Measurement of the Beam-Normal Single-Spin Asymmetry Using Deep Inelastic Scattering With SoLID

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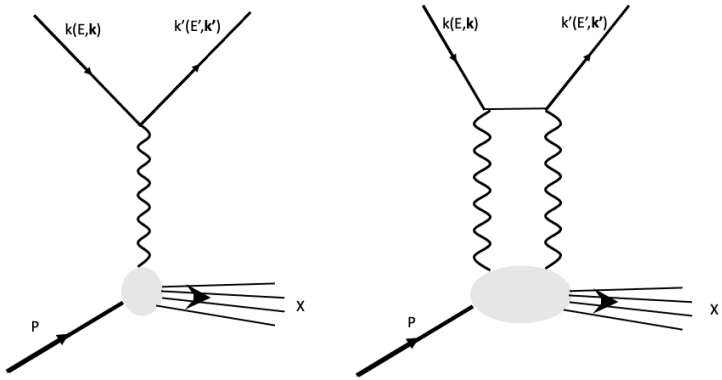
Hall A/C Collaboration Meeting

Motivation

- At the Born level, normal SSAs are zero due to time-reversal invariance as well as parity conservation
  - N. Christ and T.D. Lee., Phys. Rev. 143 (1965)
- A non-zero normal single-spin asymmetry indicates multi-photon exchange
- Normal single-spin asymmetries provide access to the imaginary part of the TPE
  - Due to the interference of single and two photon



Beam-Normal SSA

$$A_n \propto \frac{\alpha_{em} m_e}{Q} \underbrace{\epsilon_{\gamma\delta\lambda\mu} S^\gamma P^\delta k^\lambda k'^\mu}$$

S= spin of electron

P = four-momentum of target

k(k') = four-momentum of initial (scattered) electron

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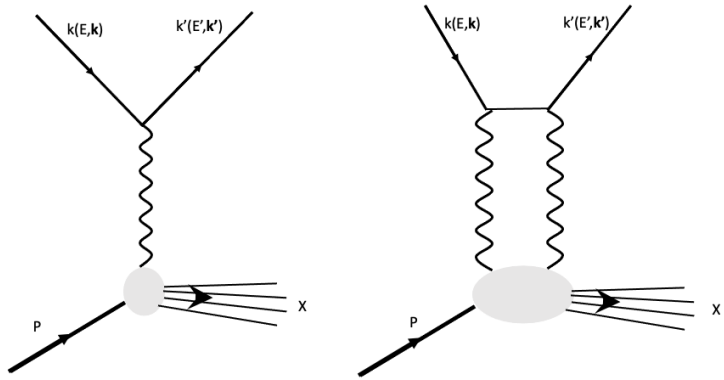

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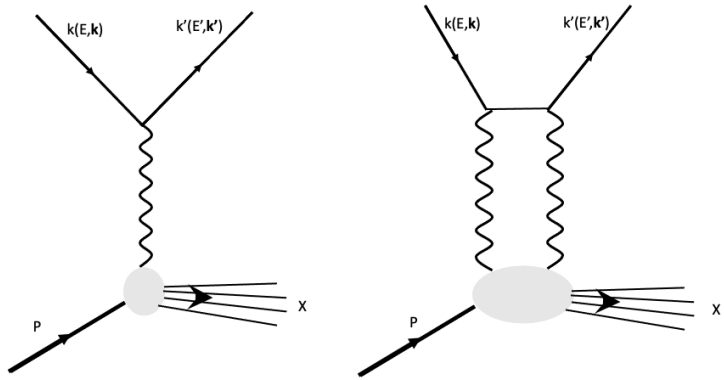

Beam-Normal SSA

$$A_n \propto 2\mathbf{Im} T_{2\gamma} T_{1\gamma}^{*}$$

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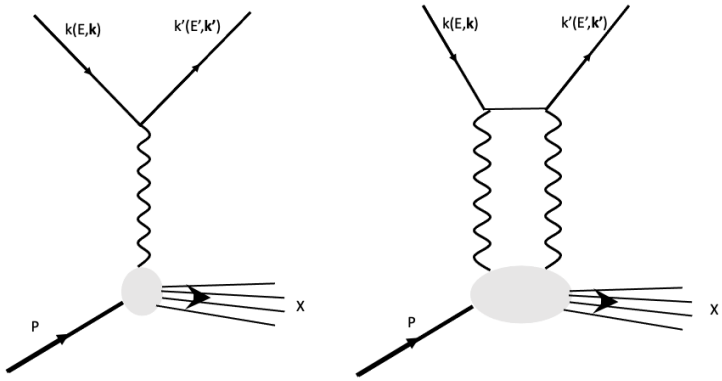

