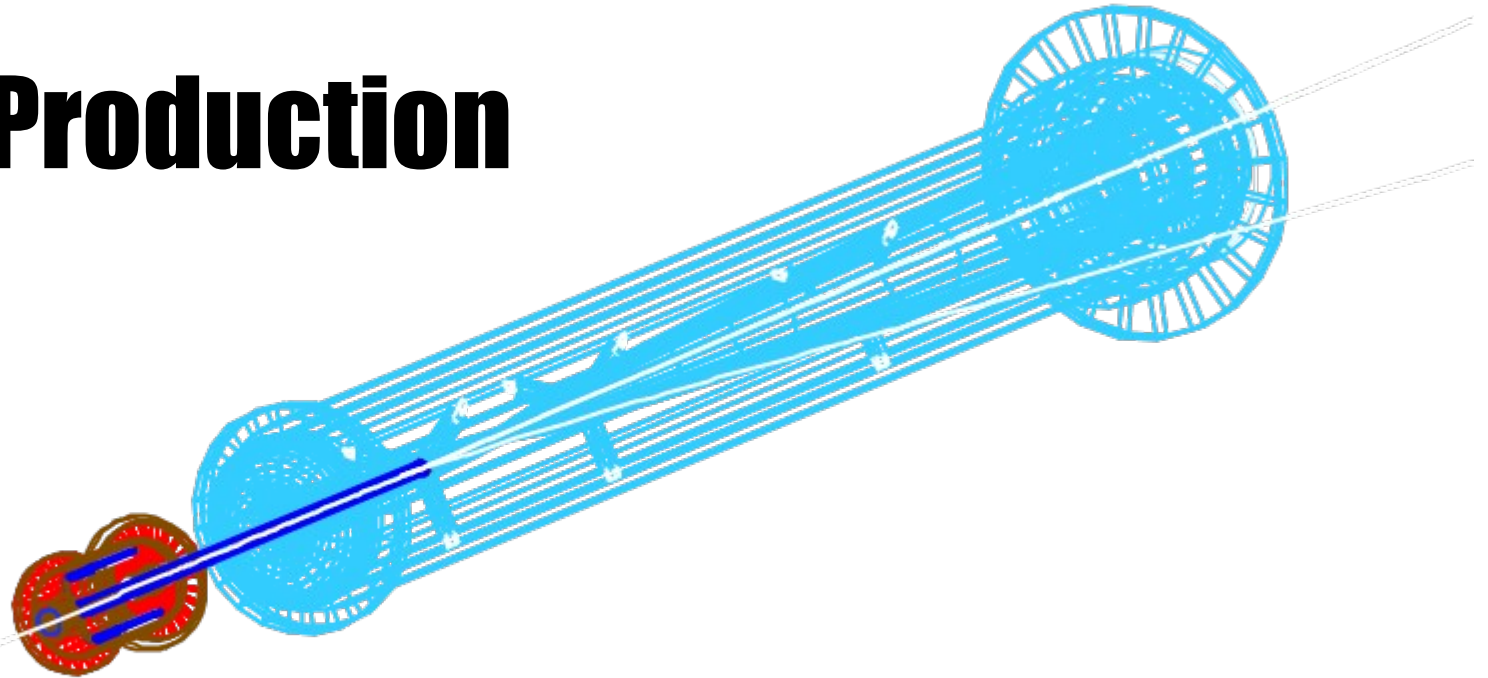


# NuMI Neutrino Flux & Hadron Production



- Who makes  $\nu_{\mu}$ ?
- Existing HP data
- Current workplan
- The future

Mike Kordosky  
(William & Mary)

Intensity Frontier  $\nu$  WG  
Oct 23, 2011

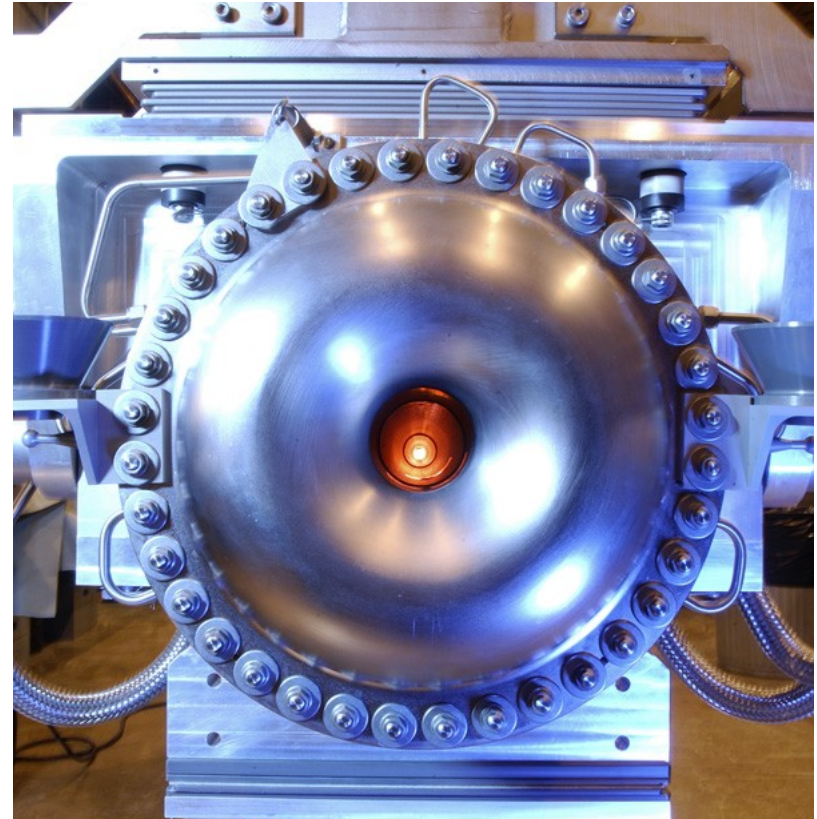
# Where are mesons created?

Geant4 based simulation of the NuMI beamline

*Z. Pavlovic, L. Loiacono,  
J. Ratchford, J. Koskinen,  
M. Jerkins, T. Le, et al.*

