NuMI Beam Flux Studies for MINERνA

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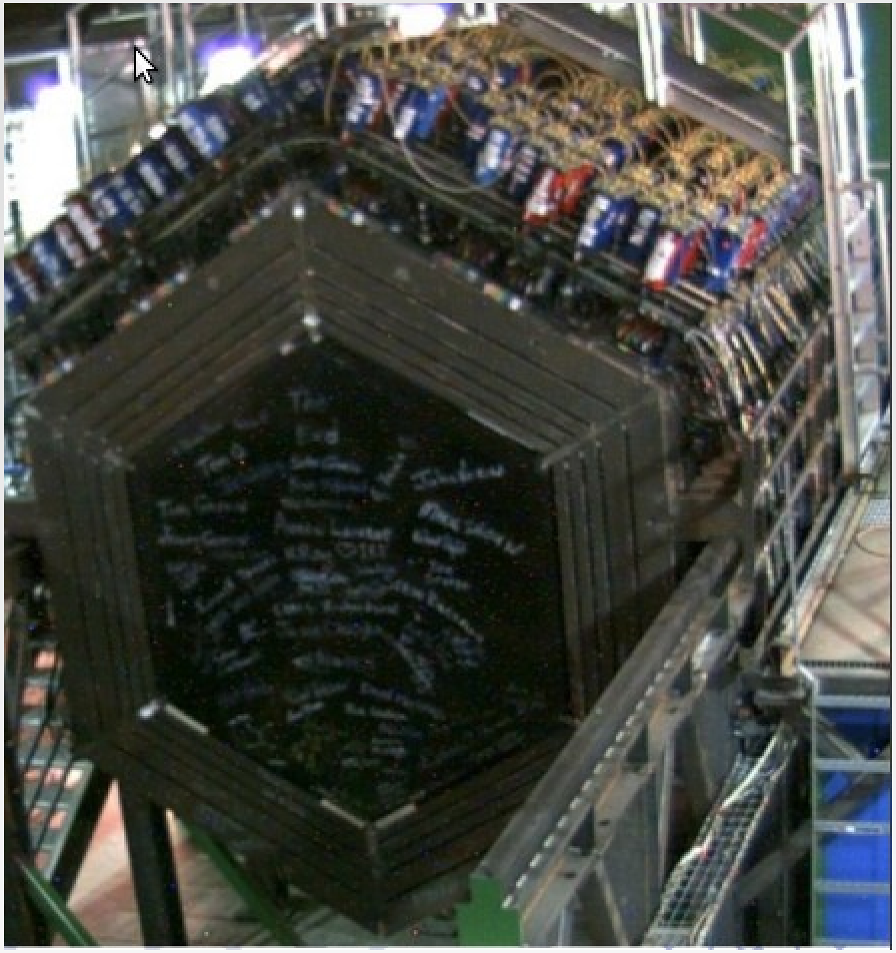
Outline

- A brief description of MINERνA and NuMI.
- Prediction for the neutrino flux using external data.
- Preliminary results.
- Conclusions and next steps.

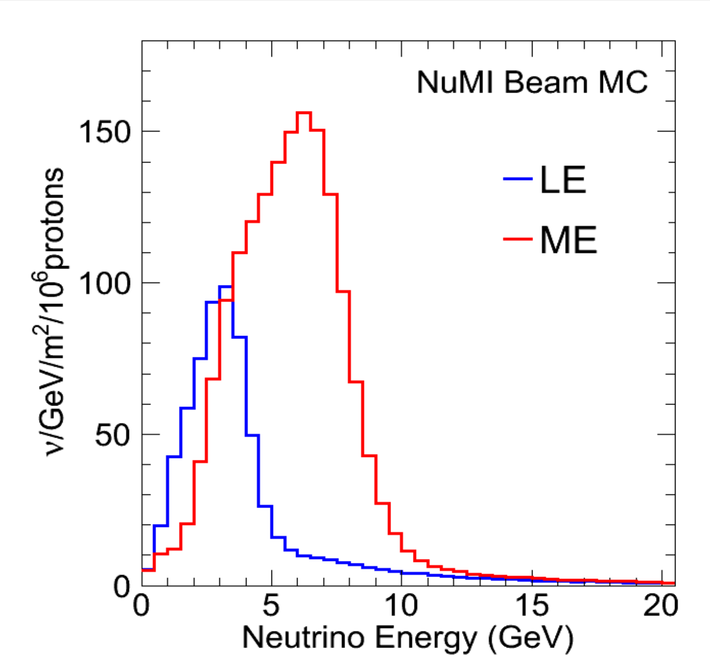


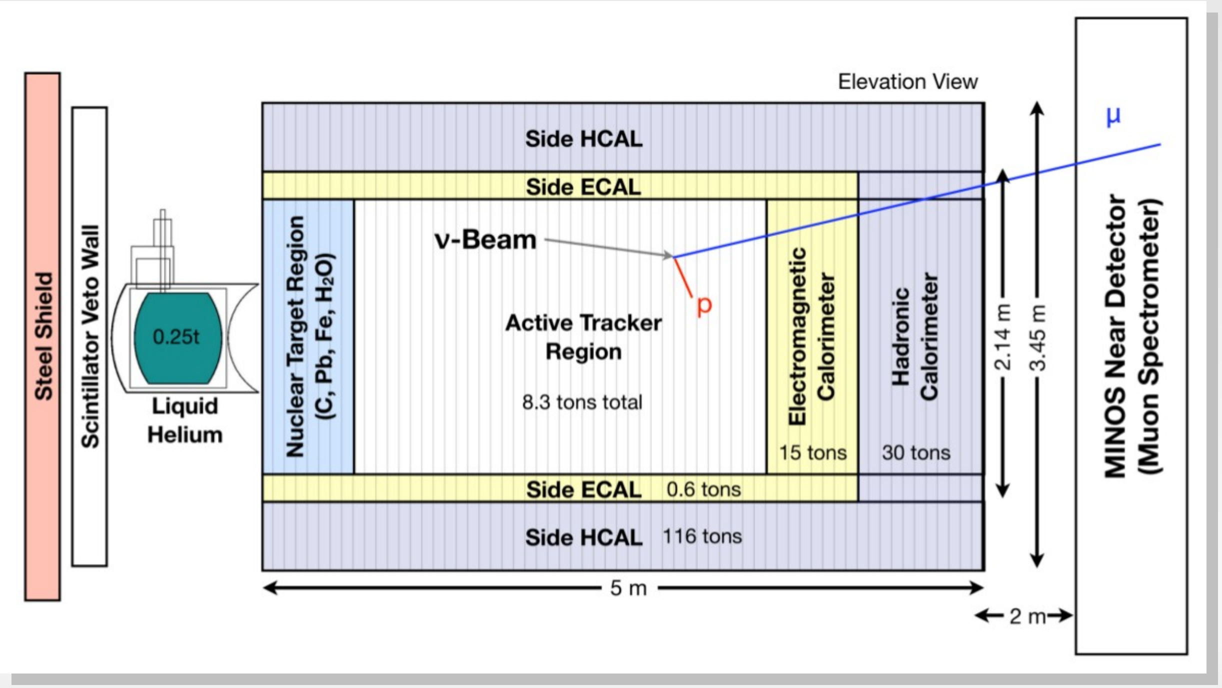
Main INjector ExpeRiment ν-A

MINERνA is a high precision neutrino scattering located in the NuMI beamline at Fermilab (~1Km from production point). Our main goals are to measure:

- Neutrino-nucleus interaction for exclusive and inclusive final states in few GeV region.
- The nuclear effects on the ν-A interactions and form factors and structure functions.

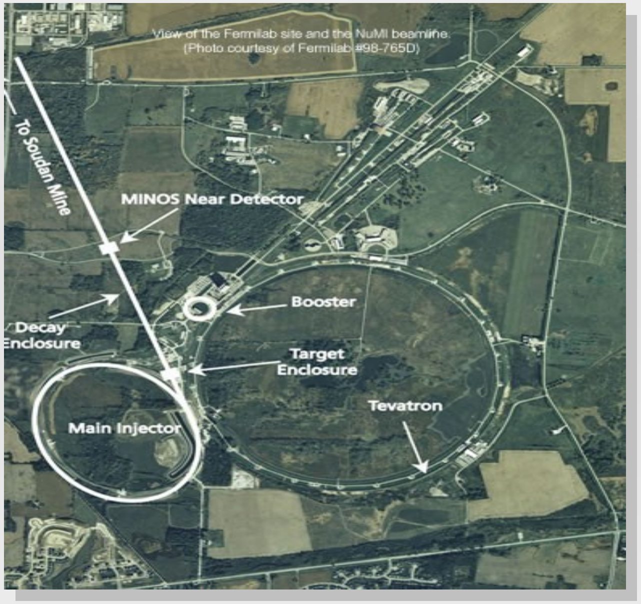
To accomplish this task, we need to know our flux as well as we can.

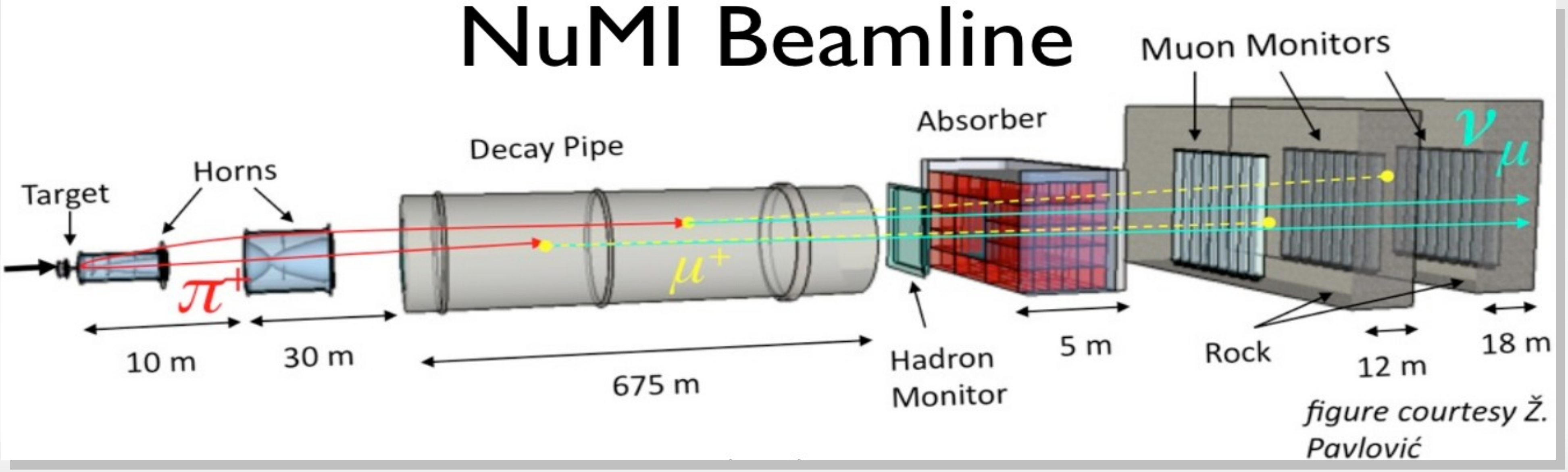




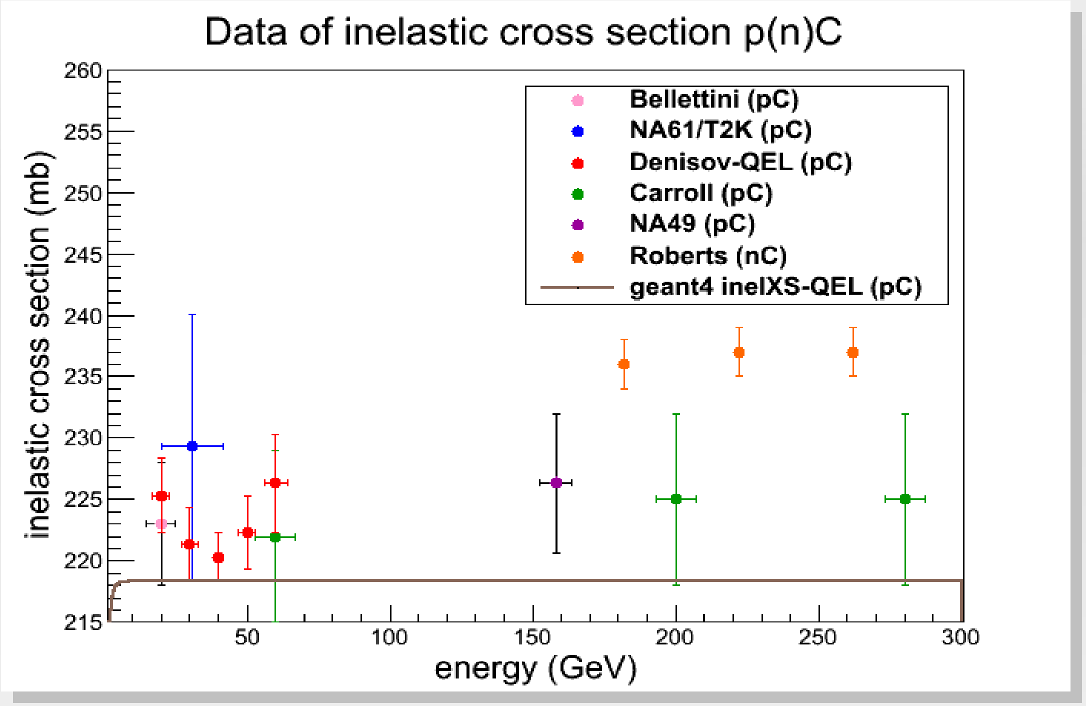
Production of Neutrino Flux

- *120 GeV protons collide with graphite target (~2 interaction length).*
- **The flux determination is hard:** uncertainties from beam focusing, hadron production, horn current model, etc.





