Quark spin distributions in the proton at large x

Wally Melnitchouk

Jefferson Lab

Large-x PDFs

- Most direct connection between quark distributions and models of nucleon structure is via *valence* quarks

  → most cleanly revealed at $x > 0.4$

$$F_2^p \approx \frac{4}{9} x u_v + \frac{1}{9} x d_v$$

$$F_2^n \approx \frac{1}{9} x u_v + \frac{4}{9} x u_v$$

- Needed to understand backgrounds in searches for physics *beyond the Standard Model* in high-energy colliders *e.g.* the LHC

  → Q^2 evolution feeds *high* x, *low* Q^2 to *low* x, *high* Q^2 where *e.g.* Higgs, SUSY most likely to produce signals

Large-x PDFs

- Nonperturbative & perturbative QCD predictions for d/u ratio in $x \to 1$ limit:

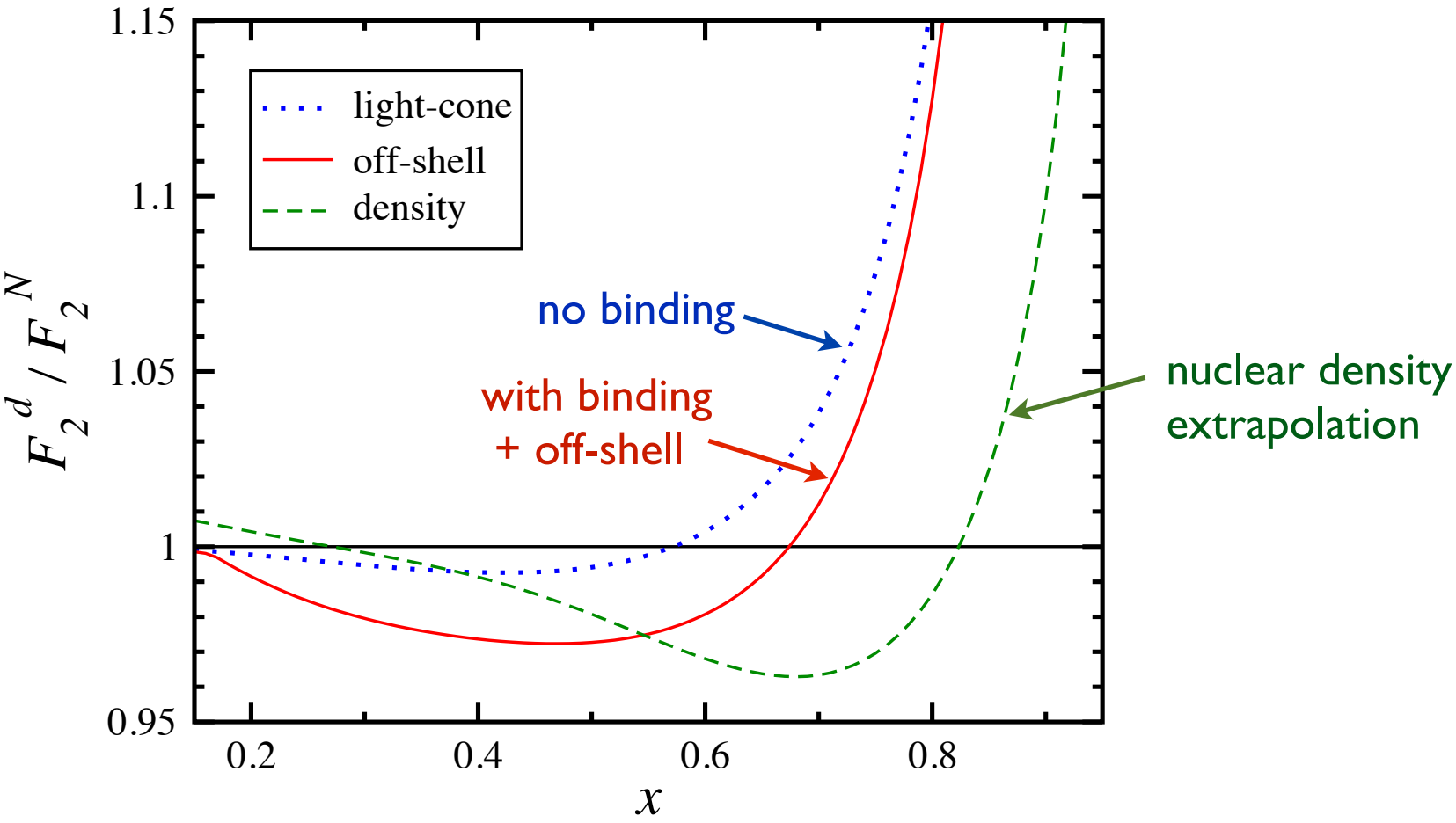
  - $d/u \to 1/2$ — SU(6) symmetry
  - $d/u \to 0$ — $S = 0$ qq dominance
  - $d/u \to 1/5$ — $S_z = 0$ qq dominance
  - $d/u \to \dfrac{4\,\mu_n^2/\mu_p^2 - 1}{4 - \mu_n^2/\mu_p^2}$ — local quark-hadron duality* ($\mu_{p,n}$ magnetic moments)

*see e.g. WM, Ent, Keppel Phys. Rep. **406**, 127 (2005)*

*structure function at $x \to 1$ given by elastic form factor at $Q^2 \to \infty$

