# New Experiments with Tensor Polarized Targets

The Proton Mass:
At the heart of most visible matter

Trento, Italy
4/4/2017

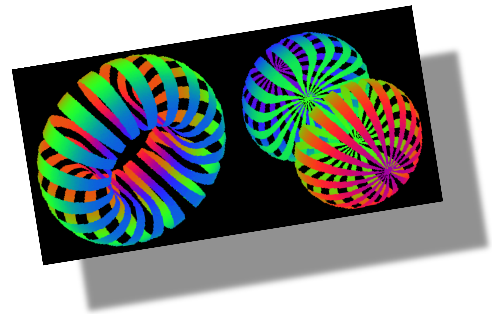
Karl Slifer
University of New Hampshire

# This Talk

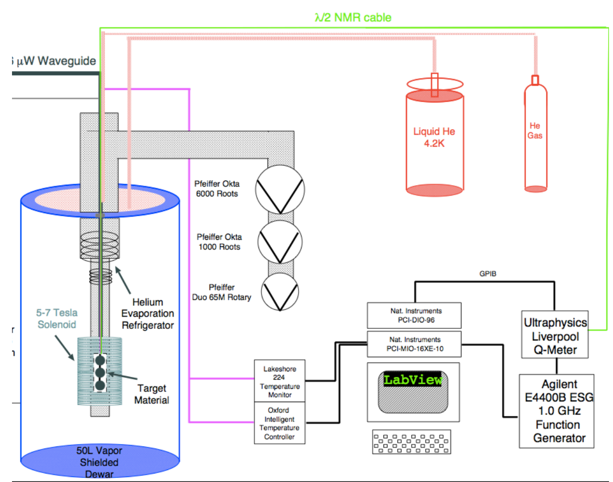
Brief Review of Tensor Polarization

JLab Tensor Structure Program

E12-13-011: "The $b_1$ experiment"
E12-15-005: "$A_{zz}$ for x>1"
LOI-12-16-006: "Nuclear Gluometry"



Latest Technical Developments

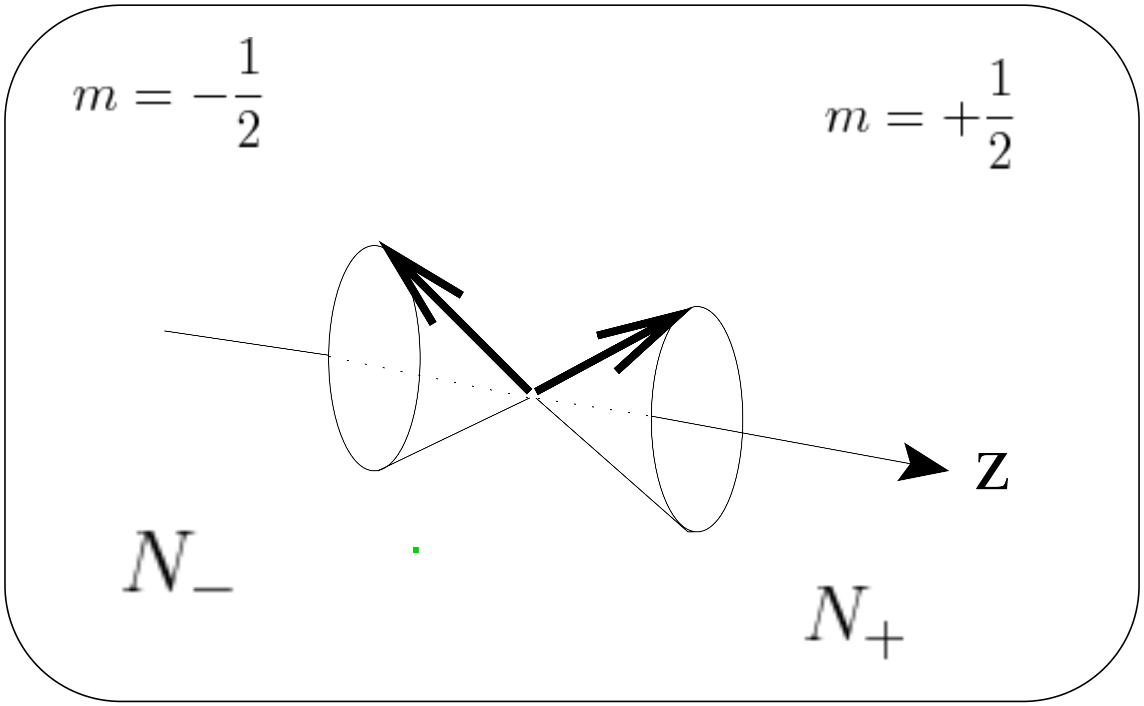



Future


thank you to the organizers for accommodating a talk slightly off-topic!

# Spin-1/2

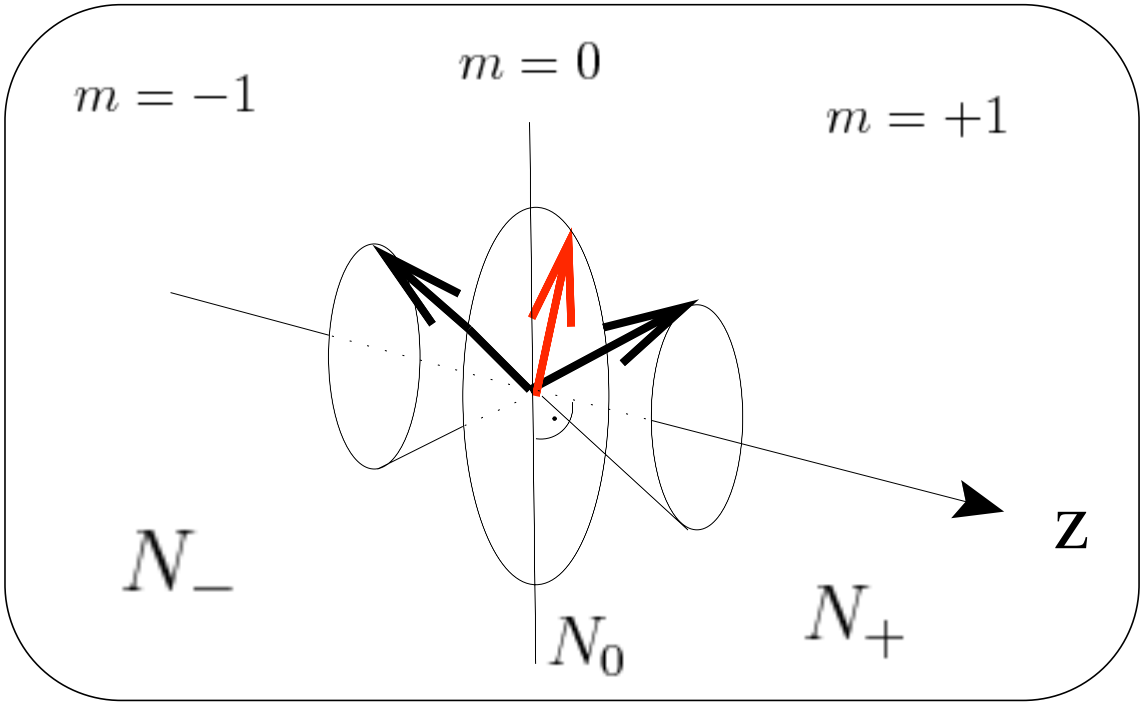
Spin-1/2 system in B-field leads to 2 sublevels due to Zeeman interaction




$$P_z = \frac{N_+ - N_-}{N_+ + N_-}$$

$\boxed{-1 < P_z < +1}$

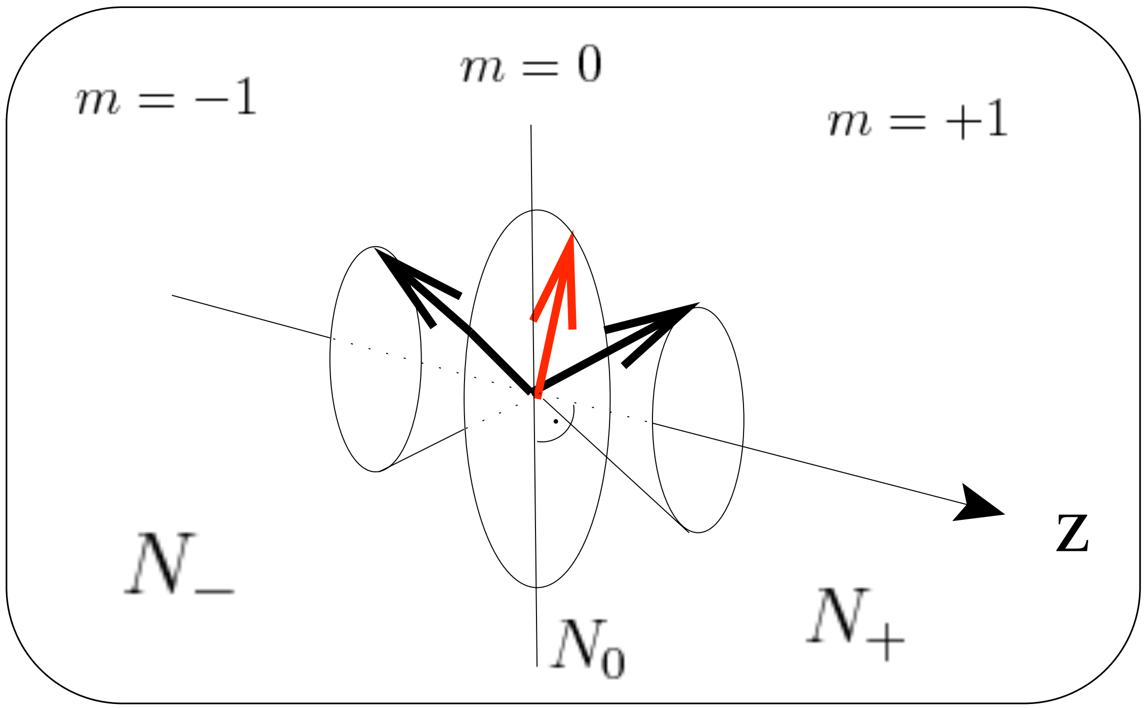
# Spin-1




$$P_z = \frac{N_+ - N_-}{N_+ + N_-}$$

$$P_{zz} = \frac{(N_+ - N_0) - (N_0 - N_-)}{N_+ + N_0 + N_-} = \frac{(N_+ + N_-) - 2N_0}{N_+ + N_0 + N_-}$$

# Spin-1

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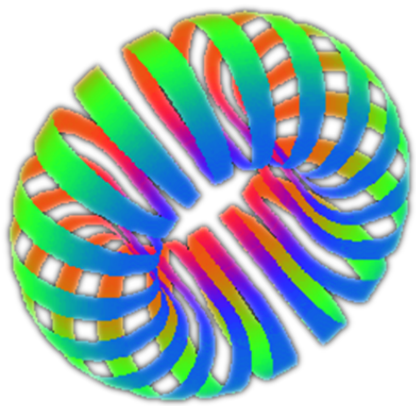
$\boxed{-2 < P_{zz} < +1}$

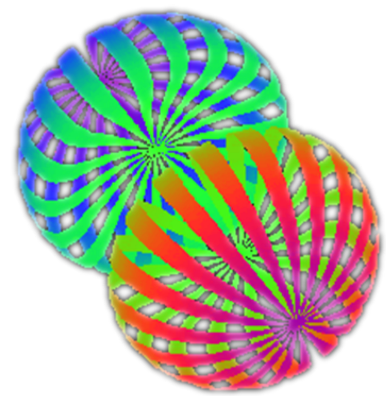
# Spin-1



$$P_{zz} = -2$$

Pure Tensor Polarization

All spins in the m=0 level



$$P_{zz} = +1$$

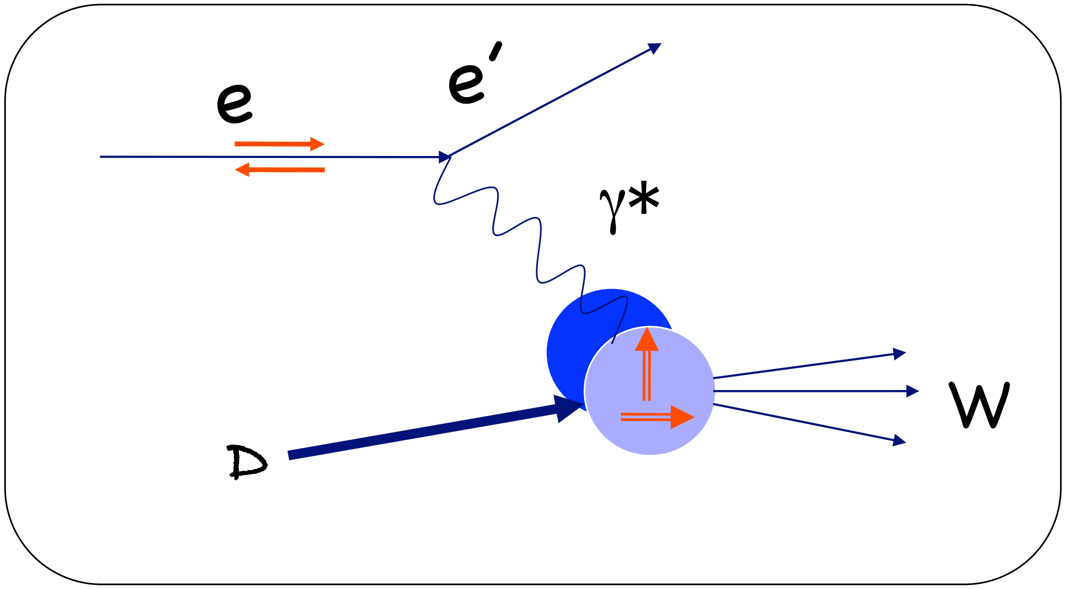
Pure Vector Polarization

m=0 level depopulated

$$P_{zz} = \frac{(N_+ - N_0) - (N_0 - N_-)}{N_+ + N_0 + N_-} = \frac{(N_+ + N_-) - 2N_0}{N_+ + N_0 + N_-}$$

$$\boxed{-2 < P_{zz} < +1}$$

# Inclusive Scattering




Construct the most general Tensor W consistent with Lorentz and gauge invariance

Frankfurt & Strikman (1983)

