NEW RESULTS FROM HARP (mainly for atmospheric ν)

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

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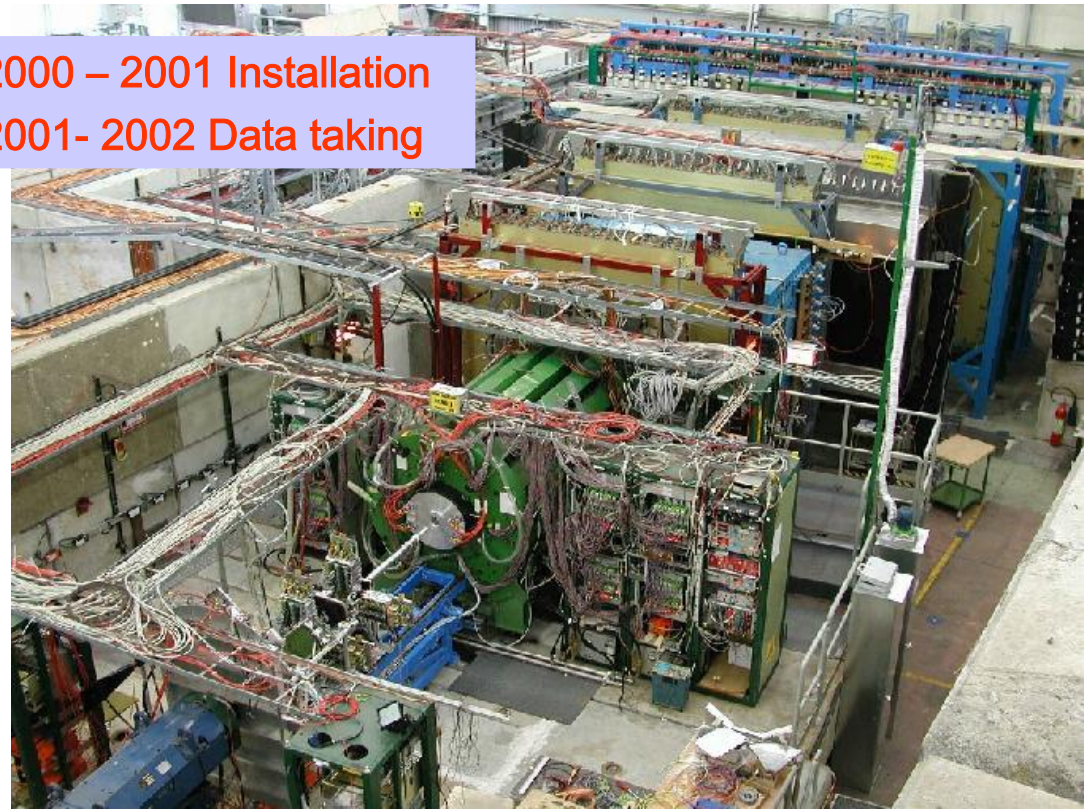
Physics goals of HARP

2000 – 2001 Installation
2001- 2002 Data taking



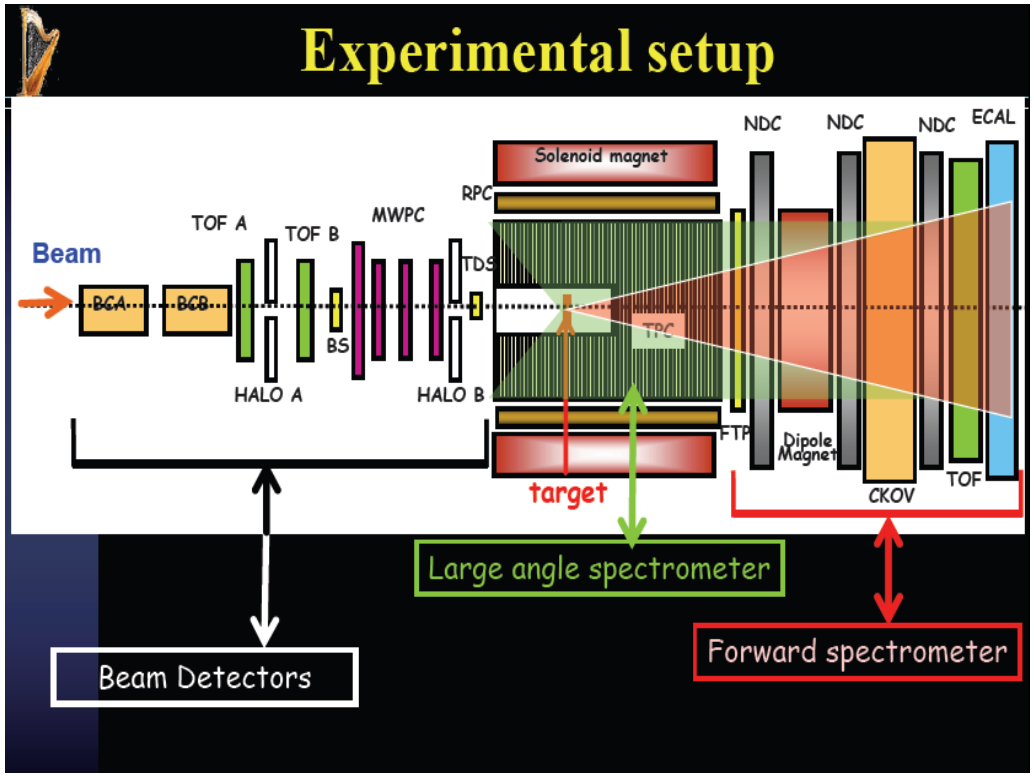
Systematic study of hadron production:
Beam momentum: 3-15 GeV/*c*
Target: from hydrogen to lead
•Acceptance over full solid angle
•Final state particle identification

•Input for prediction of neutrino fluxes for the MiniBooNE and K2K experiments

•Pion/Kaon yield for the design of the proton driver of neutrino factories and SPL- based super-beams

•Input for precise calculation of the atmospheric neutrino flux and EAS

•Input for Monte Carlo generators (GEANT4, e.g. for LHC or space applications)

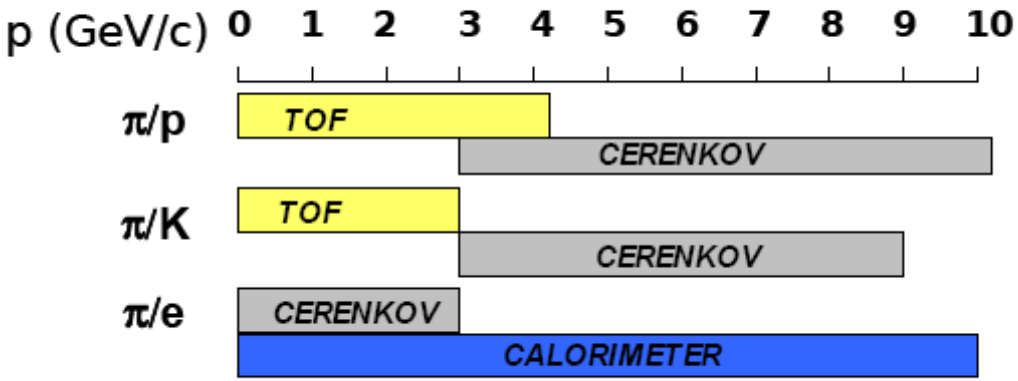


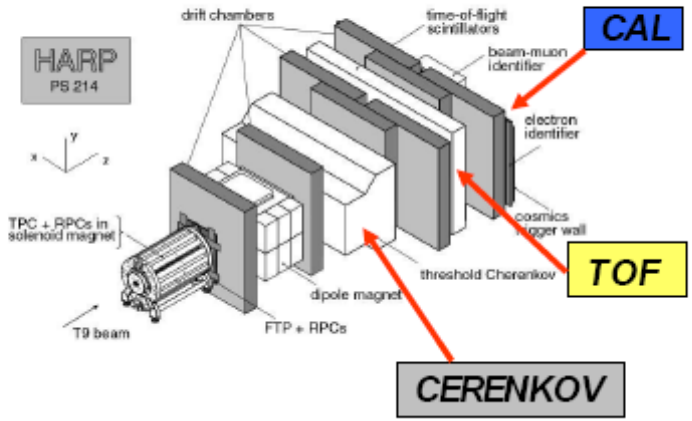
Harp detector layout and data taken .

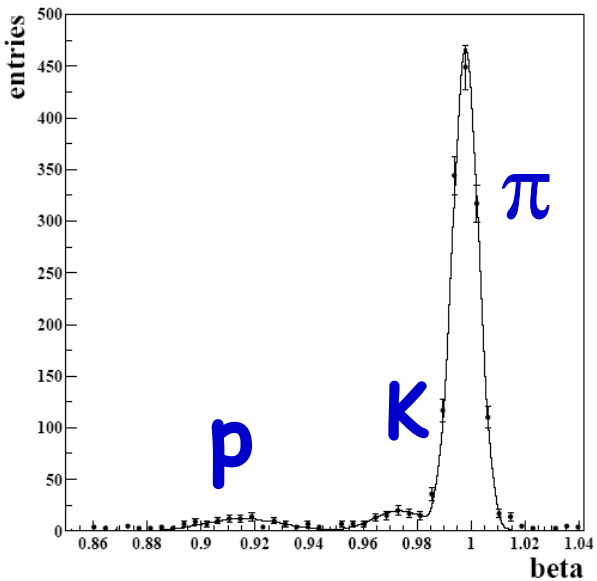
Barrel spectrometer (TPC) + forward spectrometer (DCs) to cover the full solid angle, complemented by PID detectors

	Targetl	Target length (λ%)	Beam Momentum (GeV)	#events (Mevts)
Solid targets	Be	2 (2001) 5 100	±3 ± 5 ± 8 ± 12 ± 15 For negative polarity, only 2% and 5%	233.16
	C			
	Al			
	Cu			
	Sn			
	Ta			
	Pb			
K2K	Al	5, 50, 100, replica	+12.9	15.27
MiniBooNE	Be		+8.9	22.56
Cu "button"	Cu		+12.9, +15	1.71
Cu "skew"	Cu	2	+12	1.69
Cryogenic targets	N_7	6 cm	±3 ± 5 ± 8 ± 12 ± 15	58.43
	0_8			
	D_1			
	H_1			
	H_2	18 cm	±3, ±8, ±14.5	13.83
Water	H_20	10, 100	+1.5, +8(10%)	9.6

