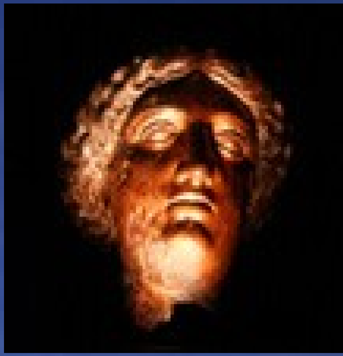
International Workshop on Neutrino Factories, Super Beams and Beta Beams

July 23-28, 2012, Williamsburg, VA, USA



NuMI Flux,

Current Uncertainties And Future Plans

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William & Mary

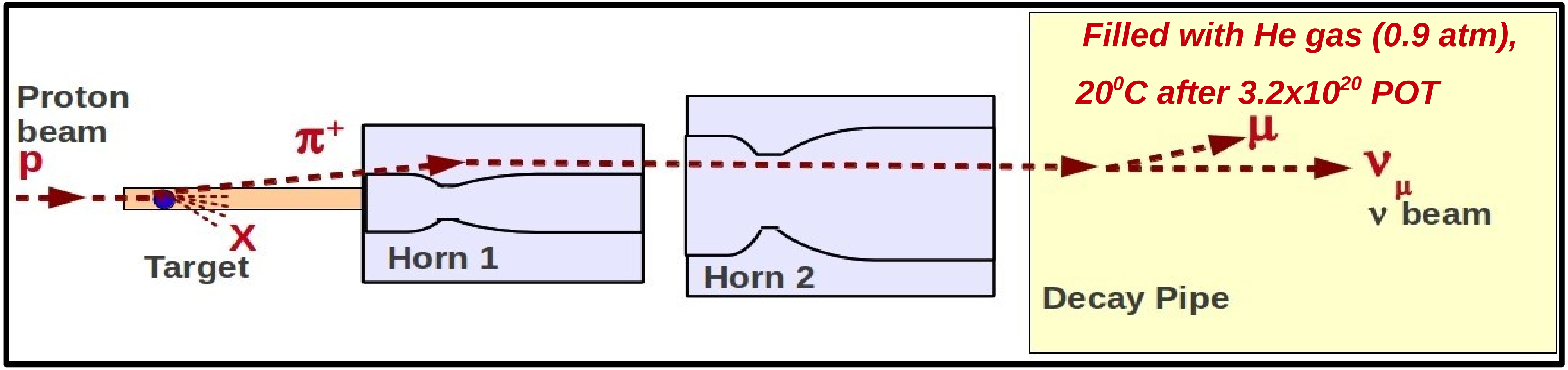
July 25, 2012

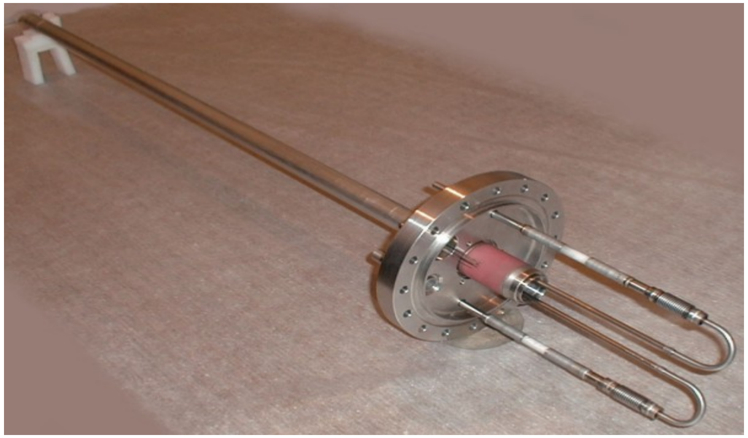
Photo by Ed Hartouni

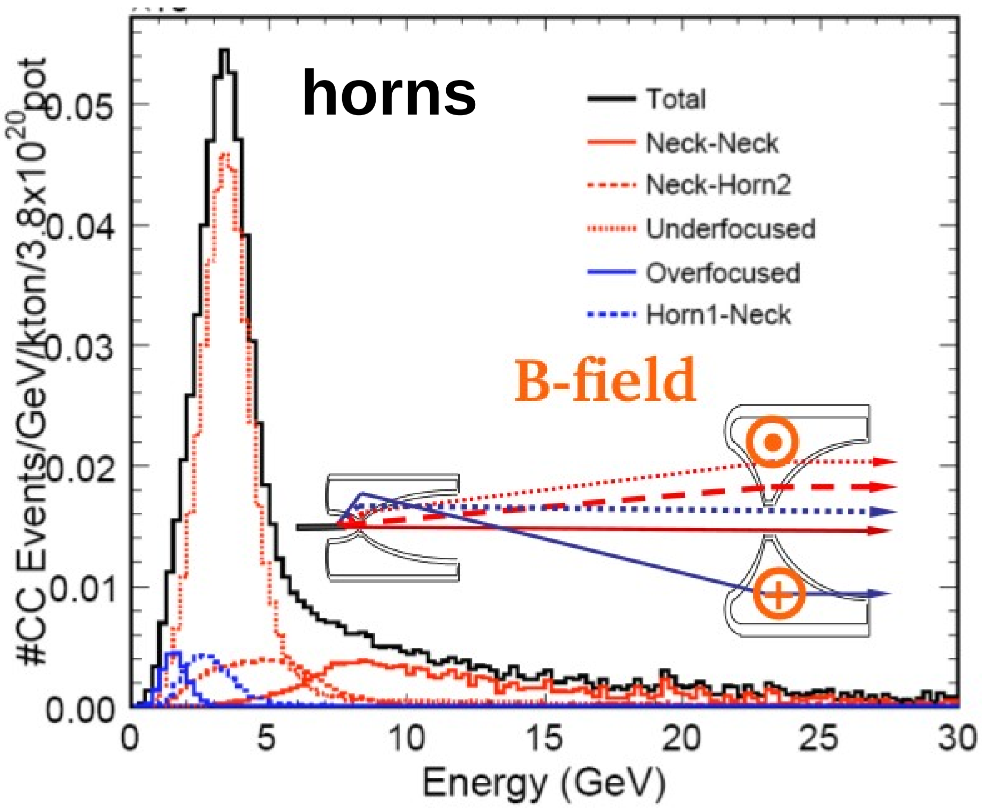
Outline

- Description of NuMI.
- Understanding NuMI Flux.
- Improving the Flux knowledge (Minerva's strategy).
- Conclusions and next steps.

Hadron production and focusing

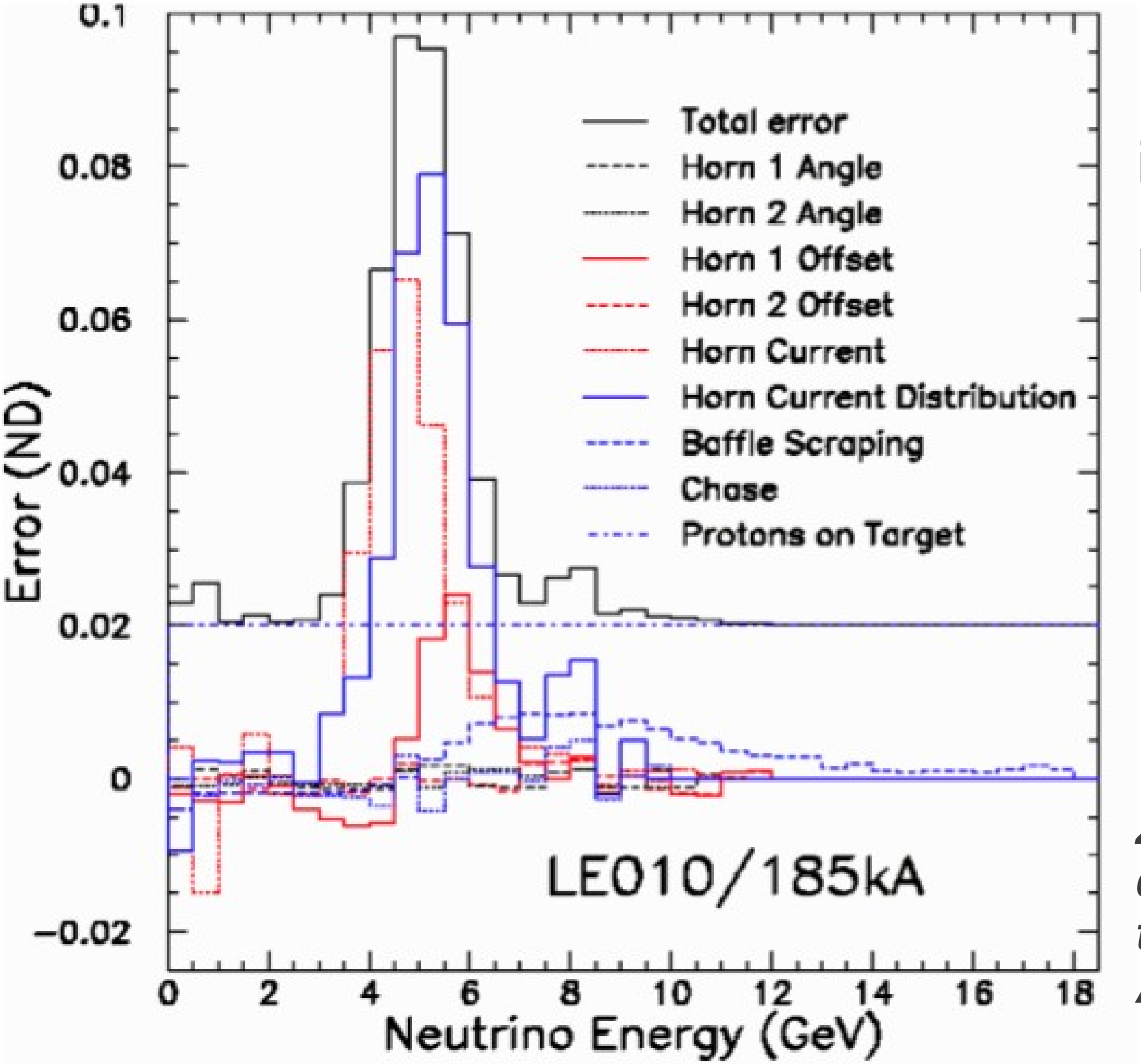






- *Rectangular graphite rod, 6.4 x 15mm^2.*
- *Segmented in 47 “fins”.*
- *Total length 940mm (~2 λ).*
- *Water cooled and Enclosed in He filled.*

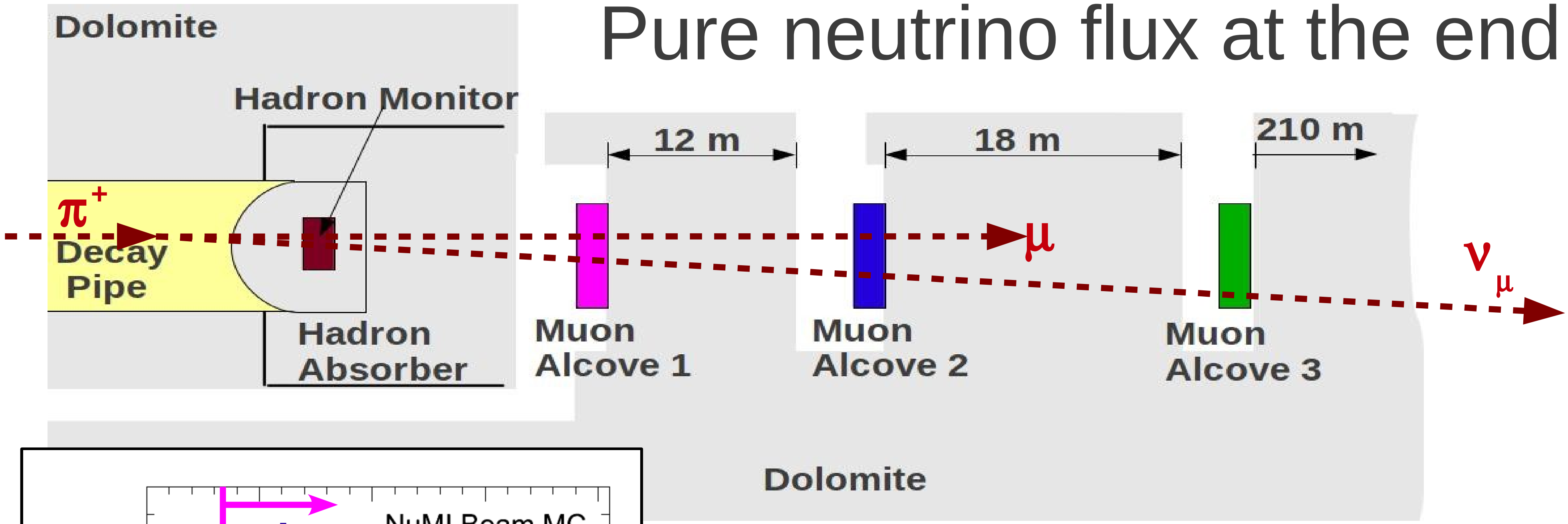
Focusing total uncertainties...

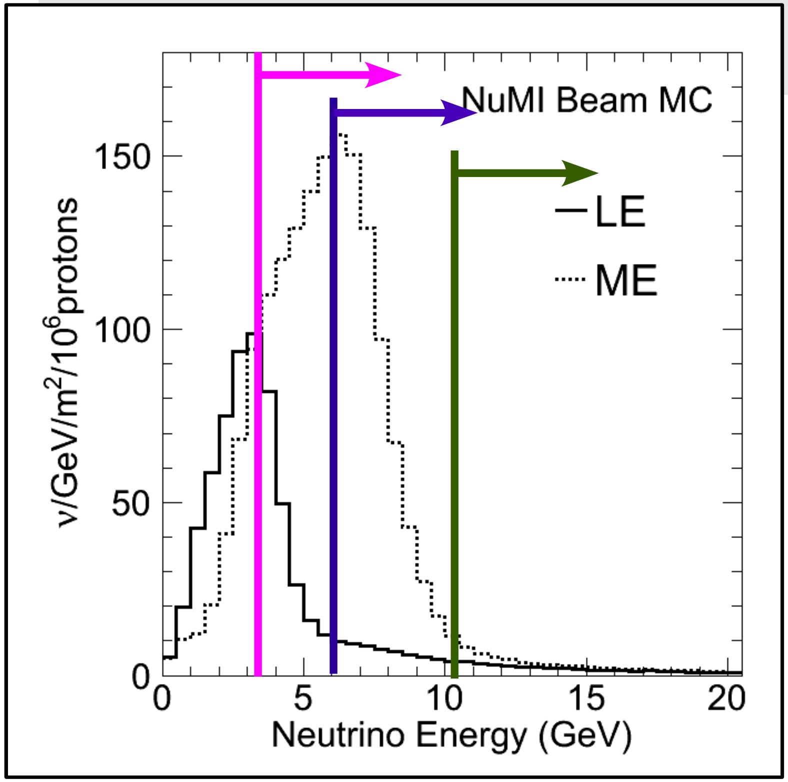


Focusing uncertainties are small in comparison with hadron production uncertainties.

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

Pure neutrino flux at the end..

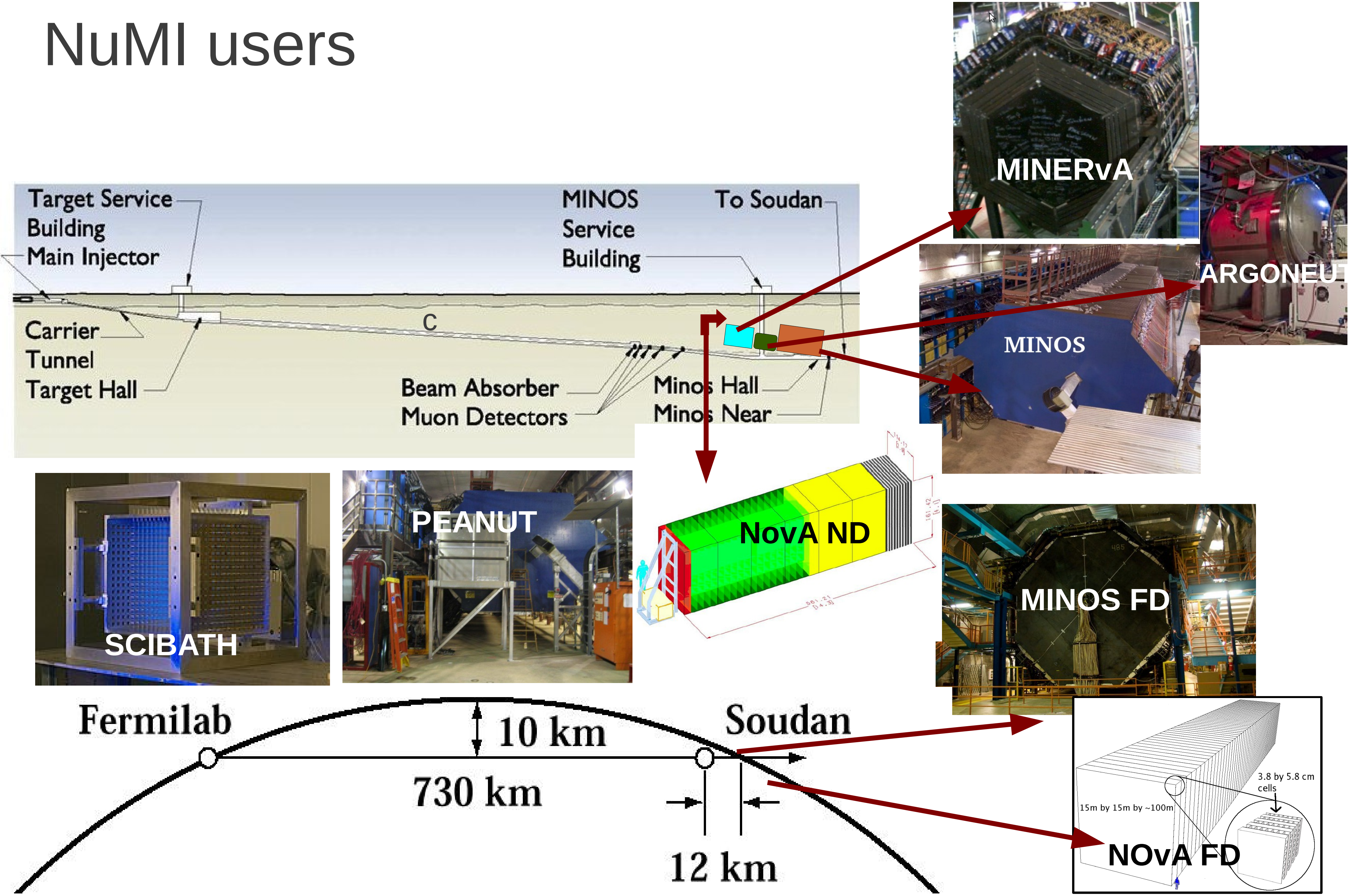




Muon Monitor 1: $E_{\mu,\pi}$ > 4.2 GeV & E_ν > 1.8 GeV
Muon Monitor 2: $E_{\mu,\pi}$ > 11 GeV & E_ν > 4.7 GeV
Muon Monitor 3: $E_{\mu,\pi}$ > 21 GeV & E_ν > 9.0 GeV

