Status Report of the HARP experiment

- The HARP Experiment
  - Physics goals and motivations
  - Summary of the experimental programme
  - Detector overview and performance
- TPC
  - Calibration status
- The fist physics analysis: pion yields for K2K target
  - Goals
  - Results

Jaap Panman, CERN
On behalf of the HARP Collaboration

Physics goals

Precise (~2-3% error) measurement of

$$d^2\sigma/dp_T dp_L$$

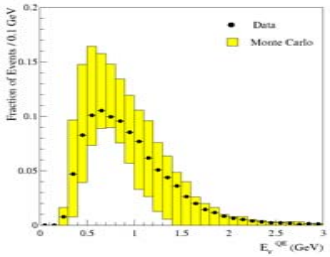
for secondary HAdRon Production by incident p and $\pi^{\pm}$ with

- Beam momentum from 1.5 to 15 GeV/c
- Large range of target materials, from Hydrogen to Lead

►Acceptance over large solid angle

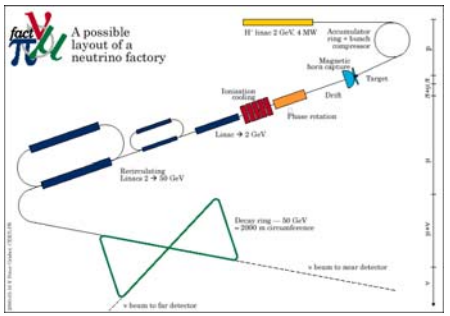
►Final state particle identification

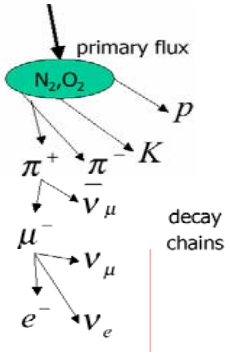
Physics motivations



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

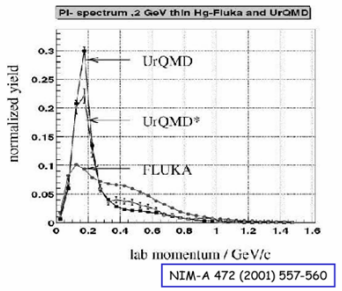
Pion/Kaon yield for the design of the proton driver and target system of **Neutrino Factories** and SPL- based Super-Beams





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

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



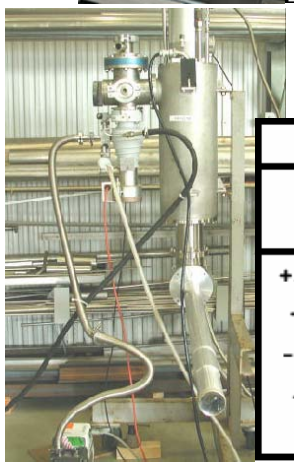
Data taking summary

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



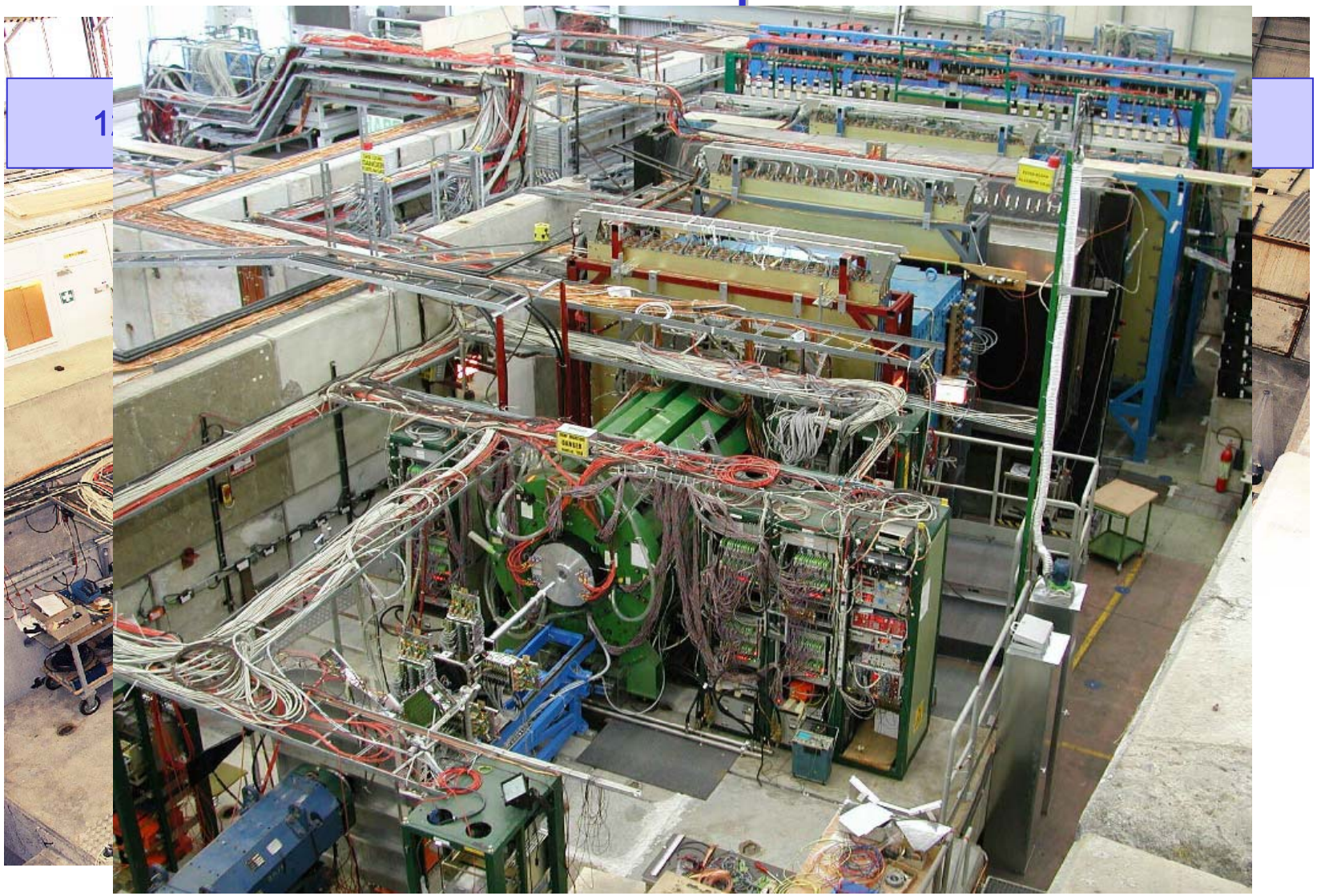
CRYOGENIC:

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

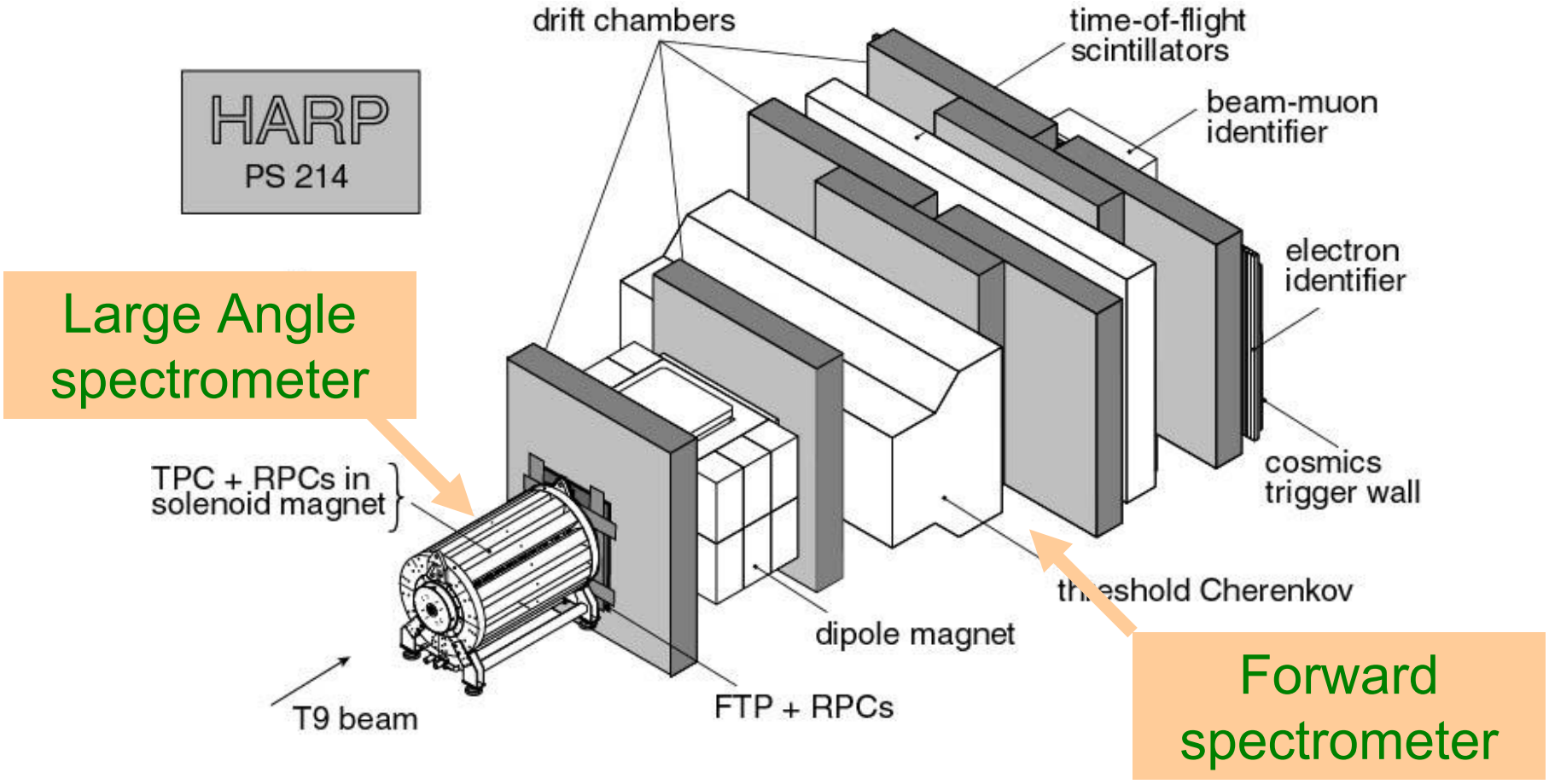
ν EXP:

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

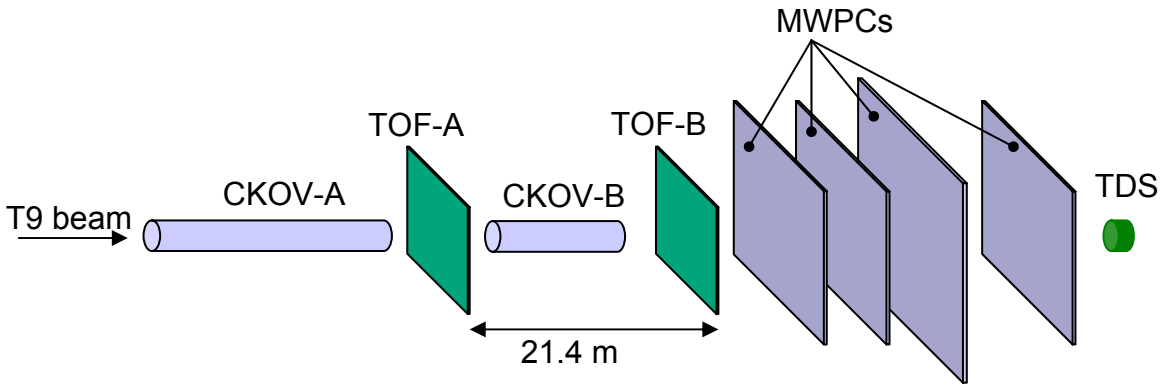
The HARP experiment



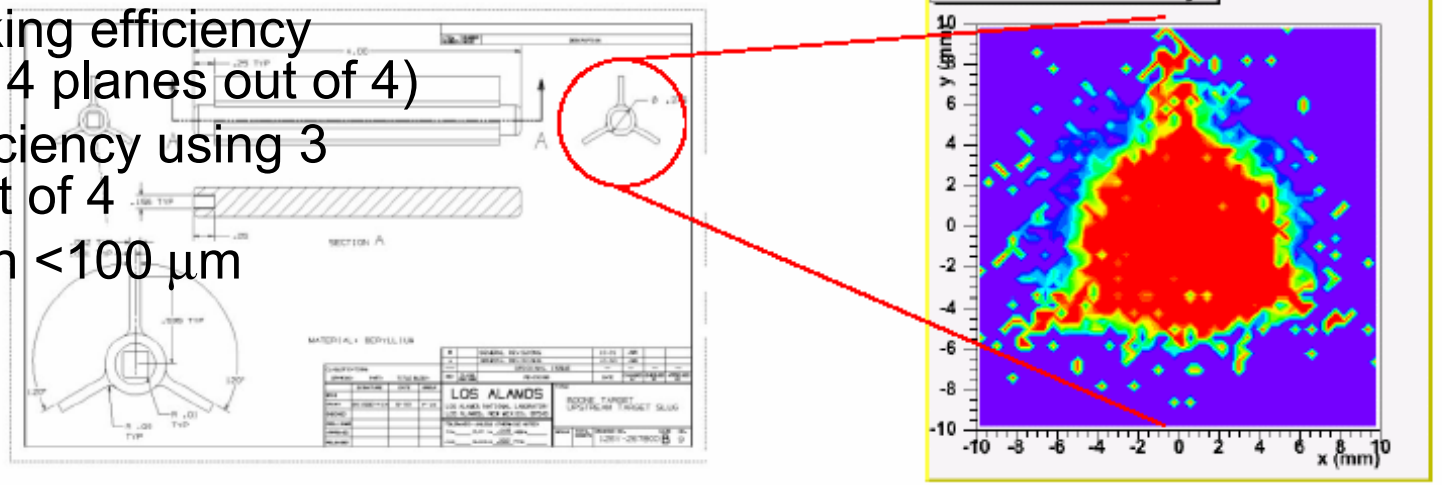
Detector layout



Beam detectors

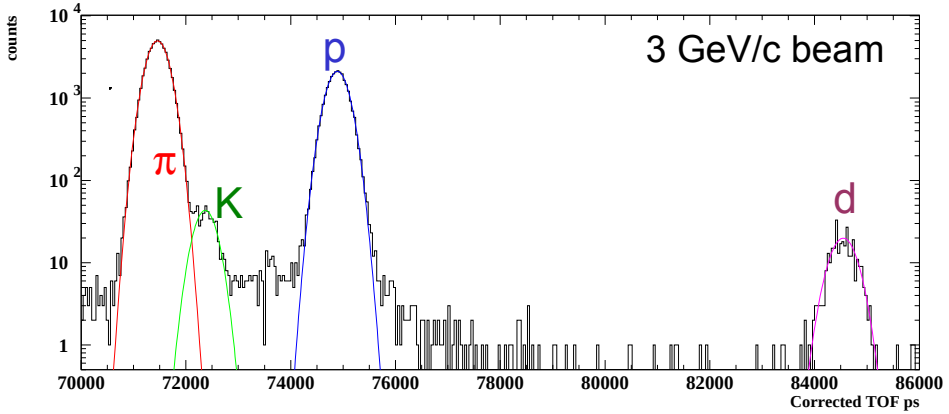


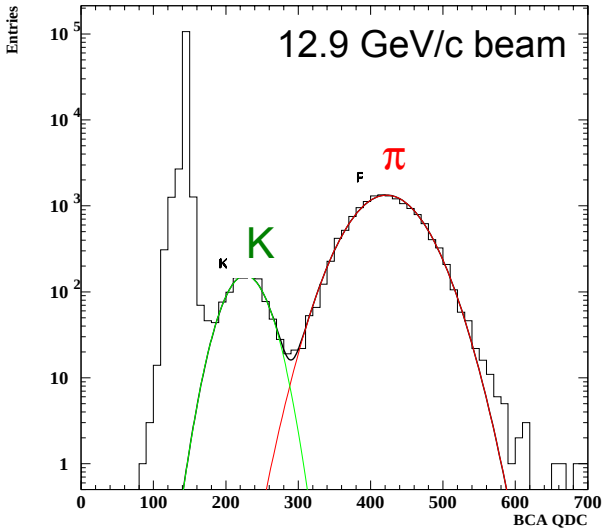
- Beam tracking with MWPCs :
  - 96% tracking efficiency (requiring 4 planes out of 4)
  - >99% efficiency using 3 planes out of 4
  - Resolution <100 μm



MiniBooNE target

Beam particle selection





- Beam TOF:
  - separate π/K/p at low energy over 21m flight distance
  - time resolution 170 ps after TDC and ADC equalization
  - proton selection purity >98.7%
  - Combined time resolution for time definition: 70 ps

- Beam Cherenkov (two counters):
  - Identify electrons at low energy, π at high energy, K above 12 GeV
  - ~100% eff. in e-π tagging

Large angle detectors

- TPC
  - Full track reconstruction available
  - Calibration campaign with TPC in T9 area in 2003
    - Calibration with sources
    - Calibration with cosmic rays
  - Systematic study of corrections
    - Basic calibrations revisited (time, charge, position)
    - Cross-talk correction
    - Distortion correction
  - Ready for physics analysis
- RPCs
  - Results later

Raw Data

Equalisation

Clustering

Distortion Correction

Track finding

Track fit

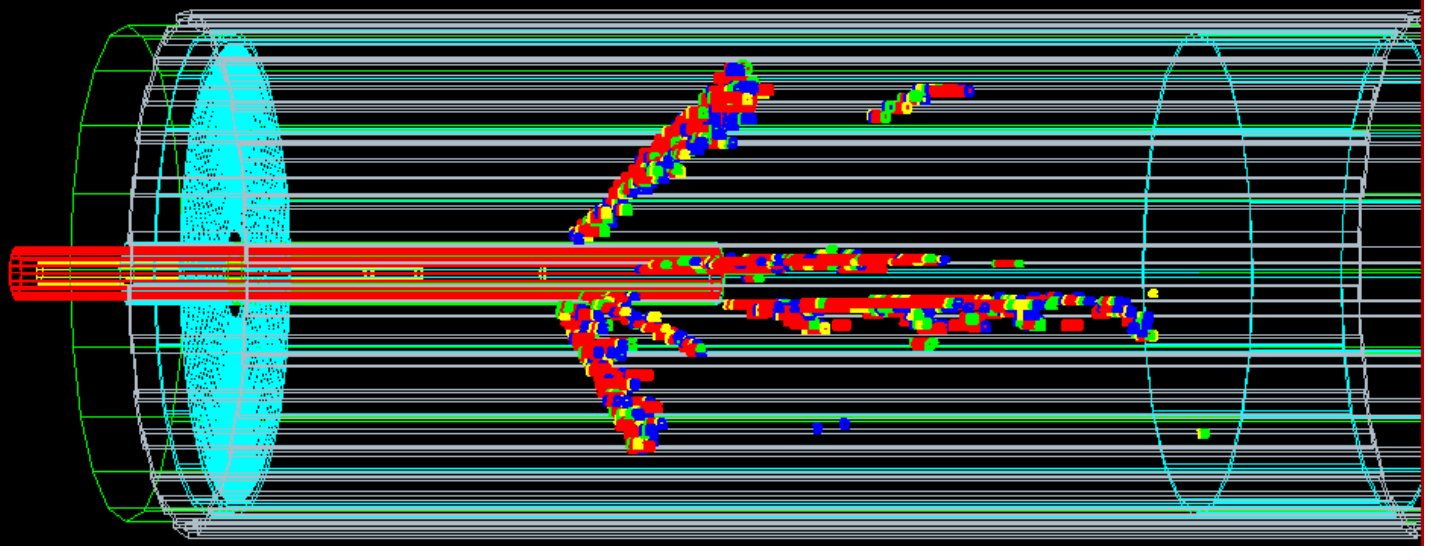
Kalman filter

Momentum

dE/dx Algorithm

Run 9200 Event 114

Track reconstruction



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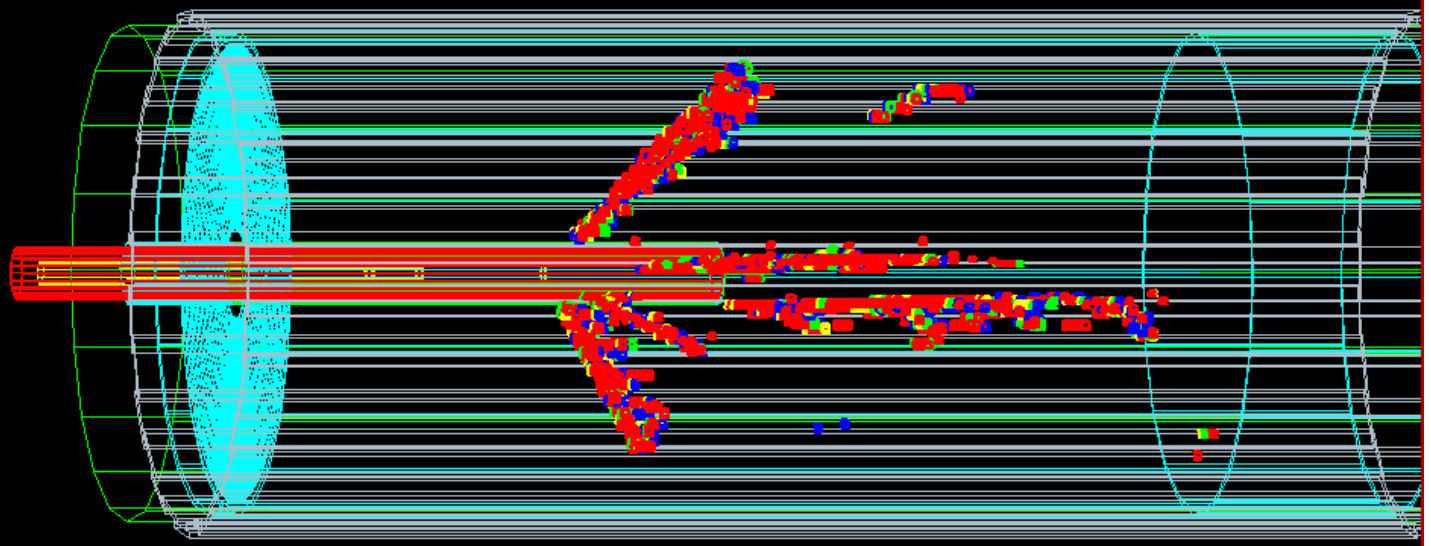

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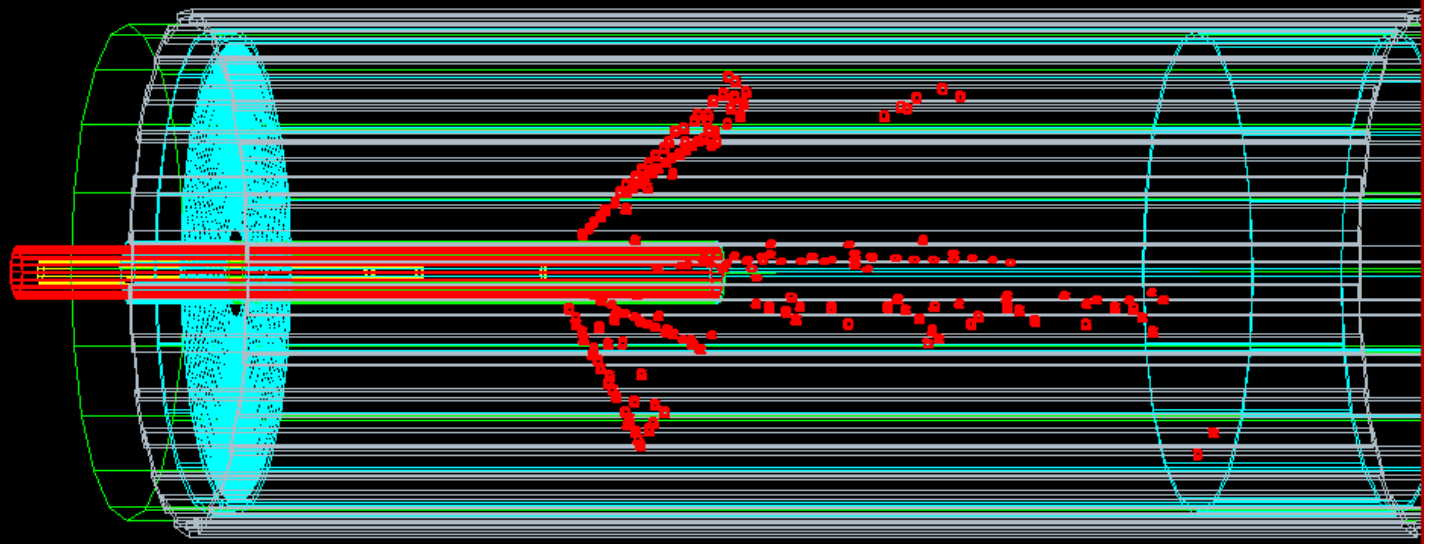

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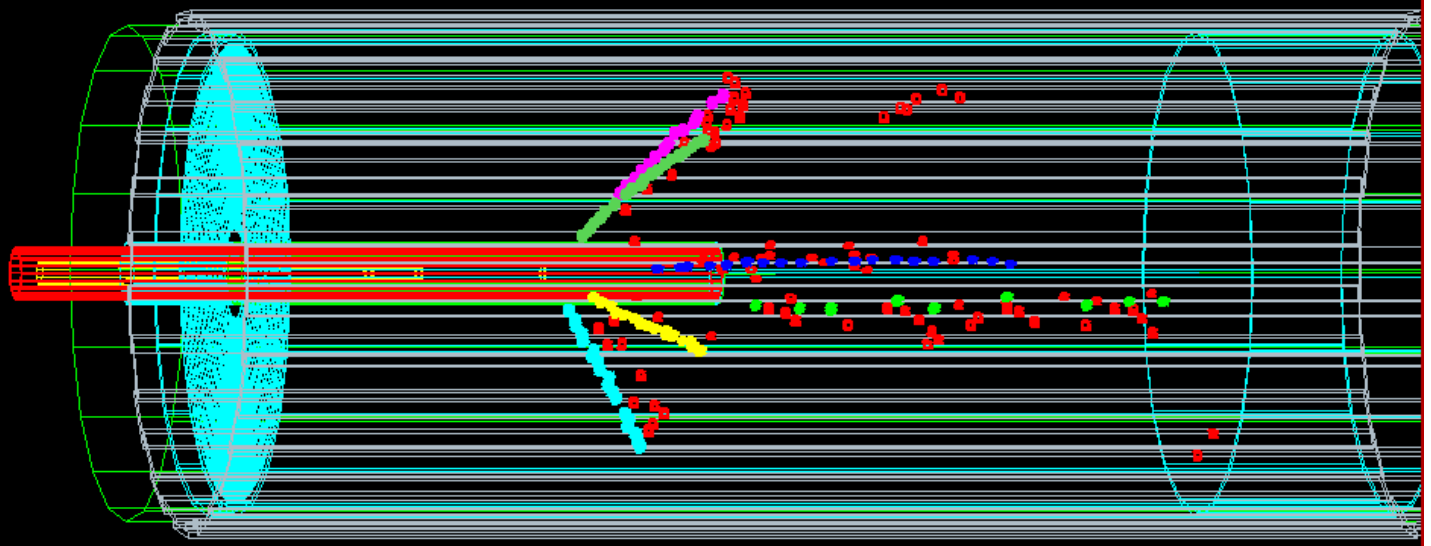

