STATUS AND PROSPECTS FOR HADRON PRODUCTION EXPERIMENTS

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Outline

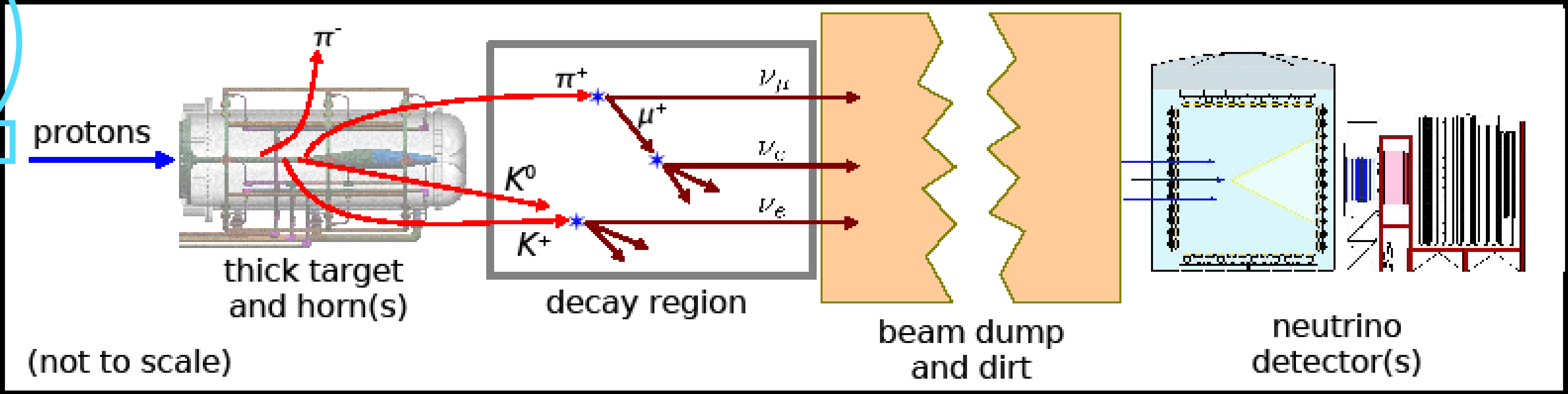
- Motivations and scenario at the end of the previous millennium….
- Present measurements: *Harp* results
  - K2K & MiniBoone fluxes
  - Super Beams & Neutrino Factory Design
  - Atmospheric fluxes (< 15 GeV)
- But also Na49 at higher Energies (158 GeV/C)
- Coming soon …
  - MIPP@FermiLab
  - Na61 : Atmospheric (< 200 GeV) & T2K neutrino Flux
- The High Energy Frontier : Hadroproduction@LHC
  - Totem : Total X-section @ 14 TeV
  - LHCF & LHCB

Why Hadron Productions

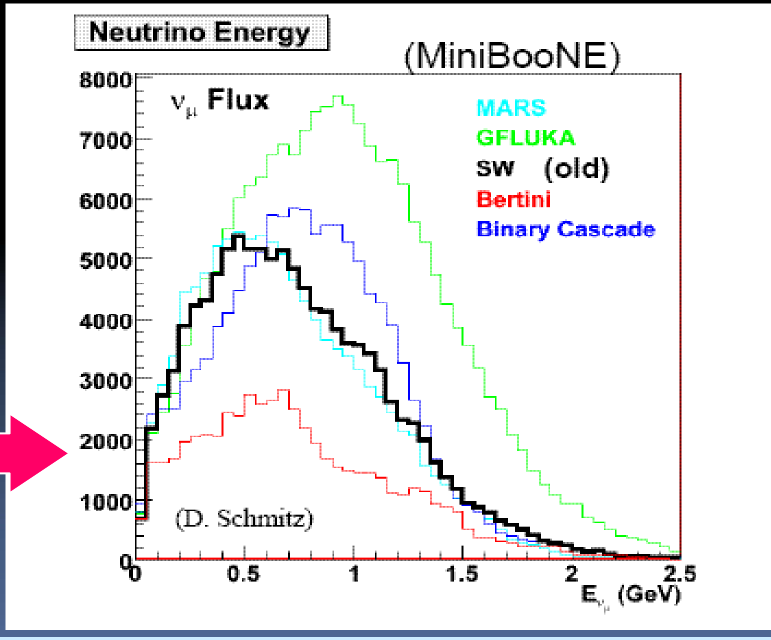
- Neutrino sources from hadron interactions
  - From accelerators
  - From cosmic rays **NEW**
- Design parameters of future neutrino beams influenced by target/energy choices **NEW**

Neutrino Beams: a "typical" example… MiniBooNE

8.9 GeV Booster



- Energy, composition, geometry of the neutrino beam is determined by the development of the hadron interaction and cascade
- It's hard to make this kind of measurements in situ. Normally MC generators are used for this scope
- Various models are known to have large differences in neutrino rate predictions (MiniBoone 2004 –no harp data)



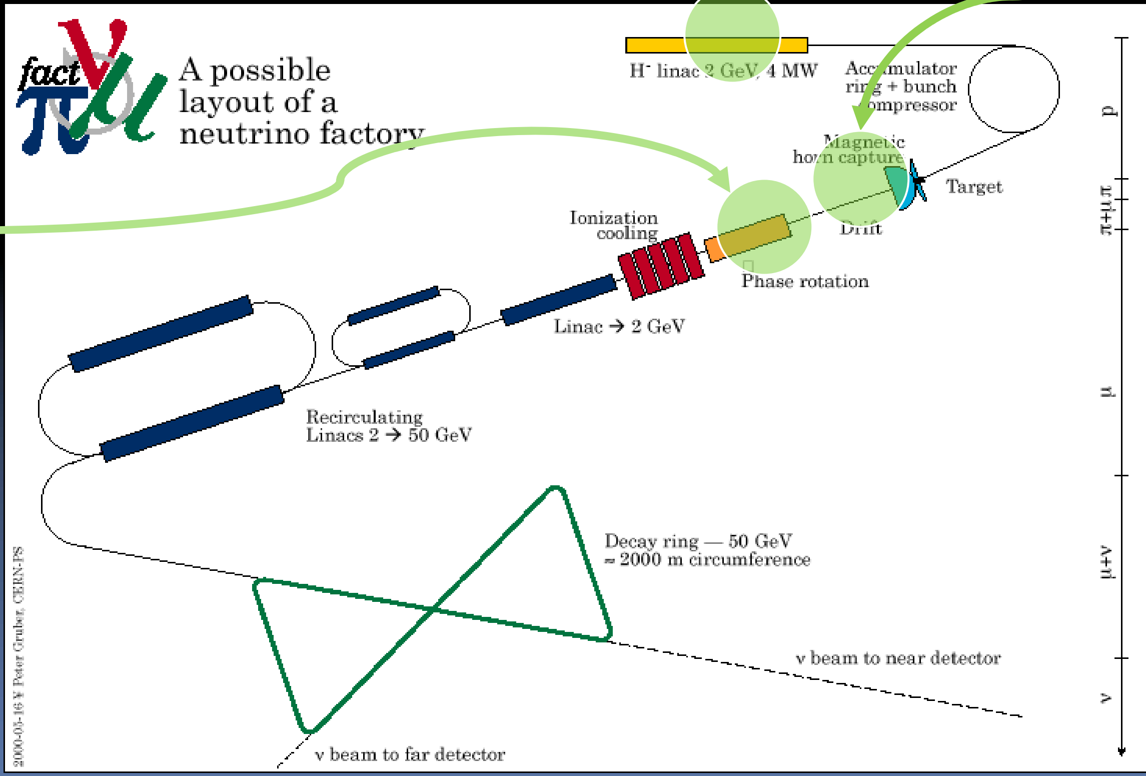
It is vital to calibrate neutrino production targets in a proton beam !

Example of future projects

Primary energy, target material and geometry, collection scheme
- maximizing the π^+, π^- production rate /proton /GeV
- knowing with high precision (<5%) the P_T distribution

First CERN scenario: 2.2 GeV/c proton linac.

Phase rotation
- *longitudinally freeze* the beam: slow down earlier particles, accelerate later ones
- need good knowledge also of P_L distribution



Atmospheric neutrino fluxes: motivations for measurements

Initial reaction – well above the highest energy accelerator available.

Shower develops – a large number of lower energy interactions – accelerator measurements are helpful.

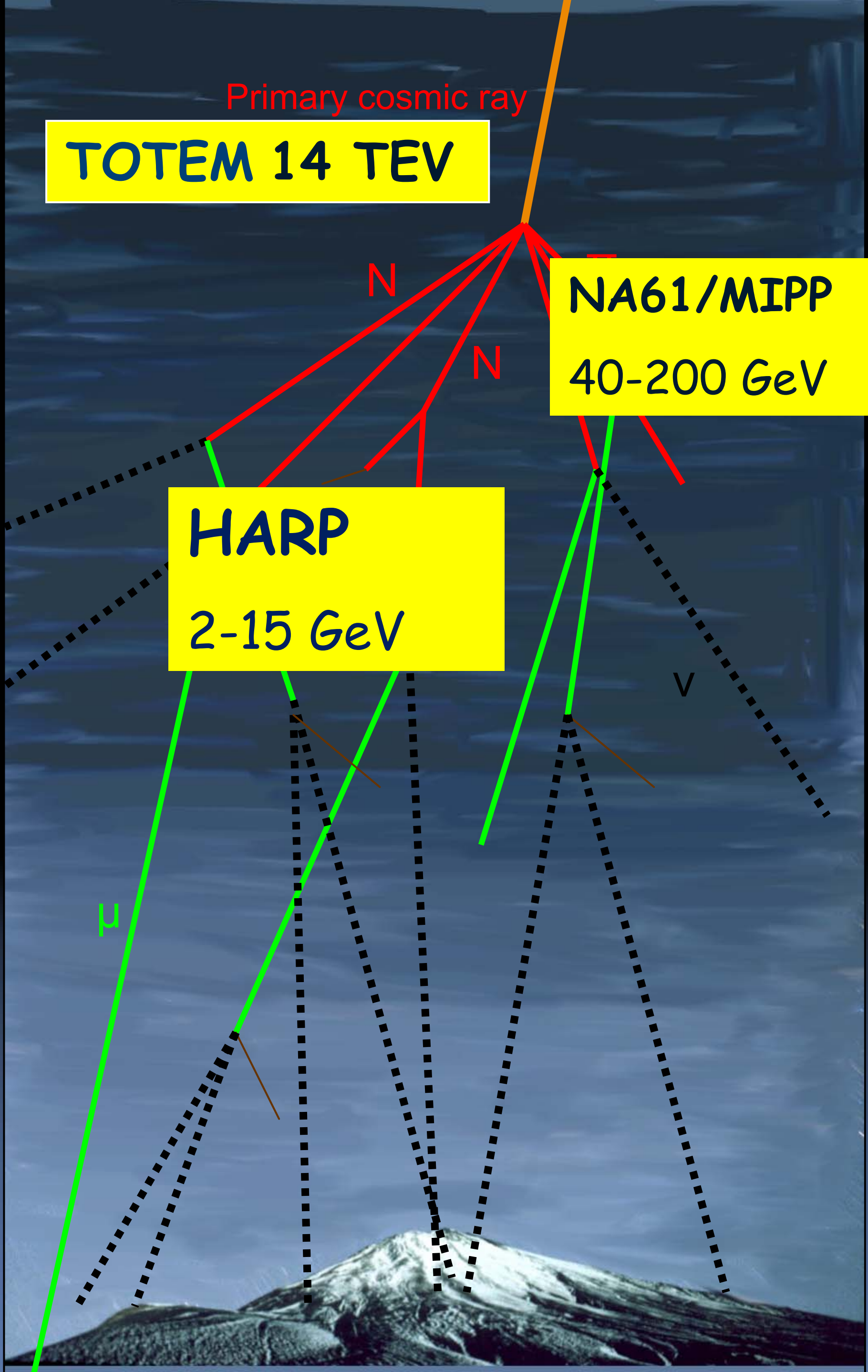
- Energy region: from few GeV
  → 200 GeV (contained)
  → 2 TeV (through going)

Accelerator measurements are very sparse.

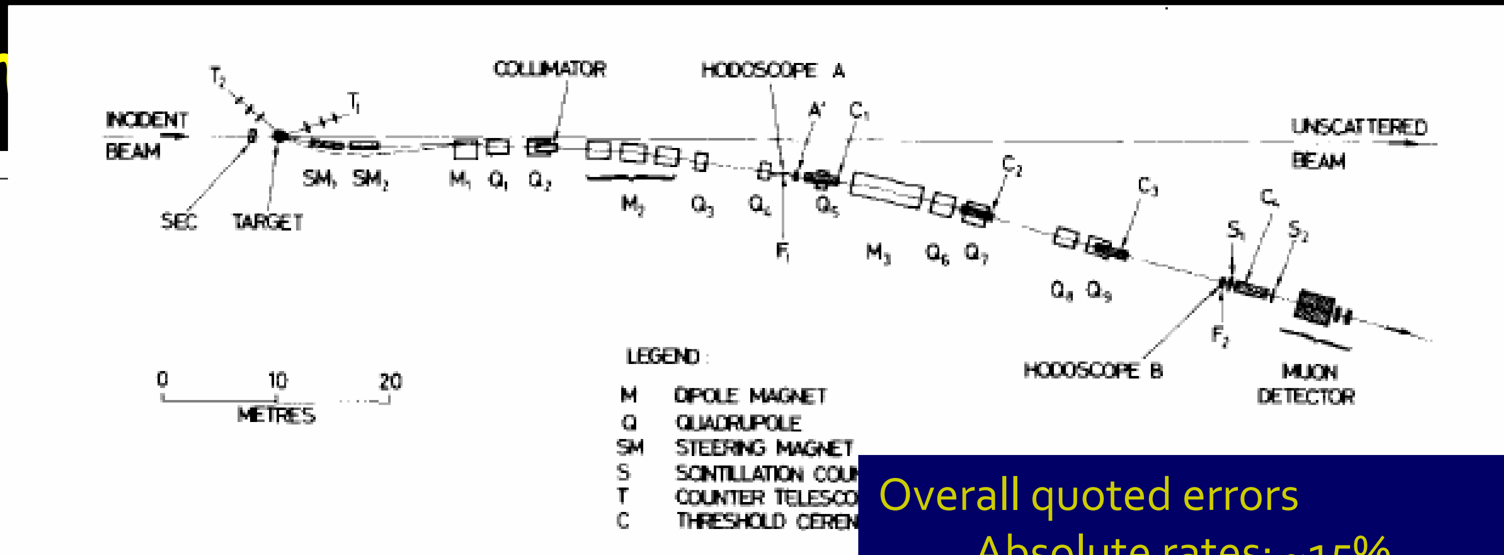
- Colliders: most particles close to beam and don't enter the detector.

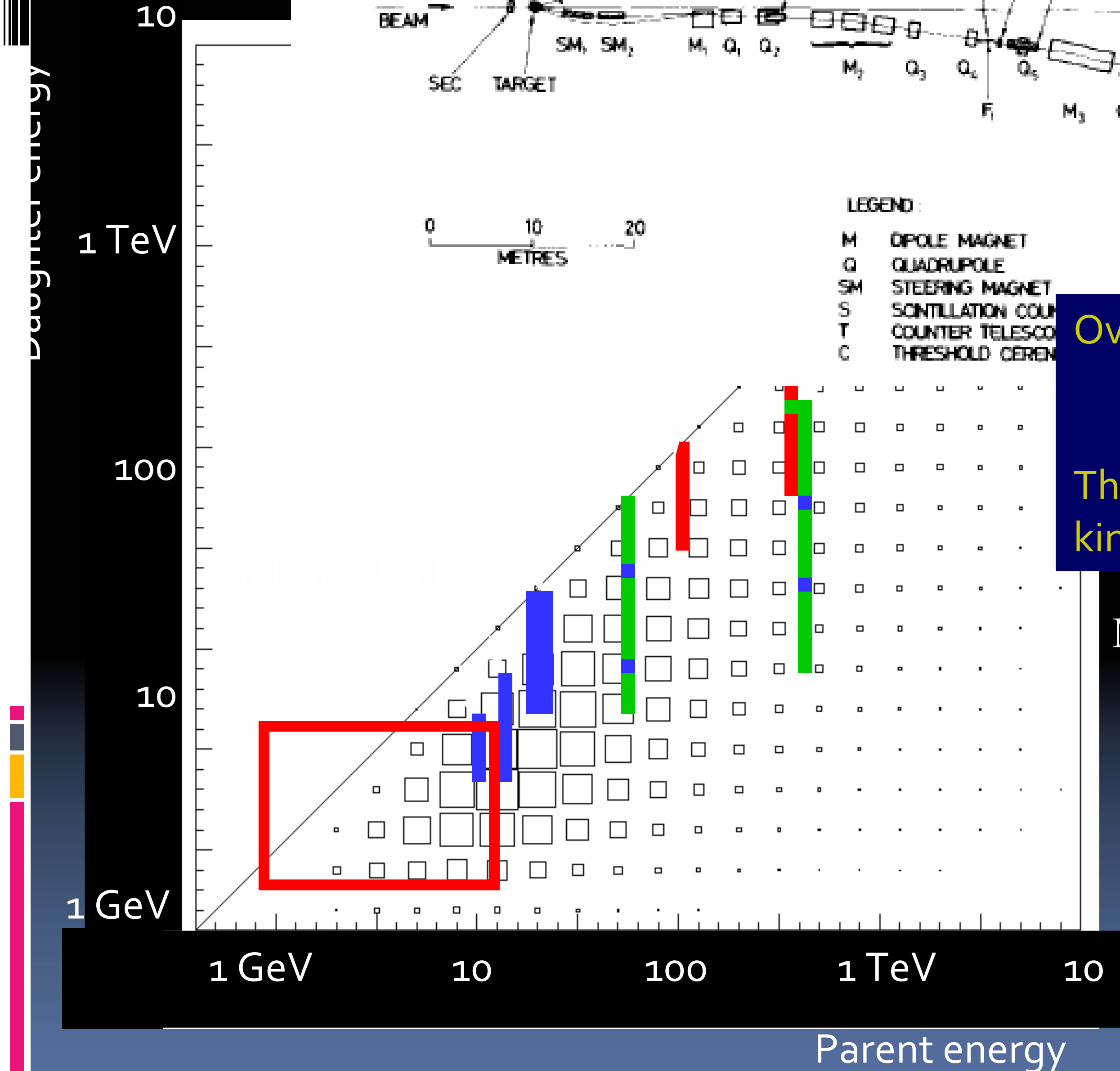
- Fixed target: The energies are much lower and few experiments have published.

- **No data available on O_2 & N_2**



Existin





Overall quoted errors

Absolute rates: ~15%

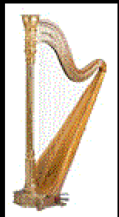
Ratios: ~5%

These figures are typical of this kind of detector setup

Measurements.

- 1-2 p_T points
- 3-5 p_T points
- >5 p_T points

Eichten et. al.



Harp

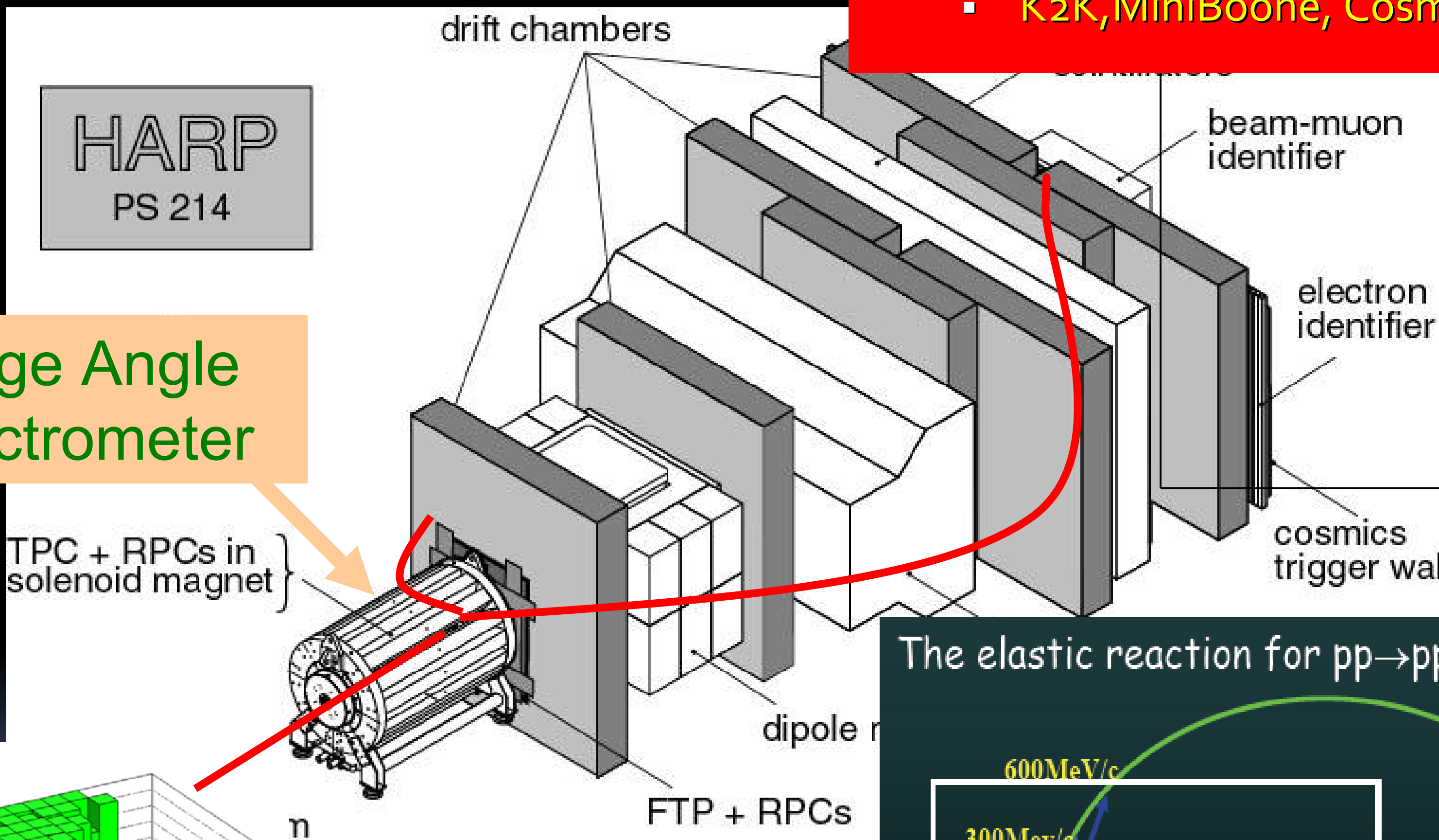
- Inaugurates a new era in Hadron Production for Neutrino Physics:
- Based on a design born for Heavy Ions physics studies
  - Full acceptance with P.Id.
  - High event rate capability (3KHz on TPC)
- Built on purpose
- Collaboration includes members of Neutrino Oscillation & Cosmic rays experiments

  (124 Physicists from 20 institutions)
- And makes measurements on specific targets of existing neutrino beams.

