On the duality in neutrino-nucleon interactions

“Neutrino Physics at Accelerators”
DLNP, JINR, January 23, 2008

Oleg Teryaev
BLTP, JINR

Outline

- Borel sum rules and Bloom-Gilman duality in QCD
- Bloom-Gilman duality in QCD: for which structure it holds better?
- Perturbative-Non-perturbative “duality”: HT vs APT
- Example from PC spin-dependent DIS: GDH and Bjorken sum rules and duality
- Conclusions

Structure functions

- General expression
- 1,2 – also in PC
- 3 – V-A interference

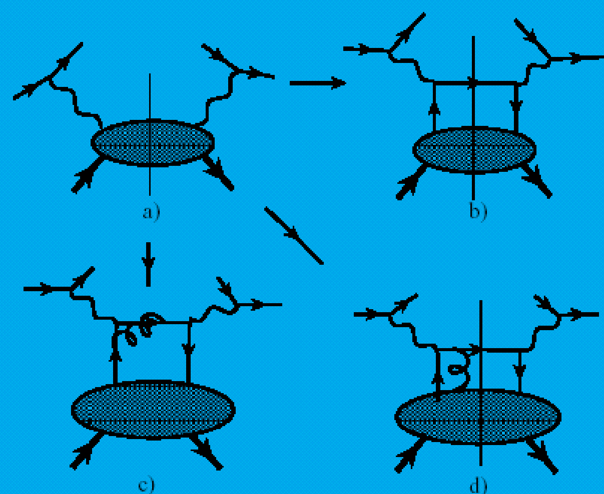
$$W_{\mu\nu}(p,q) = -g_{\mu\nu}W_1(\nu,q^2) + \frac{p_\mu p_\nu}{M^2}W_2(\nu,q^2)$$
$$-i\epsilon_{\mu\nu\alpha\beta}\frac{p^\alpha q^\beta}{2M^2}W_3(\nu,q^2) + \frac{q_\mu q_\nu}{M^2}W_4(\nu,q^2)$$
$$+\frac{p_\mu q_\nu + q_\mu p_\nu}{2M^2}W_5(\nu,q^2).$$

- 4,5 – non-transverse in q - direct signature of axial current, suppressed by lepton masses. But – essential contribution to heavy lepton polarization.

Bloom-Gilman duality in QCD and Borel Sum Rules

- Methods of QCD SR

1. Calculate (handbag+higher twists) contribution to DIS



2. Write the (Borel) dispersion relation (with respect to $s = Q^2/(1-x)$, which is a natural scale of higher twists)

- Only 1/(1-x) - enhanced (dependent on s, rather than Q) higher twist corrections should be considered (Gardi, Kortchemsky,Ross,Tafat)

Bloom-Gilman duality in QCD and Borel Sum Rules -II

3. Take the ansatz for spectral functions which includes RESONANCE contribution below the threshold defined by DUALITY interval and leading perturbative one above that threshold.

$$\rho(s) = \theta(s - s_0)\rho^{pert}(s) + \theta(s_0 - s)\rho^{Res}(s) \qquad (1)$$

4. Put Borel parameter $M \to \infty$ (higher twists corrections disappear) and assume the finite limit of duality interval $\to$ BG duality.

Determination of the duality interval from QCD - requires the power corrections calculation.

BG duality in QCD -III

- The resulting QCD SR:

$$\int_{s_{\min}}^{s_0} ds(\rho^{\text{pert}}(s) - \rho^{\text{Res}}(s)) = 0$$

- Separation between Resonance and DIS contribution – upper bound for Resonance and lower for DIS - the same!
- Depends on the structure function

Longitudinal vs transverse polarization

- Longitudinal – more simple :
- i) kinematically – enhanced by Lorentz boost (massless particle= definite helicity)
- ii) in helicity formalism (transverse = interference)
- BUT! For invariant amplitudes vice versa: important for duality.

“Duality” between pQCd and NPQCD

- Border between pQCD and NPQCD – matter of convention
- Possibility to shidt HT to N...NLO (Kataev,Parente,Sidorov; talk of S. Alekhin)
- Modified QCD couplings (APT, Freesing...) – what are HTs?

