University of Pittsburgh's

Department of Physics and Astronomy
PITT PACC Workshop:

Flux Measurement and Determination in the Intensity Frontier Era Neutrino Beams

December 6-8, 2012, Pittsburgh, PA, USA

MINERνA Flux:

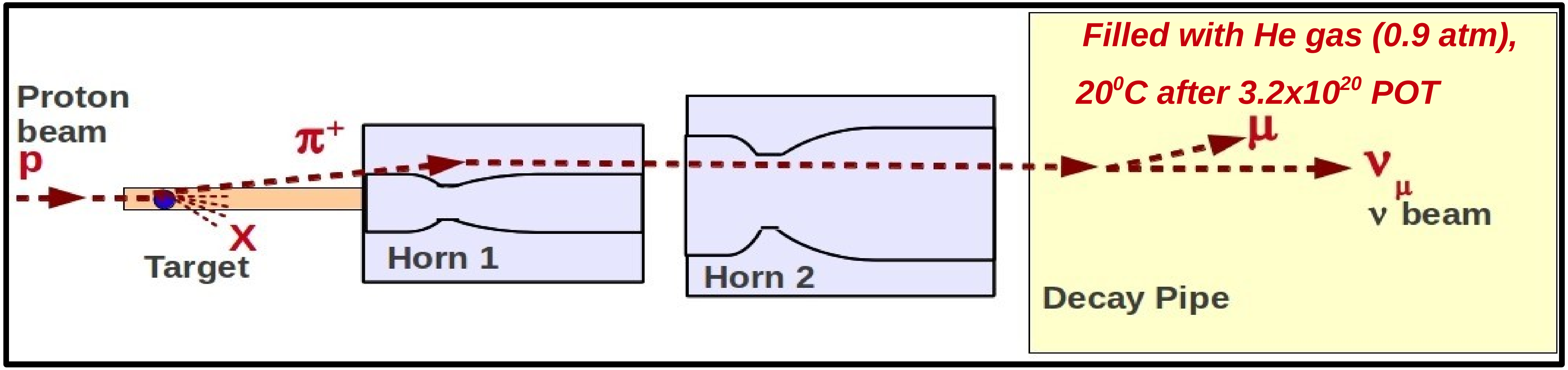
Current Uncertainties And Future Plans

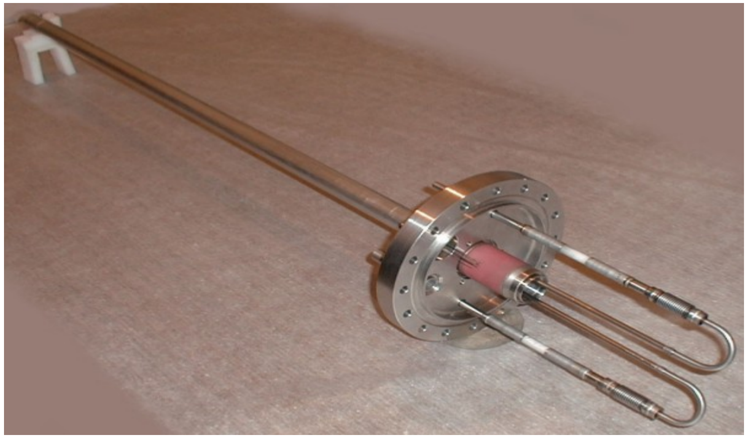
Leonidas Aliaga
(presented by Vittorio Paolone/UPitt)
William & Mary

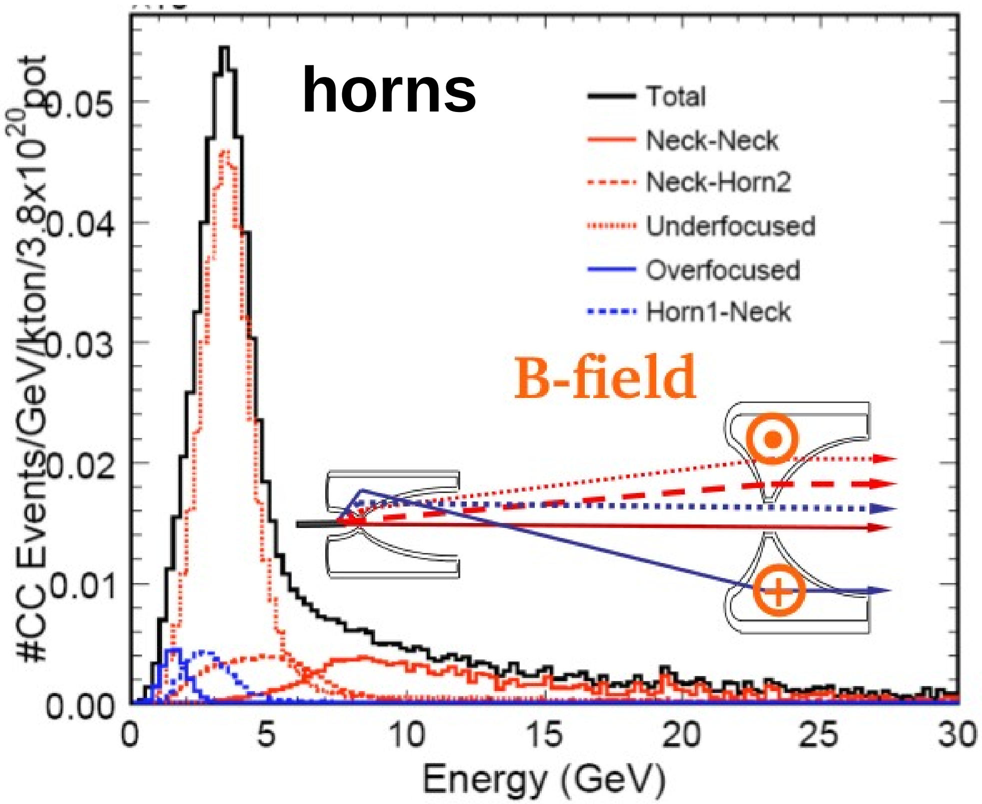
Outline

- (Quick) Description of NuMI.
- Our Present Understanding of the NuMI Flux.
- Improving our Flux knowledge
  - Minerva's strategy
- Conclusions and future steps.

Hadron production and focusing

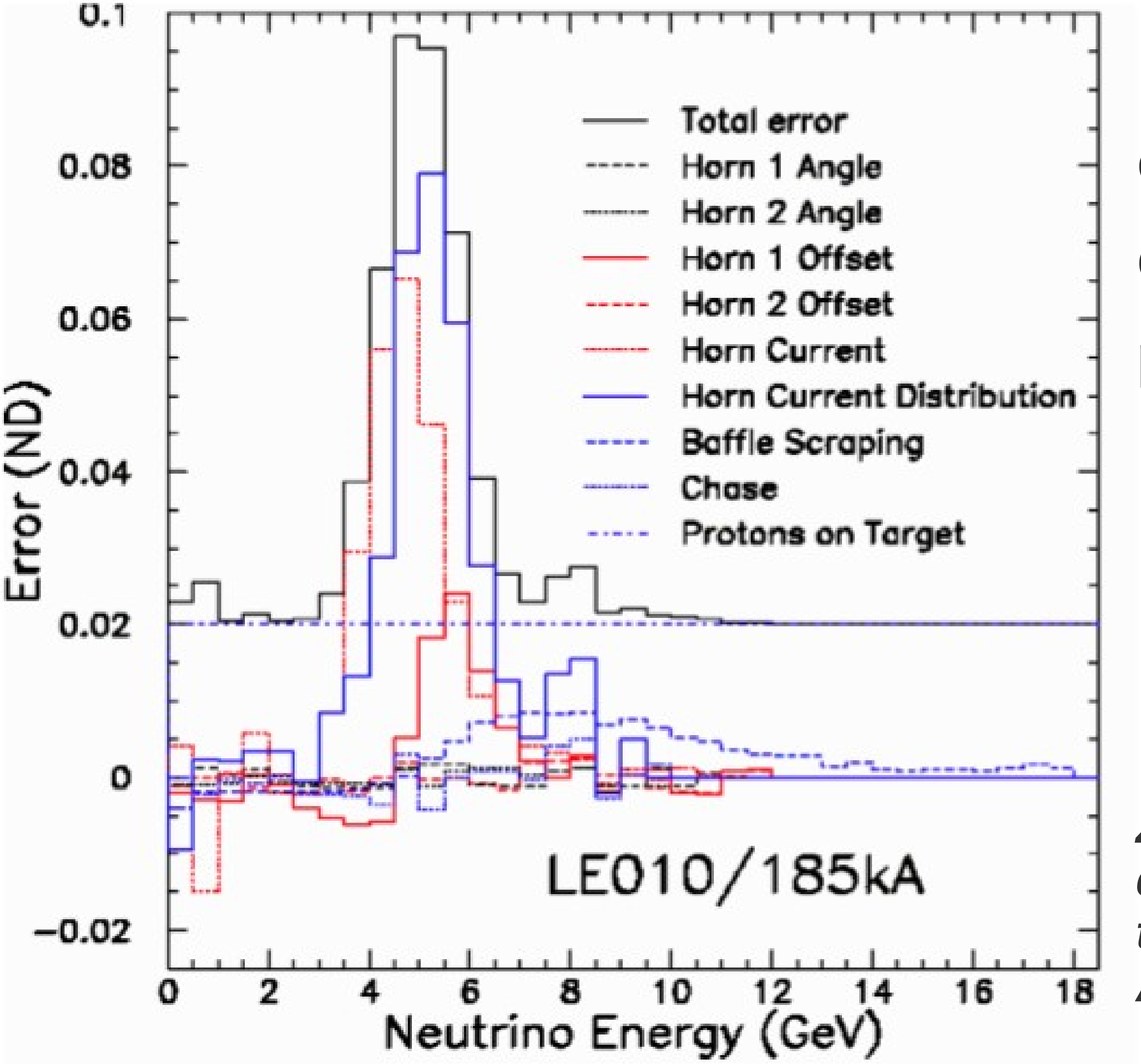






- *Rectangular graphite rod, 6.4 x 15mm^2.*
- *Segmented in 47 "fins".*
- *Total length 940mm (~2 λ).*
- *Water cooled and Enclosed in He filled.*

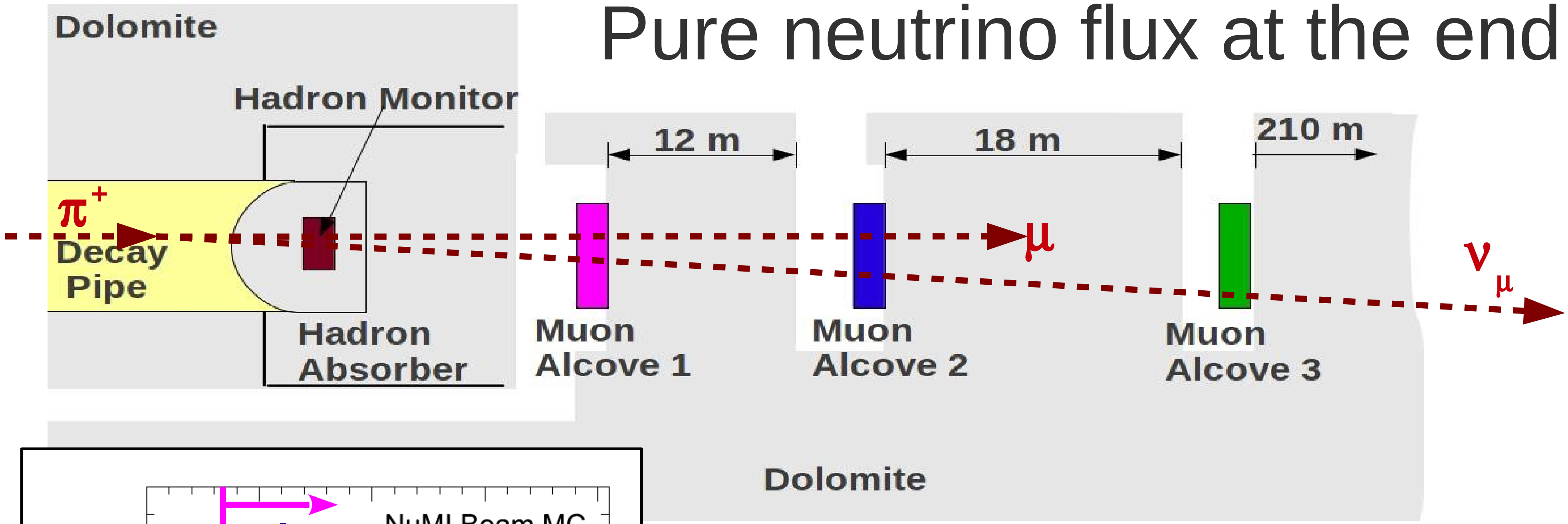
Total focusing uncertainties...

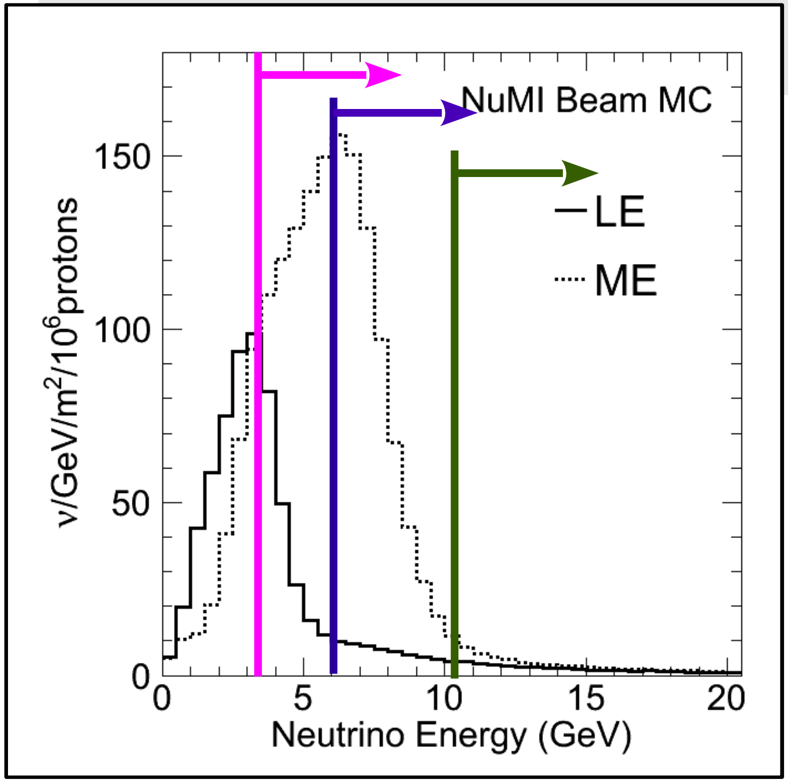


Focusing uncertainties are expected to be small in comparison with hadron production uncertainties.

Z. Pavlovich, "Observation of disappearance of muon neutrinos in the NuMI beam", PhD thesis, UT Austin 2008

Pure neutrino flux at the end..





