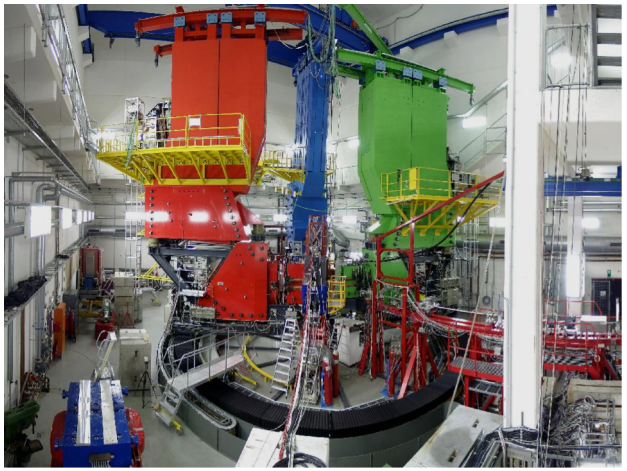
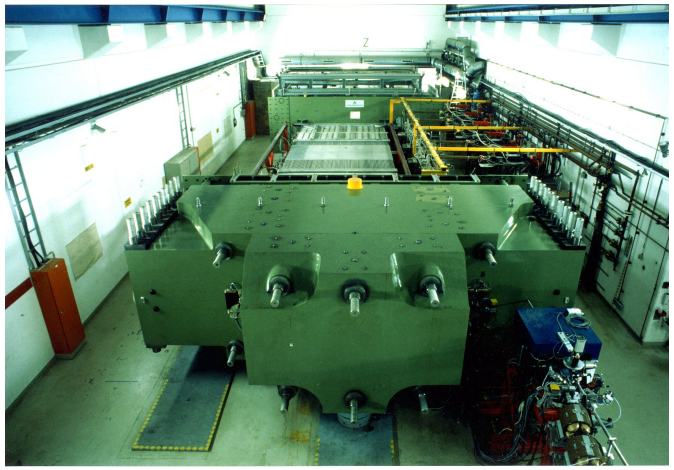
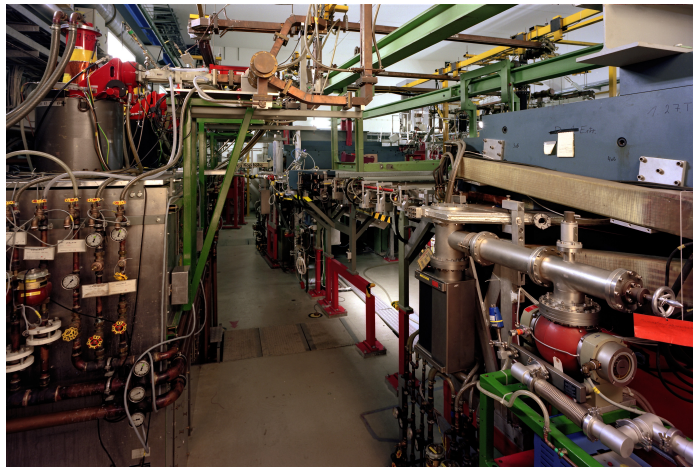




Neutrino related nuclear scattering experiments at MAMI

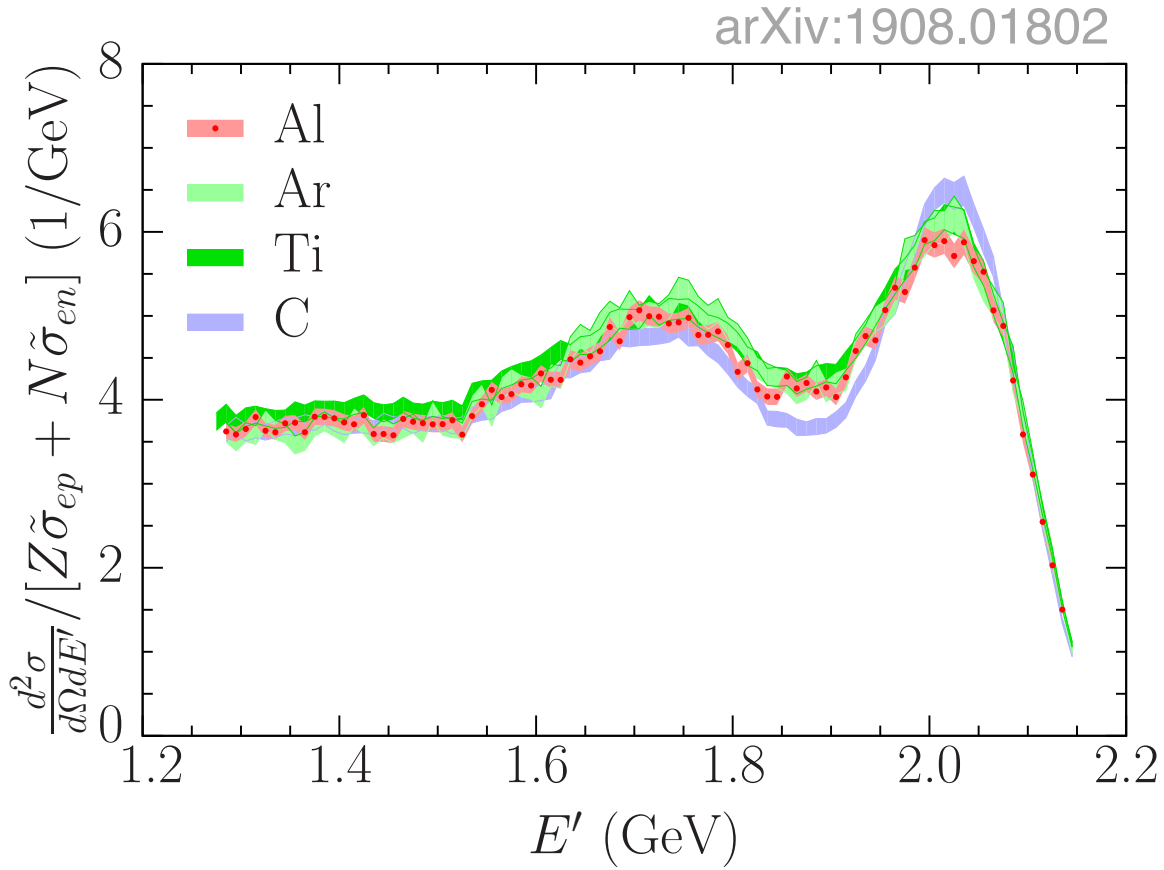
Miha Mihovilovič

NSL 2023

Mainz, 28. 6. 2023

Motivation – E12-14-012

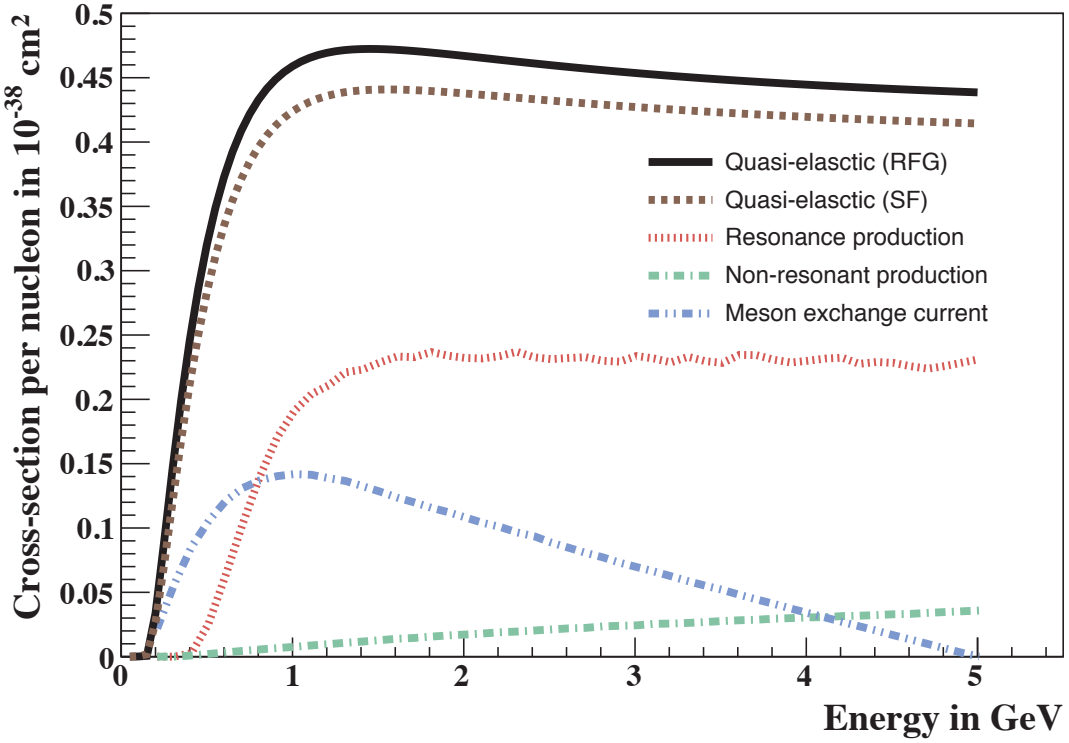
- Successful experiment performed at Jefferson Lab.
- Inclusive (and exclusive) data collected for C, Al, Ar, Ti targets at 2.2 GeV and 15.5°.

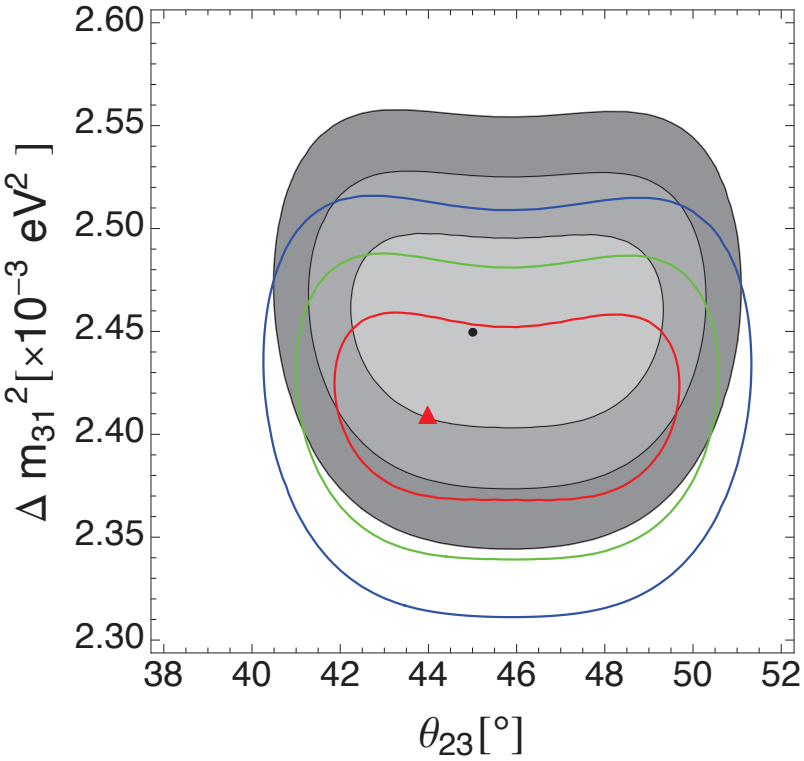


- Experiment confirmed approximate scaling.

Motivation - Neutrino experiments

- Provide new input to competing models employed to interpret signals detected in accelerator-based neutrino experiments.

