Measurement of the Q^2-evolution of the Bjorken integral at low Q^2

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The Bjorken sum rule

$$\int g^{p}_{1} - g^{n}_{1} \, dx = \frac{1}{6} g_{A} \left(1 - \frac{\alpha_{s}}{\pi} - 3.58\left(\frac{\alpha_{s}}{\pi}\right)^{2} - \ldots\right) + HT$$

Bjorken
Limit

Leading Twist
(DGLAP eq.)

Higher
Twists

with $\alpha_{s}(Q^{2})$

Cornerstone of polarized pQCD studies

The Bjorken sum rule is connected to the Gerasimov-Drell-Hearn (GDH) sum rule:

When $Q^{2} \rightarrow 0$, $\int g_{1} dx \rightarrow \frac{Q^{2}}{16\pi^{2}\alpha} \int \sigma^{1/2} - \sigma^{3/2} \frac{d\nu}{\nu}$

$\sigma^{1/2(3/2)}$: photoproduction cross sections

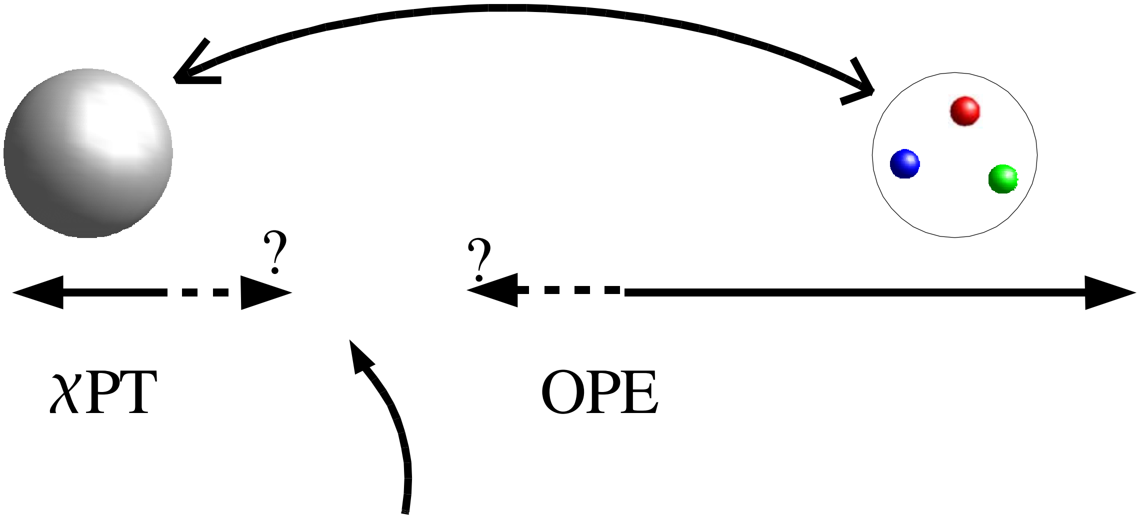
Historically: Origin of the generalization of the GDH sum rule to finite Q^{2}.

The generalized GDH sum at intermediate Q^2

Main interest: Study of the transition from pQCD to non-perturbative QCD:

GDH(Q^2) sum: Measurable *and* calculable (in principle) at any Q^2.

⇒Important tool to explore the transition



Lattice QCD should bridge the gap

⇒No fundamental theoretical description over the full Q^2-range yet.

The Bjorken and GDH integrals

$$\text{Bjorken integral} = \frac{Q^2}{16\pi^2\alpha}\left[GDH^p(Q^2) - GDH^n(Q^2)\right]$$

p-n non-singlet quantity → simplifications

Partonic side:

- Sum rule without hypothesis beyond QCD
- More reliable low-x extrapolation
- Easier DGLAP Q^2-evolution

Hadronic side:

- Δ_{1232} contribution cancels ⇒ easier χPT calculations

⇨ Easier for theory to bridge parton-hadron gap

➡Because of its non-singlet structure, the Bjorken integral may be the most convenient quantity to study the parton-hadron transition

Available data

Until recently:

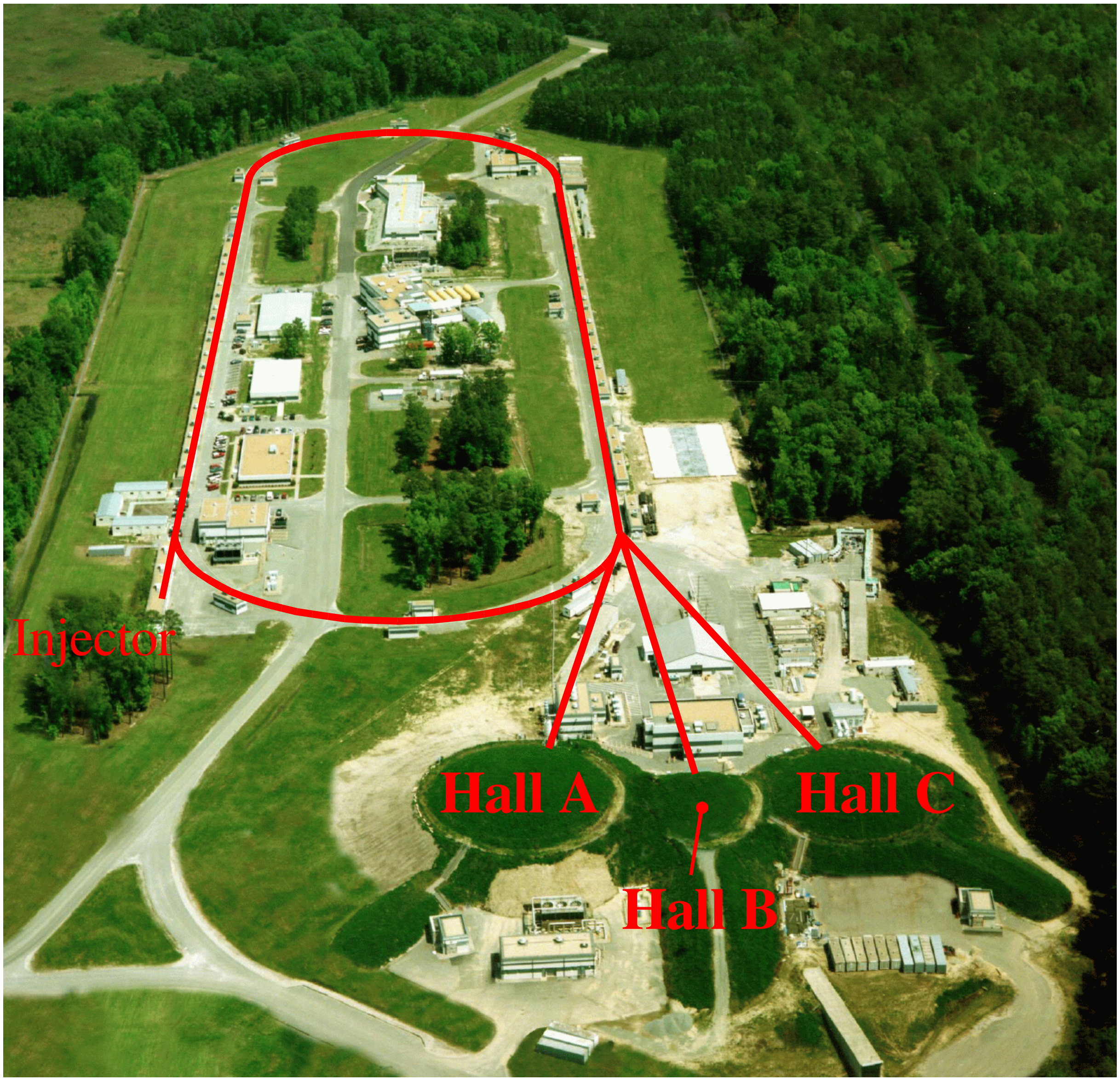
- CERN / SLAC / HERMES: DIS
- SLAC E143: 2 points in the resonance domain (large uncertainties)

Recently: High precision Γ_1 data available from JLab:

- Proton: CLAS Phys. Rev Lett. **91** 222002 (2003)
- Deuterium: CLAS Phys. Rev C **67** 055204 (2003)
- Neutron (^{3}He): Hall A Phys. Rev Lett. **92** 022301 (2004)

Jefferson Lab

- Facility for fixed target experiments
- 3 experimental halls
- Up to 6 GeV continuous electron beam
- Up to 200 μA beam current
- Up to 85% beam polarization

