Results from HARP

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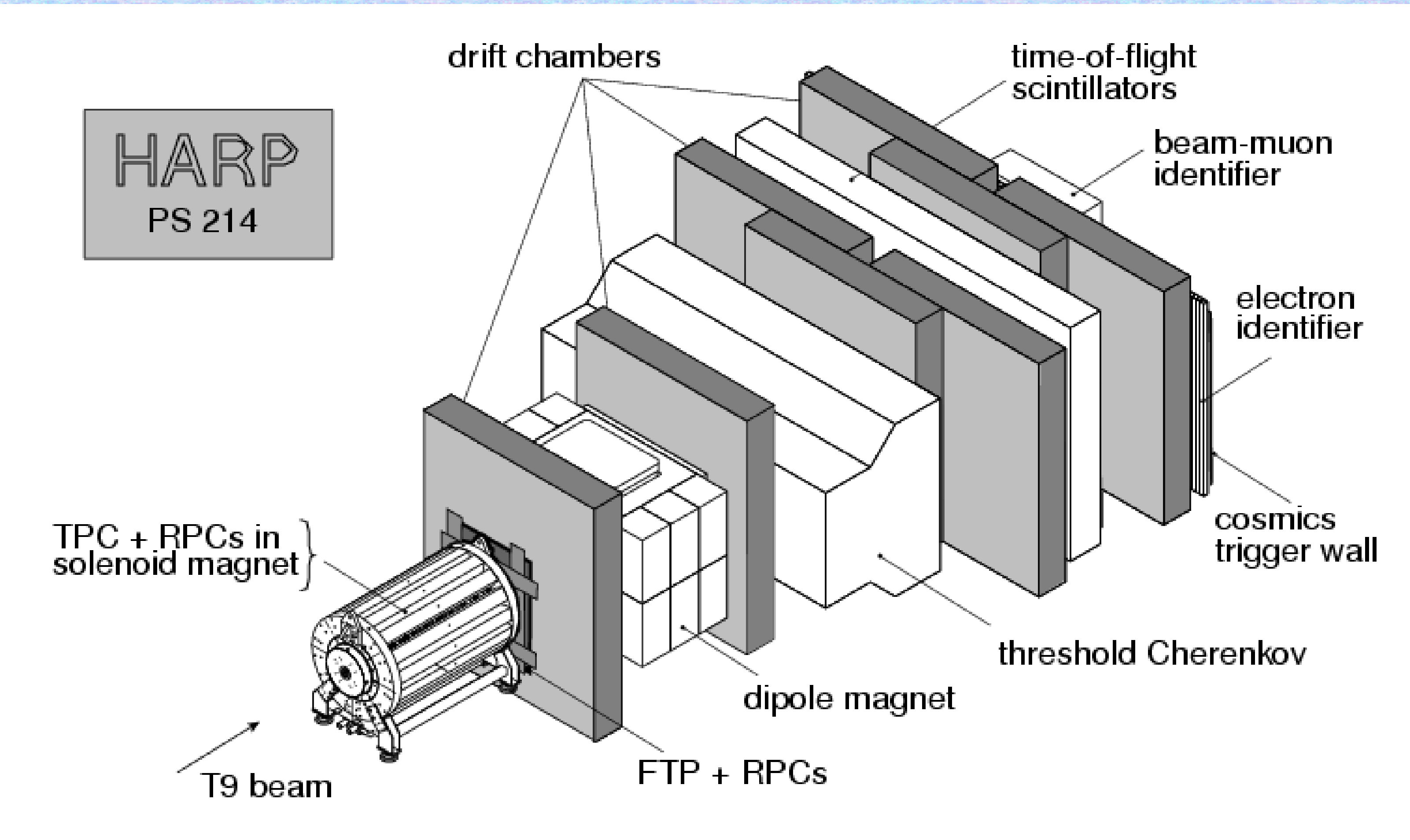
On behalf of the HARP collaboration
DPF Meeting
Riverside, August 2004

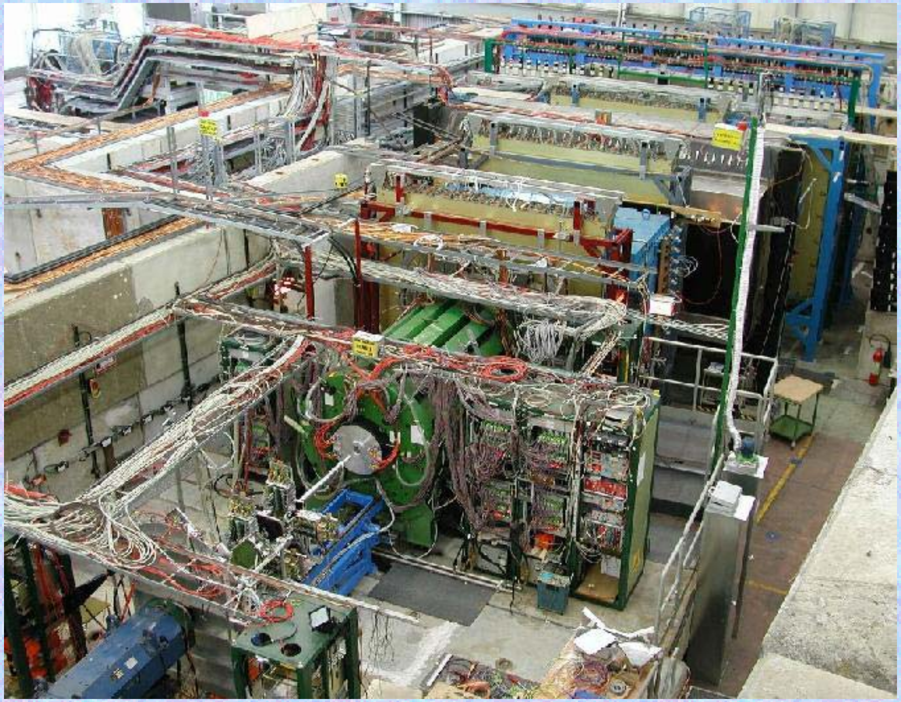
The HAdRon Production Experiment



124 physicists

24 institutes

Physics Goals



Systematic study of HAdRon Production:

Beam energy: *2-15 GeV*
Target: *from hydrogen to lead*.

- Input for precise calculation of ***atmospheric neutrino flux***
- 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 ***Monte Carlo*** generators (GEANT4, e.g. for LHC, space applications)

Data Taking Summary

HARP took data at the CERN PS T9 beam-line 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

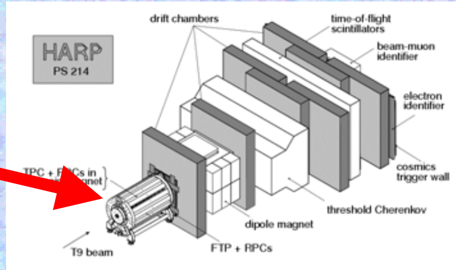
CRYOGENIC:

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:

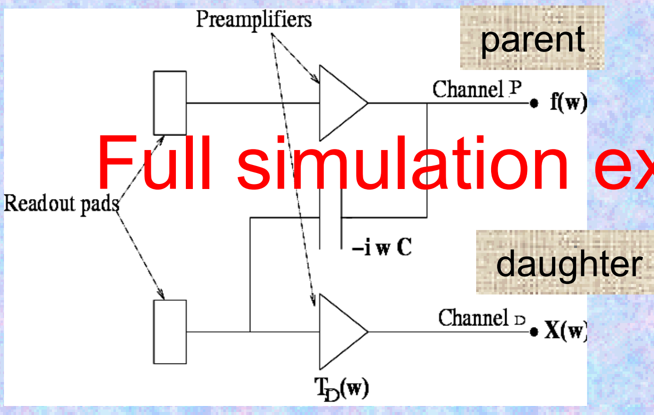
K2K: Al	MiniBoone: Be	LSND: H_2O
5% 50% 100% Replica	5% 50% 100% Replica	10% 100%
+12.9 GeV/c	+8.9 GeV/c	+1.5 GeV/c

TPC – Large Angle



- Full track reconstruction available
- Calibration campaign in 2003:
  - Calibration with sources (^{55}Fe, ^{83}Kr)
  - Calibration with cosmic rays.
- Systematic study of corrections:
  - Basic calibrations revisited (time, charge, position)
  - Cross-talk correction
  - Distortion corrections

