Neutrino nucleus reactions at high energies within the GiBUU model

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GiBUU
The Giessen Boltzmann-Uehling-Uhlenbeck Project

GiBUU model

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GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

– the semiclassical transport model in couple channels –
simulates the transport of hadrons through nuclear matter in space and time

GiBUU describes several reactions both in resonance and high energy regions, is extensively checked against experimental data

for heavy ion collisions, pA, πA, γA, e^- A

Aim: many reactions with one microscopic model

Review: Buss et al. (2011) ArXiV: 1106.1344
Open source code: http:/gibuu.physik.uni-giessen.de/GiBUU

Code ...

is written in Fortran 95/2003 (very different from Fortran 77)

- modern features: function overloading, allocatable arrays, optional arguments, possibility to derive new types

- module structure with philosophy that each molude should initialize itself on the first call; private and public variables

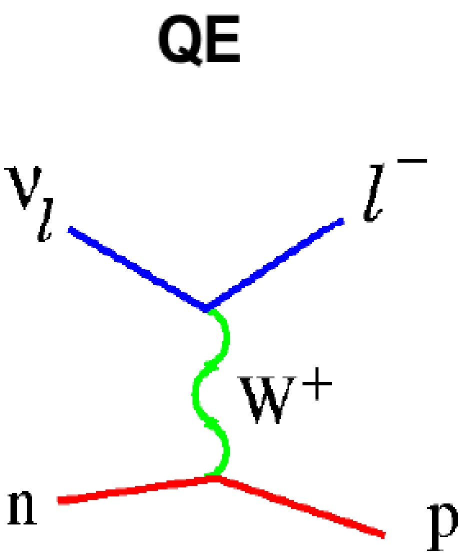
Can one change the parameters?

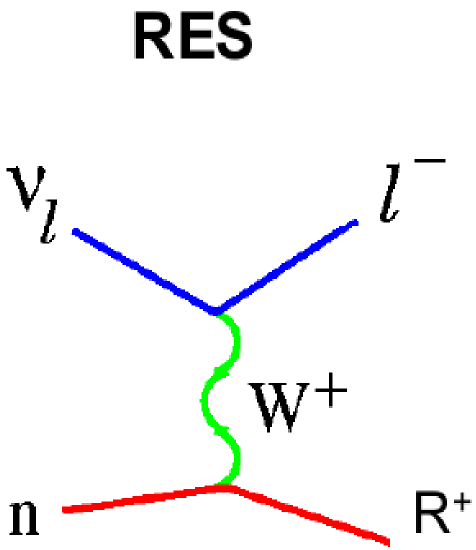
many of them **YES** reading data out of the “jobcard”

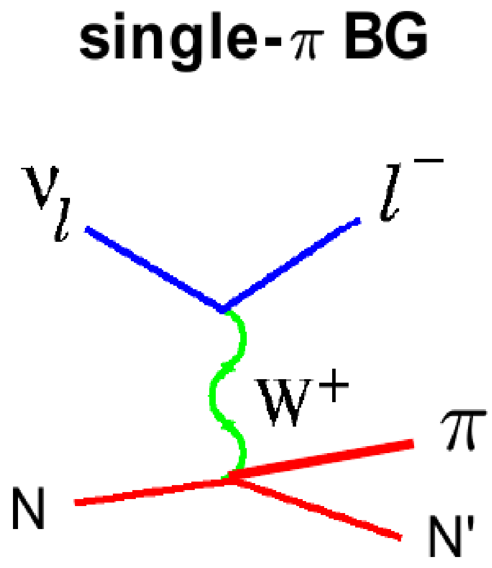
```
$neutrino_induced
includeQE=.true.
includeRES=.true.
includeDIS=.true.
$end
```

ASCII file

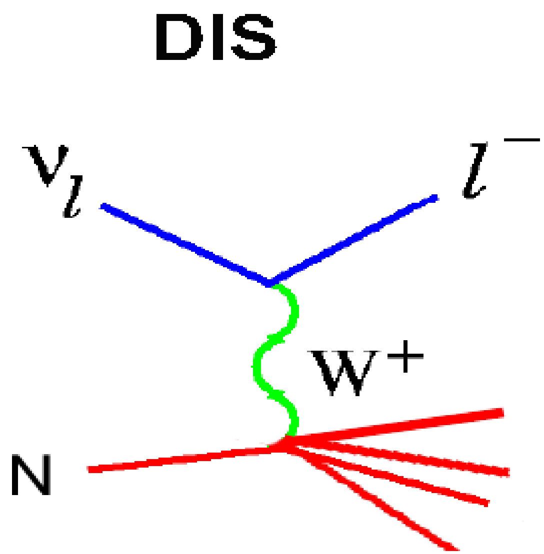
Primary interactions







13 resonances from 19 PDG 3* and 4*



Recently implemented

DIS

via PYTHIA code

Elementary input

- QE: vector FF BBBA2007, axial FF M_A=1 GeV
- RES: vector FF: related to el-m FF by CVC, MAID parametriz

(MAID, Drechsel EPJA 34: Mainz unitary isobar model for pion photo- and electroproduction on the nucleon; it provides the resonance helicity amplitudes, from which el-m transition form factors are derived;)

axial FF: PCAC, fitted to ANL $p\pi^+$ data

- Single-π BG: vector part based on MAID, axial part fitted to ANL
- Joining RES and DIS

