First CLAS12 results on inclusive electron scattering

Teleworkshop on the Strong QCD from Hadron Structure Experiments

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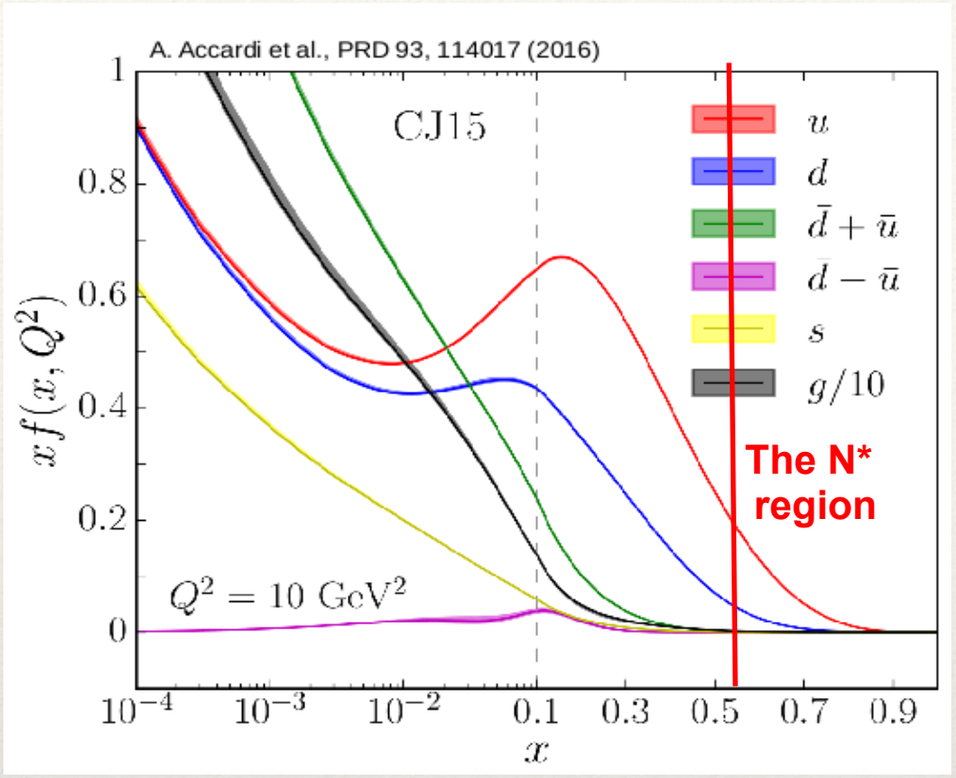
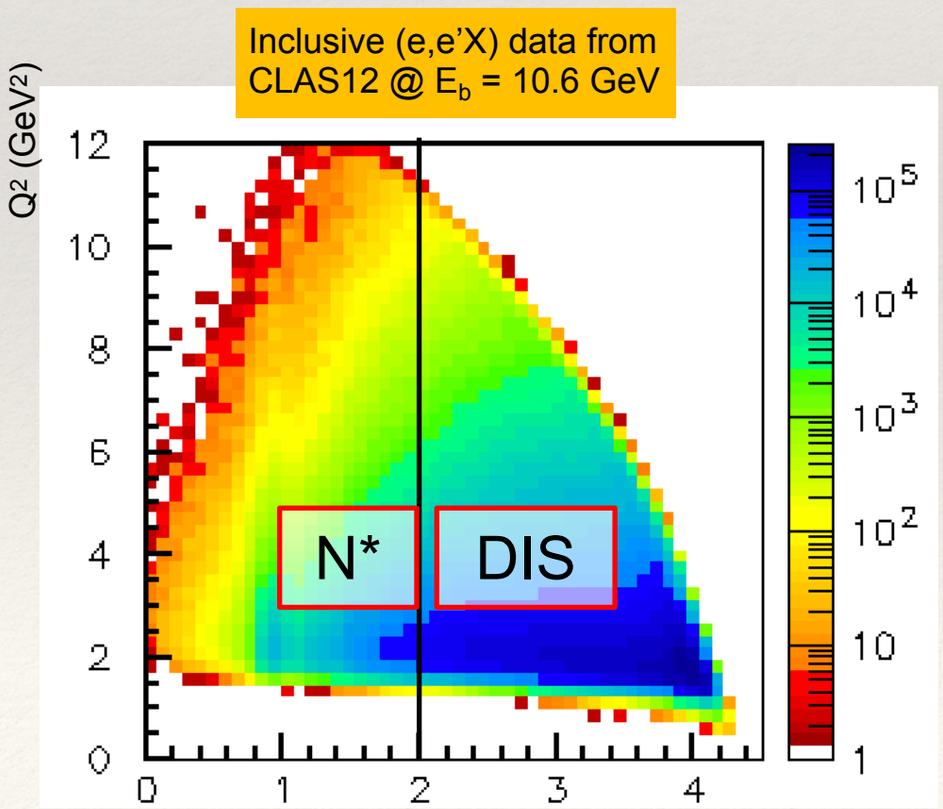
June 9, 2021

Overview

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

Extending Knowledge of the Nucleon PDF in the Resonance Region

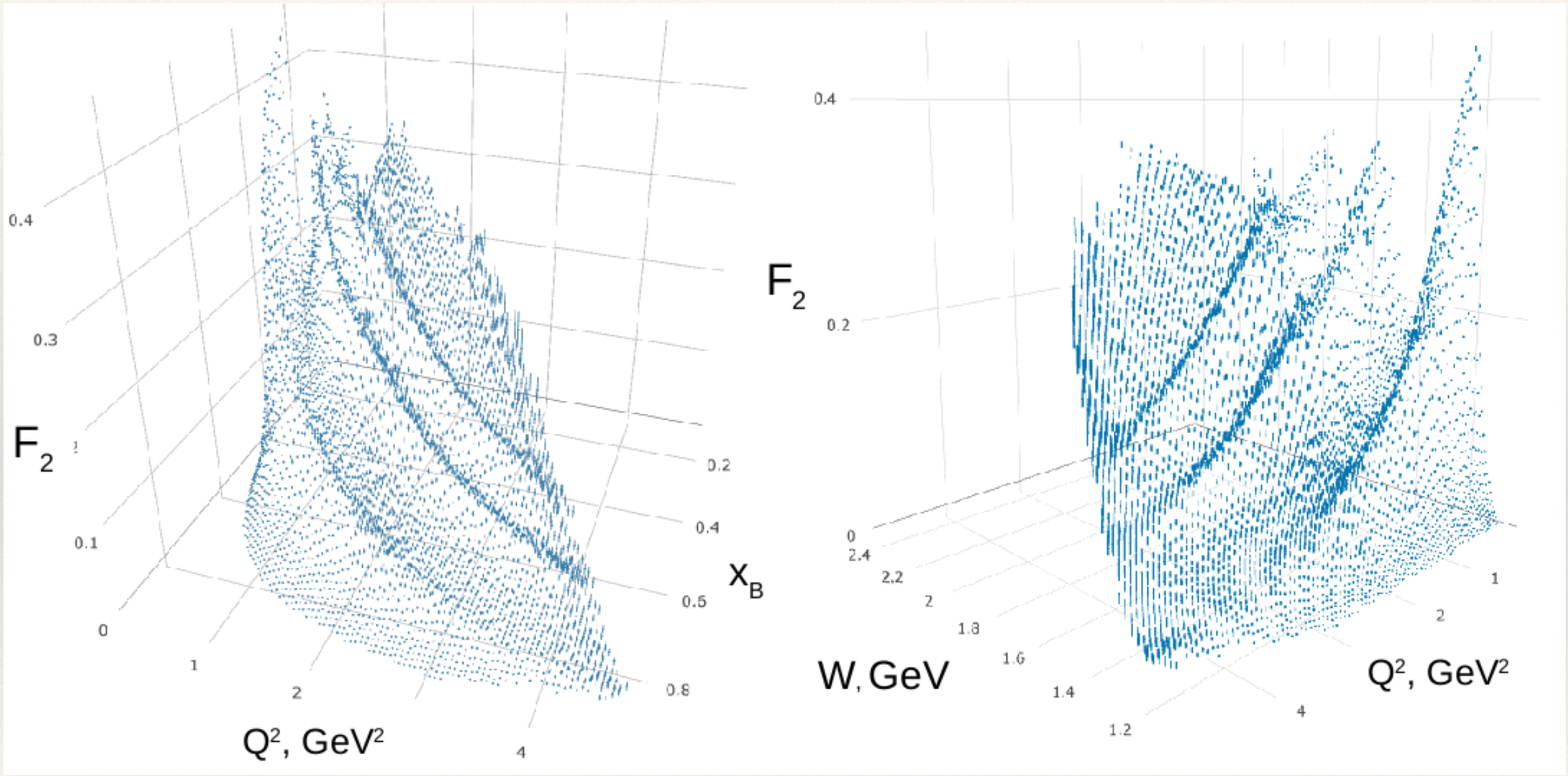




- Study of ground state nucleon PDF from inclusive electron scattering offers an effective tool for nucleon structure exploration
- The global QCD-driven analyses have provided detailed information on the quark and gluon PDFs in a wide range of Bjorken variable x_B from 10^{-4} to ~0.9 and at photon 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

