Polarized Proton DIS with SBS/BB at 12 GeV

SBS Collaboration Meeting

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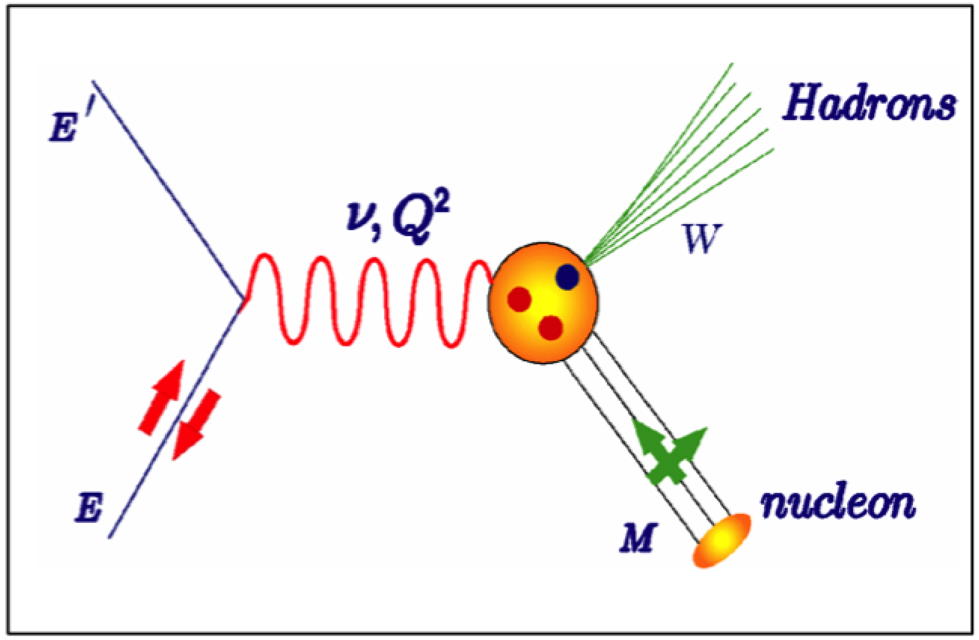
DIS Structure Functions

Unpolarized cross section:

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{4E^2\sin^4\frac{\theta}{2}}\left(\frac{2}{M}F_1(x,Q^2)\sin^2\frac{\theta}{2} + \frac{1}{\nu}F_2(x,Q^2)\cos^2\frac{\theta}{2}\right)$$

- Unpolarized structure functions F_1 and F_2 contain information about the momentum structure of the target nucleon.



Polarized cross section:

$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Uparrow - \uparrow\Uparrow) = \frac{4\alpha^2 E'}{MQ^2\nu E}\left[(E+E'\cos\theta)g_1(x,Q^2) - \frac{Q^2}{\nu}g_2(x,Q^2)\right] = \Delta\sigma_\parallel$$

$$\frac{d^2\sigma}{dE'd\Omega}(\downarrow\Rightarrow - \uparrow\Rightarrow) = \frac{4\alpha^2\sin\theta E'^2}{MQ^2\nu^2 E}\left[\nu g_1(x,Q^2) + 2Eg_2(x,Q^2)\right] = \Delta\sigma_\perp$$

- Polarized structure functions g_1 and g_2 encode information about the spin structure of the target nucleon.

Q^2 = 4-momentum transfer squared of the virtual photon

ν = E-E' = energy transfer

θ = scattering angle

x = Fraction of nucleon momentum carried by the struck quark

Polarized Structure Function and Asymmetries

Target Transversly Polarized

$$A_{\perp} \equiv \frac{\sigma^{\rightarrow\Uparrow} - \sigma^{\leftarrow\Downarrow}}{\sigma^{\rightarrow\Uparrow} + \sigma^{\leftarrow\Downarrow}} = \frac{1}{2}\frac{(\sigma^{\rightarrow\Uparrow} - \sigma^{\leftarrow\Downarrow})}{\frac{d^2\sigma^{Unpol}}{d\Omega dE'}}$$

Target Longitudinally Polarized

$$A_{\parallel} \equiv \frac{\sigma^{\rightarrow\Rightarrow} - \sigma^{\leftarrow\Rightarrow}}{\sigma^{\rightarrow\Rightarrow} + \sigma^{\leftarrow\Rightarrow}} = \frac{1}{2}\frac{(\sigma^{\rightarrow\Rightarrow} - \sigma^{\leftarrow\Rightarrow})}{\frac{d^2\sigma^{Unpol}}{d\Omega dE'}}$$