EMC effect in deuteron

- No free neutron targets → use d as effective n target

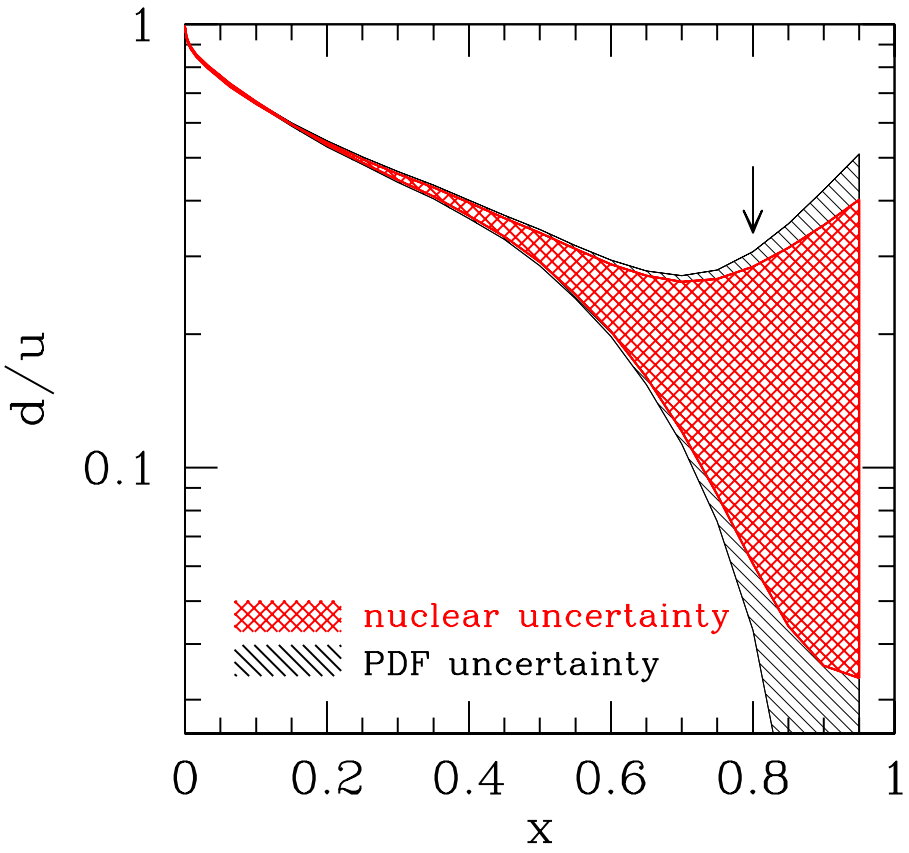


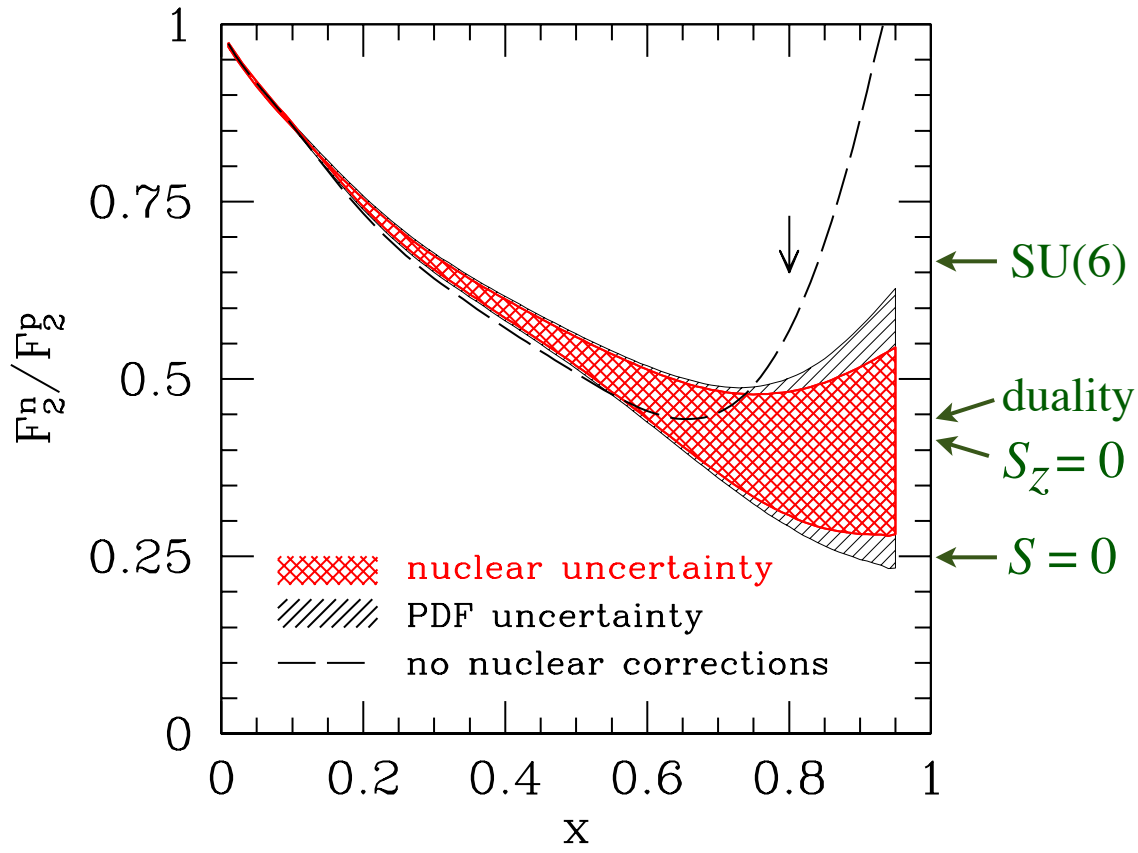
→ uncertainties in nuclear corrections at large x