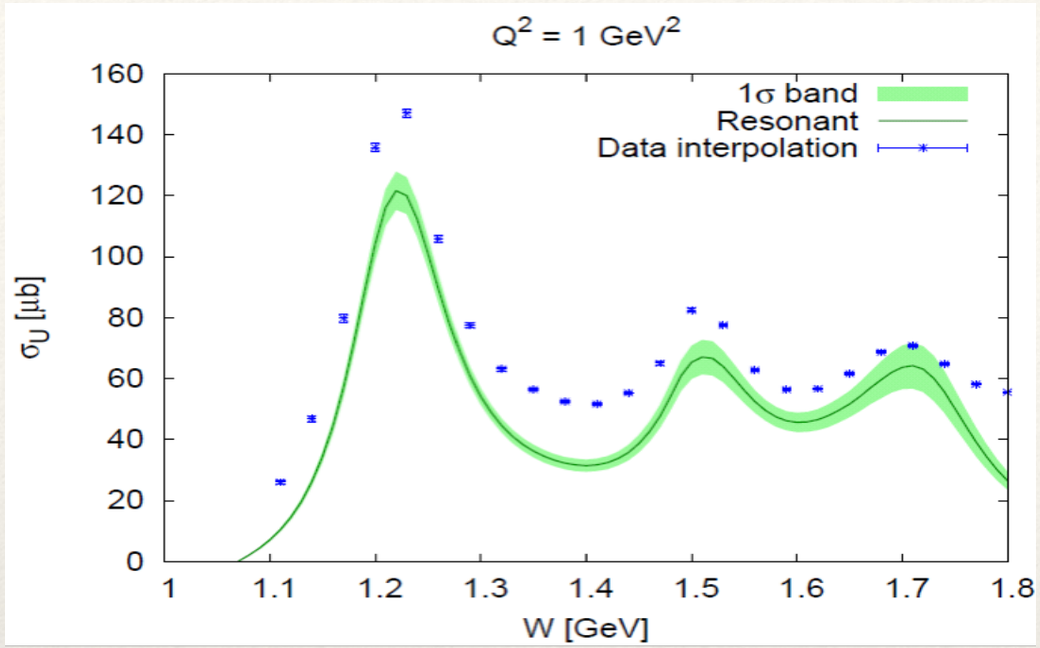
The F_2 structure function was measured with CLAS in the N* region with large coverage over x_B/W as a function of Q^2

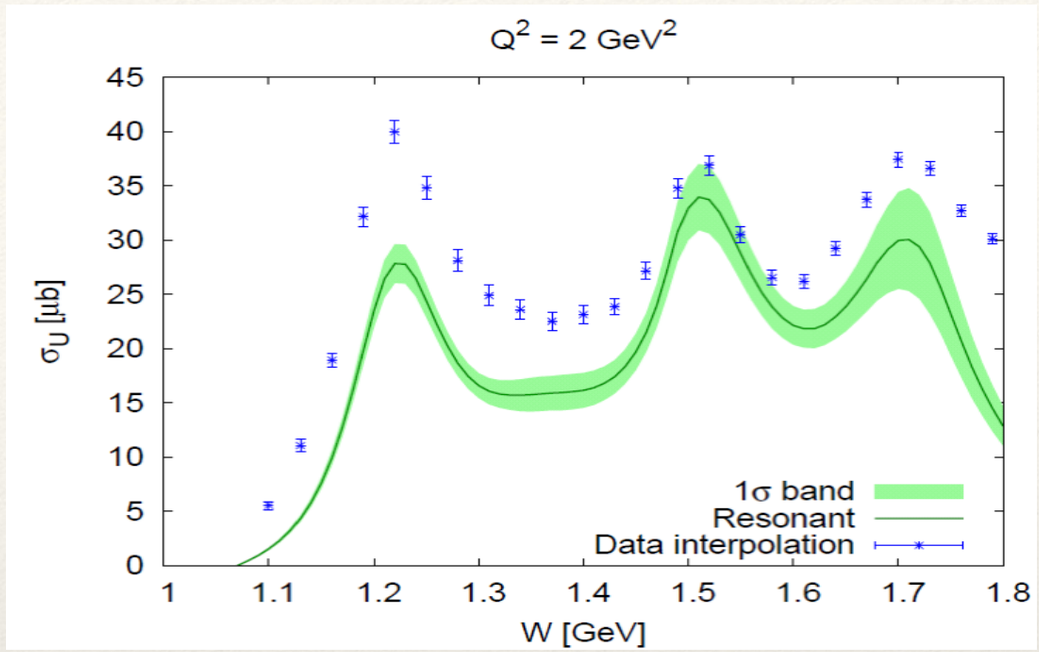


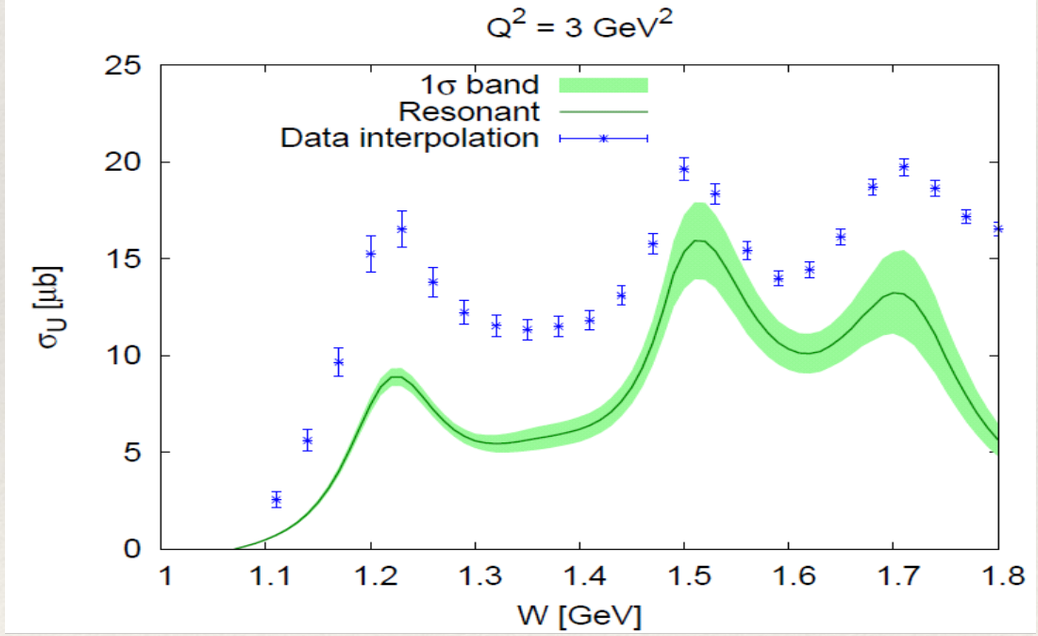
Three pronounced resonance structures are evident

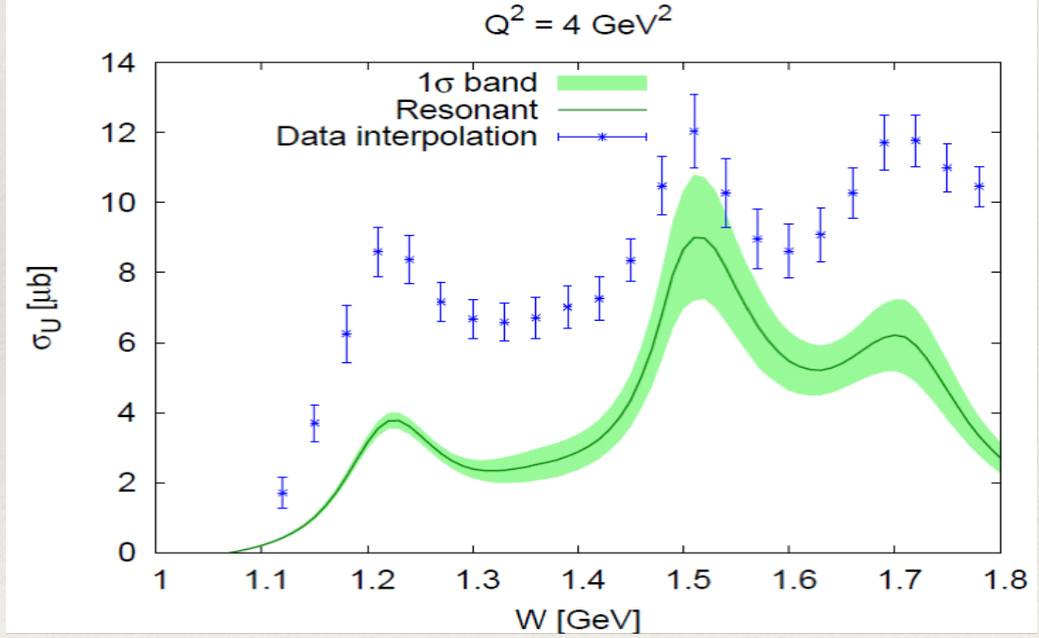
M. Osipenko *et al.*, *(CLAS Collaboration)*, Phys. Rev. D 67, 092001 (2003)