W>1.6 - 1.65 GeV: DIS is smoothly turned ON

W<2.0 -2.05 GeV : RES are smoothly turned OFF

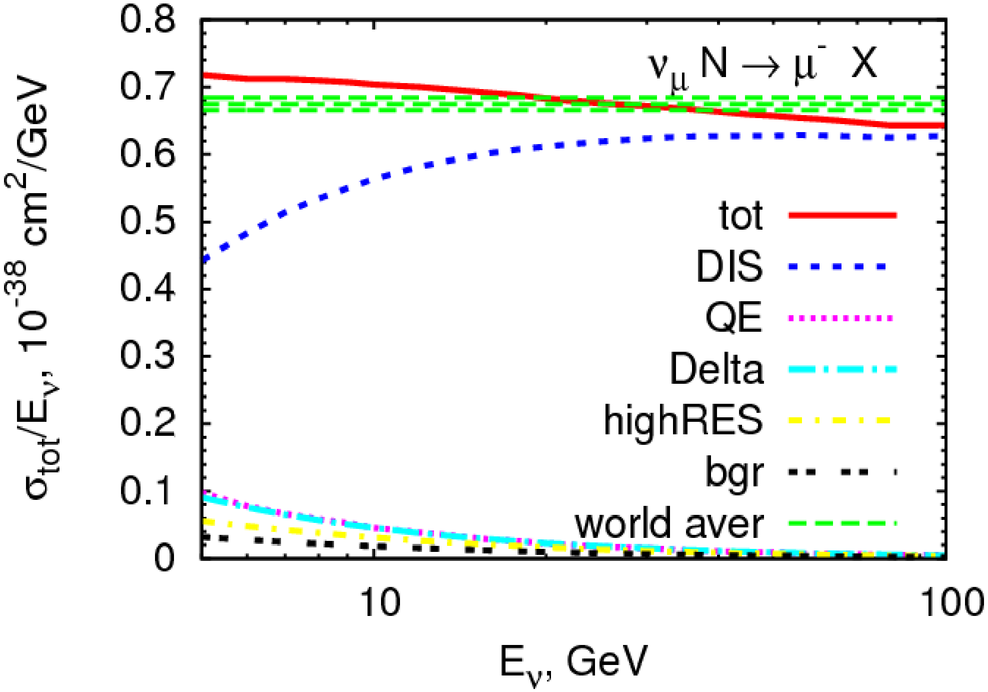
Motivated by fitting electron data

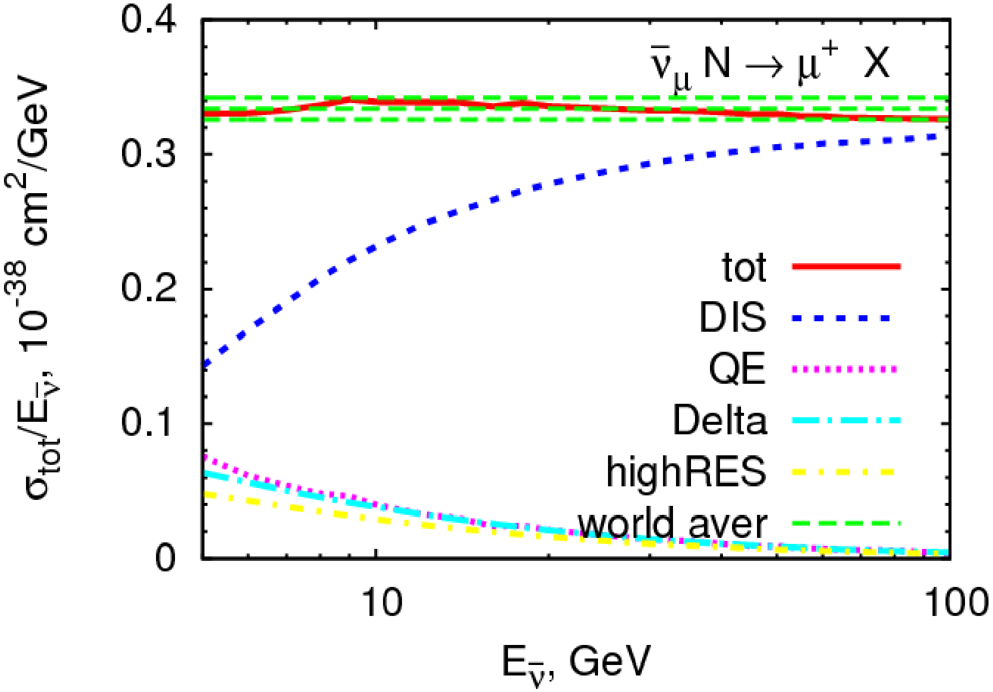
Double counting? NO Taking into account 2-, 3-, 4- ...pion, … bgr

Isoscalar cross section

neutrinos

antineutrinos





Calculations are done with default GiBUU parameters, no fine tuning

Steps in the GiBUU code

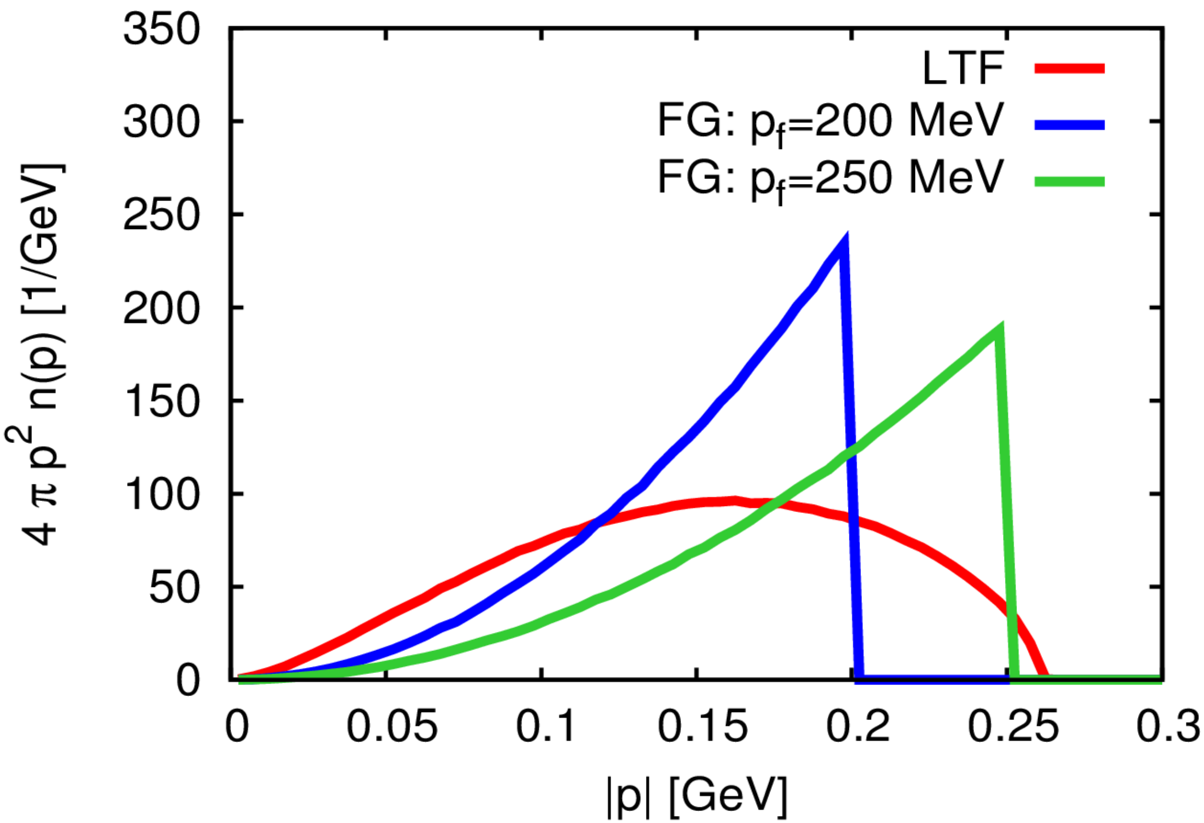
1. Initialize nucleus

- local density approximation with realistic density profile
- density + momentum-dependent mean-field potential
- local Thomas-Fermi gas model

! very different from global Fermi gas

example:

Momentum density distribution of proton in oxigen



Steps in the GiBUU code

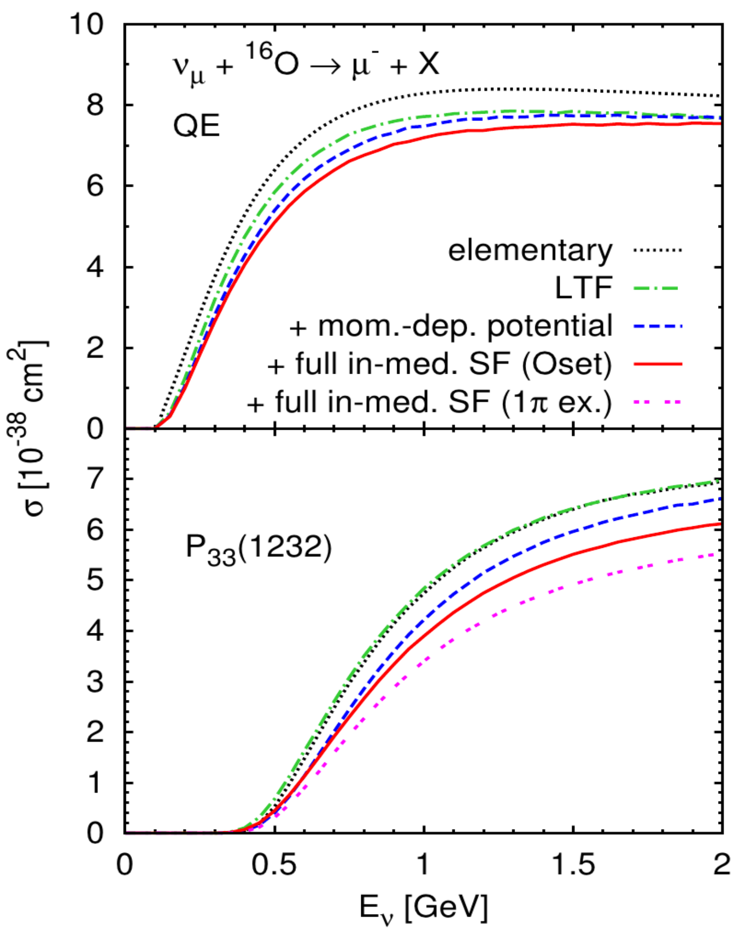
2. Calculate in-medium cross section

- vacuum form factors for QE and RES production
- broadening of the resonances (collisional or Oset/Salsedo)
- in-medium modified cross section
- full in-medium kinematics
- Pauli blocking

typical result:

Medium inclusive cross section

for QE and Delta suppressed



? Medium DIS cross section ?

PYTHIA code calculates *free* DIS cross section

We should some how “remove” (or no not remove) in-medium potential in order

to provide the input kinematics for PYTHIA code

No unique prescription how to do this. Several possibilities:

F-NO

F-CM

F-THRE

Difference between them is the intrinsic uncertainty of the GiBUU

Medium PDF ?