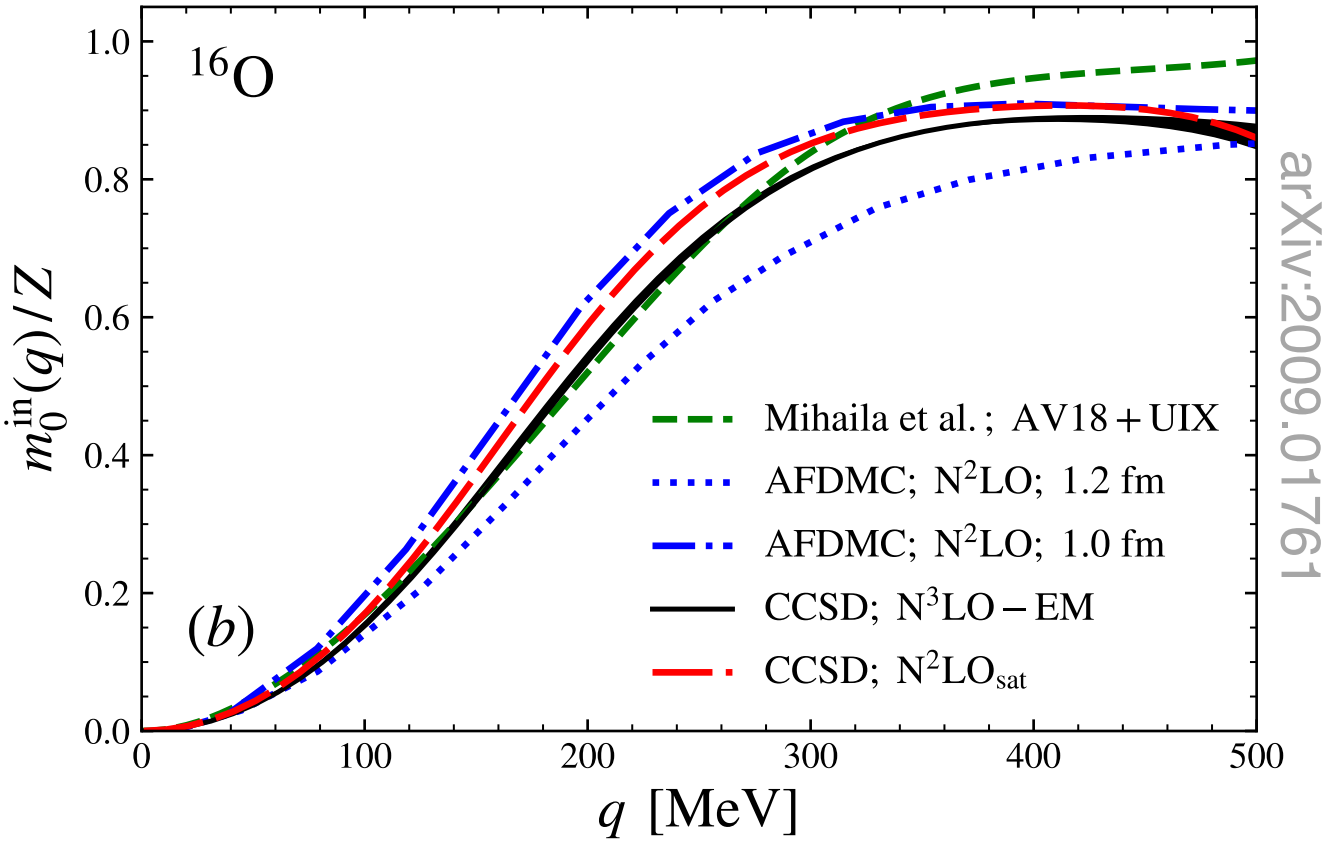




A.M. Ankowski, C. Mariani (arXiv:1609.00258)

Coulomb Sum Rule – ^{16}O

- Study the nuclear structure and validate existing theories.



- Coulomb sum rule for Oxygen using coupled cluster theory (J. E. Sobczyk).
- Theory extendable to ab-initio studies of neutrino-nucleus cross-sections.
- **No data exist!**

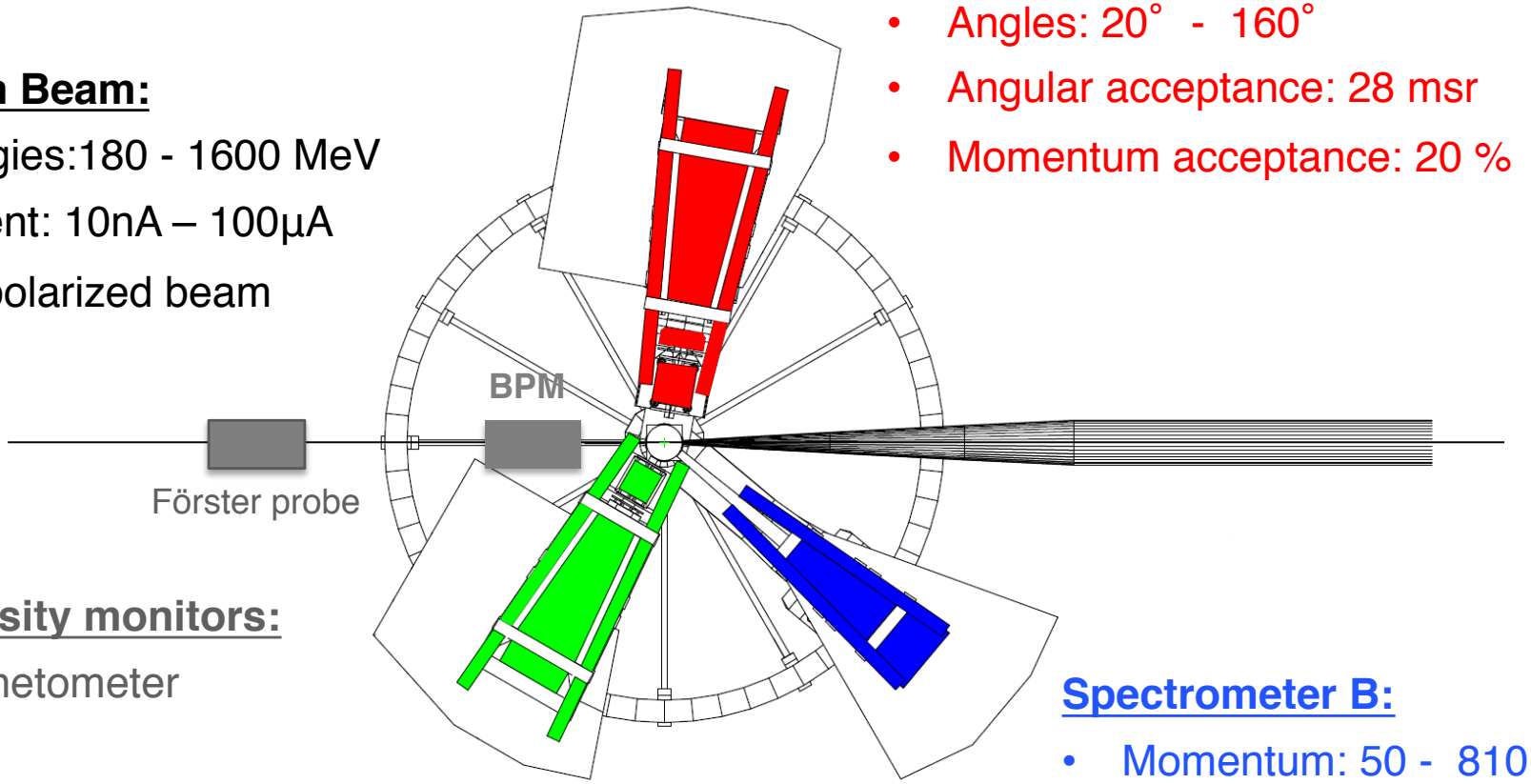
A1 Setup

Spectrometer A:

- Momentum: 50 - 660 MeV/c
- Angles: 20° - 160°
- Angular acceptance: 28 msr
- Momentum acceptance: 20 %

Electron Beam:

- Energies:180 - 1600 MeV
- Current: 10nA – 100µA
- (Un)polarized beam



Luminosity monitors:

- magnetometer

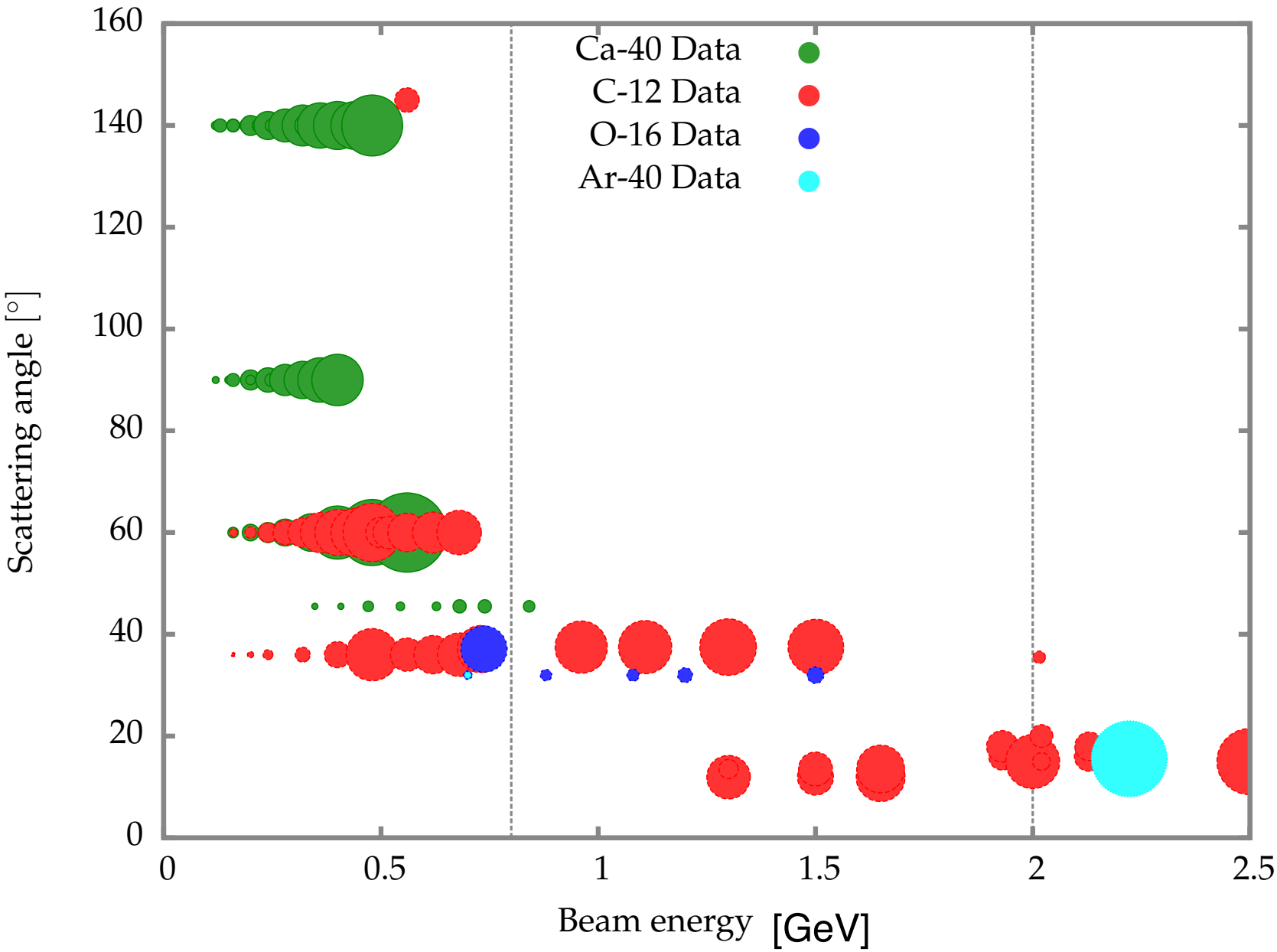
Spectrometer B:

- Momentum: 50 - 810 MeV/c
- Angles: 15° - 62°
- Angular acceptance: 5.6 msr
- Momentum acceptance: 15 %

Spectrometer C:

- Momentum: 50 - 490 MeV/c
- Angles: 50° - 108°
- Angular acceptance: 28 msr
- Momentum acceptance: 25 %