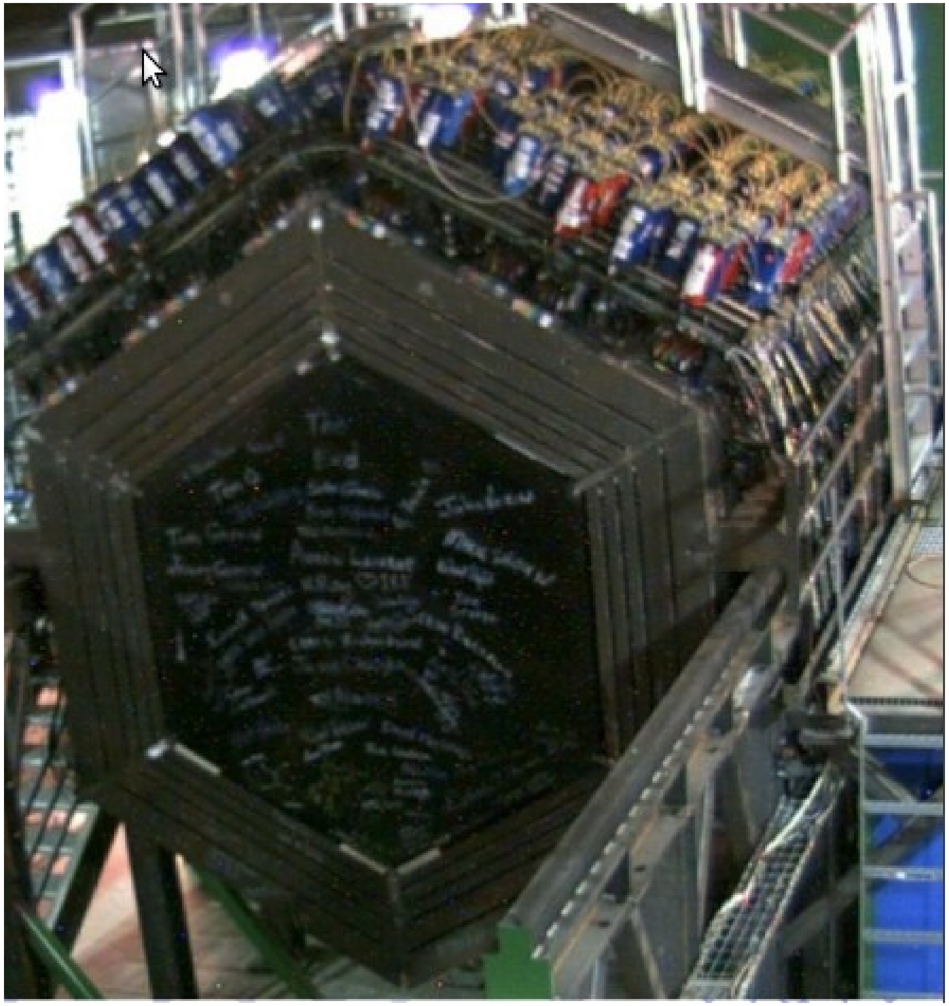
- *Detected by He gas but contamination of neutron and δ-rays.*
- *kinematics related to hadrons off the target and ν .*

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
SCIBATH
PEANUT
NovA ND
MINOS FD
Fermilab
10 km
Soudan
730 km
12 km
3.8 by 5.8 cm cells
15m by 15m by ~100m
NOvA FD

Particularly 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.***

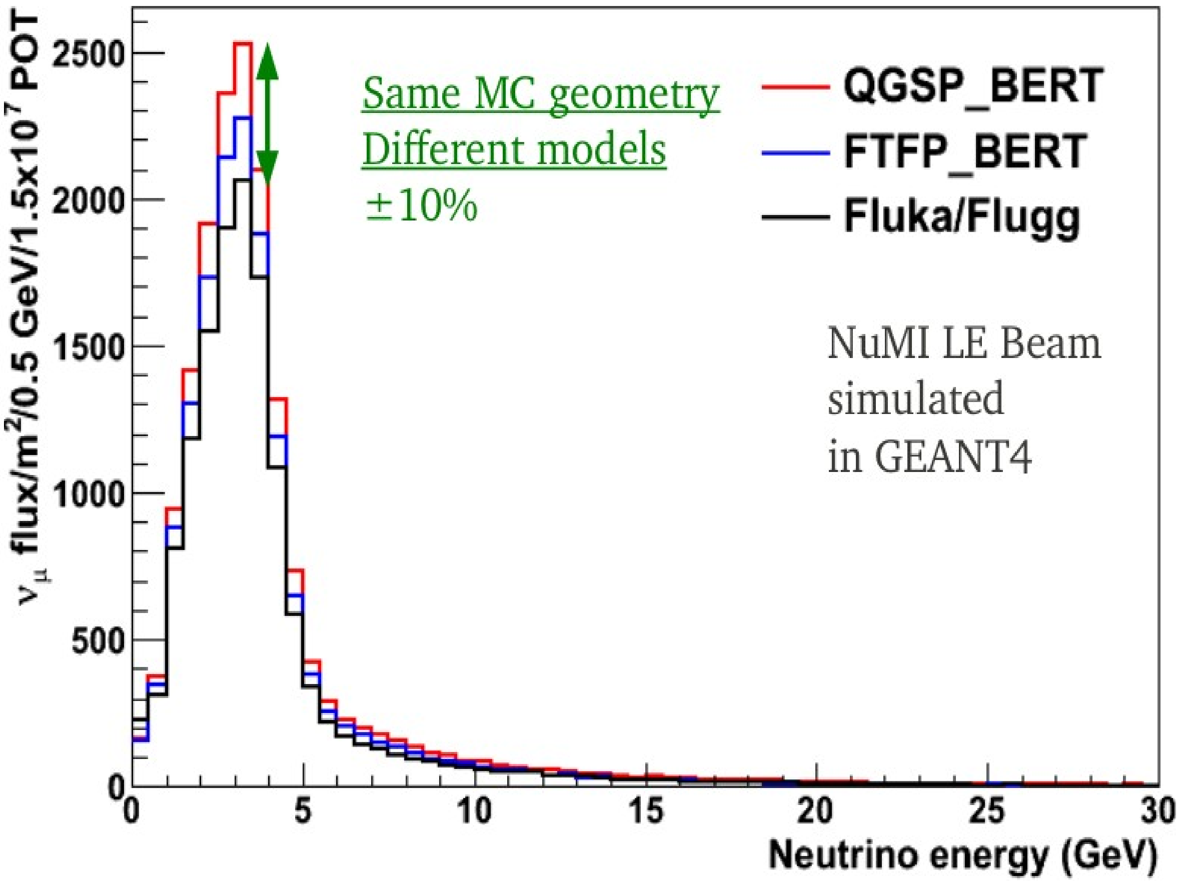
To have a high precision measurement...

we need to know our flux as well as we can.

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?



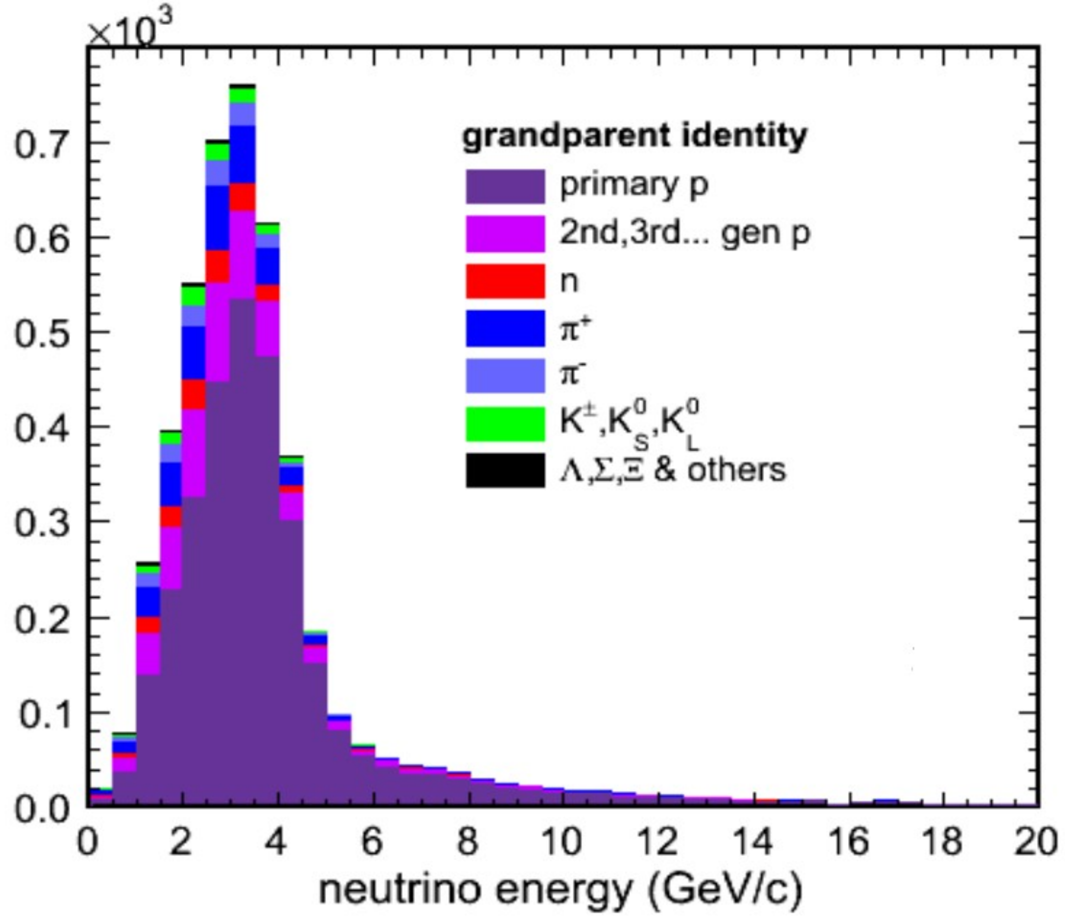
- *MINERvA uses a geant4 based MC for Flux simulation and QGSP (**Q**uark **G**luon **S**tring **P**re-compound) as a hadronic model.*

π^+ which produce ν_μ hitting MINOS/MINERvA

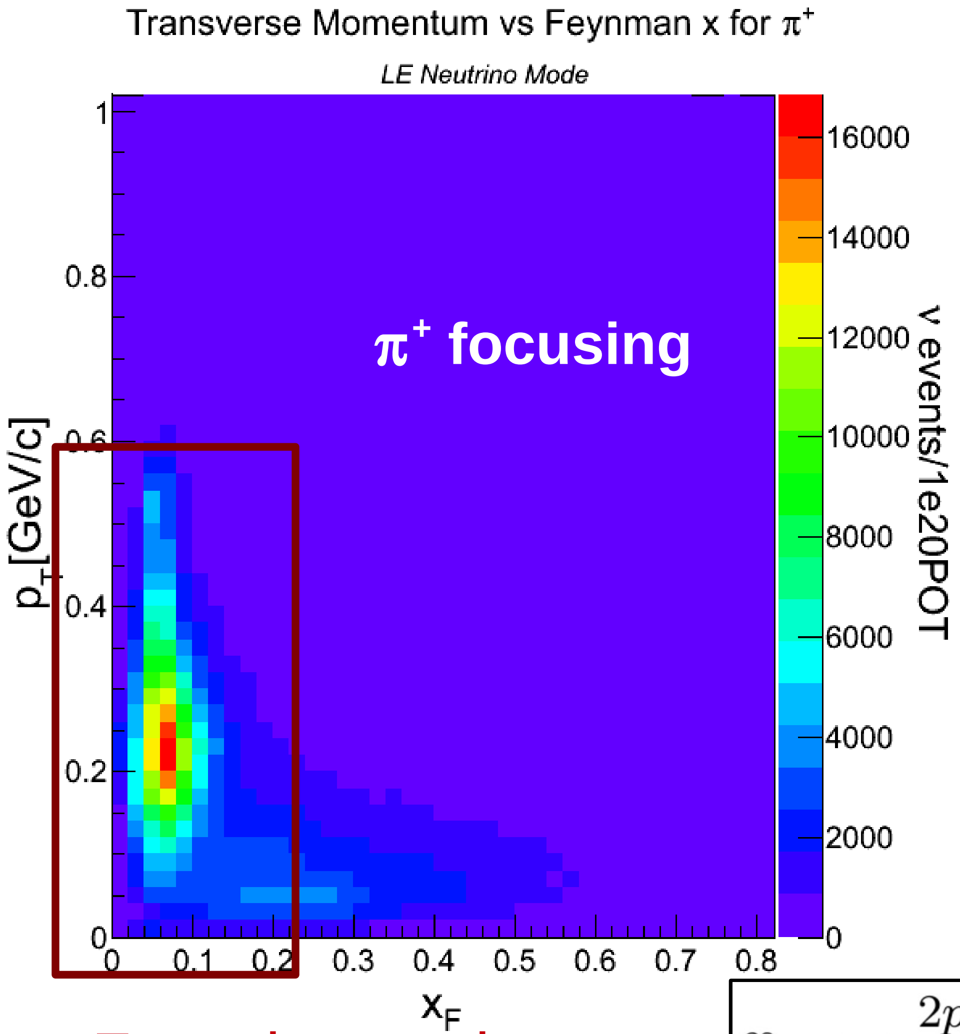
Origin

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 s of π^+



How is pC-> $\pi^{+/-}$X?



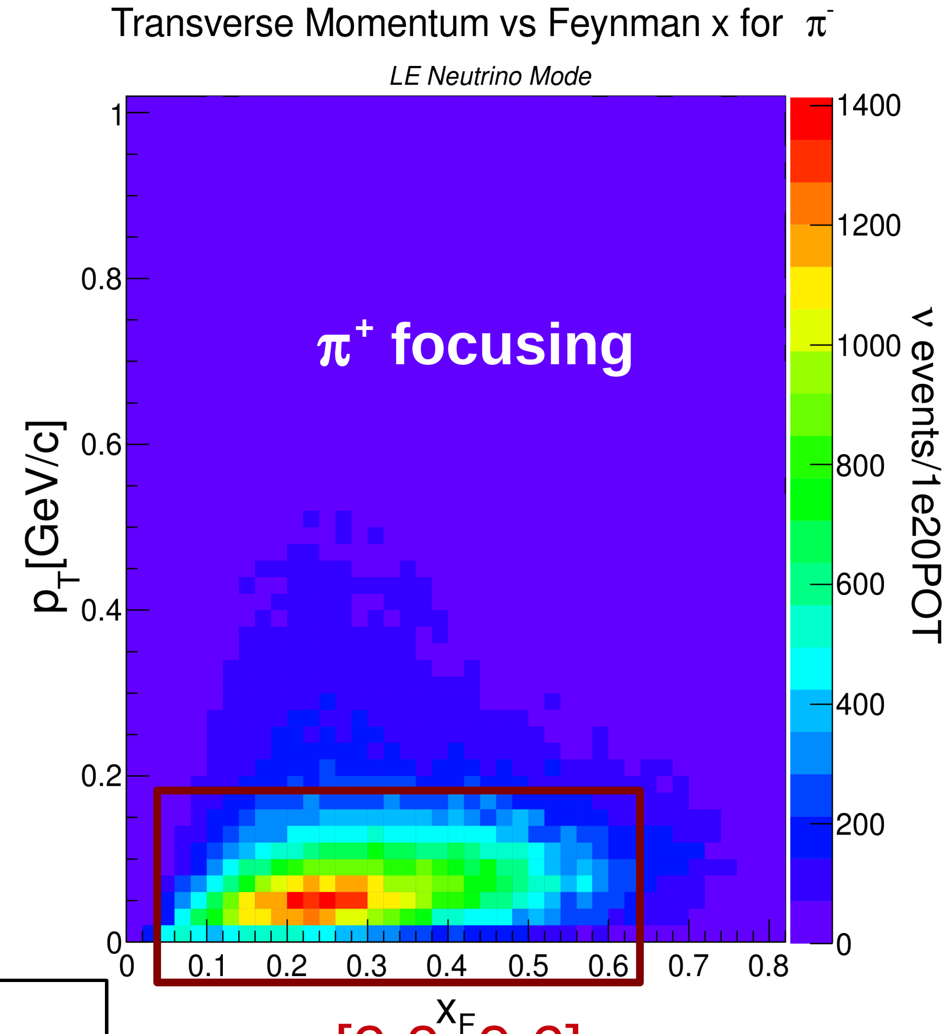
Focusing peak:

x_F [0.0, 0.16]

