Inclusive electron scattering off the proton in the resonance region with CLAS12 at Jefferson Lab

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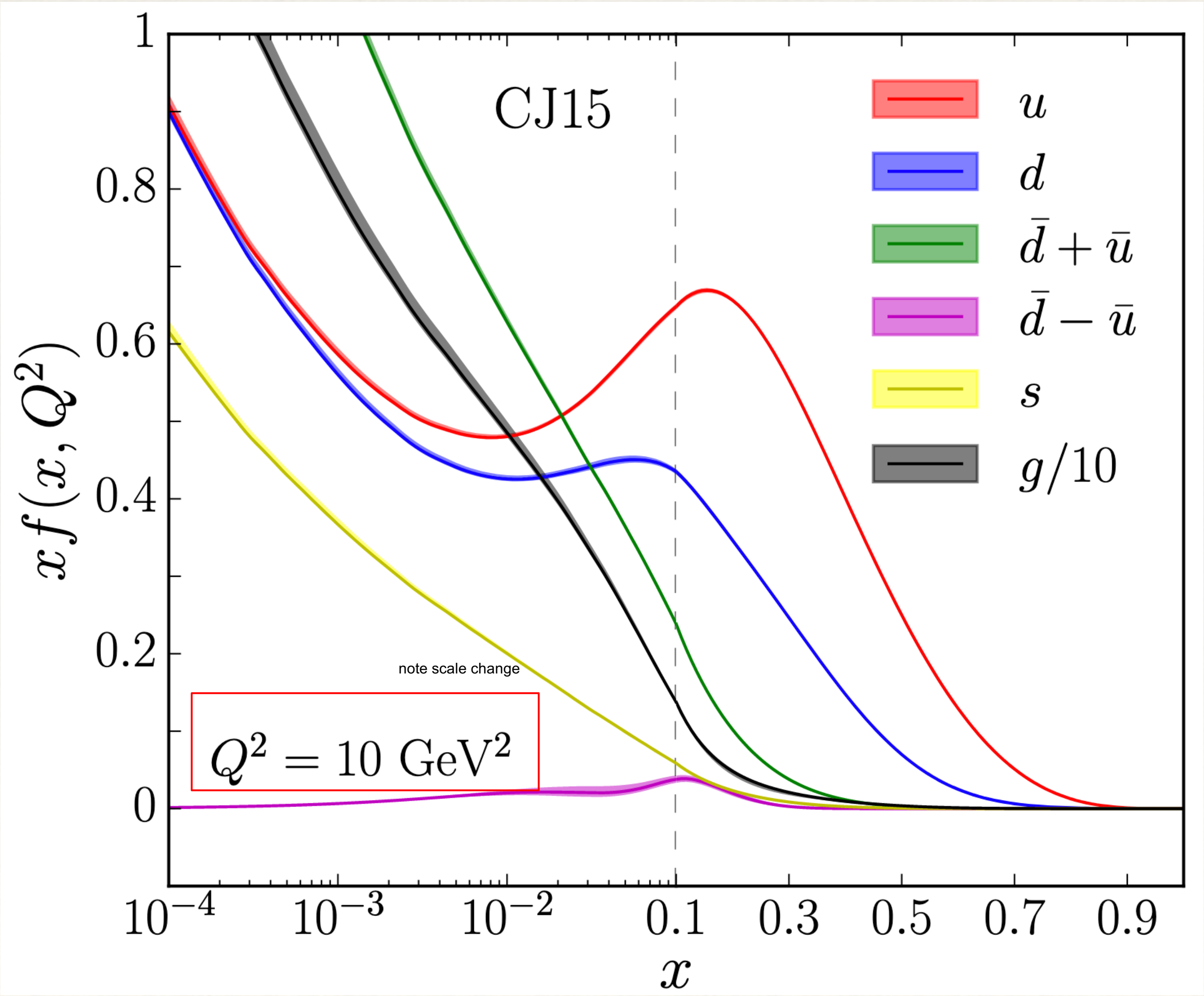
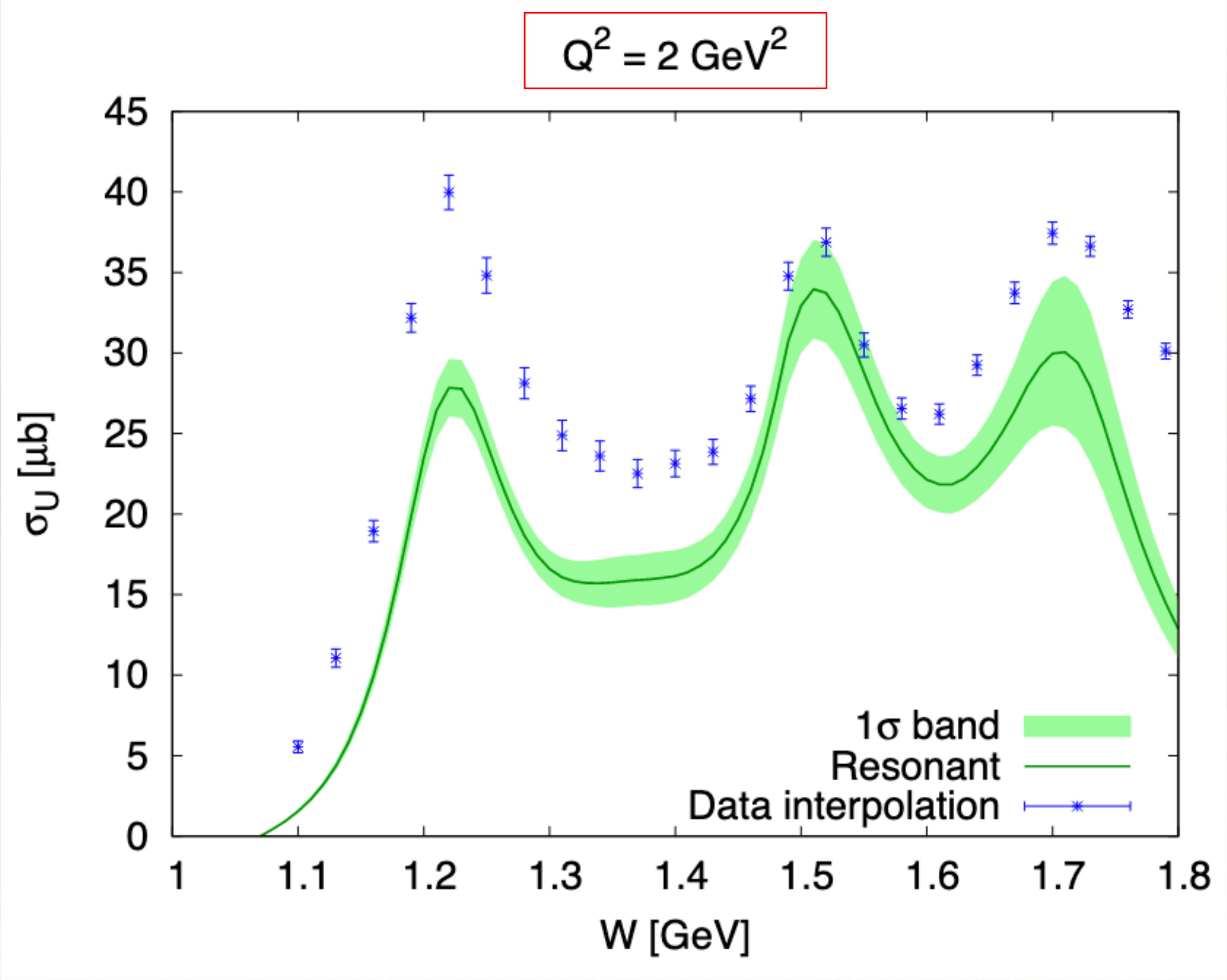
Extending Knowledge of the Nucleon PDF in the Resonance Region

- Global QCD analyses have provided detailed information on the nucleon PDFs in a wide range of parton fractional longitudinal momentum, x, from 10^{-4} to 0.9.
- At large x, in the nucleon resonance region W < 2.5 GeV, the PDFs are significantly less explored.
- Extractions in this region require accounting for higher twist effects, target-mass corrections and evaluation from the nucleon resonance electroexcitations.