Existing inclusive data



The Mainz program

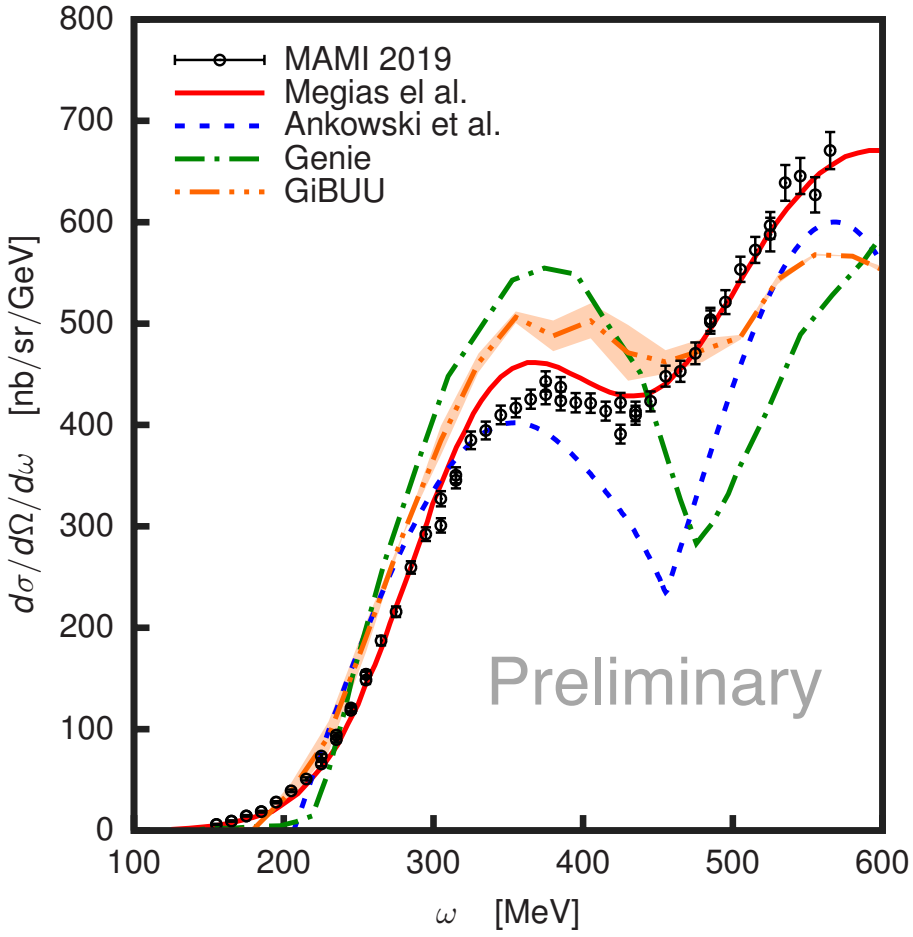
- **2019** – First test measurements on ^{12}C.
- **2020** – Full experimental agenda on ^{12}C **(see talk of L. Doria).**
- **2021** – Experiment on ^{40}Ar with Jet target **(see talk of L. Doria).**

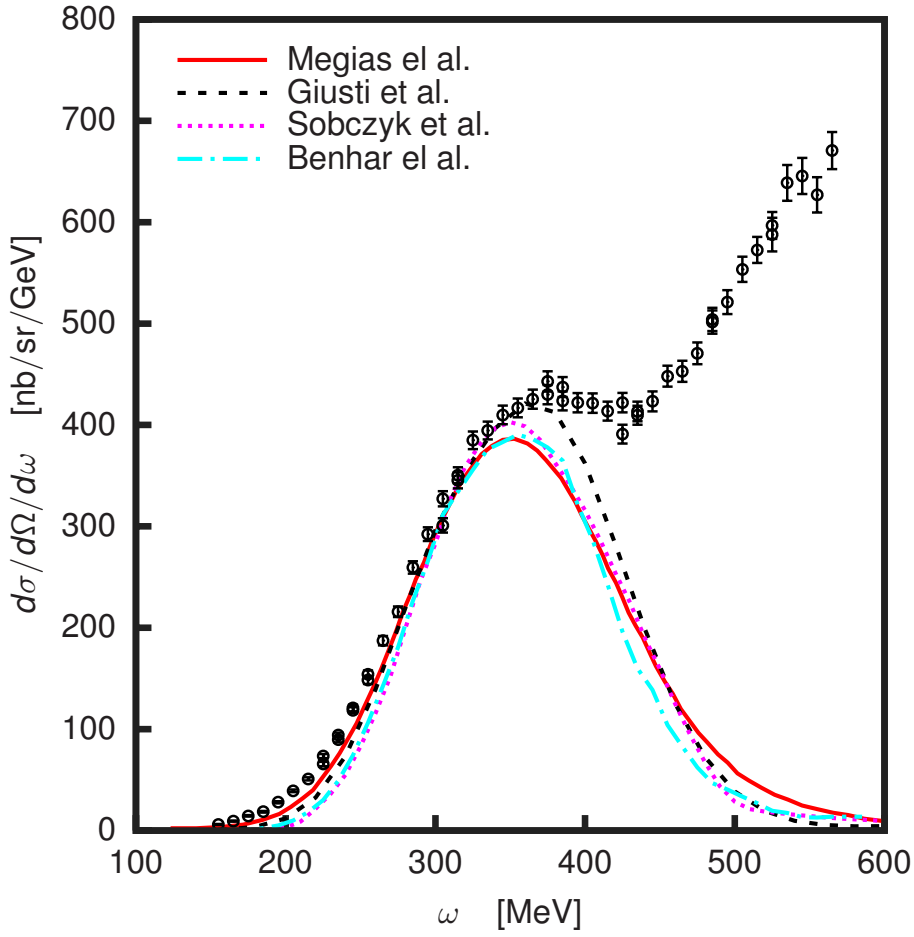
Today

- **2025** – Experiment on ^{16}O?

Results of Pilot Carbon Experiment

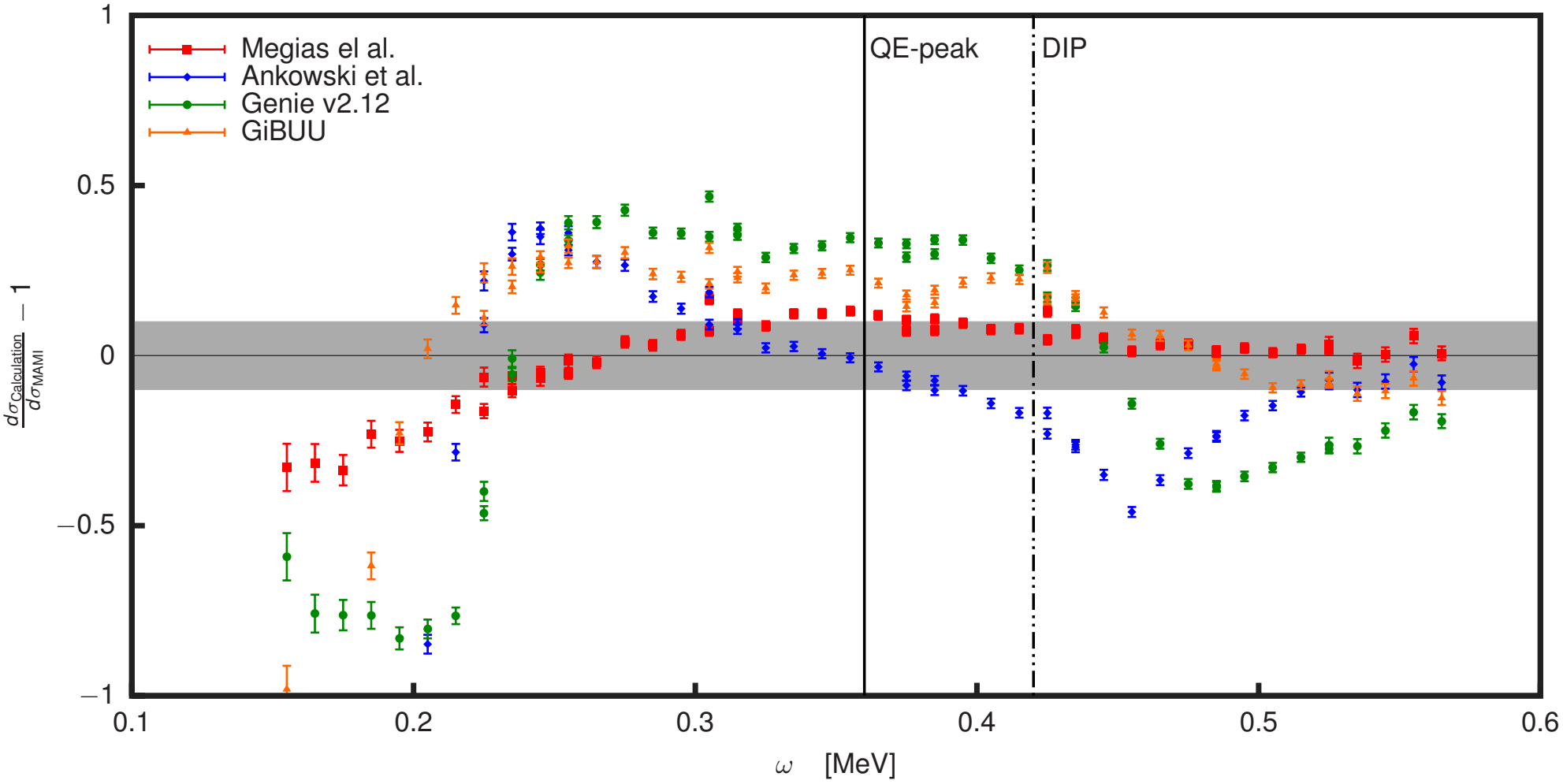
- Proof-of-principle measurement at **855 MeV** (70°)
- Comparison with the full calculations (QE+Δ+MEC)
- Comparison with QE calculations.





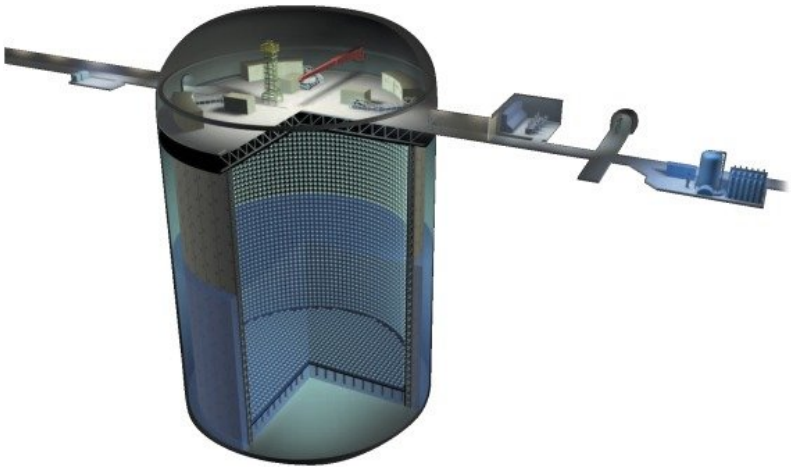
How precise are the existing calculations?

- Precision of neutrino generators ~ 30%.
- SUSAv2 precise to 10% (RPWIA regime).
- Ankowski et al. precise to 30% (RFG model).