p_T [0.0, 0.6] GeV/c

$$x_F = \frac{2p_L^*}{\sqrt{s}}$$

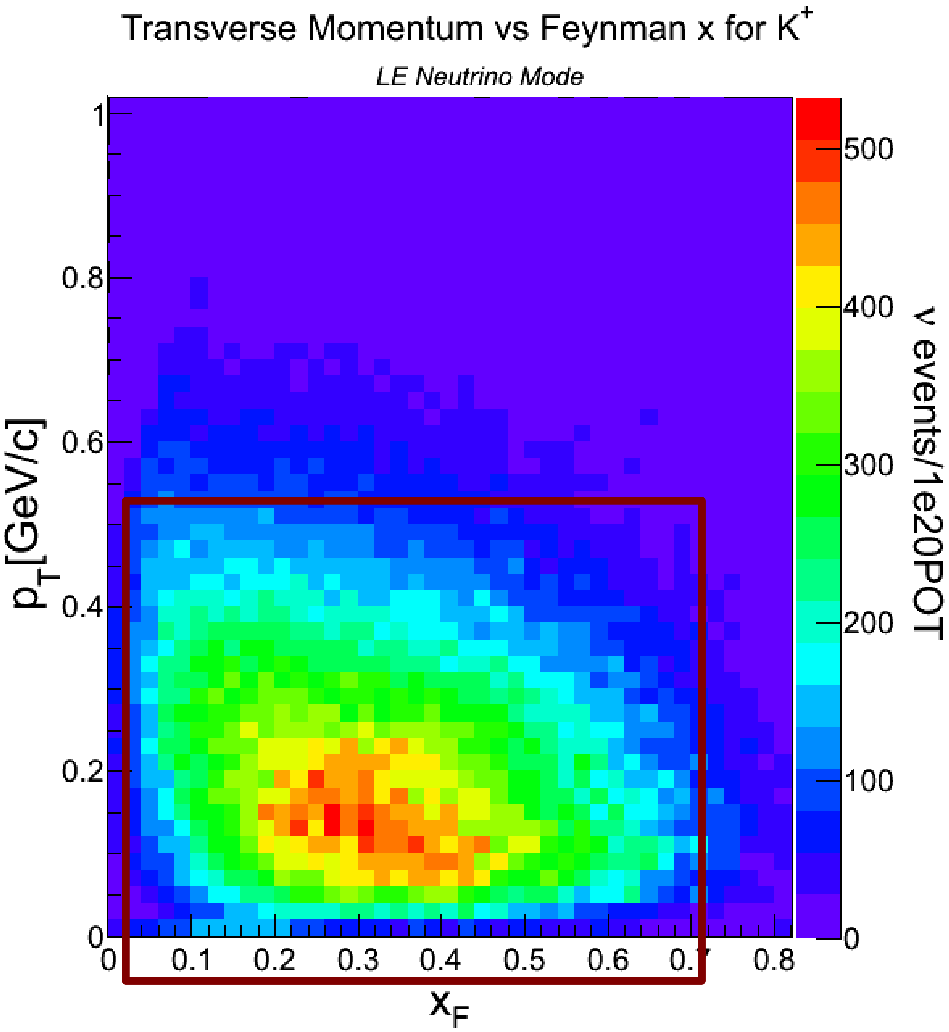
x_F: Feynman-x

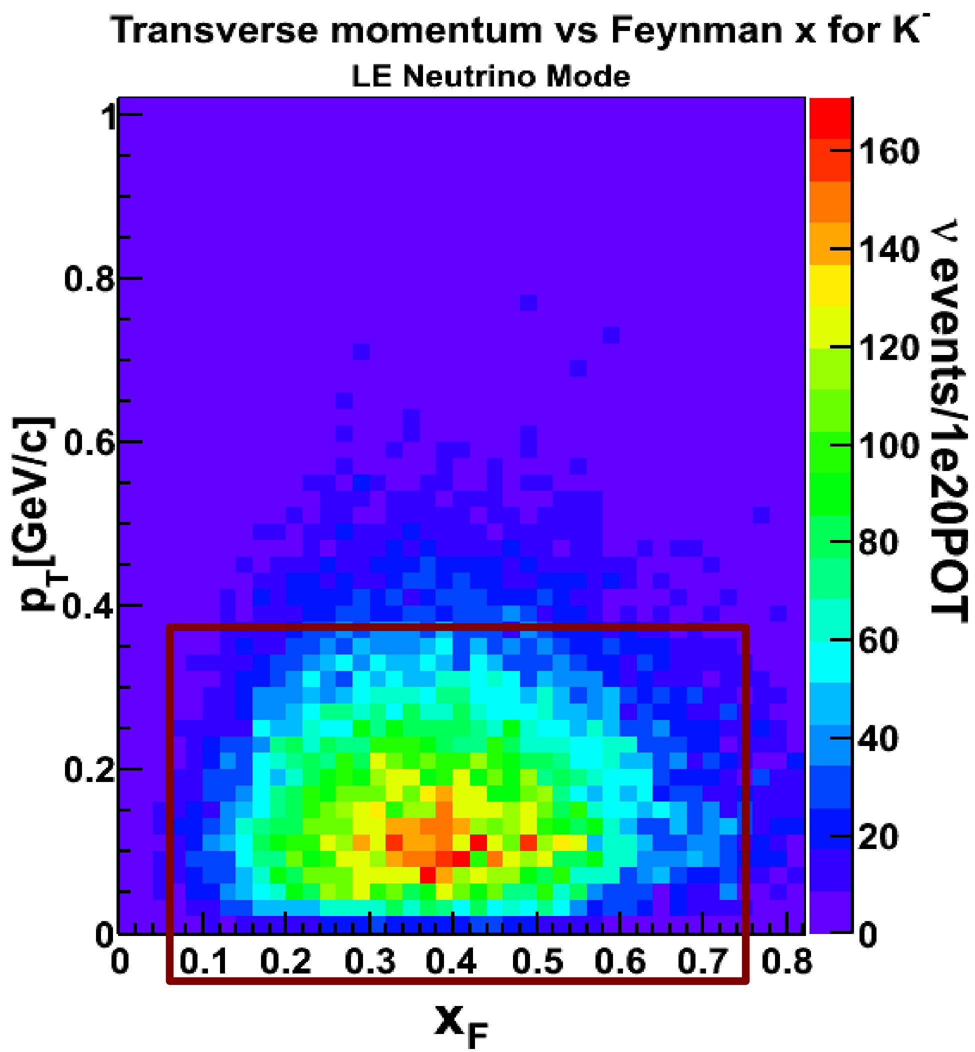


x_F [0.0, 0.6]

p_T [0.0, 0.2] GeV/c

How is pC-> $K^{+/-}X$?





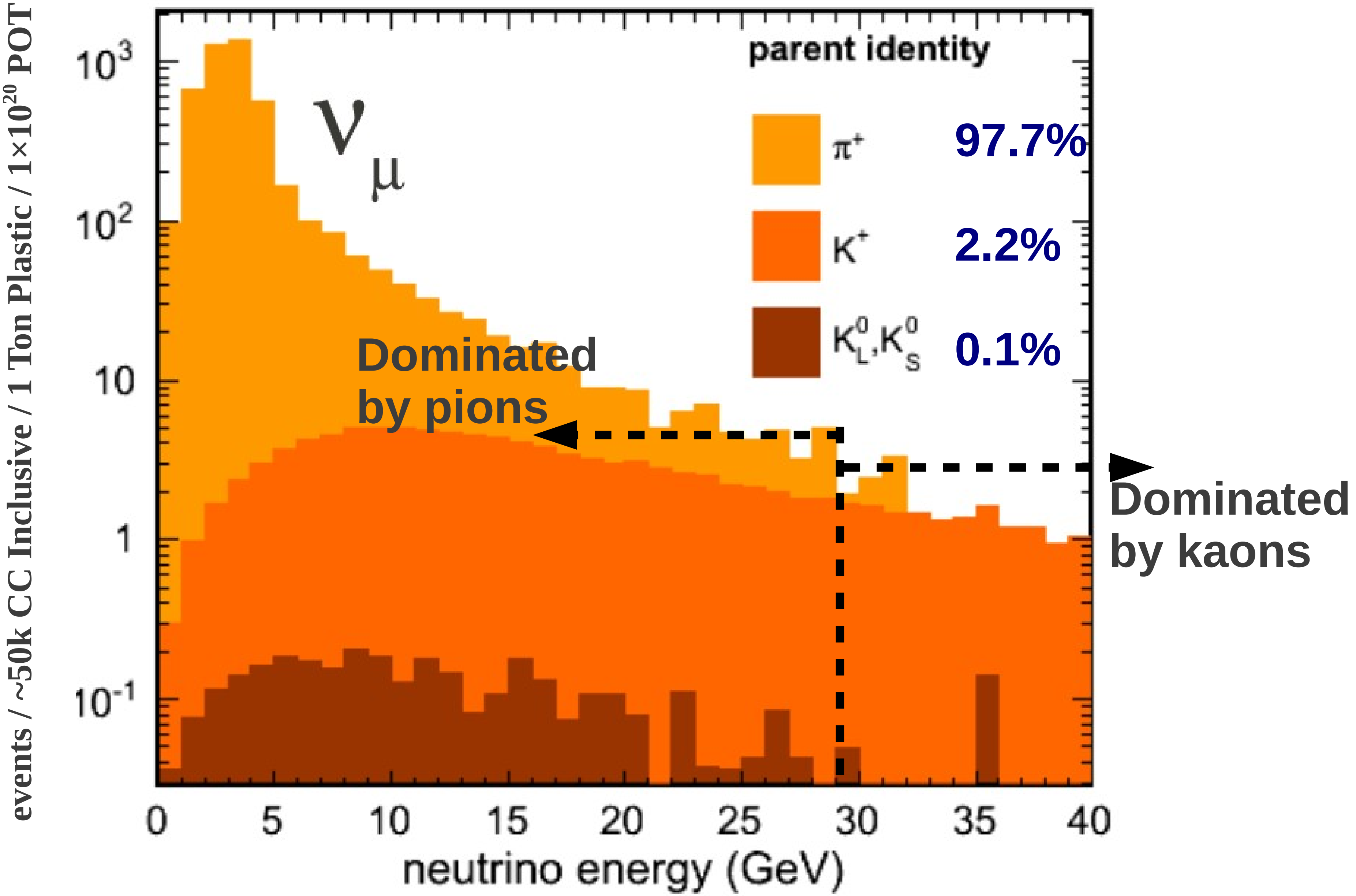
x_F [0.0, 0.7]

p_T [0.0, 0.5] GeV/c

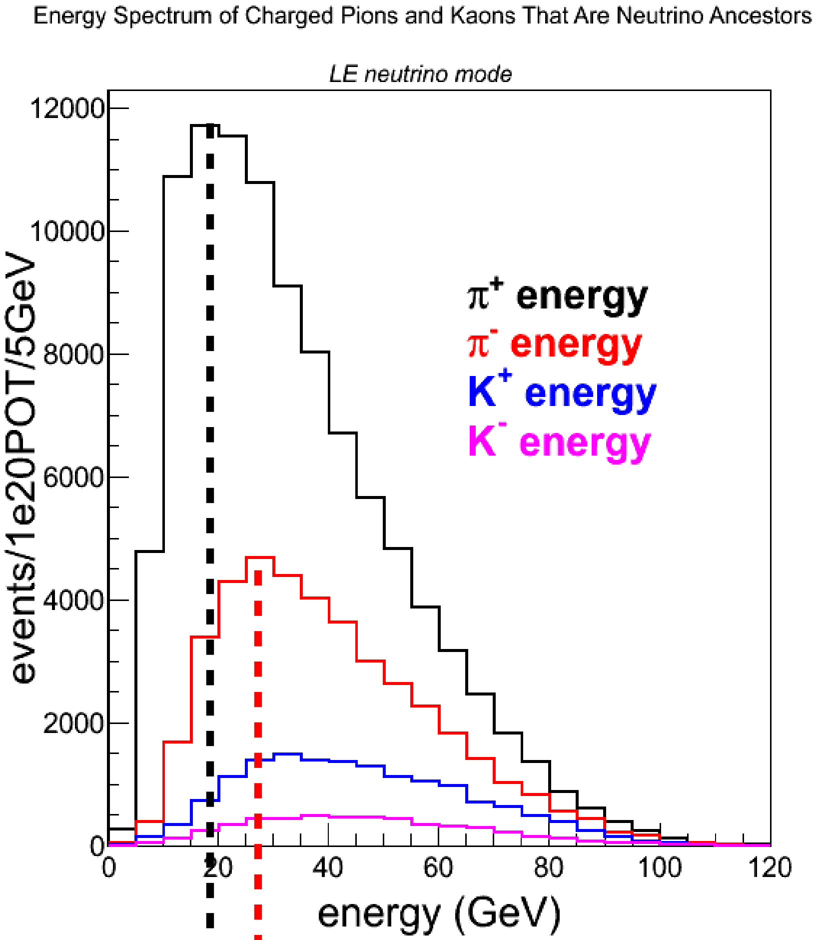
x_F [0.1, 0.6]

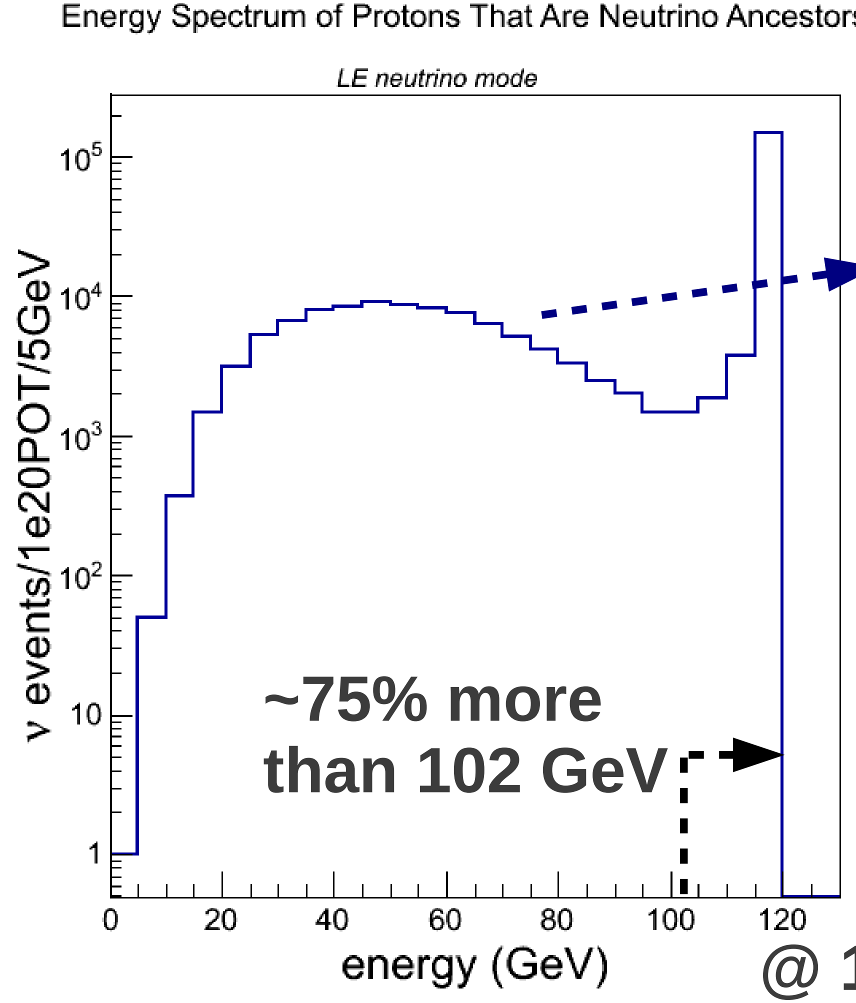
p_T [0.0, 0.4] GeV/c

Predicted Neutrino Flux from target



Secondaries that interact in the target





~20 GeV

~30 GeV

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

~75% more than 102 GeV

< 120 GeV

$$pC \to pX$$
$$pC \to pN'n$$

@ 120 GeV

$$pC \to pX$$
$$pC \to pN'n$$

Improving the flux

Multi-prong approach:

- Using the Muon Monitor Data.
- Varying the beam parameters (horn current, target position).
- Looking into the ν_e – atomic electron interactions.
- Using low ν-method (See Arie's talk)
- **Using external hadron production data.**

I will show our first results on this

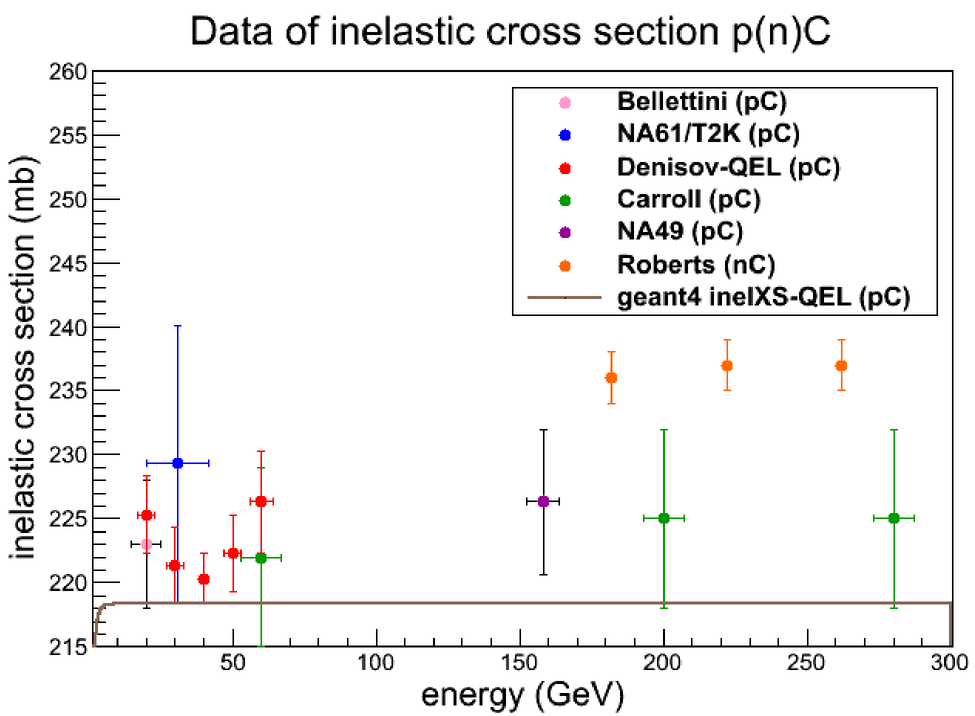
⇒ Constraint the MC flux to get the right shape and uncertainty.

