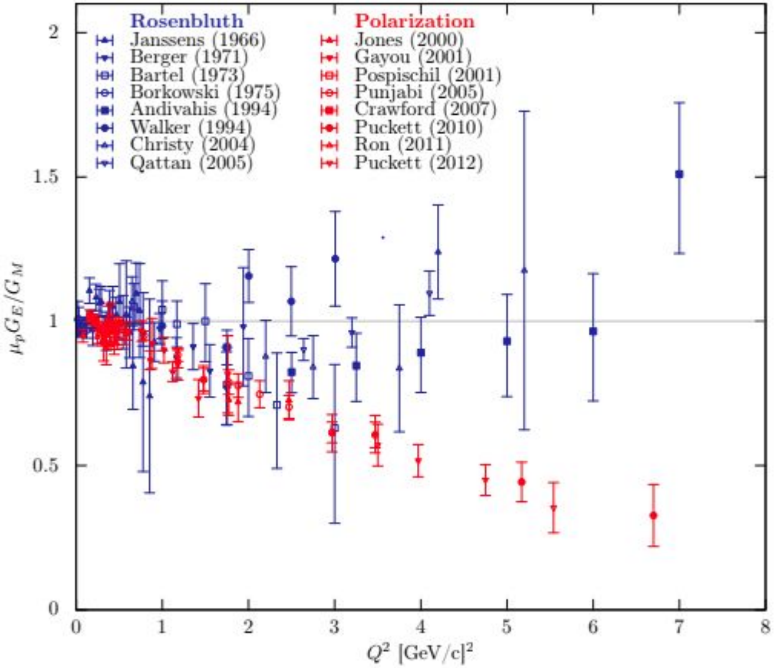
Estimates for SSA Measuring Experiment at JLab

By August Friebolin

Motivation

- Two Photon Exchange (TPE) is a potential solution to the form factor ratio disparity when comparing results from Rosenbluth separation and polarization transfer
- The difference in scattering asymmetry for e^-p and e^+p is solely dependent on TPE
- Theoretical calculations of Single Spin Asymmetry (SSA) are strongly model dependent and can be improved with more experimental data from e^-p scattering



Schmidt 2016

SSA Measurements

- There have been several recent experiments measuring beam normal asymmetries (QWEAK, CREX, and PREX at JLab, A4 at Mainz) that measured SSA on the ppm scale
- Target normal SSA provides higher asymmetries relative to beam normal (on the order of 1%), but a polarized target is harder to maintain
- In the target normal configuration SSA is measured from L/R differences in scattering with a vertically polarized target rather than changing the polarization of the beam

CLAS12 Transverse Target

- Plan to install a transverse polarized proton target in Hall B
    - Dynamically polarized ammonia beads
    - Several C1 approved experiments (CLAS12 Run Group H)
- CLAS12 central detector will be removed, limiting to forward acceptance only
- Can a statistically significant amount of events be measured under these conditions?

