Inclusive Electroproduction with CLAS12 and Nucleon Structure in the Valence Quark Domain

N. Markov, Jefferson Lab
for the CLAS collaboration

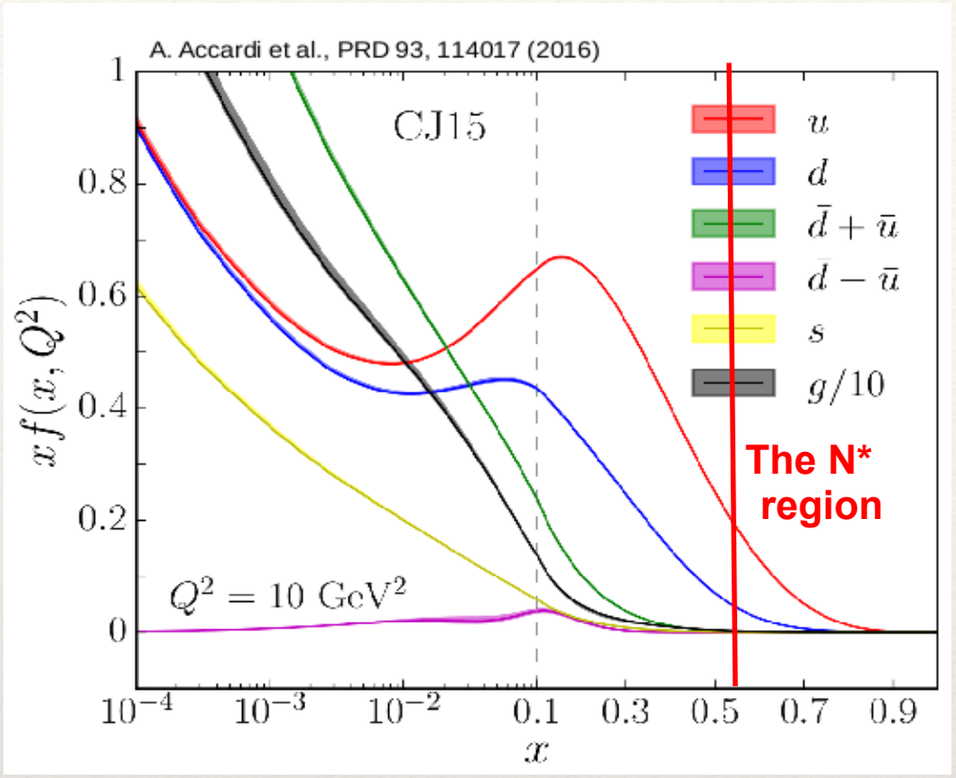
CEBAF Large Acceptance Spectrometer

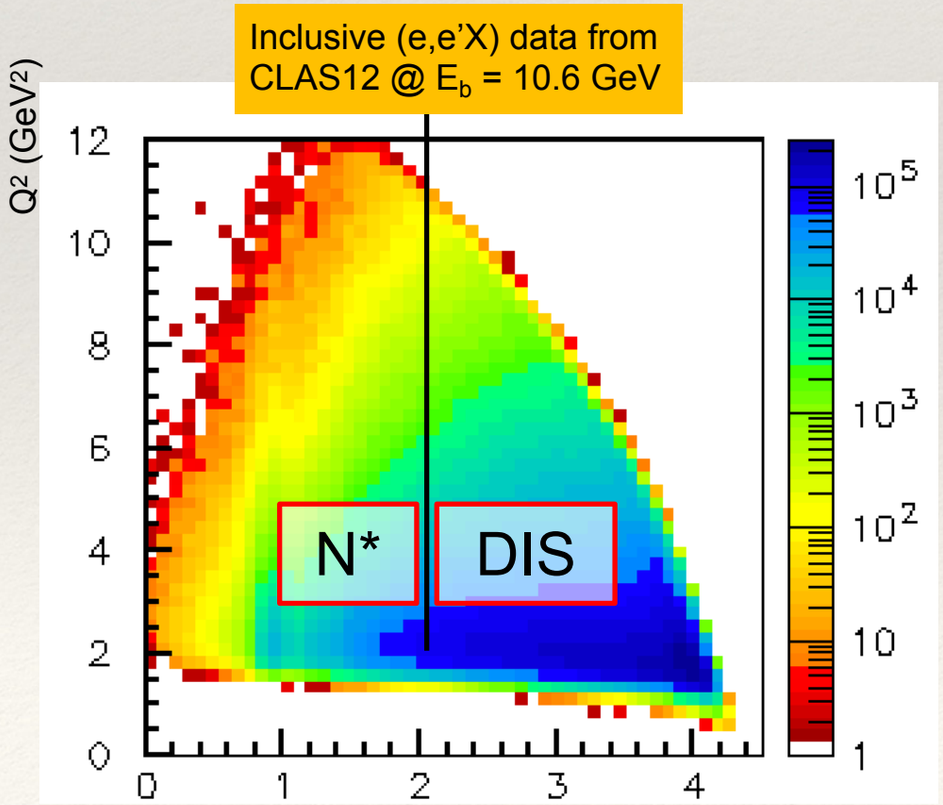
Jefferson Lab

Overview

- Introduction and motivation
- Data analysis
- Results
- Next steps and outlook
- Summary

Extending Knowledge of the Nucleon PDF in the Resonance Region

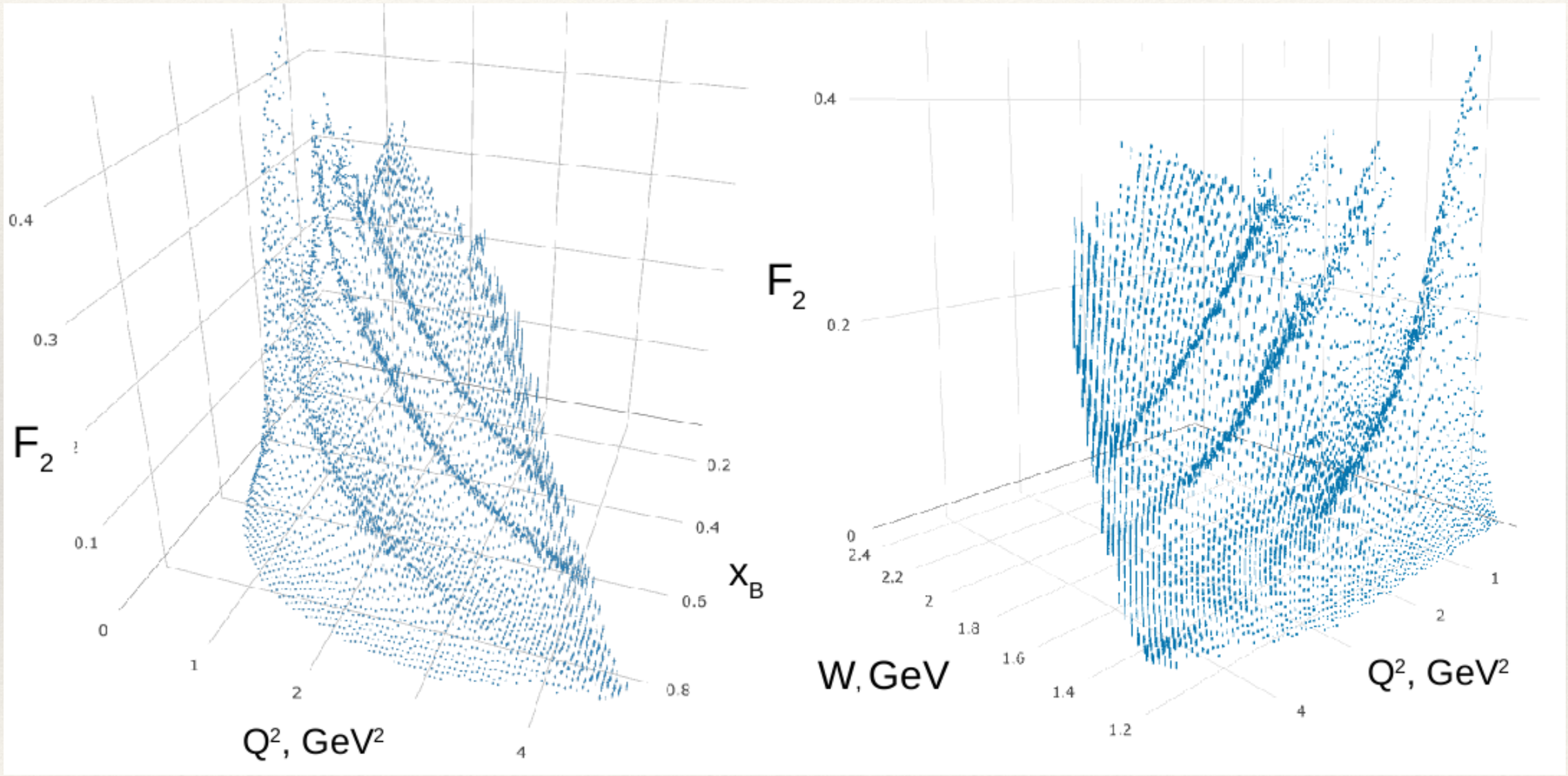




- Study of ground state nucleon PDF from inclusive electron scattering offers an effective tool for nucleon structure exploration
- The global QCD-driven analyses have provided detailed information on the quark and gluon PDFs in a wide range of Bjorken variable x_B from 10^{-4} to above 0.9 and at photon virtualities Q^2 from 1 - 10^4 GeV^2
- PDF studies in the resonance region (W<2.0 GeV or x_B >0.6) require accounting for resonance contributions
- Hall A/C provided accurate (e,e'X) data in resonance region; due to limited acceptance, data are available on correlated (W,Q^2) grid and offer limited W-coverage at a given Q^2 – a few 100 MeV at Q^2>4.0 GeV^2
- (e,e'X) data from CLAS12 with almost 4π-acceptance cover the W-range from pion threshold to >3.0 GeV in all Q^2-bins
- CLAS12 data offer opportunities to explore evolution of the ground state nucleon PDF at distances where the transition from the strong-QCD to pQCD regimes is expected

Inclusive Structure Function F_2 from CLAS Data

The F_2 structure function was measured with CLAS in the N* region with large coverage over x_B/W as a function of Q^2