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

Redundancy will make our flux more accurate

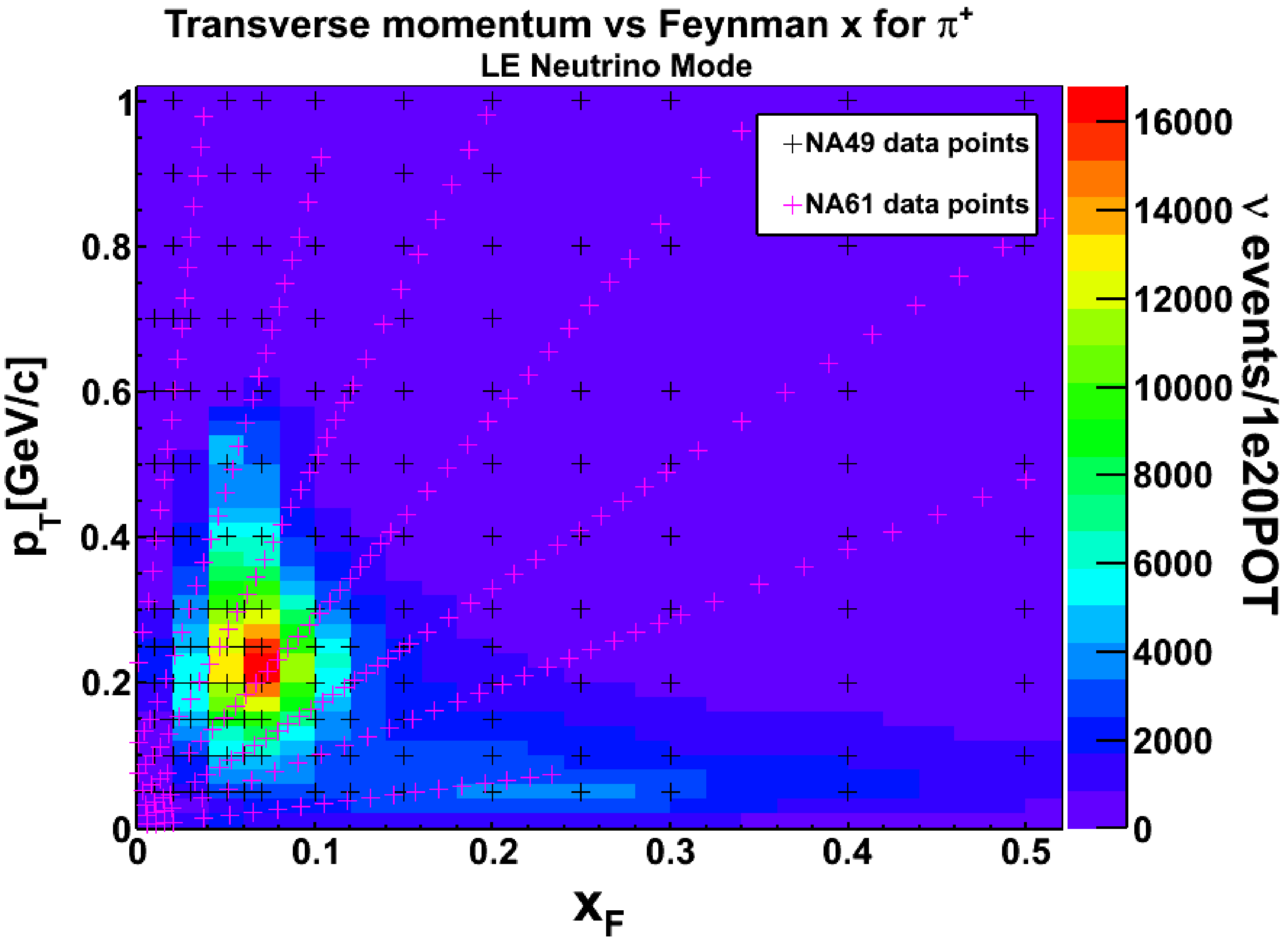
Using external Hadron Production

Inelastic cross section vs. energy: data and geant4.

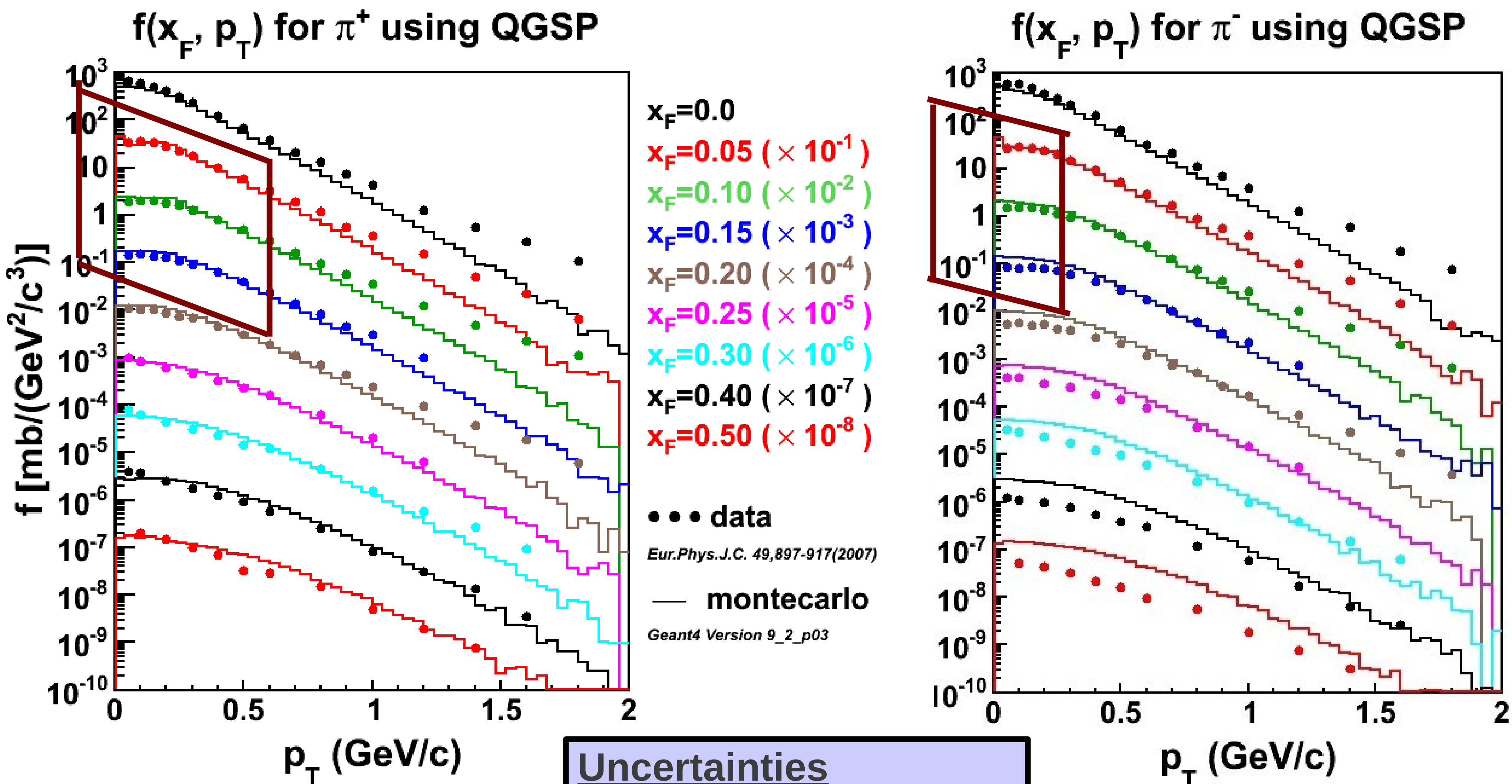


- For **pC** → $\pi^{+/-}$ **X:** NA49 @ 158 GeV (CERN), Barton @ 100 GeV (Fermilab) & NA61 @ 31 GeV (CERN) & HARP @ 3, 5, 8, 12 GeV.
- For **pC** → $K^{+/-}$ **X:** NA49 @ 158 GeV (Tinti's thesis, FERMILAB), MIPP @ 120 GeV ratio π/K (thick: Seun & thin: Lebedev).
- For $\pi^{+/-}$**C** → $\pi^{+/-}$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

NA61 & NA49 coverage for charged pions

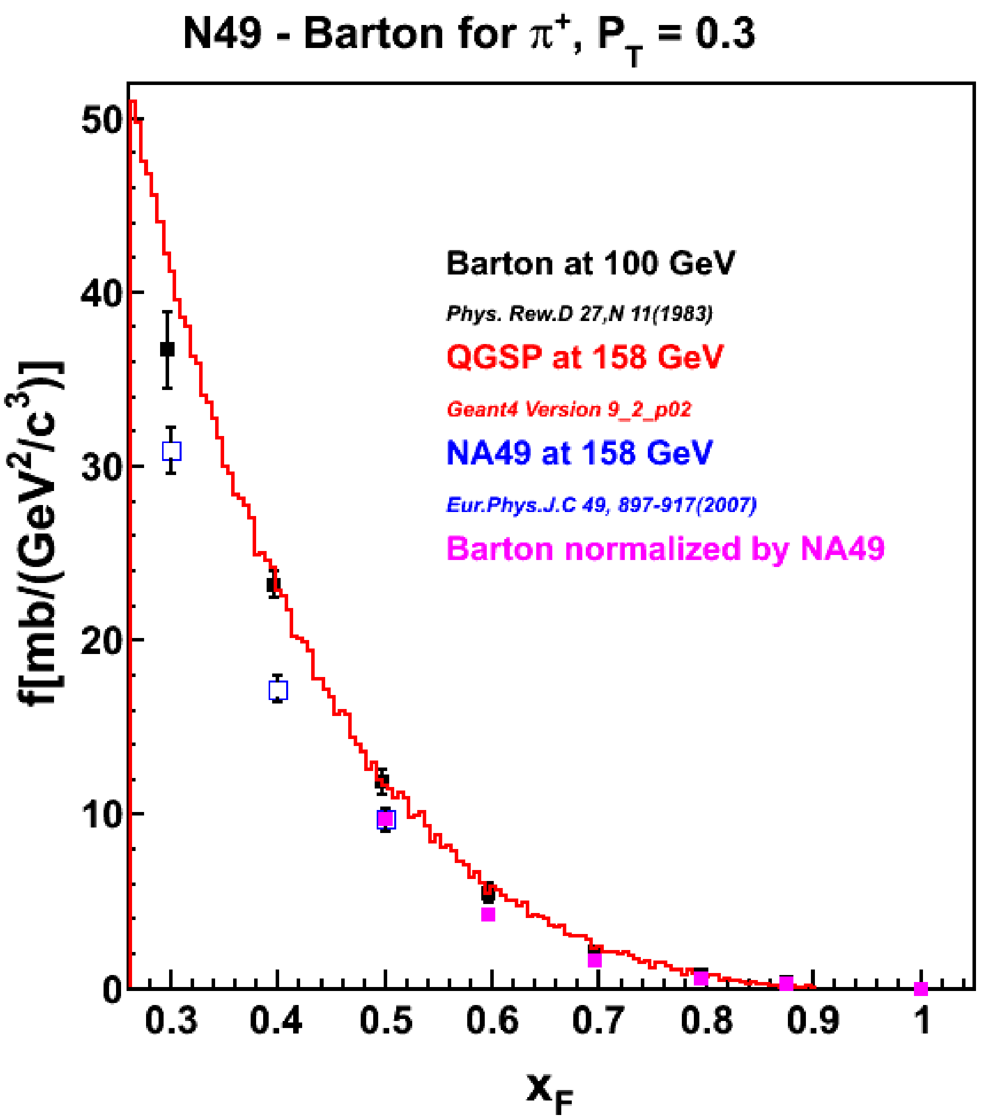


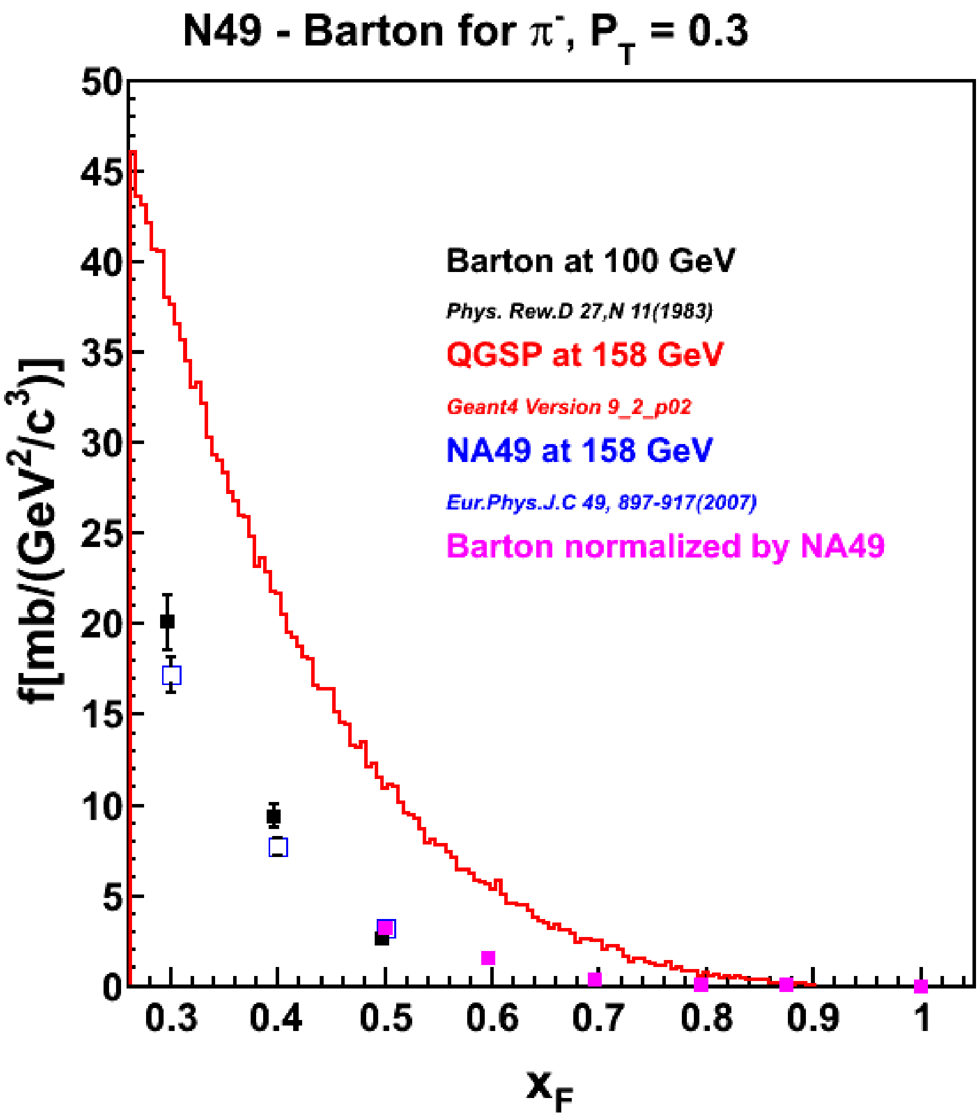
pC → pi+ X @158



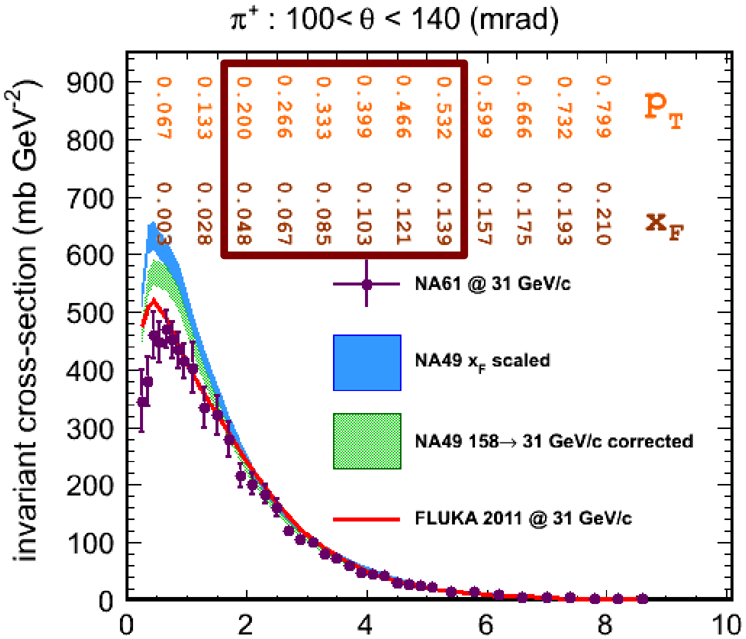
Uncertainties
7.5% systematic
2-10% statistical