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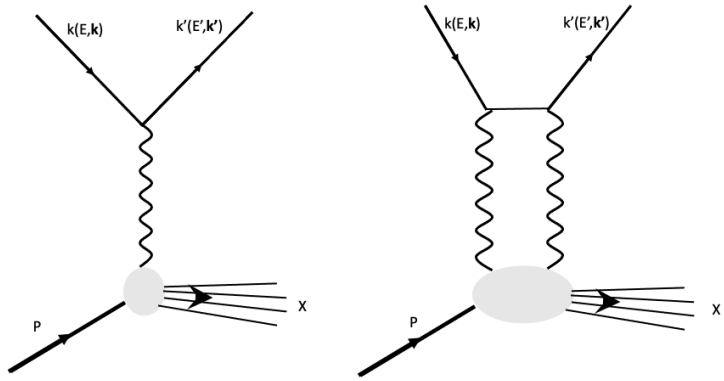

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Normal Single Spin Asymmetries

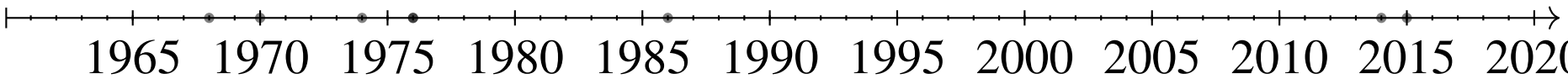
- Nomenclature
  - Transverse beam, analyzing power, etc..., **Beam-normal**
- Inclusive normal single-spin asymmetries can be separated into
  1. Target-normal single spin asymmetry
  2. **Beam-normal single spin asymmetry**
     - **Electron beam polarized normal to the scattering plane**
     - **Unpolarized target**
- From the ϕ dependence of the measured asymmetry, the beam-normal SSA can be determined

$$\boxed{\frac{\sigma^{\uparrow}-\sigma^{\downarrow}}{\sigma^{\uparrow}+\sigma^{\downarrow}} = A_n \sin(\phi)}$$

Theoretical Predictions

- There are a limited number of theoretical predictions for the beam-normal SSA
- Current parton model predictions for the beam-normal SSA:
  - A. Metz et al., Phys. Lett. B 643 (**2006**)
  - Exchange of two photons occurs between lepton and same quark
  - **Prediction for beam-normal SSA: 10^{-6} - 10^{-7}**
- Renewed interest in BNSSA from theorists
- Since data on the two-photon exchange effect in DIS are quite limited
  - **"Measurement of A_n, to even 10% relative uncertainty, would be a major step forward"**
- A high precision measurement of the beam-normal SSA is necessary for:
  - Comparison with expected predictions
  - Constraining TPE models

Summary of Two-Photon Exchange: DIS



- Investigations in the TPE date back to measurements in the 1960's
- Measured by
  - Differences in the ratio of cross sections $\rightarrow \frac{e^+}{e^-}$ or $\frac{\mu^+}{\mu^-}$
  - Normal SSA
- TPE in the DIS regime: Far less investigation
  - **Beam-normal SSA in DIS $\rightarrow$ (nearly) non-existent**
  - **Small asymmetries challenging to measure**
  - **Possible to be measured with SoLID**

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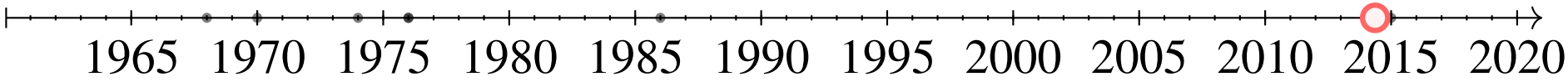
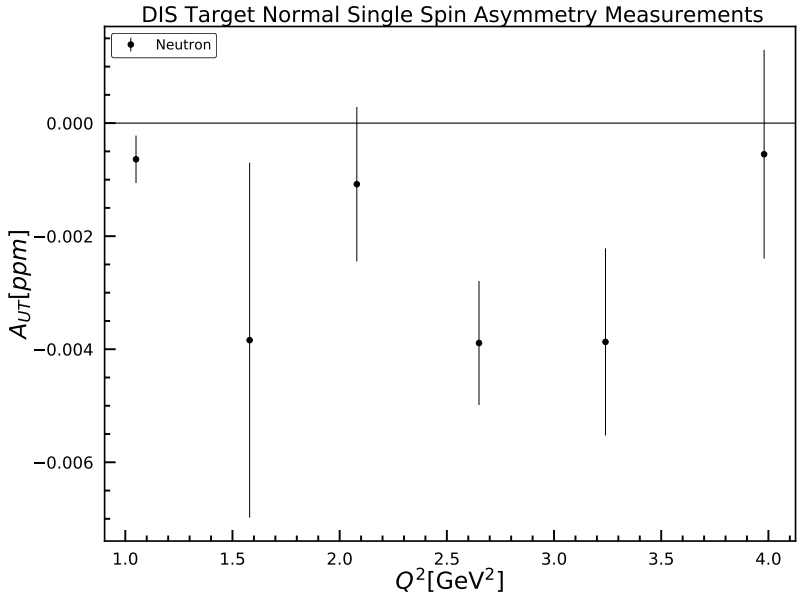