Structure Functions in terms of the observables

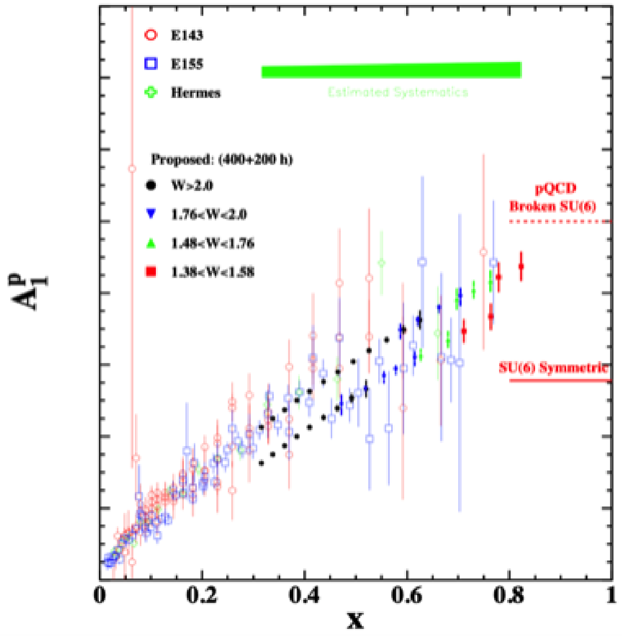
$$g_1 = \frac{M_n Q^2}{4\alpha^2}\frac{2y}{(1-y)(2-y)}\frac{d^2\sigma^{Unpol}}{d\Omega dE'}\left[A_{\parallel} + tan\left(\frac{\theta}{2}\right)A_{\perp}\right]$$

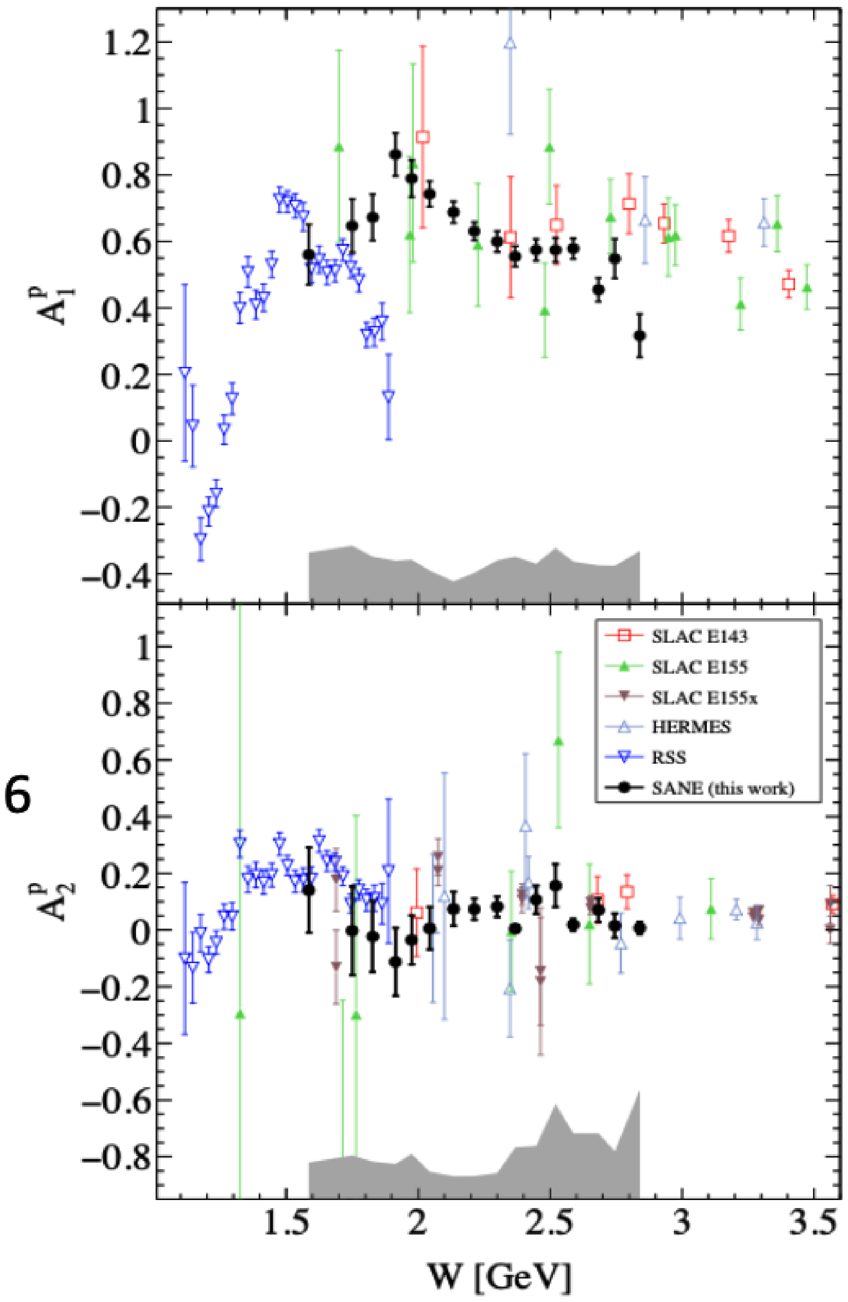
$$g_2 = \frac{M_n Q^2}{4\alpha^2}\frac{2y}{(1-y)(2-y)}\frac{d^2\sigma^{Unpol}}{d\Omega dE'}\left[-A_{\parallel} + \frac{1+(1-y)\cos\theta}{(1-y)sin\theta}A_{\perp}\right]$$

