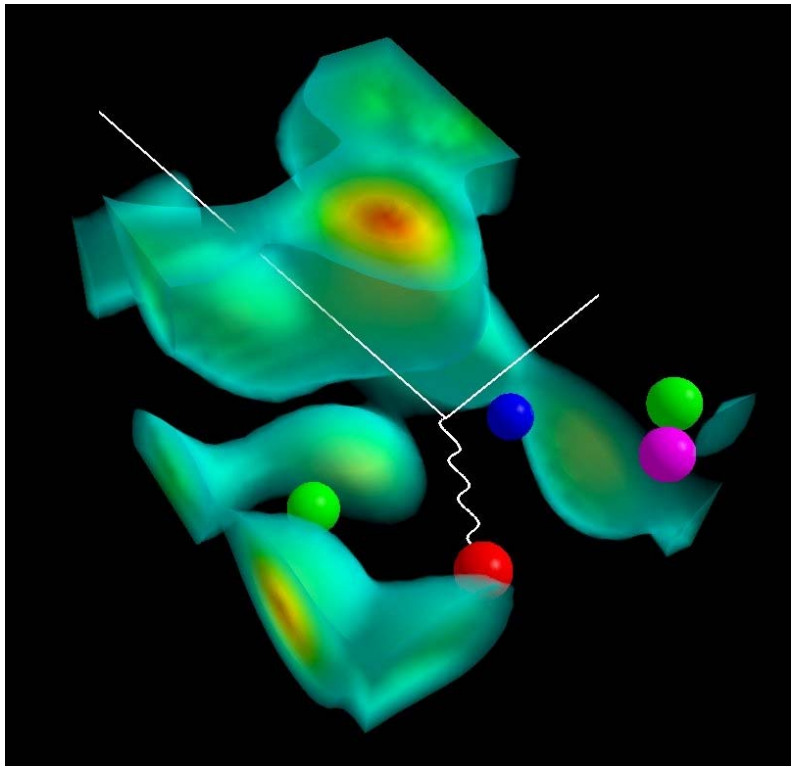
# 12 GeV Upgrade : Near and Long Term Opportunities



Anthony W. Thomas

Science Review for the 12 GeV Upgrade

April 7th, 2005

# Highlights of the 12 GeV Program

- **Revolutionize Our Knowledge of Spin and Flavor Dependence of Valence PDFs**

- **Revolutionize Our Knowledge of Distribution of Charge and Current in the Nucleon**

- **Totally New View of Hadron (and Nuclear) Structure: GPDs**
  - **Determination of the quark angular momentum**

# Highlights of the 12 GeV Program….2

- **Exploration of QCD in the Nonperturbative Regime:**
  - **Existence and properties of exotic mesons**
- **New Paradigm for Nuclear Physics:**
  **Nuclear Structure in Terms of QCD**
  - **Spin and flavor dependent EMC Effect**
  - **Study quark propagation through nuclear matter**
- **Precision Tests of the Standard Model**
  - **Factor 20 improvement in $(2C_{2u}-C_{2d})$**