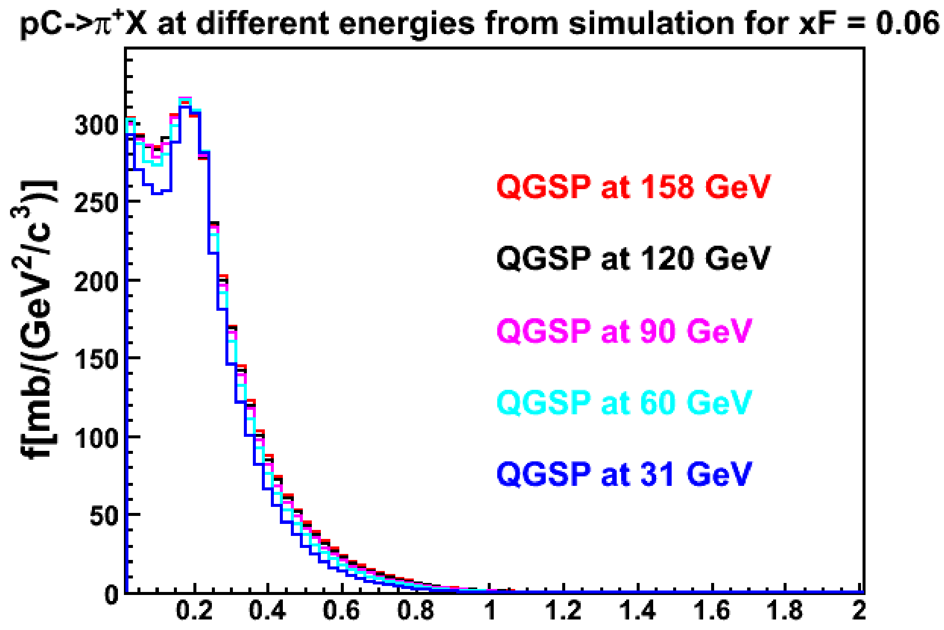
pC → pi+ X @158 (large x_F)

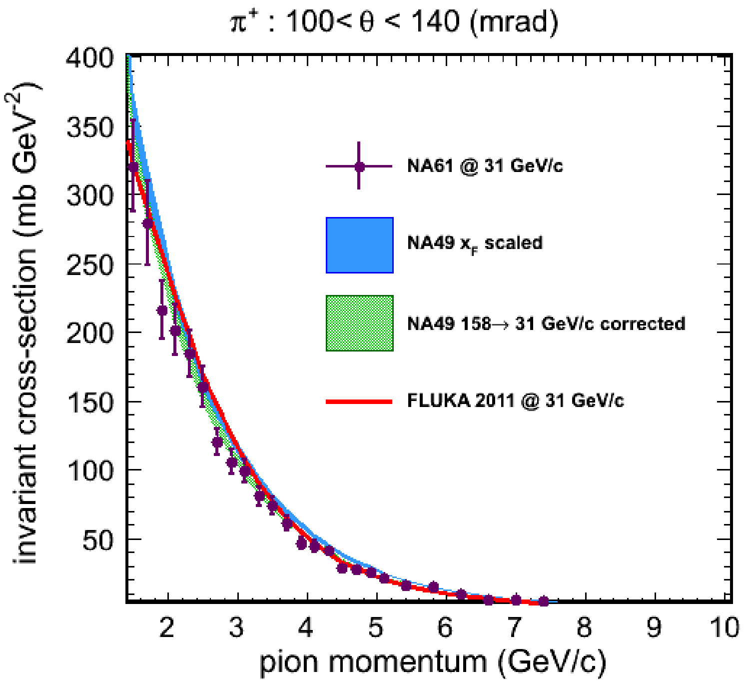


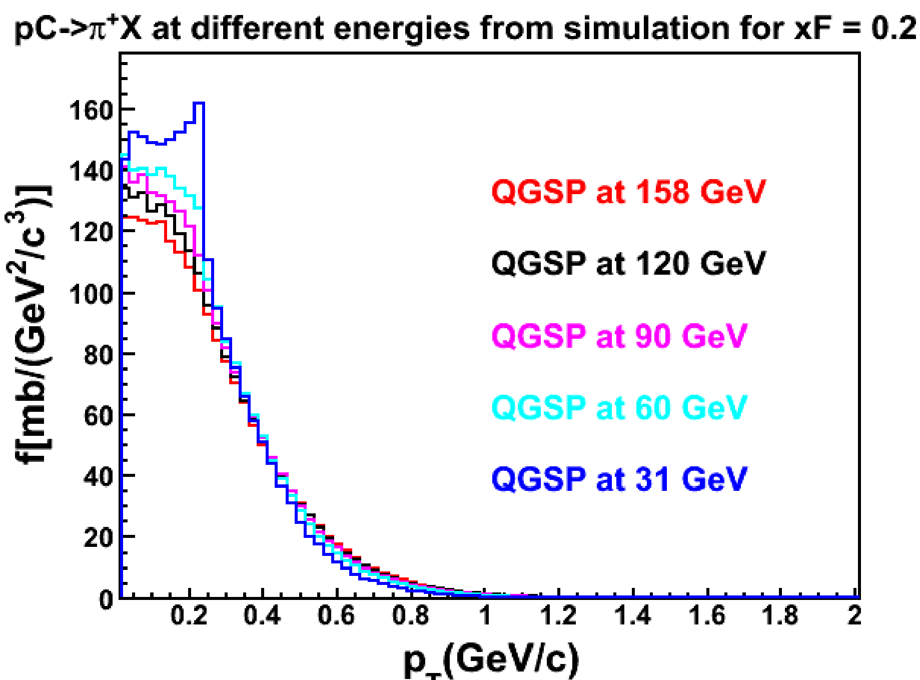


Comparison pC @ 31 GeV vs pC @ 158 GeV

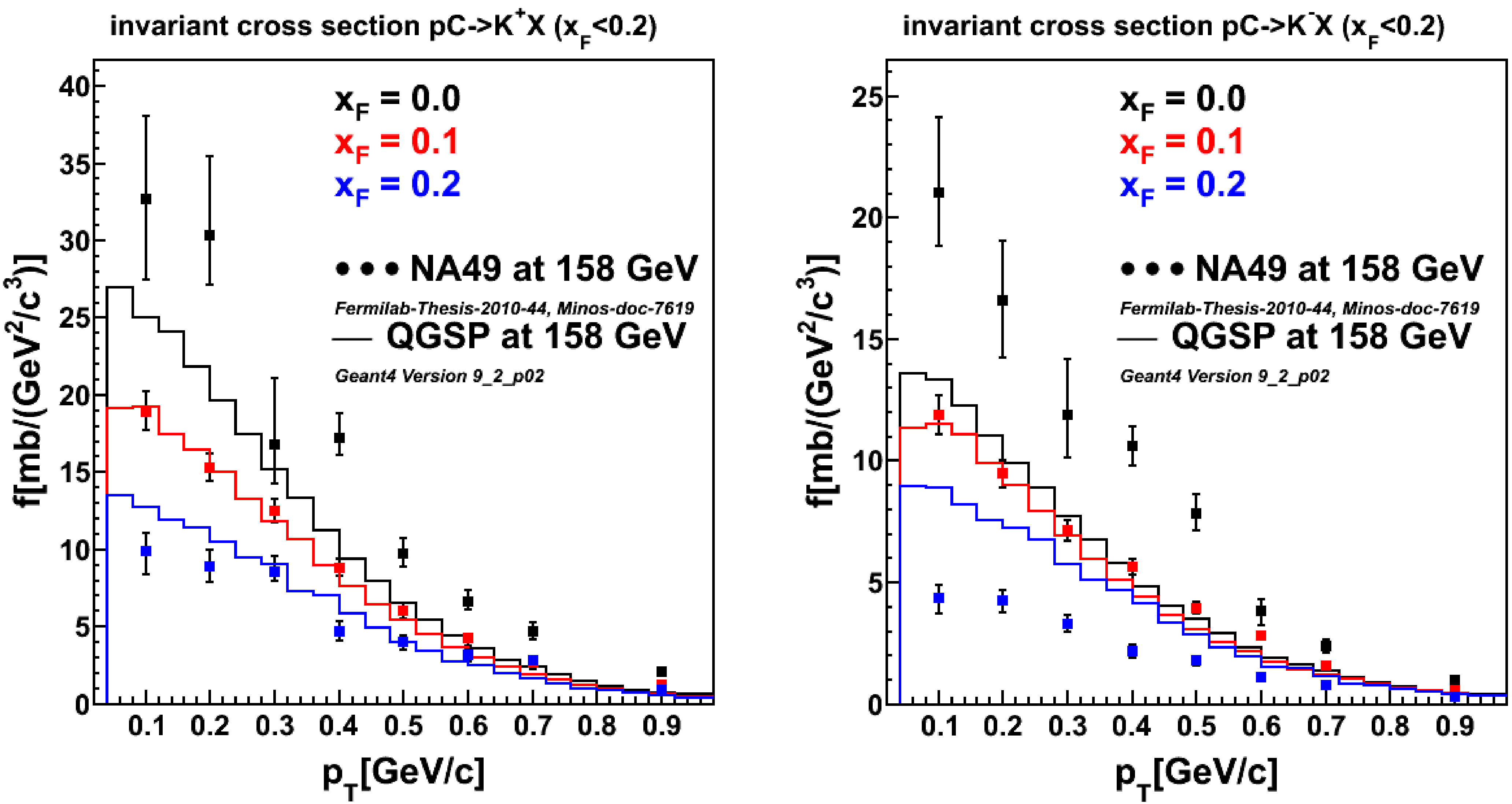








pC → K+ X @158

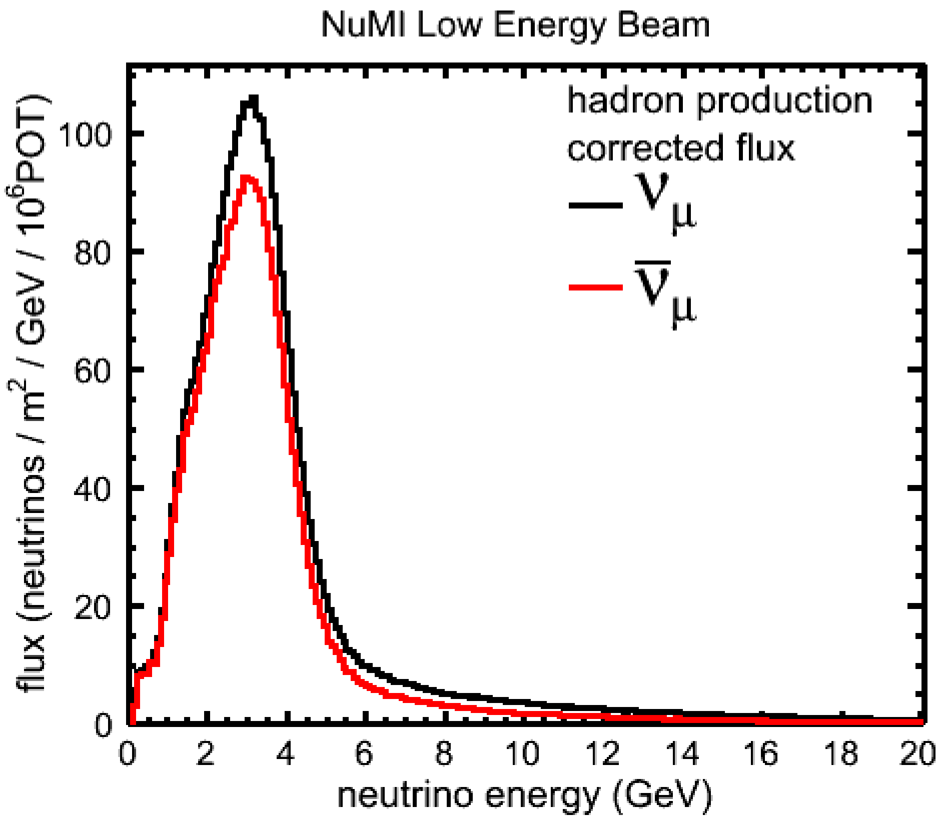


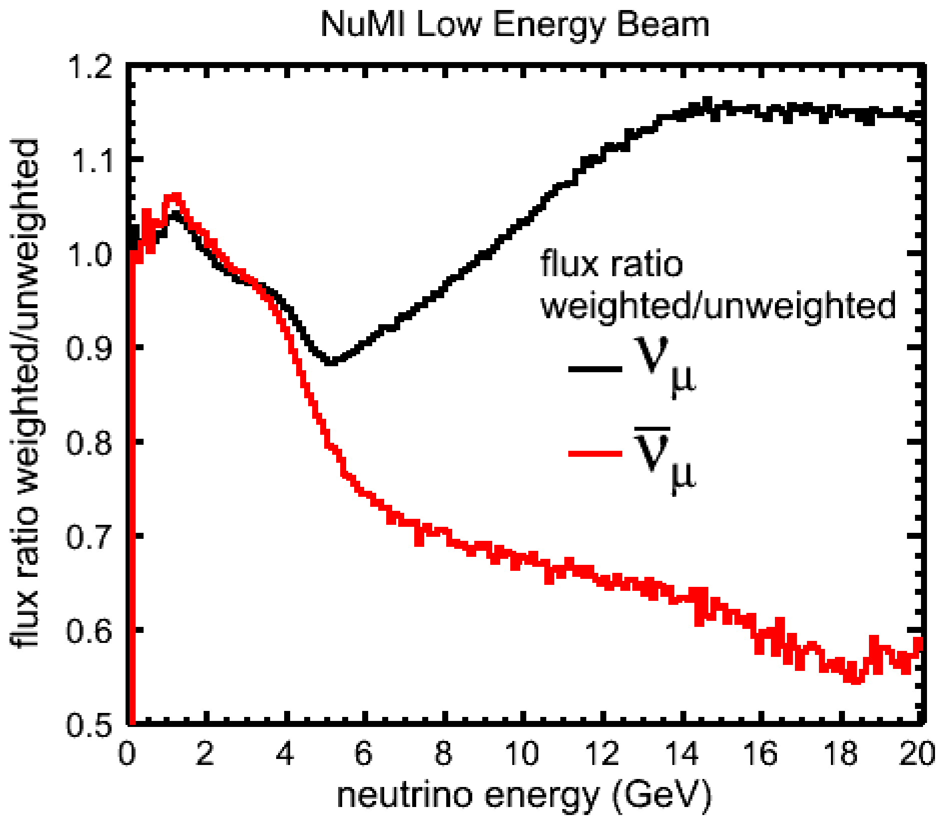
invariant cross section pC->K+X (xF<0.2)
invariant cross section pC->K-X (xF<0.2)
xF = 0.0
xF = 0.1
xF = 0.2
NA49 at 158 GeV
Fermilab-Thesis-2010-44, Minos-doc-7619
QGSP at 158 GeV
Geant4 Version 9_2_p02
f[mb/(GeV2/c3)]
pT[GeV/c]

Results to Neutrino flux

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

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



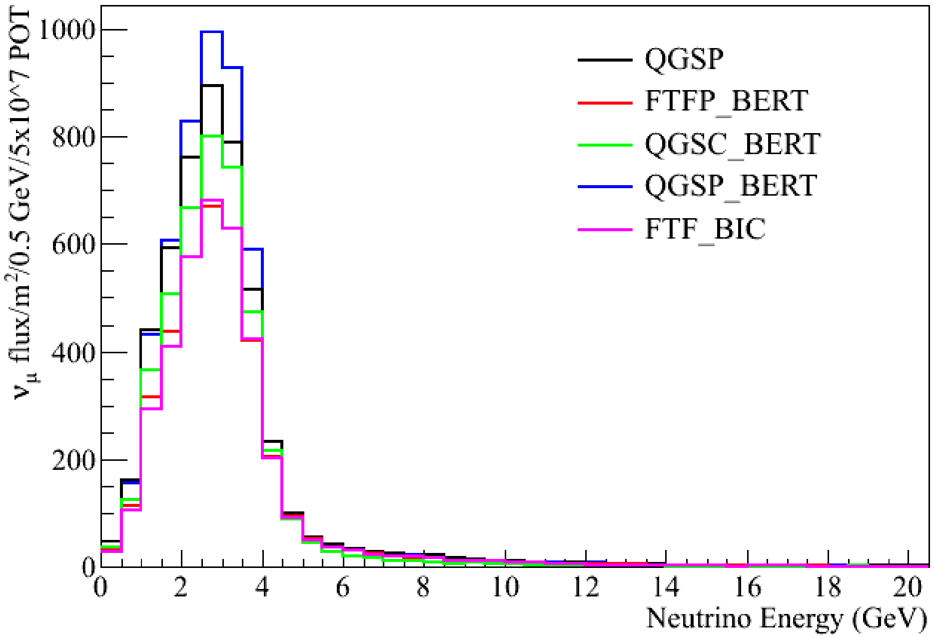


- υ_μ is the neutrino spectra when we focus π^+.
- $\overline{\upsilon}_\mu$ is the antineutrino spectra when we focus π^-.

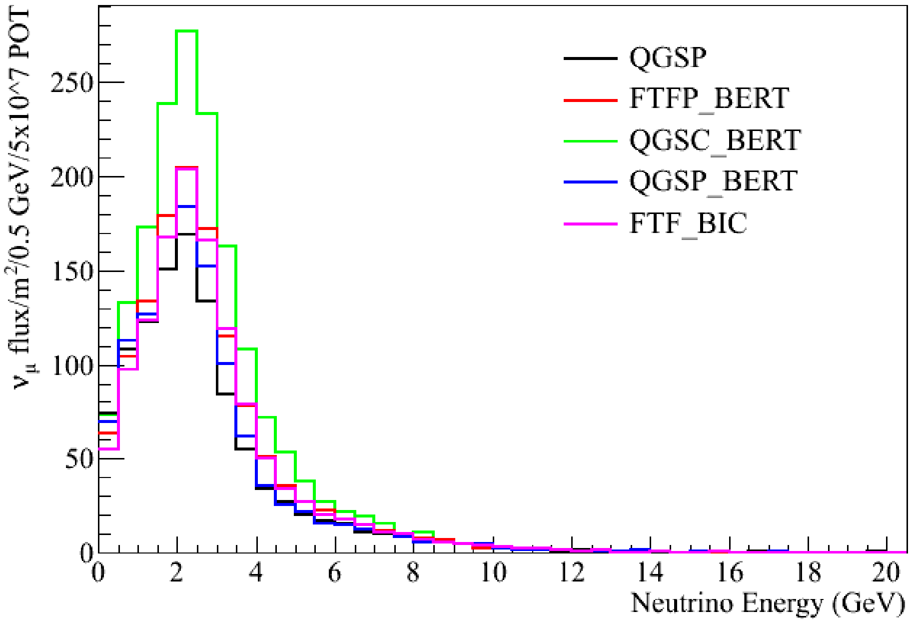
Model Spread Uncertainties

- The maximum model between geant4 models for Non-NA49 uncertainties.
- Divide in categories: π,K,p,n,other secondary interactions in target, in horns, decay pipe walls or He, target hall chase.
- Large project to: add more models and gradually replace model spread with existing and new data.

