Spin Asymmetries on the Nucleon Experiment
HMS results

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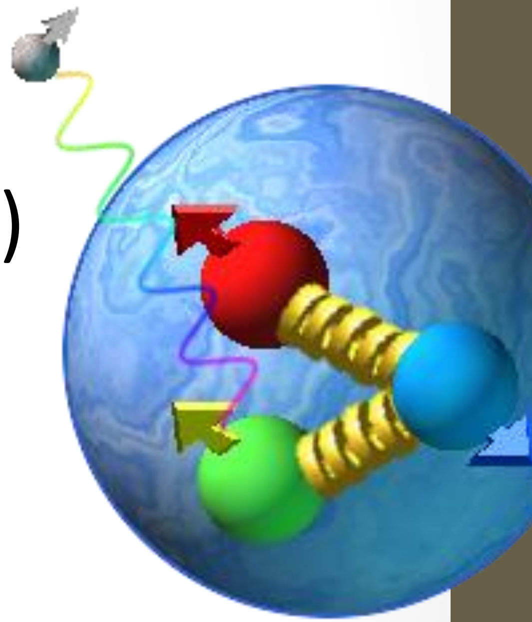
(Seoul National University)
For SANE Collaboration



Hall C Users Meeting
January 16, 2015

Outline

- Introduction to SANE-HMS
- Experimental Setup and SANE-HMS
- Dilution Factor
- Radiative Corrections
- HMS Asymmetries
- Spin Structure Functions
- d_2 , Twist-3 Matrix Element
- Summary

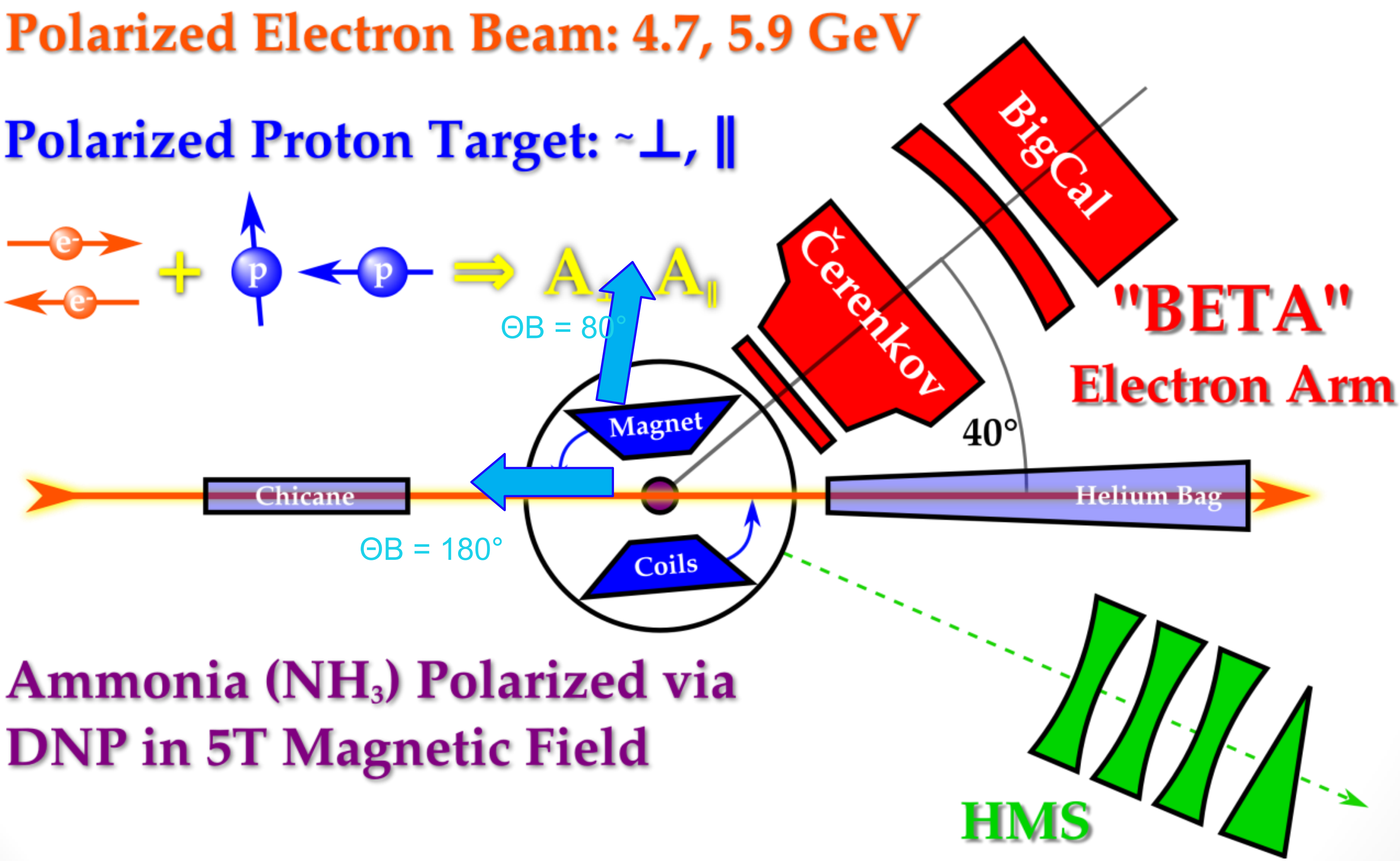
Purpose of SANE-HMS

SANE-HMS resonance data explores

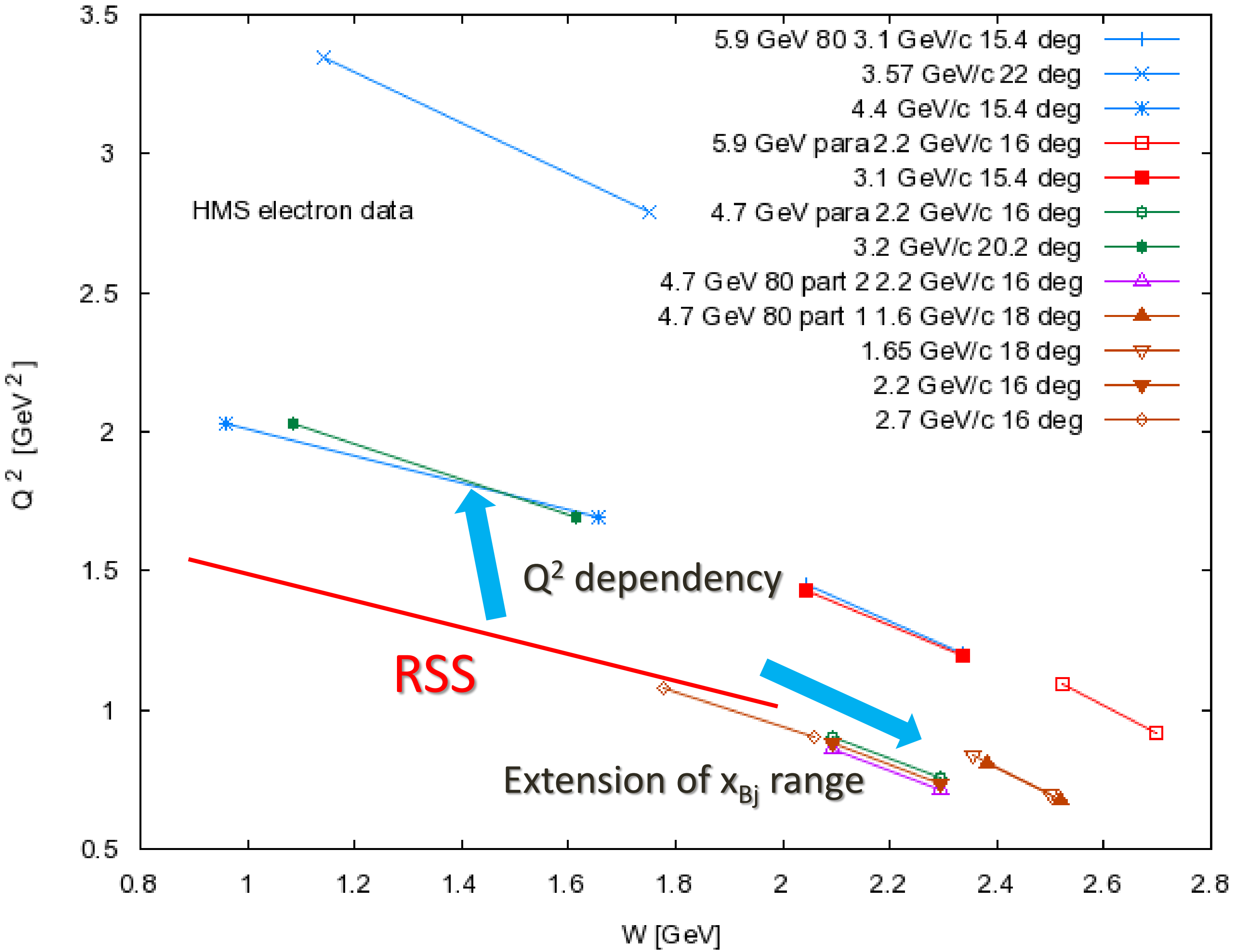
high Bjorken x region at intermediate Q^2:

- Resonances and Q^2 dependence of A_1 and A_2
- SSF $g_2(x, Q^2)$
- Higher twist effects
- Twist-3 d_2 matrix element

Experimental Setup



HMS Coverage for SANE



Dilution Factor from Packing Fraction

The target and beam are not completely polarized. It contains also un-polarizable materials.

$$A = \frac{1}{P_b P_t f} \frac{d\sigma^{\downarrow\uparrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\downarrow\uparrow} + d\sigma^{\uparrow\uparrow}}$$

Beam Polarization ~80%

Proton(target) Polarization ~70%

Dilution Factor

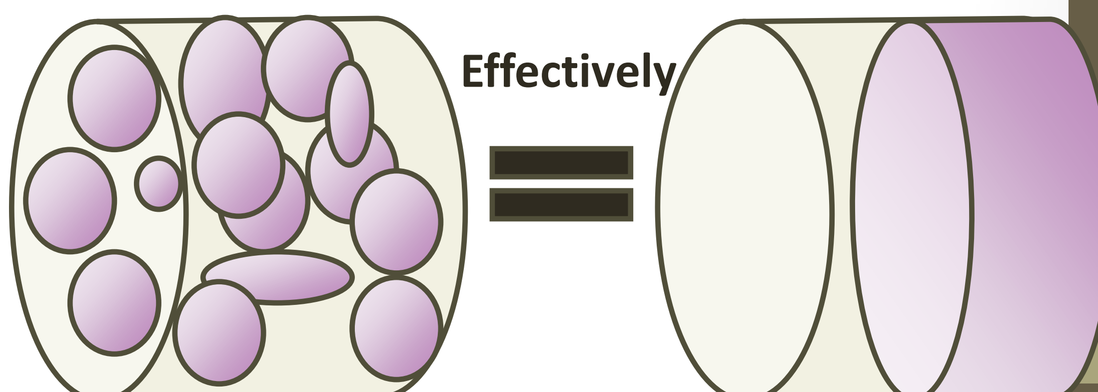
Dilution factor f is the ratio of free polarizable nucleons to the total amount of nucleons in the sample.

$A = A_{180}$ or A_{80} is the measured asymmetry without radiative corrections.

Dilution Factor from Packing Fraction

Packing fraction is the relative volume ratio of ammonia to the target cell, or the fraction of the cell's length that would be filled with ammonia by cylindrical symmetry.

$$f = \frac{3H}{(3H + N)pf + He(1 - pf) + Others}$$



Dilution Factor from Packing Fraction

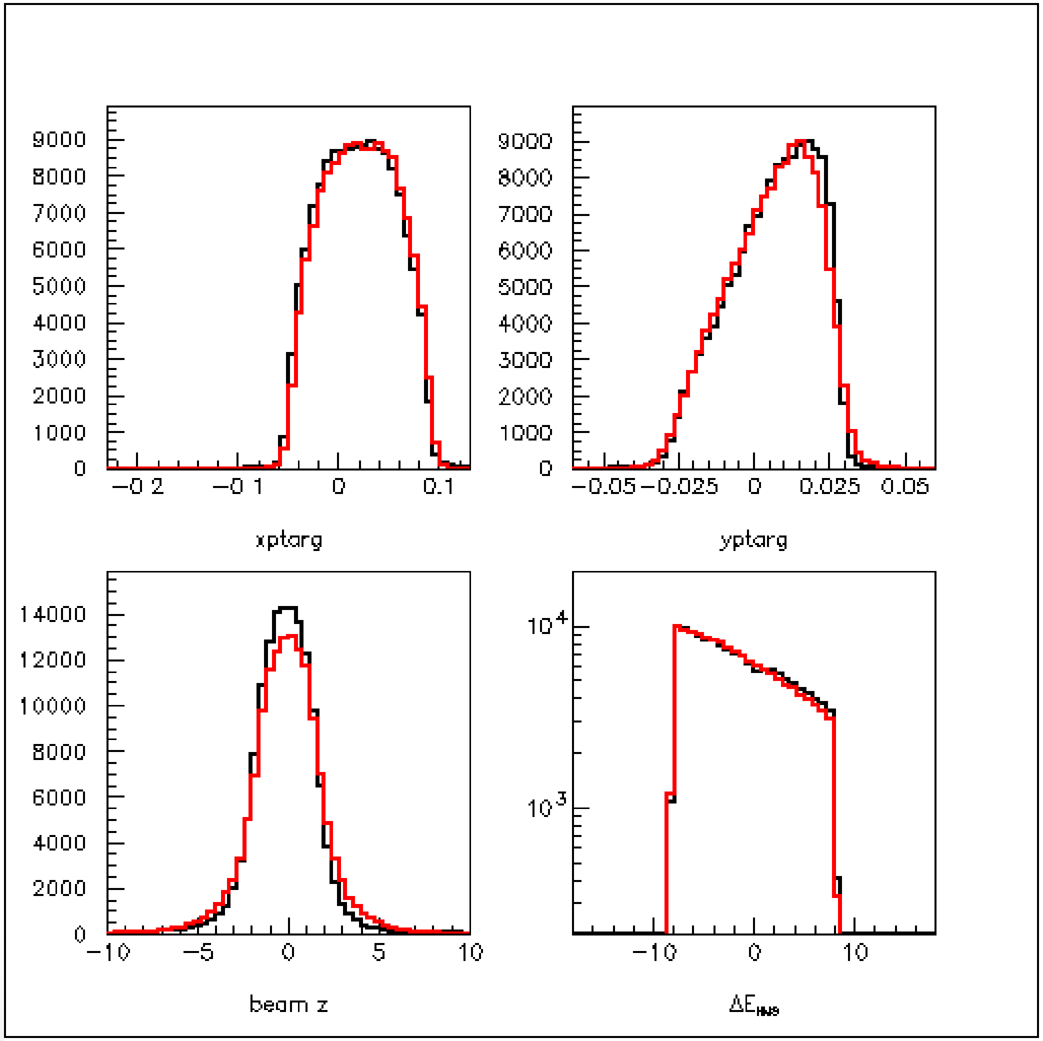
Total yield has linear relation with packing fraction:

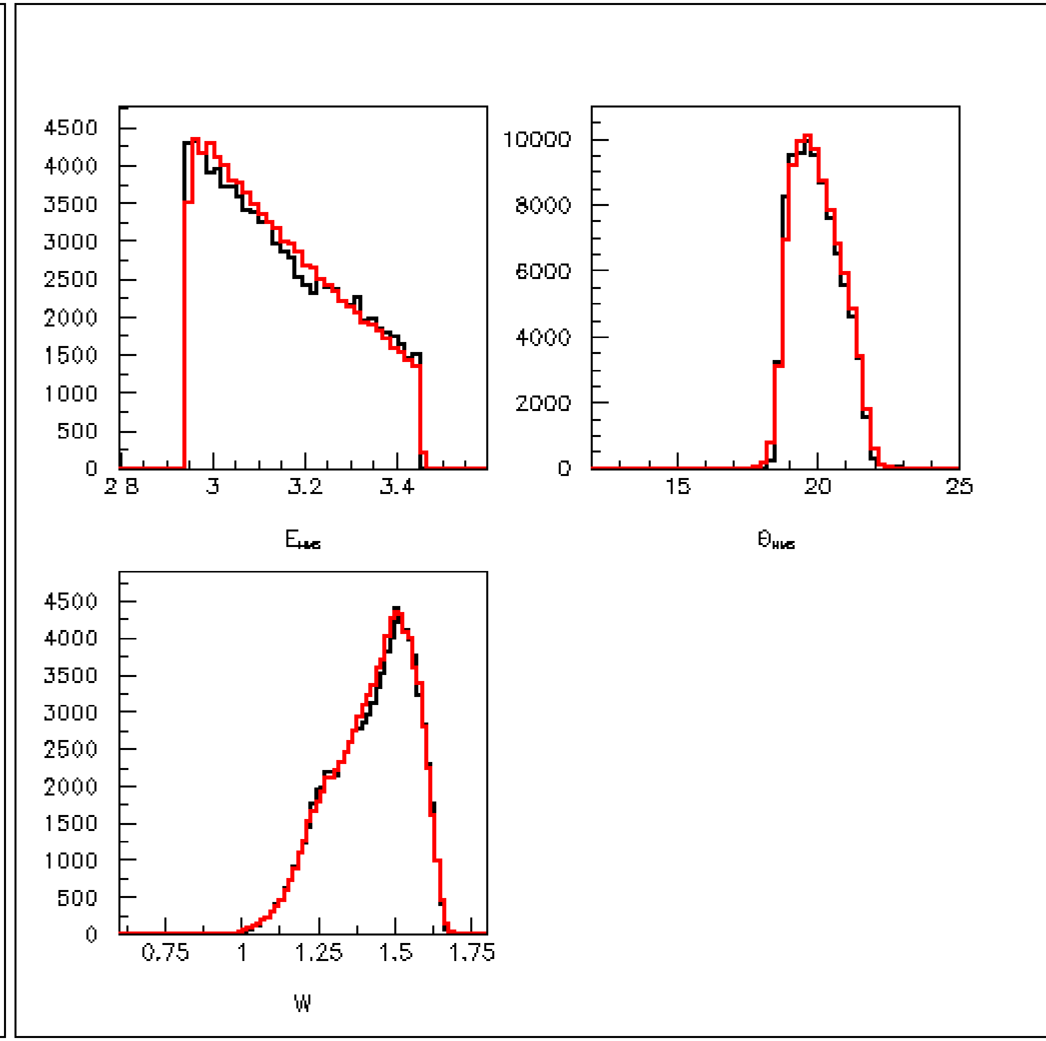
$Y_T = m\, pf + b$

Using MC (P. E. Bosted and M. E. Christy, PRC81 (2010) 055213) assuming two different *pf*, the slope(m) and intercept(b) can be calculated and then the yield of real data produces *pf* of real target.

SANE packing fractions are 56% - 62% with ~4.5% error.

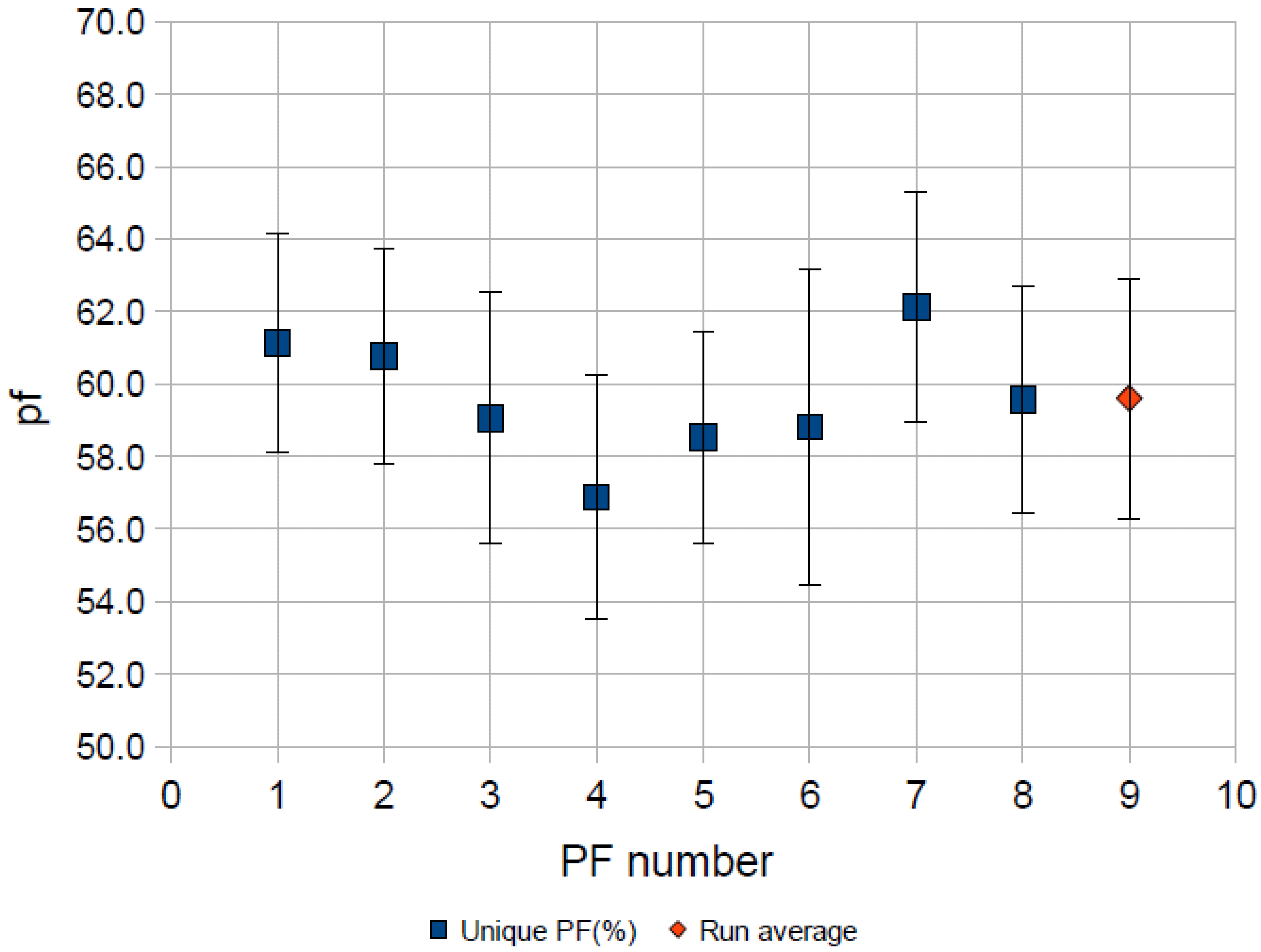
Packing Fraction





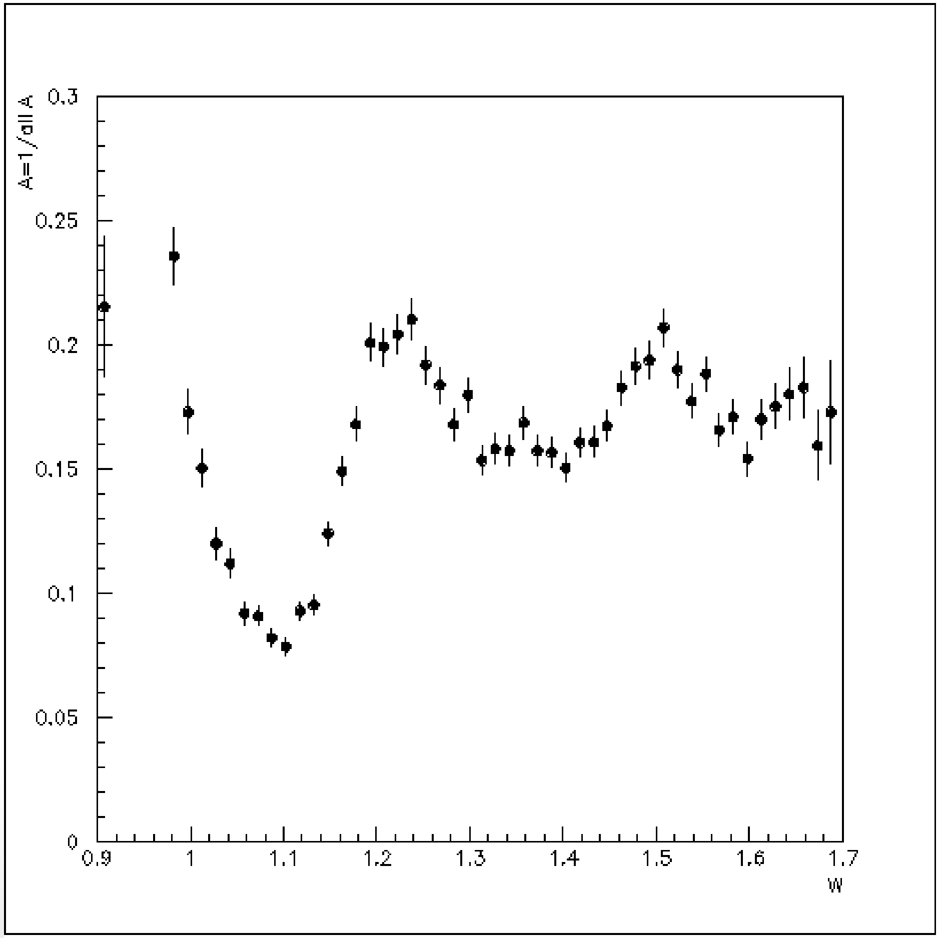
Data and MC comparison (Red is MC)

Packing fraction

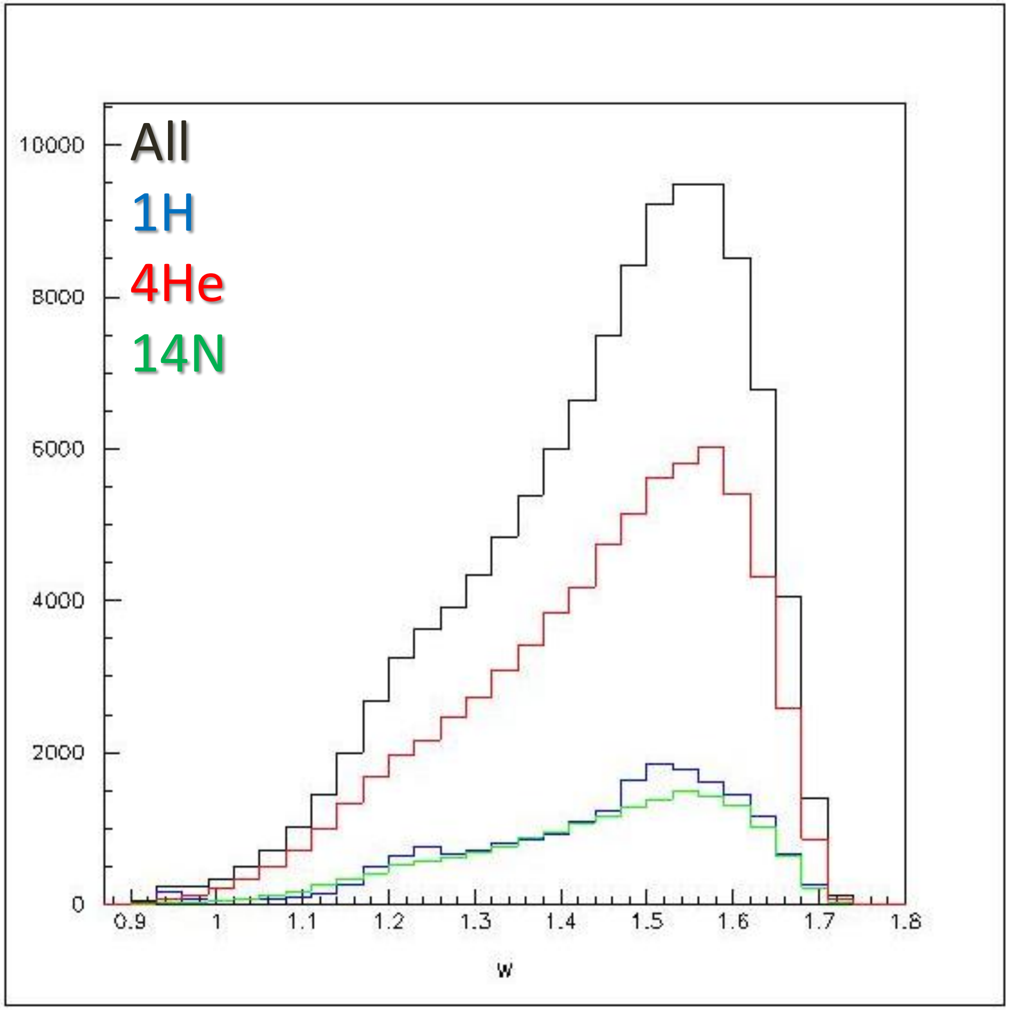


Dilution Factor

Dilution factor is calculated using MC, comparing cross sections of each materials in target cell. And packing fraction is the only necessary input for each target cell.