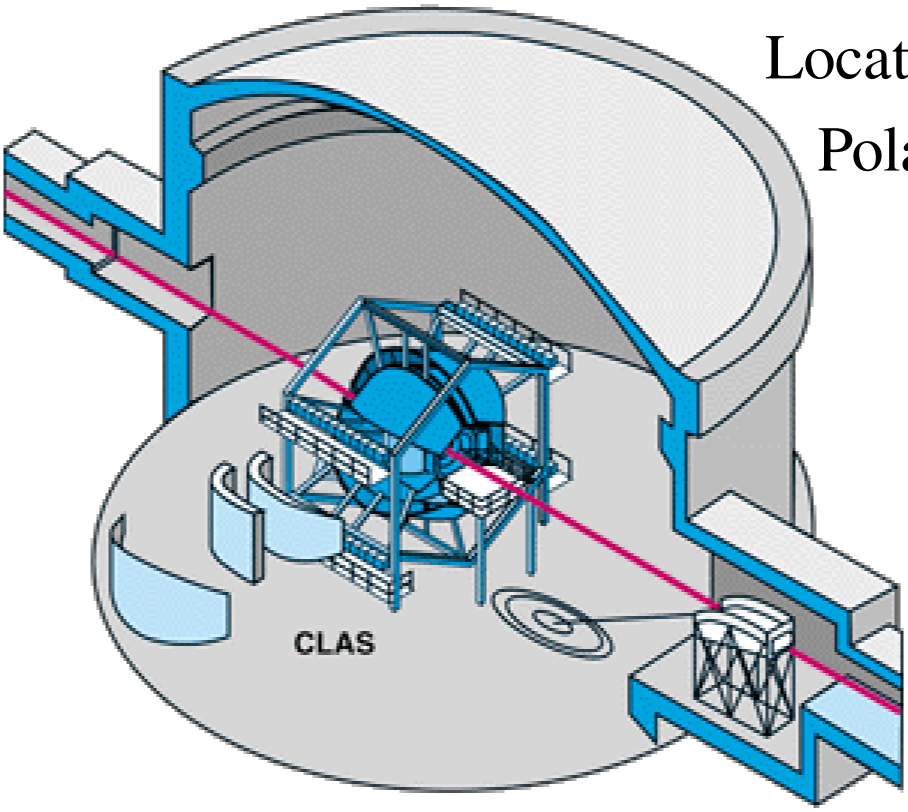


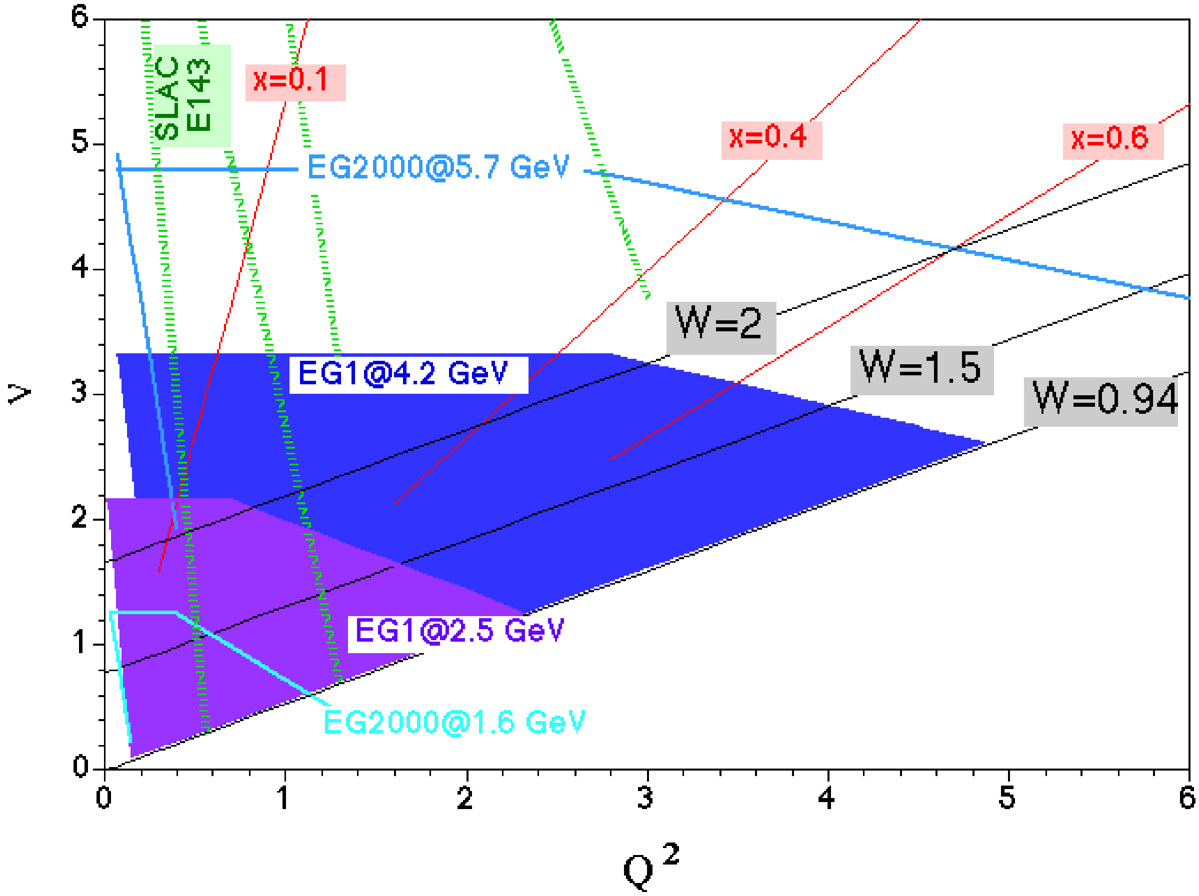
CLAS

Jefferson Lab large acceptance spectrometer

Located in Hall B

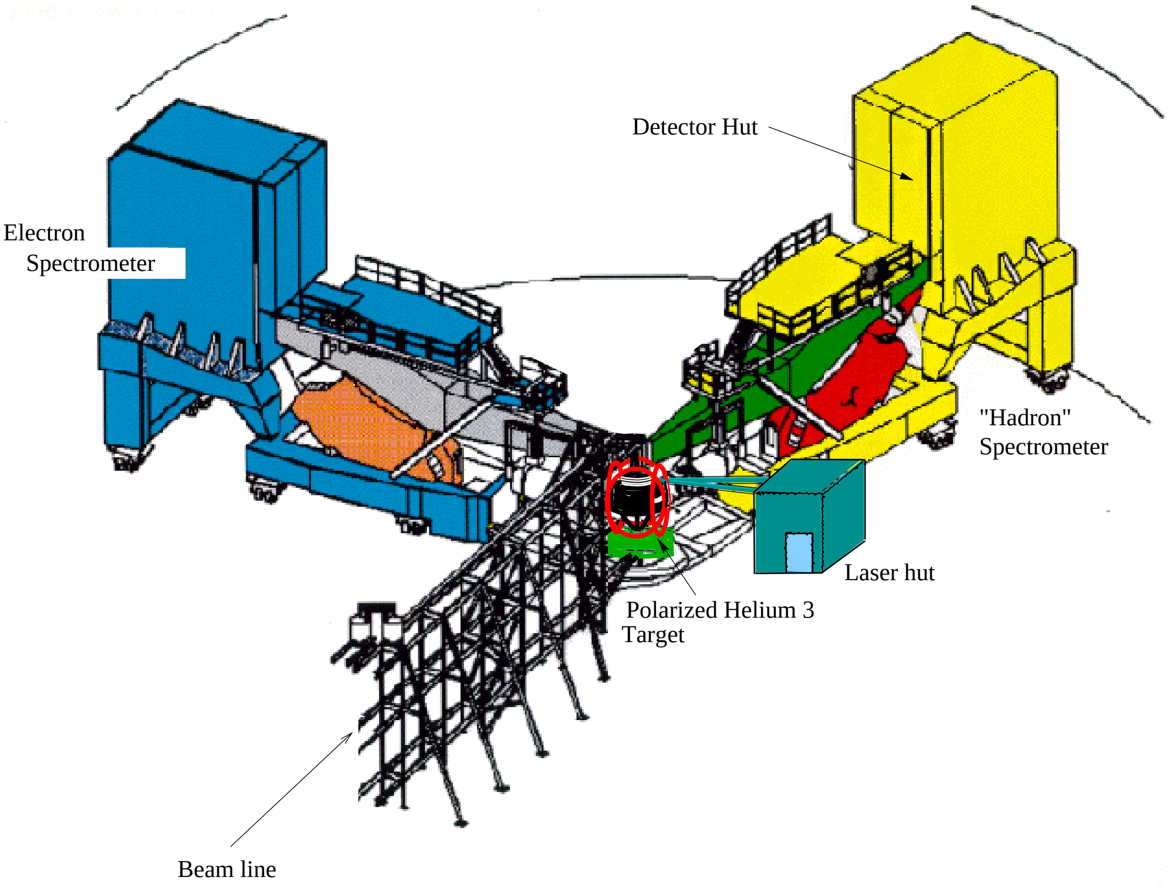
Polarized p & n

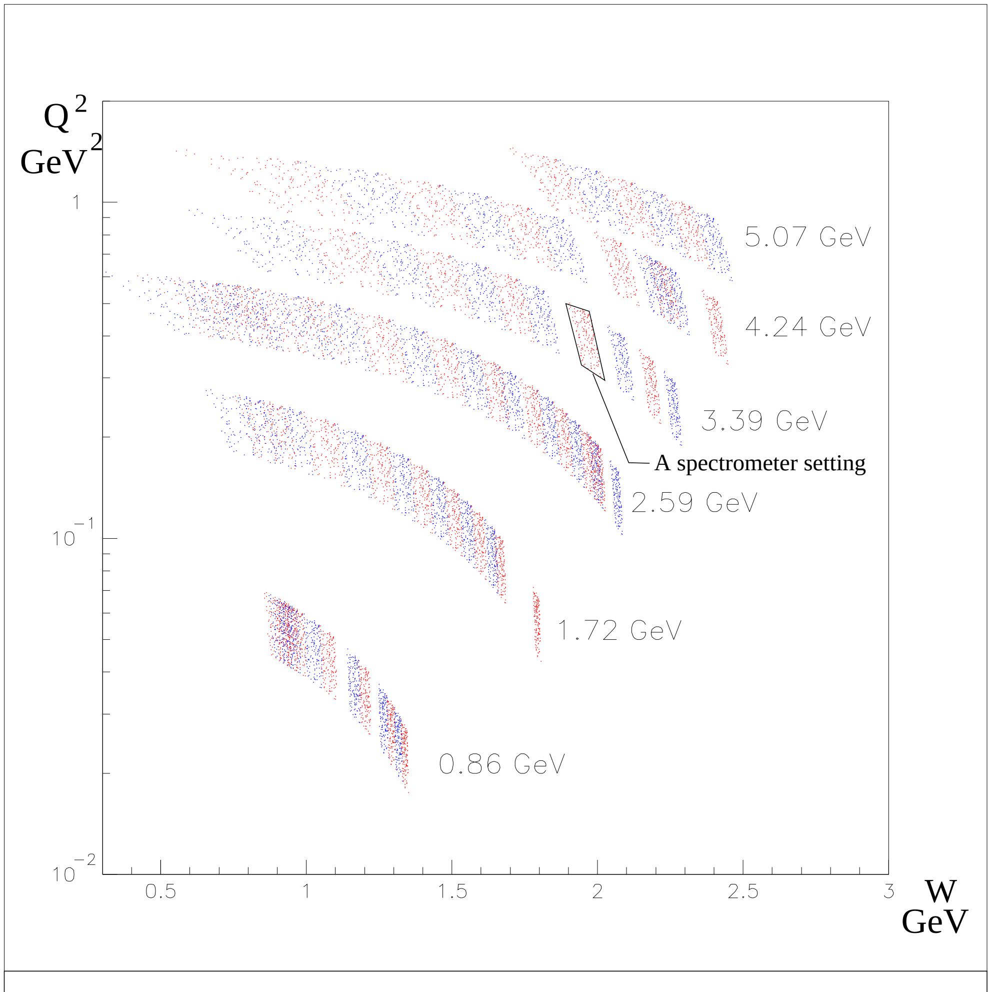




Hall A

Jefferson Lab large acceptance spectrometer

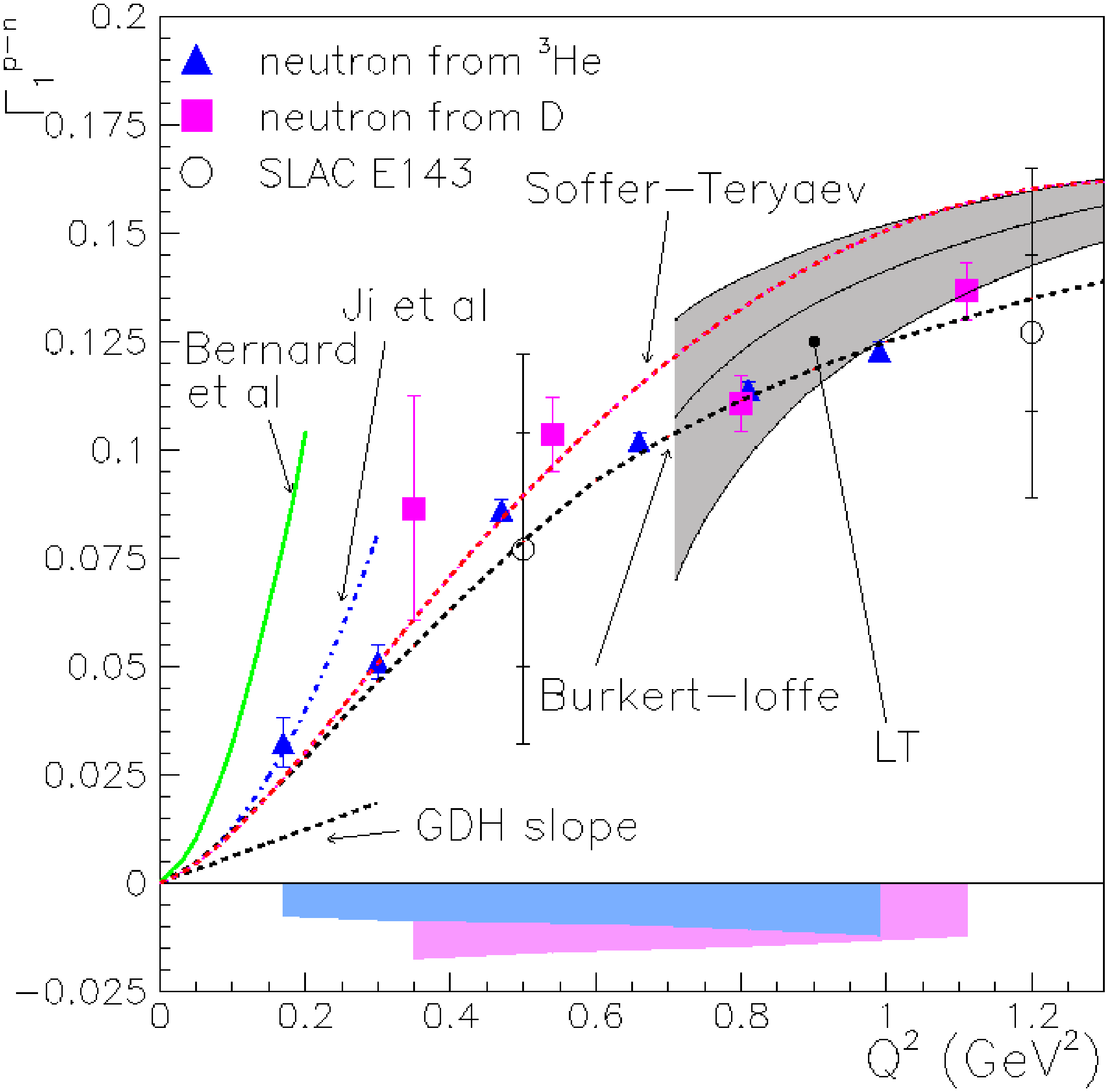




We used these data to extract the Bjorken integral. Some re-analysis was necessary:

- Q^2 matching
- Consistent low-x estimate

Bianchi and Thomas, Phys . Lett B450 439 (1999)



χPT and OPE are still not linked

OPE at leading twist match well the data

⇒Higher Twists small ?

Higher Twist analysis

Higher twists are mechanisms that build up the coherent response of the nucleon to the virtual photon.

⇒Specific processes to study to understand the hadron-parton transition.

OPE: $$\Gamma_1^{p-n} = \Gamma_1^{p-n}\Big|_{LT} + \sum_{i=1}^{\infty} \frac{\mu_{2i+2}^{p-n}}{Q^{2i}}$$

$$\mu_4^{p-n} = (a_2^{p-n} - 4d_2^{p-n} \boxed{-4f_2^{p-n}})$$

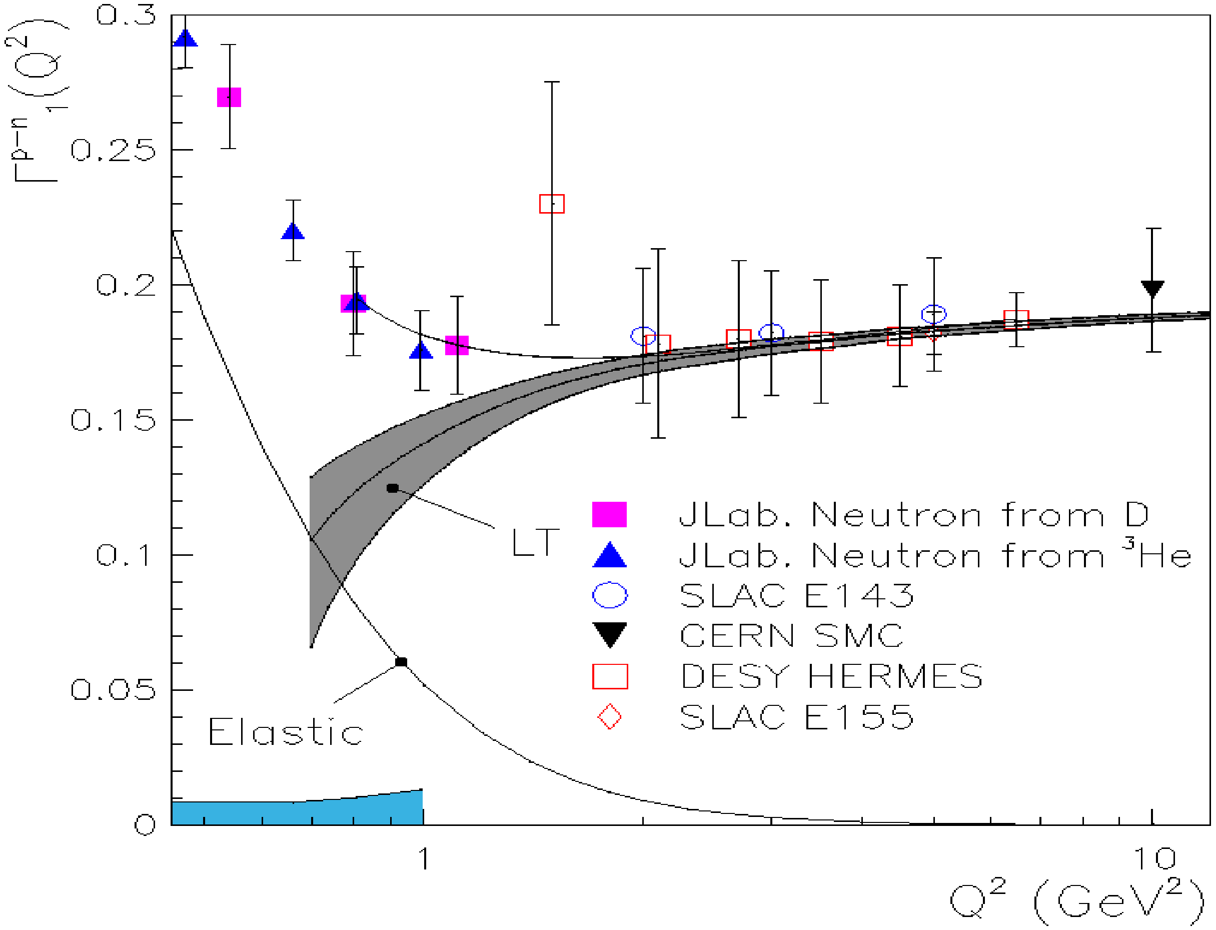
Target mass correction Twist 2

Twist 3

Twist 4

a_2^{p-n} and d_2^{p-n}, moments of g_1 and g_2 : Measured.
SLAC, JLab

f_2^{p-n} extracted from fit.



Low-x contributions of world data are re-estimated using BT parametrization.

