Deuteron Spin Structure at low Q^2 from the CLAS EG4 experiment

A. Deur

Jefferson Lab

03/09/2018

K.P. Adhikari *et al.* (CLAS Collaboration),
"Measurement of the Q^2 dependence of the Deuteron Spin Structure Function g_1 and its Moments at Low Q^2 with CLAS"
Phys. Rev. Lett. 120, 062501 (2018)

The EG4 experiment Group

Main goal: measurement of the generalized Gerasimov-Dreall-Hearn (GDH) sum for the proton and deuteron at low Q^2.

E03-006 (NH_3):

Spokespeople: **M. Ripani**, M. Battaglieri, A.D., R. de Vita

Students: H. Kang (Seoul U.), K. Kovacs✦ (UVa)

E06-017 (ND_3)

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Students: K. Adhikari✦ (ODU)

EG4 ran from Feb. to May 2006.

Main goal: inclusive analyses. Also, exclusive analysis by X. Zheng

X. Zheng *et al.* (CLAS Collaboration), PRC 94, 045206 (2016)

✦ Graduated.

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The GDH and Generalized GDH Sum Rules

Sum rule: relation between an integral of a dynamical quantity (cross section, structure function,...) and a global property of the target (mass, spin,...).

Can be used to:

- Test theory (e.g. QCD) and hypotheses with which they are derived. Ex: GDH, Ellis-Jaffe, Bjorken sum rules.
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GDH sum rule: derived for real photons ($Q^2=0$):

fine structure constant

$$\boxed{\int_{\nu_{thr}}^{\infty}\frac{\sigma_A(\nu)-\sigma_P(\nu)}{\nu}d\nu = \frac{-4\pi^2 S\alpha\kappa^2}{M^2}}$$

target anomalous magnetic moment

target spin

target mass

photoprod. cross section with photon spin anti-parallel to S

photon spin anti-parallel to S

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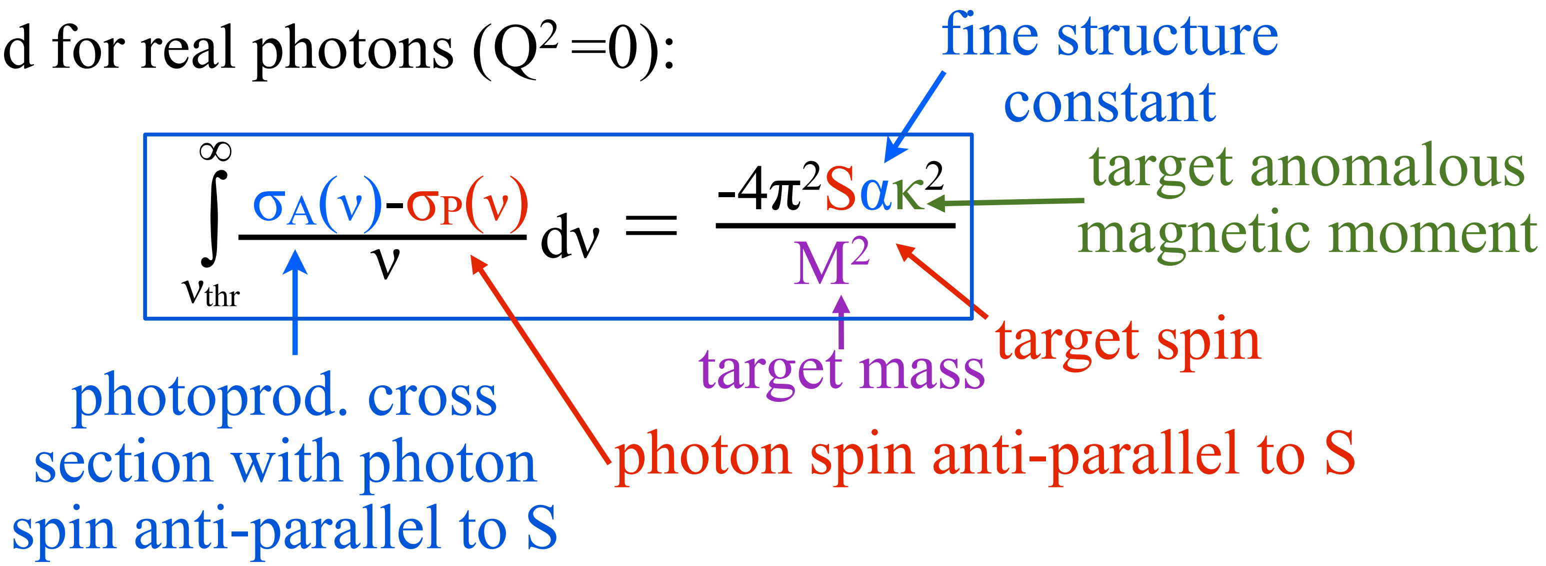

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Generalized GDH sum rule: valid for any Q^2. Recover the original GDH sum rule at $Q^2=0$

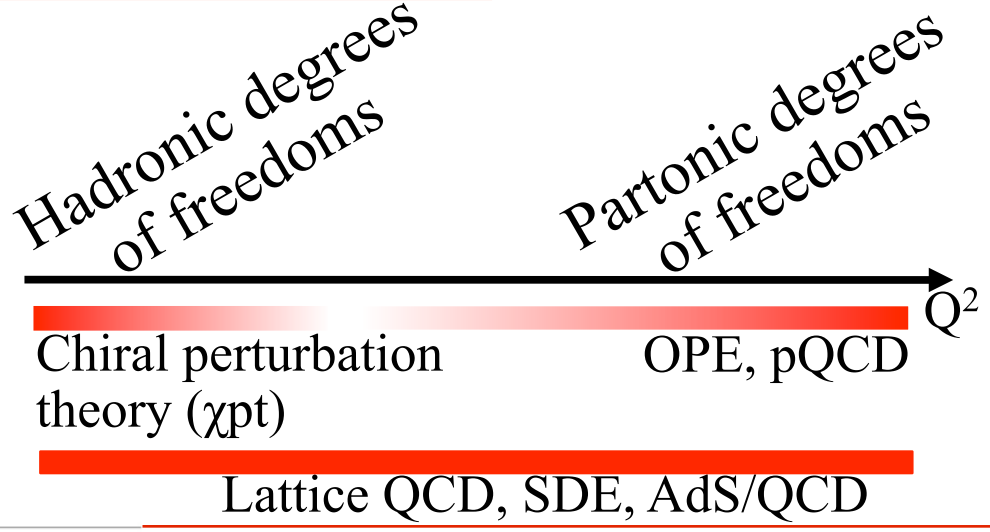
$$\boxed{\Gamma_1(Q^2) = \int_0^{x_{th}} g_1(x,Q^2)dx = \frac{Q^2}{2M^2} I_1(0,Q^2)}$$

$g_1(\nu,Q^2)$: first spin structure function (mostly a longit. target pol. observable)

$I_1(\nu,Q^2)$: first covariant polarized VVCS amplitude

⇒Study QCD at any scale

$I_1(0,Q^2)$:



Hadronic degrees of freedoms

Partonic degrees of freedoms

Chiral perturbation theory (χpt)

OPE, pQCD

Lattice QCD, SDE, AdS/QCD

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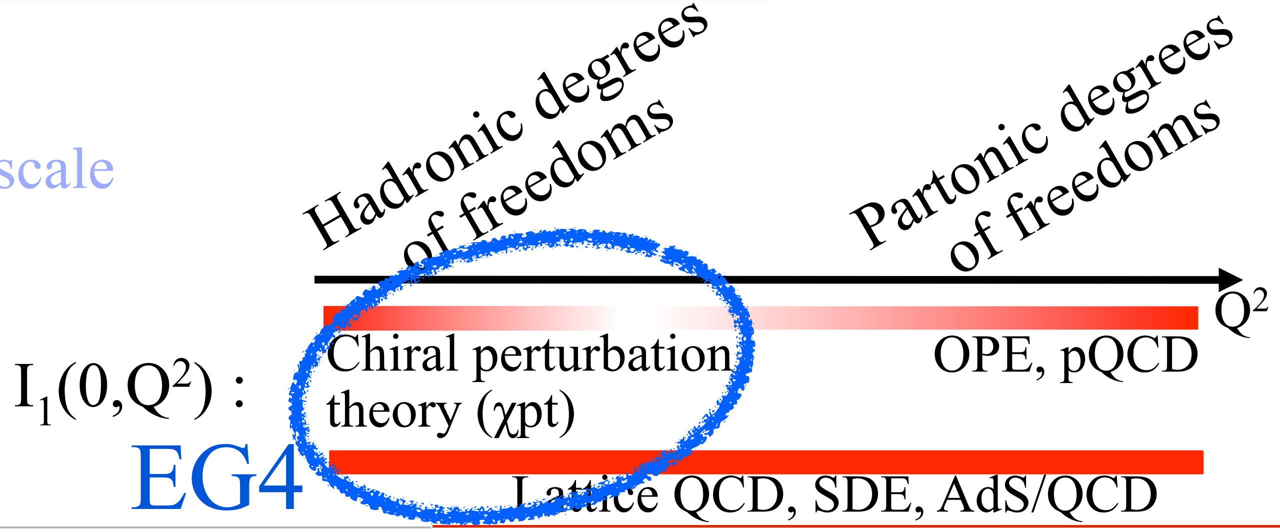

Spin polarizabilities sum rules

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Spin polarizability sum rules involve higher moments:

Generalized forward spin polarizability:

$$\gamma_0 = \frac{4e^2M^2}{\pi Q^6} \int x^2 (g_1 - \frac{4M^2}{Q^2} \; x^2 g_2) dx$$

$g_2(\nu,Q^2)$: second spin structure function (mostly a perp. target pol. observable)

Longitudinal-Transverse polarizability:

$$\delta_{LT} = \frac{4e^2M^2}{\pi Q^6} \int x^2 (g_1 + g_2) dx$$

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$g_2(\nu,Q^2)$ suppressed in γ_0