A. N. Hiller Blin et al., *Phys. Rev. C* 100 (2019) 3, 035201, [hep-ph 1904.08016]

A. Accardi et al., *Phys. Rev. D.* 11, 114017 (2016), [hep-ph 1602.03154]





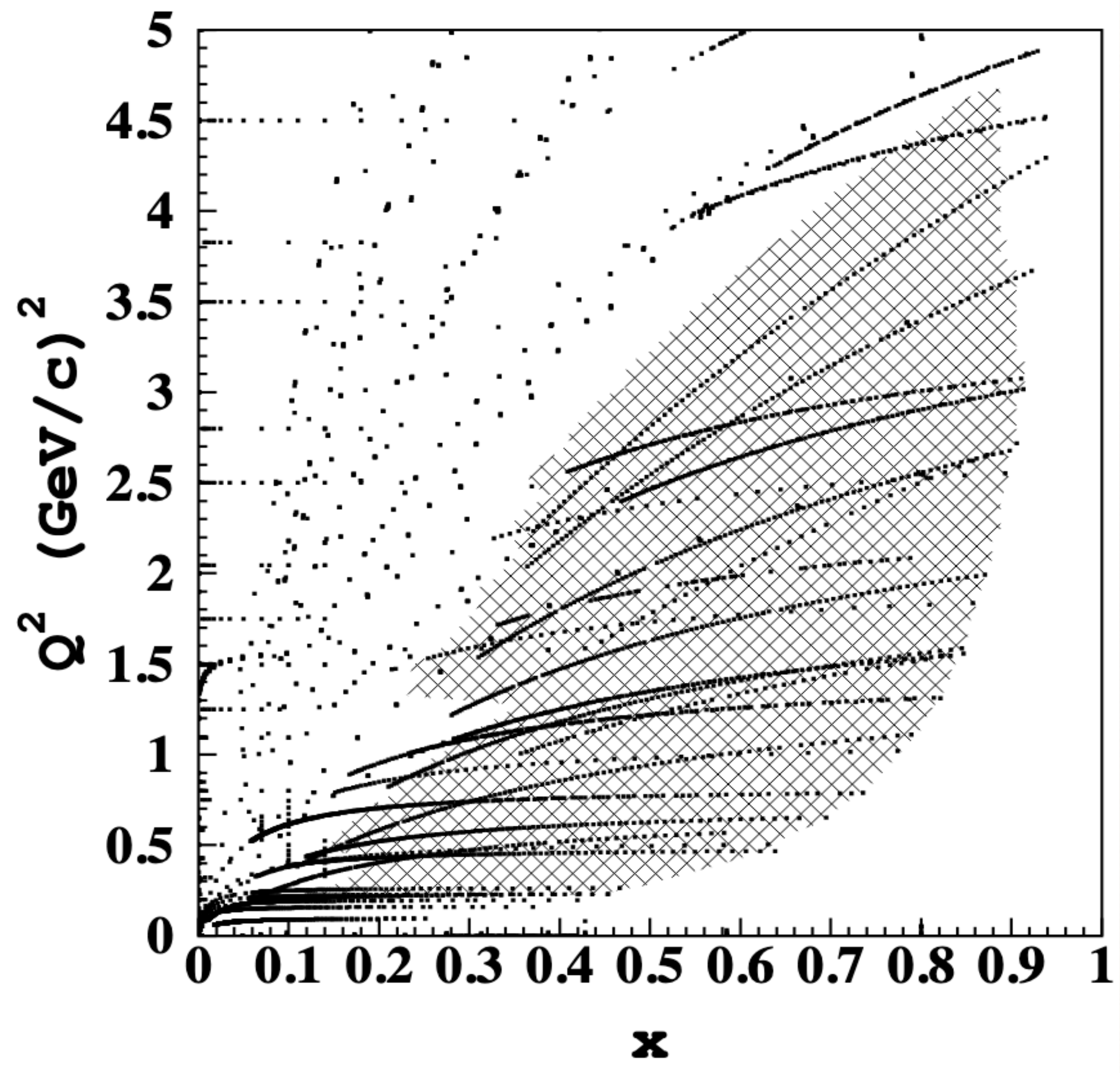
CLAS Results with 6 GeV

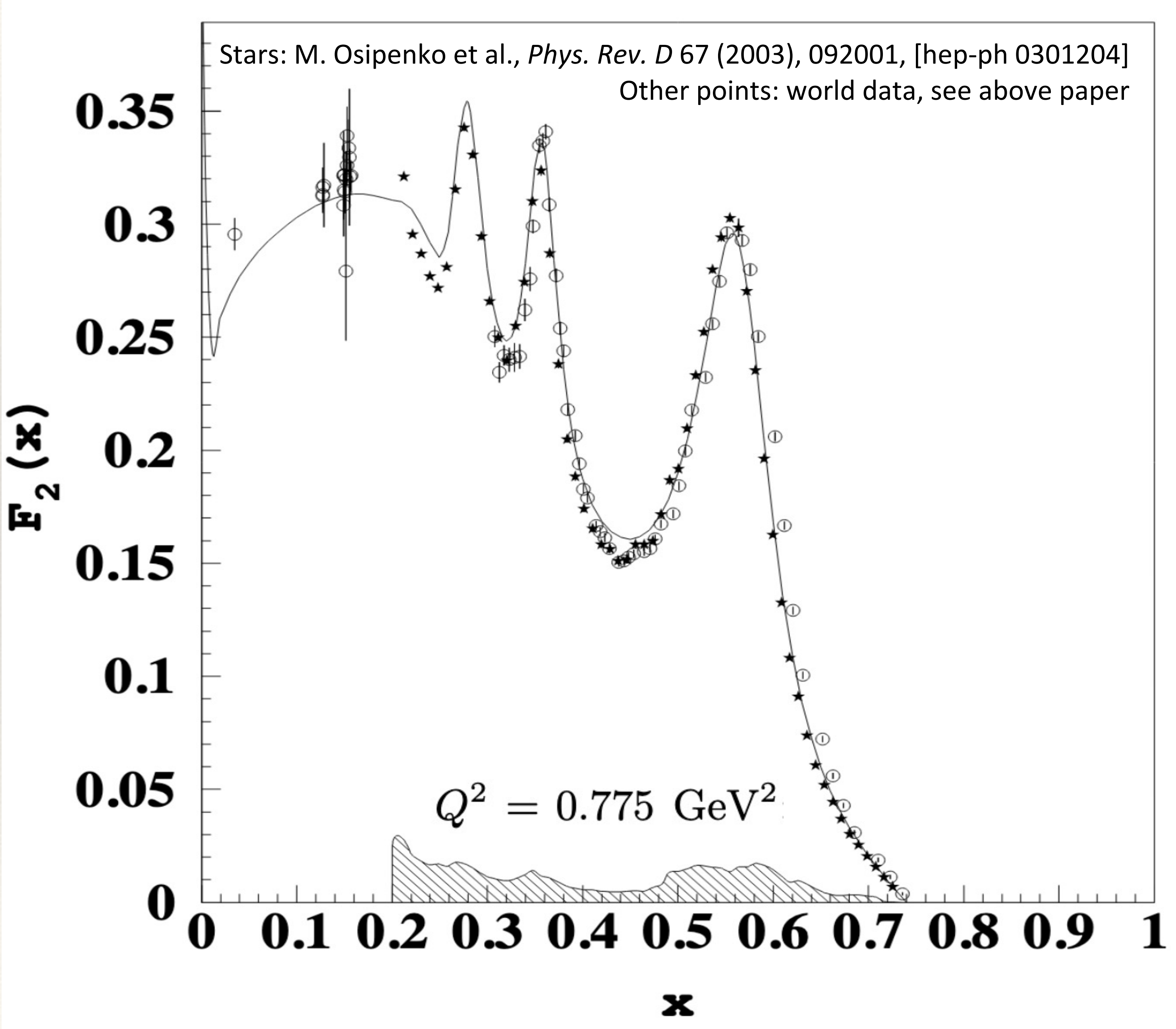
- CLAS with 6 GeV measured the inclusive cross sections up to x = 0.9 and Q^2 from 0.25 to 4.5 GeV^2.

  M. Osipenko et al., *Phys. Rev. D* 67 (2003), 092001

- Owing to large acceptance of CLAS, the information on inclusive structure function F_2 can be obtained within a wide range of W from pion threshold to maximal kinematically allowed W-values in any given bin of Q^2 covered in the measurements.

World data used for moment evaluations of F_2. Shaded area corresponds to CLAS.





Resonant Contributions

- CLAS results on $\gamma_v pN^*$ electrocouplings for most N* in the mass range W<1.8 GeV allowed us to evaluate the resonant contributions to F_2 structure function from the experimental results on resonance electroexcitation amplitudes.
- Resonant contributions demonstrate pronounced evolution with photon virtuality Q^2 differently in the first, the second and the third resonance regions.
- Information on Q^2 evolution **$\gamma_v pN^*$** electrocouplings for all prominent N* for a wide range of Q^2 is needed for realistic evaluation of the resonant contribution into inclusive electron scattering observables.

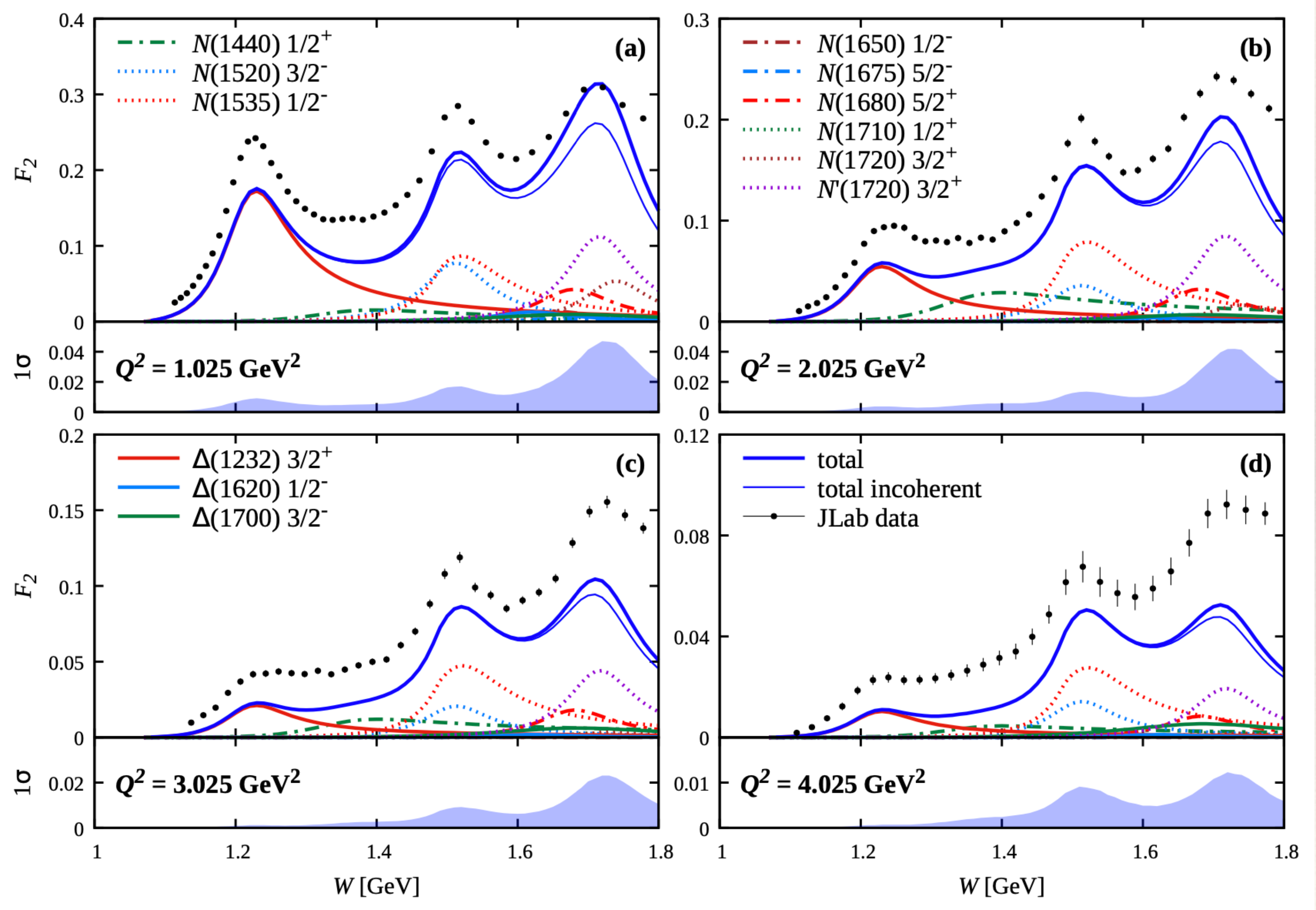
A. N. Hiller Blin et al., *Phys. Rev. C* 104 (2021) 2, 025201, [hep-ph 2105.05834]

$$\sigma^R_{T,L}(W,Q^2) = \frac{\pi}{q_\gamma^2}\sum_R (2J_R+1)\frac{M_R^2\,\Gamma_R(W)\,\Gamma^{T,L}_{\gamma,R}(M_R,Q^2)}{\left(M_R^2-W^2\right)^2+\left(M_R\Gamma_R(W)\right)^2}$$

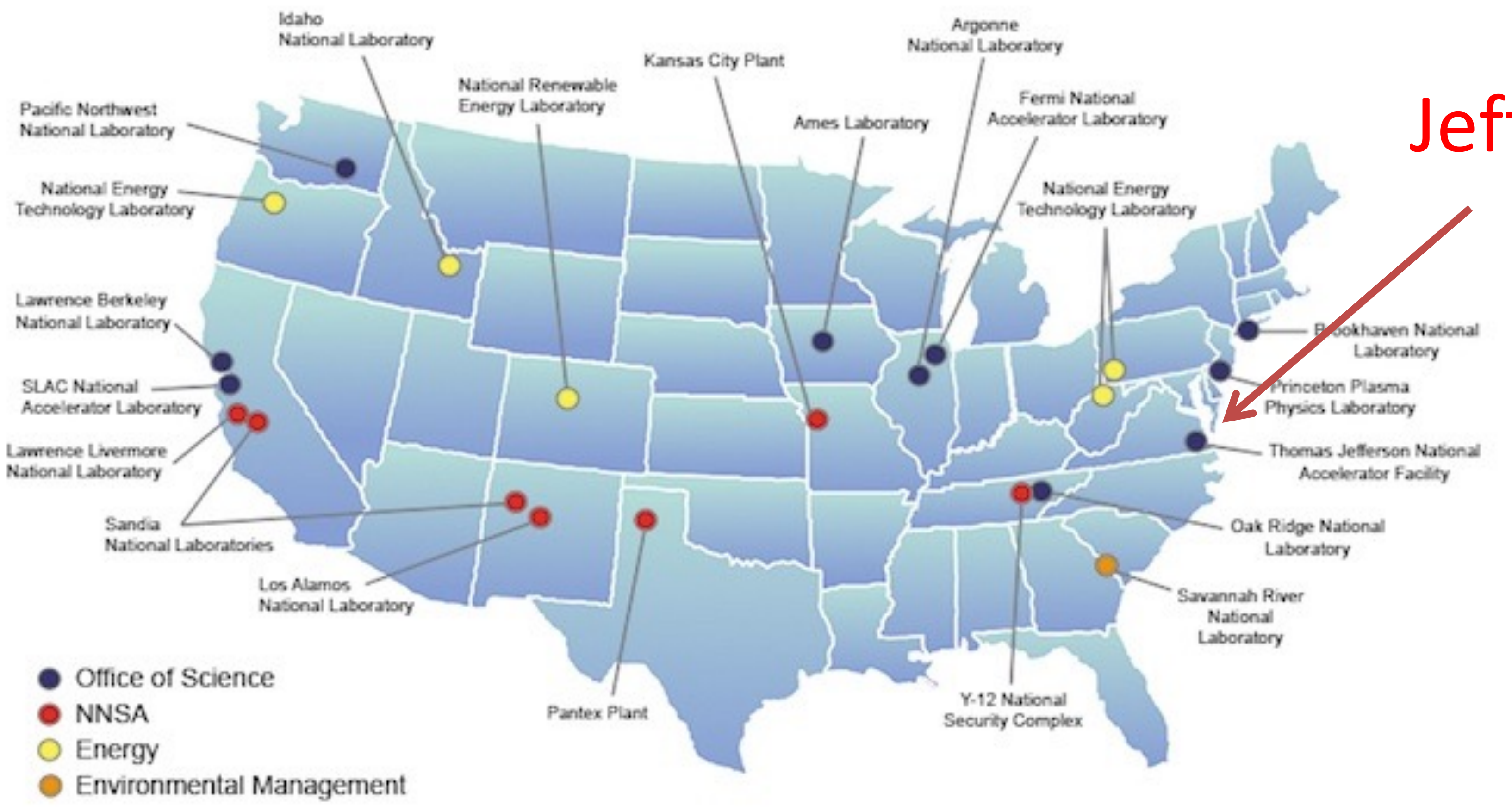
Decay widths of resonance R to γ*p related to electrocouplings from previous slide.