SANE Experiment

A1p/A2p was done with a 5.9 GeV beam by SANE

Expected in SANE proposal, 2002



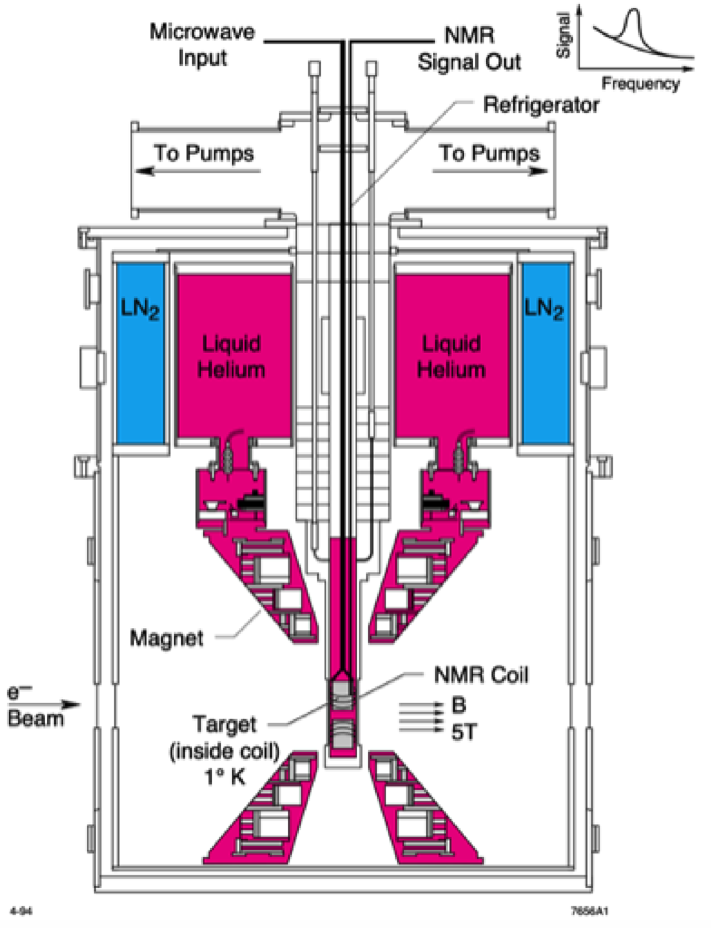


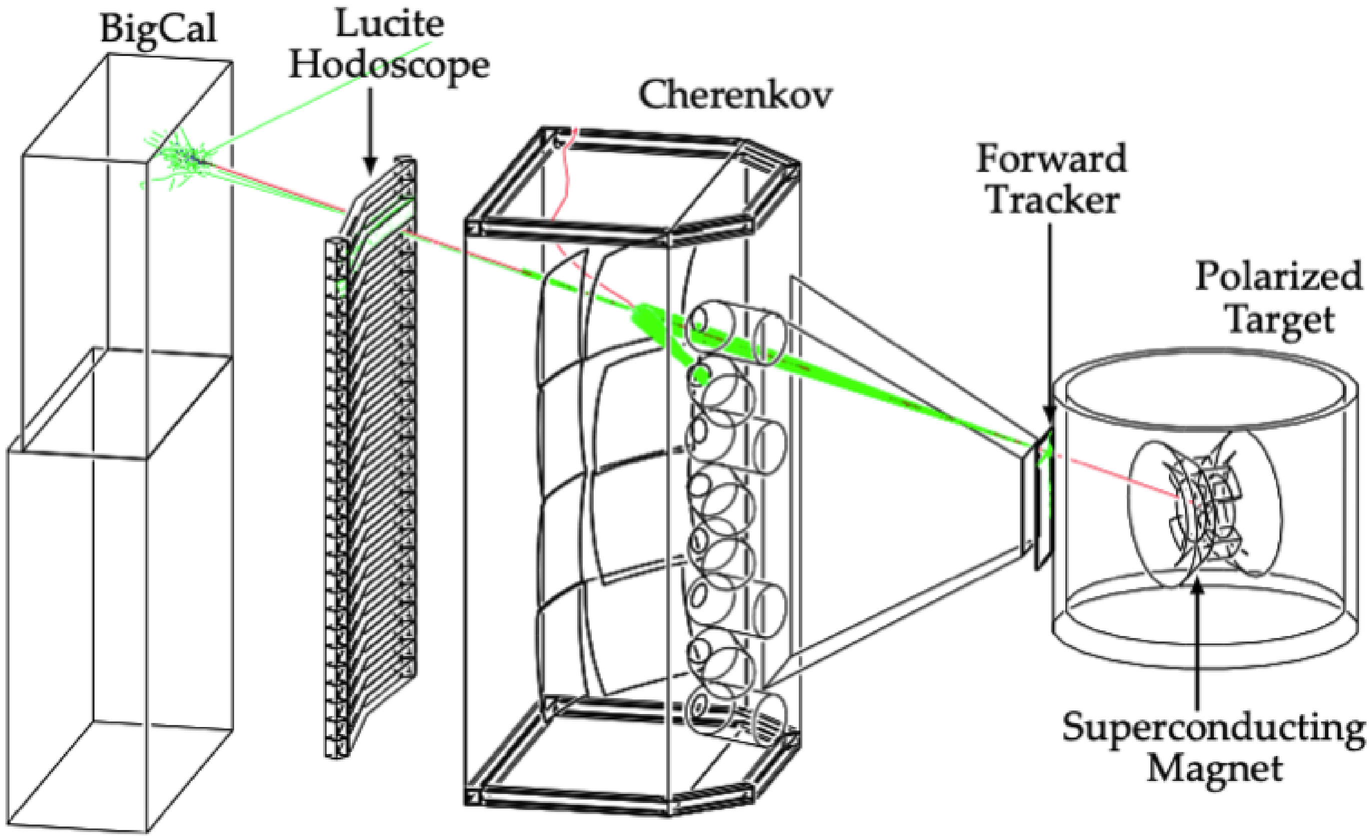
The advance in data accuracy and high x (low W) is needed. Reference to P. Bosted's comment in 2016