Longitudinal-Transverse polarizability:

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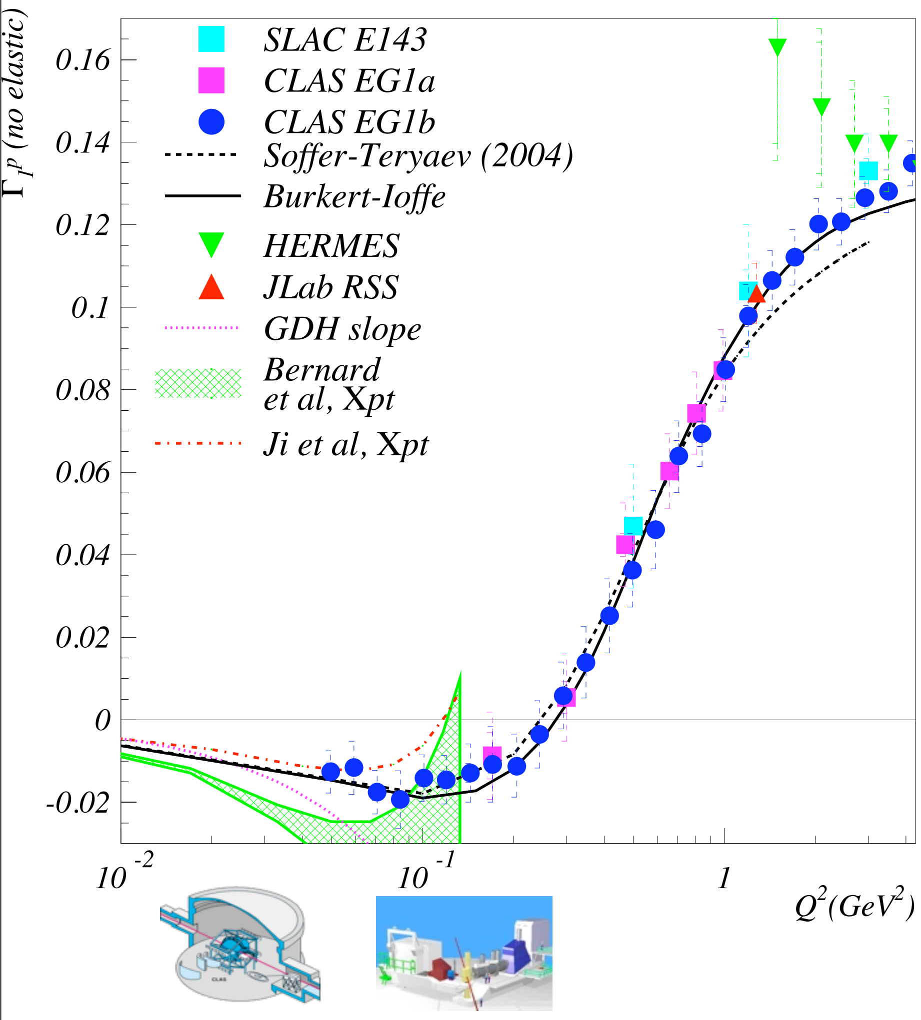
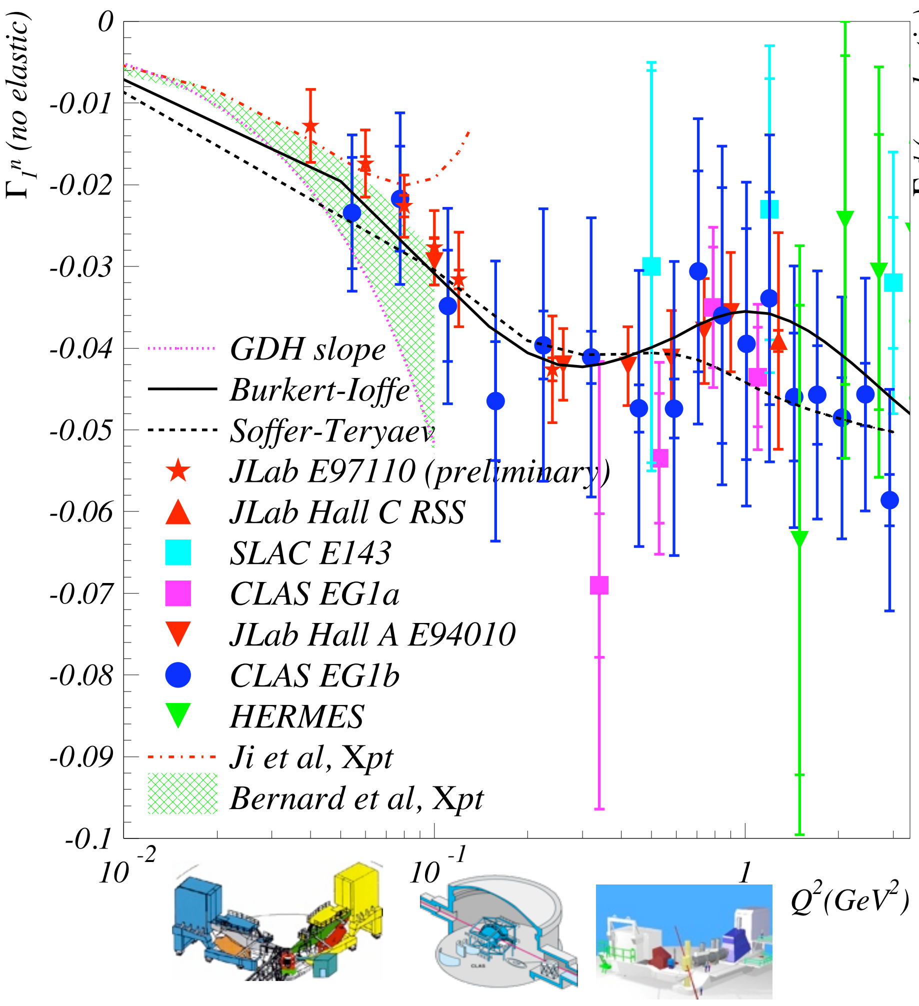
Previous data: high to intermediate Q^2

Before EG4 run (2006):

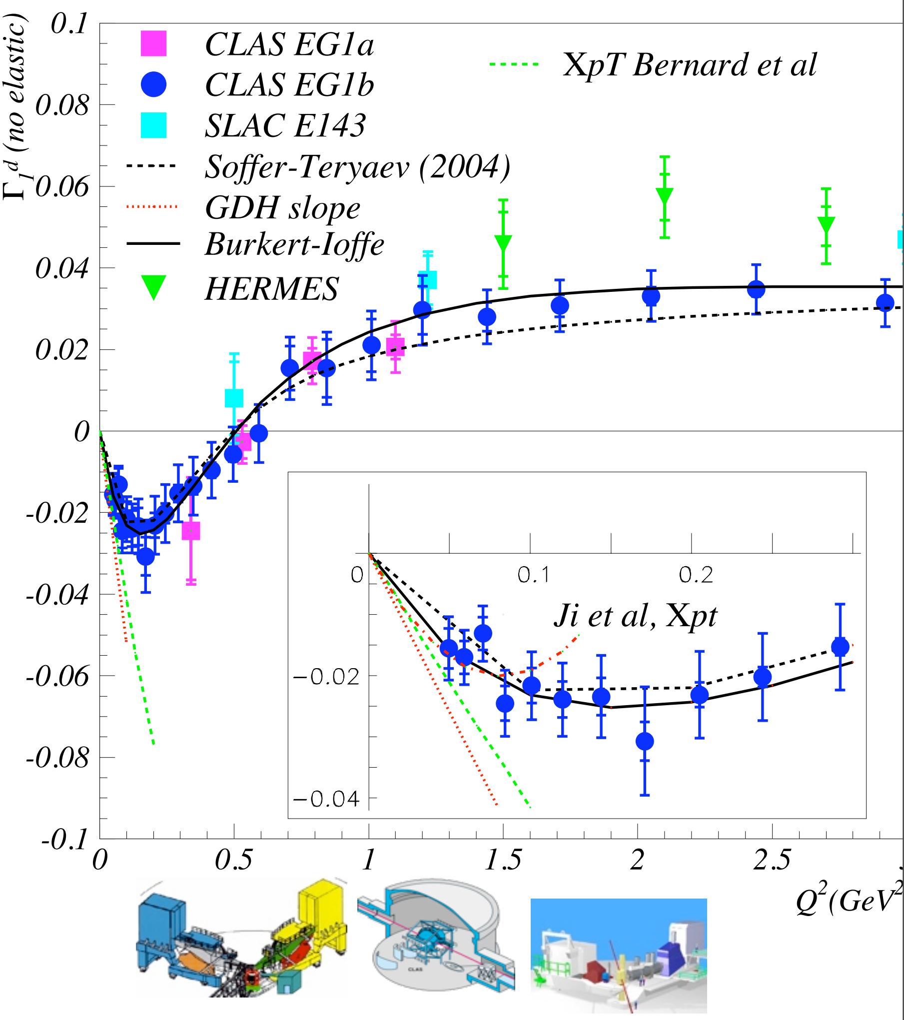
Proton



Neutron



Deuteron



Precise mapping of intermediate Q^2 region for p, n and d.
PQCD, models and data agree.
Not so clear for χpT.