Hoodbhoy, Jaffe, Manohar (1989)

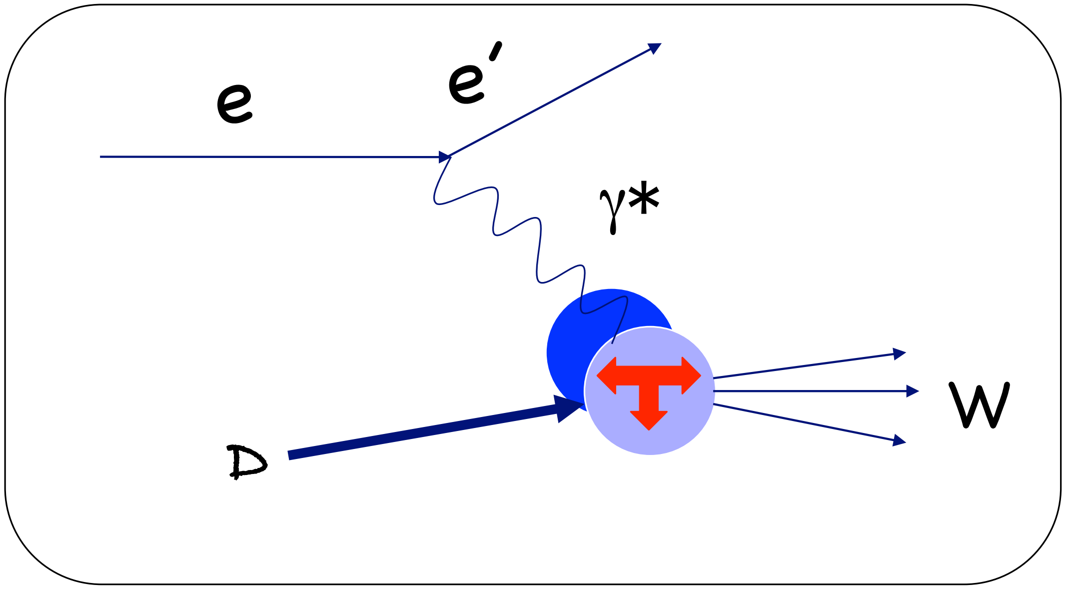
$$W_{\mu\nu} = -F_1 g_{\mu\nu} + F_2 \frac{P_\mu P \nu}{\nu}$$

Unpolarized Scattering

$$+i\frac{g_1}{\nu}\epsilon_{\mu\nu\lambda\sigma} q^\lambda s^\sigma + i\frac{g_2}{\nu^2}\epsilon_{\mu\nu\lambda\sigma} q^\lambda (p \cdot q s^\sigma - s \cdot q p^\sigma)$$

Vector Polarization

# Tensor Structure Functions

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Caution : There is an alternate similar formulation by Edelmann, Piller, Weise

# Tensor Structure Functions

| | Nucleon | Deuteron |
|---|---|---|
| $F_1$ | $\frac{1}{2}\sum_q e_q^2[q_\uparrow^{1/2} + q_{\downarrow\uparrow}^{-1/2}]$ | $\frac{1}{3}\sum_q e_q^2[q_\uparrow^1 + q_\uparrow^{-1} + q_\uparrow^0]$ |
| $g_1$ | $\frac{1}{2}\sum_q e_q^2[q_\uparrow^{1/2} - q_\downarrow^{-1/2}]$ | $\frac{1}{2}\sum_q e_q^2[q_\uparrow^1 - q_\downarrow]$ |
| $b_1$ | $\cdots$ | $\frac{1}{2}\sum_q e_q^2[q^0 - q^1]$ |

Leading Twist

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| $b_1$ | $\cdots$ | $\frac{1}{2}\sum_q e_q^2[q^0 - q^1]$ |

Leading Twist

$b_2$ : related to $b_1$ by A Callan-Gross relation

$b_4$ : Also Leading Twist, but kinematically suppressed for a longitudinally polarized target.

$b_3$ : higher twist, like $g_2$

# Parton Distributions

$q^m_{\uparrow\downarrow}$ Probability to scatter from a quark with spin up/down carrying momentum fraction x while the *Deuteron* is in state m

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$$q^0(x) = q^0_\uparrow(x) + q^0_\downarrow(x)$$

spin averaged parton distributions

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spin averaged parton distributions

$q^0$ : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state m=0

$q^1$ : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state |m| = 1

# $b_1$ Structure Function

$$b_1(x) = \frac{q^0(x) - q^1(x)}{2}$$

measured in DIS (so probing quarks), but depends solely on the deuteron spin state

Investigate nuclear effects at the level of partons!

$q^0$ : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state m=0

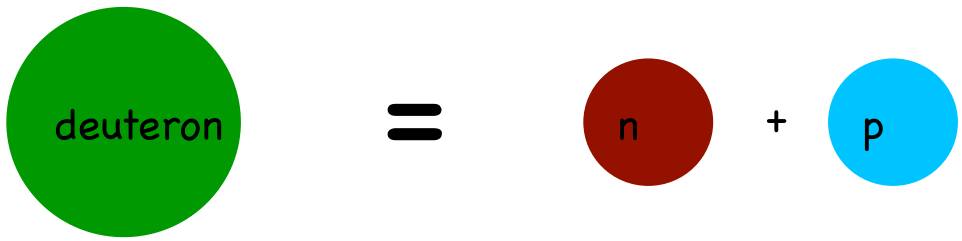
$q^1$ : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state |m| = 1

# $b_1$ Structure Function

Hoodbhoy, Jaffe and Manohar (1989)

## $b_1$ vanishes in the absence of nuclear effects

i.e. if...



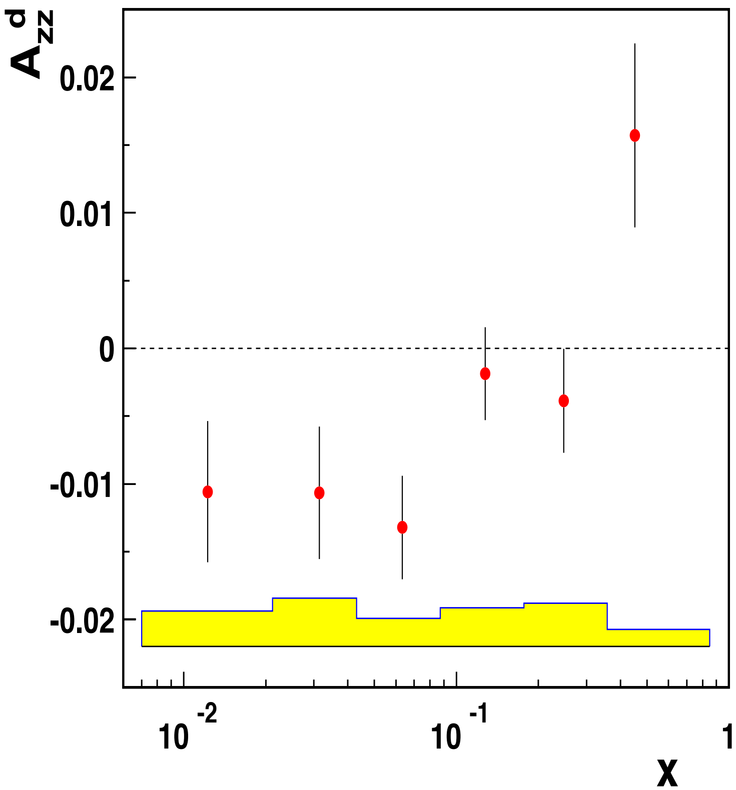

Proton Neutron in relative S-state

Even accounting for D-State admixture $b_1$ expected to be vanishingly small

Khan & Hoodbhoy, PRC 44 ,1219 (1991) : $b_1 \approx O(10^{-4})$
Relativistic convolution model with binding

Umnikov, PLB 391, 177 (1997) : $b_1 \approx O(10^{-3})$
Relativistic convolution with Bethe-Salpeter formalism

# Data from HERMES




C. Reidl PRL **95,** 242001 (2005)

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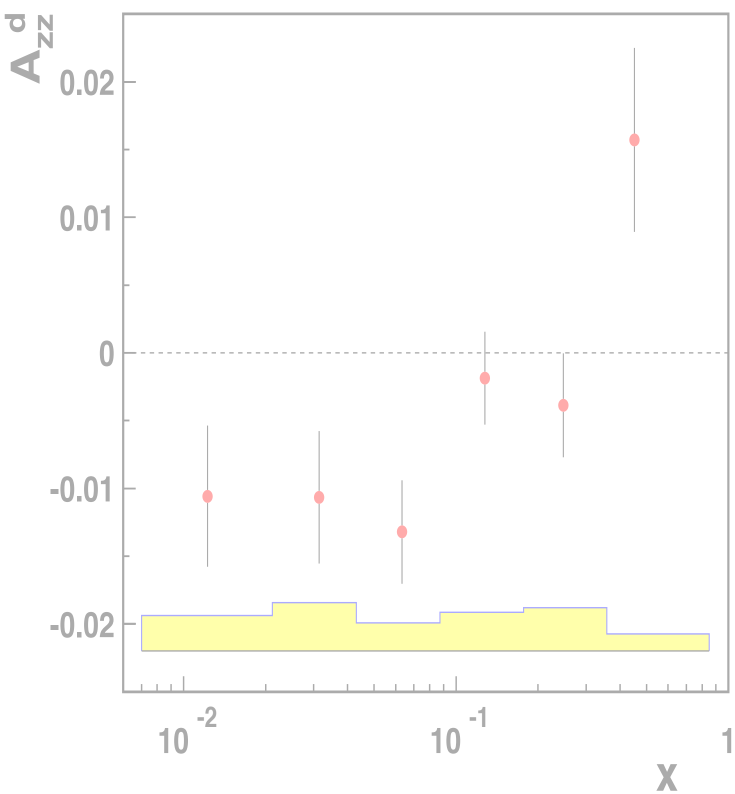
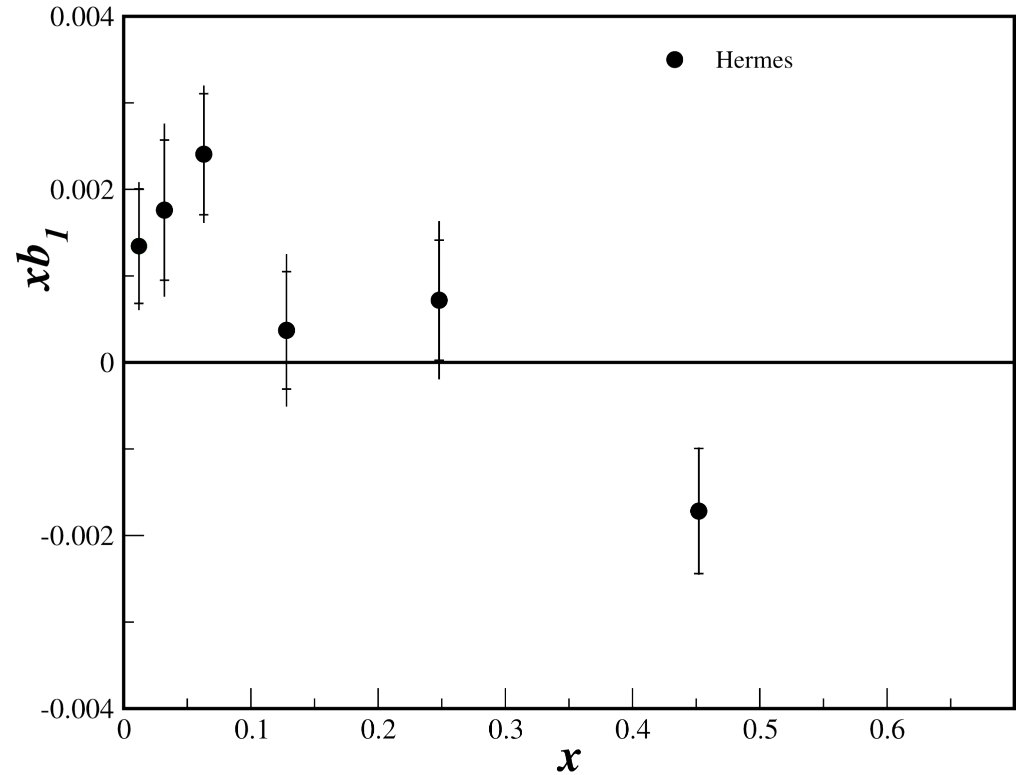
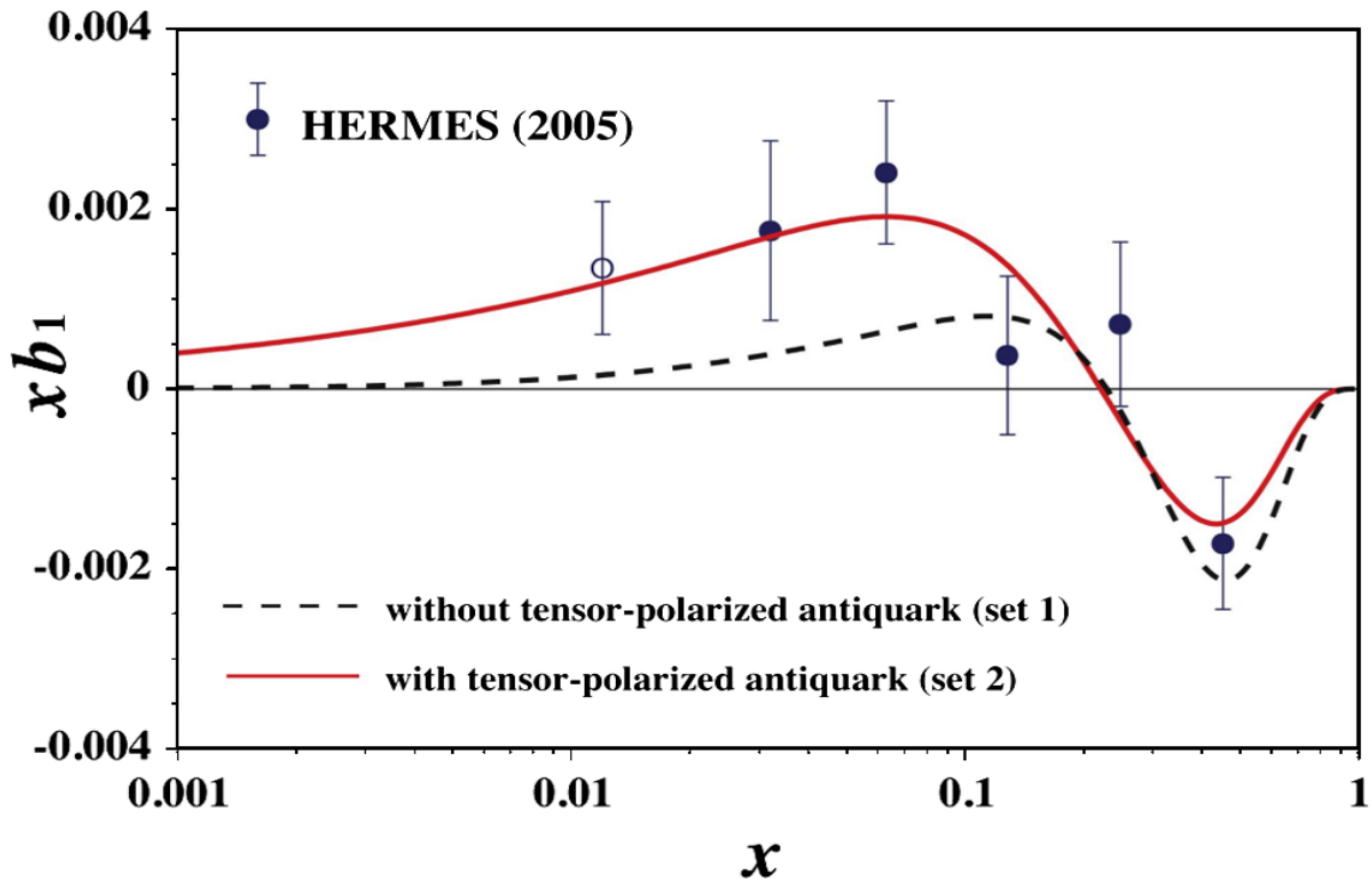