External Hadron Production Data



Inelastic cross section vs. energy: data and geant4.

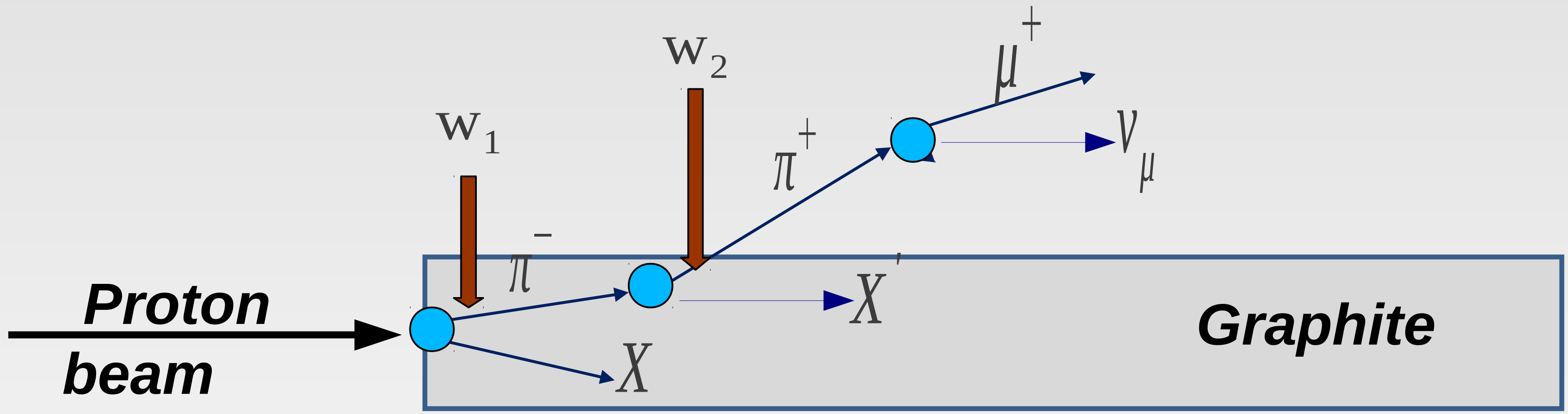
Our first interest: $pC \rightarrow \pi^{+/-} X$

- **NA49** : 158 GeV, at CERN (***Eur. Phys. J. C. 49, 897-917***).
- **Barton** : 100 GeV, at Fermilab (***Phys. Rev. D 27 2580, 1983***).
- **NA61** : 31 GeV, at CERN (***Phys. Rev. C 84 034604, 2011***)

Current strategy

MINERvA uses QGSP (**Q**uark **G**luon **S**tring **P**re-compound) model in the simulation of NuMI flux. The idea is to:

Correct neutrino flux predicted by QGSP using the hadronic production data.

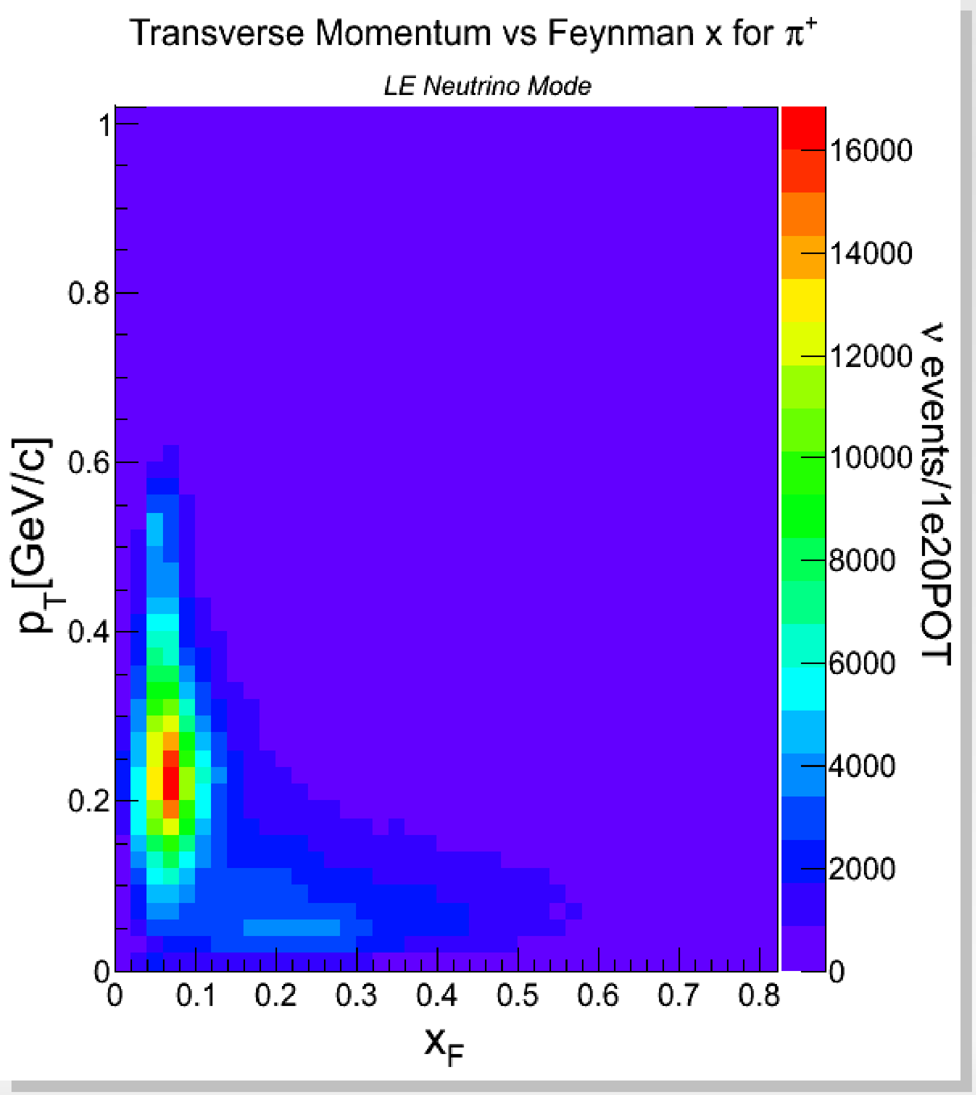


Each factor: $w_i = \frac{invXS_{data}}{invXS_{mc}}(x_F, P_T)$ and the total: $W = \prod_{i=0}^{i=ntraj-2} w_i$

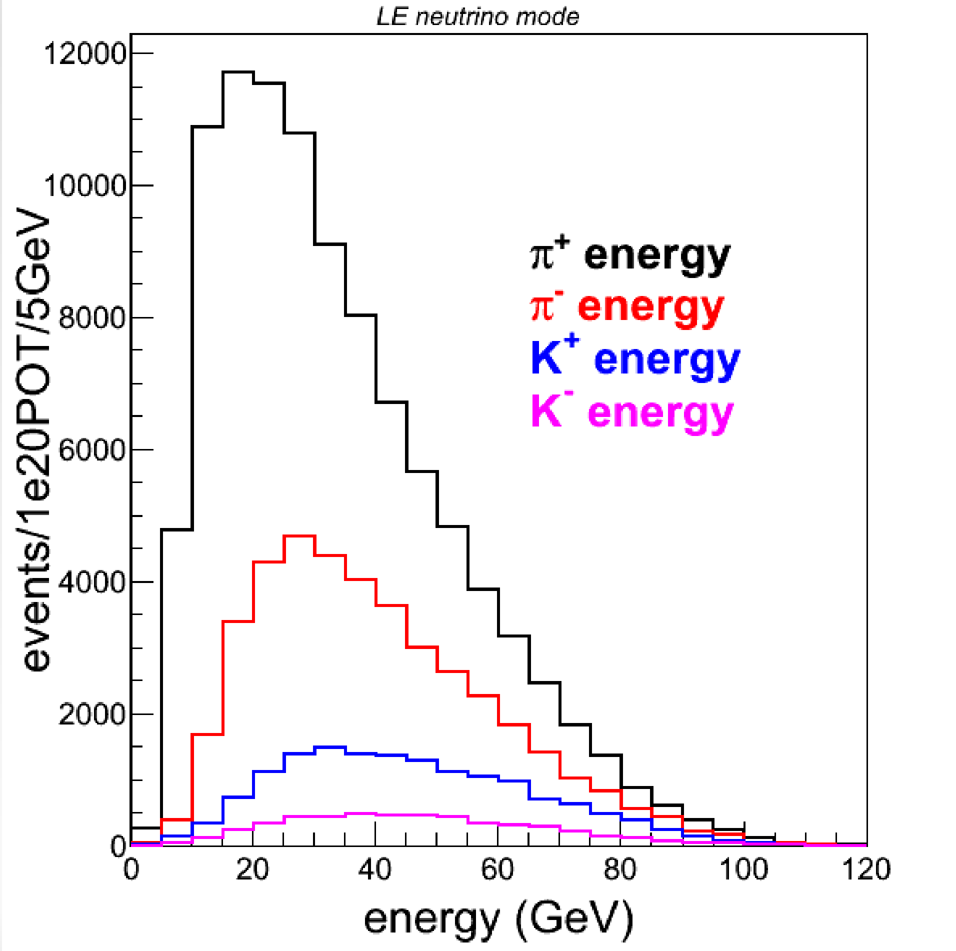
ntraj: number of interactions from the primary proton to neutrino itself.

Kinematic of Hadron Production

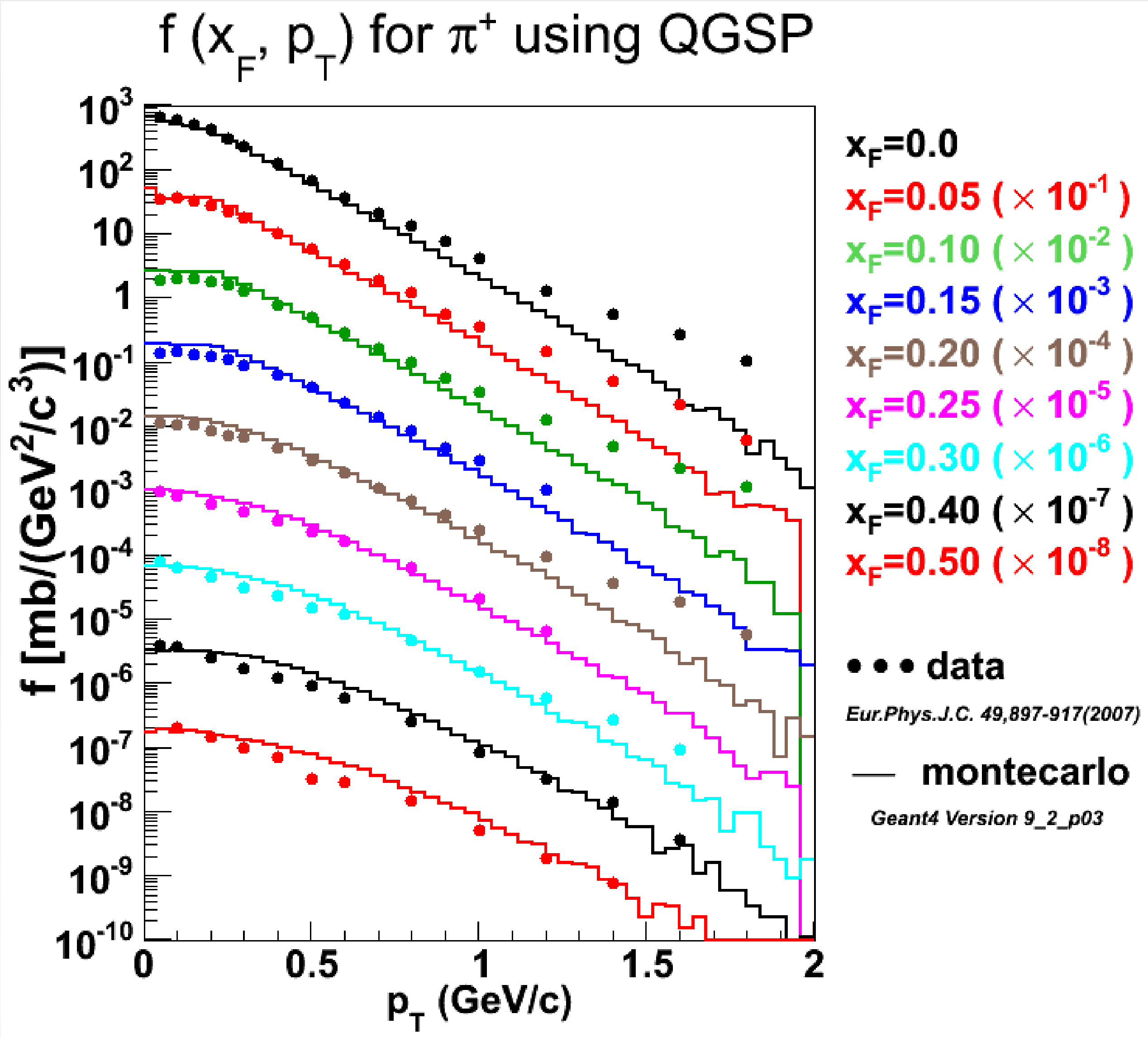
kinematics of the neutrino hadron ancestors using QGSP prediction for MINERvA:



Energies of the particles that produce neutrinos in secondary interaction



Comparison NA49 data and QGSP



- Focusing peak:

  $0.0 < \mathbf{x_F} < 0.15$

  $0.0 < p_T < 0.6$

- Every factor:

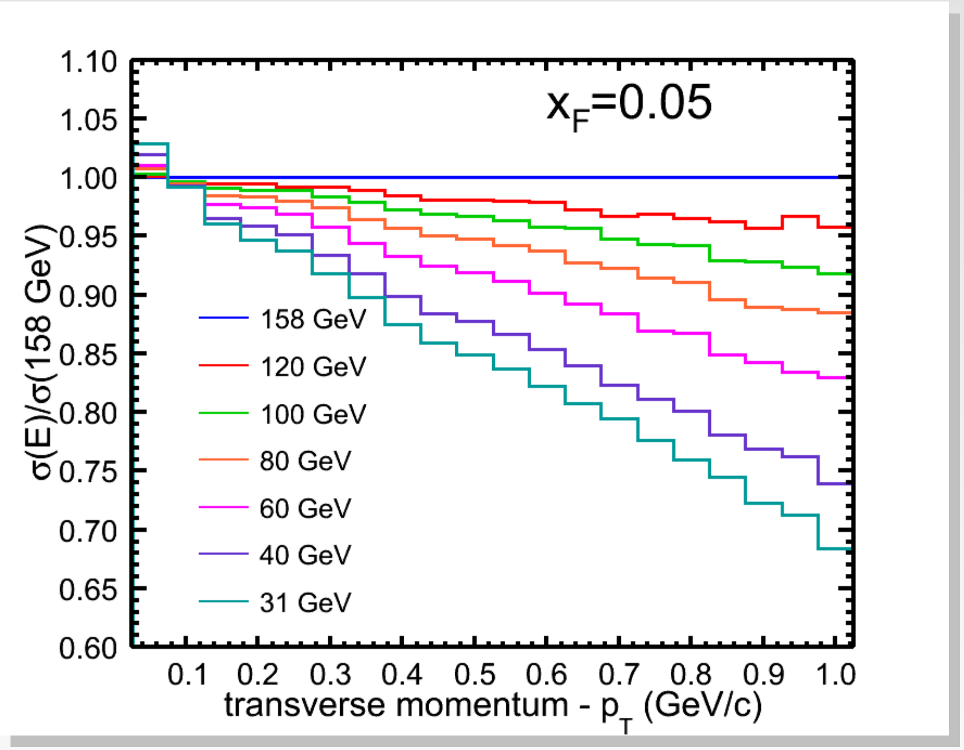
$$w_i = \frac{inv\ XS_{data}}{inv\ XS_{mc}} (x_F, p_T)$$

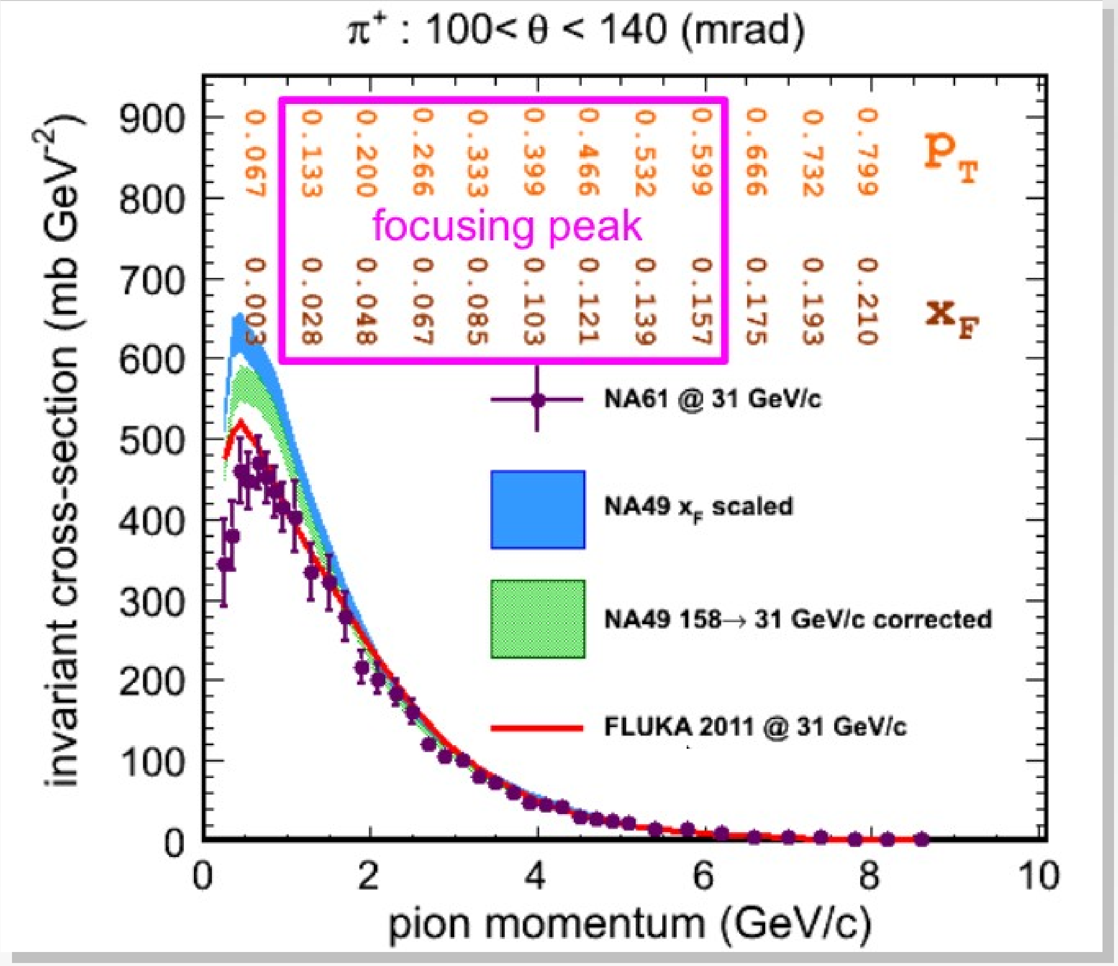
- The results for π^- show a big disagreement for large $\mathbf{x_F}$.
- We also have analyzed Barton (large $\mathbf{x_F}$) and kaons (small $\mathbf{x_F}$).

Energy Scaling

Comparison NA61 (at 31 GeV) vs. NA49 (at 158 GeV):

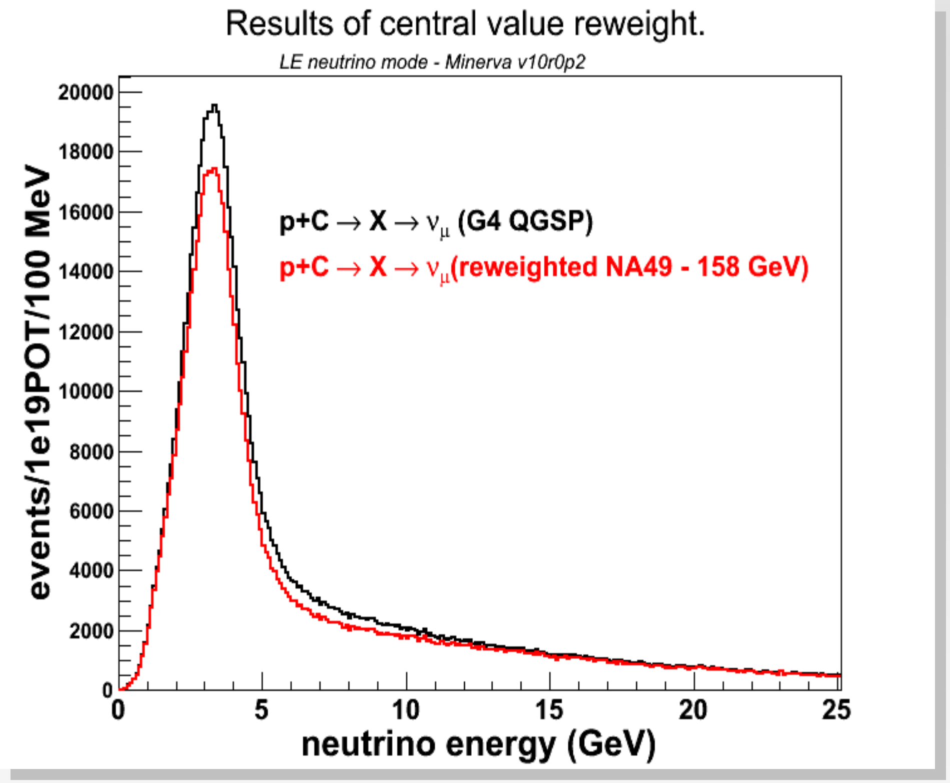
- Feynman scaling works from 158 GeV to 31 GeV:

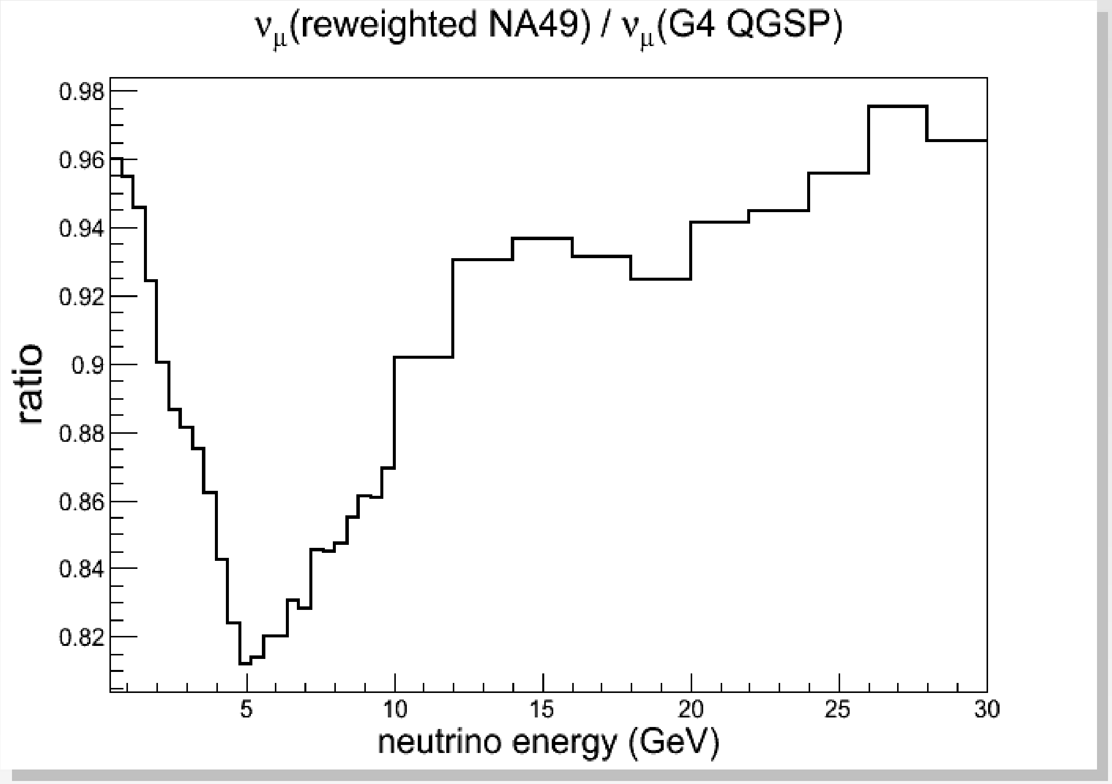




Results

Application of factors to neutrino energy spectrum seen in MINERvA:





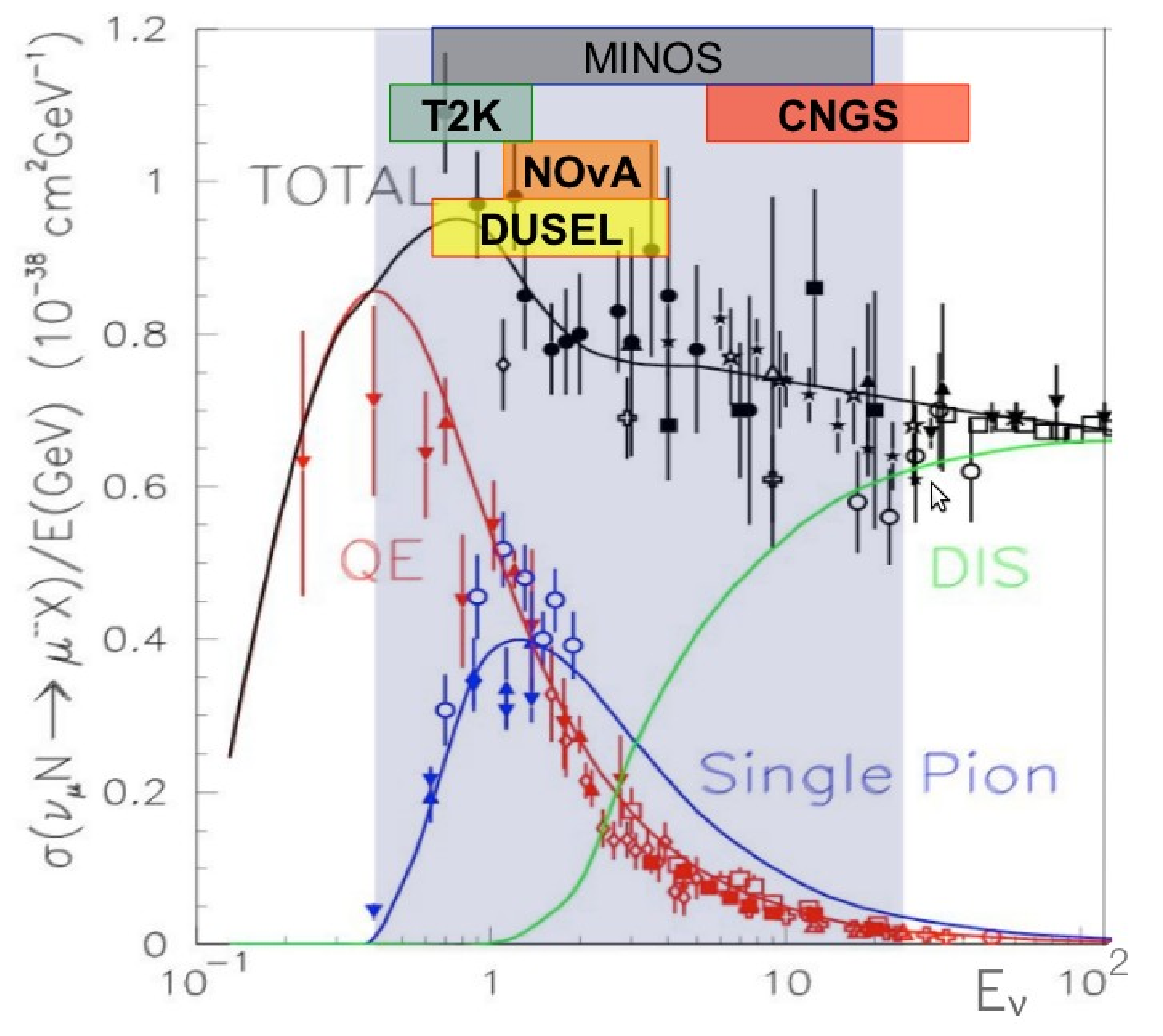
- The NA49 uncertainties are not large.

Conclusions and Next Steps

- We start using the existing hadron production data to correct the Montecarlo prediction for NuMI flux but we still need to incorporate all the data available.
- Other techniques under study can give us more inputs of the flux determination.
- MINERvA and other experiments are going to explore the hadron production with SHINE Collaboration at CERN this summer.

Backup slides

Neutrino Cross Sections

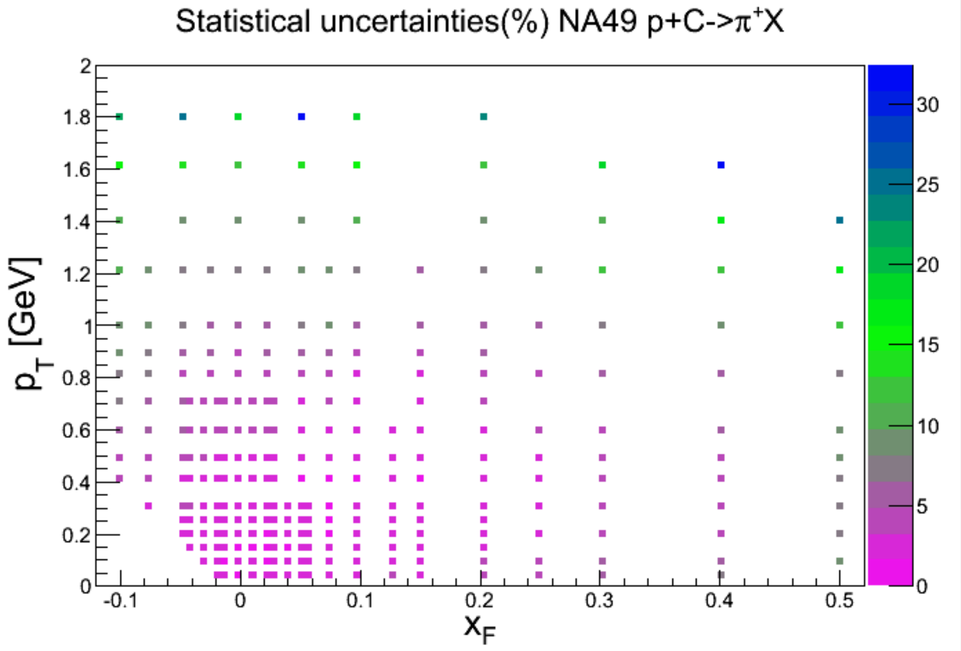


NA49 Uncertainties

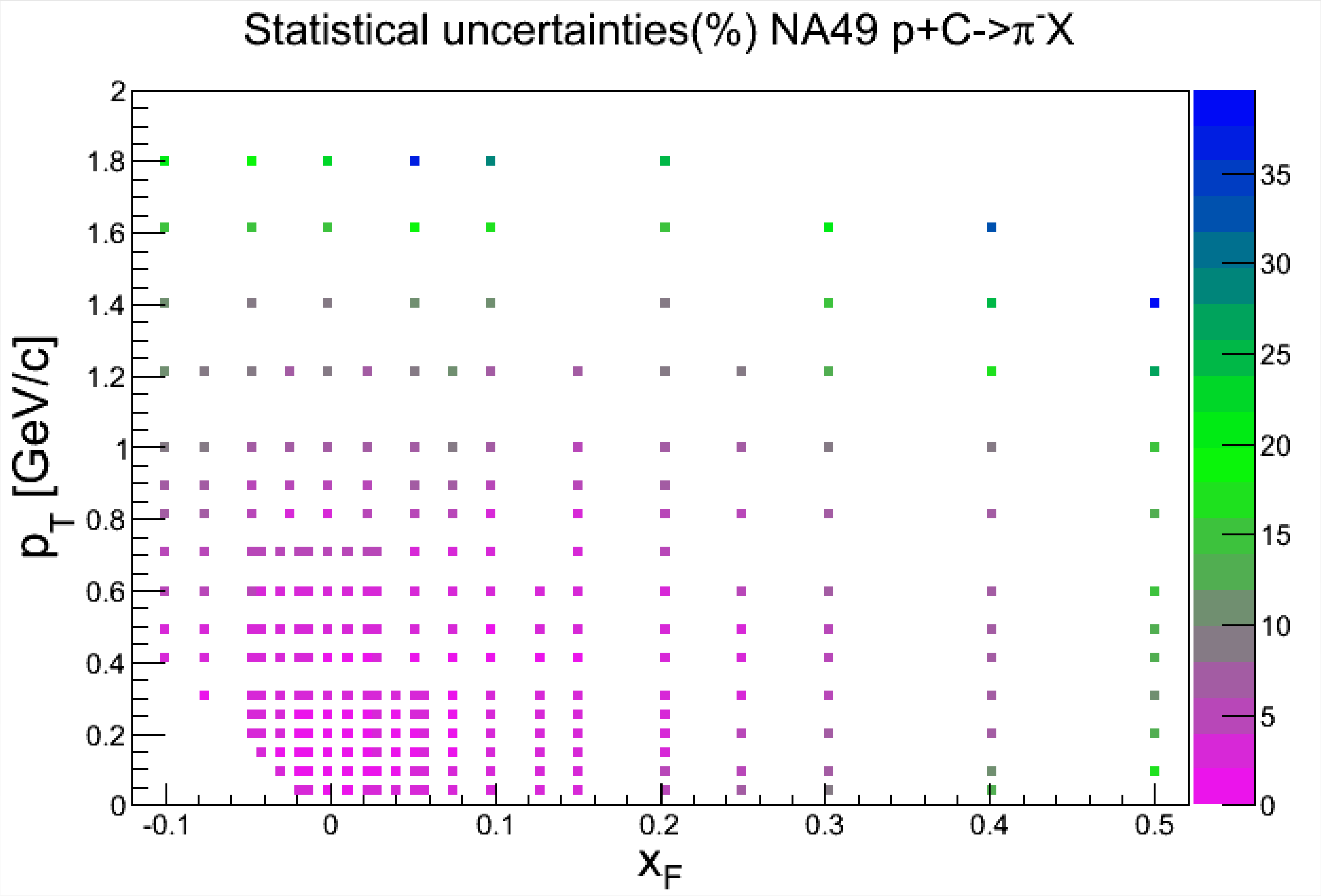
Inclusive production of charged pions in p + C collisions
at 158 GeV/c beam momentum (***Eur. Phys. J. C. 49, 897-917)***

Table 3. Summary of systematic errors

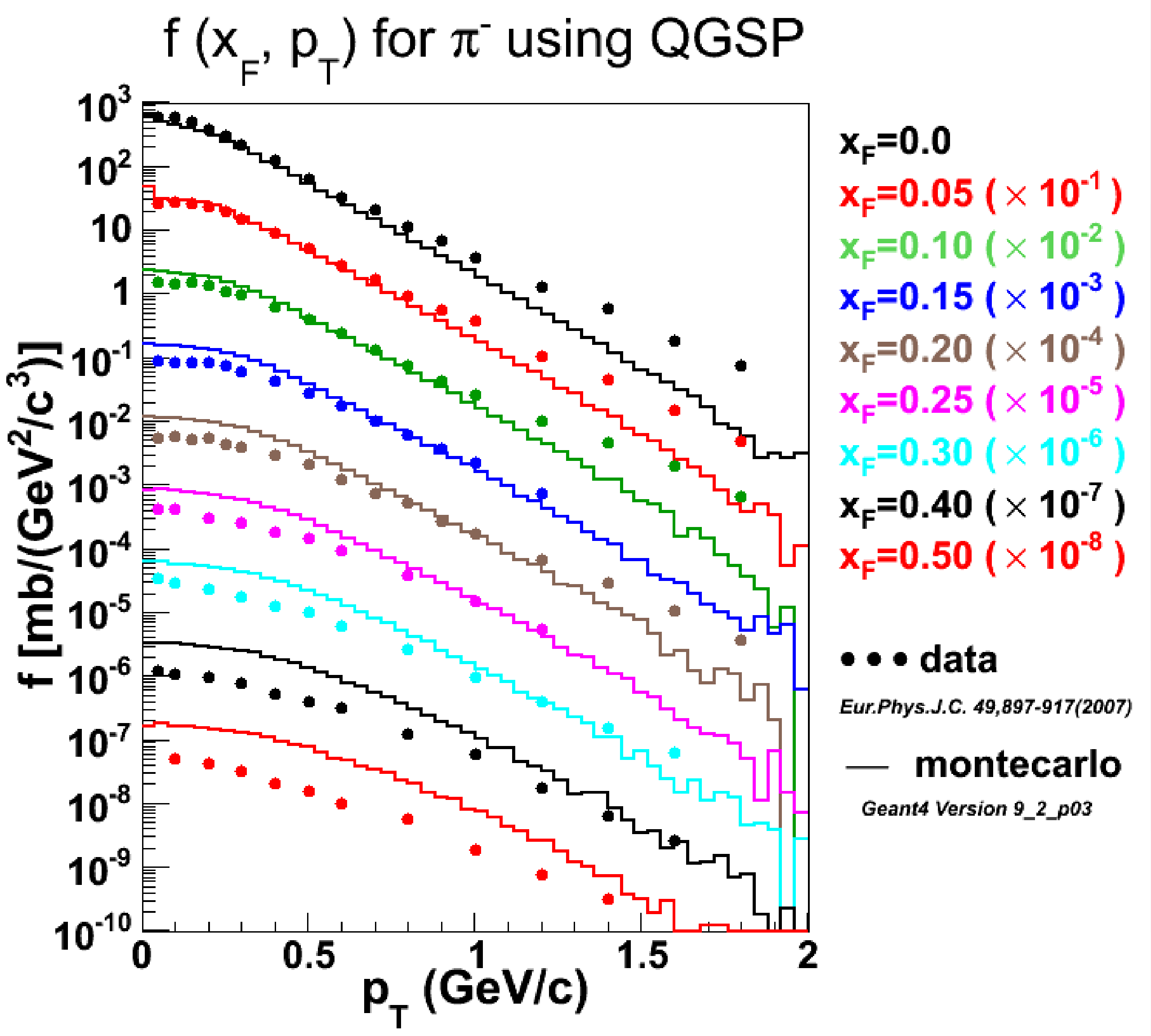
Normalisation	2.5%
Tracking efficiency	0.5%
Trigger bias	1%
Feed-down	1–2.5%
Detector absorption	
Pion decay $\pi \rightarrow \mu + \nu_\mu$	0.5%
Re-interaction in the target	
Binning	0.5%
Total (upper limit)	7.5%
Total (quadratic sum)	3.8%