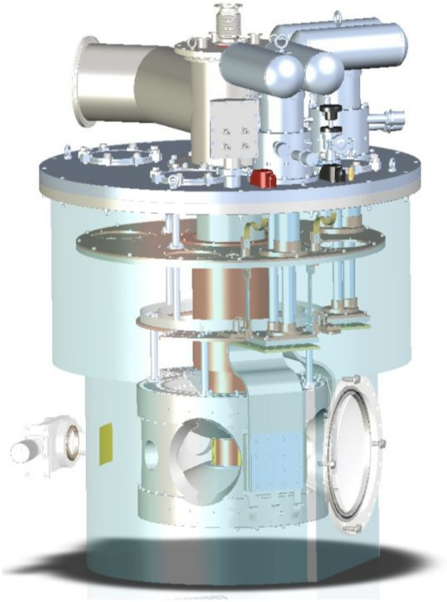


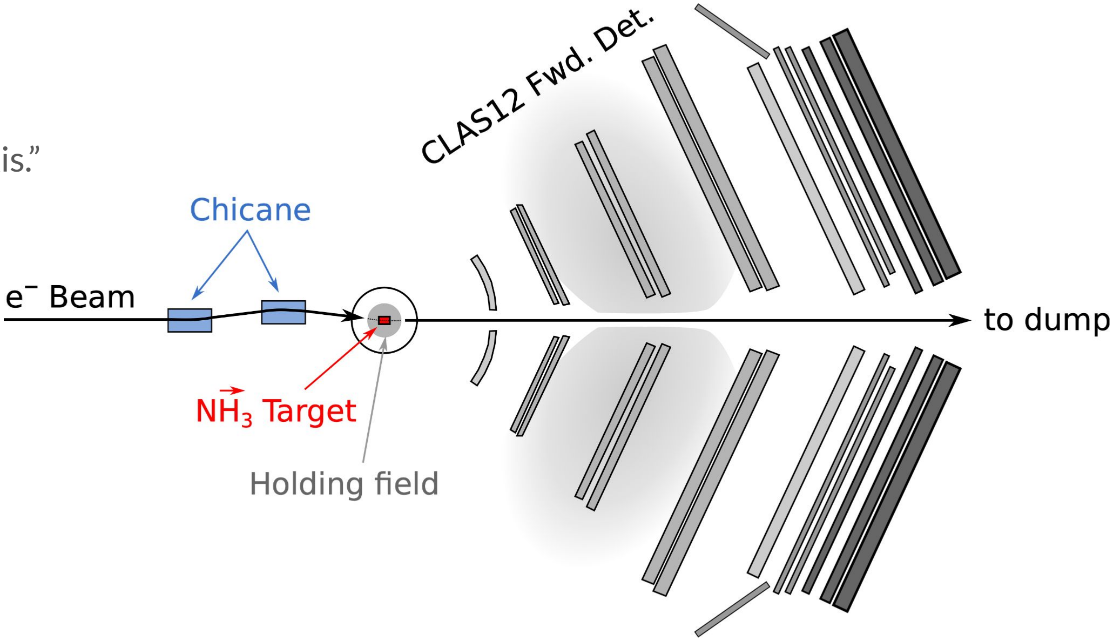
Image credit: C. Keith, SPIN 2023

Assumed Conditions

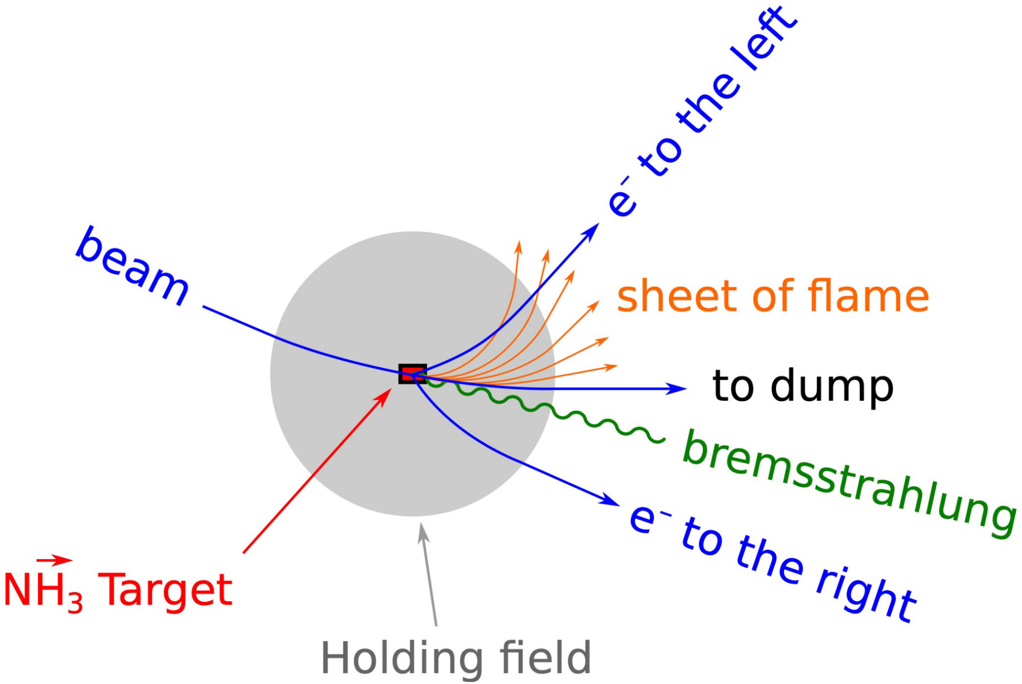
- Total Luminosity: 5.5×10^{34} /cm^2/s
    - 3/17 of that luminosity is on polarized hydrogen
    - Total Lumi. on Hydrogen = 9.7×10^{33} /cm^2/s
- Rosenbluth cross section with dipole proton form factors, i.e.
    - $d\sigma/d\Omega = d\sigma/d\Omega_{\mathrm{Mott}} \, (\tau/\varepsilon(1+\tau)) \, [\varepsilon/\tau \, G_E^2 + G_M^2]$
- Particle trajectories are bent by the vertical holding field for the target.
    - Assuming 1 Tm entering and leaving the target region
        - Holding field: 5 T
        - Field radius: 0.2 m

The target holding field will shift trajectories.

Incoming beam will be “off axis.”



The target holding field will shift trajectories.



Left and right kinematics will not be exactly symmetric.

To minimize systematics, it will be important to periodically reverse the polarization direction of the protons (while keeping the holding field constant).

Shift due to holding field

The holding field will shift the horizontal angle $\theta = \tan^{-1}(x/z)$ by:

- $\Delta\theta = 2 \sin^{-1} [\, 1.5 \text{ GeV} / p \,]$

For the simulation the spherical coordinates are converted to cylindrical about the y axis (vertical axis), the shift is applied, then the resulting vector is re-calculated.

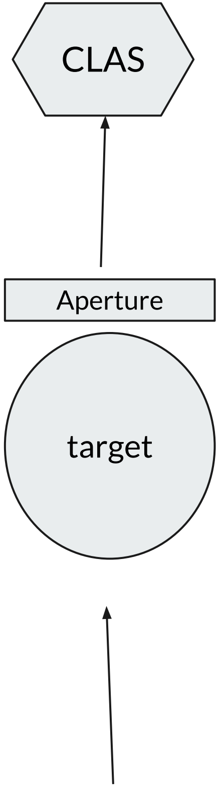
There are two shifts

- The incoming beam is shifted as it reaches the target; at the target, the beam is shifted off the hall axis.
- After scattering, the outgoing electrons are shifted in the opposite direction.

Aperture Modeling

In order to reach the detectors, outgoing electrons (after shift) must meet two conditions:

- Exit within the target chamber window aperture
  - Assumed to be a region ± 25° out of plane from the beamline (in the y direction) and ± 65° in plane (xy plane), forming a section of a cylinder.
- Enter one of the six sectors of the CLAS forward detector.
  - Each sector has an azimuthal acceptance of ±25° for Θ in the range of 16˚-35˚.
  - In the forward region (Θ: 8˚–16°), the phi acceptance pinches to ±(25˚/8˚)(Θ-8˚)
  - Sectors are centered at φ=0˚, 60˚, 120˚, 180˚, 240˚ and 300˚



Monte Carlo

- The Monte Carlo generates random theta and phi, accounts for the holding field shift, and checks for if electrons scatter through magnet support aperture and into the CLAS acceptance range

- Binning done per degree in Θ with N = 1000 for rate estimates(N=1000 total in figure 1)

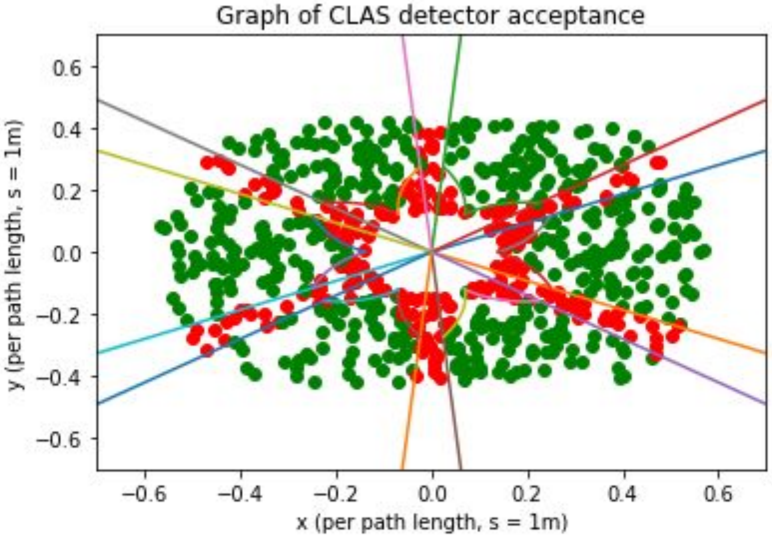
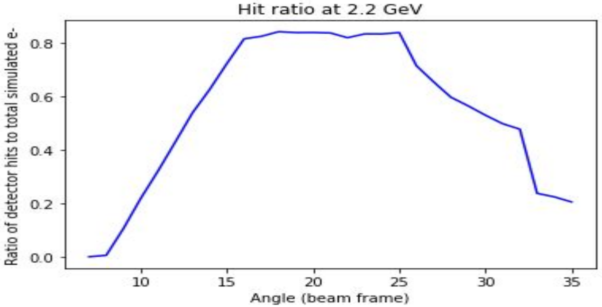


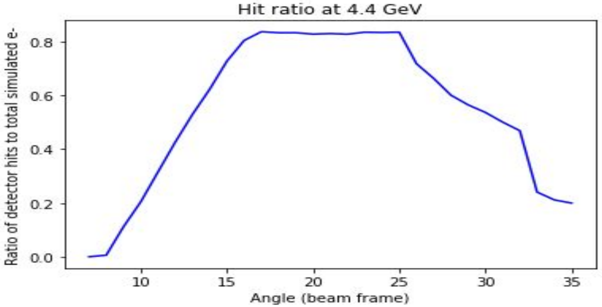
Fig. 1 CLAS Detector Monte Carlo Plot. Colored straight lines are acceptance ranges of each segment of the detector and the curved lines are the low angle pinch. Green dots represent particles that hit the detector in the acceptance range and are ones that fall outside the range.

