IceDune Workshop

Neutrino Cross Sections

Alfonso Garcia

Overview

- Overall picture.

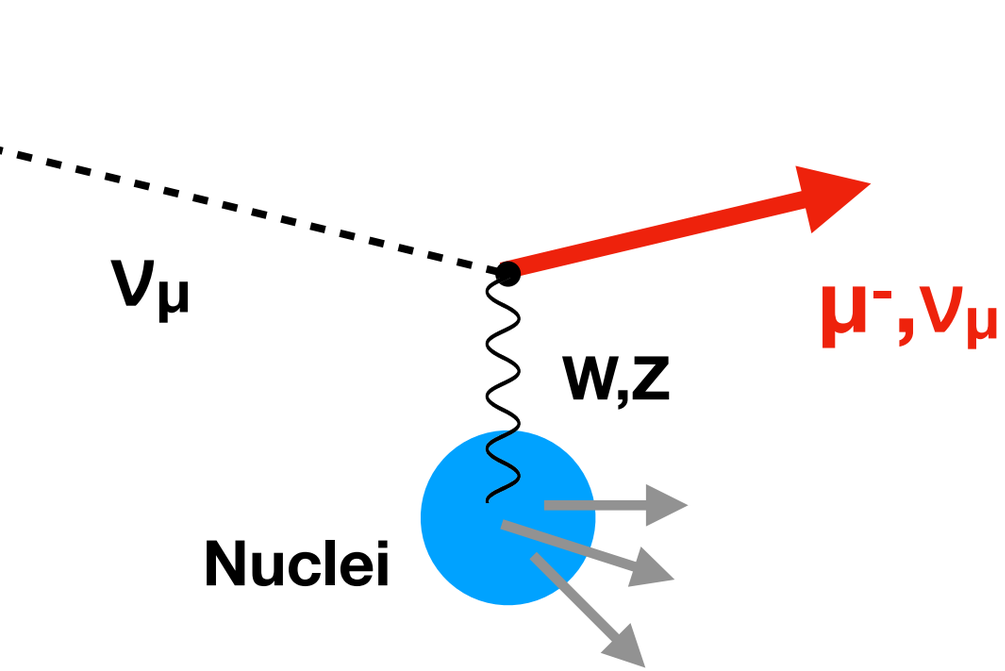
- Cross sections above 50 GeV.
  - pQCD vs Bodek-Yang.
  - Nuclear effects.
  - Flavour effects.

- Other effects.

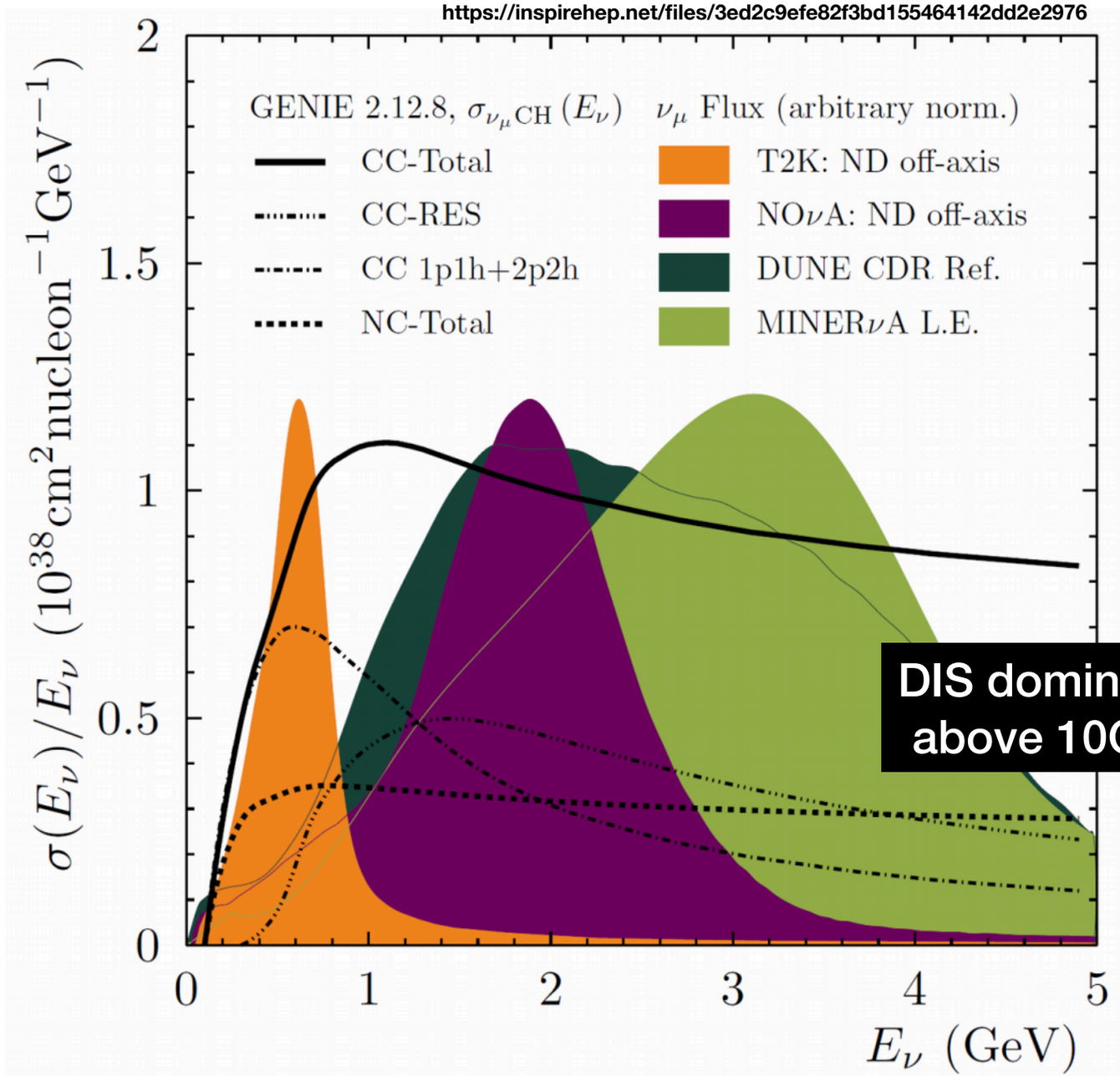
Neutrino-Nucleus scattering

- Neutrino-nucleus cross section dominates over a vast energy range.
- Many studies ongoing in the few-GeV region -> long baseline experiments

Quasielastic (1p1h)
MEC (2p2h)
Resonant
DIS



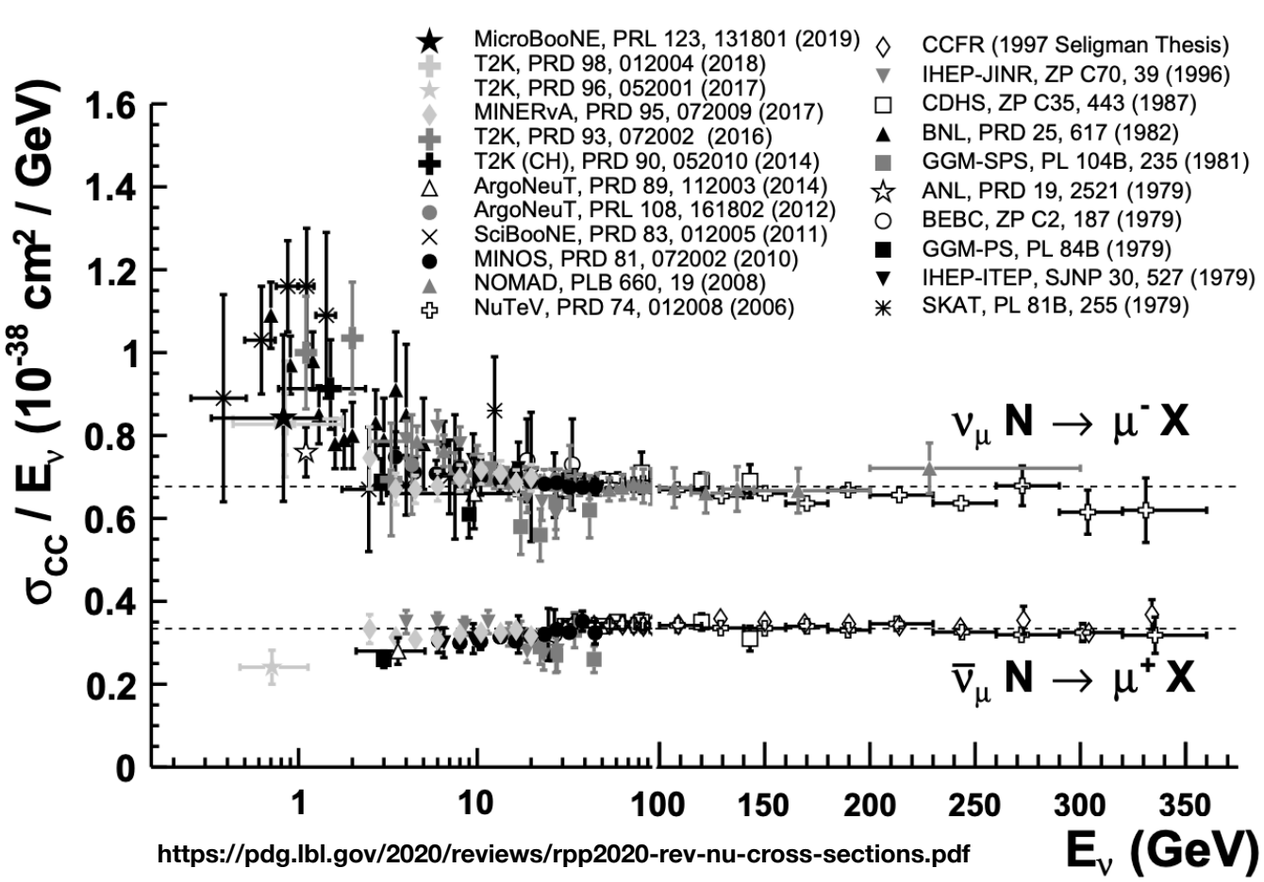
https://inspirehep.net/files/3ed2c9efe82f3bd155464142dd2e2976



