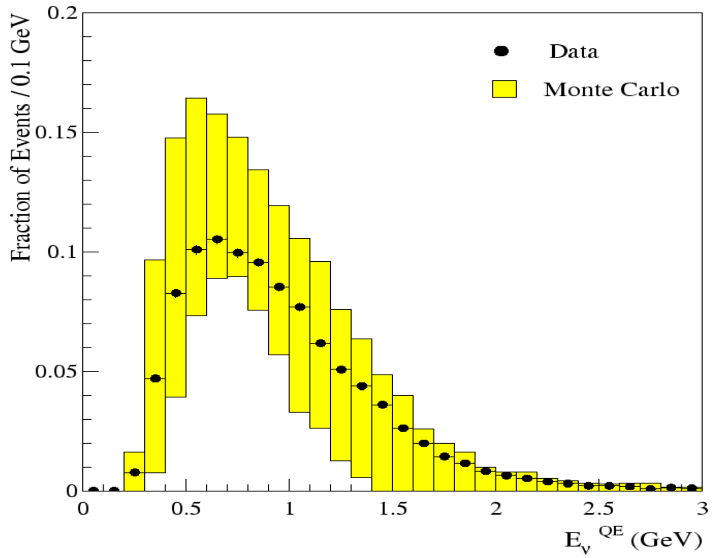
Prospects for future hadron production experiments

(for neutrino physics)

- Importance of hadron production for neutrino experiments
- Physics scenario
- Present data and activities
- T2K experiment
- Prospects (at CERN)
- Conclusions

Jaap Panman, CERN
On behalf of the HARP Collaboration

Motivations for production measurements

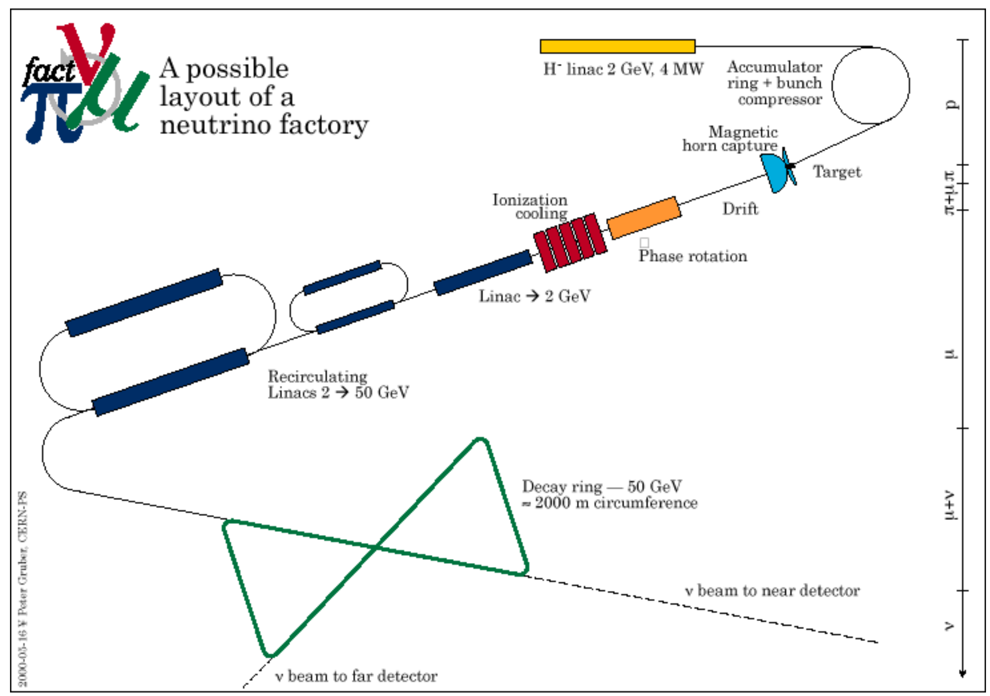


Measurements of hadron yields for neutrino beams

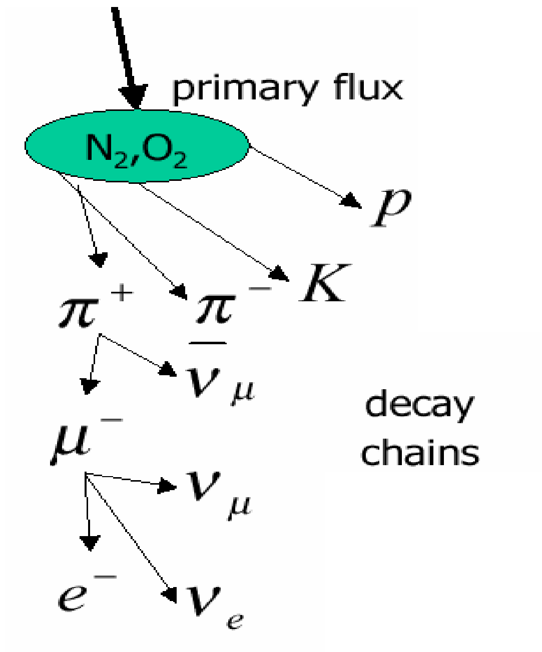
E.g. SPY for the **WANF** beam
HARP for the **MiniBooNE** and **K2K**
MIPP for **NuMI**

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

Primary target material, geometry, focusing

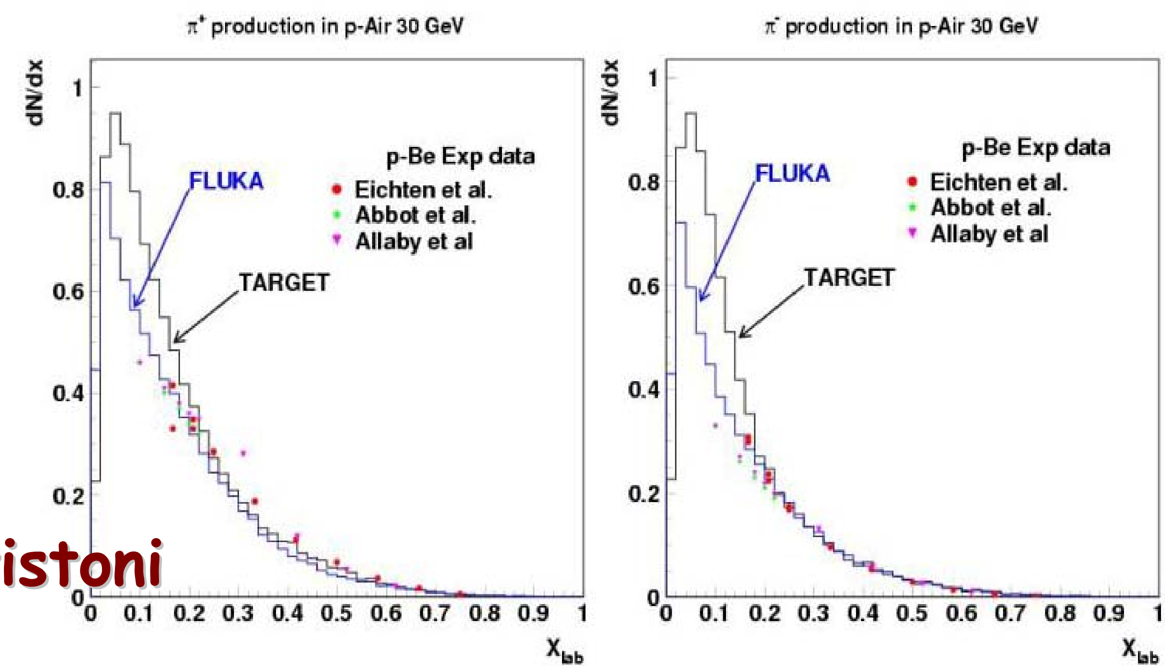


Motivations for production measurements (2)



- Input for precise calculation of the **atmospheric neutrino** flux (from yields of secondary π, K)
- Primary flux now better known (~10%)
- Uncertainty now dominated by hadron interaction model
- About 30% uncertainty in extrapolations
- Cryogenic targets or easier approximation: carbon

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



G.Battistoni

Neutrino oscillation scenario

Precision:

θ_{23}

Δm^2

Limits/measurements:

θ_{13}

δ

Sign of Δm^2

participation of European groups

Europe comes in here!

M. Lindner

Long Baseline: Projects and Plans (partly)

running: K2K establish / test atm. osc. with beams

construction: MINOS (2005) ≃ 10% for Δm_{31}^2, $\theta_{23,}$ improve θ_{13} ?
CNGS: **ICARUS & OPERA** (2006)

approved: T2K (JHF-SK) (2008) few% for Δm_{31}^2, $\theta_{23,}$ improve θ_{13}

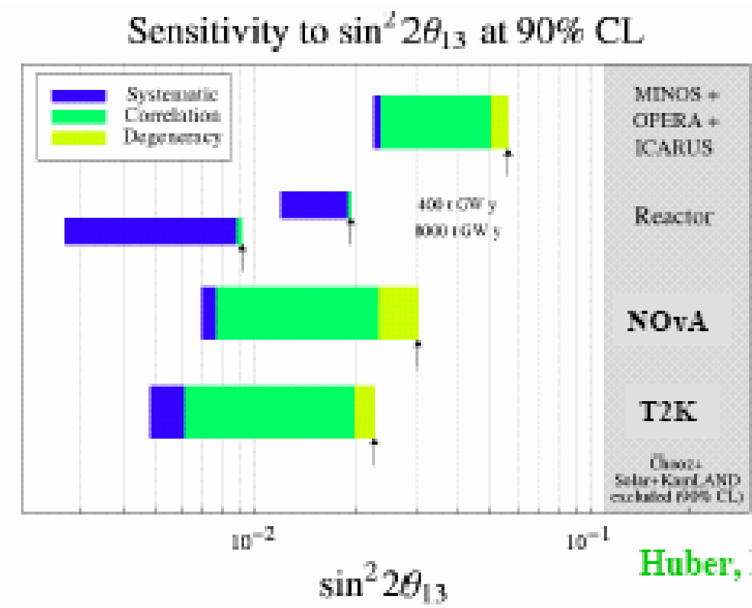
LOIs: NOνA (NuMI-OA) (200x)
T2H = JHF-HK (201x) % for Δm_{31}^2, $\theta_{23,}$ ➔ θ_{13}, CP, sgn(Δm^2)

long term: β–beams, neutrino factory, ... (201x) ➔ precision
.....muon collider.... ➔ **precision neutrino physics**

- every stage is a necessary prerequisit for the next
- continuous line of improvements for beams, detectors, physics!