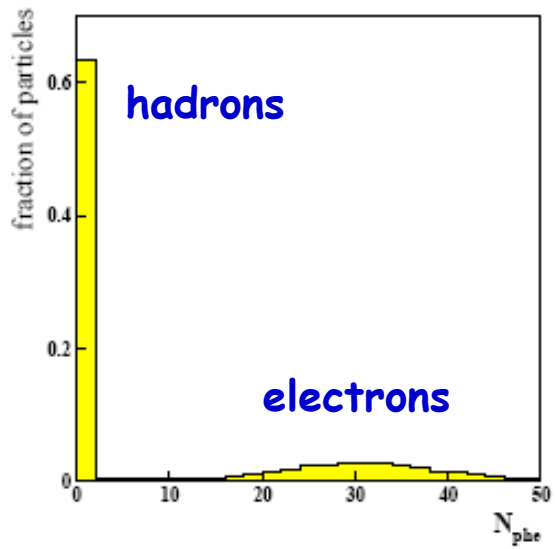
HARP forward Particle identification



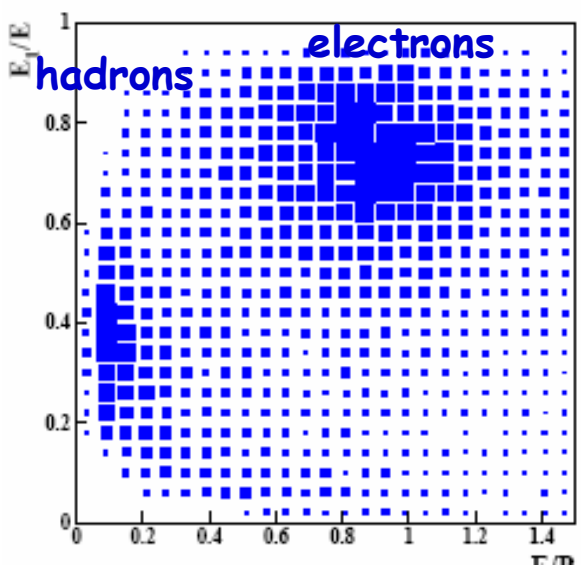




TOF for p=2+-0.25

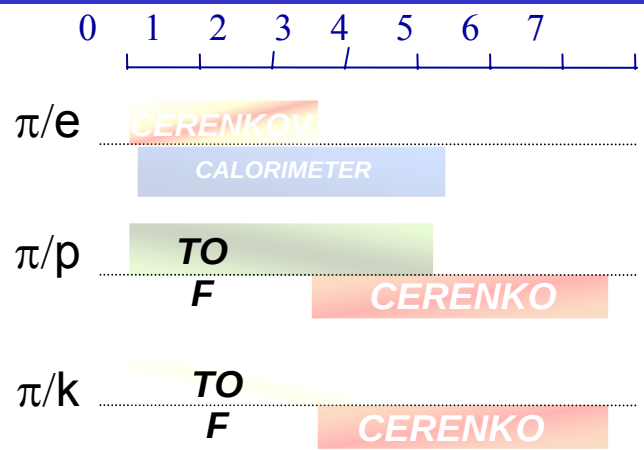


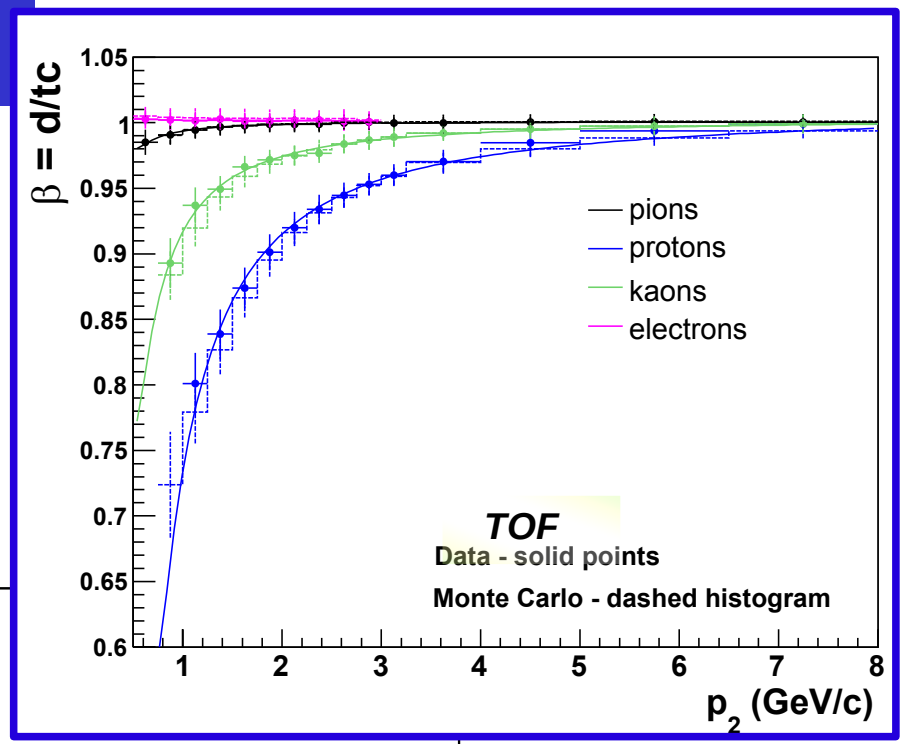
$N_{cherenkov}$
for p below pion threshold

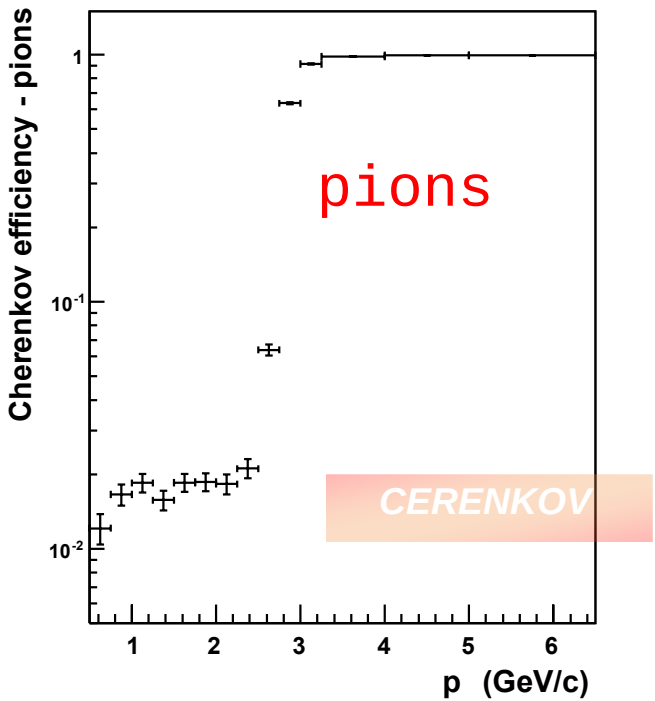


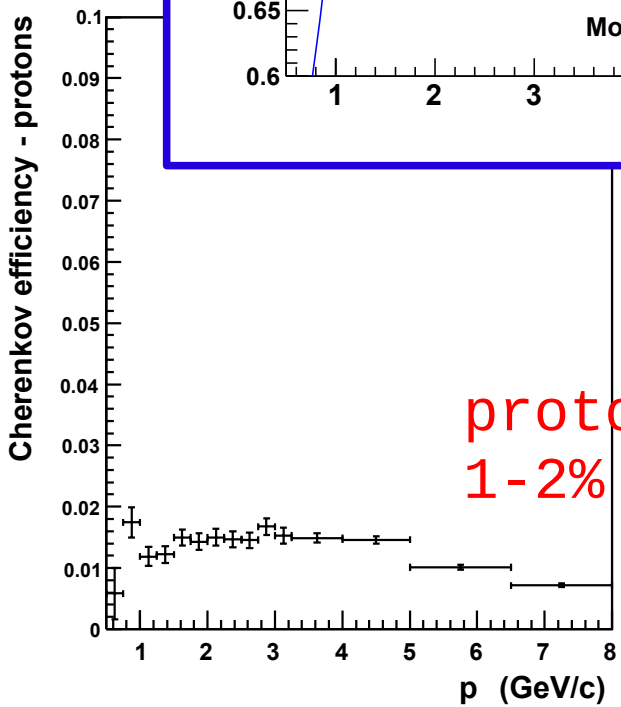
Calorimeter
E/p and E(1st layer)/E
for p above pion threshold

PID performance



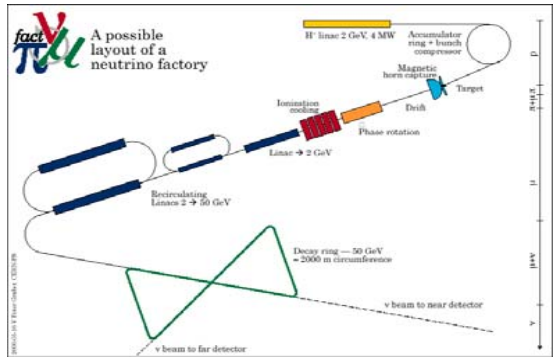


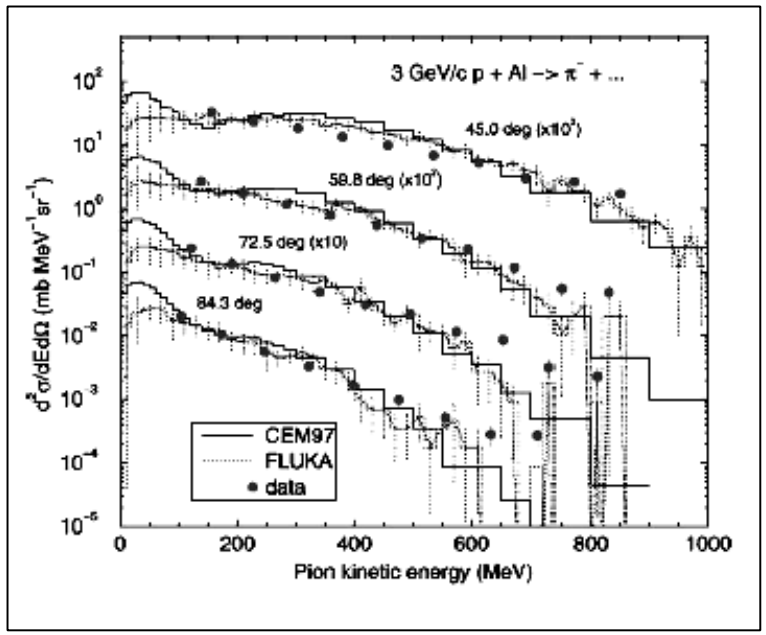




ν factory design

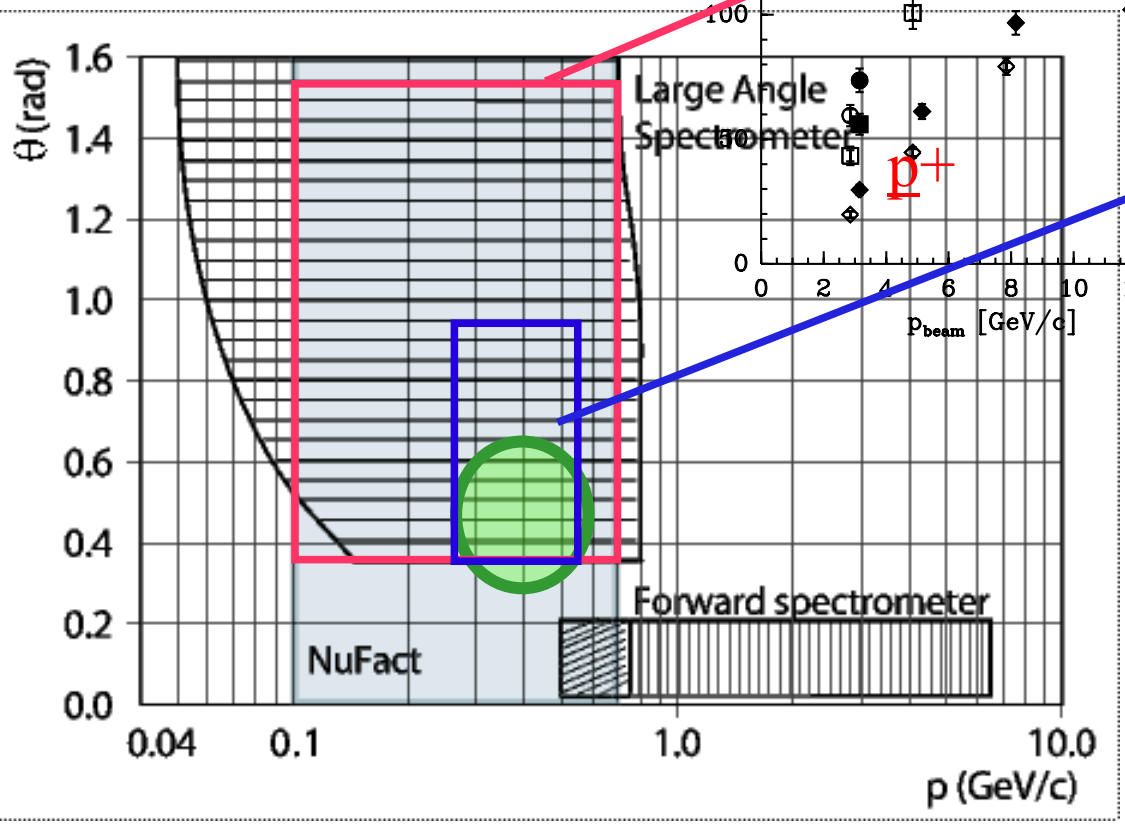
- maximize $\pi^+(\pi^-)$ production yield as a function of:
  - proton energy
  - target material
  - geometry
  - collection efficiency (p_L,p_T)
- but different simulations show large discrepancies for π production distributions, both in shape and normalization. Experimental knowledge is rather poor (large errors: poor acceptance, few materials studied)