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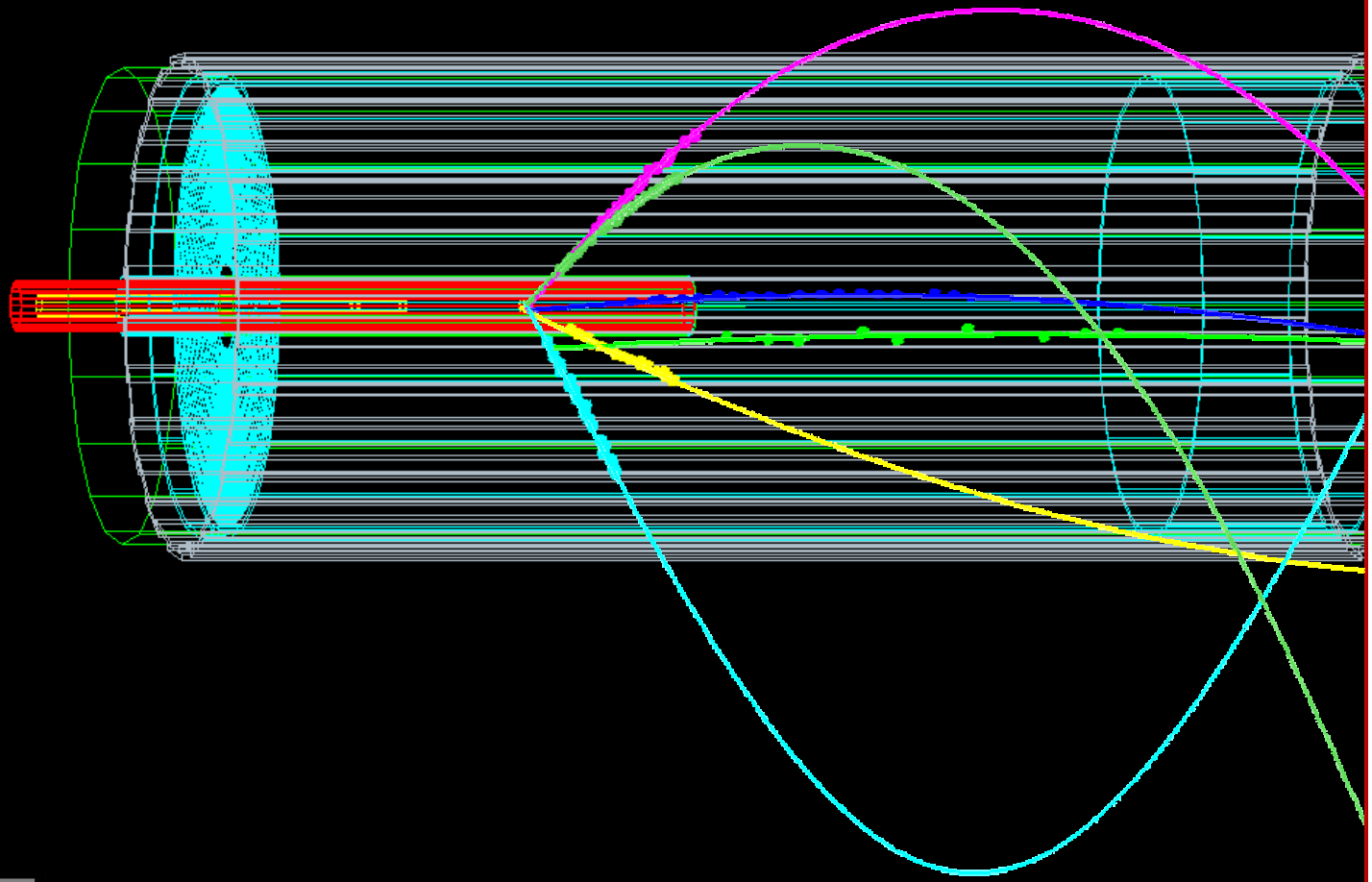

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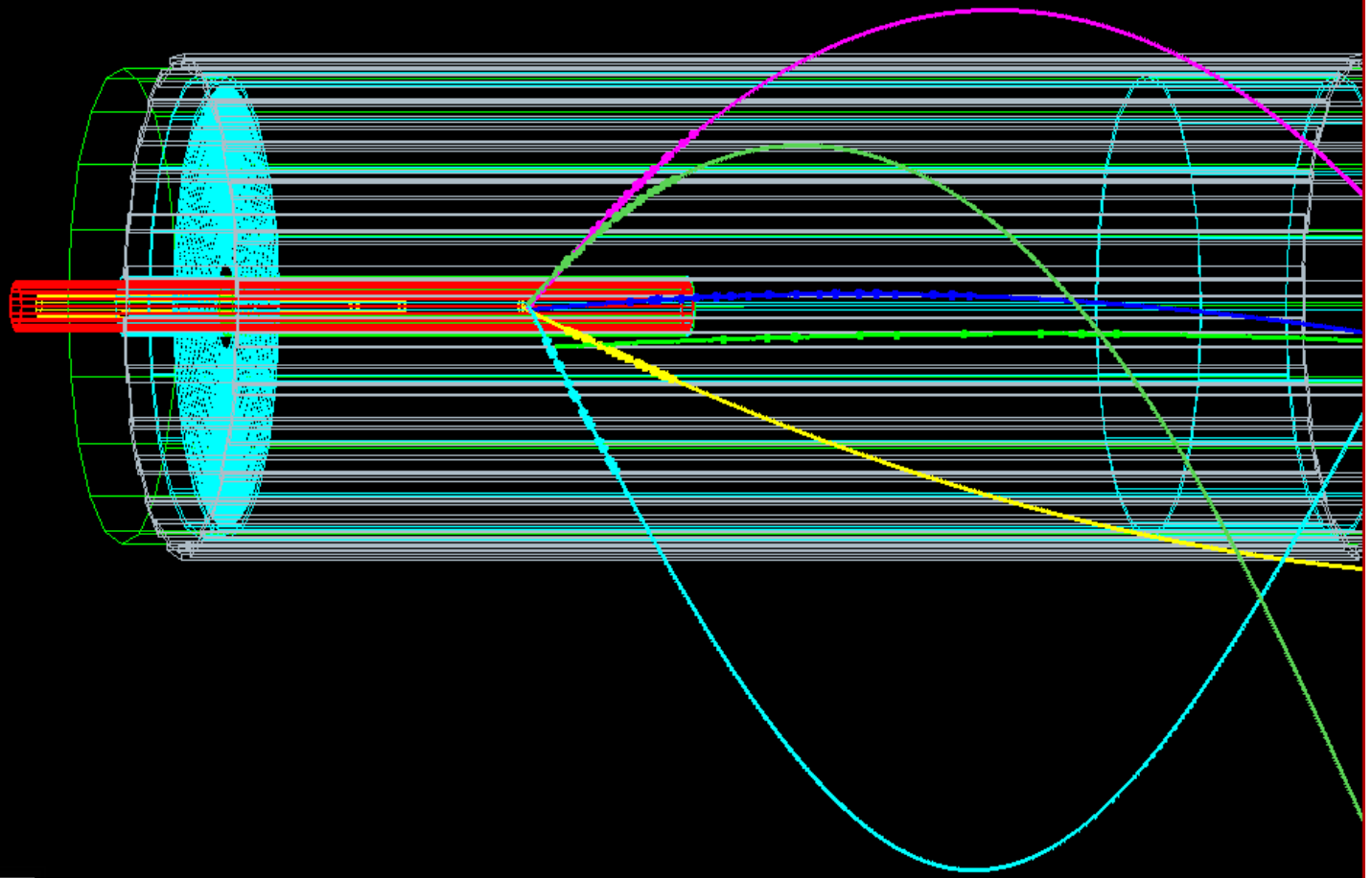
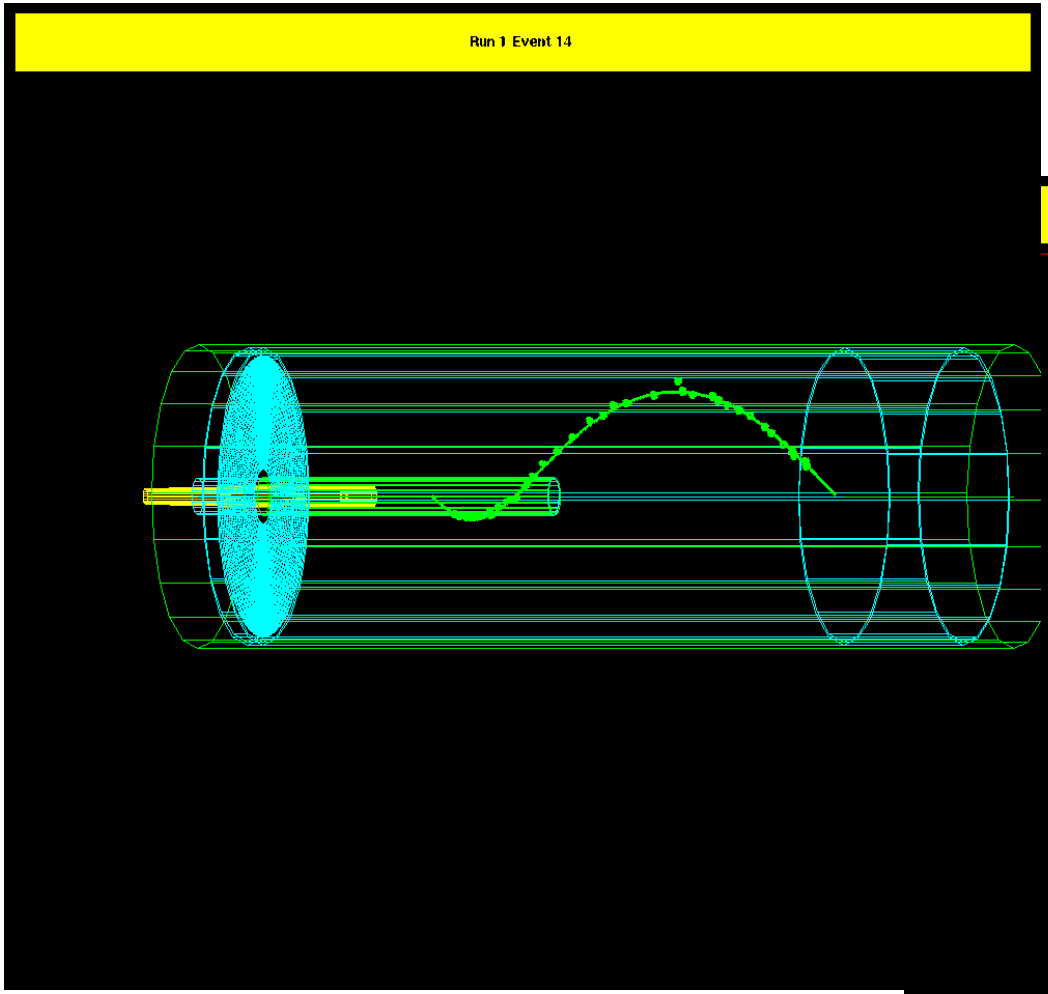
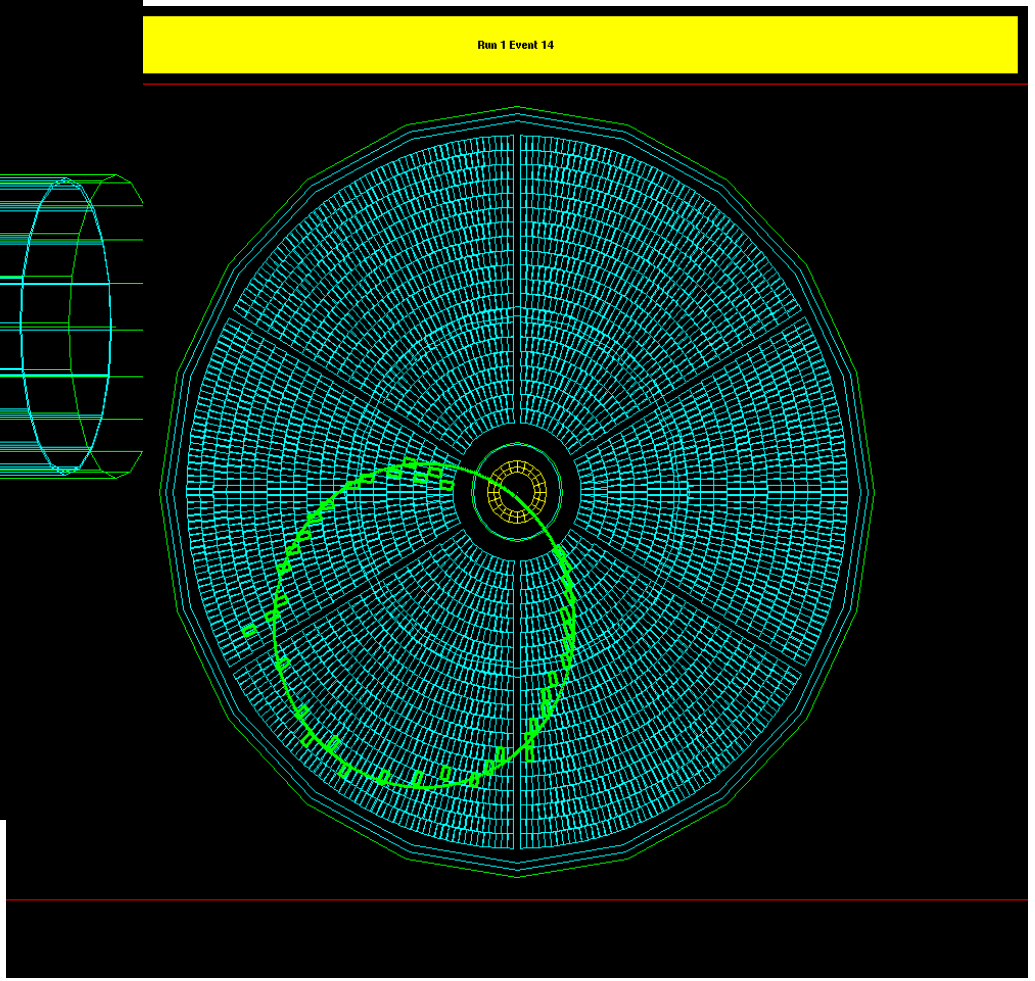


