HARP and NA61 (SHINE) hadron production experiments

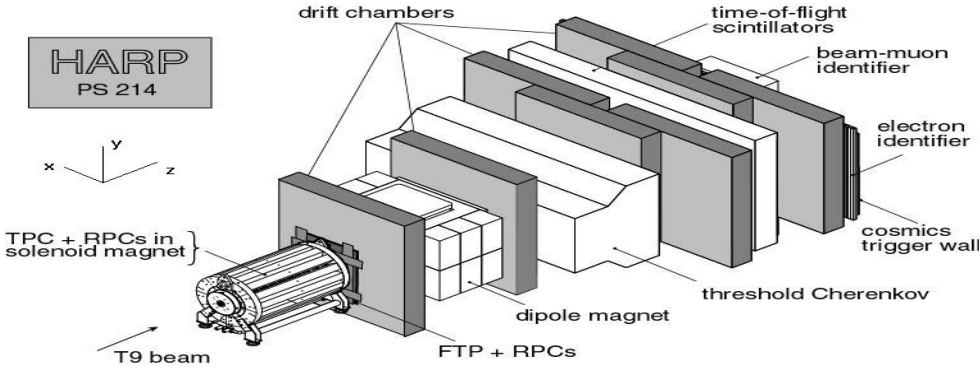
and their implications for neutrino physics

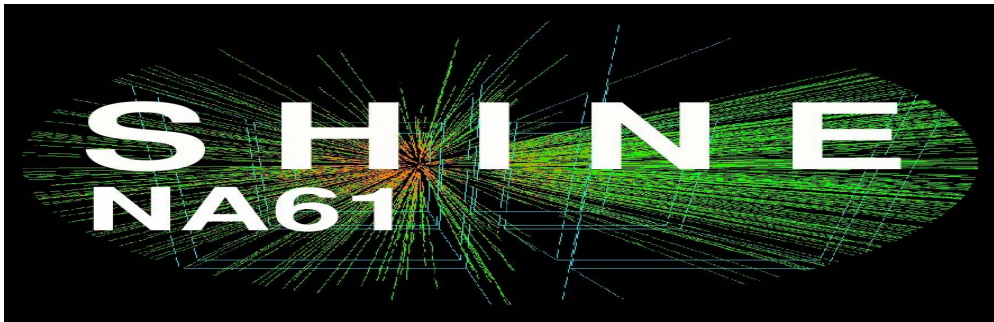
VIth International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region

May,18-22 2009, Sitjes, Barcelona, Spain

Boris A. Popov (LPNHE, Paris & JINR, Dubna) for the HARP and NA61 Collaborations

- HARP experiment
- Physics goals
- Results and Impacts
- NA61 experiment
- Status and plans
- Summary





HARP – PS214 at CERN

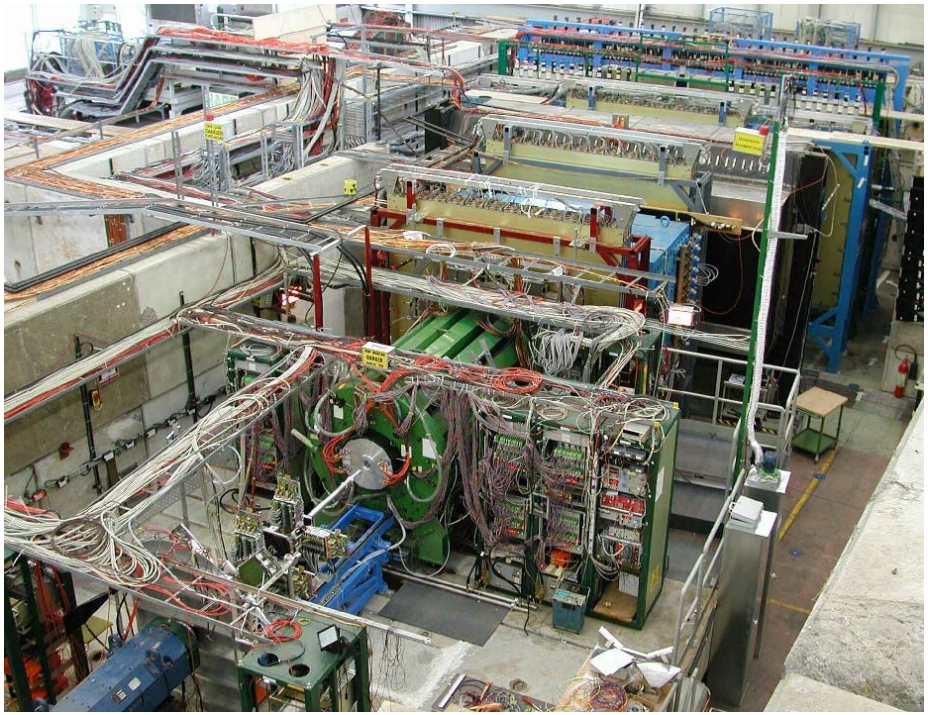
HARP is a large acceptance spectrometer to measure hadron production from various nuclear targets and a range of incident beam momenta

- Nuclear target materials : A = 1 – 200
- Nuclear target thickness : λ = 2 – 100 %
- Beam particles : h = p, π^{+-},e^{+-}
- Beam momenta : p_{beam} = 1.5 – 15 GeV/c
- Secondaries measured : h = p, π^{+-},K^{+-}
- Kinematic acceptance

p = 0.5 – 8.0 GeV/c θ = 25 – 250 mrad (forward)

p = 0.1 – 0.8 GeV/c θ = 350 – 2150 mrad (large angle)

forward spectrometer



large angle spectrometer

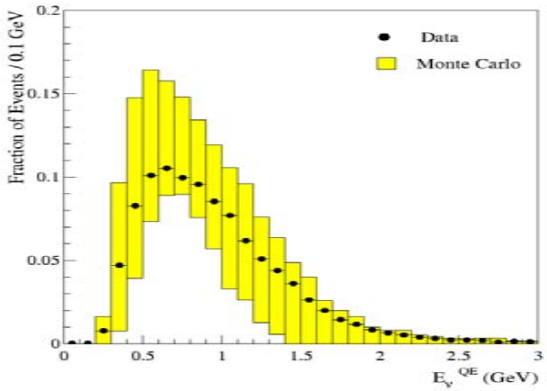
Data taking in 2001-2002

hadron production measurements in "*seven dimensions*"

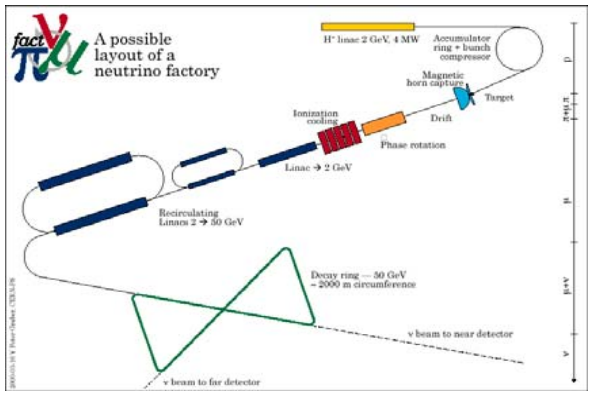
Detailed description of the experimental apparatus

NIM A571 (2007) 524

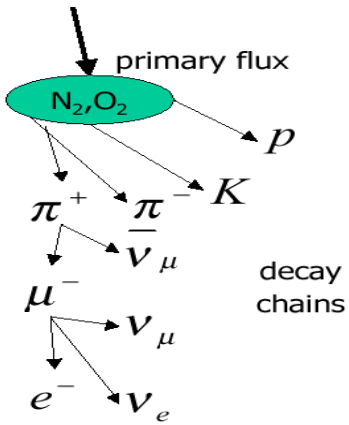
HARP physics goals



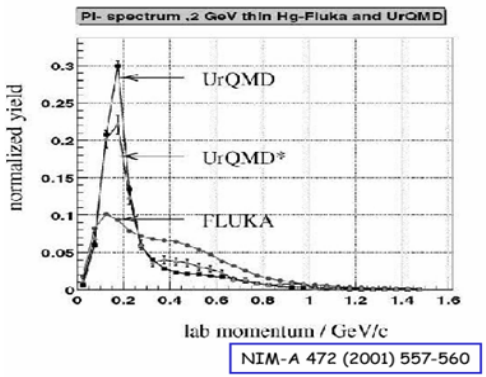
Input for prediction of neutrino fluxes for the **K2K** and **MiniBooNE / SciBooNE** accelerator experiments



Pion/Kaon yield for the design of the proton driver and target system of **Neutrino Factories** and **Super-Beams**



Input for precise calculation of the **atmospheric neutrino** flux (from yields of secondary π,K)

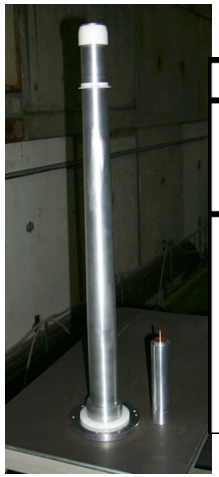


Input for **Monte Carlo** generators (GEANT4 and others)

HARP: Data taking summary

HARP took data at the CERN PS T9 beamline in 2001-2002

Total: 420 M events, ~300 settings



SOLID:

Be	C	Al	Cu	Sn	Ta	Pb	H_2O	Empty
2% 5% 100%	2% 5% 100%	2% 5% 100%	2% 5% 100%	2% 5% 100%	2% 5% 100%	2% 5% 100%	10% 100%	0%
+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+1.5, +3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+1.5, +3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+1.5,+8 GeV/c	+1.5, +3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c

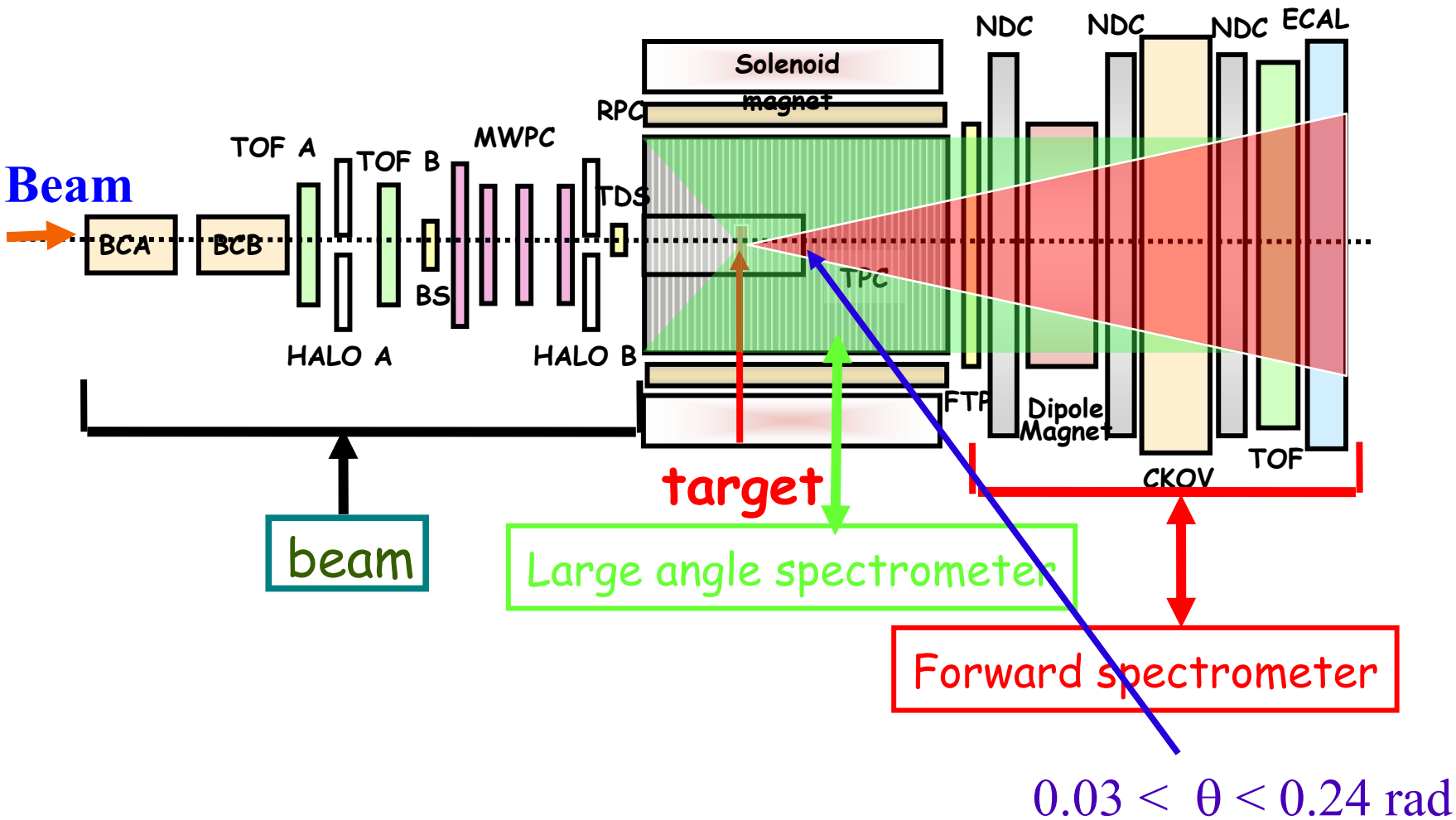
CRYOGENIC:

H	D	N	O	Empty
0.8% 2.4%	2.1%	5.5%	7.5%	0%
+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c	+3,+5,+8, +12,+15 -3,-5,-8, -12,-15 GeV/c

ν EXP

K2K: Al	MiniBooNE: Be	LSND: H_2O
5% 50% 100% Replica	5% 50% 100% Replica	10% 100%
+12.9 GeV/c	+8.9 GeV/c	+1.5 GeV/c

HARP: Analyses with the forward spectrometer



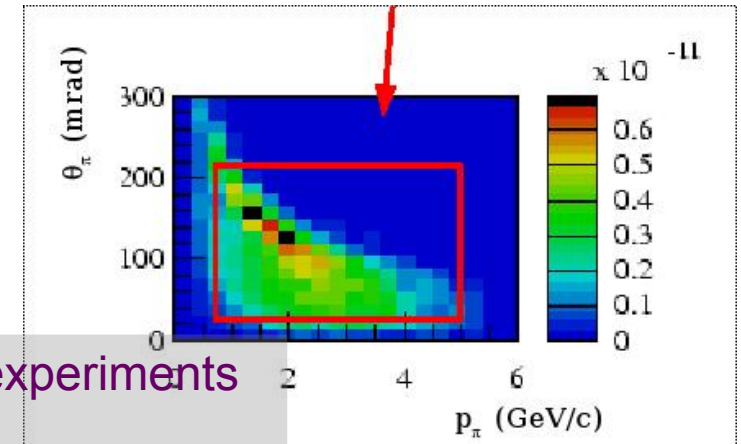
HARP: Analyses with the forward spectrometer

Neutrino Oscillation Experiments at Accelerators

Neutrino fluxes of conventional accelerator neutrino beams *are not known accurately.*

measure 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:*



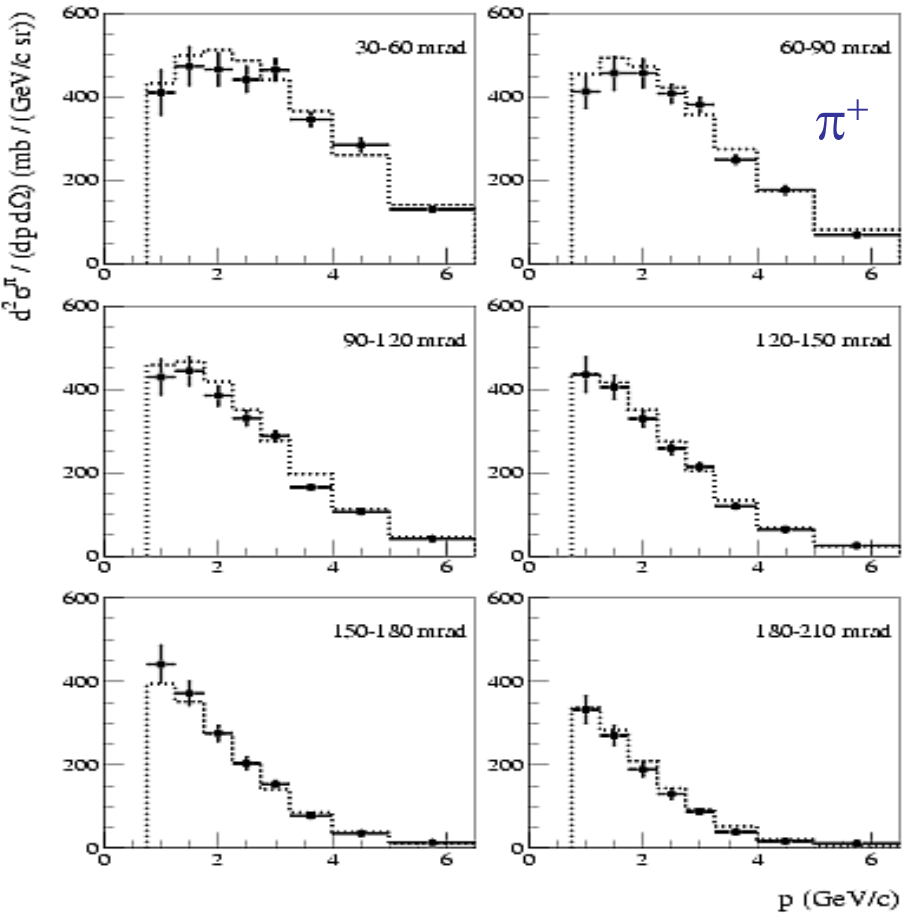
Momentum and Angular distribution of pions decaying to a neutrino that passes through the MB detector.

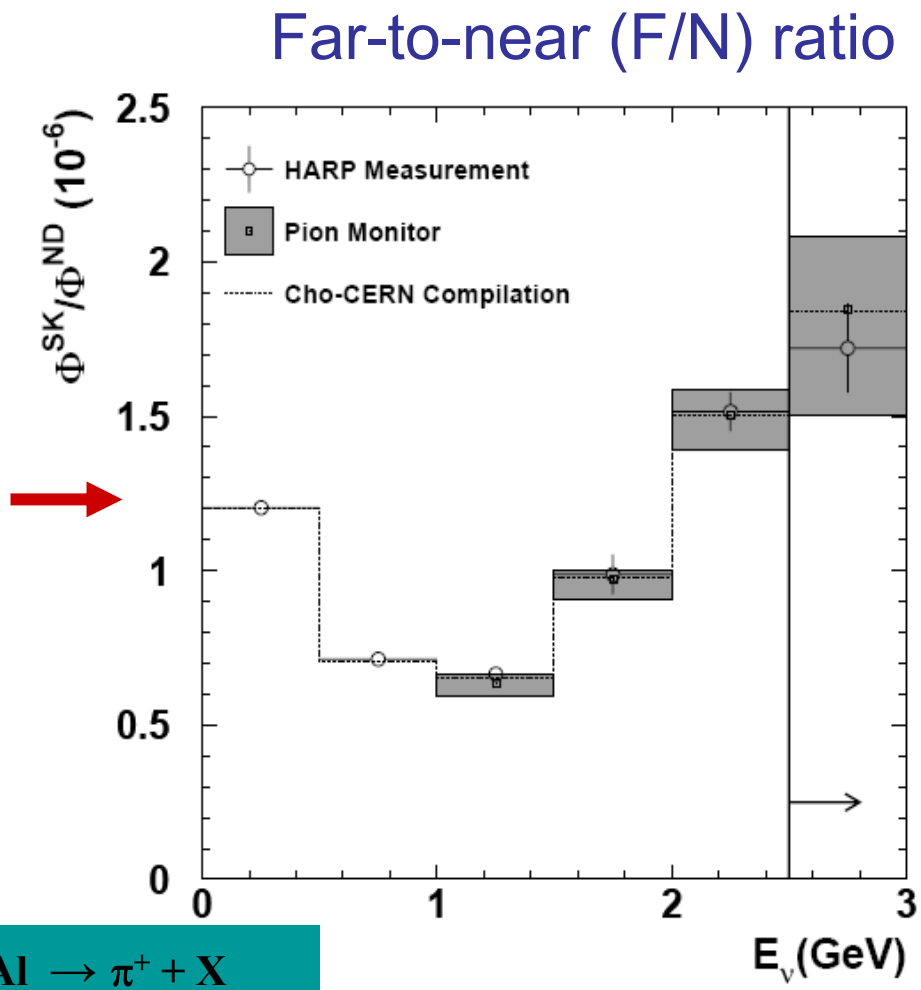
Removes *major* source of uncertainties for these experiments

(in collaboration with *K2K* and *MiniBooNE*)

HARP p-Al data 12.9 GeV/c:
M. G. Catanesi et al., HARP Collaboration, Nucl. Phys. **B732** (2006) 1
K2K results, with detailed discussion of relevance of hadron production measurement:
M. H. Ahn et al., K2K Collaboration, Phys. Rev. **D74** (2006) 072003
HARP p-Be data 8.9 GeV/c:
M. G. Catanesi et al., HARP Collaboration, Eur. Phys. J. **C52** (2007) 29
MiniBooNE results with HARP input:
A. A. Aguilar-Arevalo et al., MiniBooNE Collaboration, Phys. Rev. Lett. **98** (2007) 231801

K2K Far/Near flux ratio prediction





Nucl. Phys. B732 (2006) 1

p(12.9 GeV/c) + Al $\rightarrow \pi^+ + X$

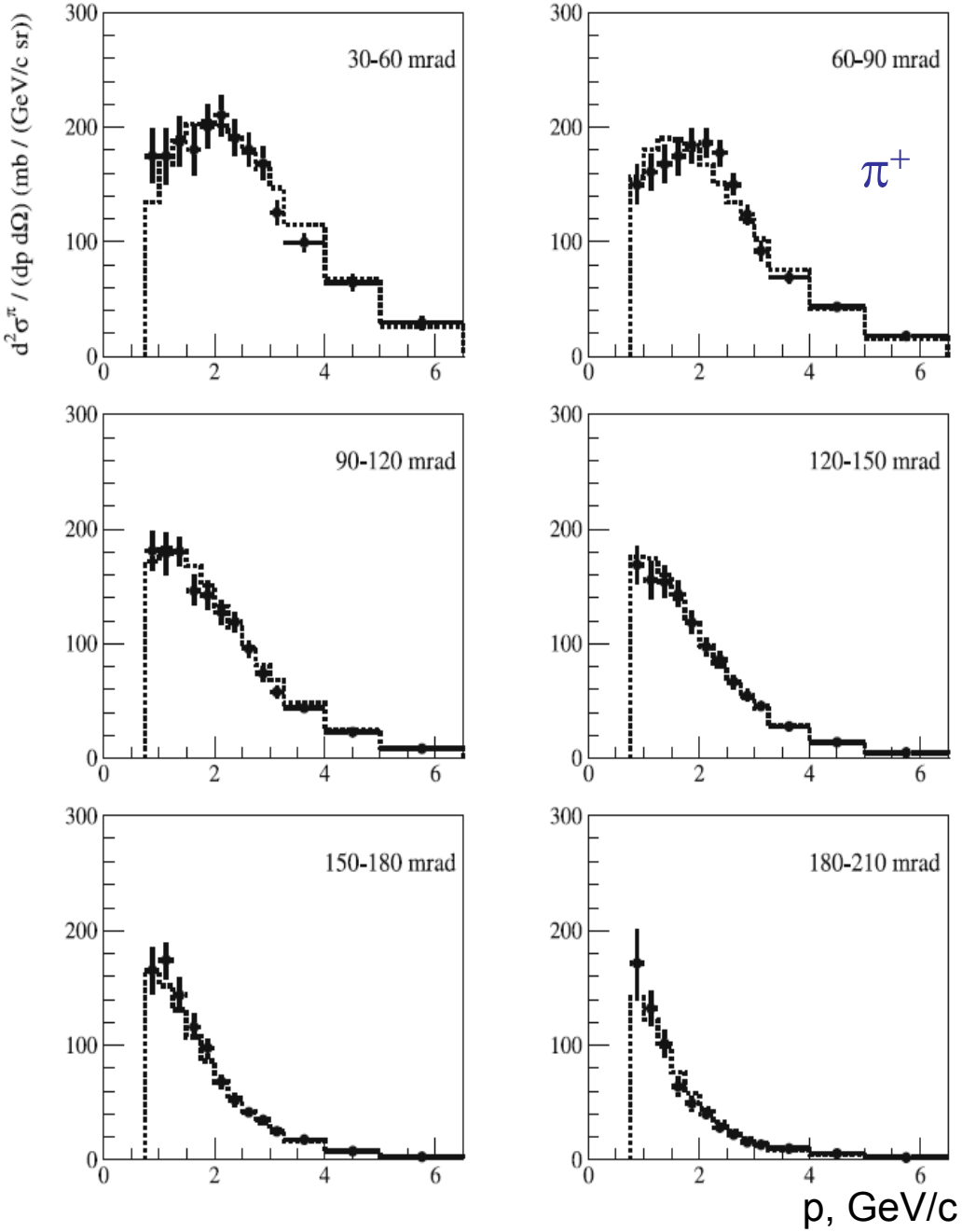
- HARP Al cross-section results have provided an important cross-check on previous K2K flux predictions. Results completely consistent in shape

HARP measurements allowed to reduce the main systematic error by a factor of 2

- F/N ratio is no longer a dominant systematic error

Phys. Rev. D74 (2006) 072003

HARP : p+Be at 8.9 GeV/c



5% λ Be target

EPJ C 52 (2007) 29

θ_π = [30, 60, 90, 120, 150, 180, 210] mrad

p_π = [0.75 – 6.5] GeV/c

typical error on point = 9.8%

error on integral = 4.9%

analysis includes significant improvements relative to Al measurement in PID and momentum resolution description

p(8.9 GeV/c) + Be → π^+ + X

An aside on the SW parameterization

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

- X : any other final state particle
- p_{beam} : proton beam momentum (GeV/c)
- p, θ : pion lab-frame momentum (GeV/c) and angle (rad)
- c_1,..., c_8 : empirical fit parameters

Parameter	Value
c_1	$(8.22 \pm 1.98) \cdot 10^1$
c_2	(6.47 ± 1.62)
c_3	$(9.06 \pm 2.03) \cdot 10^1$
$c_4 = c_5$	$(7.44 \pm 2.30) \cdot 10^{-2}$
c_6	(5.09 ± 0.49)
c_7	$(1.87 \pm 0.53) \cdot 10^{-1}$
c_8	$(4.28 \pm 1.36) \cdot 10^1$

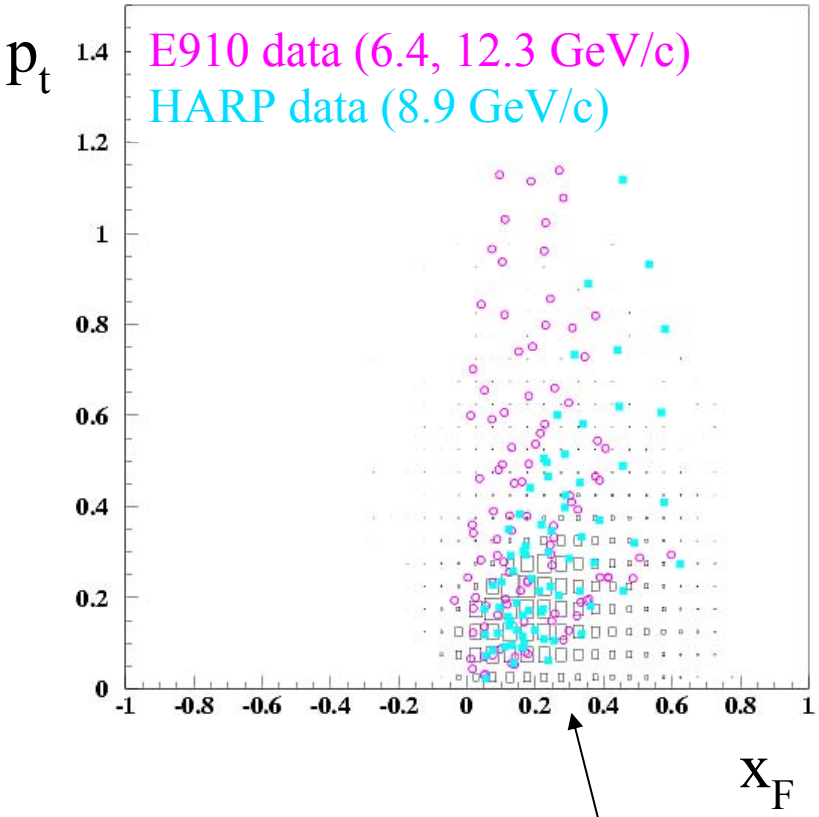
Parameter	c_1	c_2	c_3	$c_4 = c_5$	c_6	c_7	c_8
c_1	1.000						
c_2	0.327	1.000					
c_3	0.986	0.482	1.000				
$c_4 = c_5$	-0.559	0.596	-0.411	1.000			
c_6	0.091	-0.467	-0.006	-0.545	1.000		
c_7	0.011	-0.101	-0.004	-0.129	0.234	1.000	
c_8	-0.080	0.411	0.006	0.471	-0.776	0.215	1.000

HARP measurements for p+Be at 8.9 GeV/c

J. R. Sanford and C. L. Wang "Empirical formulas for particle production in p-Be collisions between 10 and 35 BeV/c", Brookhaven National Laboratory, AGS internal report, (1967) (*unpublished)*