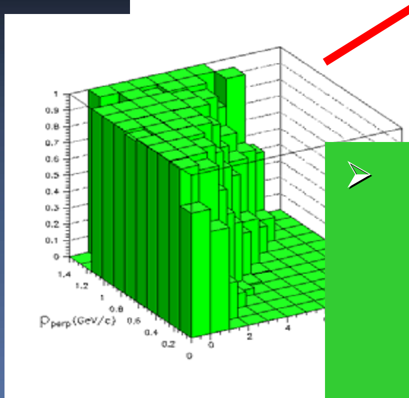
See also M.Bonesini Talk

Detector

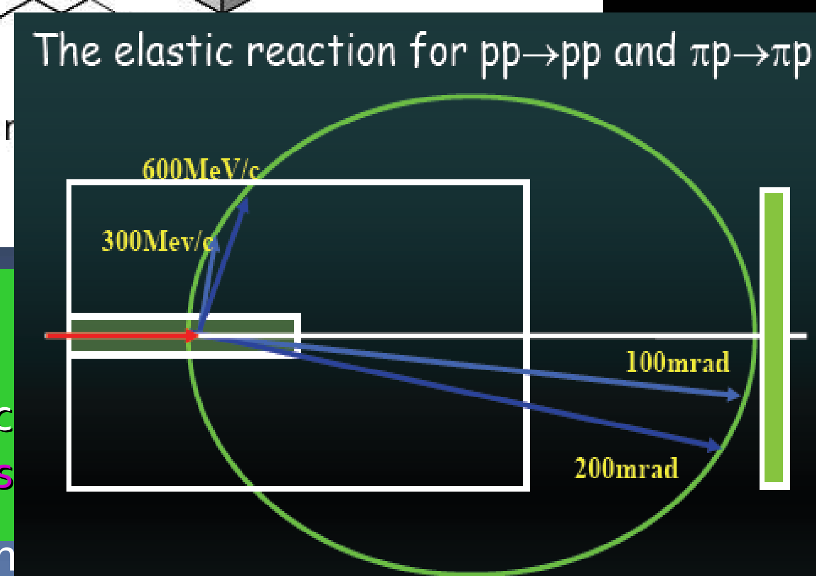
- Forward Spectrometer:
  - 30 mrad < θ < 210 mrad.
  - 750 MeV/c < p < 6.5 GeV/c
  - K2K,MiniBoone, Cosmic rays



Large Angle spectrometer



- Large Angle Spectrometer:
  - 0.35 rad < θ < 2.15 rad
  - 100 MeV/c < p < 700 MeV/c
  - Super Beams - Nufactories

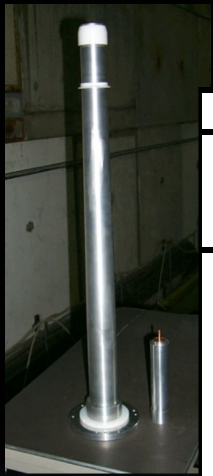


More details in the NIM paper “The Harp Detector @ th

HARP: Data taking summary

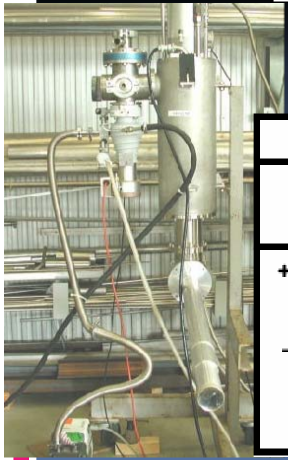
HARP took data at the CERN PS T9 beamline in 2001-2002

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



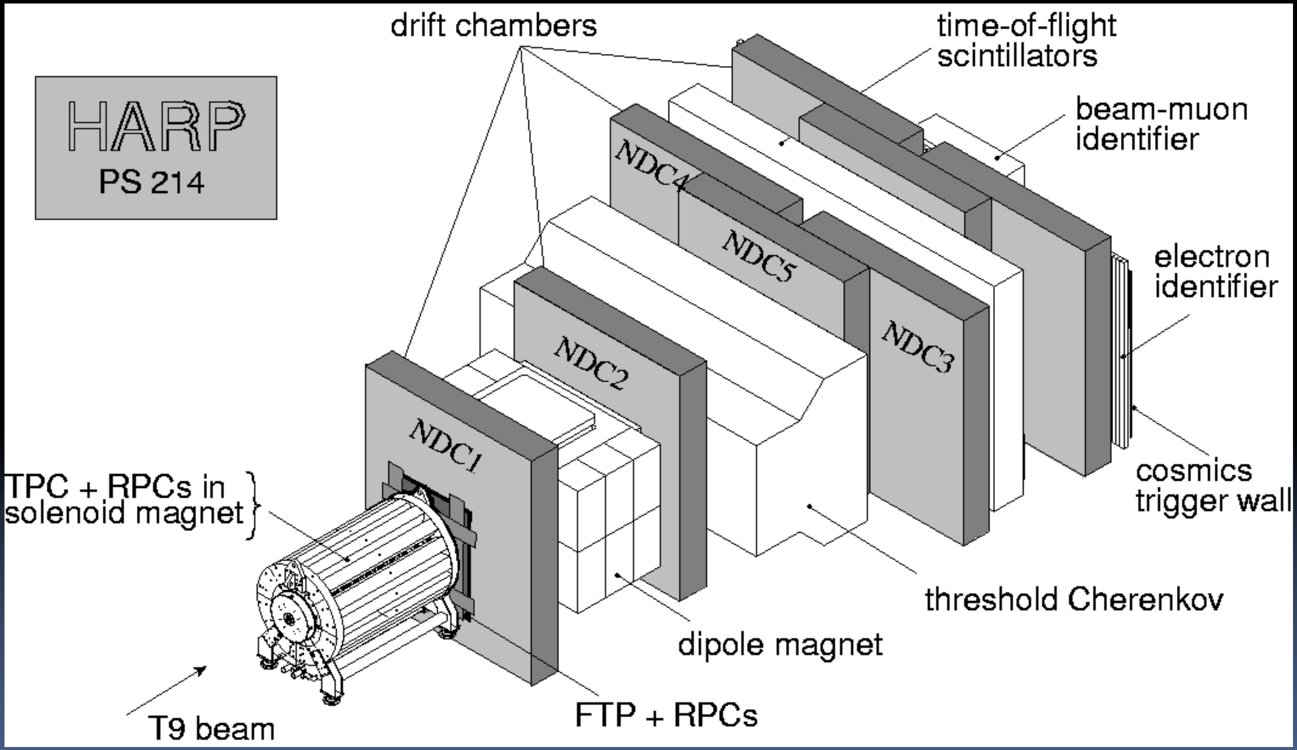
CRYOGENIC:

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

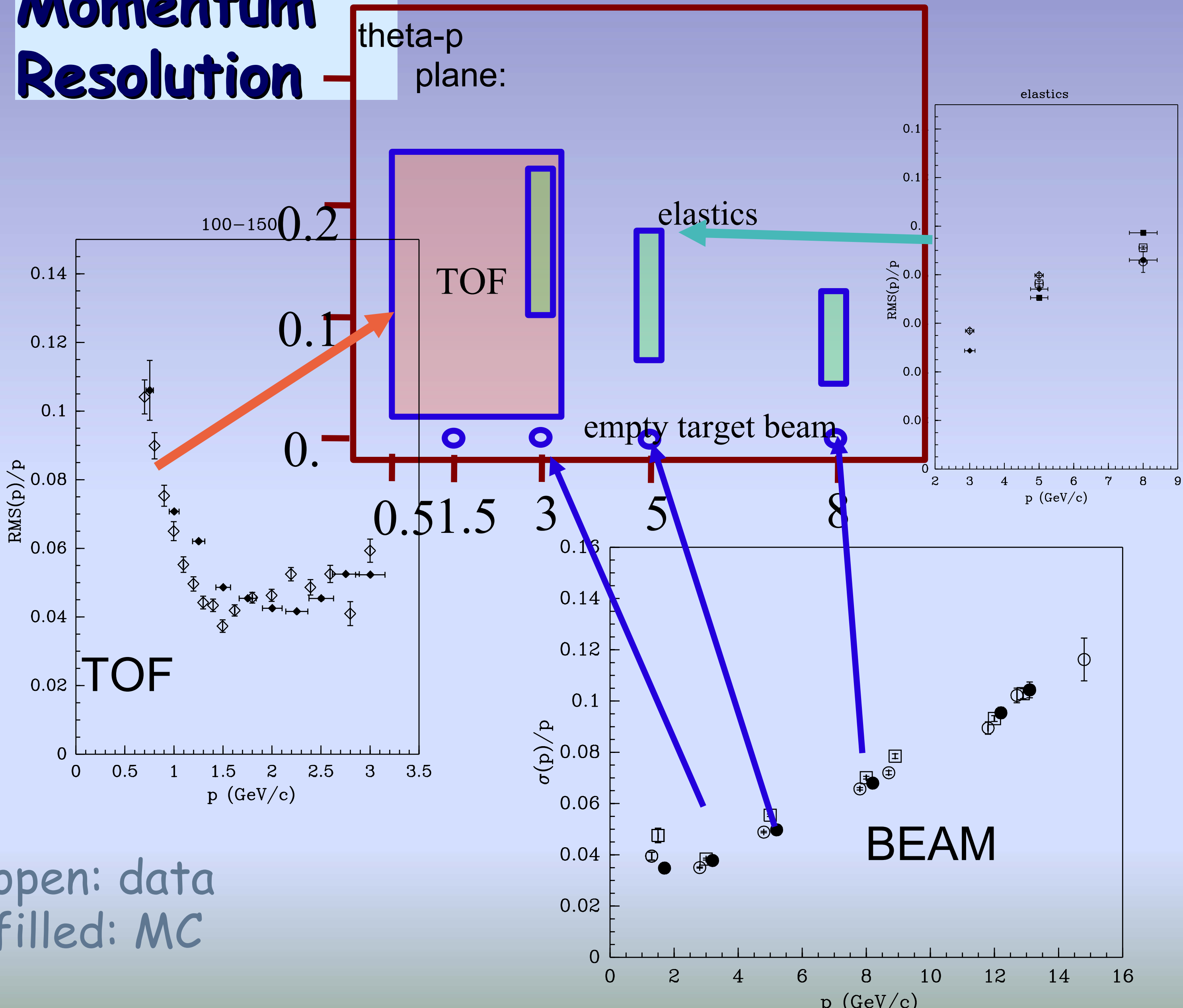
K2K: Al	MiniBoone : Be	LSND: H_2O
5% 50% 100% Replica	5% 50% 100% Replica	10% 100%
+12.9 GeV/c	+8.9 GeV/c	+1.5 GeV/c

FORWARD ANALYSIS



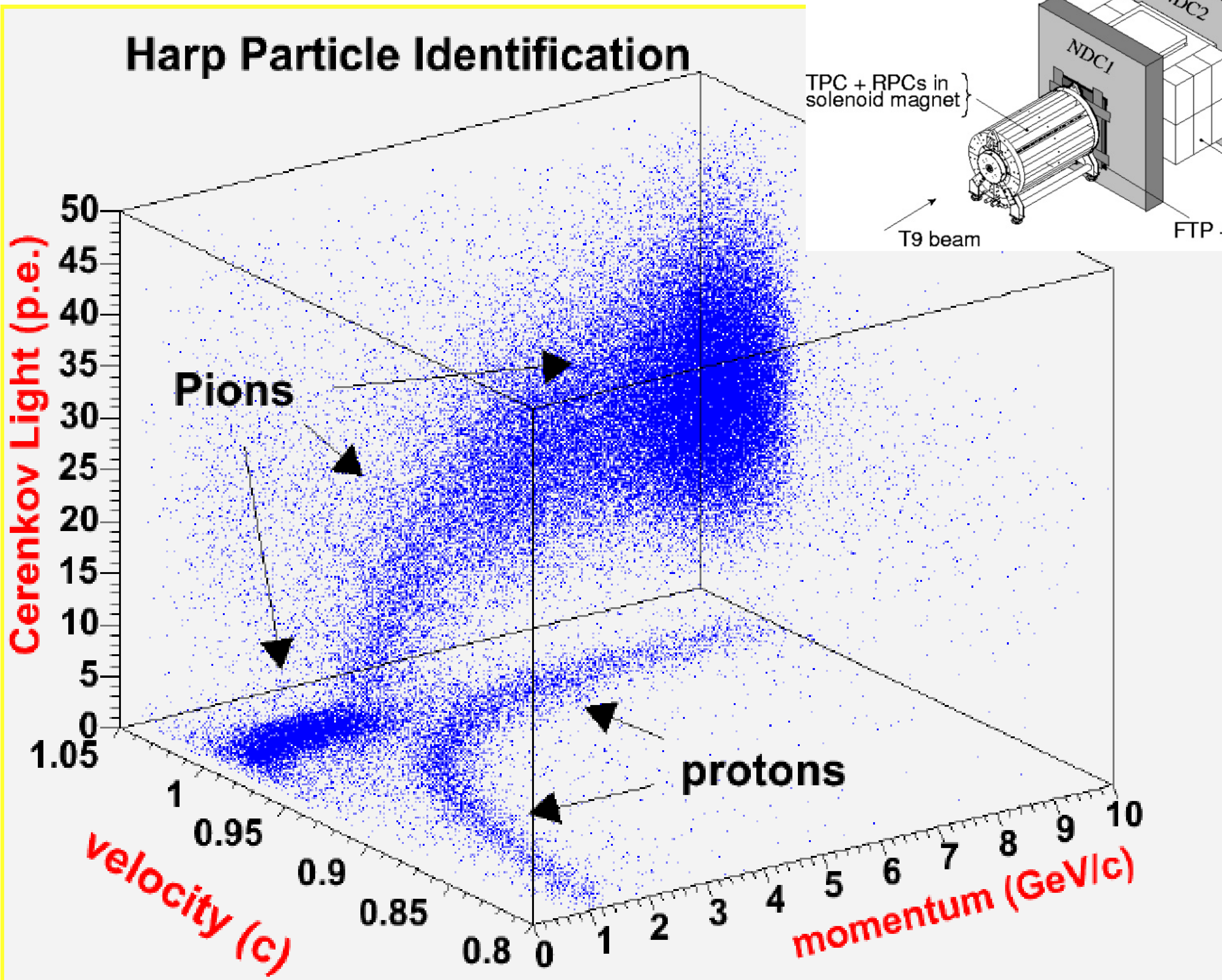
FW: Momentum Resolution

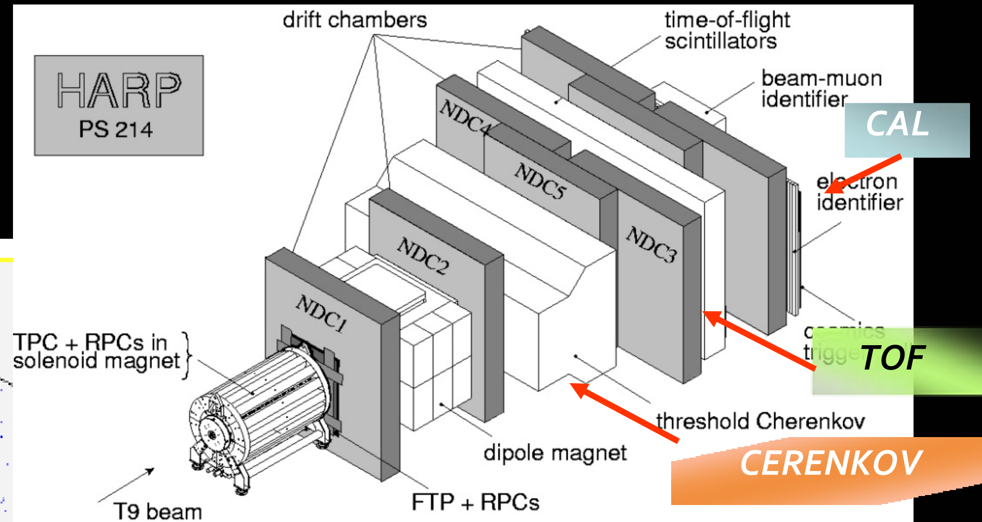
ELASTICS



open: data
filled: MC

FW: PID principle

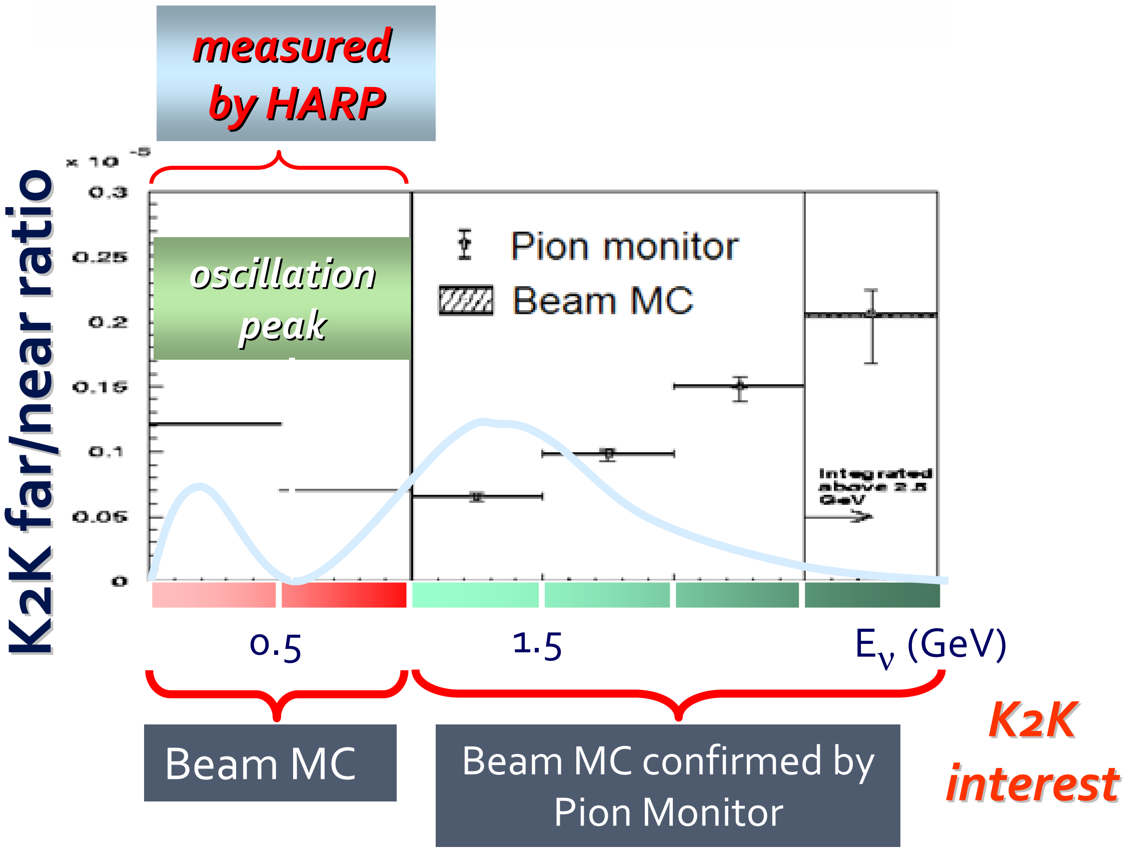


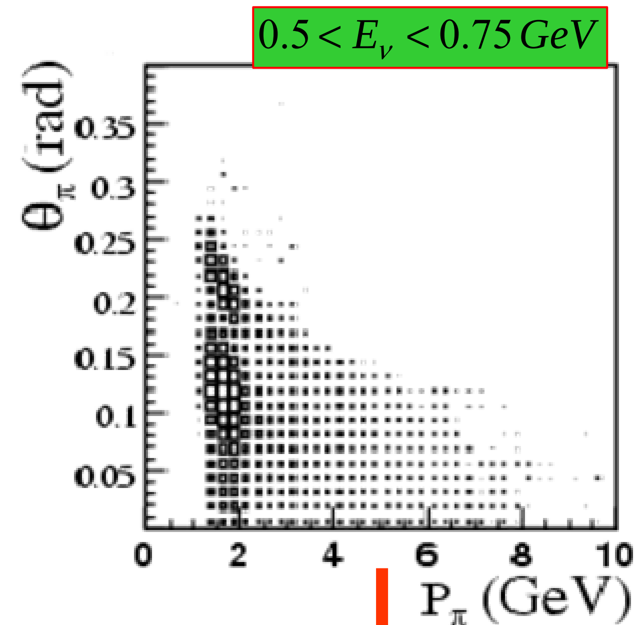


Relevance of HARP for K2K neutrino beam

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

pions producing neutrinos in the oscillation peak



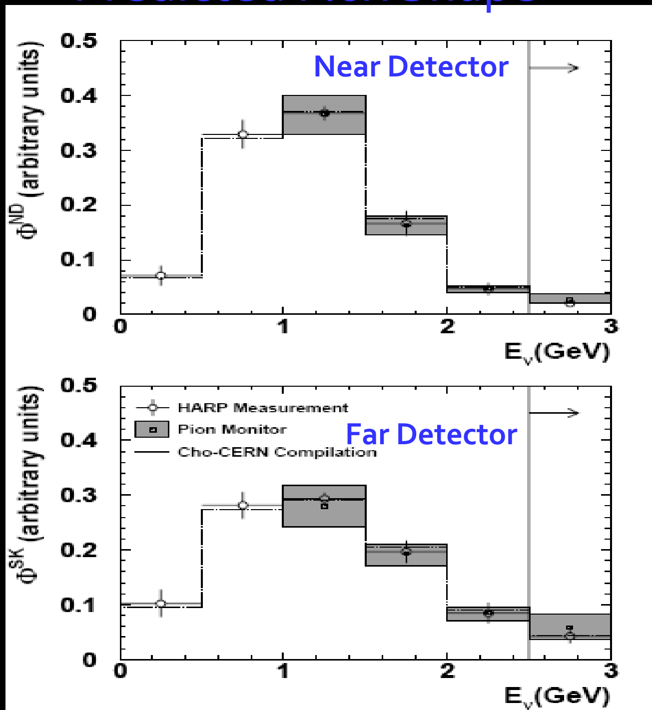


$$P_\pi > 1\,GeV$$

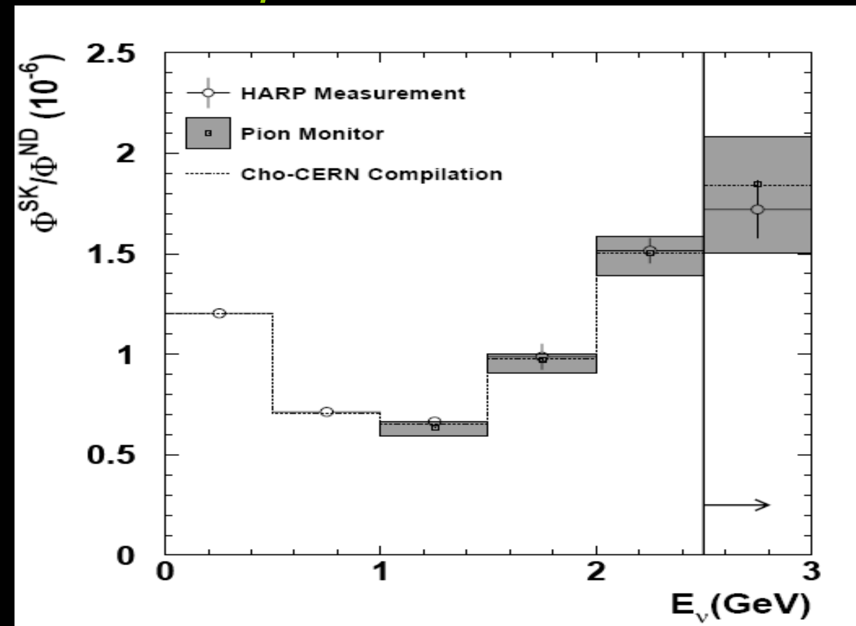
$$\theta_\pi < 250\,mrad$$

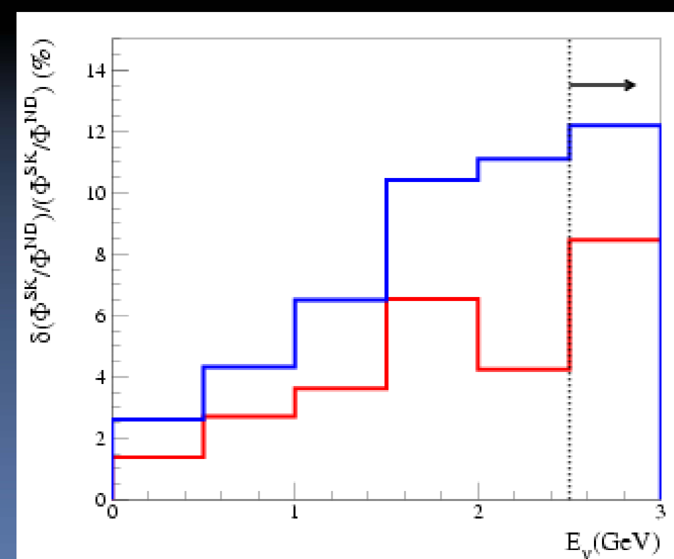
Far/Near Ratio in K2K

Predicted Flux Shape



Predicted Far/Near Ratio

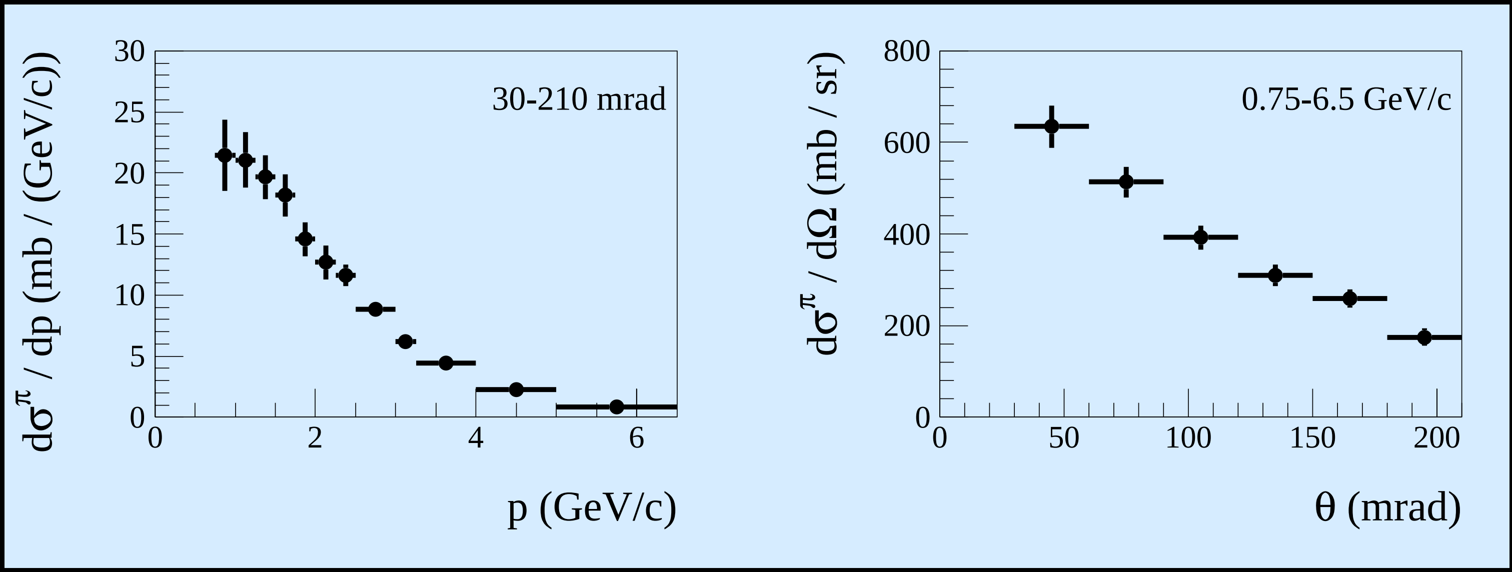




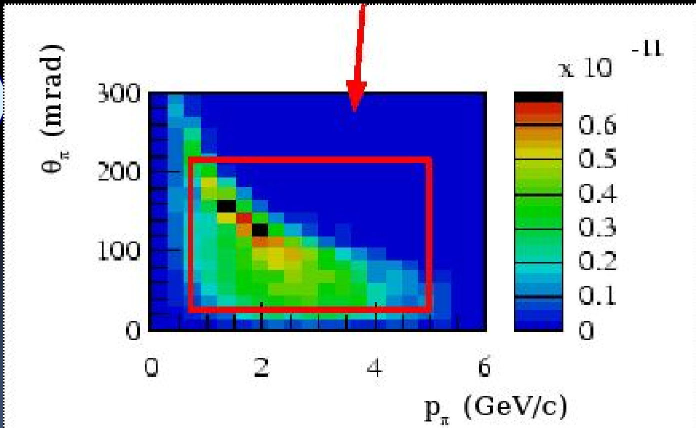
HARP gives ~ factor 2 error reduction across all energies

