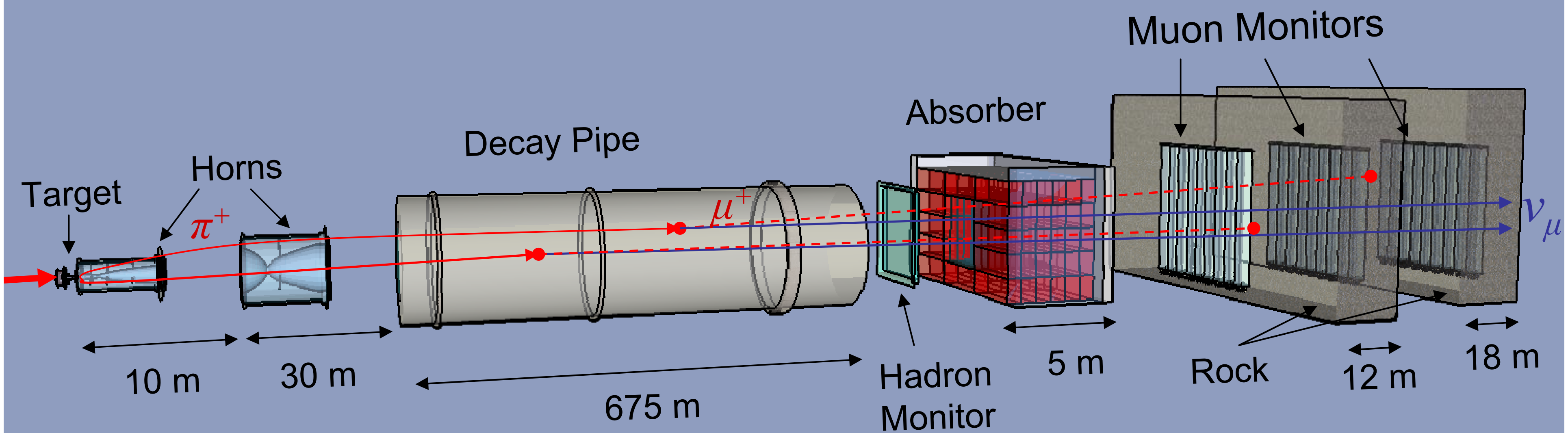
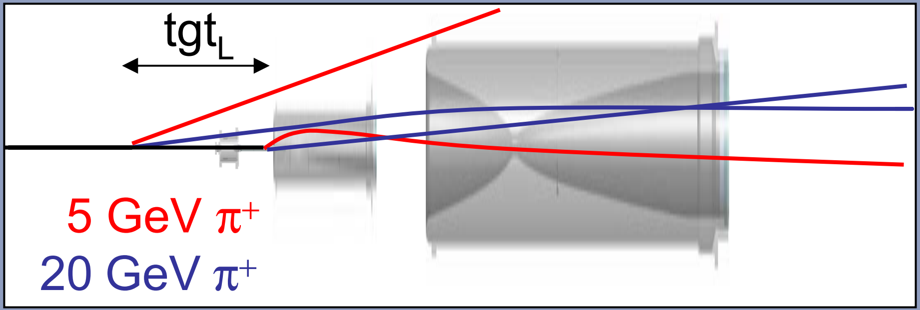
NuMI Beam Monte Carlo and Hadron Production Uncertainties

Žarko Pavlović
The University of Texas at Austin

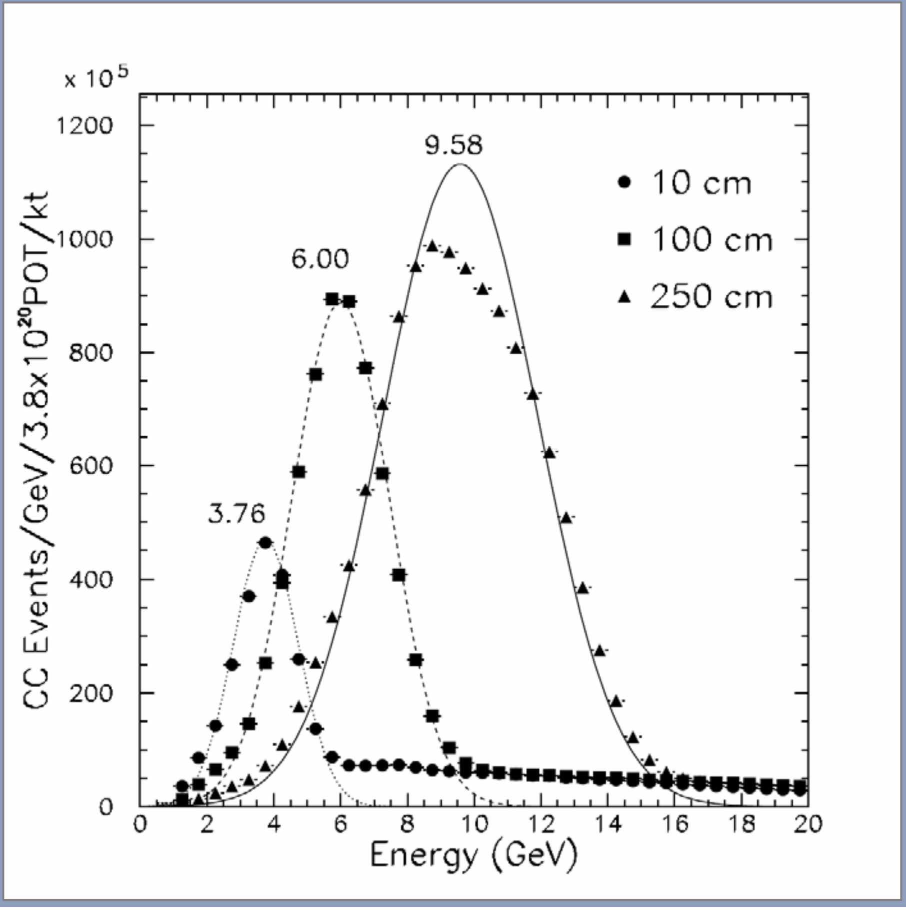


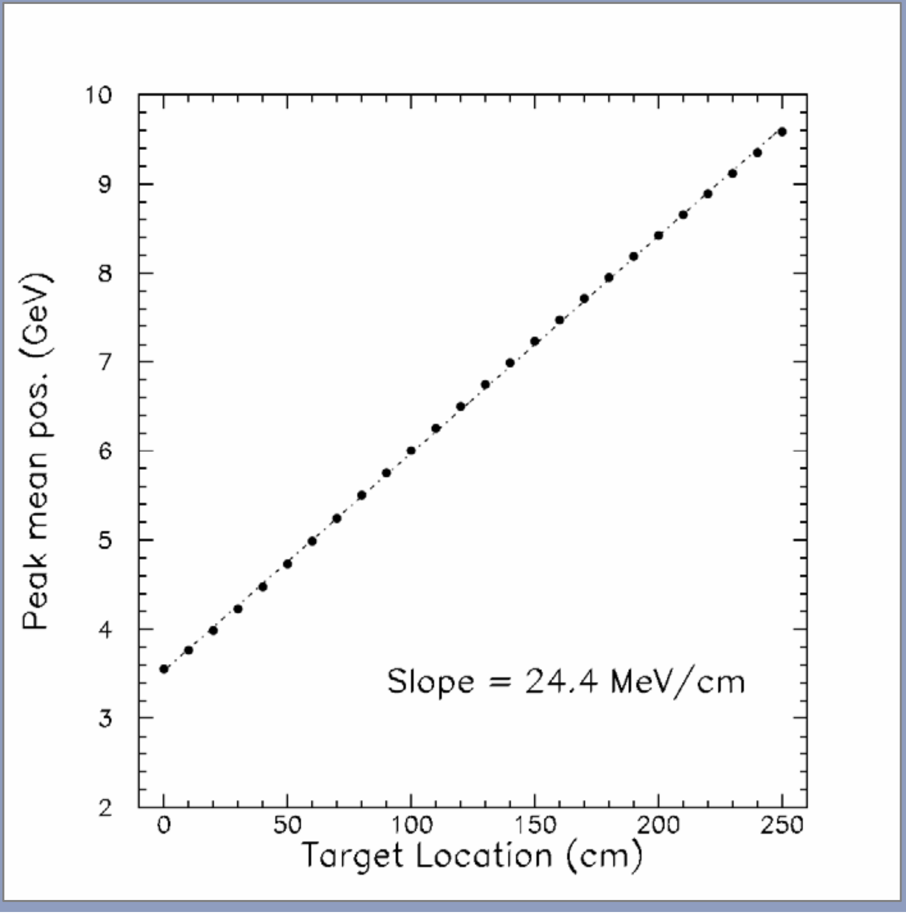
Variable energy beam



$\tan(\theta) \approx \langle p_T \rangle / p_z = r_{Horn} / tgt_L$

$E_\nu \sim p_Z \sim tgt_L$





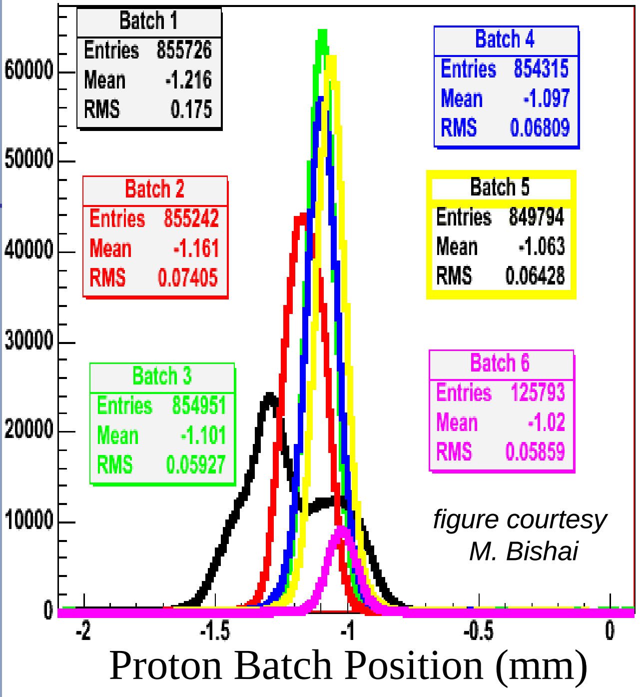
Study of Beam systematics

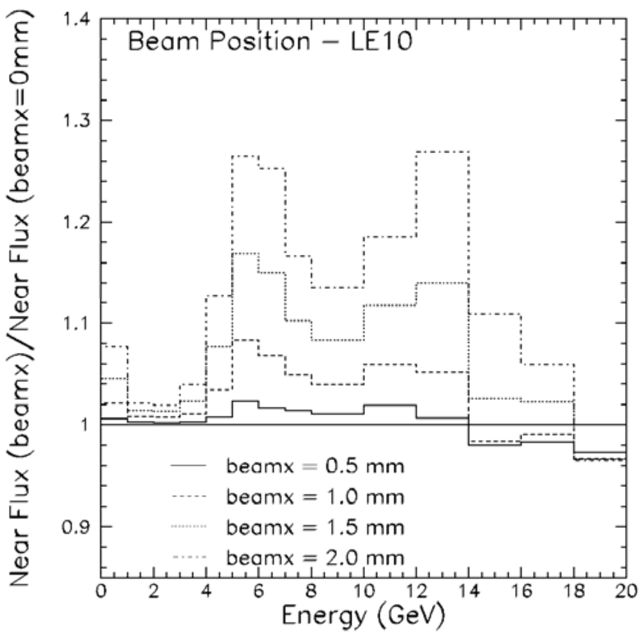
- Non-hadron production
  1. Proton beam
  2. Secondary focusing modelling
  3. MC geometry
- Hadron Production

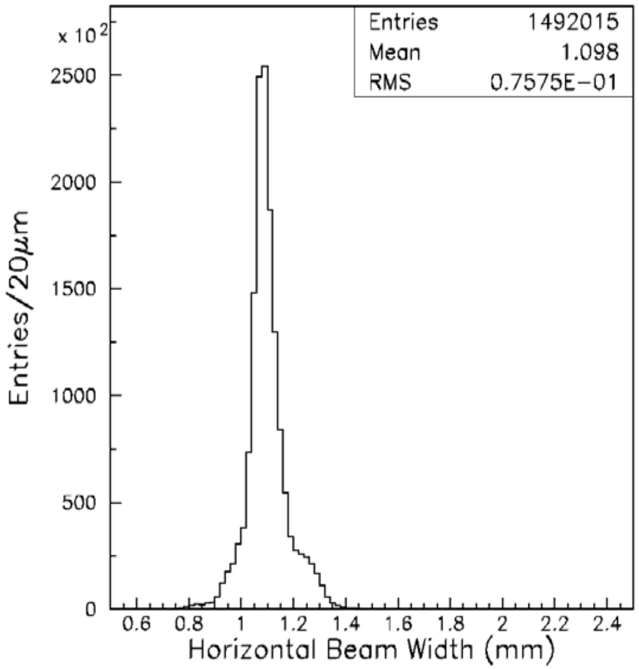
NB: Much of the inputs backed up with beamline instrumentation

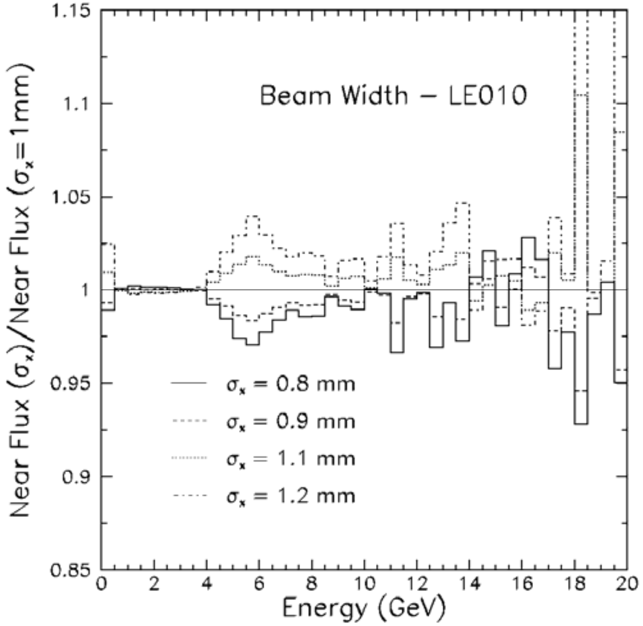
1. Proton Beam

- Beam position and width can change the neutrino flux:
  - protons missing the target
  - reinteractions in target
- Use profile monitor measurements to correct MC