Looping track example

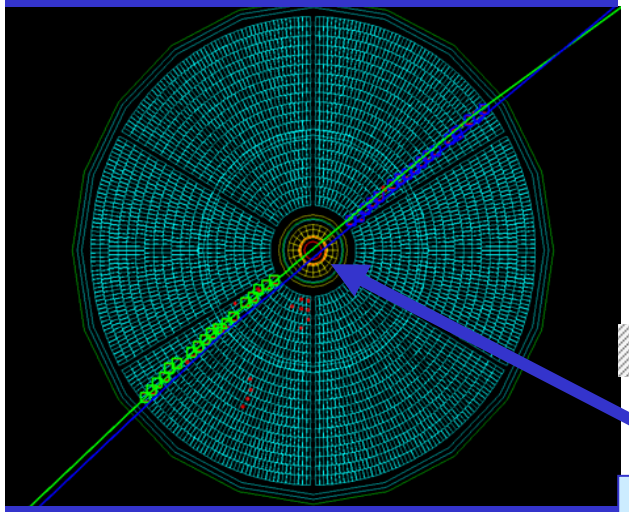


36 MeV track



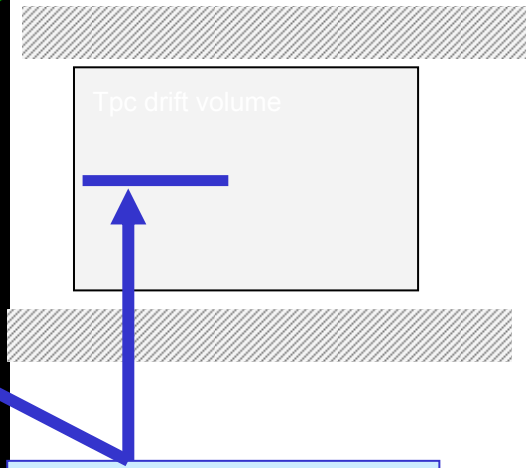
TPC calibration campaign

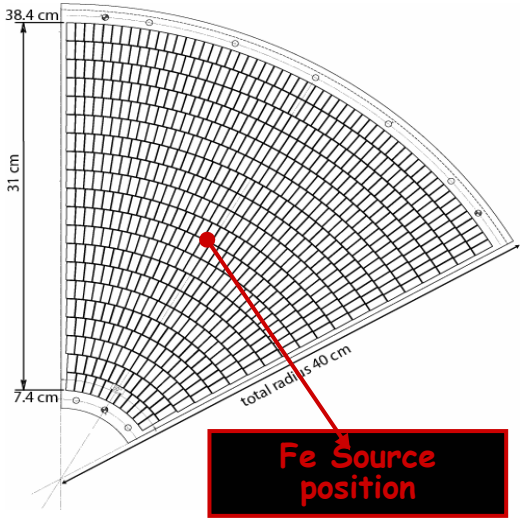
TPC re-installed in T9 Area



Cosmic data taking during 2003:
Trigger (scintillator of 2 cm thickness) inside inner field cage:
-345 mm < z < 255 mm

High statistic cosmic ray calibration and calibration with ^{55}Fe and ^{83}Kr sources





Mapping of gain

Mapping of dead pads

First dE/dx evaluation

Evaluation of the performance of correction for cross-talk effect and distortions

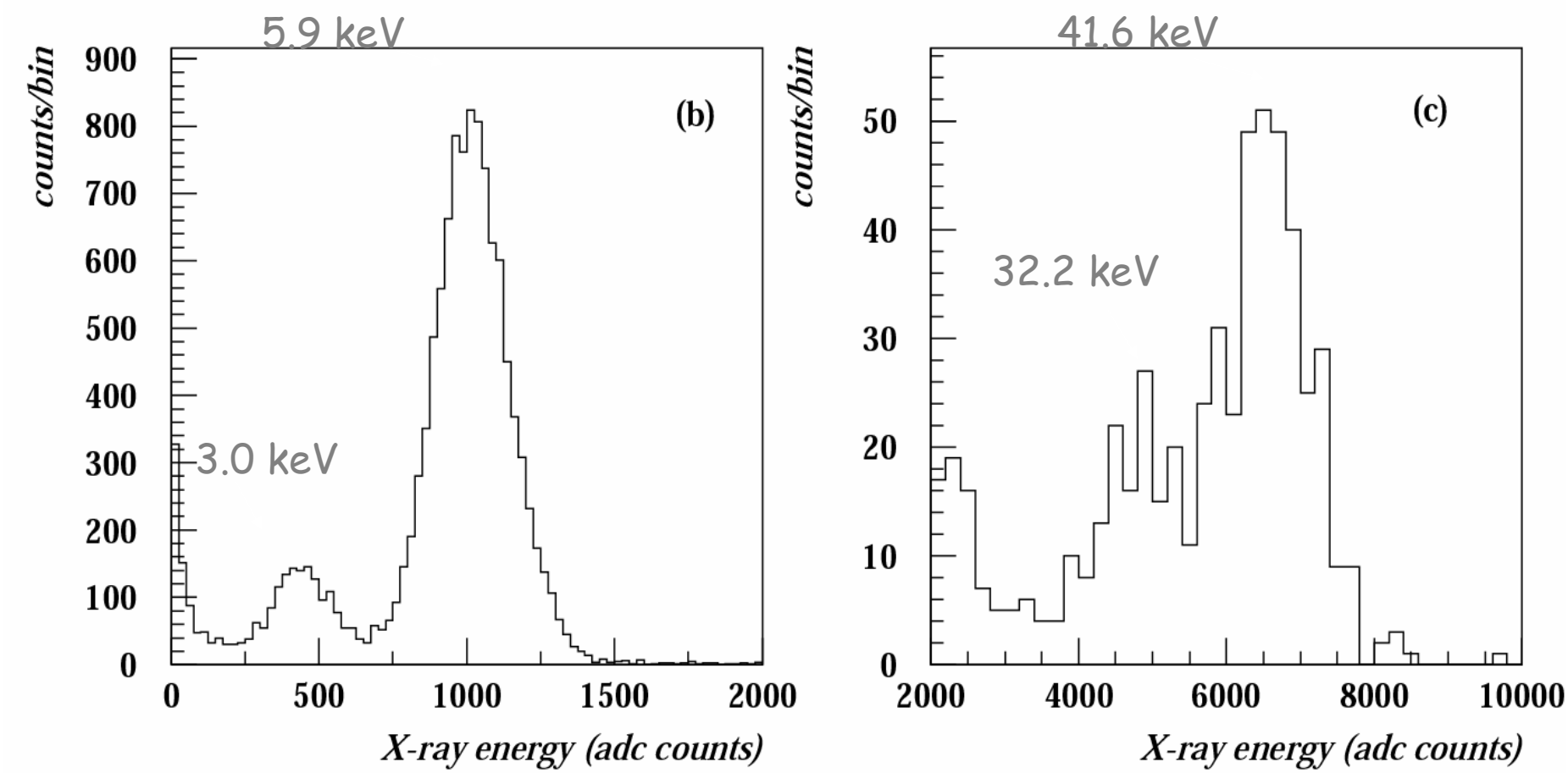
Charge calibration data with sources

^{55}Fe

E = 3.0 keV 5.9 keV

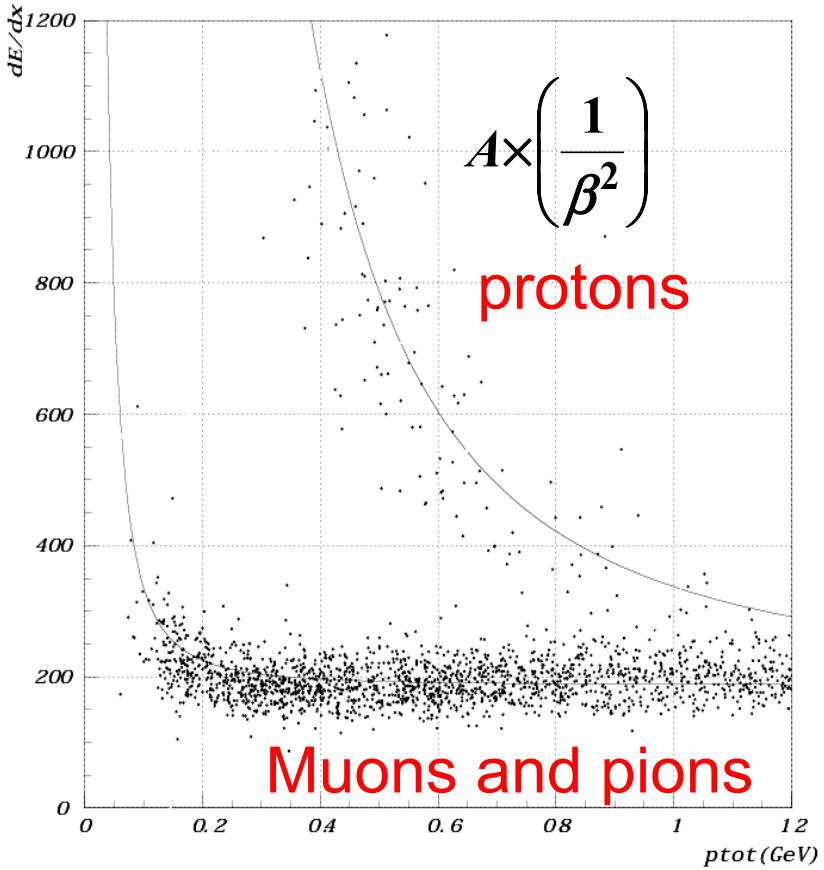
^{83}Kr

E = 32.2 kev 41.6 kev



Momentum and dE/dx response

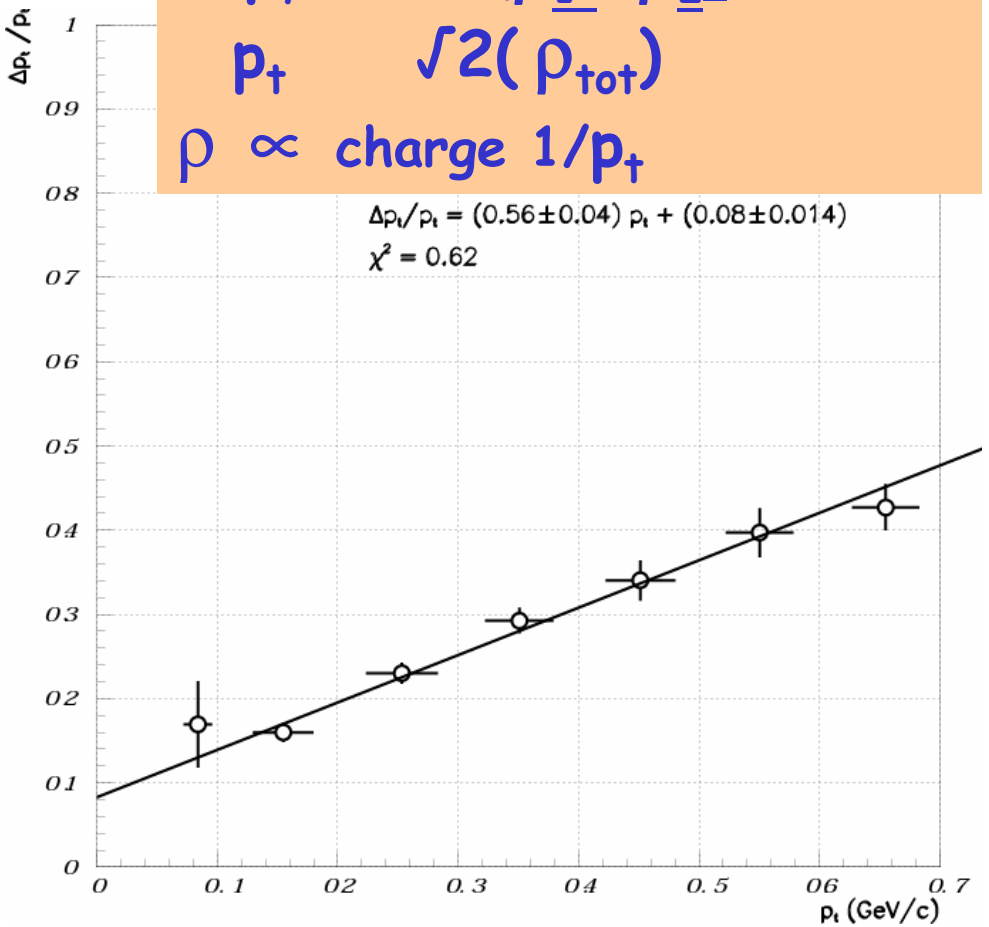
dE/dx over full track



Compare single arm with full track

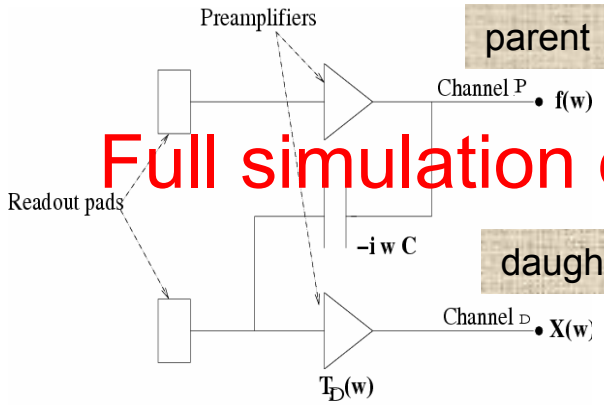
$$\frac{\Delta p_t}{p_t} = \frac{\text{abs}(\rho_1 + \rho_2)}{\sqrt{2}(\rho_{tot})}$$

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



TPC-Cross talk

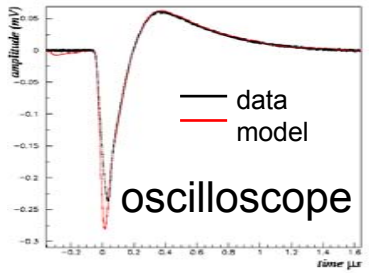
cross-talk model: previous report
Simulation: implemented 3Q 2003
Correction: implemented 4Q 2003

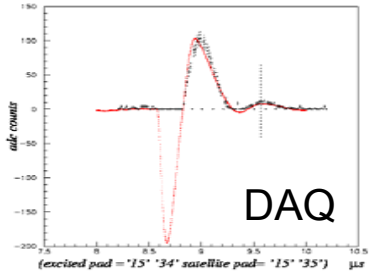


Full simulation exists

cross-talk model

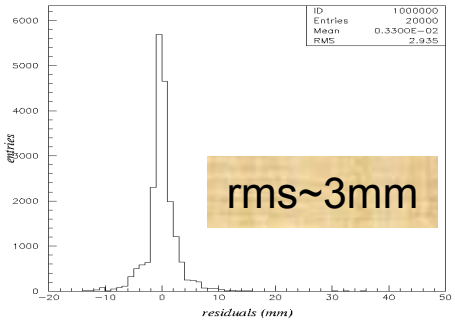
capacitive couplings
+
preamplifier transfer functions