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

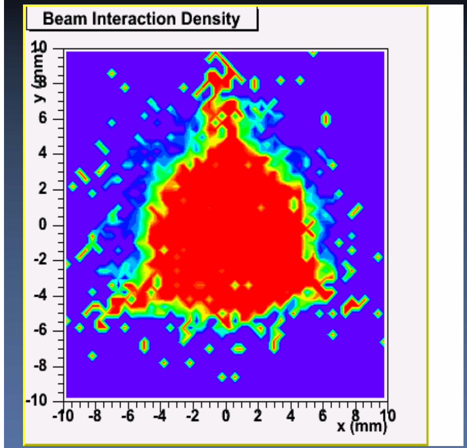
MiniBoone : Harp Be 8.9 GeV 5% λ π^+

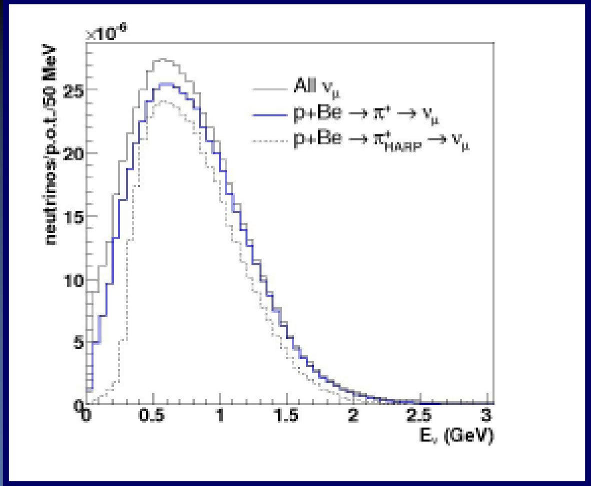


Harp Forward Spectrometer Acceptance

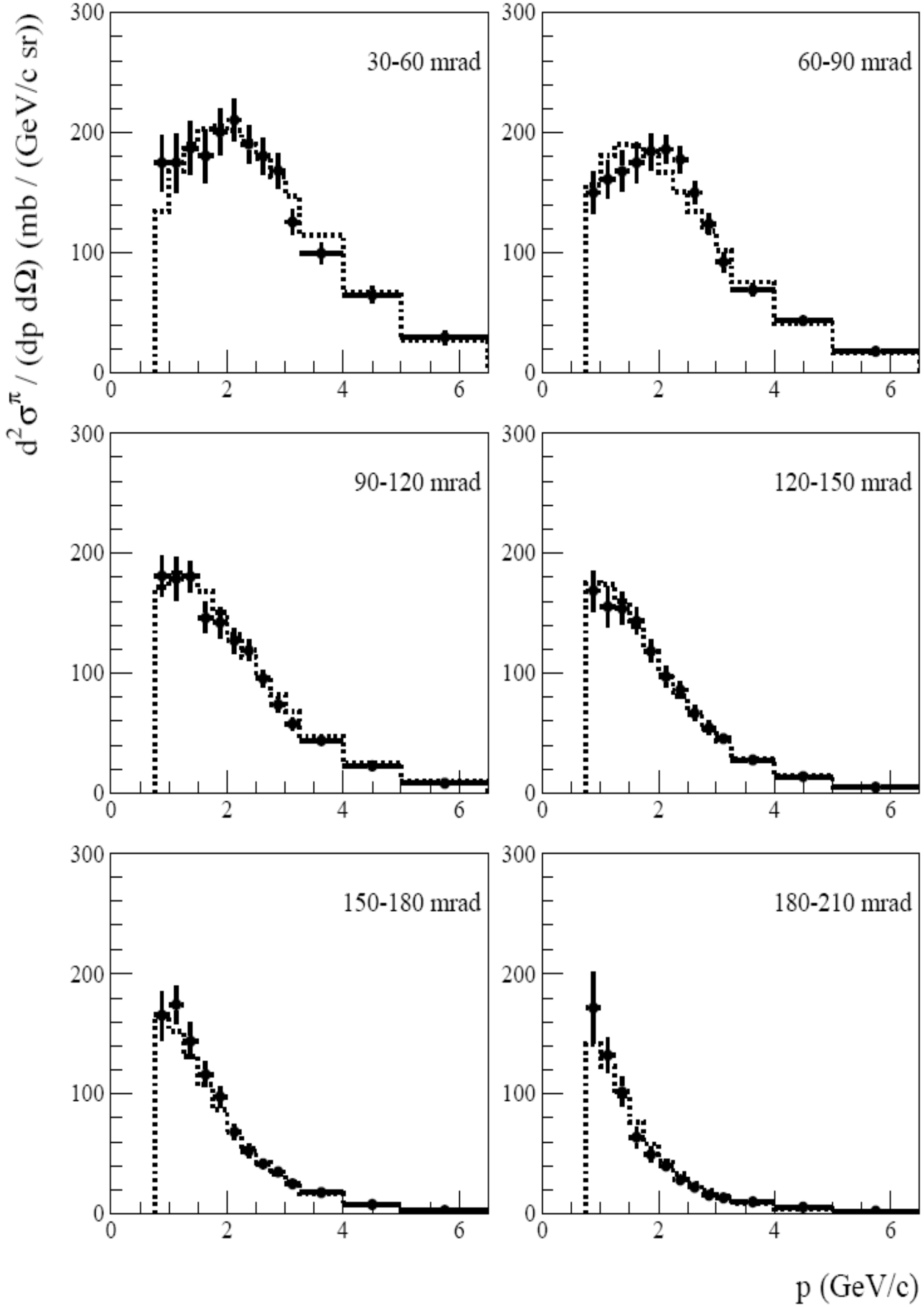


Momentum and Angular distribution of pions decaying to a neutrino that passes through the MB detector.





(But also SCIBOONE)



HARP
Be 8.9 GeV/c data
Sanford-Wang parametrization

$$\frac{d^2\sigma(\mathrm{p+A} \rightarrow \pi^+ + X)}{dp d\Omega}(p,\theta) =$$

$$\exp[A] p^{c_2} (1 - \frac{p}{p_{\mathrm{beam}}})(1 + \frac{p}{p_{\mathrm{beam}}})^{c_9\theta(p - c_7 p_{\mathrm{beam}} \cos^{c_8}\theta)}$$

$$A = c_1 - c_3 \frac{p^{c_4}}{p_{\mathrm{beam}}^{c_5}} - c_6\theta(p - c_7 p_{\mathrm{beam}} \cos^{c_8}\theta) ,$$

Parameter	Value
c_1	(5.13 ± 0.41)
c_2	(1.87 ± 0.52)
c_3	(6.67 ± 1.69)
$c_4 = c_5$	(1.56 ± 0.55)
c_6	$(1.19 \pm 0.18) \cdot 10^1$
c_7	$(1.73 \pm 0.31) \cdot 10^{-1}$
c_8	$(1.98 \pm 0.69) \cdot 10^1$
c_9	$(1.60 \pm 0.44) \cdot 10^1$

More HARP data for accurate flux predictions coming:

$K^{\pm}$ production data

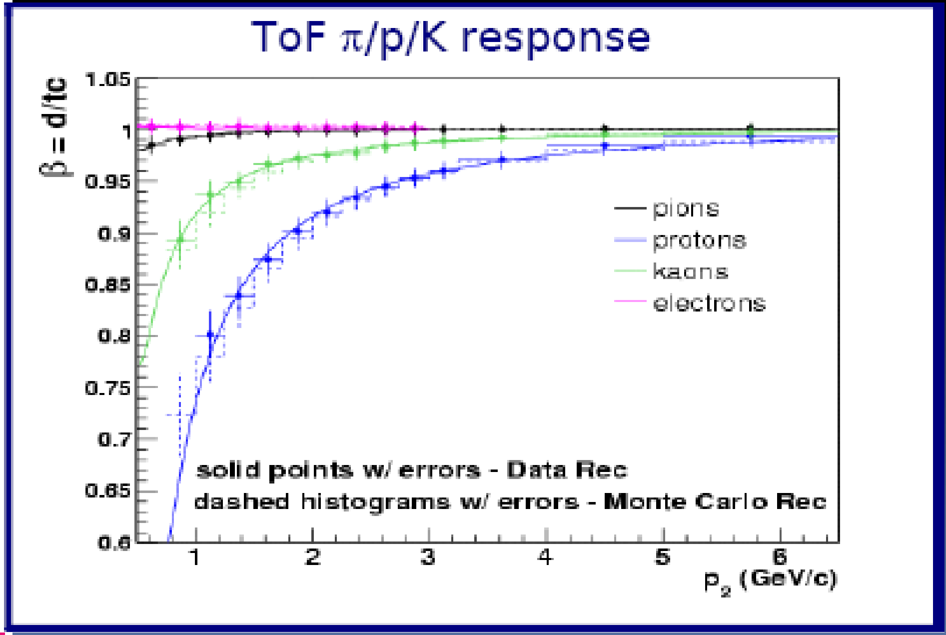
thick targets

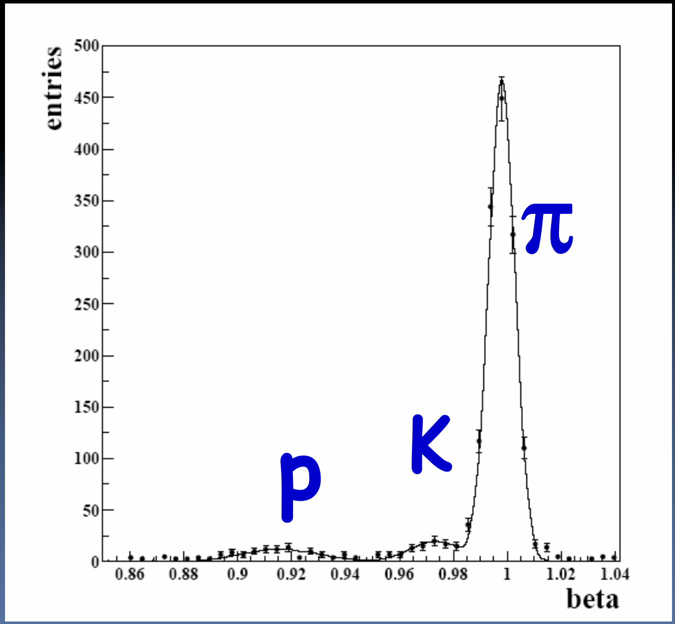
π^{-} production data

main source of ν_e flux for MiniBooNE

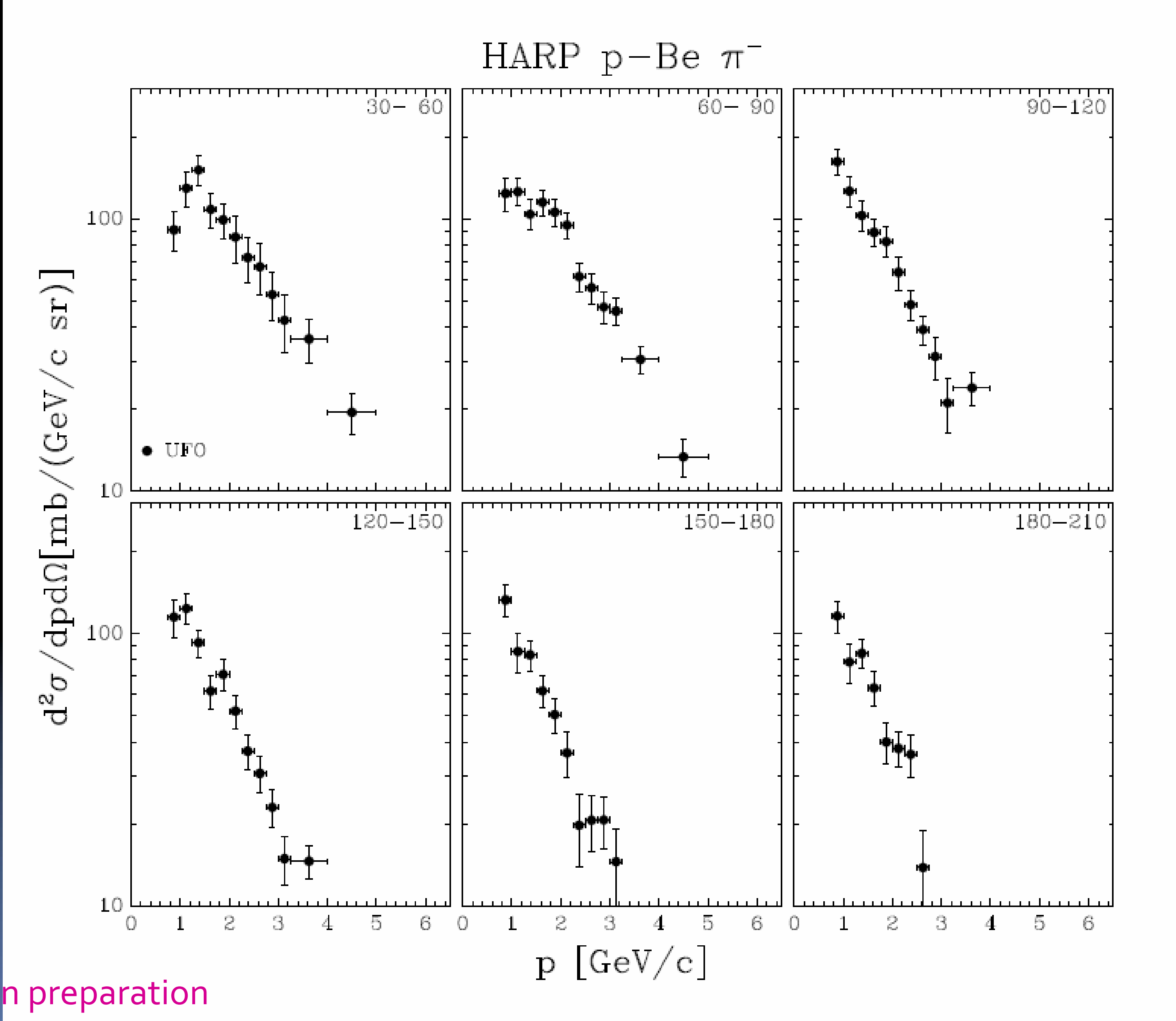
Direct measurement with rescattering and absorption

Anti-neutrino flux measurement



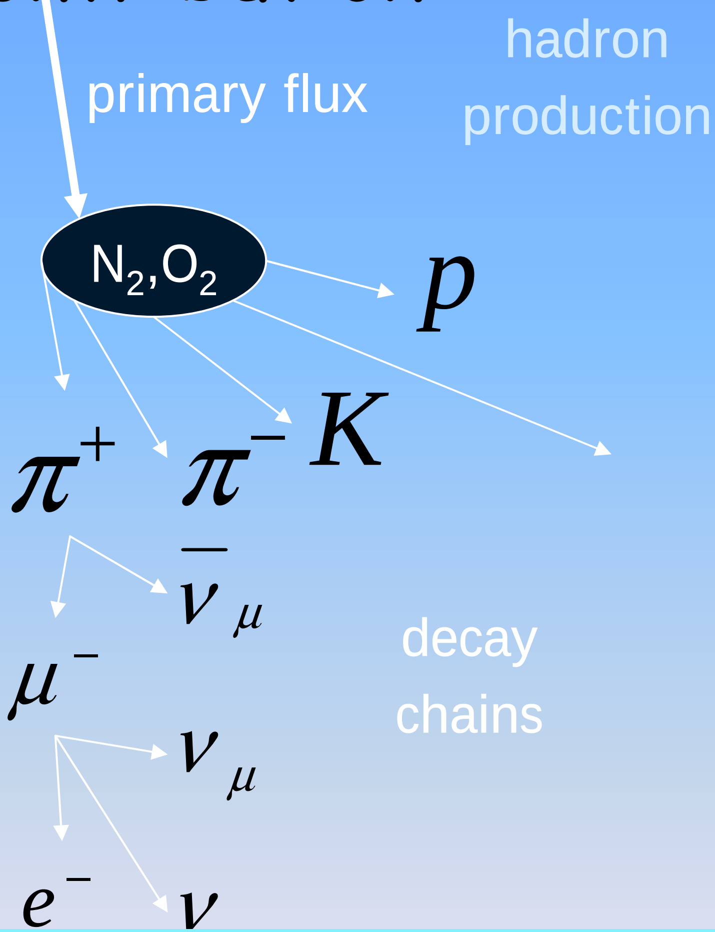


π^- data needed for MiniBooNE antineutrino flux

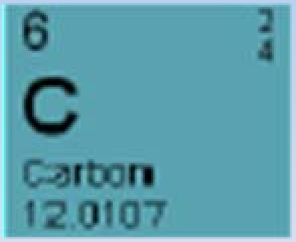


Paper in preparation

Atmospheric neutrino fluxes : the Harp contribution

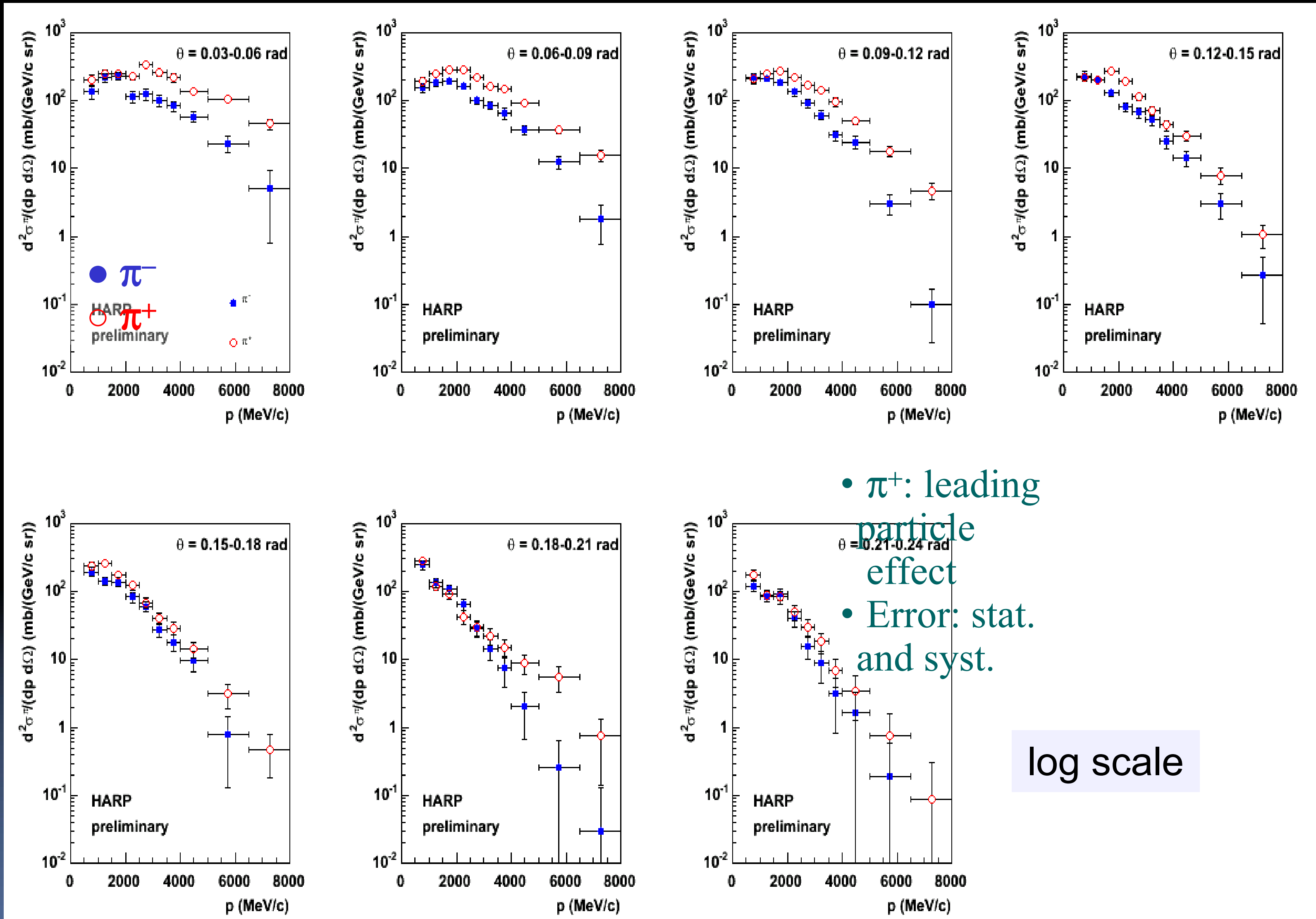


- Most of the uncertainty comes from the lack of data to construct and calibrate a reliable hadron interaction model.
- Model-dependent extrapolations from the limited set of data leads to about 30% uncertainty in atmospheric fluxes
- → cryogenic targets



78% nitrogen
21% oxygen

p+C @ 12 GeV/c

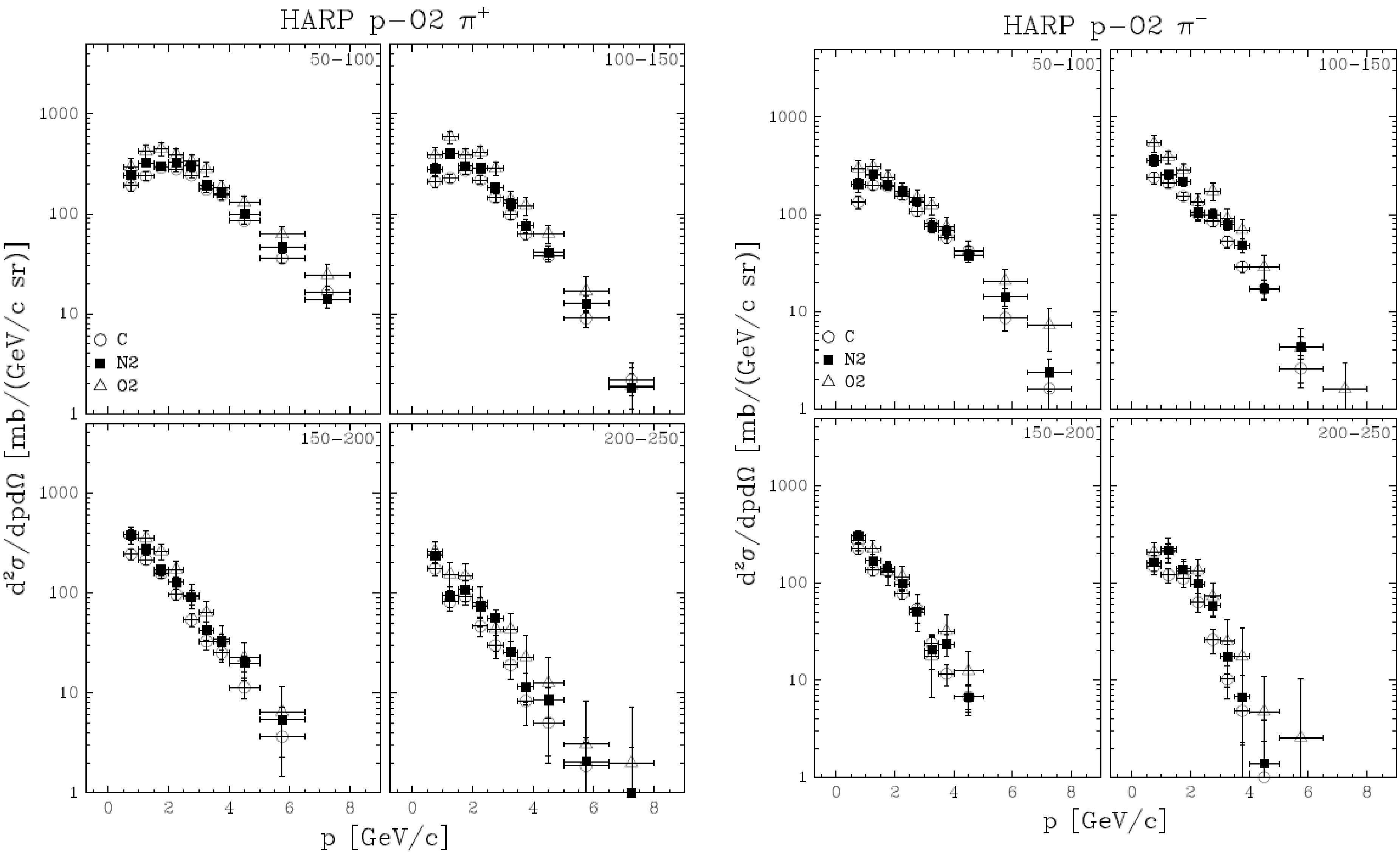


- π⁺: leading particle effect
- Error: stat. and syst.

log scale

Also π+π- beams results are now published

Now also results for p+O_2 or p+N_2 cryo targets available



HARP publications

Forward analysis

Measurement of the production cross-section of positive pions in p-Al collisions at 12.9 GeV/c (K2K target measurement)

M.G. Catanesi et al, hep-ex/0510039, **Nucl. Phys. B732: 1-45 (2006)**

Measurement of the production cross-section of positive pions in the collision of 8.9 GeV/c protons on beryllium (MiniBooNE target measurement)

M.G. Catanesi et al, **Eur.Phys.J.C52:29-53,2007**.