Previous data: high to intermediate Q^2

State of χpT affairs
before EG4 run (2006):

No low-x (γ_0)

No low-x
No Δ (δ_{LT})

No low-x (d_2)

No Δ → P-N

	Γ_1	γ_0	δ_{LT}	d_2
Proton	a^{exp}=4.31±0.31±1.36 a^{Ji}=3.89 Up to Q^2~0.08 GeV^2	🟥	*No low Q^2 data*	*No low Q^2 data*
Neutron	🟨	Up to Q^2~0.1 GeV^2 (Bernard *et al.* only)	"δ_{LT} crisis"	🟥
P-N	a^{exp}=0.80±0.07±0.23 a^{Ji}=0.74, $a^{B.}$=2.4 Up to Q^2~0..3 GeV^2	🟥	*No low Q^2 data*	*No low Q^2 data*
P+N	a^{exp}=6.97±0.96±1.48 a^{Ji}=7.11 Up to Q^2~0.1 GeV^2	🟥	*No low Q^2 data*	*No low Q^2 data*

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⇒Need new data on p and n (d+^{3}He) at very low Q^2 (i.e. for sums, low angles).

Purpose of EG4.

Previous data: high to intermediate Q^2

Up to date state of χpT affairs (2018):

~no low-x

Ref.	Γ_1^p	Γ_1^n	$\boldsymbol{\Gamma_1^{p-n}}$	Γ_1^{p+n}	γ_0^p	γ_0^n	$\boldsymbol{\gamma_0^{p-n}}$	γ_0^{p+n}	$\boldsymbol{\delta_{LT}^n}$	d_2^n
Ji et al. 1999	X	X	A	X	-	-	-	-	-	-
Bernard et al. 2002	X	X	A	X	X	A	X	X	X	X
Kao et al. 2002	-	-	-	-	X	A	X	X	X	X
Bernard et al. 2012	X	X	A	X	X	A	X	X	X	-
Lensky et al. 2014	X	A	A	A	A	X	X	X	∼ A	A

Δ suppressed

Δ suppressed

Δ suppressed
“δ_{LT} crisis”

A: agree with data

X: disagree with data

-: no calculation available

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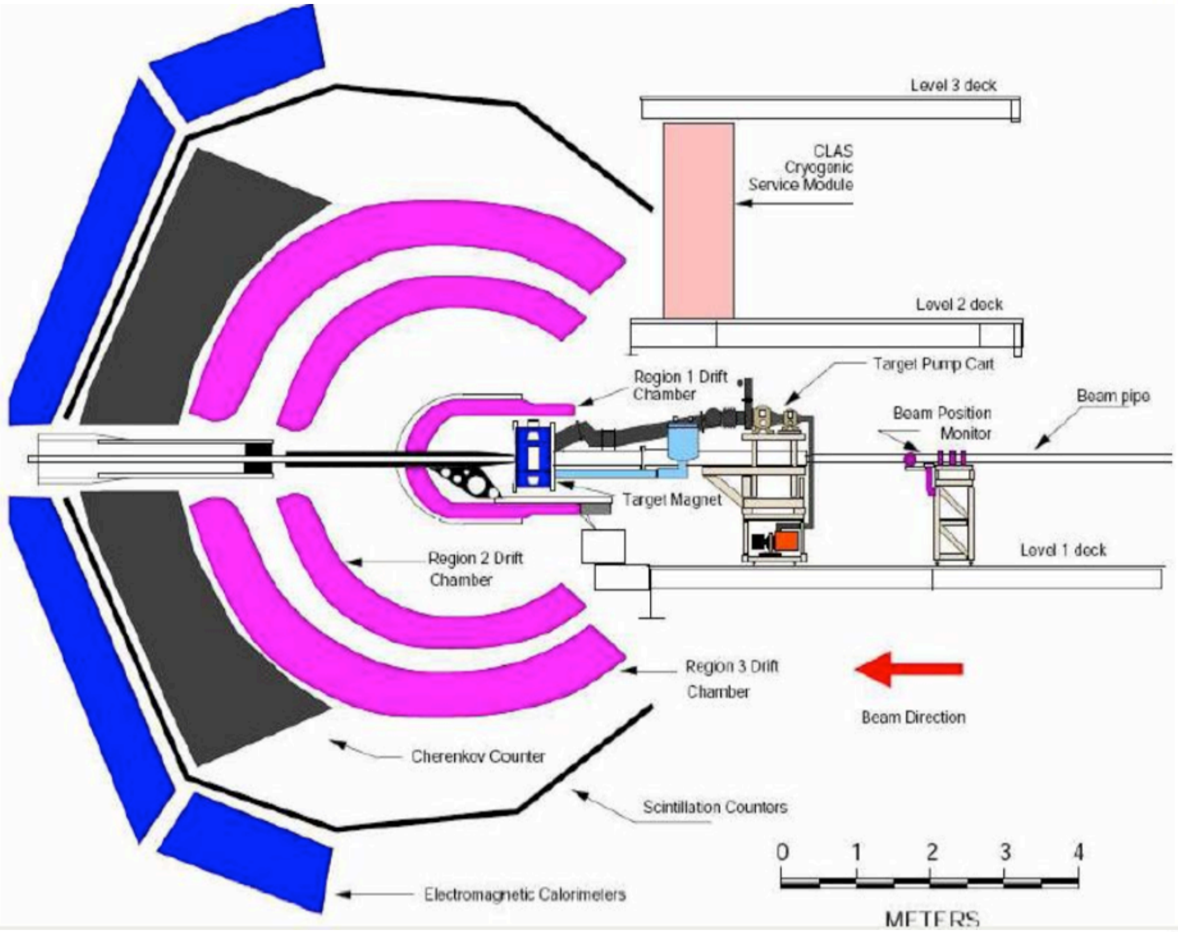
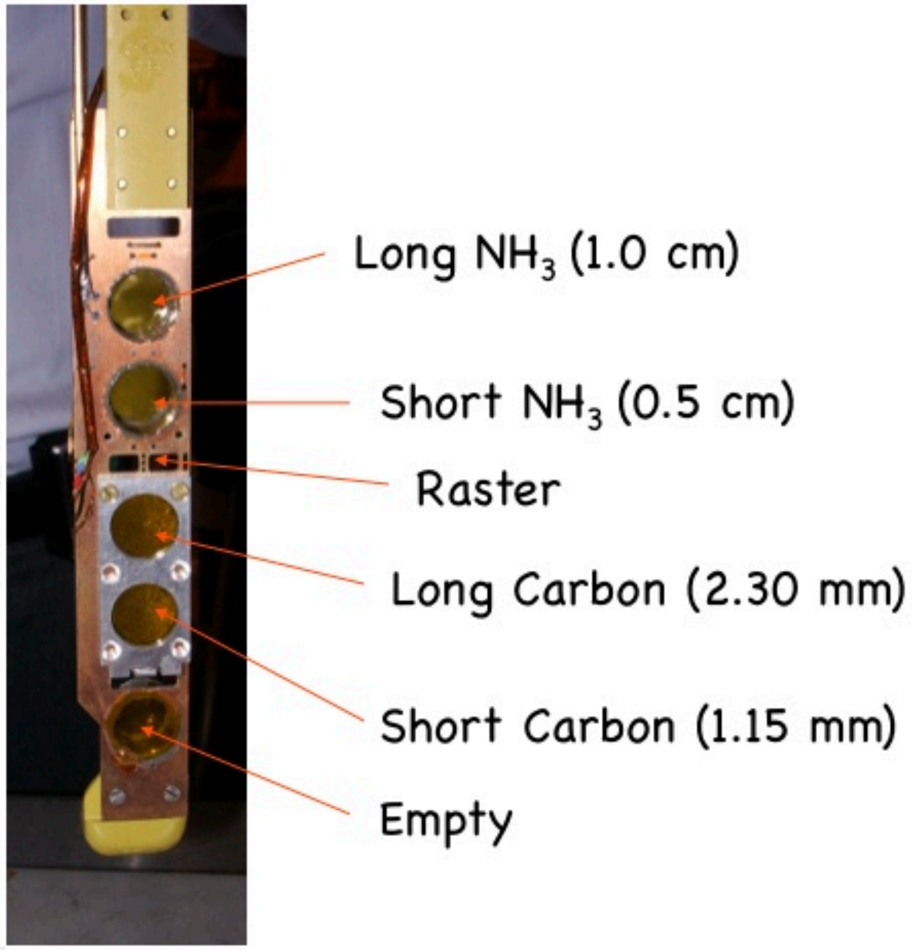
EG4 setup

- Q^2>0: electron beam (polarized). Energies: 3.0, 2.3, **2.0, 1.3** & 1.0 GeV
- $g_1^{p,n}$: ~longitudinally polarized target

DNP NH_3 and ND_3 target:





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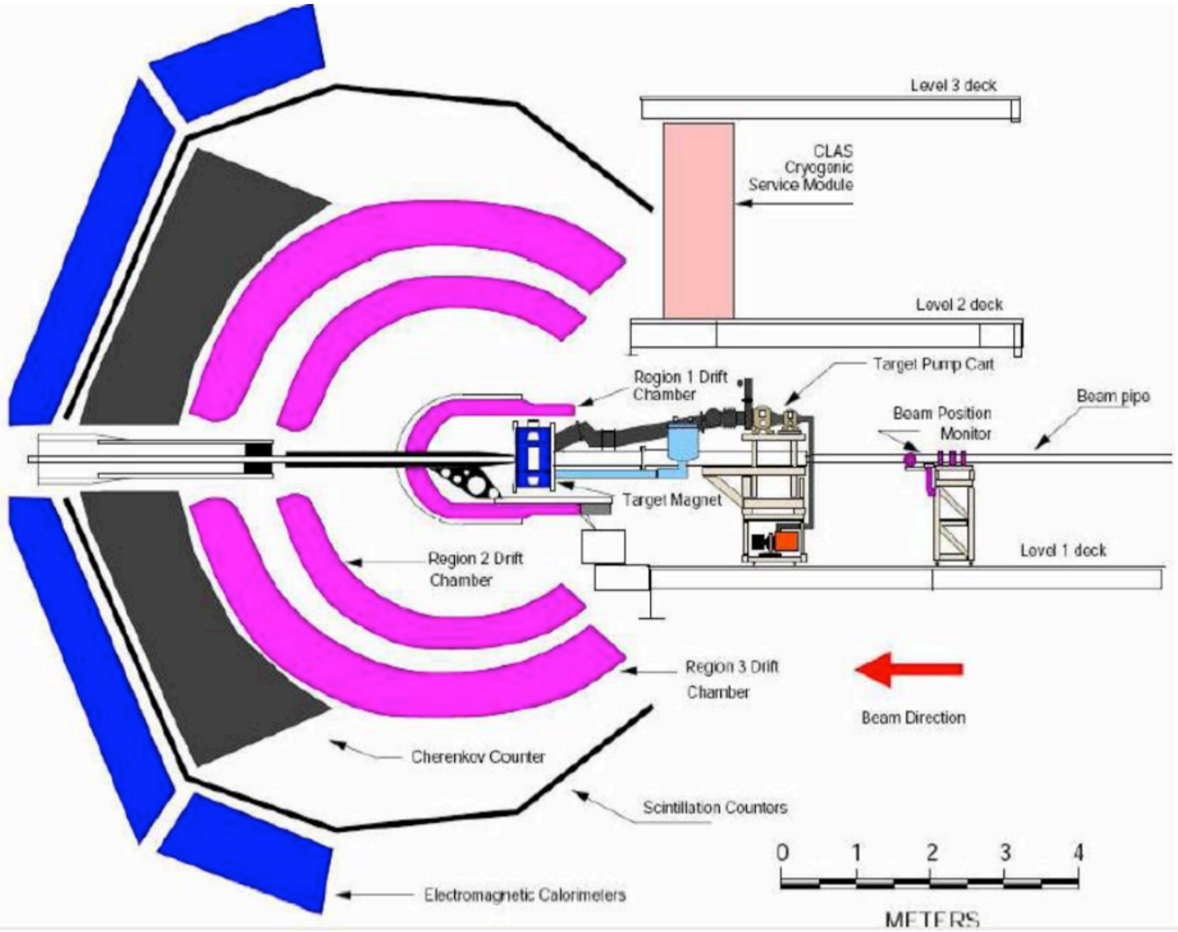
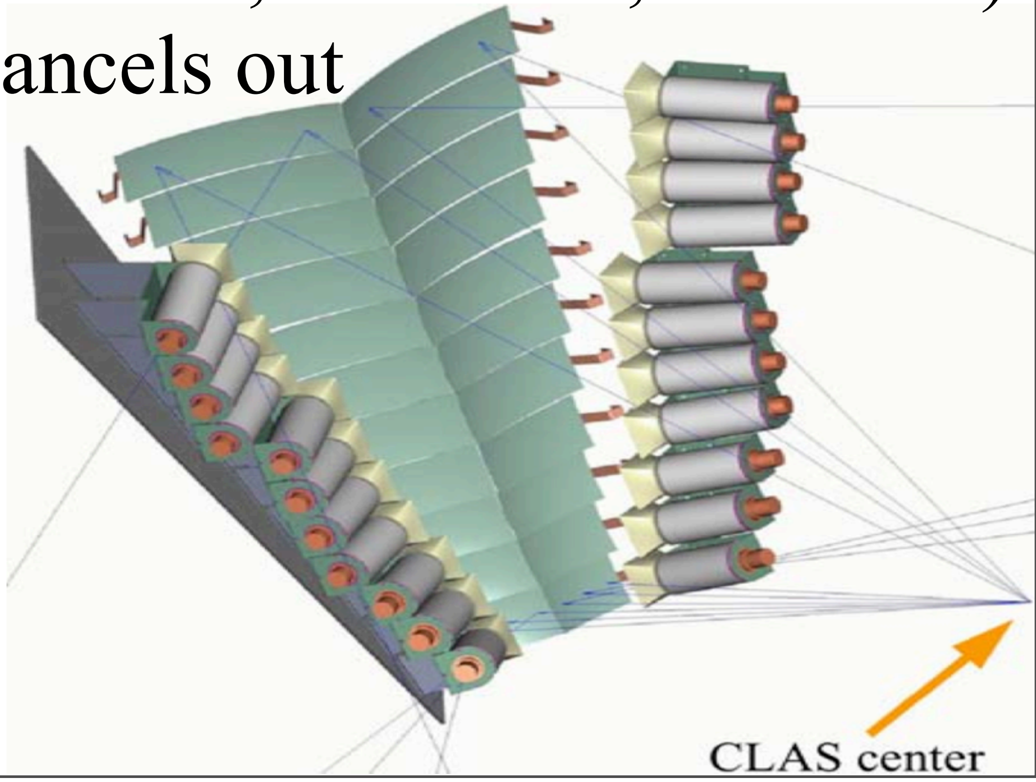


- g_1 from pol. cross-section differences (not asymmetries, as in EG1, EG1dvcs)

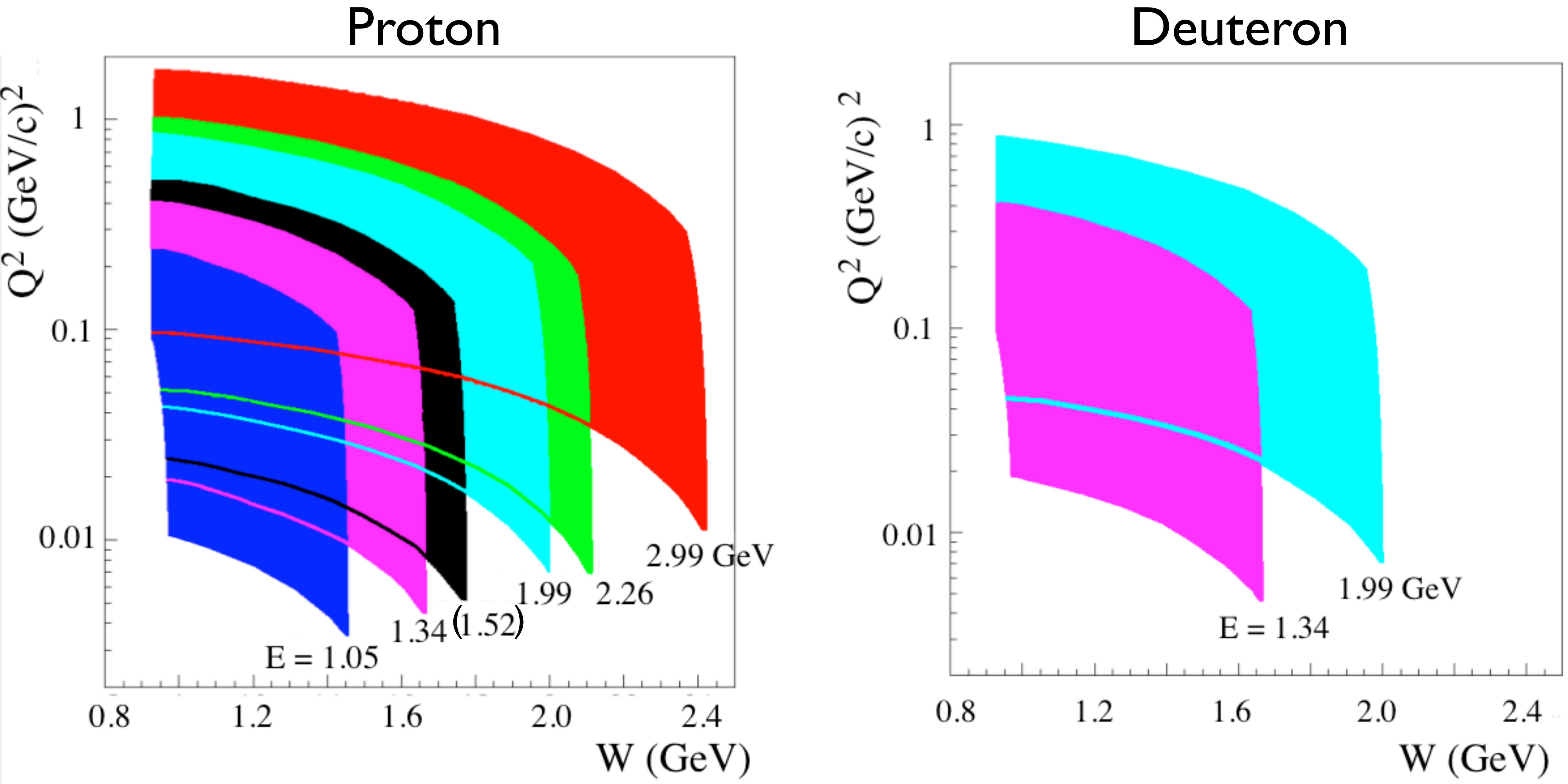
Advantage: dilution from unpol. target material cancels out

- Small angles: outbending torus field, new Möller shield; target at -1m

- Cross-section ⇒ controlled (i.e high) efficiency at small angles. New Cerenkov detector (INFN). Installed in sector 6. Cover down to 6°