$$b_1 = -\frac{3}{2} F_1 A_{zz}$$

C. Reidl PRL **95,** 242001 (2005)

# Tensor polarization of the sea




S Kumano, PRD **82** 017501 (2010)

Fit improves when tensor polarization of the antiquark distributions is included

# Close-Kumano Sum Rule

$$\int b_1(x)dx = \frac{1}{9}\Theta Q_s$$

$$\boxed{\int b_1(x)dx = 0}$$

if the sea quark tensor polarization vanishes

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<u>Hermes result</u>

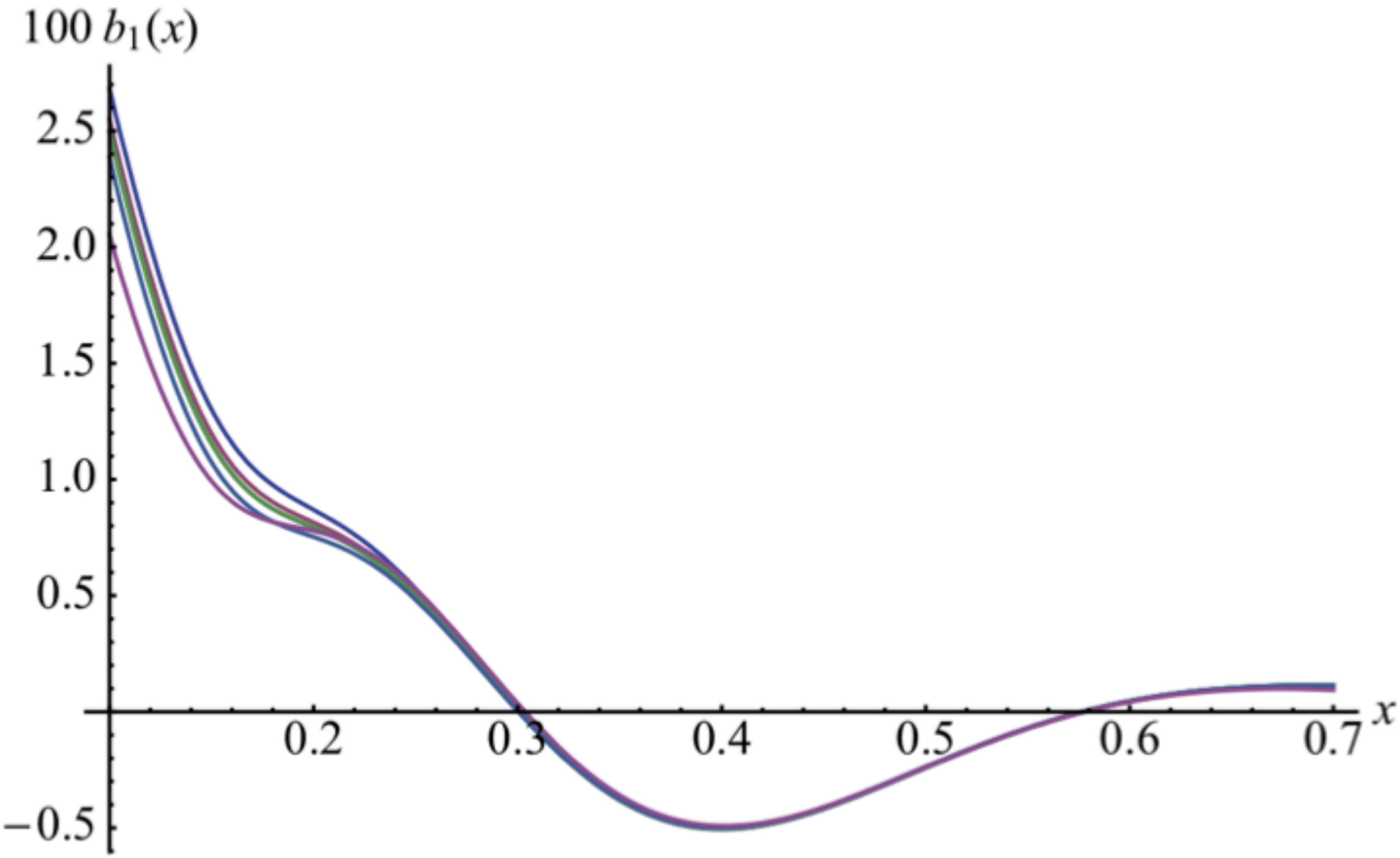
$$\int_{0.0002}^{0.85} b_1(x)dx = 0.0105 \pm 0.0034 \pm 0.0035$$

2.2 $\sigma$ difference from zero

# 6-quark, Hidden Color

G. Miller **PRC89 (2014) 045203**

"Pionic and Hidden-Color, Six-Quark Contributions to the Deuteron **b**1 Structure Function"



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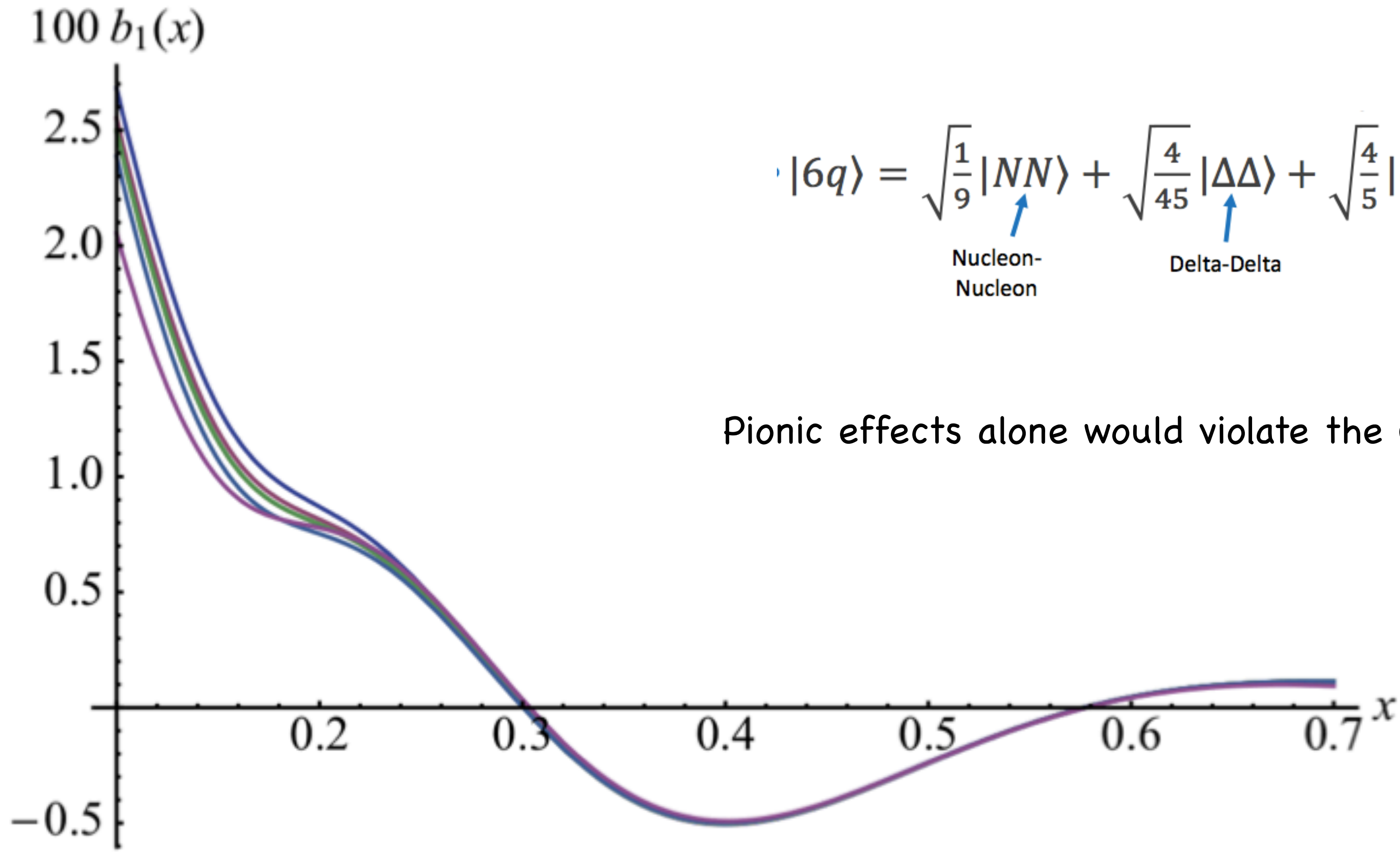
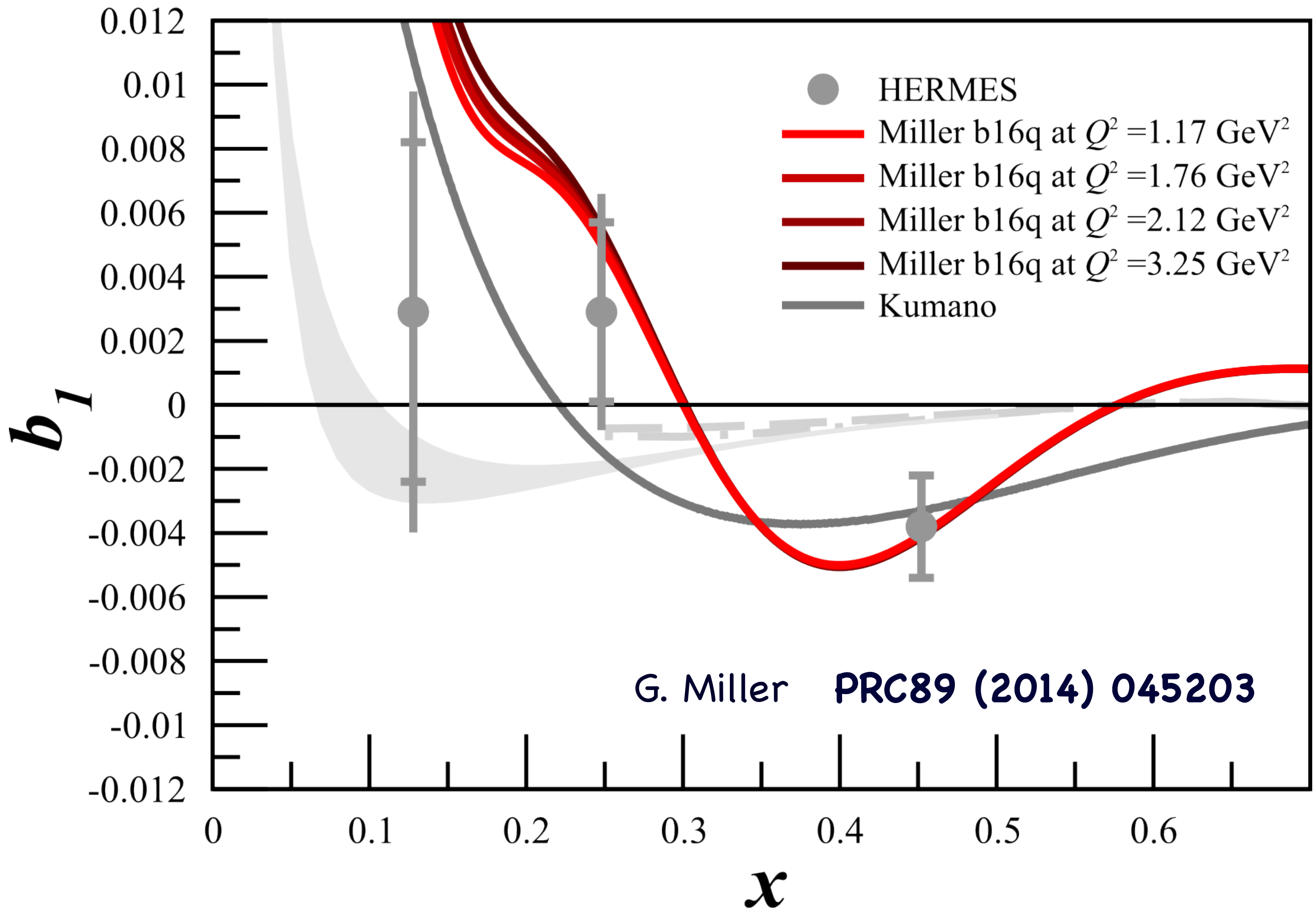



$$|6q\rangle = \underbrace{\sqrt{\tfrac{1}{9}}\,|NN\rangle}_{\text{Nucleon-Nucleon}} + \underbrace{\sqrt{\tfrac{4}{45}}\,|\Delta\Delta\rangle}_{\text{Delta-Delta}} + \underbrace{\sqrt{\tfrac{4}{5}}\,|CC\rangle}_{\text{Hidden Color}}$$

Pionic effects alone would violate the Ck sum rule

# Unique Signal of Hidden Color




no conventional nuclear mechanism can reproduce the Hermes data,

but that the 6-quark probability needed to do so ($P_{6Q}$ = 0.0015) is small enough that it does not violate conventional nuclear physics.

