Particle Production Measurements using the MIPP Detector at Fermilab

MIPP

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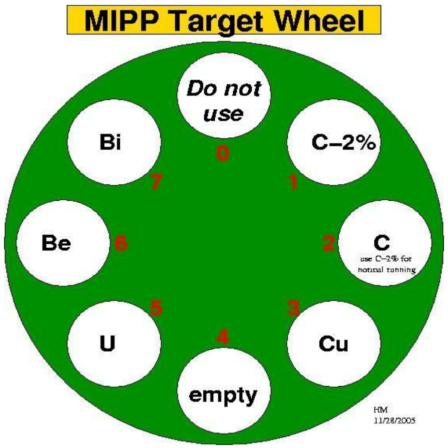
Outline of the talk

- **Introduction**
- **Detector description**
- **Inelastic cross section measurements**
- **Charged particle production cross sections**
- **Summary**

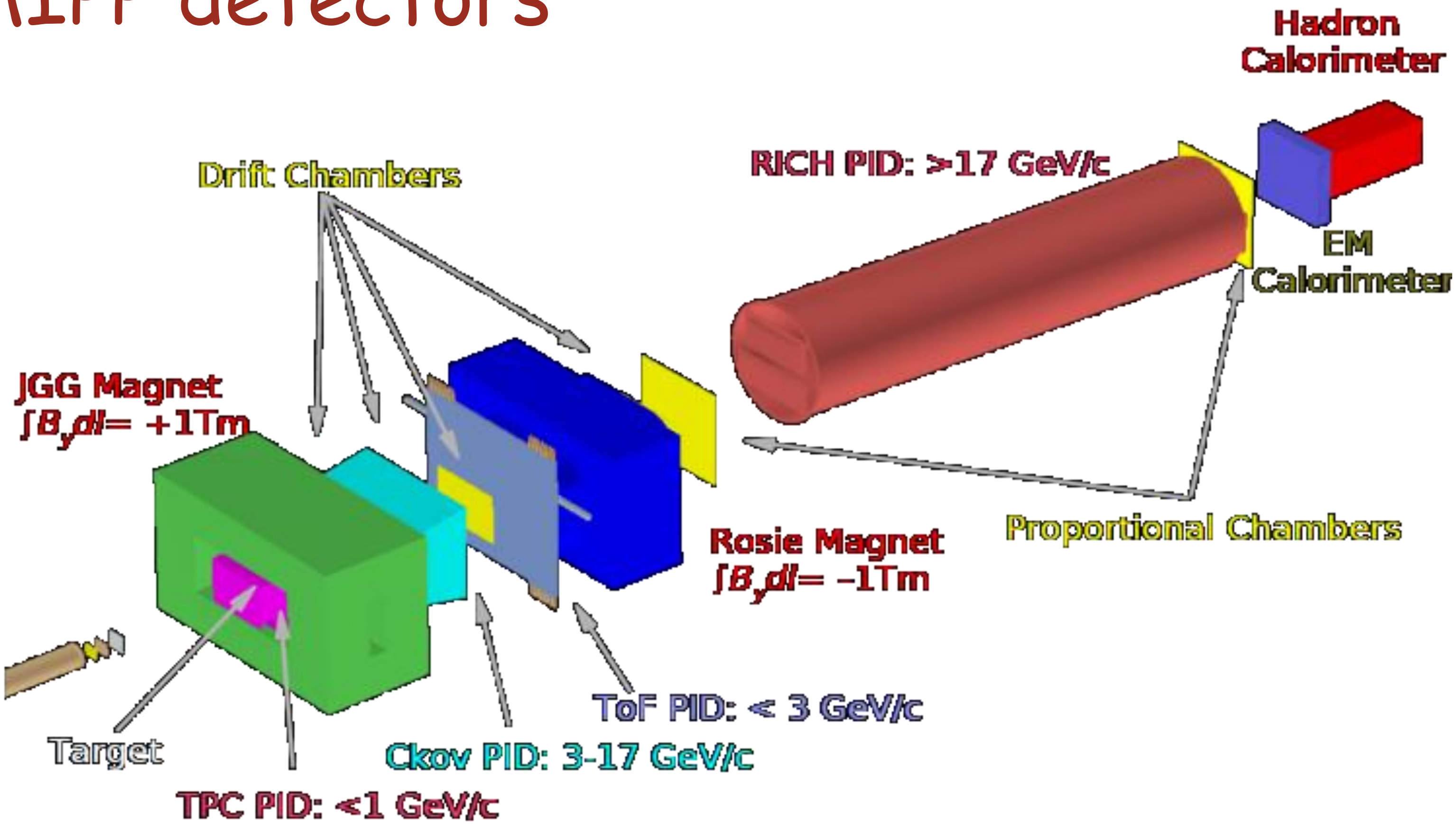
Introduction

- MIPP stands for Main Injector Particle Production
- It is a fixed target hadron production experiment located in the Meson Center beam line at Fermilab
- Operated from January 2005 to February 2006 and collected ~18 million events
- Primary Beam – 120 GeV/c protons from Main Injector
- Secondary Beams – $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ from 5 to 90 GeV/c
- Targets:

  Liquid Hydrogen (1.5 % λ_{I}, 14 cm long and 3.8 cm diameter)
  Be
  C (2 % λ_{I}, 1 cm thick and 2 inch diameter)
  NuMI
  Bi
  U
  (A=1 to A=238)



MIPP detectors



- TPC, 4 drift chambers and 2 proportional wire chambers for tracking
- 2 magnets for charge and momentum measurement
- 2 Beam Cherenkov for beam particle ID. TPC, Time of Flight, Cherenkov and RICH for outgoing particle ID, and Calorimeter for neutrons

