# Possible Measurements of Polarized EMC Effect

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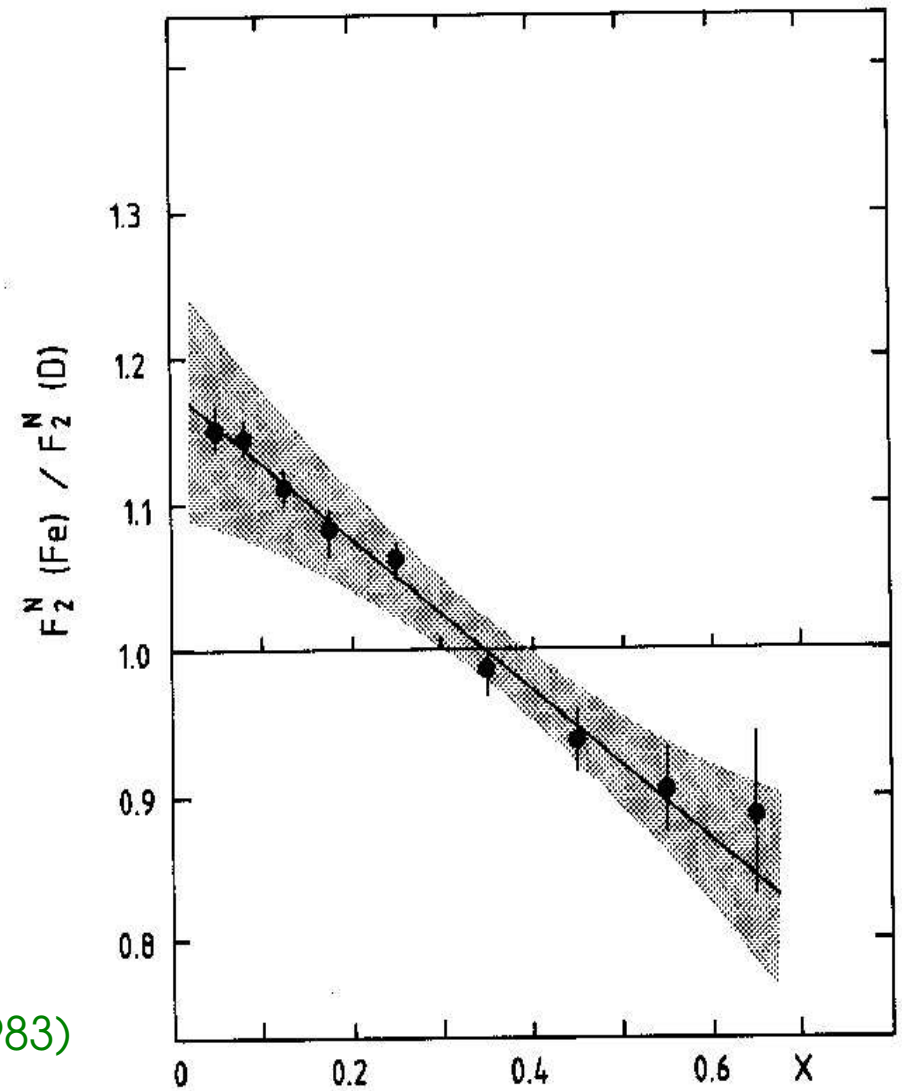
Argonne National Lab
December 06, 2005

- What is Polarized EMC Effect and What Do We Expect?
- What Are Our Challenges?
- Possible Measurement on the neutron using $^{129}$Xe
  - Polarized 129Xe target
  - Uncertainty estimation
  - Nuclear corrections
- Summary and Outlook

# EMC Effects (Unpolarized)

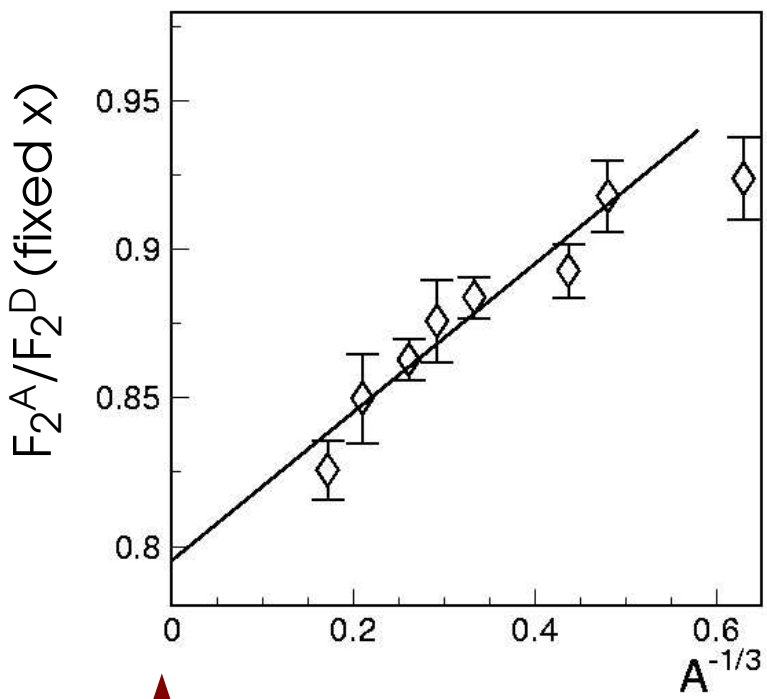
- In 1983, first data on $F_2^{Fe}/F_2^{D}$ showed significant deviation from 1;
  - Expected:
    - (anti) shadowing at low x
    - >1 at high x
  - Not expected:
    - $F_2^{Fe}/F_2^{D}<1$ for $0.3<x<0.7$



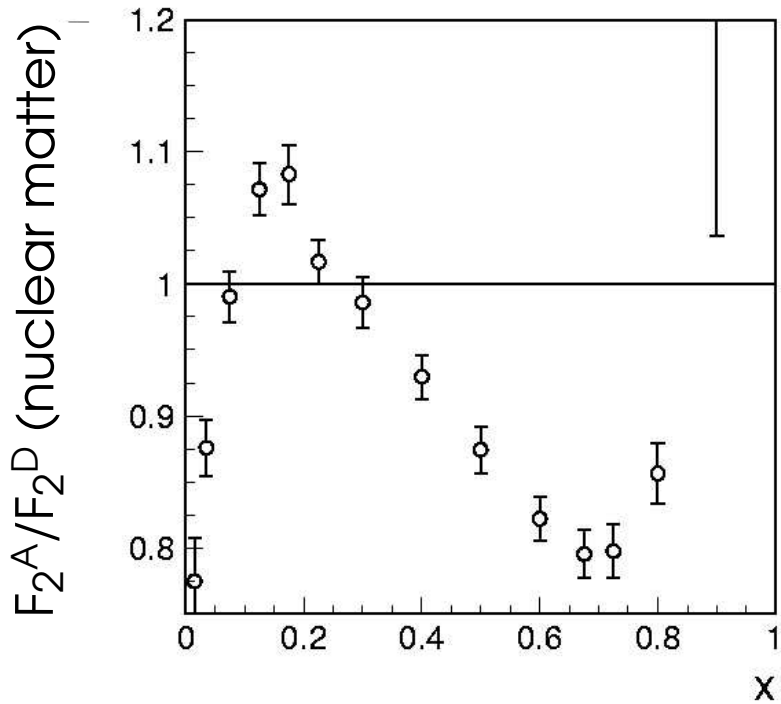

J. Aubert et al., Phys. Lett. B123, 275 (1983)

# EMC Effects (Unpolarized)

- Since then, large amount of data on $F_2^A/F_2^D$, wide A, x and $Q^2$ ranges;
- Linear in $A^{-1/3}$, nearly independent of $Q^2$ ;




nuclear matter (A=∞)




I. Sick, D. Day, Phys. Lett. B274, 16 (1992)

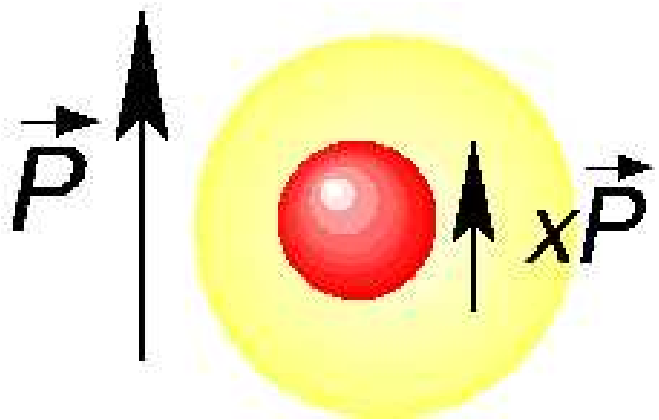
# EMC Effects (Unpolarized)

- People have been strived to understand/explain it theoretically
  - No consistent explanation for the whole 0<x<1 region.