(short-range NN interaction, N off-shell deformation)

leads to large uncertainties in d quark at $x > 0.5$

CJ (CTEQ-JLab) global PDF analysis



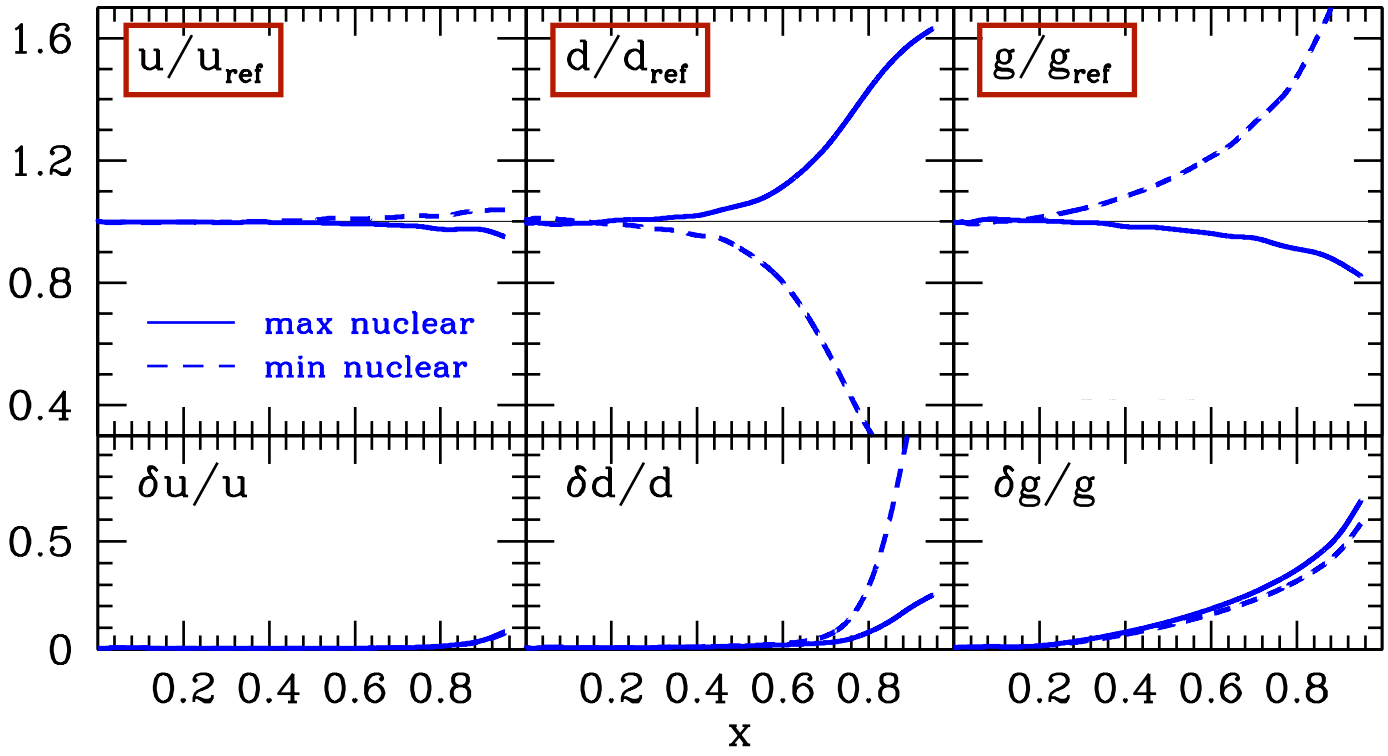


*Accardi et al., PRD **84**, 014008 (2011)*

→ nuclear correction uncertainties sizable at $x > 0.5$

→ $x \to 1$ limiting value depends critically on deuteron model

CJ (CTEQ-JLab) global PDF analysis



Accardi et al.
PRD ***84****, 014008 (2011)*

→ very little effect on u quark PDF
(tightly constrained by DIS & DY proton data)

→ gluon PDF anti-correlated with d quark
(g compensates for smaller d quark contribution in jet data)