Event selection for inelastic cross section measurements

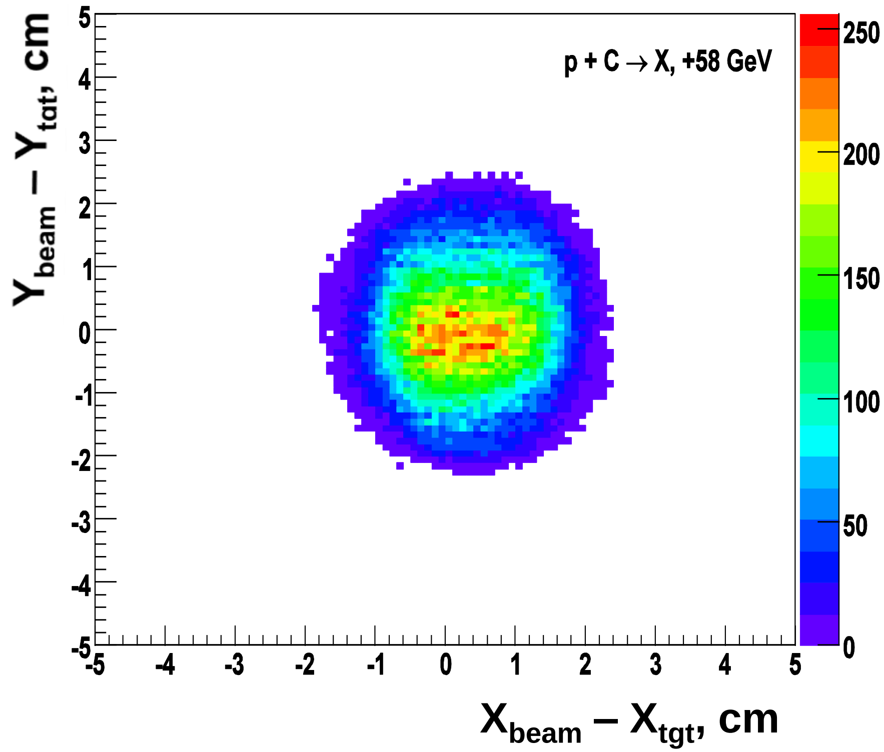
Data sets used: 58 and 85 GeV/c proton on LH_2 target
58 and 120 GeV/c proton on Carbon target

- Select interactions using interaction trigger
- Scintillator-based interaction trigger requires at least 3 charged particles for the scintillator to fire
- Incident beam should be within the target dimensions
- Empty target subtraction to reject the interactions with the scintillator

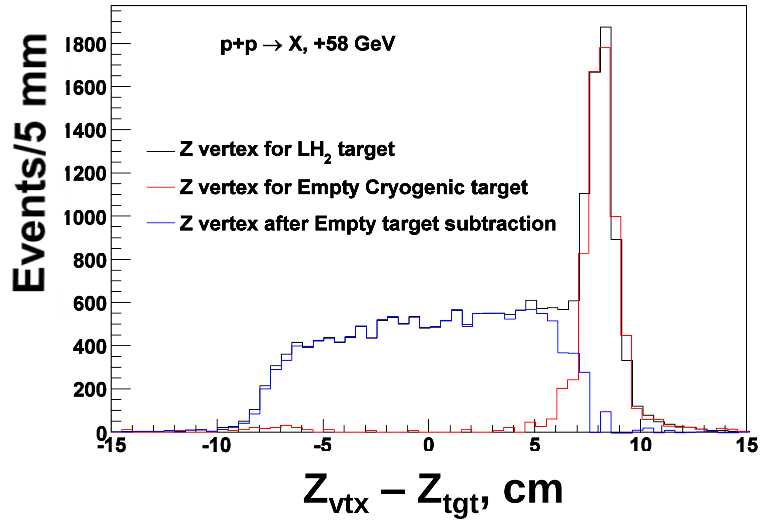
$$\text{Cross section} = \frac{N_{int}}{N_{beam} \times n_t \times \varepsilon}$$

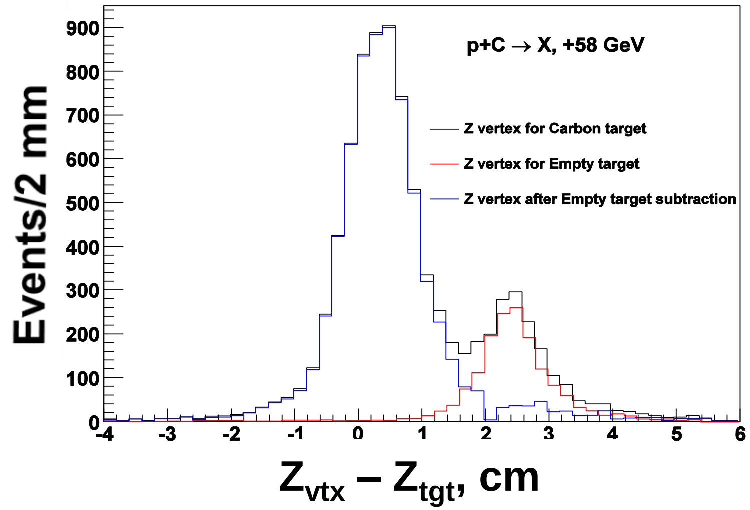
$$n_t = \frac{N_A \times \text{density} \times \text{thickness}}{\text{Atomic weight}}$$

Beam spot position



Z vertex wrt target





Inelastic cross section for 58 and 85 GeV/c proton interactions on LH_2 target

Energy (GeV)	PDG (mb)	DPMJET (mb)	MIPP (MC ε_{trig} applied) (mb)	MIPP (Data ε_{trig} applied) (mb)
58	31.13	31.6	31.94 ± 0.98 (stat) $^{+3.53}_{-4.08}$ (syst)	33.75 ± 1.03 (stat) $^{+3.81}_{-4.38}$ (syst)
85	31.42	31.8	34.51 ± 0.83 (stat) $^{+3.88}_{-4.47}$ (syst)	36.08 ± 0.87 (stat) $^{+4.11}_{-4.71}$ (syst)

Inelastic cross section for 58 and 120 GeV/c proton interactions on Carbon target