EG4 kinematic coverage

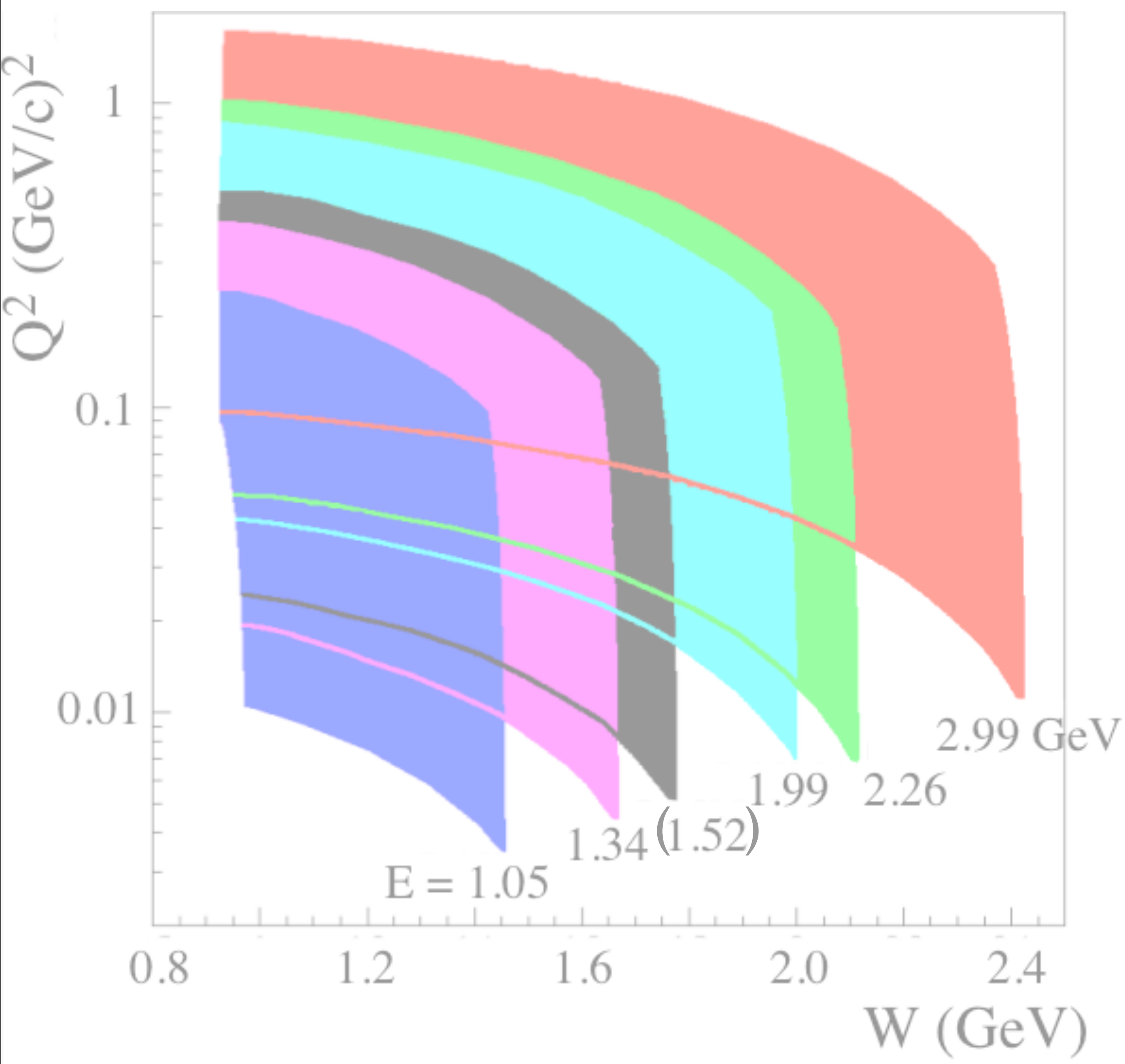


Proton

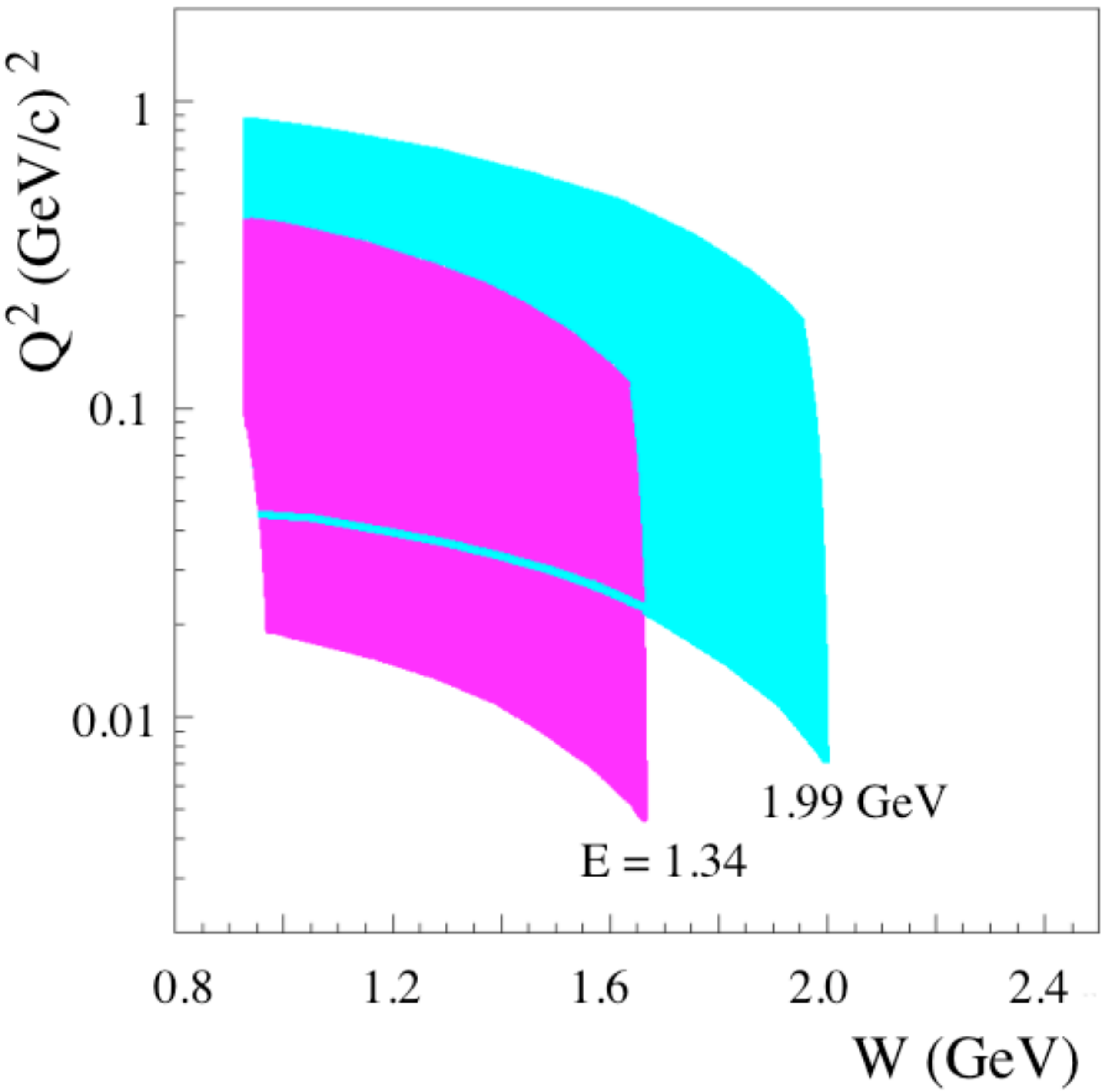
Deuteron

EG4 kinematic coverage

Proton

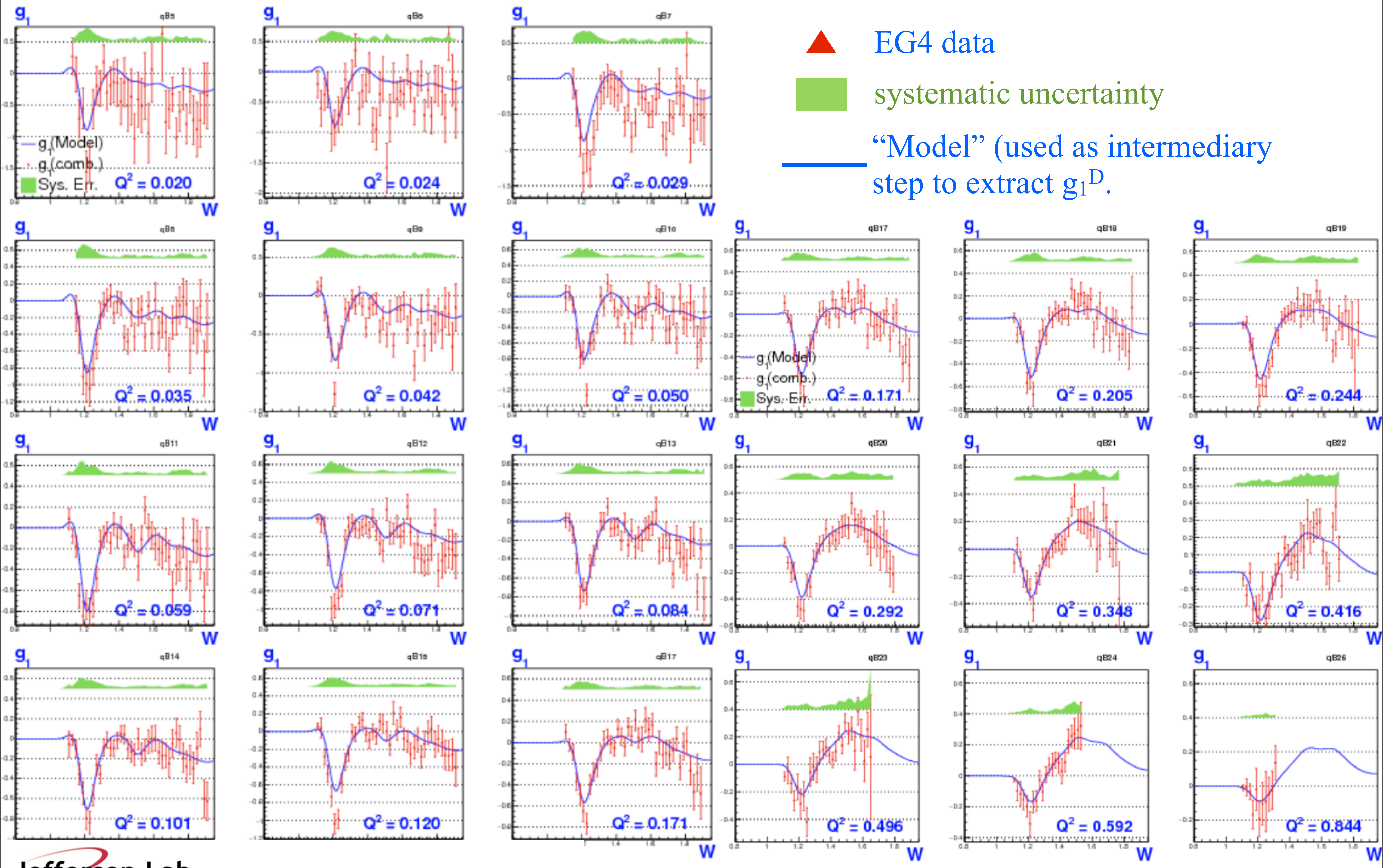


Deuteron



g_1^D from EG4 polarized cross-section difference

K. Adhikari, S. Kuhn



▲ EG4 data

🟩 systematic uncertainty

— "Model" (used as intermediary step to extract g_1^D.