Three pronounced resonance structures are evident

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

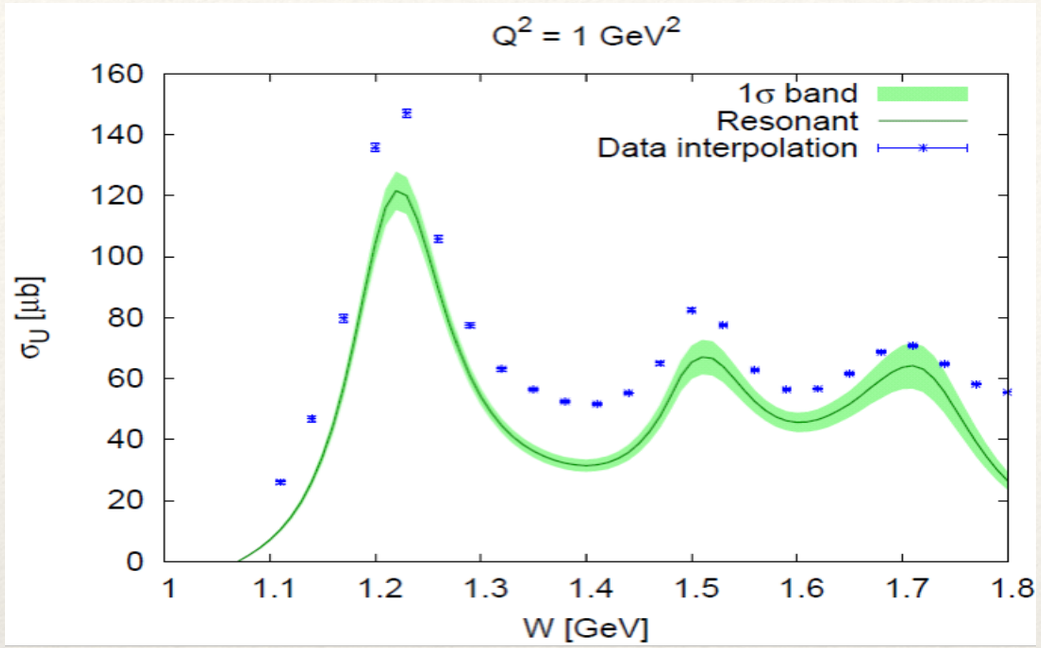
Summary of Results on $\gamma_v pN^*$ Electrocouplings from CLAS

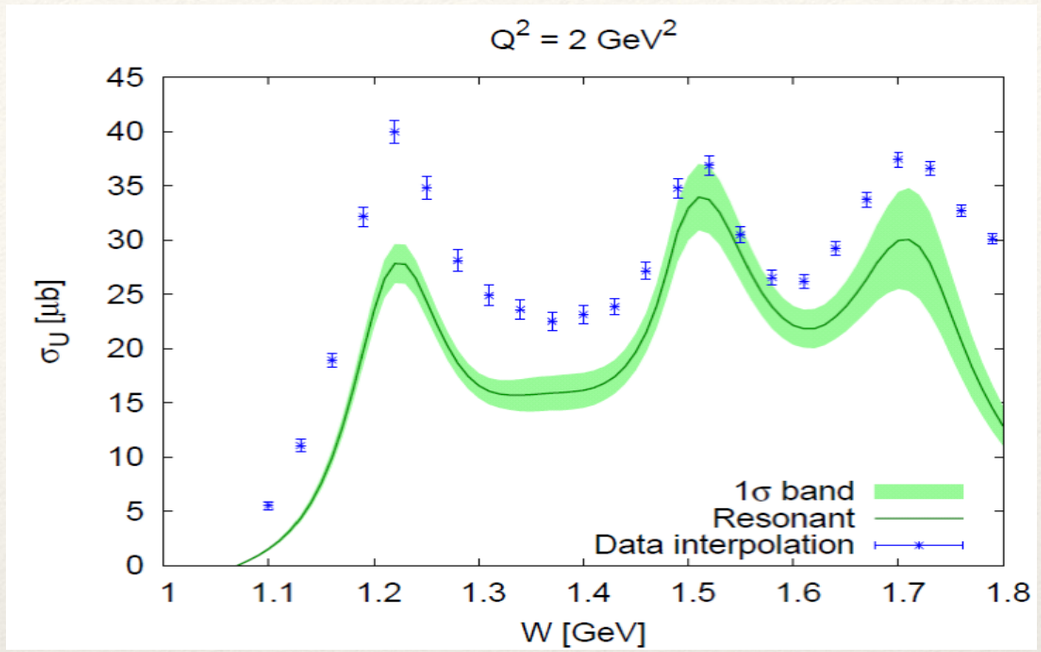
Exclusive meson electroproduction channels	Excited proton states	Q^2-ranges for extracted $\gamma_v pN^*$ electrocouplings, GeV^2
$\pi^0 p$, $\pi^+ n$	$\Delta(1232)3/2^+$	0.16-6.0
	$N(1440)1/2^+$,$N(1520)3/2^-$, $N(1535)1/2^-$	0.30-4.16
$\pi^+ n$	$N(1675)5/2^-$, $N(1680)5/2^+$ $N(1710)1/2^+$	1.6-4.5
ηp	$N(1535)1/2^-$	0.2-2.9
$\pi^+\pi^- p$	$N(1440)1/2^+$, $N(1520)3/2^-$ $\Delta(1620)1/2^-$, $N(1650)1/2^-$,	0.25-1.50
	$N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$	0.5-1.5

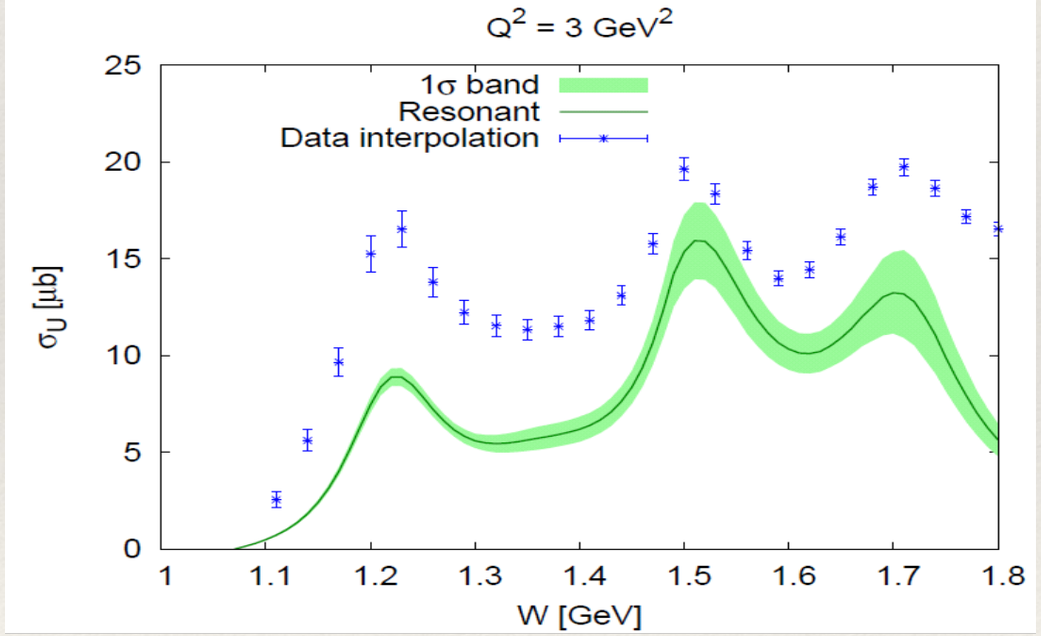
Ref: https://userweb.jlab.org/~mokeev/resonance_electrocouplings/

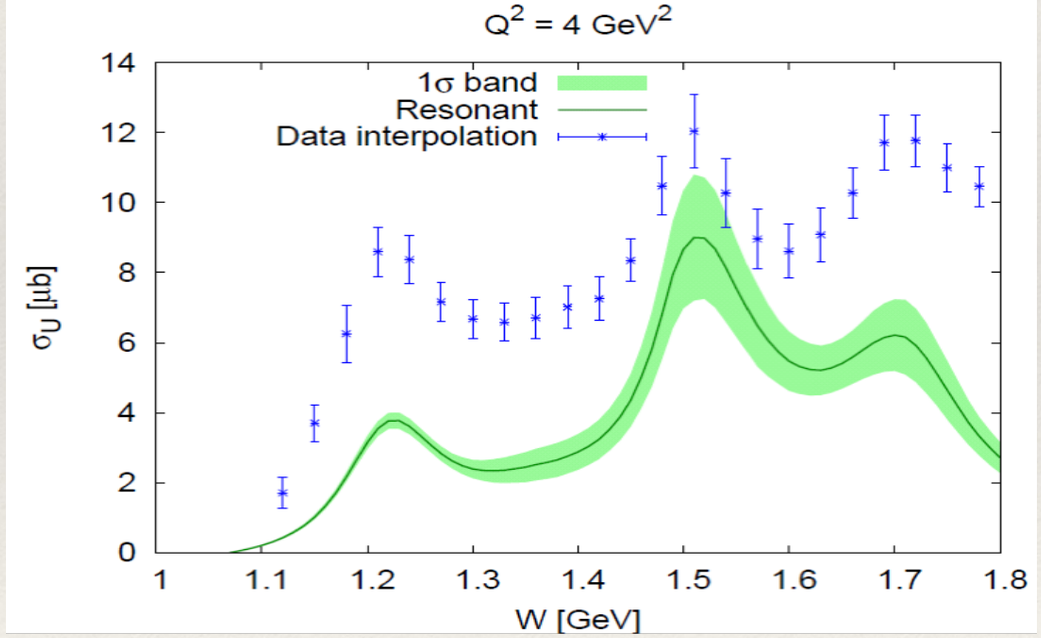
Interpolated/extrapolated CLAS $\gamma_v pN^*$ electrocouplings for $W < 1.8$ GeV and $Q^2 < 5.0$ GeV^2