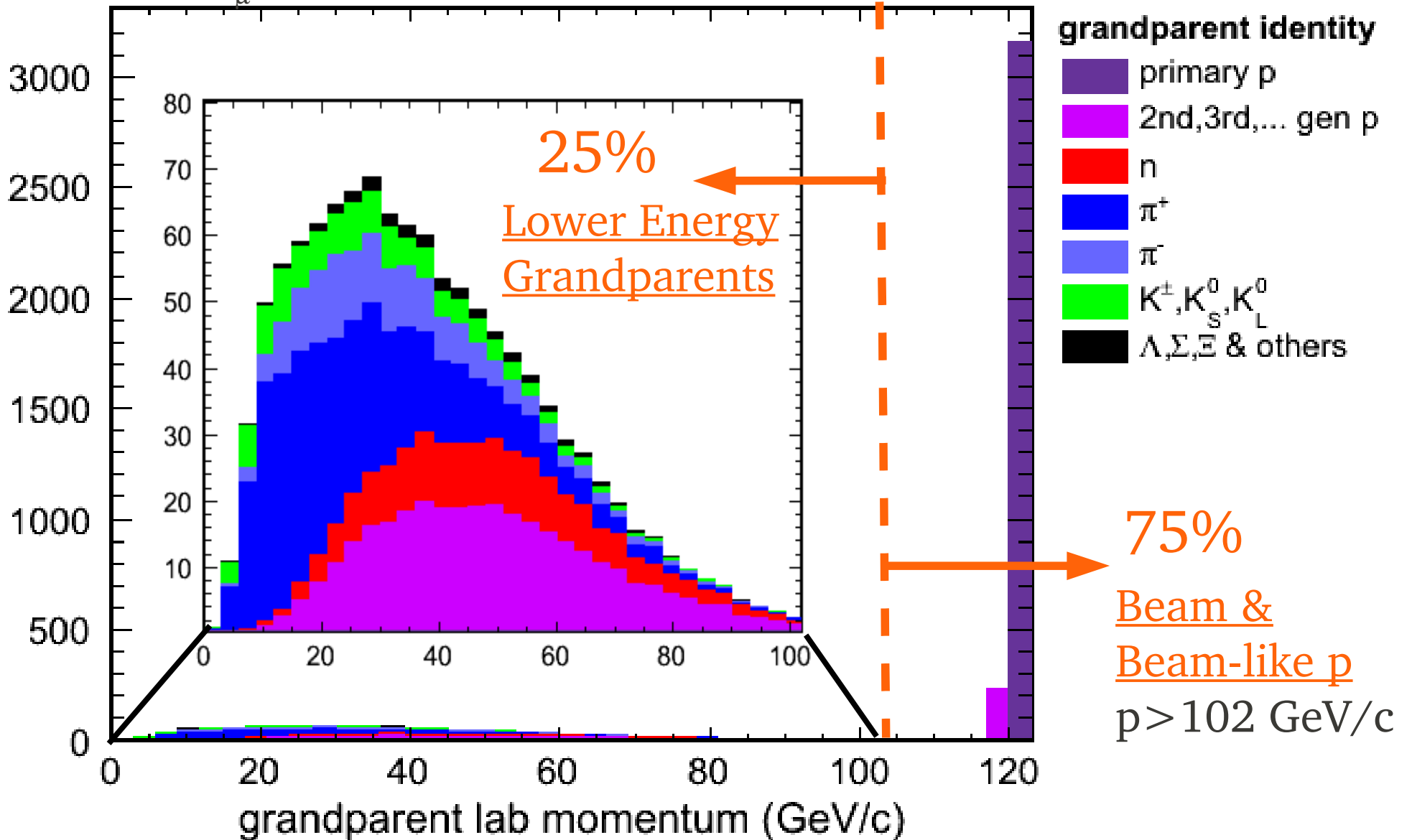
**Origin of  $\pi^+$  which produce  
 $\nu_\mu$  hitting MINOS/MINERvA**