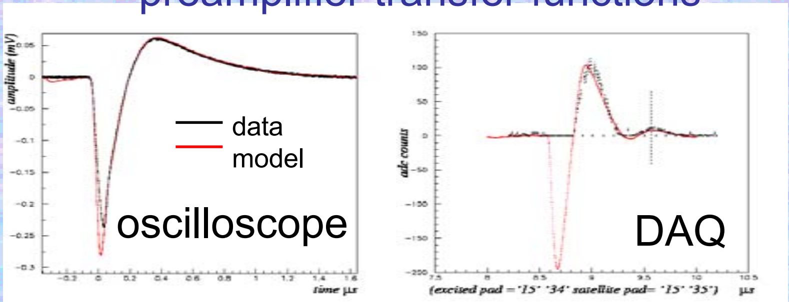
TPC Cross talk



Full simulation exists

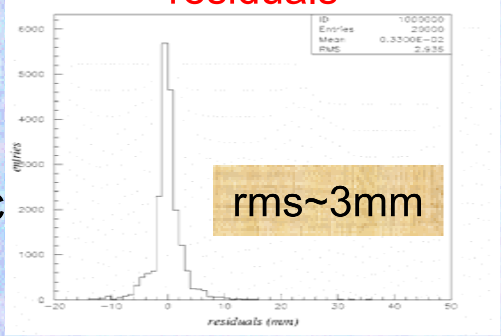
cross-talk model

capacitive couplings
+
preamplifier transfer functions



Introduced in MC

residuals

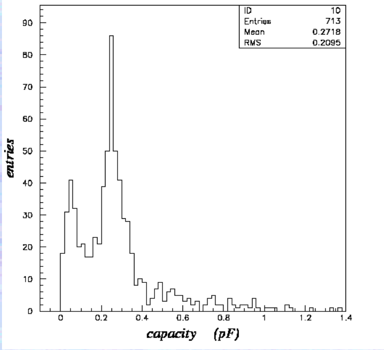


cross-talk measurements

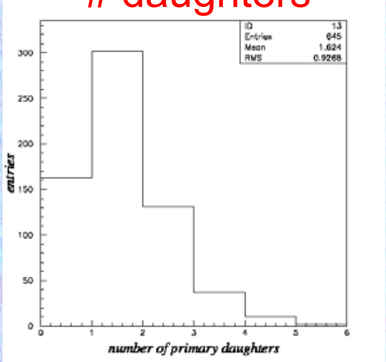
Individual pulse injection in all pads

- 50% of pads affected by x-talk
- x-talk only relates neighbouring pads

capacitive couplings

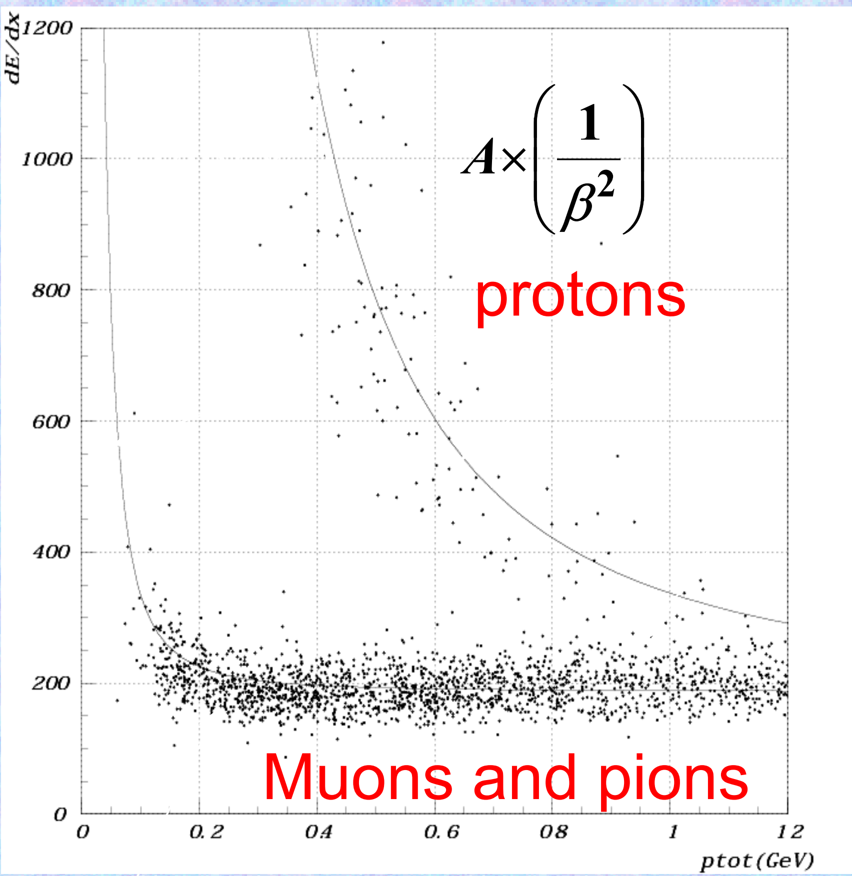


daughters



Momentum & dE/dx

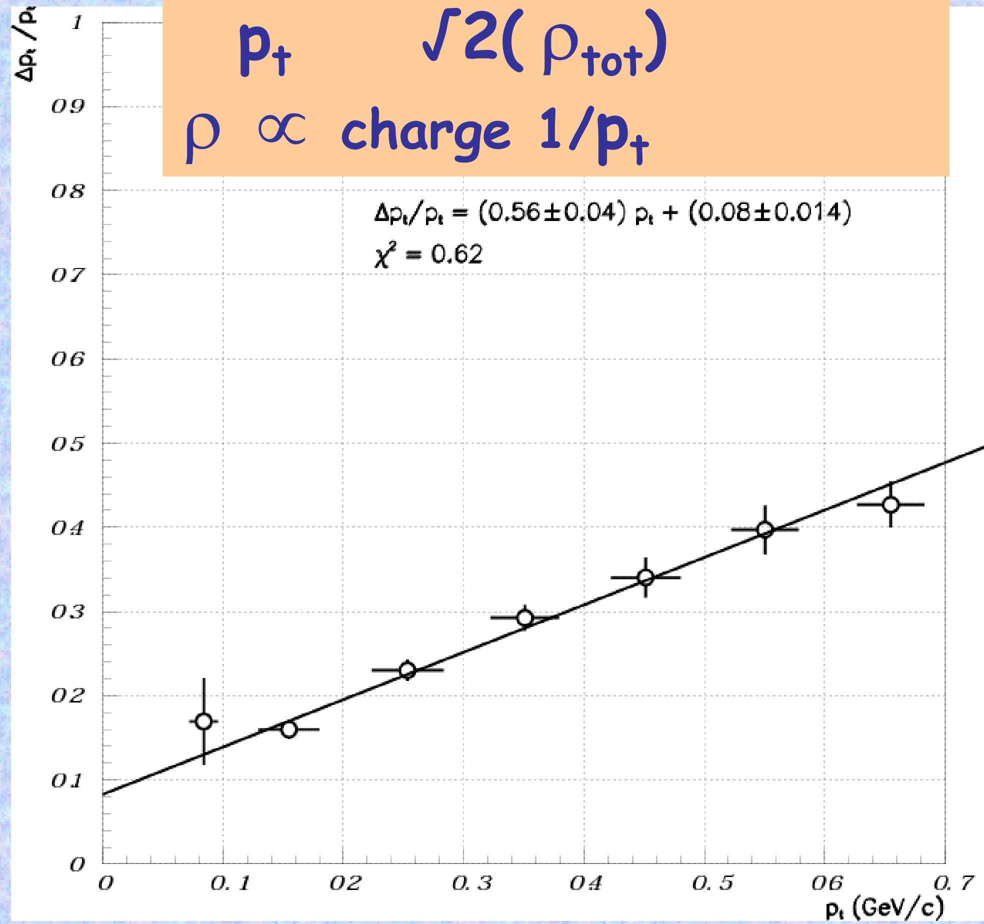
dE/dx over full track



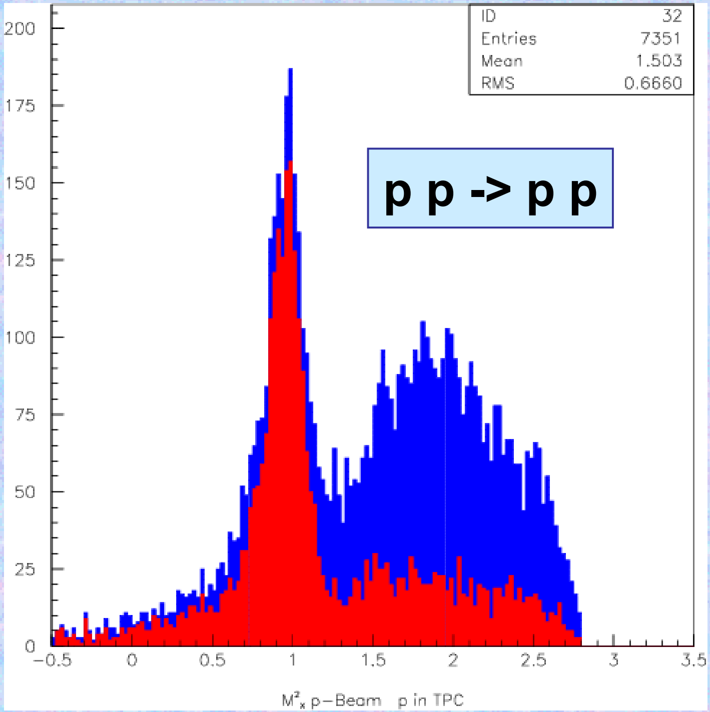
Compare single arm with full track

