Potential Impact of Future HP Data on the LBNF Flux Uncertainties

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Introduction

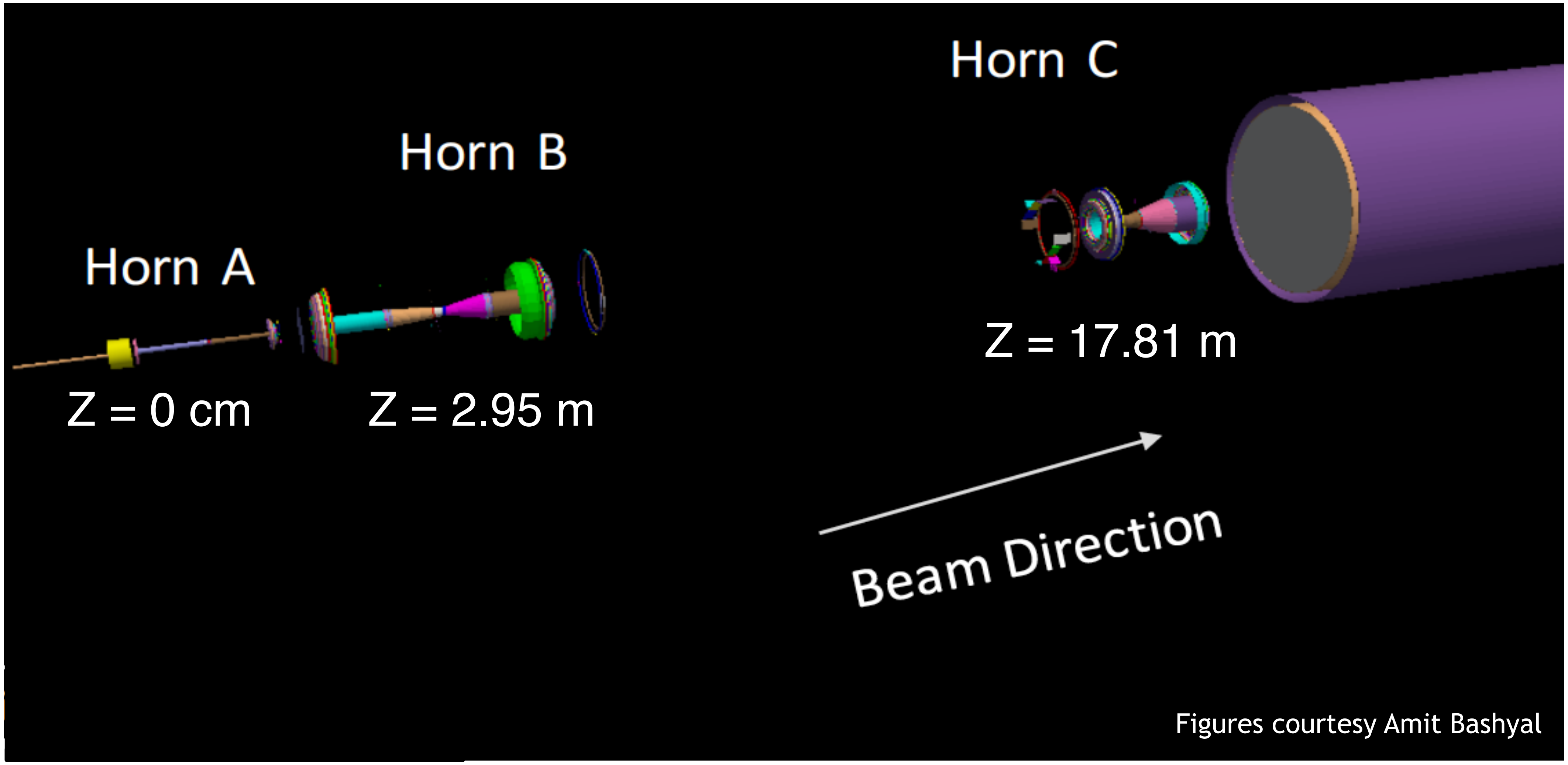
- This is a first look at the potential impact of the upcoming hadron production data (such as EMPHATIC and NA61) on the DUNE flux systematic uncertainties.

- This talk is focused on reducing 3 uncertainties:
  - Kaon incident cross section
  - Proton production from interactions currently covered by data with an especial know for proton quasi-elastics.
  - Meson incident differential cross sections.

- For this work I used a modified version of PPFX to include these assumptions.

LBNF Optimized Beamline

- Primary proton momentum: 80 GeV.
- 2 m long graphite fin target
- Set of 3 aluminum horns, run at 300 kA
- 200 m long decay pipe

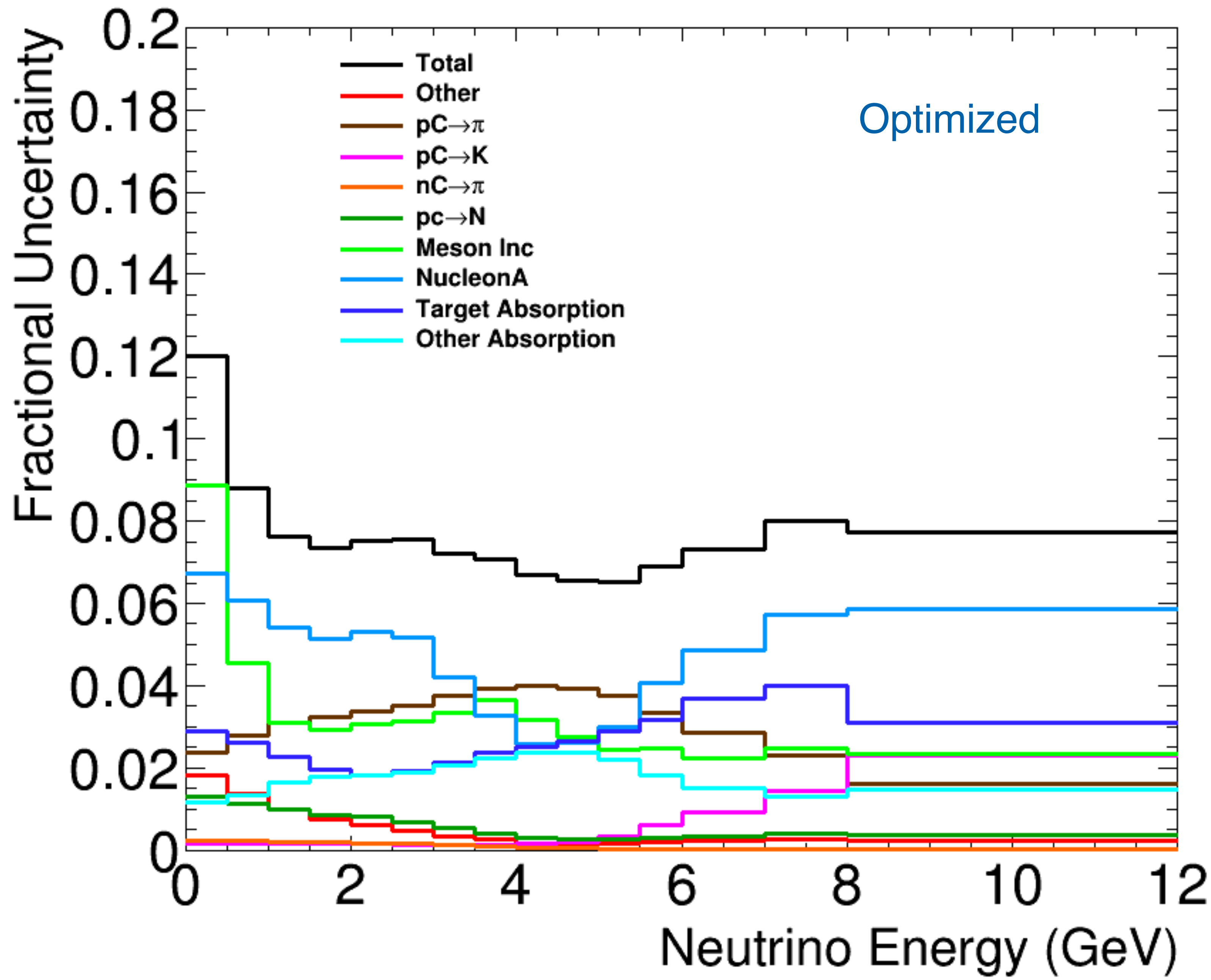


Hadron Production Uncertainties

- Same procedure as MINERvA applied to DUNE beam simulation

- Total HP uncertainty ~7% in the peak and 12% for very low energies.

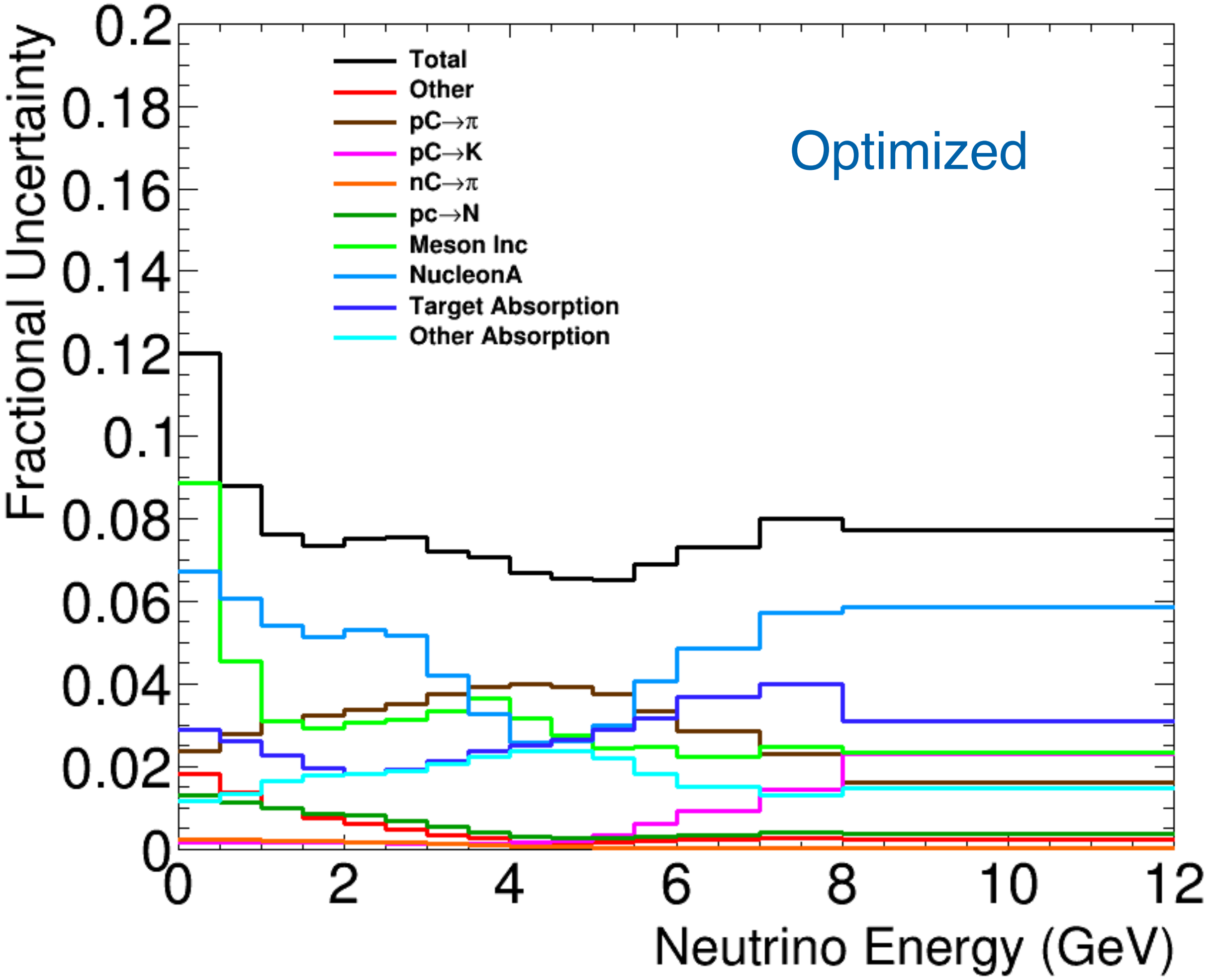
L. Fields (NA61 Workshop 2017)



