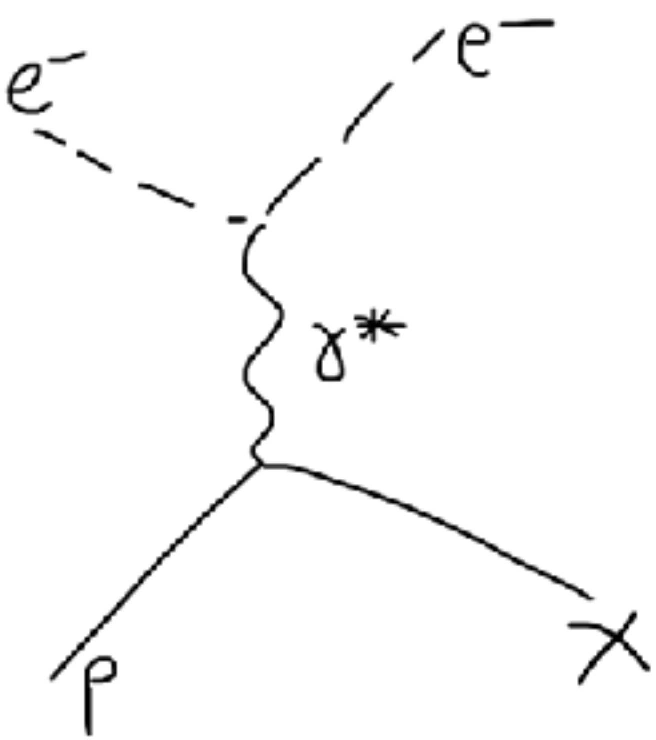
APCTP Workshop - JLAB physics in the 12-GeV era

# FESR constraints on electron and Compton scattering

*2018-07-01*



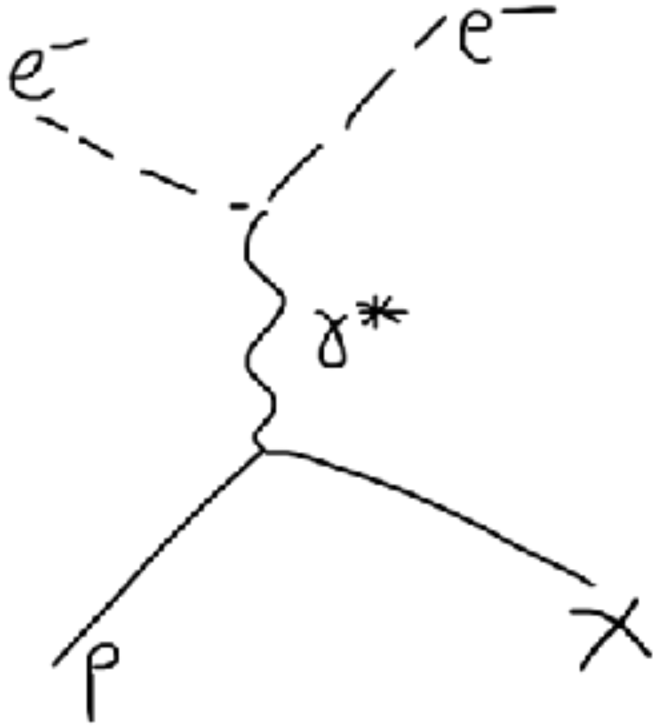


**Astrid N. Hiller Blin**

**JGU Mainz**

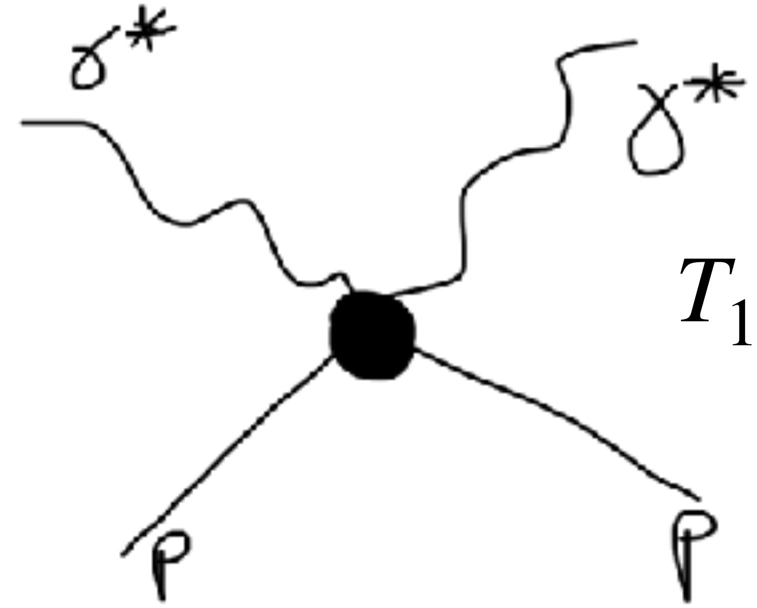
In collaboration with M. Vanderhaeghen and JPAC

# $e^-$ scattering and VVCS: connection




$F_1, F_2$

$\sigma_T, \sigma_L$

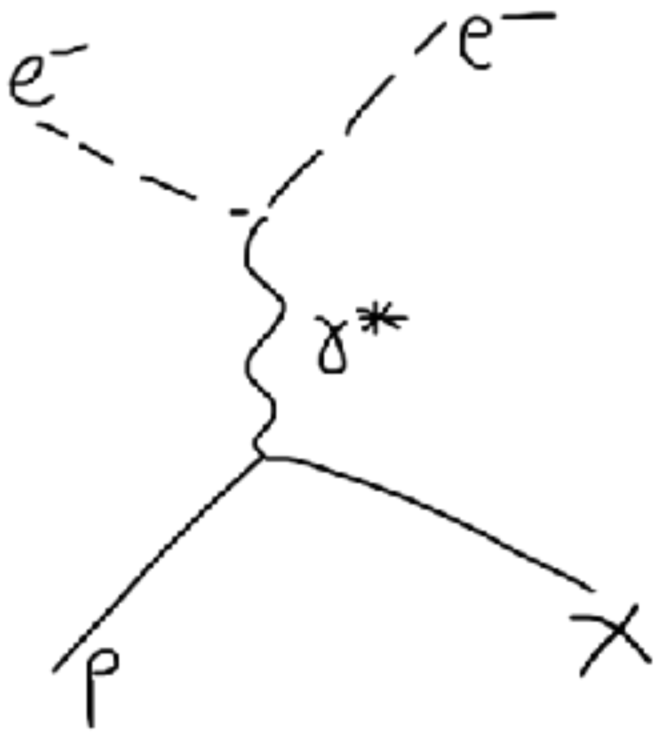



$T_1, T_2$

$$F_1(\nu, q^2) \propto \sigma_T(\nu, q^2)$$

$$F_2(\nu, q^2) \propto \sigma_T(\nu, q^2) + \sigma_L(\nu, q^2)$$

# e⁻ scattering and VVCS: connection

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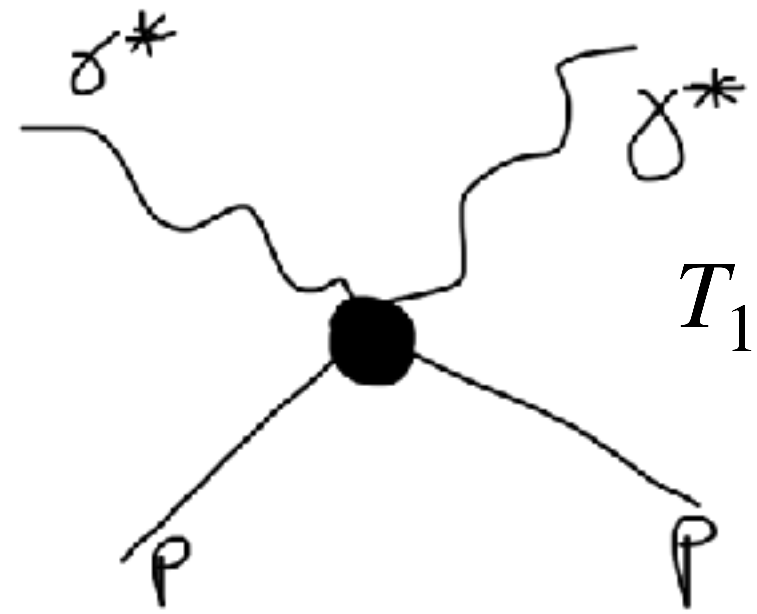


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$$T^{\mu\nu} = \left(-g^{\mu\nu} + \frac{q^\mu q^\nu}{q^2}\right) \boxed{T_1(\nu, q^2)} + \frac{1}{M^2}\left(p^\mu - \frac{p\cdot q}{q^2}q^\mu\right)\left(p^\nu - \frac{p\cdot q}{q^2}q^\nu\right)\boxed{T_2(\nu, q^2)}$$

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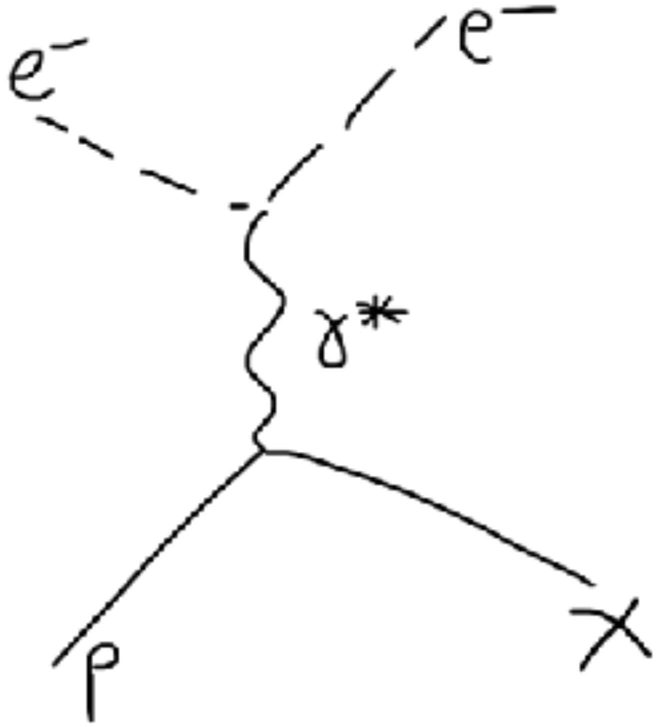


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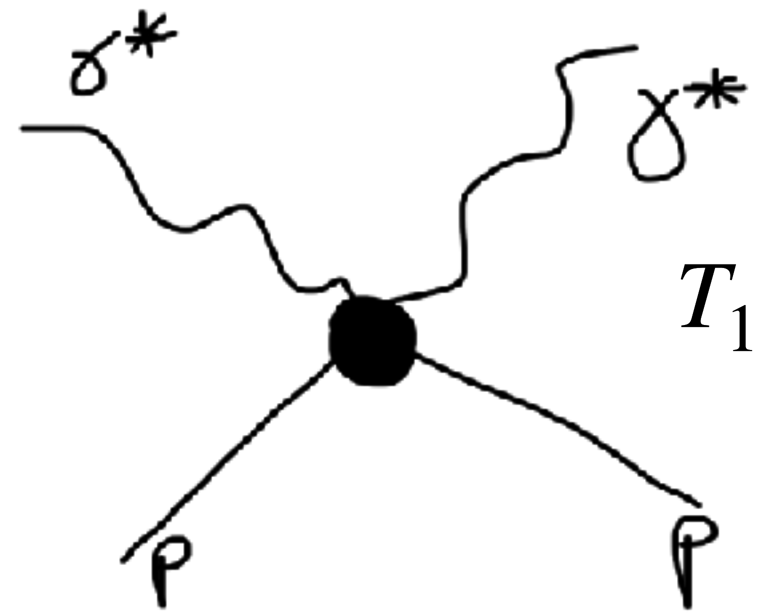


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$$\mathrm{Im} T_1(\nu, q^2) = \frac{e^2}{4M} F_1(\nu, q^2)$$

$$\mathrm{Im} T_2(\nu, q^2) = \frac{e^2}{4\nu} F_2(\nu, q^2)$$

# Interest in electron-scattering structure functions

- Tests on quark-hadron duality
- Comparison with CLAS(12) **$F_2$ data**:
  **Existing** narrow binning in $Q^2$ and W;
  Experiments at higher $Q^2$ in **12-GeV era**
- Connection with CLAS(12) **electrocouplings**
  (see talk by V. Mokeev)