g_1^D from EG4 polarized cross-section difference

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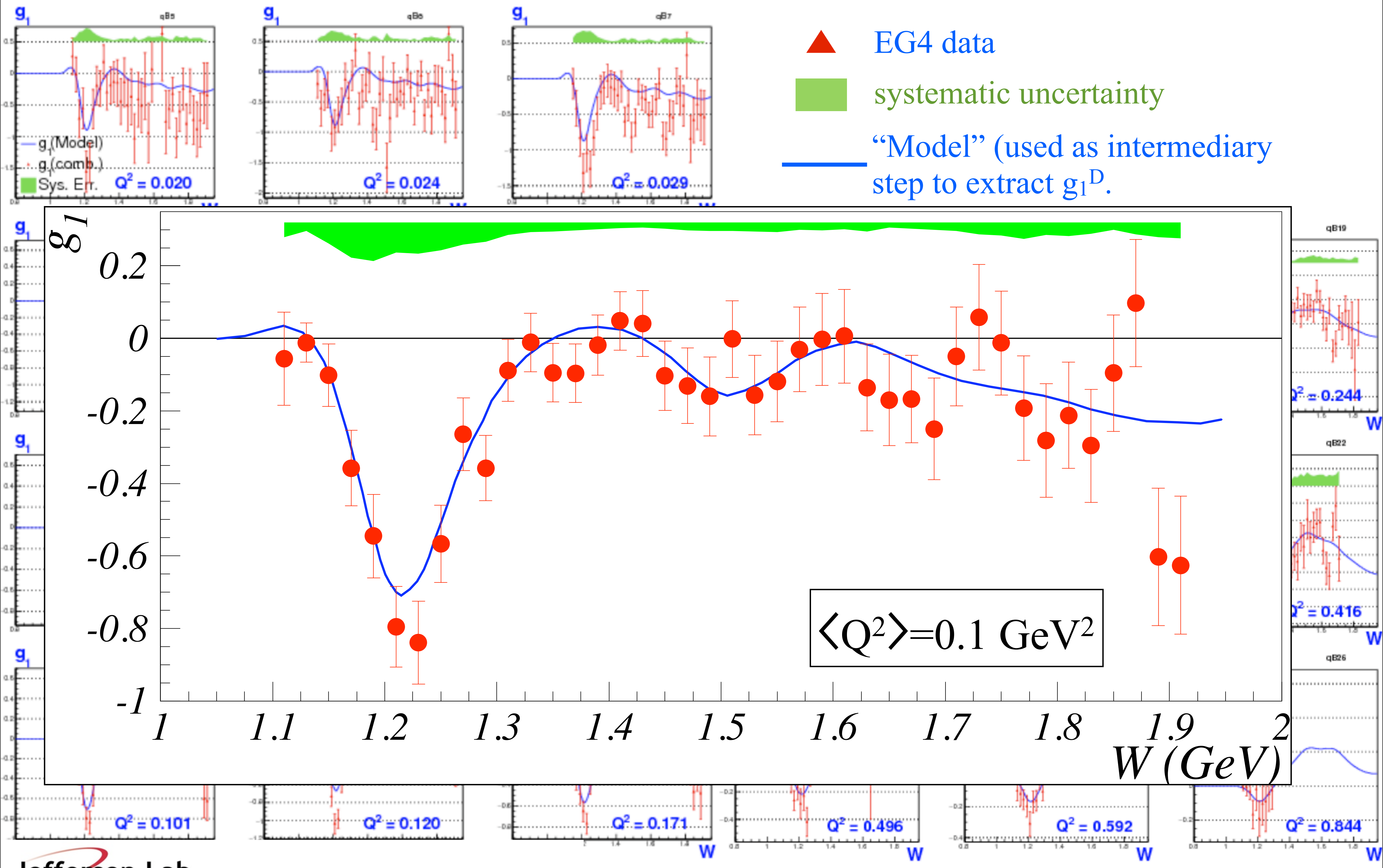

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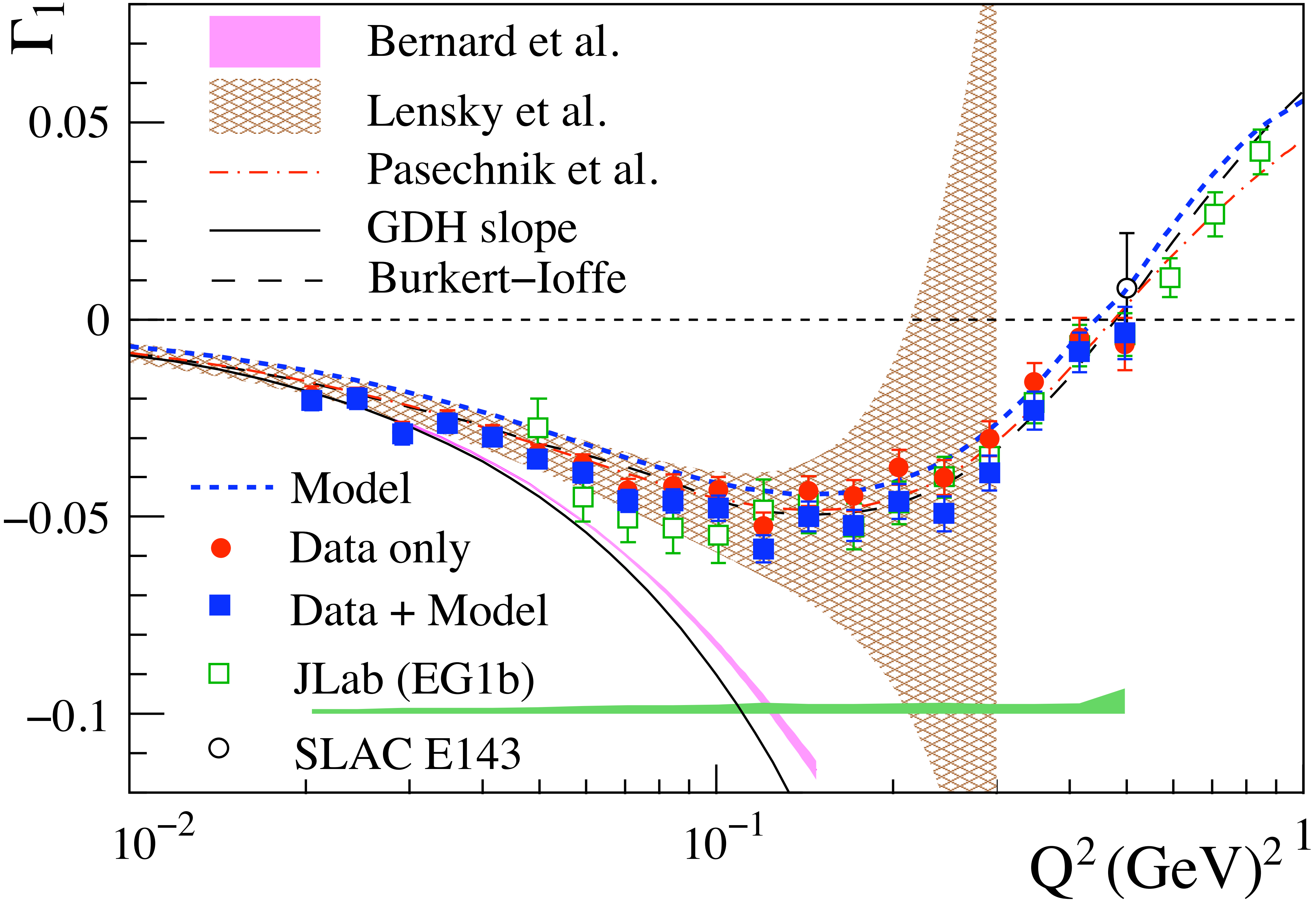
$\Gamma_1^D = \int g_1^D(x,Q^2)dx$

K. Adhikari, S. Kuhn

K.P. Adhikari *et al.* (CLAS Collaboration). PRL 120, 062501 (2018)



- Lowest Q^2 decreased by factor of ~2.5
- Much improved precision
- Small unmeasured low-x and large-x contributions

