Inclusive Electron Scattering For Neutrinos With CLAS12



Matan Goldenberg
Under the guidance of Dr. Adi Ashkenazi

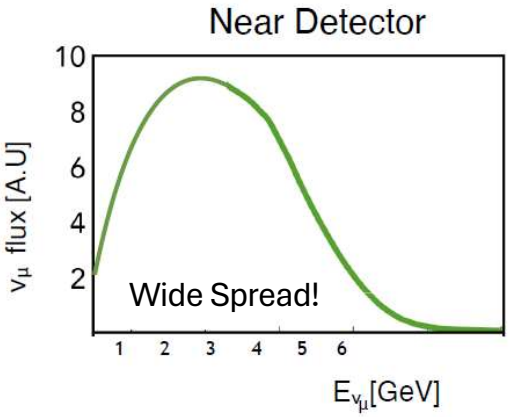
CLAS Collaboration November 2026
18.11.2026

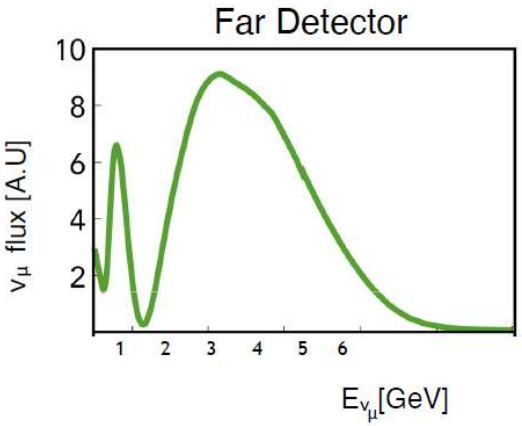




Motivation:
The Big Goal

- Measuring neutrino oscillation parameters!





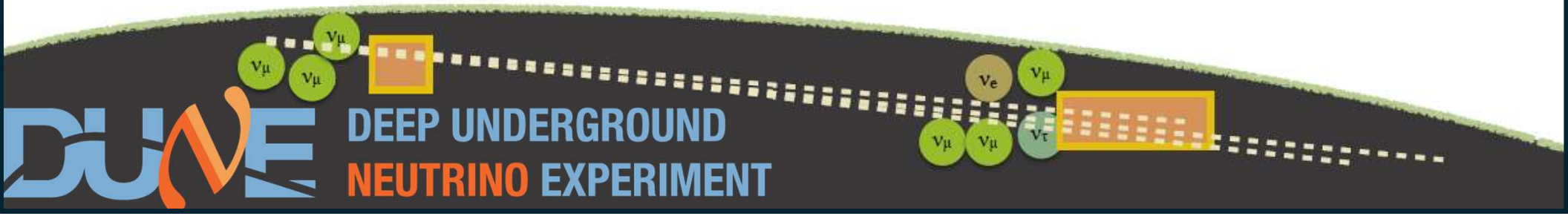
- **Very Challenging!**



- **Requires an event generator! (Which use many models with many parameters!)**



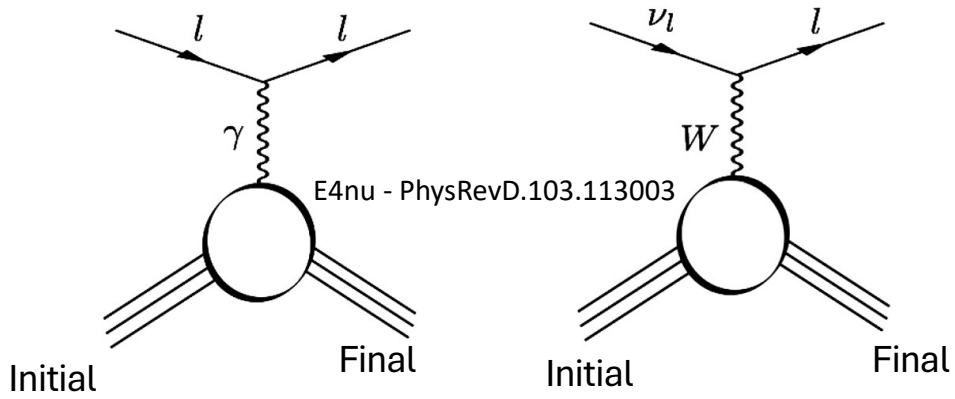
- **Problem: Data is not always sufficient for all needs!**



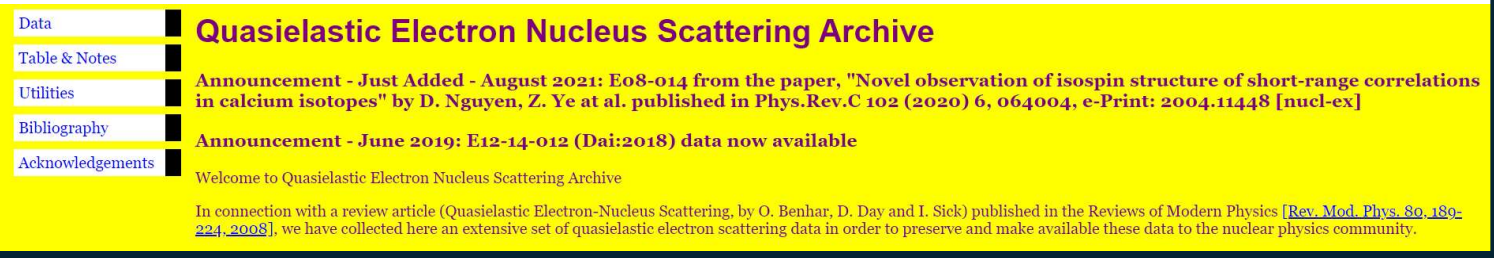
Solution: use electron-nucleus scattering data as well!

So Why **Electrons**?

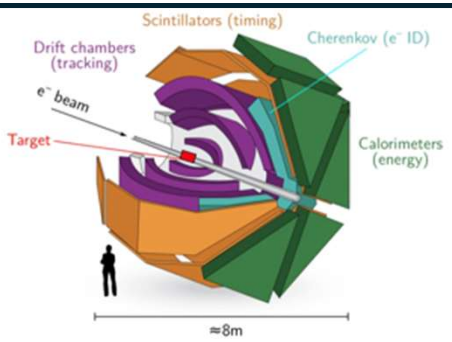
- Same target – the atomic nucleus
- Similar vector part of interaction
- Mono-chromatic beams – Easier!
- High statistics
- Abundant historical & **near future** measurements!

