Transverse Spin Asymmetry Observations

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Transverse Spin Asymmetry Observations

Outline

- Introduction
- Review Motivations
- Review Experiments: Past, present, future
- Solicit new calculations
- Summary

Beam Normal Single Spin Asymmetry

Introduction

- Electron beam polarized transverse to beam direction
- Induces azimuthal parity-conserving asymmetry (A_n)

  $\longrightarrow A_n = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow}$, with $\uparrow$ ($\downarrow$) parallel (anti-parallel) to normal pol. vector $\hat{n} = \frac{(\vec{k} \times \vec{k\prime})}{|\vec{k} \times \vec{k\prime}|}$; $\vec{k}$ ($\vec{k\prime}$) initial (final) electron mom.

  $\longrightarrow A_{meas}(\phi) = A_n \vec{P}_e \cdot \hat{n}$ where ϕ is angle between $\vec{P}_e$ and $\hat{n}$
- A_n vanishes in the Born approximation, thus can provide sensitive probe of two (or multi) photon exchange effects
- Order of magnitude: $A_n \sim \alpha_{em} \cdot \frac{m_e}{E_e} \sim 10^{-6} - 10^{-5}$

  $\longrightarrow$ Historically, very challenging measurement

  $\longrightarrow$ Precision measurements feasible with PV expt. setup

Beam Normal Single Spin Asymmetry

Measurement Motivations

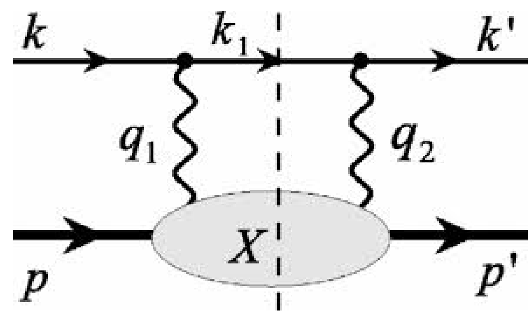
- One of the largest potential false asymmetries in precision PVeS experiments
- As PVeS experiments push envelope of precision, corrections for BNSSA leakage become increasingly important
  - ⟶Leakage suppressed by axially symmetric detectors and minimizing transverse polarization component
  - ⟶But still has potential for large systematic contribution
  - ⟶PVeS experiments perform dedicated measurements of A_n to quantify leakage correction
- Test theoretical framework of calculations, and specifically the 2γ exchange contribution, to further push the precision frontier

Beam Normal Single Spin Asymmetry

Calculation Motivations

- A_n provides direct access to absorptive part of the 2γ exchange amplitude (A. De Rujula *et. al.*, Nucl. Phys. B **35**, 365 (1971))
- General formalism developed: M. Gorchtein, P.A.M. Guichon, M. Vanderhaeghen, Nucl. Phys. A **741**, 234 (2004)

$$A_n = \frac{2\mathrm{Im}(T^*_{1\gamma} \cdot \mathrm{Abs}T_{2\gamma})}{|T_{1\gamma}|^2}$$