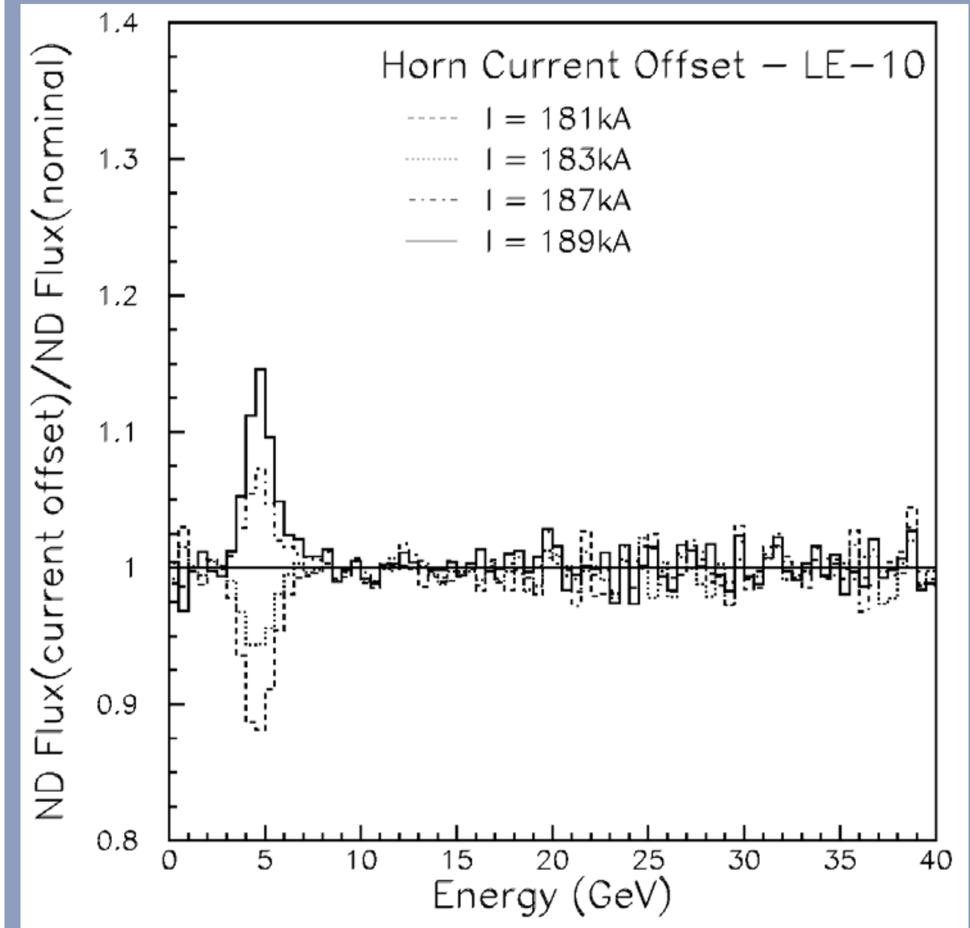


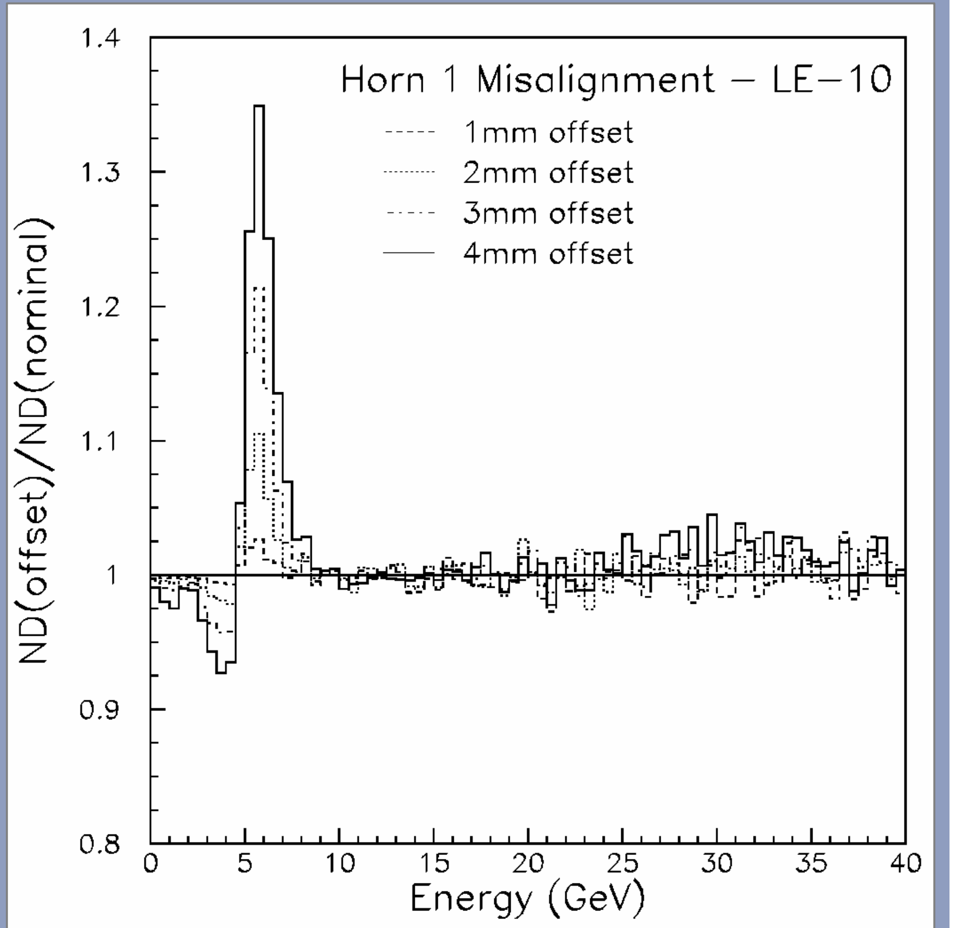






2. Modelling of Focusing

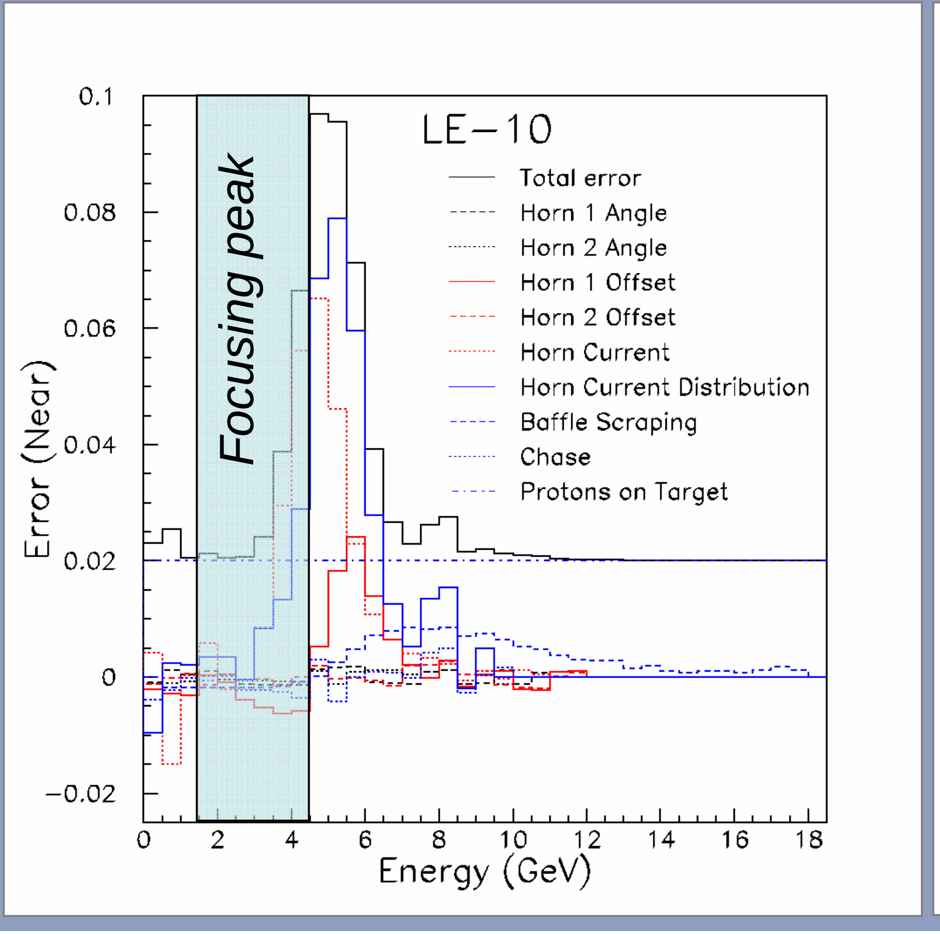


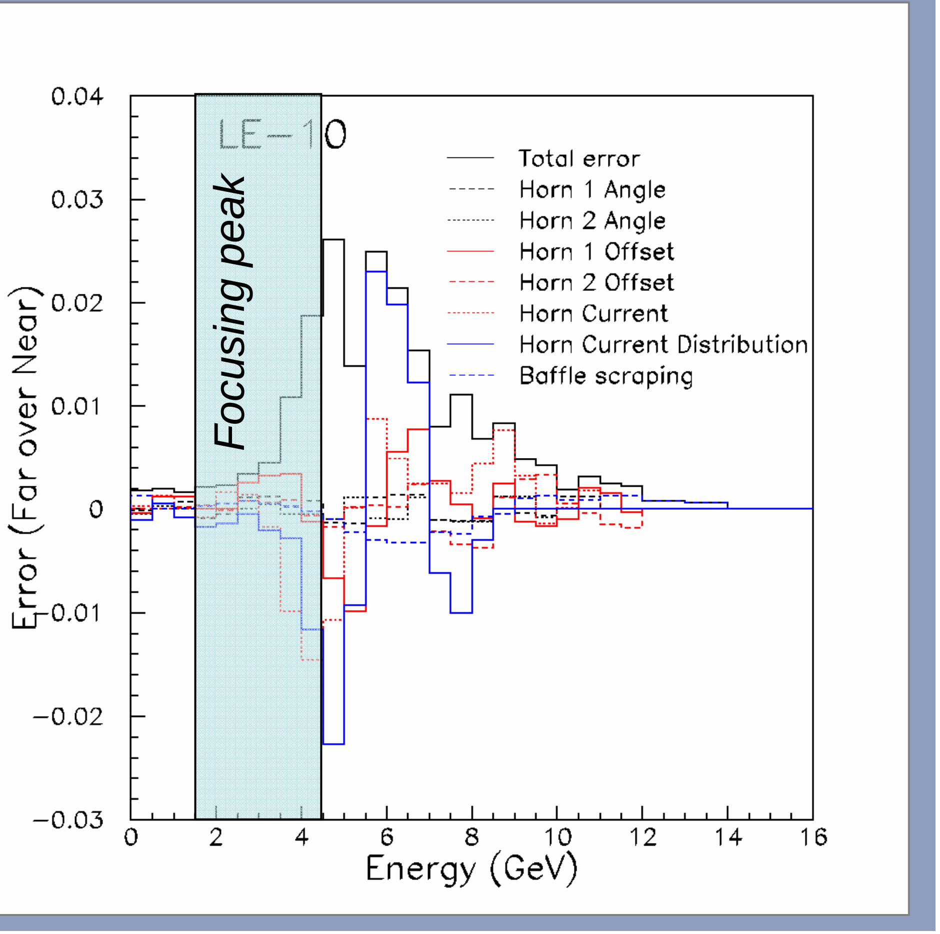


- Also studied: Horn current miscalibration, skin depth, horn transverse misalignment, horn angle

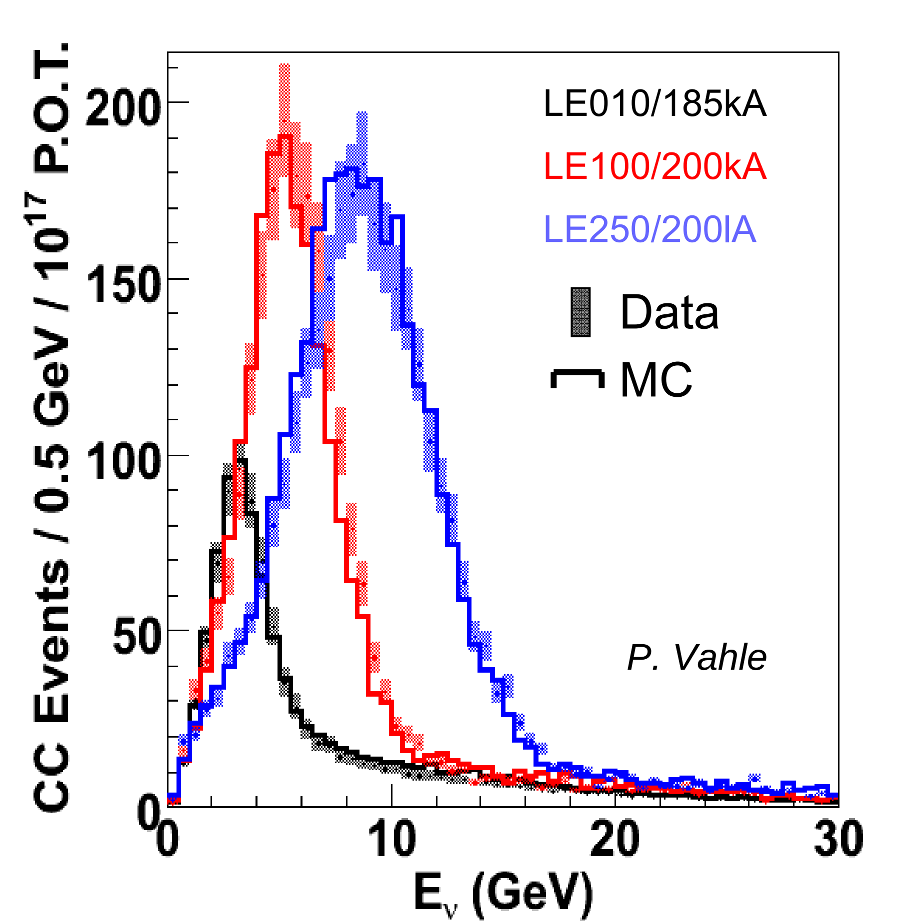
Non-hadron production systematic

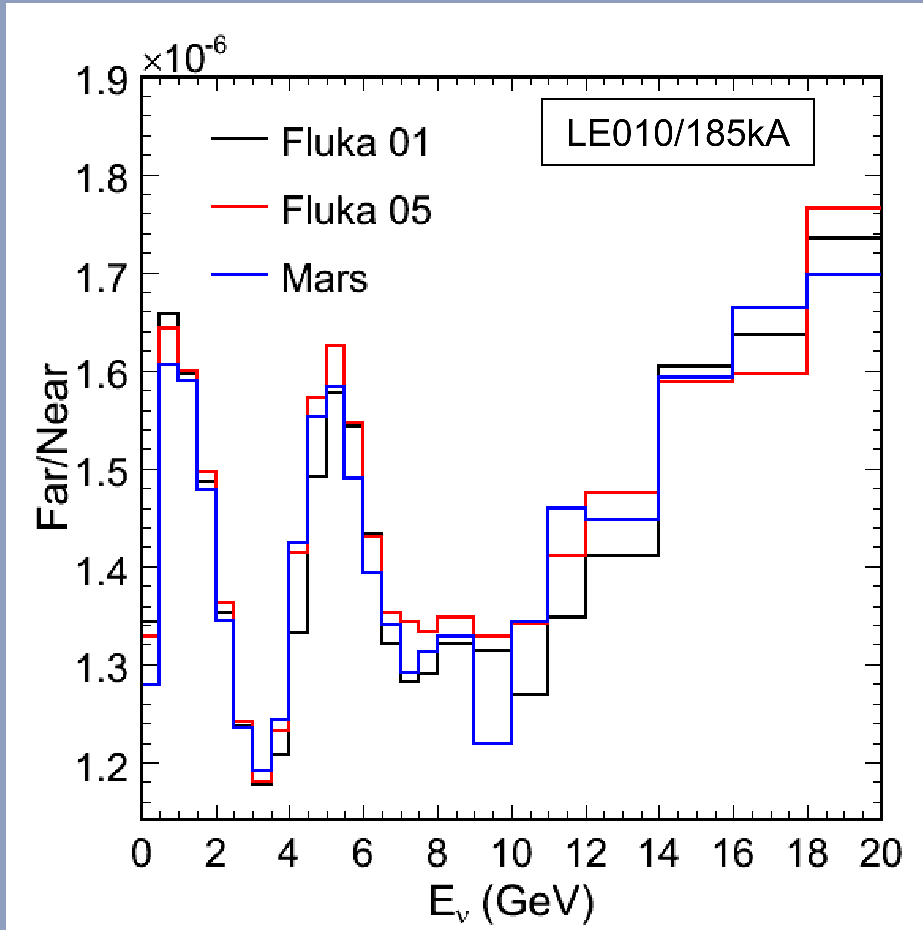
- Non-hadron production systematics affect the falling edge of the peak the most
- Far over near ratio affected by less then 2%