Energy (GeV/c)	FLUKA (mb)	MIPP (MC ε_{trig} applied) (mb)	Other measurements (mb)
58	239.14	286.09 ± 13.8 (stat) $^{+29.7}_{-34.9}$ (syst)	252 ± 4 (stat) (Nucl. Phys. B61, (1973), 62) 222 ± 7 (stat+syst) (Phys. Lett. B80, (1979), 319)
120	240.15	223.09 ± 2.5 (stat) $^{+22.9}_{-27.0}$ (syst)	

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 probability of producing n charged particles at a particular energy 's', <n(s)> is average multiplicity and Ψ(n/<n(s)>) is the KNO function

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

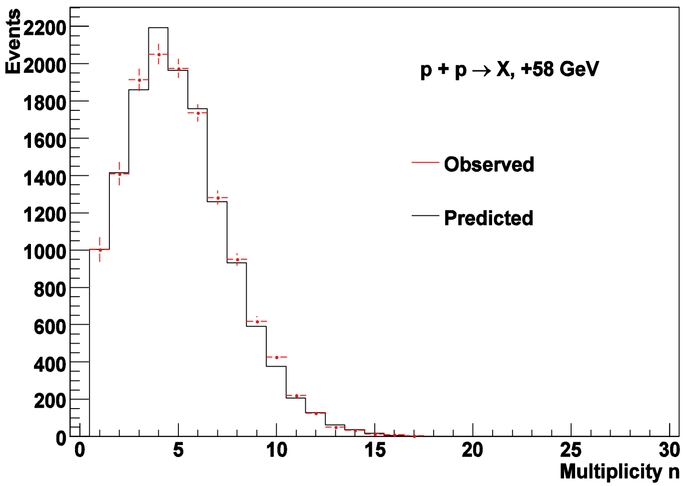
- The method uses a K matrix $K(n_o|n_t)$ – probability of obtaining observed multiplicity n_o, given a true multiplicity n_t (trigger is not required)
- This matrix is multiplied by true probabilities from KNO function to get the predicted distribution
- The observed distribution is fitted to the predicted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

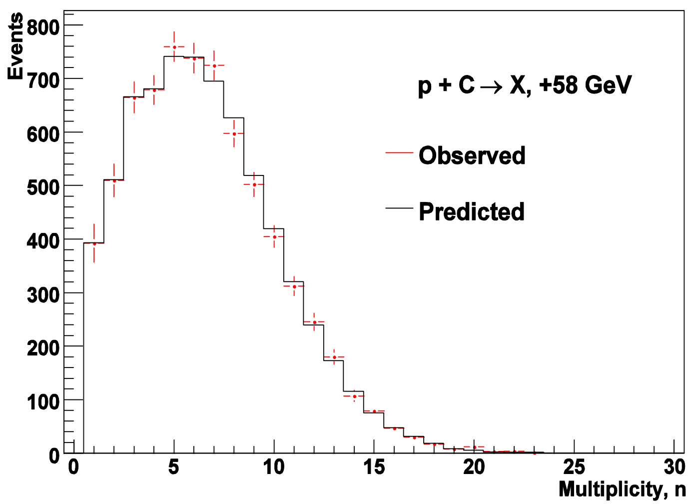
  $$\chi^2 = (\text{Observed} - \text{Predicted})^2/\sigma^2$$

- Trigger efficiencies are the parameters going to be fitted

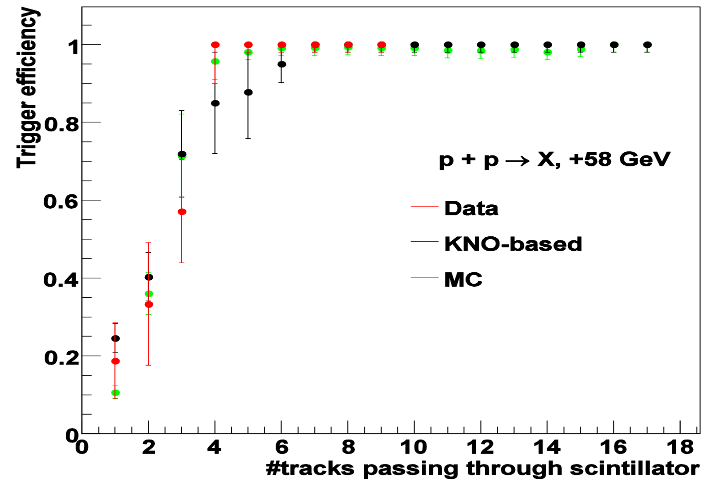
KNO fit results

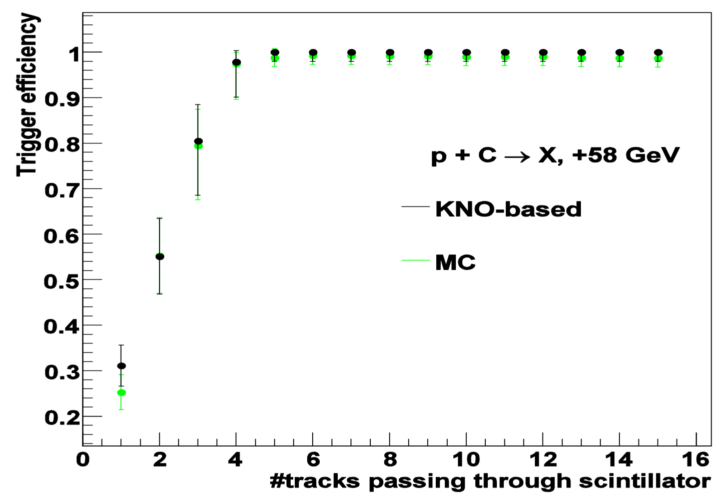
Comparison of observed and predicted multiplicity distributions at the minimum