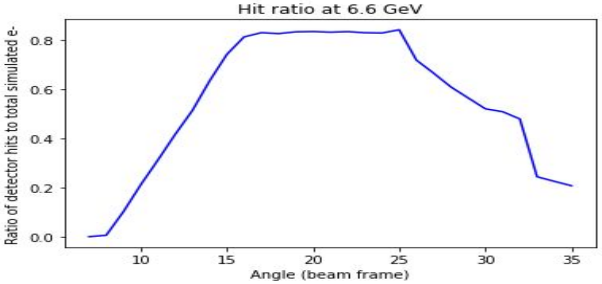
Unweighted Monte Carlo Results

- Acceptance is independent of beam energy, as expected.
- Initial linear trend is from the beam pinch at low angles
- Plateau around θ = [16°, 25°], where the azimuthal acceptance is constant
- Decrease at θ>25° from the holding field shift

Note: the holding field shift makes it impossible to get asymmetry data above Θ = 32°







Preliminary Statistical Uncertainties

The first set of projection figures will use a simplified uncertainty estimate:

Since $A = (N_L - N_R)/(N_L + N_R)$, and assuming that $N_L \approx N_R \approx N/2$,

$$\delta A = 1/\sqrt{N}$$

This neglects the effects of

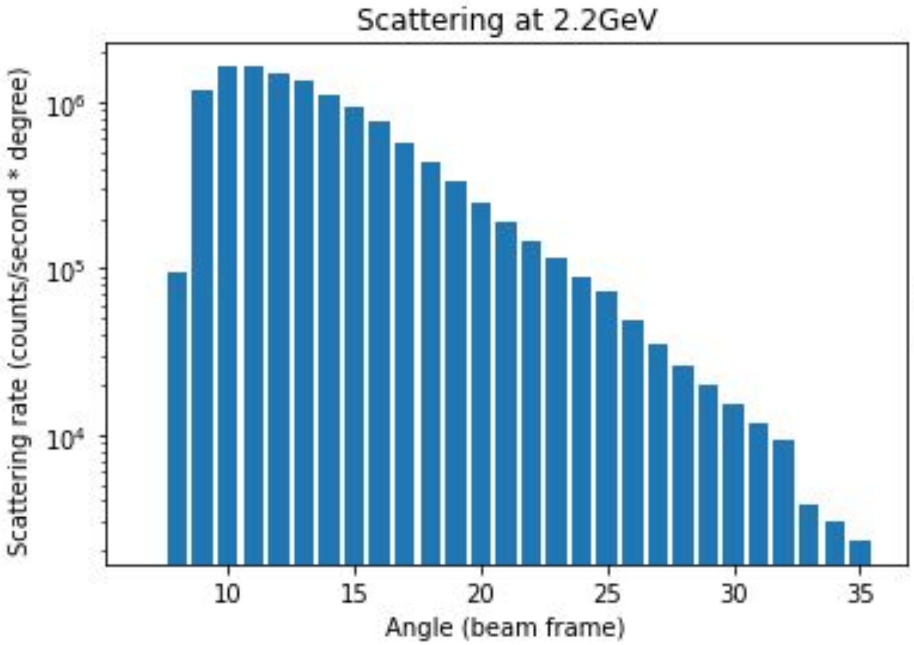
- Target polarization < 100%
- Quasi-elastic background from scattering on N, He nuclei
- Azimuthal dependence of asymmetry

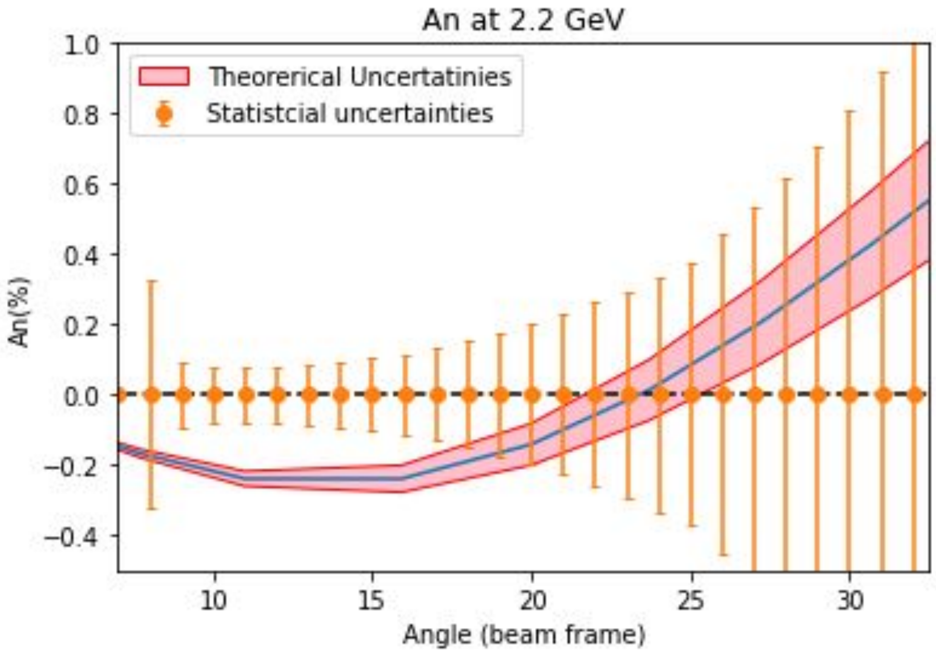
In the following slides scattering rates for different beam energies are shown alongside $\delta A(\Theta)$ superimposed on plots of theoretical predictions for A_n provided by Peter Blunden (PRC **108**, 055202, 2023)