Resonance Contributions into the Virtual Photon Cross Sections





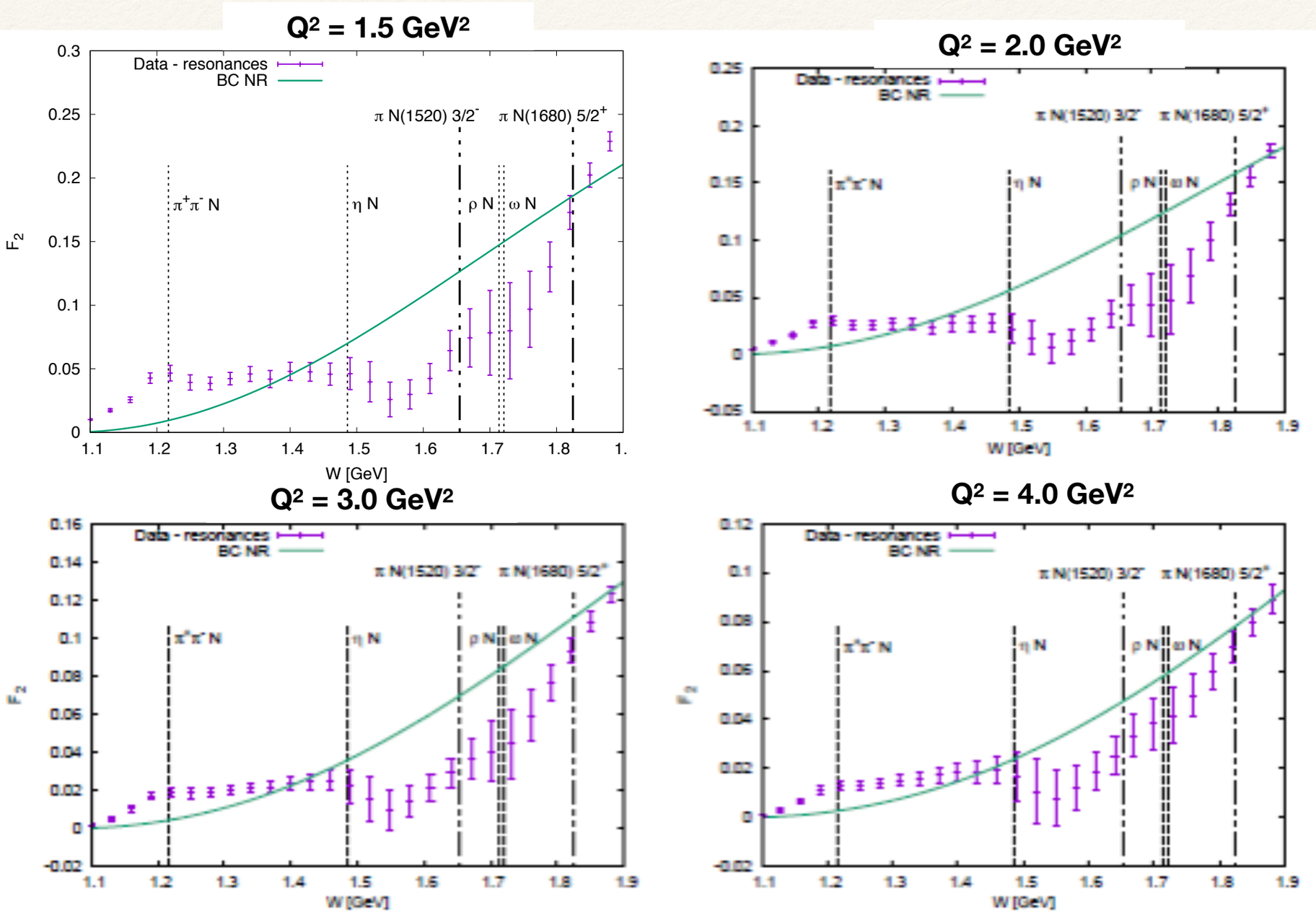




For the first time the resonant contributions were evaluated from the experimental results on the $\gamma_v pN^*$ electrocouplings from CLAS at W<1.8 GeV

A.N. Hiller Blin *et al.*, Phys. Rev. C 100, 035201 (2019)

Impact of the Resonant Contributions to Insight of PDF



F2 structure function from the Extrapolation from DIS
M.E.Christy, P. Bosted, PRC 81, 055213 (2010)

F_2 structure function after subtraction of resonant contributions

- Difference in the resonance region between the subtracted F2 and the non-resonant contributions obtained by just extrapolating from the DIS region, demonstrate a significance of realistic evaluation of the resonance contributions to the measured F2 for the insight to the ground nucleon PDF.
- Analysis method for realistic evaluation of the resonance contribution to the CLAS12 (e,e'X) data has been developed and published in A.N. Hiller Blin et al., Phys. Rev. C100, 035201 (2019)

Data analysis overview

- Data overview
- Data processing
- Corrections
- Results and cross check
- Physics Analysis

Data analysis

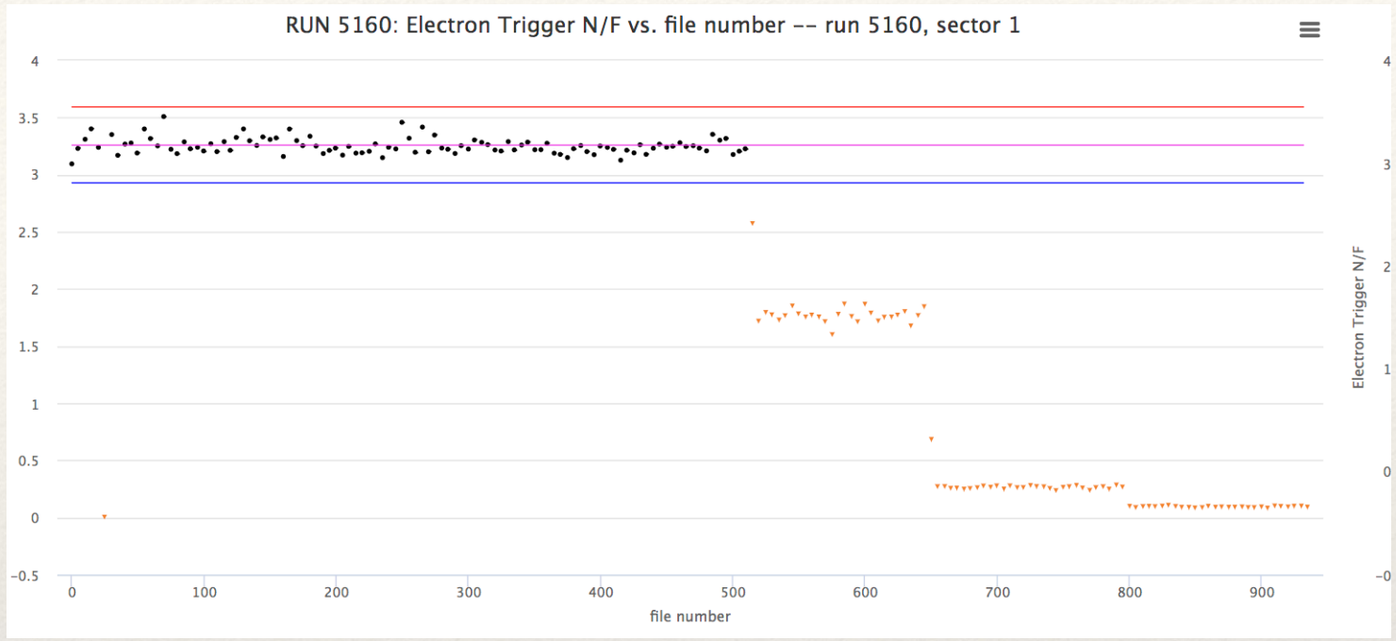
Dataset

- RGA Fall 2018
- 10.6 GeV electron beam
- Torus -100%
- Solenoid -100%
- 5 cm liquid hydrogen target
- 5% of currently available data analyzed
- 62 runs, 5032 - 5262
- “DNP” cook (working on having pass1 data analyzed)

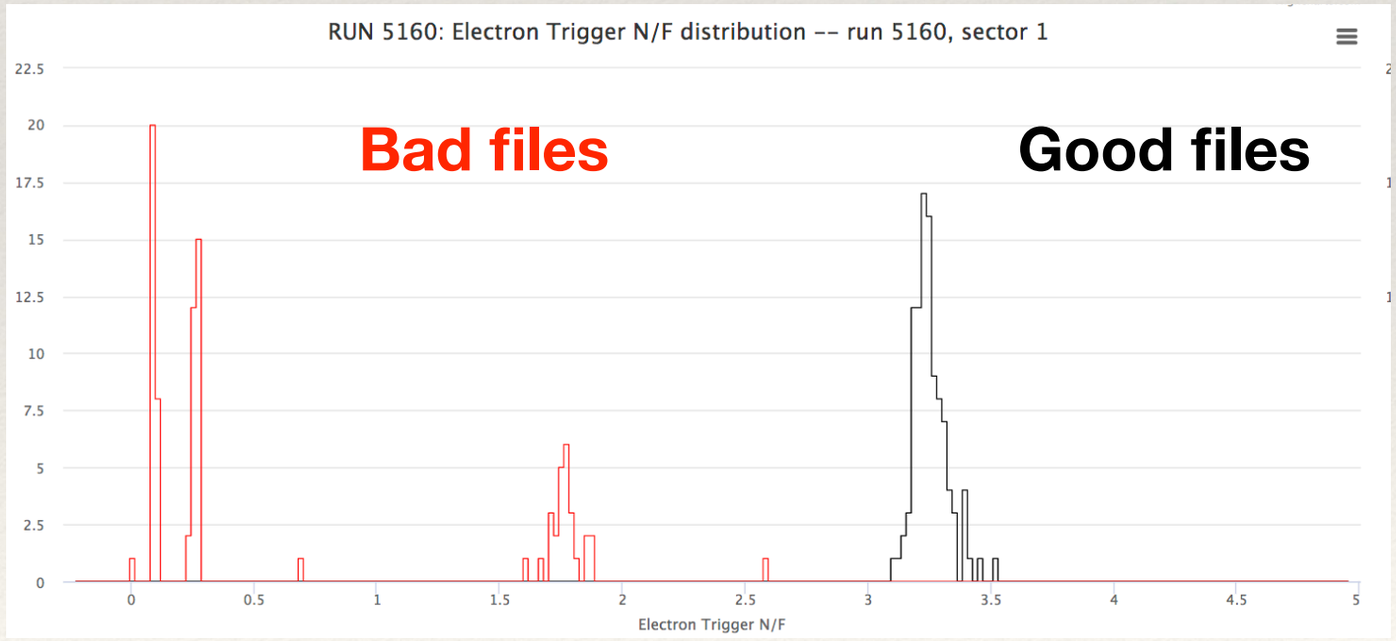
Data analysis

Data quality monitoring

Electron event yield per file



Good files/run selection based on the electron event yield per file



Tool is in development by Chris Dilks (DUKE) and Andrey Kim (UCONN)