Hadron Production

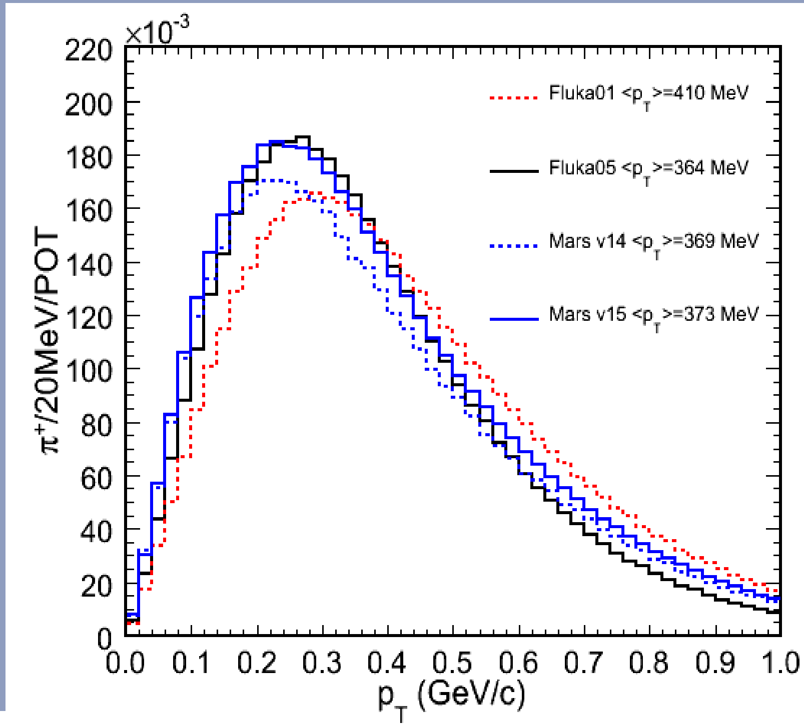


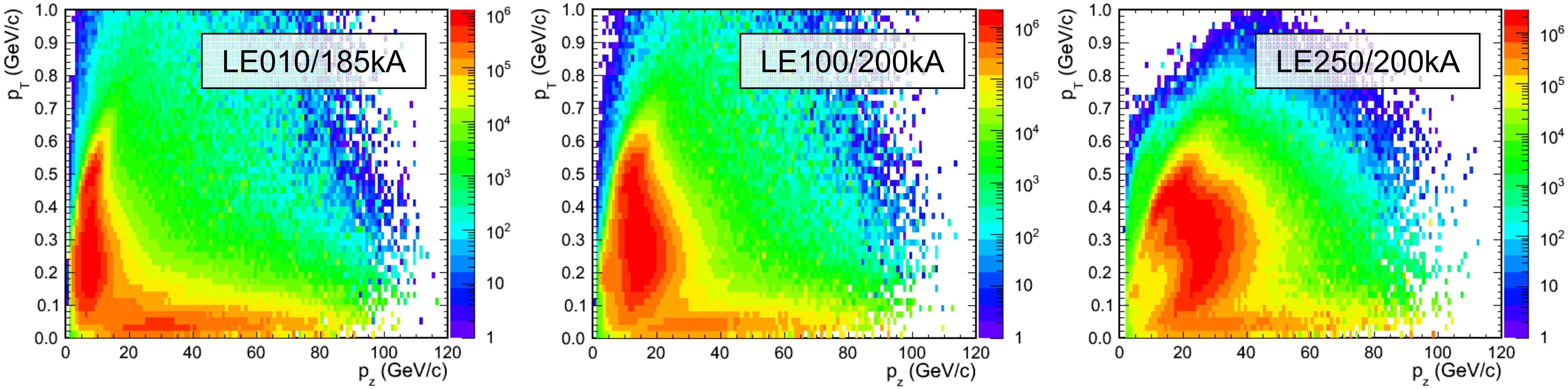


- Agreement ‘OK’ in ND
- Model spread large

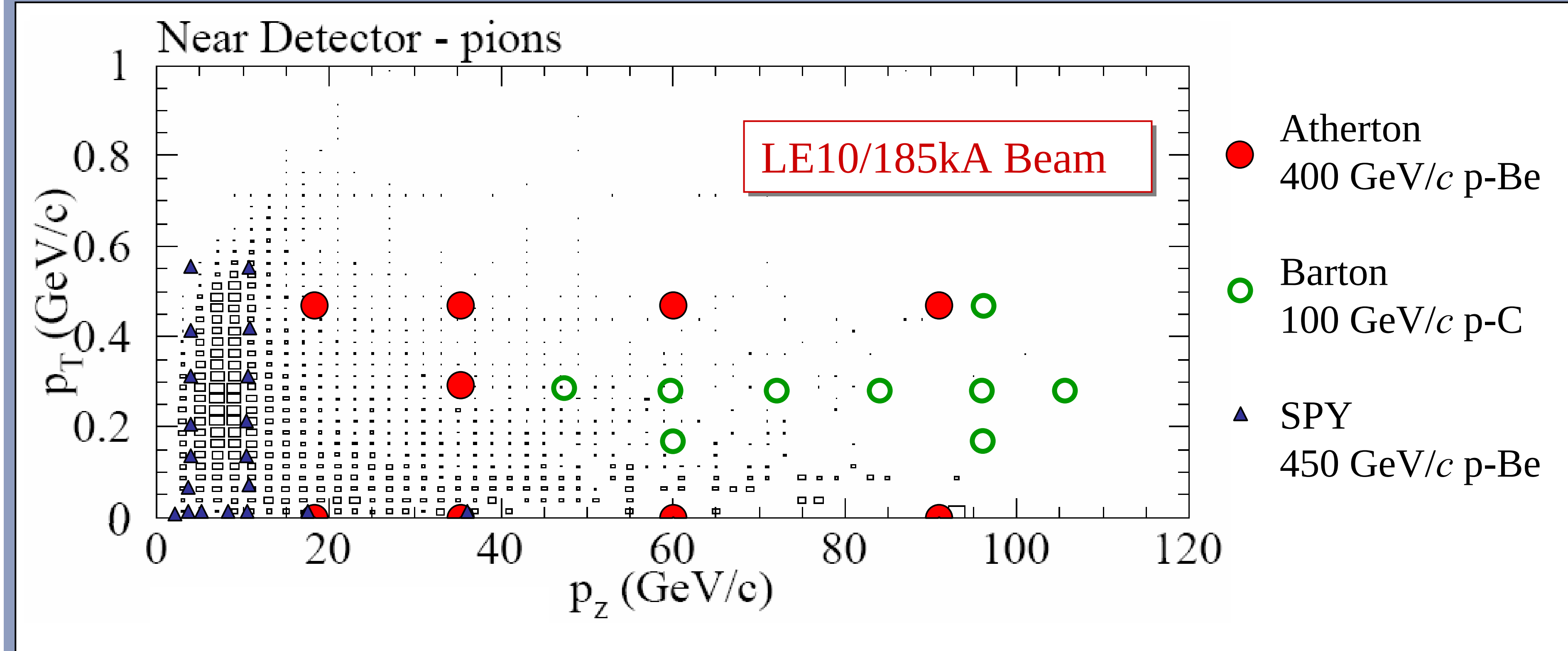
Underlying Hadron Production

- Different beams access regions of π's (x_F,p_T) off the target.
- Models disagree on these distributions
- Use variable beam configurations to map this out.





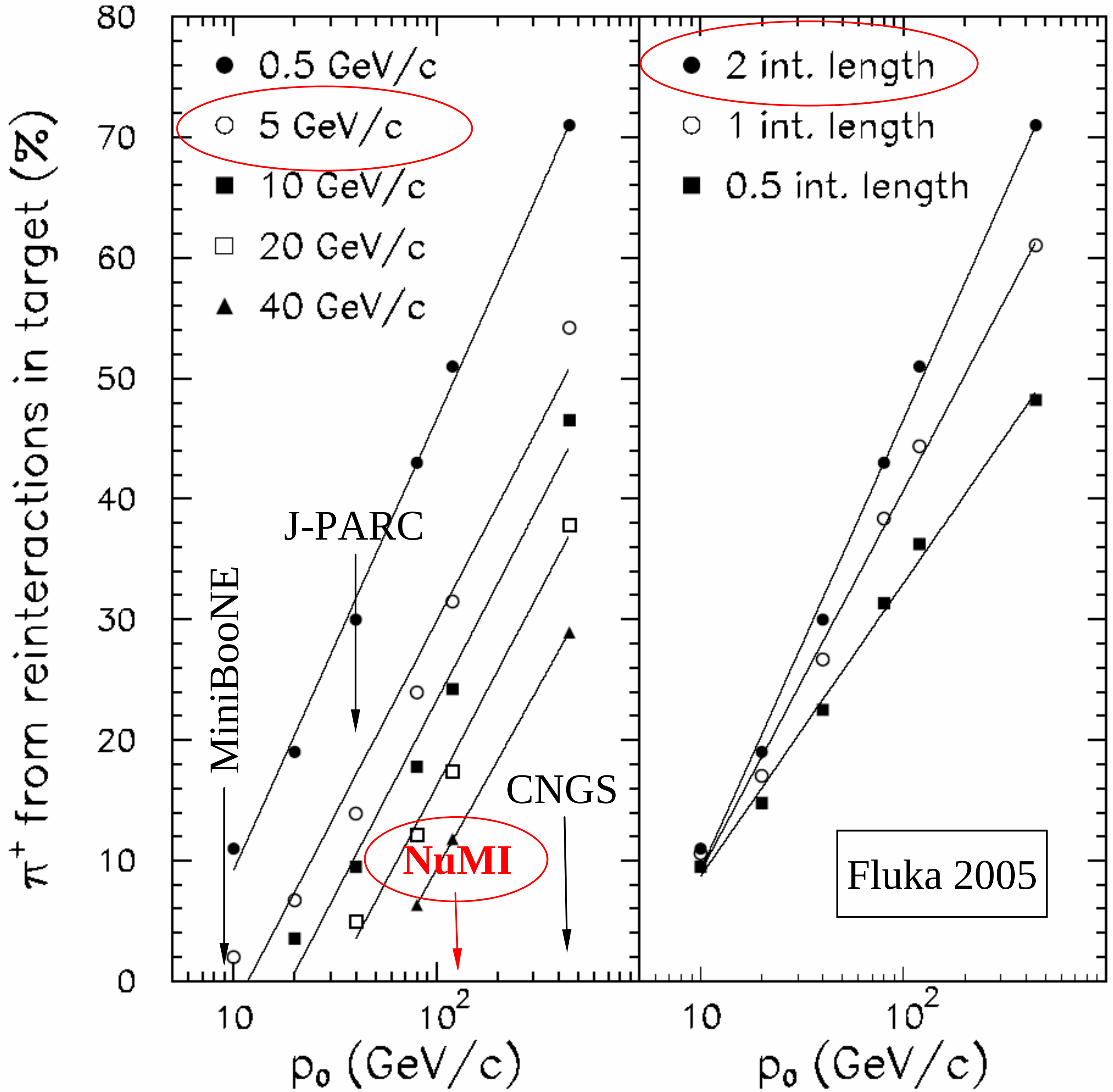
Data Upon Which Models are Based



- Available input data is sparse for “high energy” protons
- Now there is extensive data available from NA49 (not true at time of NuMI/MINOS analysis), eventually also FNAL/E907.

Thick-Target Effects

- Hadron production data largely from 'thin' targets.
- Particles are created from reinteractions in NuMI target.
- Approx 30% of yield at NuMI p_0=120 GeV/c



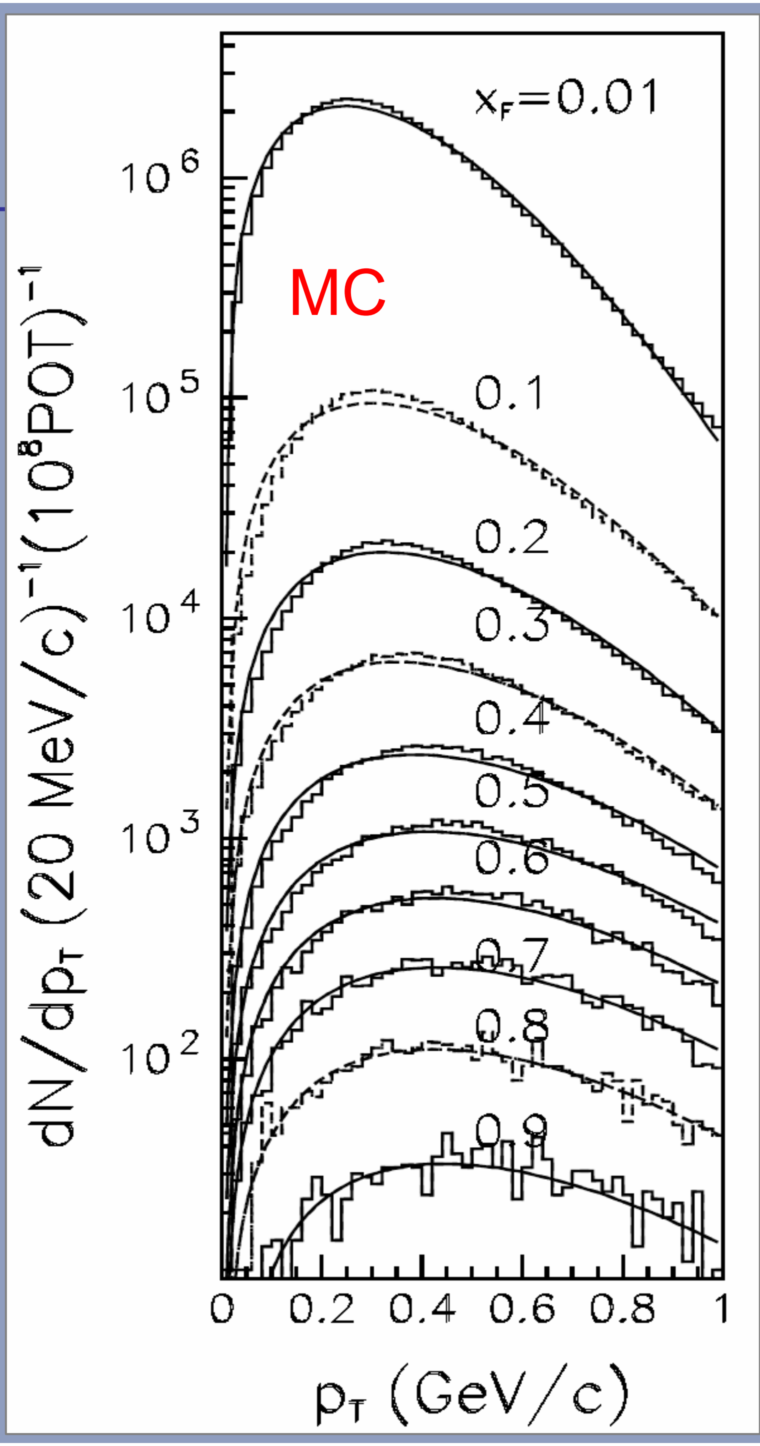
Parameterizing Hadron Production

- Used empirical form *similar* to BMPT to parameterize Fluka2005:

$$\frac{d^2N}{dx_F dp_T} = \{A(x_F) + [B(x_F) p_T]\} e^{-C(x_F) p_T^{3/2}}$$

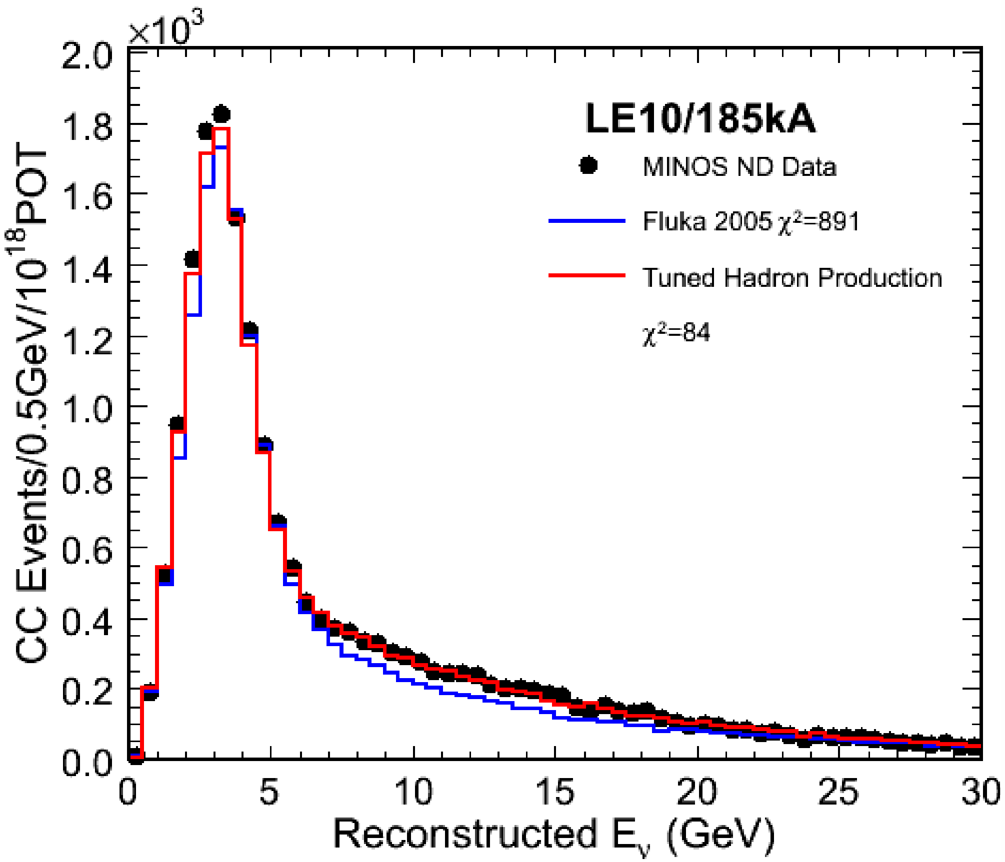
$$\begin{aligned} A(x_F) &= a_1 * (1. - x_F)^{a_2} * (1. + a_3 * x_F) * x_F^{-a_4} \\ B(x_F) &= b_1 * (1. - x_F)^{b_2} * (1. + b_3 * x_F) * x_F^{-b_4} \\ C(x_F) &= c_1 / x_F^{c_2} + c_3 \end{aligned}$$

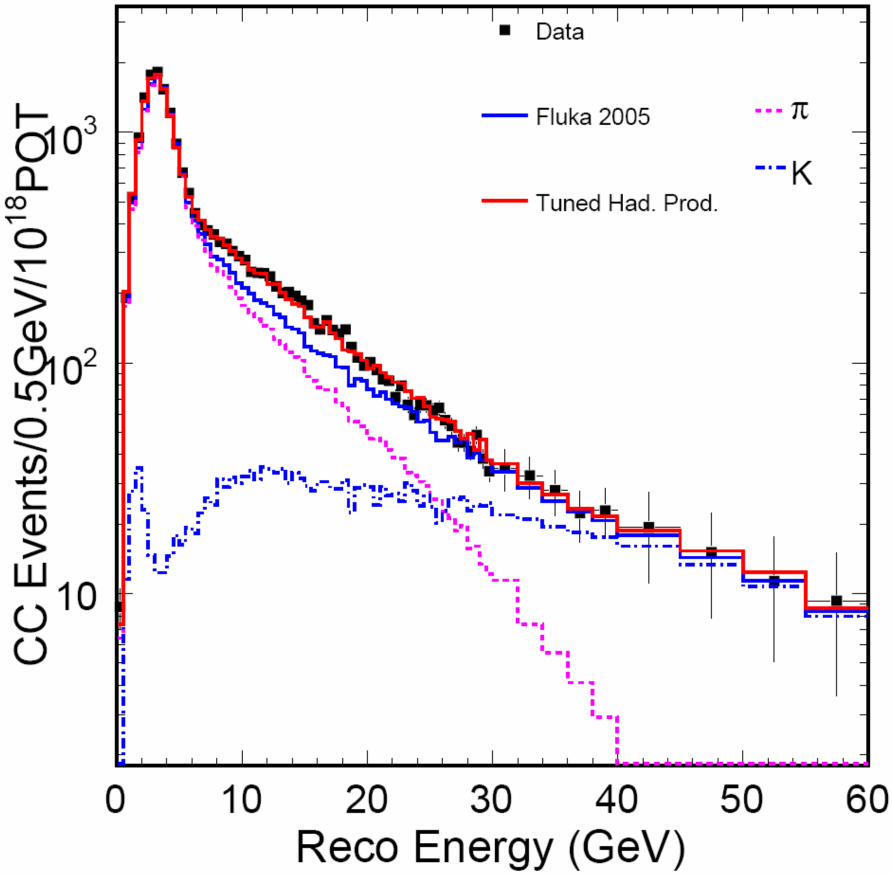
- Fit was to a MC of our thick-target yield estimated by Fluka2005.
- Tune parameters of the fit to match ND data.