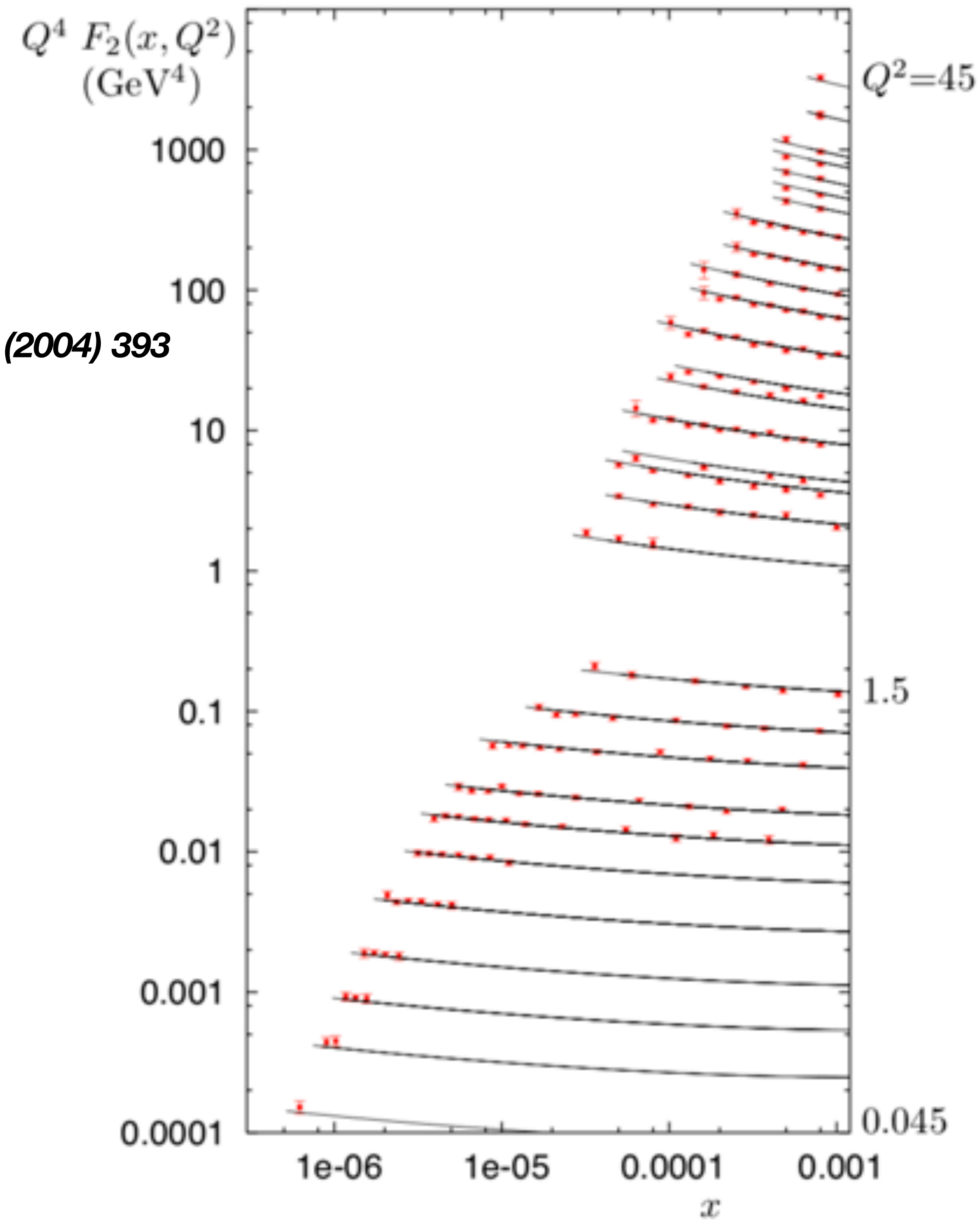
# The interest in $T_1$

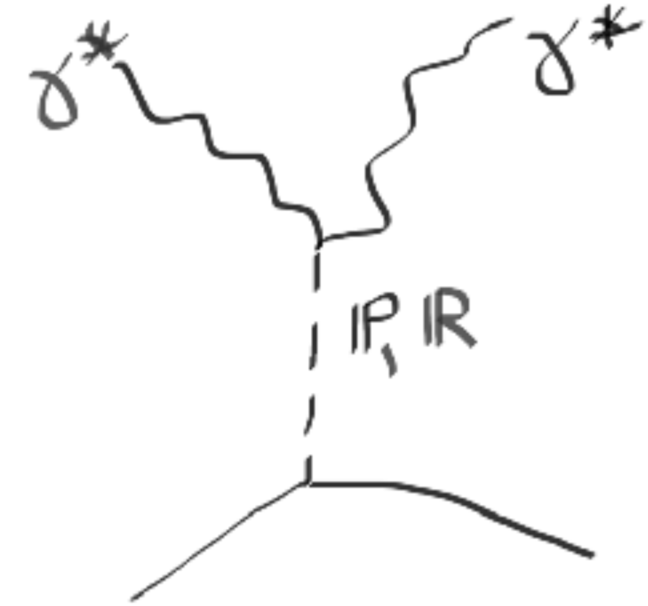
- **Lamb shift** and **Cottingham formula**
- Determining $T_1$ is intricate:
  unlike $T_2$, **subtracted** dispersion relation
- Want: parametrization of $T_1$ at all W and $Q^2$

# Data & model status: high energies

***Donnachie and Landshoff, PLB 595 (2004) 393***

***HERA data***



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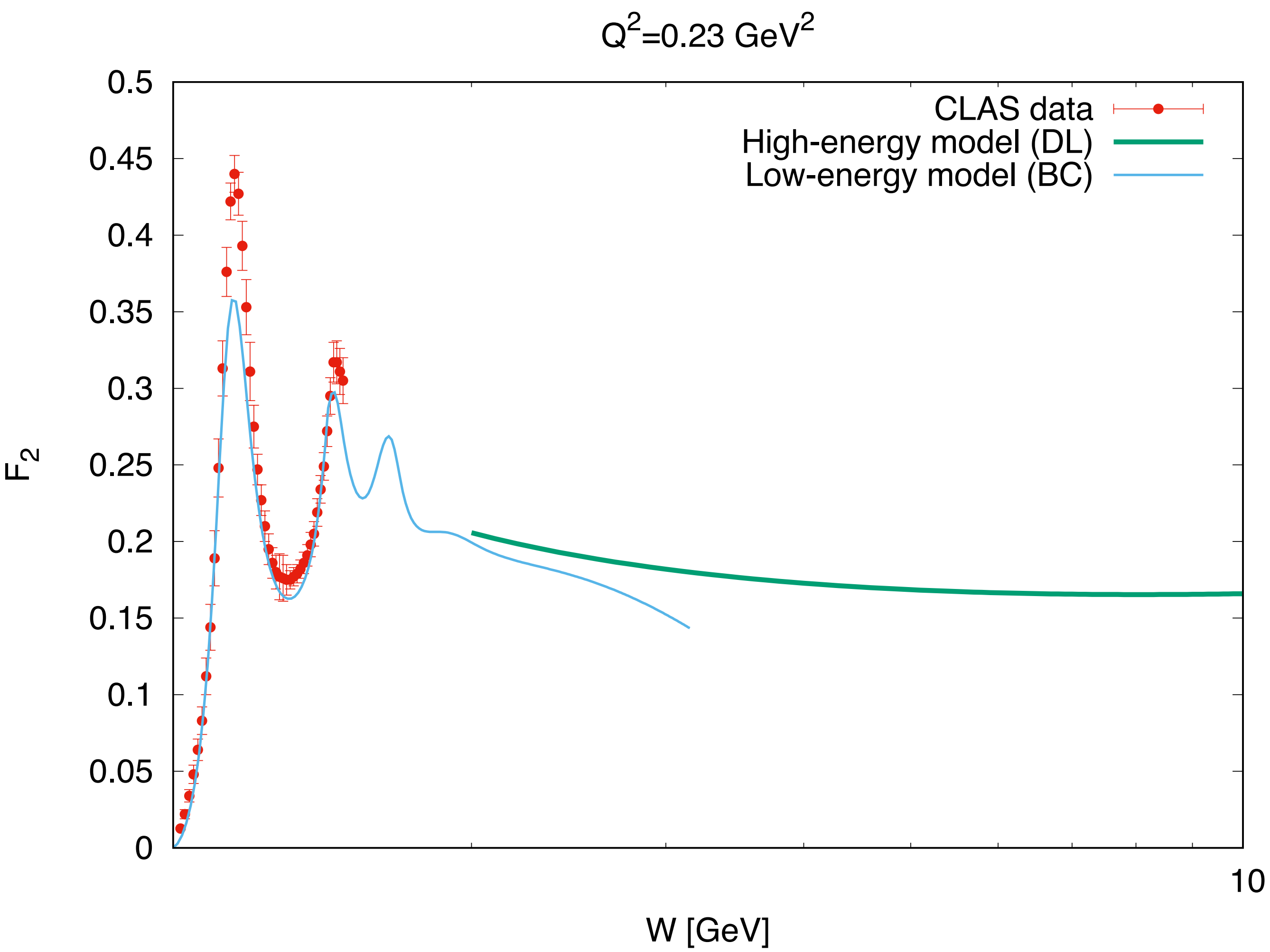