Data analysis

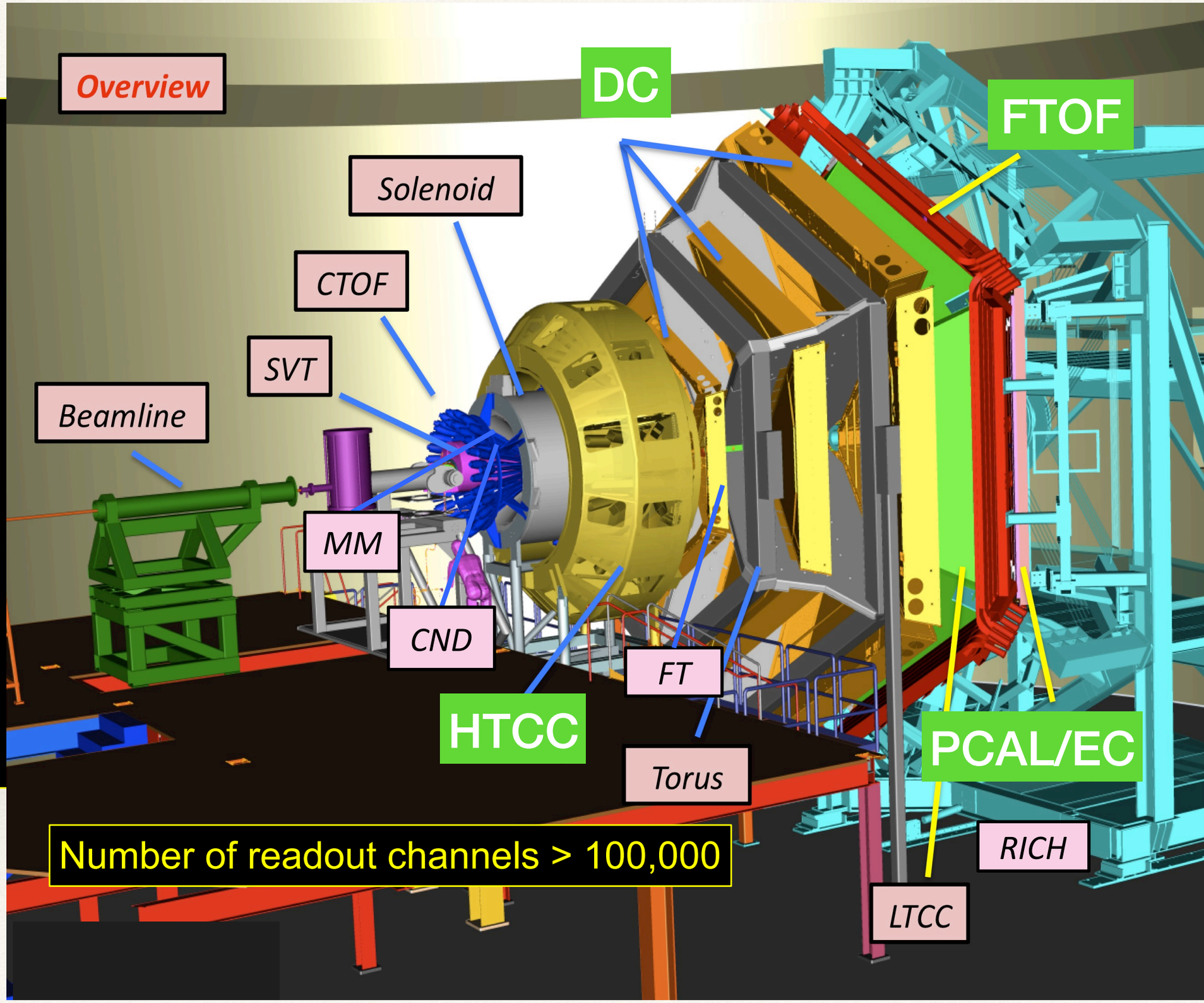
Electron ID

Forward Detector (FD)

- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Pre-shower calorimeter
- E.M. calorimeter
- Forward Tagger
- RICH detector

Central Detector (CD)

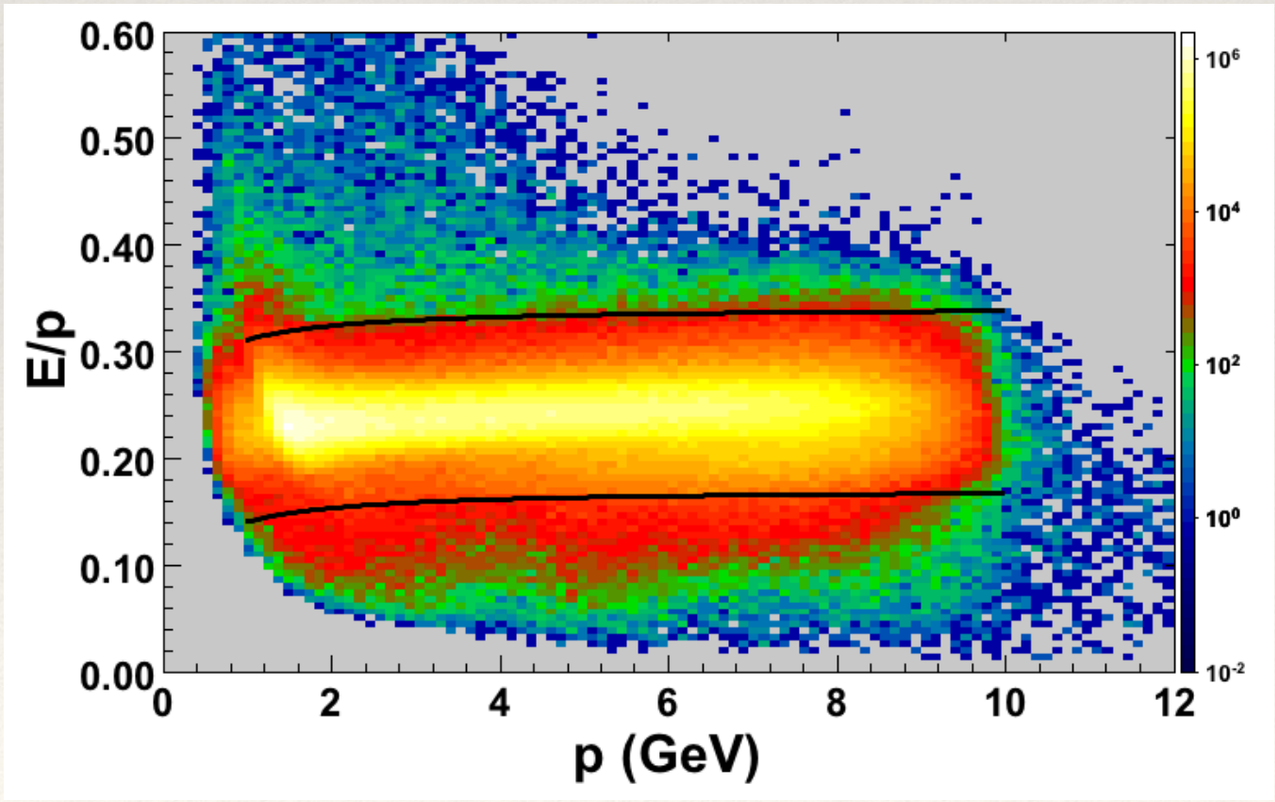
- Solenoid magnet
- Silicon Vertex Tracker
- Central Time-of-Flight
- Central Neutron Detector
- MicroMegas



Data analysis

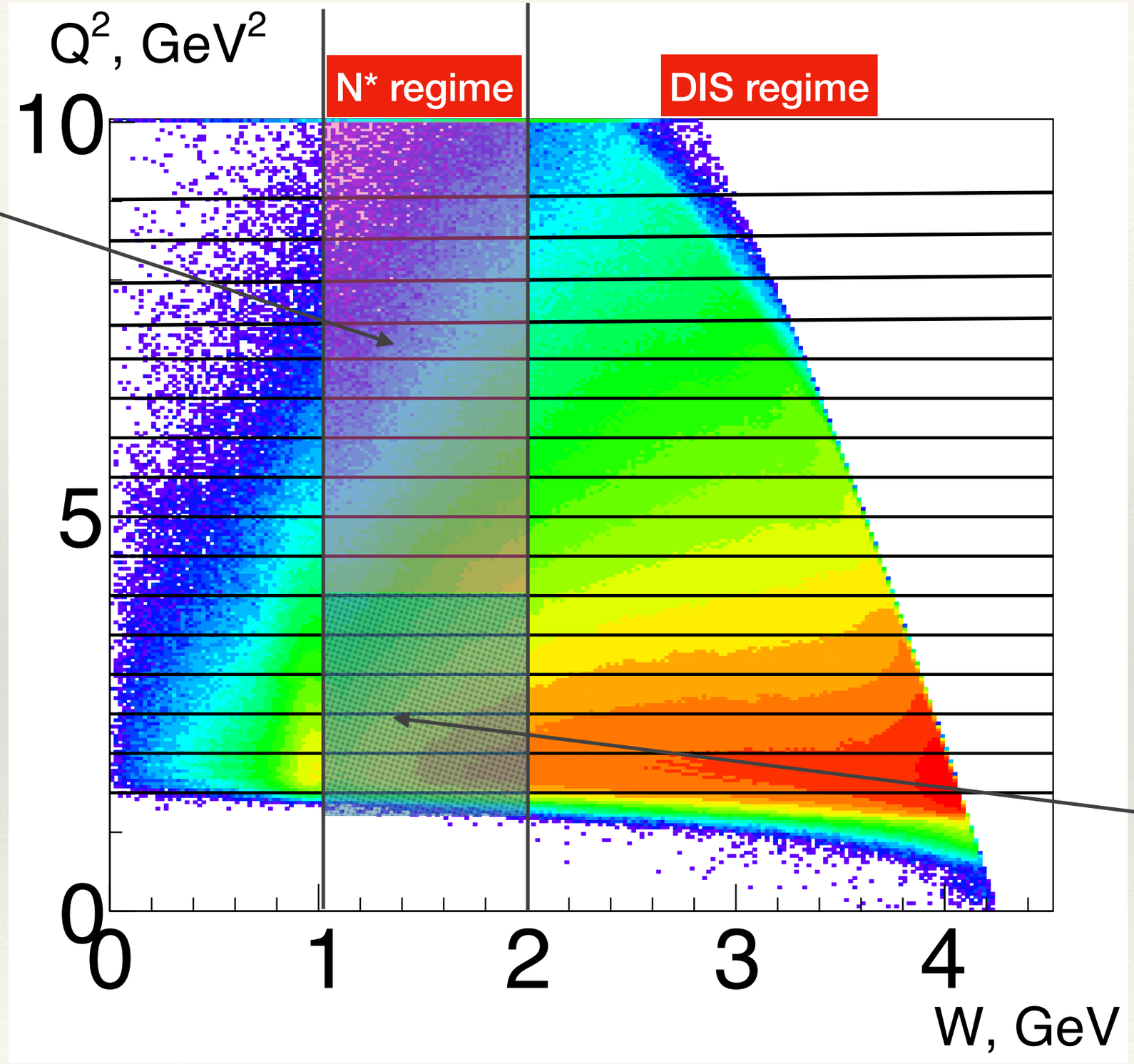
Electron ID

- Limited to Forward Detector (5 -35 degrees coverage in polar angle)
- Electrons are selected by the CLAS12 Event Builder
  - Negative track with a hit in TOF, ECAL and HTCC;
  - 2.0 photoelectrons in HTCC;
  - 60 MeV in PCAL;
  - 5-sigma cuts on a parameterized momentum-dependent sampling fraction.



