γZ box (ing) discussion

What we agree on

- γZ corrections are important & we know (more or less) how to calculate them (in principle)!

- Main uncertainty from poor knowledge of γZ structure functions

  $\longrightarrow$ most important contributions from low W, low Q^2

- Should use available empirical information to constrain γZ corrections

What we disagree on

- How to constrain γZ structure functions in low W, low Q^2 region

- How (whether?) to match structure functions across boundaries

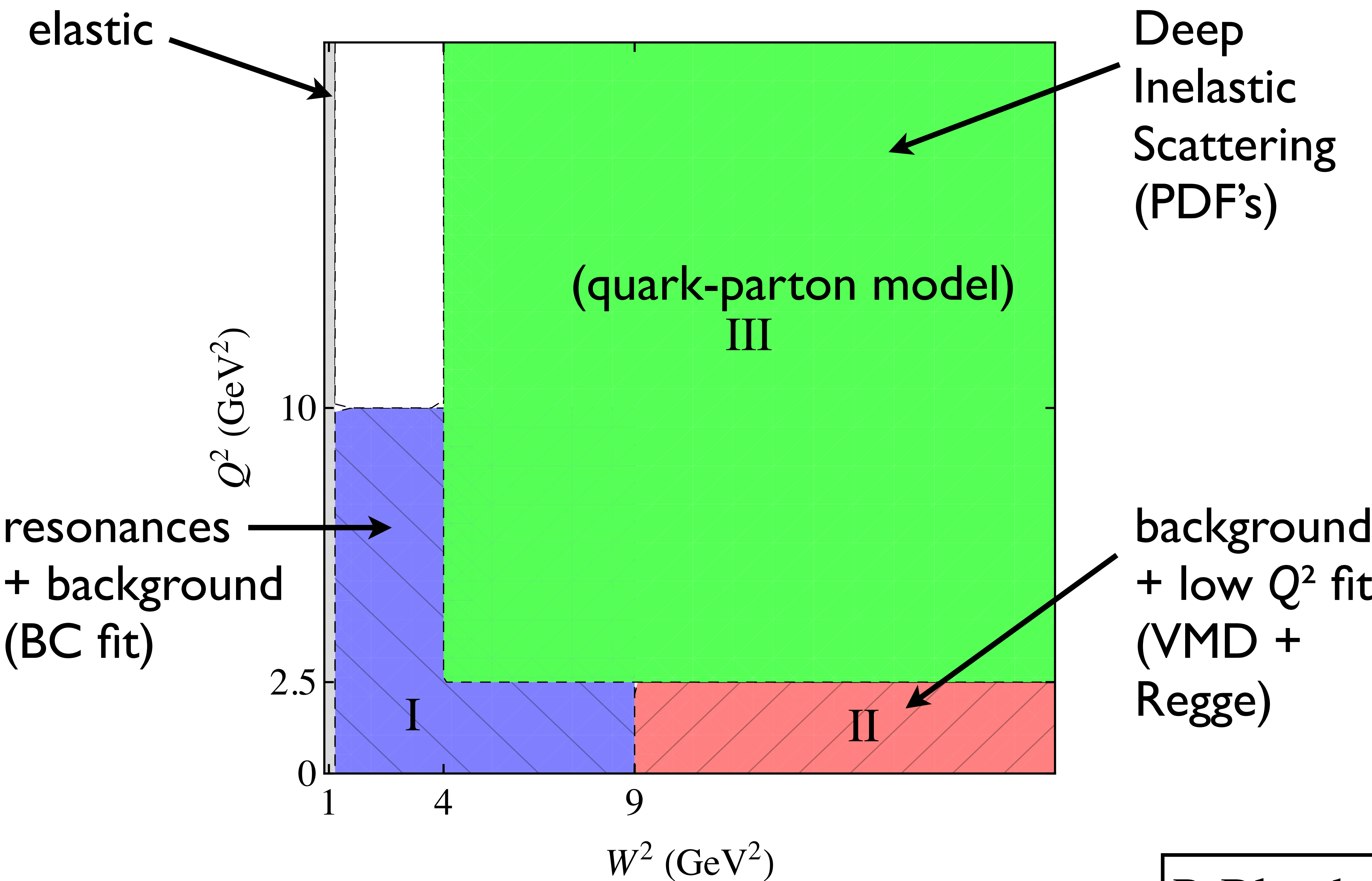
  → match onto "DIS" region, where (leading twist) structure functions understood

- How to use information from other observables (d PVDIS, PDFs) to constrain unknown structure functions