DIS dominates above 10GeV

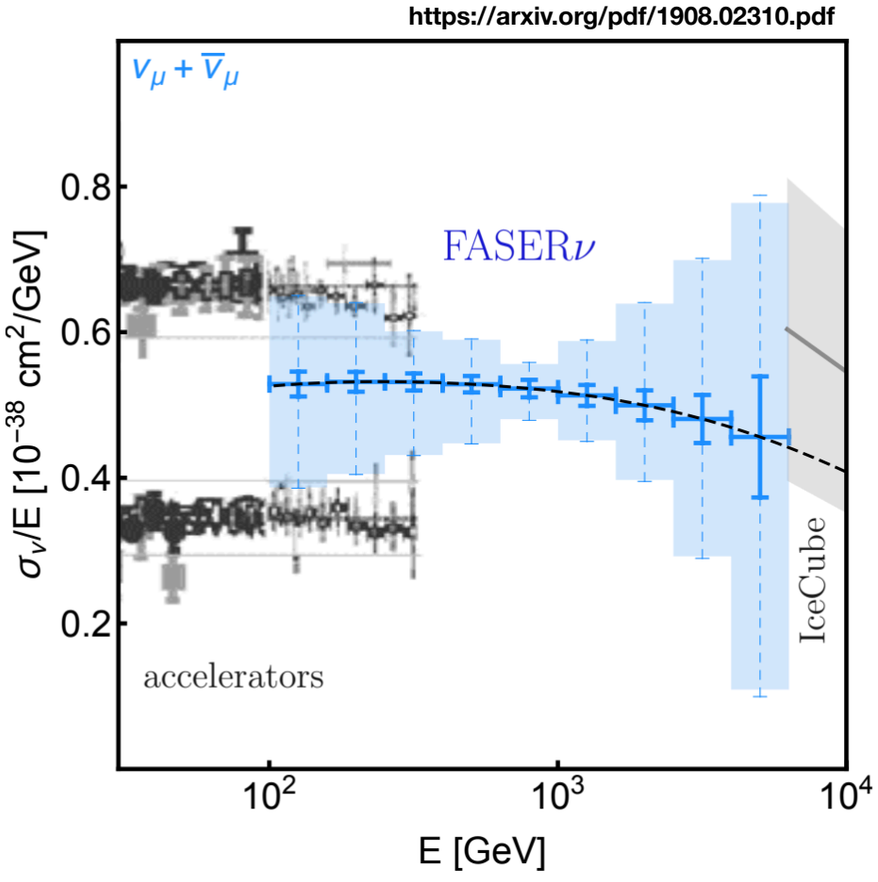
Available data

- 100GeV-1TeV region very important for studies with atmospheric neutrinos:
  - Precise measurements up to 300GeV (NuTev, NOMAD,etc.).
  - First measurements at E>10TeV from IceCube.
  - Promising prospects from FASERnu in the gap.



https://pdg.lbl.gov/2020/reviews/rpp2020-rev-nu-cross-sections.pdf

https://arxiv.org/pdf/1908.02310.pdf



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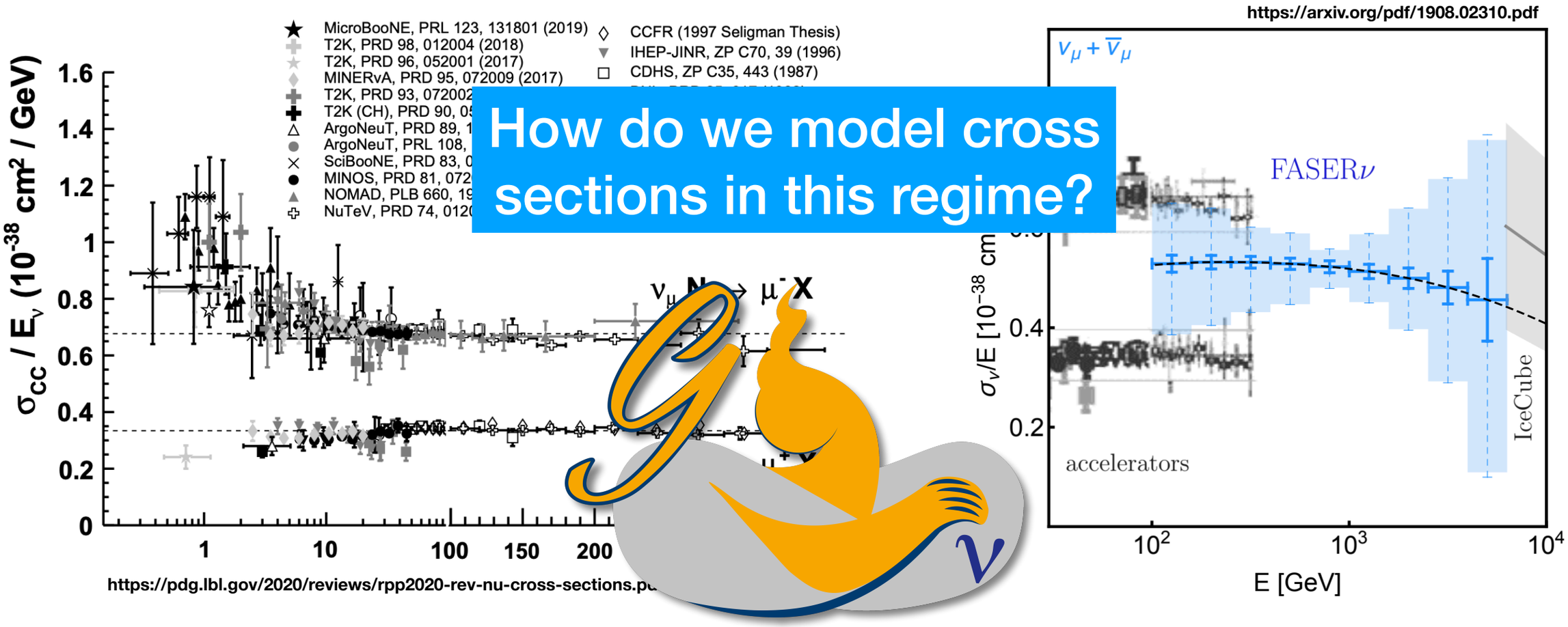
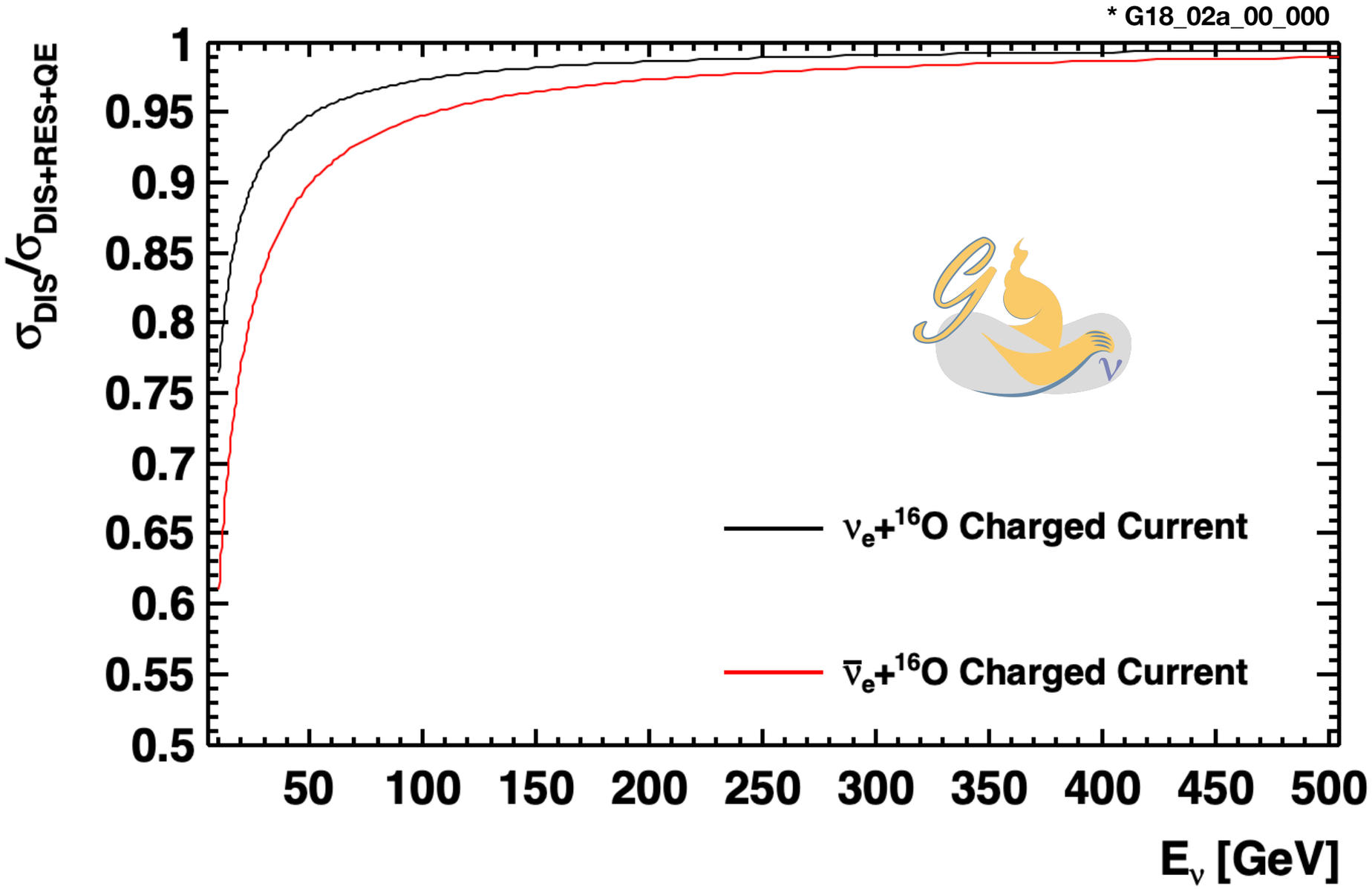


>10GeV

- Above 50GeV non-DIS contribution is <5%.
- Resonant contribution for antineutrinos enhanced.



DIS model

https://arxiv.org/pdf/hep-ph/0107261.pdf

$$\frac{\mathrm{d}\sigma^{\nu,\bar{\nu}}}{\mathrm{d}x\mathrm{d}y} = \frac{G_F^2 M E_\nu}{\pi}\Big[y\Big(xy + \frac{m_l^2}{2E_\nu M}\Big)F_1 + \Big(1 - y - \frac{Mxy}{2E_\nu} - \frac{m_l^2}{4E_\nu^2}\Big)F_2 \pm \Big(xy(1-\frac{y}{2}) - y\frac{m_l^2}{4ME_\nu}\Big)F_3 + \Big(xy\frac{m_l^2}{2ME_\nu} + \frac{m_l^4}{4M^2E_\nu^2}\Big)F_4 - \frac{m_l^2}{2ME_\nu}F_5\Big]$$

- Mass effect relevant for tau production and low energies.
- Structure functions summarise the dynamics of nuclei.

$$F_i\left(x,Q^2\right) = \sum_j \int_x^1 \frac{\mathrm{d}z}{z} f_j\left(z,Q^2\right) C_{i,j}\left(\frac{x}{z},Q^2\right)$$

Parton Density Functions

- Calculated from fit to hadron data.
- Lookup tables (x,Q2) .