Choice of Q^2-range ?

Range 0.66-10 GeV^2 : $f_2^{p-n} = -0.18 \pm 0.05$ (uncor) $\pm^{0.04}_{0.05}$ (cor)

$\mu_6^{p-n}/M^4 = 0.12 \pm 0.02$ (uncor) ± 0.01 (cor)

For Q^2=1 GeV^2

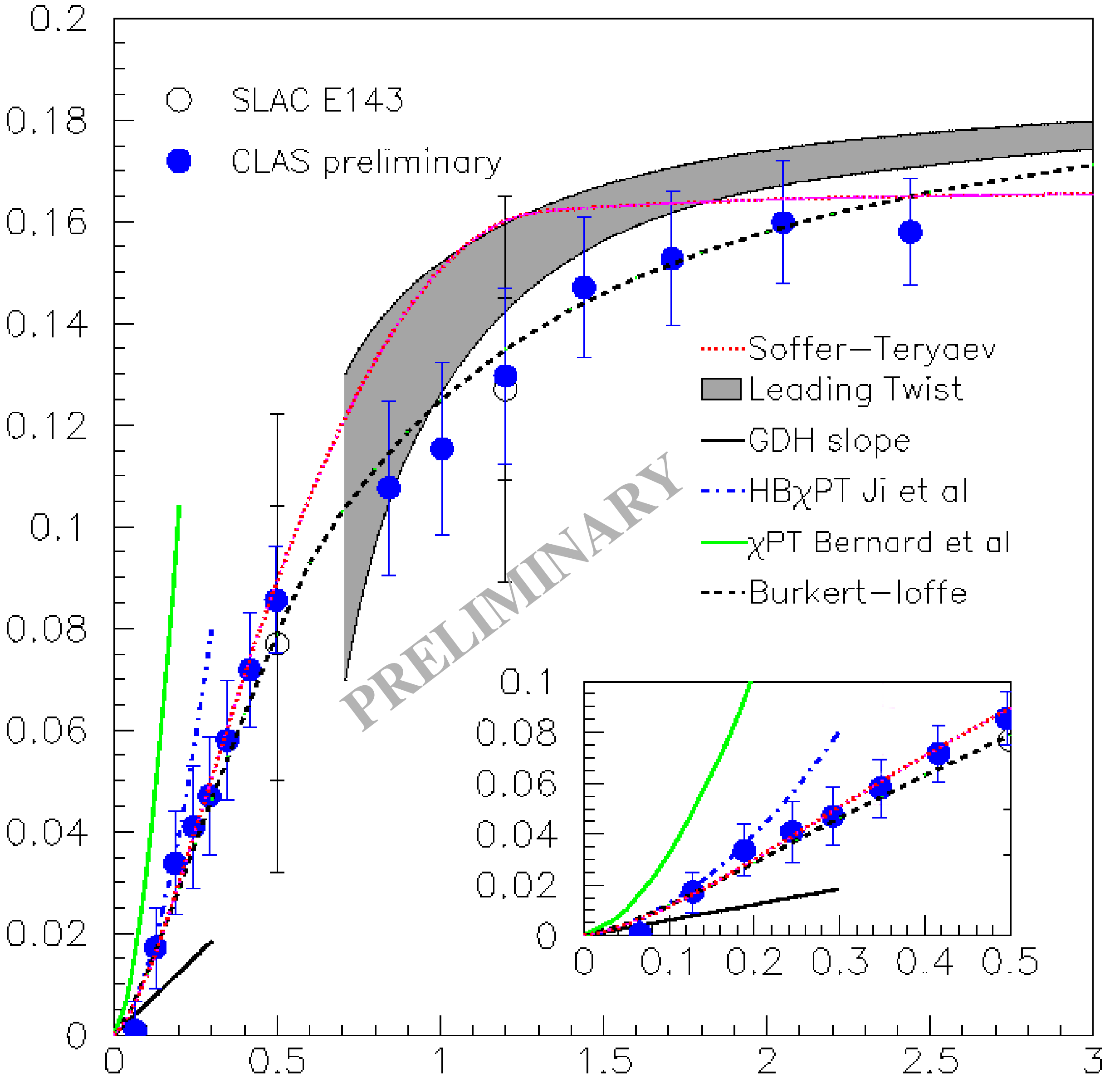
Range 0.8-10 GeV^2 : $f_2^{p-n} = -0.13 \pm 0.15$ (uncor) $\pm^{0.04}_{0.03}$ (cor)

$\mu_6^{p-n}/M^4 = 0.09 \pm 0.06$ (uncor) ± 0.01 (cor)

$\Rightarrow \mu_6^{p-n}/Q^4 \simeq 0.09 \pm 0.02$ and $\mu_4^{p-n}/Q^2 \simeq -0.06 \pm 0.02$

Overall HT are small.

Preliminary new data available from CLAS EG1b experiment.



(The low-x part of the eg1b data are not yet estimated using BT)

Effective strong coupling constant

Work done in collaboration with. V. Burkert, J.P. Chen and W. Korsh

$$\Gamma_1^{p-n}(Q^2) = f(\alpha_s) + \sum_{i=1}^{\infty} \frac{\mu_{2i+2}^{p-n}(\alpha_s)}{Q^{2i}}$$

$\Rightarrow \alpha_s$ can been extracted from DIS data where HT are negligible.

