Electron scattering experiments for neutrino cross sections

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based on
A. M. A. and Alexander Friedland, PRD 102, 053001 (2020)
A. M. A. and Alexander Friedland, and Shirley Li, in preparation

GENIE in a nutshell

- Generator of choice for all ongoing Fermilab-based neutrino experiments, used also by T2K

- **Not tuned to electron-scattering data**
  In principle, an opportunity to determine various systematic uncertainties

- From the mission statement:

> "The GENIE Collaboration shall provide electron-nucleus, hadron-nucleus and nucleon decay generators in the **same physics framework** as the neutrino-nucleus generator."

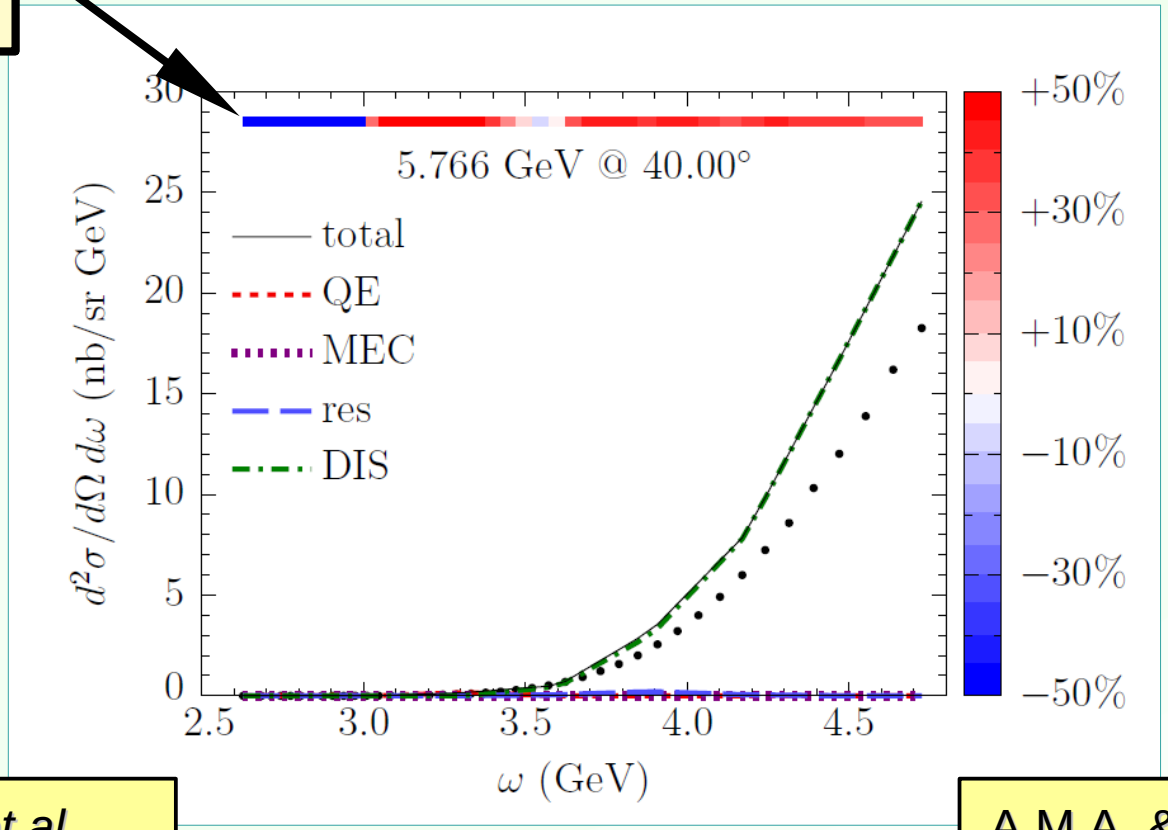
GENIE 2 in a nutshell

- **Nuclear model**: relativistic Fermi gas of Bodek & Ritchie **('81)**
- **Quasielastic** interactions: Llewellyn-Smith (Rosenbluth) formula for neutrinos (electrons). Parameters fitted to deuteron data. **('72)**
- **Meson-exchange currents**: Phenomenological Dytman approach developed to fit the MiniBooNE ν data **('88, '13)**
- **Resonance excitation**: model of Rein and Sehgal (16 resonances with updated parameters) **('81)**
- **Deep-inelastic scattering**: model of Bodek and Yang, used also to calculate nonresonant background for low invariant hadronic masses, $W < 1.7$ GeV. **('05)**

What are the origins of the discrepancies in GENIE?

C(*e*, *e*') in GENIE

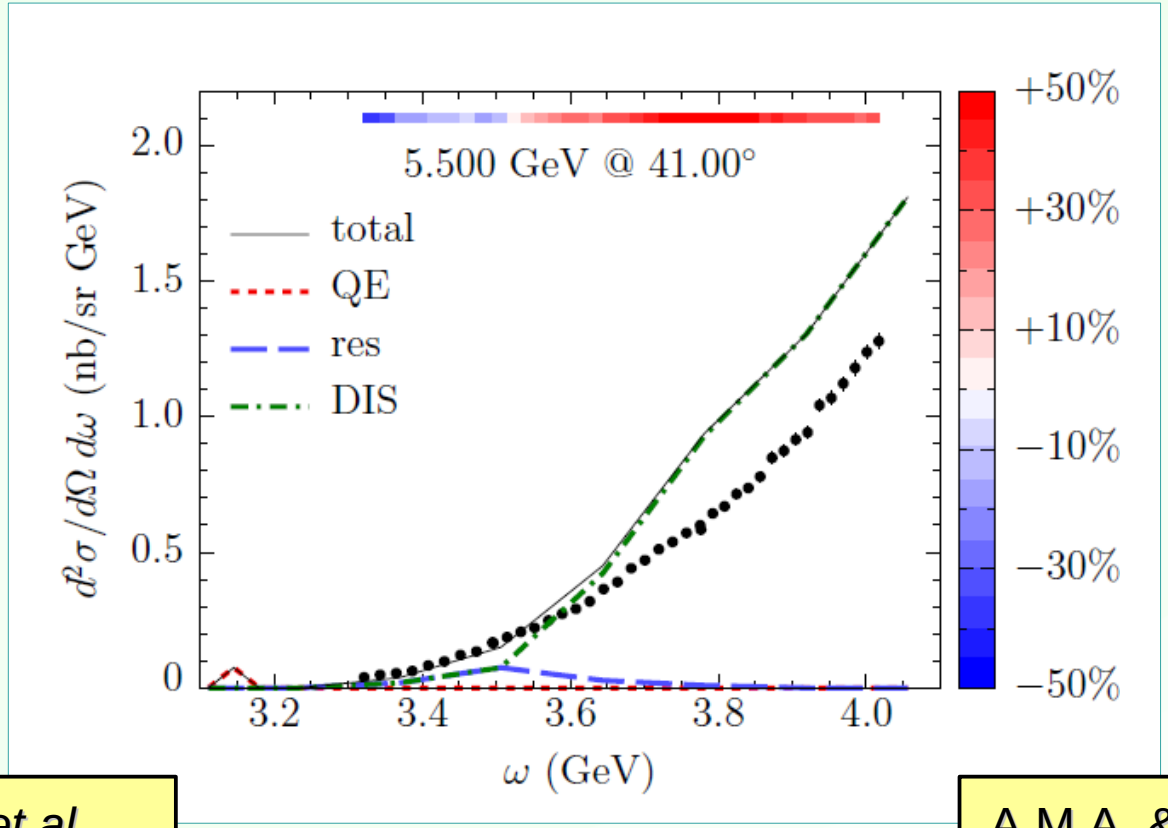
GENIE – data
data



data: Fomin *et al.*,
PRL **105**, 212502 (2010)

A.M.A. & Alex Friedland,
PRD 102, 053001 (2020)

D(*e*, *e*') in GENIE



data: Malace *et al.*, PRC **80**, 035207 (2009)

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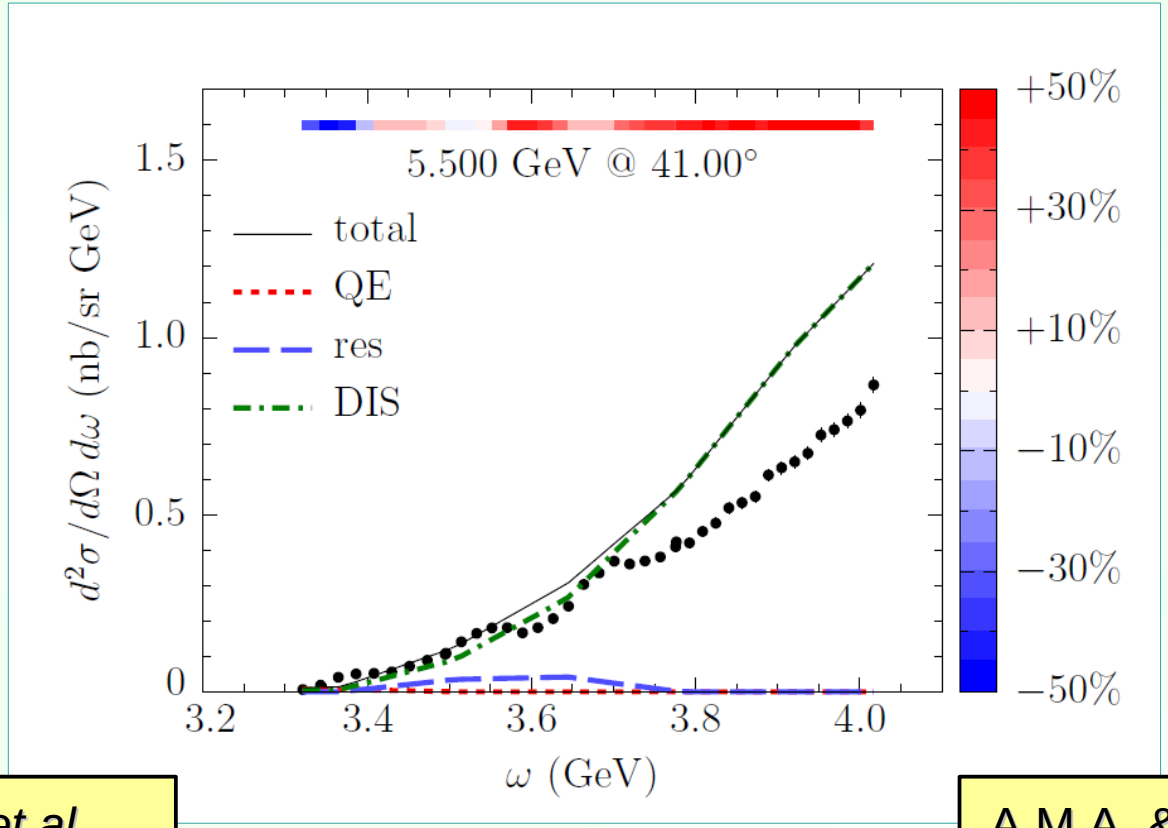
H(*e*, *e*') in GENIE