  - Binning for counts are for per 1°

Preliminary Uncertainty Estimates, 1 hour duration

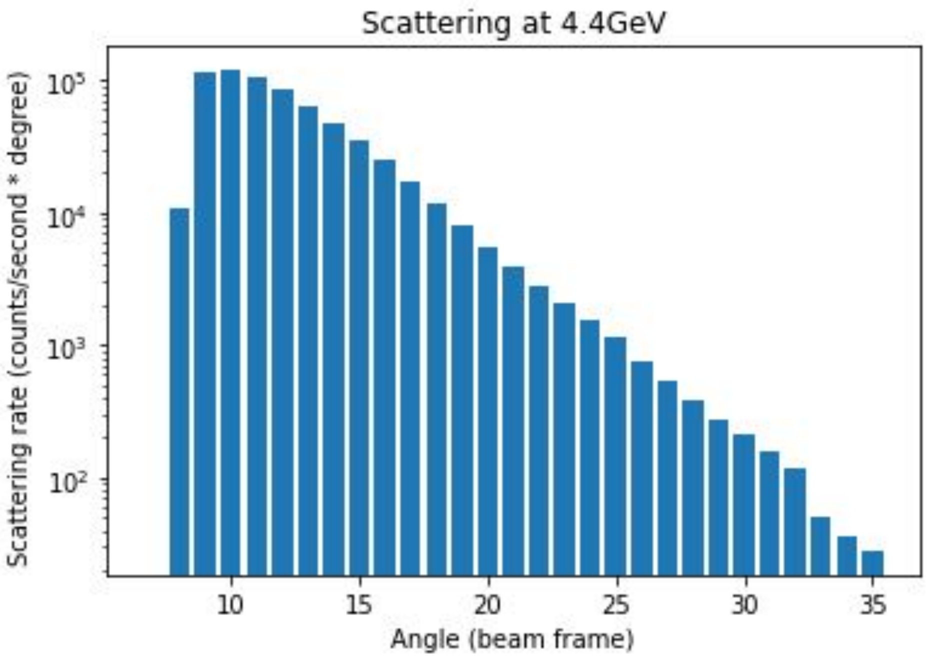
2.2 GeV

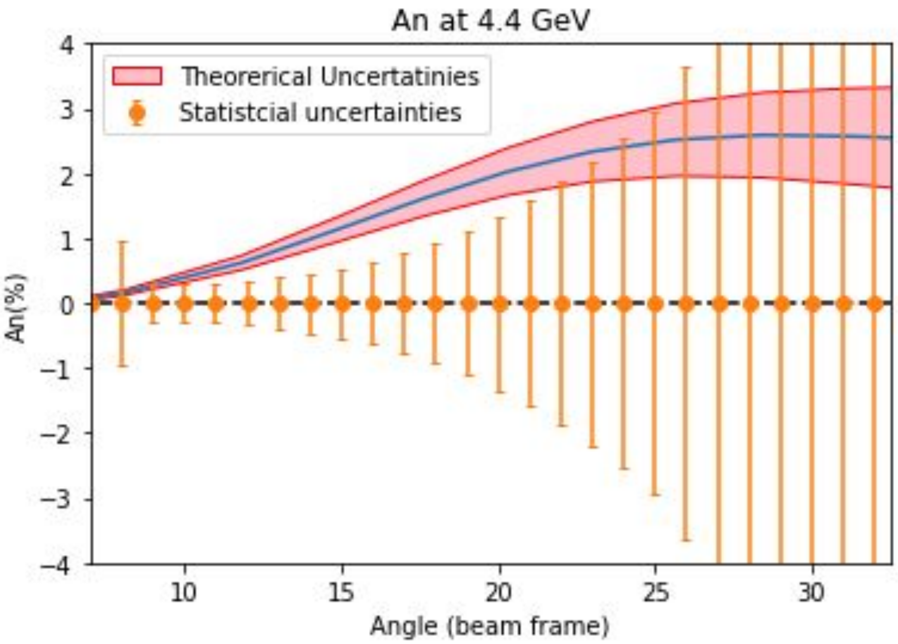




Preliminary Uncertainty Estimates, 1 hour duration

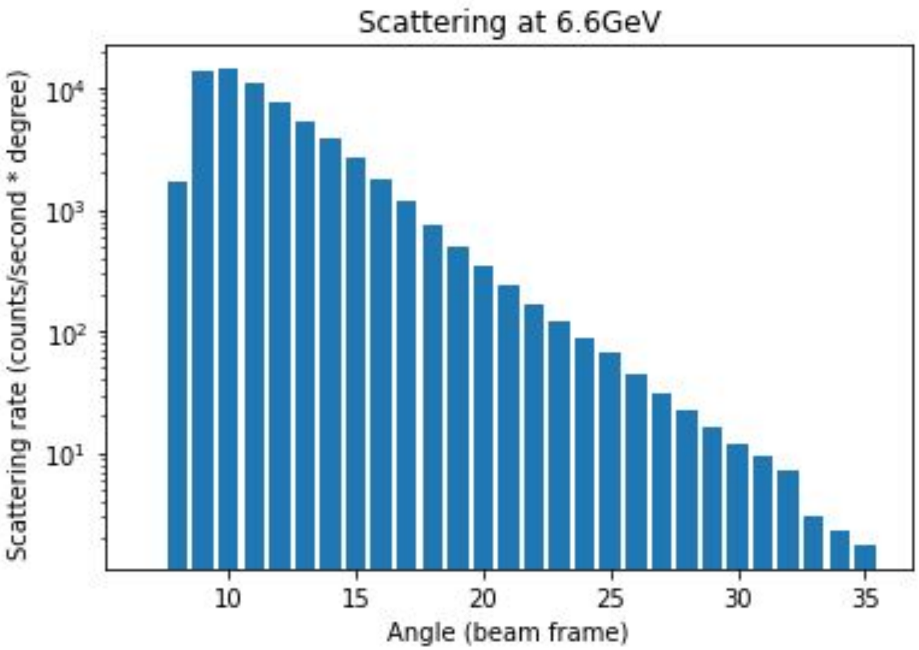
4.4 GeV

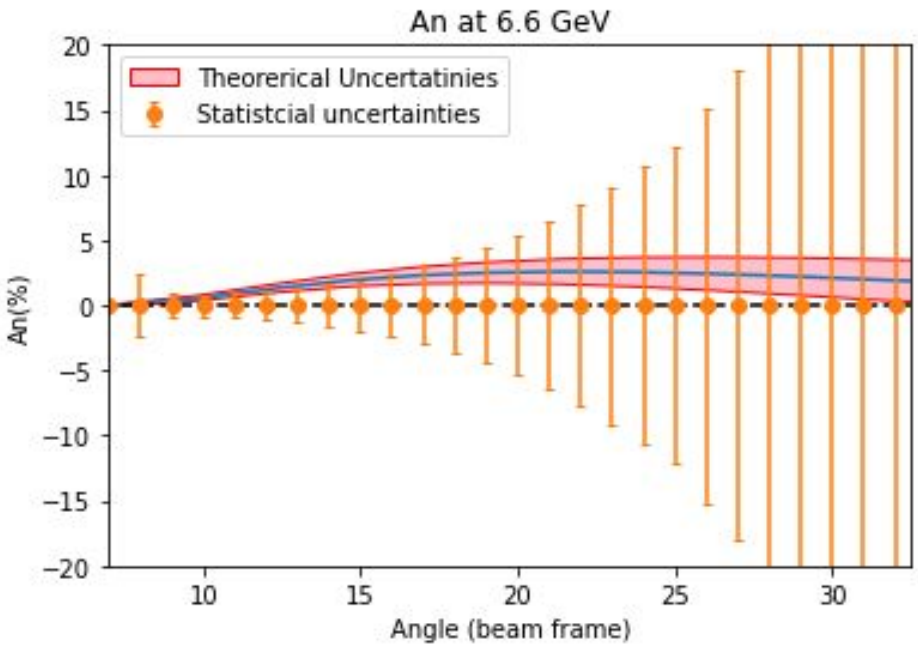




Preliminary Uncertainty Estimates, 1 hour duration

6.6 GeV

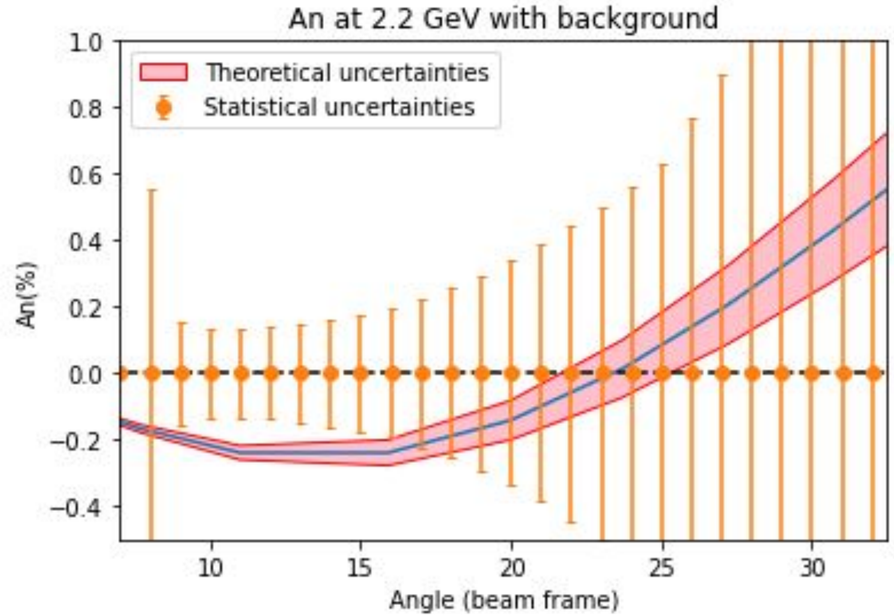


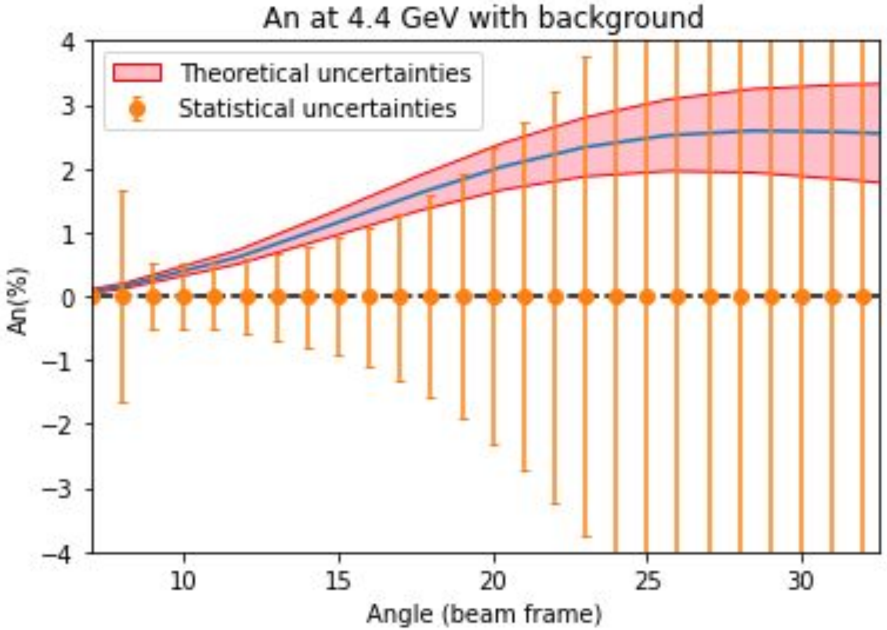


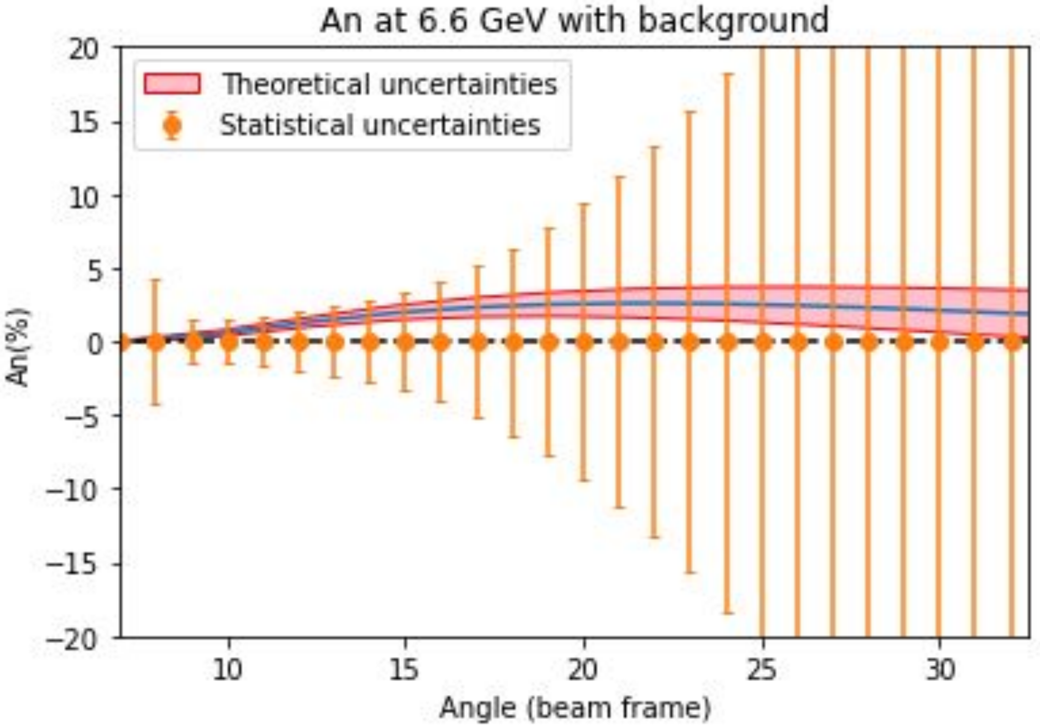
Additional Uncertainties

- Uncertainties without background are calculated from $A = N_L - N_R / N_L + N_R$, $\delta A = 1/\sqrt{N}$
- Complications
    - 60% average target polarization factor
    - 3/14 of luminosity is useful (nitrogen dilution)
    - Elastic peak sits on quasi-elastic background (assume 500 MeV smearing)
- For systematic uncertainty we use a preliminary estimate of $\delta S = 0.001$ added in quadrature with δA
- Using these equations and the counts per time generated from the Monte Carlo simulation error bars for our scattering data can be generated
- With background and systematics we assume: $\delta A = (1/0.6)\sqrt{((3/14)*0.04*E_p(\Theta)/0.5)+1/N + \delta S^2)}$