For a review of theories and data, see: → D.F. Geesaman, K. Saito, A.W. Thomas, Annu. Rev. Nucl. Part. Sci. 45, 337, (1995)

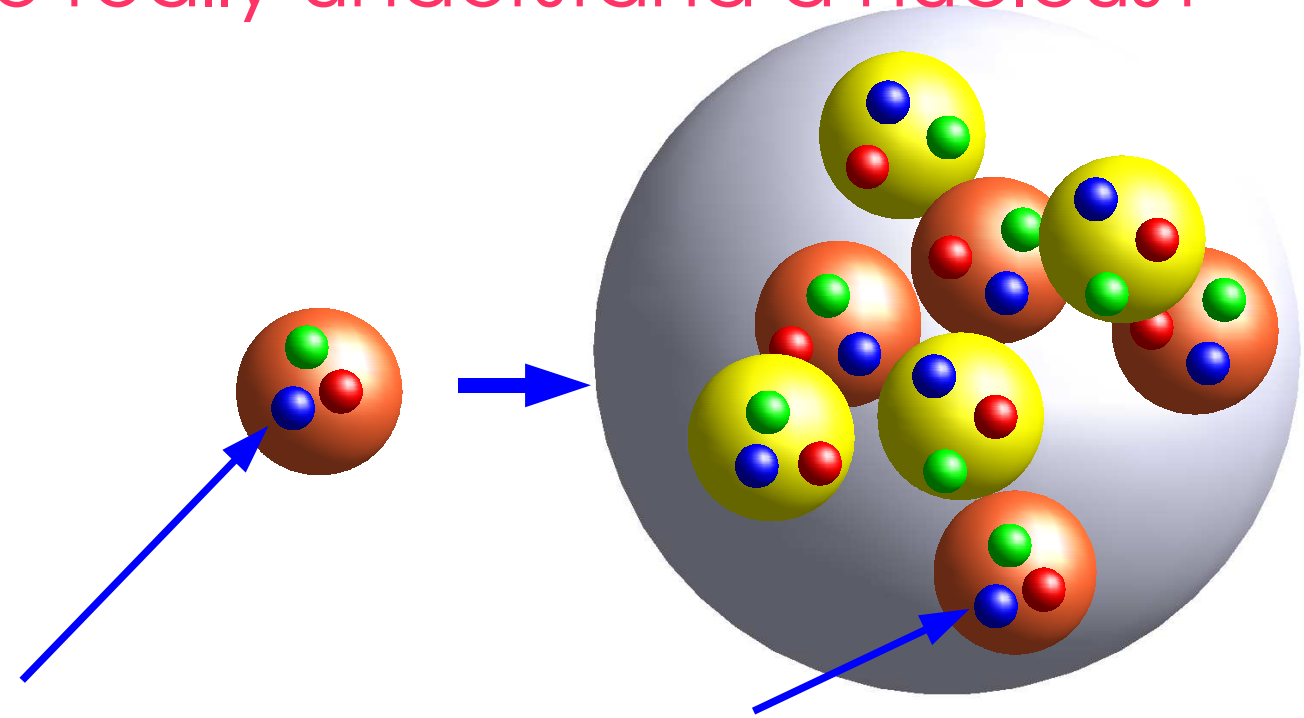
- The internal structure of the nucleon changes in nuclear matter

$$F_2(x) = 2\,xF_1(x) = x\,\Sigma_i e_i^2 [q_i(x)]$$




  - $q_i(x)$ describes how quarks carry nucleon's momentum

# Do we really understand a nucleus?



Q: are these quarks behaving the same as those ?

A: Probably Not!

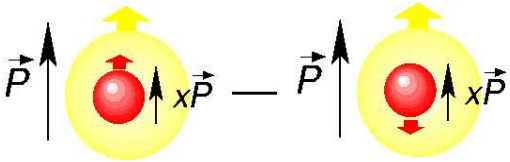
- $q_i^A(x) \neq q_i(x)$, reveal more on how strong interaction governs the behavior of quarks and gluons

# Polarized EMC Effects (theories)

- How does the internal spin structure of the nucleon changes in nuclear matter?

$$g_1(x) = \frac{1}{2}\Sigma_i e_i^2[q_i^{\uparrow}(x) - q_i^{\downarrow}(x)] = \frac{1}{2}\Sigma_i e_i^2[\Delta q_i(x)]$$

$$\Delta u, \Delta d$$




- Dynamic rescaling

  F.E. Close, R. G. Roberts, G.G. Ross, Nucl. Phys. B 296, 582 (1988)

- Nuclear shadowing + enhancement

  L. Frankfurt, V. Guzey, M. Strikman, Phys. Lett. B381, 379 (1996)
  V. Guzey, M. Strikman, Phys. Rev. C 61, 014002 (1999)

- Chiral quark-soliton model

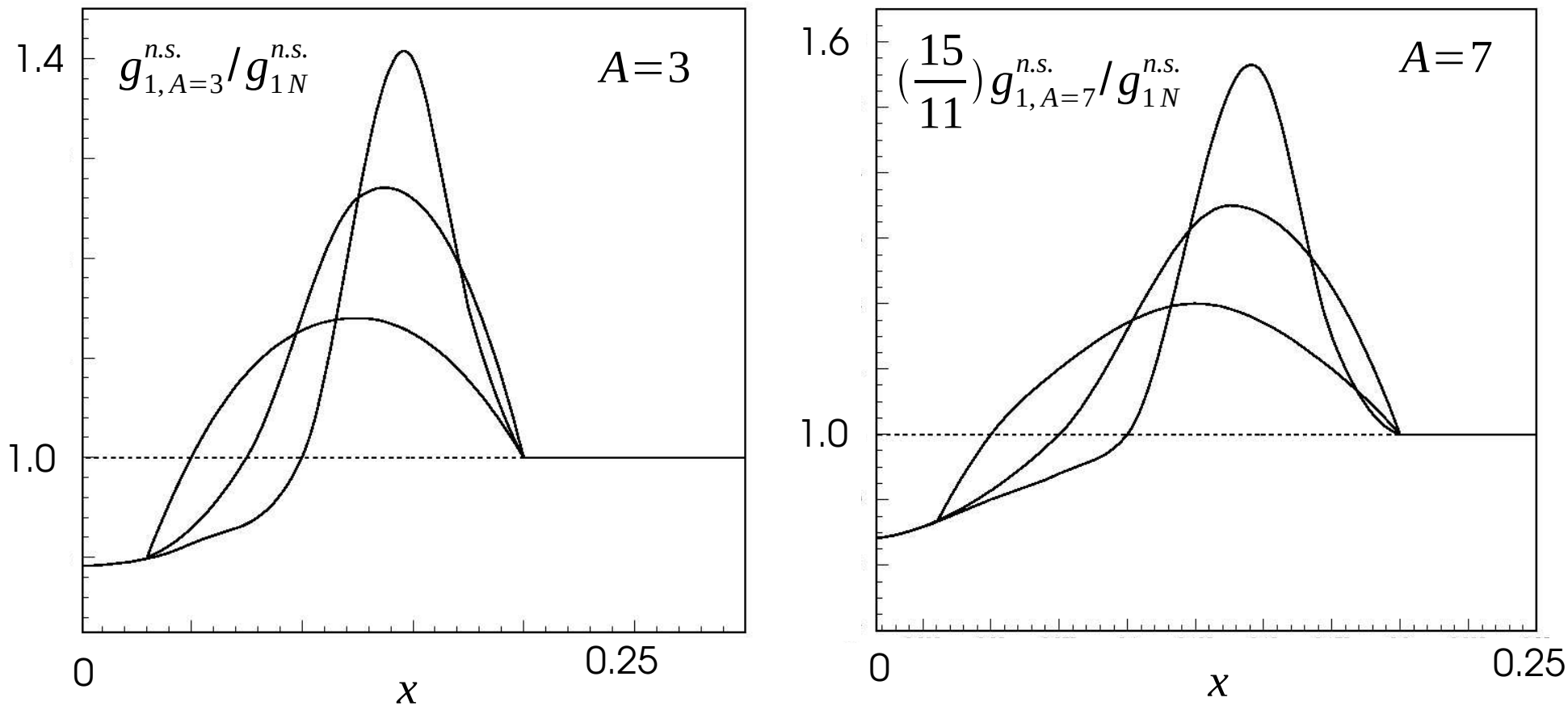
  J. R. Smith, G.A. Miller, Phys. Rev. C 72, 022203 (R) (2005)