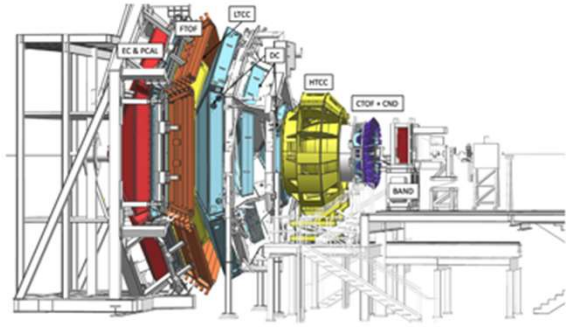


E4nu - PhysRevD.103.113003



The CLAS12 experiment & RGM's Data





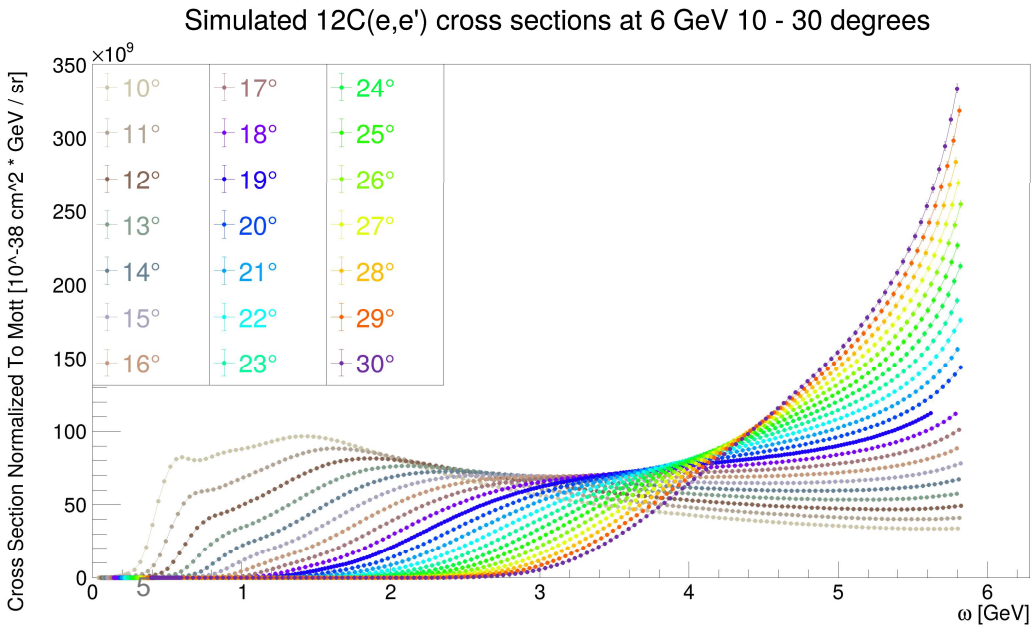
	CLAS	CLAS12
Run years	1996-2013	2017 - ?
Luminosity		
Targets	**C & Fe**	**H, D, C, (O), ^{40}Ar and more**
Beam Energy	**1.1, 2.2, 4.4 GeV**	**(1), 2, 4, 6 GeV**
Electron acceptance	$\theta_e > 15^o$	$\theta_e > 5^o$
Solid angle coverage	$\sim 2\pi$	$\sim 3\pi$
Magnetic field	V	V
Particle thresholds	150 (300) MeV/c for e (p)	200 (400) MeV/c for e (p/n)
Events	~10M C(e,e') events	~100M ^{40}Ar (e,e') events

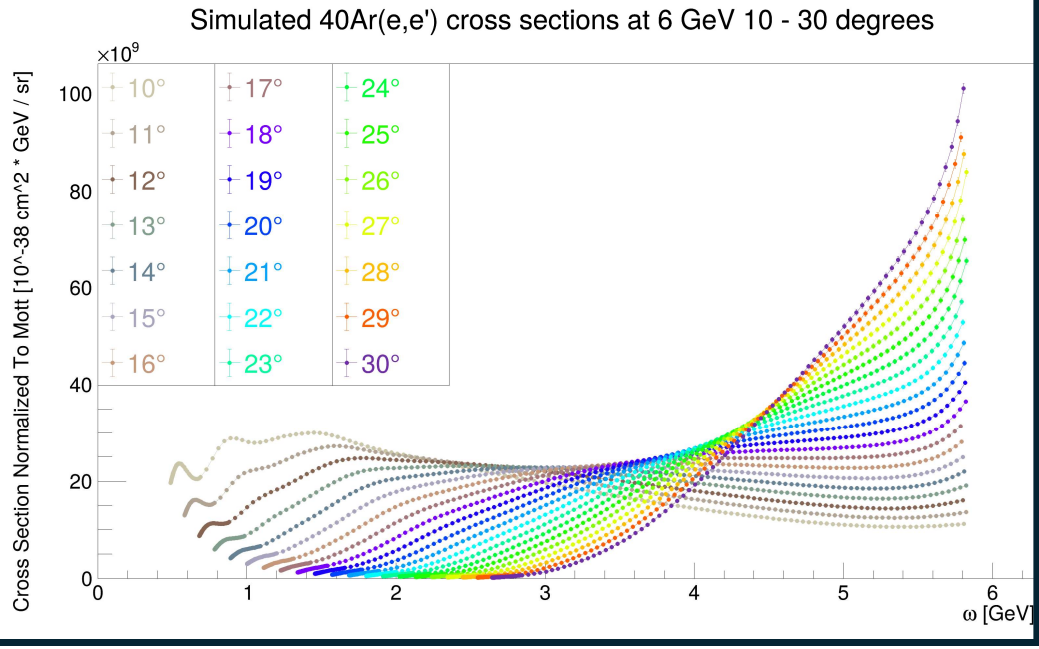
Slide is courtesy of Dr. Julia Tena Vidal

CLAS12 data is invaluable for neutrino oscillation physics

- electron-12C & electron-40Ar.
- 2, 4, 6 GeV beam energies
- Various scattering angles probing many interaction mechanisms!

Simulations are courtesy of Prof. Eric Christy!





Inclusive Electron Scattering Cross Sections & Rosenbluth Separation

- Nuclei have an internal structure.
- This structure can be probed by inclusive electron scattering:

$$\left(\frac{d\sigma_{Lab}}{d\Omega}\right) = \left(\frac{(Z\alpha)^2}{4E^2 sin^4\frac{\theta}{2}}\right)\frac{E\prime}{E}\left[\frac{G_E^2+\tau G_M^2}{1+\tau} cos^2\frac{\theta}{2} + 2\tau G_M^2 sin^2\frac{\theta}{2}\right]$$

In the Sachs parametrization.

- Extracting the Form Factors can teach us about the internal structure of the nucleus.

Inclusive Electron Scattering Cross Sections & Rosenbluth Separation

- For Proton / Nucleus in Sachs representation:
- Def: $\tau = \frac{-Q^2}{4M^2}$; $\boldsymbol{\varepsilon} = \frac{1}{1+2(1+\tau)ta\ ^2\frac{\theta}{2}}$
- One can get:

The inclusive measurement

- $\boldsymbol{\epsilon}(1+\tau) * \left(\frac{\left(\frac{d\sigma_{La}}{d\Omega}\right)}{\left(\frac{d\sigma_{Mott}}{d\Omega}\right)} \right) = \tau G_M^2(Q^2,\omega) + \boldsymbol{\varepsilon}\, G_E^2(Q^2,\omega)$

Sachs Form Factors

- The trick: $\boldsymbol{\varepsilon}$ is **not** a function of just (Q^2,ω) !

Inclusive Electron Scattering Cross Sections & Rosenbluth Separation

- (e,e’)40Ar data from 3 experiments:

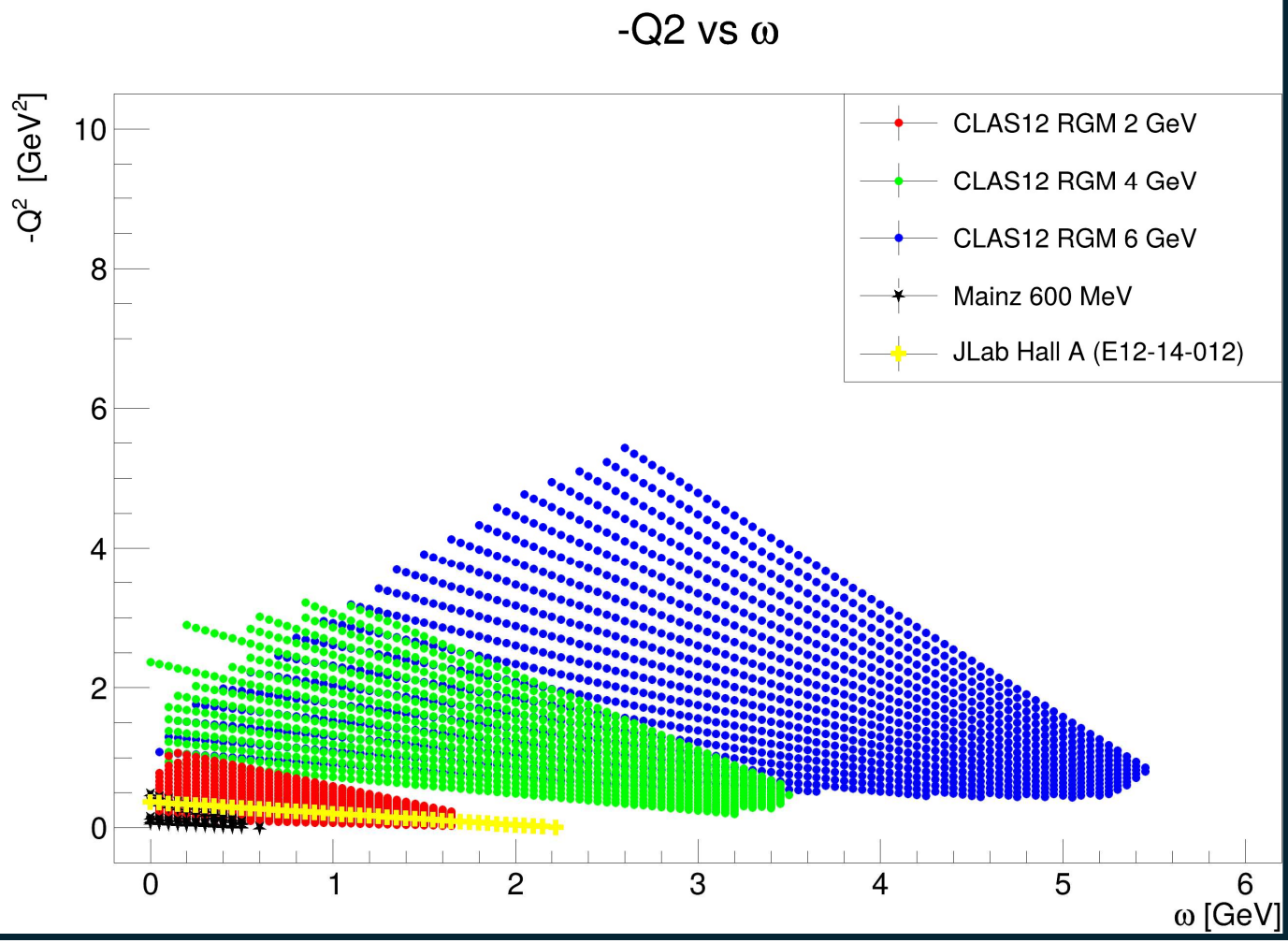
This study
- CLAS12 RGM 2 GeV
- CLAS12 RGM 4 GeV
- CLAS12 RGM 6 GeV