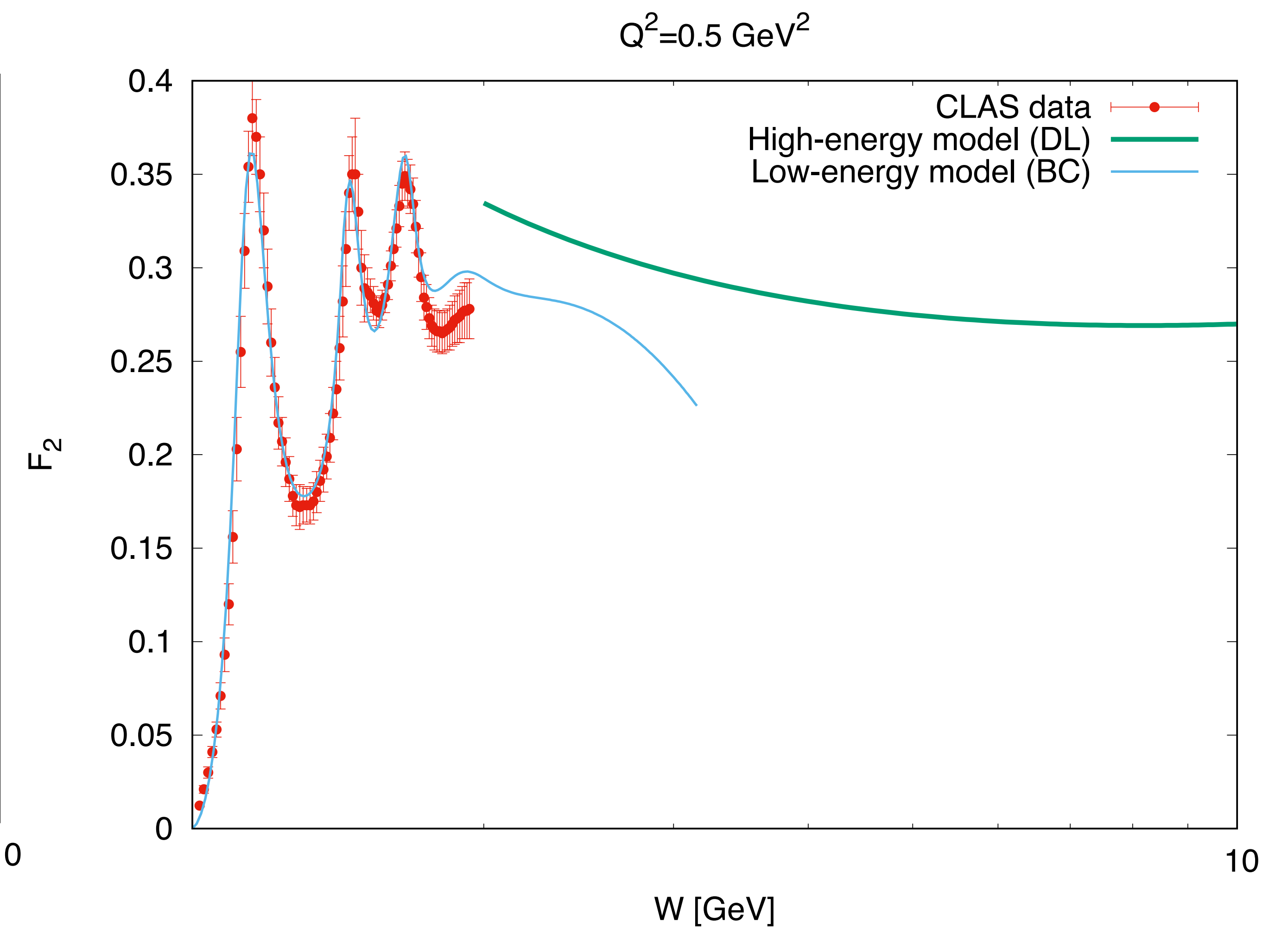


**At low $Q^2$: high- and low-energy theories compatible in overlap region**

# Low energies: status

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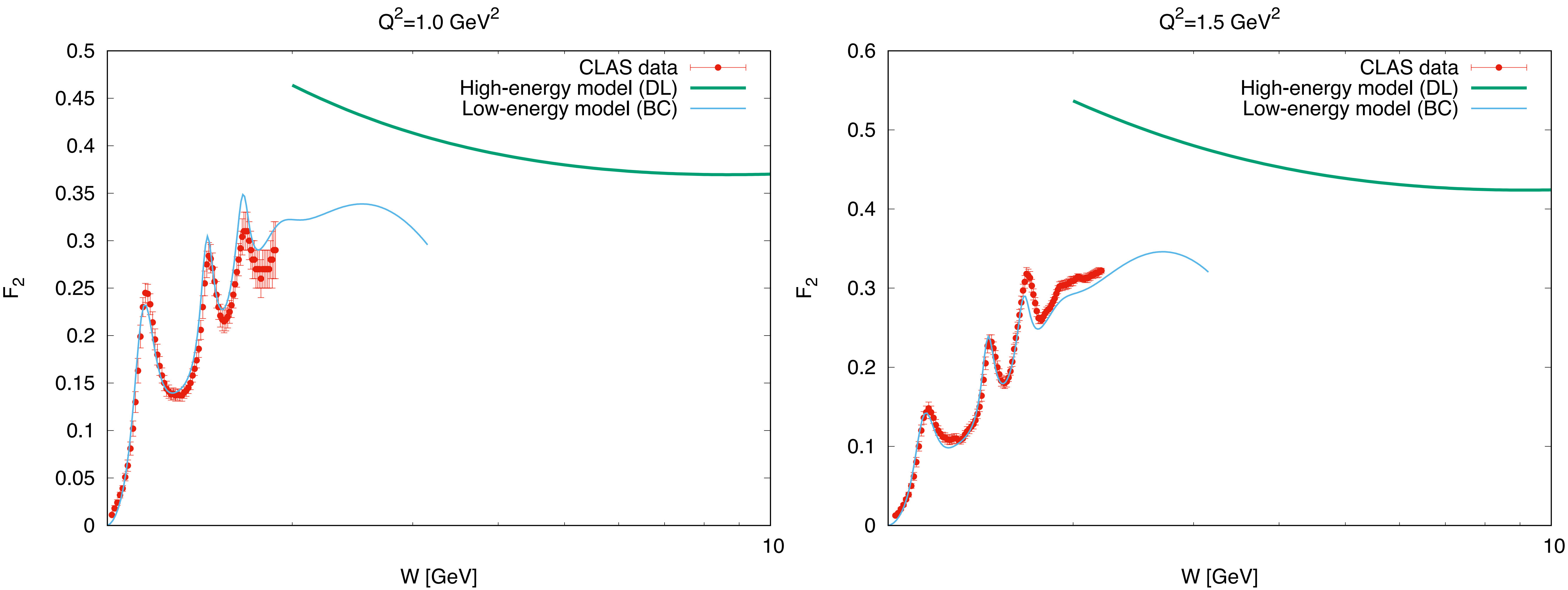


**For larger $Q^2$: huge gap between high and low-energy models in overlap region**

**Low energies: describing the resonant region**

**Our tool: finite-energy sum rules**

**High-energy model**

**Goals: high and low-energy connection**

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# Background: status

*Mokeev et al., PRC 86 (2012) 035203*

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

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**The non-resonant background**

$$\sigma^{NR}_{T}(W,Q^2) = x'_T \sum_{i=1}^{2} \frac{\sigma^{NR,i}_{T}(0)}{(Q^2 + a_i^T)^{[b_i^T + c_i^T Q^2 + d_i^T Q^4]}} (W - m_\pi - M_N)^{i+1/2}$$

$$\sigma^{NR}_{L}(W,Q^2) = \frac{(1-x'_L)^{[a_1^L t + b_1^L]} {x'_L}^{[d_1^L + e_1^L t]}}{1-x} \frac{\sigma^{NR,1}_{L}(0)(Q^2)^{c_1^L}}{(Q^2 + {Q_0^2}^L)^{[1+c_1^L]}}$$

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- **Do not fulfill dispersion relations/analiticity**
- **Need to be revisited/fixed by FESR**

# Resonance model

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**Breit-Wigner resonance model**

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

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**Electrocouplings from CLAS data and fits**

*https://userweb.jlab.org/~isupov/couplings/*

$$\Gamma_\gamma^T(M_r,Q^2) \sim |A_{1/2}(Q^2)|^2 + |A_{3/2}(Q^2)|^2$$

$$\Gamma_\gamma^L(M_r,Q^2) \sim 2\frac{\nu^2}{Q^2}|S_{1/2}(Q^2)|^2$$

$$\Gamma_{\text{tot}}(W) = \Gamma_{\pi N}(W) + (1 - \text{BF}_{\pi N})\Gamma_r$$

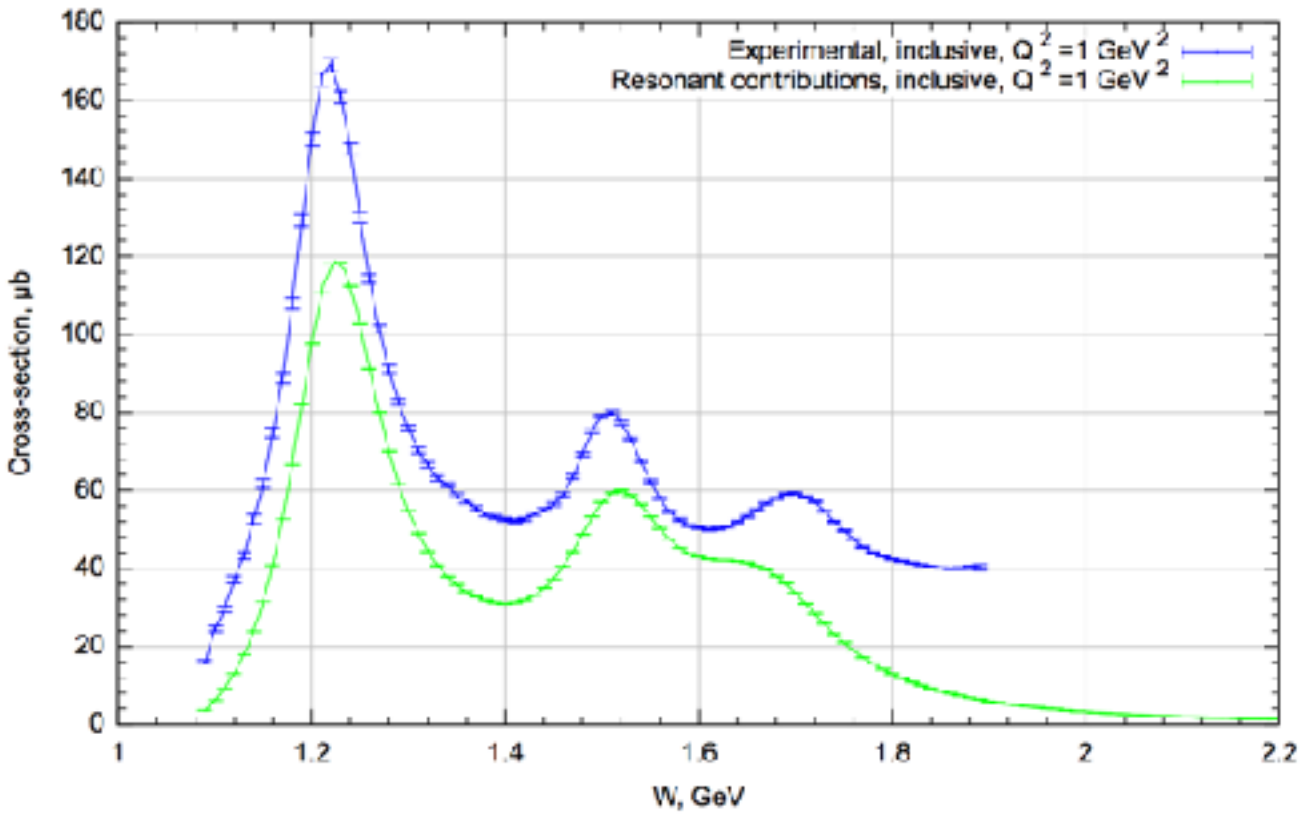
**Energy-dependence from decays into πN and ππN**