Dilution factor for resonance with PF of 61.9%



Dilution Factor

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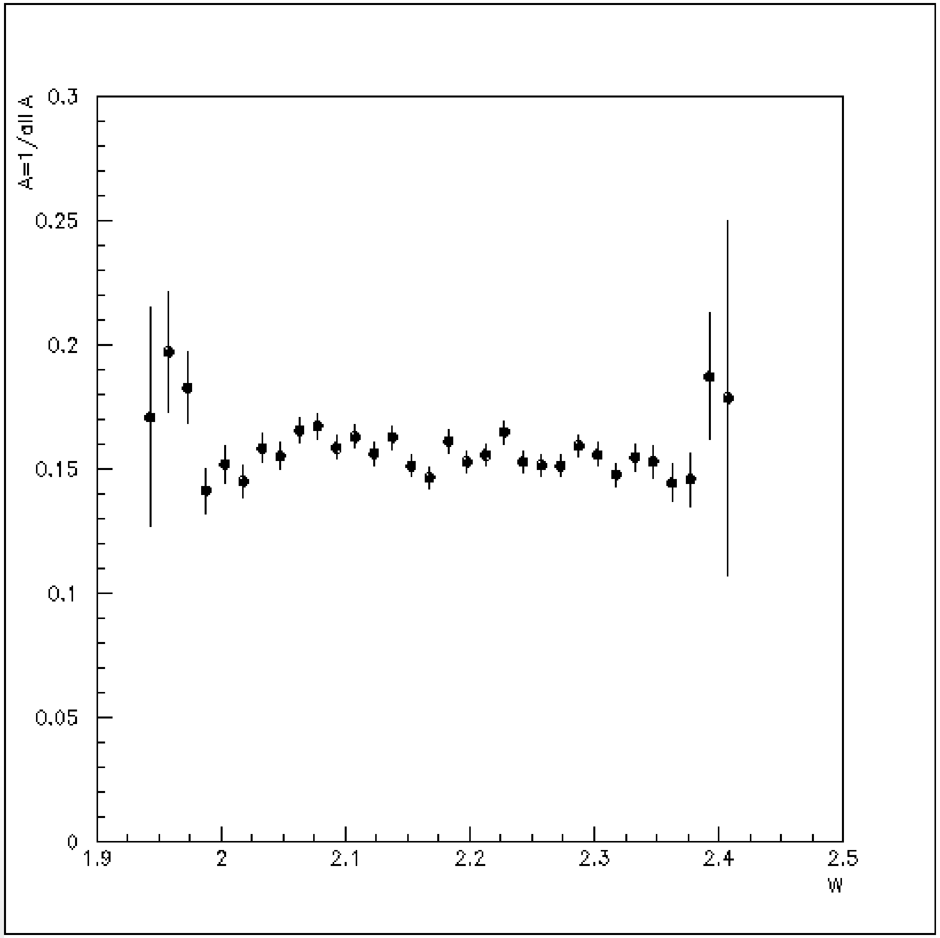
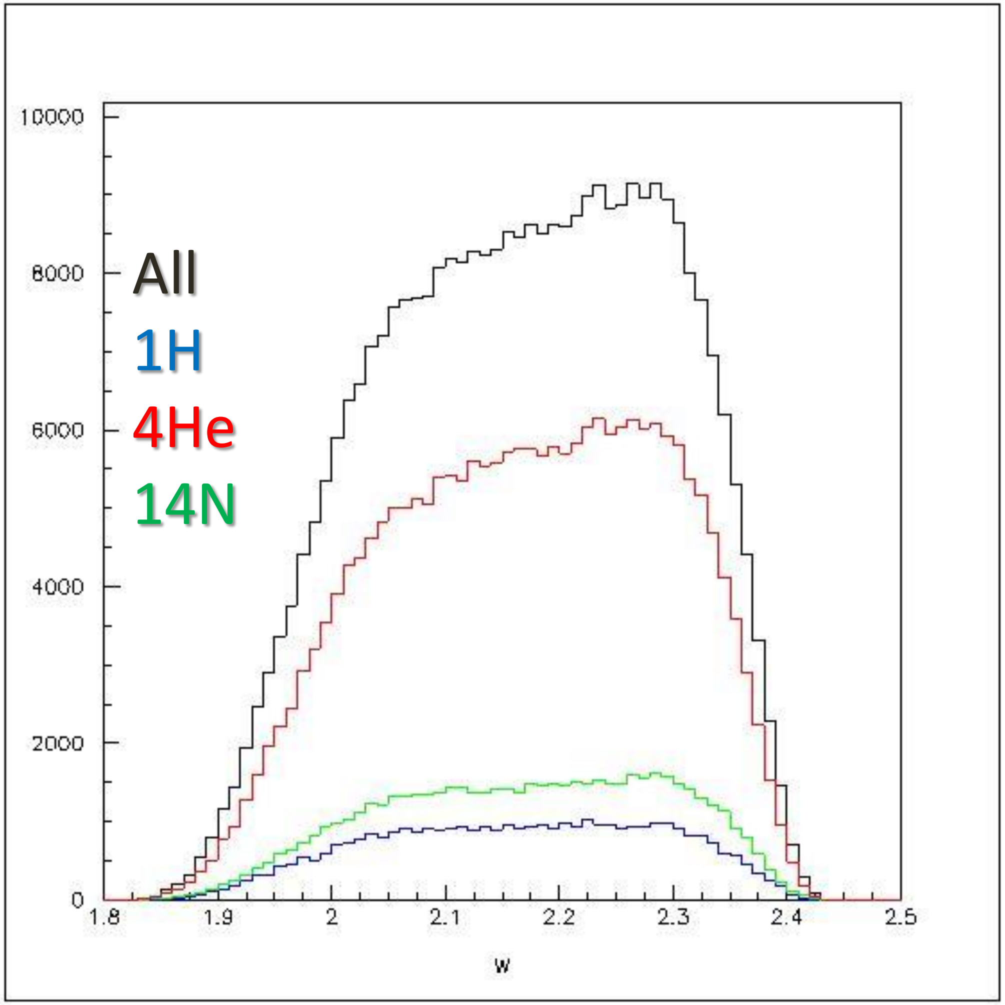
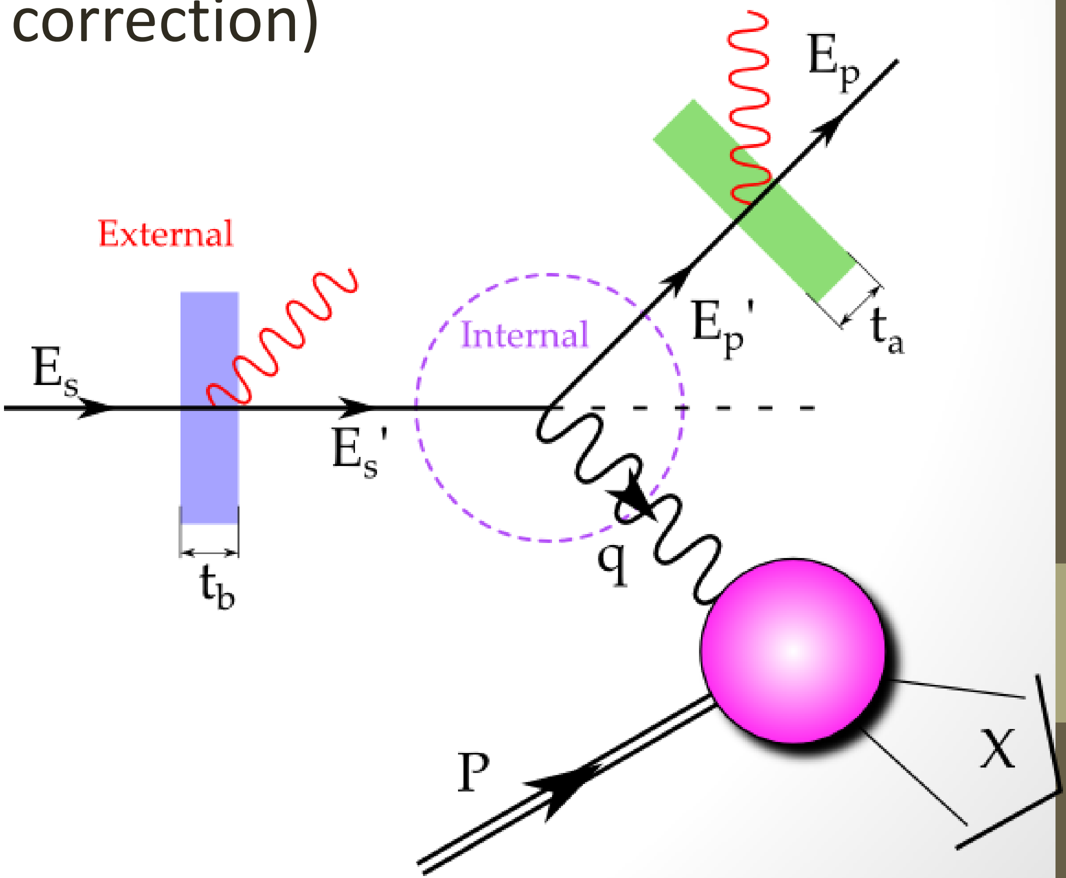


Dilution factor for DIS with PF of 58.8%

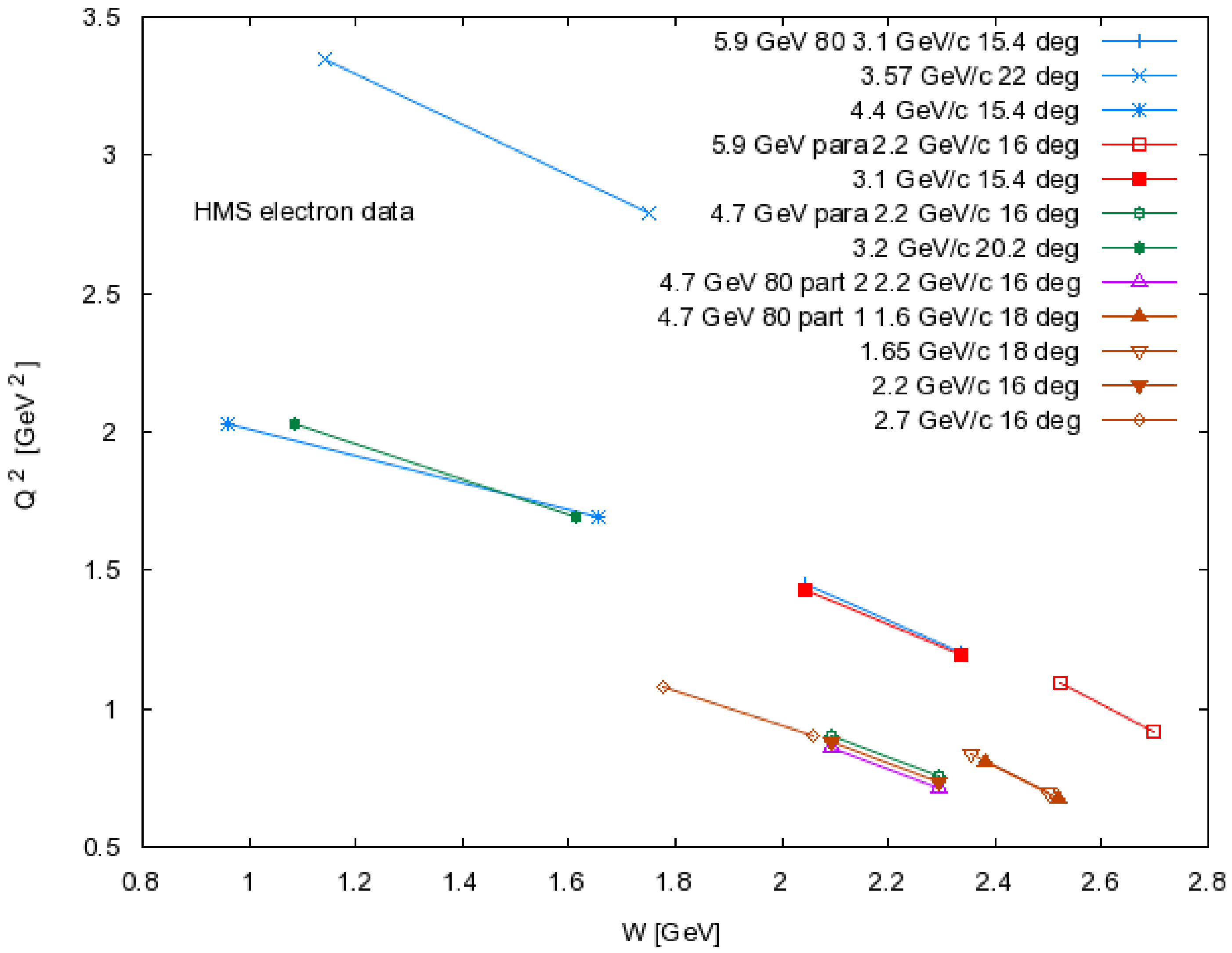


Radiative Corrections

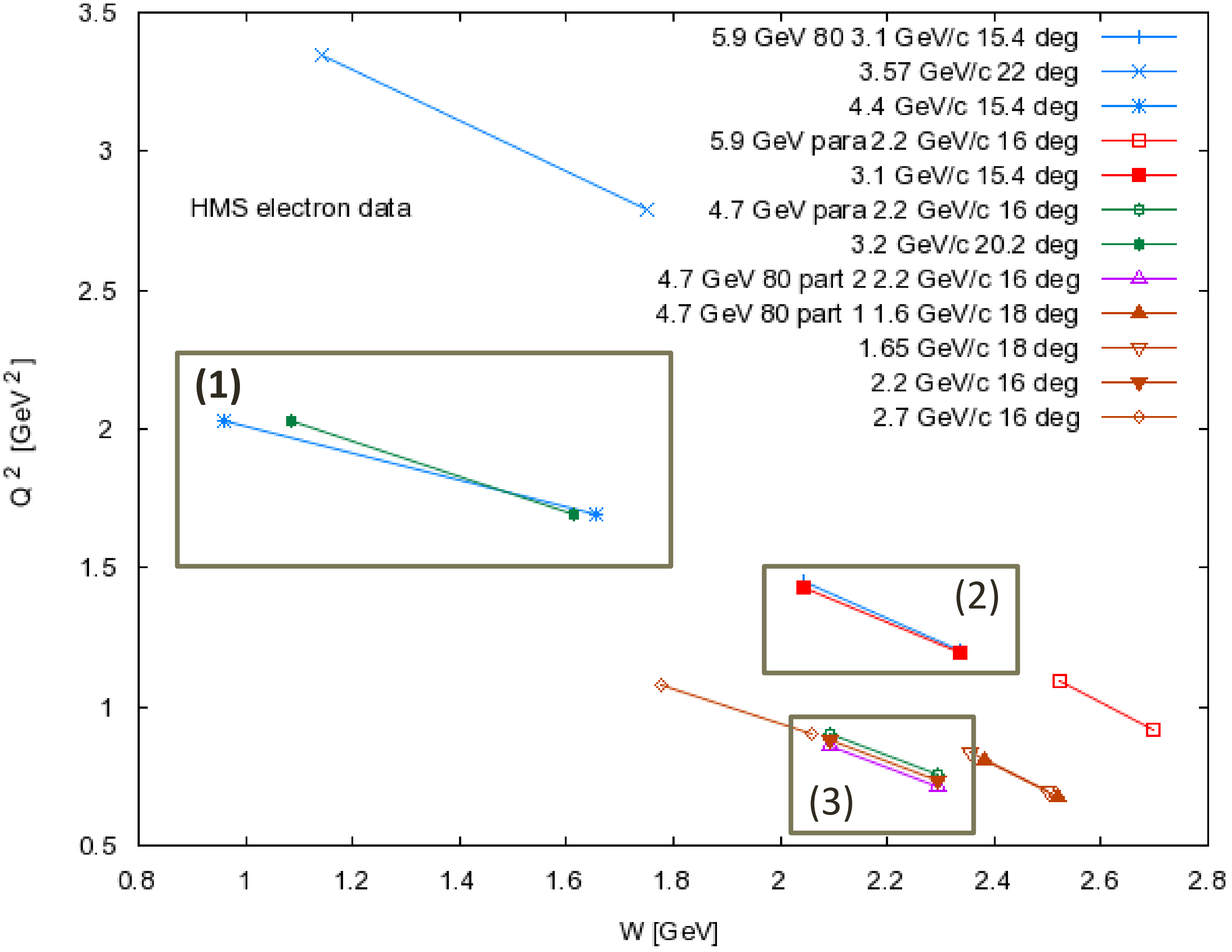
Following S. Stein et al., PRD12 (1975) 1884, corrections were mainly done by POLRAD 2.0
Initial fit parameters came from RSS, basically Breit-Wigner resonance and polynomial (with some correction) deep inelastic tail.
Newly corrected data was refitted to iterate.



HMS Asymmetries



HMS Asymmetries



HMS Asymmetries

Setting	Beam energy (GeV)	HMS central momentum (GeV)	HMS angle from beamline (degree)	$<Q^2>$ (GeV^2)	$<W>$ (GeV)
(1)	4.7 (par) / 5.9 (per)	3.2 (par) / 4.4 (per)	20.2 (par) / 15.4 (per)	1.863	1.353
(2)	5.9	3.1	15.4	1.313	2.196
(3)	4.7	2.2	16	0.806	2.196

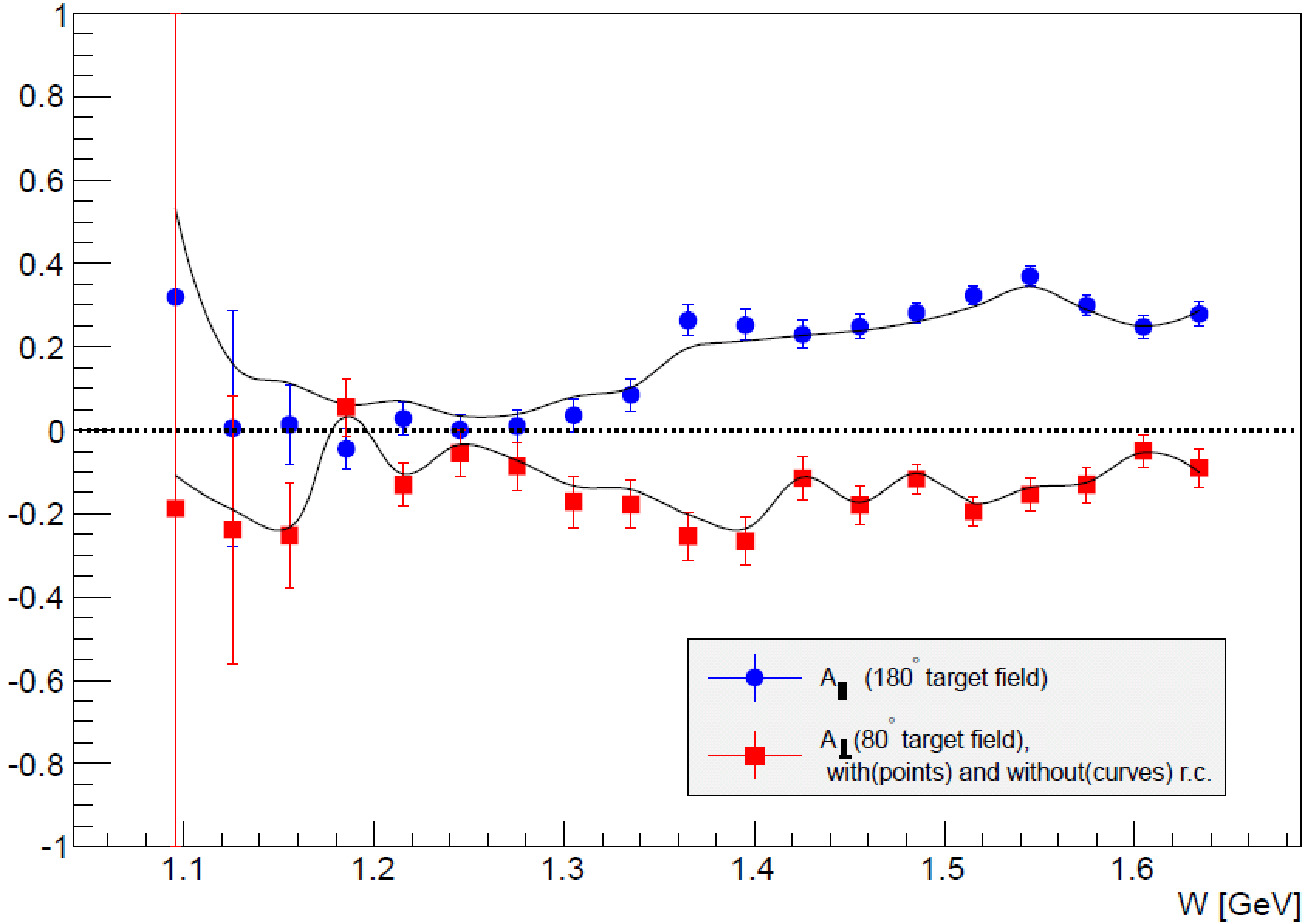
SANE-HMS Region 1

$$Q^2 = 1.86\ GeV^2$$

Resonance region

Parallel and Perpendicular Asymmetries

$Q^2 = 1.86\ GeV^2$



Asymmetries A_1 and A_2

A_1 and A_2 are virtual photoabsorption asymmetries.

$$A_1 = \frac{\sigma^T_{1/2} - \sigma^T_{3/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \frac{\sigma_{TT}}{\sigma_T} = \frac{g_1 - \gamma^2 g_2}{F_1}$$

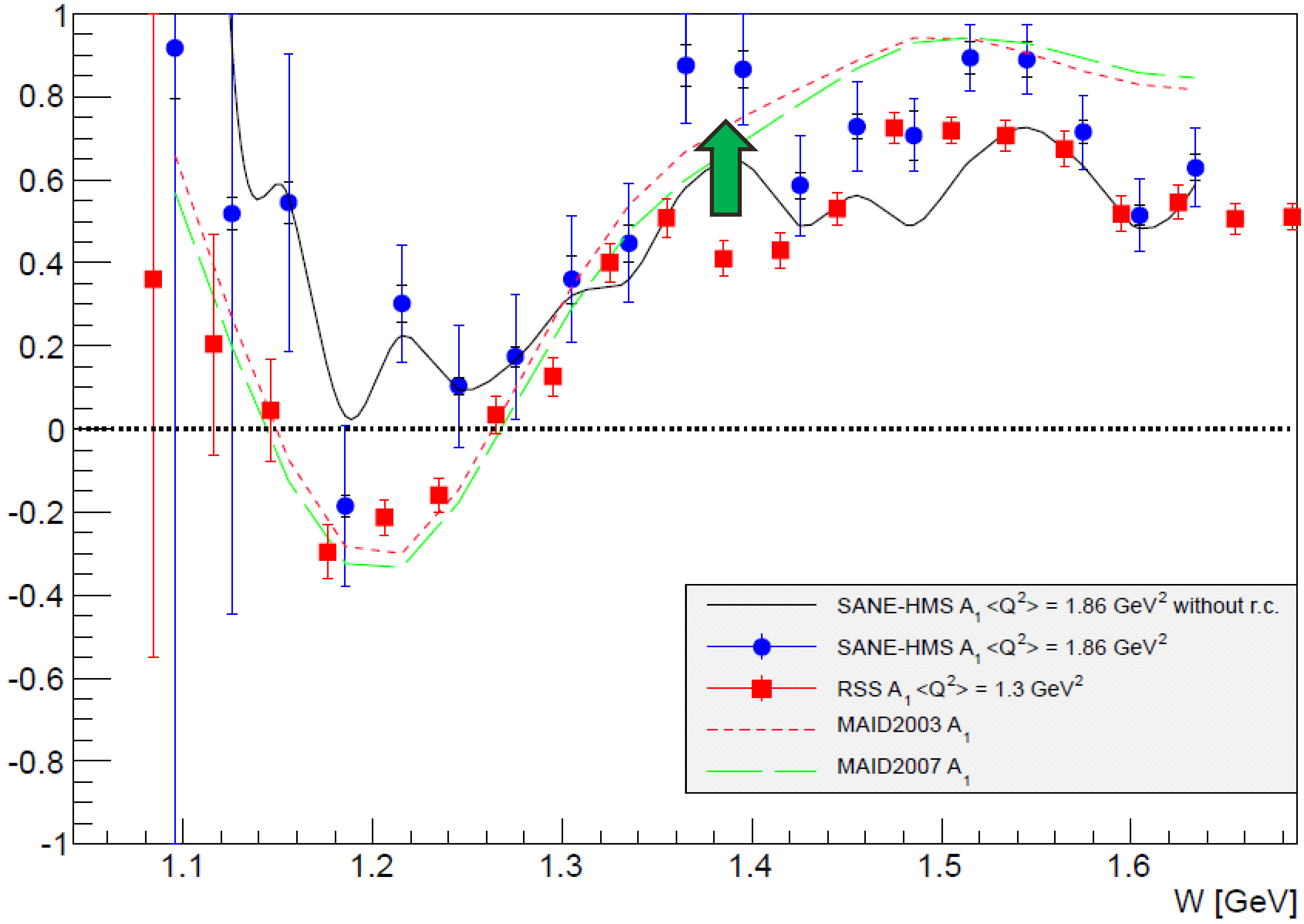
$$A_2 = \frac{2\sigma_{LT}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \frac{\sigma_{LT}}{\sigma_T} = \frac{\gamma(g_1 + g_2)}{F_1}$$

$\sigma^T_{1/2}$ and $\sigma^T_{3/2}$ are the virtual photon absorption transverse cross sections when total helicity of photon and nucleon is 1/2 and 3/2 respectively. σ_{LT} is the interference term between the transverse and longitudinal photon-nucleon amplitude.