Mainz 600 MeV

JLab Hall A (E12-14-012)

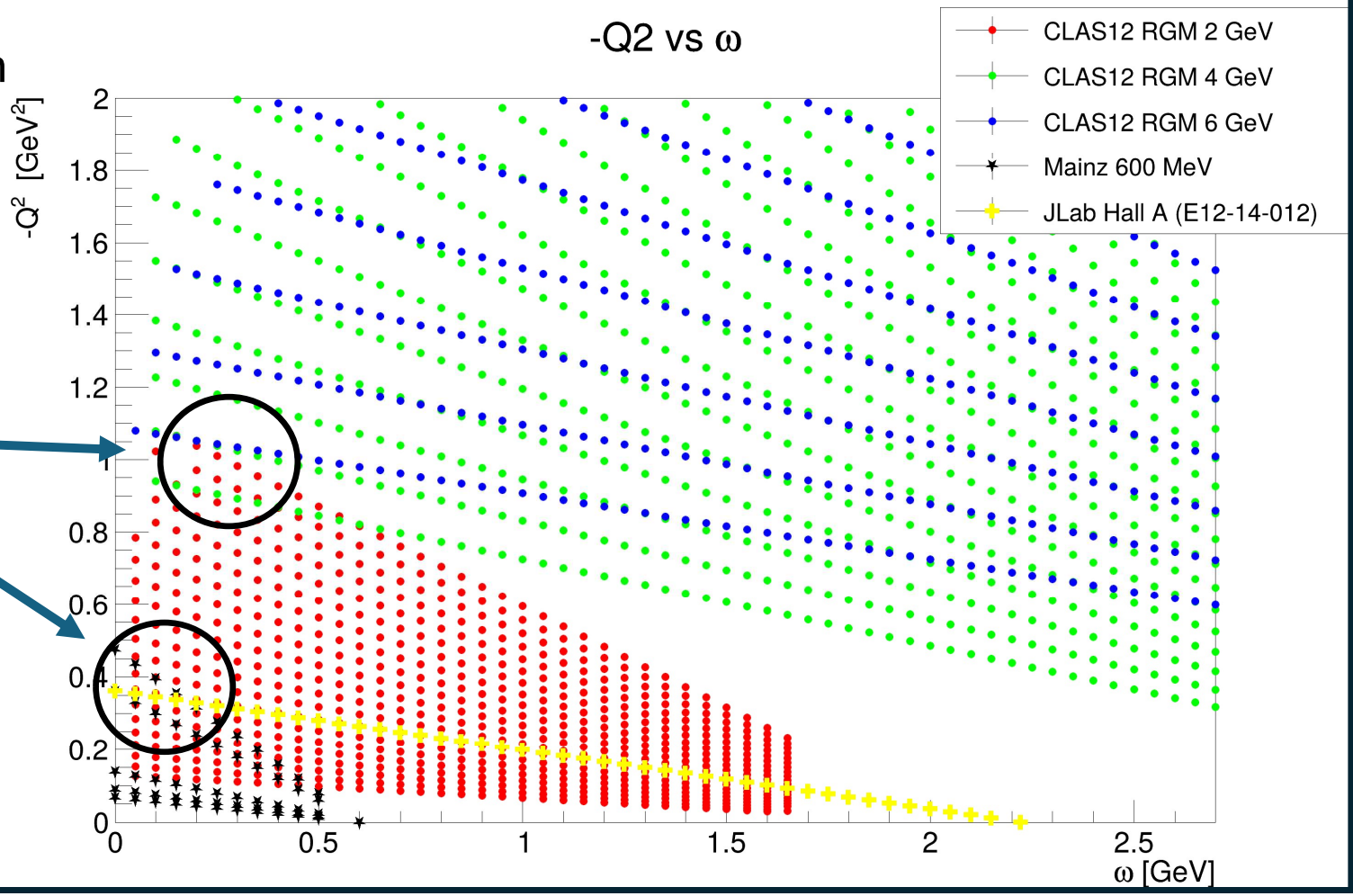
Rosenbluth Separation potential for 40Ar:

- A wide kinematical phase space coverage.
- First time for Argon!



Rosenbluth Separation potential for 40Ar:

- A classical Rosenbluth separation requires several data sets at same Q2 and omega.
- Available 3-data sets overlaps!
- Very large kinematical region with available 2-data sets overlap!



RGM Inclusive Cross Section Extraction

RGM Inclusive Cross Section Extraction :

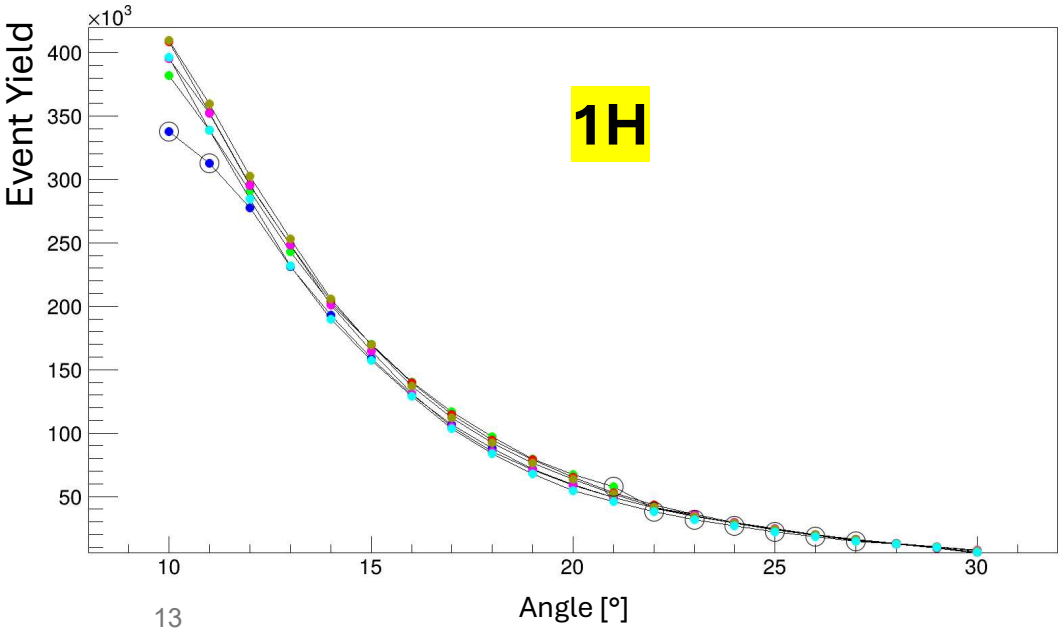
- A work in progress!
- Will focus today on 2 GeV
- With radiative corrections
- Accounting to the detector’s effective angle acceptance
- More details in Backup