Medium parton distribution functions : based on el-m data, intended for both charged-lepton- and neutrino- induced reactions (Hirai et al 2009 - review and recent parameterizations)

In GiBUU for comparison: “nuclear PDF”: Calculation without microscopic nuclear effects, but with medium PDF: EKS98
K.J. Eskola, V.J. Kolhinen and C.A. Salgado, Eur. Phys. J. C9 (1999) 61

On the other hand: recent analysis shows, that medium effects for electron and neutrino are different (next talk by J.Morfin)

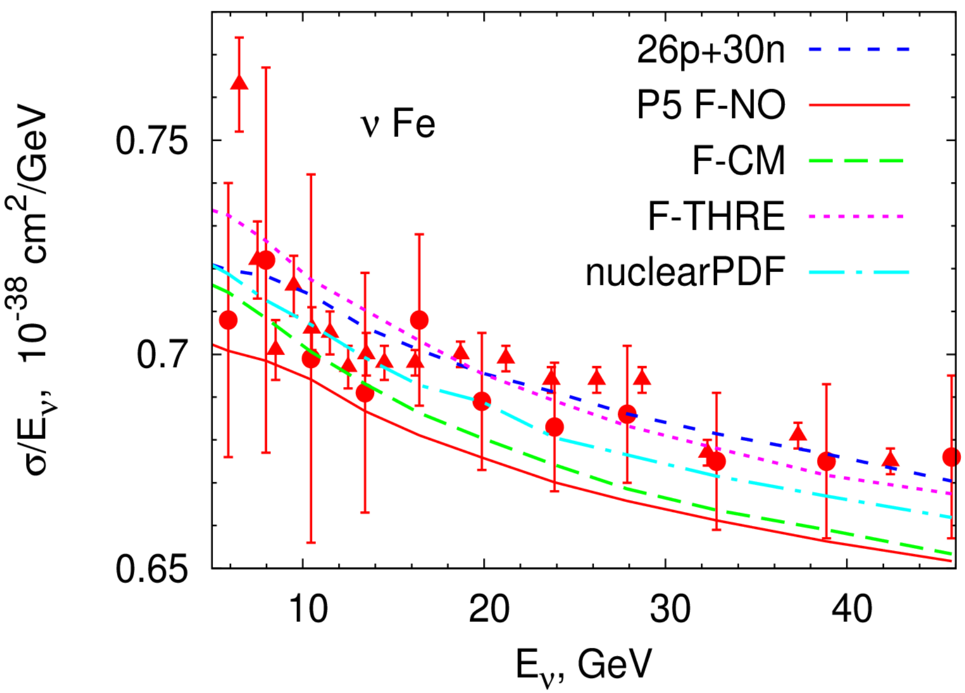
Waiting for precise measurements on C, O, CH, Fe, Pb from Minerva!