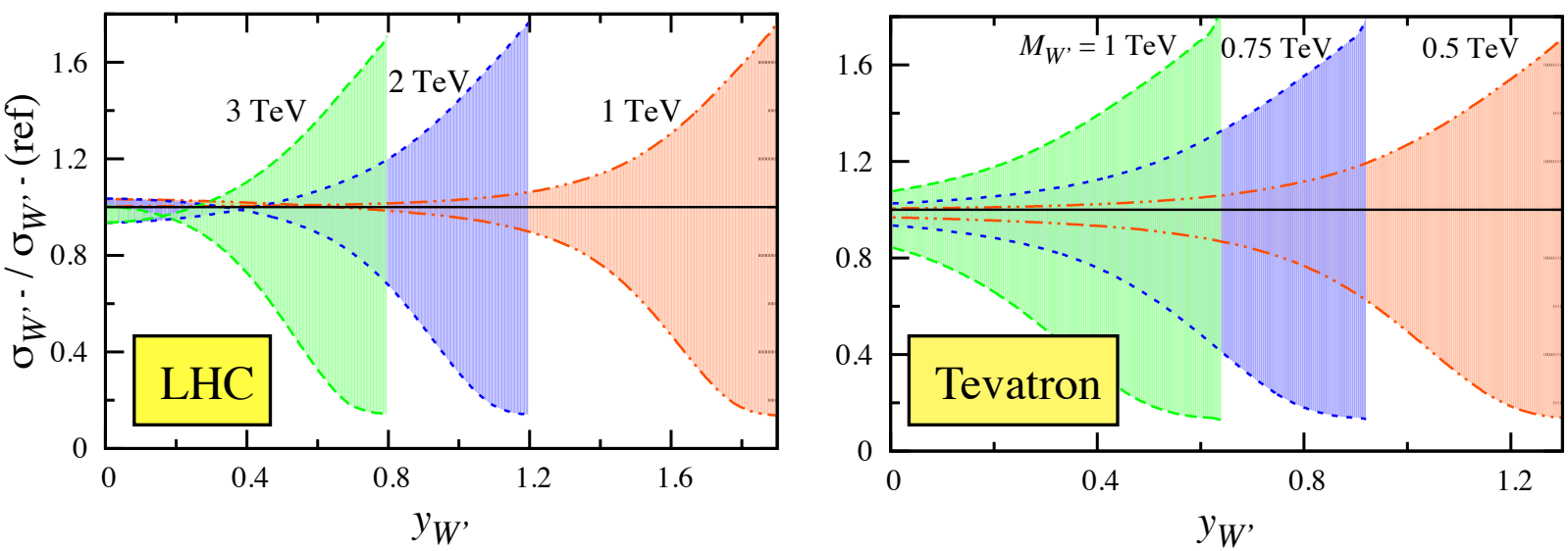
→ uncertainty in d feeds into larger uncertainty in g at high x

Heavy Z', W' boson production

- Observation of new physics signals requires accurate determination of QCD backgrounds — depend on PDFs!

  (since $x_{1,2} \sim M_{Z',W'}$, large-x uncertainties scale with mass!)

  - for W'^{-} production



→ dominated by $d * \bar{u}$ → dominated by $d * u + u * d$

> 100% uncertainties at large y !

Brady, Accardi, WM, Owens
arXiv:1110:5398

12 GeV d/u experiments

- Nuclear correction uncertainties expected to be resolved with new experiments at JLab–12 GeV uniquely sensitive to d quarks (up to $x \sim 0.85$)