Published results
arXiv:1805.08835v4
PRL 122, 022002 (2019)

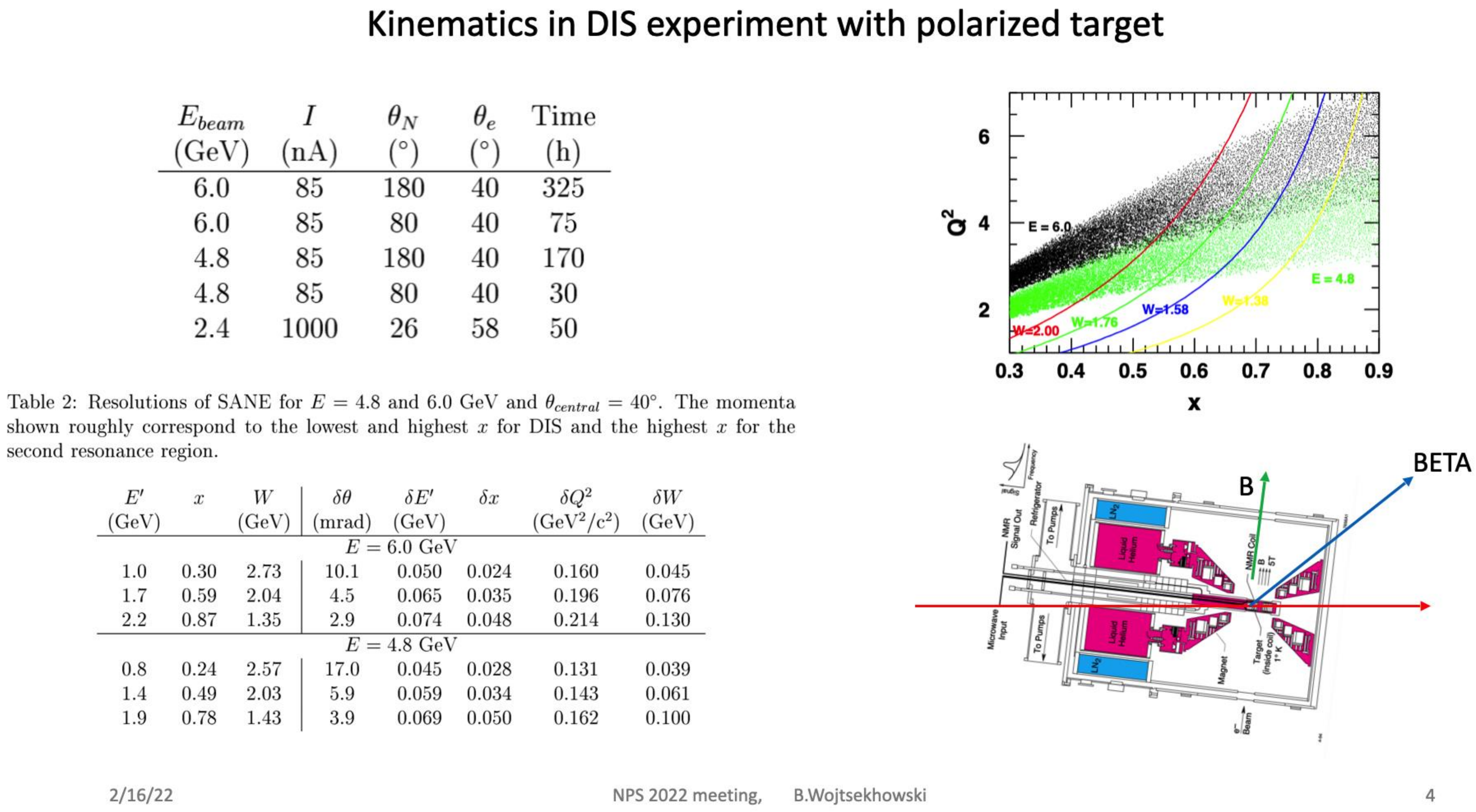
SANE Experiment

Apparatus in SANE experiment





SANE Experiment



Kinematics in DIS experiment with polarized target

E_{beam} (GeV)	I (nA)	θ_N (°)	θ_e (°)	Time (h)
6.0	85	180	40	325
6.0	85	80	40	75
4.8	85	180	40	170
4.8	85	80	40	30
2.4	1000	26	58	50

Table 2: Resolutions of SANE for $E = 4.8$ and 6.0 GeV and $\theta_{central} = 40°$. The momenta shown roughly correspond to the lowest and highest x for DIS and the highest x for the second resonance region.