Hall A E07-013

J. Katich et al., Phys. Rev. Lett. 113 (2014)



$$A_y = (-1.09 \pm 0.38) \times 10^{-2}$$

Non-zero: 2.89 σ

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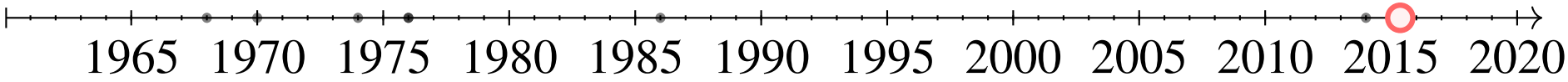
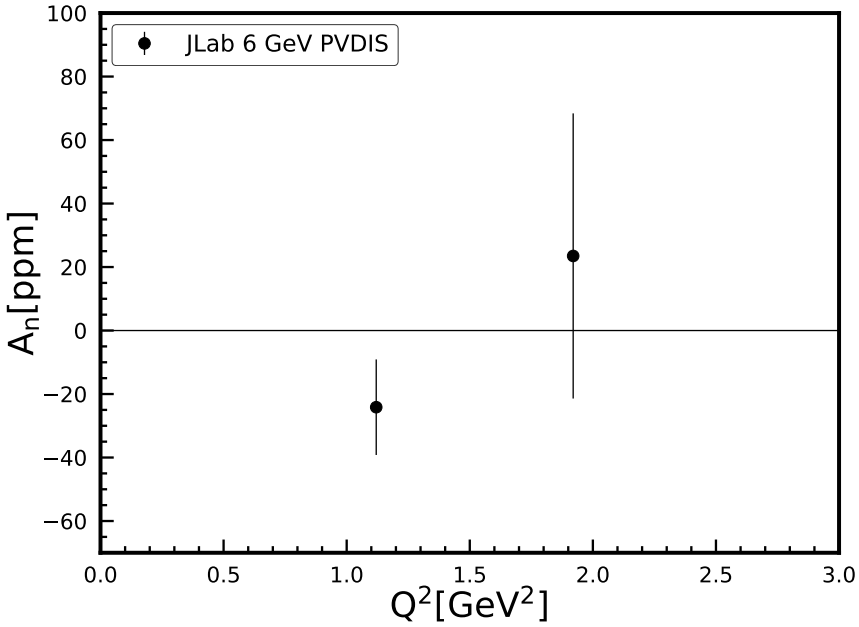


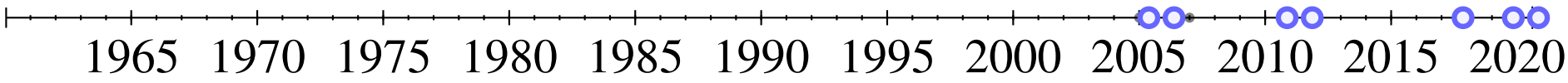
Hall A E08-011 (PVDIS)