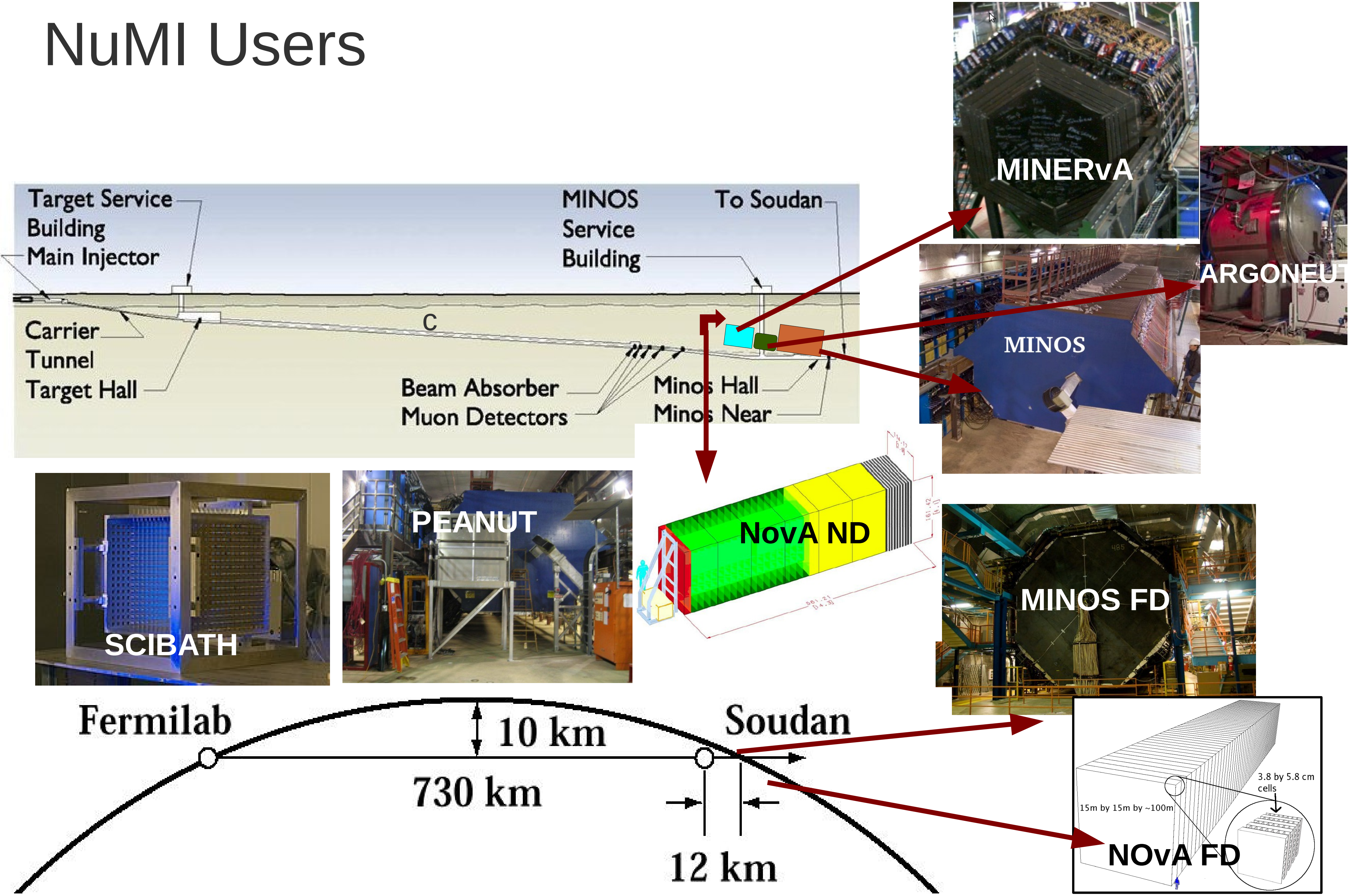
Muon Monitor 1: $E_{\mu,\pi}$ > 4.2 GeV & E_ν > 1.8 GeV

Muon Monitor 2: $E_{\mu,\pi}$ > 11 GeV & E_ν > 4.7 GeV

Muon Monitor 3: $E_{\mu,\pi}$ > 21 GeV & E_ν > 9.0 GeV

- *Detectors: He ionization chambers (However there is contamination by neutrons and δ-rays.)*
- *Kinematics related to hadrons produced off the target and ν's.*

NuMI Users

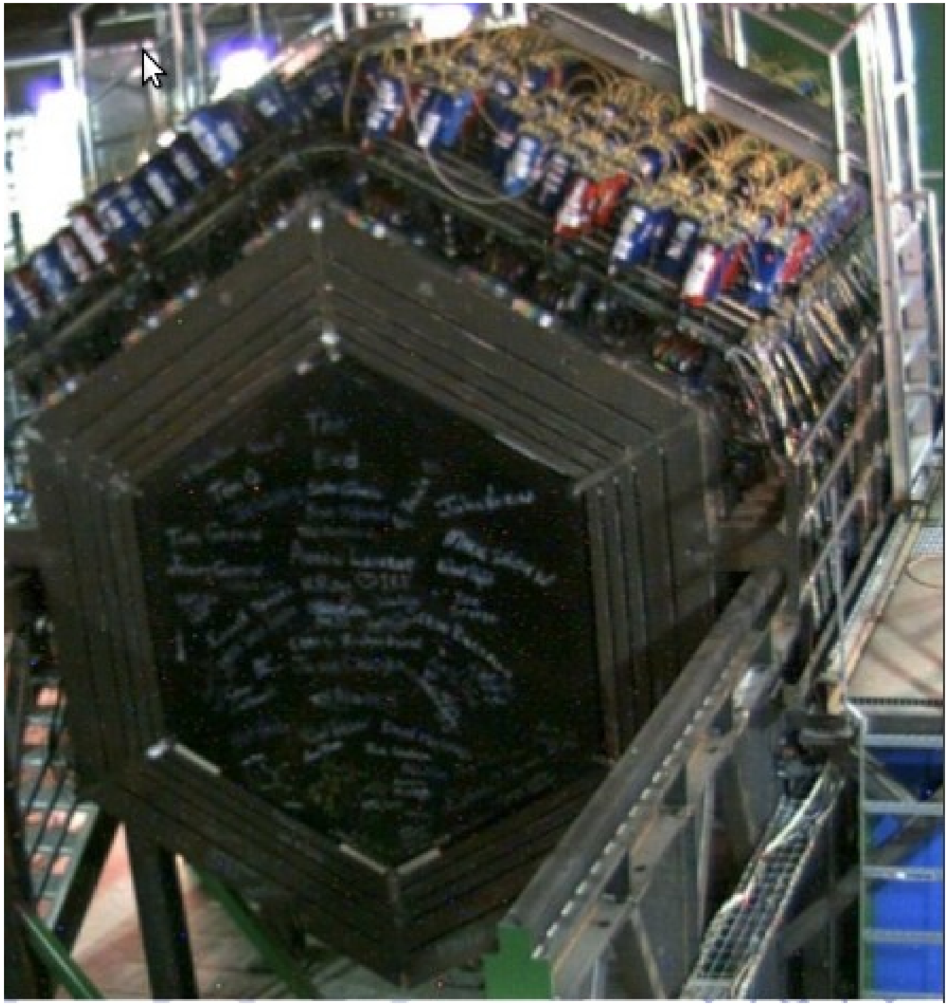


MINERvA
ARGONEUT
MINOS
Target Service Building
Main Injector
MINOS Service Building
To Soudan
C
Carrier Tunnel
Target Hall
Beam Absorber
Muon Detectors
Minos Hall
Minos Near
NovA ND
SCIBATH
PEANUT
MINOS FD
Fermilab
10 km
Soudan
730 km
12 km
3.8 by 5.8 cm cells
15m by 15m by ~100m
NOvA FD

But in this talk we're particularly interested in Minerva...

Our main goals are to measure:

- ***Neutrino-nucleus cross sections of exclusive and inclusive final states.***
- ***The nuclear effects on the ν-A interactions and form factors and structure functions.***



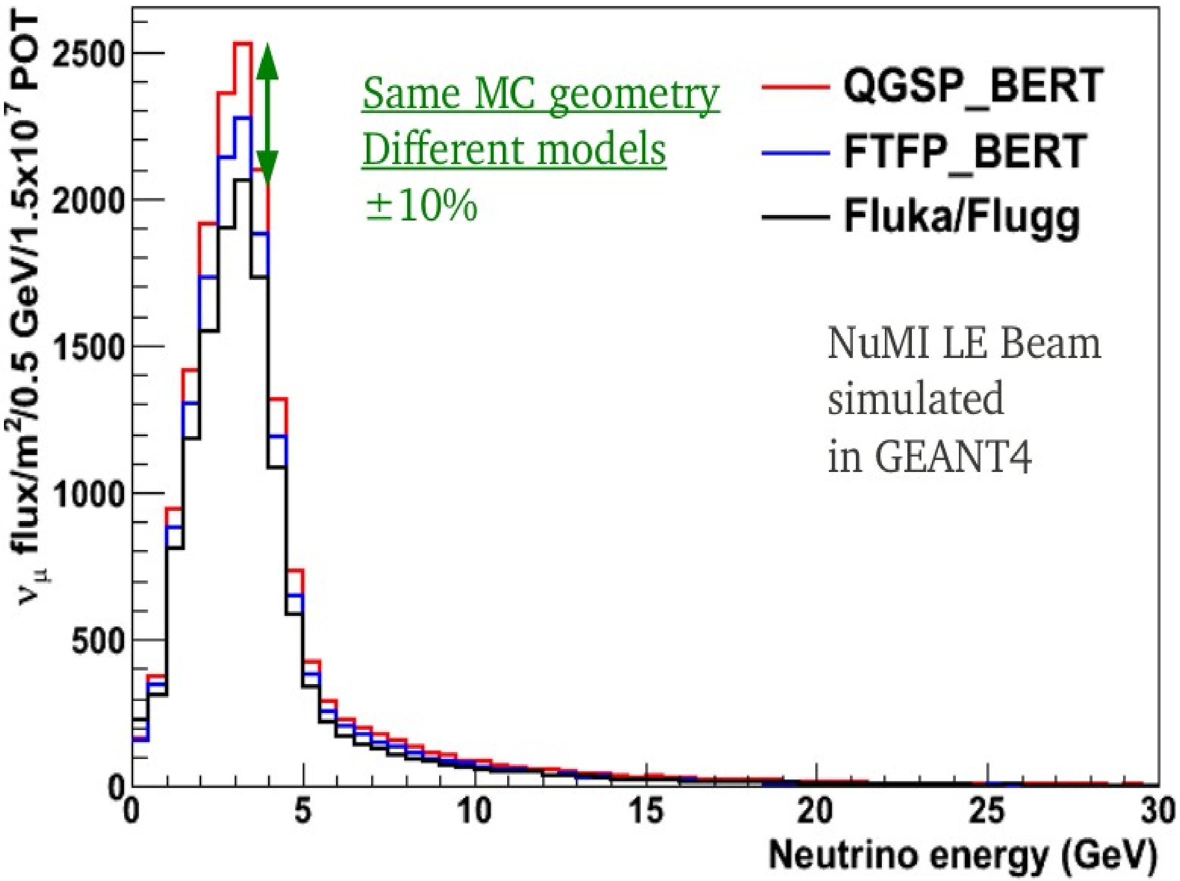
To produce high precision measurements of absolute cross sections...

→ We need to know our flux

Understanding the Flux

- *Big discrepancies between predictions from hadronic models.*
- *We need to go back to the history of every neutrino:*

What happens with the neutrino ancestors and their interactions?



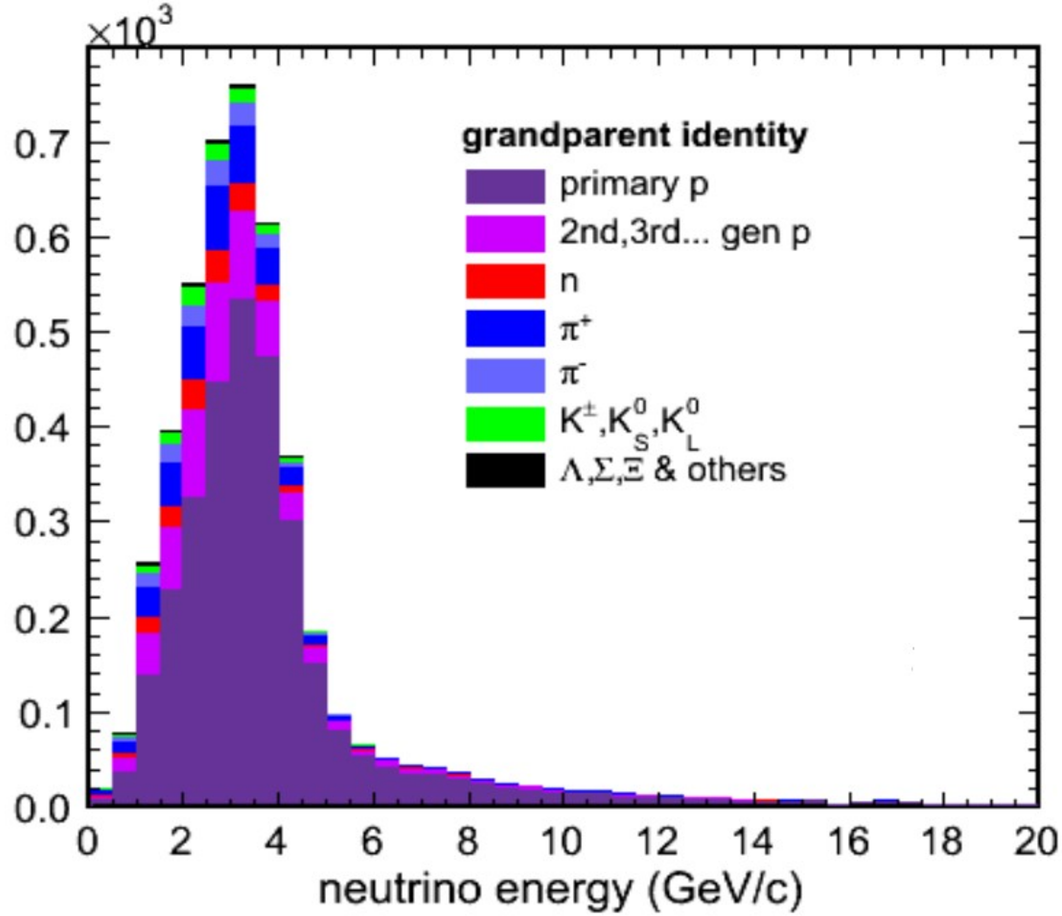
- *MINERvA uses a geant4 based MC for Flux simulation and FTFP **(FRITIOF Precompound (FTFP) model)***

π^+ which produce ν_μ passing through MINOS/MINERvA

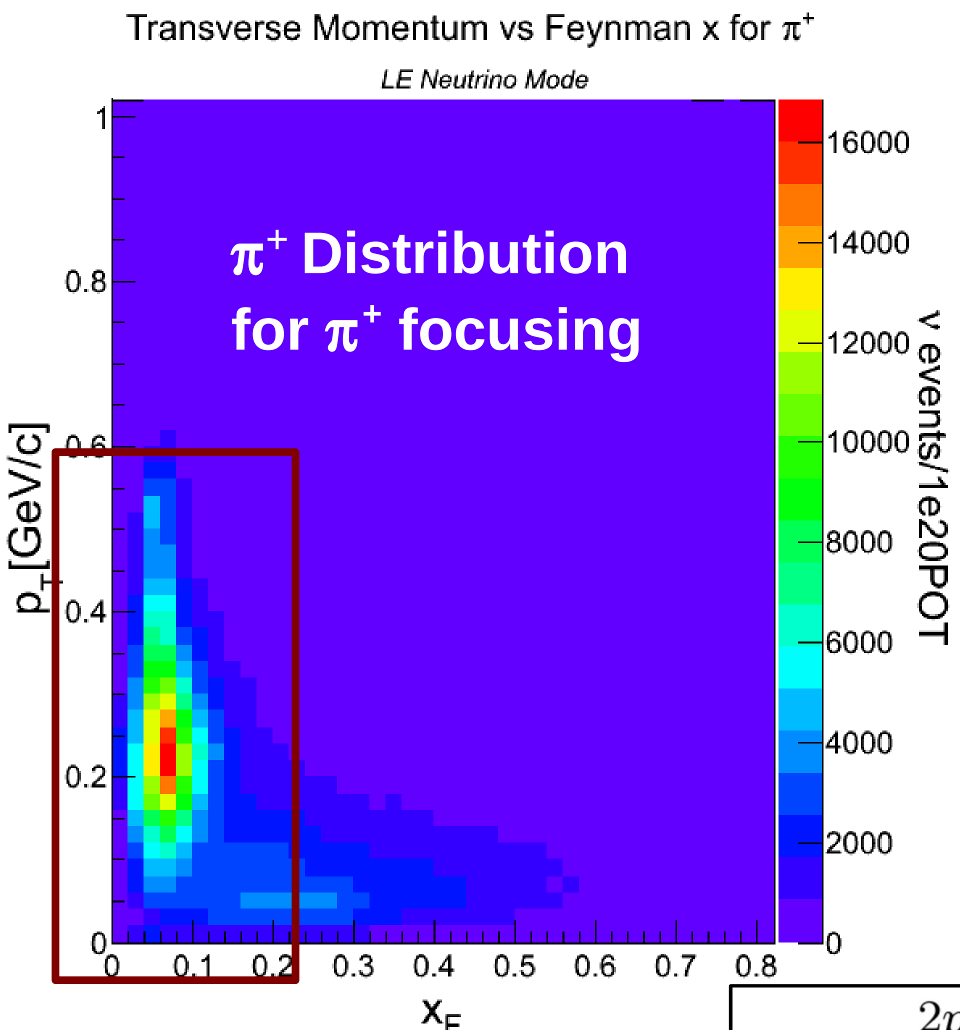
Origin

Target Fins (84.4%) & "Budal Monitor (4.6%) [C]"	**89.0 %**
Decay Pipe Walls [Fe]	**2.6%**
Target Hall Chase [air]	**2.2%**
Decay Pipe [He]	**1.8%**
Horn 1 Inner Conductor [Al]	**1.5%**
All other summed	**2.9%**

