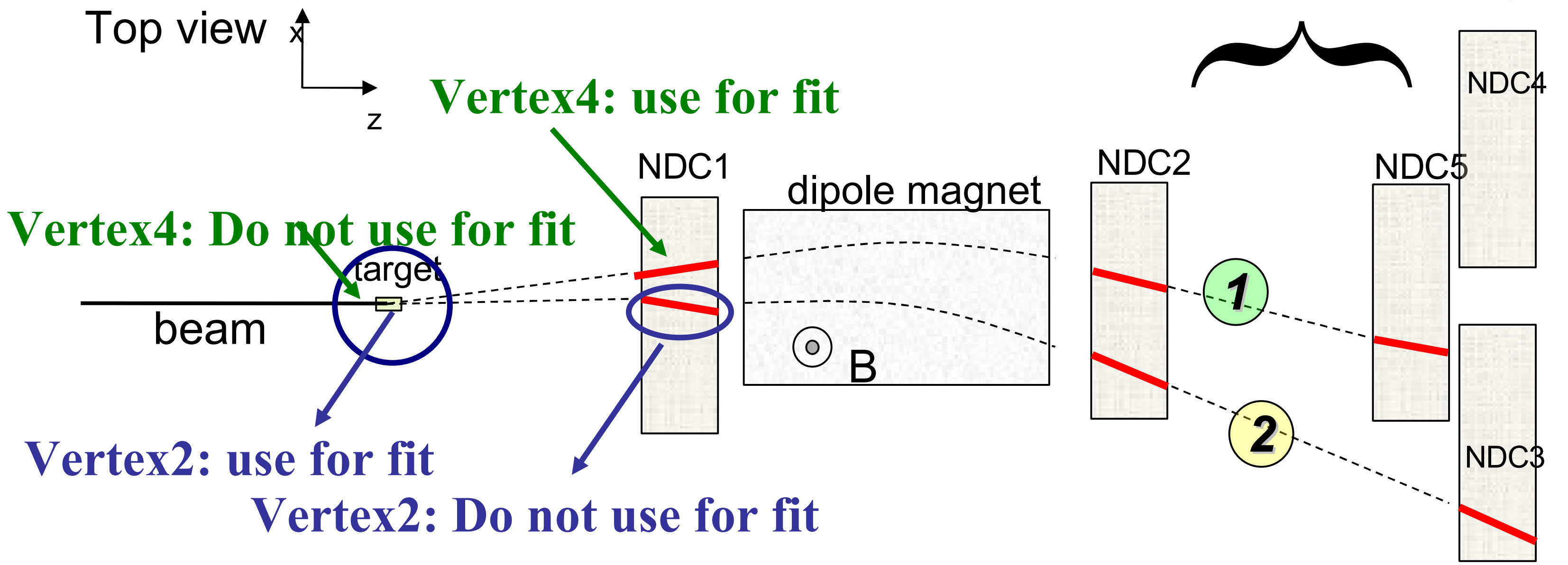
$$\frac{d^2\sigma^{\pi}}{dp\,d\Omega} \propto \frac{\Delta^2 N^{\pi}}{\Delta p \Delta \Omega} \frac{correction\ \ factors(p,\theta)}{N_{pot}}$$

- Select events identified as **primary protons** interacting in the target
- For each event, **reconstruct tracks** and their 3-momentum
- **Identify pions** among secondary tracks
- **Count protons on target** corresponding to selected events
- **Apply corrections**, for reconstructed-to-true pion yield conversion:
    - Momentum resolution
    - Spectrometer angular acceptance
    - Track reconstruction efficiency
    - Efficiency and purity of pion identification
    - Other

Track Reconstruction in dipole spectrometer

Reused NOMAD drift chambers:
5 modules x 4 (chambers/module) x 3 (planes/module)

Downstream track:
99.5% efficiency

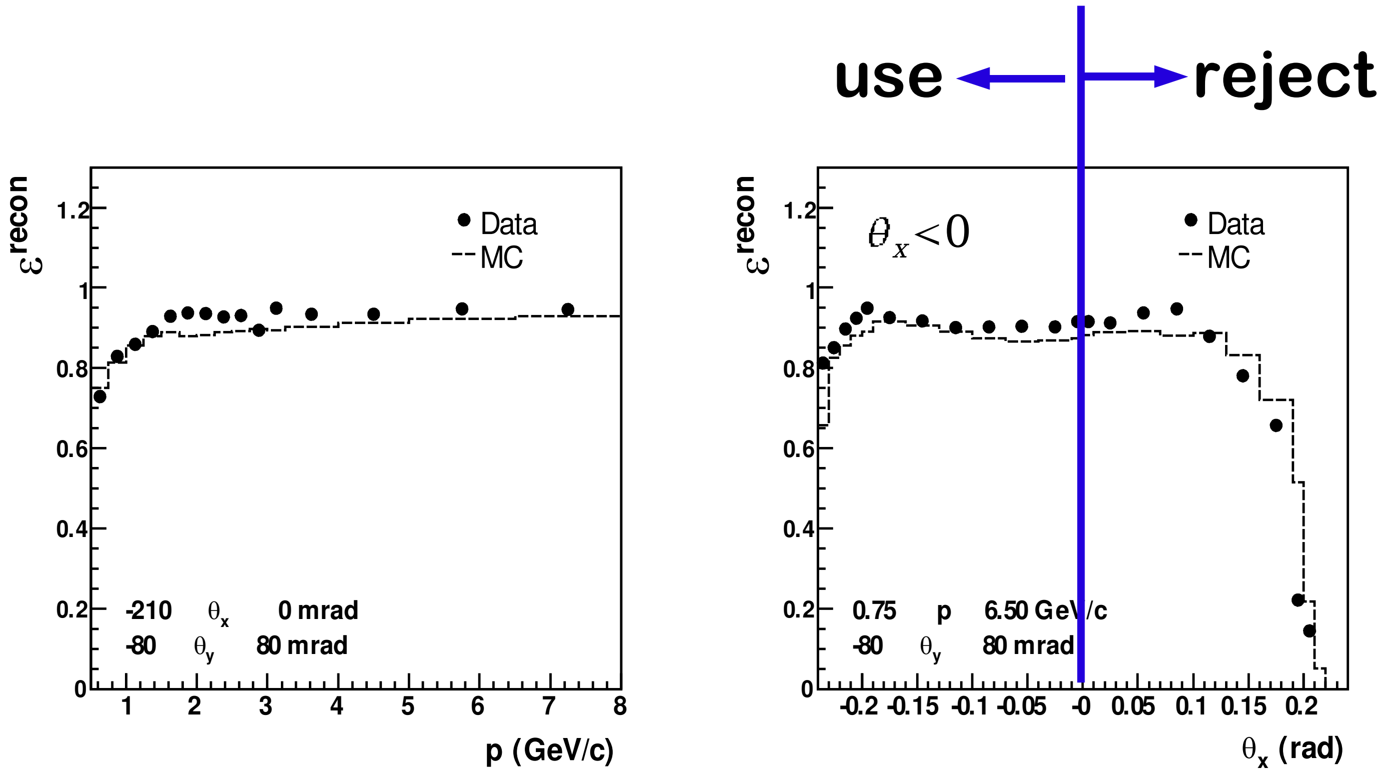


- **TWO WAYS to get momentum:**
  - Vertex2 tracks: 3D track segment **DOWNSTREAM**, plus successful **vertex match**
    - » used to measure pion yield.
  - Vertex4 tracks: 3D track segment **DOWNSTREAM**, plus 3D segment **UPSTREAM**
    - » used to measure track reconstruction efficiency of vertex match