Case study - Spin dependent DIS

- Two invariant tensors

$$W_A^{\mu\nu} = \frac{-i\epsilon^{\mu\nu\alpha\beta}}{pq} q_\beta (g_1(x,Q^2) s_\alpha + g_2(x,Q^2)(s_\alpha - p_\alpha \frac{sq}{pq})) =$$
$$\frac{-i\epsilon^{\mu\nu\alpha\beta}}{pq} q_\beta ((g_1(x,Q^2) + g_2(x,Q^2)) s_\alpha - g_2(x,Q^2) p_\alpha \frac{sq}{pq})$$

- Only the one proportional to $g_T = g_1 + g_2$ contributes for transverse (appears in Born approximation of PT)
- Both contribute for longitudinal
- Apperance of g_1 only for longitudinal case –result of the definition for coefficients to match the helicity formalism

Generalized GDH sum rule

- Define the integral – scales asymptotically as $\frac{1}{Q^2}$

$$I_1(Q^2) = \frac{2M^2}{Q^2}\Gamma_1(Q^2) \equiv \frac{2M^2}{Q^2}\int_0^1 g_1(x,Q^2)dx\ .$$

- At real photon limit (elastic contribution subtracted) – $\frac{1}{Q^2}+\frac{1}{Q^4}+\ldots$ - Gerasimov-Drell-Hearn SR

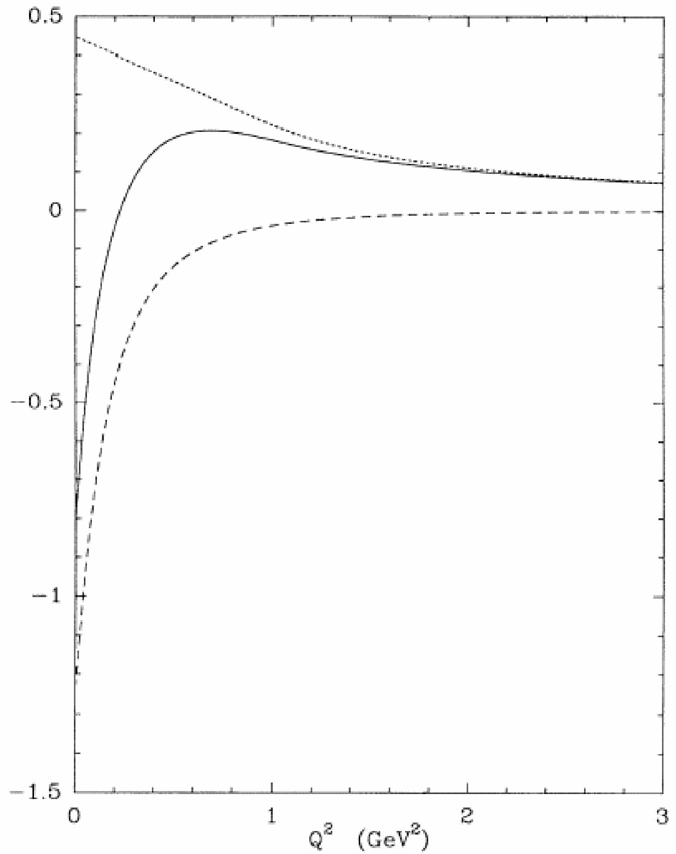
$$I_1(0) = -\frac{\mu_A^2}{4}$$

- Proton- dramatic sign change at low Q!

Decomposition of $g_1 = g_T - g_2$ (J. Soffer, OT '92)