Coefficient functions

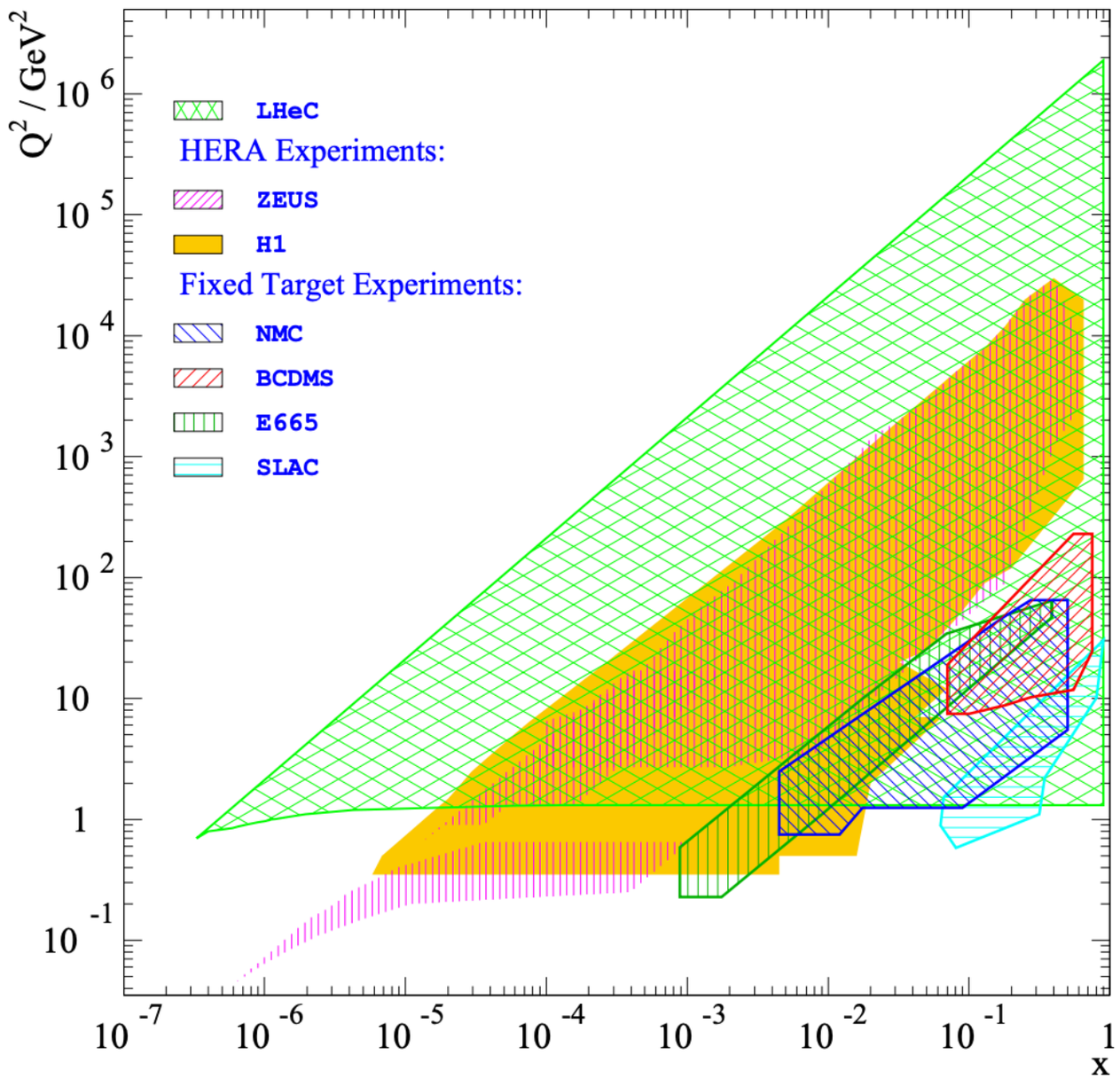
- Calculated from Feynman diagrams.
- Depend on order in pQCD.

Phase Space

- Probing different regions of x, Q^2 depending on the energy of the neutrino.

PDFs mainly based on fits to these experiments.

https://arxiv.org/pdf/hep-ex/0603016.pdf



Phase Space

- Probing different regions of x,Q^2 depending on the energy of the neutrino.

Ev = 50GeV

- Low Q2 contributions.
- Double-counting between RES and DIS is important.
- pQCD fails at these energies.
- Non-perturbative QCD corrections.

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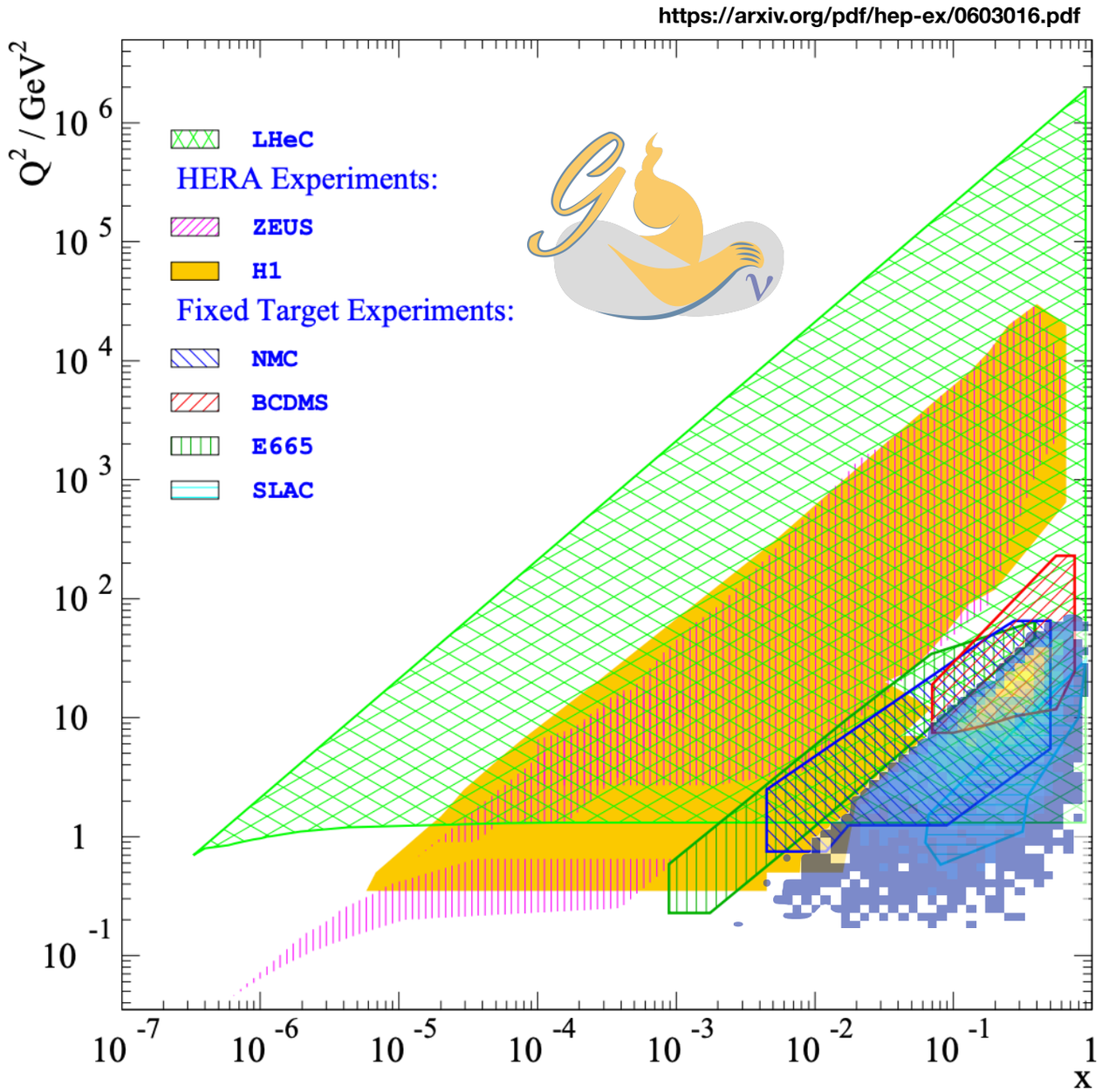

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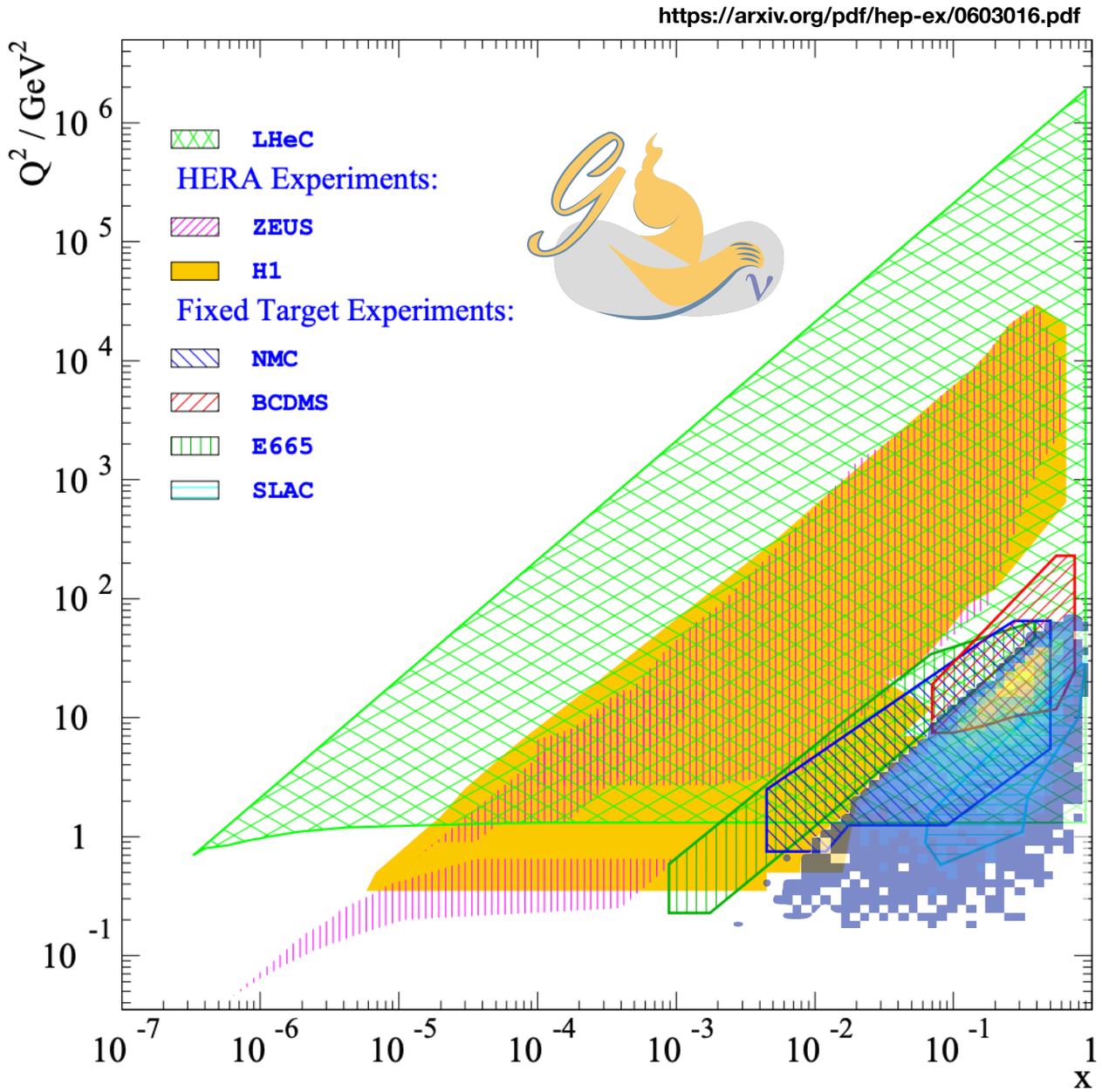
BODEK-YANG

PDF: GRV98lo -> $Q^2_{min} = 0.8$ (GeV/c)^2

https://arxiv.org/pdf/hep-ex/0603016.pdf



Phase Space

- Probing different regions of x,Q^2 depending on the energy of the neutrino.

Ev = 1TeV

- Medium Q2 contributions.
- pQCD works at these energies.
- Charm production is relevant.