Introduced in MC

residuals

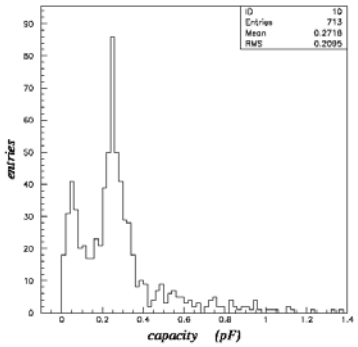


cross-talk measurements

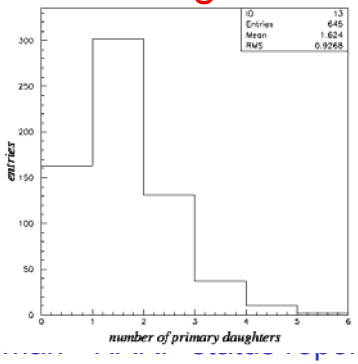
Individual pulse injection in all pads

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

capacitive couplings



daughters

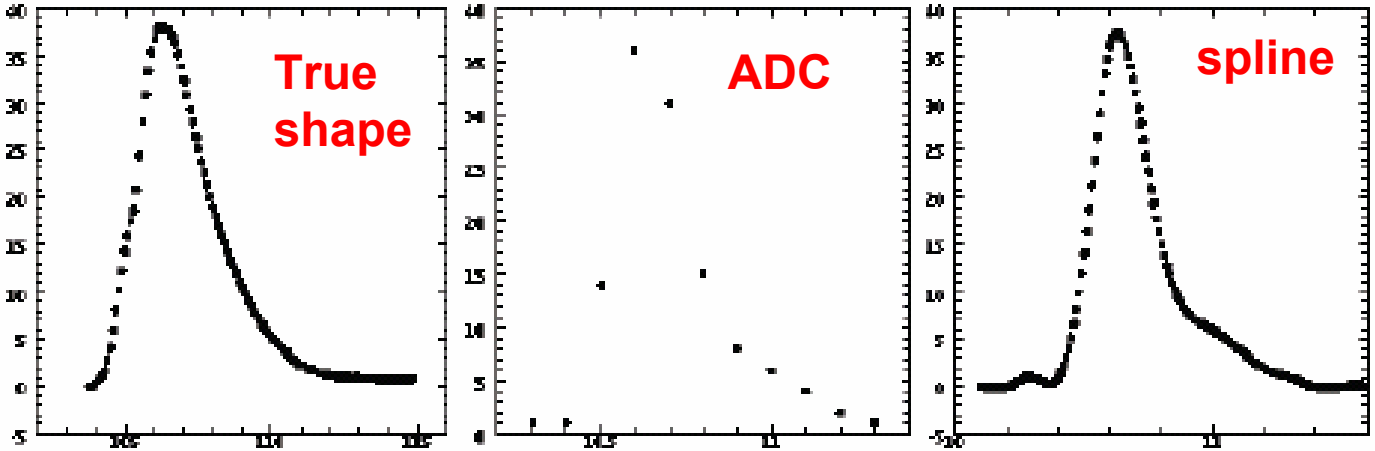


Cross-talk correction

First use pads with no mother pad with signal
Calculate cross-talk signals due to these pads
Subtract these from daughter pad signals
Now the daughter pad signals are known
Repeat until all signals corrected

Most important: use measured transfer functions for electronics

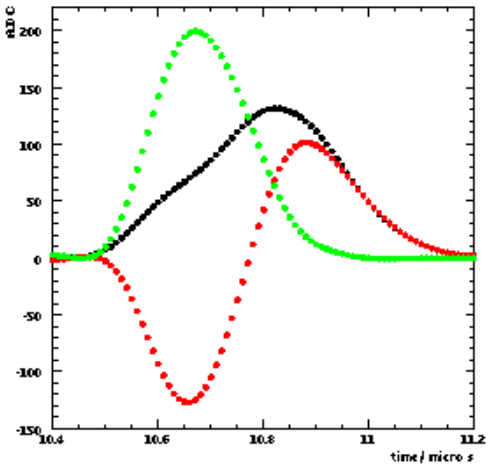
Need first to smoothen the measured pulse (spline fit):



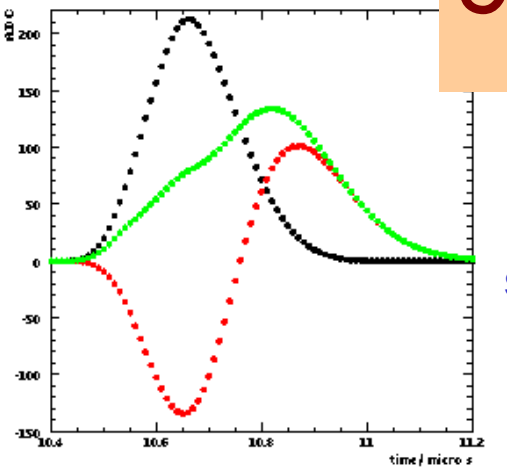
Cross-talk correction

LOSS OF INFORMATION:
Only record positive signals!