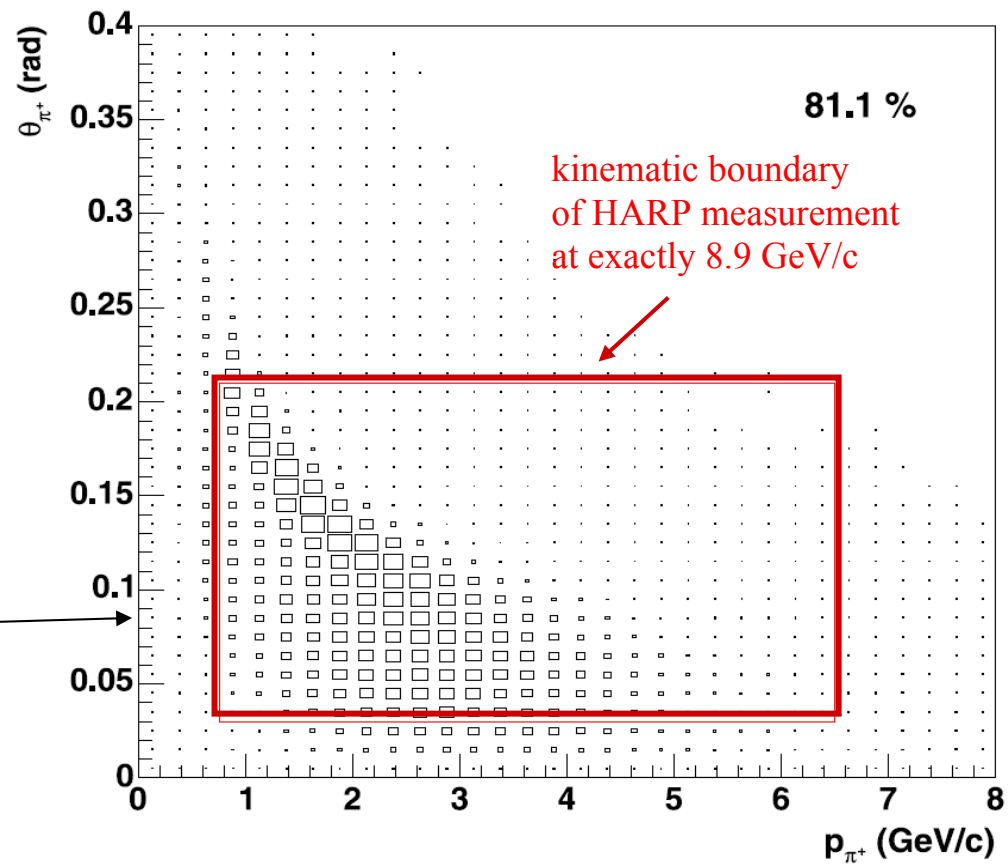
EPJ C 52 (2007) 29

MiniBooNE ν_μ flux prediction



- combining **HARP** and **E910** data gives maximal coverage of the relevant pion phase space for **MiniBooNE**

- Use the parameterization of Sanford and Wang and fit to both data sets combined



- black boxes are the distribution of π^+ which decay to a ν_μ that **passes through the MiniBooNE detector**

$p(8.9\ \mathrm{GeV/c}) + \mathrm{Be} \rightarrow \pi^+ \rightarrow \nu_\mu^{MB}$

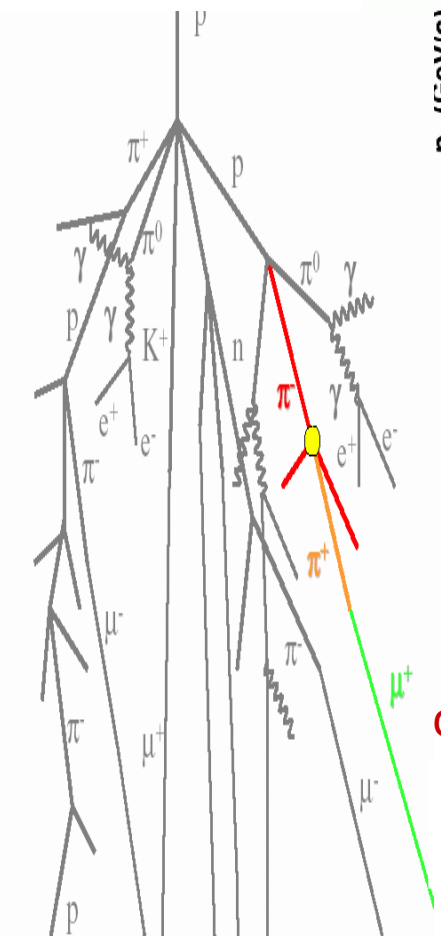
HARP Be measurements were used for the neutrino flux prediction in MiniBooNE

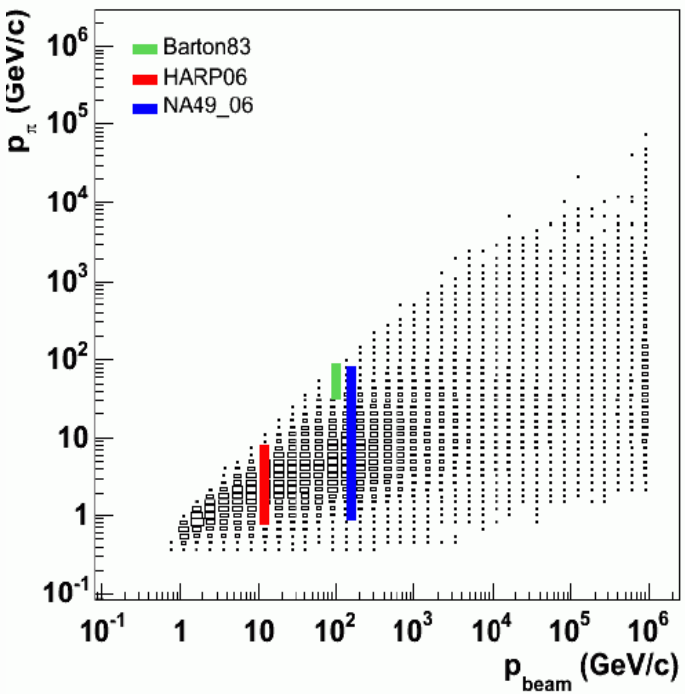
Phys. Rev. Lett. 98 (2007) 231801

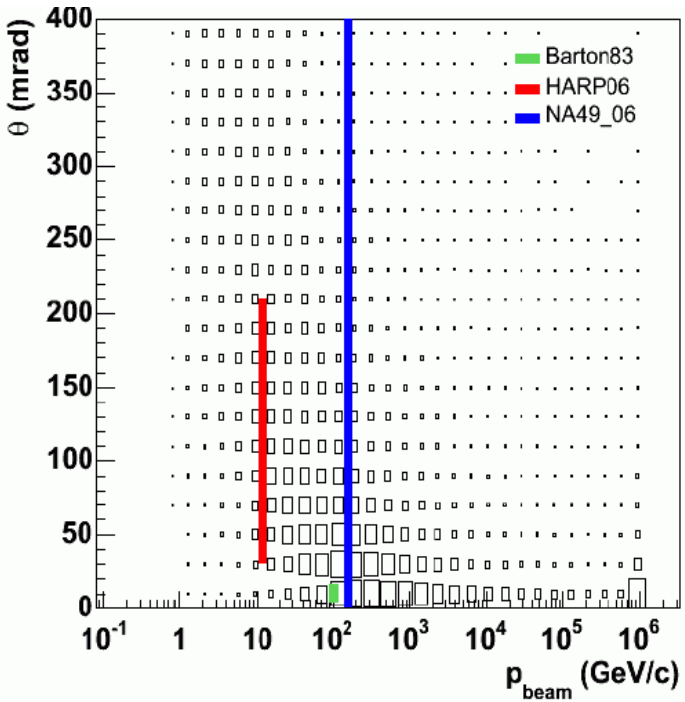
0806.1449 [hep-ex]

Atmospheric neutrino flux predictions

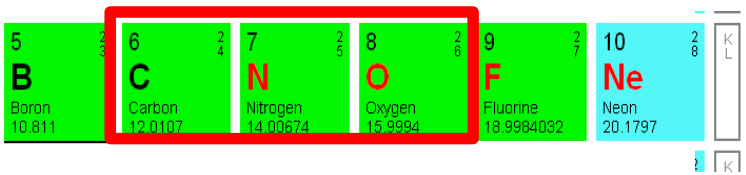
- **HARP p+C @ 12 GeV/c** data are relevant to the prediction of atmospheric neutrino fluxes and EAS simulations







carbon is isoscalar as nitrogen and oxygen

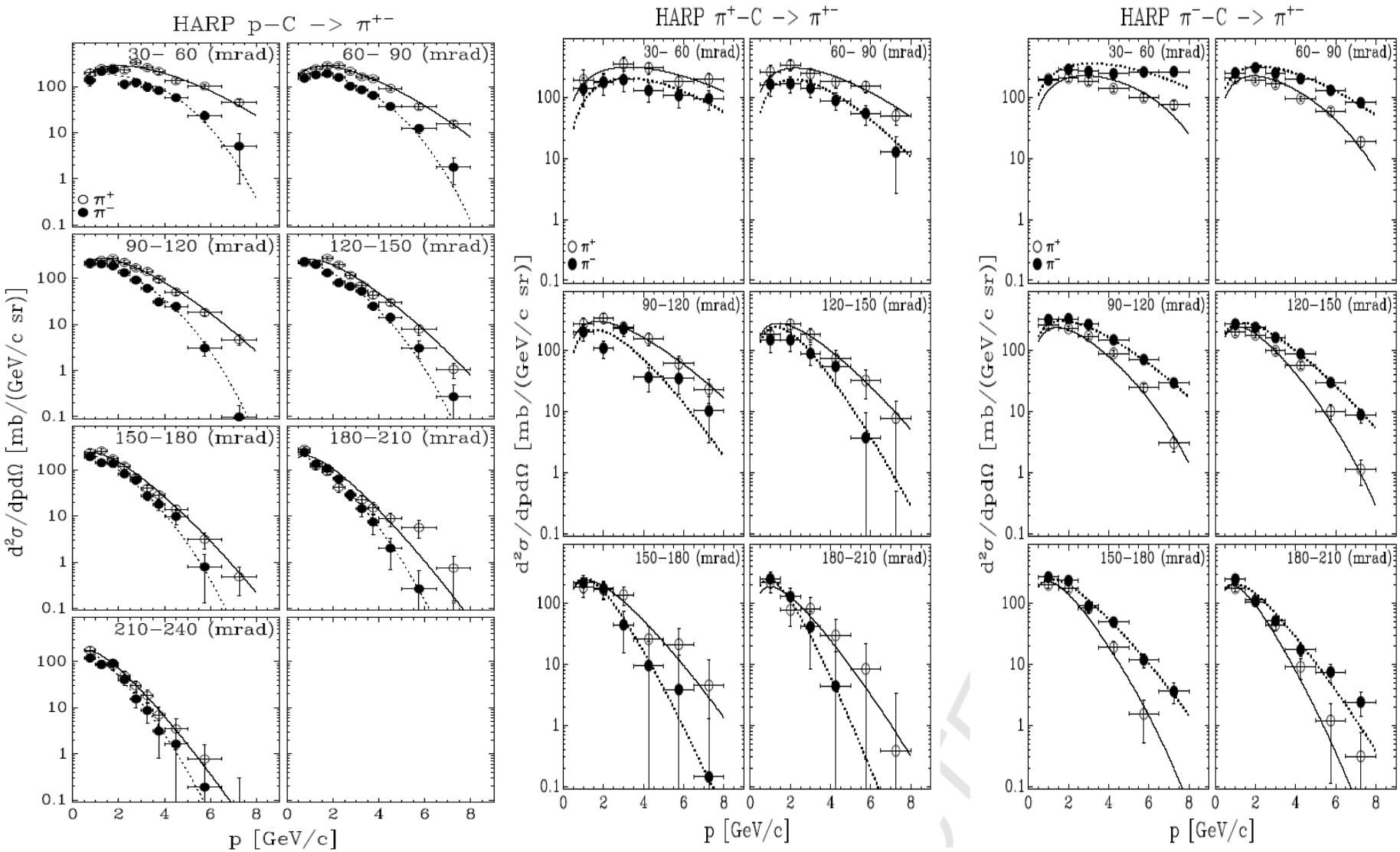


78% nitrogen

21% oxygen

Simulations predict that collisions of protons with a carbon target are very similar to proton interactions with air. This hypothesis can be tested with HARP data.

HARP : p, $\pi^{\pm}$+C at 12 GeV/c and SW parameterizations

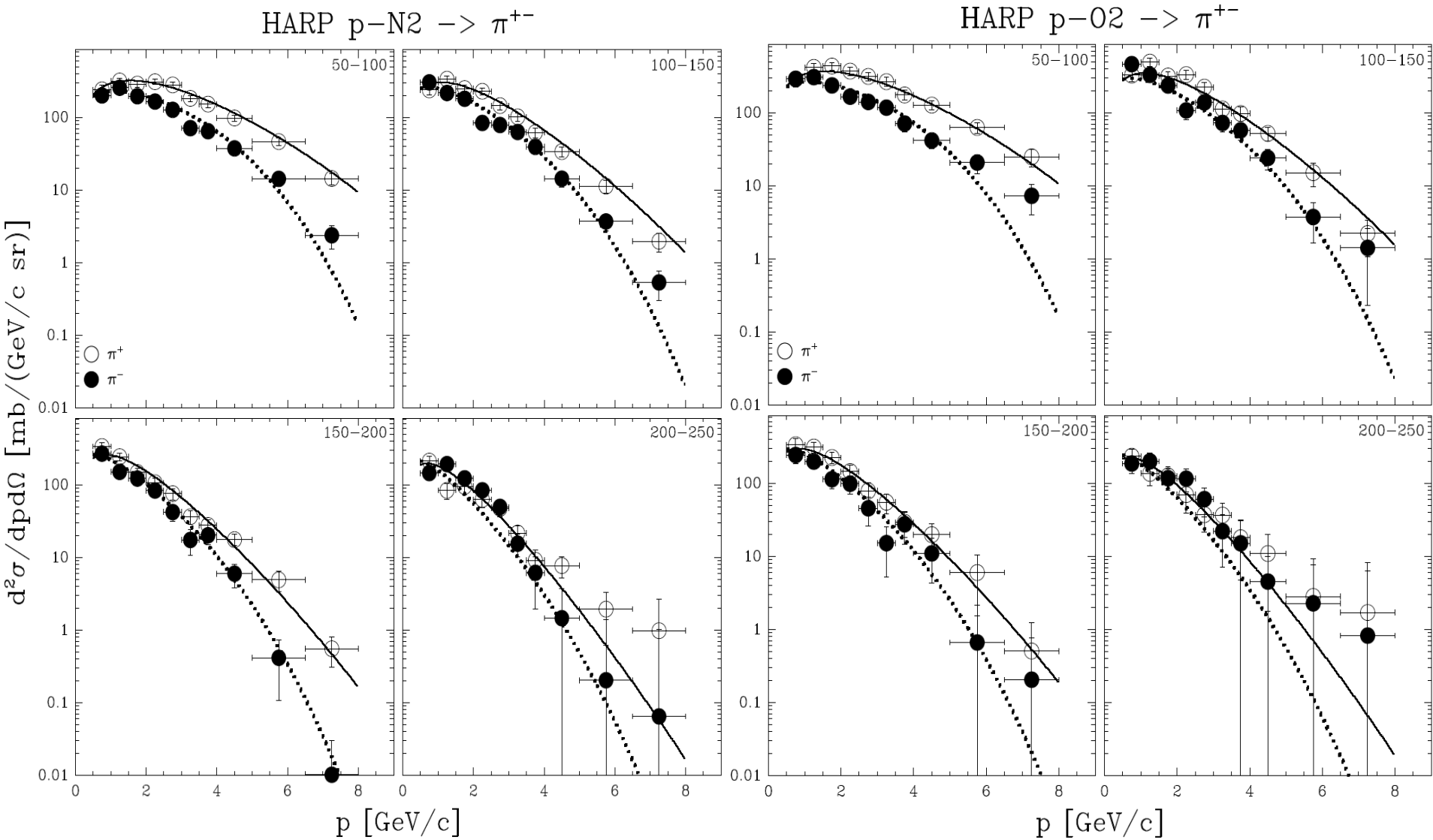


HARP p, $\pi^{\pm}$ +C @ 12 GeV/c data, SW parameterizations and comparison with models

Incoming charged pion HARP data are the first precision measurements in this kinematic region

Astropart. Phys. 29 (2008) 257

HARP : p + N_2 / O_2 @ 12 GeV/c

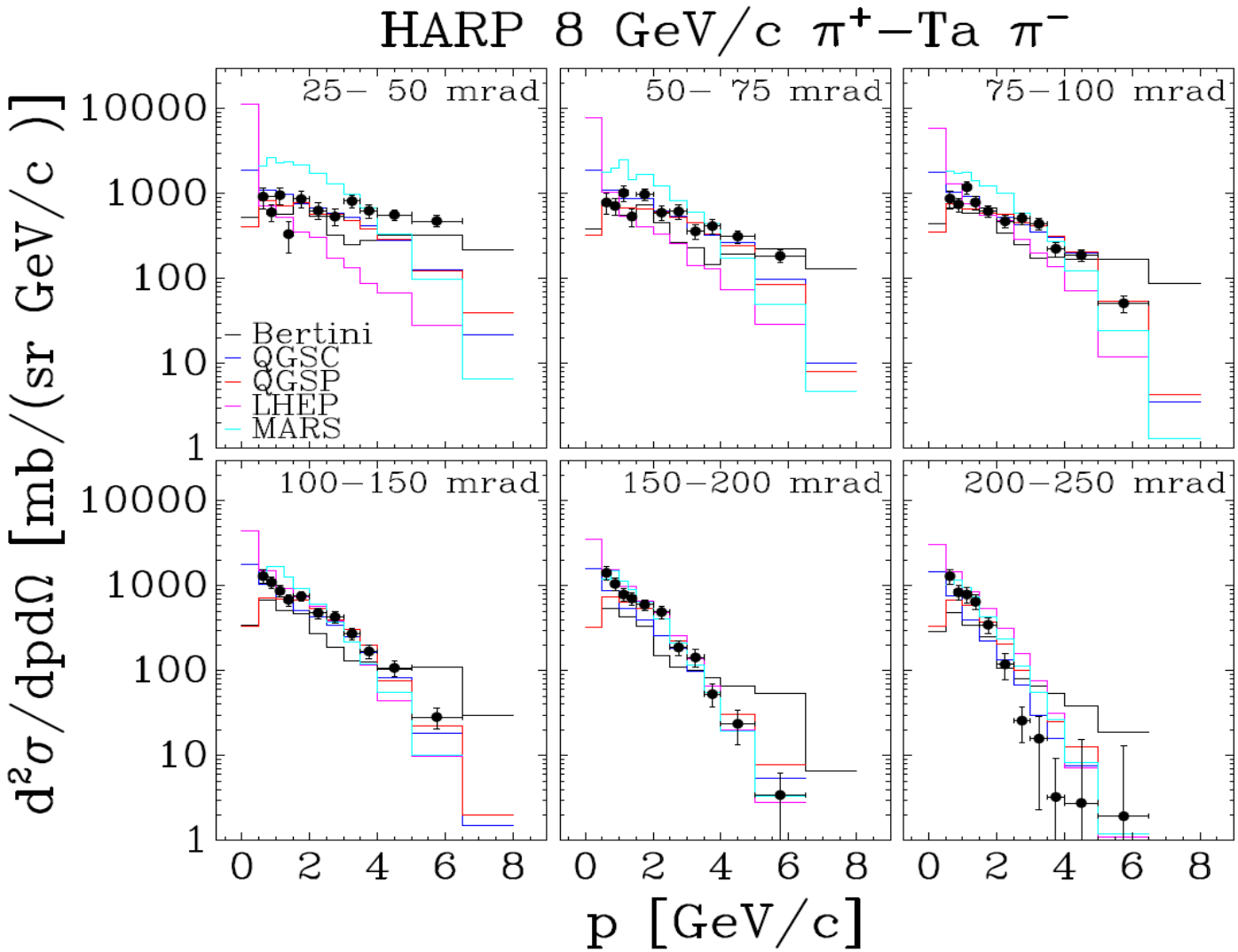


First precision measurements for N_2 and O_2 in this energy range, SW parameterizations for p-C data

HARP results confirm that p-C data can be used to predict p-N_2 and p-O_2 pion production

Astropart. Phys. 30 (2008) 124

HARP : more FW data with incident $\pi^{\pm}$



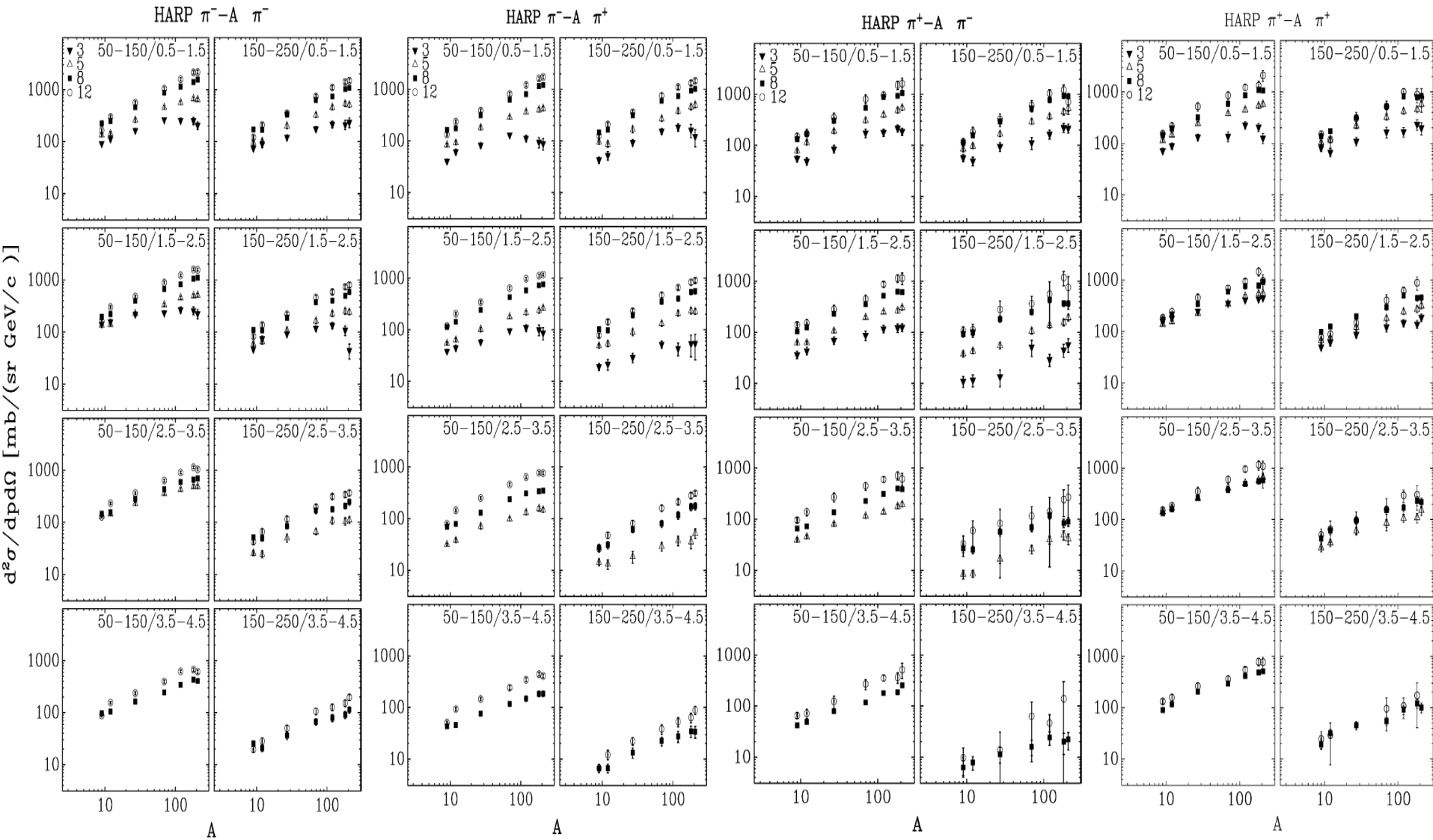
An example of more HARP data on the FW production with incident pions

Model comparisons

- All thin target FW data taken in pion beams are now published
- Interesting to tune models for re-interactions, etc.

Nucl. Phys. A 821 (2009) 118

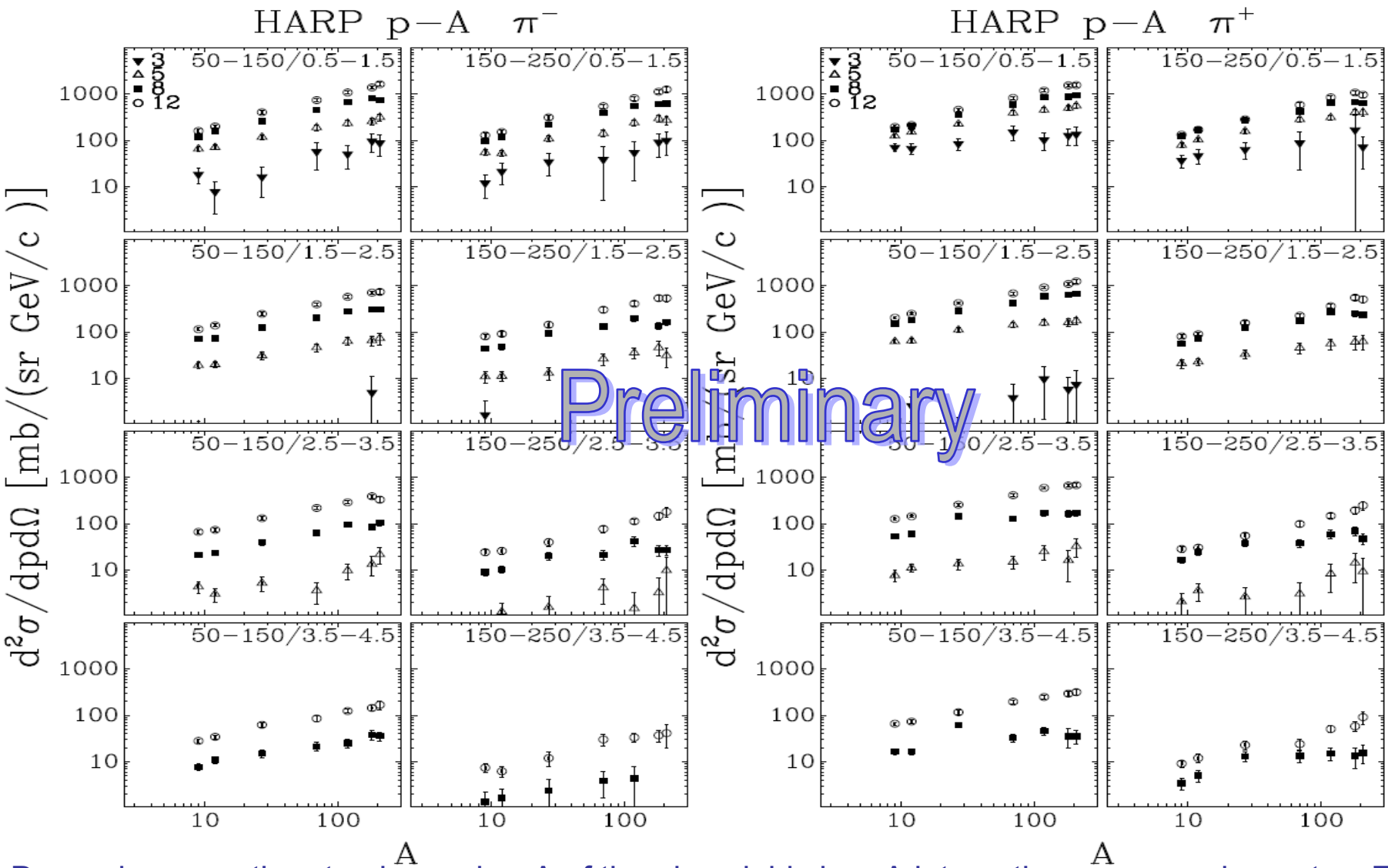
HARP : more FW data with incident pions



Dependence on the atomic number A of the pion yields in π-A interactions averaged over two FW angular regions ([50,150], [150,250] rad) and four momentum regions ([0.5-1.5], [1.5,2.5], [2.5,3.5], [3.5,4.5] GeV/c) for incoming beam momenta 3,5,8,12 GeV/c