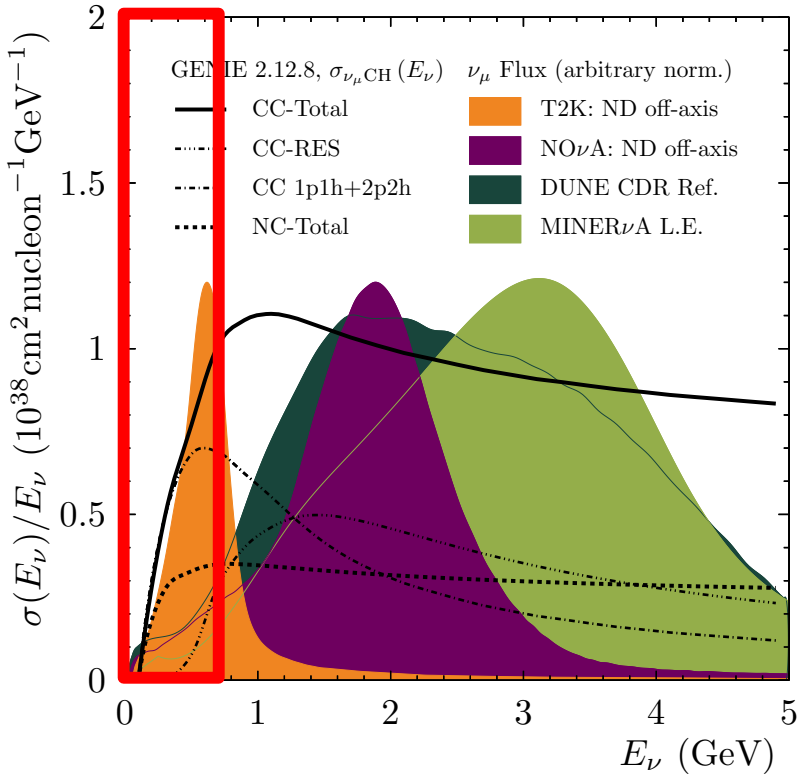


New experiment on ^{16}O

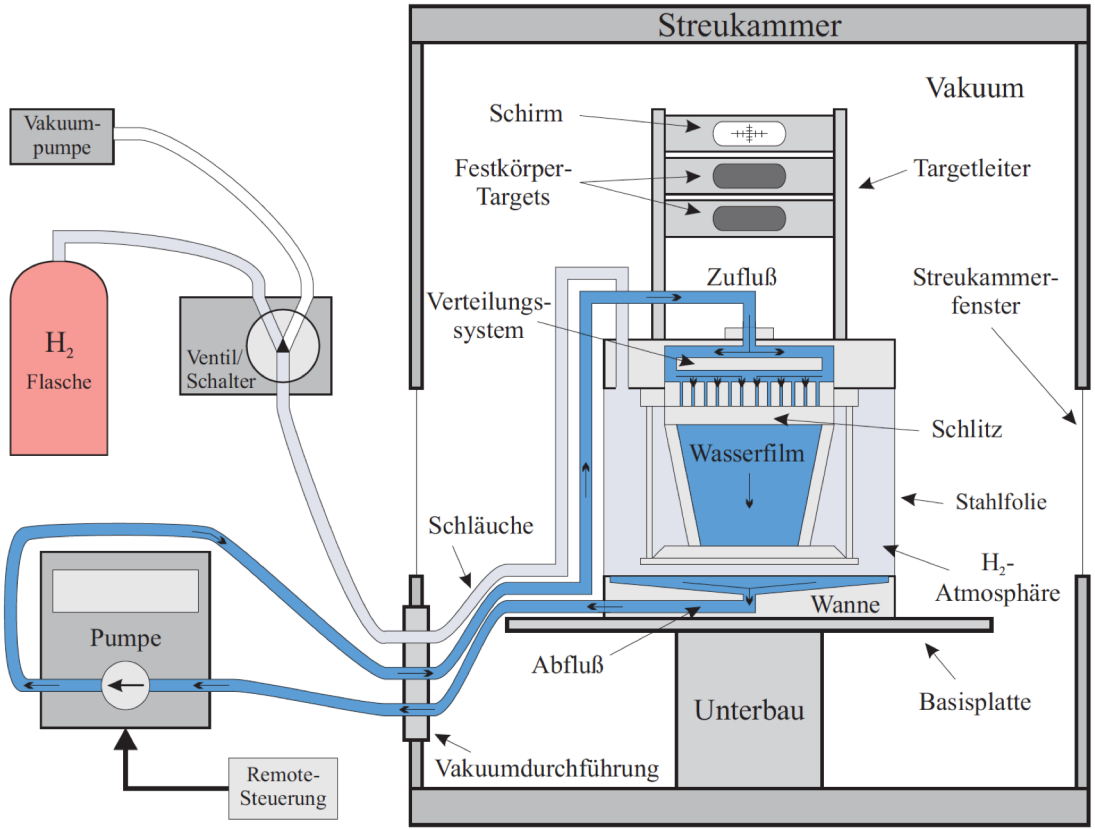
- Precision electron-induced scattering experiment on oxygen and carbon.
- Measurement of inclusive cross-sections in quasi-elastic and delta resonance.
- **Quenching of the Coulomb sum rule**.
- **Test models used in neutrino experiments.**
- Kinematics most relevant for T2K.



K. Mahn et al. (arXiv:1803.08848)

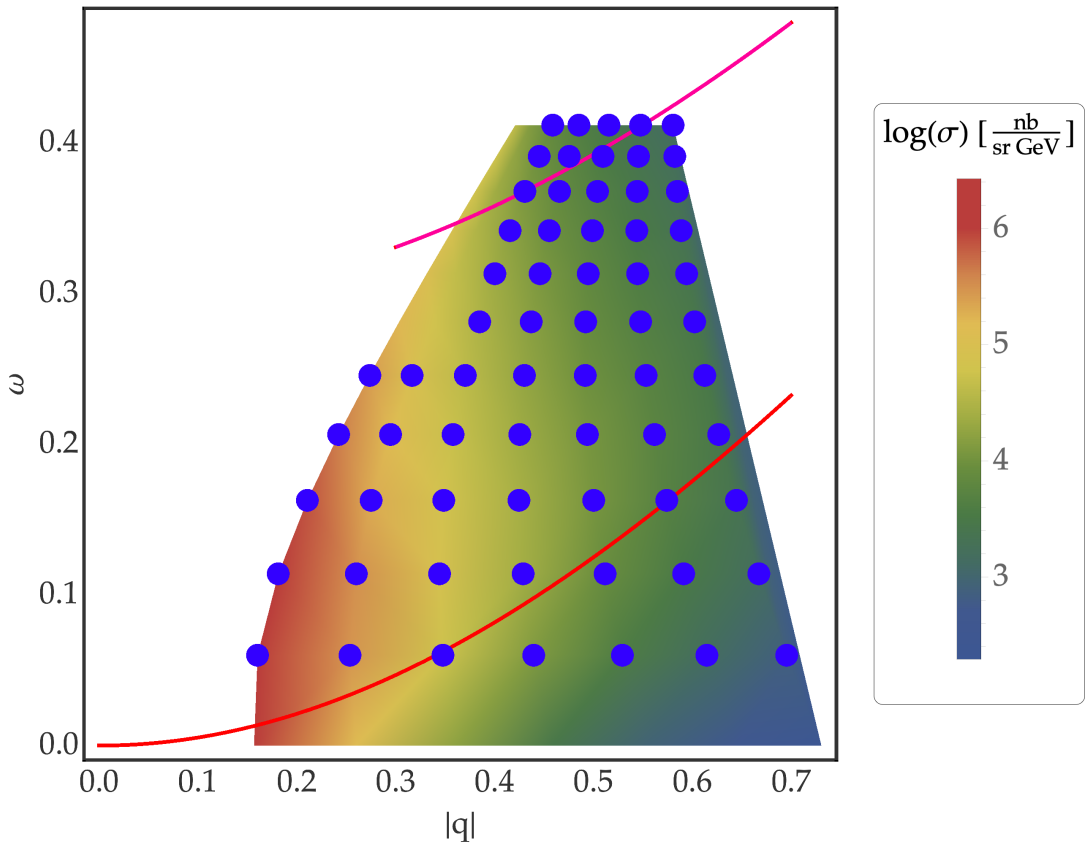


Target



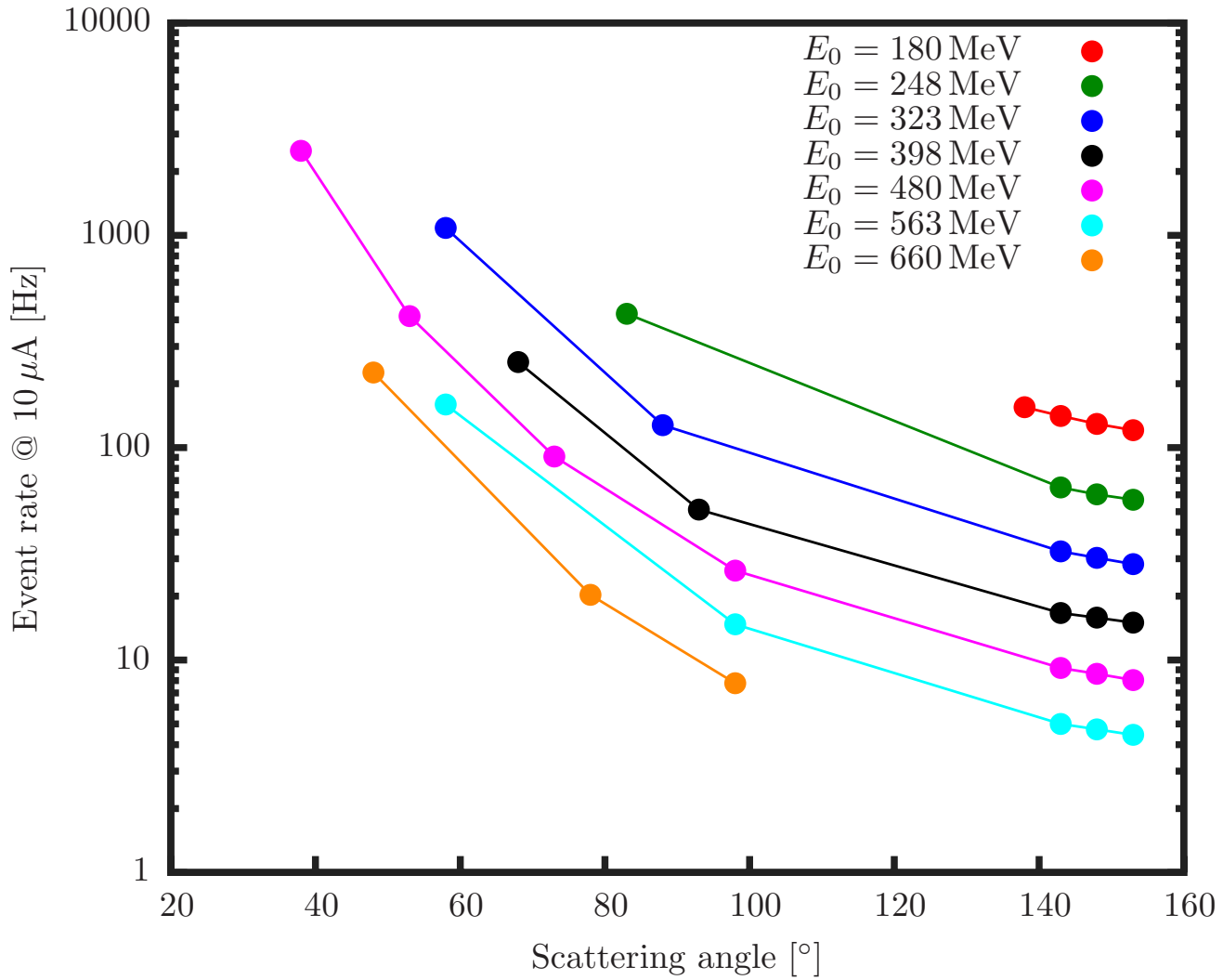
- Waterfall target is established equipment of A1.
- Measurement without background from target walls.
- Hydrogen background subtracted using sophisticated simulations.
- **Luminosity of $4 \cdot 10^{35}/cm^2/s$ at 20µA.**

Kinematics



- Data will cover both QE and DR regime.
- R_L and R_T could be separated and individually studied.
- Coulomb sum for 0.3 GeV ≤ |q| ≤ 0.8 GeV could be determined.
- **Hypothesis: Deviations between theory and data at large scattering angles are expected.**

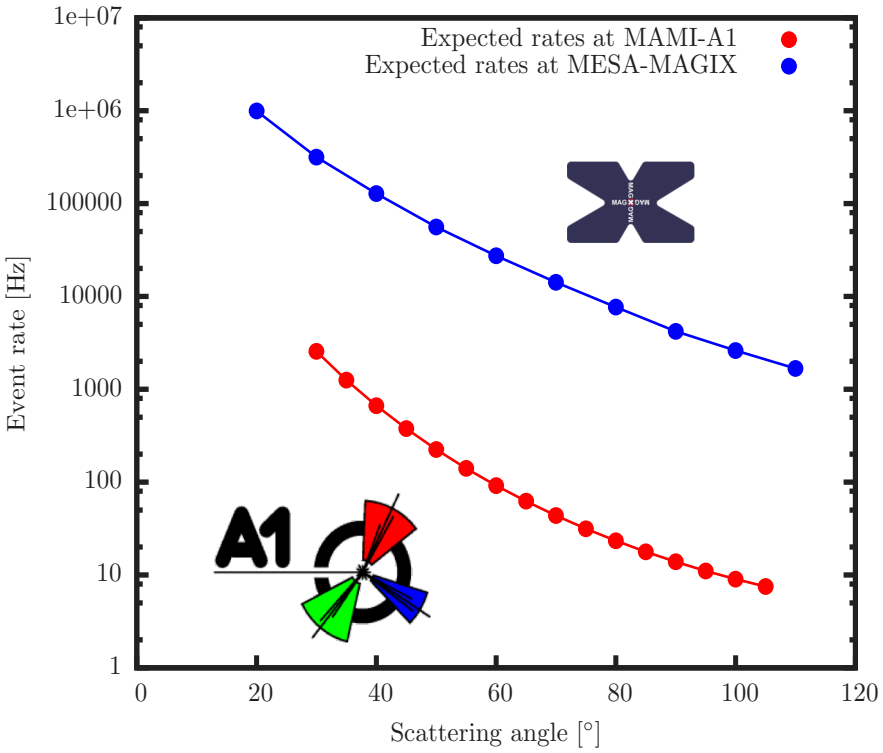
Experimental Rates

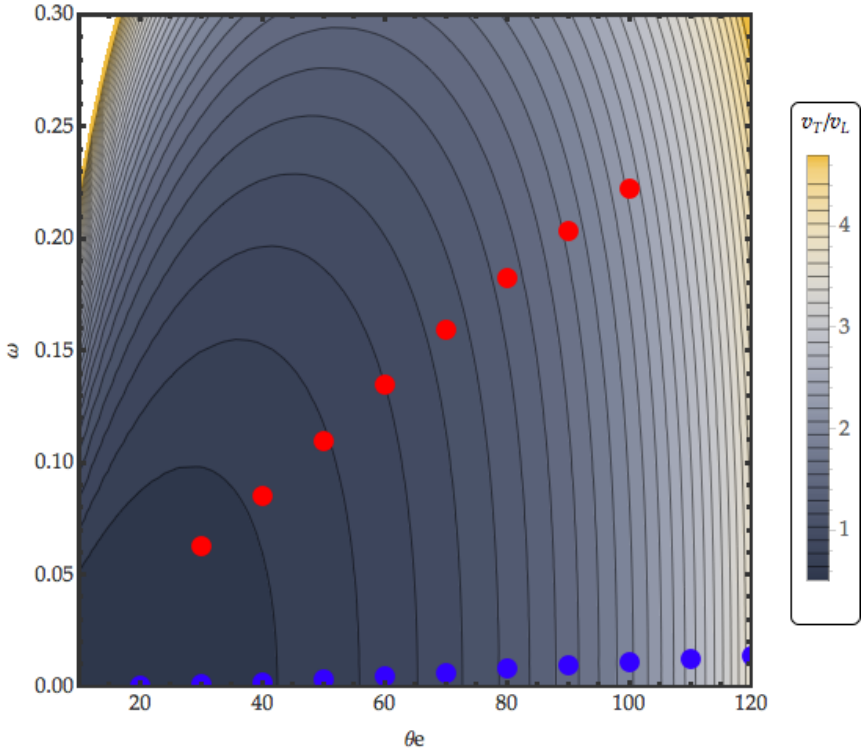


- With beam current of ~20μA rates between 20Hz and 500Hz are expected.
- 50 days to complete experimental agenda.