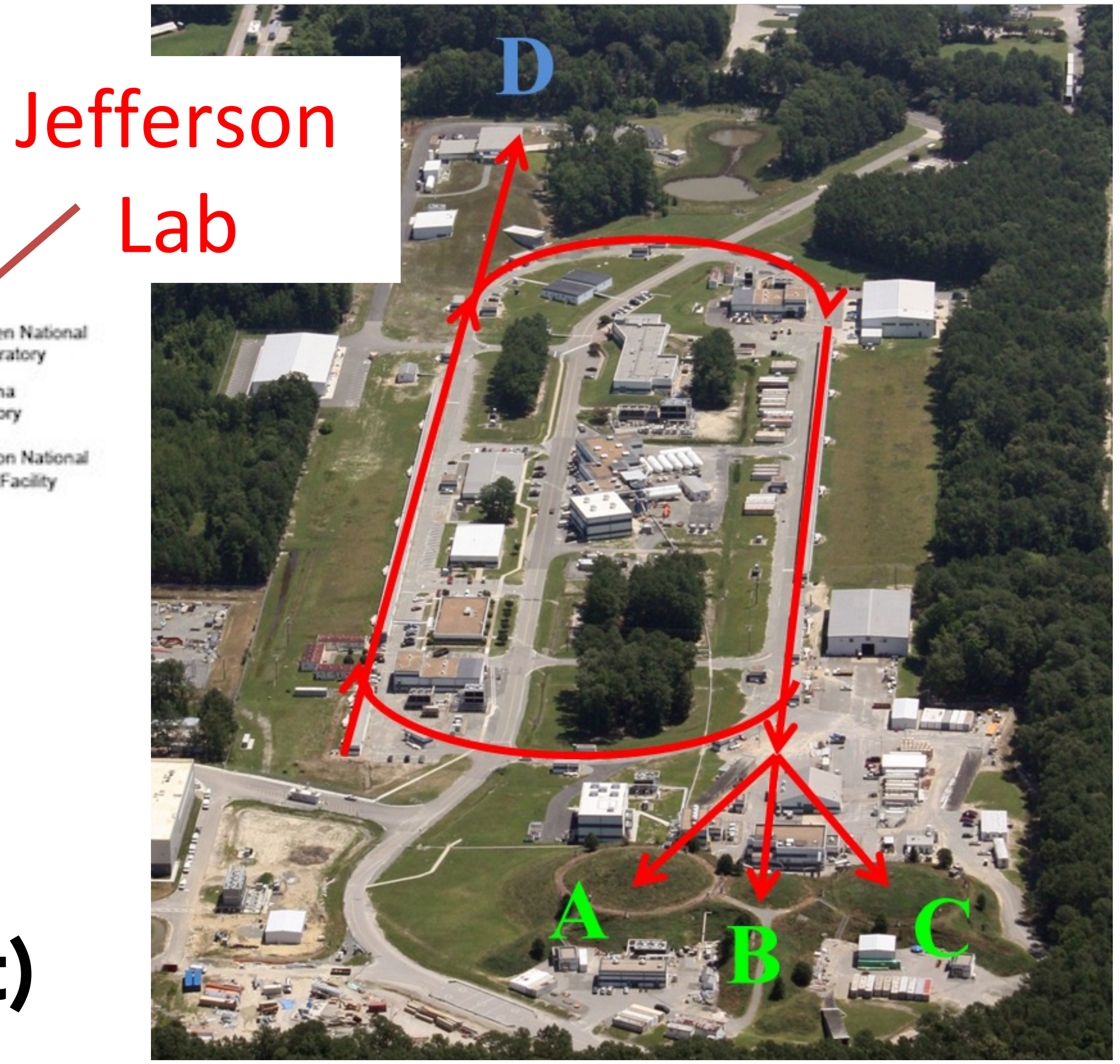
$$\Gamma^T_{\gamma,R}(W=M_R,Q^2) = \frac{q^2_{\gamma,R}(Q^2)}{\pi}\frac{2M}{(2J_R+1)M_R} \times\left(\left|A^R_{1/2}(Q^2)\right|^2+\left|A^R_{3/2}(Q^2)\right|^2\right),$$

$$\Gamma^L_{\gamma,R}(W=M_R,Q^2) = \frac{2q^2_{\gamma,R}(Q^2)}{\pi}\frac{2M}{(2J_R+1)M_R} \times\left|S^R_{1/2}(Q^2)\right|^2,$$



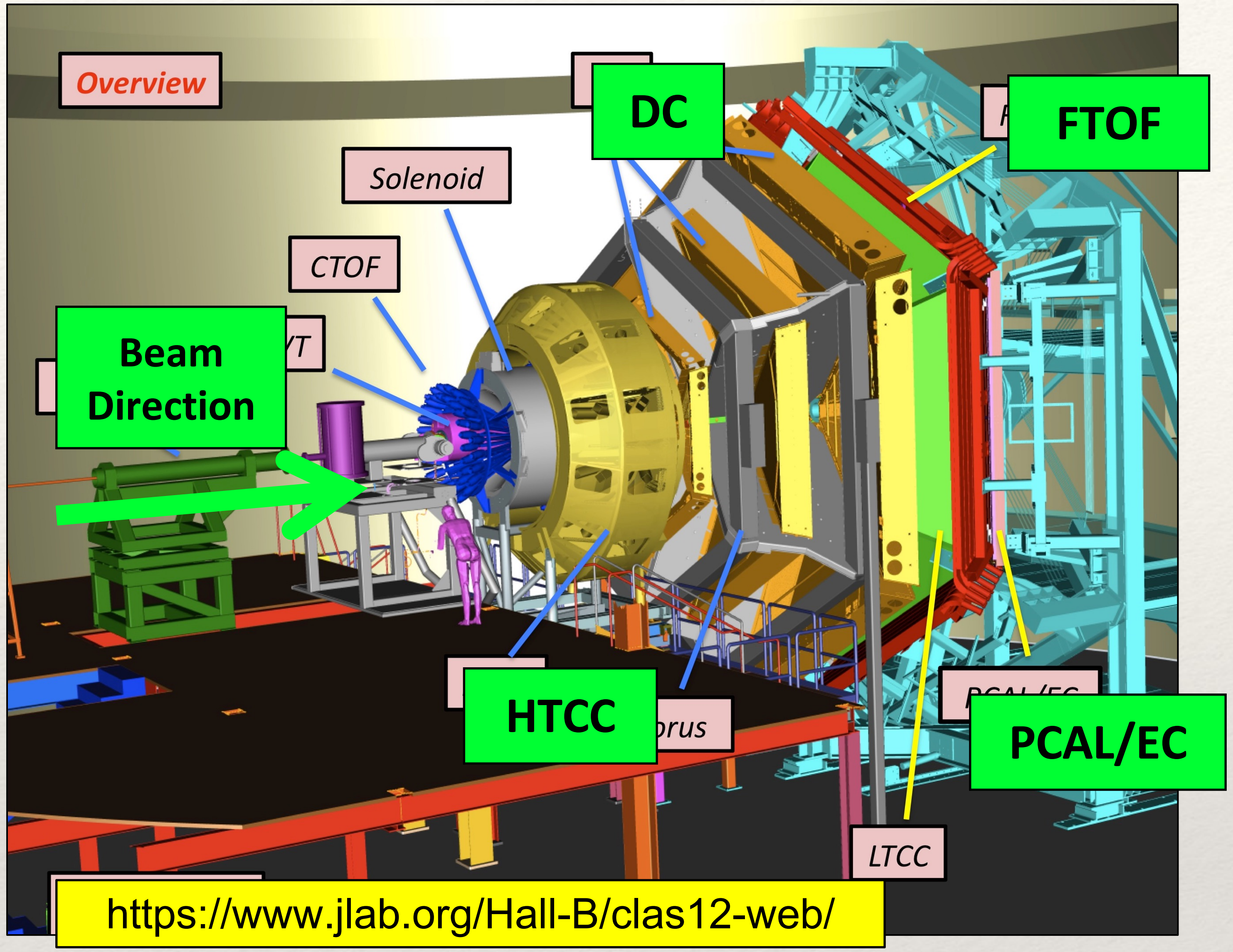
Thomas Jefferson National Accelerator Facility (Jefferson Lab)

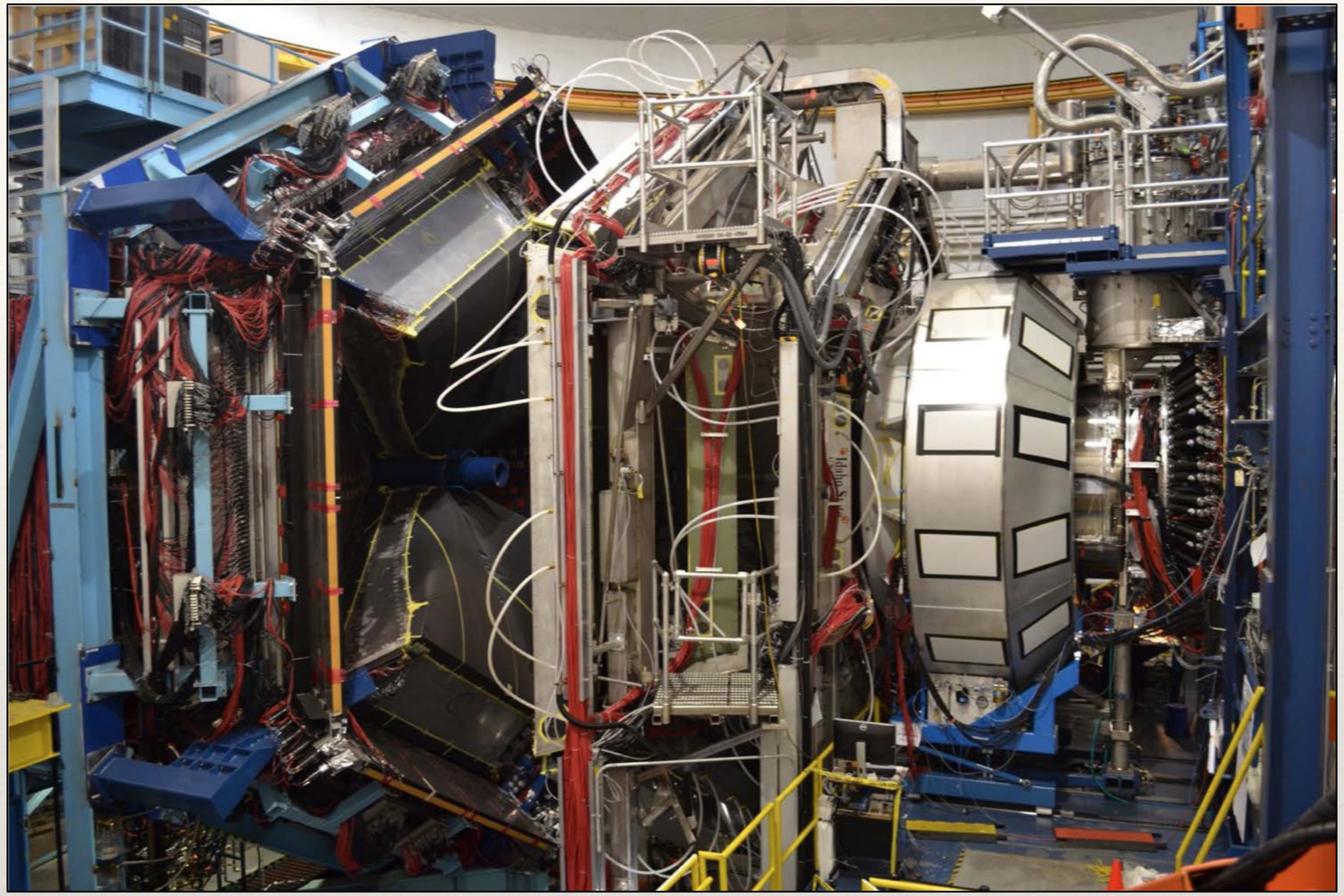




- **Newport News, Virginia (US east coast)**
  - **1995 - 2012 6 GeV electron beam**
- **2018 - today 11 / 12 GeV electron beam / photon beam**