Parent of π^+

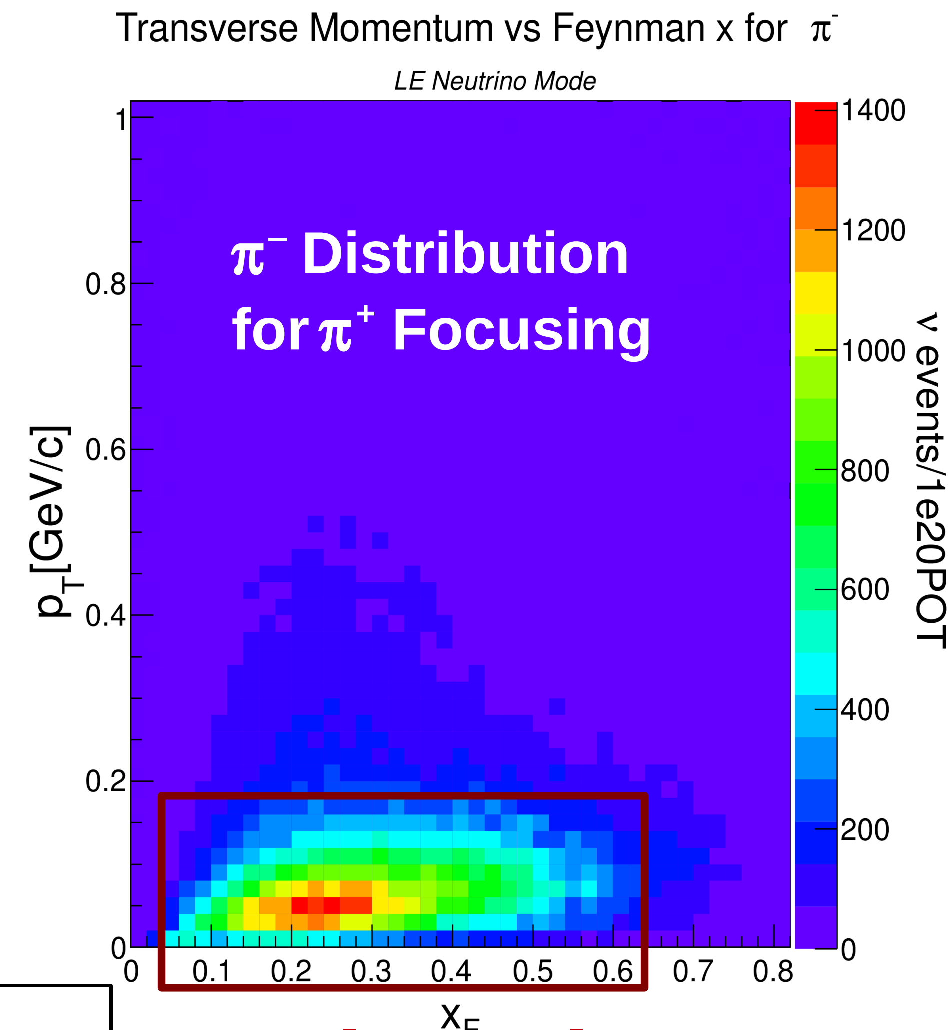


pC-> $\pi^{+/-}$X Distributions for LE Configuration



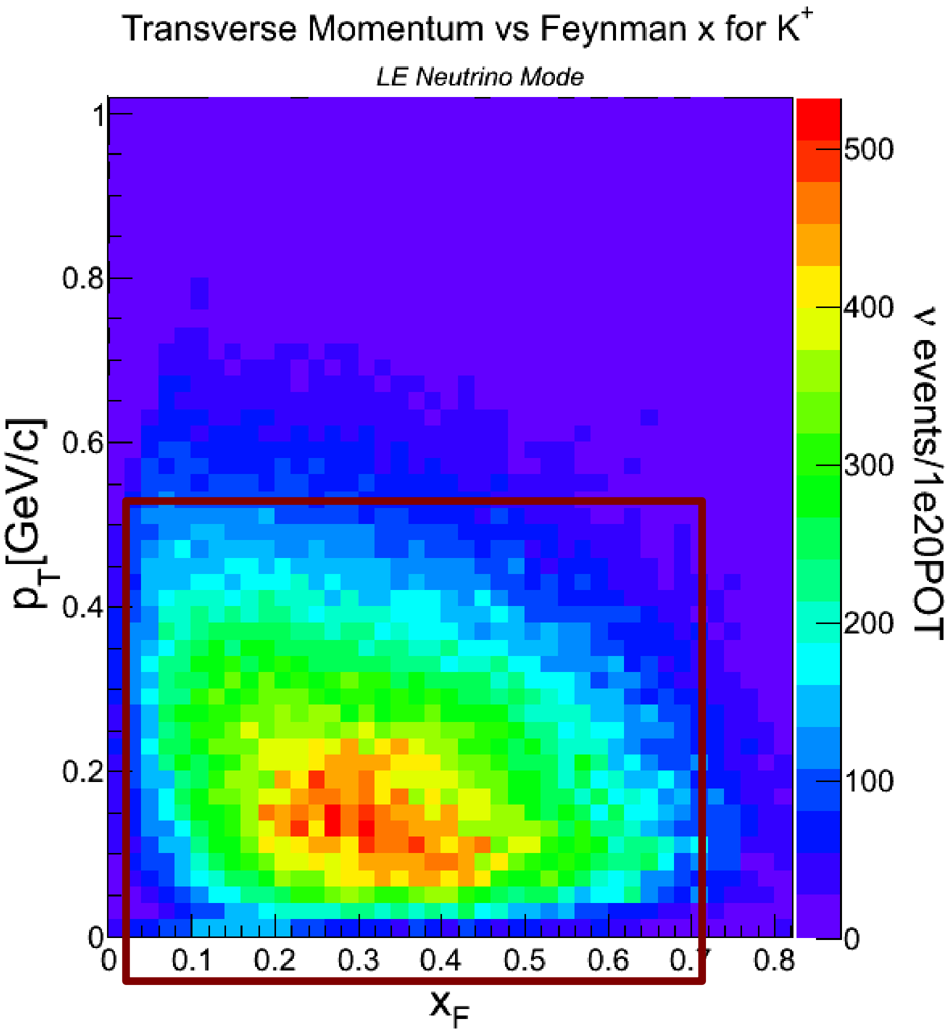
Focusing peak:
x_F [0.0, 0.16]
p_T [0.0, 0.6] GeV/c

$$x_F = \frac{2p_L^*}{\sqrt{s}}$$
x_F: Feynman-x



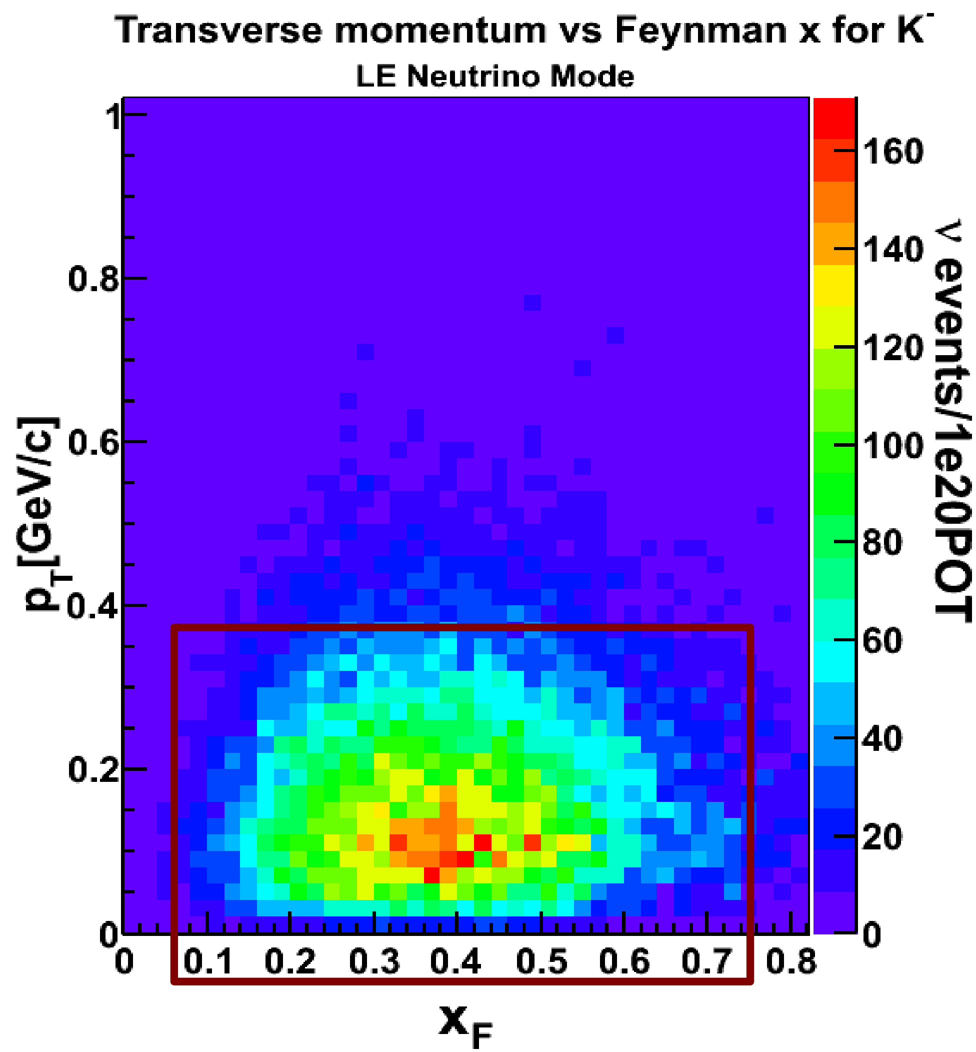
x_F [0.0, 0.6]
p_T [0.0, 0.2] GeV/c

pC-> $K^{+/-}X$ Distributions for LE Configuration



x_F [0.0, 0.7]

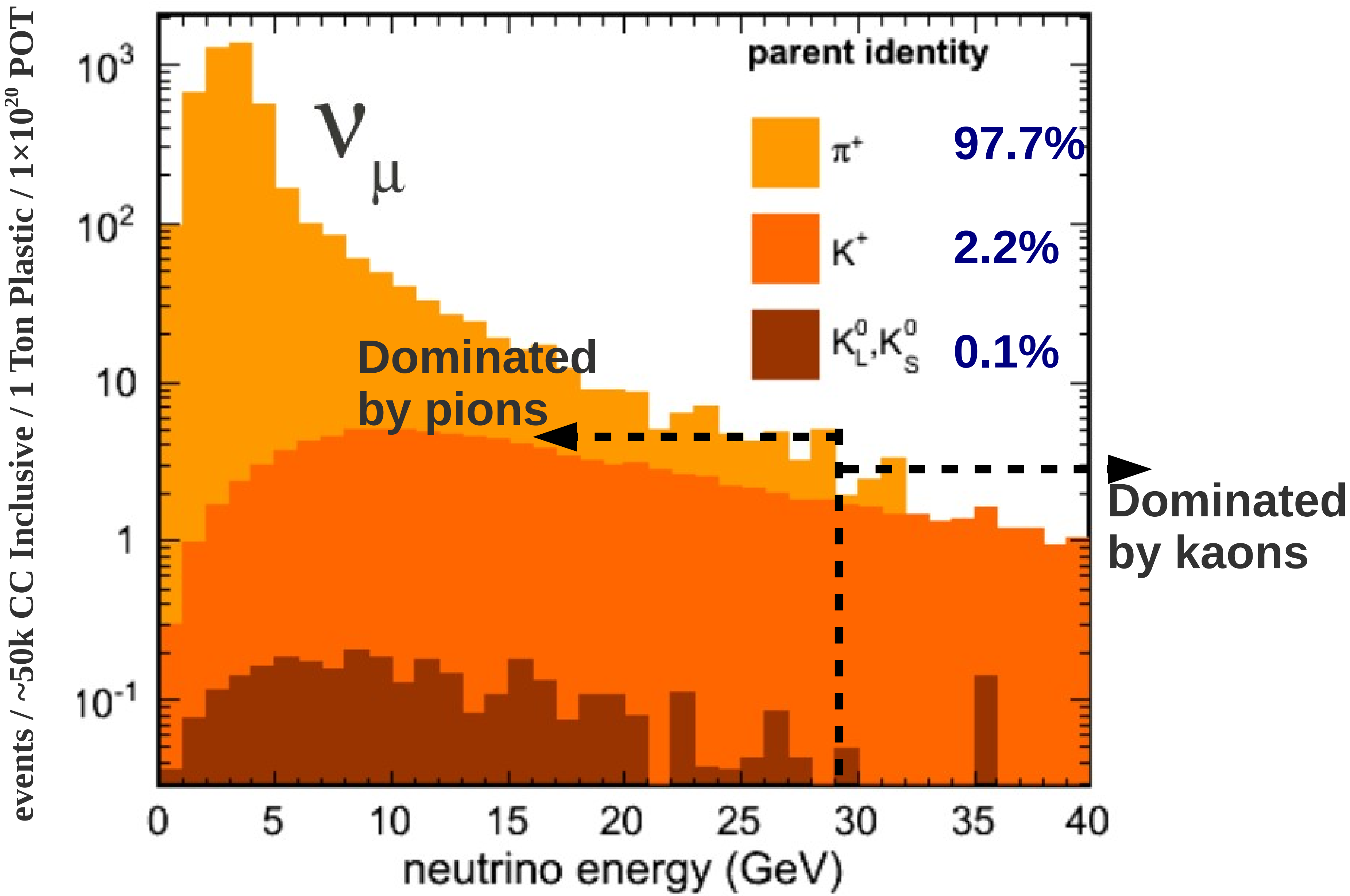
p_T [0.0, 0.5] GeV/c



x_F [0.1, 0.6]