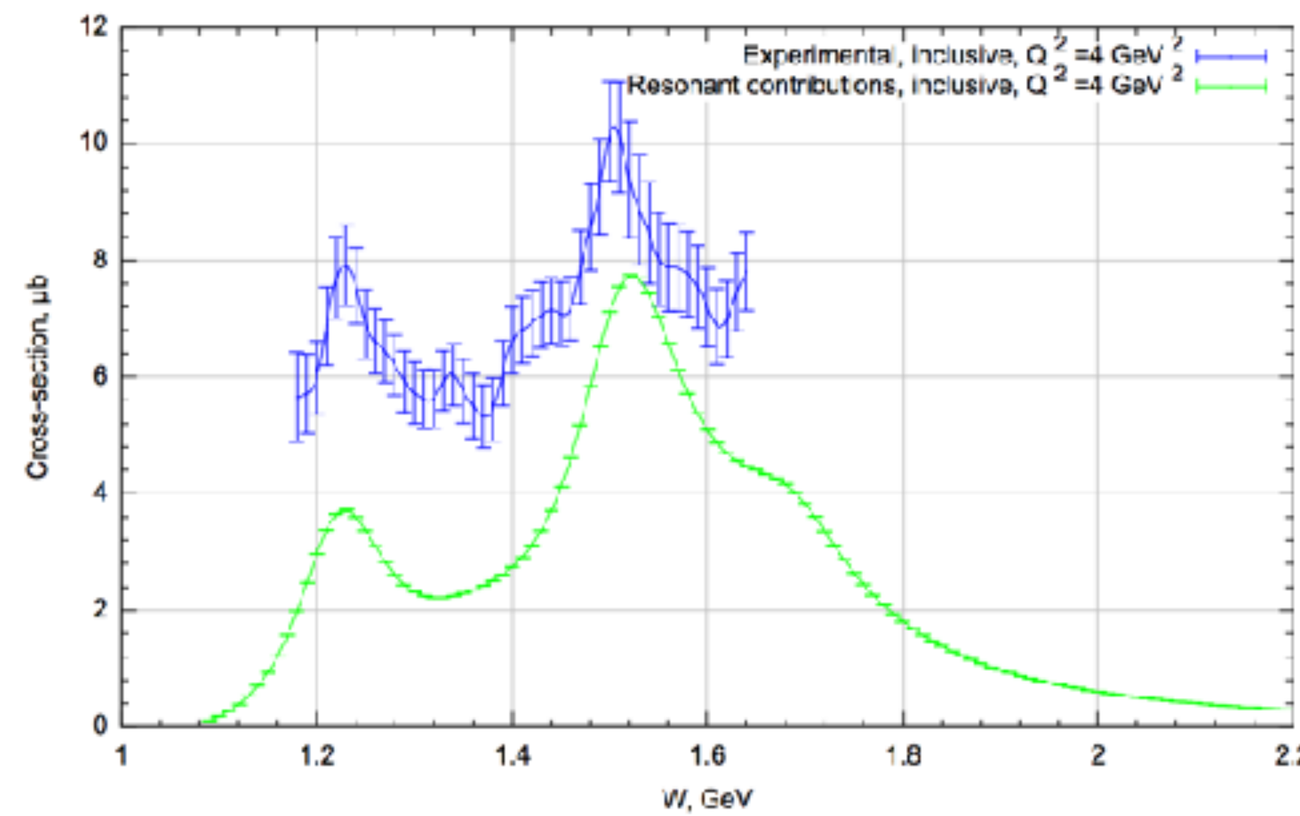
*Aznauryan, PRC 67 (2003) 015209*

# Resonances compared to CLAS data

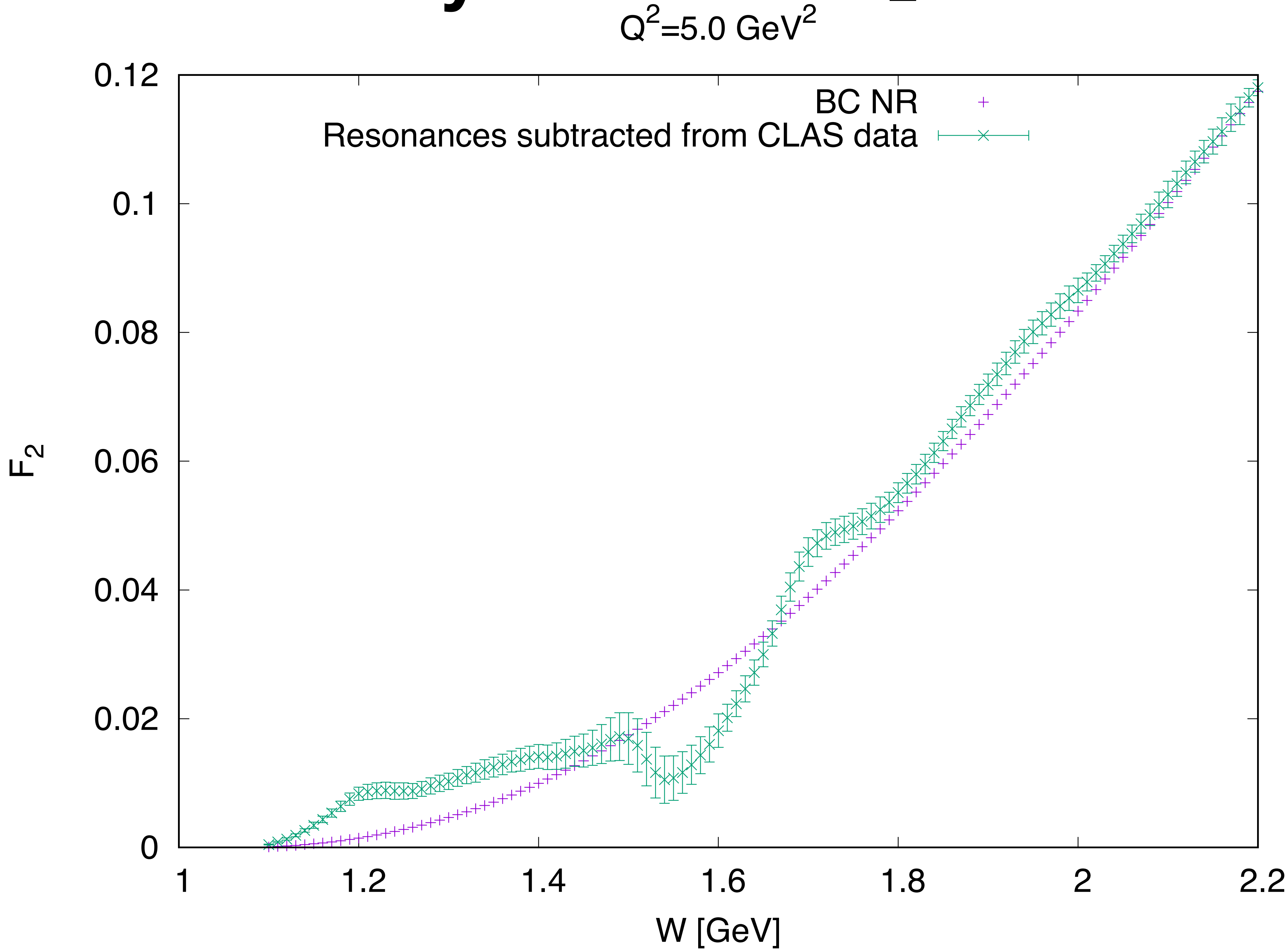
**CLAS structure functions and cross sections: user choice of W, Q² and beam energy**

***http://clas.sinp.msu.ru/strfun/***



# Duality in CLAS $F_2$ data



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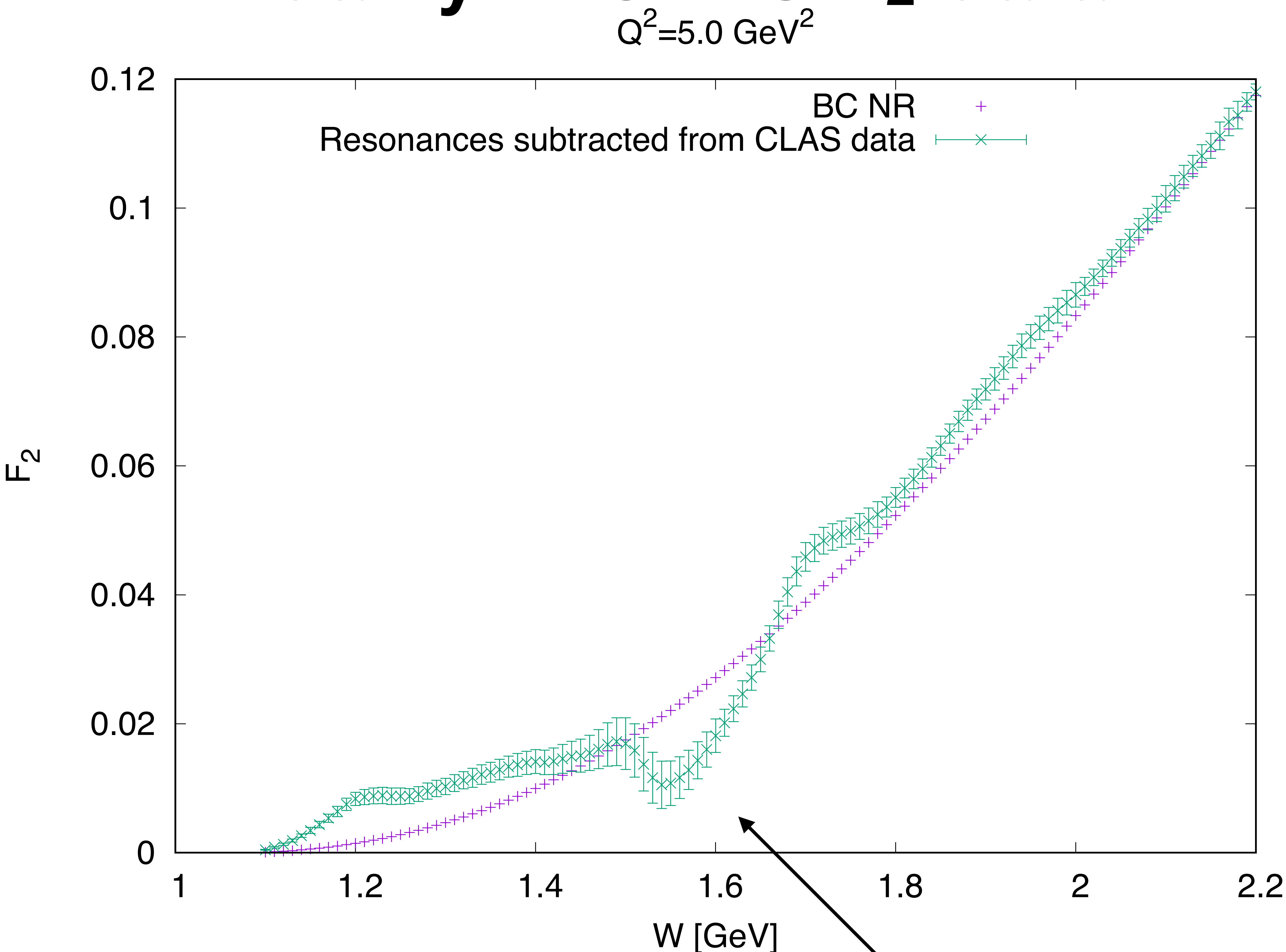



**The dip is expected from opening of meson-production channels!**

**Low energies: describing the resonant region**

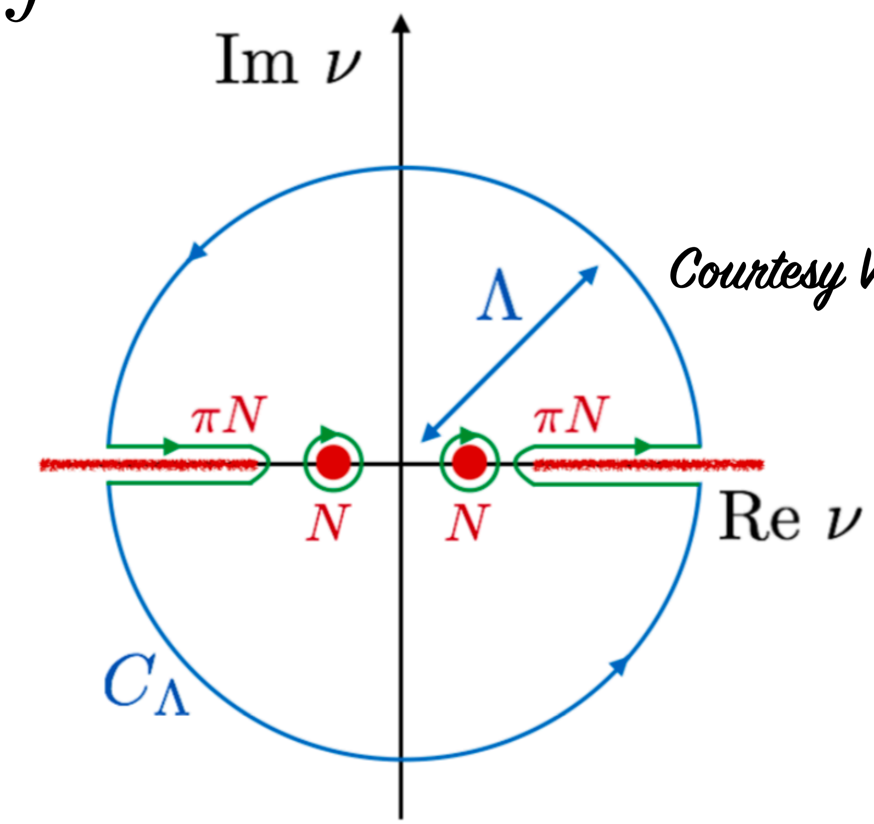
**<u>Our tool: finite-energy sum rules</u>**