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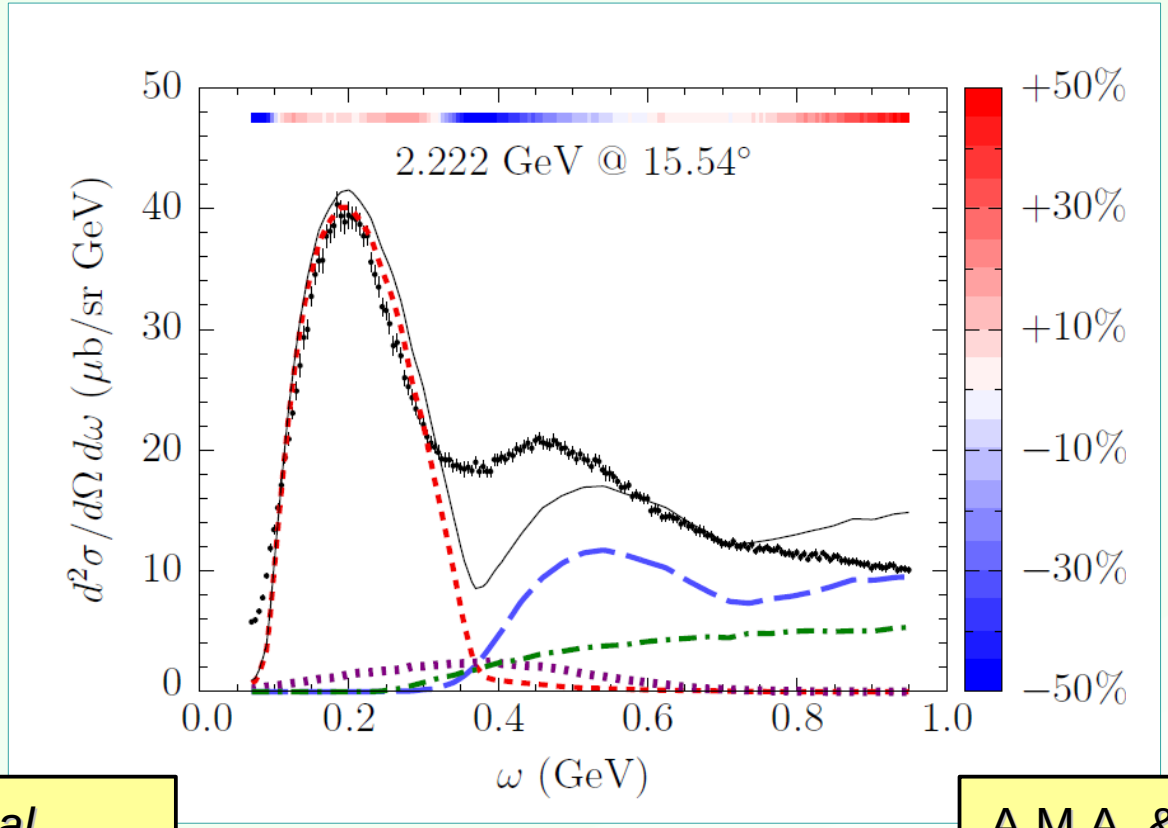

data: Dai *et al.*,
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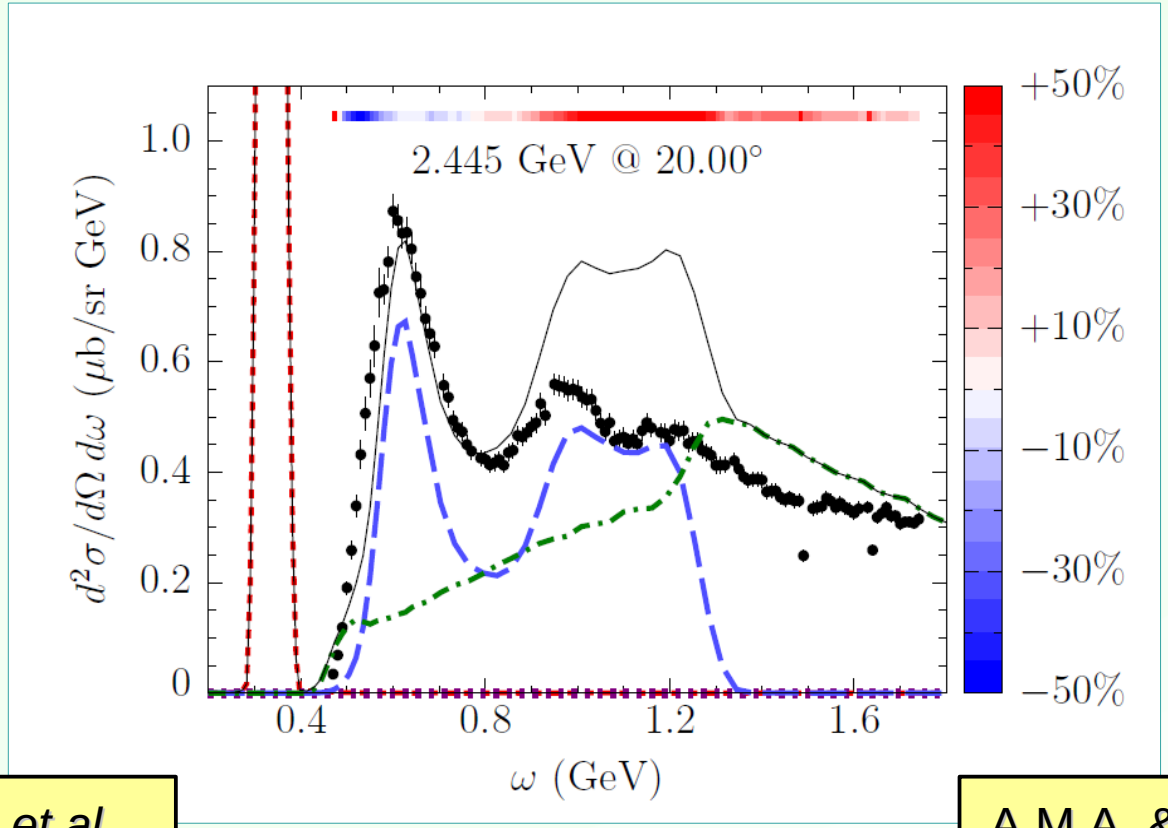

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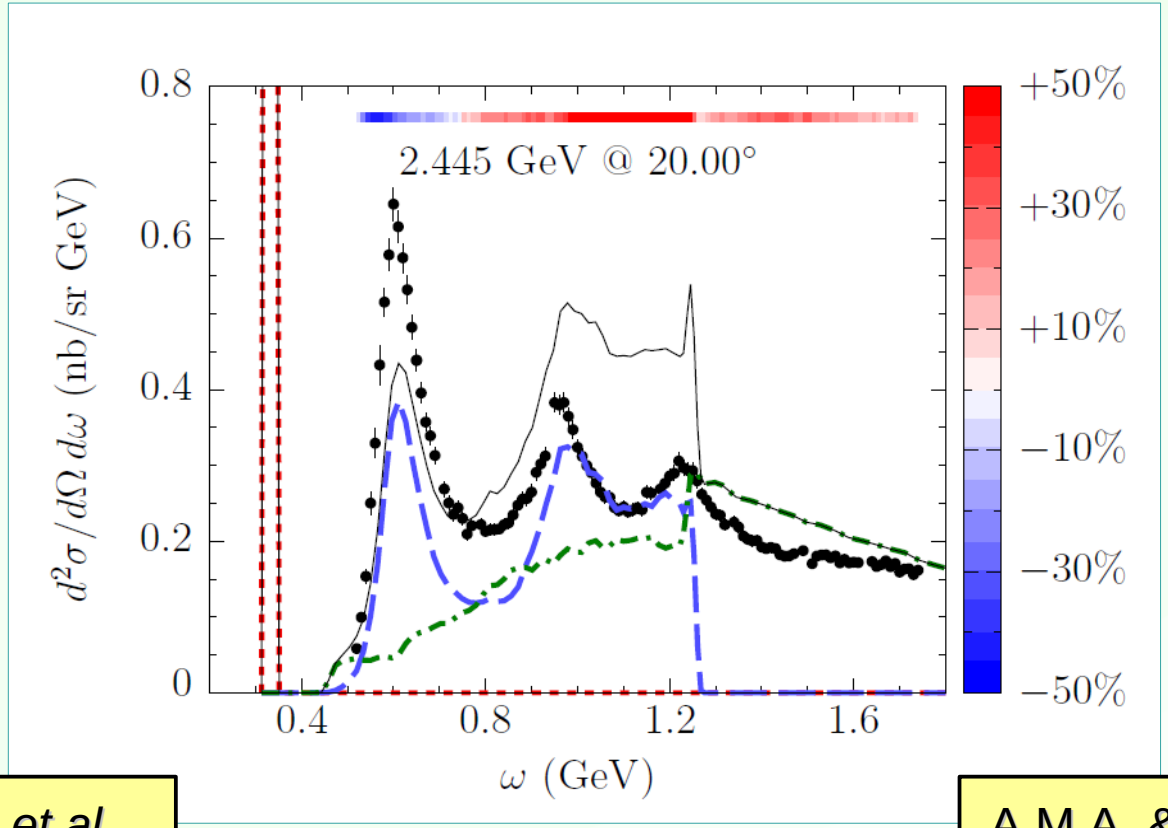