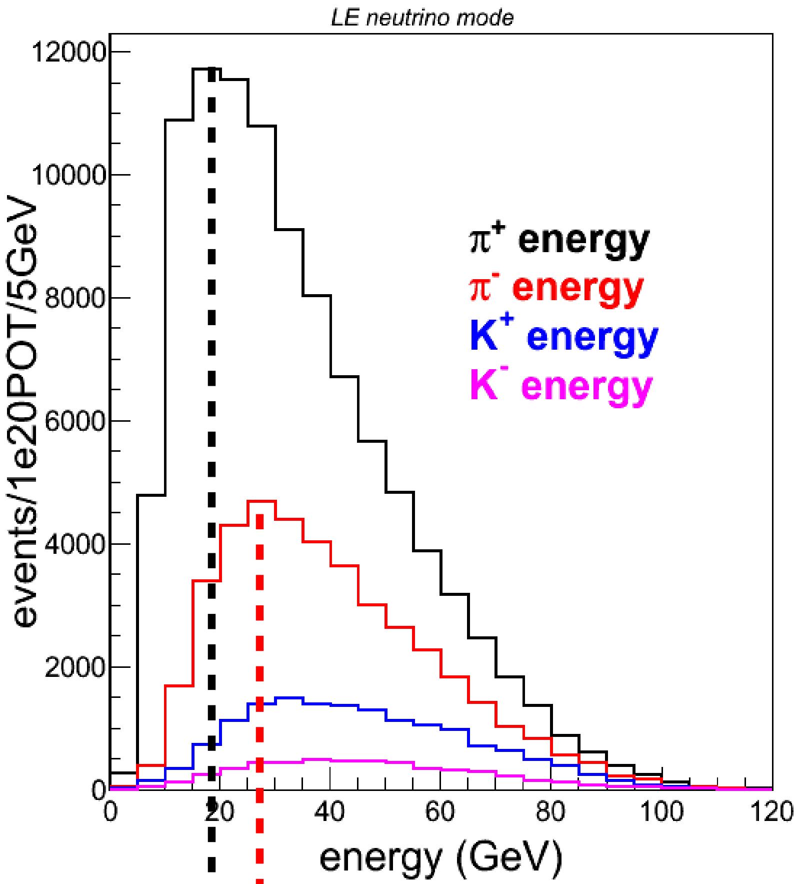
p_T [0.0, 0.4] GeV/c

Predicted Neutrino Flux from target



Secondaries That Interact in the Target

Energy Spectrum of Charged Pions and Kaons That Are Neutrino Ancestors

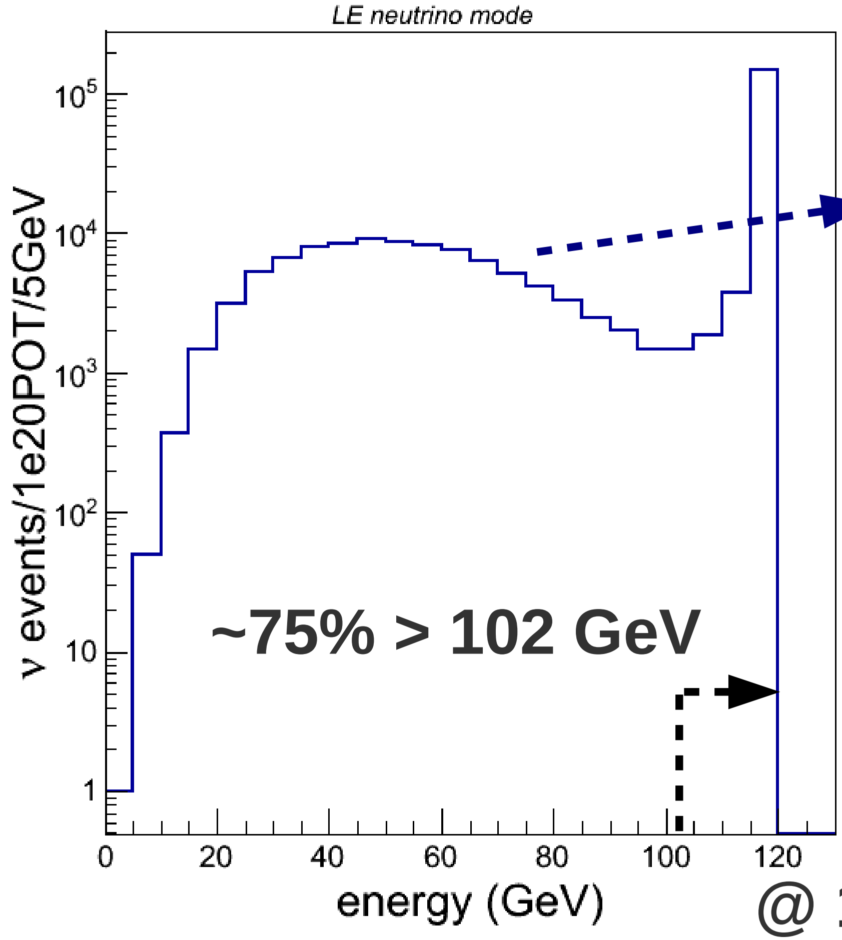


~30 GeV

~20 GeV

$$\pi^+ C \rightarrow \pi^\pm X$$
$$\pi^+ C \rightarrow pX$$
$$\pi^- C \rightarrow \pi^\pm X$$
$$\pi^- C \rightarrow pX$$

Energy Spectrum of Protons That Are Neutrino Ancestors



< 120 GeV

$$pC \rightarrow pX$$
$$pC \rightarrow pN'n$$

@ 120 GeV

$$pC \rightarrow pX$$
$$pC \rightarrow pN'n$$

Improving our Flux Constraint

Multi-prong approach:

- Use the Muon Monitor Data.
- Take Special runs: Vary the beam parameters (horn current, target position).
- Use ν_μ – atomic electron interactions (see Jaewon's talk)
- Using low ν-method (See Arie's talk)
- **Using external hadron production data.** **Results shown here**

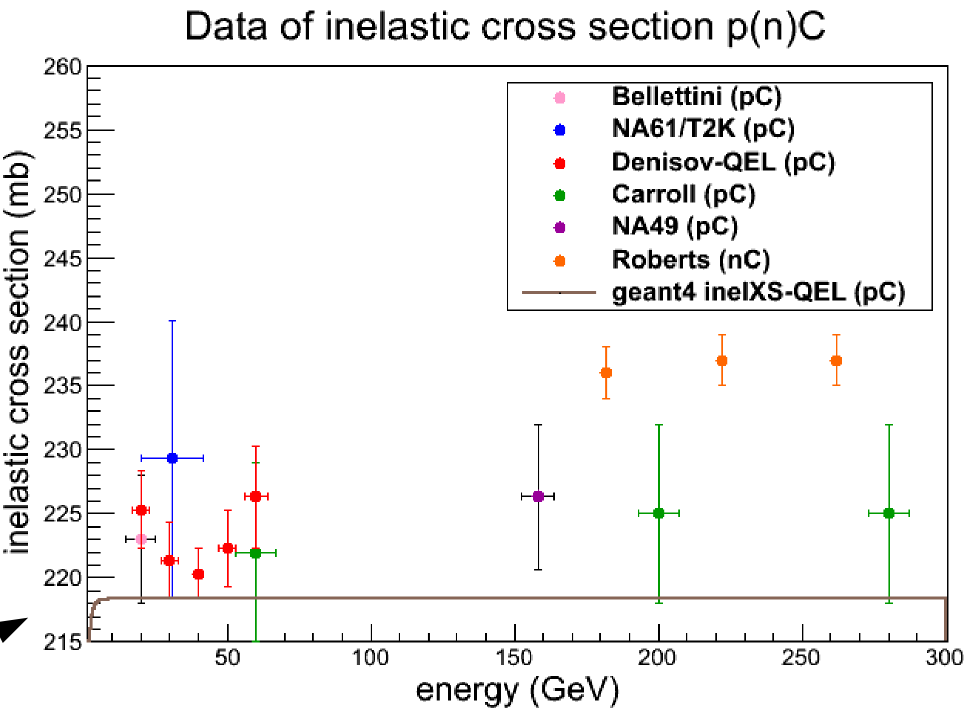
Constraint the MC flux to get the right shape and uncertainty.

$$\Phi(E_\upsilon) \equiv \Phi(x_F, p_T)$$

Redundancy will improve our accuracy...

Using external Hadron Production

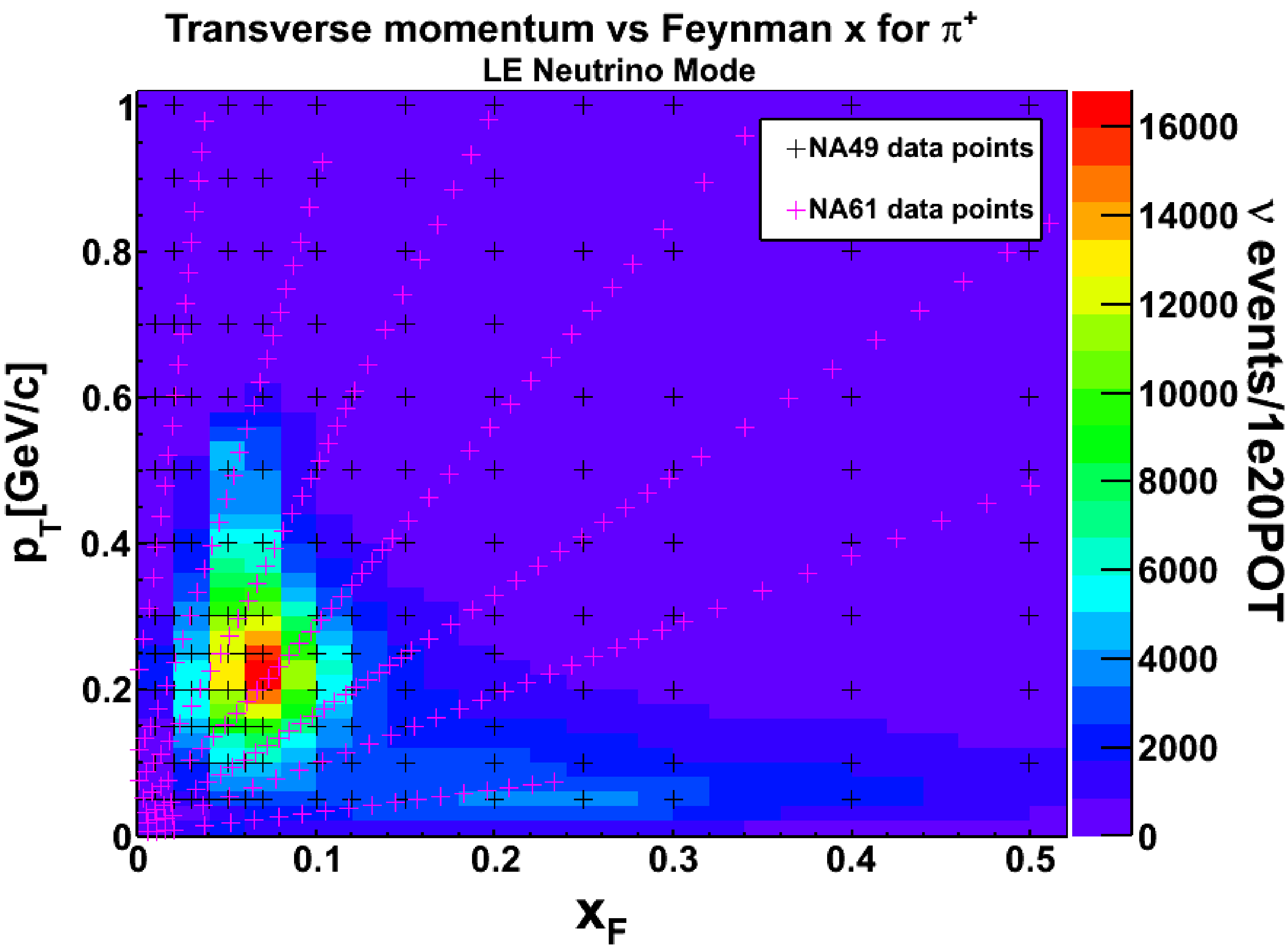
Inelastic cross section vs. energy: data and geant4.



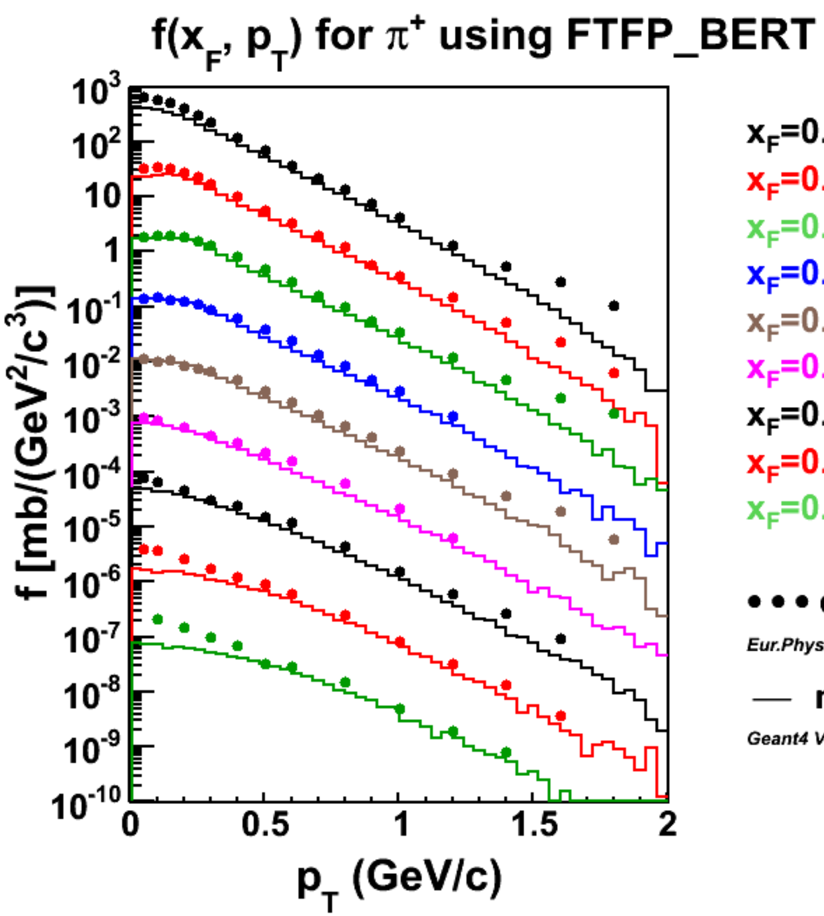
(Note suppressed zero)

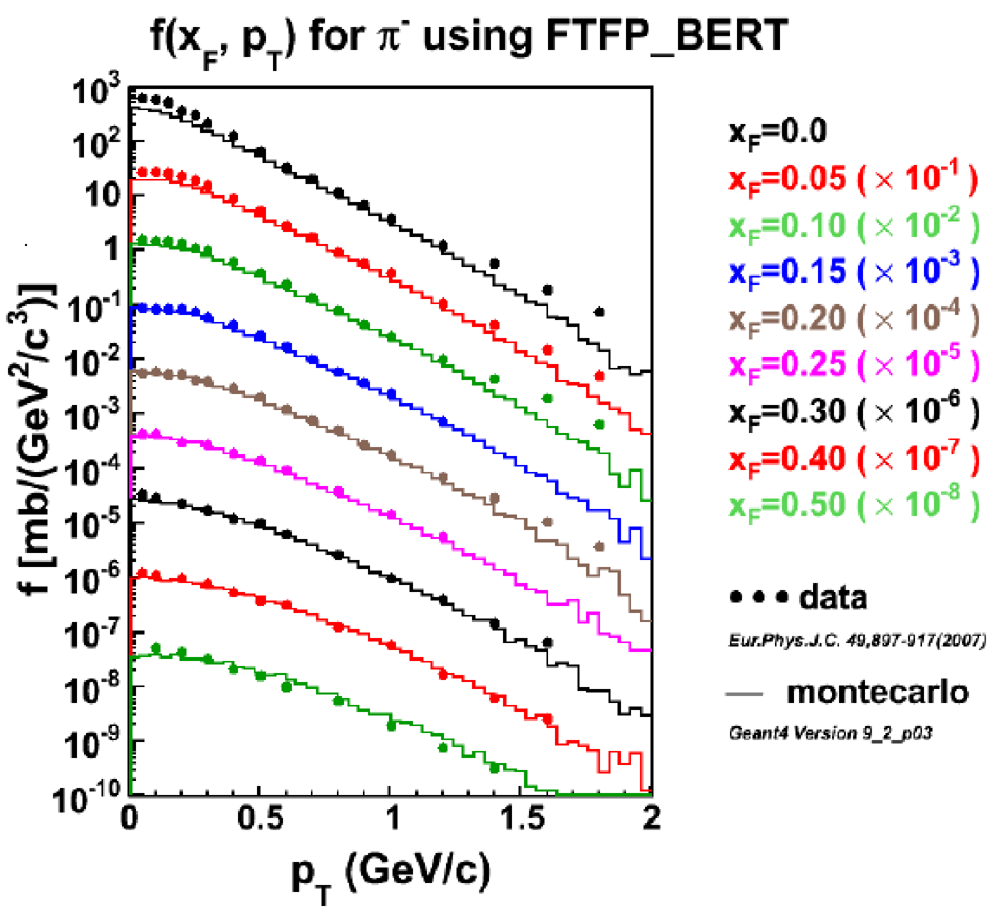
- For **pC → $\pi^{+/-}$ X:** NA49 @ 158 GeV (CERN), Barton @ 100 GeV (Fermilab) & NA61 @ 31 GeV (CERN) & HARP @ 3, 5, 8, 12 GeV.
- For **pC → $K^{+/-}$ X:** NA49 @ 158 GeV (Tinti's thesis, FERMILAB), MIPP @ 120 GeV ratio π/K (thick: Seun & thin: Lebedev).
- For **$\pi^{+/-}$C → $\pi^{+/-}$ X:** HARP @ 3, 5, 8, 12 GeV.