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%

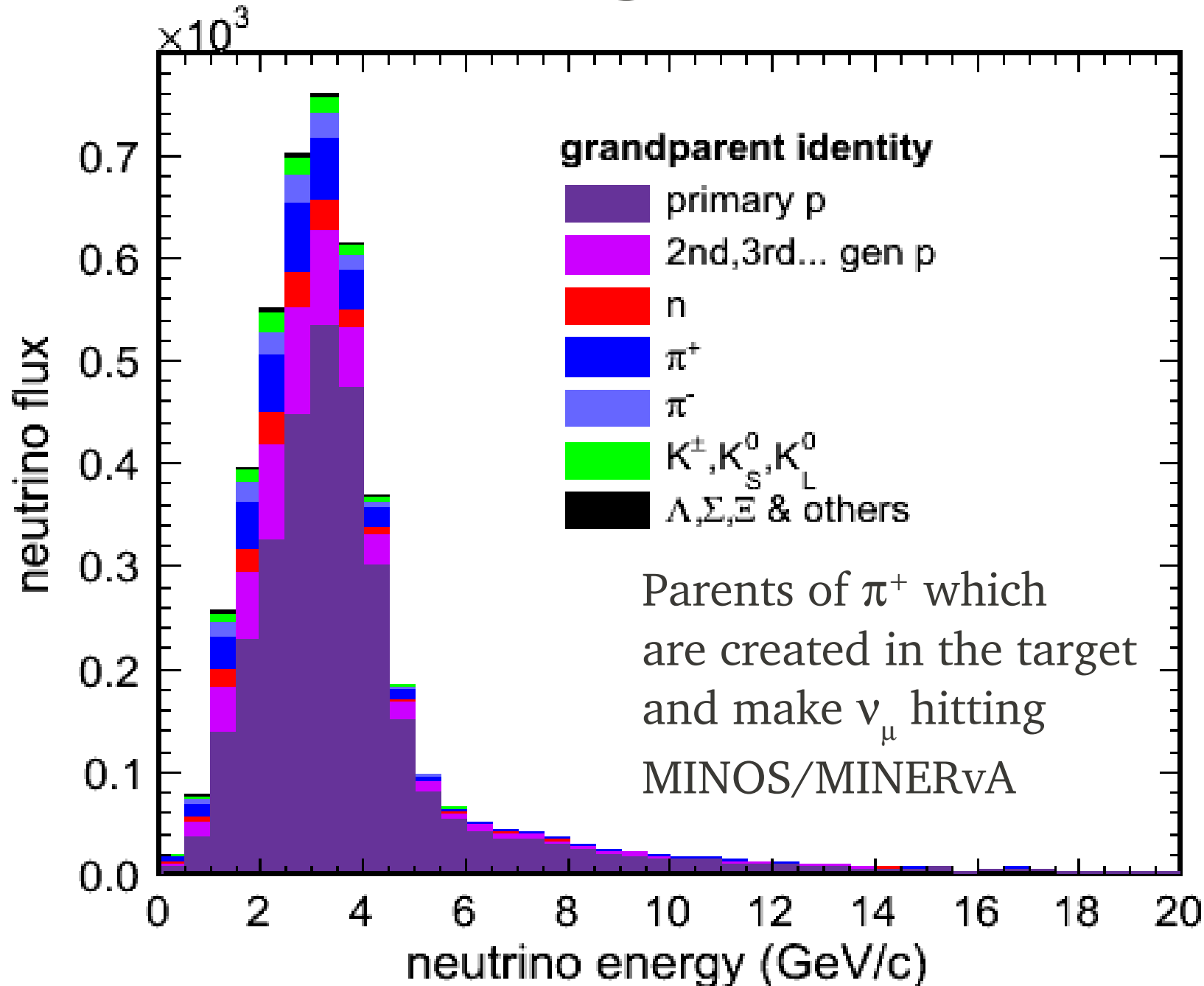


# Neutrino grandparents?

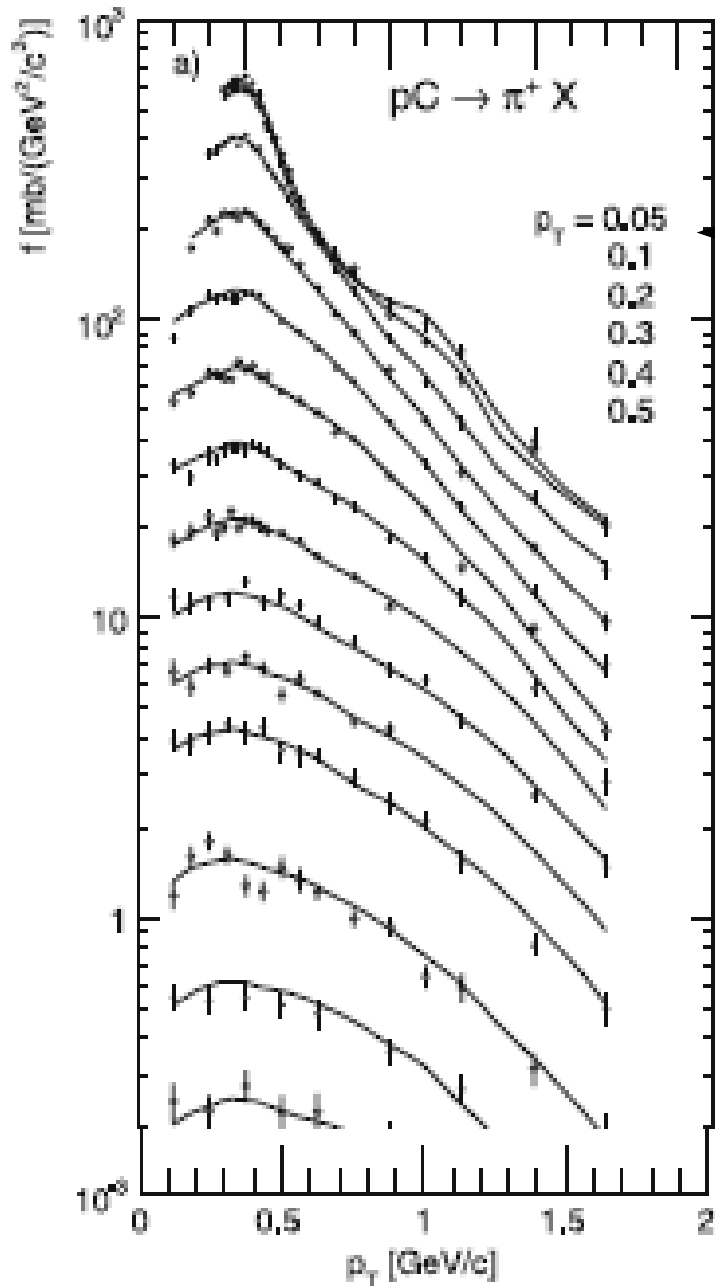
Parents of  $\pi^+$  which are created in the target and make  $\nu_\mu$  hitting MINOS/MINERvA



# Neutrino grandparents?



# HP data: what exists

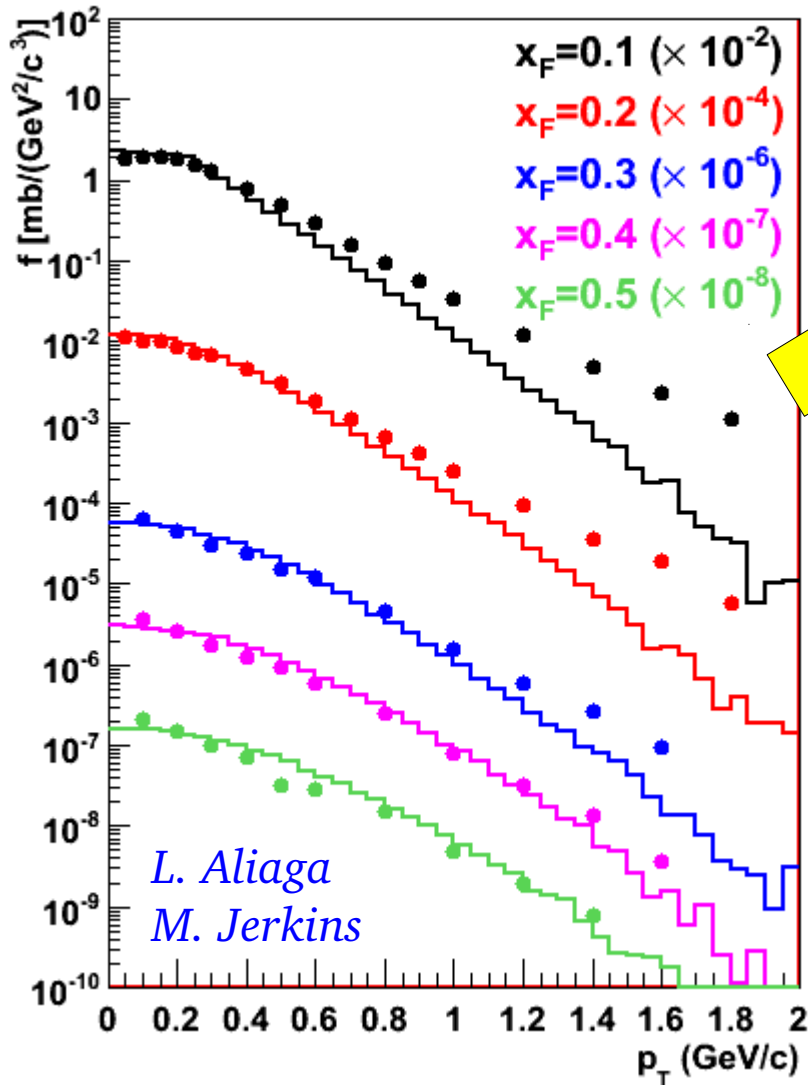


## thin target

- NA49 @ 158 GeV/c
    - pC  $\rightarrow$   $\pi$ /K X
    - pp  $\rightarrow$  p/n/ $\pi$  X
  - NA61 @ 31 GeV
    - pC  $\rightarrow$   $\pi$ /K X
  - Less comprehensive: Barton, Denisov
- ## NuMI target
- MIPP @ 120 GeV
    - K/ $\pi$  ratio at  $x > 0.2$

# Current thoughts & efforts

pC → πX @ 158 GeV/c



reweight

p(120 GeV) C → π (10 GeV) X secondary π production  
 ↓  
 π(10 GeV) → μ ν(4 GeV)