Radiative correction done by iterating the fits of A_1 and A_2 until they converged.

Asymmetry $A_1 = \frac{\sigma_{TT}}{\sigma_T}$

$Q^2 = 1.86\ GeV^2$



Asymmetry $A_1 = \frac{\sigma_{TT}}{\sigma_T}$

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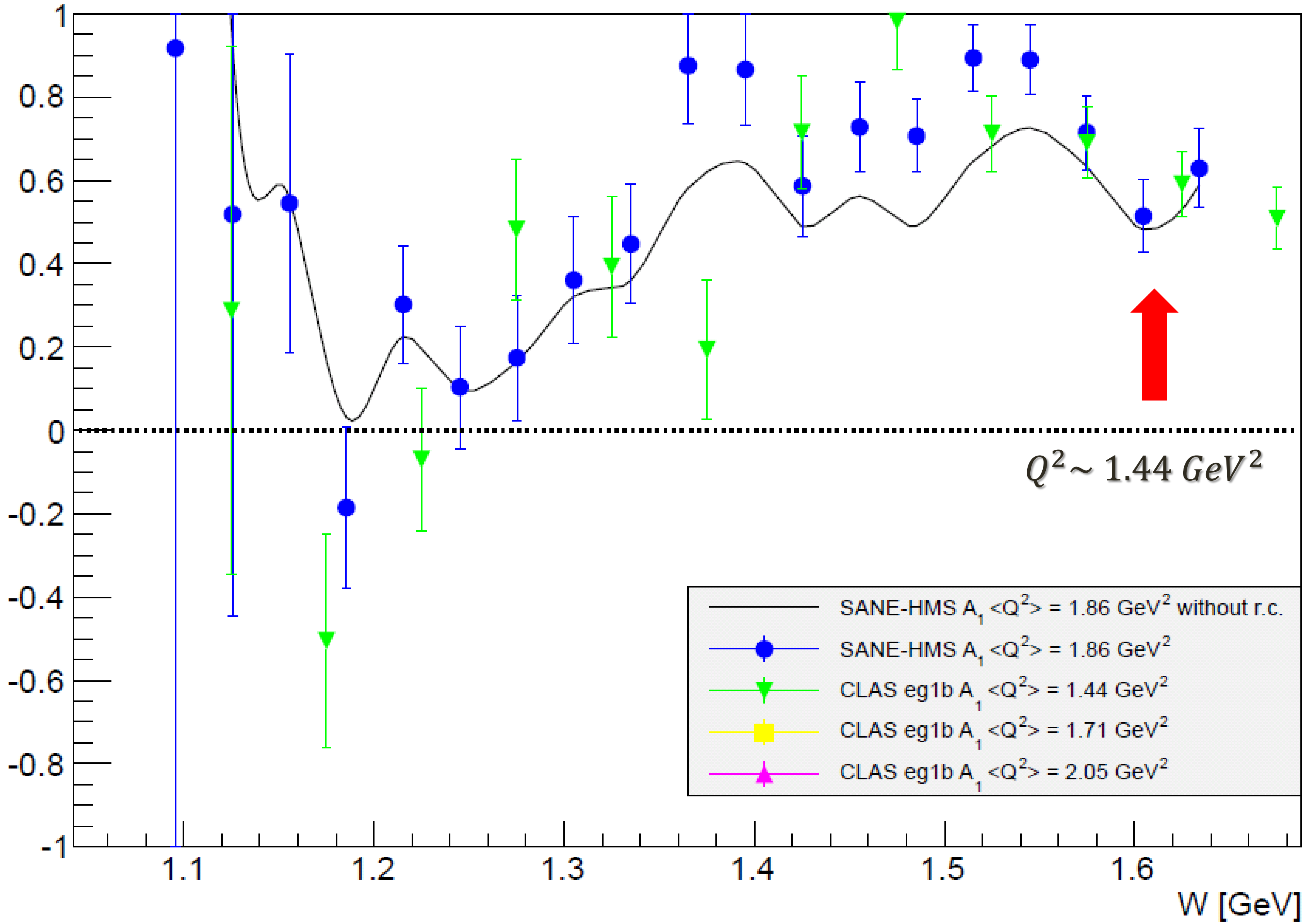

Asymmetry $A_1 = \frac{\sigma_{TT}}{\sigma_T}$

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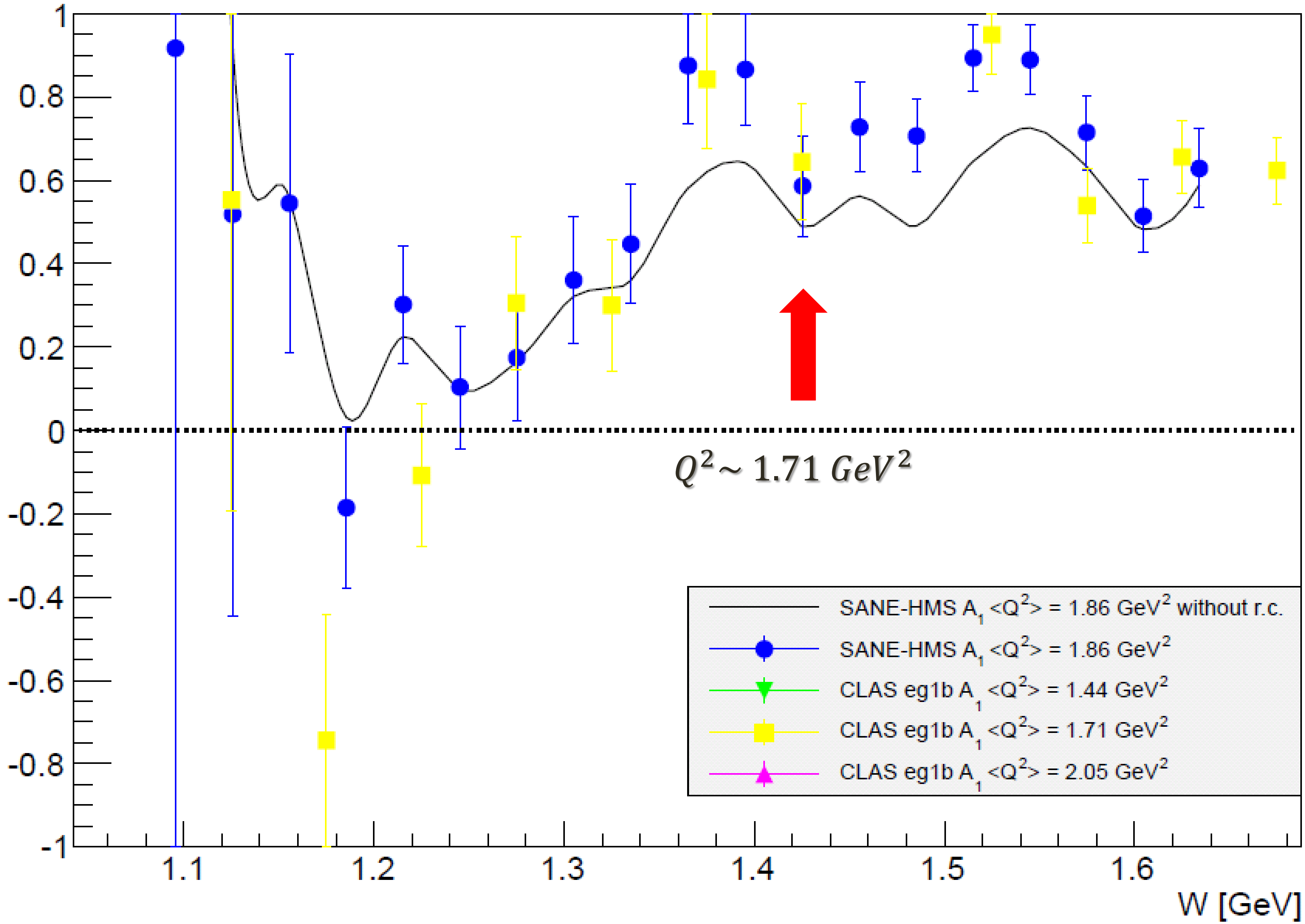

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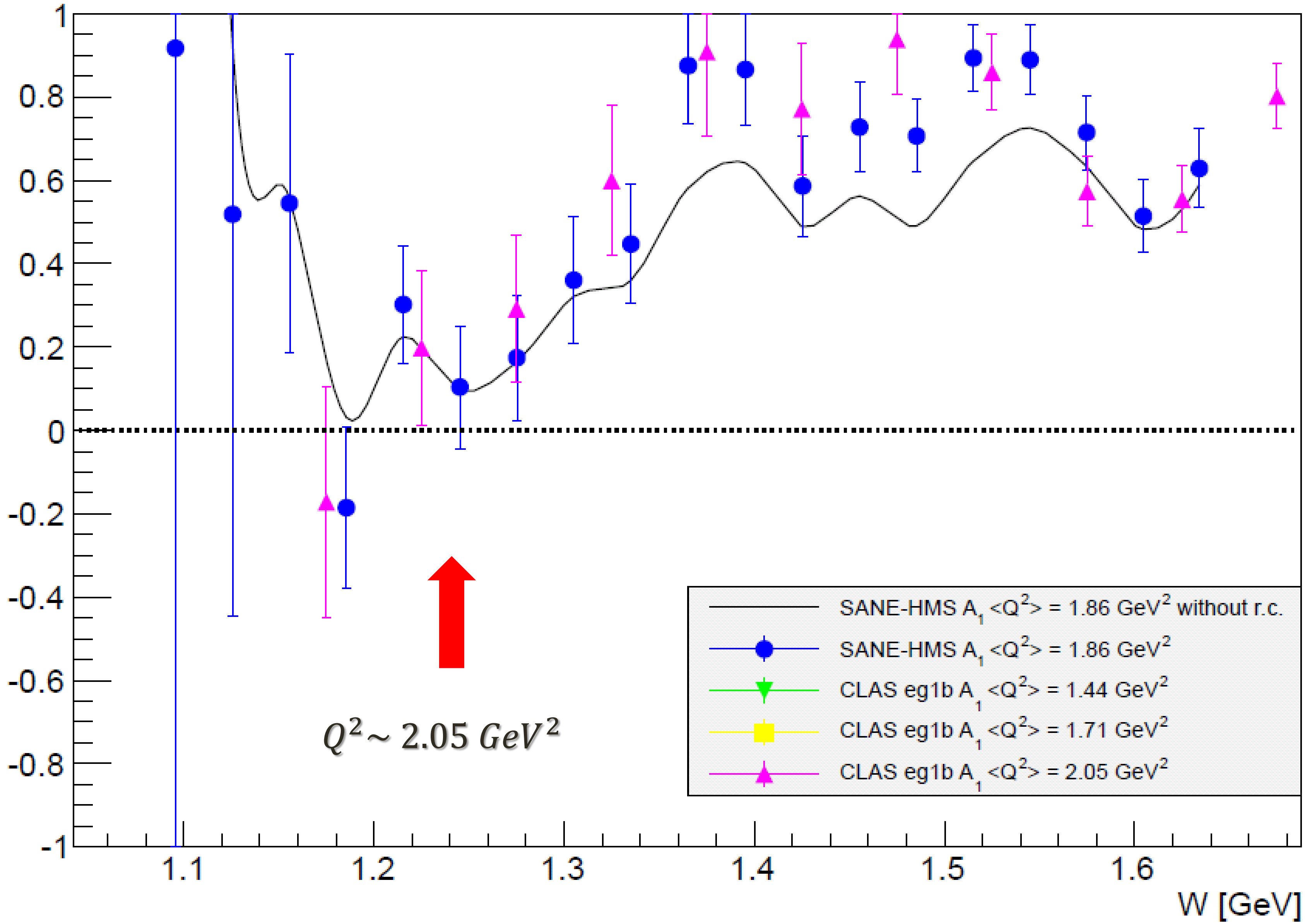
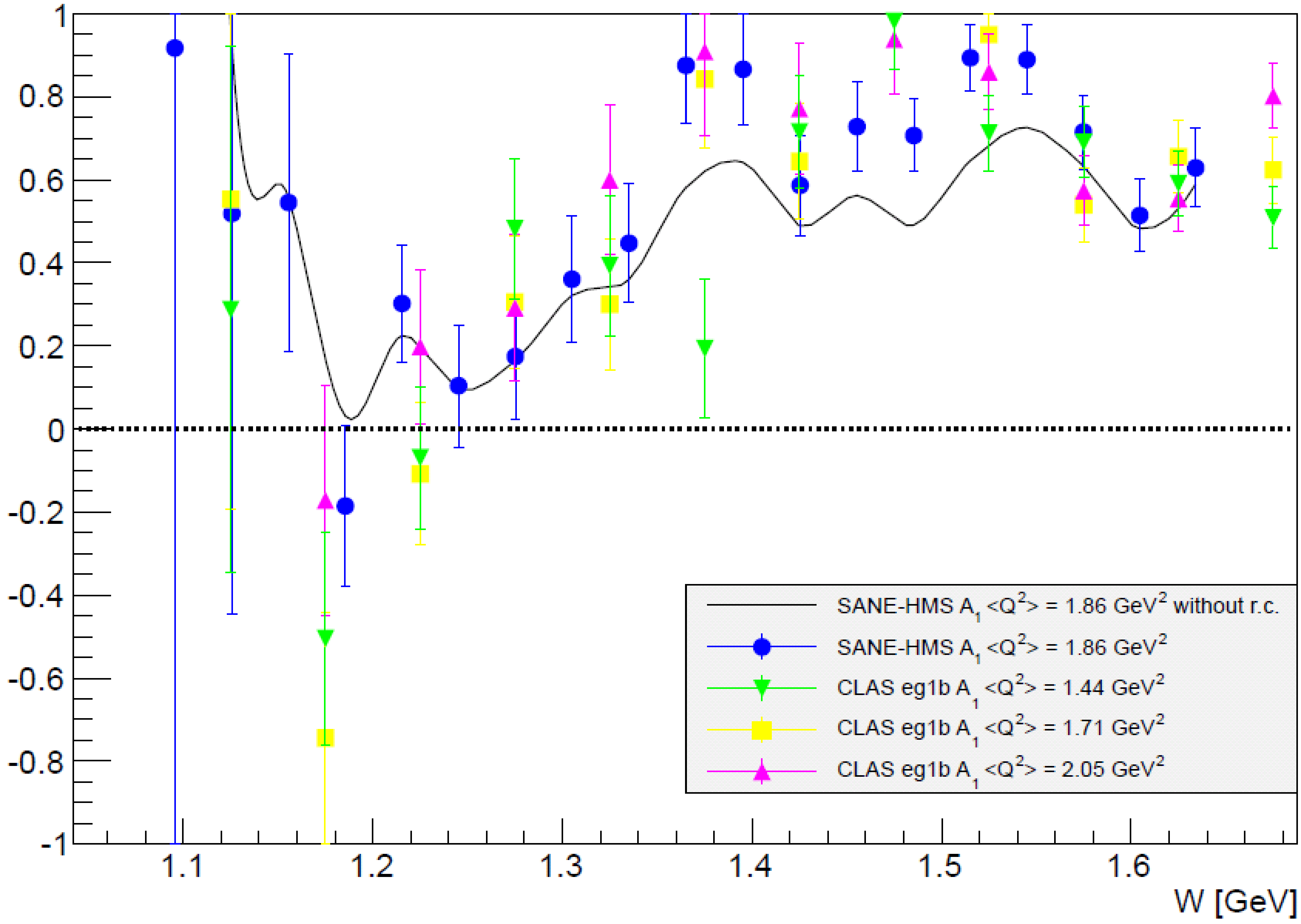


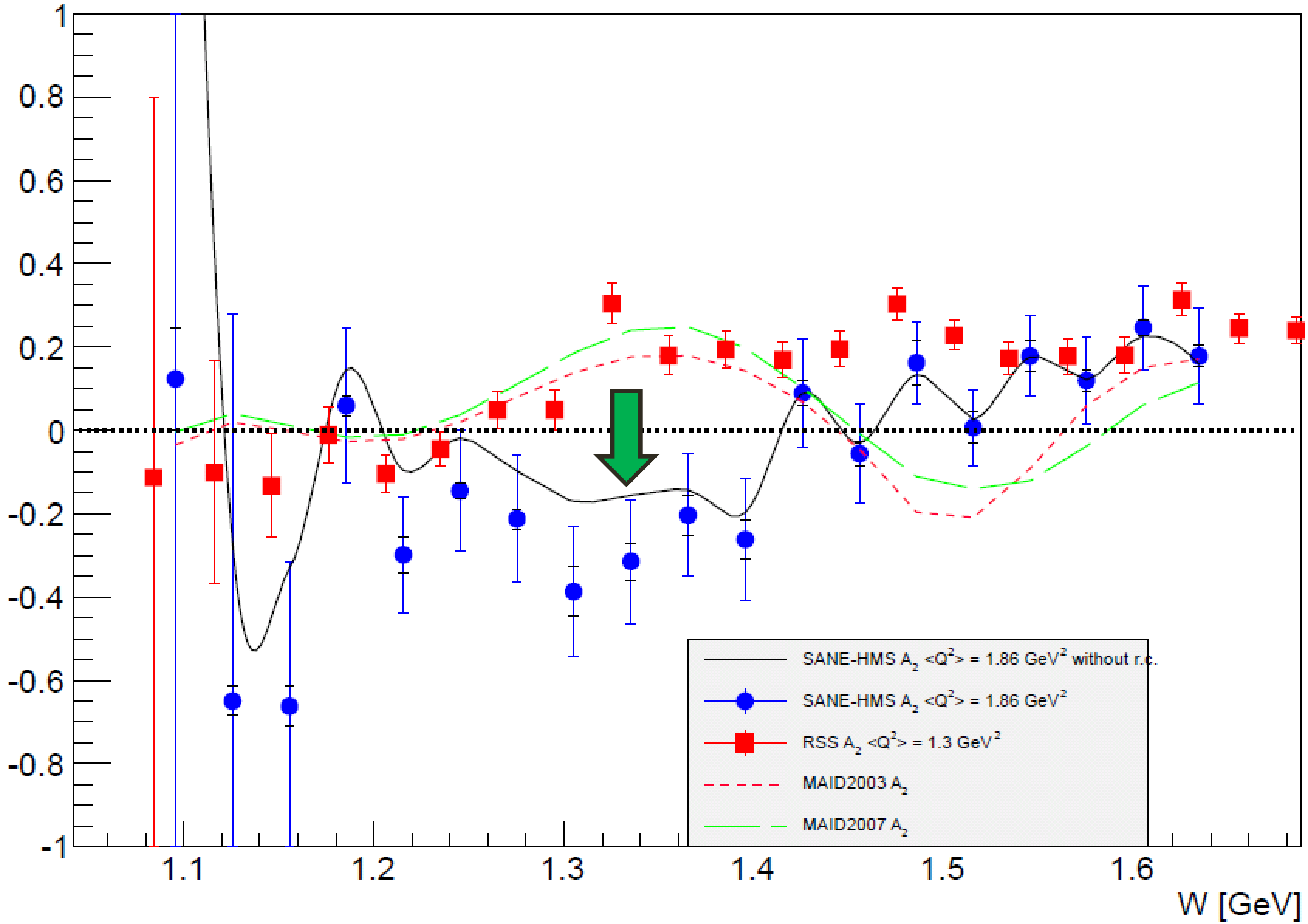
Asymmetry $A_1 = \frac{\sigma_{TT}}{\sigma_T}$

$Q^2 = 1.86\ GeV^2$



Asymmetry $A_2 = \frac{\sigma_{LT}}{\sigma_T}$

$Q^2 = 1.86\ GeV^2$



Fitting Function

$$\text{fit} = \underbrace{\sum_{i=1}^{4} BW_i}_{\text{Resonances}} + \underbrace{x^{\alpha}\sum_{n=0}^{3}\beta_n\, x^n}_{\text{DIS}} \underbrace{\times \frac{1}{\sqrt{Q^2}}}_{A_2 \text{ only}}$$

where

$$BW_i = \frac{a_i\ \kappa_i^2\ w_i^2\ \Gamma_i\ \Gamma_i^{\gamma}}{\kappa_{cm}^2\ \left[(w_i^2 - W^2)^2 + w_i^2\ \Gamma_i^2\right]}$$

$$= g_i \left(\frac{q_{cm}}{q_i}\right)^{(2l_i+1)} \left(\frac{q_i^2 + X_i^2}{q_{cm}^2 + X_i^2}\right)^{l_i}$$

$$= g_i \left(\frac{\kappa_{cm}}{\kappa_i}\right)^{(2j_i)} \left(\frac{\kappa_i^2 + X_i^2}{\kappa_{cm}^2 + X_i^2}\right)^{j_i}$$

$$\kappa_i = \sqrt{\frac{(w_i^2 + M^2 + Q^2)^2}{4w_i^2} - M^2}$$

$$q_i = \sqrt{\frac{(w_i^2 + M^2 - m_\pi^2)^2}{4w_i^2} - M^2}$$

$$\kappa_{cm} = \sqrt{\frac{(W^2 + M^2 + Q^2)^2}{4W^2} - M^2}$$

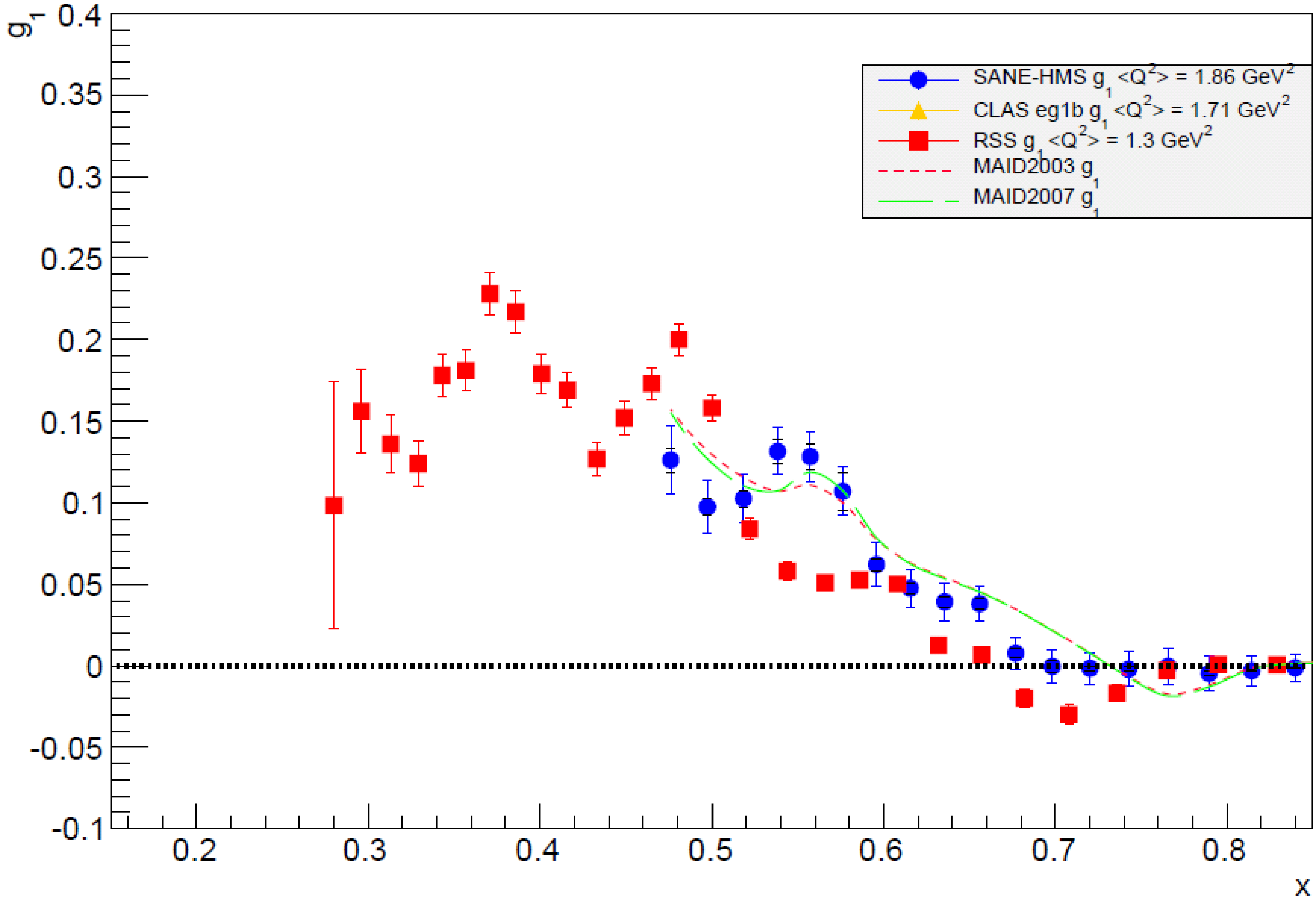
$$q_{cm} = \sqrt{\frac{(W^2 + M^2 - m_\pi^2)^2}{4W^2} - M^2}$$

Table 3.2: The fitting parameters of A_1 and A_2. a_i is the amplitude, ω_i is the centroid, and g_i is the width of the i-th BW peak.