NA61 & NA49 coverage for charged pions



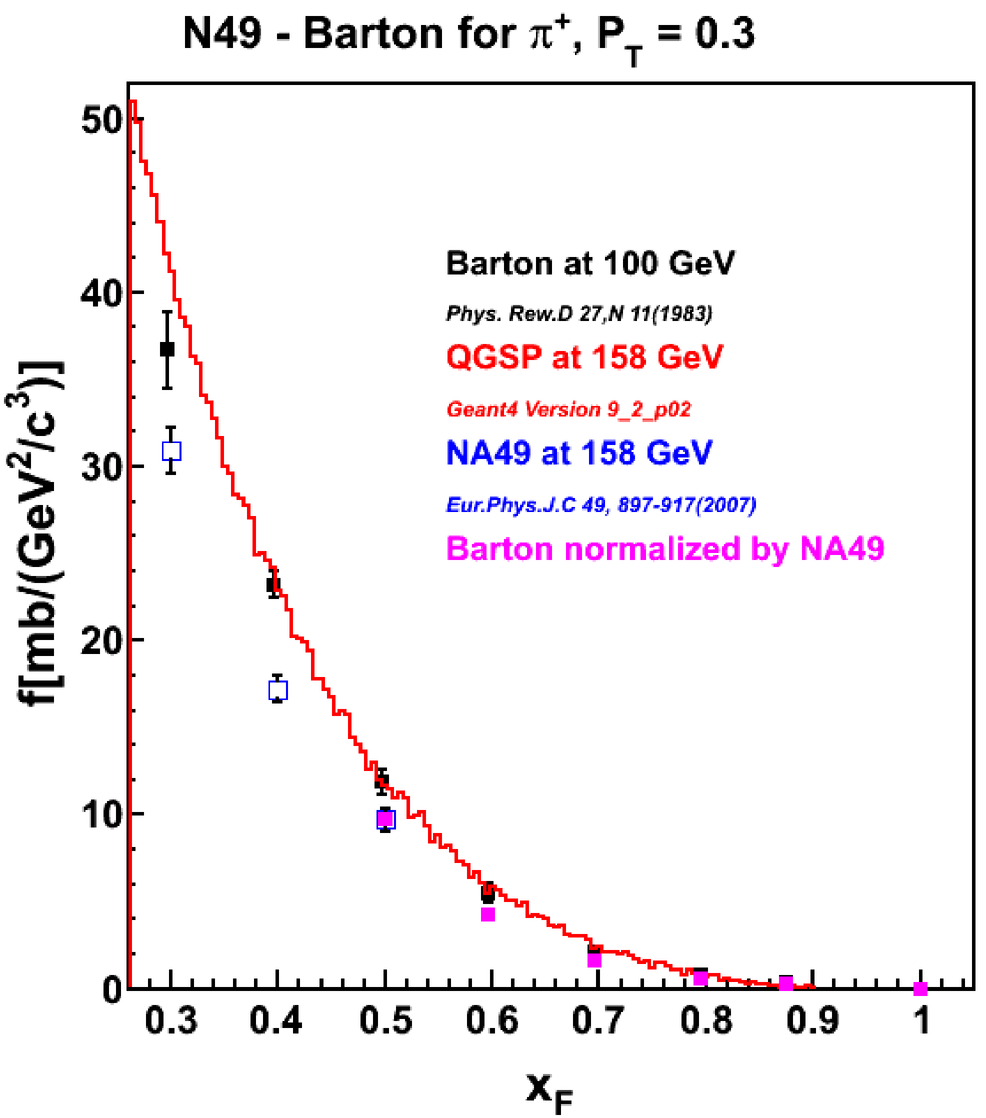
pC → pi+ X @158

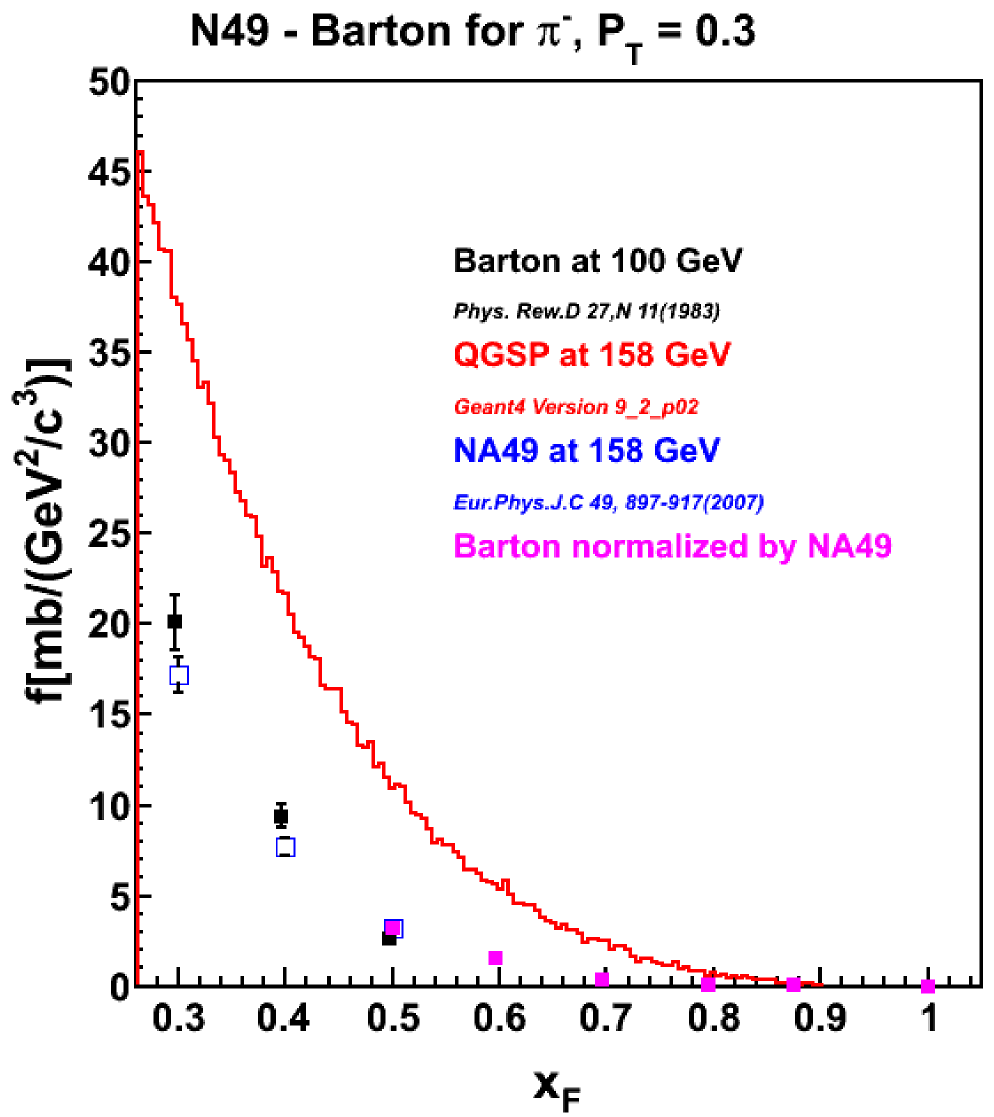




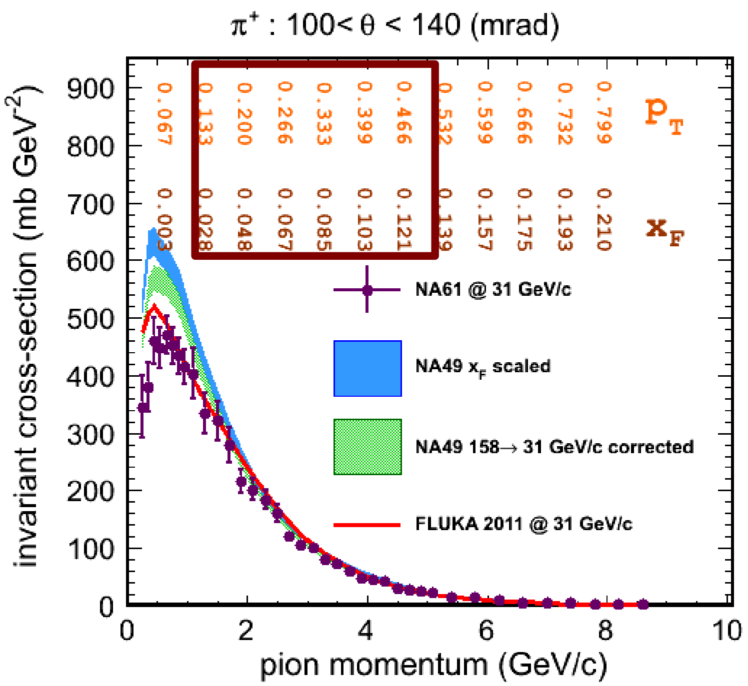
Uncertainties
7.5% systematic
2-10% statistical

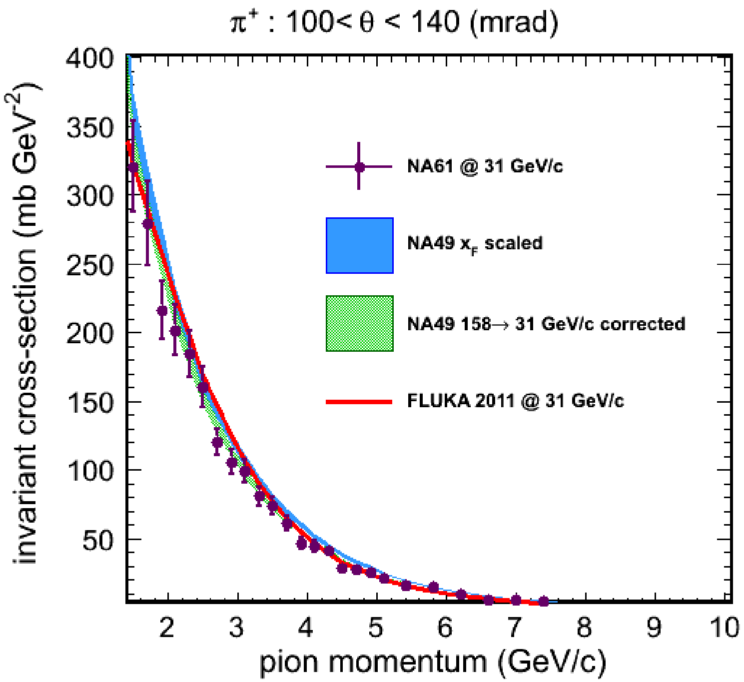
pC → pi+ X @158 (large x_F)