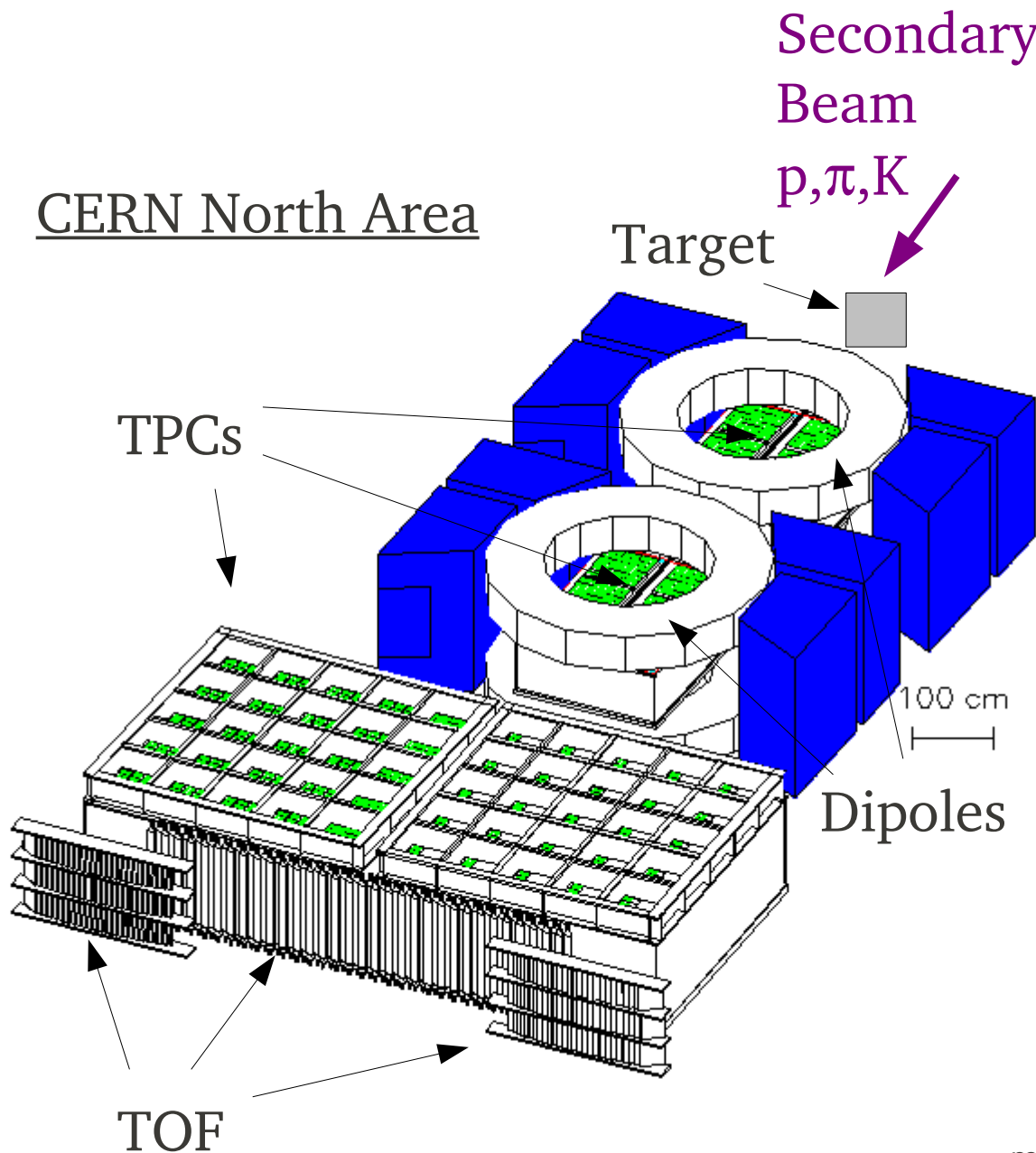
p(120 GeV) C → p(60 GeV) X typical tertiary π production chain  
 ↓  
 p(60 GeV) C → π(10 GeV) X'

NA49 pp data?  
 Barton?

Interpolate NA49/61  
 31 ↔ 158 GeV/c?

π(10 GeV) → μ ν(4 GeV)

# HP at NA61/SHINE



- High acceptance spectrometer built for nuclear physics
- Systematics  $\sim 5\%$
- 10m triggers=2 weeks
- Analysis $\approx 15$  person $\cdot$ yrs
- Long but not “replica” target
- Bolsters 2 det. expts
- Enables short baseline, cross-sections, etc.

# Backups

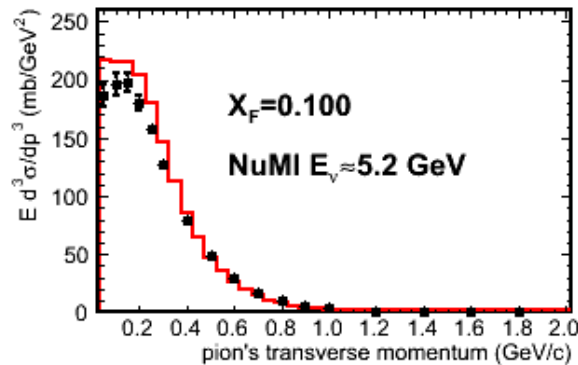
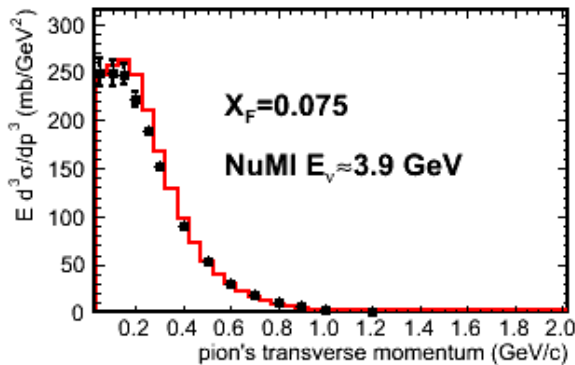
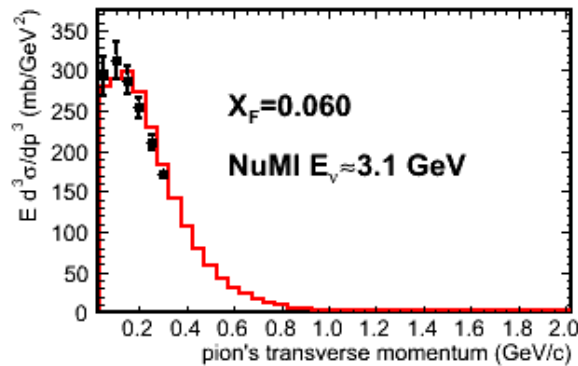
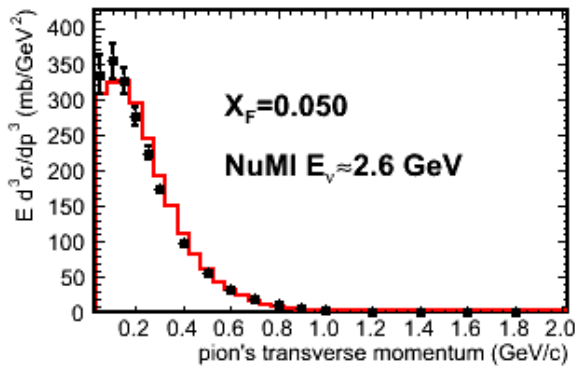
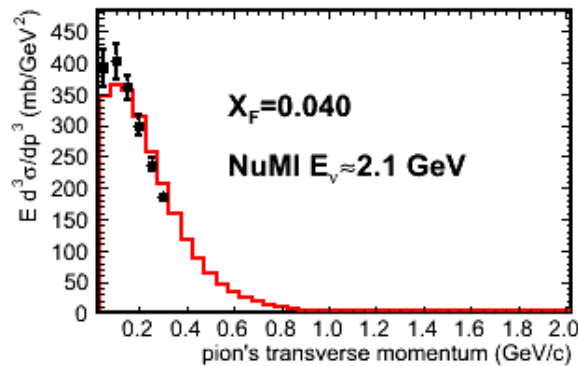
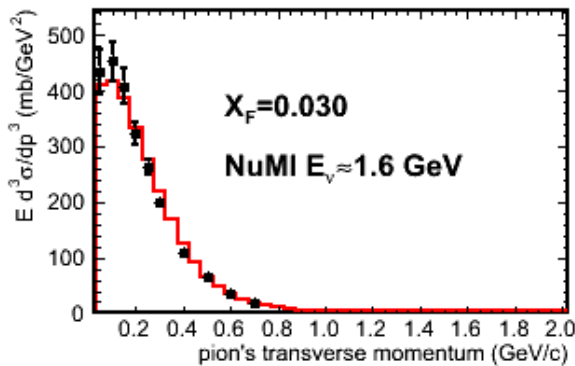


# HP data: what you'd like

Aside from thick/replica target...