Parameter	A_1 Fit	A_2 Fit
a_1	-0.553 ± 0.204	-0.306 ± 0.152
a_2	0.724 ± 0.267	-0.474 ± 0.210
a_3	0.615 ± 0.071	–
ω_1	1.186 ± 0.016	1.232 (fixed)
ω_2	1.381 ± 0.006	1.323 ± 0.010
ω_3	1.547 ± 0.012	–
g_1	0.031 ± 0.025	0.070 ± 0.057
g_2	0.053 ± 0.036	0.058 ± 0.035
g_3	0.197 ± 0.068	–

Spin Structure Function g_1

$Q^2 = 1.86\ GeV^2$



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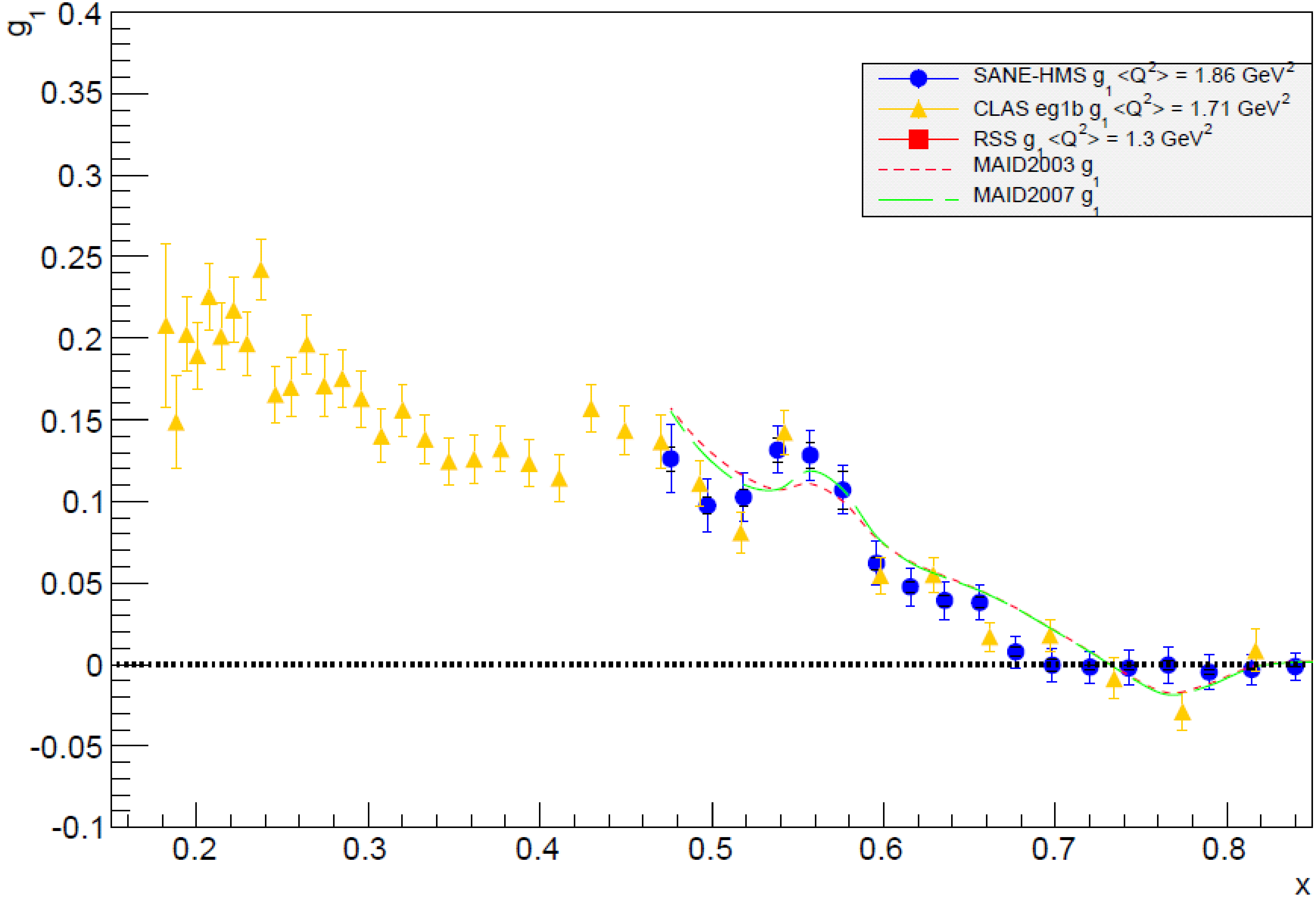

Spin Structure Function g_1

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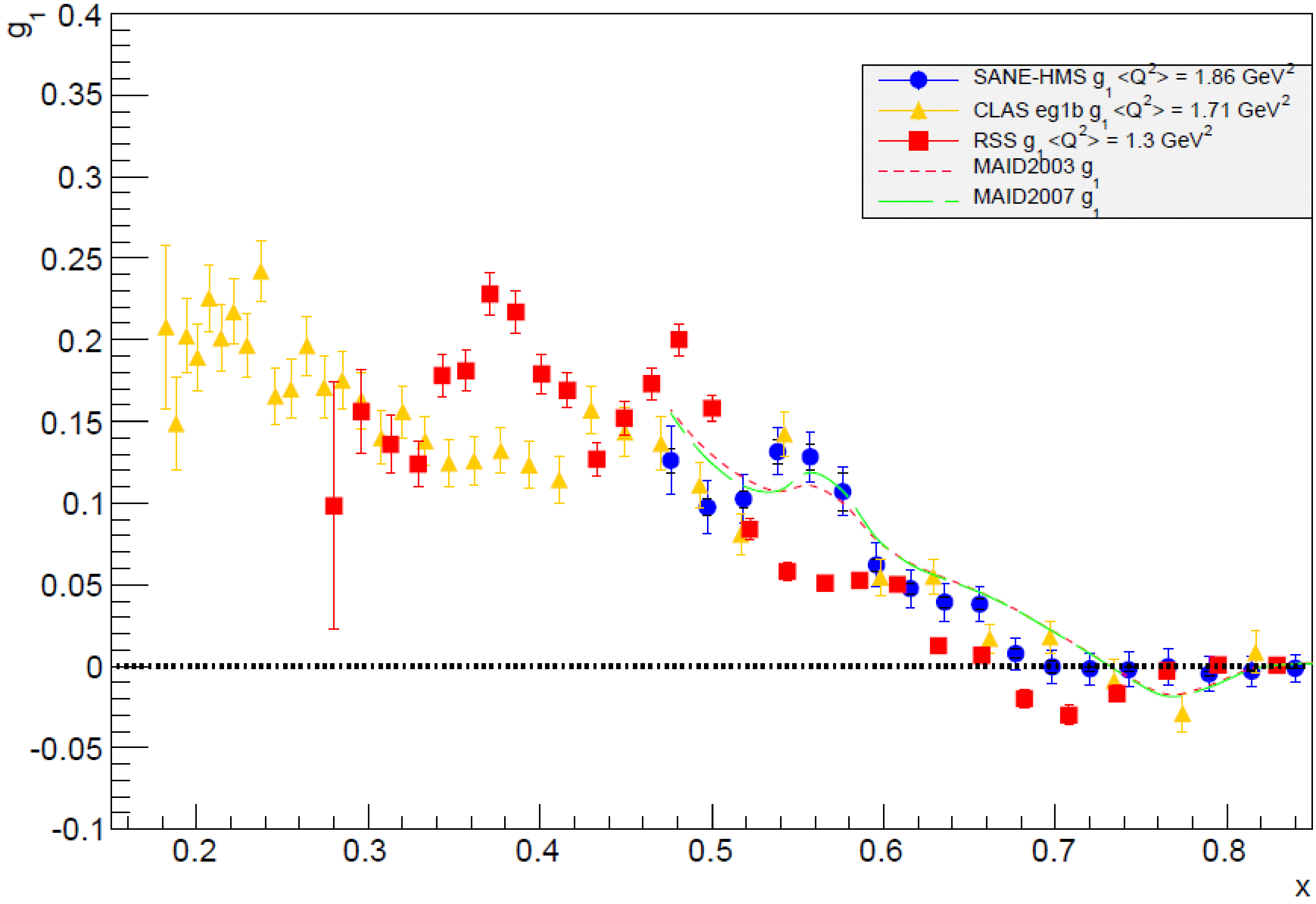
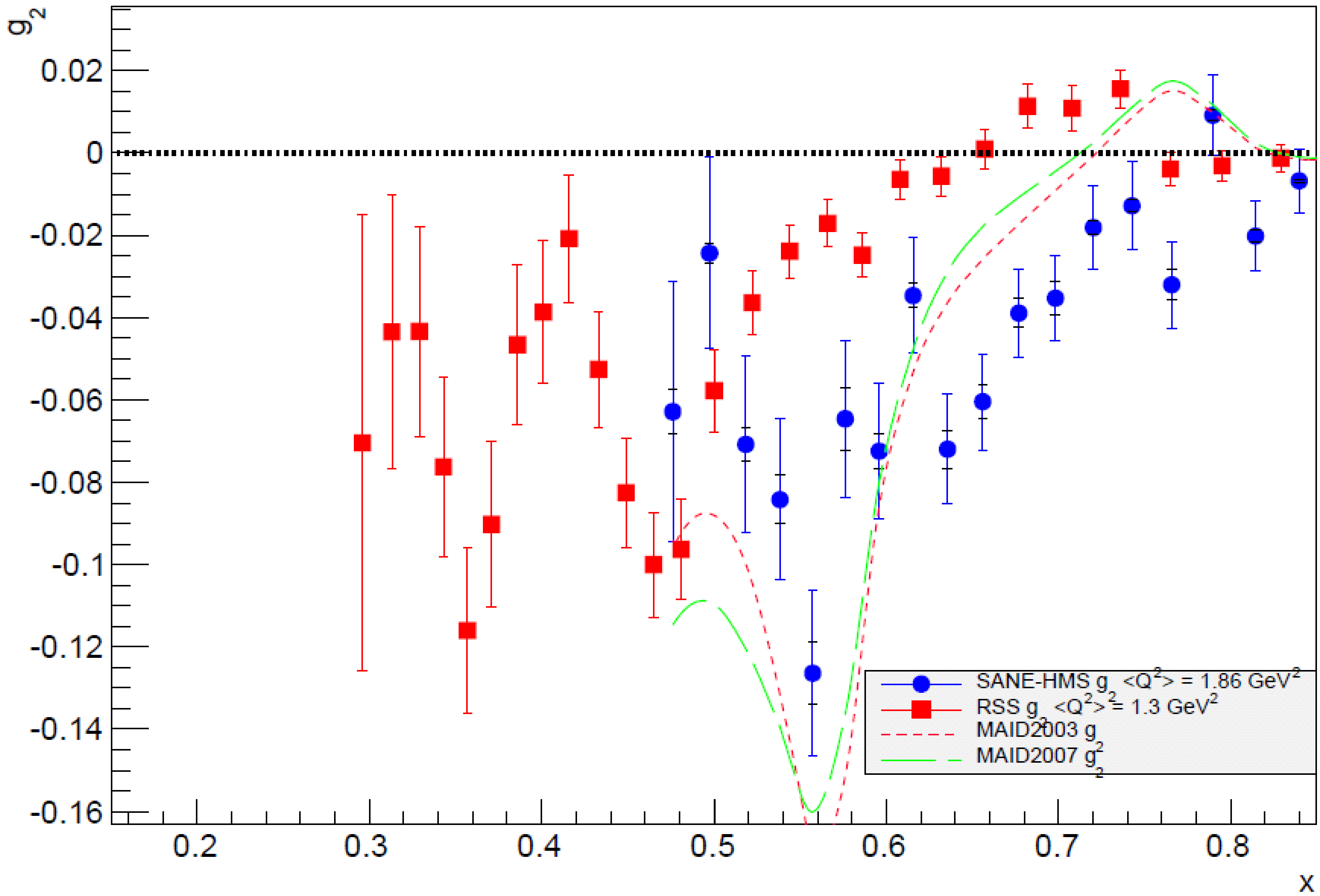


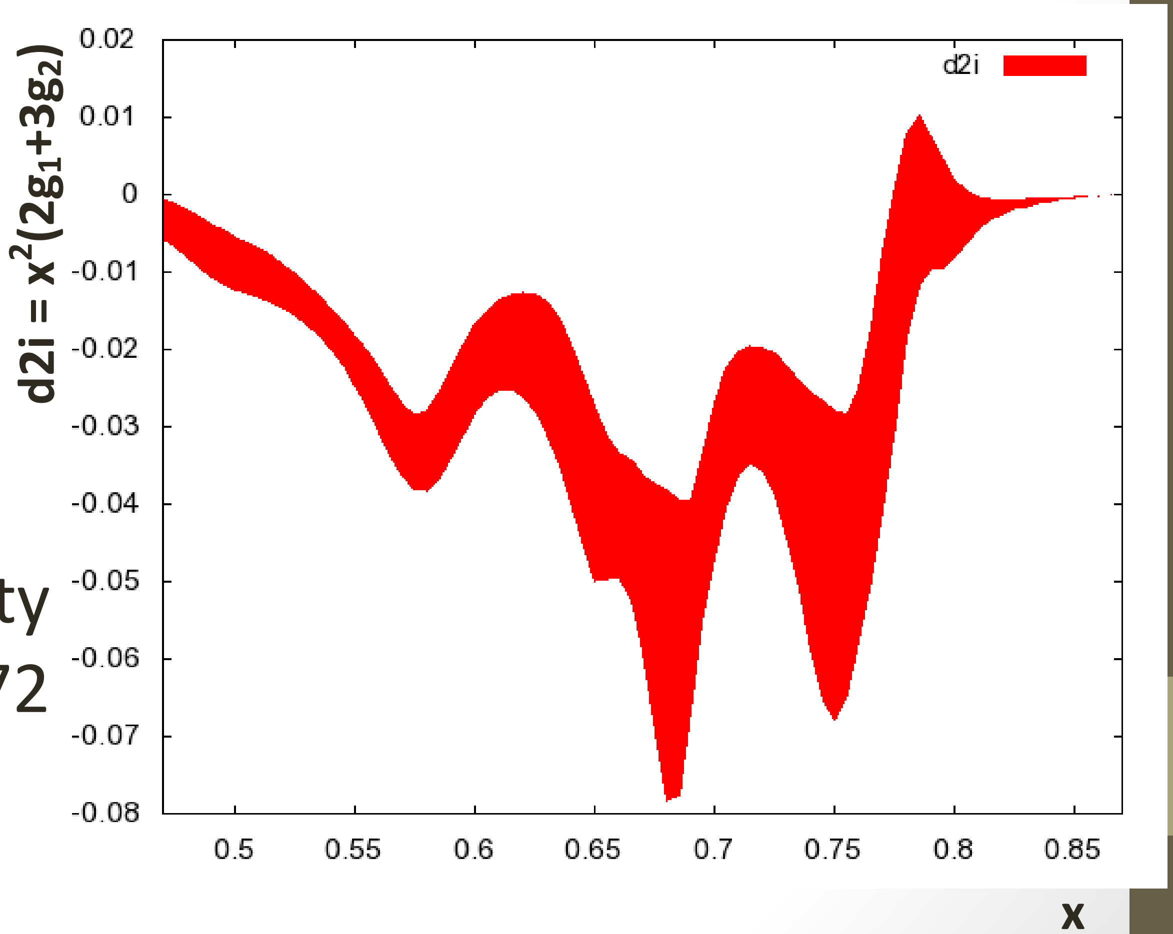
Spin Structure Function g_2

$Q^2 = 1.86\ GeV^2$



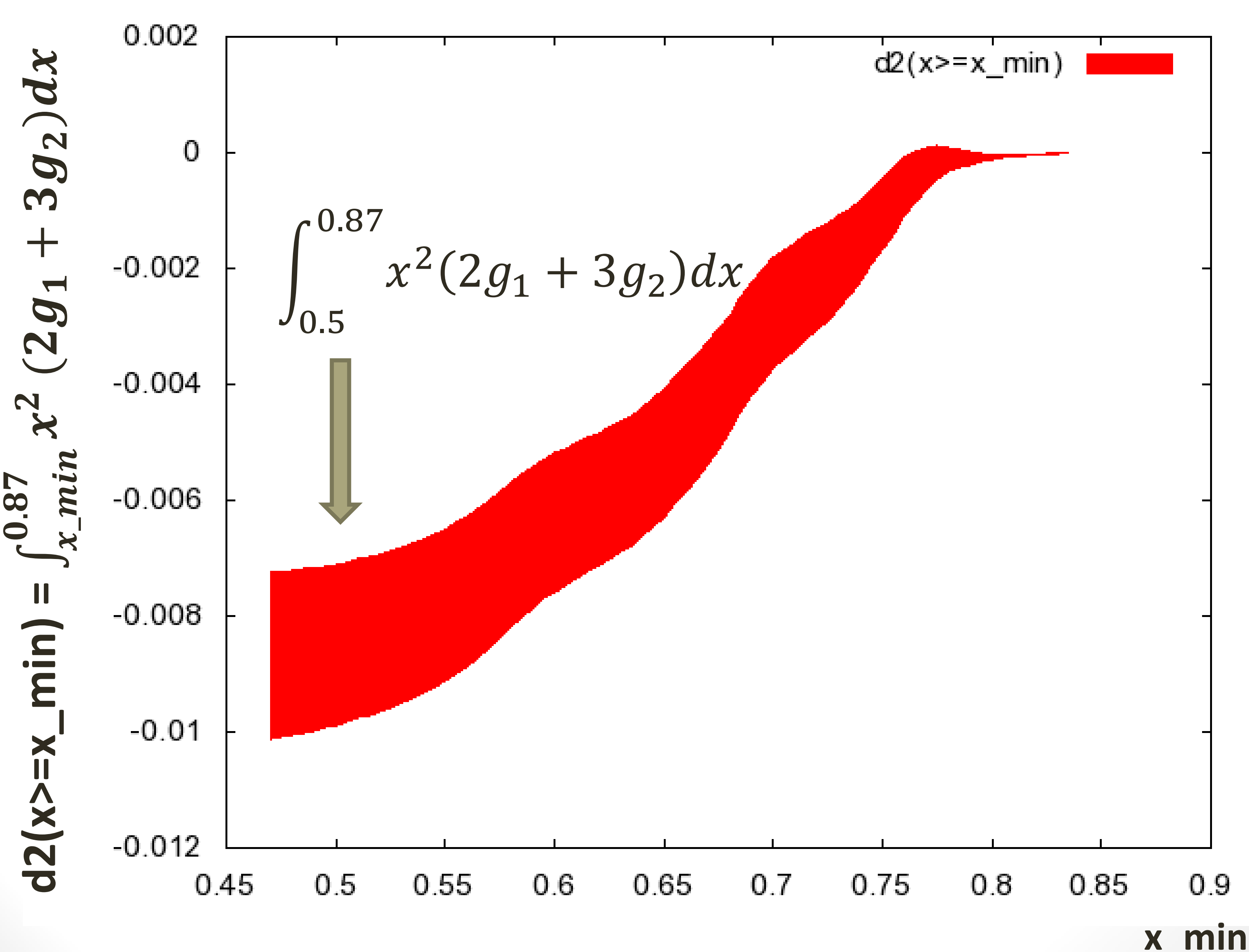
Preliminary Twist-3 d_2 for the Region 3

$$d_2 = 3\int_0^1 x^2(g_2 - g_2^{WW})dx = \int_0^1 x^2(2g_1 + 3g_2)dx$$



OPE valid to
$N = 2 < Q^2/M_0^2 \sim 1.8/0.5^2$
per DIS – resonances duality
Ji & Unrau, PRD52 (1995) 72