Nucl. Phys. A 821 (2009) 118

HARP : more FW data with incident protons

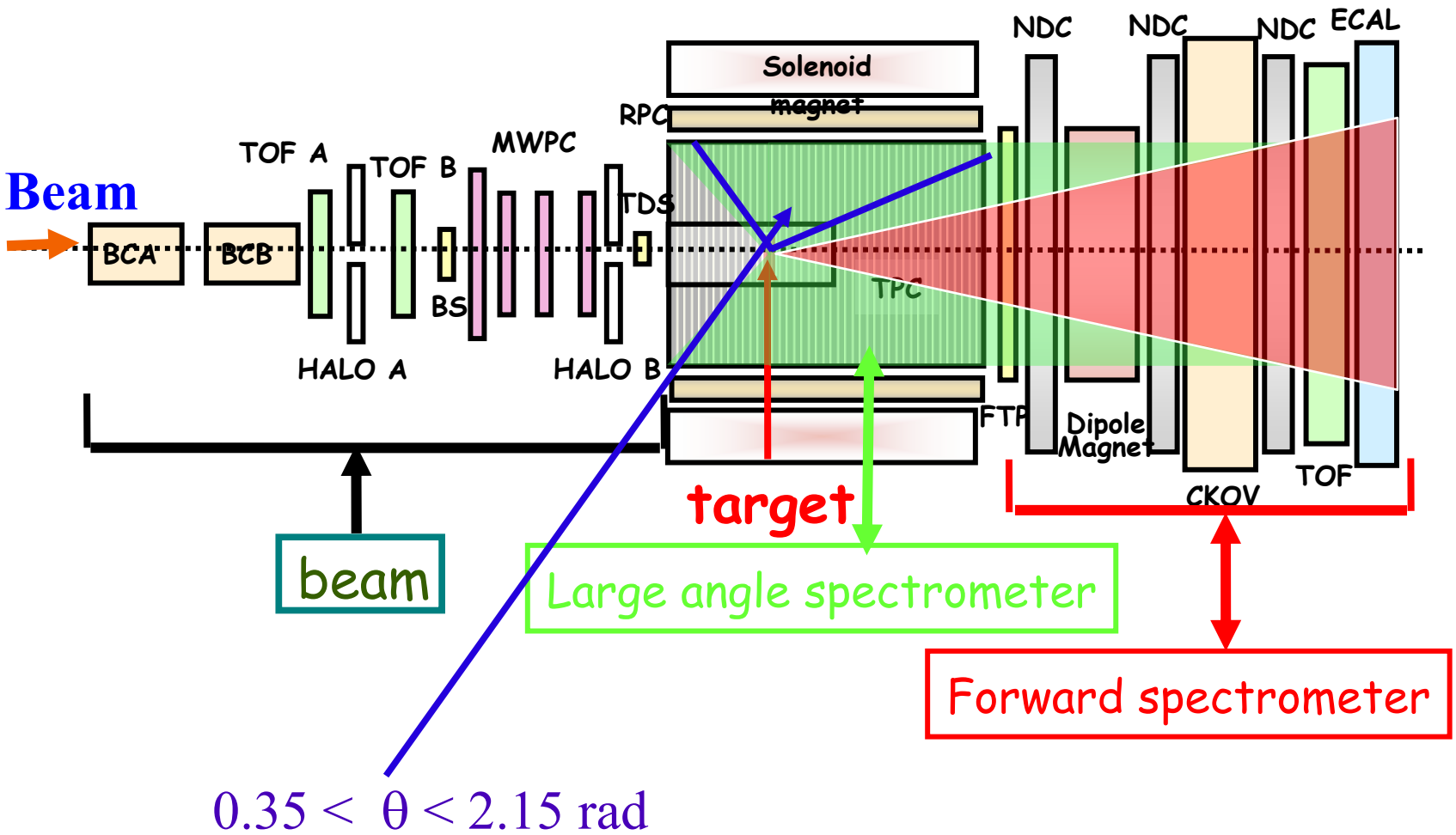


Dependence on the atomic number A of the pion yields in p-A interactions averaged over two FW angular regions ([50,150], [150,250] rad) and four momentum regions ([0.5-1.5], [1.5,2.5], [2.5,3.5], [3.5,4.5] GeV/c) for incoming beam momenta 3,5,8,12 GeV/c

Paper in preparation

HARP: Analyses with the large angle spectrometer

Large Angle (LA) spectrometer: TPC



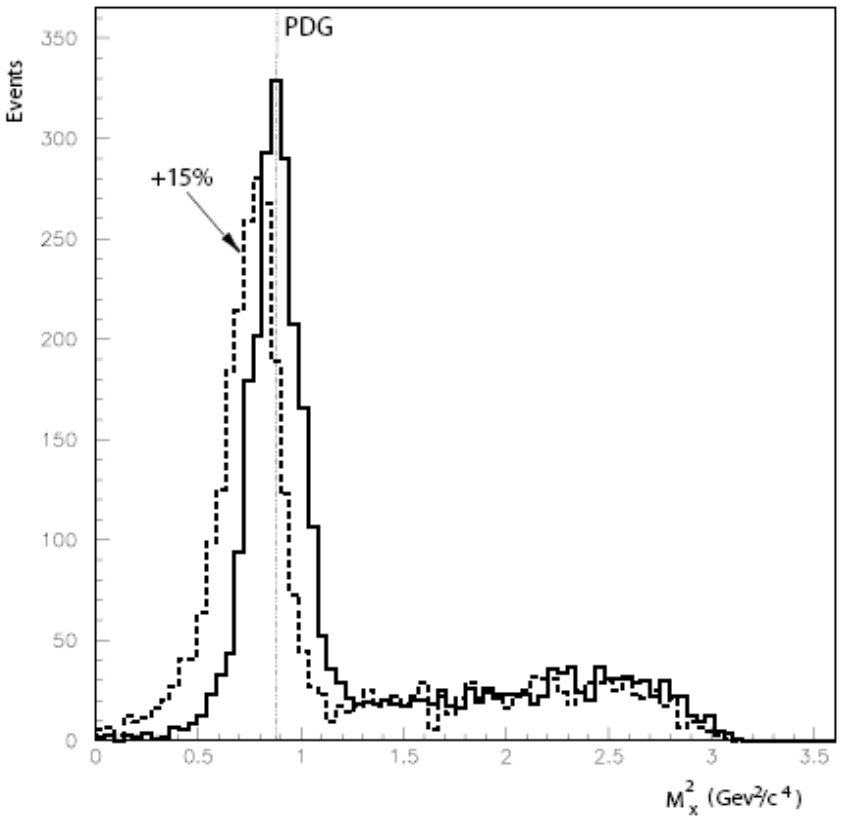
$0.35 < \theta < 2.15$ rad

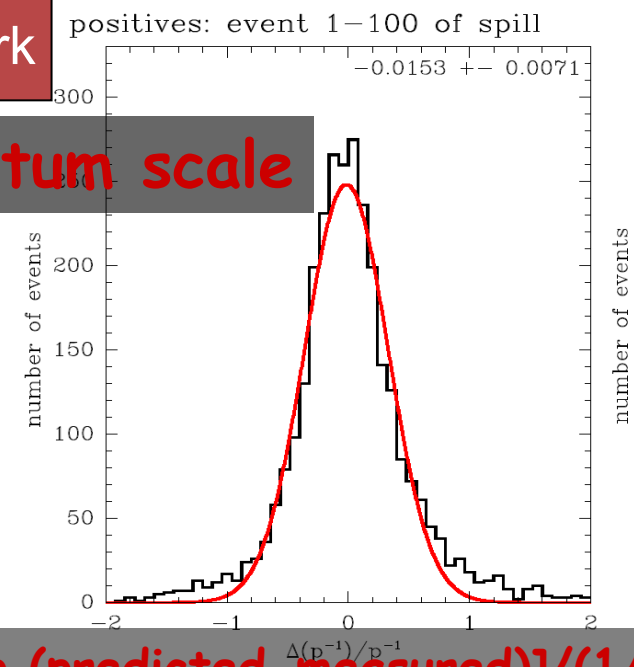
HARP: Analyses with the large angle spectrometer

Beam momenta:
3, 5, 8, 12 GeV/c
beam particle selection and normalization same as previous analysis
Data:
5% λ targets Be, C, Al, Cu, Sn, Ta, Pb
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)
all data in spill are analysed now (the results are compatible within errors)
Corrections:
Efficiency, absorption, PID, momentum and angle smearing by unfolding method
(same as p-C 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^{+-}.

Full statistics now analysed ("full spill data" with dynamic distortion corrections). No significant difference is observed with respect to first analyses of the partial data (first 100-150 events in spill)

HARP TPC calibration: elastic scattering benchmark



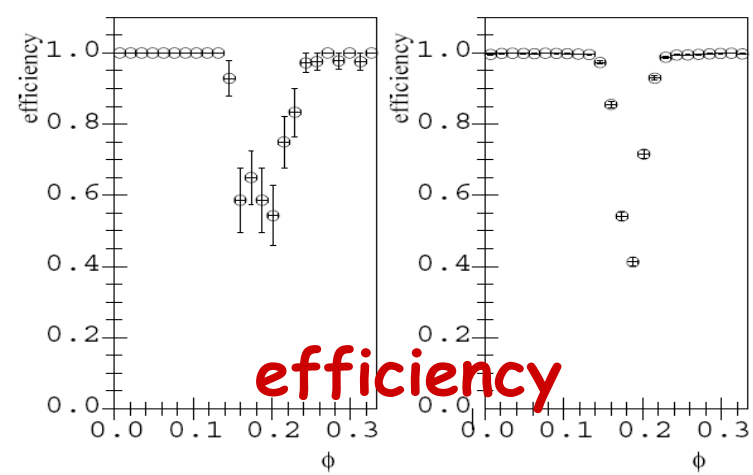


momentum scale

[1/p (predicted-measured)]/(1/p)

Comparison of predicted vs measured track allows LA tracking benchmark

missing mass peak from large angle proton track (position of peak verifies momentum scale: +15% shift is completely excluded)

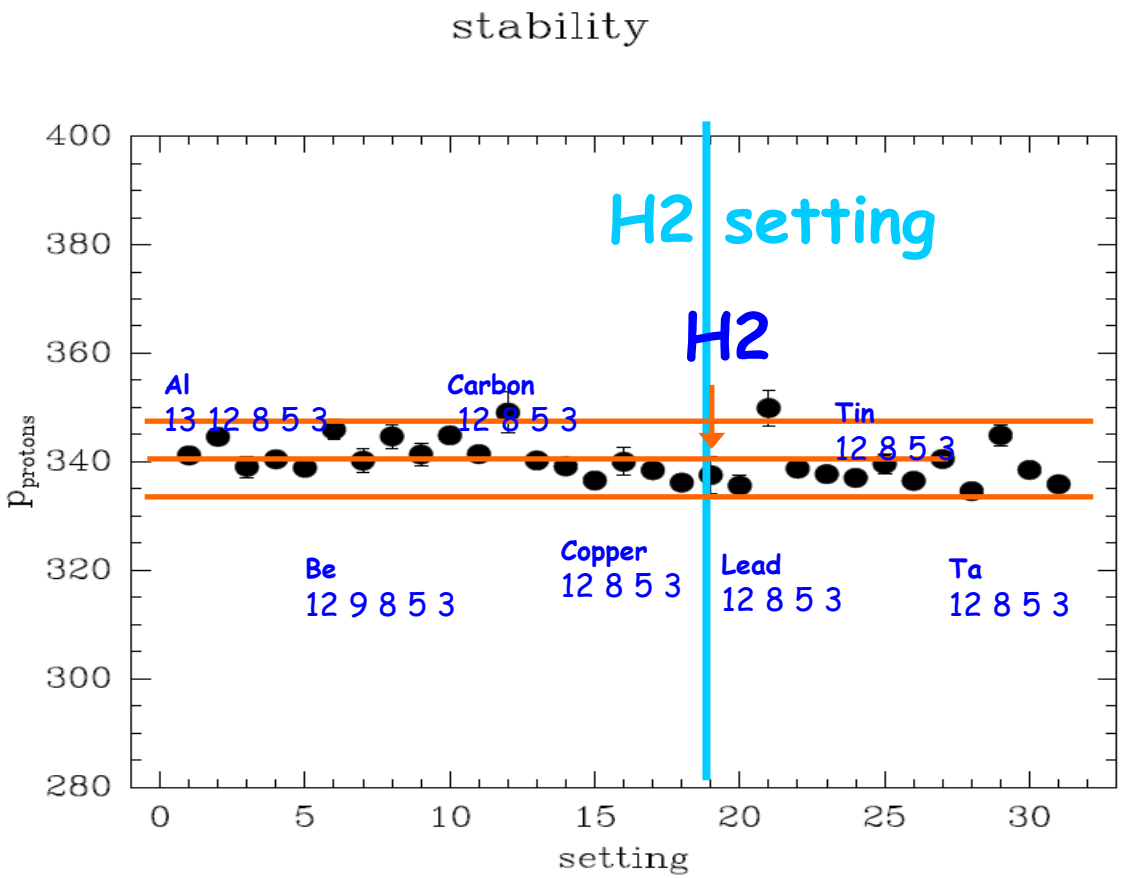


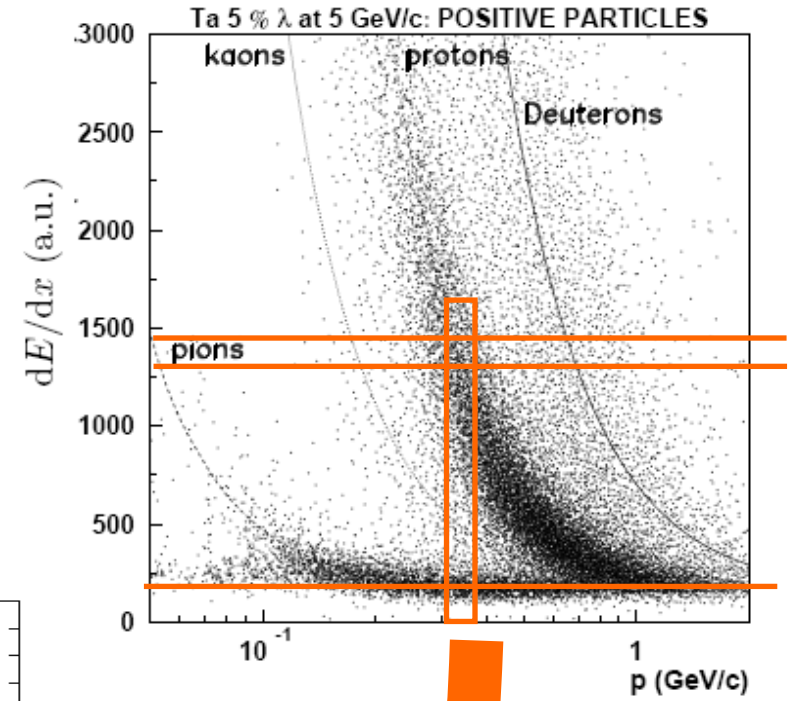
efficiency

JINST 3: P04007 (2008)

Stability from LH2 target to other targets

consider average momentum of protons with dE/dx ∈[7-8] MIPs



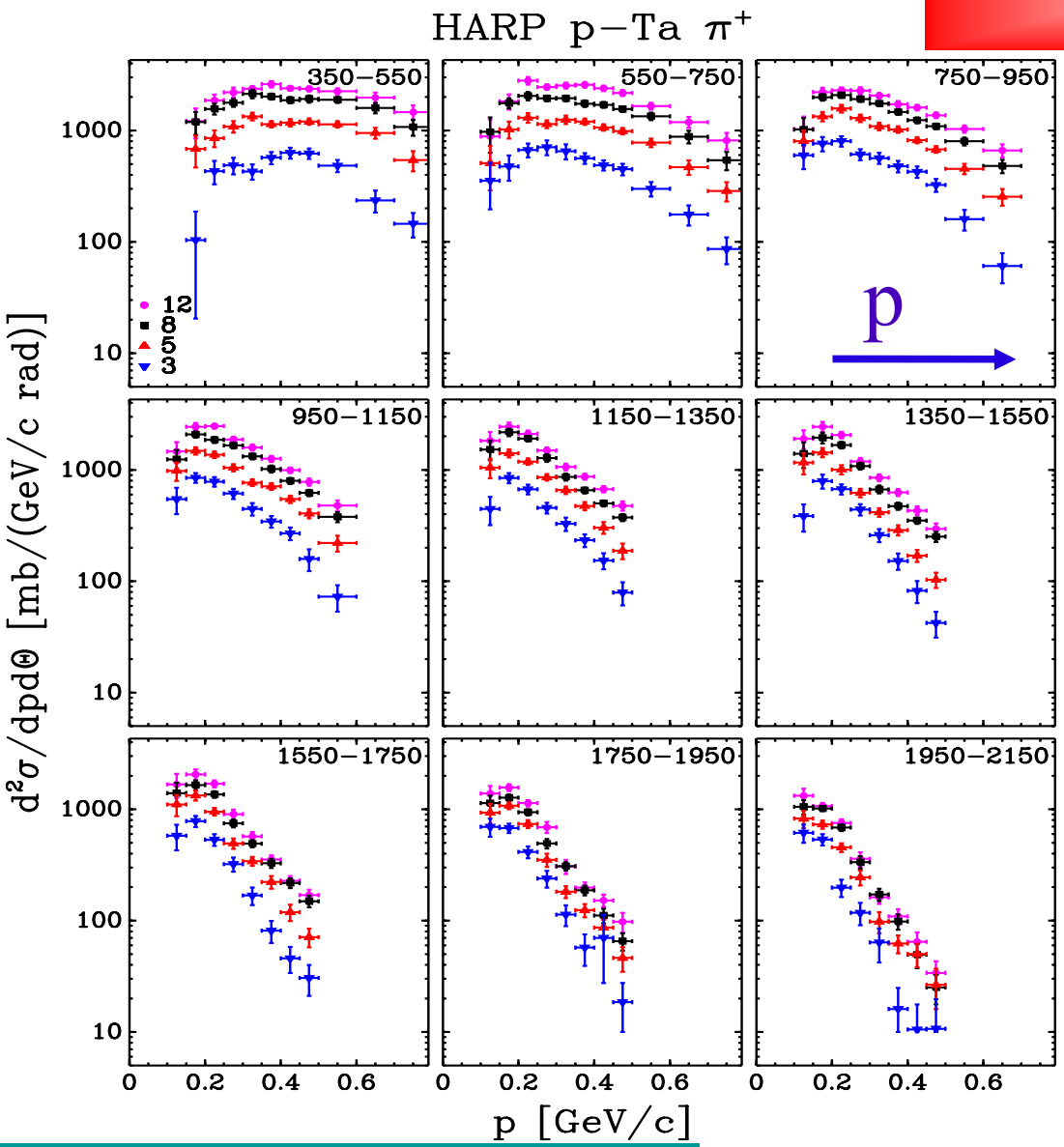


±2%

JINST 3: P04007 (2008)

Pion production yields

9 angular bins: p-Ta π^+



stat. and syst. errors combined

forward
$350 < \theta$ (mrad) < 1550

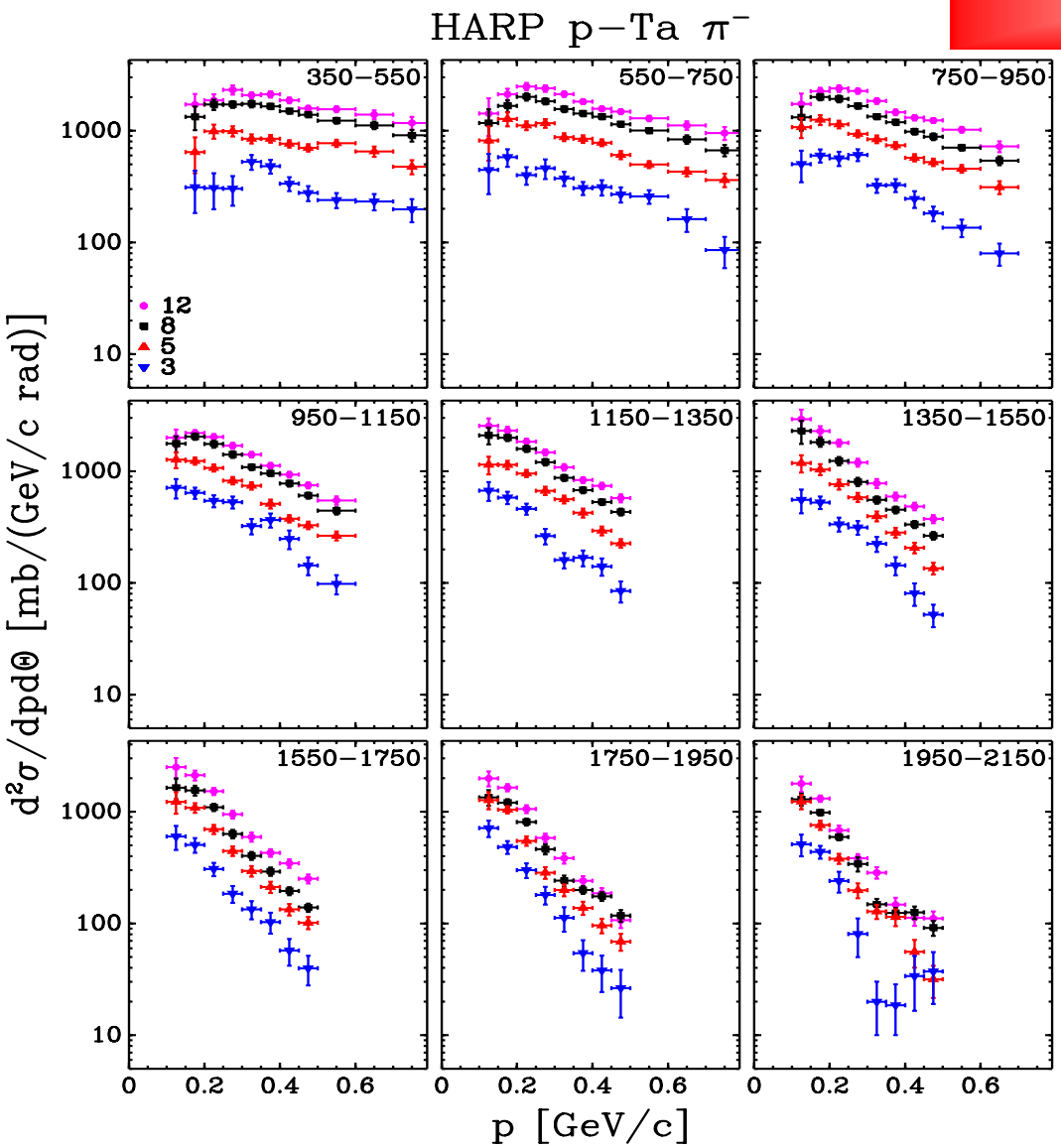
backward
$1550 < \theta$ (mrad) < 2150

momentum range $0.1 < p < 0.8$ GeV/c

EPJ C 51 (2007) 787

Pion production yields

p-Ta π^-



stat. and syst. errors combined

forward
$350 < \theta(\text{mrad}) < 1550$

backward
$1550 < \theta(\text{mrad}) < 2150$

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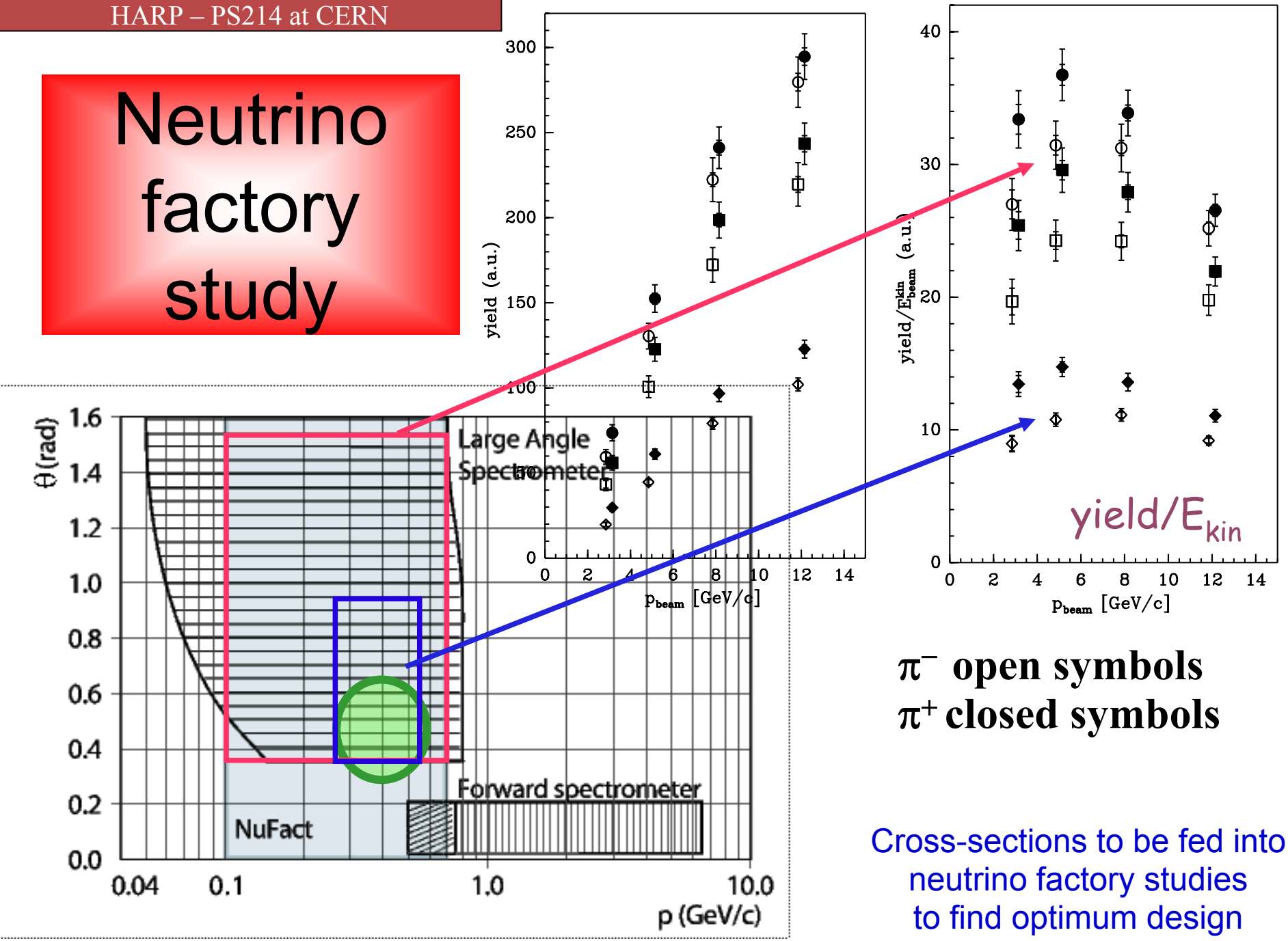
momentum range $0.1 < p < 0.8$ GeV/c

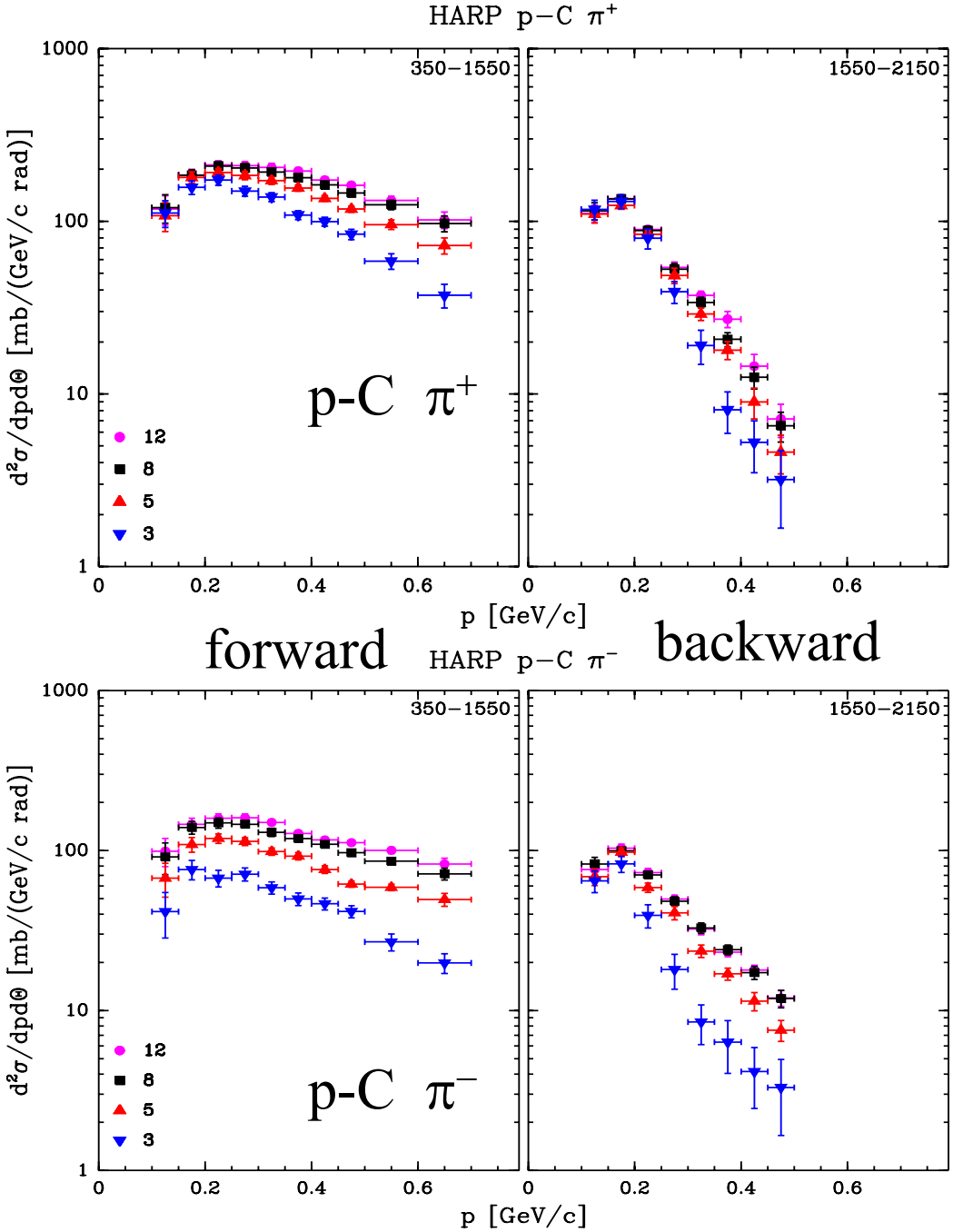
Neutrino factory study



π^- open symbols
π^+ closed symbols

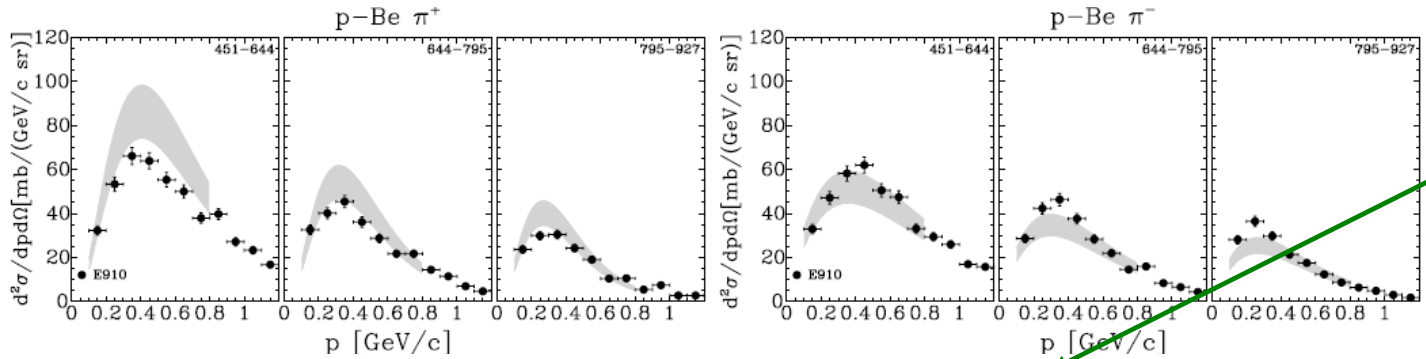
Cross-sections to be fed into neutrino factory studies to find optimum design