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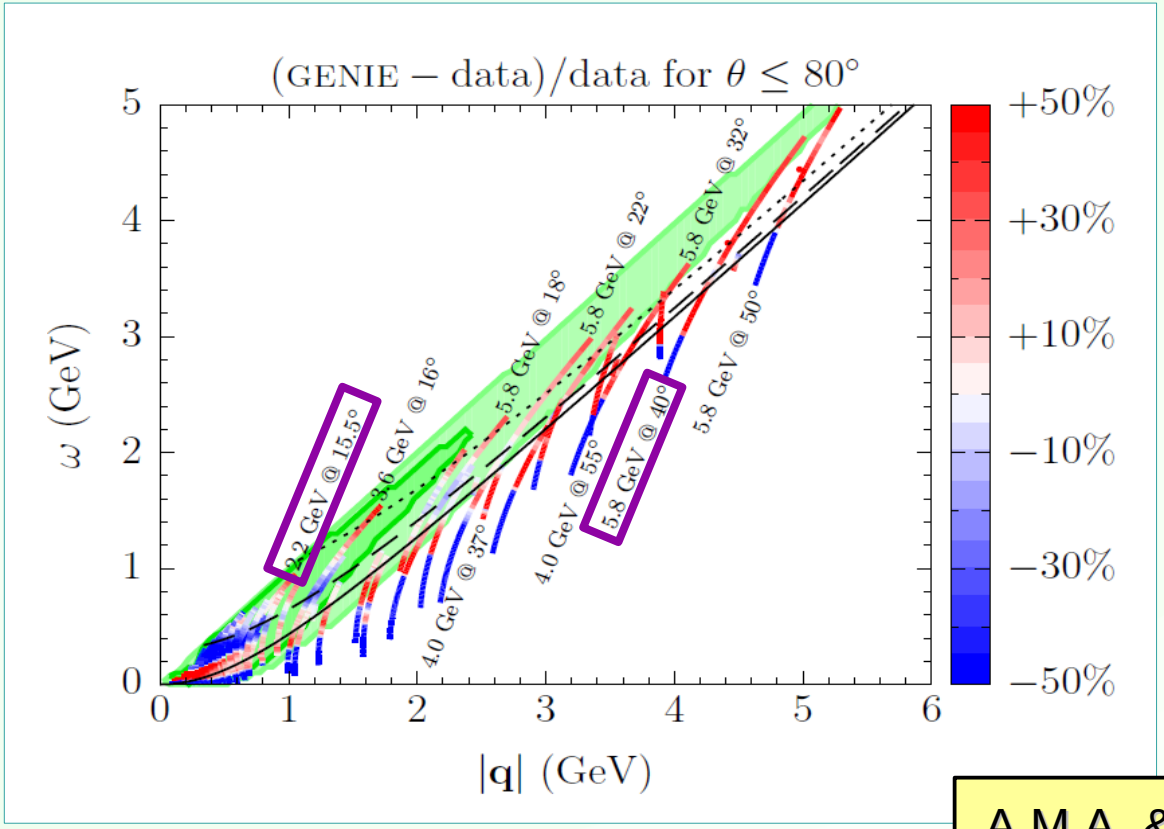

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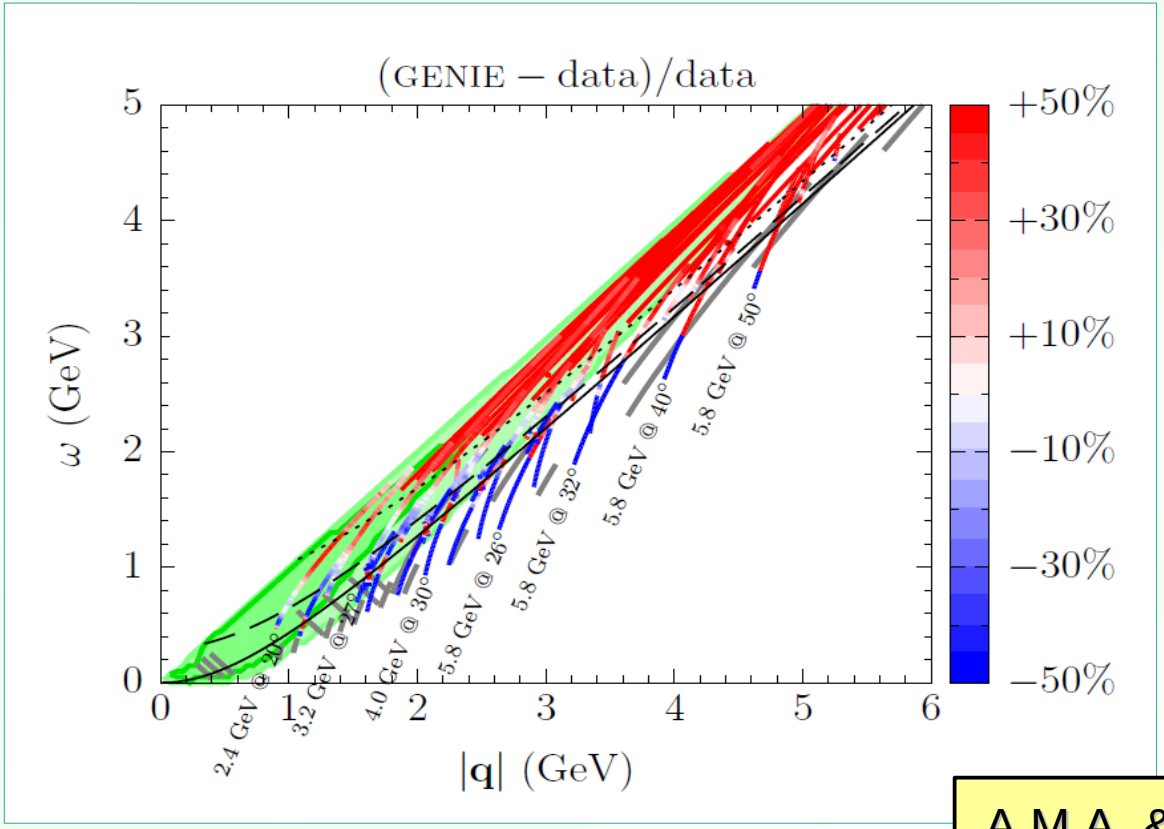

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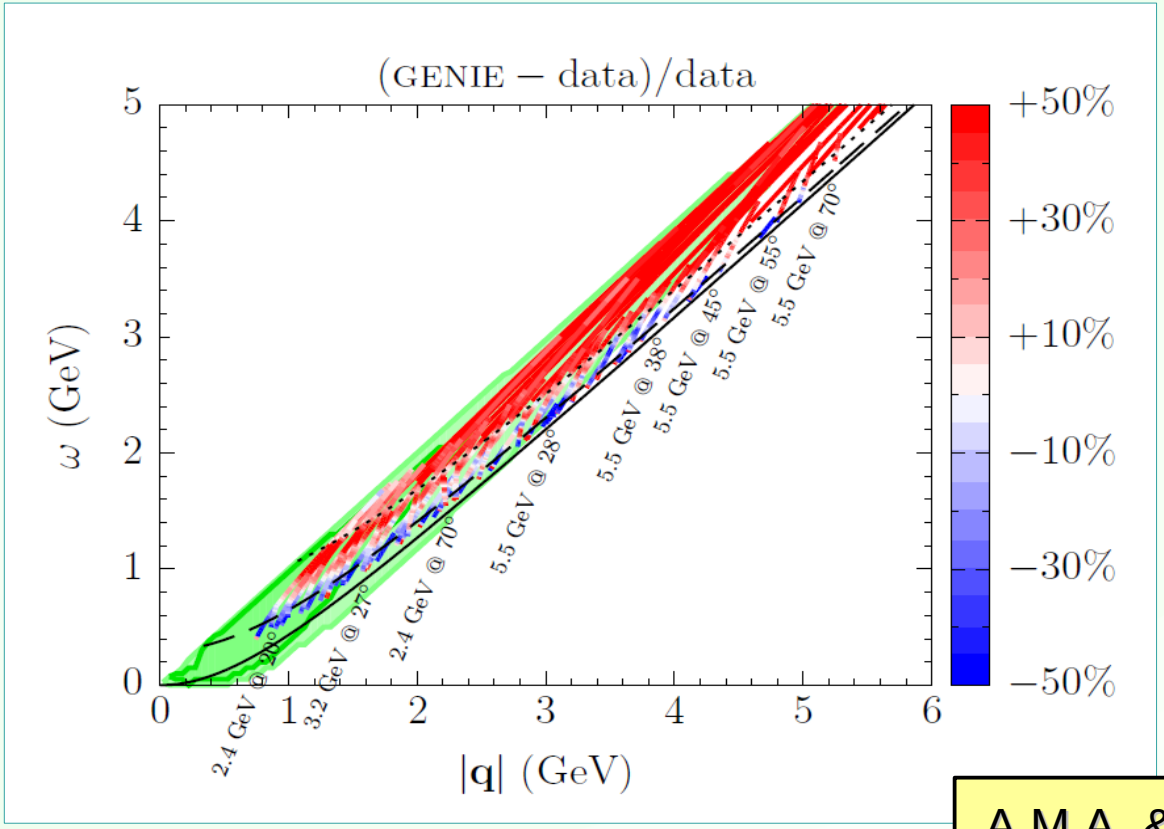

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Findings for complex nuclei

- In the **quasielastic** peak GENIE works best (some implementation issues observed), but the contribution of **meson-exchange currents** worsens it for higher energy transfers
- **Delta peak** position is not correct, strength underestimated
- **Higher resonances** not visible in data, clearly overestimated in GENIE
- **Deep-inelastic scattering** is significantly overestimated

Findings for light targets

- **Delta peak** position is correct, strength underestimated more for proton than for deuteron. Better model necessary.