- How to add errors

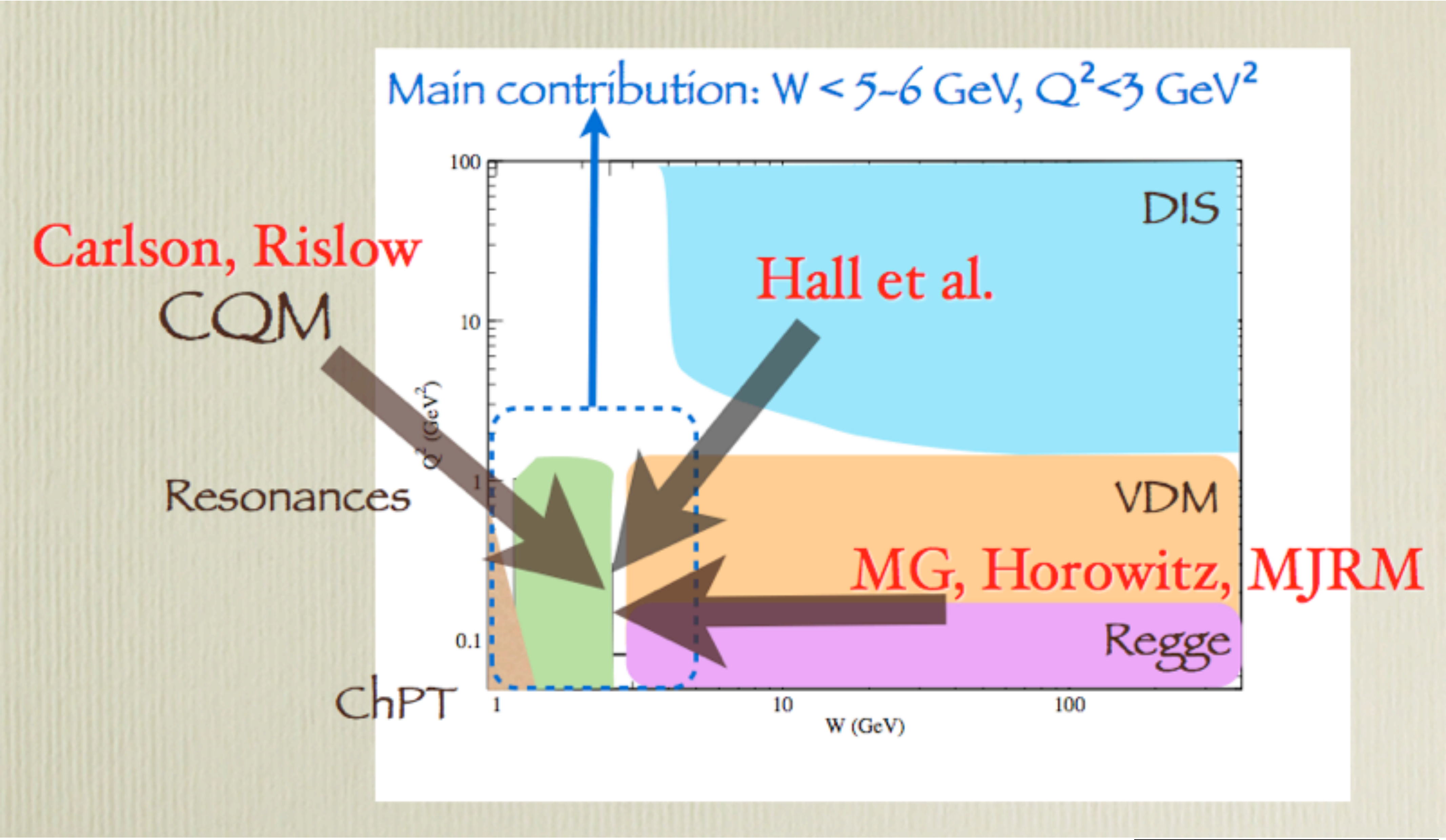
  → Gaussian, square, ... distributions

Integration region



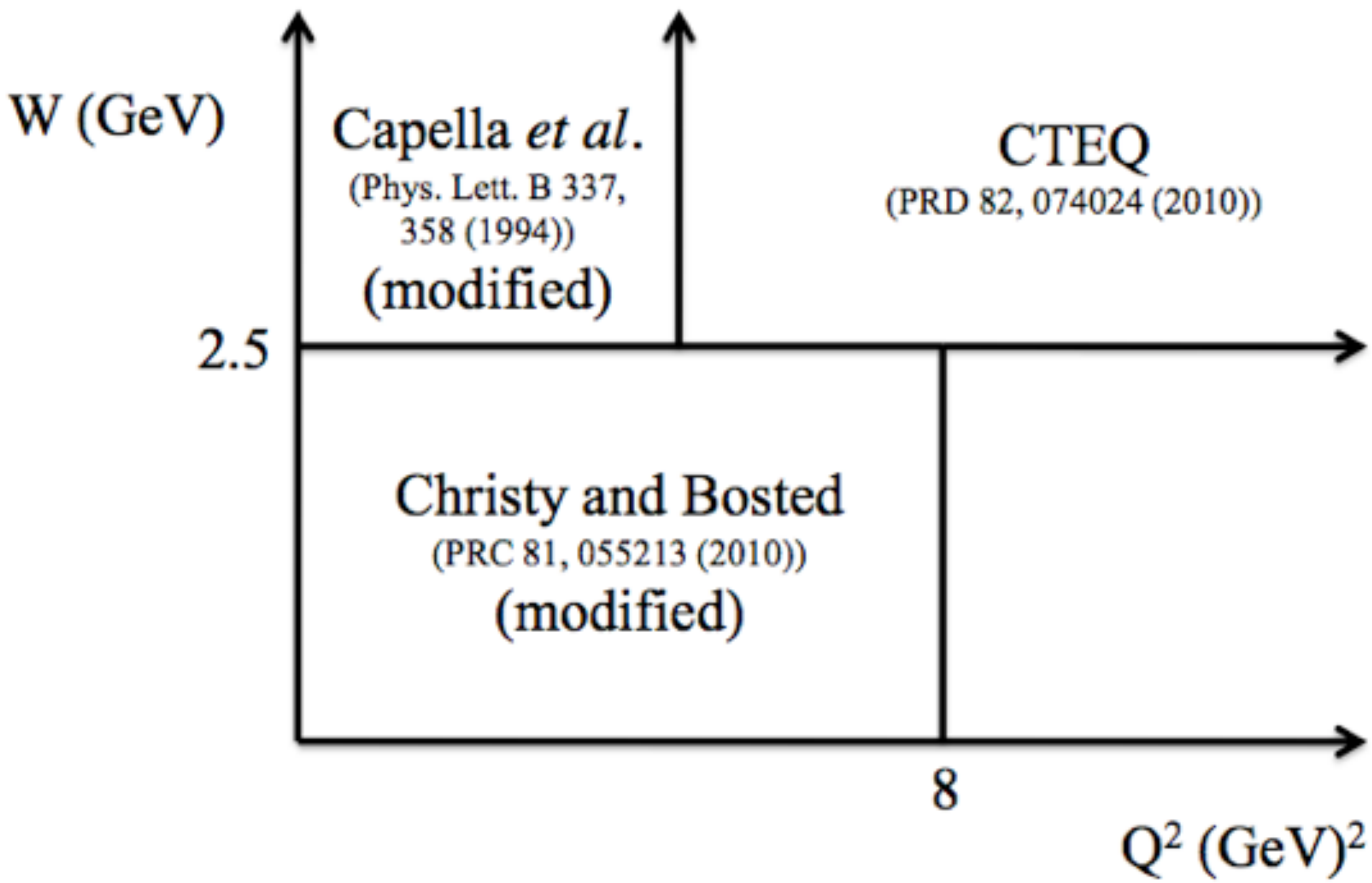
P. Blunden

Integration region

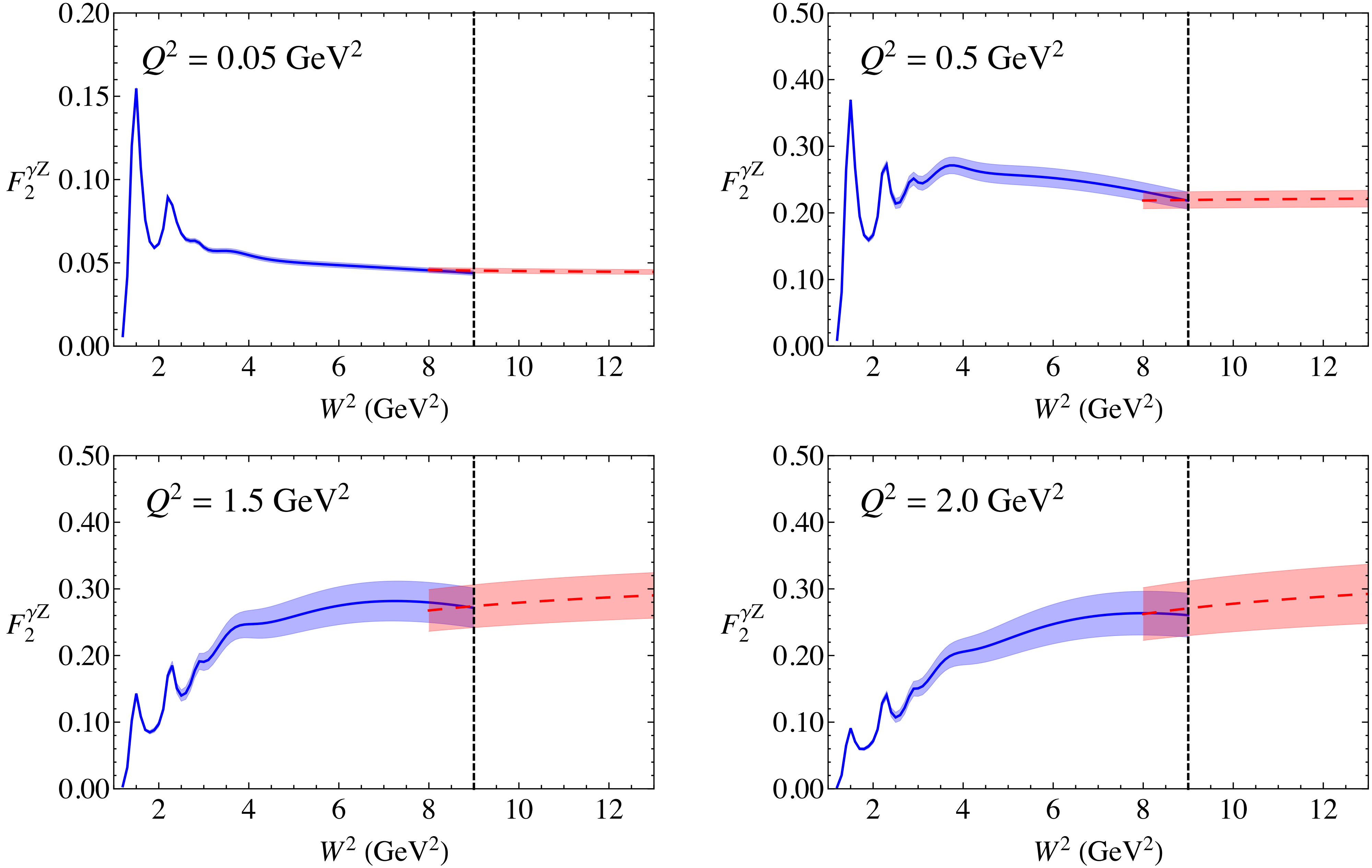


M. Gorshteyn

Integration region

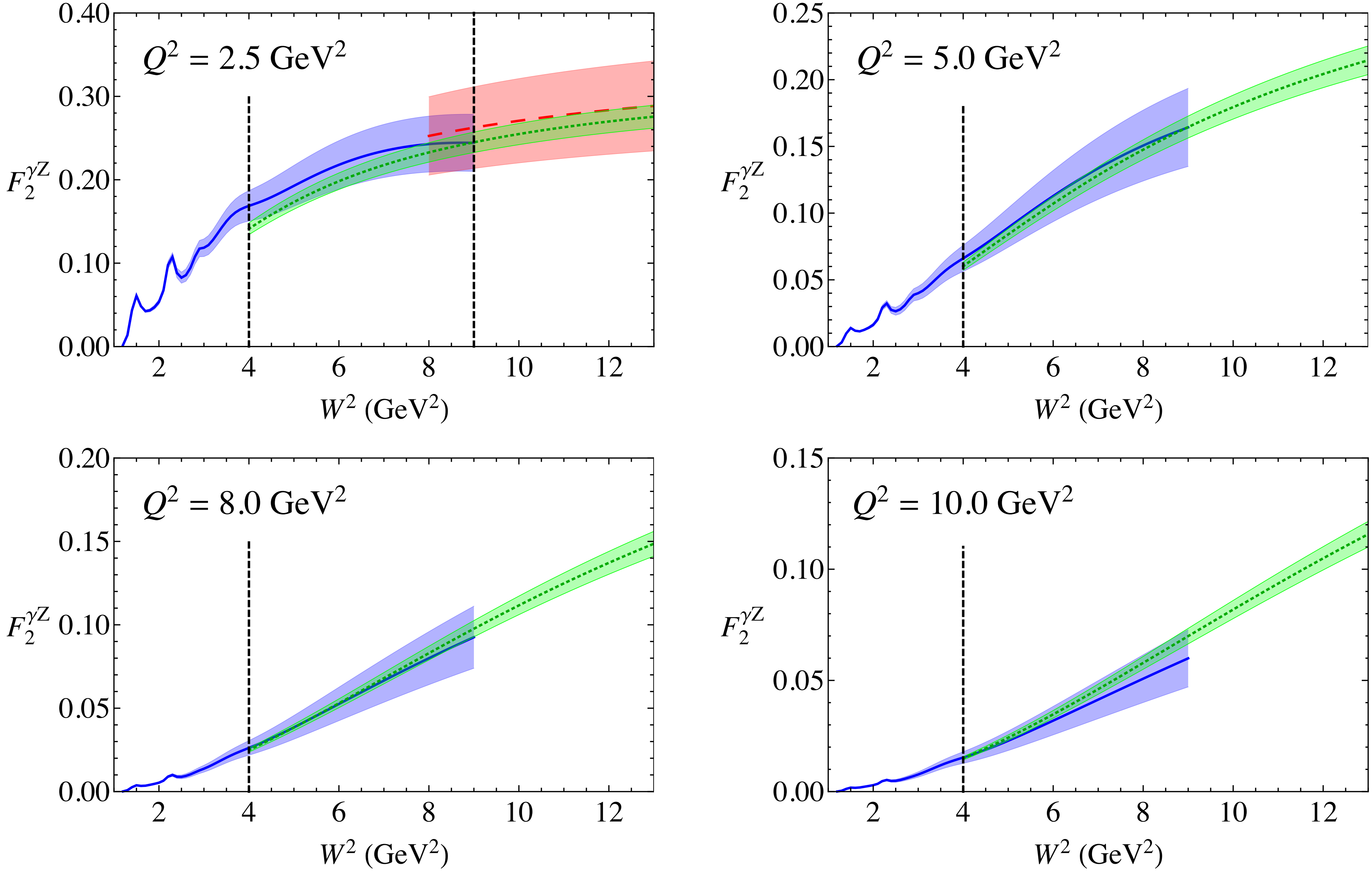


C. Carlson



Region I and II matching

P. Blunden



Region I and III matching

P. Blunden

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%

~ 30% from "DIS" region

M. Gorshteyn

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%
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$Q^2 < 3\ GeV^2$	69.4%	87.9%	90.0%	92.7%	93.3%
All Q^2	70%	91.1%	94.1%	98.6%	100%

~ 40% from "DIS" region with duality

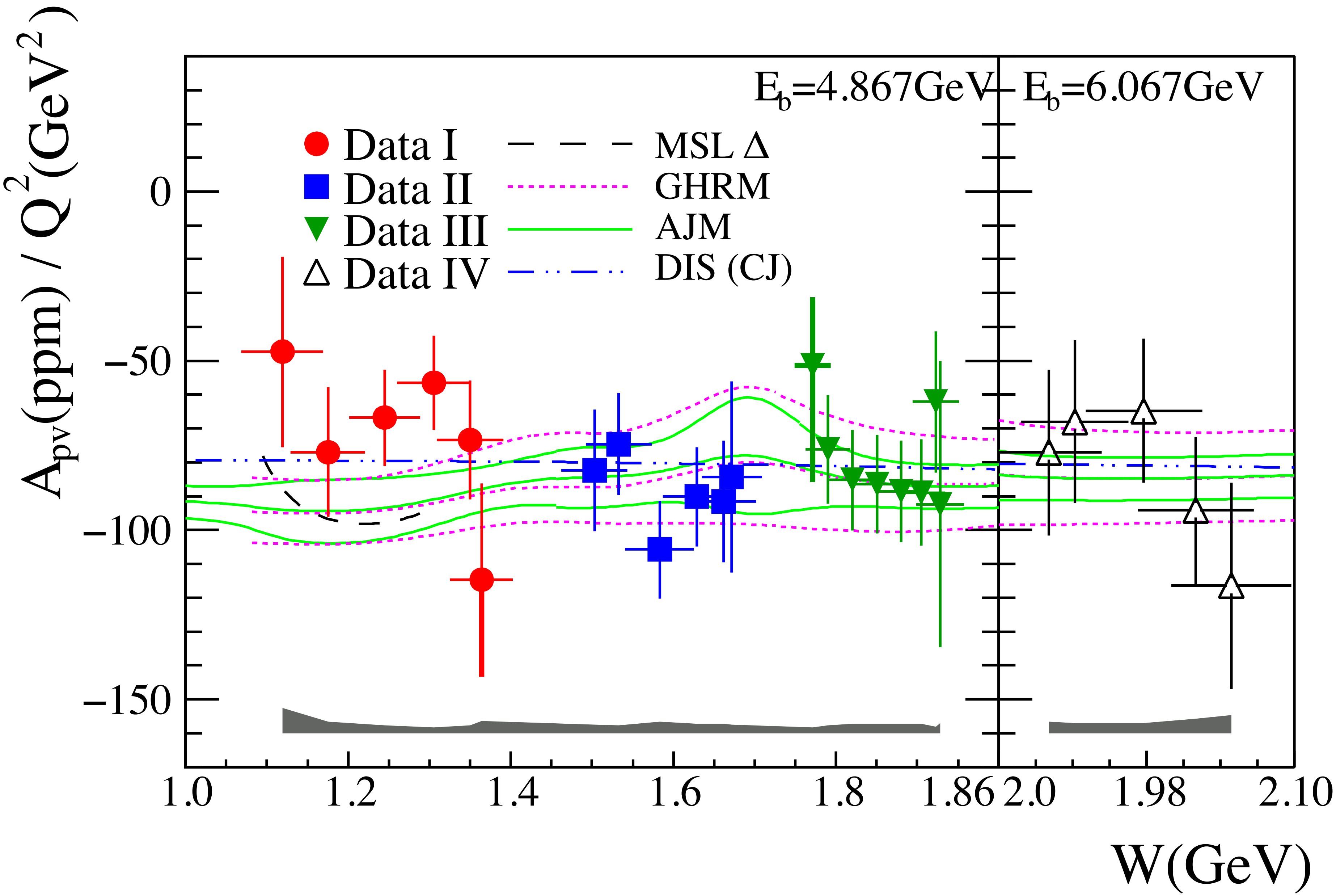
M. Gorshteyn

- Can higher twists in γZ be very large & very different from those in $\gamma\gamma$?
(isospin dependence of HTs?)