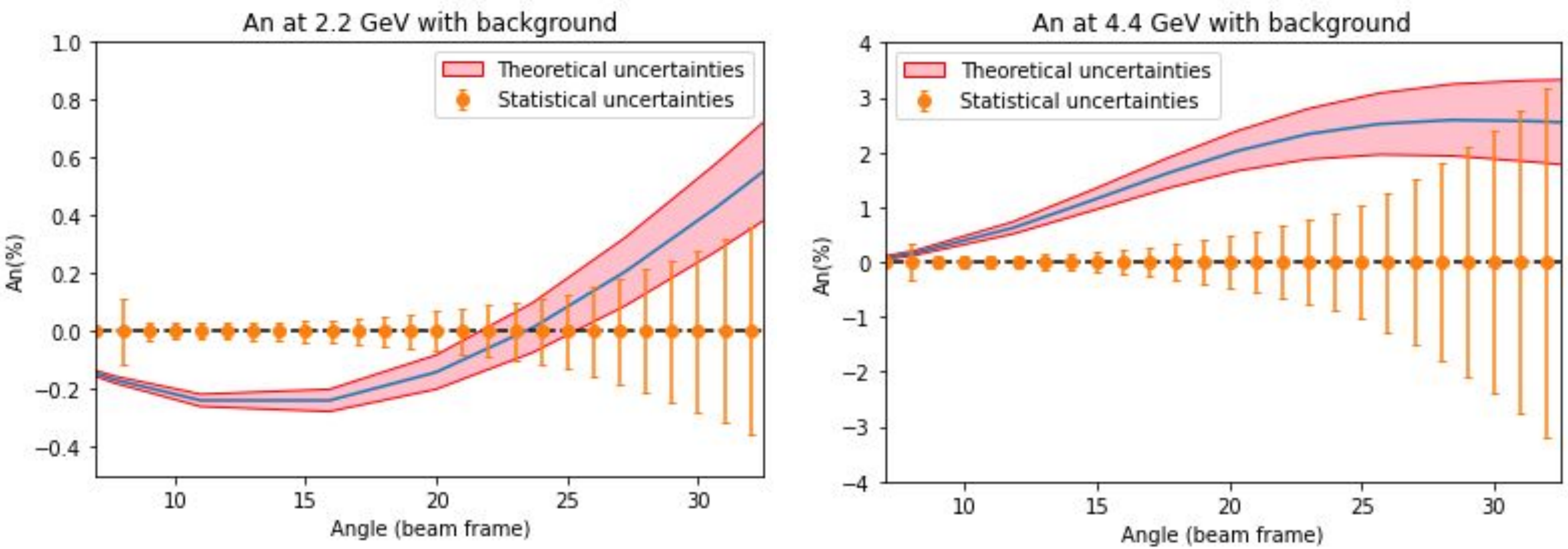
Plots at one hour with background

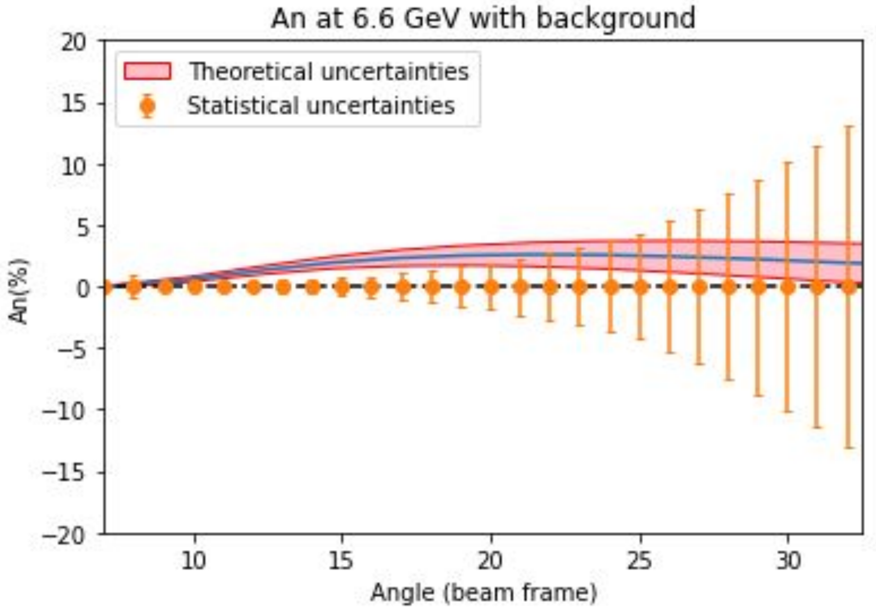




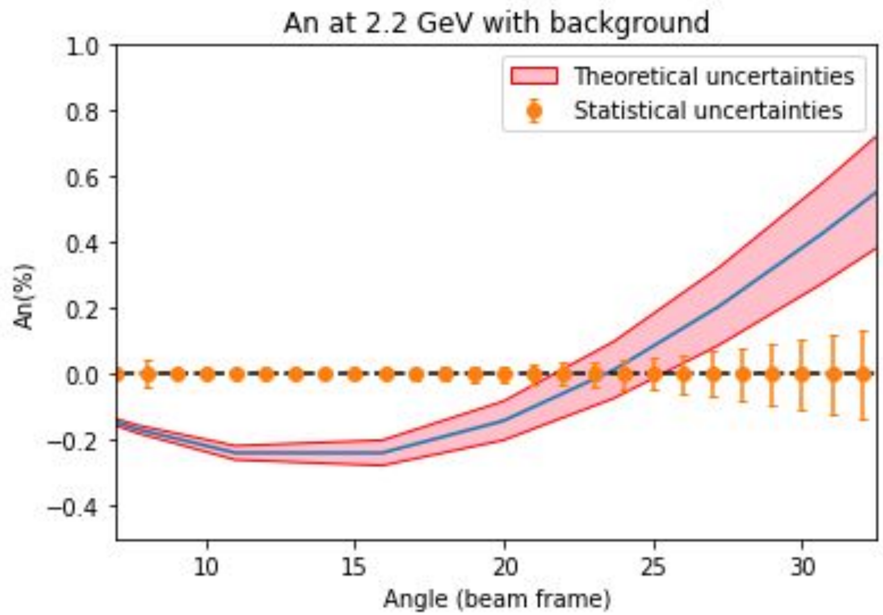

An at 6.6 GeV with background
Theoretical uncertainties
Statistical uncertainties
An(%)
20
15
10
5
0
−5
−10
−15
−20
10
15
20
25
30
Angle (beam frame)

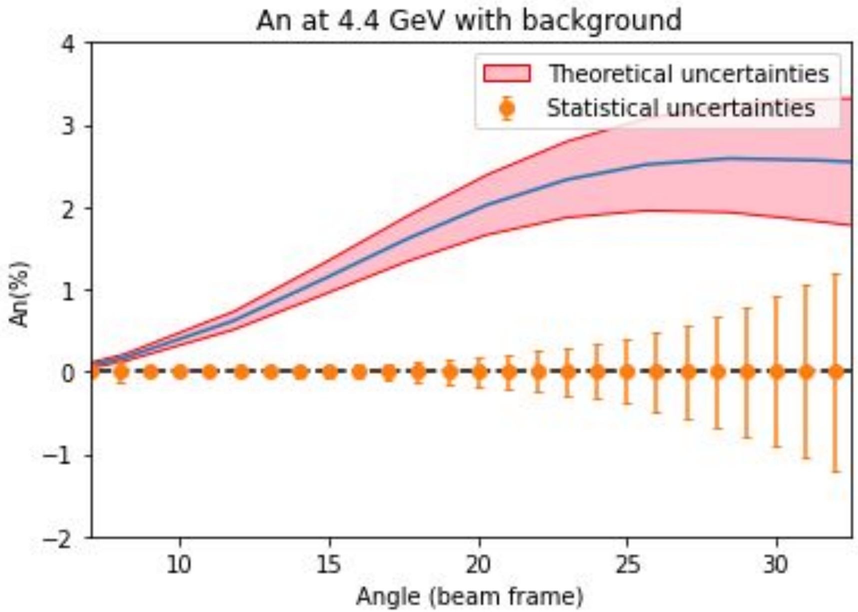
Errorbars at 24 hours with background

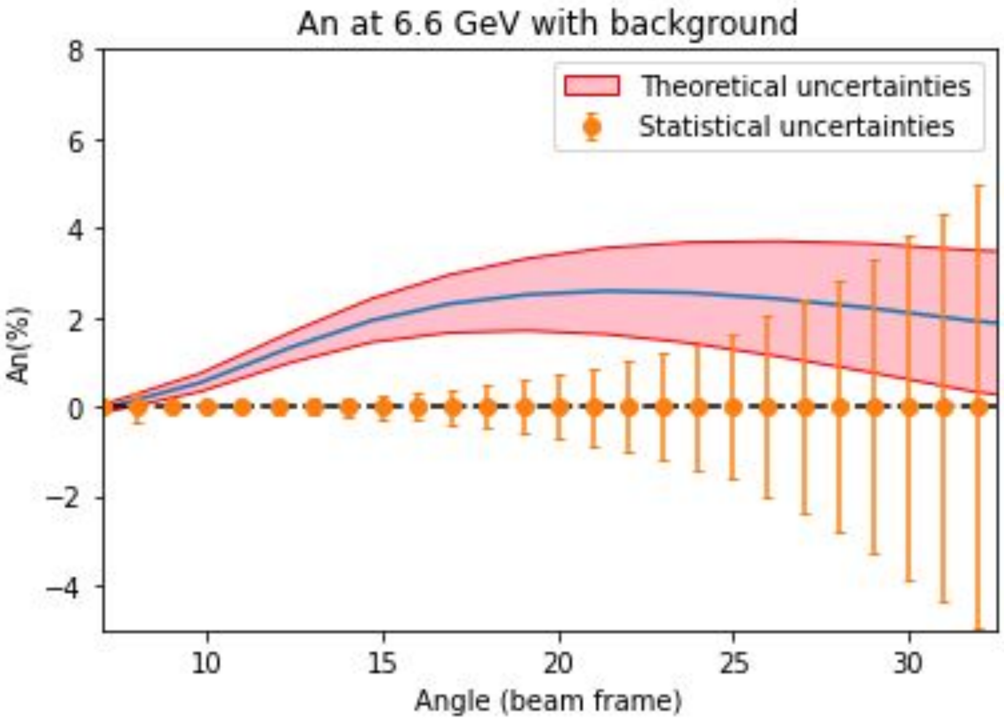



An at 6.6 GeV with background
Theoretical uncertainties
Statistical uncertainties
An(%)
20
15
10
5
0
−5
−10
−15
−20
10
15
20
25
30
Angle (beam frame)