- Modified NJL model

  I.C. Cloet, W. Bentz, A.W. Thomas, Phys. Rev. Lett. 95, 052302, (2005)

# Polarized EMC Effects (theories, cont.)

- Nuclear shadowing + enhancement: $g_1^{n.s.}=g_1^{p}-g_1^{n}$

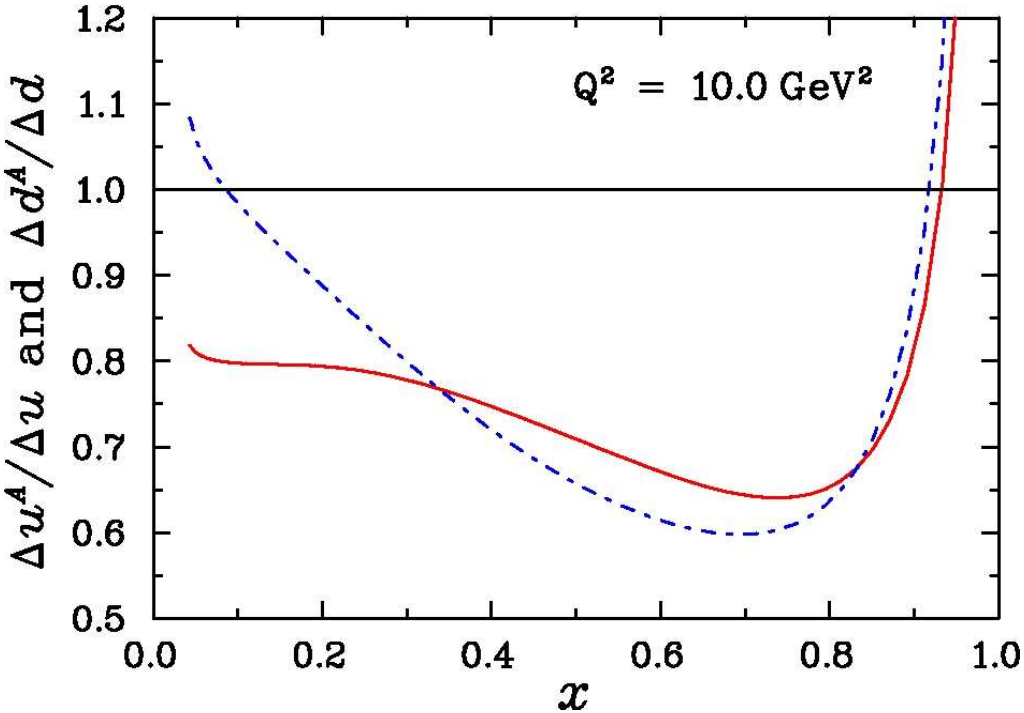


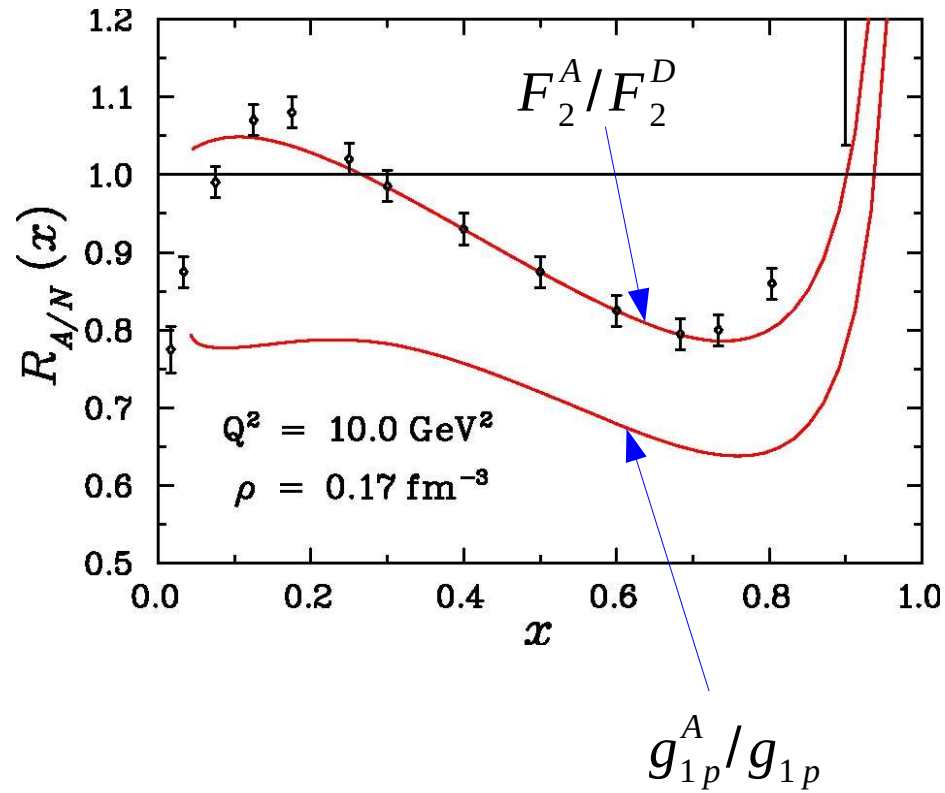

L. Frankfurt, V. Guzey, M. Strikman, Phys. Lett. B381, 379 (1996)

V. Guzey, M. Strikman, Phys. Rev. C 61, 014002 (1999)

# Polarized EMC Effects (theories, cont.)

- Quark-Meson Coupling
  + Modified NJL model



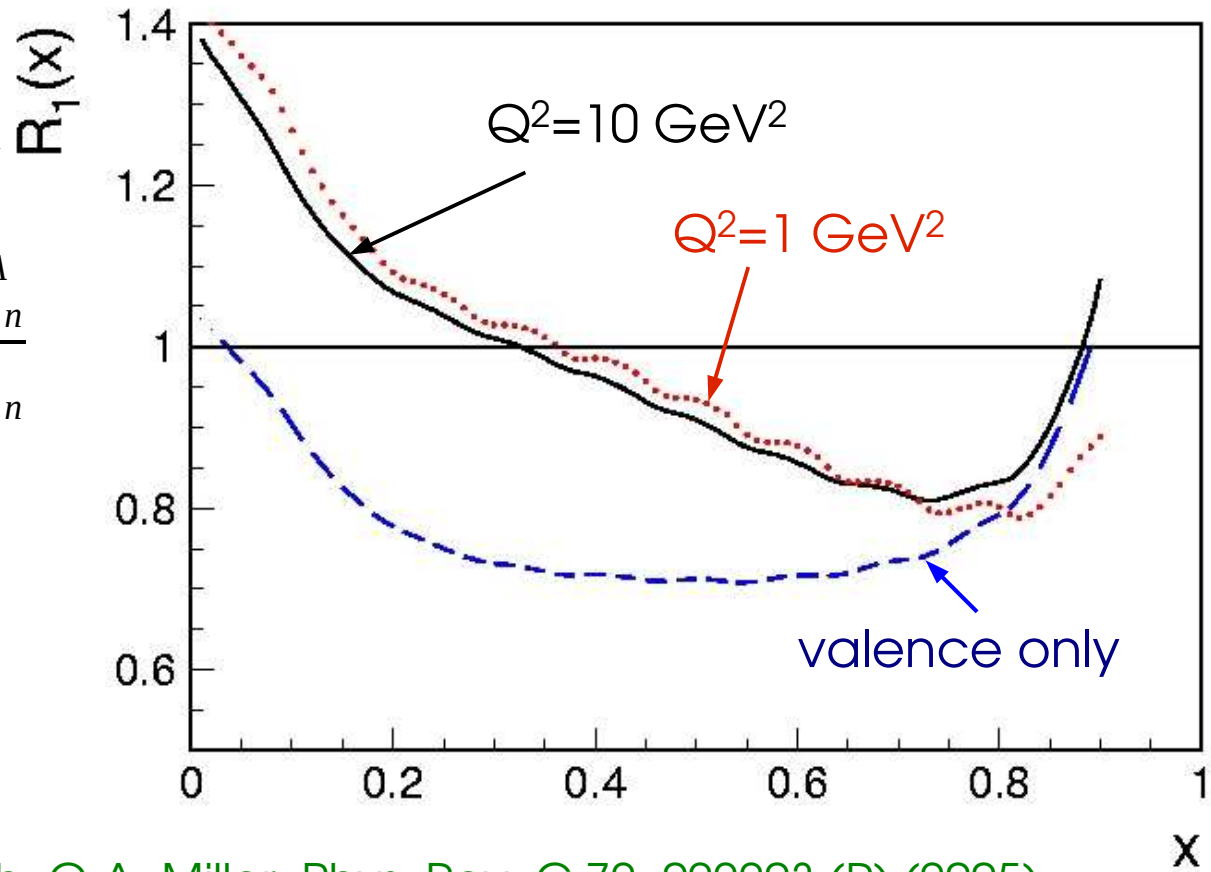




I.C. Cloet, W. Bentz, A.W. Thomas, Phys. Rev. Lett. 95, 052302, (2005)

# Polarized EMC Effects (theories, cont.)

- Chiral quark-soliton (CQS) model
  - $g_1^{n.s.}$ (isovector) ~ O(Nc); $g_1$(isoscalar) ~ $g_1^p+g_1^n$~($\Delta u+\Delta d$) ~ O(1)