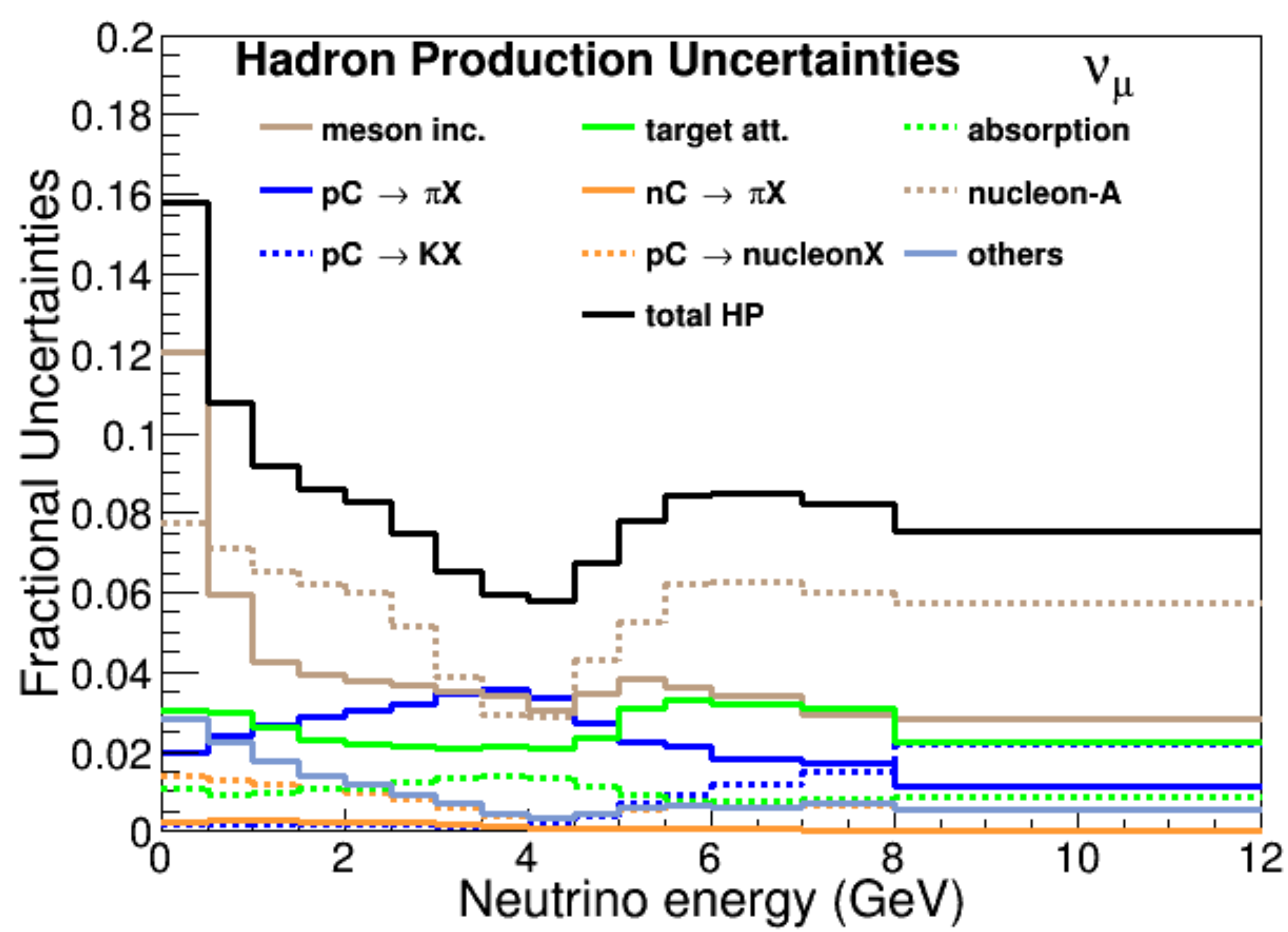
Trying to reproduce the current uncertainties

- I was not able to reproduce the current uncertainties (some discrepancies at low energy and at ~4 GeV).
- The differences are especially for the absorption uncertainties.

L. Fields (NA61 Workshop 2017)



My plot

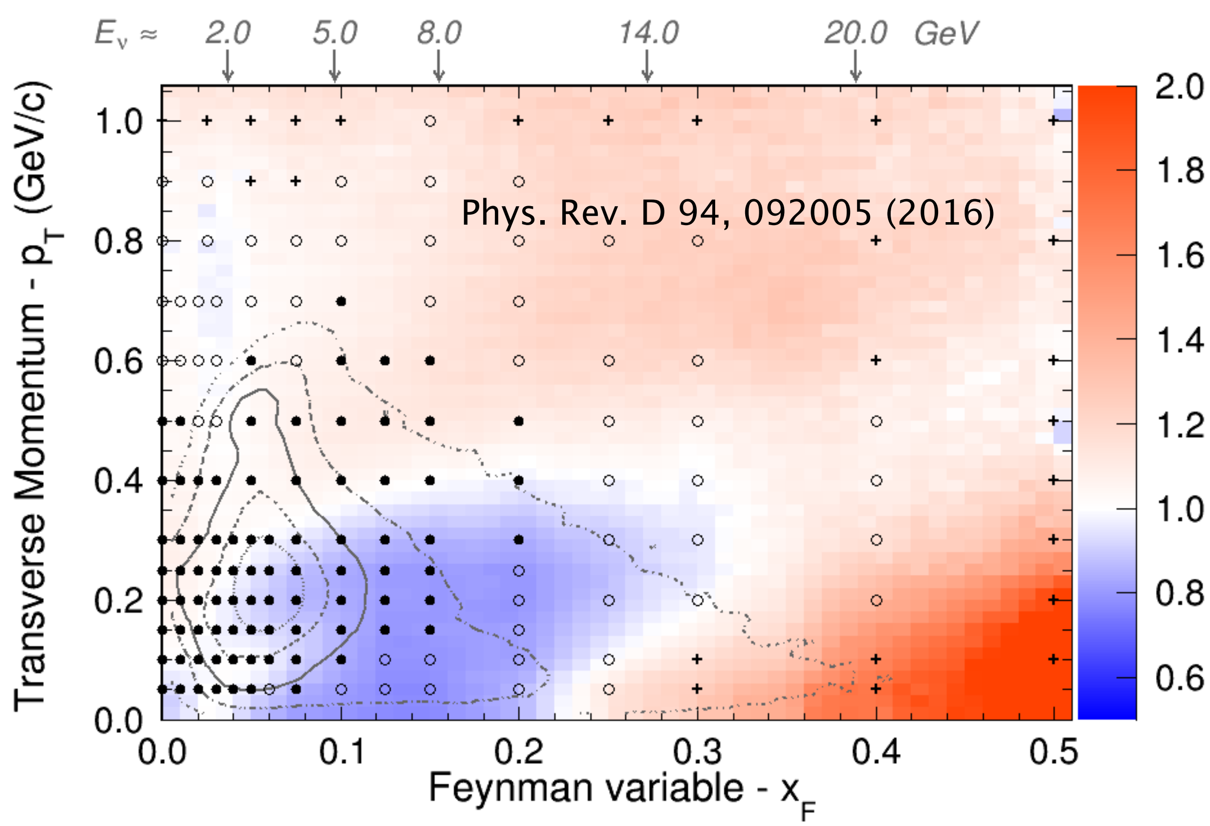


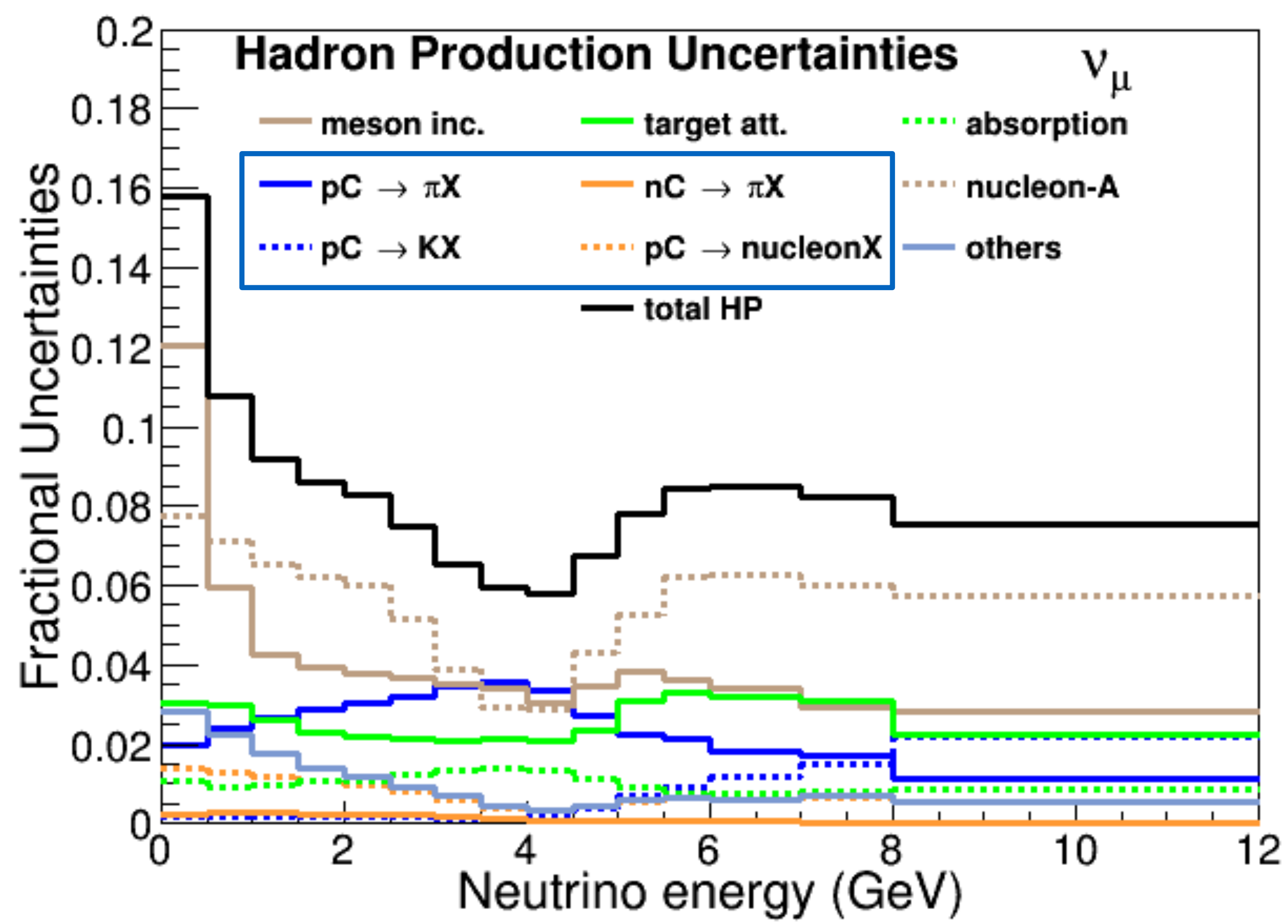
Data for differential cross section correction

- We applied direct data such as NA49, Barton, etc.

$$correction(x_F, p_T, E) = \frac{f_{Data}(x_F, p_T, E = 158GeV) \times scale(x_F, p_T, E)}{f_{MC}(x_F, p_T, E)}$$

- NA49 has small systematics (3.8%) and in general small statistical uncertainties.