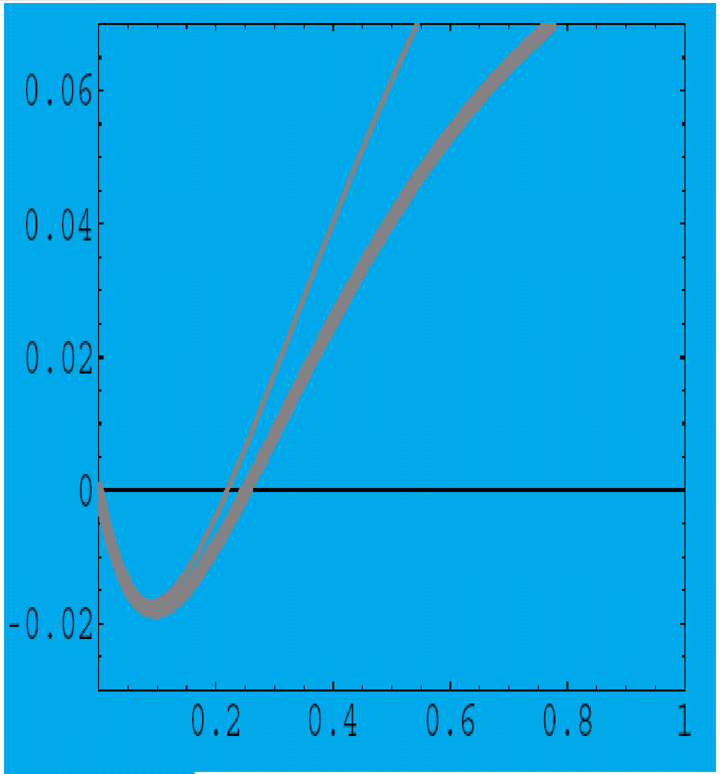
- Inspired by the fact that
  $$I_T(0) = +\frac{\mu_A}{4}$$
- Linear in μ_A, quadratic term from g_2
- Natural candidate for NP (like QCD SR!) analysis – hope to get low energy theorem via WI (C.f. pion F.F. – Radyushkin) - smooth model
- For g_2 -strong Q – dependence due to Burkhardt-Cottingham SR

$$I_2(Q^2) = \frac{1}{4}\,\mu G_M(Q^2)[\mu G_M(Q^2) - G_E(Q^2)]$$



Models for g_T :proton

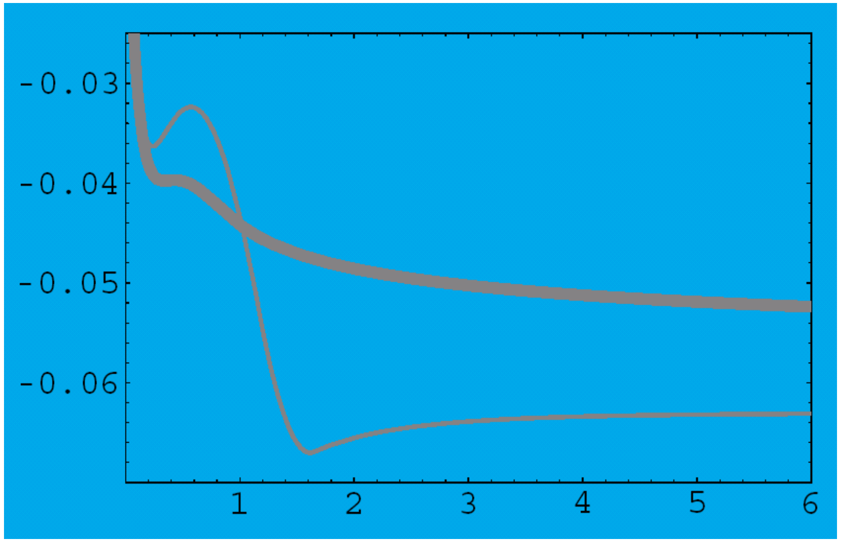
- Simplest - linear extrapolation – PREDICTION (10 years prior to the data) of low (0.2 GeV) crossing point
- Accurate JLAB data – require model account for PQCD/HT correction – matching of chiral and HT expansion
- HT – values predicted from QCD SR (Balitsky, Braun, Kolesnichenko)
- Rather close to the data, like the resonance approach of Burkert and Ioffe (the latter similarity to be discussed below)