Fitting near detector data

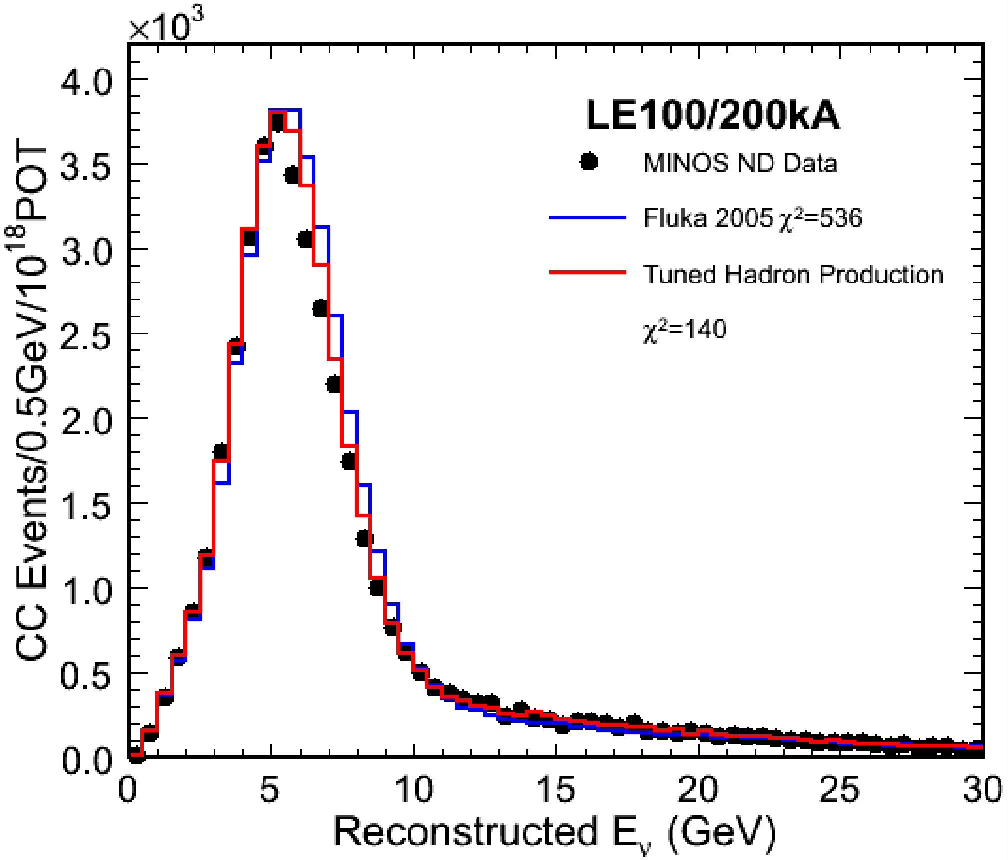
- Target at z = -10 cm
- Horn current = 185kA

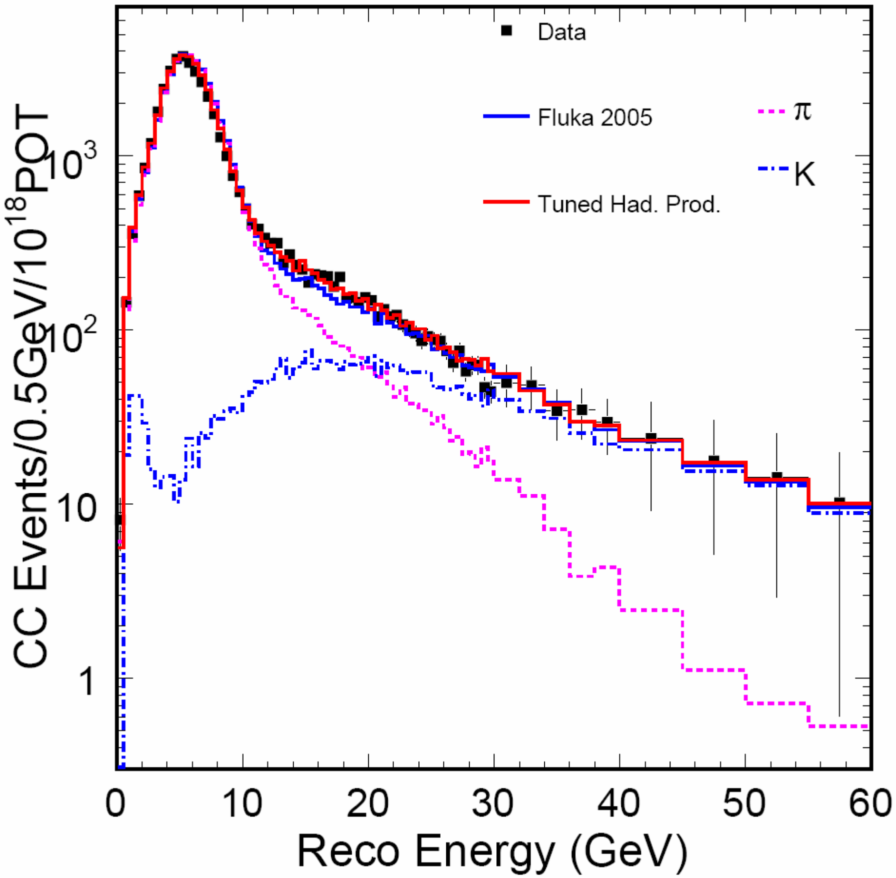




Fitting near detector data

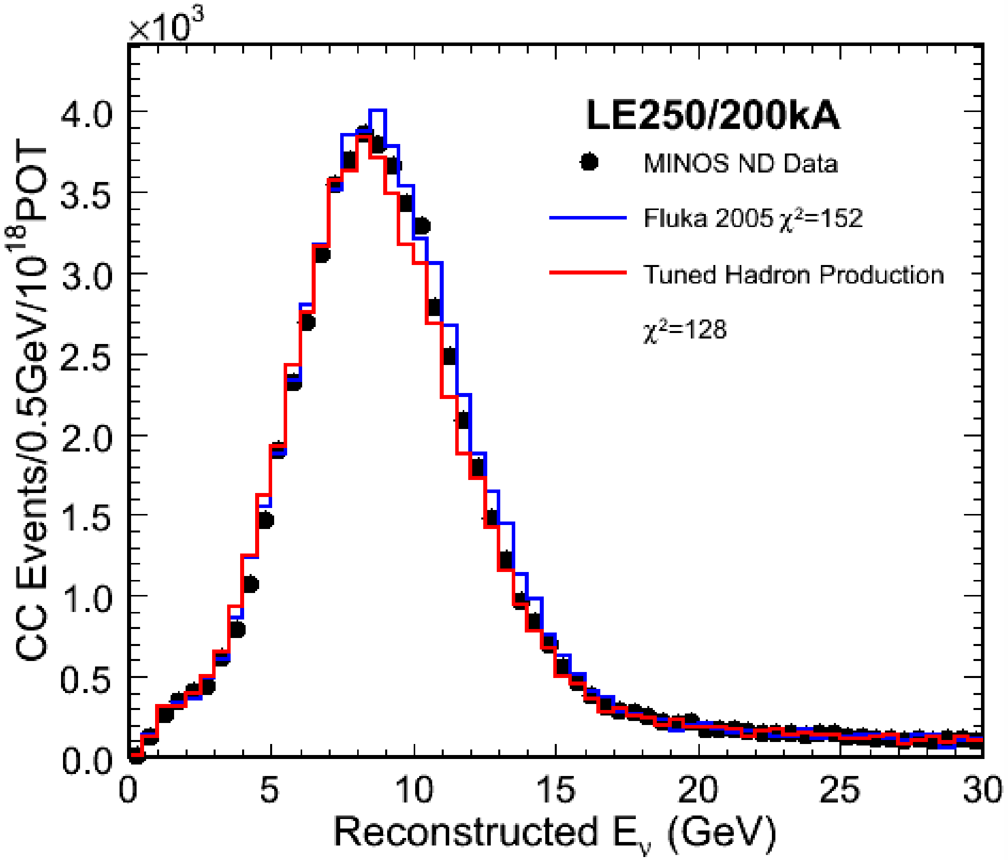
- Target at z = -100 cm
- Horn current = 200kA

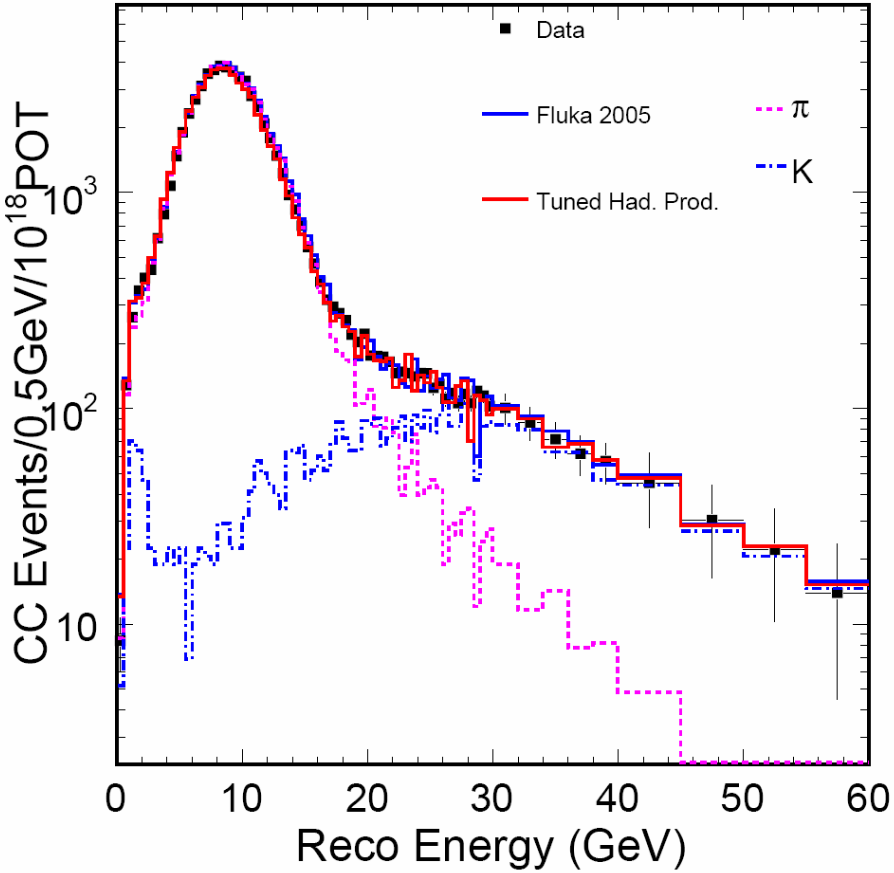




Fitting near detector data

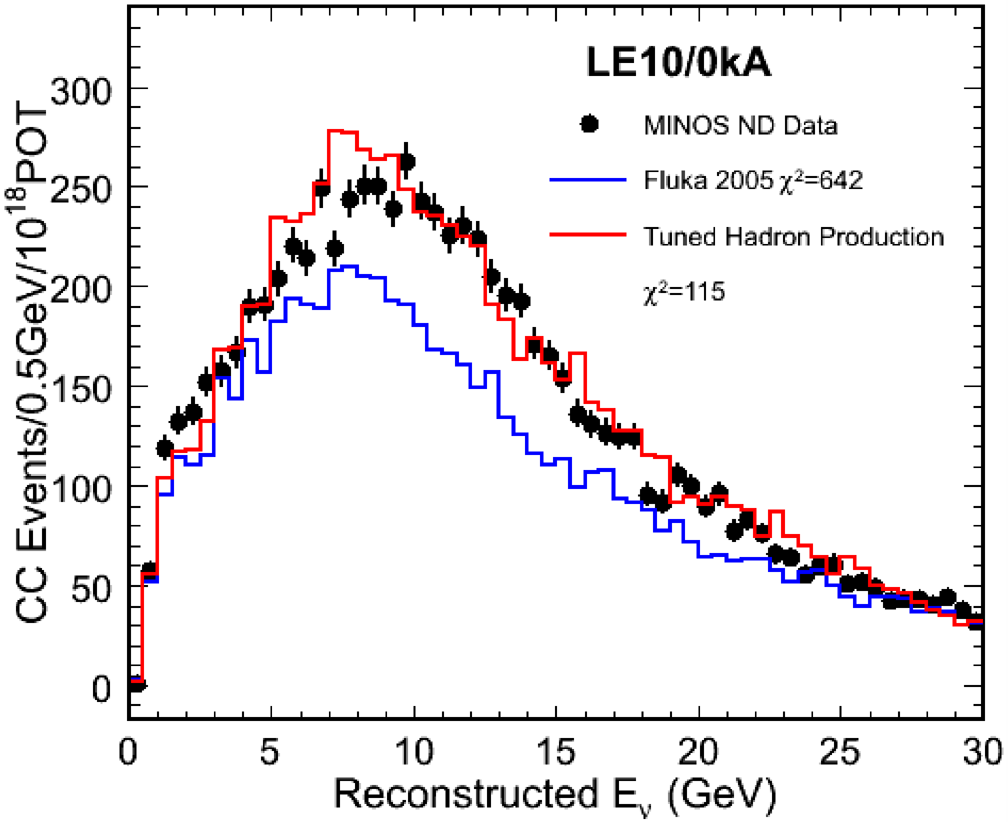
- Target at z = -250 cm
- Horn current = 200kA

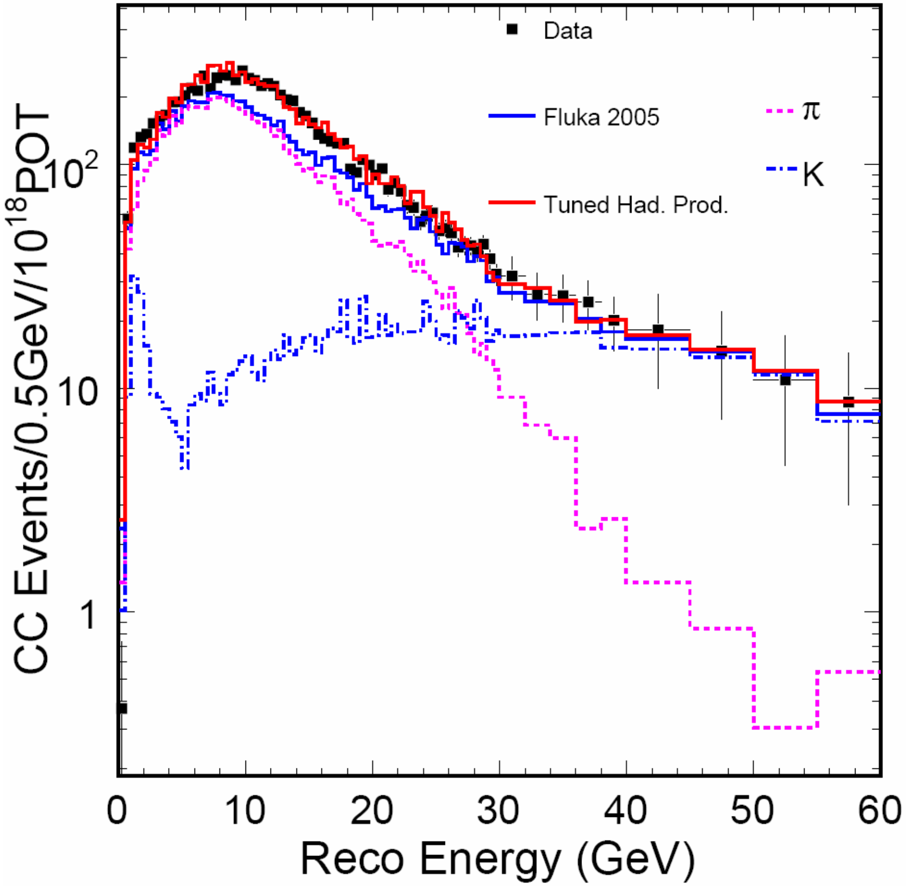




Fitting near detector data

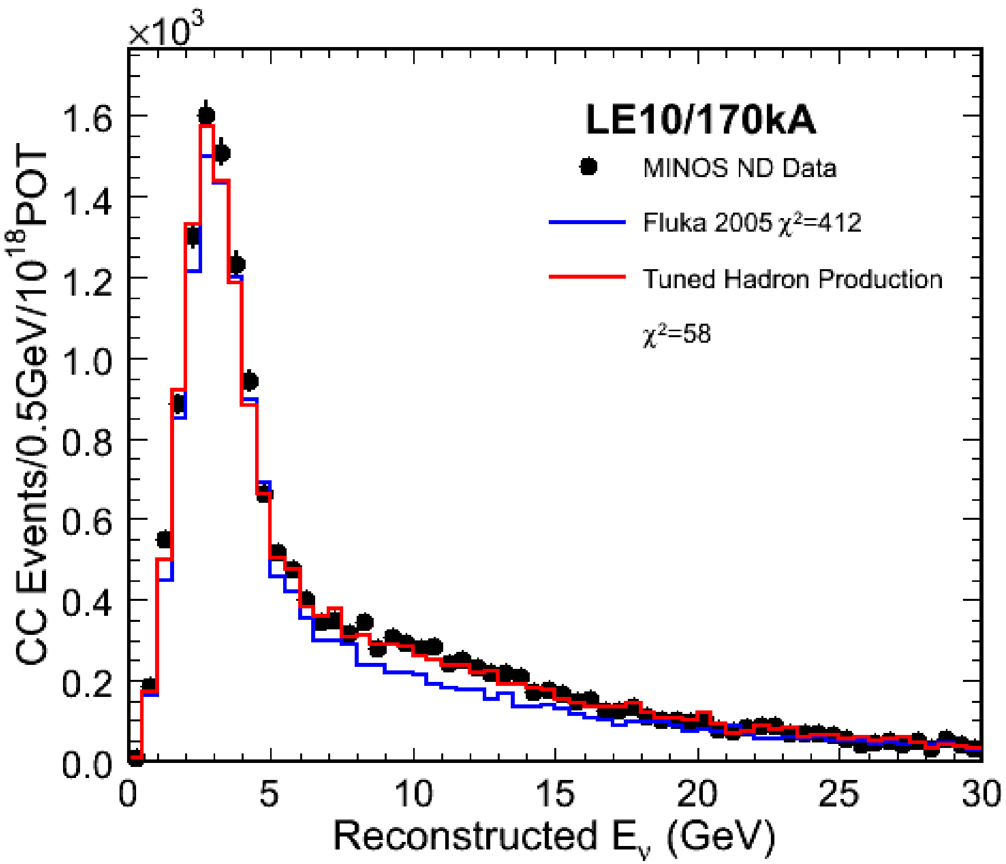
- Target at z = -10 cm
- Horn current = 0kA