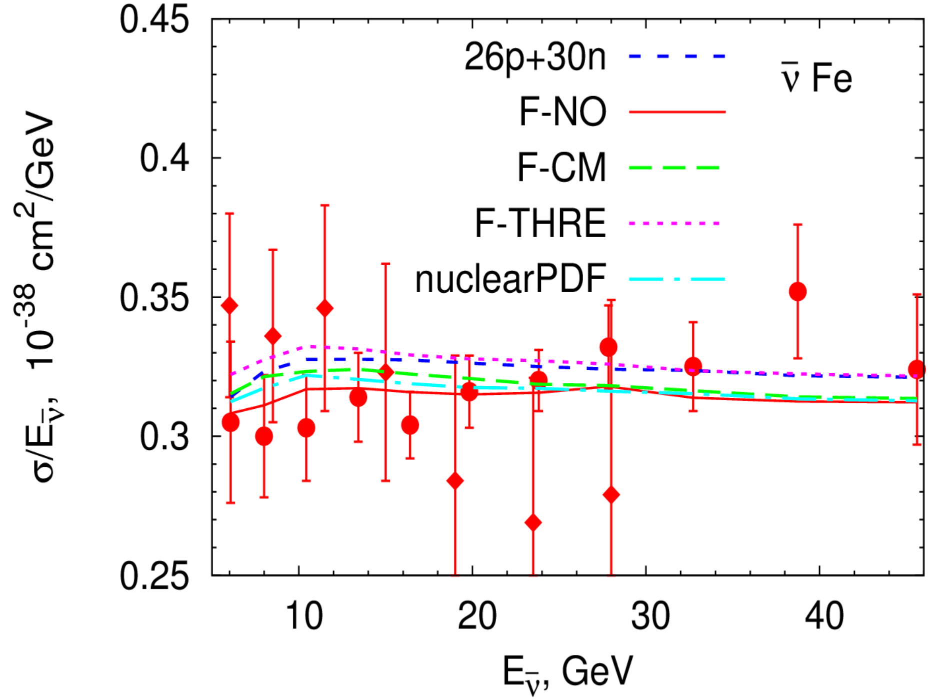
Medium DIS cross section

GiBUU uncertainty in DIS nuclear effects ~ 4%

neutrino

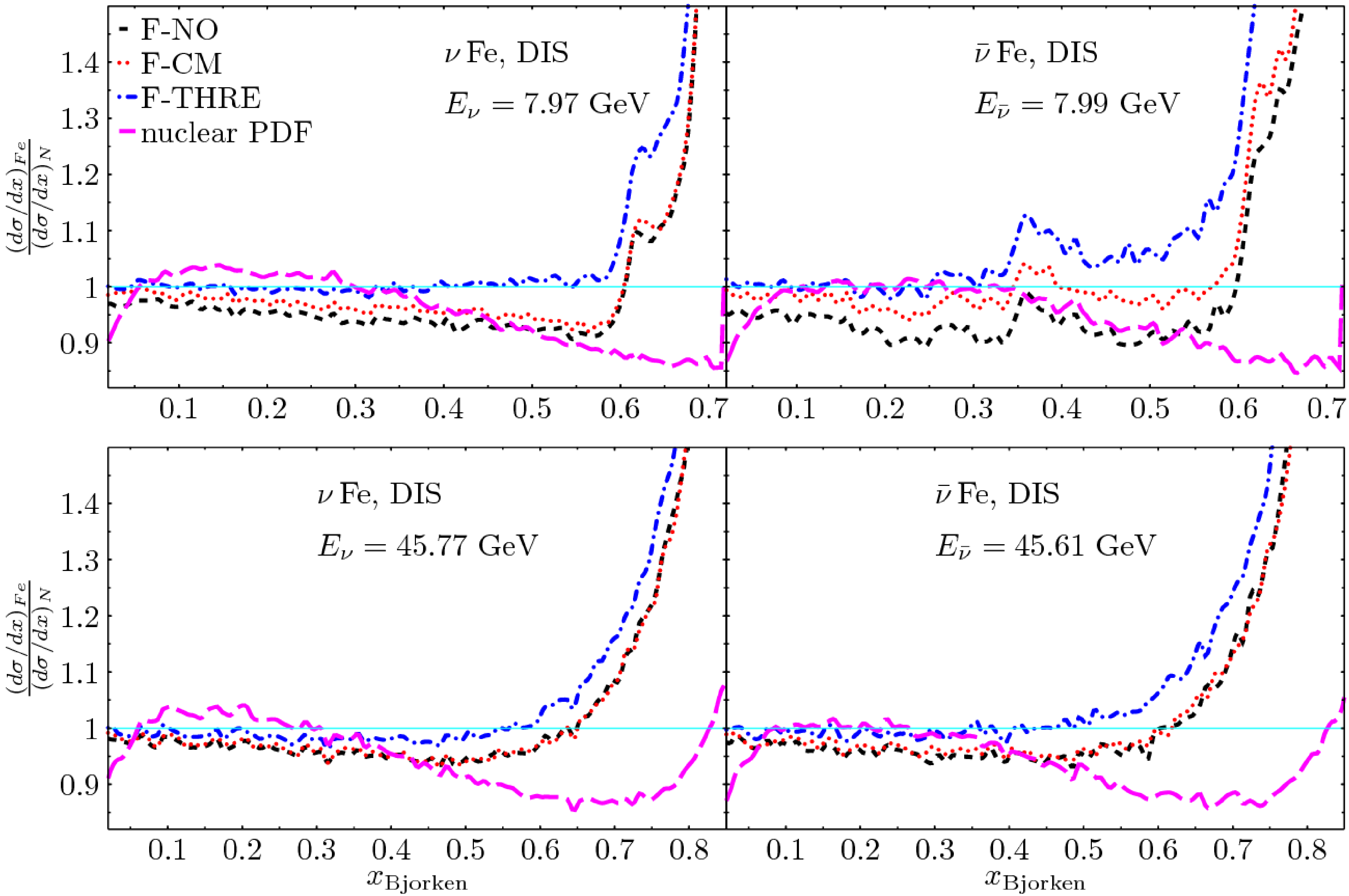
antineutrino





Data: NOMAD, MINOS, IHEP-JINR

Differences to EKS98 nuclear PDF



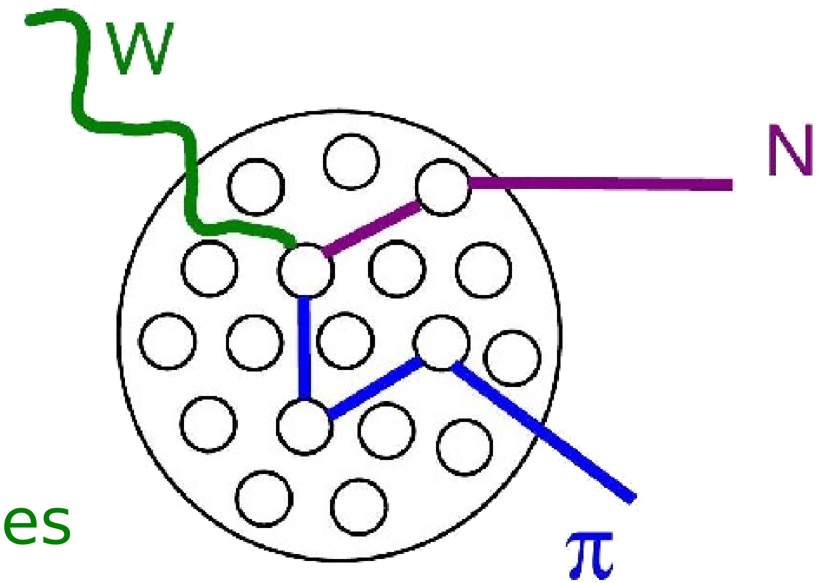
Steps in the GiBUU code

3. Propagate outgoing particles through nucleus

according to the Boltzmann-Uehling-Uhlenbeck equation

$$\frac{df_i}{dt} = \left(\partial_t + (\nabla_{\vec{p}} H_i)\nabla_{\vec{r}} - (\nabla_{\vec{r}} H_i)\nabla_{\vec{p}}\right) f_i(\vec{r}, p, t) = I_{coll}\left[f_i, f_N, f_\pi, f_\triangle, \ldots\right]$$

- 61 baryons and 21 mesons coupled through the collision integral
- decay of unstable particles
- elastic and inelastic 2- and 3- body scattering
- Pauli blocking for fermions



result: spectra of the outgoing particles with and without FSI are different

Processes in the FSI (e.g. pion)

- Absorption

  $\pi N \to \Delta$ (dominant) $\pi N \to \eta\Delta$ followed by $\Delta N \to NN$