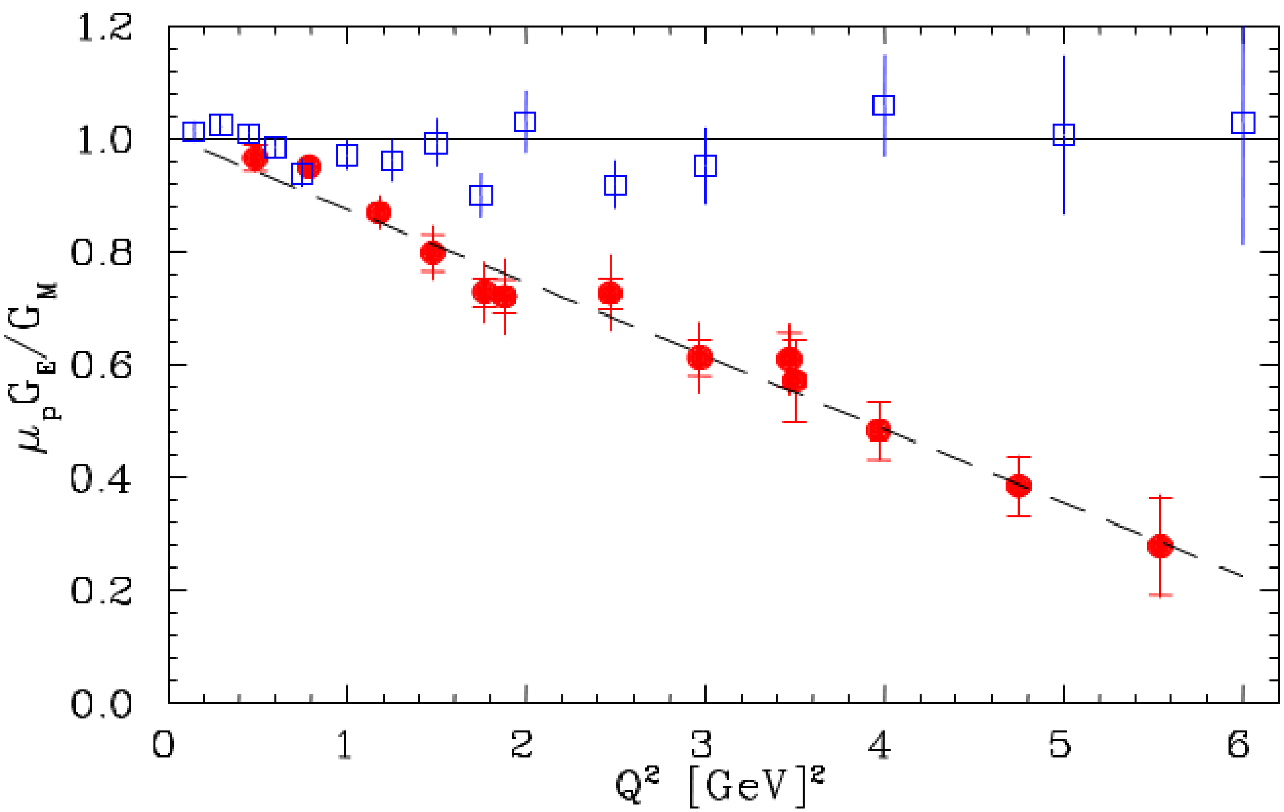
$\longrightarrow$Calculations sensitive to treatment of intermediate hadronic states $X = N$, πN, ...

- Understanding of 2γ exchange contributions here could be useful in extending framework to EW processes ($\Box_{\gamma Z}$, ...)

Beam Normal Single Spin Asymmetry

Motivation

- Theoretical and experimental inputs into understanding the imaginary part of $T_{2\gamma}$ can give better understanding of the real part (help resolve Rosenbluth$\Longleftrightarrow$Pol.Transfer discrepancy)



Elastic BNSSA Measurements (Published)

Expt	Tgt	E_b(GeV)	θ_e	Q^2(GeV^2)	A_n(ppm)
SAMPLE	^{1}H	0.192	146°	0.10	-15.4 ± 5.4
A4	^{1}H	0.569	35°	0.11	-8.59 ± 1.16
A4	^{1}H	0.855	35°	0.23	-8.52 ± 2.47
HAPPEX	^{1}H	3.03	6°	0.099	-6.80 ± 1.54
HAPPEX	^{4}He	3.03	6°	0.077	-13.97 ± 1.45
G0	^{1}H	3.03	20.2°	0.15	-4.06 ± 1.17
G0	^{1}H	3.03	25.9°	0.25	-4.82 ± 2.11
G0	^{1}H	0.362	108°	0.22	-176.5 ± 9.4
G0	^{1}H	0.687	108°	0.63	-21.0 ± 24
PREX	^{12}C	1.06	5°	0.0098	-6.49 ± 0.38
PREX	^{208}Pb	1.06	5°	0.0088	0.28 ± 0.25

Elastic BNSSA Meas. (Unpub./prel./future)

Expt	Tgt	E_b(GeV)	θ_e	Q^2(GeV^2)	A_n(ppm)
E158	^{1}H	46	3°	0.04	-2.89 ± 0.40
E158	e	46	3°	0.04	7.04 ± 0.25
A4	^{1}H	0.315	145°	0.22	-87 ± 6 (prel.)
Qweak	^{1}H	1.165	7.9°	0.025	Buddhini's Talk
Qweak	^{27}Al	1.165	7.9°	0.025	Buddhini's Talk
Qweak	^{12}C	1.165	7.9°	0.025	anal. in progress
CREX	^{40}Ca	2.2	4°	0.022	future expt
CREX	^{48}Ca	2.2	4°	0.022	future expt
MOLLER	^{1}H	11	0.5°	0.006	future expt
MOLLER	e	11	0.5°	0.006	future expt
MESA-P2	^{1}H	0.200	20°	0.0025	future expt
MESA-P2	^{1}H	?	bkwd	?	future expt?