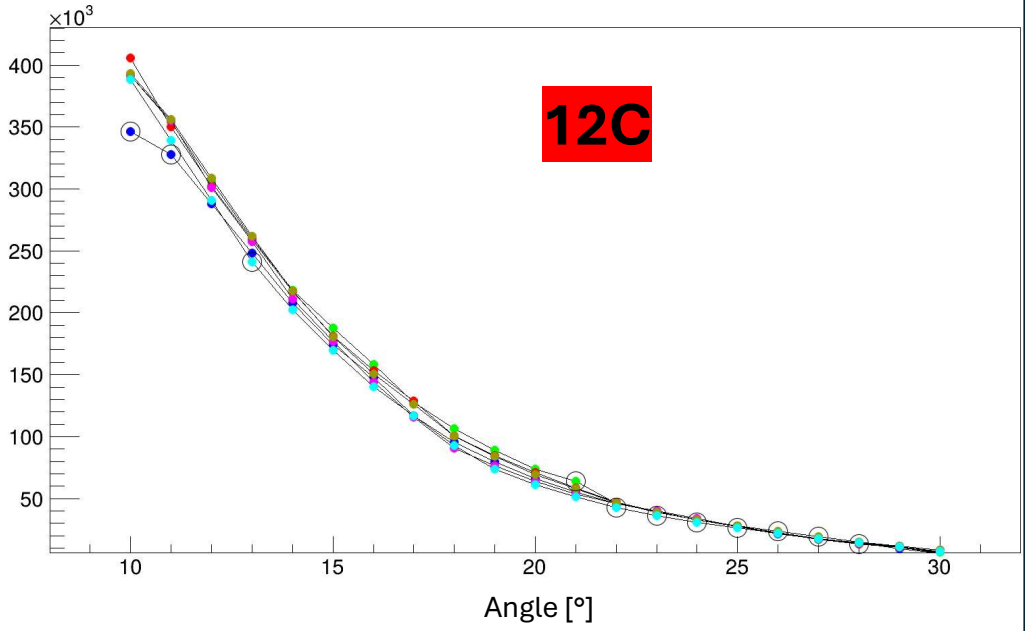
Preliminary Results: 2 GeV on 1H and 12C

Event yields in CLAS12's 6 Sectors:

- Each color stands for a different sector

- Some variance between the sectors
- 1H and 12C are very similar.



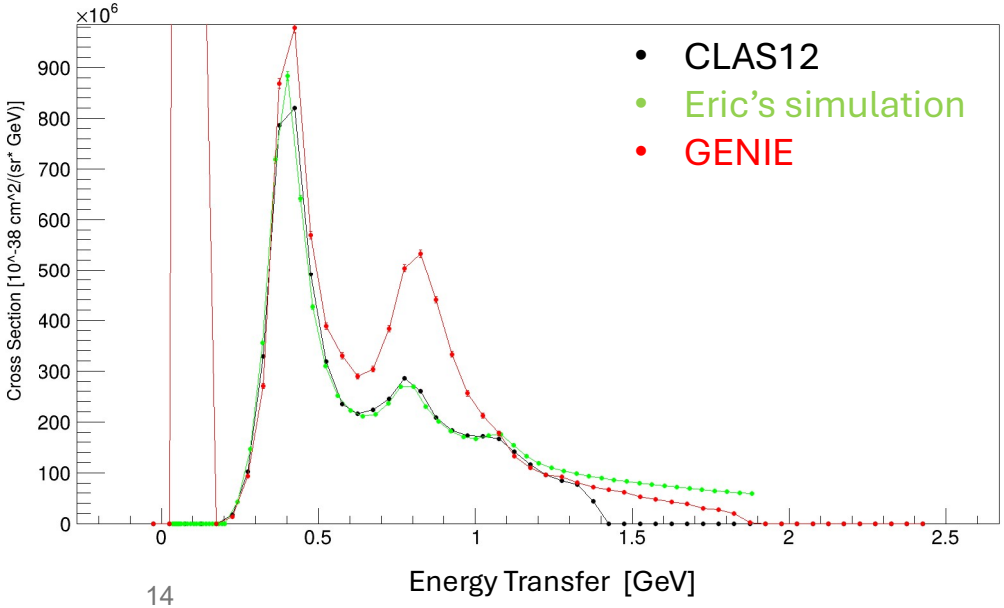


Preliminary Results: 2 GeV on **1H** at 12°

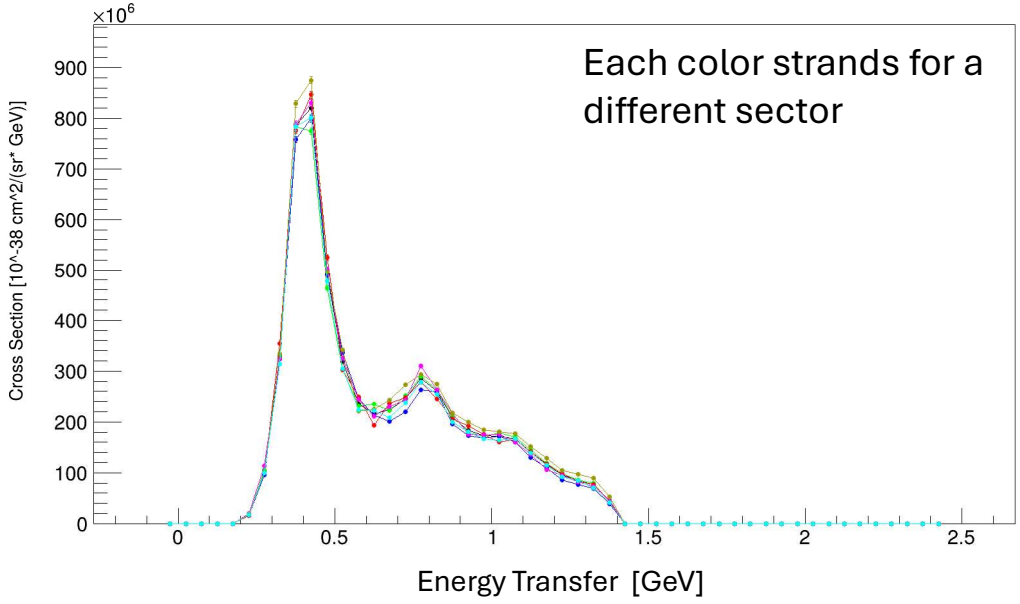
Resulting cross sections:

- A very good agreement between measurement and Eric's model.
- Getting 1H correctly is a good indication for 12C & 40Ar.
- GENIE does a lot less good.