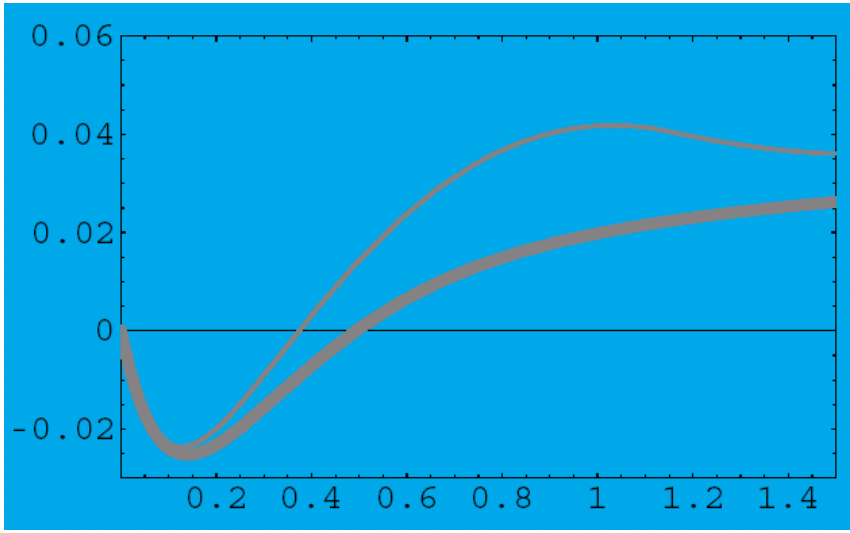


$\Gamma_1(Q^2)$ For Proton

Models for g_T :neutron and deuteron

- Access to the neutron – via the (p-n) difference – linear in μ_A
- Deuteron – refining the model eliminates the structure





$\Gamma_1(Q^2)$ for neutron and deuteron

Duality for GDH – resonance approach

- Textbook (Ioffe, Lipatov. Khoze) explanation of proton GGDH structure – contribution of $\Delta(1232)$ dominant magnetic transition form factor
- Is it compatible with g_2 explanation?!
- Yes!– magnetic transition contributes entirely to g_2 and as a result to $g_1 = g_T - g_2$

$\Delta(1232)$ and Bloom-Gilman duality

- Observation (Ricco et al): $\Delta(1232)$ violates BG duality for g_1
- Natural explanation : $\Delta(1232)$ contributes only via g_2
- For g_2 BG duality is difficult to reach: due to BCSR elastic contribution should compensate all the integral from 0 to 1 (global duality enforced by rotational invariance) – O.T. (2005)
- g_T -natural candidate for BG duality