# Gluon Contribution to Tensor Structure

$$\int b_1(x)dx = 0$$

$$\int x b_1(x)dx = 0$$

**Efremov and Teryaev (1982, 1999)**

Gluons (spin 1) contribute to both moments

Quarks satisfy the first moment, but

Gluons may have a non-zero first moment!

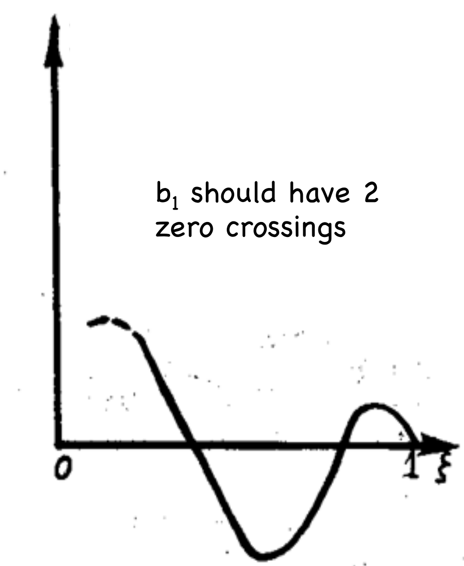



Рис. 1


Efremov, Teryaev, JINR PreprintR2-81-857(1981), Yad. Phys. 36, 950 (1982)
A.V. Efremov, O. V. Teryaev JINR-E2-94-95 (1999)
Jaffe, Manohar Phys.Lett. B223 (1989) 218

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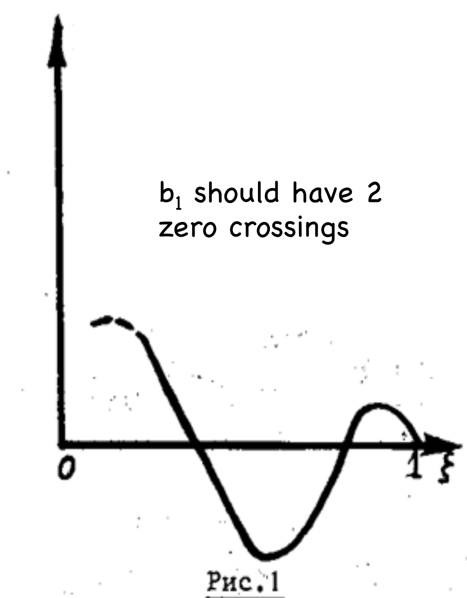


## Efremov and Teryaev (1982, 1999)

Gluons (spin 1) contribute to both moments

Quarks satisfy the first moment, but

Gluons may have a non-zero first moment!

2nd moment more likely to be satisfied experimentally since the collective glue is suppressed compared to the sea

Study of $b_1$ allows to discriminate between deuteron components with different spins (quarks vs gluons)


Efremov, Teryaev, JINR PreprintR2-81-857(1981), Yad. Phys. 36, 950 (1982)
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# Tensor Program

E12-13-011: *"The $b_1$ experiment"*

30 Days in Jlab Hall C
A- Physics Rating
Conditional Approval (Target Performance)

Contact : K. Slifer

E12-15-005: *"$A_{zz}$ for $x>1$"*

44 Days in Jlab Hall C
A- Physics Rating
Conditional Approval (Target Performance)

Contact : E. Long

# The Deuteron Polarized Tensor Structure Function $b_1$

## JLAB E12-14-011

**$A^-$ rating by PAC40**

**(C1: conditional on target performance)**

**Spokespersons**

Slifer, Solvignon, Long, Chen, Rondon, Kalantarians

# Experimental Method

$$A_{zz} = \frac{2}{fP_{zz}} \frac{\sigma_\dagger - \sigma_0}{\sigma_0}$$

$$= \frac{2}{fP_{zz}} \left( \frac{N_\dagger}{N_0} - 1 \right)$$

$$b_1 = -\frac{3}{2} F_1^d A_{zz}$$

Observable is the Normalized XS Difference

B-Field, density, temp, etc. held same in both states

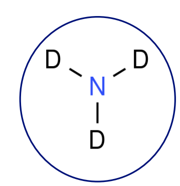
$\sigma_\dagger$ : Tensor Polarized cross-section

$\sigma_0$ : Unpolarized cross-section

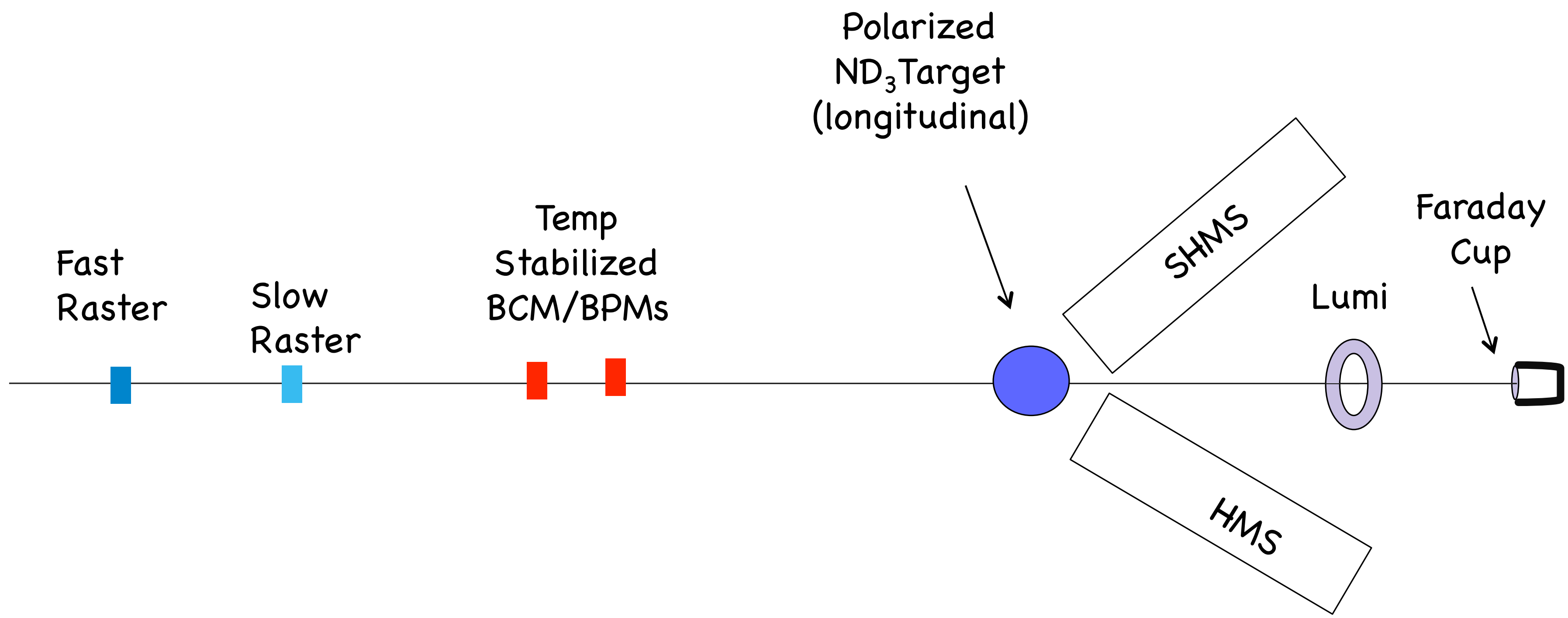
$P_{zz}$ : Tensor Polarizzation

dilution factor

$$f \approx \frac{6}{20}$$



# Jlab Hall C

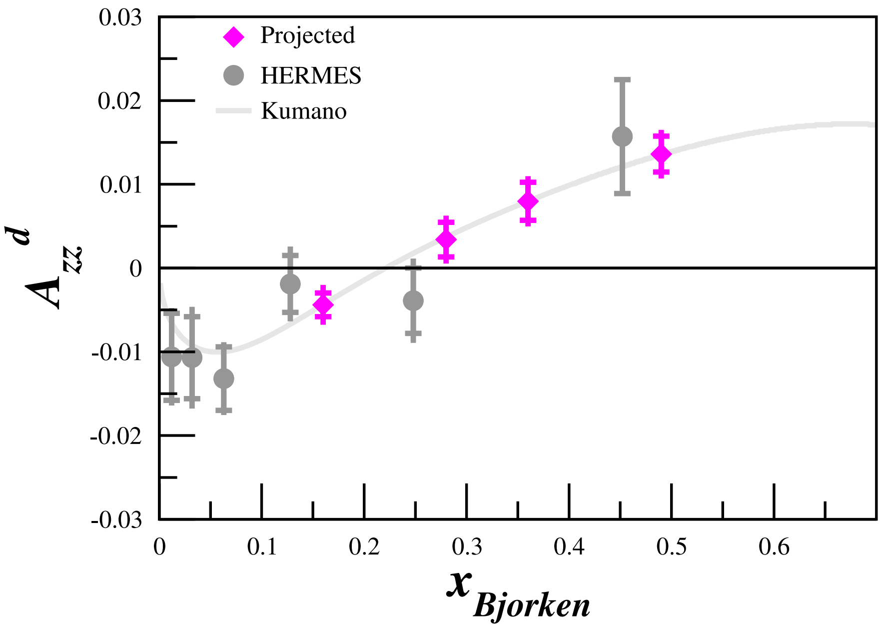



Unpolarized Beam
UVa/JLab Polarized Target

Magnetic Field Held Along Beam Line at all times

$\mathcal{L}=10^{35}$

# Projected Results for $P_{zz}$ = 35%




30 Days in Jlab Hall C

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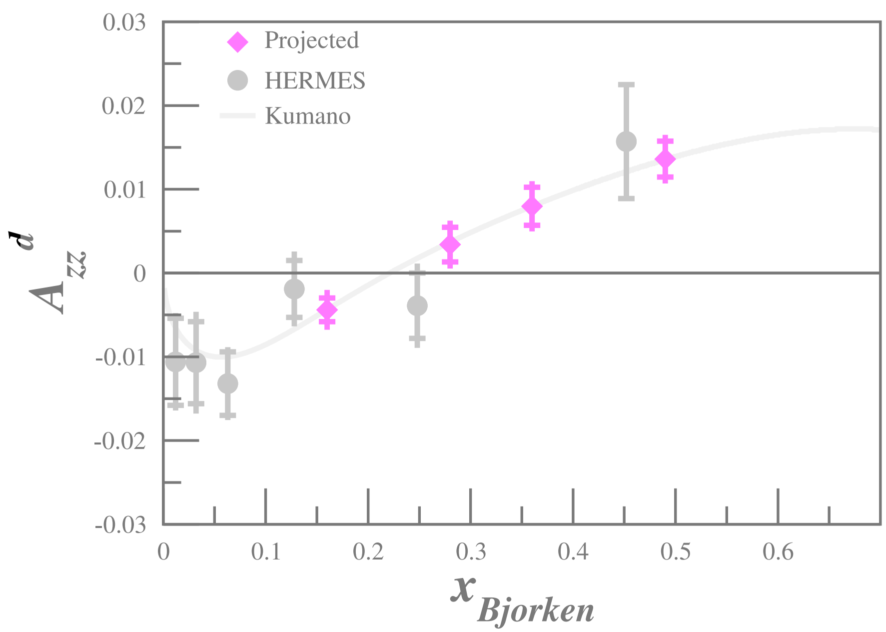
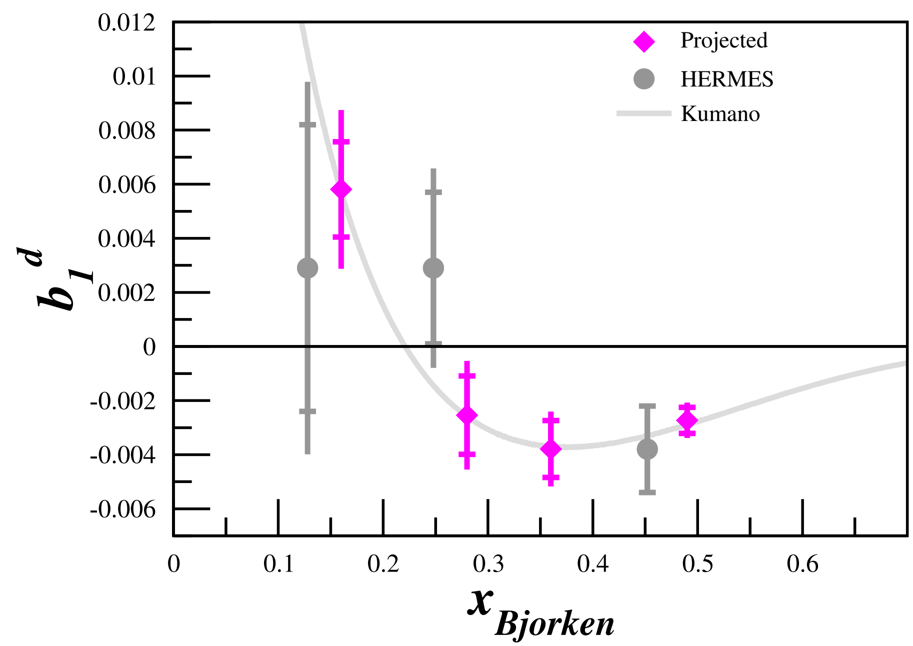