- $pC \rightarrow pX$  at  $p \approx 120$  GeV/c and  $0.25 < x_F < 0.6$
- $pC \rightarrow \pi X$  at  $20 < p < 70$  GeV/c and  $x_F \approx 0.1$ 
  - Try to evolve NA49 @ 158 GeV/c to NA61 @ 31 GeV/c
- $\pi C \rightarrow \pi X$  at  $10 < p < 40$  GeV/c
  - did NA61 collect this data?
  - What else is there?

# Hadron production uncertainties



Agreement between  
MC models and data

Fluka2005 vs NA49  
 $pC \rightarrow \pi^+ X @ 158$  GeV/c

Eur.Phys.J. C49 (2007) 897-917

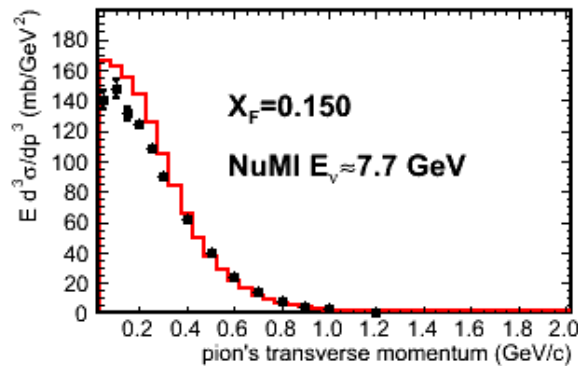
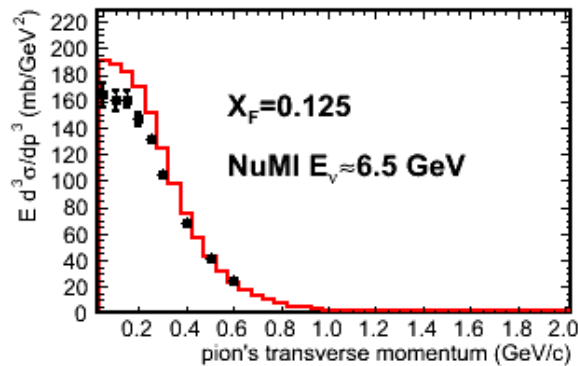
"The FLUKA code: Description and benchmarking"

G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari,  
S. Roesler, A. Fassò, J. Ranft,  
AIP Conference Proceeding 896, 31-49, (2007)

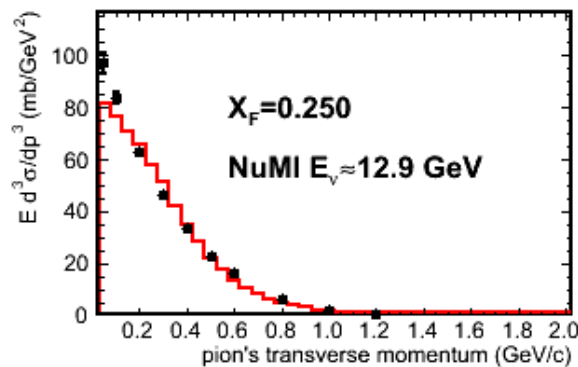
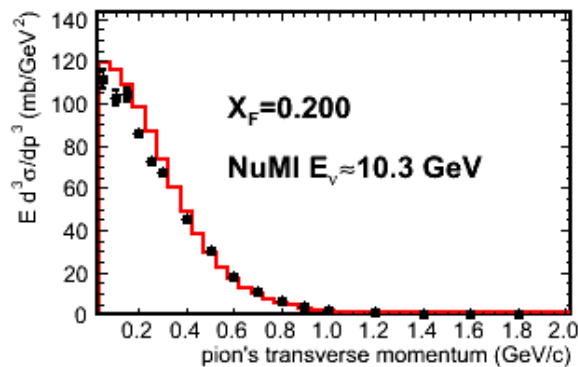
"FLUKA: a multi-particle transport code"

A. Fassò, A. Ferrari, J. Ranft, and P.R. Sala,  
CERN-2005-10 (2005), INFN/TC\_05/11, SLAC-R-773

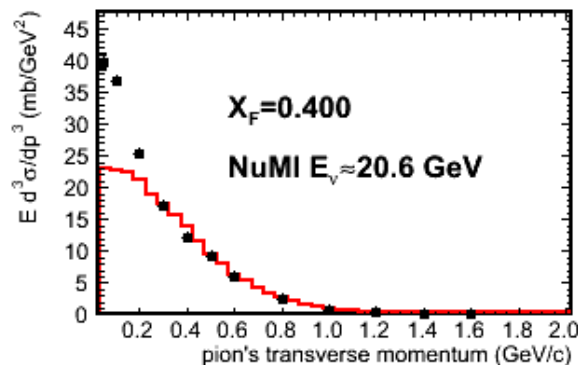
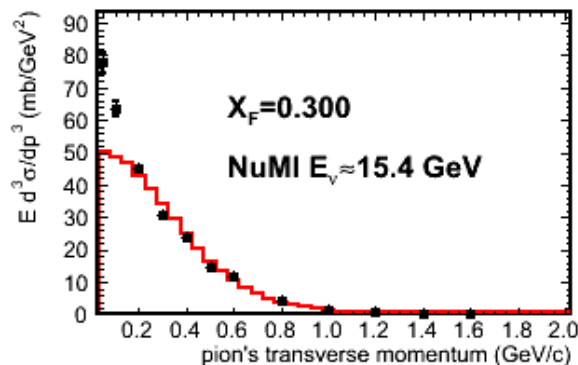
# Hadron production uncertainties