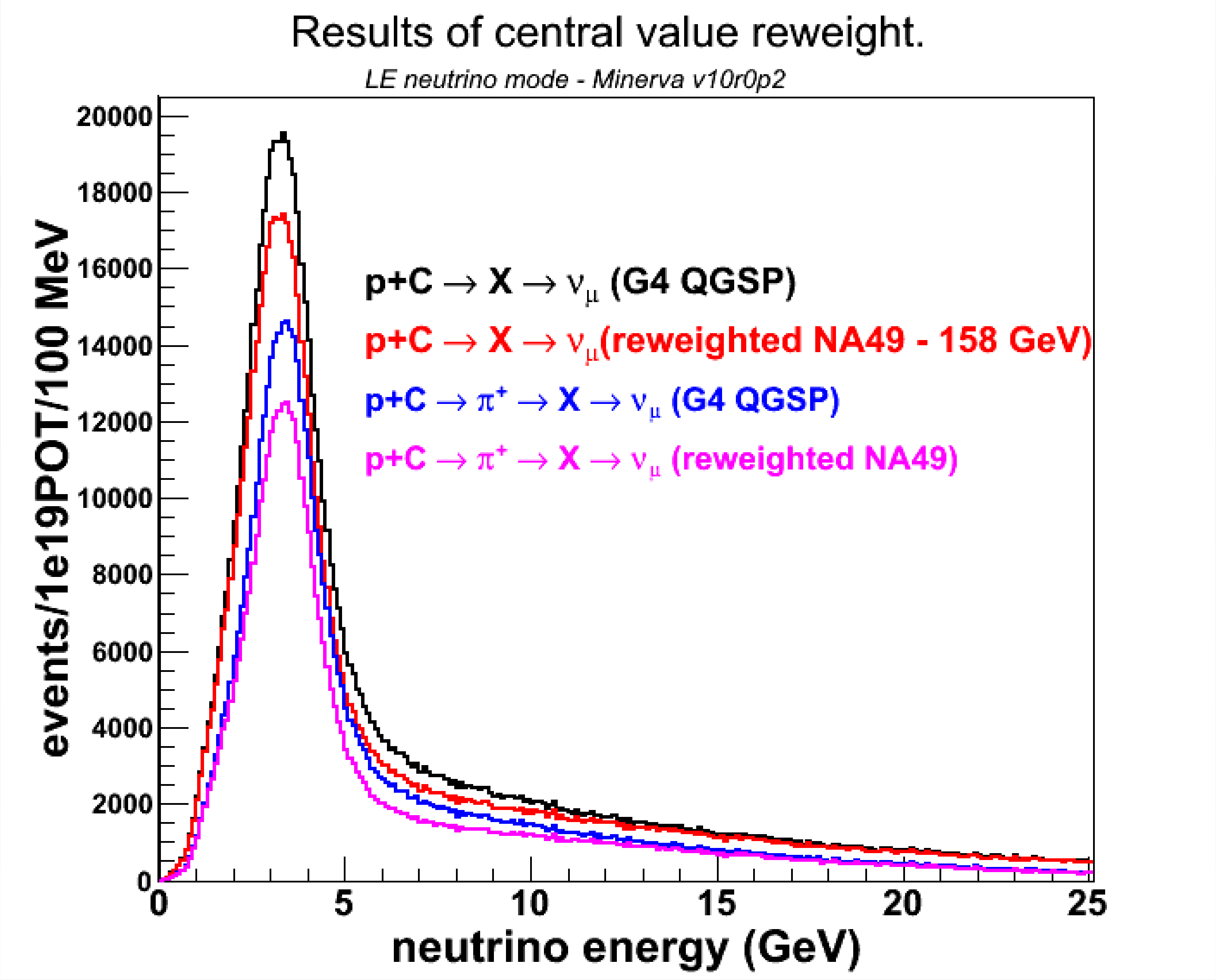
NA49 Uncertainties



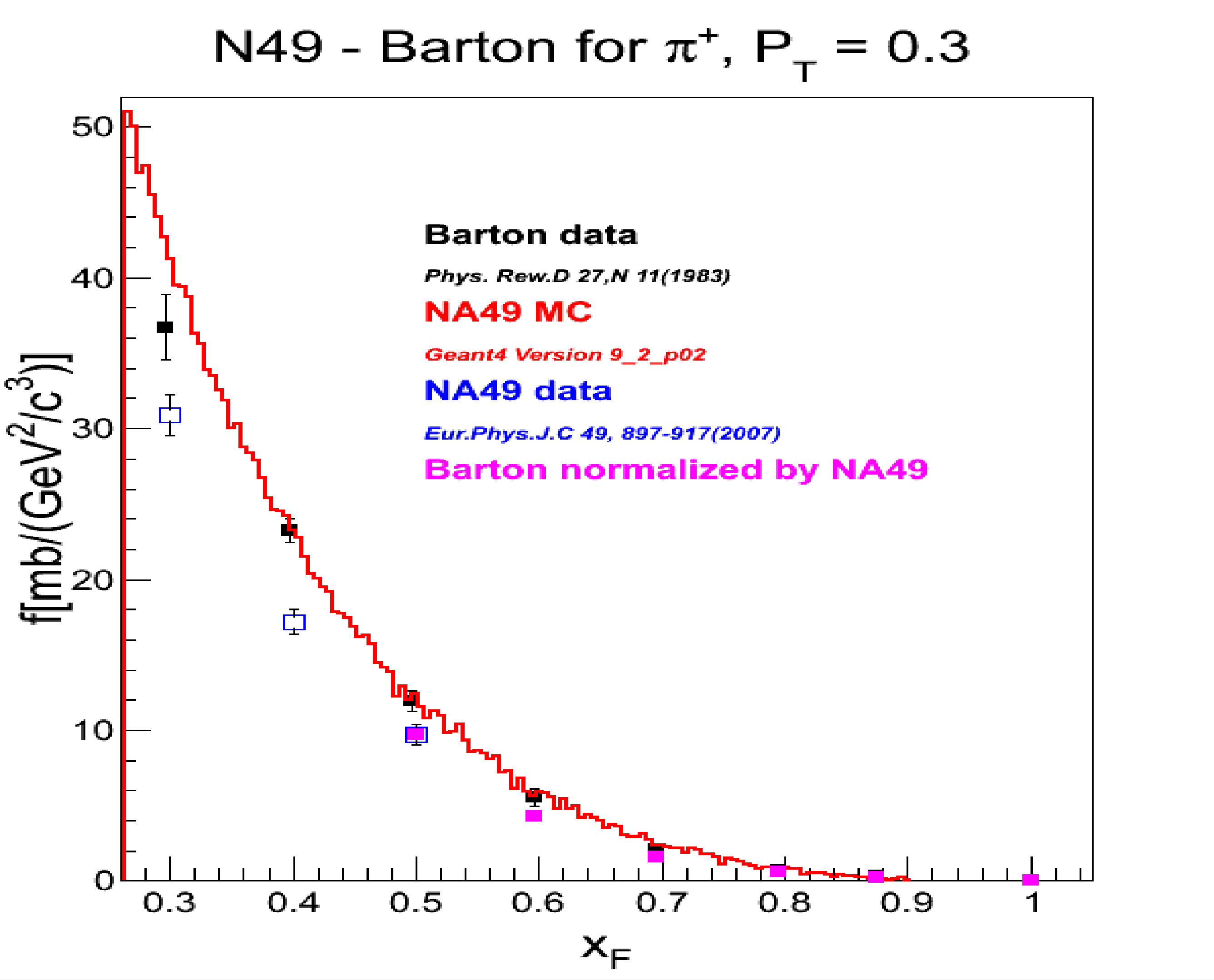
NA49 Data – MC Comparison



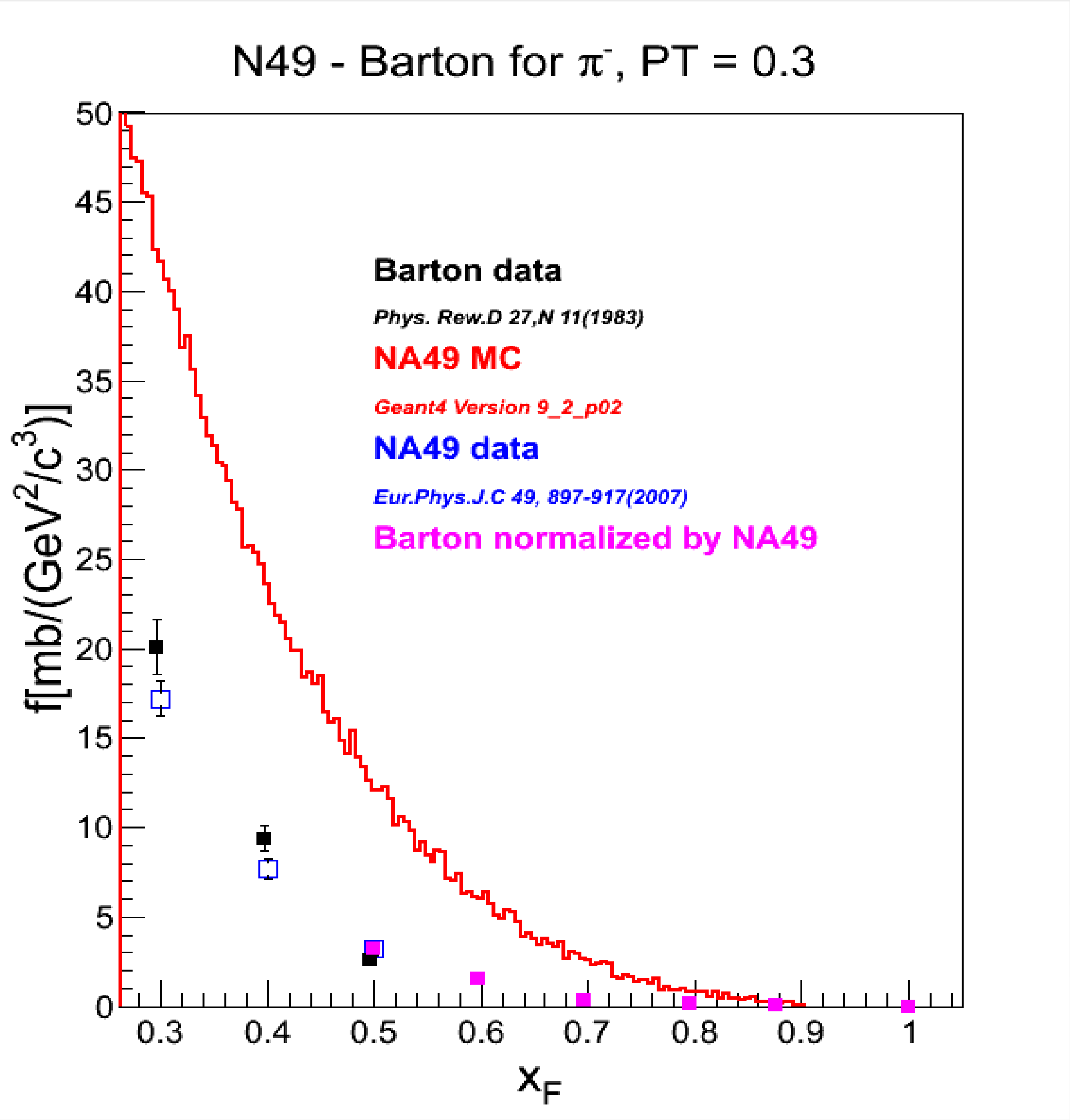
Reweighted Neutrino Energy and Pion Component



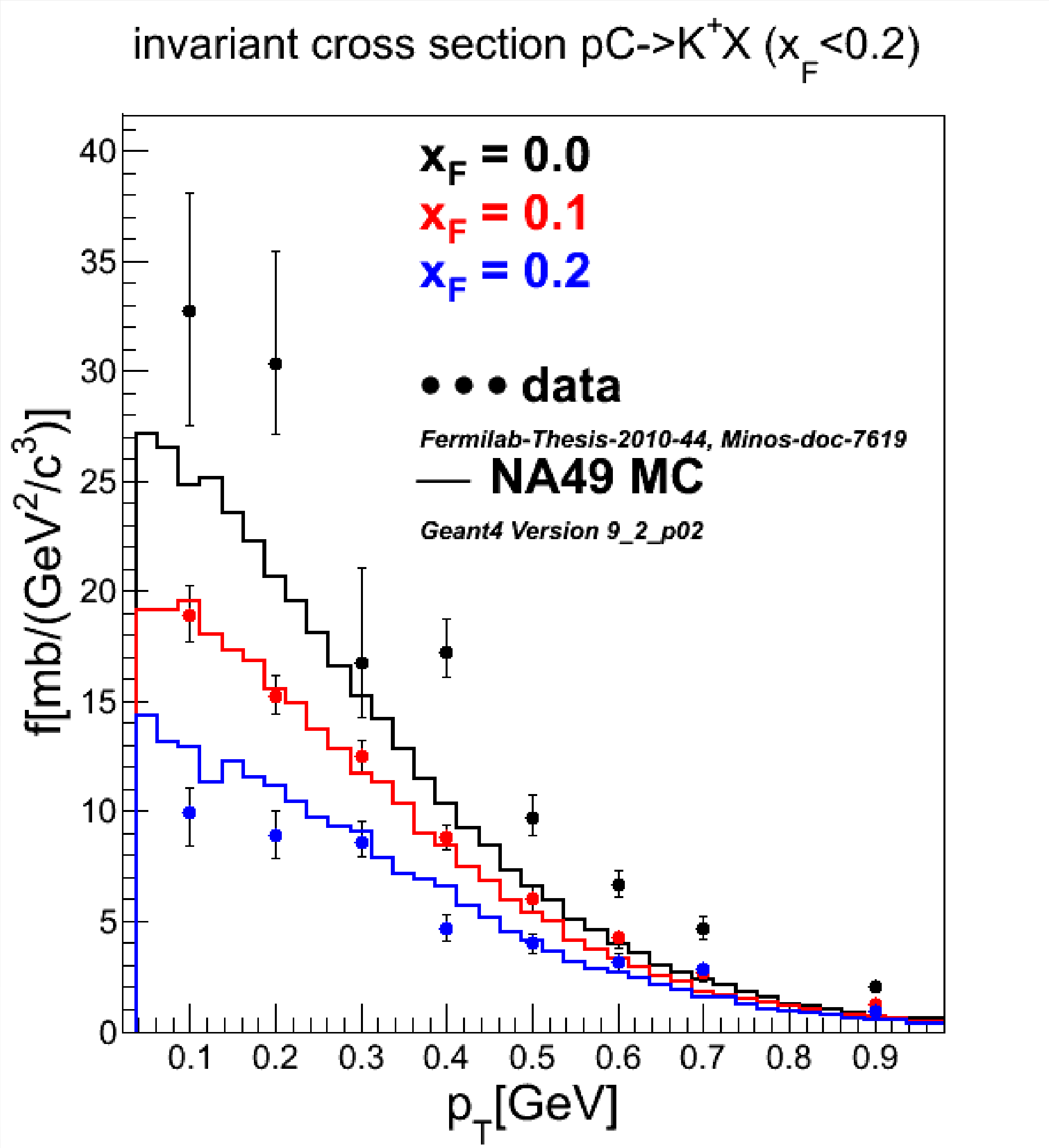
Barton Normalized by NA49 for PT=0.3 and Kaon Plus