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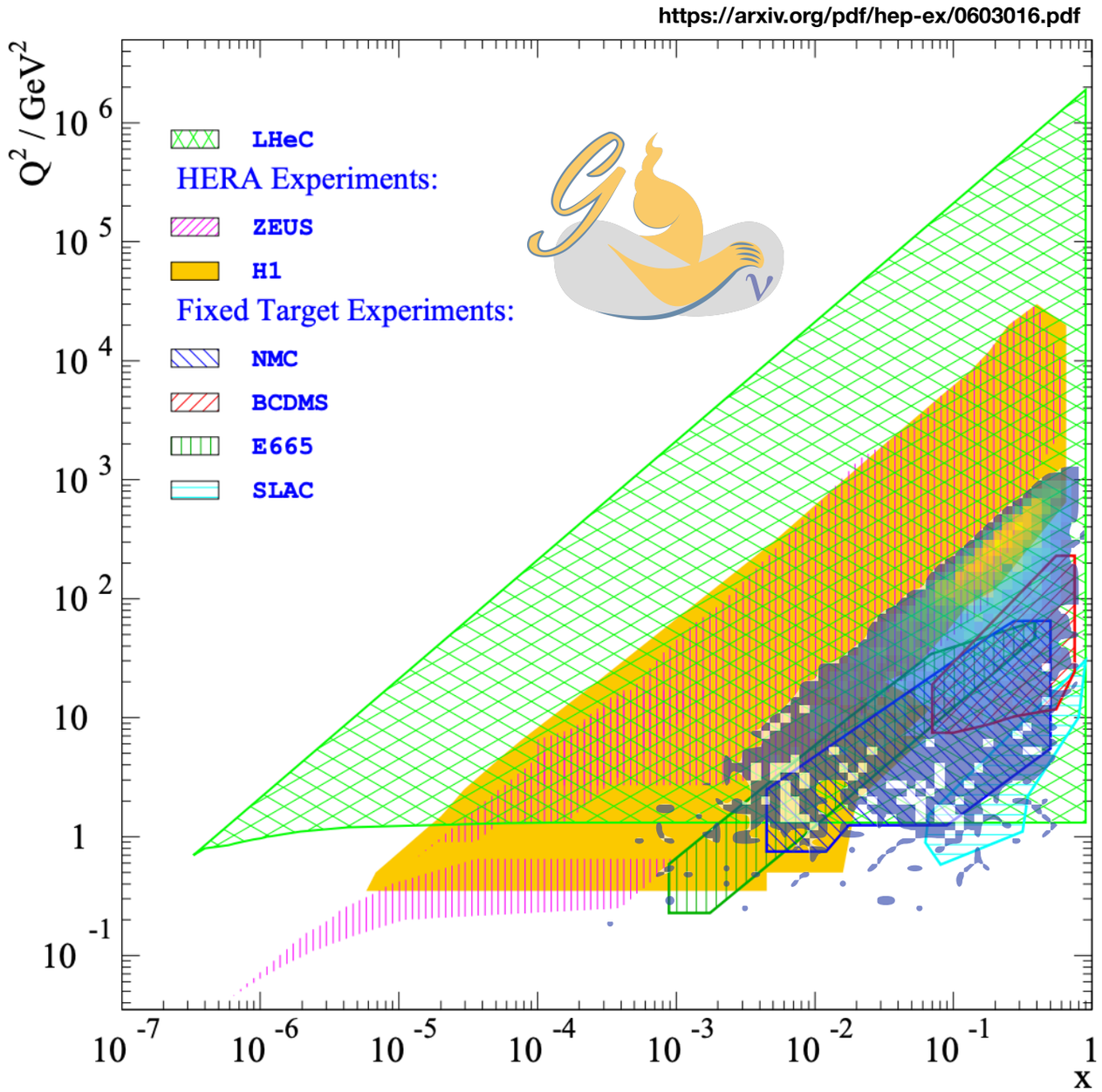

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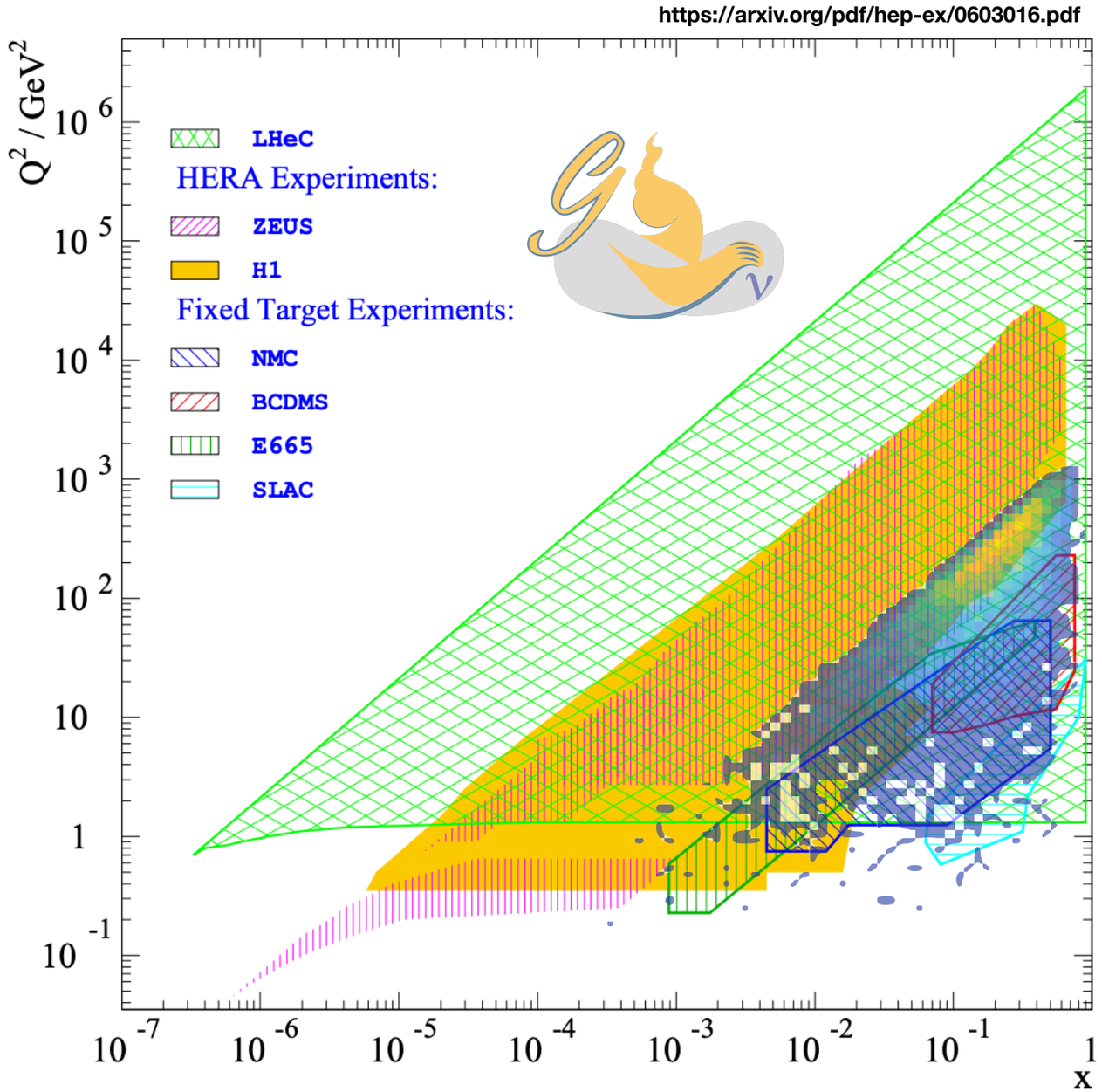
CSMS

PDF: HERAPDF15NLO

Q^2_{min} = 1.0 $(GeV/c)^2$

https://arxiv.org/pdf/hep-ex/0603016.pdf



Phase Space

- Probing different regions of x, Q^2 depending on the energy of the neutrino.

Ev = 1PeV

- High Q2 & low x contribution.
- Lack of PDFs data in this regime.
- Top production is relevant.

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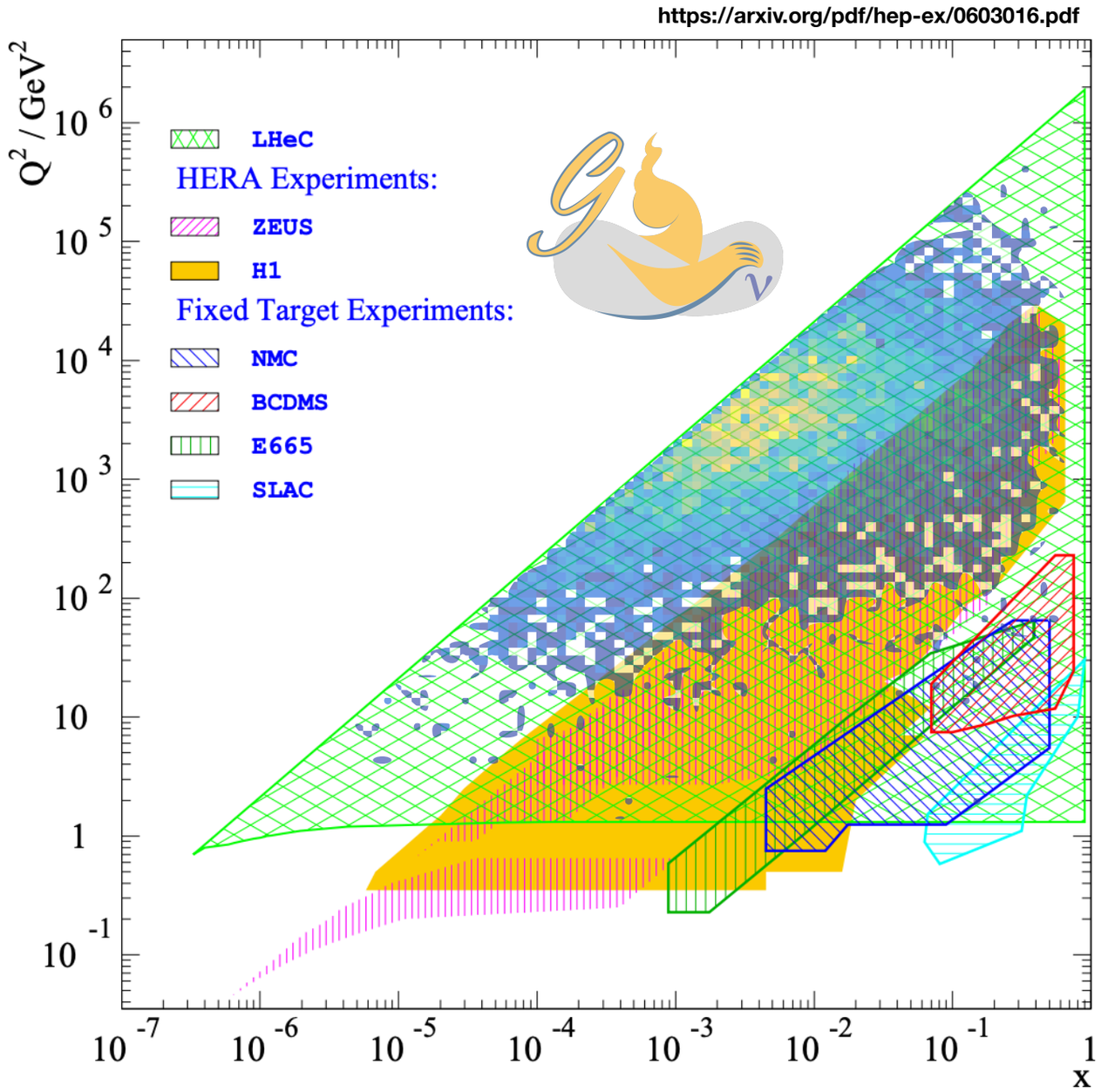

