SFB 1044
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

γZ-Box from Dispersion Relations

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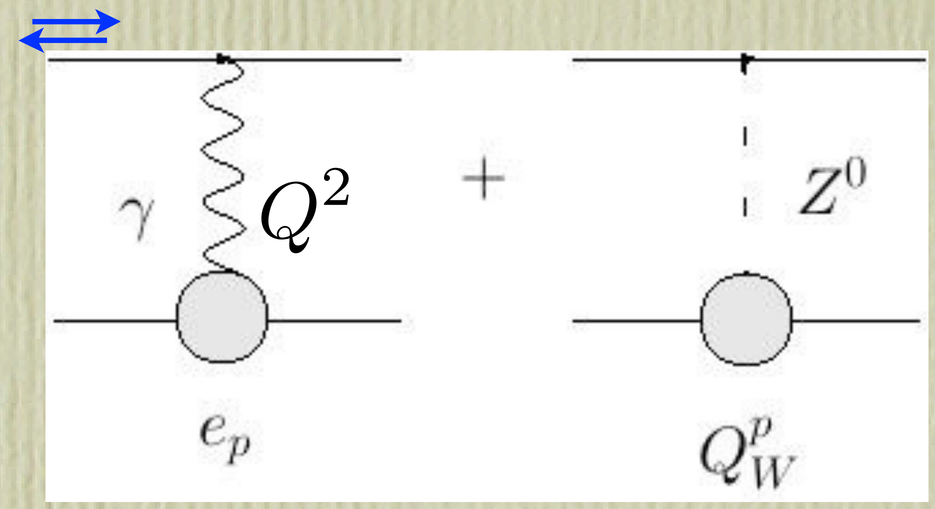
γZ-Box(ing) Mini-Workshop - Jefferson Lab, Newport News, VA - 16 December 2013

Weak Charge of the Proton



Elastic e-p scattering
with polarized e$^-$ beam

$$A^{PV} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha_{em}} Q_W^p + \mathcal{O}(Q^4)$$

Effective e-q interaction

$$-\mathscr{L}^{eh} = -\frac{G_F}{\sqrt{2}} \sum_i \left[C_{1i}\, \bar{e}\, \gamma_\mu \gamma^5 e\, \bar{q}_i\, \gamma^\mu q_i + C_{2i}\, \bar{e}\, \gamma_\mu e\, \bar{q}_i\, \gamma^\mu \gamma^5 q_i \right]$$

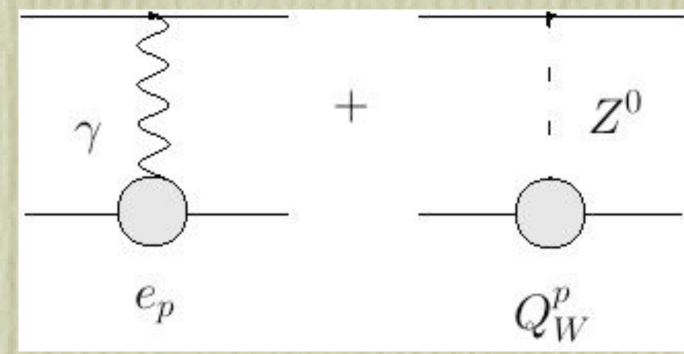
Standard Model (tree-level)

$$Q_W^{p,\,tree} = -2(2C_{1u} + C_{1d}) = 1 - 4\sin^2\theta_W \approx 0.05$$

Weak Charge of the Proton: EW corrections

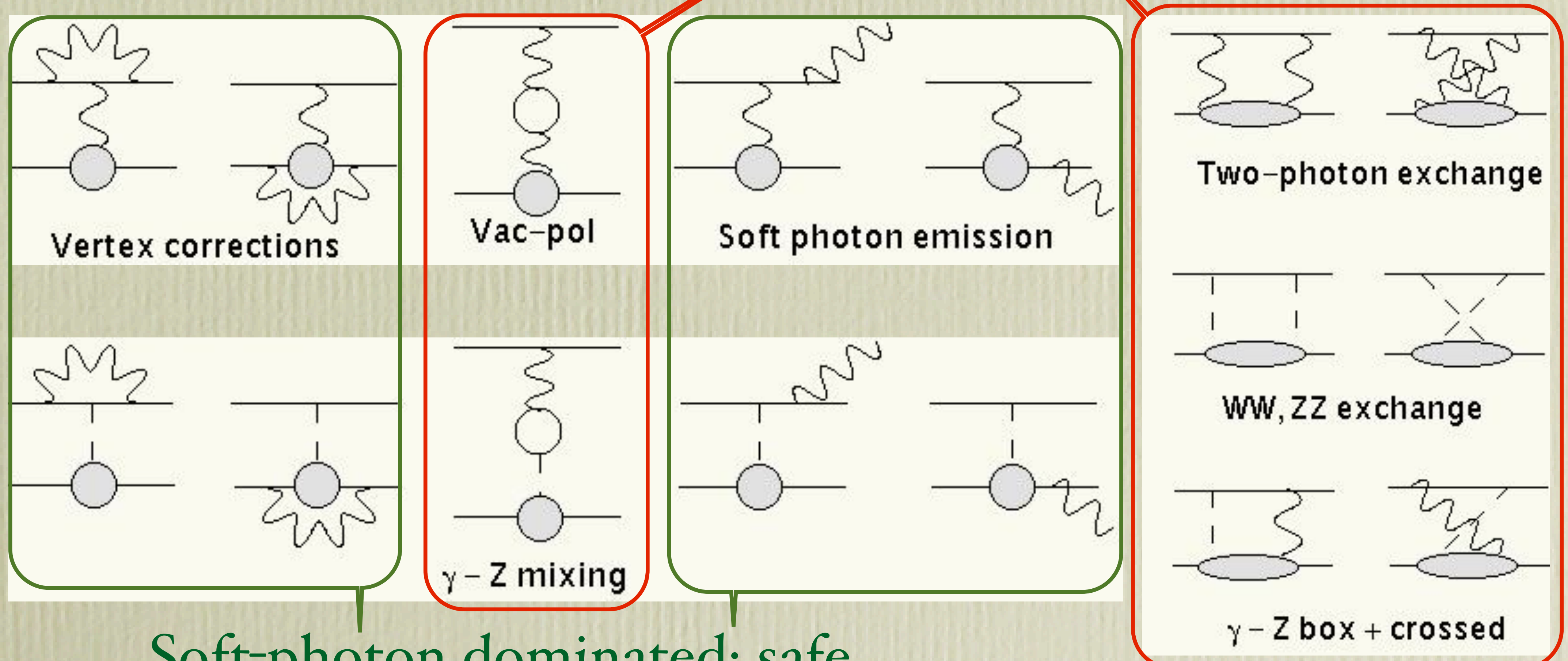
To match the experimental precision - include radiative corrections

$\mathcal{O}(1)$



Hadronic structure-dependent

$\mathcal{O}(\alpha_{em})$ $\alpha_{em} \approx 1/137$



Soft-photon dominated: safe

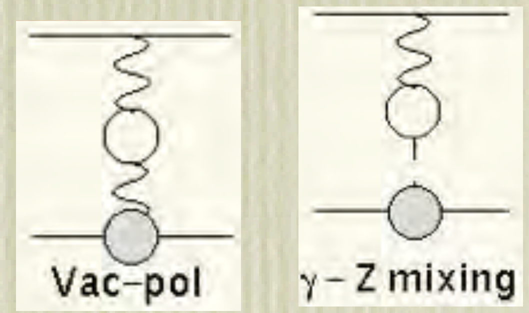
Weak Charge of the Proton: EW corrections

Hadronic structure effects are under control

$$Q_W^p = \boxed{(1+\Delta_\rho+\Delta_e)(1-4\sin^2\hat{\theta}_W+\Delta_e')+\Box_{WW}+\Box_{ZZ}}+\boxed{\Box_{\gamma Z}}$$

W. J. Marciano and A. Sirlin, PRD **27**, 552 (1983); **29**,75 (1984); **31**, 213 (1985).
M.J. Ramsey-Musolf, PRC 60, 015501 (1999).

