Towards a combined analysis of inclusive/exclusive electroproduction

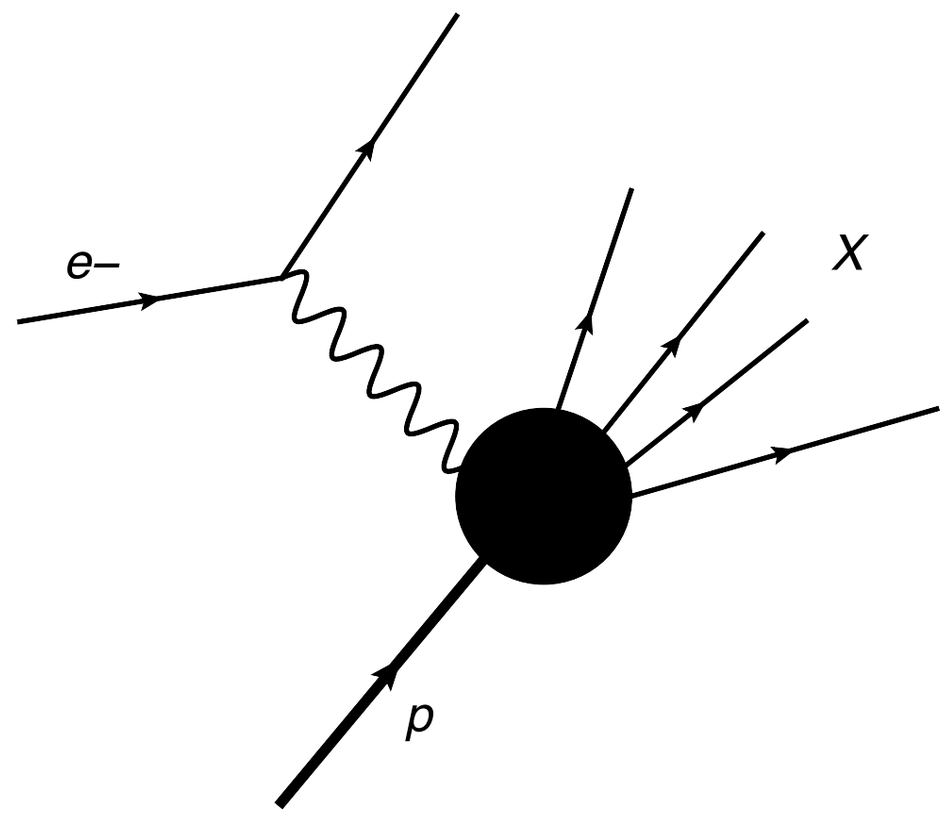
Astrid N. Hiller Blin
in collaboration with
Mainz Institute for Nuclear Physics
and Hall B

arXiv:1904.08016 [hep-ph]

NStar2019

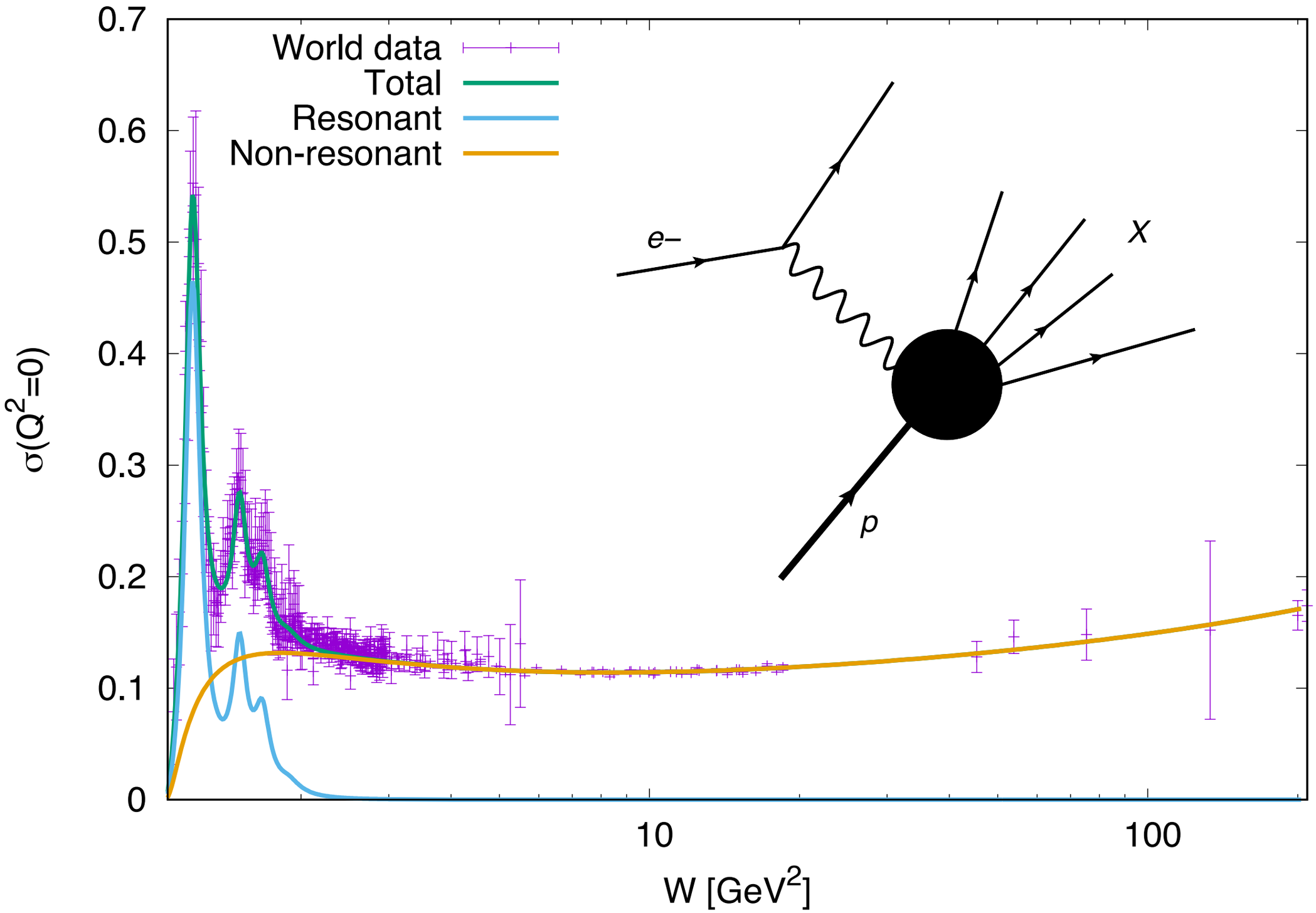
2019-06-12

Nucleon excitation structure

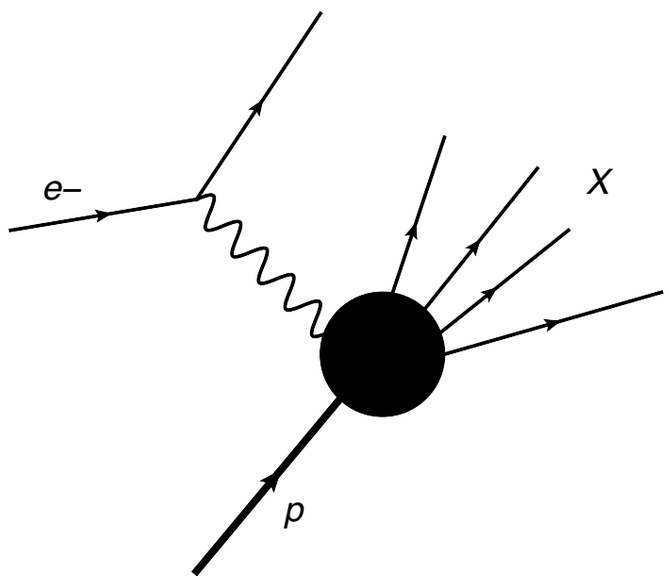


Nucleon excitation structure

Photoproduction σ_T



Inclusive electron scattering



$$F_1 \propto \sigma_T(W, Q^2)$$

$$F_2 \propto \sigma_T(W, Q^2) + \sigma_L(W, Q^2)$$

$$\sigma_U(W, Q^2) = \sigma_T(W, Q^2) + \epsilon_T \sigma_L(W, Q^2)$$

- Gives access to structure functions
- Here: unpolarized structure functions
- Related to forward virtual Compton scattering (VVCS) amplitudes

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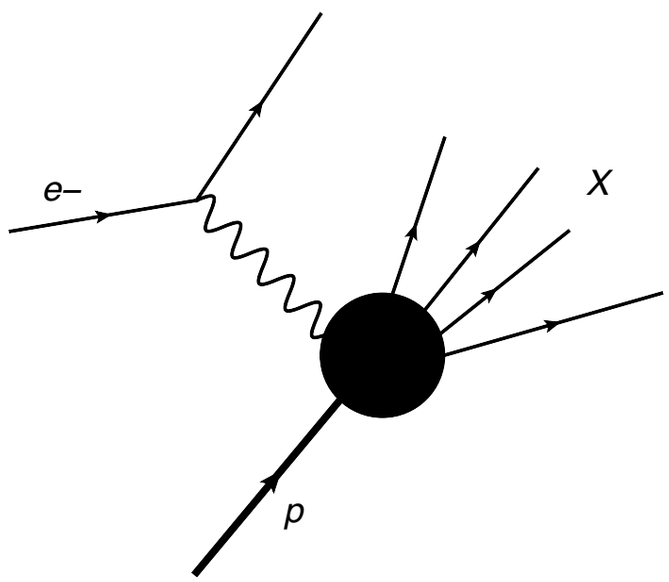

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$$\Im T_1(\nu, Q^2) = \frac{\pi\alpha}{M} F_1(\nu, Q^2)$$

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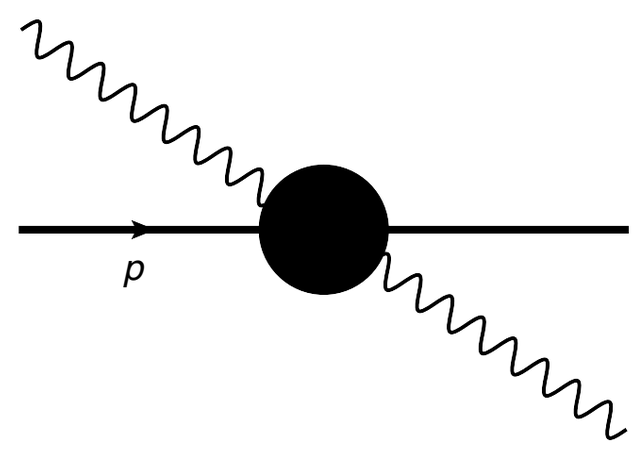

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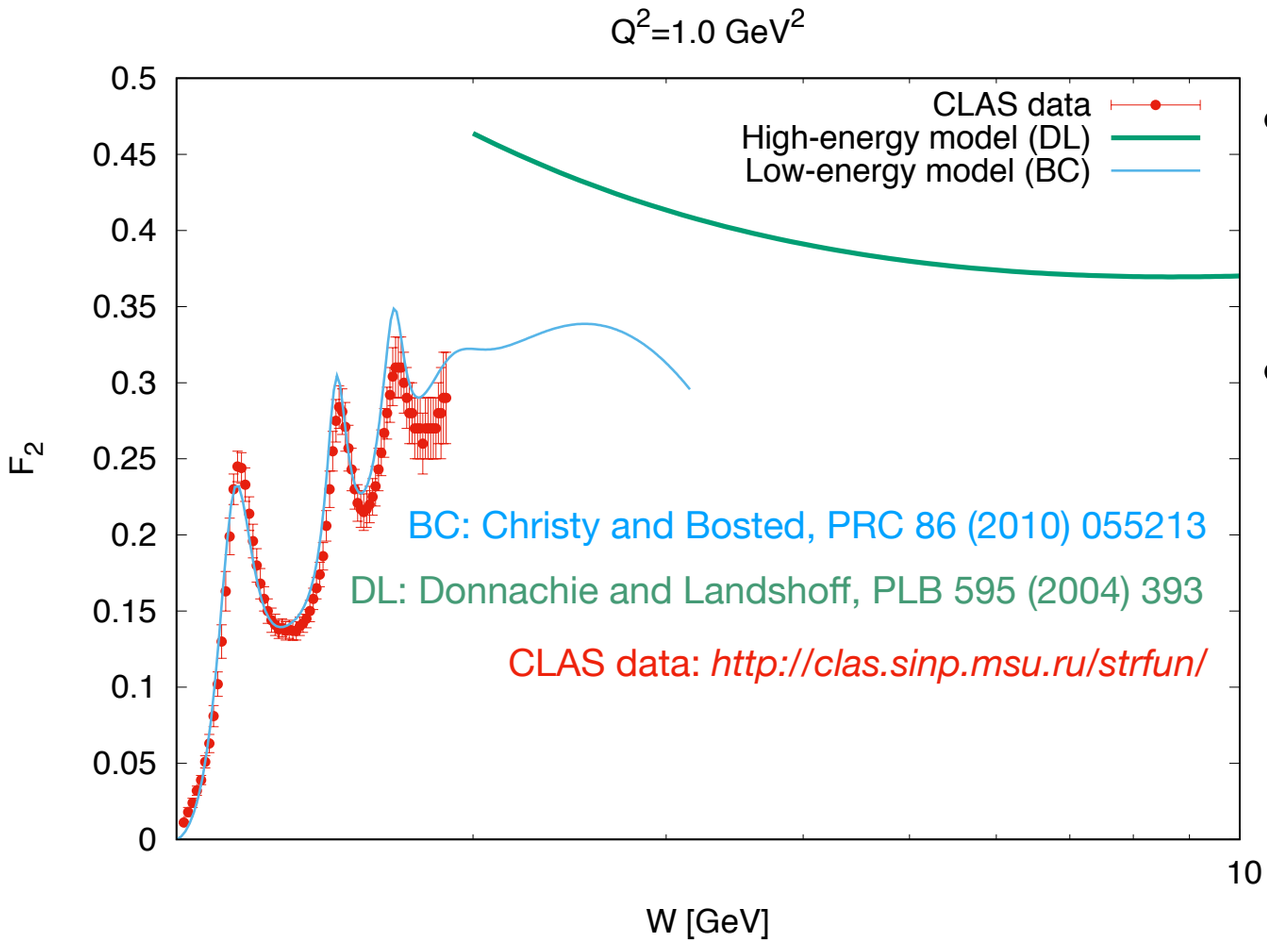
Inclusive data and models on the market



- **At low energies: precise CLAS data**
  Well covered up to 3rd resonance regime: towards parton distributions at large x
- CLAS12 is to reach
  $0.05\ \mathrm{GeV}^2 < Q^2 < 12\ \mathrm{GeV}^2$, W up to 4 GeV

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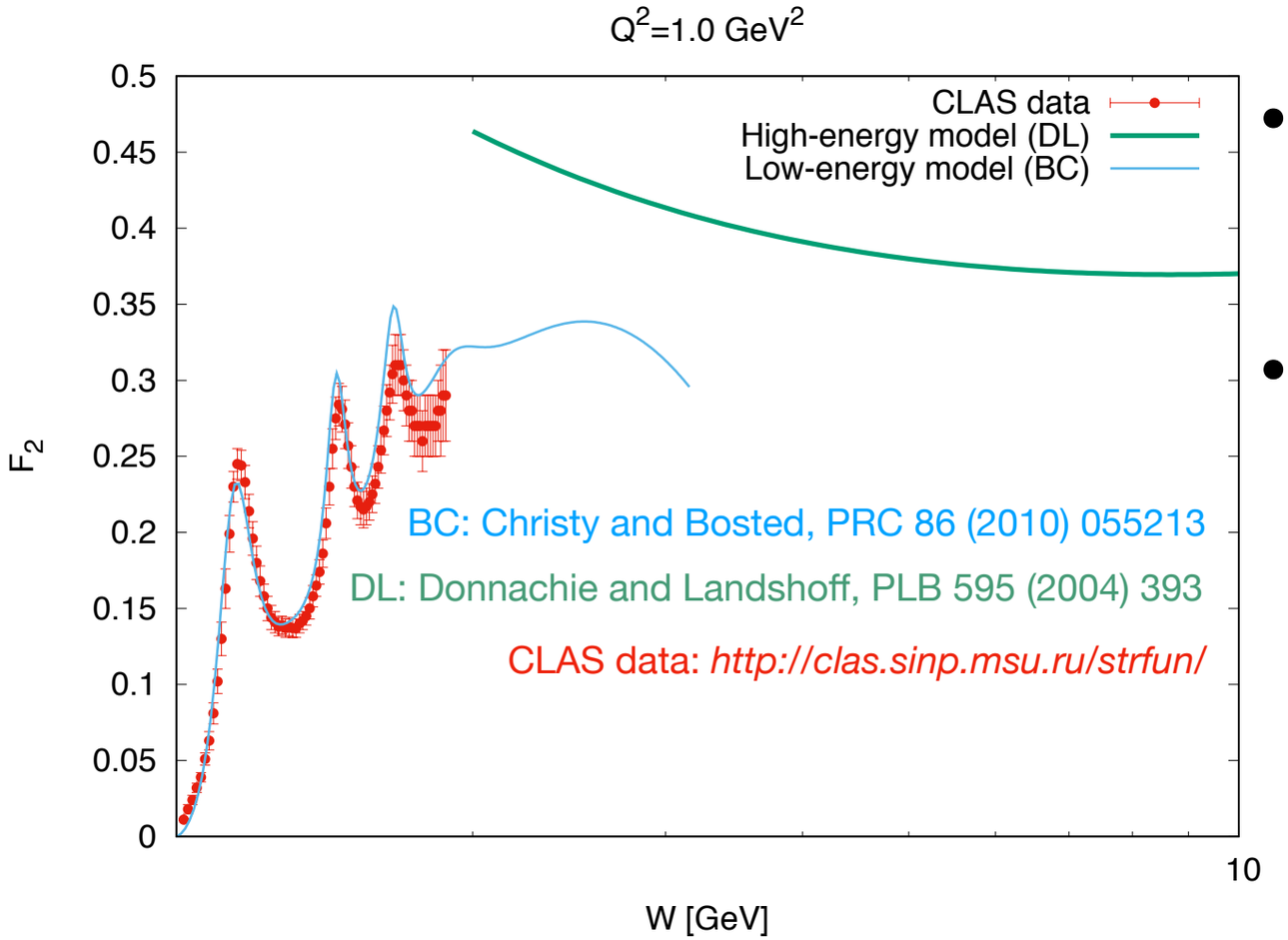