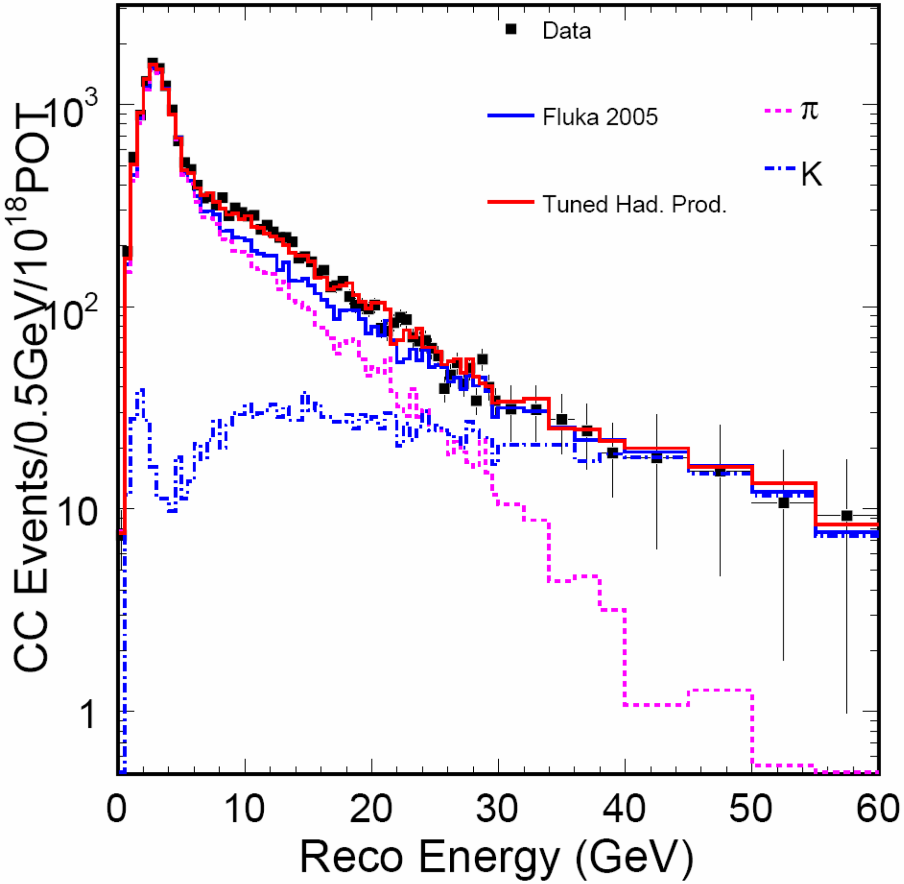




Fitting near detector data

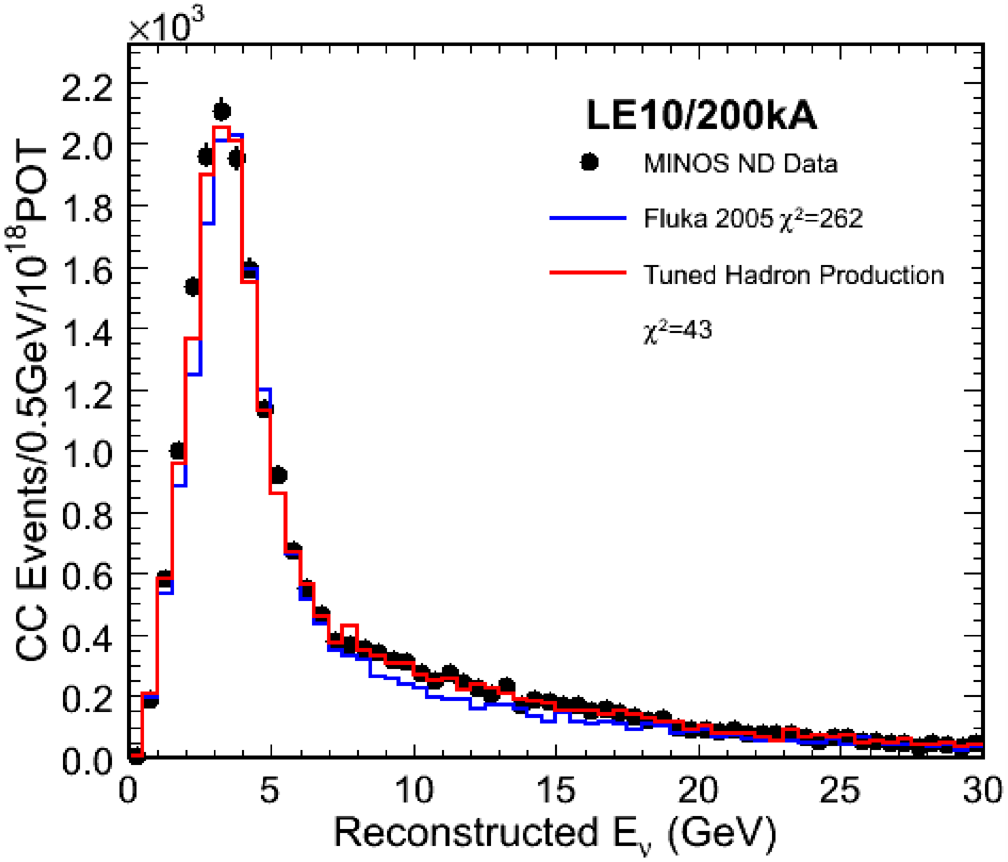
- Target at z = -10 cm
- Horn current = 170kA

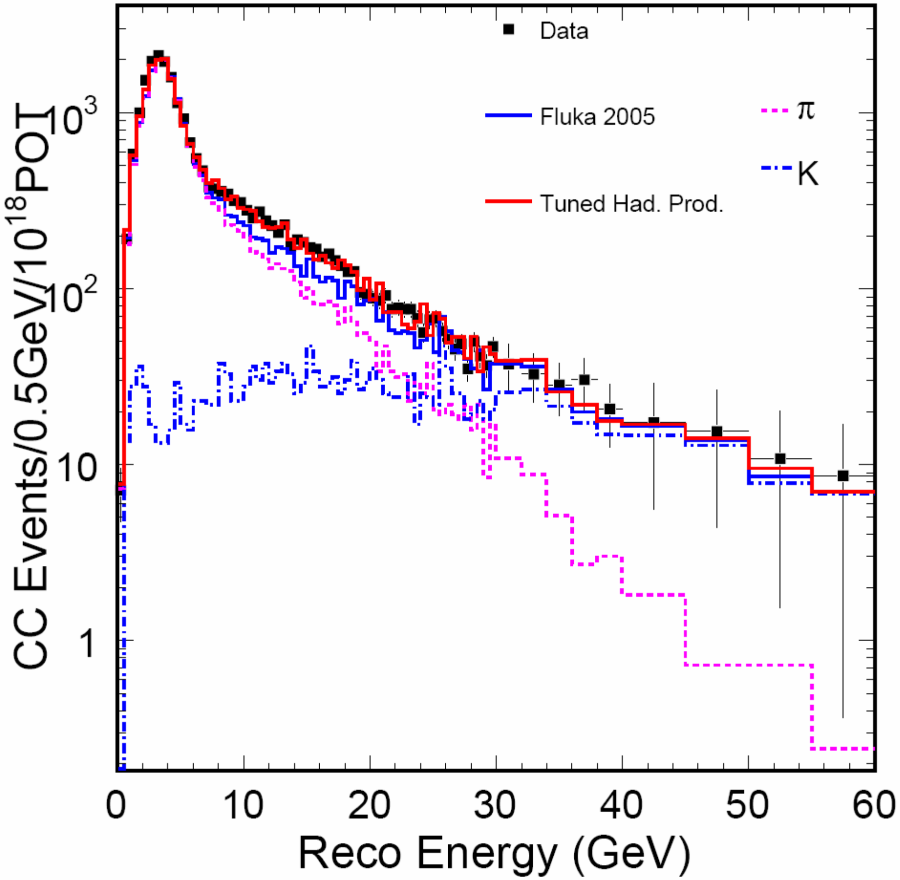




Fitting near detector data

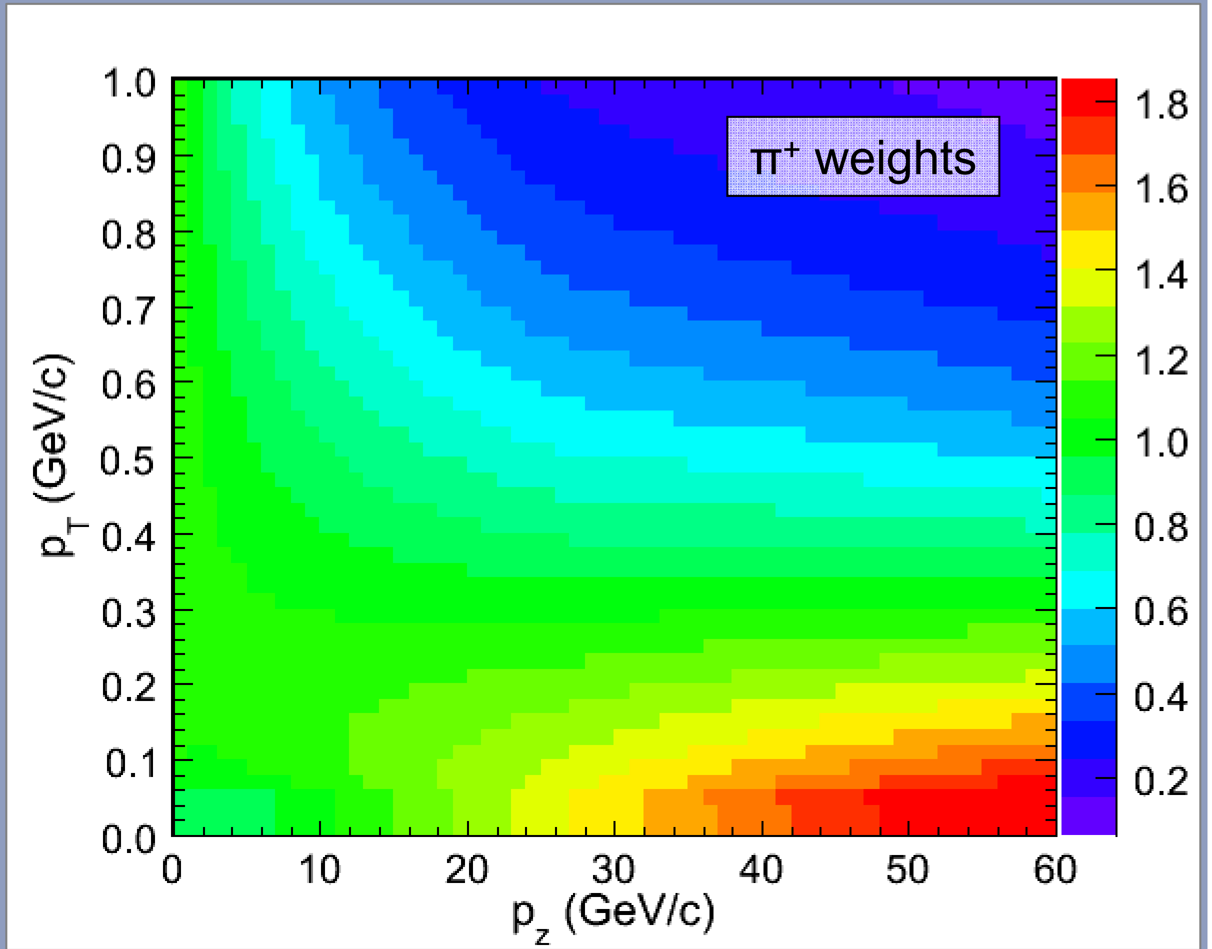
- Target at z = -10 cm
- Horn current = 200kA





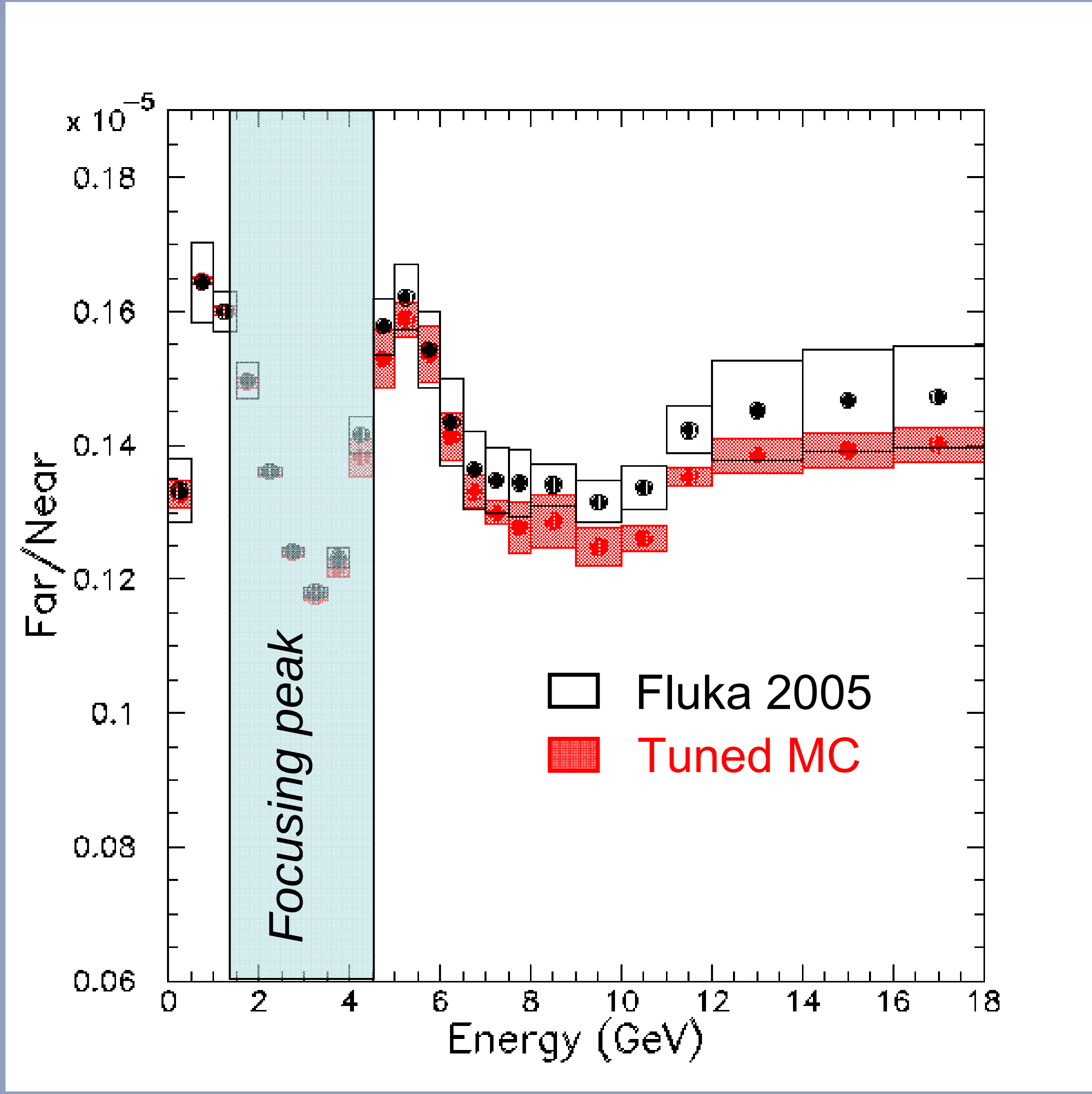
p_T-x_F weights

- Result of the fit is a set of weights in p_T-x_F plane that should be applied to pion/kaon yields
- Data prefers more low p_T pions



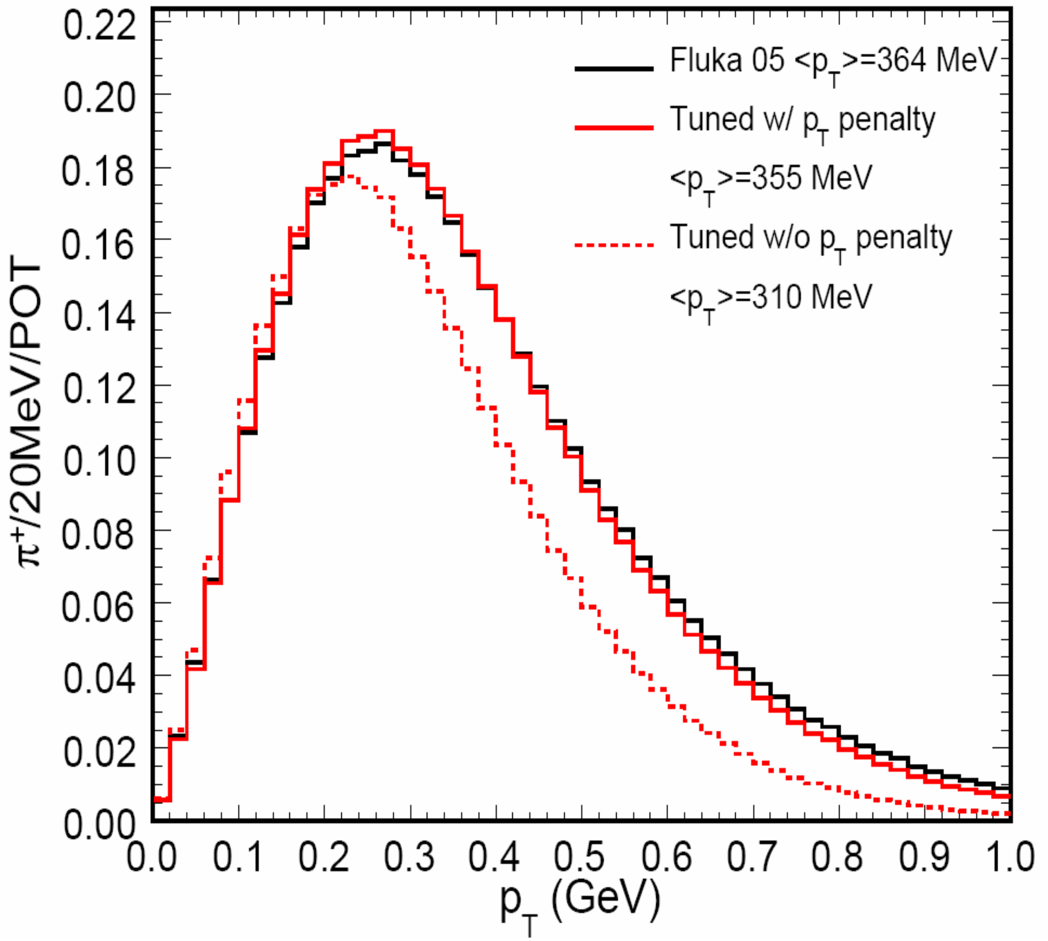
How Stable is this Procedure?