$$\frac{\Delta p_t}{p_t} = \frac{abs(\rho_1 + \rho_2)}{\sqrt{2}(\rho_{tot})}$$

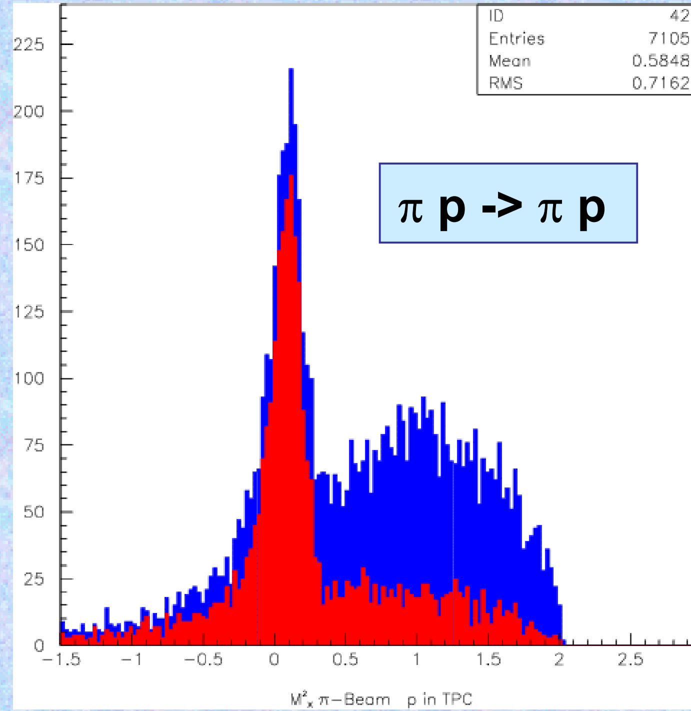
$\rho \propto$ **charge $1/p_t$**



Elastic Scattering



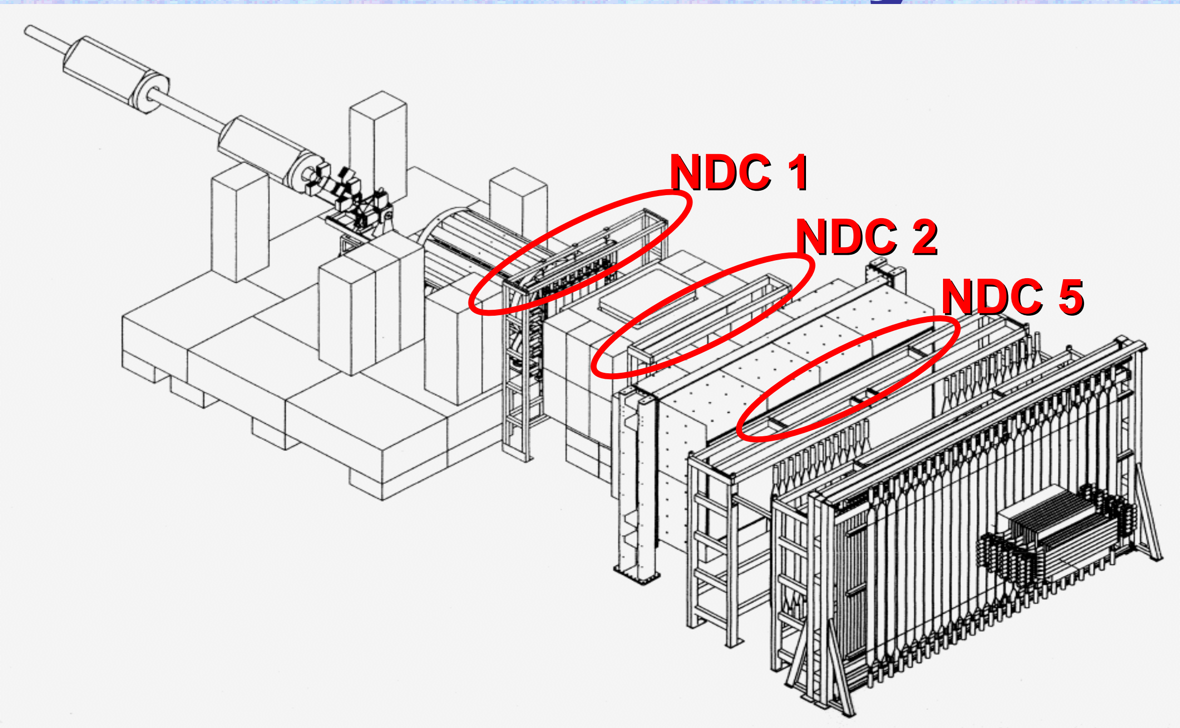
Red: using dE/dx for PID



missing mass for **p p→p p and πp → π p**

- Select p and π in the beam by ToF
- **BLUE**: Simple selection
  - Only 1 pos. track in the TPC coming from the target
- **RED**: Additional cut on dE/dx in TPC (select proton)

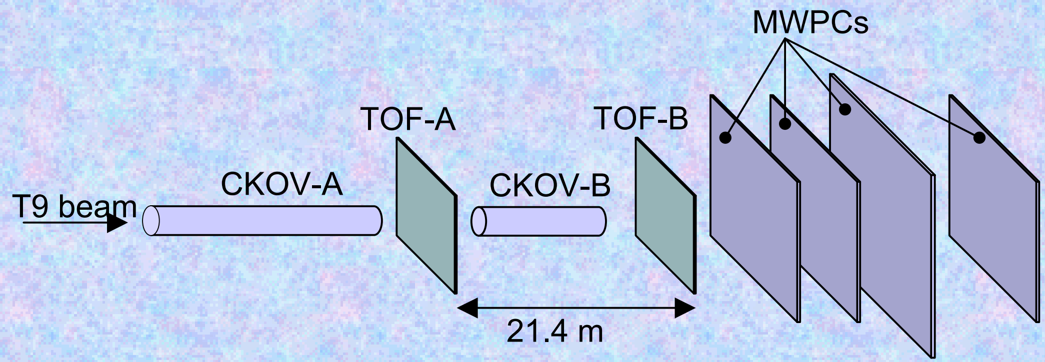
Forward Analysis



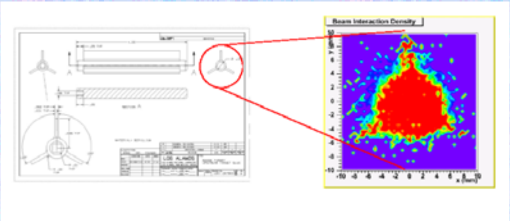
- $p_{\pi} > 1$GeV/c
- $\theta_{\pi} < 250$ mrad
- Main tracking detector: NOMAD drift chambers
- Forward PID detectors