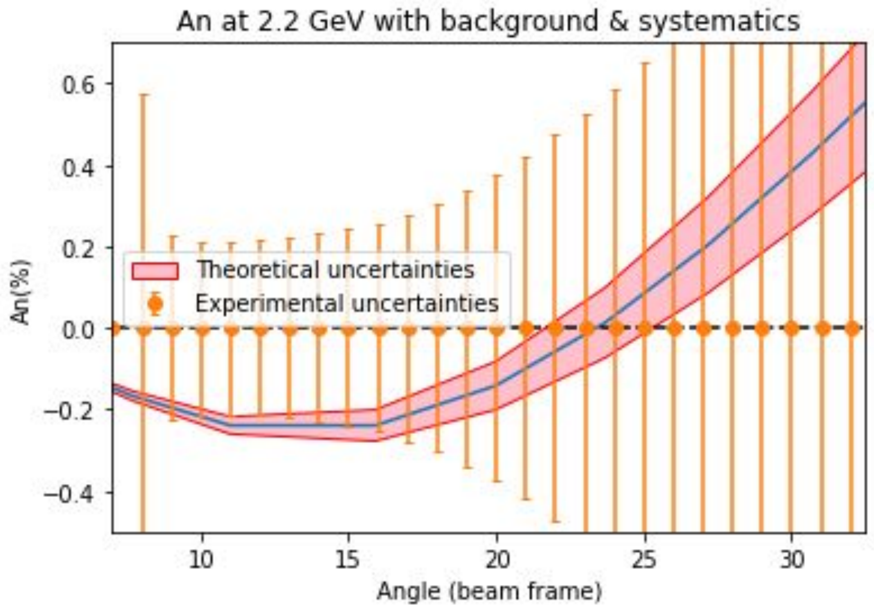
Errorbars at 1 week



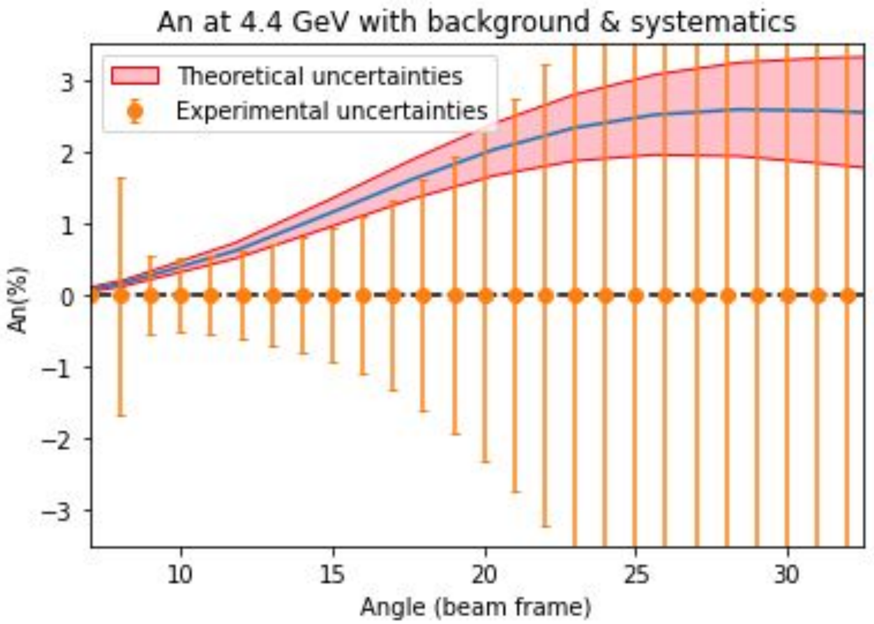



An at 6.6 GeV with background
Theoretical uncertainties
Statistical uncertainties
An(%)
8
6
4
2
0
−2
−4
10
15
20
25
30
Angle (beam frame)

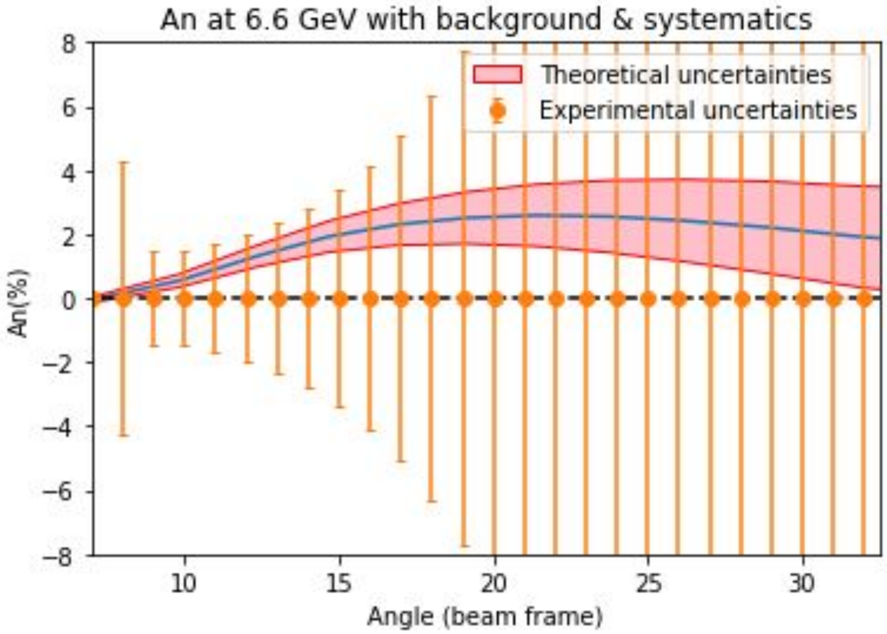
Errorbars with background and systematics at 1 hour



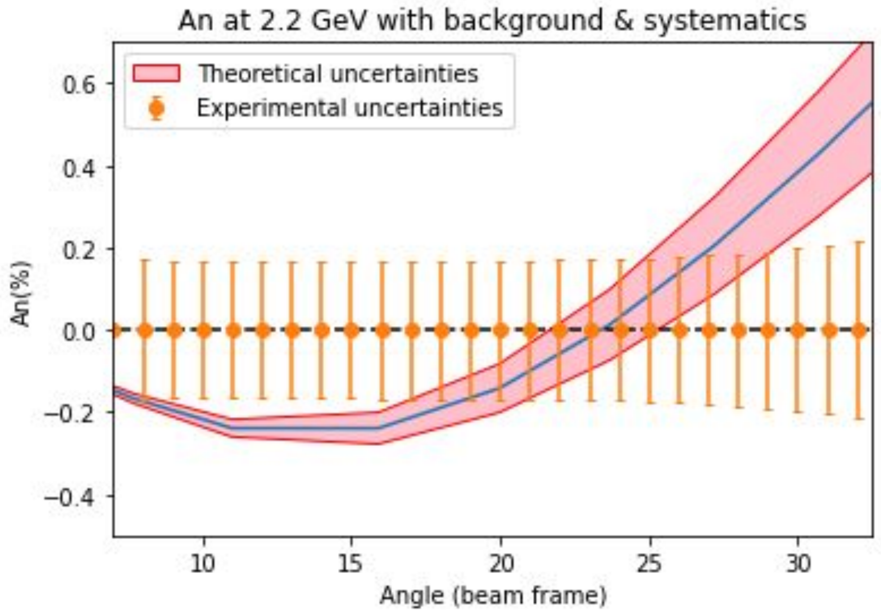
An at 2.2 GeV with background & systematics