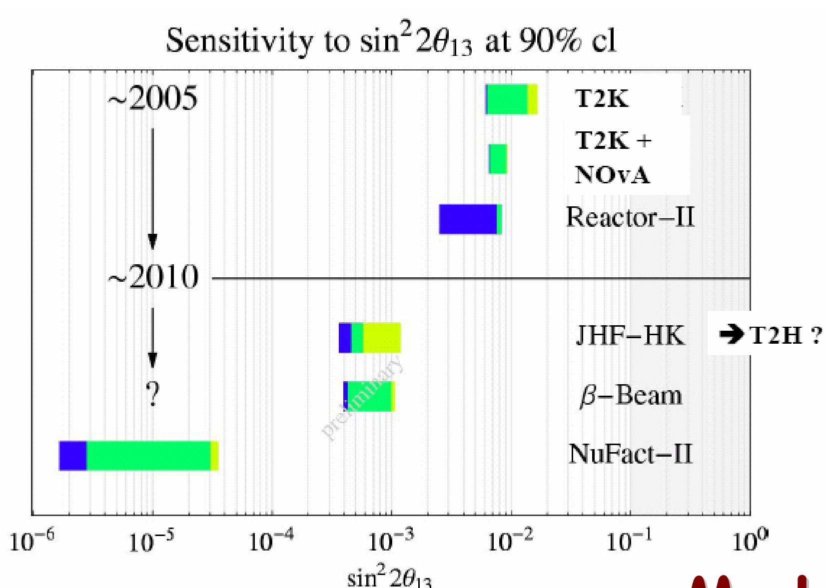
M. Lindner Nobel Symposium 7

Expected evolution θ_{13} measurement



Compare:
- 5 years each
- 5% flux uncertainty

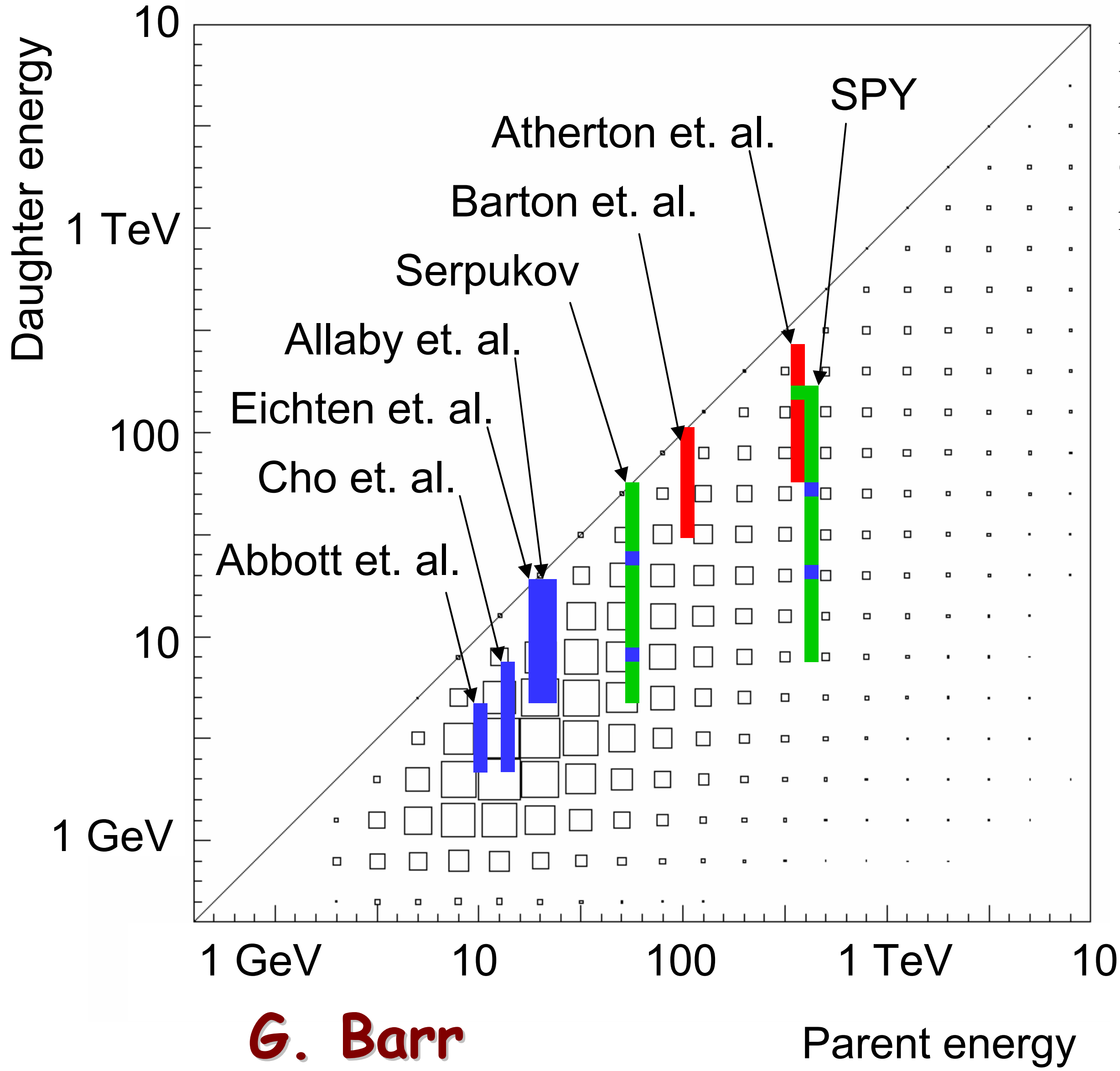
Huber, ML, Rolinec, Schwetz, Winter



As an example evolution of θ_{13} measurement with options for facilities

M. Lindner

Atmospheric neutrinos: P_T range covered



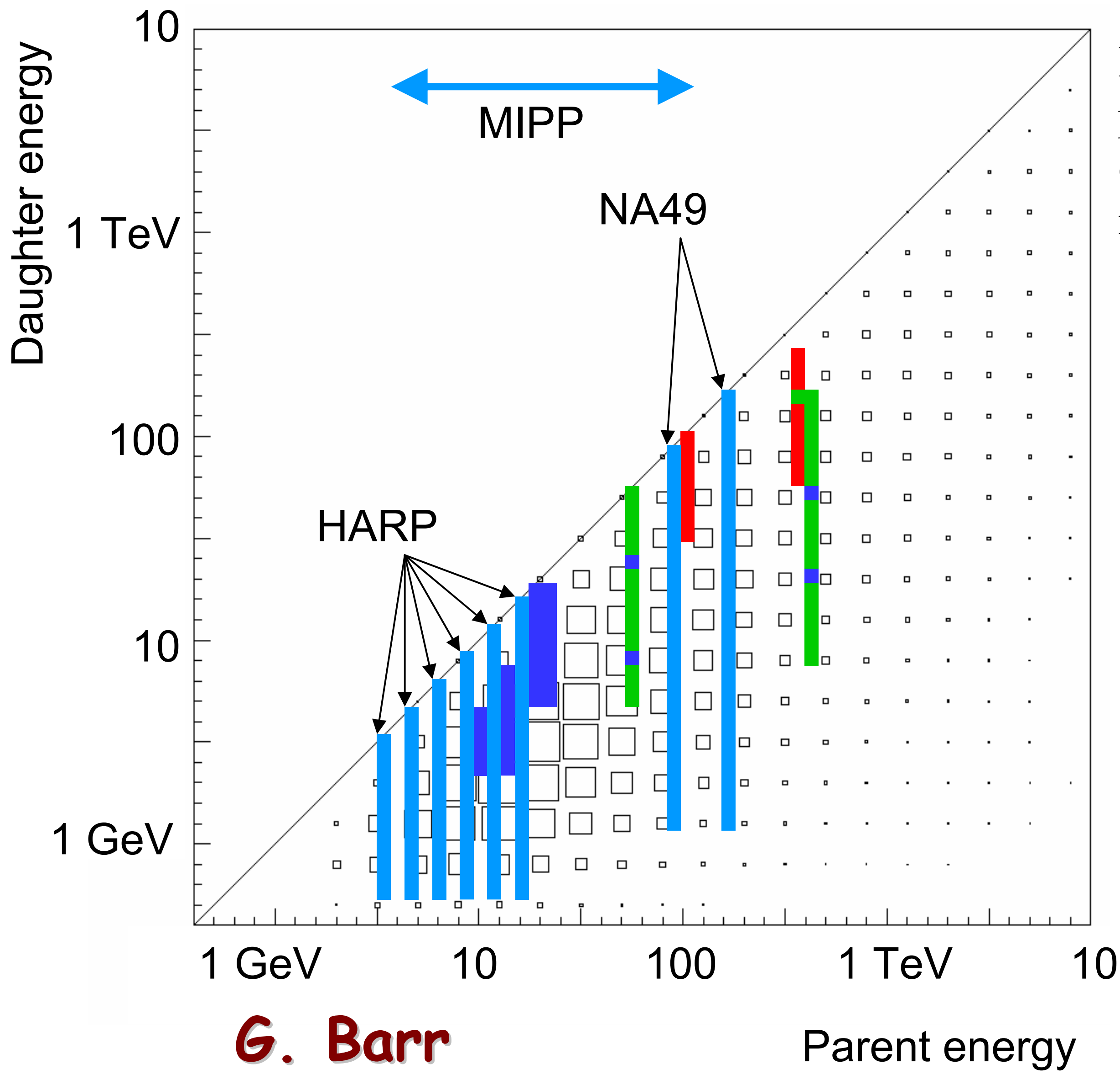
Boxes show importance of phase space region for contained atmospheric neutrino events.

Measurements.

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

G. Barr

New measurements



Boxes show importance of phase space region for contained atmospheric neutrino events.

New measurements.

G. Barr

Past and present

In the past at CERN:

For the PS: Eichten et al.

For the SPS: Atherton et al.

SPY (NA52/NA56)

Single arm spectrometers

Present activities:

BNL-E910

HARP

MIPP

Open geometry multi-particle spectrometers with PID

Similar to heavy-ion experiments, but optimised for high event rate

Eichten et Al. based on CERN-70-12

PARTICLE PRODUCTION IN PROTON INTERACTIONS IN NUCLEI AT 24 GeV/*c*

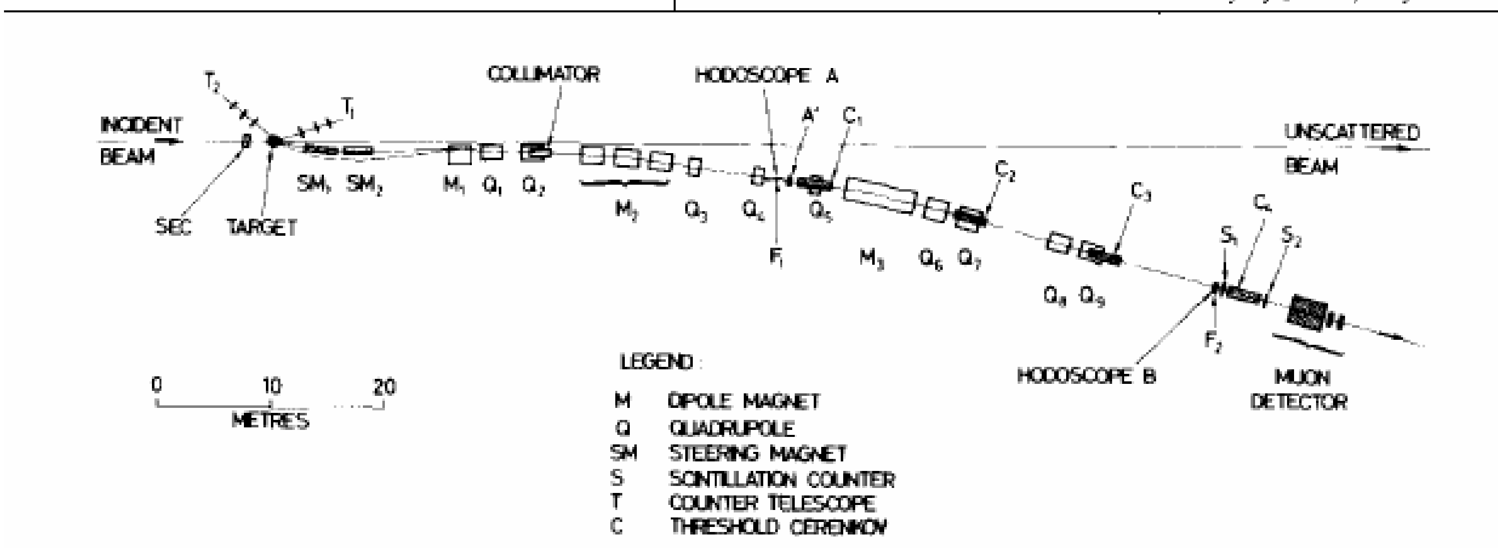
T. EICHTEN and D. HAIDT
III. Physikalisches Institut, Aachen, Germany

J.B.M. PATTISON, W. VENUS, H.W. WACHSMUTH and O. WÖRZ
CERN, Geneva, Switzerland

T.W. JONES
UCL, London, England

B. AUBERT, L.M. CHOUNET and P. HEUSSE
Laboratoire de l'Accélérateur Linéaire, Orsay, France

C. FRANZINETTI
University of Torino, Italy

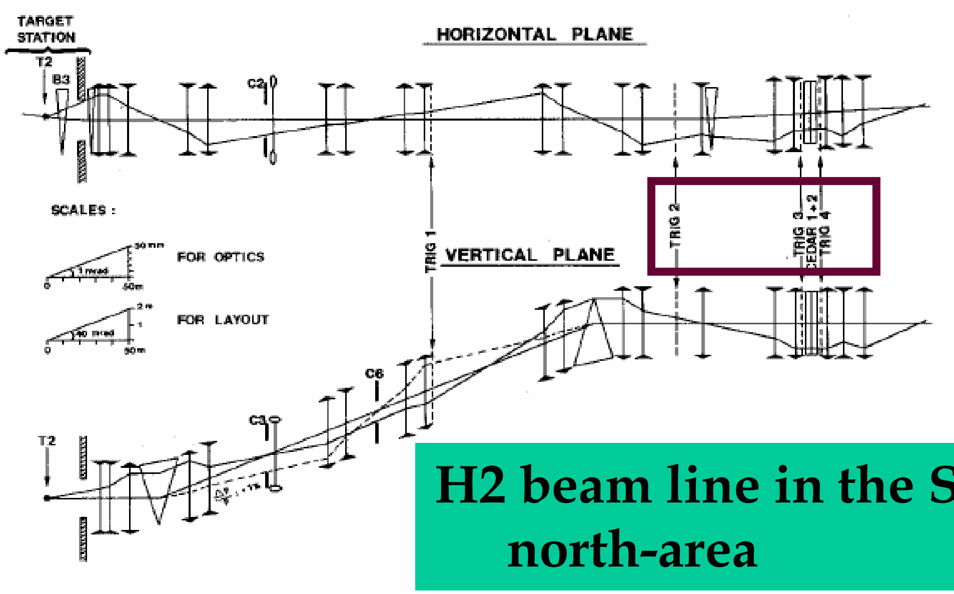


, Cu and Pb has been
tra measured over a range
V/c are given in a table.

NA20 (Atherton et al.) @ CERN-SPS

Secondary energy scan:

60, 120, 200, 300 GeV



H2 beam line in the SPS north-area

Fig. 1 Layout and optics of H2 beam

List of targets

Length (in beam direction) (mm)	Width (horizontal) (mm)	Height (vertical) (mm)
500	160	2.0
300	160	2.0
300	160	1.5
100	160	2.0
40	160	2.0

Overall quoted errors

- Absolute rates: ~15%
- Ratios: ~5%

These figures are typical of this kind of detector setup

The total measurement error is dominated by the following three systematic errors:

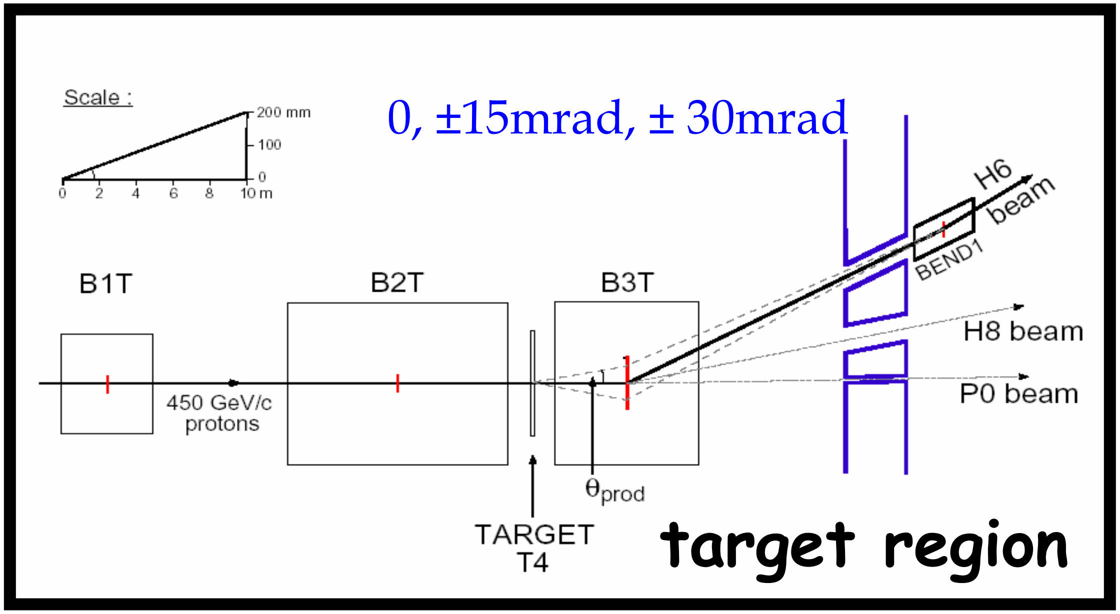
i) SEM calibration, see Section 3.2.1 ≃ 5%