D. Wang et al., Phys. Rev. C 91 (2015)



Beam-normal single spin asymmetry DIS measurement

Summary of Elastic Beam-Normal Single Spin Asymmetry



F. E. Maas et al., Phys. Rev. Lett. 94 (2005)

D. S. Armstrong et al., Phys. Rev. Lett. 99 (2007)

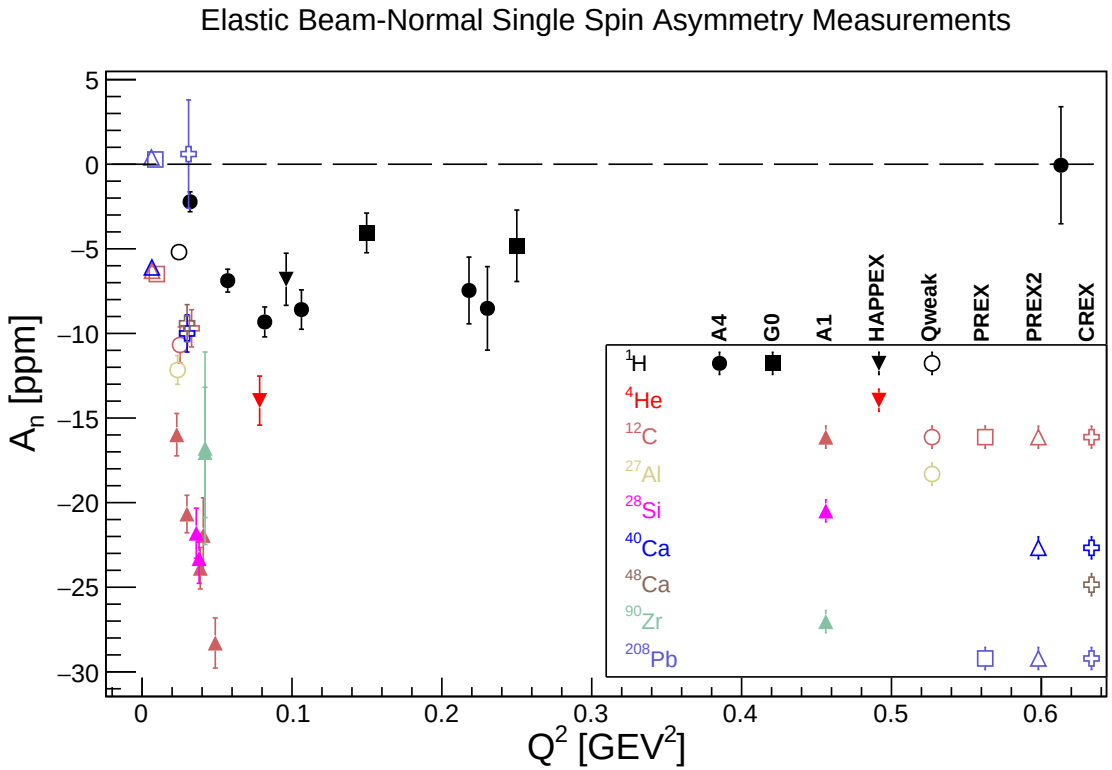
D. Androić et al., Phys. Rev. Lett. 107 (2011)

S. Abrahamyan et al., Phys. Rev. Lett. 109 (2012)

A. Esser et al., Phys. Rev. Lett. 121 (2018).

B. Gou et al., Phys. Rev. Lett. 124 (2020)

D. Androić et al., Phys. Rev. C 104 (2021)

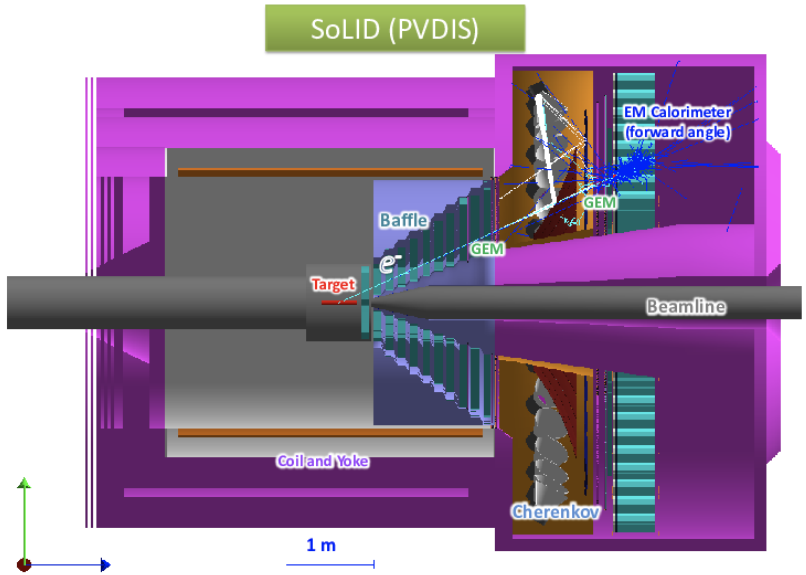


Solenoidal Large Intensity Deivde (SoLID)

- M. Schlegel Phys. Rev.D 87
  - "In principle, single-spin observables in inclusive DIS with either the lepton or nucleon being transversely polarized are equally fundamental"
- Beam-normal SSA measurement is challenging due to the smallness of the asymmetry
- **SoLID PVDIS configuration**
  - ✓ High Luminosity
  - ✓ Large azimuthal coverage
- Provides a unique opportunity to measure the BNSSA
- Approved SoLID run group experiment E12-11-108A/E12-10-006A
  - TNSSA measurement on transversely polarized proton and polarized ^{3}He (neutron) targets