d_2 Matrix Element

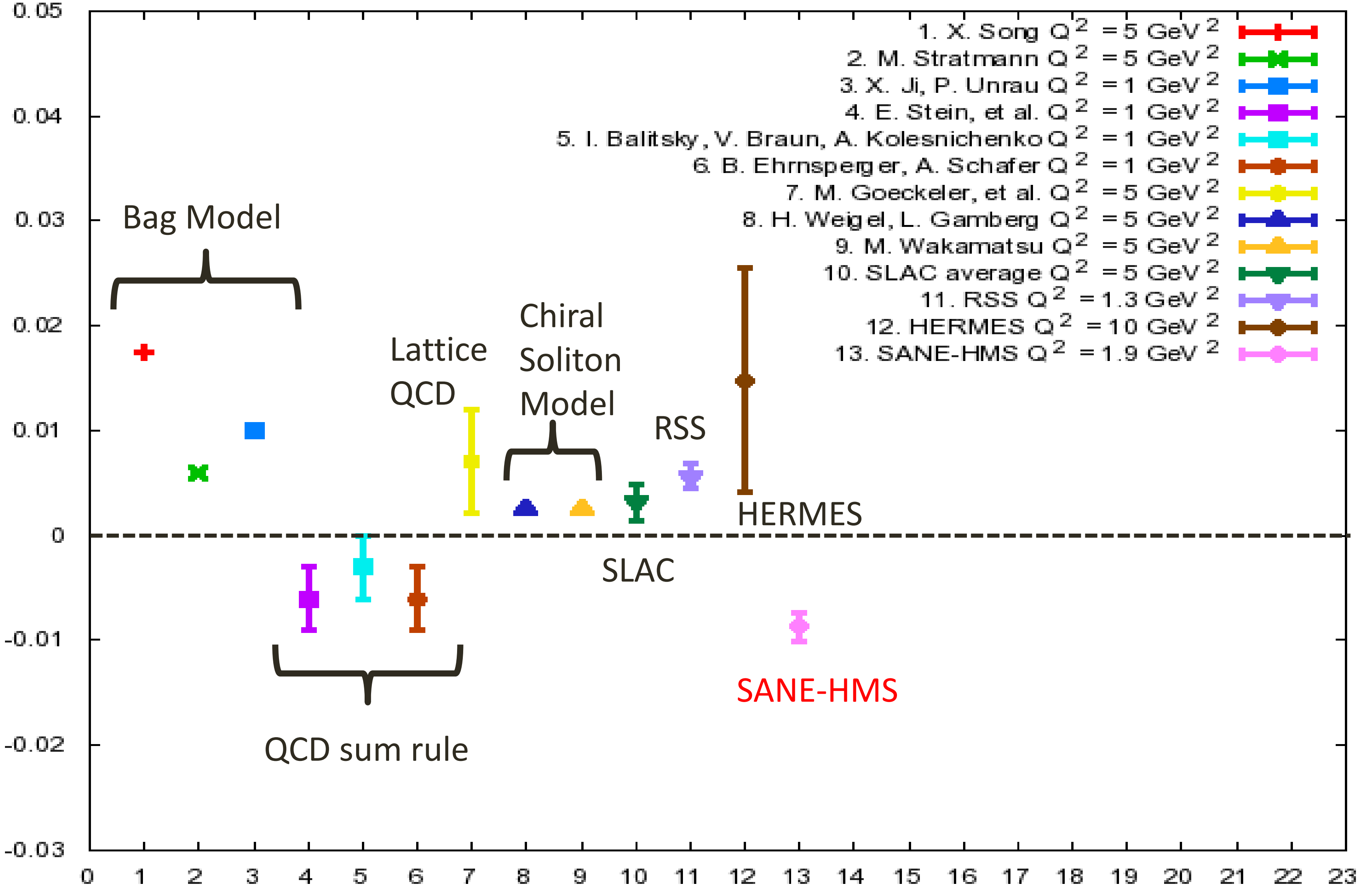


d_2 Matrix Element

$$\overline{d_2} = -0.0087 \pm 0.0014$$

$$\overline{d_2} = \int_{0.47}^{0.87} x^2(2g_1 + 3g_2)dx$$

d_2 Matrix Element



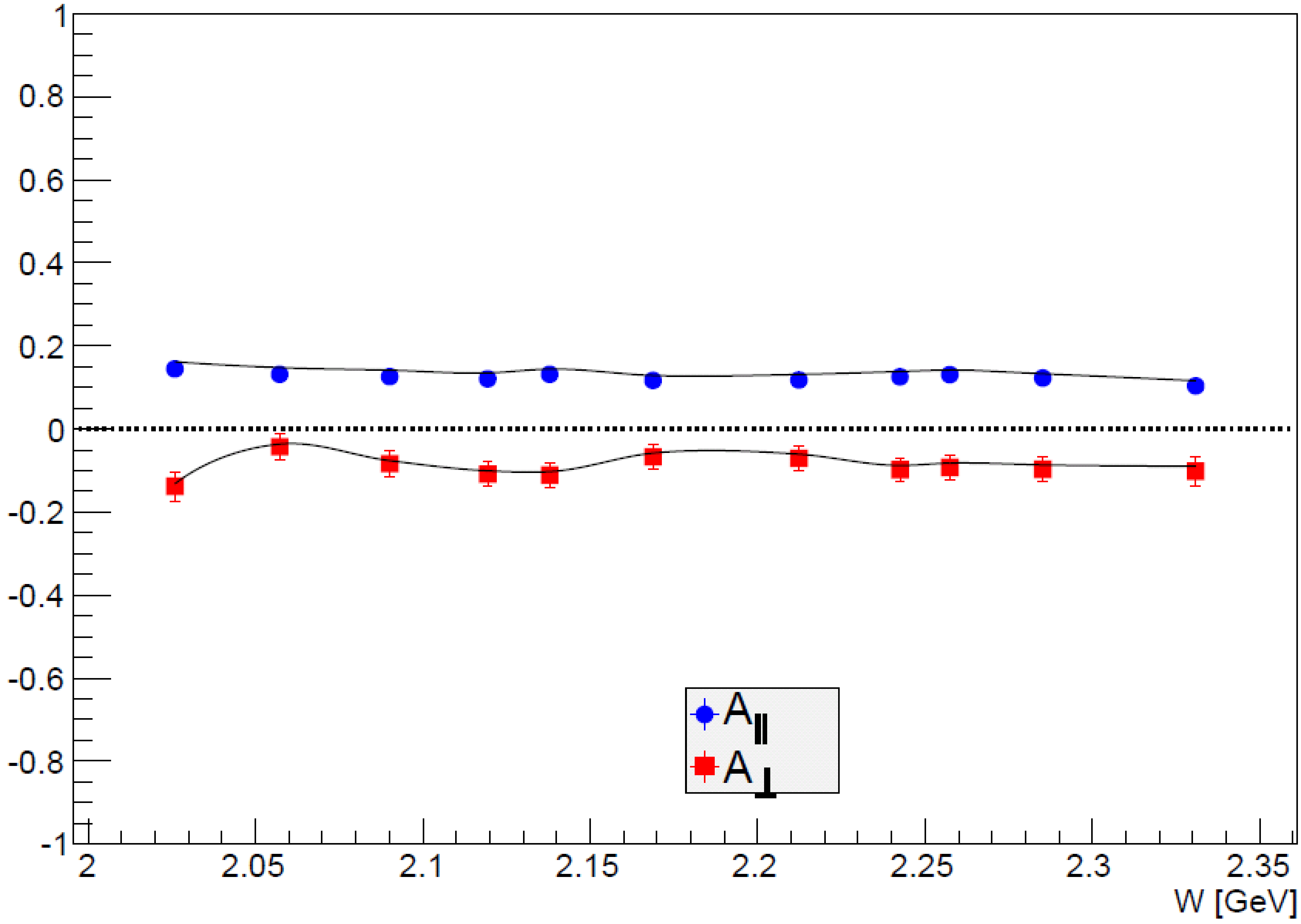
SANE-HMS Region 2

$$Q^2 = 1.31\ GeV^2$$

Extension of RSS data into DIS

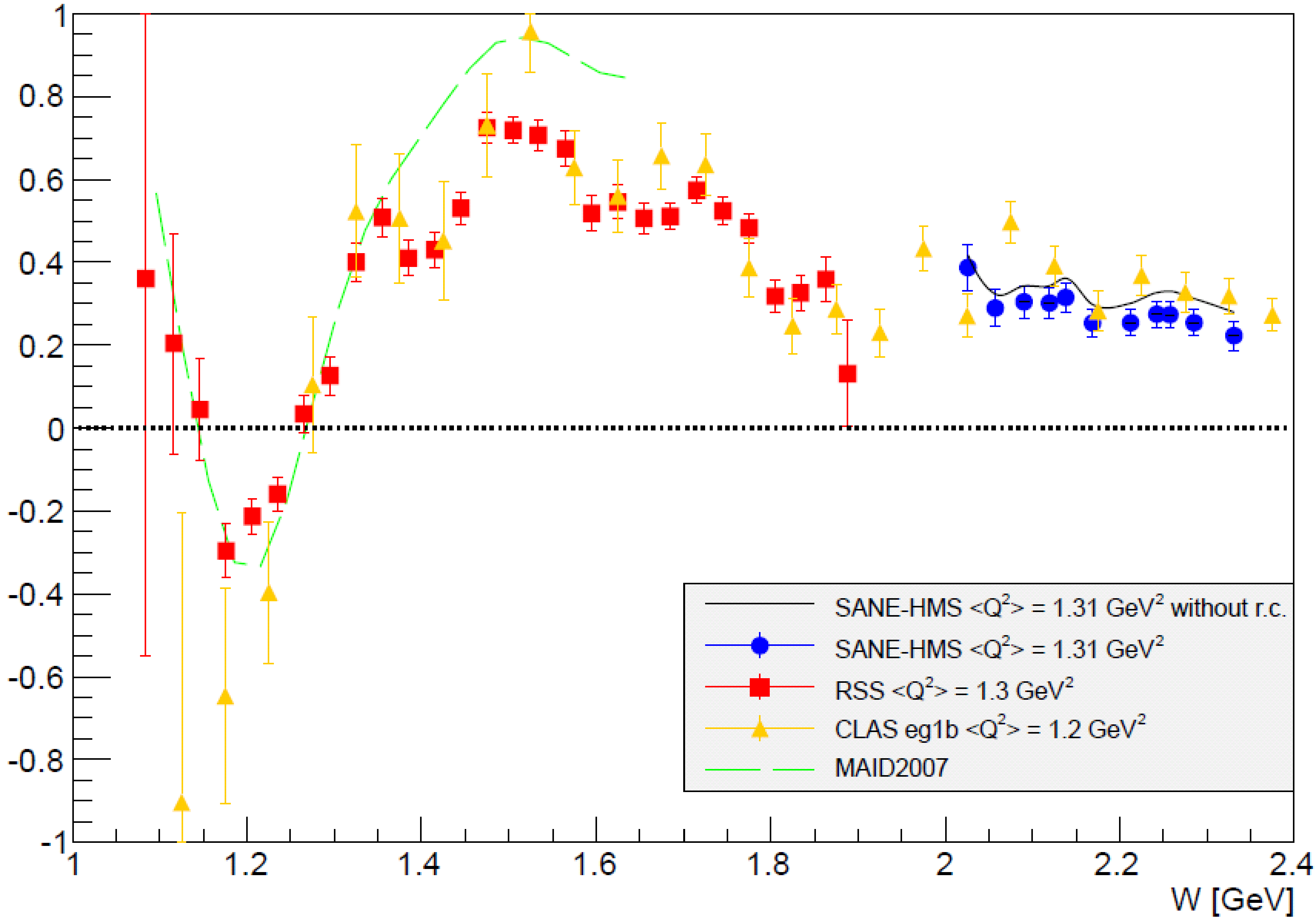
Parallel and Perpendicular Asymmetries

$Q^2 = 1.31\ GeV^2$



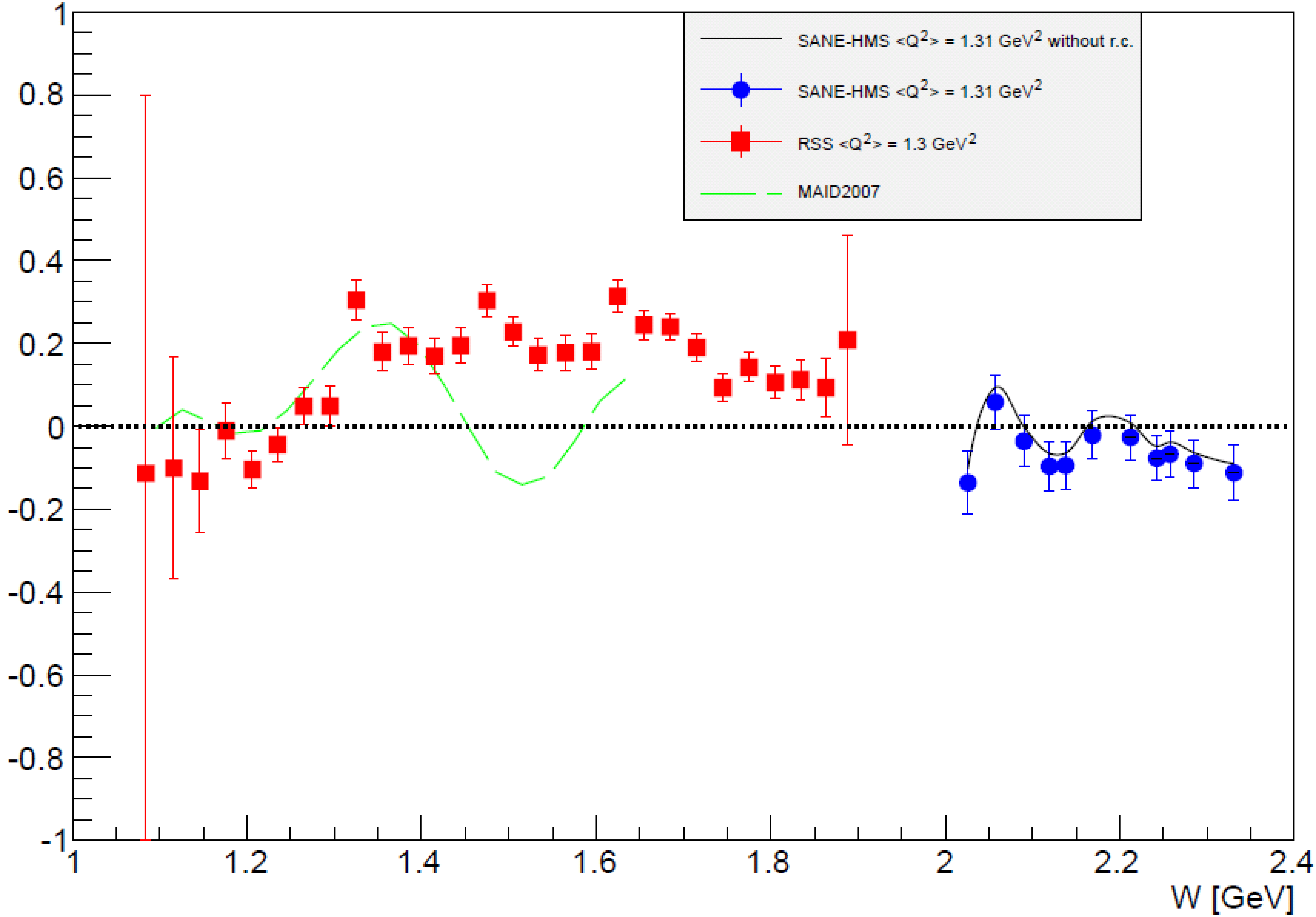
Asymmetry $A_1 = \frac{\sigma_{TT}}{\sigma_T}$

$Q^2 = 1.31\ GeV^2$



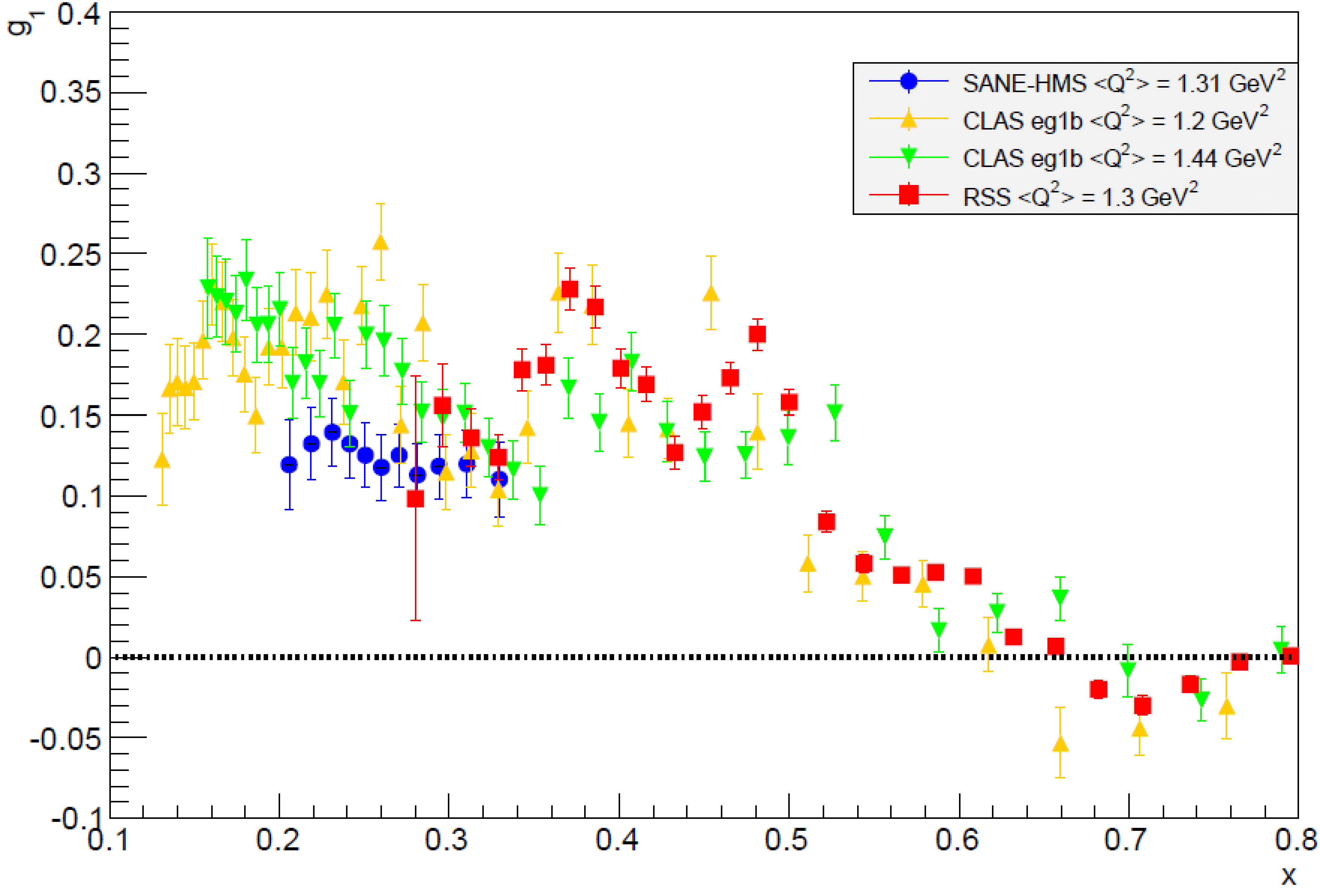
Asymmetry $A_2 = \frac{\sigma_{LT}}{\sigma_T}$

$Q^2 = 1.31\ GeV^2$



Spin Structure Function g_1

$Q^2 = 1.31\ GeV^2$



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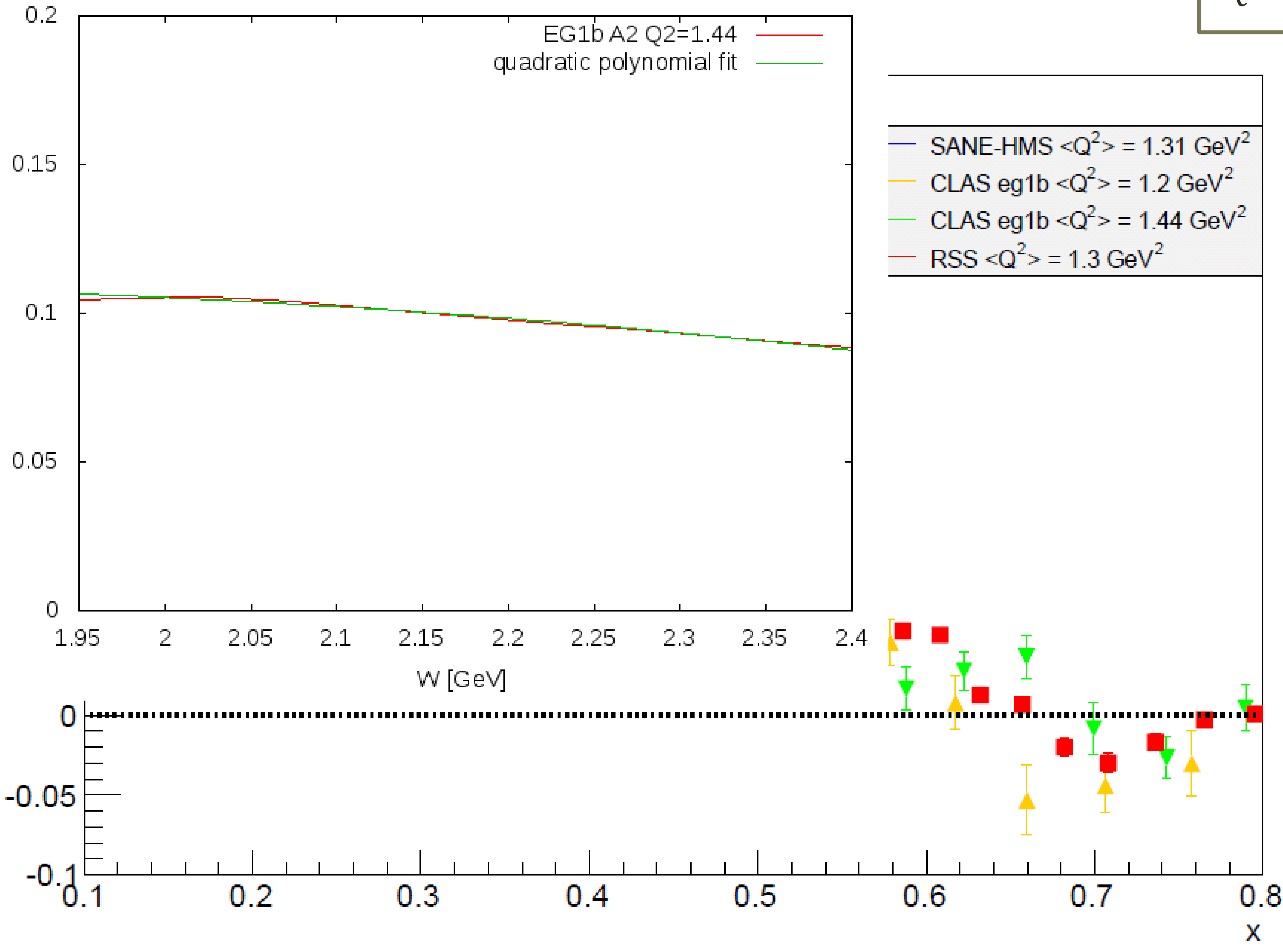
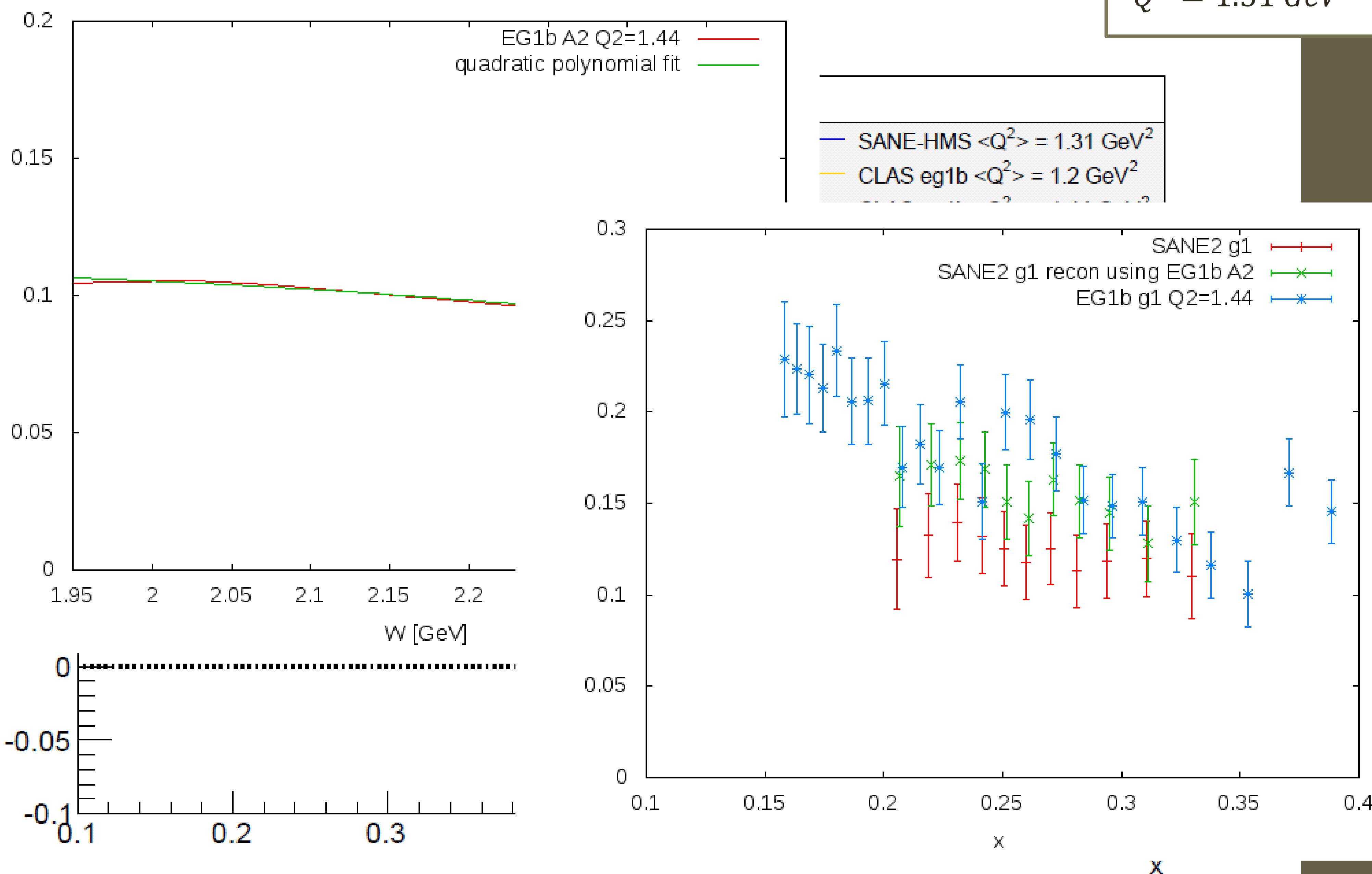