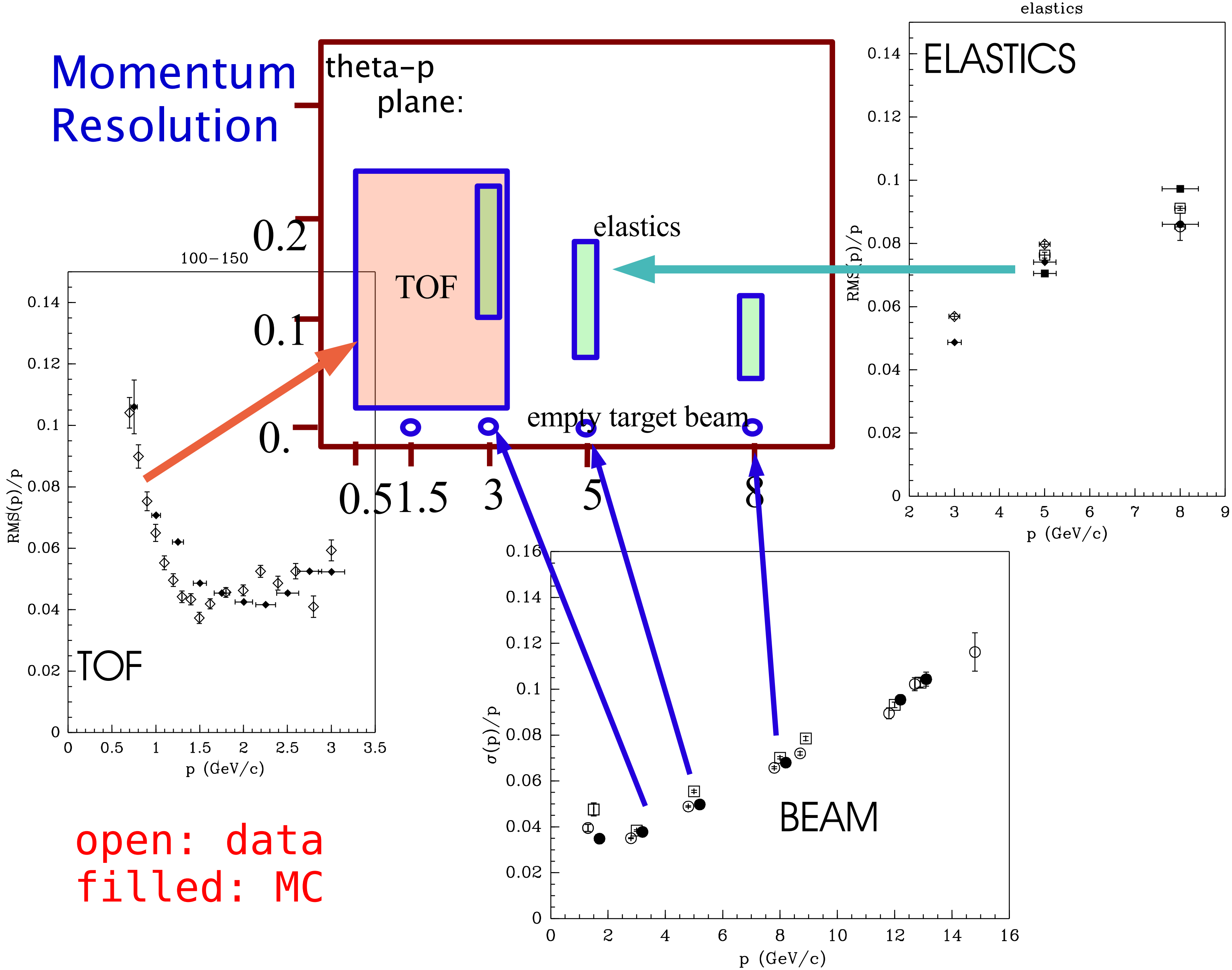
Track Reconstruction Efficiency

only focused tracks: charge x $\theta_x < 0$

Within geometrical acceptance:
efficiency high and nearly flat in p and theta



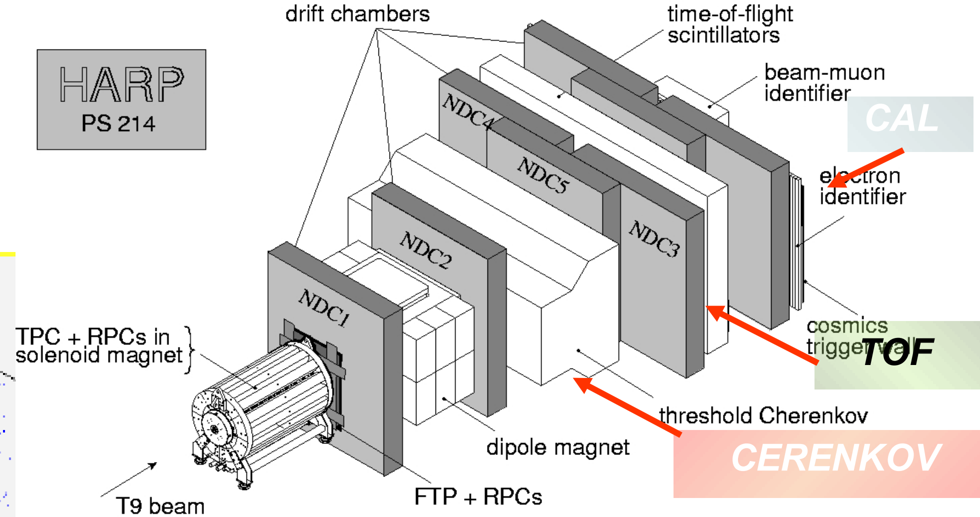
Momentum Resolution

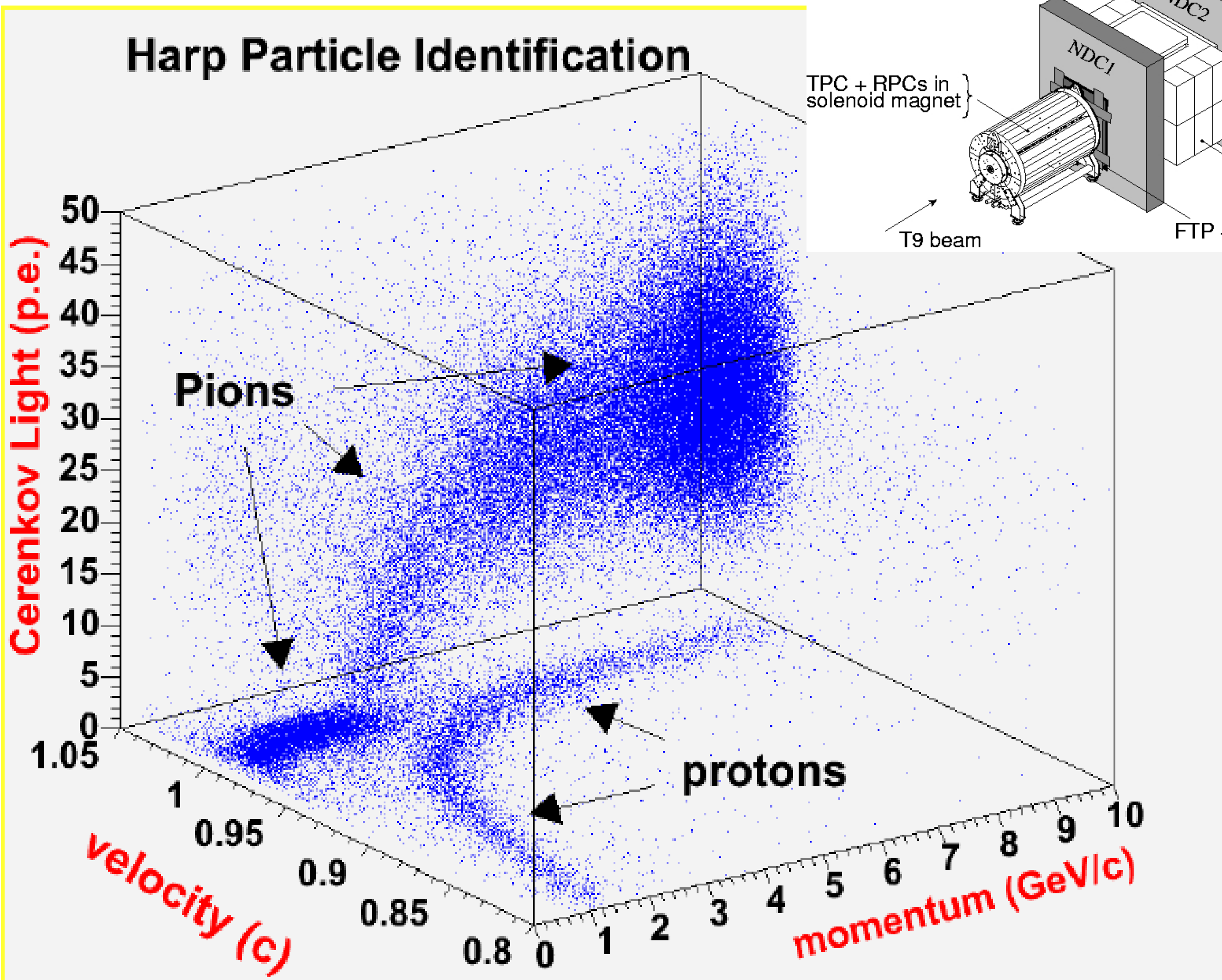


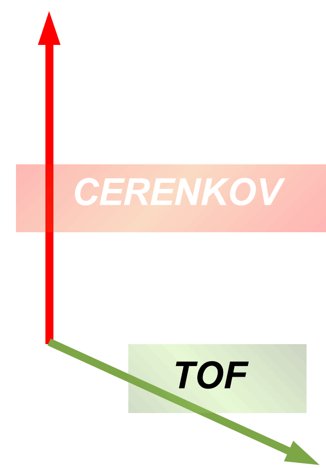
open: data
filled: MC

PID principle

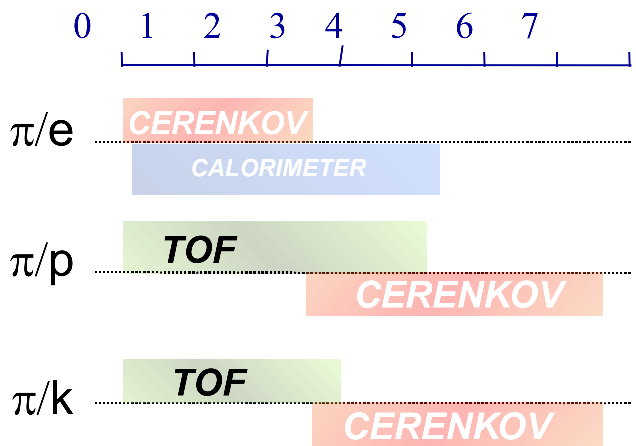
HARP
PS 214

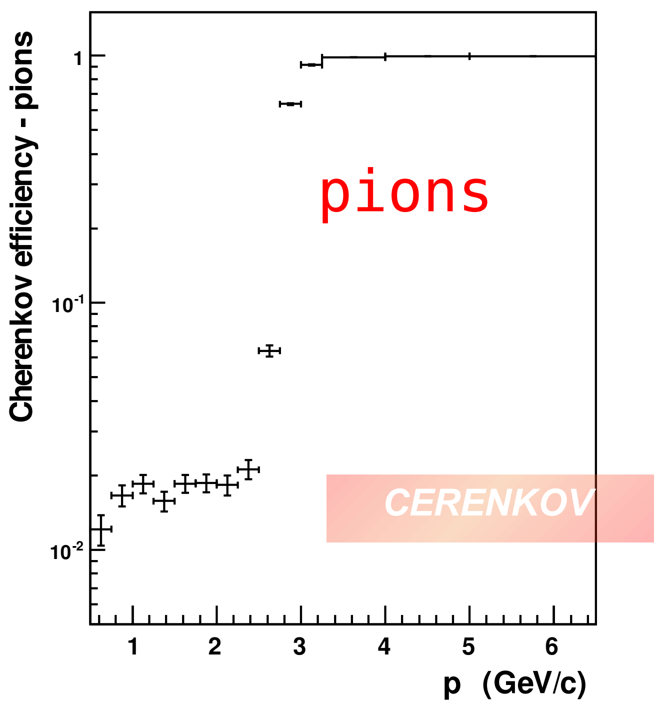


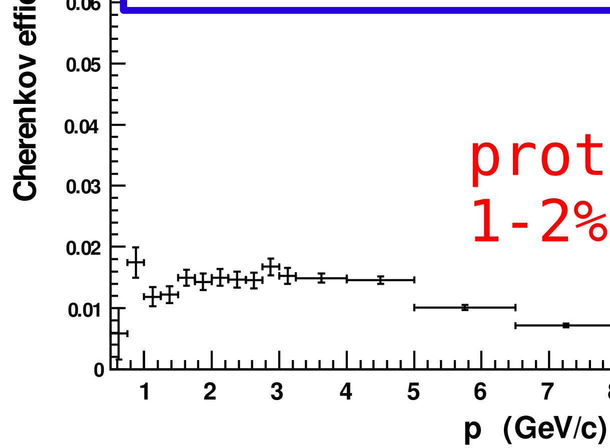


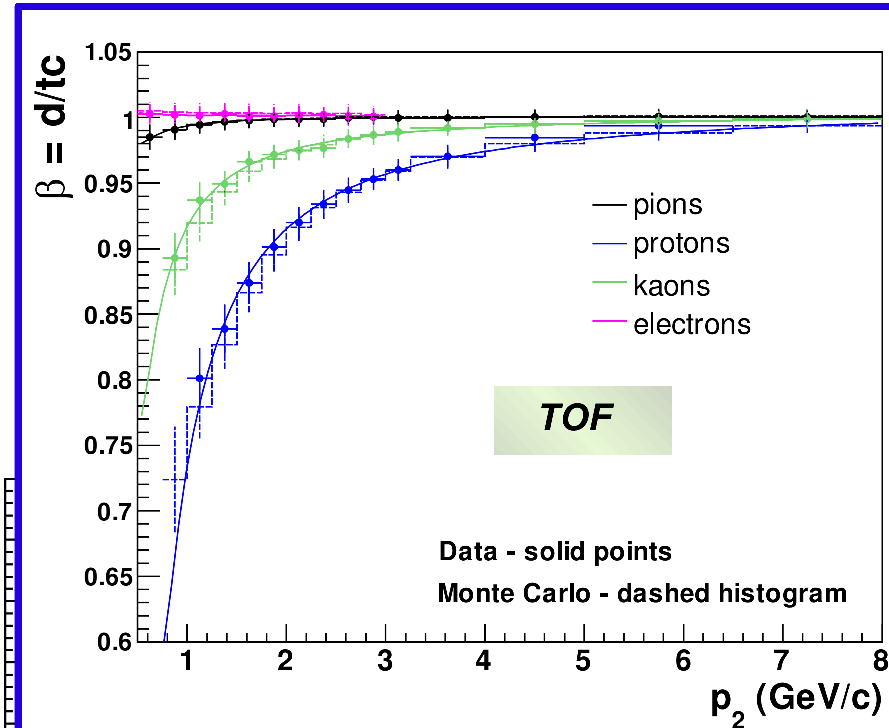


PID performance

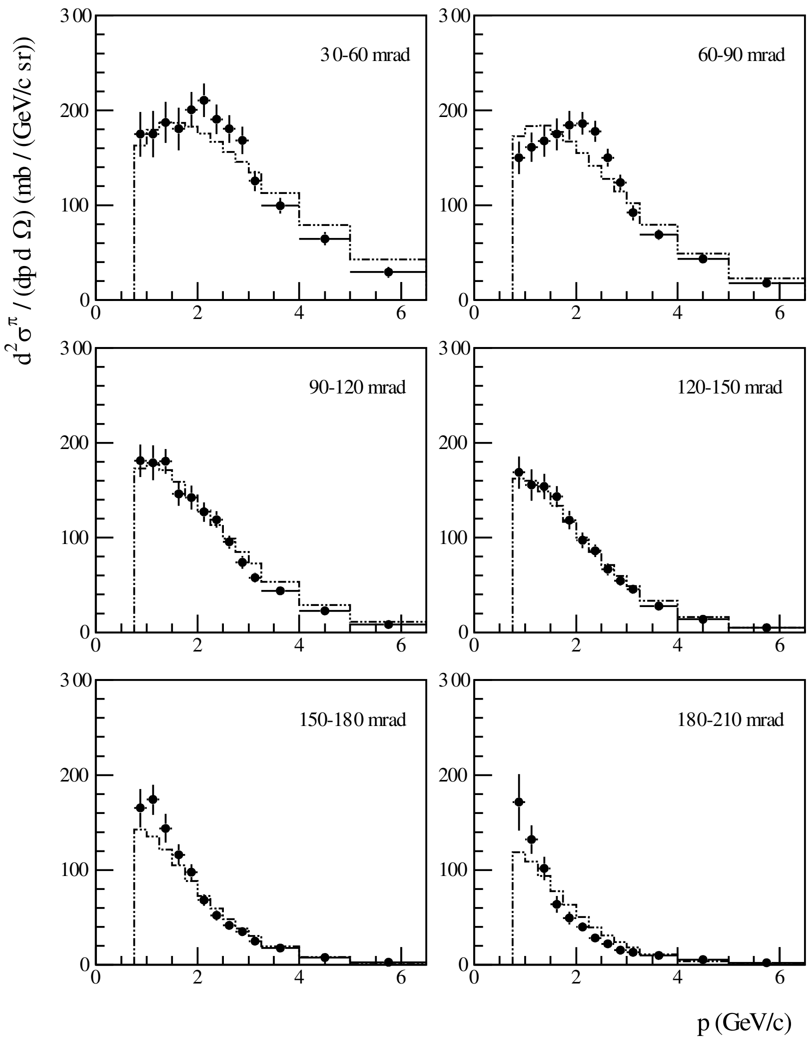




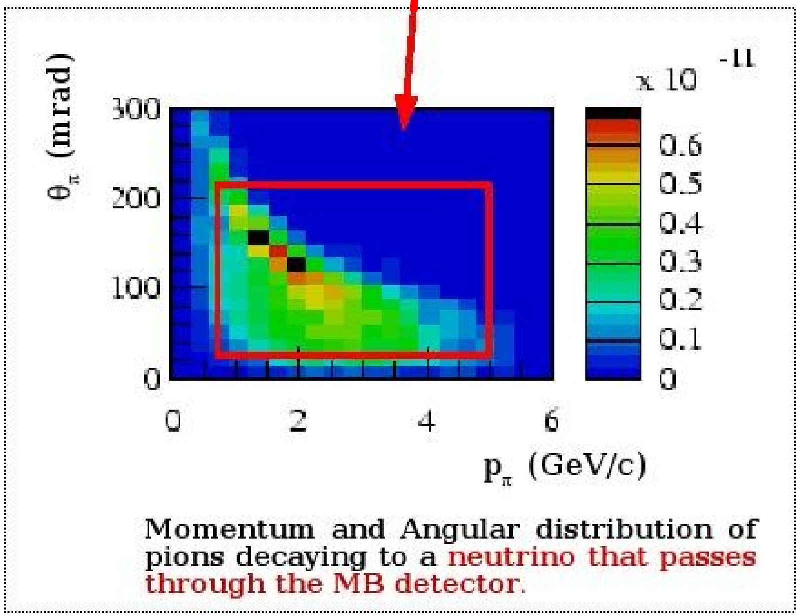




HARP Be 5% 8.9 GeV/c Results



0.75<p<5 GeV/c
30<theta<210 mrad
relevance for MiniBooNE



D. Schmitz

HARP results (data points), parametrization of HARP results (histogram)

Parametrization of HARP Data

HARP data on inclusive pion production fitted to **Sanford-Wang** parametrization:

$$\frac{d^2\sigma(p+Al\rightarrow\pi^{+}+X)}{dp\,d\Omega}(p,\theta)=c_1\,p^{c_2}\left(1-\frac{p}{p_{beam}}\right)\exp\left[-c_3\frac{p^{c_4}}{p_{beam}^{c_5}}-c_6\,\theta\left(p-c_7\,p_{beam}\cos^{c_8}\theta\right)\right]$$

where:

X: any other final state particle

$p_{beam}=12.9$: proton beam momentum (GeV/c)

$p,\ \theta$: π^{+} momentum (GeV/c), angle (rad)

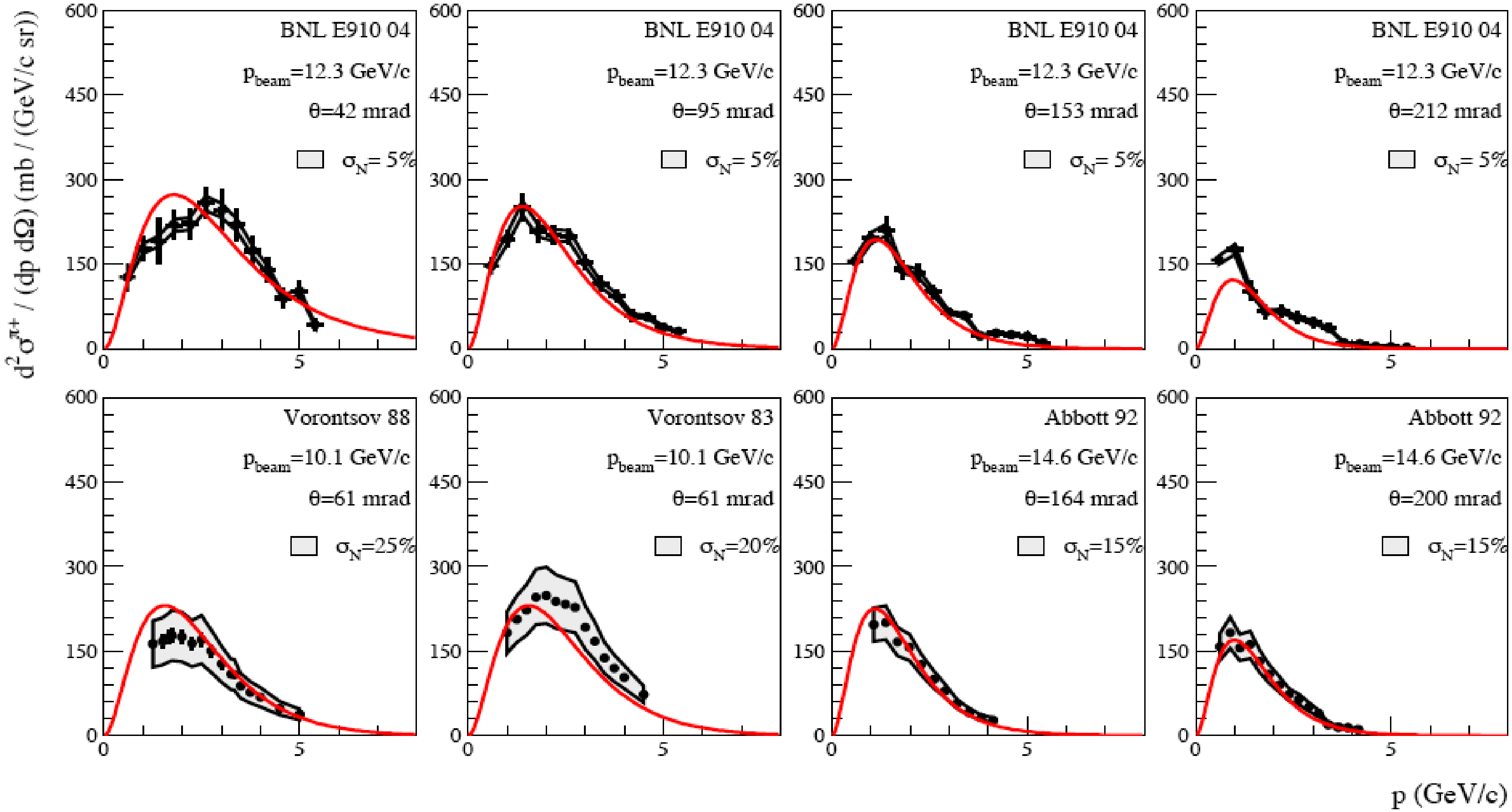
$d^2\sigma/(dp\,d\Omega)$ units: $mb/(GeV/c\,sr)$, where $d\Omega\equiv 2\pi\,d(\cos\theta)$

$c_{1},\ldots,c_8$: emprical fit parameters

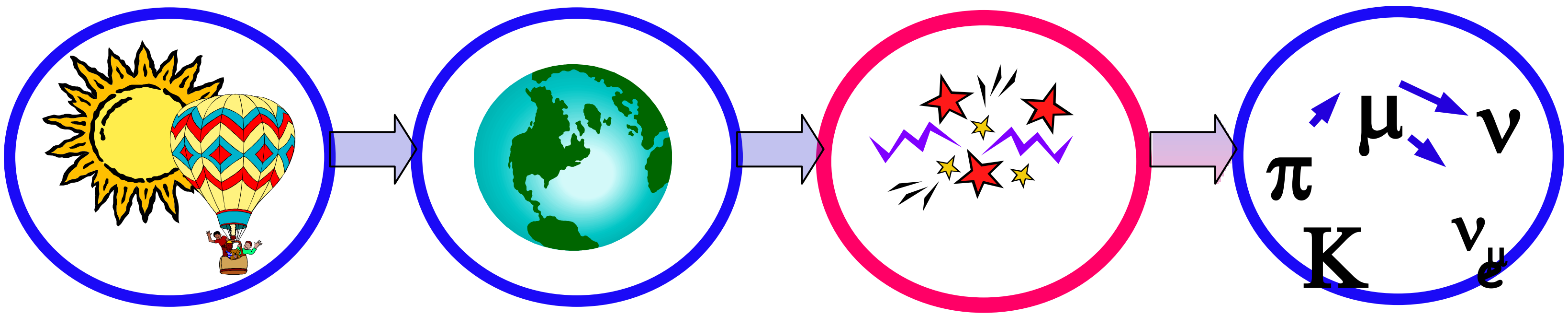
Sanford-Wang parametrization used to:

- Use HARP data in K2K and MiniBooNE beam MC
- Translate HARP pion production uncertainties into flux uncertainties
- Compare HARP results with previous results in similar beam momentum, pion phase space range

Comparison with older data data
(at different beam momenta)



Atmospheric Neutrino Flux



Proton fluxes: balloons, satellites

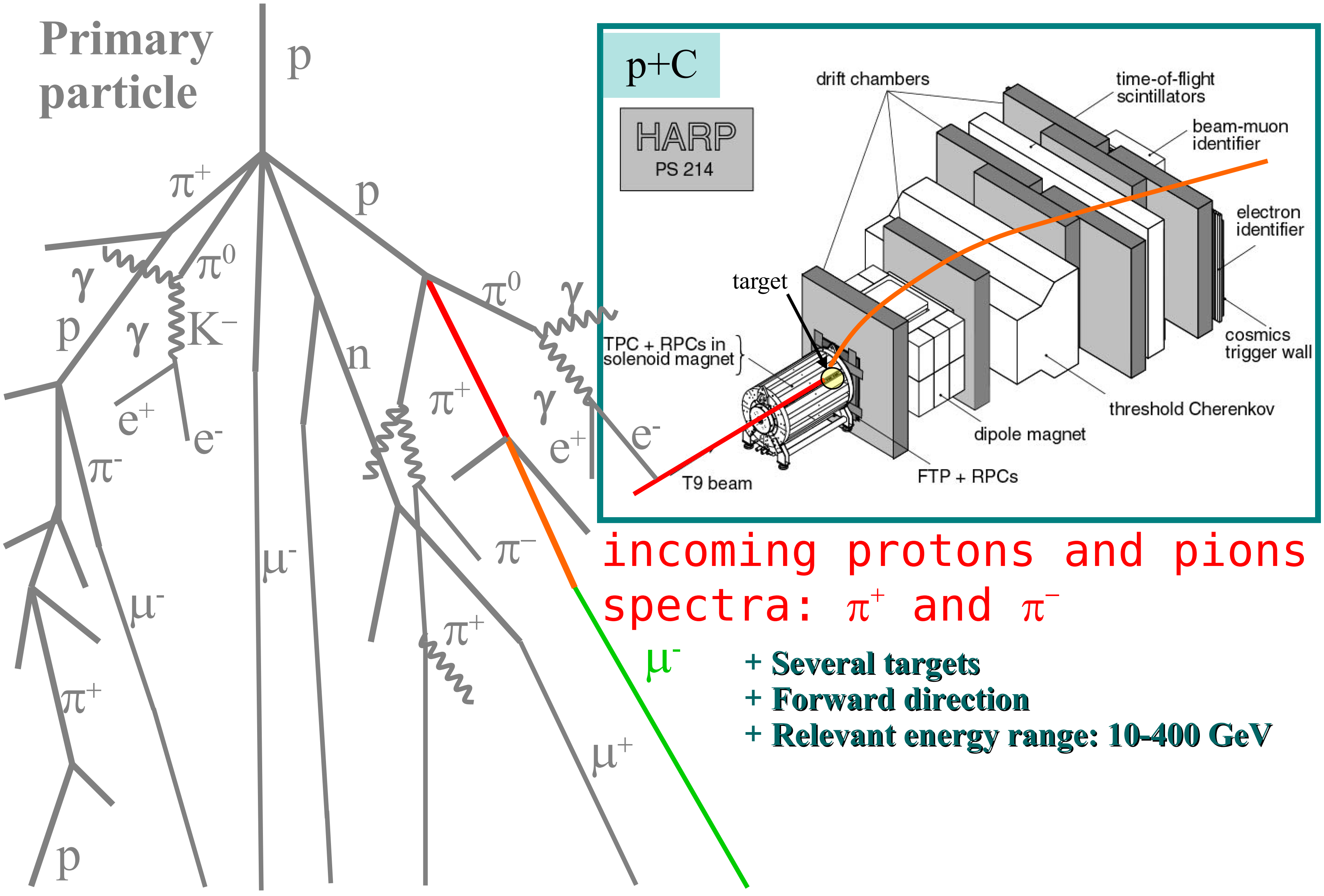
Geomagnetic field

Hadroproduction: 30% errors

decay chains

- Ideally Cryogenic targets: N_2, O_2
- First measurements with carbon
- Full solid angle
- Higher beam momenta

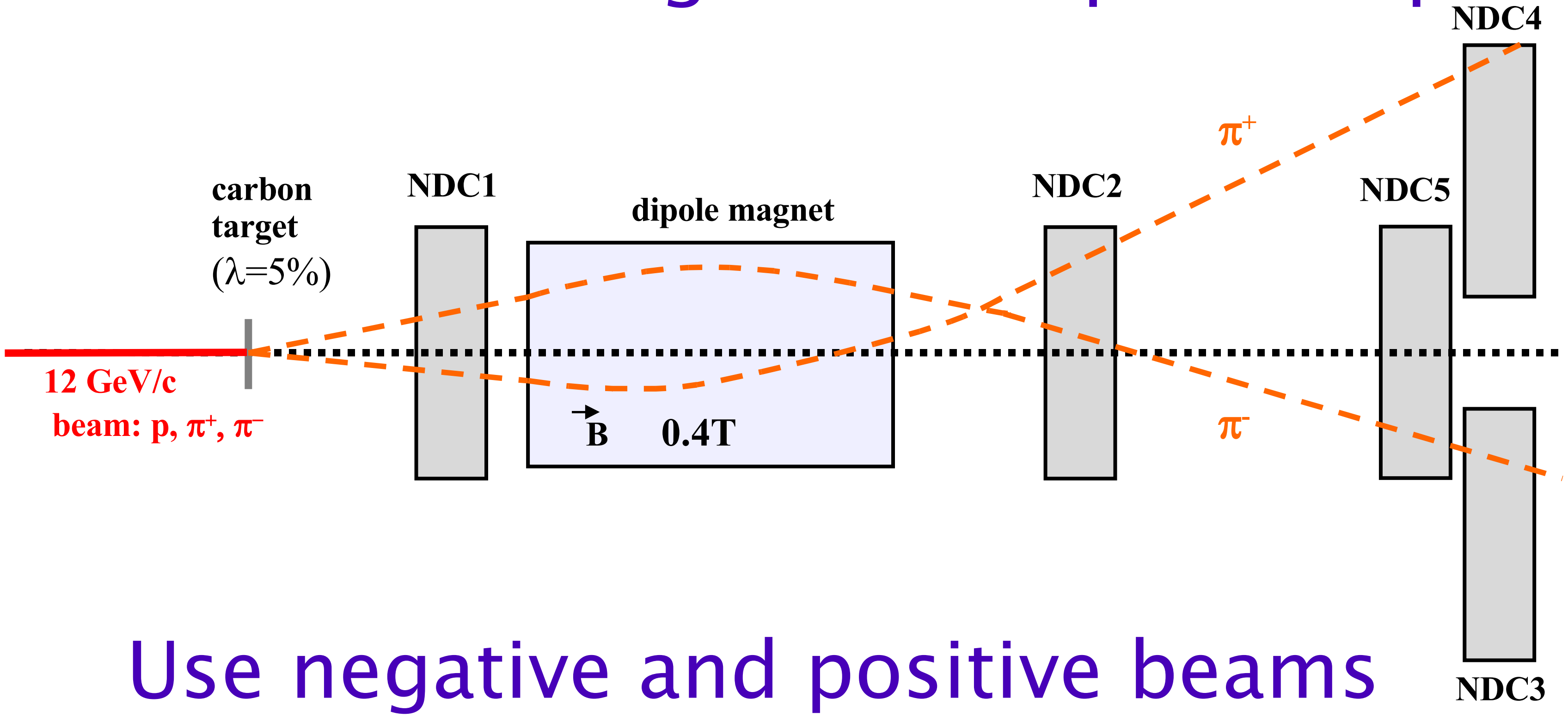
Extended Air Showers



incoming protons and pions spectra: π^+ and π^-

- + **Several targets**
- + **Forward direction**
- + **Relevant energy range: 10-400 GeV**

Use focused negative and positive pions

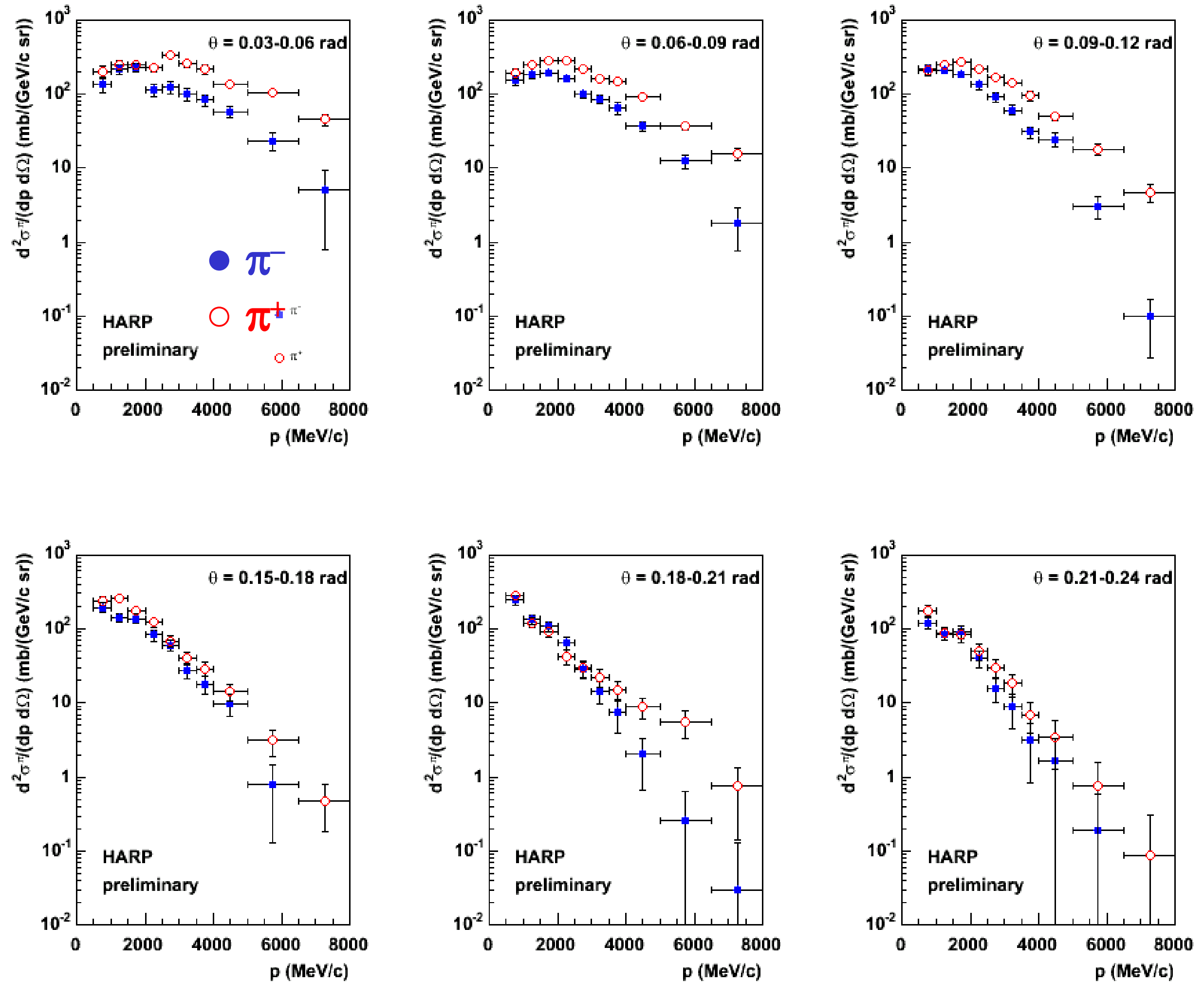


Use negative and positive beams

Selection of secondary particles (π^+, π^-) in forward hemisphere using the drift chambers.

No of events (pos. beam):	1,000k
No of events after cuts:	460k (p+C)
	40k (π^++C)
No of events (neg. beam):	646k
No of events after cuts:	350k (π^-+C)

p+C @ 12 GeV/c

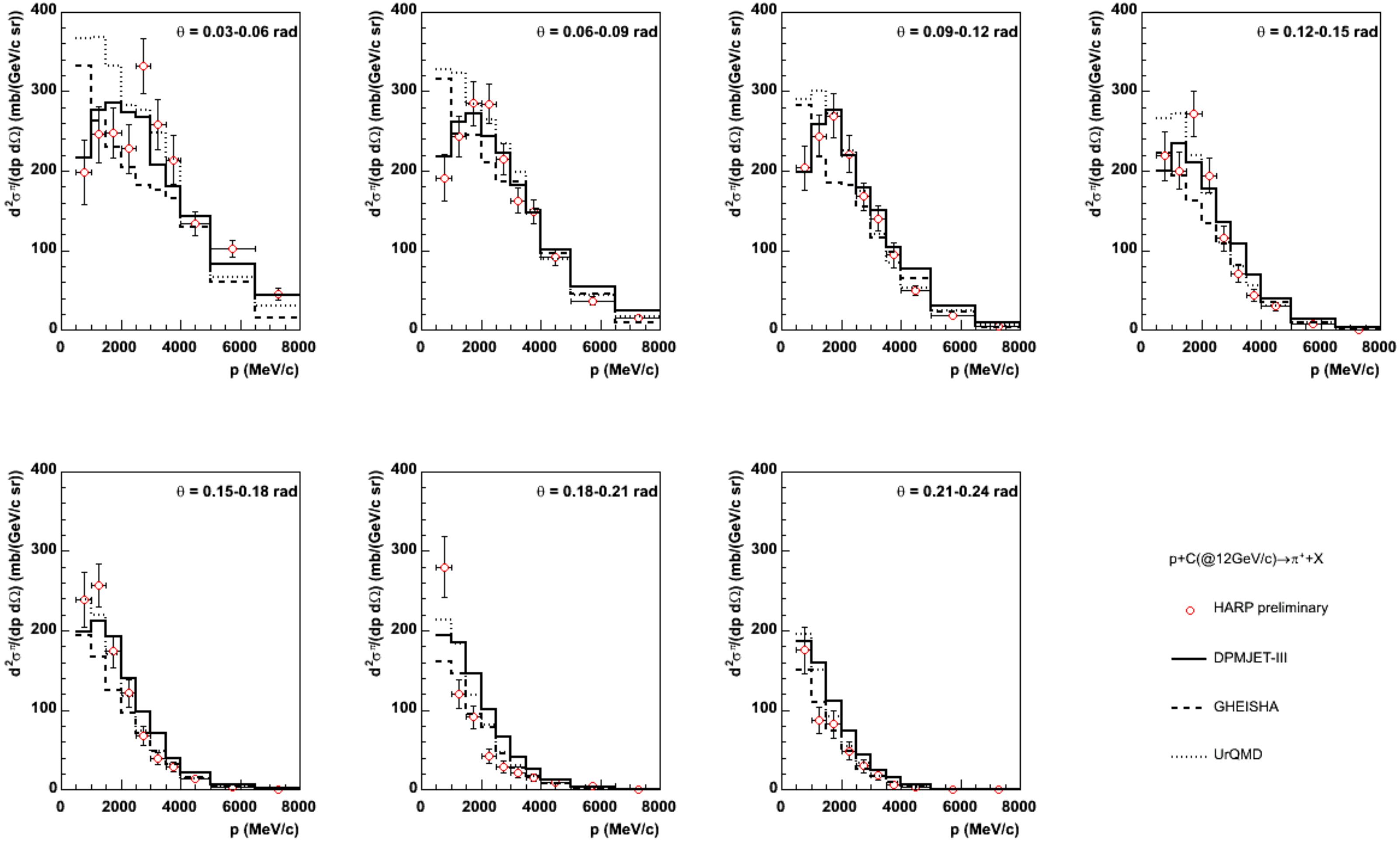


- π^+: leading particle effect
- Error: stat. and syst.