Experiment Overview

- SoLID configuration: PVDIS
  - Scattering angle $22^\circ < \theta < 35^\circ$
  - Large azimuthal coverage
- Beam Energies
  - 6.6 GeV and 11 GeV
- Beam Polarization
  - Transversely polarized
- Beam current
  - 6.6 GeV: 70 μA
  - 11 GeV: 70 μA
  - SoLID Review Committee suggestion to investigate higher beam current
- Target
  - PVDIS Hydrogen target



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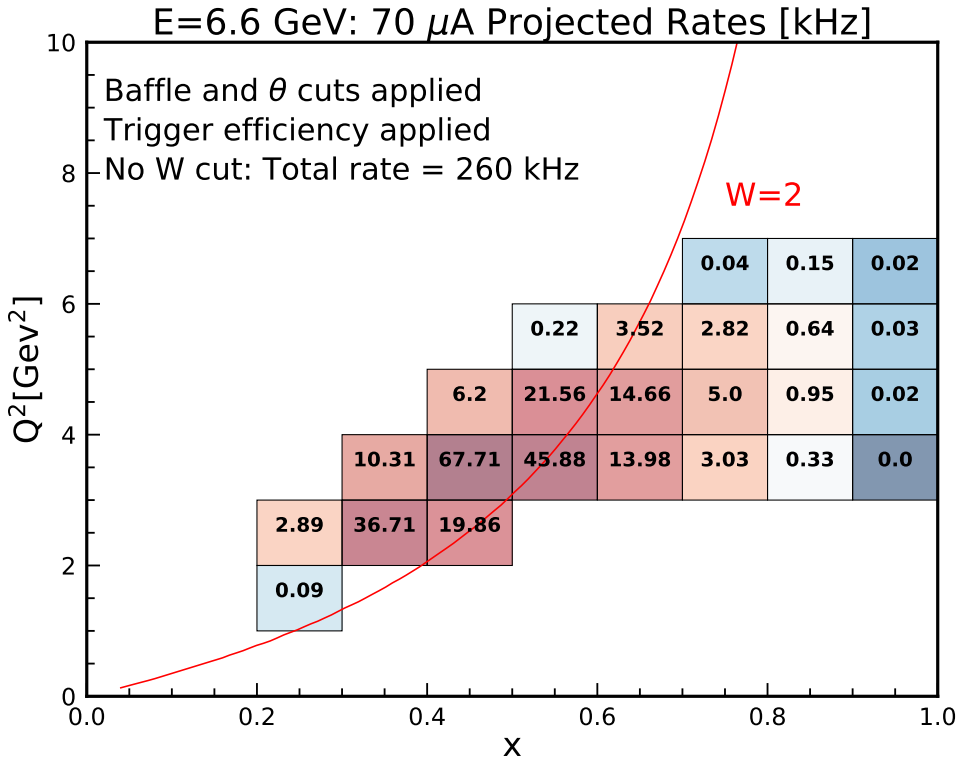

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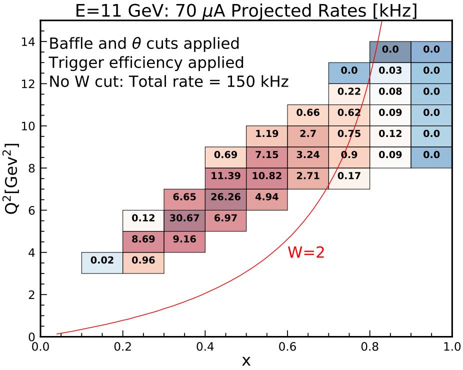

Beam Polarization and Systematic Uncertainties

- Electron beam can be polarized transversely at the injector
- The polarization can be measured using Moller (but requires rotation prior to measurement)
- Mott polarimeter at the injector can be used in addition to Moller

- Pion background: 1%
- Polarimetry: 5%
  - Nominal 3% plus additional uncertainty from rotating spin
- Mott: 2-3%
- Logitudinal Polarization: <1%
- **Uncertainties will be dominated by statistics**

Projected Results

- Full SoLID simulation to estimate statistical uncertainty
  - $\Delta_{stat} = 1/\sqrt{N}/P_b$
- Generate pseudo-data following $A_n \sin(\phi)$ form: (A_n=20 ppm)
- Studied the impact of an S_L component to the extracted A_n
  1. Subtract S_L A_{PVDIS} and fit $\sin(\phi)$ distribution: 3° uncertainty in S_L included
  2. $\sin(\phi)$ weighted integral to extract beam-normal SSA
  3. **Multi-parameter fit of the form:** $A_n \sin(\phi + \phi_{offset}) + S_L\ A_{PVDIS}$