Resonance Contributions into the Virtual Photon Cross Sections





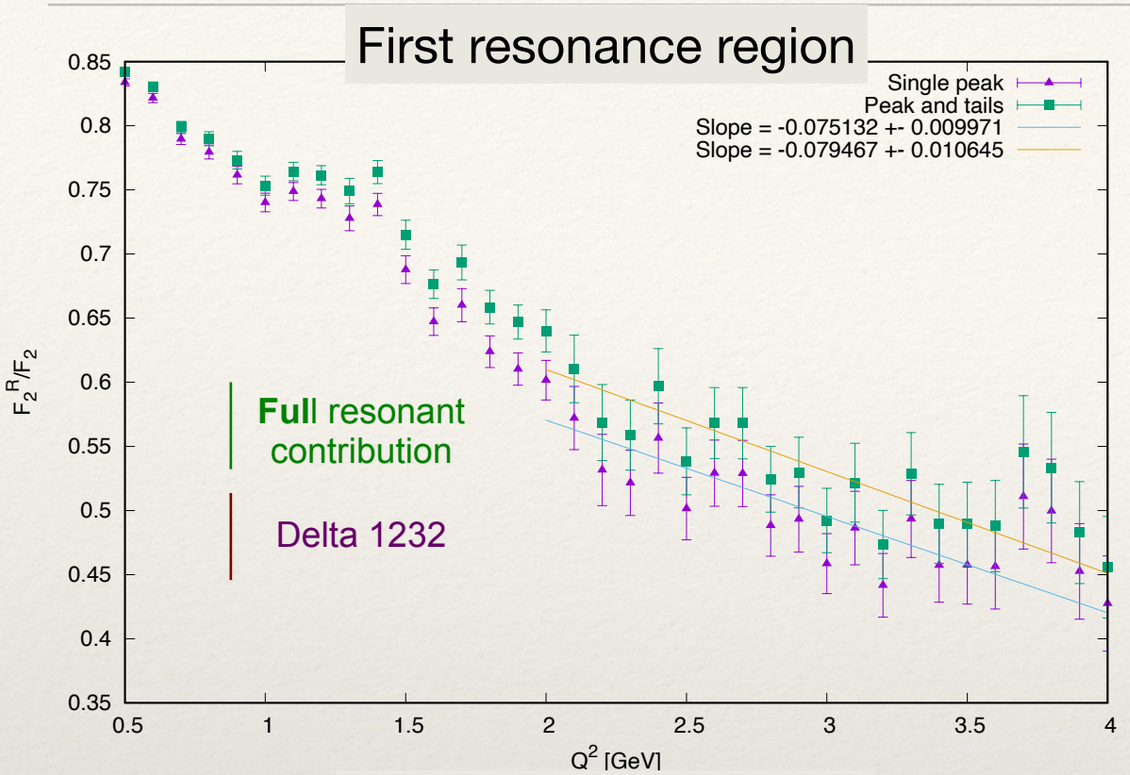


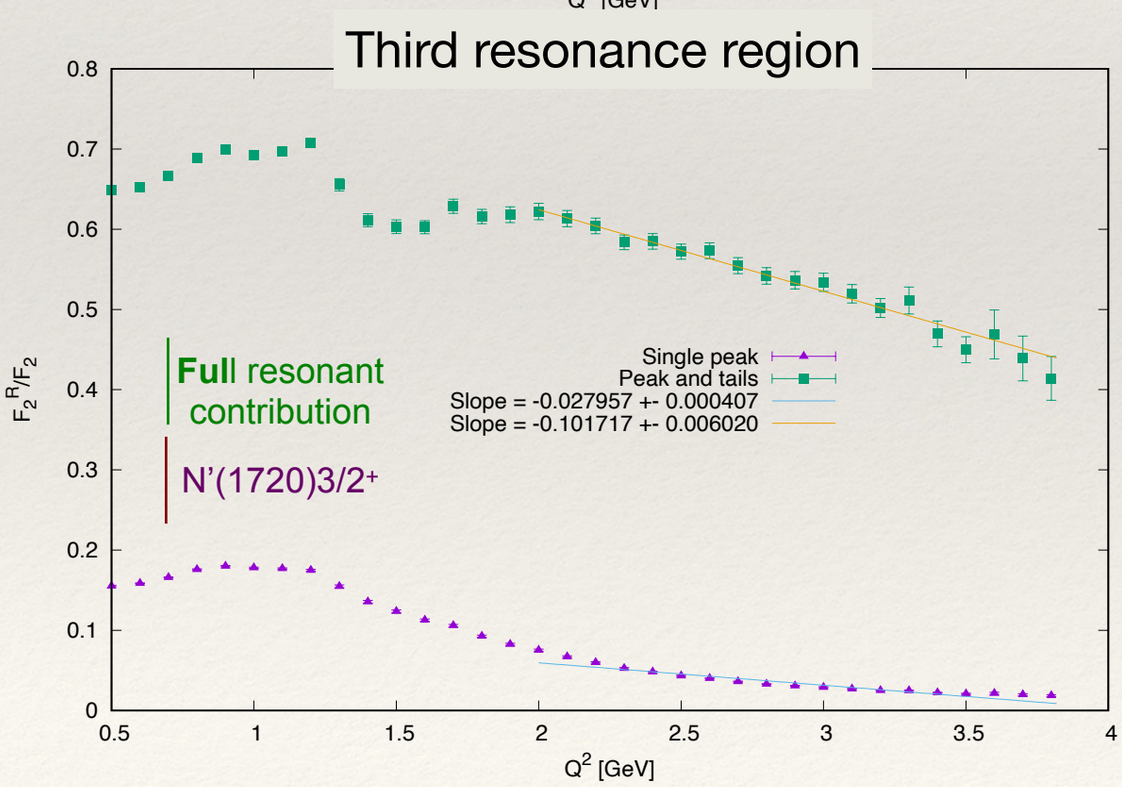


For the first time the resonant contributions were evaluated from the experimental results on the $\gamma_v pN^*$ electrocouplings from CLAS at W<1.8 GeV

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

Resonant Contributions into Inclusive Electron Scattering from the JLab Data



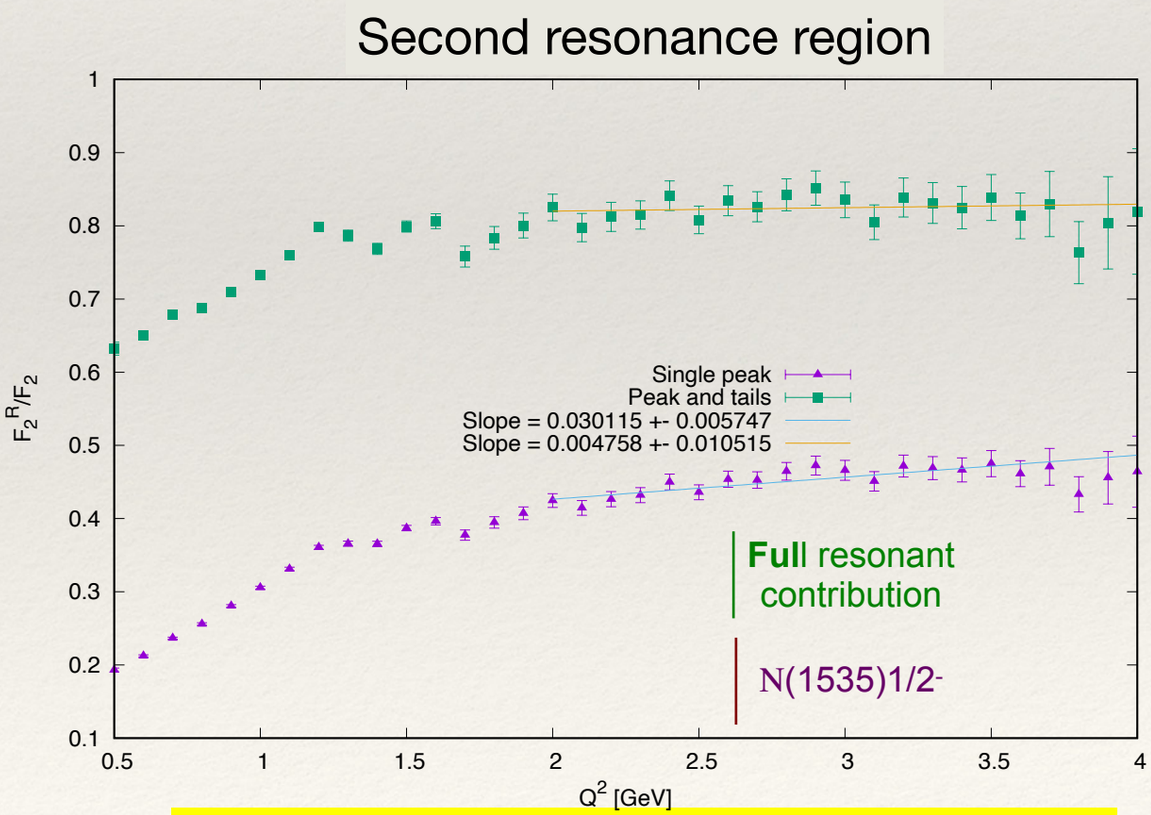


New N' (1720)3/2+ state has been recently observed:
V.I.Mokeev et al, Phys.Lett B 805,13457 (2020).

Resonance contribution into F2 structure function

- Significant (>40%) resonant contributions at Q^2<4.0 GeV^2 in the region of W<1.8 GeV
- Very different Q^2 evolution of the resonant contributions

see the talk by A.N. Hiller-Blin for details



A.N. Hiller Blin, et al
JPAC,Theory and Physics Div. 2105.05834 [hep-ph]