Pion yields

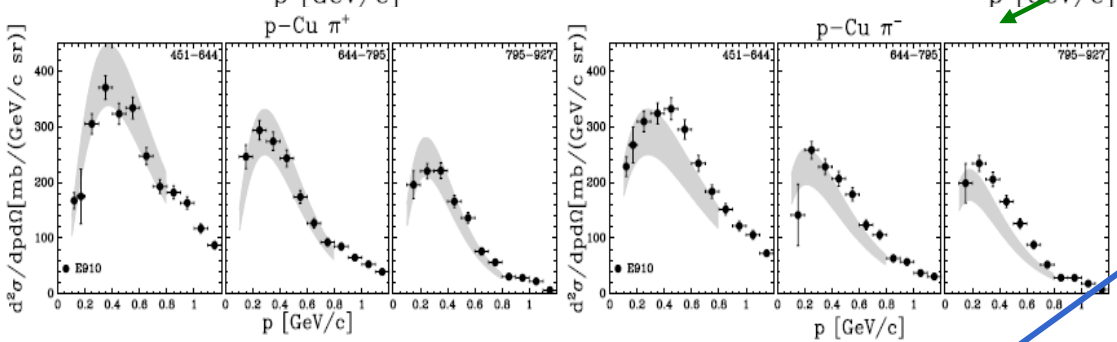


p-C data as an example of many other available spectra

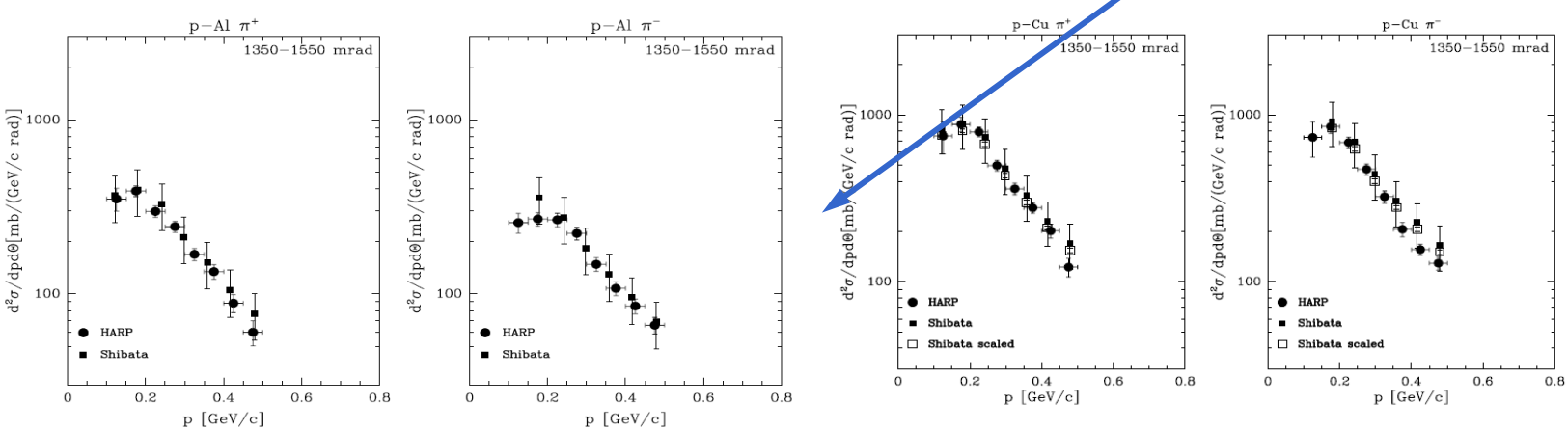
Comparison with…



BNL E910 at 12.3 GeV/c: data points; HARP: shaded region



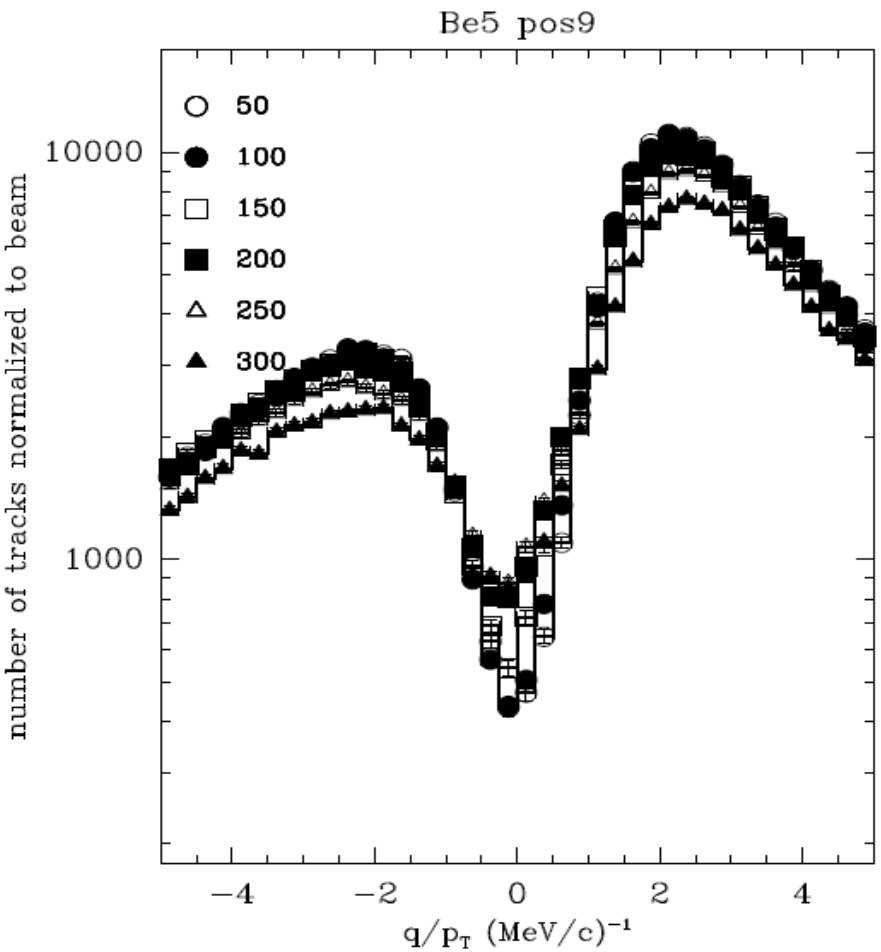
squares: Shibata et al. (KEK), 12 GeV/c at 90°; circles: HARP data



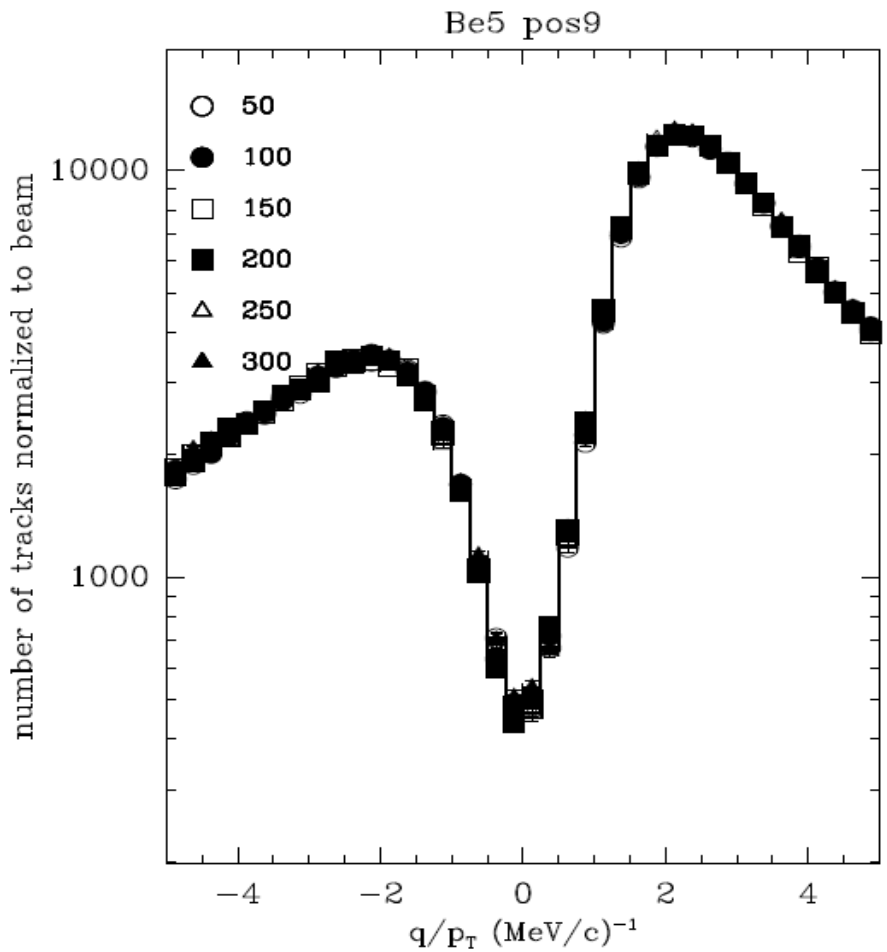
HARP TPC: corrections for dynamic distortions

arXiv:0903.4762 [physics.ins-det]

before



after



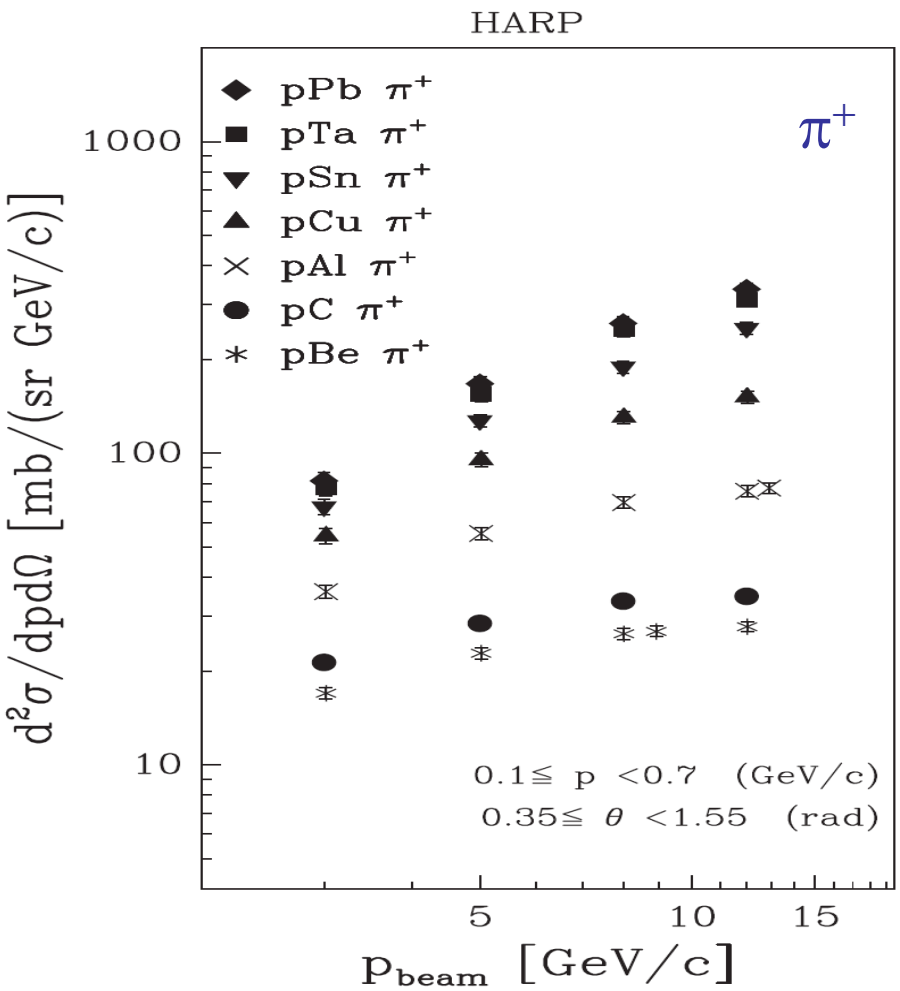
Analyses of full data sample

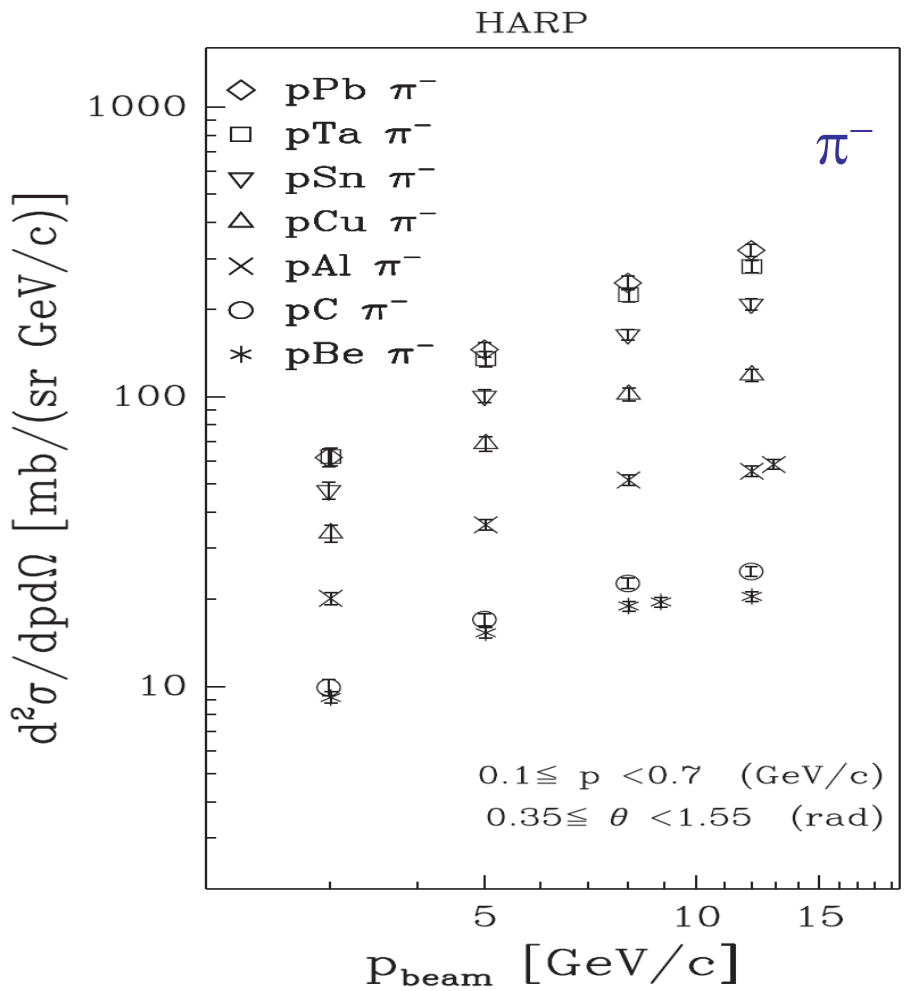
Phys. Rev. C 77 (2008) 055207

Pion yields

comparison of π^+ and π^- yields in p-A for Be, C, Al, Cu, Sn, Ta and Pb as a function of beam momentum (full spill data)

forward production only $0.35 < \theta < \mathbf{1.55}$ rad





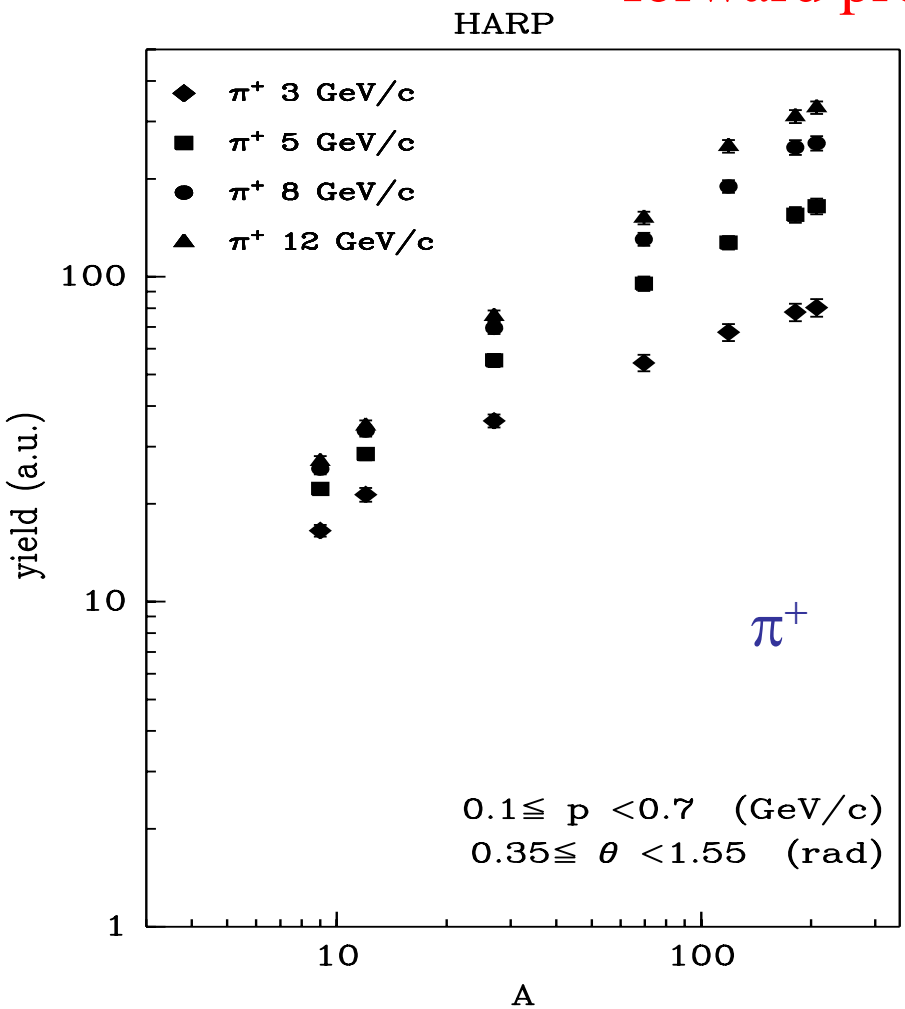
Phys. Rev. C 77 (2008) 055207

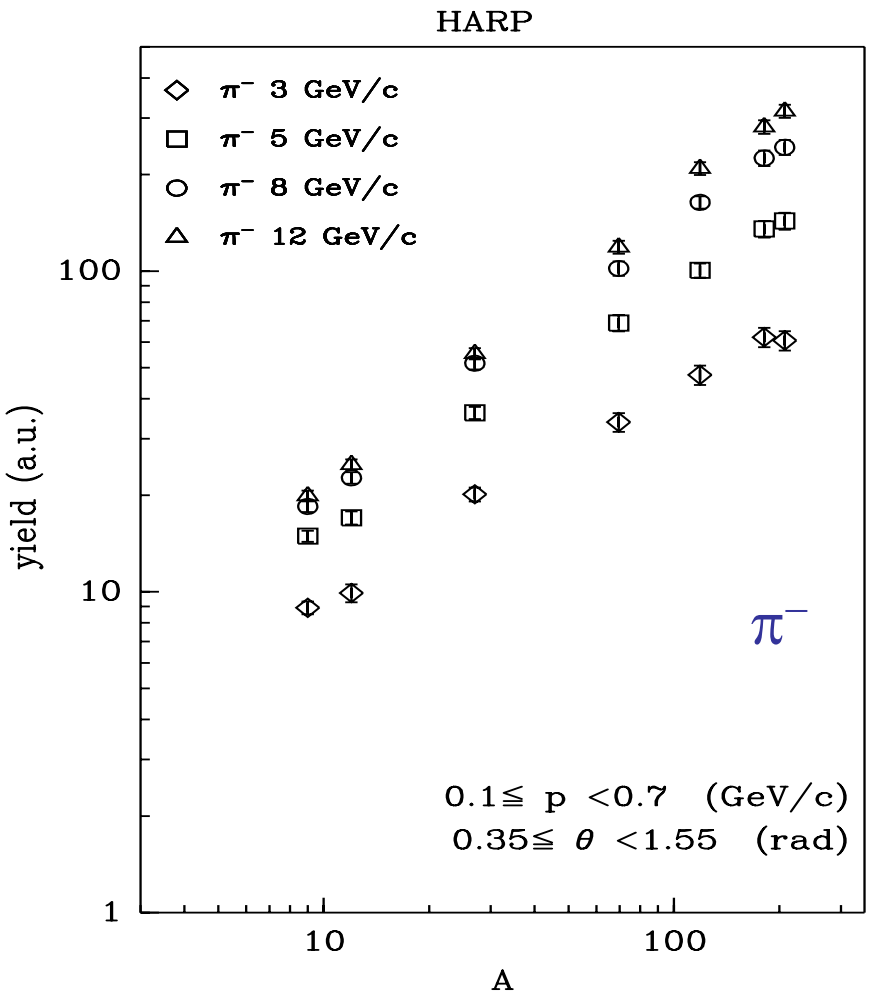
Pion yields

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

Full spill data

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

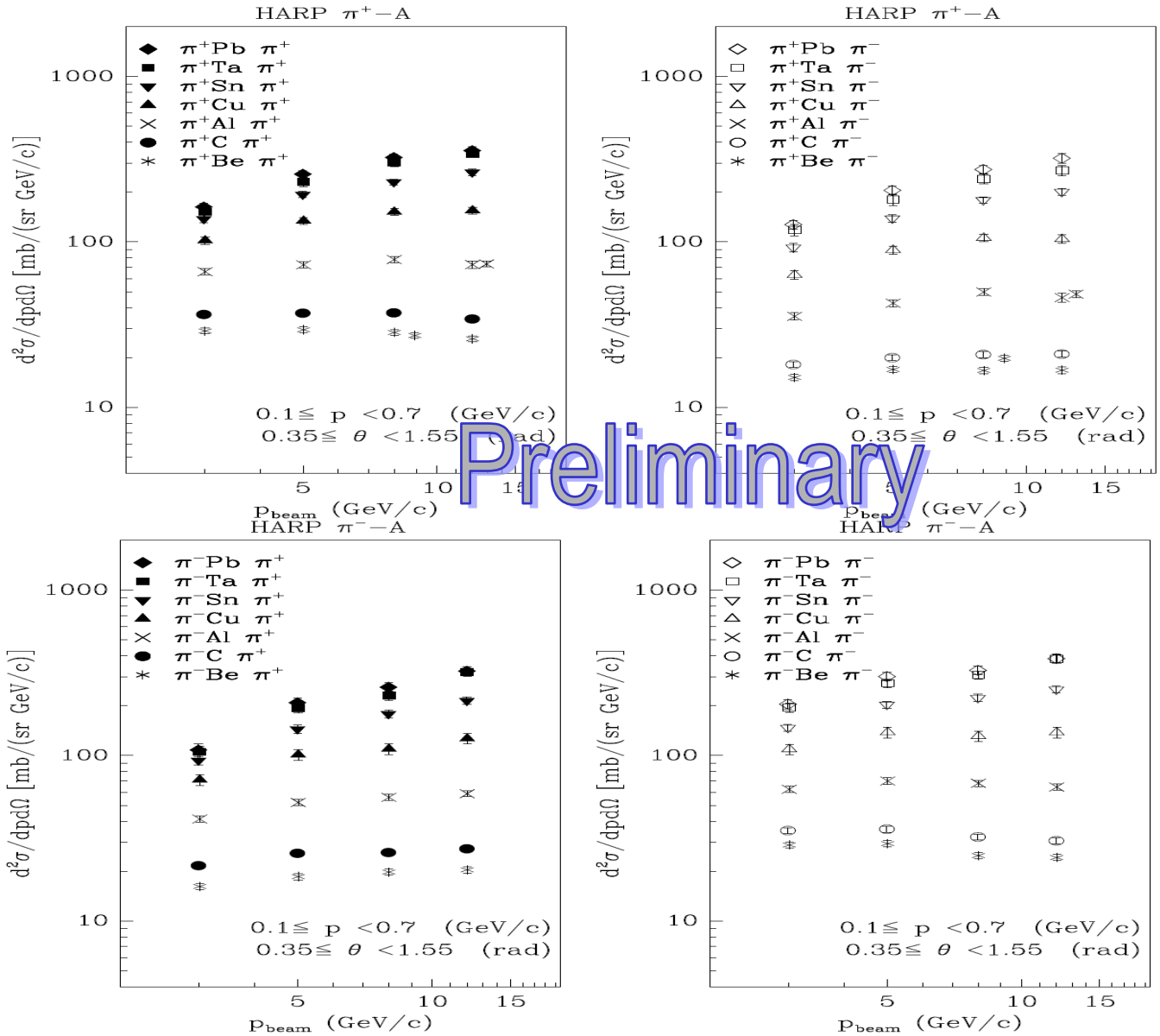




Phys. Rev. C 77 (2008) 055207

Measured with the same detector!