Inelastic BNSSA Measurements (Unpub./future)

Expt	Tgt	E_b(GeV)	θ_e	Q^2(GeV^2)	A_n(ppm)
Qweak	^{1}H	1.165	7.9°	0.021	Buddhini's Talk
Qweak	^{27}Al	1.165	7.9°	0.021	anal. in progress
Qweak	^{12}C	1.165	7.9°	0.021	anal. in progress
Qweak	^{1}H	3.350	7.9°	0.08	anal. in progress
MOLLER	^{1}H	11	0.5°	0.008	future expt

More A4 Transverse Spin Measurements

Forward angle

Beam energy [MeV]	Momentum transfer [GeV²]	Target
315	0.03	Hydrogen
420	0.06	Hydrogen
510	0.09	Hydrogen
570	0.11	Hydrogen
855	0.23	Hydrogen
1508	0.63	Hydrogen

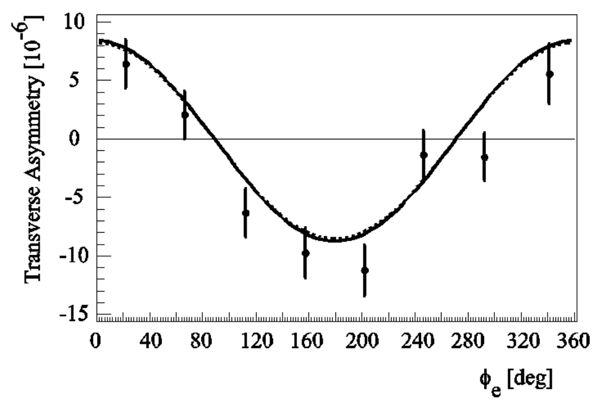
Backward angle

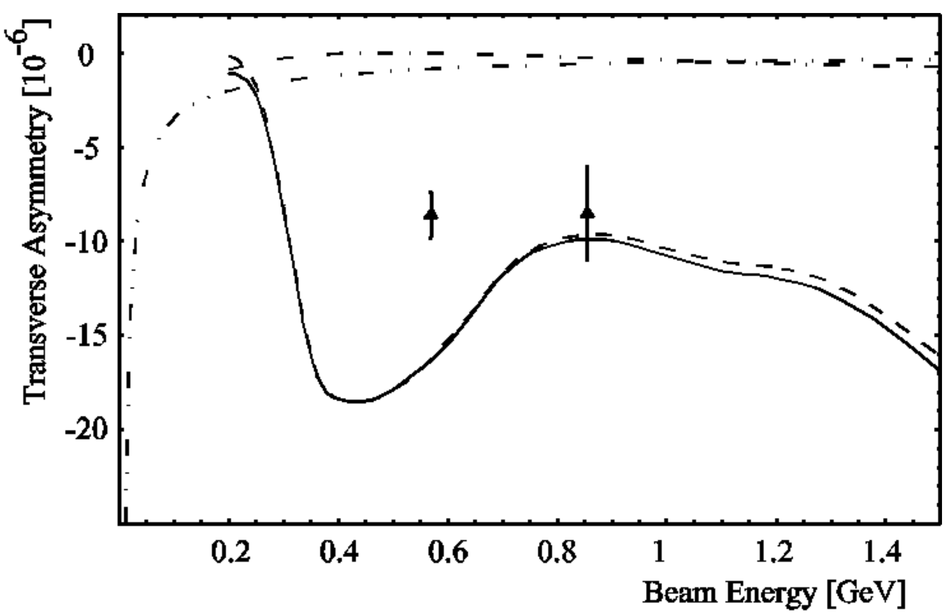
Beam energy [MeV]	Momentum transfer [GeV²]	Target
210	0.11	Hydrogen
210	0.11	Deuterium
315	0.23	Hydrogen
315	0.23	Deuterium
420	0,35	Hydrogen
420	0,35	Deuterium

From Sebastian Baunack

Data and Calculations: A4 (forward)

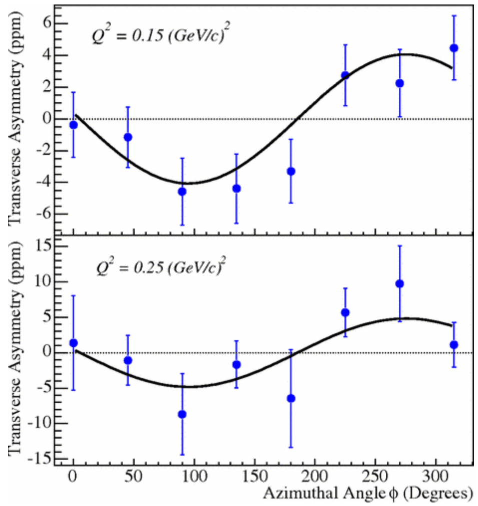
- F. Maas *et. al.*, [MAMI A4 Collab.] Phys. Rev. Lett. **94**, 082001 (2005)
- B. Pasquini, M. Vanderhaeghen: Phys. Rev. C **70**, 045206 (2004)
- Surprising result: Dominance of inelastic intermediate states!