Future A(e,e') experiments at MAGIX

- Accessing $\mathbf{R_L}$ (charge) and $\mathbf{R_T}$ (EM currents).
- Much higher rates.
- New precise measurements at low Q^2 and small ω.
- **This is interesting for 10s MeV neutrino physics.**

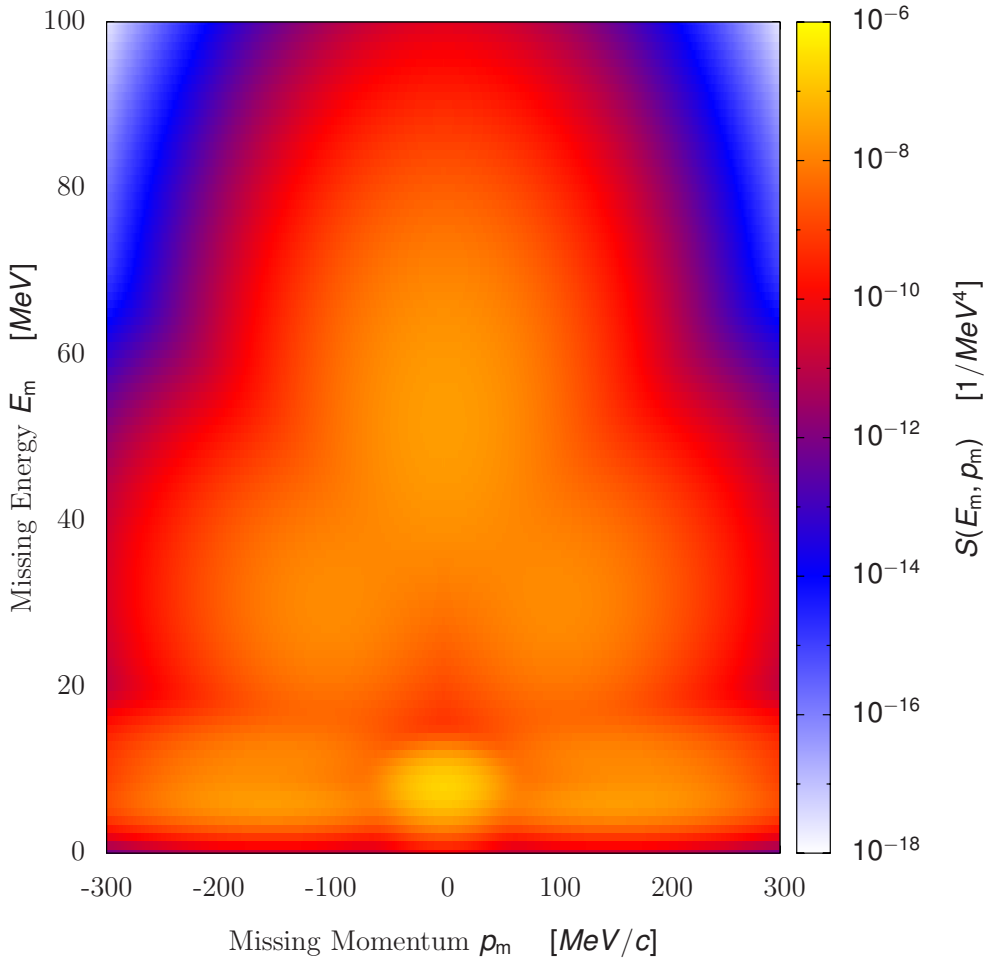




^{40}Ar(e,e'p) experiment

$$\frac{d\sigma}{dE_{e'}d\Omega_{e'}dE_p d\Omega_p} = K\sigma_{ep}S(E_m, p_m)$$

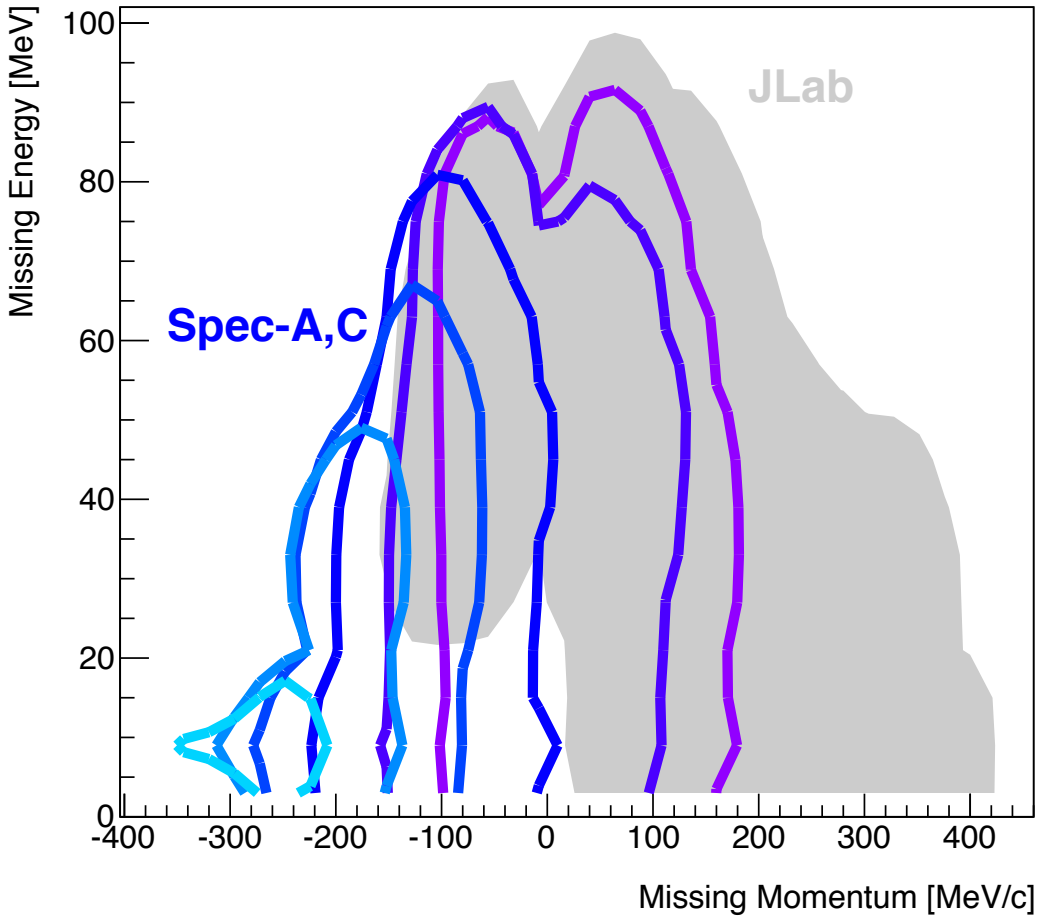
- The spectral function combines the **complete response** of a nucleus.
- Experimental data validate the predictions of the many-body theories.
- First measurements done at Jefferson Lab @ 2.2 GeV.



^{40}Ar(e,e'p) experiment at MAMI

- JLab's E12-14-012 provided data only for $p_m > 0$.

- Experiment at A1 complements JLab experiment with measurements at $p_m < 0$ for complete picture of nuclear response.



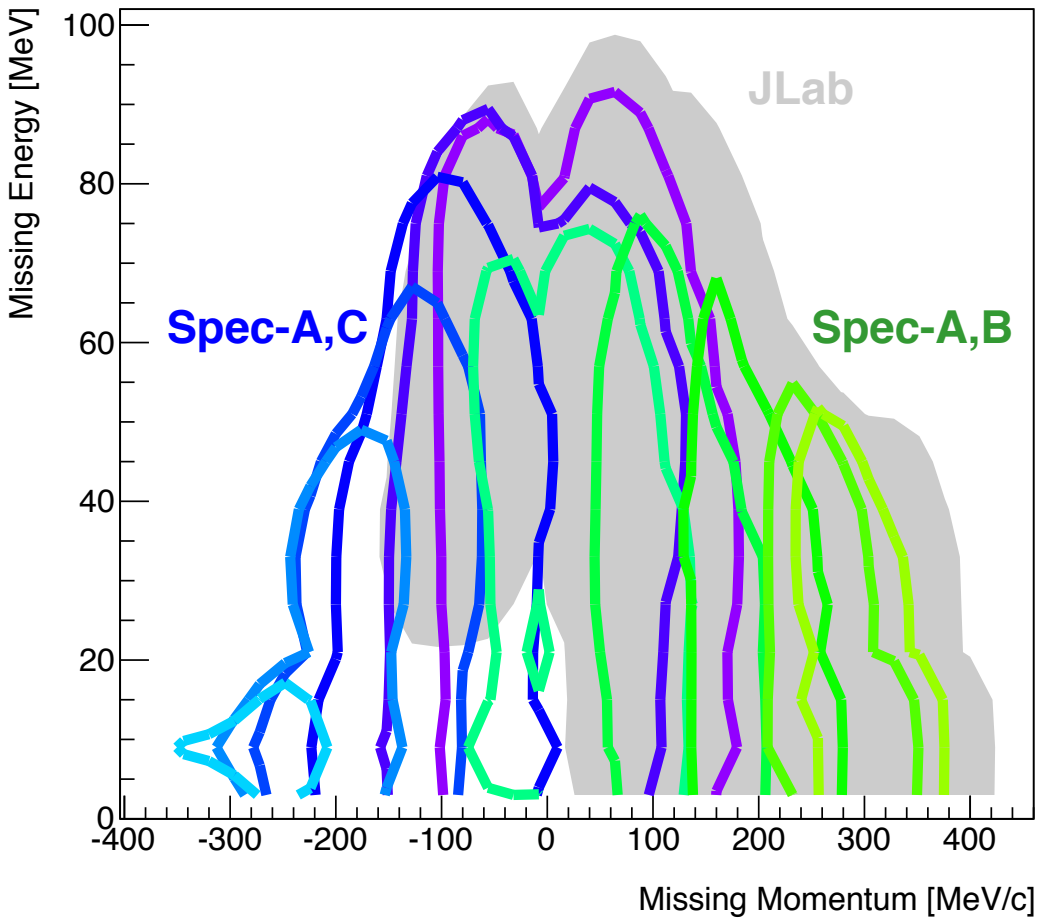
Kinematics:

E_{beam}:	600 MeV
E':	450 MeV
$\theta_{e:}$:	50^o – 100^o
p_p:	512 MeV/c
$\theta_{p:}$:	33^o – 49^o
Target:	4cm gas cell
L:	$4 \cdot 10^{35}$ cm^{-2} s^{-1}

^{40}Ar(e,e'p) experiment at MAMI

- Exclusive coincidence experiment required two spectrometers (A & C).

- Including third spectrometer to the measurement, the $p_m > 0$ data can be obtained for free (with A & B) to double check the JLab data.