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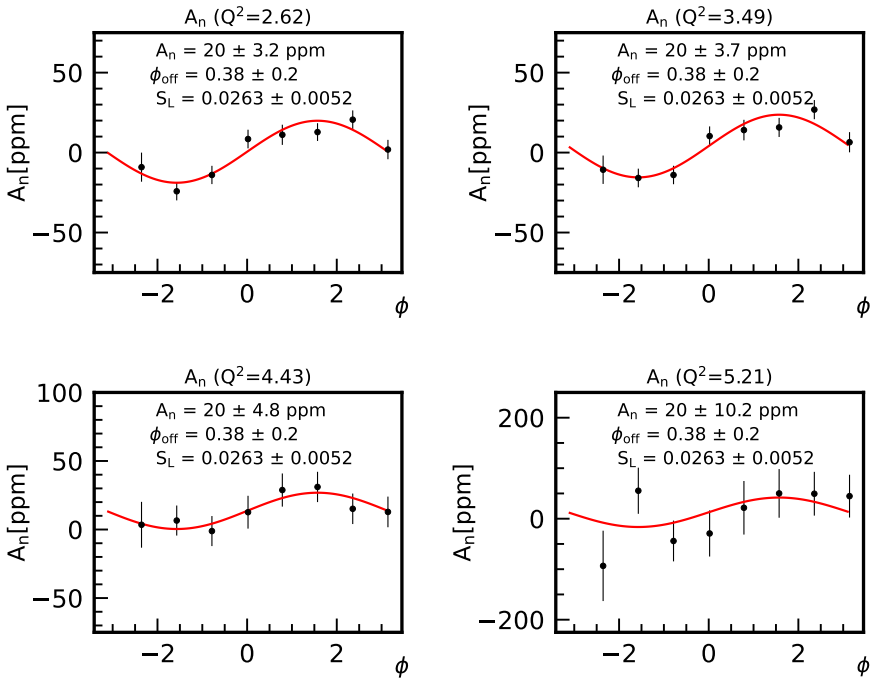
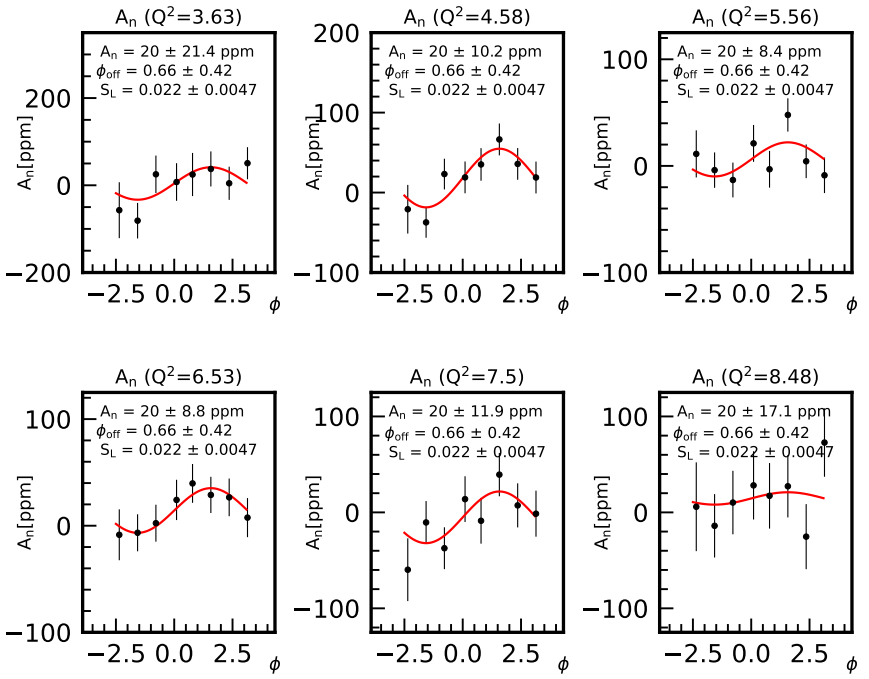
$A_n(\phi)$ Distribution: 6.6 GeV