(closed circles = statistical error < 2.5%, Open circles = statistical error 2.5-5.0%, Crosses > 5%)

Fermilab

Beam Attenuation correction

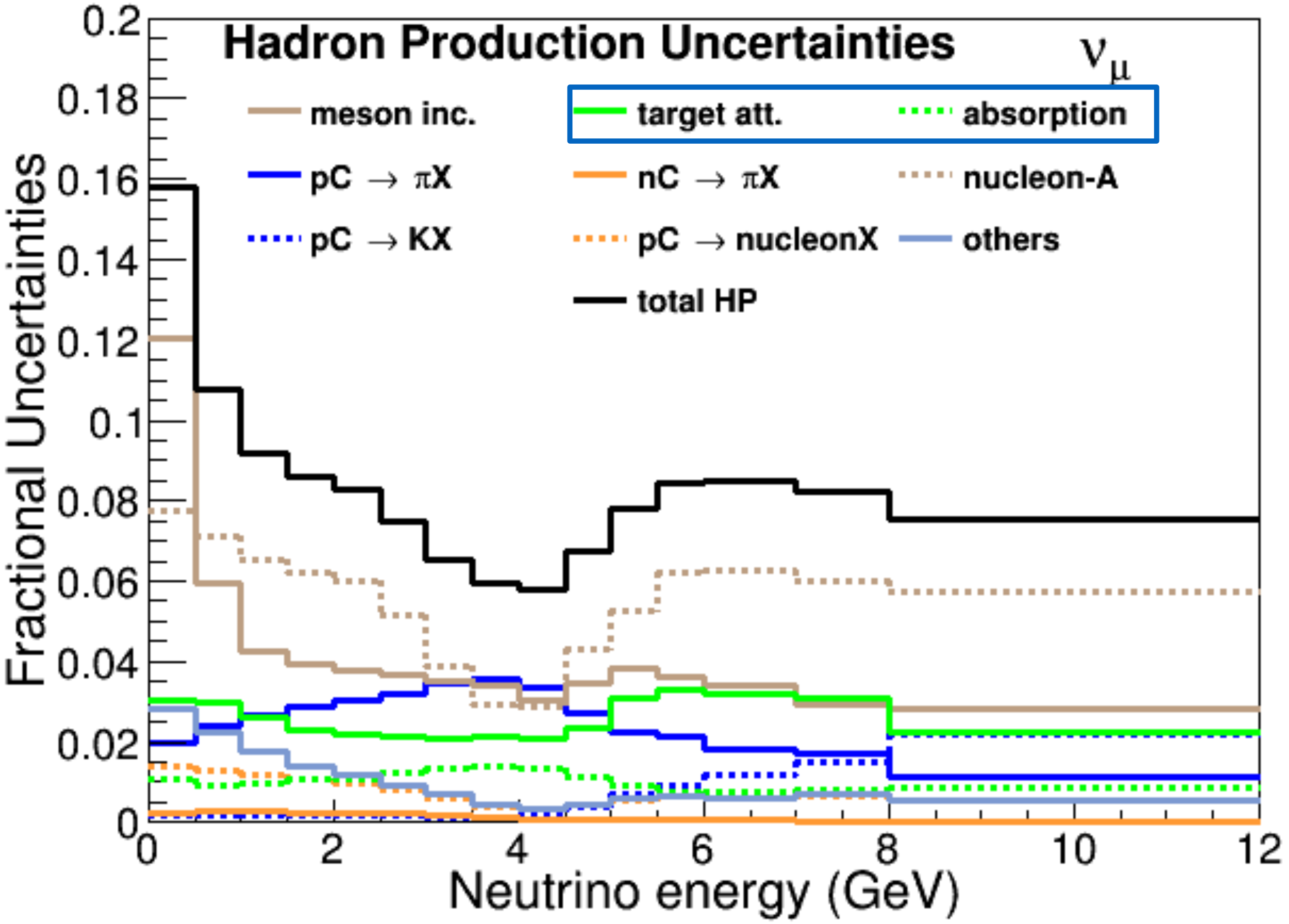
When the particle interacts in a volume

$$correction(r) = \frac{\sigma_{Data}}{\sigma_{MC}} e^{-r\frac{N_A \rho(\sigma_{Data}-\sigma_{MC})}{A}}$$

N_A: Avogadro Number, ρ: density, A: mass number

When the particle passes through the volume without interacting

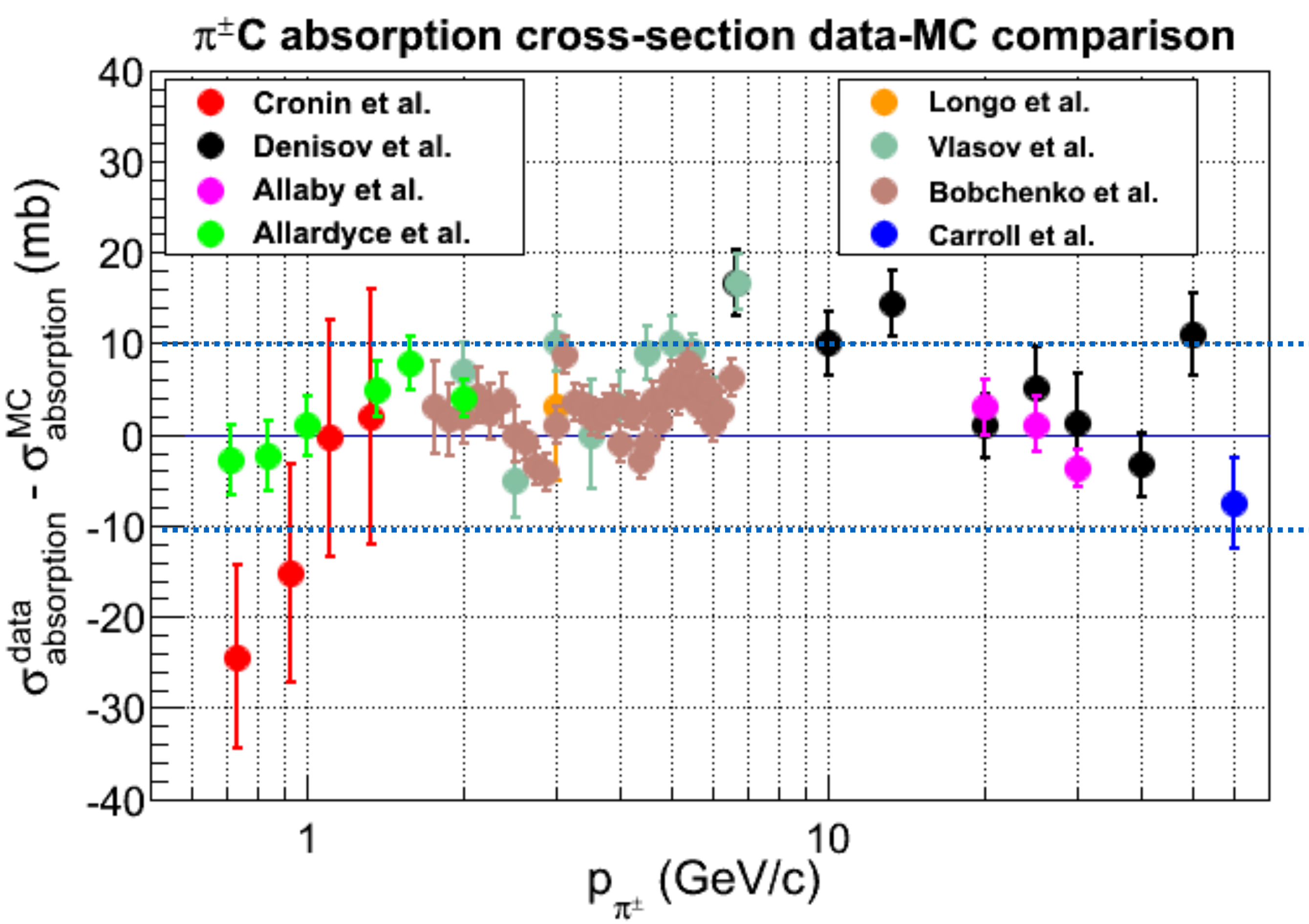
$$correction(r) = e^{-r\frac{N_A \rho(\sigma_{Data}-\sigma_{MC})}{A}}$$

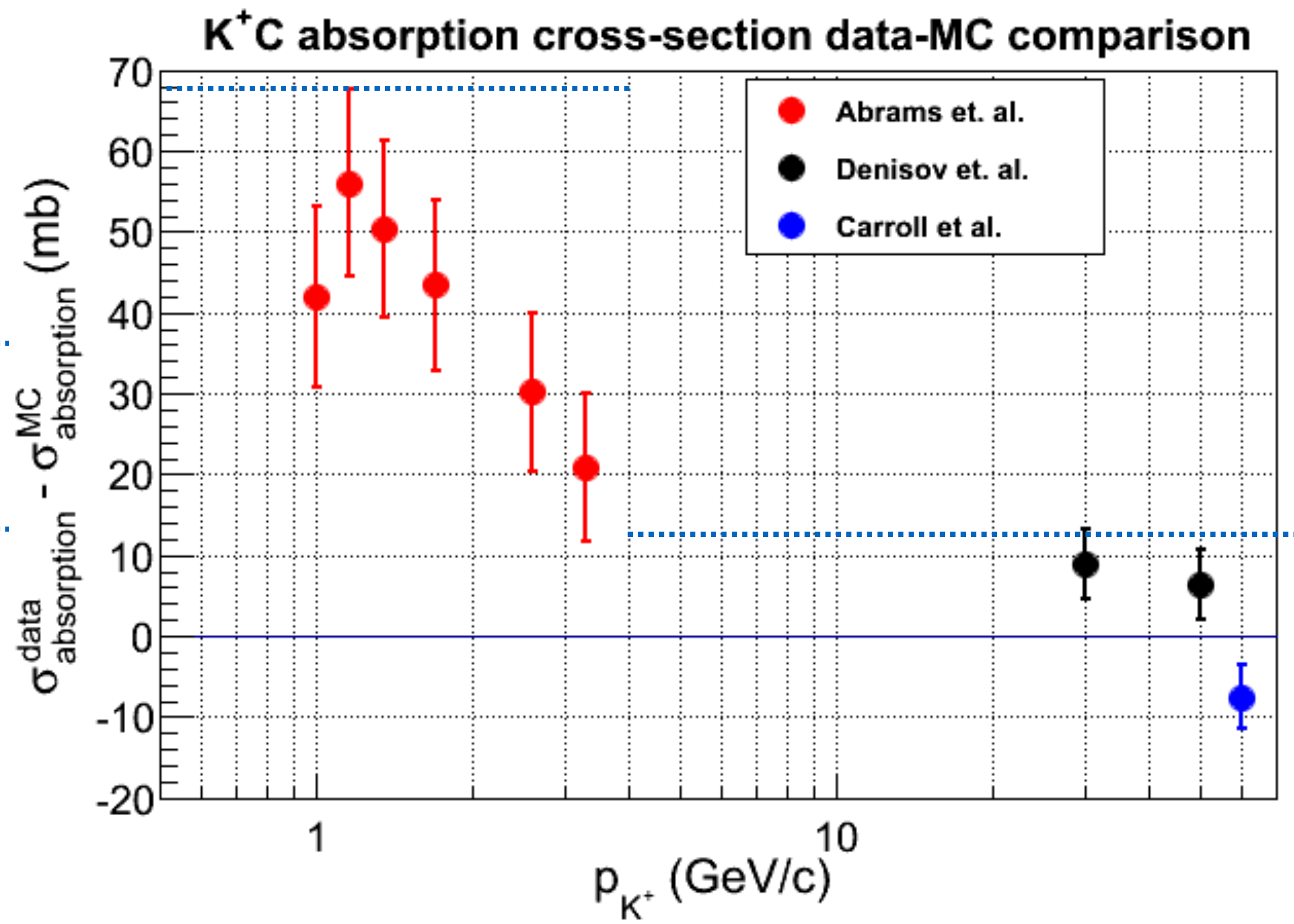


Data for absorption correction

1. Total inelastic cross section:

Dashed blue line is what is currently used in DUNE.