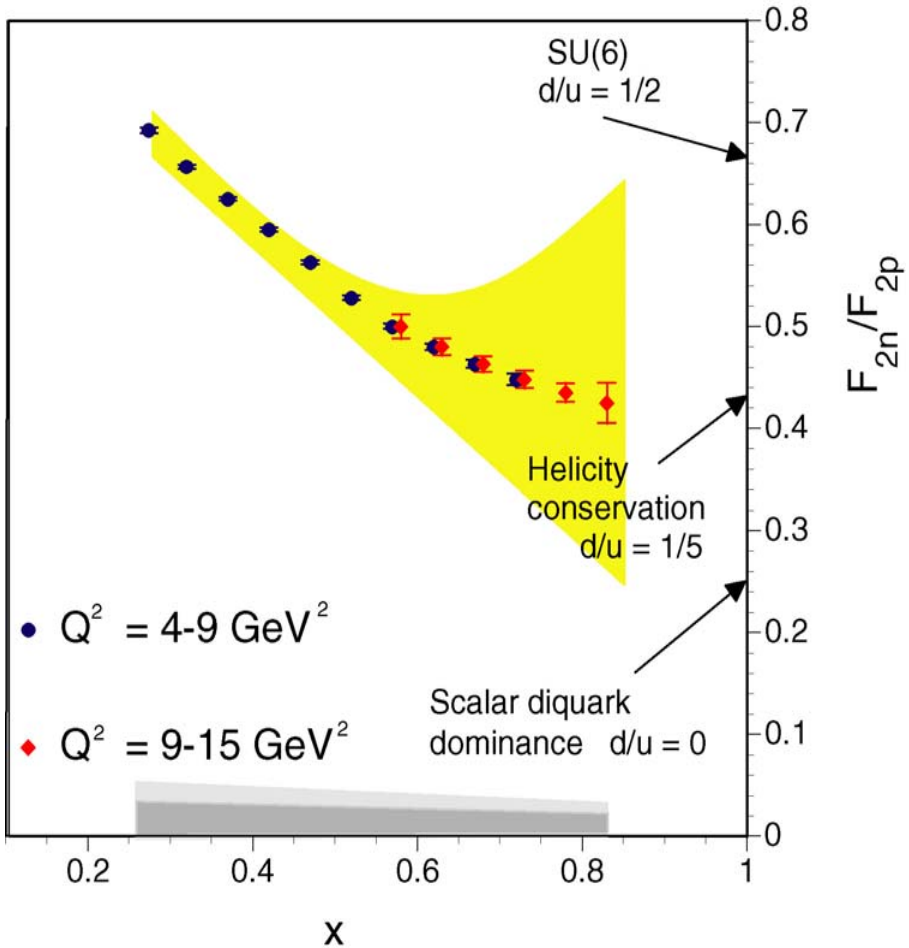
# Behavior of d/u at large-x

At large $x$ (sea quarks, gluons suppressed)

$$F_2^p \sim \frac{4}{9}\,u + \frac{1}{9}\,d$$

$$F_2^n \sim \frac{1}{9}\,u + \frac{4}{9}\,d$$

$$\frac{d}{u} \sim \frac{4 - F_2^n/F_2^p}{4F_2^n/F_2^p - 1}$$



# Exotica*

R. L. Jaffe†

arXiv:hep-ph/0409065 v2 25 Oct 2004

exotic baryons has stirred up new interest in hadron spectroscopy. At present the experimental situation is confused; so is theory. The recent discoveries are striking. So too is the complete *absence* of exotic mesons, and, except for the recent discoveries, of exotic baryons as well. Whether or not the new states are confirmed, the way we look at complicated states of confined quarks and gluons has changed. Perhaps the most lasting result, and the one emphasized in these notes, is a new appreciation for the role of diquark correlations in QCD.