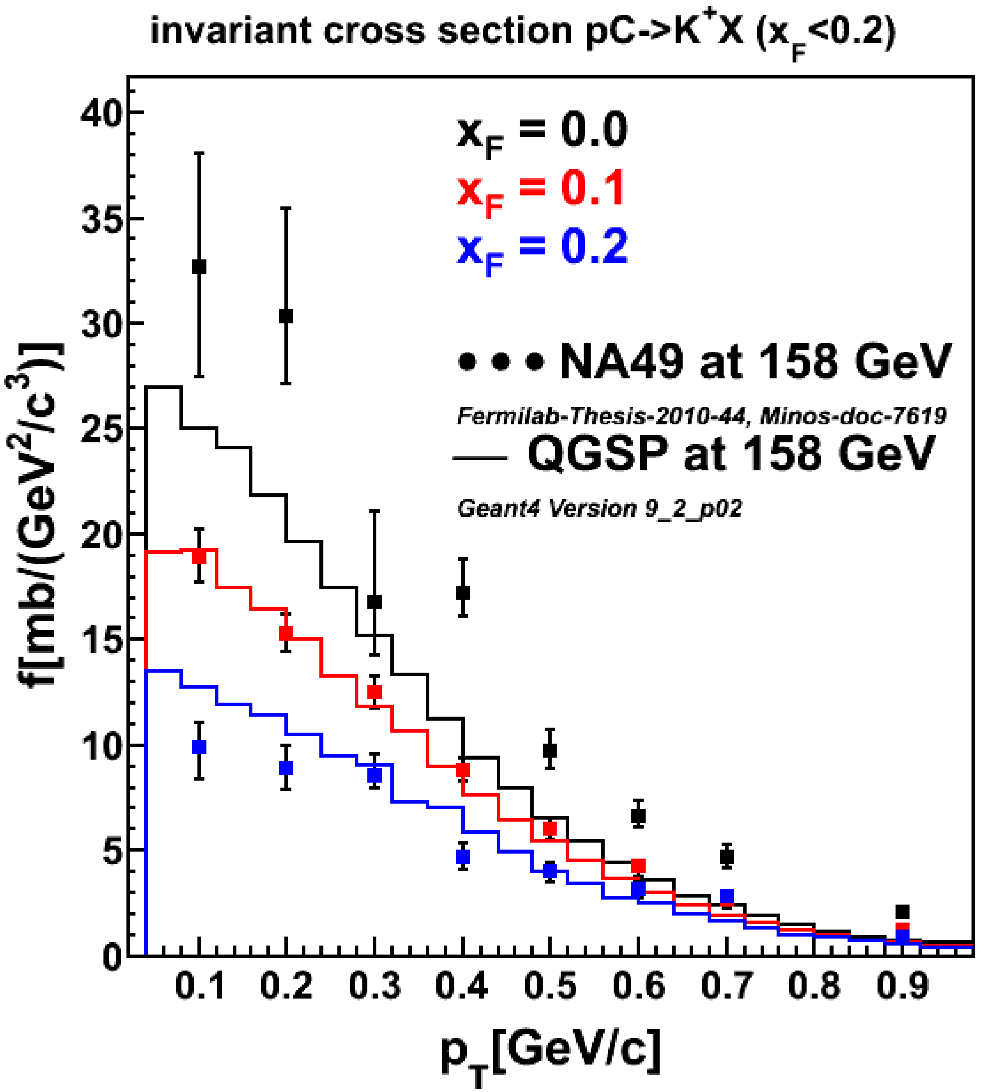


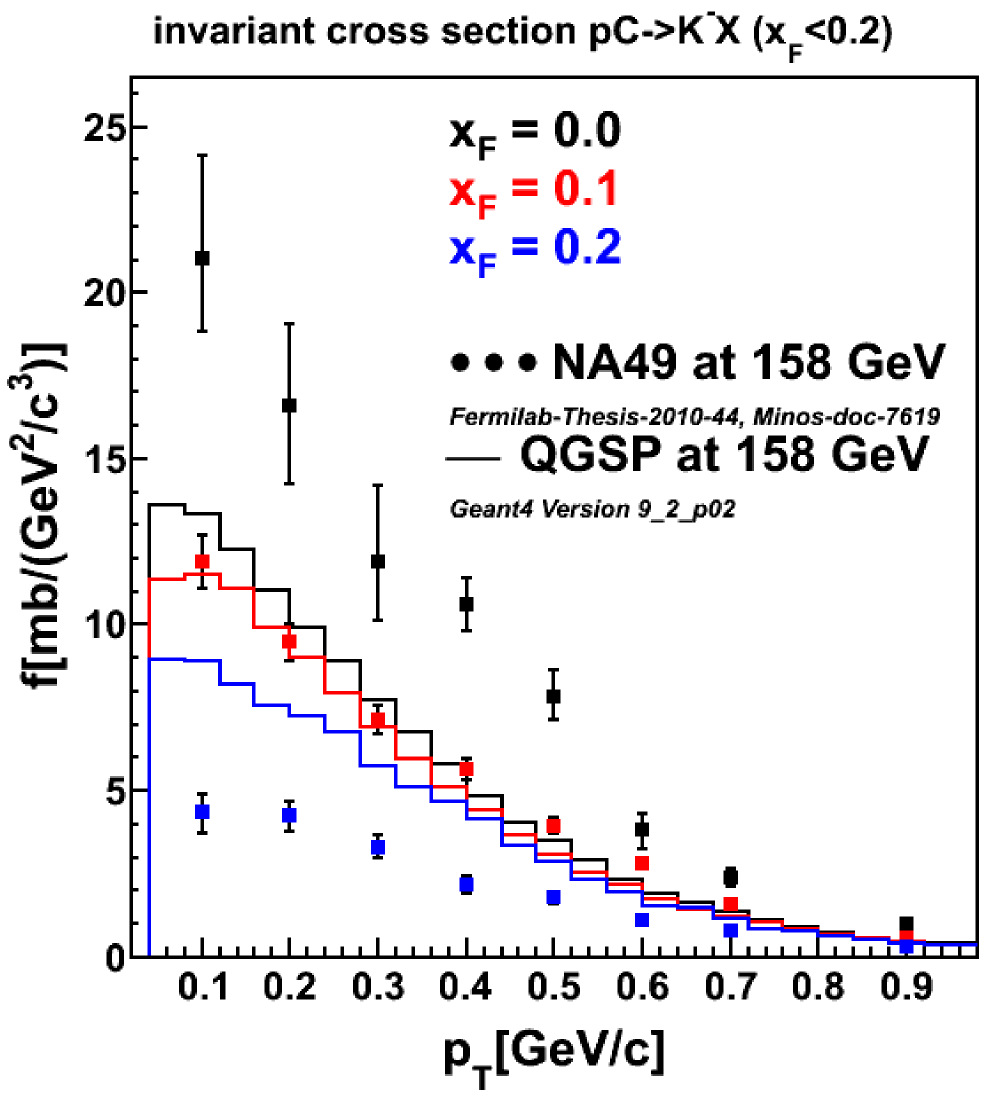
Comparison pC @ 31 GeV vs pC @ 158 GeV





pC → K+ X @158

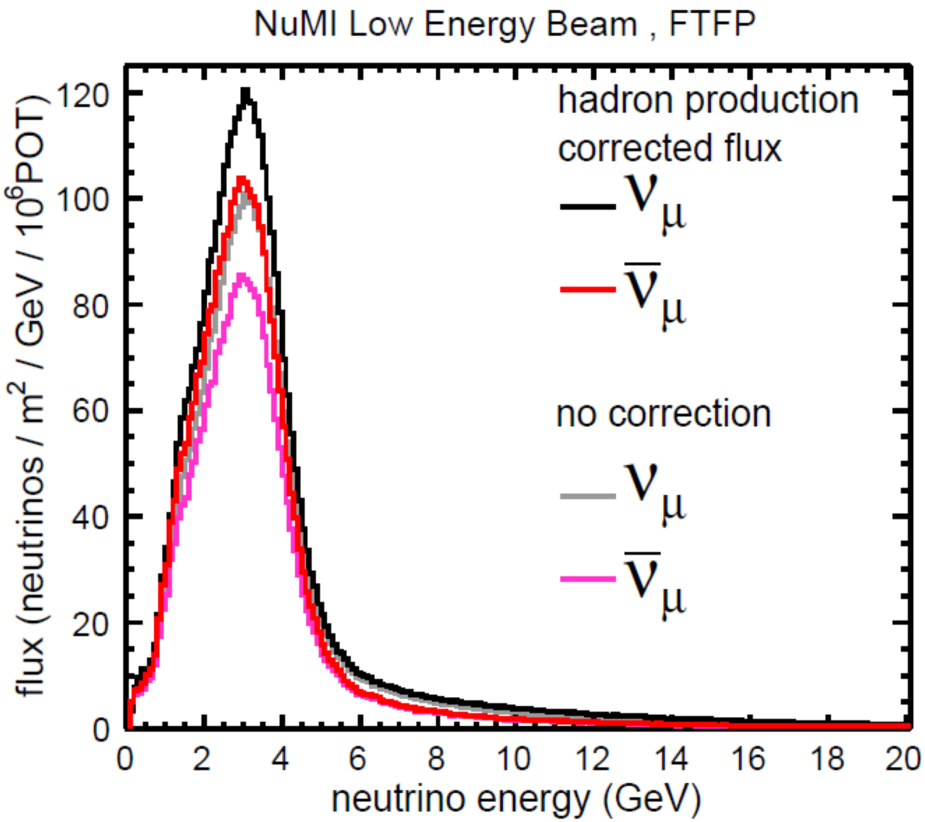

invariant cross section pC->K+X (xF<0.2)
xF = 0.0
xF = 0.1
xF = 0.2
NA49 at 158 GeV
Fermilab-Thesis-2010-44, Minos-doc-7619
QGSP at 158 GeV
Geant4 Version 9_2_p02
f[mb/(GeV2/c3)]
pT[GeV/c]

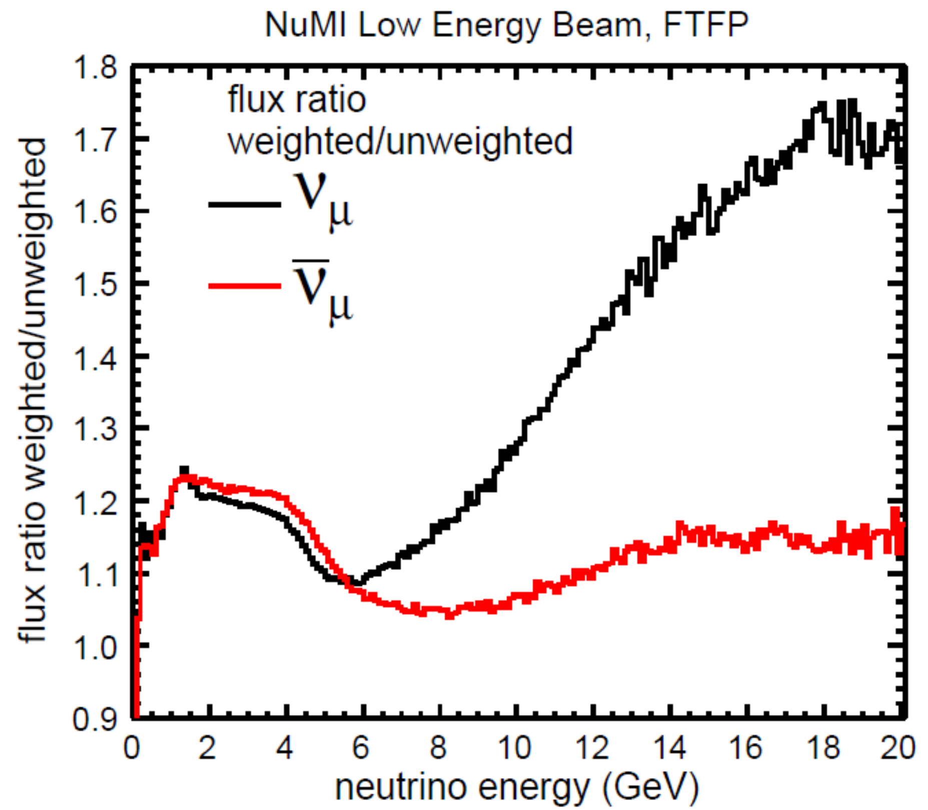

invariant cross section pC->K-X (xF<0.2)
xF = 0.0
xF = 0.1
xF = 0.2
NA49 at 158 GeV
Fermilab-Thesis-2010-44, Minos-doc-7619
QGSP at 158 GeV
Geant4 Version 9_2_p02
f[mb/(GeV2/c3)]
pT[GeV/c]

Results to Neutrino flux

Applying corrections to $\pi^+ C \rightarrow \pi^\pm X$ of $E\frac{d^3\sigma}{dp^3}$:

$$w(x_F, p_T) = \frac{NA49(x_F, p_T, 158GeV)}{FTFP\,'(x_F, p_T, 158GeV)}$$



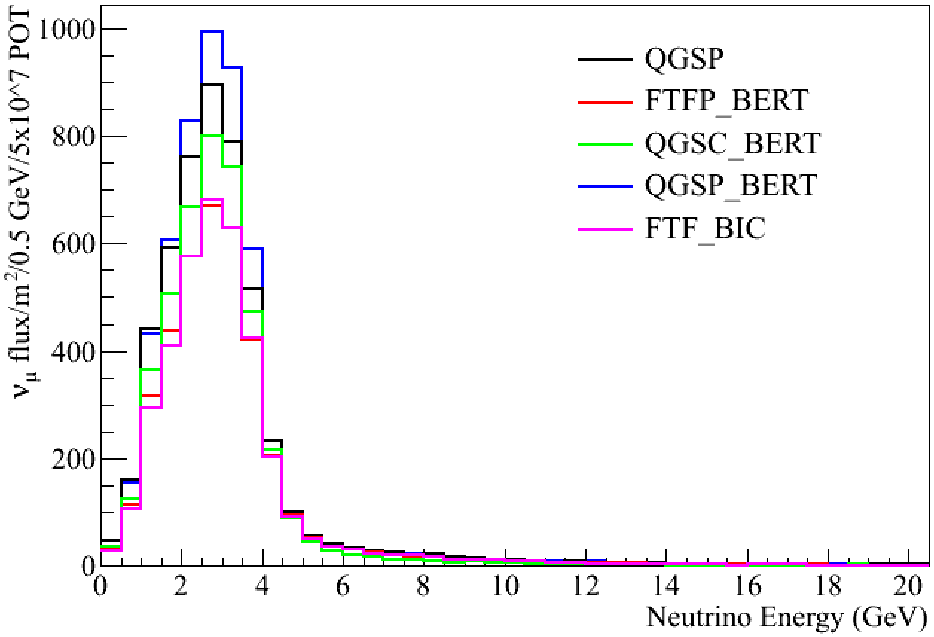


- υ_μ the neutrino spectra when we focus π^+.
- $\overline{\upsilon_\mu}$ the anti-neutrino spectra when we focus π^-.

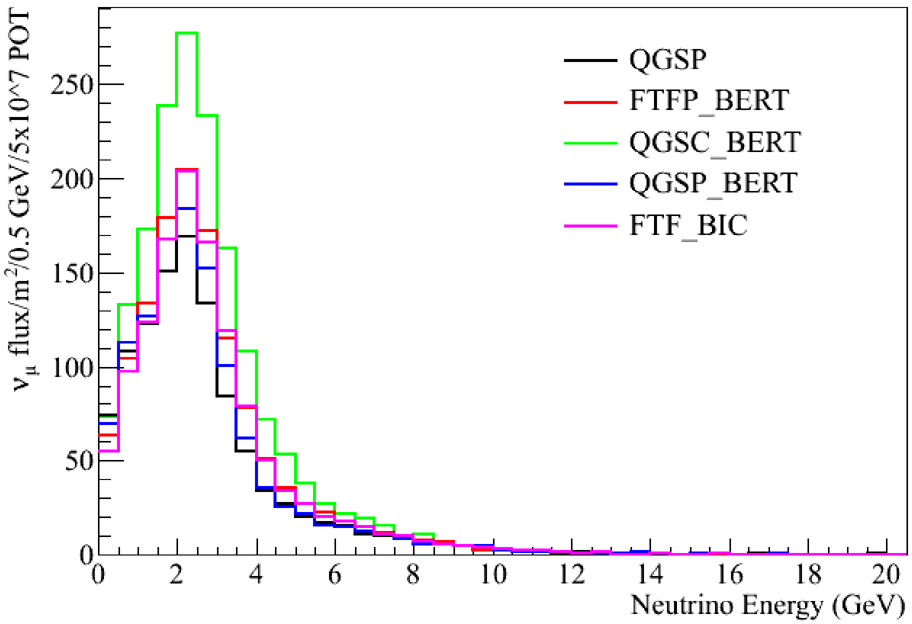
Model Spread Uncertainties

- Spread shown between geant4 models for Non-NA49 uncertainties.
- Divide into categories: π, K, p, n and other secondary interactions in target, in horns, decay pipe walls or He, target hall chase.
- A lot of work is required to add more models and gradually replace model spread with existing and new data.