Jefferson Laboratory

CLAS12

10.6 GeV electron beam
5 cm liquid hydrogen target

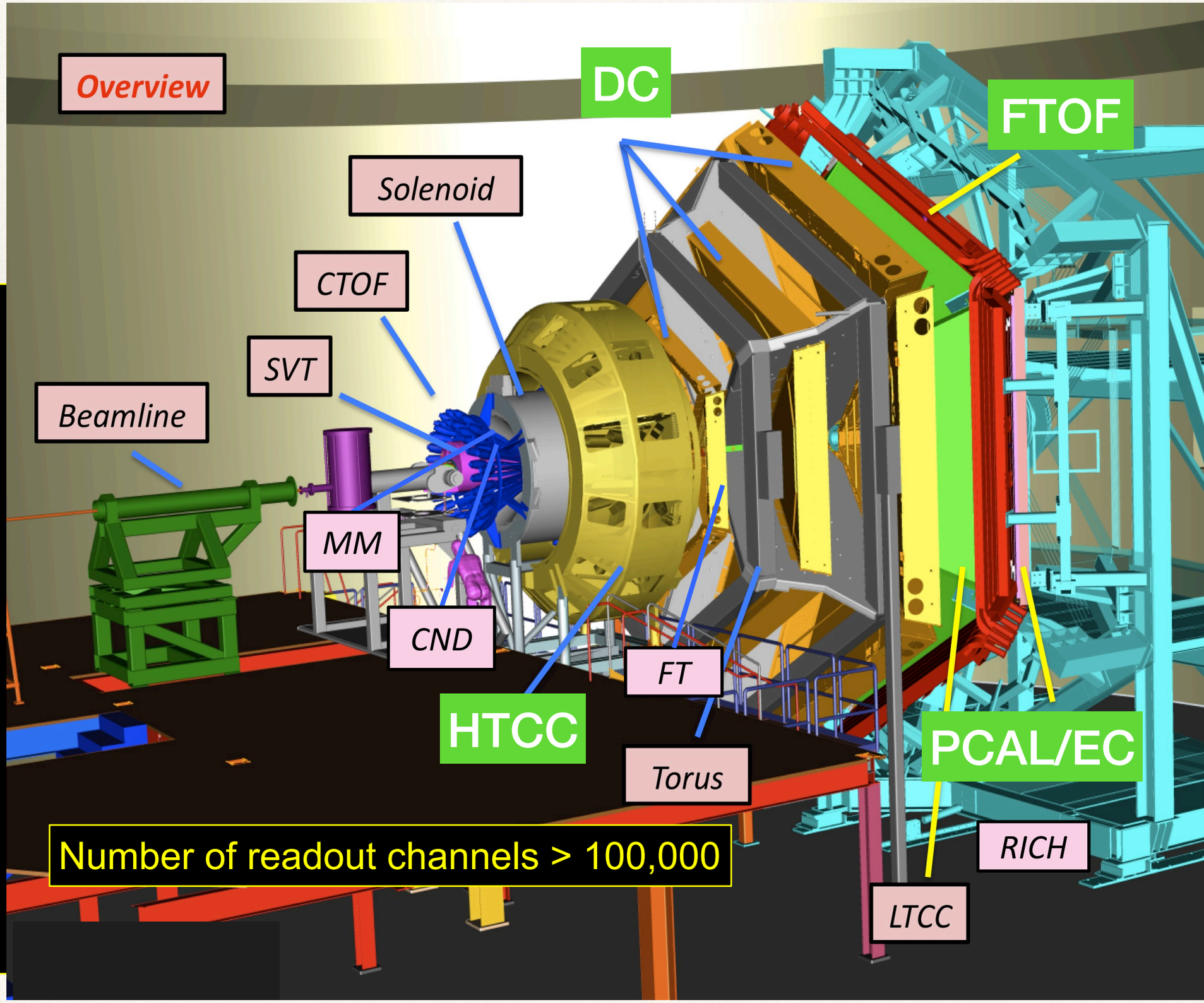
Electron ID

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



Experimental program

- **Run Group A**:
  - 13 experiments
  - 10.2-10.6 GeV polarized electrons
  - Liquid-hydrogen target
  - ~300 mC, ~50% of approved beam time

- **Run Group K**:
  - 3 experiments
  - 6.5, 7.5 GeV polarized electrons
  - Liquid-hydrogen target
  - ~45 mC, ~12% of approved beam tim

- **Run Group B**:
  - 7 experiments
  - 10.2-10.5 GeV polarized electrons
  - Liquid-deuterium target
  - ~155 mC, ~43% of approved beam time

- **Run Group F (BONUS)**:
  - 1 experiment
  - 10.2 GeV polarized electrons (+2.2 GeV for calibration)
  - Gas-deuterium target +RTPC
  - ~92% of approved beam time

Credit: M. Battaglieri

RGA, overview

The CLAS12 RG-A experiments were designed to perform complementary measurements to study proton structure for both the ground and excited states, 3D imaging, and gluonic excitations with the core mission to understand the manner in which the constituents of protons are held together by the strong force and the emergence of the dominant part of hadron mass.

RG-A is composed of 13 experiments driven by an international collaboration grouped in 5 categories:

1. **Deep Exclusive Processes (E12-06-119, E12-06-108 and E12-12-00):** *Study of Generalized Parton Distributions (GPDs), (2 +1)-D imaging of the proton and the study of its gravitational and mechanical structure*
2. **Deep inclusive & SIDIS (E12-06-112, E12-06-112A and E12-06-112B):** *Study of the Transverse Momentum Distributions (TMDs) and the 3D structure in momentum space*
3. **Nucleon structure (E12-09-003, E12-06-108A, E12-06-108B)**: *Study of nucleon resonance structure at Q^2 from 2.0 to 12 GeV^2*
4. **Quasi photo-production (E12-12-001 and E12-12-001A):** *Study of J/ψ photoproduction, LHCb pentaquarks, and Time-like Compton Scattering*
5. **MesonX program (E12-11-005 and E12-11-005A)**: *Study of meson spectroscopy in search for hybrid mesons*

Credit: Latifa Elouadrhiri

RGA, publications

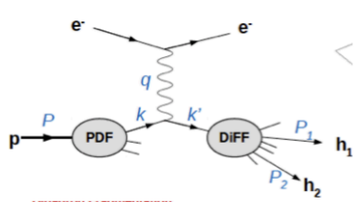
CLAS12 publications

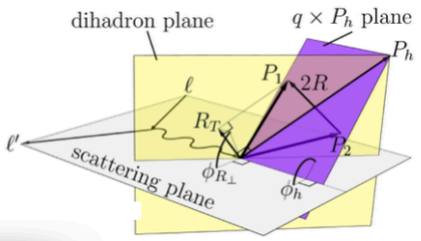

Observation of Beam Spin Asymmetries in the Process $ep \to e'\pi^+\pi^- X$ with CLAS12

ACCEPTED by PRL

First Observation of Beam Spin Asymmetries in the Process
e p → e' π⁺ π⁻ X with CLAS12

- SIDIS ingredients: q in the nucleon (PDF), hadronization (Fragmentation Functions)
- Fragmentation in 2h is sensitive to *several* TMDs and Dihadron Fragmentation Functions (DiFFs)
- Spin-momentum correlations in hadronization
- Access to PDF e(x) (transv polarized q in a unp nucleon, tw-3) and Dihadron FF G1-perp (helicity of fragmenting q)
- Complement single-hadron SIDIS, with the advantage of another degree of freedom





$$A_{LU} = \frac{1}{P_{\text{beam}}} \frac{N^+(\phi_h, \phi_{R_\perp}) - N^-(\phi_h, \phi_{R_\perp})}{N^+(\phi_h, \phi_{R_\perp}) + N^-(\phi_h, \phi_{R_\perp})} = A_{LU}^{\sin(\phi_h - \phi_{R_\perp})} \sin(\phi_h - \phi_{R_\perp}) + A_{LU}^{\sin(\phi_{R_\perp})} \sin(\phi_{R_\perp}),$$

- Ph = P1 + P2 pions 3-mom
- RT is the component of R perpendicular to Ph

$$\boldsymbol{R}_T = \left(z_2 \boldsymbol{P}_1^\perp - z_1 \boldsymbol{P}_2^\perp\right)/z$$

- Φh = azimuthal angle of q × Ph plane
- ΦR⊥ = azimuthal angle of di-hadron plane

CLAS12 publications

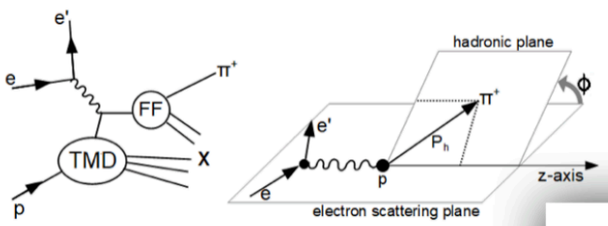

First multidimensional, high precision measurements of semi-inclusive π^+ beam single spin asymmetries from the proton over a wide range of kinematics

Submitted to PRL

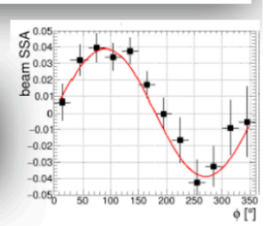
First multidimensional, high precision measurements of semi-inclusive π⁺ beam single spin asymmetries from the proton over a wide range of kinematics

- So far, good mapping of 1D PDF (longitudinal momentum dependence)
- Are the q carrying an orbital angular momentum? how is it connected to the spin of the nucleon? q correlations?
- 3-D structure accessed trough Transverse Momentum dep. Distributions (TMDs)
- Semi Inclusive DIS (SIDIS) to study the transverse structure of the nucleon
- Single Spin Asymmetries (SSA) sensitive to TMDs and Fragmentation Functions (FF)
- Beam SSA: twist-3, subleading, O(M/Q), accessible in fixed target, medium energy (~10 GeV) experiments

$$SSA(z, P_T, \phi, x_B, Q^2) = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{A_{LU}^{\sin\phi} \sin\phi}{1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos 2\phi} \cos 2\phi},$$



$$A_{LU}^{\sin\phi} = \frac{\sqrt{2\epsilon(1-\epsilon)}\, F_{LU}^{\sin\phi}}{F_{UU,T} + \epsilon F_{UU,L}},$$



- x_B = proton momentum fraction carried by the struck q
- z = γ_ν energy fraction carried by π
- PT = π transverse momentum
- F_{LU} = q-g correlation (genuine tw-3) = Convolution {Collins, Boers-Mulders, tw-3 TMD pol and unpol FF}

Beam Spin Asymmetries, not the cross sections measurements

Credit: M. Battaglieri

Analysis schema

- Measuring cross section:
  - Dataset
  - Kinematic coverage and binning
  - Channel ID (inclusive electron)
  - Simulation
  - Efficiency and acceptance correction (via GEANT4 simulation)
  - Luminosity correction
  - Radiative correction