# Perturbative QCD

arXiv:hep-ph/9401328 v2 09 Jun 1997

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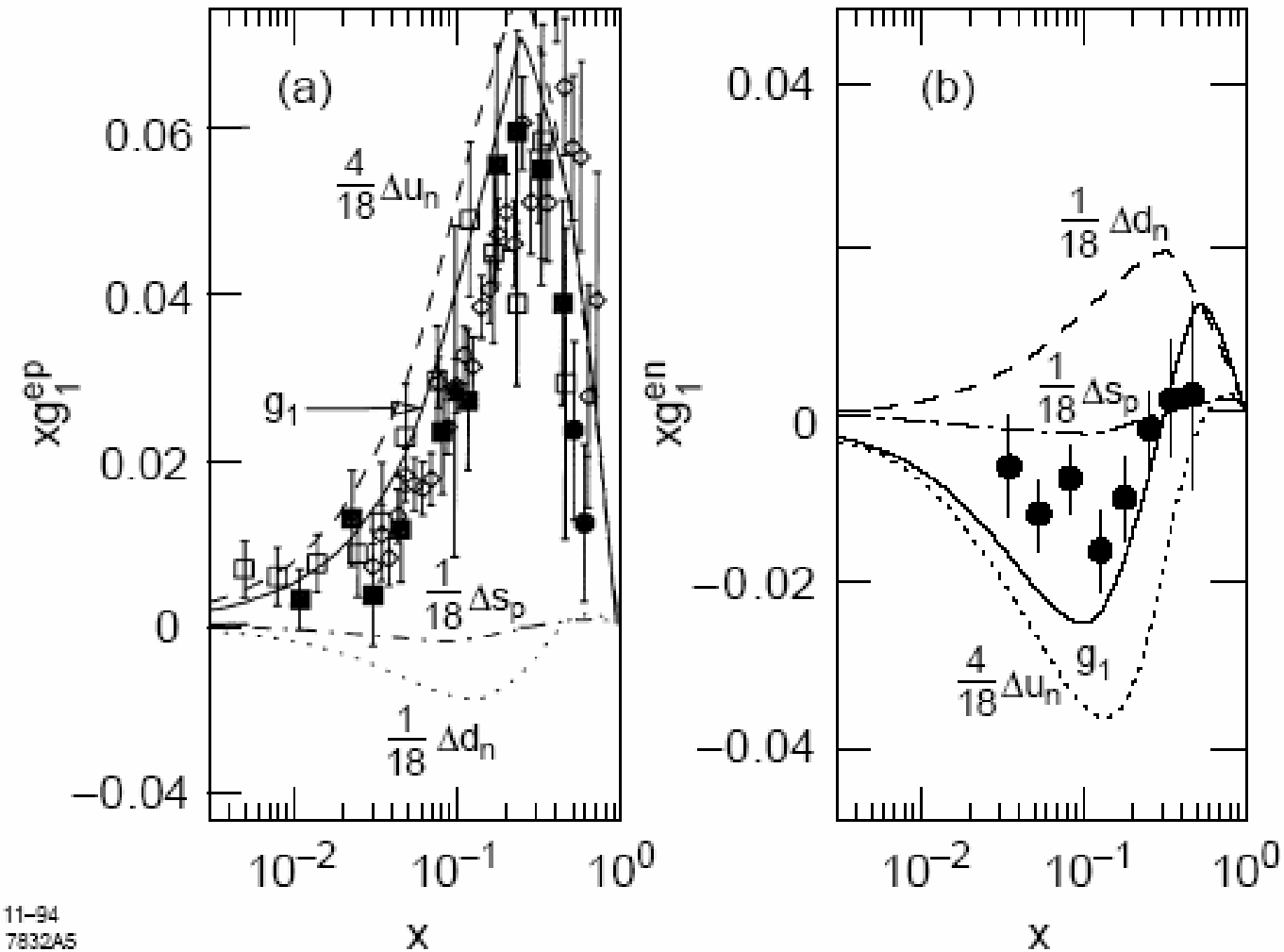
We develop simple analytic representations of the polarized quark and gluon distributions in the nucleon at low $Q^2$ which incorporate general constraints obtained from the requirements of color coherence of gluon couplings at $x \sim 0$ and the helicity retention properties of perturbative QCD couplings at $x \sim 1$. The unpolarized predictions are similar to the $D_0'$ distributions given by Martin, Roberts, and Stirling. The predictions for the quark helicity distributions are compared with polarized structure functions measured by the E142 experiment at SLAC and the SMC experiment at CERN.