In our Q^2-range:

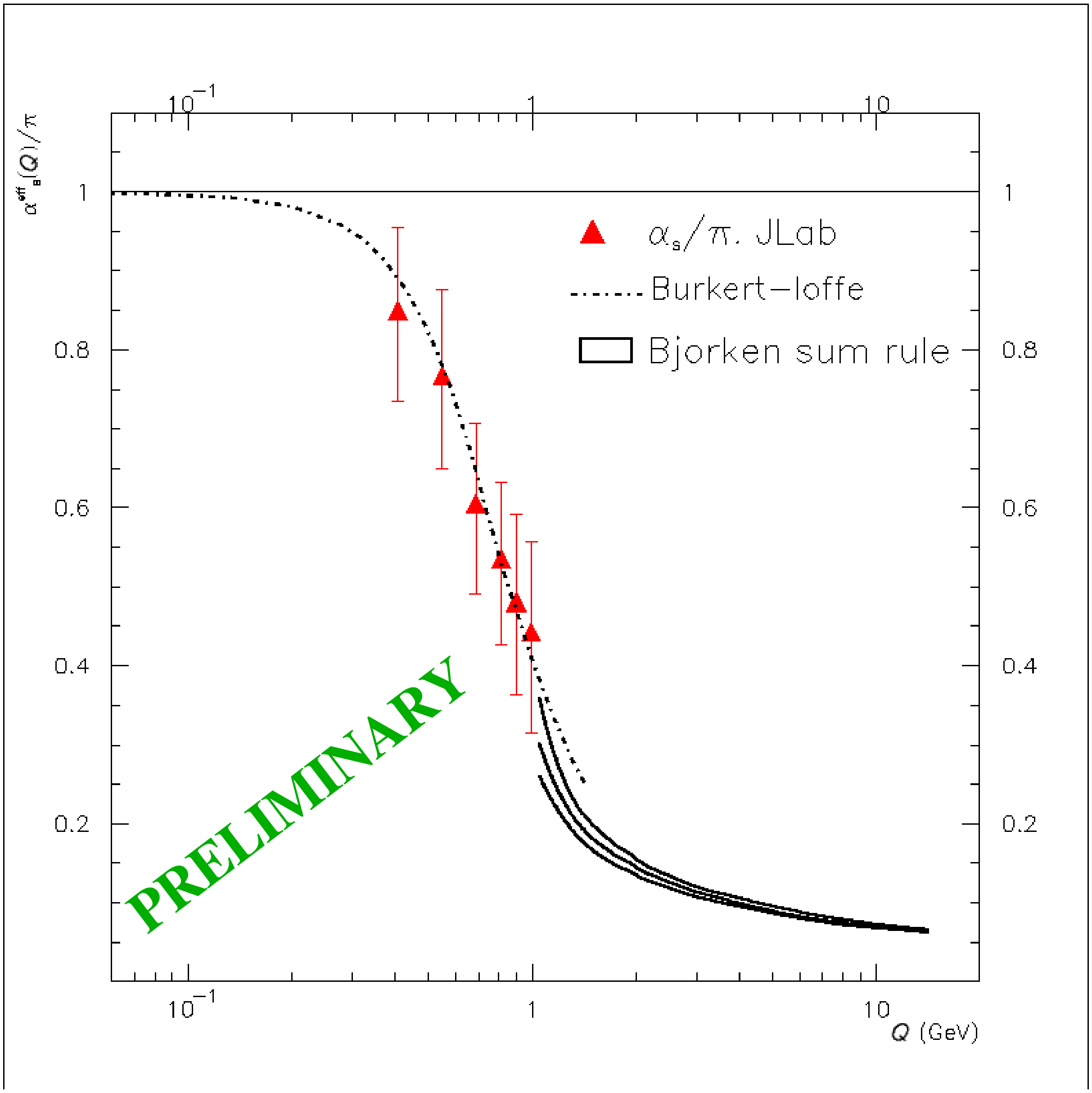
- HT might become significant
- Perturbative series don't make sense
- $\alpha_s \rightarrow \infty$ when $Q^2 \rightarrow (\Lambda_{QCD})^2$

But: we can fold the HT terms and gluon radiations into the coupling and extract an effective α_s^{eff} :"method of effective charges"

Grunberg, Brodsky,...

- α_s^{eff} makes sense at any Q^2
- α_s^{eff} well behaved
- α_s^{eff} renormalization scheme independent
- Pertinent to low Q^2 calculation/models

(Hadron spectroscopy, non-perturbative QCD calculations, lattice QCD)



- First extraction of the effective coupling constant at low Q^2.
- α_s^{eff} seems to freezes at low Q^2.

Comparison with theory ?

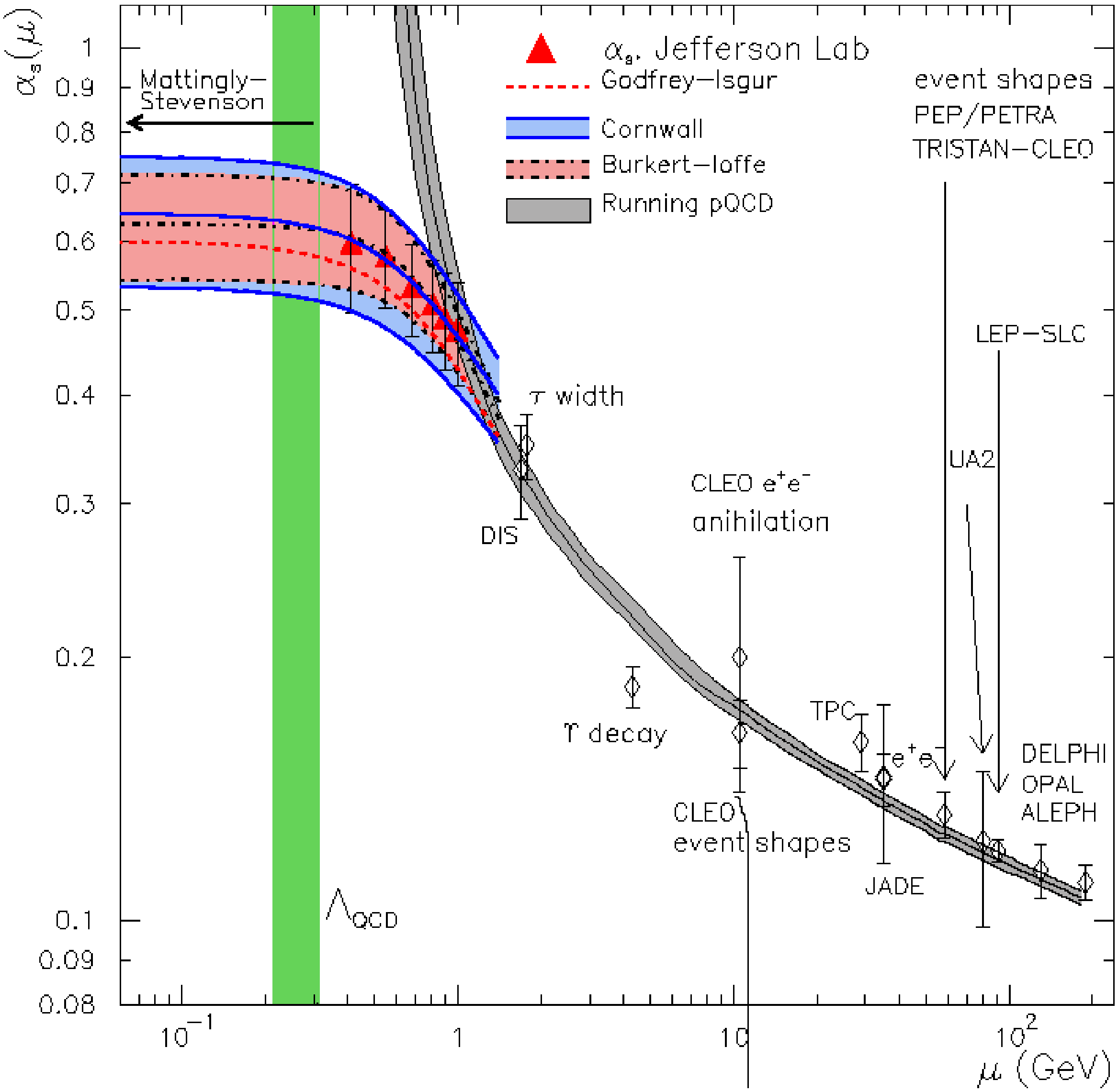
- Lattice QCD
- Schwinger-Dyson equations
- Baryon spectroscopy (constituent quark model)
- ...