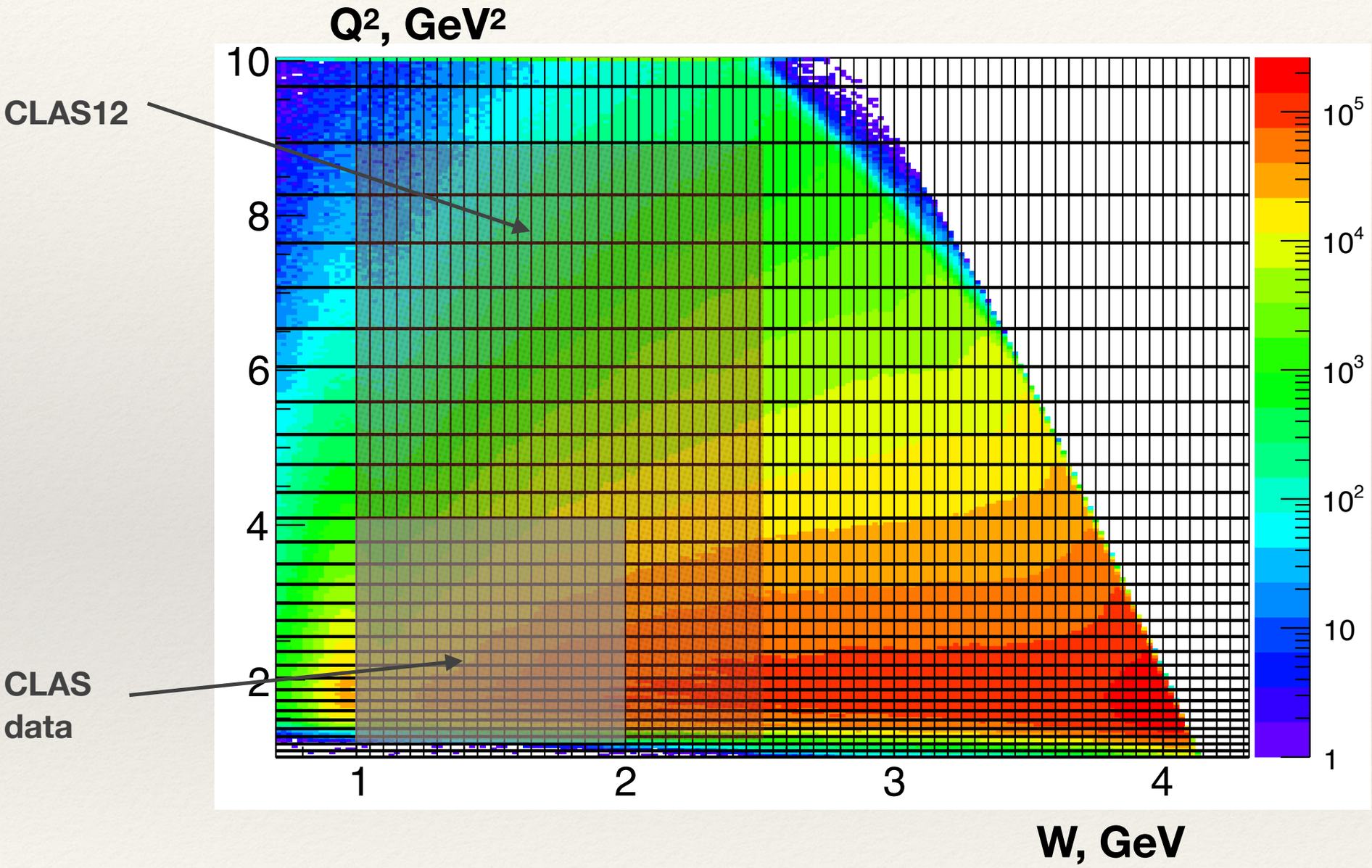
Dataset

- RGA Fall 2018
- 10.6 GeV electron beam
- Torus -100%
- Solenoid -100%
- 5 cm liquid hydrogen target
- Integrated charge 30 mCl

Kinematic Coverage and Binning

Equidistant W, log in Q^2

Substantial extension in kinematic coverage over Q^2 and W

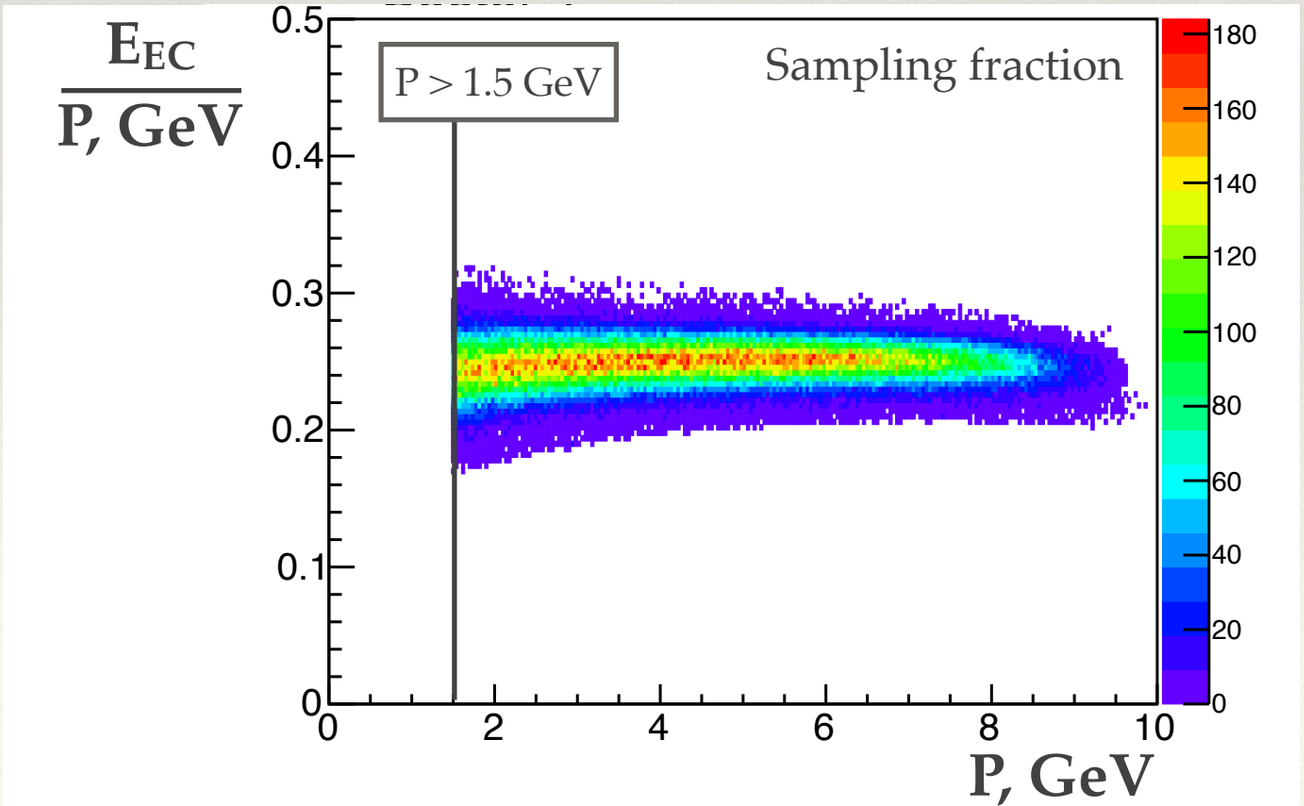


- Reasonable and comparable statistics in all Q^2 bins;
- Sufficient statistics in all (W,Q^2) bins for evaluation of inclusive cross section with the statistical accuracy of few percents
- Measurements cover both resonance and DIS regions

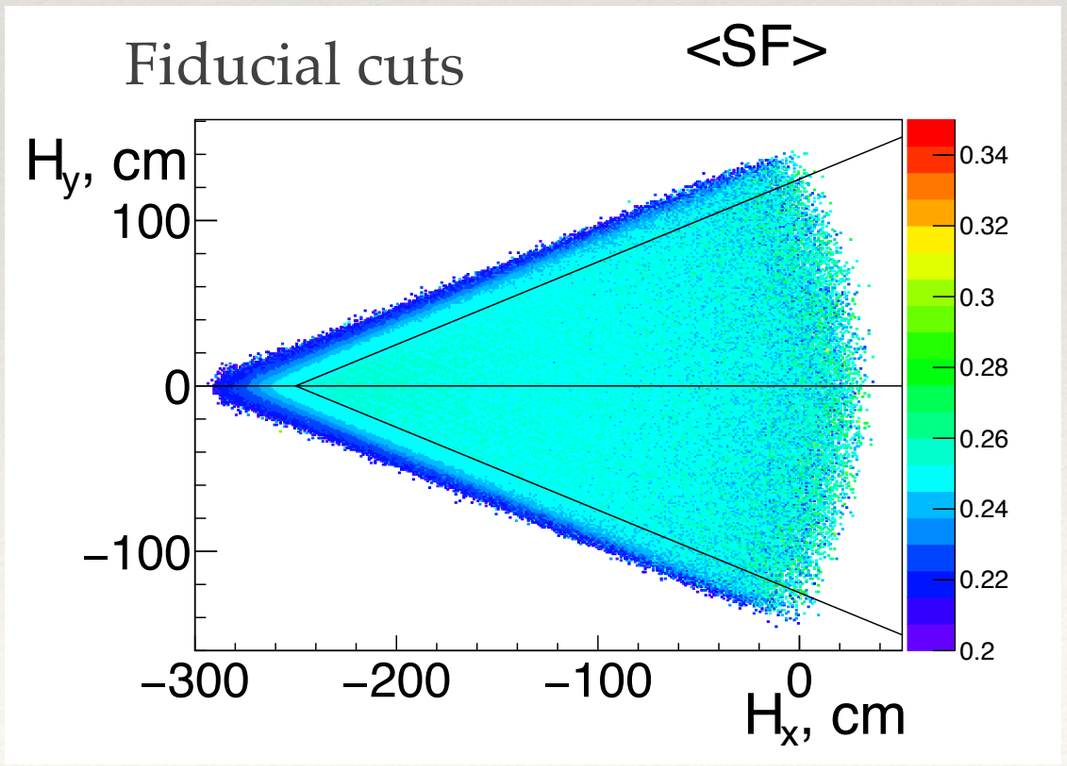
Electron ID

- Limited to Forward Detector (5 -35 degrees coverage in polar angle)
- Electrons are selected by the CLAS12 Event Builder
  - Negative track in **DC** with a hit in **TOF**, **ECAL** and **HTCC**;
  - 2.0 photoelectrons in HTCC;
  - 60 MeV in PCAL;
- Additional cuts:
  - 3σ cuts on a parameterized momentum-dependent sampling fraction;
  - Vertex cut;
  - P > 1.5 GeV;
  - PCAL fiducial cut in coordinates from tracking system.