  $\pi N \to R$ followed by $RN \to NN$, $\pi NN \to NN$

  $\pi N \to \omega N, \phi N, \Sigma K, \Lambda K, K\bar{K}N$

- Charge exchange

  $\pi^+ n \leftrightarrow \pi^0 p$

  $\pi^0 n \leftrightarrow \pi^- p$

- Redistribution of energy

  $\pi N \to \pi N, \omega\pi N, \phi\pi N, \Sigma K\pi, \Lambda K\pi$

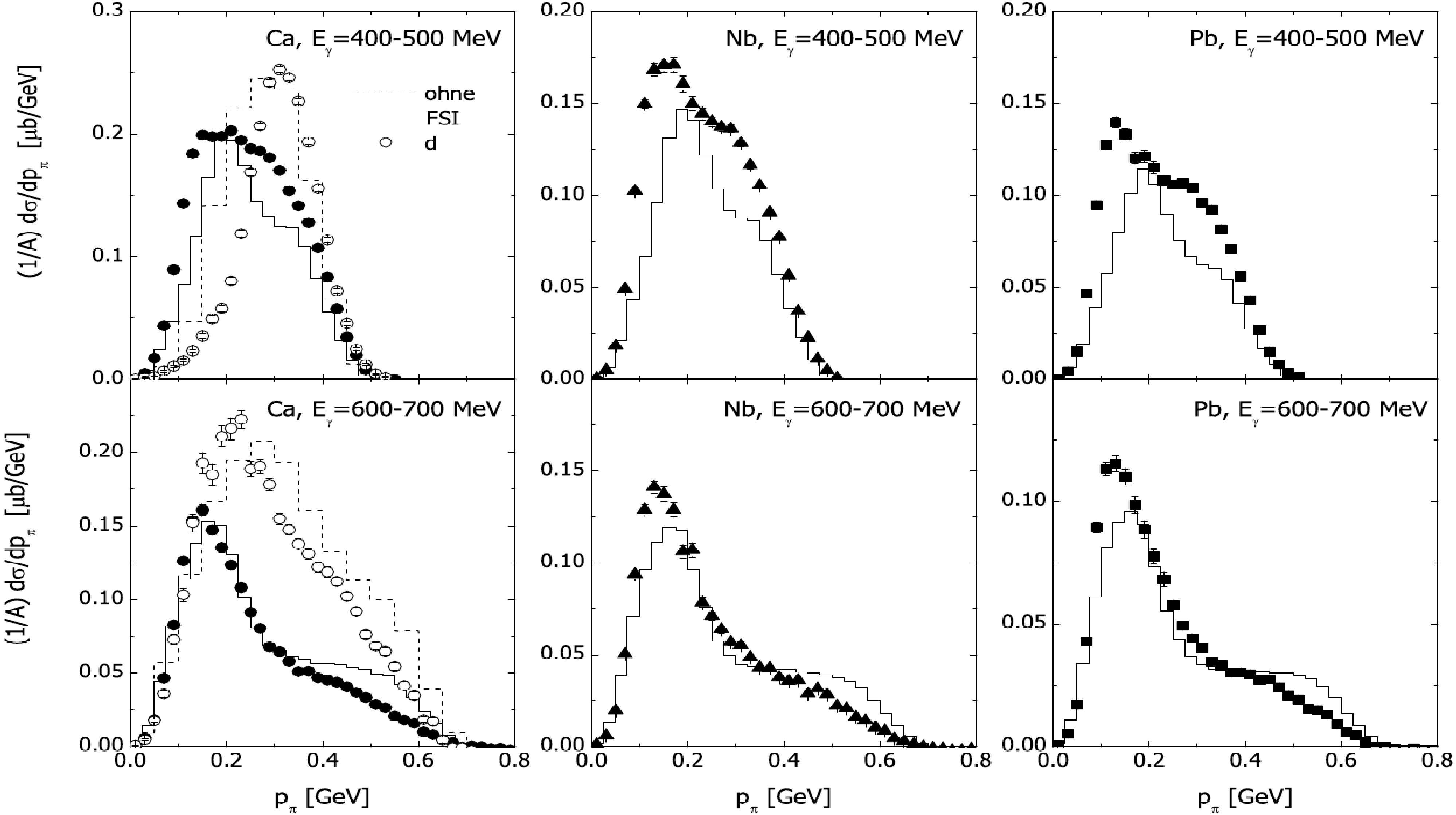
- Production

  $NN \to \Delta N$ followed by $\Delta \to \pi N$, also via other R

  $\omega N, \phi N \to \pi N$

  $\pi N \to \pi\pi N$

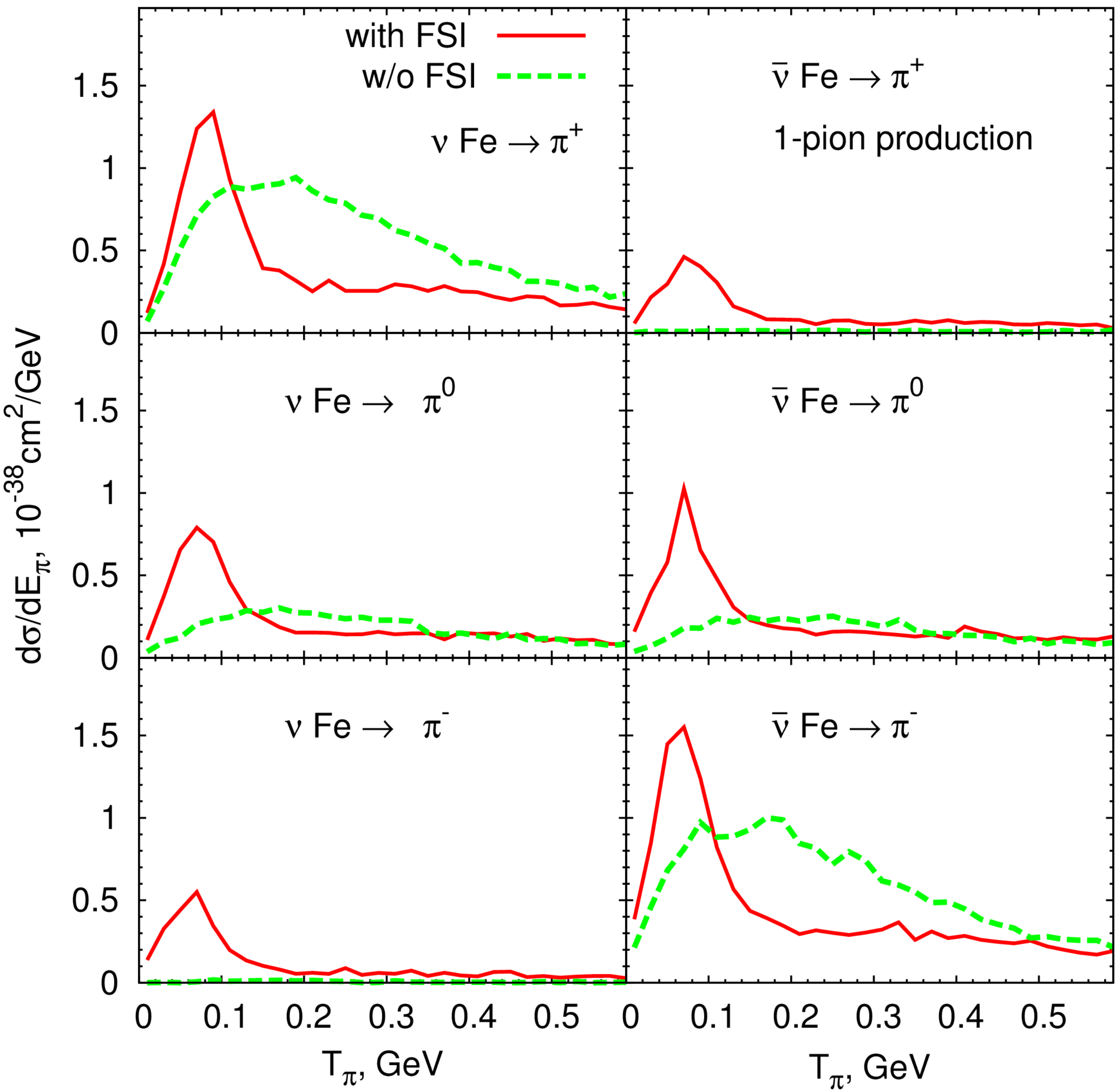
Benchmark: electroproduction



Krusche, Lehr, EPJA 22 (2004)

CLAS results on nuclei would be very interesting! (S. Manly, NuInt11)