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BGR

PDF: HERAPDF15NLO

$Q^2_{min} = 2.69\ (GeV/c)^2$

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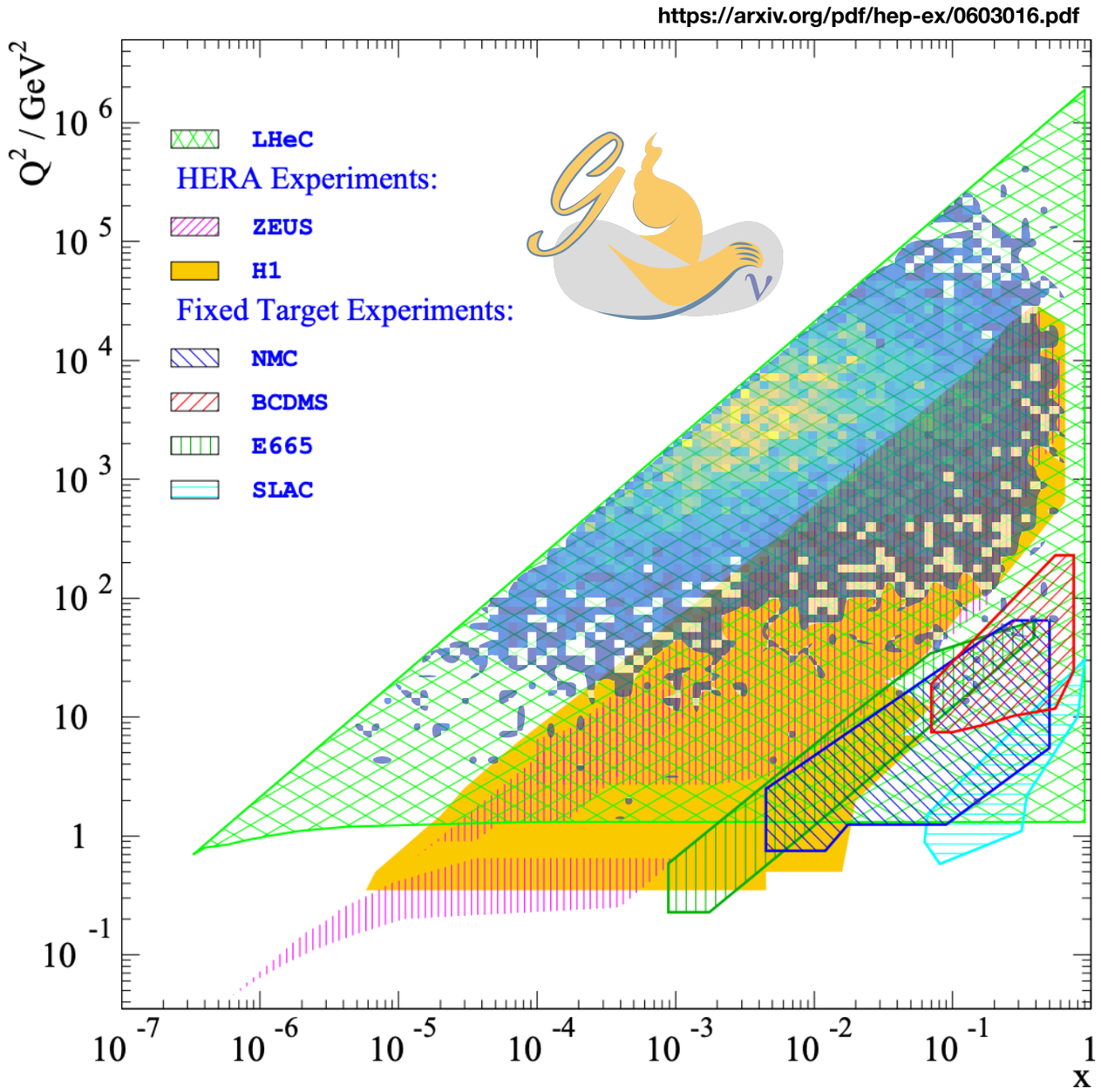

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For higher energies very low x contributions are relevant and pQCD breaks down.

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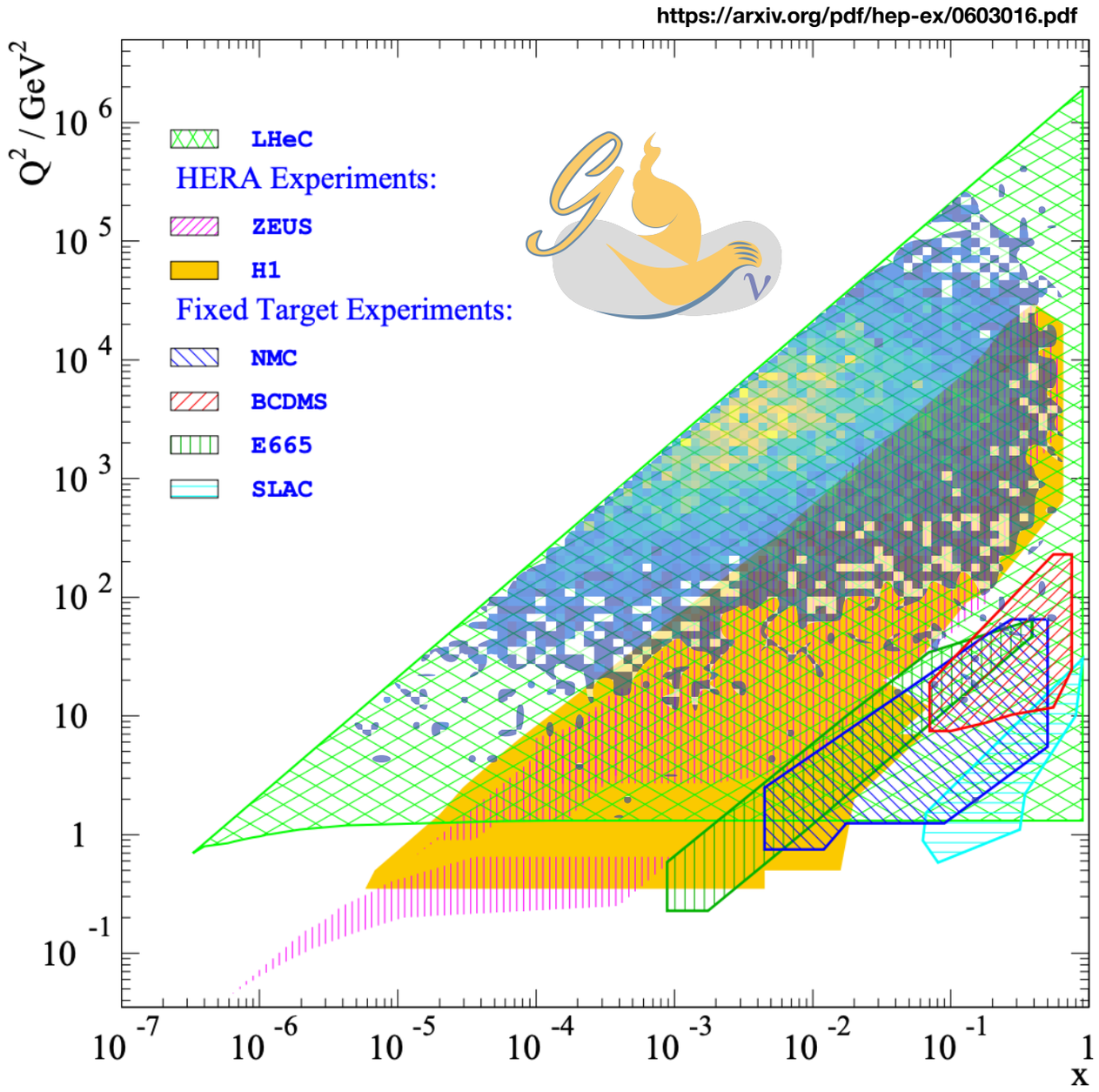
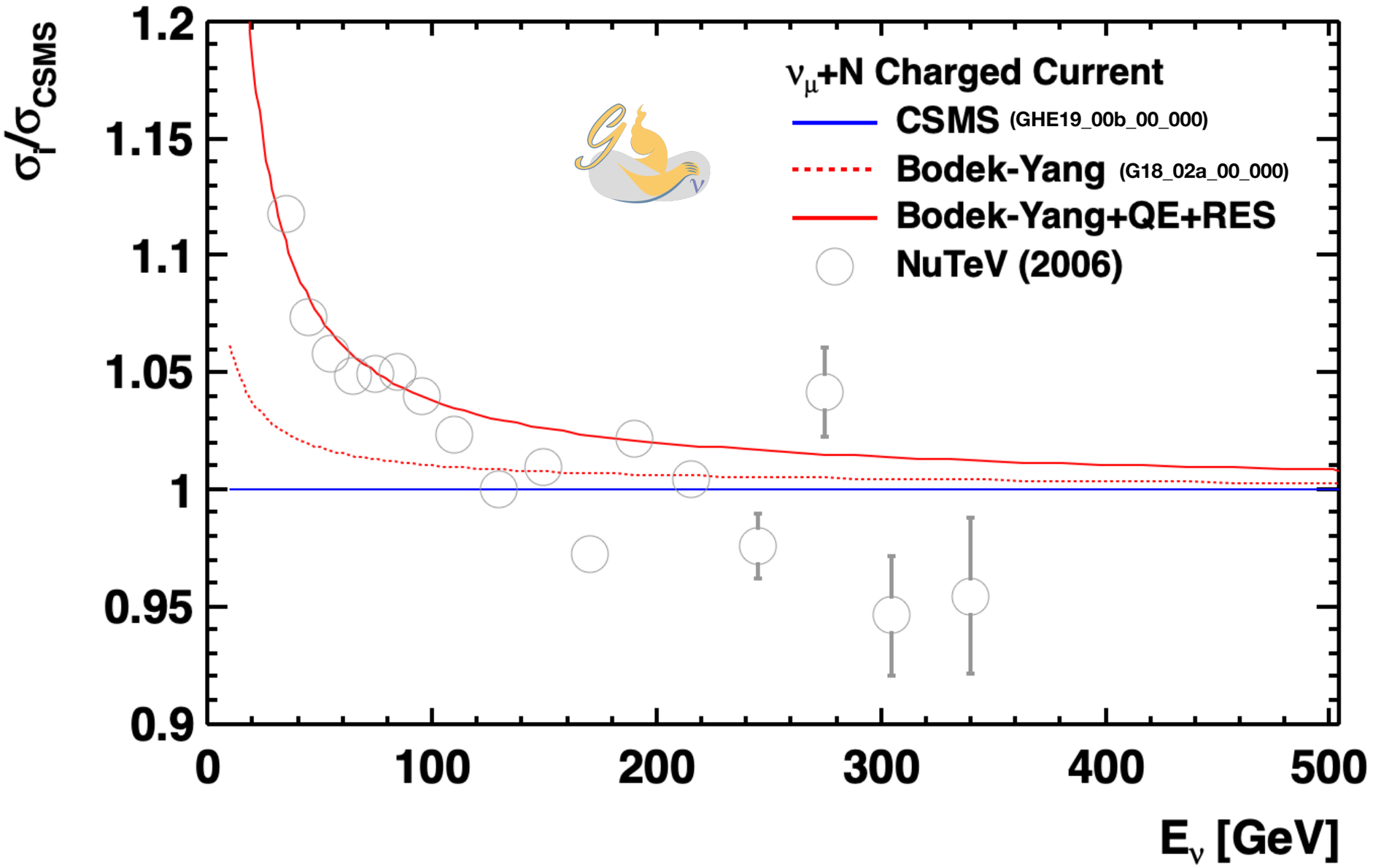


Bodek-Yang to CSMS

- The transition between non-perturbative QCD models and pQCD happens at ~100GeV.



