Particle Production Measurements using the MIPP Detector at Fermilab

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Outline of the talk

- **Introduction**
- **Detector description**
- **Motivation**
- **Preliminary results**
- **Summary**

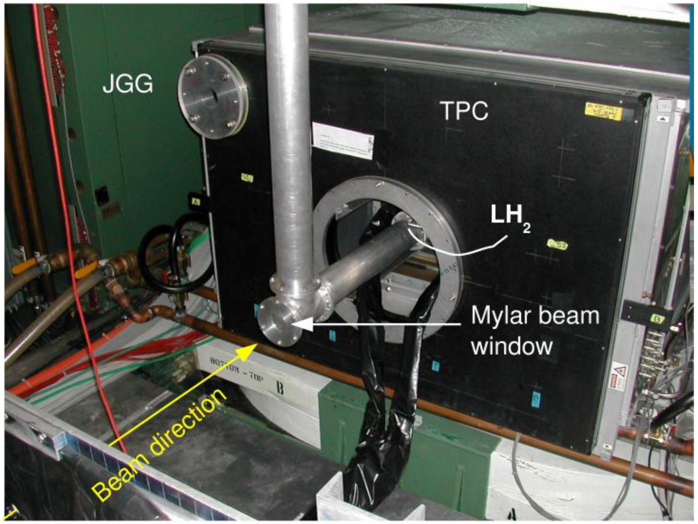
Introduction

- MIPP (E907) – stands for Main Injector Particle Production

- A fixed target hadron production experiment at Fermilab, operated from December 2004 to February 2006, collected ~18 million events

- **Primary Beam –** 120 GeV/c protons from the Main Injector
  Secondary Beams – $\pi^{\pm}$, $K^{\pm}$, p and $\overline{p}$ from 5 to 90 GeV/c

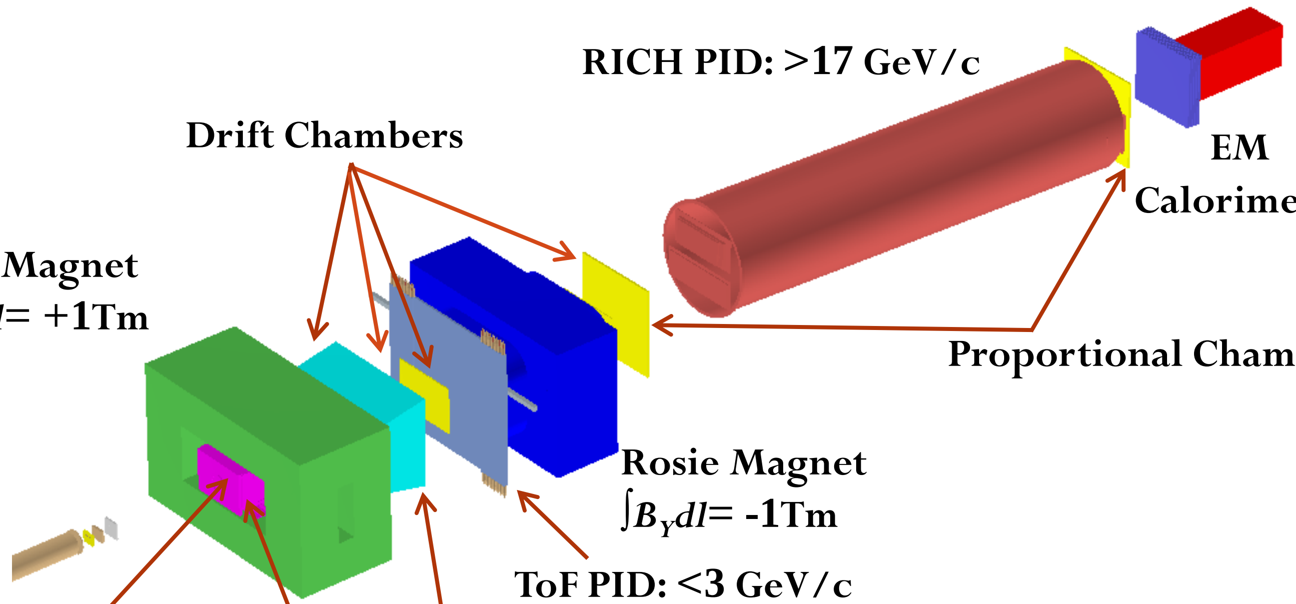
- **Targets:**
  <u>Liquid Hydrogen</u> (LH_2), Be, **<u>C</u>**, NuMI, Bi and U
  LH_2: 1.5% λ_I and 14 cm long target (shown in picture)
  C: 2% λ_I and 1 cm thick



- Inelastic cross section measurements for
  – 58 and 85 GeV/c p-H interactions
  – 58 and 120 GeV/c p-C interactions

- Particle ID algorithm and $\pi^{\pm}/K^{\pm}$ momentum spectra from 120 GeV/c p-C data

MIPP detectors



- TPC, 4 drift chambers and 2 proportional wire chambers
- Charge and momentum measurement – 2 magnets, operated with opposite polarity. Deflection got cancelled, good acceptance for downstream detectors as well
- Particle ID – 2 Beam CKOV for incoming particle ID
  – TPC, ToF, CKOV and RICH for outgoing particle ID
  – Calorimeter for neutrons

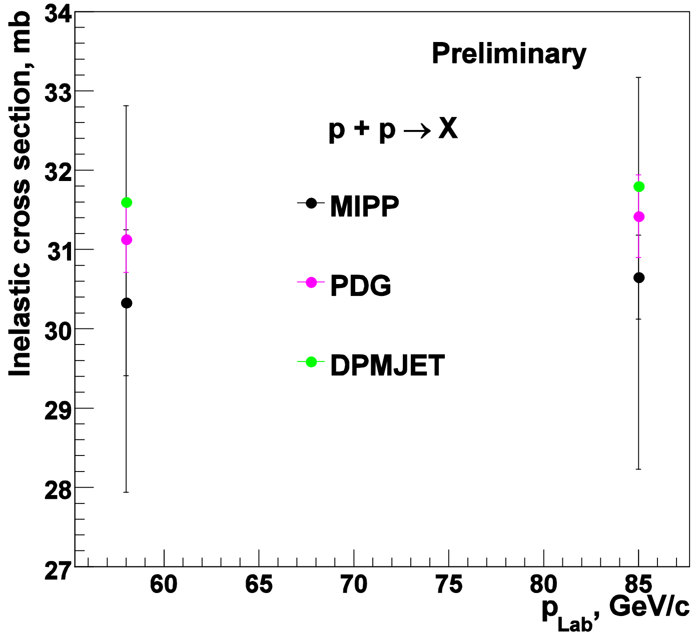
Motivation

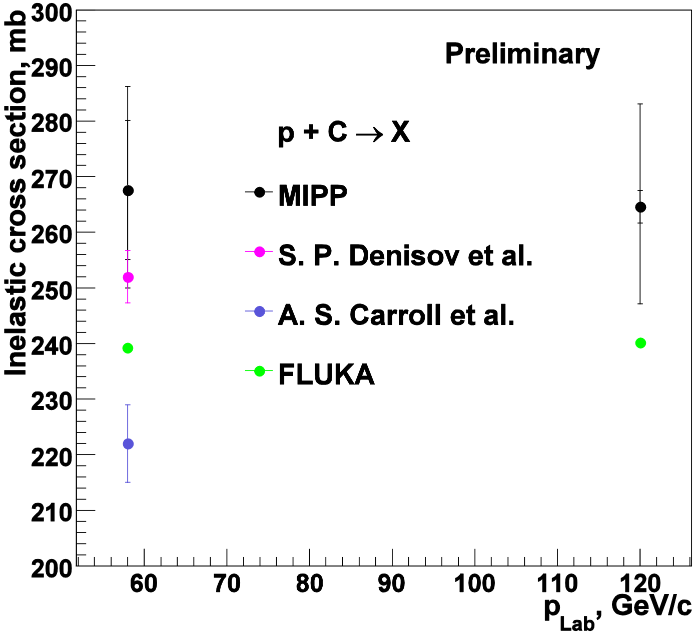
Hadronic shower simulation

- Geant4, MARS, Fluka, etc. model hadronic interactions based on available data
- MIPP – a high acceptance spectrometer, has high statistics data with 6 beam species
- These data could be used to improve simulations

Inelastic cross section measurements Comparison of MIPP data with MC and previous measurements

$$\text{Cross section} = \frac{N_{int} \times 10000}{N_{beam} \times n_t \times \varepsilon} \text{ mb}$$





- **p+p at 58 and 85 GeV:** data consistent, within error bars, with the PDG and DPMJET
- **p+C at 58 GeV:** data consistent, within error bars, with measurement of S. P. Denisov et al. **(Nucl. Phys. B61, (1973), 62)** and ~ 20% higher than the measurement of A. S. Carroll et al. **(Phys. Lett. B80, (1979), 319)**. FLUKA ~ 11% lower than the data
- **p+C at 120 GeV:** FLUKA ~ 9% lower than the data

KNO-based technique to get trigger efficiency

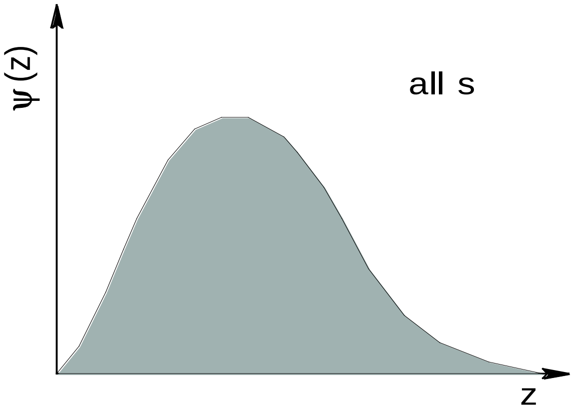
KNO Scaling relation:

$$P_n(s) = \frac{\Psi(n/\langle n(s)\rangle)}{\langle n(s)\rangle}, \quad \frac{n}{\langle n(s)\rangle} = Z$$

Where $P_n(s)$ is the probability of producing 'n' charged particles at a particular energy 's', <n(s)> is the average multiplicity and $\Psi(n/\langle n(s)\rangle)$ is the KNO function

