SANE (E07-003)

Spin Asymmetries of the Nucleon Experiment

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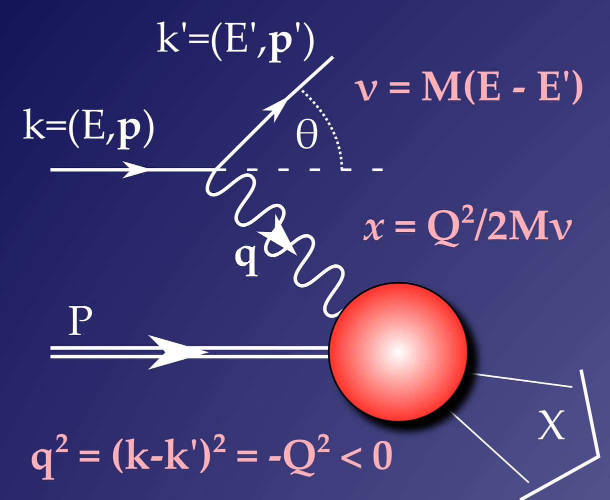
Introduction:



To probe the structure of the nucleus, we can use a high energy electron beam like a microscope, accessing finer detail with higher energy. In these scattering experiments, observables are often given in terms of Bjorken x ($x = Q^2/2M\nu$), the fraction of the nucleon's momentum carried by the struck quark in a certain reference frame.


3D Nucleon Image by U. Elschenbroich, HERMES

We parametrize quark behavior in the nucleon in terms of four functions of x: structure functions F_1 and F_2, and spin structure functions (SSFs) g_1 and g_2 which are polarization observables. g_2 remains largely unobserved, and depends on the transversity structure function and little understood higher order correlations corresponding to quark-gluon-quark interactions.

To extract spin structure functions, we measure the asymmetries of scattering yields at different orientations of electron beam helicities and nucleon polarizations:

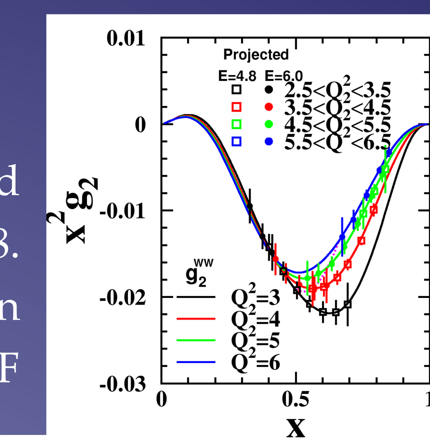
$$A_{\parallel,\perp} \sim \frac{1}{P_B P_T}\left(\frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}}\right)$$

The SSFs can then be expressed in terms of F_1 and kinematic factors:

$$A_1 = a(A_\parallel - bA_\perp) = \frac{1}{F_1}\left(g_1 - \gamma^2 g_2\right),\quad A_2 = a(cA_\parallel + dA_\perp) = \frac{\gamma}{F_1}\left(g_1 + g_2\right)$$

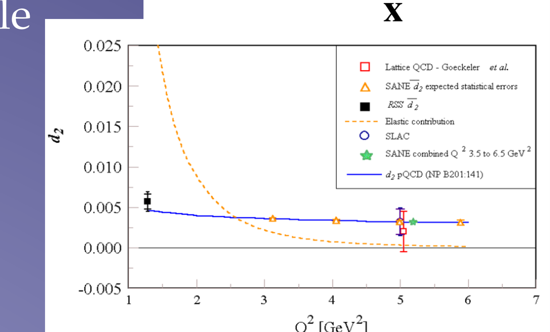
Extracting g_2 offers an unexplored look into higher-order interactions between gluons and quarks, and measuring these asymmetries at high x gives a valuable view with the sea quarks of the nucleon stripped away.