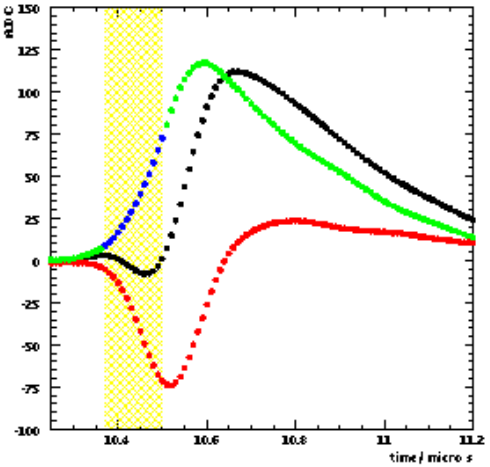
In

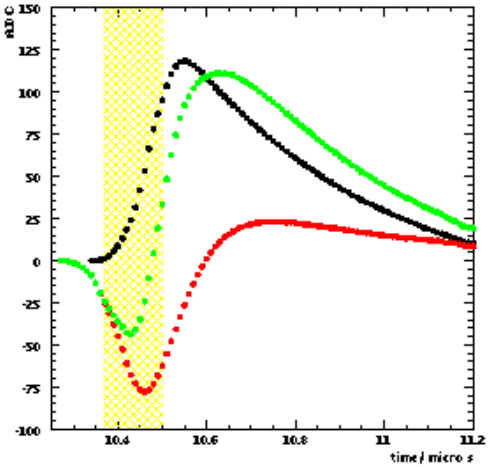


Out



No problem: negative swing smaller than signal



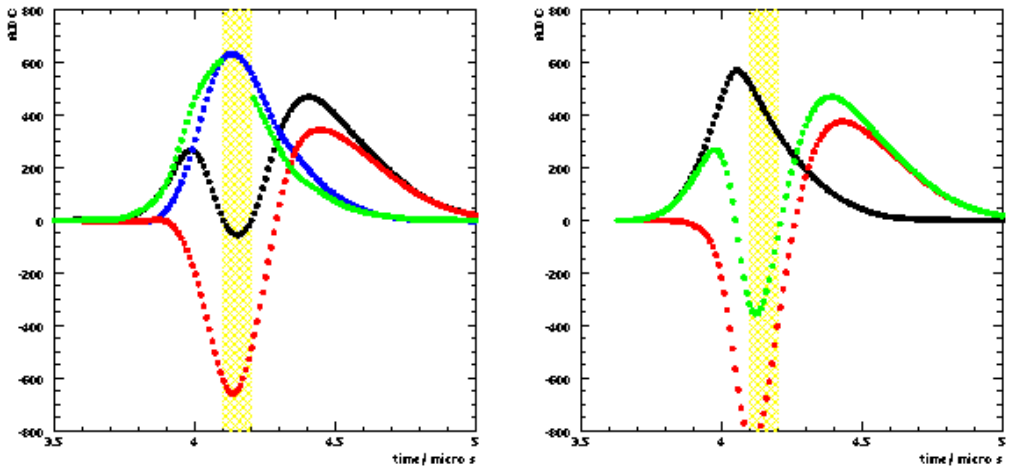


Small area with overall pulse-height negative: can be recovered with spline fit

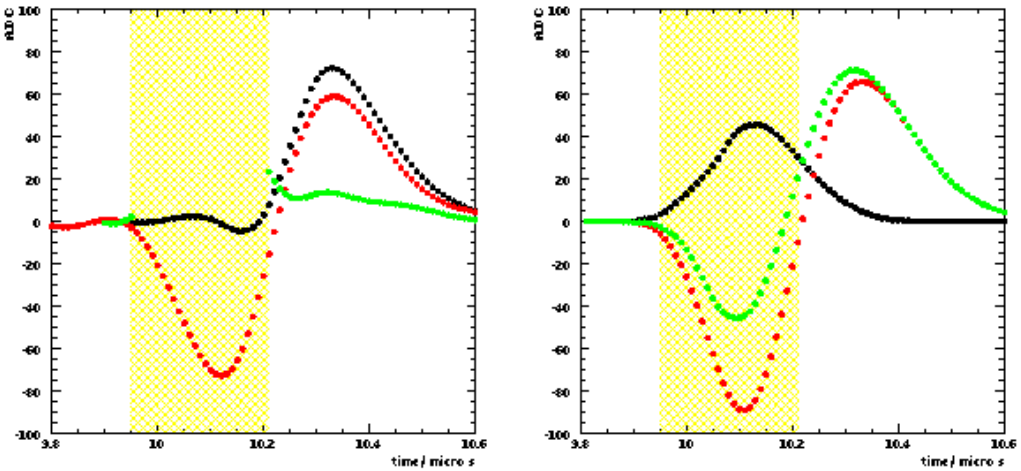
Cross-talk correction

Difficult cases

In **Out**



Large part negative: minimisation procedure recovers part of signal

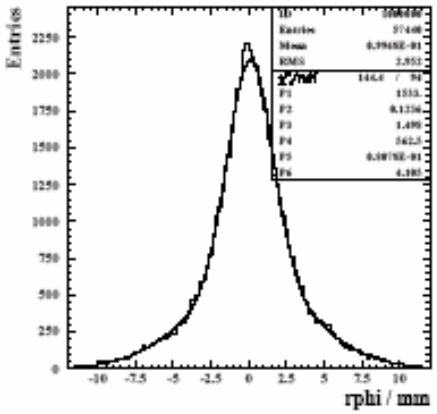


Most of signal lost: no recovery 10% of pads

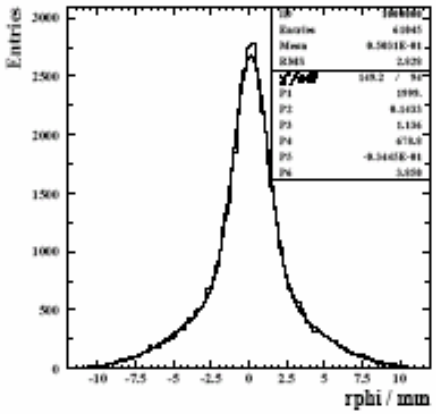
Improved position measurement

R-phi

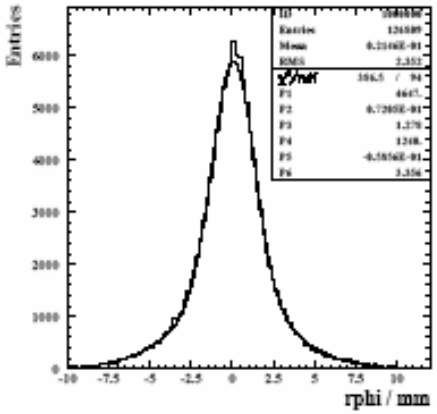
uncorrected



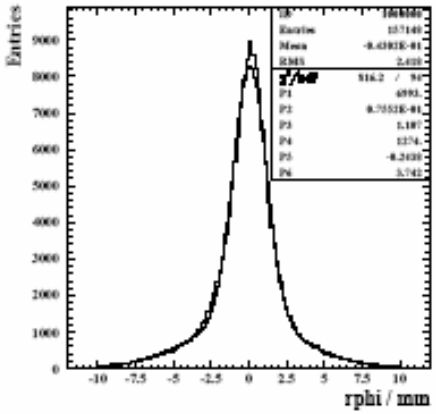
corrected



data

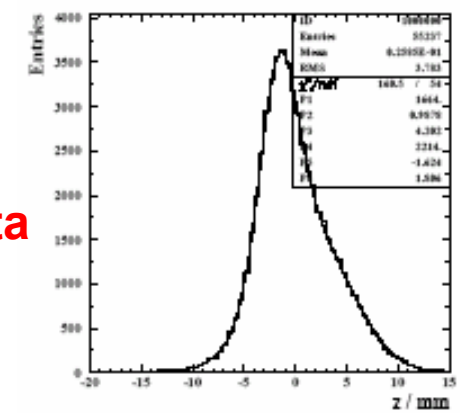


MC

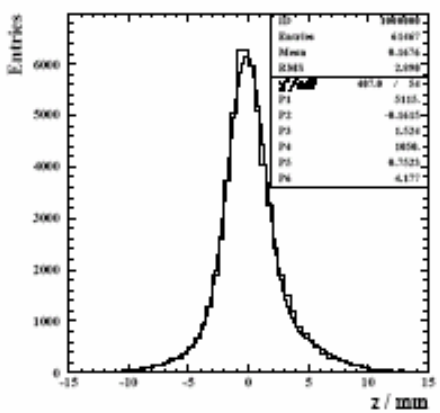


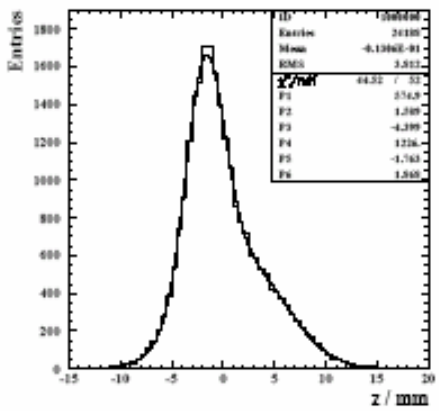
Z

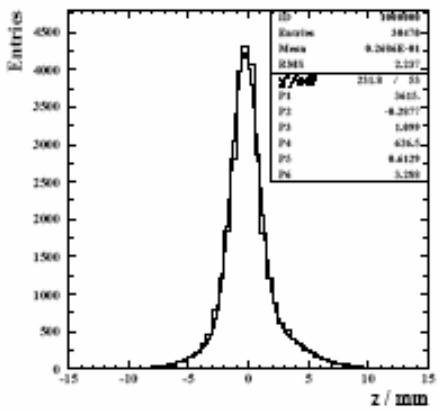
uncorrected



corrected



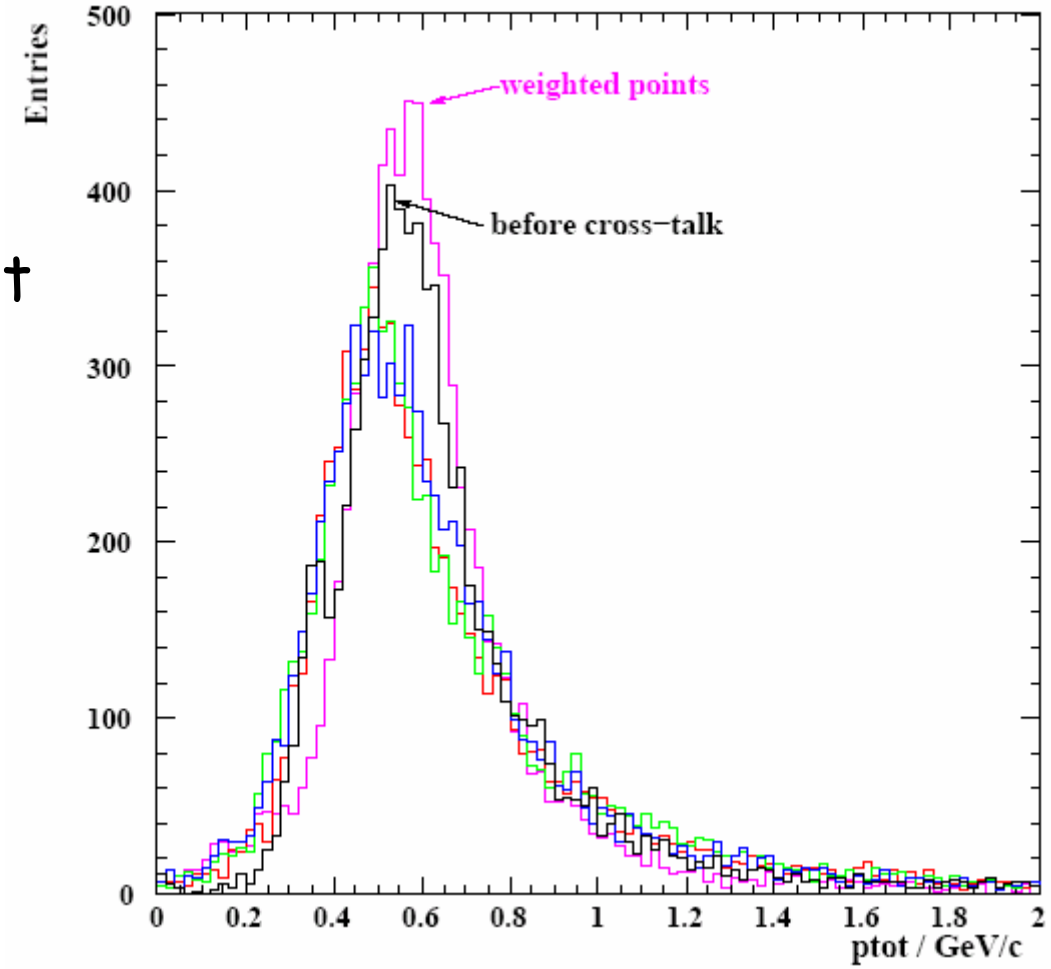




Momentum resolution (cross-talk correction)

(MC study)

Most important improvement when the knowledge how points are affected by cross-talk is used as weight in the fit



Elastic scattering

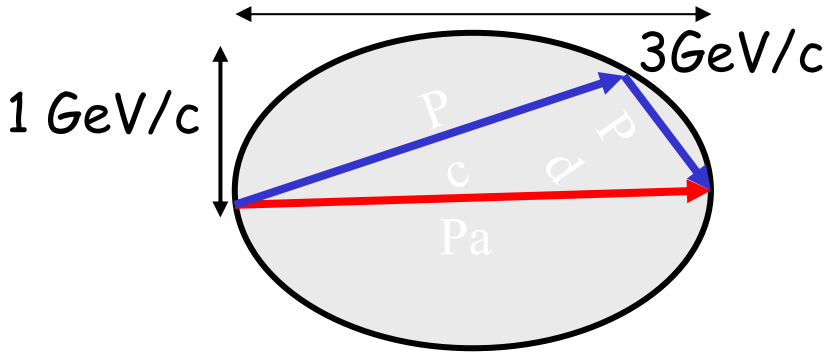
Measure elastic cross-section

- To normalise the data (elastic cross section is well known)
- To evaluate the acceptance + efficiency in TPC
- To check momentum scale
- Calibration tool for merging forward and large angle analysis

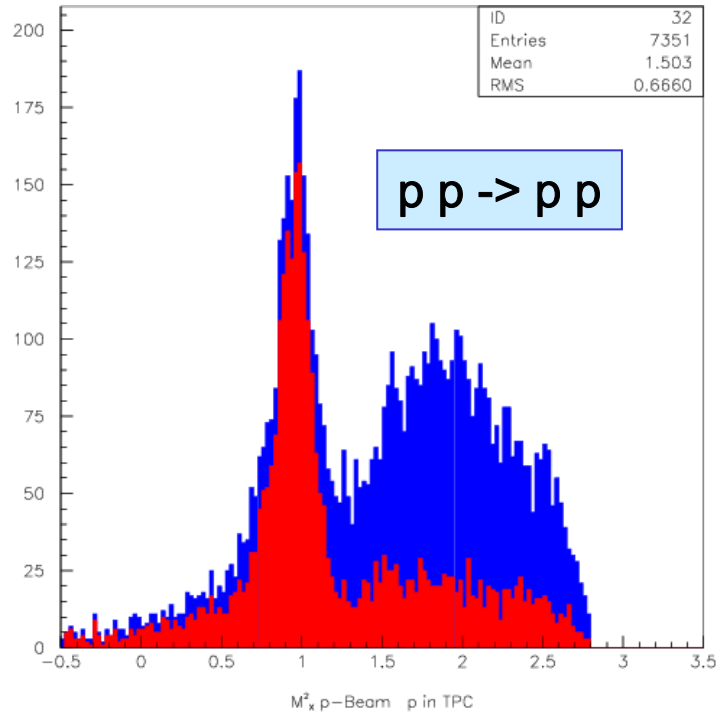
- Target: liquid H_2 (cryogenic target)
- Target length: 18 cm
- Beam of p and π of 3 GeV/c

Missing mass:

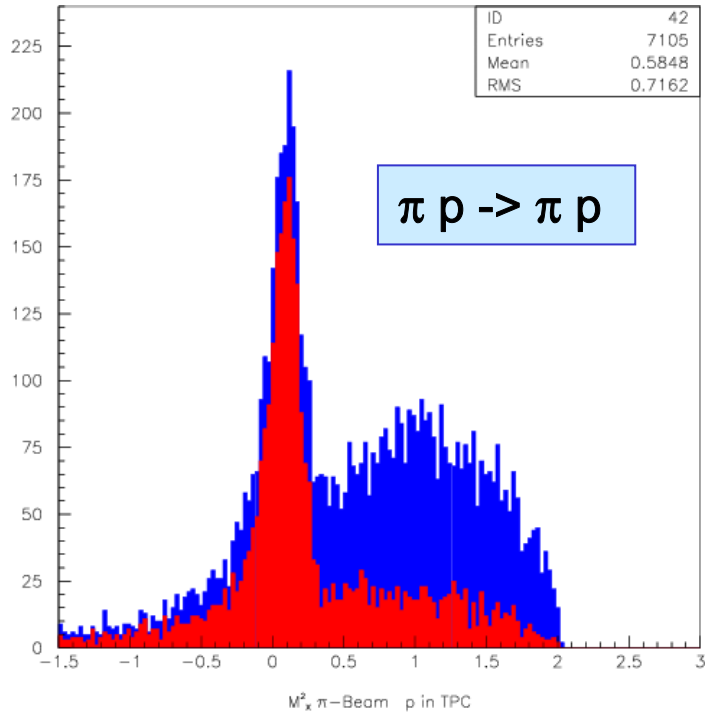
$$m_x^2 = (p_{beam} + p_{target} - p_{TPC})^2$$



Missing mass distributions



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 spectrometer

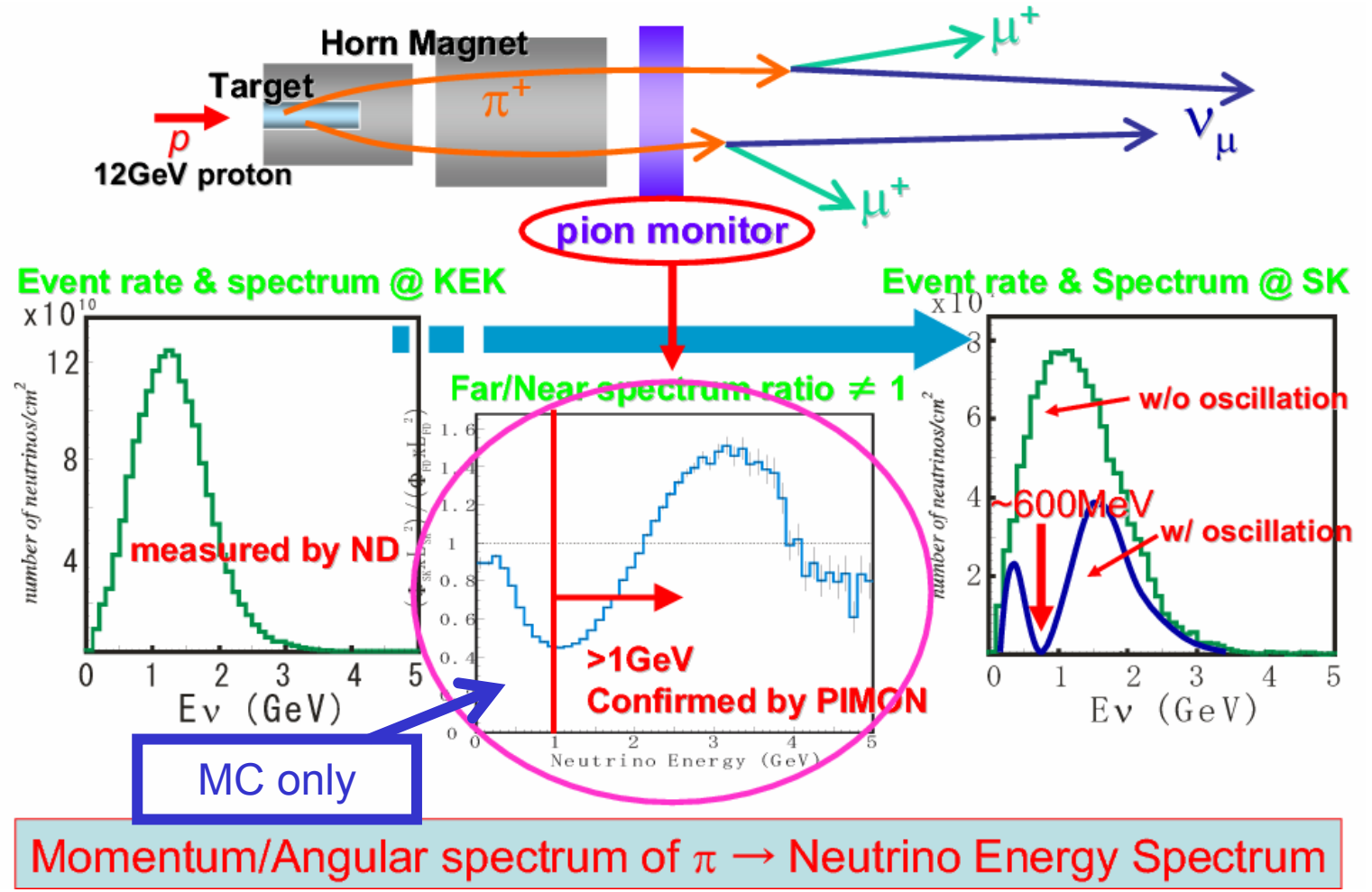
Analysis for pion yields in K2K

Analysis for K2K: motivations

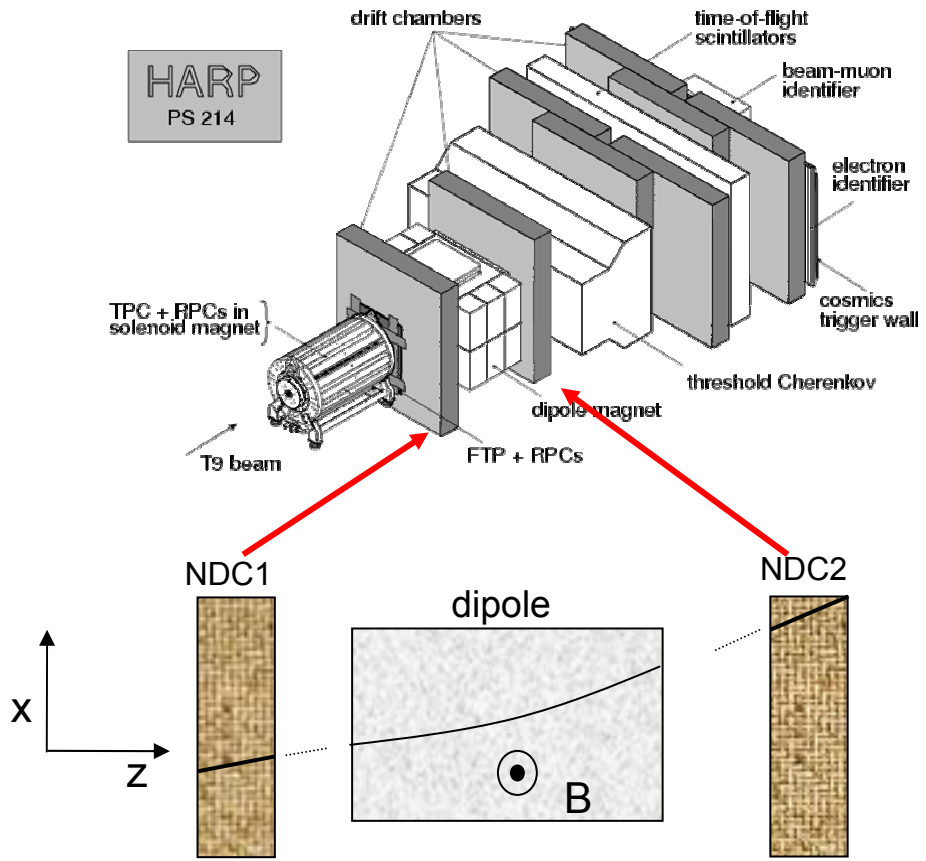
near/far ratio R

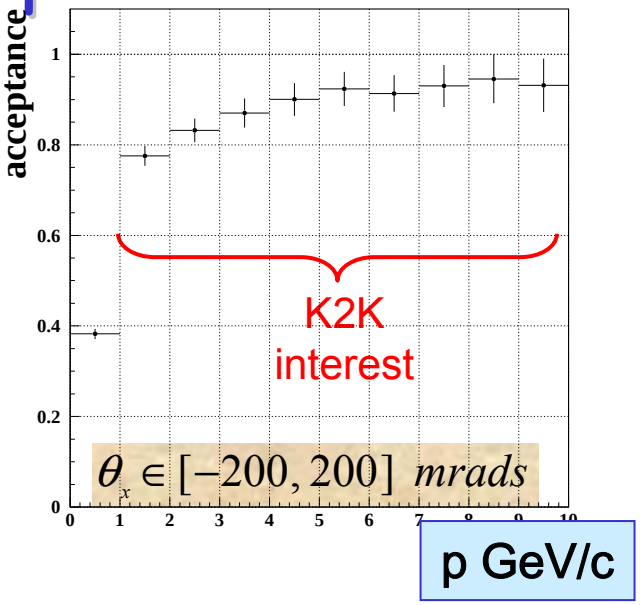
For point-like source (without oscillation), R~1/r^2