For pions, this is ~5% uncertainty

I have not applied any reduction for pions

For kaons: 60-90 % for P < 4 GeV and 12% for P > 4 GeV.

I reduced to 10% for the all momentum range.

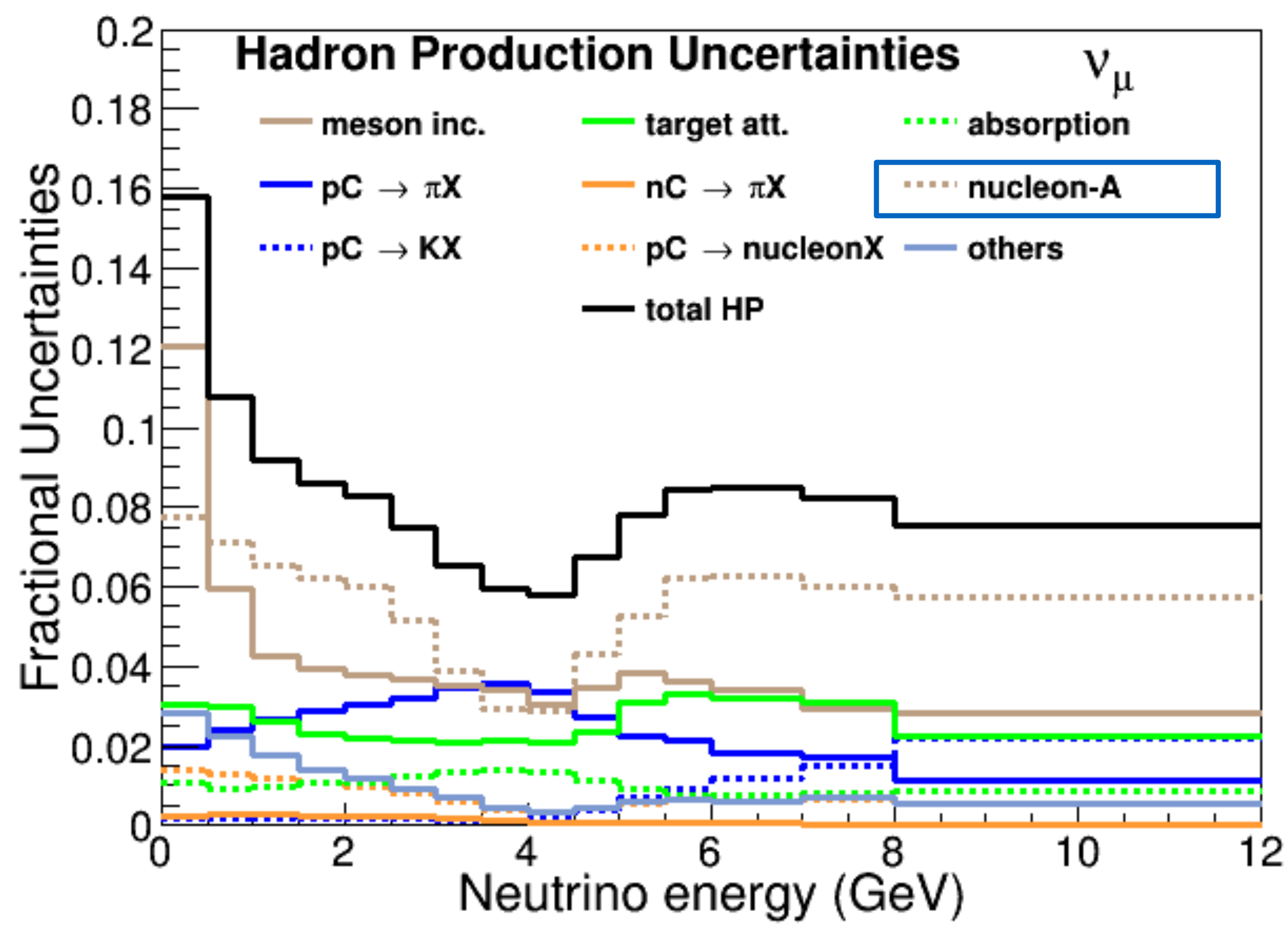
Nucleon-A

-> Constrain these interactions with pC adding an additional uncertainty found by comparing A dependence of Barton, Skubic and Eichten.

- **Proton incident on C** (not covered by the current data, NA49), **Fe and Al producing proton**. **I reduced to 10%.**

-> Quasi-elastic interactions.

- Currently 40%. **I reduced it to 10% for xF > 0.95**

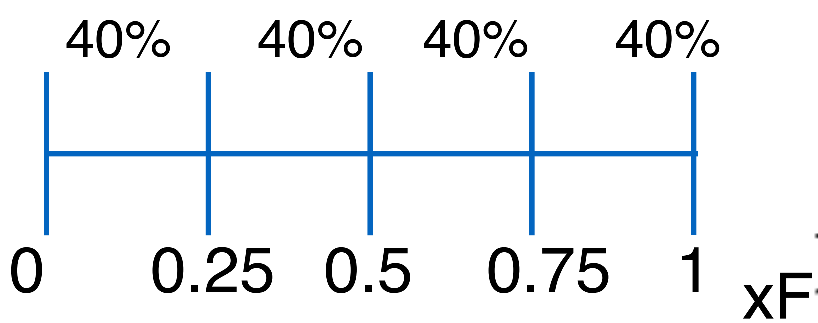


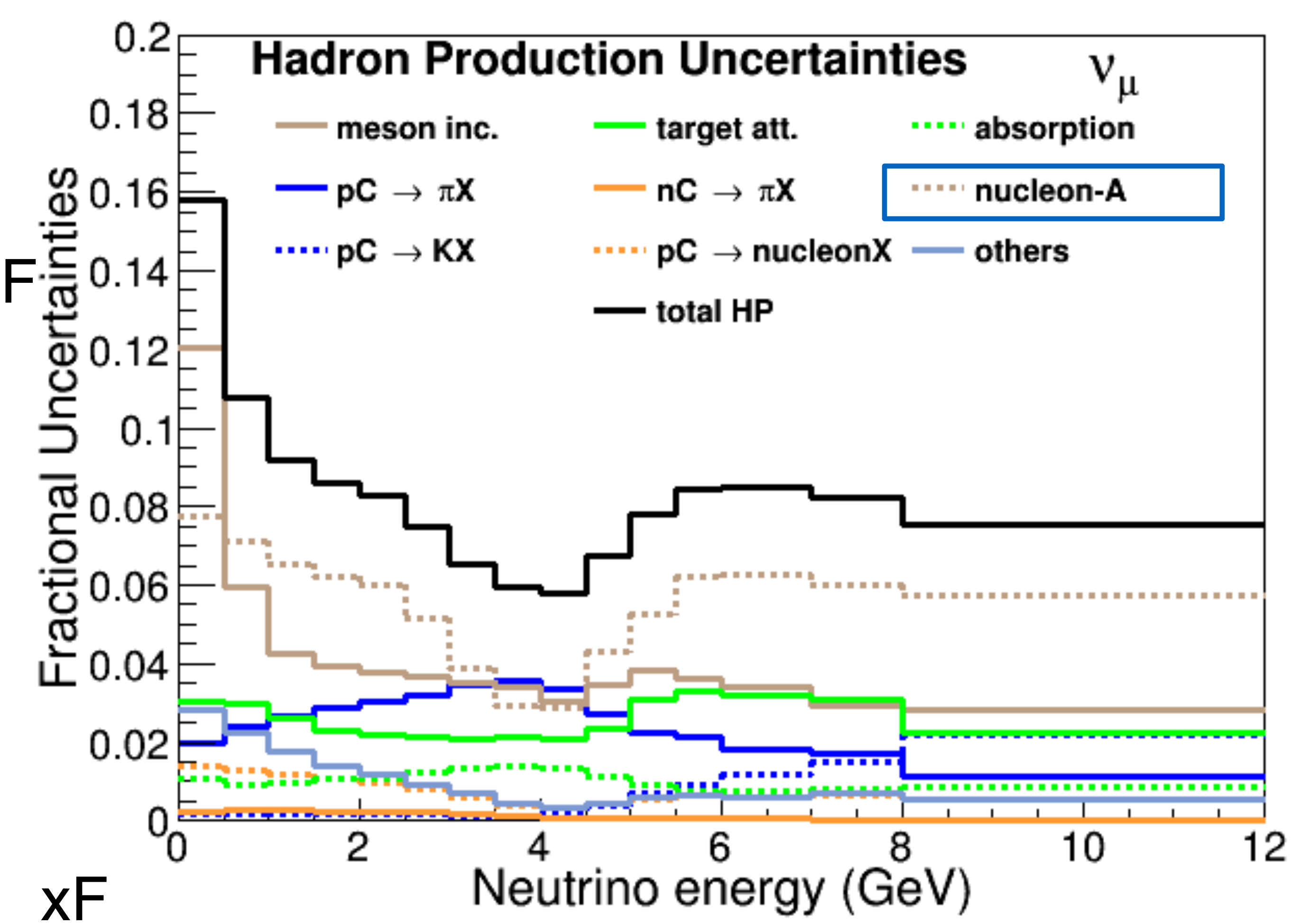
Meson incident

- **Pion and Kaon incident on C, Fe and Al producing pions** reduced from 40% to 10% and **producing kaons** from 40% to 20%.

    a. Currently it is 40% split in 4 xF independent bins in [0,1] per interaction type for all energies and materials.

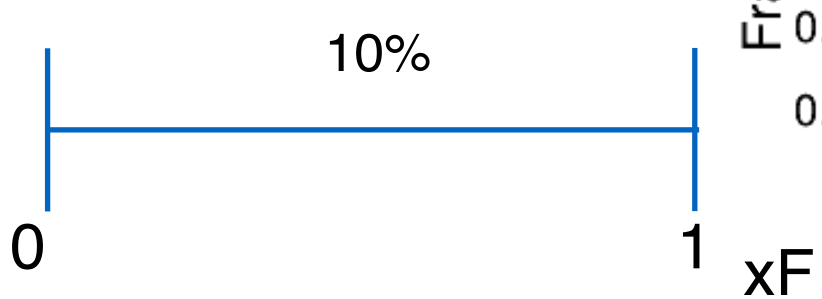
$\pi^+ \to \pi^+$
$K^+ \to \pi^-$
$K^- \to \pi^+$
...