Forward Calorimeter
sampling fraction for electrons

Coverage and Binning

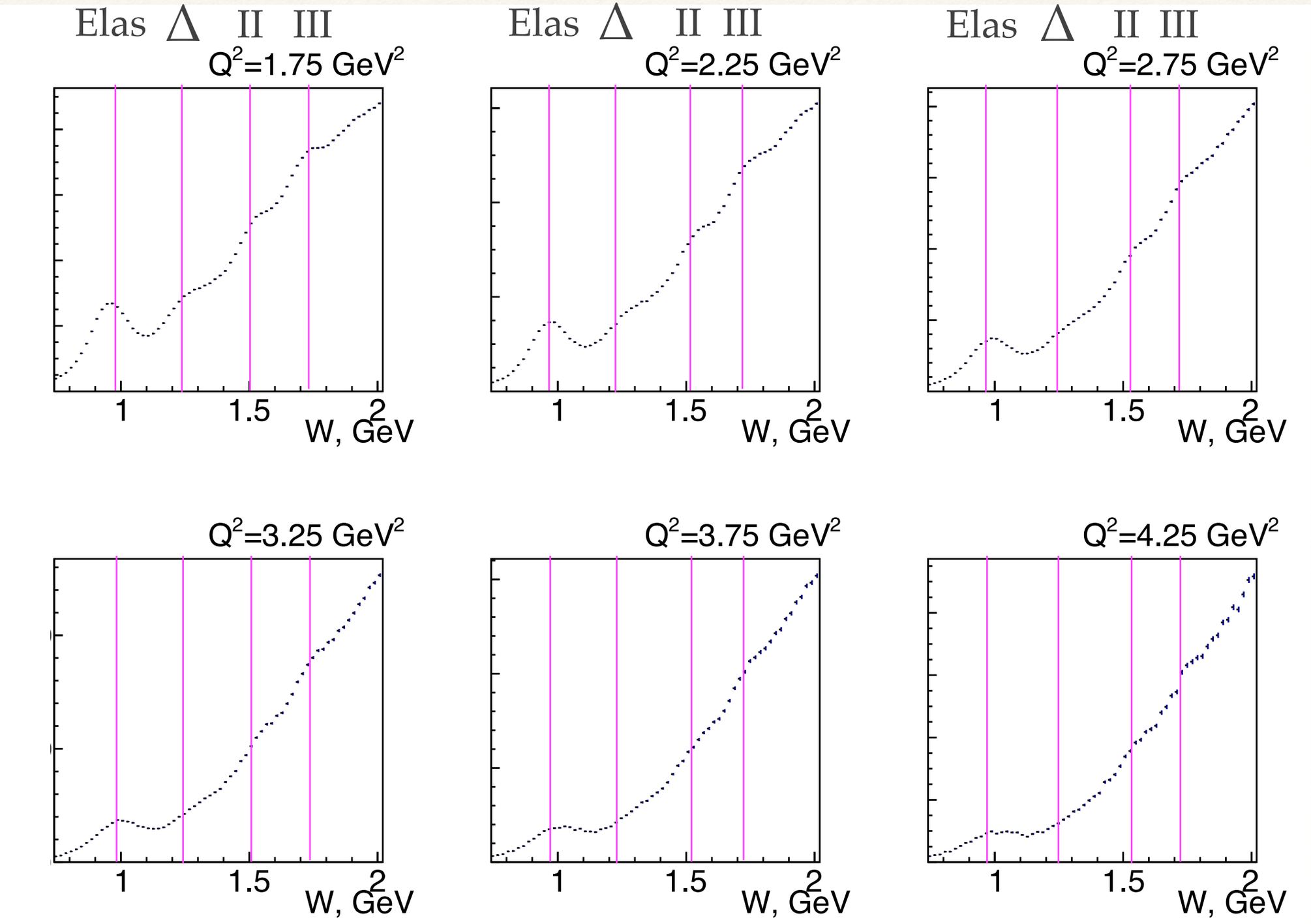


Binning:
ΔW: 0.025 GeV
ΔQ²: 0.5 GeV²

We will report data in the Q² region up to 10 GeV².

Resonance structures

We clearly see resonance structures at their appropriate places and their Q^2 evolution. Preliminary analysis show better resolution with pass 1 cook.



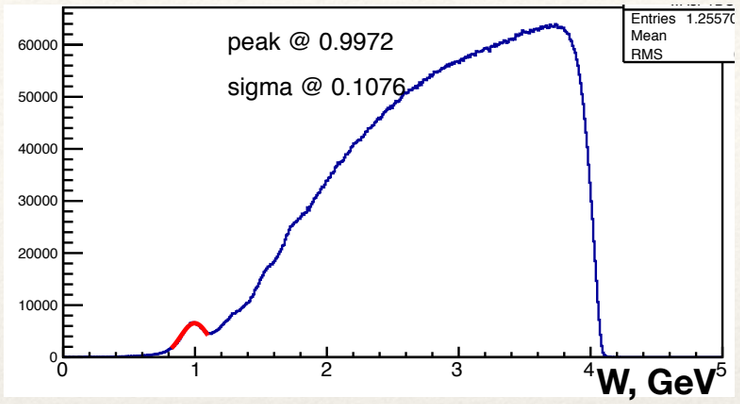
Bumps getting less prominent as Q^2 goes up.

Data analysis

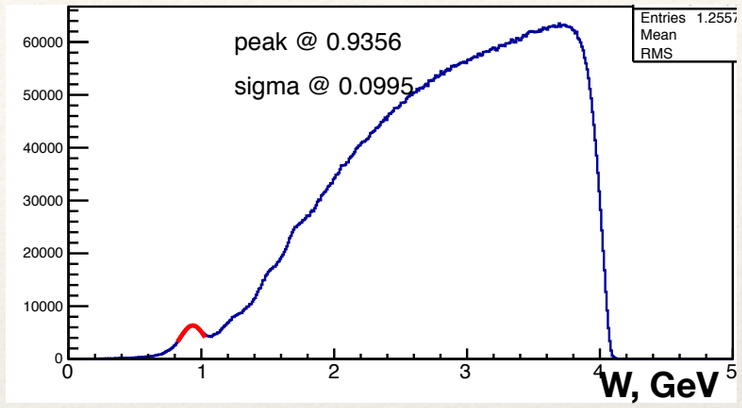
Resolution and kinematic corrections

Kinematic correction:
Based on the elastic kinematics, we correct electron momentum using beam energy and electron angle;
Will be redone for the pass1;
Ongoing work to use elastic radiative events (cover whole W range).

Before correction

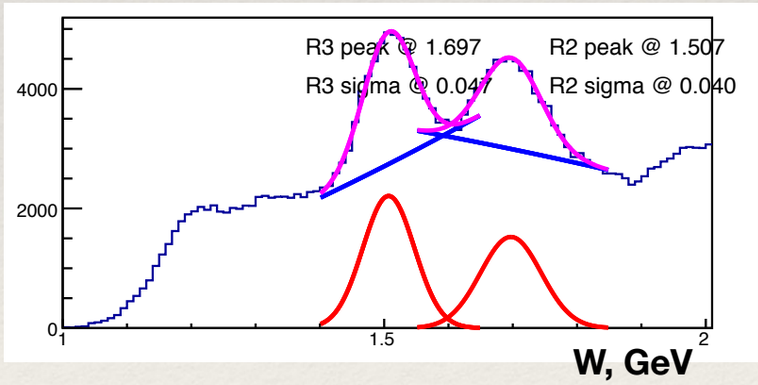


After correction

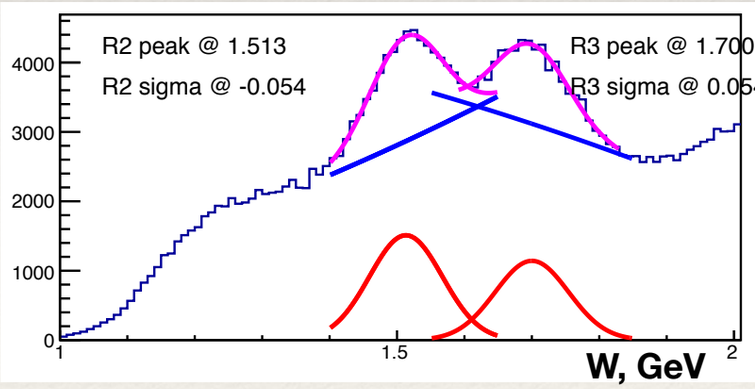


Resolution studies
Based on a single pion kinematics (aao_rad generator,
ep->ep π^0,
ep->e π^+n),
we smear electron momentum to match the widths of the resonance peaks in data in the W spectrum. This smearing factor is a measure of the CLAS12 electron momentum resolution and will be used in the subsequent analysis.

No smearing



ΔP = 50 MeV



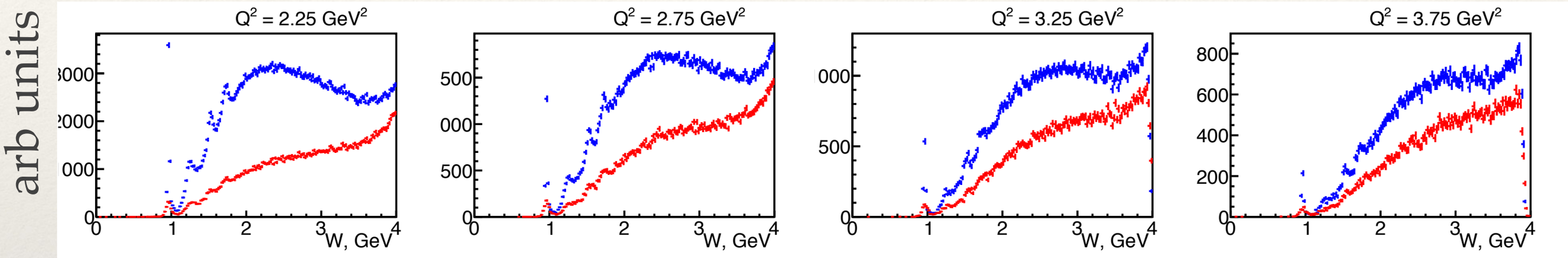
Acceptance and Luminosity Corrections

Generated events

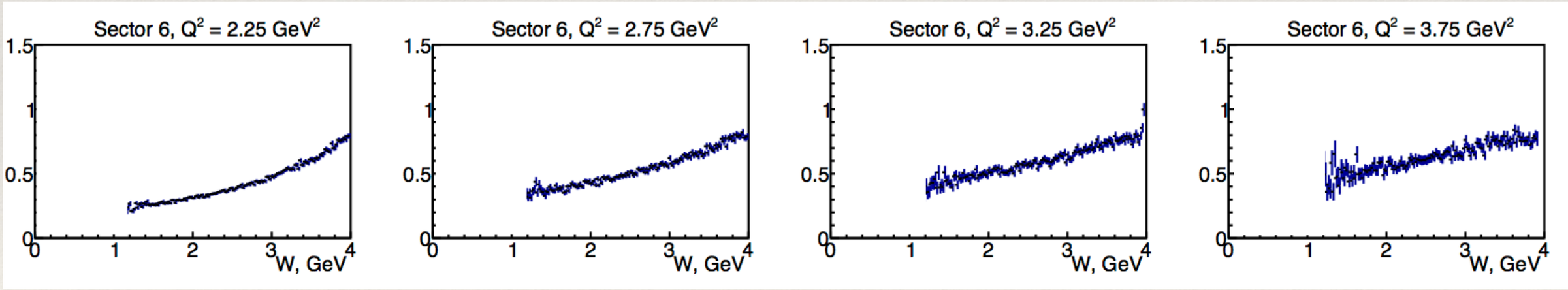
Reconstructed simulation events

Inclusive event generator: M. Sargsyan, CLAS-NOTE 90-007 (1990).
Includes elastic and radiative effects

Same reconstruction algorithms are used between data and simulation.
Both generated and reconstructed events display main features of inclusive electron cross section, namely elastic peak, resonance region with “bumps” and smooth DIS region.