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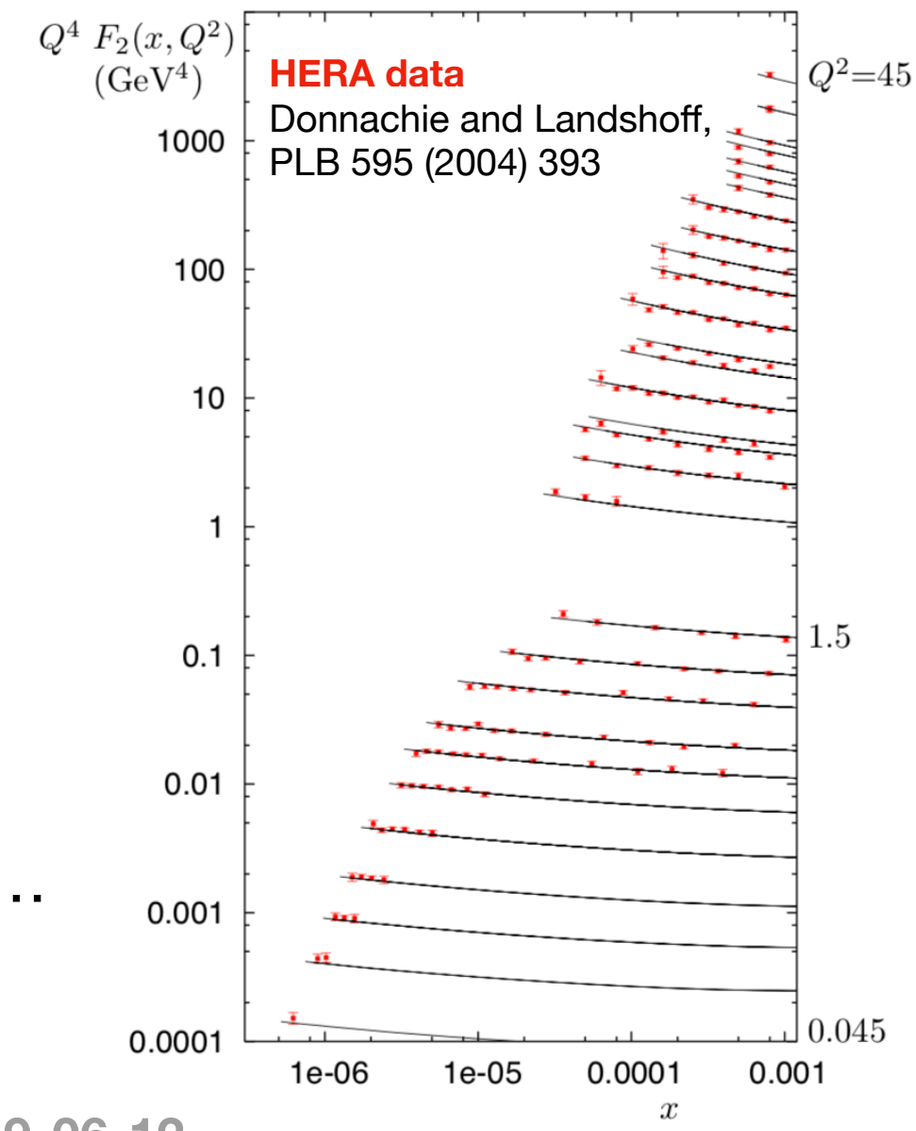
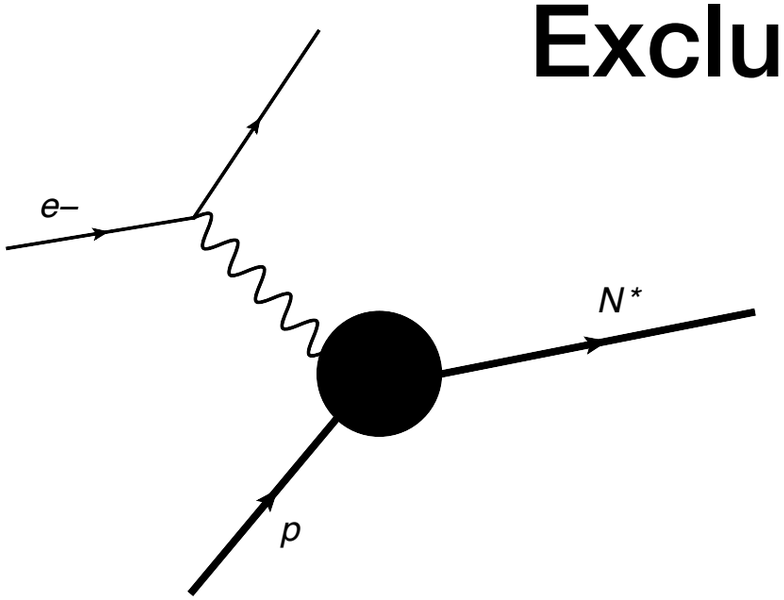


- **At high energies: HERA and ZEUS data**
  Extremely good Q² coverage at low x
- **Goal:** combining high and low-energy models
- Description of observables integrated over x:
  Cottingham formula, subtraction function in VVCS, …
- Tests on quark-hadron duality

Exclusive electron scattering



- Longitudinal and transverse electrocouplings
- Allows us to determine each of the resonant contributions separately
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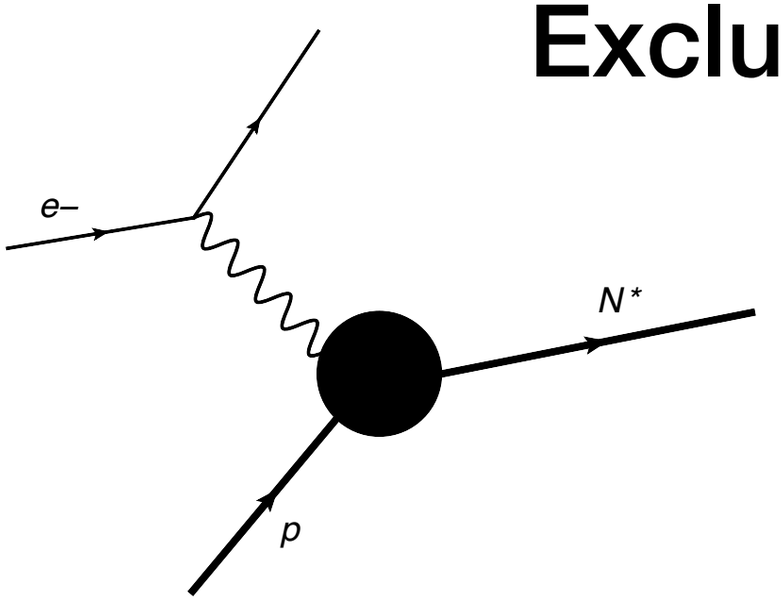

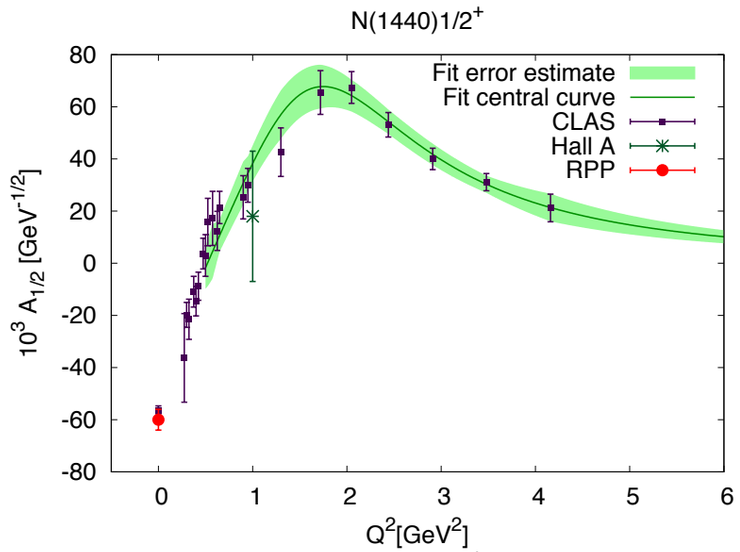

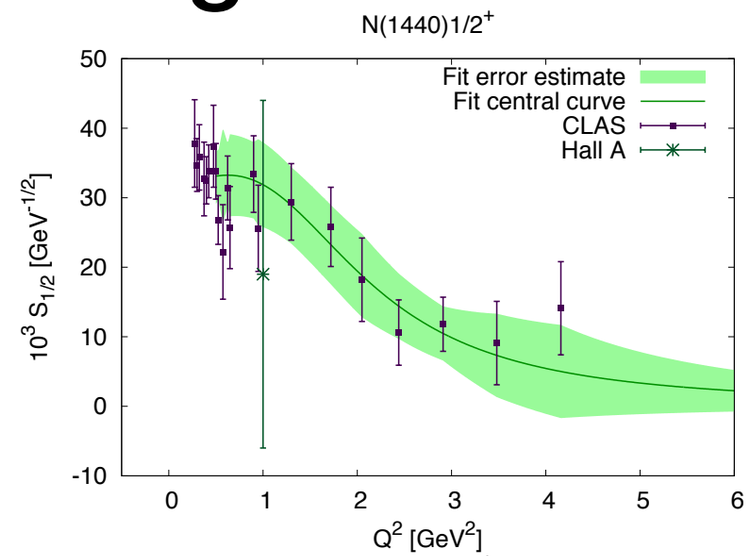

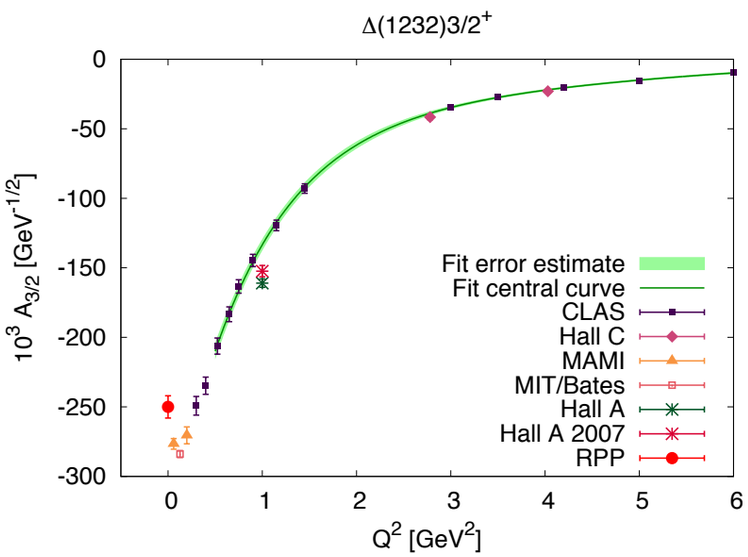

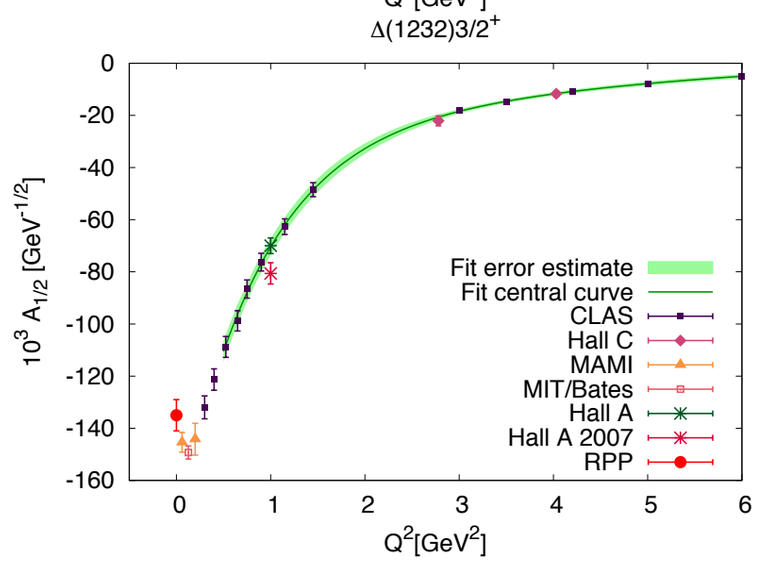

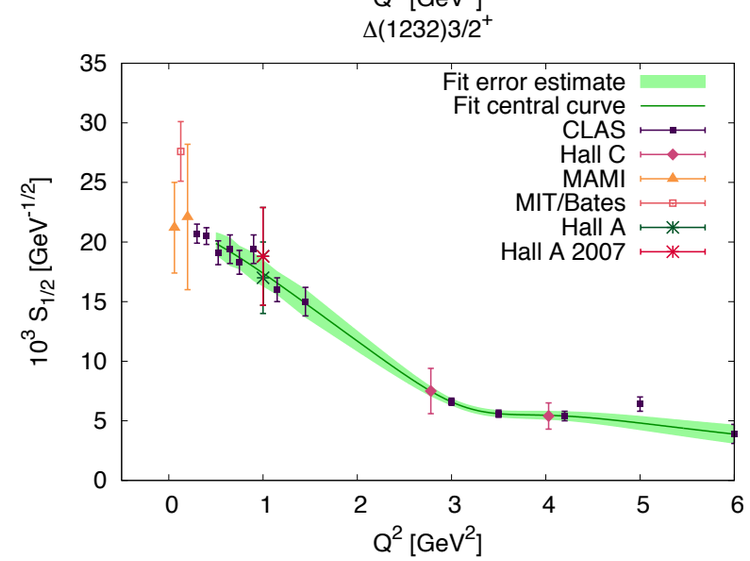

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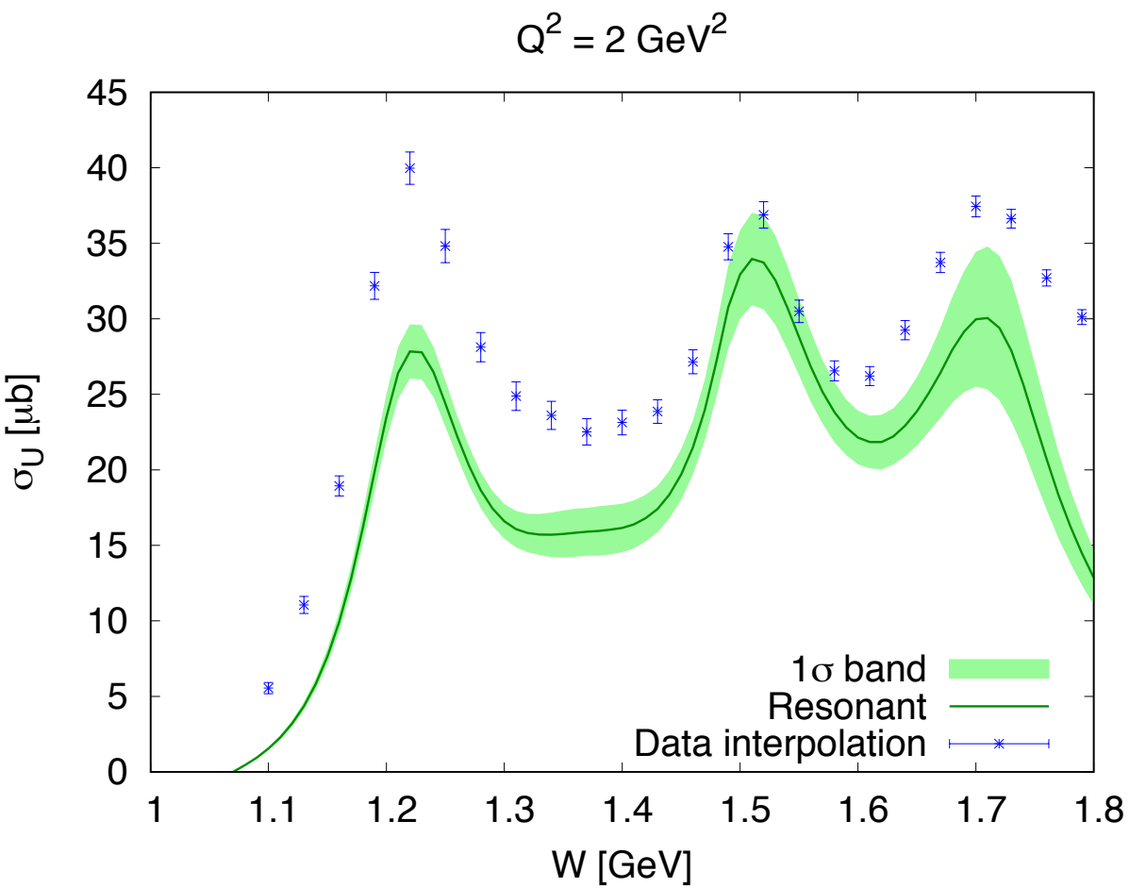
From exclusive to inclusive electron scattering