HARP: LA data with incoming pion beams



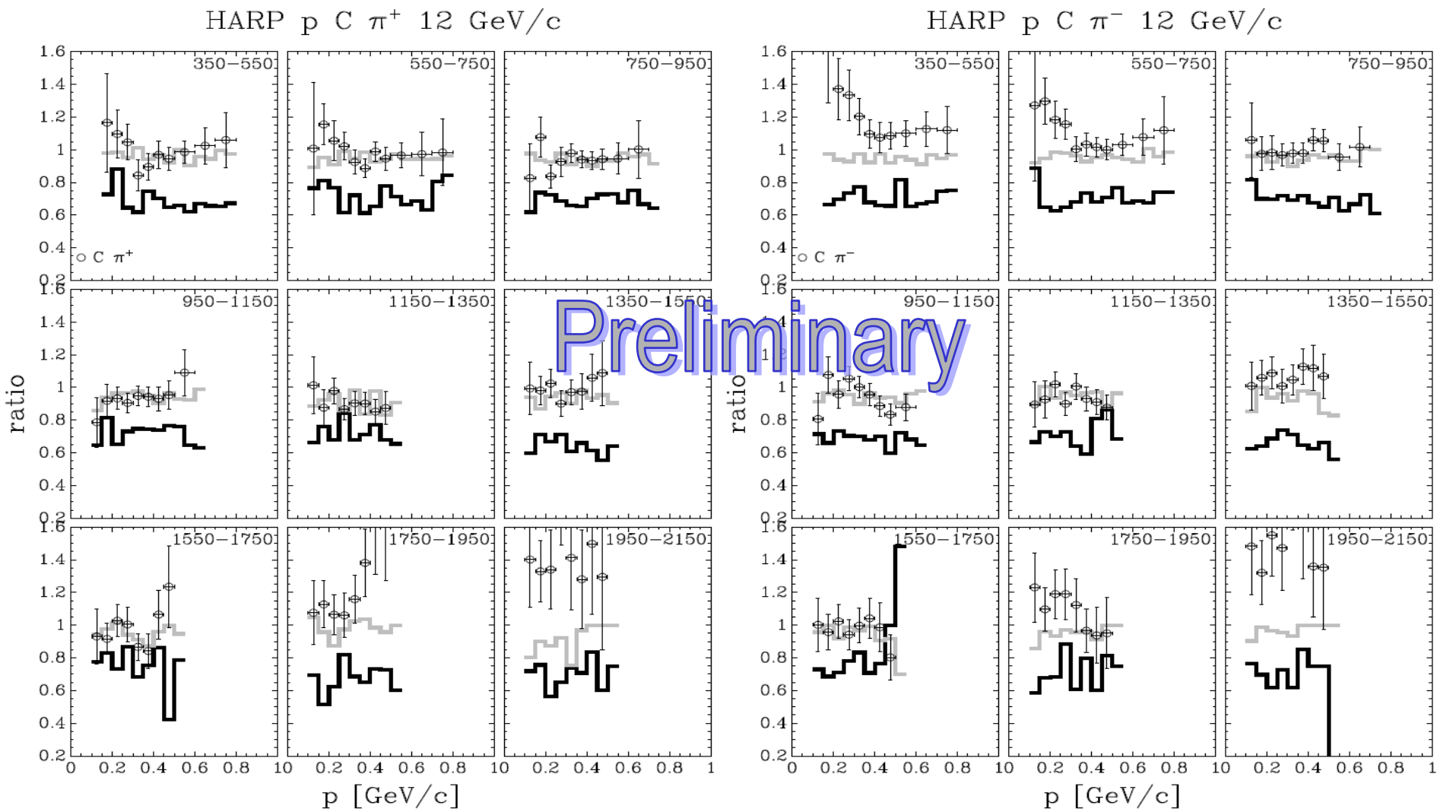
Similar measurements of the $\pi^{\pm}$ production for all available target have been performed using beams of incident pions of both polarities

Dependence of the π+ and π- yields in $\pi^{\pm}$-A interactions for Be, C, Al, Cu, Sn, Ta, Pb as a function of beam momentum (full spill data)

Paper in preparation

forward production $0.35 < \theta < 1.55$ rad

HARP: long target analyses



Ratio of pion yields in 100% λ over 5% λ Carbon target; solid line – MARS predictions; grey line – ratio of pions produced by "first generation" beam proton to all pions in MARS

Paper in preparation

HARP: comparison with MC

Many comparisons with models from GEANT4 and MARS are being done

Only some examples are shown here

Binary cascade

Bertini cascade

Quark-Gluon string (QGS)

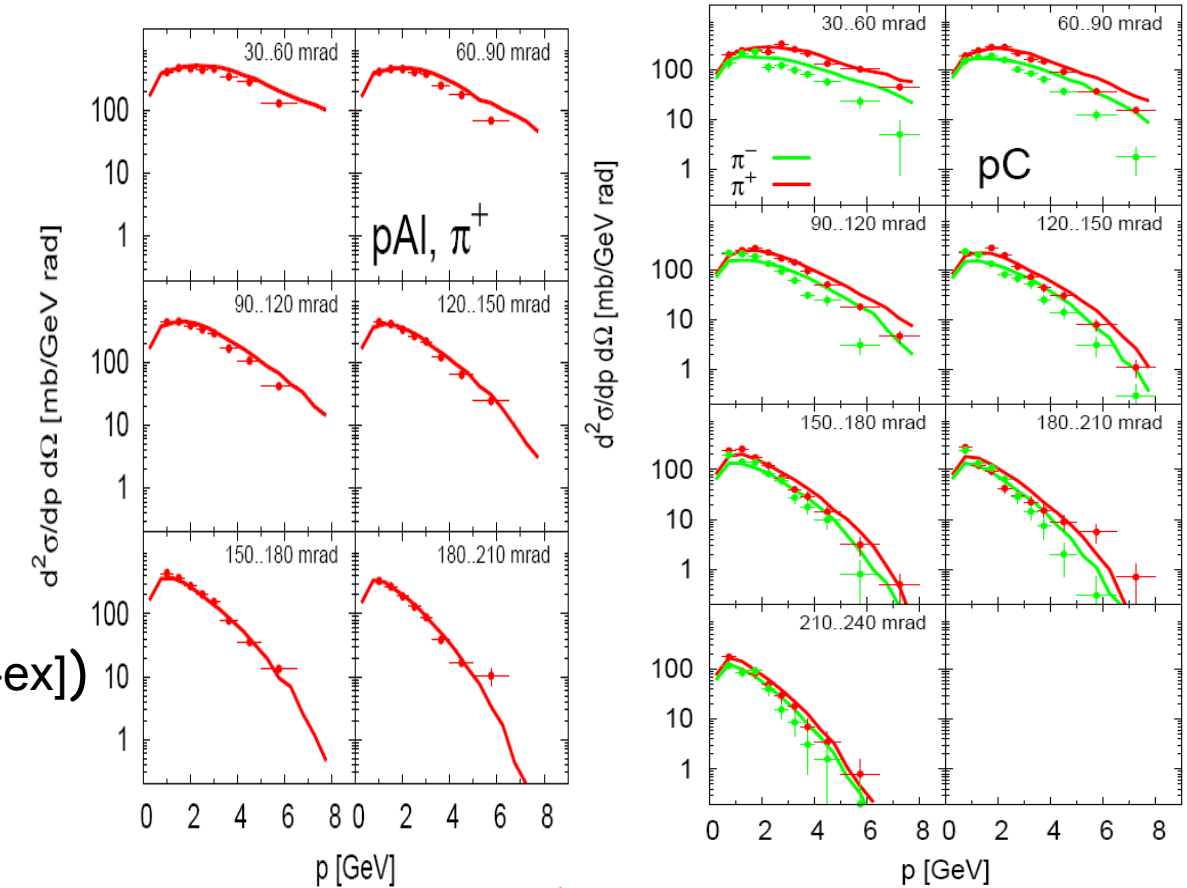
Fritiof (FTFP)

LHEP

MARS

GiBUU (arXiv:0901.1770 [hep-ex])

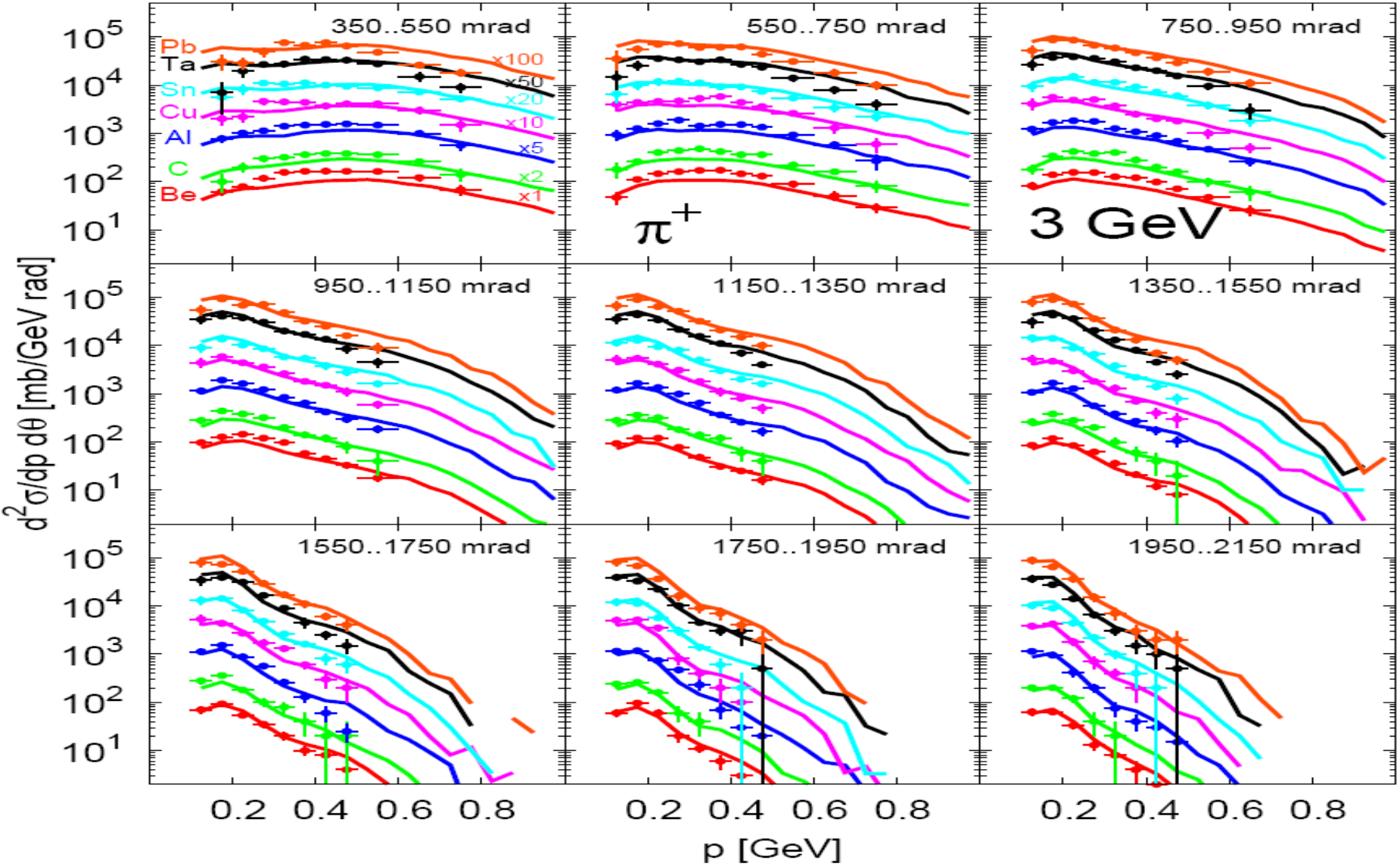
HARP vs GiBUU



Some models do a good job in some regions, but there is no model that describes all aspects of the data

HARP: π^+ LA 3 GeV/c data vs GiBUU

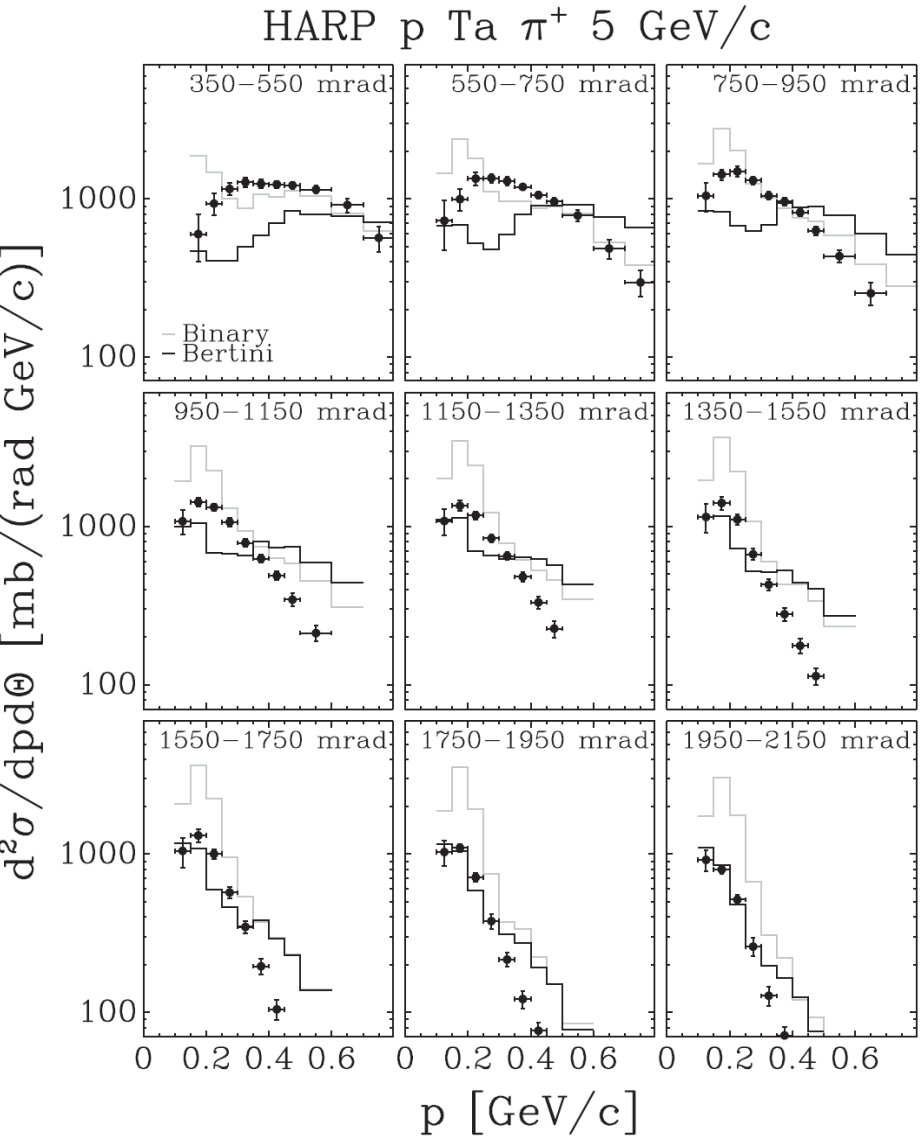
… just as an example of many other comparisons made…

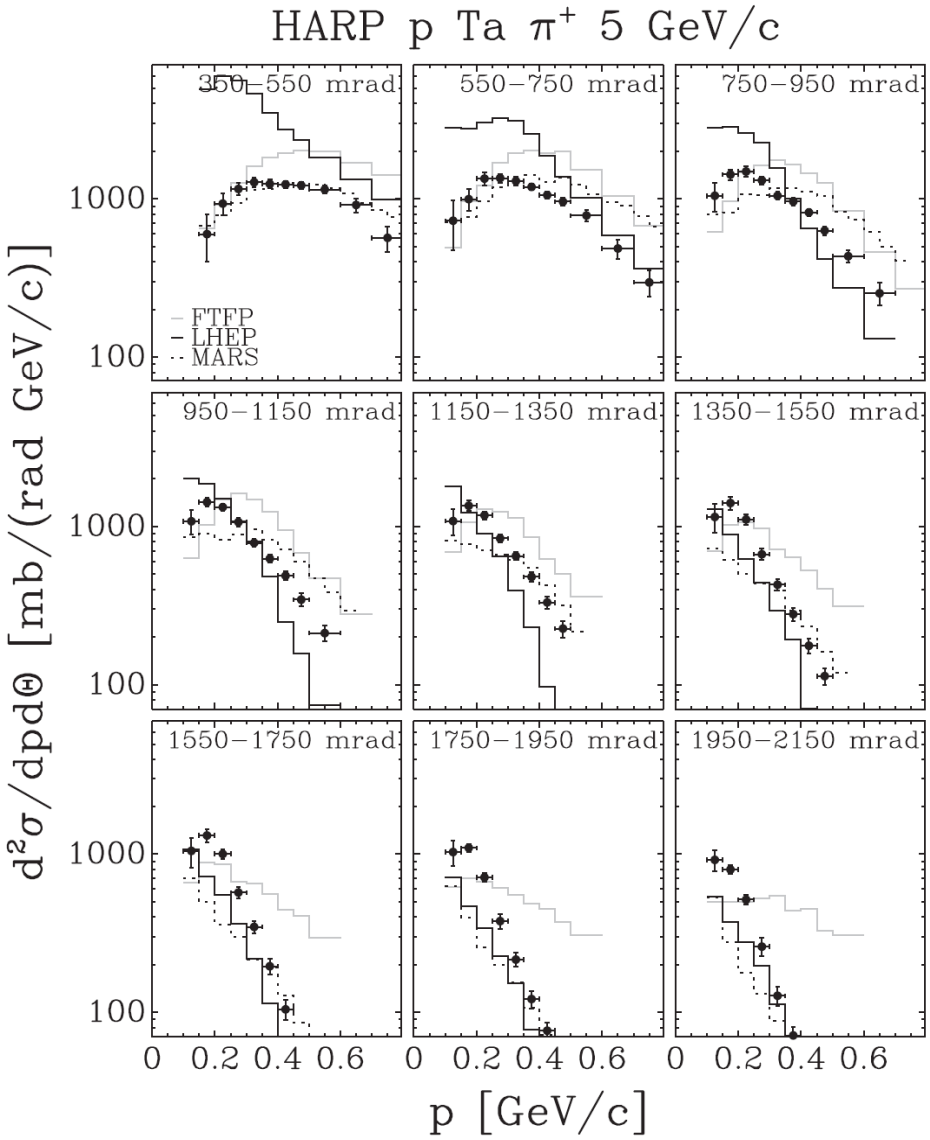


arXiv:0901.1770 [hep-ex]

HARP: 5 GeV/c p-Ta π^+

… just as an example of many other comparisons made…





Phys. Rev. C 77 (2008) 055207

HARP: Summary

HARP hadron production experiment has already made important contributions to hadronic cross-section measurements relevant to neutrino experiments

HARP results with Al target for **K2K** have been used for the final K2K publication.

HARP results with Be target for **MiniBooNE/SciBooNE** have been used for the neutrino flux predictions and for the first MiniBooNE oscillation paper.

HARP results for the **Neutrino Factory** studies for the full data set with all targets (Carbon, Copper, Tin, Beryllium, Aluminium, Tantalum and Lead) are also published.

HARP results for Carbon, N_2 and O_2 targets for **atmospheric neutrino fluxes** are published.

Production cross-section measurements for forward production of charged pions with incident pions on targets from Be to Pb have been recently published.

HARP measurements are being used to validate/tune MC hadron production models.

More production cross-section measurements are now finalized and are being prepared for publication (forward production with incident protons on targets from Be to Pb, LA production with pion beams, production with long targets, etc.).

The **HARP** detector is well understood and the analysis techniques established.

Only a small fraction of available **HARP** results could be presented during this talk…

NA61 (SHINE): PHYSICS GOALS

SHINE = SPS Heavy Ion and Neutrino Experiment

Physics of strongly interacting matter

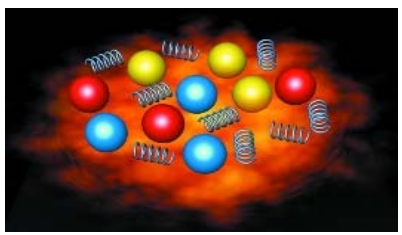
Discovery potential:

Search for the critical point of strongly interacting matter

Precision measurements:

Study the properties of the onset of deconfinement in nucleus-nucleus collisions

Measure hadron production at high transverse momenta in p+p and p+Pb collisions as reference for Pb+Pb results



Data for neutrino and cosmic ray experiments

Precision measurements:

Measure hadron production in the T2K target needed for the T2K (neutrino) physics

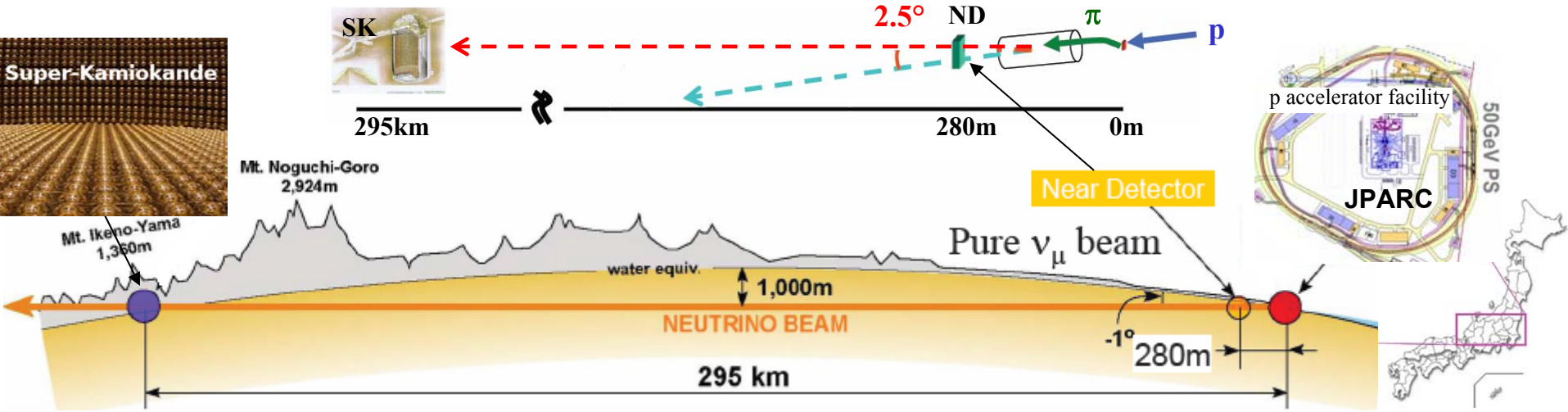
Measure hadron production in p+C interactions needed for T2K and cosmic-ray, Pierre Auger Observatory and KASCADE, experiments

NA61 : Physics Goals (I)

- **One of the main physics goals of NA61/SHINE:**

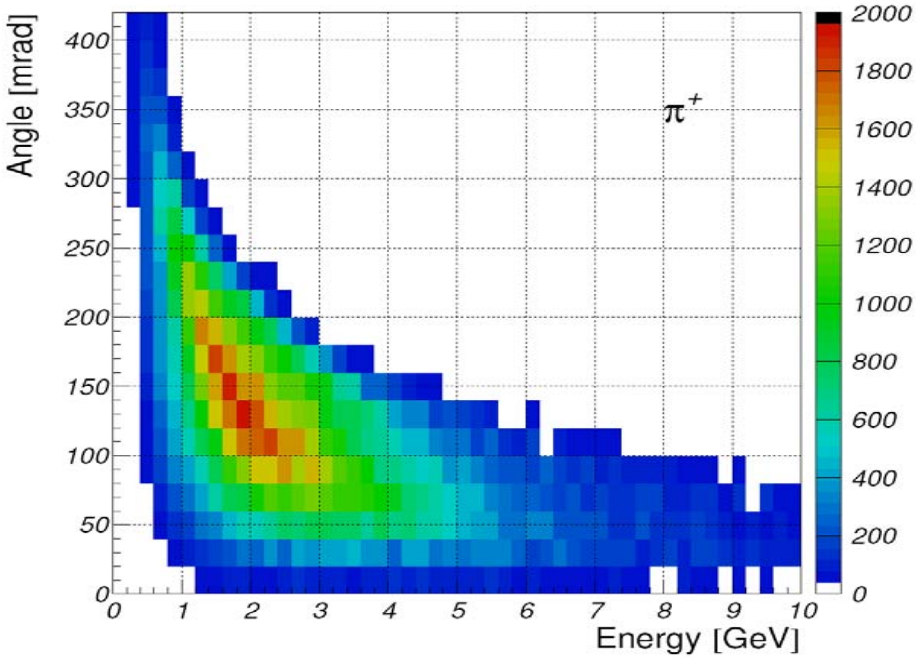
Precision measurements of hadron production for prediction of ν-fluxes in the T2K experiment

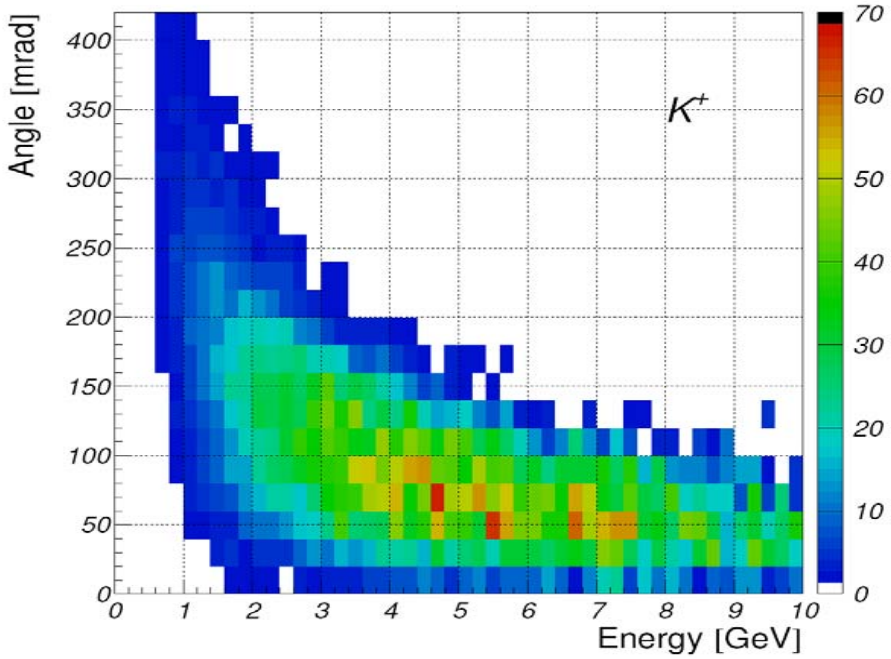
- **T2K @ JPARC (Japan):**
  - Long baseline (295km) neutrino oscillation experiment
  - Protons (30-50GeV) + carbon target (90cm) → intense off-axis ν_μ–beam
  - Neutrino spectra measured at the near and far detectors: ND280 and SK



NA61 : Physics Goals (II)

Simulated distributions of pions and kaons whose daughter neutrinos pass through the SK





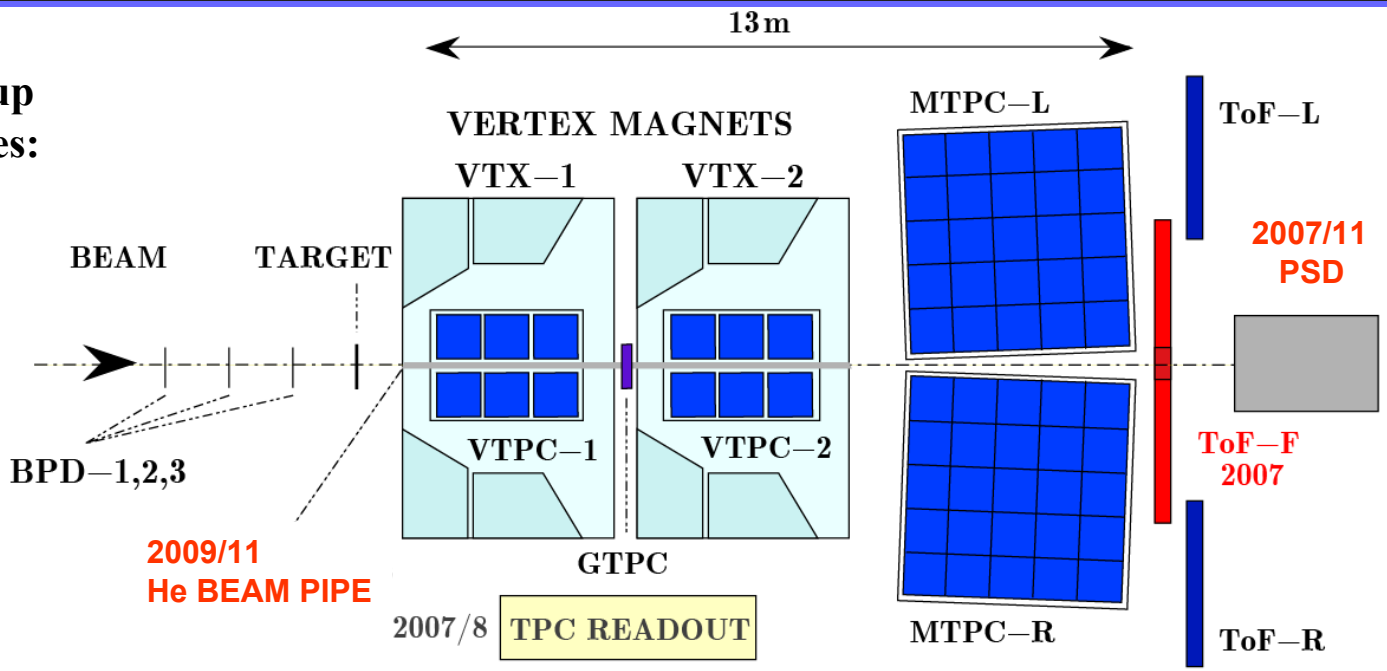
The goal is to reduce the error on the F/N ratio to a negligible level compared to other contributions to the systematics (ND280 spectrum measurements, cross-section, efficiencies, etc.), therefore we aim at: $\delta (R_{\mu,e}) < 3\%$

In order to reach this precision we need ~200k reconstructed π^+ tracks (at the same time we will collect a similar number of π^- since the NA61 acceptance is symmetric)

We also need to measure the K/π ratio with an uncertainty of: $\delta (K/\pi) < 10\%$

NA61/SHINE – Fixed Target Experiment at CERN SPS

NA49 Setup
+ Upgrades:



- **Large Acceptance Spectrometer for charged particles**
- **TPCs as main tracking devices**
- **2 dipole magnets with bending power of max 9 Tm over 7 m length** (2007-Run: 1.14 Tm)
- **New ToF-F to entirely cover T2K acceptance**
- **High momentum resolution**
- **Good particle identification:** σ(ToF-L/R) ≈ 60 ps, σ(ToF-F) ≤ 120 ps,

  $\sigma(dE/dx)/\langle dE/dx\rangle \approx 0.04$, $\sigma(m_{inv}) \approx 5$ MeV

CERN-SPS-2006-034

NA61 : Targets during 2007 pilot run

- **2 different carbon targets (isotropic graphite)**

Thin Carbon Target
- **length=2 cm, cross section 2.5x 2.5 cm^2**
- **ρ = 1.84 g/cm^3**
- **~0.04 λ_{int}**

T2K replica Target
- **length = 90 cm, Ø=2.6 cm**
- **ρ = 1.83 g/cm^3**
- **~1.9 λ_{int}**

- **During October 2007 Run (~30 days):**

- taken pilot physics data for T2K with 30.9 GeV/c protons (~2 weeks)