Measurement of the production cross-section of pi+ in p-C and pi- C Interactions at 12 GeV/c

M.G.Catanesi et al : Astroparticle Physics - volume/issue: 29/4 pp. 257-281

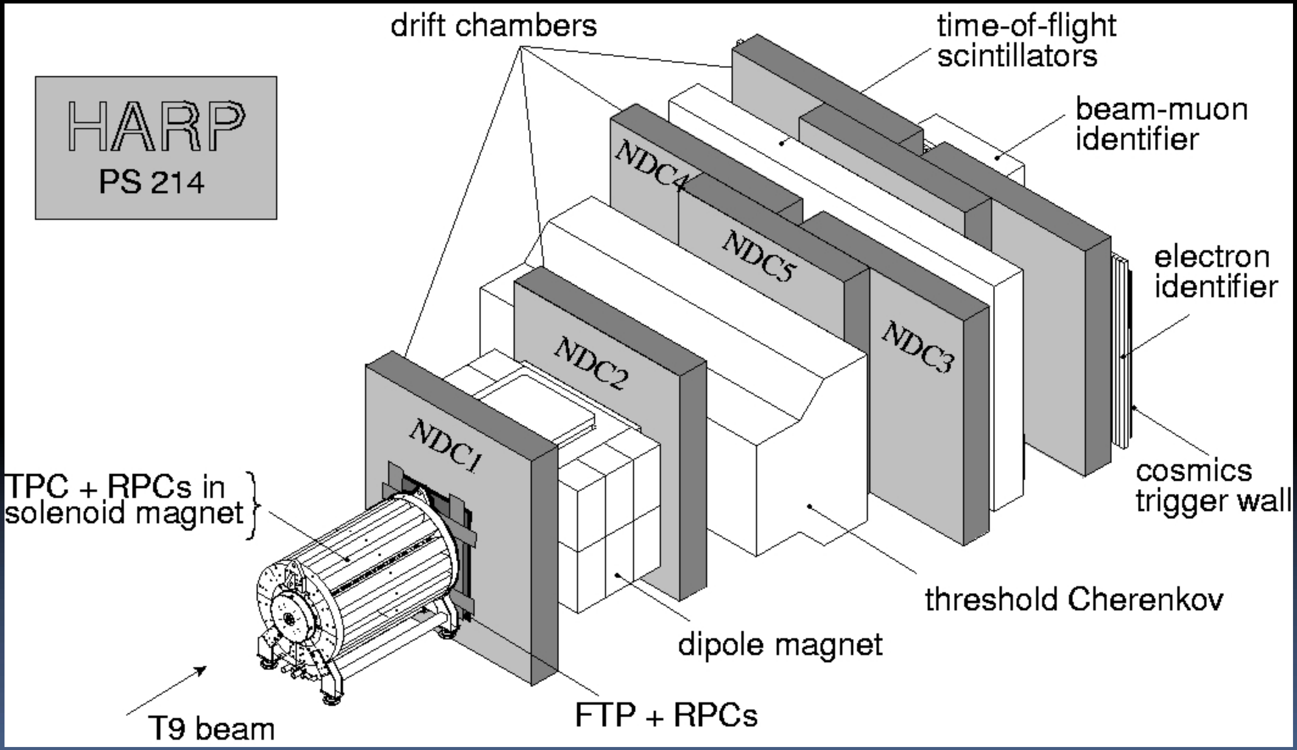
Forward production of pi+/pi- in p-O2 and pN2 interactions at 12 GeV/C

M.G.Catanesi et al : Submitted to Astroparticle Physic

In preparation :

Forward production of charged pions in the HARP experiment with incident pi+/pi- on nuclear targets

Large Angle Analysis



“Large Angle” analysis

beam momenta:
3, 5, 8, 12 GeV/c

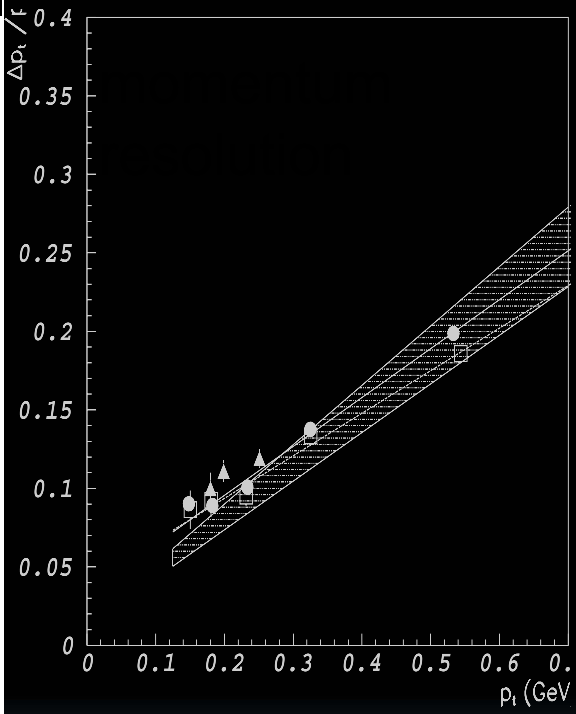
events:
require trigger in ITC (cylinder around target)

TPC tracks:
>11/20 points, momentum measured and track originating in target
PID selection
track distortions due to ion charges in TPC applied
Full sample analyzed

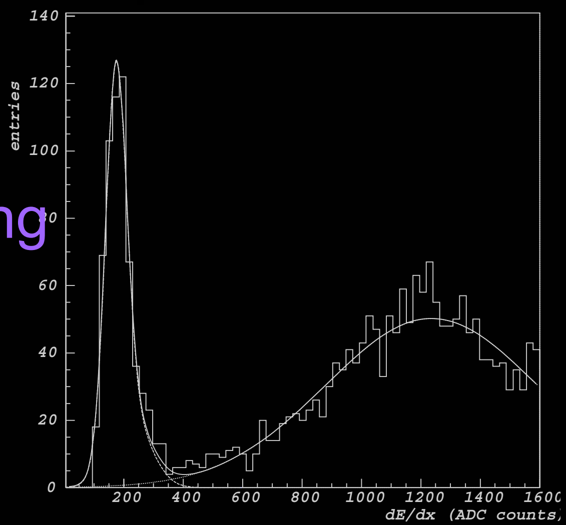
- **Corrections:**
- Efficiency, absorption, PID, momentum and angle smearing by unfolding method
- (same as pC data analysis in forward spectrometer)

- **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^{+-}.

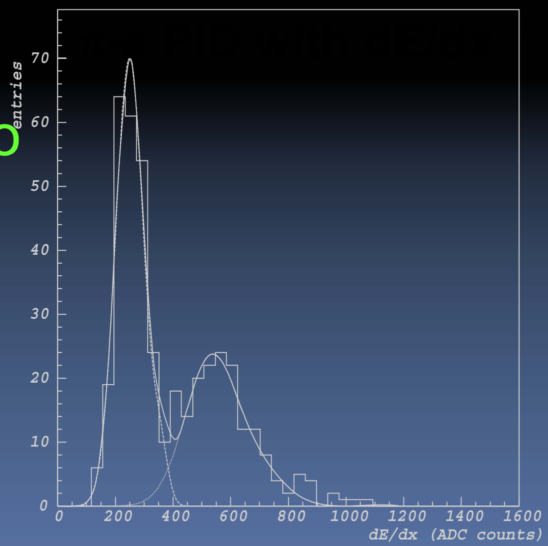
LA Spectrometer performance



momentum calibration: cosmic rays elastic scattering

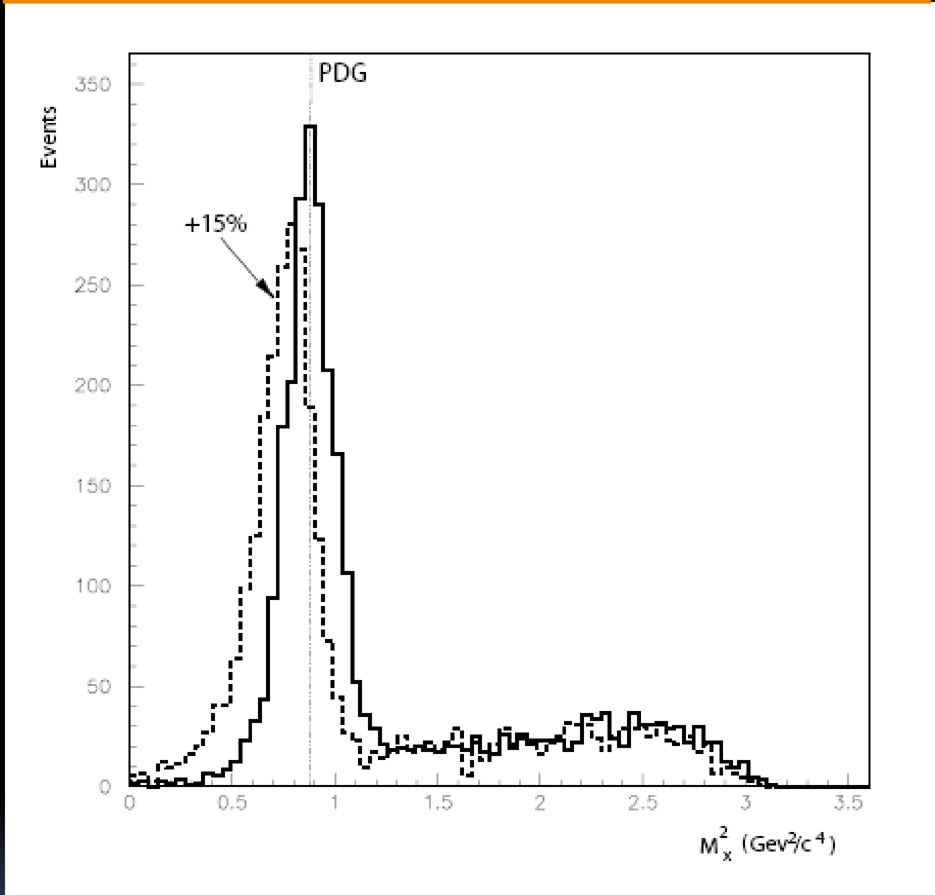


PID:
dE/dx used for analysis
TOF used to determine efficiency



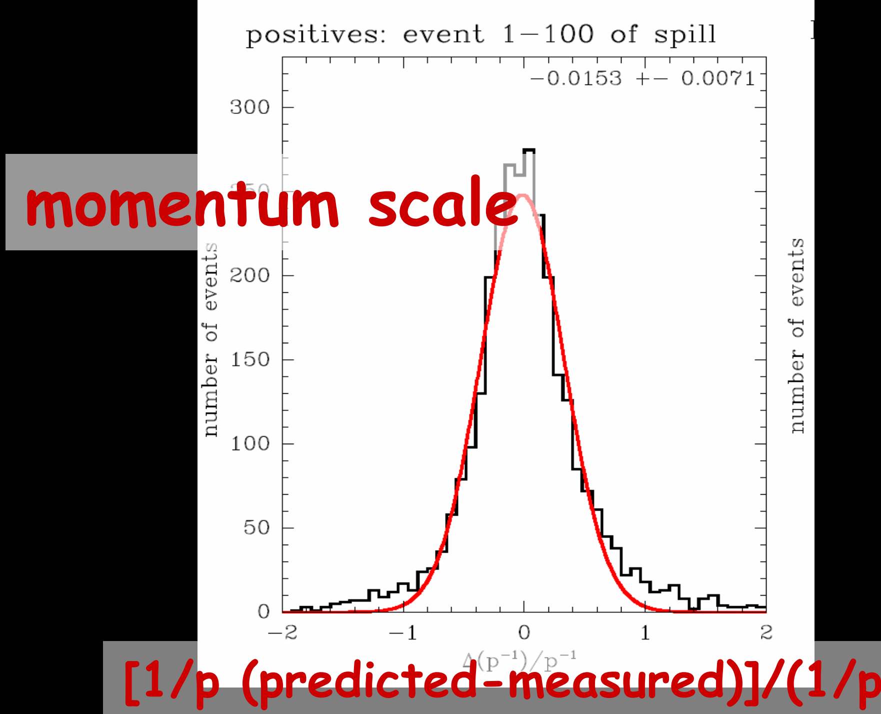
elastic scattering:
absolute calibration of
efficiency
momentum
angle
(two spectrometers!)

The elastic scattering benchmark

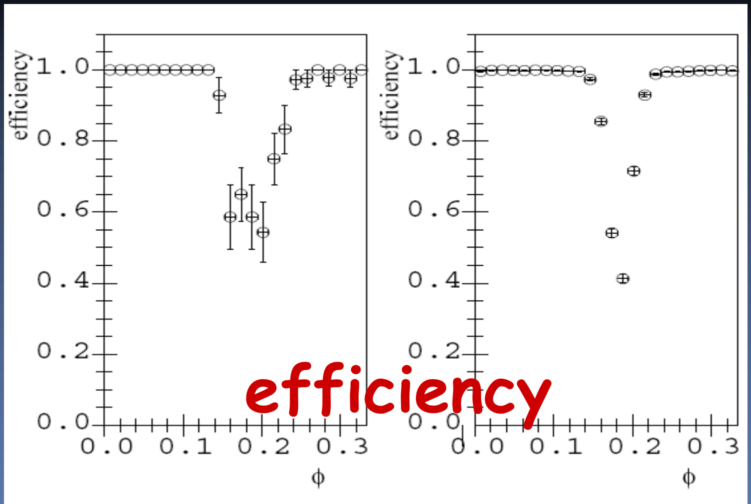


missing mass peak from large angle proton track (position of peak verifies momentum scale -- +15% shift is completely excluded)

Momentum scale Sys. Error < 3%

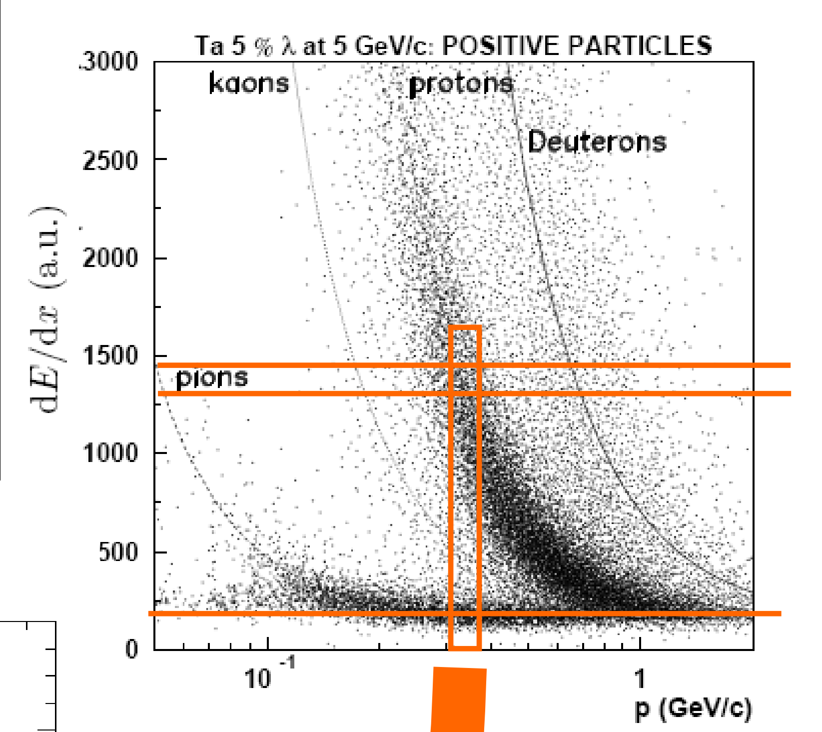


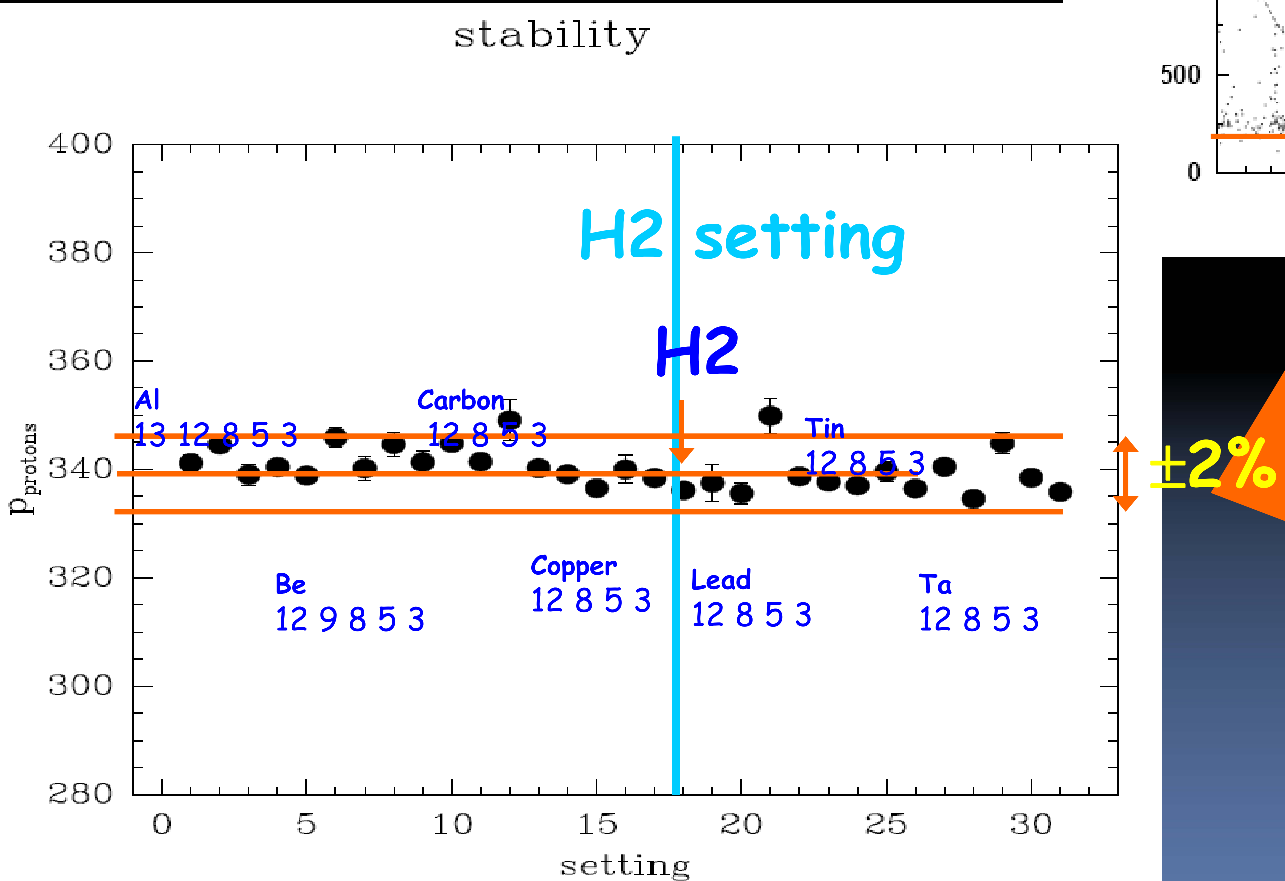
Comparison of predicted vs measured track allows LA tracking benchmark



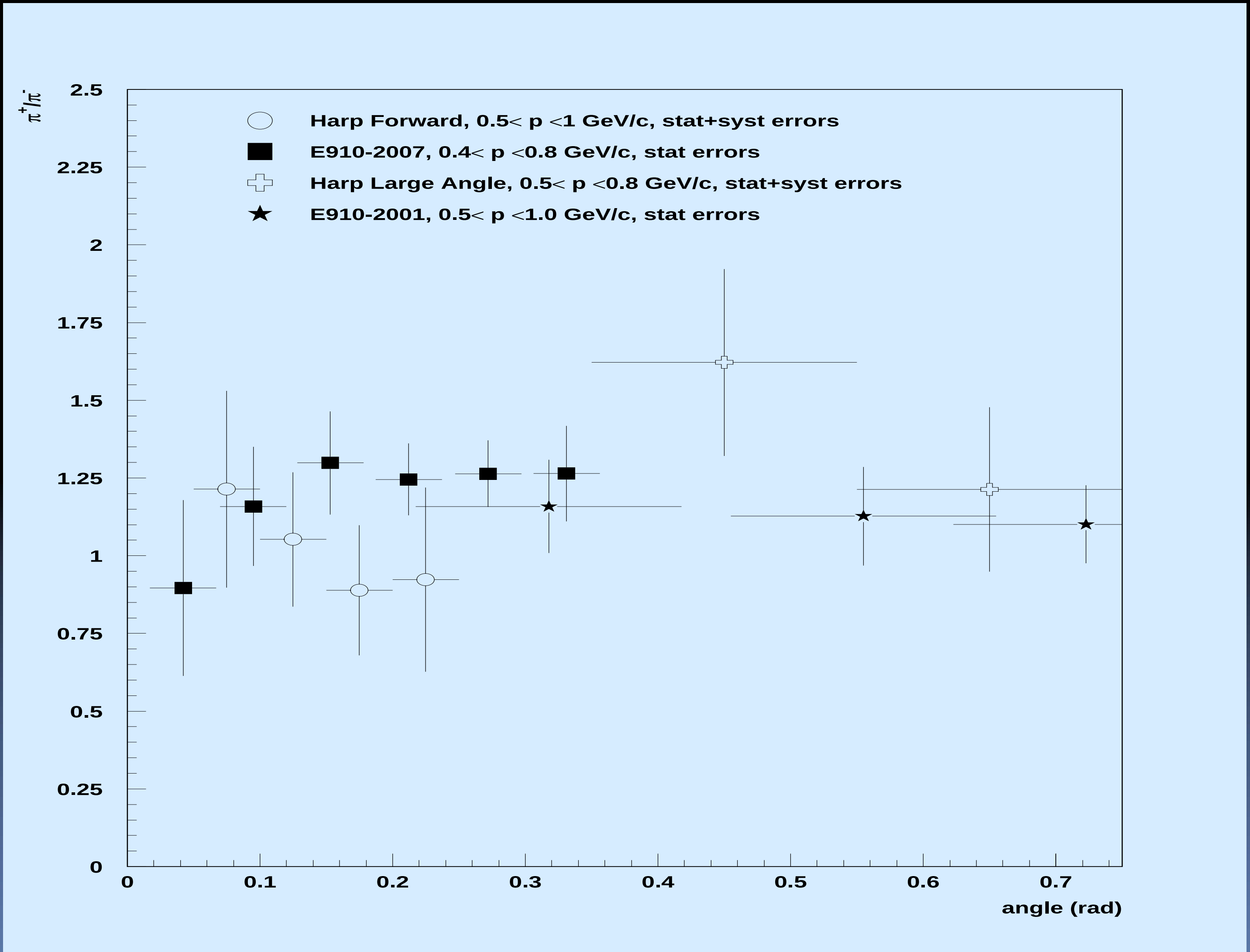
Stability from LH2 target to other targets

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



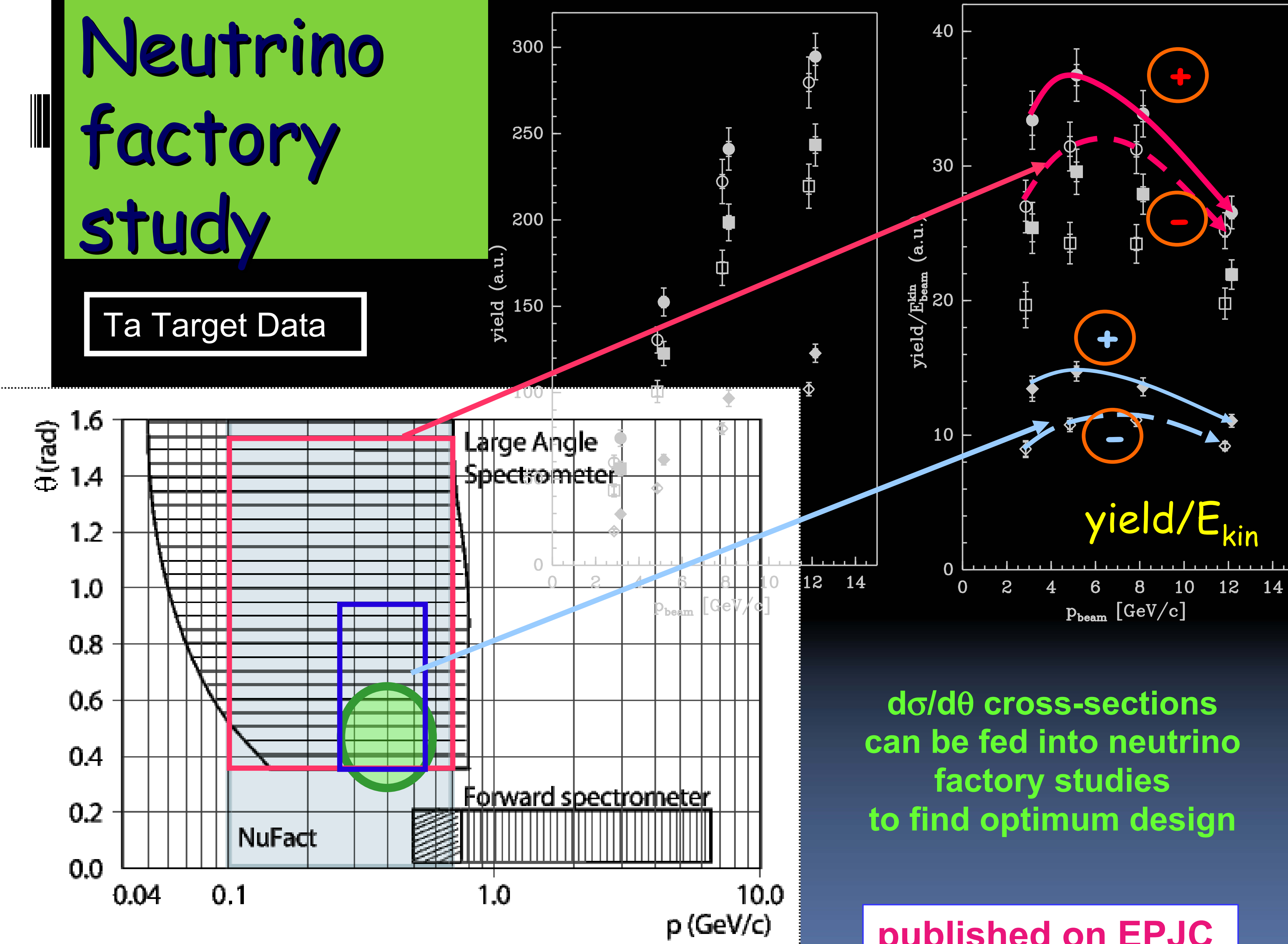


Harp vs E910 (12 GeV/c P beam)