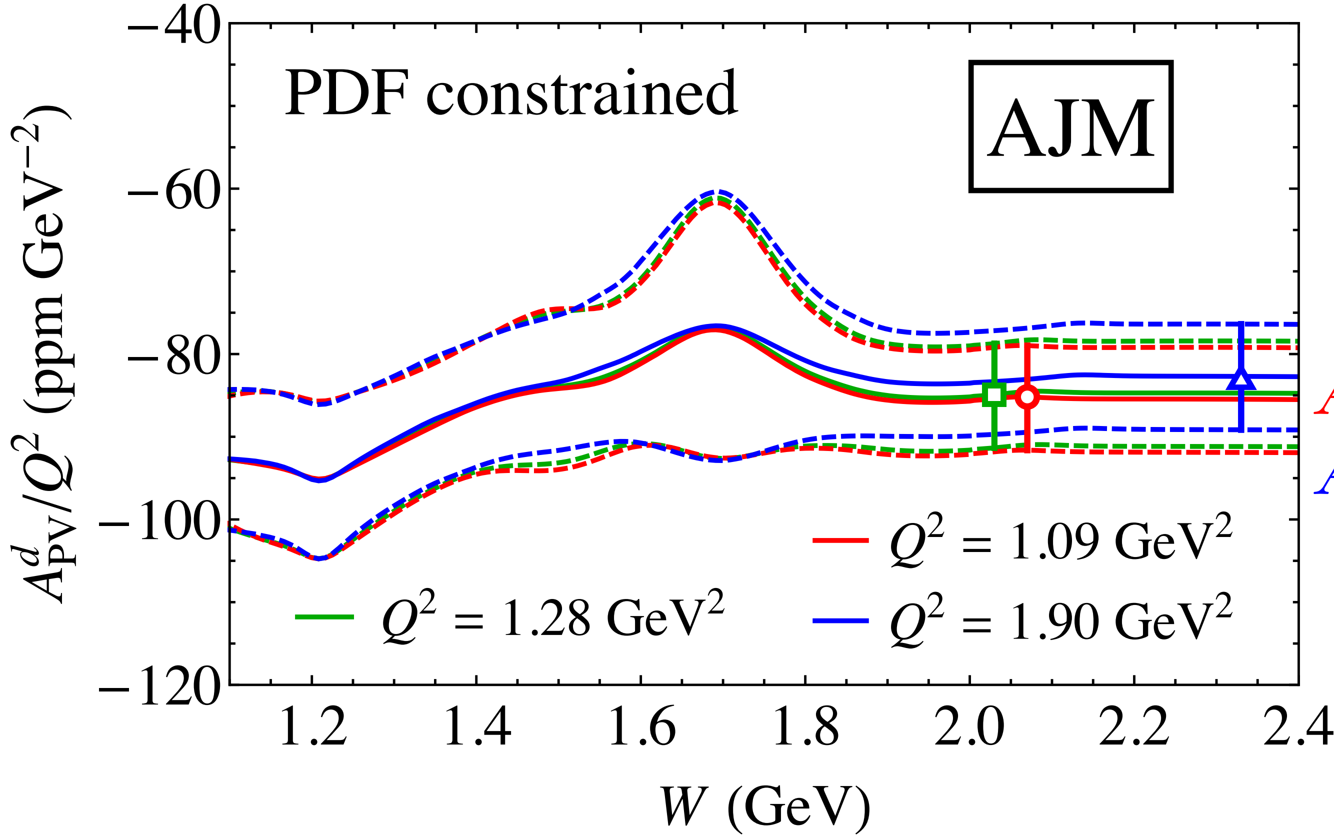
  → Tim Hobbs asked question how large $\gamma Z/\gamma\gamma$ HTs (in the form of $R^{\gamma Z}/R^{\gamma\gamma}$) would impact PVDIS measurement

  → Mantry, Ramsey-Musolf, Sacco recomputed HTs in MIT bag model (earlier Mulders), found to be "small"

  → "designer" corrections that (mysteriously) affect some observables but not others



*Wang et al. PRL **111**, 082501 (2013)*



Predictions for PV deuteron asymmetry in DIS kinematics

$A_{\rm PV} = -92.4 \pm 6.8$ ppm

$A_{\rm PV} = -157.2 \pm 12.2$ ppm

P. Blunden

E08011 DIS Results

Article accepted by Nature, in press

Kinematic I — E = 6.067 GeV, $\langle x \rangle = 0.241$, $Y_3 = 0.44$, $\langle Q^2 \rangle = 1.085$ (GeV/c)^2

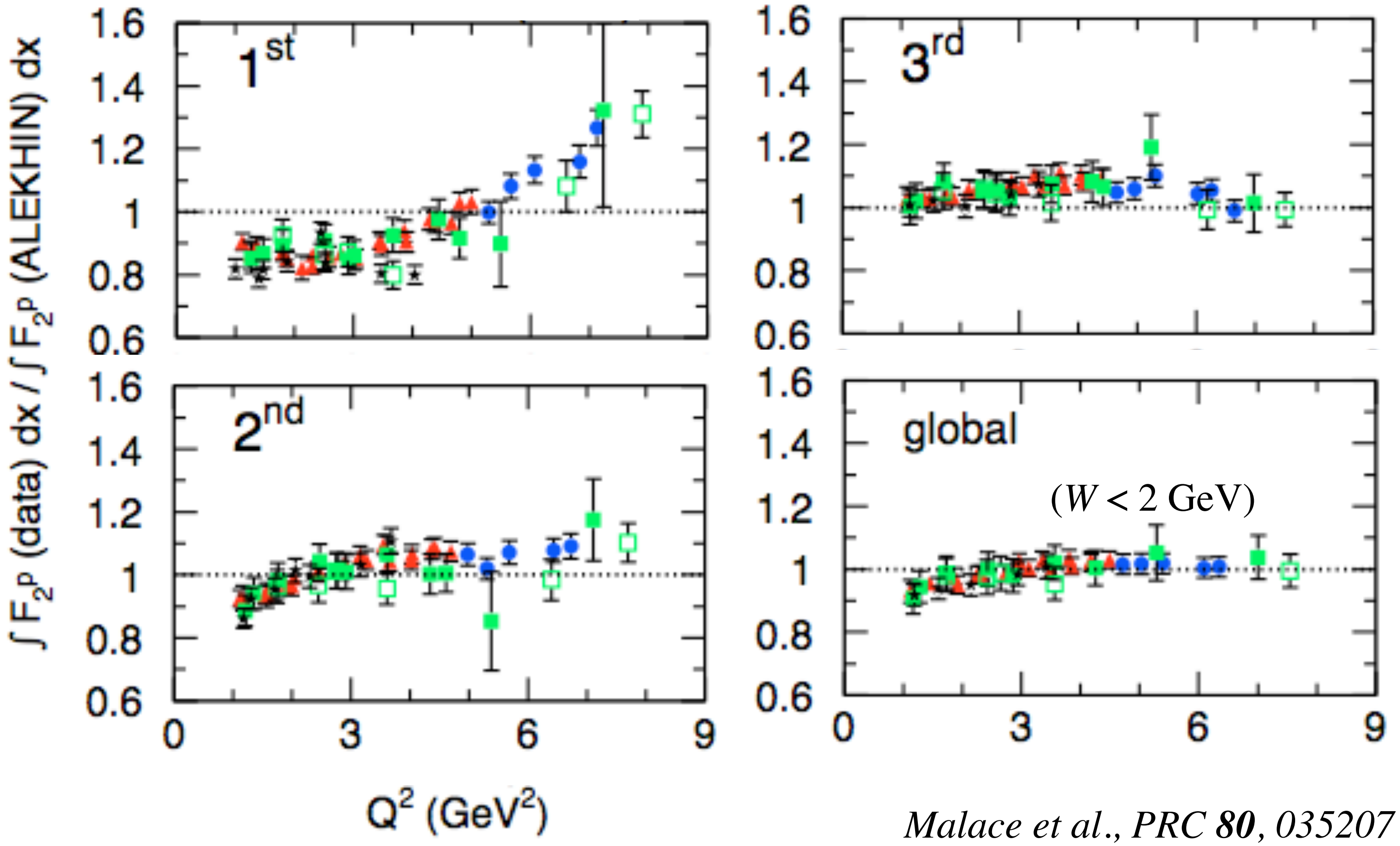
$$A_{\rm exp} = -91.1 \pm 3.1(stat) \pm 3.0\,(syst)\ \ ppm$$

Kinematic II — E = 6.067 GeV, $\langle x \rangle = 0.295$, $Y_3 = 0.69$, $\langle Q^2 \rangle = 1.901$ (GeV/c)^2

$$A_{\rm exp} = -160.8 \pm 6.4(stat) \pm 3.1\,(syst)\ \ ppm$$

R. Michaels

Quark-hadron duality in F_2^p

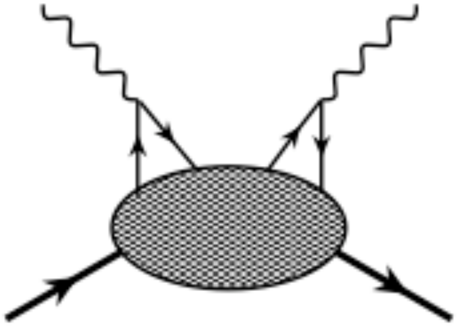


*Malace et al., PRC **80**, 035207 (2009)*
[JLab Hall C]

→ higher twists $< 10\text{–}15\%$ for $Q^2 > 1\ \mathrm{GeV}^2$

Accidental cancellations of charges?