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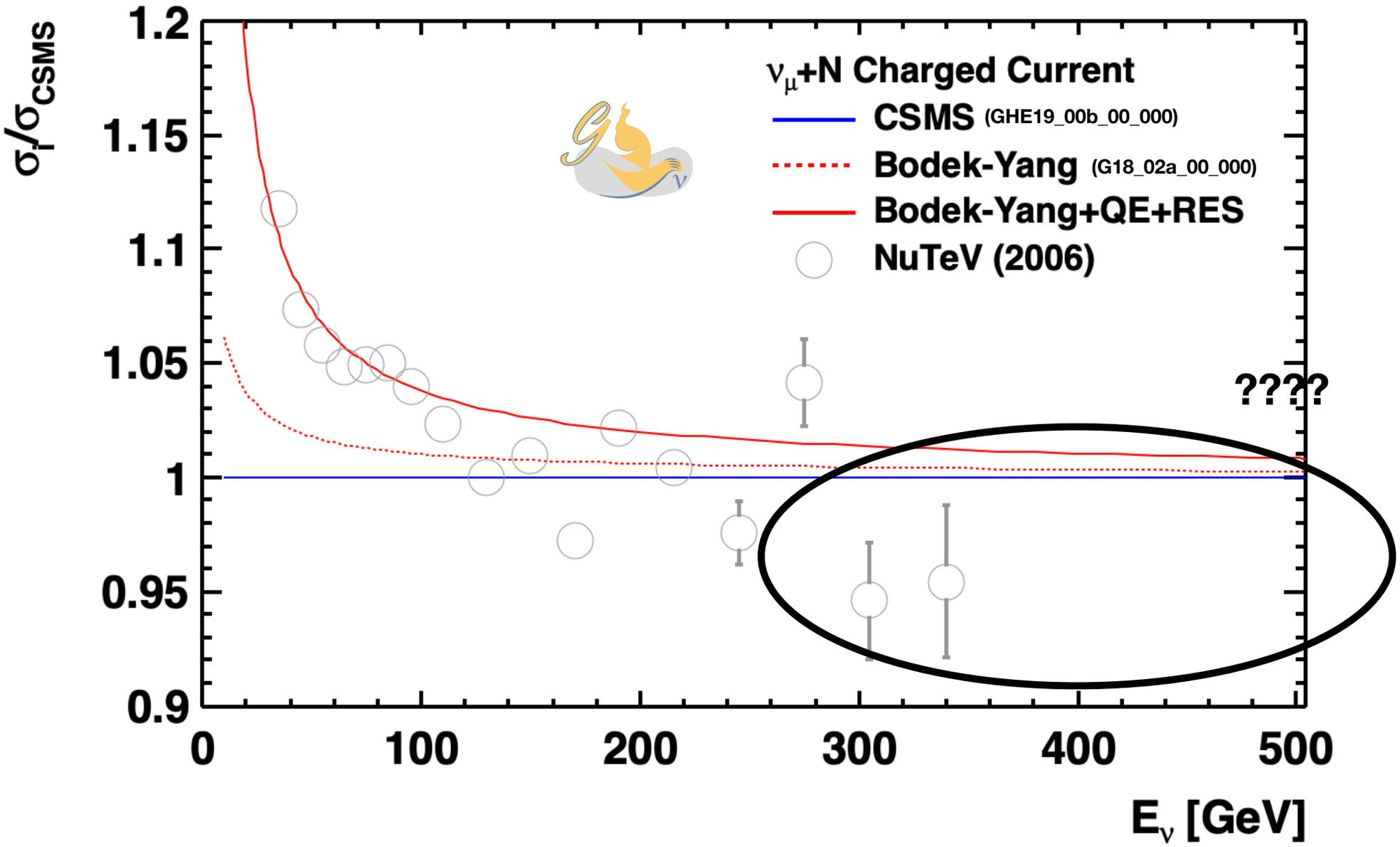

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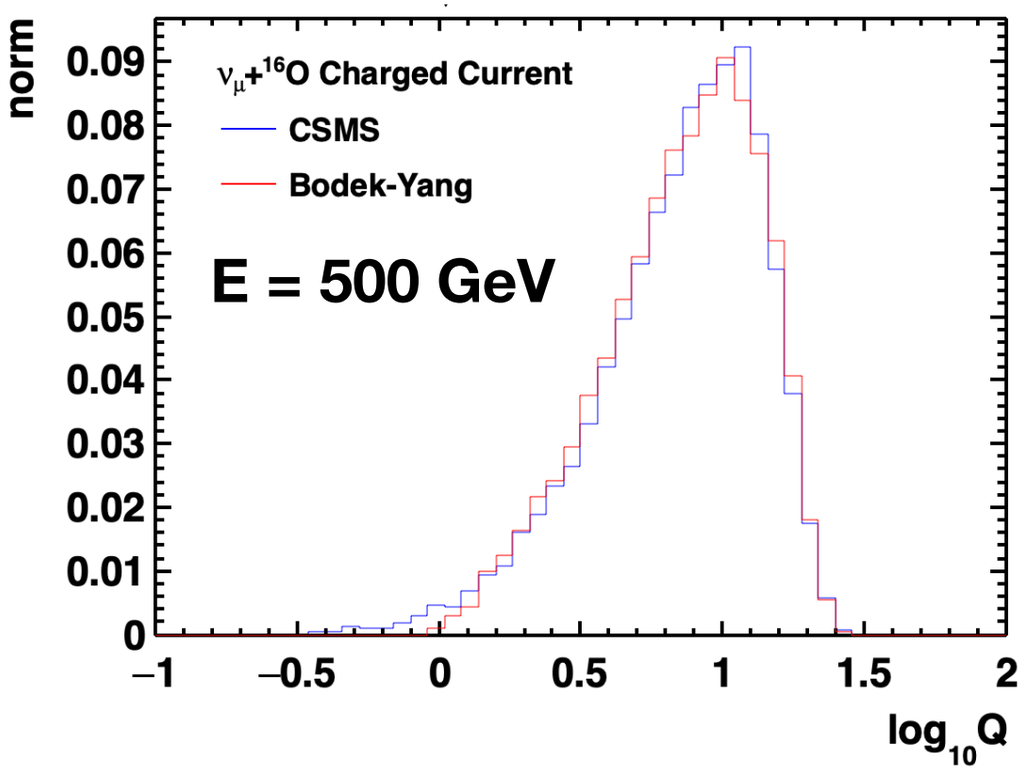
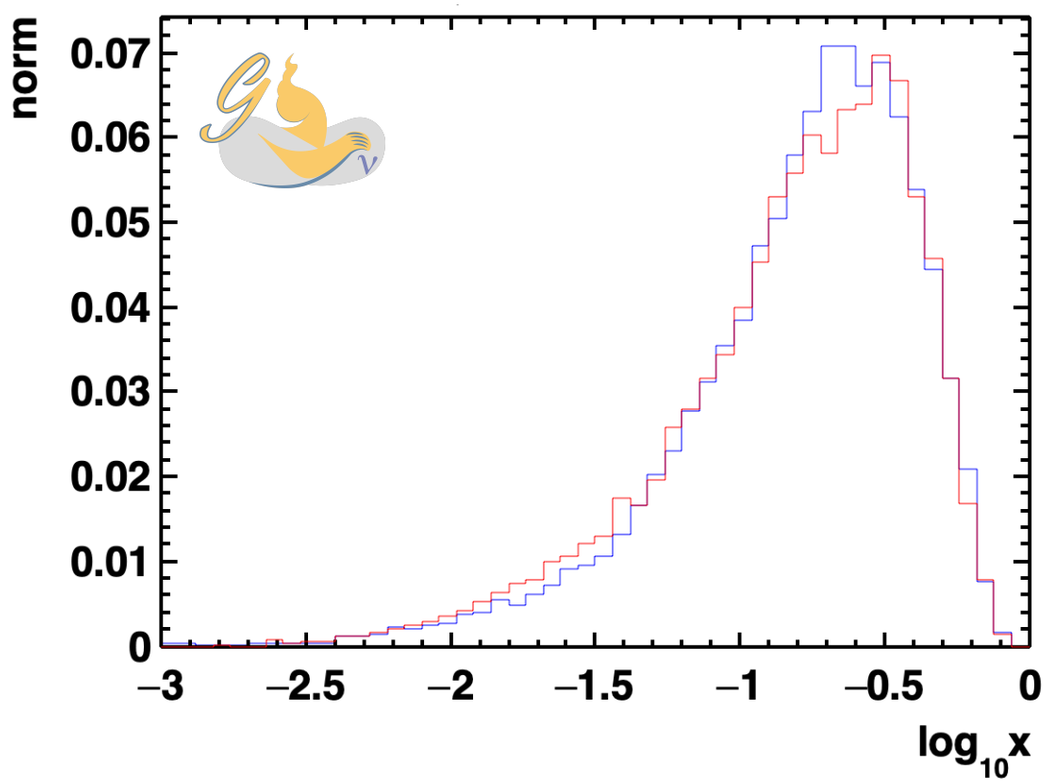
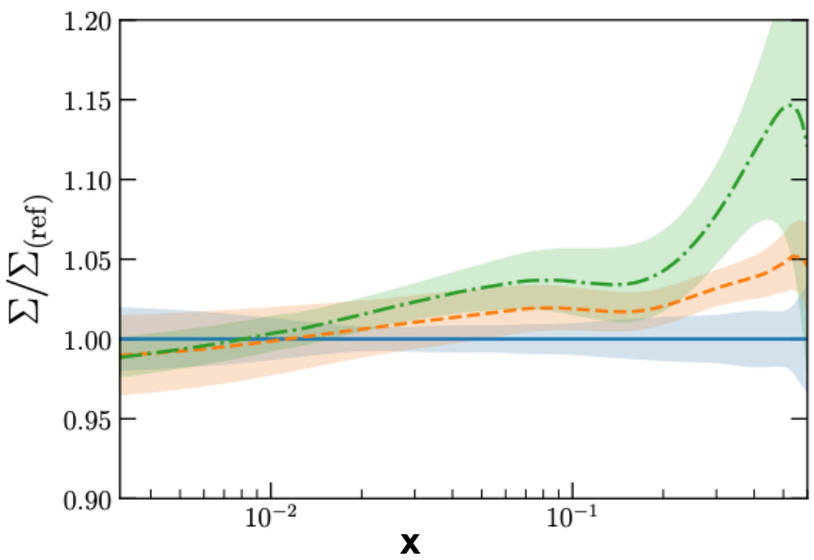
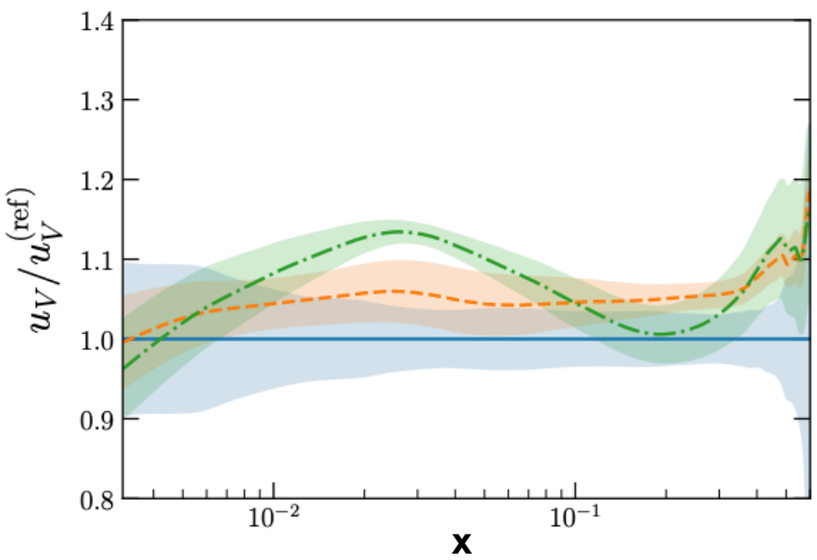
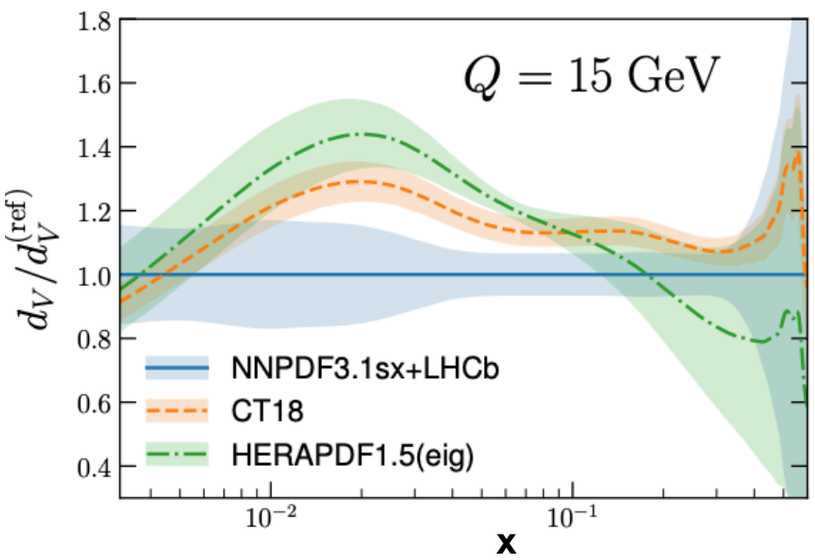