Data and Calculations: G0 (forward)

- D.S. Armstrong, *et. al.*, [Jlab G0 Collab.] PRL **99**, 092301 (2007)
- Pasquini, Vanderhaeghen: PRC **70**, 045206 (2004)
- A. Afanasev, N.P. Merenkov PLB **599**, 48 (2004)
- M. Gorchtein PLB **644**, 322 (2007)

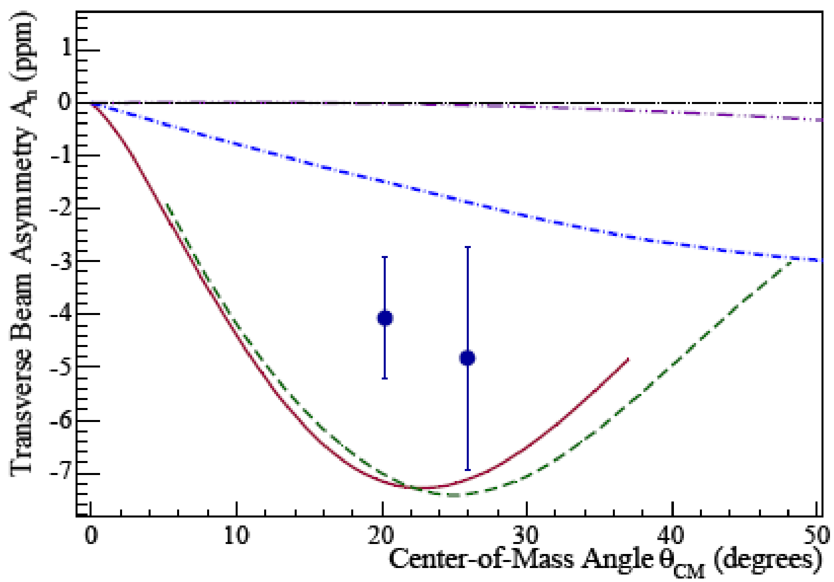


—·—P&V (elastic I.S. only)

—·—P&V (including πN I.S)

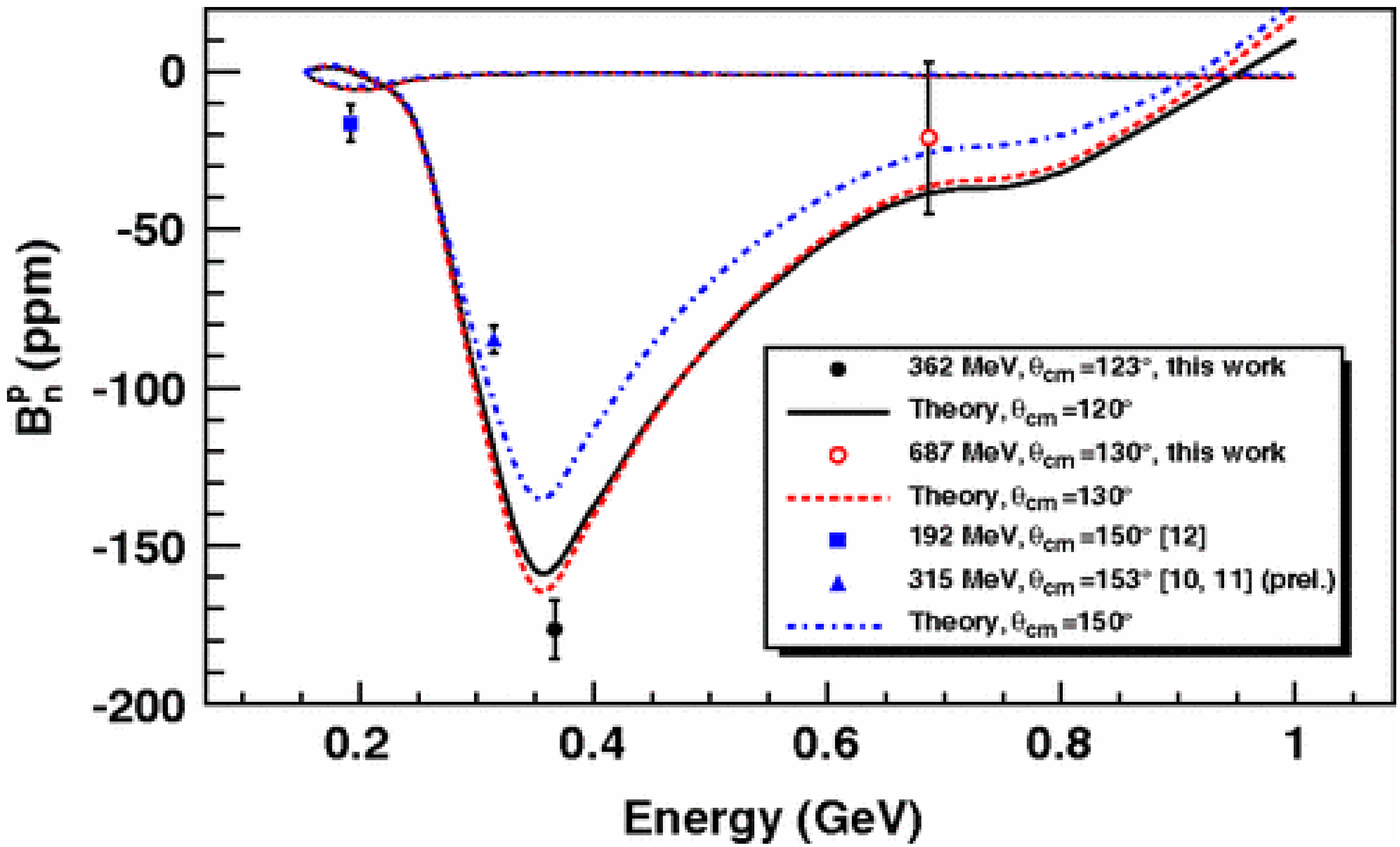
—A&M (optical theorem w/ exp. inputs)