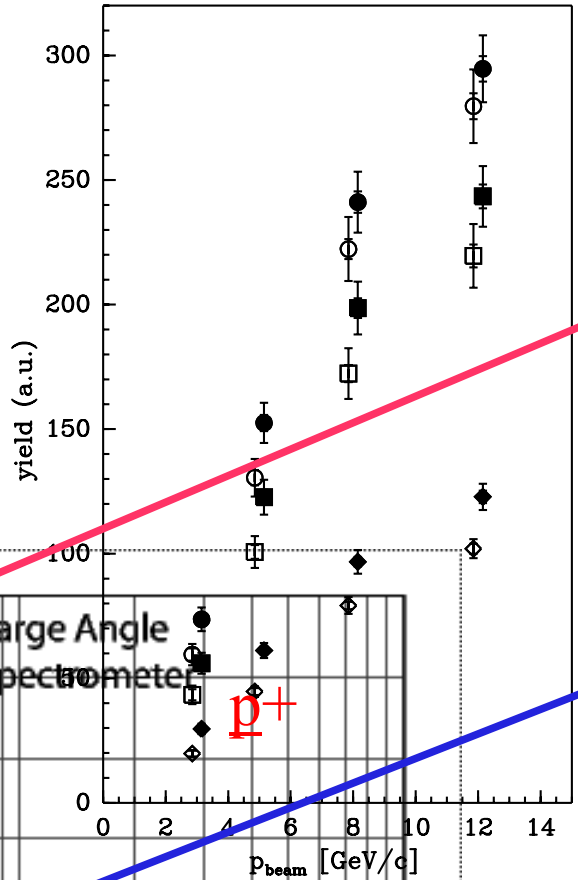


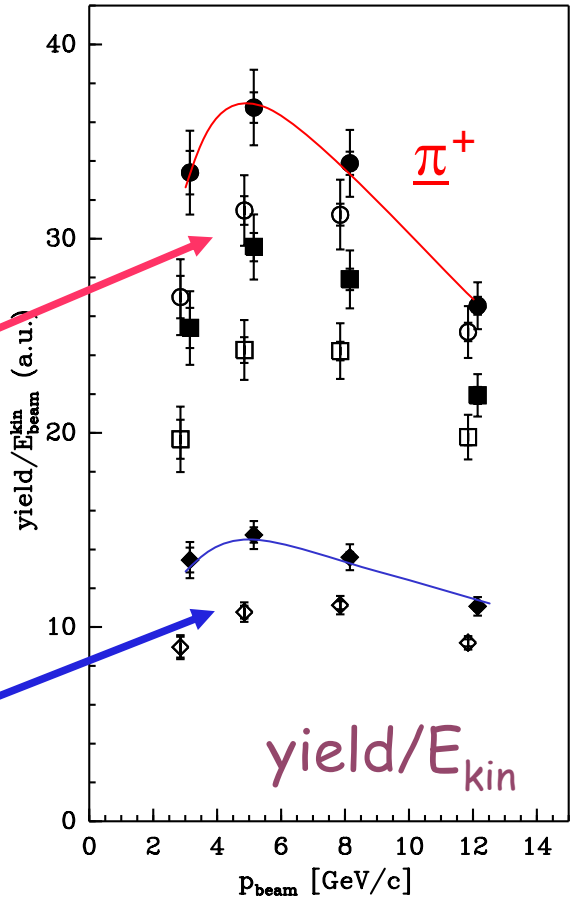


⇒ aim: measure p_T distribution with high precision for high Z targets

Neutrino factory study







Cross-sections to be fed into neutrino factory studies to find optimum design: Ta and Pb x-sections at large angle (see Eur. J. Phys C51 (2007) 787)

ν beams flux prediction

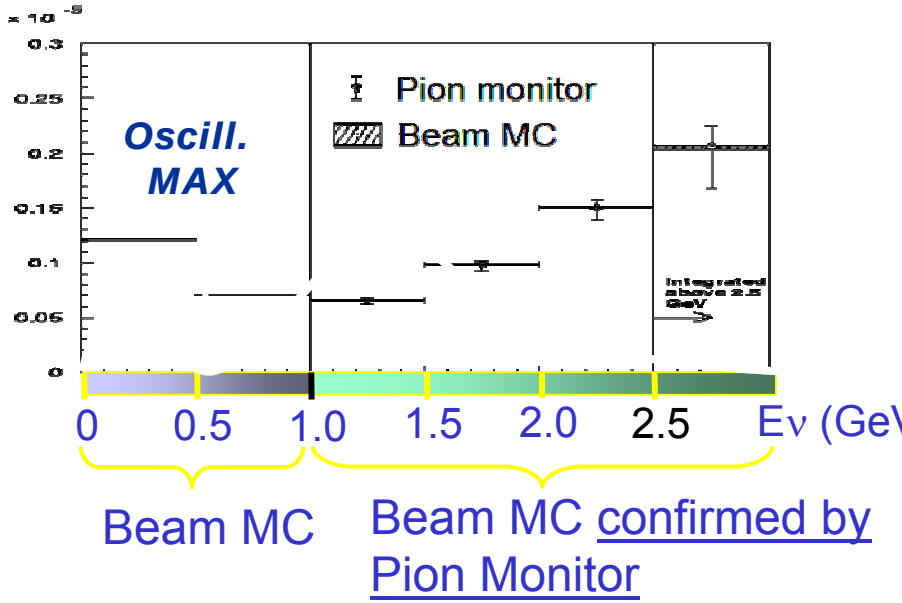
- *Energy, composition, geometry of a neutrino beam is determined by the development of the hadron interaction and cascade ⇒ needs to know π spectra, K/ π ratios*

  - K2K : Al target, 12.9 GeV/c

Al targets 5%, 50%, 100% λ (all p_{beam}), K2K target replica (12.9 GeV/c)

➔ **special program with K2K replica target**

M.G. Catanesi et al., HARP, Nucl. Phys. B732 (2006)1
M. H. Ahn et al., K2K, Phys. Rev. D74 (2006) 072003.



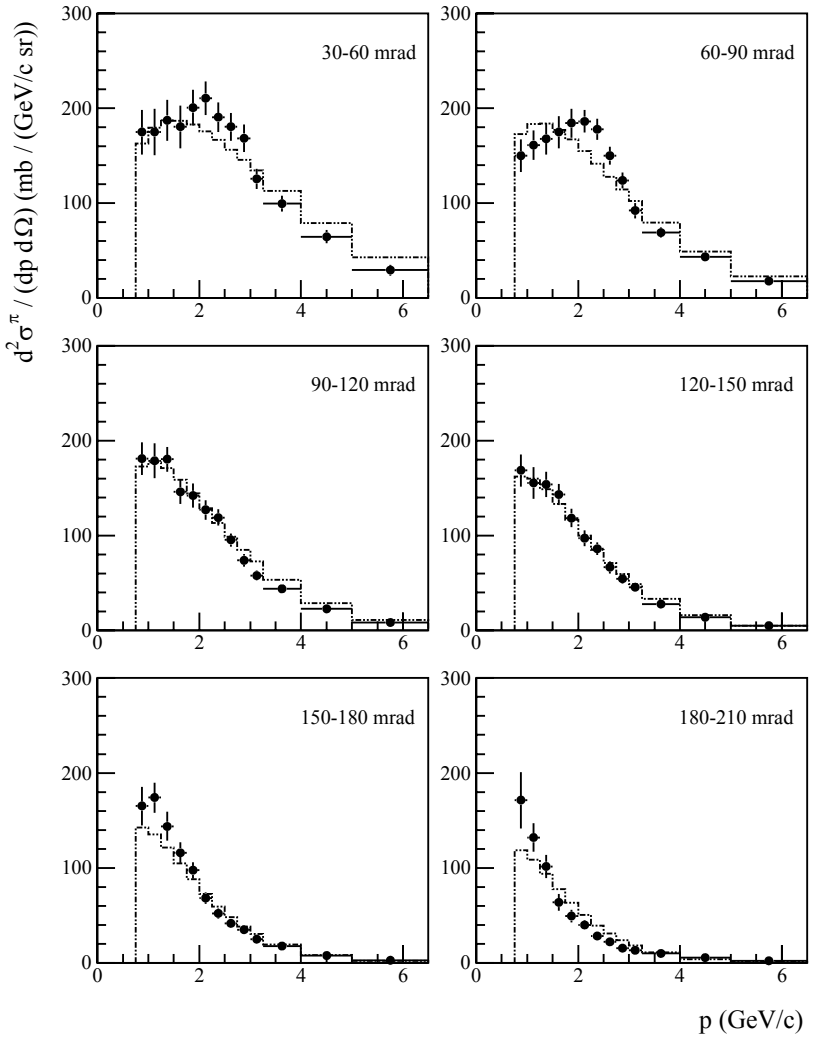
  - MiniBooNE: Be target 8.9 GeV/c

M.G. Catanesi et al., HARP, Eur. Phys. J. C52(2007) 29

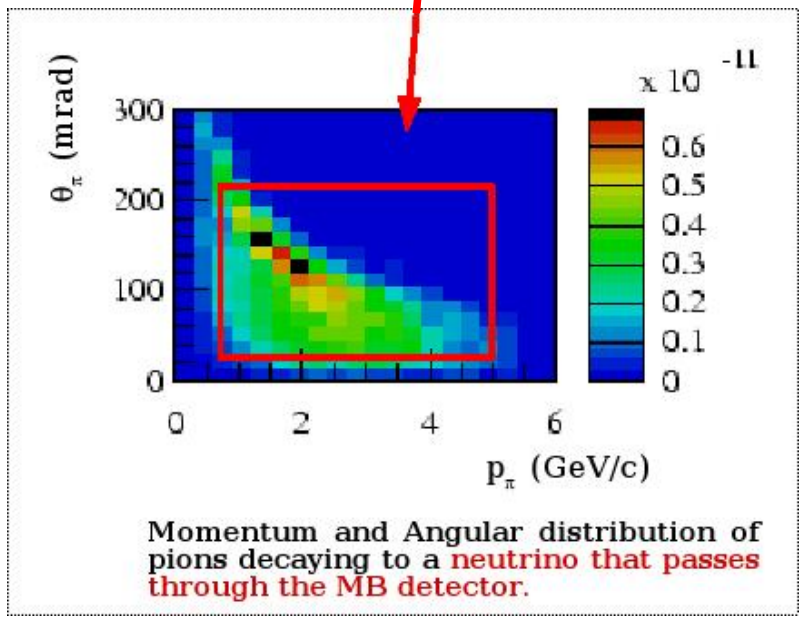
Be targets: 5%, 50%, 100% λ, MiniBoone target replica

Precise p_T and p_L spectra for extrapolation to far detectors and comparison between near and far detectors