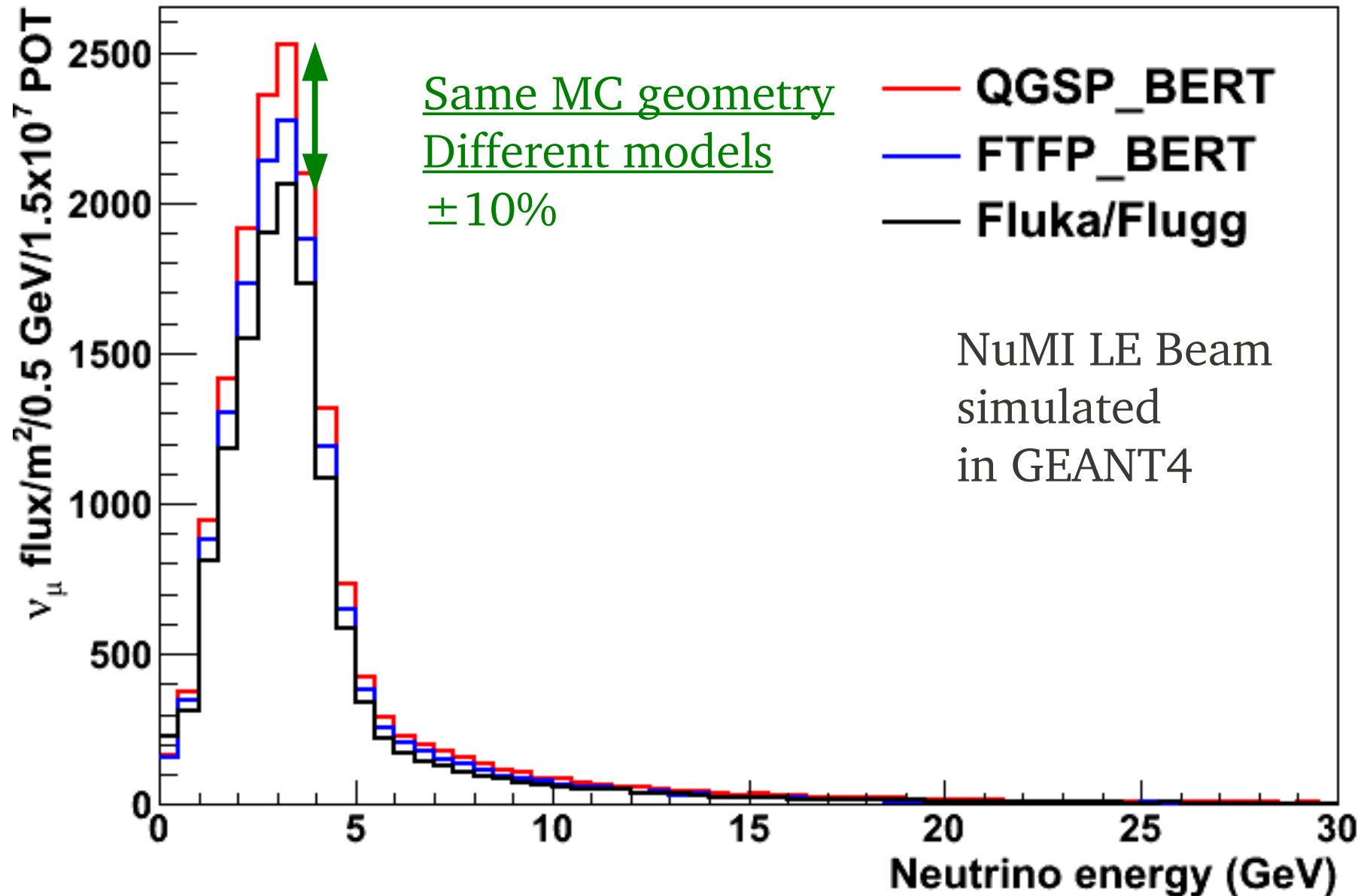
Agreement between  
MC models and data



Fluka2005 vs NA49  
 $pC \rightarrow \pi^+ X @ 158$  GeV/c

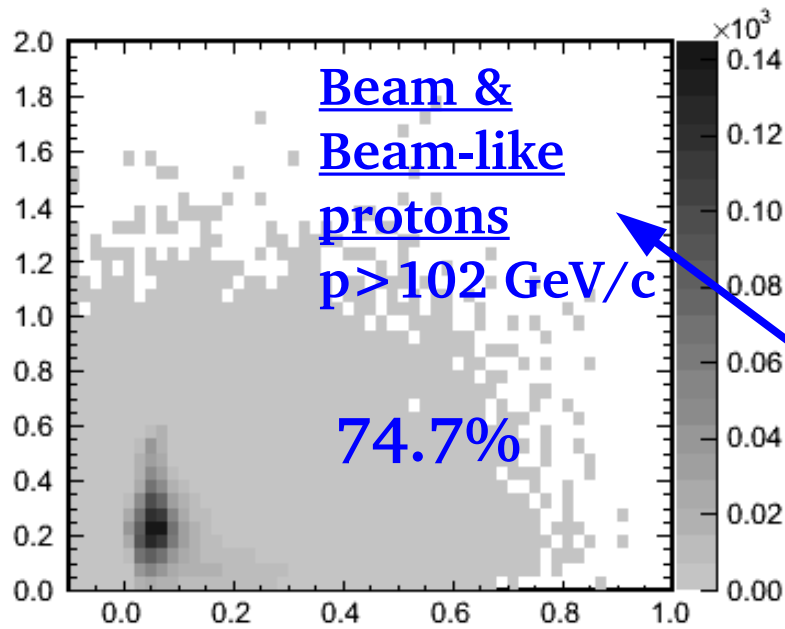


# Hadron production uncertainties

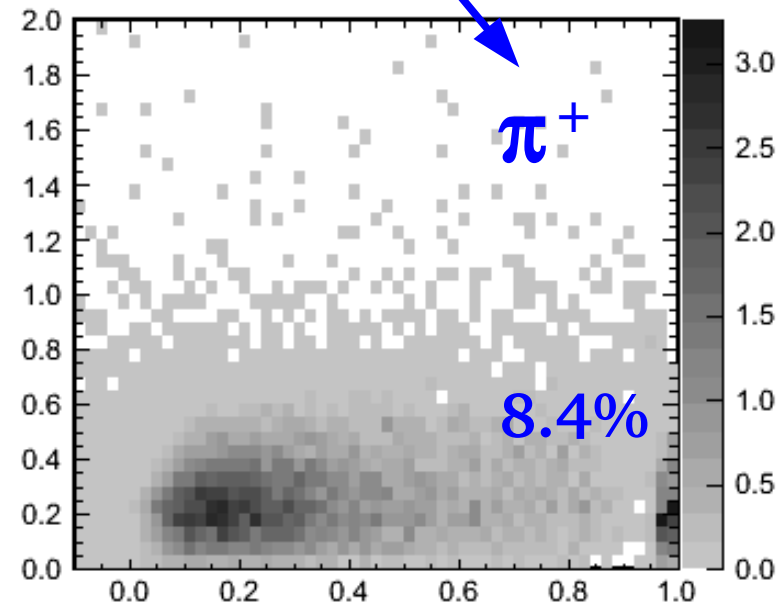
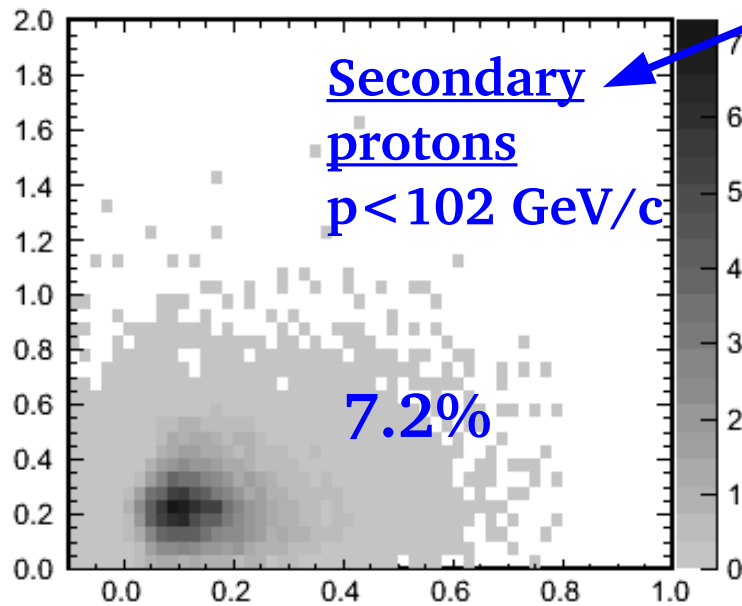


transverse momentum (GeV/c)