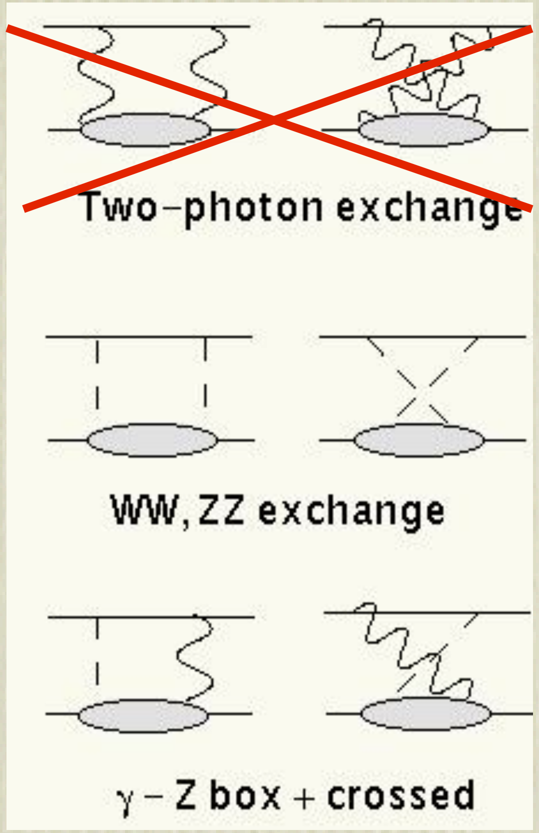
Vacuum polarization: reconstructed from $e^+e^-\rightarrow$hadrons with dispersion relations



2γ-Box: kinematically suppressed

WW,ZZ-Box: perturbative- calculable reliably

γZ: for low energies (atomic PV experiments) cancellation between box and crossed
- not true for ~1 GeV energy any more



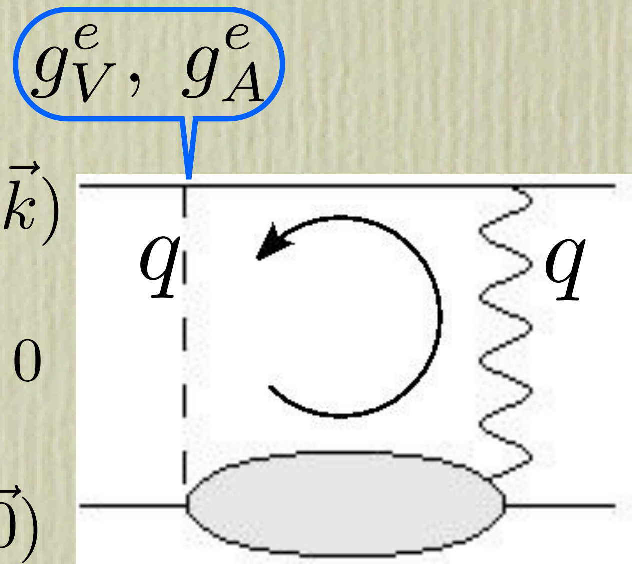
Energy dependence of the γZ-Correction

MG & C.J. Horowitz, PRL102, 091806 (2009)

$k^\mu = (E, \vec{k})$

$Q^2 = -q_\mu q^\mu \geq 0$

$p^\mu = (M, \vec{0})$



$W^2 = (p+q)^2$

Forward dispersion relation for

$$\Box_{\gamma Z} = g_V^e \Box_{\gamma Z_A} + g_A^e \Box_{\gamma Z_V}$$

Possess different symmetry between box and crossed terms:

$$\mathrm{Re}\Box_{\gamma Z_A}(E) = \frac{2}{\pi} \int_{\nu_0}^{\infty} \frac{E' dE'}{E'^2 - E^2} \mathrm{Im}\Box_{\gamma Z_A}(E')$$

$$\mathrm{Re}\Box_{\gamma Z_V}(E) = \frac{2E}{\pi} \int_{\nu_0}^{\infty} \frac{dE'}{E'^2 - E^2} \mathrm{Im}\Box_{\gamma Z_V}(E')$$

$$\mathrm{Re}\Box_{\gamma Z_A}(0) \neq 0$$

$$\mathrm{Re}\Box_{\gamma Z_V}(0) = 0$$

APV result

Can quantify the energy dependence

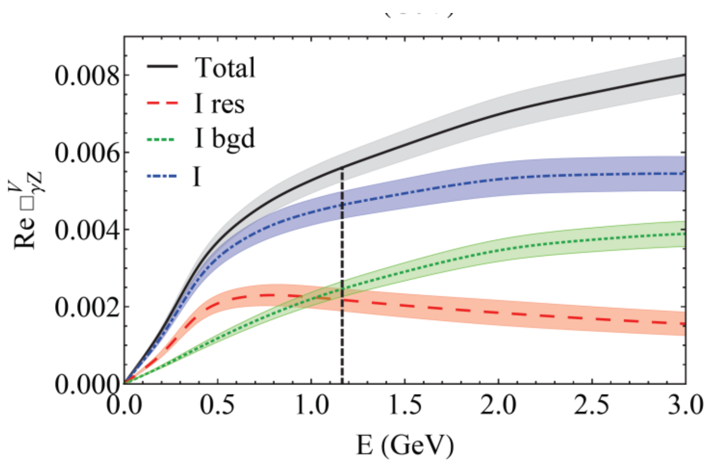
Energy dependence of the γZ-Correction

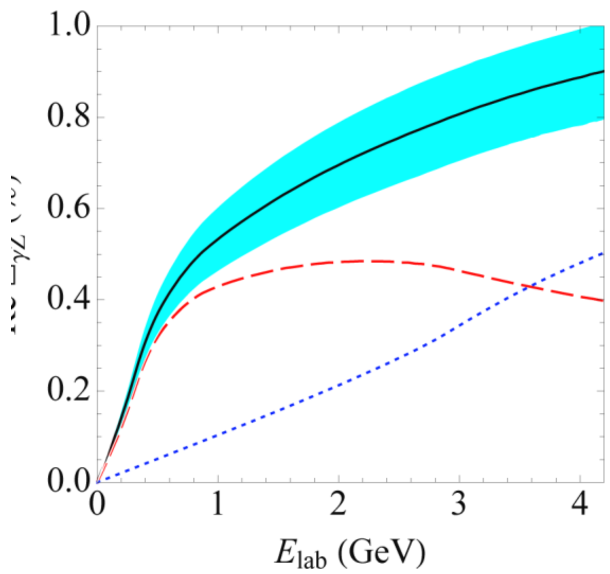
$$\mathrm{Re}\,\Box_{\gamma Z_V}(E) = \frac{2E}{\pi}\int_0^\infty dQ^2 \int_{W_\pi^2}^\infty dW^2 \left[A F_1^{\gamma Z}(W^2,Q^2) + B F_2^{\gamma Z}(W^2,Q^2) \right]$$

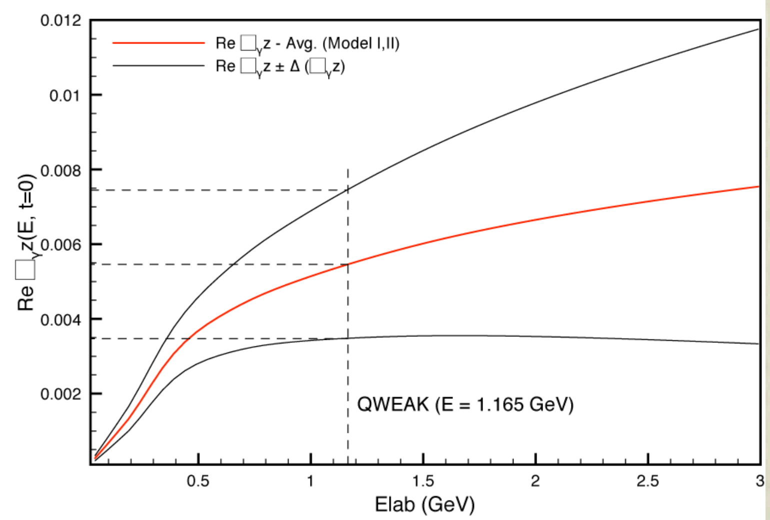
PV DIS data
- not (YET!) available

Isospin-rotate the e.-m. data
Evaluate at E = 1.165 GeV (QWEAK)

Hall *et al.*	Carlson and Rislow	Gorchtein *et al.*
PRD 88, 013011 (2013)	PRD 83, 113007 (2011)	PRC 84, 015502 (2011)







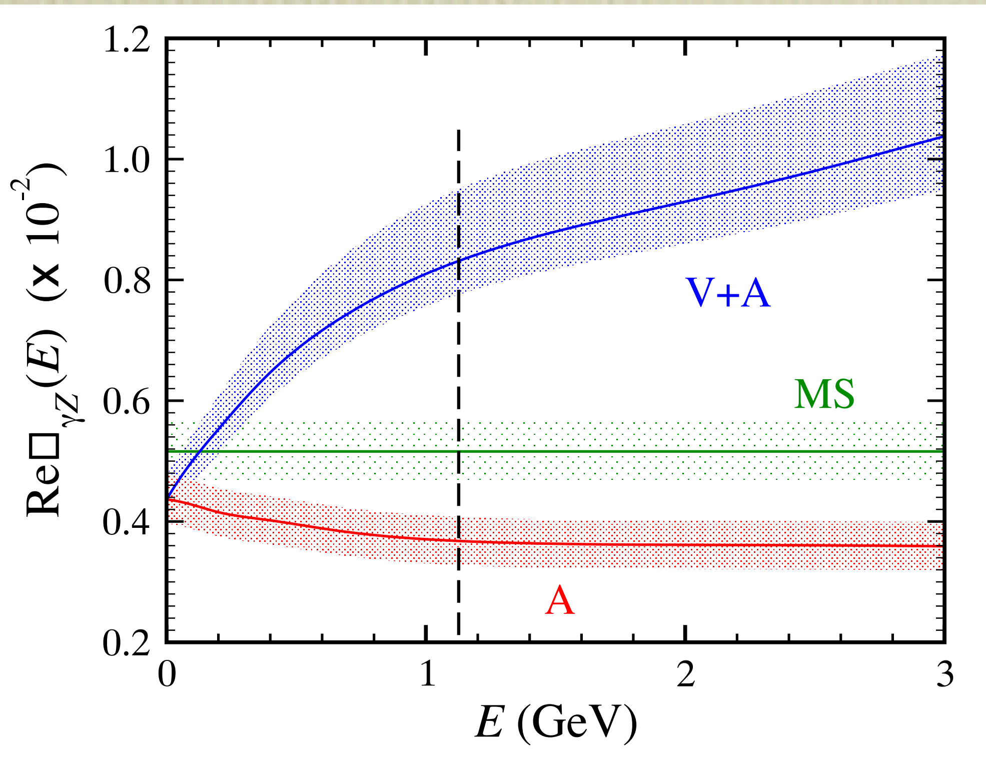
$$\mathrm{Re}\,\Box^V_{\gamma Z}(E = 1.165\ \mathrm{GeV})$$