S. Brodsky (2000)



<u>cat's ears diagram</u> (4-fermion higher twist $\sim 1/Q^2$)

$$\propto \sum_{i \neq j} e_i \, e_j \sim \Big(\sum_i e_i\Big)^2 - \sum_i e_i^2$$

↑ *coherent* ↑ *incoherent*

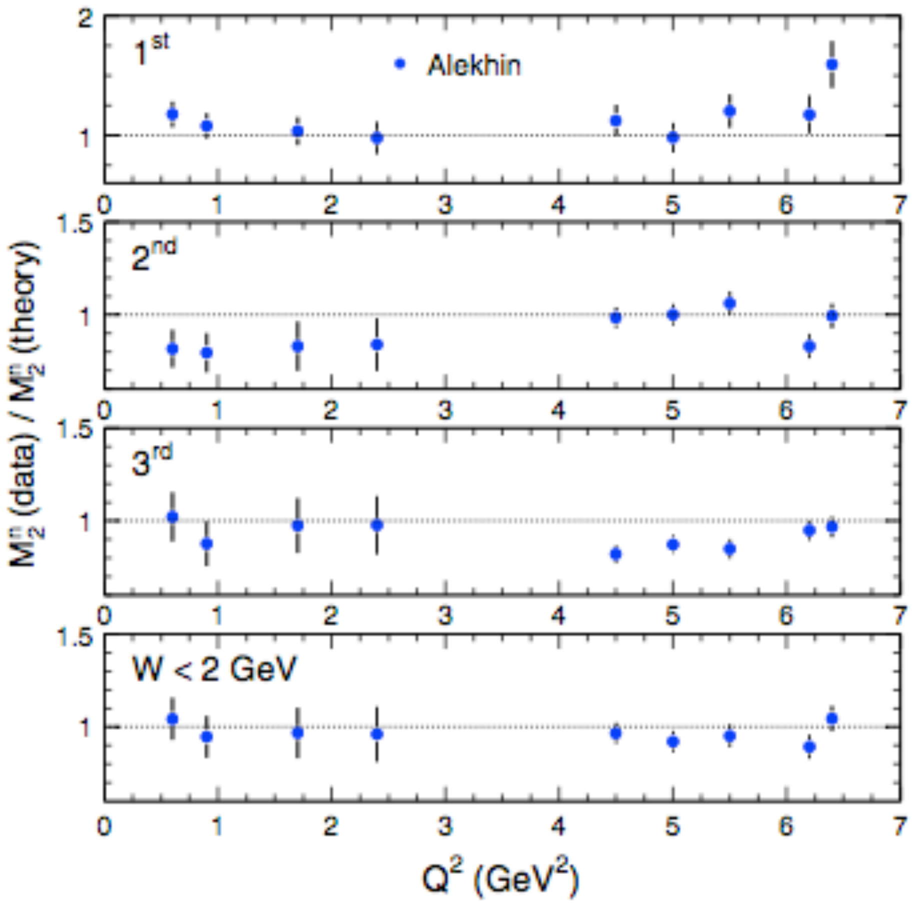
proton $\quad \mathrm{HT} \sim 1 - \left(2 \times \frac{4}{9} + \frac{1}{9}\right) = 0 \, !$

neutron $\quad \mathrm{HT} \sim 0 - \left(\frac{4}{9} + 2 \times \frac{1}{9}\right) \neq 0$

→ duality in proton a *coincidence!*

→ should *not* hold for neutron !!

Quark-hadron duality in neutron



→ "theory": fit to $W > 2$ GeV data

Alekhin et al., 0908.2762 [hep-ph]

→ *locally*, violations of duality in resonance regions < 15–20% (largest in Δ region)

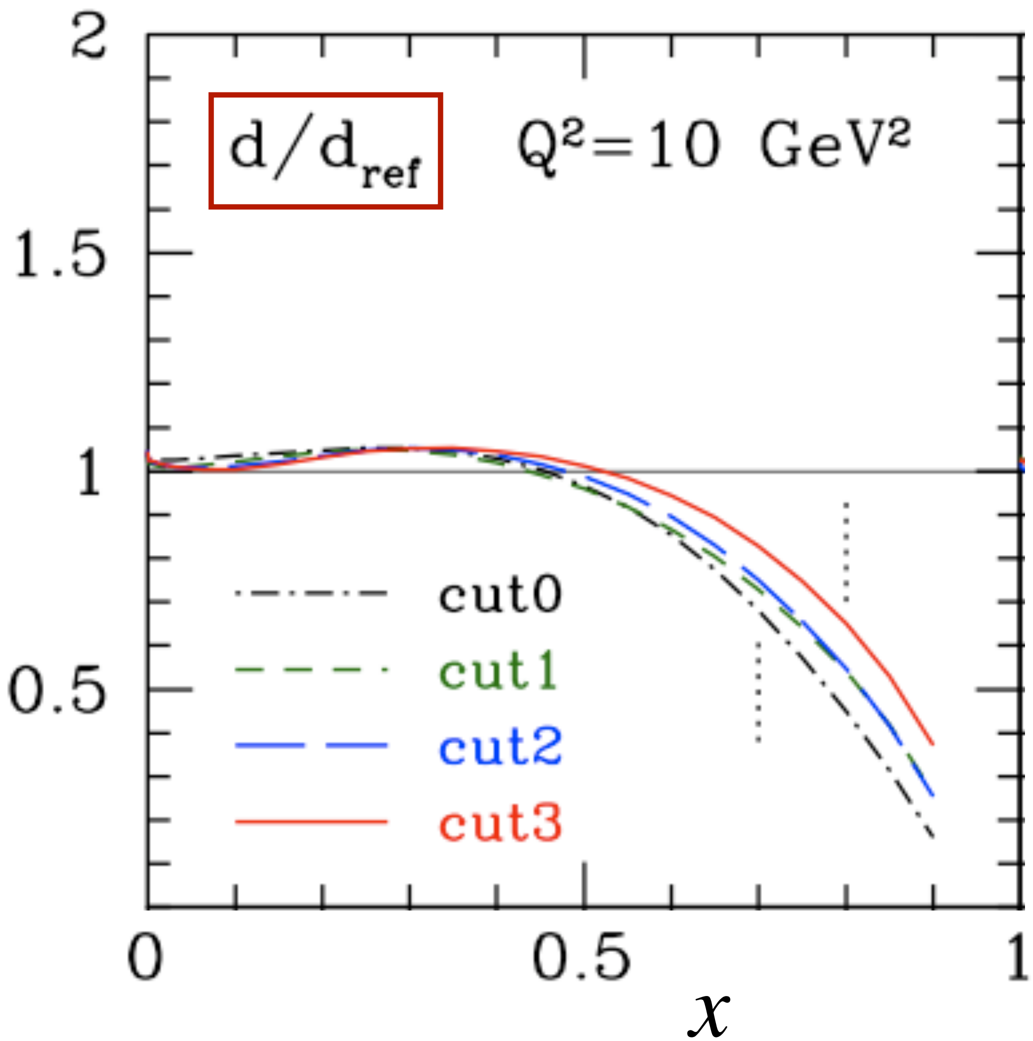
→ *globally*, violations < 10%

Malace, Kahn, WM, Keppel
*PRL **104**, 102001 (2010)*

⇒ use resonance region data to learn about *leading twist* structure functions?

Kinematic cuts

- Systematically reduce Q^2 & W cuts
- Fit includes TMCs, HT term, nuclear corrections



→ *stable* with respect to cut reduction

→ d quark suppressed by $\sim 50\%$ for $x > 0.5$ (driven by nuclear corrections)

*Accardi et al., PRD **81**, 034016 (2010)*

What should we do?

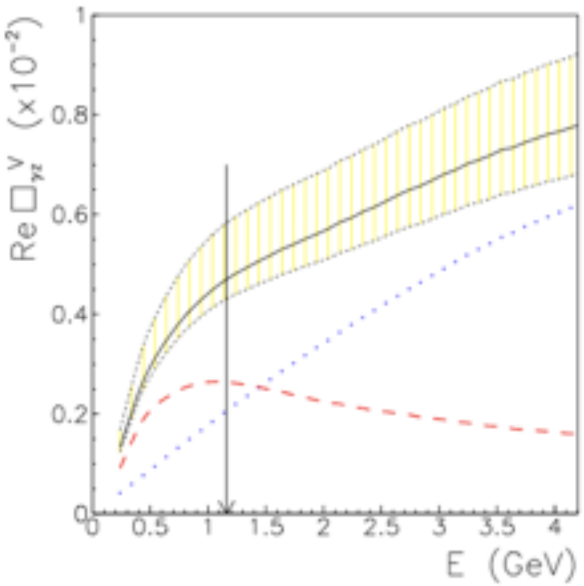
- Try to agree on error estimate that is not too wildly optimistic or too wildly pessimistic?

- • What PV (not so?)DIS measurements will best constrain the calculation? What kinematics, how many points, and to what accuracy?

- Homework
  - for theorists?
  - for experimentalists?

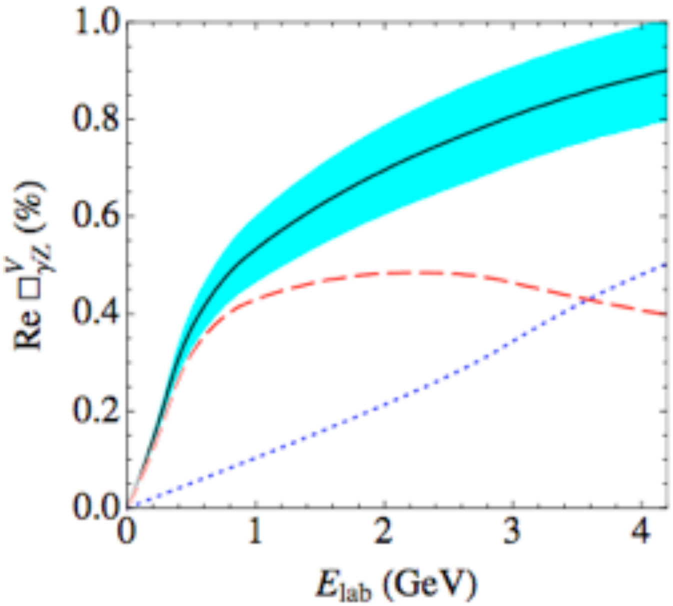
Vector h correction

Sibirtsev *et al.*



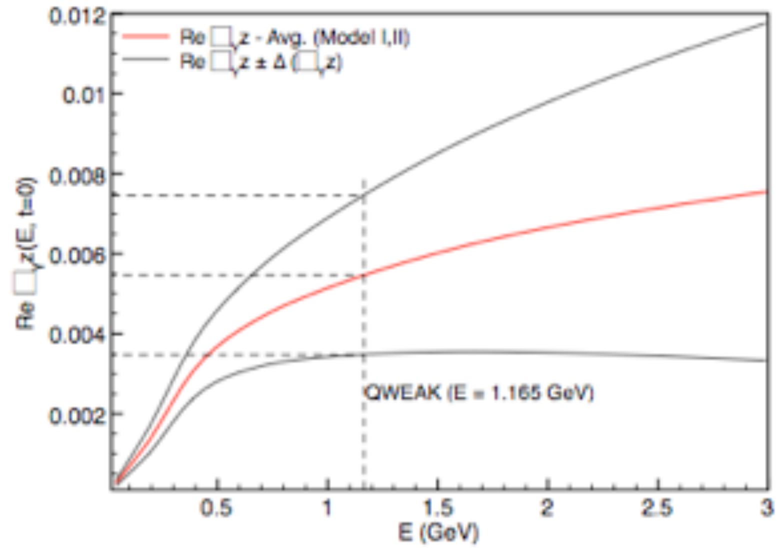
Sibirtsev, Blunden, WM, Thomas
*PRD **82**, 013011 (2010)*

Rislow & Carlson



Rislow, Carlson
*PRD **83**, 113007 (2011)*

GHRM



Gorchtein, Horowitz, Ramsey-Musolf
*PRC **84**, 015502 (2011)*

$$\Re e\, \Box_{\gamma Z}^{V} = 0.0047^{+0.0011}_{-0.0004}$$

$$\Re e\, \Box_{\gamma Z}^{V} = 0.0057 \pm 0.0009$$

$$\Re e\, \Box_{\gamma Z}^{V} = 0.0054 \pm 0.002$$

2 x larger uncertainty

$$\Re e\, \Box_{\gamma Z}^{V} = (5.39 \pm 0.27 \pm 1.88^{+0.58}_{-0.49} \pm 0.07) \times 10^{-3}$$

model, bckgnd, res., t dep.