(Pol) Bjorken SR at low Q

- The same decomposition –

- Smooth interpolation of g1 – possible but wrong

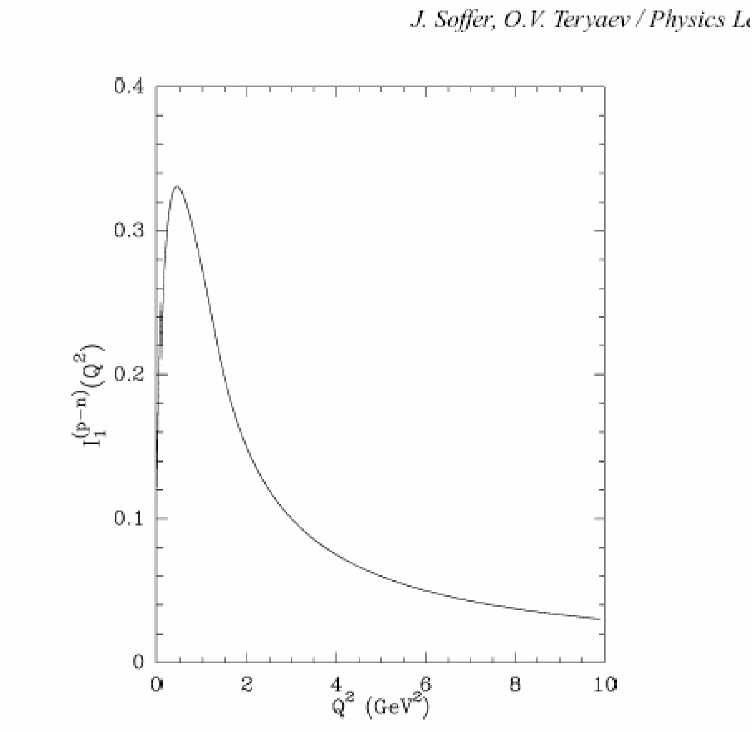
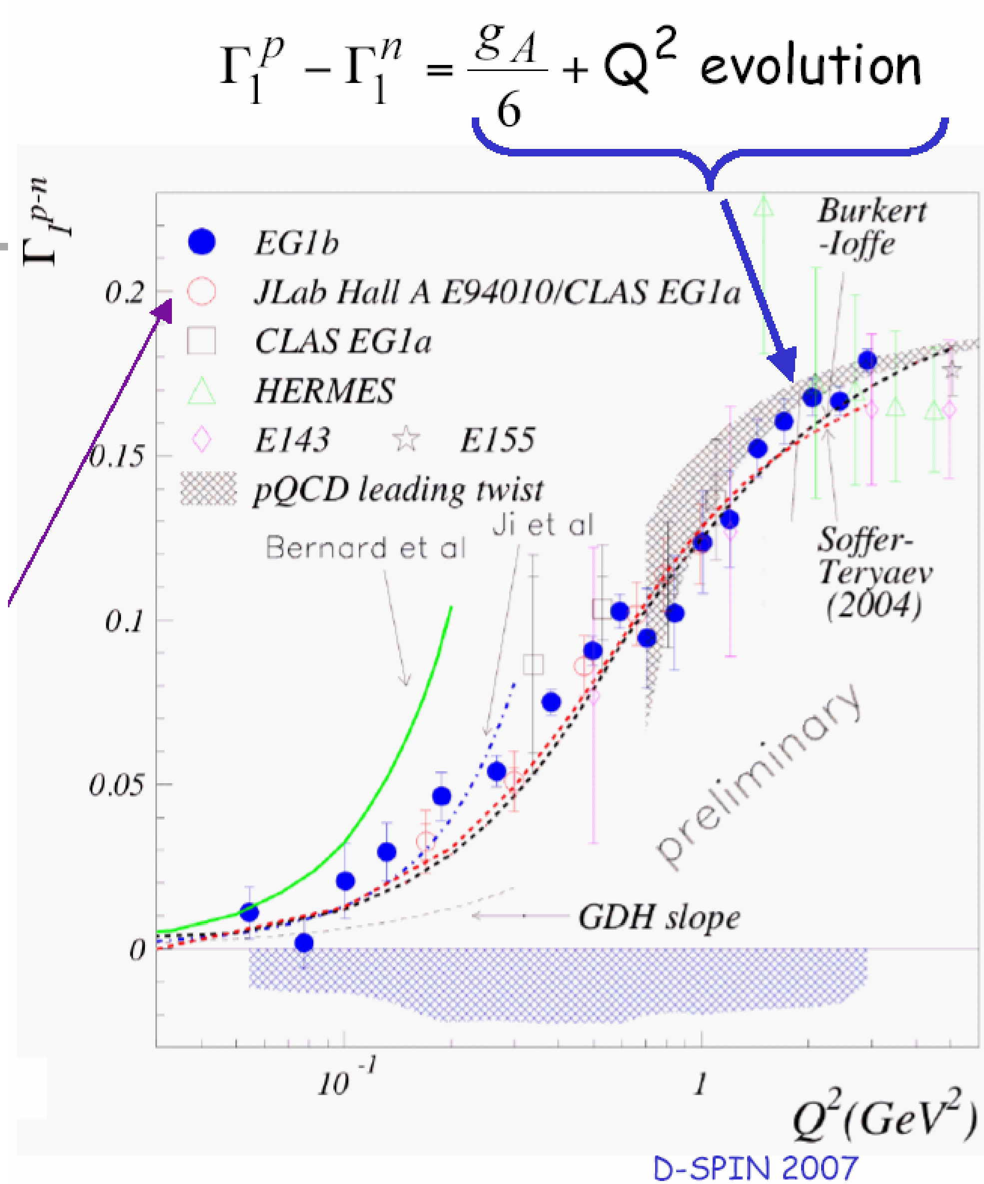


Fig. 2. Our prediction for $I_1^{p-n}(Q^2)$, directly related to the Bjorken sum rule.

JLab

- – VERY accurate data
- How to use?



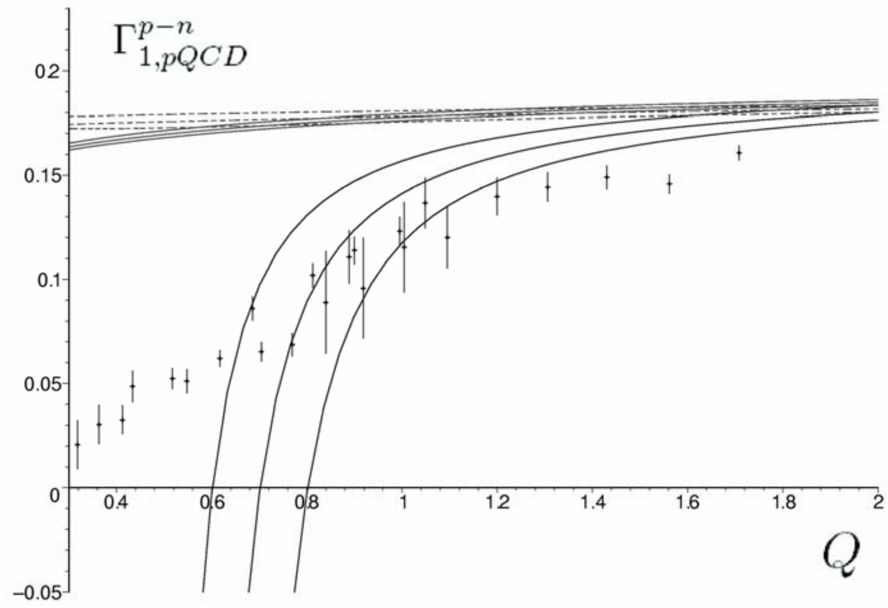
Bjorken SR and APT (R.Pasechnik, D.V.Shirkov,OT)