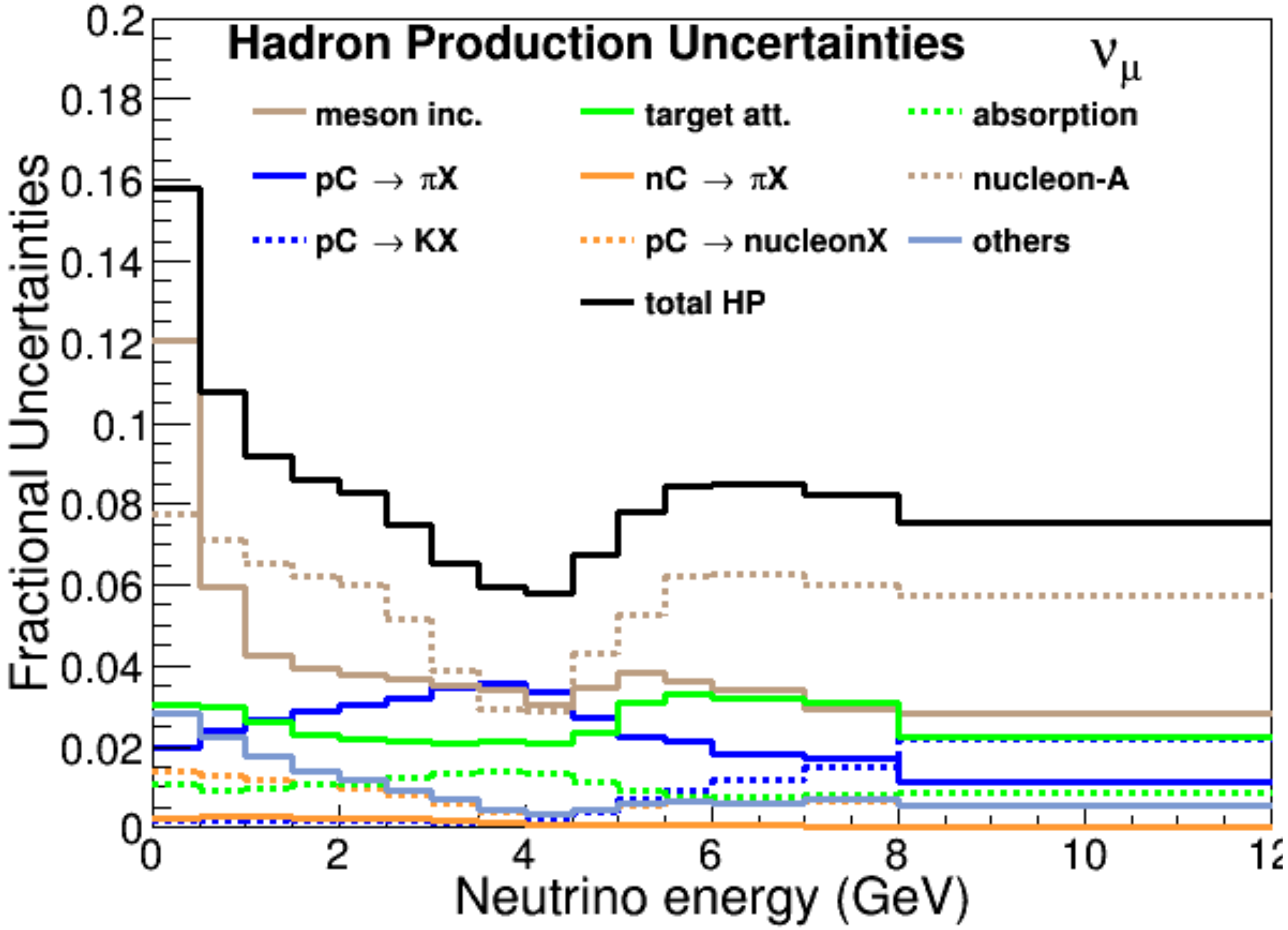


    b. For this work, I assume 10% in one bin per interaction type: π Al -> π X, π C -> K X, KAl -> π X for all energies.

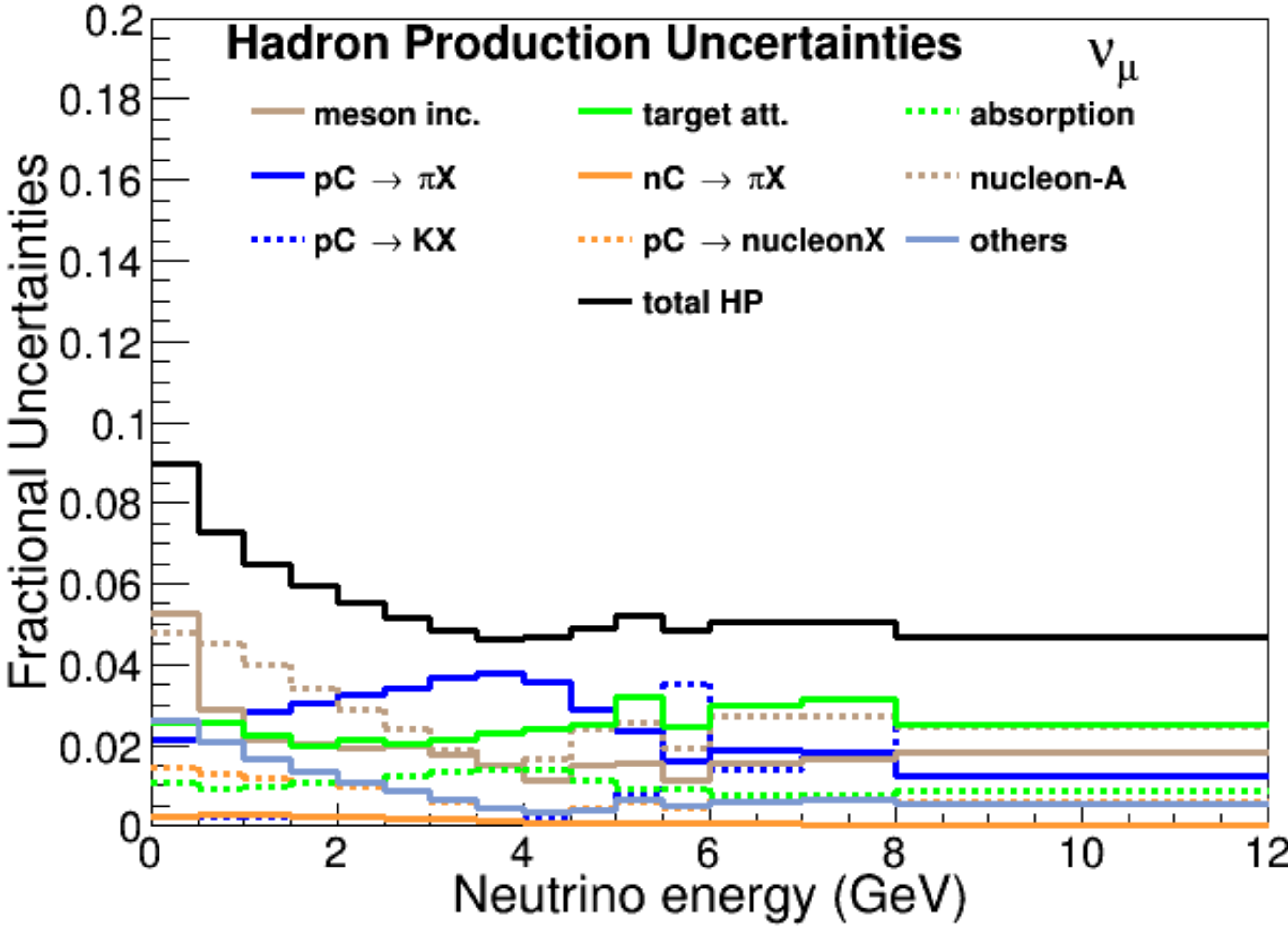
π^+ Al-> π^+ X
π^+ C-> K^- X
K^+ Fe-> K^+ X
...



Results



Hadron Production Uncertainties
ν_μ
meson inc.
target att.
absorption
pC → πX
nC → πX
nucleon-A
pC → KX
pC → nucleonX
others
total HP
Fractional Uncertainties
Neutrino energy (GeV)



Hadron Production Uncertainties
ν_μ
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pC → πX
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others
total HP
Fractional Uncertainties
Neutrino energy (GeV)