HARP Be 5% 8.9 GeV/c Results

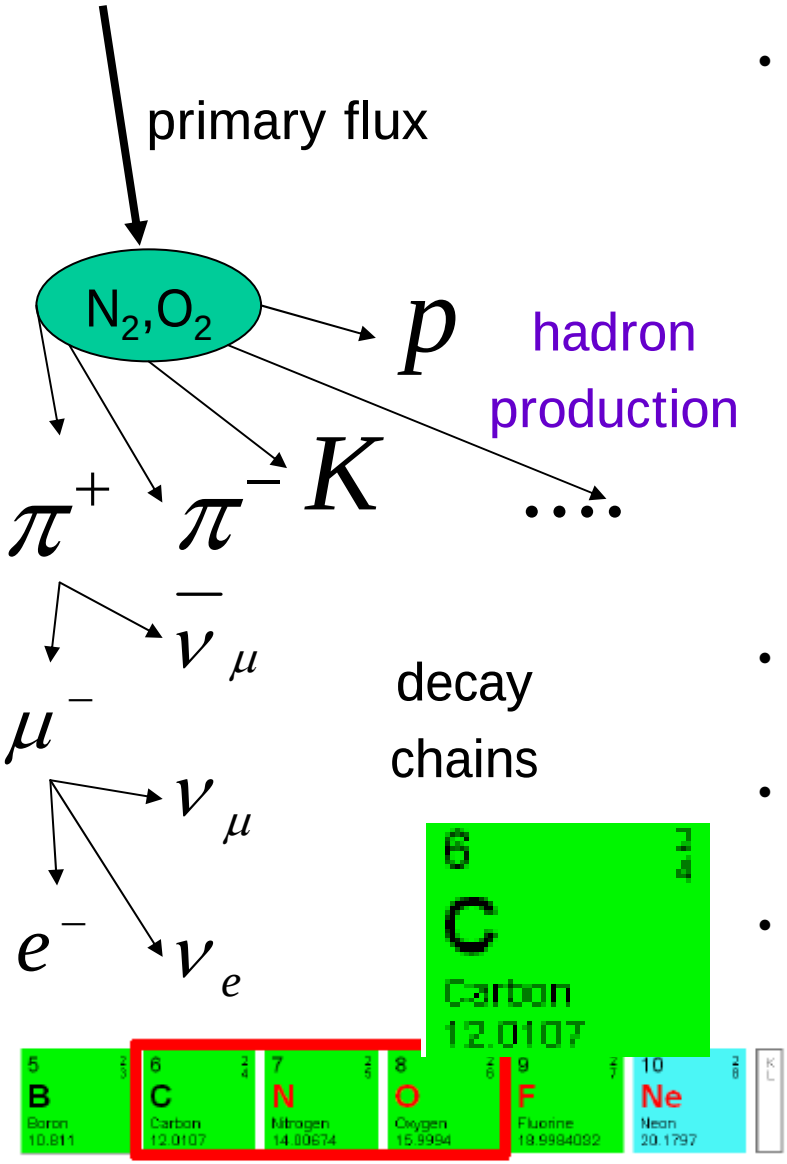


0.75<p<5 GeV/c
30<theta<210 mrad
relevance for MiniBooNE

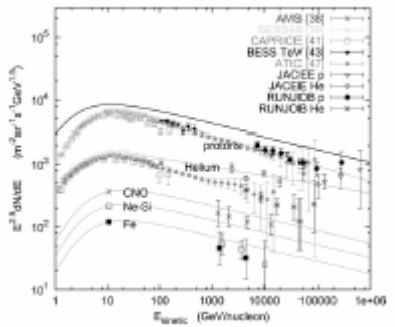


HARP results (data points), Sanford-Wang parametrization of HARP results (histogram)

Atmospheric ν flux



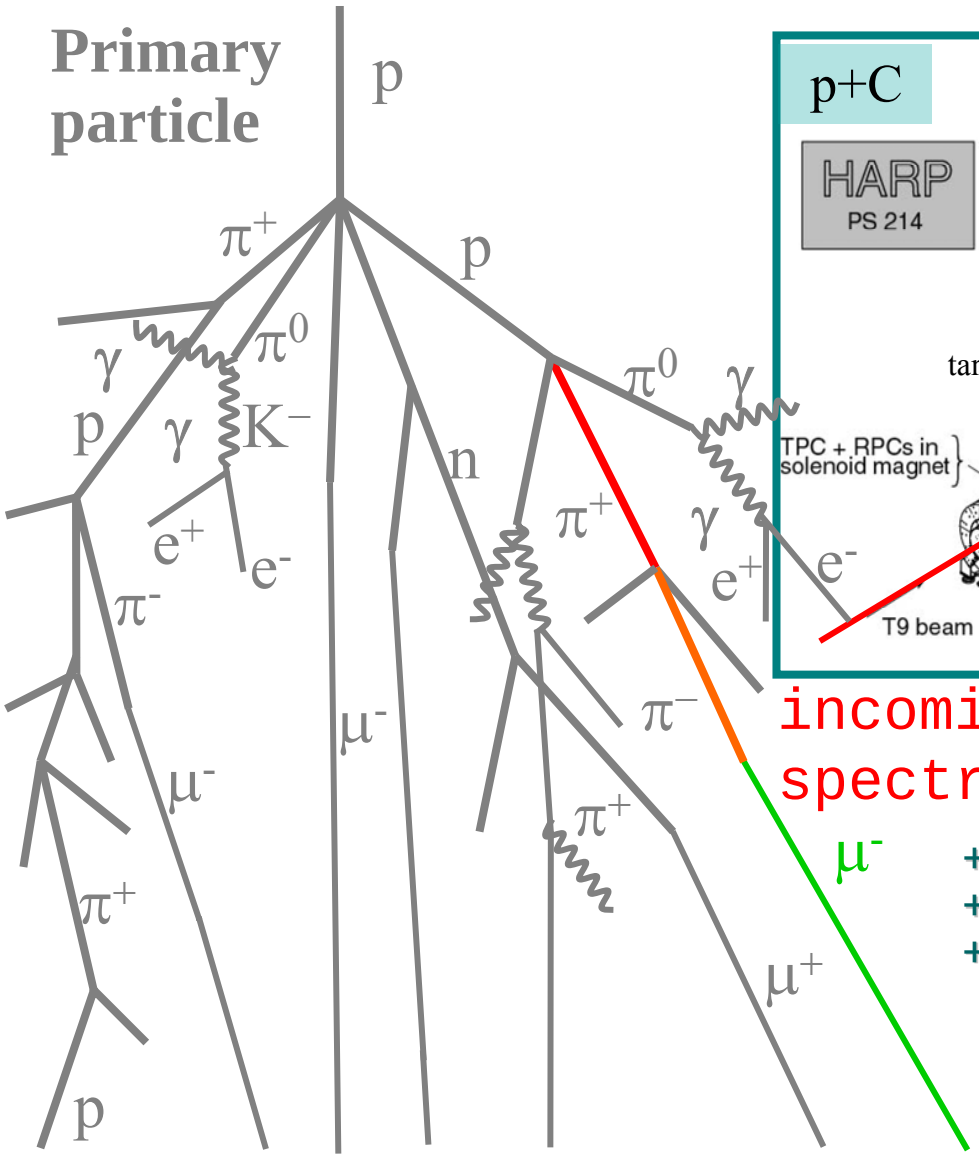
- **Primary flux (70% p, 20% He, 10% heavier nuclei) is now considered to be known to better than 15% (AMS, Bess p spectra agree at 5% up to 100 GeV, worse for He)**

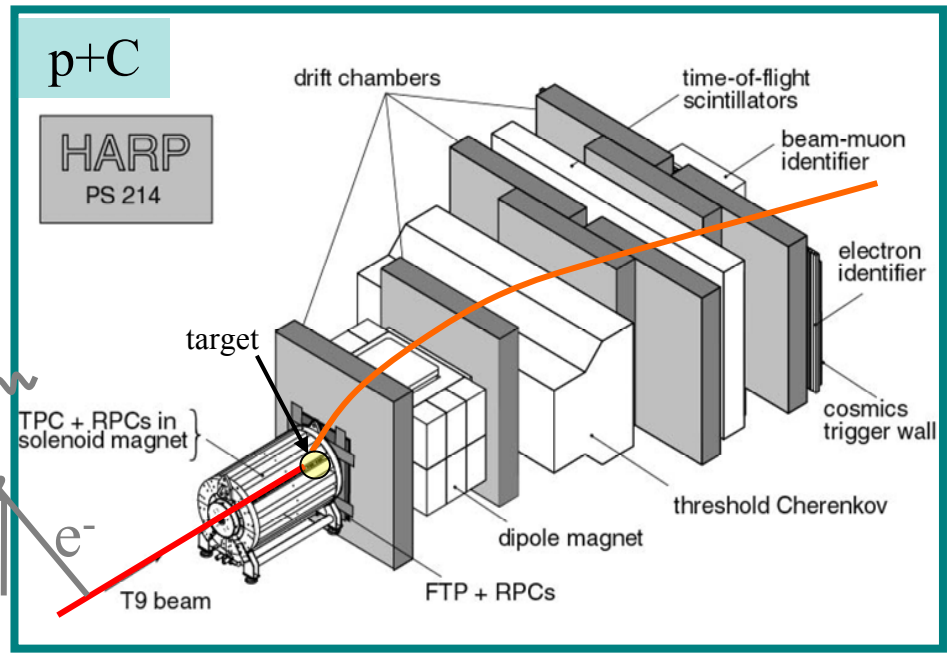


- **Most of the uncertainty comes from the lack of data to construct and calibrate a reliable hadron interaction model.**
- **Model-dependent extrapolations from the limited set of data leads to about 30% uncertainty in atmospheric fluxes**
- **→ cryogenic targets (or at least nearby C target data)**

78% nitrogen
21% oxygen

Extended Air Showers



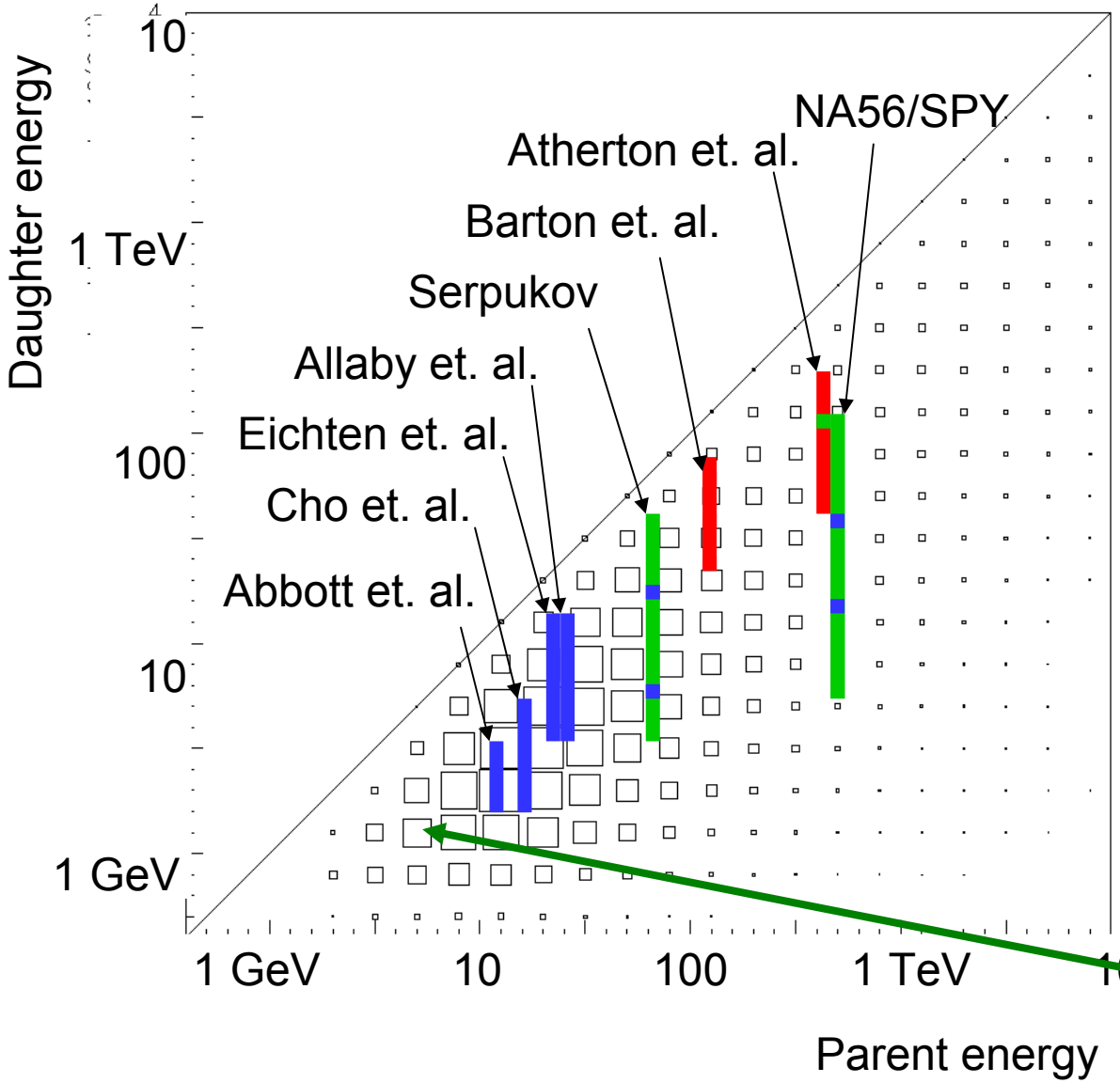


incoming protons and pions spectra: π^+ and π^-

μ^-

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

Hadron production experiments



Population of hadron-production phase-space for $pA \rightarrow \pi X$ interactions.