——Gorchtein (optical theorem w/ exp. inputs)



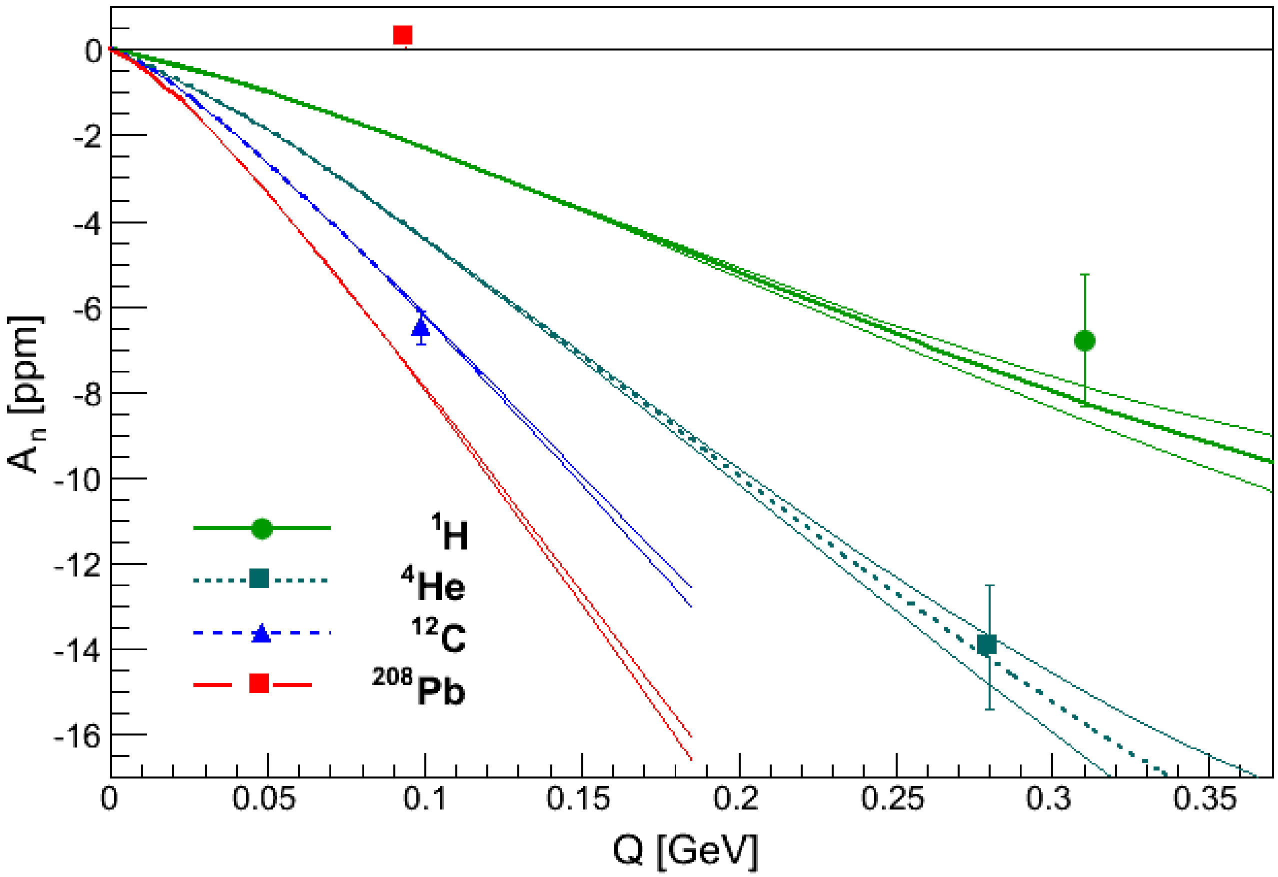
Data and Calculations: A4, G0 Backward Angles