Inclusive Electron Scattering Measurements with CLAS12





V. Burkert et al., Nucl. Instrum. Meth. A 959 (2020) 163419

- Measurements of (e,e'X) inclusive cross sections are important to understand electron detection efficiency needed for evaluation of the cross sections of semi-inclusive and exclusive processes foreseen in the exploration with the CLAS12 detector
- CLAS12: 10^{35} $cm^{-2}sec^{-1}$ luminosity, nearly 4π acceptance, $0.05\ GeV^2 < Q^2 < 10.0\ GeV^2$ coverage over photon virtuality.
- Began data taking in Spring 2018 – many "run periods" now available.
- Data from Fall 2018 - 10.6 GeV electron beam, longitudinally polarized beam, liquid H_2 target.

Cross Section Calculation

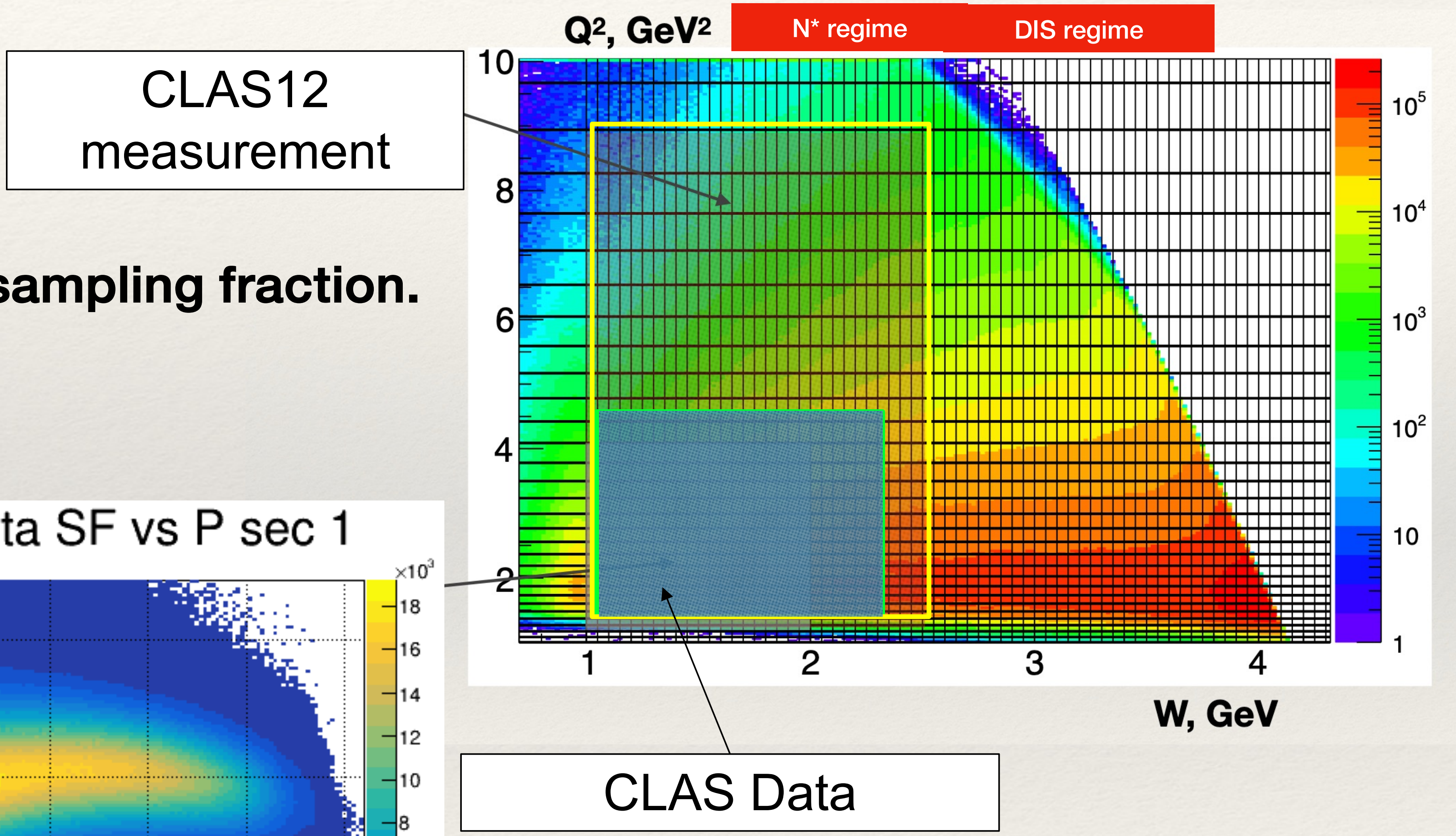
$$\frac{d\sigma}{dQ^2 dW} = \frac{1}{\Delta Q^2 \Delta W} \cdot \frac{N}{\eta \cdot R \cdot B \cdot N_0} \cdot \frac{1}{N_A \rho t / A_\omega} \quad \textbf{(1)}$$

- Q^2 - four-momentum transfer squared
- W - invariant mass of the final hadron system
- R - radiative correction factor
- B - bin size correction
- N - bin event yield
- η - is the product of geometrical acceptance and electron detection efficiency
- N_0 - live-time corrected incident electron flux summed over all data runs
- N_A - Avogadro's number
- ρ - target density
- t - target length
- A_ω - atomic weight of the target

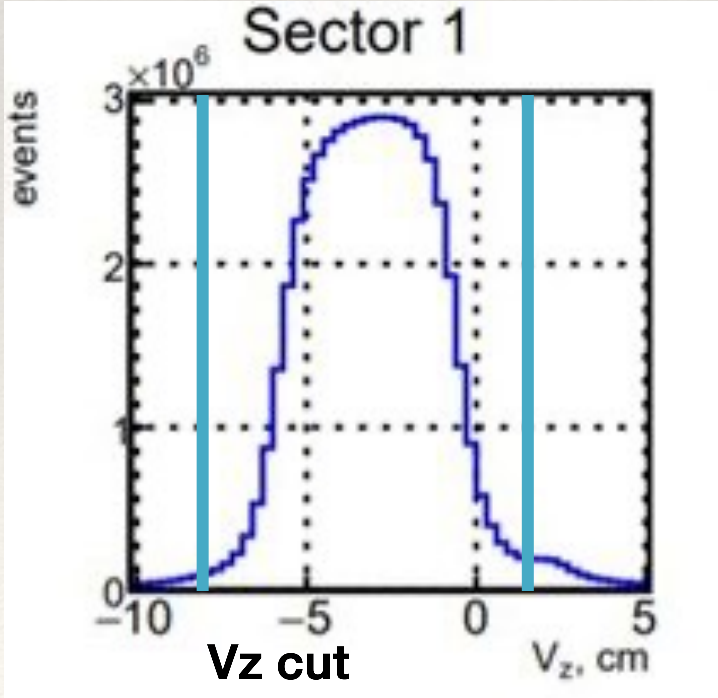
Electron PID

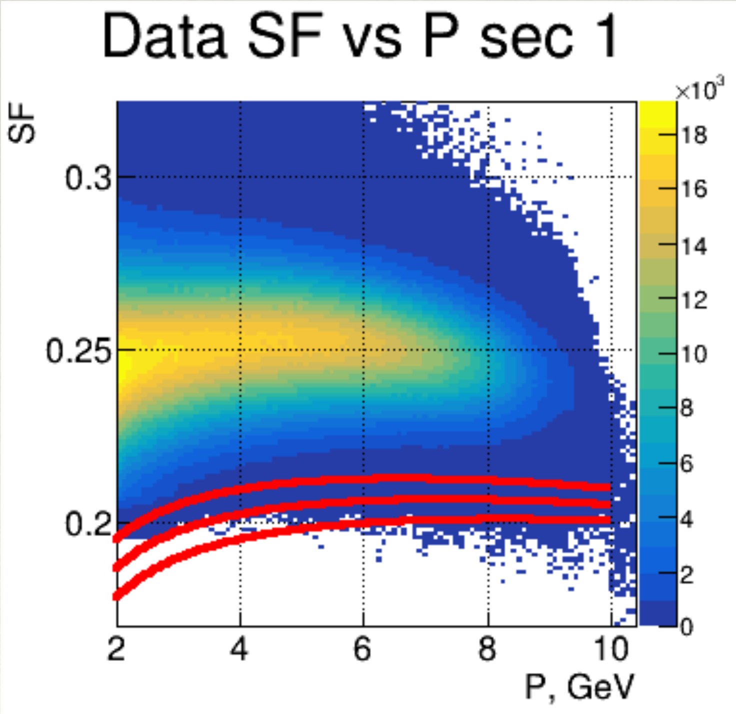
Event yield extraction **N** in (1)

- Limited to Forward Detector (5 - 35° coverage in polar angle)
- Negative track with a hit in Time-of-Flight, Electromagnetic Calorimeters and High Threshold Cherenkov Counter (HTCC
- >2.0 photoelectrons in HTCC
- **DC and PCAL Fiducial cuts.**
- **-8 < Vertex Z < 2 cm**
- **3.5-σ cuts on a parameterized momentum-dependent sampling fraction.**
- >70 MeV PCAL
- Electron/pion separation (triangular cut)



DC fid cut





Forward Calorimeter sampling fraction for electrons:
3.5σ ± 0.5σ

Acceptance Corrections

Acceptance η in (1)

- Measurement is distorted and transformed by various effects such as finite resolution, limited acceptance of the detector, and detection efficiency so a correction is required

- Basic method for acceptance correction is **bin-by-bin** method

$$Acceptance = \frac{\#\ Events\ Reconstructed}{\#\ Events\ Generated}$$

  - it does not take into account the connection between generated and reconstructed events, so it has a potentially large bias by relying on truth MC.

- Matrix deconvolution method – minimize the model dependence of MC.