π+ from π that interact in the target

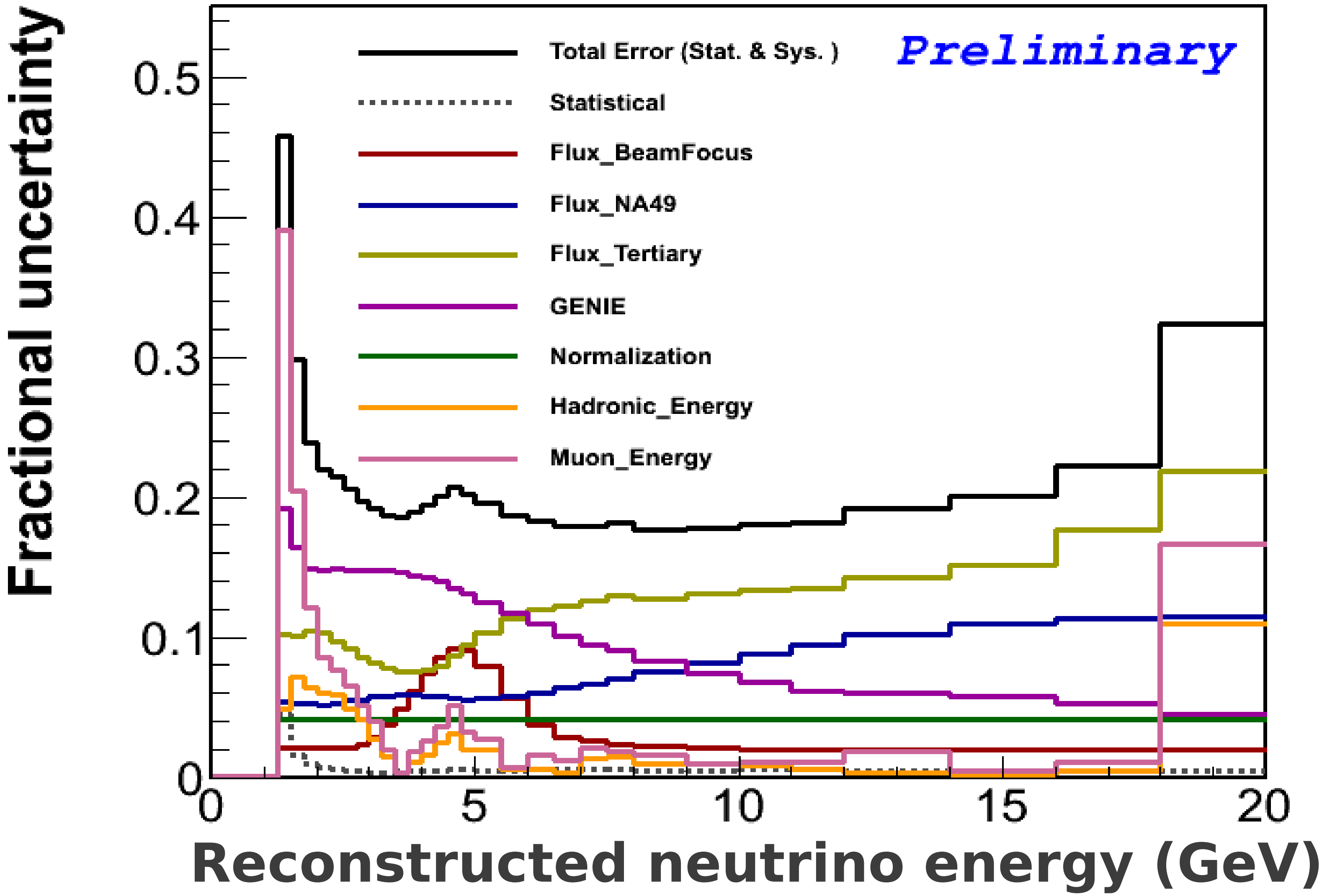


π+ from interactions in the horns



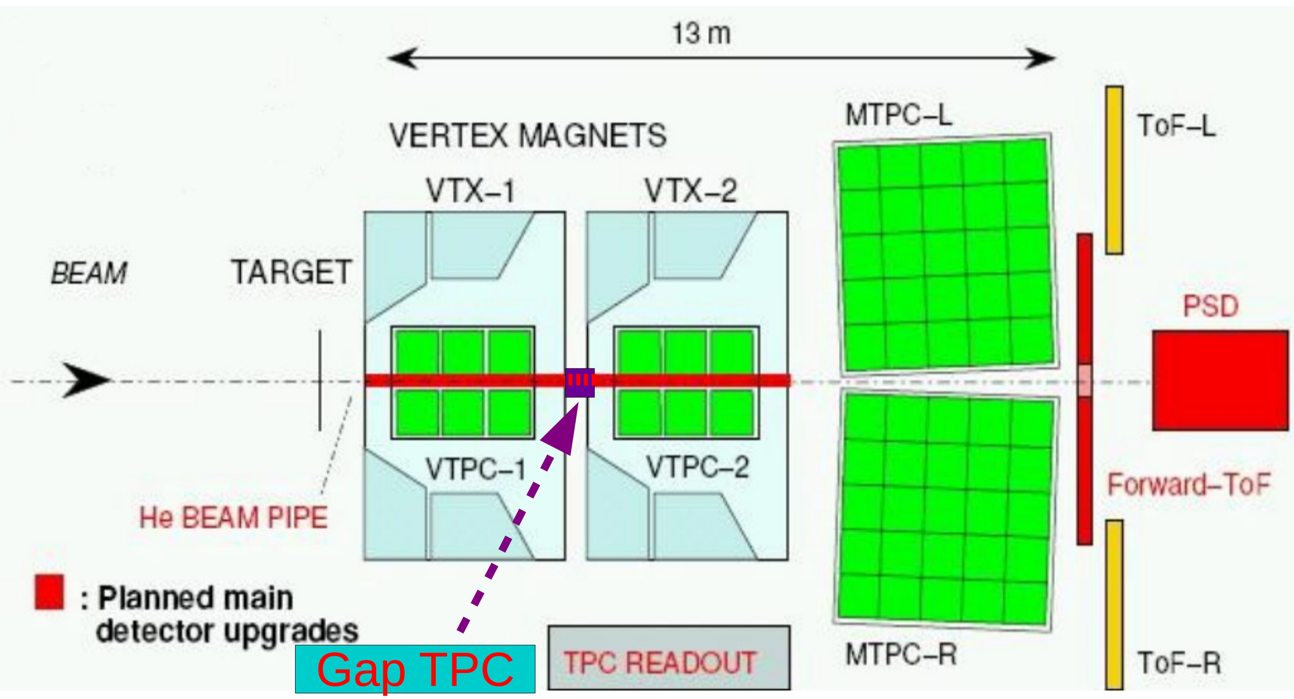
Total Uncertainties to reconstructed E_ν

Inclusive Charged Current ν_μ interaction



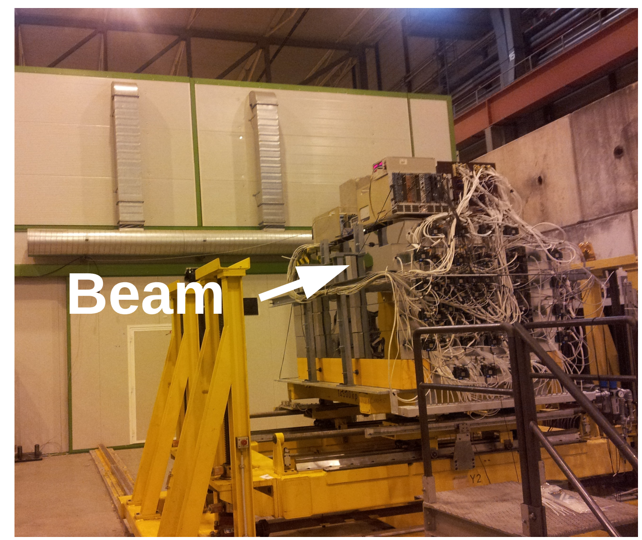
Hadron Production Test at NA61/SHINE

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 just 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).***

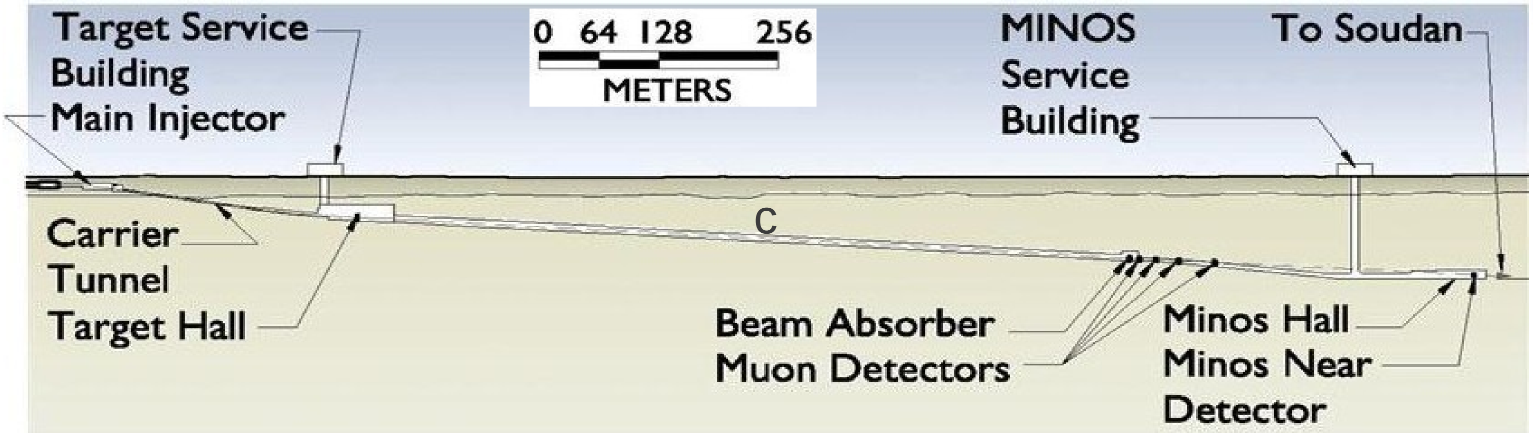
Conclusions

- ***For MINERvA is crucial to have a good flux shape with small uncertainties to deliver ν cross sections.***
- ***We are following different and independent approaches to constraint the flux.***
- ***We showed today our first results using external hadron production data and it is going to improve using more inputs.***

Backup slides

NeUtrinos at **M**ain **I**njector

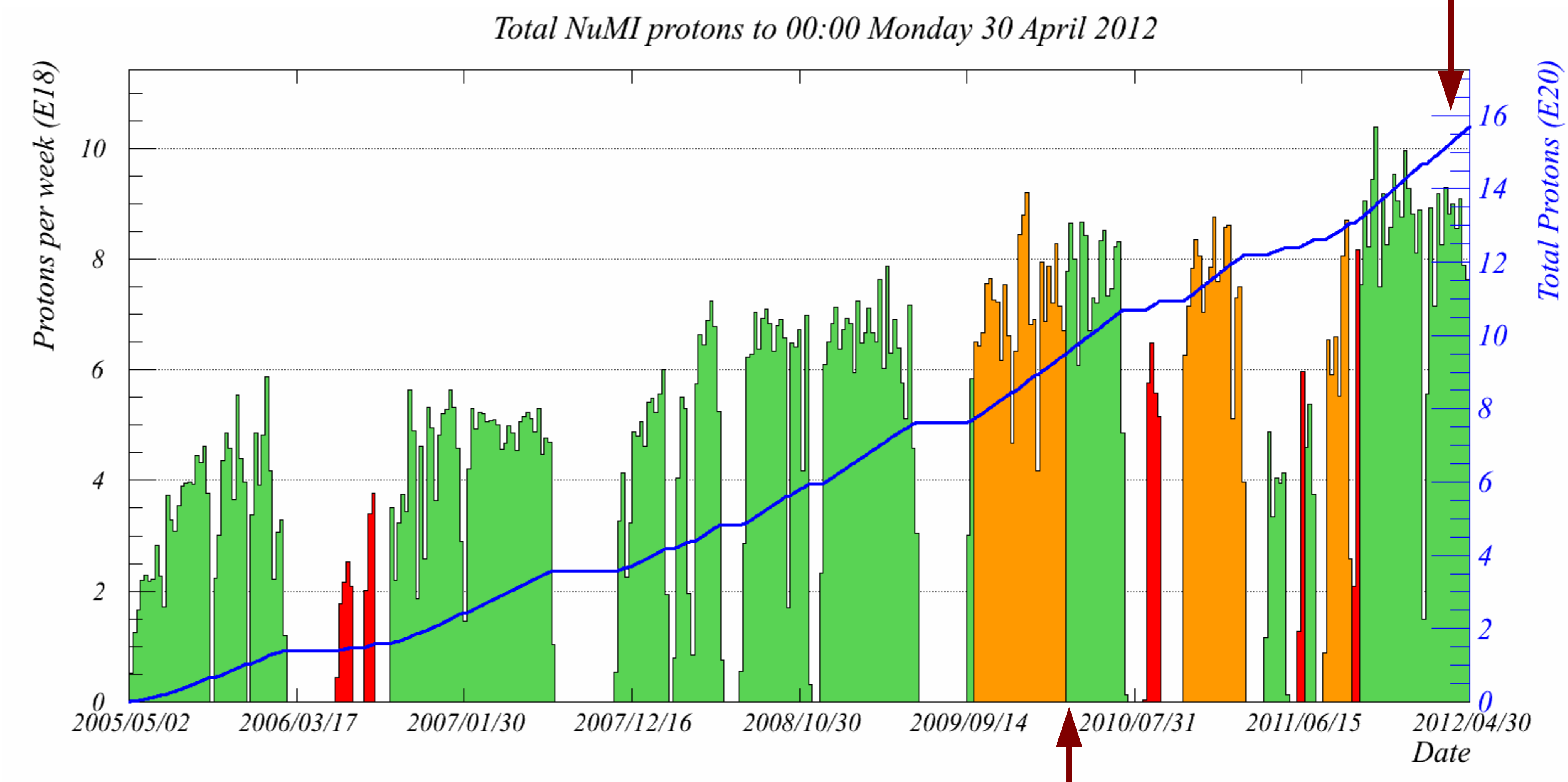
- Fast extracted of 120 GeV/c protons from **M**ain **I**njector collide on Carbon target.
- 1 spill/2.2 s, 10 μs long (~ 35×10^{12} POT/spill).
- Beam power: ~300 kW (full power).



- Neutrino beam from focused meson decays with variable energy

Successful Low Energy Run!!

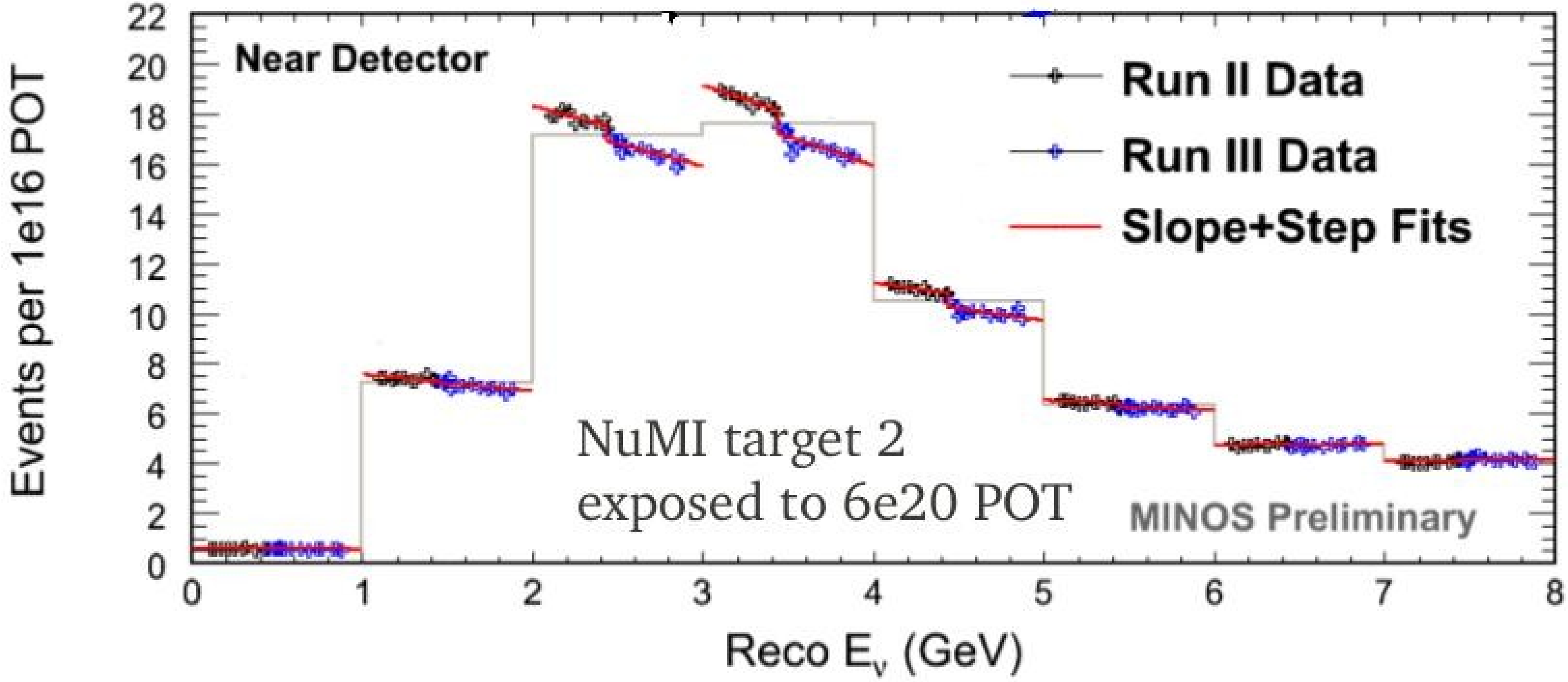
- 157.1x10^{19} POT total since 2005 to 2012.