$(5.6 \pm 0.36)\times 10^{-3}$ $(5.7 \pm 0.9)\times 10^{-3}$ $(5.4 \pm 2.0)\times 10^{-3}$

Energy dependence of the γZ-Correction

Evaluate the axial part through a DR
- check Marciano & Sirlin's calculation

Blunden et al., PRL 107 (2011) 081801



New SM prediction for the proton's weak charge

$$Q_W^p + \mathrm{Re}\Box_{\gamma Z}(E = 1.165\,\mathrm{GeV}) = 0.0767 \pm 0.0008 \pm 0.0020_{\gamma Z}$$

To be compared to the previous prediction $Q_W^p = 0.0713 \pm 0.0008$

4σ(theory) effect was missed in the original QWEAK analysis;
Theory uncertainty needs to be further reduced

Uncertainty is dominated by the γZ_V - asses all the sources of the uncertainty

Saturation of the dispersion integral for γZv-box

$$\mathrm{Re}\Box_{\gamma Z_V}(E) = \frac{2E}{\pi}\int\limits_0^\infty dQ^2 \int\limits_{W_\pi^2}^\infty dW^2 \left[A F_1^{\gamma Z}(W^2,Q^2) + B F_2^{\gamma Z}(W^2,Q^2) \right]$$

Q-Weak: E = 1.165 GeV

	W < 2GeV	W < 4GeV	W < 5GeV	W < 10GeV	All W
$Q^2 < 1$ GeV^2	62.6%	79.8%	81.2%	82.8%	83.2%
$Q^2 < 2$ GeV^2	68.3%	85.8%	87.6%	89.9%	90.4%
$Q^2 < 3$ GeV^2	69.4%	87.9%	90.0%	92.7%	93.3%
All Q^2	70%	91.1%	94.1%	98.6%	100%

Saturation of the dispersion integral for γZv-box

$$\mathrm{Re}\Box_{\gamma Z_V}(E) = \frac{2E}{\pi}\int_0^\infty dQ^2 \int_{W_\pi^2}^\infty dW^2 \left[AF_1^{\gamma Z}(W^2,Q^2) + BF_2^{\gamma Z}(W^2,Q^2)\right]$$

Mainz/MESA: E = 0.180 GeV

	W < 2GeV	W < 4GeV	W < 5GeV	W < 10GeV	All W
$Q^2 < 1$ GeV²	75.0%	86.4%	87.4%	88.6%	88.8%
$Q^2 < 2$ GeV²	78.4%	90.3%	91.6%	93.2%	93.5%
$Q^2 < 3$ GeV²	79.1%	91.7%	93.2%	95.1%	95.5%
All Q^2	79.5%	93.9%	95.9%	99.0%	100%

Saturation of the dispersion integral for γZν-box

For the Q-Weak kinematics

- Input at $Q^2 > 2$ GeV^2 only constrains 10% of the γZν-box
- Input at $Q^2 < 0.5$ GeV^2 constrains 63% of the γZν-box

For MESA kinematics

- Input at $Q^2 > 2$ GeV^2 only constrains 6% of the γZν-box
- Input at $Q^2 < 0.5$ GeV^2 constrains 77% of the γZν-box

Input for the dispersion integral for $\gamma Z \nu$-box

Only indirect input available - e.-m. structure functions

We also need the rule how to obtain the γZ structure functions from the e.-m. ones

Parametrization of the inclusive data by Christy & Bosted

$$1.1\ \mathrm{GeV} < W < 3.1\ \mathrm{GeV},\ 0 < Q^2 < 8\ \mathrm{GeV}^2$$

M.E. Christy, P.E. Bosted, Phys.Rev. C81 (2010) 055213

This parametrization is used by all the three groups

Can be a common bias?

Sibirtsev et al., Phys.Rev. D82 (2010) 013011

$$(4.7^{+1.1}_{-0.4}) \times 10^{-3} \leftrightarrow (5.4 \pm 2.0) \times 10^{-3}$$

Identification and parameters of resonances should be (critically) assessed

Isospin rotation of e.-m. data: resonances

Based on: quantum numbers & strengths (Christy & Bosted); relative size and sign of helicity amplitudes (PDG)

Isospin 1/2, 3/2 resonances $\langle X|J^\mu_{NC,V}|p\rangle = (1-4s^2\theta_W)\langle X|J^\mu_{em}|p\rangle - \langle X|J^\mu_{em}|n\rangle$

$$\langle p|J^\mu_{em}|R\rangle\langle R|J^\mu_{NC,V}|p\rangle = (1-4s^2\theta_W)|\langle R|J^\mu_{em}|p\rangle|^2 - \langle p|J^\mu_{em}|R\rangle\langle R|J^\mu_{em}|n\rangle$$

Rescale each resonance in C&B parametrization to obtain γZ cross section

$$\xi^R_{Z/\gamma} \equiv \frac{\sigma^{\gamma Z,p}_{T,R}}{\sigma^{\gamma\gamma p}_{T,R}} = (1-4s^2\theta_W) - \underbrace{\frac{A^p_{R,1/2}A^{n*}_{R,1/2} + A^p_{R,3/2}A^{n*}_{R,3/2}}{|A^p_{R,1/2}|^2 + |A^p_{R,3/2}|^2}}_{y_R}$$

Values and uncertainties - from PDG helicity amplitudes values

	$P_{33}(1232)$	$S_{11}(1535)$	$D_{13}(1520)$	$S_{11}(1665)$	$F_{15}(1680)$	$P_{11}(1440)$	$F_{37}(1950)$
y_R	$-1.0^{-0.1}_{+0.1}$	$-0.51^{-0.71}_{+0.35}$	$-0.77^{-0.125}_{+0.125}$	$-0.28^{-0.86}_{+0.45}$	$-0.27^{-0.12}_{+0.1}$	$-0.62^{-0.2}_{+0.19}$	-1^{-1}_{+1}

Uncertainty from helicity amplitudes: An and Ap anti-correlated

Independent measurements - p and d=p+n, not p and n!

Checking input in γZ-calculation

The identification of resonances and relative strength is not the same in Christy & Bosted and PDG

PDG:

$$D_{13}(1520): \quad A^p_{3/2} = 150(15)\,\mathrm{GeV}^{-1/2},$$
$$A^p_{1/2} = -24(9)\,\mathrm{GeV}^{-1/2}$$
$$S_{11}(1535): \quad A^p_{3/2} = 0, \quad A^p_{1/2} = 90(30)\,\mathrm{GeV}^{-1/2}$$

Christy & Bosted:

$$D_{13}(1520): \quad \sqrt{(A^p_{3/2})^2 + (A^p_{1/2})^2} \approx 23\,\mathrm{GeV}^{-1/2}$$
$$S_{11}(1535): \quad A^p_{3/2} = 0, \quad A^p_{1/2} \approx 170\,\mathrm{GeV}^{-1/2},$$

Roper resonance is largely underestimated;
Δ(1232) width 136 MeV instead of 120 MeV