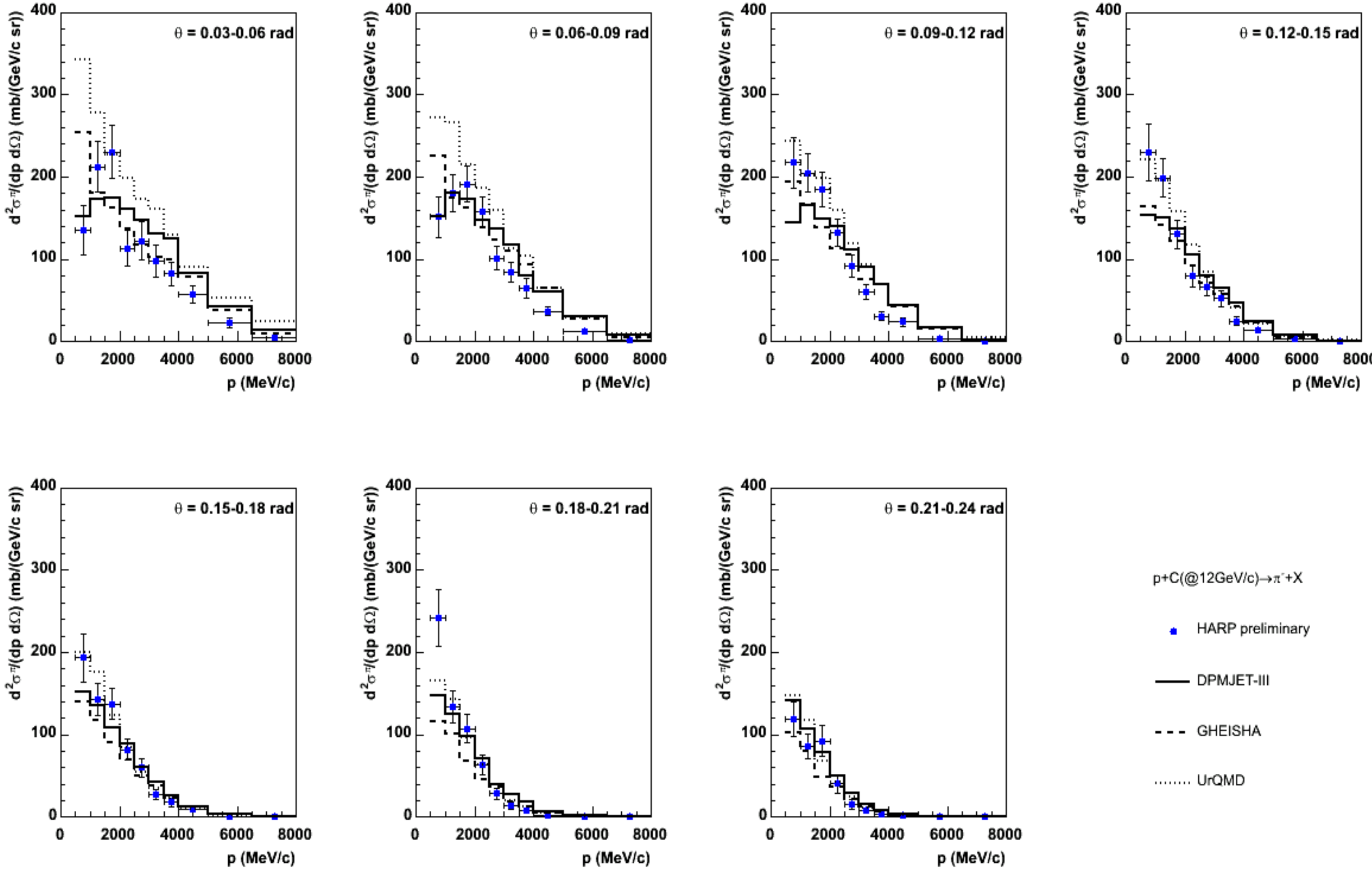
C. Meurer

log scale

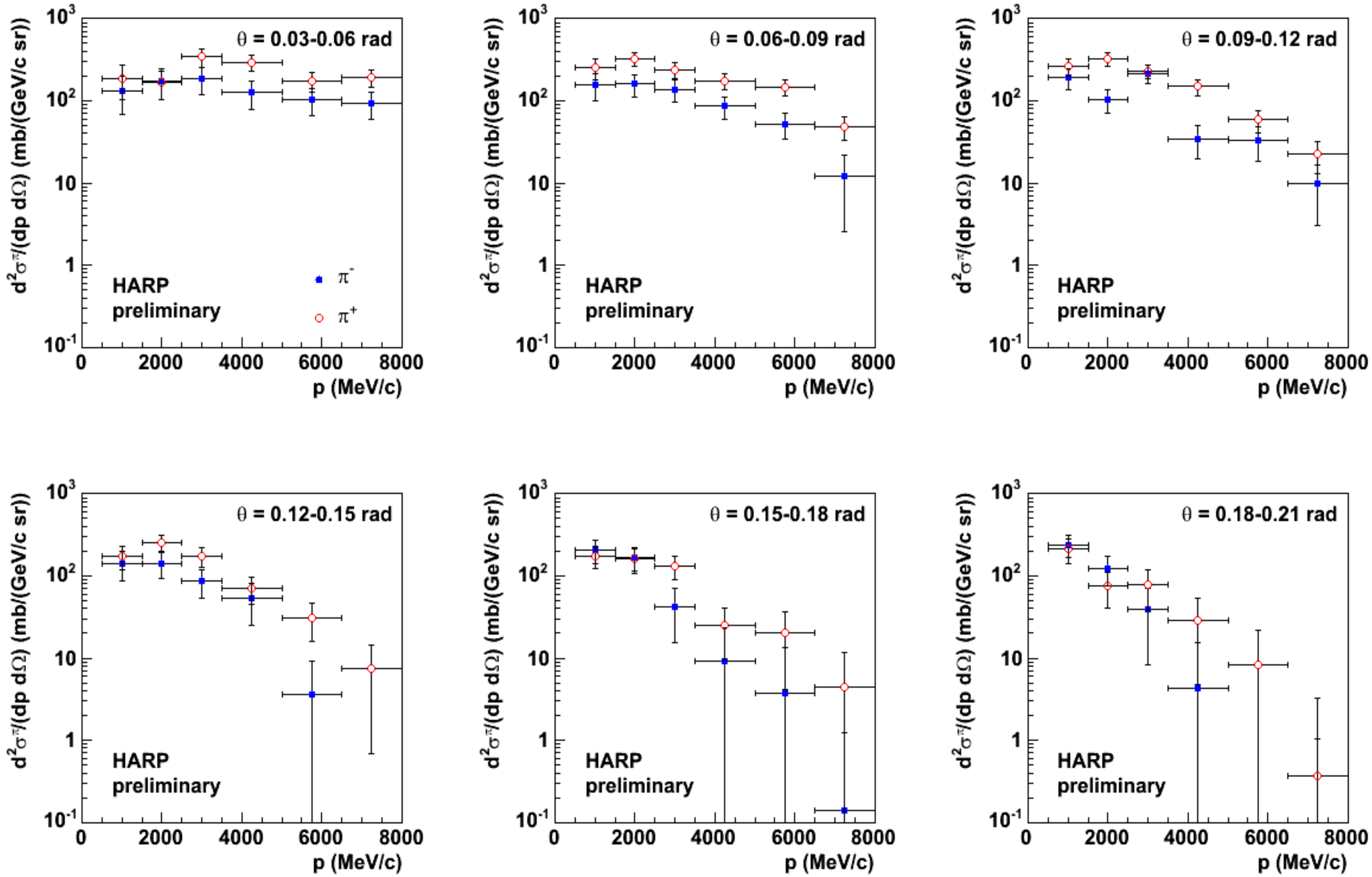
Model comparison: p+C→π^++X



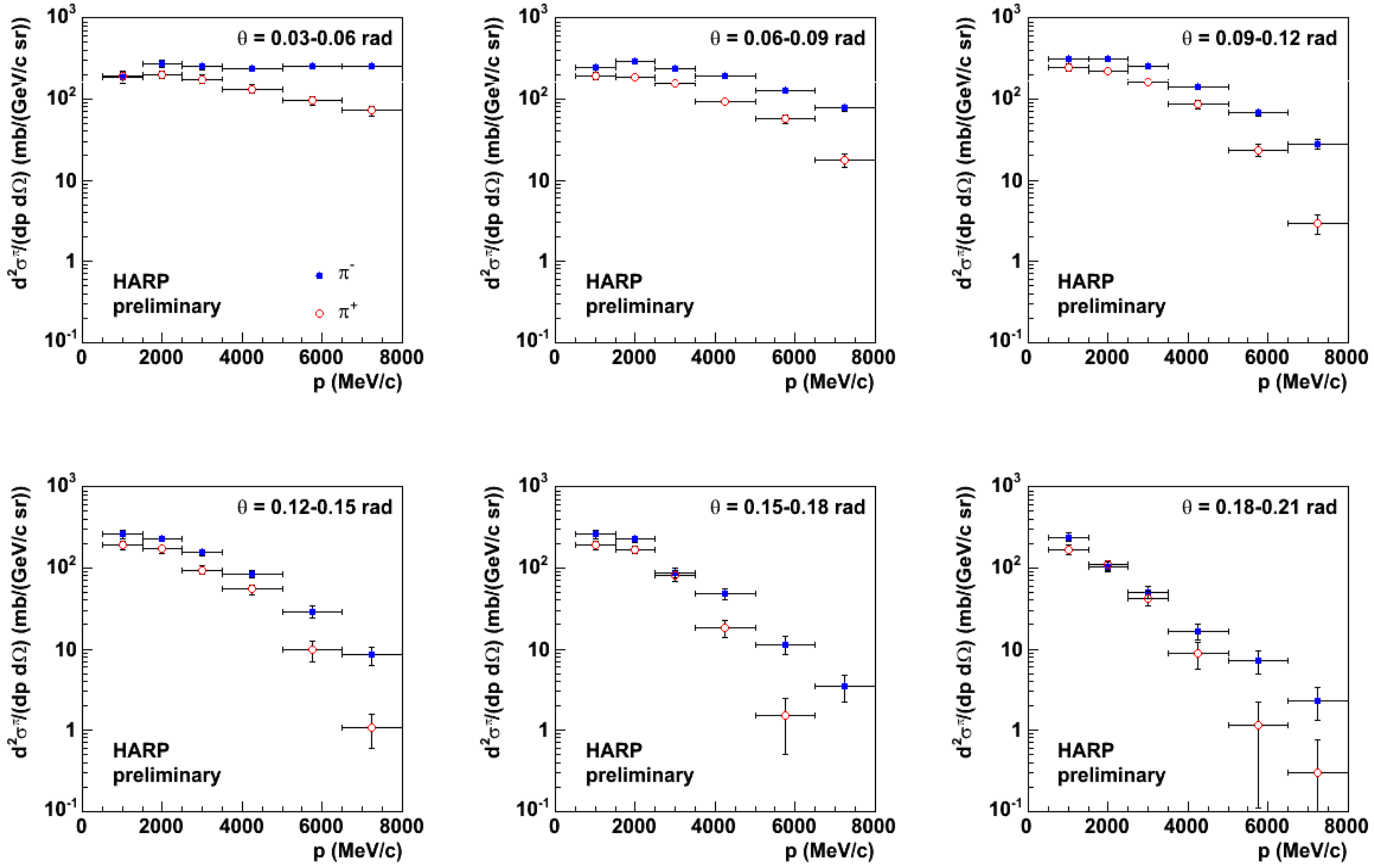
Model comparison: p+C→π^-+X



π^++C @ 12 GeV/c
(lower statistics)



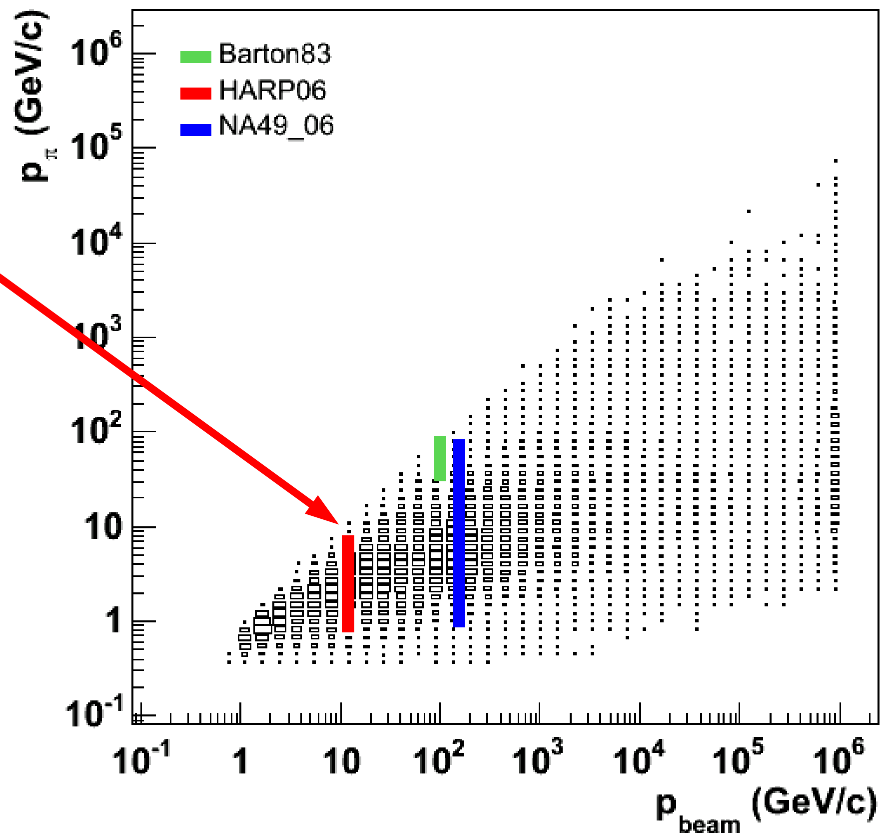
π^-+C @ 12 GeV/c
(high statistics)



Phase space region

- New data sets

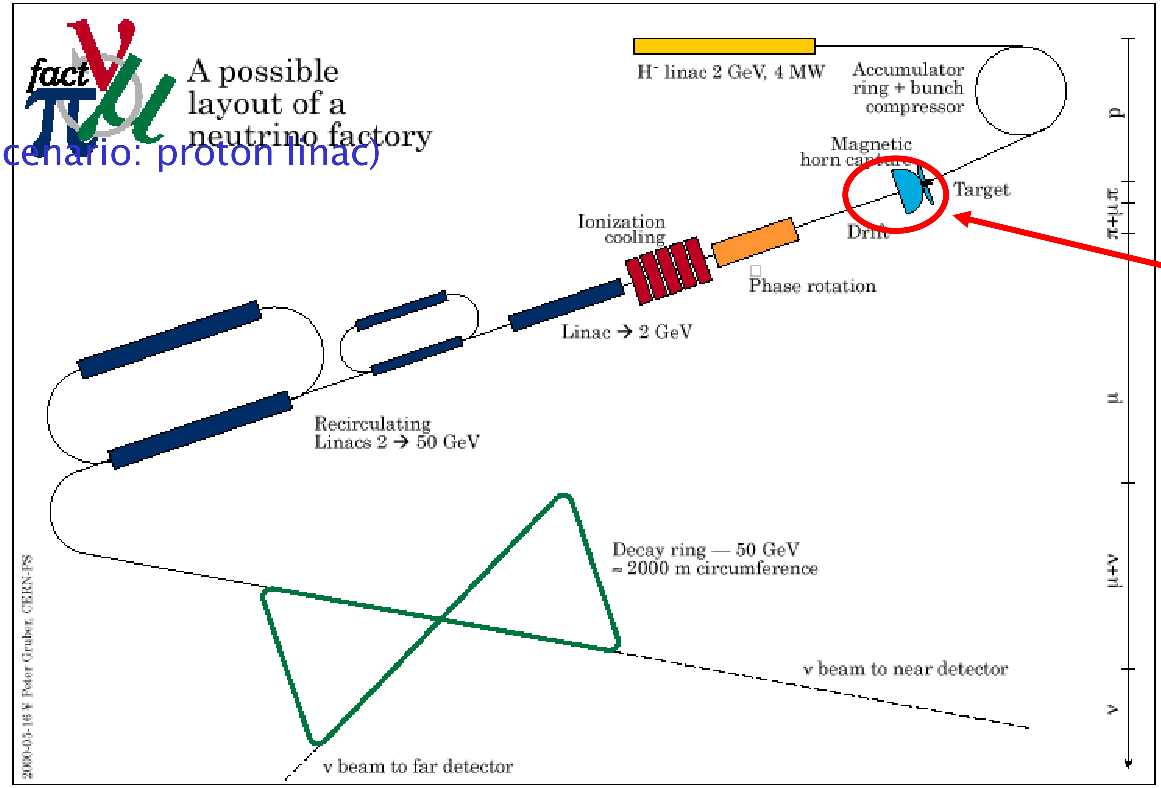
  (p+C, π^++C and π^-+C at 12 GeV/c)
- Important phase space region covered
- Data available for model tuning and simulations
- N2 and O2 data being processed now