**High-energy model**

**Goals: high and low-energy connection**

# Cauchy's Theorem

$$\oint T_i(\nu, Q^2)\mathrm{d}\nu = 0$$




Courtesy Vincent Mathieu

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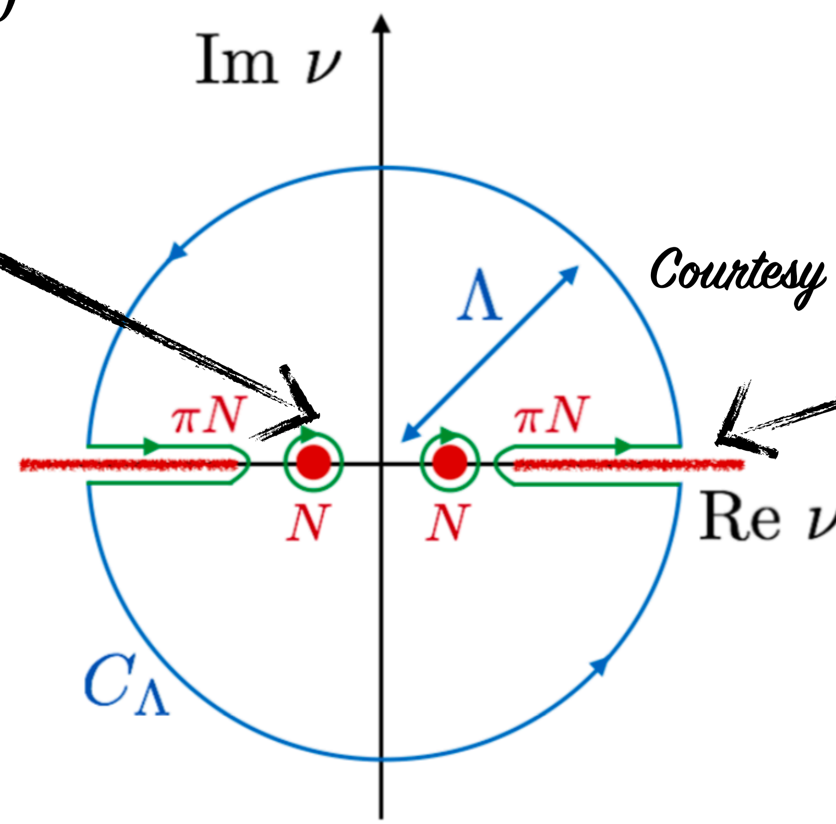
Poles: Born terms

Cuts: meson production

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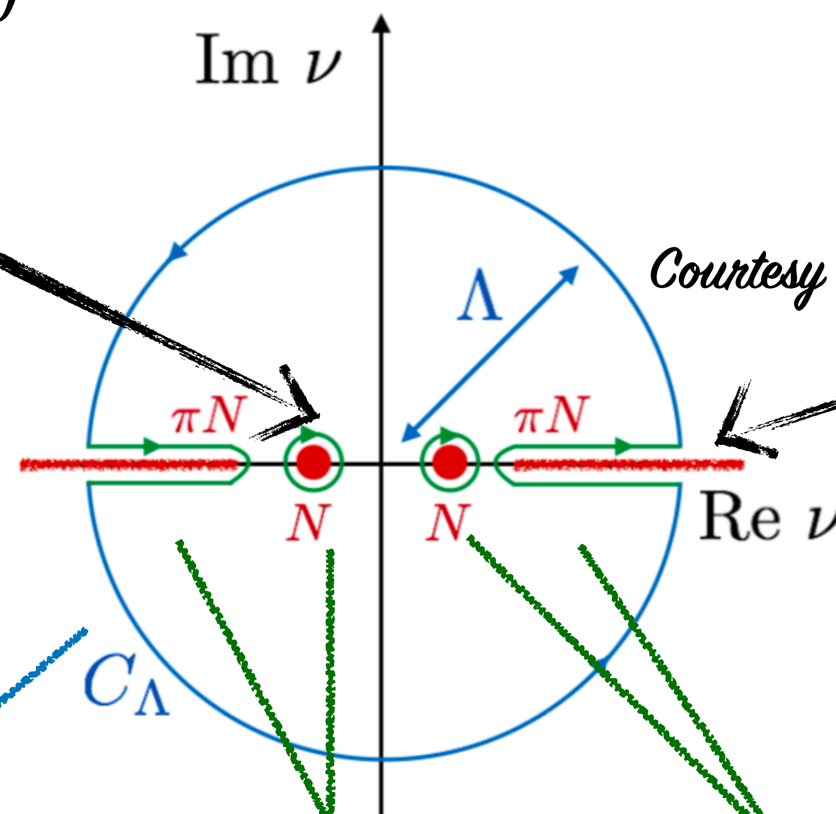


*Courtesy Vincent Mathieu*

In absence of fixed poles:

$$0 = \int_{C_\Lambda} T_i(\nu, Q^2)\nu^k \mathrm{d}\nu + \int_0^\Lambda \left[(-1)^k D_{i,L}(\nu, Q^2) + D_{i,R}(\nu, Q^2)\right]\nu^k \mathrm{d}\nu$$

$$D_{i,R}(\nu, Q^2) = \lim_{\epsilon \to 0}\left[T_i(\nu + \mathrm{i}\epsilon, Q^2) - T_i(\nu - \mathrm{i}\epsilon, Q^2)\right]$$

# FESR: the idea

- Amplitudes with correct analytic behaviour: Cauchy's theorem fulfilled exactly

- Equivalently: FESR fulfilled

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$$-\int_{C_\Lambda} T_i(\nu, Q^2)\nu^k \mathrm{d}\nu = \int_0^\Lambda \left[D_{i,R}(\nu, Q^2) + (-1)^k D_{1,L}(\nu, Q^2)\right] \nu^k \mathrm{d}\nu$$

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- We want to generalize this to:

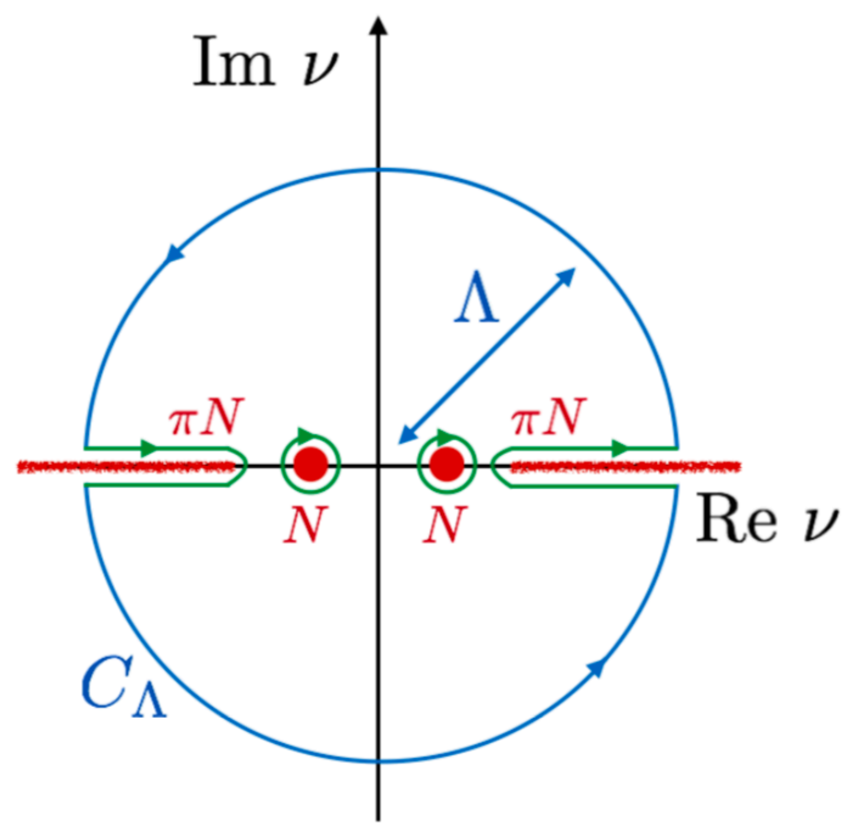
**High-energy model = LHS** **Low-energy model = RHS**

Appropriate **cutoff Λ** needed! Larger than resonance region, but still sensitive to it.

# RHS: low energies

$$\text{RHS} = \int_0^\Lambda \left[D_{i,R}(\nu, Q^2) + (-1)^k D_{1,L}(\nu, Q^2)\right] \nu^k \mathrm{d}\nu$$

$$= -2\mathrm{i}\left(\pi B_i(Q^2)\nu_N^k + \int_{\nu_0}^\Lambda \mathrm{Im}T_i(\nu, Q^2)\nu^k \mathrm{d}\nu\right)(1 + \tau_i(-1)^k)$$



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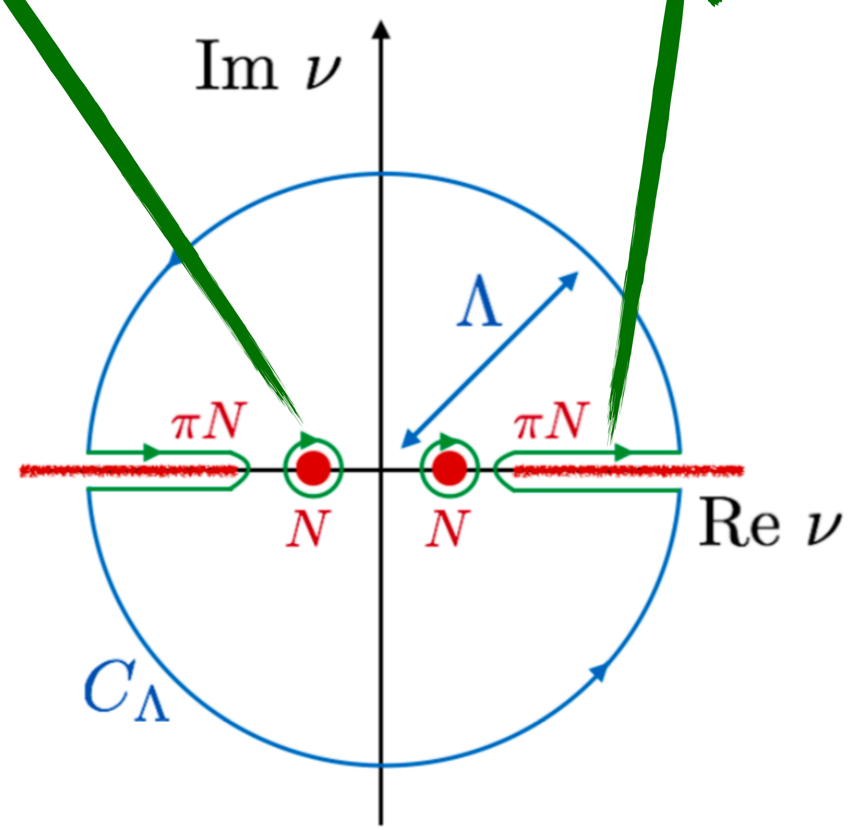



**Form factors from A1 collaboration**
*Bernauer et al., PRC 90 (2014) 015206*

**Low energies: describing the resonant region**

**Our tool: finite-energy sum rules**

**High-energy model**

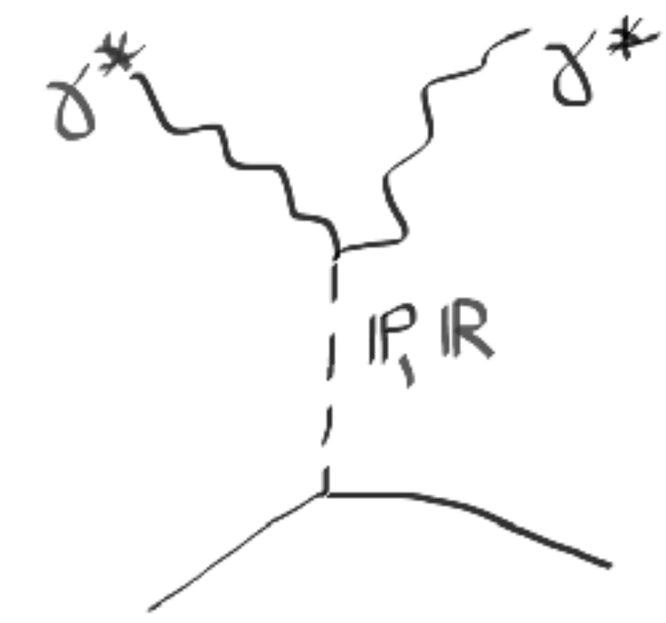
**Goals: high and low-energy connection**

# LHS: high-energy model

*Donnachie and Landshoff, PLB 595 (2004) 393*

$$F_2(x, Q^2) = f_h(Q^2)x^{-\epsilon_h} + f_s(Q^2)x^{-\epsilon_s} + f_r(Q^2)x^{-\epsilon_r}$$