$\Psi(Z) = (3.97Z + 33.7Z^3 - 6.64Z^5 + 0.332Z^7)e^{-3.04Z}$

P. Slattery, Phys. Rev. Lett. 29, (1972), 1624

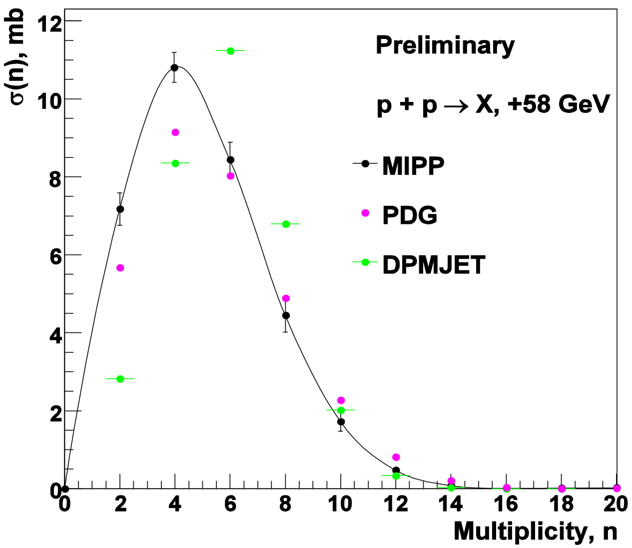


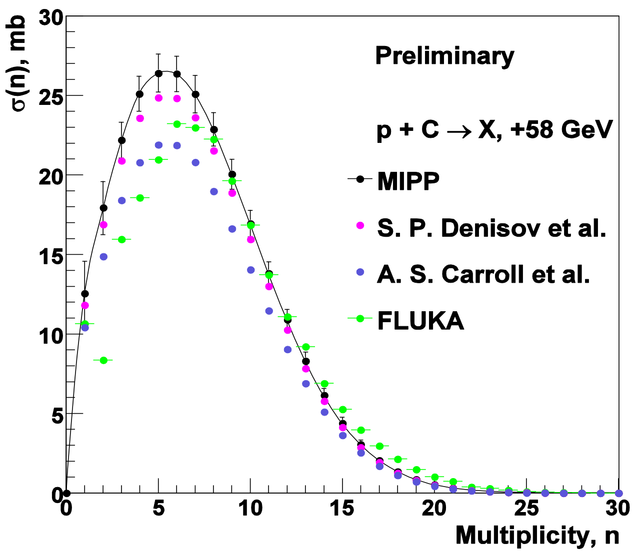
- The method uses a K matrix $K(n_o|n_t)$ – probability of obtaining observed multiplicity n_o, given a true multiplicity n_t (trigger is not required)
- This matrix multiplied by true probabilities from KNO function to get the predicted distribution
- The observed distribution fitted to the predicted distribution to extract the trigger efficiencies
- The fit function is:

  $$\chi^2 = (\text{Observed} - \text{Predicted})^2/\sigma^2$$

- Trigger efficiencies are the parameters going to be fitted

LH_2 and Carbon multiplicities





- For LH_2 target, charged multiplicities should be even. Both even and odd multiplicities observed in data because of acceptances and reconstruction inefficiencies
- KNO Scaling function used to get the data true probabilities. The <n> from our data used. Probabilities multiplied by the average inelastic cross section to get the cross sections as a function of multiplicity
- Similarly cross sections calculated for Carbon target where multiplicities are both odd and even
- For LH_2 target, discrepancies found between the data and PDG at the lower end and tails. For Carbon target, the data consistent, within error bars, with measurement of S. P. Denisov et al. and consistent with measurement of A. S. Carroll et al. for n>15
- The DPMJET and FLUKA shapes not consistent with the data

Global PID Algorithm

- Four hypotheses considered for particle identification (PID) – e/π/K/p (denoted by H)
- TPC, ToF and RICH used. PID quantities dE/dx, time of flight and ring radii measured for TPC, ToF and RICH respectively
- Maximum likelihood technique used to determine the spectra of each particle type in data
- **Global PID formalism –**

A weight is formed by using the likelihood of a PID quantity for a particular hypothesis and sum of the likelihoods of that quantity for all the hypotheses i.e.

$$\text{Weight} = \frac{\text{Likelihood}}{\sum_H \text{Likelihoods}}$$

Global weight is formed using the total likelihood i.e. product of all the detector likelihoods

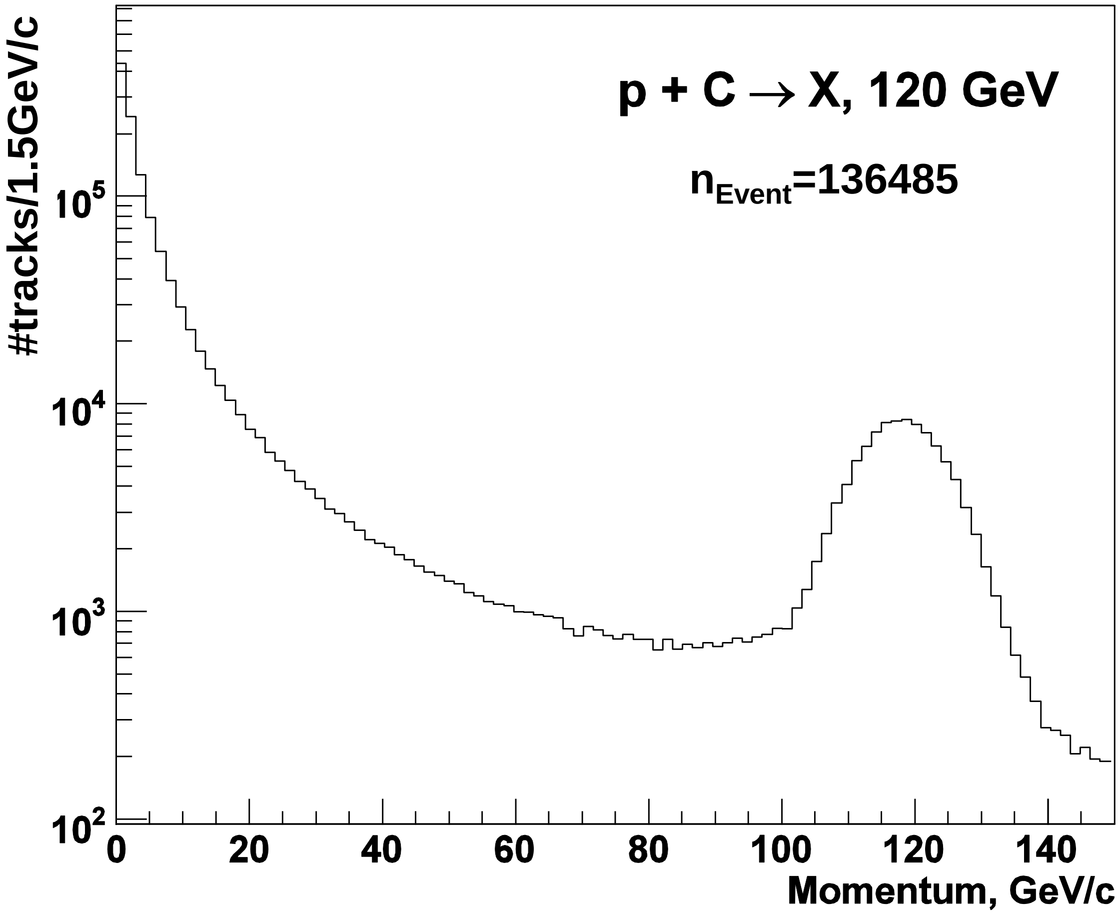
This is determined for each track and used to weight the track for each hypothesis

Each particle enters all hypothesis dependent plots with its hypothesis dependent weight

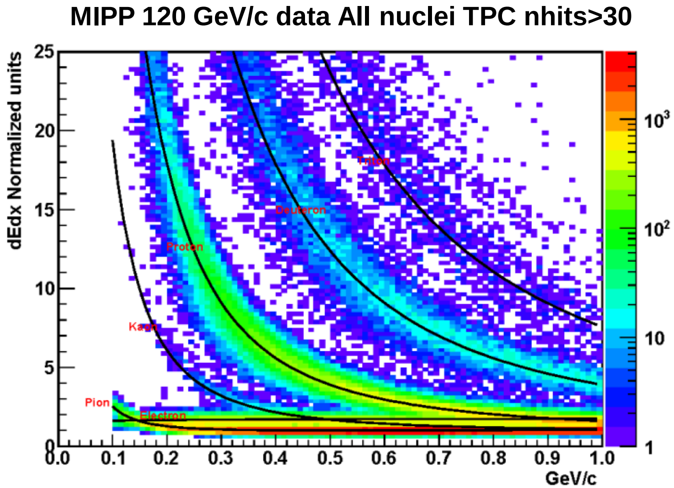
Aim: determine the momentum spectrum for each particle type

Reconstructed momentum distribution for 120 GeV/c proton on Carbon interactions (data)

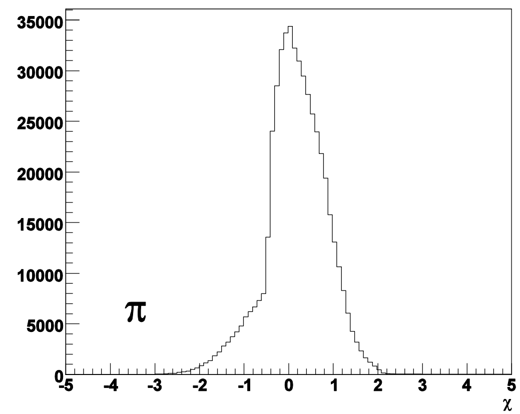
Excess ~120 GeV/c is due to the beam protons which are either uninteracted or diffractively scattered with small number of secondary particles produced

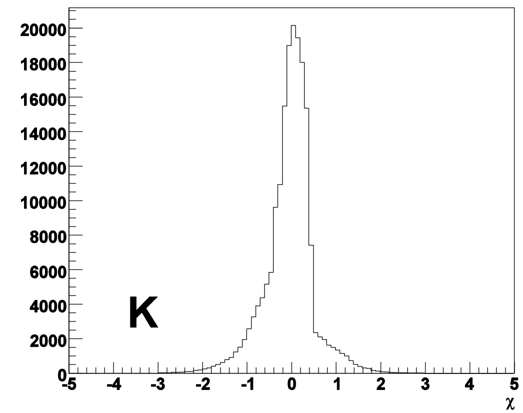


TPC PID (Preliminary)