ν_μ flux (represented by boxes) as a function of the parent and daughter energies.

Measurements.

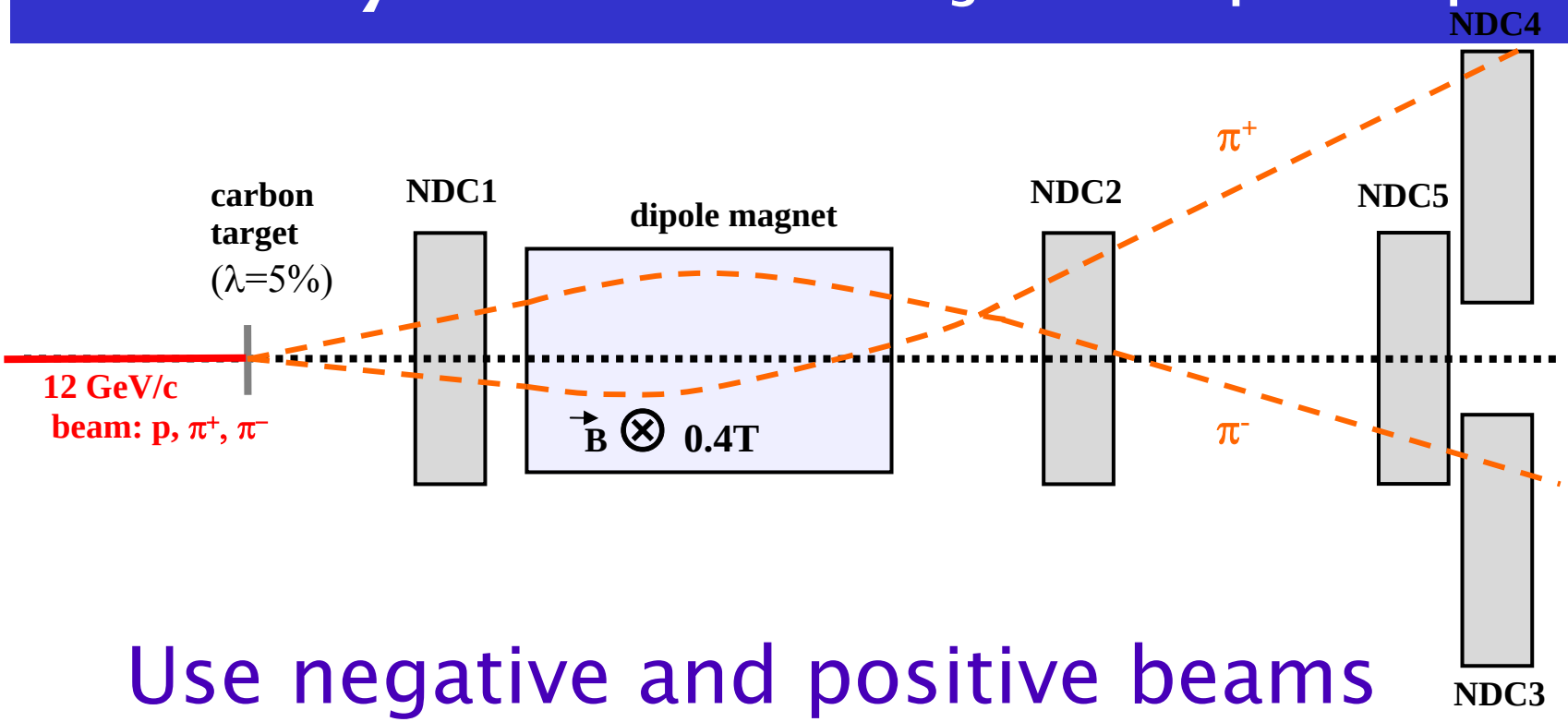
1-2 p_T points

3-5 p_T points

>5 p_T points

But with different targets (mainly Be)

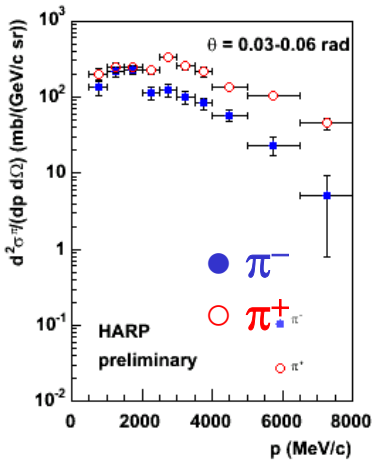
C analysis: use focused negative and positive pions

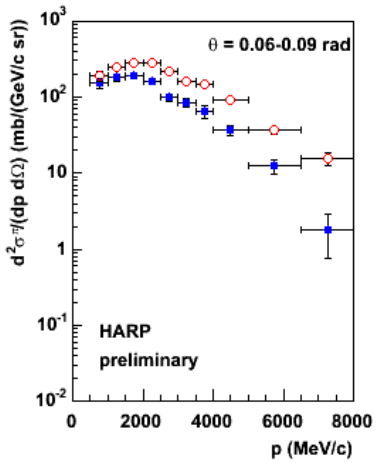


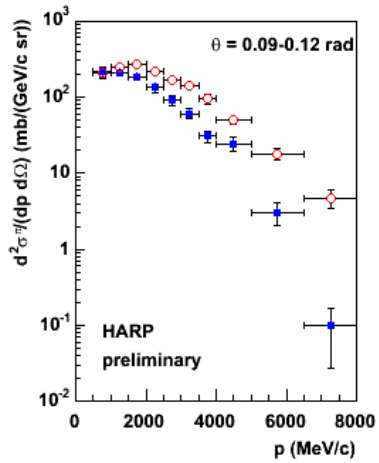
Use negative and positive beams

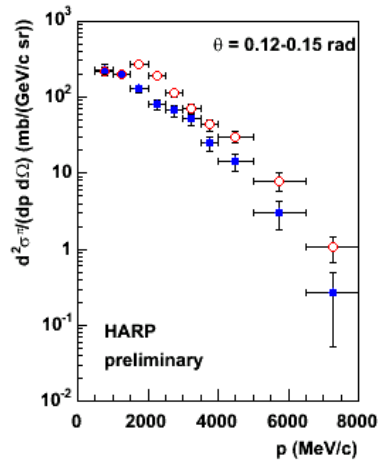
Selection of secondary particles (π^+, π^-) in forward hemisphere using the drift chambers.
No of events (pos. beam): 1,000k
No of events after cuts: 460k (p+C)
40k (π^++C)
No of events (neg. beam): 646k
No of events after cuts: 350k (π^-+C)