- **Higher resonances** clearly overestimated in GENIE (double counting and lack of interference). Conceptual problem.

- **Deep-inelastic scattering** significantly overestimated, also for the data used to construct the approach of Bodek & Yang. Implementation issue.

- Note that GENIE is tuned to deuteron data.

General comments

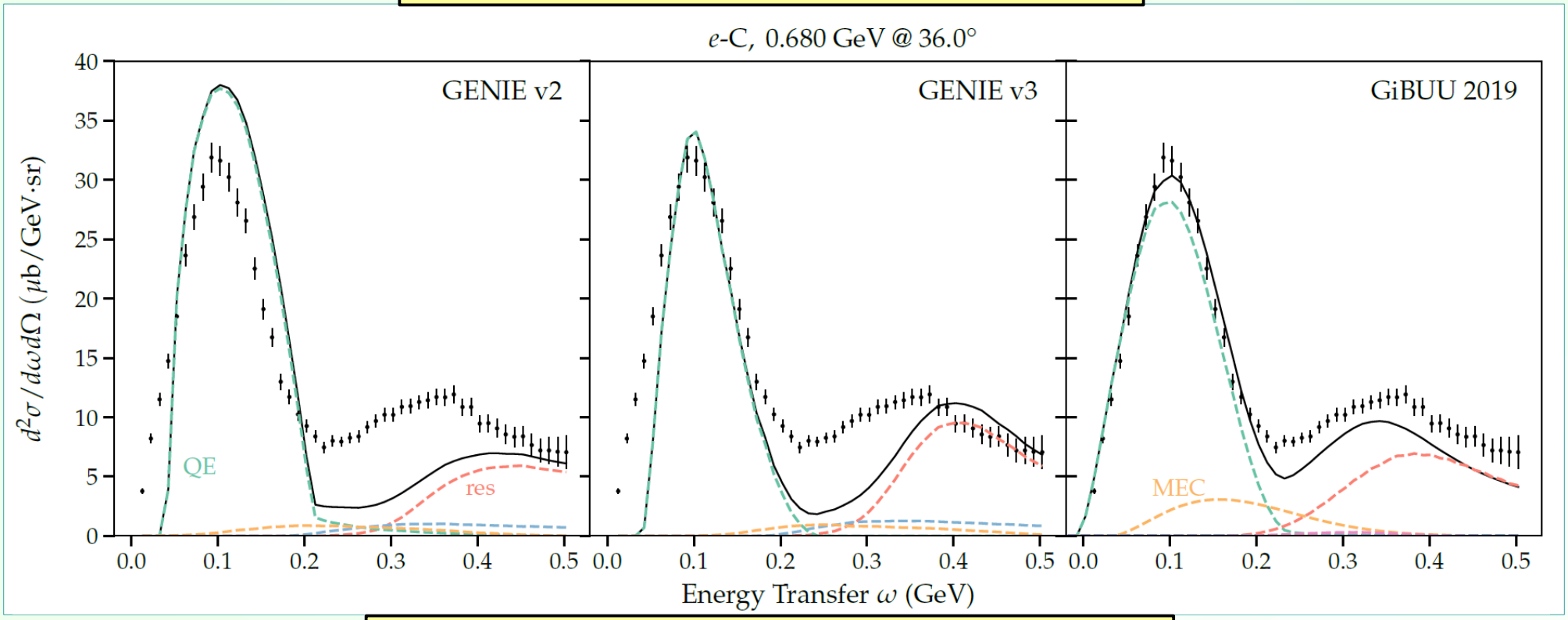
- Electron scattering data present a great opportunity to test MC generators and quantify systematic uncertainties for the neutrino-oscillation analysis

- Experiments can be easily performed changing targets, including high-pressure gas cells at room temperature, to study nuclear effects, elementary cross sections and hadronization

- Both inclusive and exclusive cross sections can be measured in great detail.

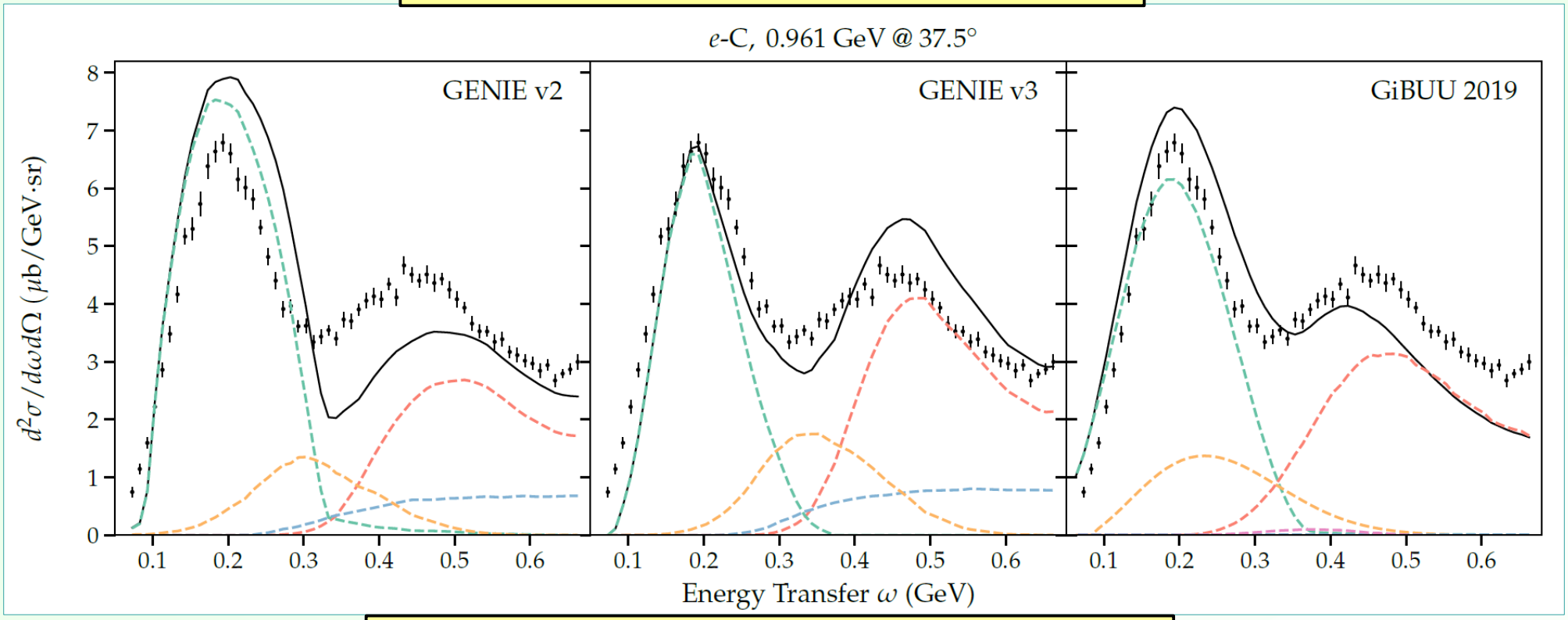
GENIE vs. GiBUU

data: Barreau *et al.*, NPA **402**, 515 (1983)



see,
A. Papadopoulou & M. Roda, Rosenbluth J fix
S. Gardner, Rosenbluth Jacobian fix for v3.2

data: Sealock *et al.*, PRL **62**, 1350 (1989)



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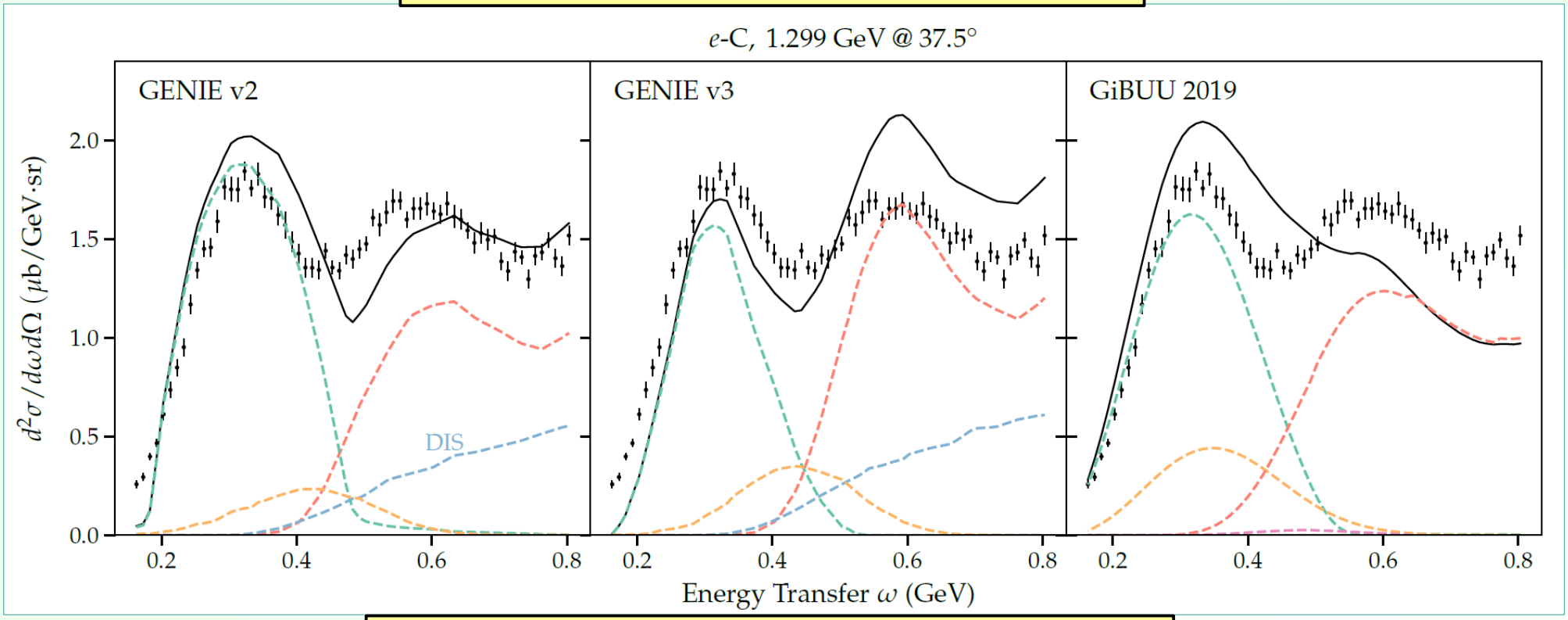