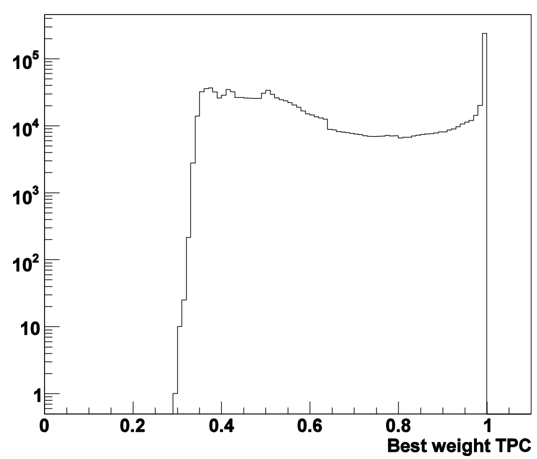


Best hypothesis χ distributions

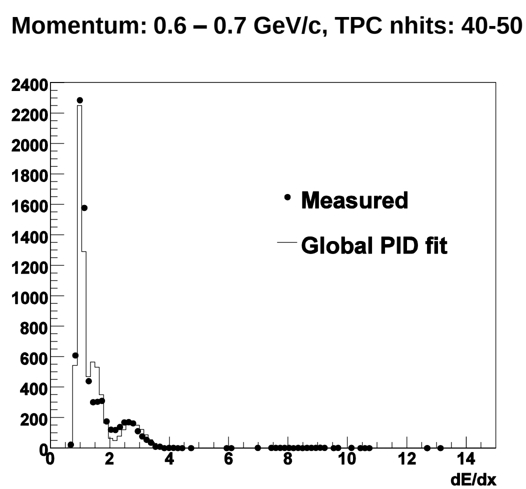


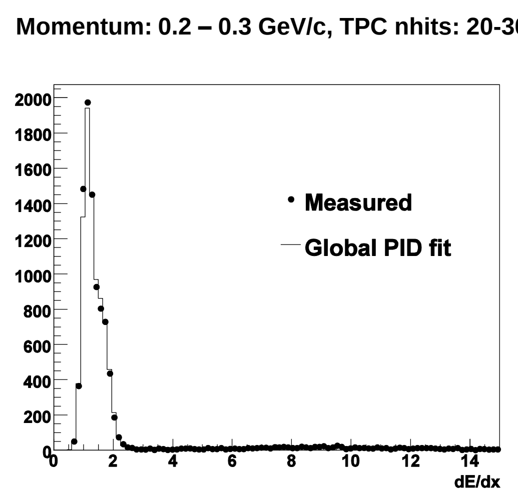


Best hypothesis weight



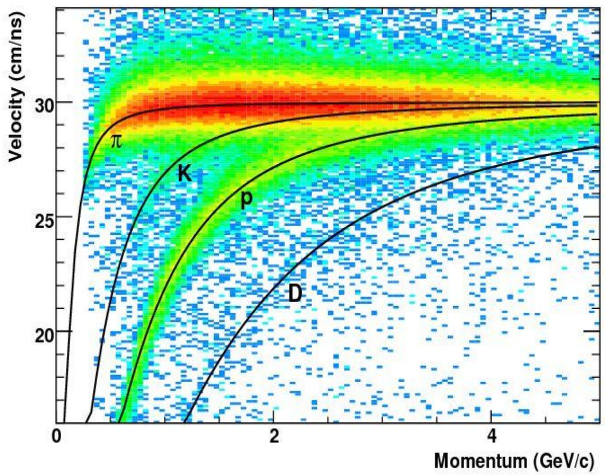
Comparison of data and model



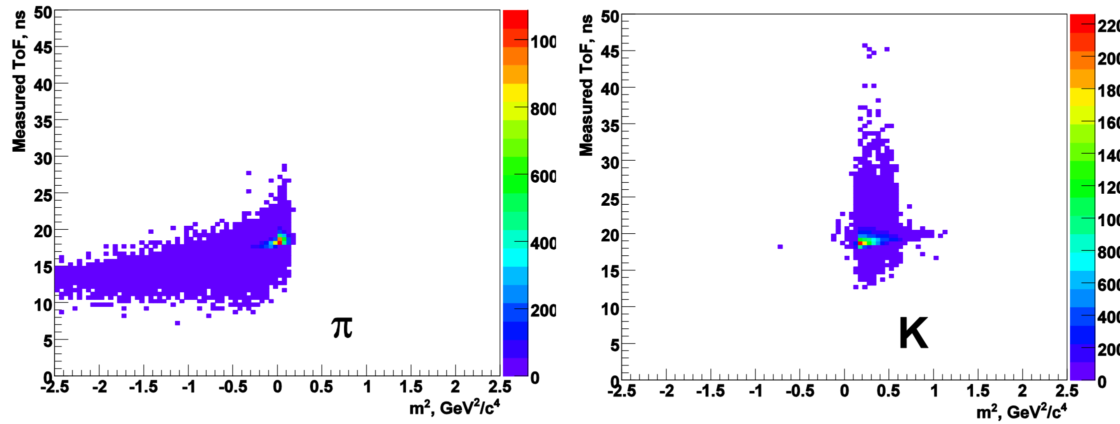


ToF PID (Preliminary)

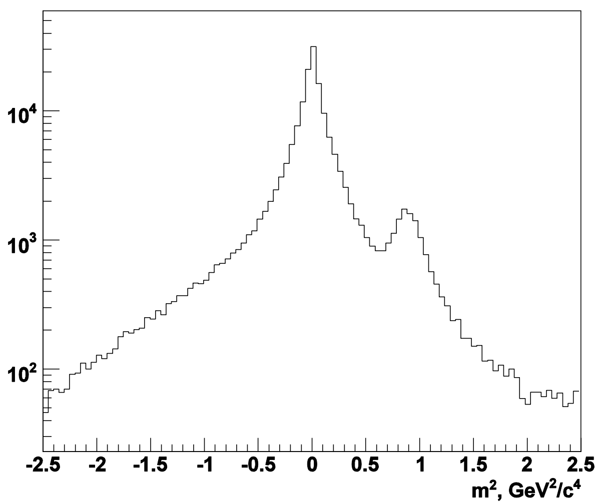
Measured velocity vs Track Momentum, Subset of Bars



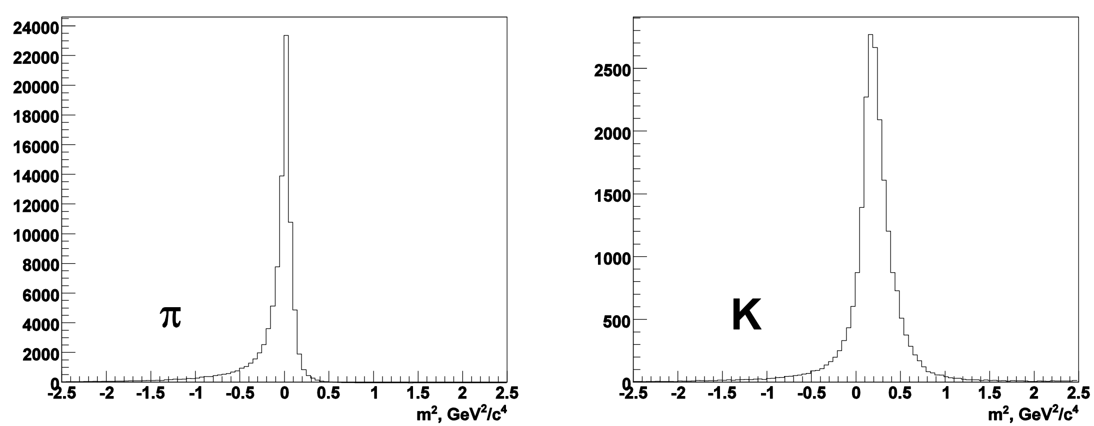
Best hypothesis ToF vs m^2 distributions



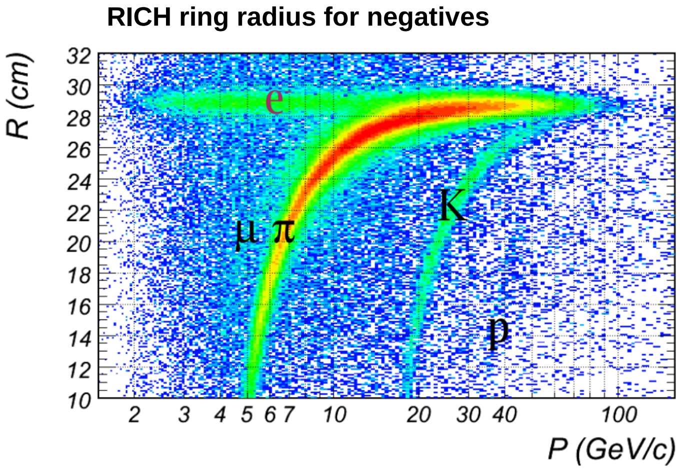
m^2 distribution no cuts

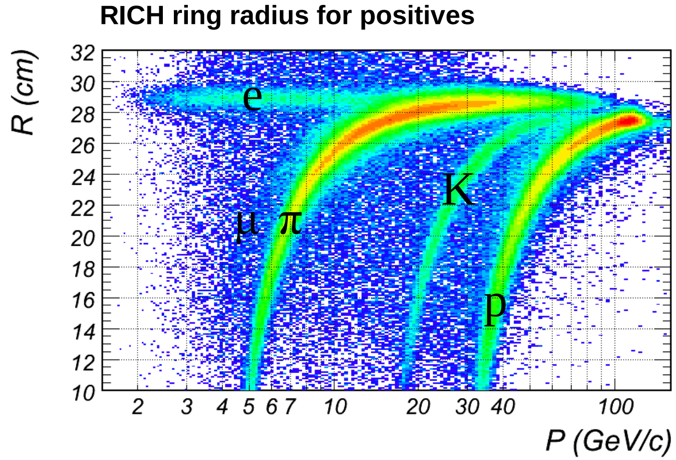


Global weighted m^2 distributions

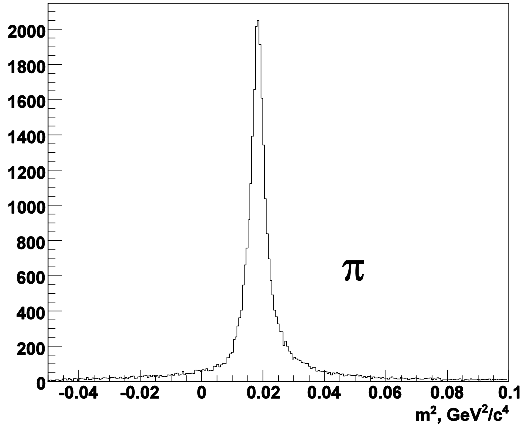


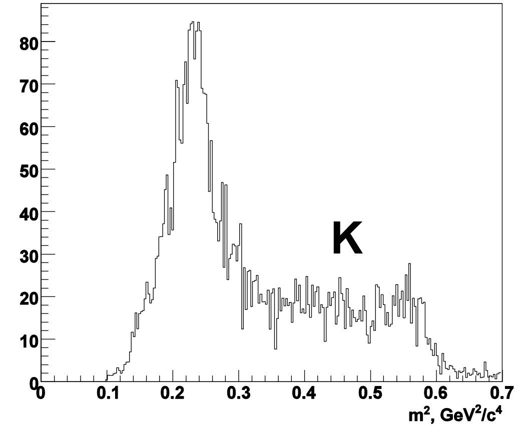
RICH PID (Preliminary)