Look for further input to constrain this change - GDH sum rule

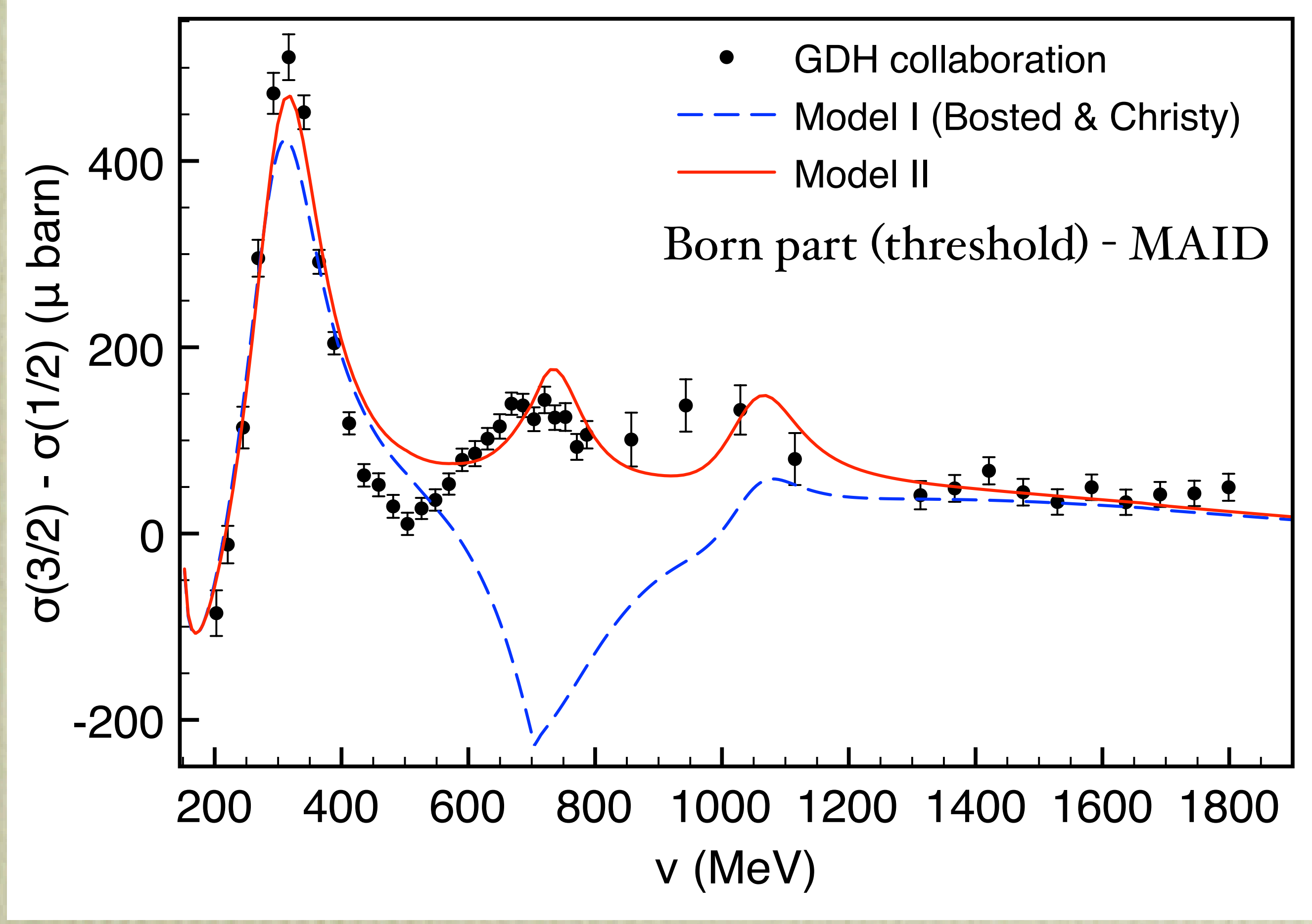
Correcting input in γZ-calculation with the GDH sum rule

MG, X. Zhang, to be submitted soon

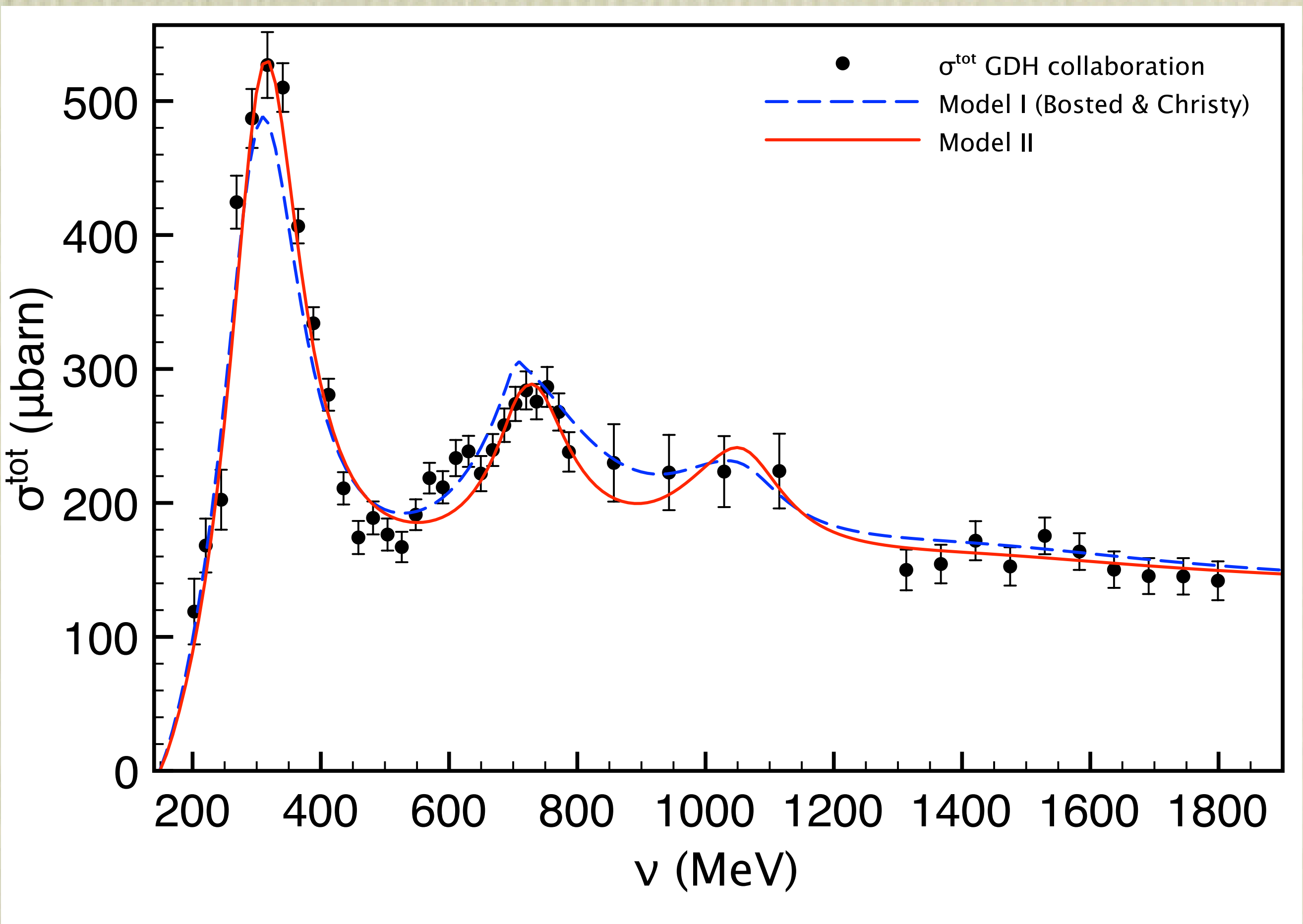
Spin-1/2 and spin-3/2 resonances can be distinguished in the helicity cross section (g1 with real photons)
Data - from GDH collaboration (Mainz, Bonn)

J. Ahrens et al, PRL 84(2000) 5950;
J. Ahrens et al, PRL 87(2001) 022003;
H. Dutz et al, PRL 91(2003) 192001

$$[\sigma^{\gamma\gamma}_{3/2}(\nu) - \sigma^{\gamma\gamma}_{1/2}(\nu)]$$



$$\sigma^{\gamma\gamma}_{T}(\nu)$$



With parameters from PDG - much better description of both observables
Not perfect: only 7 resonances, ...

Correcting input in γZ-calculation with the GDH sum rule

GDH sum rule

$$(\kappa_N^\gamma)^2 = \frac{2M^2}{\pi e^2} \int_{\nu_{thr}}^{\infty} d\nu \frac{[\sigma_{3/2}^{\gamma\gamma}(\nu) - \sigma_{1/2}^{\gamma\gamma}(\nu)]}{\nu}$$

With the “supplemented” Christy & Bosted’s fit can be evaluated

Sum rule value	Christy & Bosted	“PDG”
$\kappa_p^2 = 1.793^2 \approx 3.215$	$\kappa_p^2 \approx 0.9$	$\kappa_p^2 \approx 3.28$

Check the γZ-cross section

$$\kappa_N^\gamma \kappa_N^Z = \frac{2M^2}{\pi e^2} \int_{\nu_{thr}}^{\infty} d\nu \frac{[\sigma_{3/2}^{\gamma Z}(\nu) - \sigma_{1/2}^{\gamma Z}(\nu)]}{\nu}$$

Sum rule value	Christy & Bosted	“PDG”
$\kappa_p^\gamma \kappa_p^Z = (1 - 4s_W^2)(\kappa_p^\gamma)^2 - \kappa_p^\gamma \kappa_n^\gamma \approx 3.666$	$\kappa_p^\gamma \kappa_p^Z \approx 2.247$	$\kappa_p^\gamma \kappa_p^Z \approx 3.615$