$$\sigma_{T,L}(W,Q^2) = \sigma^R_{T,L}(W,Q^2) + \sigma^{NR}_{T,L}(W,Q^2)$$



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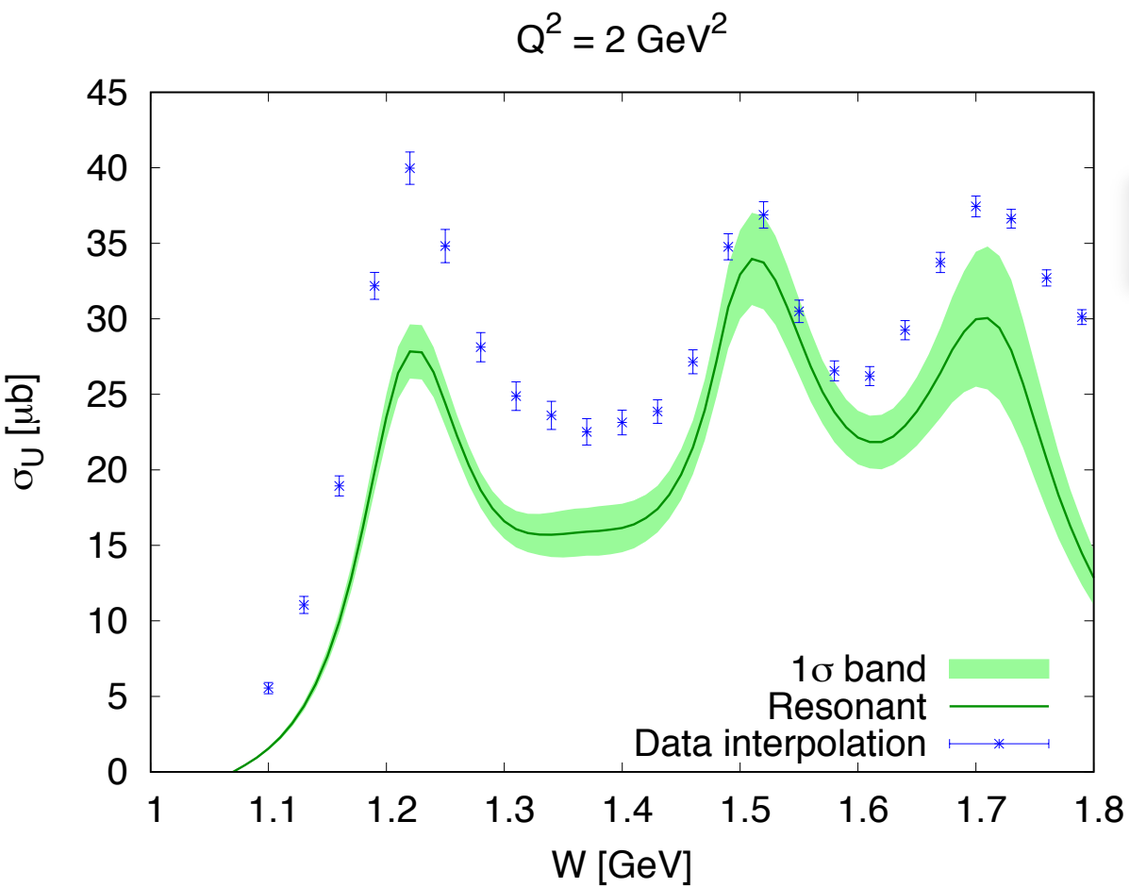

Breit-Wigner resonance model

Mokeev et al., PRC 86 (2012) 035203

$$\sigma^R_{T,L}(W,Q^2) = \frac{\pi}{q^2_\gamma} \sum_{N^*,\Delta^*} (2J_r+1) \frac{M_r^2 \Gamma_{\text{tot}}(W) \Gamma_\gamma^{T,L}(M_r)}{(M_r^2 - W^2)^2 + M_r^2 \Gamma^2_{\text{tot}}(W)}$$

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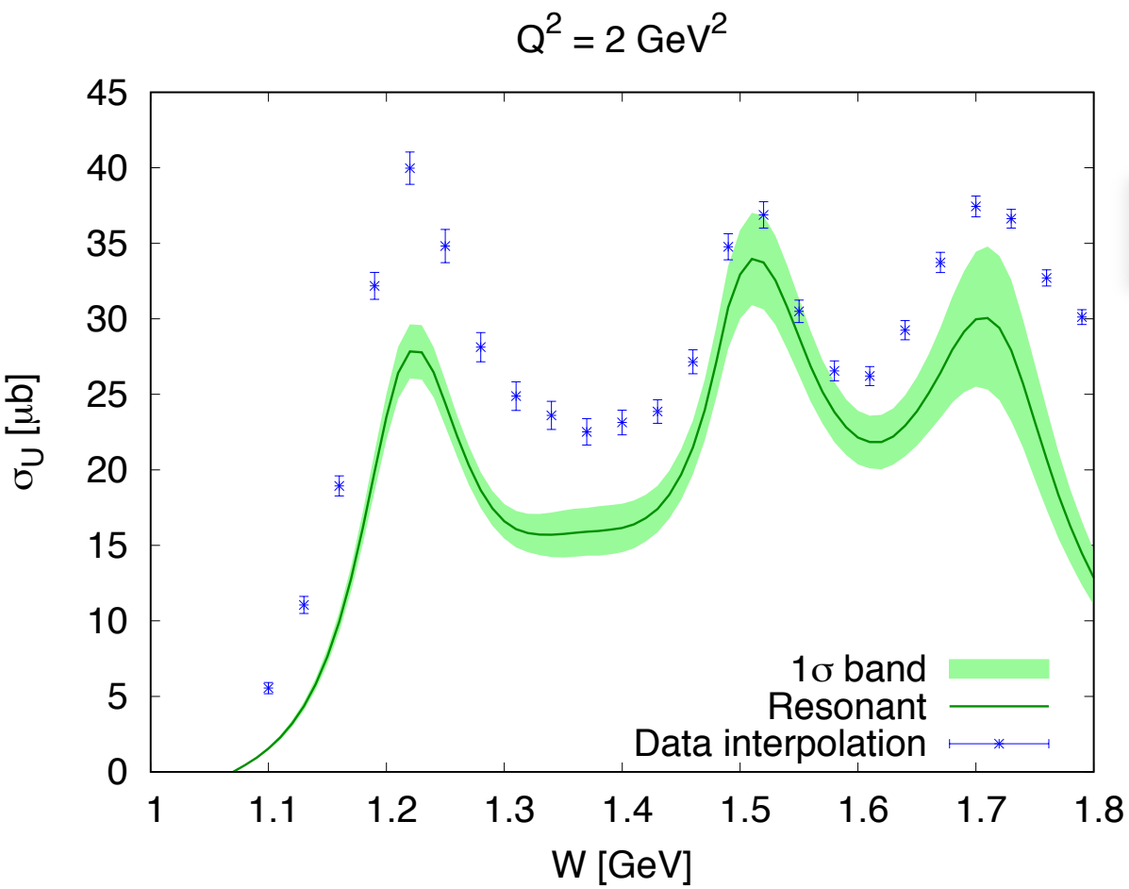

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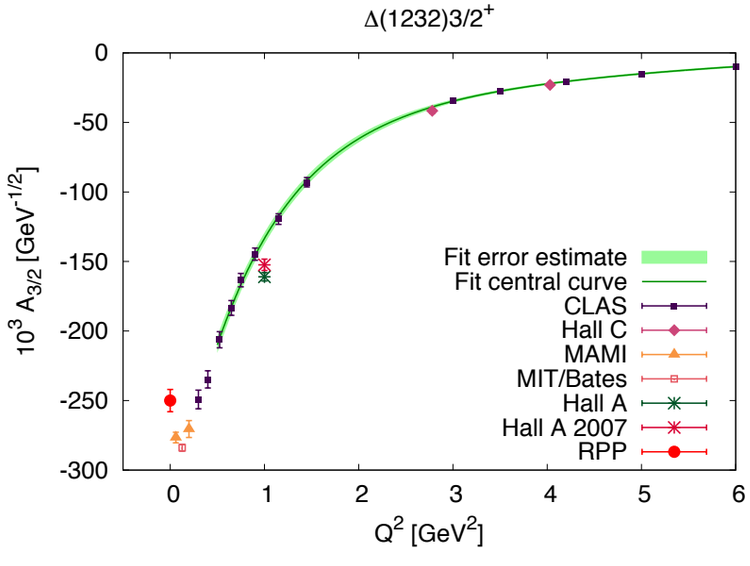
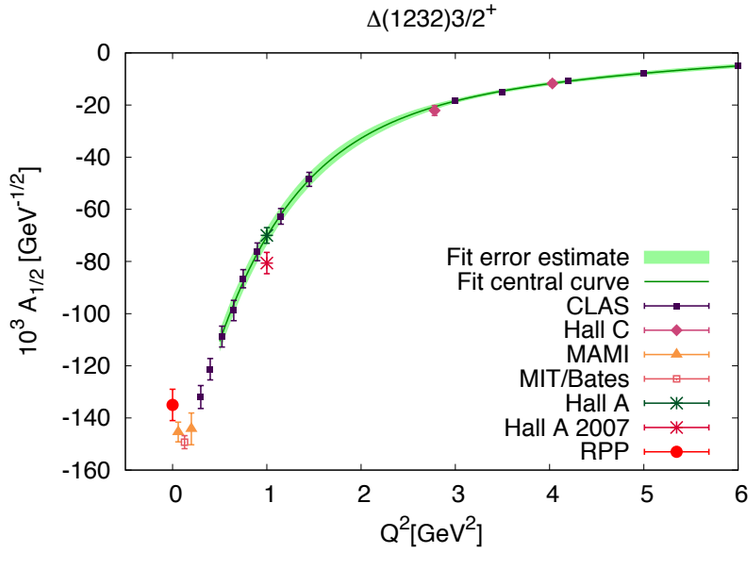
$$\Gamma^T_\gamma(M_r,Q^2) \sim \left|A_{1/2}(Q^2)\right|^2 + \left|A_{3/2}(Q^2)\right|^2$$

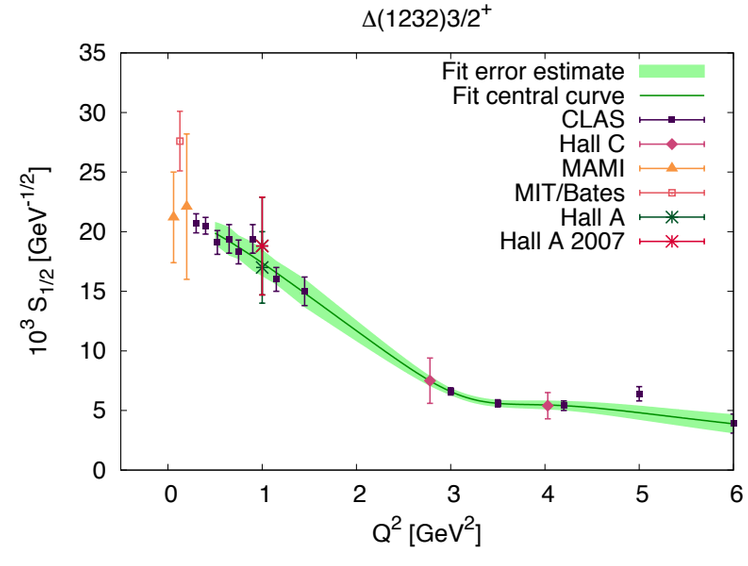
$$\Gamma^L_\gamma(M_r,Q^2) \sim \left|S_{1/2}(Q^2)\right|^2$$

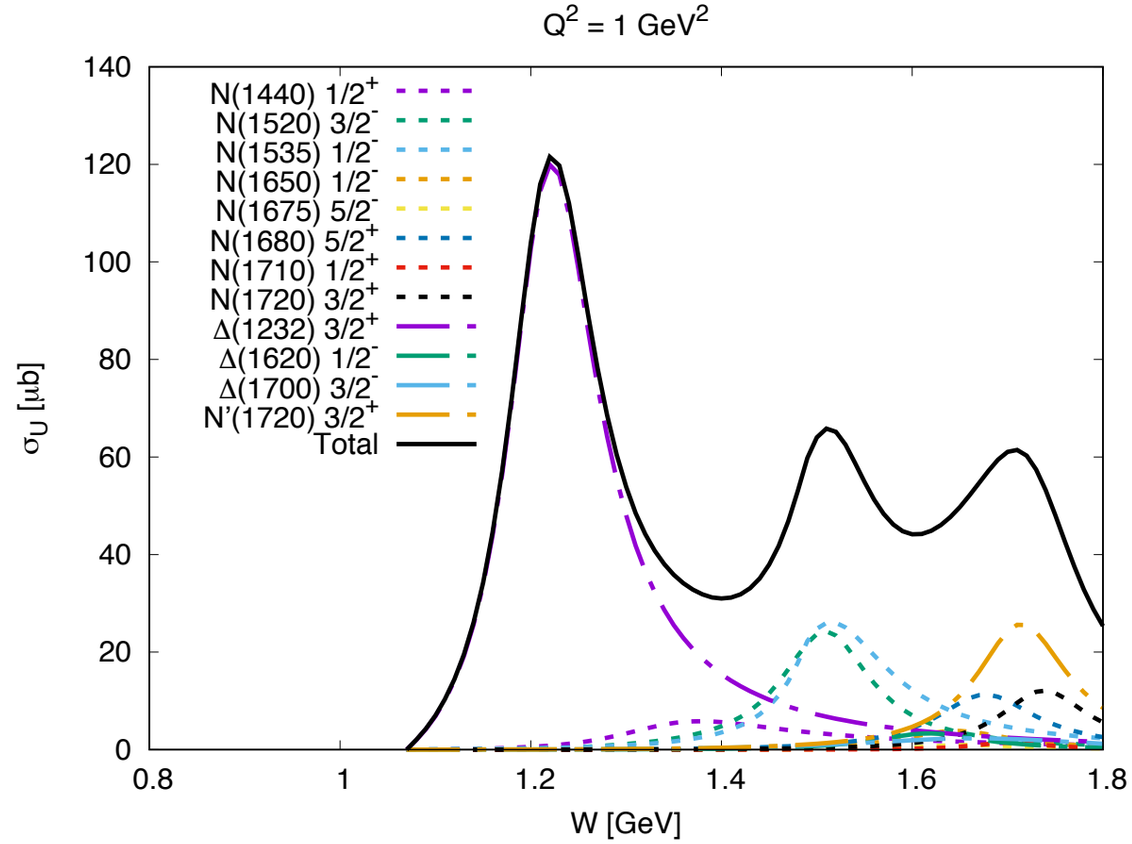
Electrocouplings from data

How electrocouplings enter inclusive data









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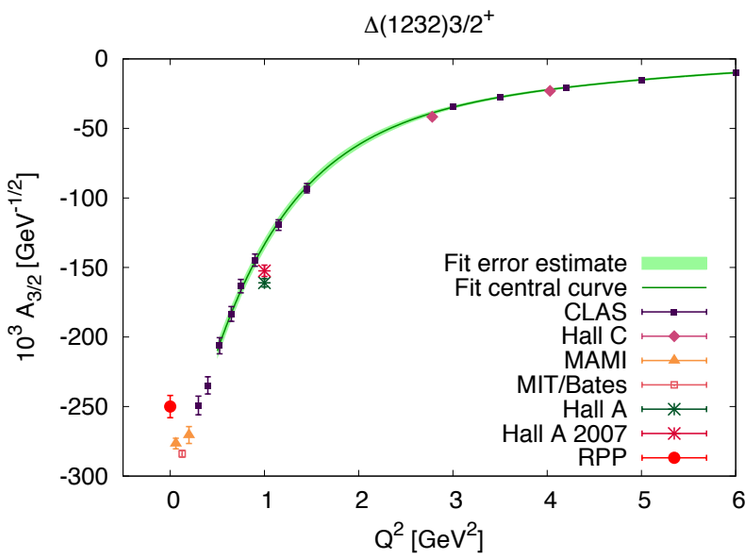