Matrix Deconvolution

Acceptance η in (1)

- **Acceptance Matrix:** $A_{(i,j)}$ describes both acceptance (geometrical acceptance and detector efficiency) and bin migration:

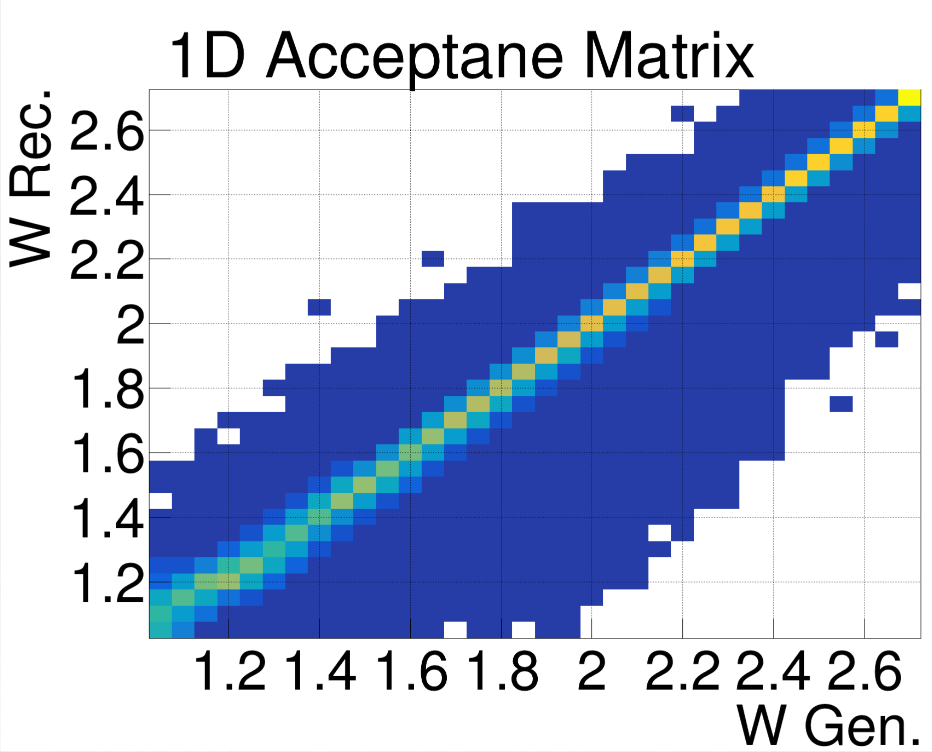
$$A_{(i,j)} = \frac{\#\ Events\ Generated\ in\ bin\ j\ but\ Reconstructed\ in\ bin\ i}{Total\ number\ of\ Events\ Generated\ in\ the\ jth\ bin}$$

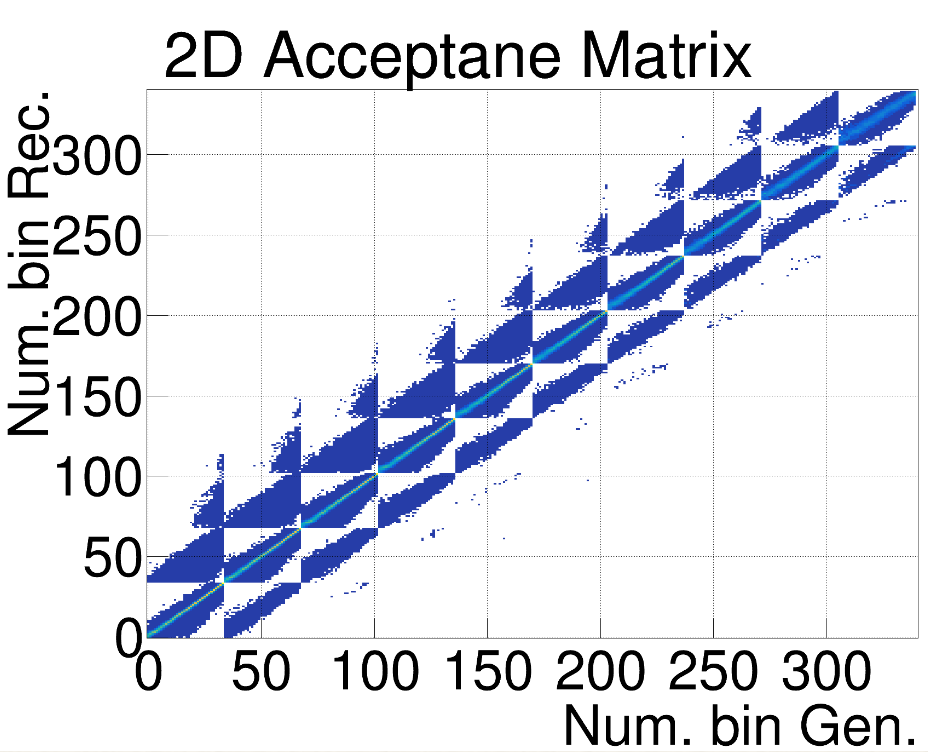
CERN RooUnfold package was used: https://gitlab.cern.ch/RooUnfold/RooUnfold

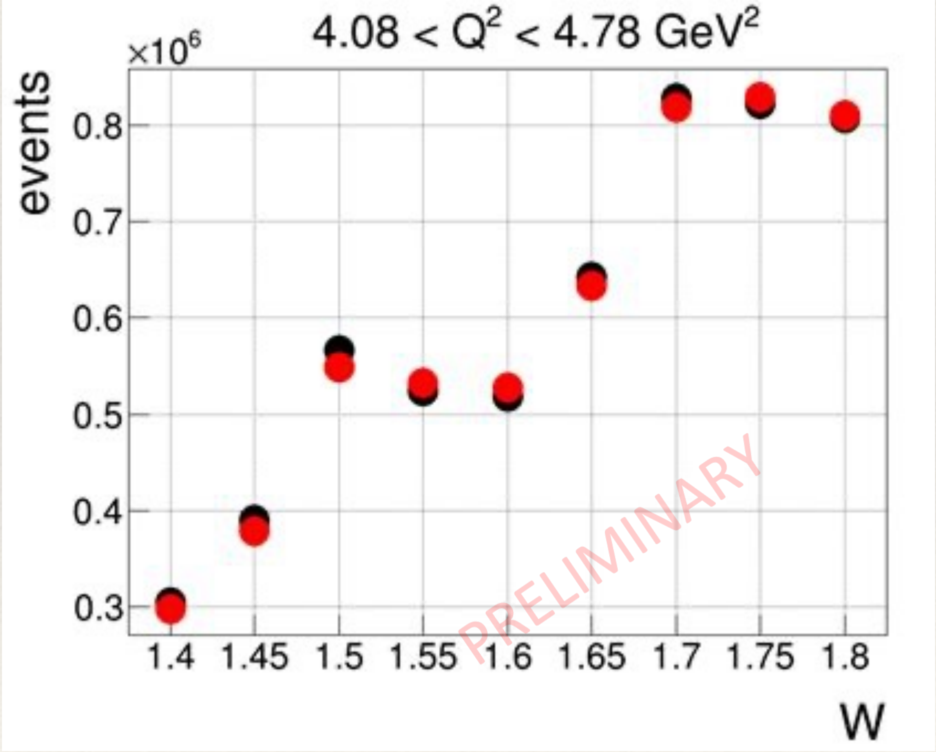
Acceptance unfolding: $Y_i = A_{(i,j)}X_j \Rightarrow X_j = A^{-1}_{(i,j)}Y_i$ where Y_i number of measured events in i-th bin, X_j is number of acceptance corrected events in j-th bin

We used:

1. SVD (singular value decomposition)
2. Bayesian matrix







Red - 2D Bayesian method
Black - Bin-by-bin method

Radiative Corrections

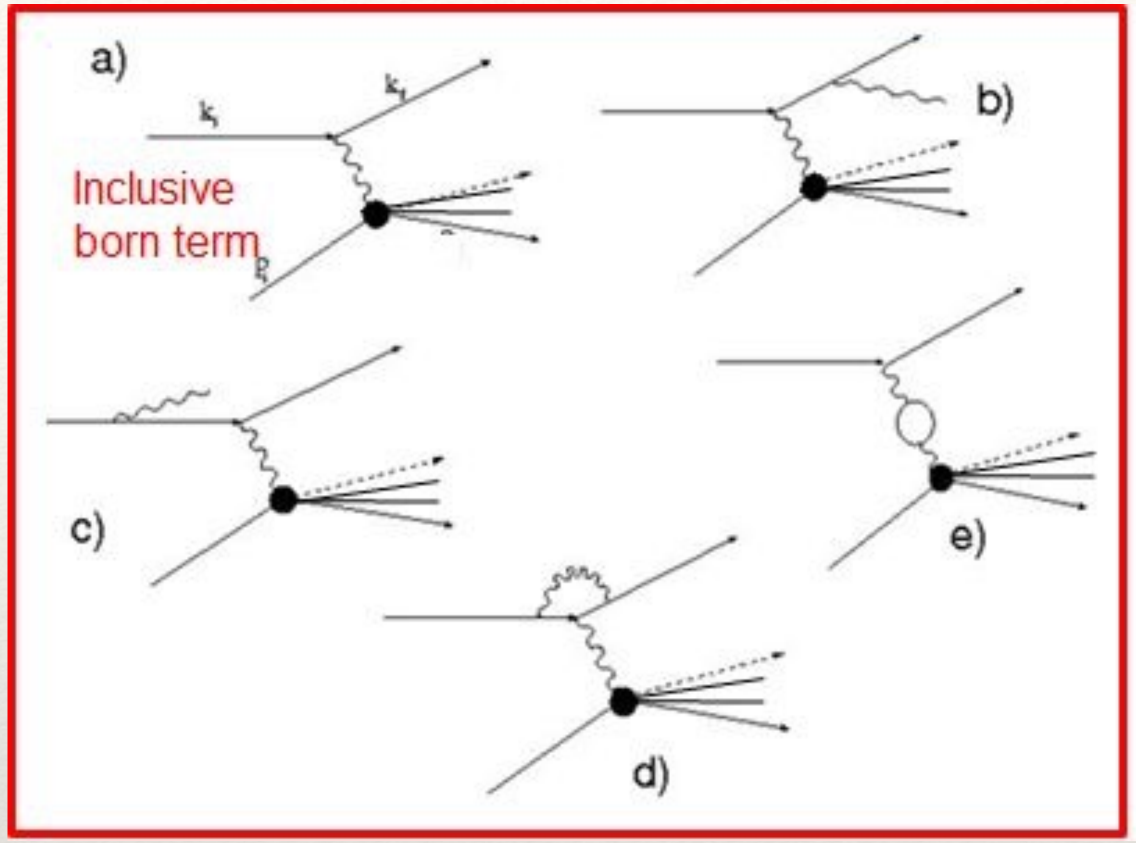
R in (1)

Each (Q^2,W) bin was divided into 21x11 sub bins. Cross Sections with rad. effects on and off were calculated in every sub bin.