Re-evaluate the γZ-box with the new resonance parametrization

Correcting the γZ-calculation with the resonances

$(\times 10^{-3})$	$P_{33}(1232)$	$P_{11}(1440)$	$D_{13}(1520)$	$S_{11}(1535)$	$S_{11}(1650)$	$F_{15}(1680)$	$F_{37}(1950)$
C & B	1.23 ± 0.12	0.06 ± 0.02	0.18 ± 0.03	$0.29^{+0.34}_{-0.17}$	$0.06^{+0.14}_{-0.06}$	0.04 ± 0.01	0.40 ± 0.36
PDG	1.23 ± 0.12	0.12 ± 0.03	0.31 ± 0.05	$0.06^{+0.08}_{-0.04}$	$0.06^{+0.14}_{-0.06}$	0.04 ± 0.02	0.39 ± 0.36

$$0.53^{+0.34}_{-0.17} \rightarrow 0.50^{+0.10}_{-0.07}$$

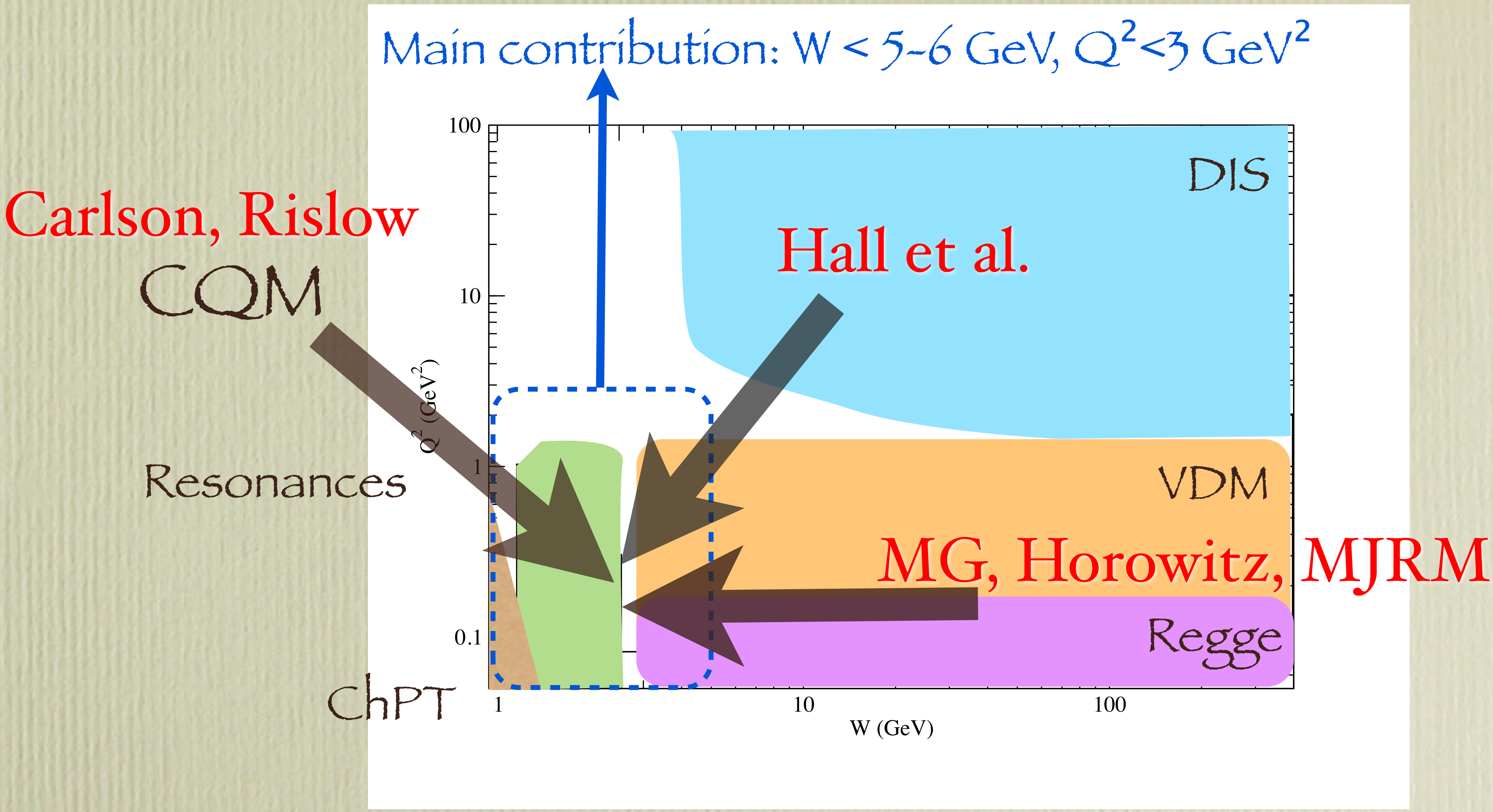
Further reduction - mainly F37(1950)
Should be possible: it is in the right place, strength about right,
proton and neutron strength is very close - quantum numbers OK
Reasonable to assume that at least 50% of F37 is really F37

0.39 ± 0.18

$$\Sigma_{res}^{OLD} = 2.24^{+0.53}_{-0.43} \qquad \Sigma_{res}^{NEW} = 2.21^{+0.25}_{-0.23}$$

Uncertainty on the resonance contribution is halved.

Uncertainty of the Background

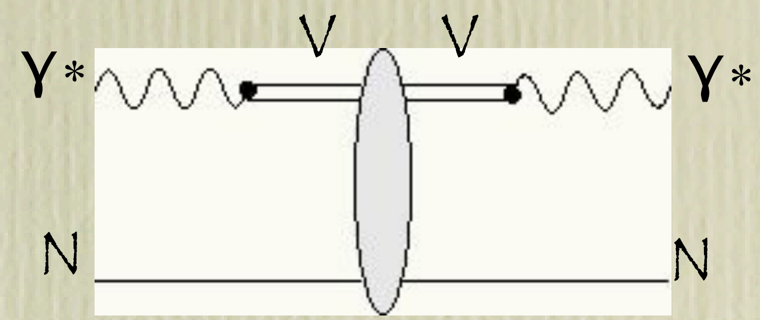


Main source of the uncertainty:
background in the resonance region and above
- how does a gamma/Z polarize vacuum in the target's proximity?

Isospin rotation of e.-m. data: background

Vector Dominance Model (VDM)

$$|\gamma^*\rangle \;=\; \sum_V C_{\gamma^* V}|V\rangle \qquad V= \rho\,,\ \omega\,,\ \phi$$



$$\sigma^{\gamma p}_{tot} \;=\; \sum_{V=\rho,\omega,\phi} \frac{4\pi\alpha}{f_V^2}\sigma_{Vp}$$

Elastic Vp cross section - independent of V

VM decay constants $\frac{4\pi}{f_V^2} \;=\; 0.4545, 0.04237, 0.05435 \quad (\rho,\omega,\phi)$

VDM sum rule:
$$\sigma_{tot}(\gamma p) \;=\; \sum_{V=\rho,\omega,\phi} \sqrt{16\pi \frac{4\pi\alpha}{f_V^2}\frac{d\sigma^{\gamma p\to Vp}}{dt}(t=0)}$$

Measured experimentally

HERA: NPB' 02 ZEUS: Z.Phys.'95,'96, PLB'96

$139 \pm 4\ (\mu b) \quad \leftrightarrow \quad 111 \pm 13\ (\mu b) \quad$ at $W = 70$ GeV

Generalized VDM - continuum contribution
$$\sigma^{\gamma p}_{tot} \;=\; \sum_{V=\rho,\omega,\phi} \frac{4\pi\alpha}{f_V^2}\sigma_{Vp} + \sigma_{Cp}$$

The 21% for continuum at Q^2=0 is the main limitation on γZ-box

Isospin rotation of e.-m. data: background

Rescale the background according to

$$\frac{\sigma^{\gamma^* p\to Zp}}{\sigma^{\gamma^* p\to\gamma^* p}} = \frac{\frac{g_V^{I=1}}{e_{I=1}} + \frac{g_V^{I=0}}{e_{I=0}}\frac{\sigma^{\gamma^* p\to\omega p}}{\sigma^{\gamma^* p\to\rho p}} + \frac{g_V^{s}}{e_s}\frac{\sigma^{\gamma^* p\to\phi p}}{\sigma^{\gamma^* p\to\rho p}} + \frac{X'}{\sigma^{\gamma^* p\to\rho p}}}{1 + \frac{\sigma^{\gamma^* p\to\omega p}}{\sigma^{\gamma^* p\to\rho p}} + \frac{\sigma^{\gamma^* p\to\phi p}}{\sigma^{\gamma^* p\to\rho p}} + \frac{X}{\sigma^{\gamma^* p\to\rho p}}}$$