MINERνA: Pions: with and w/o FSI



NuMI low-energy flux

$E_\mu > 1.5$ GeV

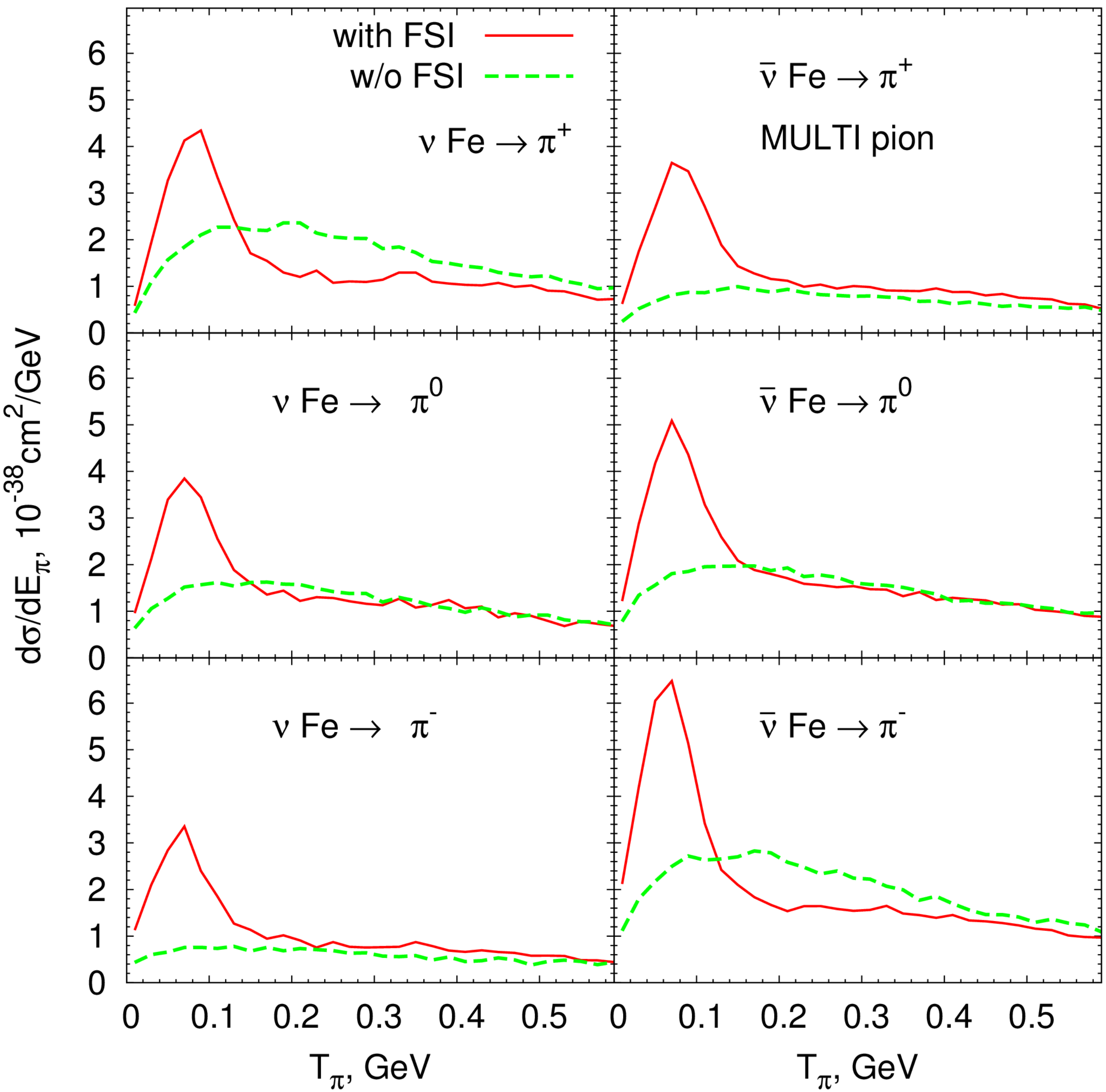
1-pion =

1 pion of a given charge
and
no other pions

FSI:
1) The shape of the spectra is changed

2) least dominant channels (π^- for ν, π^+ for $\bar{\nu}$) enhanced

Pions: with and w/o FSI



NuMI low-energy flux

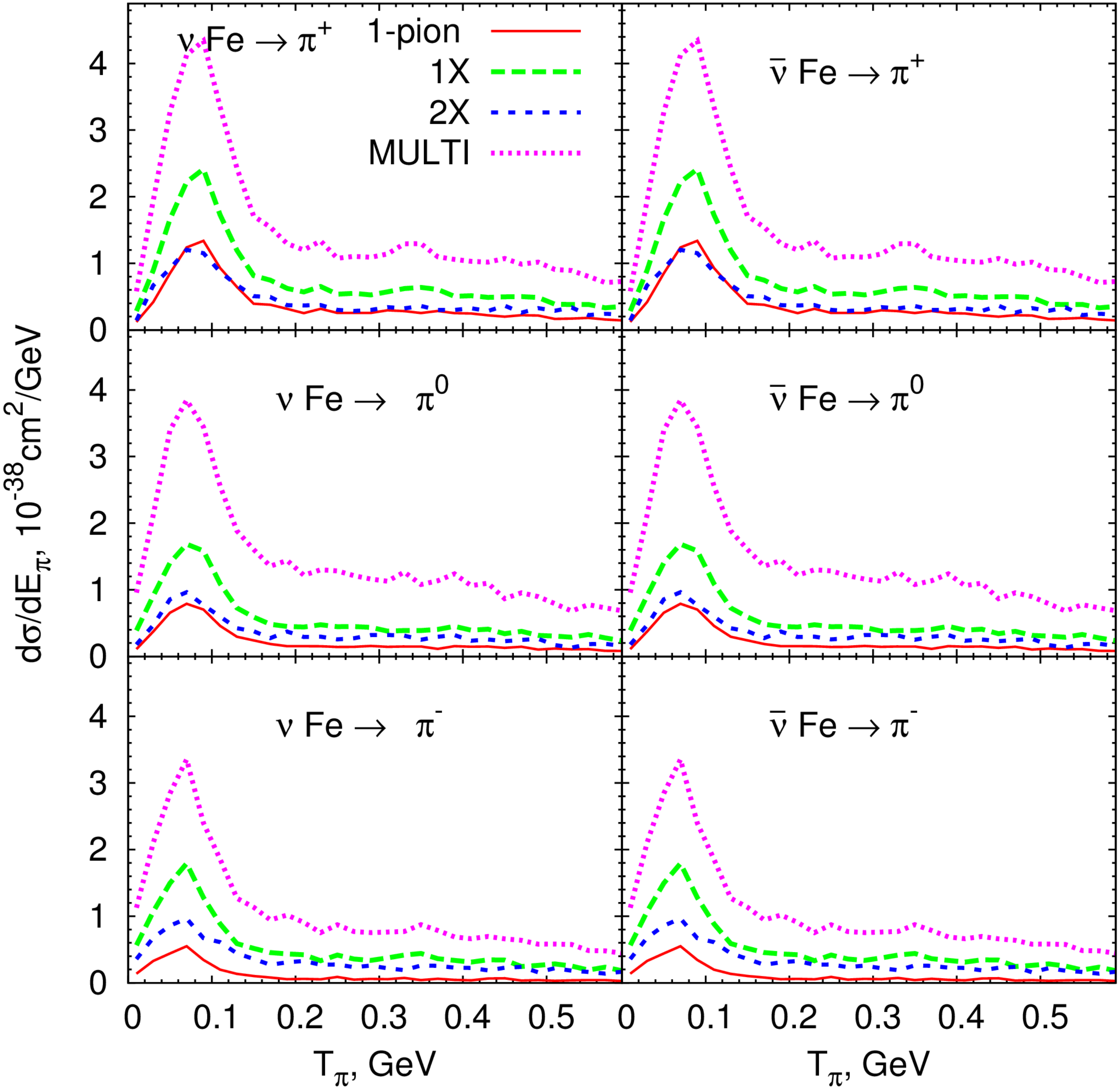
$E_\mu > 1.5$ GeV

MULTI pion =

at least 1 pion of a given charge and any number of other pions

FSI:
The output of low-energy pion increased

Pions: channels



1X=
1 pion of a given charge and
any number of other pions

2X=
2 pions of a given charge and
any number of other pions

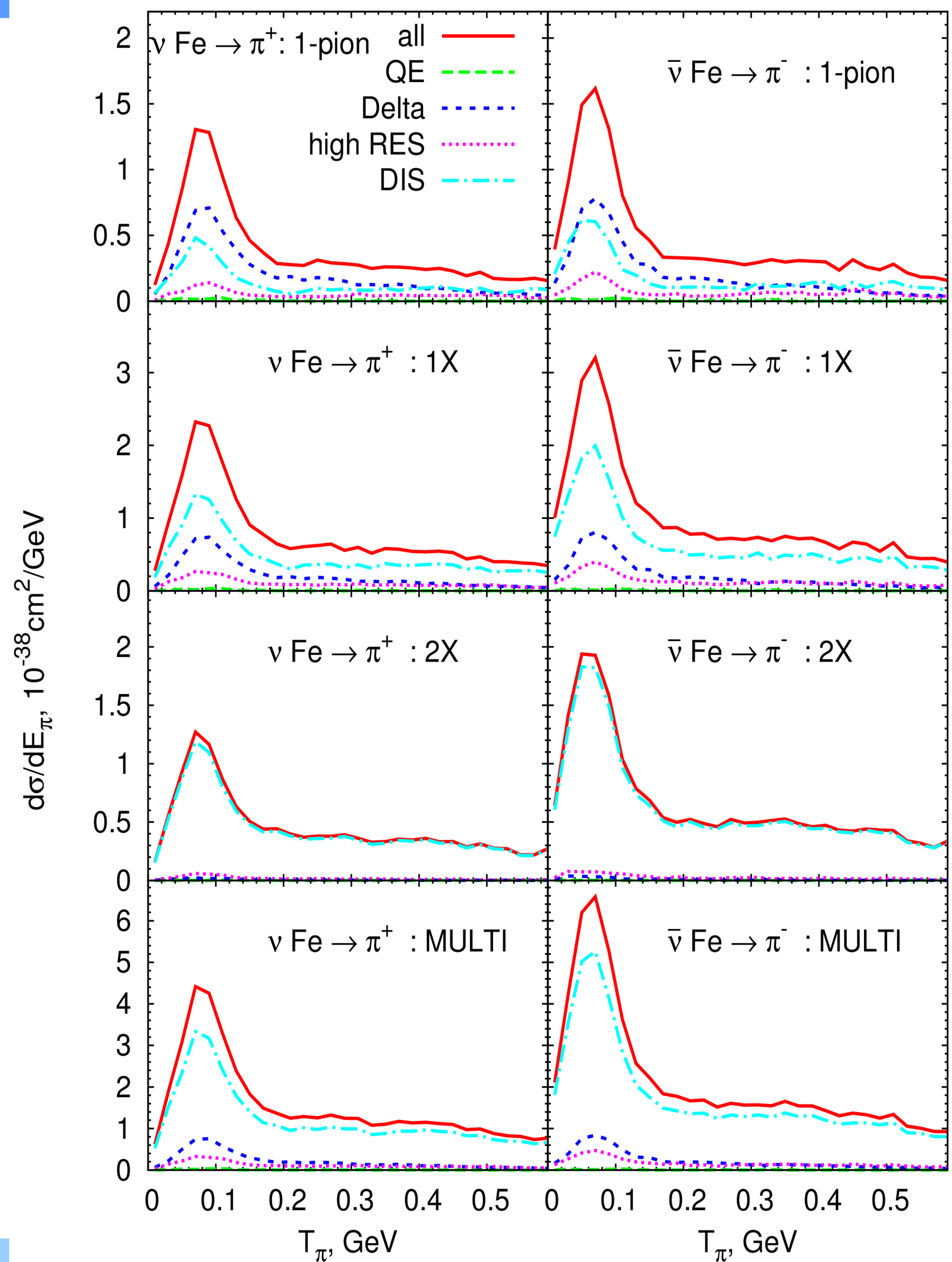
Pions: origin

1-pion: mostly from

Delta, also from DIS,

higher RES

2- and more pions:
dominantly DIS



Kaons:

Primary interactions (before FSI):