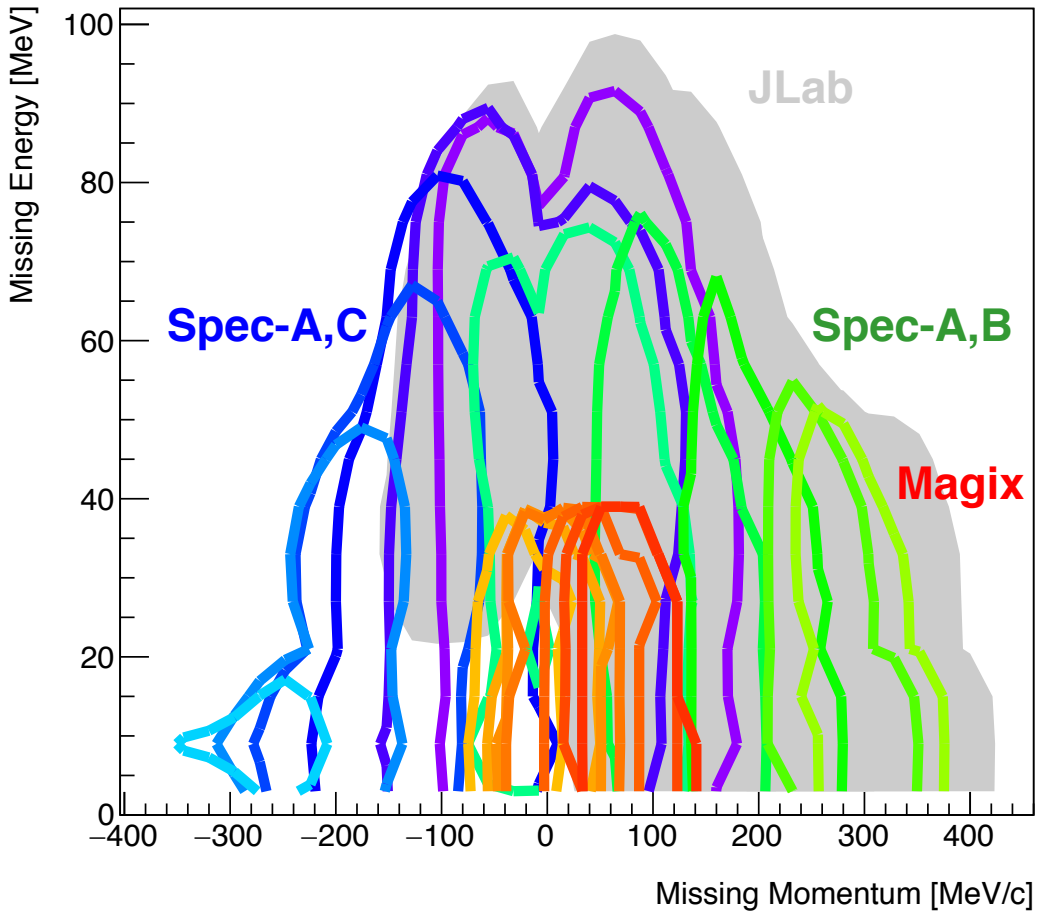
Kinematics:

E_{beam}:	600 MeV
E':	450 MeV
$\theta_{e:}$:	15^o – 50^o
p_p:	512 MeV/c
$\theta_{p:}$:	38^o – 50^o
Target:	4cm gas cell
L:	$4 \cdot 10^{35}$ cm^{-2} s^{-1}

^{40}Ar(e,e'p) experiment at Magix

- The experimental program could be extended with measurements at Magix @ MESA.

- Capacity to provide data without background in the most interesting region.

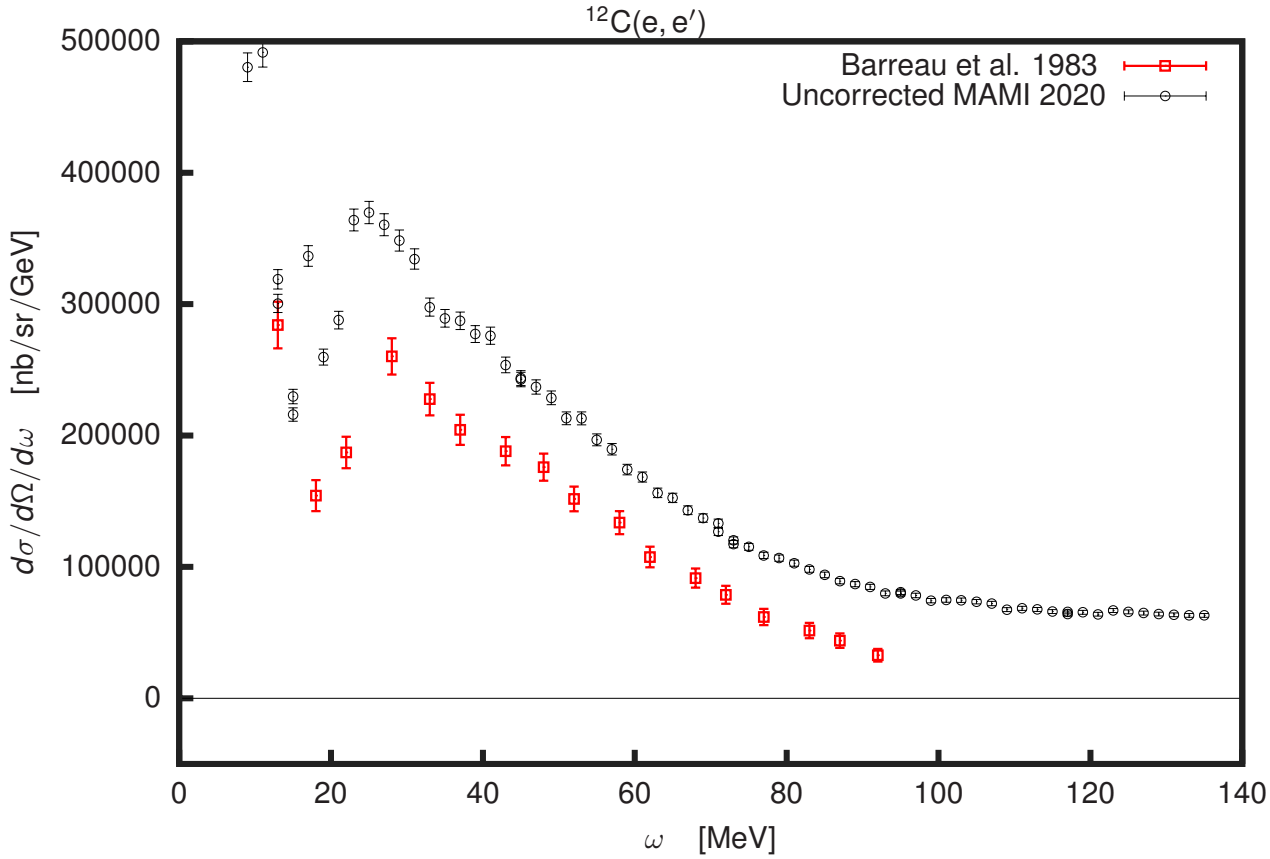


Kinematics:

E_{beam}:	100 MeV
E':	80 MeV
$\theta_{e:}$:	20^o – 120^o
p_p:	122 MeV/c
$\theta_{p:}$:	25^o – 50^o
Target:	Jet gas
L:	$9 \cdot 10^{34}$ cm^{-2} s^{-1}

Low Q^2 data

- Relevant for the studies of models of nuclear structure and dynamics.
- Accessible at A1(MAMI) and MAGIX (MESA).
- $^{12}C(e,e')$ cross-section at 315 MeV and 36°:

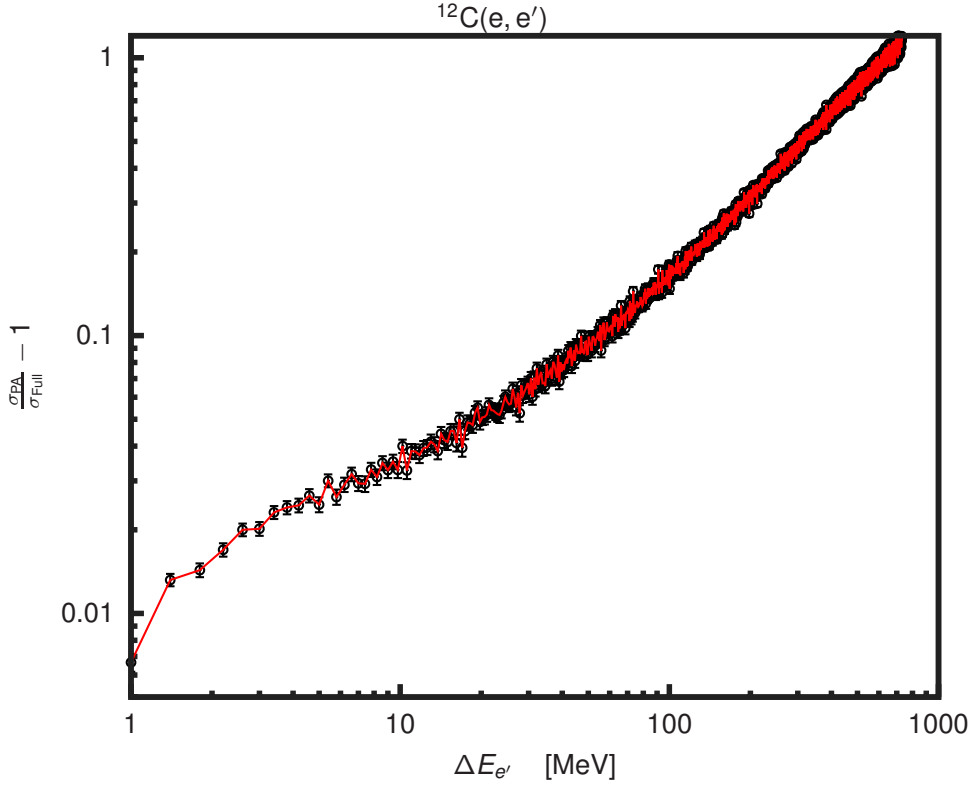


- **Data contaminated with elastic data (and nuclear excited states).**

Going beyond peaking approximation

$$\frac{d\,\sigma_a}{d\,\Delta E'} = \sigma_{elastic}\,\frac{t}{\Delta E'}\,e^{\delta(\Delta E')}$$

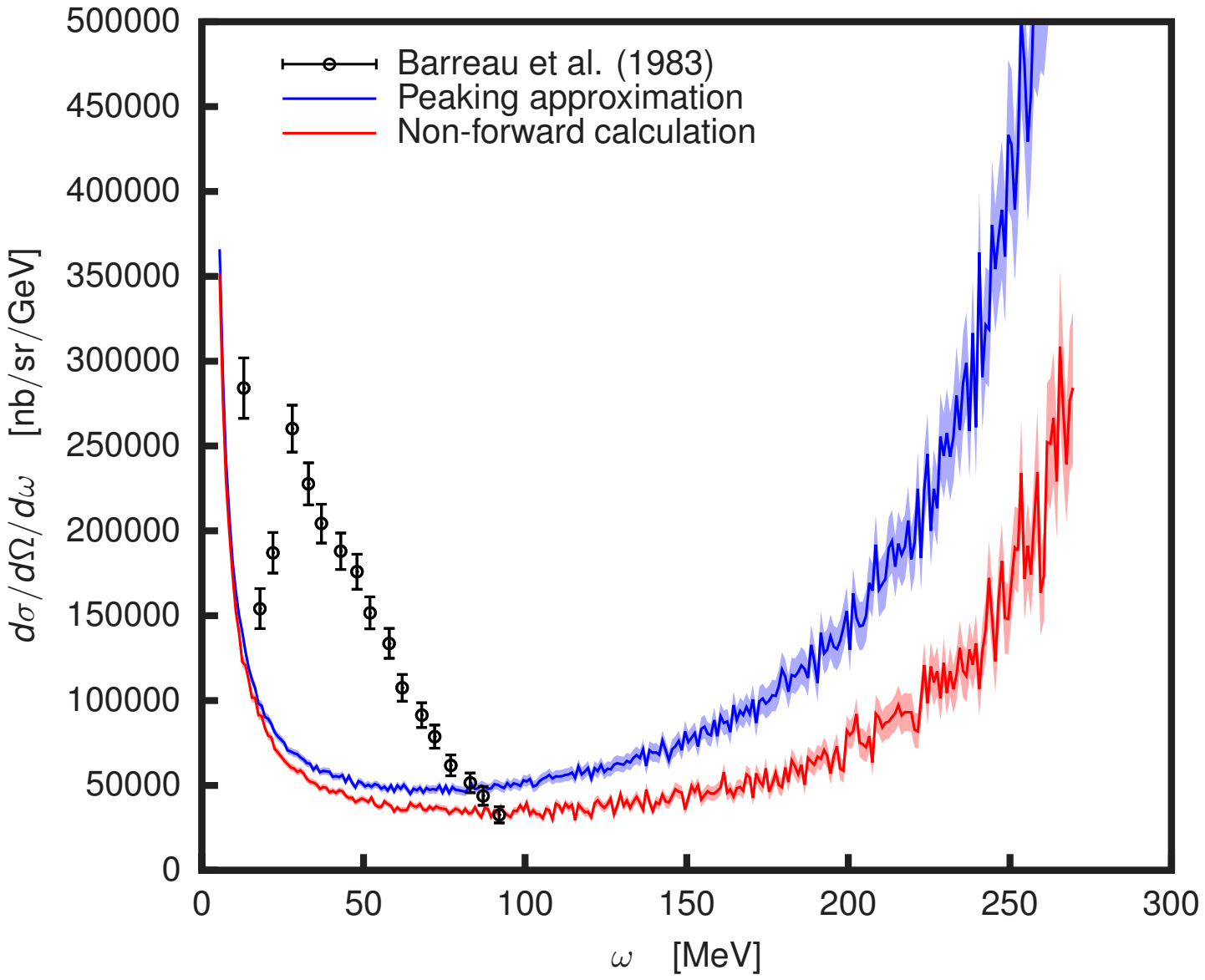
- Peaking approximations insufficient for the interpretation of such experiment.