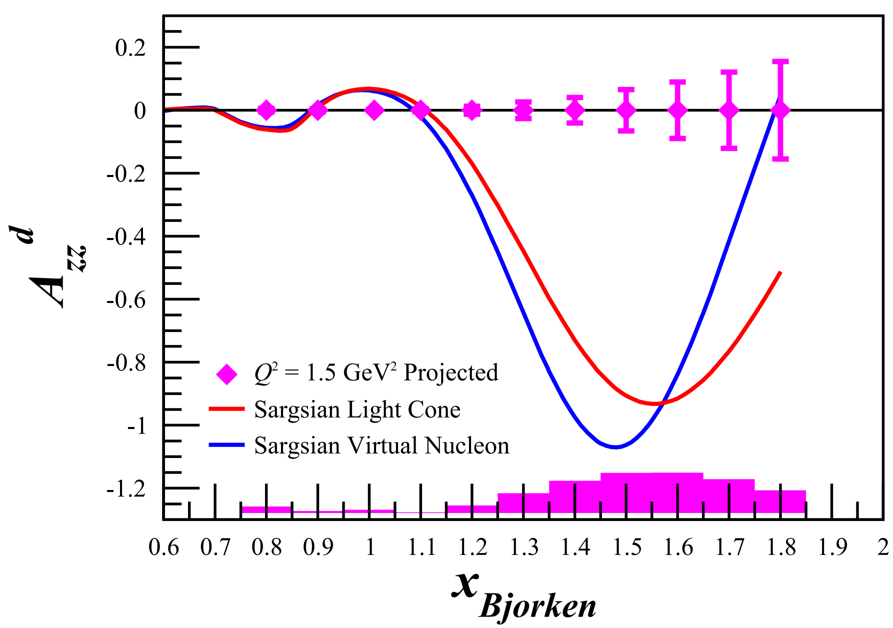

30 Days in Jlab Hall C

verification of zero crossing
essential for satisfaction of CK Sum

# E12-15-005

## $A_{zz}$ in the x>1 Region

Ellie Long, Slifer, Solvignon,
Day, Higinbothan, Keller




Very Large Tensor Asymmetries predicted

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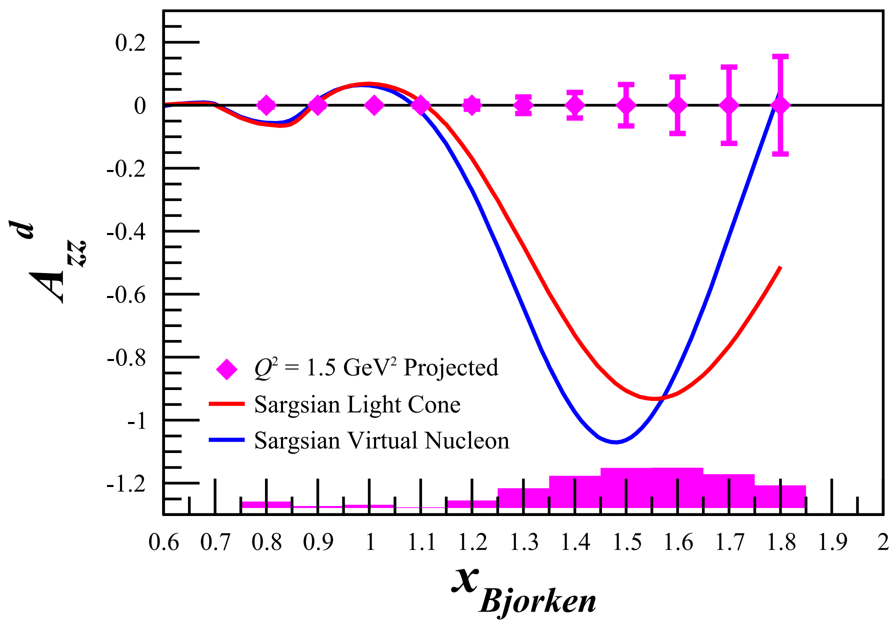


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Sensitive to the S/D-wave ratio in the deuteron wave function

4σ discrim between hard/soft wave functions
6σ discrim between relativistic models

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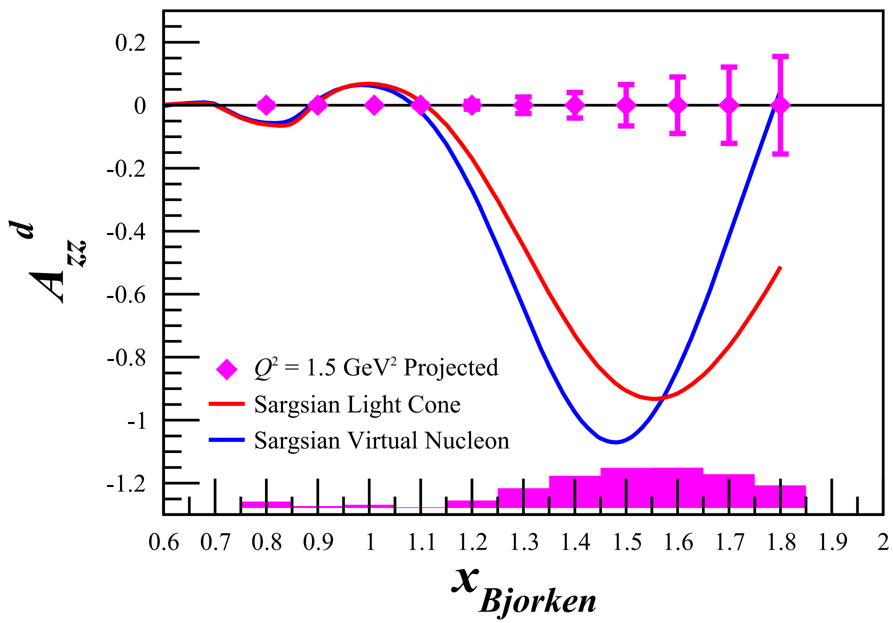


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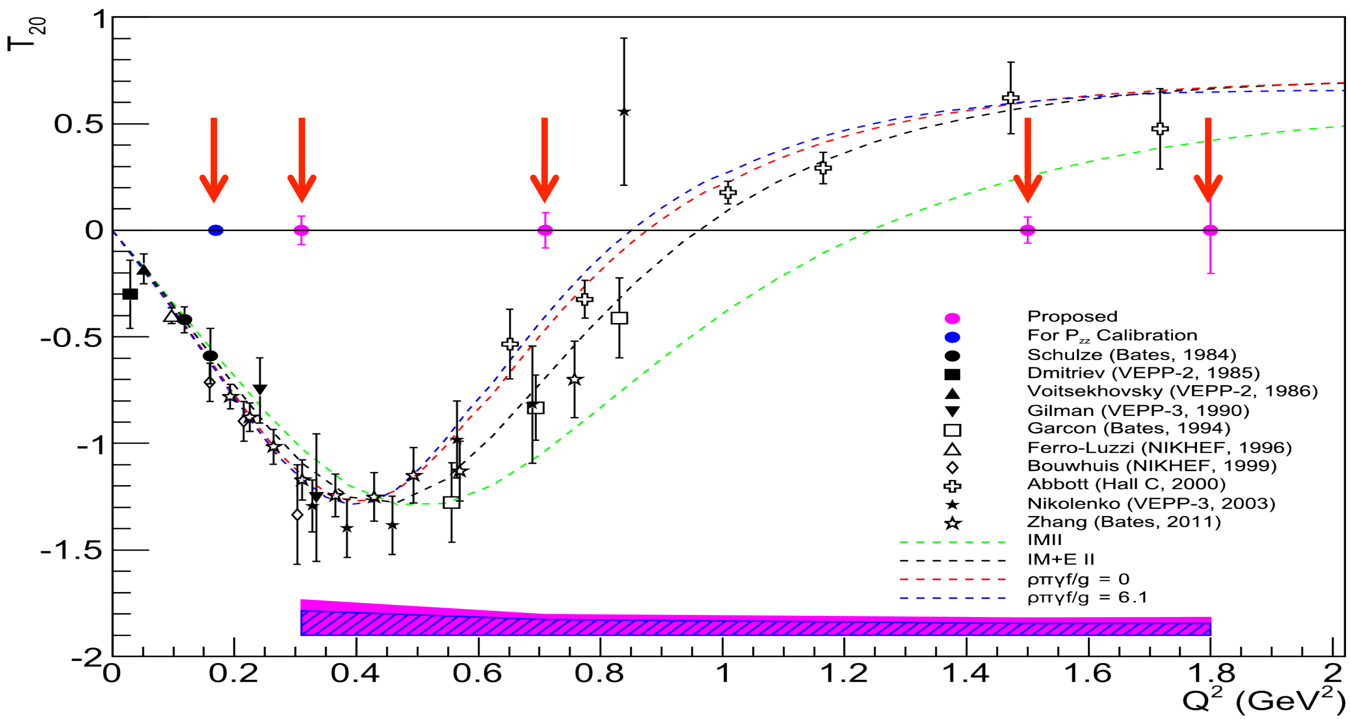
"further explores the nature of short-range pn correlations, the discovery of which was one of the most important results of the 6 GeV nuclear program."

PAC44 Theory Report

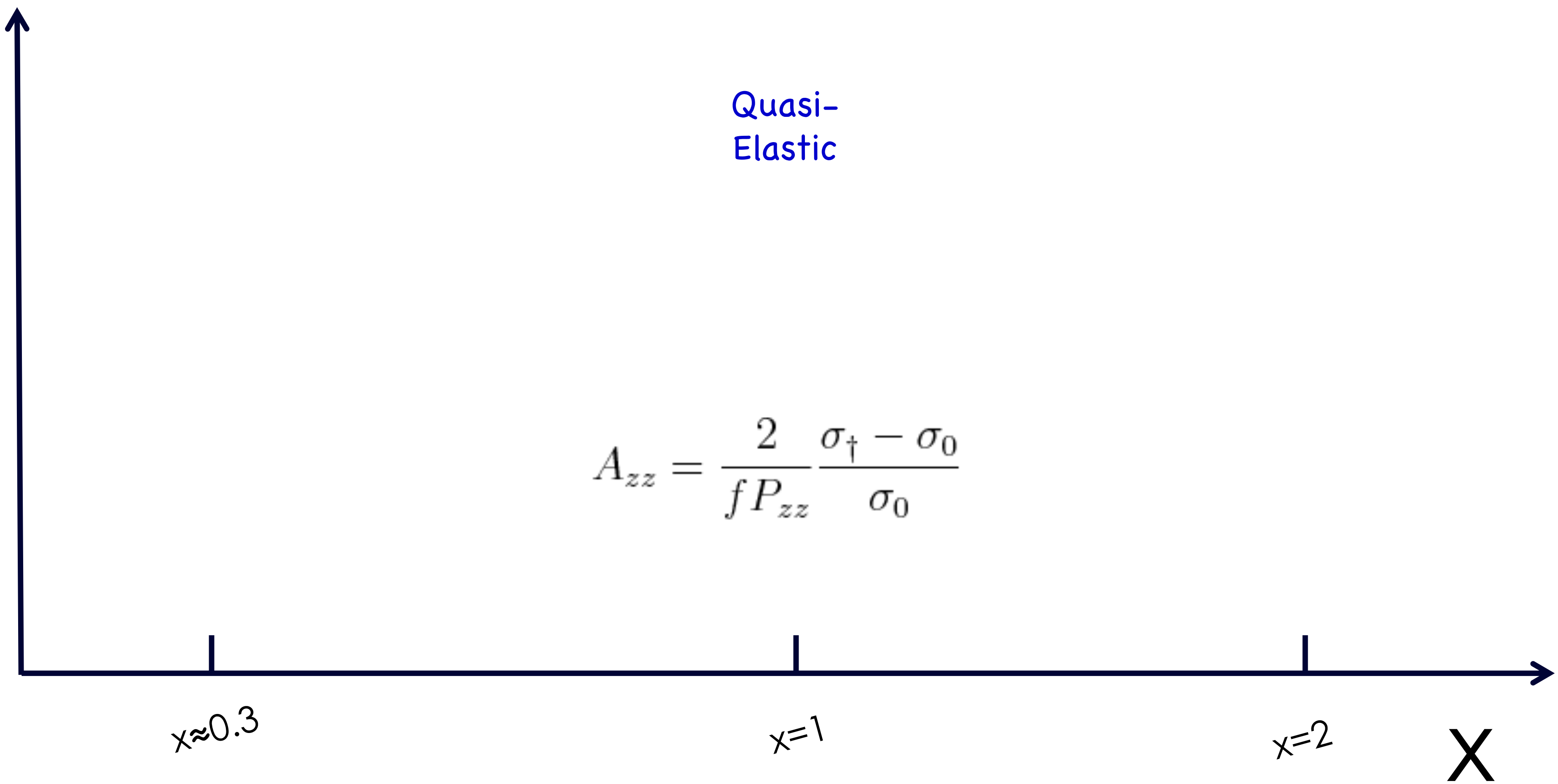
# $A_{zz}$ experiment




We simultaneously measure nuclear elastic

-> $T_{20}$ over huge $Q^2$ range
-> measure $T_{20}$ at largest $Q^2$ yet
-> will use to cross-check Pzz