$$G_{q/H} \sim (1-x)^p \quad p = 2n - 1 + 2\Delta S_z$$

Here $n$ is the minimal number of spectator quark lines, and $\Delta S_z = |S_z^q - S_z^H| = 0$ or 1 for parallel or anti-parallel quark and proton helicities, respectively[5].


(a)
0.06
0.04
0.02
0
−0.04
$xg_1^{ep}$
$\frac{4}{18}\Delta u_n$
$g_1$
$\frac{1}{18}\Delta s_p$
$\frac{1}{18}\Delta d_n$
$10^{-2}$
$10^{-1}$
$10^{0}$
x
(b)
0.04
0
−0.02
−0.04
$xg_1^{en}$
$\frac{1}{18}\Delta d_n$
$\frac{1}{18}\Delta s_p$
$\frac{4}{18}\Delta u_n$
$g_1$
$10^{-2}$
$10^{-1}$
$10^{0}$
x

11–94
7832A5

# Unambiguous Resolution at 12 GeV

**S=0 diquark dominance**

**d suppressed wrt u**

**$A_1^n$ ! 1, x ! 1**

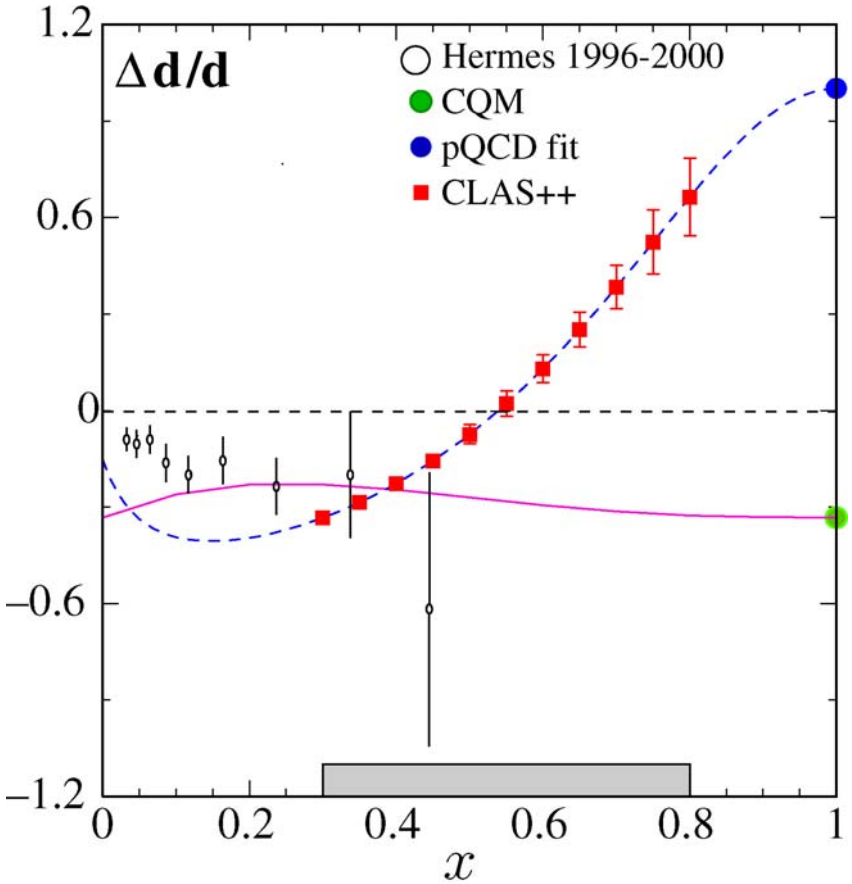
**Δ u /u ! 1 ; Δ d /d ! -1/3**

**pQCD**

**$A_1^n$ ! 1 faster**

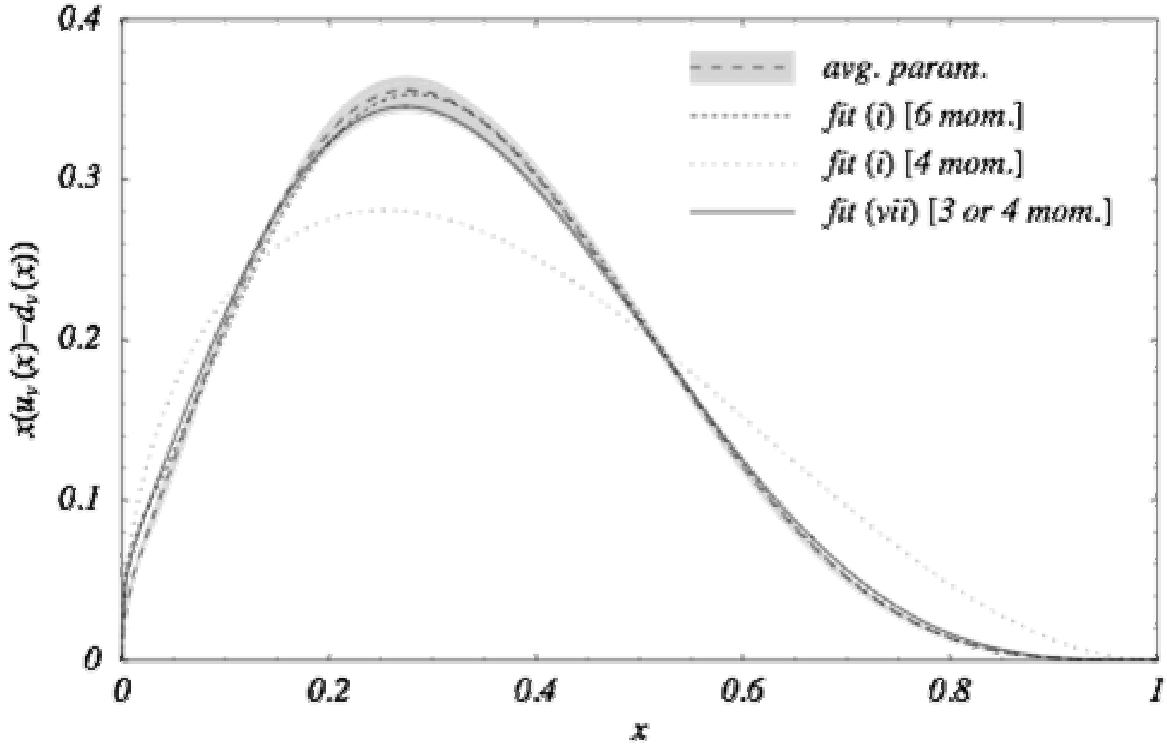
**because**

**Δ u / u <u>and</u> Δ d /d ! 1**



# Reconstruction of PDFs from Moments : Test

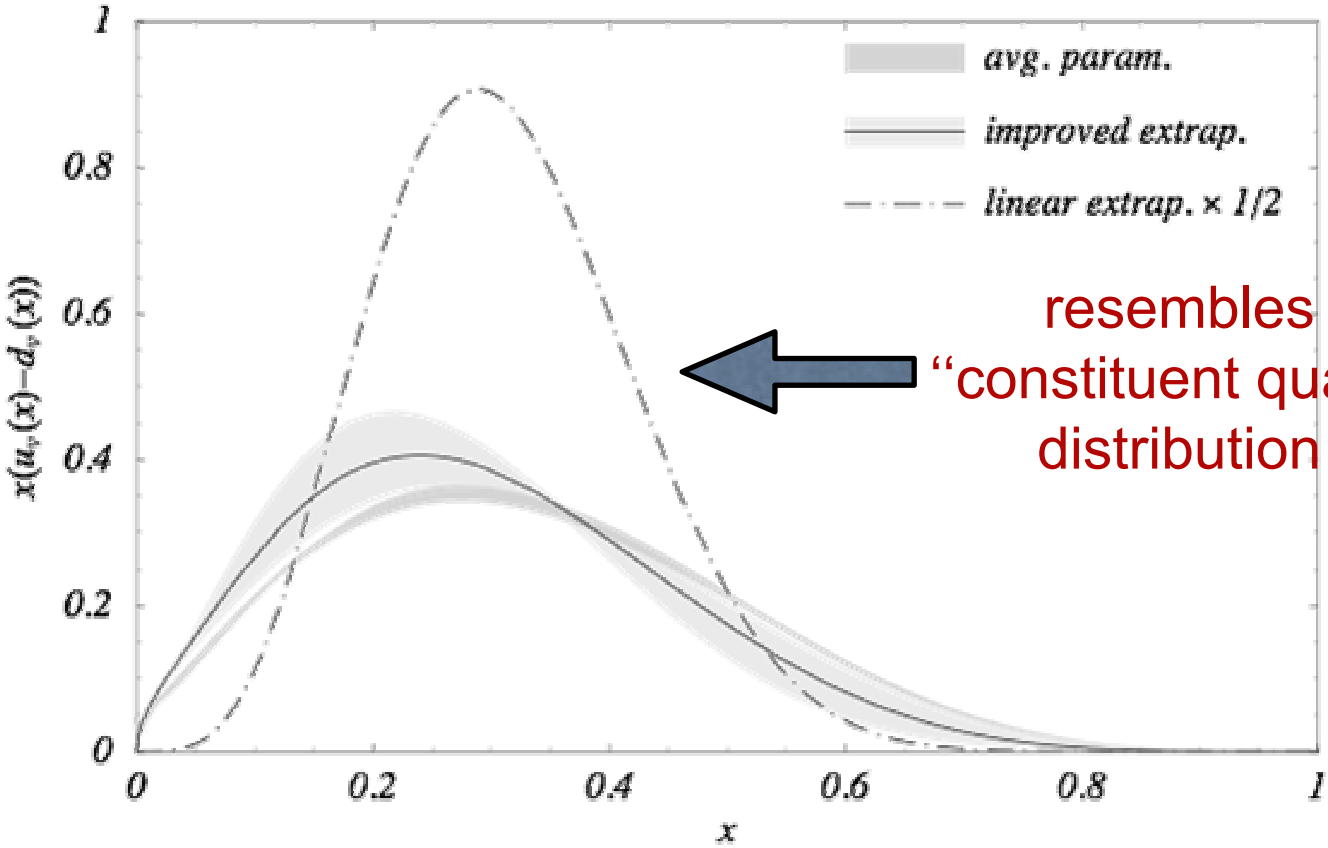
Test case:




$$xq(x) = ax^b(1-x)^c(1+\epsilon\sqrt{x}+\gamma x)$$

- $fit(i)$ : 4 unconstrained parameters $(b, c, \epsilon, \gamma)$
- $fit(vii)$ : 2 unconstrained parameters $(b, c)$

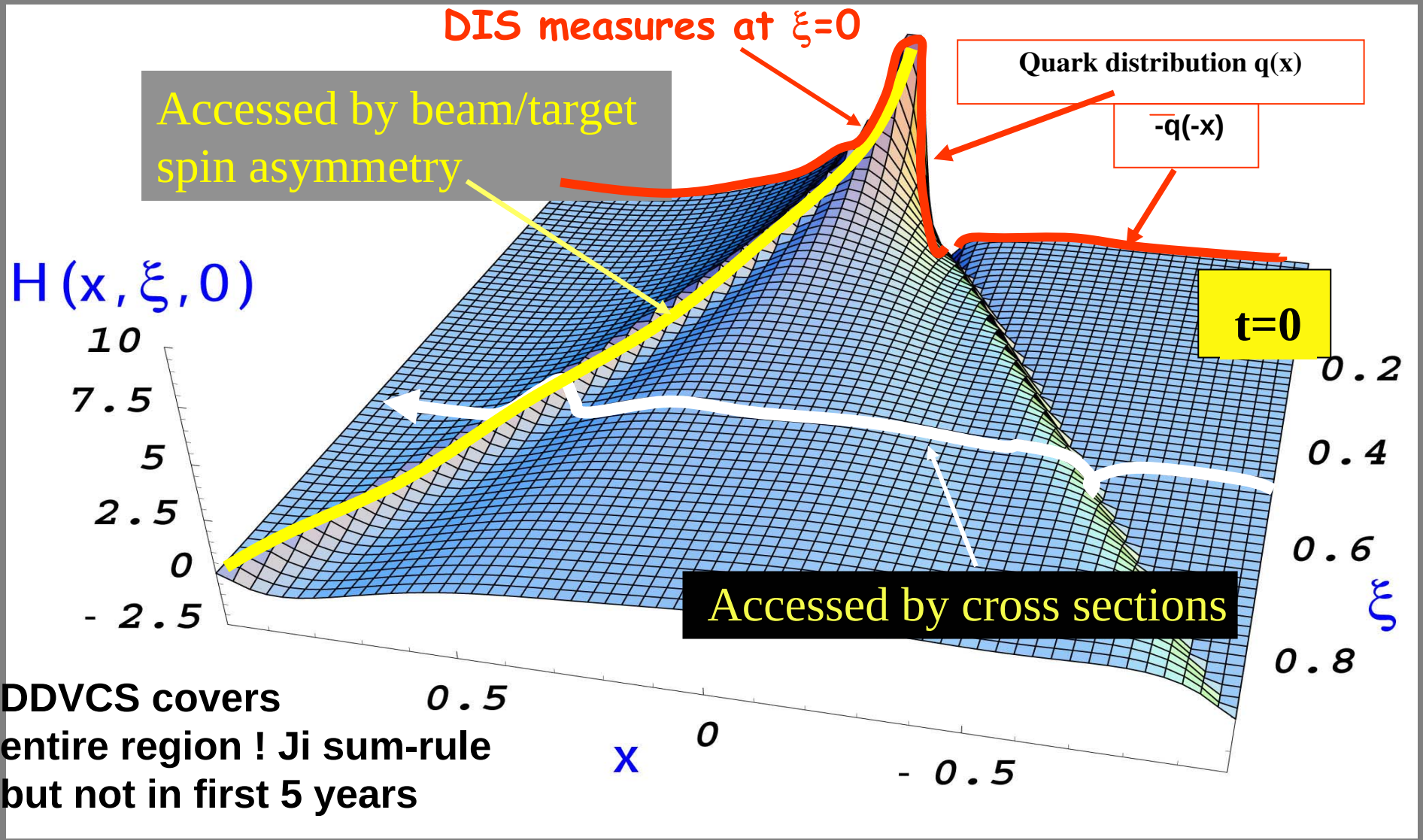
# Application to Current Lattice Data




resembles "constituent quark" distribution

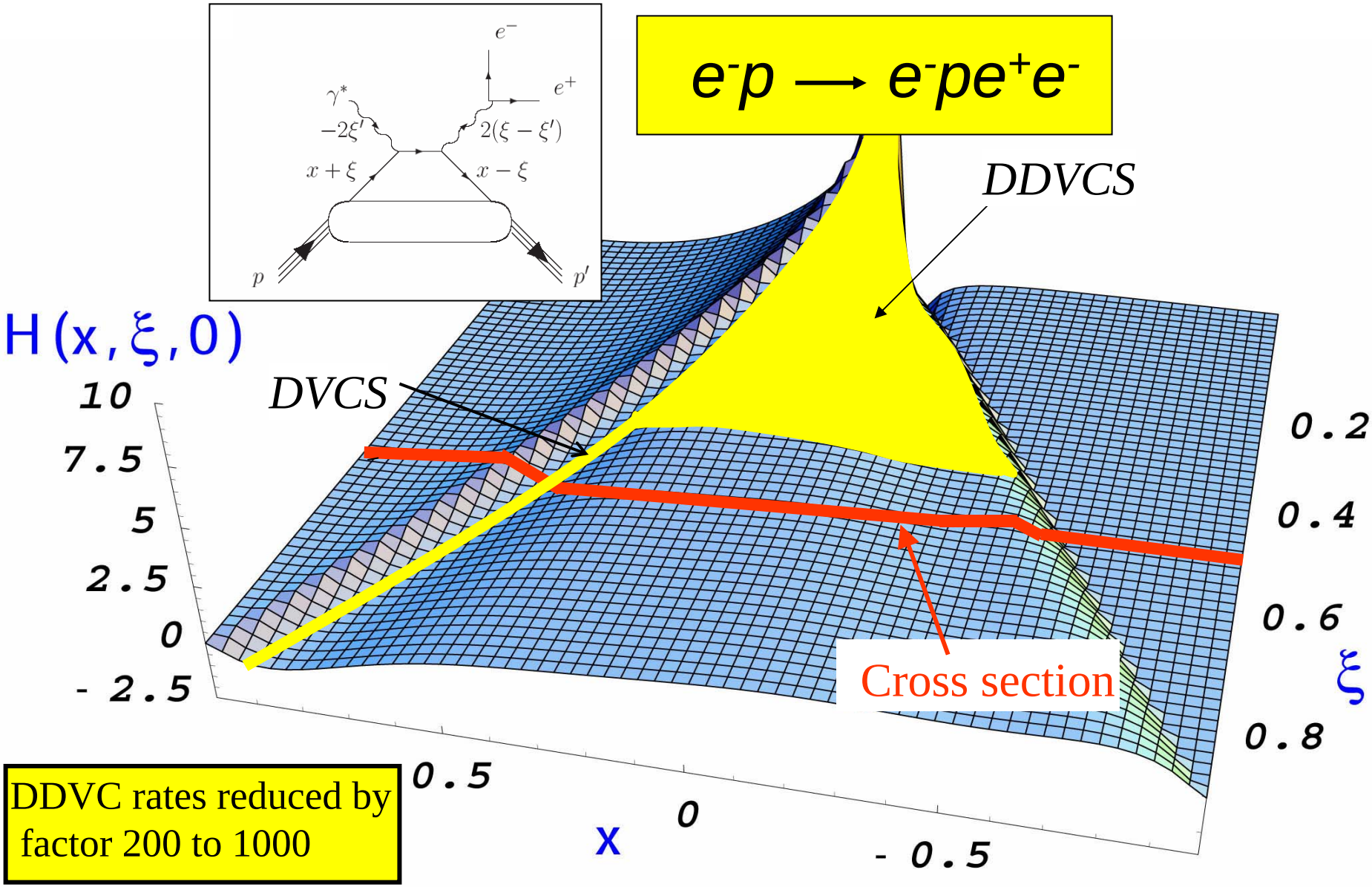
$$xq(x) = ax^b(1-x)^c(1+\epsilon\sqrt{x}+\gamma x)$$