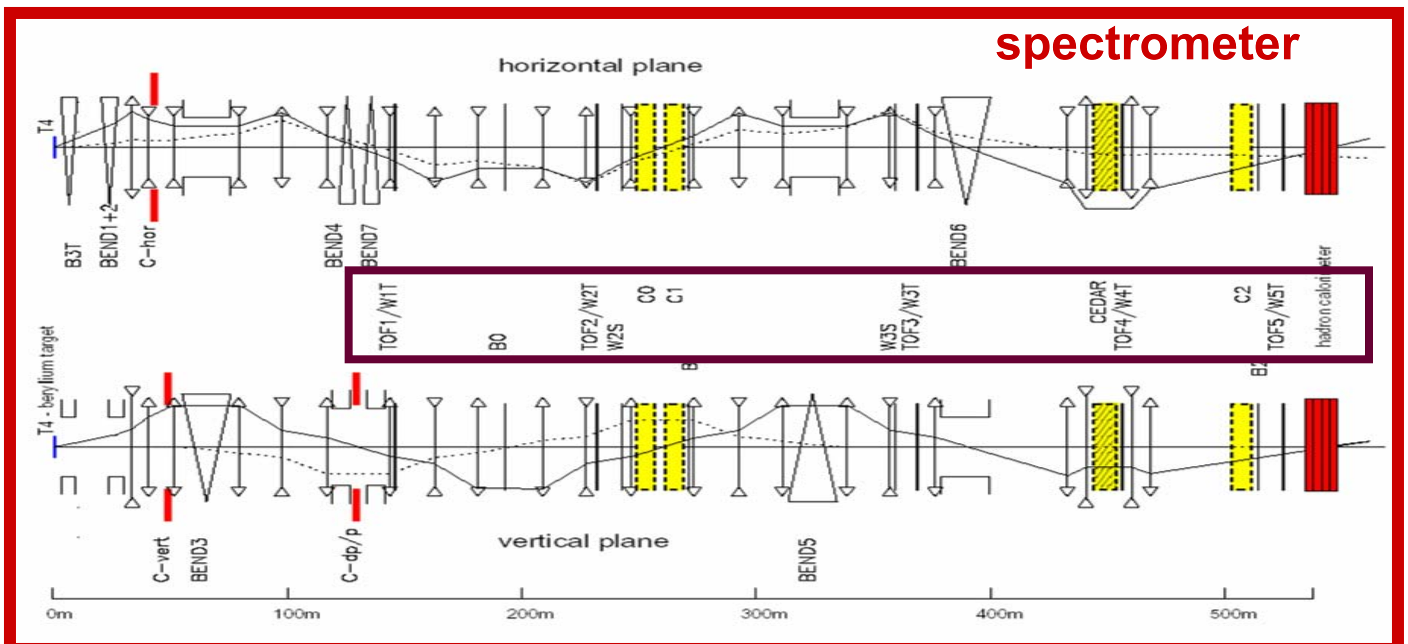
ii) errors in beam optics, see Section 3.1.4 ≃ 4%

iii) collimator opening uncertainty ≃ 1-4%.

All other corrections are of the order of or less than 1%.

SPY (NA52-NA56): 1996



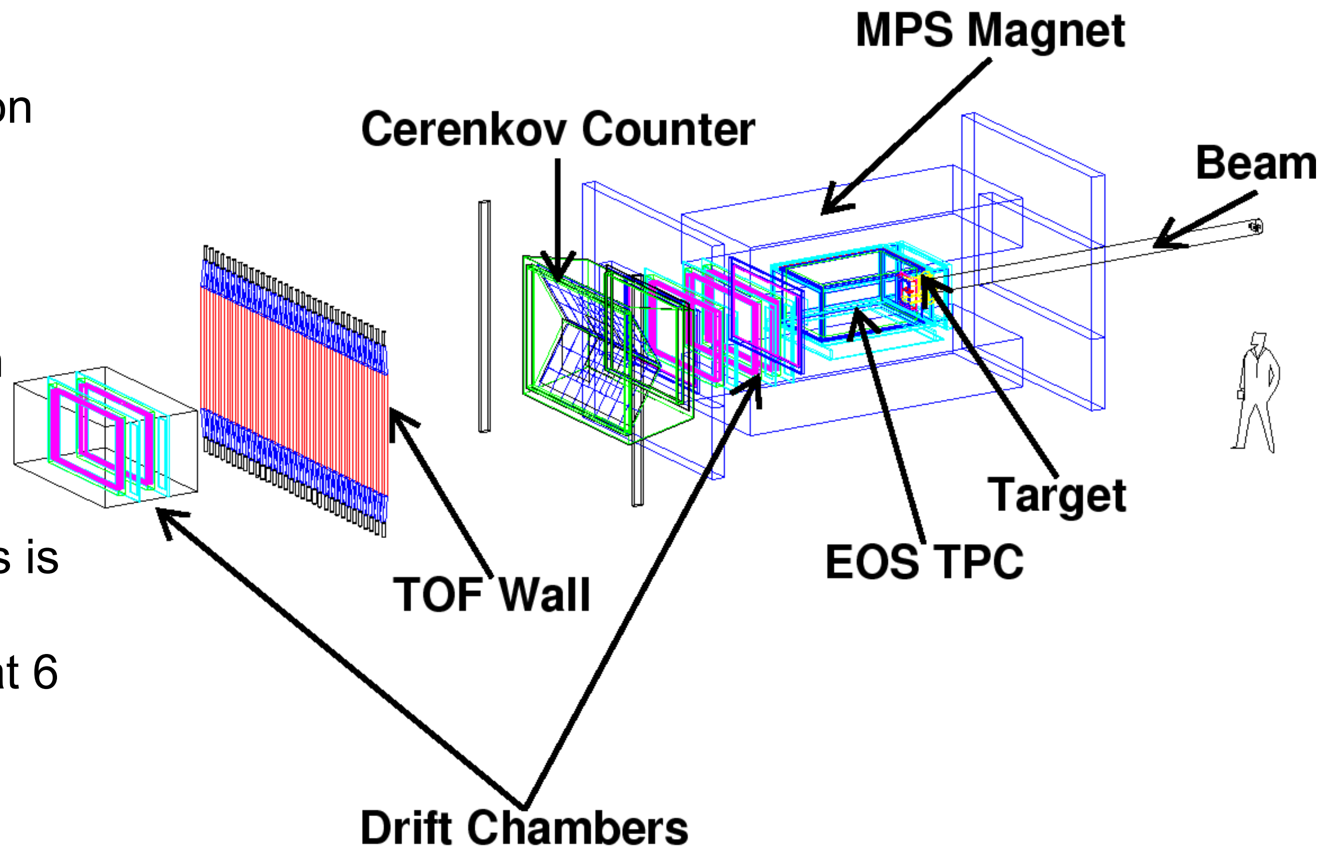


Brookhaven Experiment 910

E910 used a spectrometer with good acceptance and particle ID over the momentum and angular range of interest to MiniBooNE.

- main goal: Strangeness production in p-A collision (comparison with A-A collisions)

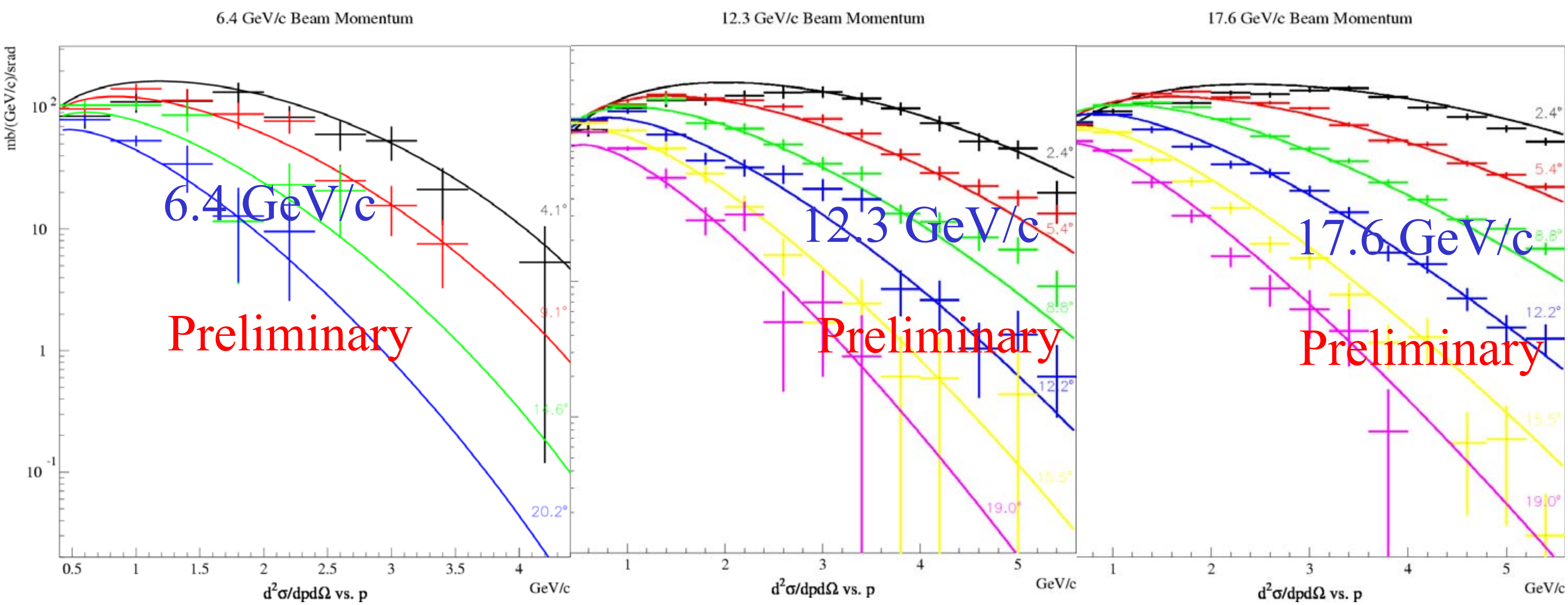
- 6,12,18 GeV/c beam proton momenta
- Thin Be, Cu, Au targets
- low statistics in general (this is common in heavy-ions experiments), very low at 6 GeV/c



Particle ID from dE/dx in the TPC, threshold Cherenkov, and Time of Flight.
E910 ran for a brief period of time with a low bias trigger.

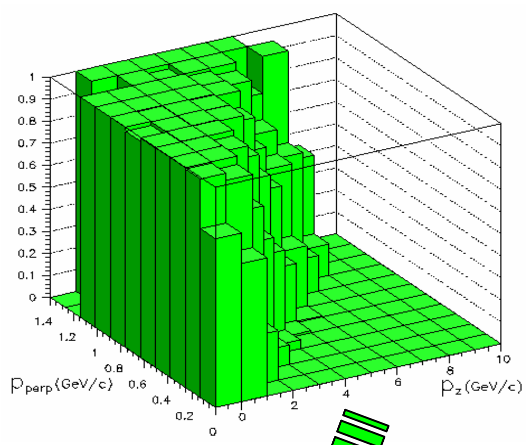
E910 low bias data set

Dataset	Beam Protons	Trigger Efficiency (ε)
6.4 GeV/c	9500	1.000
12.3 GeV/c	627,000	0.971
17.6 GeV/c	2,640,000	0.897

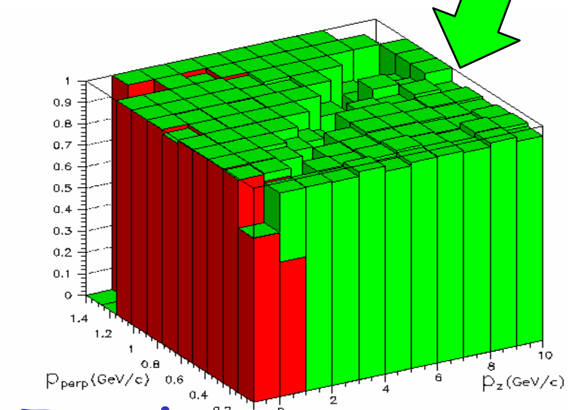


Low statistics!