⇒Clean test of χpt

$\Gamma_1^D = \int g_1^D(x,Q^2)dx$

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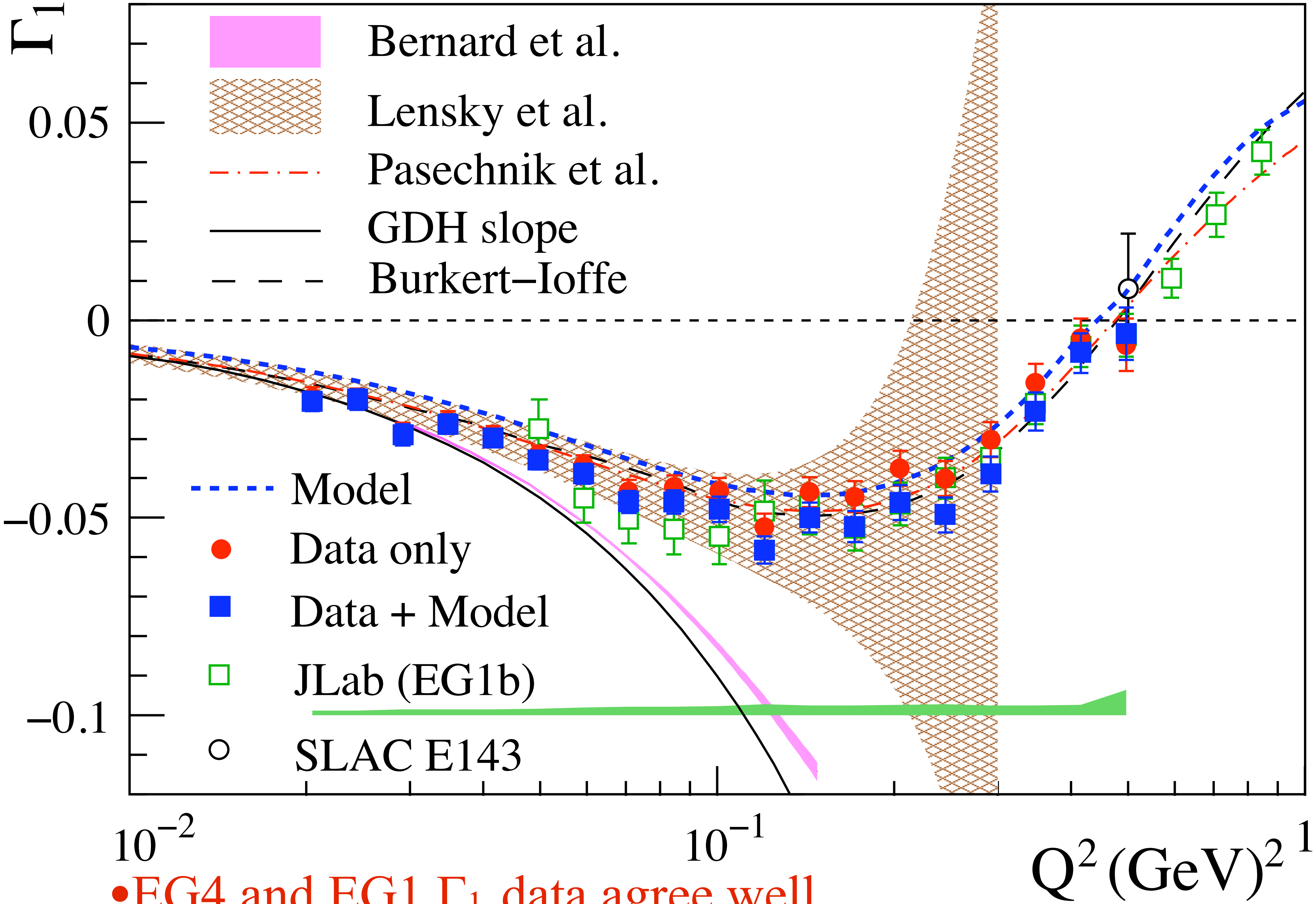
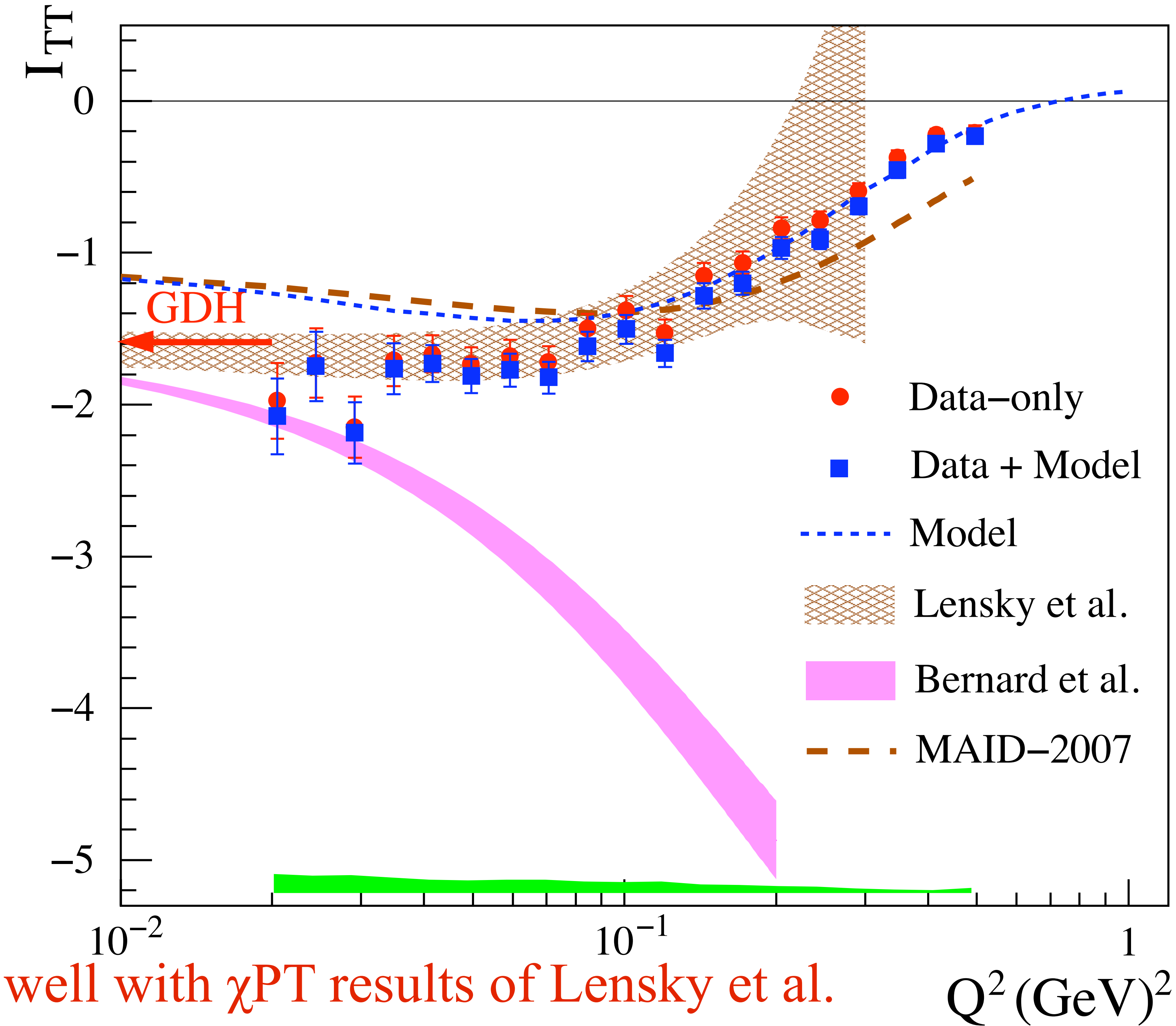


- •EG4 and EG1 Γ_1 data agree well.
- •EG4 data agree well with χPT results of Lensky et al.
- •Bernard et al. χPT calculation agrees only for the lowest Q^2 points.
- •Phenomenological models (Pasechnik et al, Burkert-Ioffe) agree well.

Generalized GDH sum $I_{TT} = \int \frac{\sigma_A(\nu)-\sigma_P(\nu)}{\nu} d\nu$



- Data agree well with χPT results of Lensky et al.
- Bernard et al. χPT calculation does not agree as well.
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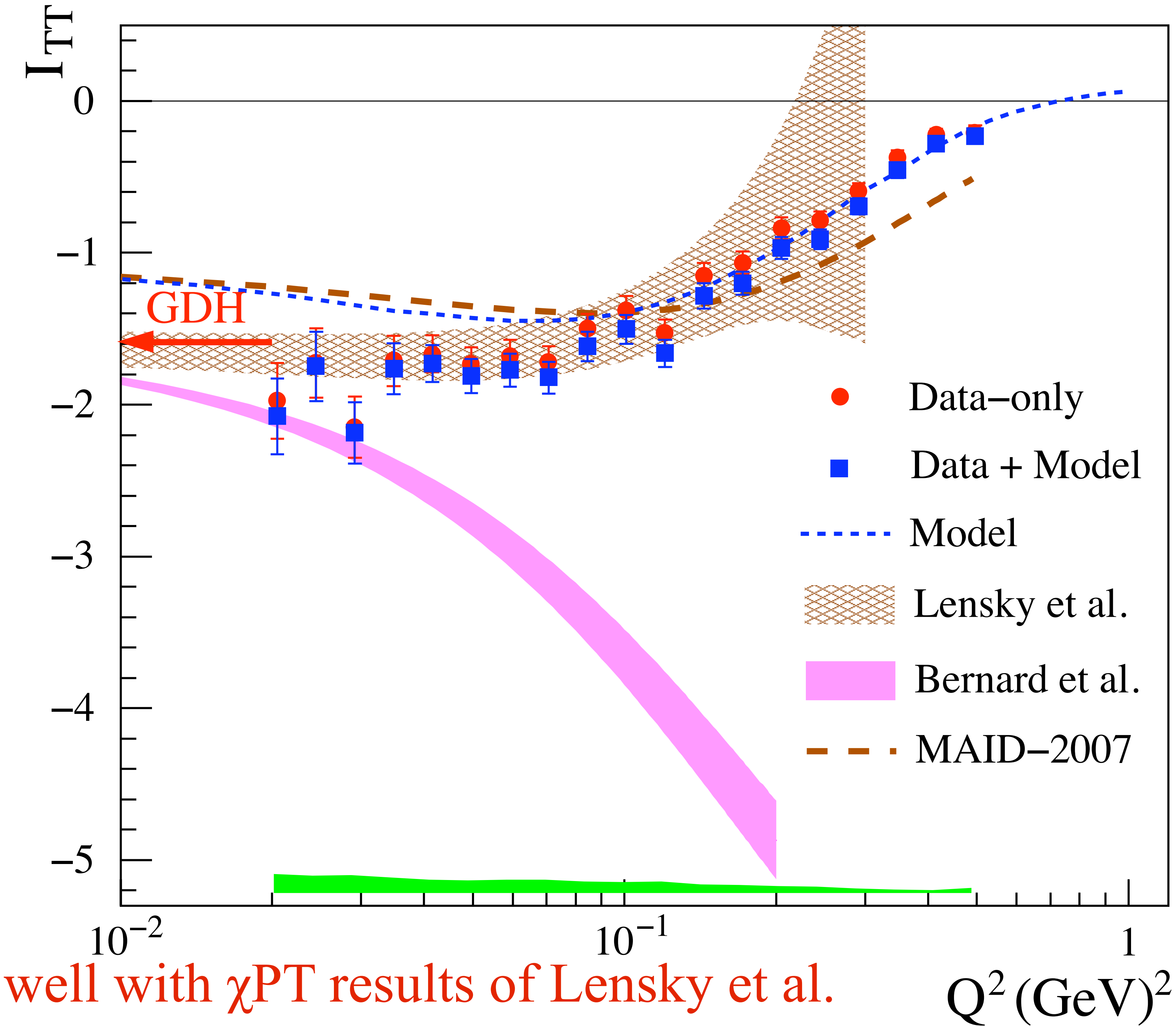