→ "spectator" protons tagged in SIDIS from deuterium

$e\ d \to e\ p_{\rm spec}\ X$ ("BoNuS") E12-06-113

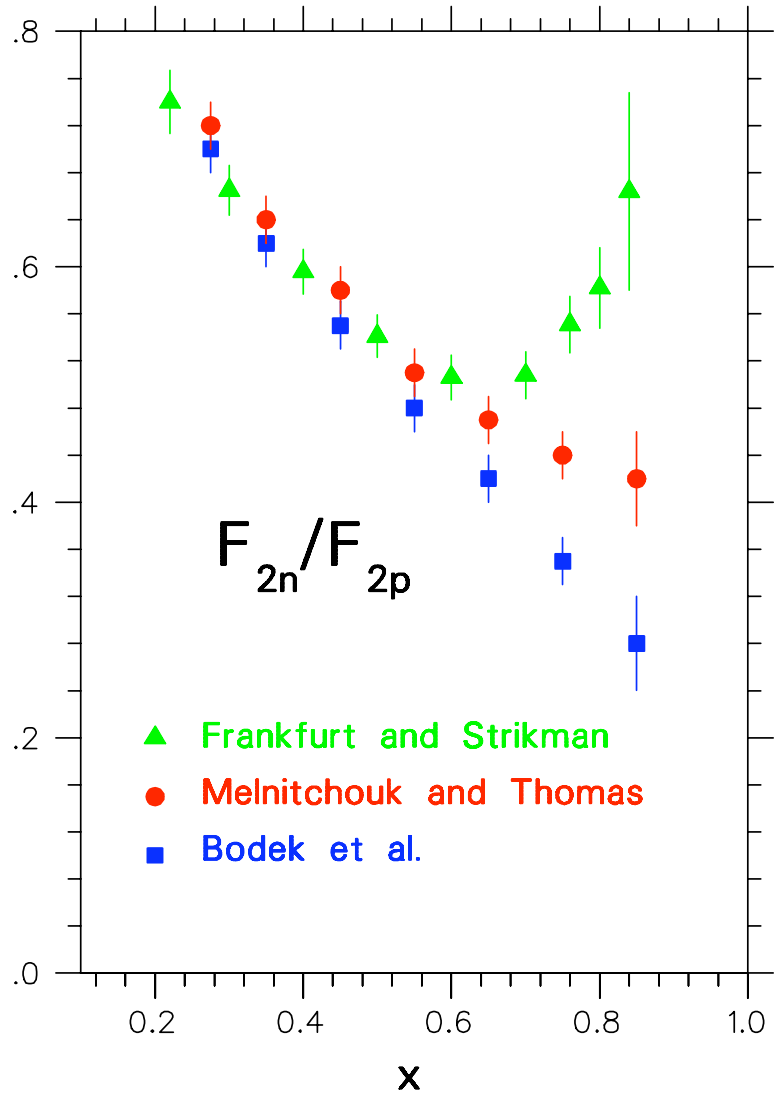
→ DIS from ^{3}He-tritium mirror nuclei

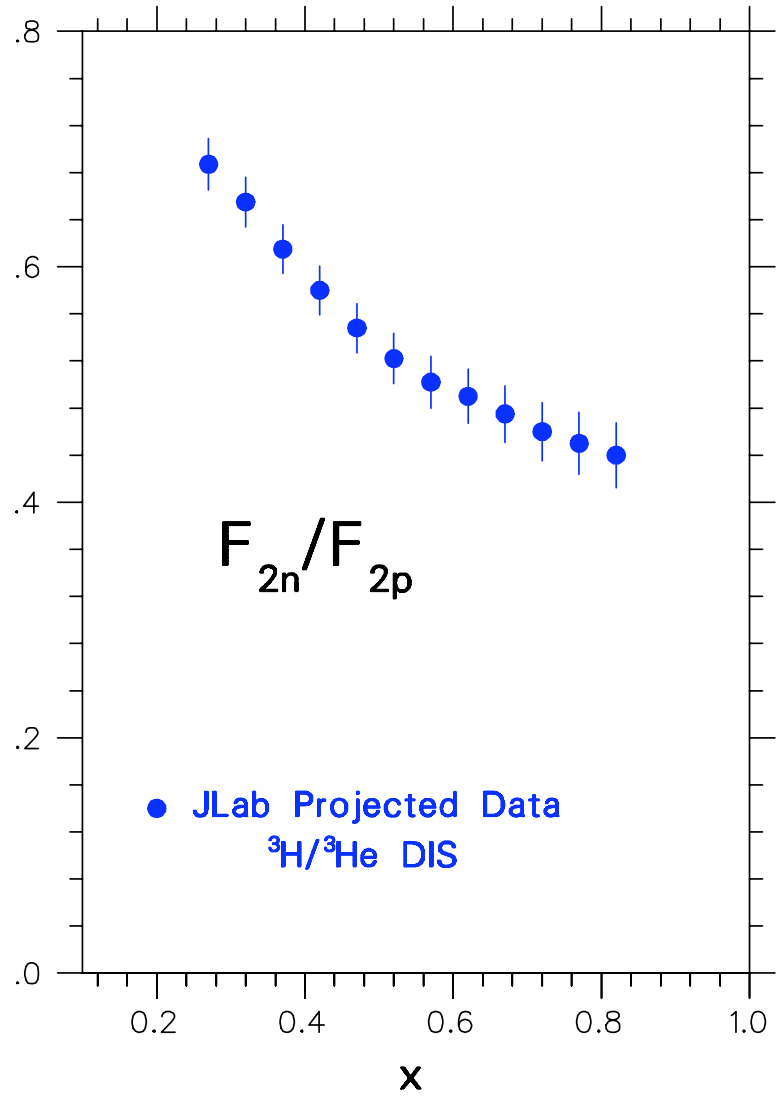
$e\ ^3{\rm He}(^3{\rm H}) \to e\ X$ ("MARATHON") E12-10-103

→ PVDIS from protons

$\vec{e}_L(\vec{e}_R)\ p \to e\ X$ ("SoLID") E12-10-007

12 GeV d/u experiments





→ will determine d/u free of nuclear uncertainties to $x \sim 0.8$

Spin-dependent PDFs at large x

- Nonperturbative & perturbative QCD predictions for $\Delta q/q$ ratio in $x \to 1$ limit:

  - $\Delta u/u \to 2/3$, $\Delta d/d \to -1/3$ } SU(6) symmetry

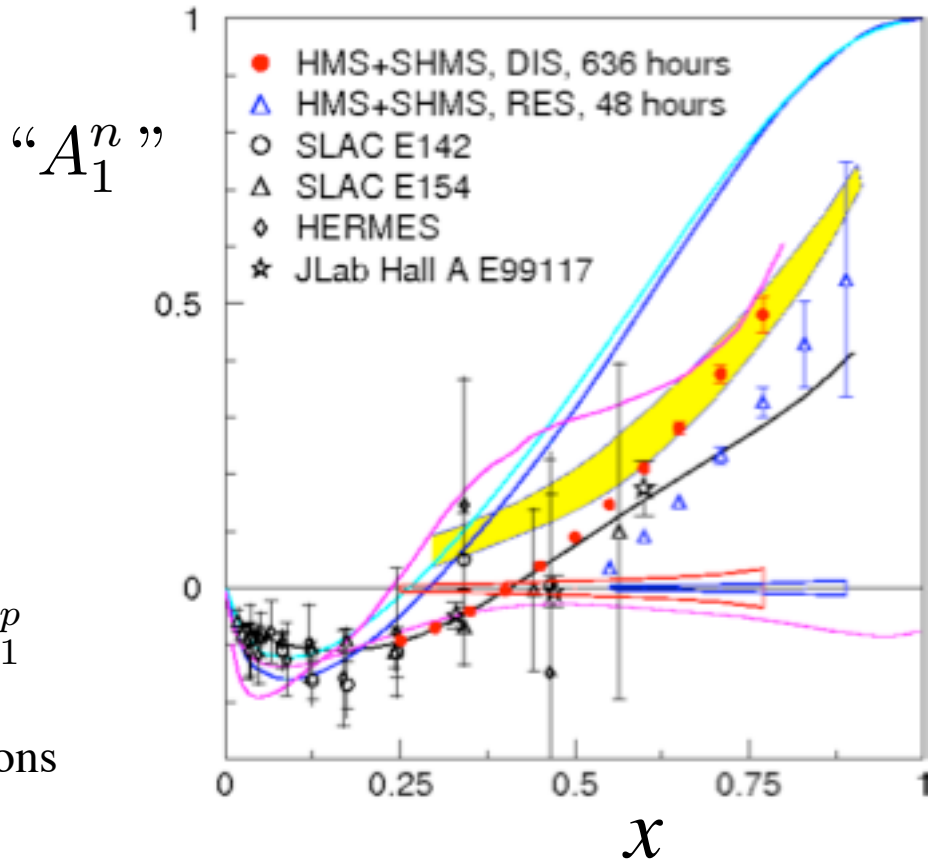
  - $\Delta u/u \to 1$, $\Delta d/d \to -1/3$ } $S = 0$ qq dominance

  - $\Delta u/u \to 1$, $\Delta d/d \to 1$ } $S_z = 0$ qq dominance *or* local duality

→ sign of d quark polarization uncertain at large x !