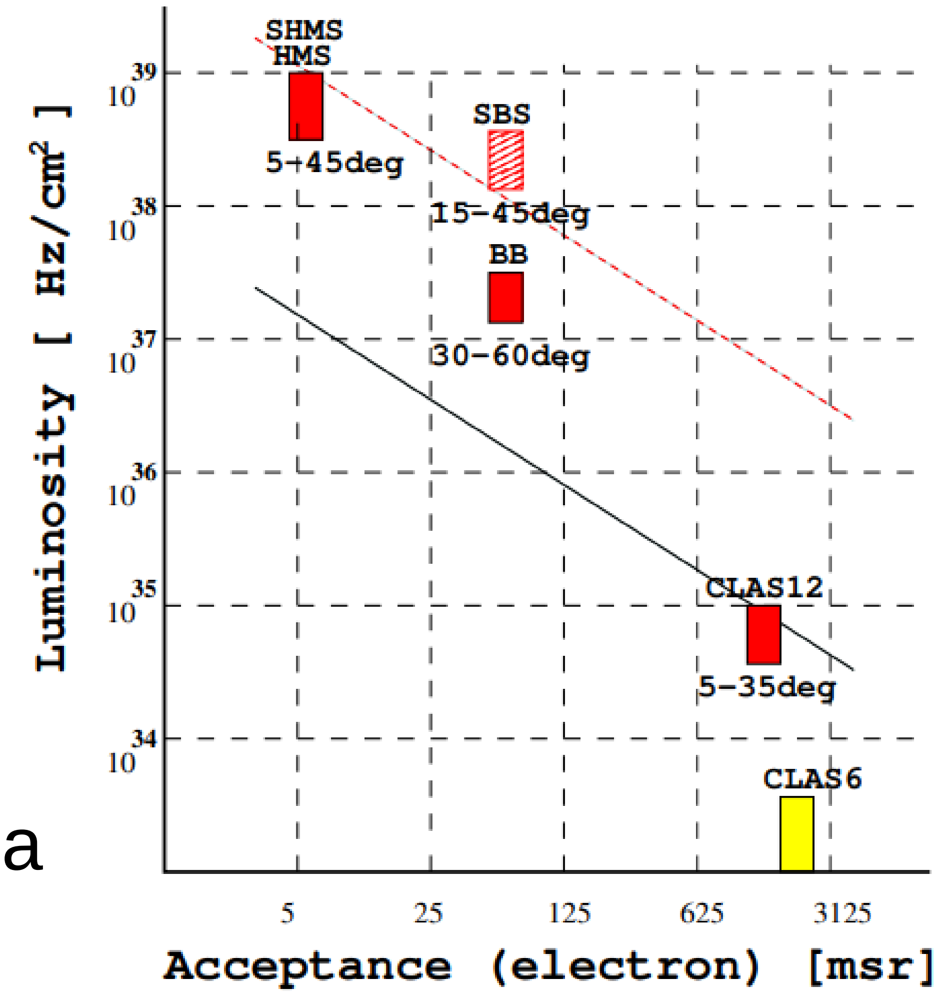
E' (GeV)	x	W (GeV)	$\delta\theta$ (mrad)	$\delta E'$ (GeV)	δx	δQ^2 (GeV^2/c^2)	δW (GeV)
$E = 6.0$ GeV							
1.0	0.30	2.73	10.1	0.050	0.024	0.160	0.045
1.7	0.59	2.04	4.5	0.065	0.035	0.196	0.076
2.2	0.87	1.35	2.9	0.074	0.048	0.214	0.130
$E = 4.8$ GeV							
0.8	0.24	2.57	17.0	0.045	0.028	0.131	0.039
1.4	0.49	2.03	5.9	0.059	0.034	0.143	0.061
1.9	0.78	1.43	3.9	0.069	0.050	0.162	0.100

2/16/22 NPS 2022 meeting, B.Wojtsekhowski 4

Polarized Proton DIS with SBS/BB

Motivation for polarized NH3 target in Hall C using SBS and BB

- Larger Acceptance than SHMS/HMS
- Higher Luminosity than possible in Hall B
- New Magnet with large opening angle
- A_{LL} style symmetric setup
- Similar to 6 GeV SANE , but in 12 GeV era