Comparison to models



Different sectors comparison

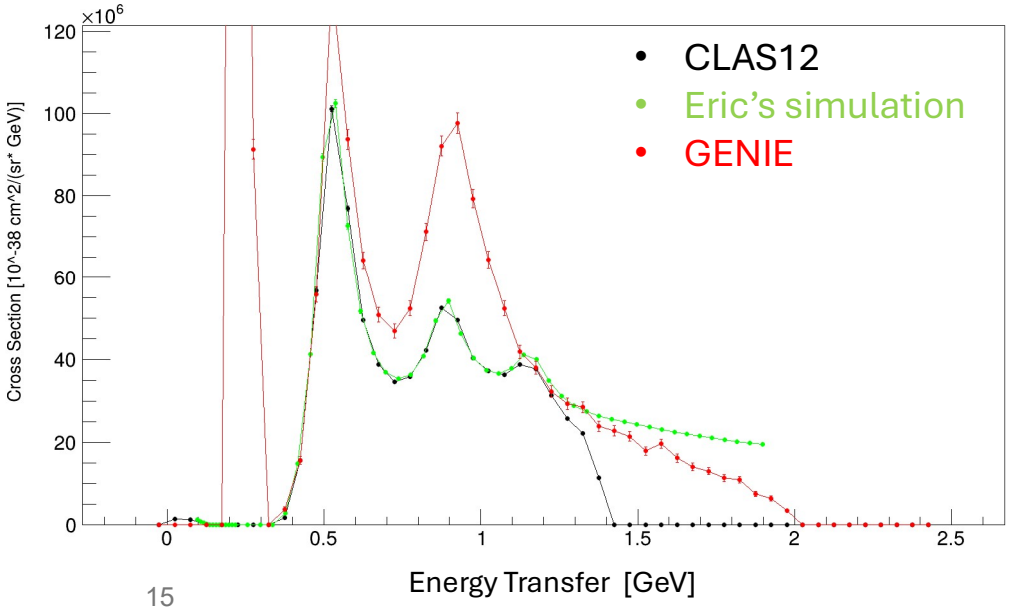


Preliminary Results: 2 GeV on 1H at 20°

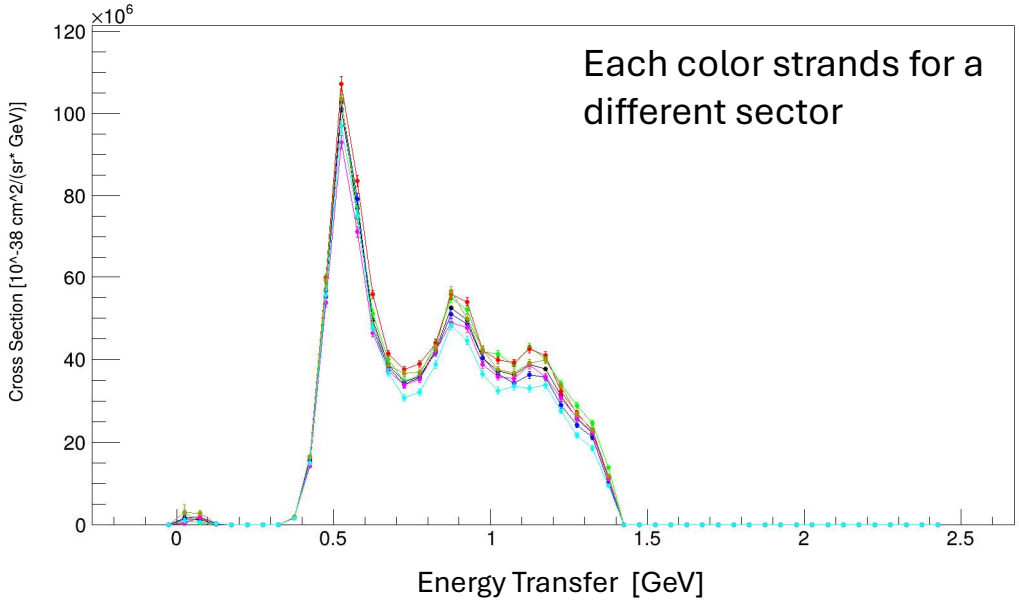
Resulting cross sections:

- The sector-to-sector cross section comparison shows some variance.
- The agreement to Eric's model is incredible.

Comparison to models



Different sectors comparison

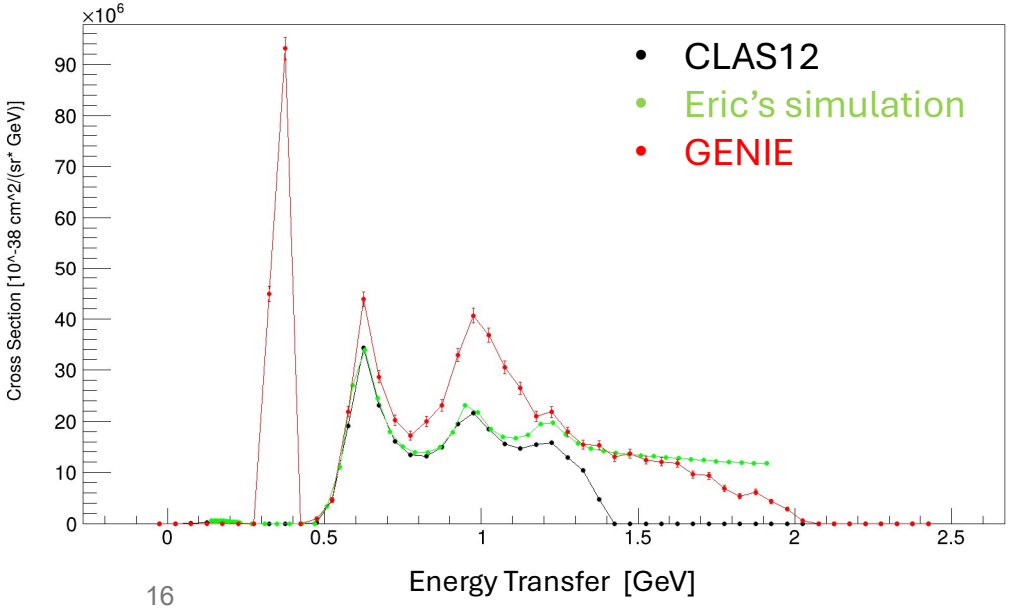


Preliminary Results: 2 GeV on 1H at 25°

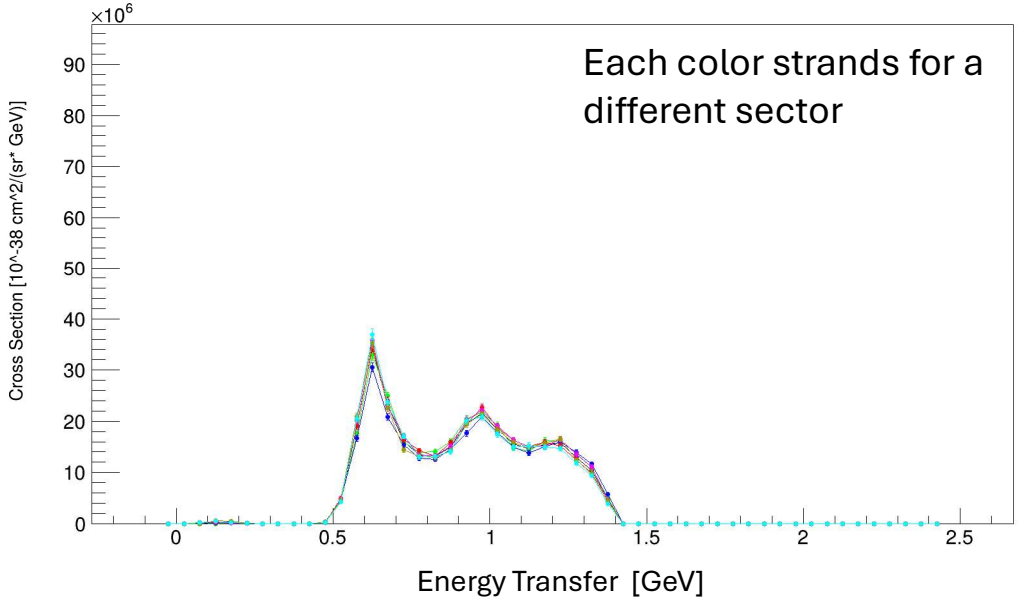
Resulting cross sections:

- At high angles and high energy transfer, there is some visible difference between the measurement and Eric's model.