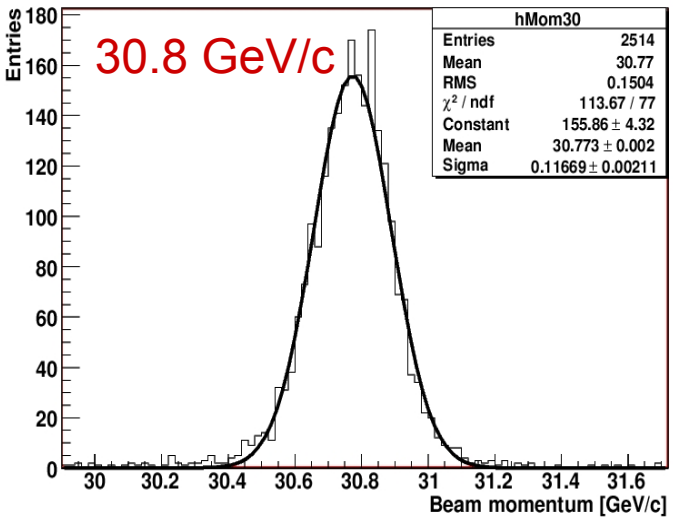
Thin target: ~670k triggers

Replica target: ~230k triggers

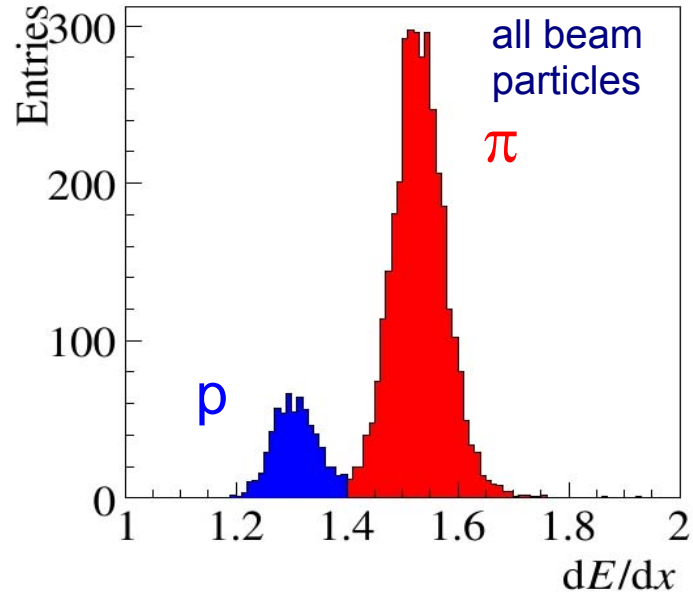
Empty target: ~80k triggers

NA61 : BEAM PROPERTIES

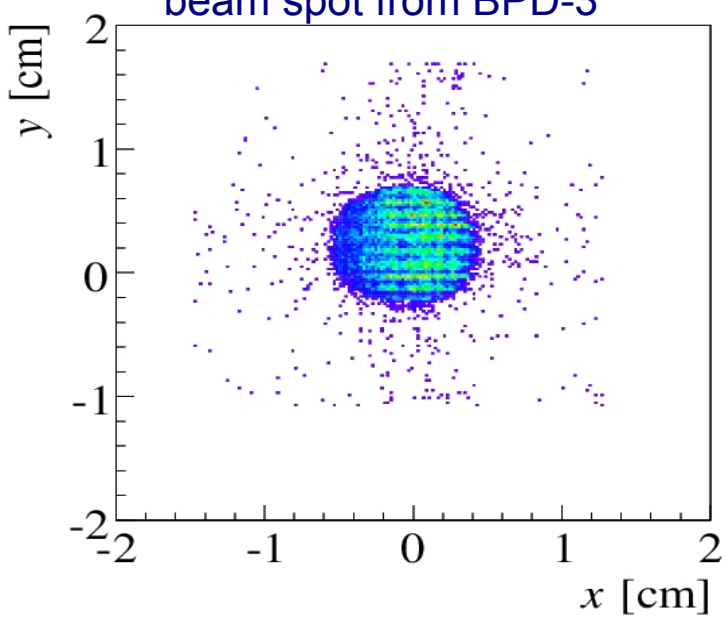
momentum from TPC

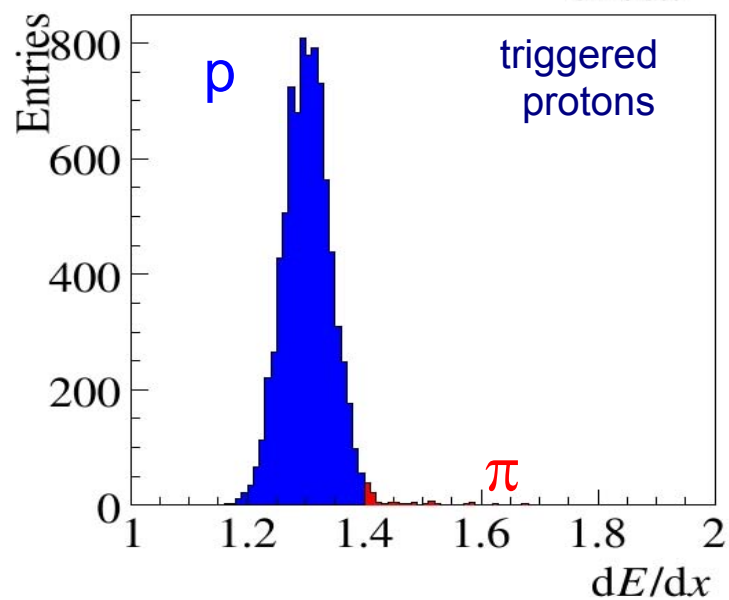


dE/dx from TPC



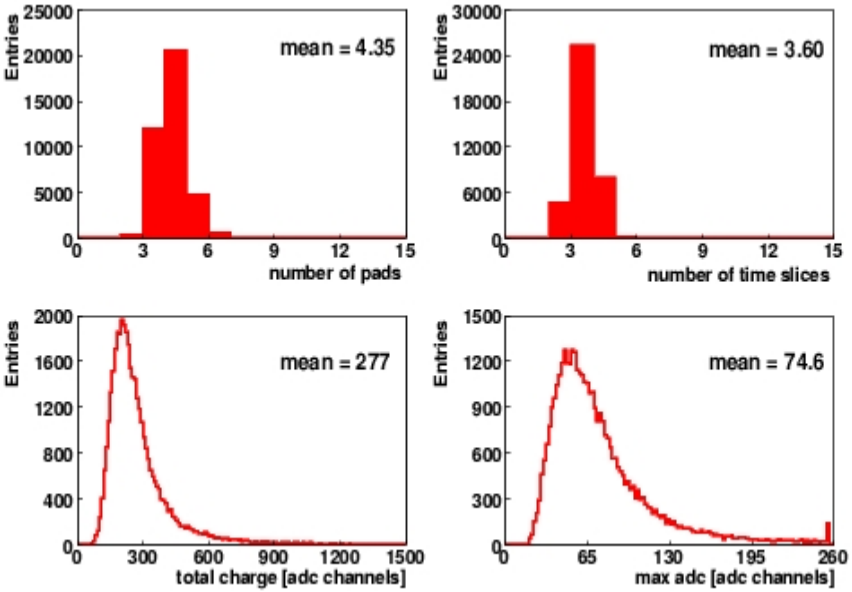
beam spot from BPD-3



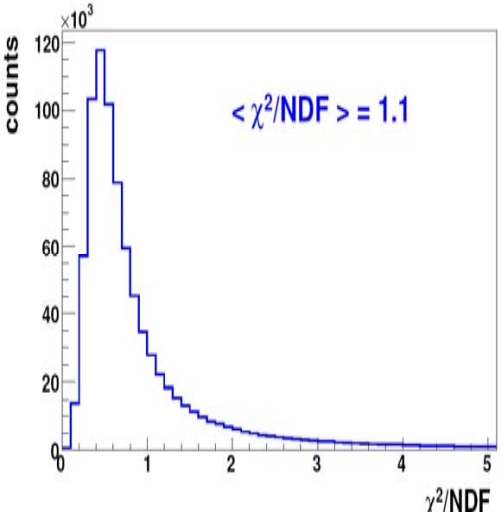


NA61 : TRACKING PERFORMANCE

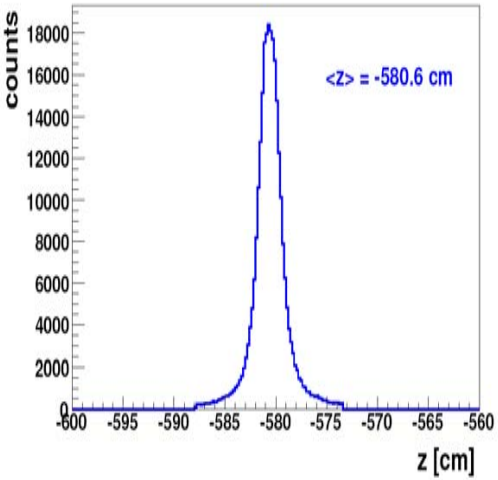
TPC cluster parameters



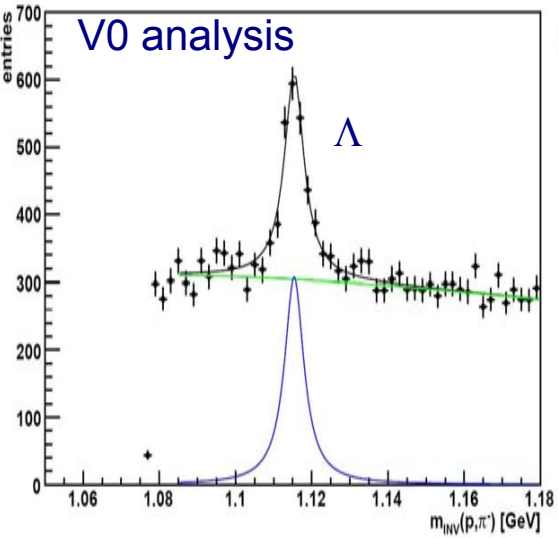
Momentum fit

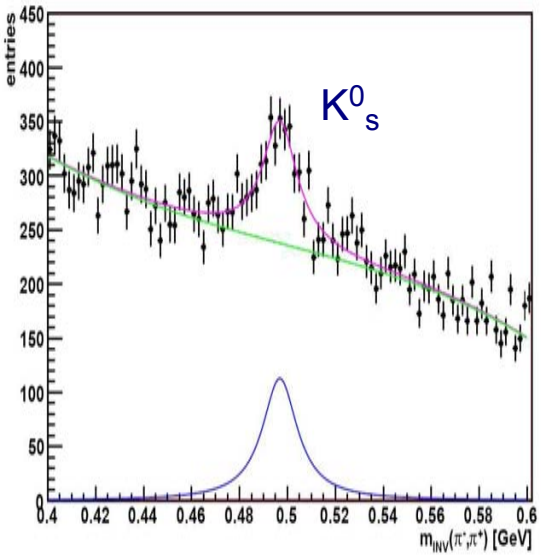


Vertex fit

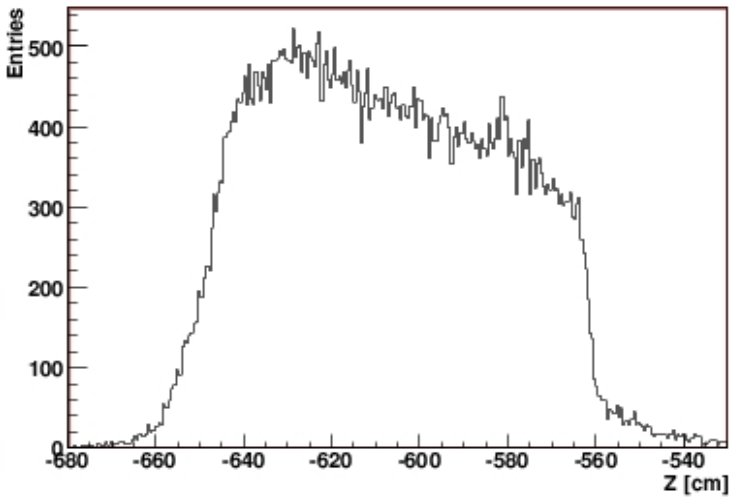


V0 analysis





T2K replica target: fitted vertex



- Measurement of the σ_{inel} for p+C @ 31 GeV/c

- Normalization of the hadron spectra to inclusive cross sections

• From the thin C target (4% λ_I) data, we measure a double differential inclusive inelastic cross-section:

$$\frac{d^2\sigma_{inel(\alpha)}}{dpd\theta} = \frac{1}{\rho L_{eff}\frac{N_A}{A}}\frac{1}{N_{beam}}\frac{d^2n_\alpha}{dpd\theta} = \frac{1}{\rho L_{eff}\frac{N_A}{A}}\frac{N_{trig}}{N_{beam}}\frac{1}{N_{trig}}\frac{d^2n_\alpha}{dpd\theta} = \frac{\sigma_{trig}}{N_{trig}}\frac{d^2n_\alpha}{dpd\theta}$$

• *p* and θ are laboratory momentum and polar angle of the produced particle α (π, K, or p) and dn_α is the number of identified particles from the target measured in the bin dpdθ

• σ_{inel} denotes the inelastic cross-section for p+C interactions, including all processes due to strong interactions with exception of elastic p+C interactions (p+C in the final state)

• inelastic interactions are selected by an interaction trigger. N_{trig} and N_{beam} are the number of collected triggers and measured beam particles on the target, respectively

NA61: Determination of the Inelastic Cross Section

- σ_{inel} can be obtained from the σ_{trig} by applying the following corrections:

1) Subtract the contribution of elastic interactions due to large angle coherent scattering

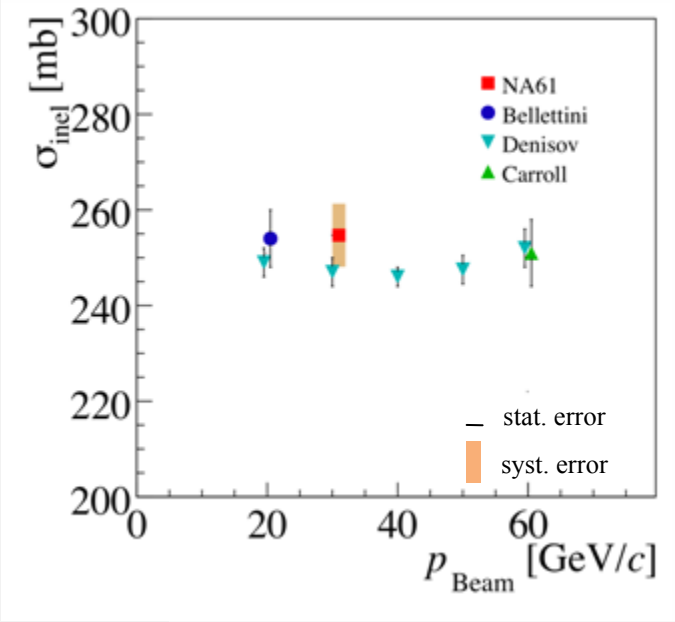
2) Add the contribution of lost events where a secondary particle hits S4 trigger counter.
Here, the major contribution comes from quasi-elastic scattering of the incident protons (σ_{loss-p}).
Also secondary pions or kaons hitting S4 have to be taken into account ($\sigma_{loss-\pi/K}$)

→ Corrections have been estimated with Geant4 simulation

	σ [mb]
σ_{trig}	297.5±0.7±3.0[1)]
σ_{loss-p}	5.8 ±0.2±?
$\sigma_{loss-\pi/K}$	0.6±0.1±?
$\sigma_{elastic}$	-49.2±0.6±5.9[2)]
σ_{inel}	254.7±1.0±6.6

1) Syst. error on σ_{trig} currently estimated with various cross-checks

2) Syst. error on $\sigma_{elastic}$ currently estimated by comparing Geant4 simulations with known exp. values



→ Preliminary value for the σ_{inel} is in good agreement with previous measurements

G. Bellettini et al. Nucl. Phys. 79 (1966) 609; S.P. Denisov et. al. Nucl. Phys. B61 (1973) 62; recalculated from A. Carroll et al. Phys. Lett. B80 (1979) 319

- Analysis of negatively charged hadrons

The analysis of negatively charged hadrons from the primary vertex is motivated by estimates that more than 90% of produced negatively charged particles at 31GeV/c proton carbon interactions are π^- mesons.

The remaining small fraction includes K^- mesons and electrons and negligible number of anti-protons. Venus-GHEISHA and Geant Monte-Carlo simulation chain is used to calculate corrections for geometrical acceptance, reconstruction efficiency, weak decays and leptons.

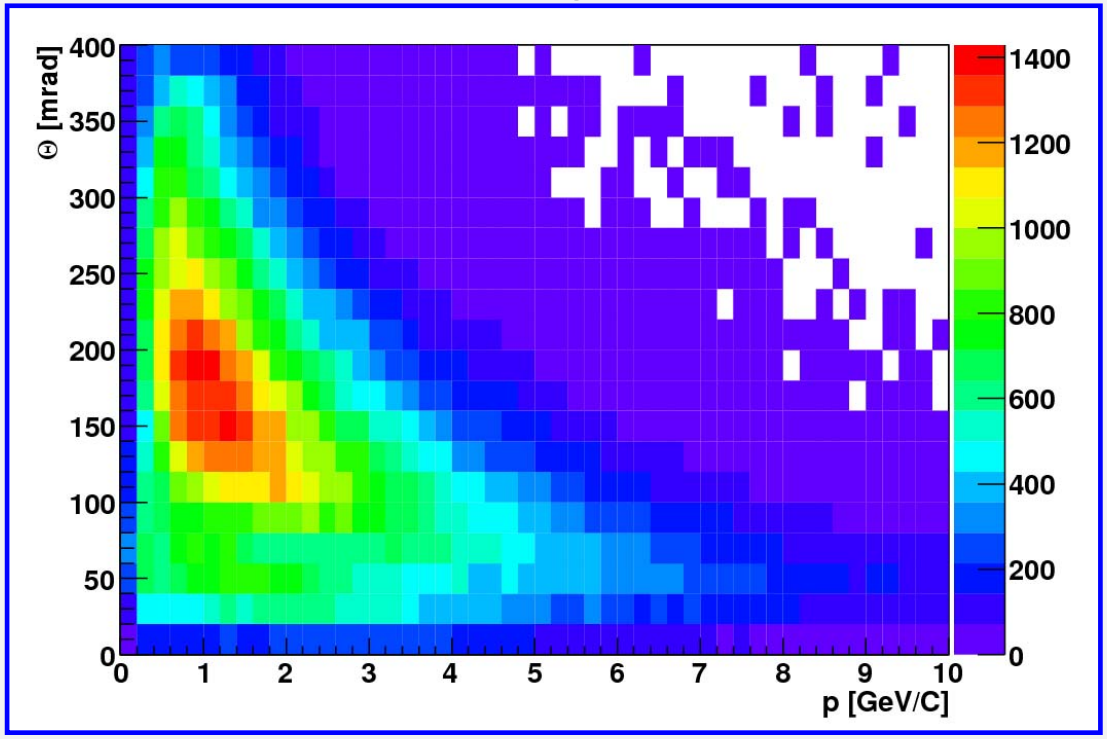
Finally corrected spectra of all negatively charged particles and only π^- mesons from the primary interaction are obtained. Results presented here are based on thin target 2007 data.

NA61: Negative hadron analysis

- The negatively charged hadrons analysis, further referred to as h- analysis, **starts from the selection of negatively charged particles from the primary vertex.**
- The analyzed runs contained 671325 events (100%). After quality cuts on beam tracks we have 537257 events (~80%)
- Track statistics after successive track quality cuts is summarized here:

All negative tracks:	427627 (100%)
Independent Momentum determination: Minimum number of points in VTPC1+2 is 5	414890 (97%)
Cut on the impact parameter	354898 (83%)
Cut on the number of potential points (larger than 30)	258173 (60%)
Cut on the ratio of measured and potential points: Ratio larger than 0.5	258160 (60%)

The uncorrected spectrum of negatively charged particles in p+C interactions at 31GeV/c registered by NA61 – (polar angle –momentum) plane



T2K phase-space fully covered

NA61: Negative hadron analysis

Venus 4.12 -GHEISHA and **Geant 3.21**Monte-Carlo simulation chain **was used to calculate corrections for**

- **geometrical acceptance,**
- **reconstruction efficiency,**
- **momentum resolution**
- **weak decays,**
- **and leptons contamination.**
- **in π - correction case also non pion contamination.**

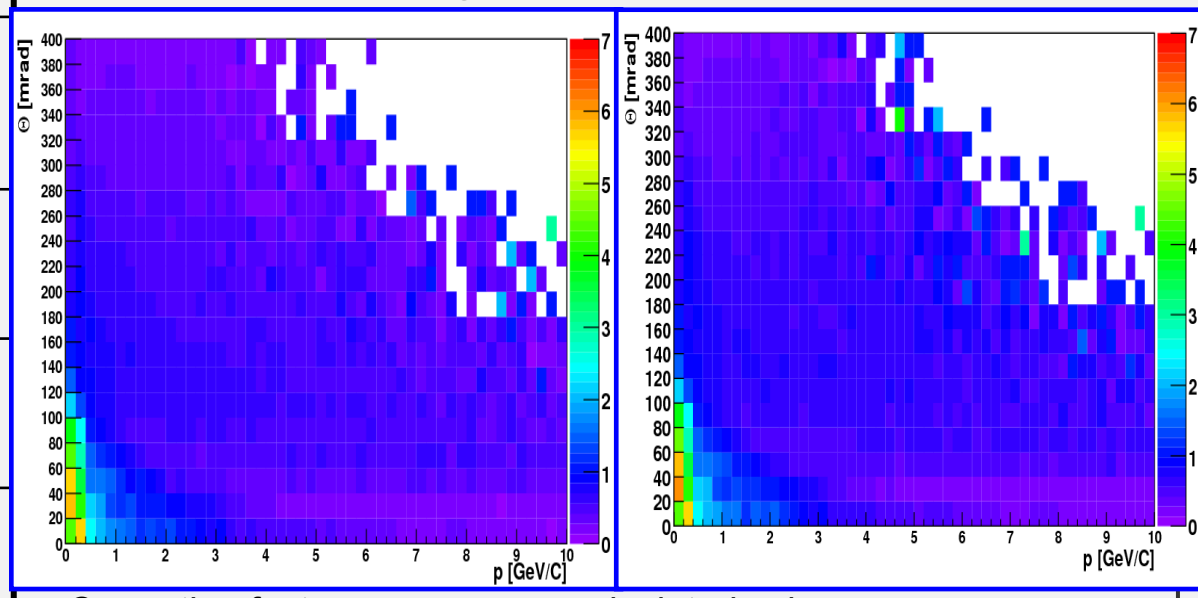
$$C^{H-}/_{\pi-}(p,\theta)_{all\_corrections} = \frac{Reconstructed\_negative\_tracks\_from\_the\_primary\_vertex(p,\theta)}{Simulated\_negative\_hadrons/_{or\_only\_pions}\_from\_the\_primary\_vertex(p,\theta)}$$

For current Monte Carlo studies we have used 281078 events.

The same track cuts were applied as for real data, effects of these cuts on the number of negatively charged tracks are summarized here:

All reconstructed negative tracks:	288134 (100%)
Independent Momentum determination: Minimum number of points in VTPC1+2 is 5	278120 (96 %)
Cut on the inpact parameter	243152 (84 %)
Cut on the number of potential points (larger than 30)	172440 (60 %)
Cut on the ratio of measured and potential points: Ratio larger than 0.5	172438 (60 %)

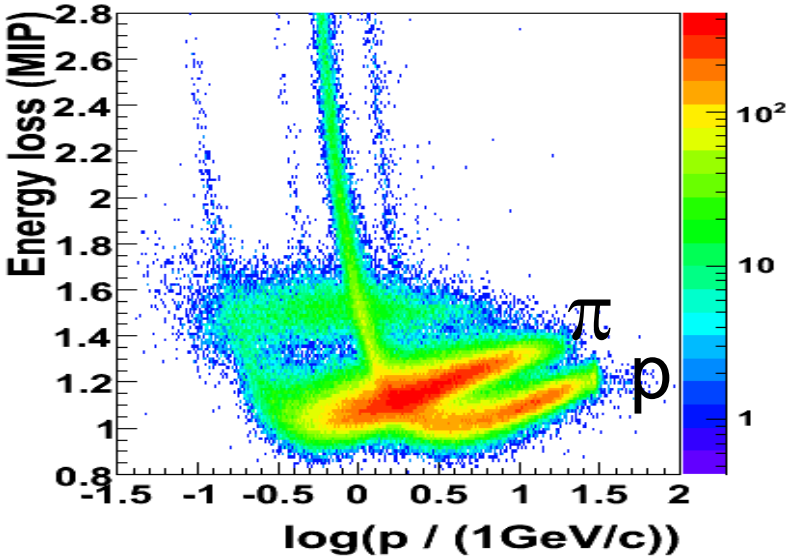
The correction factors: at the left side for the h minus case, at the right side for the π - case



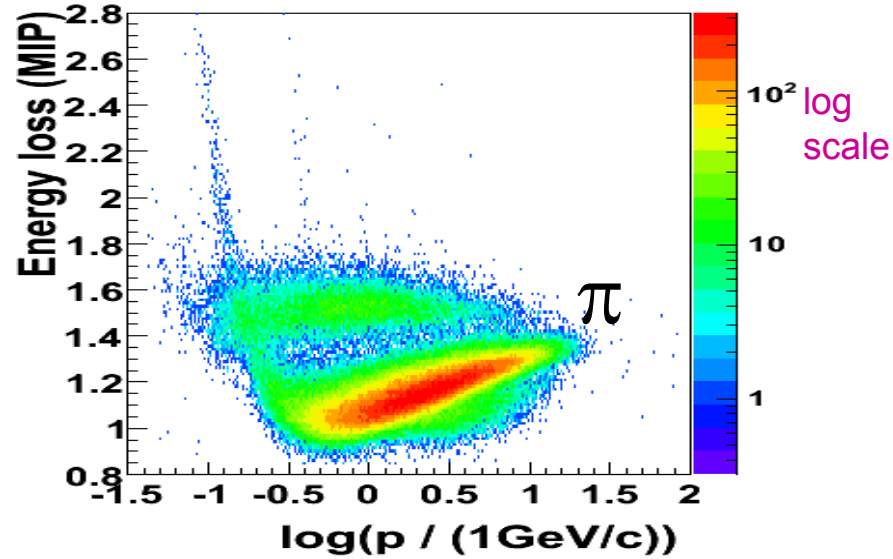
Correction factors errors were calculated using binominal distribution.

NA61 : PID by dE/dx and TOF measurements

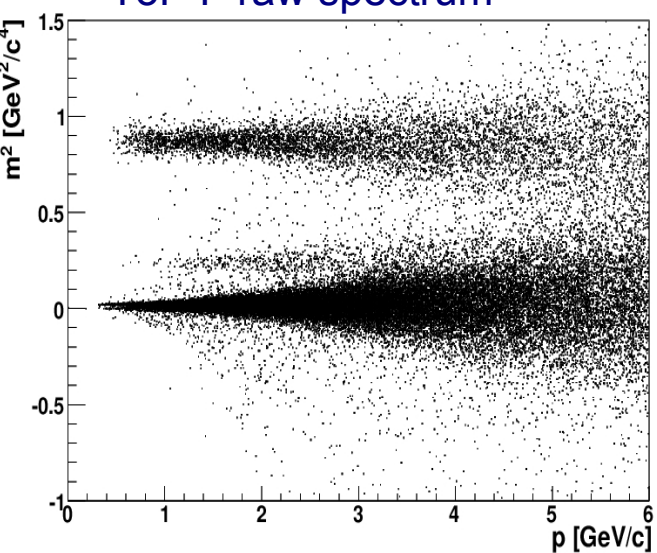
Positive particles



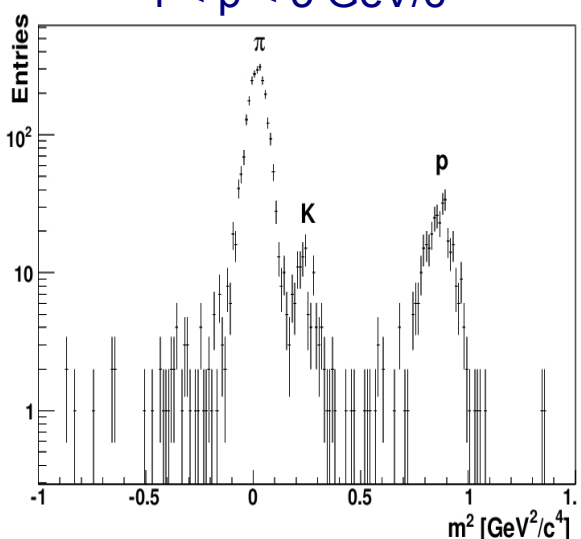
Negative particles



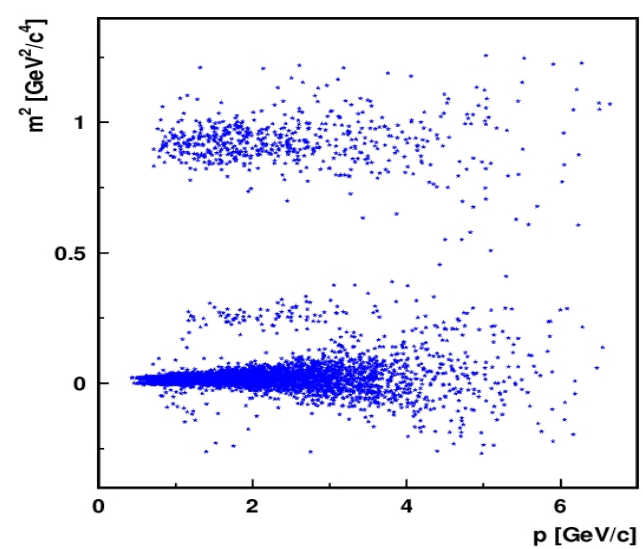
ToF-F raw spectrum



1 < p < 3 GeV/c

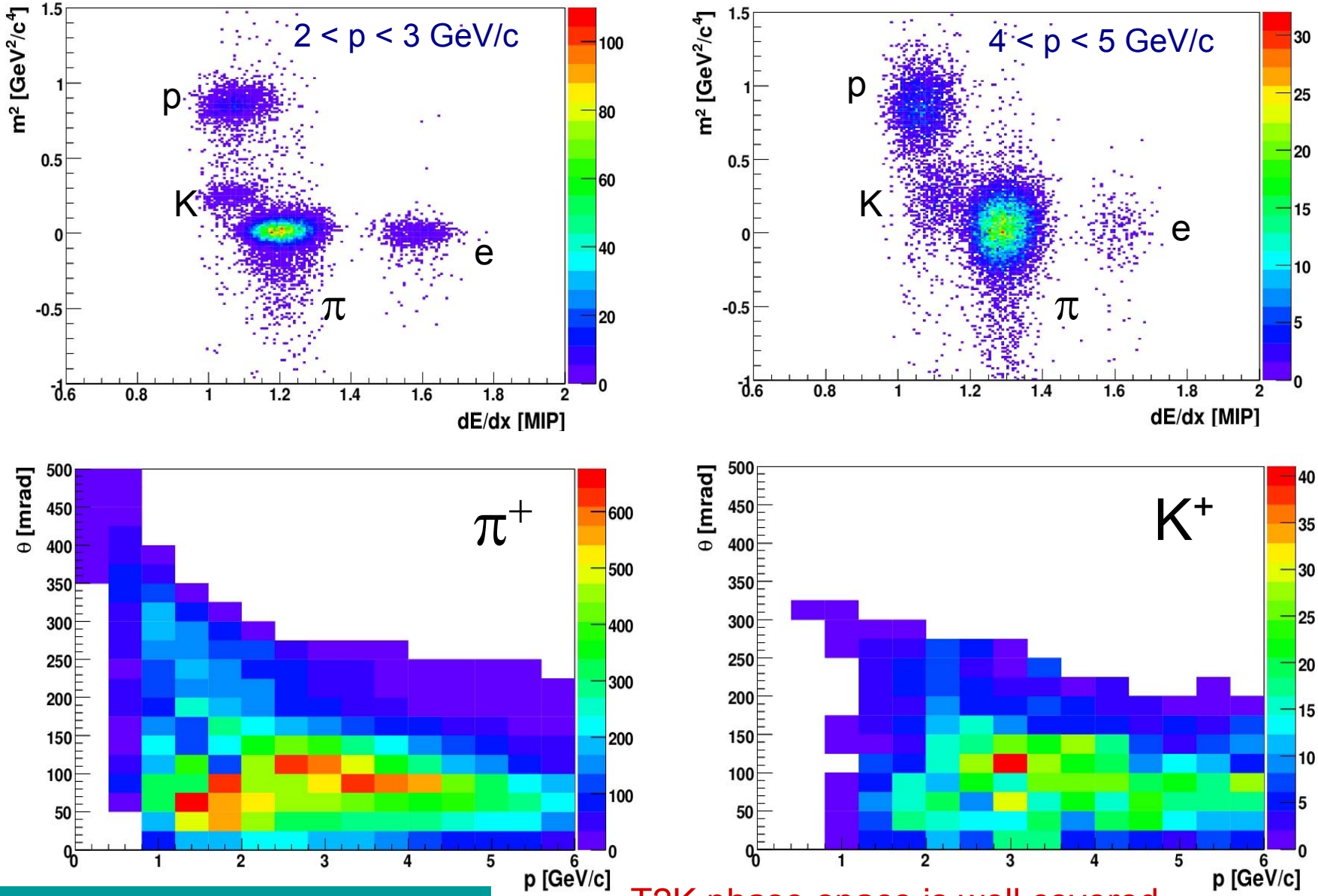


ToF-L/R raw spectrum



NA61 : PID by combined dE/dx and TOF measurements

ToF-F and TPCs



T2K phase-space is well covered

CERN-SPS-2008-018 / SPSC-SR-033

NA61 : Original plans for 2008 run

- ~50 days of beam time were foreseen for September – October 2008

  → T2K and cosmic ray measurements

- NA61 Coll. decided for a TPC read-out and DAQ upgrade before the physics run

- an increase of the event rate by a factor of 10 (crucial for NA61 physics program)
- new TPC read-out electronics and DAQ designed and tested in 2008
- total cost 400 k CHF
- the production and installation of the new electronics was completed by mid September
- during the commissioning phase the designed event rate of ~70Hz was reached