- D. Androic *et. al.*, [Jlab G0 Collab.] PRL **107**, 022501 (2011)
  - Pasquini, Vanderhaeghen: PRC **70**, 045206 (2004)

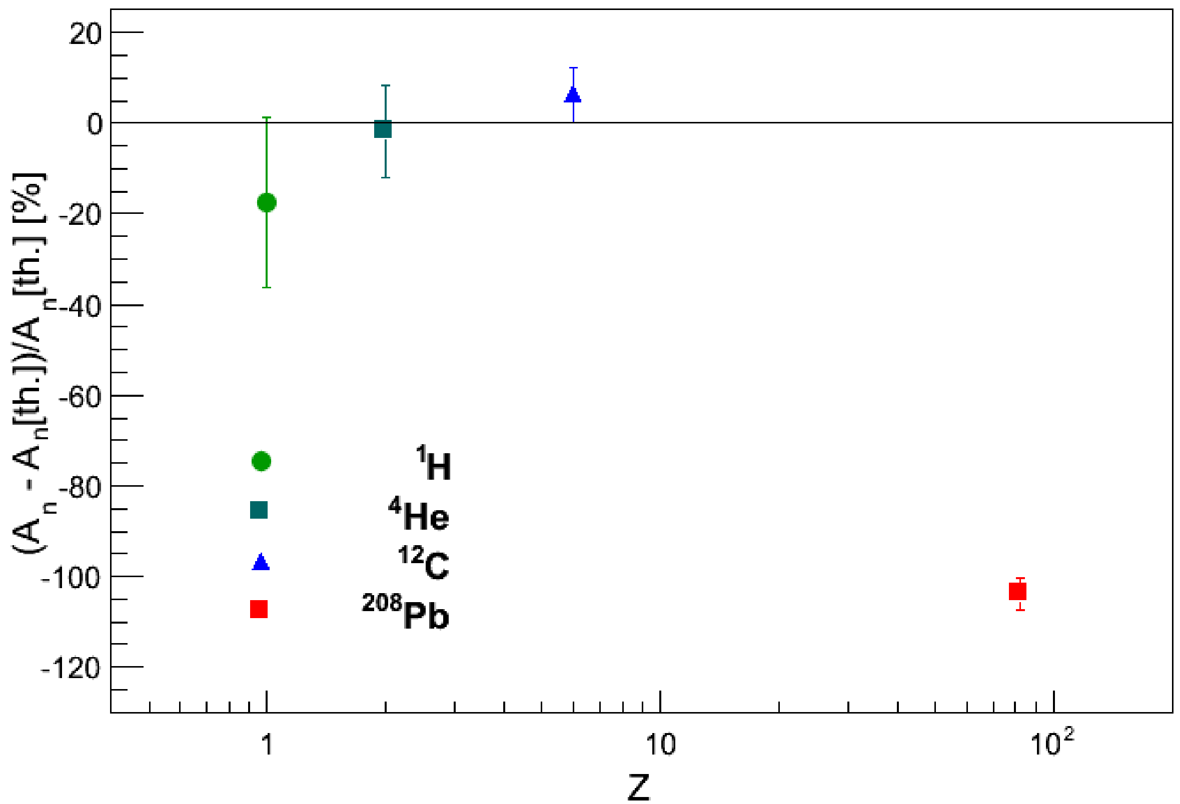


Data and Calculations: HAPPEX/PREX

- S. Abrahamyan, *et. al.*, [Jlab HAPPEX and PREX Collab.] PRL **109**, 192501 (2012)
- M. Gorchtein, C. J. Horowitz, PRC **77**, 044606 (2008)
- Surprising result: Wild disagreement for Pb measurement!



PREX Pb Discrepancy/CREX Ca Measurements



- What is the reason for wild disagreement?