- Systematic error in the peak is small
- Good prediction of far spectrum using near detector data



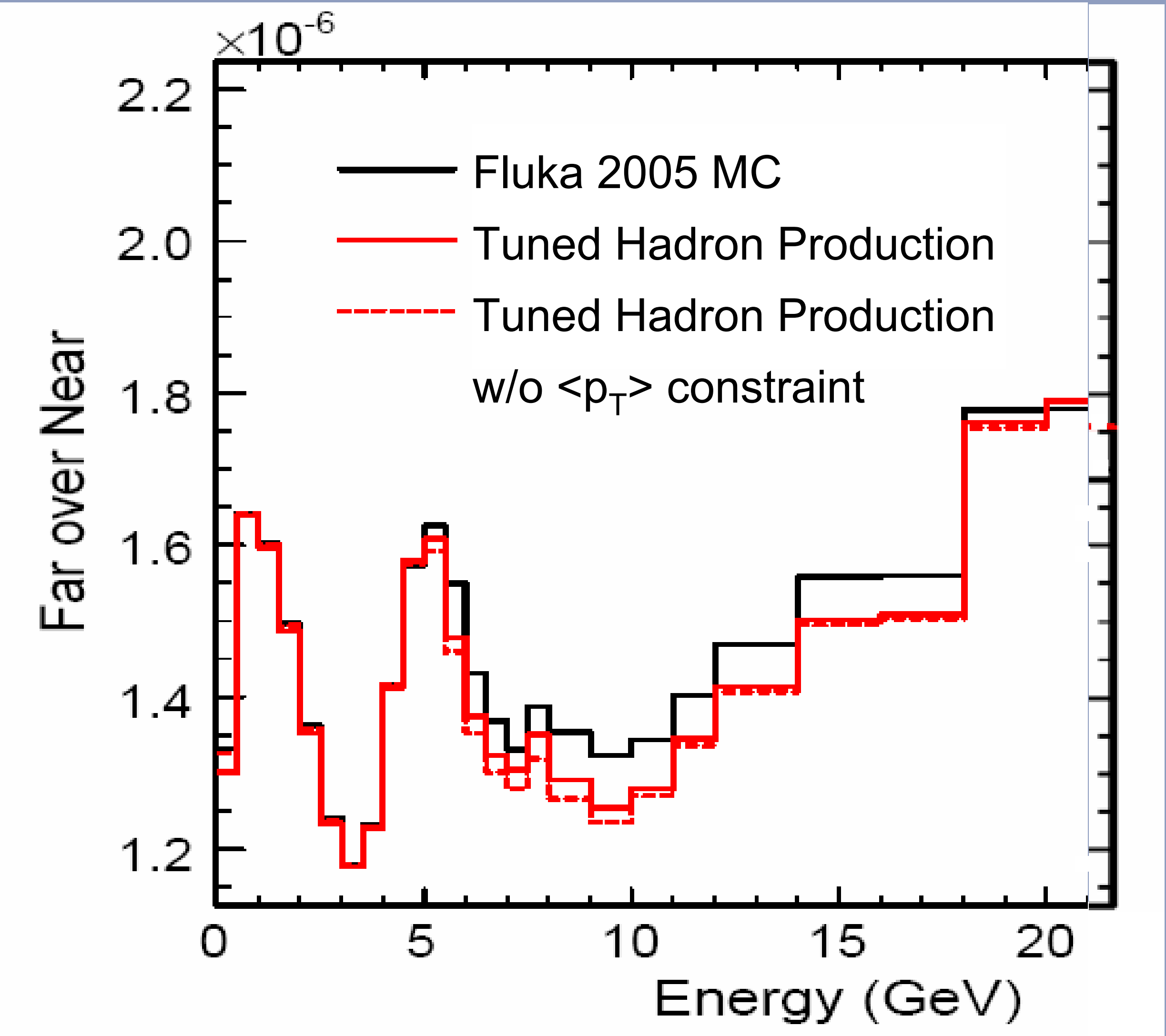
How Stable is this Procedure?

- Fit data with:
  a) constraint on $\langle p_T \rangle$
  b) Without constraint on $\langle p_T \rangle$



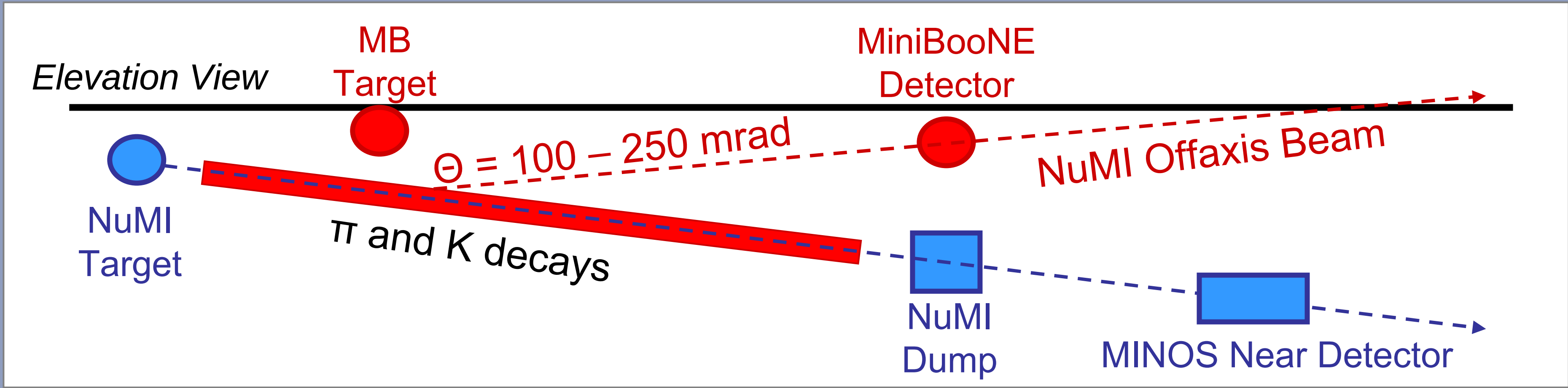
Model	$\langle p_T \rangle$ (GeV/c)
GFluka	0.37
Sanf.-Wang	0.42
CKP	0.44
Malensek	0.5
MARS v.14	0.38
Fluka 2001	0.43
Fluka 2005	0.36
Tuned MC	0.355

How Stable is this Procedure?

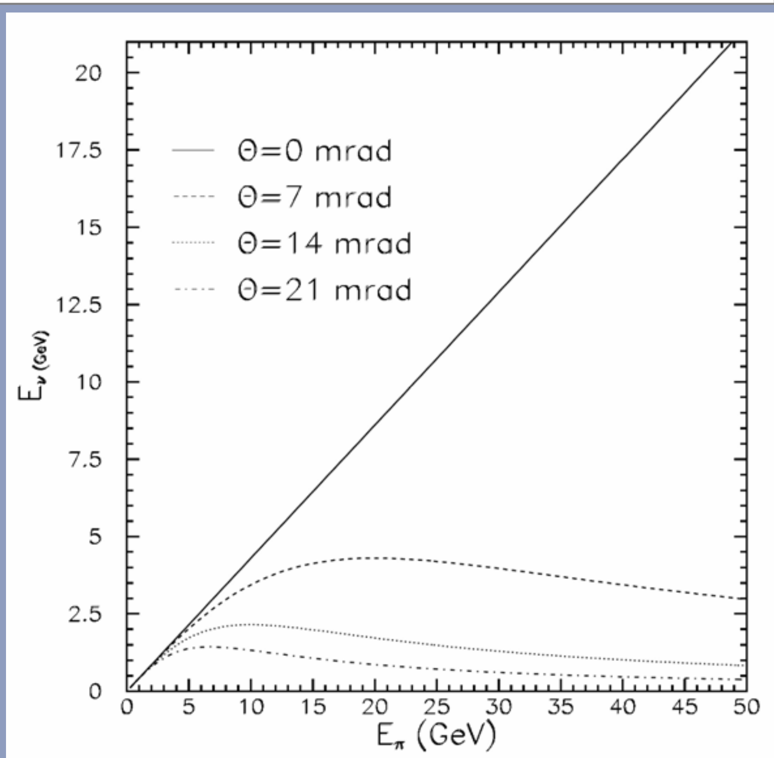


- F/N does not change in focusing peak by this procedure
- Changes in high energy tail ~10%, but stable to 2%

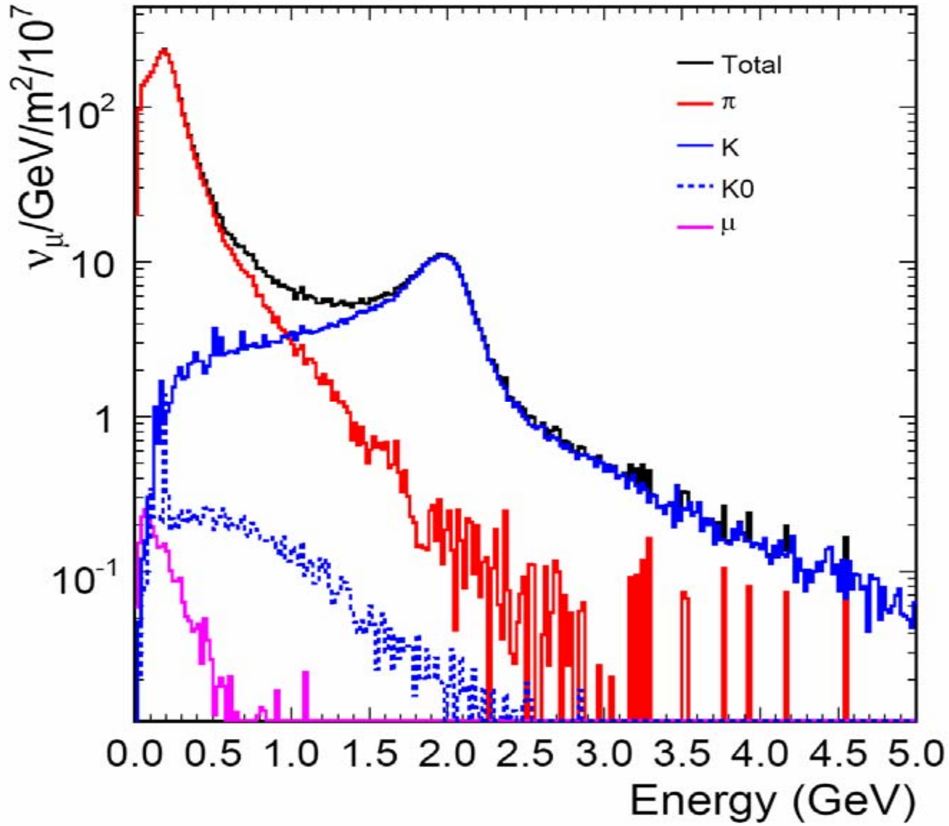
NuMI neutrinos in MiniBooNE



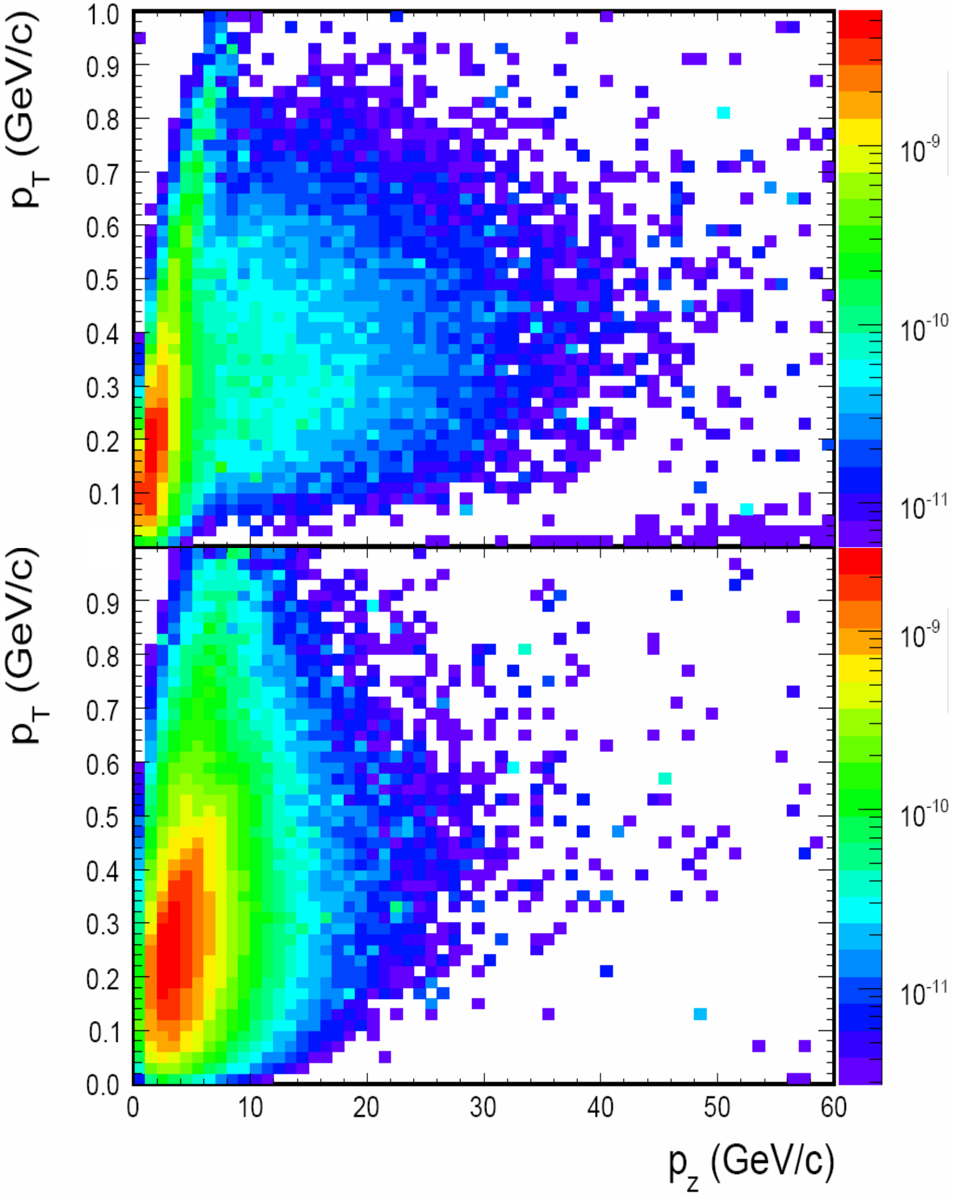
- MINOS Near Det. is not the only detector to see NuMI neutrinos
- MiniBooNE sees NuMI offaxis beam



NuMI neutrinos in MiniBooNE

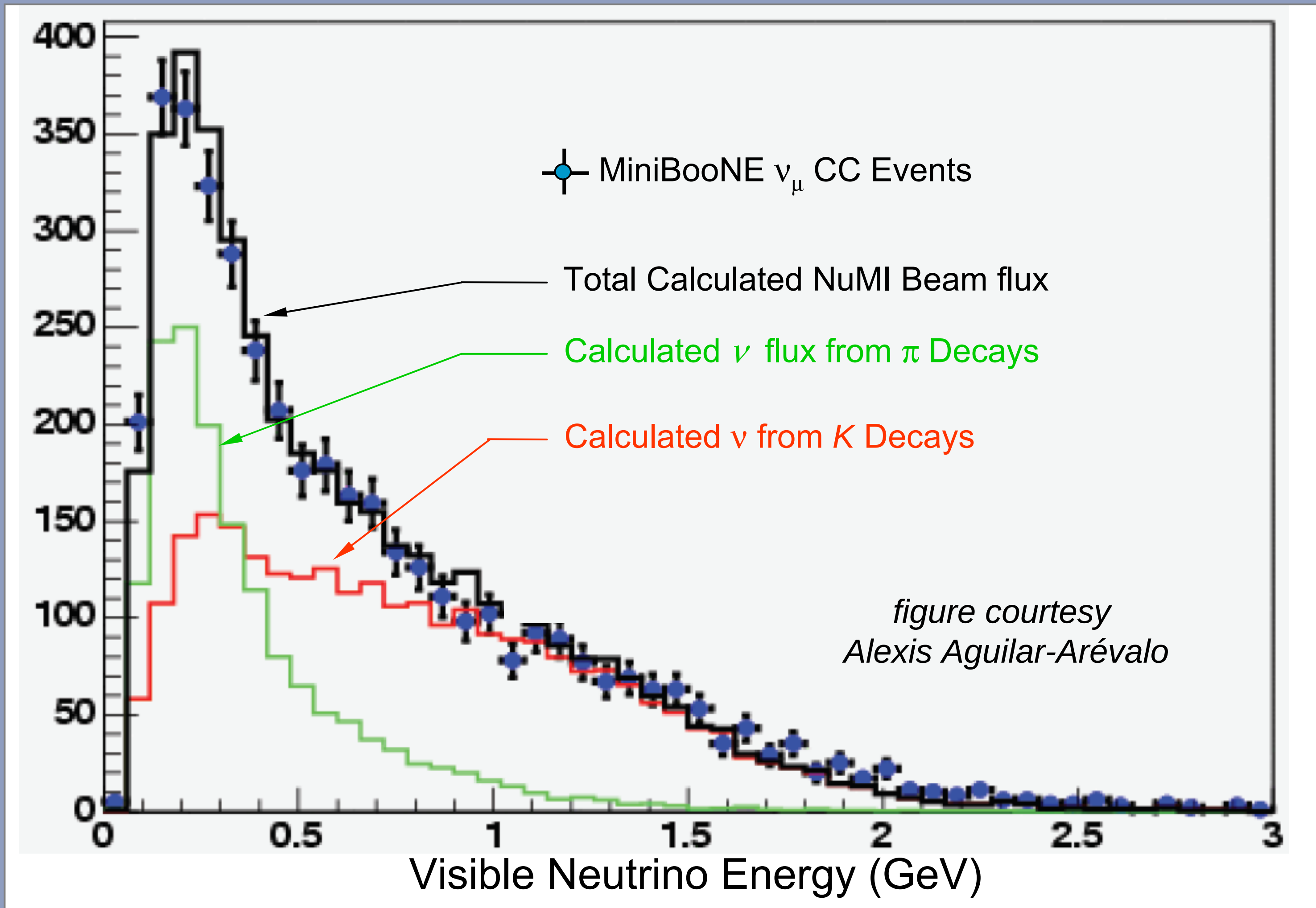


- To excellent approximation, different had. prod. models result in scaling ν_π or ν_K fluxes.
- Other systematic effects found to be negligible at θ=110mrad