MC

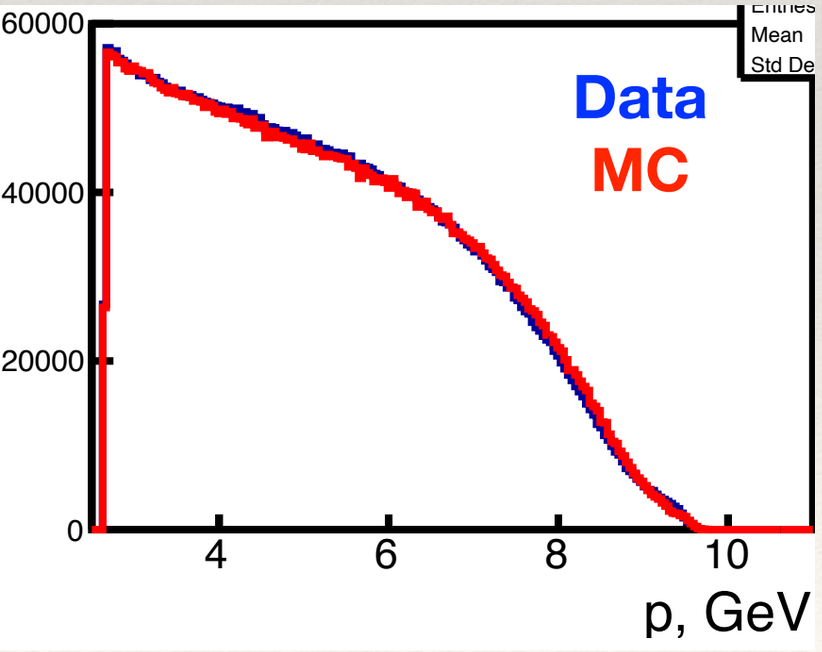


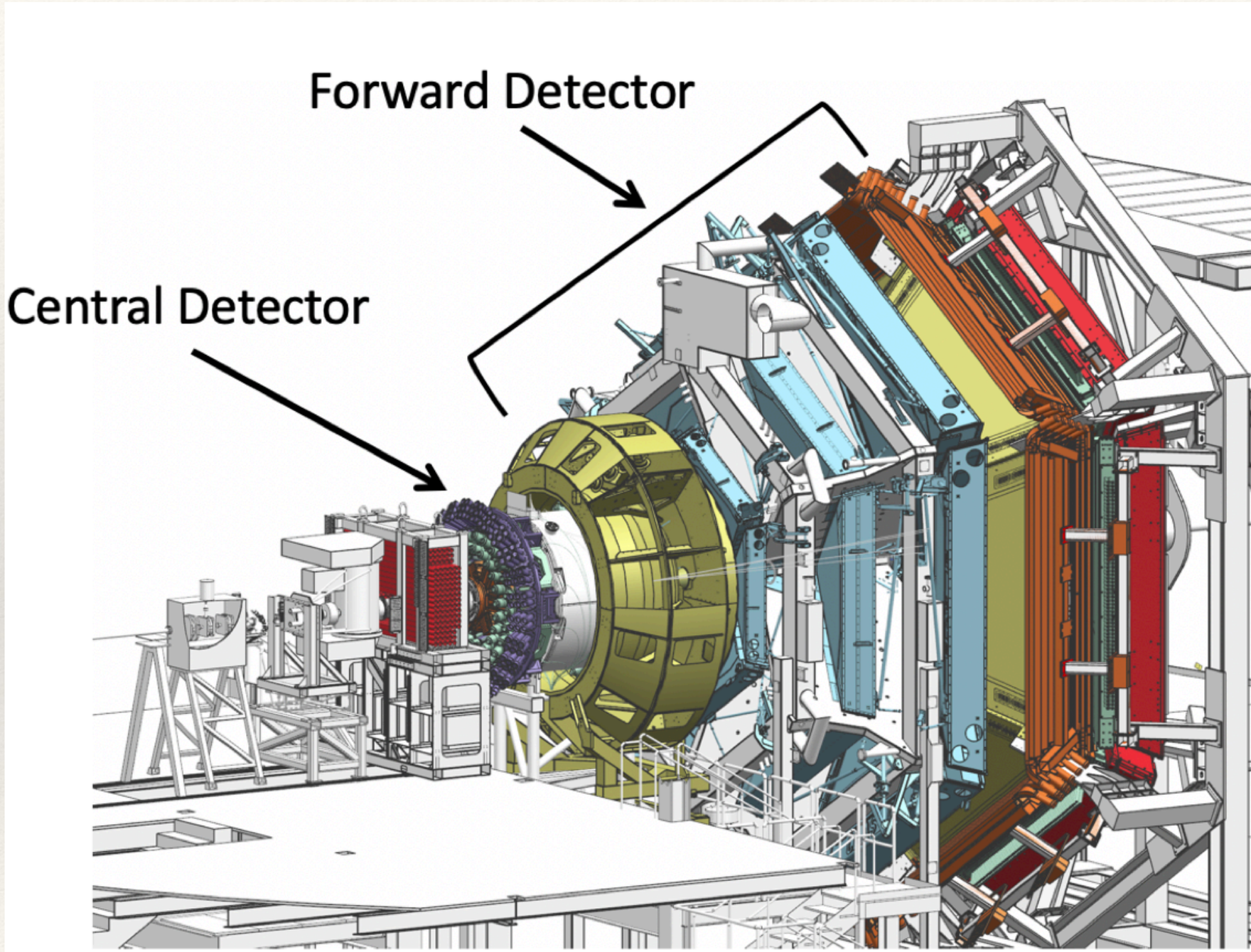
MC



CLAS12 simulation

- The Geant4 Monte-Carlo (GEMC) package is used to simulate the passage of particles through the various CLAS12 detectors
- Same reconstruction algorithms used for the data and simulation
- Allows to account for both
  - geometrical acceptance and
  - efficiencies
- Requires reliable event generator capable to reproduce real worlds event distribution