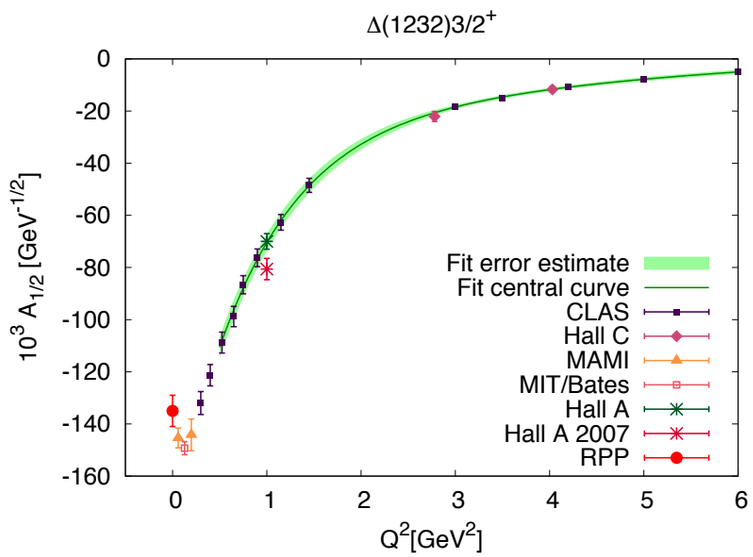

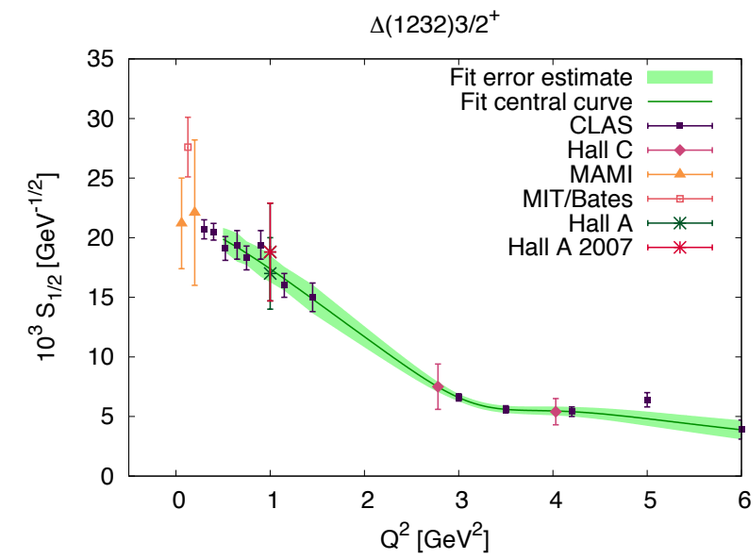

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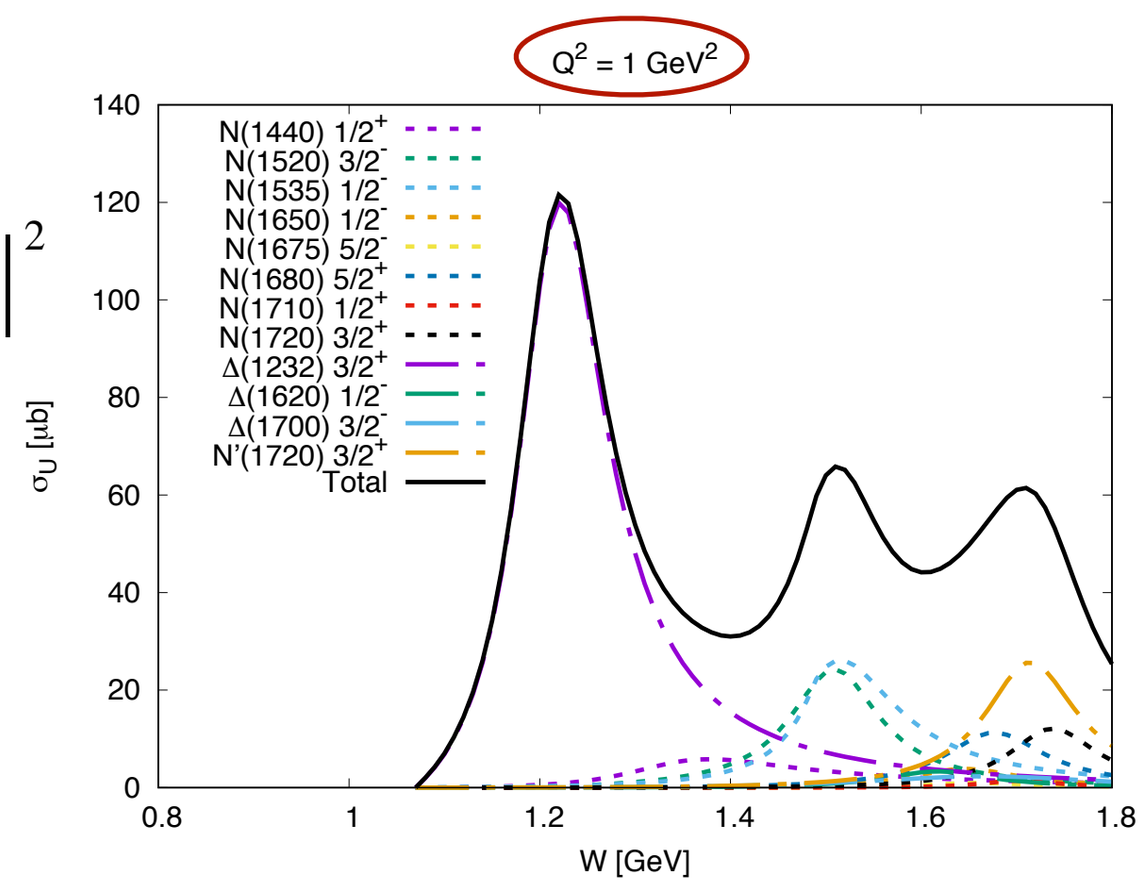

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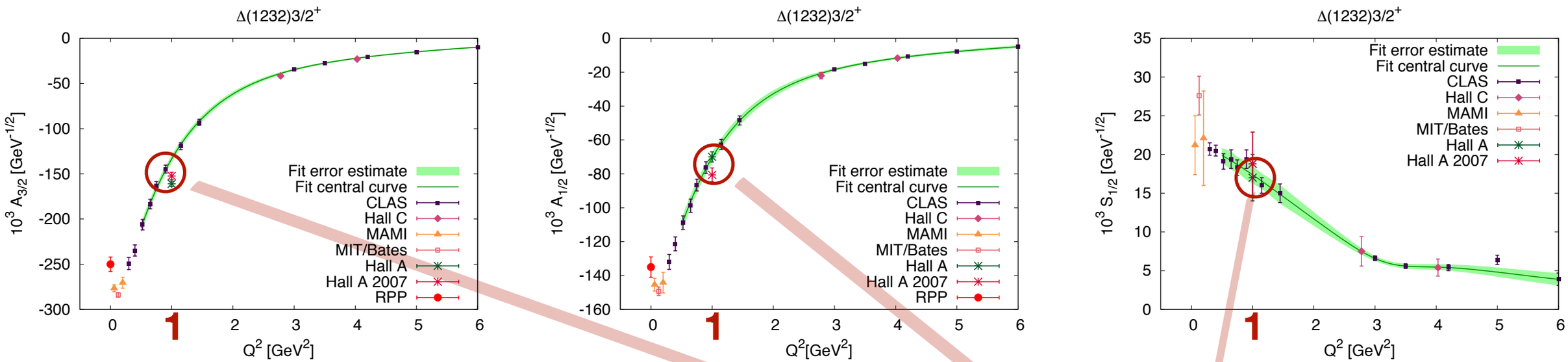

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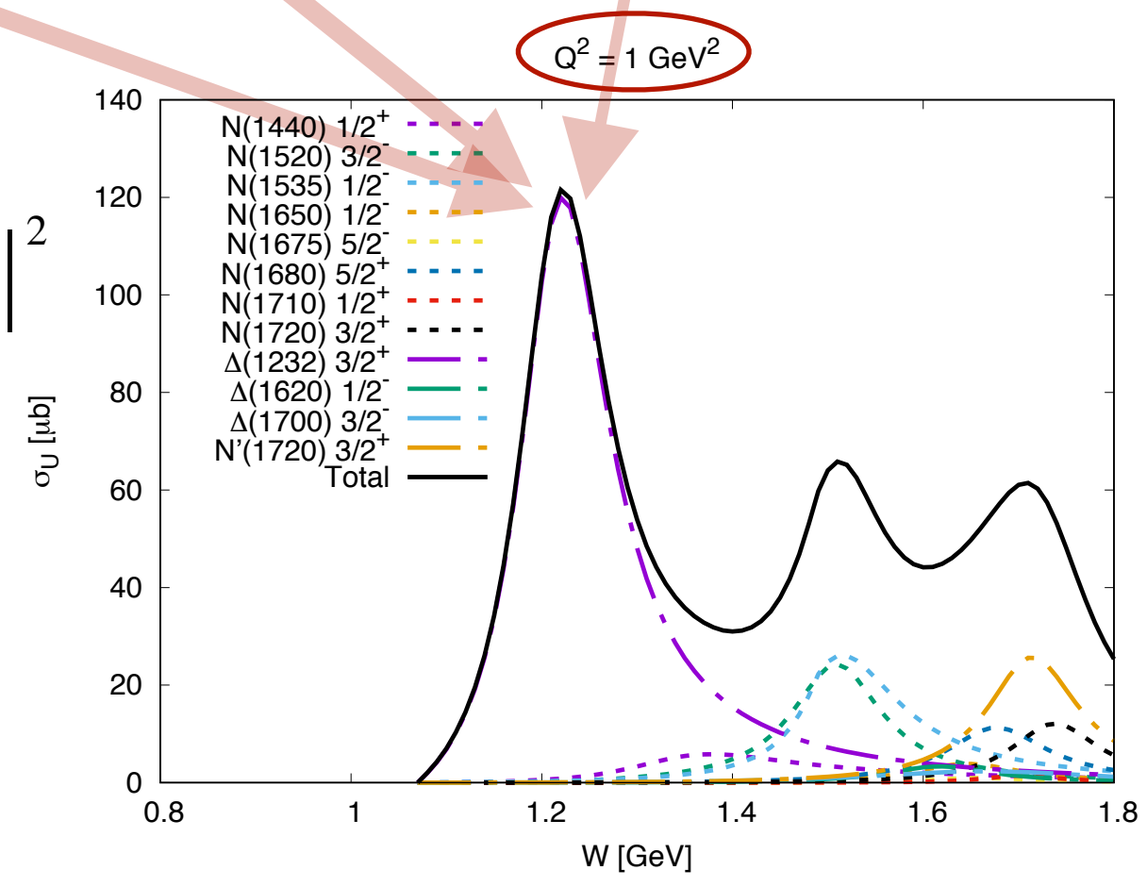
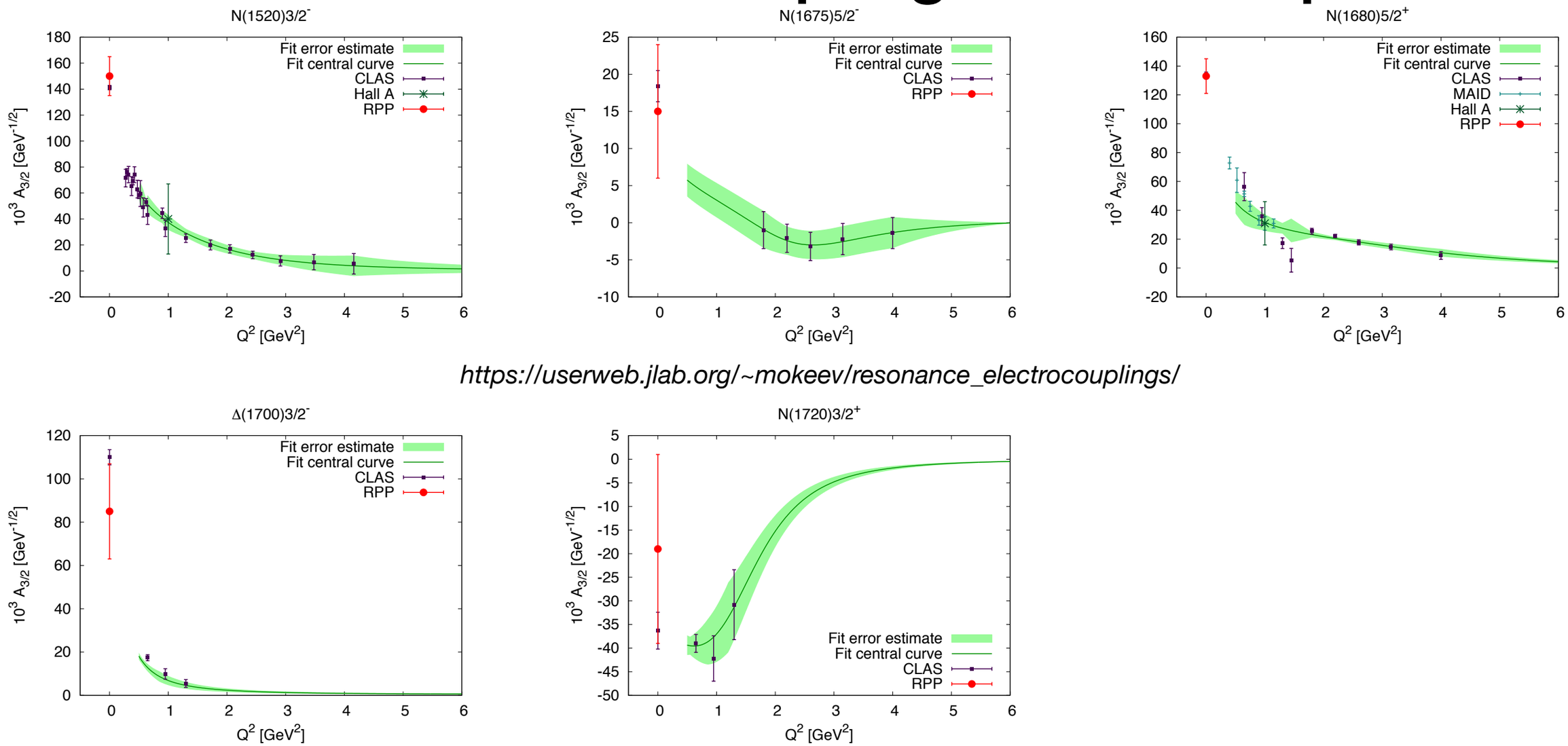


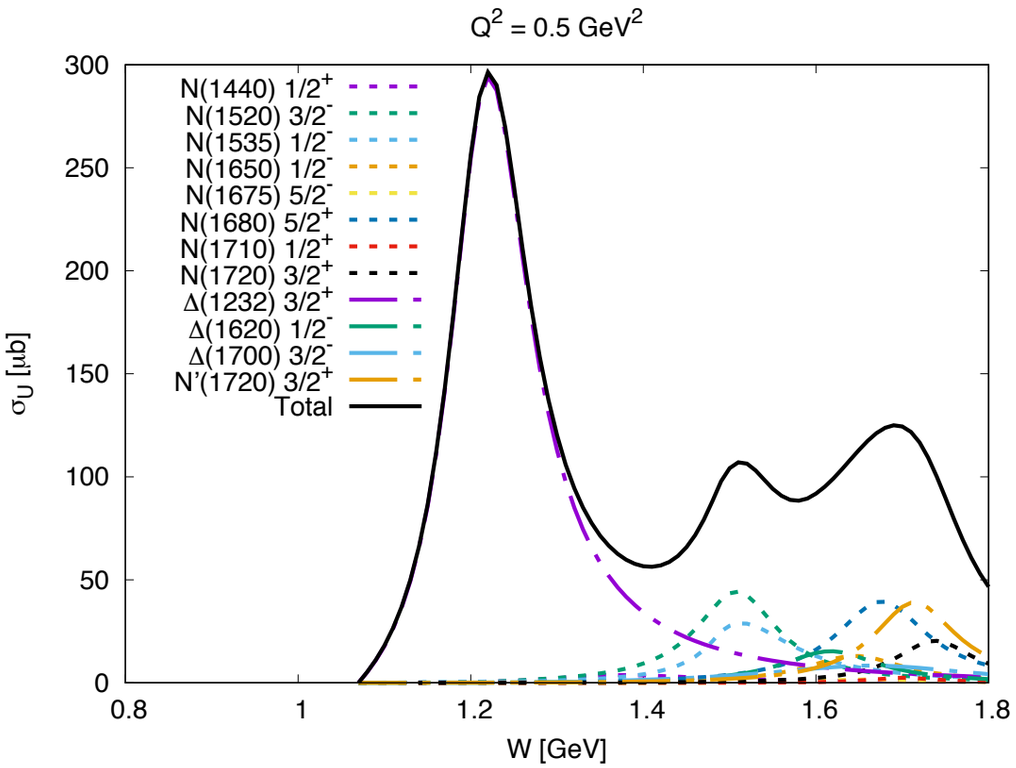
Further electrocoupling data examples

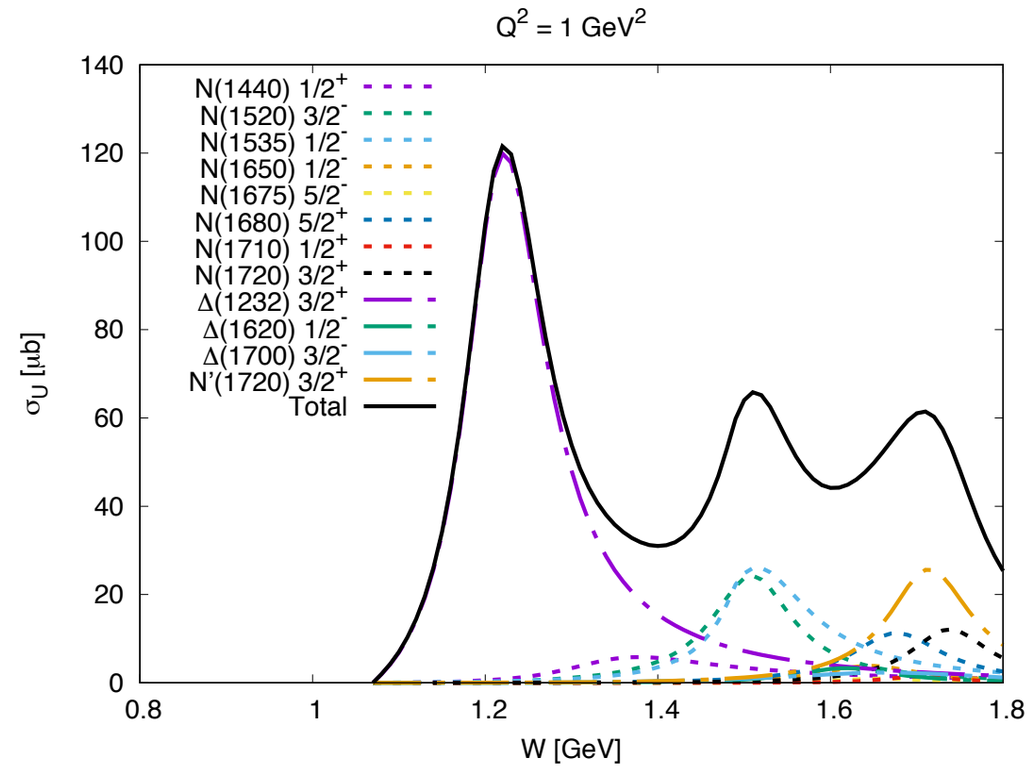


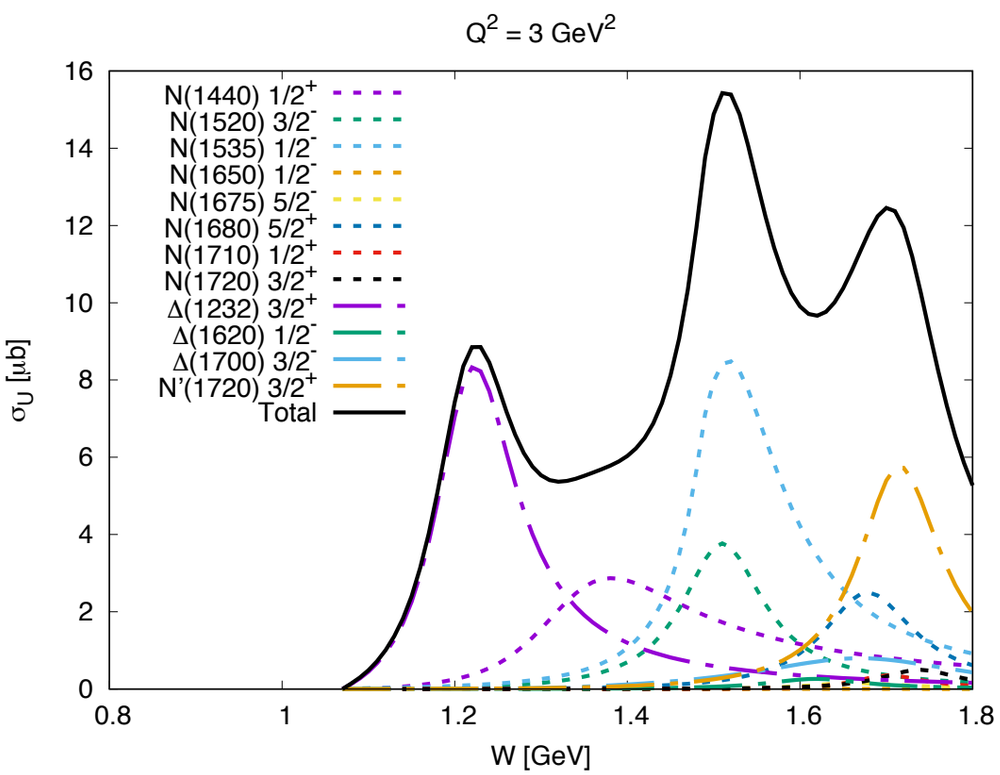
https://userweb.jlab.org/~mokeev/resonance_electrocouplings/