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



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**Hard pomeron**

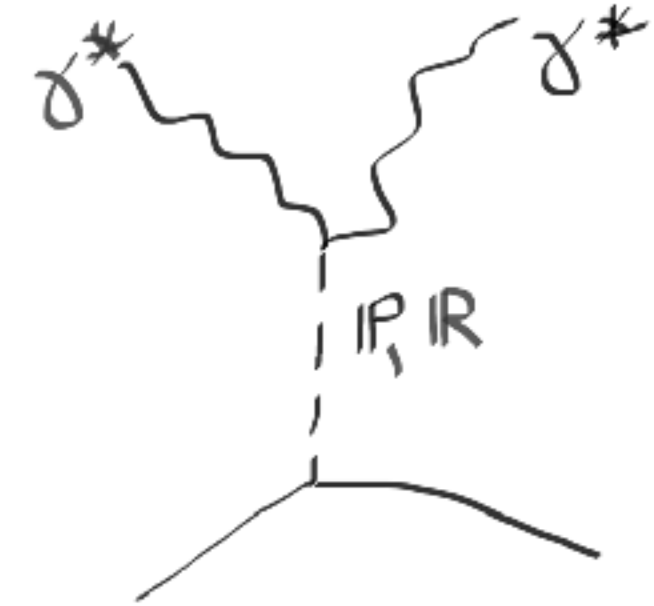
$\epsilon_h = \alpha_h - 1 = 0.452$

**Soft pomeron**

$\epsilon_s = \alpha_s - 1 = 0.0667$

**Meson exchange ($a_2$)**

$\epsilon_r = \alpha_r - 1 = -0.476$



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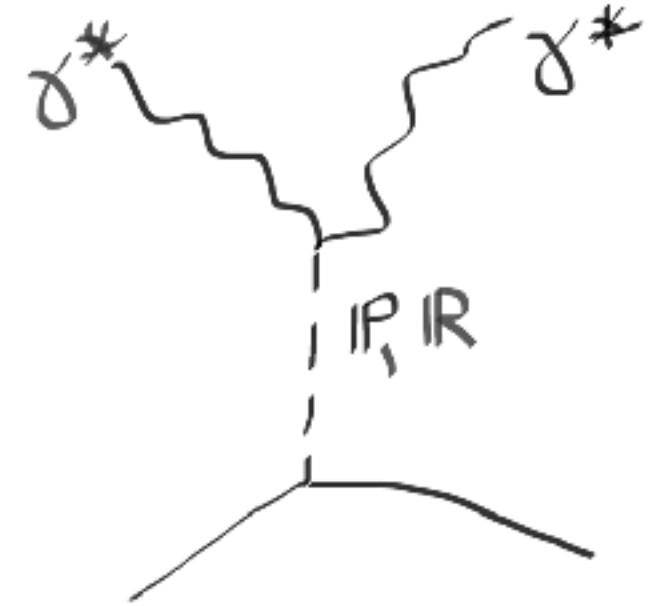
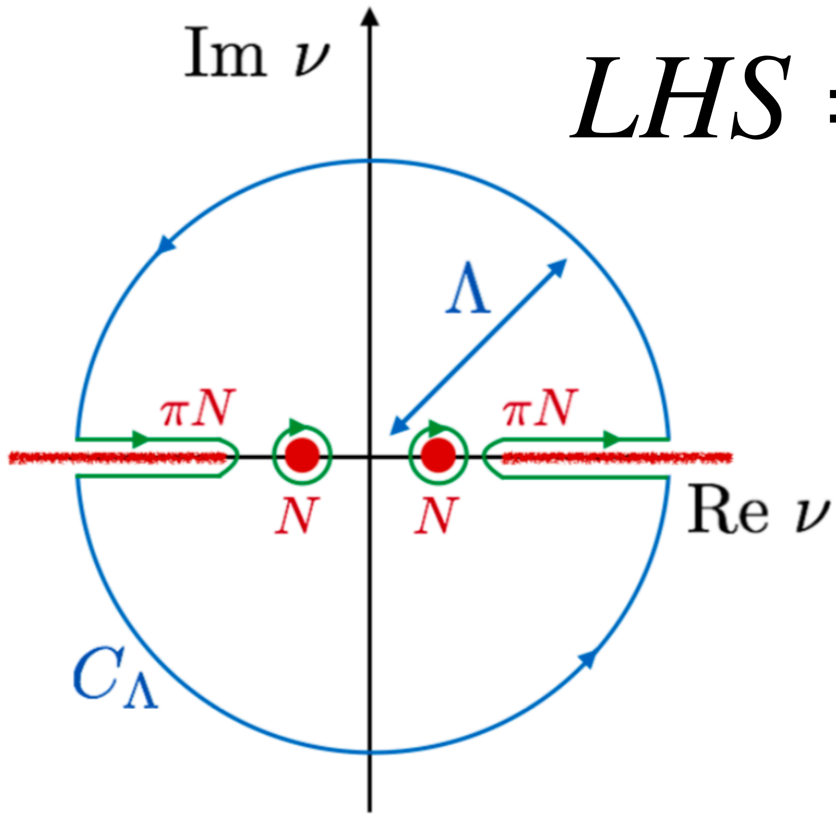
$$F_1(\nu, Q^2) = \frac{M_N\nu}{Q^2}\frac{F_2(\nu, Q^2)}{1+R}$$

$$R \propto \frac{\sigma_L}{\sigma_T}$$

*Ricco et al., NPB 555 (1999) 306*



# LHS: high energies




$$LHS = -\int_{C_\Lambda} T_i(\nu, Q^2)\nu^k \mathrm{d}\nu$$

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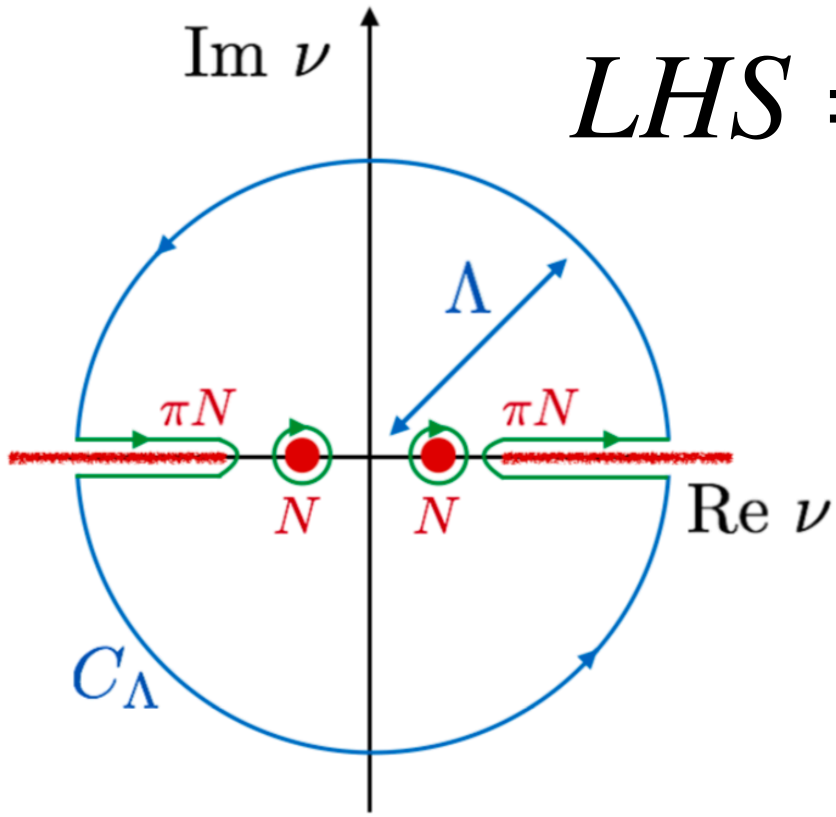


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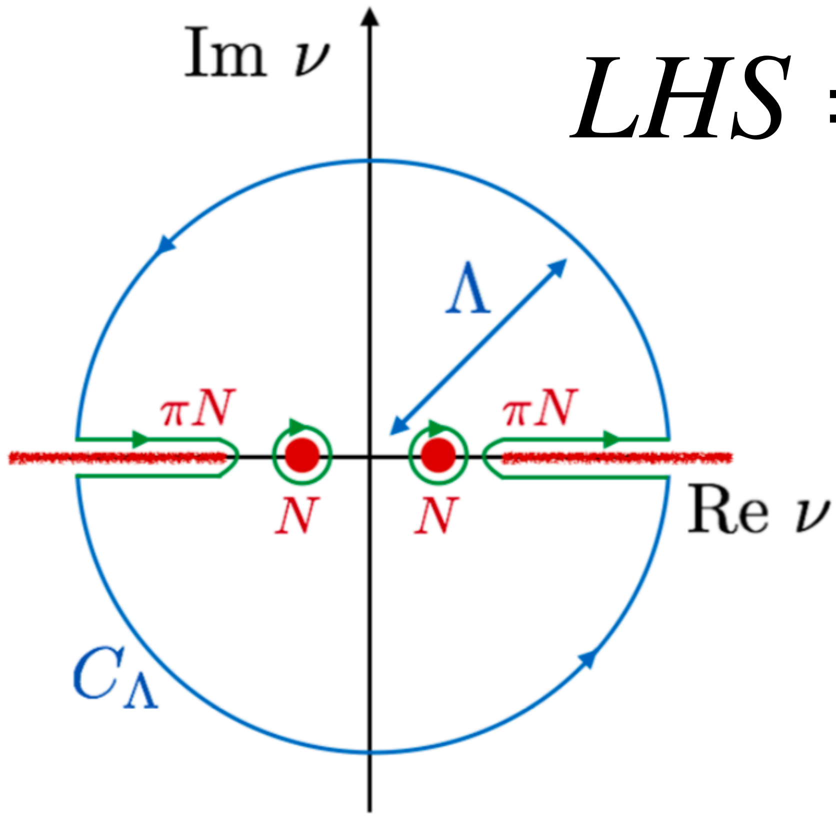


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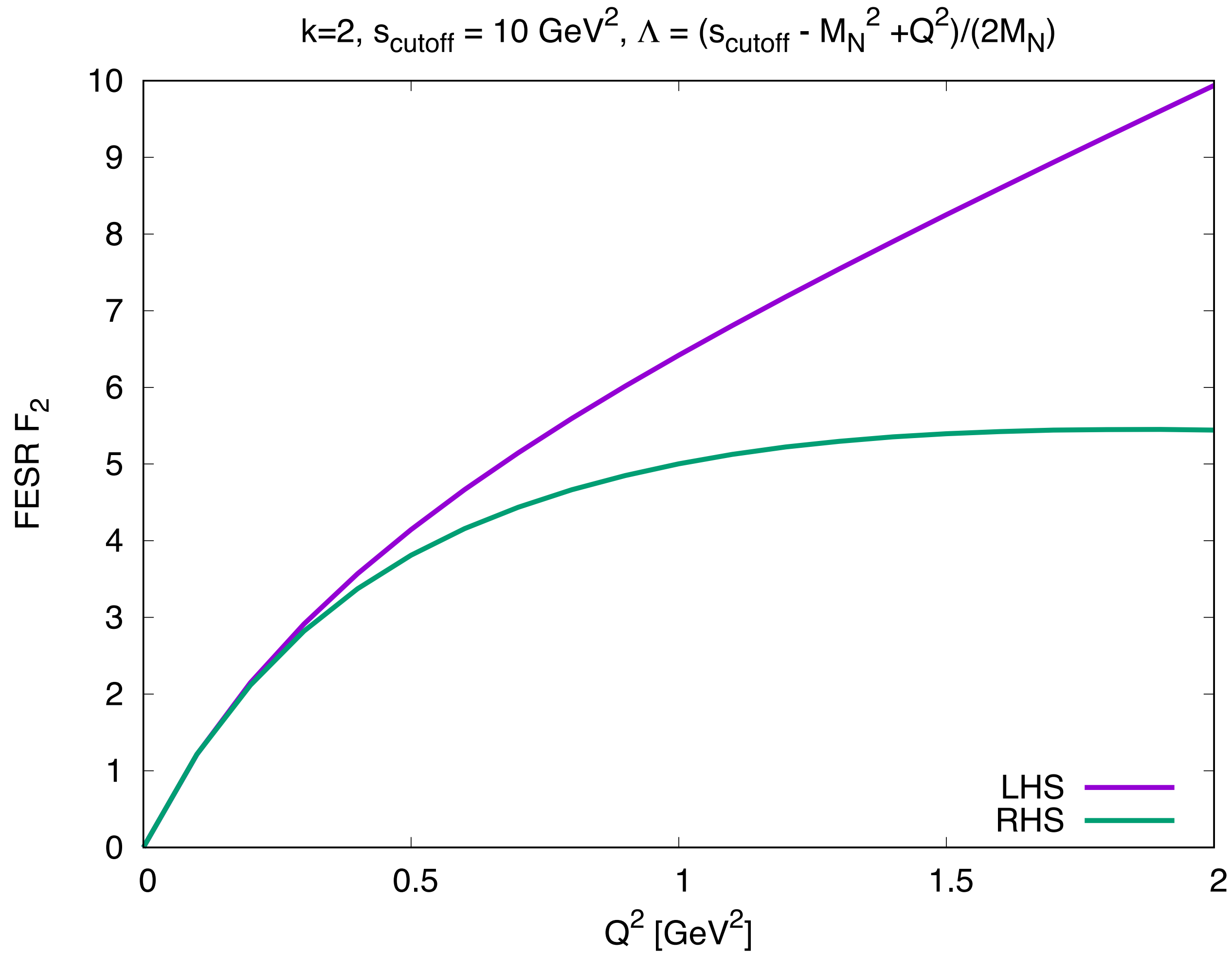
$$T_2 = \frac{\pi\alpha}{\nu} f_i(Q^2)\frac{\tau_i\left(\frac{2M_N\nu}{Q^2}\right)^{\alpha_i-1} + \left(-\frac{2M_N\nu}{Q^2}\right)^{\alpha_i-1}}{\sin(\pi\alpha_i)}$$