- Pioneering application to Bjorken SR- K. Milton, I. Solovtsov, O. Solovtsova (98)
- Fast convergence of PT!

How APT confronts recent data?

- APT – close to Simonov's freesing

- Step back??

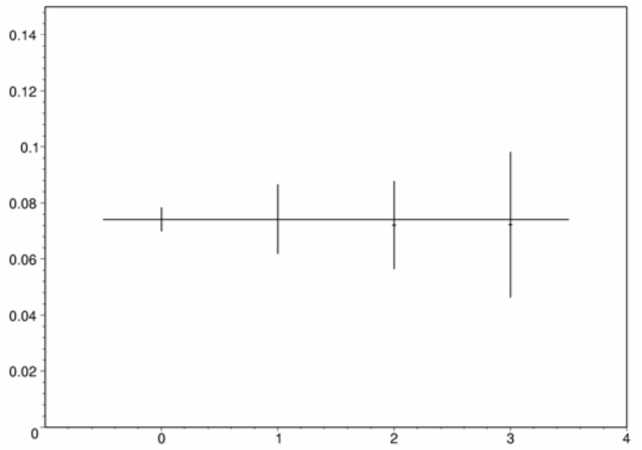


What about HT?

- Recall

Q^2, GeV^2	μ_4/M^2	μ_6/M^4	μ_8/M^6
$0.5 - 11.0$	-0.060 ± 0.063	0.086 ± 0.11	0.011 ± 0.05

- APT – quite different – Exponentially decreasing series!



Comparing HT

- Powers for coupling:

$$\Gamma^{p-n}_{1,pQCD}(Q^2) \simeq 0.21 + f(\frac{1}{\ln(Q^2/\Lambda^2)}) + 0.43\frac{\Lambda^2}{Q^2} + 1.14\frac{\Lambda^4}{Q^4} + 2.23\frac{\Lambda^6}{Q^6} + 3.69\frac{\Lambda^8}{Q^8} + ...$$

- First correction – increasing (step back)

$$\frac{\mu_4^{APT} + 0.43\Lambda^2_{QCD}}{M^2} \simeq \frac{\mu_4}{M^2} \simeq -0.061$$

- But higher – decreasing (two + steps forward!)