Acceptance Correction



Sample of the acceptance correction for a few Q^2 bins

Luminosity Correction

Luminosity correction is based on the geometry and properties of the target (5 cm long liquid hydrogen) and live-time corrected integrated beam charge on the Faraday Cup.

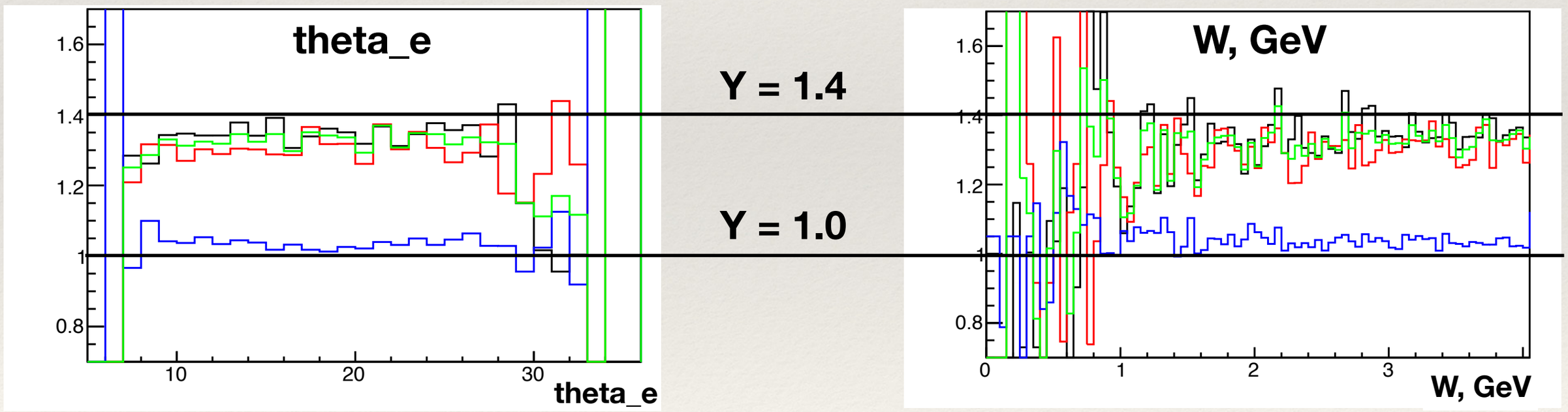
Data analysis

Efficiency correction

Tracking and overall detector efficiency depend on the detector occupancy, which is beam current dependent. We compare normalized (by Faraday Cup charge) yield of electron events at different beam currents as a function of kinematics. This give us some estimate of the overall efficiency and its dependence on current
In the future, this will be done with more details and higher precision using the background merging in the simulation. Analysis of normalized yields and elastic events were performed as well.

Ratio of normalized inclusive event yield at production current (45 nA) to 5 nA current for the intending electrons during RGA Fall 18.

As a function of



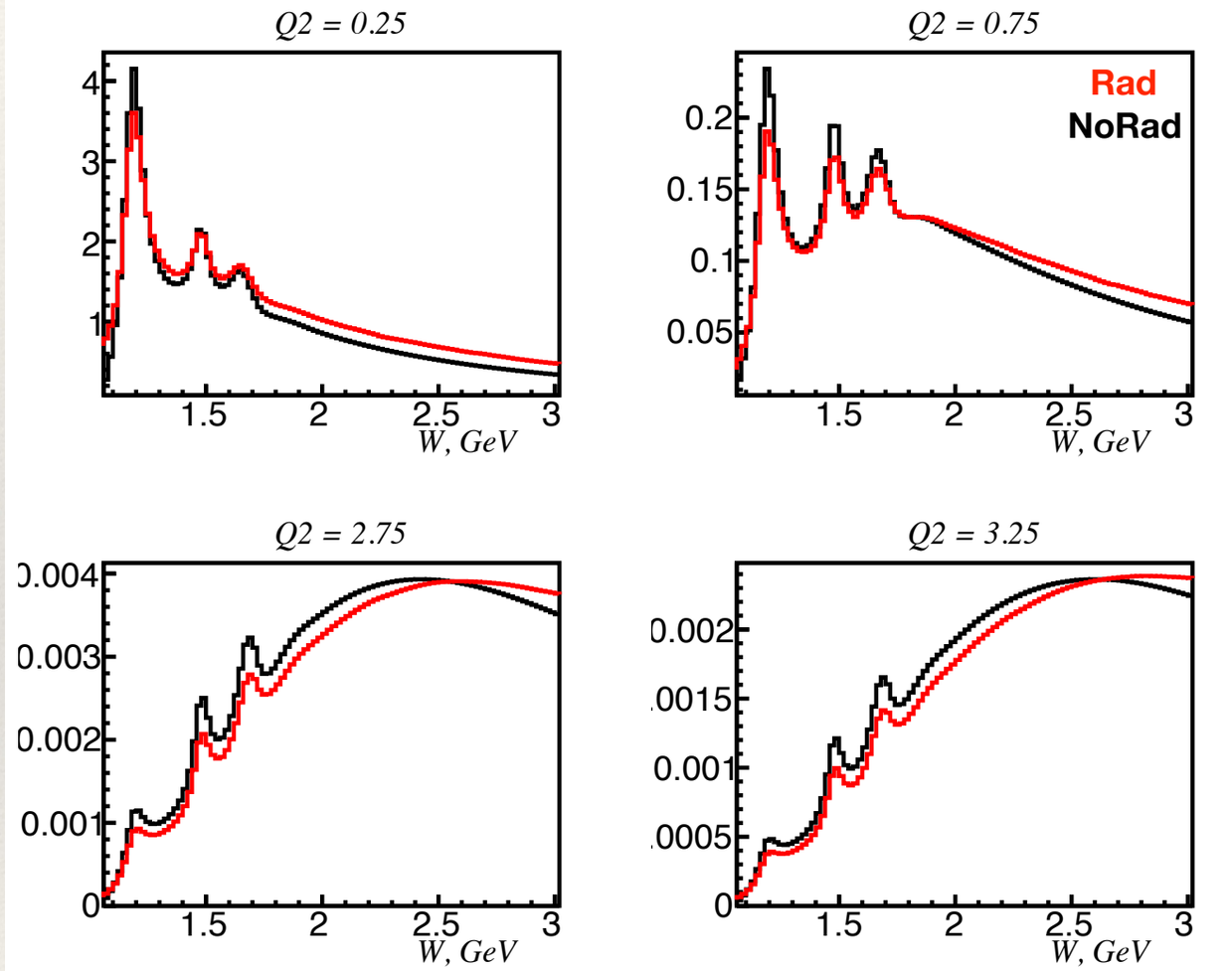
(5418 5nA)/(5306 45 nA)
(5419 5nA)/(5306 45 nA)
(5418 + 5419 5nA)/(5306 45 nA)
(5038 45nA)/(5306 45 nA)

Data analysis

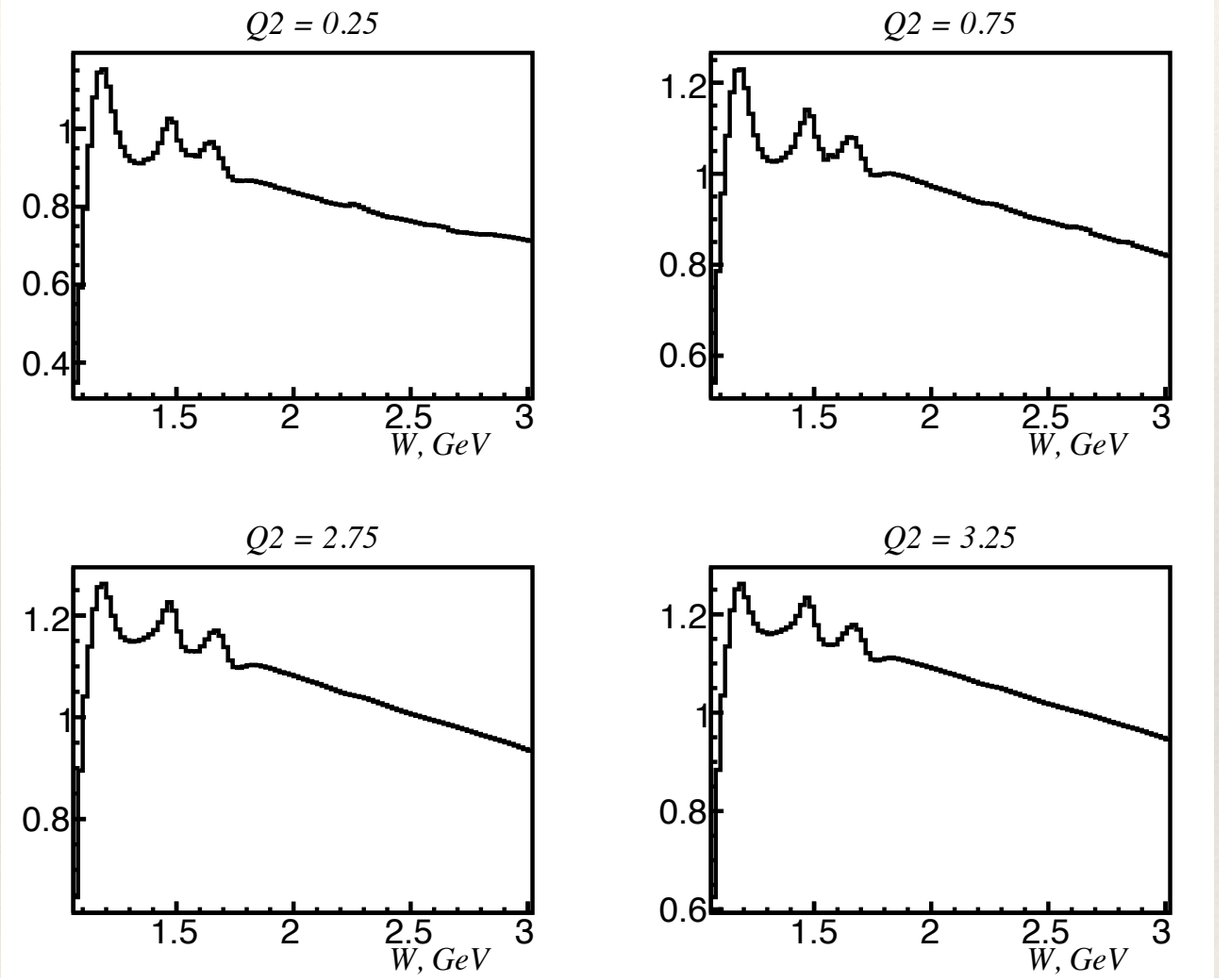
Radiation correction

Based on the inclusive event generator developed based on the Mo and Tsai formalism