Beam Instrumentation

Beam composition and direction



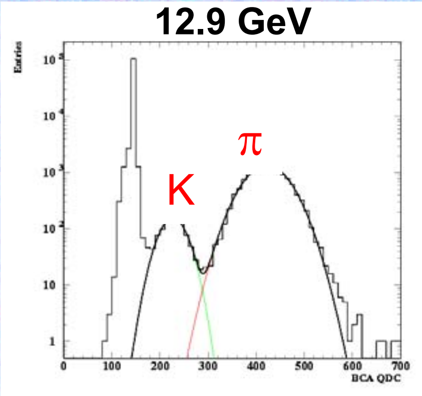
MWPCs



MiniBooNE target

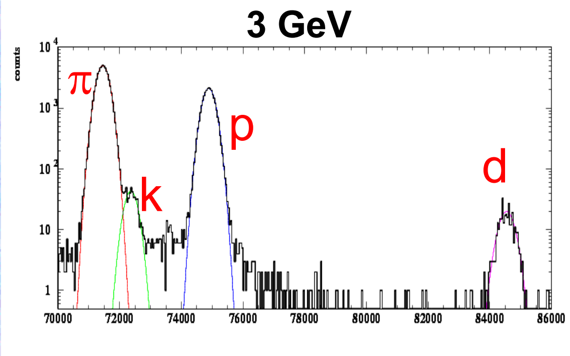
Beam Cherenkov

- K-π separation at high energy

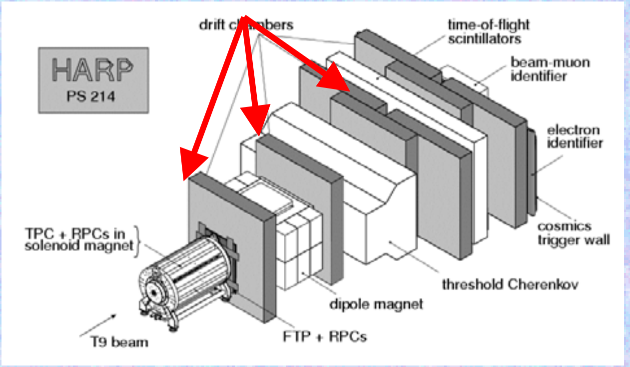


Beam Tof

- k/π/p separation at low
- T0



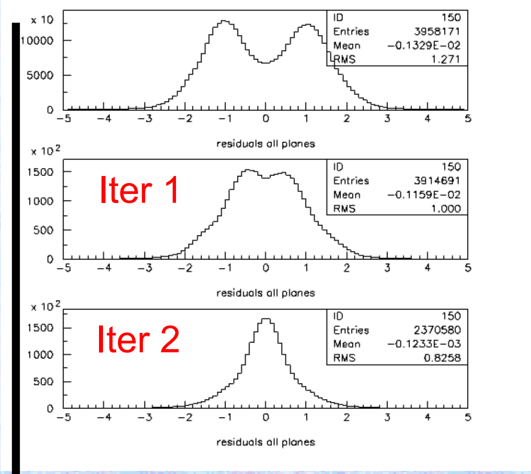
NOMAD Drift Chambers



Courtesy of NOMAD

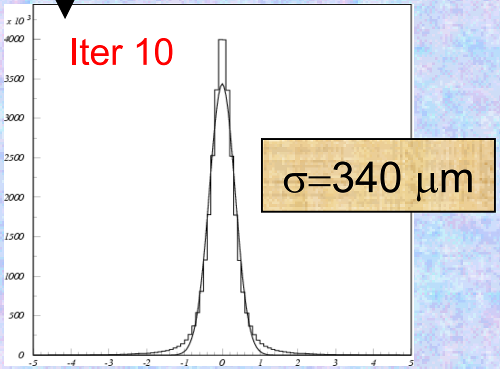
Alignment

Cosmic rays

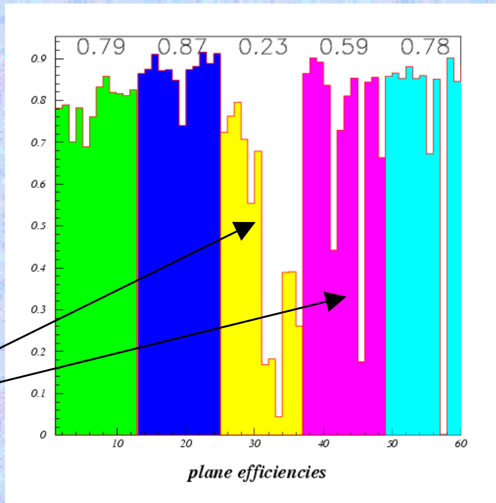


Hit reconstruction efficiency ~ 80 %

Resolution



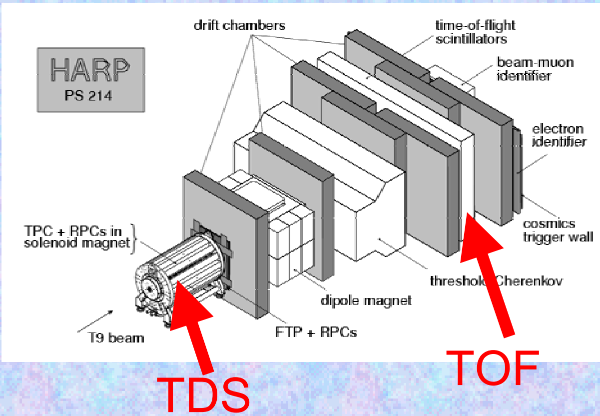
Module eff

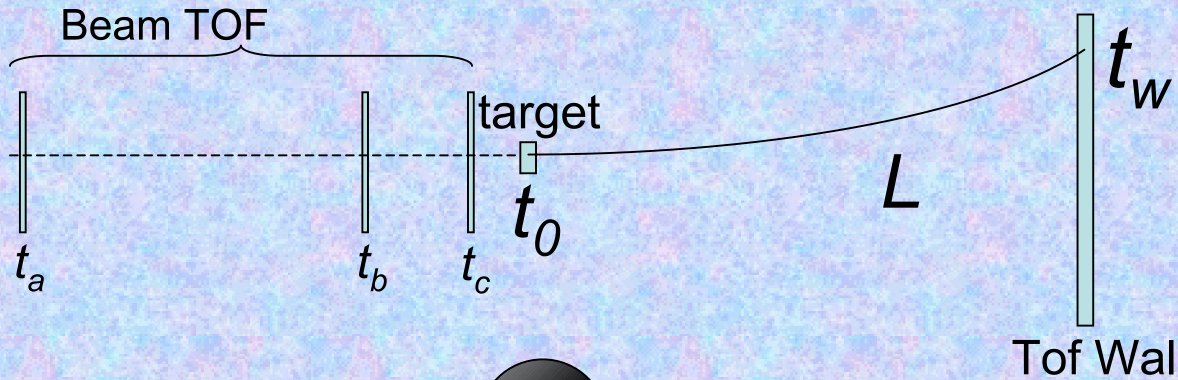


- **95 % in NOMAD**
- **Harp: Not flammable gas (safety regulations)**

π/p using TOF

0-4.5 GeV





data

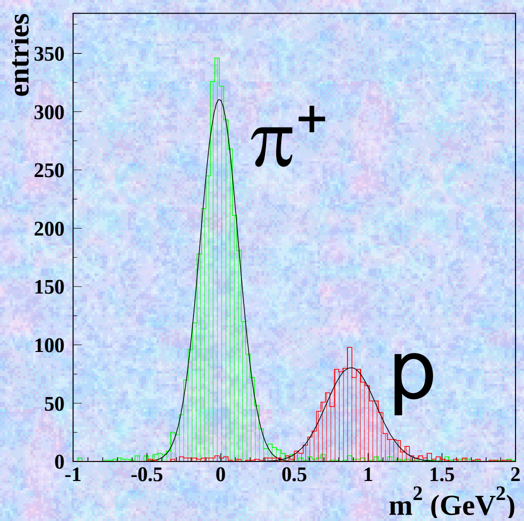
$$m^2 = p^2 \cdot \left(\left(\frac{t_w - t_0}{L} \right)^2 - 1 \right)$$