NuMI ν @ MiniBooNE

- Kaon peak washed out due to cuts
- Data suggests more kaons

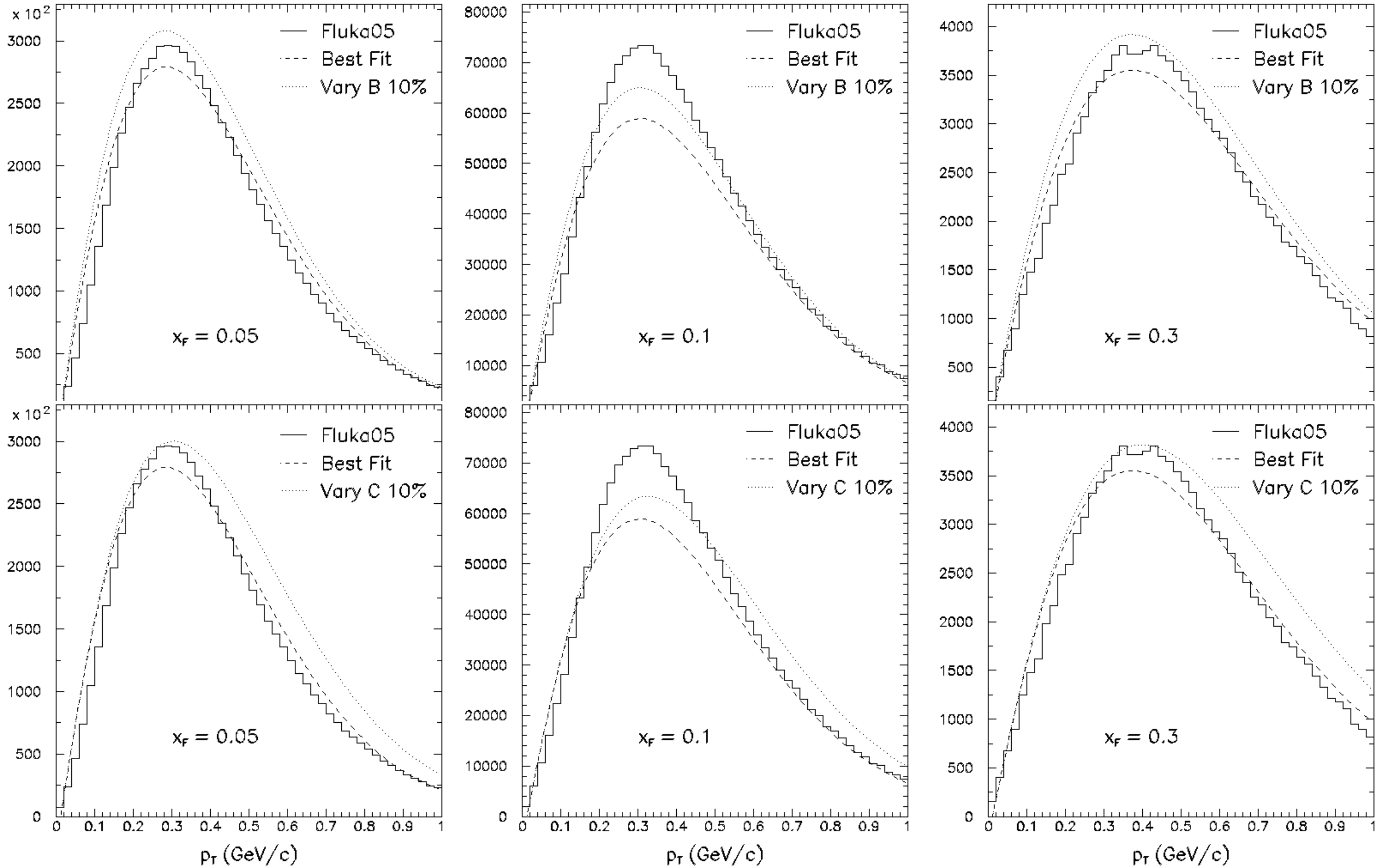


Conclusion

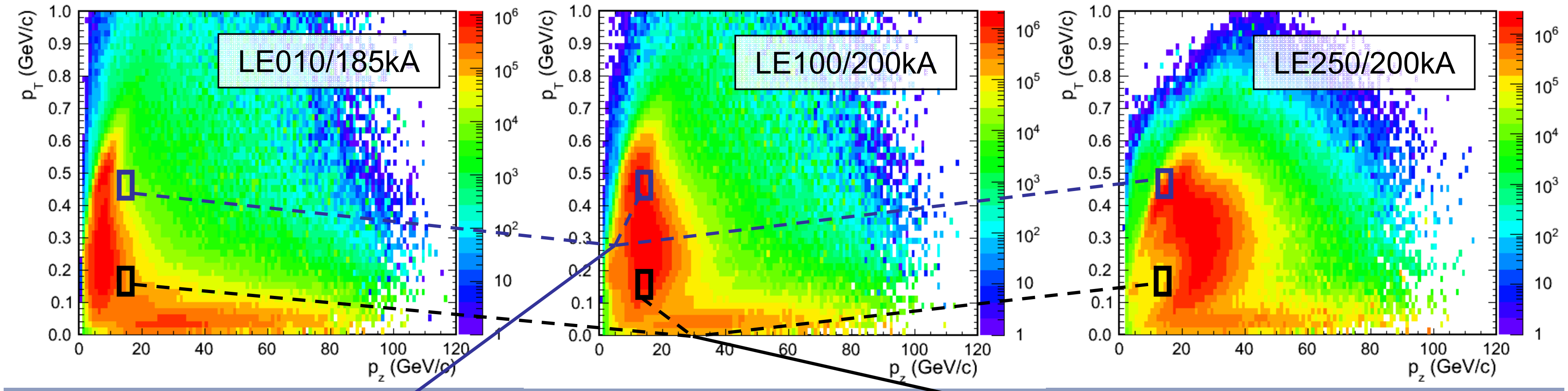
- We evaluated NuMI beam systematics and it's well under control for MINOS experiment
- Dominant source of beam flux uncertainty is hadron production
- Studying MINOS Near detector data taken with different NuMI beam configurations allows better handling of hadron production
- NuMI neutrinos at MiniBooNE can give us more insight into pi/K

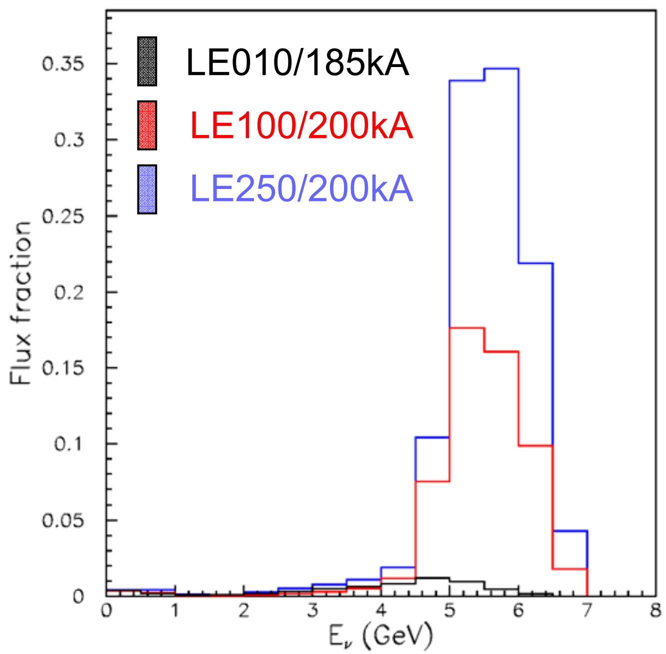
Backup slides

Tweaking Hadron Production

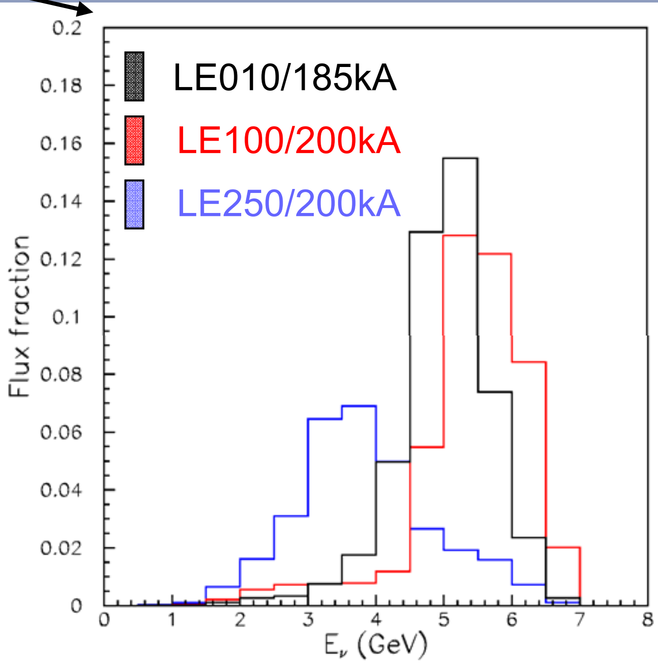


Hadron Production



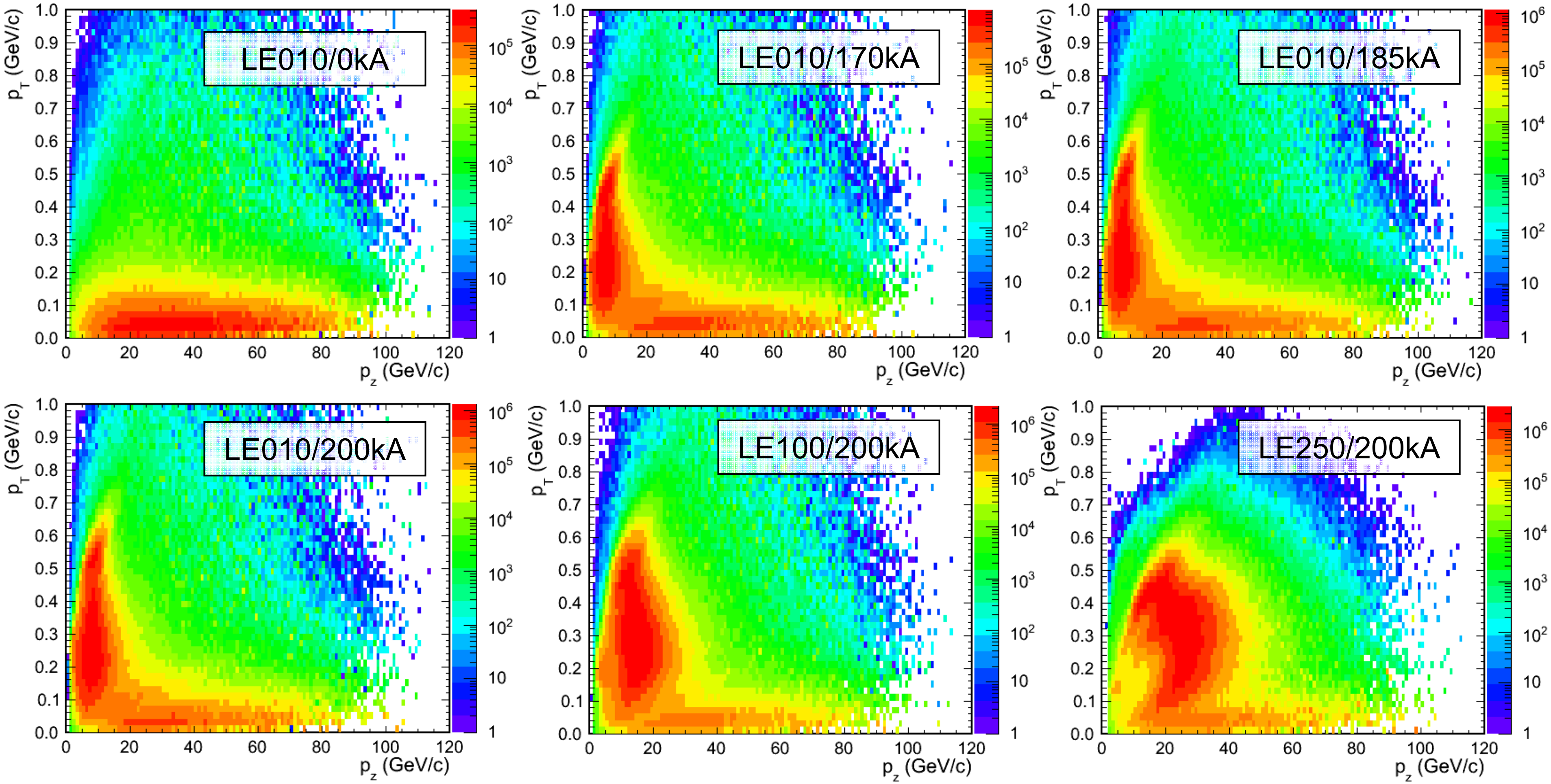


- Same p_T-x_F bin contributes differently to different beams

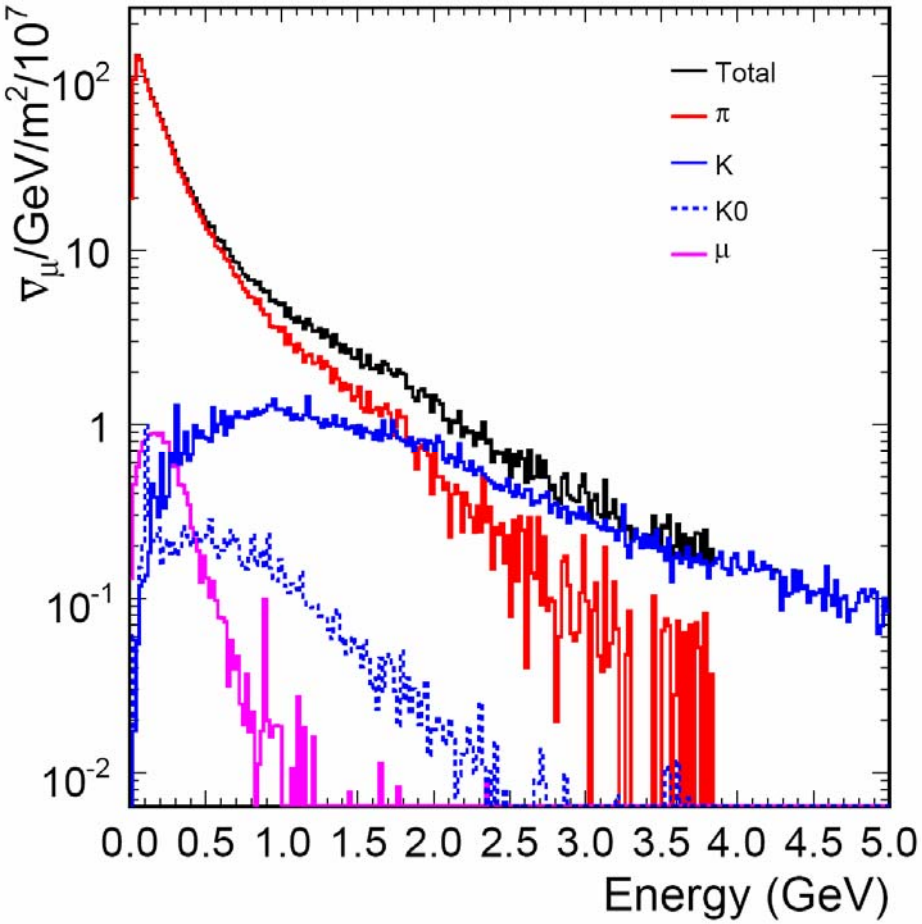


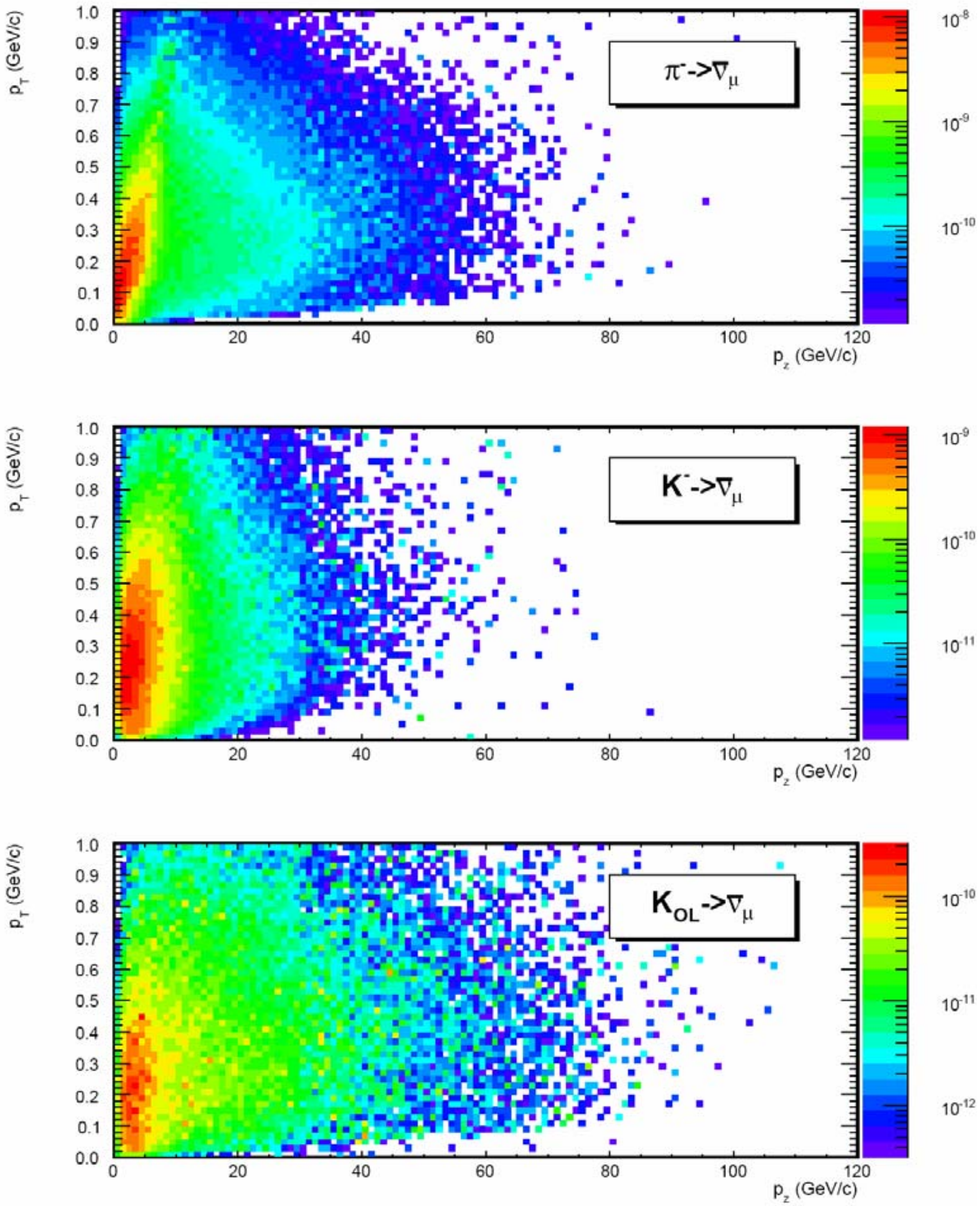
Hadron Production (cont'd)