$$\Gamma_1^{tw}(Q^2) = \frac{\xi_1}{Q^2}\, e^{-\xi_2^2/Q^2}$$

Data vs HT

- HT in PT

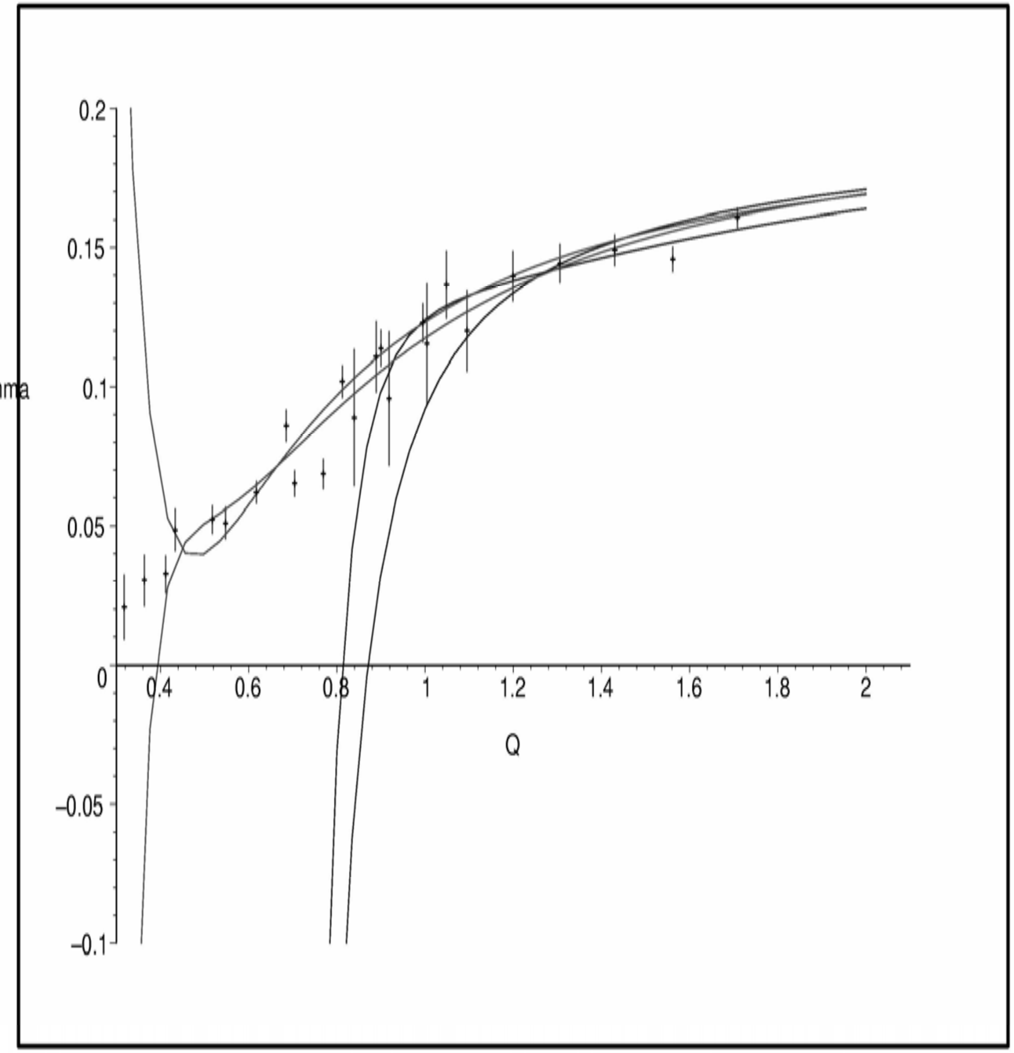
Q^2, GeV^2	μ_4/M^2	μ_6/M^4	μ_8/M^6
$0.5 - 11.0$	-0.060 ± 0.063	0.086 ± 0.11	0.011 ± 0.05

- HT in APT – frontier moving

data	Total fit			
Q^2	$0.47 - 2.918$	$0.268 - 2.918$	$0.17 - 2.918$	$0.101 - 2.918$
μ_4^{APT}/M^2	-0.0579 ± 0.0015	-0.0772 ± 0.0028	-0.0839 ± 0.0042	-0.0843 ± 0.0047
μ_6^{APT}/M^4	0	0.0129 ± 0.0011	0.0202 ± 0.0028	0.0217 ± 0.0036
μ_8^{APT}/M^6	0	0	-0.0017 ± 0.0004	-0.0027 ± 0.0006
μ_{10}^{APT}/M^8	0	0	0	$2.3(-4) \pm 0.8(-4)$
μ_{12}^{APT}/M^{10}	0	0	0	$-1.9(-5) \pm 1.0(-5)$
μ_{14}^{APT}/M^{12}	0	0	0	$1.4(-6) \pm 0.9(-6)$

Data vs HT

- Move Frontier Down!



Implications for Spin-independent and PV DIS

- 1,2 (better-protected by momentum SR)– should hold also for PV case: VV+(=)AA
- 3 – V-A interference
- 4-5 – no LO (+HT) counterpart!
- Analytic QCD couplings?

CONCLUSIONS

- Methods from QCD SR are helpful, in particular BG duality may be quantitatively understood in the framework of Borel sum rules
- Large x HT corrections are important.
- g_T - natural candidate for Bloom-Gilman duality and allows for good description of GGDH SR
- Generalization for PV –special role of 4,5
- Analytic couplings – intriguing results from BjSR