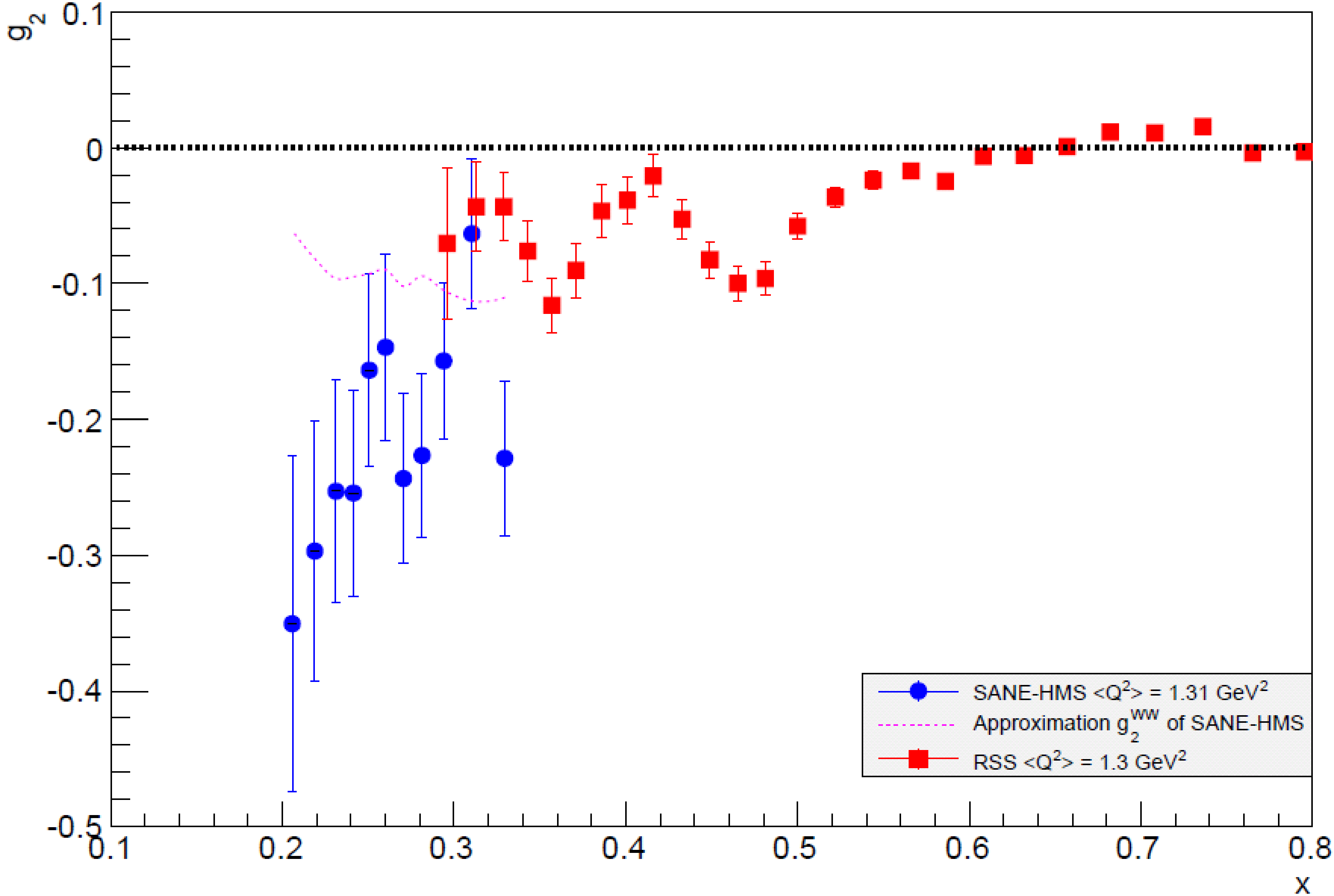
Spin Structure Function g_1

$Q^2 = 1.31\ GeV^2$



Spin Structure Function g_2

$Q^2 = 1.31\ GeV^2$



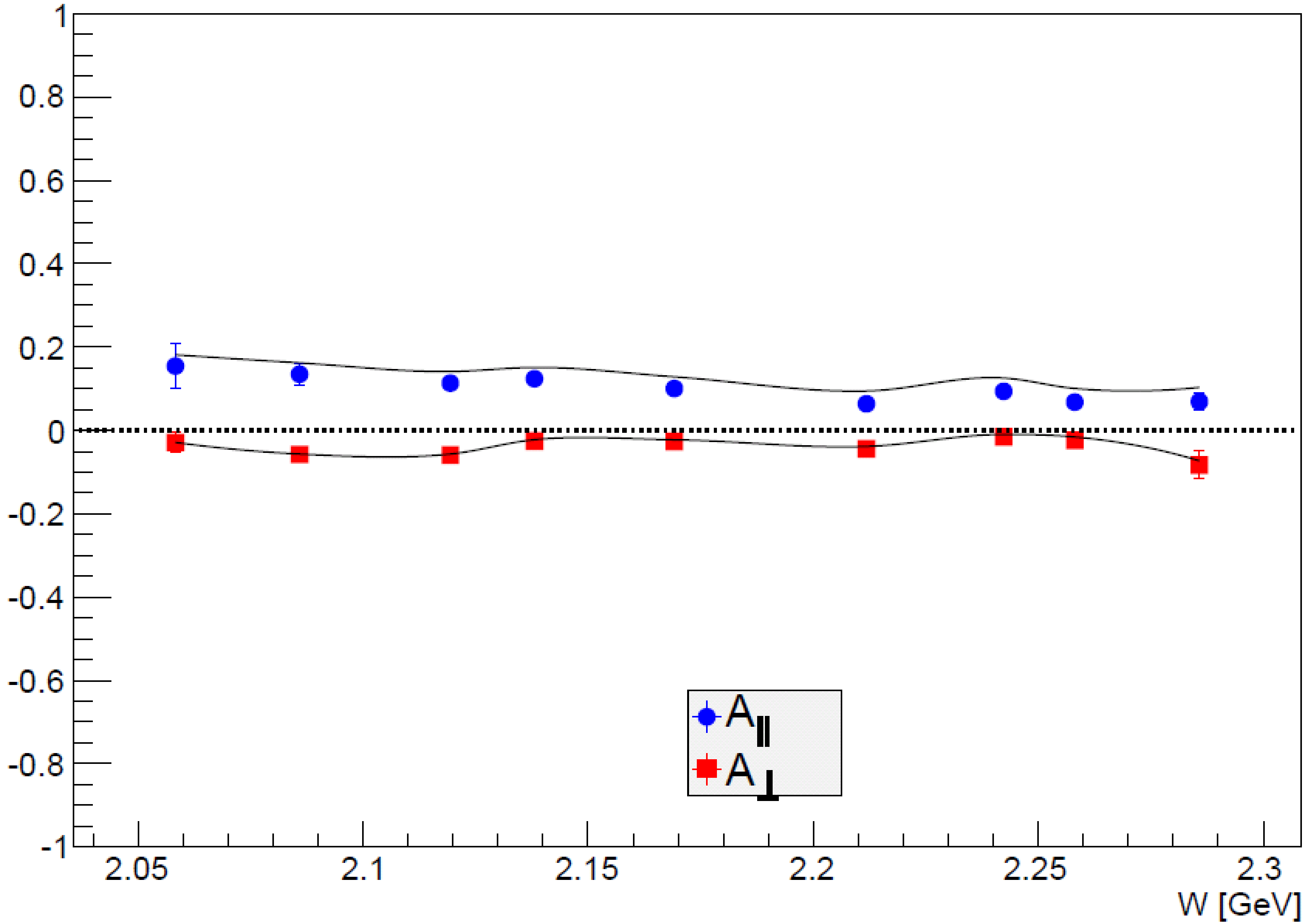
SANE-HMS Region 3

$$Q^2 = 0.81\, GeV^2$$

DIS region

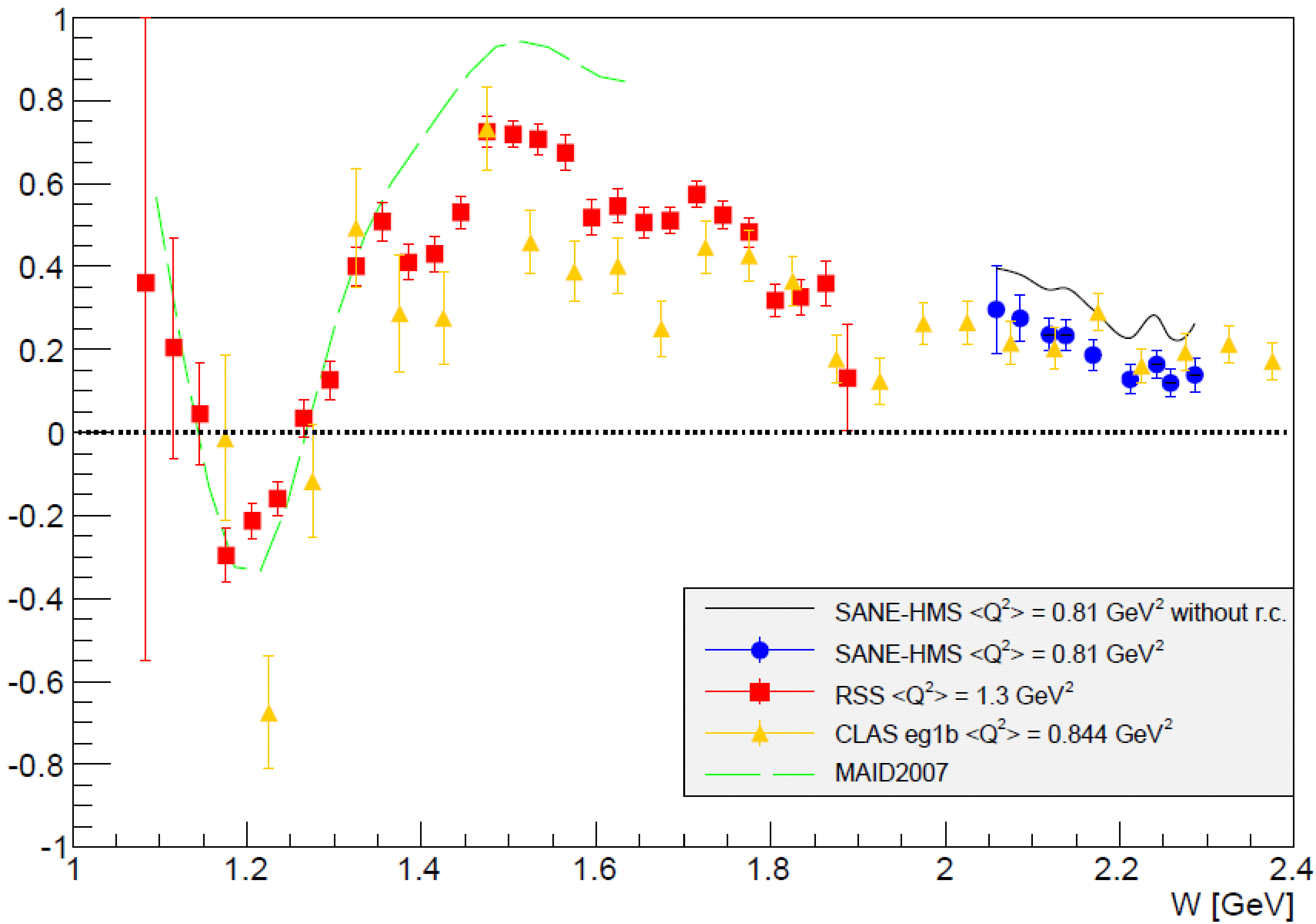
Parallel and Perpendicular Asymmetries

$Q^2 = 0.81\ GeV^2$



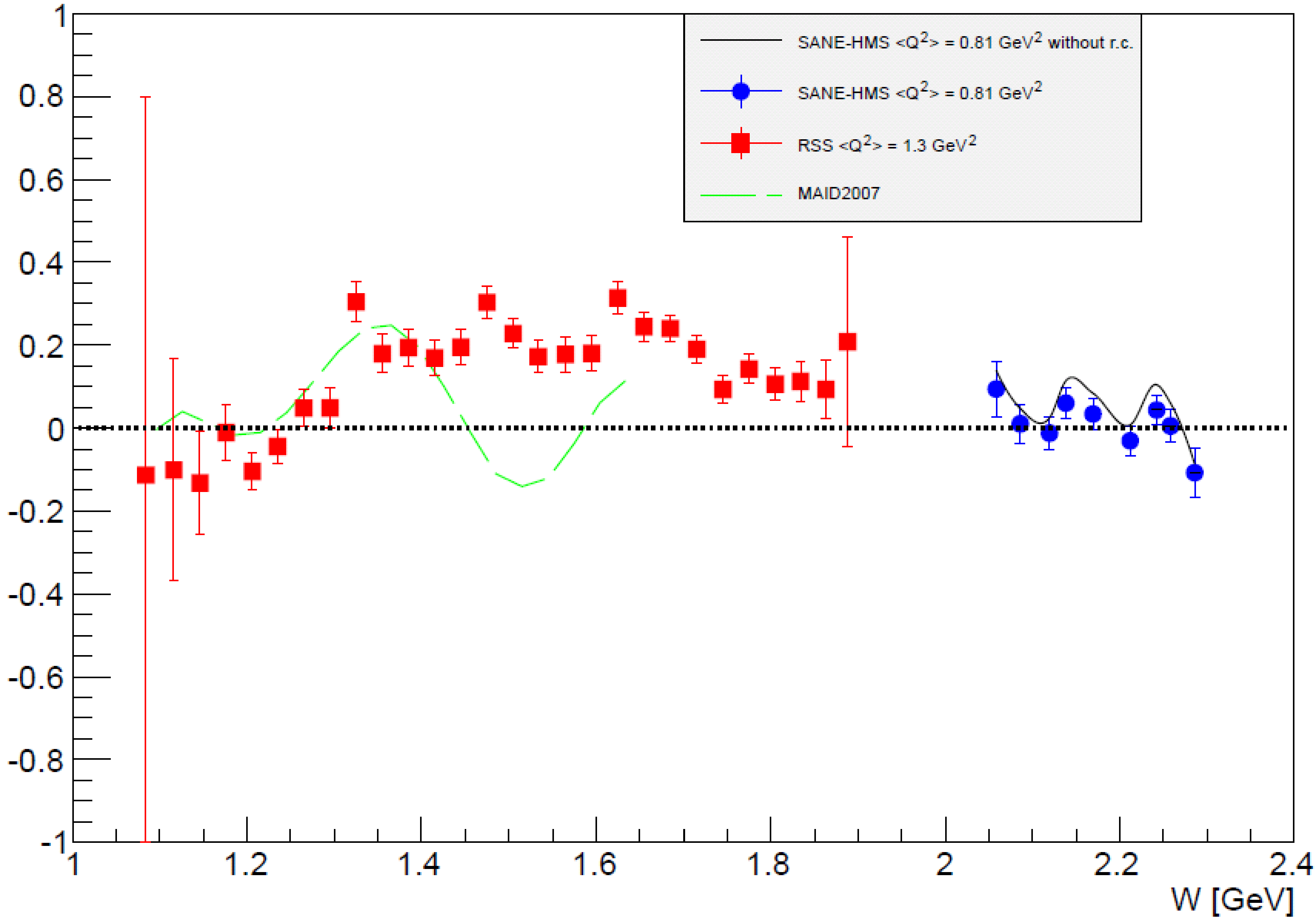
Asymmetry $A_1 = \frac{\sigma_{TT}}{\sigma_T}$

$Q^2 = 0.81\ GeV^2$



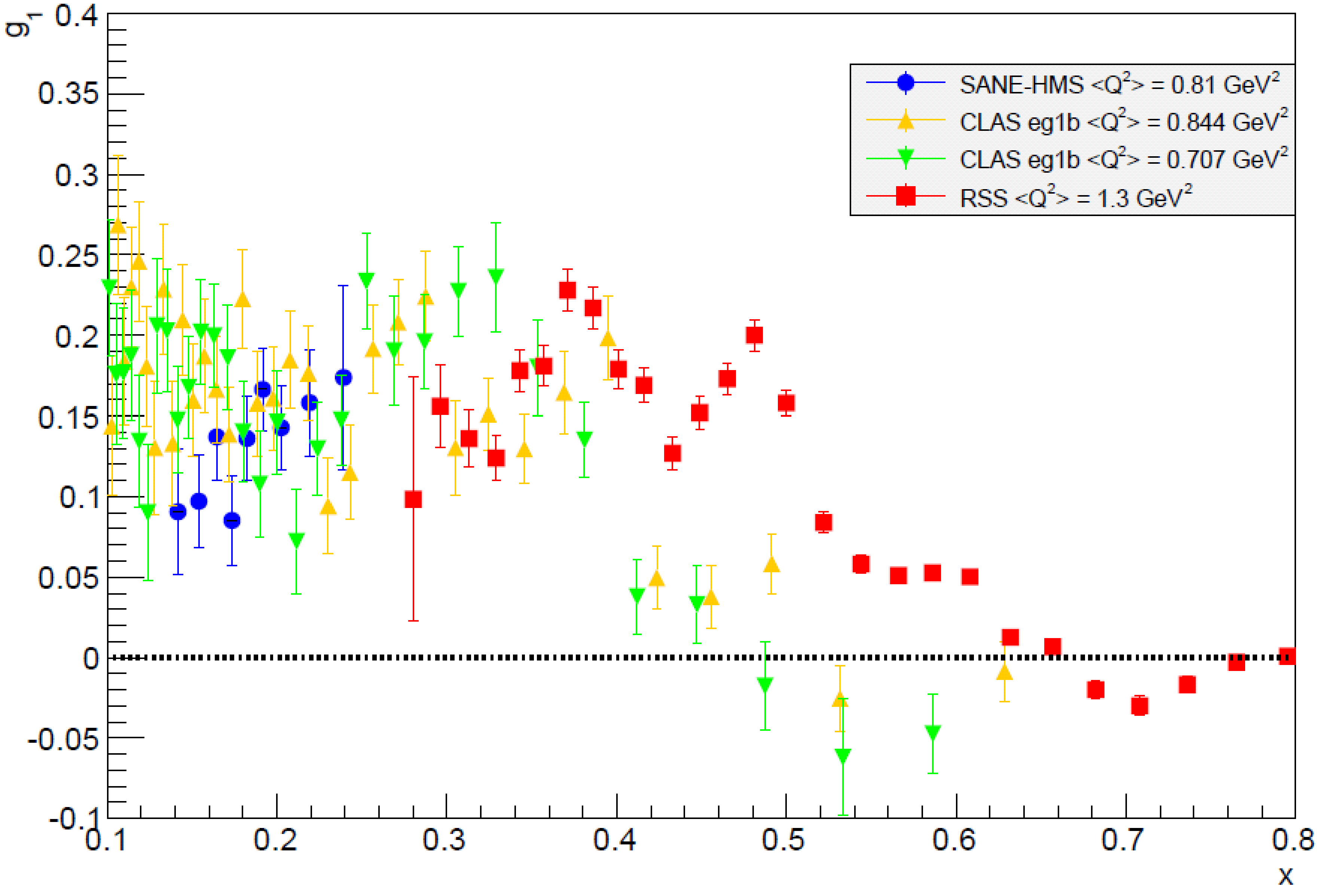
Asymmetry $A_2 = \frac{\sigma_{LT}}{\sigma_T}$

$Q^2 = 0.81\ GeV^2$



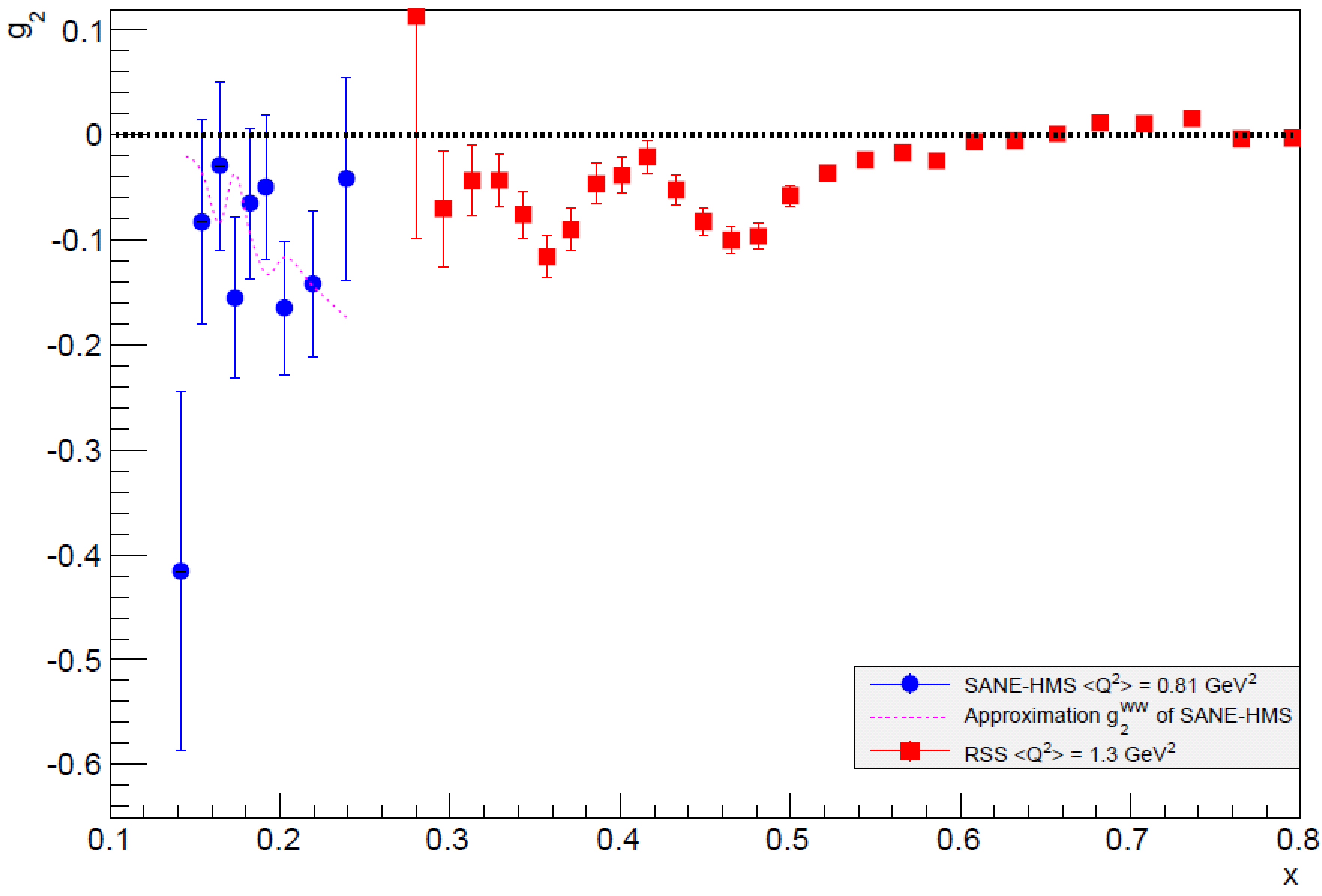
Spin Structure Function g_1

$Q^2 = 0.81\ GeV^2$



Spin Structure Function g_2

$Q^2 = 0.81\ GeV^2$



SANE collaboration

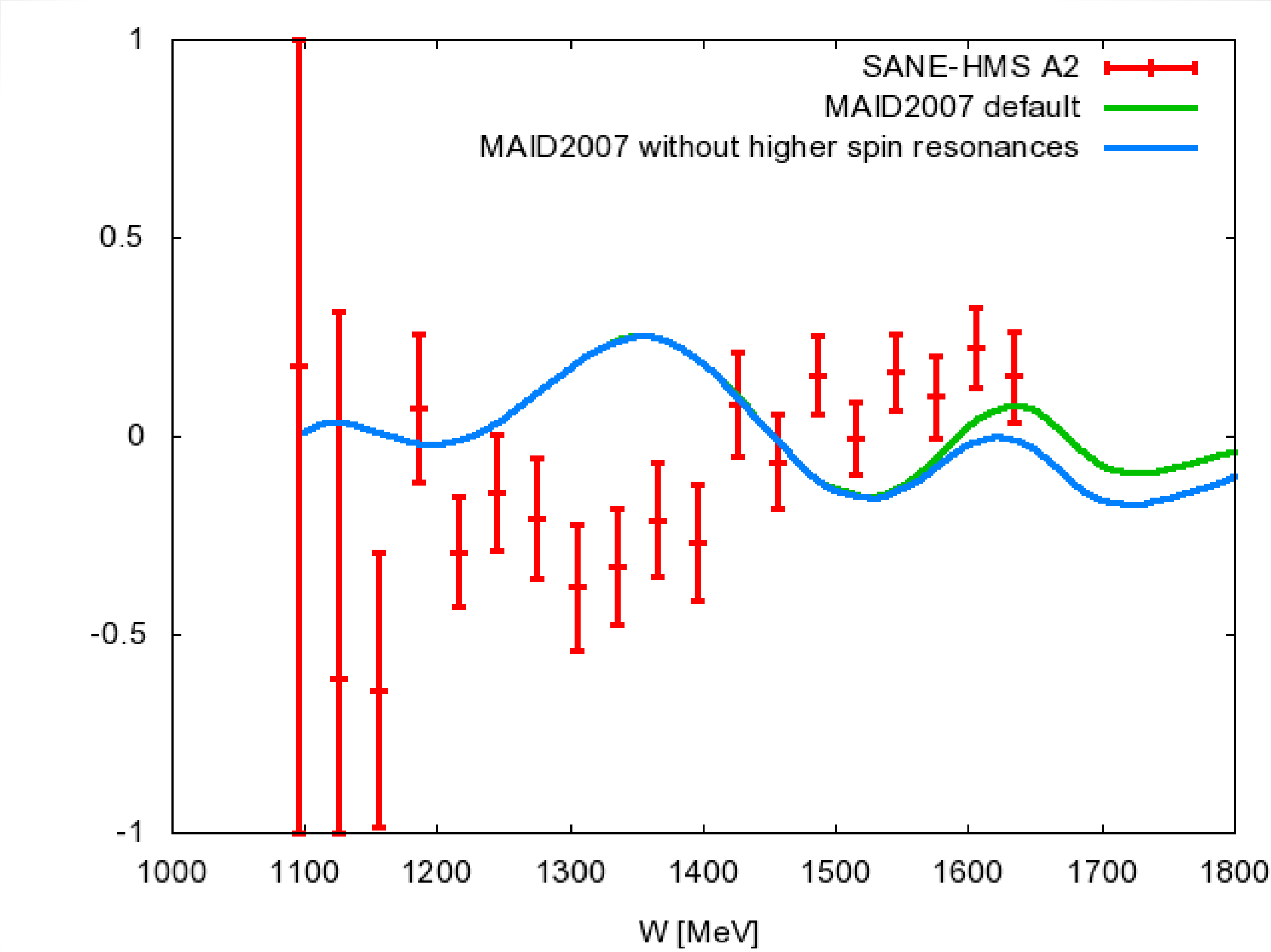
U. Basel, Florida International U., Hampton U., Norfolk S. U., North Carolina A&T S. U., IHEP-Protvino, U. of Regina, Rensselaer Polytechnic I., Rutgers U., Seoul National U., Temple U., TJNAF, U. of Virginia, College of William & Mary, Yerevan Physics I.