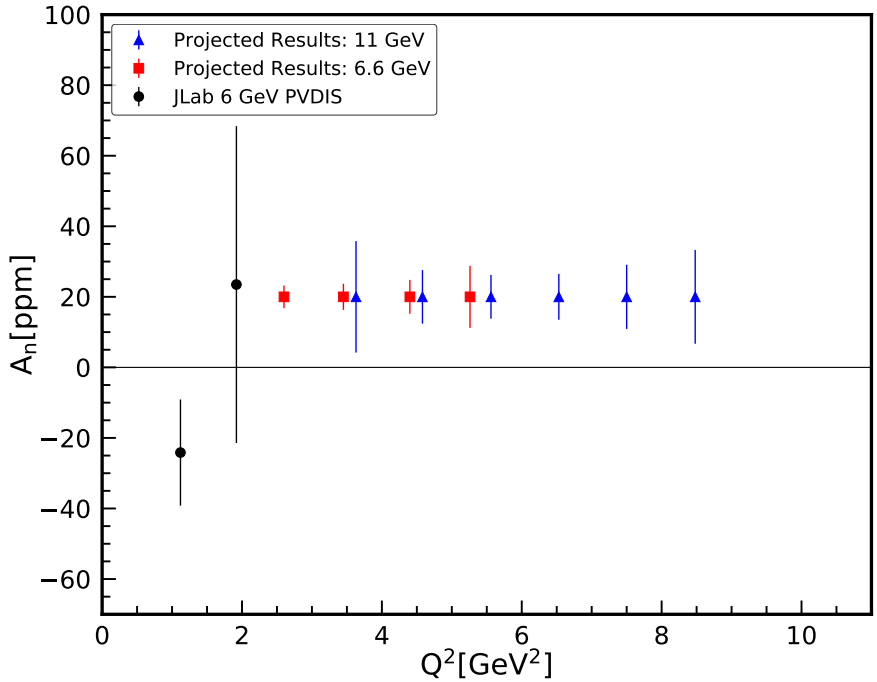


$A_n(\phi)$ Distribution: 11 GeV



Projection: Results and Uncertainty

- Combining bins, can determine the beam-normal SSA to the level of:
  - 6.6 GeV ≈2 ppm
  - 11 GeV ≈3 ppm
- Check Q^2 dependence



Beam Time Request

Purpose	Time (Days)	Energy (GeV)	Beam Current (μA)
Commissioning	2	varies	as needed
Polarimetry	4	varies	as needed
Pass change	0.67	N/A	N/A
Reverse SoLID polarity	0.67	N/A	N/A
Reverse polarity run	0.33	6.6	70
Reverse polarity run	0.33	11	70
40-cm LH_2 Production	17	11	70
40-cm LH_2 Production	13	6.6	70