Coulomb Distortions? Something else? Need new calculation

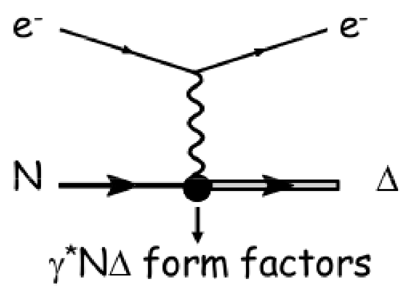
- Will measure intermediate Z nuclei ^{40}Ca and ^{48}Ca: Can provide further understanding of dispersion versus Coulomb corrections

Inelastic BNSSA Calculations

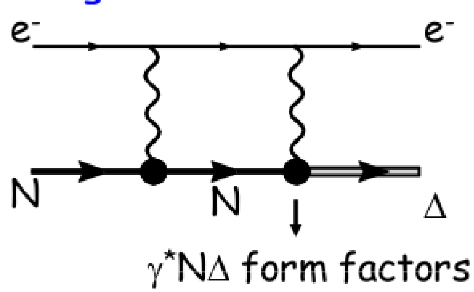
Beam Spin Asymmetry in inelastic eN scattering with Δ in the final state

$$B_n = = \frac{\mathrm{Im}(T^{*1\gamma}_{f1}\,\mathrm{Abs}T^{2\gamma}_{fi})}{|T^{1\gamma}_{fi}|^2}$$

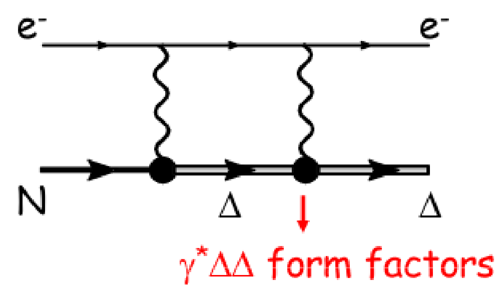
- 1γ exchange



- 2γ exchange



for s* M^2_Δ



unique tool to learn about the γ*ΔΔ form factors

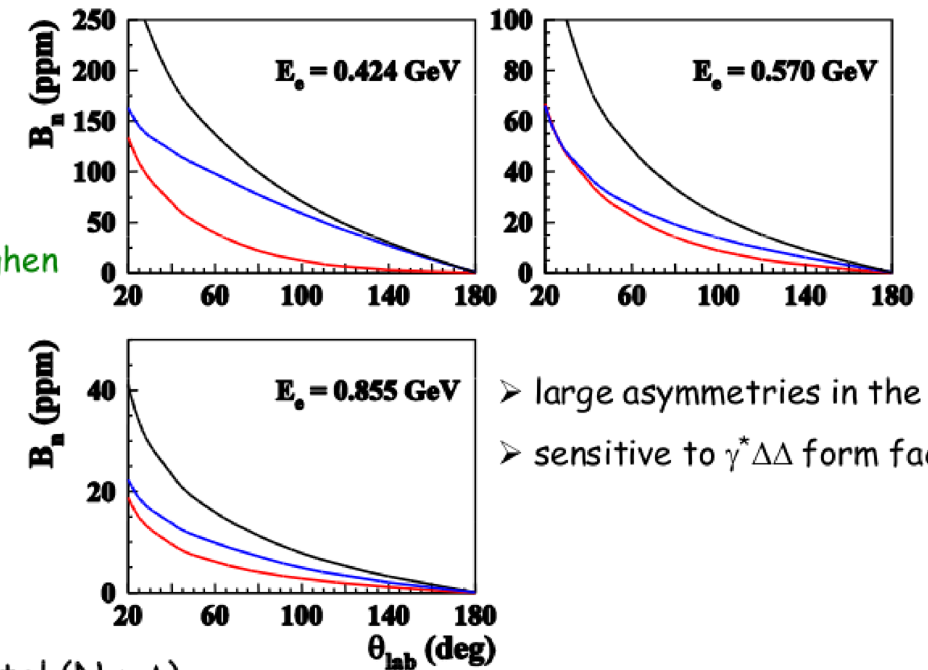
Barbara Pasquini, MAMI and Beyond, 30 March - 3 April 2009

http://wwwkph.kph.uni-mainz.de/T/MAMIandBeyond/02%20Dienstag/08%20Pasquini.pdf

Inelastic BNSSA Calculations

Beam asymmetry in inelastic electron scattering

B.P. & Vanderhaeghen
in preparation



- large asymmetries in the forward region
- sensitive to $\gamma^*\Delta\Delta$ form factors