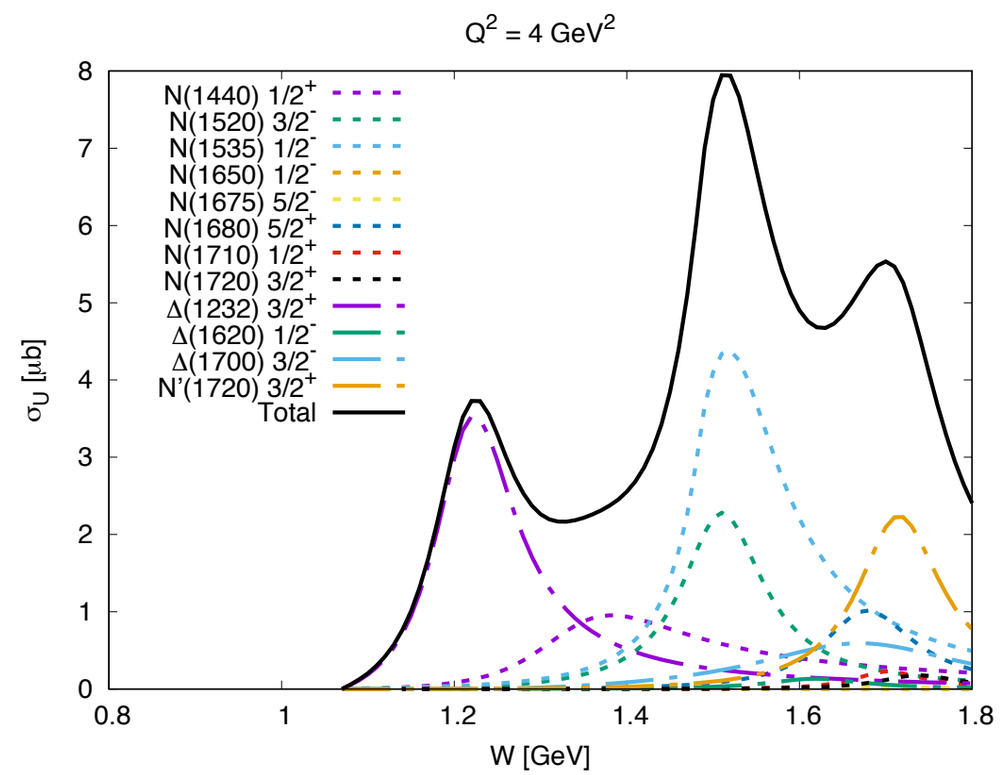
- Interpolation/extrapolation functions: *https://userweb.jlab.org/~isupov/couplings/*
  in good agreement with world data and preliminary CLAS12 results at higher Q^2
- Error bands estimated from data uncertainties
  and scaled with coupling size in extrapolation region

Resonant contributions at different Q^2









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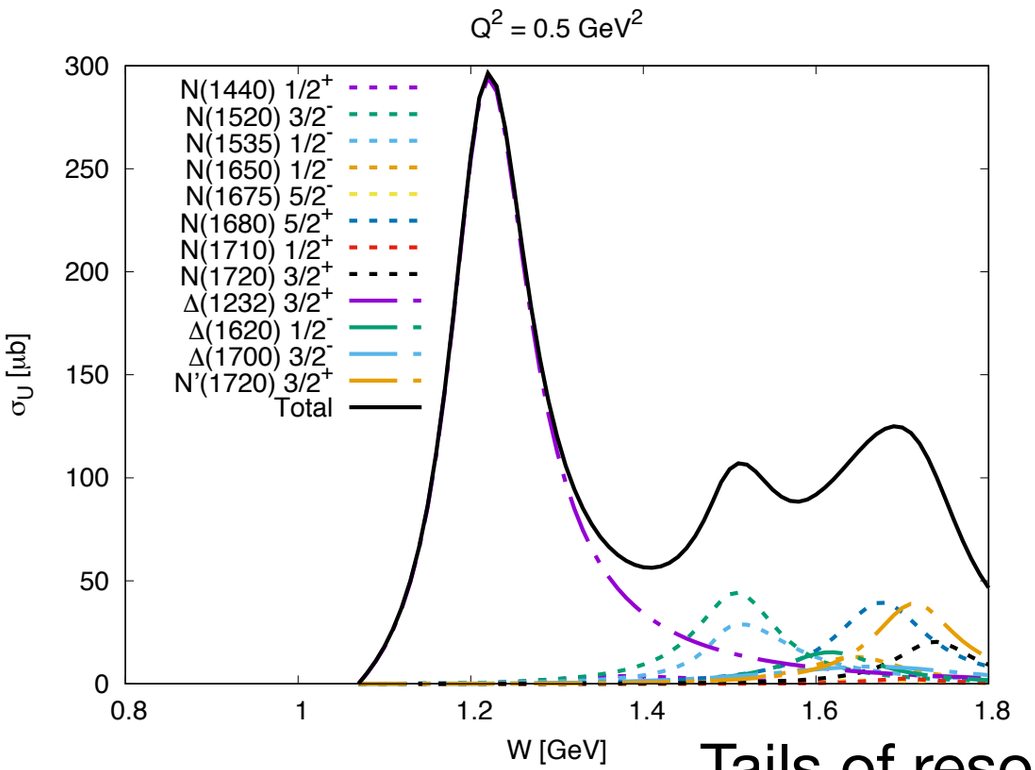
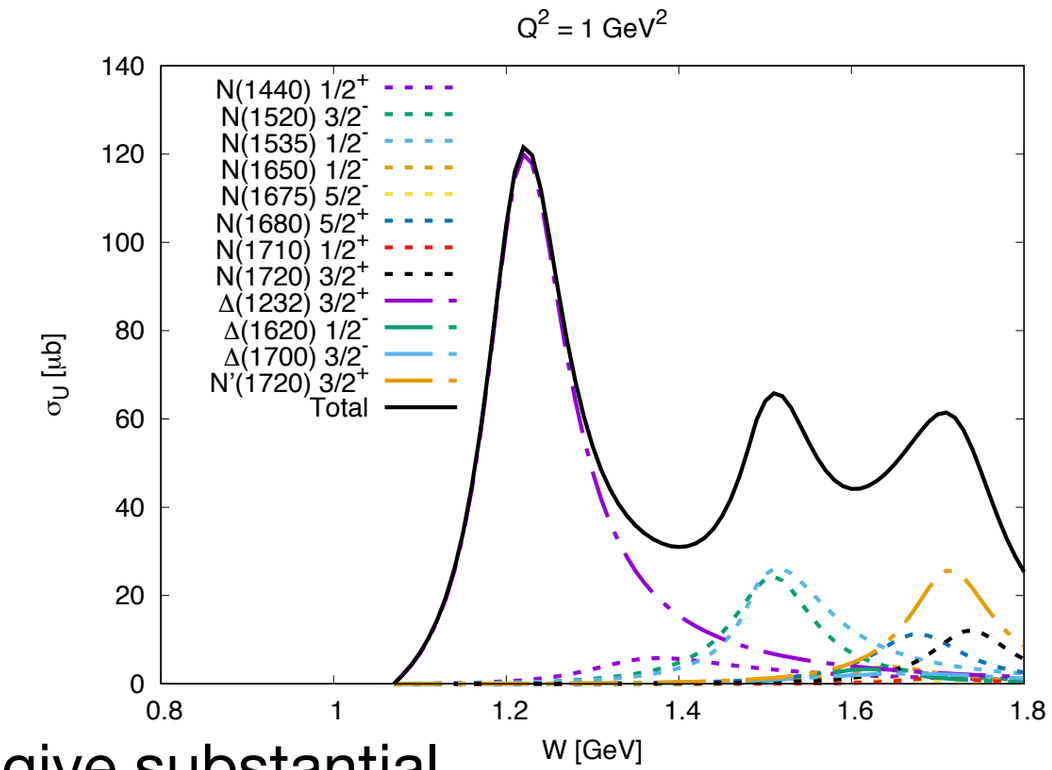
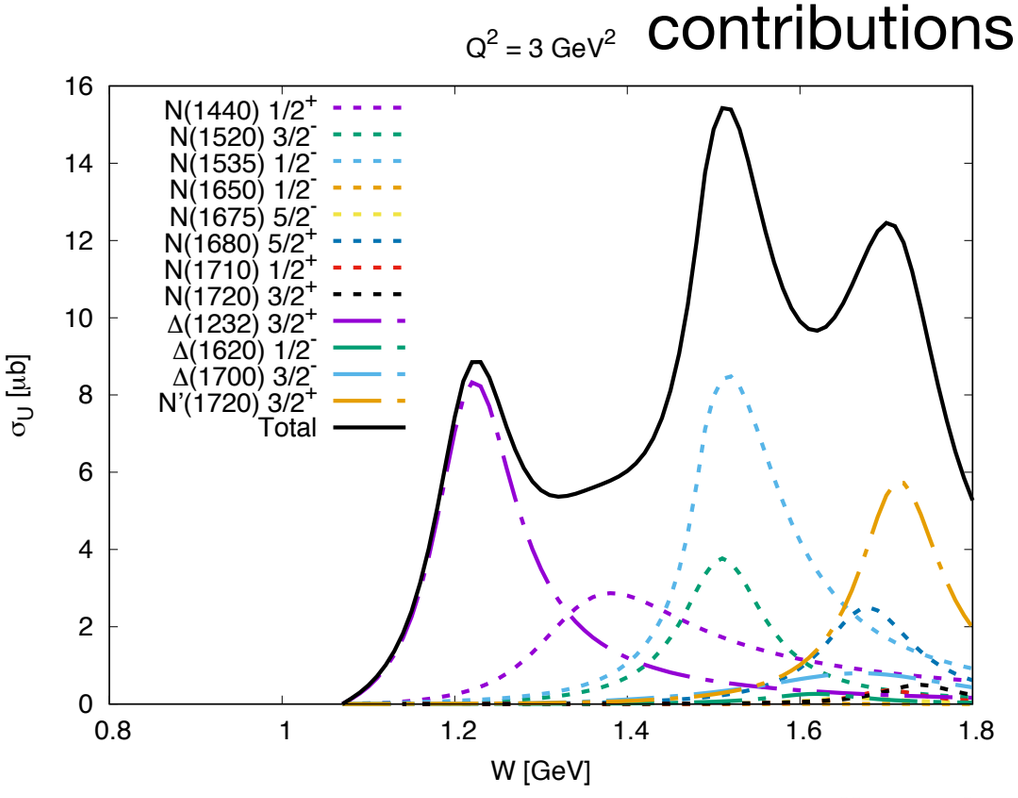
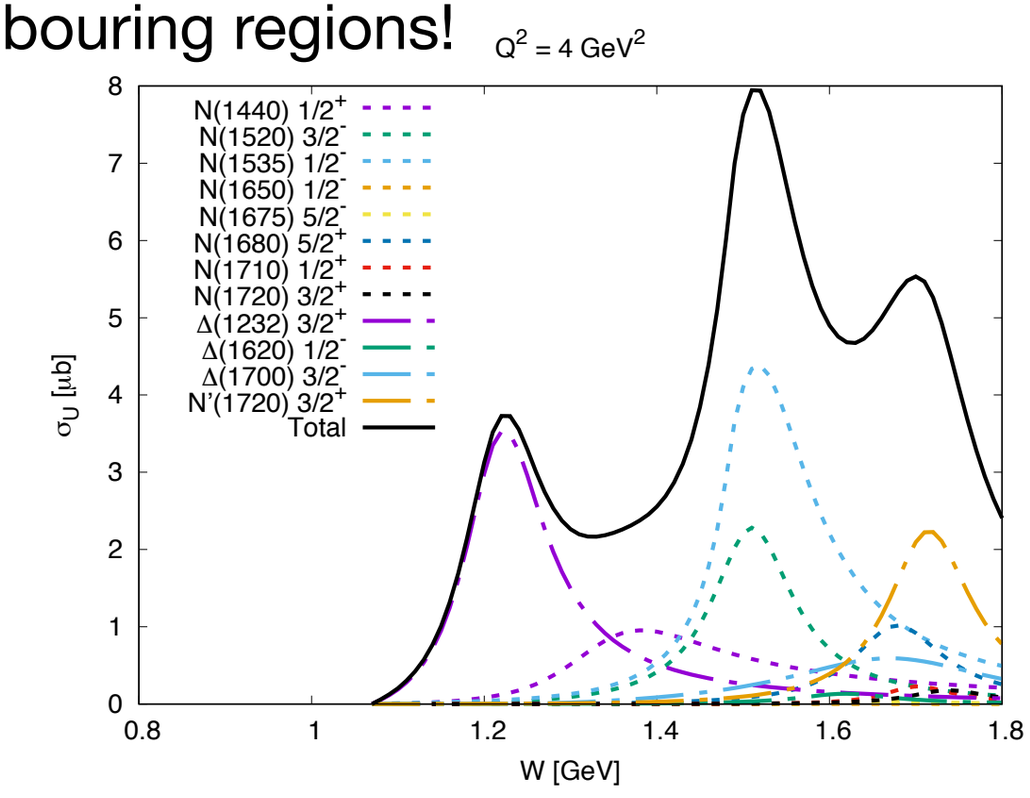


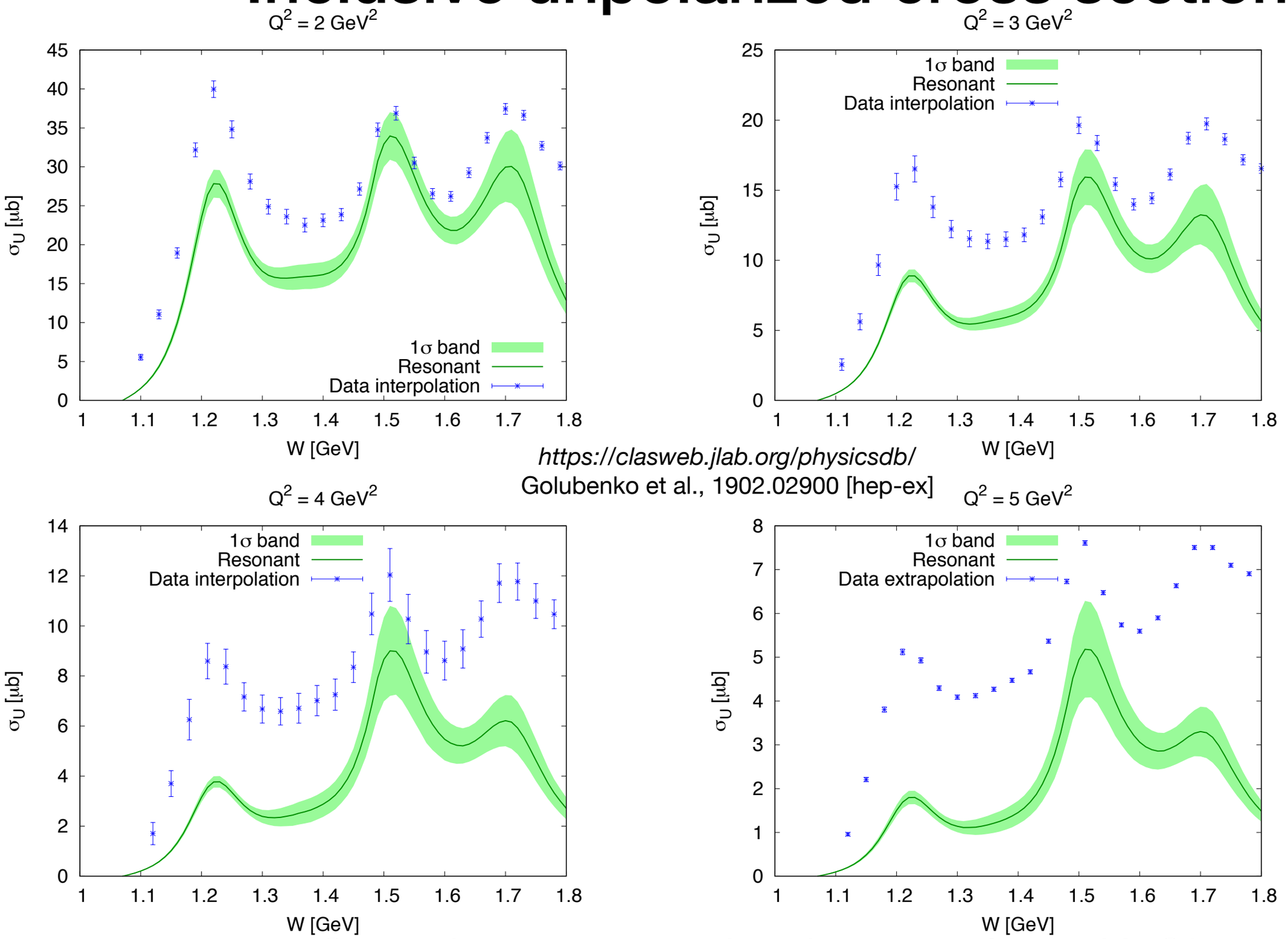


Tails of resonances give substantial contributions to neighbouring regions!