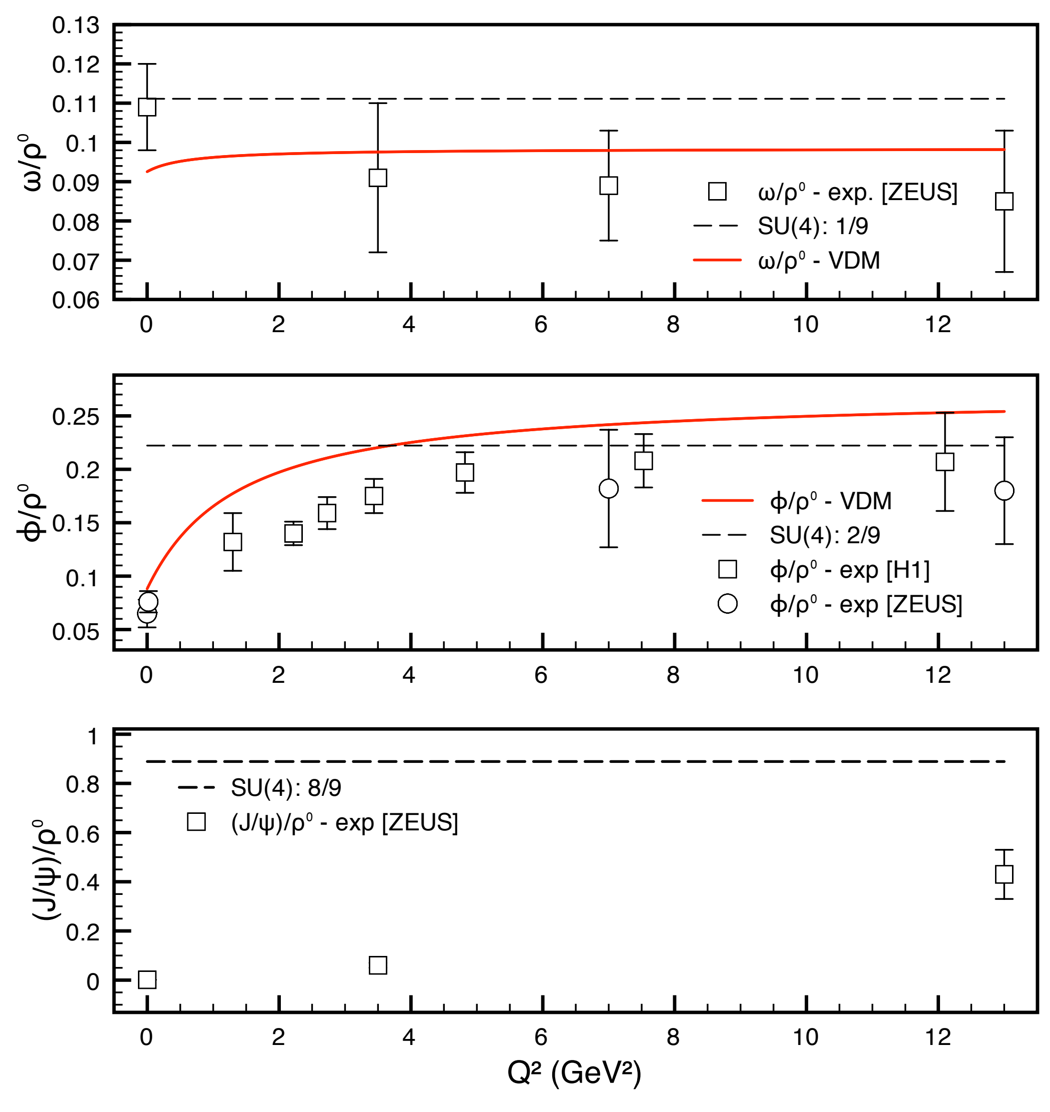
VDM: identify X(X') with continuum

$$\frac{\sigma^{\gamma^* p\to Vp}}{\sigma^{\gamma^* p\to\rho p}} = \frac{r_V}{r_\rho}\frac{m_V^4}{m_\rho^4}\frac{(m_\rho^2+Q^2)^2}{(m_V^2+Q^2)^2}$$

Uncertainty estimate - from data!

$$\Delta\xi_{Z/\gamma}^{V,Model\ A} = \left[\left(\frac{\sigma^{\gamma^*\to V}}{\sigma^{\gamma^*\to\rho}}\right)^{exp} - \left(\frac{\sigma^{\gamma^*\to V}}{\sigma^{\gamma^*\to\rho}}\right)^{Model\ A}\right]\sigma^{\gamma^*\to V\to Z}$$

Exp. data: W = 40-120 GeV



Continuum - 100% uncertainty

Pure isovector: $r_C^{\gamma Z}/r_C^{\gamma\gamma} \approx 1$

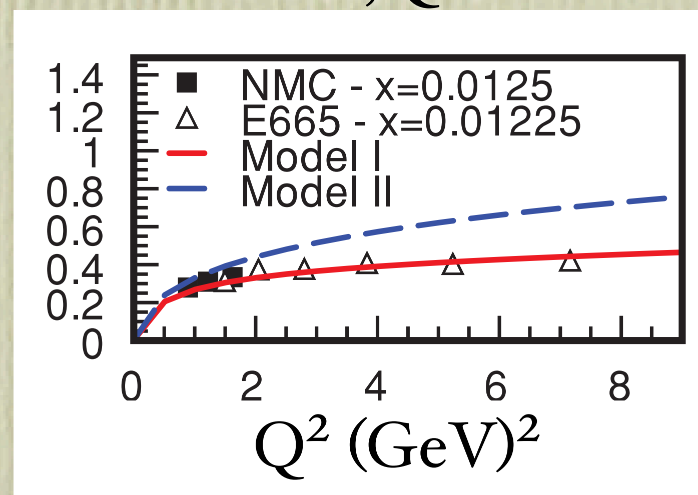
Pure isoscalar: $r_C^{\gamma Z}/r_C^{\gamma\gamma} \approx -1$

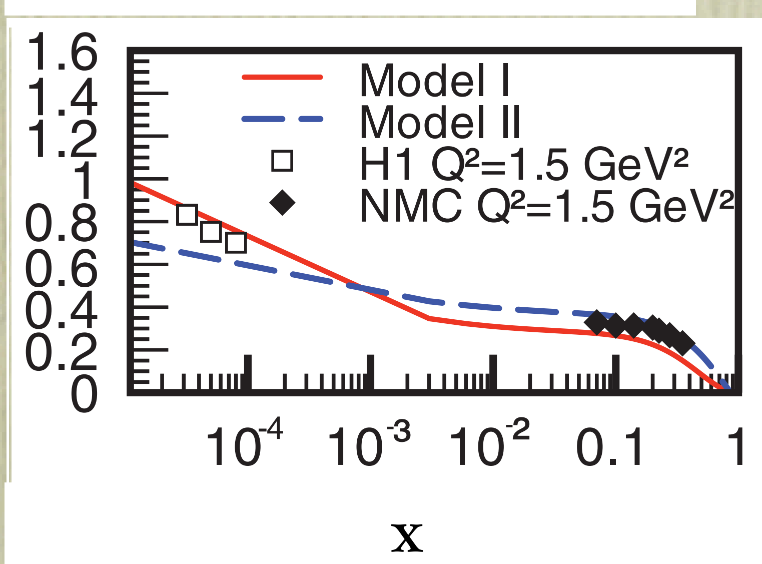
Isospin rotation of e.-m. data: background

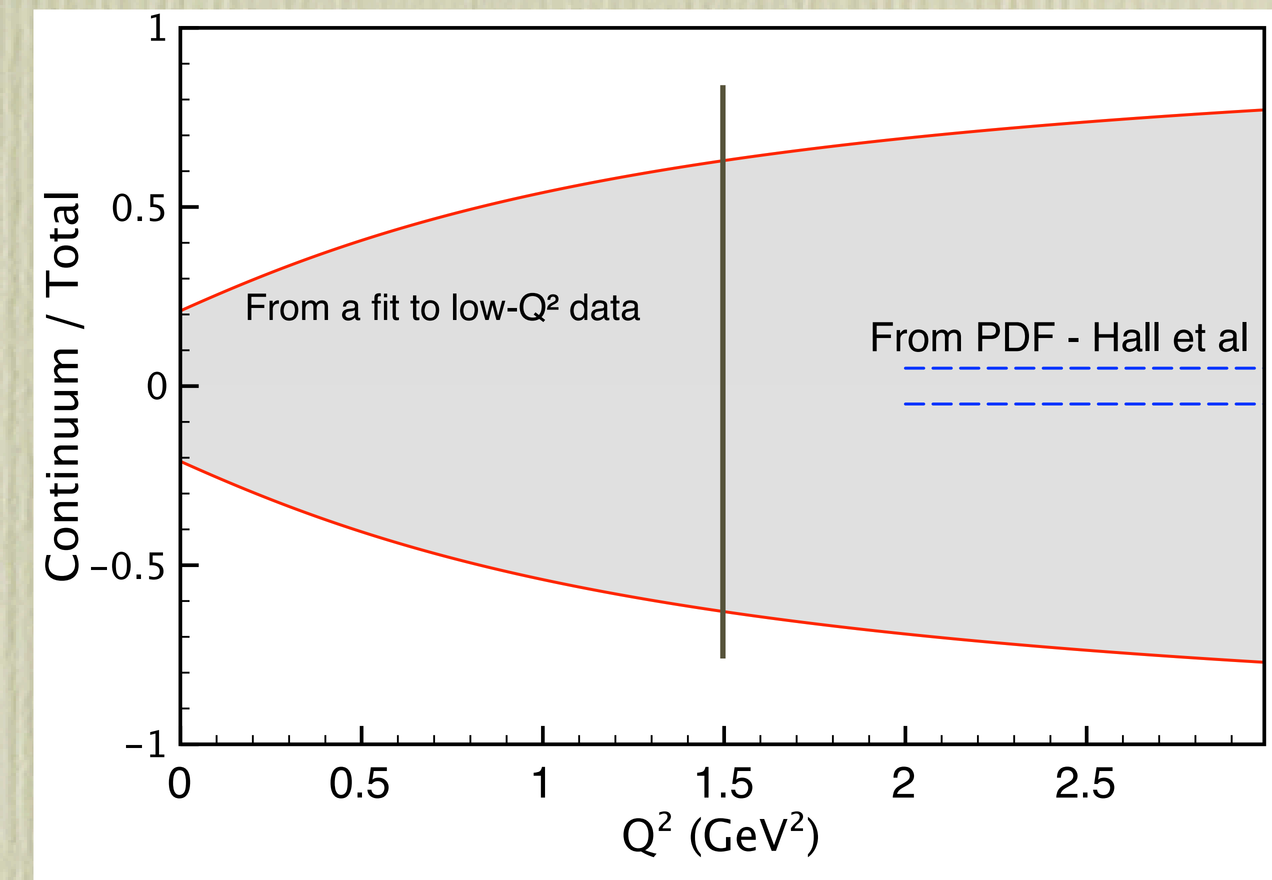
Generalized VDM - virtual photons

$$\sigma_T^\gamma(\nu,Q^2)=\sigma_T^{Regge}(\nu)\left[\frac{0.67}{(1+Q^2/m_\rho^2)^2}+\frac{0.061}{(1+Q^2/m_\omega^2)^2}+\frac{0.059}{(1+Q^2/m_\phi^2)^2}+\frac{0.21}{1+Q^2/m_0^2}\right]$$