Comparison to models



Different sectors comparison

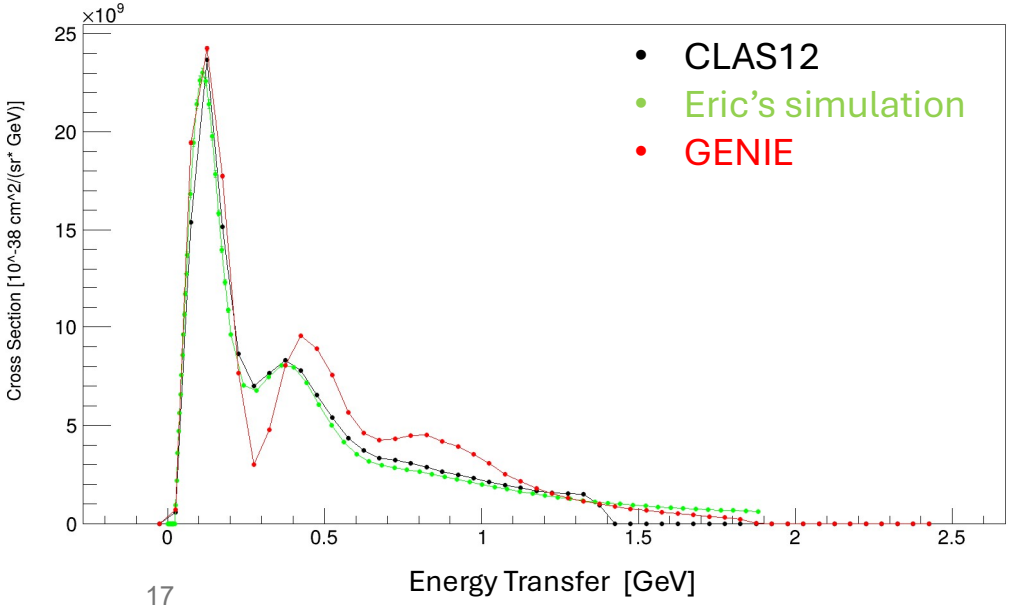


Preliminary Results: 2 GeV on **12C** at 12°

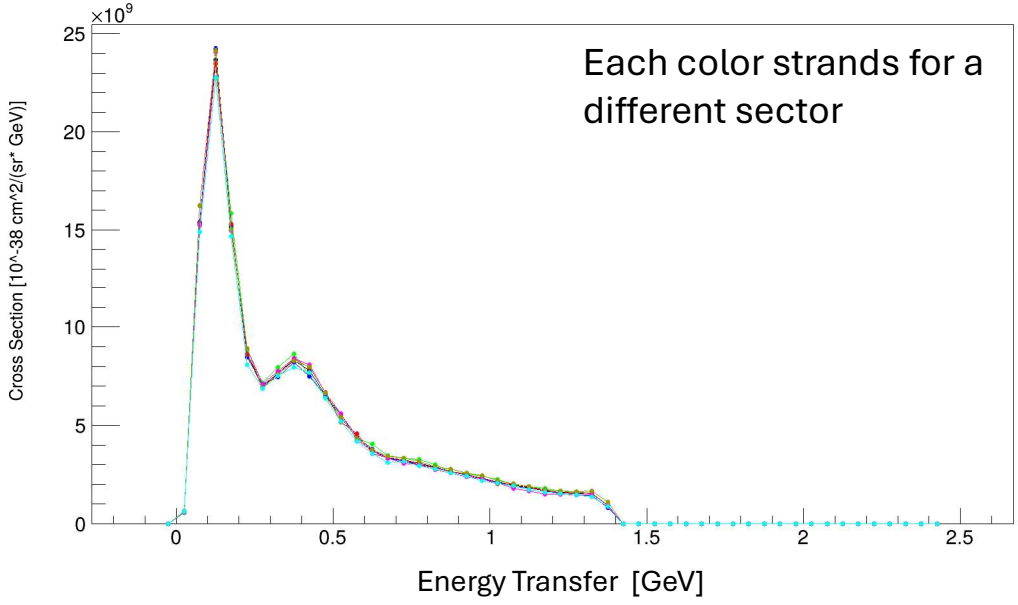
Resulting cross sections:

- Again - a very good agreement between measurement and Eric's model.
- GENIE does a lot less good.
- Agreement between the sectors.

Comparison to models



Different sectors comparison

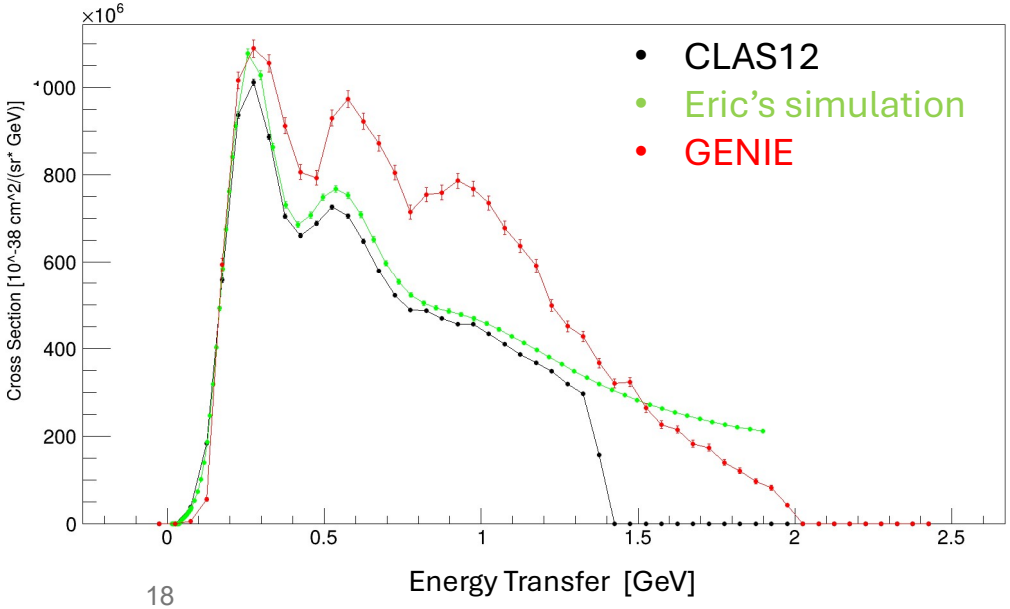


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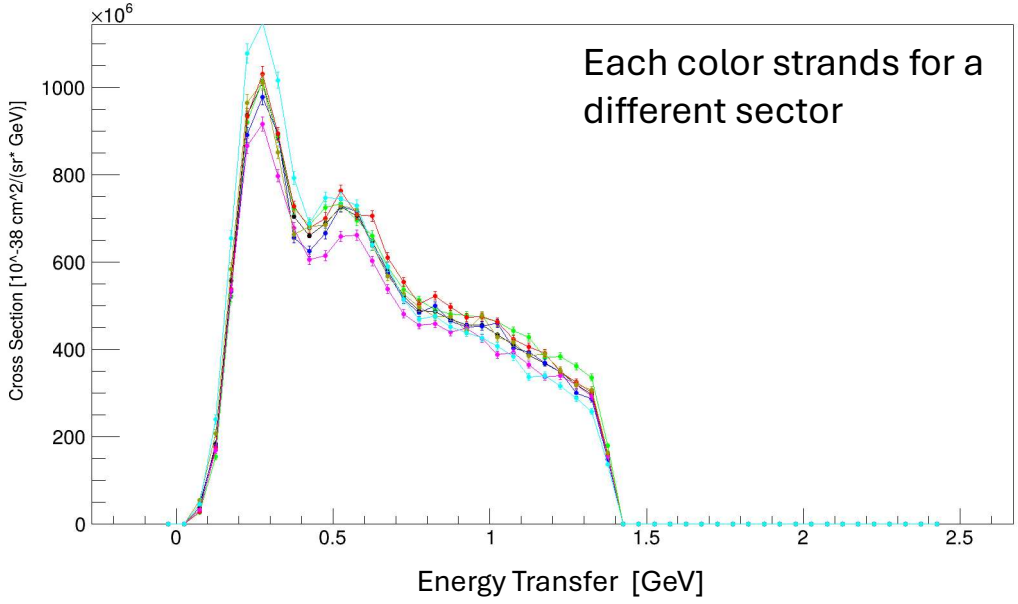
Resulting cross sections:

- Big sector-to-sector difference.