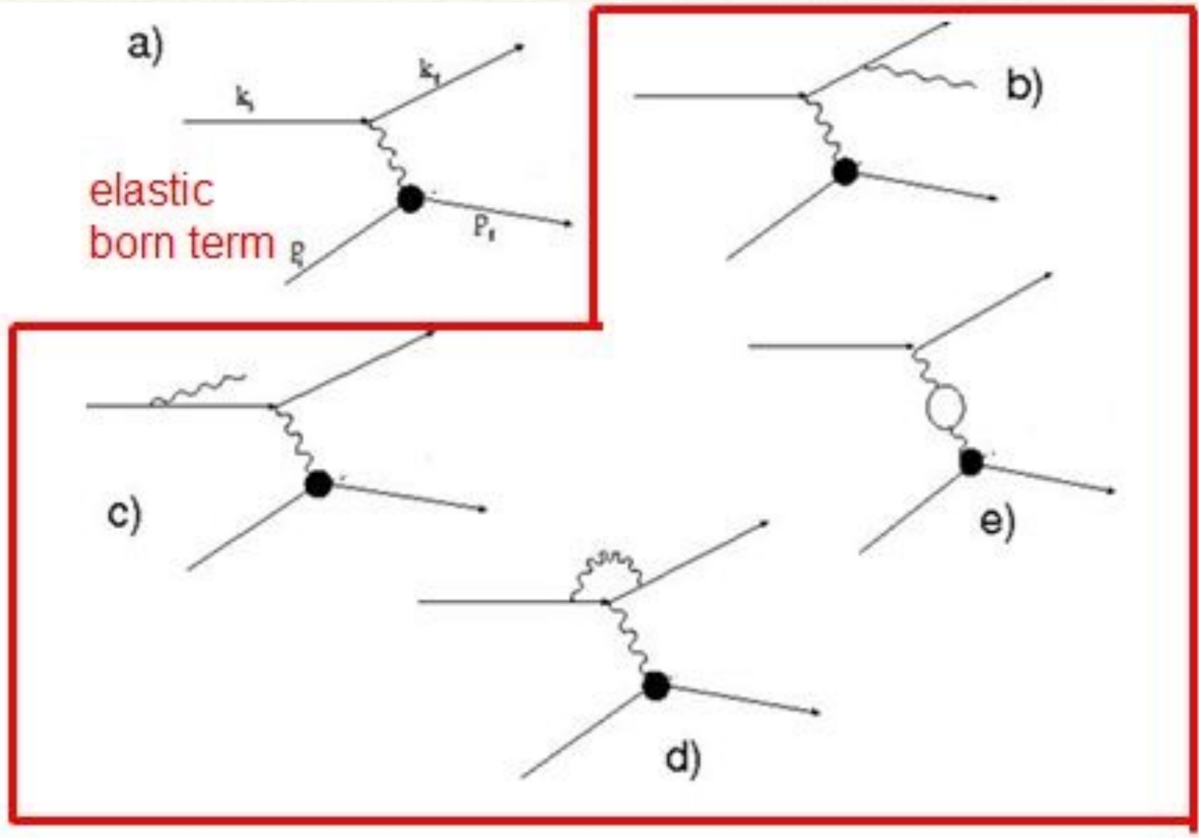
Radiative Correction factor:

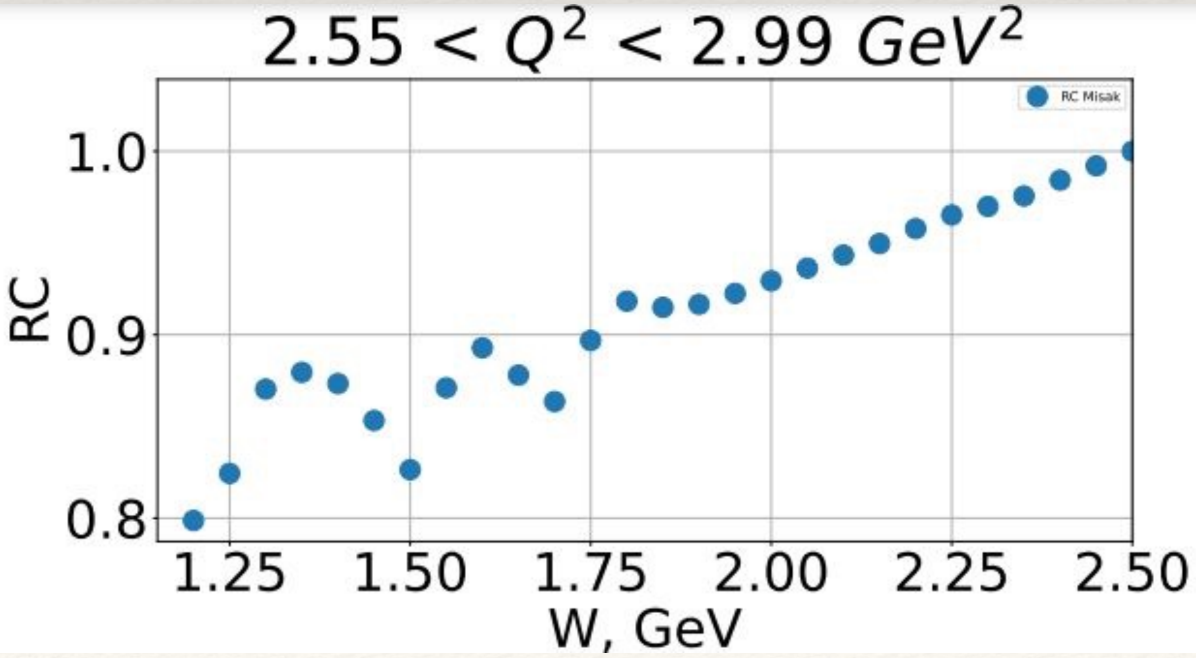
$$\frac{Mean\ Cross\ Section\ (Rad)}{Mean\ Cross\ Section\ (No\ Rad)}$$

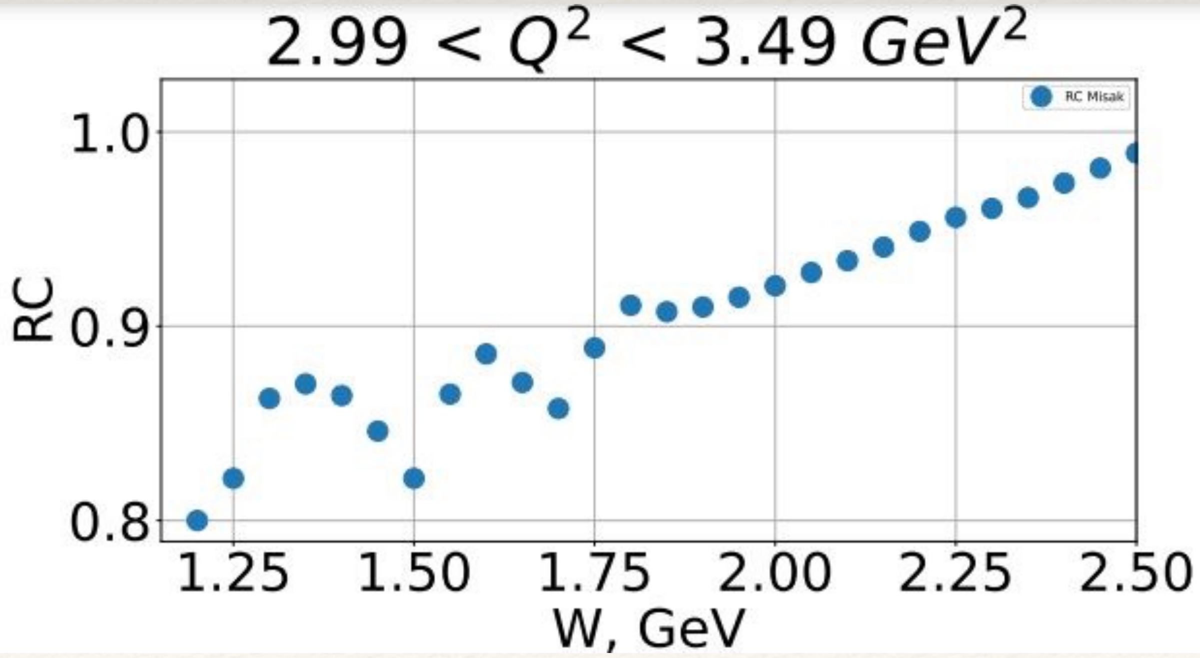
Inclusive with radiative effects

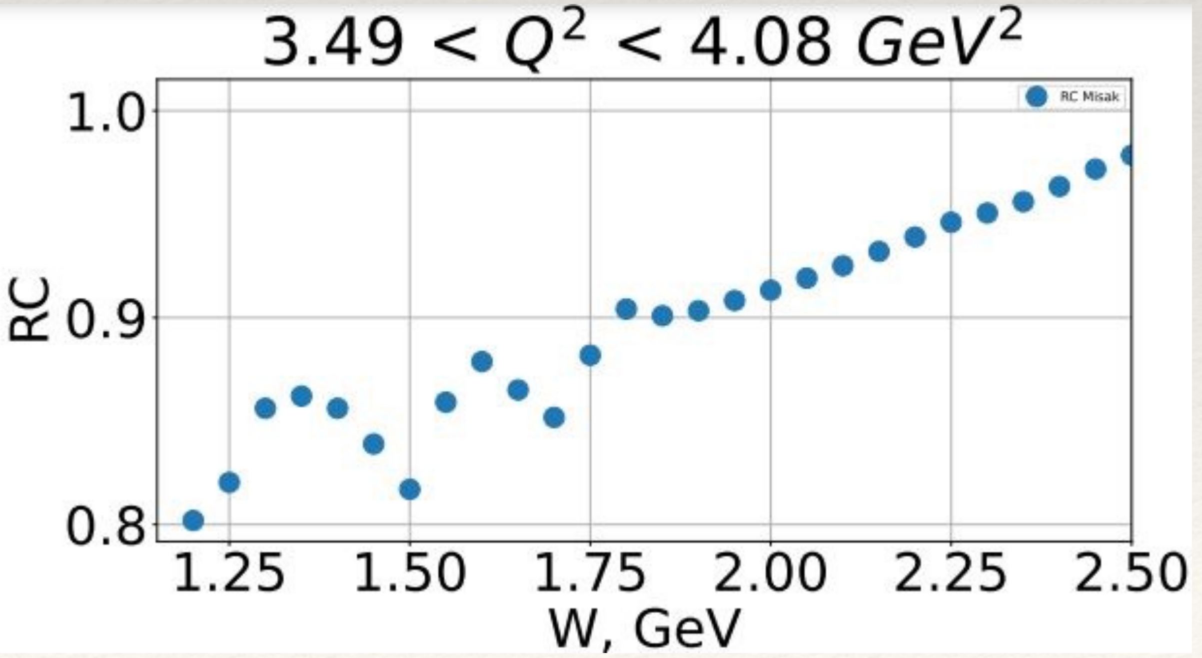


Elastic with radiative effects









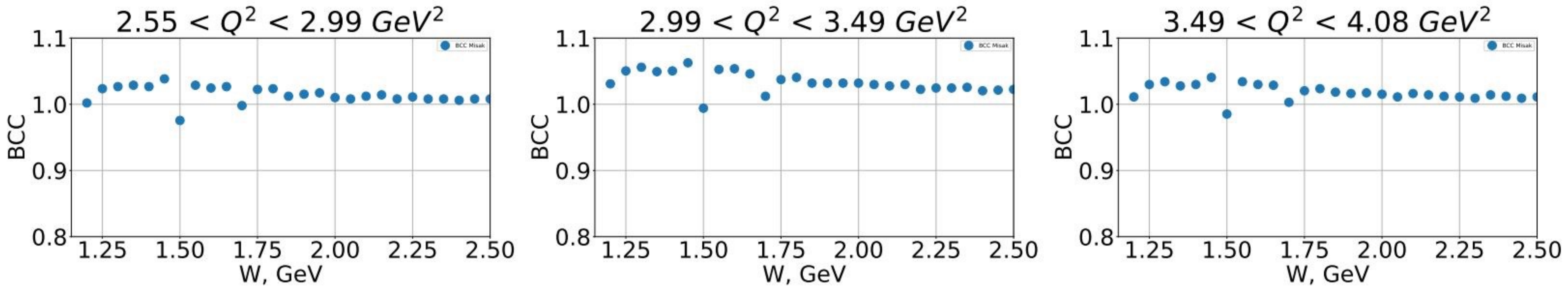
Bin Size Corrections

B in (1)

$$\frac{d\sigma}{dQ^2dW} = \frac{1}{\Delta Q^2 \Delta W} \cdot \frac{N}{\eta \cdot R \cdot B \cdot N_0} \cdot \frac{1}{N_A \rho t / A_\omega}$$

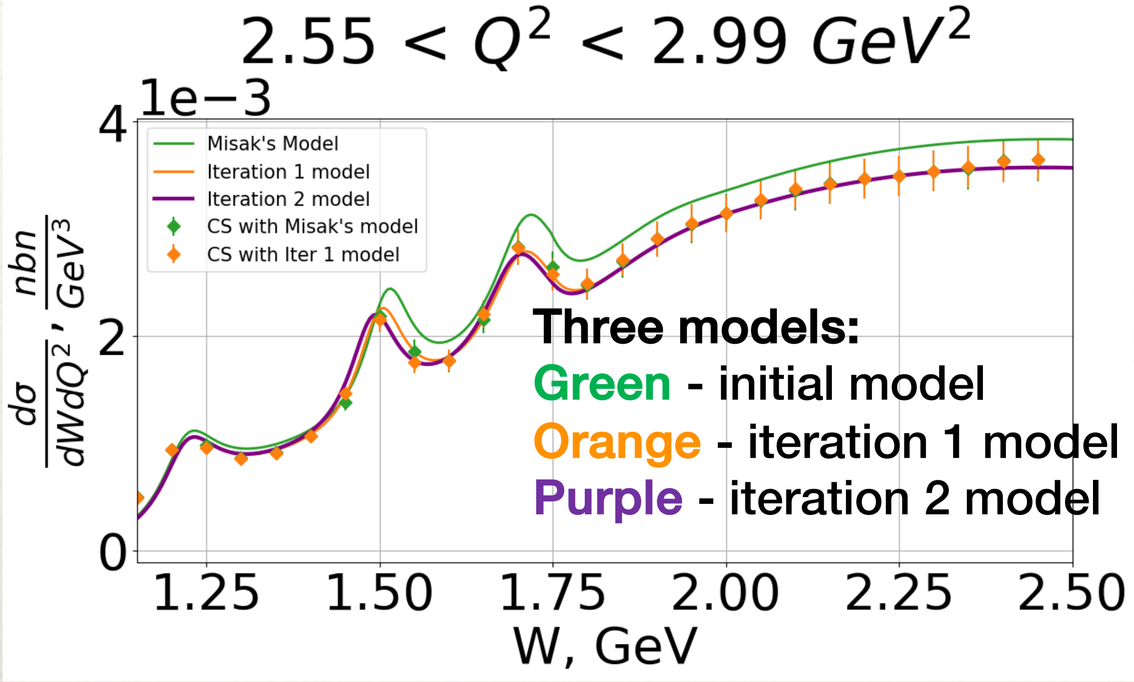
Each (Q^2,W) bin was divided into (the same) 21x11 sub bins.