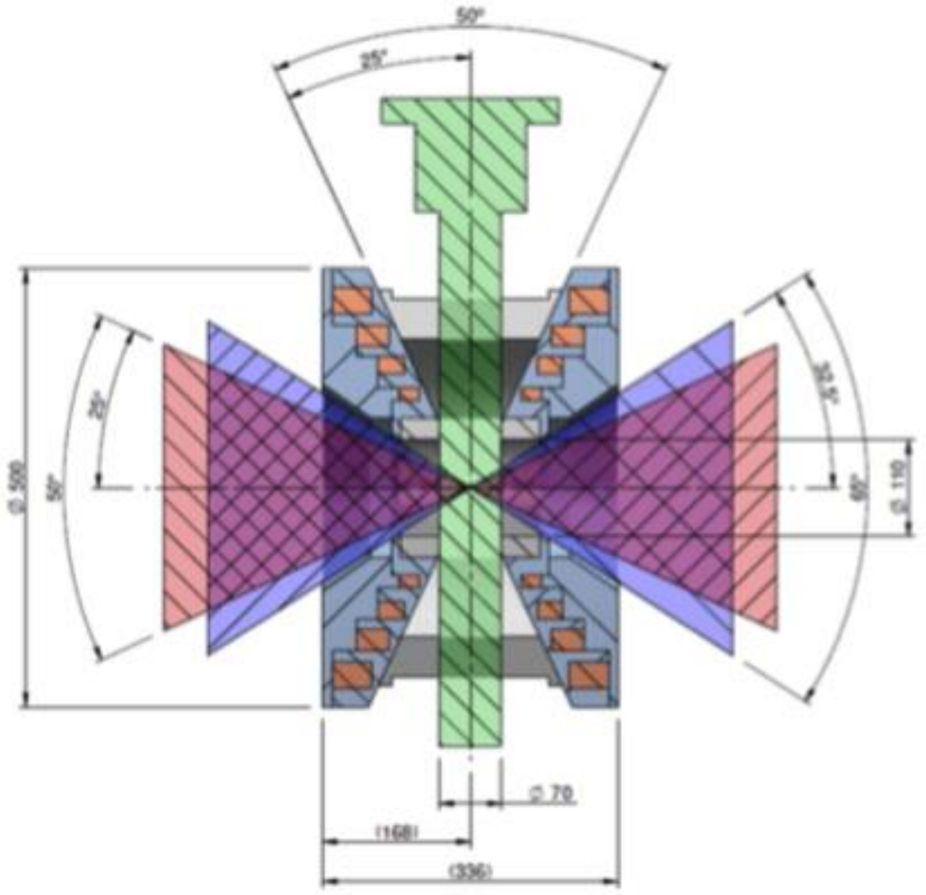


Target Magnet

A new magnet with improved acceptance for transverse polarization was procured for experiments in Hall C.
Compared to the original Hall B and C magnets:

±35° acceptance for longitudinal polarization (30% smaller)

±25° acceptance for transverse polarization (67% larger)



Cross-section through the magnet showing the beam and cold finger access diameters (in mm) and

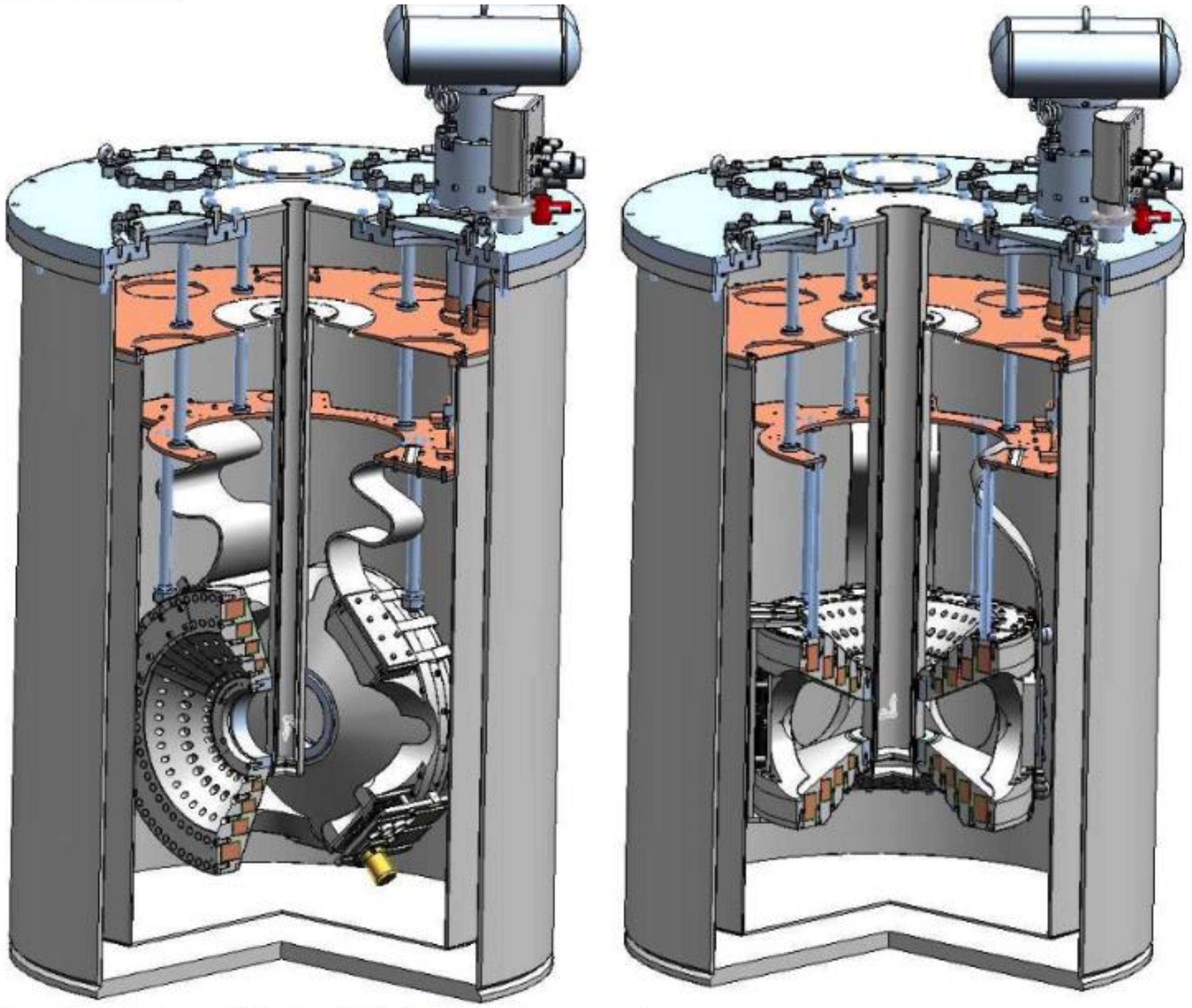
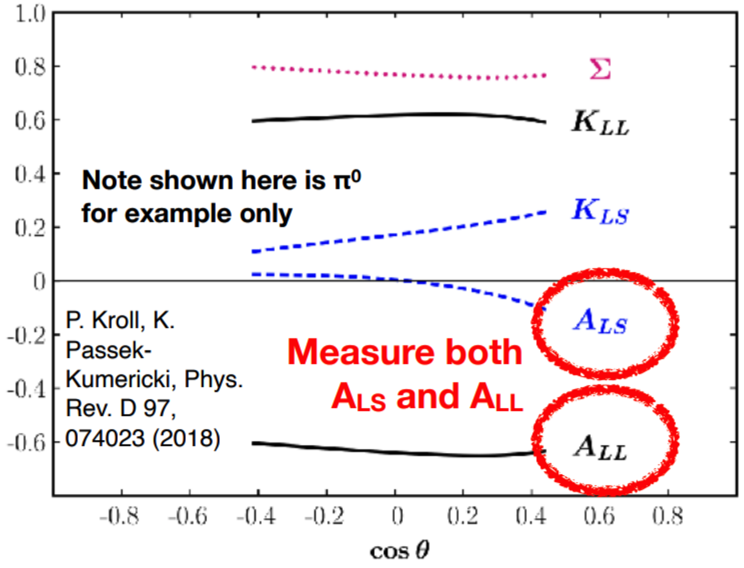