$$\frac{g_{1p}^A - g_{1n}^A}{g_{1p} - g_{1n}}$$



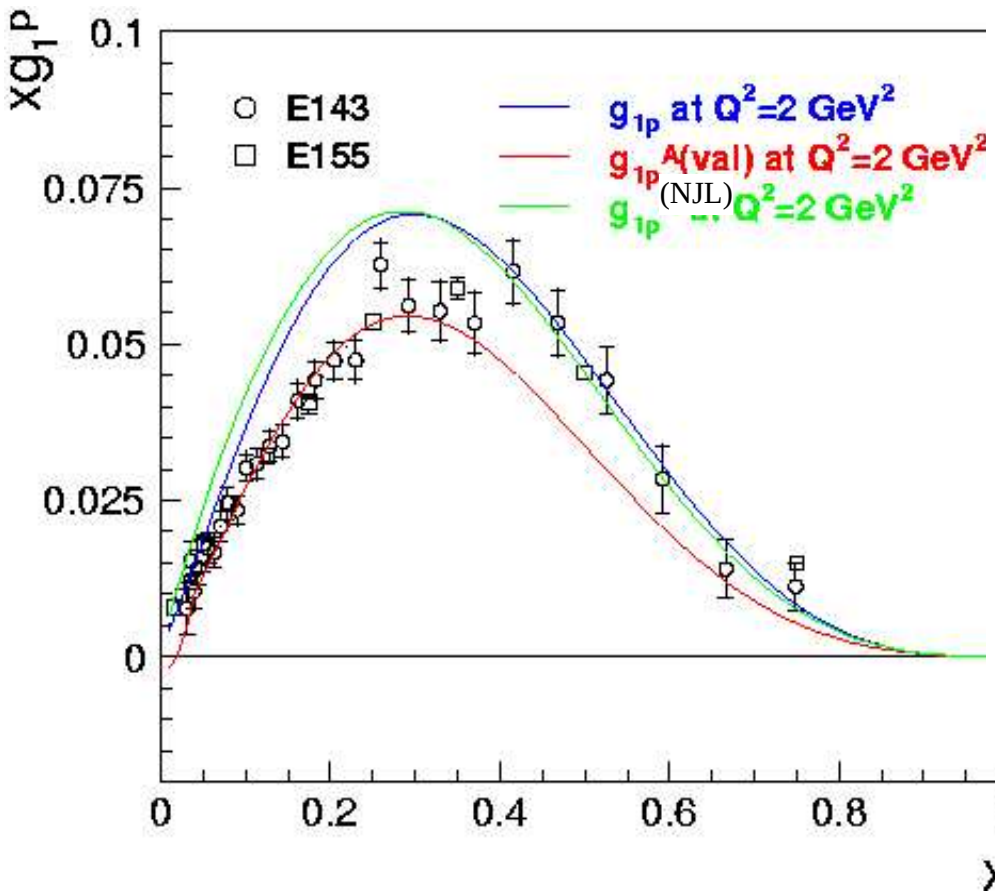

J. R. Smith, G.A. Miller, Phys. Rev. C 72, 022203 (R) (2005)

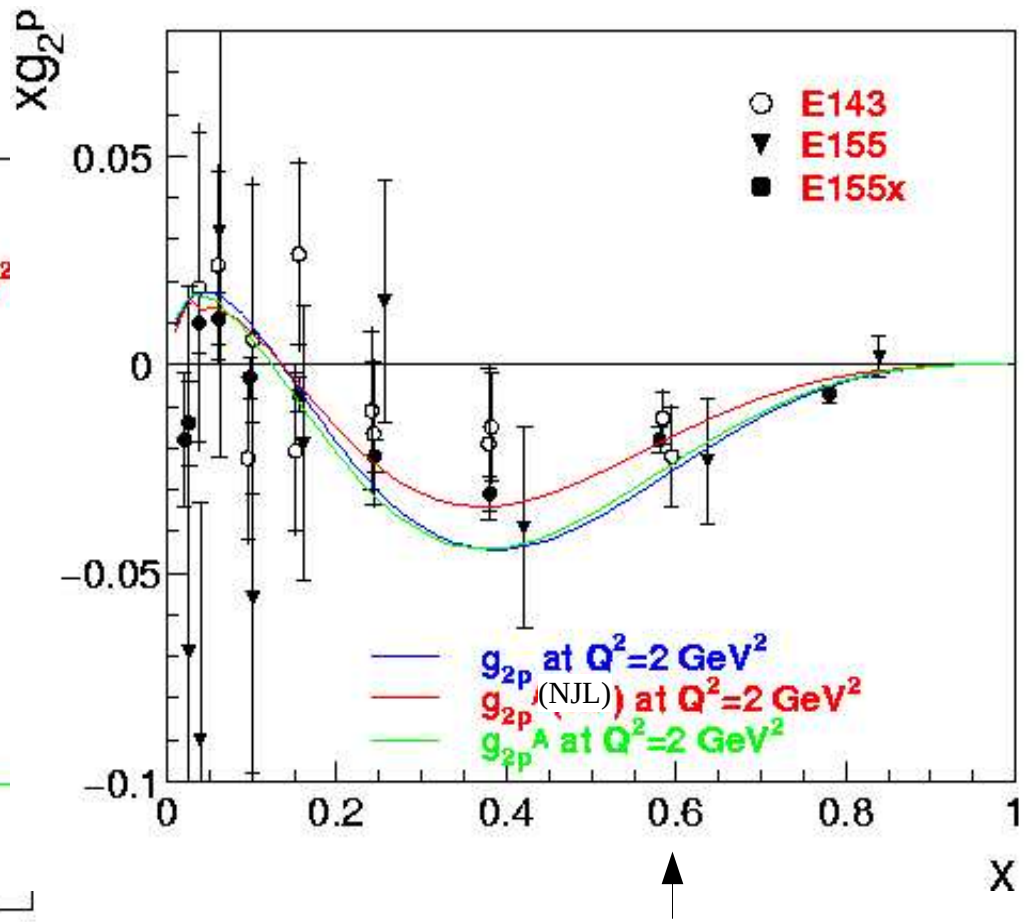
# Polarized EMC Effects on $g_{1,2}^p$

Free nucleon $g_{1,2p}$ from ave. (4) pol. PDF fits;

$g_{1,2p}^A$ from Pol. PDF + NJL/QSM

$g_{1,2p}^A$ from Pol. PDF + CQS



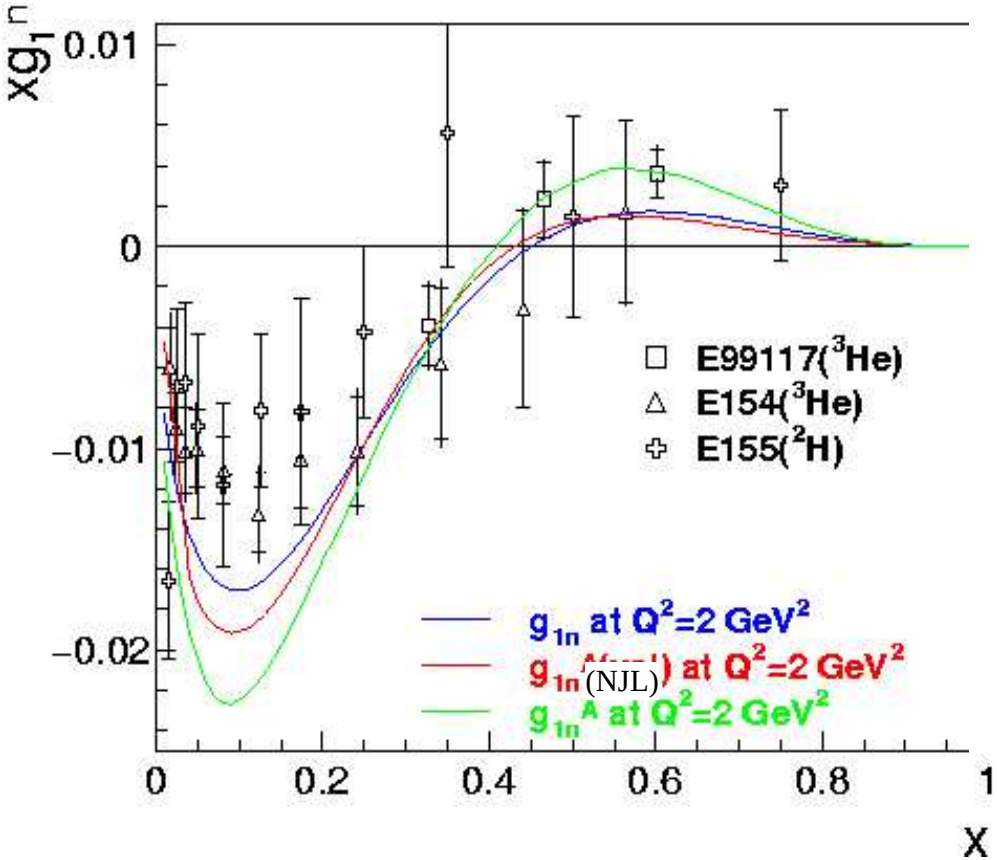

Using $g_2^{WW}$

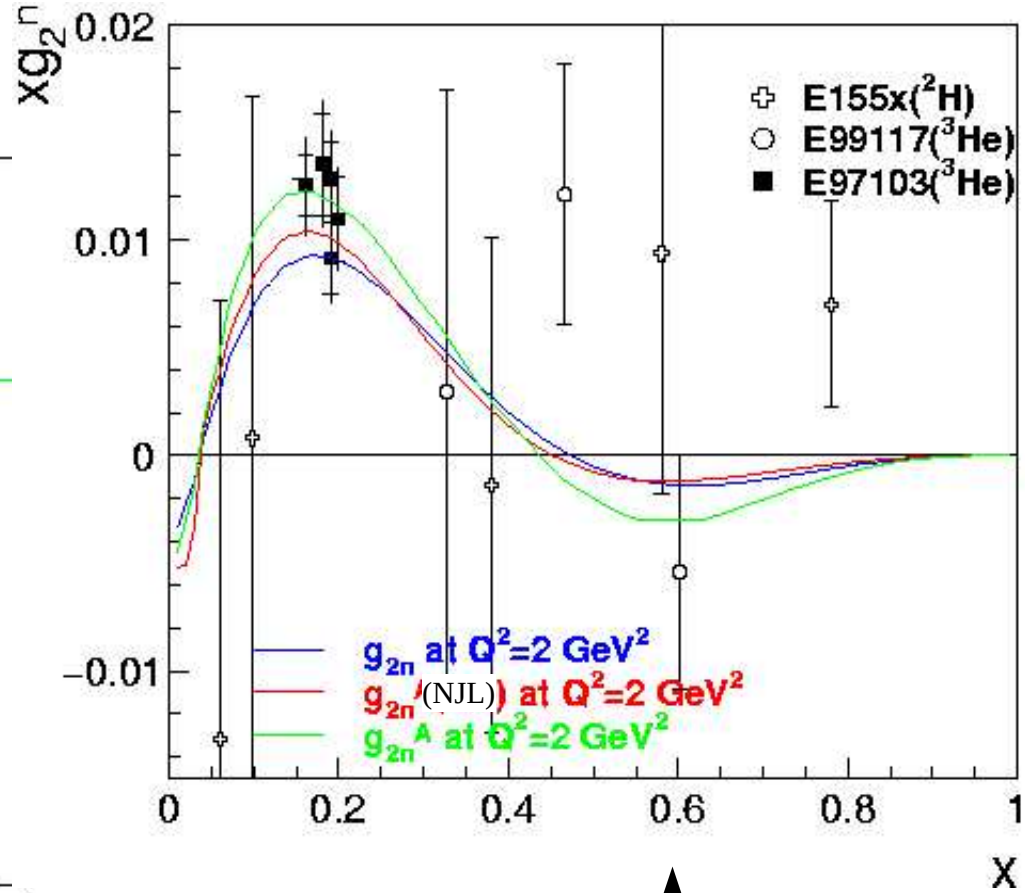
# Polarized EMC Effects on $g_{1,2}^n$

Free nucleon $g_{1,2n}$ from ave. (4) pol. PDF fits;

$g_{1,2n}^A$ from Pol. PDF + NJL/QSM

$g_{1,2n}^A$ from Pol. PDF + CQS




Using $g_2^{WW}$

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This artist's rendition shows quarks as spinning tops inside protons, with the protons embedded in a nucleus. A new theoretical calculation reveals that the spins of quarks may be modified by the environment of the protons and neutrons.
Spin Structure of Protons and Neutrons
Just as a top spins on a table, the tiny quarks inside protons and neutrons also spin. Now a complex calculation by theoretical nuclear physicists at Jefferson Lab has revealed that a quark's spin may be altered by the surroundings of the proton or neutron in which it resides. This surprising result, recently published in the journal Physical Review Letters, may lead to new insights about how ordinary matter is constructed.
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low $x$. For this reason in Figs. 3 and 4 we do not plot our results in this region.