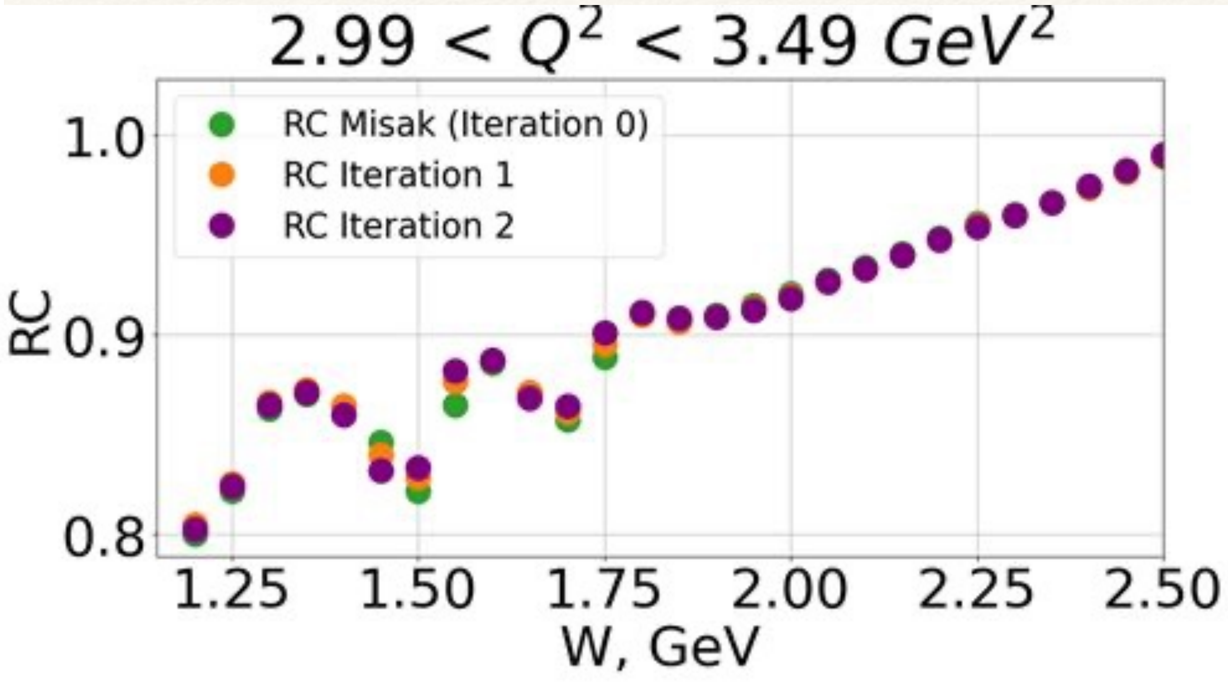
$$B = \frac{Cross\ Section\ (No\ Rad)\ in\ the\ central\ point}{Mean\ Cross\ Section\ (No\ Rad)}$$

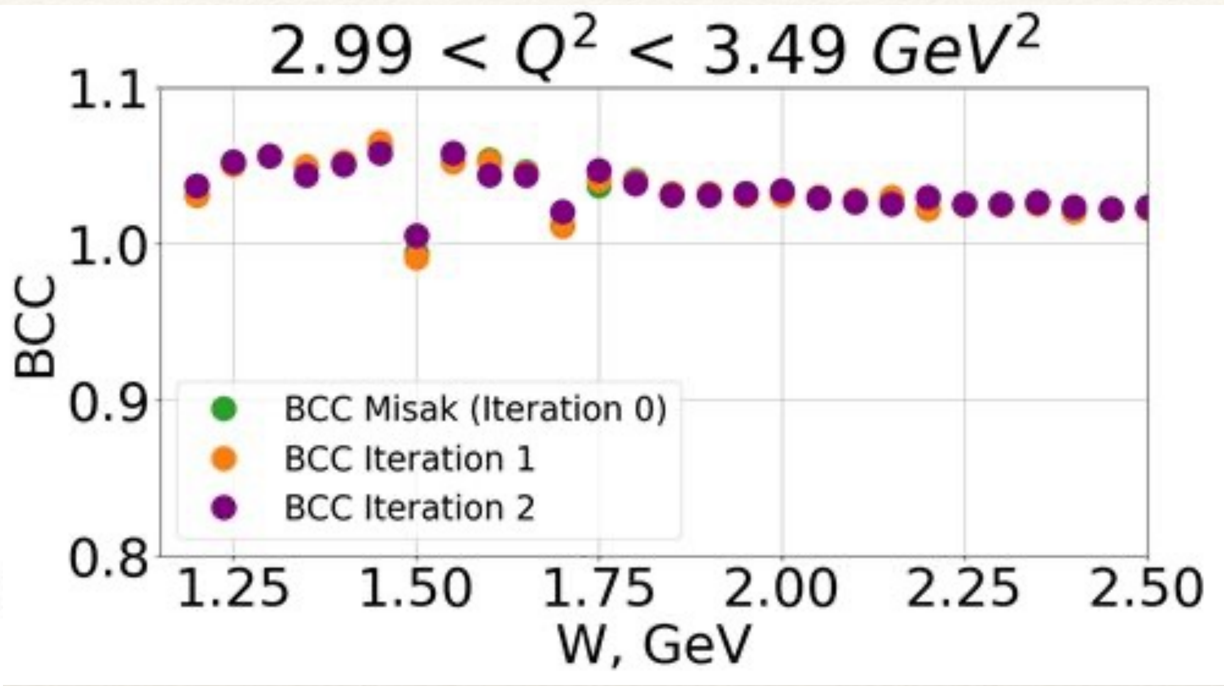


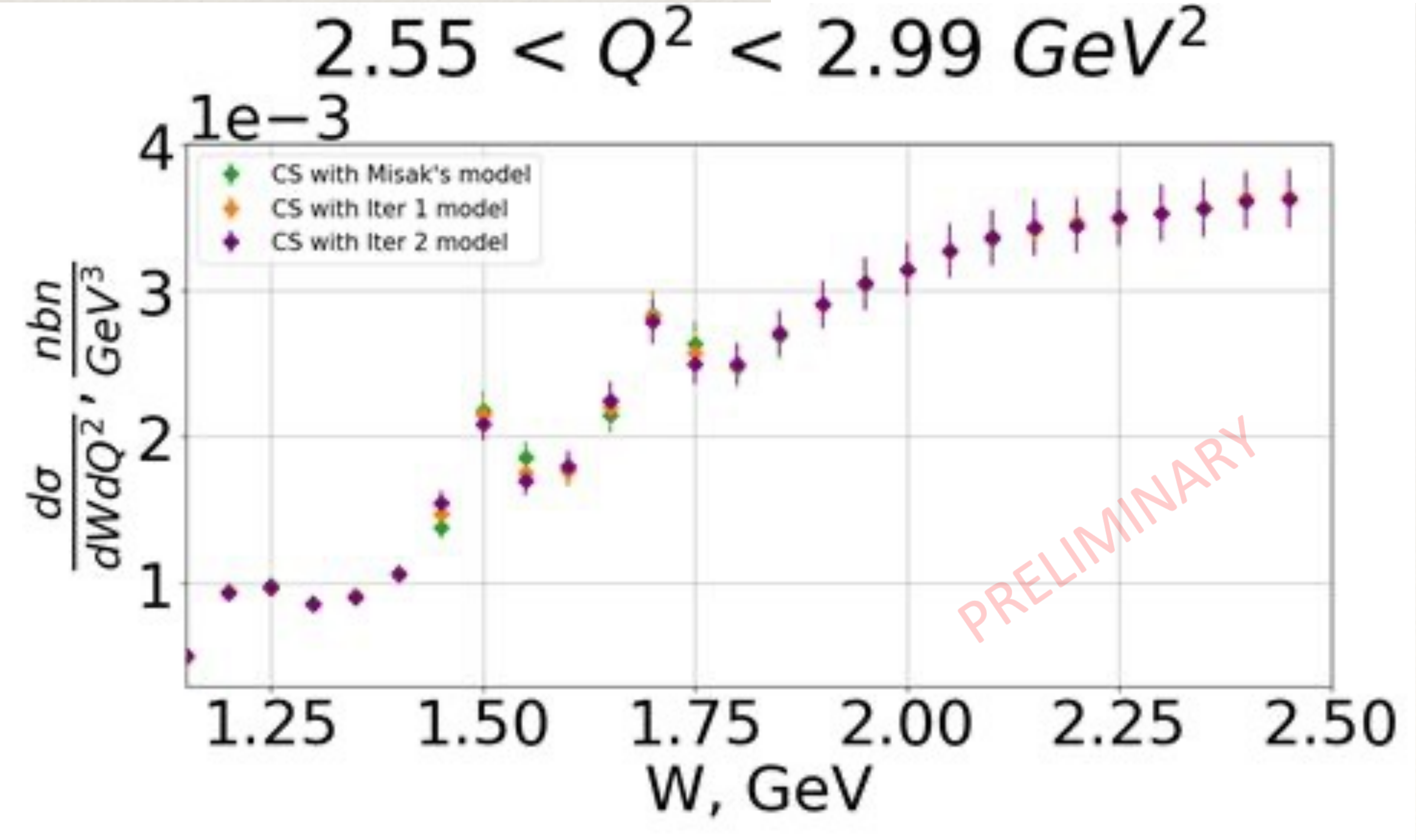
Iterations

After applying all the corrections and normalization accordingly to faraday cup charges we obtained preliminary cross section. That cross sections can be used as a base for new event generator and as a new model for RC and BC estimation.