# Access GPDs through x-section & asymmetries




**DDVCS covers entire region ! Ji sum-rule but not in first 5 years**

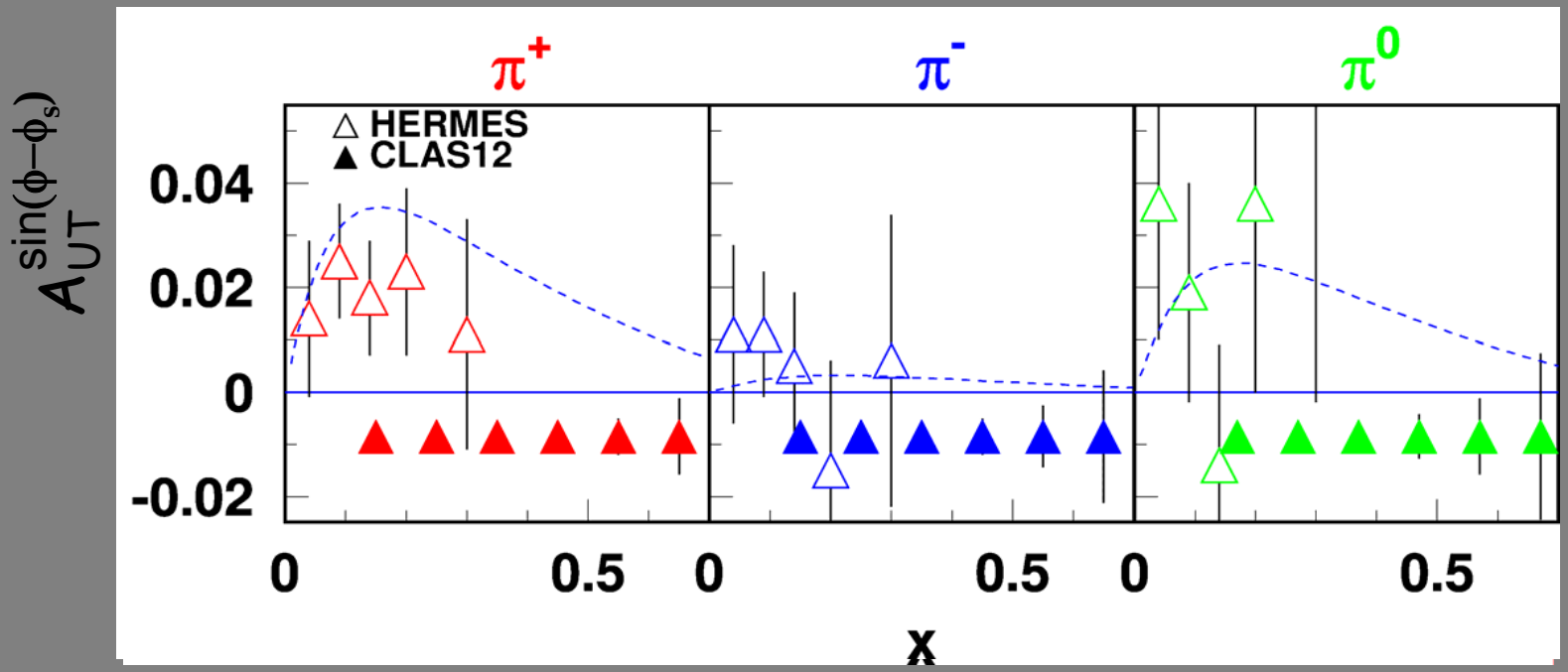
# Double DVCS (DDVCS)




DDVC rates reduced by factor 200 to 1000

# SIDIS Azimuthal Asymmetry - Sivers effect

## - accessing Ji Sum-rule (again not first 5 years)




- Probes orbital angular momentum of quarks by measuring the imaginary part of s-p-wave interference in the amplitude.

- Extraction of Sivers function $f_{1T}^{\perp}$ from asymmetry.

# DRAFT OUTLINE OF FIRST 5 YEARS OF UPGRADE OPERATION

# Hall B

- One year of running with unpolarized target at **11 GeV** (DVCS, NΔ at high $Q^2$)
- ½ year of running with longitudinally polarized $H_2$ target at **11 GeV**

  (Single Spin Asymmetry, $A^1_p$ at large x, Δd and Δu)

# Hall B…..

- ½ year **11 GeV** unpolarized D: Bonus d/u
- ½ year of running with nuclear targets at **11 GeV** (hadron attenuation, sea/valence, quark energy loss)
  - ½ year of running with polarized $^{7}$Li target at 8.8 GeV (polarized EMC effect)
  - ½ year of running transverse target polarization 8.8 GeV

**Total: 2.5 years of 11 GeV, 1.0 year of other**

# Hall C

- ¼ year of running for x > 1 at **11 GeV**
- ½ year of $A_1^n$ (and $d_2^n$ ) at **11 GeV**
- ¼ year of **11 GeV** running for L/T separations (pion form factor and separated structure functions)
- ½ year of running on DISparity at **11 GeV**

$(2C_{2u} - C_{2d})$

# Hall C…..

- ¾ year of $G_E^p$ at 8.8 GeV ($Q^2$ = 12 or 14 $GeV^2$)
- ½ year of deuteron photodisintegration at 6.6/8.8 GeV
- ¾ year of lower than **11 GeV** running for L/T separations (pion form factor and separated structure functions)

**Total: 1.5 years of 11 GeV, 2 years of other**

# Hall A

– One year of the first large installation experiment at **11 GeV** (start of the program to measure CSV, HT, and d/u at large x)

- One year of hypernuclear spectroscopy at 2.2 GeV
- ½ year of A(e,e'p) studies at high $Q^2$ at 6.6/8.8 GeV
- ½ year of few body form factor measurements at 8.8 GeV

**Total: 1 year of 11 GeV, 2 years of other**

# NSAC Long Range Plan, April 2002 "Opportunities in Nuclear Science"

- **<u>Recommendation 4:</u>**

**We strongly recommend the upgrade of CEBAF at Jefferson Laboratory to 12 GeV as soon as possible.**

**The 12 GeV upgrade of the unique CEBAF facility is critical for our continued leadership in the experimental study of hadronic matter. This upgrade will provide new insights into the structure of the nucleon, the transition between the hadronic and quark/gluon descriptions of matter, and the nature of quark confinement.**

"QUARKS. NEUTRINOS. MESONS. ALL THOSE DAMN PARTICLES YOU CAN'T SEE. THAT'S WHAT DROVE ME TO DRINK. BUT NOW I CAN SEE THEM."