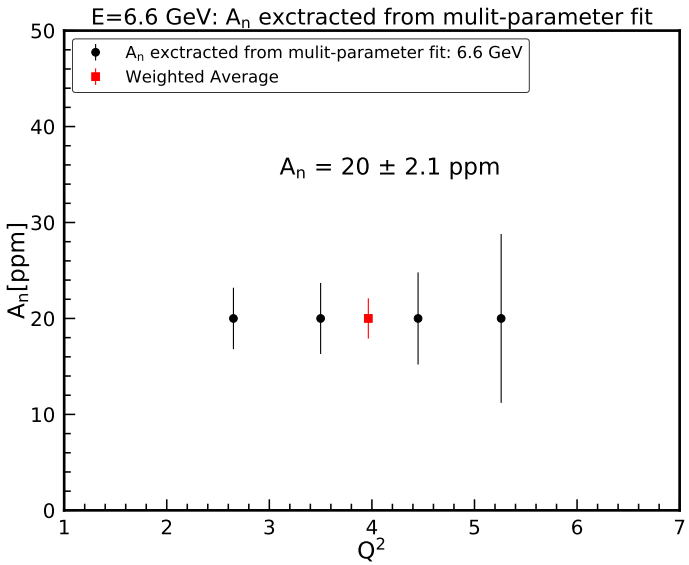
A total of 38 PAC days

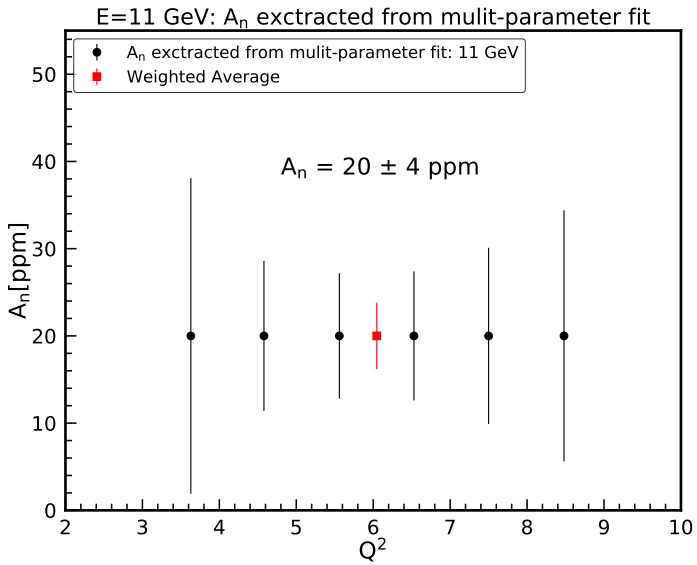
Summary

- Will be the first high-precision measurement of the beam-normal single spin asymmetry in deep inelastic scattering
- Uses the standard PVDIS configuration and target system
  - Use of a transversely polarized beam will largely be a scheduling issue
- Beam-normal single spin asymmetry provides a powerful tool to study the two-photon exchange effect
- Important for theory models
  - How close to the simple parton model calculation? Enhancement?
  - Useful in constraining TPE models

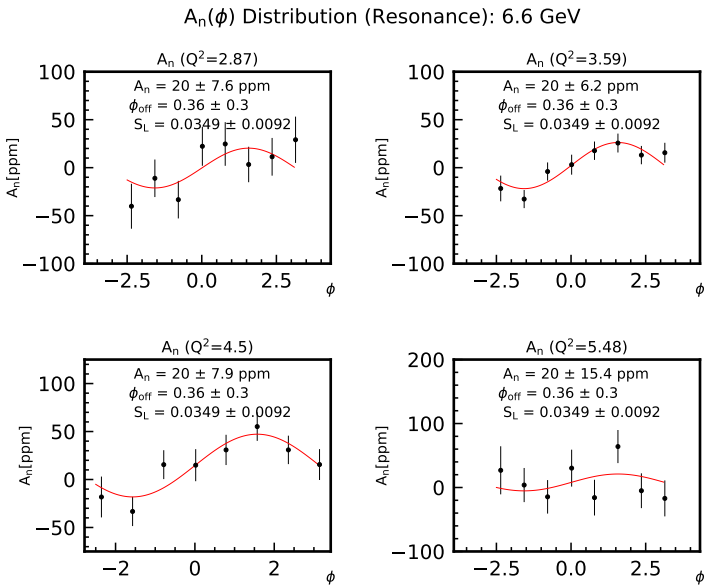
Thank You!

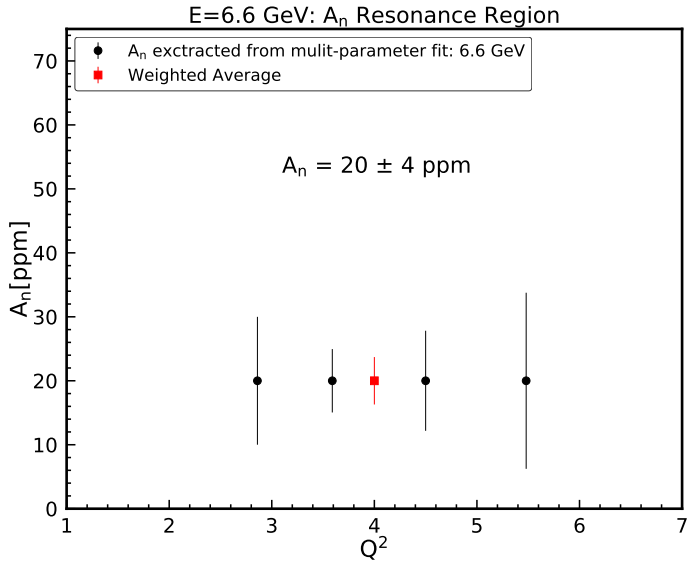
Extracted A_n





Resonance


A_n(φ) Distribution (Resonance): 6.6 GeV
A_n (Q²=2.87)
A_n = 20 ± 7.6 ppm
φ_off = 0.36 ± 0.3
S_L = 0.0349 ± 0.0092
A_n (Q²=3.59)
A_n = 20 ± 6.2 ppm
φ_off = 0.36 ± 0.3
S_L = 0.0349 ± 0.0092
A_n (Q²=4.5)
A_n = 20 ± 7.9 ppm
φ_off = 0.36 ± 0.3
S_L = 0.0349 ± 0.0092
A_n (Q²=5.48)
A_n = 20 ± 15.4 ppm
φ_off = 0.36 ± 0.3
S_L = 0.0349 ± 0.0092
A_n[ppm]
φ


E=6.6 GeV: A_n Resonance Region
A_n exctracted from mulit-parameter fit: 6.6 GeV
Weighted Average
A_n = 20 ± 4 ppm
A_n[ppm]
Q²

Pair Production Background