# Tensor Spin Observables

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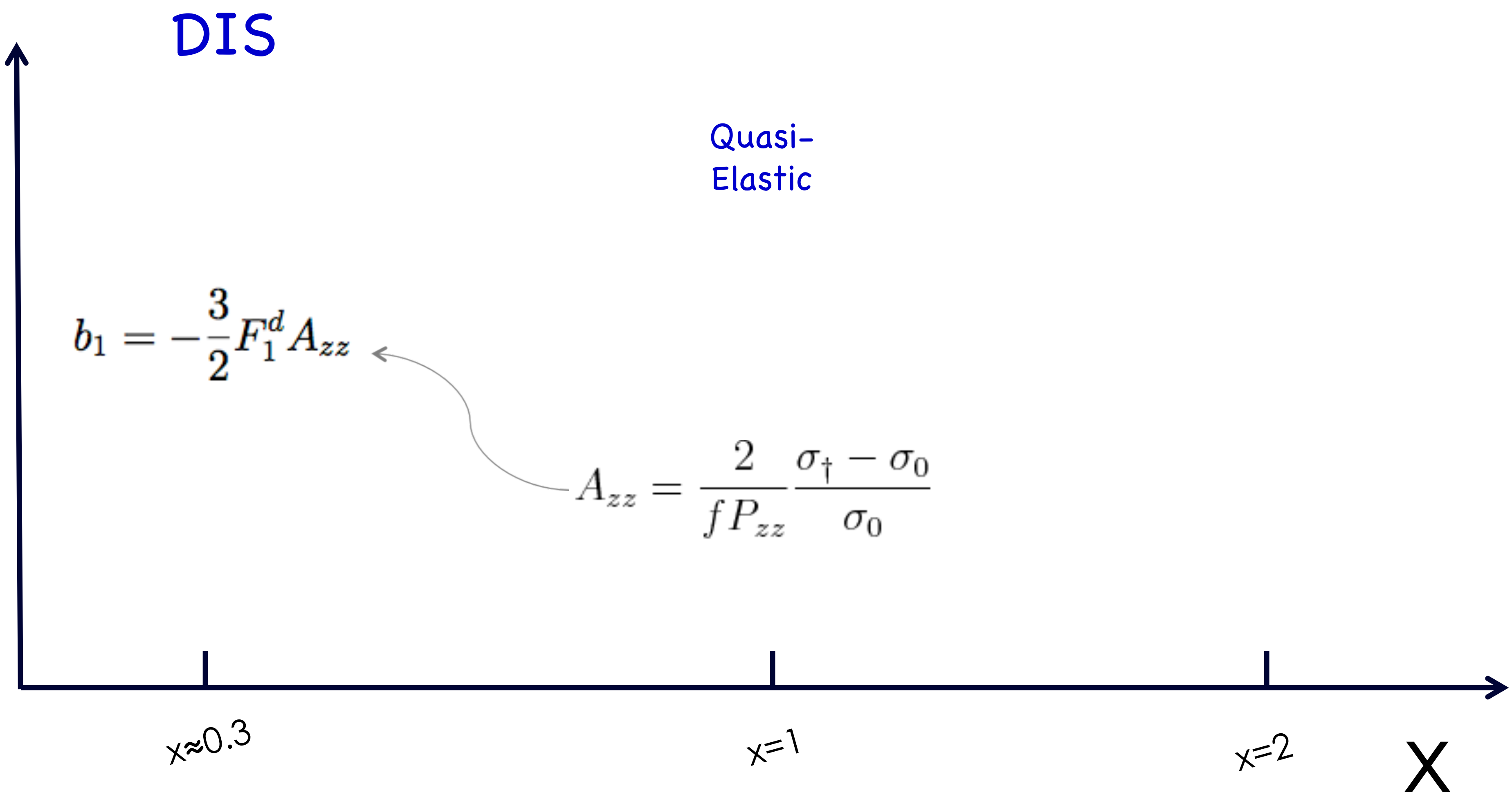


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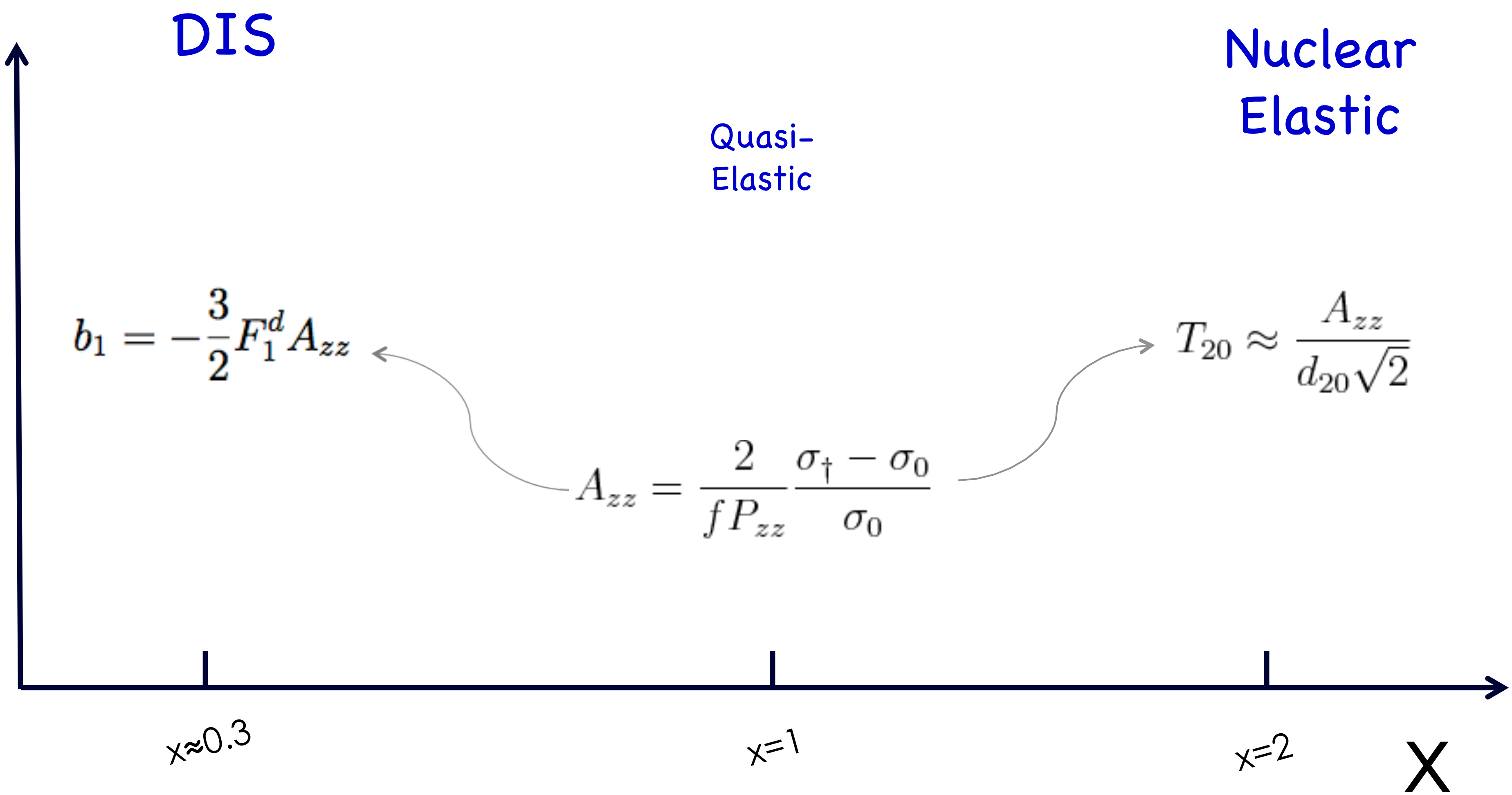
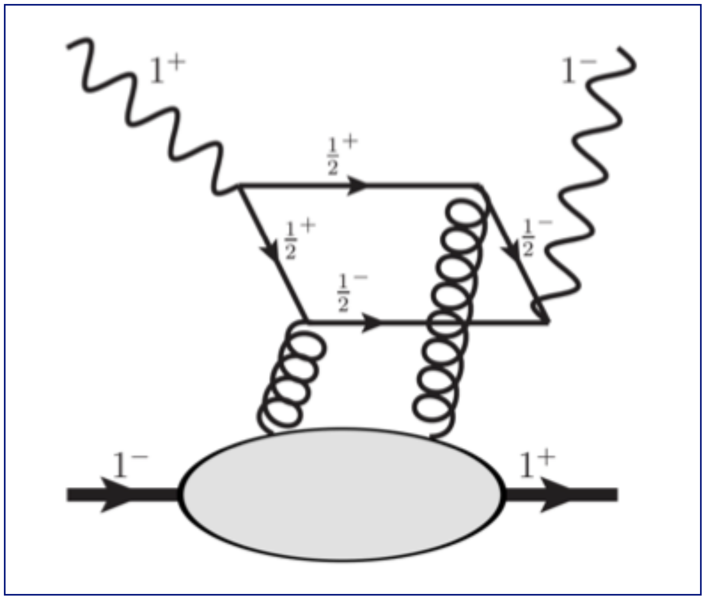


# LOI-12-16-006

James Maxwell (contact)

"Nuclear Gluonometry"




Look for novel gluonic components in nuclei that are not present in nucleons

Non-zero value would be a clear signature of exotic gluon states in the nucleus

$\Delta(x,Q^2)$ double helicity flip structure function

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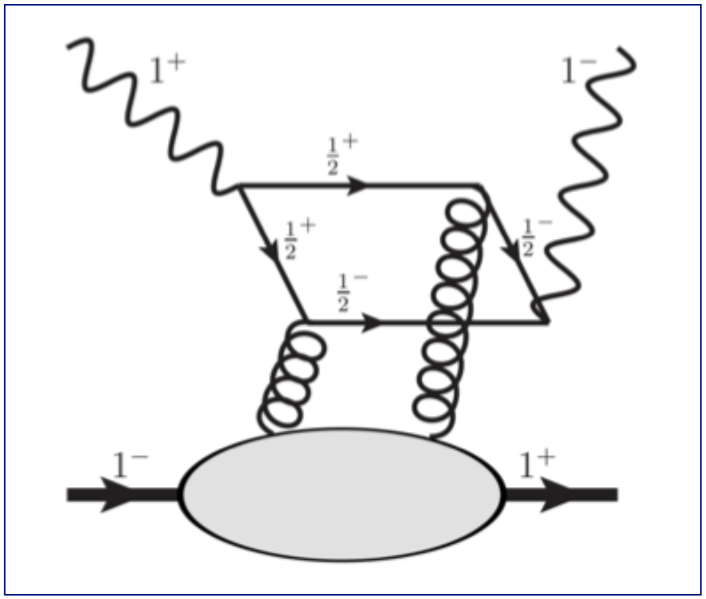


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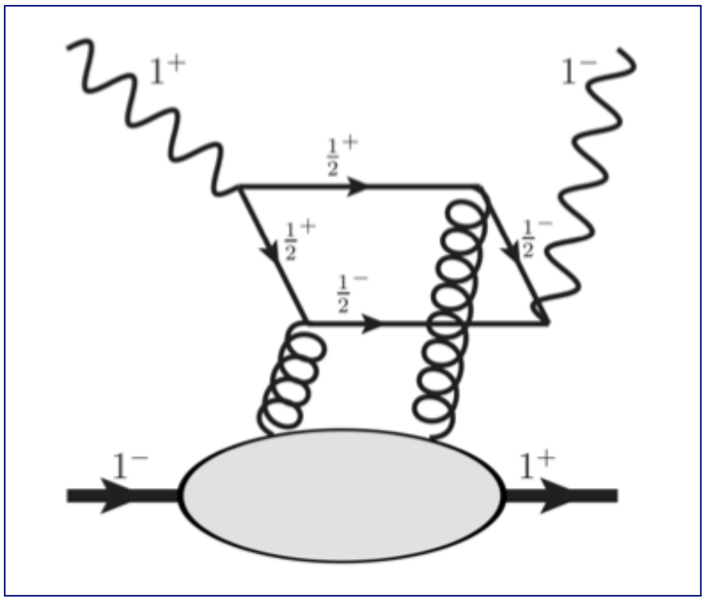
Deep inelastic scattering experiment:
- Unpolarized electrons
- Polarized $^{14}NH_3$ Target
- Target spin aligned transverse to beam

$\Delta(x,Q^2)$ double helicity flip structure function

Encouraged for full submission by PAC44

# LOI-12-16-006

See R. Milner @ Spin2016
"State and Future of Spin Physics"