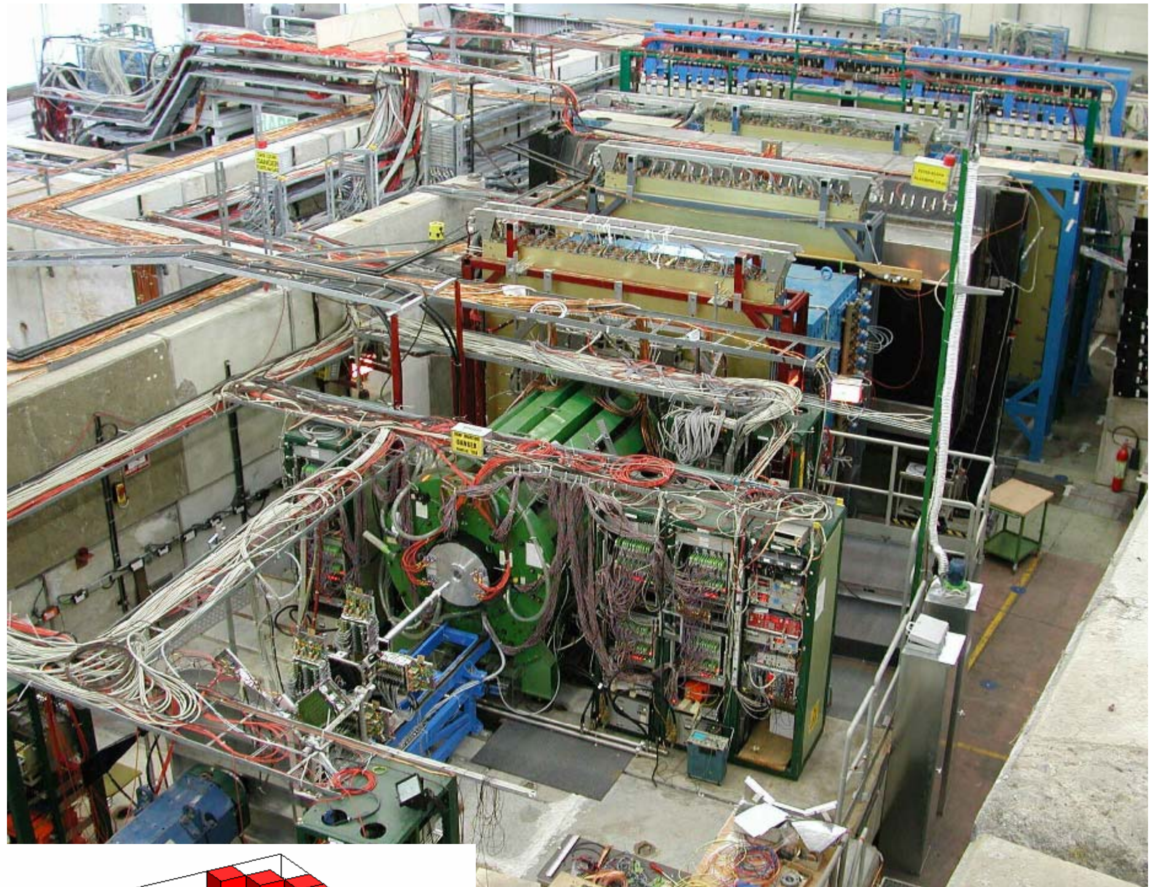
The HARP experiment

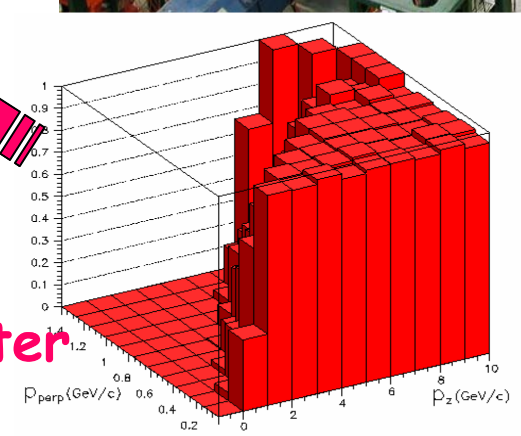


TPC



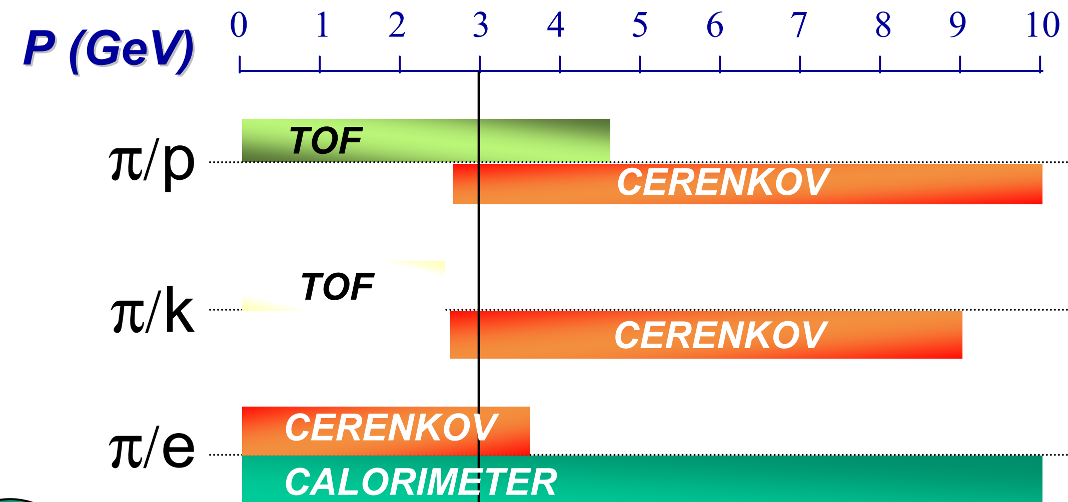
Total Acceptance

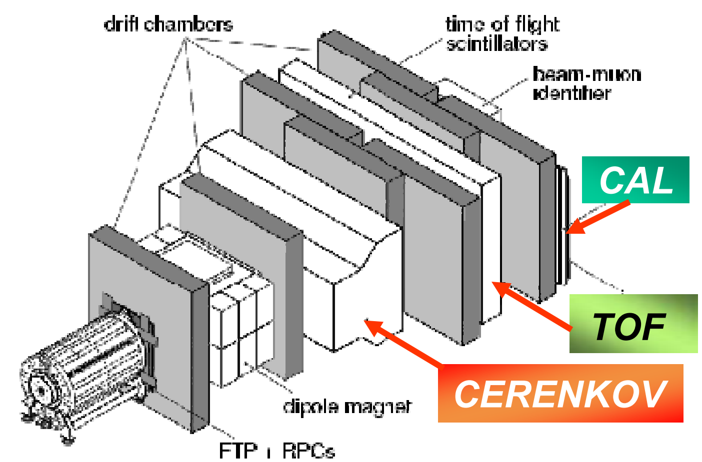




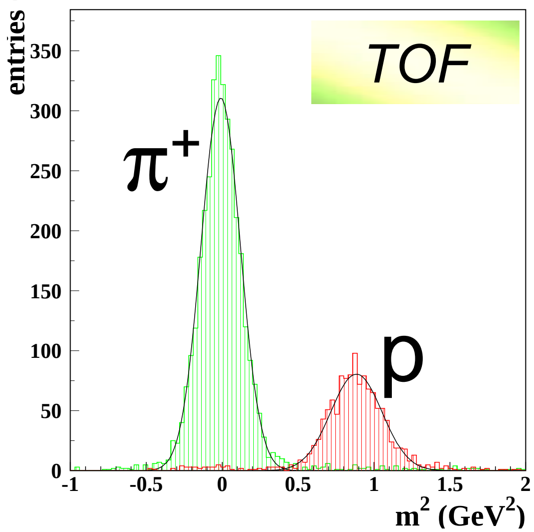
Forward Spectrometer

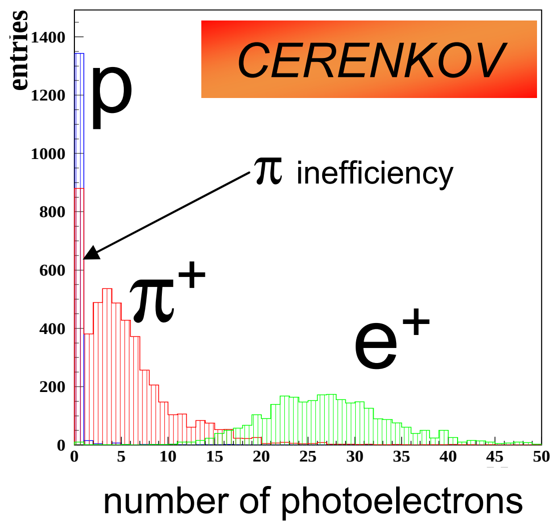
Particle identification (FW spectr)