- 62.0x10^{19} POT deliver for Minerva Full detector.

Components are consumables...

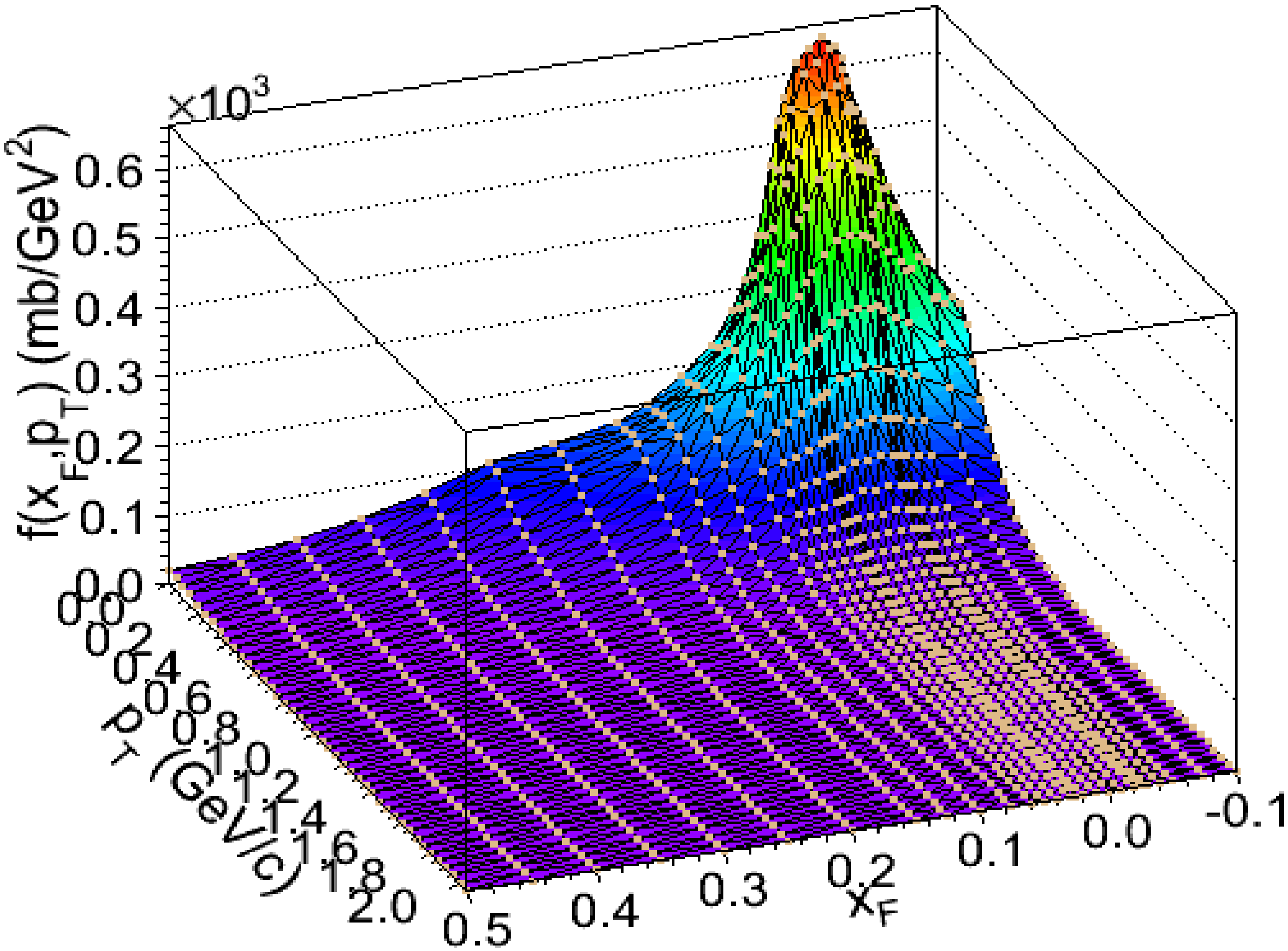
- High radiation, thermal stress, mechanical stress, water leaks affect all components.
- Replaced: 6 times targets, horns and hadron monitors.
- Gradual slope due to radiation damage.



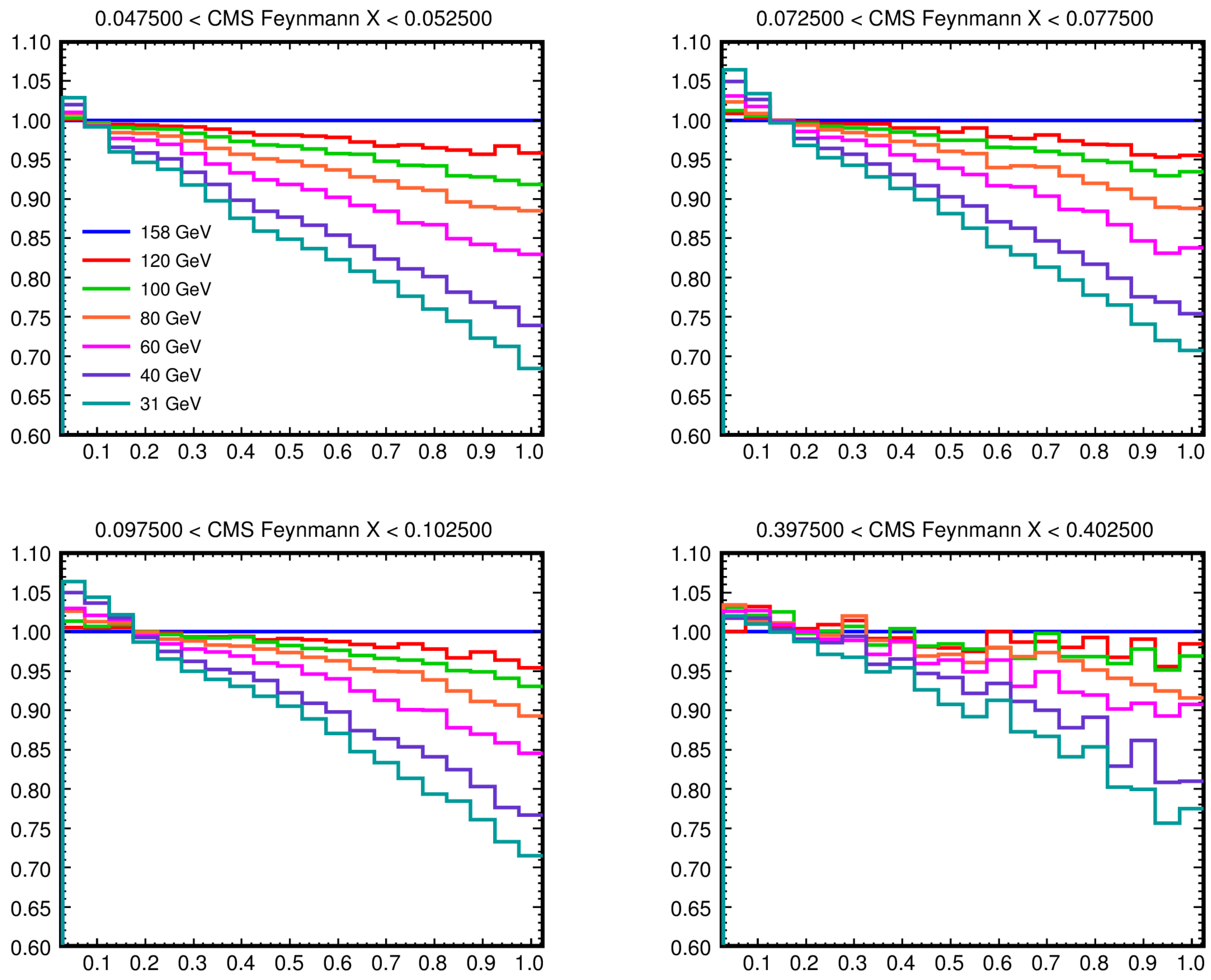
Sources of the focusing uncertainties

- **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.