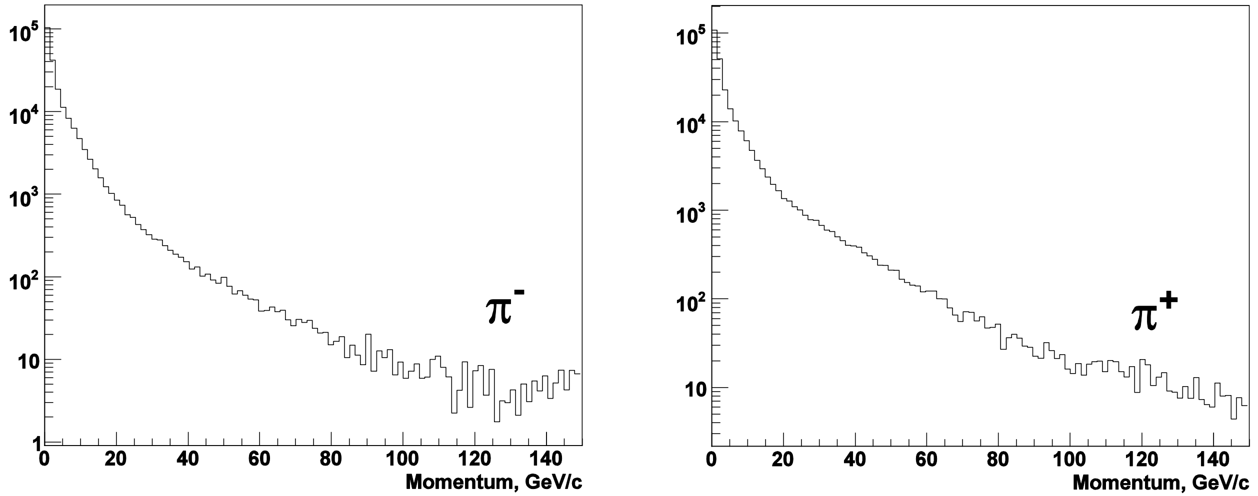
Global weighted m^2 distributions



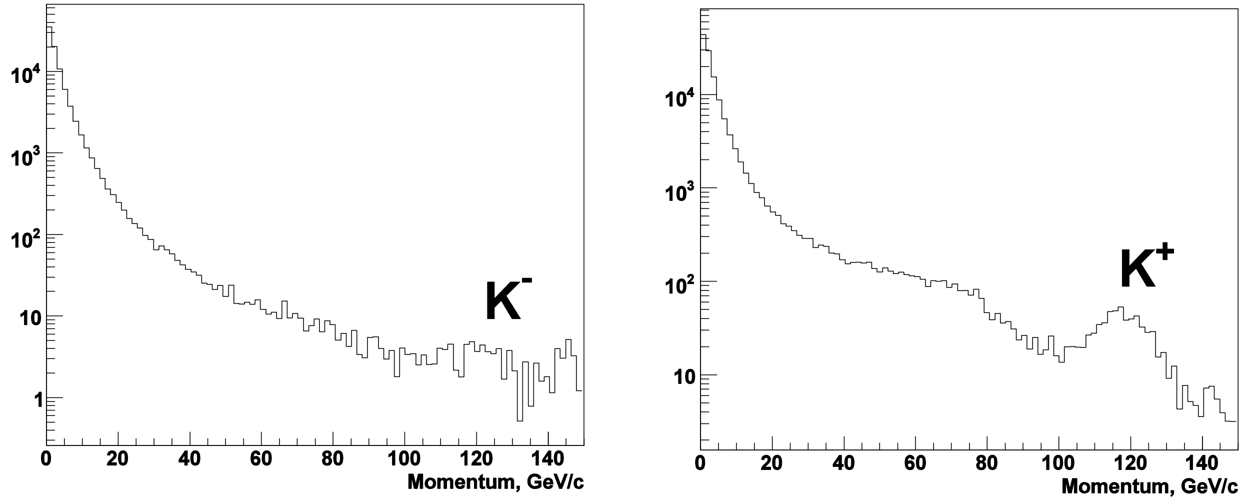


Momentum spectra (Preliminary)

$\pi^{\pm}$ momentum spectra from 120 GeV/c p-C interactions



$K^{\pm}$ momentum spectra from 120 GeV/c p-C interactions



Summary

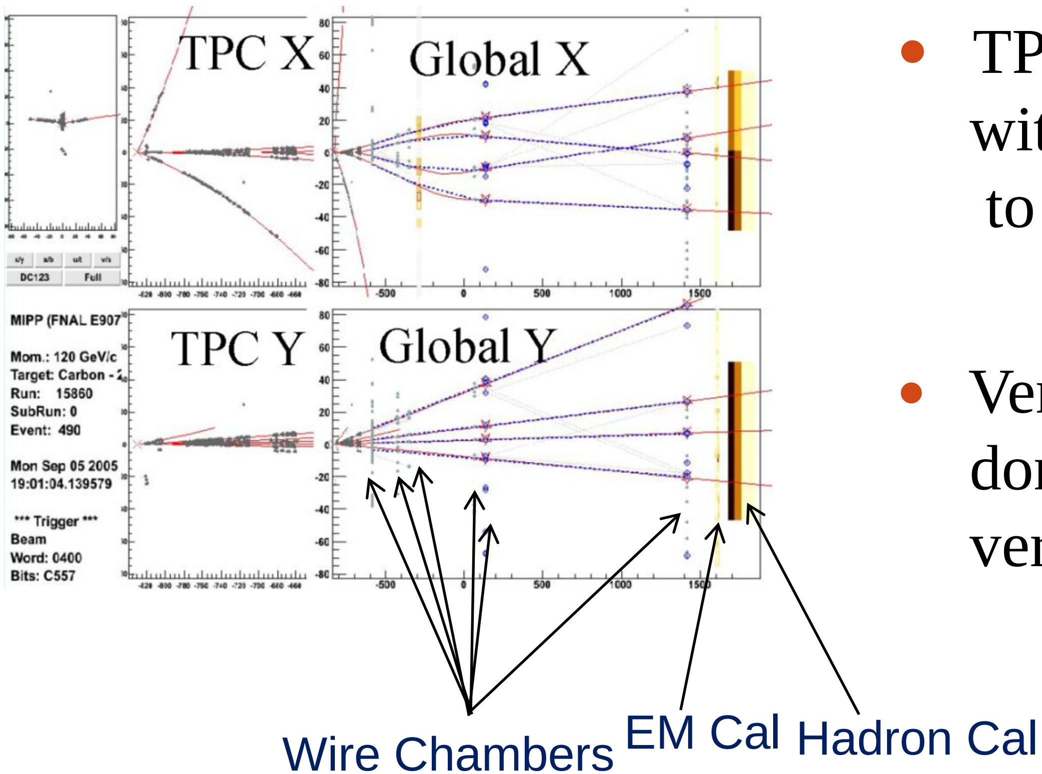
- ✓ Inelastic cross sections measured for p-H and p-C interactions at different energies
- ✓ MIPP data compared with the MC predictions and previous measurements
- ✓ A KNO-based technique to get the trigger correction developed and the cross sections cross checked using this method as well
- ✓ Inelastic cross sections also measured in bins of multiplicity
- ✓ Data and MC charged particle production cross sections also measured in bins of momentum, p_T^2 and x_F for 58 and 120 GeV/c p-C interactions, and compared
- ✓ Particle ID algorithm described and $\pi^{\pm}$ and $K^{\pm}$ momentum spectra measured from p-C interactions at 120 GeV for the data
- ✓ **Next tasks:** Work out the $\pi^{\pm}$ and $K^{\pm}$ production cross sections as a function of momentum, p_T^2 and x_F for p-H and p-C interactions. Compare the data with MC

THANK YOU

Backup slides

Track and vertex reconstruction

Reconstructed 120 GeV/c proton on Carbon event

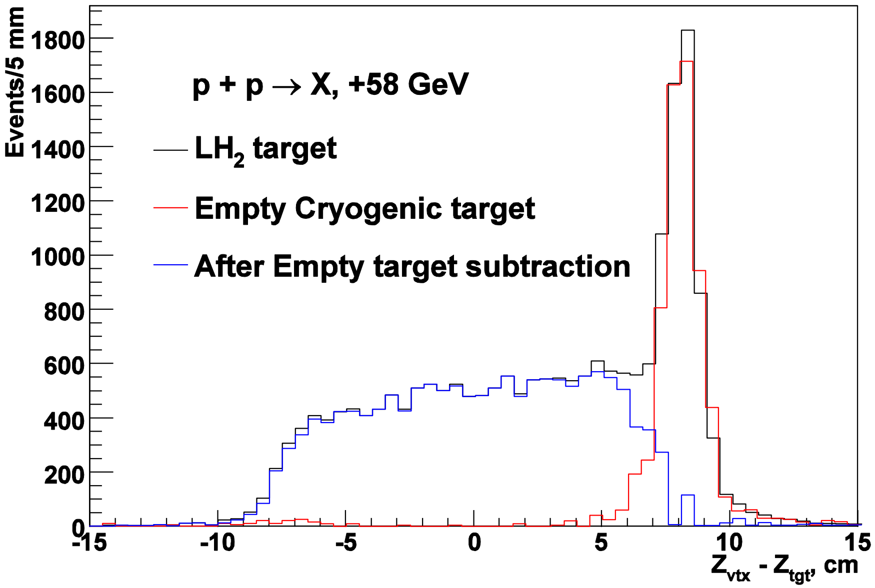


- TPC tracks combined with wire chambers hits to form global tracks
- Vertex constrained fit is done to form the vertices