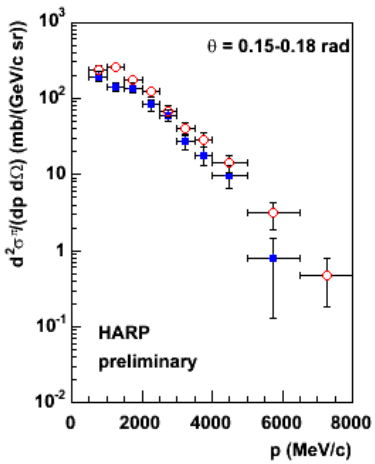
p+C @ 12 GeV/c: forward

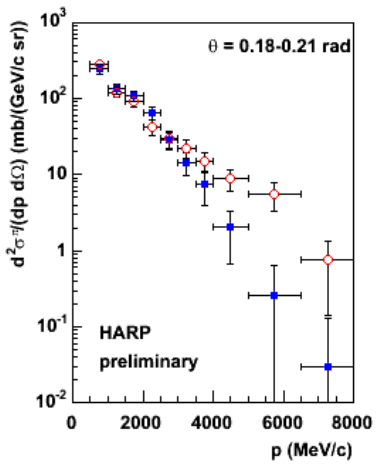


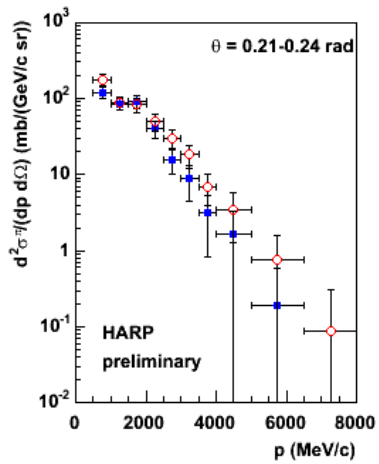






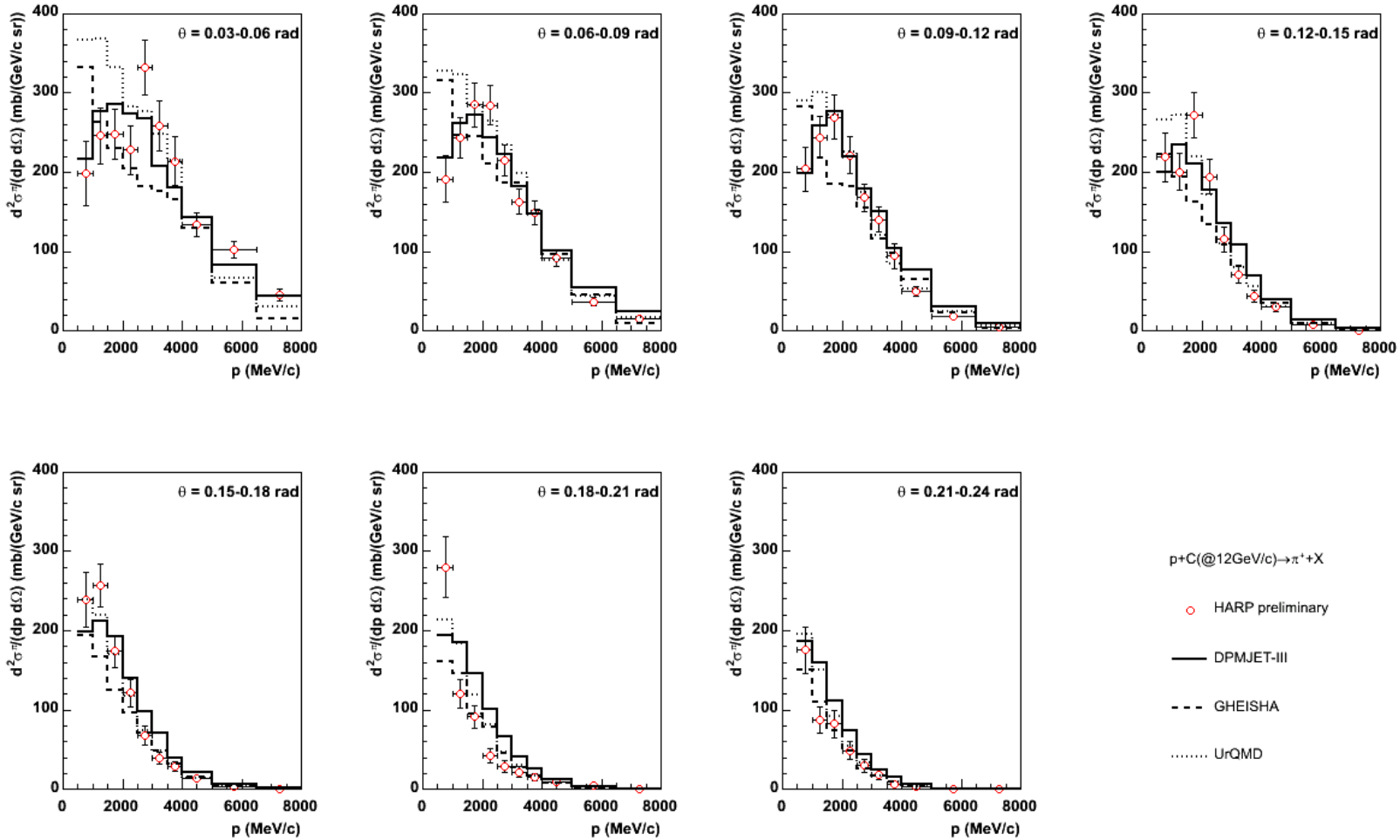




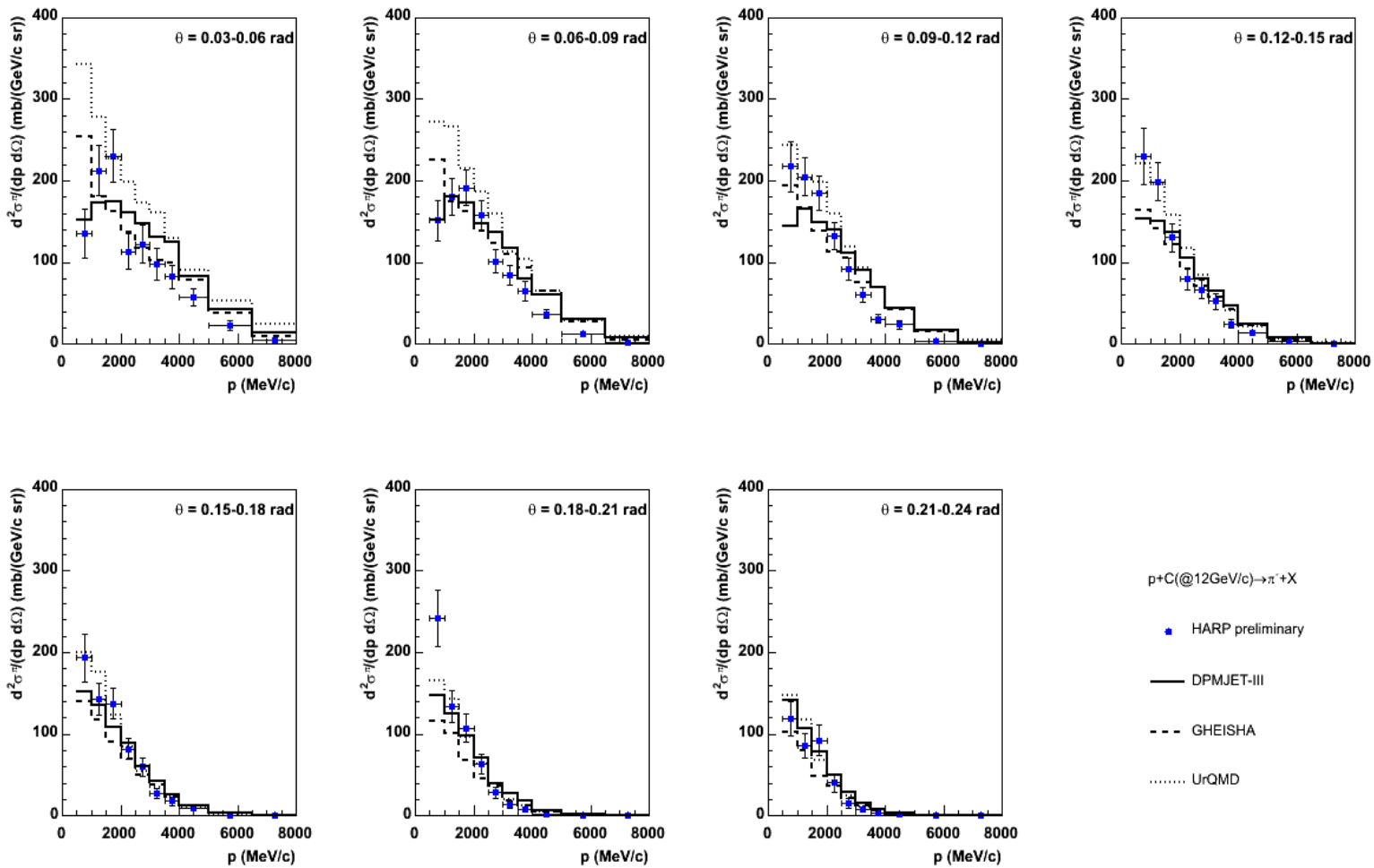


- π^+: leading particle effect
- Error: stat. and syst.
- Syst error ~ 10%

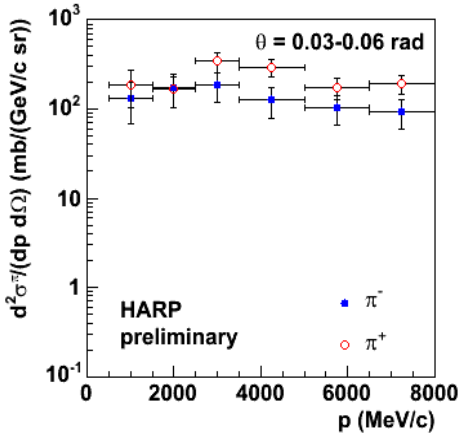
Model comparison: p+C→π^++X

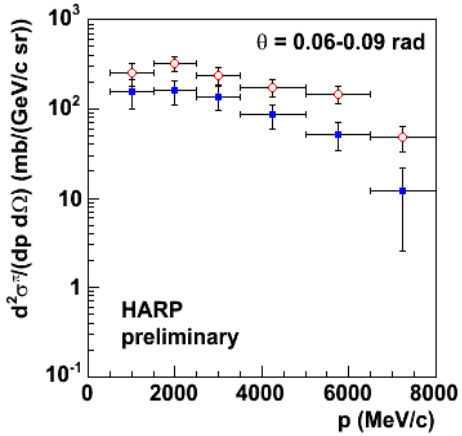


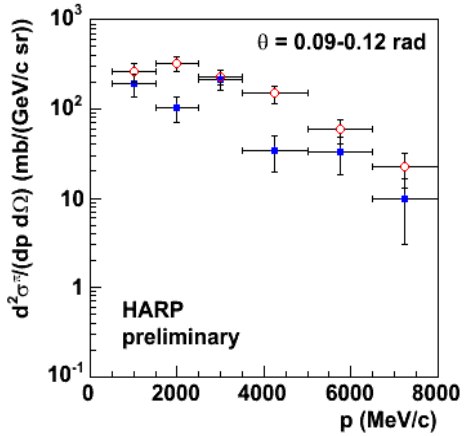
Model comparison: p+C→π^-+X

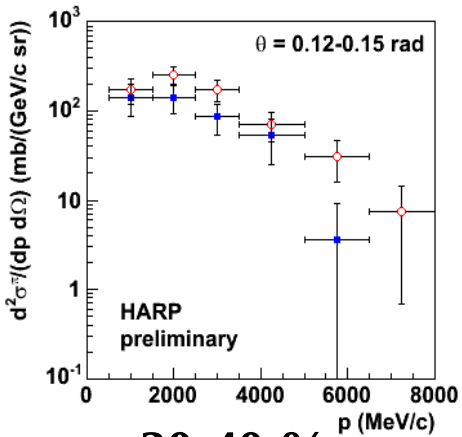


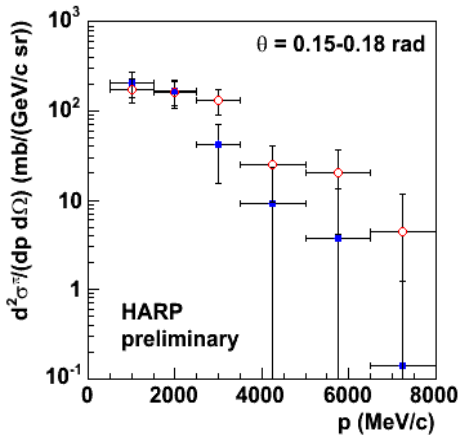
π^++C @ 12 GeV/c
(lower statistics)

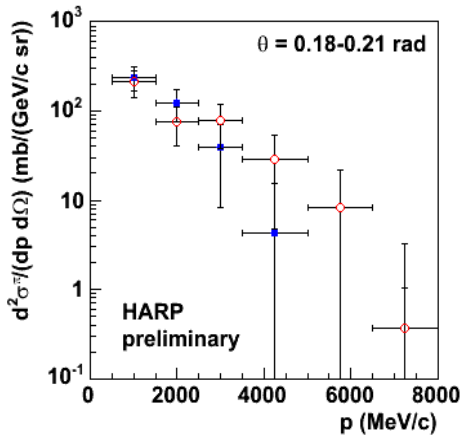






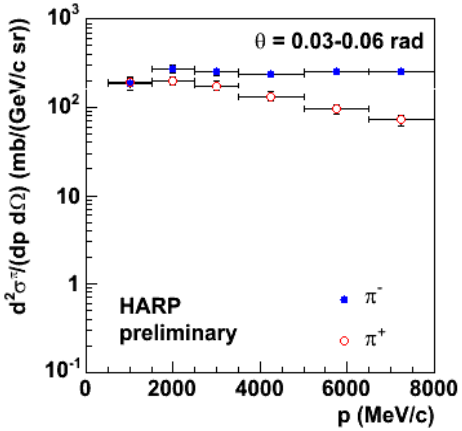


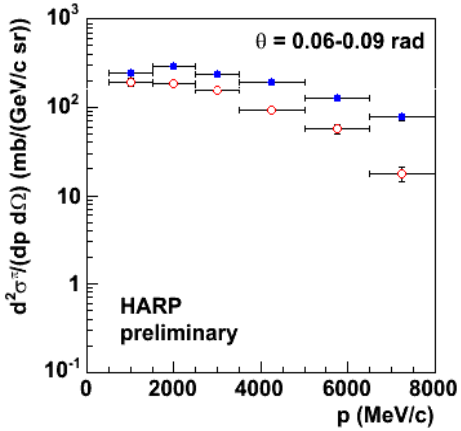


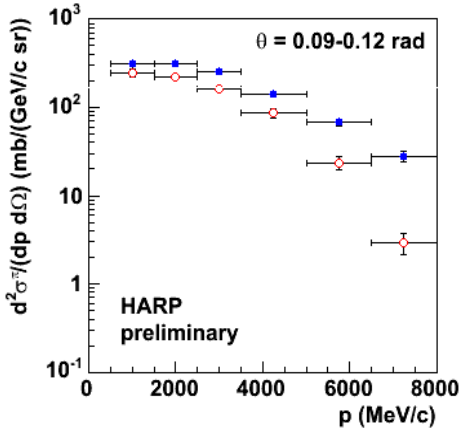


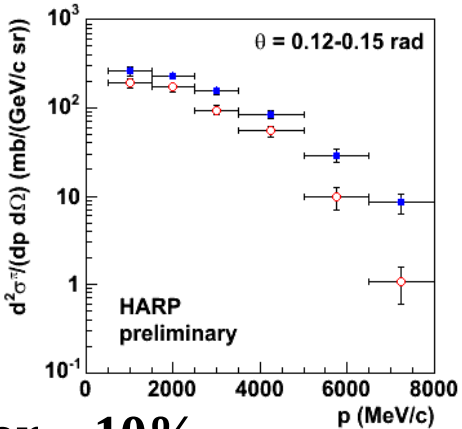
- **stat error ~ 30-40 %**
- **syst error ~ 10%**