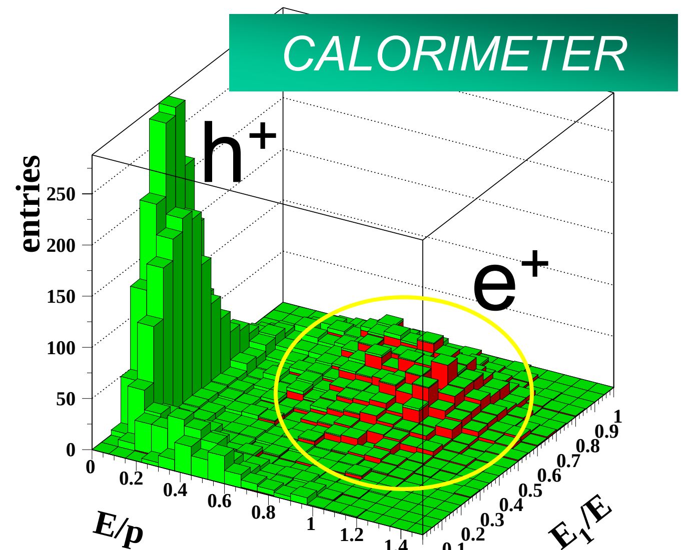




data — **3 GeV/c beam particles**



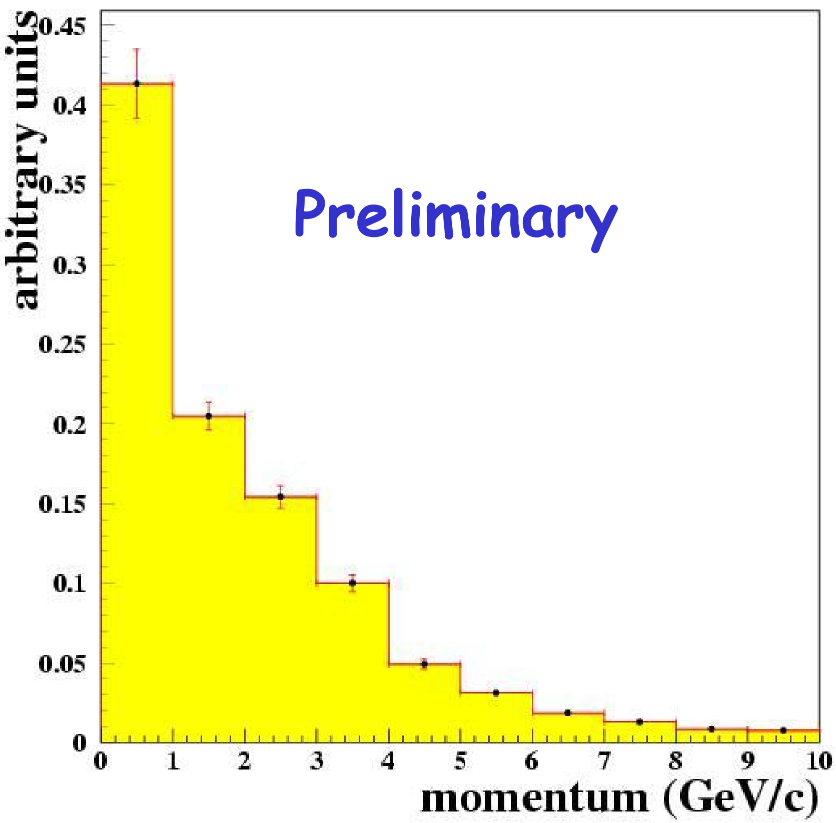


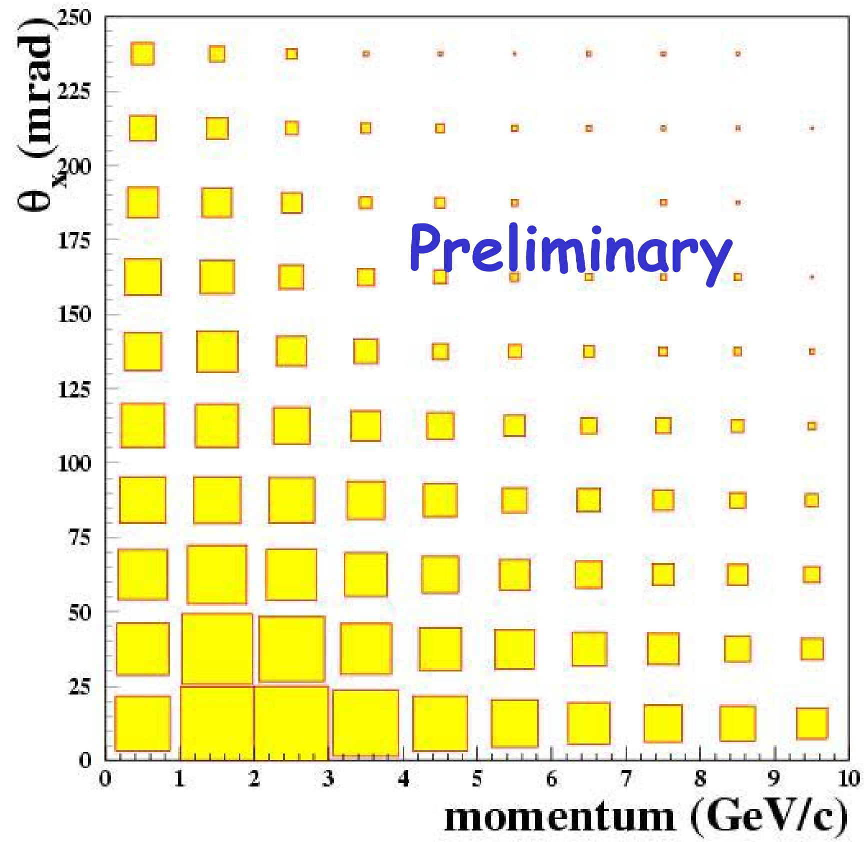


Analysis for pion yields in K2K

p > 0.2 GeV/*c*
$|\theta_y| < 50$ mrad
$25 < |\theta_x| < 200$ mrad

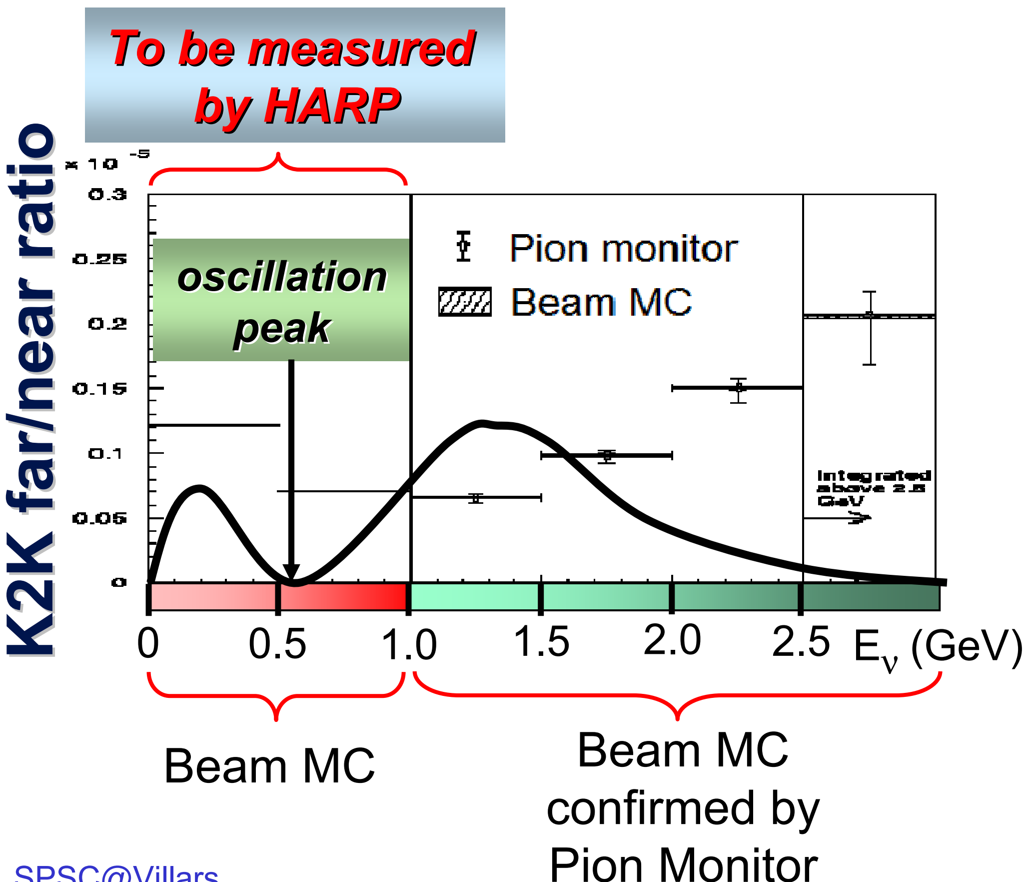
To do:
Correction for resolutions
Absolute normalisation
Empty target subtraction
θ=0 region, full statistics

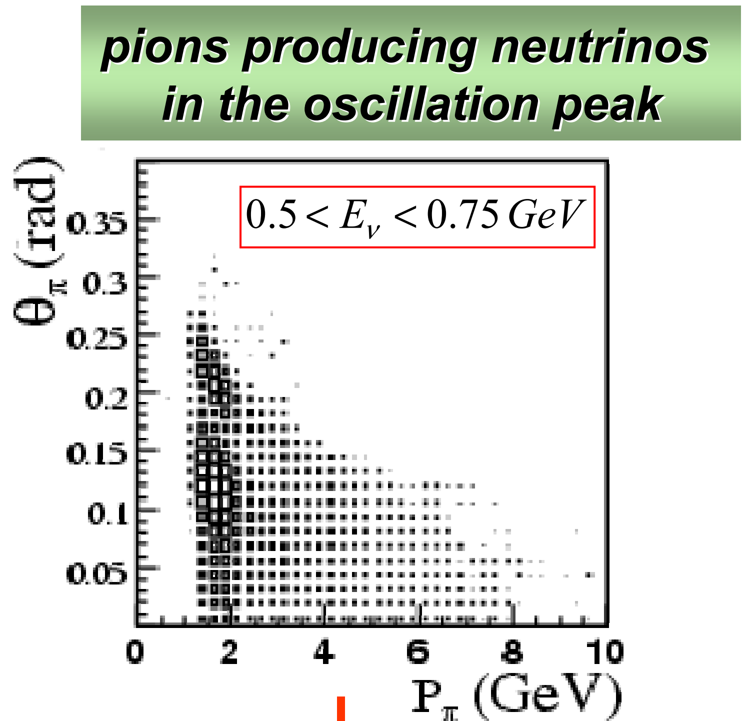




Relevance of HARP for K2K neutrino beam

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





K2K interest

$$\begin{cases} P_\pi > 1\ GeV \\ \theta_\pi < 250\ mrad \end{cases}$$

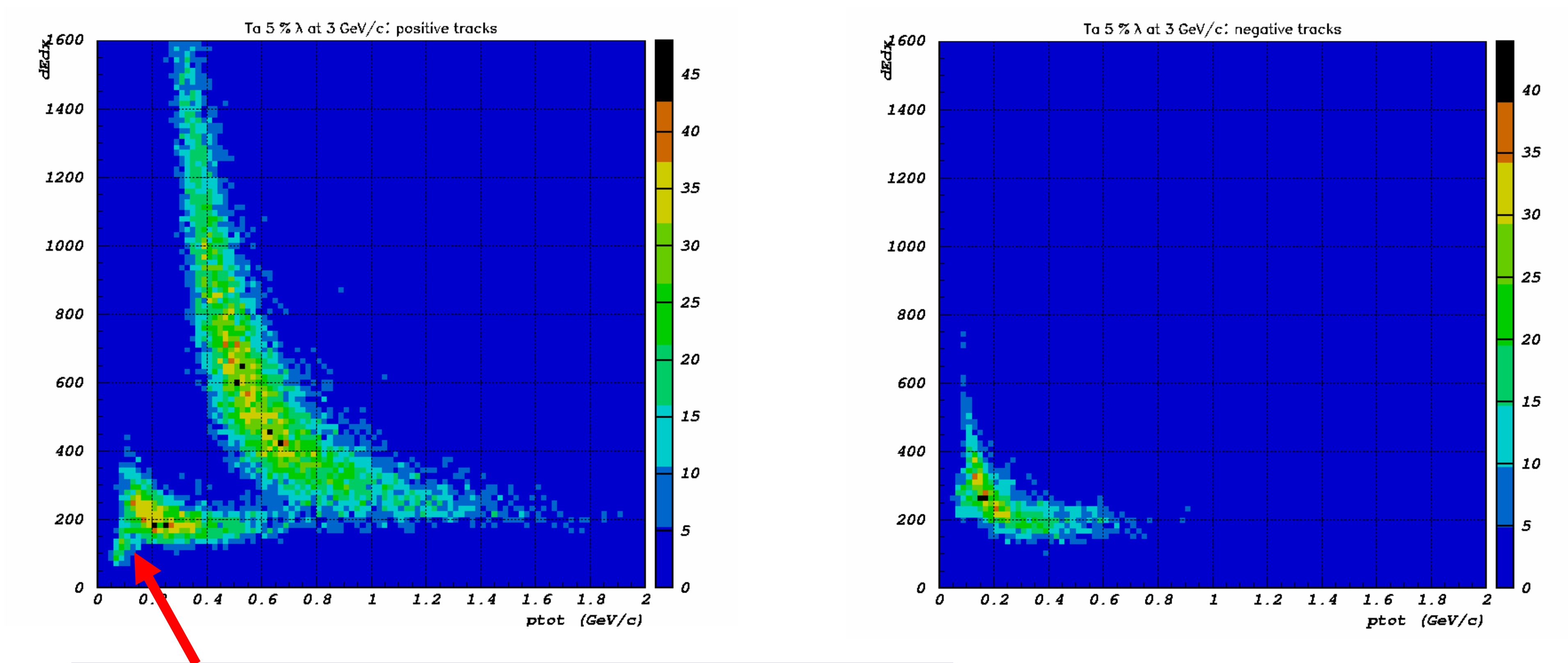
Preliminary large angle analysis for neutrino factory 3 GeV/c Ta

TPC covers the interesting phase space for this measurement

PID by dE/dx and TOF

dEdx in TPC

Good separation of protons from pions



ExB effect combined with space charge

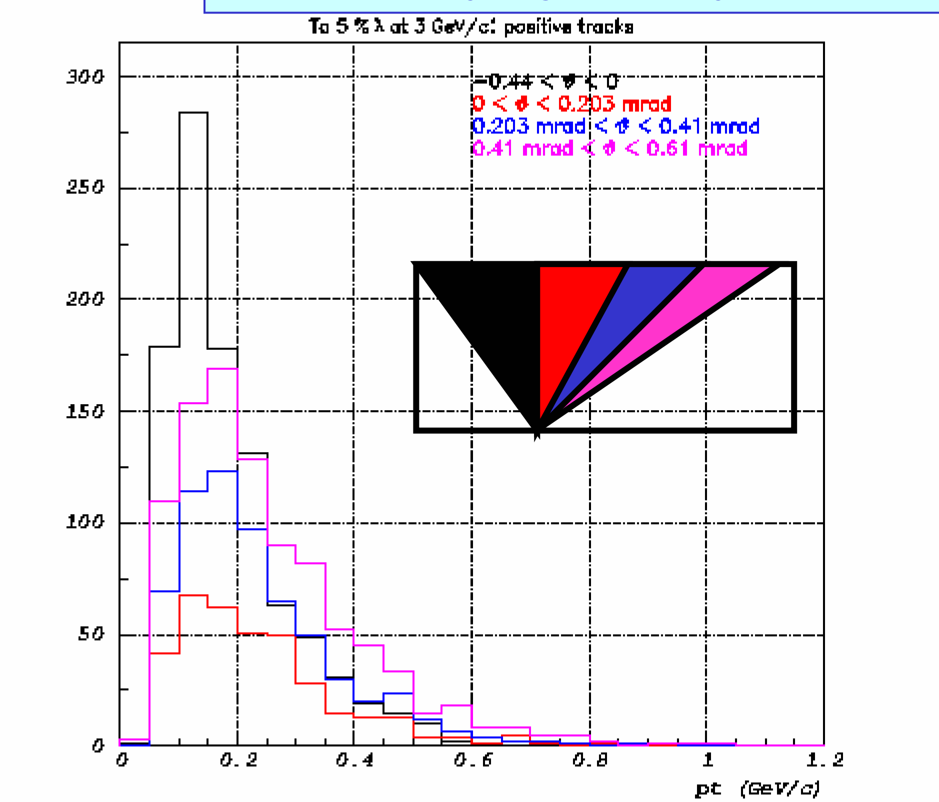
p_T spectra with the TPC

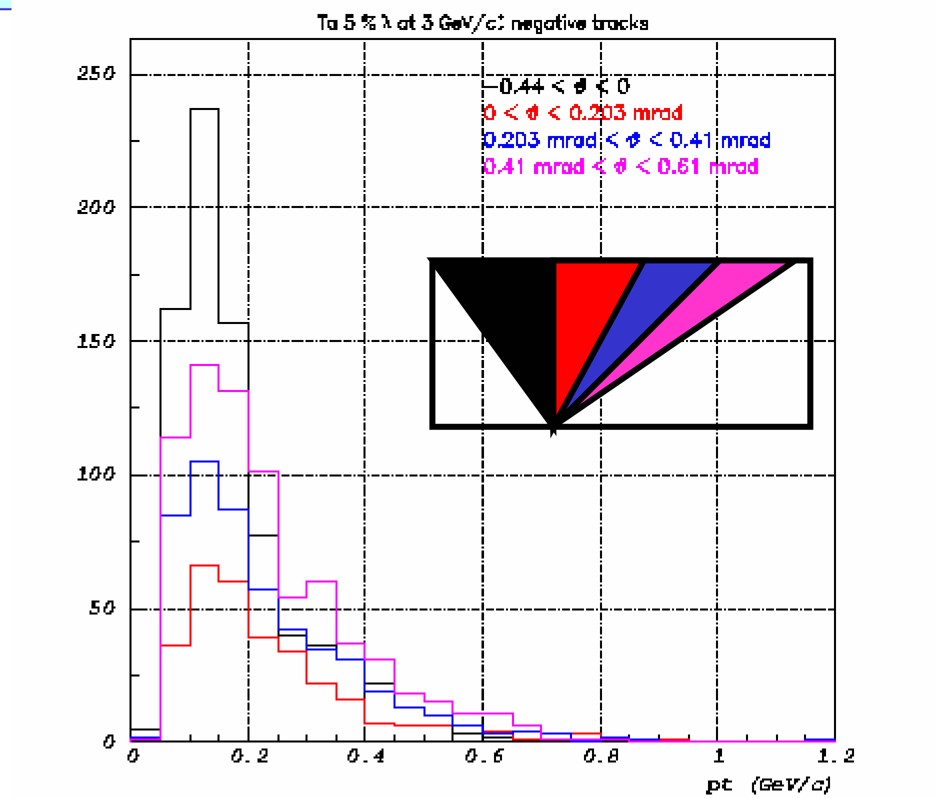
Relevant for neutrino factory

Raw p_T spectra in angular bins for 3 GeV/c Ta proton-data

Yield of pions (with electron contamination at low p)

Protons fully rejected by dEdx





Comments on these data

Improved momentum resolution in the TPC:

Smearing effects not very important (deconvolution will be done later)