Comparison to models



Different sectors comparison

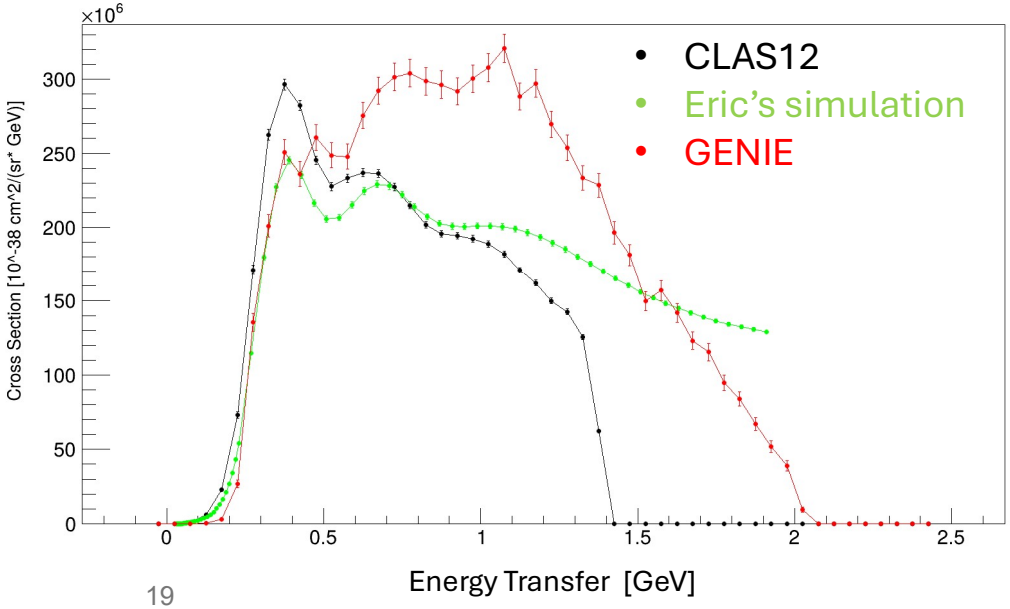


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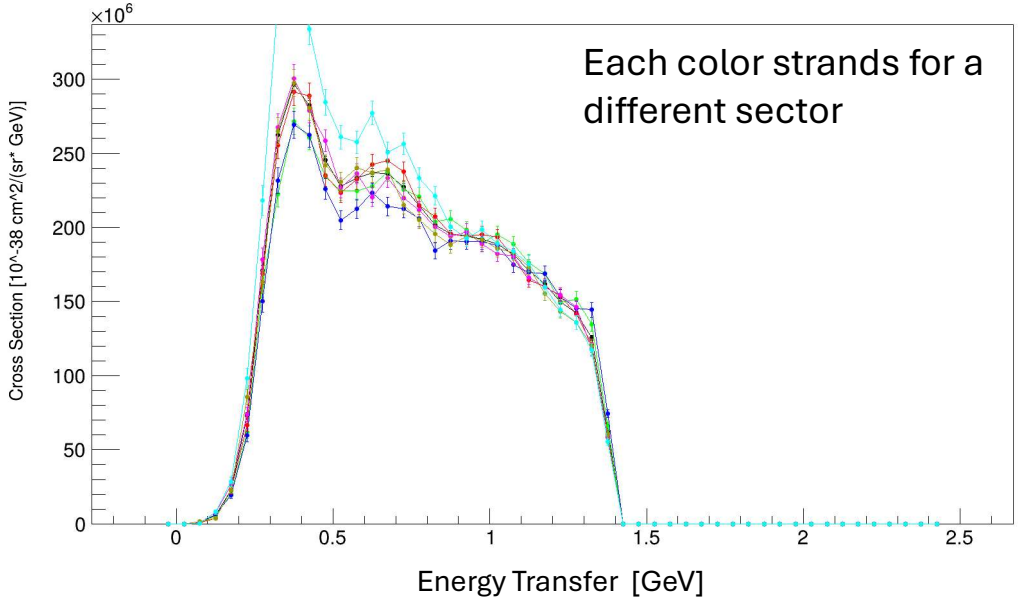
Resulting cross sections:

- Clear difference form Eric's model.