# $x_F$ $p_T$ of $\pi^+$ neutrino parents

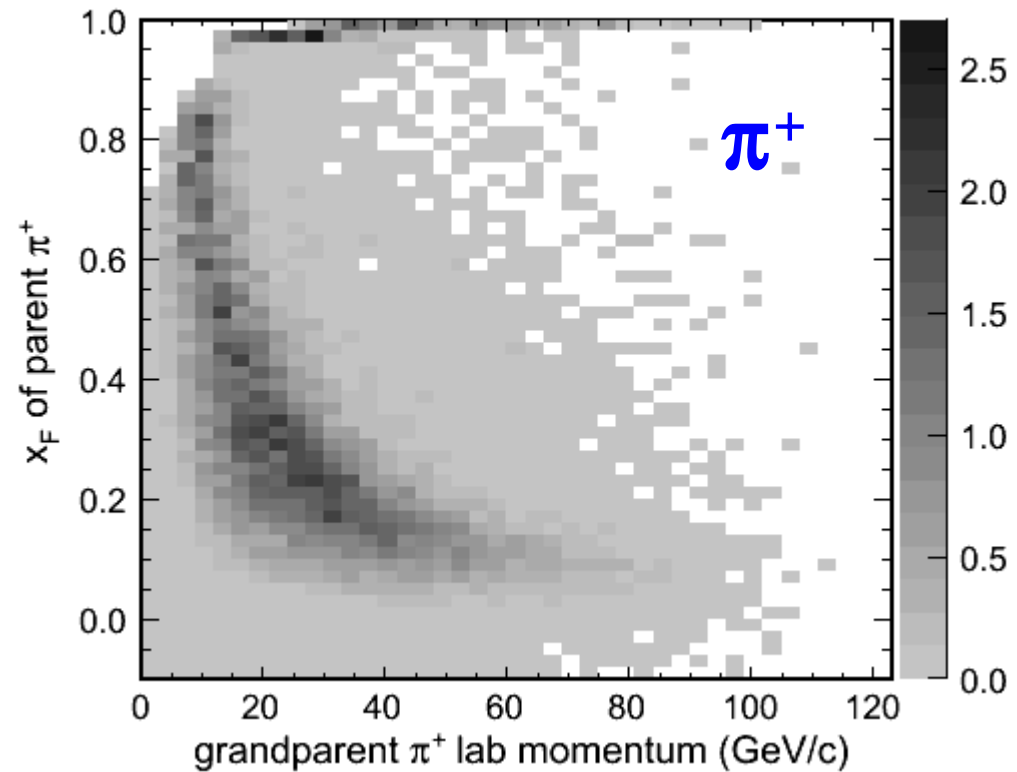
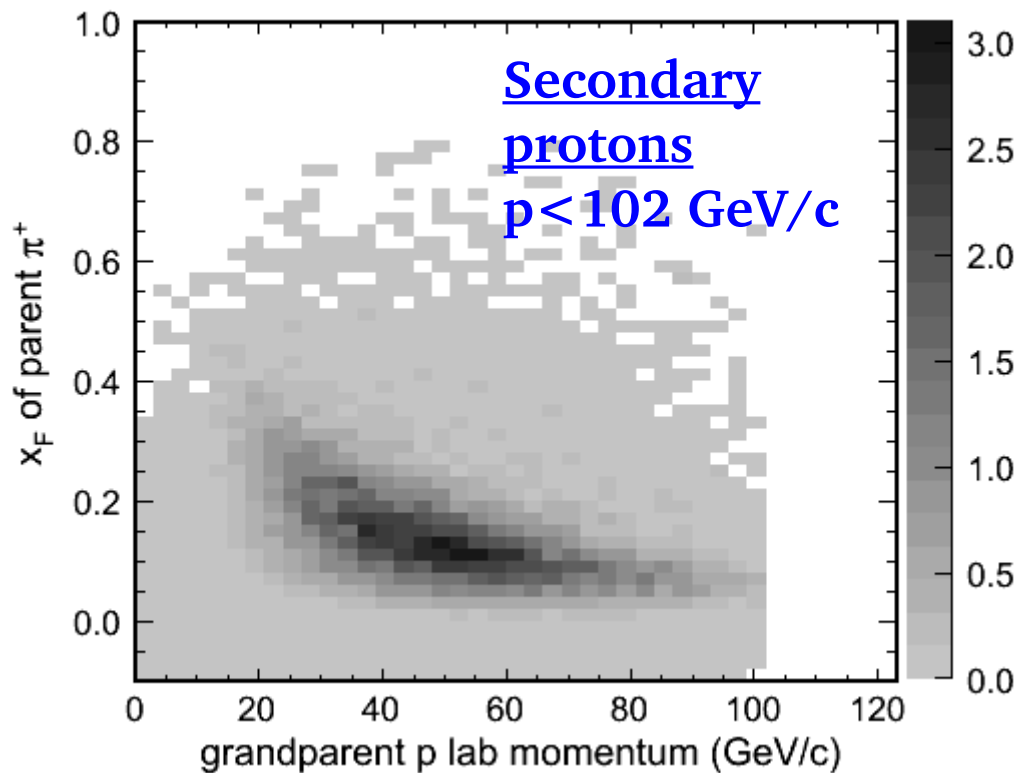