AJM γZ model

- $F_{1,2}^{\gamma Z}$ structure functions

  - for background at low Q^2, weak isospin rotation uses VMD

$$\sigma_V^{\gamma Z} = \kappa_V \, \sigma_V^{\gamma\gamma}$$

$$\kappa_\rho = 2 - 4\sin^2\theta_W, \quad \kappa_\omega = -4\sin^2\theta_W, \quad \kappa_\phi = 3 - 4\sin^2\theta_W$$

$$\frac{\sigma^{\gamma Z}}{\sigma^{\gamma\gamma}} = \frac{\kappa_\rho + \kappa_\omega R_\omega + \kappa_\phi R_\phi + \kappa_C R_C}{1 + R_\omega + R_\phi + R_C}$$

$$R_V = \frac{\sigma^{\gamma^* p \to V p}}{\sigma^{\gamma^* p \to \rho p}}$$

production cross section ratio for vector meson V to ρ meson

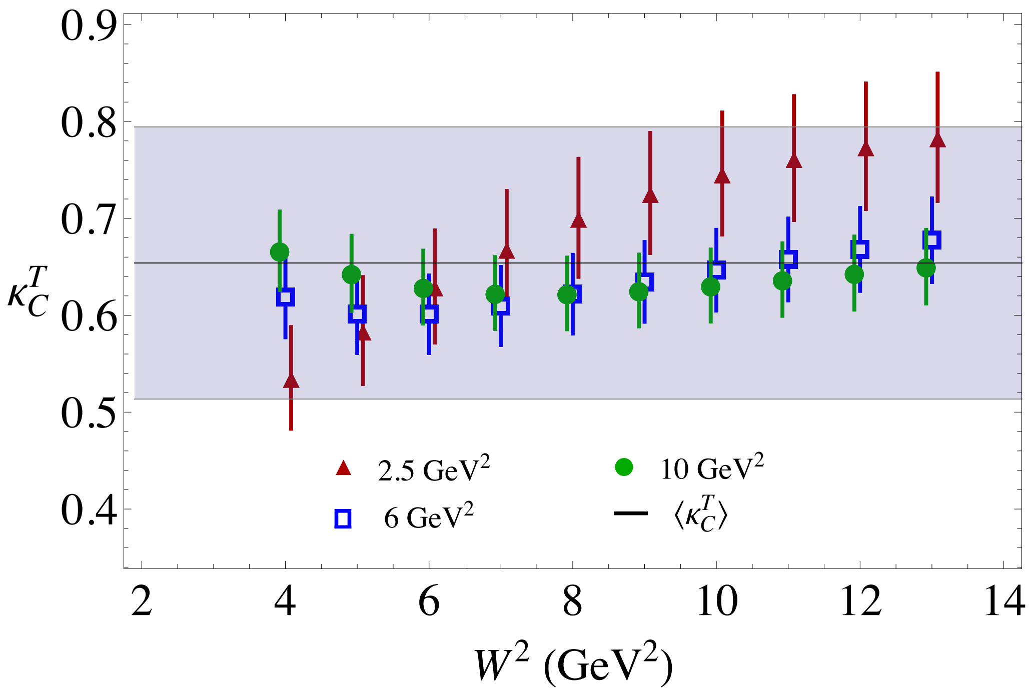
→ continuum parameter κ_C not constrained in VMD

→ GHRM assume $\kappa_C = 1 \pm 1$ ← largest source of error!

AJM γZ model

- Region where continuum contributions are relevant overlaps with typical reach of global PDF fits

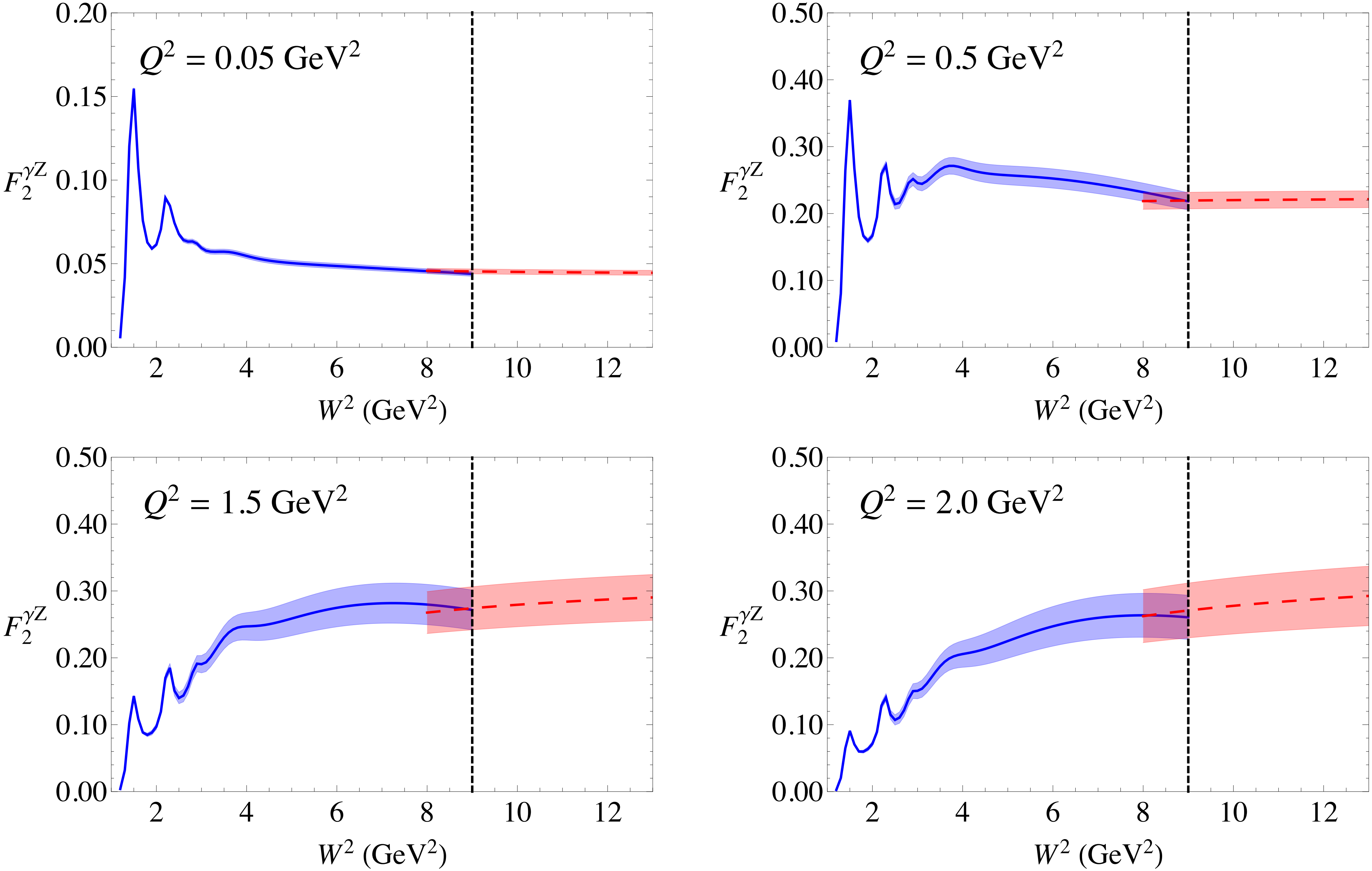
→ constrain κ_C using PDF parametrizations by requiring matching of $F_{1,2}^{\gamma Z}$ to DIS structure functions



→ $$\kappa_C^T = 0.65 \pm 0.14, \quad \kappa_C^L = -1.3 \pm 1.7$$

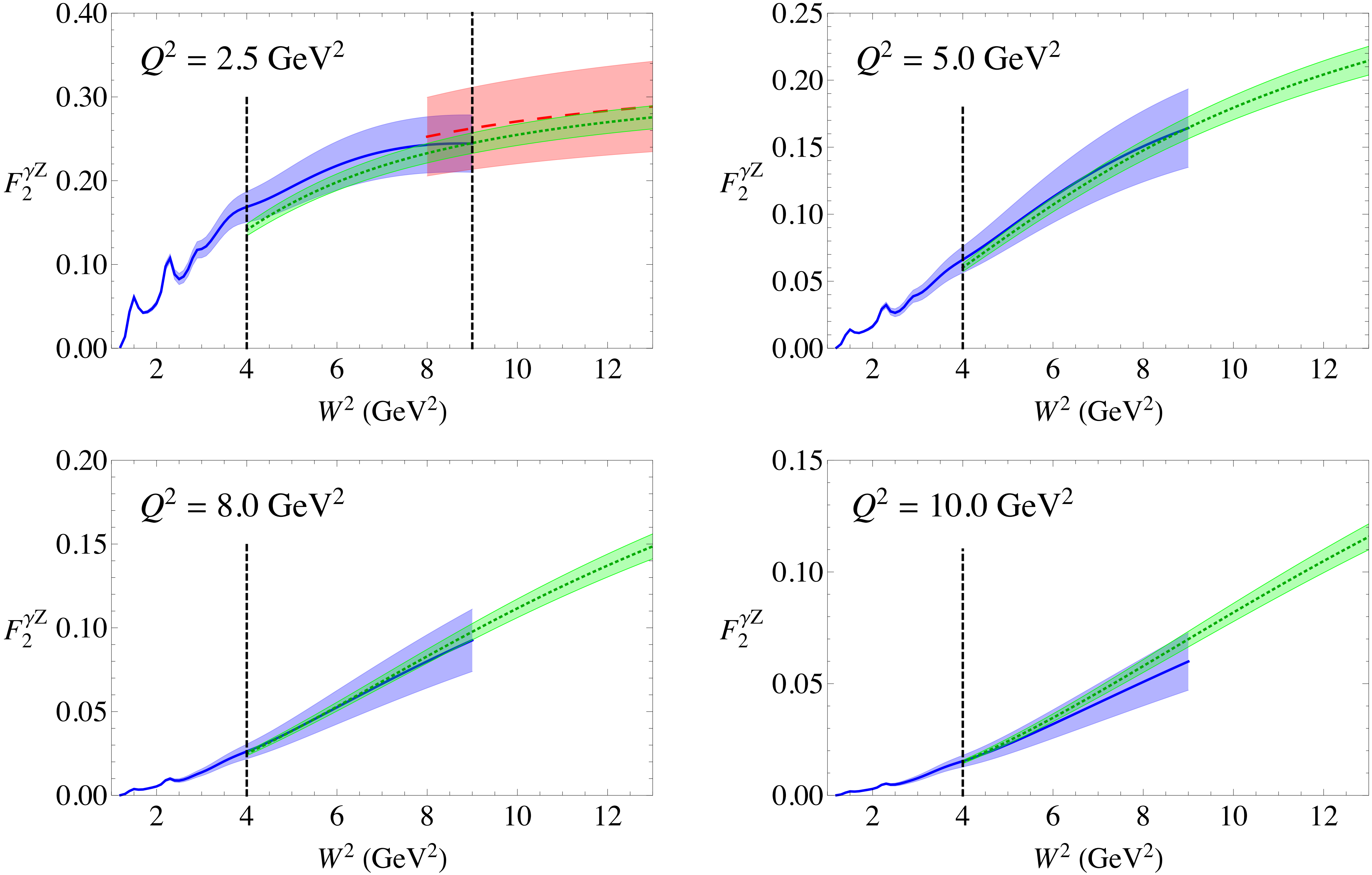
(small contribution to asymmetry)