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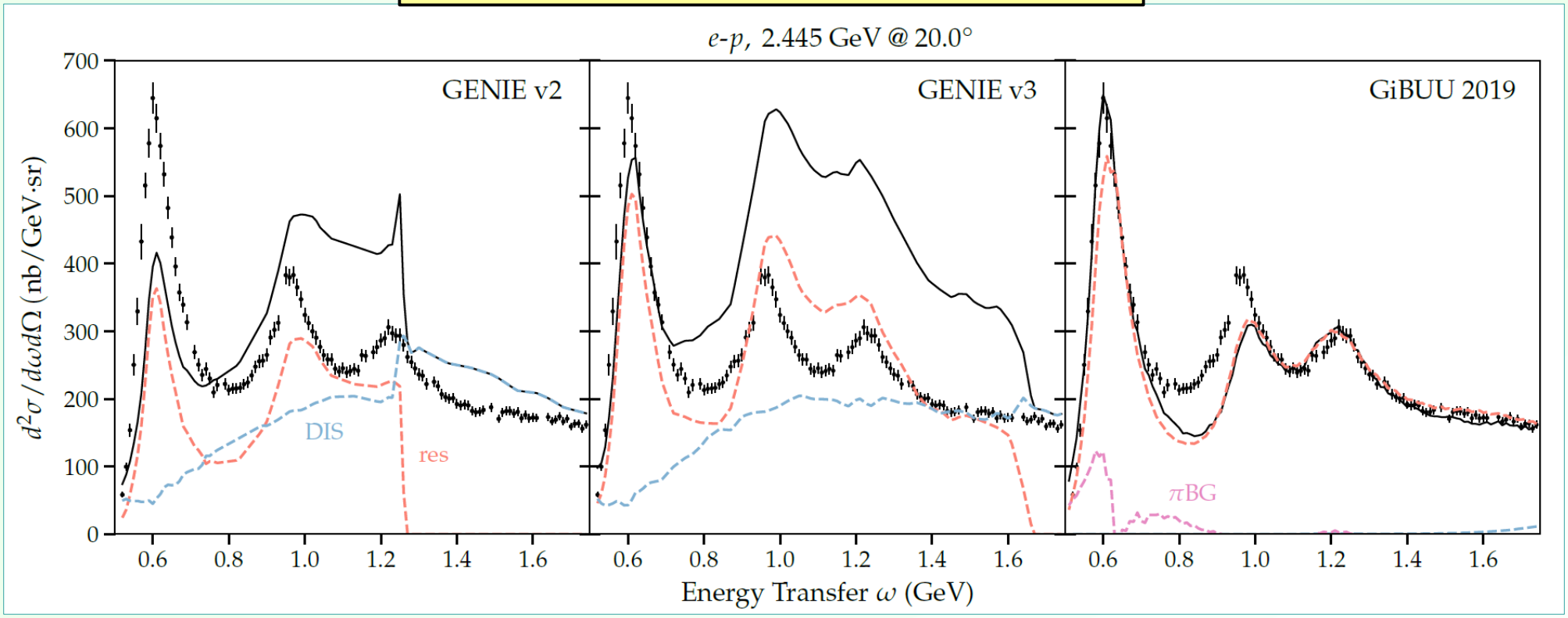

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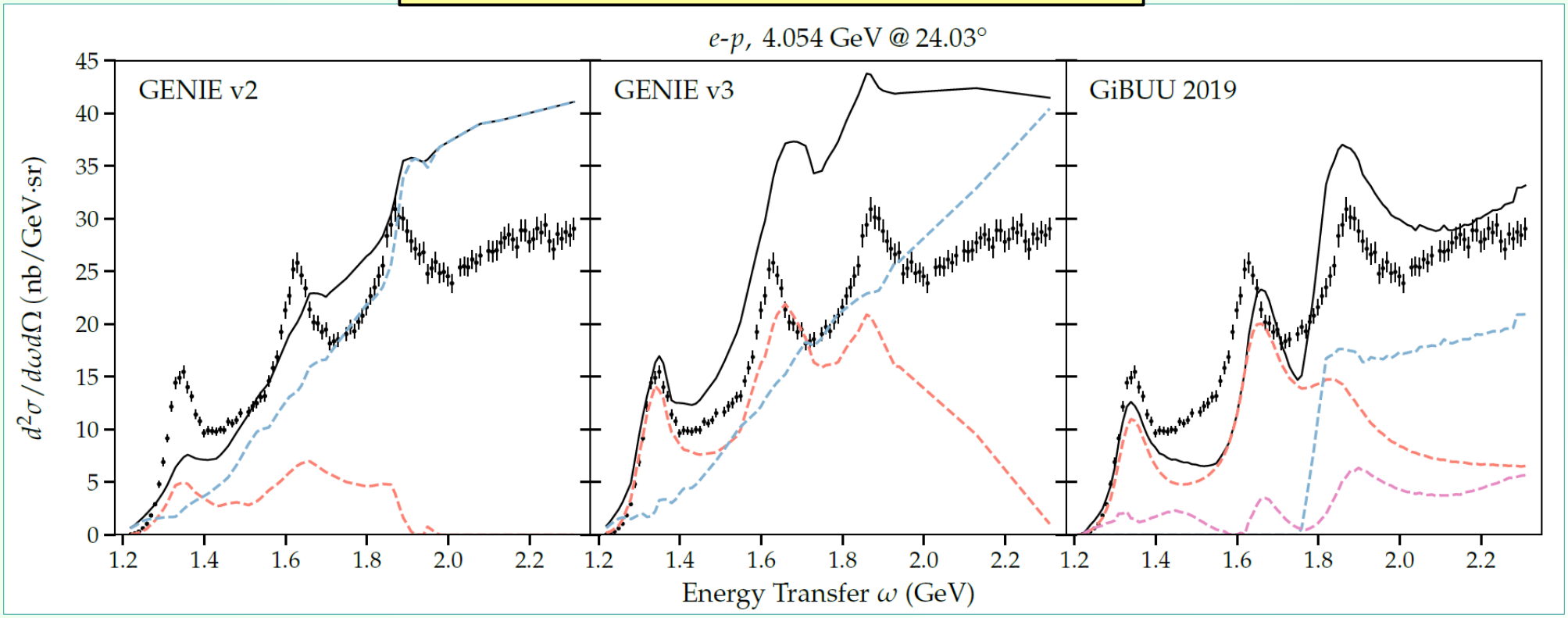


Conclusions

- **Consistent description of all interaction channels is a general problem of the considered generators**

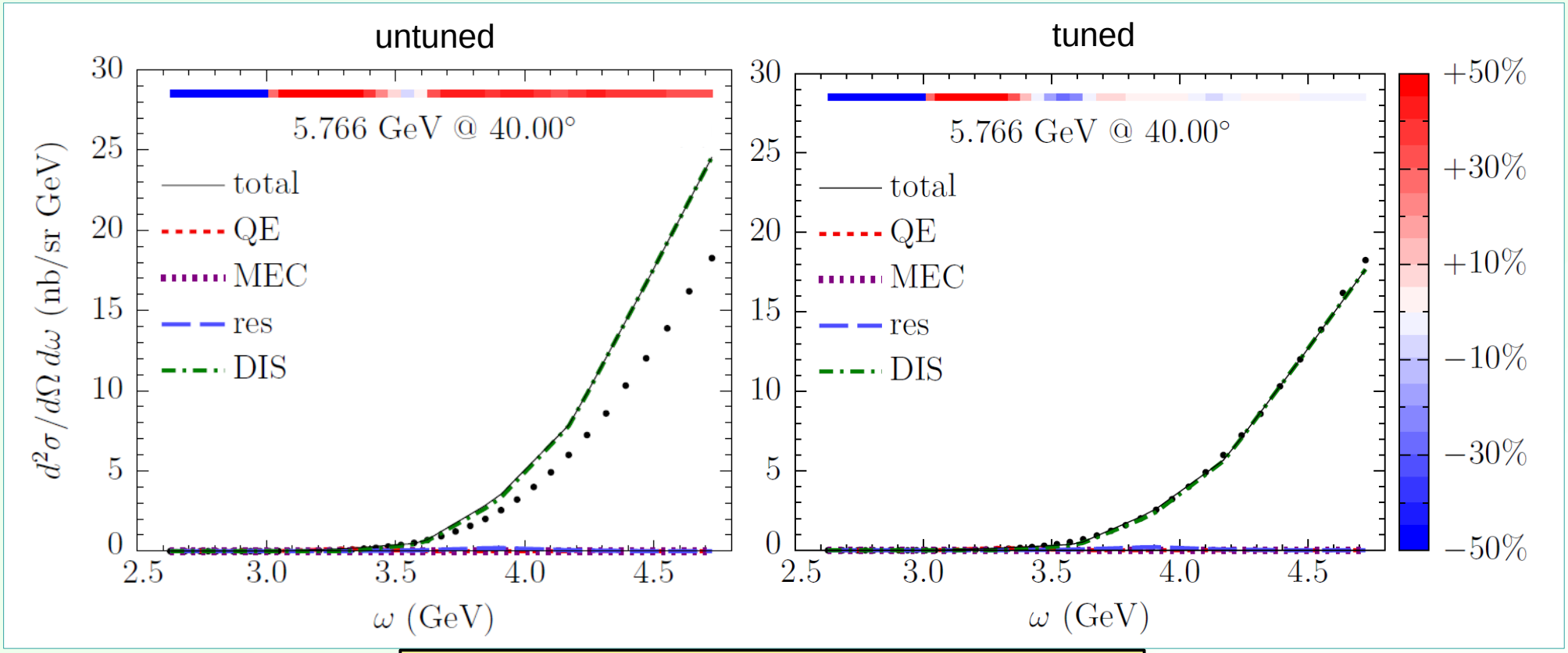
- QE: implementation issues in GENIE (2&3), GiBUU more accurate. Large MEC worsens agreement.