Three largest grandparent components % of  $\nu_\mu$



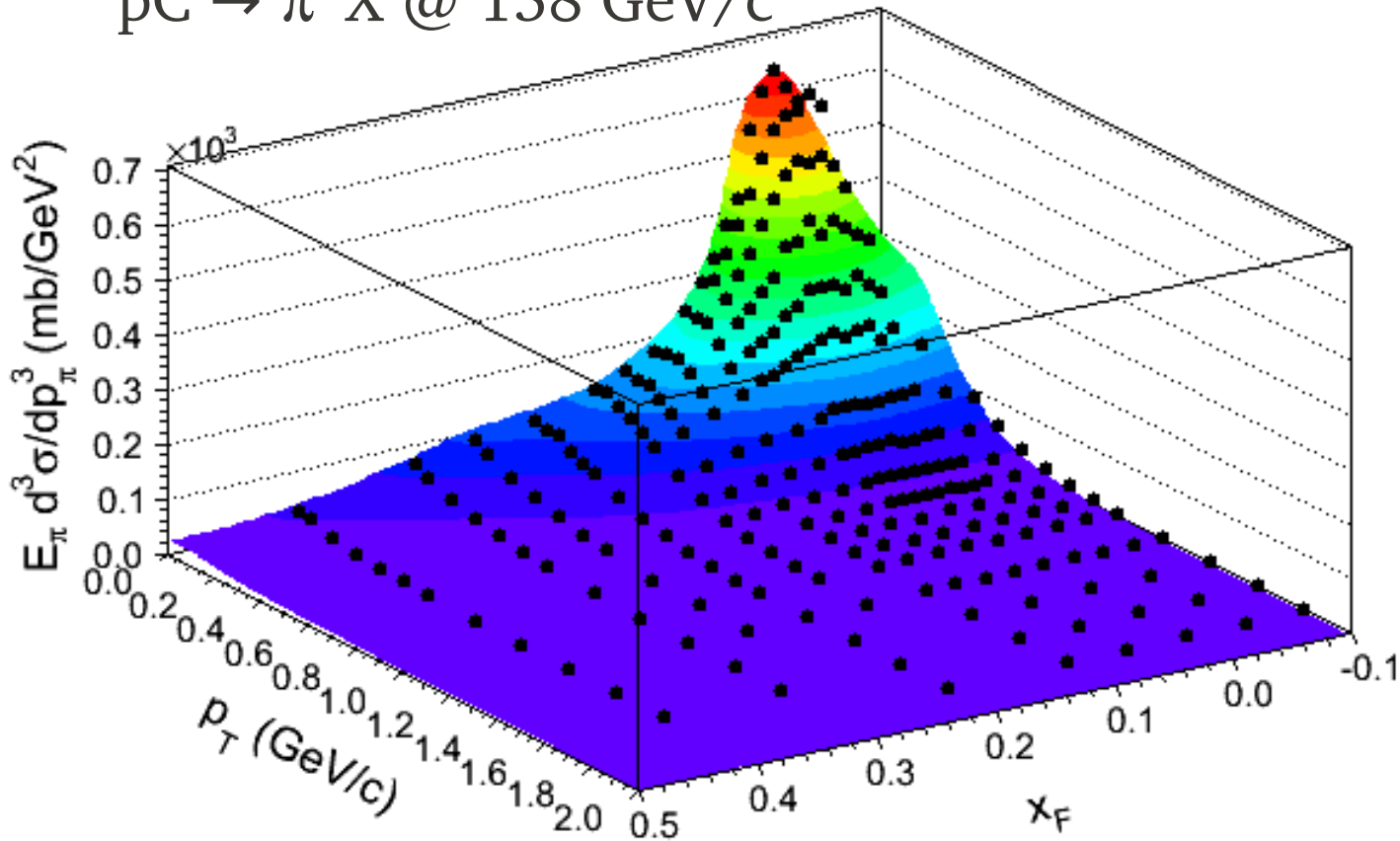
$x_F$

# Relating $x_F$ and grandparent $p_{\text{LAB}}$



# Using hadron production data

NA49 data Eur.Phys.J. C49 (2007) 897-917  
 $pC \rightarrow \pi^+ X @ 158 \text{ GeV}/c$



NA49 invariant  $\sigma$   
interpolated in 2D

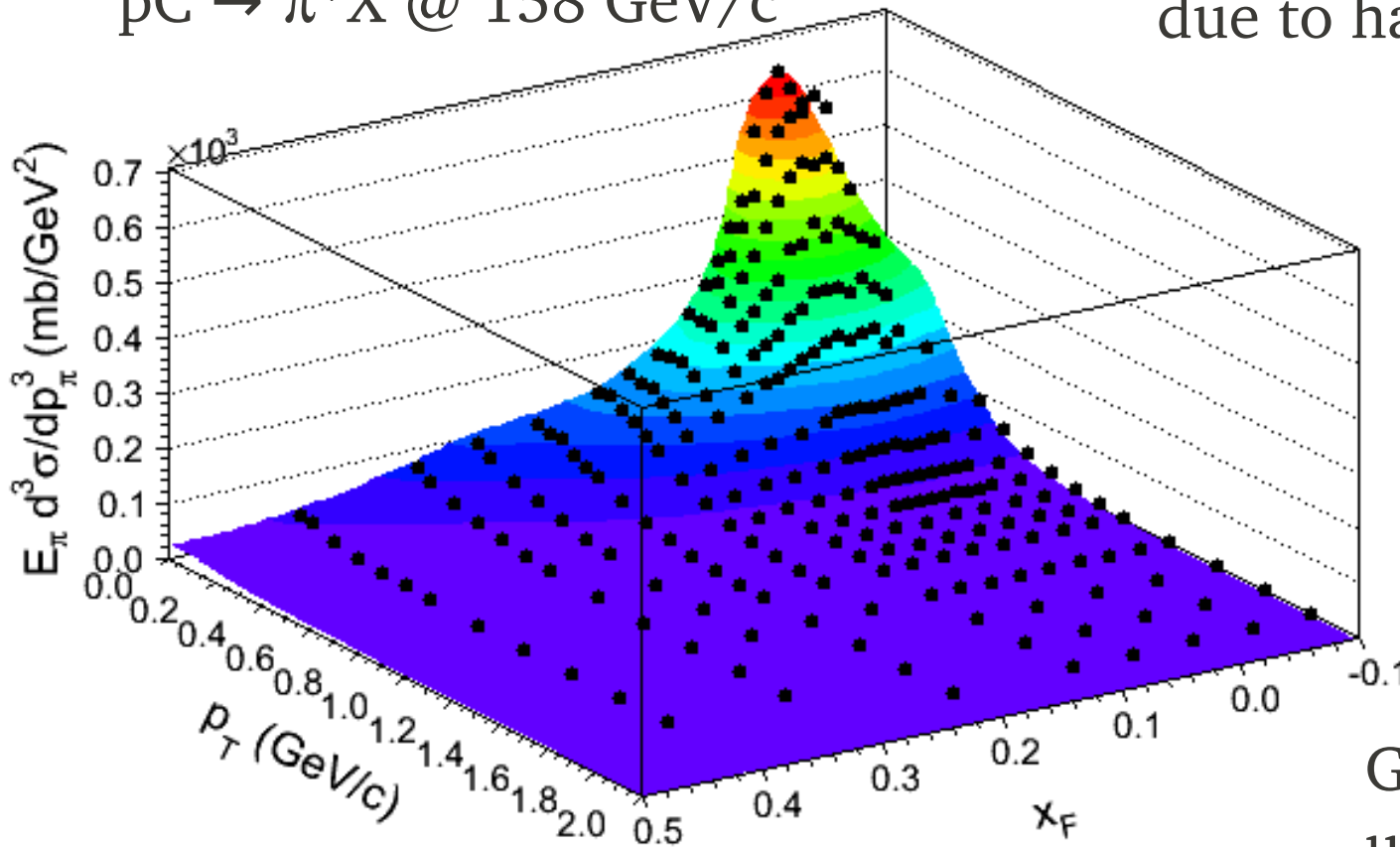
Build similar surface  
for default model  
(Fluka, G4, etc)

Weight events using  
ratio of the two

# Using hadron production data

NA49 data  
 $pC \rightarrow \pi^+ X @ 158 \text{ GeV}/c$

Possible to estimate, event by event, the uncertainty due to hadron production.



Record relevant NA49 bin, then vary bin scales according to NA49 uncertainties.

Correlated?  
Uncorrelated?

Gets you some of the uncertainty.



# Predicted Neutrino Flux

Geant4 based simulation  
of the NuMI beamline

*Z. Pavlovic, L. Loiacono,  
J. Ratchford, J. Koskinen,  
M. Jerkins, T. Le, et al.*

Event Rate  
~50k  $\nu_\mu$ -CC  
for 1t plastic  
and  $1 \times 10^{20}$  POT