Spin-dependent PDFs at large x

- Inclusive DIS measurements from polarized ^{3}He at 12 GeV will constrain A_1^n and $\Delta d/d$ up to $x \sim 0.75$



E12-06-110

E12-06-122

$$A_1^{^3\mathrm{He}} \approx p_n\, A_1^n + 2\, p_p\, A_1^p$$

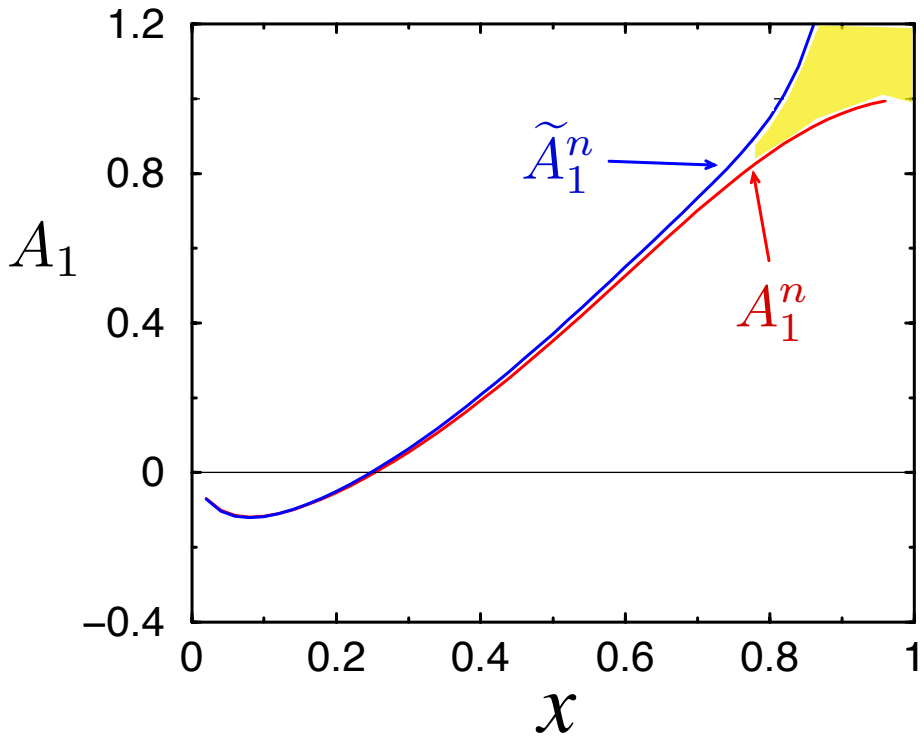
effective polarizations

→ planned measurement up to $x = 0.77$ (0.89) in DIS (resonance)

Nuclear effects in spin structure functions

- At $x \gtrsim 0.7$, nuclear correction uncertainties also expected to be large in polarized structure functions & asymmetries

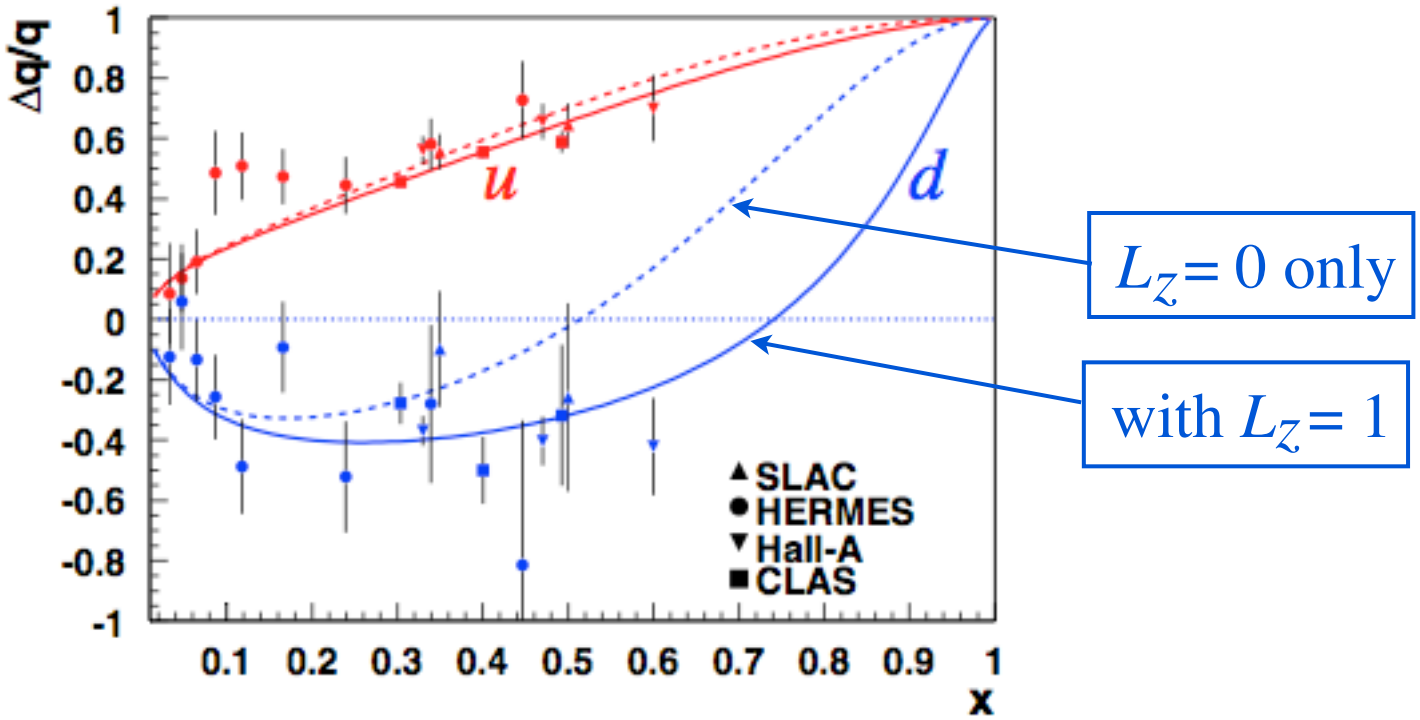
  → will contaminate extraction on free $\vec{n}$ structure