- Δ peak: quite accurate for *p*'s in GENIE 3 & GiBUU, for nuclei improvements needed (MEC too large in GENIE, neutrons may be too low in GiBUU)

- Matching higher resonances and DIS without double counting is a common issue

Tuning

C(*e*, *e*') in GENIE



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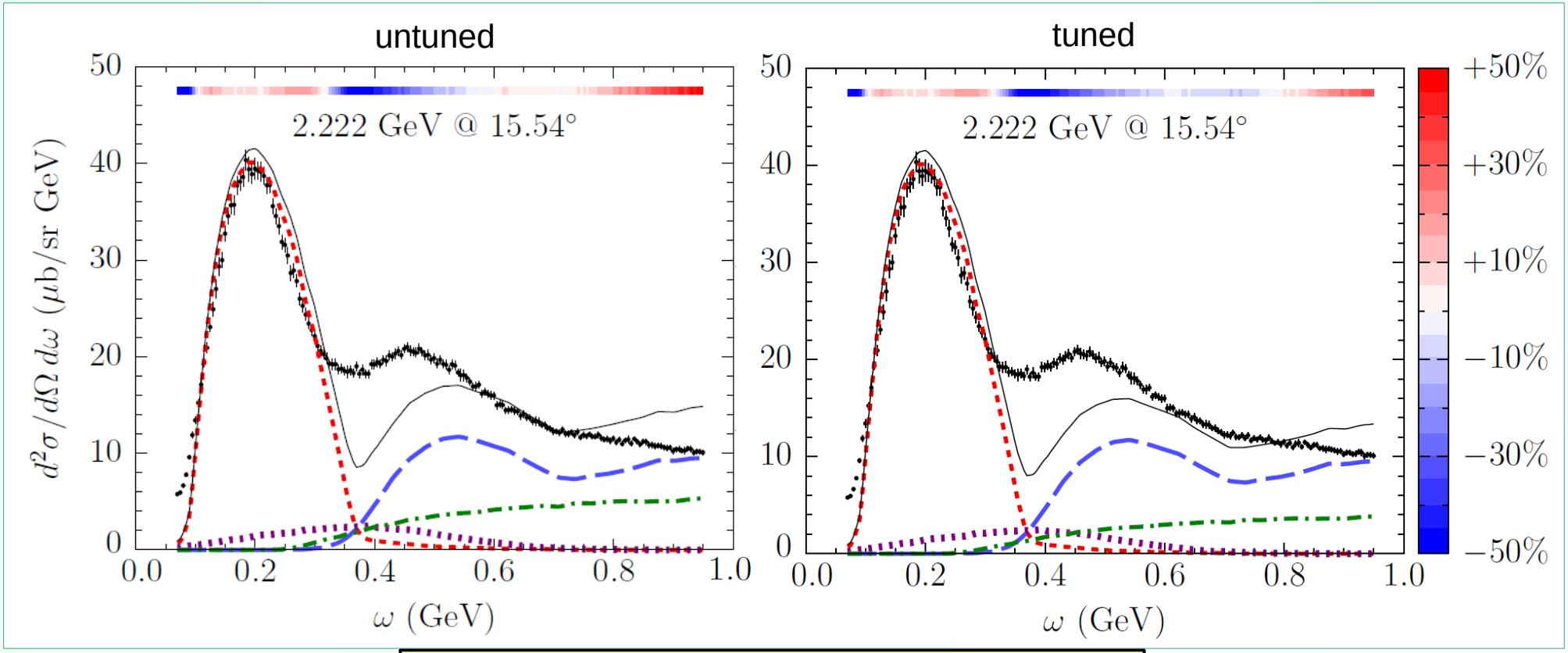

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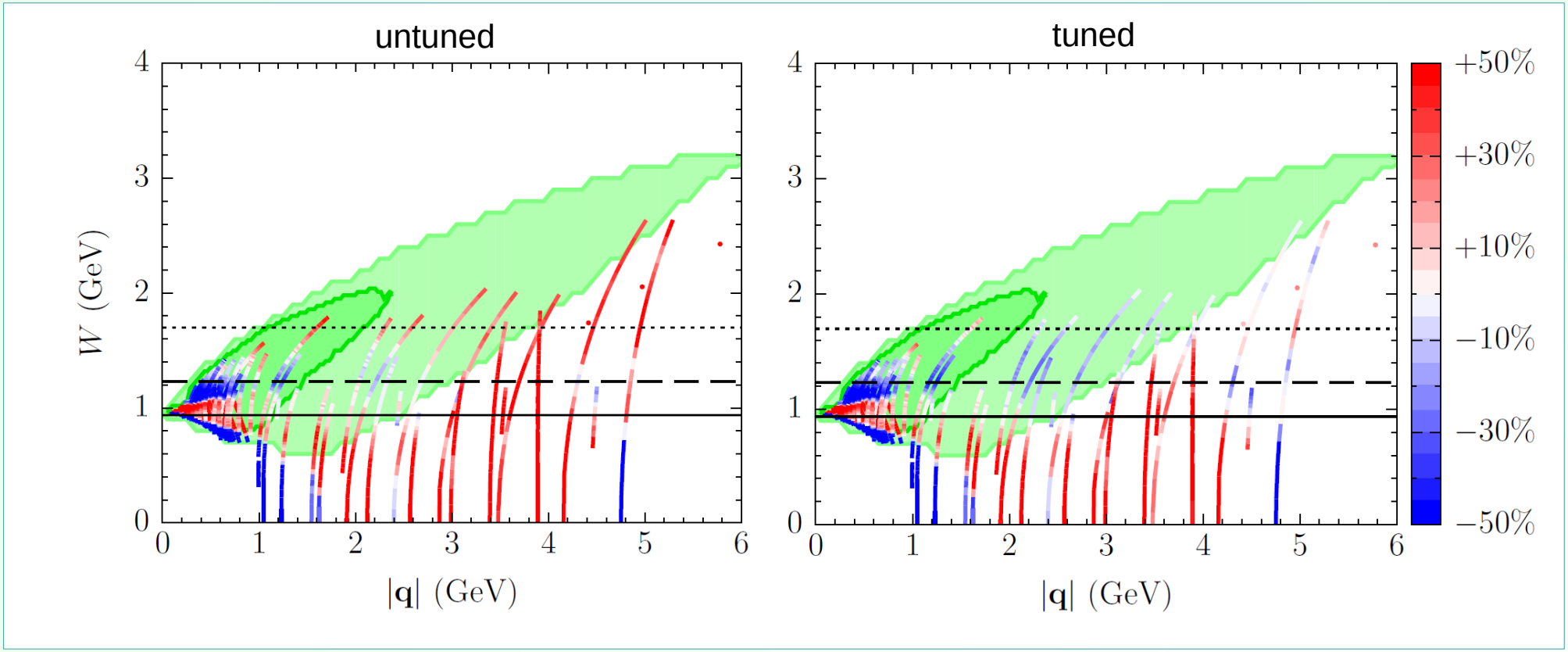

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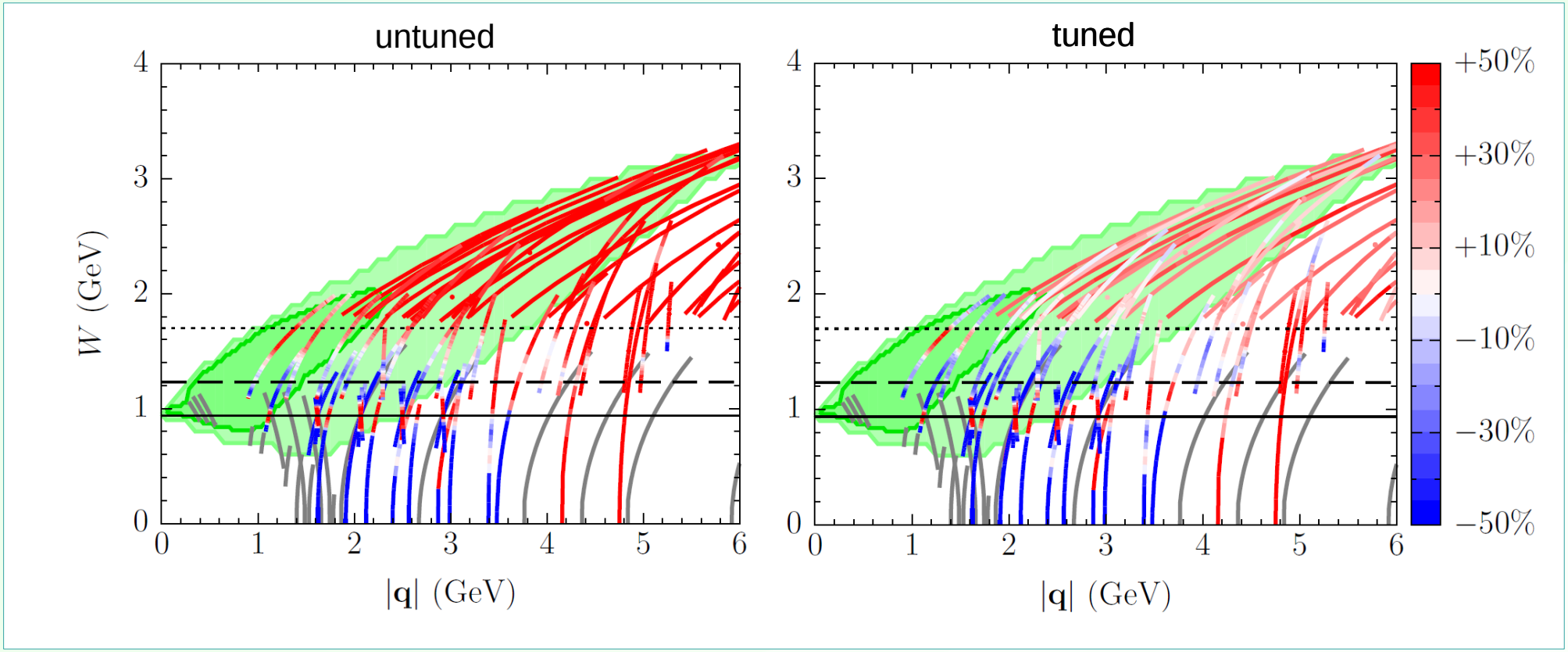