- *Tof ~160 ps*

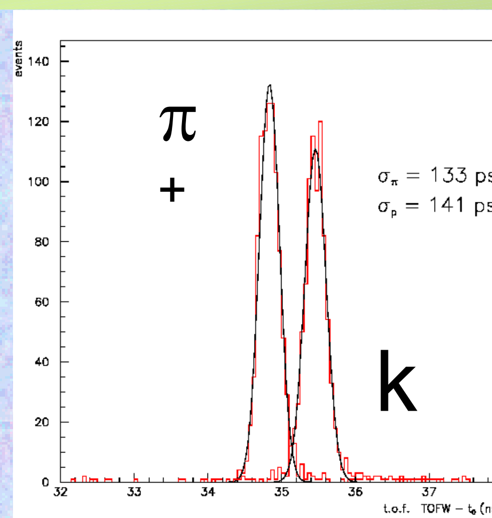
7σ π/p @ 3 GeV

- *Beam ~70 ps*

3 GeV beam particles

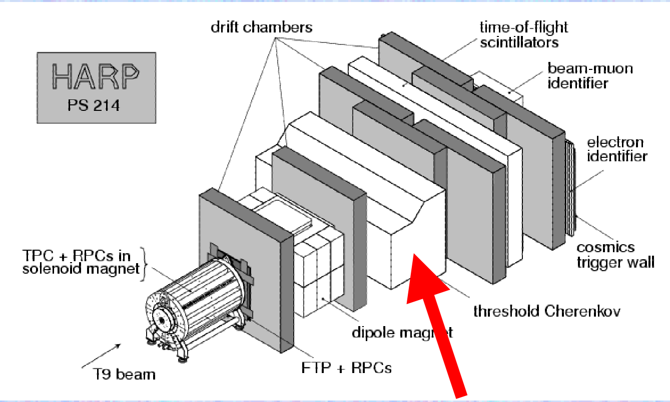


5 GeV beam particles



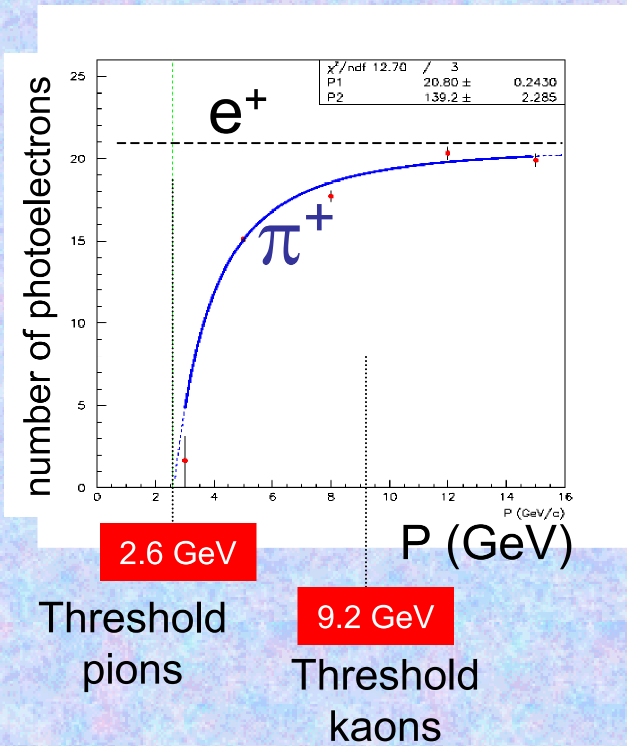
π/p using Cherenkov

3-15 GeV

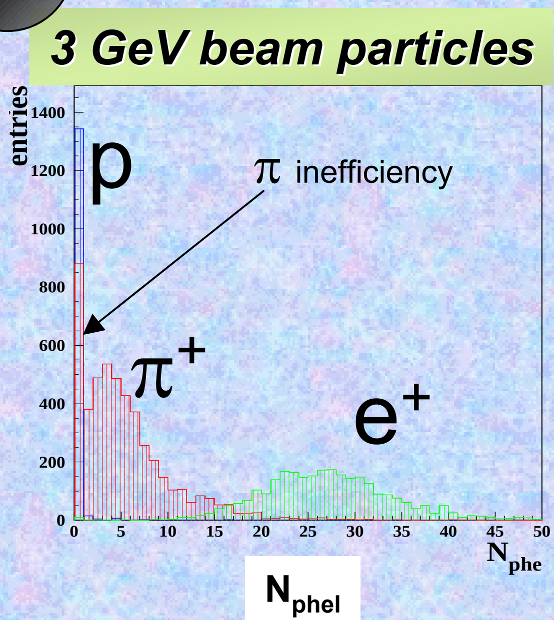


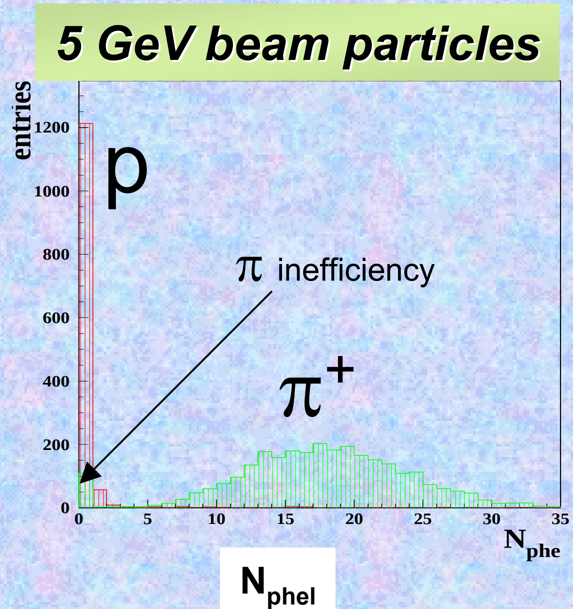
Cherenkov

- $\pi / p \quad p > \quad 3$ GeV
- $\pi / k \ 3 < P < 9$ GeV



data

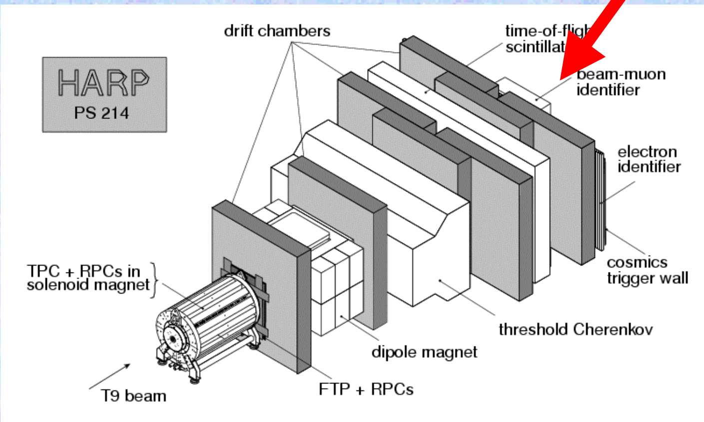




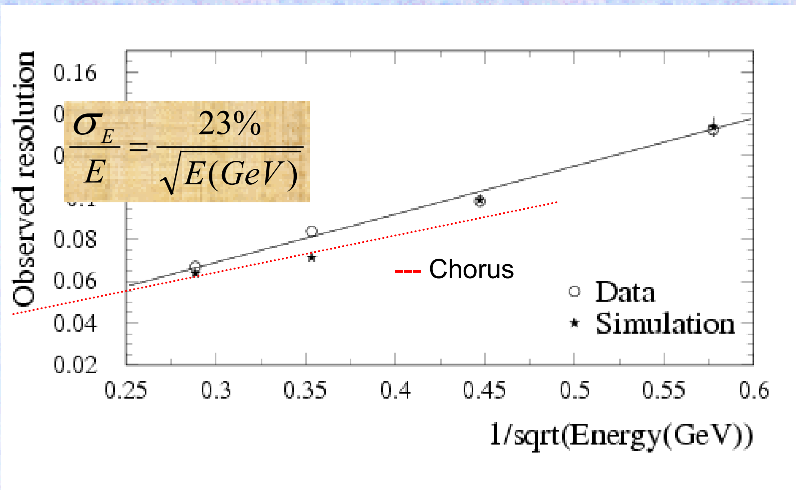
$$N_{phel}\ \alpha\ N_0\left(1-\frac{1}{n^2}\left(1+(m/p)^2\right)\right)$$

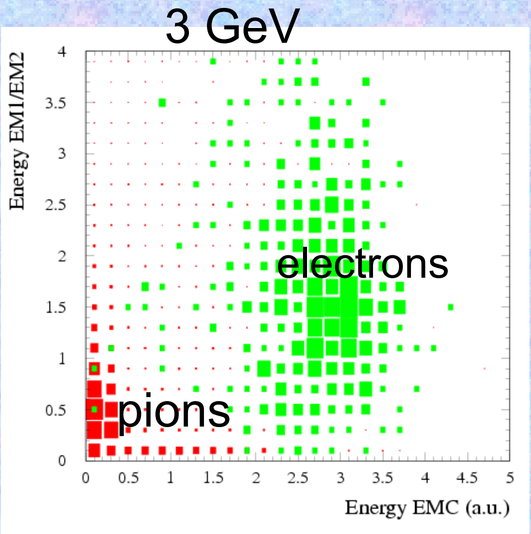
e/π using calorimeters

- "Spaghetti" type
- Courtesy of the CHORUS experiment
- 2 planes (EM1, EM2)