New motherboard (1 out of 250)

- In addition to the TPC read-out and DAQ upgrade
  - upgrade of Data Control System for gas, LV, HV and trigger systems to new PCs running Scientific Linux (in place of old Macintoshes)
  - commissioning of new beam position detectors of 5x5 cm^2 area (instead of 3x3 cm^2) to fully cover cross section of the T2K replica target

LHC incident…

NA61 : SUMMARY

- **Significant progress in data calibration and analysis**
  - **Status report to SPSC:** http://cdsweb.cern.ch/record/1113279
- **Good quality of 2007 data, though limited in statistics**
  - **High quality of track reconstruction and particle identification has been achieved**
  - **First preliminary results for the thin target data to be released soon.**
  - **Work on T2K replica target is in progress**
- **Important detector upgrades, TPC read-out and DAQ upgrade**
- **We will hopefully be able to recover the lost beam time during 2009 run**
  - **NA61 has 3 months of beam time in 2009**
- **First preliminary fully corrected hadron spectra for T2K have been obtained and the work continues to make full use of the PID detector capabilities, to minimize systematic biases and to estimate systematic errors**
- **Plan to release first results during this summer**

Thank you for your attention

Backup slides

HARP – PS214 at CERN

HARP collaboration

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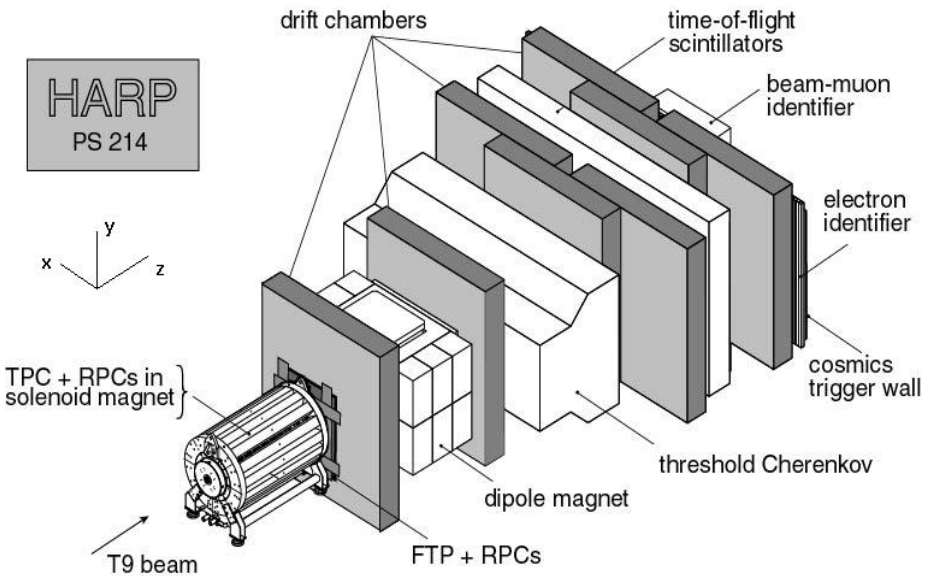
Instituto de Física Corpuscular, IFIC, CSIC and Universidad de Valencia, Spain

24 institutes
~120 collaborators

forward spectrometer

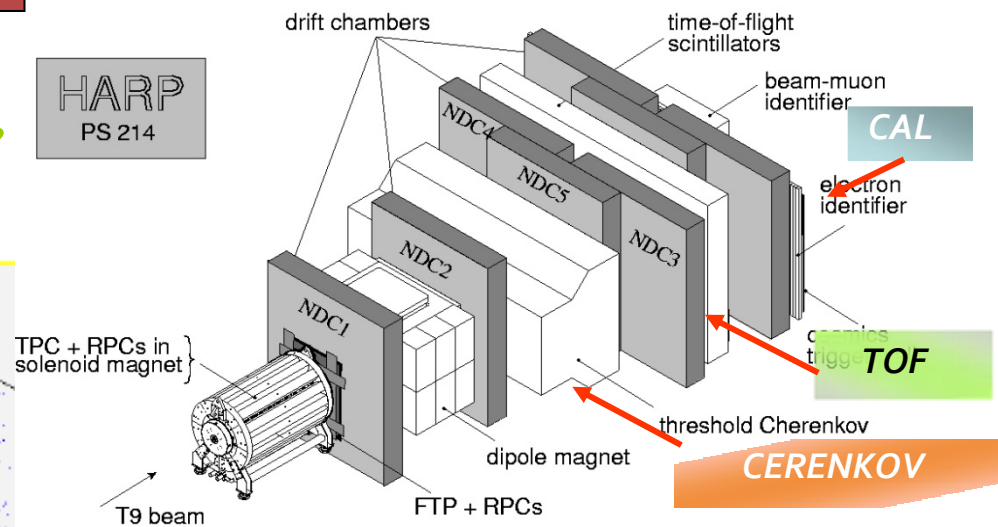


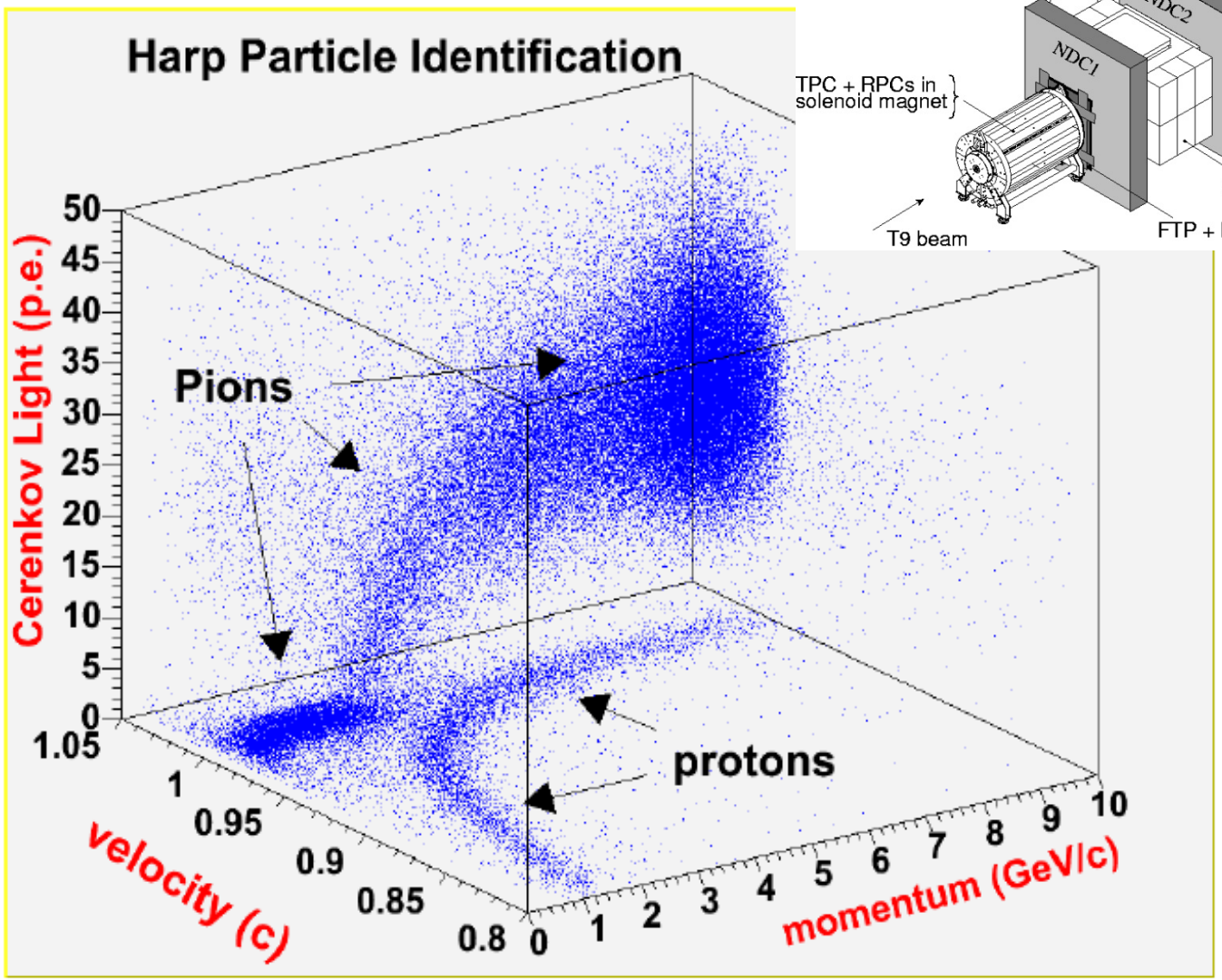
large-angle spectrometer

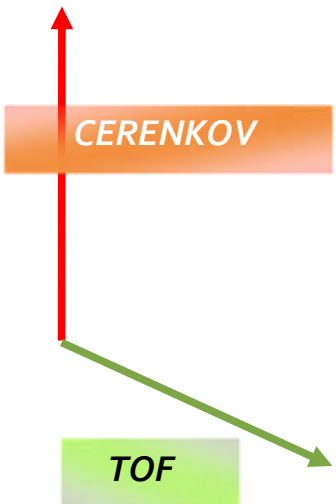
Detailed description of the experimental apparatus

NIM A571 (2007) 524

FW: PID principle

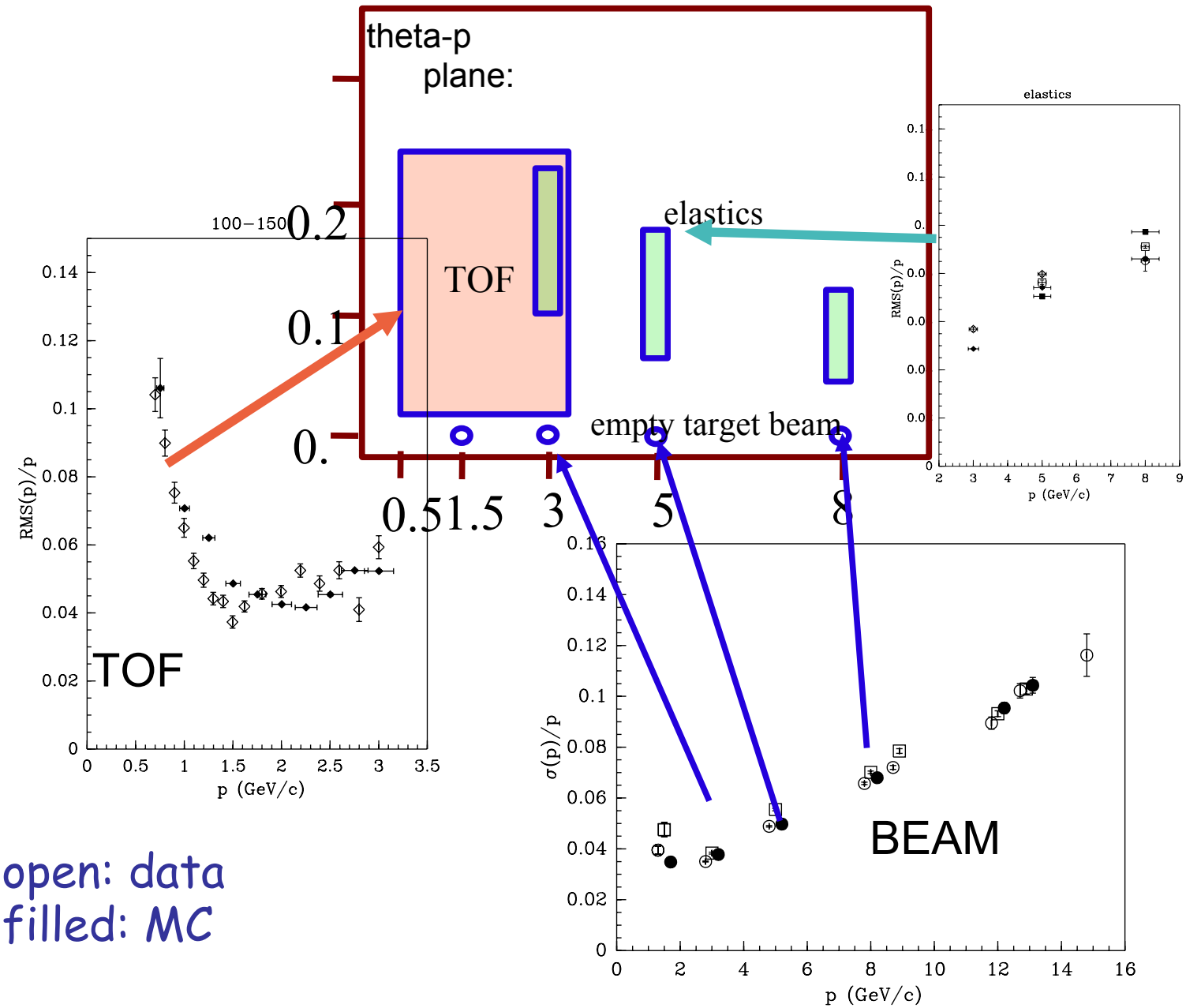






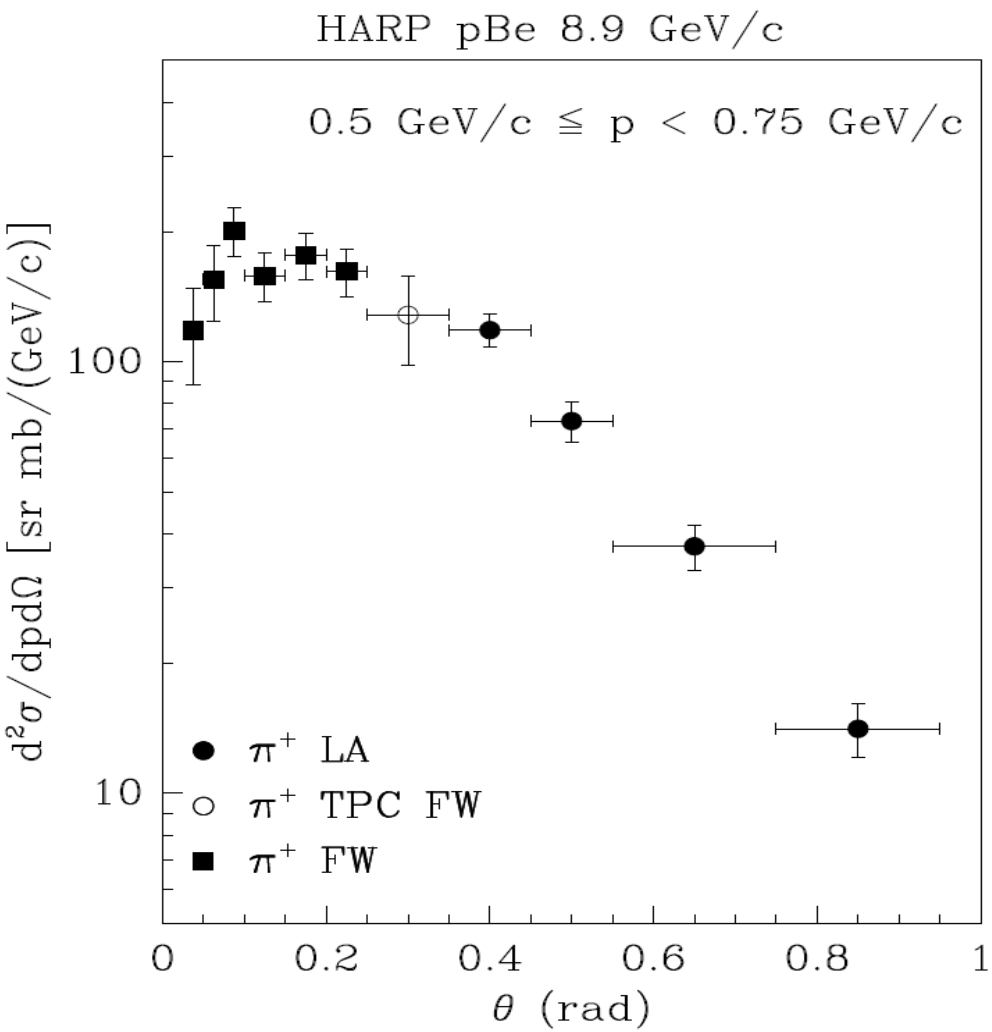
FW: Momentum Resolution

ELASTICS

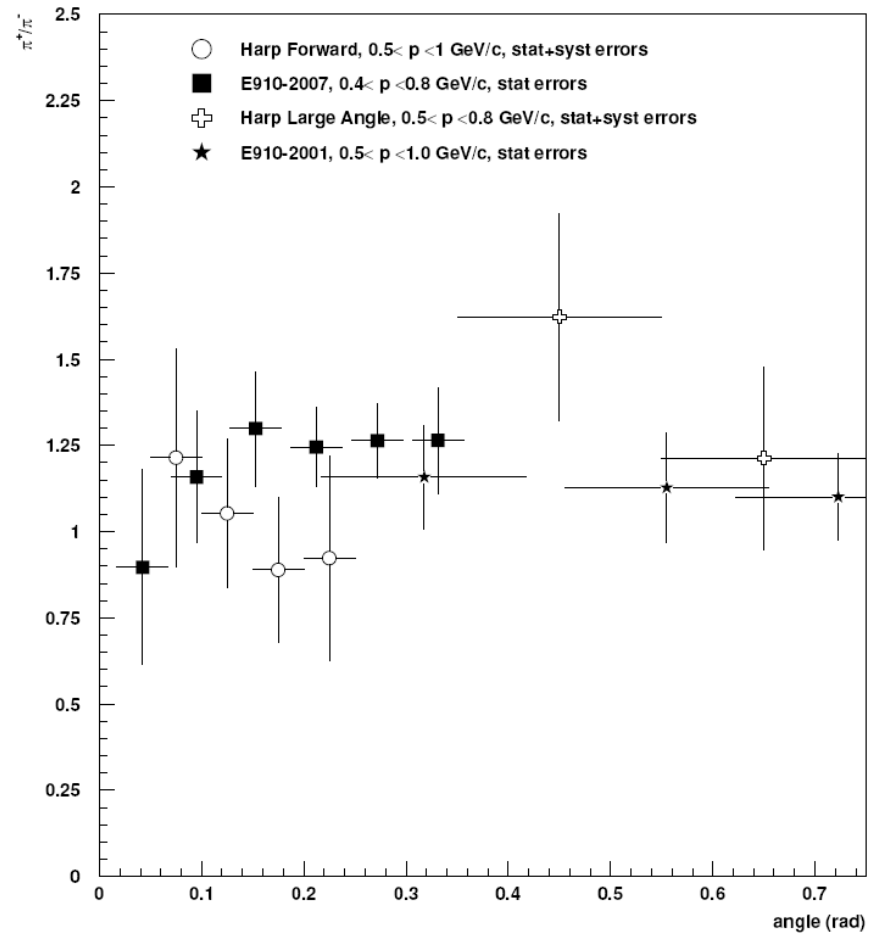


open: data
filled: MC

HARP: two spectrometers match each other

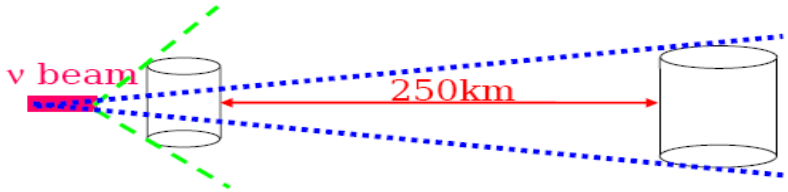


π^+ / π^- ratio in pBe at 12 GeV/c

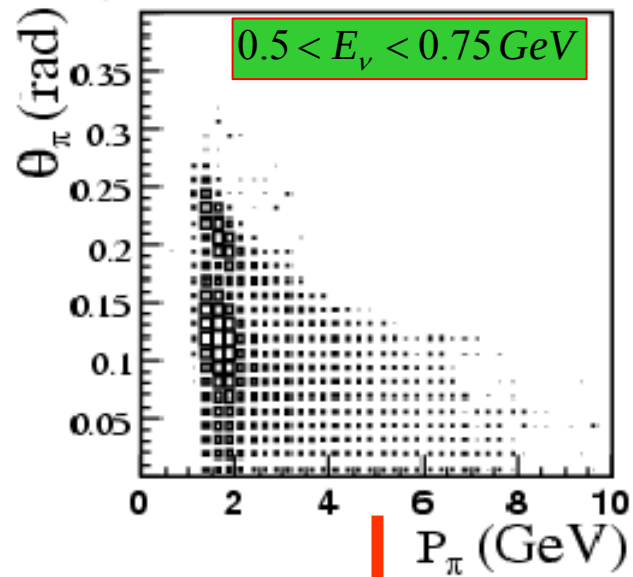


Relevance of HARP for K2K neutrino beam

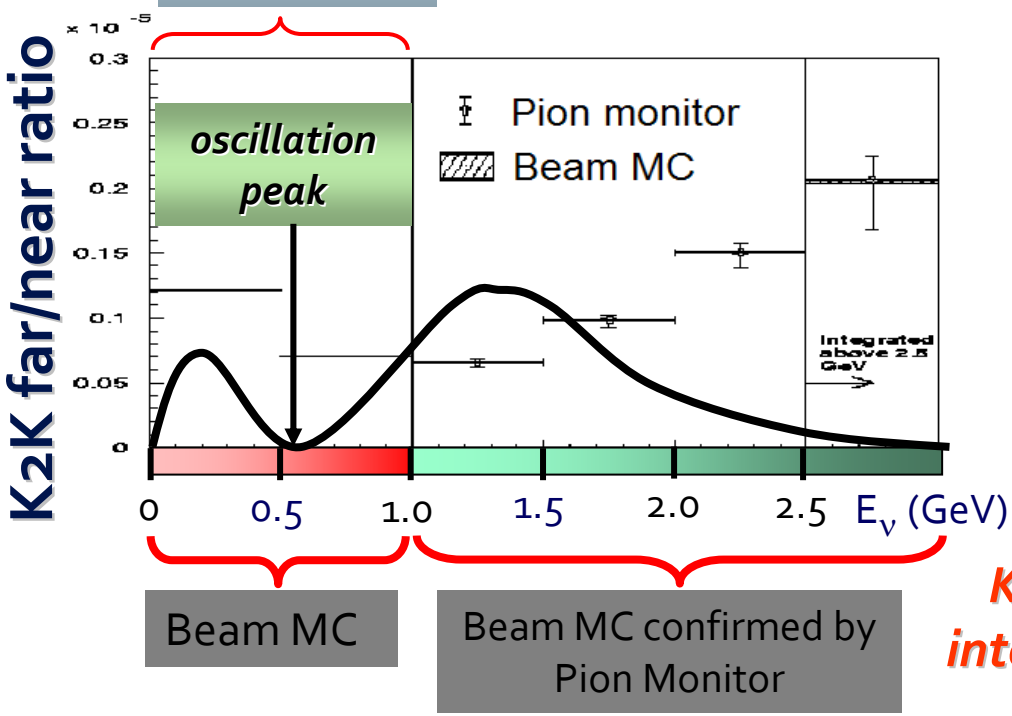
One of the largest K2K systematic errors comes from the uncertainty of the far/near ratio