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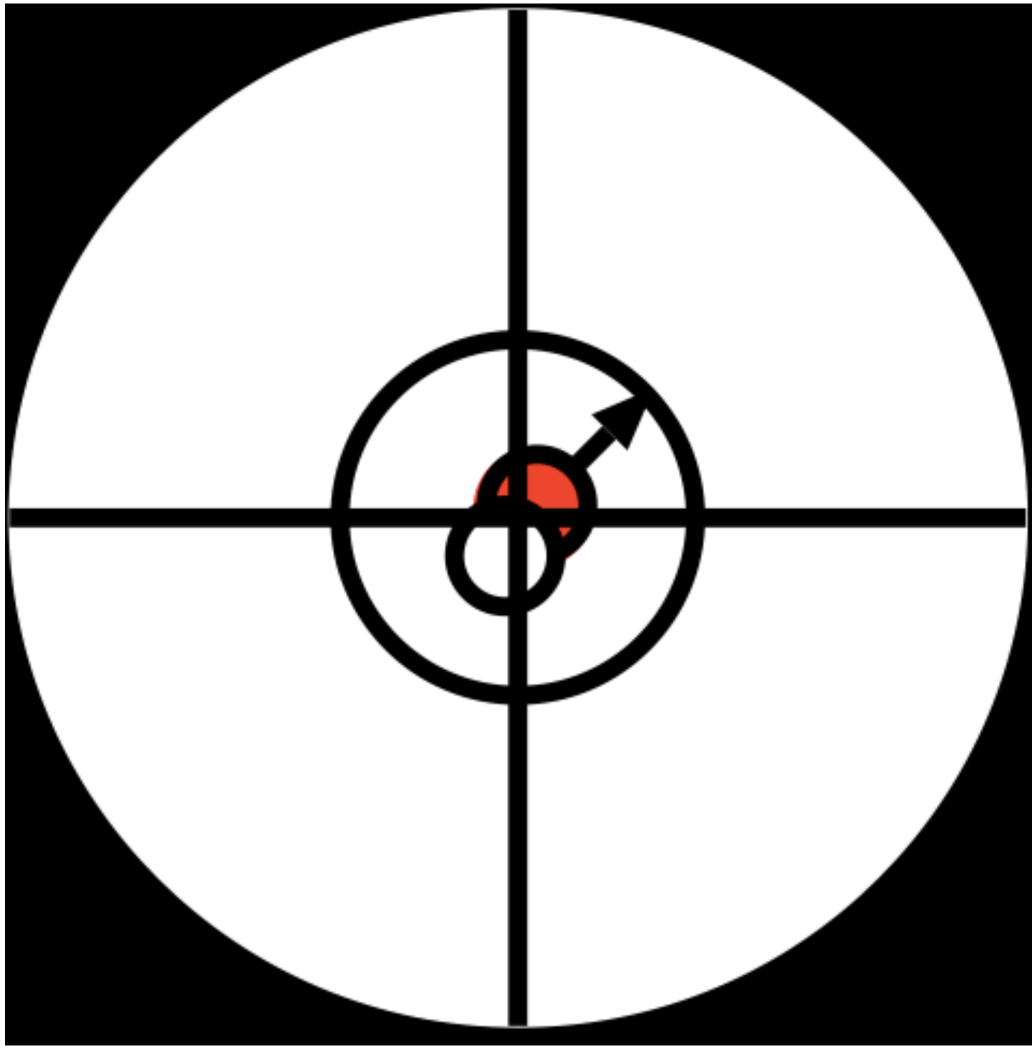
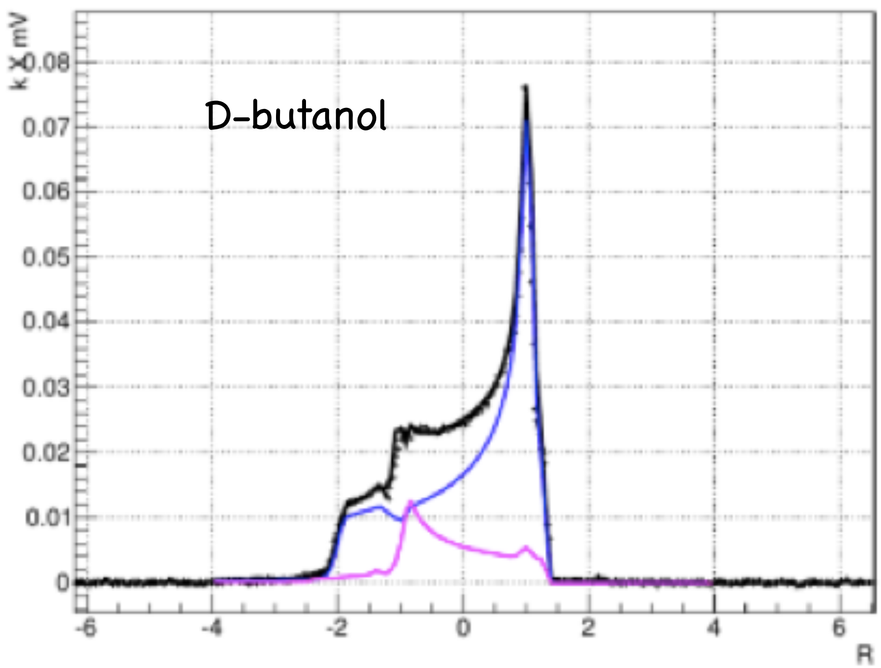


# Tensor Polarized Target




MC overlap with d-but. NMR experimental points (Pn=51→45,Qn:20→31%)

## Significant progress at UVa

Enhancing $P_{zz}$ via semi-selective saturation

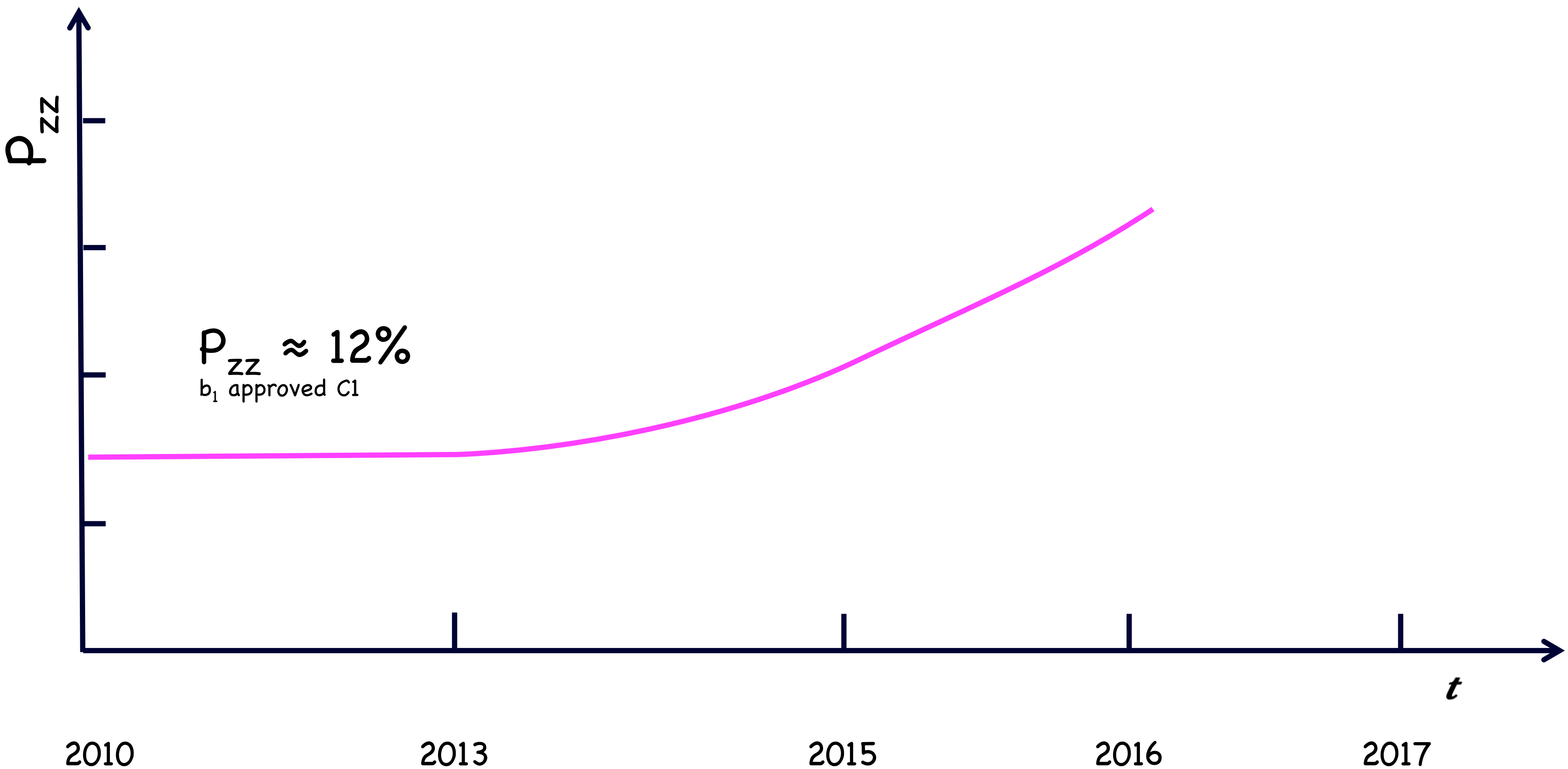
understanding the NMR lineshape

D Keller, Eur.Phys.J.A., in review (2016)
D Keller, PoS, PSTP2015:014 (2016)
D Keller, J.Phys.Conf.Ser., **543**(1):012015 (2014)
D Keller, Int.J.Mod.Phys.Conf.Ser., **40**(1):1660105 (2016)

Promising, but need to confirm in $ND_3$

$T_{20}$ measurement at Higs to verify NMR analysis

# Tensor Polarization progress



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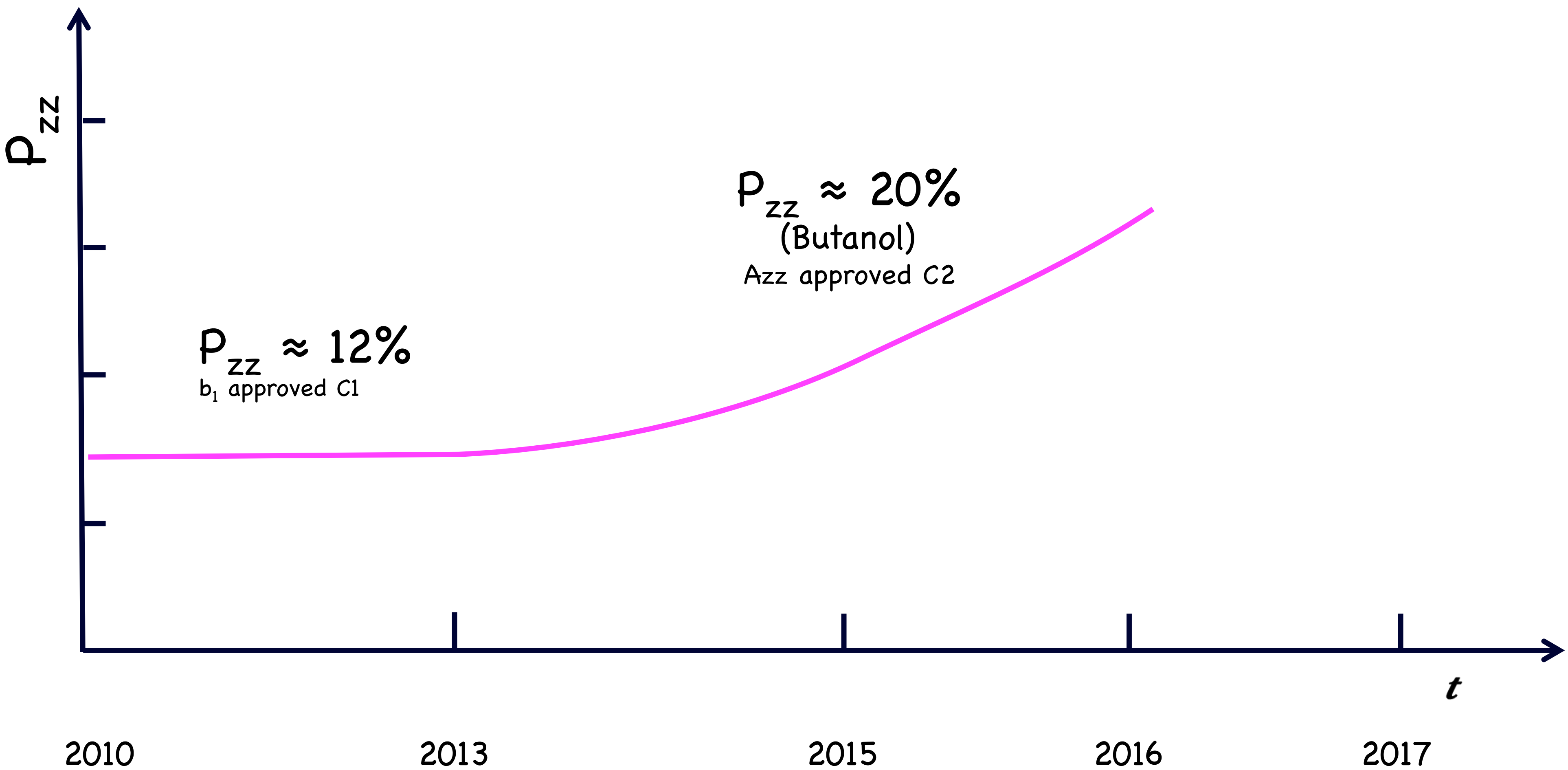