- Different PDFs show large difference in this region of phase space.
- New data in this region will be very valuable.

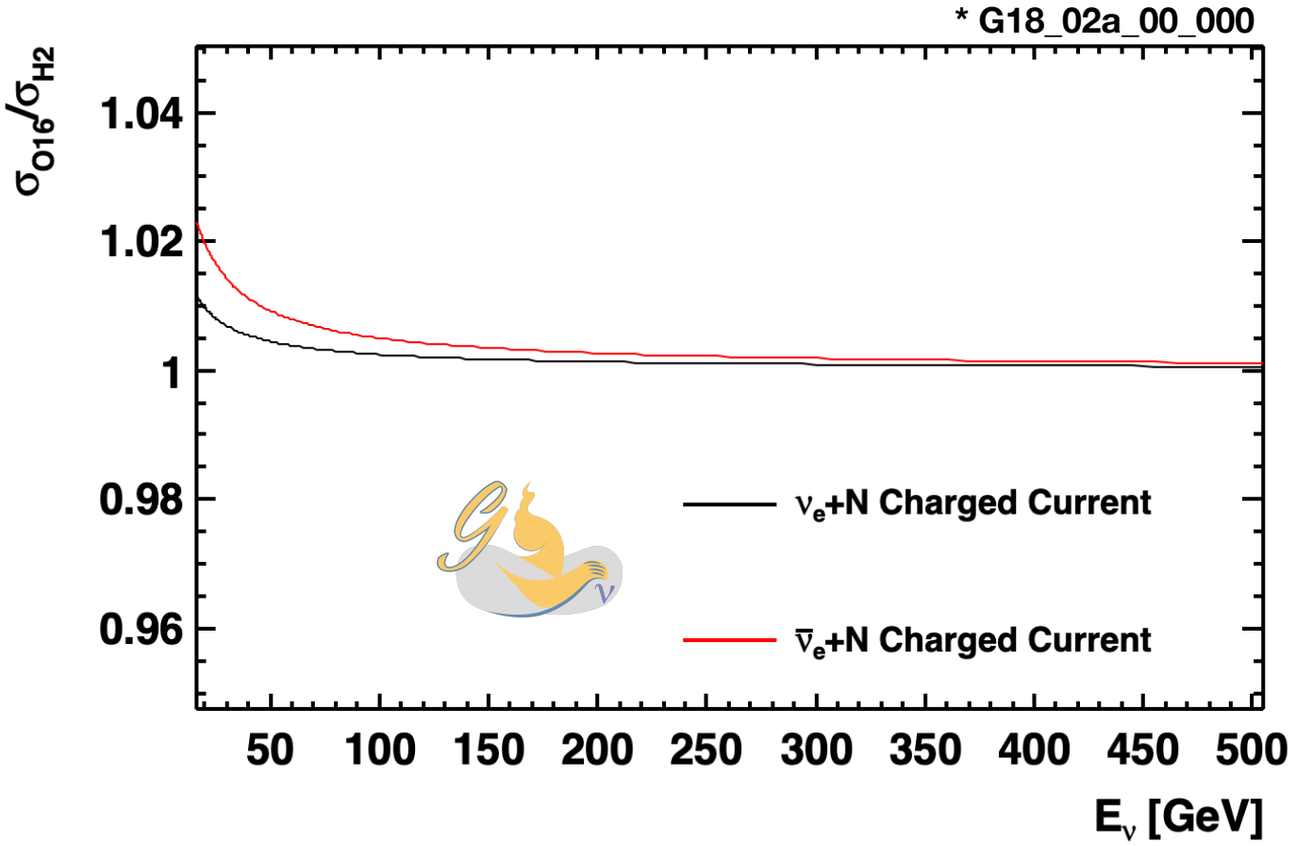


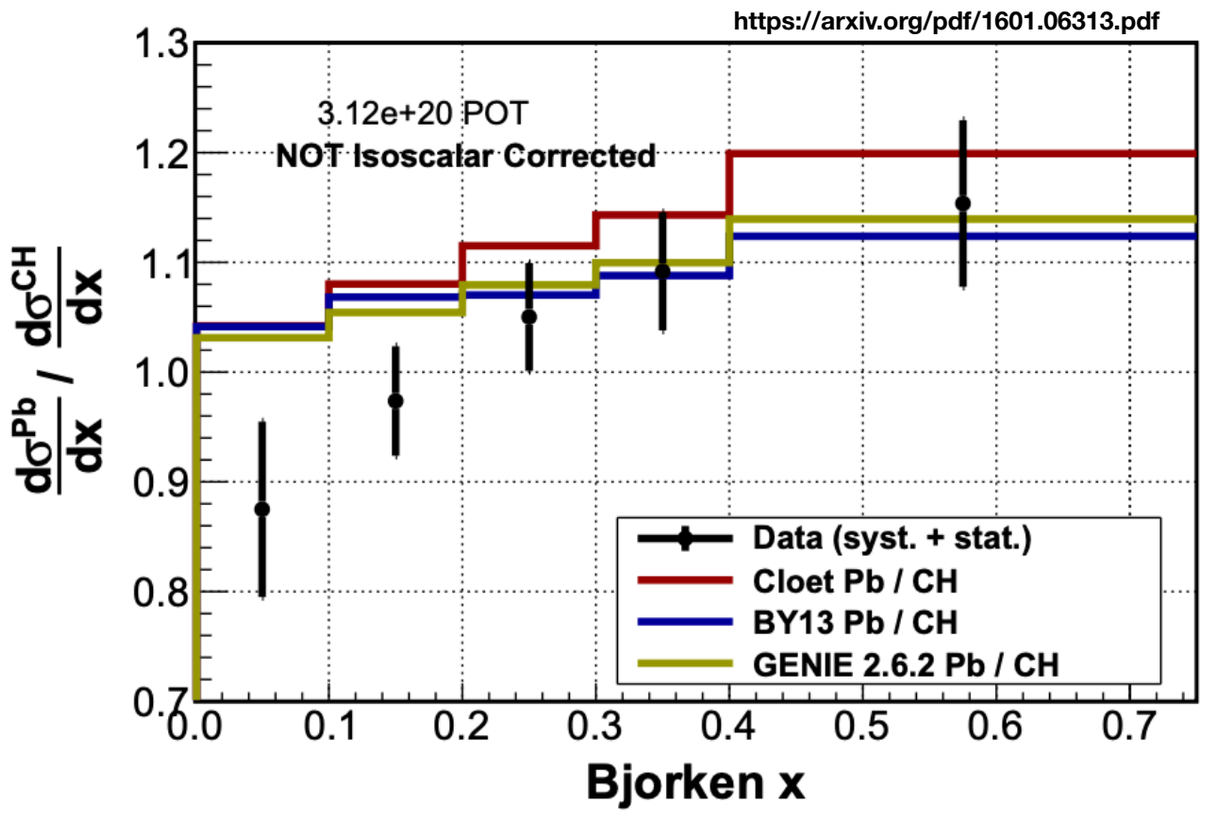




Nuclear effects

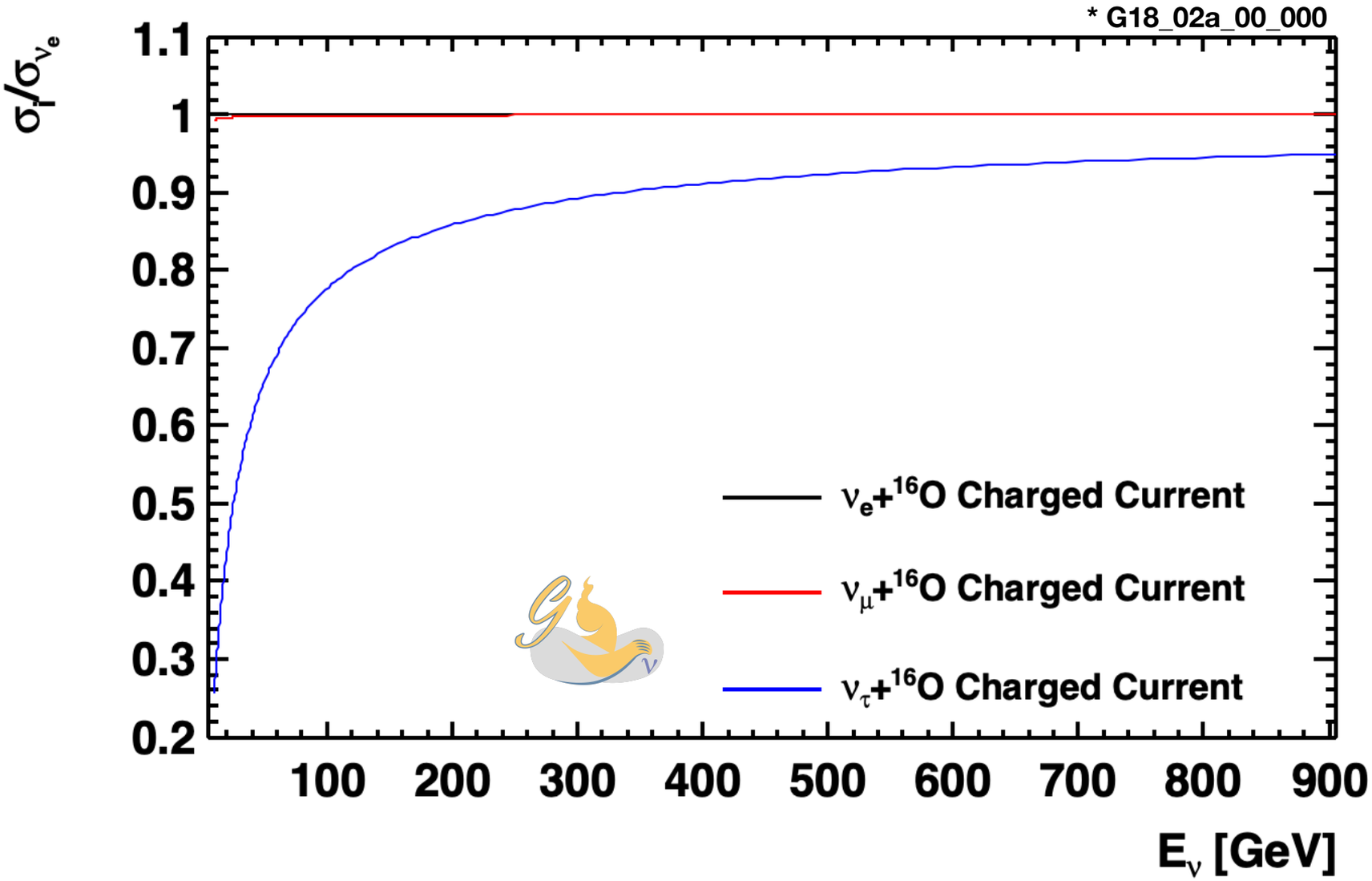
- Simple implementation (just nucleon scaling) in neutrino generators.
- Experiments (like Minerva) are showing nuclear effects not modelled.
- Are these effects similar to those observed in charged lepton-nucleon scattering?





Flavor effects

- Big impact of tau mass at low energies (threshold).
- Predictions of 5% reduction at 1TeV.



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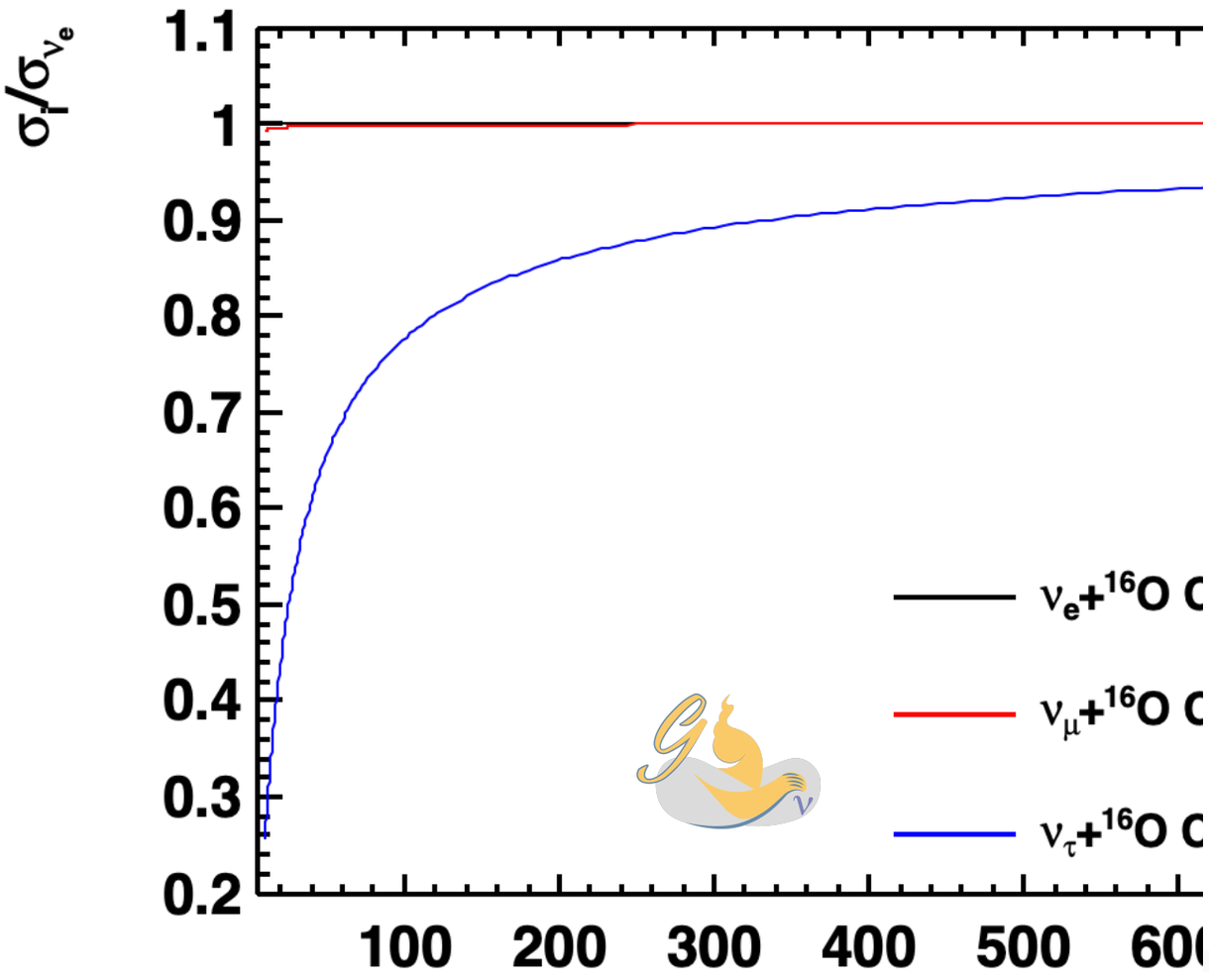

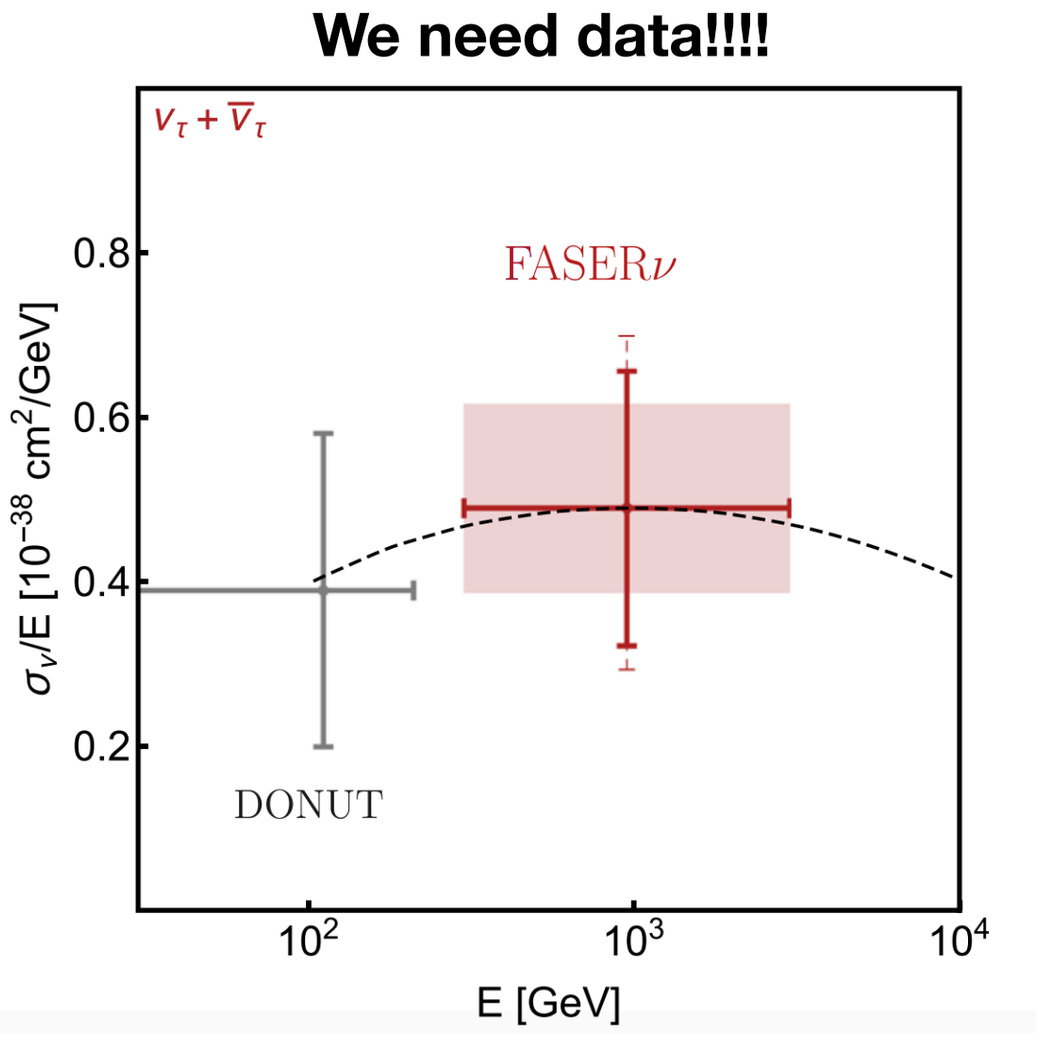

E_ν [GeV]

Others

- Tau polarisation:
  - Spin polarisation of Taus produced in neutrino-nucleus CC cross section.
  - Energy distribution of the different tau products depends on the helicity of the decaying tau.

- Hadronization:
  - Details of hadronic shower are currently poorly understood.
  - Simulations assume simplistic partonic models.
  - Heavy hadrons (mainly charmed) are non-negligible for E>100GeV.
  - Can we learn something from other simulation packages (LHC, Auger, etc.)?

Conclusions

- Understanding of Neutrino-Nucleus cross section at percent level to do precise measurements with IceCube and DUNE.

- Treatment of systematics uncertainties must be revised for E>10GeV.

- Main items:
  - Transition region between pQCD and non perturbative.
  - Differences in PDFs in a region of phase space relevant for 0.1-1TeV neutrino interactions.
  - Are nuclear effects relevant in this energy range?
  - Tau mass effects (cross section reduction, polarisation).
  - Hadronization.

Acknowledgement:

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