AJM γZ model



* continuum uncertainty only

AJM γZ model

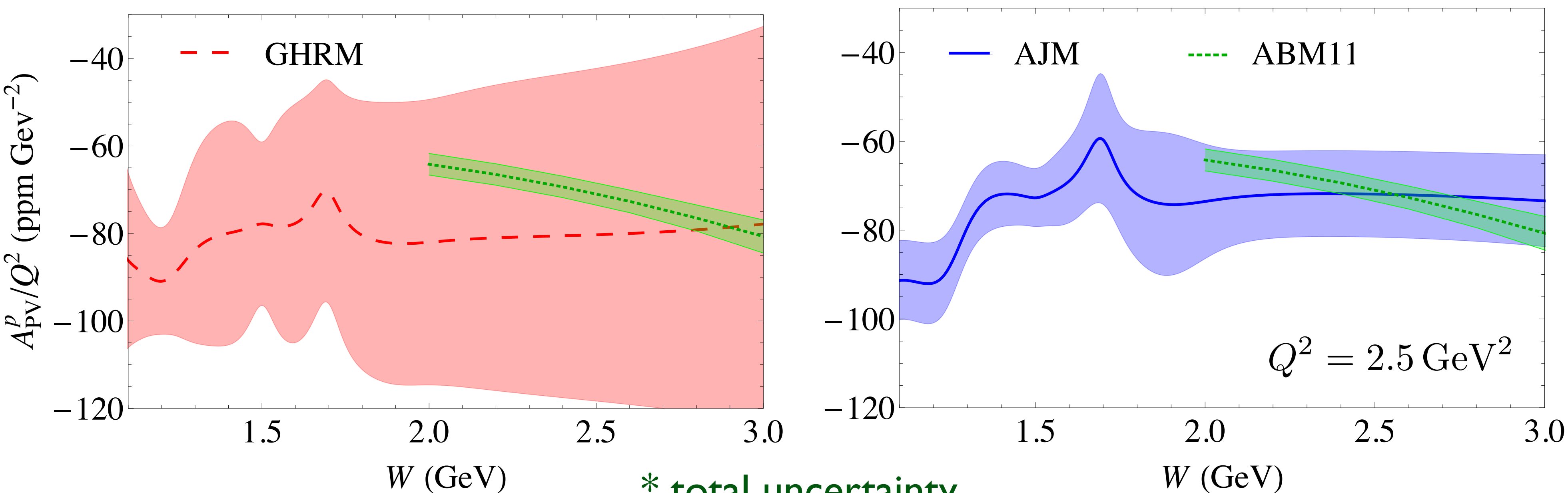


* continuum uncertainty only

AJM γZ model

- PVDIS asymmetry

$$A_{\rm PV} = g_A^e \left(\frac{G_F Q^2}{2\sqrt{2}\pi\alpha}\right) \frac{xy^2 F_1^{\gamma Z} + (1-y)F_2^{\gamma Z} + \frac{g_V^e}{g_A^e}(y - y^2/2)xF_3^{\gamma Z}}{xy^2 F_1^{\gamma\gamma} + (1-y)F_2^{\gamma\gamma}}$$

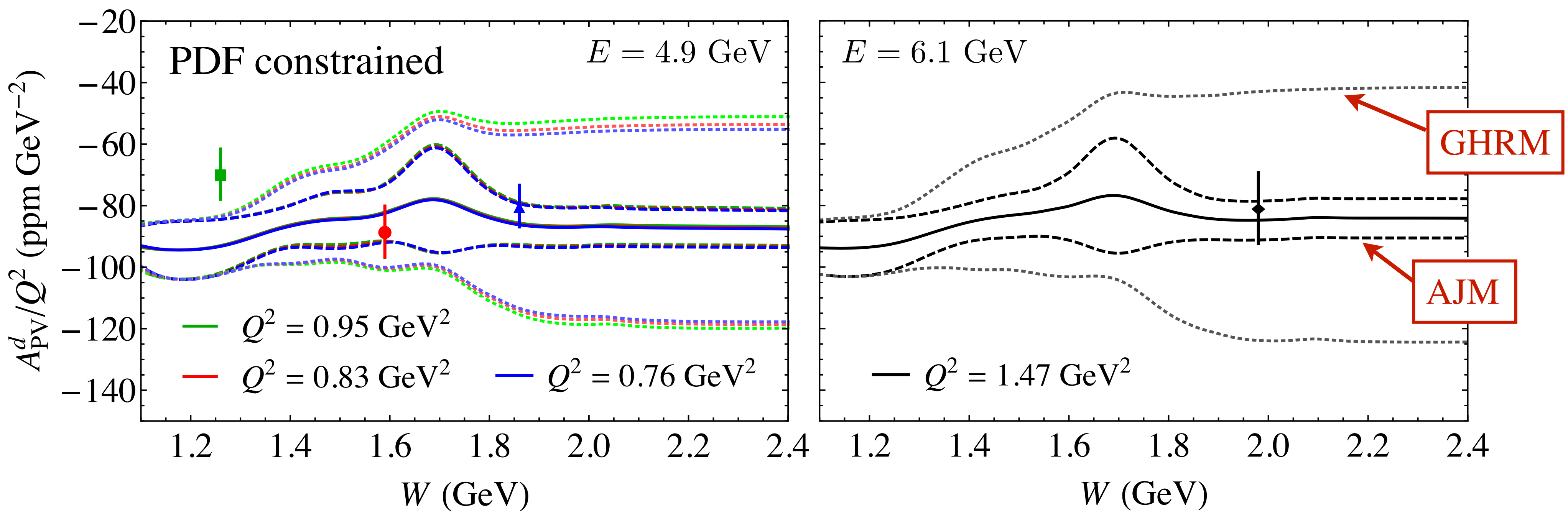


* total uncertainty

→ significantly smaller uncertainties (at typical JLab kinematics) for constrained model

Inclusive PV asymmetries

- Procedure can be tested by comparing with new JLab data on PV asymmetries on deuteron (E08-011*)



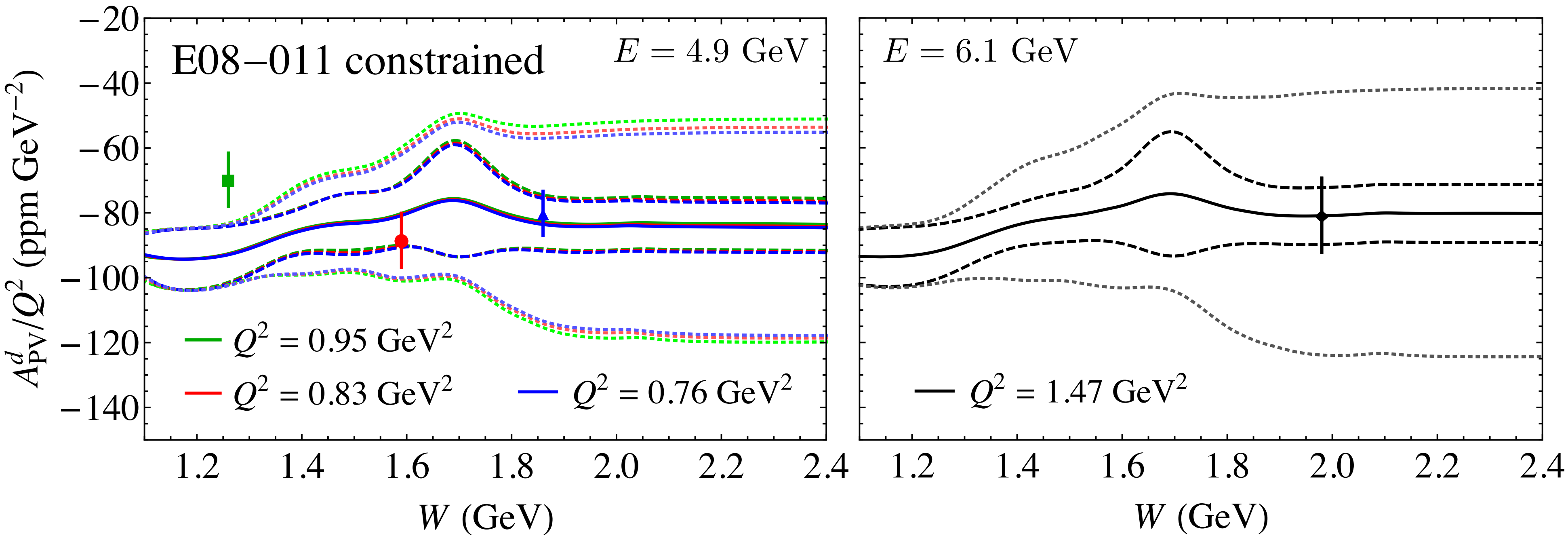
→ agrees well with resonance region PVDIS data

(question about Δ region datum)