- Different beams sample different pions



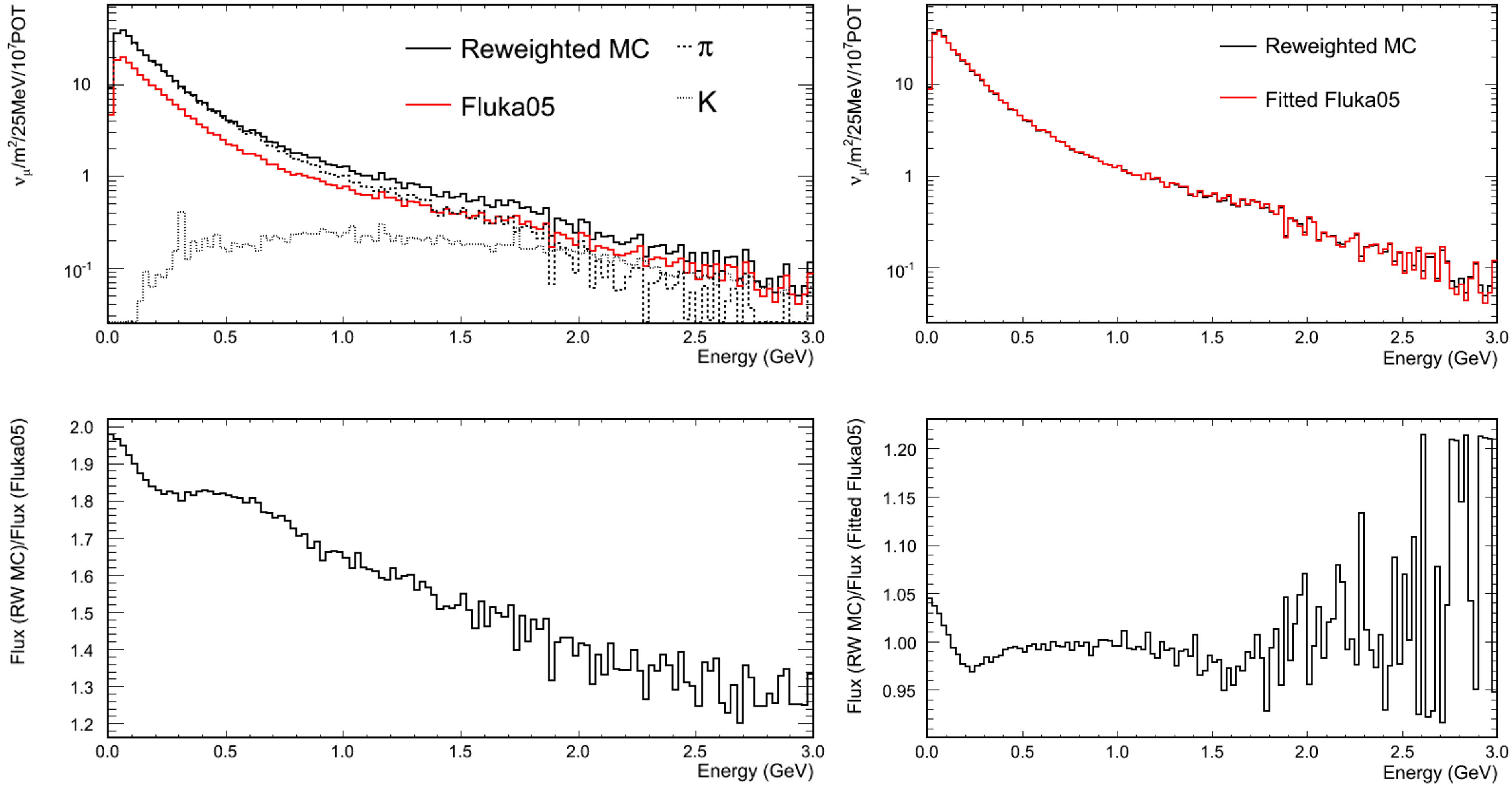
NuMI $\bar{\nu}_\mu$ @MiniBooNE





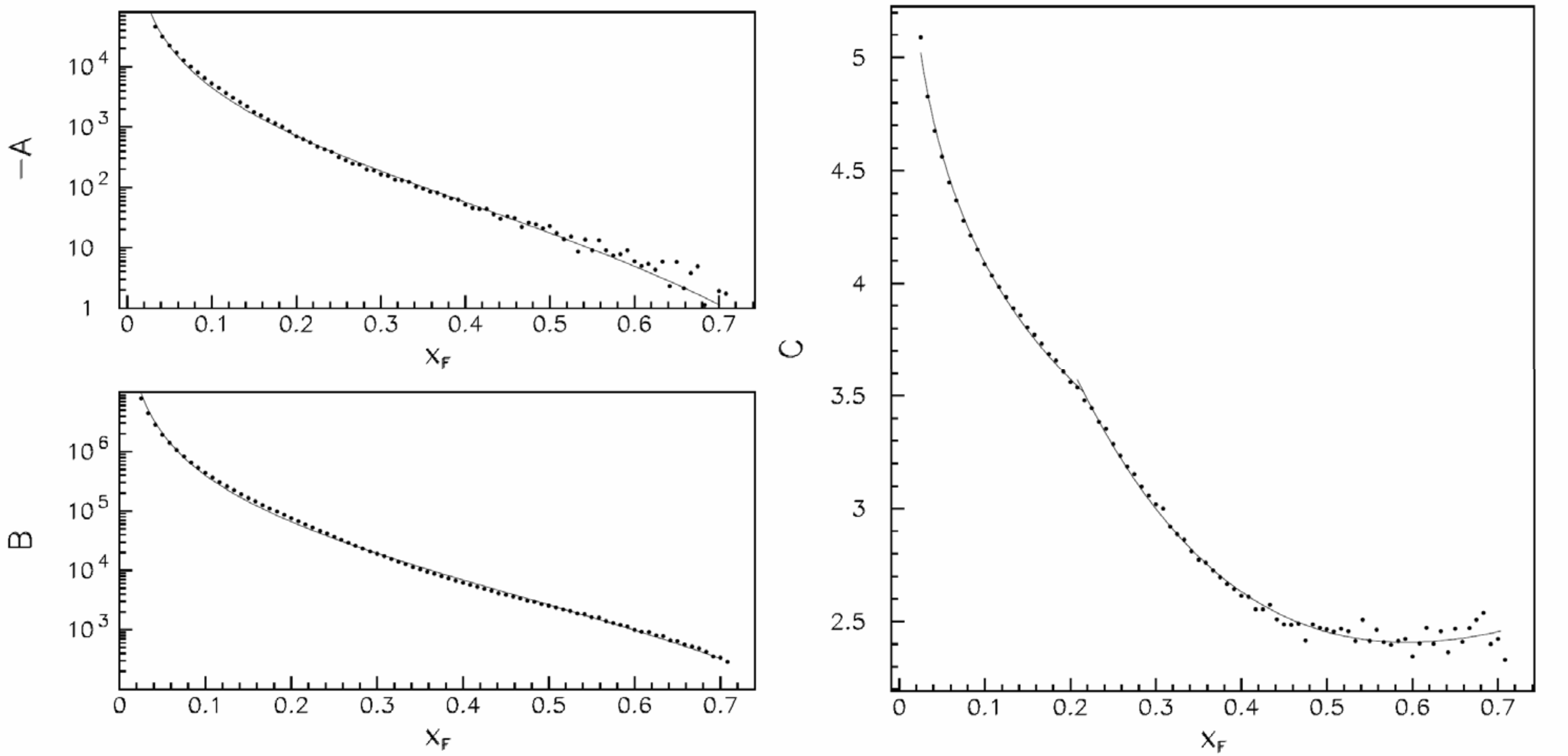
NuMI $\bar{\nu}_\mu$ @MiniBooNE

- $\bar{\nu}_\mu$ also sensitive only to pi/K



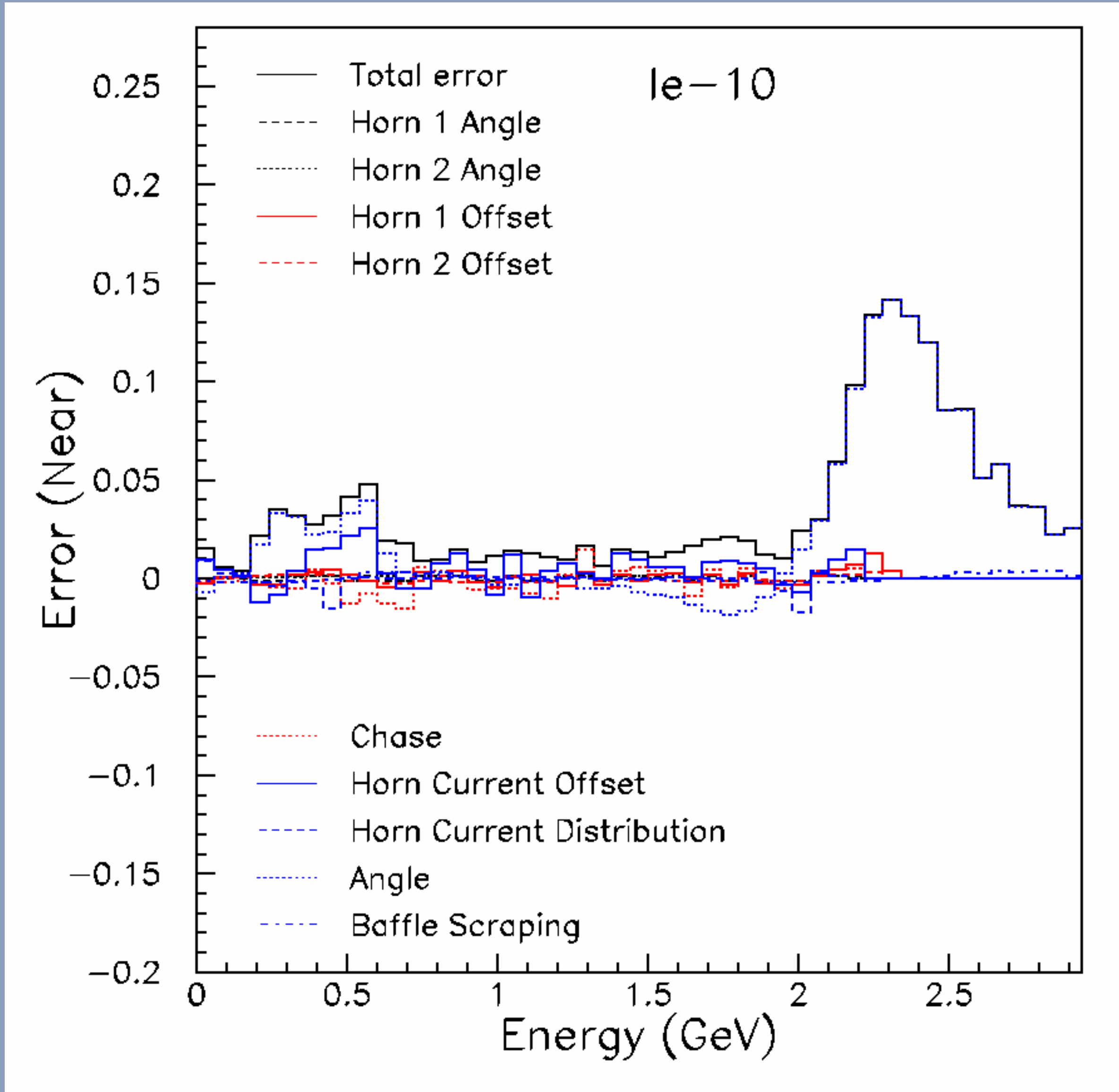
Parameterizing Hadron Production (cont'd)

- Fit parameters A, B and C with functions of x_F

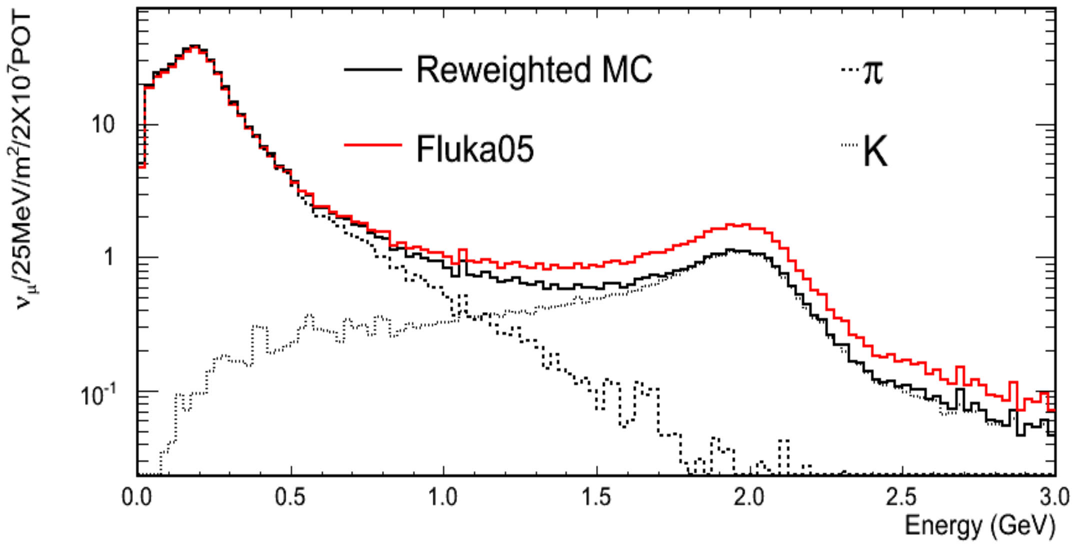


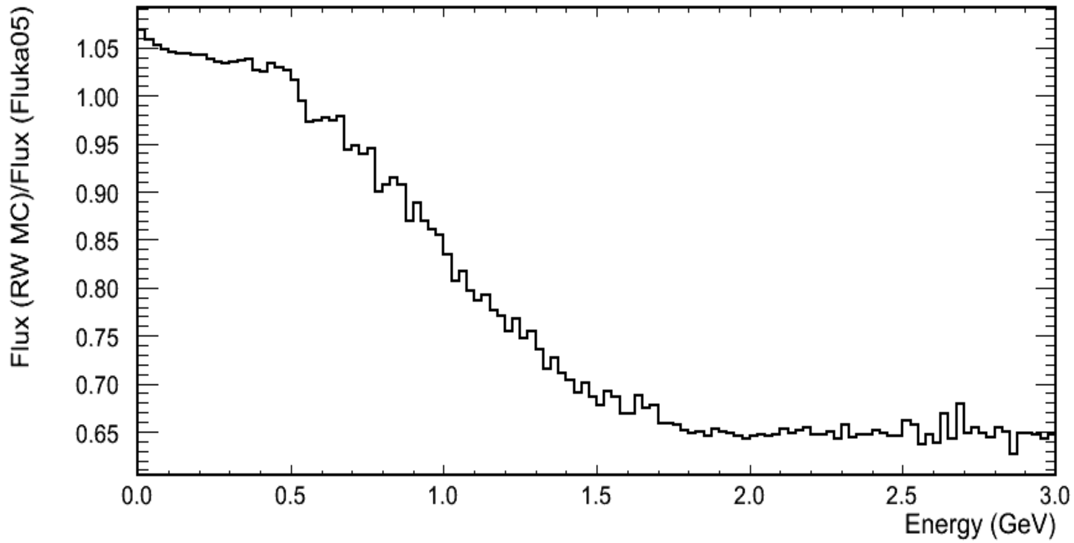
NuMI@MiniBooNE systematics

- Summary of non-hadron production systematics



NuMI neutrinos in MiniBooNE





- Looked at nominal and reweighted MC (different hadron production) and their flux prediction at MiniBooNE