The Experiment:

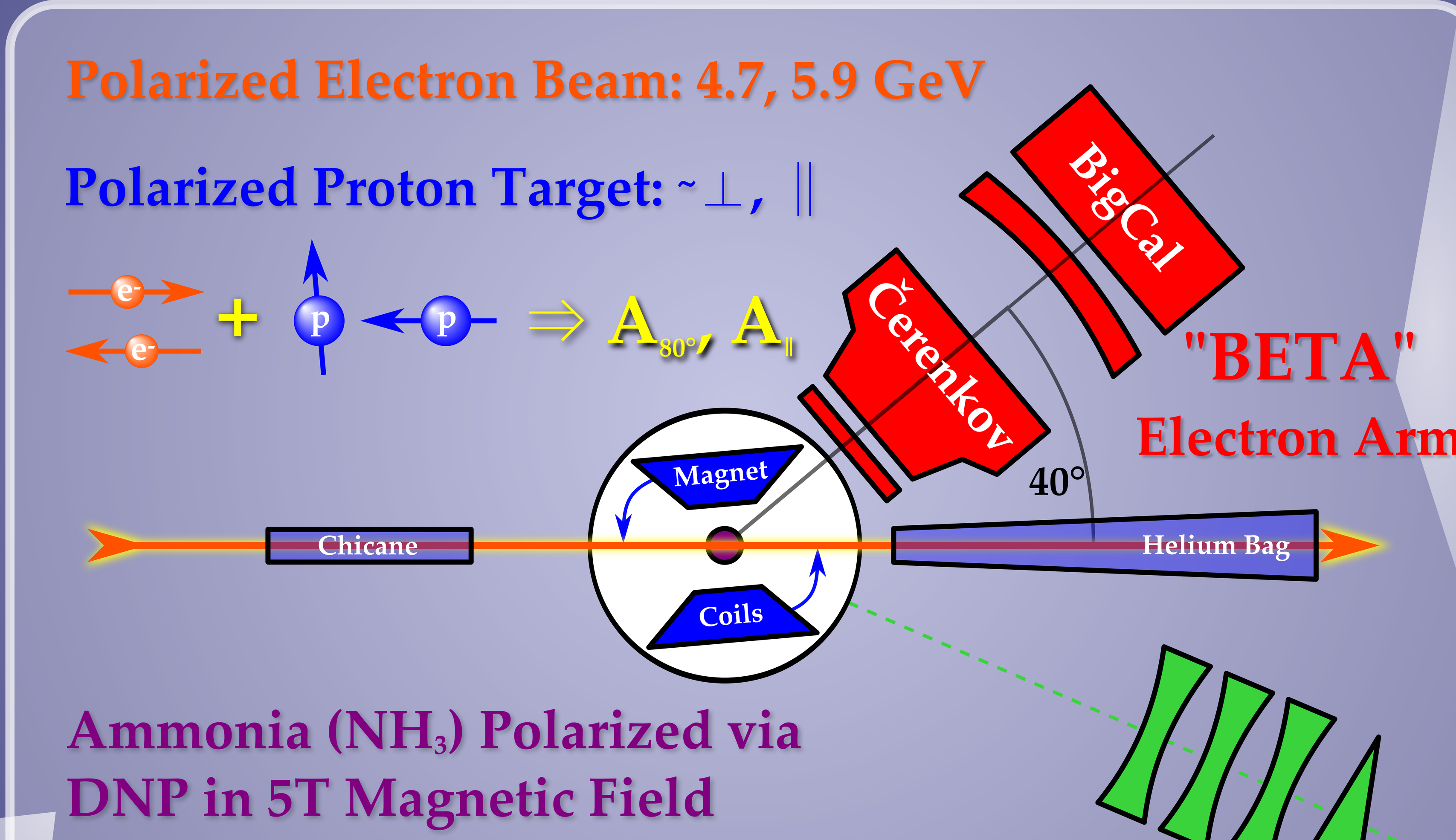


SANE is a measurement of proton spin asymmetry A_1 and spin structure function g_2 at $2.5<Q^2<6.5$ GeV^2 and $0.3<x_{Bj}<0.8$. This kinematic range offers an unexplored frontier when using a target polarization near perpendicular to the CEBAF electron beam. New lessons of an inclusive, double polarization measurement include:

- Twist-3 correlations from SSF moments: d_2
- Comparison of Lattice QCD, QCD sum rules, bag models, and chiral quark predictions
- Exploration of A_1 as x_{Bj} approaches 1



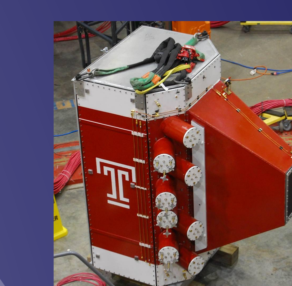
Above plots from SANE update to PAC 31, SANE Collaboration, 2006.



SANE Overview

Electron Detector Package:

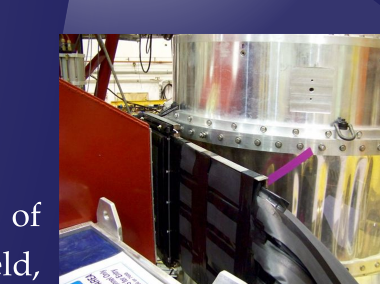
The "Big Electron Telescope Array" (BETA), was the centerpiece of SANE. With a solid angle of 0.2sr, pion rejection of 1000:1, energy resolution of 10%/√E, and angular resolution of ~1mr, BETA did not bend particles in a B field like a spectrometer. Drift space between the calorimeter and Čerenkov made it a *telescope* to isolate events in the scattering chamber.



Threshold Čerenkov: Determined speed of particles passing through it via the Čerenkov effect, to differentiate electrons and positrons from much heavier pions.

"Big Cal": This Big Calorimeter consisted of 1744 Pb-glass blocks which can stop incoming electrons. As they stop, they emit a shower of secondary electrons and photons, which are then gathered by photo-tubes. By reconstructing the shower from the photo-tube signals, we can determine the energy of the incoming electron, and its position.

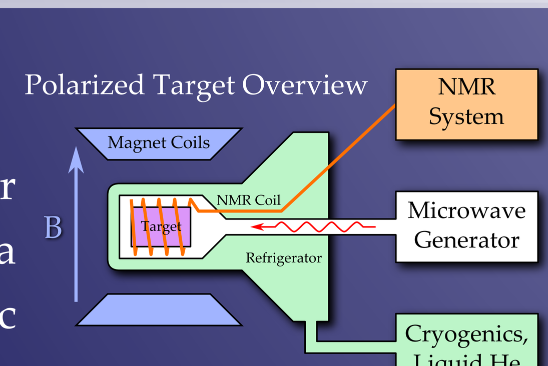
Lucite Hodoscope: Determined position of incoming particles and allowed background rejection.



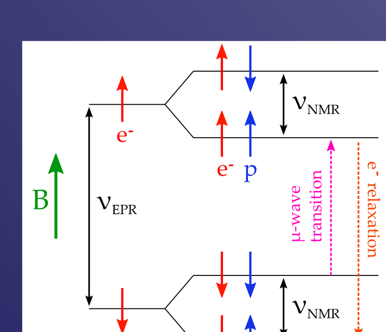
Front Tracker: Gave position of particles close to target magnetic field, to differentiate electrons and positrons.

Polarized Target:

To provide polarized protons needed for double spin asymmetries, the UVa polarized target operates via dynamic nuclear polarization, or DNP, which leverages hyperfine splitting of electron-proton pairs in a large magnetic field and at very low temperature (1K).