[Barton83] Phys. Rev. D 27 (1983) 2580 (Fermilab)
[NA49_06] Eur. J. Phys., hep-ex/0606028 (SPS)
HARP (PS)

Neutrino Factory R&D

(CERN scenario: proton linac)

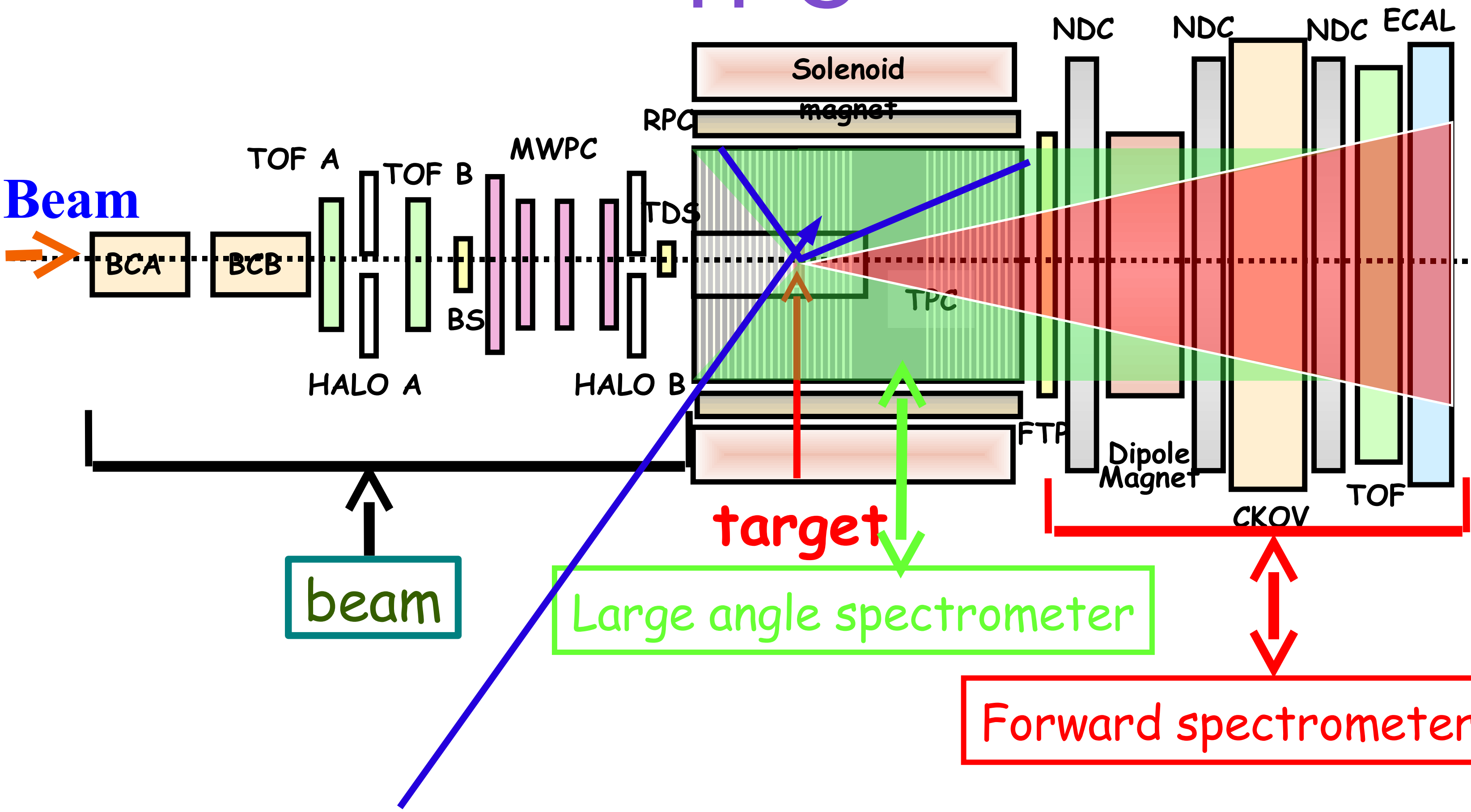


Maximize: π^+, π^- production rate (/proton /GeV)

- Primary energy
- Target material
- Geometry
- Collection scheme

- Measure the p distribution with high precision
- Solid targets, preferably high Z

Large Angle spectrometer: TPC



$0.35 < \theta < 2.15$ rad

TPC Track Reconstruction

Equalisation

↓

Clustering

↓

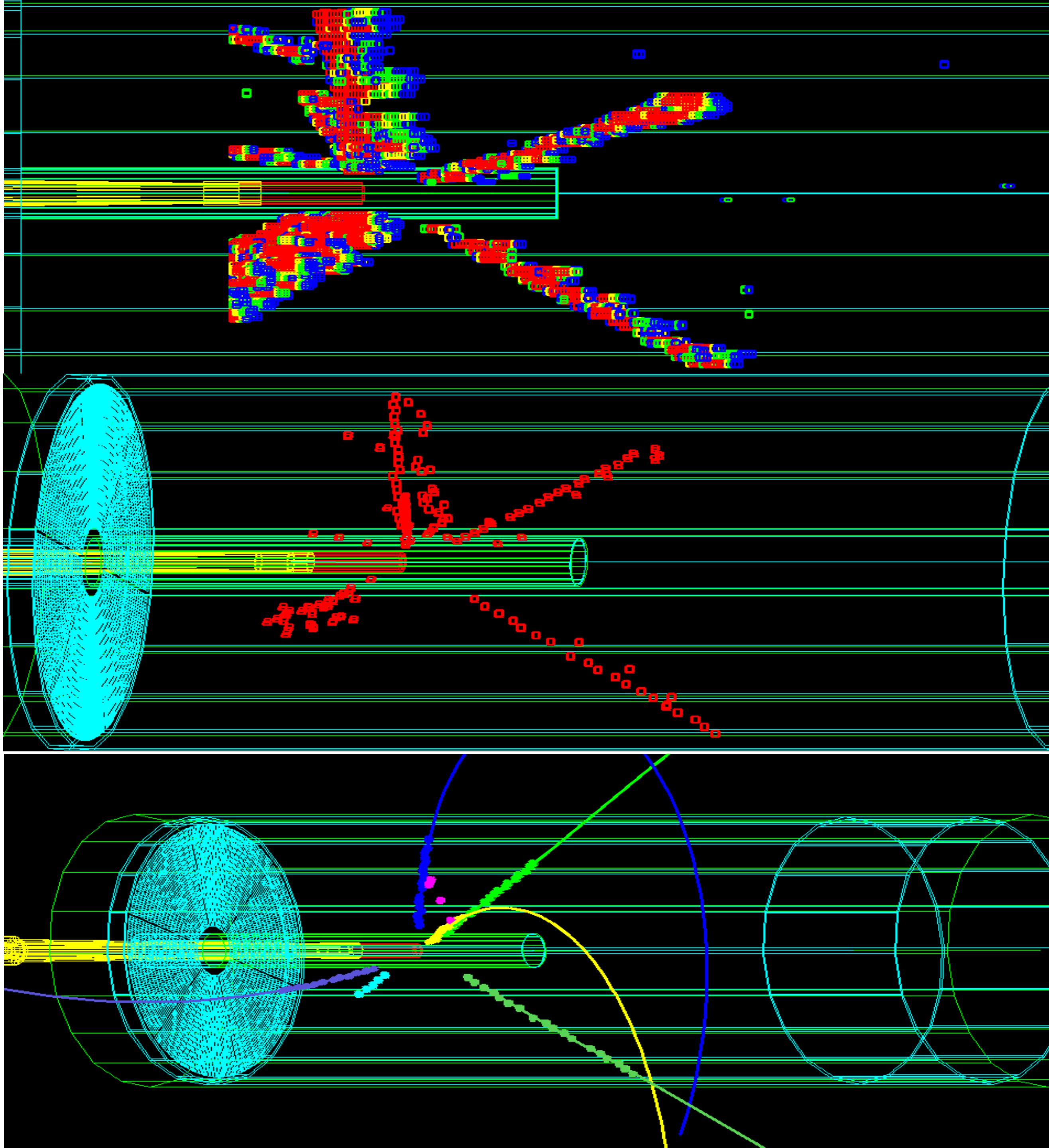
Pattern recognition

↓

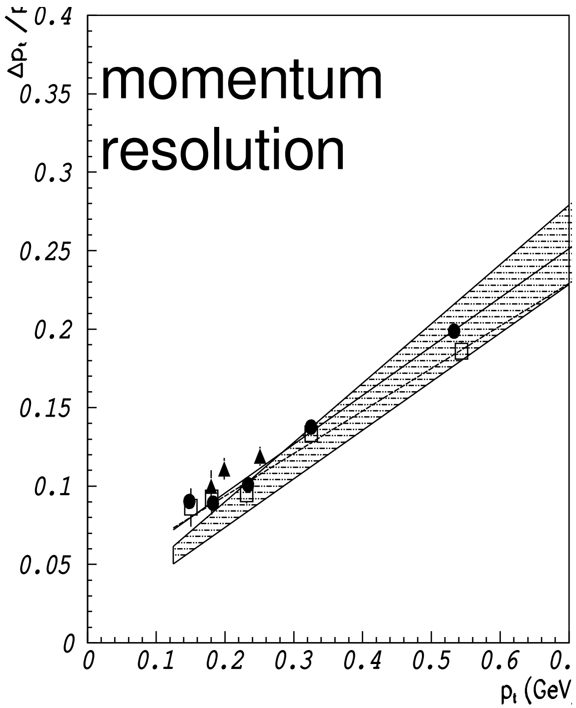
Track fit (helix)

↓

Momentum fit



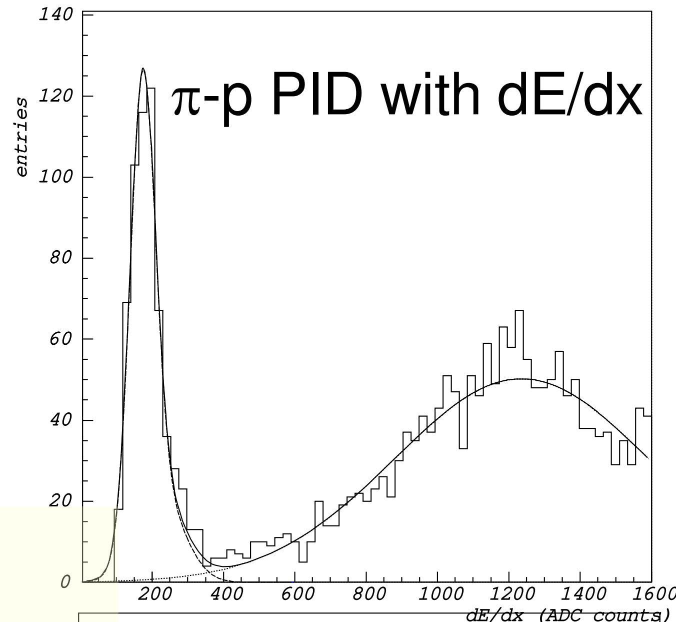
Spectrometer performance

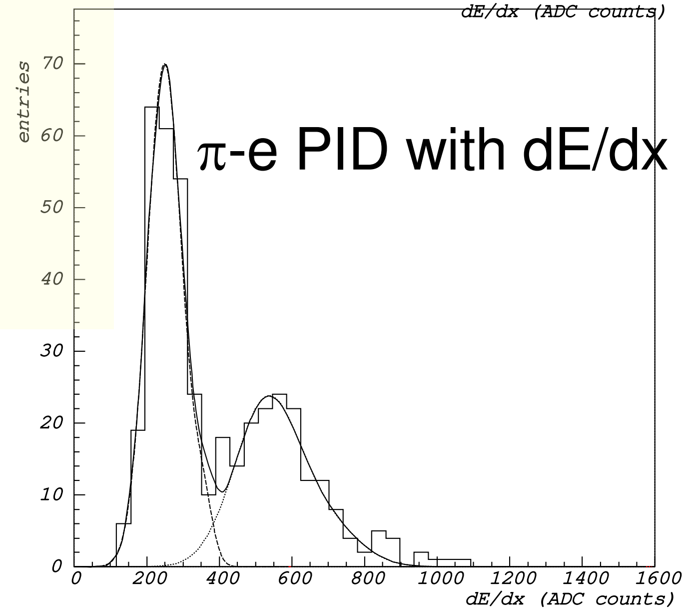


momentum
calibration:
cosmic rays
elastic scattering

elastic scattering:
absolute calibration of
efficiency
momentum
angle
(two spectrometers!)

PID:
dE/dx used
for analysis
TOF used to
determine
efficiency





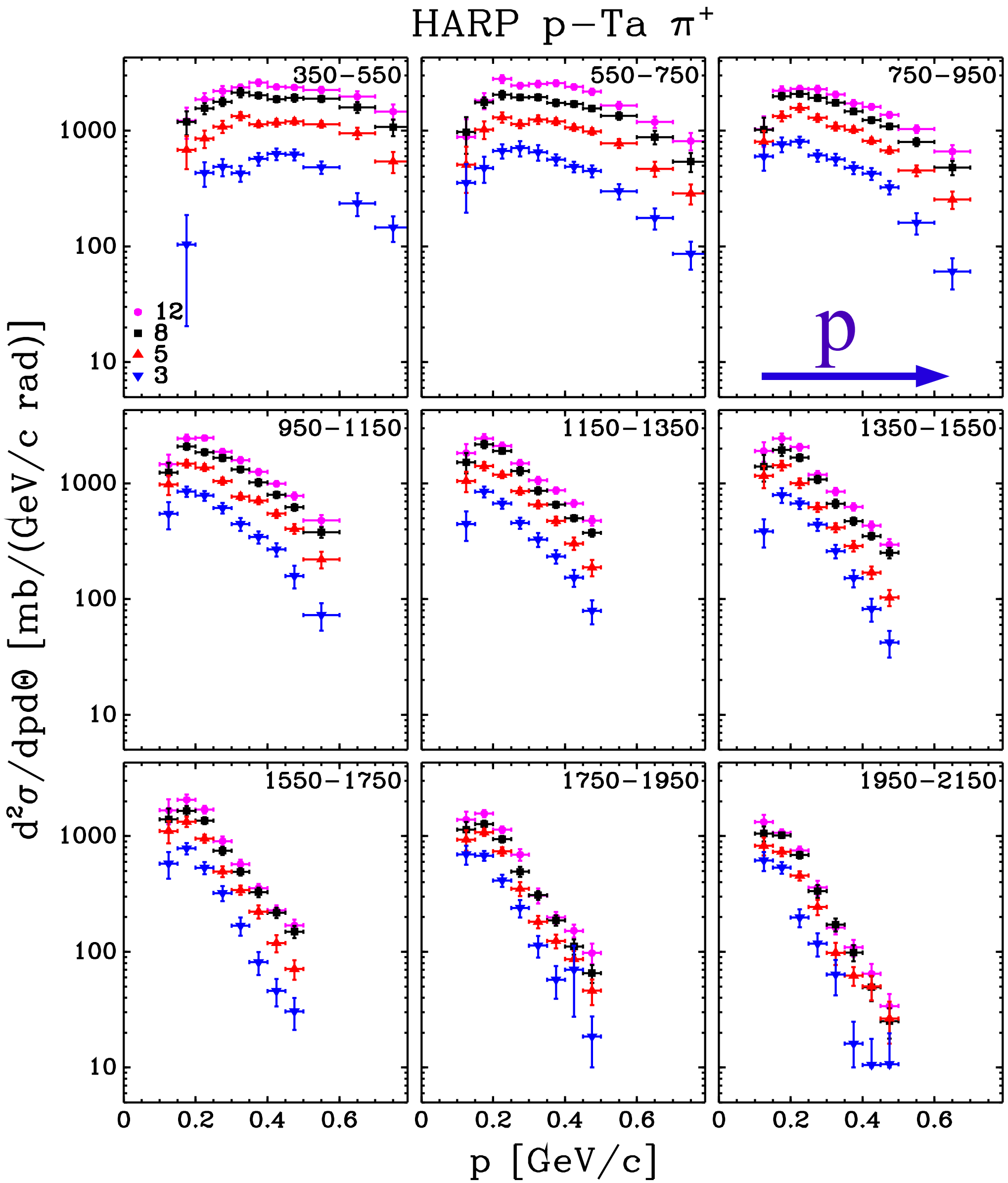
"Large Angle" analysis

beam momenta:
3, 5, 8, 12 GeV/c
beam particle selection and normalization same as previous analysis
events:
require trigger in ITC (cylinder around target)
TPC tracks:
>11 points and momentum measured and track originating in target
PID selection

additional selection to avoid track distortions due to ion charges in TPC:
first part of spill (30-40% typically of data kept, correction available for future)
Corrections:
Efficiency, absorption, PID, momentum and angle smearing by unfolding method
(same as pC data analysis in forward spectrometer)
Backgrounds:
secondary interactions (simulated)
low energy electrons and positrons (all from π^0)
predicted from π^+ and π^- spectra (iterative) and normalized to identified e^{+-}.