pions producing neutrinos in the oscillation peak



measured by HARP



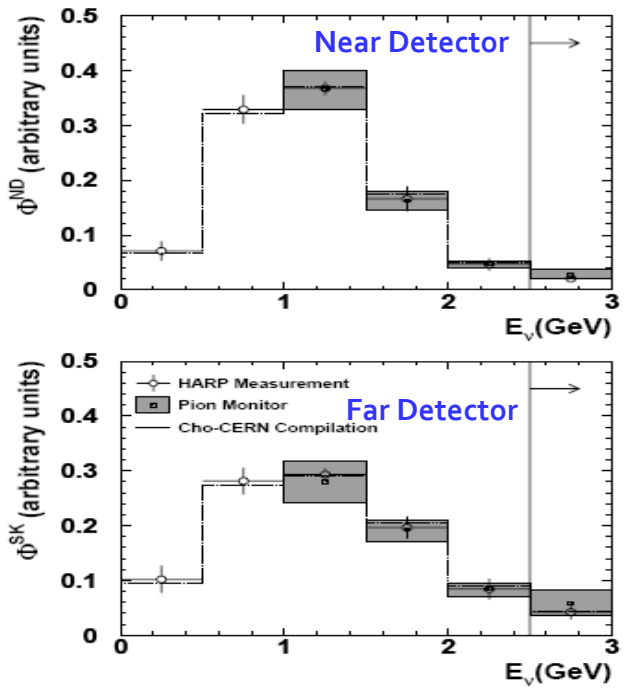
K2K interest

$$P_\pi > 1\,GeV$$

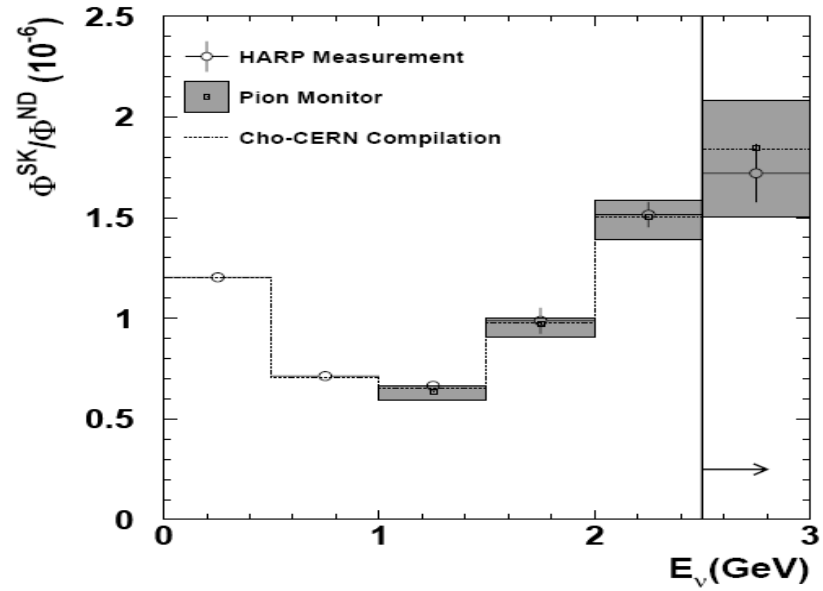
$$\theta_\pi < 250\,mrad$$

Far/Near Ratio in K2K

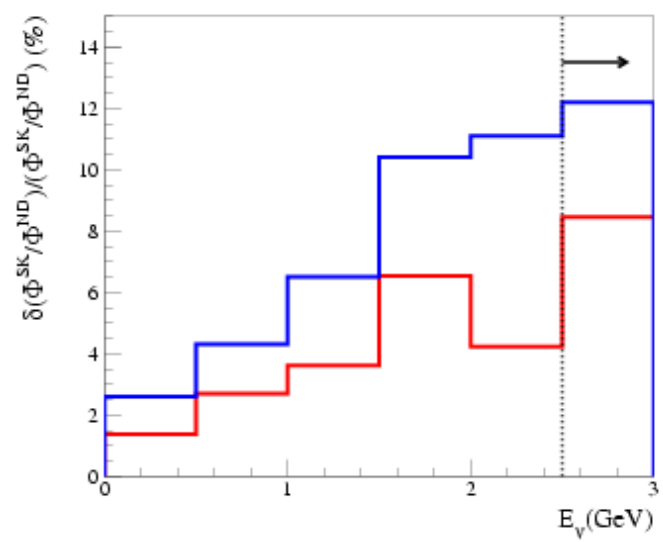
Predicted Flux Shape



Predicted Far/Near Ratio



HARP gives ~ factor of 2 error reduction across all energies

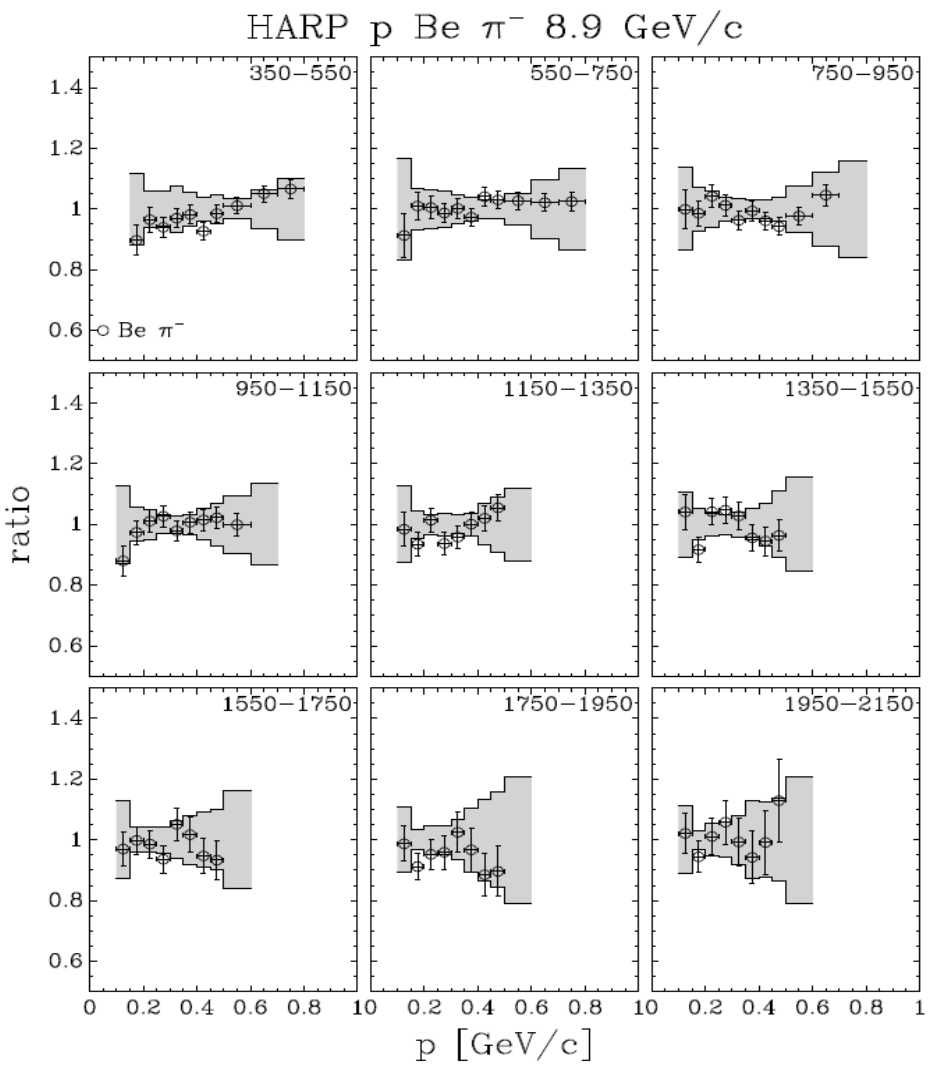


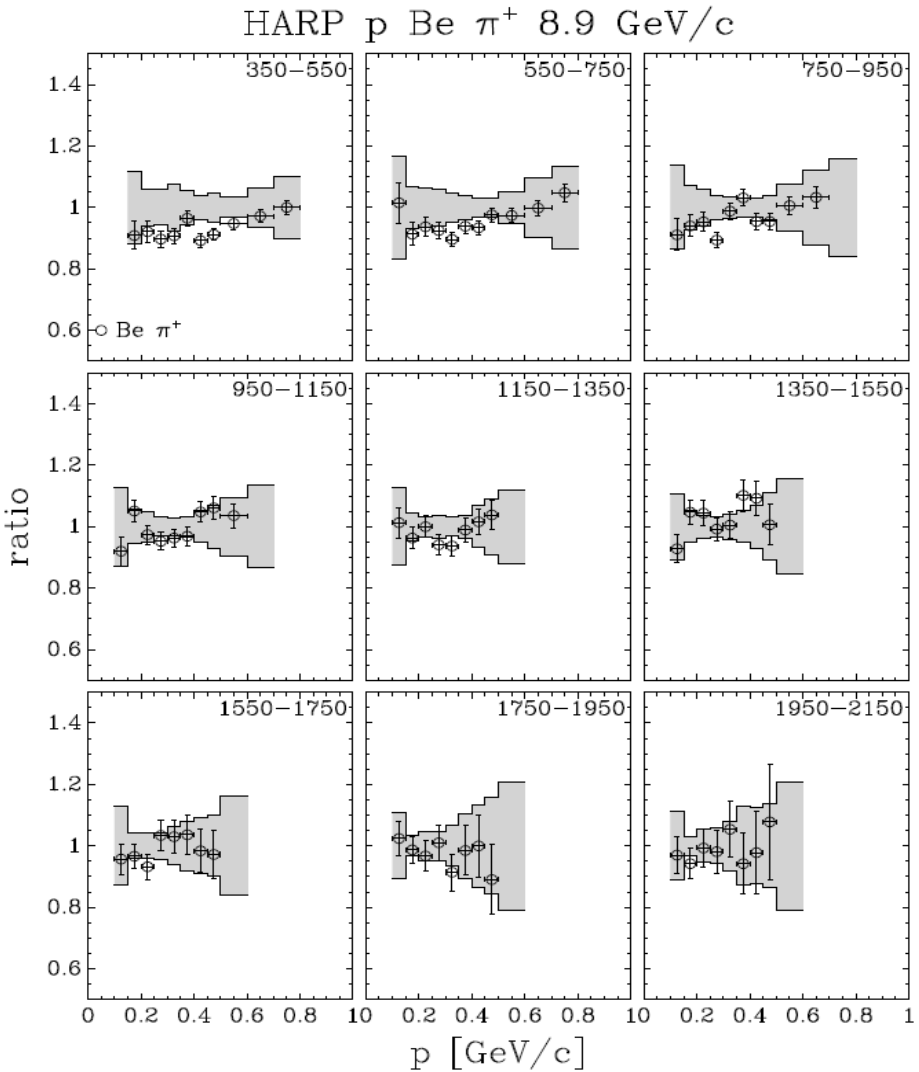
Nucl.Phys.B732:1-45,2006
hep-ex/0510039

HARP: p-Be

Corrections for dynamic distortions: ratio of the cross-sections without and with corrections

Phys. Rev. C 77 (2008) 055207

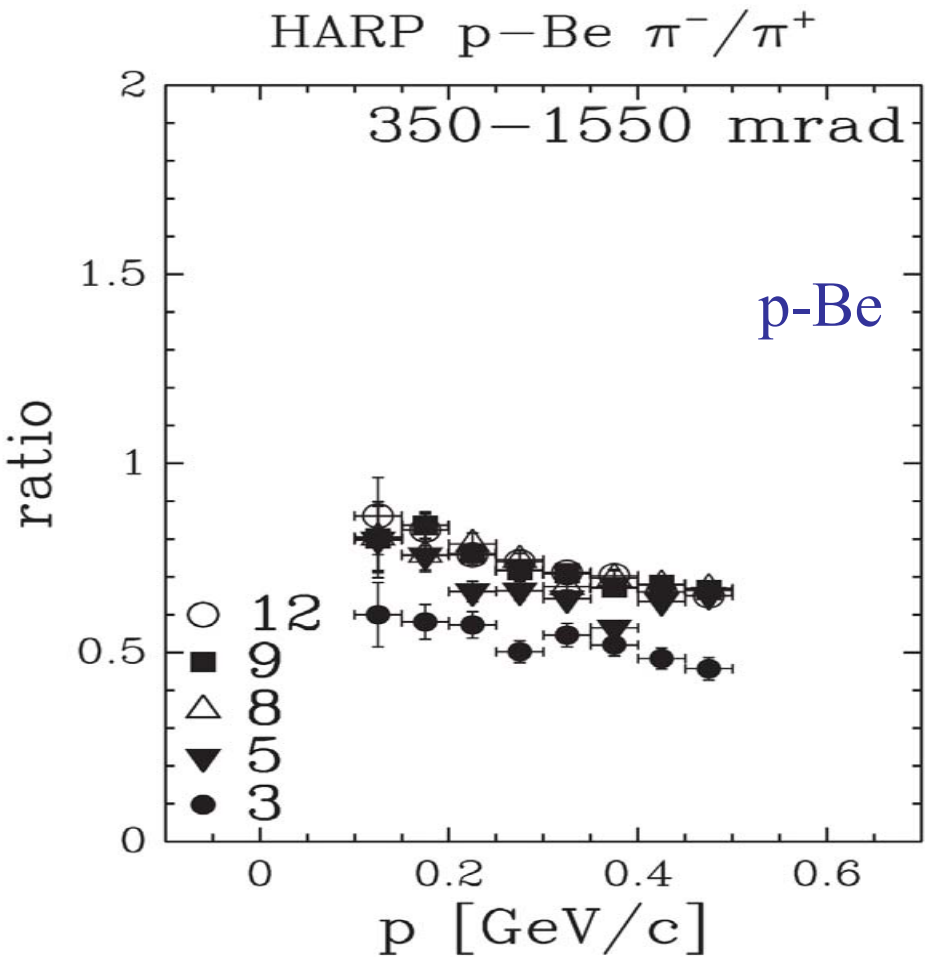


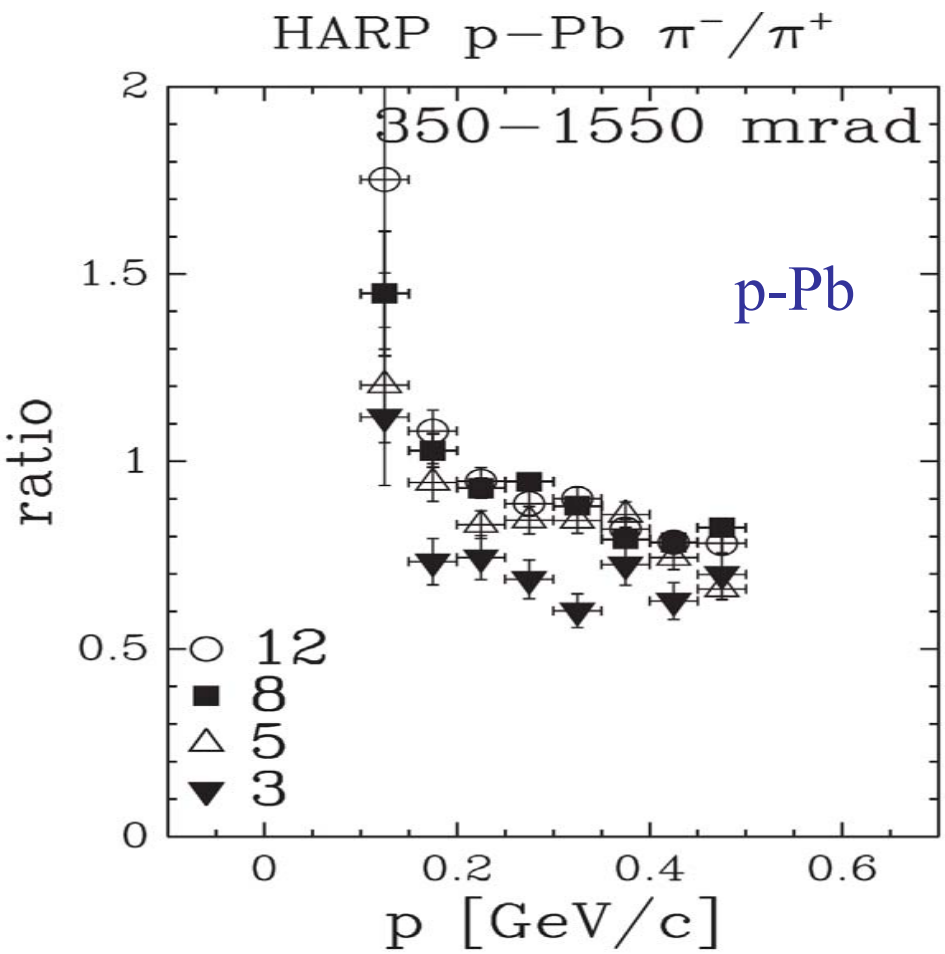


HARP: pion yields

comparison of π^-/π^+ ratio for light and heavy nuclei

forward production only $350 < \theta(\text{mrad}) < 1550$



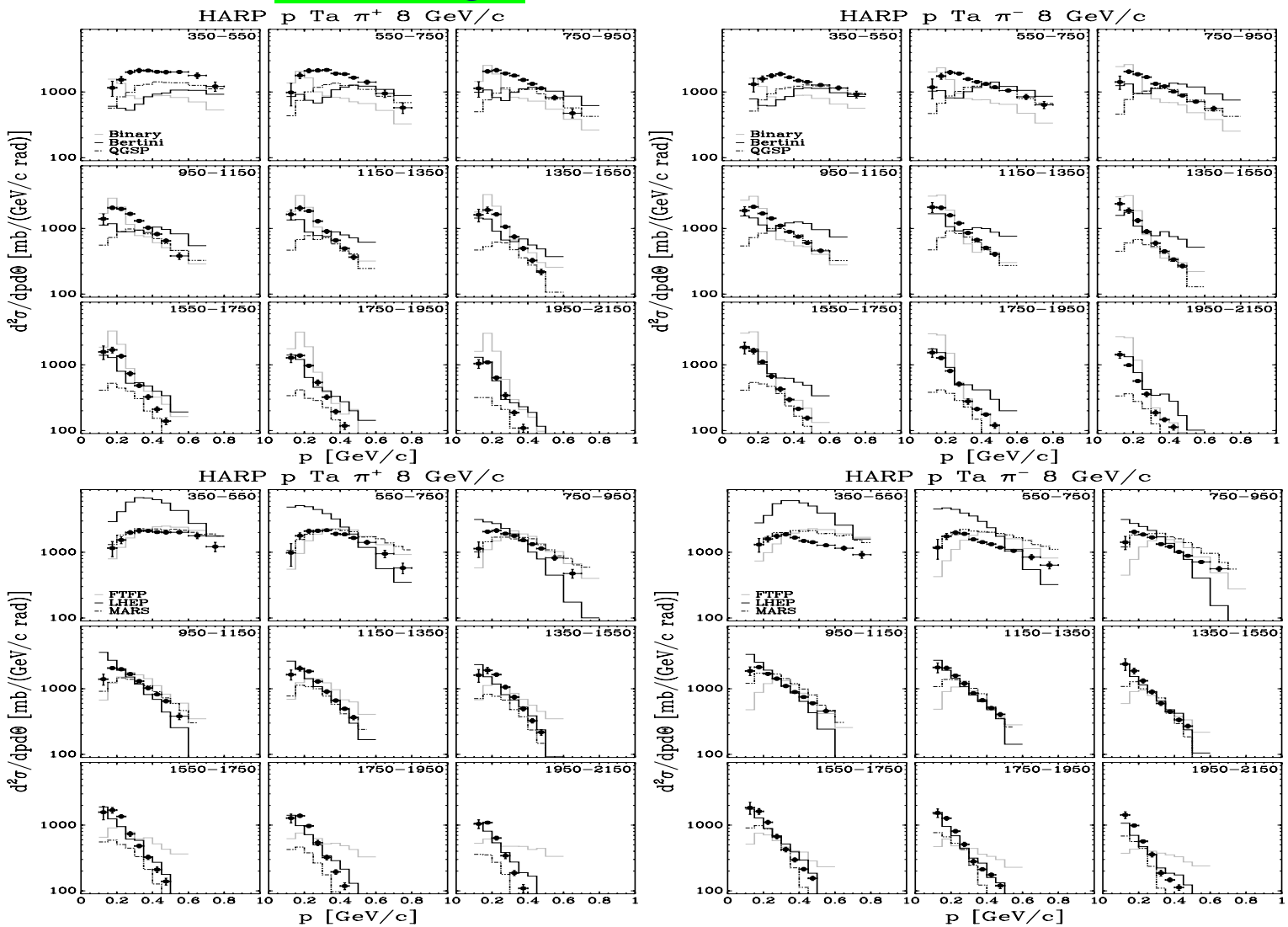


Phys. Rev. C 77 (2008) 055207

8 GeV/c p-Ta $\pi^{+/-}$

5% λ target

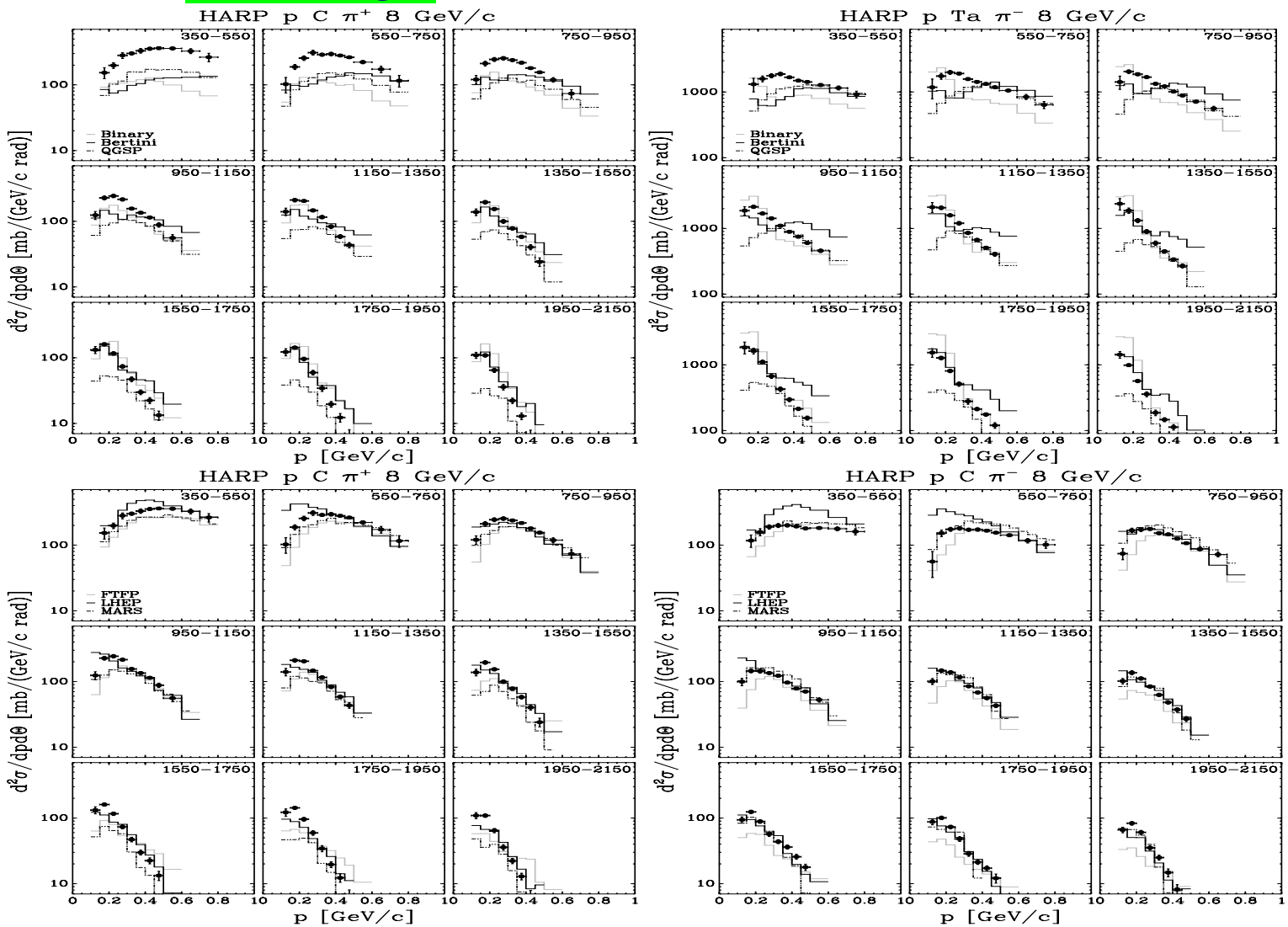
MODELS



8 GeV/c p-C $\pi^{+/-}$

5% λ target

MODELS



HARP: comparison with MC at LA

1. **Data available on many thin (5%) targets from light nuclei (Be) to heavy ones (Ta,Pb)**
2. **Comparisons with GEANT4 and MARS15 MonteCarlo show large discrepancies both in normalization and shape**
   - **Backward or central region production seems described better than more forward production**
   - **At higher energies FTP models (from GEANT4) and MARS look better, at lower energies this is true for Bertini and binary cascade models (from GEANT4)**
   - **In general π^+ production is better described than π^- production**
   - **Parametrized models (such as LHEP) have big discrepancies**

– **CONCLUSIONS: MCs need tuning with HARP data for p_{inc}< 15 GeV/c**

NA61 : COLLABORATION

121 physicists from 24 institutes and 14 countries:

University of Athens, Athens, Greece
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
KFKI IPNP, Budapest, Hungary
Cape Town University, Cape Town, South Africa
Jagiellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Fachhochschule Frankfurt, Frankfurt, Germany
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
Forschungszentrum Karlsruhe, Karlsruhe, Germany
Swietokrzyska Academy, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
LPNHE, Universites de Paris VI et VII, Paris, France
Pusan National University, Pusan, Republic of Korea
Faculty of Physics, University of Sofia, Sofia, Bulgaria
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
KEK, Tsukuba, Japan
Soltan Institute for Nuclear Studies, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
University of Warsaw, Warsaw, Poland
Rudjer Boskovic Institute, Zagreb, Croatia
ETH Zurich, Zurich, Switzerland

NA61 : DOCUMENTS AND REFERENCES

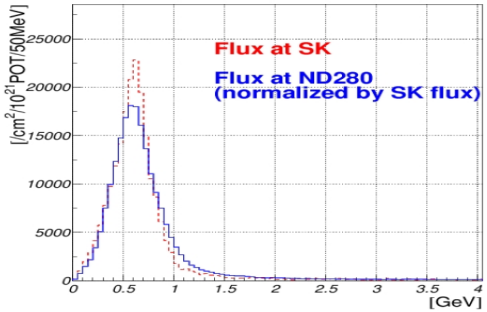
Status Report: CERN-SPSC-2008-018, SPSC-SR-033 (July 2, 2008)

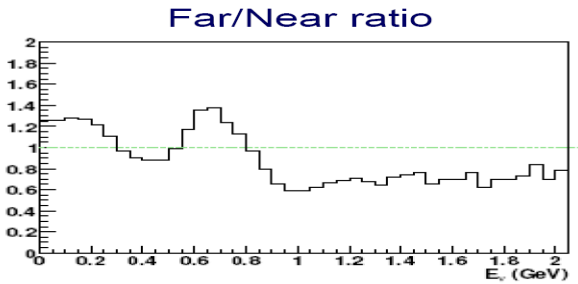
Addendum-3 CERN-SPSC-2007-033, SPSC-P-330 (November 16, 2007)
Addendum-2: CERN-SPSC-2007-019, SPSC-P-330 (June 15, 2007)
Addendum-1: CERN-SPSC-2007-004, SPSC-P-330 (January 25, 2007)
Proposal: CERN-SPSC-2006-034, SPSC-P-330 (November 3, 2006)
Status Report: CERN-SPSC-2006-023, SPSC-SR-010 (September 5, 2006)
LoI: CERN-SPSC-2006-001, SPSC-I-235 (January 6, 2006)
EoI: CERN-SPSC-2003-031, SPSC-EOI-001 (November 21, 2003)

Report from the NA61/SHINE experiment at the CERN SPS, CERN-OPEN-2008-012
Na61/Shine at the CERN SPS, CPOD 2007, arXiv:0709.1867

NA61 : Physics Goals (II)

- **Main aims of T2K:**
  - o **Search for and measurement of the $\nu_\mu \rightarrow \nu_e$ appearance**
    - » **improved sensitivity to the so far unknown mixing angle θ_{13}**
  - o **Refinement of ν_μ disappearance measurements**
    - » **improved determination of θ_{23} and Δm^2_{23}**





- **Both analyses rely on the comparison of ν spectra measured at SK and the extrapolated spectra at SK from the ND measurement:**

Extrapolated at SK

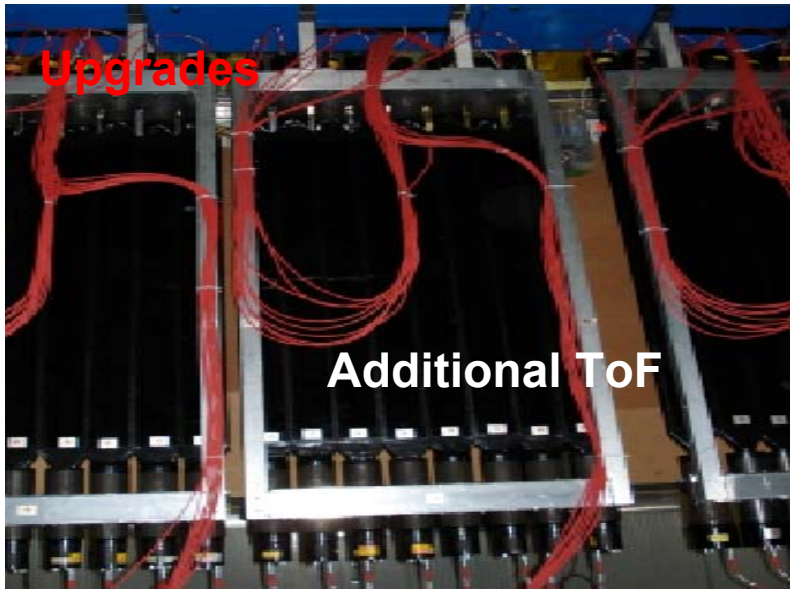
$$\Phi^{SK}_{\mu,e}(E_\upsilon) = R_{\mu,e}(E_\upsilon) \times \Phi^{ND}_{\mu,e}(E_\upsilon)$$

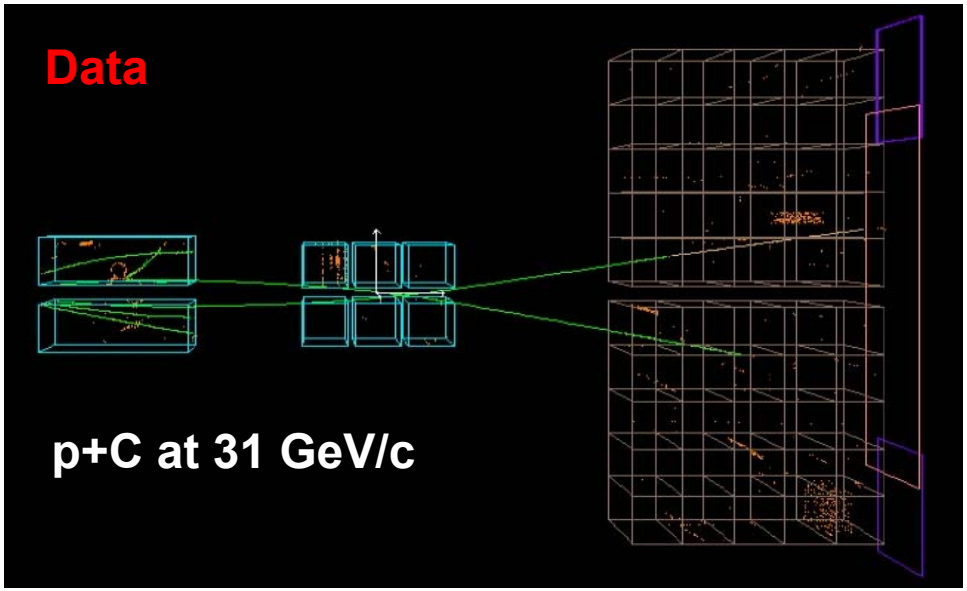
Measured at ND

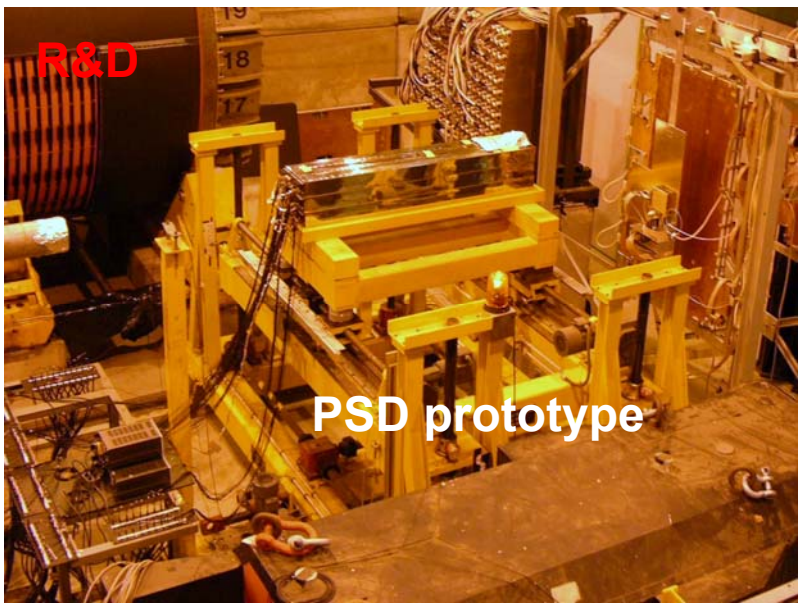
- **Far to Near (F/N) ratio R:** **is not constant with respect to the ν energy and therefore depends on the particle production properties**

→ To fulfill the T2K goals detailed information on the pion and kaon production off the T2K target is needed!

NA61 : 2007 PILOT RUN







-event visualization of data after different stages of reconstruction and in different formats