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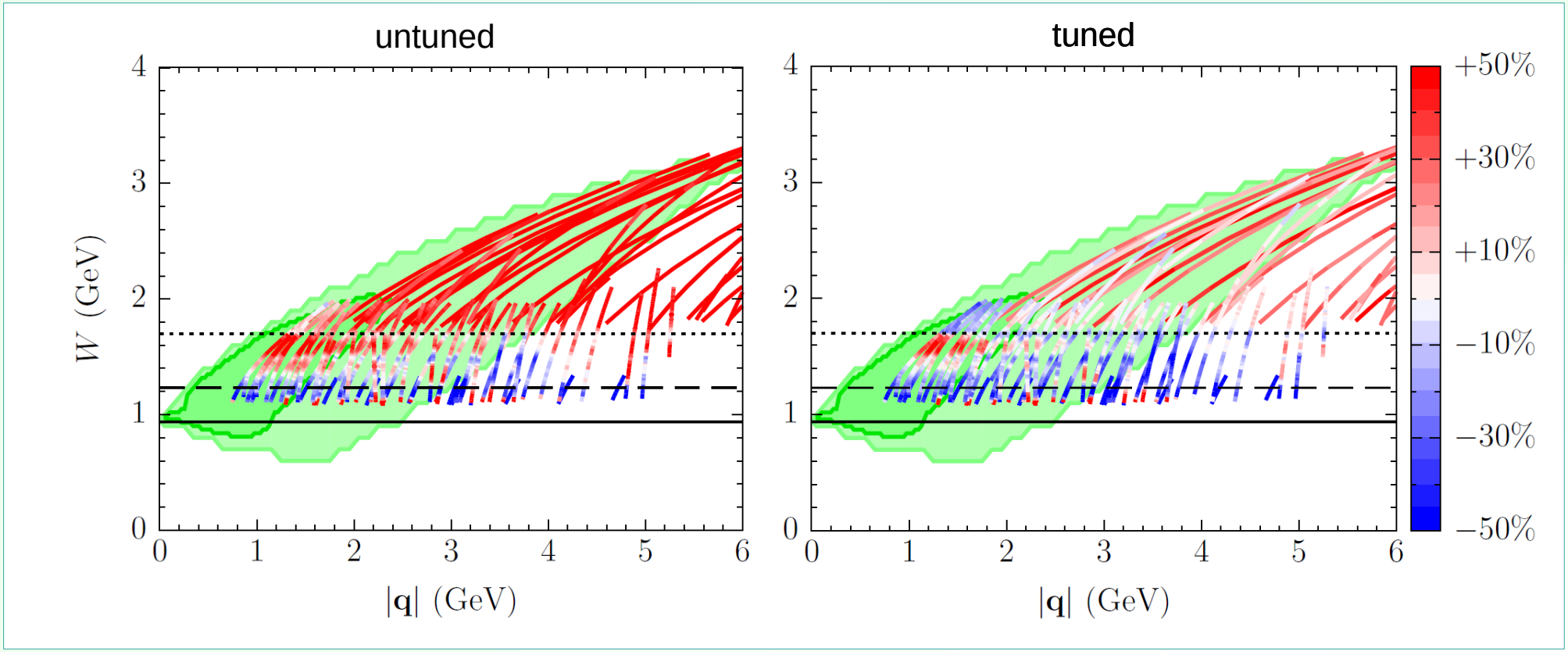
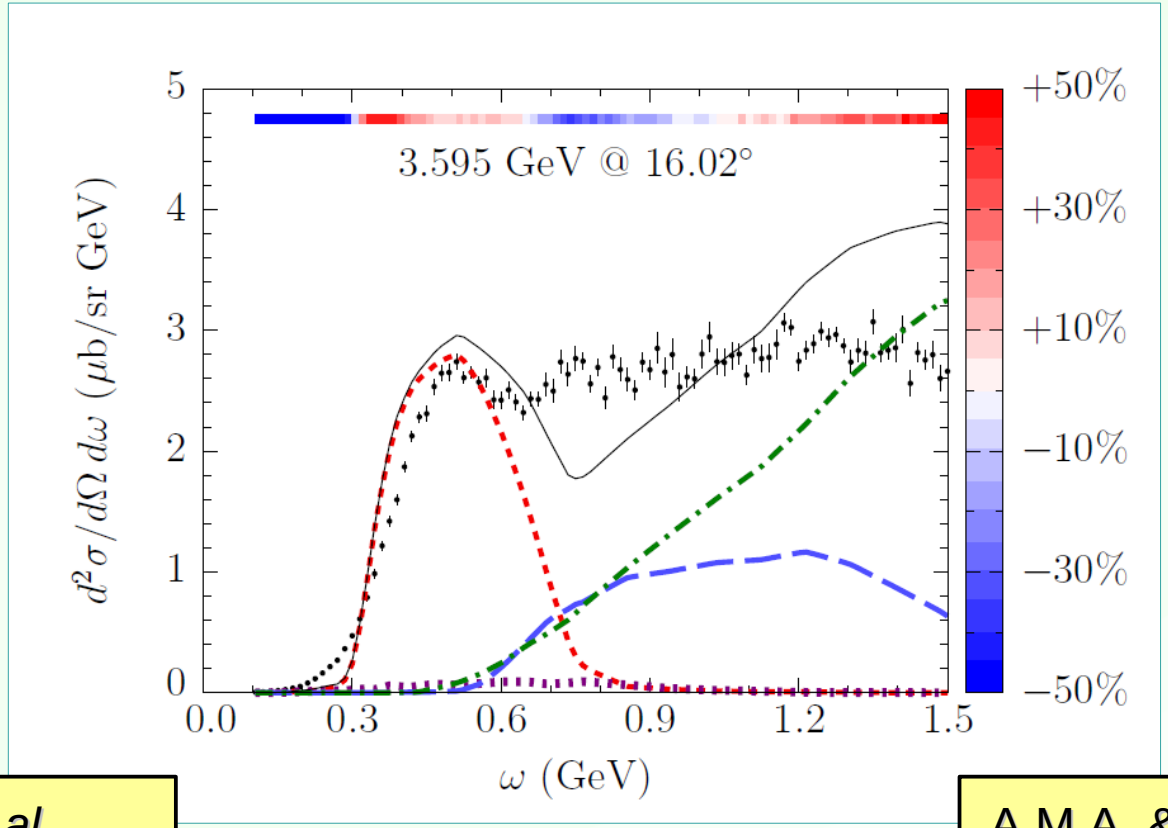


Backup slides

C(*e*, *e*') in GENIE



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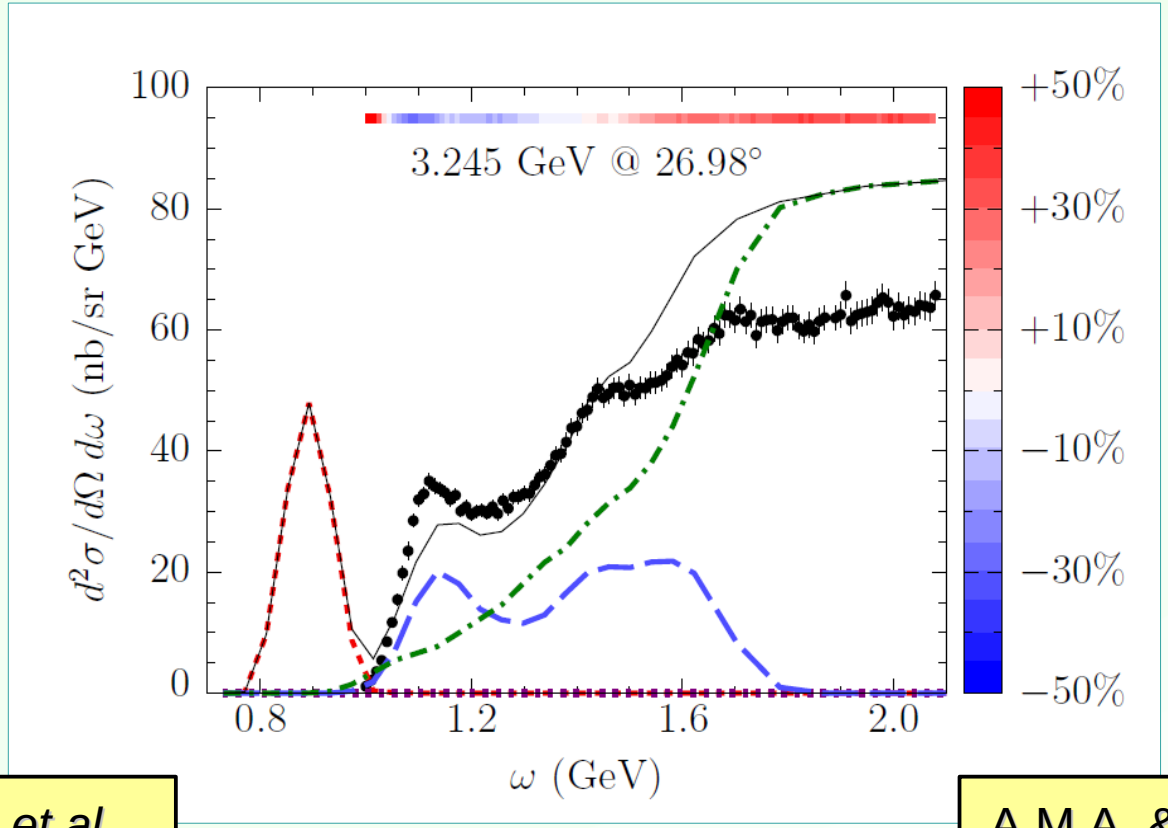