- Kaon production in low-energy region

  not implemented
- Kaons only from DIS

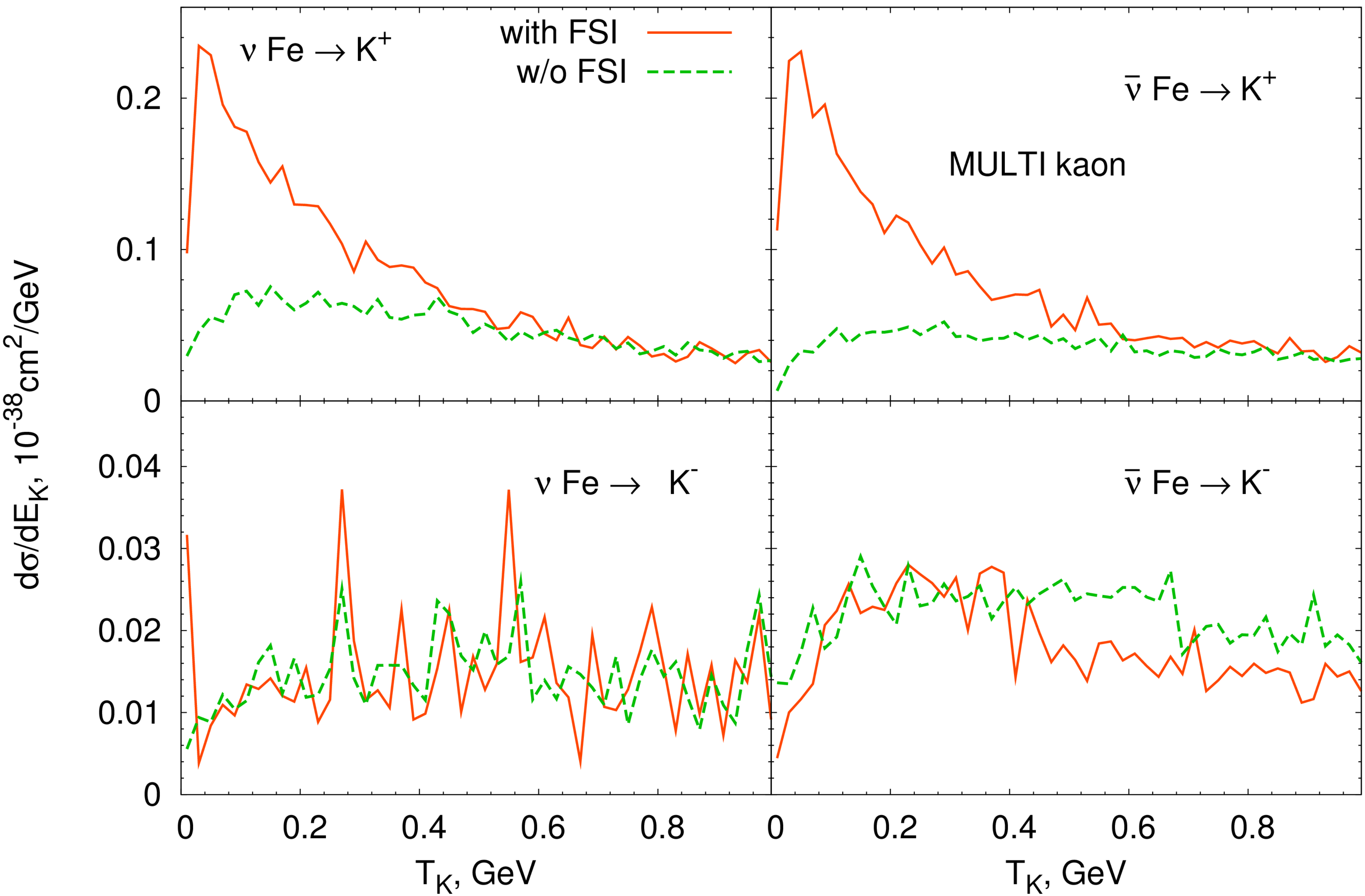
- FSI:
  - Outgoing pions/nucleons/resonances can rescatter

    $\pi N \to \Sigma K, \Lambda K, K\bar{K}N$

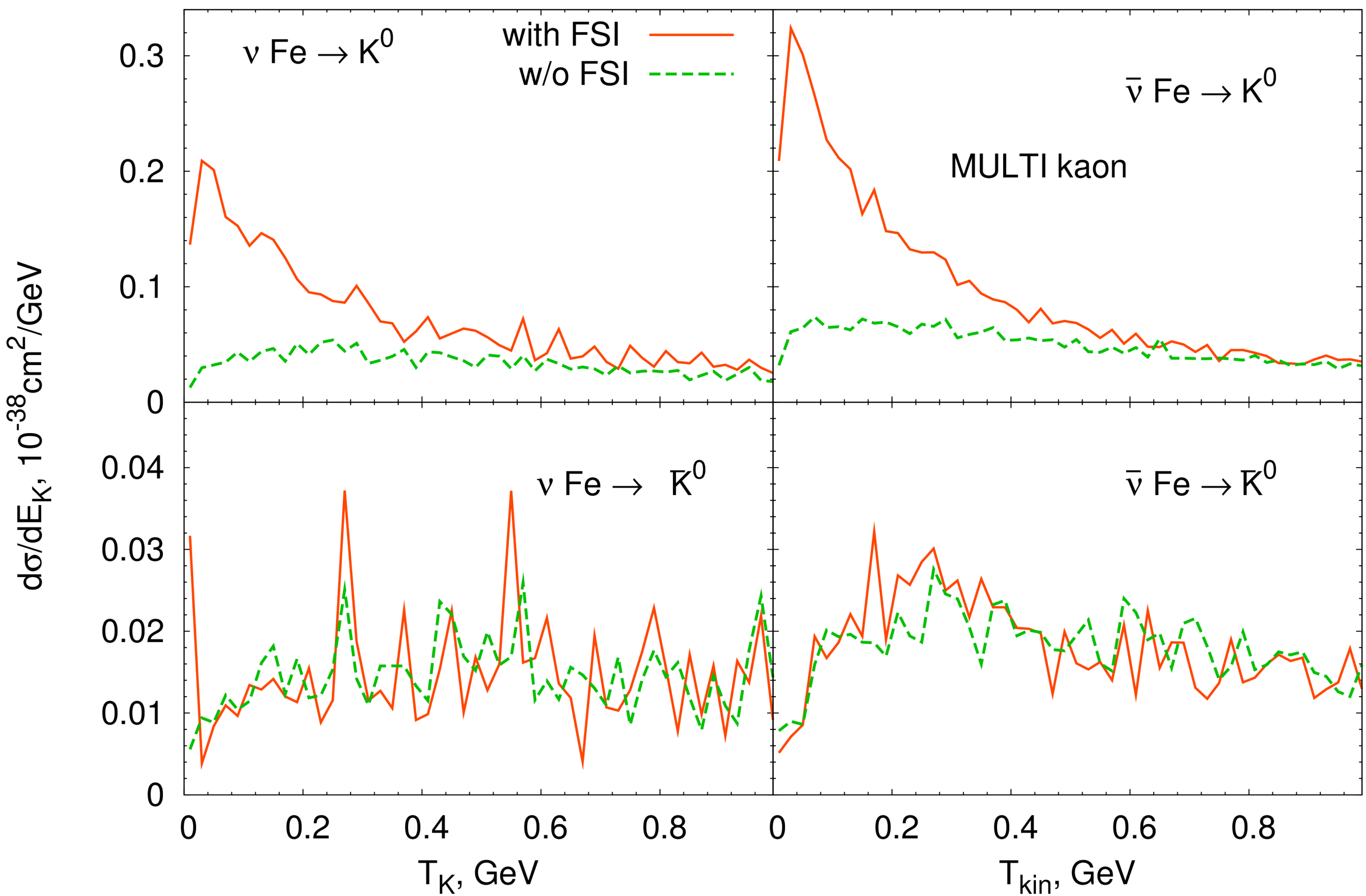
    $NN \to N\Sigma K, N\Lambda K$

    $NN \to NR, NR' \to NR$ with R decaying to kaons
  - Kaons can rescatter $KN \to KN, \Lambda\pi, \Sigma\pi$