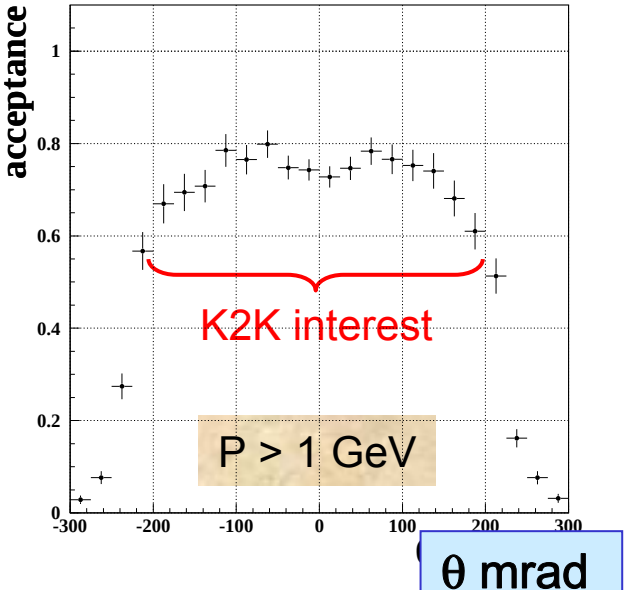
If the near detector does not see a point-like source -> R depends on E_ν



Forward acceptance

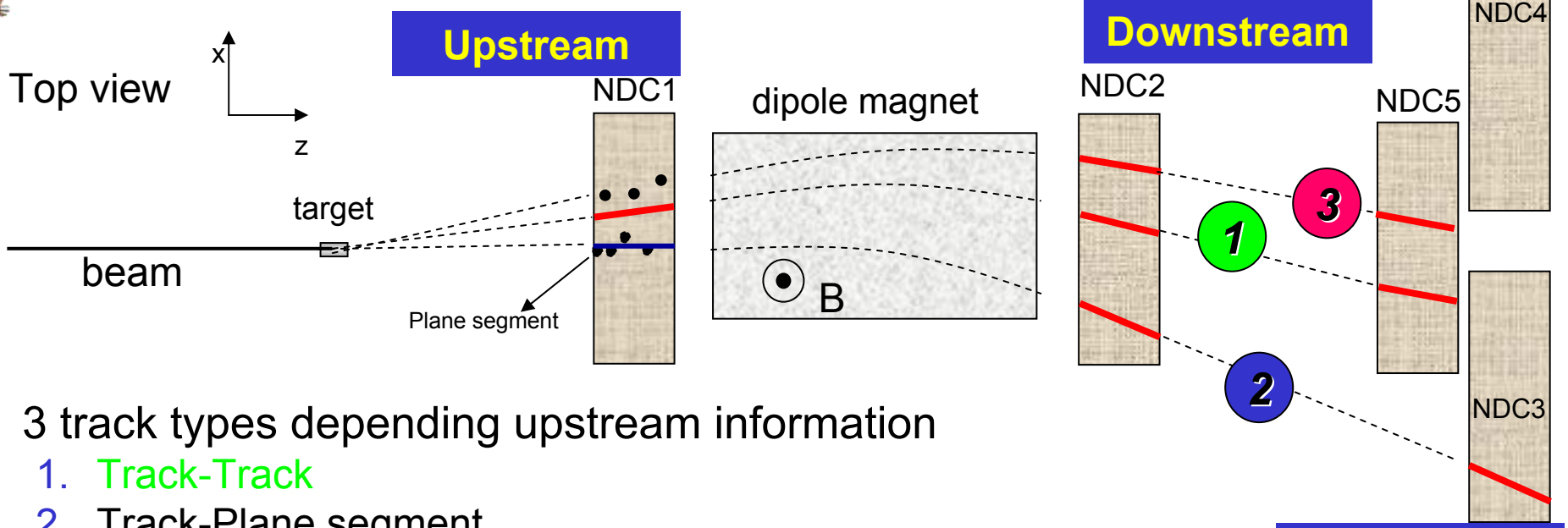






A particle is accepted if it reaches the second module of the drift chambers

Forward tracking



- 3 track types depending upstream information
  1. Track-Track
  2. Track-Plane segment
  3. Track-Target/vertex
- recover efficiency and avoid dependencies on track density in 1st NDC module (model dependence)
- Calculate efficiency separating downstream system first:

$$\varepsilon^{track} = \varepsilon^{down} \cdot \varepsilon^{up-down}$$

Downstream tracking efficiency ~99%

Up-downstream matching efficiency ~75%

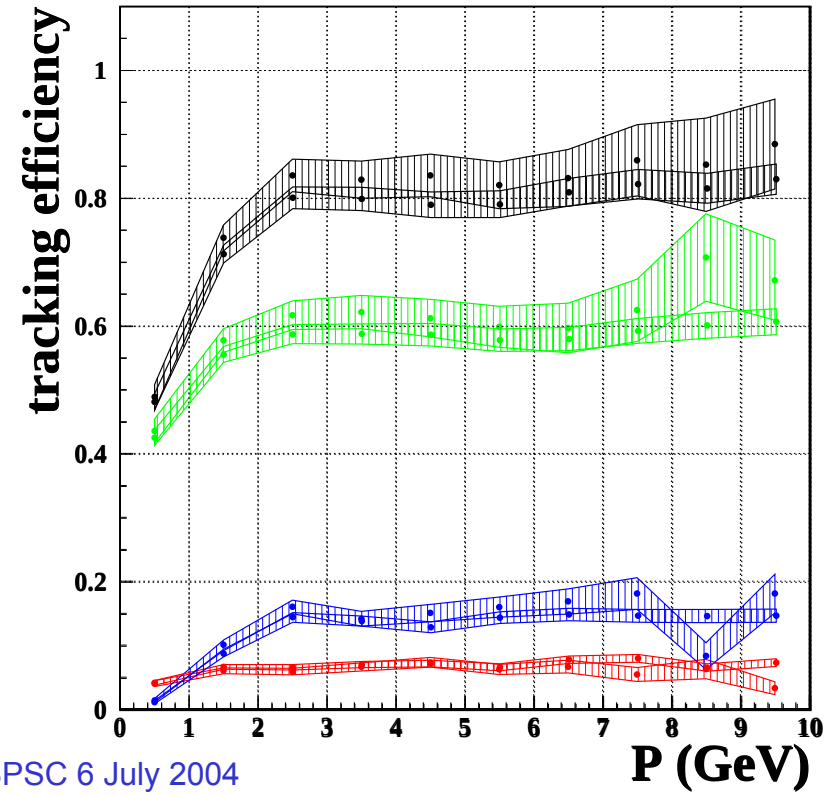
Tracking efficiency

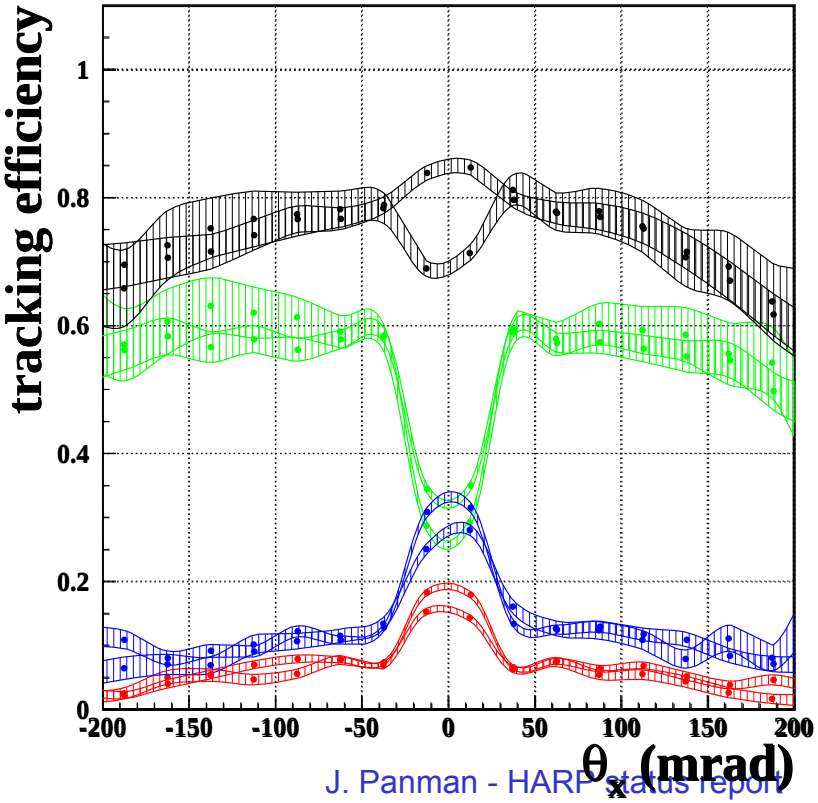
MC + data

- Computed with DATA and MC
  - DATA: detector inefficiencies and finite resolution
  - MC: Geometrical effects
- Known now to ~5%

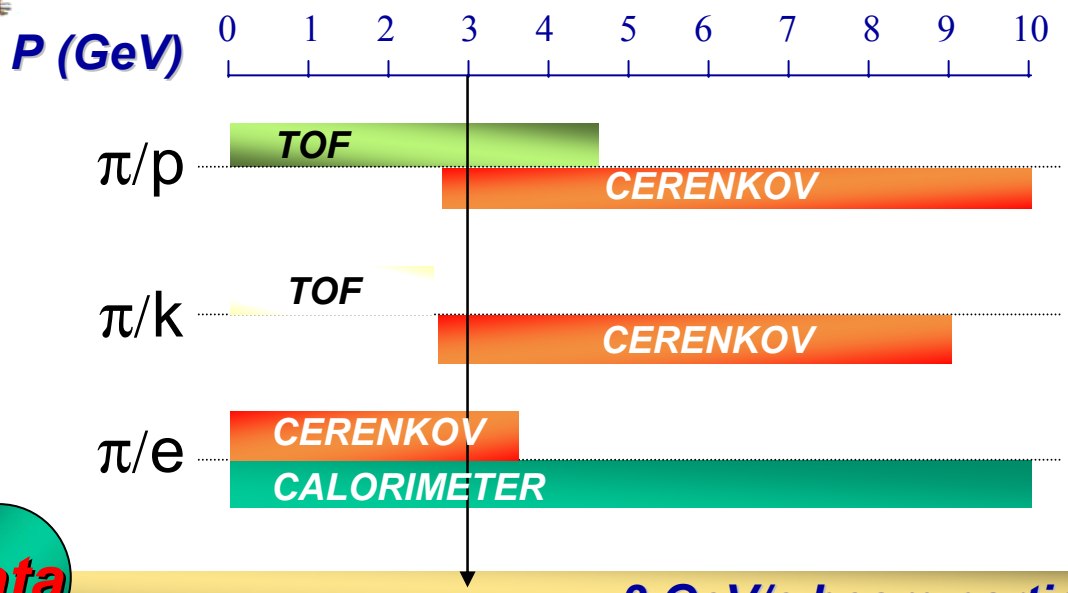
Green: type 1
Blue: type 2
Red: type 3

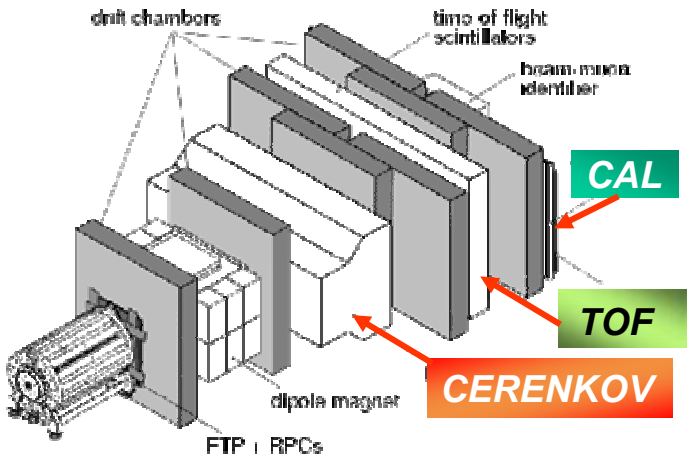
Black: sum of normalized efficiency for each type