Cross section



Radiative correction



- Sample for several Q^2 bins;
- Radiative correction is obtained as a ratio of radiated to nonradiated cross sections in the W and Q^2 bins of interest;

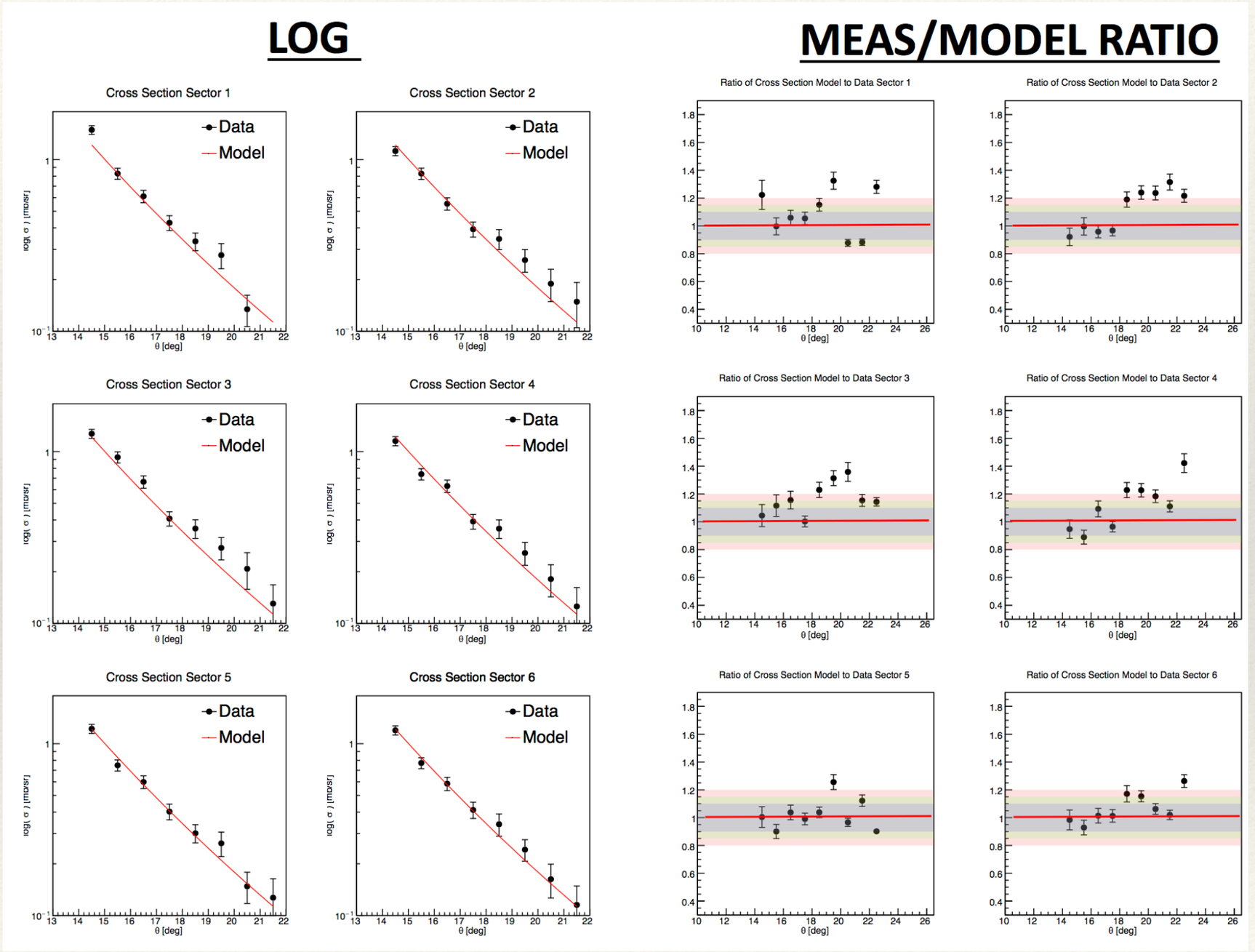
Cross check with elastic cross section

Elastic cross section from CLAS12 @ 2 GeV

Beam energy 2.221 GeV
Torus/solenoid -0.6/-0.6

Analysis currently includes:

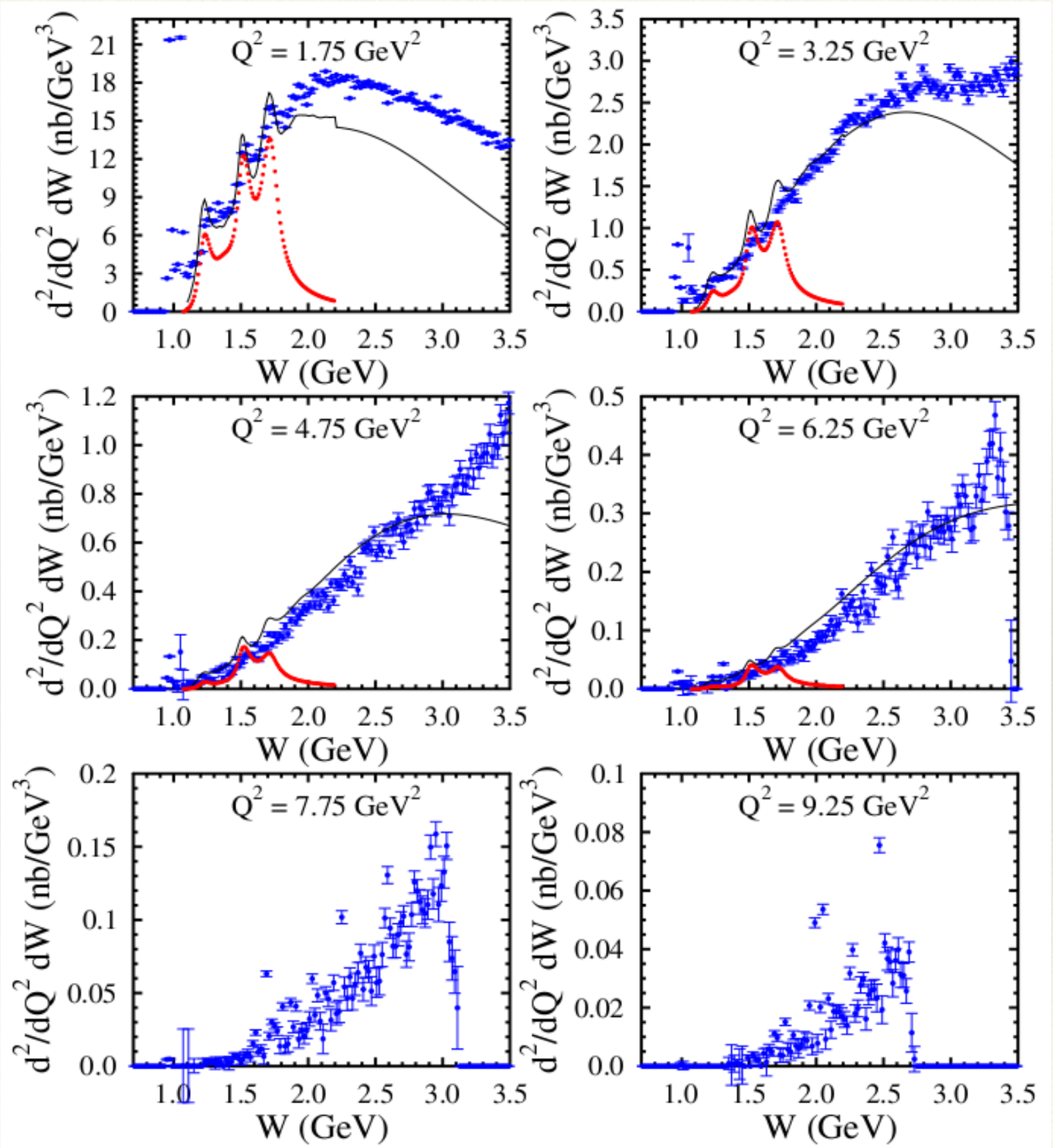
- Electron ID;
- Fiducial cuts;
- Simulation and acceptance correction;
- Luminosity;
- Radiative correction;
- Bin centering correction.



Procedure to extract cross section is developed;
Working to extend to higher beam energies.