* *X. Zheng, P. Reimer, R. Michaels et al.*

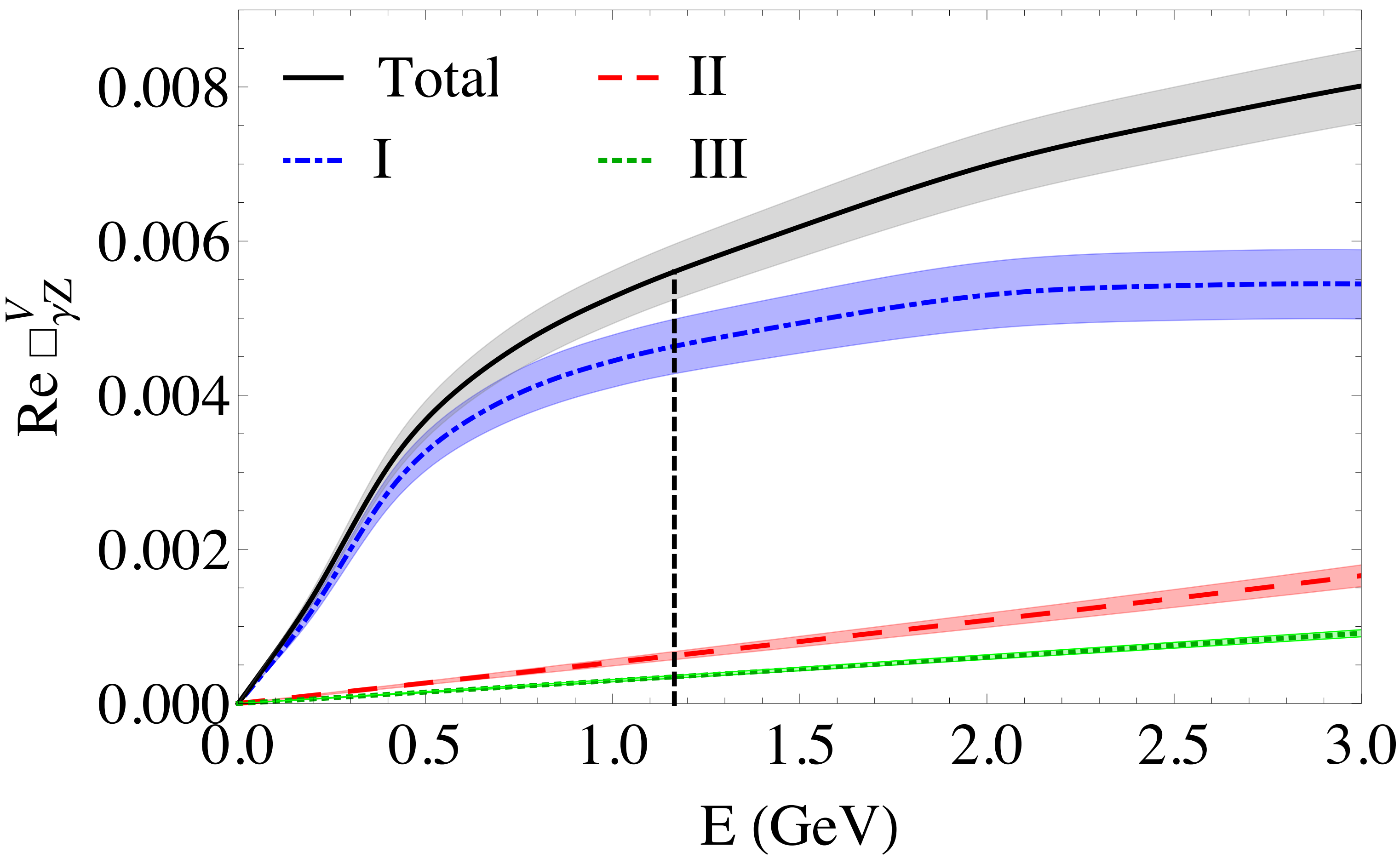
Inclusive PV asymmetries

- Can also use PVDIS-resonance data themselves as constraint, to test consistency of model



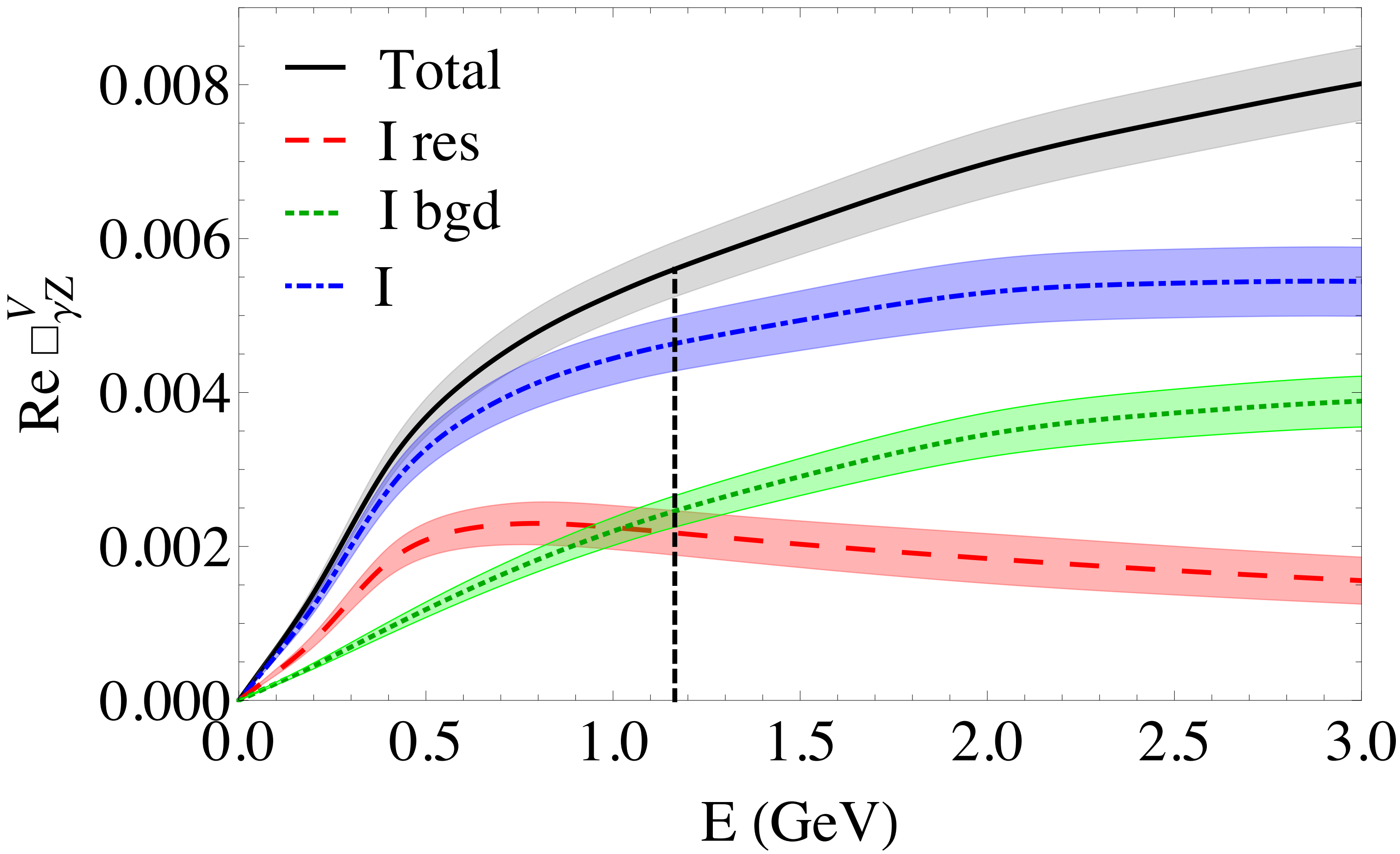
→ slightly larger uncertainties than with PDF constraint, but still ~ 3–4 times smaller (at $W \gtrsim 1.8$ GeV) than GHRM