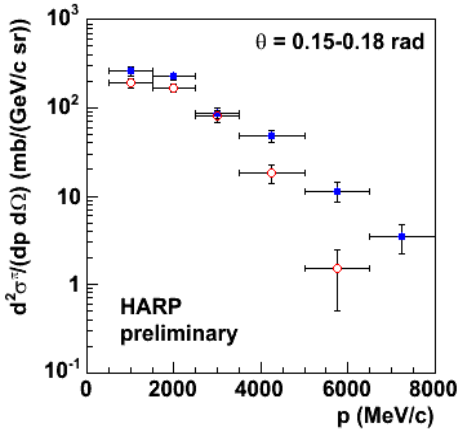
π^-+C @ 12 GeV/c
(high statistics)

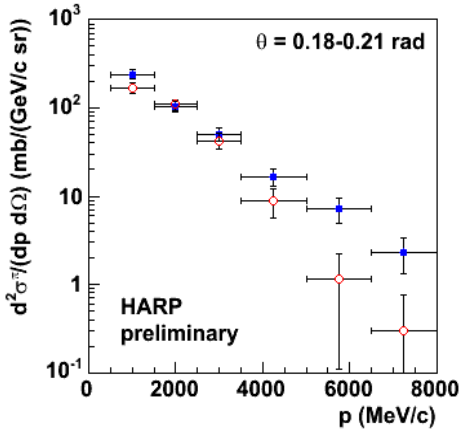






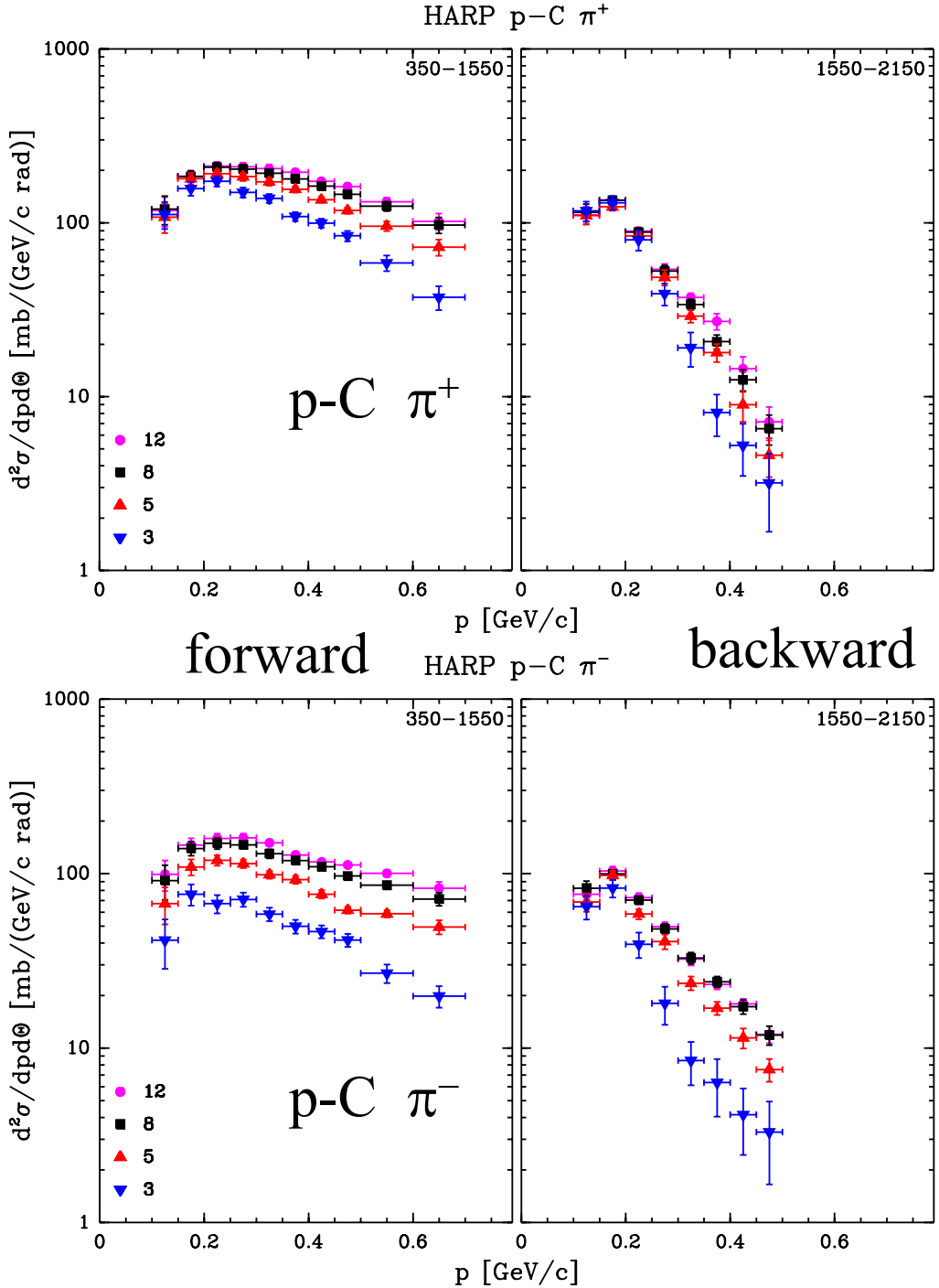






Stat error ~ 10%

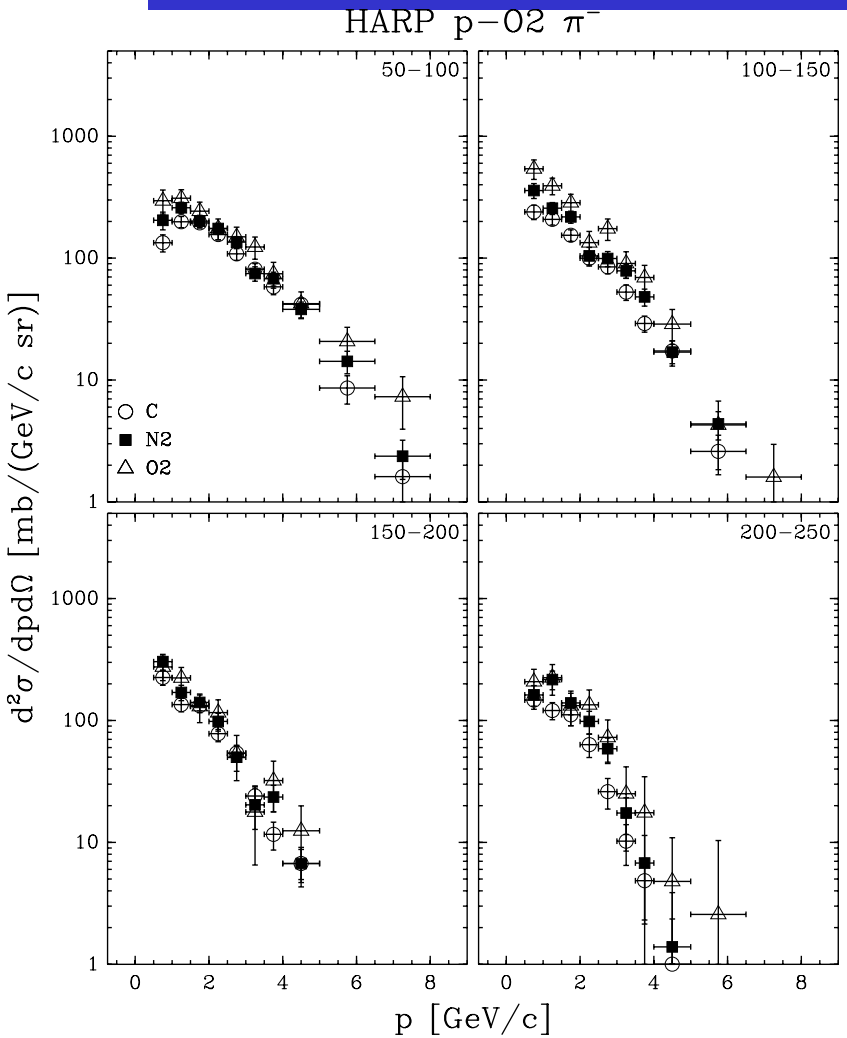
Syst error ~ 10%

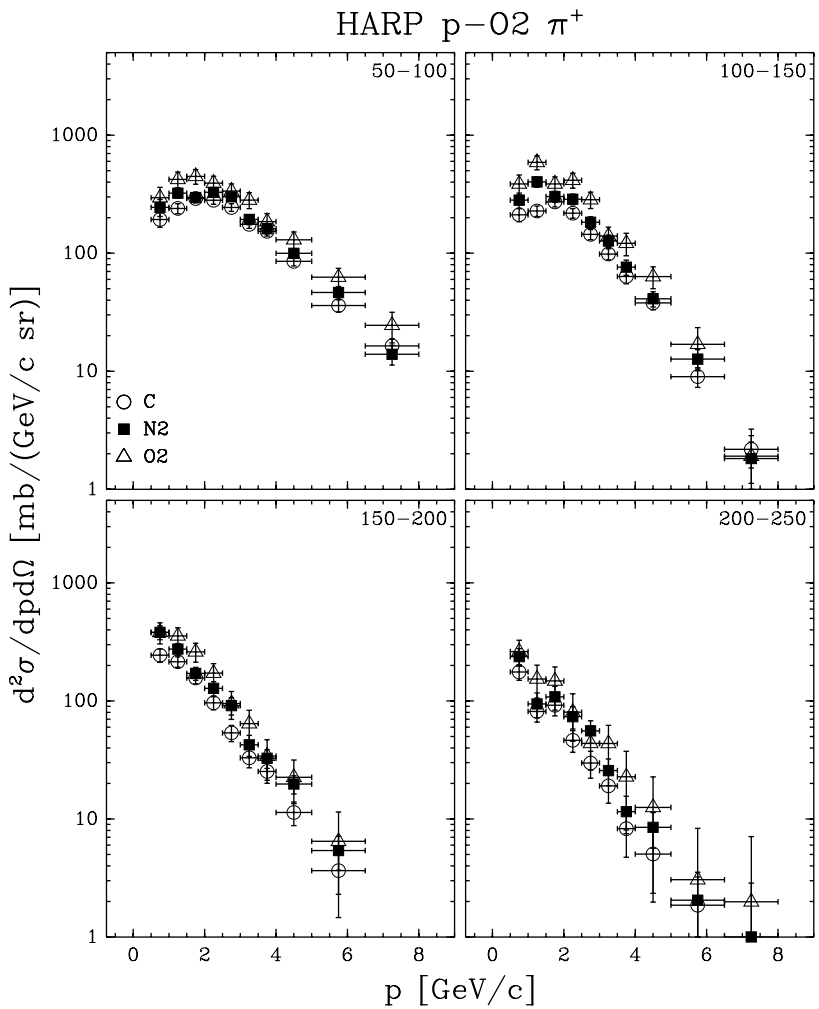


p+C at large angle

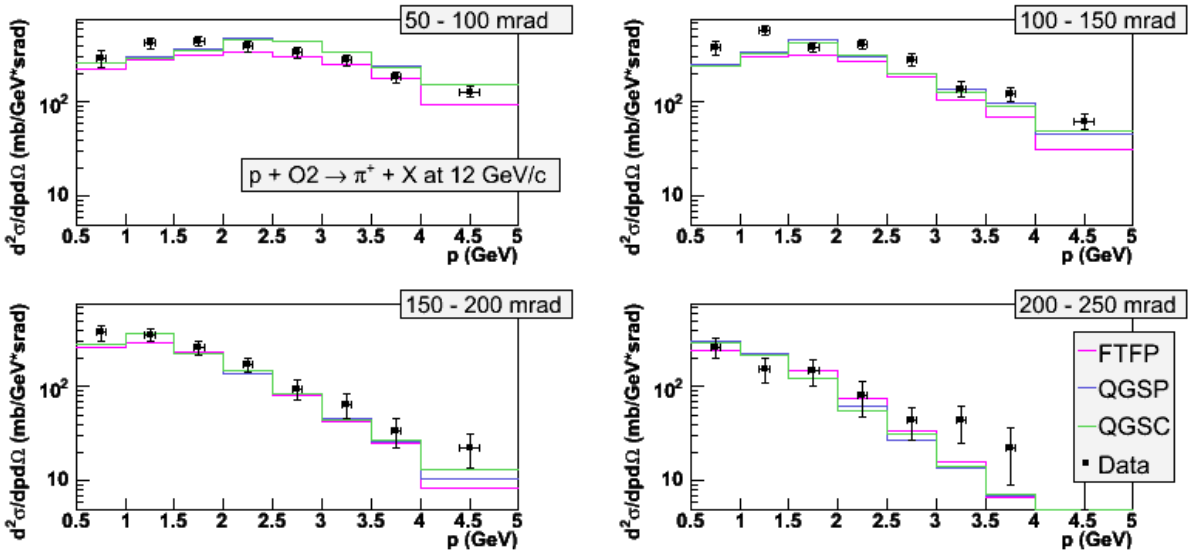
- **p+C data at large angle: measure p+C production on "full solid angle" in the same experiment**
- **large angle analysis with TPC (other results available for Be, C, Al, Cu, Sn, Pb, Ta): tracking + PID**