Brandon Clary (UCONN)

Resonant Contributions to the Preliminary CLAS12 (e,e'X) Data



Parameterization of world data:

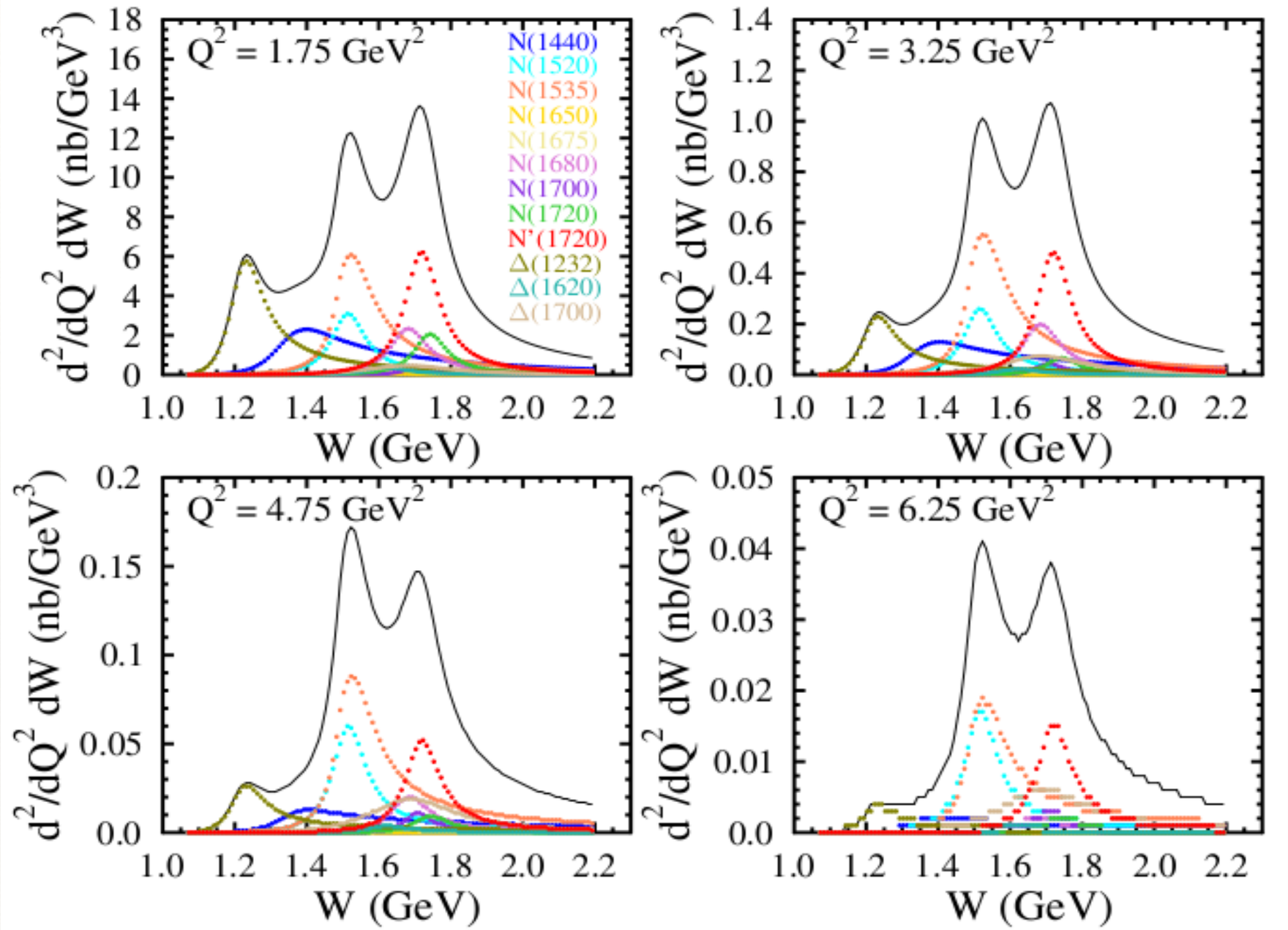
A. Golubenko *et al.*, Phys. Part. Nucl. 50, 587 (2019)

Resonant contributions evaluated from CLAS results on $\gamma_v pN^*$ electrocouplings:

A.N. Hiller Blin

Pronounced differences in Q^2 evolution of the resonant structures seen in the first, second, and third resonance regions related to the different structure of the contributing N* states

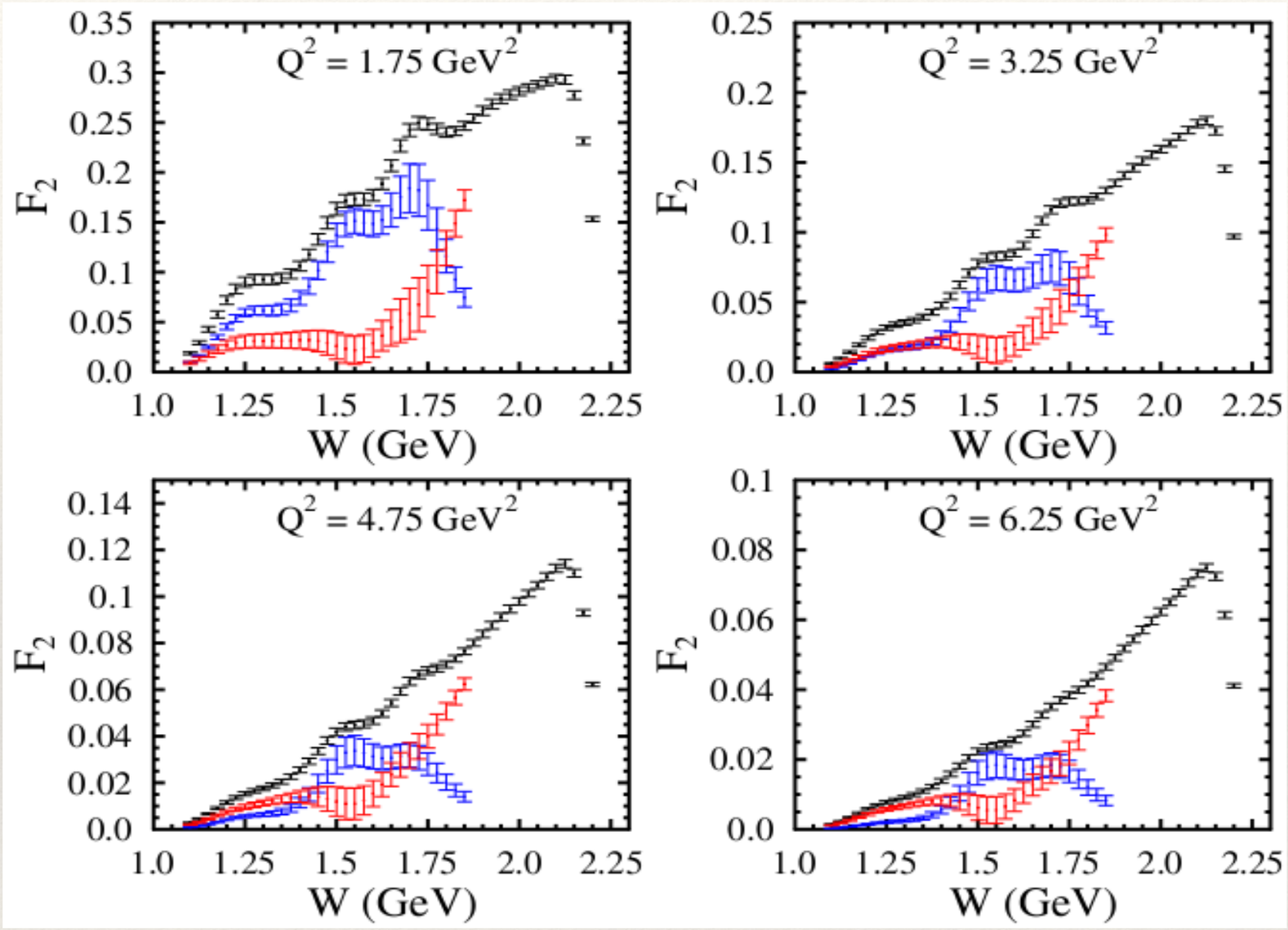
Decomposition of the Resonant Contributions



Hall B/JPAC:
A.N. Hiller Blin,
V.I. Mokeev

- New N'(1720)3/2$^+$ resonance has the biggest contribution to the resonant structure in the third resonance region
- Data on $g_v pN^*$ electrocouplings of all prominent N* are needed for reliable evaluation of the resonant contribution to inclusive electron scattering

Gaining Insight into the Ground State Nucleon PDF in Resonance Region



Hall B/JPAC:
A.N. Hiller Blin,
V.I. Mokeev

World data Gaussian smeared with CLAS12 W-resolution

Resonant contributions

F_2 after subtraction of resonant contributions

- F_2 decomposition through the resonant/non-resonant contributions offers full information from the side of experiment for the extraction of the ground state nucleon PDF in the transition from strong-QCD to pQCD
- Recent advances in theory make it possible to evaluate the ground state nucleon PDF starting from the QCD Lagrangian:

Y.Q. Ma, J.Qiu, PRL 120, 022003 (2018), A.V. Radyushkin, PRD 96, 034025 (2017)

Paper draft

Inclusive Electron Scattering in the Resonance Region from a Hydrogen Target with CLAS12

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[5] *Ohio University, Athens, Ohio 45701*

(Dated: March 19, 2020)

Inclusive electron scattering cross sections from a hydrogen target at a beam energy of 10.6 GeV have been measured with data collected from the CLAS12 spectrometer at Jefferson Laboratory. These high-precision data cover a wide kinematic area in invariant energy W up to 4 GeV and four-momentum transfer Q^2 from 1 to 10 GeV^2. Using a framework developed based on the resonant contributions determined with data from the CLAS spectrometer spanning W up to 2 GeV and Q^2 up to 4.5 GeV^2 that has been extrapolated into the kinematic regime of the CLAS12 measurements, estimates for the resonant contributions to inclusive electron scattering have been determined with small systematic uncertainties. Together these data from CLAS and CLAS12 provide important information regarding the nucleon parton distributions through the nucleon resonance region in the regime of large Bjorken scaling variable x_B, as well as detailed insight for studies of quark-hadron duality.

A complete draft of the paper intended for the publication in Phys. Rev. Lett. is prepared and was circulated in the Hadron Spectroscopy Working Group.
It will be more widely circulated within the First Experiment Group in the coming weeks for feedback.

Future plans

- Improvement of electron ID procedure;
- Introduction of fiducial cuts;
- Better understanding of detector/tracking efficiency, both from the low lumi data analysis and background merging procedure with simulation;
- Bin centering corrections;
- Improved momentum corrections;
- Better understanding of the CLAS12 resolution;
- Understanding of the simulation needs and requirements based on the pass1 dataset and OSG and/or JLAB scicomp resources;
- Application of developed procedures to the pass1 data.

Summary

- Preliminary results on the inclusive electron scattering cross section are available from the CLAS12 in the kinematic area of 1.1 GeV <W< 4.0 GeV and 1.5 GeV^2 < Q^2 < 10 GeV^2;

- The approach for the evaluation of the resonance contributions to inclusive electron scattering based on the CLAS results on $\gamma_v pN^*$ electrocouplings has been developed and applied to this dataset;

- Inclusive electron scattering data from CLAS12 and the evaluated resonant/non-resonant contributions will provide insight into the ground state nucleon PDF in the resonance region and will shed light on the onset of quark-hadron duality;

- The CLAS12 Q^2 coverage will allow for the exploration of the ground state nucleon PDF at distance-scales where the transition from strong- to pQCD is expected.

- These experimental results (based only on electron detection in the Forward Detector) and the developed physics analysis tools make this work an excellent candidate for a first publication from CLAS12.

CEBAF Large Acceptance Spectrometer

Jefferson Lab

BACKUP

- Dataset
- Data quality monitoring and run selection
- Electron ID
- Kinematical coverage and distributions
- Resolution and kinematical correction
- Simulation
- Binning
- Acceptance corrections
- Radiative corrections
- Tracking efficiency
- Empty target studies
- Faraday cup and luminosity
- Normalization
- Cross section extraction
- Cross checks
- Physics analysis and preliminary results