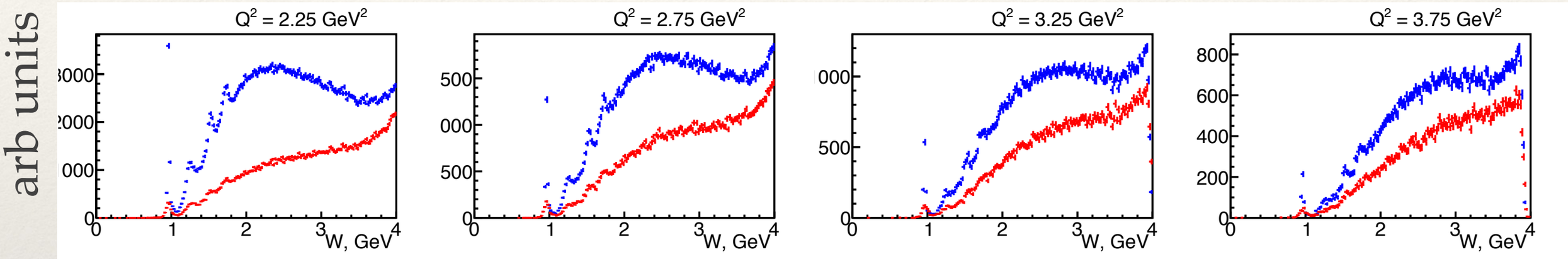
Acceptance and Luminosity Corrections

Generated events

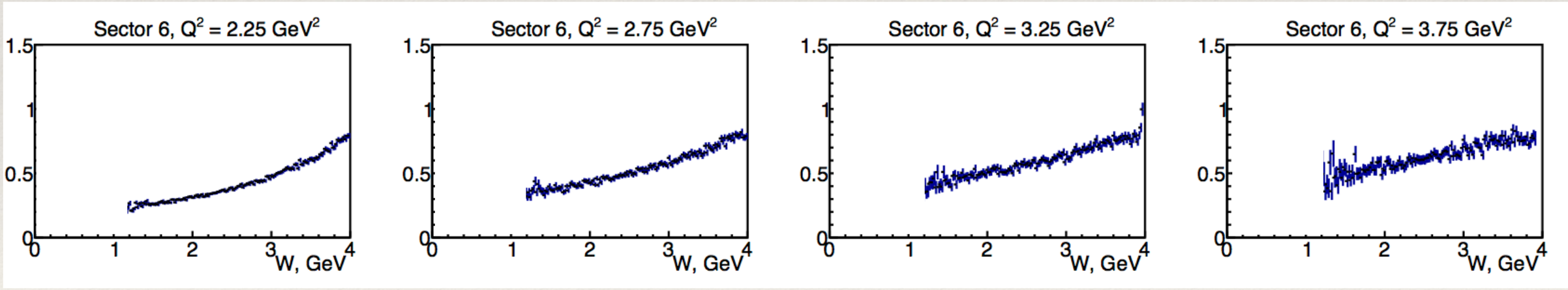
Reconstructed simulation events

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

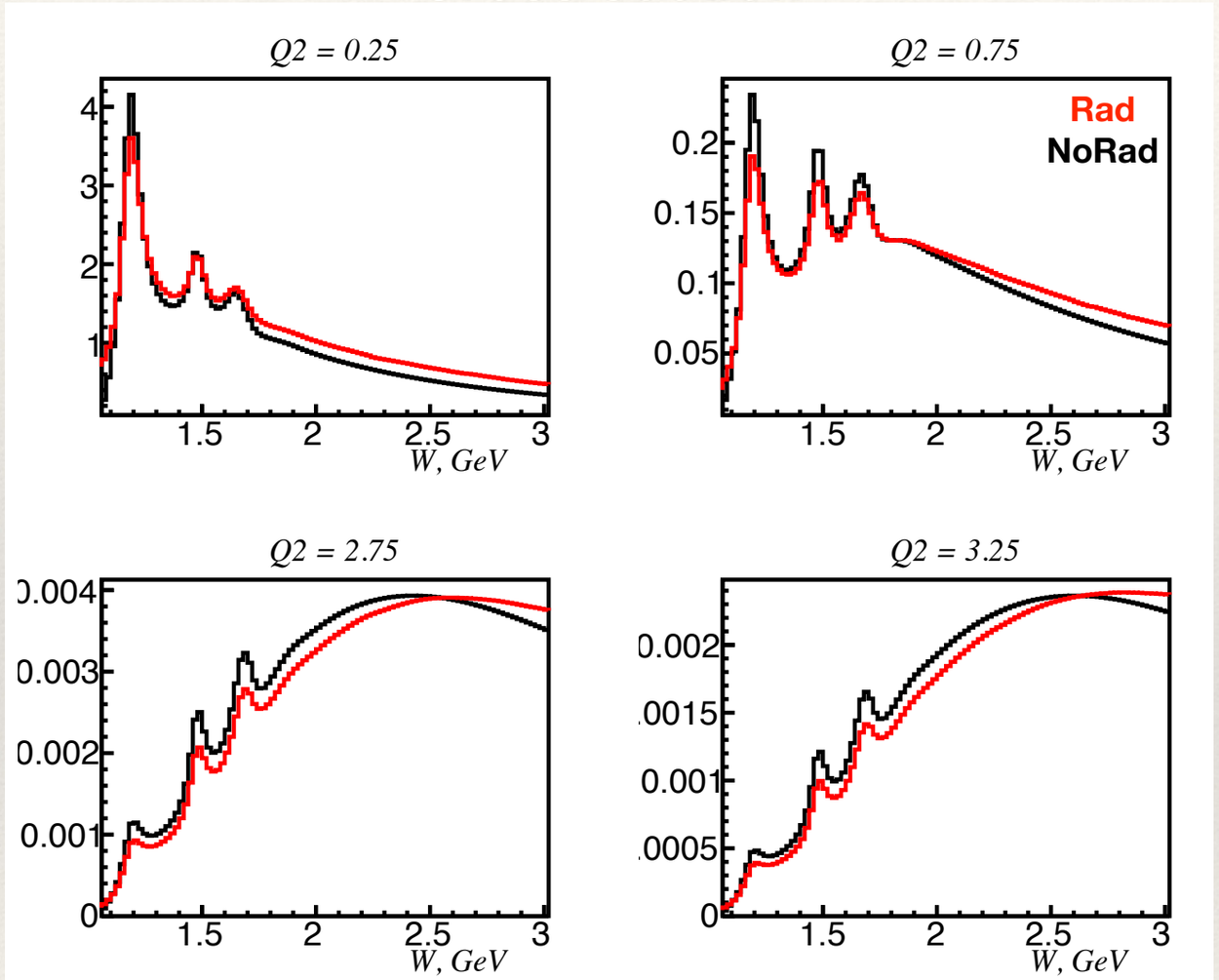
Luminosity Correction

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.

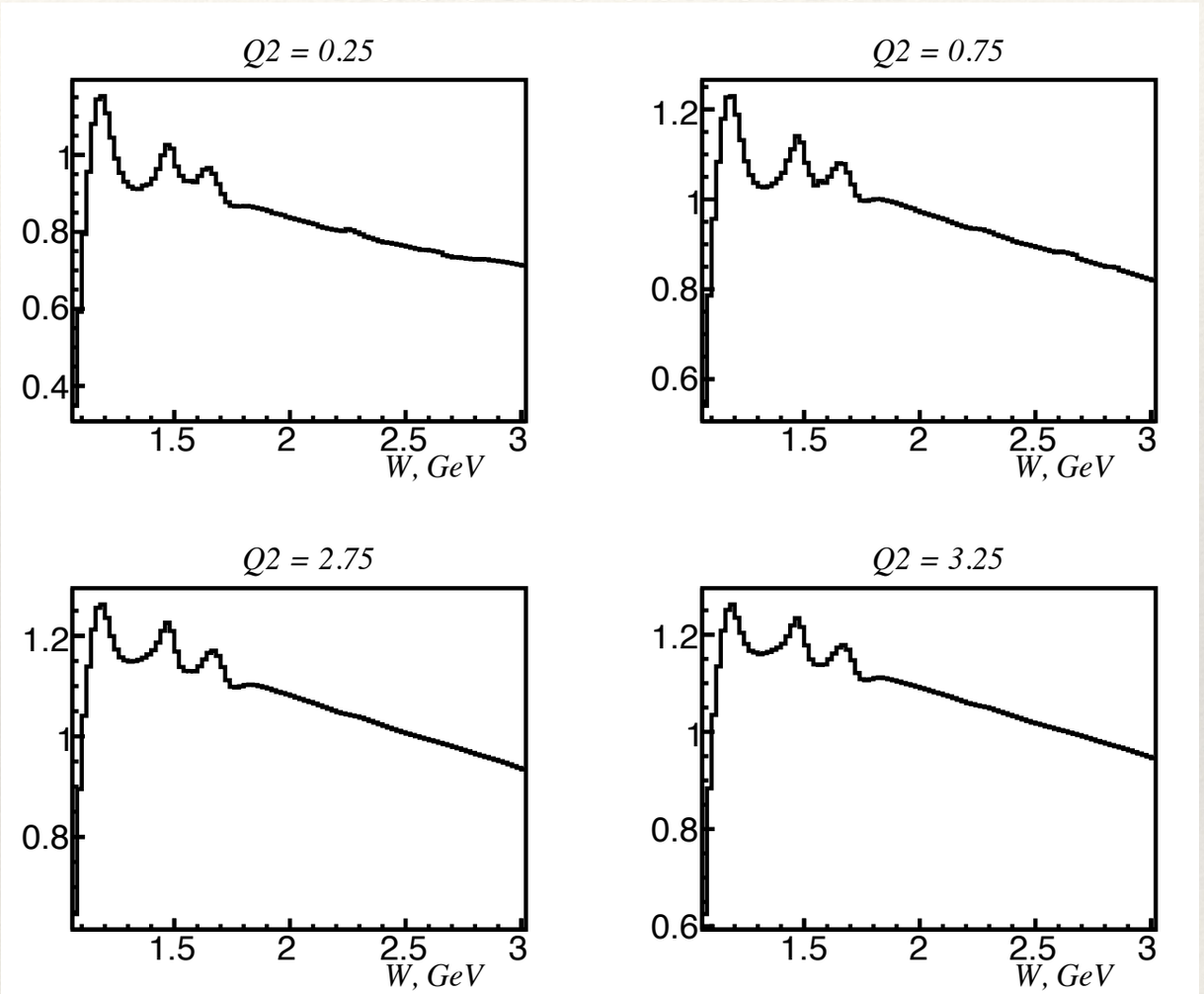
Radiative corrections

Based on the inclusive event generator developed using the Mo and Tsai formalism for the radiative effects

Cross section



Radiative correction

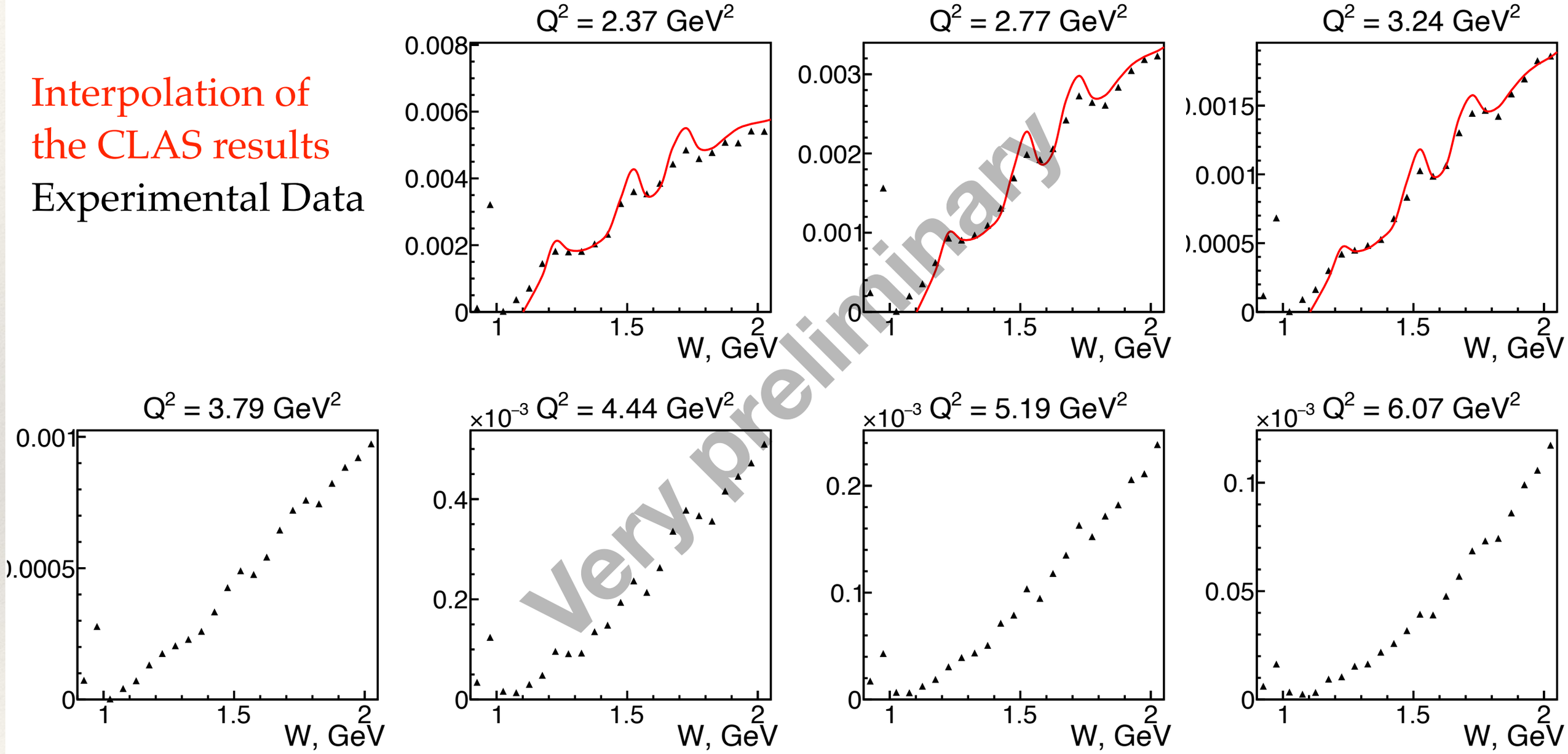


- Sample for several Q^2 bins;
- Radiative correction is obtained as a ratio of radiated to nonradiated cross sections in the W and Q^2 bins of interest;