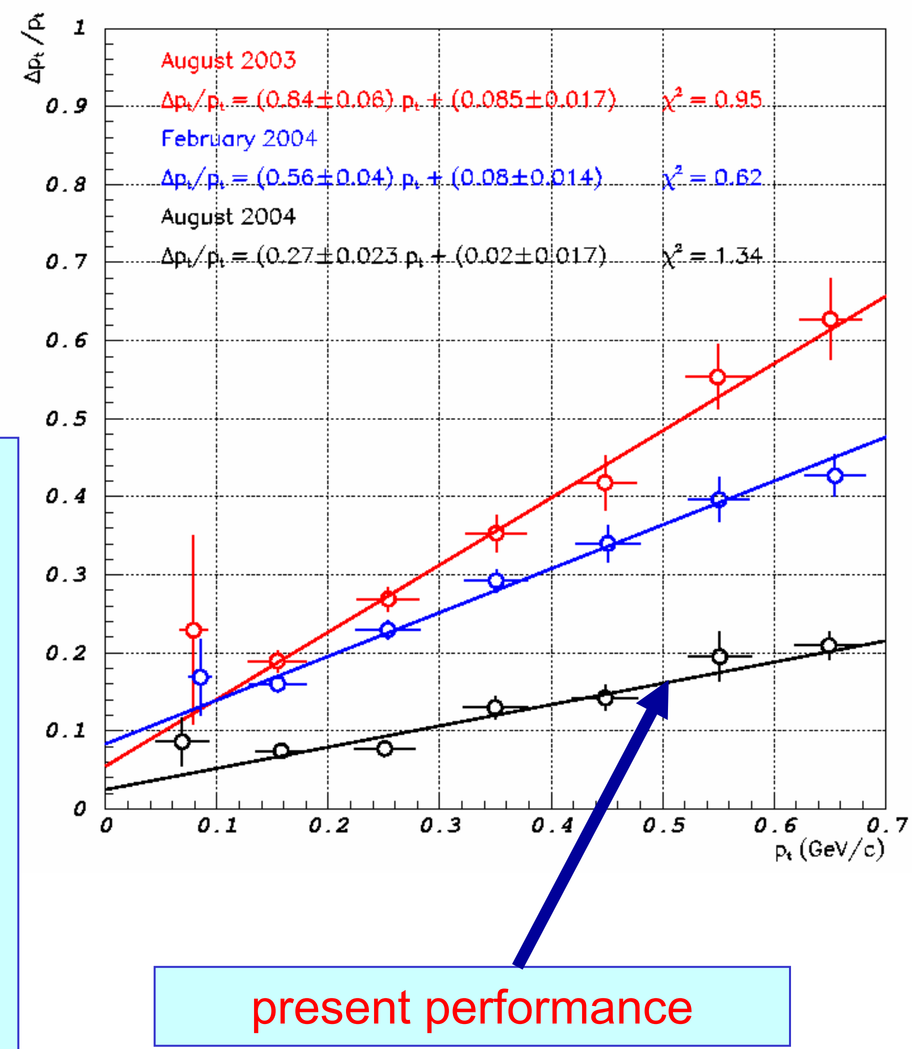
Very preliminary analysis of combined PID with dEdx and TOF:

e-π separation shows that e-contamination

is negligible for p>250 MeV/c **(relevant range for neutrino factory),**

is as large as ~60% between 50 and 100 MeV/c and

~40%/30% between 100 and 150 MeV/c for negatives/positives.



Importance of hadron yield measurements for the T2K experiment

Importance of Hadron Production for T2K

K2K

Direct measurement of hadron (pion) spectrum, but limited to higher momenta.

T2K

Pion monitor may be impossible due to high momentum and high intensity and will have same limitation

Dependence on MC for Hadron Production Model

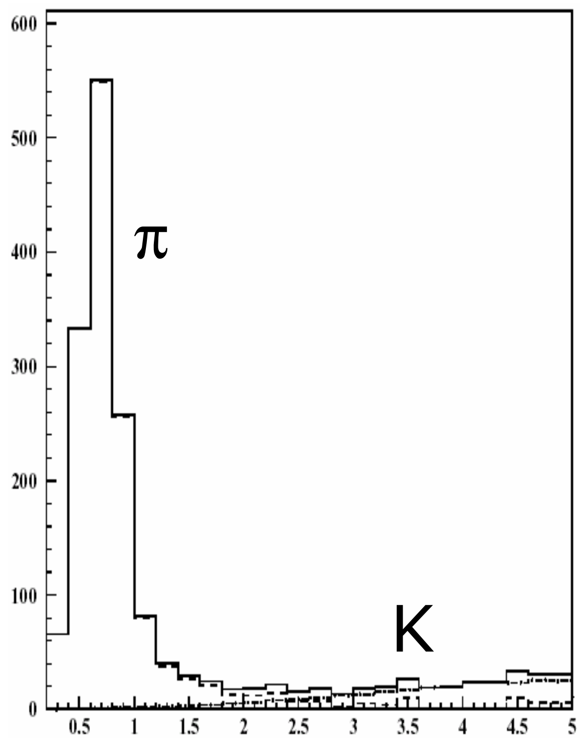
Smaller problem with an eventual 2km detector, but still present

ν_μ rates

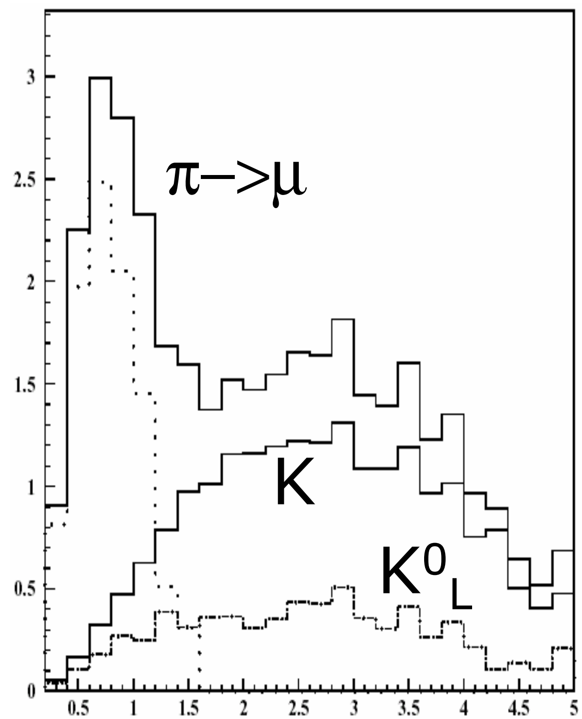
AND

ν_e rates

important

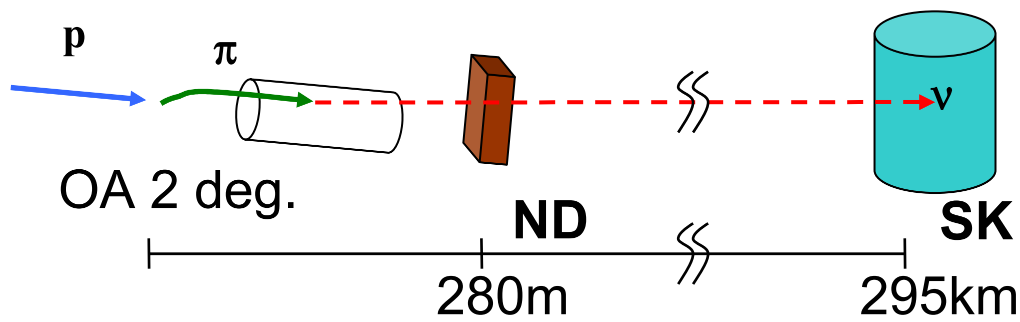


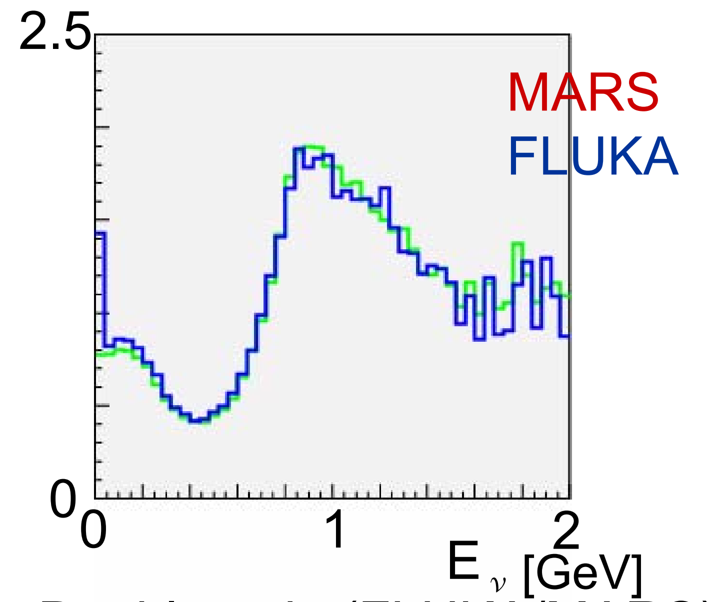
ν_μ rates



ν_e rates

Model Dependence of Far/near ratio



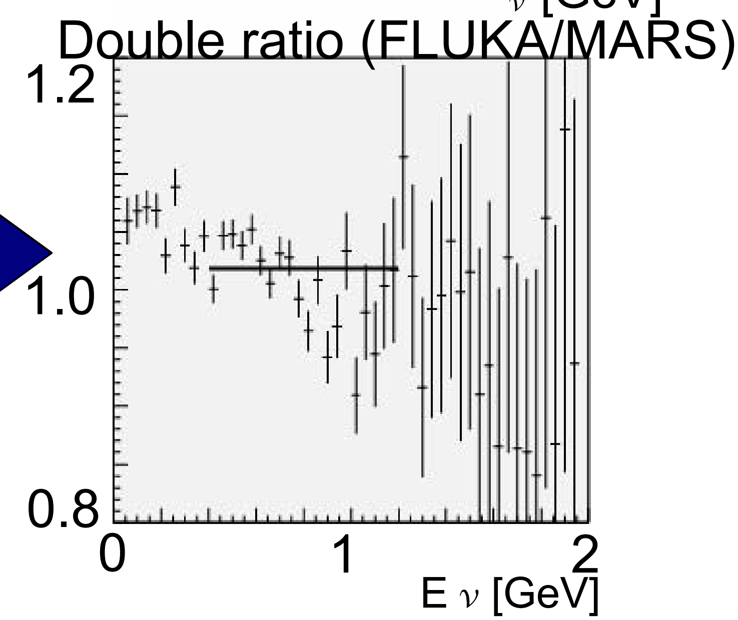


Flux @SK = Flux @ND ×[Far/near ratio]

From MC simulation

The Difference of Far/near ratio is ～1.9±0.4%

(Energy range:0.4～1.2[GeV])



Model Dependence of Far/near ratio (2)

1. Model dependence on (@ND off-axis)
   - total flux ~14%
   - π + momentum ~10%
   - ν energy ~4%

   Off Axis effect

2. Model dependence on Far/near ratio
   ~2% @280m

NB No particular reason to trust Fluka or MARS, but
It shows that uncertainties can be very large

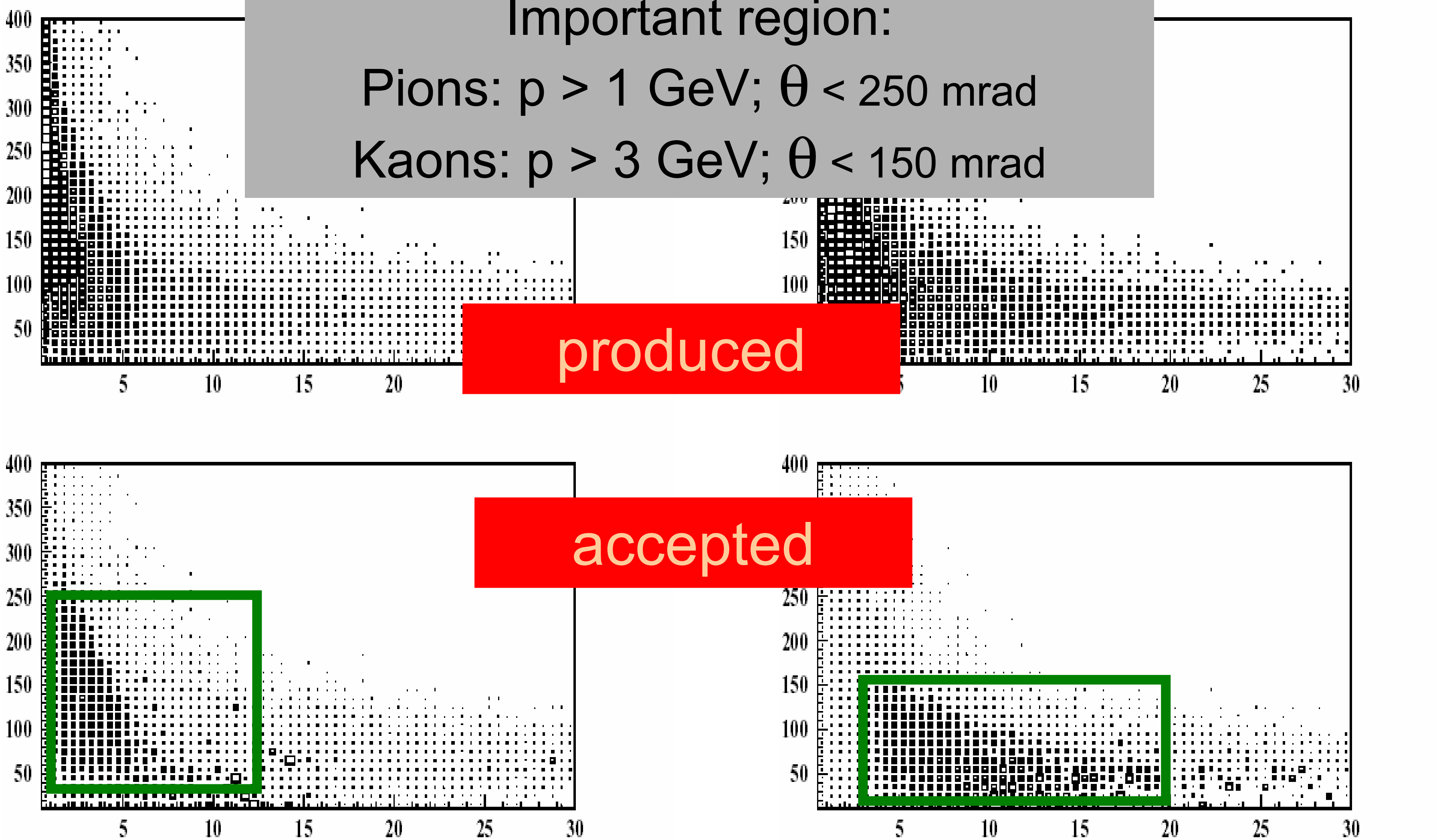
Minimum needs:
data with thin target of same material (carbon?)
data with replica target and intermediate length target