$F_2(x,Q^2)$







For virtual photons VDM sum rule works worse

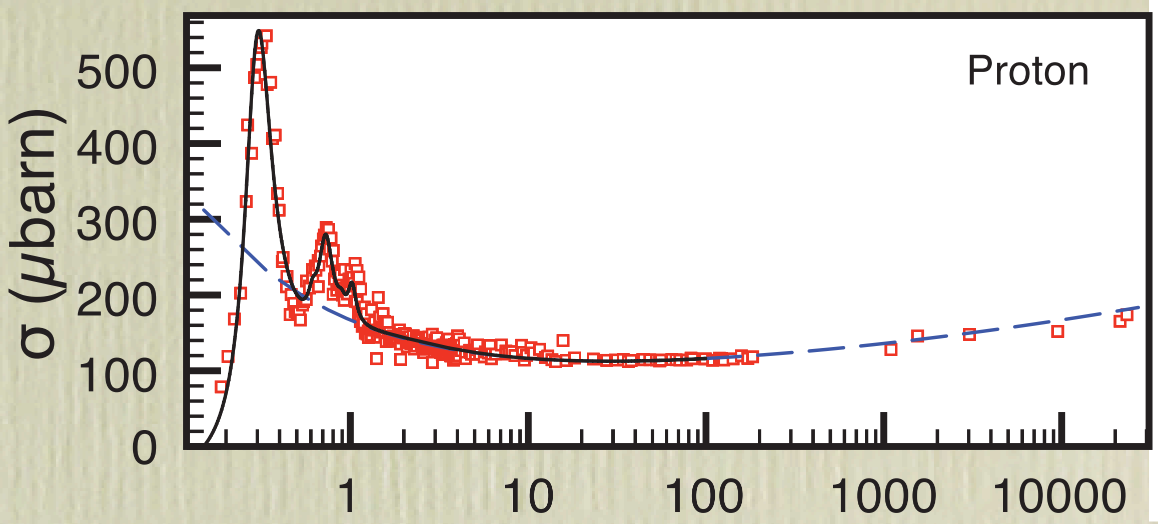
We know less of the isospin of 1 GeV^2 virtual photons

How to extrapolate VDM sum rule down to JLab energies?
How to extend it to virtual photons without losing predicting power?

Constrain the background: Finite Energy Sum Rule

FESR: DR for Compton amplitude without Regge-behaved part

$$C_\infty^{\gamma\gamma} = -\frac{\alpha}{M} - \frac{1}{2\pi^2}\int_{\nu_{thr}}^{N} d\nu\,\sigma_T^{\gamma\gamma}(\nu) + \frac{\nu_0}{2\pi^2}\sum_i c_i^{\gamma\gamma}\frac{N^{\alpha_i(0)}}{\alpha_i(0)}$$



Recent extraction:

$$C_\infty^{\gamma\gamma} = -0.72 \pm 0.35\,\mu\text{b}\,\text{GeV}$$

MG, T. Hobbs, A. Szczepaniak, PRC 84 (2011) 065202

Fit to real photon data only; 5 resonances

With Christy & Bosted based parametrization: new evaluation

"PDG"	Christy & Bosted
$C_\infty^{\gamma\gamma} = -1.12\,\mu\text{b}\,\text{GeV}$	$C_\infty^{\gamma\gamma} = -1.68\,\mu\text{b-GeV}$

Indicate a possibly underestimated systematical error (fit form)

New extraction: $C_\infty^{\gamma\gamma} = -0.97 \pm 0.35(stat.) \pm 0.35(syst.)\,\mu\text{b}\,\text{GeV}$

Constrain the background: Finite Energy Sum Rule

Similar for the γZ-interference $$C_\infty^{\gamma Z} = -\frac{\alpha Q_W^p}{M} - \frac{1}{2\pi^2}\int_{\nu_{thr}}^{N} d\nu \sigma_T^{\gamma Z}(\nu) + \frac{\nu_0}{2\pi^2}\sum_i c_i^{\gamma Z}\frac{N^{\alpha_i(0)}}{\alpha_i(0)}$$

With the parametrization of the γγ data + isospin rotation:

"PDG"

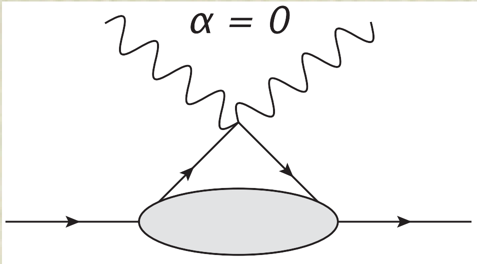
$$C_\infty^{\gamma Z} = 2.61 \pm 2.02(back.)^{+0.93}_{-0.78}(res.)\,\mu\mathrm{b\,GeV}$$

Christy & Bosted

$$C_\infty^{\gamma Z} = 2.47 \pm 2.02(back.)^{+2.17}_{-1.33}(res.)\,\mu\mathrm{b\,GeV}$$

What is the l.h.s likely to be?

If - like the Thomson term: $$\frac{C_\infty^{\gamma Z}}{C_\infty^{\gamma\gamma}} = Q_W^p(0) \approx 0.05$$



Asymptotically: effective point-like two-boson coupling

SU(6) symmetric $$\frac{C_\infty^{\gamma Z}}{C_\infty^{\gamma\gamma}} \sim \frac{2\sum_{q=u,d,s,c,t,b} g_V^q e_q}{\sum_{q=u,d,s,c,t,b} e_q^2} = \frac{9}{5} - 4s_W^2 \approx 0.85$$

Valence only $$\frac{C_\infty^{\gamma Z}}{C_\infty^{\gamma\gamma}} \sim \frac{2(2g_V^u e_u + g_V^d e_d)}{2e_u^2 + e_d^2} = \frac{5}{3} - 4s_W^2 \approx 0.71$$

Only sure thing: same sign as γγ, slightly smaller: $$C_\infty^{\gamma Z} = -0.5 \pm 0.5\,\mu\mathrm{b\,GeV}$$

Constrain the background: Finite Energy Sum Rule

"Extracted from data"

$$C_\infty^{\gamma Z} = -0.5 \pm 0.5\,\mu\text{b GeV}$$

"PDG"

$$C_\infty^{\gamma Z} = 2.61 \pm 2.02(back.)^{+0.93}_{-0.78}(res.)\,\mu\text{b GeV}$$

Continuum contribution:

$$2.02 \pm 2.02\,\mu\text{b GeV}$$

It was assumed that

$$r_C^{\gamma Z} = r_C^{\gamma\gamma}(1 \pm 1)$$

Equally possible
exact isovector: -1
exact isoscalar: -1

$$r_C^{\gamma Z} = r_C^{\gamma\gamma}(0 \pm 1)$$

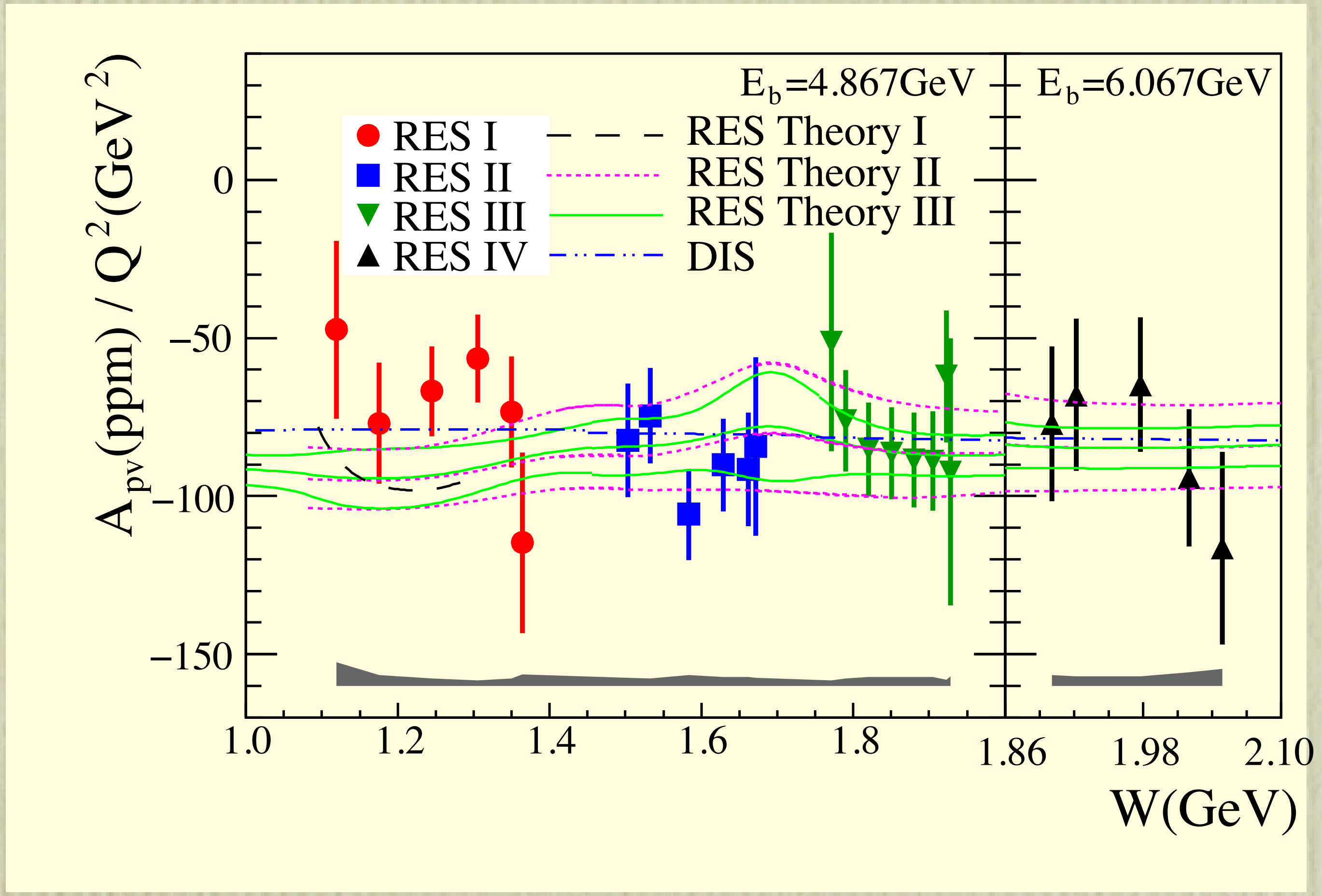
Supported by the FESR

To bring in accord, adjust the background
(resonances are fixed by c.s. and GDH)

$$(5.4 \pm 2.0) \times 10^{-3} \to (3.5 \pm 1.9 \pm 0.25) \times 10^{-3}$$

Impact of PVDIS data

FESR suggests that the continuum contribution might be largely overestimated



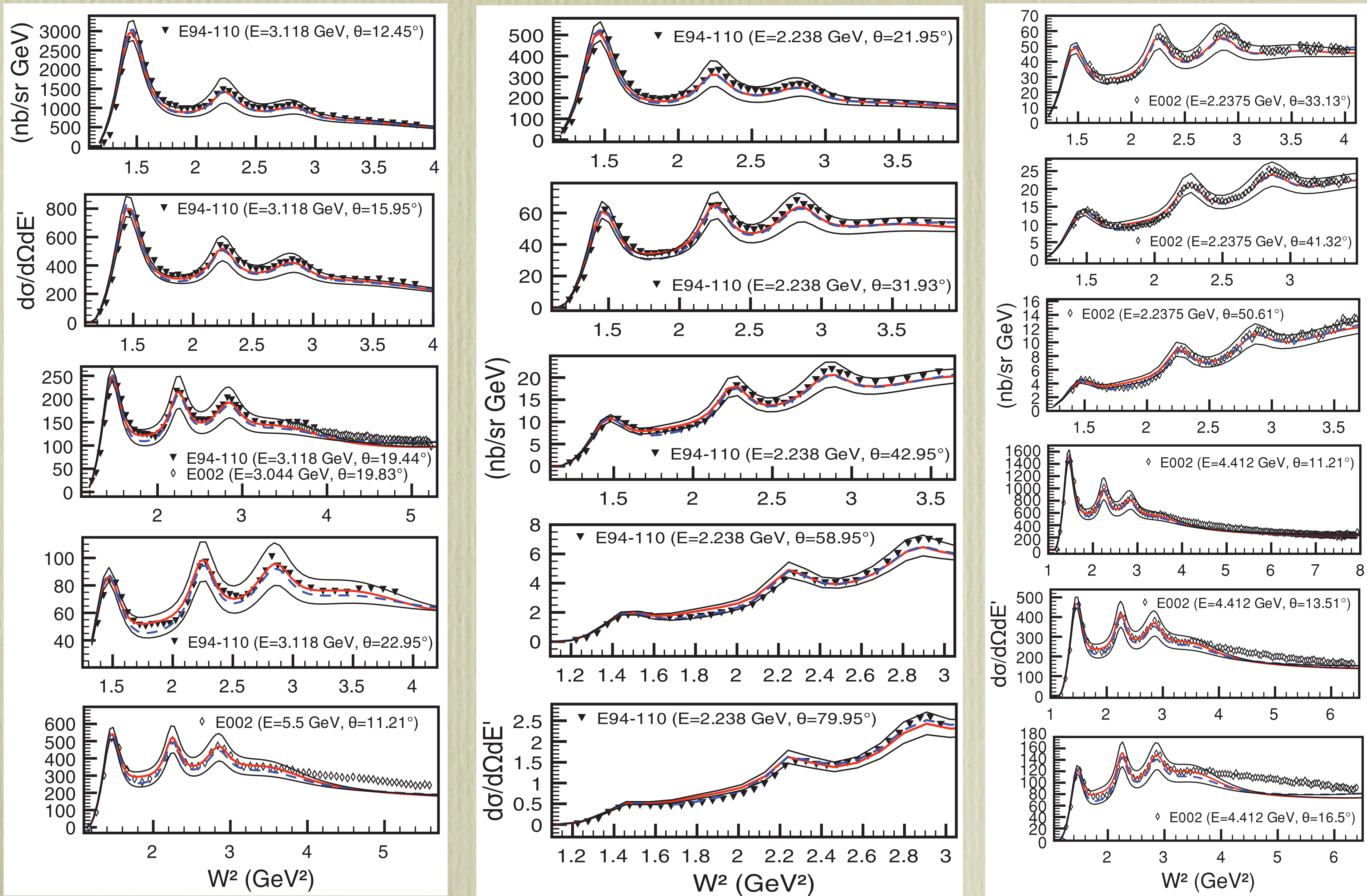
Most red points (central values) are outside of the theory band - is this uncertainty conservative?

Could this discrepancy support the FESR-driven conclusion?

New data on PV DIS structure functions coming - PV DIS, SOLID, MOLLER

SUMMARY & OUTLOOK

- γZ box in Q-Weak kinematics: uncertainty is due to the isospin structure of the background (~66%) and resonance excitation of the neutron (~30%)
- Uncertainty estimate: combining unrelated data sets: total cross sections on proton and deuteron, helicity cross section on the proton, exp. test of the VDM sum rule
- Using GDH sum rule - half the resonance uncertainty
- FESR: continuum overestimated? (at real photon point)
- VDM sum rule at JLab energies?


(nb/sr GeV)
dσ/dΩdE'
E94-110 (E=3.118 GeV, θ=12.45°)
E94-110 (E=3.118 GeV, θ=15.95°)
E94-110 (E=3.118 GeV, θ=19.44°)
E002 (E=3.044 GeV, θ=19.83°)
E94-110 (E=3.118 GeV, θ=22.95°)
E002 (E=5.5 GeV, θ=11.21°)
W² (GeV²)
(nb/sr GeV)
dσ/dΩdE'
E94-110 (E=2.238 GeV, θ=21.95°)
E94-110 (E=2.238 GeV, θ=31.93°)
E94-110 (E=2.238 GeV, θ=42.95°)
E94-110 (E=2.238 GeV, θ=58.95°)
E94-110 (E=2.238 GeV, θ=79.95°)
W² (GeV²)
(nb/sr GeV)
dσ/dΩdE'
E002 (E=2.2375 GeV, θ=33.13°)
E002 (E=2.2375 GeV, θ=41.32°)
E002 (E=2.2375 GeV, θ=50.61°)
E002 (E=4.412 GeV, θ=11.21°)
E002 (E=4.412 GeV, θ=13.51°)
E002 (E=4.412 GeV, θ=16.5°)
W² (GeV²)

SUMMARY & OUTLOOK

	W < 2GeV	W < 4GeV	W < 5GeV	W < 10GeV	All W
$Q^2 < 1$ GeV^2	62.6%	79.8%	81.2%	82.8%	83.2%
$Q^2 < 2$ GeV^2	68.3%	85.8%	87.6%	89.9%	90.4%
$Q^2 < 3$ GeV^2	69.4%	87.9%	90.0%	92.7%	93.3%
All Q^2	70%	91.1%	94.1%	98.6%	100%