# Example FESR evaluation




**Result for the current Bosted&Christy model vs. Donnachie&Landshoff**

**Good match at $Q^2 = 0$ as expected, less compatible the larger $Q^2$!**

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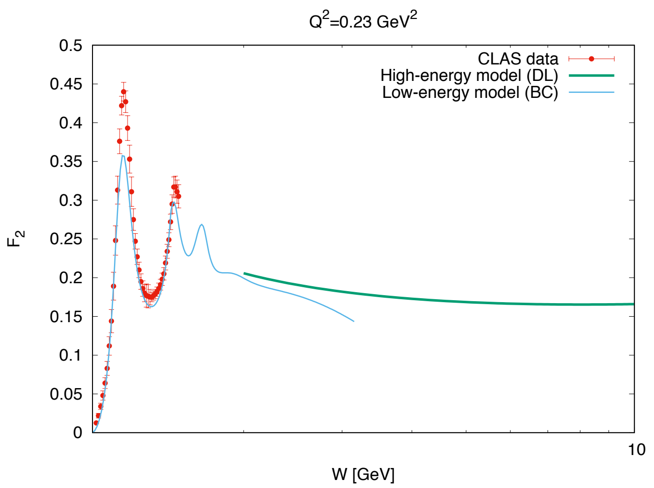


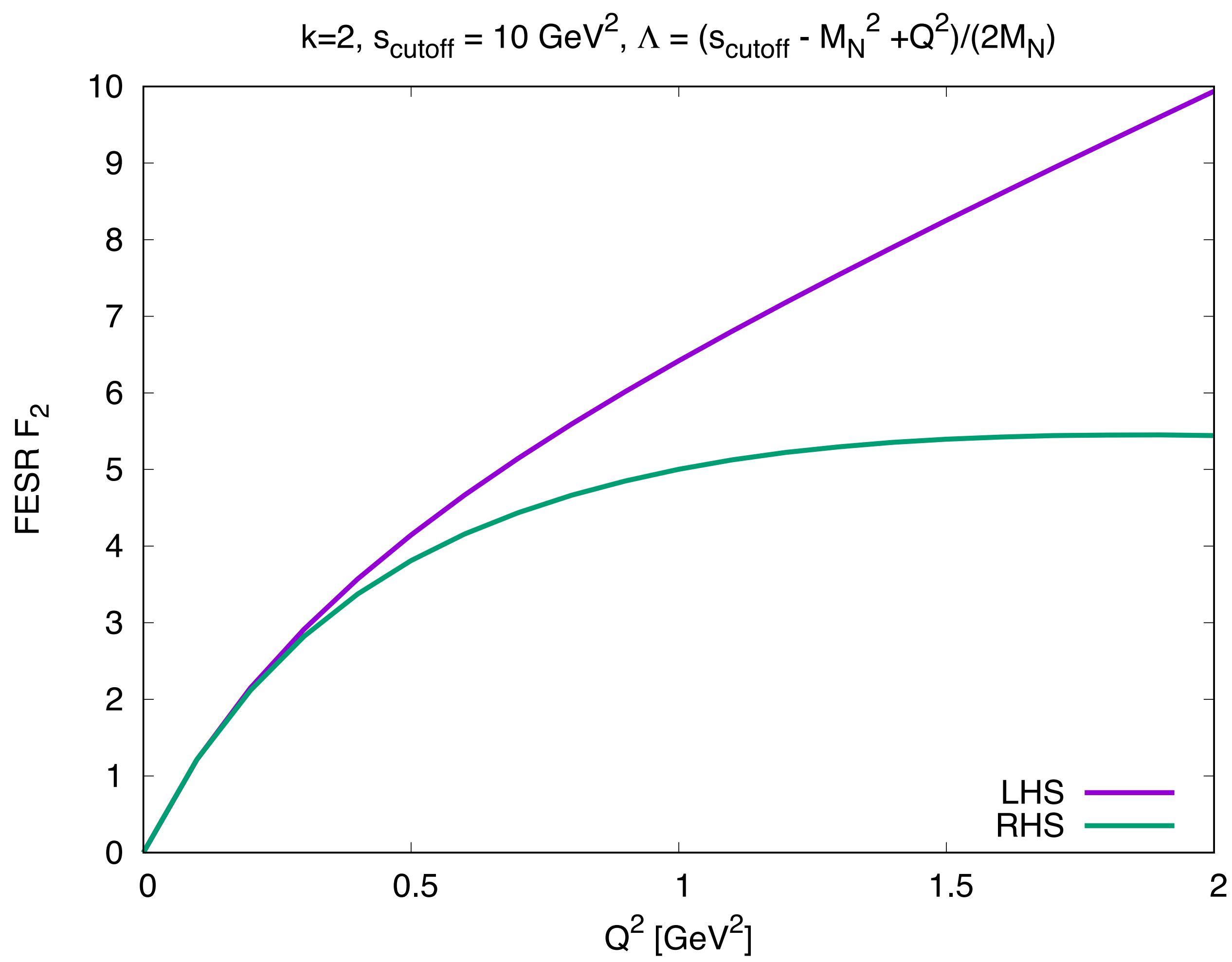


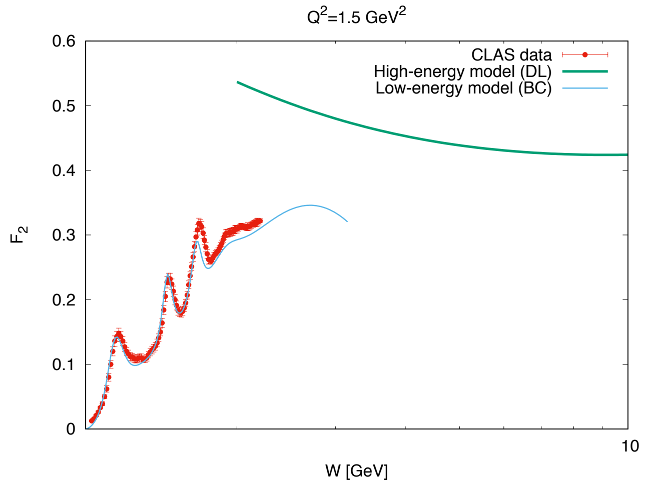


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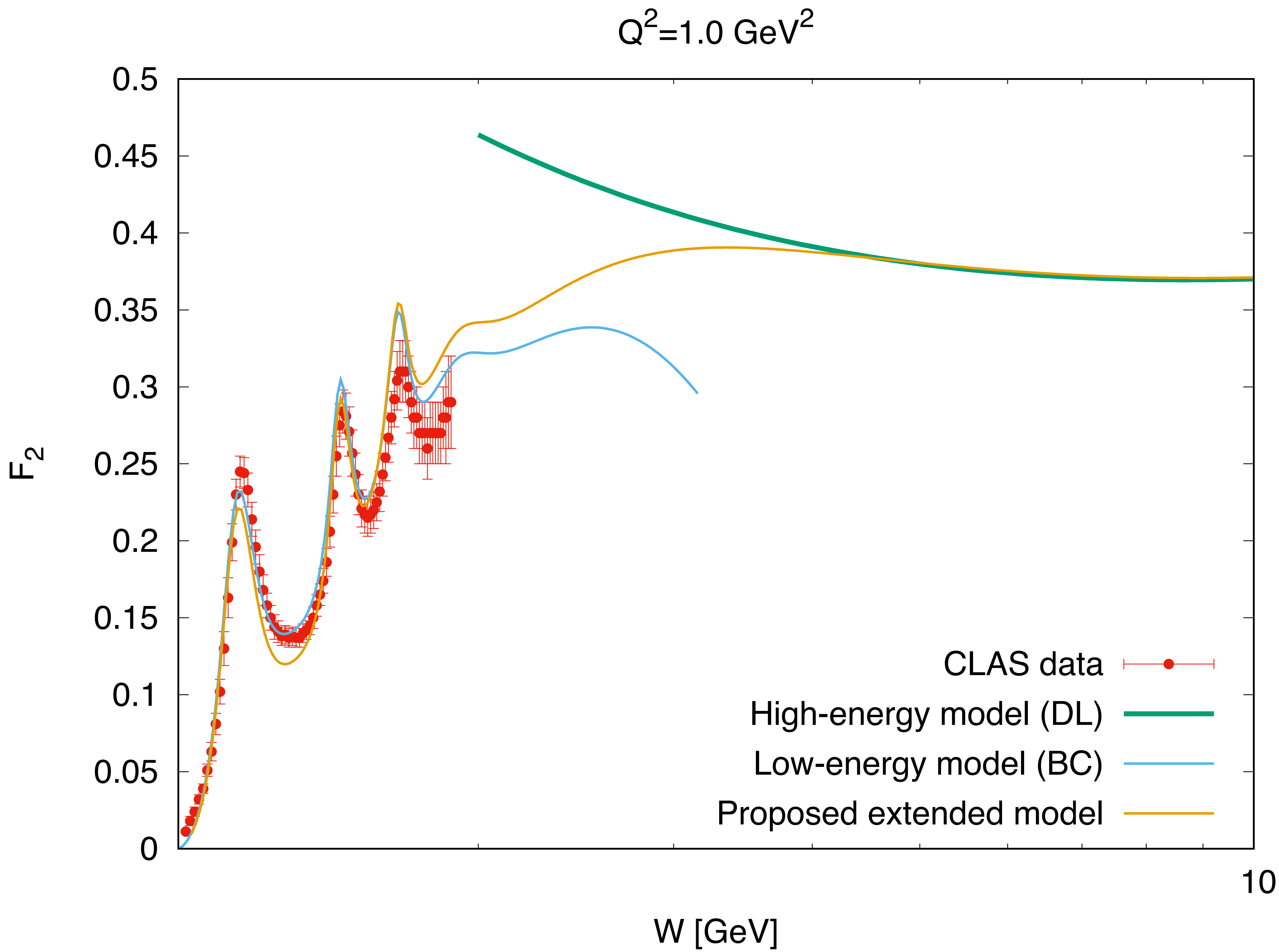
# Preliminary: overlap region



# Summary

- New resonant model:
  Full information on **N* electrocouplings** from CLAS data;
  **No fits needed!**