A thorough understanding of how nuclear medium effects arise from the fundamental degrees of freedom – the quarks and gluons – represents an important challenge for the nuclear physics community. An experimental measurement of the polarized EMC effect would be another important step toward this goal, providing important insights into the quark polarization degrees of freedom within a nucleus. Our prediction of a remarkably large signature suggests that this measurement is feasible, and if these results are confirmed experimentally would yield vital, new information on quark dynamics in the nuclear medium.


[17] R. L. Jaffe, M
*Alamos Schoo*
*N.Mex., Jun*
[18] V. Barone, A
**359**, 1 (2002)
[19] N. Ishii, W.
617 (1995).
[20] M. Hirai, S.
Commun. **108**
[21] I. Sick and D.
[22] The subscript
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# Measurement of Polarized EMC Effect

# What Are Our Challenges?

# Challenges in Experimental Technique/Design

- Measure $g_{1p,n}$ from a polarized nuclear target
  - Choice of nuclei:
    - Non-zero spin; Spin 1/2 is preferred (no tensor polarization);
    - Odd, large A;
    - High "nucleon polarization": prefer s-shell unpaired nucleon;
    - Easy to polarize; High polarization already achieved are preferred.
  - Difficulties:
    - only 1 (out of A) nucleon is polarized, large dilution, difficult to achieve high statistics;

# Challenges in Analysis/ Interpretation

- Then compare $g_1(A)$ with free nucleon $g_{1p,n}$
  - Extract $g_{1p,n}^A$ from nuclear $g_1(A)$
    - How the unpaired N *and* the other (A-1) paired nucleons polarized?

$$g_1^A = P_n g_{1n} + P_p g_{1p}$$

    - Even for s-shell unpaired neutron, $P_n \neq 1$, $P_p \neq 0$

$^3$He: $$P_n = 0.86^{+0.036}_{-0.02}, P_p = -0.028^{+0.009}_{-0.004}$$

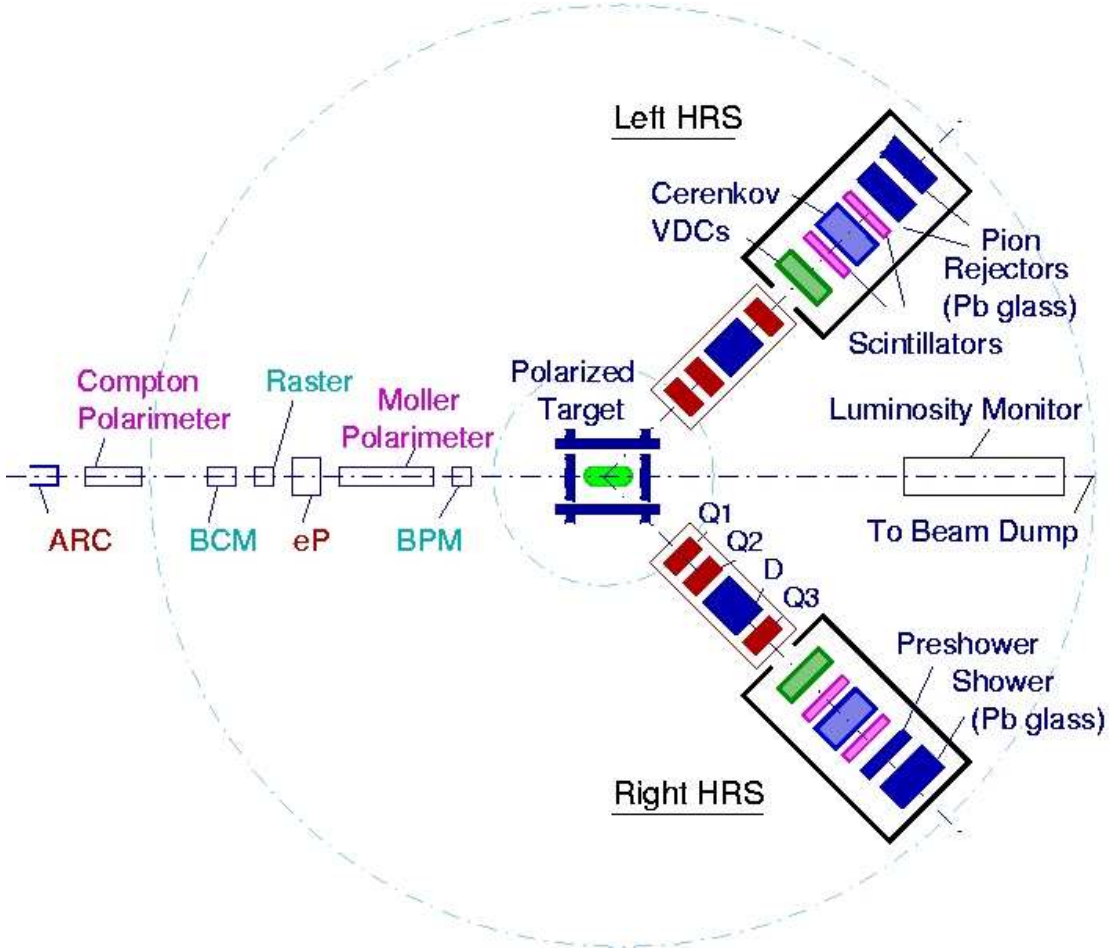
Ciofi degli Atti *et al.*, Phys. Rev. C48, 968 (1993); Phys. Lett. B404, 223 (1997)

    - Unpaired n (p): subtract $P_p$ ($P_n$), then correct for $P_n$ ($P_p$)
  - Difficulties: Need to know $P_{p,n}$ – extremely difficult for heavy nuclei
  - Or, should we correct for $P_{p,n}$ at all? (part of the nuclear effects)
    - If not, need different calculations for pol EMC for each nucleus — again need nucleon wavefunctions.

# Measurement of PolEMC on the Neutron

(A. Deur, X. Zheng)