9 angular bins: p-Ta π^+

Pion production yields



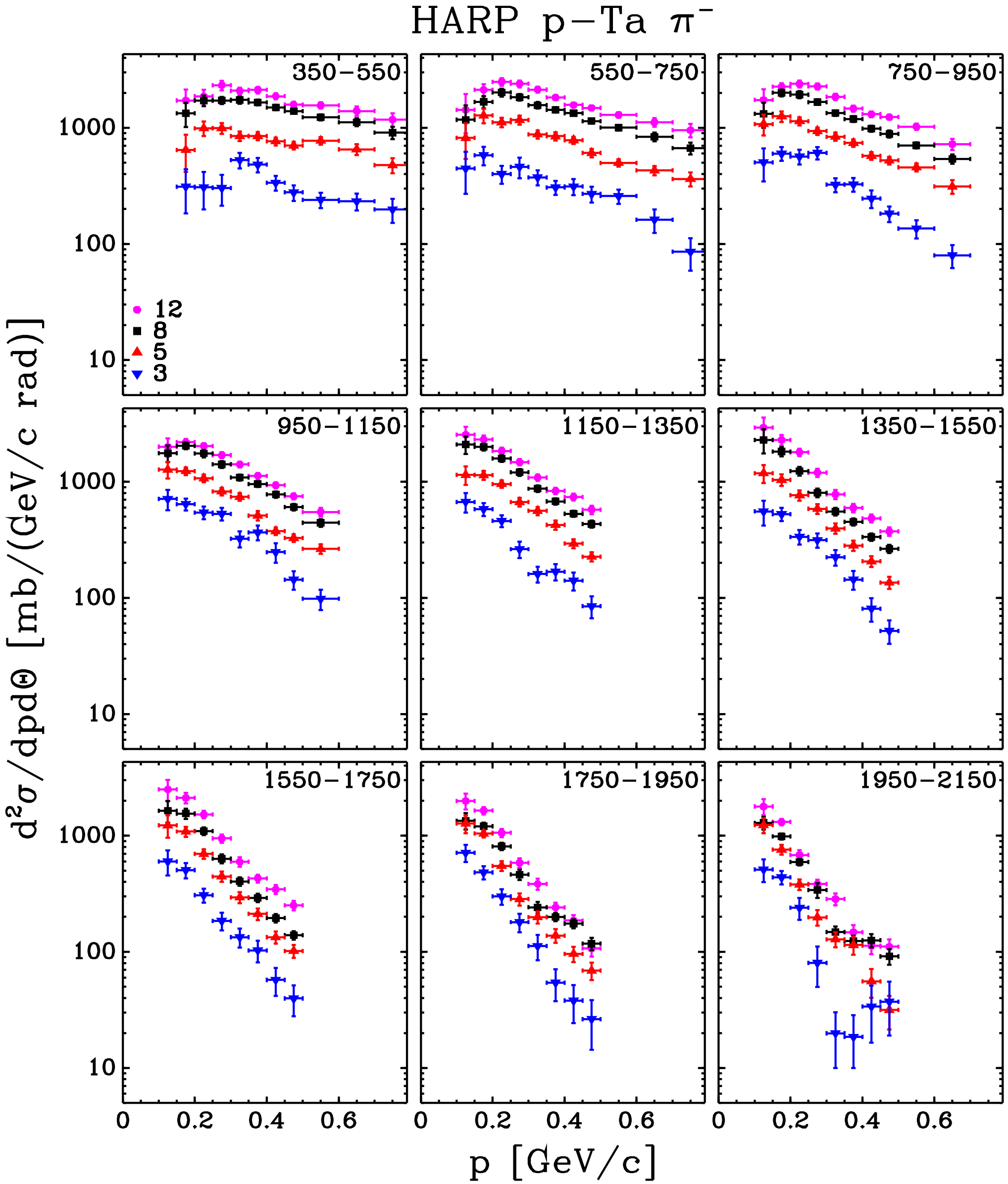
forward
$0.35 < \theta < 1.55$

backward
$1.55 < \theta < 2.15$

S. Borghi

p-Ta π^-

Pion production yields



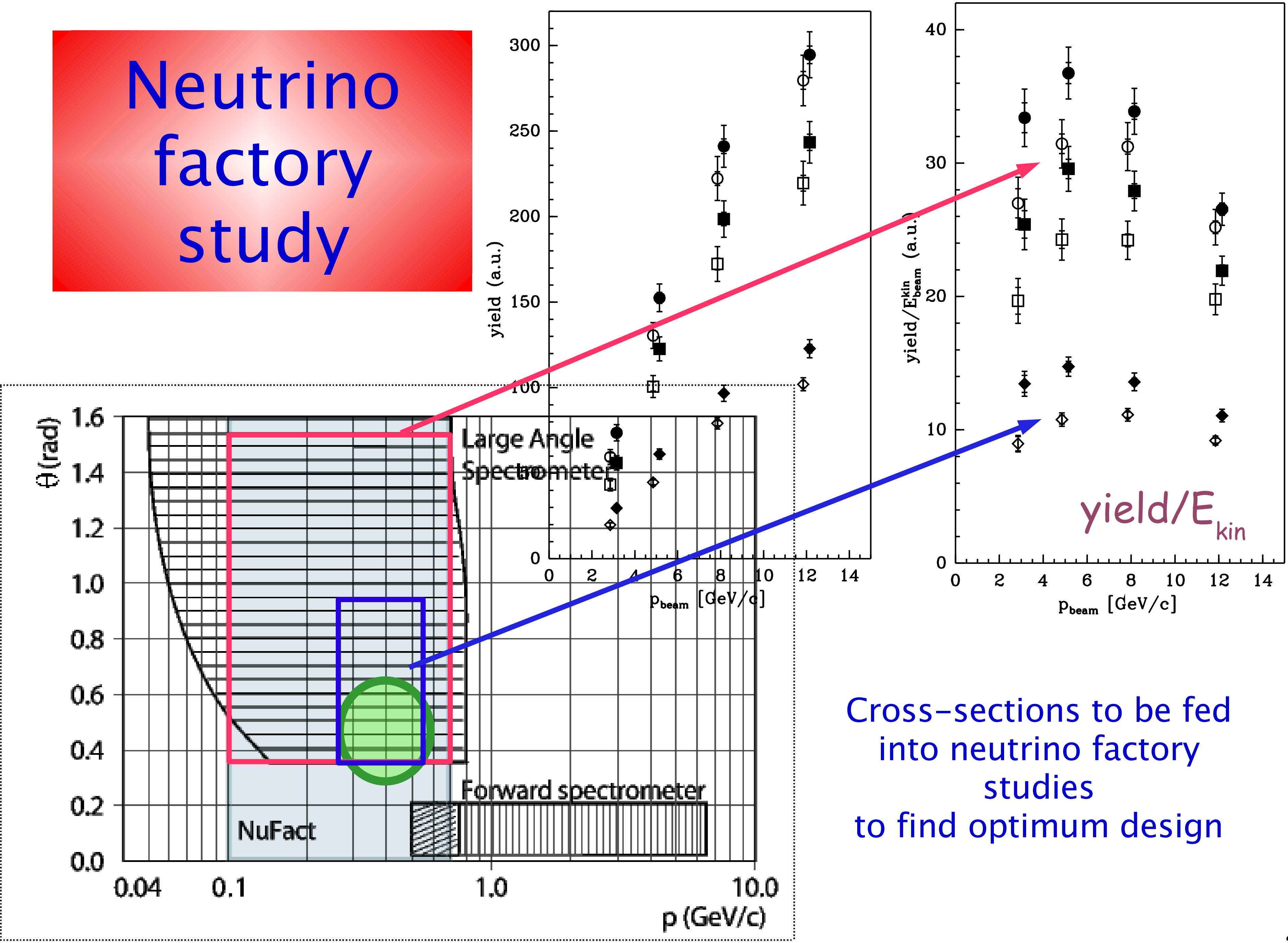
forward

$0.35 < \theta < 1.55$

backward

$1.55 < \theta < 2.15$

Neutrino factory study



Cross-sections to be fed into neutrino factory studies to find optimum design

Hadronic Generators

General problem: *little experimental data*, large uncertainties in calculations.

many target materials and momenta

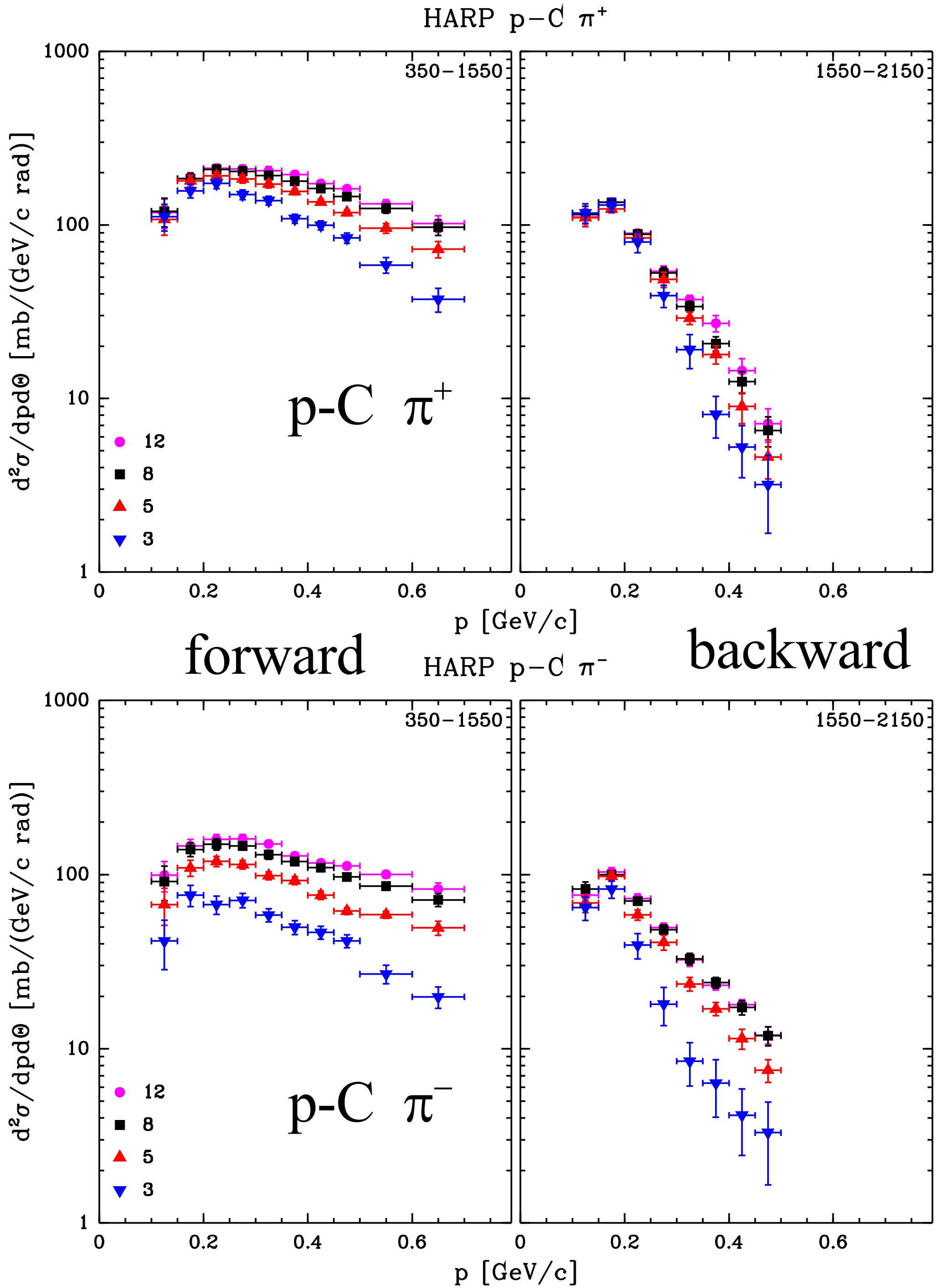
Full PID, large solid angle

Input/calibration for hadronic generators and models

(in collaboration with GEANT4)

example spectra

Pion yields

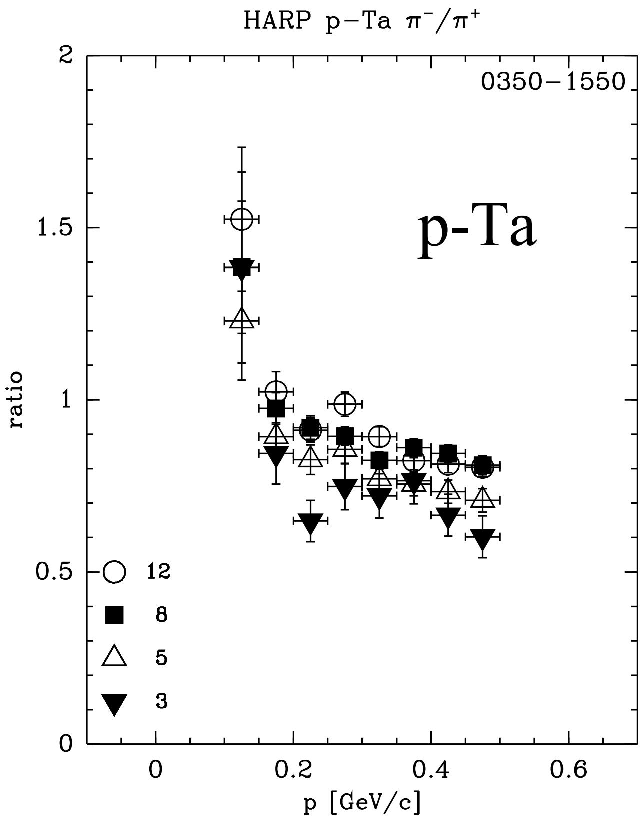


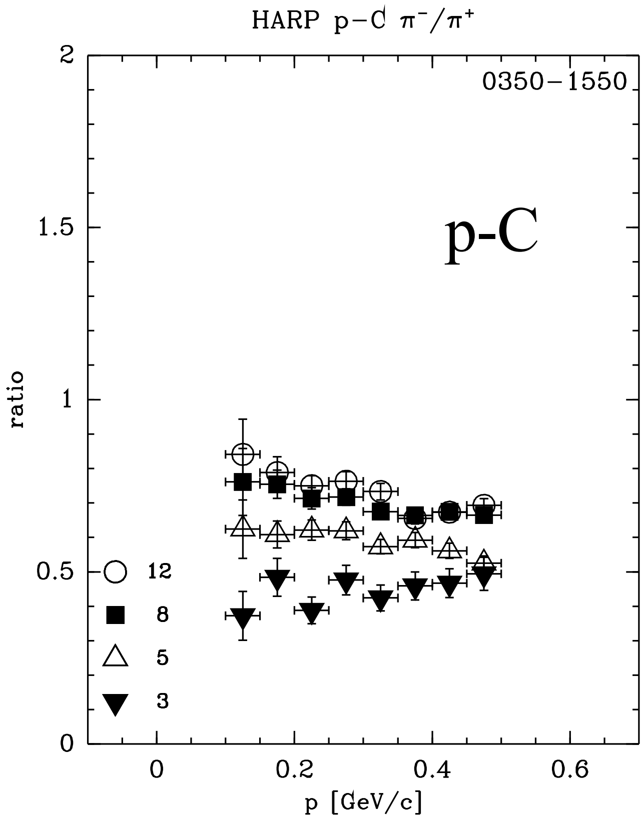
p-C data as an example of many other available spectra