Inclusive unpolarized cross sections



https://clasweb.jlab.org/physicsdb/
Golubenko et al., 1902.02900 [hep-ex]

Second resonance region decreases less with Q^2:
intricate differences in Q^2 evolution of electrouplings

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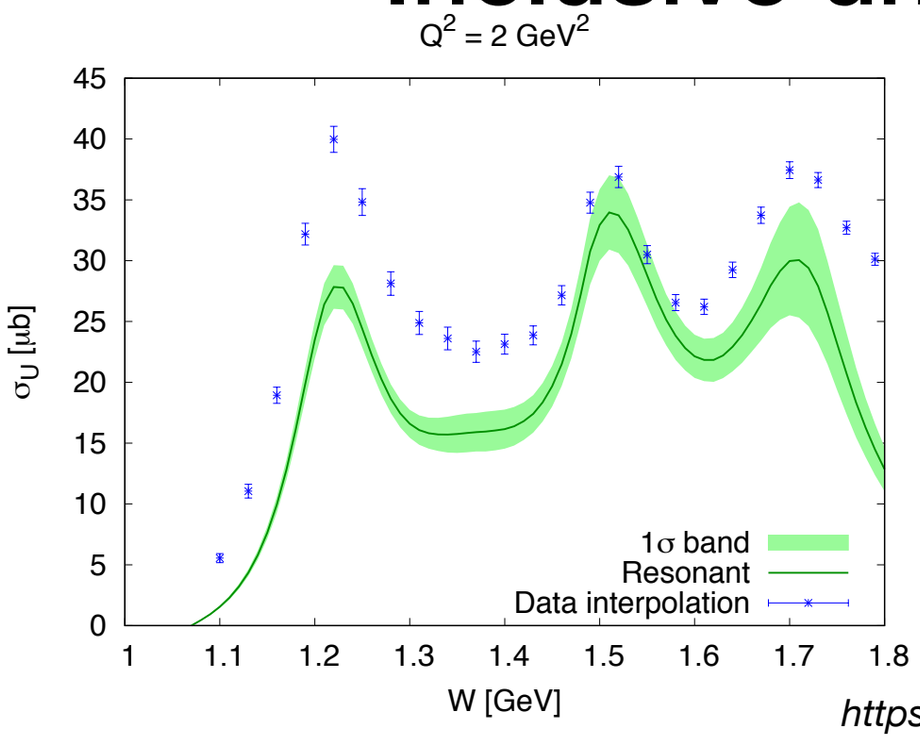

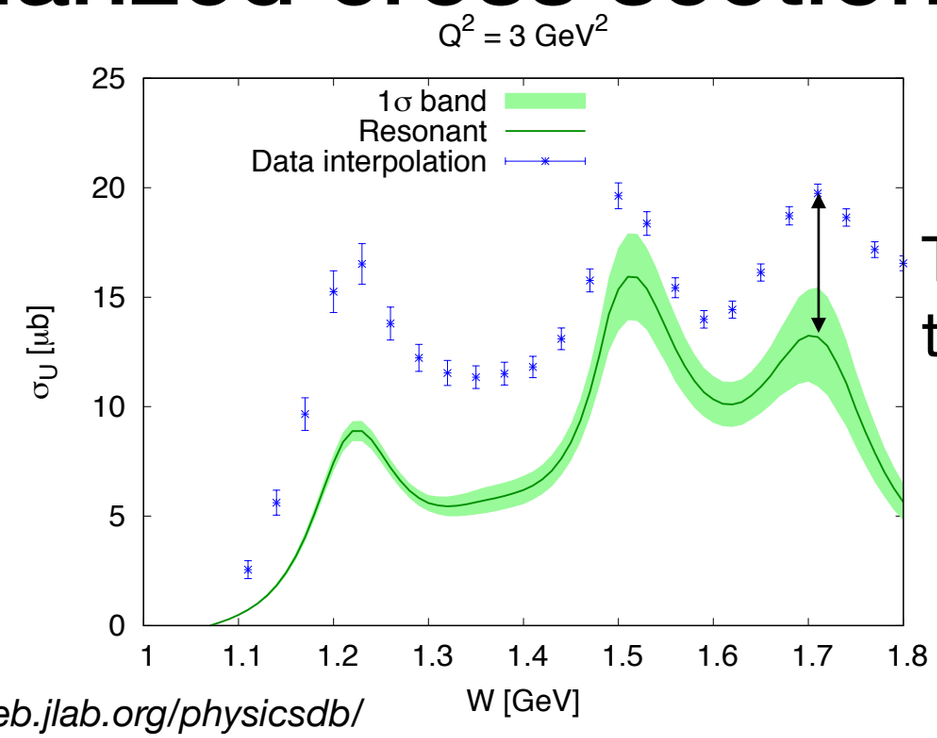

Time to figure out the background!

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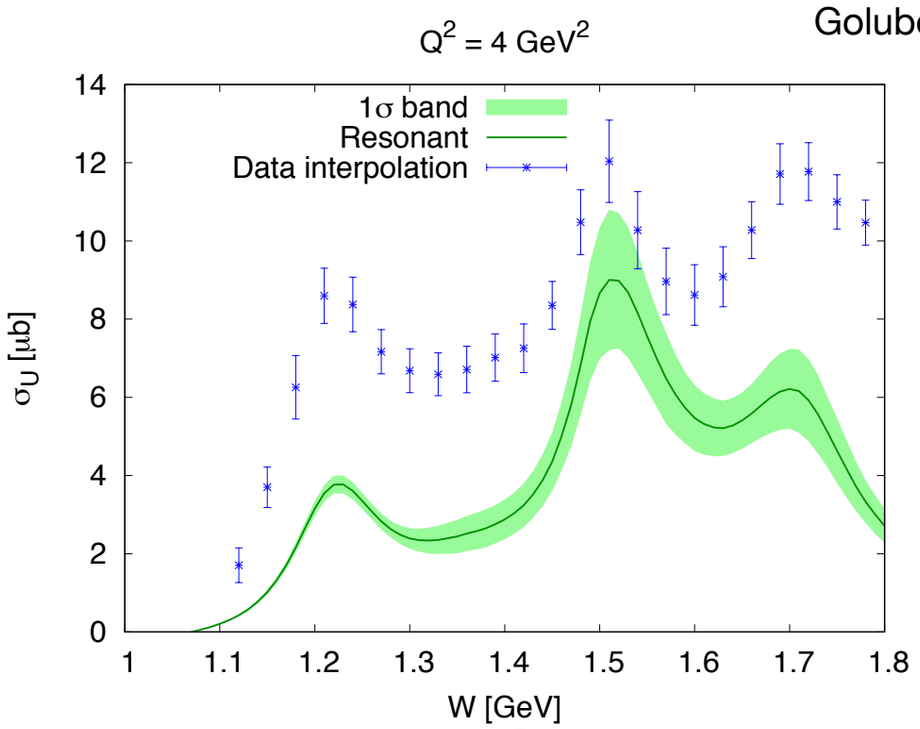
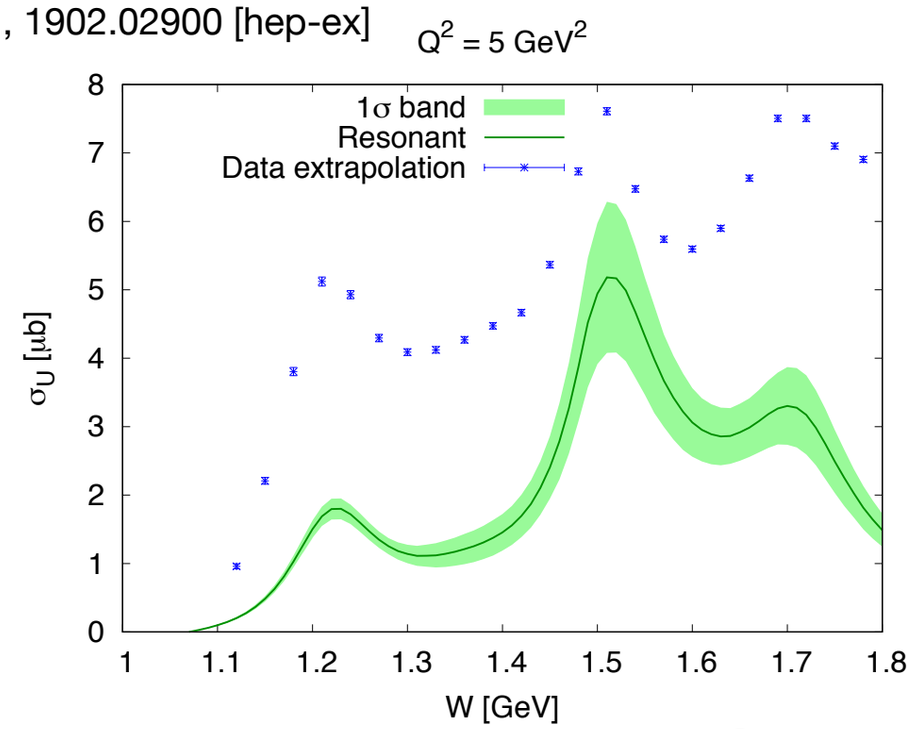
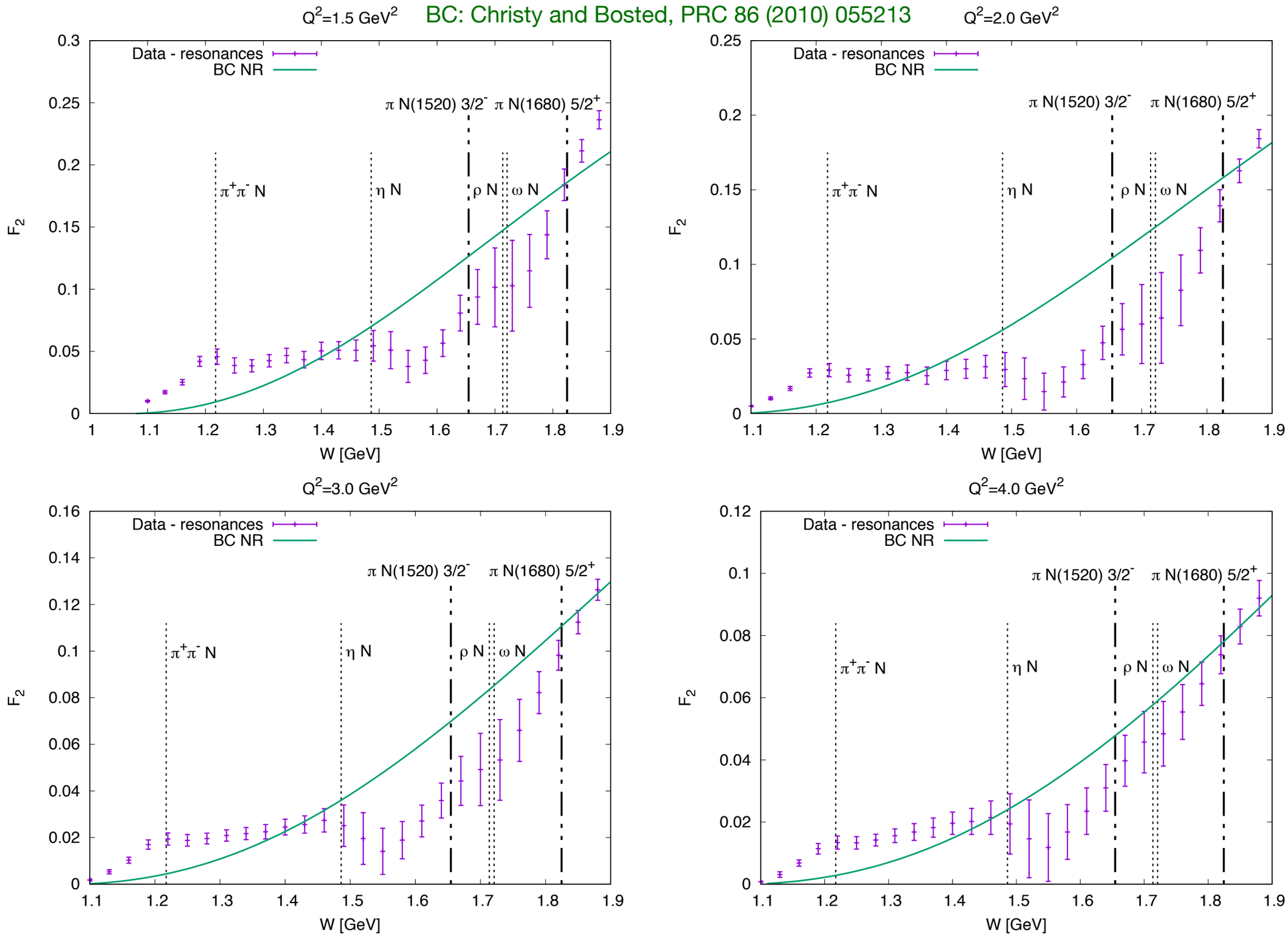




Second resonance region decreases less with Q^2: intricate differences in Q^2 evolution of electrouplings

First estimates to background

BC: Christy and Bosted, PRC 86 (2010) 055213



Background continuation to high energies

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Regge background

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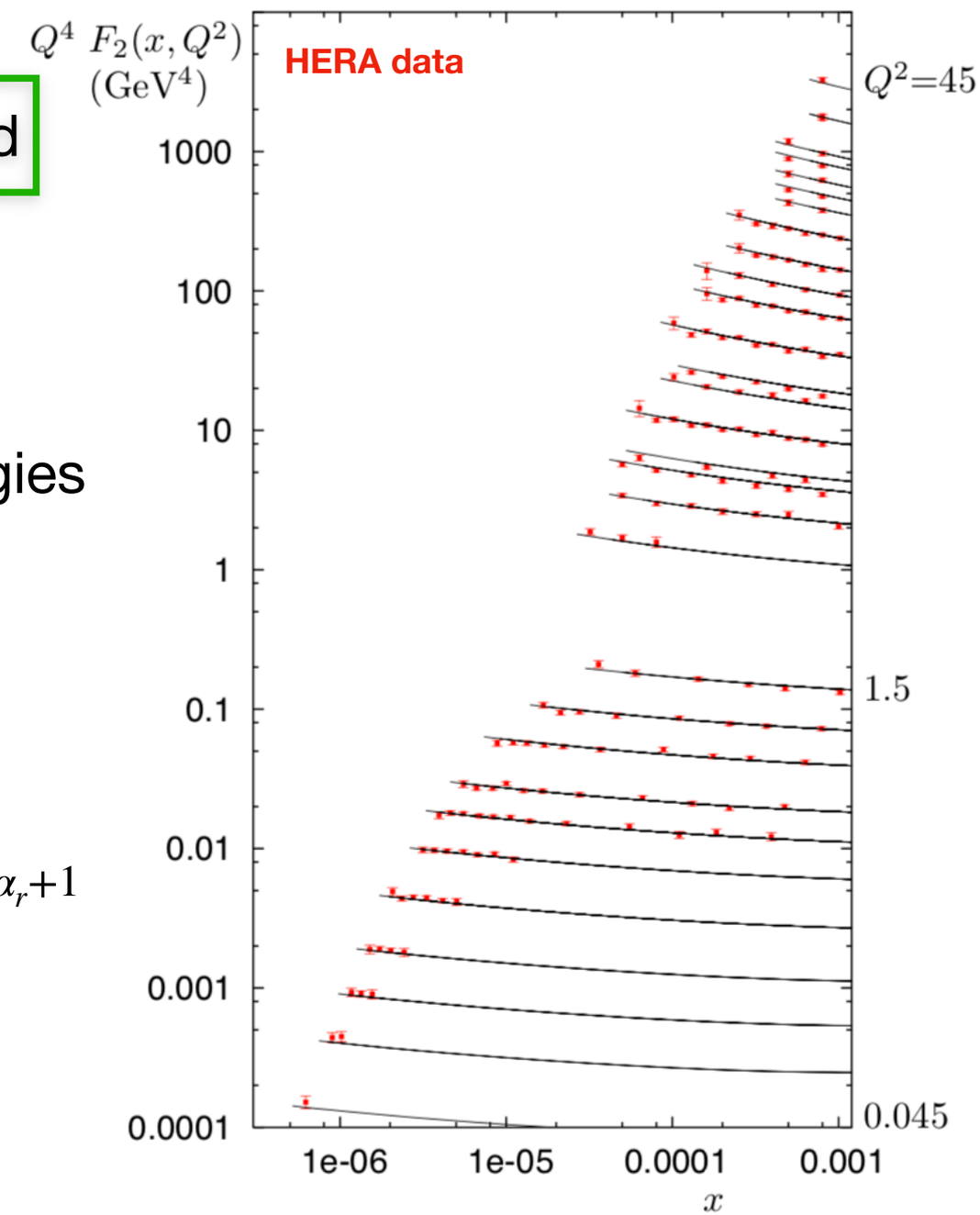