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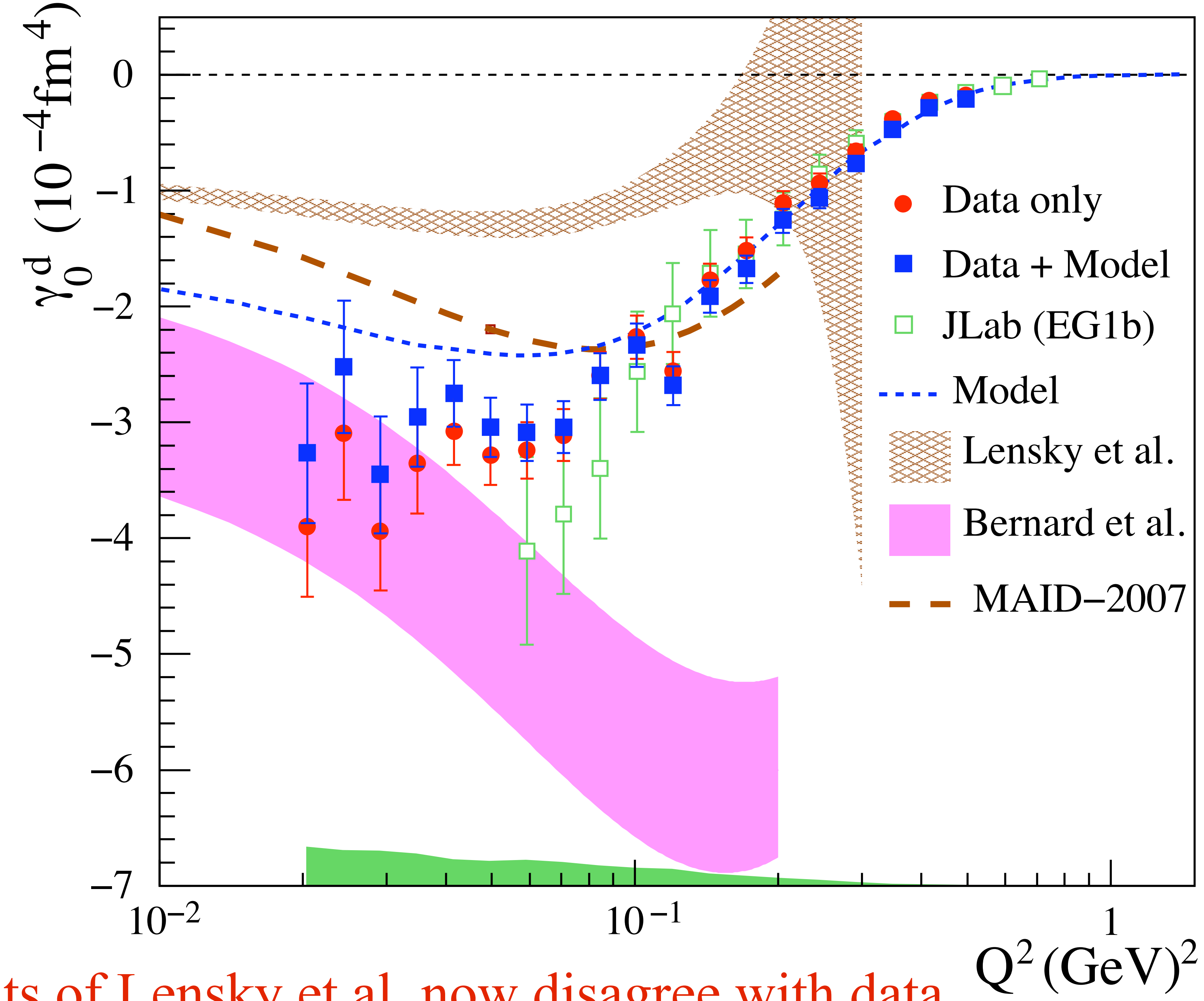
- Extrapolation to Q^2=0 tests original GDH sum rule:

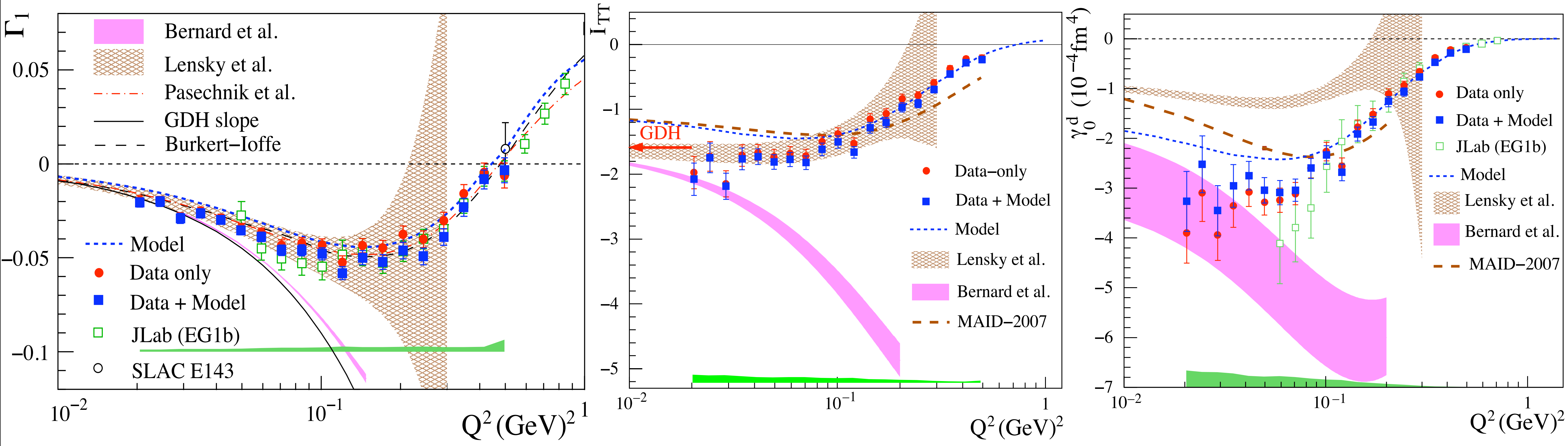
$I_{TT}^d = -1.724 \pm 0.027(\text{stat}) \pm 0.050(\text{syst})$
Sum rule expectation: −1.574±0.026
$I_{TT}^n = -0.955 \pm 0.040(\text{stat}) \pm 0.113(\text{syst})$
Sum rule expectation: −0.803

Higher moment γ_0^D



- χPT results of Lensky et al. now disagree with data.
- Bernard et al. χPT calculation agree for lowest Q^2 points only.
- Maid model disagrees at low Q^2.

Conclusion



No χPT single method describes well both Γ_1, I_{TT}, and γ_0, except at the lowest Q^2.

A satisfactory theoretical description of spin observables at low Q^2 remains challenging.

Summary and perspectives

- EG4: Low Q^2 measurement using polarized e^- on polarized p and d, over a large x-range in order to study spin sum rules.
- New detector necessary to reach these kinematics.
- Main goal: unambiguous test of χPT.
- Doubly polarized inclusive cross-section analysis.
- Exclusive data for π^+ and π^- spin-dep. electroprod. on p published in 2016 (asym. analysis).

X. Zheng *et al.* (CLAS Collaboration), PRC 94, 045206 (2016)

- Inclusive analysis on d just published.

K.P. Adhikari *et al.* (CLAS Collaboration). PRL 120, 062501 (2018)

- Data on Γ_1, I_{TT}, and γ_0 for the deuteron shows that χPT has mixed success, depending on the χPT method and observable.
- Original GDH sum rule (Q^2=0) checked on d and n.
- First result of larger JLab program to measure benchmark spin observables for χPT

$\Rightarrow$More low Q^2 data to come:

  - g_1, Γ_1, I_{TT}, and γ_0 for the proton (CLAS EG4). Late 2018, early 2019.
  - g_1, g_2, Γ_1, Γ_2, I_{TT}, γ_0 and δ_{LT} for the neutron and ^{3}He (Hall A E97110). Soon.
  - g_2, g_1, Γ_2, Γ_1, I_{TT}, δ_{LT} and γ_0 for the proton (Hall A E08027). Soon.

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x_{th} ... Q^2

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χpt: low energy effective theory of QCD obtained using a Lagrangian consistent with QCD's chiral symmetry (neglecting quark masses).
Captures the main essence of QCD at low Q^2, without the complicated details.
Systematic perturbative expansion valid for e.g. $Q \ll m_\pi$.