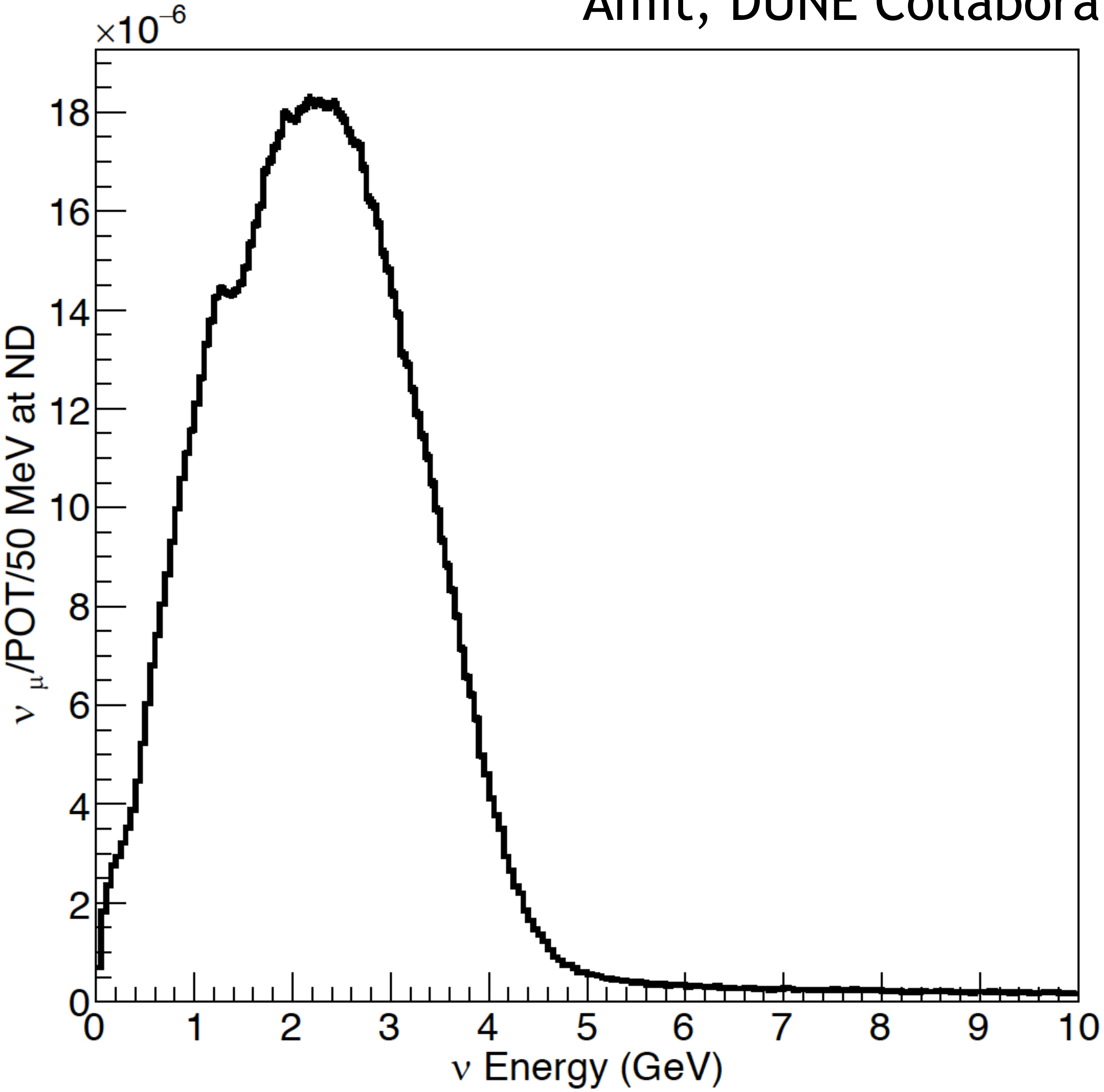
Conclusion

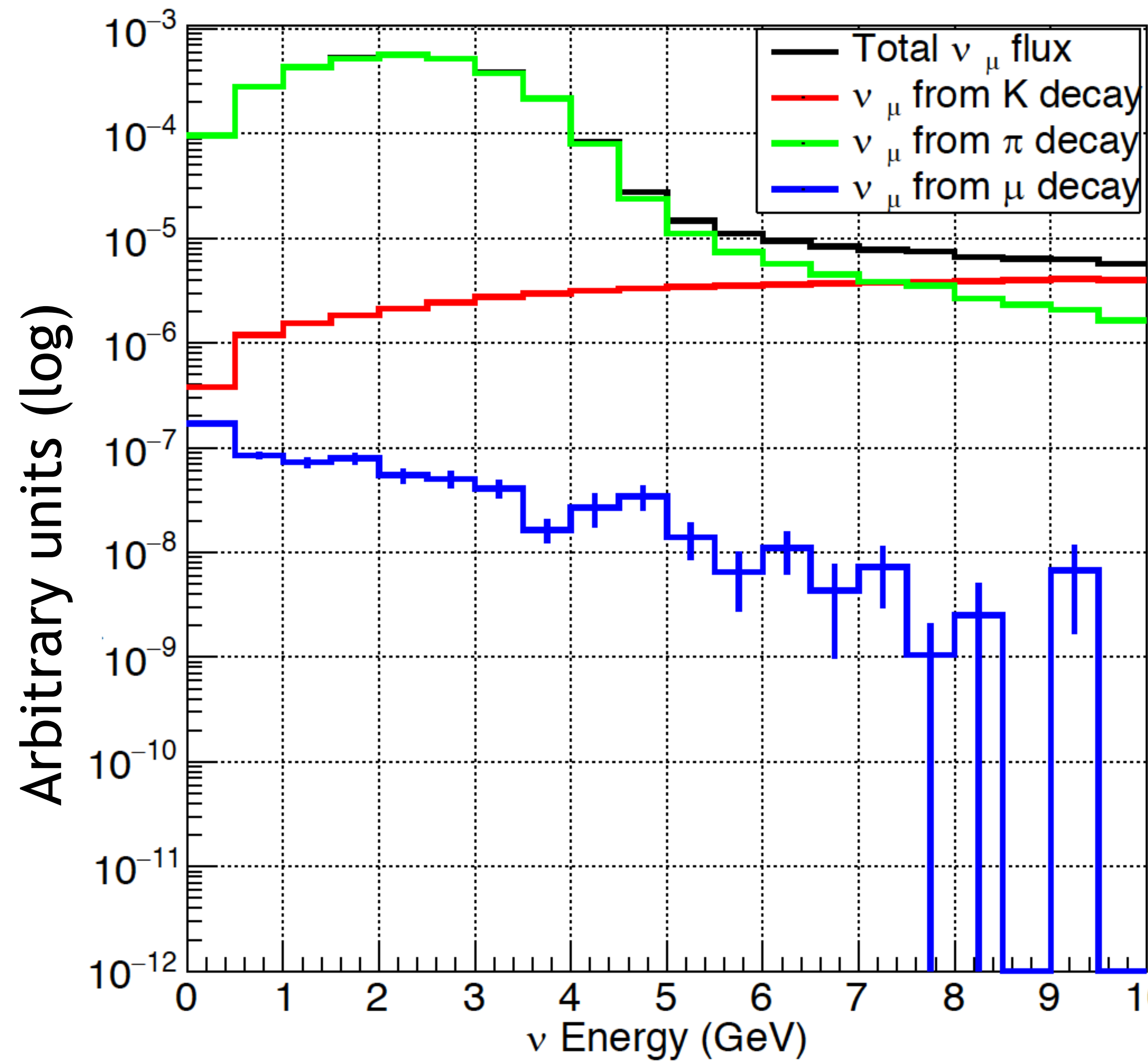
- It seems that new HP data such as EMPHATIC can have a significant impact on quasi-quasi-elastic and meson incident HP uncertainties.
- More refined assumptions can be made (energy dependence, bin-to-bin correlation, the size of the uncertainty, etc).
- Any suggestions?

backup

LBNF Optimized Neutrino Beam at the 574 m

Amit, DUNE Collaboration Meeting, May 2018

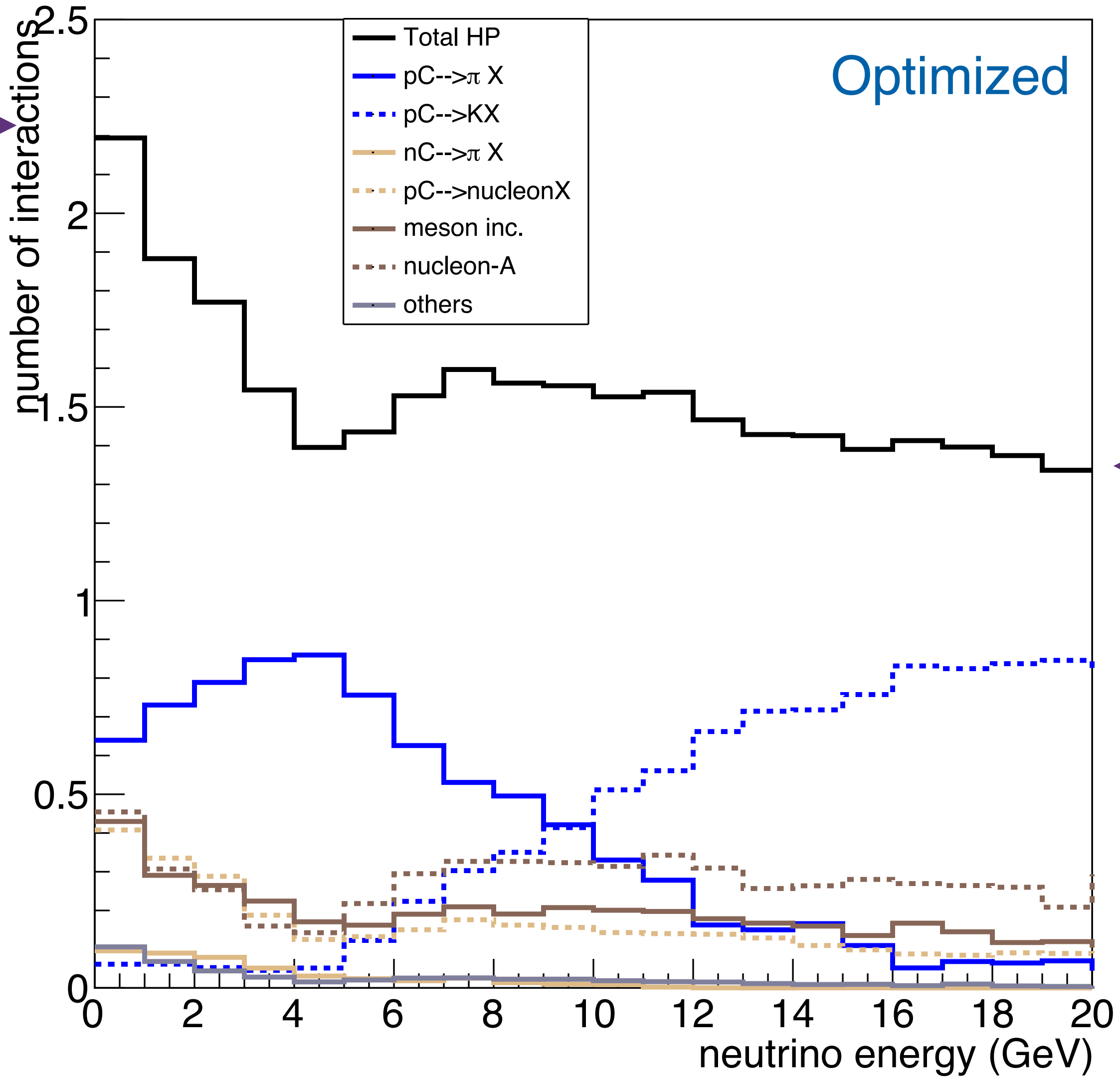




Interactions per muon neutrino at ND

- ***π**, **K** and **nucleons** productions from **pC** based on data (mainly NA49).*
- **nucleon-A:** quasi-elastics, extension from carbon to other materials, etc.
- *No data applied to meson incidents: assuming large uncertainties.*

L. Fields (NA61 Workshop 2017)



> 2.2 for very low E_ν and 1.4-1.6 for the rest

Hadron Production Uncertainties

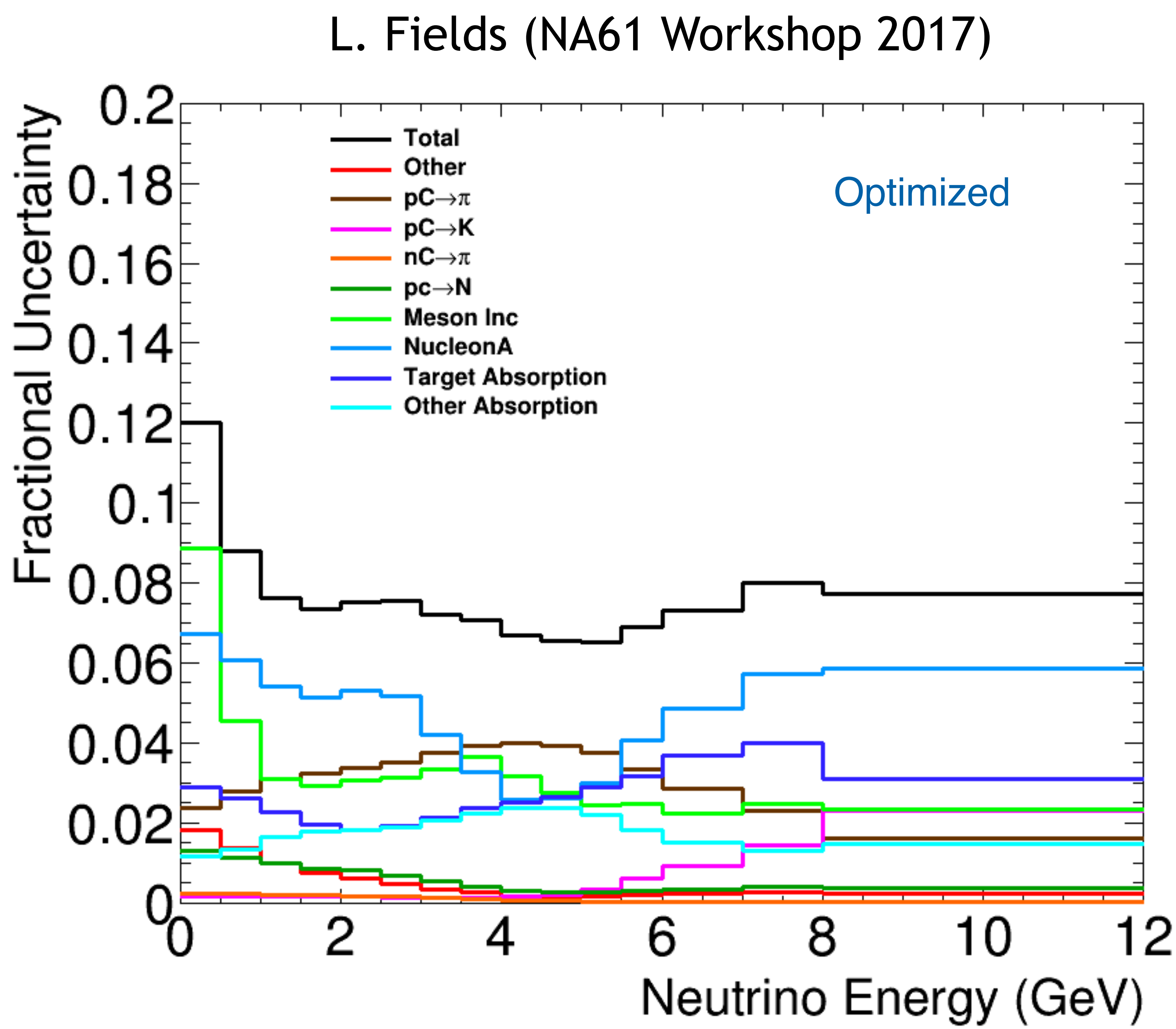
Particle production in proton carbon interactions:

- **Pions (pC -> π)**
- **Kaons (pC -> K)**
- **Nucleons (pC -> N)**

All covered by external data (mainly NA49).
 (for high energy kaons, a combination of NA49 + MIPP k/π)

The magnitude of this uncertainty depends both on uncertainties reported by experiments.