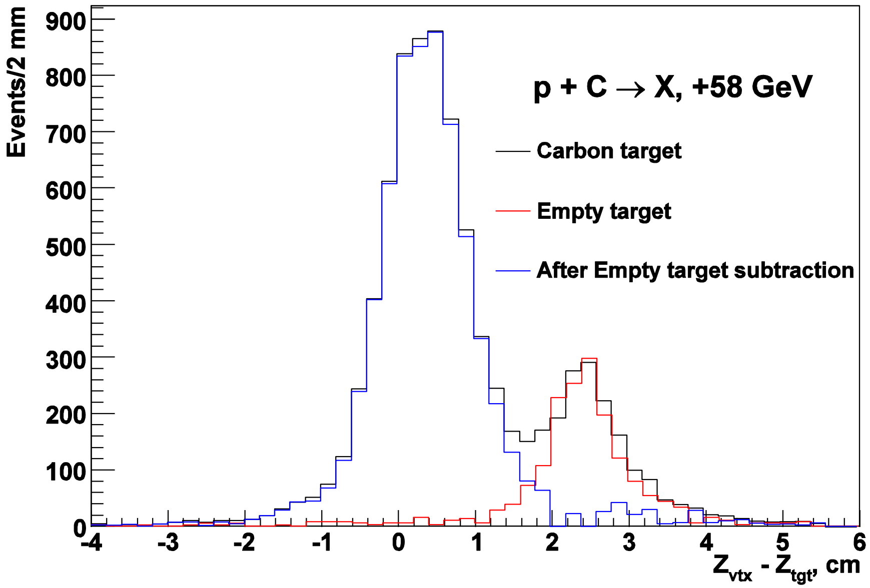
Event selection for inelastic cross section measurements

- Selection of "good" beam events using:
  - Single beam track
  - Cut on transverse beam position so that the beam spot is consistent with target size
  - Cut on beam track time to reject out of time beam tracks
- Selection of interactions using interaction trigger. Scintillator-based interaction trigger requires at least 3 charged particles for the scintillator to fire
- Cuts on vertex positions in X, Y and Z to select interactions within the target only
- Empty target subtraction to reject the interactions with the scintillator

Z vertex wrt target for 58 GeV p-H interactions

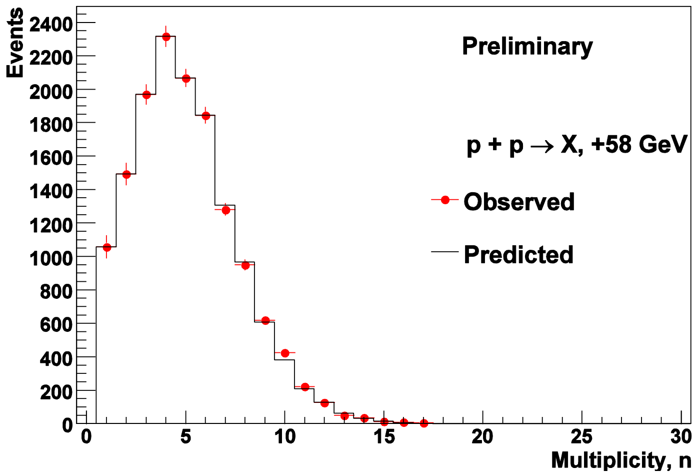


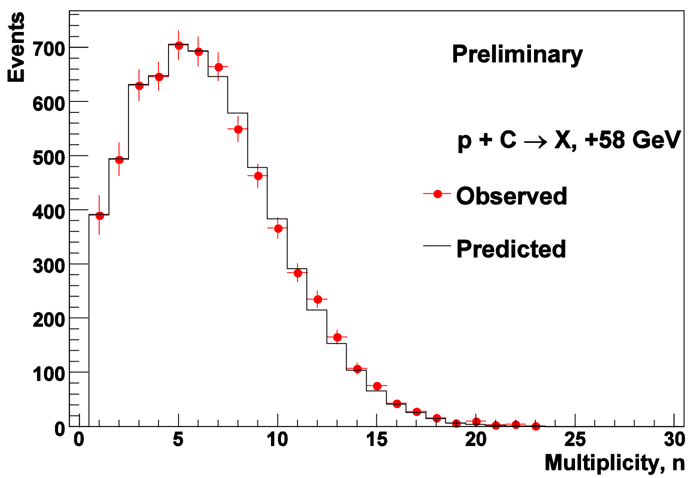
Z vertex wrt target for 58 GeV p-C interactions



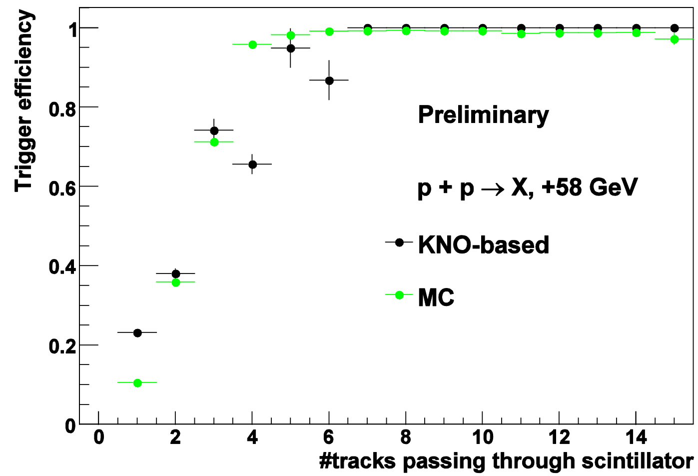
KNO fit results

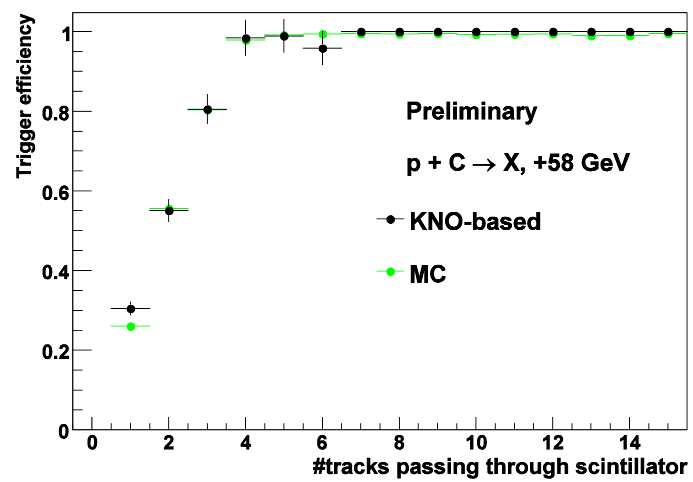
Comparison of observed and predicted multiplicity distributions at the minimum





Comparison of trigger efficiencies





Charged particle production cross sections

- All charged particles from the primary interaction selected and particle production cross sections calculated in bins of momentum, p_T^2 and x_F

- Formula used:

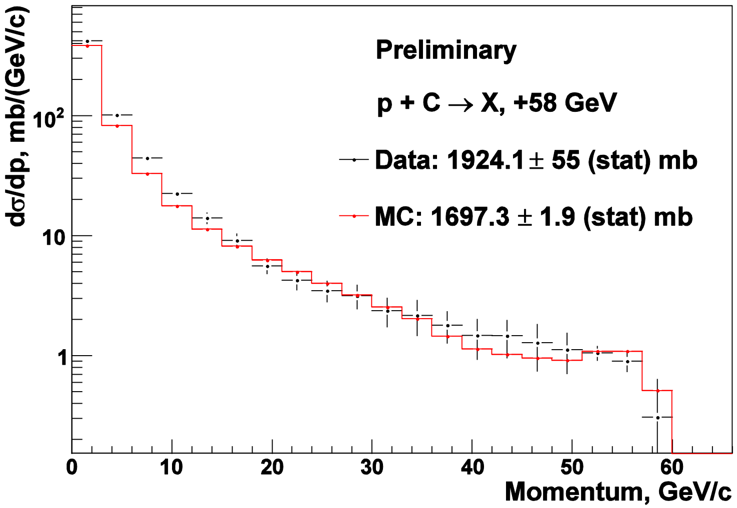
  For example, in case of momentum

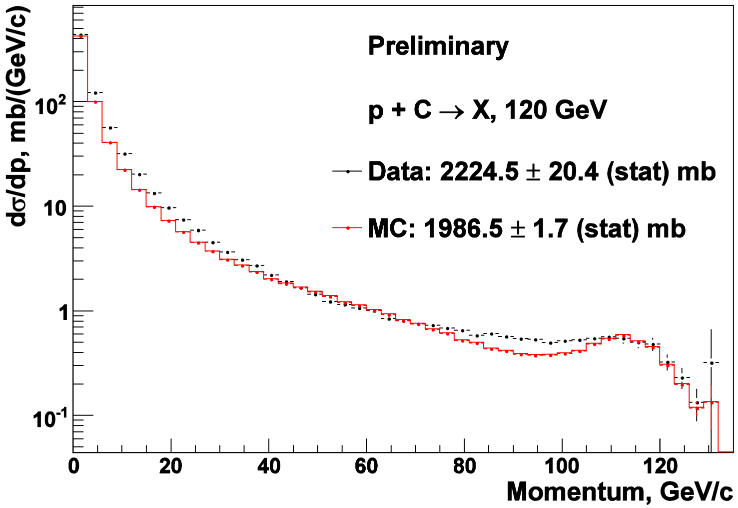
$$\frac{d\sigma}{dp} = \frac{N_{int} \times 10000}{N_{beam} \times n_t \times \varepsilon \times \Delta p} \quad \text{mb/(GeV/c)}$$

Δp is the momentum bin width

- Data and Monte Carlo cross sections calculated and compared

Production cross sections in bins of momentum – data and MC comparison



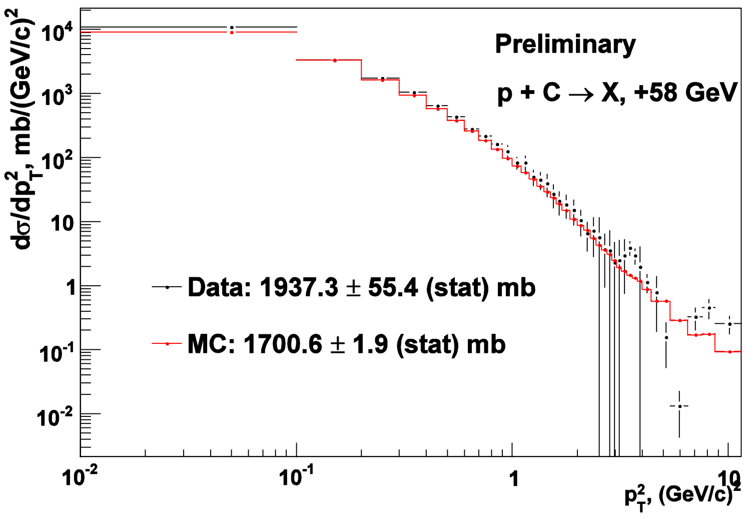


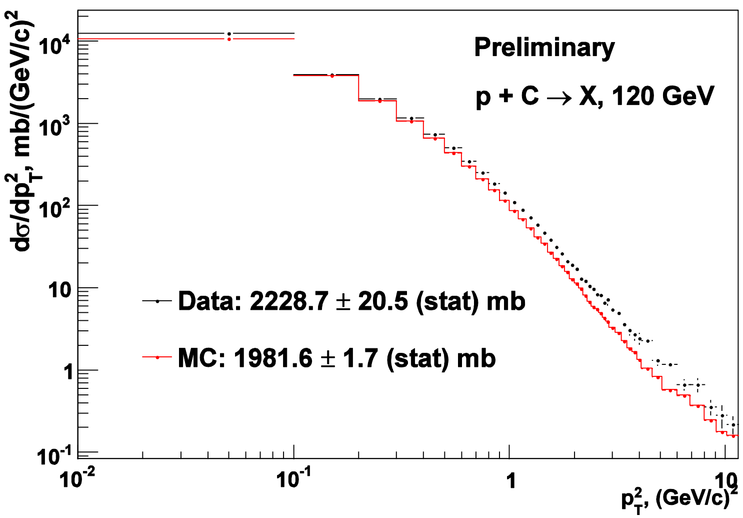
Average production cross sections for the data and MC