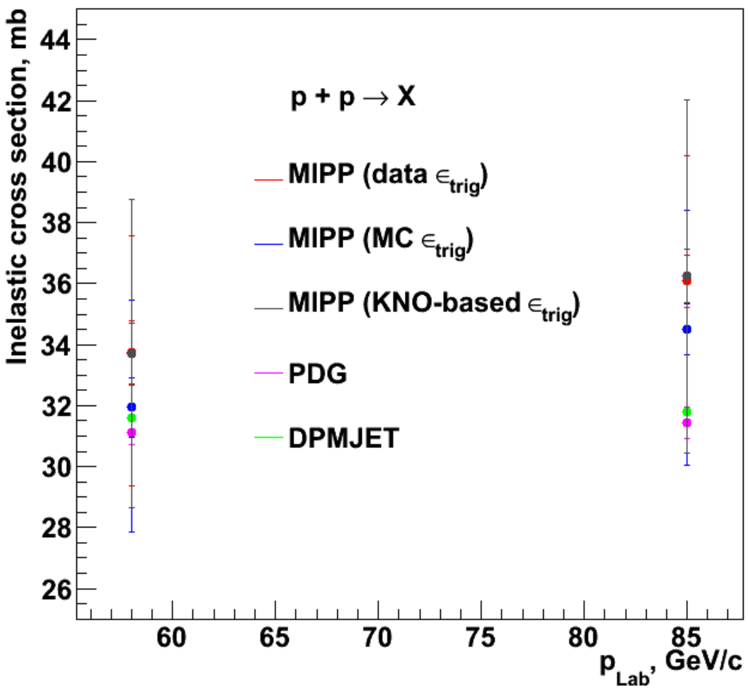


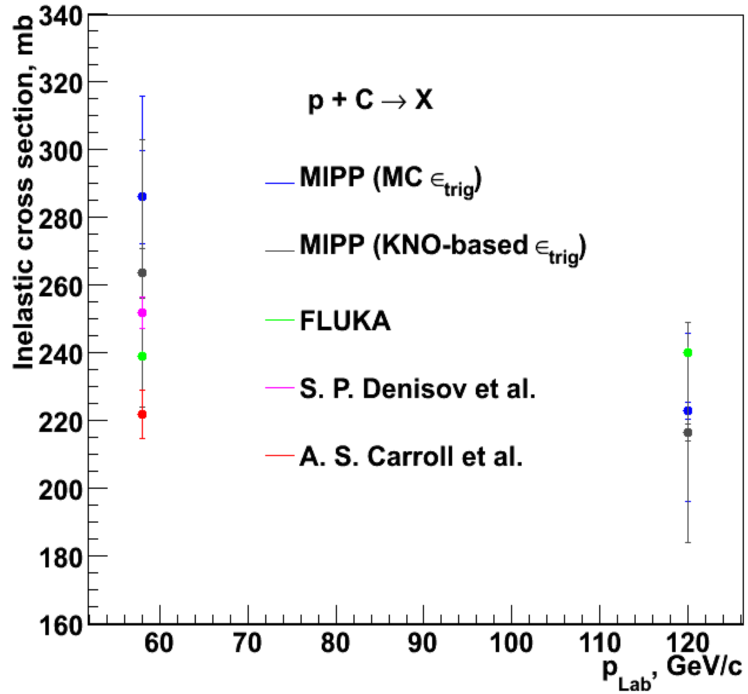
Comparison of trigger efficiencies





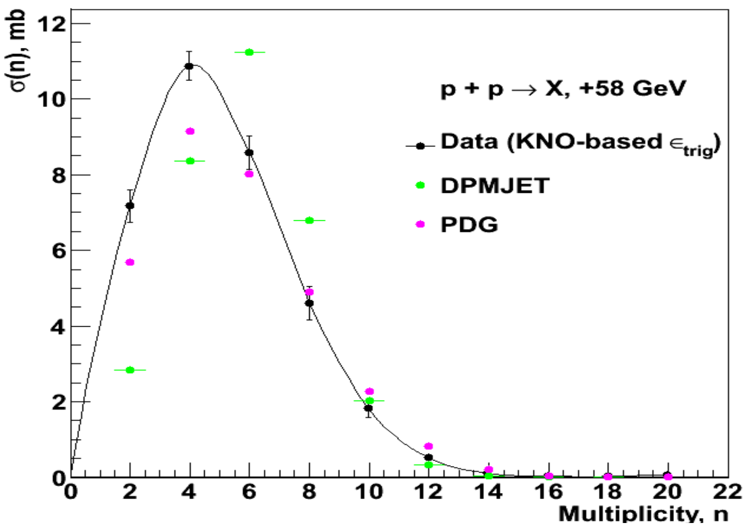
Comparison of MIPP data, MC and other available cross sections

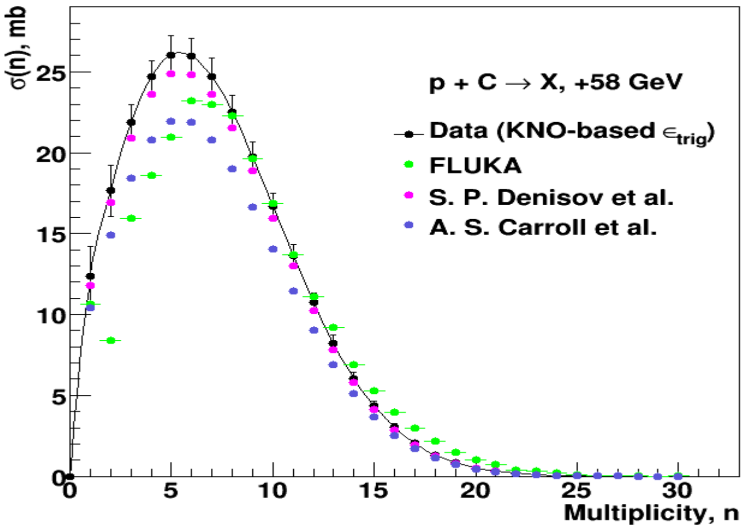




- p+p at 58 and 85 GeV consistent, within error bars, with the DPMJET and PDG
- p+C at 58 GeV consistent, within error bars, with the available measurements and the FLUKA
- p+C at 120 GeV consistent, within error bars, with the FLUKA