Charged kaons: with and w/o FSI

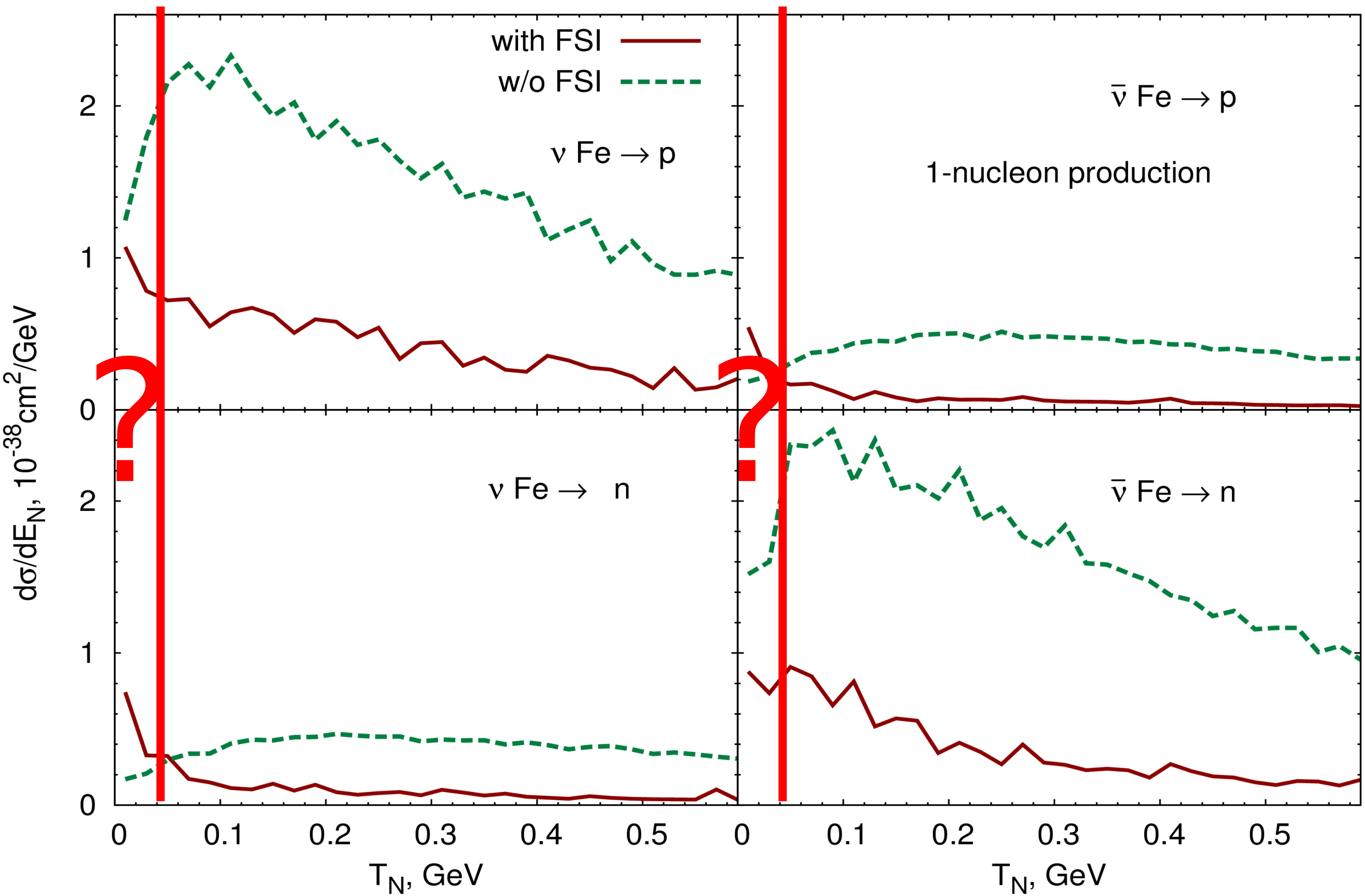


Neutral kaons: with and w/o FSI



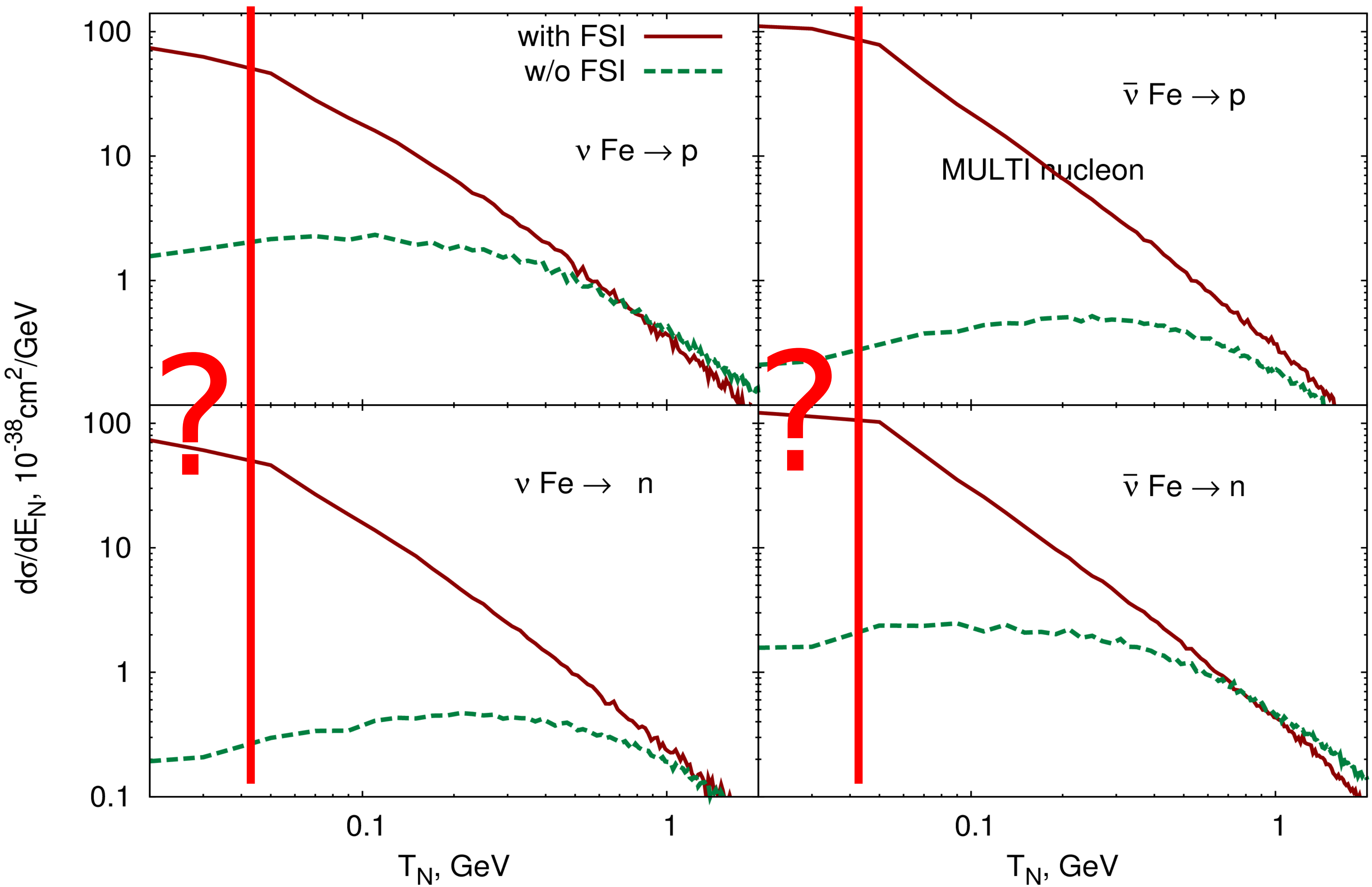
Nucleons: with and w/o FSI

FSI decrease 1-nucleon output



Nucleons: with and w/o FSI

FSI increase multi-nucleon output at low energies



Conclusions

- With DIS recently implemented in the GiBUU code , calculations for high energy neutrino scattering are possible
- Preliminary estimate of the nuclear effects uncertainty 4-5%
- Even within this uncertainty – a clear difference between the model and the EKS98 nuclear PDFs
- Predictions for energy distributions of various outgoing particles