Correction to Qweak



→ Region I dominates correction & its uncertainty

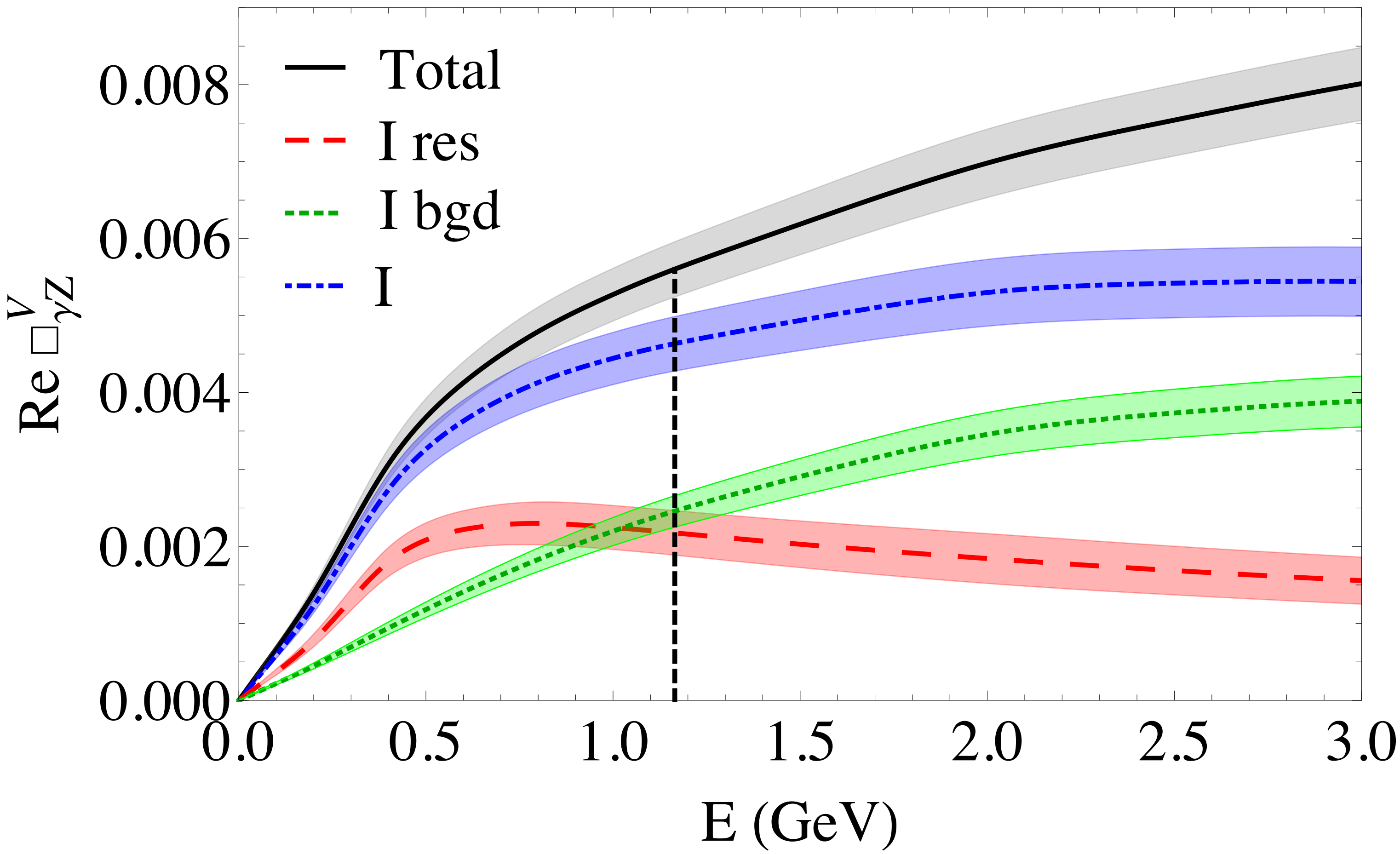
Correction to Qweak



→ Region I dominates correction & its uncertainty

→ resonance & background similar at $E \sim 1$ GeV

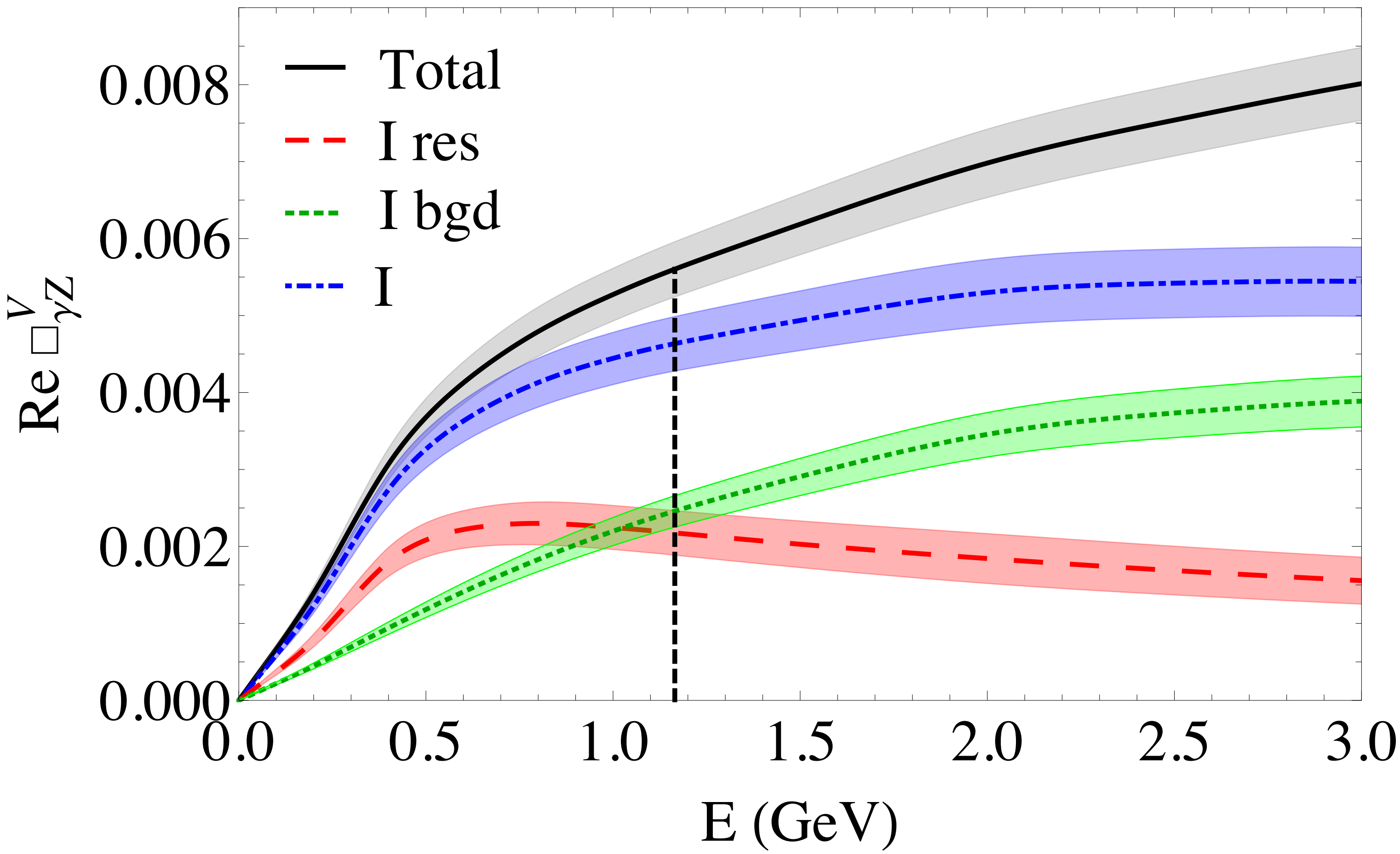
Correction to Qweak



$$\rightarrow \quad \Re e\,\Box^{V}_{\gamma Z} = (5.60 \pm 0.22 \pm 0.29 \pm 0.02) \times 10^{-3}$$

background resonance DIS

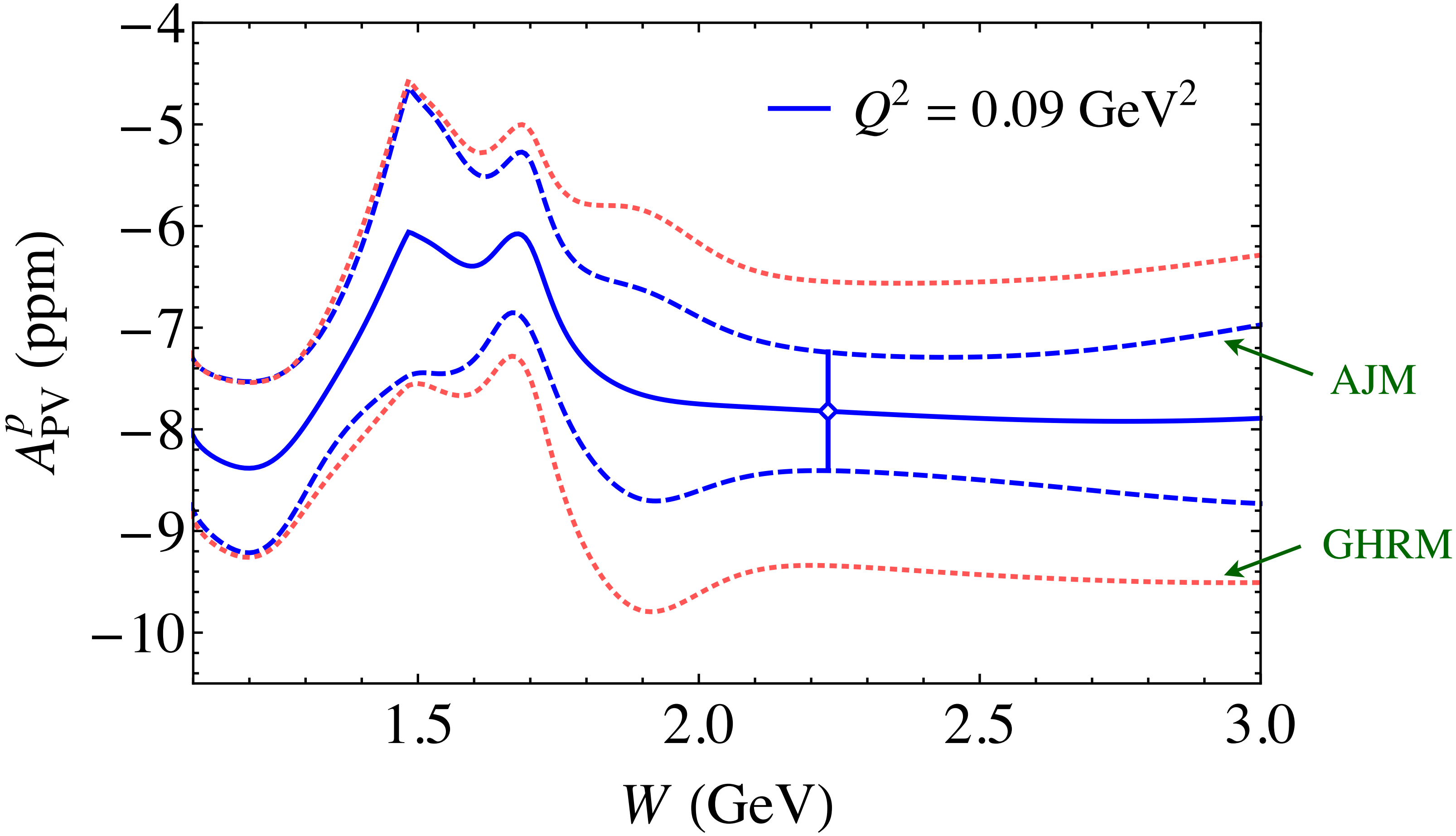
Correction to Qweak



→ $\Re e\, \square_{\gamma Z}^{V} = (5.60 \pm 0.36) \times 10^{-3}$

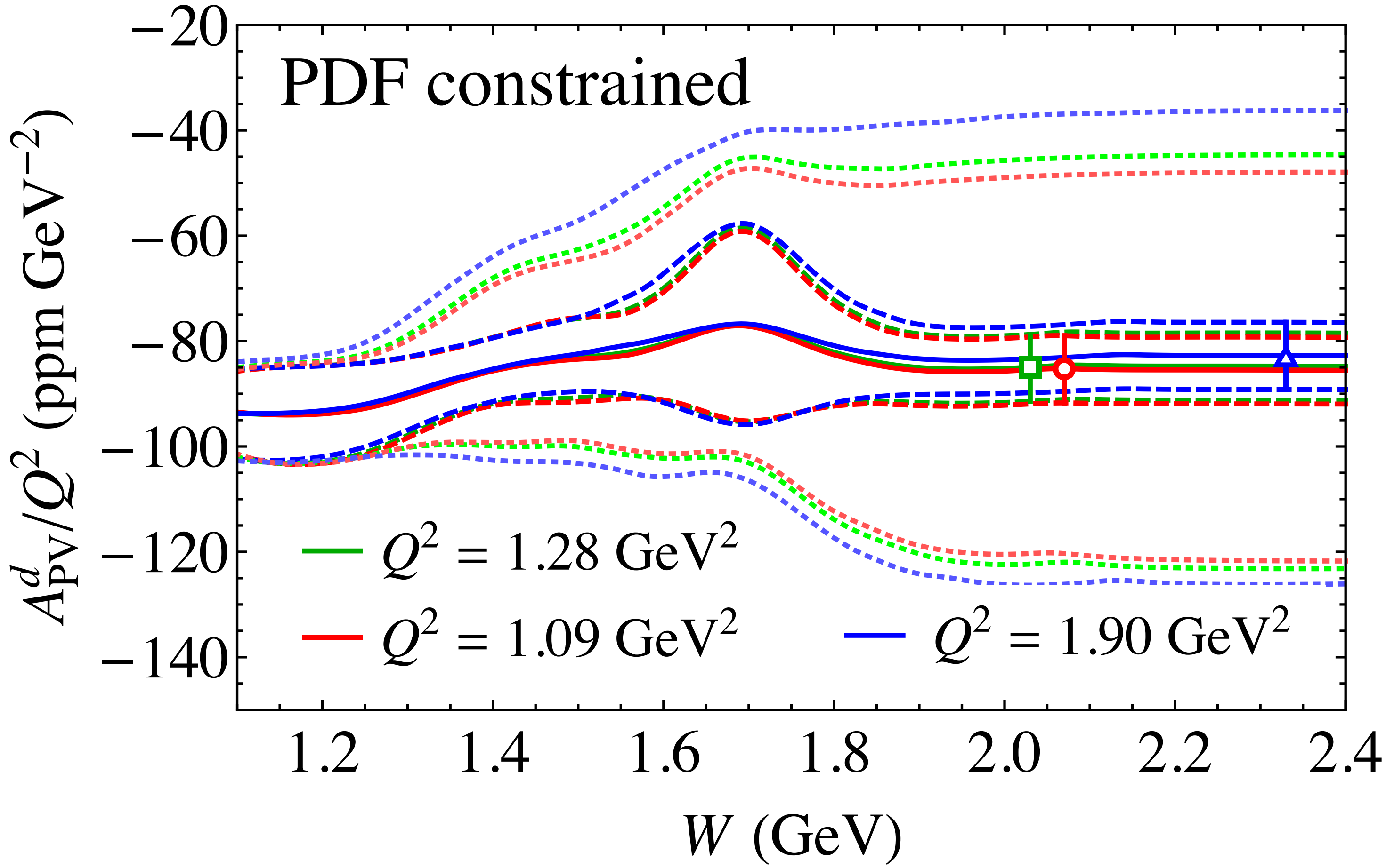
→ ~ 5 times smaller uncertainty *cf.* GHRM

■ Expected inelastic asymmetry from Qweak *



* *R. Carlini, M. Dalton et al.*

Expected inelastic asymmetry from E08-011 *



* *X. Zheng, P. Reimer, R. Michaels*

Summary

- γZ box corrections computed *via* dispersion relations from inclusive γZ interference structure functions

  → new formulation in terms of moments puts on firmer footing earlier estimates within free−quark model

- Axial-vector hadron γZ corrections to APV in $^{133}\mathrm{Cs}$

  → shift relative to MS value for $Q_W(\mathrm{Cs})$ of -0.16%
  ($\Delta \sin^2 \theta_W \approx 4$ x SM uncertainty)

- Significant constraints on vector hadron correction from new "PVDIS" asymmetry data & global PDF fits

  → reduces uncertainty on $\Re e\, \Box^V_{\gamma Z}$ by factor ~ 2.5 − 5

  → additional "PVDIS" data (E08-011, Qweak, SOLID) will further constrain $\Re e\, \Box^V_{\gamma Z}$