Measurements with N_2,O_2 cryogenic targets

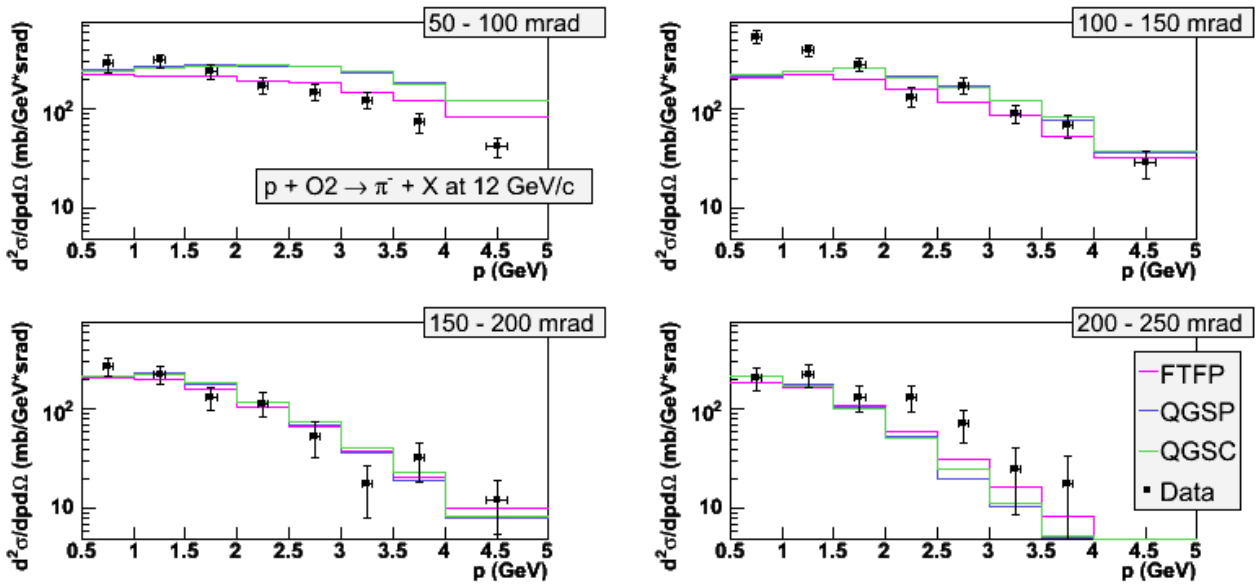




Shape looks similar =>may use simpler C target data (solid, not cryogenic target)



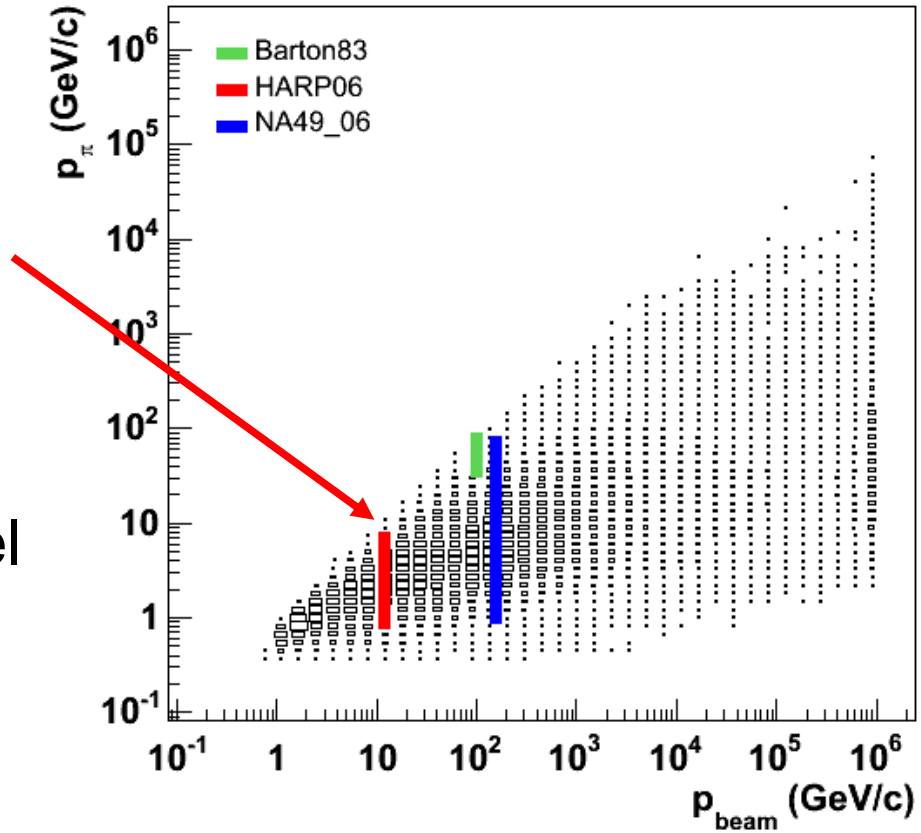
Comparison with GEANT4



preliminary

Covered phase space region

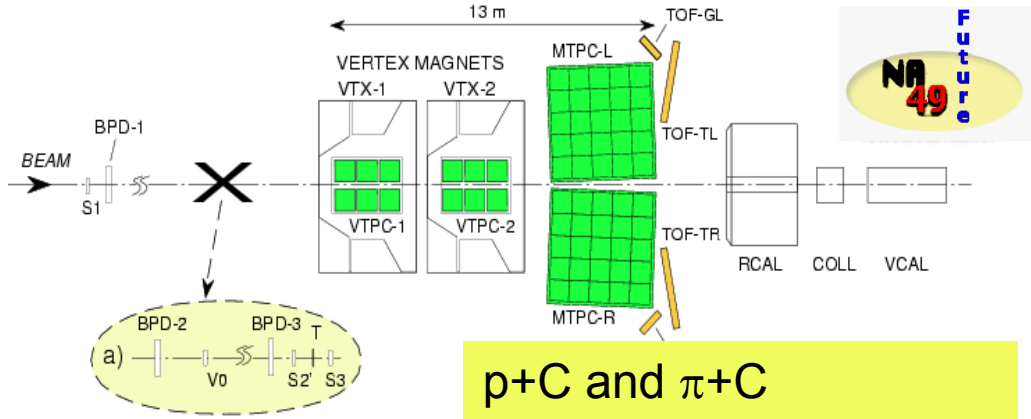
- New data sets
  (p+C, π^++C and π^-+C, pO_2, pN_2 at 12 GeV/c)
- Important phase space region covered
- Data available for model tuning and simulations
- Results on N2 and O2 data are preliminary



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

Planned future measurements/analyses

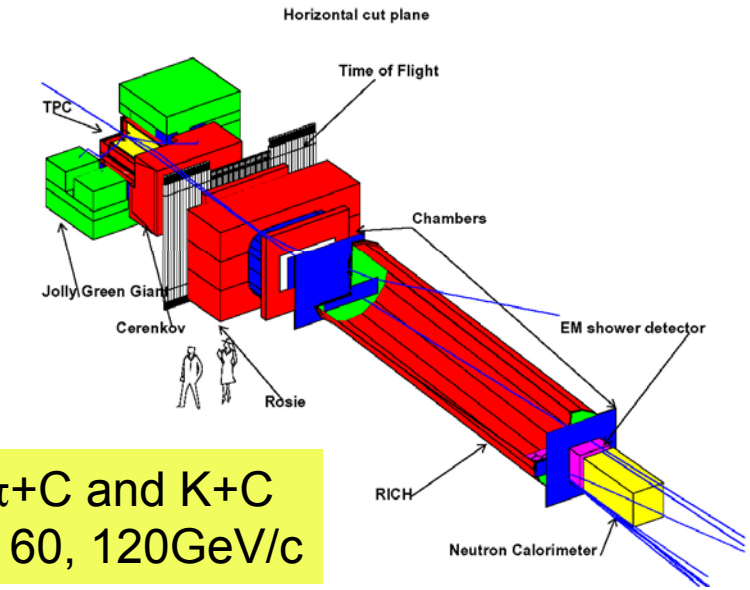
Energy range and phase space of interest	
$\langle E_{beam} \rangle$	8-1000 GeV
p	0.5-11.0 GeV/c
θ	0-300 mrad



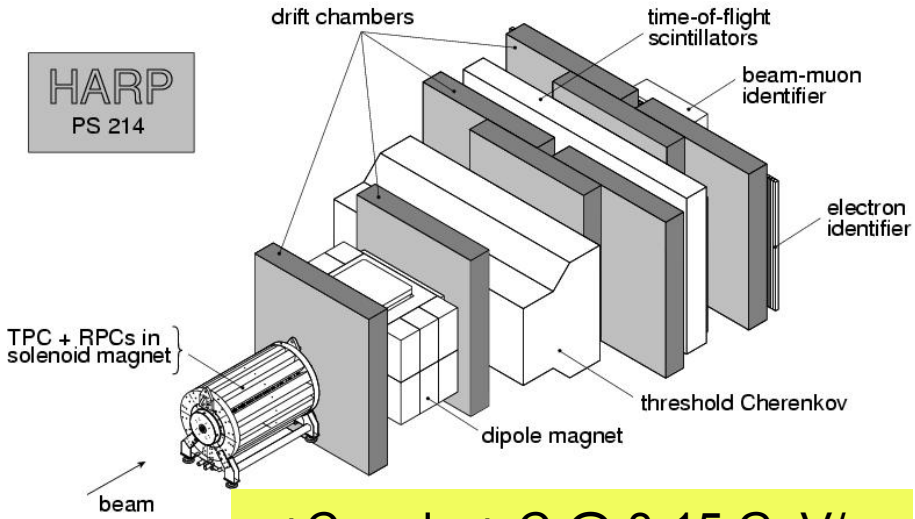
p+C and π+C
@ 30, 40, 50, 158GeV/c

MIPP

Main Injector Particle Production Experiment (FNAL-E907)



p+C, π+C and K+C
@ 20, 60, 120GeV/c



p+C and π+-C @ 3-15 GeV/c
N_2,O_2 targets

Summary

- **Results for K2K, MiniBoone conventional ν beams have been published.**
- **Tantalum results for the Neutrino Factory studies are published (Pb coming).**
- **Carbon data for atmospheric neutrino fluxes are available (N2, O2 preliminary).**
- **HARP is giving results useful for conventional ν beams study, ν factory design, EAS, atmospheric ν studies and in addition for general MC tuning (Geant4, FLUKA …) with full solid angle coverage, good PID identification on targets from H to Pb at low energies (< 15 GeV) with small total errors (syst+stat < 10 %)**
- **More results coming**