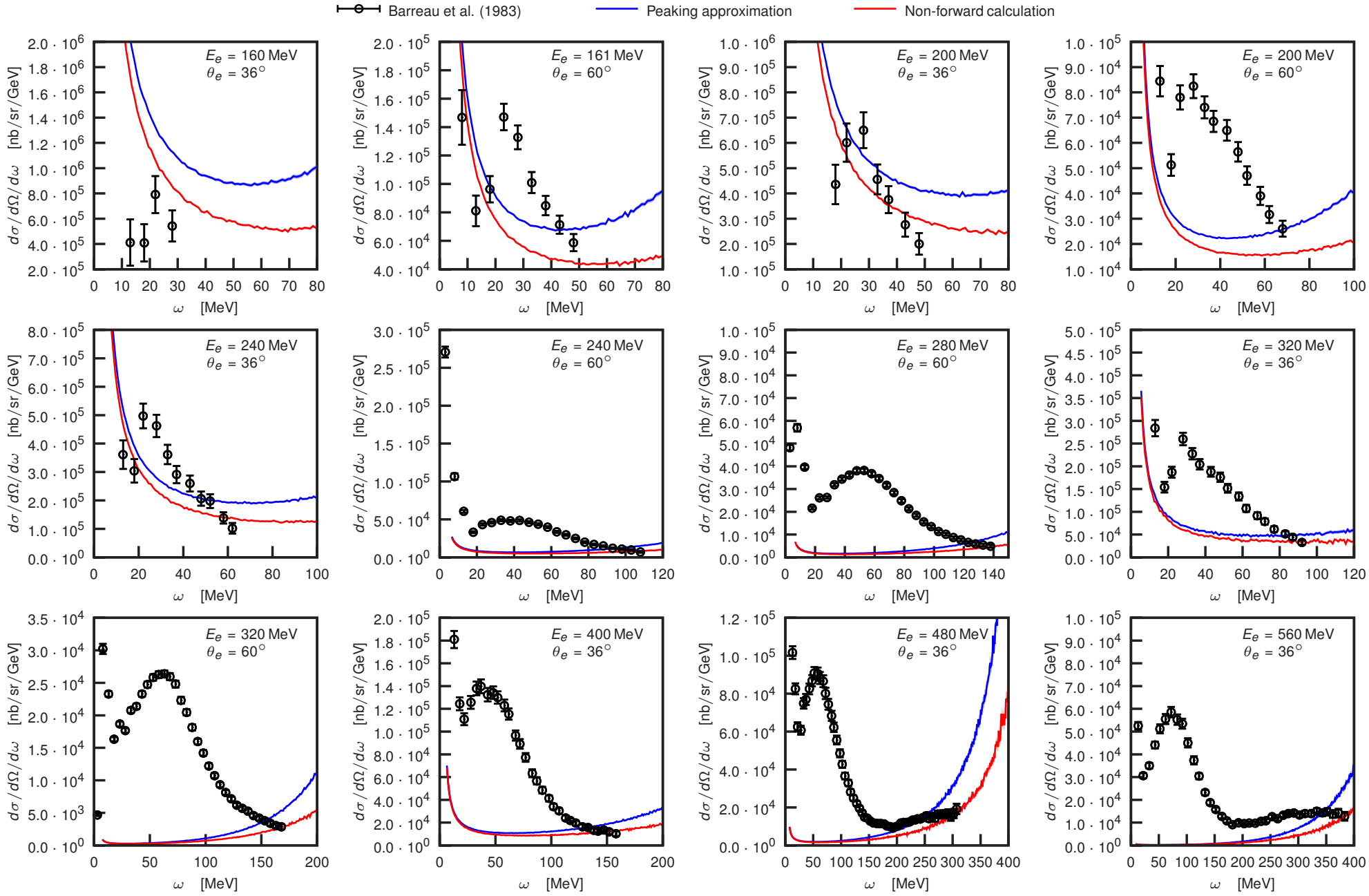
- A detailed description of radiative corrections required considering angular dependence of emitted photons, and full energy range of emitted photons.

Comparison of radiative tail simulations

- The radiative tail can contribute significant part of collected statistics.

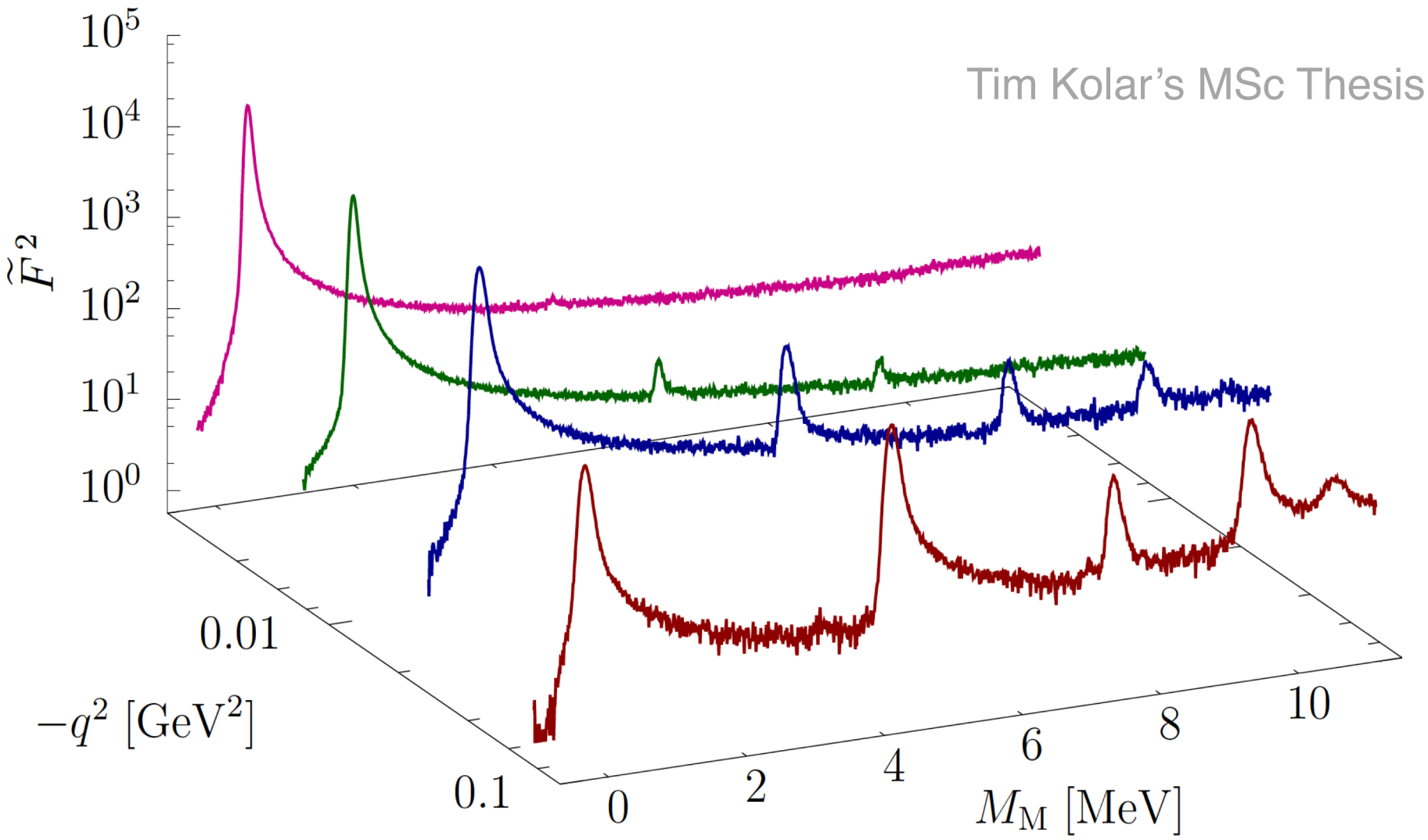


Comparison extd.



Elastic vs. excited states

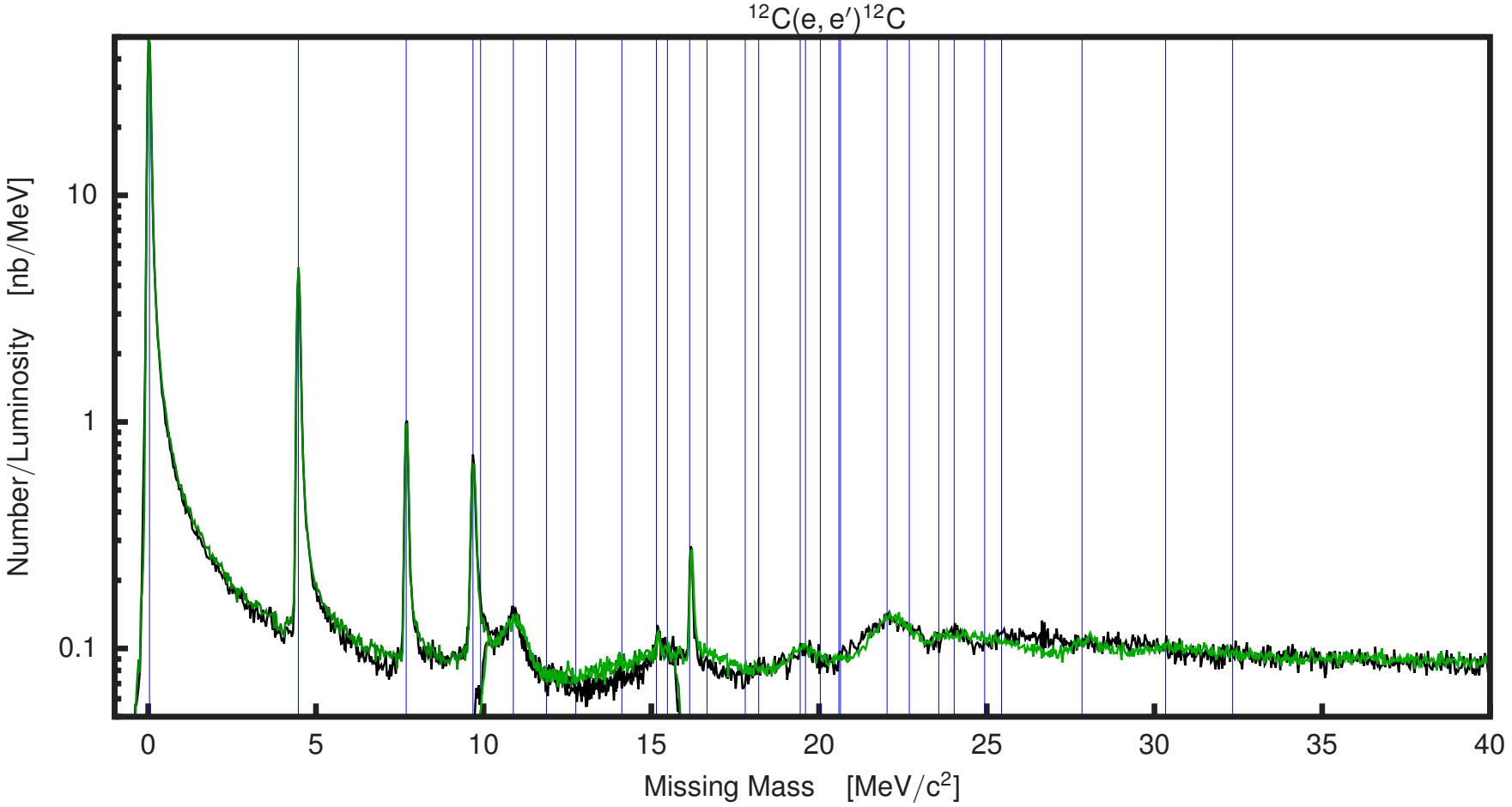
- The contributions of excited states increase with the increasing Q^2.