The correlations of the datasets are not reported by experiments. We assumed 100% for the systematics (conservative approach from MINERvA).



Hadron Production Uncertainties

Nucleon interactions (NucleonA)

-> Constrain these interactions with pC adding an additional uncertainty found by comparing A dependence of Barton, Skubic and Eichten.

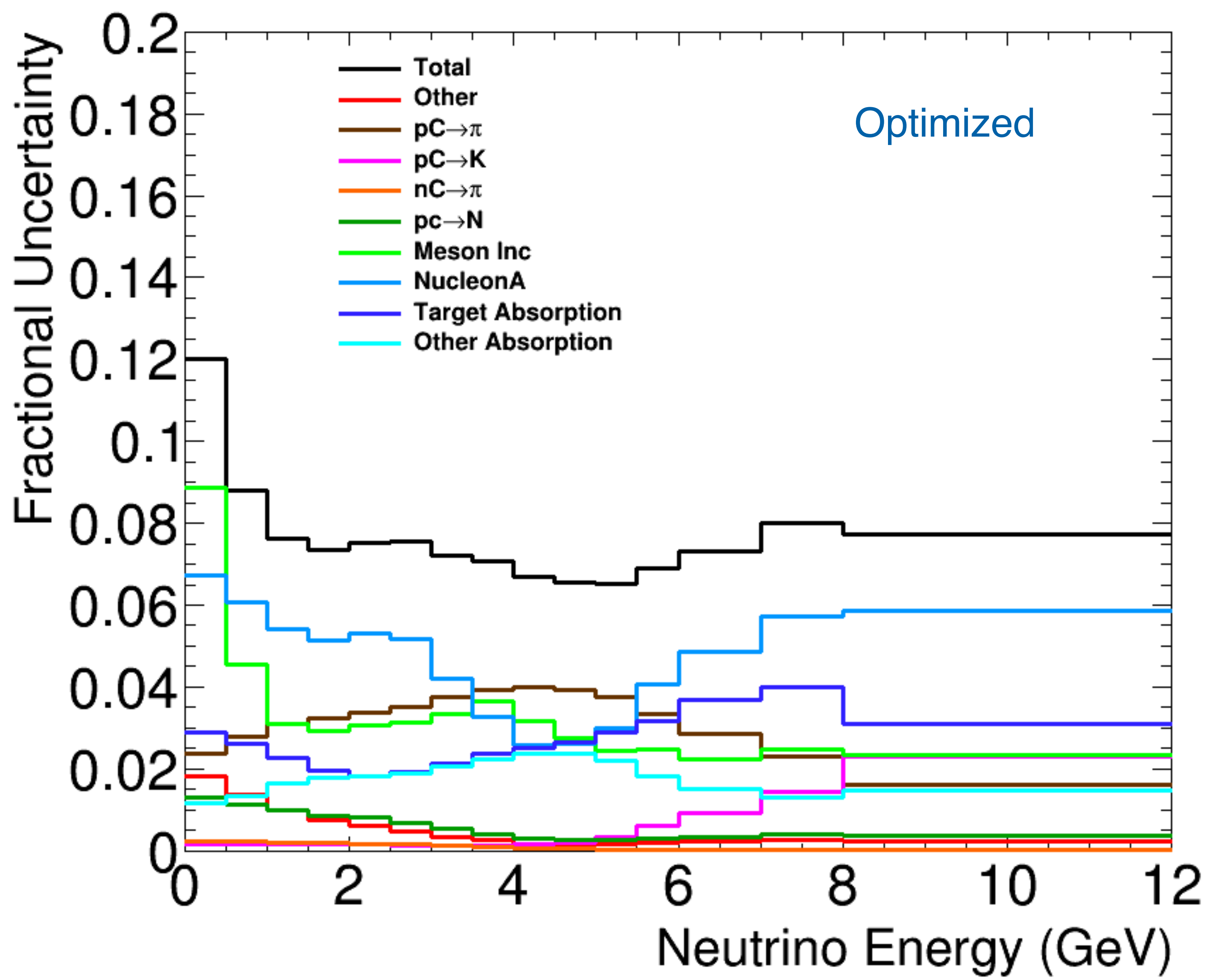
-> Quasi-elastic interactions.

When there is not data coverage, like:

Incident Mesons (Meson Inc)

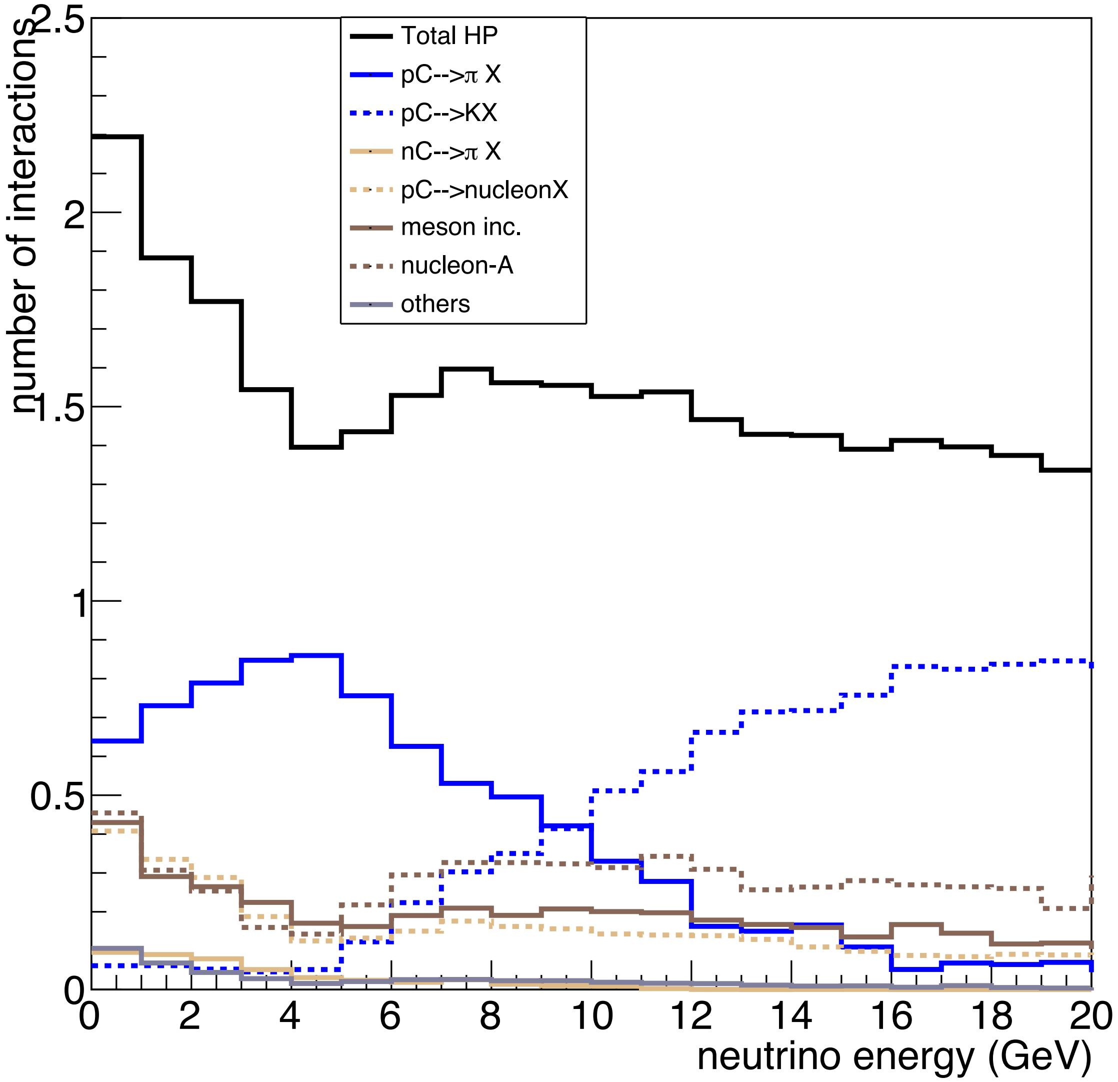
Guided by the agreement with other datasets: processes categorized by meson and produced particle. 40% error assigned in 4 x_F bins.

L. Fields (NA61 Workshop 2017)



How can we reduce the a priori uncertainties

More thin target data

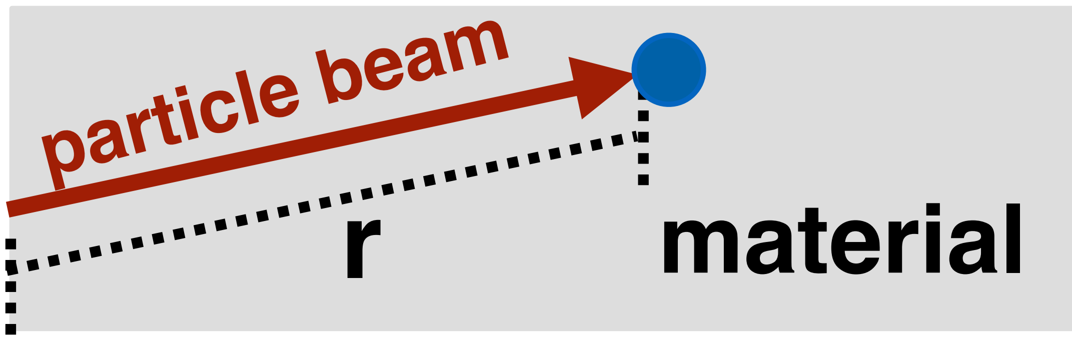


L. Fields (NA61 Workshop 2017)

- **Inelastic cross-sections** of π, K and protons in different materials (C, Fe, Al, He).
- **Differential cross-sections** in different materials
- **Proton quasi elastic cross-sections**
  - π -> π at a wide range 10-60 GeV.
  - pA-> π (K) X, where X != C