LH_2 and Carbon multiplicities





- For LH_2 target, charged multiplicities should be even. Both even and odd multiplicities in data because of acceptances and reconstruction inefficiencies

- KNO Scaling function is used to get the true probabilities. The <n> from our data is used. Probabilities are multiplied by the average inelastic cross section to get the cross sections as a function of multiplicity

- The multiplicities from Carbon target will be 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 one of the two available measurements. The DPMJET and FLUKA shapes not consistent with the data

Charged particle production cross sections

- Select all the charged particles from the primary interaction and calculate the particle production cross sections as a function of momentum, p_T^2 and x_F
- Formula used:

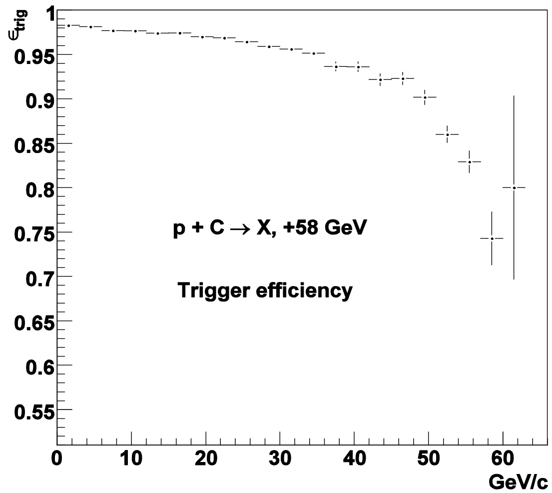
  For example, in case of momentum

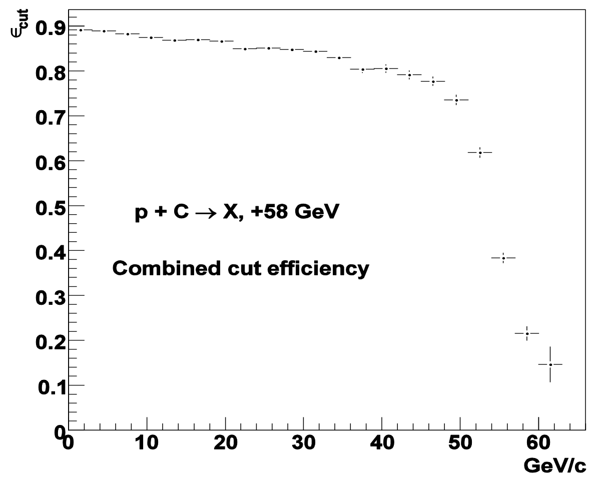
$$\frac{d\sigma}{dp} = \frac{N_{int}}{N_{beam} \times n_t \times \varepsilon \times \Delta p}$$

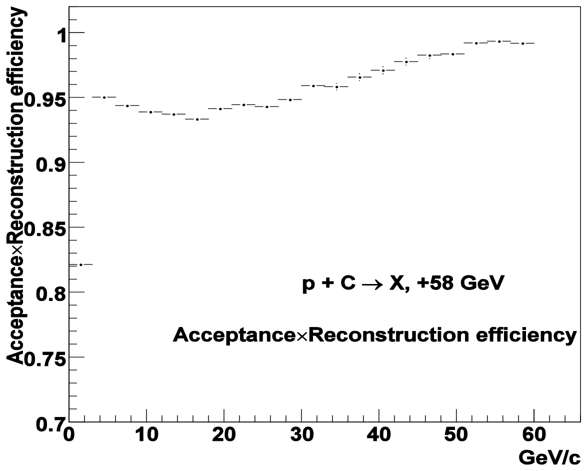
Δp is the momentum bin width

- The data and Monte Carlo cross sections are calculated and compared

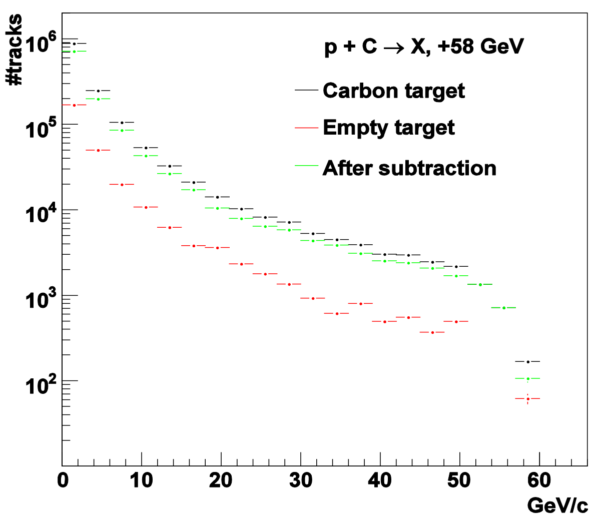
Cut efficiencies in bins of momentum for p+C interaction at 58 GeV