Nuclear effects in spin structure functions

- At $x \gtrsim 0.7$, nuclear correction uncertainties also expected to be large in polarized structure functions & asymmetries

  → difficult to observe $\log^2(1-x)$ enhancement of $q^{\downarrow}$ predicted from $L_z = 1$ component of wave function



Avakian, Brodsky, Deur, Yuan
*PRL **99**, 082001 (2007)*

Nuclear effects in spin structure functions

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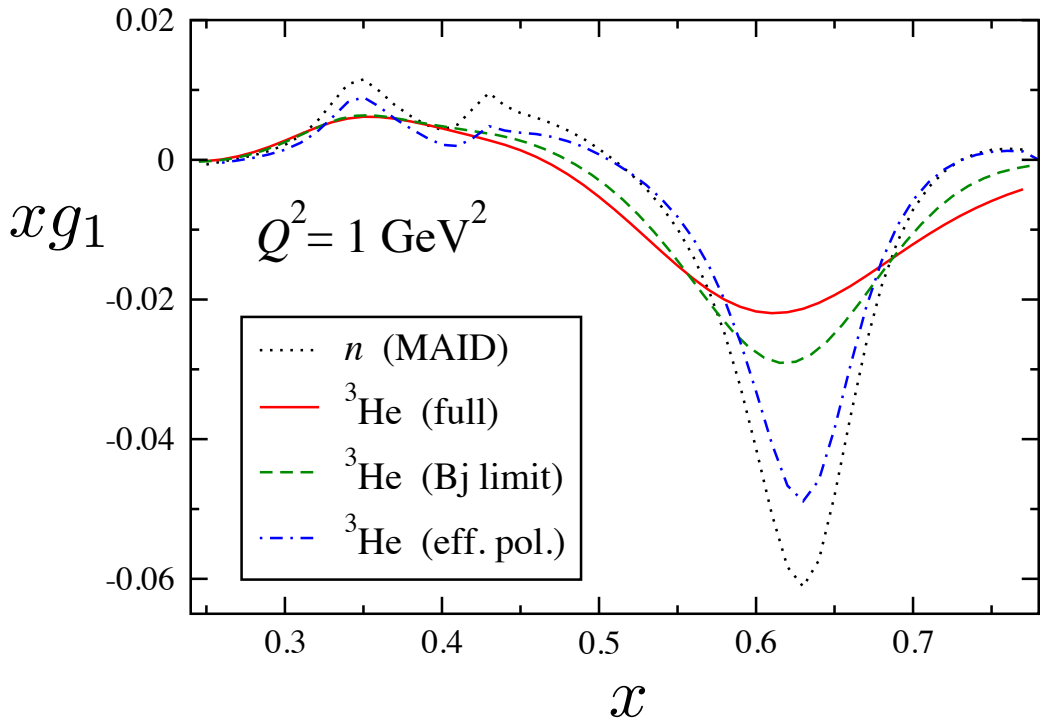
  → more significant effects expected in resonance region at even smaller x



Kulagin, WM
*PRC **78**, 065203 (2008)*

Possible $\Delta q/q$ experiments?

- Are experiments which minimize or eliminate nuclear uncertainties at large x feasible?

  → DIS from *polarized* ^{3}He-tritium mirror nuclei

  $\vec{e}\ ^3\overrightarrow{\mathrm{He}}(^3\overrightarrow{\mathrm{H}}) \to e\ X$ ("Polarized MARATHON")

Possible $\Delta q/q$ experiments?

- Polarized EMC ratios for A=3 mirror nuclei

$$R^{^3\mathrm{He}} = \frac{g_1^{^3\mathrm{He}}}{2g_1^p + g_1^n} \qquad R^{^3\mathrm{H}} = \frac{g_1^{^3\mathrm{H}}}{g_1^p + 2g_1^n}$$

→ extract n/p ratio from measured ^{3}He-^{3}H ratio

$$\frac{g_1^n}{g_1^p} = \frac{g_1^{^3\mathrm{He}}/g_1^{^3\mathrm{H}} - 2\mathcal{R}}{\mathcal{R} - 2g_1^{^3\mathrm{He}}/g_1^{^3\mathrm{H}}}$$

→ model dependence of $\mathcal{R} = R^{^3\mathrm{He}}/R^{^3\mathrm{H}}$ expected to be small

Possible $\Delta q/q$ experiments?