Figure 7: Cut-away of the 2 orientations for the magnet.

Similar Concept as A_{LL}

Plan To Now Measure A_{LL} and A_{LS}



Note shown here is π^0 for example only

P. Kroll, K. Passek-Kumericki, Phys. Rev. D 97, 074023 (2018)

Spin dependent observables for test of twist-3 dominance

$$A_{\rm LL}^{\rm twist-3} = -K_{\rm LL}^{\rm twist-3} = -4\,\frac{S_T^{\pi^0}\left[S_T^{\pi^0} - \frac{t}{2m^2} S_S^{\pi^0} + \kappa \frac{\sqrt{-t}}{2m} \bar{S}_T^{\pi^0}\right]}{F^{\pi^0}}$$

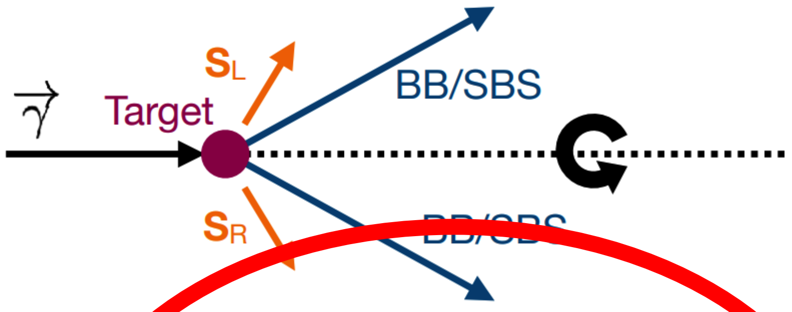
$$A_{LS}^{\rm twist-3} = -K_{LS}^{\rm twist-3}\, 2\,\frac{S_T^{\pi^0}}{F^{\pi^0}}\left[\frac{\sqrt{-t}}{m}\bar{S}_T^{\pi^0} - 2\kappa\left(S_T^{\pi^0} - \frac{t}{2m^2} S_S^{\pi^0}\right)\right]$$

A_{LL} = helicity of incoming photon and longitudinal polarisation of initial nucleon
A_{LS} = helicity of incoming photon and sideway polarisation of initial nucleon

- Measure A_{LS} AND A_{LL} (concept from Bogdan)
- Compensate for loss in photons by making 2 simultaneous measurements
- Double productivity by accessing A_{LS} simultaneously without target change

- BB and SBS symmetric around beam line, a
- Target polarised at 60˚ to beam
- Cannot easily change target to flip transverse polarisation
  - But have BB/SBS either side of beam line
- Measure p and π- in both BB and SBS arms
- Flip of transverse polarisation (**S**) around beam line equivalent to measuring in either BB or SBS
- Longitudinal component stays same (not affected by imaginary rotation)

- Raw asymmetry has contributions from A_{LL} and A_{LS}
- Asymmetry observed by BB compared to SBS differs by opposite signs of A_{LS} contributions only
- A_{LL} will be average and A_{LS} will be difference in BB/SBS asymmetries

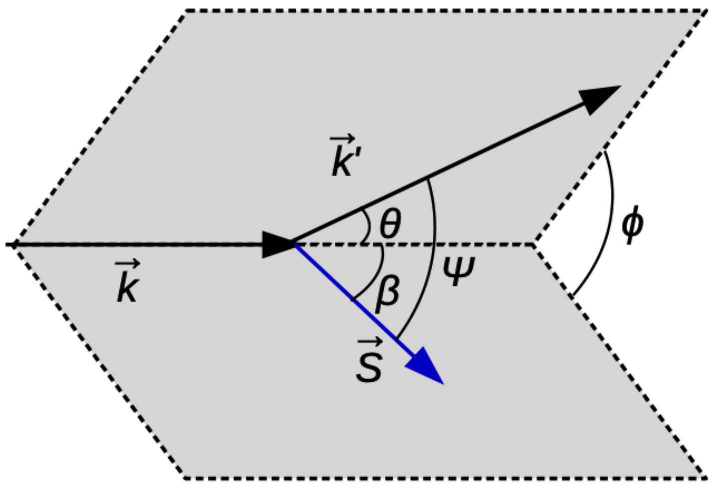


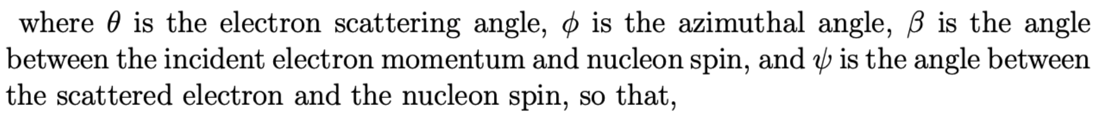
Transverse part cancels due to opposite signs