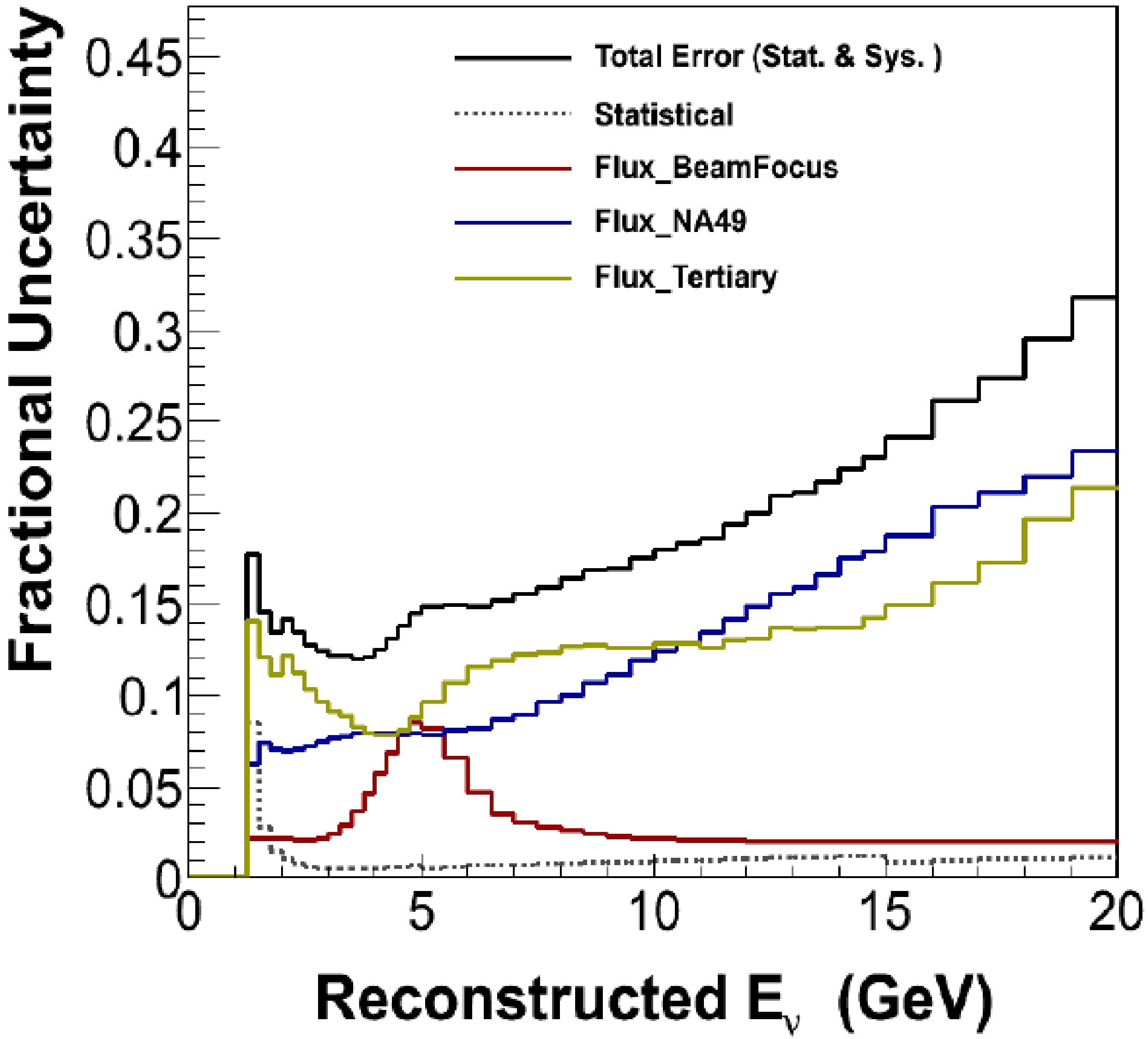
π^+ from π that interact in the target



π^+ from interaction in the horns

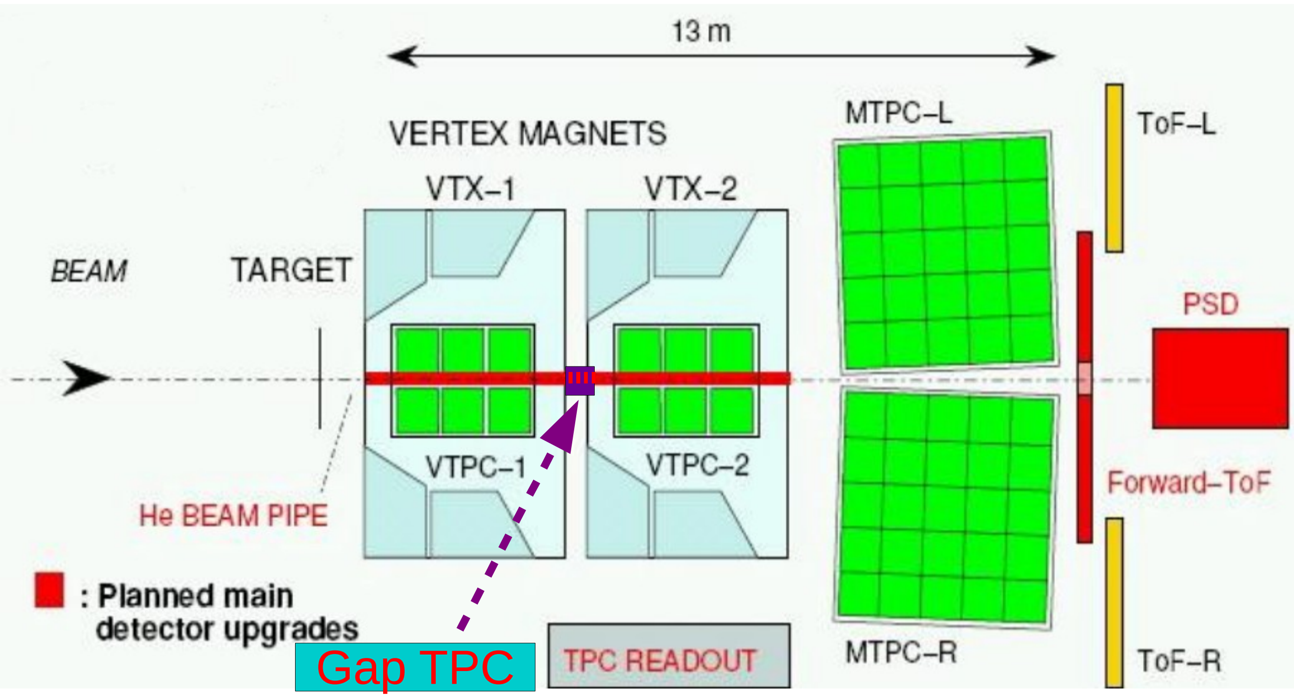


Total Uncertainties: Reconstructed E_ν



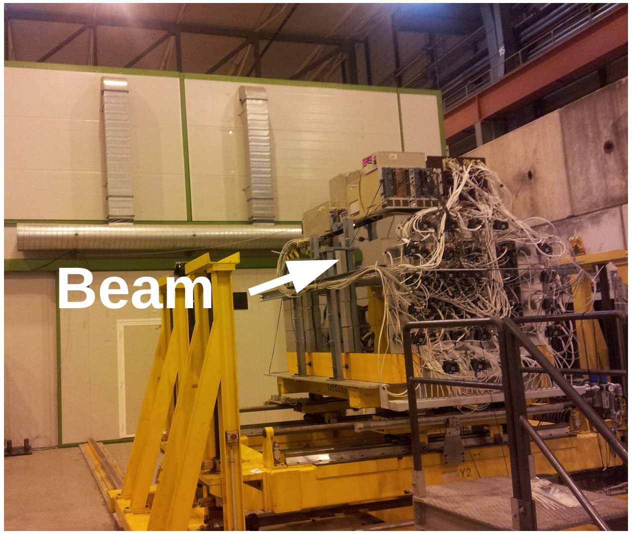
Hadron Production Test at NA61/SHINE

NA61 (SPS Heavy Ion and Neutrino Experiment) at CERN is a large acceptance hadron spectrometer in the North Area H2 beamline of the SPS.



Projectile **S**pectrometer **D**etector

- ***Measure energy of forward particles.***
- ***We took data pC @120 GeV with PSD last June 25.***



Plan:

- ***pC @ 120 GeV full detector (thin target).***
- ***pC @ 120 GeV full detector (thick target).***
- ***Great opportunity to take $\pi^{+/-}$C at lower energies (10-50 GeV).***

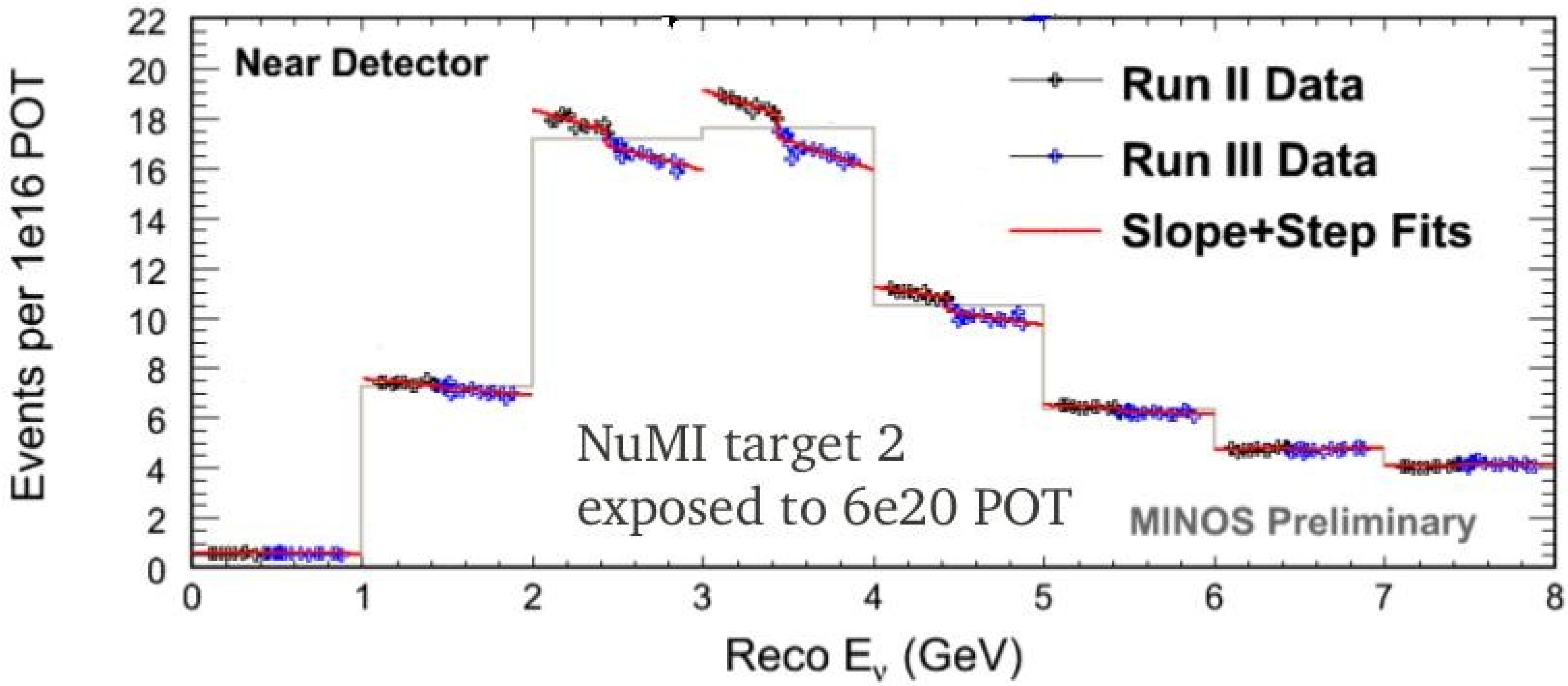
Conclusions

- ***For MINERvA it is crucial to have solid flux constraints with small uncertainties to measure absolute ν cross sections.***
- ***We are employing multiple approaches to constrain the flux.***
- ***Presented here are our first results using external hadron production data and we expect further improvement using more measurements (i.e NA61).***

Backup slides

Components are consumables...

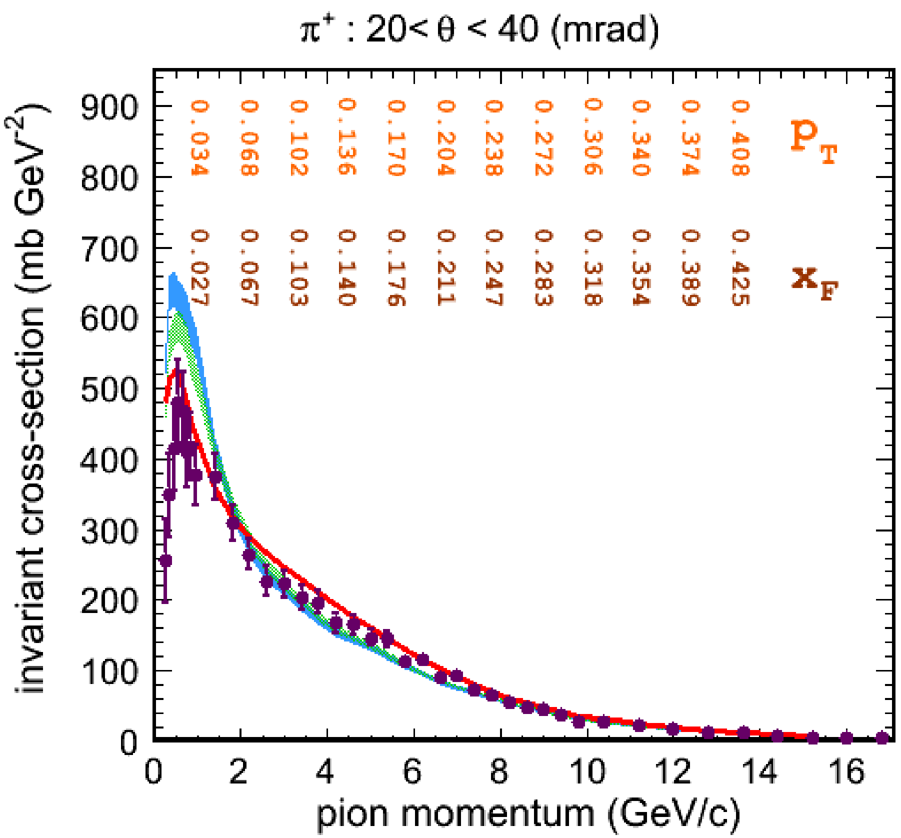
- High radiation, thermal stress, mechanical stress, water leaks affect all components.
- Replaced: 6 times targets, horns and hadron monitors.
- Gradual slope due to radiation damage.

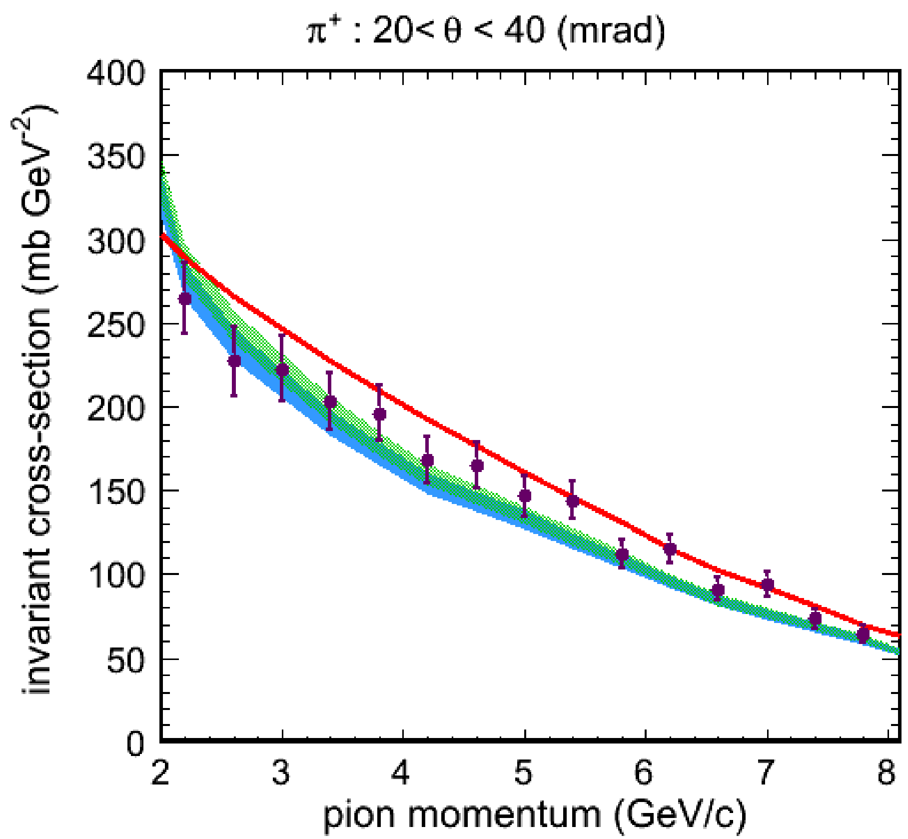


Sources of the focusing uncertainties

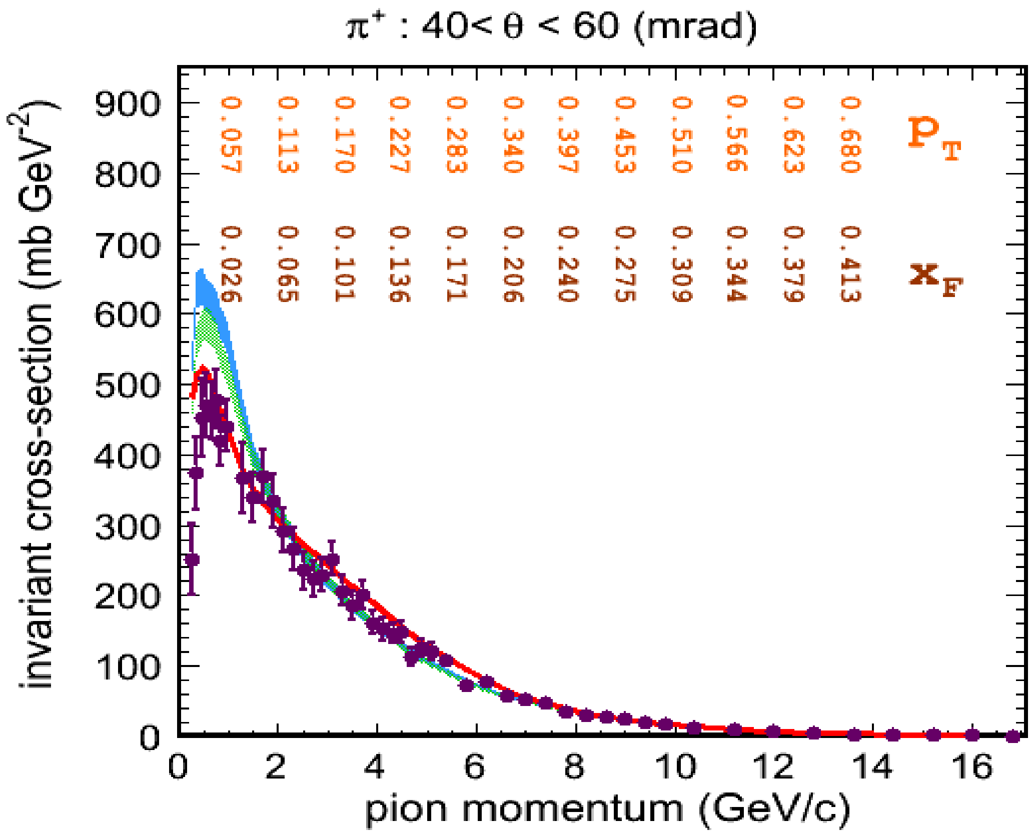
- **Horn angles.** Horn tilt 0.2 mrad.
- **Horn offsets.** 1.0 mm. Transverse misalignment
- **Horn current**. 1.0%. Miscalibration.
- **Horn current distribution.** δ=6mm / δ=infinitive.
- **Baffle scraping.** 0.25%.
- **Protons on target.** 2.0 %. Beam intensity, size and position of the beam. MC Beam size: 1.1x1.2 mm2 and target size: 6.4x15mm2.