- High-energy data described well by Regge models

- FESR to fix overlap-region behaviour for any $Q^2$:
  Modified Regge-like amplitude with threshold parameters

| $N^*$ | $M_r$ [MeV] | $\Gamma_r$ [MeV] | $J_r$ | $L_r$ | $\mathrm{BF}_{\pi N}$ |
|---|---|---|---|---|---|
| 1440 | 1430 | 350 | $\frac{1}{2}$ | 1 | 0.65 |
| 1520 | 1515 | 115 | $\frac{3}{2}$ | 2 | 0.60 |
| 1535 | 1535 | 150 | $\frac{1}{2}$ | 0 | 0.45 |
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**All (****) resonances included**

$$A_{1/2}(Q^2),\ A_{3/2}(Q^2),\ S_{1/2}(Q^2)$$

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| 1700 | 1700 | 300 | $\frac{3}{2}$ | 2 | 0.15 |
| 1905 | 1880 | 330 | $\frac{5}{2}$ | 3 | 0.12 |
| 1910 | 1890 | 280 | $\frac{1}{2}$ | 1 | 0.23 |
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*https://userweb.jlab.org/~isupov/couplings/*

**From CLAS data and fits**

**From Bonn model**

*Ronniger and Metsch, EPJA 49 (2013) 8*

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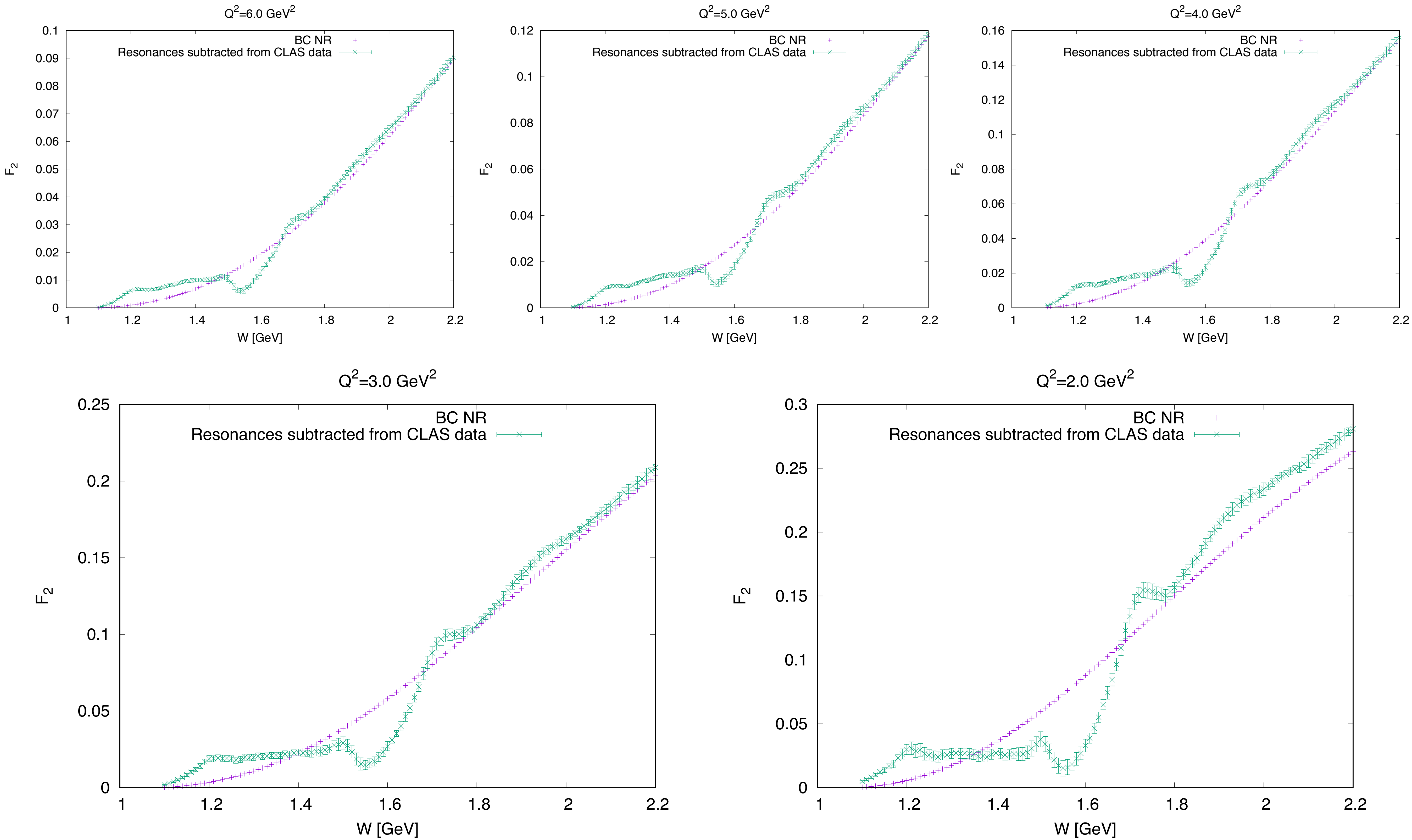
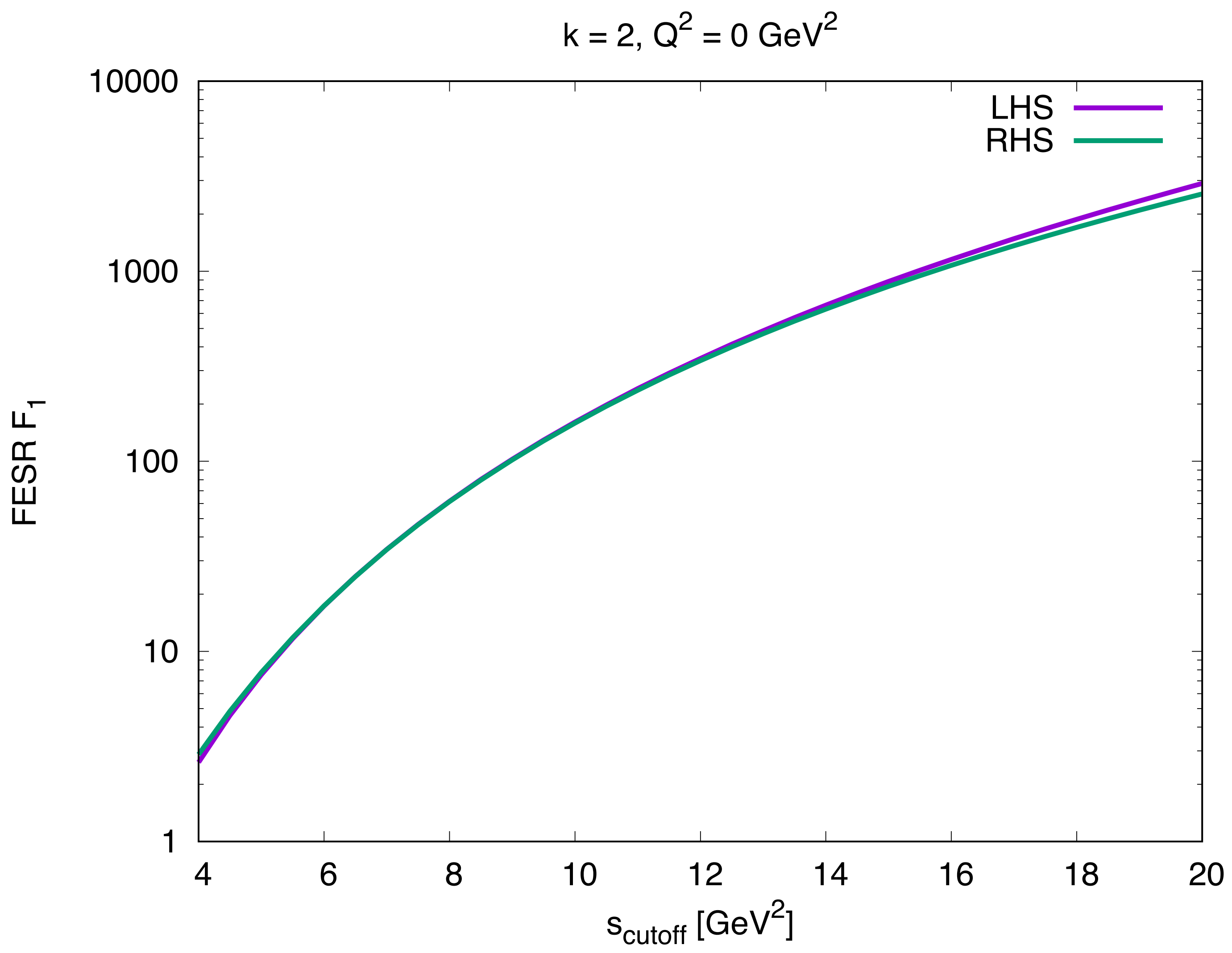
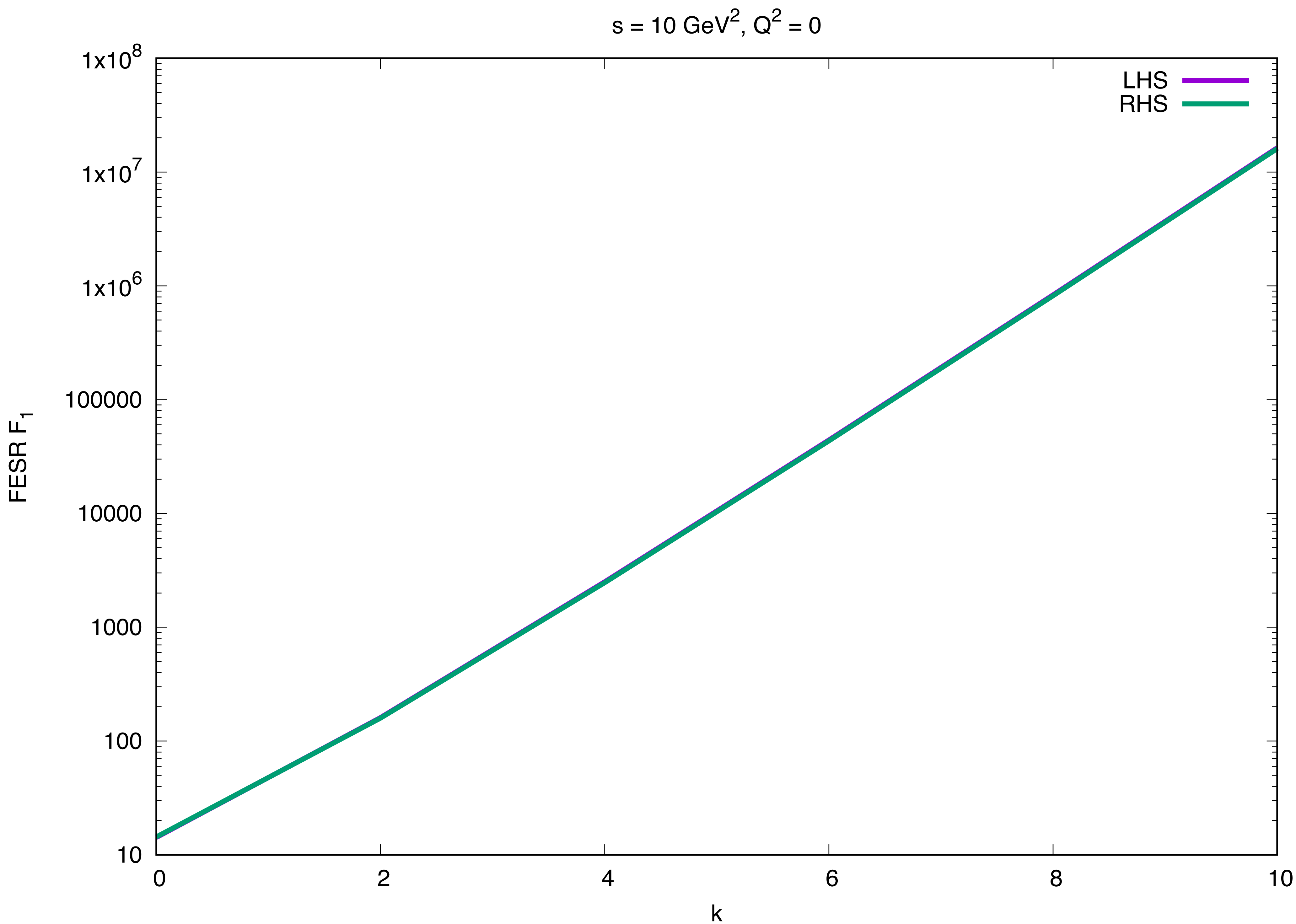
# Duality in CLAS $F_2$ data



# FESR cutoff dependence



# FESR variation with k

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