Neutrino factory study

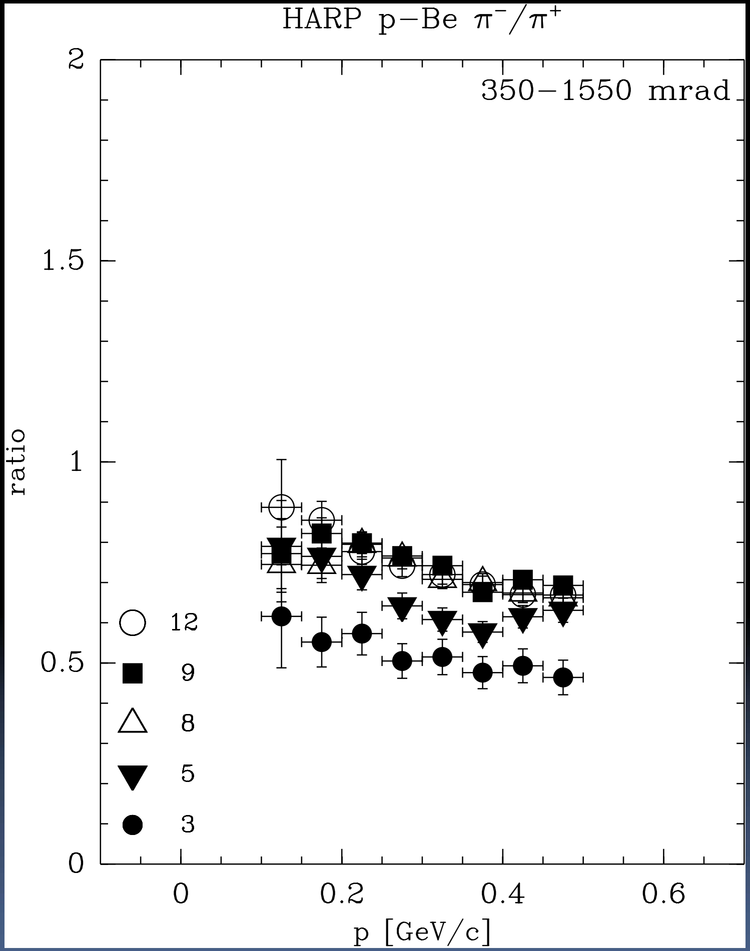
Ta Target Data

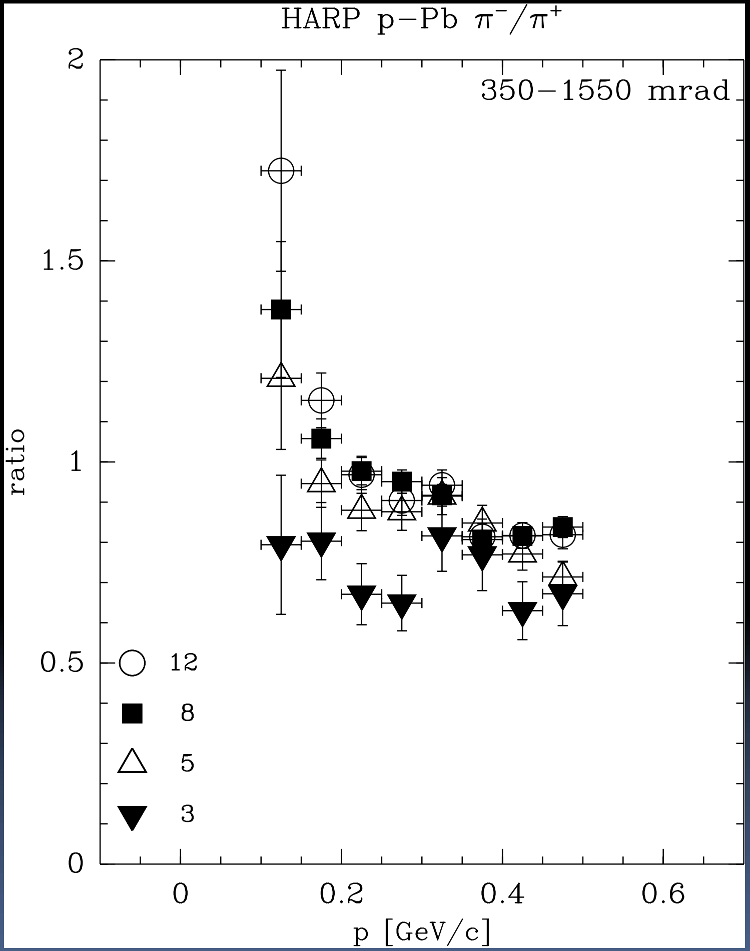


dσ/dθ cross-sections can be fed into neutrino factory studies to find optimum design

published on EPJC

π-π+ ratios for light and heavy nuclei

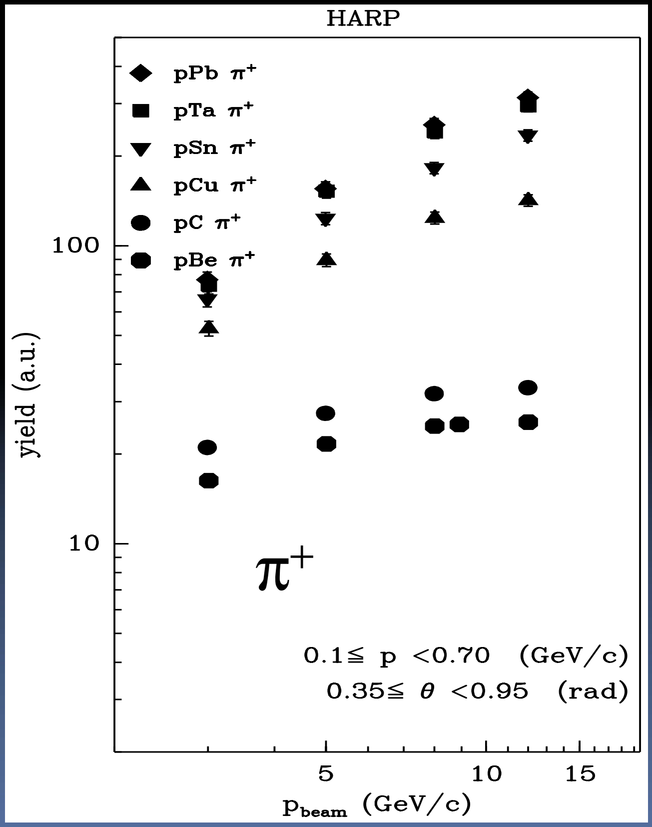


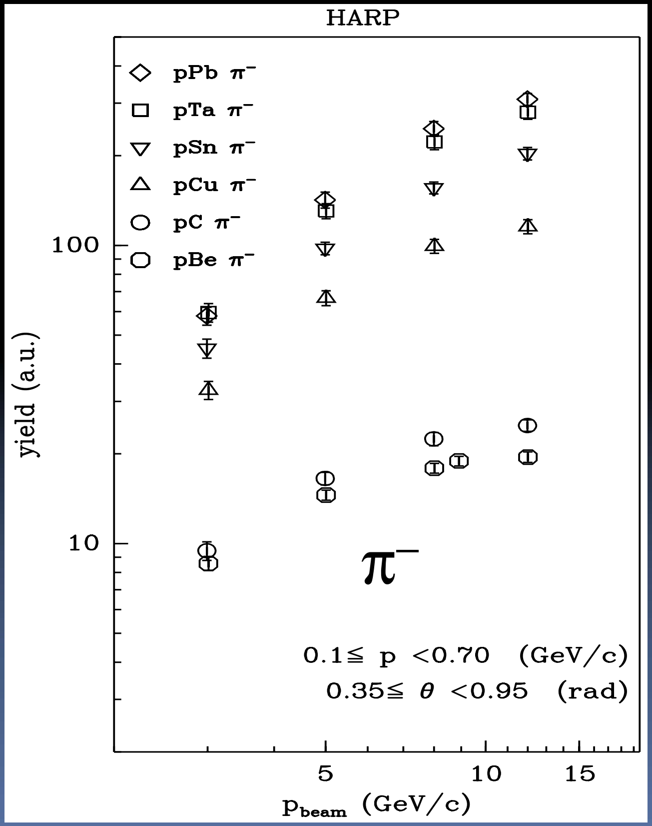


Pion yields

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

forward production only $0.35 < \theta < \mathbf{0.95}$ rad

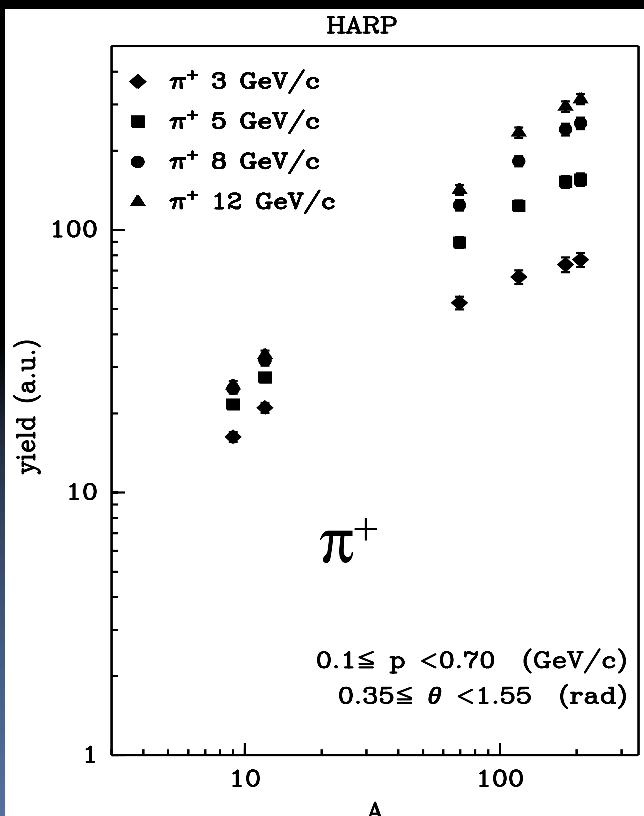


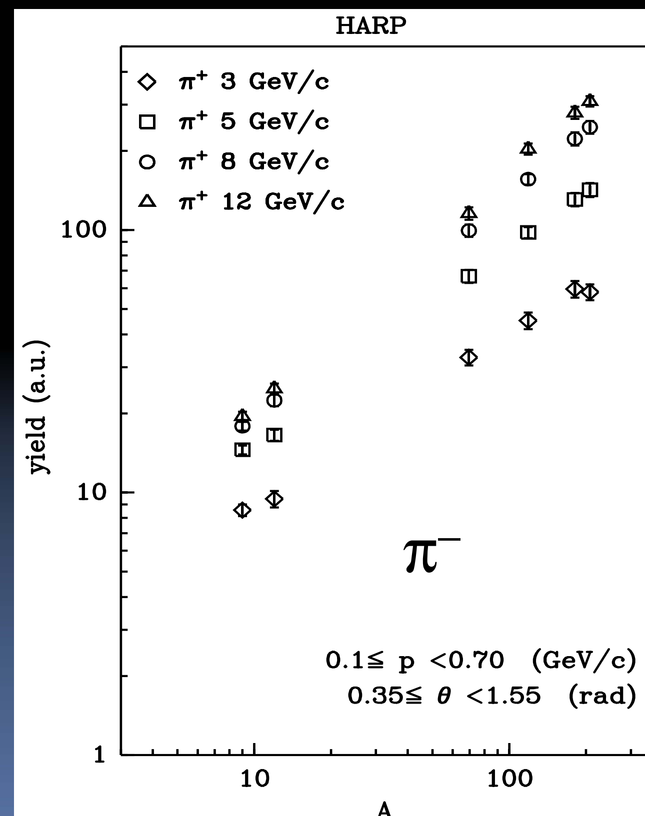


Pion yields

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 $0.35 < \theta < 1.55$ rad





proton beams on long targets

Data analysed on tantalum and carbon targets (lead later)

Especially useful for the neutrino factory target

Interesting to tune models for re-interactions (and shower calculations in calorimeters etc.)

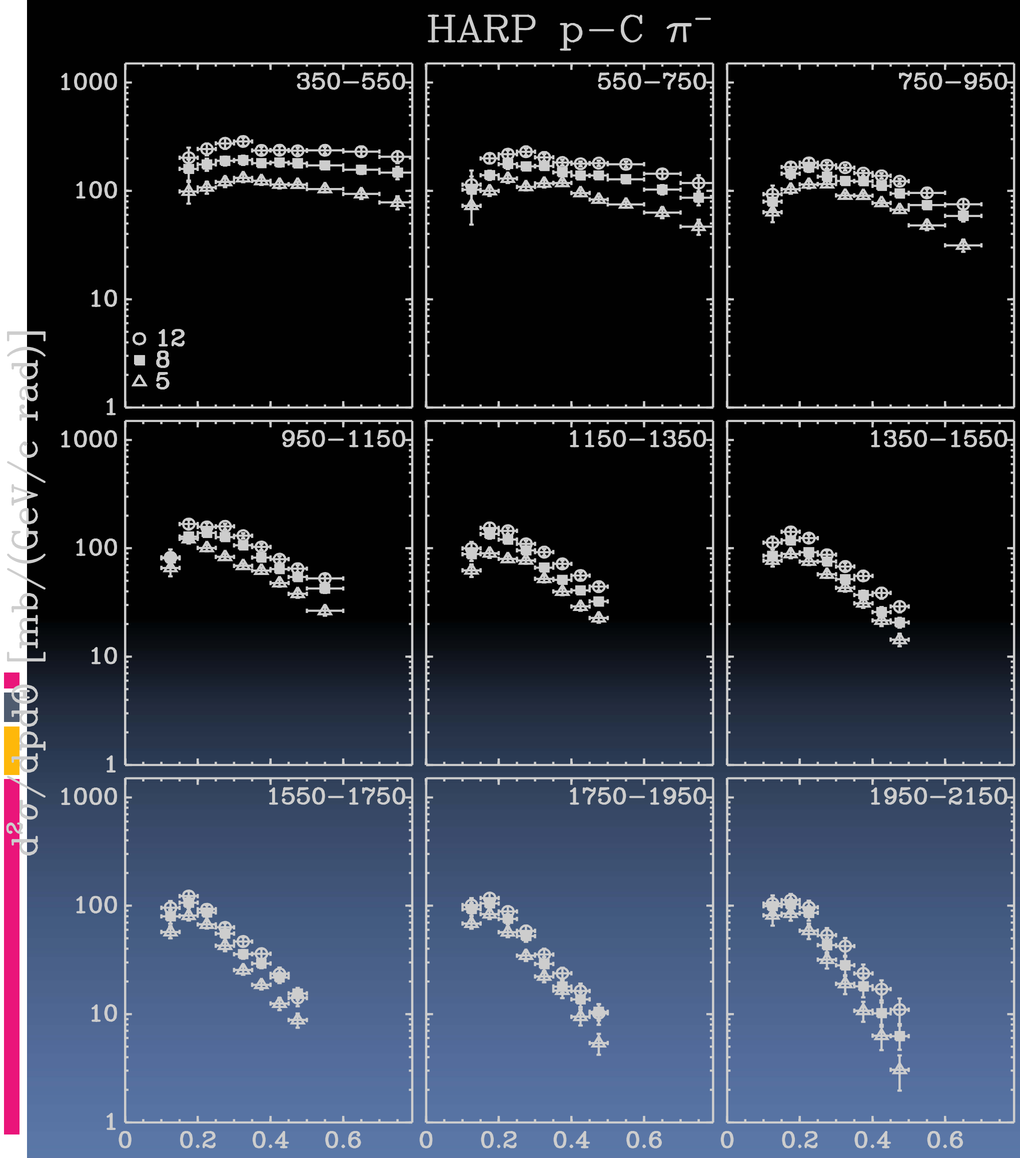
As for the thin targets, corrections for the absorption and re-interaction of the produced particles are made

NO correction is made for the absorption and re-interaction of the beam proton (this is what we want to measure)

Data are not directly applicable: our targets are 30mm in diameter: more re-interactions of the scattered proton

p-C π^-

LONG C TARGET



PRELIMINARY

forward

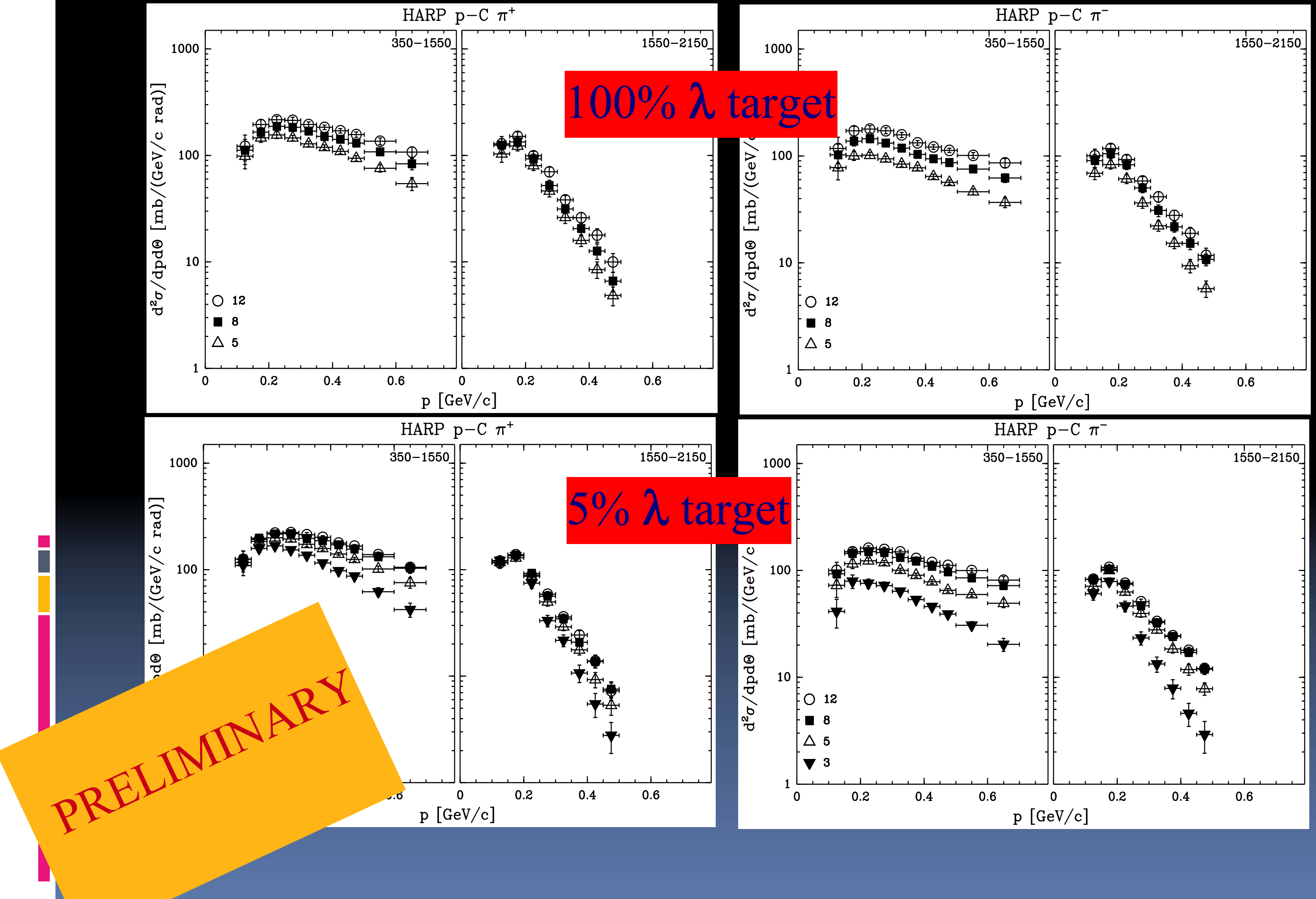
$0.35 < \theta < 1.55$

backward

$1.55 < \theta < 2.15$

FW and BW p-C π^+

100% vs 5% TARGET



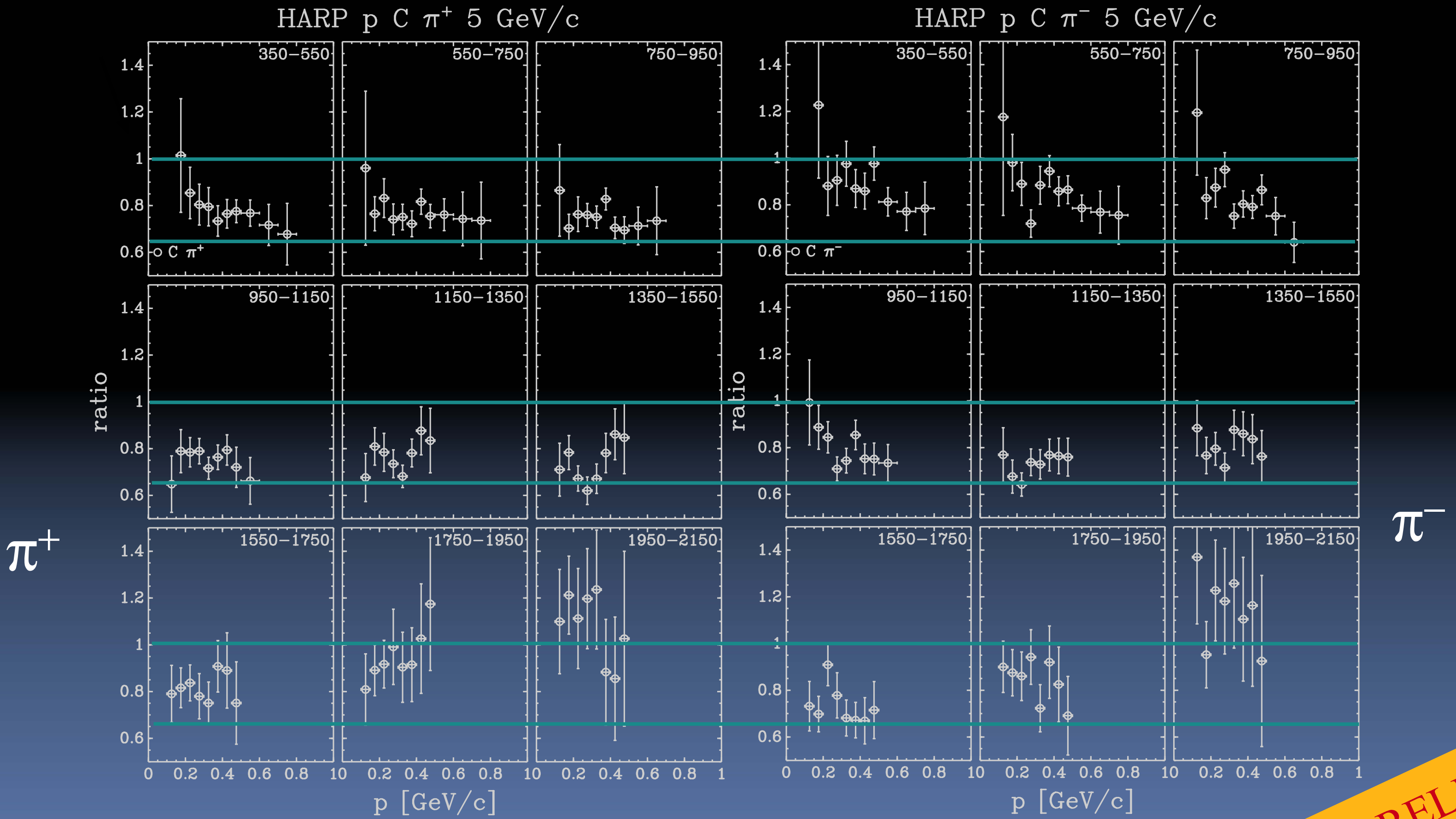
bin-by-bin ratio
5 GeV/c beam: p-C $\pi^{+/-}$

100% / 5% TARGET

Large corrections !

If no effect from absorption of p: expect ratio = 1

If all interacting p are lost: expect ratio = 0.65

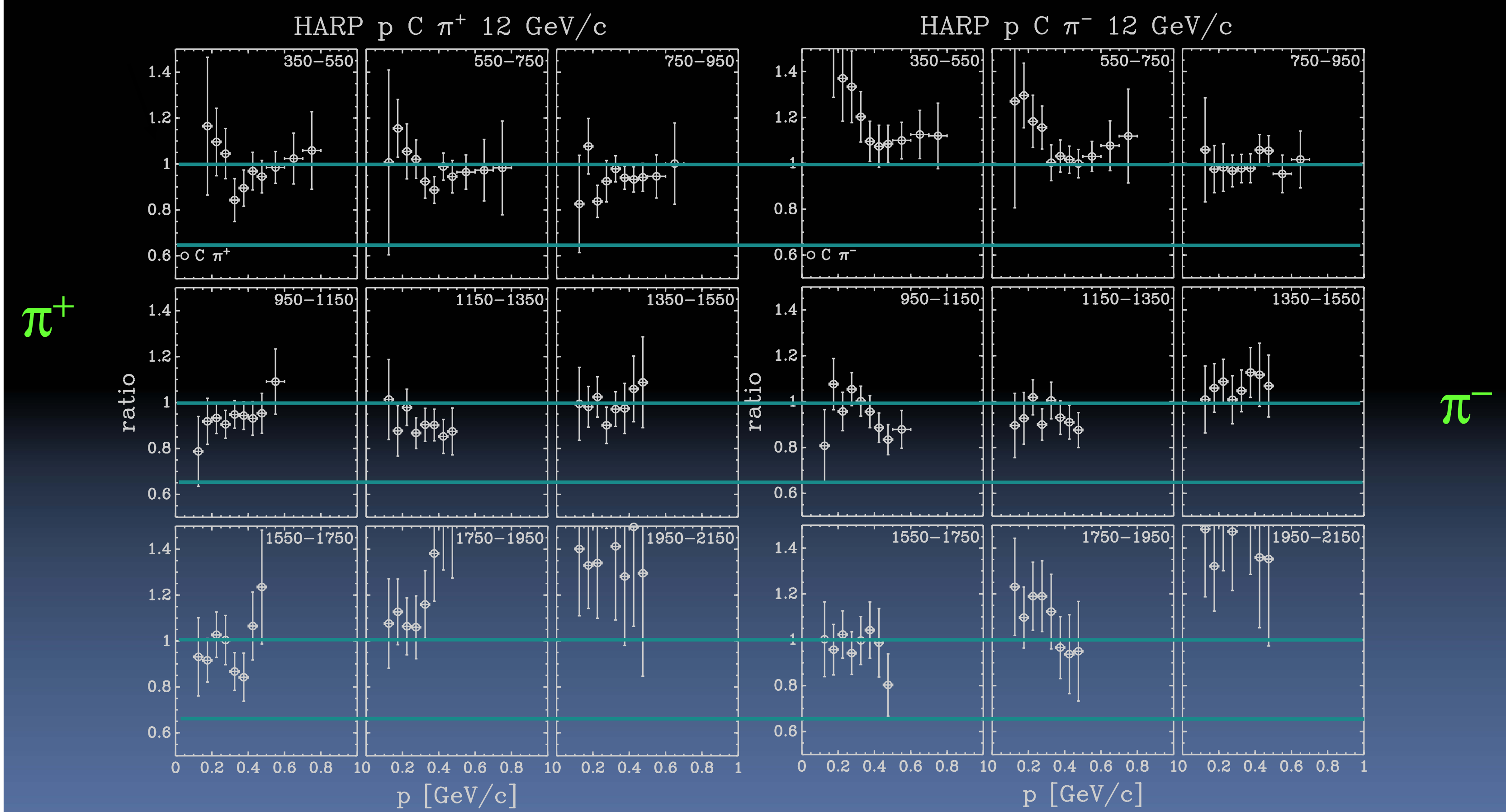


PRELIMINARY

bin-by-bin ratio
12 GeV/c beam: p-C $\pi^{+/-}$

100% / 5% TARGET

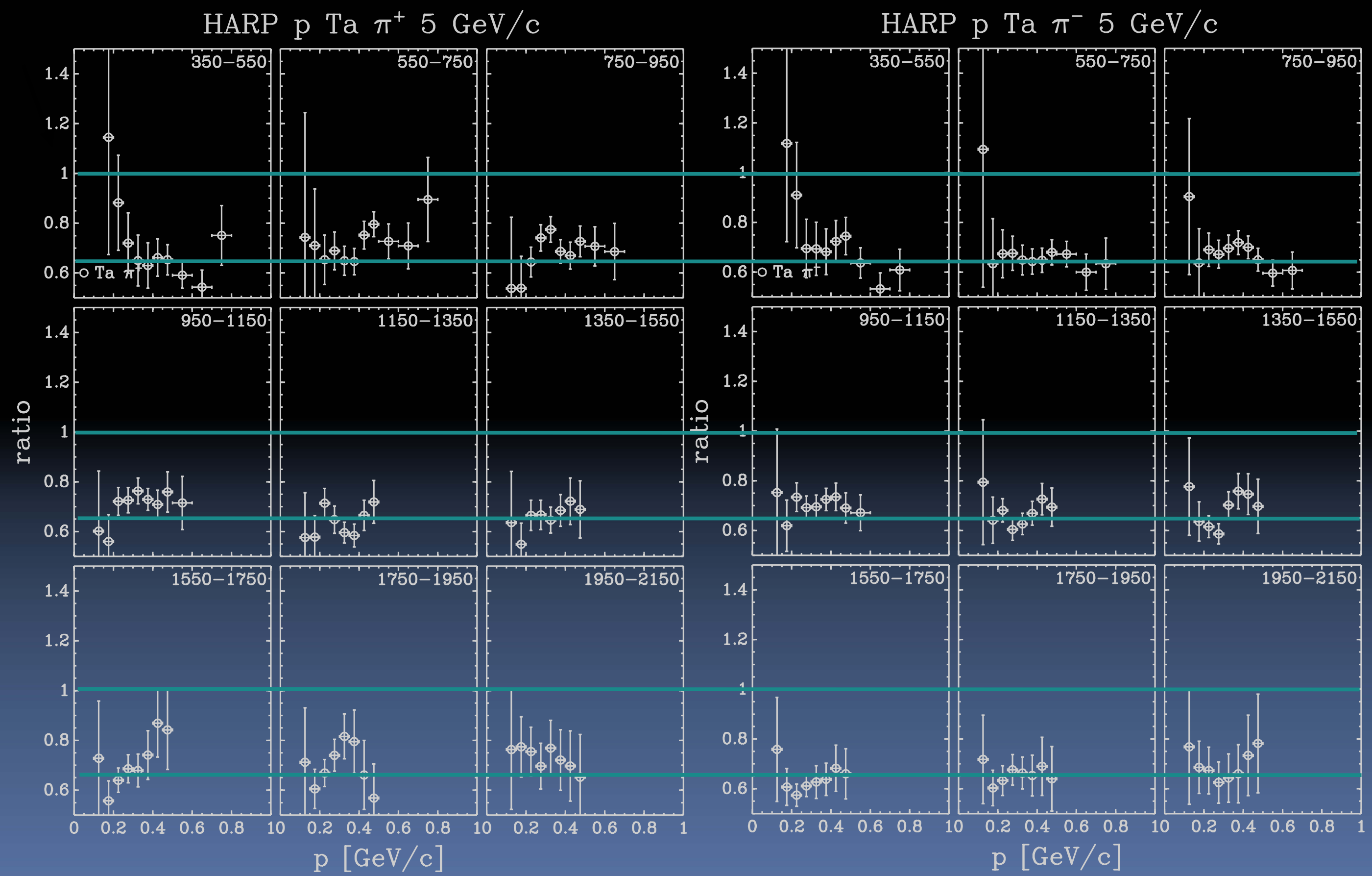
If no effect from absorption of p: expect ratio = 1
If all interacting p are lost: expect ratio = 0.65



bin-by-bin ratio
5 GeV/c beam: p-Ta $\pi^{+/-}$

100% / 5% TARGET

If no effect from absorption of p: expect ratio = 1
If all interacting p are lost: expect ratio = 0.65