Energy (GeV)	Data cross section (mb)	MC cross section (mb)
58	1924.1 ± 55 (stat) $^{+89.5}_{-94.2}$ (syst)	1697.3 ± 1.9 (stat) $^{+51.1}_{-51.1}$ (syst)
120	2224.5 ± 20.4 (stat) $^{+92.5}_{-97.1}$ (syst)	1986.5 ± 1.7 (stat) $^{+51.5}_{-51.5}$ (syst)

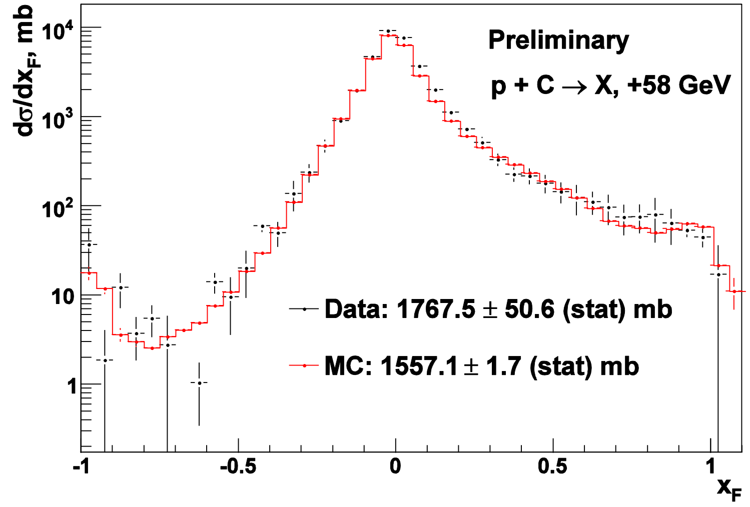
MC ~ 12% lower than data at 58 GeV and
~ 11% lower than data at 120 GeV

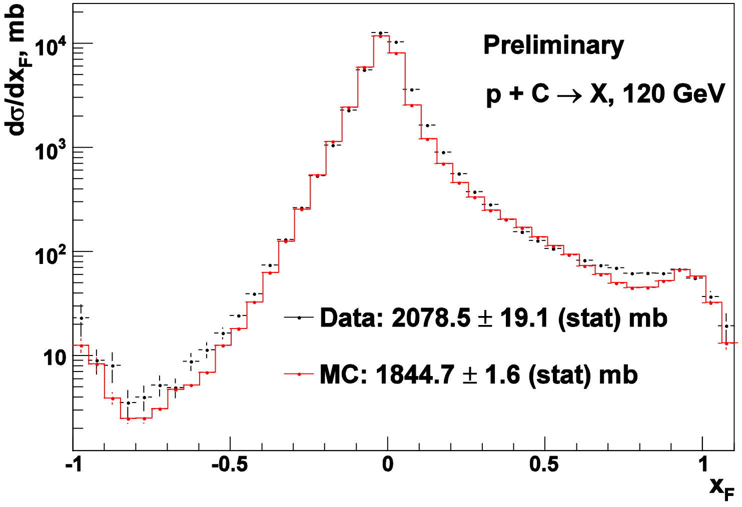
Production cross sections in bins of p_T^2 – data and MC comparison



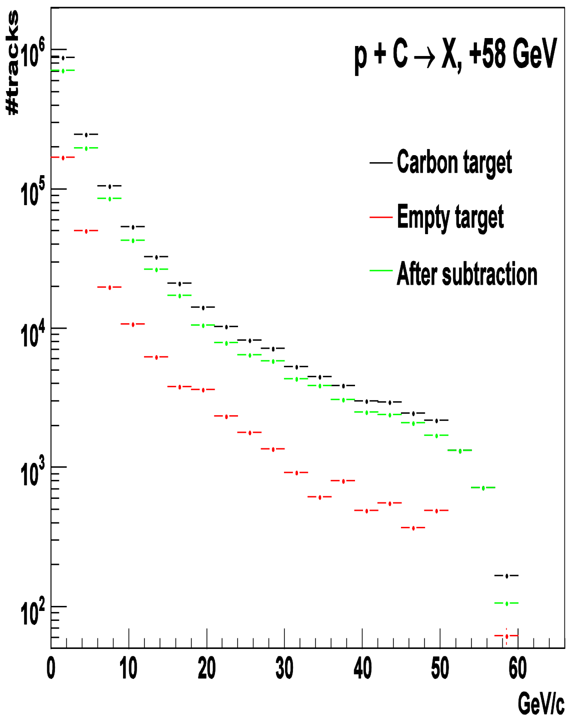


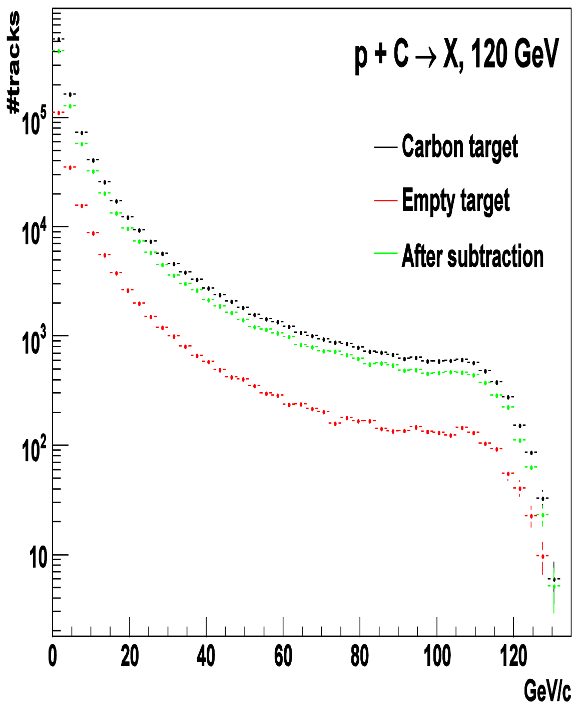
Production cross sections in bins of x_F - data and MC comparison