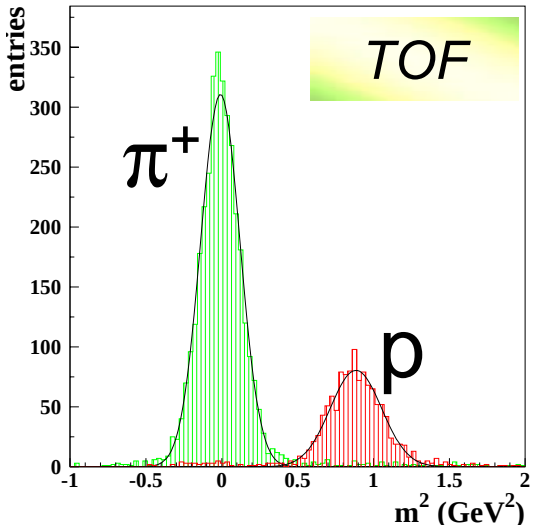


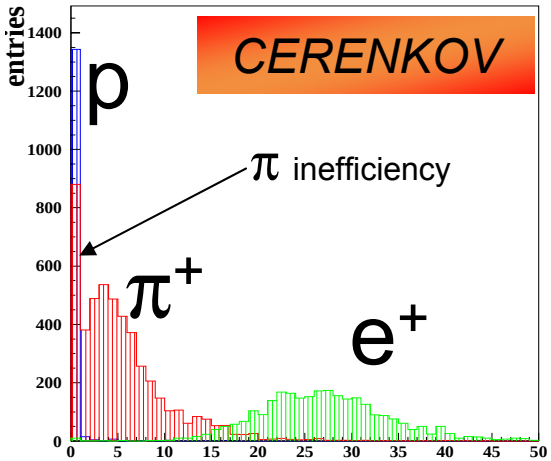
Particle identification

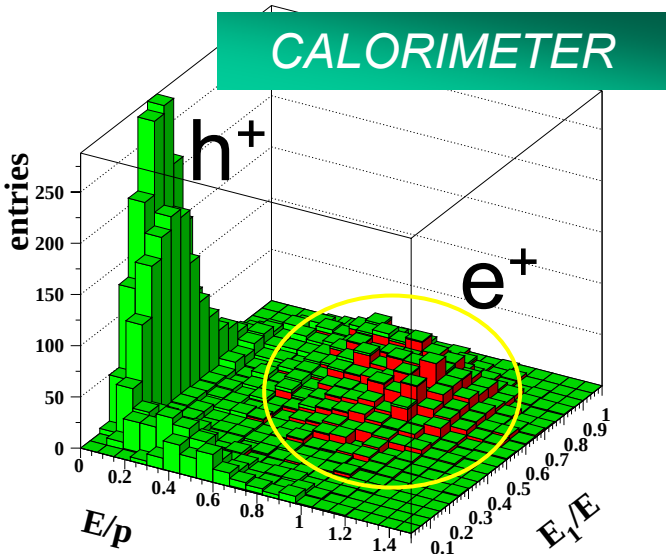




data — ***3 GeV/c beam particles***

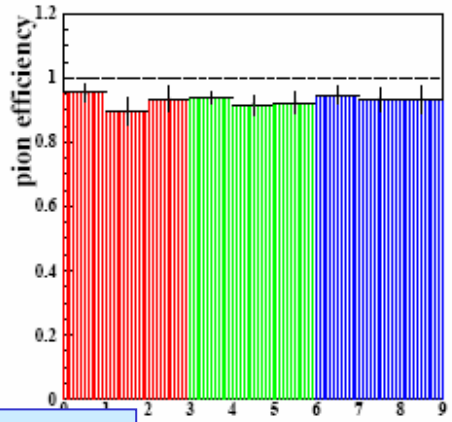


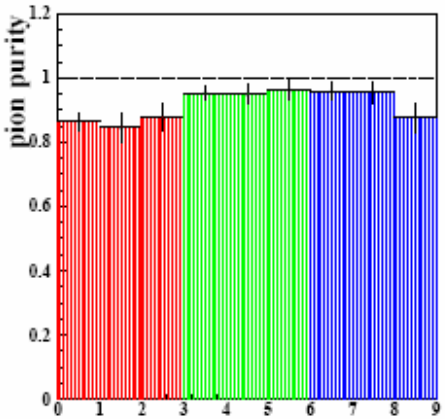




Combined PID correction factor

The yield of each type of track must be corrected by pion efficiency and purity:
computed using beam particles (clean particle selection from beam detectors)



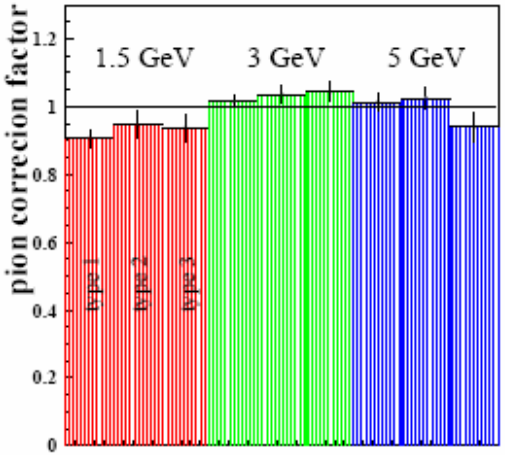


Pion purity:

$\eta_j^{\pi\text{-(t)}} = N_j^{\pi\text{-true-obs}} / N_j^{\pi\text{-obs}}$

Pion efficiency:

$\varepsilon_j^{\pi\text{-(t)}} = N_j^{\pi\text{-true-obs}} / N_j^{\pi\text{-true}}$



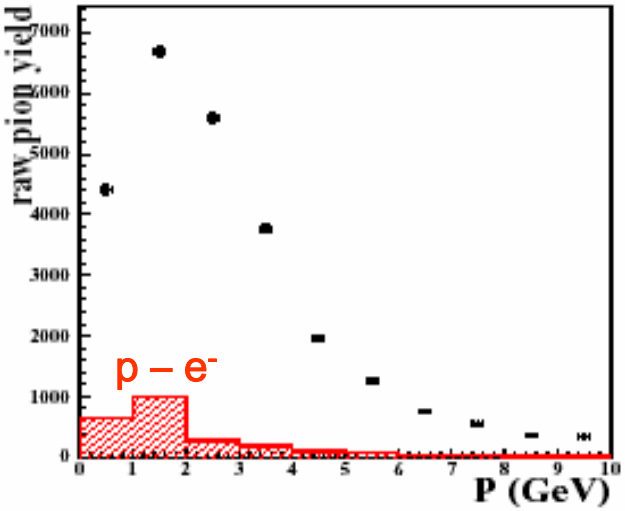
Pion yield:

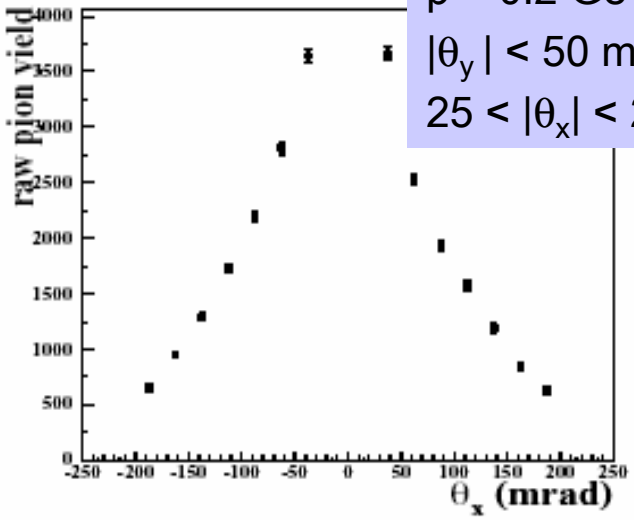
$N_j^{\pi\text{-true-obs}} = N_j^{\pi\text{-obs}} - N_j^{bkg}$

Pion yields

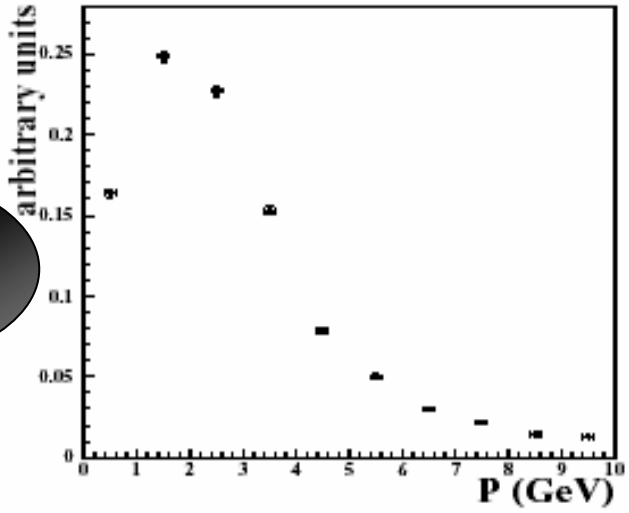
p > 0.2 GeV/*c*
$|\theta_y| < 50$ mrad
$25 < |\theta_x| < 200$ mrad

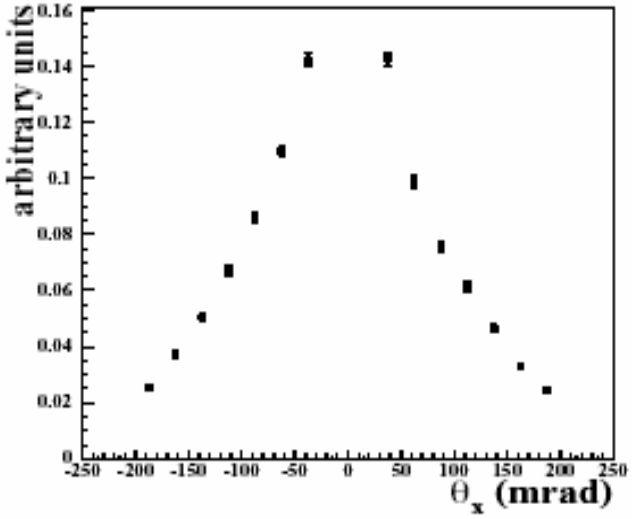
Raw data





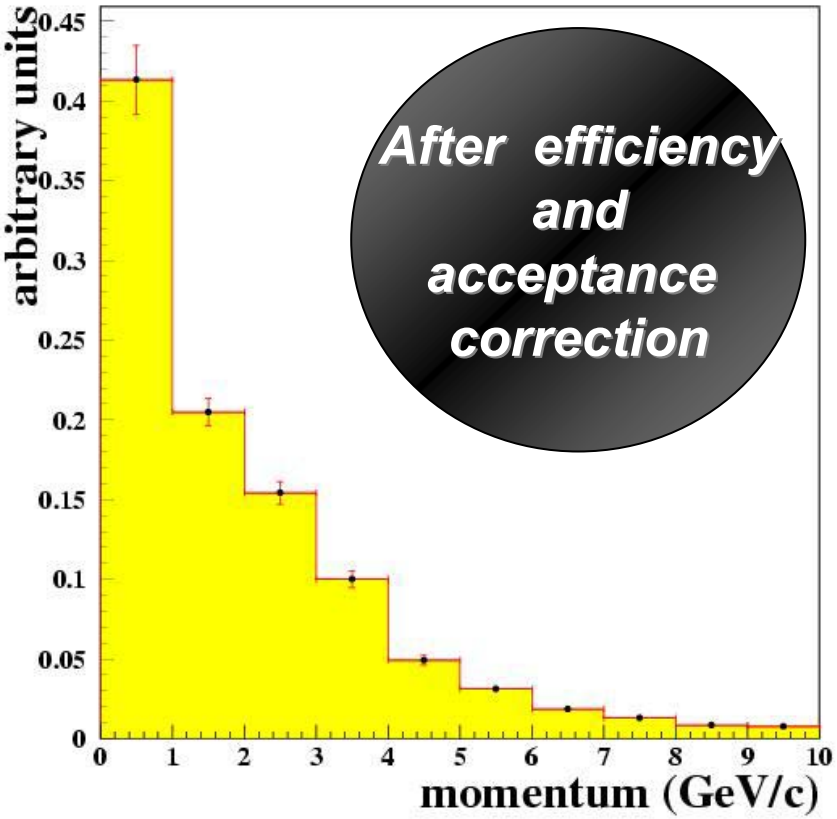
After PID correction



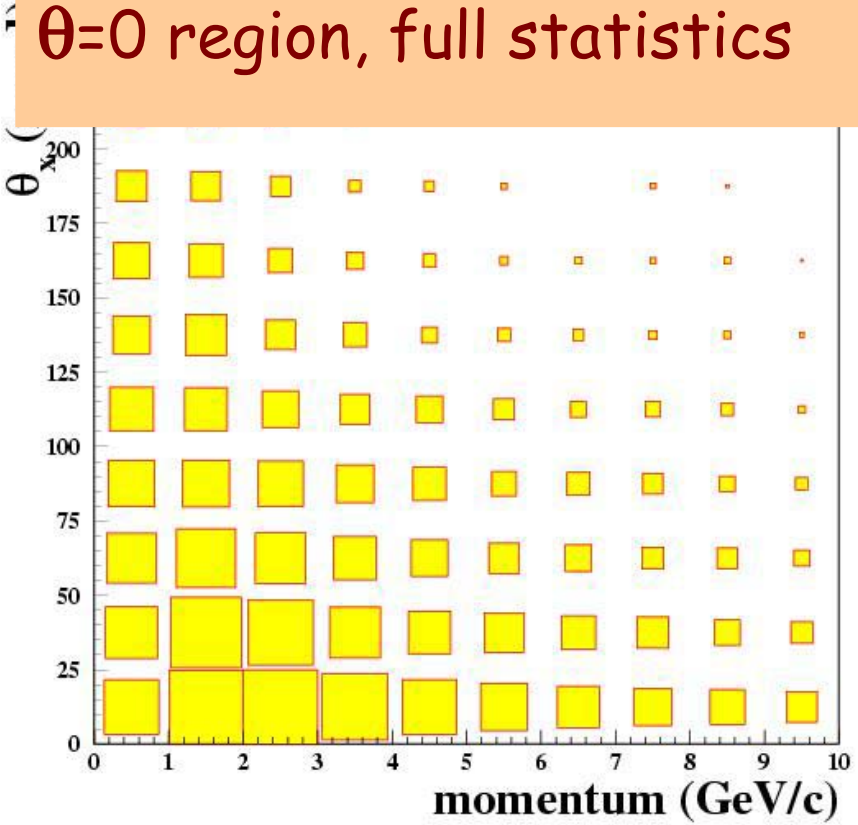


Preliminary results

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



Summary

- The HARP Experiment has collected data for hadron production measurements with a wide range of beam energies and targets
- Status of detector
  - Forward region: good tracking and PID
  - Large angle: much recent progress
- First physics results are available: K2K target replica
  - Using forward region of the detector

- Next: MiniBooNE analysis and first large angle analysis
- TPC calibration nearly complete, physics can start now

HARP needs more support to finish its physics programme
From CERN and national funding agencies

Measurements that will be provided by HARP in the near future are important for neutrino physics