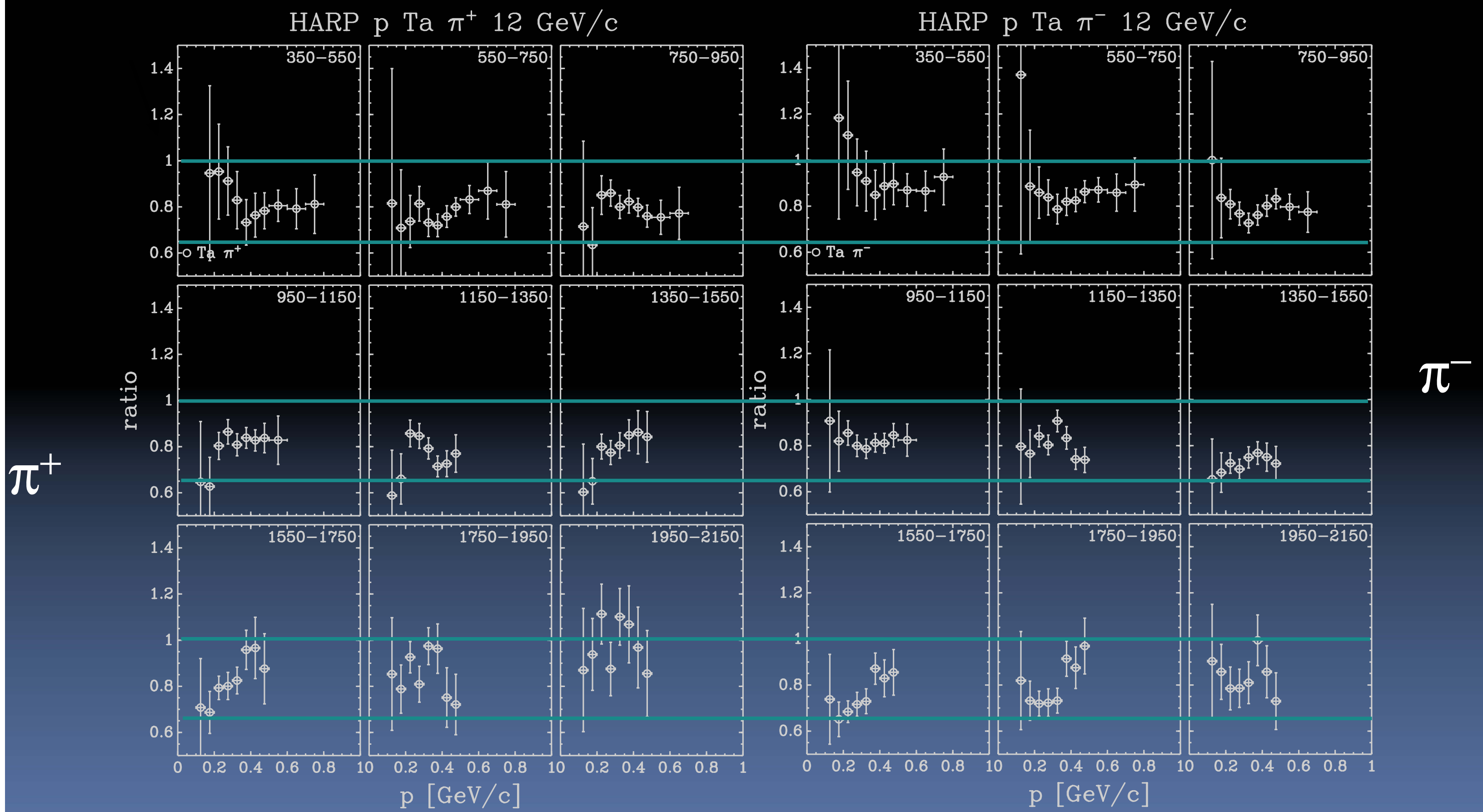


π^+ π^-

bin-by-bin ratio
12 GeV/c beam: p-Ta $\pi^{+/-}$

100% / 5% TARGET

If no effect from absorption of p: expect ratio = 1
If all interacting p are lost: expect ratio = 0.65



HARP publications

Large Angle analysis
(Neutrino Factory measurements)

Measurement of the production of charged pions by protons on a tantalum target
M.G. Catanesi et al, **Eur. Phys. J. C51 (2007) 787**

Large-angle production of charged pions by 3 GeV/c–12 GeV/c protons on carbon copper and tin targets
M.G. Catanesi et al, **Eur. Phys. J. C53:177-204,2008**

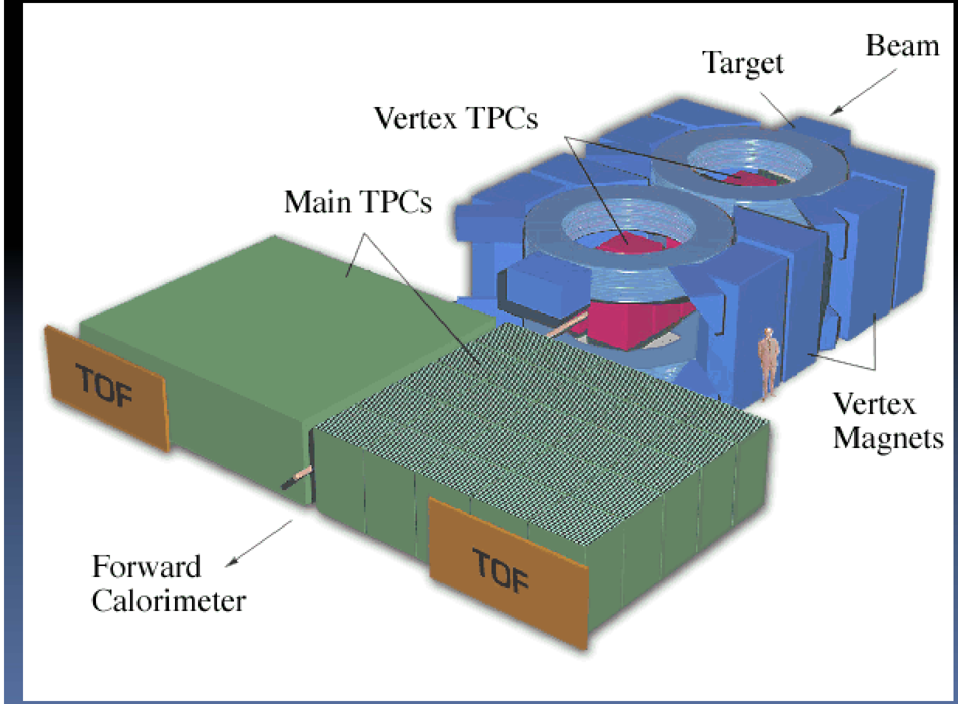
Large-angle production of charged pions by 3 GeV/c–12 GeV/c protons on a beryllium , aluminum and lead targets:
M.G. Catanesi et al, **Eur. Phys. J. C54:37-60,2008**

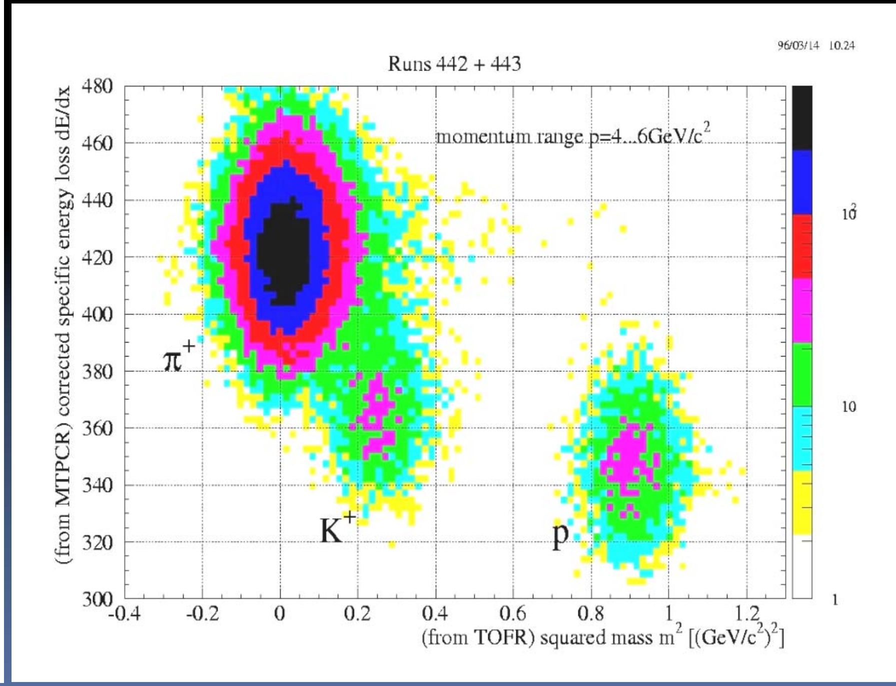
Large-angle production of charged pions in the HARP expriment with <u>incident protons</u> on nuclear targets :
M.G.Catanesi et al. Phys. Rev. C 77, 055207 (2008)

In preparation :
Large-angle production of charged pions in the HARP expriment with <u>incident pions</u> on nuclear targets : M.G. Catanesi et al. (Draft in preparation)
(beams 3 GeV/c -12.9 GeV/c , Al, Be,C, Cu, Pb,Sn,Ta targets)

An existing facility: NA49

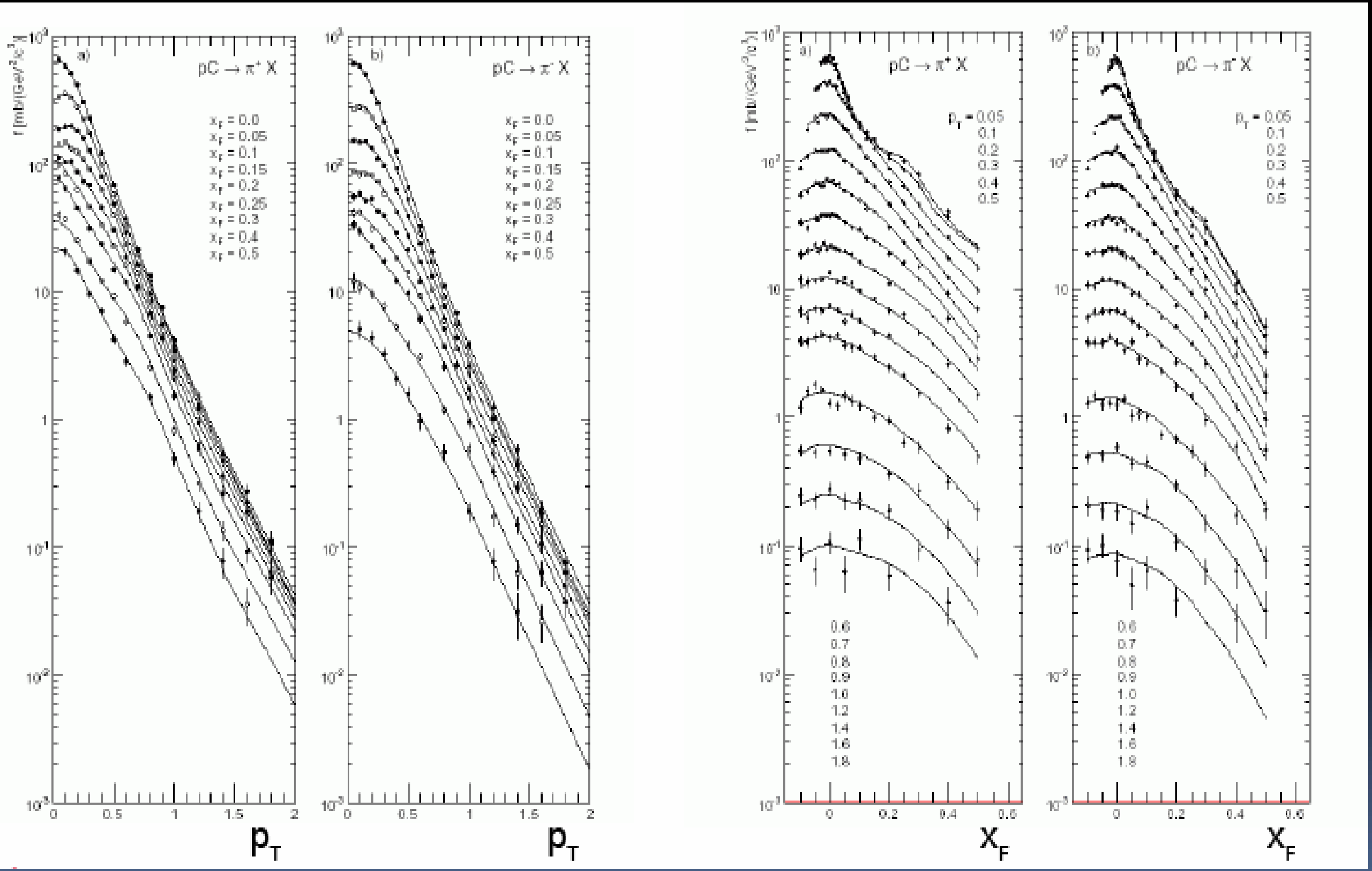
- particle ID in the TPC is augmented by TOFs
- rate somehow limited (optimized for VERY high multiplicity events).
  - order 10^6 event per week is achievable (electronic upgrade needed !)
- NA49 is located on the H2 fixed-target station on the CERN SPS.
  - secondary beams of identified π, K, p; 40 to 350 GeV/c momentum
- Measurements relevant for atmospheric neutrinos have been performed in 2002 with two beam settings (100 and 158 GeV/c) with a 1% Carbon target (these data without TOF)





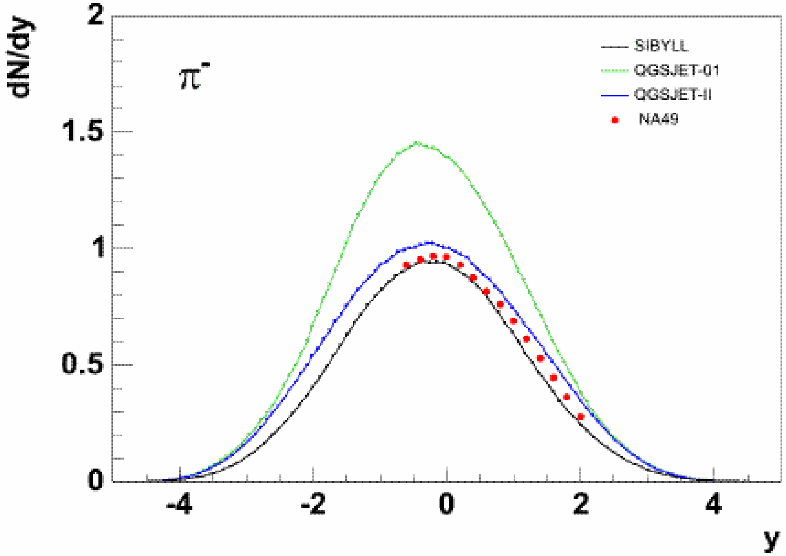
NA49: p+C @158 GeV

$\pi^+ \pi^-$

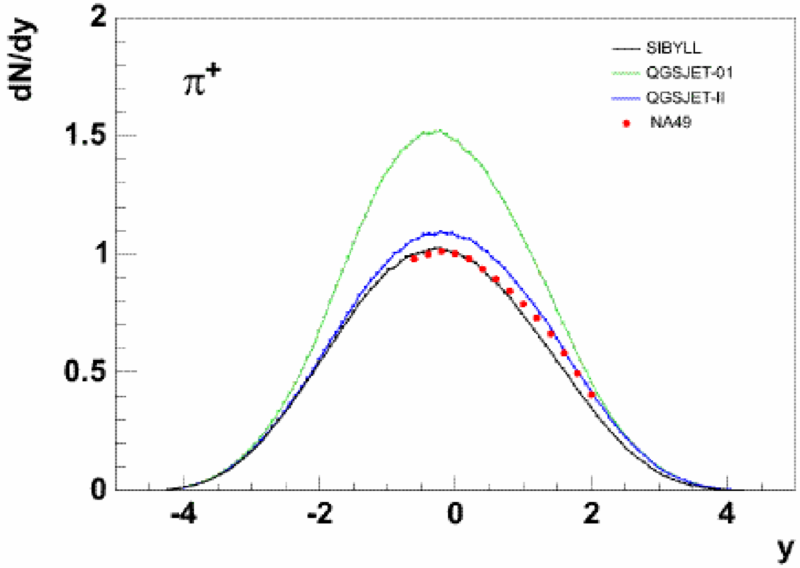


C.Alt et al. hep-ex/0606028

NA49: p+C @158 GeV



Comparison: models – data:
SIBYLL and QGSJET-II:
reasonable agreement with data
QGSJET-01:
overestimation of factor ~ 1.5



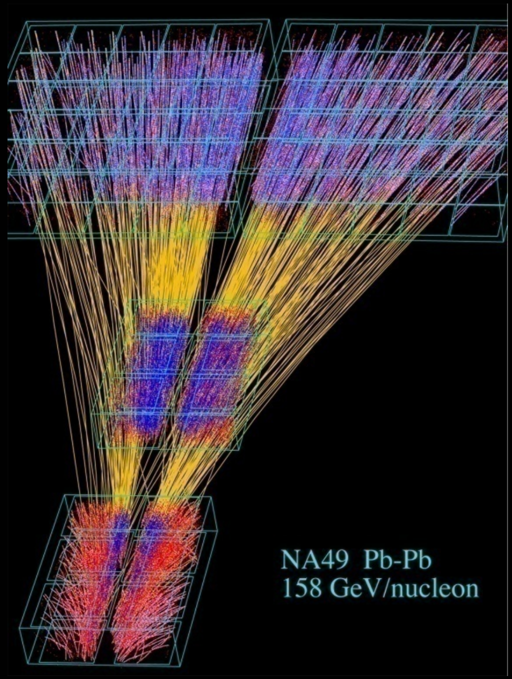
Error of NA49 data:
stat. error ~ 5%
syst. error ~ 5%

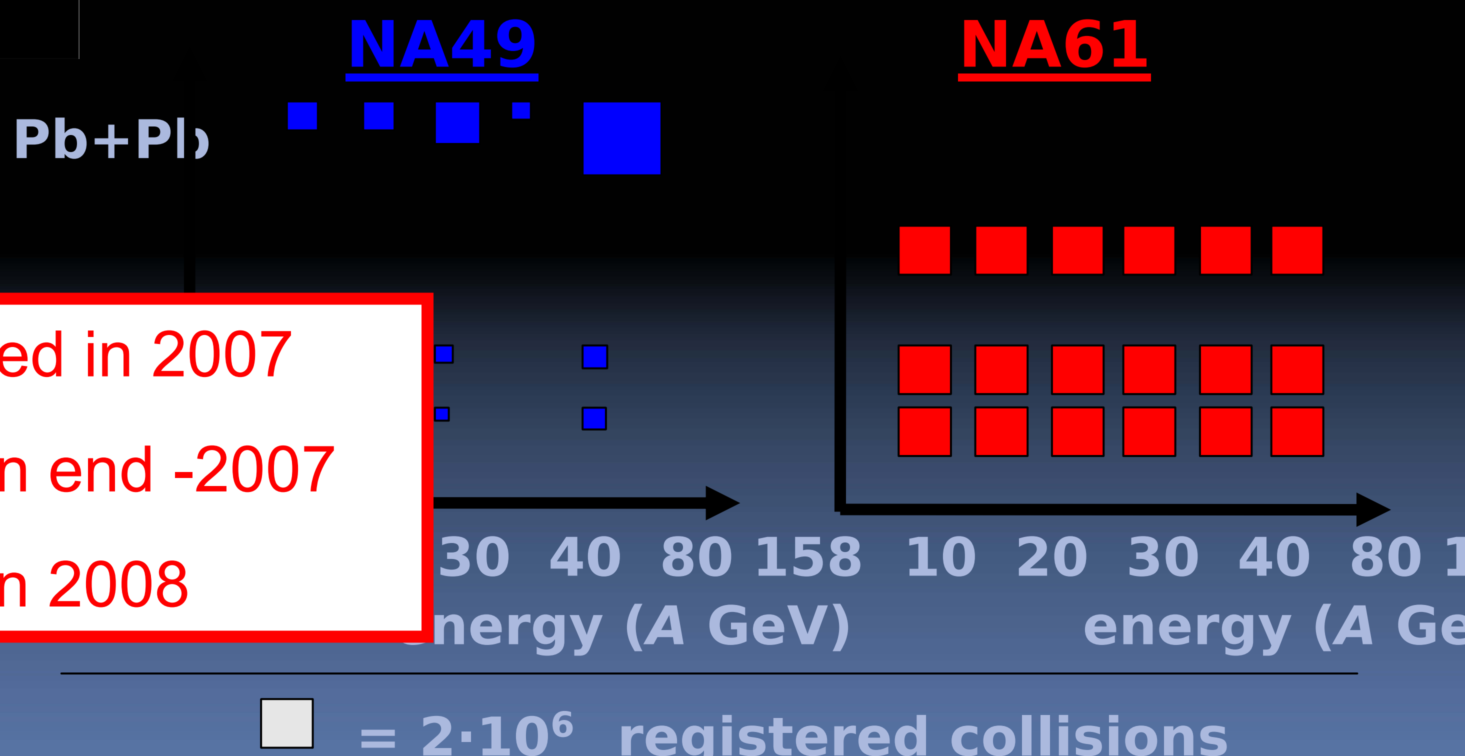
C.Alt et al. (NA49 collaboration) hep-ex/0606028

NA61 Plans :

1. perform a comprehensive scan in energy and size of colliding nuclei to study the properties of the transition between hadron gas and quark gluon plasma

2. measure hadron production in hadron-nucleus interactions needed for neutrino and astroparticle physics





NA61 approved in 2007

Technical Run end -2007

T2K target run 2008

WHAT NEXT …

Mipp@Fermilab

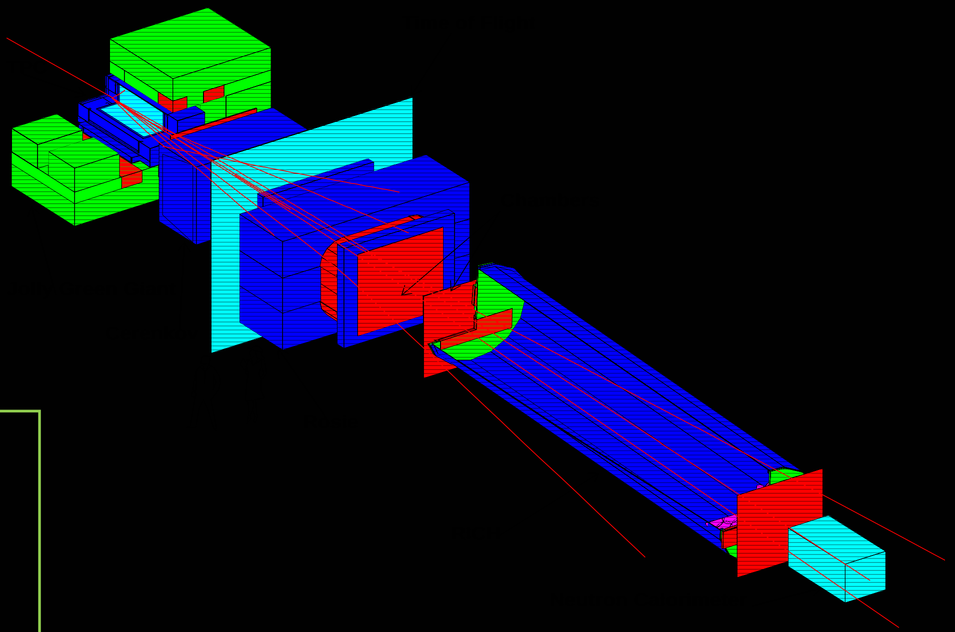
Beams:
Pure p,π ±, K± beams
Energy range 5-120 GeV/c