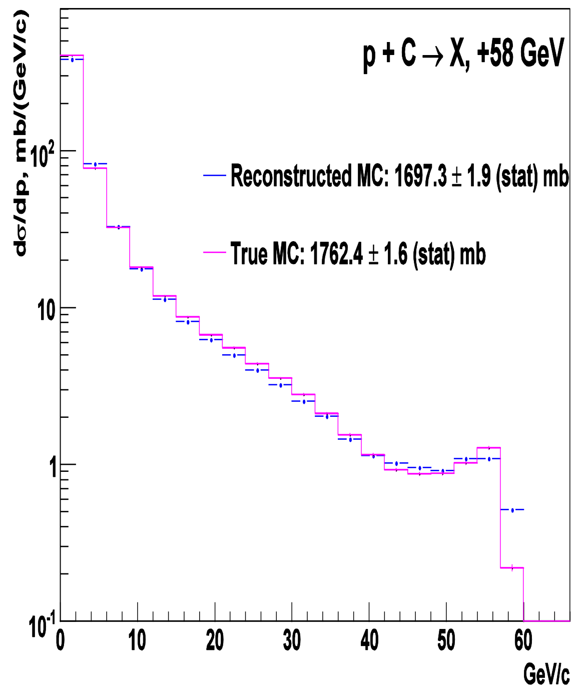




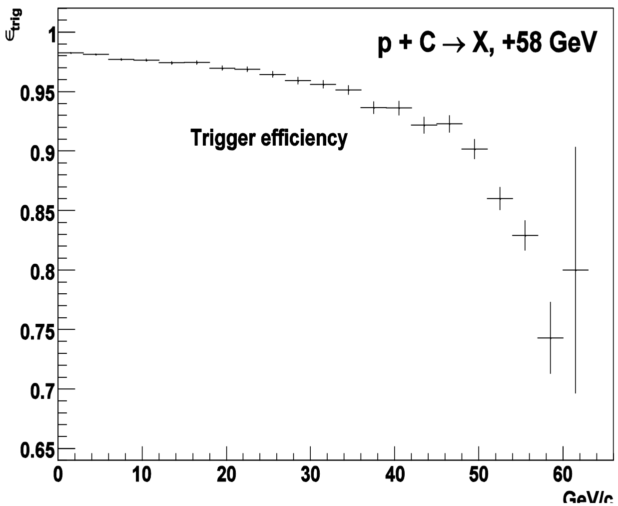
Momentum distributions

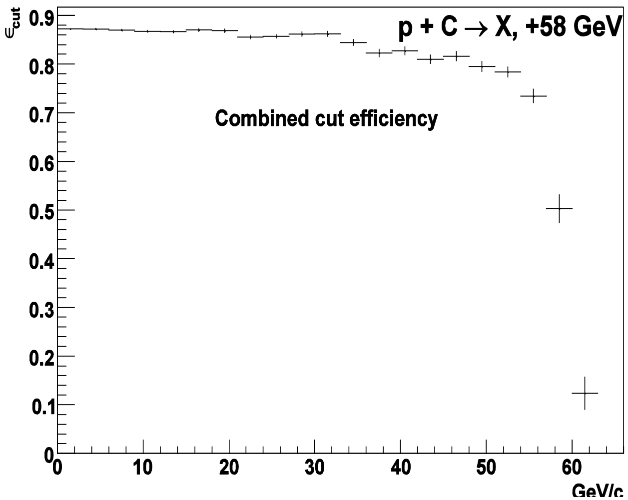


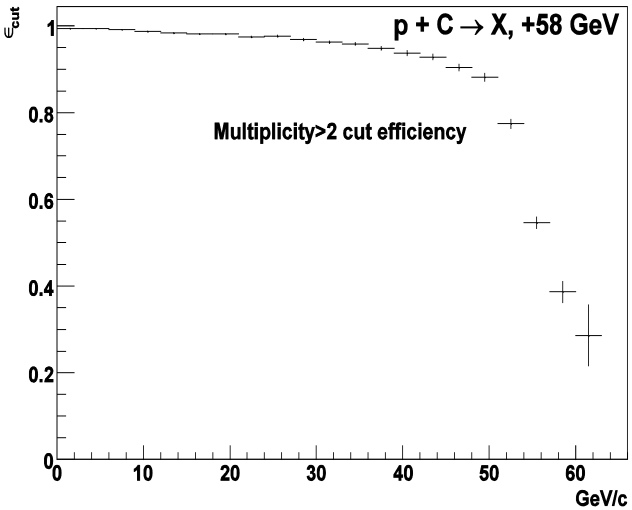


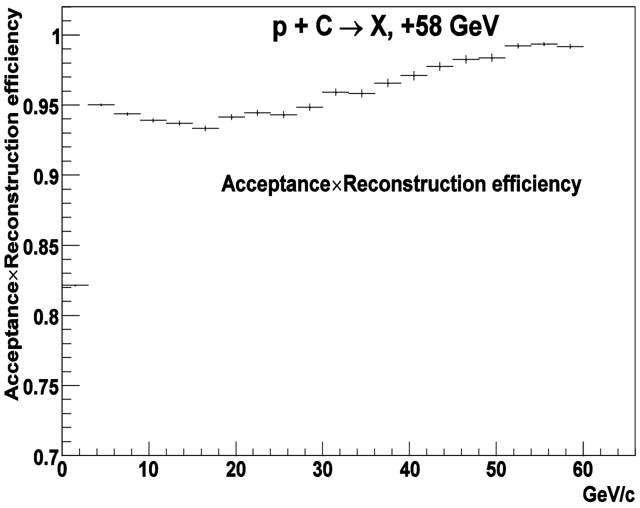


Cut efficiencies in bins of momentum

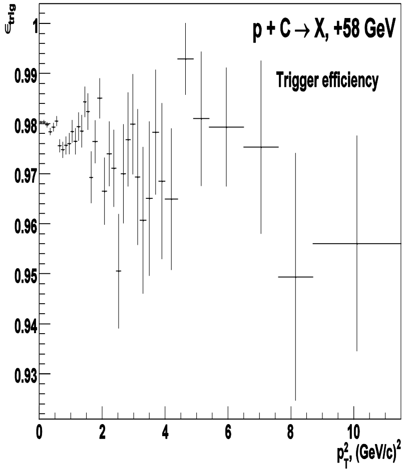


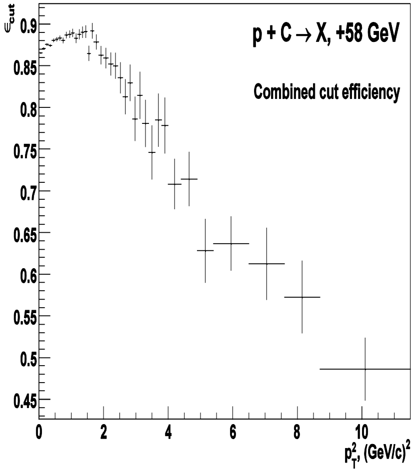


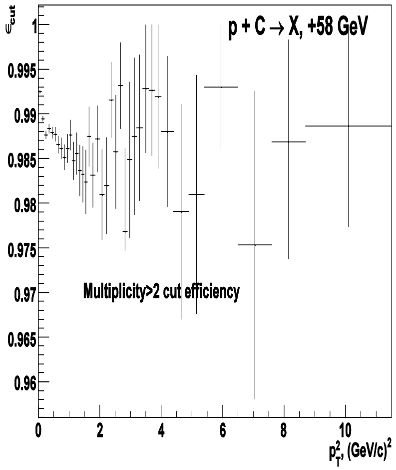


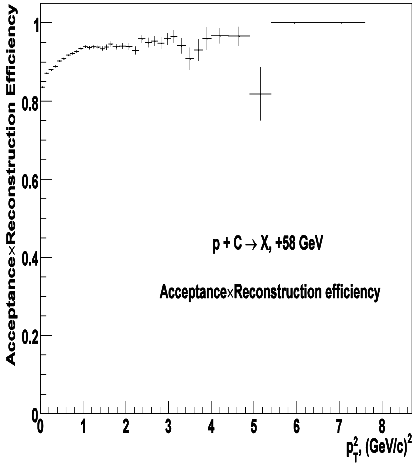


Cut efficiencies in bins of p_T^2

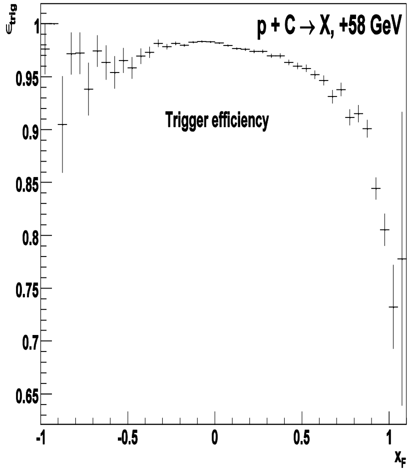


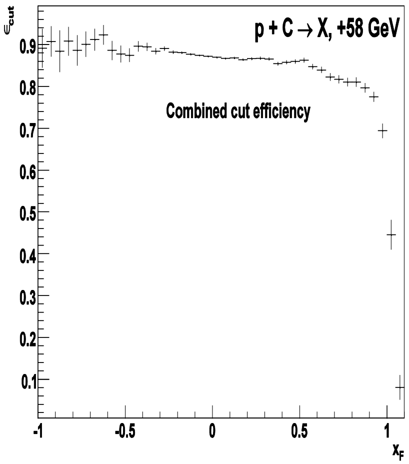


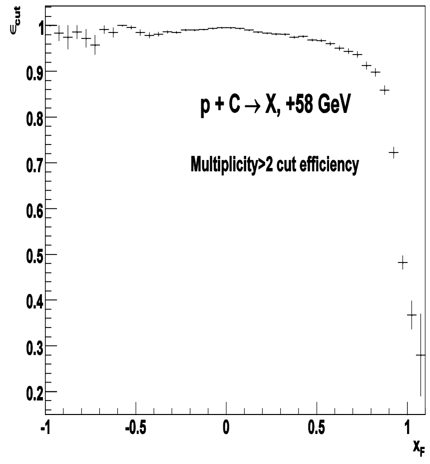


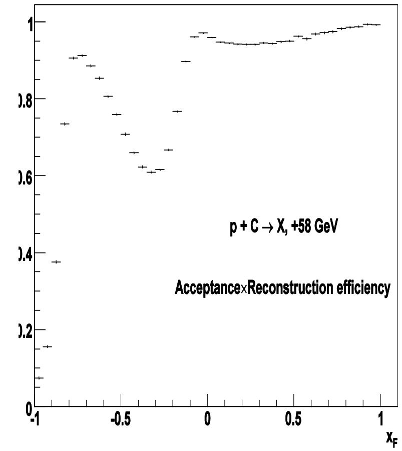


Cut efficiencies in bins of x_F

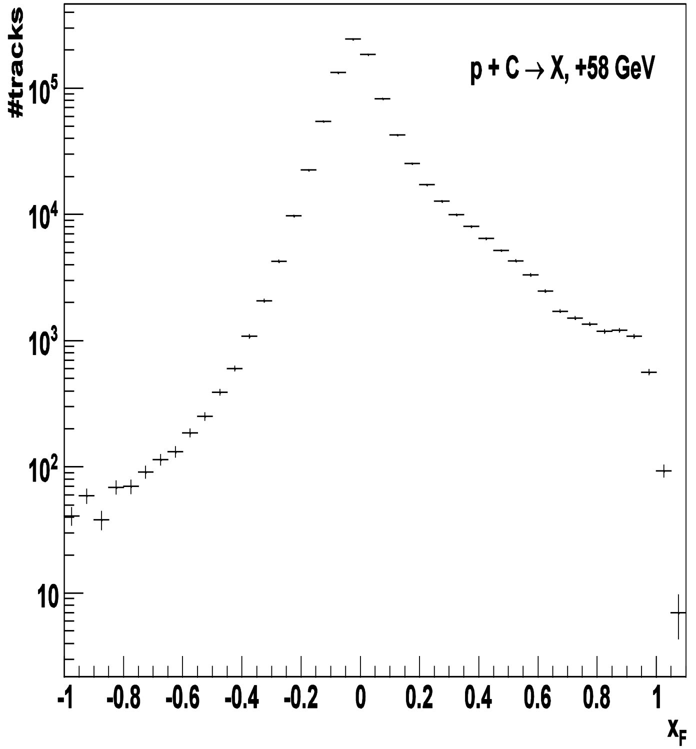








x_F calculation