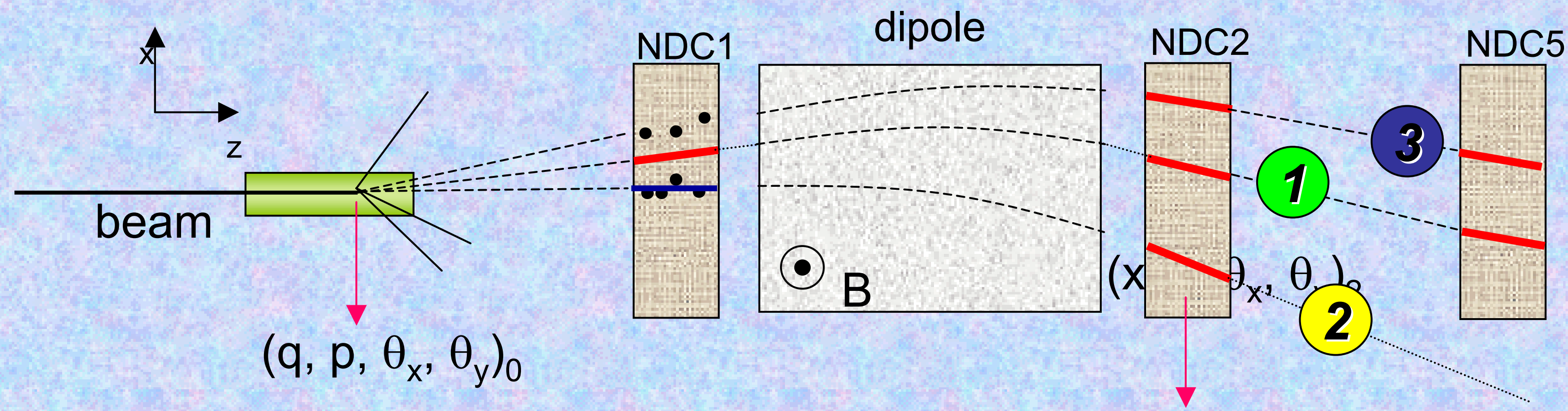


Resolution





NDC Tracking Efficiency



- Multi-track events (hit efficiency, hit density, pattern recognition) → tracks type 1 (3-d segment in NDC1) "migrate" to type 2 tracks (2-d segment in NDC1) and type 3 tracks (hits in NDC1)
- Tracks type 2 & 3 + vertex constrain → measure (p,θ,q).
  - **Size of migration → hadronic model dependent**
  - **Total efficiency → hadronic model independent**

Cross section

$$\sigma_{ij}^{\pi} = F_{norm} \cdot M_{ij}^{kl} \cdot \frac{1}{\varepsilon_{kl}^{\pi}} \cdot \left(N_{kl}^{\pi} - N_{kl}^{bkg} \right)$$

(p,θ)

absolute normalization

Migration matrix

Total efficiency

Pion Yield

Background

$$\sigma_i^{\pi} = \frac{1}{\varepsilon_i^{acc}} \frac{1}{\varepsilon_i^{track}} \sum_{t=1}^{3} \left[M_{ij}^{(t)} \frac{1}{\varepsilon_j^{(t)-\pi}} \eta_j^{(t)-\pi} \cdot N_j^{(t)-\pi} \right]$$

Cross section revisited

track types

$$\sigma_i^{\pi} = \frac{1}{\varepsilon_i^{acc}} \frac{1}{\varepsilon_i^{track}} \sum_{t=1}^{3} \left[M_{ij}^{(t)} \frac{1}{\varepsilon_j^{(t)-\pi}} \eta_j^{(t)-\pi} \cdot N_j^{(t)-\pi} \right]$$

Runs on bins of (p,θ)

acceptance

Tracking efficiency

Migration matrix

Pion efficiency

Pion purity

Measured pion yield

Tracking efficiency

Number of primary particles with P measured

$$\varepsilon_i^{track} = \frac{N_i^p}{N_i^{acc}} = \frac{N_i^{down}}{N_i^{acc}} \cdot \frac{N_i^p}{N_i^{down}} = \varepsilon_i^{down} \cdot \varepsilon_i^{up-down}$$

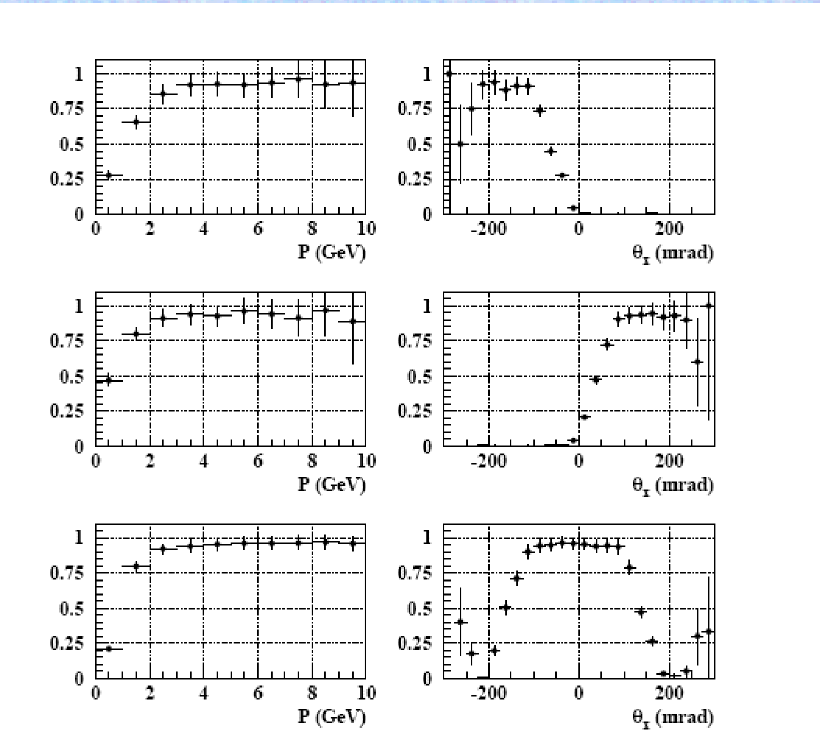
Number of primary particles accepted

Number of primary particles accepted with a reconstructed track segment downstream the dipole