Results

Interpolation of the CLAS results

Experimental Data

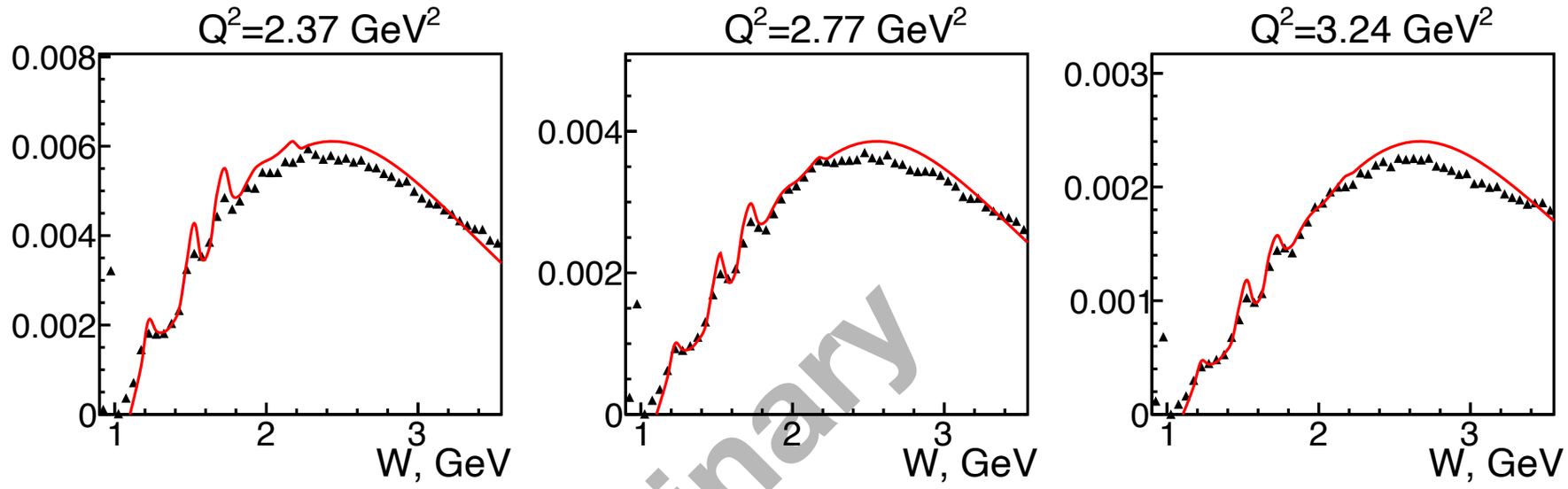


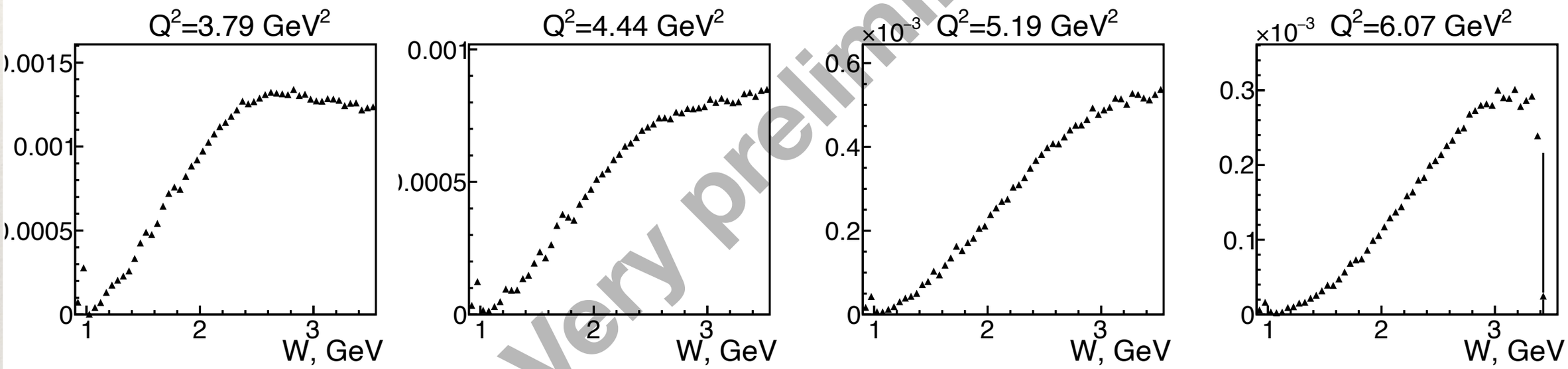
- Luminosity and acceptance corrected yield with radiative corrections.
- Consistent with CLAS/world (e,eX') data parameterization within 10%.

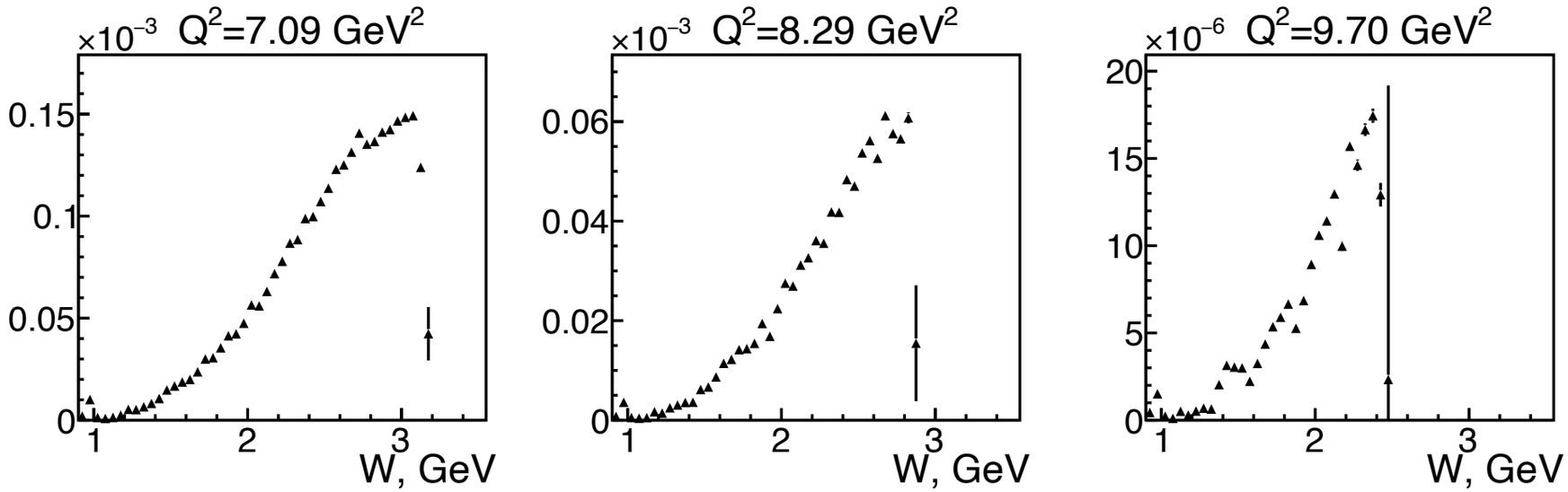
Results

Interpolation of the CLAS results

Experimental Data







Future plans

- Improvement to electron ID procedure
- Better understanding of detector/tracking efficiency
- Better understanding of the CLAS12 resolution
- Improvement of simulation
- Systematics studies

Conclusion and outlook

- Preliminary results on the acceptance corrected and luminosity normalized yields of inclusive electron scattering events have become available from CLAS12 in the range of 1.1 GeV <W<2.5 GeV at Q^2 at 2.0 GeV^2 <Q^2<9.0 GeV^2;
- The shapes of the W-dependencies of the event yields are in a reasonable agreement with the those obtained from the interpolation of the CLAS/world data on inclusive electron scattering;
- At Q^2 < 3.5 GeV^2 our preliminary results are consistent with the available data within~10%
- The near term efforts are focused on the extraction of the inclusive electron scattering cross section with detailed studies of normalization and electron detection efficiency of particular importance for the semi-inclusive and fully exclusive cross section measurements with the CLAS12;
- The developed approach for evaluation of the resonant contributions into inclusive electron scattering from the CLAS results on the γ_vpN* electrocouplings opens up new opportunities for gaining insight into the ground state nucleon PDF at large x_B and for the studies of quark-hadron duality.

CEBAF Large Acceptance Spectrometer

Jefferson Lab