Spokespersons: S. Choi (Seoul), M. Jones(Jlab), Z-E. Meziani (Temple), O. A. Rondon (U. of Virginia)

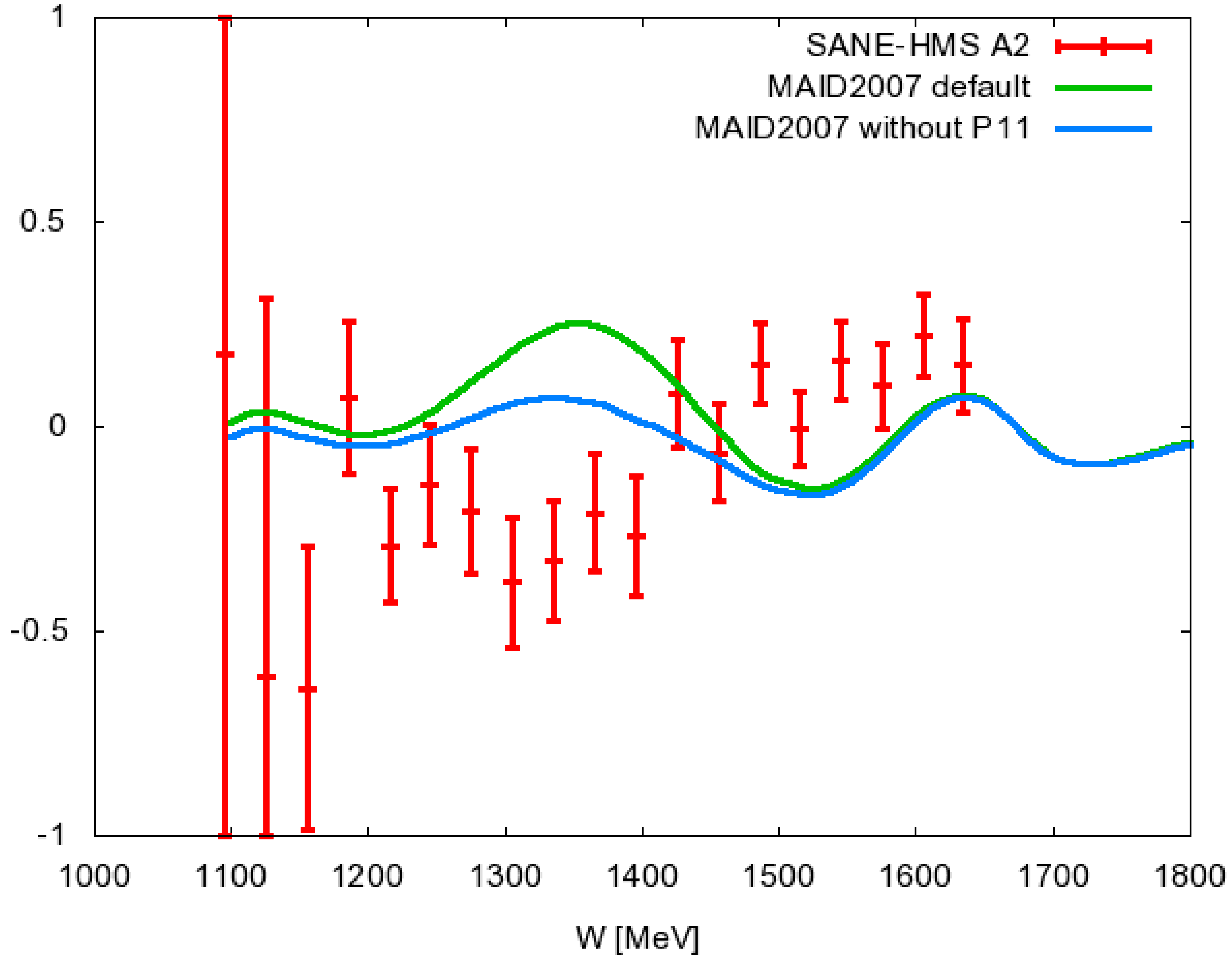
Summary

- **SANE-HMS is a measurement of spin structure functions in high Bjorken x and intermediate Q^2.**
- **Parallel and perpendicular asymmetries and structure functions show good agreement with previous experiments.**
- **A_2 and g_2 show significant Q^2 evolution. Negative A_2 at W=1.3 GeV is shown. And negative A_2 at DIS region can affect g_1 deduced from parallel asymmetry only (e.g. Hall B results).**
- $\overline{d_2} = -0.0087 \pm 0.0014$ **is the first negative result of d_2 matrix element, although its integration range is limited.**

Backup Slides



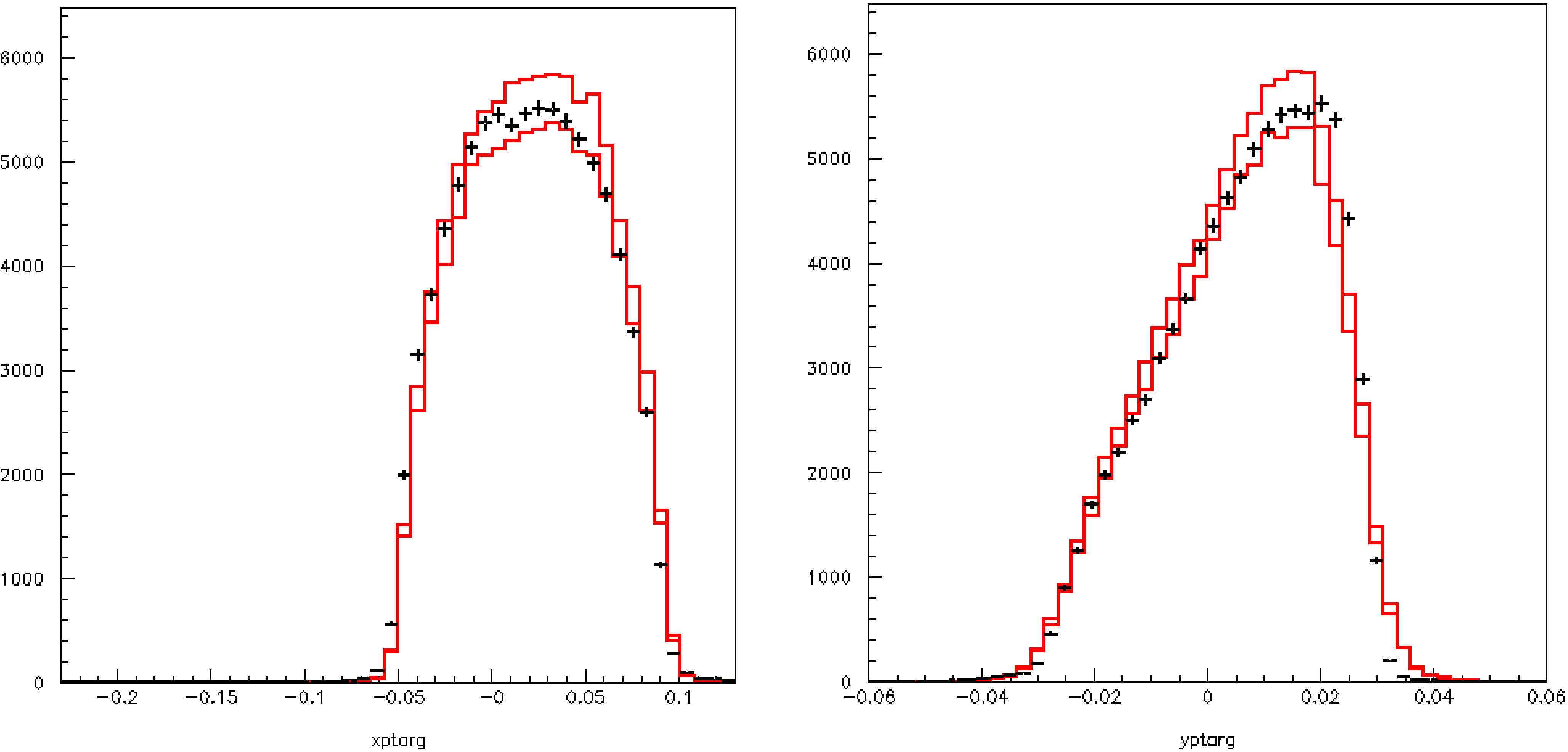
SANE-HMS A2
MAID2007 default
MAID2007 without higher spin resonances
1
0.5
0
-0.5
-1
1000
1100
1200
1300
1400
1500
1600
1700
1800
W [MeV]



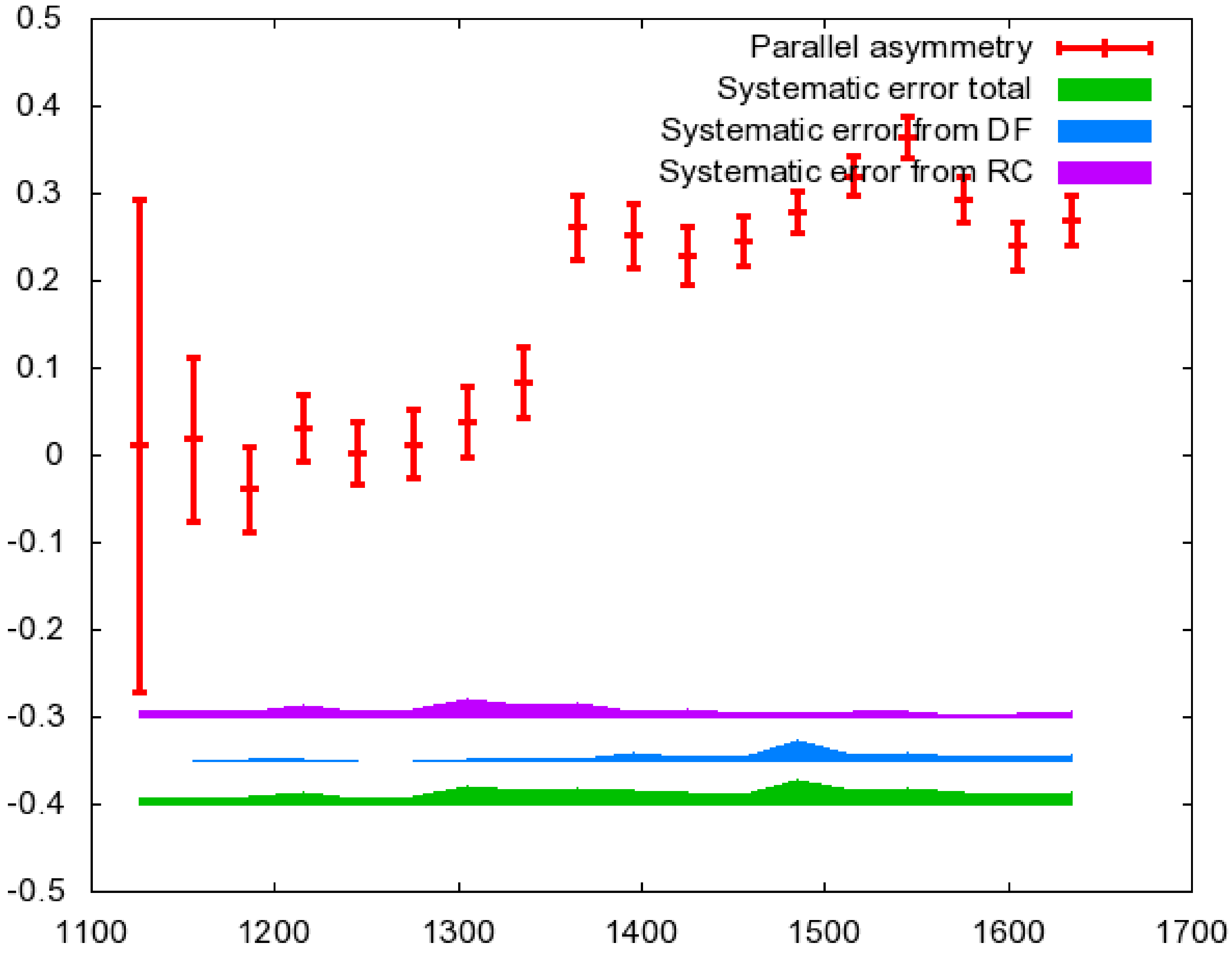
SANE-HMS A2
MAID2007 default
MAID2007 without P11
1
0.5
0
-0.5
-1
1000
1100
1200
1300
1400
1500
1600
1700
1800
W [MeV]

Systematic Errors

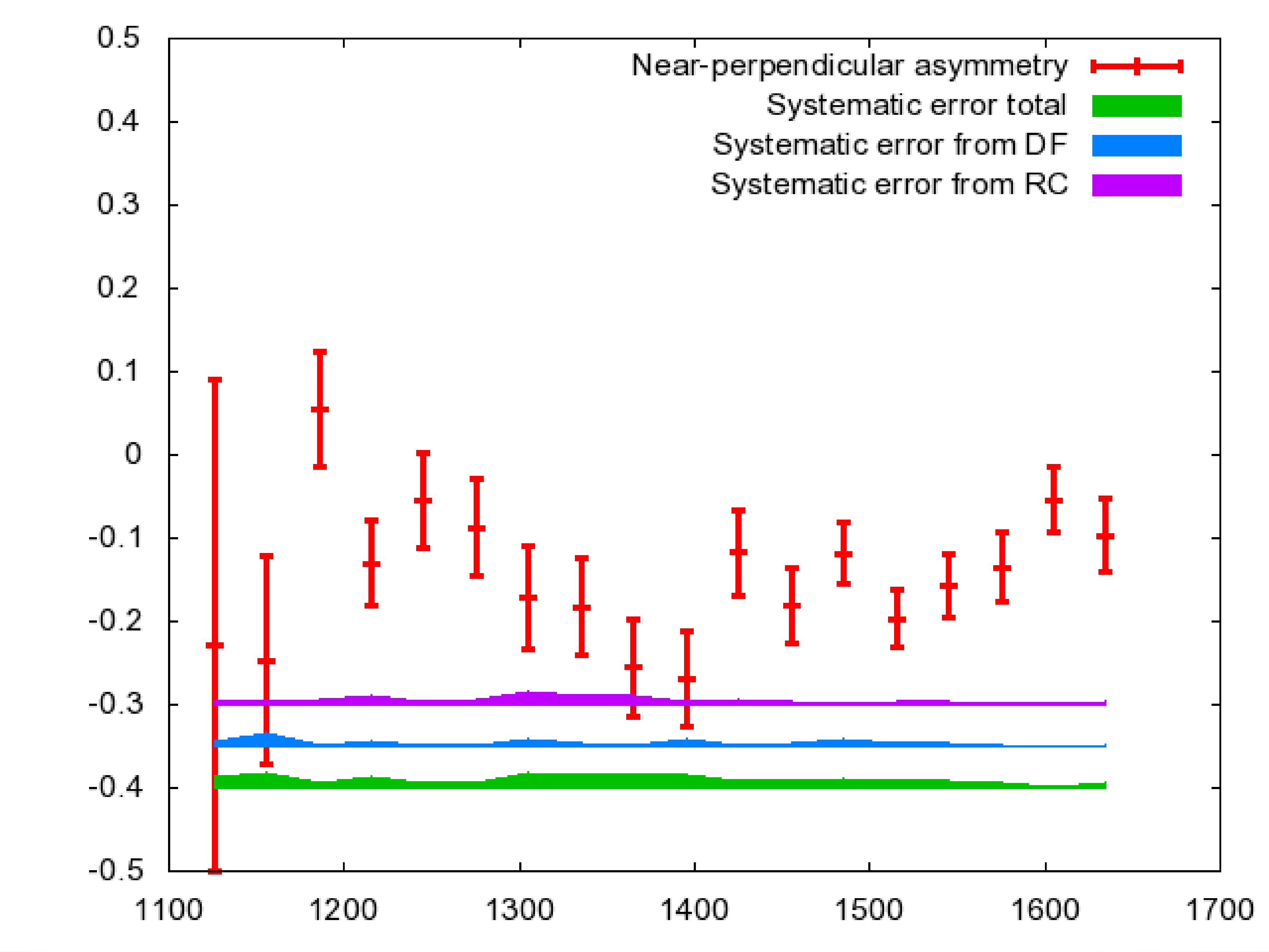
Error Source	Average
Target Polarization	4.0%
Beam polarization	1.5%
Dilution Factor	3.3%
Nitrogen Correction	0.4%
Radiative Corrections	10% (A_1 and A_2)
Kinematic Reconstruction	0.5%



6000
5000
4000
3000
2000
1000
0
−0.2
−0.15
−0.1
−0.05
−0
0.05
0.1
xptarg
6000
5000
4000
3000
2000
1000
0
−0.06
−0.04
−0.02
0
0.02
0.04
0.06
yptarg

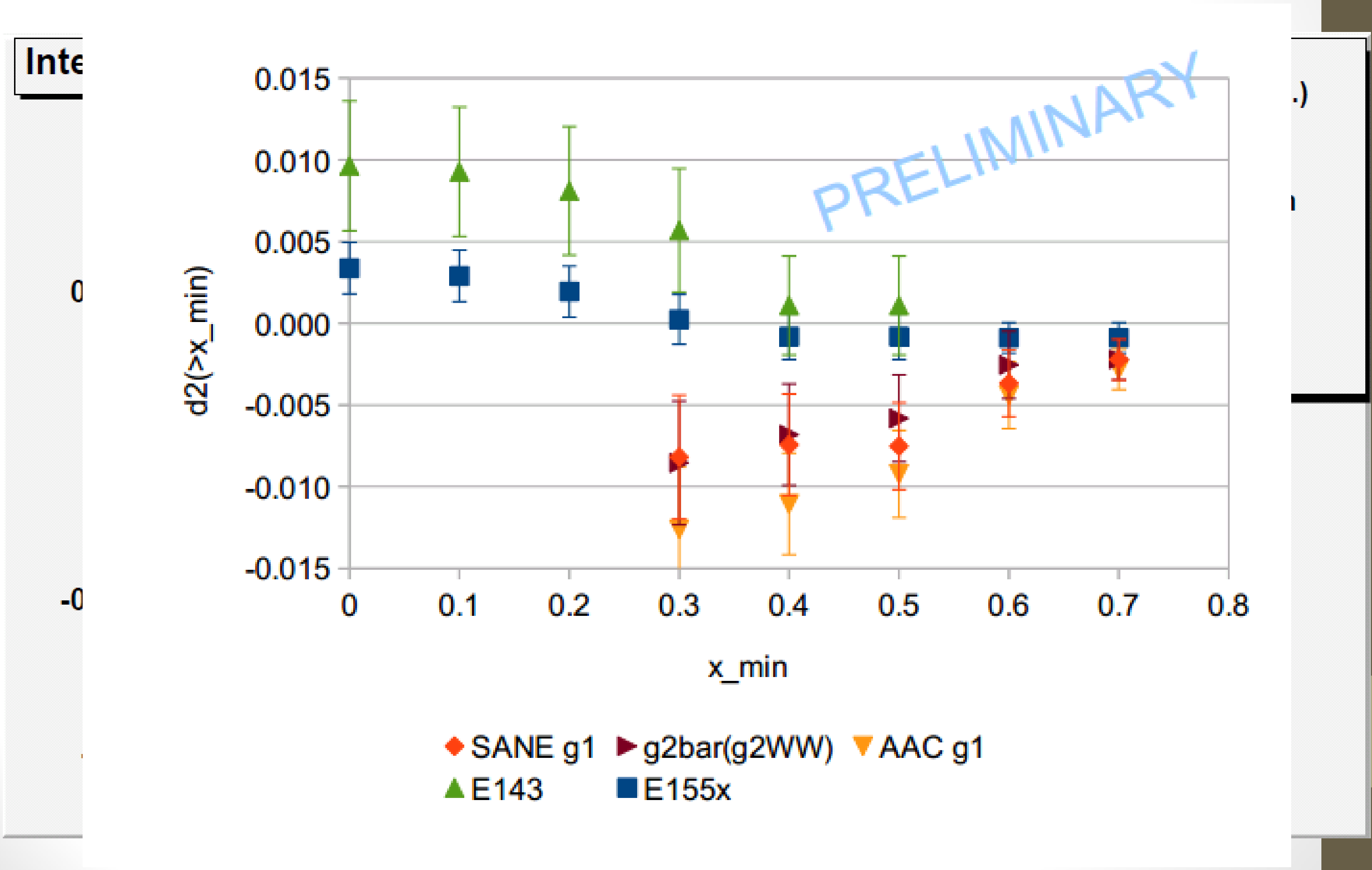


Parallel asymmetry
Systematic error total
Systematic error from DF
Systematic error from RC
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1100
1200
1300
1400
1500
1600
1700



0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1100
1200
1300
1400
1500
1600
1700
Near-perpendicular asymmetry
Systematic error total
Systematic error from DF
Systematic error from RC

Twist-3 d_2



PRELIMINARY
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
d2(>x_min)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x_min
SANE g1
g2bar(g2WW)
AAC g1
E143
E155x

Useful relations

$$g_1 = \frac{F_1}{1+\gamma^2}(A_1 + \gamma A_2),$$

$$g_2 = \frac{F_1}{1+\gamma^2}(-A_1 + \frac{A_2}{\gamma})$$

$$A_1 = \frac{g_1 - \gamma^2 g_2}{F_1}$$

$$A_2 = \gamma \frac{g_1 + g_2}{F_1},$$

$$A_{||} = D(A_1 + \eta A_2),$$

$$A_{\perp} = d(A_2 - \zeta A_1),$$

Spin Structure Functions

Inclusive DIS cross section depends on four structure functions, two unpolarized (F_1, F_2) and two polarized (g_1, g_2). The spin structure functions g_1 and g_2 can be experimentally determined by measuring spin asymmetries:

$$A_{\parallel} = \frac{\sigma^{\downarrow\uparrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\downarrow\uparrow} + \sigma^{\uparrow\uparrow}}, \quad A_{\perp} = \frac{\sigma^{\downarrow\rightarrow} - \sigma^{\uparrow\rightarrow}}{\sigma^{\downarrow\rightarrow} + \sigma^{\uparrow\rightarrow}}.$$

$$g_1(x,Q^2) = \frac{F_1(x,Q^2)}{d'}\left[A_{\parallel} + \tan(\theta/2) A_{\perp}\right],$$

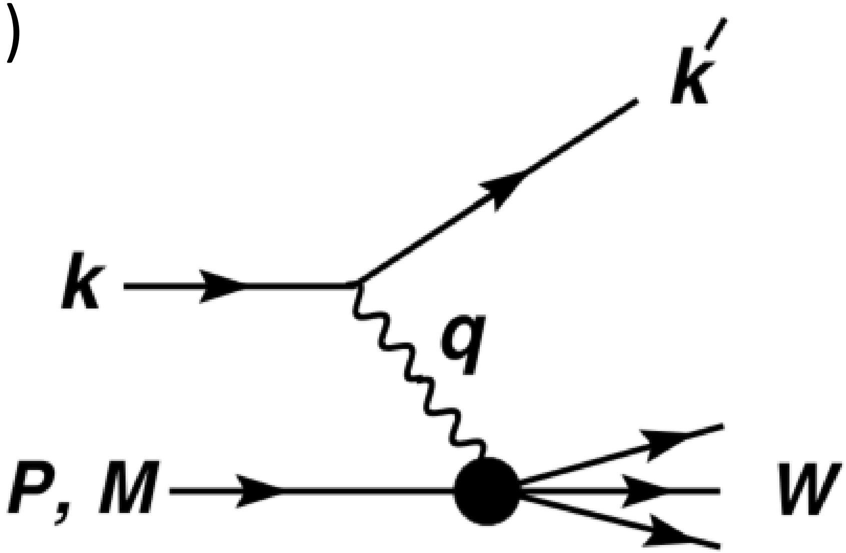
$$g_2(x,Q^2) = \frac{y F_1(x,Q^2)}{2d'}\left[\frac{E + E' \cos(\theta)}{E' \sin(\theta)} A_{\perp} - A_{\parallel}\right]$$

ep deep inelastic scattering

High-energy electron-nucleon scattering(Deep Inelastic Scattering) ep → e'X

k and k' are the four-momenta of the incoming and outgoing electrons, P is the four-moemntum of a proton with mass M, and W is the mass of the recoiling system X.

q is the four-momentum of the virtual photon(the exchanged particle). ($Q^2 = -q^2$)