Targets:
Many different target including the NUMI replica

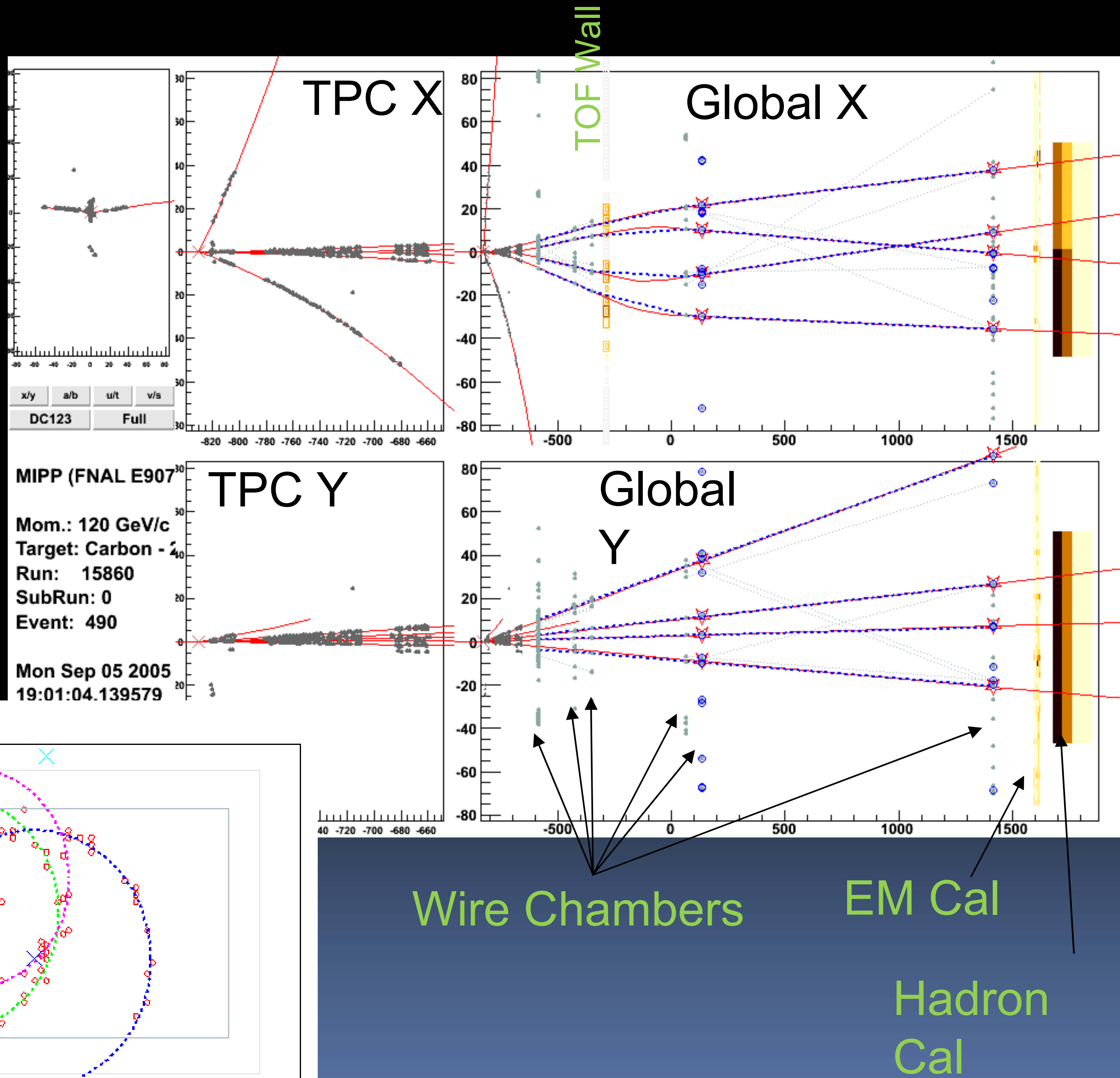
Beam instrumentation:
- incoming particle impact point and direction with drift chambers
- incoming particle ID with beam theshold Cherenkov detectors

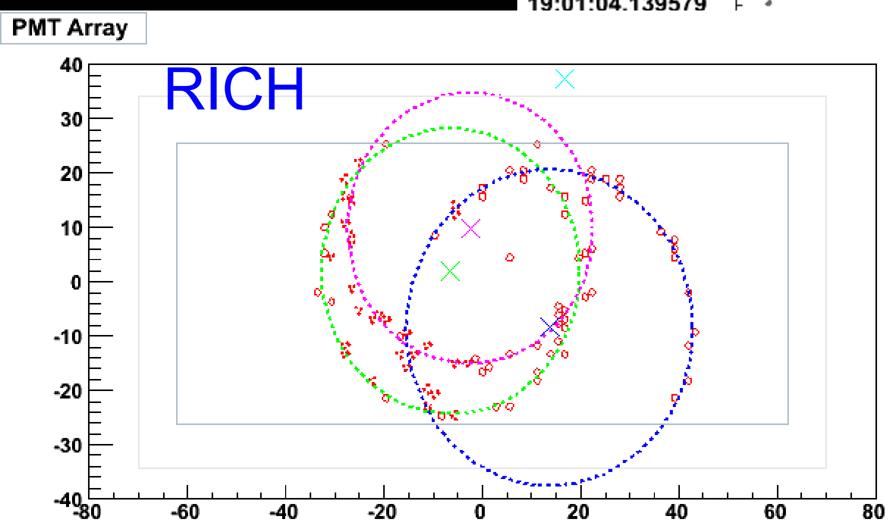
Track Reconstruction:
- two dipole magnets deflecting in opposite directions
- TPC + drift chambers + PWCs

Particle Identification:
- Time Projection Chamber
- Time of Flight Wall
- Threshold Cherenkov Detector
- Ring Imaging Cherenkov Detector



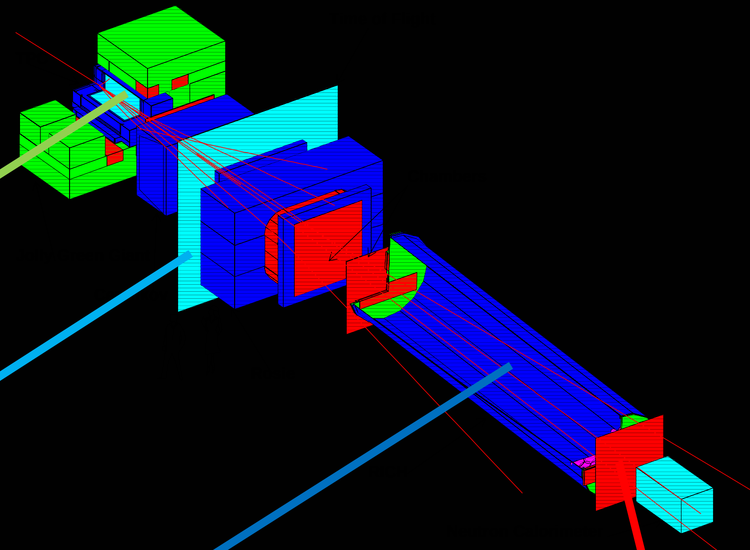
MIPP: Reconstructed Proton-Carbon at 120 GeV/c Event

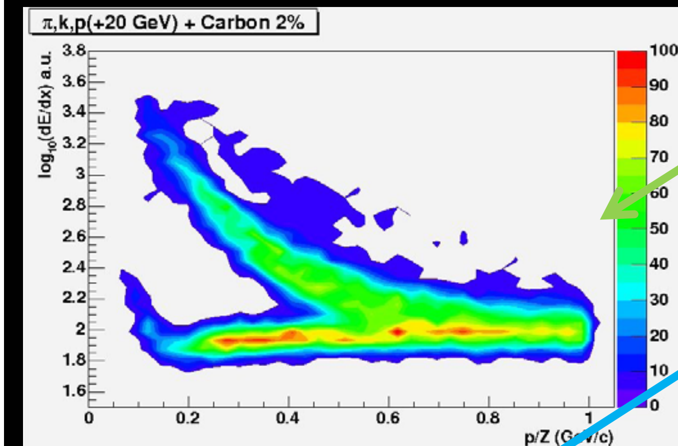


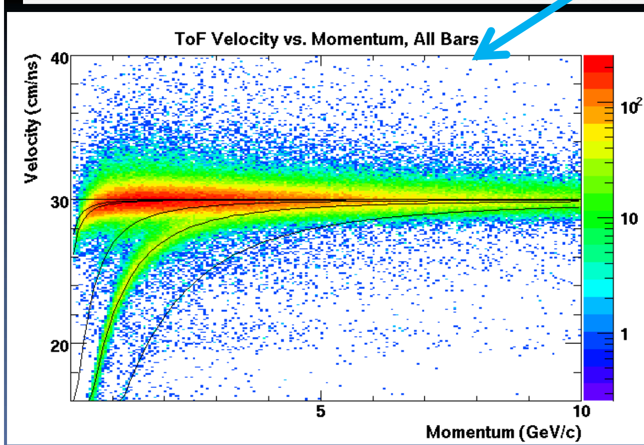


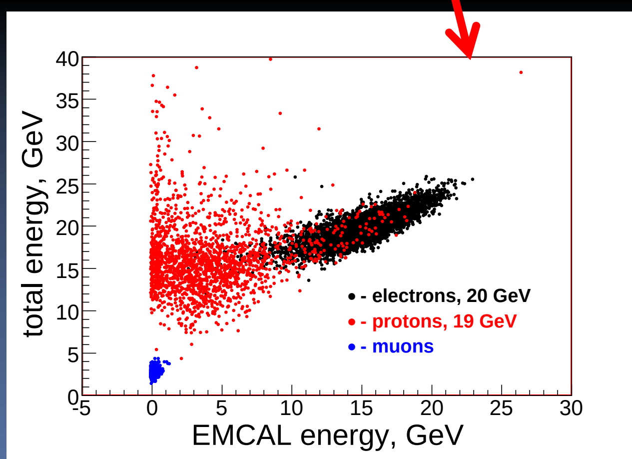
MIPP PID Strategy

- Compute TPC dE/dX, track ToF, Cherenkov likelihood
- Match tracks to RICH rings and compute likelihoods
- Match tracks to calorimeter showers



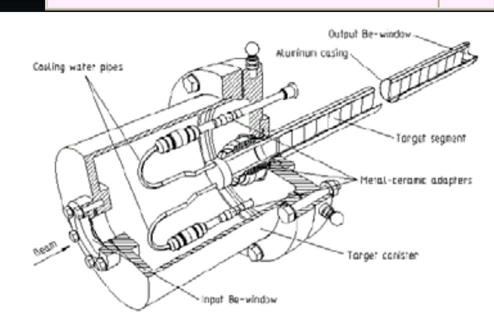


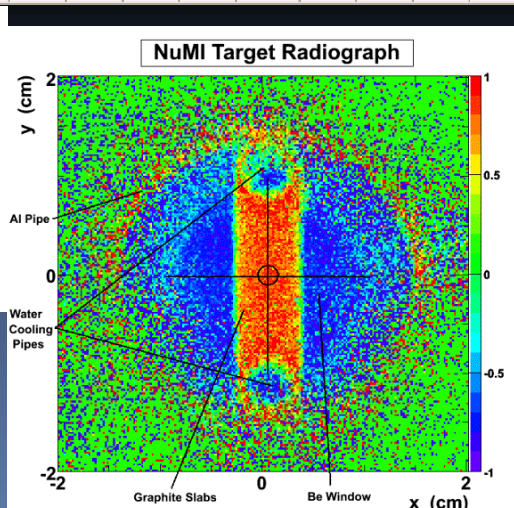


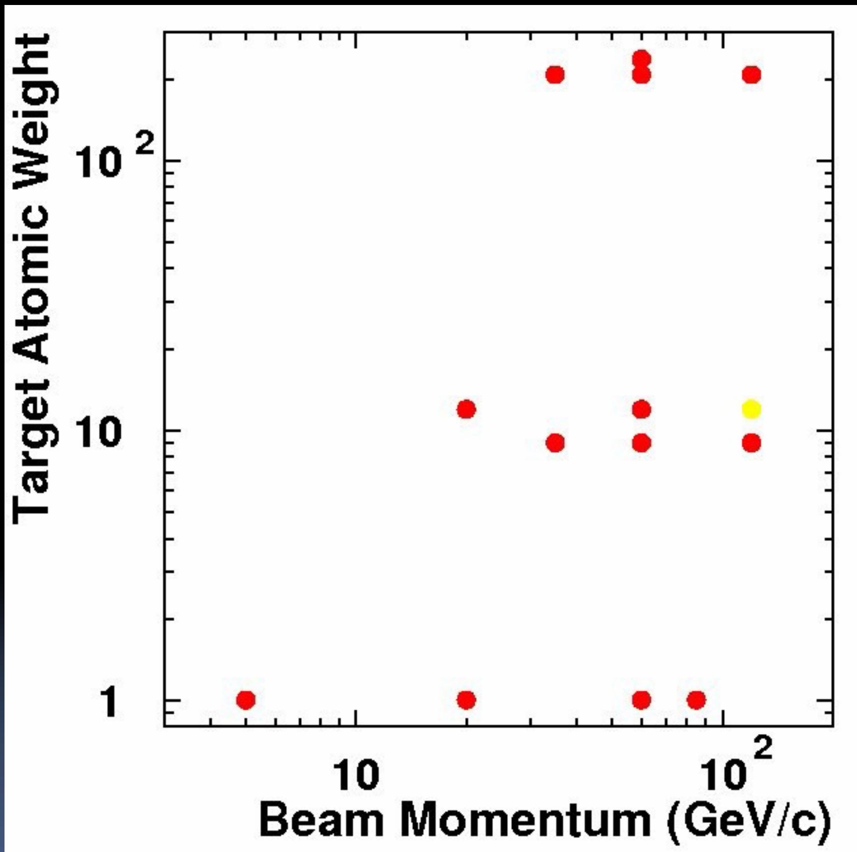


MIPP collected data

Data Summary 27 February 2006			Acquired Data by Target and Beam Energy Number of events, x 10^6									
Target			E									Total
Z	Element	Trigger Mix	5	20	35	40	55	60	65	85	120	
0	Empty[1]	Normal	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	*1.01*
	K Mass[2]	No Int.	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	*14.33*
	Empty LH[1]	Normal	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	7.08
1	LH	Normal	[redacted]	1.94	[redacted]	[redacted]	[redacted]	1.98	[redacted]	1.73	[redacted]	
4	Be	*p* only	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.75
		Normal	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
6	C	Mixed	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.21	[redacted]	[redacted]	[redacted]	1.33
	C 2%	Mixed	[redacted]	0.39	[redacted]	[redacted]	[redacted]	0.26	[redacted]	[redacted]	0.47	
	NuMI	*p* only	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.78	1.78
13	Al	Normal	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	*0.10*
83	Bi	*p* only	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.83
		Normal	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
92	U	Normal	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.18
Total			0.21	2.73	0.86	5.48	0.50	13.97	0.96	2.04	4.63	31.38

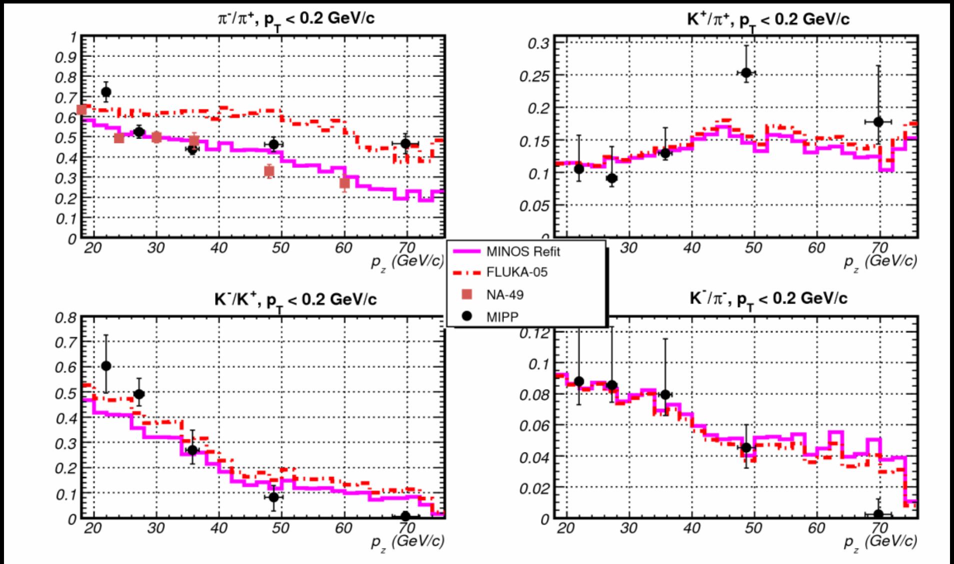




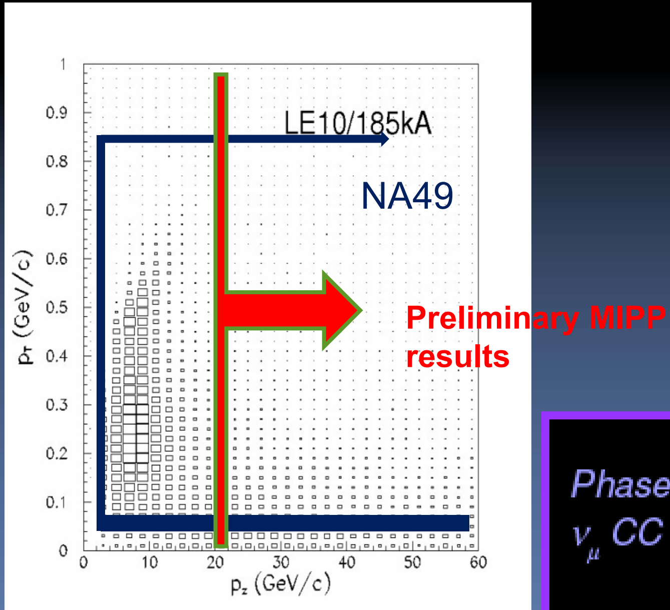


Preliminary Results
Collected

Hadron Productions and Minos



Protons 120 GeV/C – C target 2% lambda



- Hadron production constrained in two ways:
  1) **MINOS near spectrum fit**
  Several beam configurations and fit parameters, including pion (p_z, p_t) yields and kaon yield normalization

NA49
- excellent phase space coverage
- higher beam momentum: 158 GeV/c
- thin C target
- $\pi^\pm$ production cross sections

MIPP
- preliminary results only cover high E_ν
- NuMI beam momentum: 120 GeV/c
- both thin C and NuMI targets
- preliminary results: fully corrected $\pi^\pm$, $K^\pm$ particle yield ratios only
- $K^\pm$ important for MINOS $\nu_\mu \to \nu_e$

Phase space at production of π^+'s producing ν_μ CC interactions in MINOS far:

MIPP Upgrade

- Proposal to upgrade the MIPP experiment has been submitted
- MIPP was severely limited by DAQ rate, dominated by the TPC readout time (~30 Hz). This resulted in MIPP only collecting ~1/5 of desired statistics for the NuMI target run. In addition, the Jolly Green Giant magnet failed at end of run
- An upgrade of the TPC electronics, using the ALICE ALTRO chip, can increase this readout speed by up to a factor of 50. Other improvements would result in:
  - more stable TCP performance
  - greatly reduced ExB effects in the TPC
  - an improved beamline for low (down to ~1 GeV/c) momentum running
- An upgraded MIPP would allow for the measurement of hadron production for any target in a matter of just a few days
- FNAL has purchased ALTRO chips for the TPC upgrade and repair of the JGG dipole magnet has begun

HADRON PRODUCTION FOR T2K at NA61/SHINE

T2K experiment

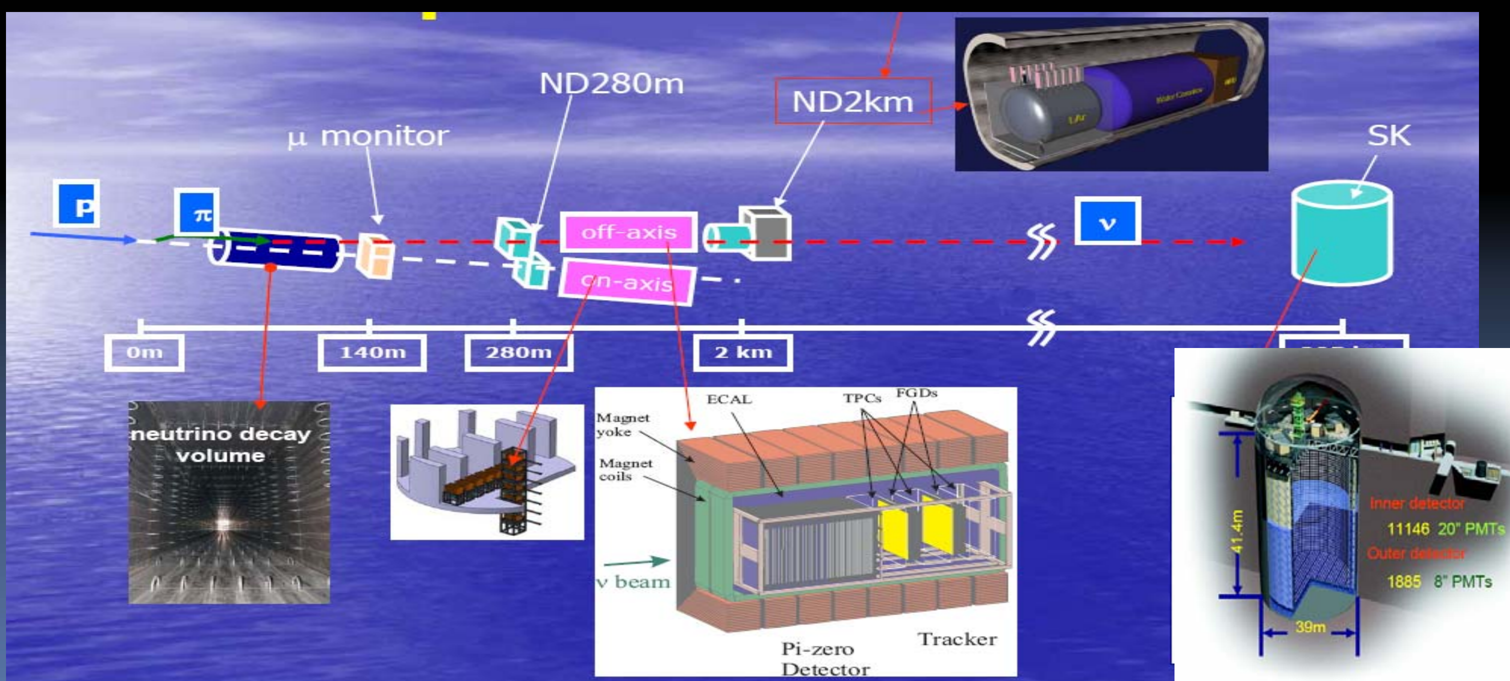
Physics goals

- Discovery of $\nu_\mu \rightarrow \nu_e$ appearance
- Precise meas. of

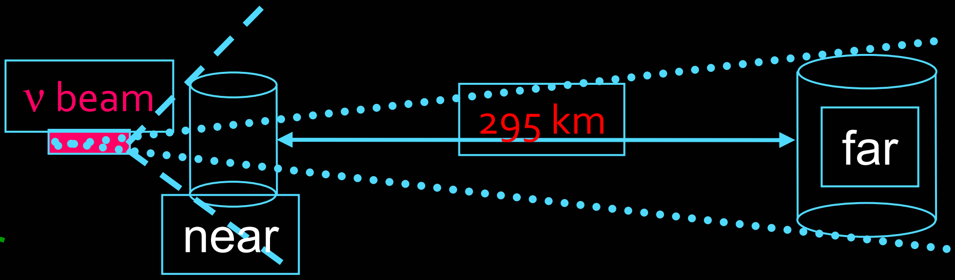
disappearance $\nu_\mu \rightarrow \nu_x$

- Neutral current events
- Discovery of CP violation

(Phase2)



T2K ν beam



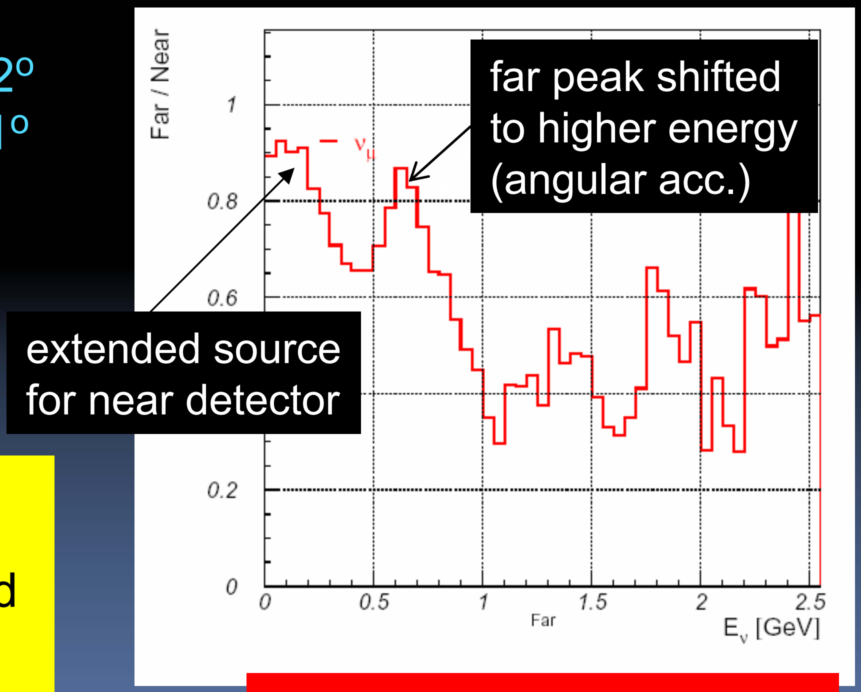
1. predict ν_μ flux at far detector
2. estimate ν_e background

Near and far detectors see different solid angles:

1. far detector: point like source at 2º
2. near detector: extended source 1º to 3º (wide off axis angular range)

⇒ complicated far to near flux ratio

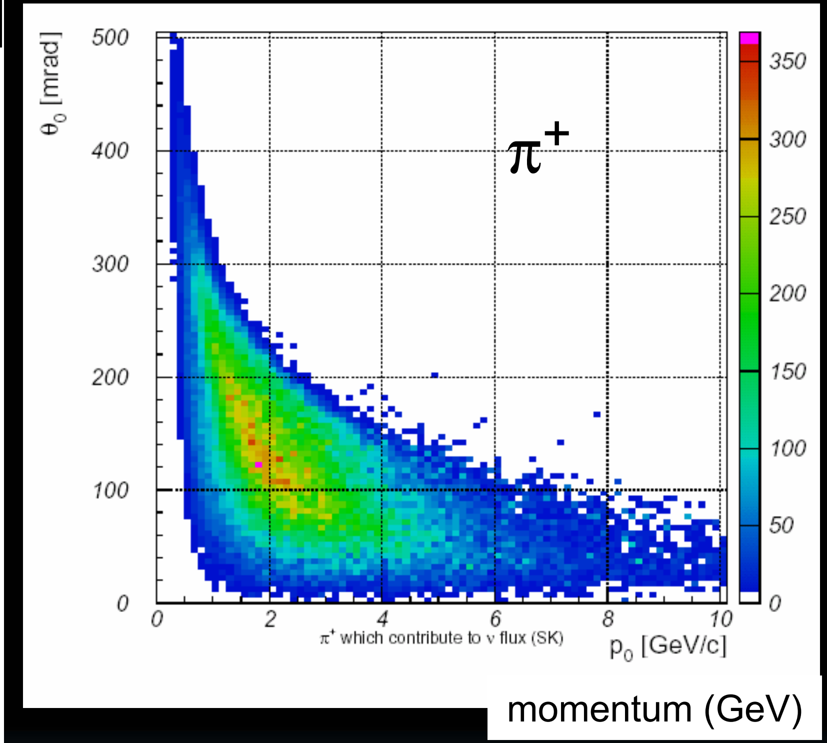
far-to-near flux ratio (T2K beam MC prediction)

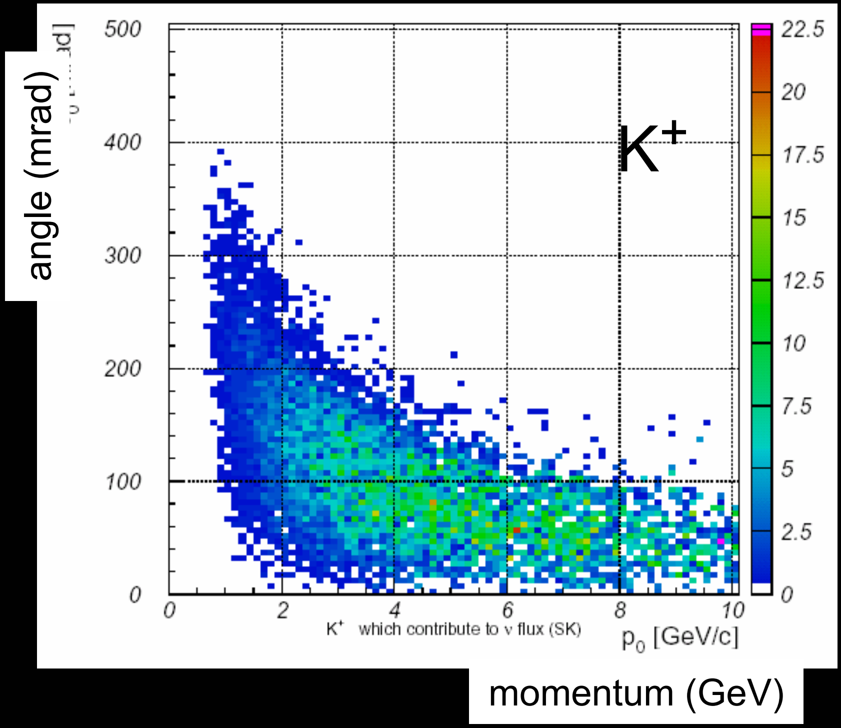


T2K F/N ratio should be know with a precision < 3% to match the physic requirements (20% without dedicated measurements)

NA61 is needed !