Acceptance ν_μ flux

Important region:

Pions: p > 1 GeV; θ < 250 mrad

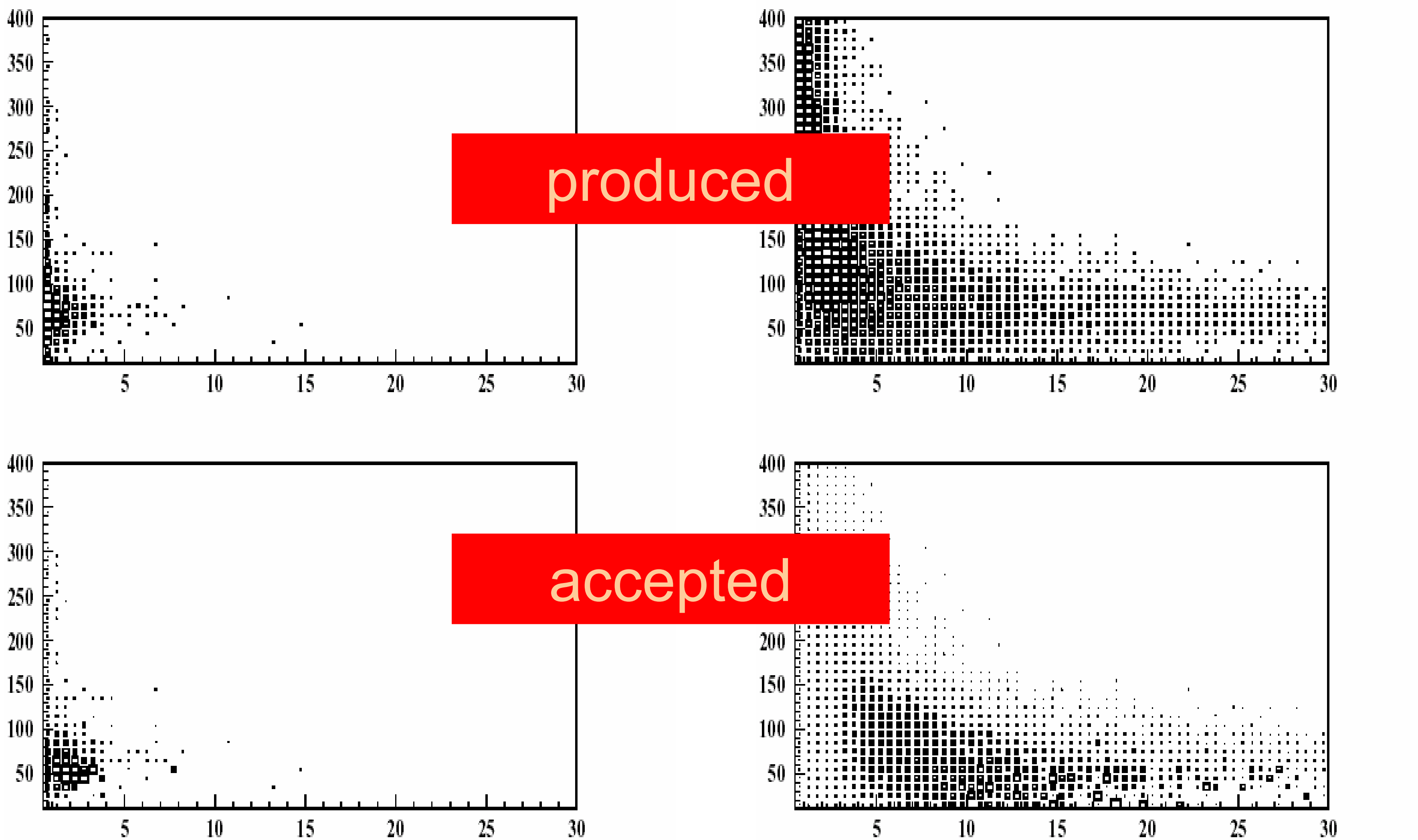
Kaons: p > 3 GeV; θ < 150 mrad



π acceptance

K acceptance

Acceptance ν_e flux

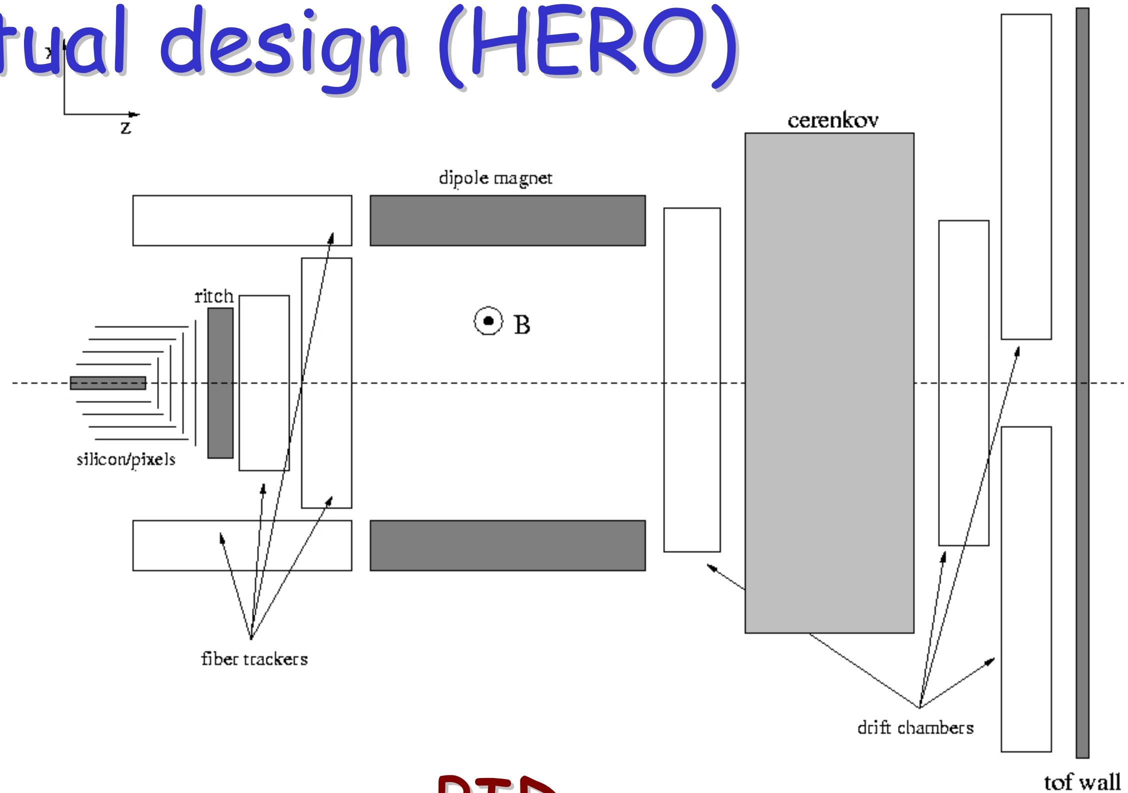


$\pi \rightarrow \mu$ acceptance

K acceptance

Options for new hadroproduction experiments

Conceptual design (HERO)



tracking

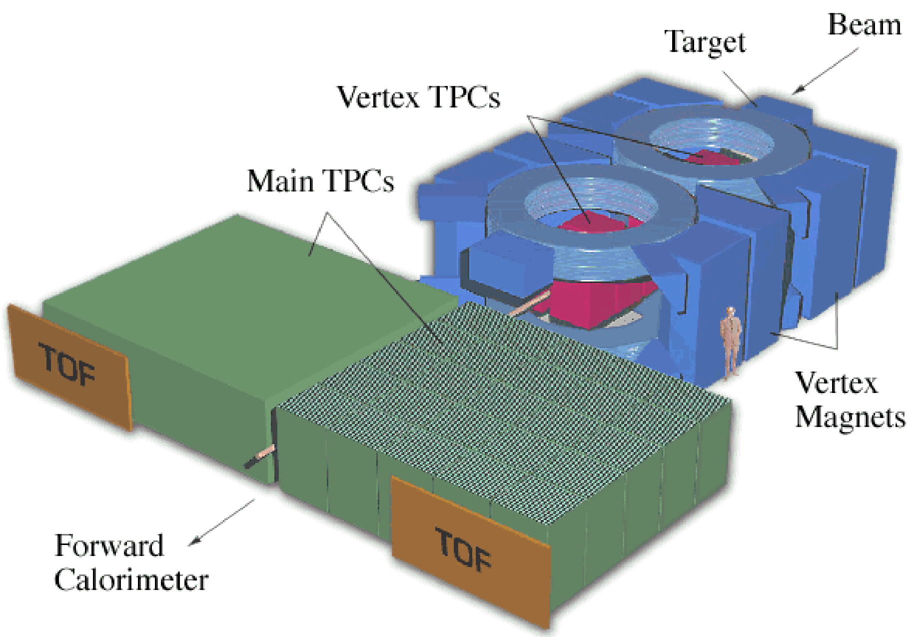
- High tracking efficiency for pions of >1 GeV
- Good spatial resolution, particularly near target
  - Two-track separation
  - K^0_s tagging
- Handle moderate multiplicities (up to 10 tracks)
- Good P and θ resolution

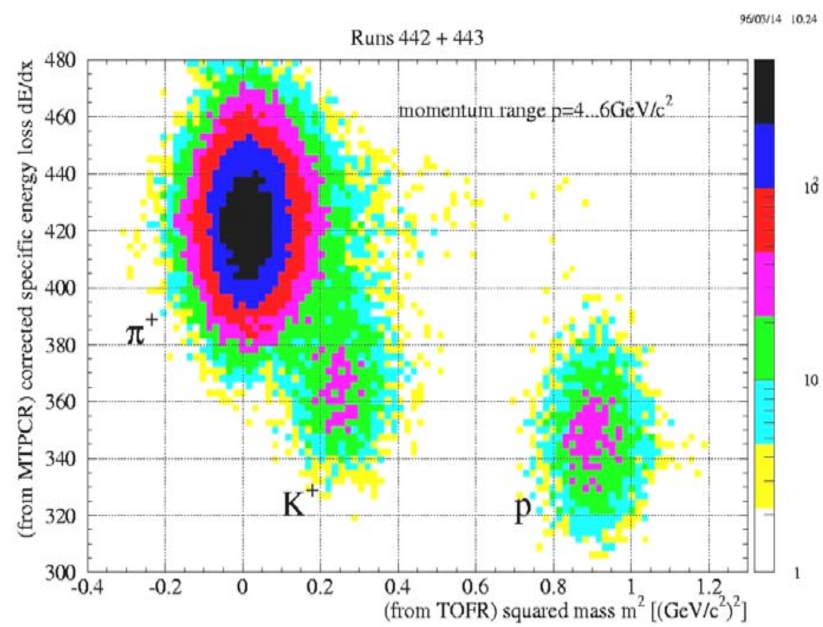
PID

- Need to separate p/π and π/K up to about 30 GeV.
- Between 1-3 GeV p/π, π/K TOF techniques
- From 3 GeV: Cherenkov, RICH.
- Redundancy (cross calibration)
- RICH needed above 16 GeV

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 and NuMI have been performed in 2002 with two beam settings (100 and 158 GeV/c) with a 1% Carbon target (these data without TOF)





NA49

Present performances for a hadron yield measurement:

Angular acceptance adequate

Momentum well measured down to low values

PID by dEdx and TOF

Low speed DAQ: 50 triggers per spill

A new group of people talk about upgrading the readout speed by a factor ten

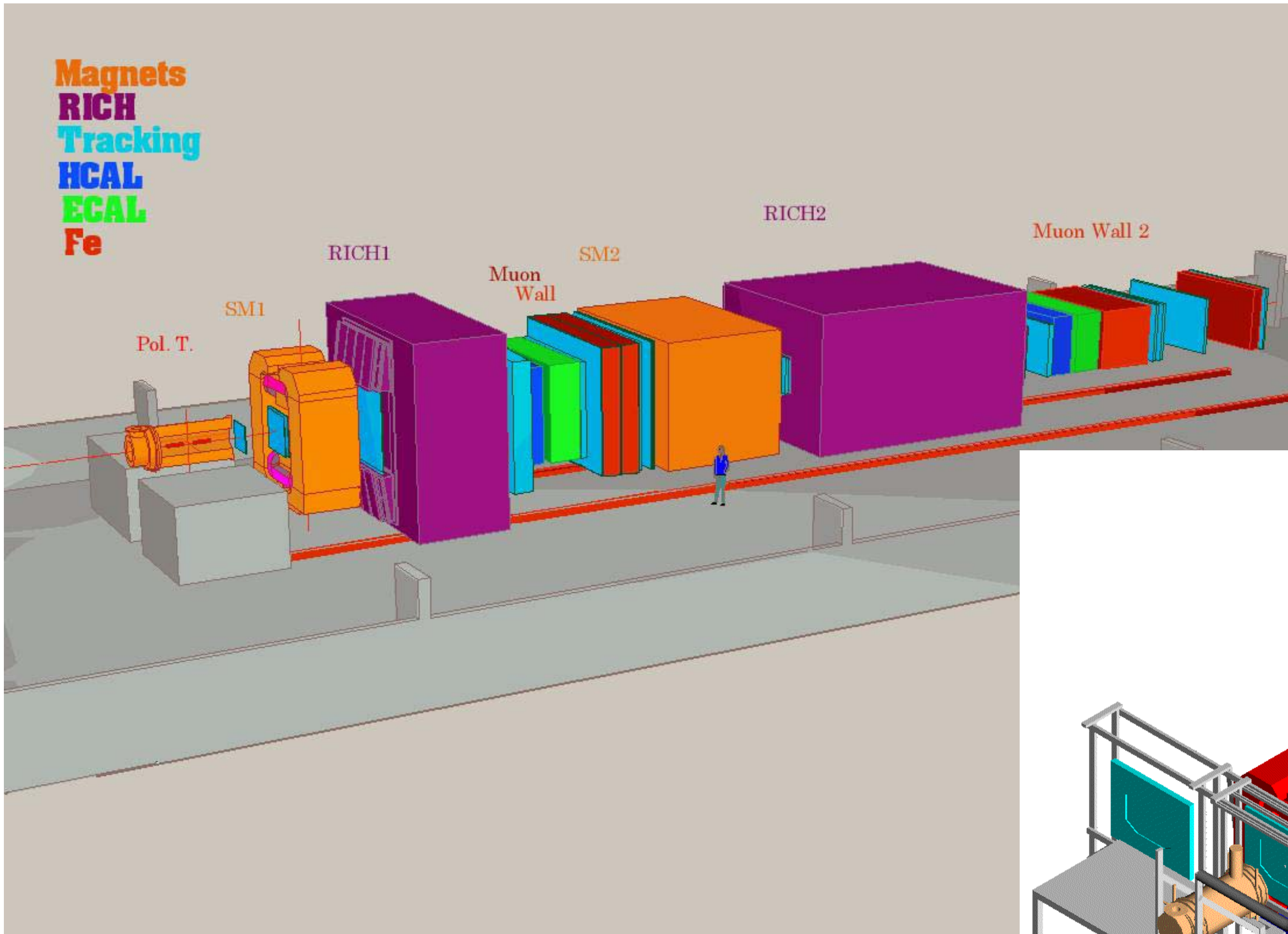
Interest in measurements for atmospheric neutrinos already being expressed (very similar requirements)