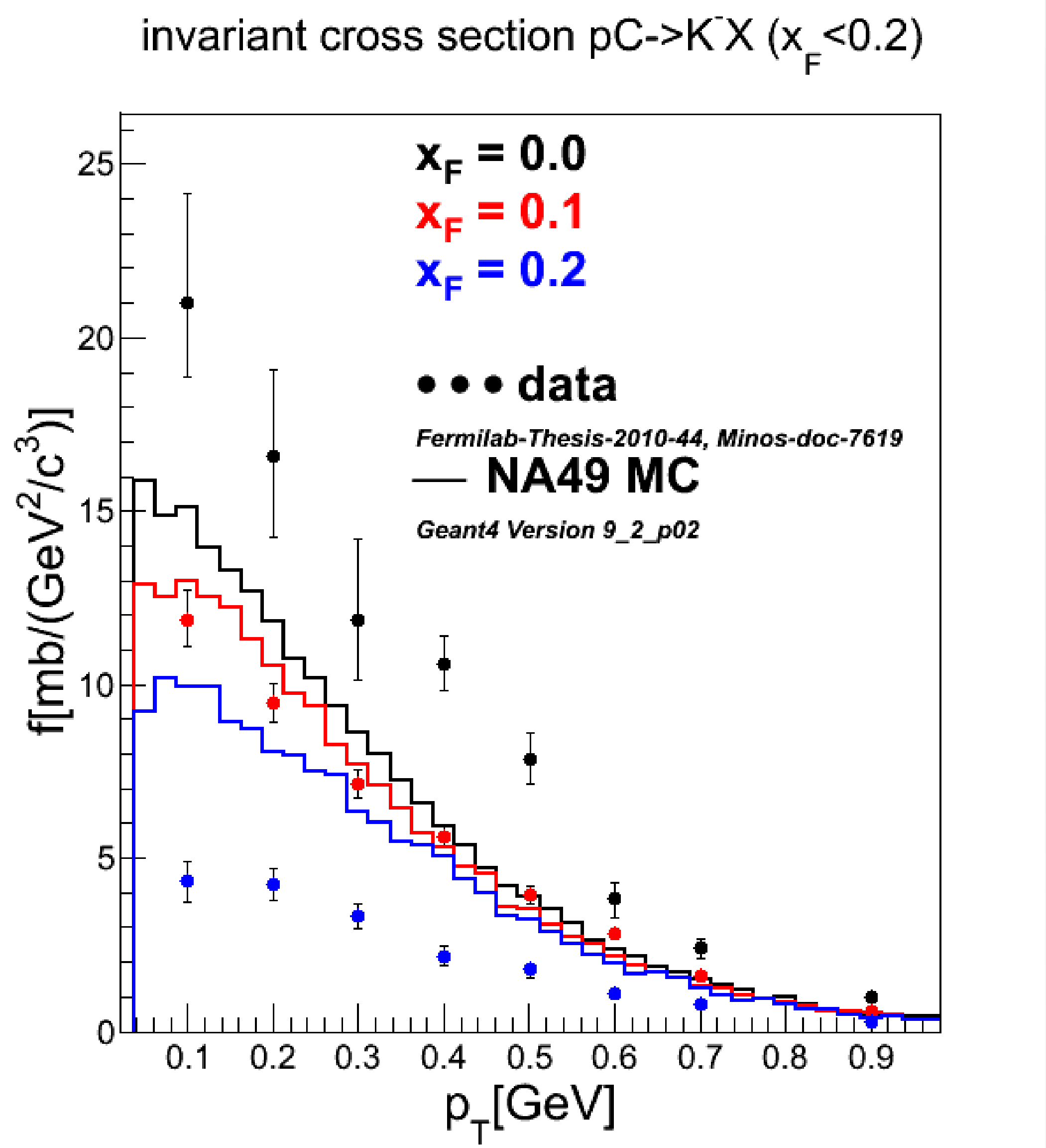
Barton Normalized by NA49 for PT=0.3 and Kaon Minus



NA49 Kaon Data – MC Comparison



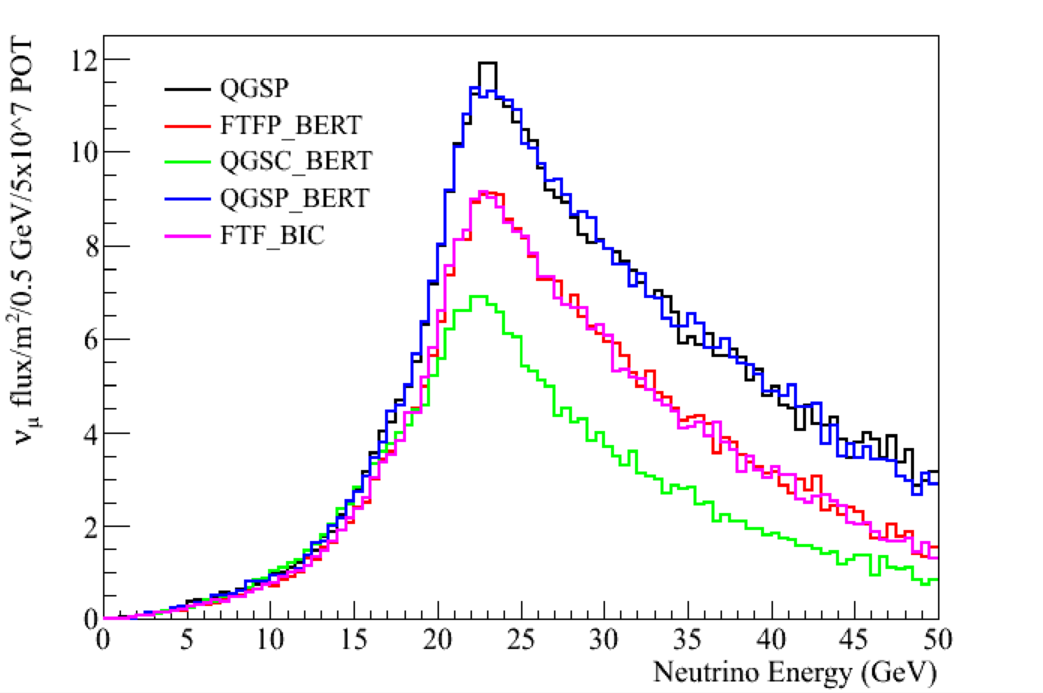
NA49 Kaon Data – MC Comparison



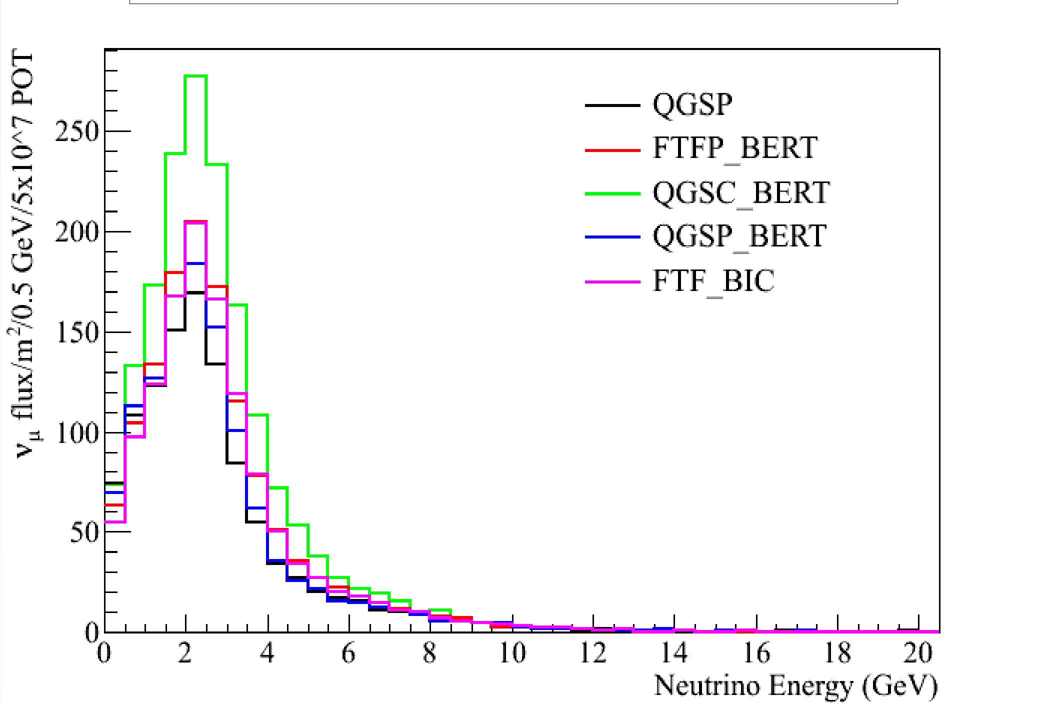
Model Spread

- For events like NA49 we use the uncertainties given by the NA49 results.
- For events that are not NA49-like events we can use the model spread in the neutrino flux predicted by hadronic models:

From K^+ with large xf and that no interact in the target

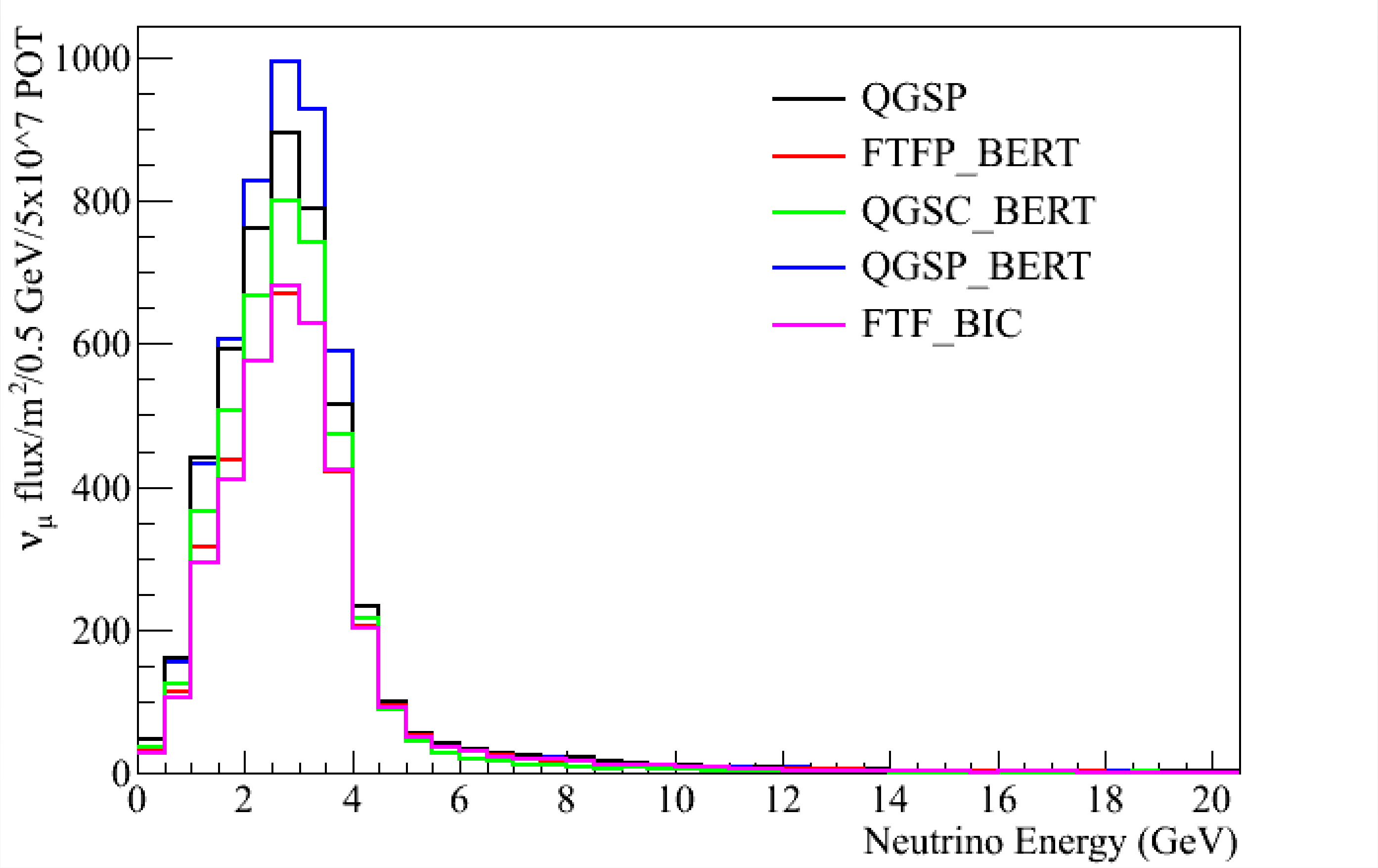


From π^+ piplus created downstream in the horn

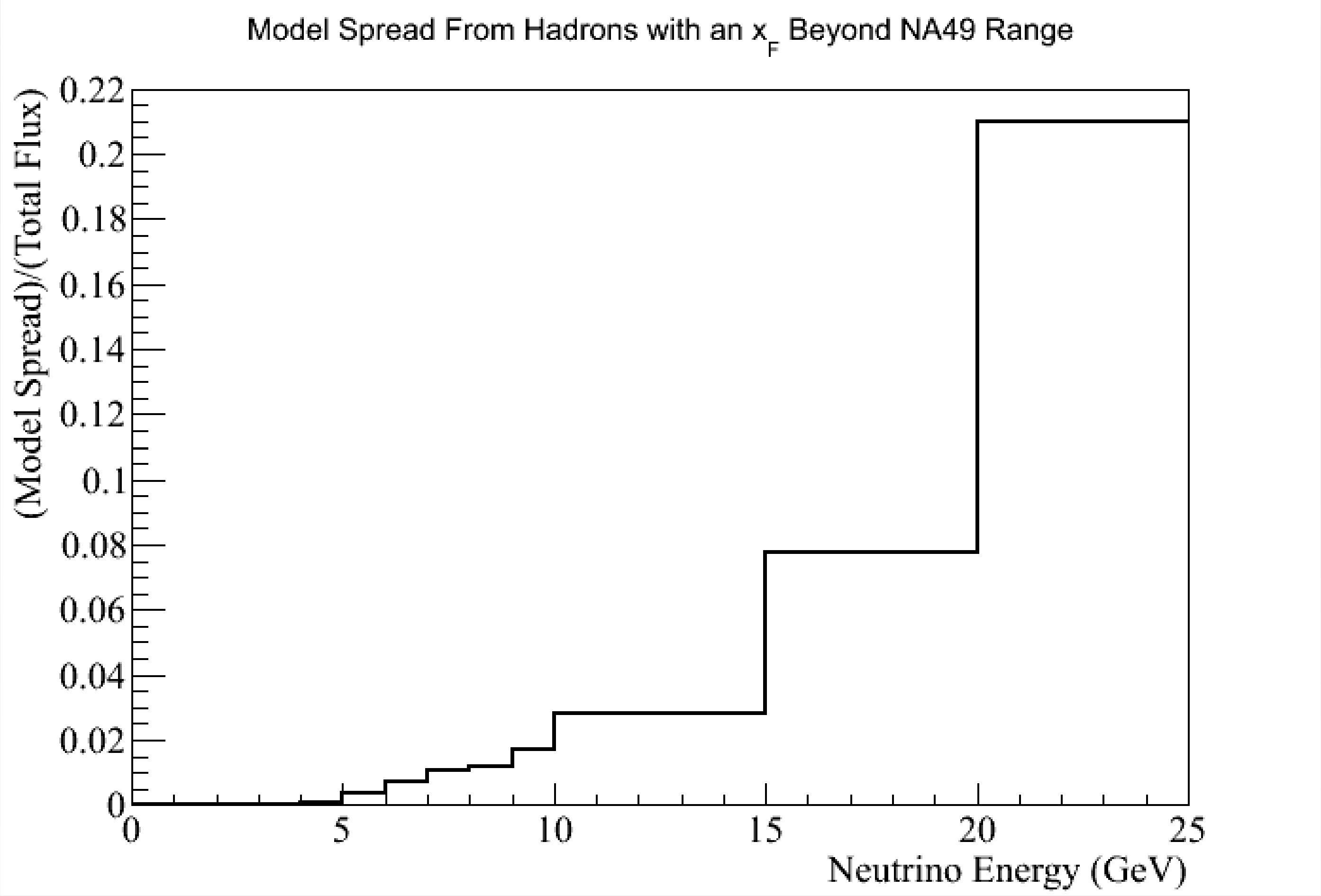


Another Example of Model Spread

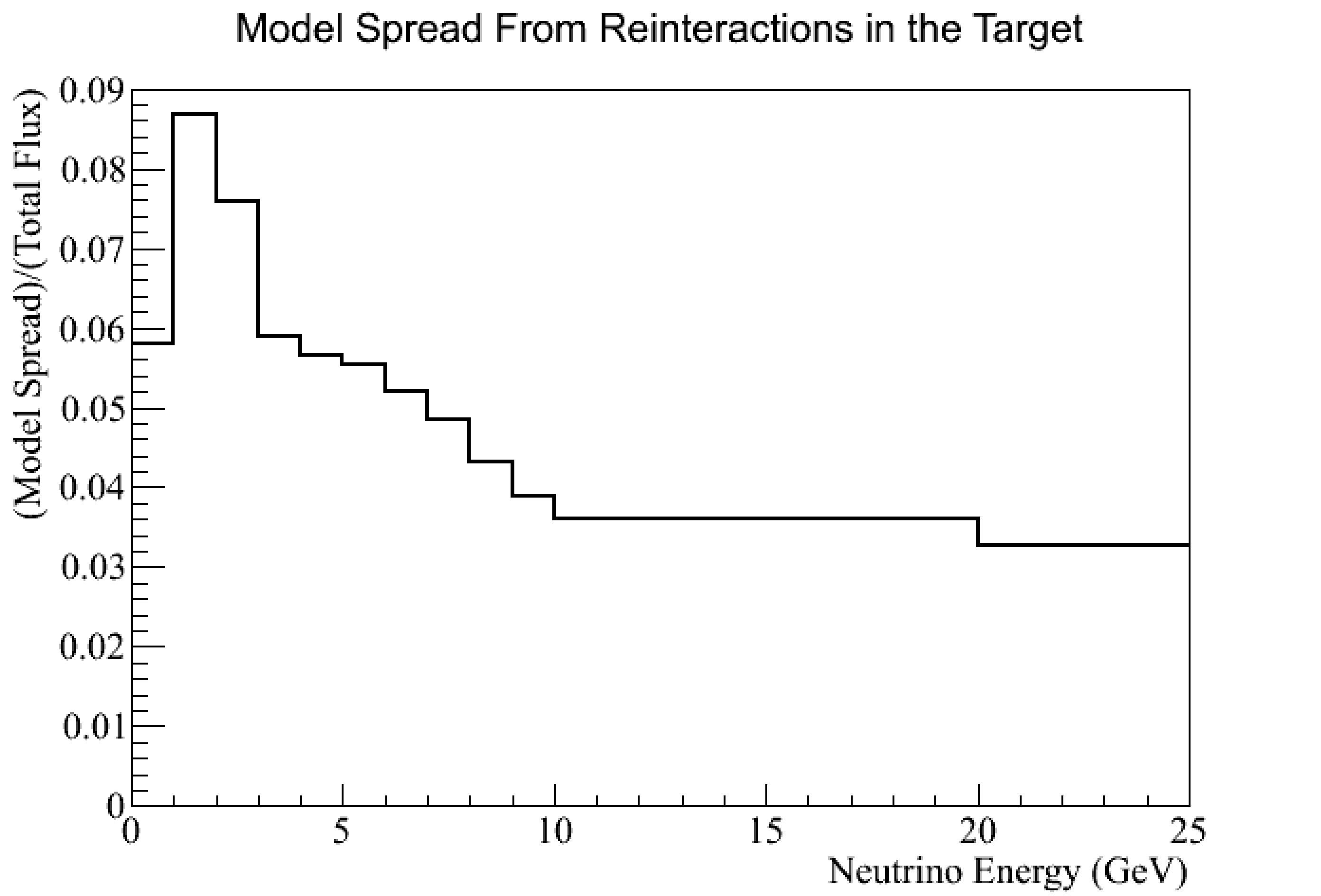
From π^+ with a pion that interact in the target