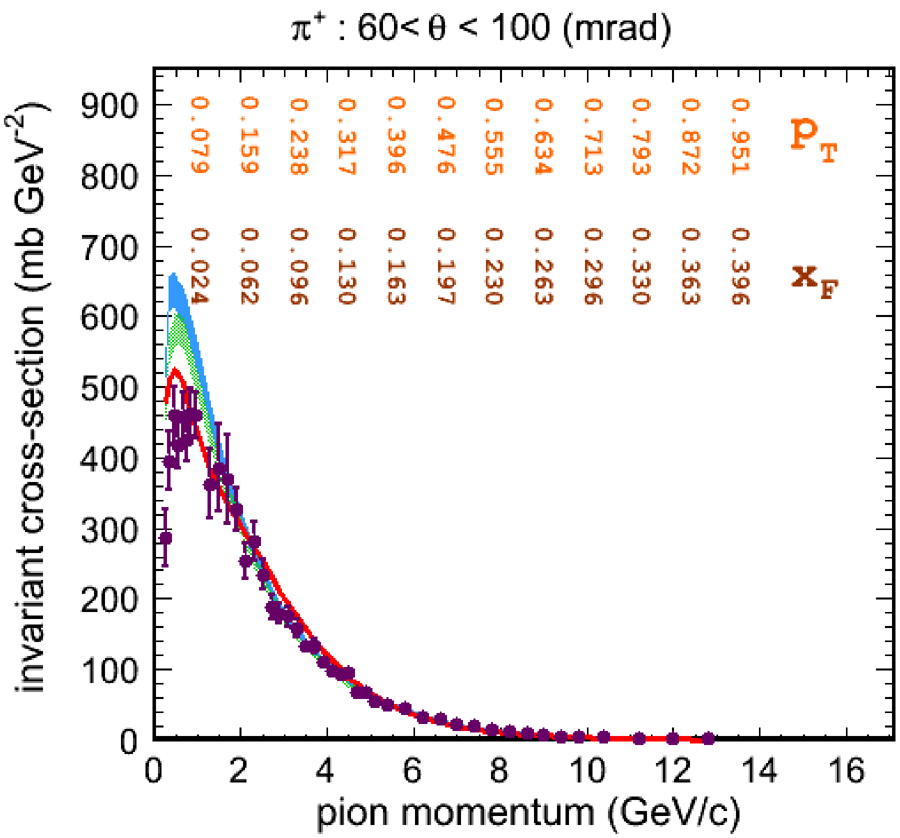
Comparison NA61 and NA49



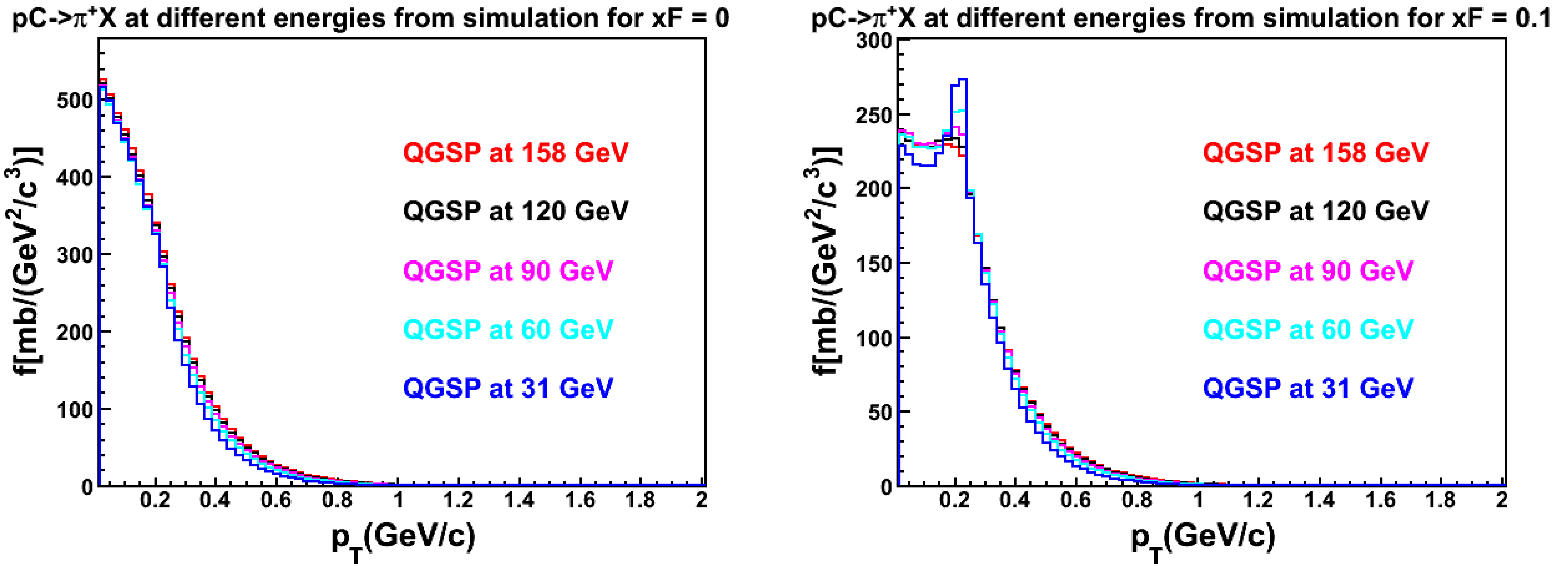


Comparison NA61 and NA49

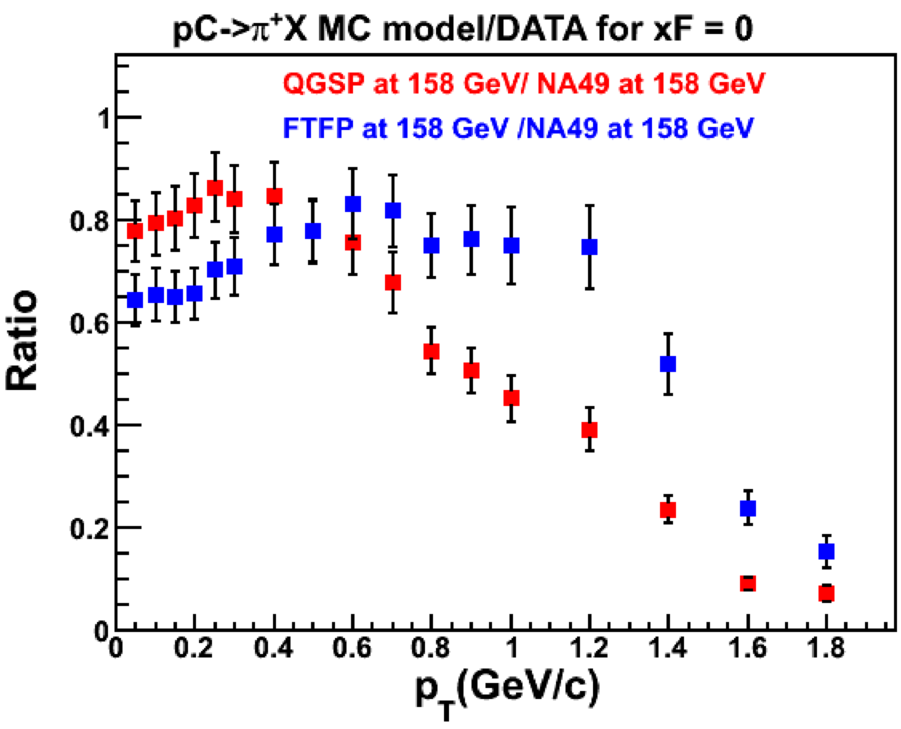


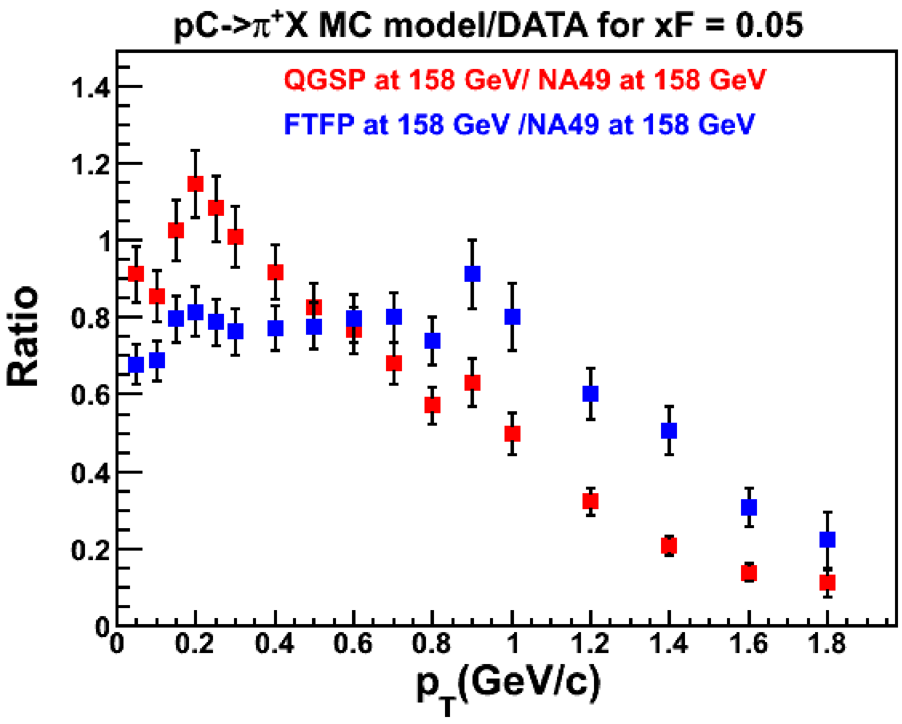


QGSP @ different energies

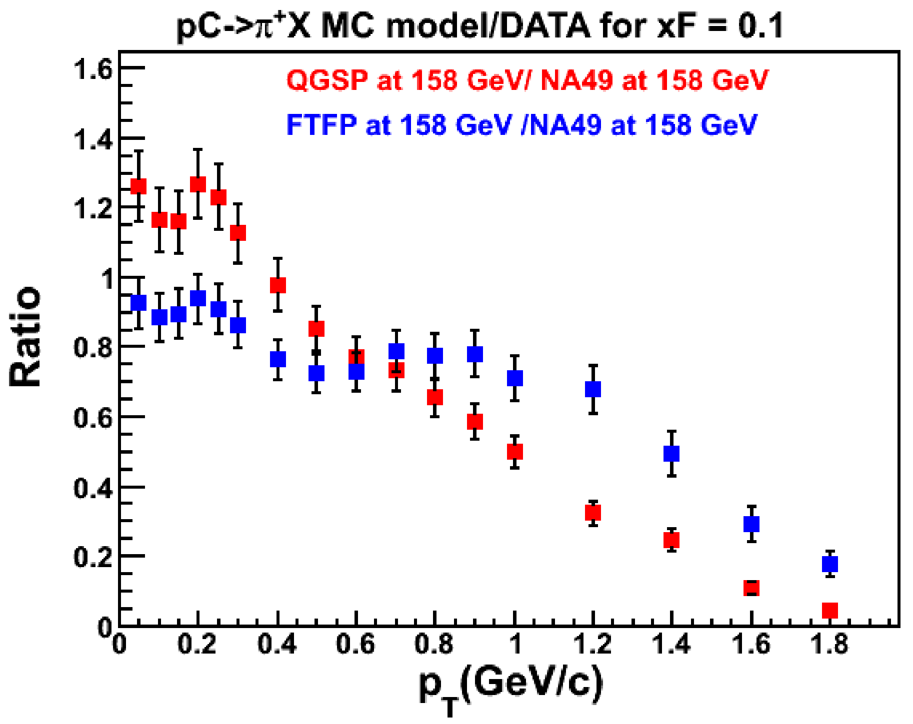


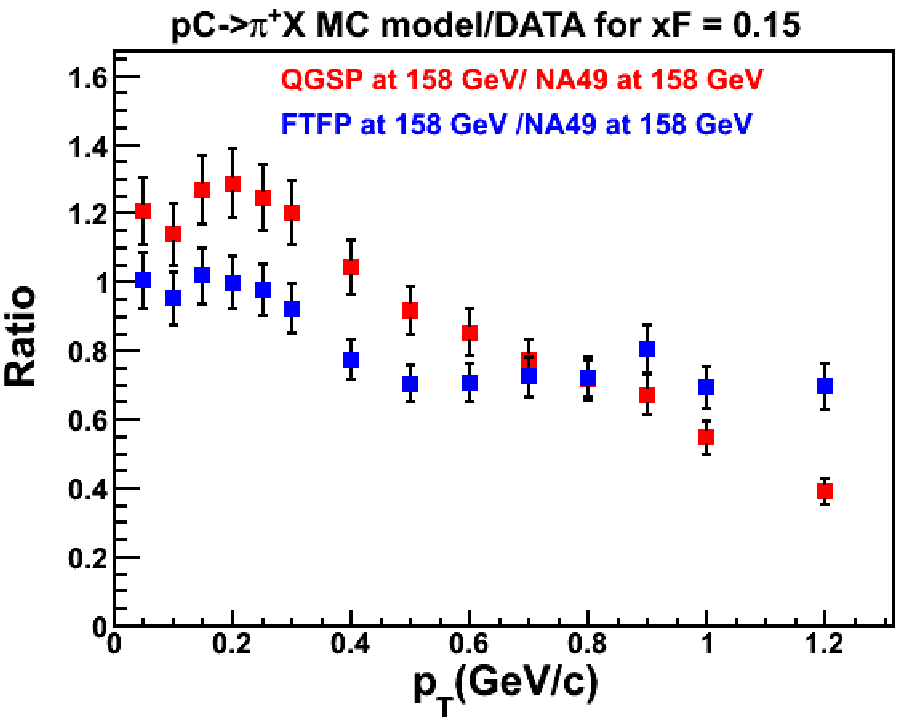
QGSP FTFP vs Data Comparison





QGSP FTFP vs Data Comparison





CC Inclusive Neutrino Reconstructed Energy