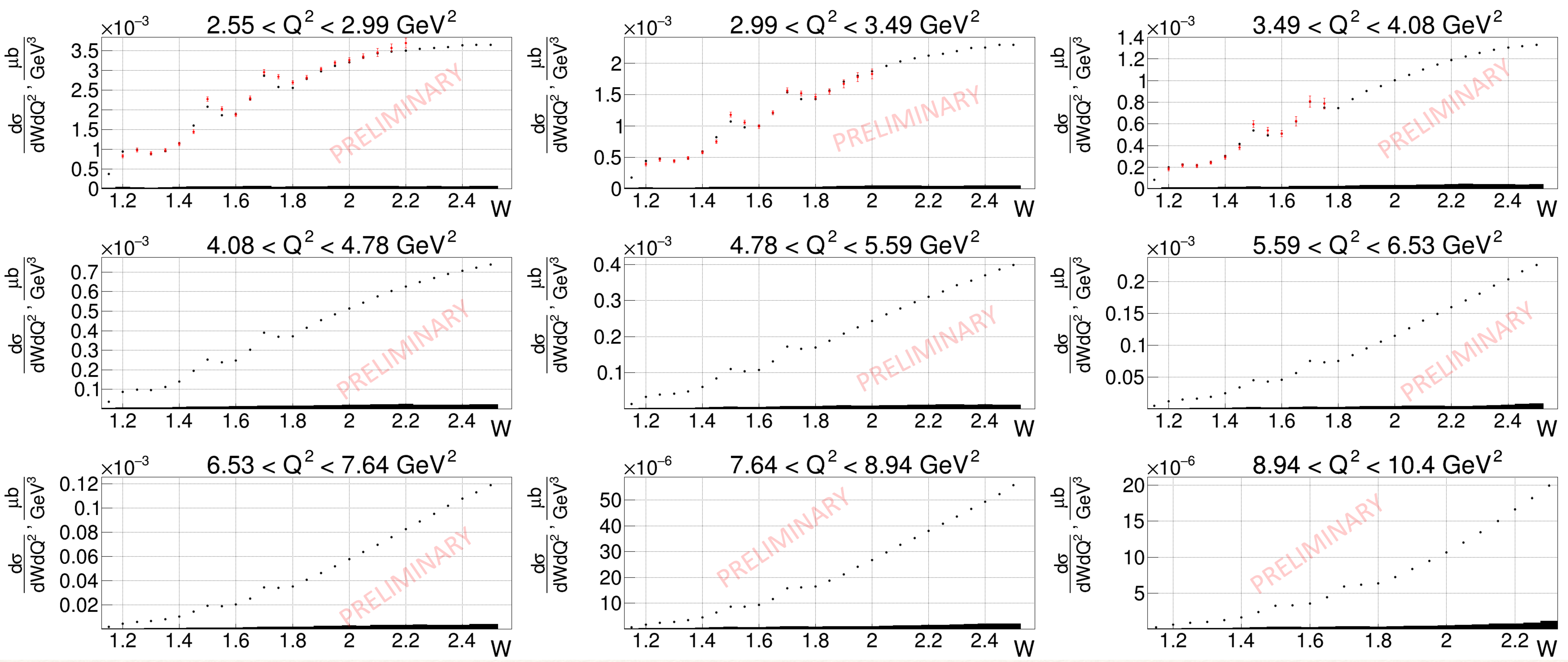


Cross Section with three models:
Green – Cross Sections with initial model
Orange - Cross Sections with iteration 1 model
Purple - Cross Sections with iteration 2 model

There is small peak shift. Peaks become narrower with iterations number.

Preliminary Cross Section

- Preliminary CLAS12 measurements.
- CLAS data (after interpolation into the grid of our experiment), Phys. Rev. D67, 092001 (2003).



Summary

- Preliminary results on inclusive electron scattering cross sections are available from CLAS12 in the kinematic range of $1.15 < W < 2.5$ GeV and $2.55 < Q^2 < 10.0$ GeV^2. Our new measurements show reasonable agreements with world data in overlapping Q^2 regions.

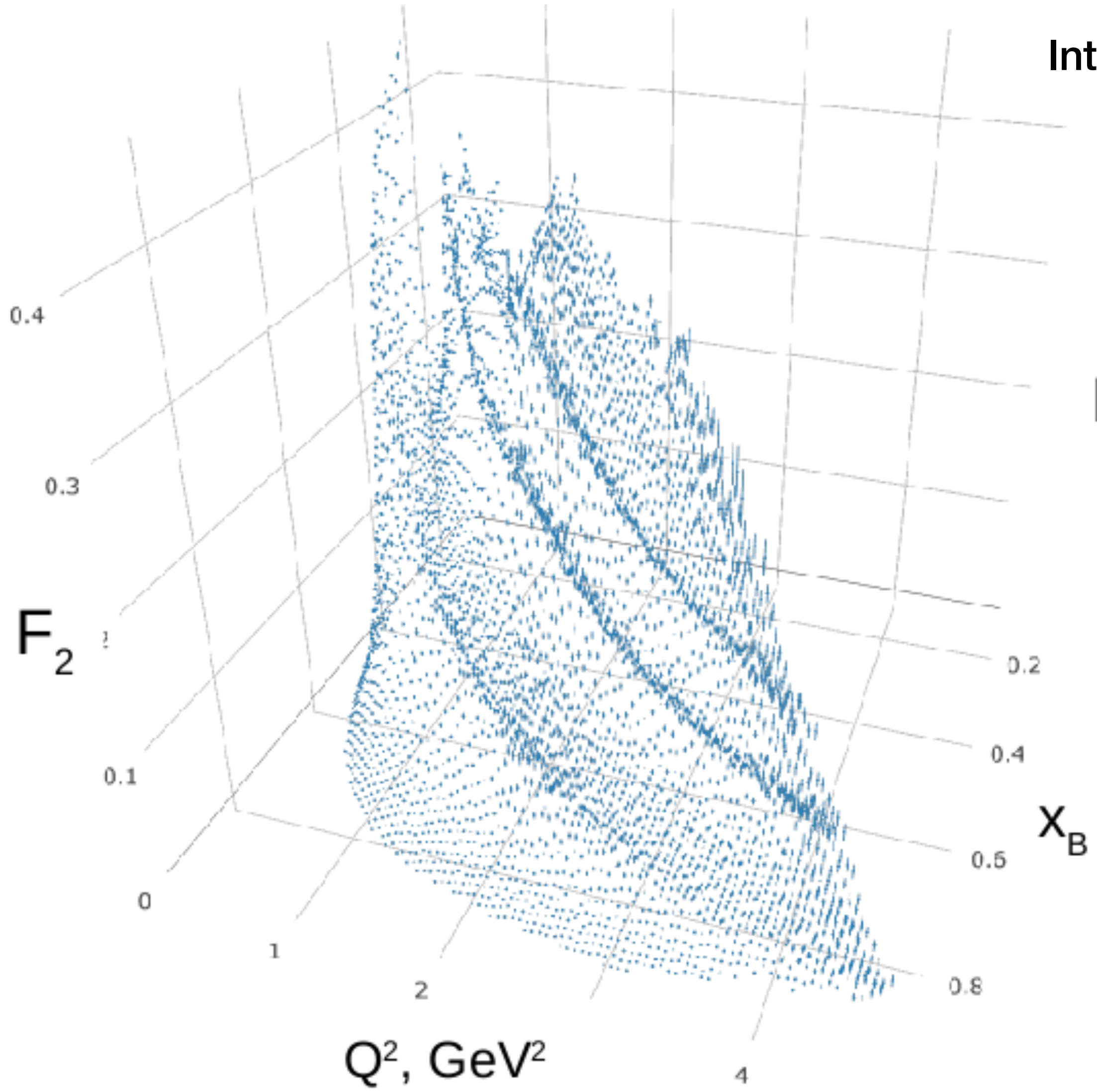
- Evaluation of the resonant contributions from exclusive meson electroproduction data will pave a way to extend knowledge on PDF at large x in the resonance region.

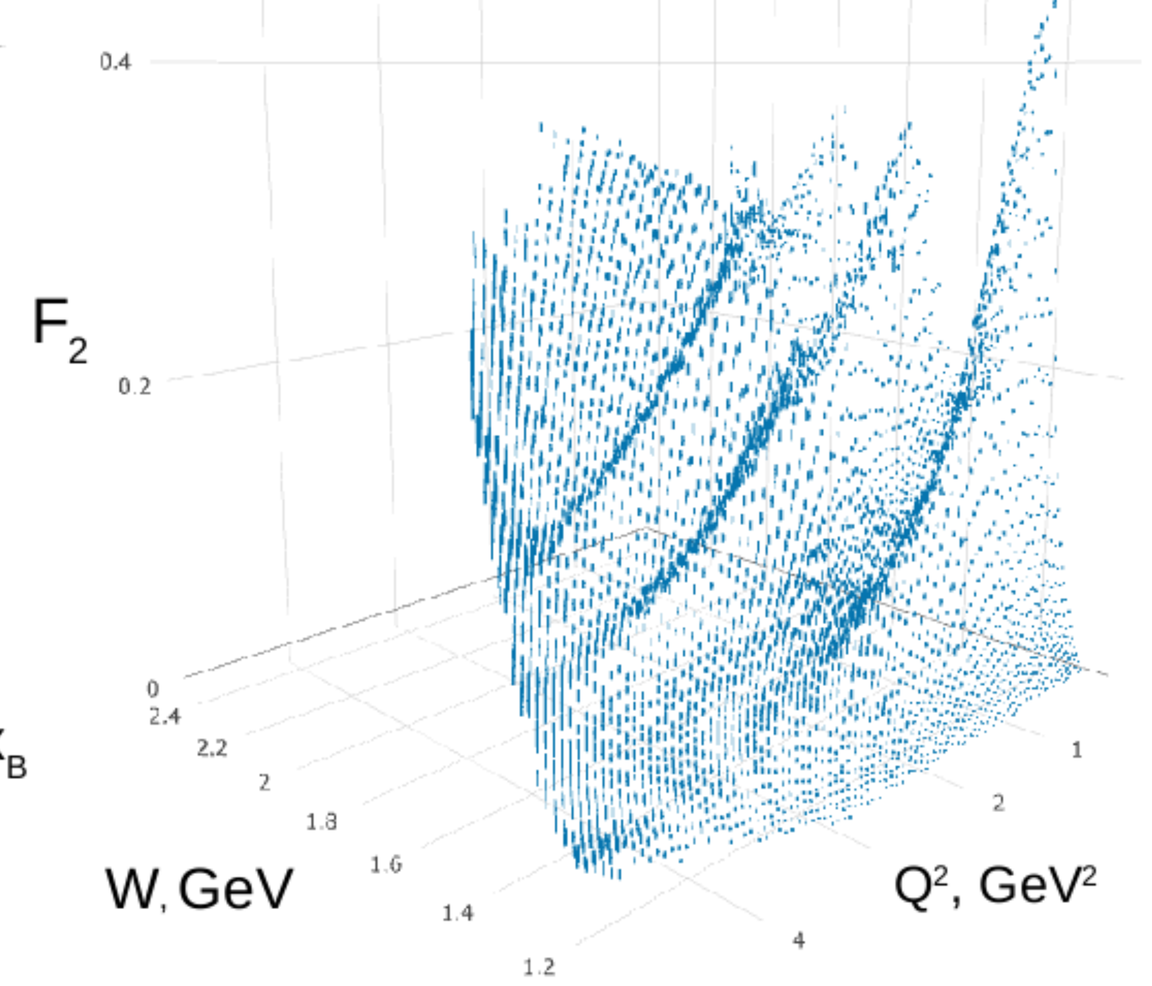
- The (e,e'X) data from CLAS12 offer an opportunity to explore evolution of inclusive structure function F_2 within the range of distances where the transition from strongly coupled to pQCD regimes is anticipated.

Evaluation of the Inclusive Structure Functions F_1 and F_2 at 1.07 GeV <W< 4.0 GeV and 0.7 GeV^2 <Q^2<4.0 GeV^2

F_2 (W,Q^2) structure functions were measured with CLAS in the N* region and interpolated onto the kinematic grid of interest by employing 2D polynomial interpolation

Interpolation tools: V. Chesnokov et al, Phys.Part. Nucl. 53, 184 (2022)





Osipenko et al. (CLAS Collaboration), Phys. Rev. D 67, 092001, 2003

Outside of the region covered by CLAS data, the parameterization of the world data was used: M.E. Christy and P.E. Bosted, Phys. Rev. C81, 055213 (2010).
F_1(W,Q^2) structure functions were computed from F_2 (W,Q^2) by employing the values of $R=\sigma_l/\sigma_t$ from the parameterization A.N. Hiller Blin et al., Phys. Rev. C104, 025201 (2021).