Pion yields

comparison of p-C π^-/π^+ and p-Ta π^-/π^+ ratios

forward production only $0.35 < \theta < 1.55$ rad

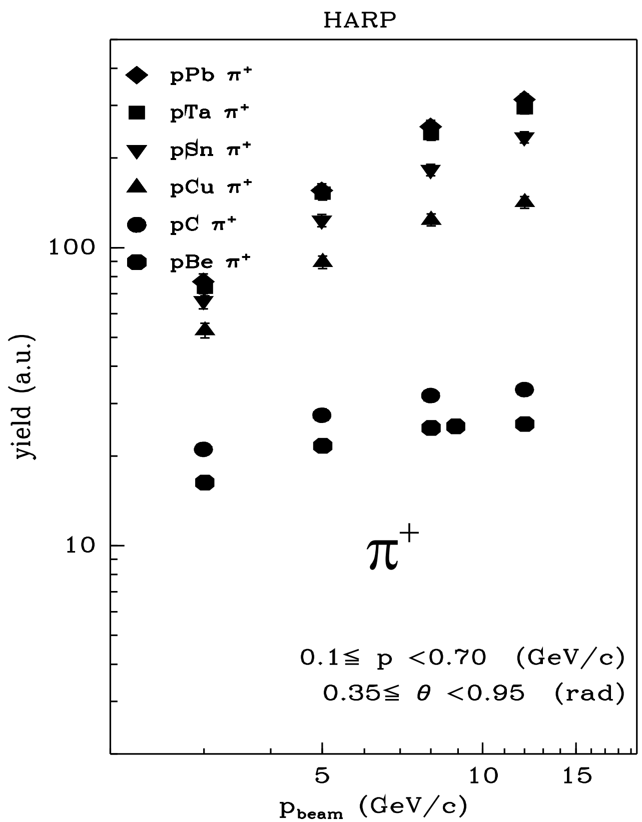


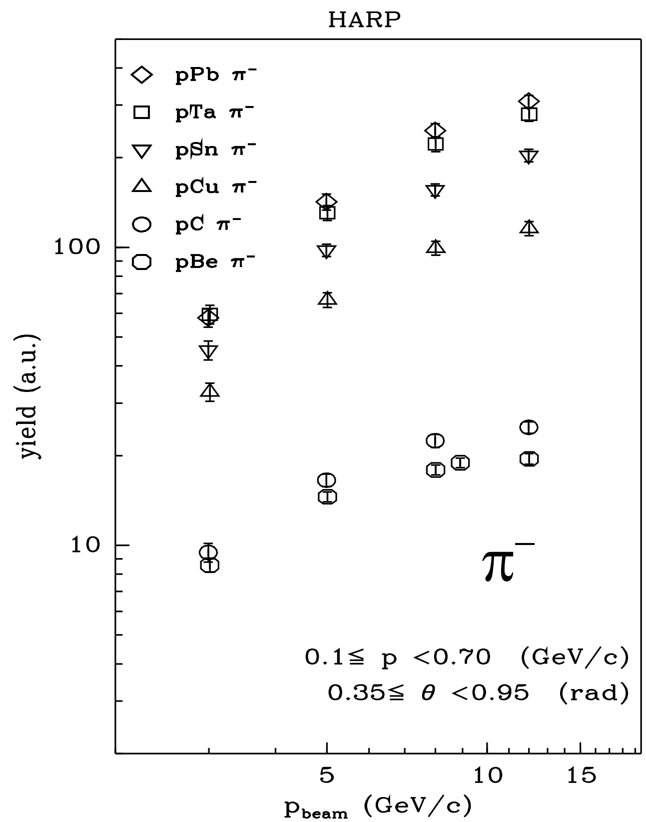


Pion yields

comparison of π^+ and π^- and yields for p-A for Be, C, Cu, Sn, Ta and Pb

forward production only $0.35 < \theta <$ **0.95** rad

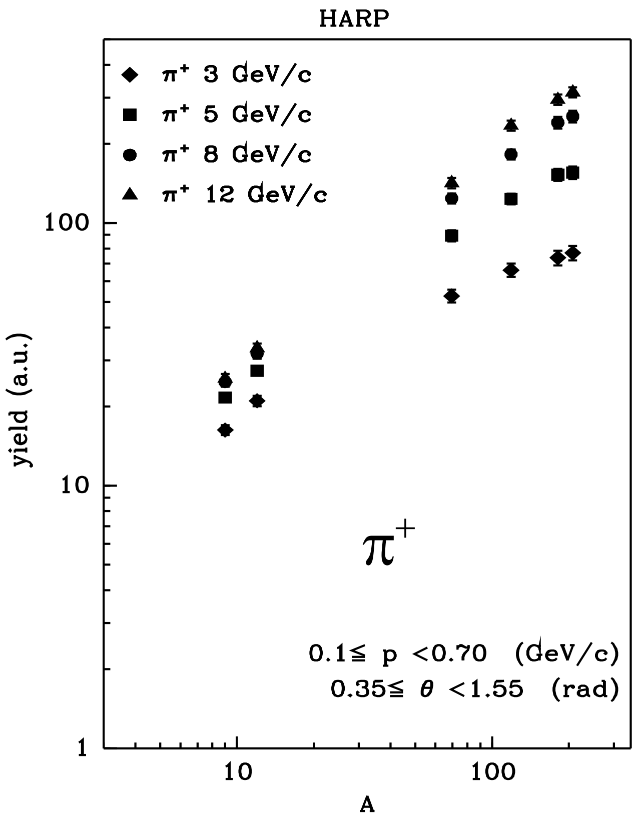


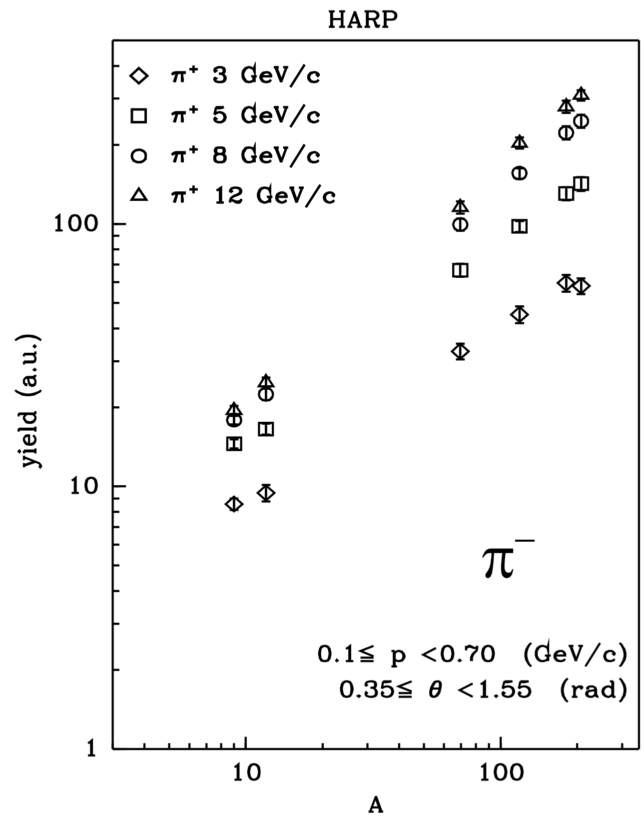


Pion yields

A-dependence of π^+ and π^- and yields for p-A
for Be, C, Cu, Sn, Ta and Pb (3, 5, 8, 12 GeV/c)

forward production only 0.35 < θ < 1.**55** rad





Summary

Results for K2K have been published.

Results for MiniBooNE are ready. These measurements are already being used by MiniBooNE.

Tantalum results for the Neutrino Factory studies are ready (Pb coming).

Carbon data for atmospheric neutrino fluxes are available (N2, O2 coming).

More production cross-section measurements are basically finished and can be used to understand hadron production models.

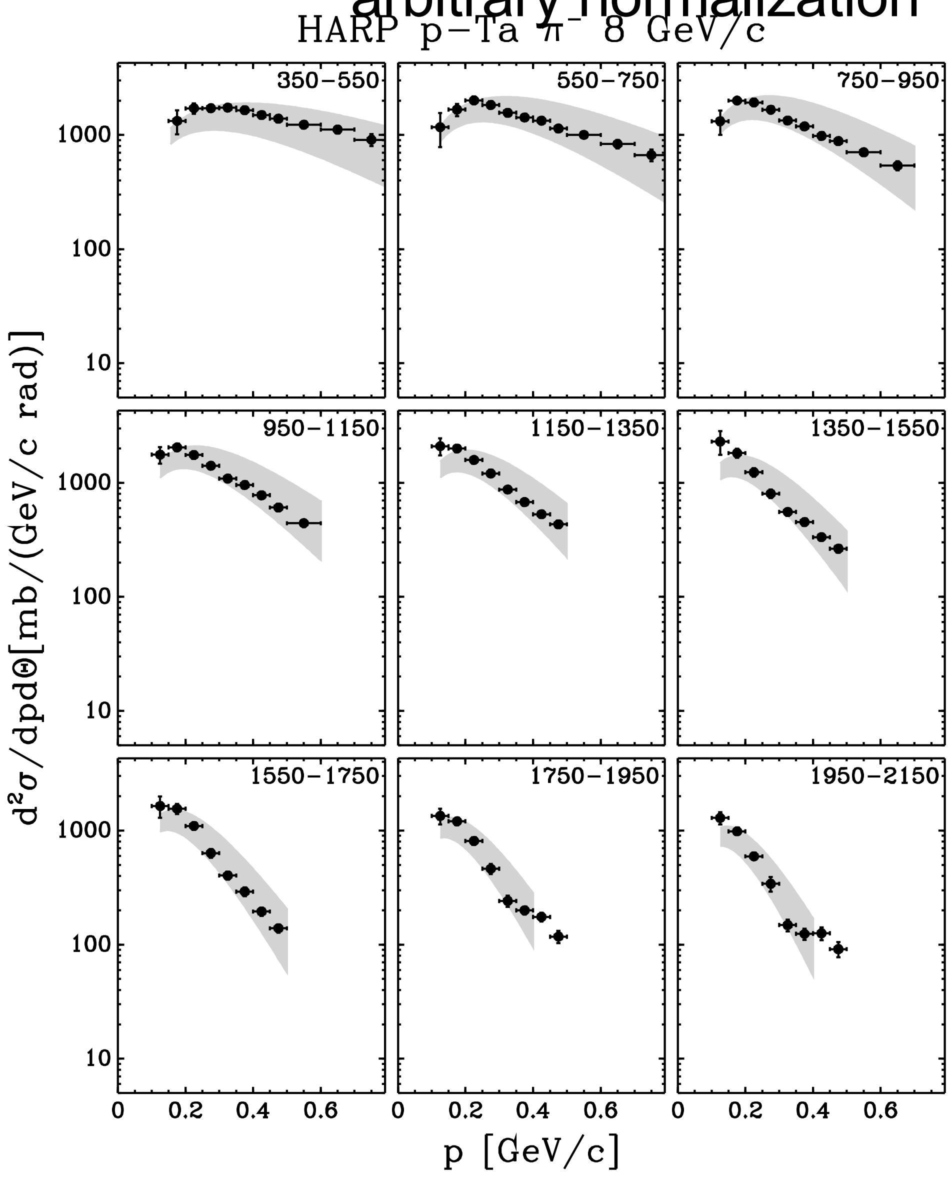
To get all data out, still a large number of data sets need day-to-day calibrations. The detector is well understood and the analysis techniques established.

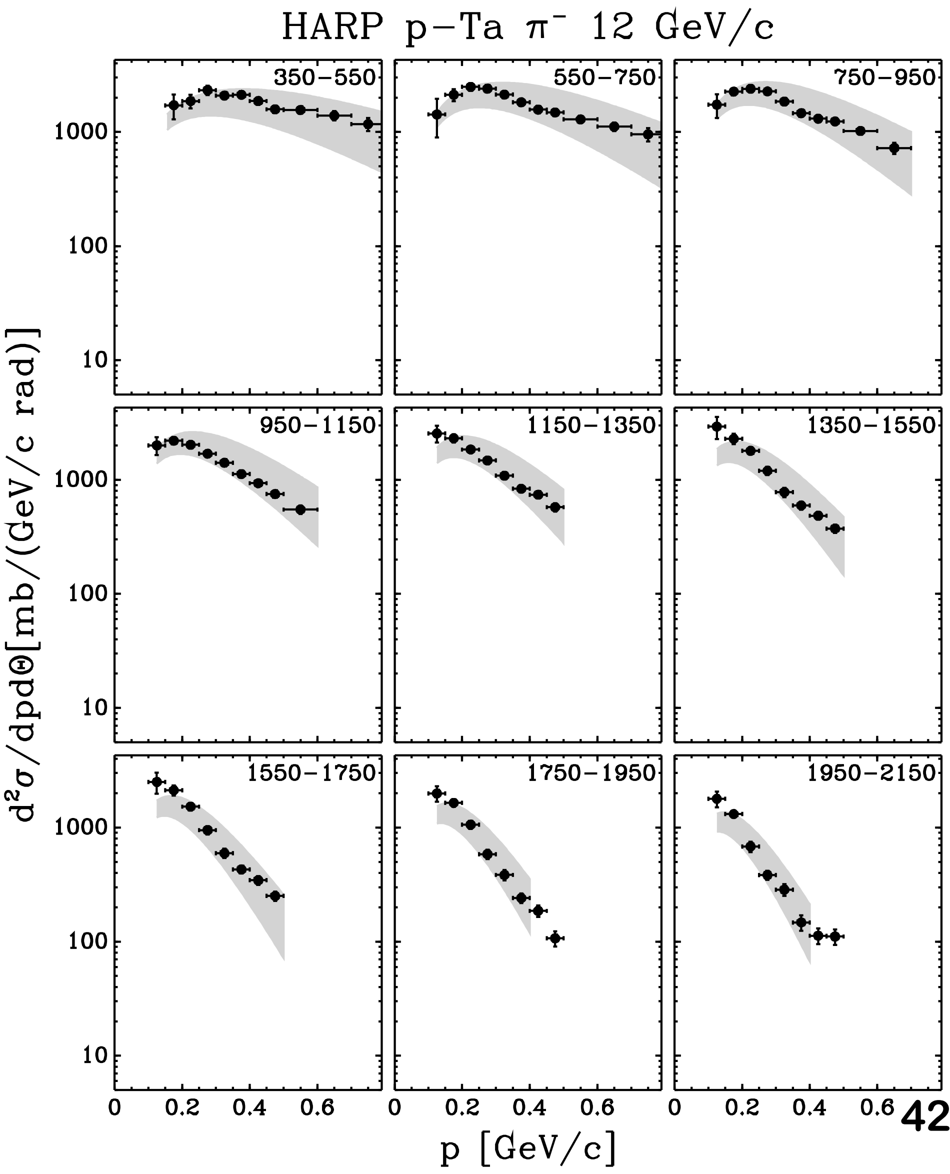
I would like to thank the organisers for their generous support

backup slides

p-Ta

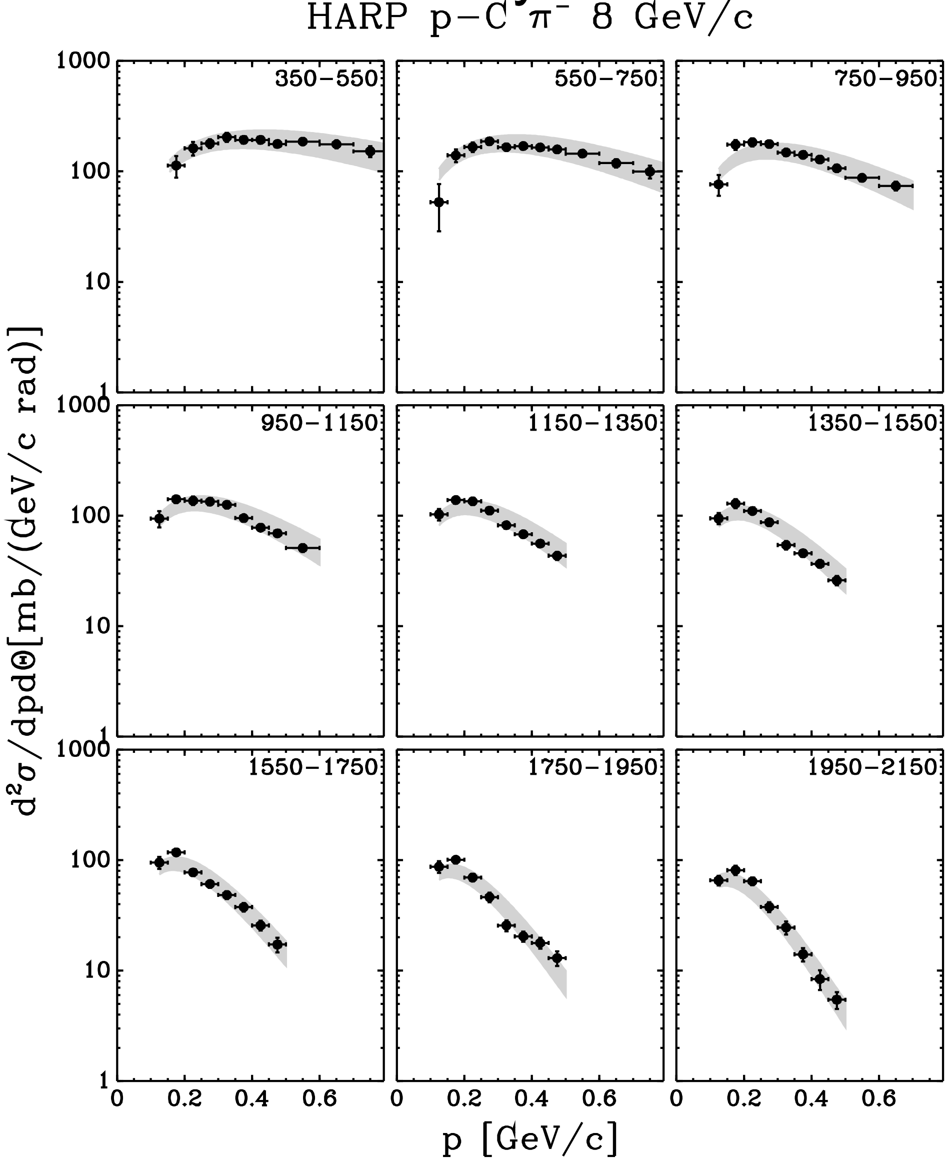
comparison with JINR 10 GeV/c data (bubble chamber), arbitrary normalization