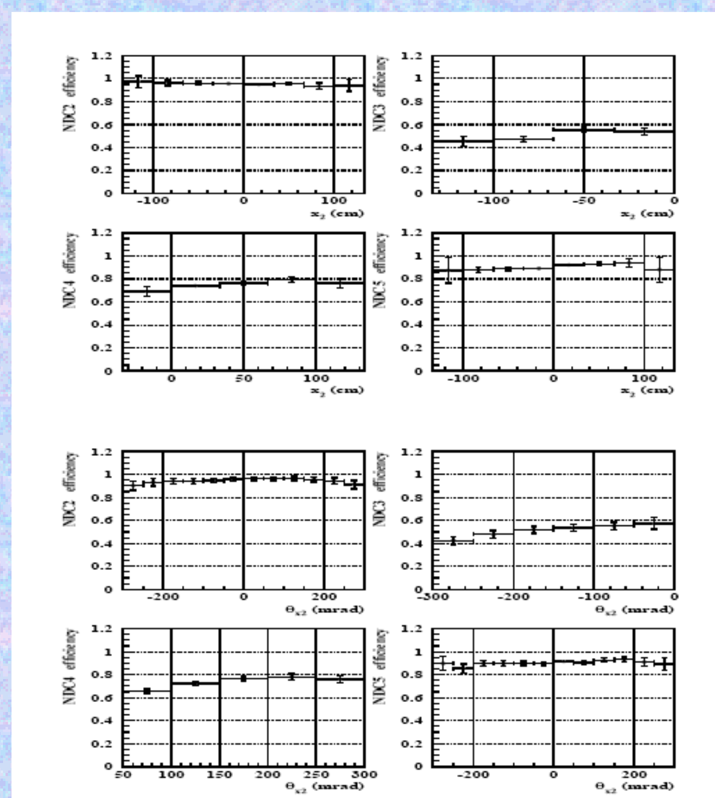
Downstream tracking efficiency

up-down matching efficiency

Module acceptance and efficiency

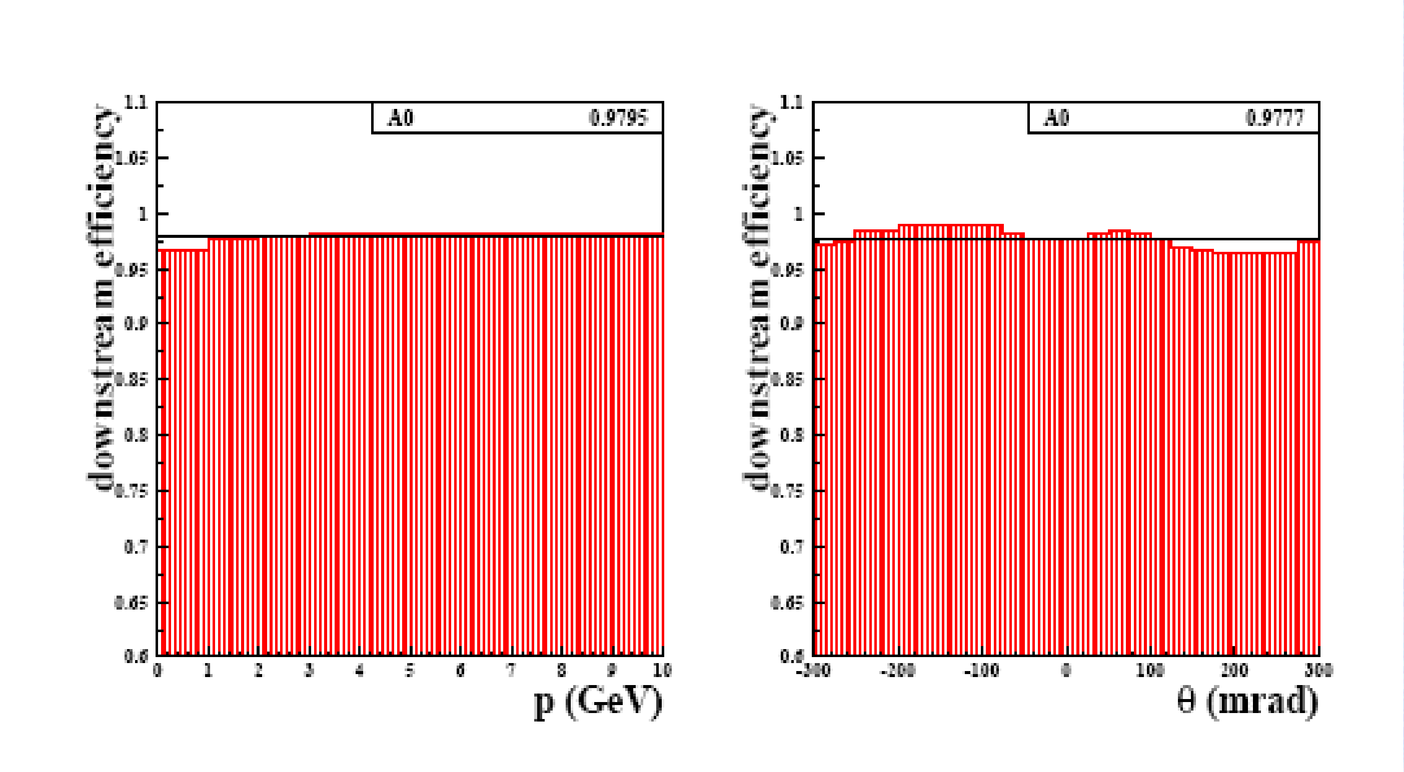


Acceptance of modules 3,4 & 5 normalized to acceptance in module 2 as a function of p and θ_x (MC)



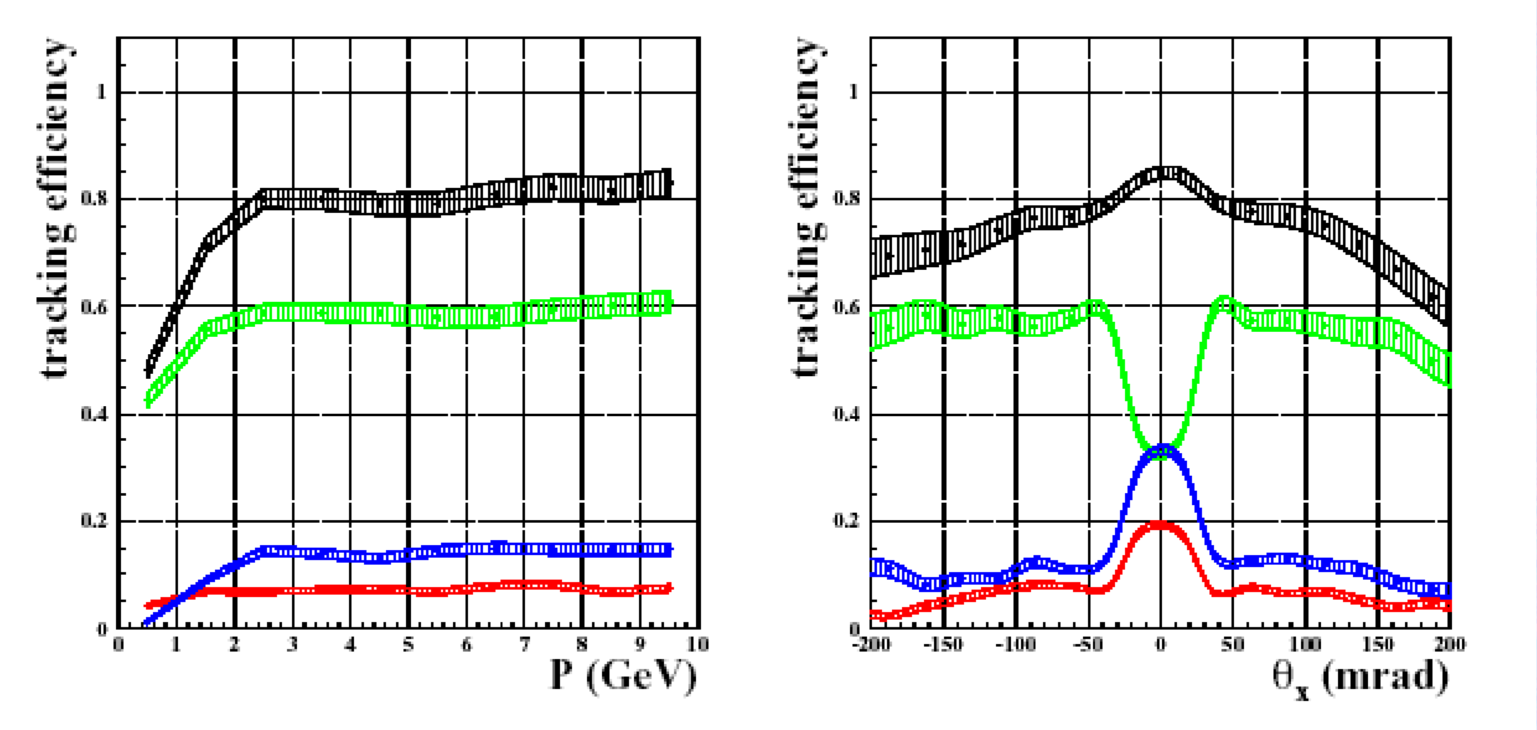
Tracking efficiency of modules downstream the dipole as a function of x_2 and θ_{x2} (DATA)

Downstream tracking efficiency



E_{down} ~ cte(p,θ) = 98 %

Total tracking efficiency



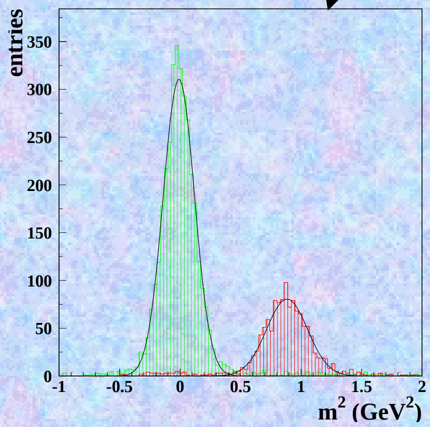
Total tracking efficiency as a function of p(left) and θ_x (right) computed using MC properly scaled by data