Theoretical calculations usually compute the dressed gluon propagator.

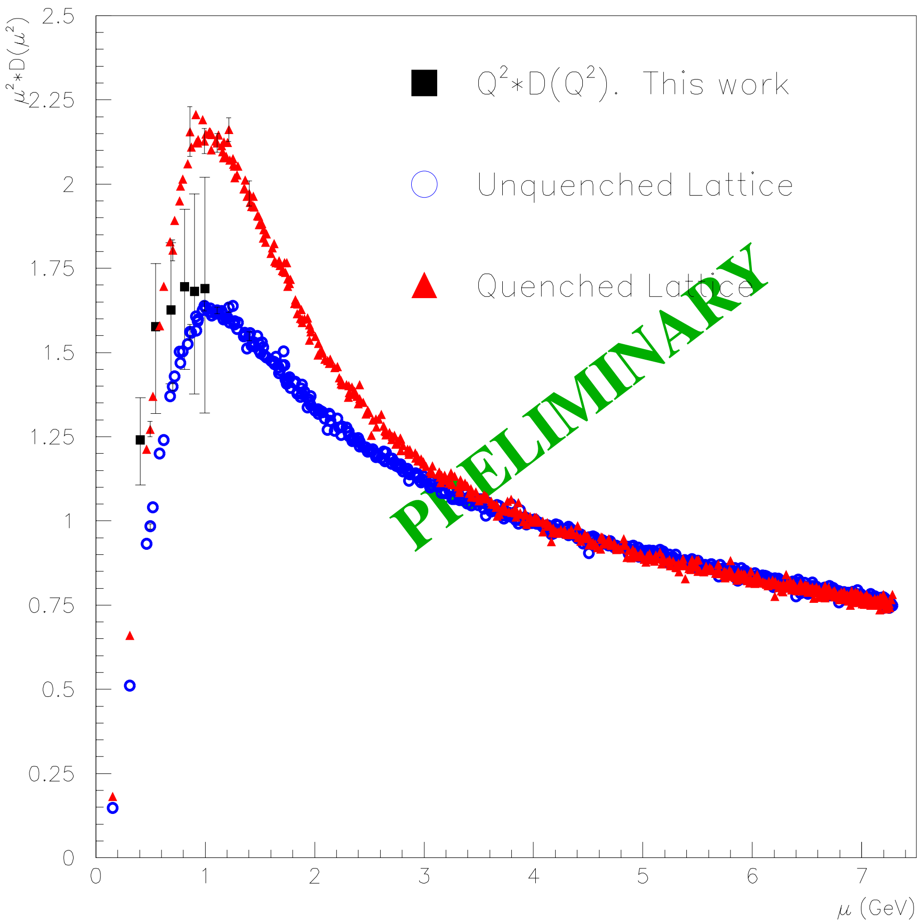
⇒To compare to theory we should not fold the QCD radiative corrections into α_s^{eff} (?).

⇒Only HT should be folded in.

If I do that:



Lattice QCD usually gives the dressed gluon propagator (not an observable)



Lattice calculation: Bowman et al.
Phys.Rev. D70 (2004) 034509

A quantity that links different sectors of QCD and parametrizes the strong force at any Q^2 ?

But, questions on the legitimacy of such approach:

- Are we comparing same quantities ?
- Separation of DGLAP and HT ambiguous at low Q ?
- No process dependence in theoretical calculations

Summary, perspectives

- The Bjorken sum was extracted in the Q^2-range of 0.16 - 1.1 GeV^2.

- Although χPT might work in larger domain, the gap between OPE and χPT is not bridged

- HT appears to be small at Q^2= 1 GeV^2.

- α_s^{eff} was extracted. Indication that it freezes at low Q^2.

- High precision data from CLAS on a larger kinematics range will be available soon. Preliminary results were shown.

- Low Q^2 data (0.02-0.5 GeV^2) will be available in the next few years:
  Neutron (^{3}He): Hall A.
  Data taken during summer 2003
  Proton: CLAS.
  Data to be taken in 2005