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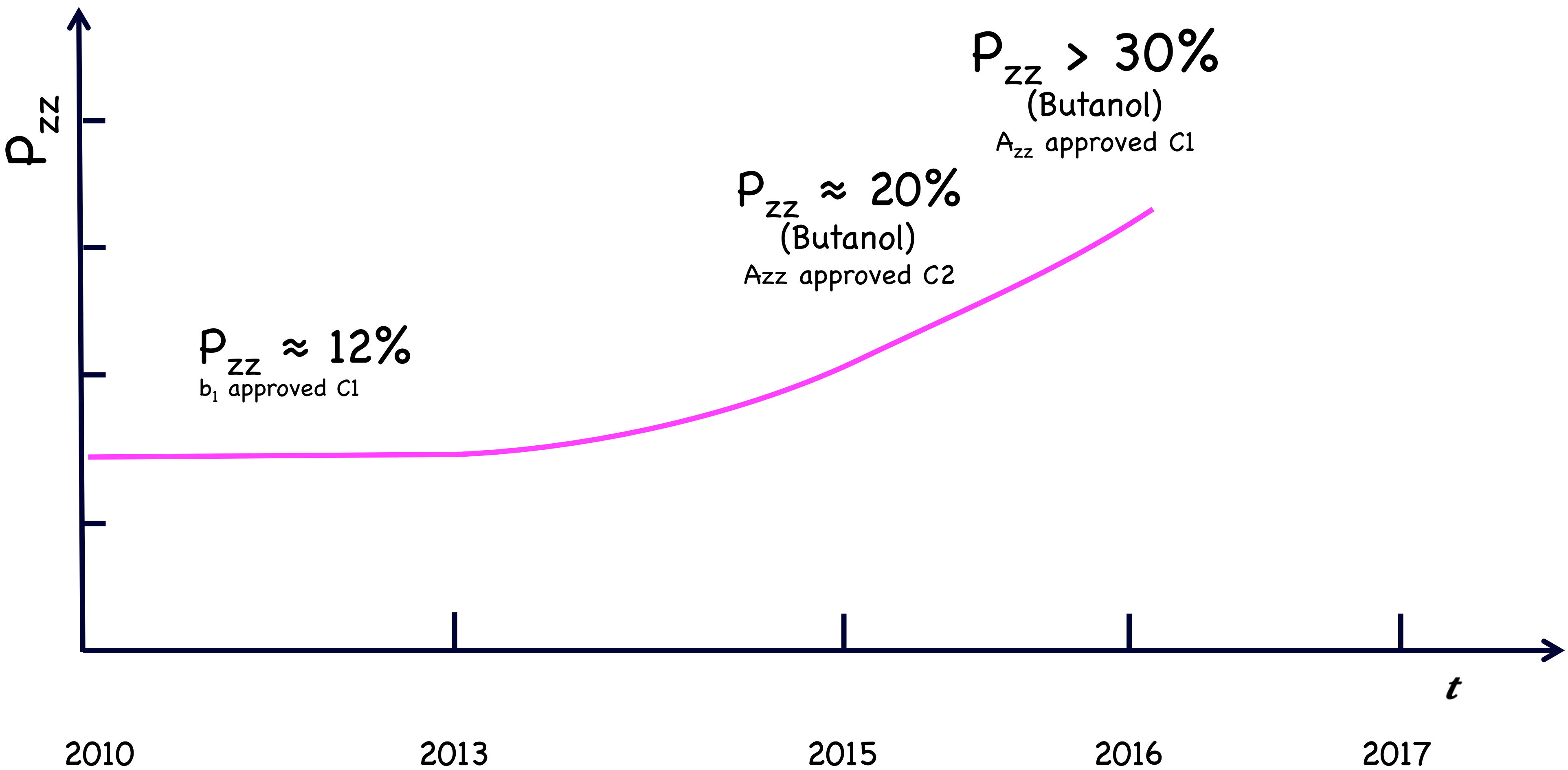

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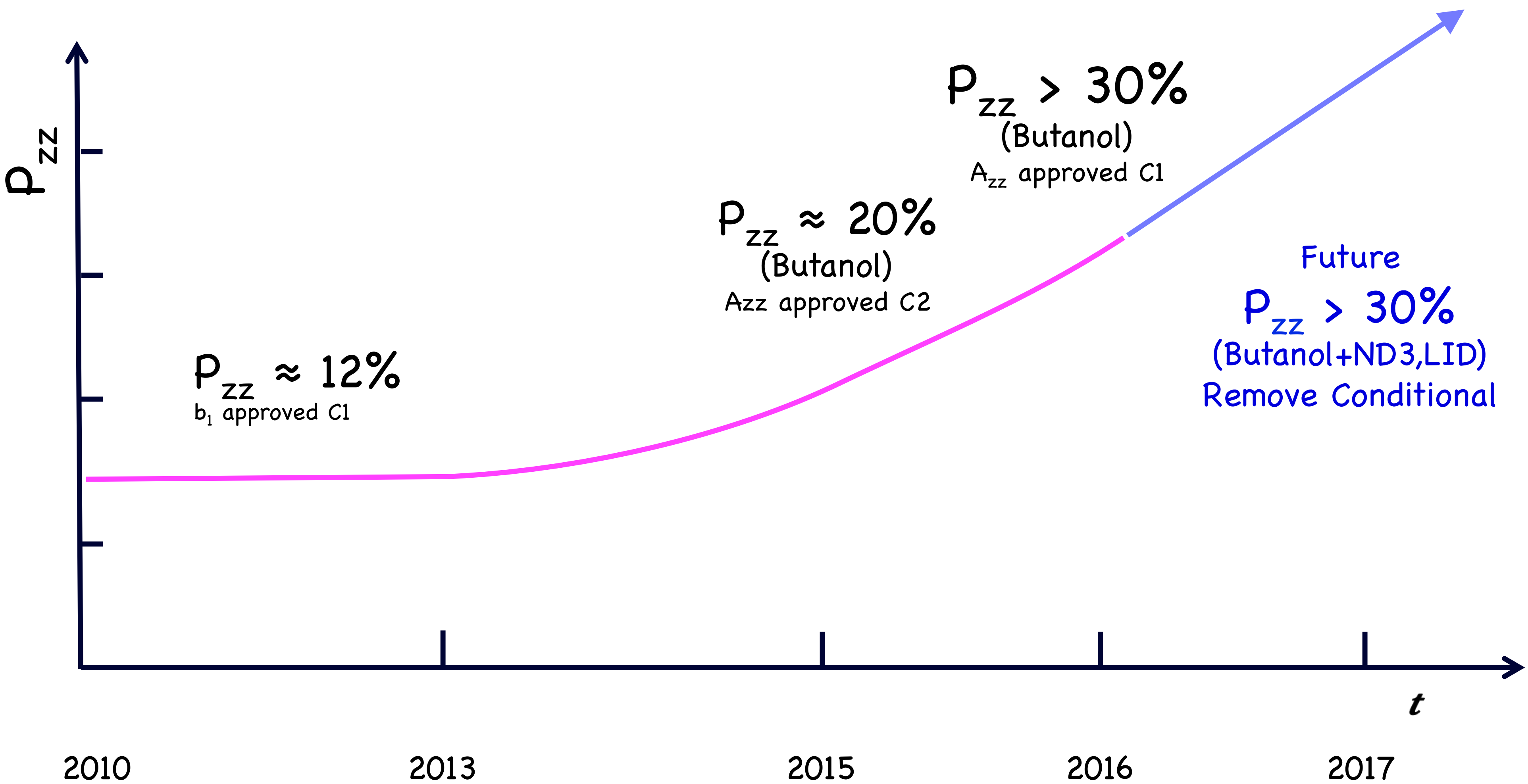
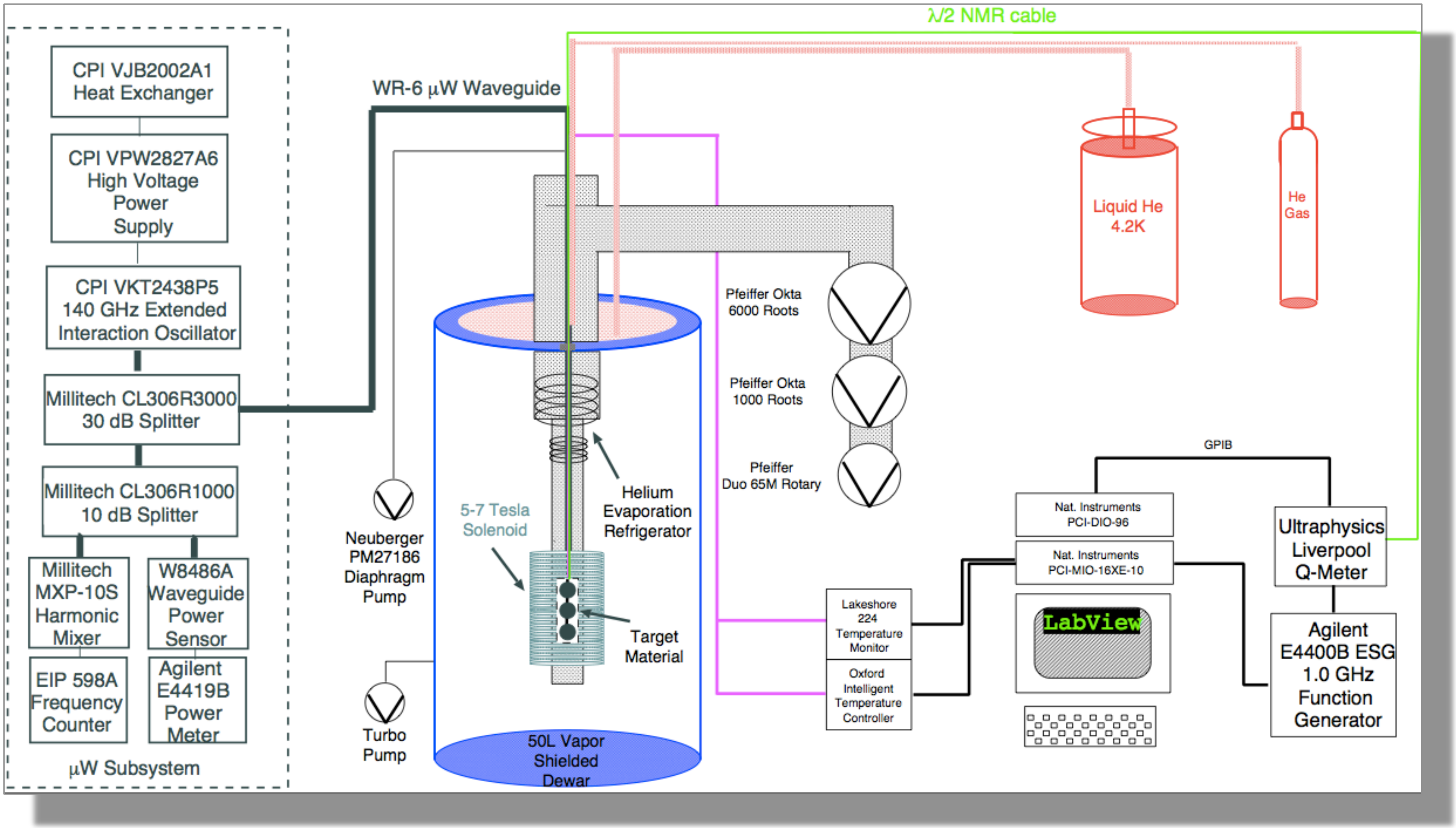


# UNH Polarized Target Lab




Very complicated / difficult system!

hats off to Uva for making this look easy for 30 years!

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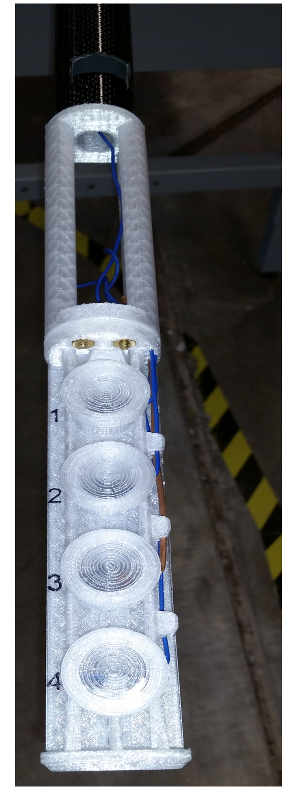
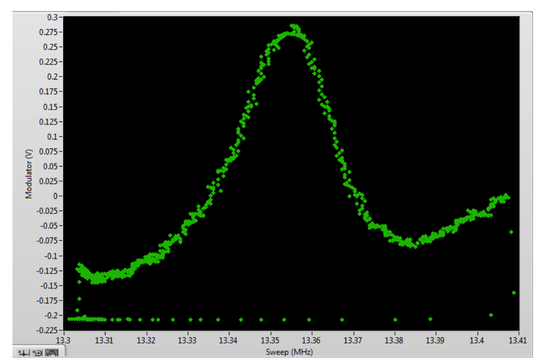



Reached 1K/7T
Have Working NMR system
Developing high vacuum expertise
Just Began Construction of new fridge
Still need to finish the microwave subsystem



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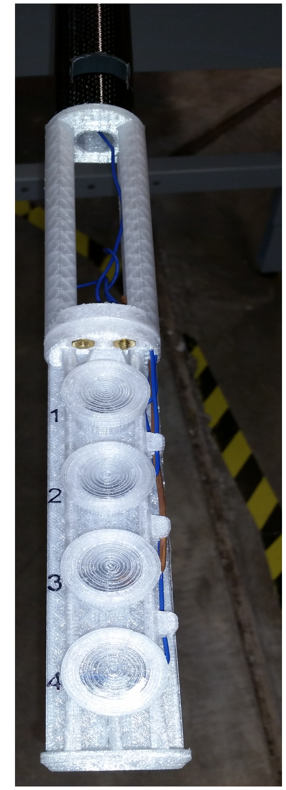


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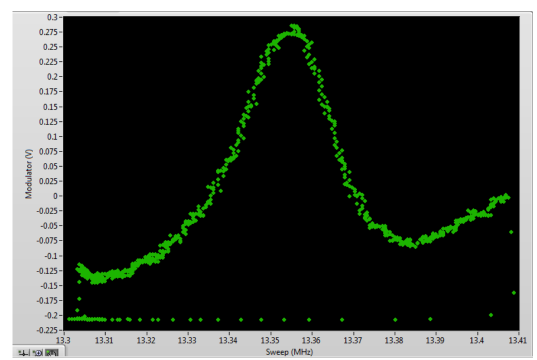


New Faculty hire (Elena Long)
University made a significant investment in infrastructure
We should be fully operational by end of year

# Summary

Tensor Program

E12-13-001: Tensor Polarized Structure function b1 of the Deuteron

E12-14-002: Tensor Asymmetry $A_{zz}$ for x>1

LOI12-14-001: Tensor Structure Function $\Delta$

Significant progress

High tensor polarizations demonstrated at Uva

Next step is to remove the Conditional status

UNH target lab goal to be fully operational by end of year.

Seeking Theory input to:

Make sure there is a clear interpretation of the observables we can measure

Brainstorm ideas for new physics to investigate with this target.

# Splitting