Need to have a good trigger and long running time (~week per setting)

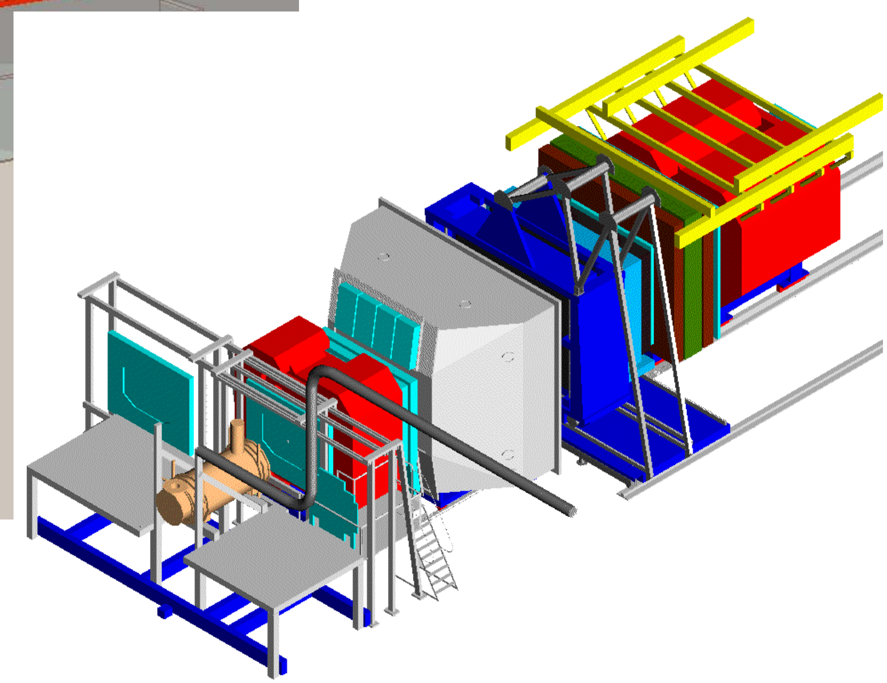
Old detector, which may need refurbishing

Limited in number of settings due to data-taking speed

COMPASS



Running
Experiment
also beyond 2005



COMPASS

Present performances for a hadron yield measurement:

Angular acceptance +- 180 mrad

Momentum well measured for p > 2.5 Gev

Excellent PID (RICH) for pions above ~3 GeV, kaons above ~9 GeV

Very high speed DAQ: 50,000 triggers per spill x 5000 spills per day!!

-> even without trigger a 5% λ target would give enough data in one day/setting (minimum programme one week)

Need to supplement PID at low momenta: TOF

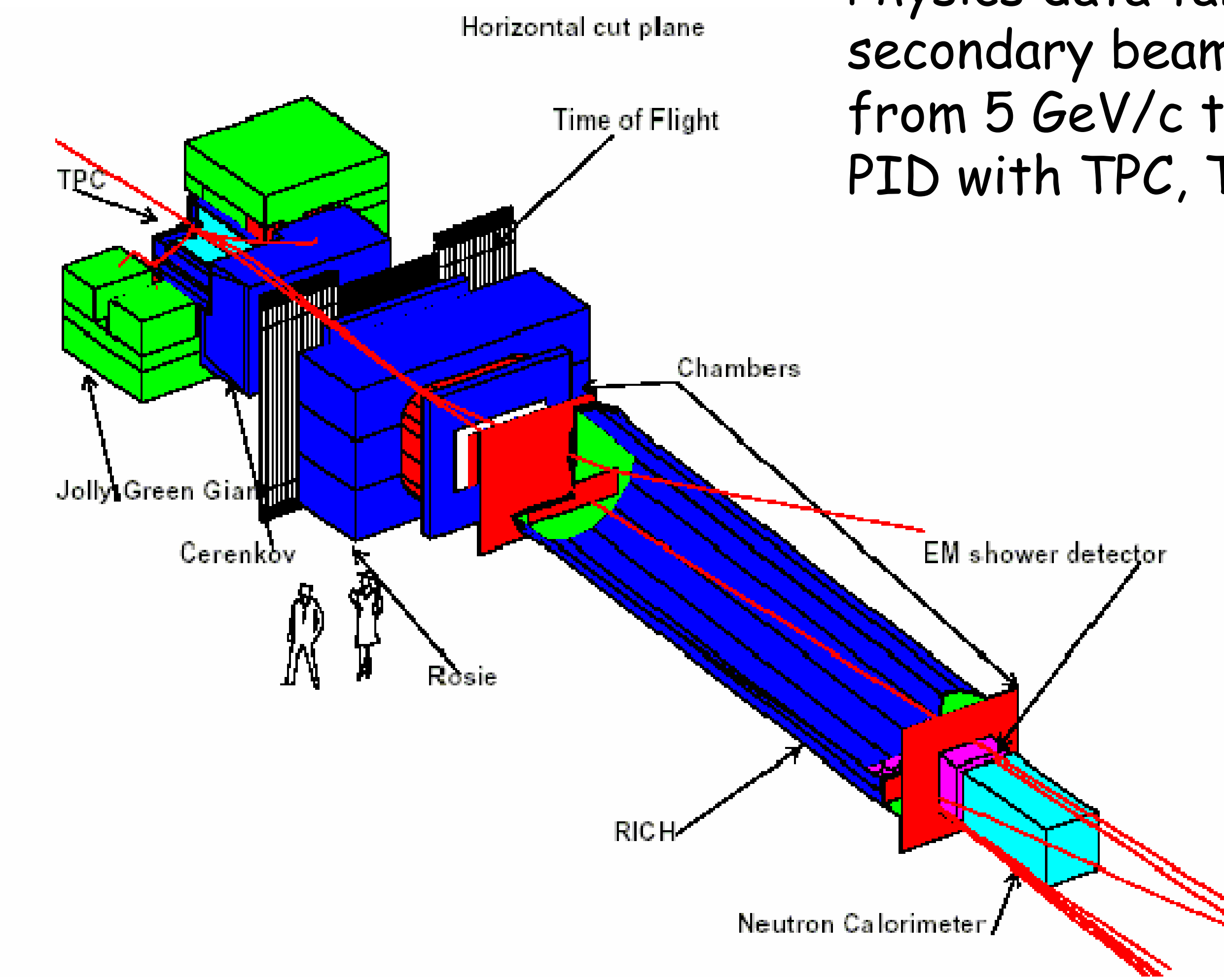
(HARP TOF is still available including the electronics and is perfect for the job)

Need to study low momentum tracking (possibly magnet powered at lower field and/or an extra chamber inside the magnet)

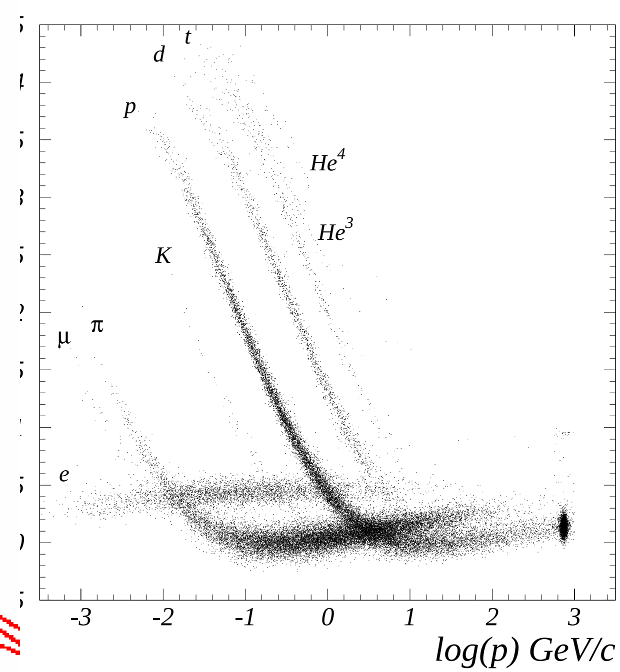
Study the effect of the beam hole (forward angle acceptance)

MIPP: FNAL-E907

Approved November 2001
Technical run 2004
Physics data taking 2005
secondary beams of $p^{\pm}$ $K^{\pm}$ $p^{\pm}$
from 5 GeV/c to 100 GeV/c
PID with TPC, TOF, RICH



TPC dE/dx Particle ID- BNL E910



MIPP Current status

Commissioning-Beam tuning going on.

All detectors in readout. Beam chambers fully functional. Drift chambers coming on line.

ToF, Cherenkov in readout

Calorimeters fully operational

TPC in readout. Zero suppression algorithm being worked on.

RICH being refurbished after fire. Should be operational shortly.

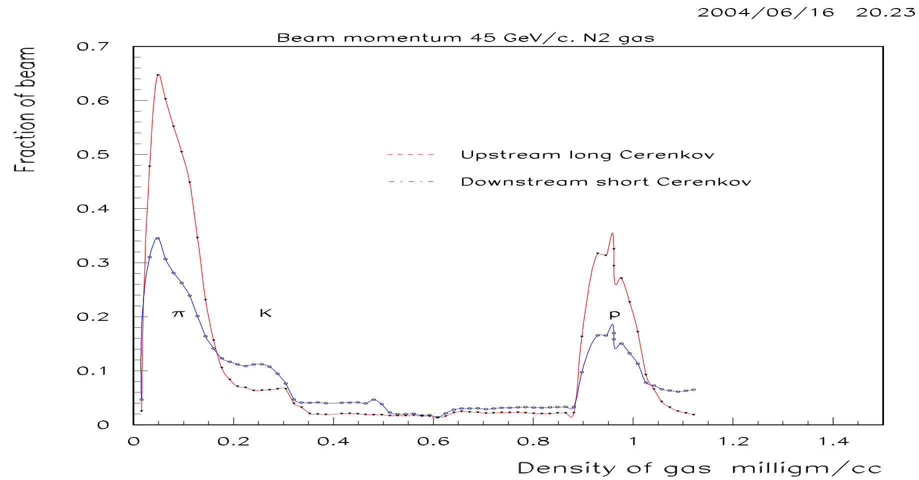
Beam Cherenkov pressure curves being taken.

Plans --Continue data taking in 2005.

thinking about TPC electronics upgrading: 1KHz

Probably incompatible with MINOS data taking in 2006

Beam Cerenkov Pressure Curve Beam at 45 GeV/c



TPC installation

MIPP: Physics Programme

- Particle Physics-To acquire unbiased high statistics data with complete particle id coverage for hadron interactions.
  - Study non-perturbative QCD hadron dynamics, scaling laws of particle production
  - Investigate light meson spectroscopy, pentaquarks, glueballs
- Nuclear Physics
  - Investigate strangeness production in nuclei- RHIC connection
  - Nuclear scaling
  - Propagation of flavor through nuclei

Target	Physics	Data Points	Primary proton Average Intensity/spill	Total number of Primary Protons
Numi 1	MINOS	3.3	125000	2.06E+10
NUMI 2	MINOS	3.3	125000	2.06E+10
H2	Scaling	6	9.76E+09	2.93E+15
N2	Atmospheric ν	4	9.76E+09	1.95E+15
Be	pA	2	9.76E+09	9.76E+14
Be	Survey	1	9.76E+09	4.88E+14
C	Survey	1	9.76E+09	4.88E+14
Cu	pA	2	9.76E+09	9.76E+14
Cu	Survey	1	9.76E+09	4.88E+14
Pb	pA	2	9.76E+09	9.76E+14
Pb	Survey	1	9.76E+09	4.88E+14
Total		26.6		9.76E+15

- **Neutrino related Measurements**
  - Atmospheric neutrinos – Cross sections of protons and pions on Nitrogen from 5 GeV- 120 GeV (5, 15, 25, 50, 70, 90)
  - Improve shower models in MARS, Geant4
  - Make measurements of production of pions for neutrino factory/muon collider targets
  - MINOS target measurements – pion production measurements to control the near/far systematics
- **Complementary with HARP at CERN**

Conclusions

- Neutrino oscillation experiments move from discovery to precision measurements
- Knowledge of neutrino cross-section and neutrino production is essential
- Hadron production measurements should be seen as integral part of the Neutrino Experiments
- CERN has the opportunity to contribute significantly to this field for the next generation of oscillation experiments
- Existing detectors at CERN, COMPASS and NA49 can be used to do these measurements and need only small additions to cover a large range of the phase space for the T2K experiments
- MIPP is unlikely to do dedicated measurements for T2K (fully committed programme)

- Present trends (see HARP & MIPP) are
  - Full-acceptance detectors (single arm spectrometers in the past)
  - High statistics
  - Characterization of the actual neutrino beam targets to reduce MC extrapolation to the minimum
  - Direct interest of neutrino experiments in hadron production
  - atmospheric neutrino predictions need similar measurements