# World Community in 2012 and Beyond

- With Upgrade will have three major new facilities investigating nuclear physics at hadronic level (QCD) : GSI (Germany), J-PARC (Japan) and JLab*

- Complementary programs (e.g. charmed vs light-quark exotics, hadrons in-medium….)

- Wonderful opportunities to build international community and take our field to a new level

* Unique: only electromagnetic machine

# End of Presentation

- $d_2$ is related to the color field in the nucleon

$$\langle PS|\frac{1}{4}\bar{\psi}g\tilde{F}^{\sigma(\mu}\gamma^{\nu)}\psi|PS\rangle = 2d_2 S^{[\sigma}P^{(\mu]}P^{\nu)} \ ,$$

where $\tilde{F}^{\mu\nu} = (1/2)\epsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}$, and $(\cdots)$ and $[\cdots]$ denote symmetrization and antisymmetrization of indices respectively.

- $d_2$ is a linear combination of the electric $\chi_E$ and magnetic $\chi_B$ polarizabilities

When a nucleon is polarized in its rest frame, how does the gluon field inside respond?

Define the color-singlet operators as:

$$O_B = \psi^\dagger g\vec{B}\psi$$

$$O_E = \psi^\dagger\vec{\alpha}\times g\vec{E}\psi$$

Define the gluon-field polarizabilities $\chi_B$ and $\chi_E$ in the rest frame of the nucleon as:

$$\langle PS|O_{B,E}|PS\rangle = \chi_{B,E}2M^2\vec{S}$$

$$\boxed{d_2 = (2\chi_B + \chi_E)/3}$$

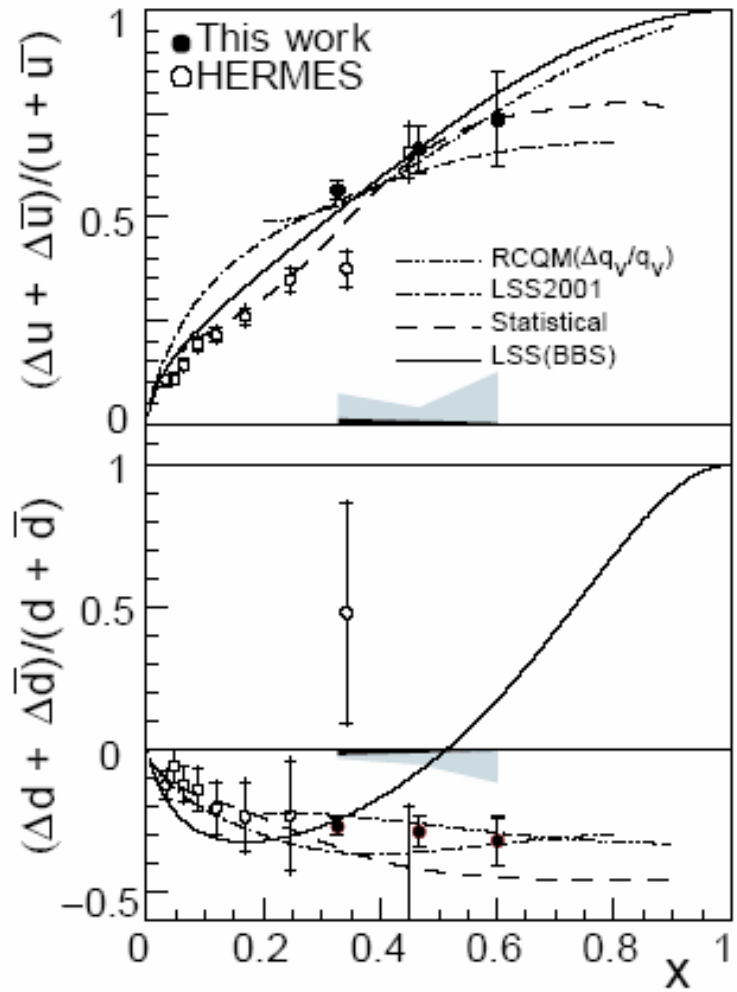
**The $d_2$ matrix element is a measure of the response of the color magnetic and electric fields to the polarization of the nucleon**

# S=0 diquark dominance

d suppressed wrt u

$A_1^n$ ! 1, x ! 1

$\Delta u/u$ ! 1 ; $\Delta d/d$ ! -1/3




pQCD

$A_1^n$ ! 1 faster

because

$\Delta u / u$ <u>and</u> $\Delta d/d$ ! 1