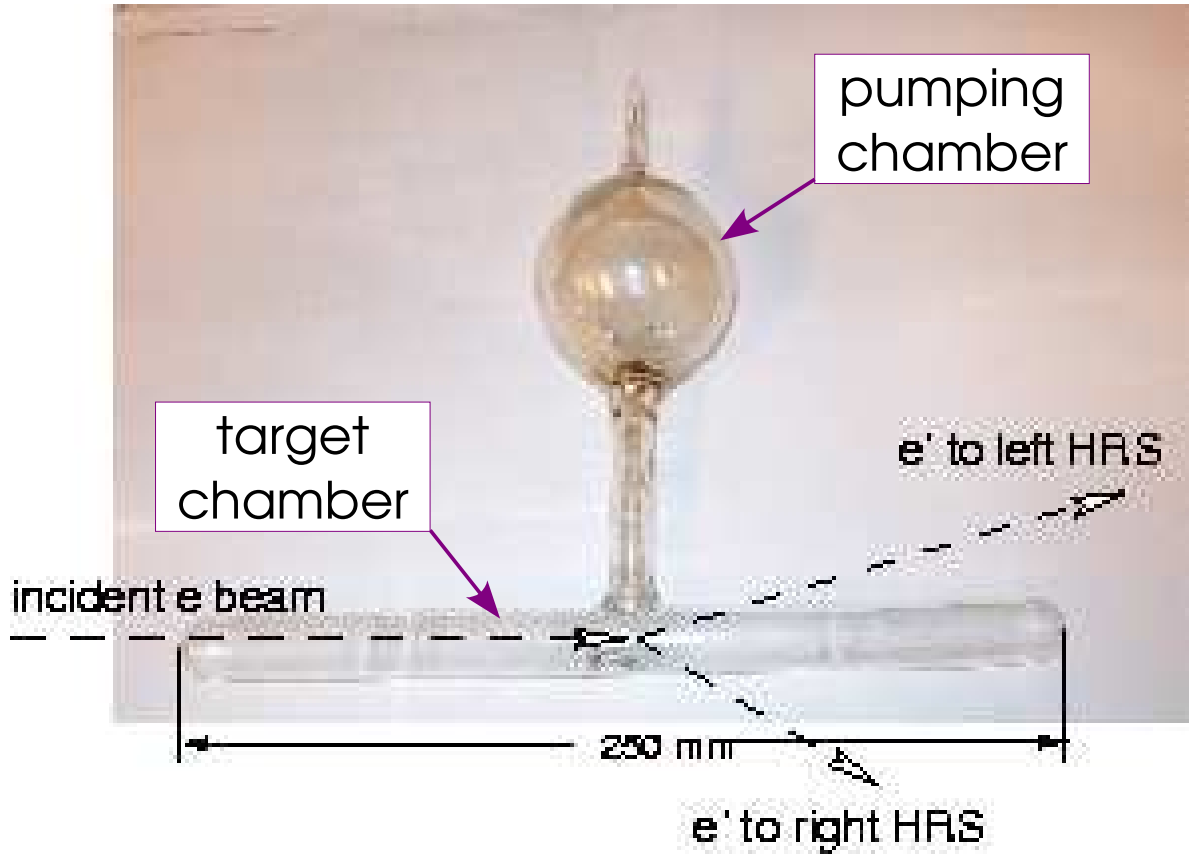
# Experimental Setup




- Same setup as 5 Hall A inclusive polarized 3He experiments;
- Straightforward... except the target (cell).

# Let's start from Polarized $^3$He Target

- Principle:
  - Optical Pumping of Rb
  - Spin exchange during Rb-$^3$He collisions




- Can be used for any alkaline metal + noble gas
  - Great! We can simply substitute 3He by a heavy noble gas!

# Choice of Nucleus

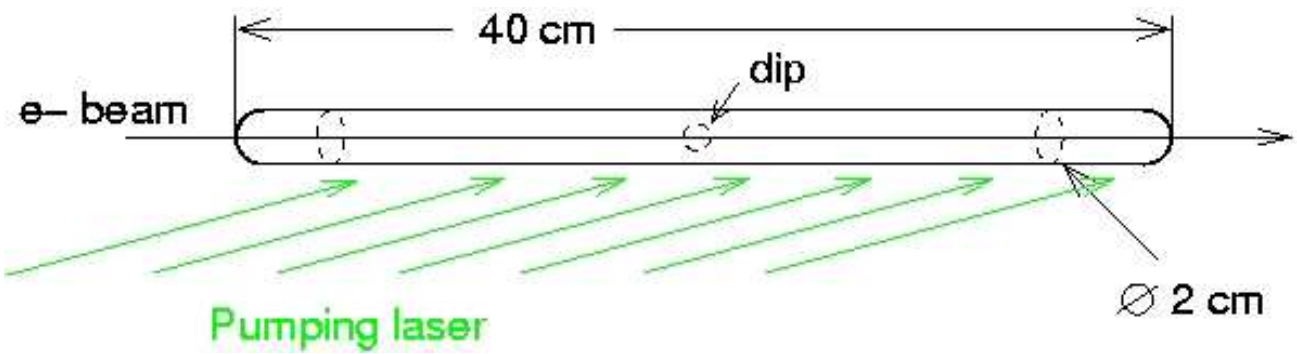
| Z | Isotope | spin | shell | abundance | Polarized? |
|---|---|---|---|---|---|
| 2 | $^{3}He$ | 1/2 | 1s | 0.00014% | Yes |
| | $^{4}He$ | 0 | | | |
| 10 | $^{20}Ne$ | 0 | | | |
| | $^{21}Ne$ | 3/2 | 1d | 0.27% | Yes (research only) |
| 18 | $^{36,38,40}Ar$ | 0 | | | |
| 36 | $^{78,80,82,84,86}Kr$ | 0 | | | |
| | $^{83}Kr$ | 9/2 | 1g | 11.5% | |
| 54 | $^{128,130,132,134,136}Xe$ | 0 | | | |
| | $^{129}Xe$ | 1/2 | 3s | 26.4% | Yes (widely used in med.phys) |
| | $^{131}Xe$ | 3/2 | 2d | 21.2% | Yes, but hi. depol. |
| 86 | $^{219}Rn$ | 5/2 | | Trace | |
| | $^{220,222}Rn$ | 0 | | Trace | |

# Polarized $^{129}$Xe Target

- If we use exactly the same setup as for 3He, we have 0.1% $^{129}$Xe polarization in the target chamber;
  - Xe too heavy, Rb depolarizes fast from Rb-Xe collisions;
  - Too heavy, Xe do not diffuse from pumping to target chamber fast enough.

# Polarized $^{129}$Xe Target

- A new design is needed:
  - only one chamber;
  - laser narrowing technique: reduce linewidth from 1THz to 50GHz; total 120W.
- To be studied:
  - deterioration of glass under: heating + beam + high power laser




- Technically new, but can be done;
- Might reach 1.7 amg, 50% Xe target w/ 30uA beam (theoretically).

# Analysis/Interpretation of Xe Measurement

## Nuclear Corrections for $^{129}$Xe

- It is extremely challenging for theorists to calculate Pn and Pp for $^{129}$Xe
- Shell model:
  - S. Grimes (OhioU), B.R. Barrett (Arizona), P. Navratil (LLNL) – useful suggestions
  - V. Zelevinsky and A. Brown (MSU): $^{21}$Ne, $^{129}$Xe in progress;
  - A. Poves (Universidad Autonoma, Madrid, Spain): $^{129}$Xe Pn=0.724, Pp=0.016
    - First shell model calculation developed for 50<N, Z<82;
    - Largest shell model calculation ever, w/ a basis dimension of 3 billion!
    - hard to quote uncertainties – how to test it (via Q-E, like the approved measurement of Ax, Az for 3He?).?
- Mean field calculations?

# More about Neutron Pol. EMC Measurement

## Other difficulties:

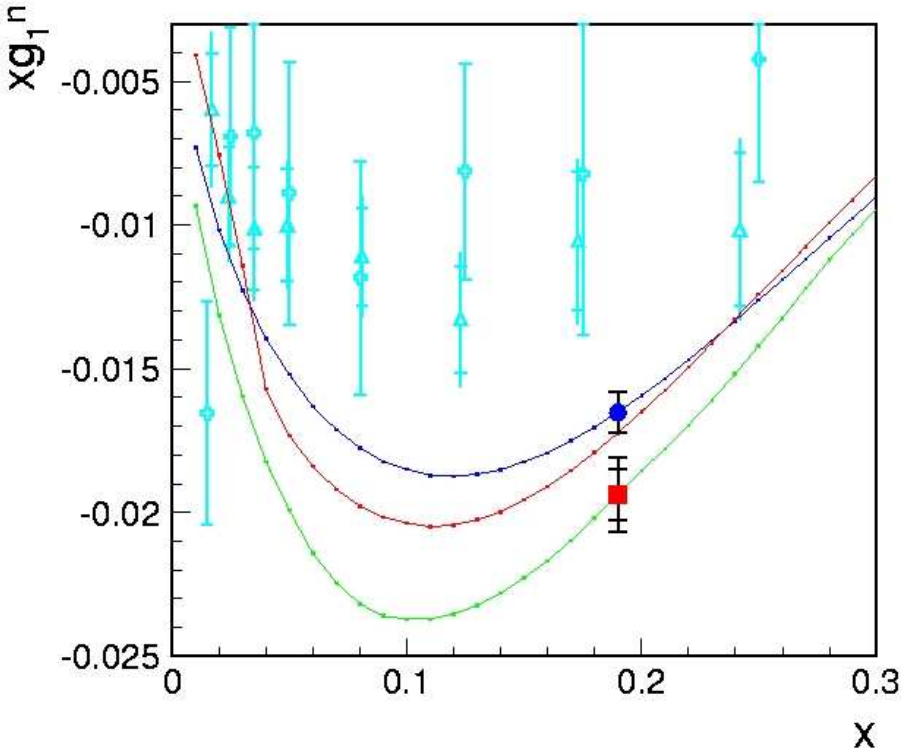
- $g_{1n}$ itself is small, crosses zero at x~0.5, hard to reach high precision;
- Need to subtract proton "contamination" carefully: $g_{1p} >> g_{1n}$
  => (need to know Pp to better than 30%)