Model Spread

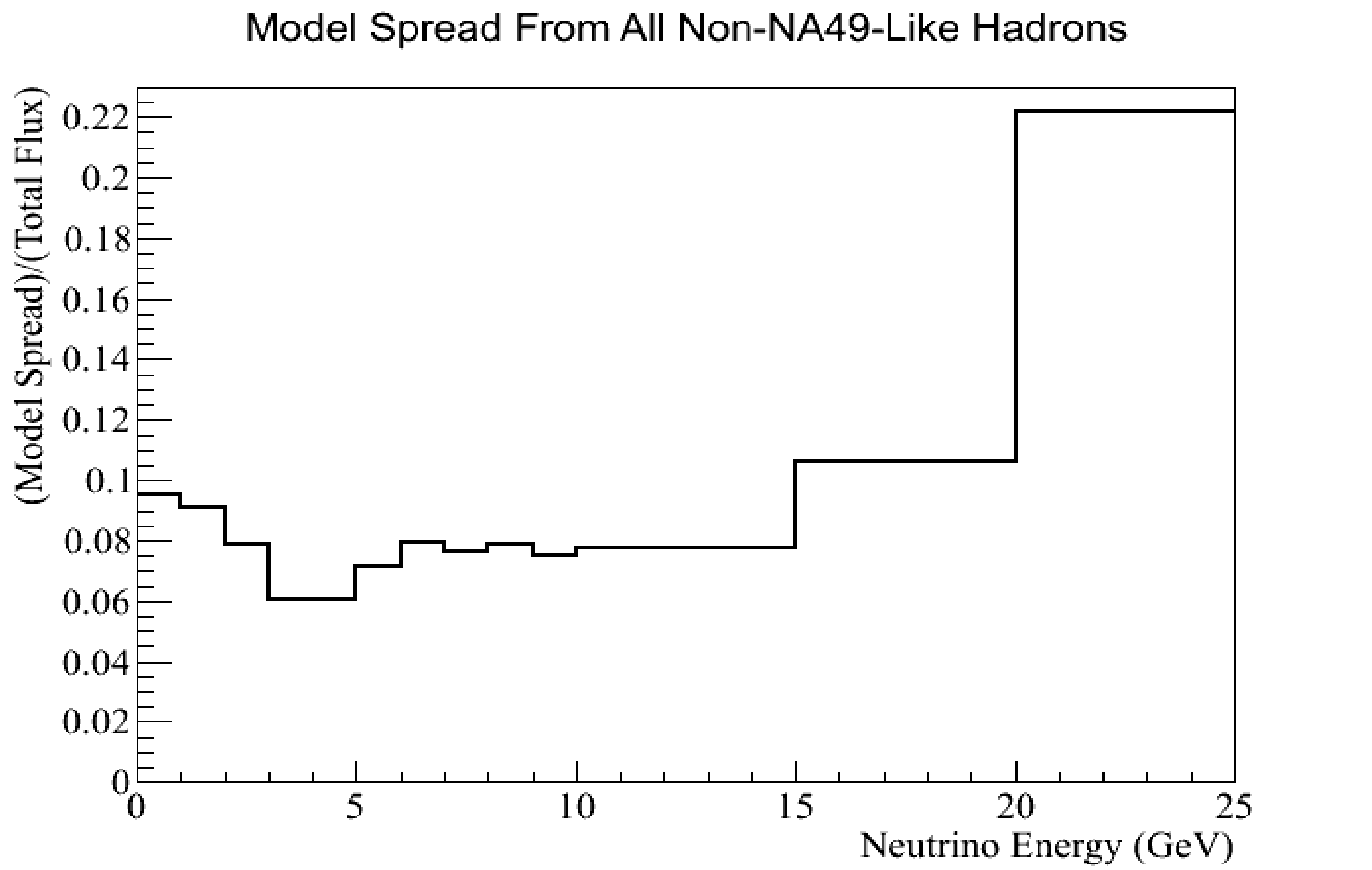


Model Spread

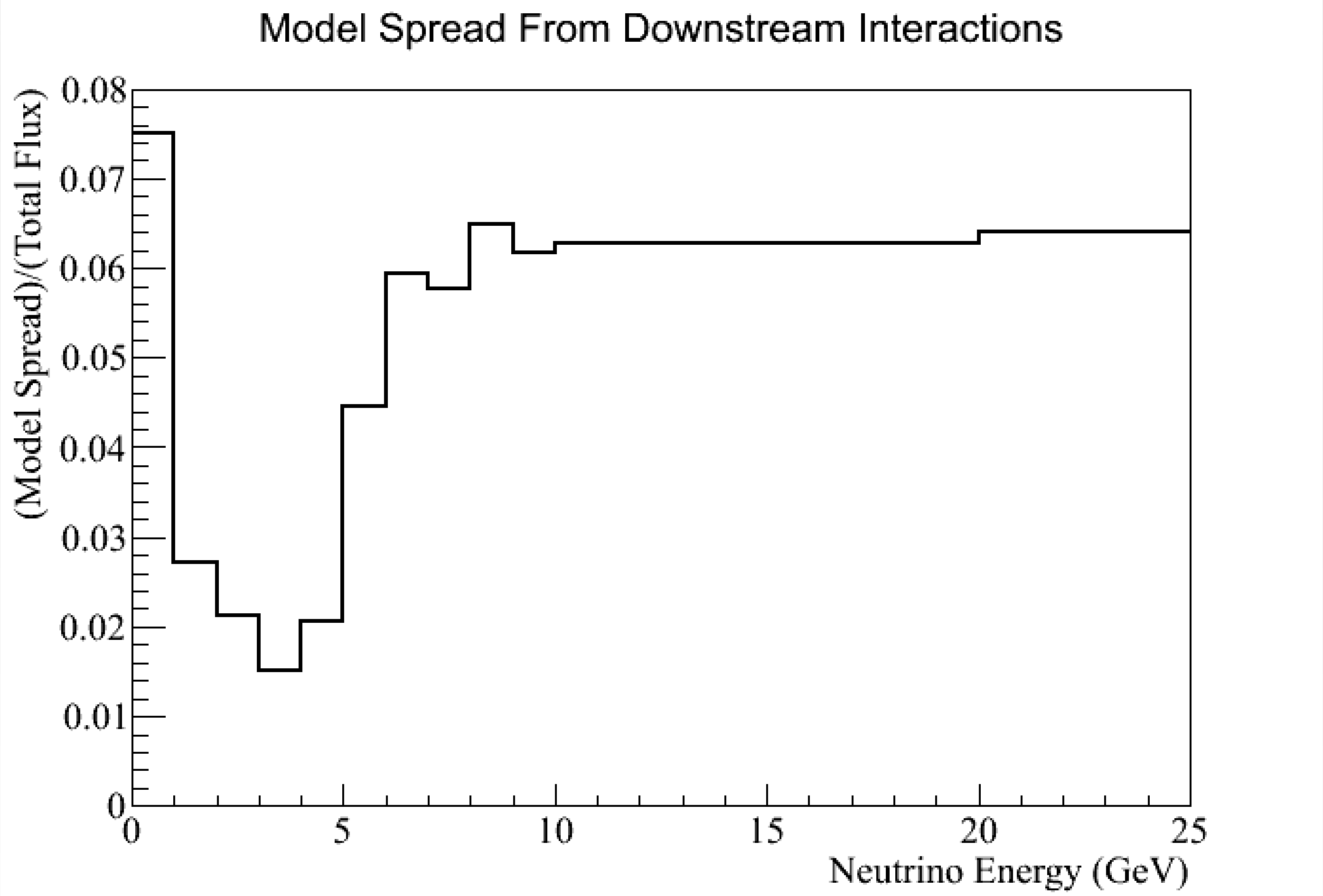


Results from Model Spread

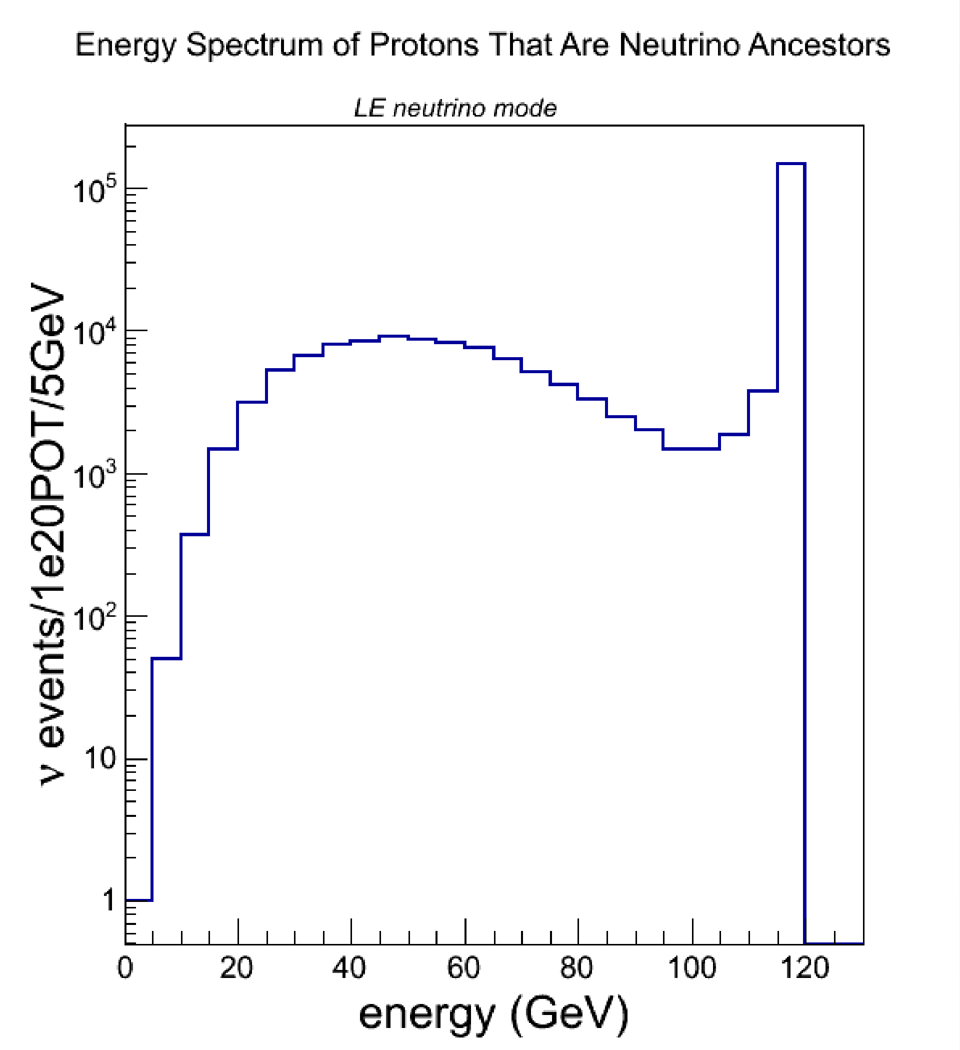
For events no NA49-like



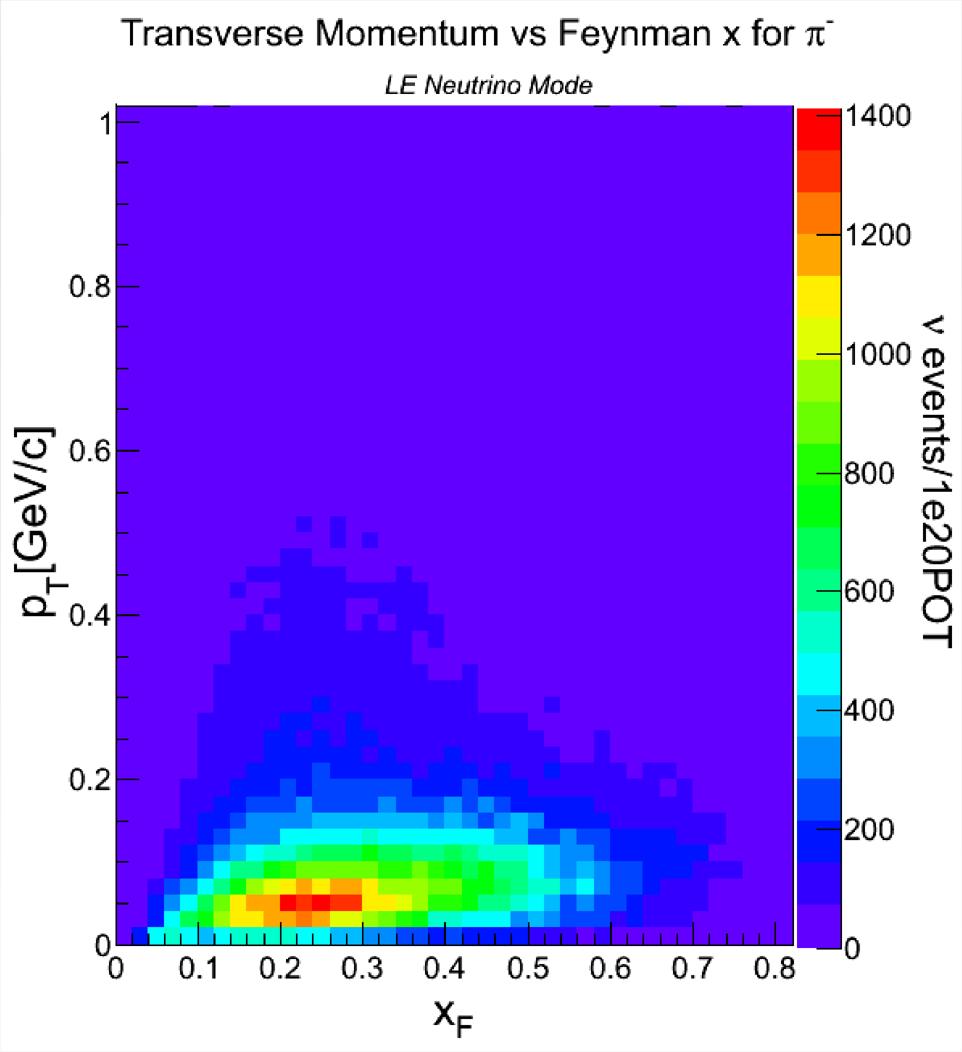
Model Spread



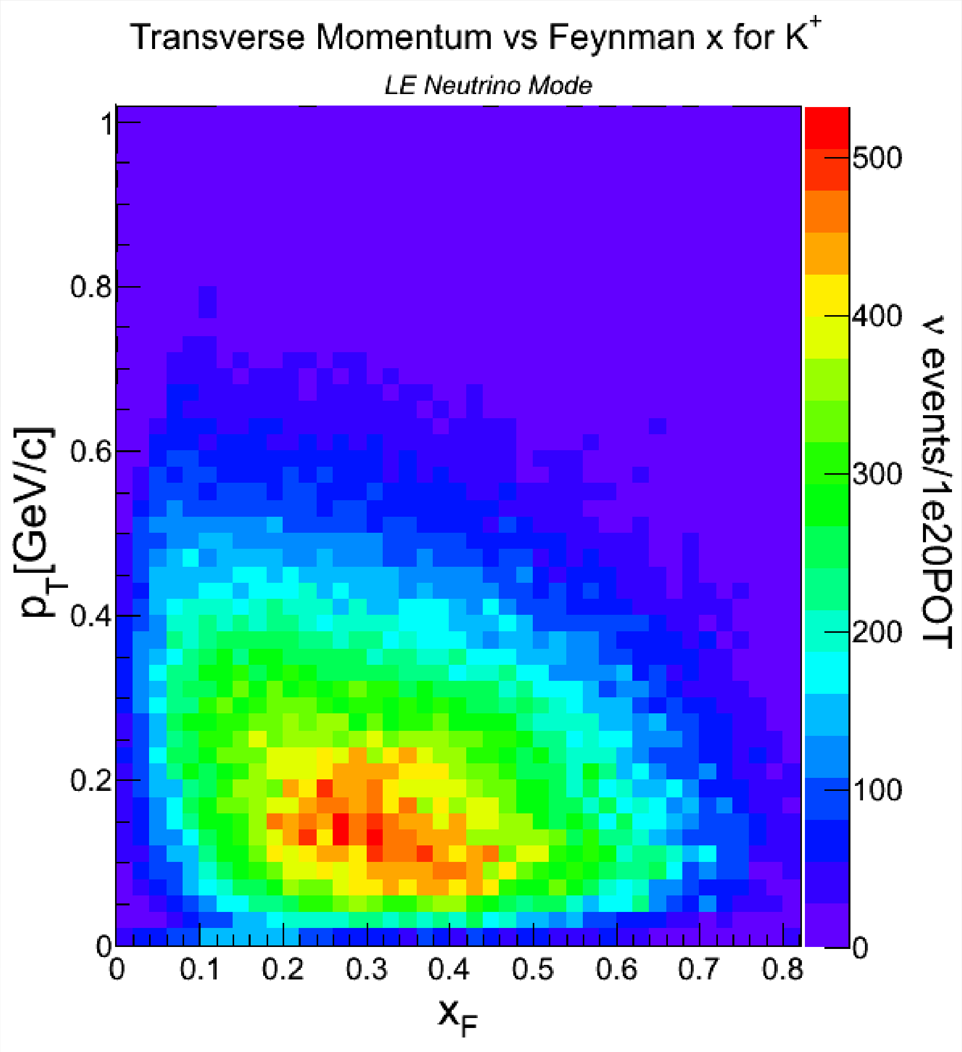
Proton Energy Produced at pC



Kinematic of Pion Minus Produced at pC



Kinematic of Kaon Plus Produced at pC



Kinematic of Kaon Minus Produced at pC