x_F distribution for p+C interactions at 58 GeV for the reconstructed MC

$$x_F = \frac{p_Z(CM)}{p_{max}(CM)}$$

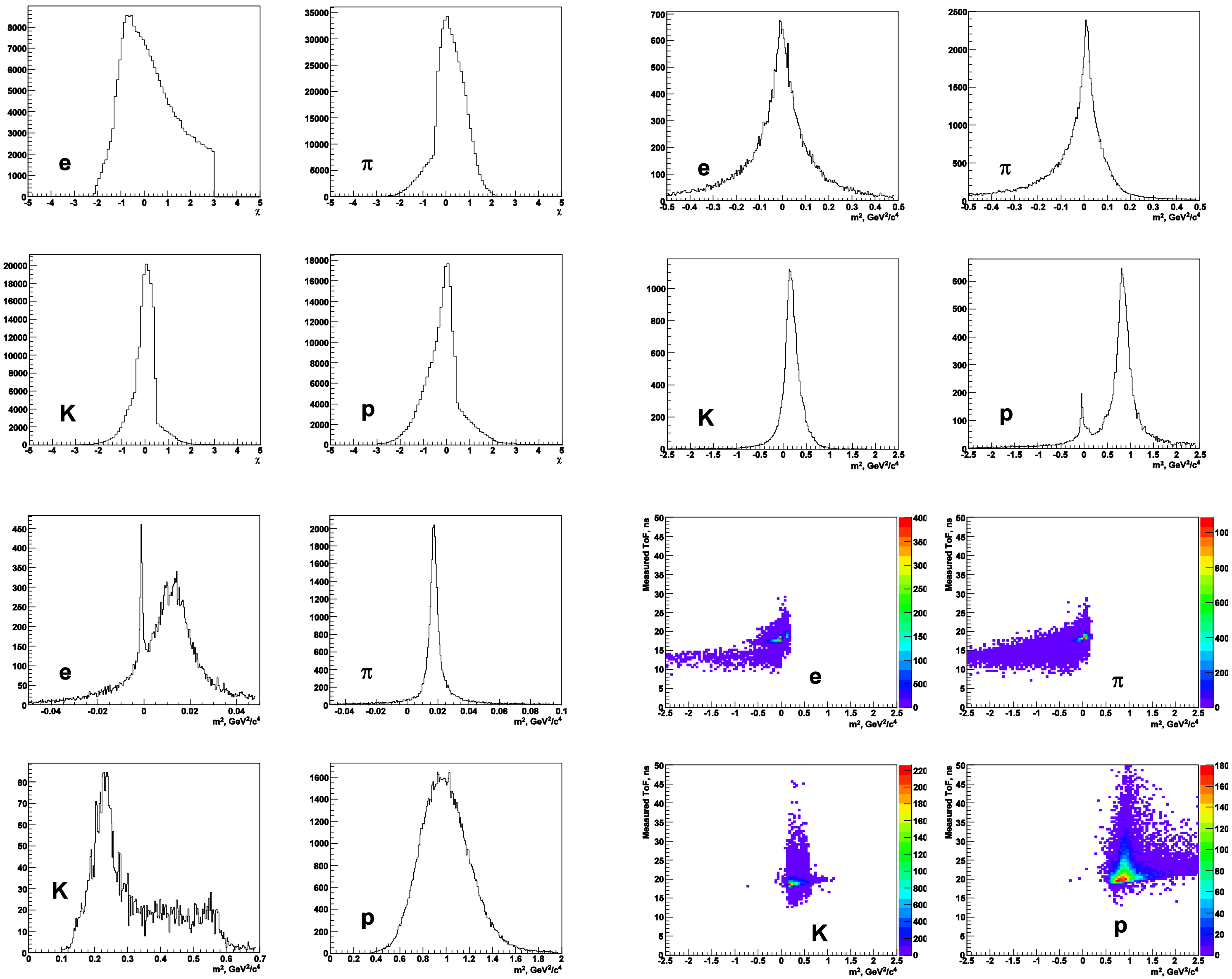
p_Z of particle in center-of-mass (CM) frame is calculated using Lorentz transformation

$$p_{max}(CM) = \frac{\sqrt{\lambda}}{2 \text{ x } ECM}$$

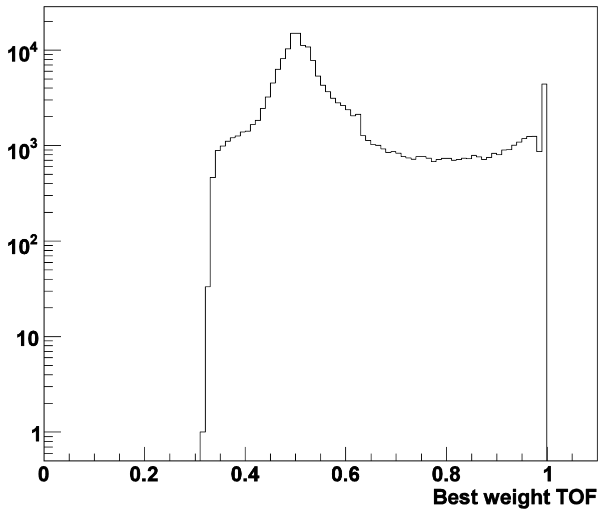
ECM is the center-of-mass energy

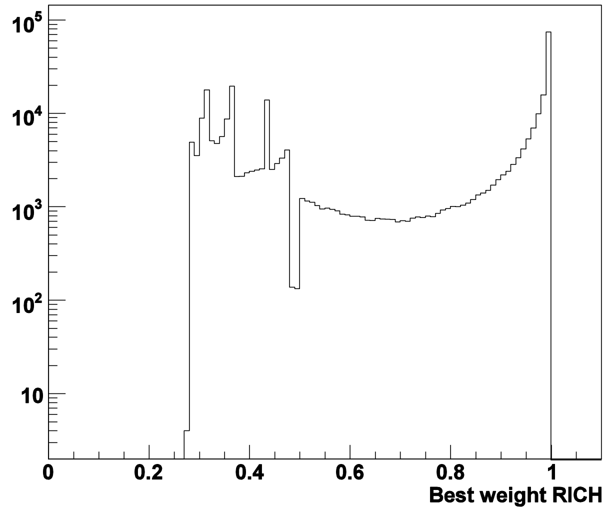
$\lambda=(ECM^2-(m_{Beam}+m_{Tgt})^2) \text{ x } (ECM^2-(m_{Beam}-m_{Tgt})^2)$

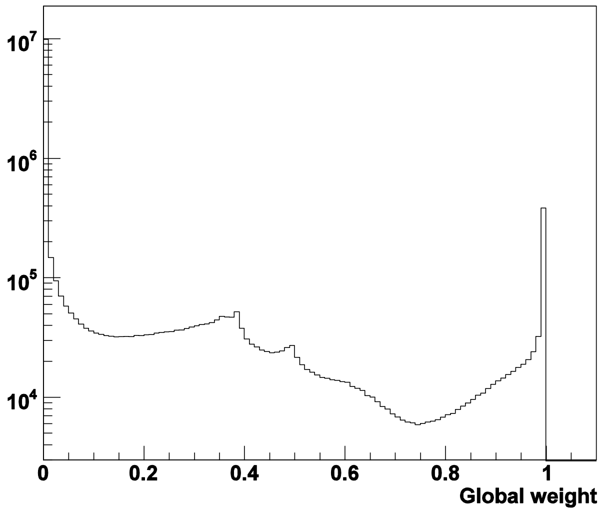
Here beam is proton and target is nucleon

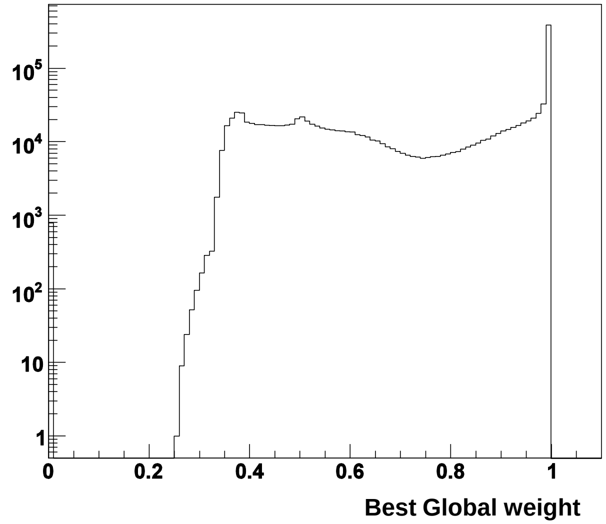


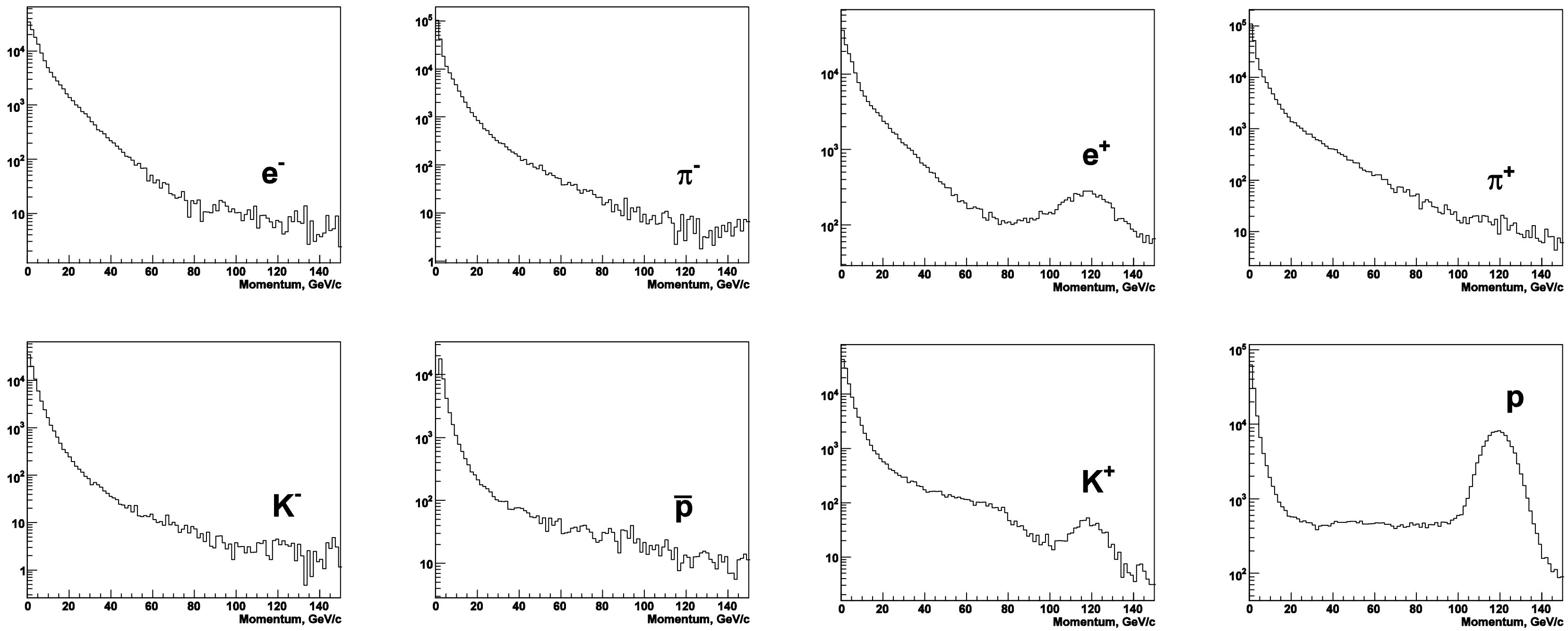
e
π
K
p
χ
m², GeV²/c⁴
Measured ToF, ns


Best weight TOF


Best weight RICH


Global weight


Best Global weight



e⁻
π⁻
e⁺
π⁺
K⁻
p̄
K⁺
p
Momentum, GeV/c