1. Beam Attenuation

When the particle interacts in a volume

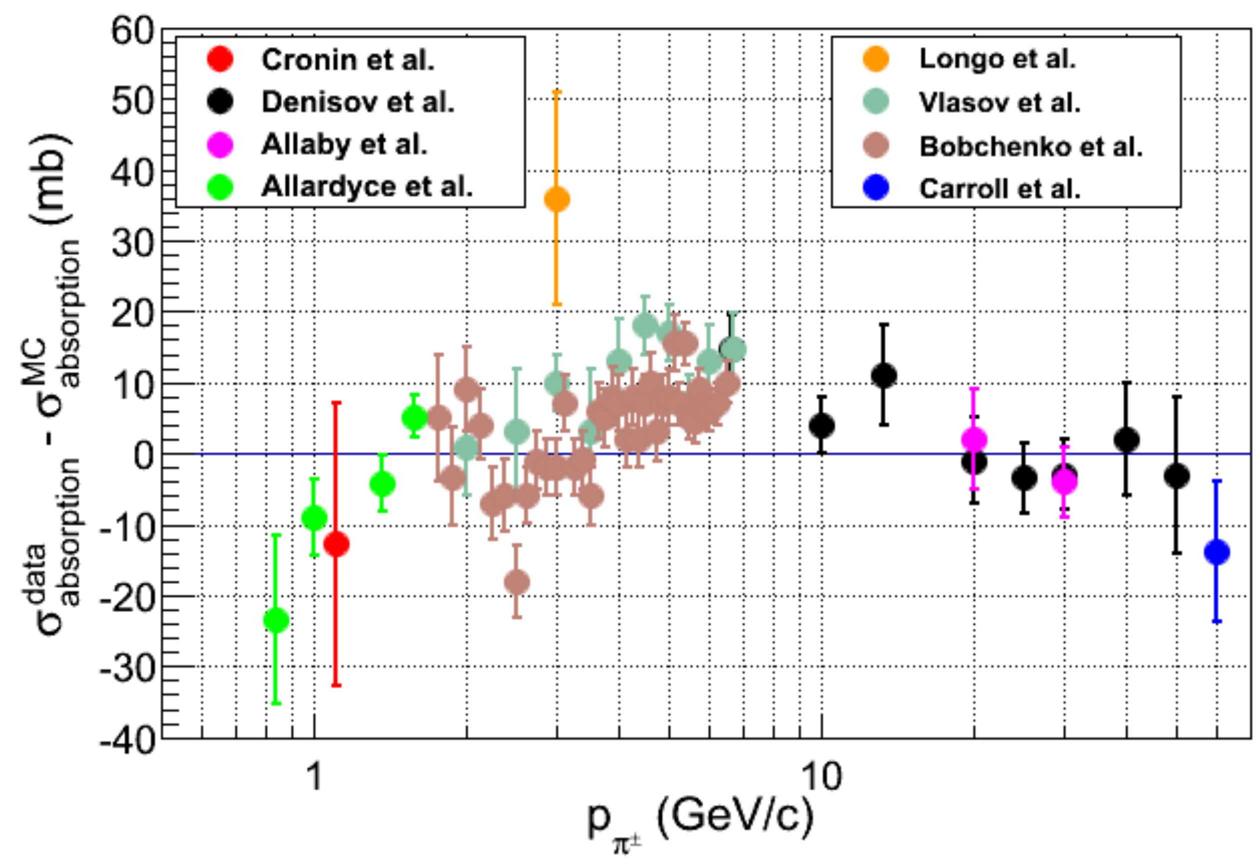


$$correction(r) = \frac{\sigma_{Data}}{\sigma_{MC}} e^{-r\frac{N_A \rho(\sigma_{Data}-\sigma_{MC})}{A}}$$

N_A: Avogadro Number, ρ: density, A: mass number

When the particle passes through the volume without interacting the survival probability is calculated.

- **Example: Absorption cross section of pion on Aluminum**



Reference (Geant4):

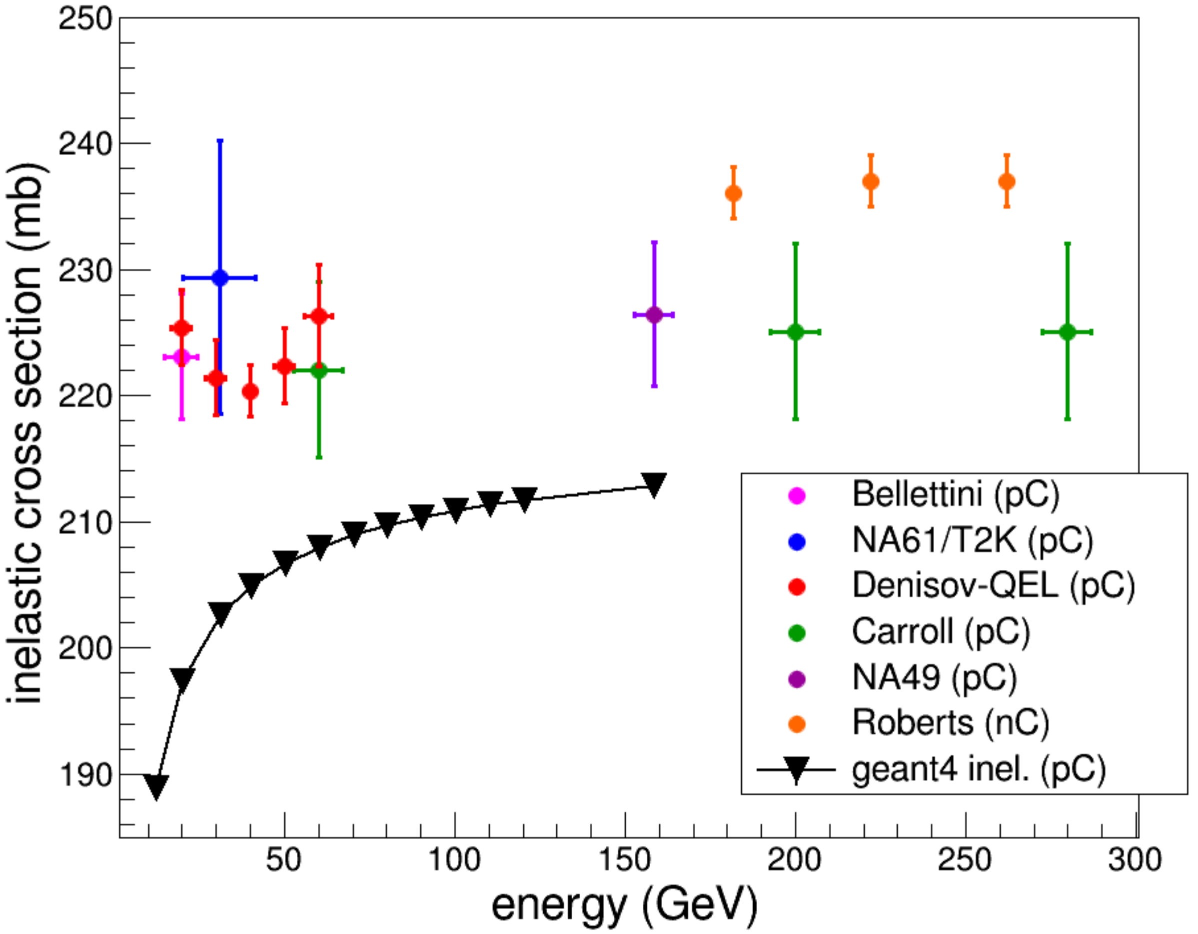
$\sigma_{absorption}$ = 344 mbar

- Most of the cross-section discrepancies are less than 6%.

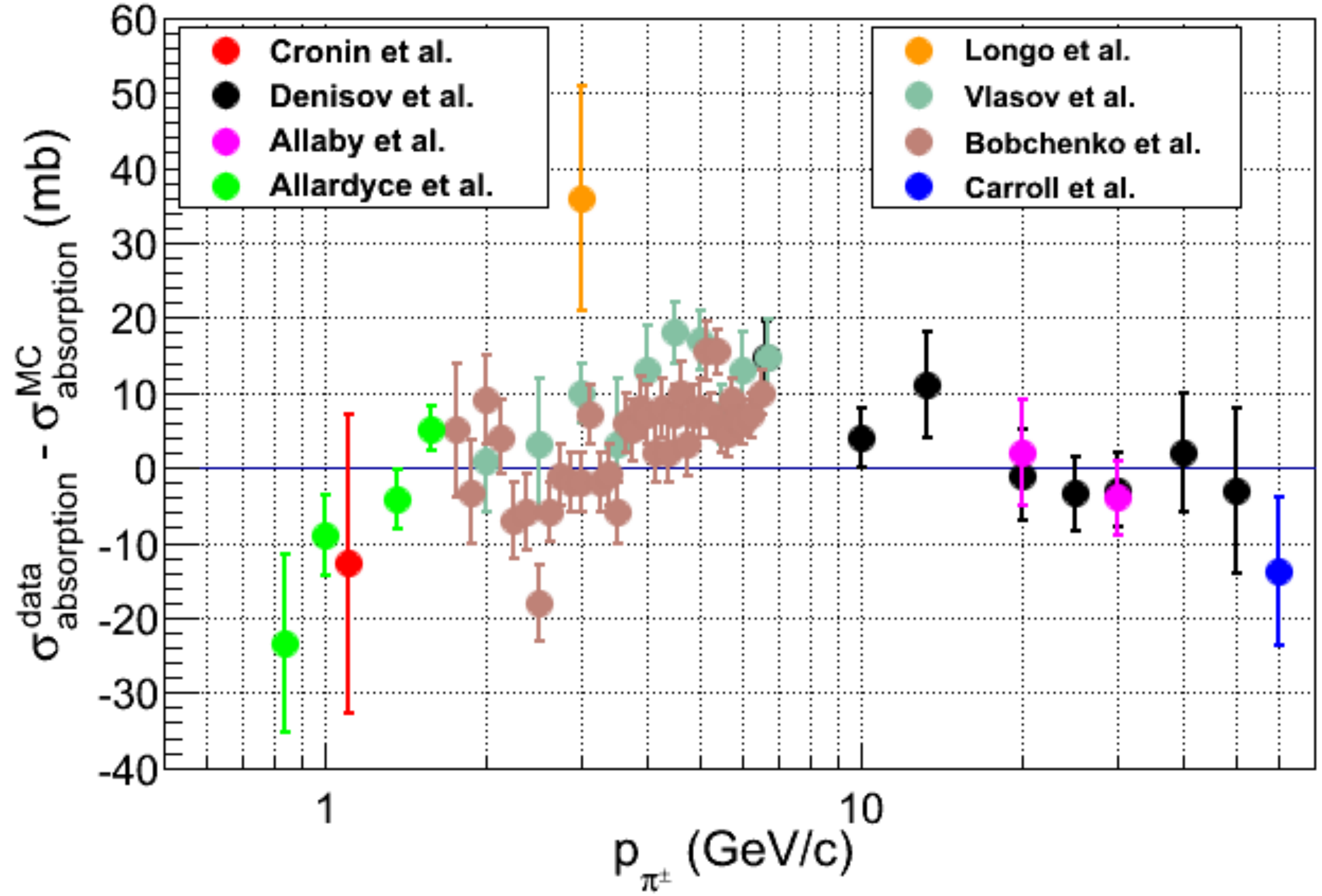
Data - MC Comparison

- Inelastic cross section
- Absorption cross section

Proton on Carbon



Pion on Aluminum



Reference (Geant4):

$\sigma_{absorption}$ = 243.2 mbar

Reference (Geant4):

$\sigma_{absorption}$ = 344 mbar

$$\sigma_{total} = \sigma_{elastic} + \underbrace{\sigma_{inelastic} + \sigma_{quasi-elastic}}_{\sigma_{absorption}}$$

Fermilab

If There is not Direct Data

Extending the data coverage

- Constrain pA interactions with pC adding an additional uncertainty found by comparing A dependence of Barton, Skubic and Eichten.

- Use theoretical guidance (isospin arguments, quark counting arguments, etc.)

What if data is not available?

- Guided by the agreement with other datasets: processes categorized by projectile and produced particle. 40% error assigned in 4 x_F bins.