Excellent fit to data at high energies

Donnachie and Landshoff, PLB 595 (2004) 393

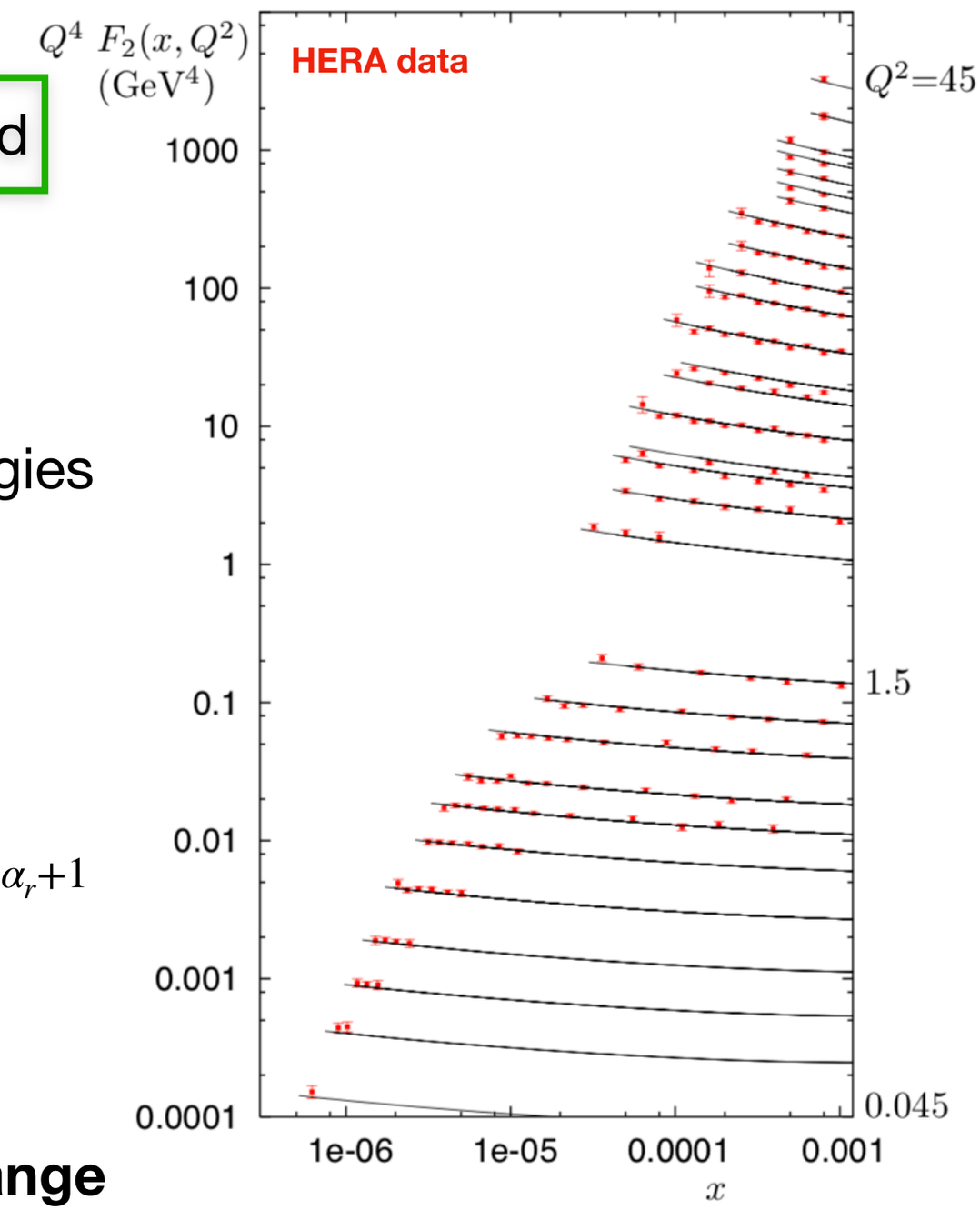
$$F_2(x,Q^2) = f_h(Q^2)x^{-\alpha_h+1} + f_s(Q^2)x^{-\alpha_s+1} + f_r(Q^2)x^{-\alpha_r+1}$$

$$x = \frac{Q^2}{2M_N\nu}$$

Background continuation to high energies

$$\sigma_{T,L}(W,Q^2) = \sigma^R_{T,L}(W,Q^2) + \sigma^{NR}_{T,L}(W,Q^2)$$

Regge background



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Hard pomeron

$\alpha_h = 1.452$

Soft pomeron

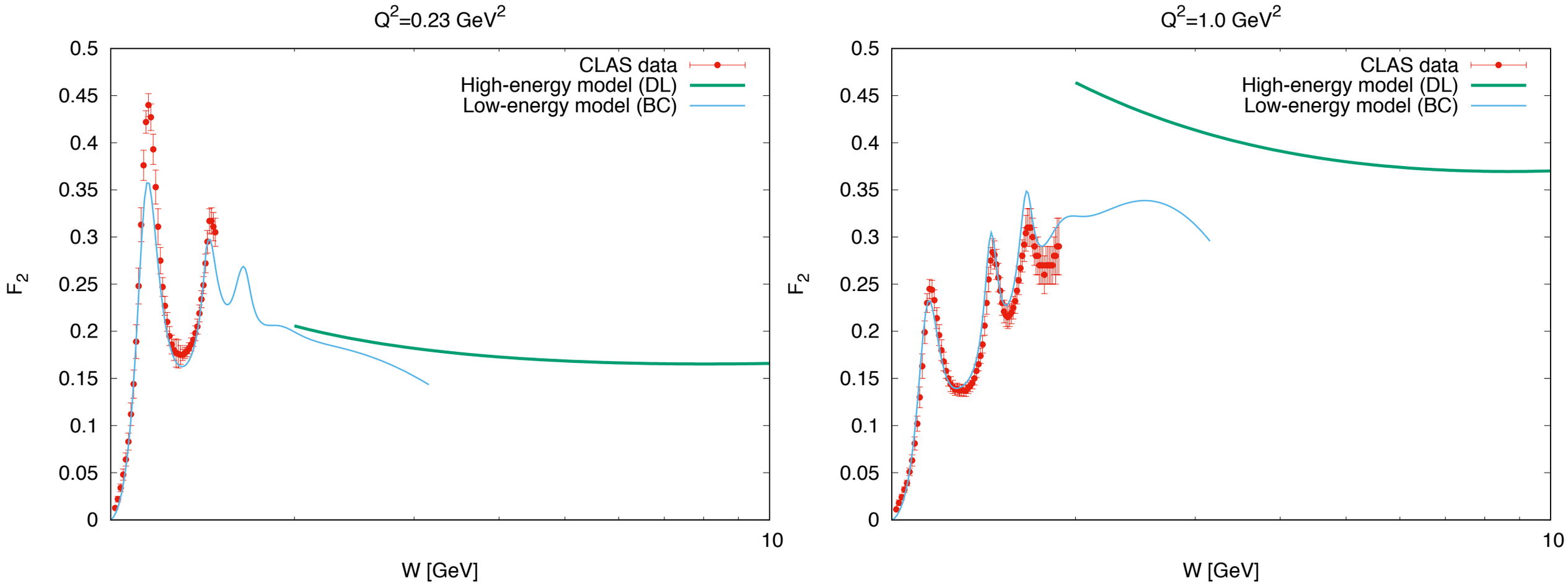
$\alpha_s = 1.0667$

Meson exchange

$\alpha_r = 0.524$

High and low energies: previous works

BC: Christy and Bosted, PRC 86 (2010) 055213 DL: Donnachie and Landshoff, PLB 595 (2004) 393 CLAS data: *http://clas.sinp.msu.ru/strfun/*



- Excellent description of data at low and high energies, separately
- At low Q^2: high- and low-energy theories compatible in overlap region
- At slightly **higher Q^2: huge gap** between high and low-energy models
- Leads to difficulties in extracting observables integrated over x (or energies)

Proposal for updated parametrization

$$F_1(\nu, Q^2) = F_1^{\text{res}}(\nu, Q^2) + \sum_{i=0}^{2} \gamma_{\alpha_i}(Q^2)(\nu - \nu_{\text{thr}})^{\alpha_i} \left(1 - \frac{\nu_{\text{thr}}}{\nu}\right)^{a_i(Q^2)} \left(1 + \frac{\nu_{\text{thr}}}{\nu}\right)^{b_i(Q^2)}$$

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- Automatically recovers Regge behaviour at high energies for $\alpha_i < 1$

$$F_1(\nu, Q^2) \longrightarrow \sum_{i=0}^{2} \gamma_{\alpha_i}(Q^2)\nu^{\alpha_i}$$

- For the Pomerons we have the requirement

$$b_i(Q^2) = a_i(Q^2) + \alpha_i, \quad 1 \leq \alpha_i < 2$$

- Implements threshold and resonant behaviour

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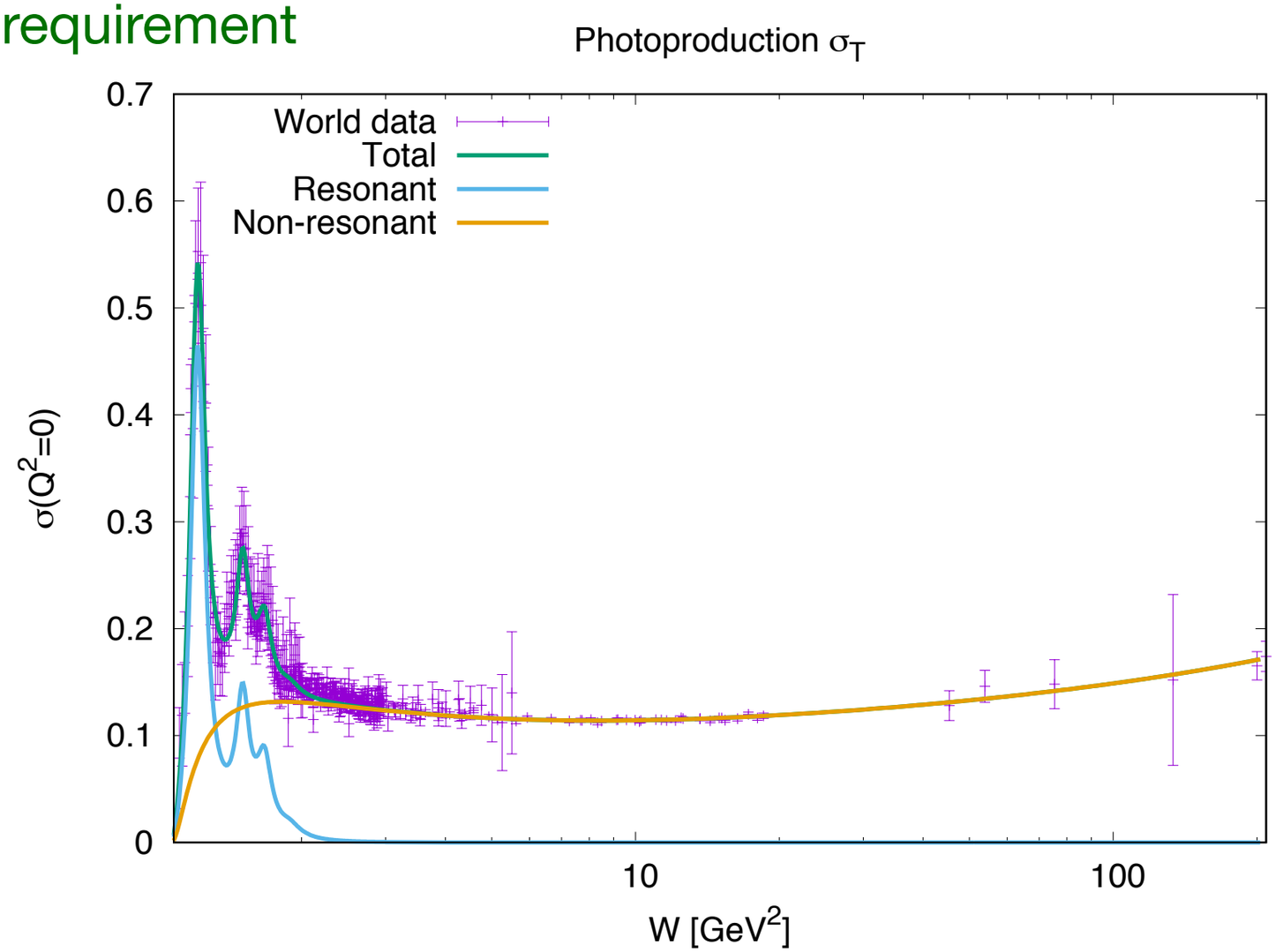

Additional fit constraints

$$F_1(\nu, Q^2) = F_1^{\mathrm{res}}(\nu, Q^2) + \sum_{i=0}^{2} \gamma_{\alpha_i}(Q^2)(\nu - \nu_{\mathrm{thr}})^{\alpha_i} \left(1 - \frac{\nu_{\mathrm{thr}}}{\nu}\right)^{a_i(Q^2)} \left(1 + \frac{\nu_{\mathrm{thr}}}{\nu}\right)^{b_i(Q^2)}$$

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- F1 ~ imaginary part of T1:
  additional constraints obtained by imposing for subtraction function

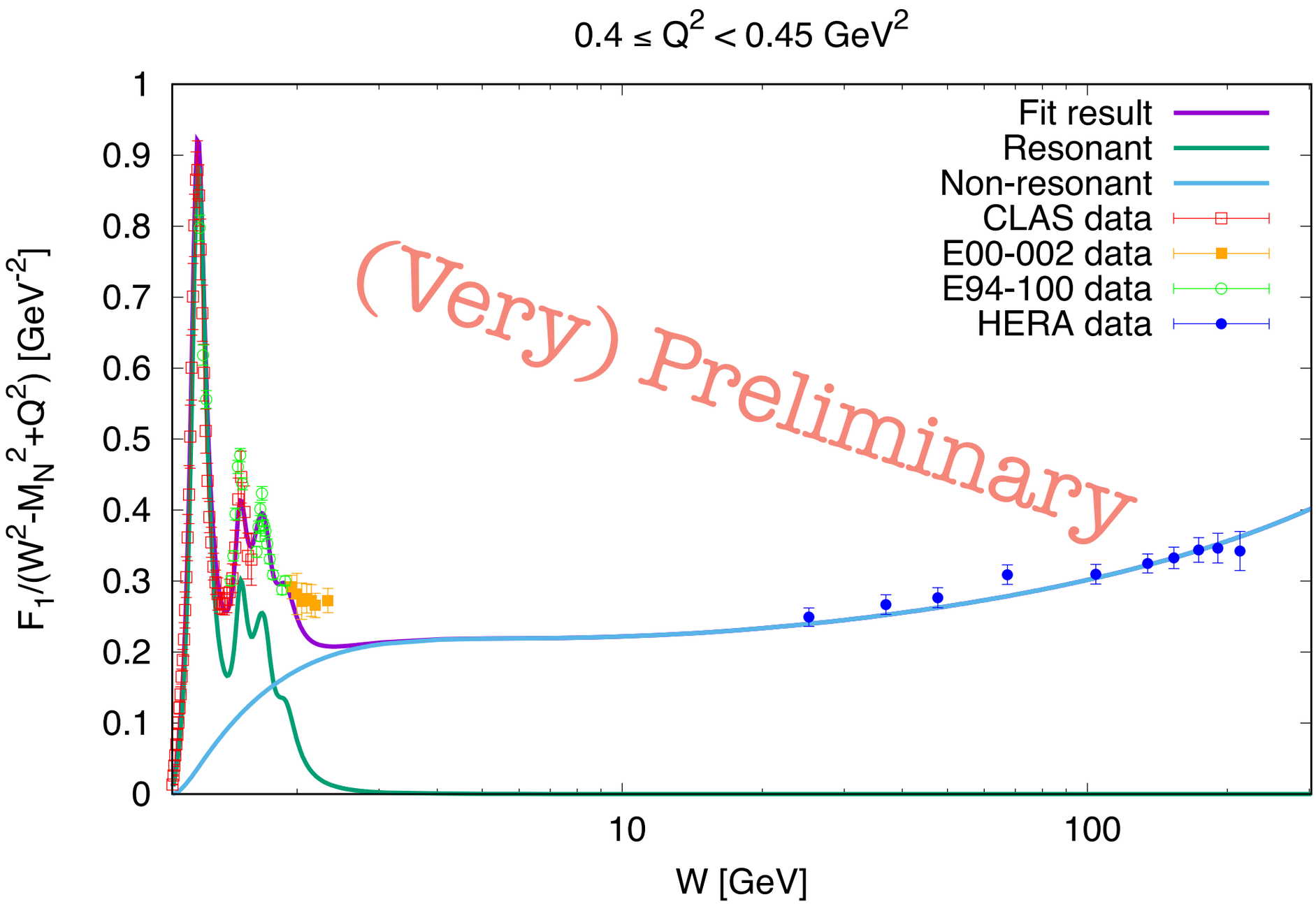
$$\overline{\mathbf{T}}_1(0, 0) = 0$$

  and using the known value of the magnetic polarizability:

$$\beta_{M1} = \frac{\mathrm{d}}{\mathrm{d}Q^2} \overline{T}_1(0, Q^2) \Big|_{Q^2=0}$$

- Reduces the fit parameter space even further

Preliminary results at non-vanishing Q^2



First combined model for low and high energies!