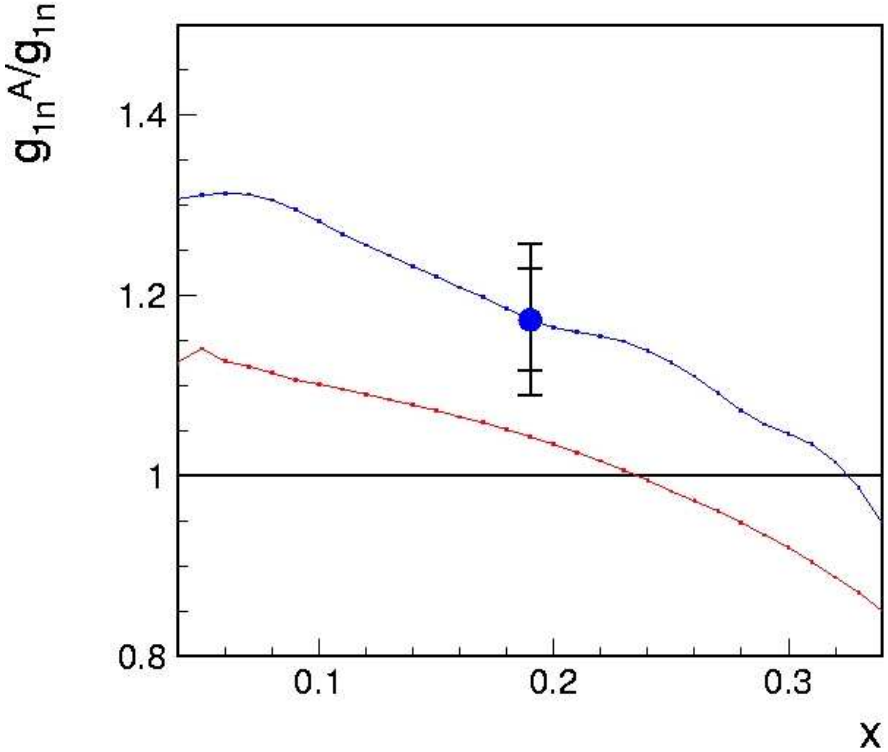
## It is important to have both neutron and proton data:

- To separate $\Delta u$ and $\Delta d$;
- To test Bjorken sum rule for heavy nuclei.

# Experimental Design and Expected Results

- 6 GeV 80% parity-quality beam, 15uA on $^{3}He$, 30uA on $^{129}Xe$;
- Hall A HRS, fast DAQ (fADC-based);
- Total of ~24 days beam time: (including 2 days commissioning)
- <u>(if assuming $P_n^{Xe}/P_n^{He}$ known to 4%, $P_p^{Xe}$ known to 30%)</u>



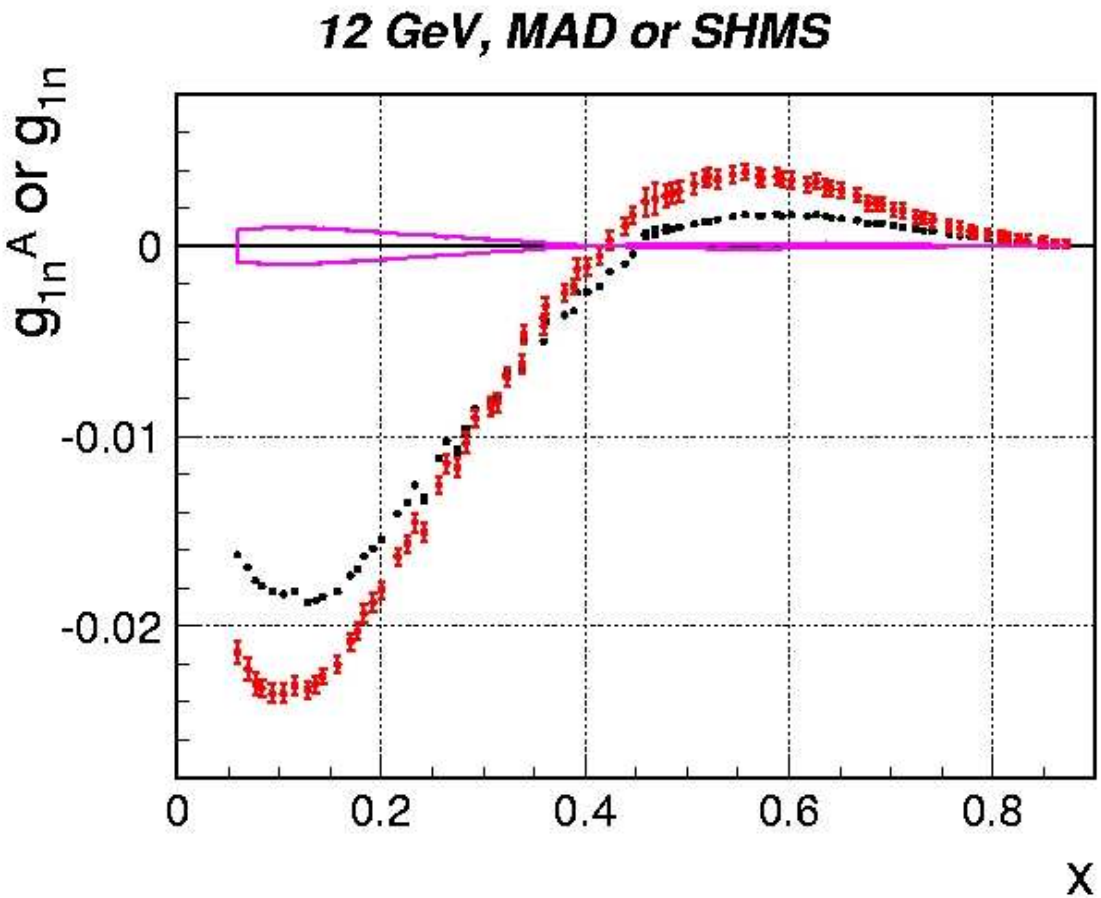




http://www.jlab.org/~xiaochao/pac29/LOI_polemc.pdf

# A Lighter Nuclear Target?

- If Xe is difficult to interpret, may use $^{21}Ne$:
  - Need hybrid optical pumping, 250°C, to achieve the same f.o.m.: 30uA, 40% (theoretically), 5 amg; (More R&D!)
  - spin 3/2, complication from tensor polarization;
  - more reliable shell model calculation Pn=0.58;
  - less dilution from (A-1) unpolarized nucleons;
- Overall, factor of 4 improvement in FOM (half beam time to achieve similar statistical precision)

# Neutron Polarized EMC Effect at 12 GeV




- Each pair of He/Xe data at ONE x needs 20 days beam;
- Nuclear correction uncertainty now shown – only scales g1(Xe)

# Summary

- Unpolarized EMC effects started from experiments;
- Now its theorists' turn to lead us to explore polarized EMC effect
  - What do we expect?
  - How do we compare data with theories?
    - Calculations for Pn and Pp for heavy nuclei;
- With sufficient effort to overcome technical difficulties (target), and with strong theoretical support, we will be able to measure polarized EMC;
  - First g1 data on heavy nuclei;
  - First data on polarized EMC effect on the neutron;
- **Why does it worth it?**
  - After all, did anyone ever try to do flavor separation of unpol EMC ($u^A/u$, $d^A/d$)? - No, polEMC will open a new horizon;
  - Adding the spin observable will explore more about medium modification of nucleon structure, and thus the nature of the strong interaction;