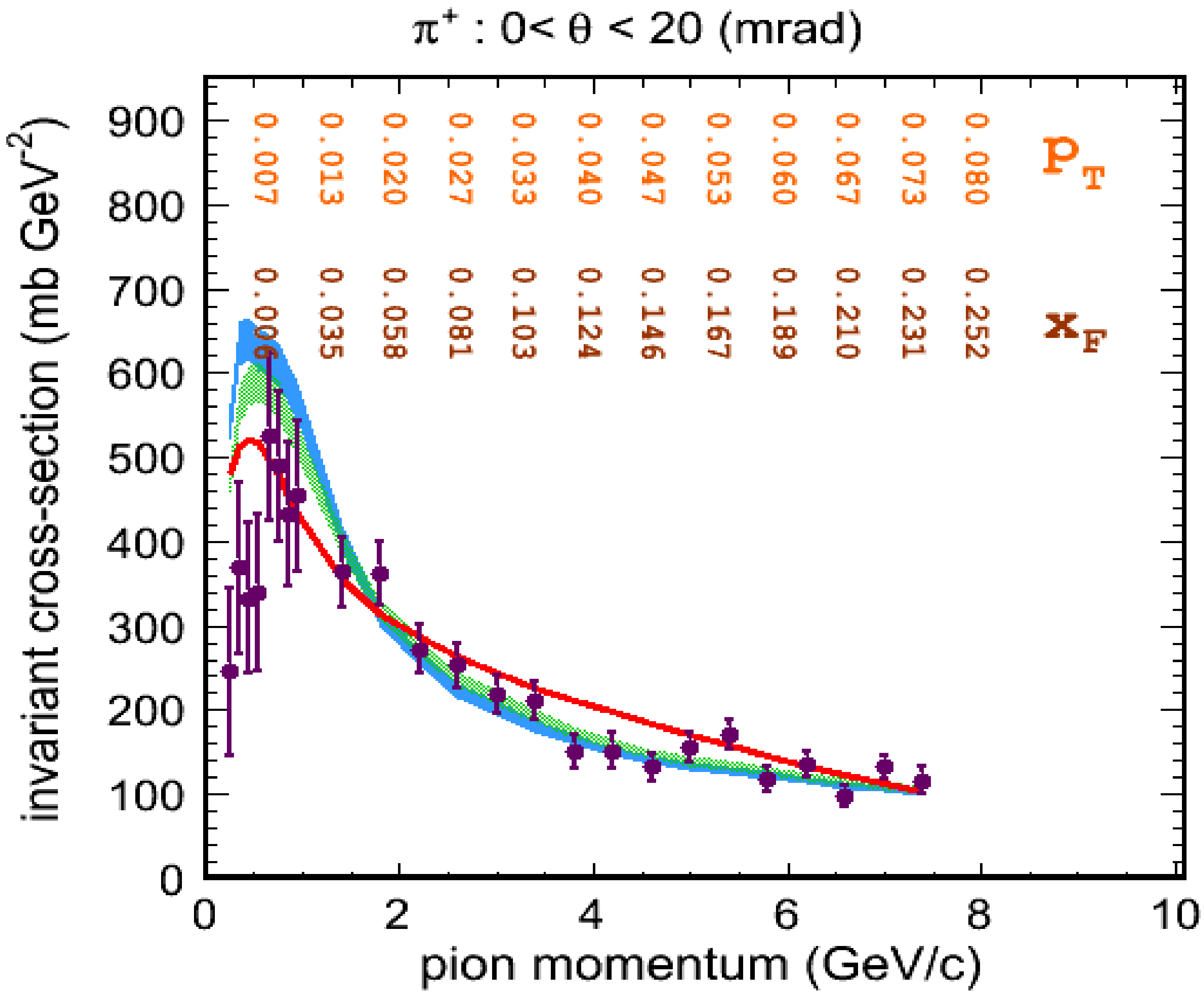
NA49 interpolation



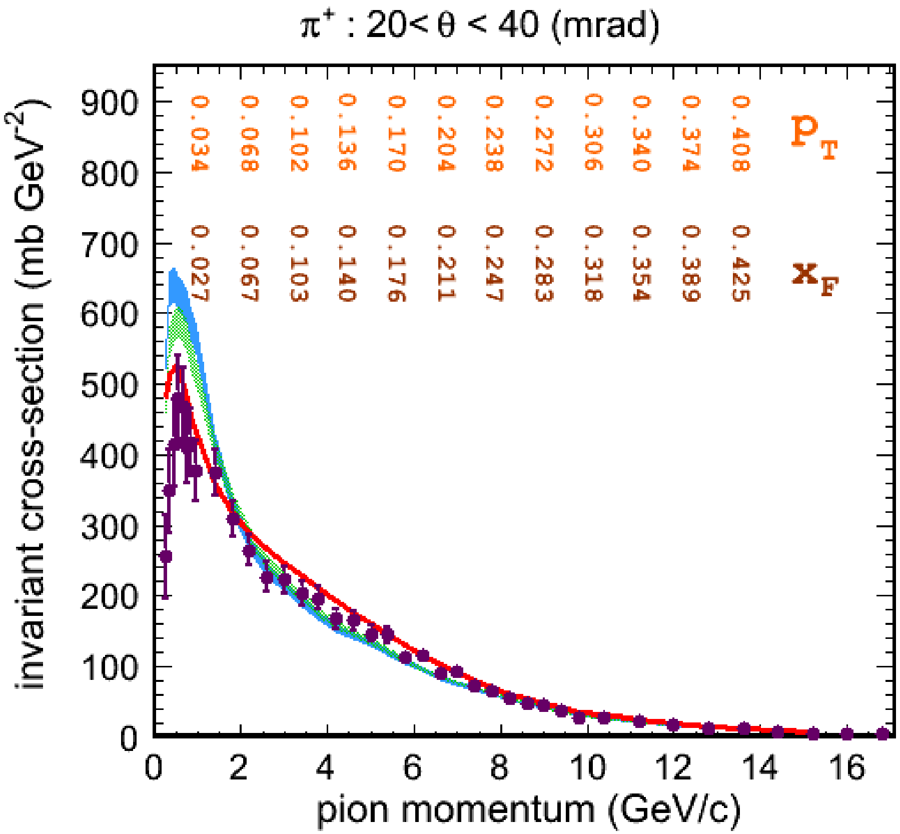
Corrections to Energy scale by Fluka

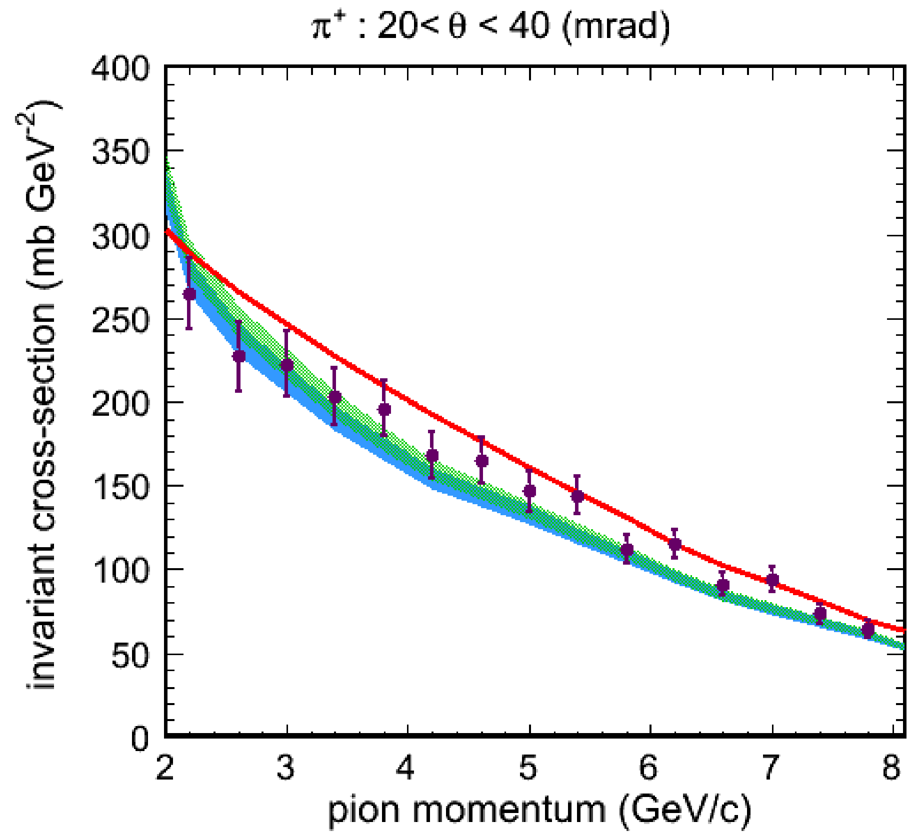


Comparison NA61 and NA49

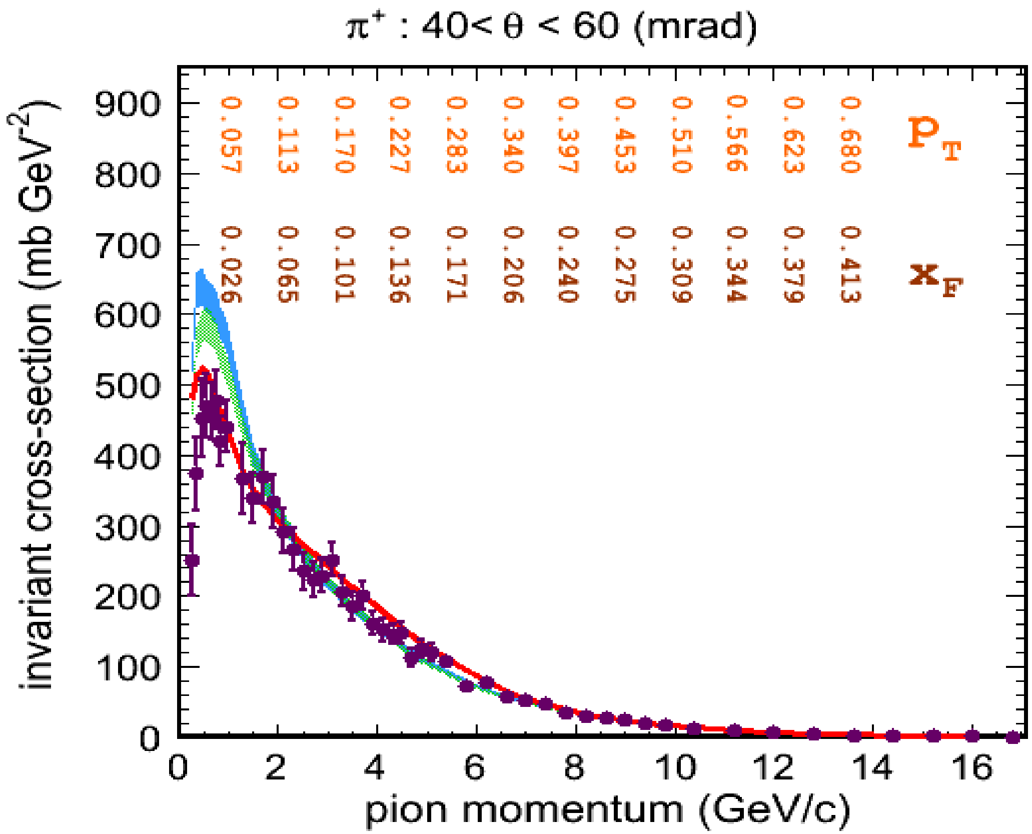


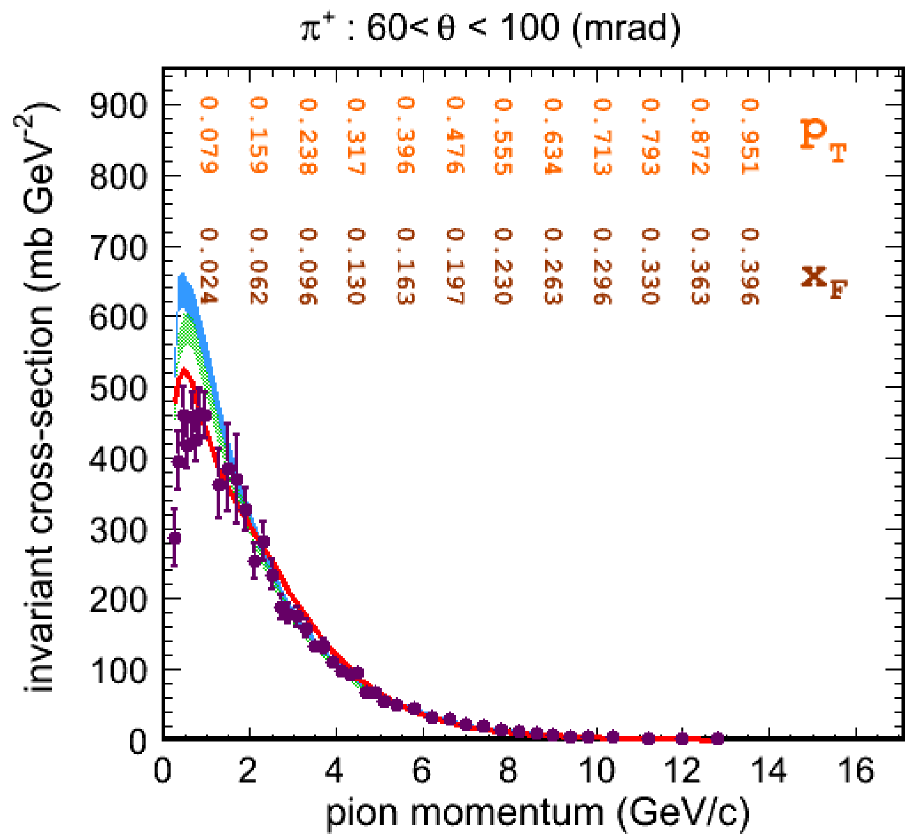
Comparison NA61 and NA49



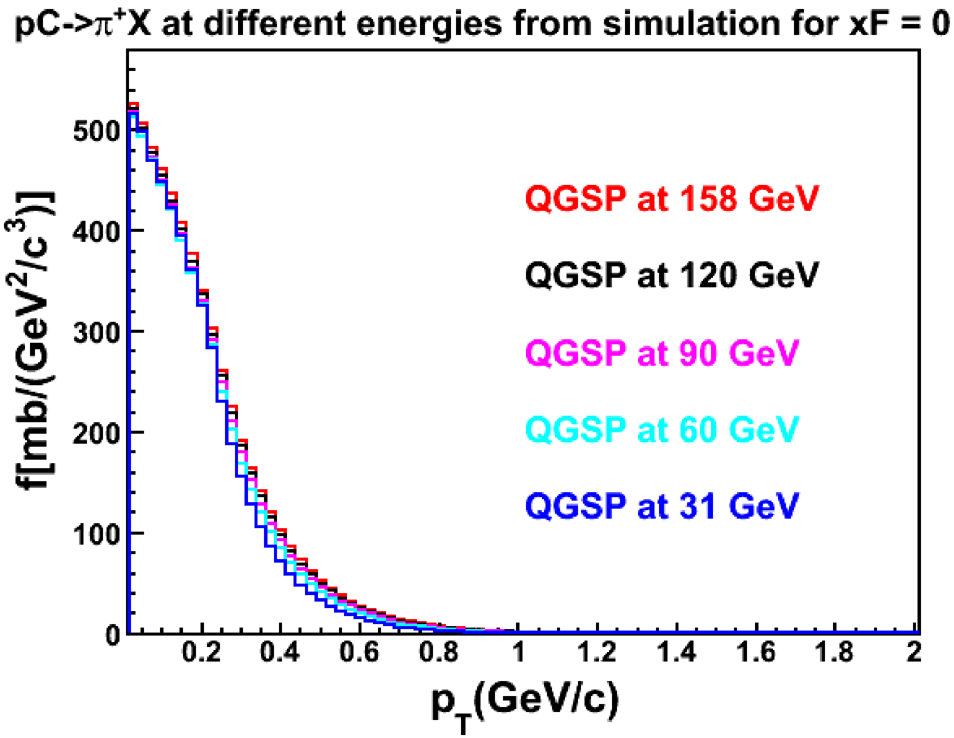


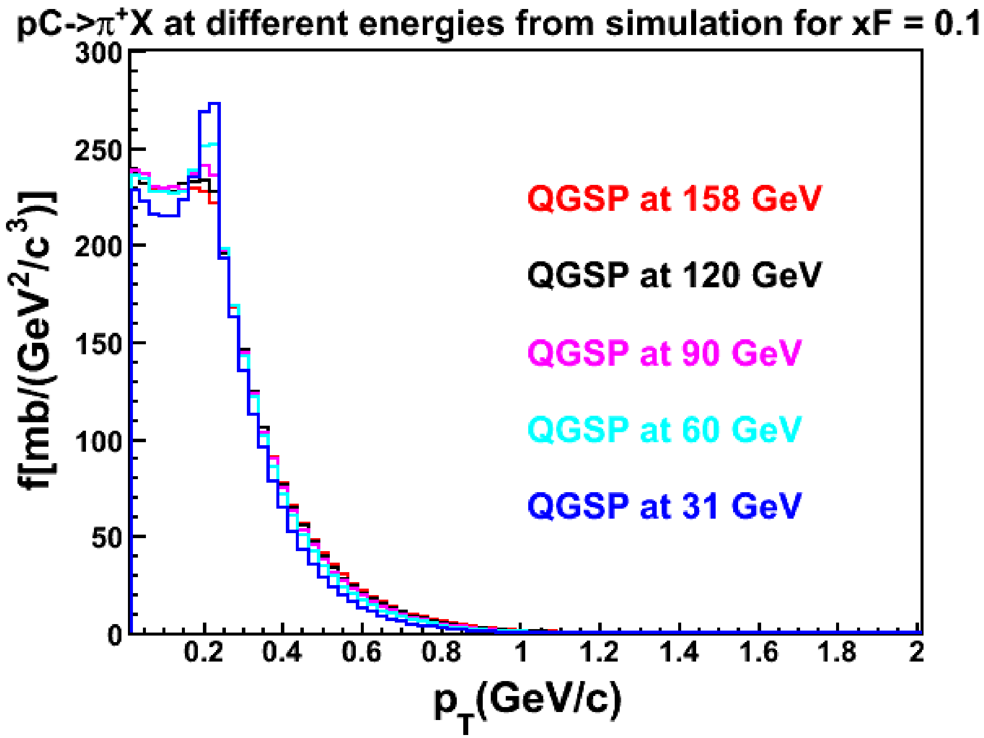
Comparison NA61 and NA49



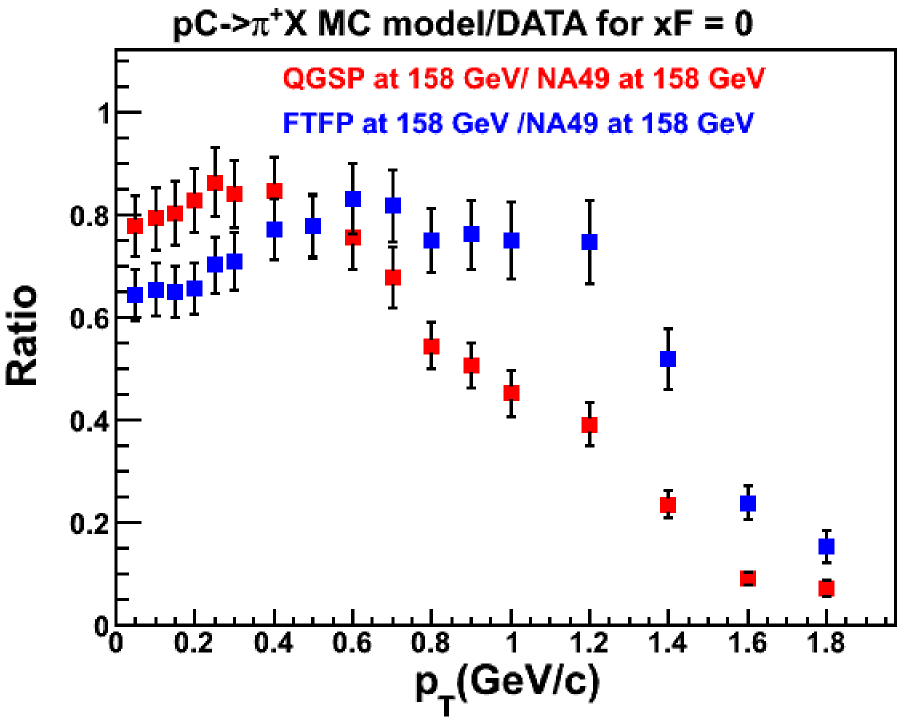


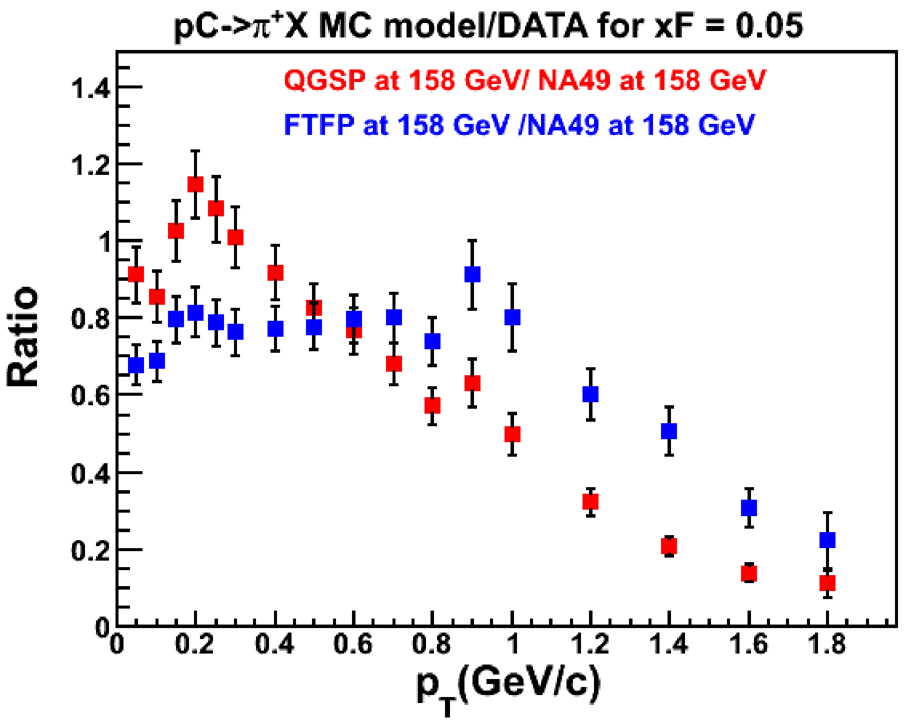
SSS


pC->π⁺X at different energies from simulation for xF = 0
f[mb/(GeV²/c³)]
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
p_T(GeV/c)
QGSP at 158 GeV
QGSP at 120 GeV
QGSP at 90 GeV
QGSP at 60 GeV
QGSP at 31 GeV

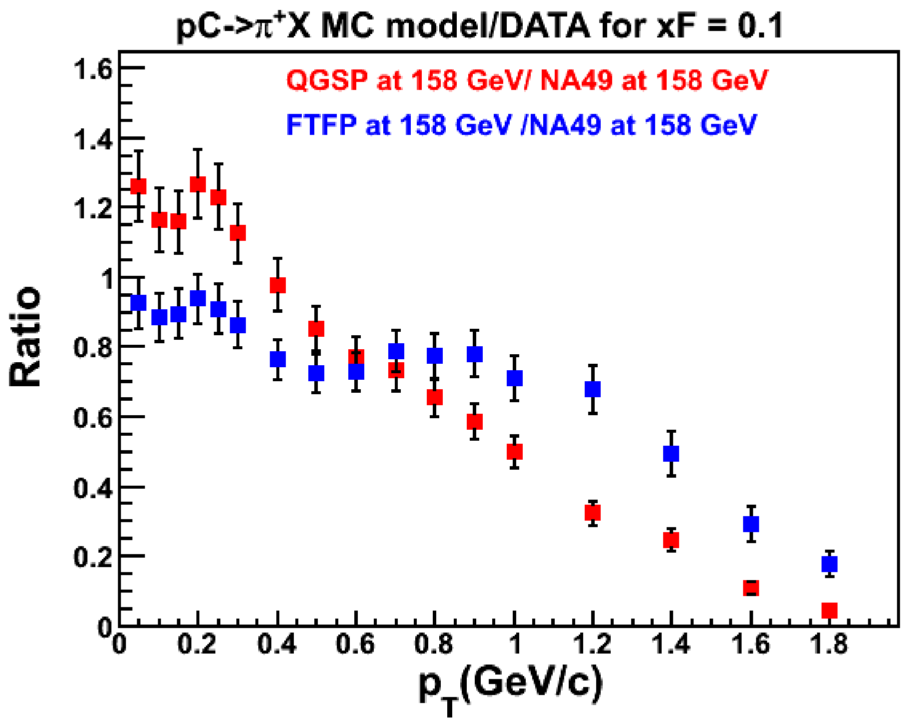

pC->π⁺X at different energies from simulation for xF = 0.1
f[mb/(GeV²/c³)]
0
50
100
150
200
250
300
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
p_T(GeV/c)
QGSP at 158 GeV
QGSP at 120 GeV
QGSP at 90 GeV
QGSP at 60 GeV
QGSP at 31 GeV

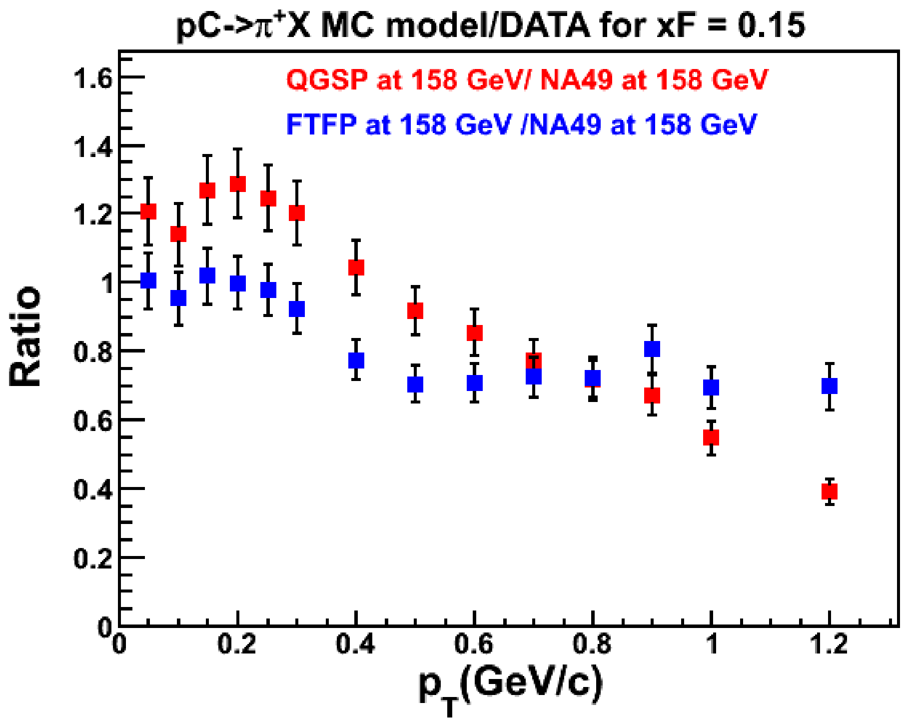
QGSP FTFP vs Data Comparison





QGSP FTFP vs Data Comparison





CC Inclusive Neutrino Reconstructed Energy