T2K ν parent hadron phase space





need to cover all this kinematical region and identify the outgoing hadrons

K component important for ν_e appearance signal (background)

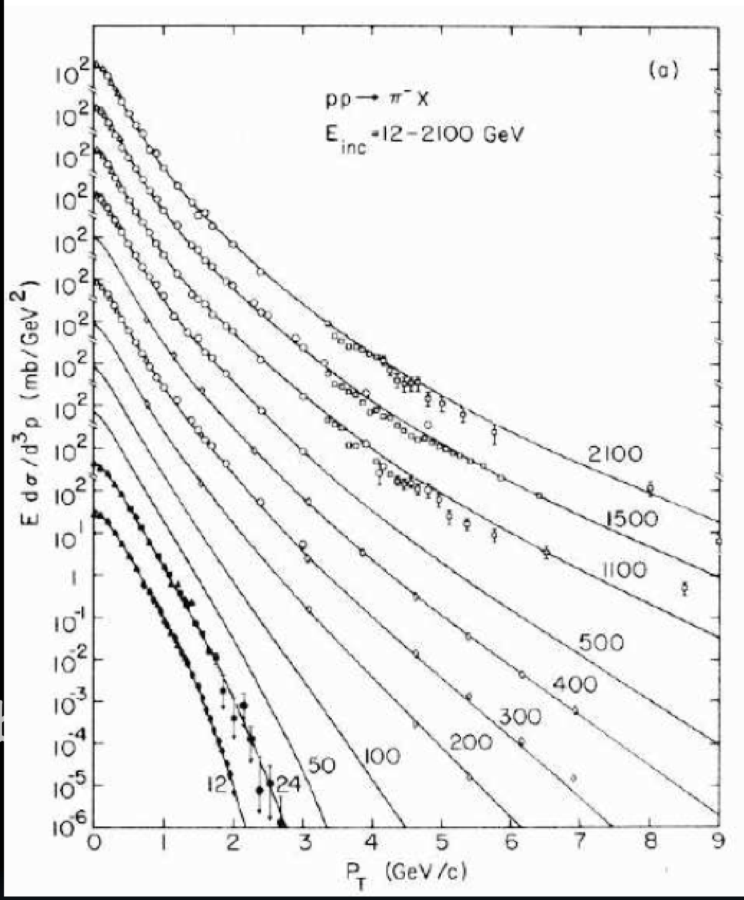
requires: large acceptance and particle ID

Region of interest for pions (0.5< P <5 GeV/c and 0 <θ < 250 mrad)

Region of interest for Kaons (1< P <10 GeV/c and 0 <θ < 350 mrad)

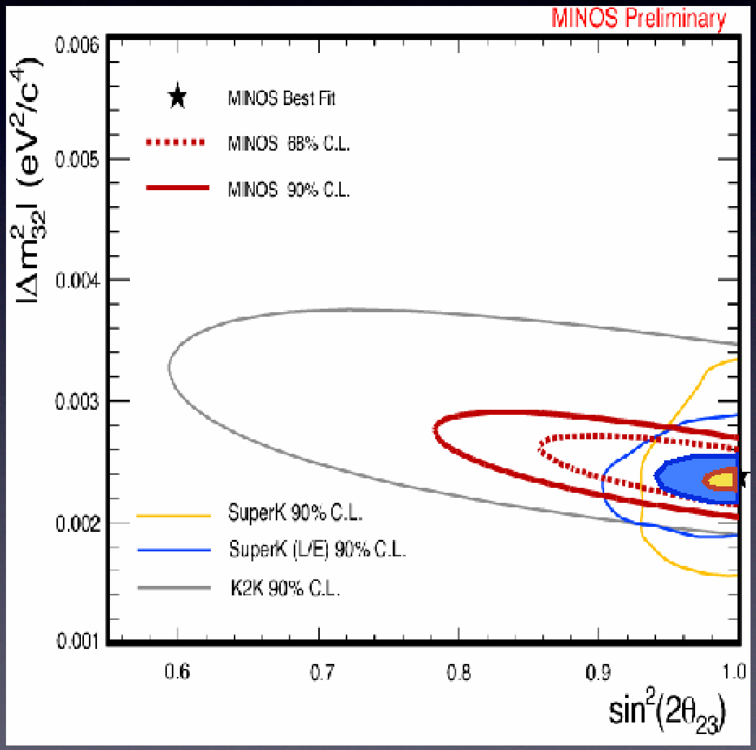
Why hadron measurements for T2K?

- phase-space of T2K ν beam
- no data at these energies 30 – 50 GeV, in particular for large production angles (θ> 100 mrad)
  extrapolations possible but not too reliab
- reinteractions / absorbtion of few GeV pions poorly described (up to factors of ~ 2)
- prefer to base ν beam description rather than more or less reliable



Without the NA61 data T2K will not reach the required sensitivity

Visual impact of NA61



T2K without NA61

T2K with NA61

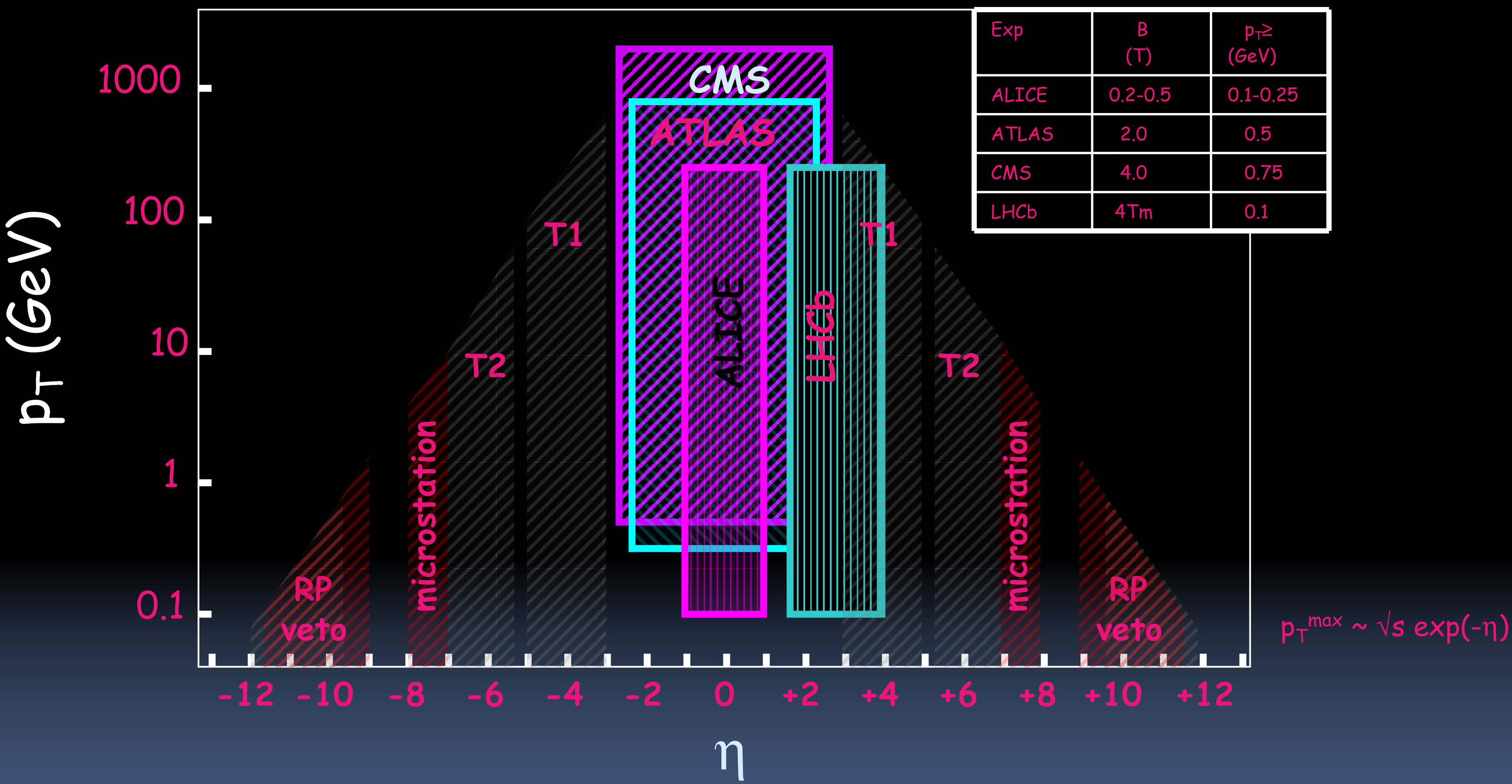
THE HIGH ENERGY FRONTIER: HADRONPRODUCTIONS @ LHC

Totem @ cern

- Totem @ cern is the only LHC experiment that will explore the forward region at ή > 3.1
- The main goal is the measurement of the total and elastic x-section @ 14 TeV and the study of diffractive physics in the forward region
- Totem shares the interaction point with the CMS experiment
- A common physic TDR was presented to make an extensive program of forward physic @ LHC including hadron production for EAS

LHC Experiments: p_T-η coverage

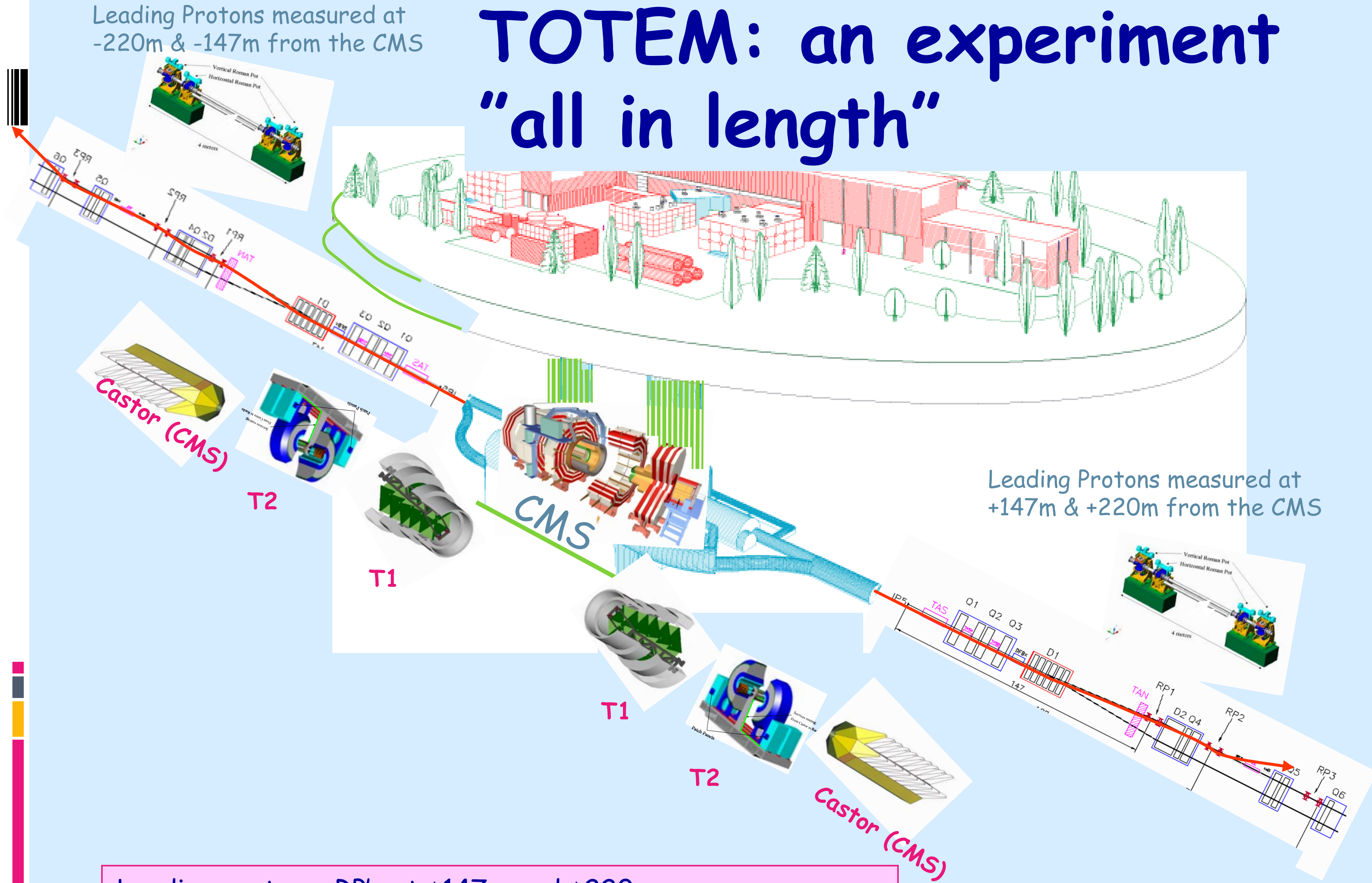
CMS fwd calorimetry up to $|\eta| \approx 5$ + Castor + ZDC



Exp	B (T)	$p_T \geq$ (GeV)
ALICE	0.2-0.5	0.1-0.25
ATLAS	2.0	0.5
CMS	4.0	0.75
LHCb	4Tm	0.1

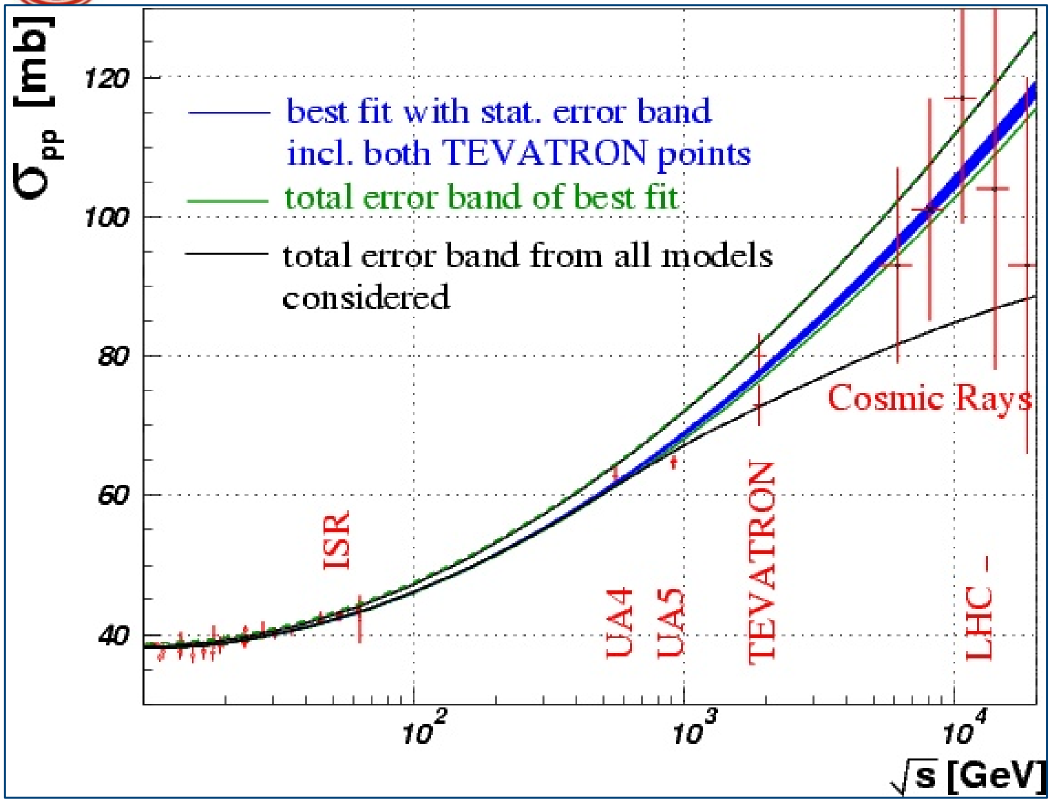
The base line LHC experiments will cover the central rapidity region.
TOTEM will complement the coverage in the forward region.

TOTEM: an experiment "all in length"



Leading protons: RP's at ±147m and ±220m
Rap gaps & Fwd particle flows: T1 & T2 spectrometers
Veto counters at: ±60m & ±140m?

TOTEM Physics: Total p-p Cross-Section



- Current models predictions: 90-130 mb
- Aim of TOTEM: **~1%** accuracy

Prediction for LHC

$$\sigma_{tot} = 111.5 \pm 1.2 \begin{matrix} +4.1 \\ -2.1 \end{matrix} \text{ mb}$$

$$L\sigma_{tot}^2 = \frac{16\pi}{1+\rho^2} \times \left.\frac{dN}{dt}\right|_{t=0}$$

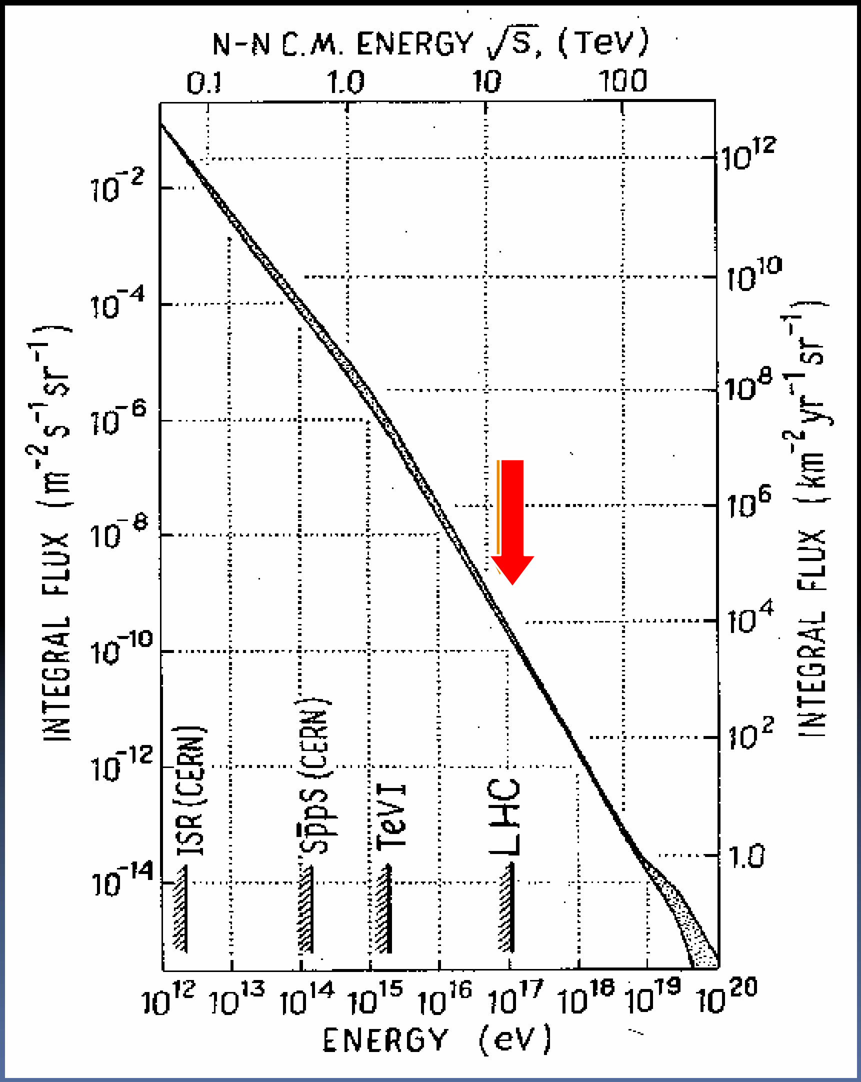
$$L\sigma_{tot} = N_{elastic} + N_{inelastic}$$

Optical Theorem

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \times \frac{(dN/dt)|_{t=0}}{N_{el} + N_{inel}}$$

TOTEM @ CERN

Integral flux of high energy cosmic rays



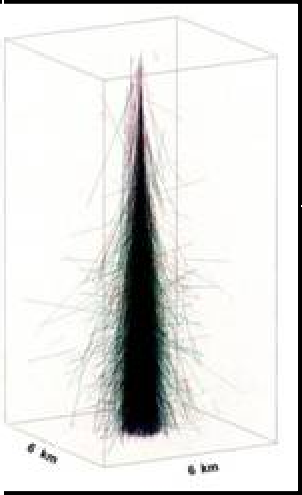
Measurements of the **very forward energy flux** (including diffraction) and of the **total cross section** are essential for the understanding of cosmic ray events

At LHC *pp* energy:

10^4 cosmic events Km^{-2} $year^{-1}$

$> 10^7$ events at the LHC in one day

LHCf: The direct measurement of the π° production cross section as function of p_T is essential to correctly estimate the energy of the primary cosmic rays (LHC: 10^{17} eV)



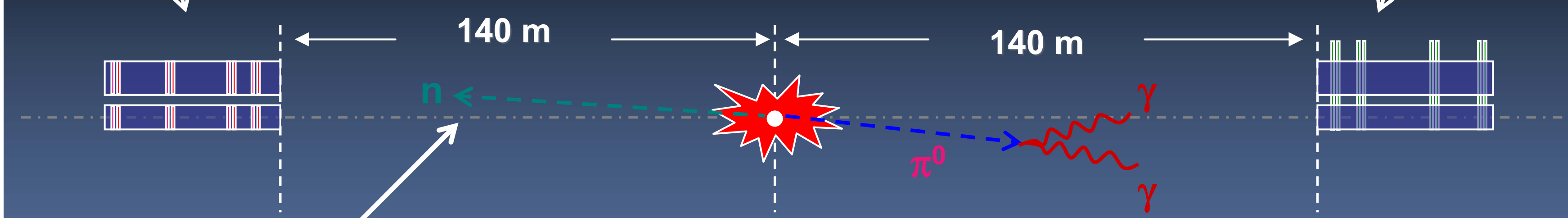
Simulation of an atmospheric shower initiated by a 10^{19} eV proton.

LHCf experimental method is based on 2 independent detectors installed on both sides of IP1

Detector I
Tungsten
Scintillator
Scintillating fibers

ATLAS INTERACTION POINT
(IP1)

Detector II
Tungsten
Scintillator
Silicon μ–strips



Beam line

Some ideas from LHCB to measure the EAS flavour compositions

- The detector is unique for LHC because of its acceptance to small angles/large eta and "superb" PID. The idea is to measure with first data the pi, K, K_S, Lambda, phi production rates. This would be done in 10TeV collisions in 2008, and 14 TeV in 2009.
- It's possible that in the future they can collect collisions at fixed target rates in beam-gas interactions.
- Momentum resolution is 0.5%. (maximum angles are ~300 mrad)

Conclusions

- Hadron production for Neutrino Experiments is a well established field @ CERN since the '70s
- Present trends (Harp@cern & Mipp@FNAL)
  - Full-acceptance, low systematic errors, high statistics
  - Search for smaller and smaller effects → characterization of actual neutrino beam targets to reduce MC extrapolation to the minimum
  - Direct interest of neutrino experiments in hadron production

Many interesting results published by HARP and more are coming

- Also in the future the hadron production will be an important ingredient for a successfully neutrino experiment.
- Thanks to NA61 and MIPP many new data will become available
- Also LHC (withTOTEM, LHCf …etc.) will contribute to this effort (EAS)