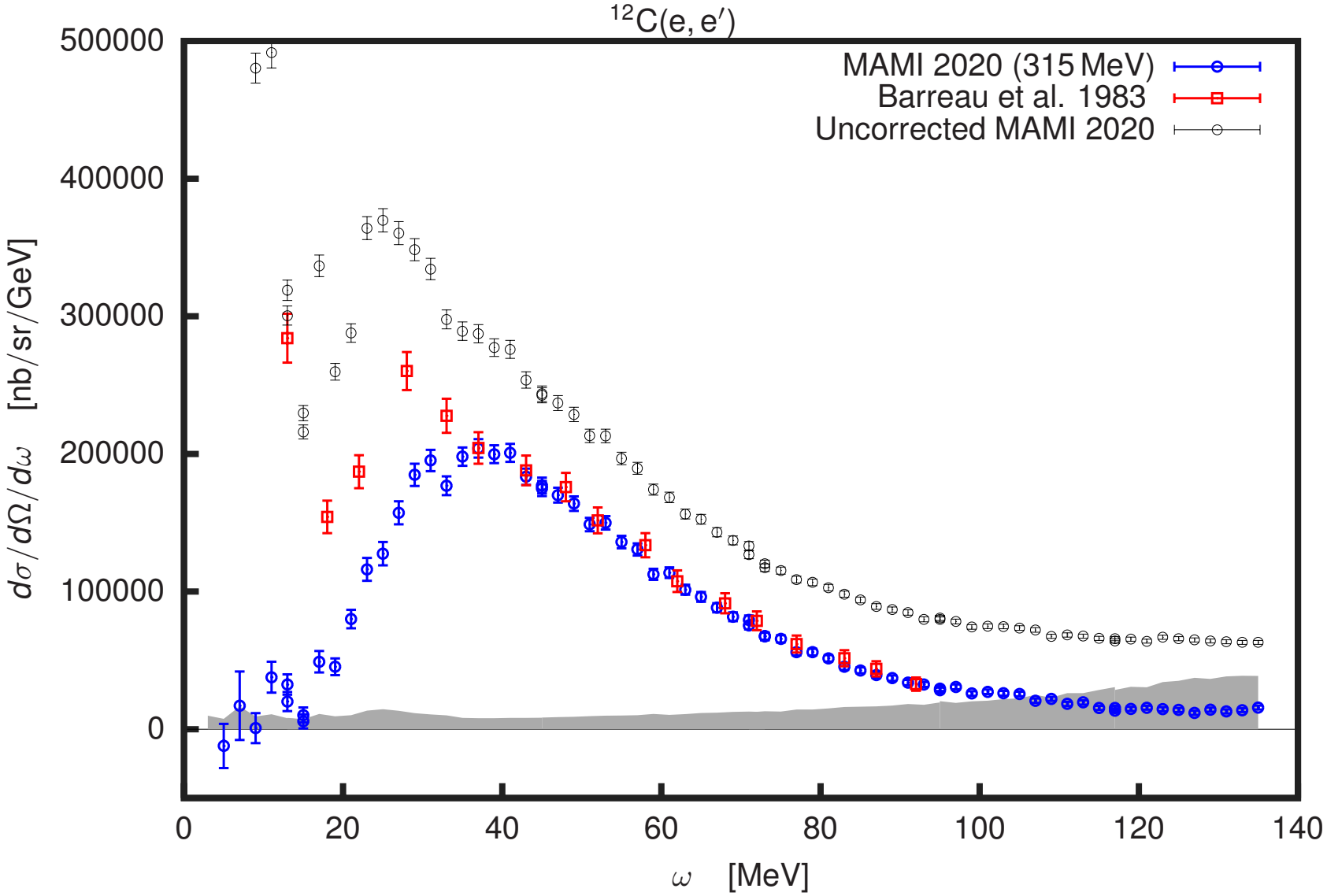
Contributions of excited states

- Contamination of QE data with contributions of excited states and corresponding radiative tails.

- Background subtraction using models for ^{12}C (e, e')$^{12}C^{*}$ and simulation.



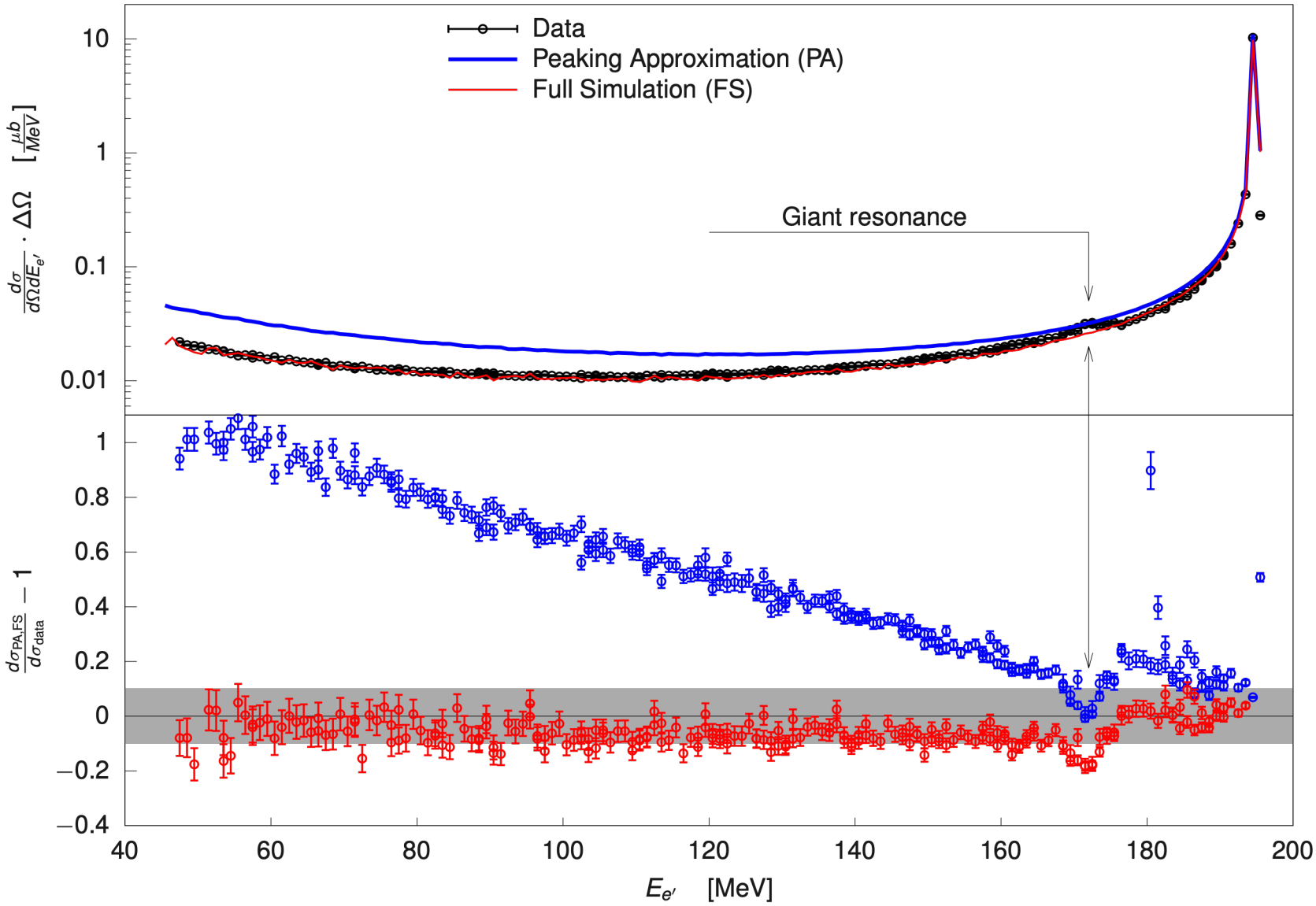
Background-free cross-section



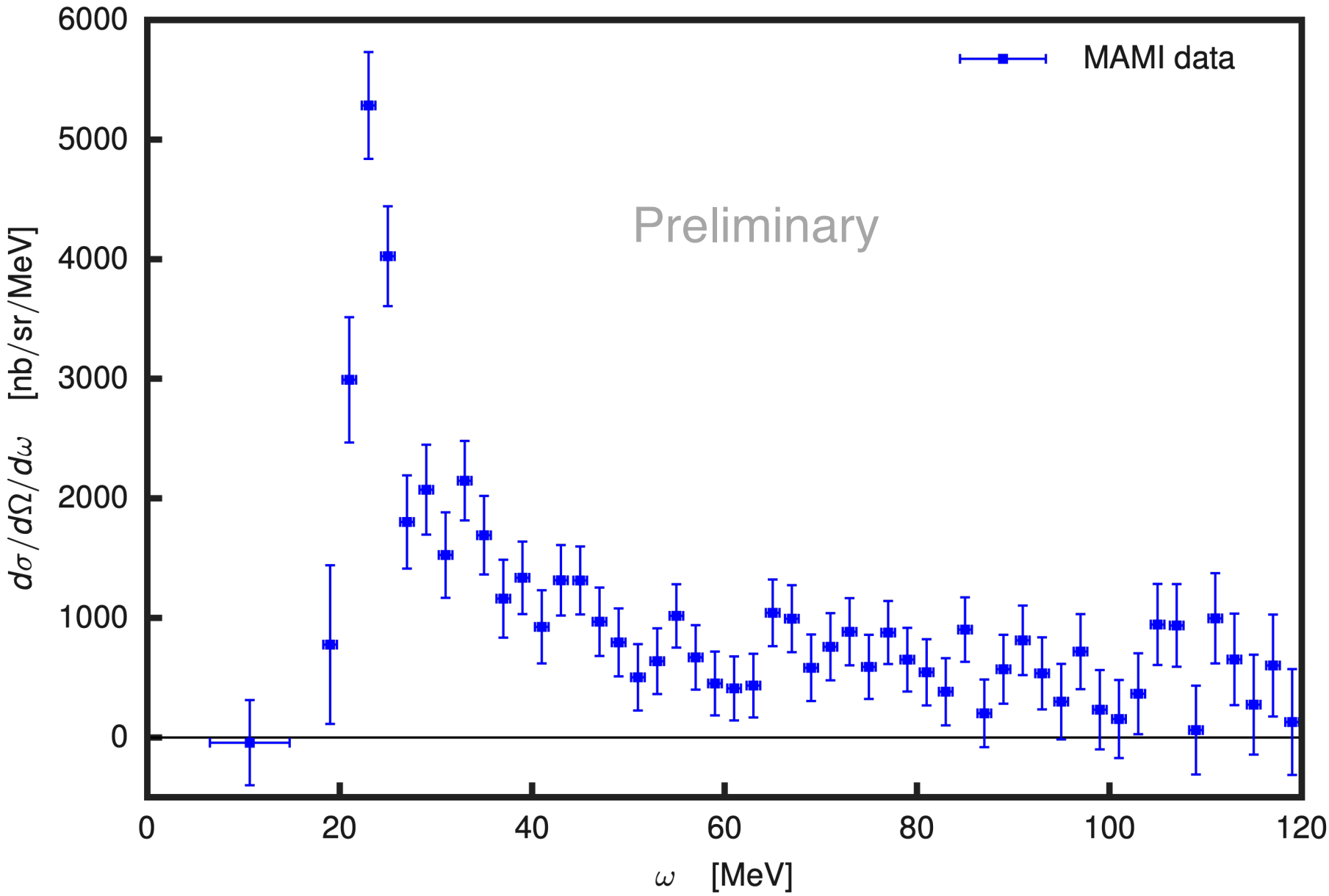
- Systematic uncertainty governed by the error of the radiative corrections.

ISR experiment @ MAMI

- Beam energy of 195 MeV and scattering angle of 15.3°.



^{12}C inclusive cross-section @ Q^2=0.0025 GeV^2



Conclusions

- MAMI perfect setup for nuclear cross-section measurements at ~1GeV.
- New data sets for ^{12}C, ^{40}Ar and ^{40}Ca targets:
  - Several “parasitic” measurements.
  - Two full experimental agendas.
- **Approved experiment on ^{16}O is pending.**
- Precise description of radiative correction crucial for the reliable interpretation of e-N scattering data. Improvements are needed.
- Investigation of exclusive channels and polarization degrees of freedom also possible.

Thank you!