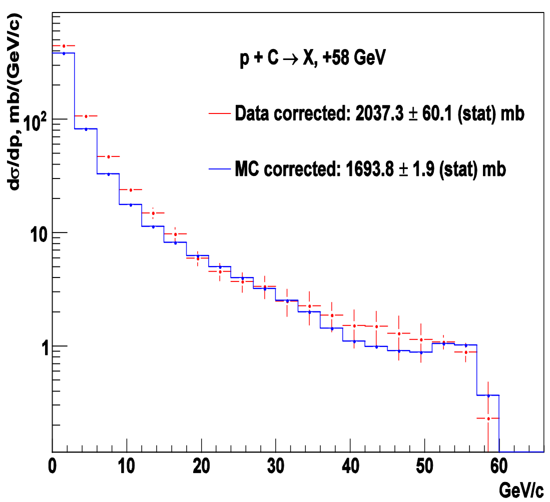


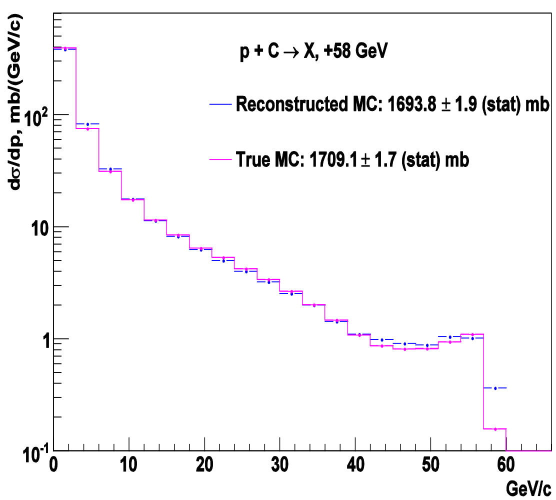




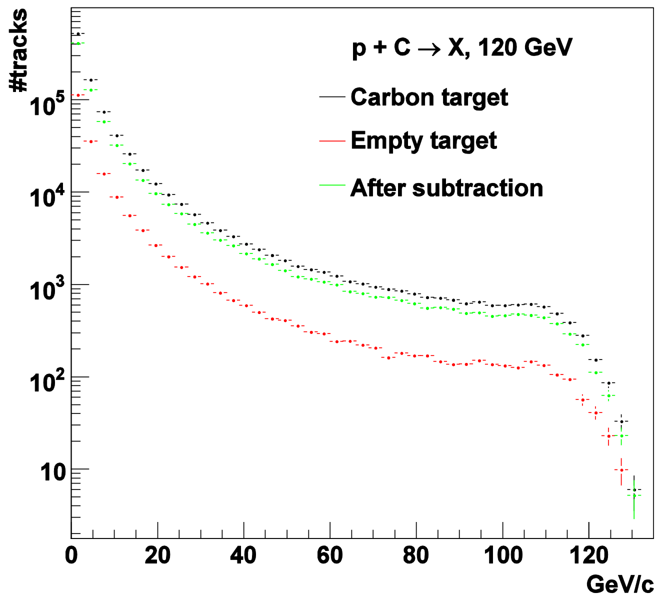
Production cross sections in bins of momentum

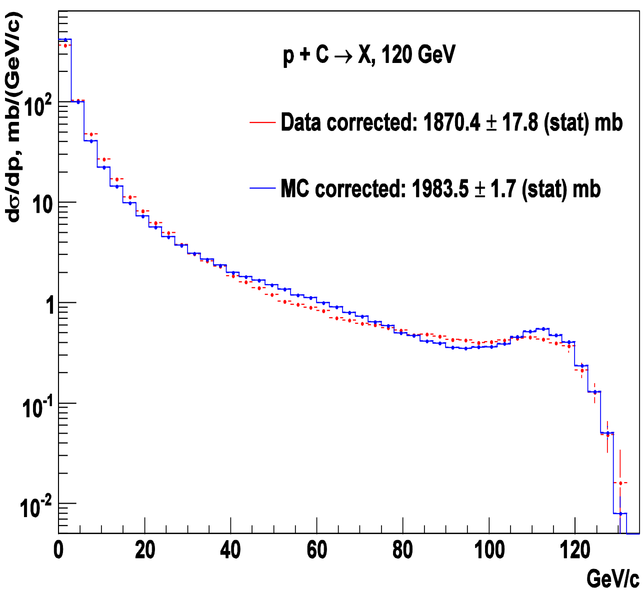






Production cross sections in bins of momentum at 120 GeV





Data cross section for p+C interaction at 58 GeV: 2037.3 ± 60.1 (stat) $^{+141.4}_{-166.7}$ (syst) mb

MC cross section for p+C interaction at 58 GeV: 1693.8 ± 1.9 (stat) $^{+90.6}_{-100.6}$ (syst) mb

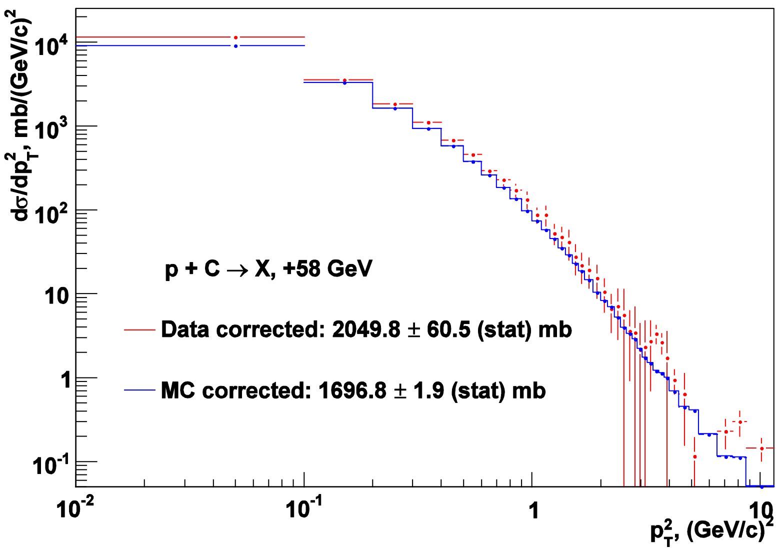
Data is 20% higher than MC for 58 GeV

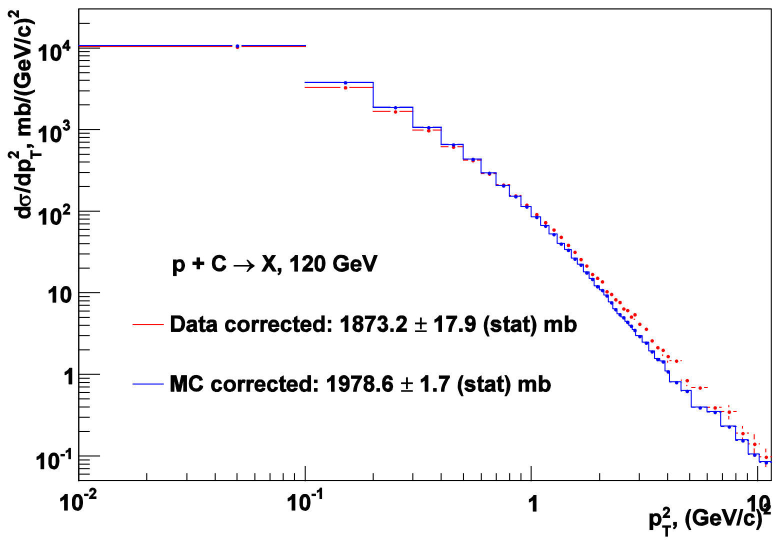
Data cross section for p+C interaction at 120 GeV: 1870.4 ± 17.8 (stat) $^{+117.7}_{-138.6}$ (syst) mb