Comparison to models



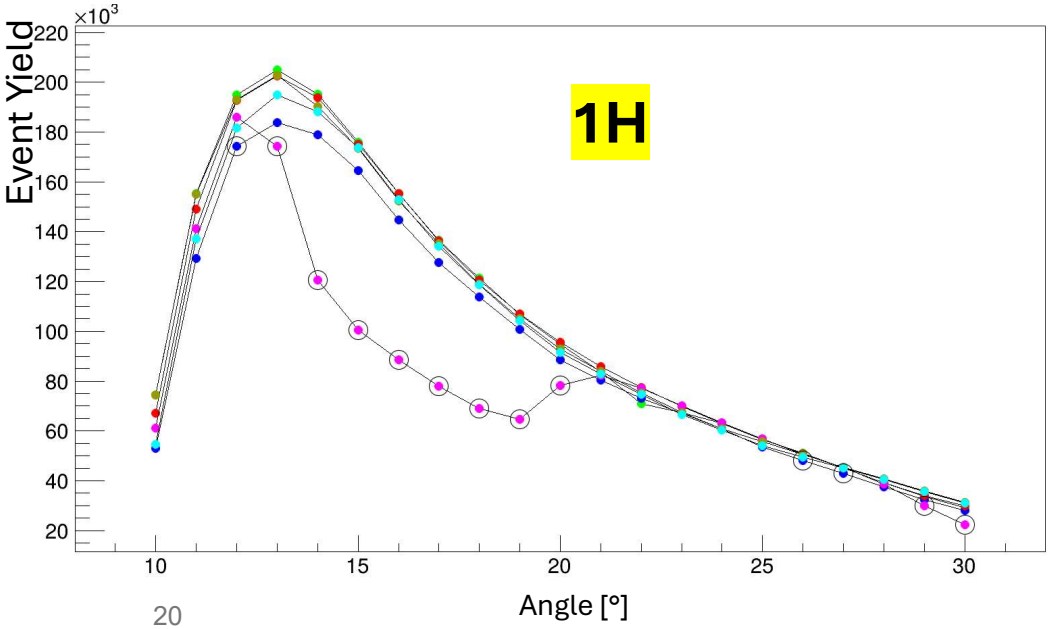
Different sectors comparison

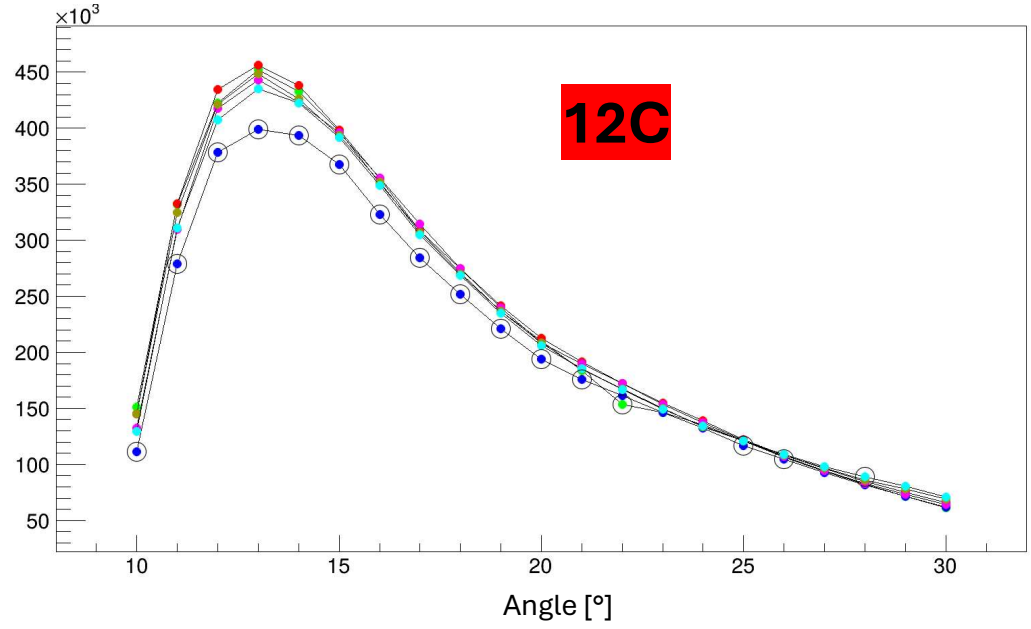


Preliminary Results: 6 GeV on 1H and 12C

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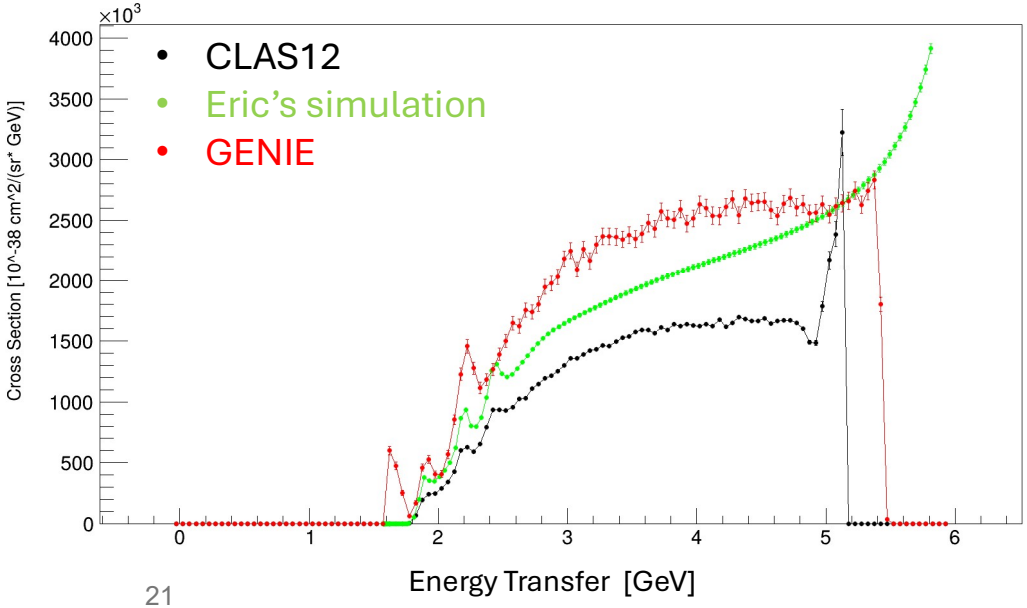


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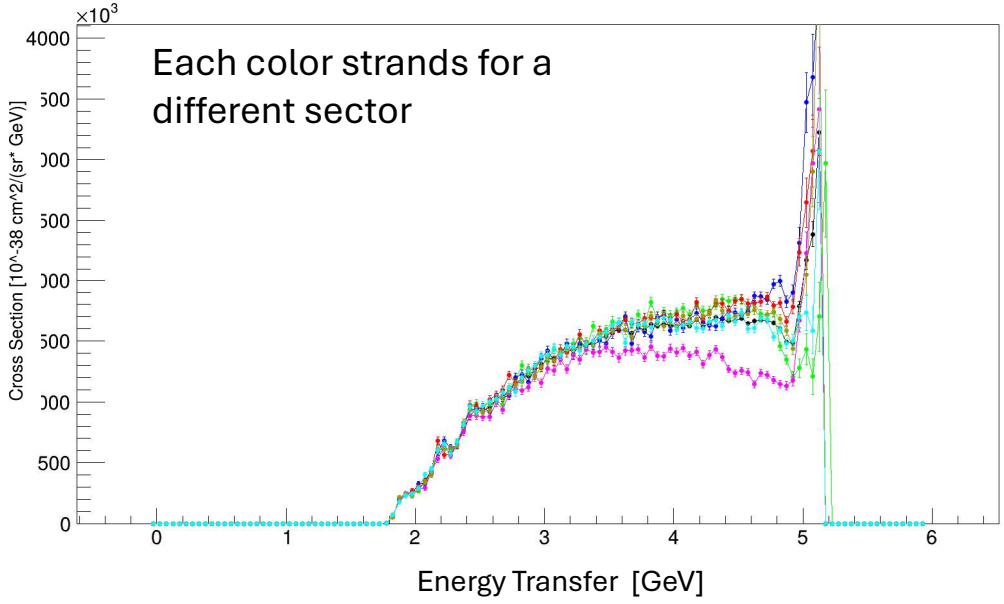
Resulting cross sections:

- The measurement does not match the model.
- Large variance between the sectors.
- Blow-up at the high energy transfer is artificial.

Comparison to models



Different sectors comparison

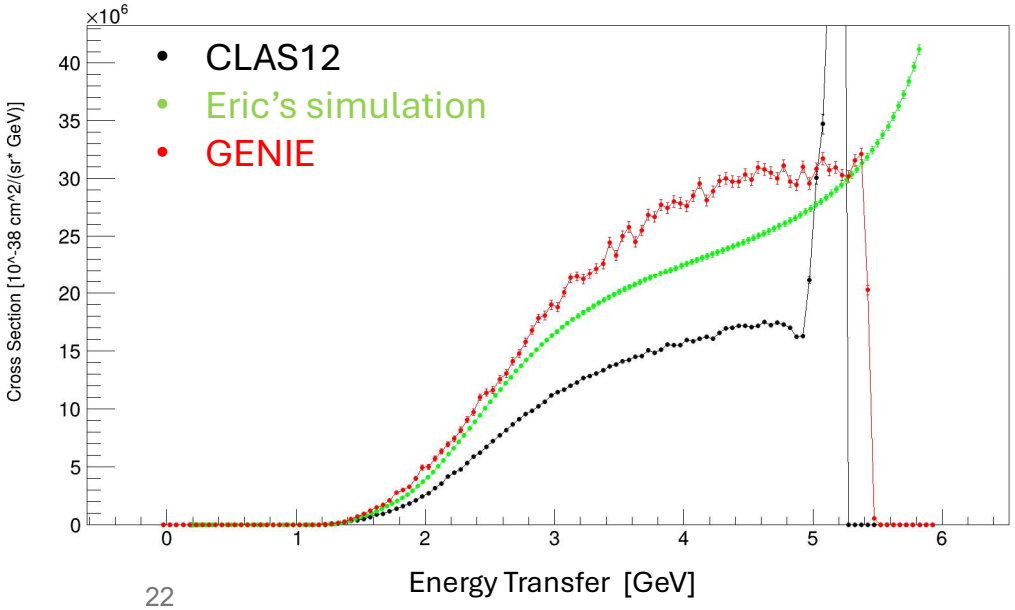


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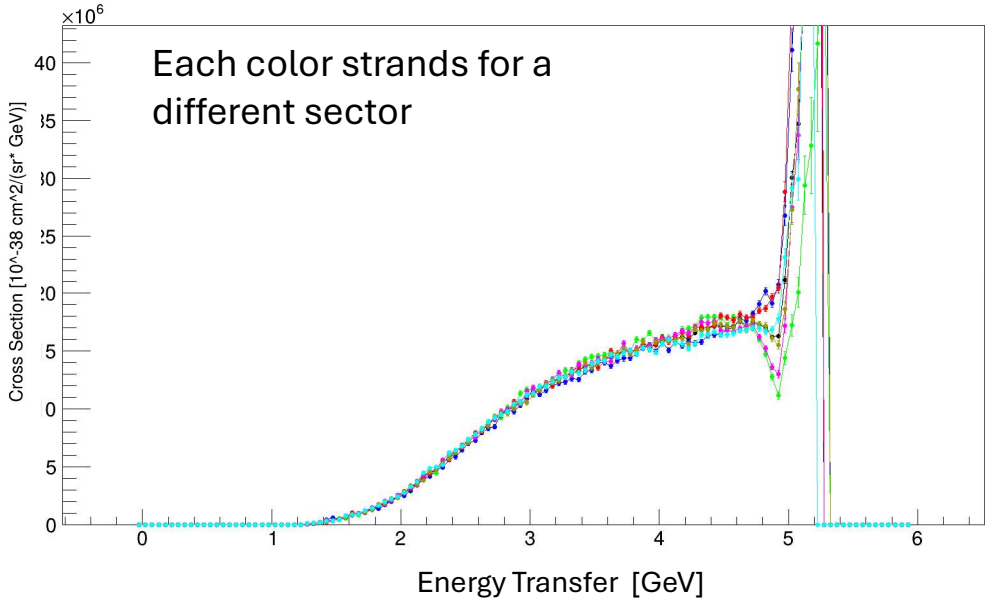
Resulting cross sections:

- Similar to 1H

Comparison to models



Different sectors comparison



Conclusion

- New inclusive cross sections are on the go, including 40Ar, the target nucleus of the near future DUNE experiment.
- Now focusing on understanding what is seen in 6 GeV.
- First-time Rosenbluth separation on 40Ar is possible!

Thank you!