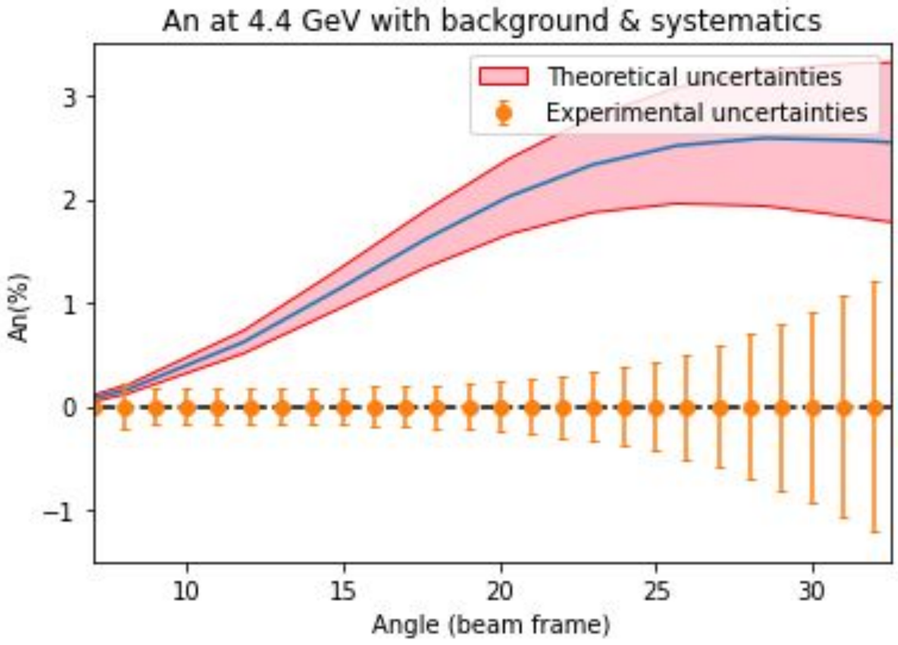


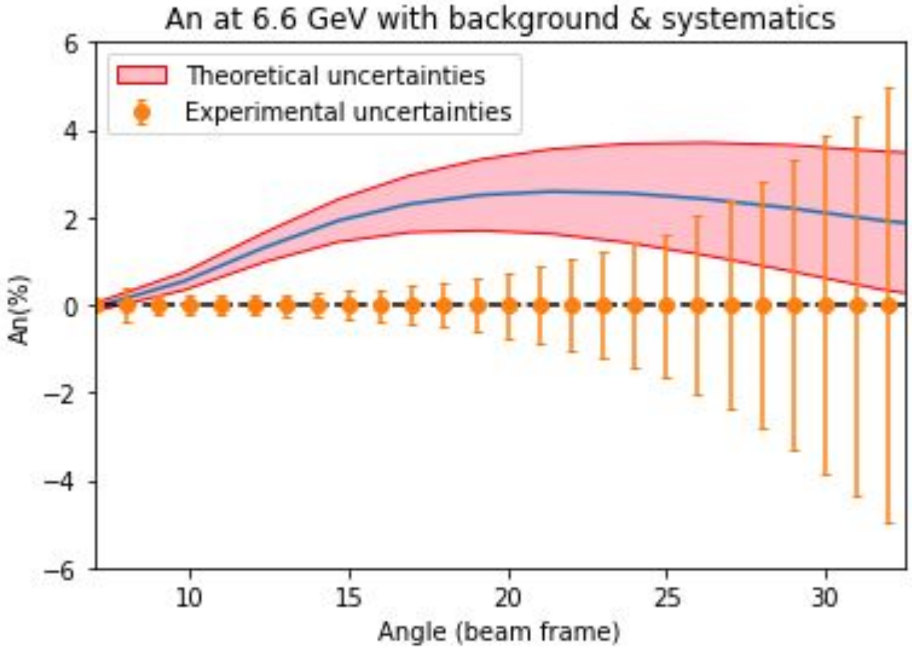
An at 4.4 GeV with background & systematics


An at 6.6 GeV with background & systematics
Theoretical uncertainties
Experimental uncertainties
An(%)
8
6
4
2
0
−2
−4
−6
−8
10
15
20
25
30
Angle (beam frame)

Errorbars with background and systematics at 1 week

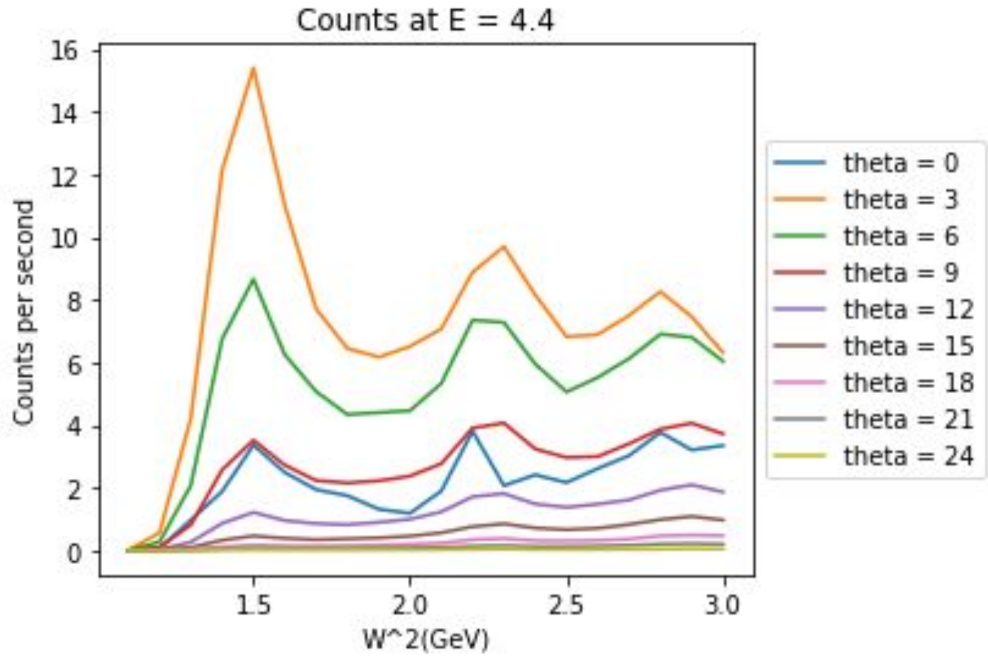

An at 2.2 GeV with background & systematics


An at 4.4 GeV with background & systematics


An at 6.6 GeV with background & systematics
Theoretical uncertainties
Experimental uncertainties
An(%)
6
4
2
0
−2
−4
−6
10
15
20
25
30
Angle (beam frame)

Conclusion

- From this estimate we are requesting a few weeks of beam access to account for uncertainties in target polarization
- At 2.2 GeV the effect may be too small to measure considering systematic uncertainties
- Next steps:
  - Inclusive inelastic estimates
    - Assuming Bosted-Christy fit
    - Bootstrap asymmetry uncertainty calculation to compensate for sheet of flame



References

- Jaseer Ahmed, P. G. Blunden, and W. Melnitchouk, Phys. Rev. C **108**, 055202 – Published 14 November 2023
- Axel Schmidt, https://doi.org/10.48550/arXiv.1711.09894