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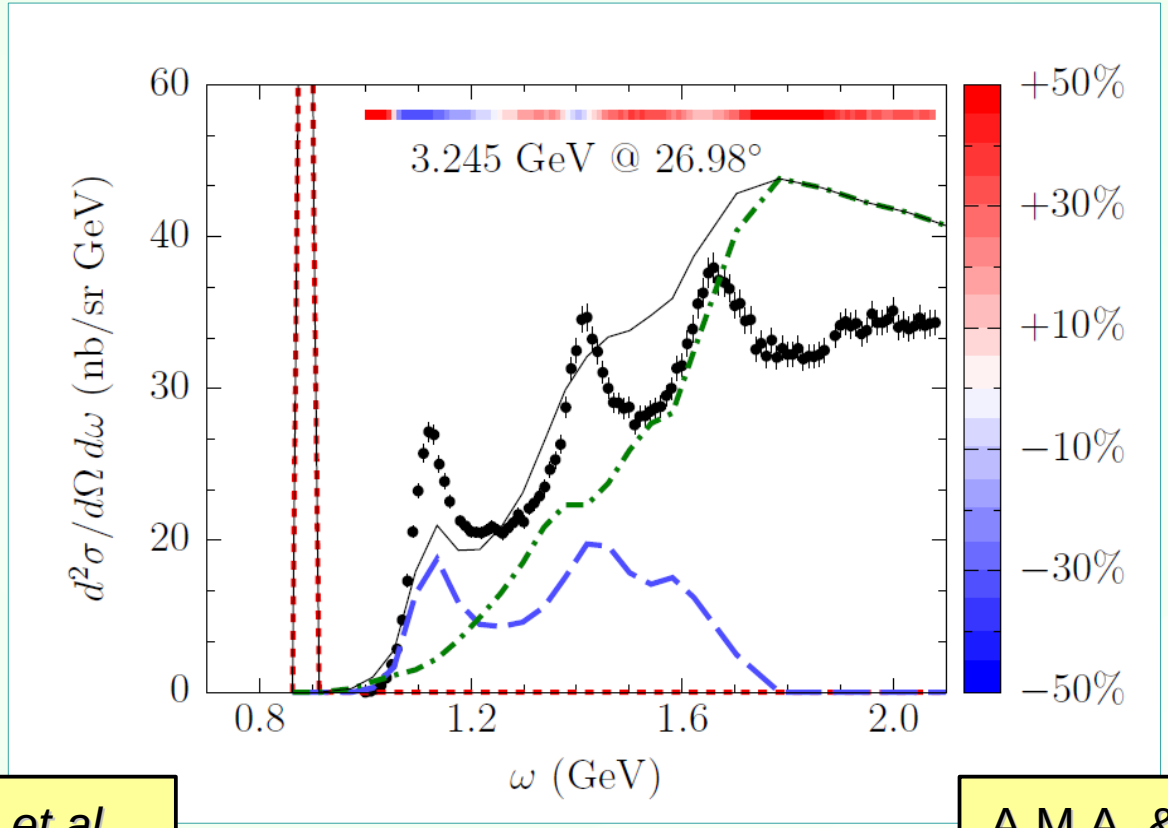

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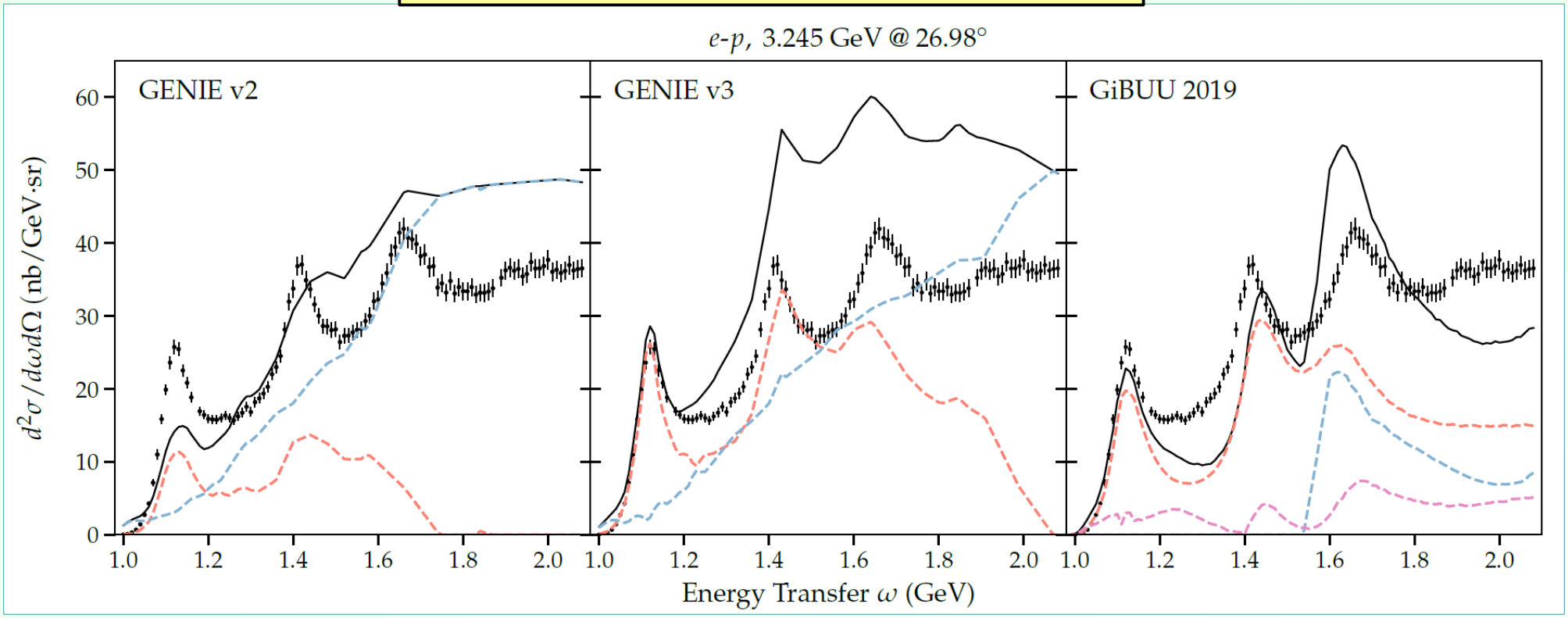

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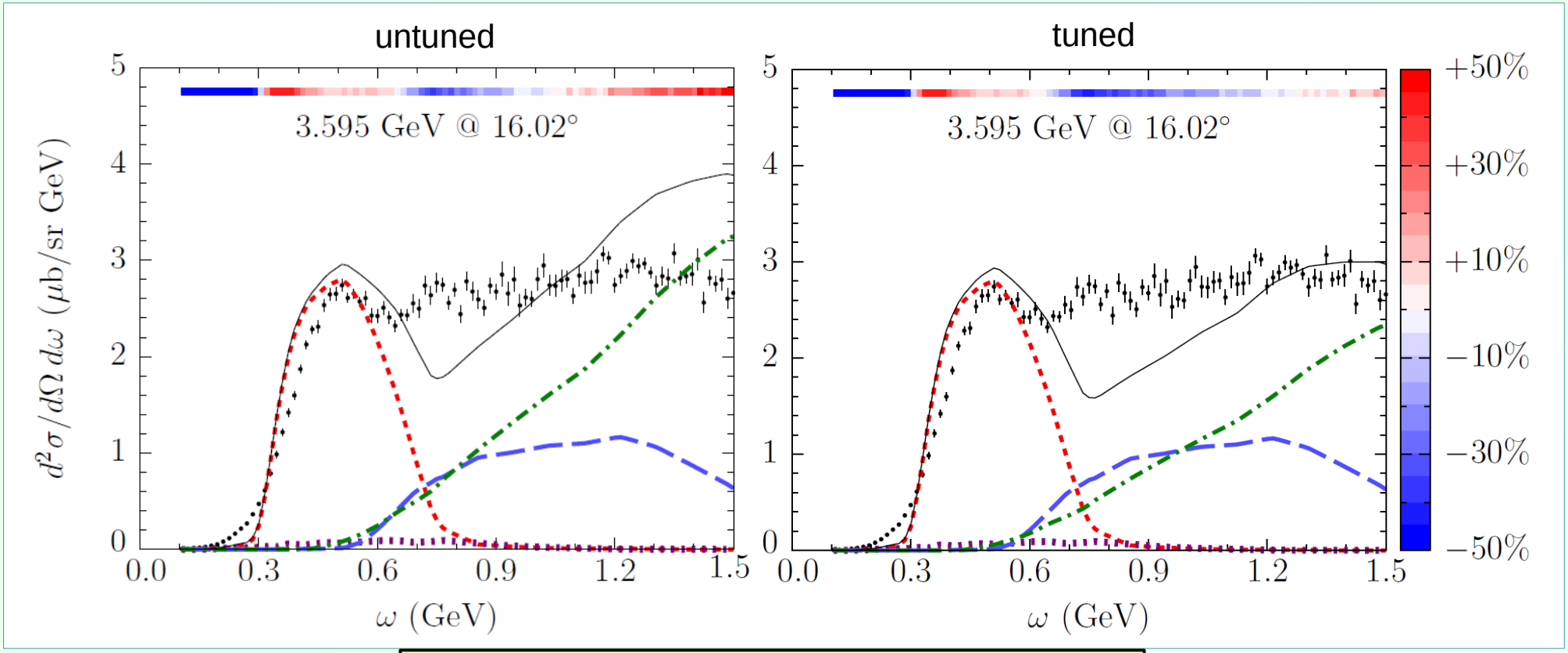

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