— total (N + Δ)

— Δ intermediate state

— N intermediate state

$\gamma^*\Delta\,\Delta$ form factors from LATTICE QCD
Alexandrou et al., arXiv:0901.3457 [hep-ph]

$\gamma^*N\Delta$ form factors
from MAID07 parametrization

Barbara Pasquini, MAMI and Beyond, 30 March - 3 April 2009
http://wwwkph.kph.uni-mainz.de/T/MAMIandBeyond/02%20Dienstag/08%20Pasquini.pdf

New Calculations for BNSSA

Inelastic (Resonant)

- C. Carlson will have numbers within a month for existing data with Qweak kinematics (Similar approach to Vanderhaeghen–calculates transition FF using MAID inputs)
- Carlson also willing to do calculations for A4. I think he just needs details of the measurement kinematics
- W. Melnitchouk has also promised to do these calculations using the same framework he used for gamma-Z calculations (with all intermediate states included)

Elastic

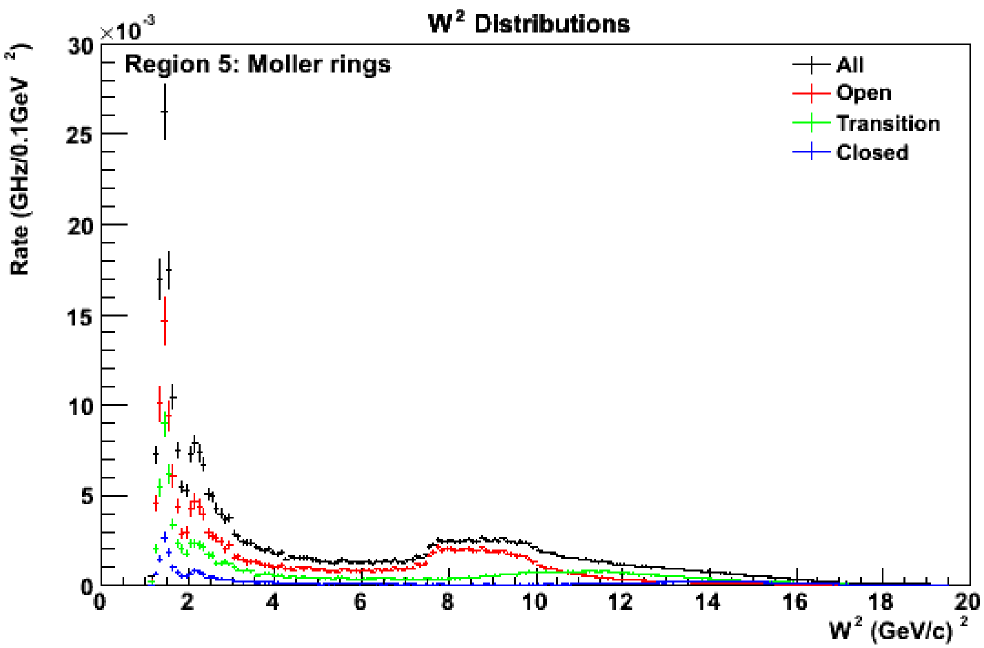
- C. Horowitz and X. Roca Maza have indicated willingness to do new calculation for PREX Pb measurement–need to fold Coulomb distortions into calculation framework
- Calculations are also needed for ^{40}Ca and ^{48}Ca–likely using same framework as new Pb calculations

New Calculations for BNSSA

Inelastic (Non-resonant)

- Qweak collected first data ever for this and is being analyzed
- There are currently no theoretical underpinnings for interpreting this data...because nobody has ever cared about it
- W. Melnitchouk says he will look into this

Future MOLLER reach



Summary

- Much activity, both experimental and theoretical, on this subject over the past decade
- Precision of recent and upcoming experiments pushing need for more detailed calculations to give valuable insight into fundamental interaction processes
- The connection to Imaginary 2γ exchange amplitudes is clear and can help better understand the real part of amplitude – broad interest in this
- Overall data and calculations tend to have better agreement for forward scattering at higher energies and lower Q^2
- New calculations needed for Pb will perhaps show importance of Coulomb distortions for high Z targets
- Measurements on ^{40}Ca and ^{48}Ca could provide insight into dispersion corrections...same Z but different A

- New data and calculations? for ^{27}Al
- Carlson and Melnitchouk to calculate the inelastic BNSSA for Qweak kinematics using very different technique...very exciting to see which way agrees more with data
- Non-resonant inelastic data collected by Qweak for ^{1}H at $W \sim 2.2$ GeV. Theory needed for interpretations
- Future MOLLER data will reach high W at very low Q^2