Spin structure functions

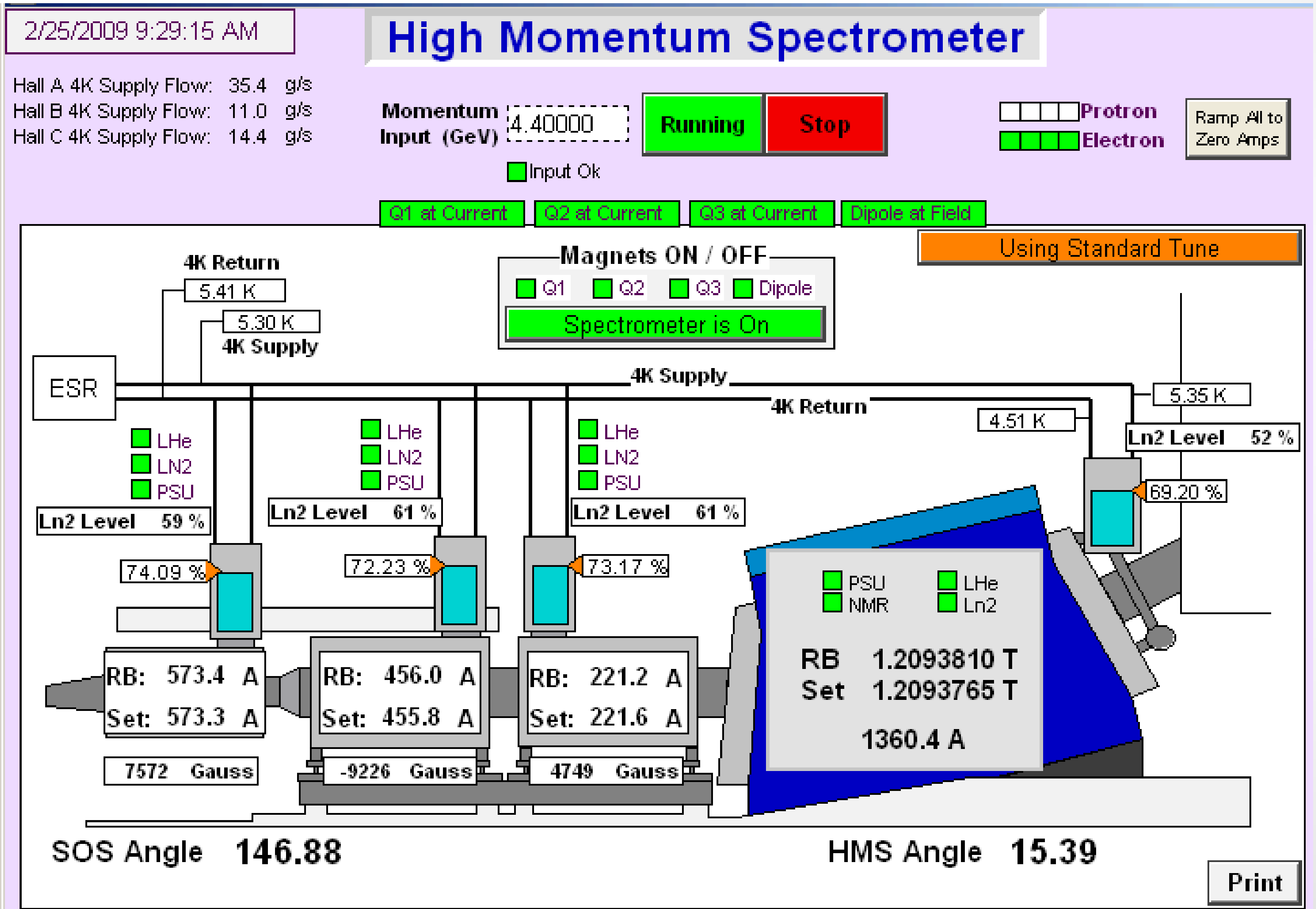
When the spins of electron and nucleon are all polarized, we can see the dependence of scattering cross section on the spin structure functions $g_1(x, Q^2)$ and $g_2(x, Q^2)$.

$$g_1 = \frac{1}{2}\sum_i e_i^2[q_i^+ - q_i^-]$$

$$g_2 = g_2^{WW} + \overline{g_2}$$

$$g_2^{WW}(x, Q^2) = -g_1(x, Q^2) + \int_x^1 \frac{g_1(x', Q^2)}{x'} dx'$$

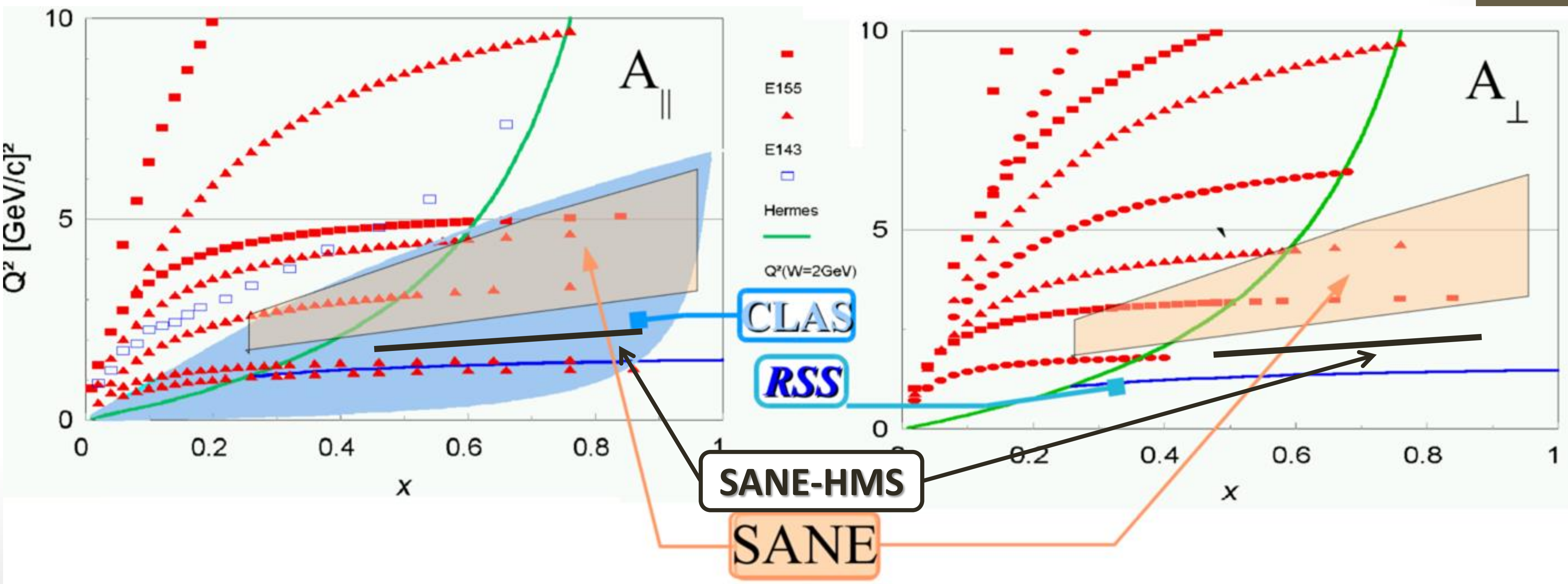
High Momentum Spectrometer



World Data and SANE Region

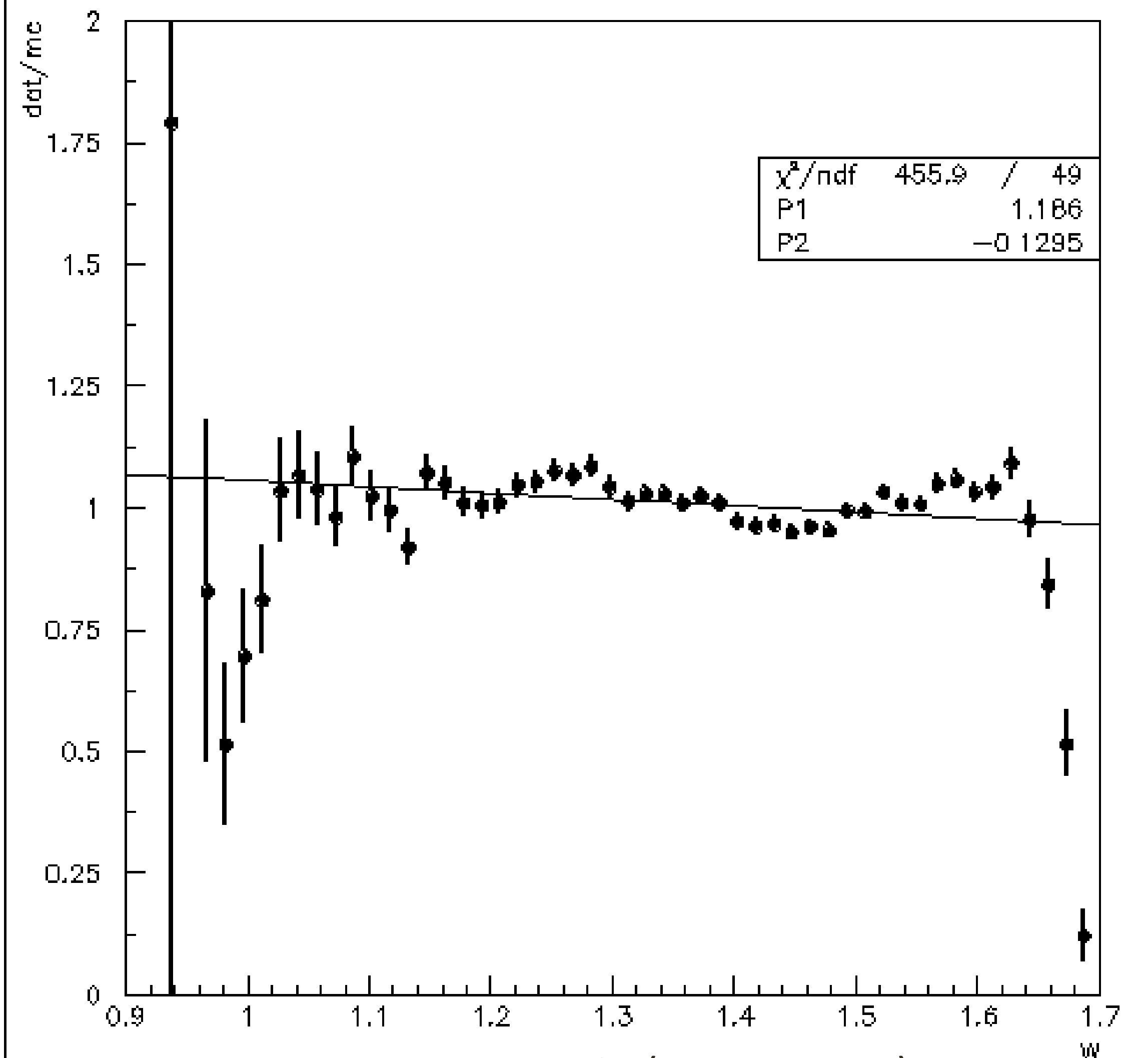
World data lacks big region, especially in the perpendicular asymmetry. SANE covers broad region of

$$0.3 \leq x \leq 0.8, \qquad 2.5GeV^2 \leq Q^2 \leq 6.5GeV^2$$



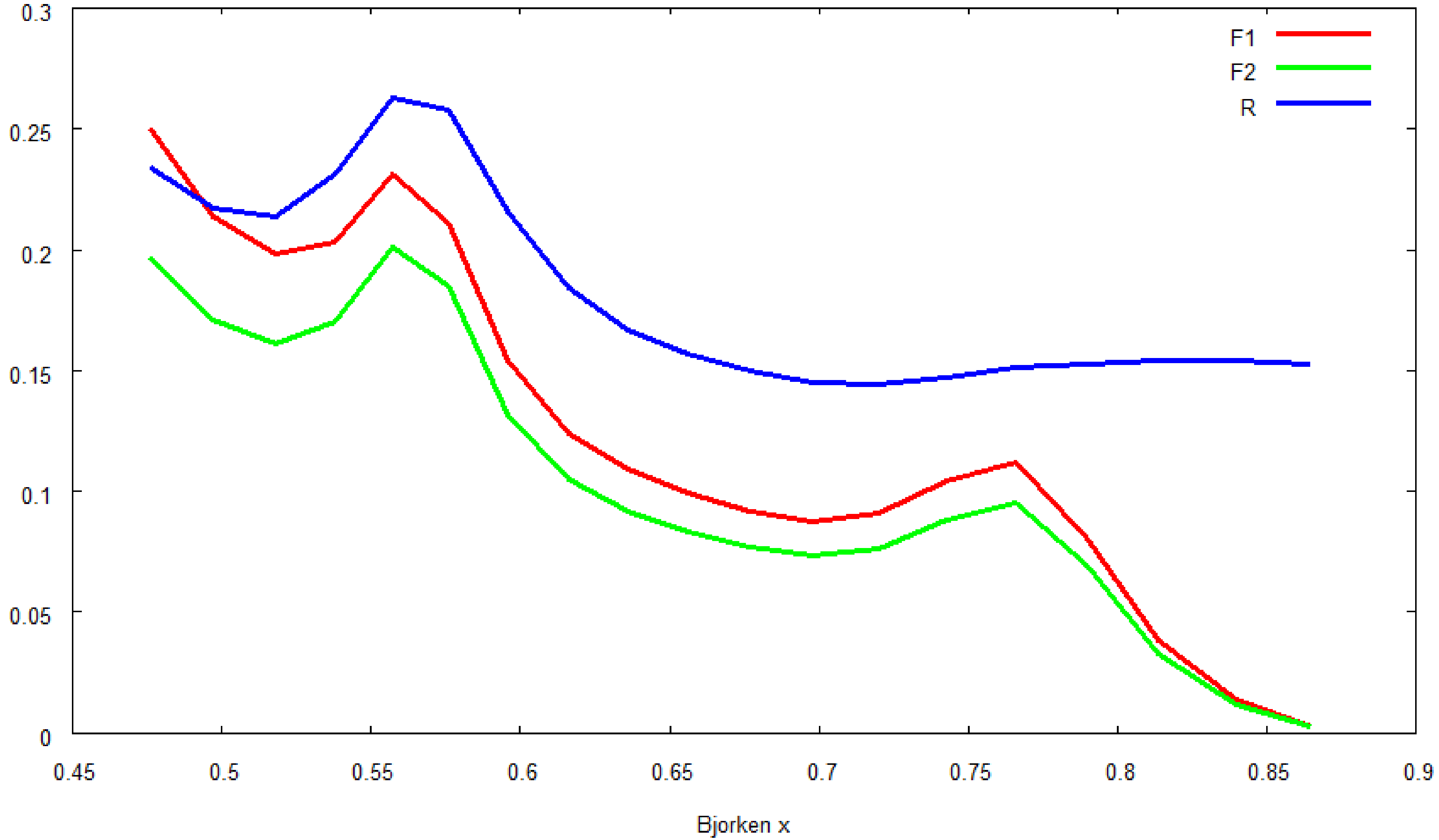
Packing Fraction

Comparing data with Monte Carlo results assuming 50% and 60% packing fraction of target, 60.9% packing fraction is determined for the target material #9 6-28-07 14NH3.



Data to MC ratio (W spectrum)

Unpolarized Strucuture Functions



ep deep inelastic scattering

Invariant quantities:

$\nu = \dfrac{q \cdot P}{M} = E - E'$ is the lepton's energy loss in the nucleon rest frame (in earlier literature sometimes $\nu = q \cdot P$). Here, E and E' are the initial and final lepton energies in the nucleon rest frame.

$Q^2 = -q^2 = 2(EE' - \overrightarrow{k} \cdot \overrightarrow{k}') - m_\ell^2 - m_{\ell'}^2$ where $m_\ell(m_{\ell'})$ is the initial (final) lepton mass. If $EE' \sin^2(\theta/2) \gg m_\ell^2, m_{\ell'}^2$, then

$\approx 4EE' \sin^2(\theta/2)$, where θ is the lepton's scattering angle with respect to the lepton beam direction.

$x = \dfrac{Q^2}{2M\nu}$ where, in the parton model, x is the fraction of the nucleon's momentum carried by the struck quark.

$y = \dfrac{q \cdot P}{k \cdot P} = \dfrac{\nu}{E}$ is the fraction of the lepton's energy lost in the nucleon rest frame.

$W^2 = (P + q)^2 = M^2 + 2M\nu - Q^2$ is the mass squared of the system X recoiling against the scattered lepton.

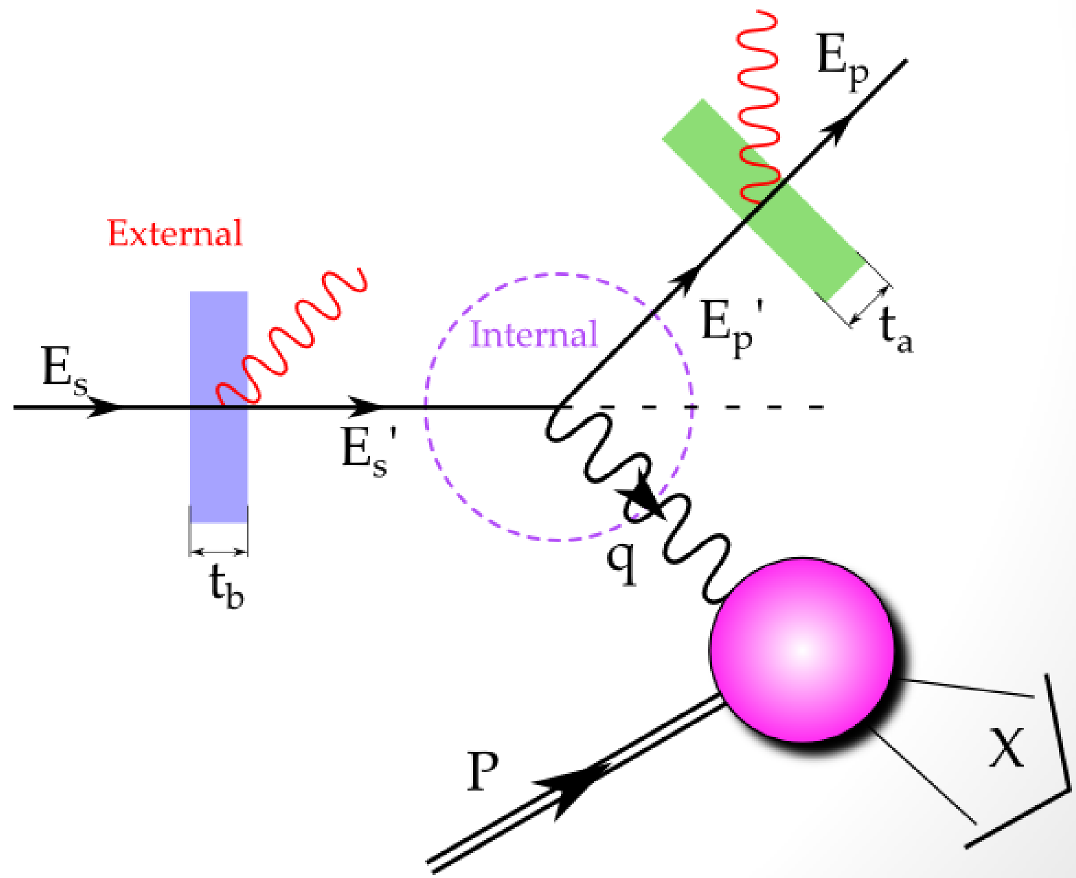
C. Amsler et al., Physics Letters B667, 1 (2008)

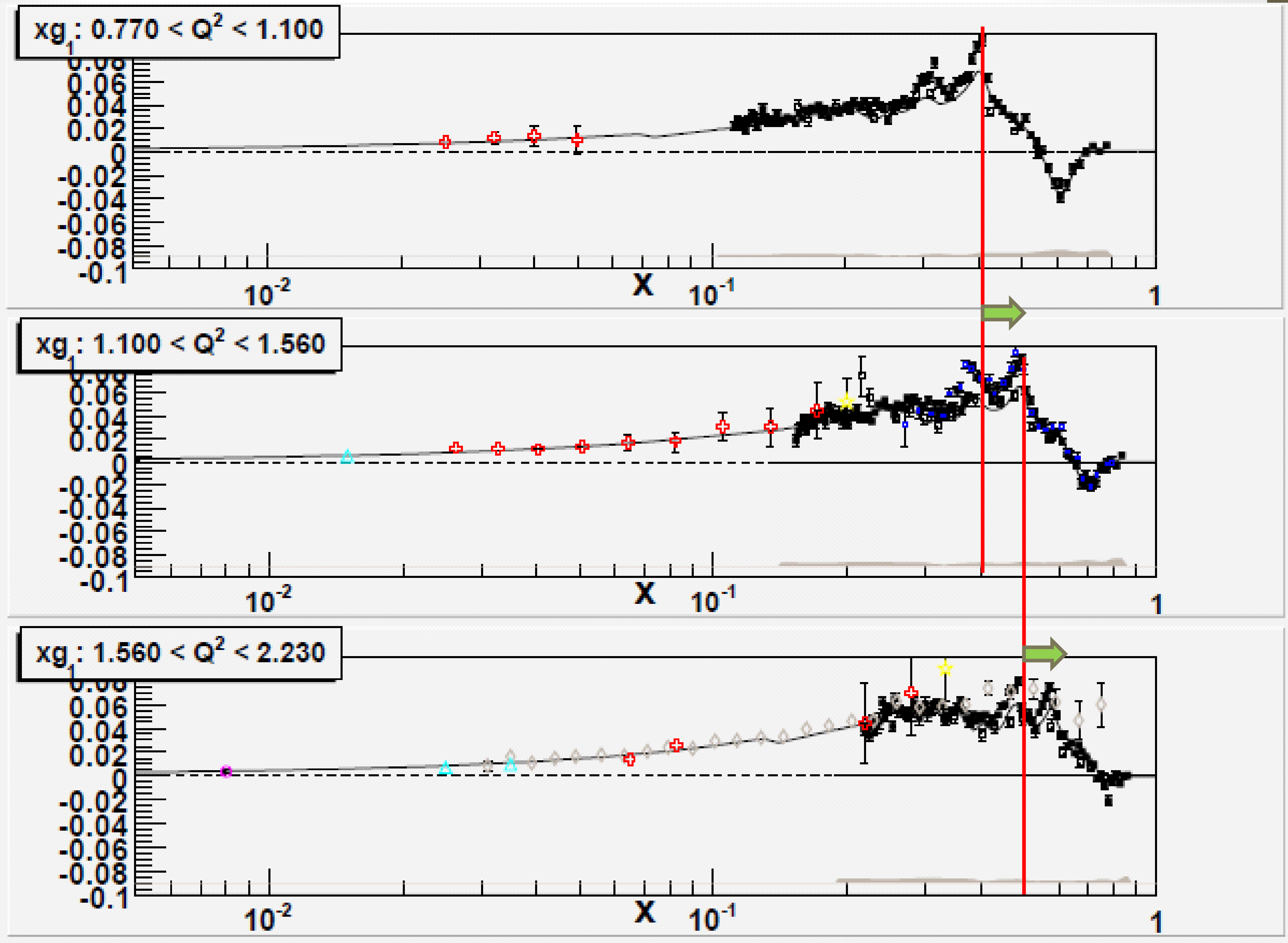
Radiative Correction

$$A = \frac{1}{f C_N P_b P_t f_{RC}} \frac{d\sigma^{\downarrow\uparrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\downarrow\uparrow} + d\sigma^{\uparrow\uparrow}} + A_{RC}$$

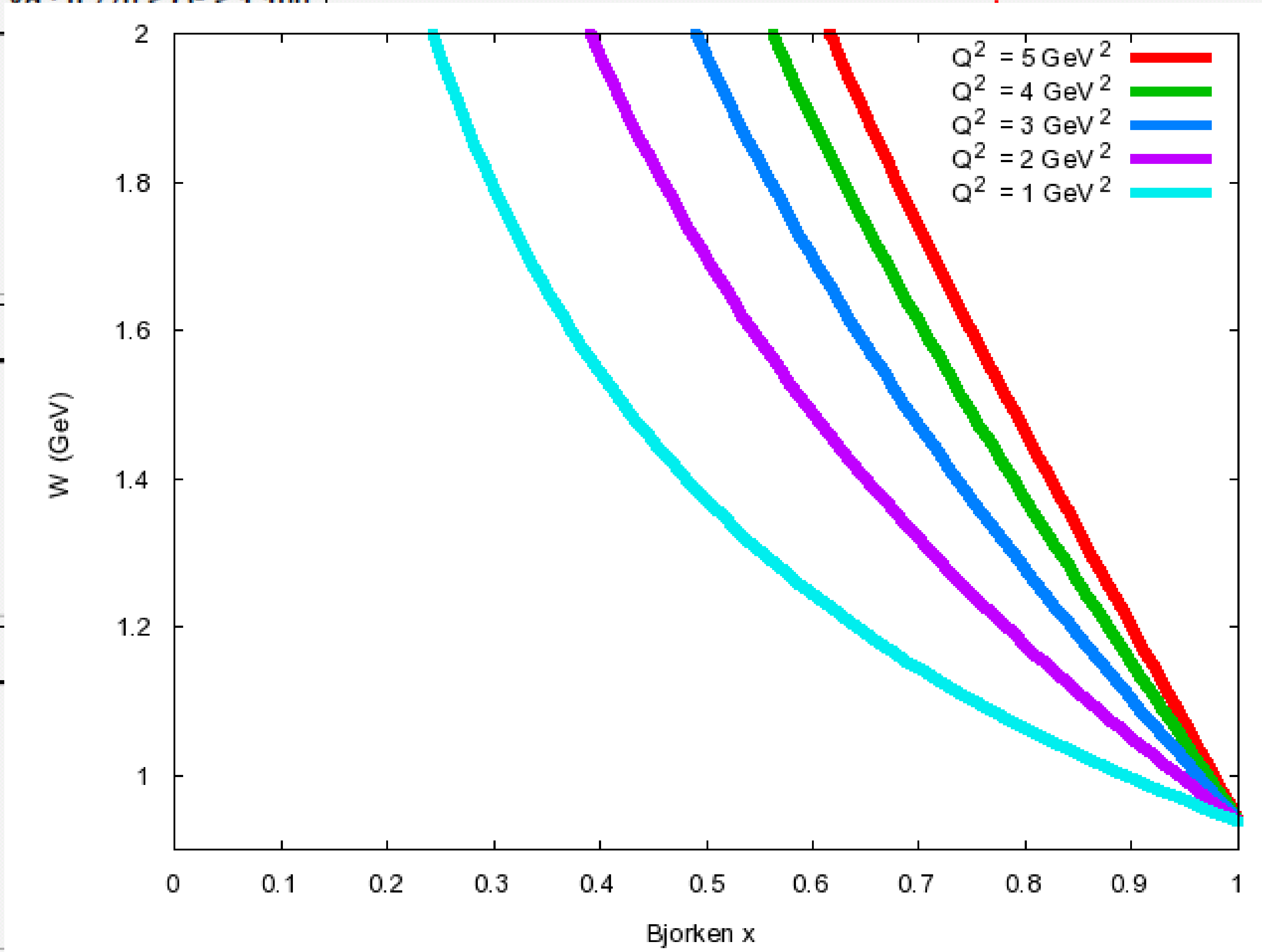
Radiative Correction

1. Incoming and outgoing electron lose energy before and after scattering.
2. Elastic tail should be subtracted.
3. QED processes other than Born contributes to data.





CLAS eg1b data



CLAS eg1b data