MC cross section for p+C interaction at 120 GeV: 1983.5 ± 1.7 (stat) $^{+108.3}_{-123.7}$ (syst) mb

Data is consistent, within error bars, with MC for 120 GeV

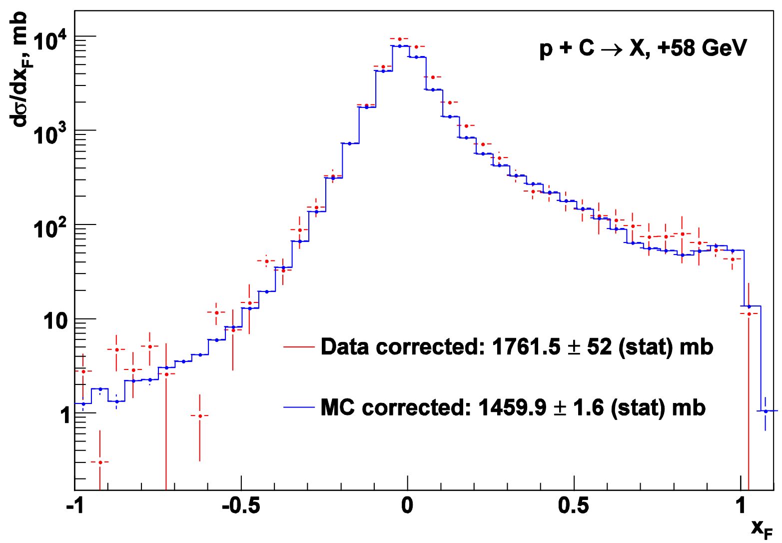
Production cross sections in bins of p_T^2 – data and MC comparison

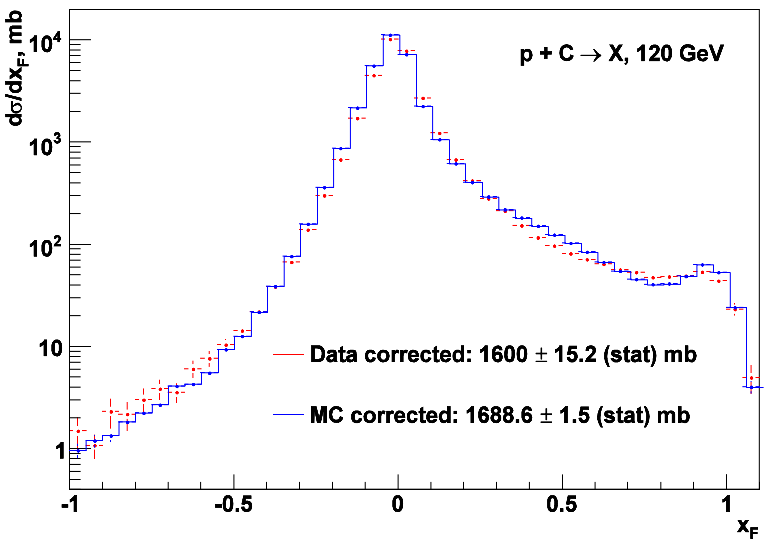




Production cross sections in bins of x_F - data and MC comparison

Acceptance not applied





Summary

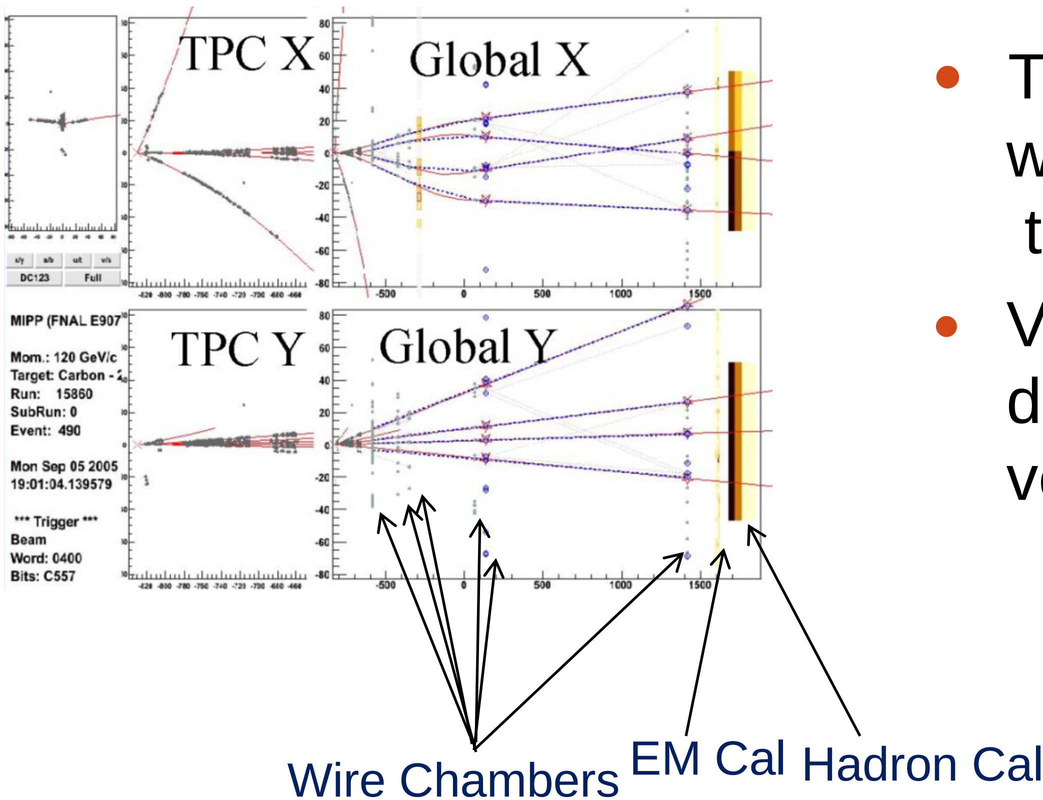
- ✓ Inelastic cross section measurement has been done for proton interaction at different beam energies with Liquid Hydrogen and Carbon target
- ✓ Described KNO-based technique to get the trigger efficiency
- ✓ Compared MIPP data cross sections with MC and other available measurements
- ✓ Data and MC charged particle production cross sections have been measured in bins of momentum, p_T^2 and x_F for p+C interaction at 58 and 120 GeV and compared
- ✓ Detailed study of systematic errors in progress
- ✓ Our next step is the charged particle identification. $\pi^{\pm}$ and $K^{\pm}$ production cross sections as a function of p_T^2 and x_F will be calculated