- Test Bjorken sum rule for A=3 nuclei

$$\int_0^1 dx \, (g_1^{^3\mathrm{H}} - g_1^{^3\mathrm{He}}) = g_A^*$$

→ $\sim 4\%$ smaller than g_A for free nucleon

→ Δ degrees of freedom in A=3 nuclei

Bissey, Guzey, Strikman, Thomas
PRC ***65****, 064317 (2002)*

→ polarized tritium target?

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Possible $\Delta q/q$ experiments?

- Unpolarized electron – polarized proton asymmetry

$$A^{\rm PV} = \frac{\sigma^{\rm PV}(S_L) - \sigma^{\rm PV}(-S_L)}{\sigma^{\rm PV}(S_L) + \sigma^{\rm PV}(-S_L)}$$

$$= \frac{G_F Q^2}{2\sqrt{2}\pi\alpha\, F_1^\gamma} \left(g_A^e\, f(y)\, g_1^{\gamma Z} + g_V^e\, g_5^{\gamma Z} \right)$$

$1 - 4\sin^2\theta_W$ suppressed

→ $g_1^{\gamma Z} = \sum_q e_q\, g_V^q\, \Delta q$

independent combination of Δu and Δd

→ extract Δd free of nuclear corrections!

Possible $\Delta q/q$ experiments?

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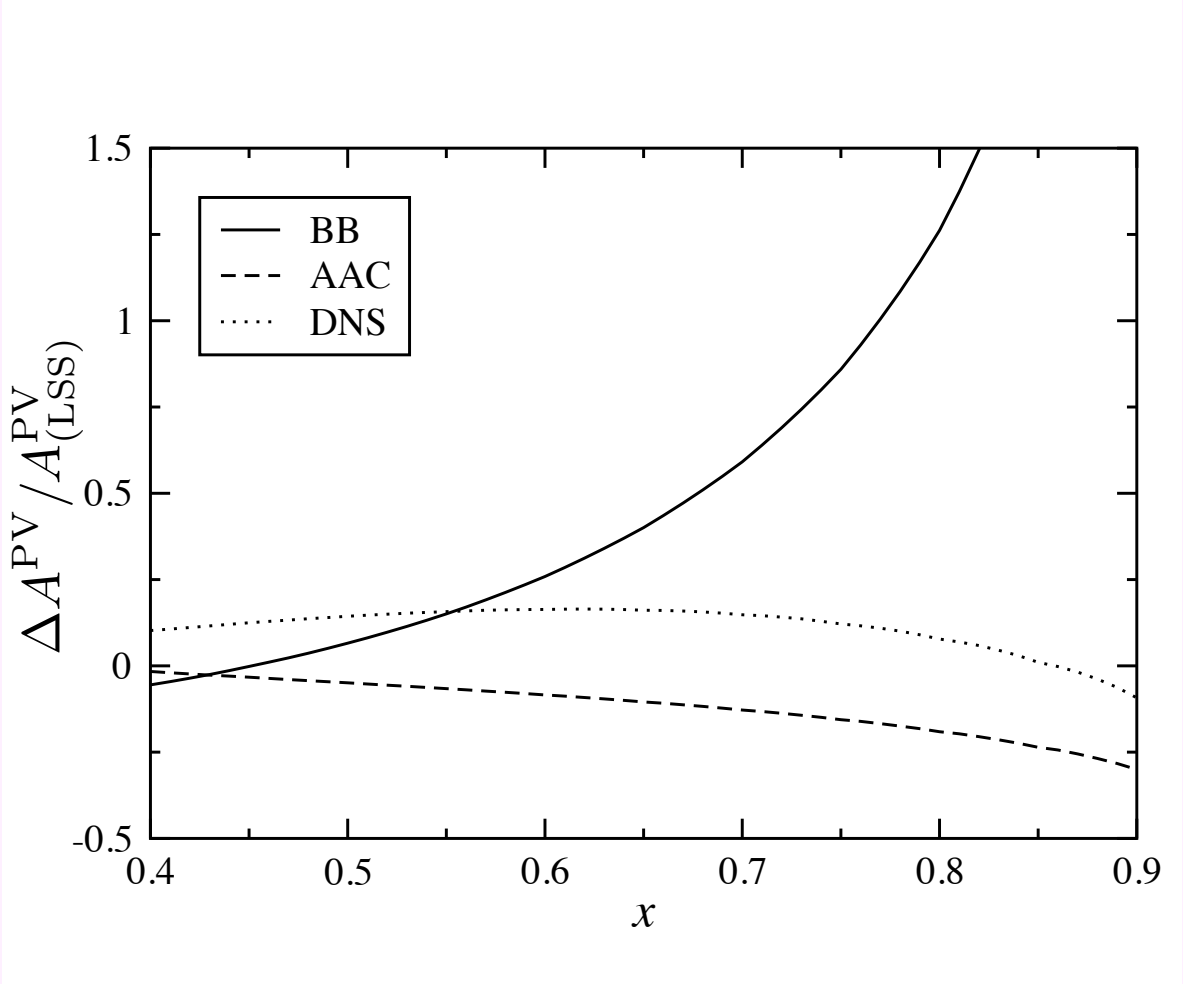

→ sensitivity to Δd at large x,
free of nuclear corrections

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  $\vec{e}\ \vec{d} \to e\ p_{\mathrm{spec}}\ X$ ("BoNuS")

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→ ~~"spectator" protons tagged in SIDIS from deuterium~~

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→ other methods?

(polarized $^3\vec{\mathrm{He}}$ in BoNuS?)