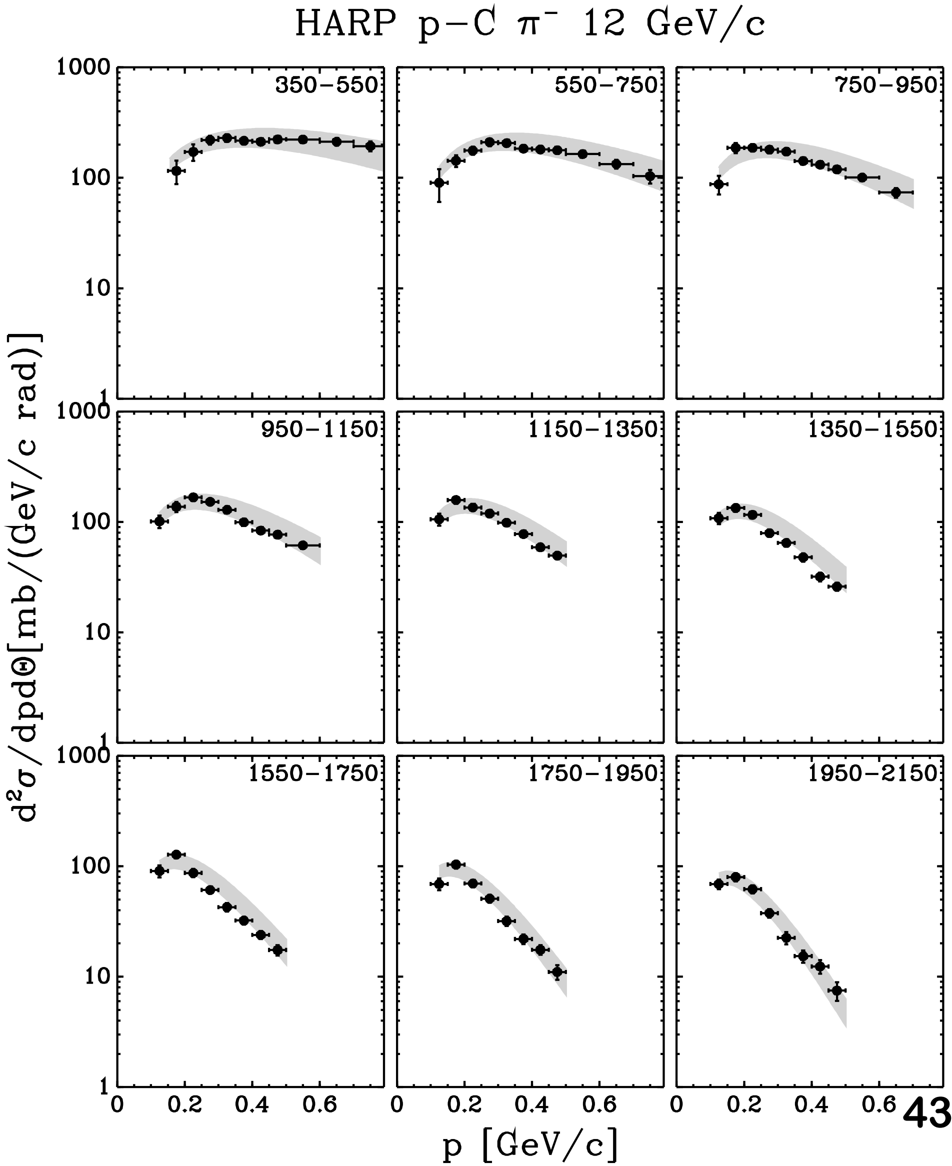




p-C

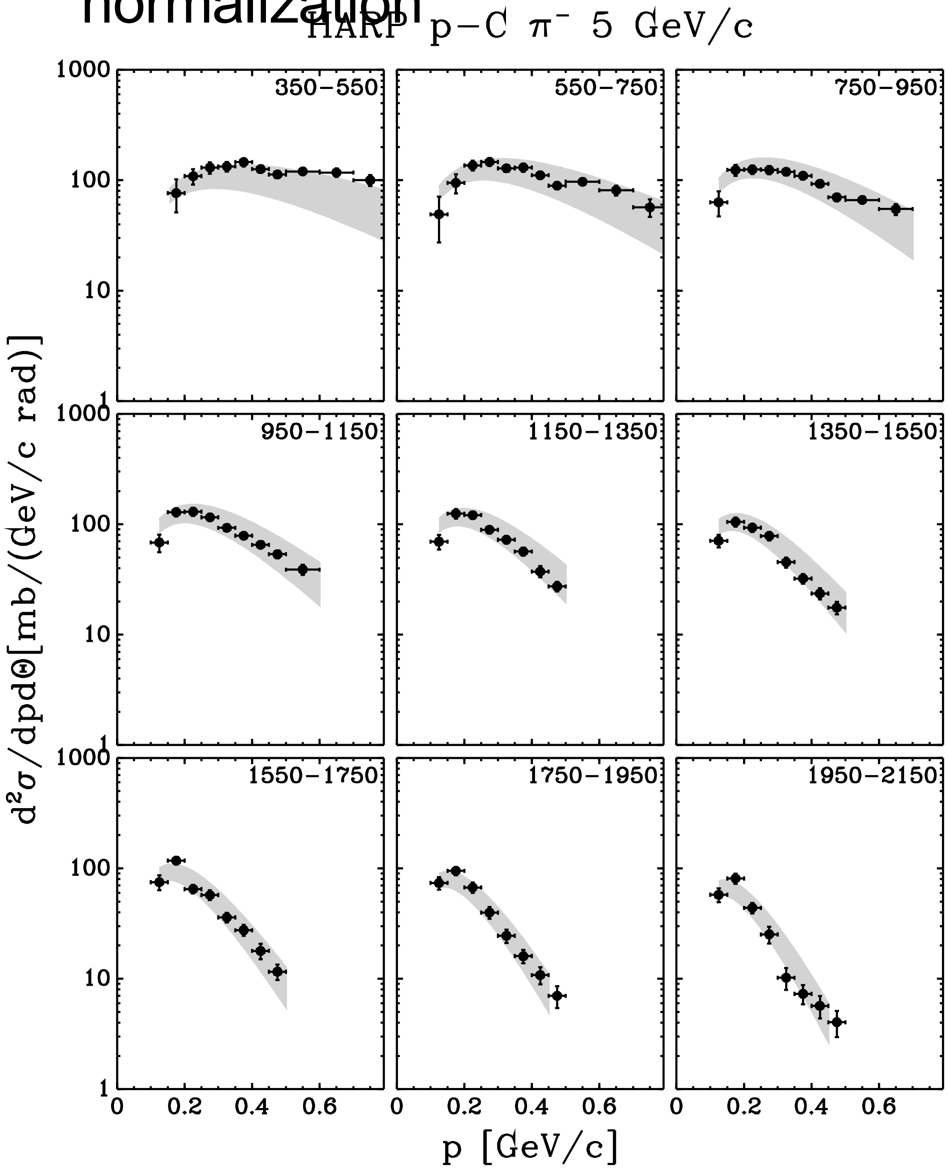
comparison with JINR 10 GeV/c data (bubble chamber), arbitrary normalization





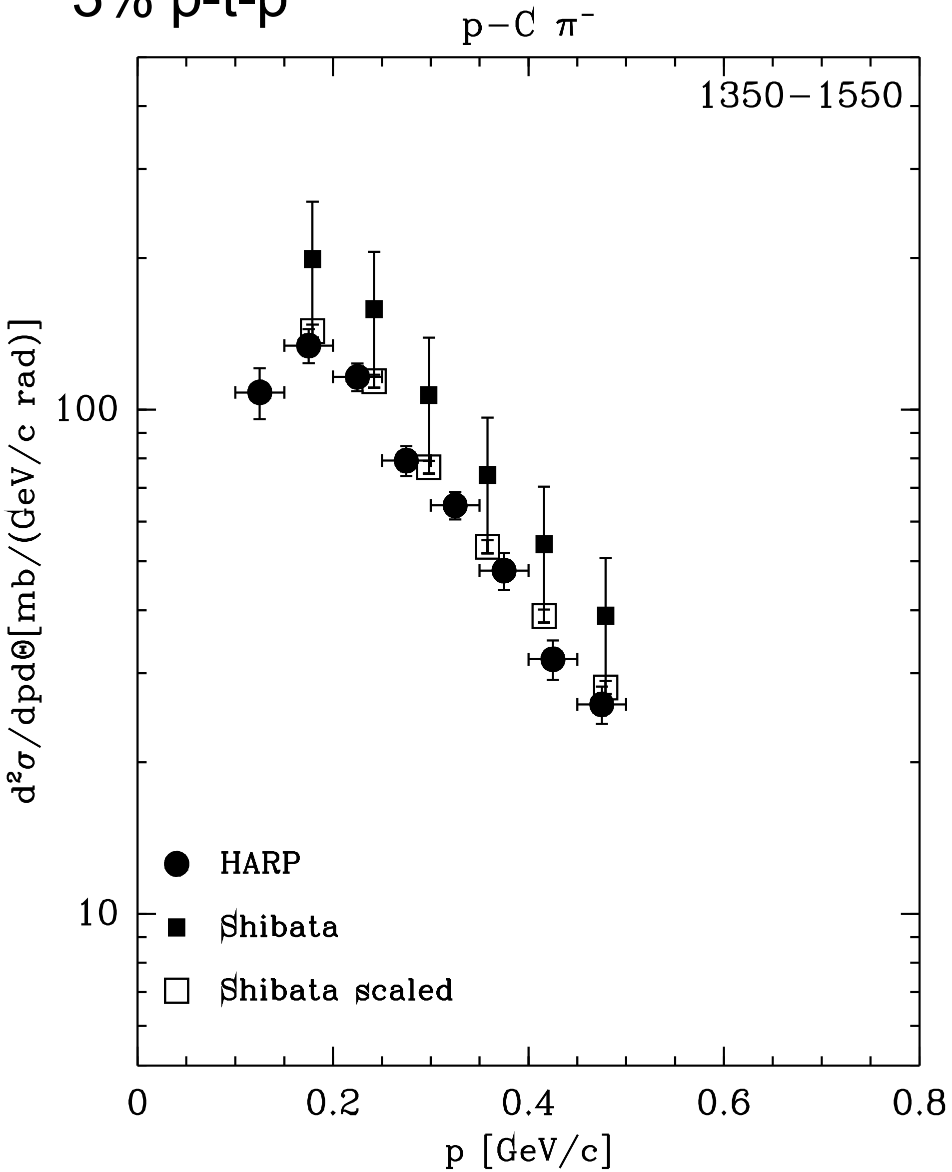
p-C

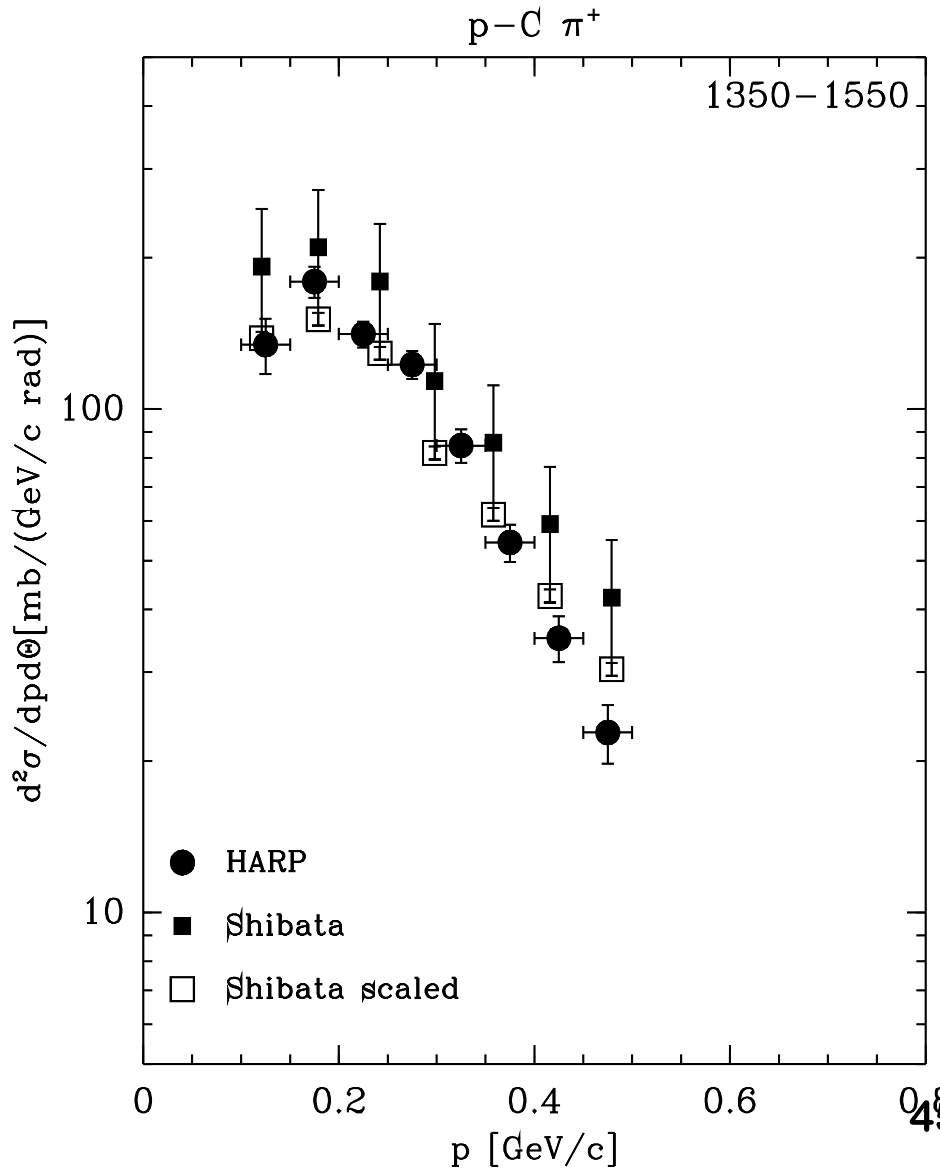
with JINR 4.2 GeV/c data (bubble chamber), arbitrary normalization



p-C

Shibata 12 GeV/c (magnetic spectrometer), 30% acceptance uncertainty, 3% p-t-p





p-Cu

Shibata 12 GeV/c (magnetic spectrometer), 30% acceptance uncertainty, 3% p-t-p