PID probabilities

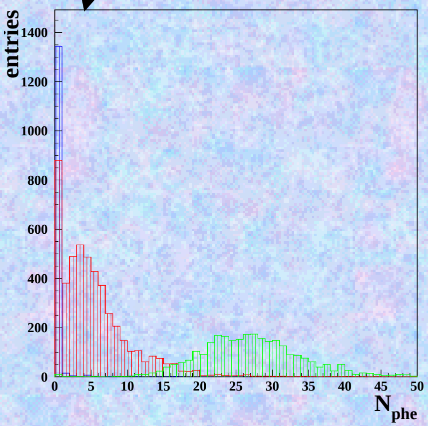
$$P(p, \lambda \mid \pi) \qquad P(p, \overline{N}_{phe} \mid \pi) \qquad P(p, E_1, E_2 \mid \pi)$$

tof ***cherenkov*** ***ecal***

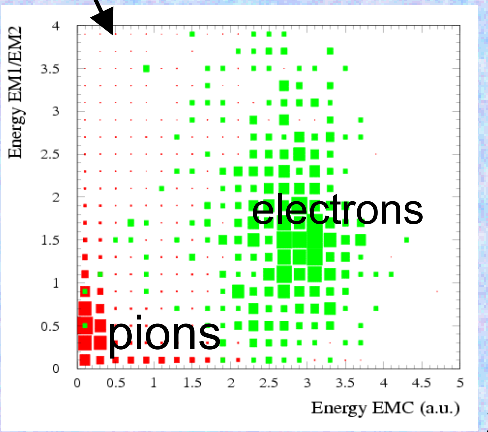
λ=m²/p²



Nphe



E_1 vs E_2

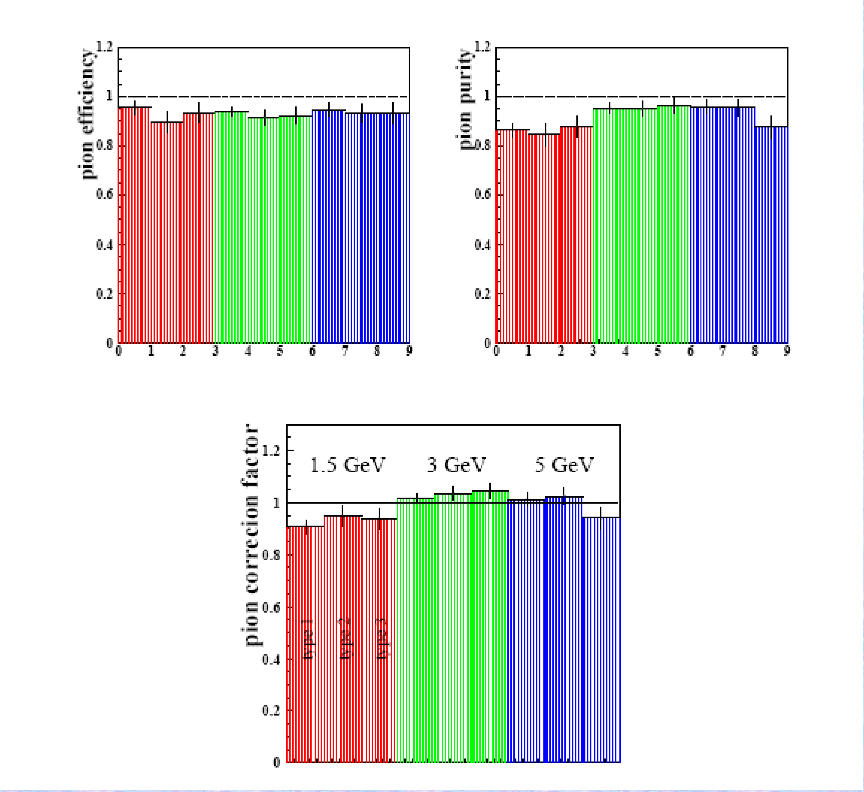


Pion correction factor

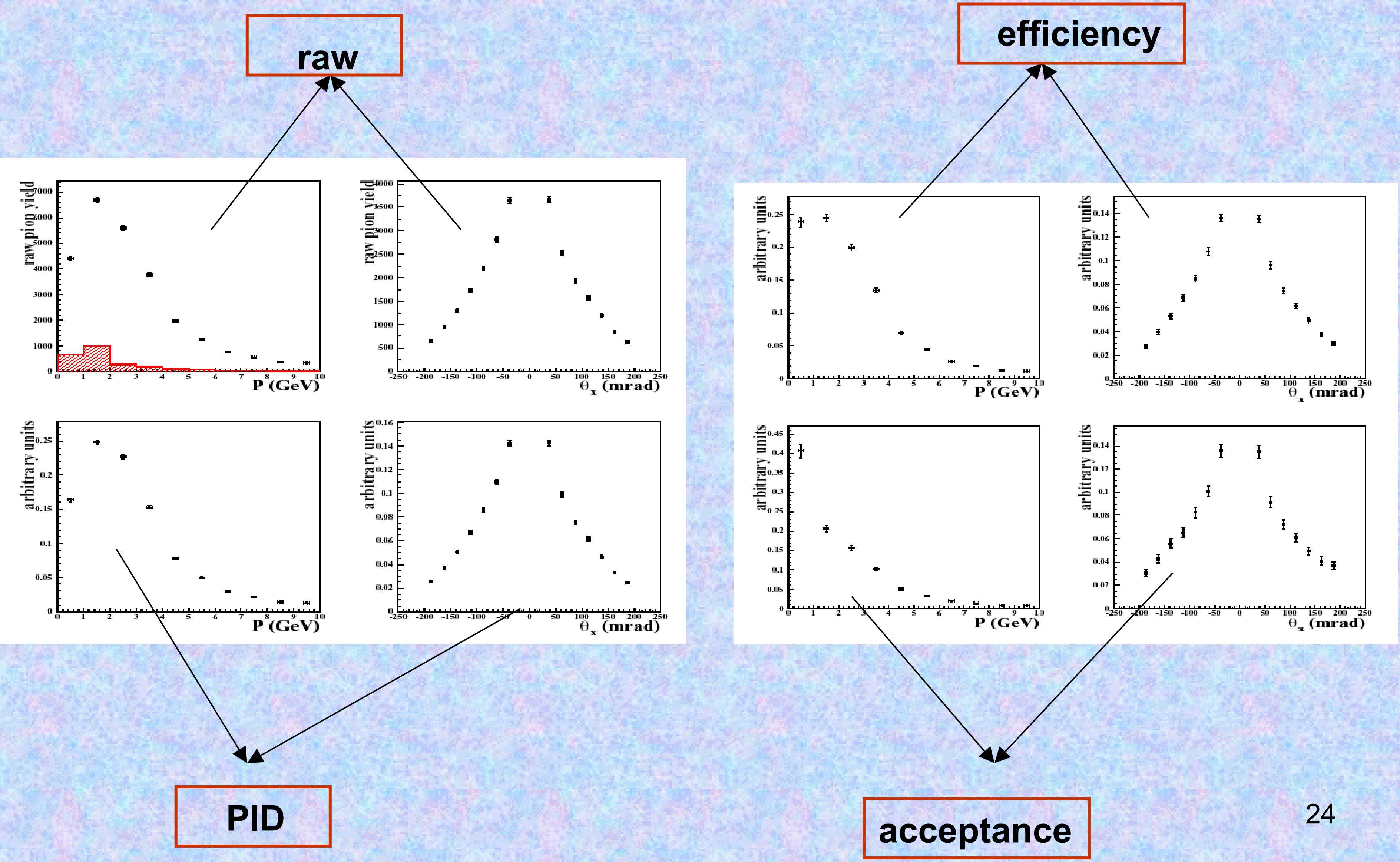
- The yield of each track type must be corrected by pion efficiency & purity
- Compute using beam particles (clean particle selection from beam detectors)

$$\varepsilon_i^{\pi-(t)} = \frac{N_i^{\pi-true-obs}}{N_i^{\pi-true}} = \frac{tracked\ true\ pions\ identified\ as\ such}{tracked\ true\ pions}$$

$$\eta_i^{\pi-(t)} = \frac{N_i^{\pi-true-obs}}{N_i^{\pi-obs}} = \frac{tracked\ true\ pions\ identified\ as\ such}{tracked\ particles\ identified\ as\ pions}$$



K2K target – Pion yield



Summary and Outlook

- HARP first results using the K2K replica target are now available.
- Measurement needed to improve the calculation of the far/near ratio in K2K will come soon.
- A similar analysis is proceeding on the MiniBooNE replica target (see talk by L.Coney)
- Further measurements of interest to the neutrino physics community will be provided by HARP in the near future...