THANK YOU

Backup

Track and vertex reconstruction

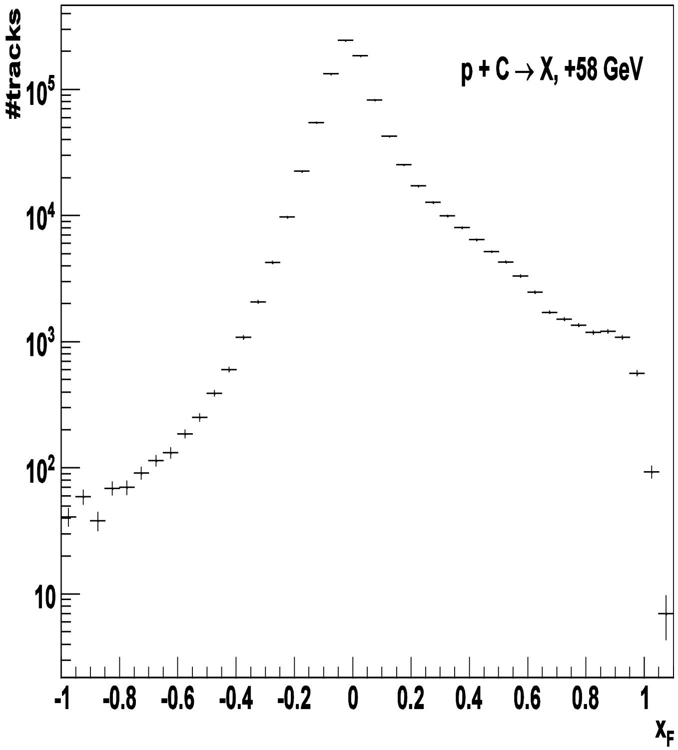
Reconstructed 120 GeV/c proton on Carbon event



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

Backup

x_F calculation



x_F distribution for p+C interaction at 58 GeV for 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

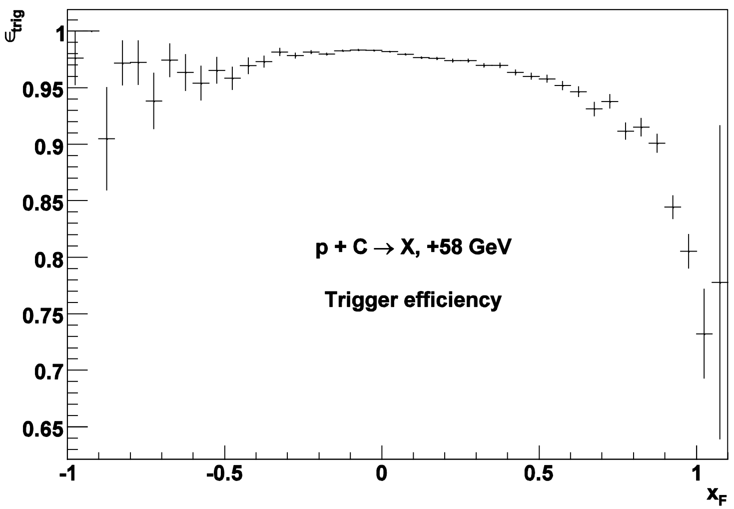
$$p_{max}(CM) = \frac{\sqrt{\lambda}}{2xECM}$$

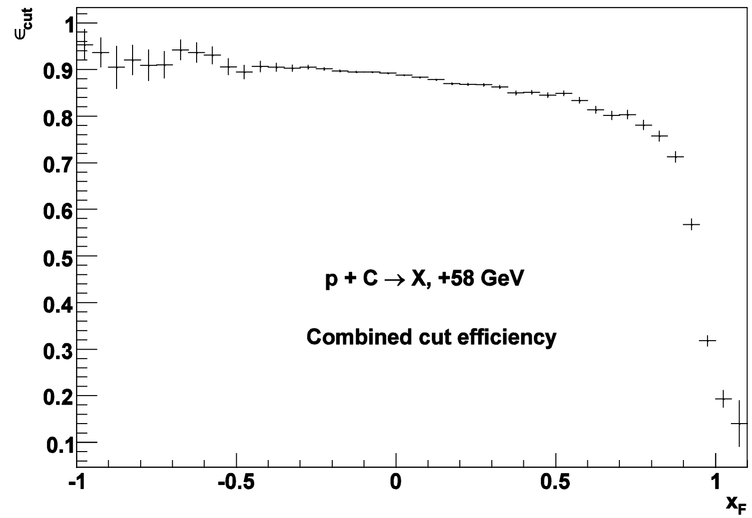
ECM is the center-of-mass energy

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

Here beam is proton and target is nucleon

Cut efficiencies in bins of x_F (Backup)





Cut efficiencies in bins of p_T^2