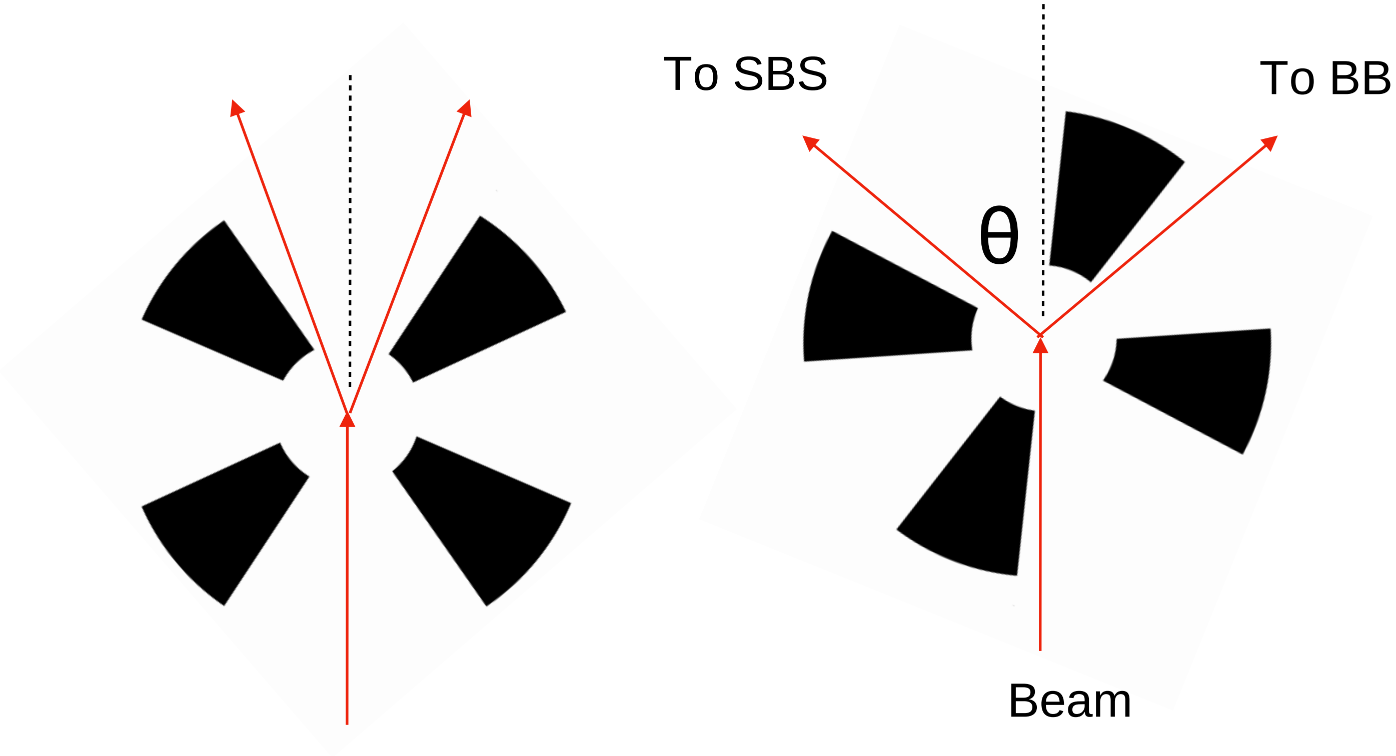
$$A_{LL} = \frac{A_{BB} + A_{SBS}}{2}$$

$$A_{LS} = \frac{A_{BB} - A_{SBS}}{2}$$

Advantage of a symmetric setup




where θ is the electron scattering angle, ϕ is the azimuthal angle, β is the angle between the incident electron momentum and nucleon spin, and ψ is the angle between the scattered electron and the nucleon spin, so that,



If $\theta_{SBS} = -\theta_{BB}$, then

$$A_{BB} = DP_{targ}P_{beam}(Cos(\beta)A_{||} + Sin(\beta)A_{\perp})$$
$$A_{SBS} = DP_{targ}P_{beam}(Cos(\beta)A_{||} - Sin(\beta)A_{\perp})$$

$$\Longrightarrow$$

$$A_{||} = (A_{SBS} + A_{BB})/2$$
$$A_{\perp} = (A_{SBS} - A_{BB})$$

Summary/Outlook

- Concept introduced for using SBS and BB in Hall C to measure the proton spin structure functions using a polarized NH3 target
- A symmetric setup of SBS and BB allows simultaneous measurement of A_perp and A_parallel
- Larger acceptance than SHMS/HMS and higher luminosity than Hall B provides large Figure of Merit
- Proposal at next year PAC