Using microwaves of specific frequency, spin flips are induced to transfer the naturally high polarization of electrons in the B field to the protons. Our "proton" target was ammonia ($^{14}NH_3$) doped with paramagnetic centers via irradiation. Operating at 5T, the target's Helmholtz pair magnet allows incident beam both parallel and perpendicular to the field.



DNP Hyperfine Splitting Transitions

Purple ammonia target material in the target insert

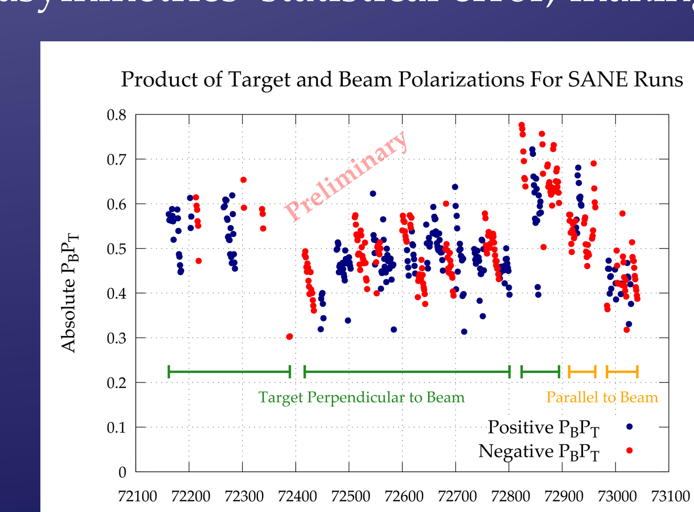
Preliminary Results:

SANE took over 300 hours of beam in Jefferson Lab's Hall C from January to March of 2009, at two beam energy settings, 4.7 and 5.9 GeV, and two target polarization orientations, parallel and near perpendicular. The largest portion of time, nearly 250 hours, was given to the measurement of perpendicular asymmetries.

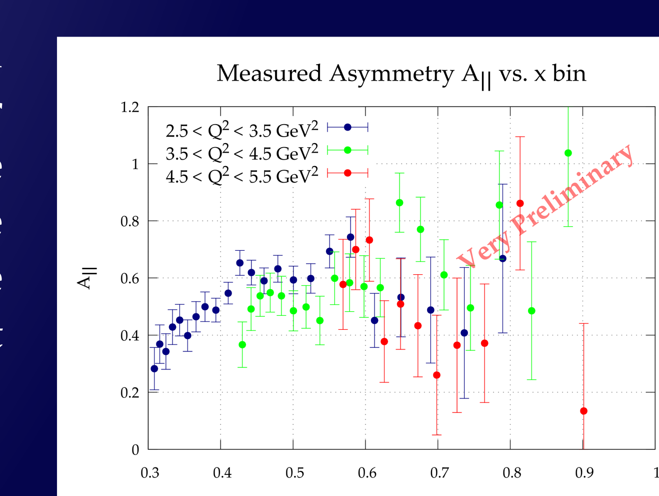
In addition to scaling the asymmetries, the proton target and electron beam polarizations are inversely proportional to the asymmetries' statistical error, making high polarization crucial:

$$dA \sim \frac{1}{P_B P_T \sqrt{N}}$$

To the right is shown the product $P_B P_T$ for all SANE runs, the result of analysis efforts for the beam and target data. Target polarization is measured via NMR of the target material *in situ*, and beam polarizations are based on fits to several Møller scattering measurements.



At right are shown measured asymmetries $A_\parallel$ and $A_{80°}$ versus x for several Q^2 bins. These results are asymmetries of helicity yields which have been corrected for $P_B P_T$, charge normalization, and preliminary target dilution factor.



Using these asymmetries, the spin structure function $g_2(x)$ will be extracted, via the equations in the introduction, using a data parametrization of F_1. Radiative corrections and error studies also remain to be done.

SANE data offers precise, ground-breaking measurements in this kinematic range, and will represent a significant advancement of our understanding of the structure of the nucleon.