Summary

- New resonance model: **N* electrocouplings** from CLAS(12) allow to describe the **resonant contributions** to inclusive electron-scattering

- Intricate behaviour with W and Q^2 in the resonance regime

- First estimates for the background behaviour

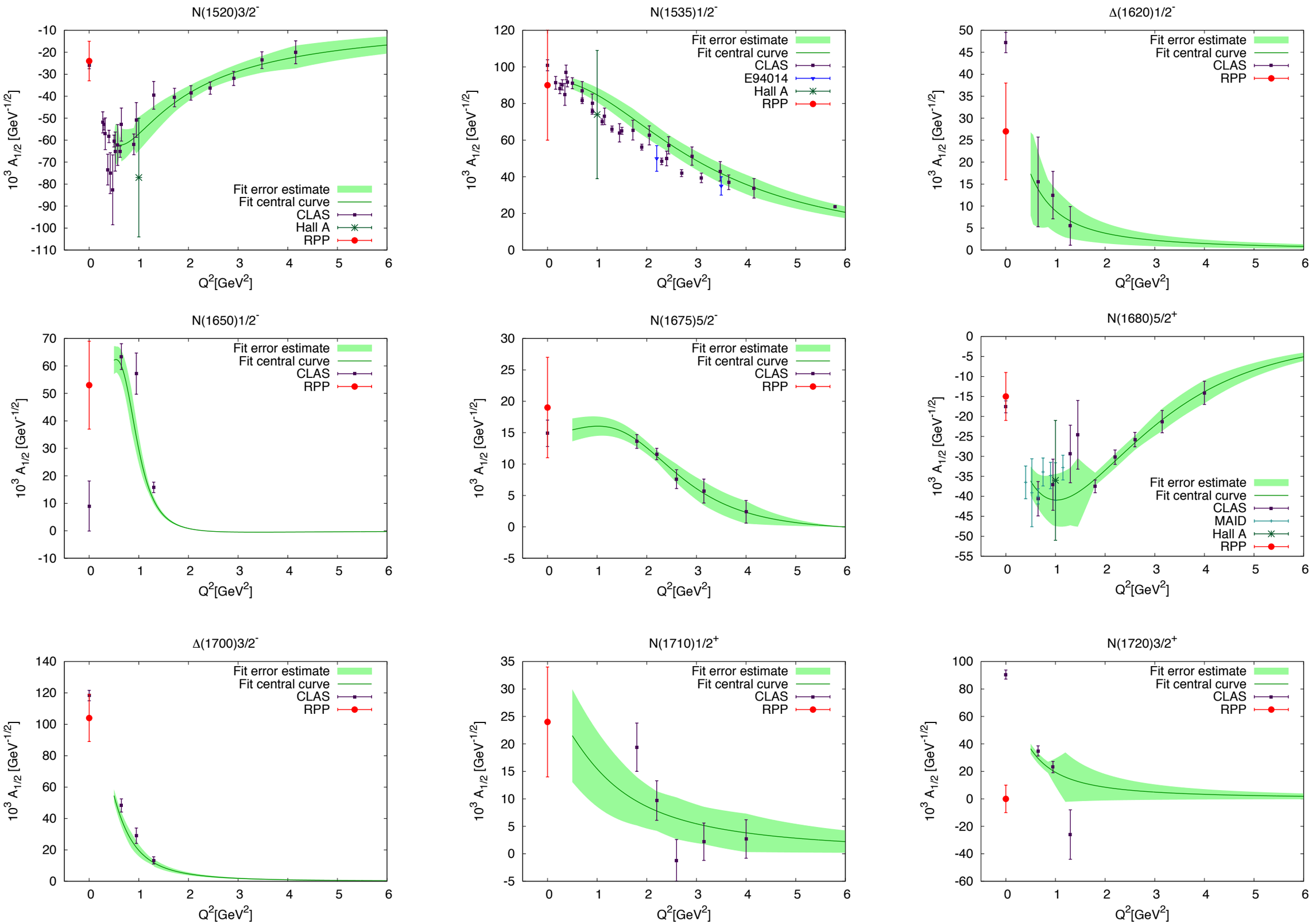
Work in progress

- Transition between low and high *x* (or energies): important for VVCS subtraction function

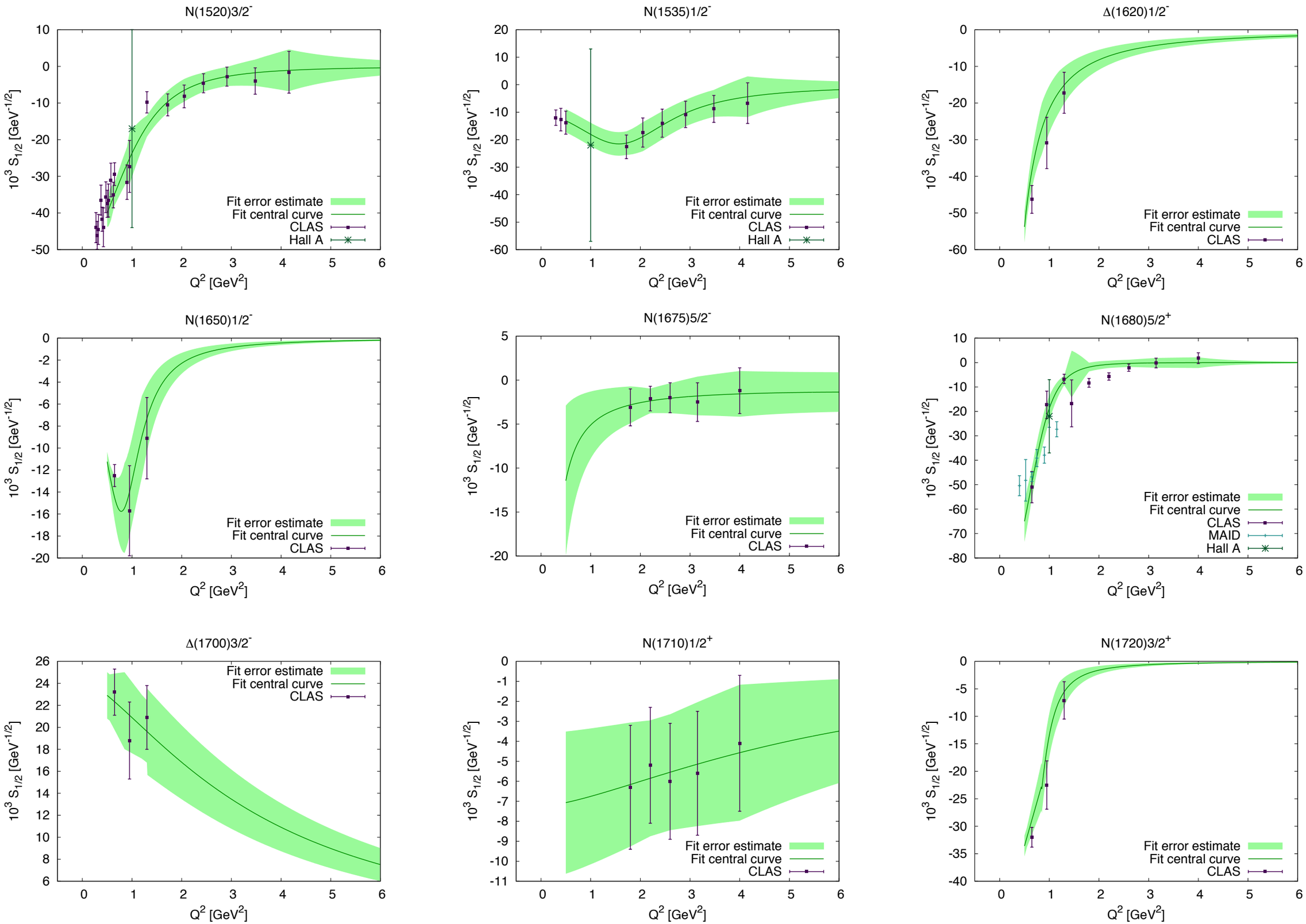
- High-energy data described well by Regge models: update with threshold parameters and resonance contributions

- Updates on inclusive and exclusive electron scattering CLAS12: coming soon!

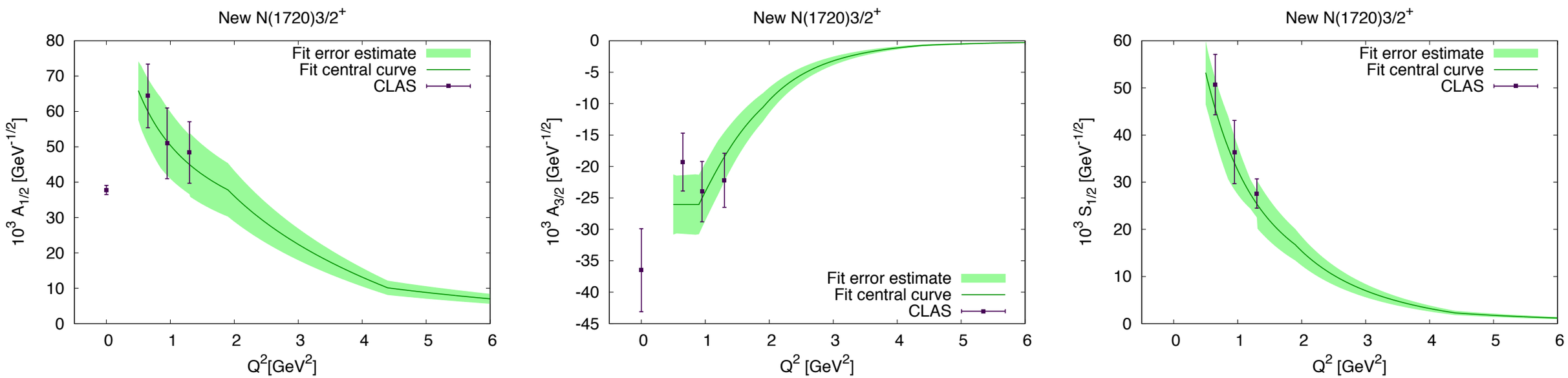
$A_{1/2}$

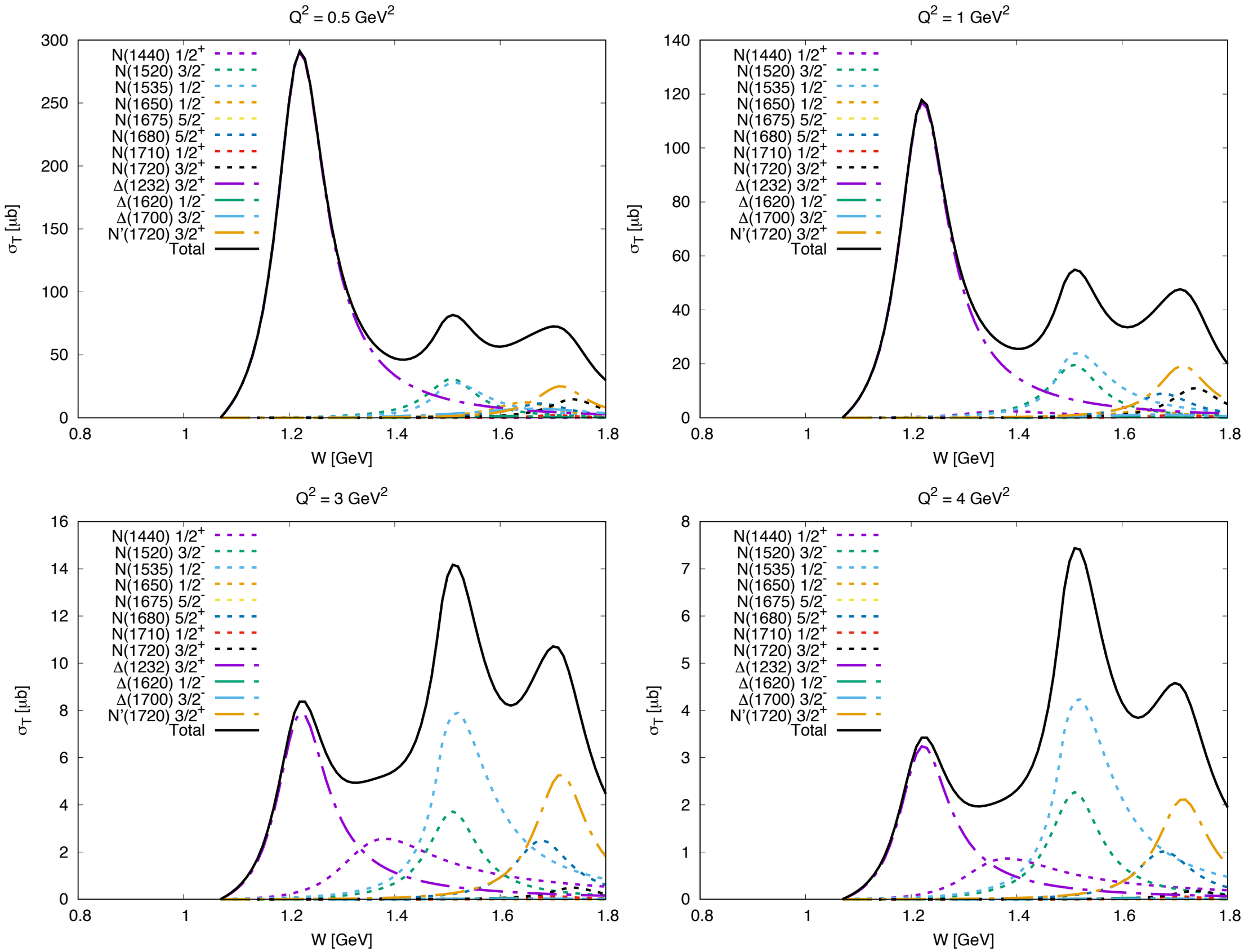

N(1520)3/2⁻
N(1535)1/2⁻
Δ(1620)1/2⁻
N(1650)1/2⁻
N(1675)5/2⁻
N(1680)5/2⁺
Δ(1700)3/2⁻
N(1710)1/2⁺
N(1720)3/2⁺
Fit error estimate
Fit central curve
CLAS
E94014
Hall A
MAID
RPP
$10^3 A_{1/2}$ [GeV$^{-1/2}$]
Q^2[GeV^2]

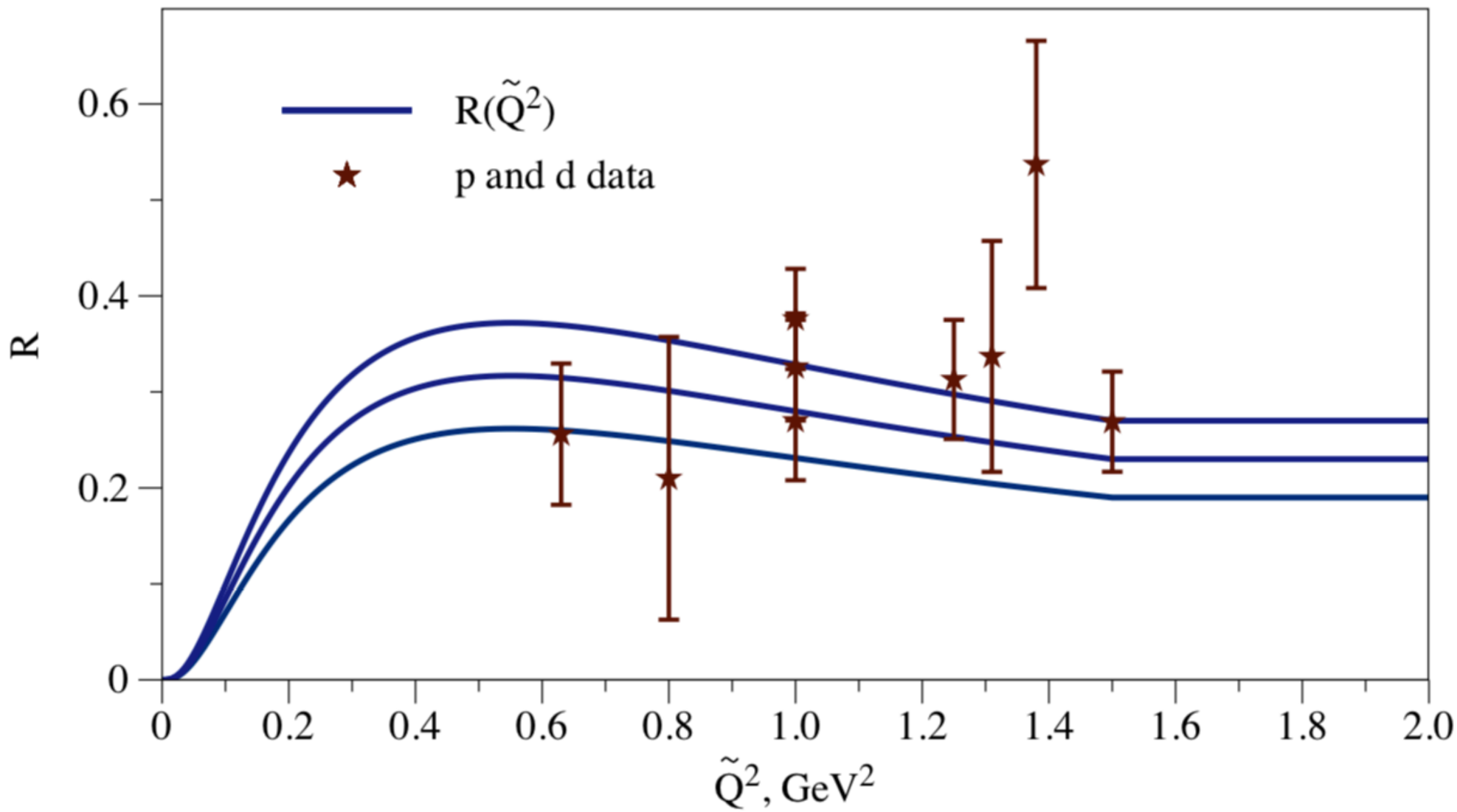
$S_{1/2}$


N(1520)3/2⁻
N(1535)1/2⁻
Δ(1620)1/2⁻
N(1650)1/2⁻
N(1675)5/2⁻
N(1680)5/2⁺
Δ(1700)3/2⁻
N(1710)1/2⁺
N(1720)3/2⁺
10³ S1/2 [GeV⁻¹/²]
Q² [GeV²]
Fit error estimate
Fit central curve
CLAS
Hall A
MAID

New resonance




Q2 = 0.5 GeV2
Q2 = 1 GeV2
Q2 = 3 GeV2
Q2 = 4 GeV2
N(1440) 1/2+
N(1520) 3/2-
N(1535) 1/2-
N(1650) 1/2-
N(1675) 5/2-
N(1680) 5/2+
N(1710) 1/2+
N(1720) 3/2+
Δ(1232) 3/2+
Δ(1620) 1/2-
Δ(1700) 3/2-
N'(1720) 3/2+
Total
σT [μb]
W [GeV]


R($\tilde{Q}^2$)
p and d data
0.6
0.4
0.2
0
R
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
$\tilde{Q}^2$, GeV^2