Experimental Results in DIS from Jefferson Lab

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Jefferson Lab in Perspective

Slightly Enlarged...

HERA

Topics JLab Can Address:

- Inclusive (D)IS
 - Valence PDFs (d/u , $\Delta d/d$ and $\Delta u/u$ as $x \rightarrow 1$)
 - QCD evolution, higher twist, duality
 - Moments, sum rules, OPE
 - Structure of bound nucleons
- Semi-inclusive DIS
 - Tagged (spin) structure functions
 - Transversity, TMD PDFs
(Single Spin Asymmetries)
- Hard Exclusive Processes
 - Generalized PDs
 - DVCS, Deeply virtual meson production

Experimental Hall A

Experimental Hall B

CLAS

Experimental Hall C

BETA detector

Structure Functions - Bread & Butter (Wine?)

High Precision L/T separation
in Hall C

Nachtmann Moments -
Global analysis by M. Osipenko
(including CLAS data)

Valence PDFs

- Behavior of PDFs still unknown for $x \rightarrow 1$
 - SU(6): $d/u = 1/2$, $\Delta u/u = 2/3$, $\Delta d/d = -1/3$ for all x
 - Relativistic Quark model: Δu , Δd reduced
 - Hyperfine effect (1-gluon-exchange): Spectator spin 1 suppressed, $d/u = 0$, $\Delta u/u = 1$, $\Delta d/d = -1/3$
 - Helicity conservation: $d/u = 1/5$, $\Delta u/u = 1$, $\Delta d/d = 1$
 - Orbital angular momentum: can explain slower convergence to $\Delta d/d = 1$
- d/u knowledge limited by lack of free neutron target (nuclear binding effects in d , ^3He)
- Large x requires very high luminosity

➡ See also C. Keppel's talk -
Session SF-9

d/u: The BoNuS Approach

“**B**arely **O**ff-shell **N**e $\mathbf{U}$ tr $\mathbf{O}$ n **S**cattering”

The Problem: nuclear binding uncertainties prevent us from knowing F_{2n} and $d/u(x \rightarrow 1)$

Require low p_s to suppress FSI, binding and off-shell effects

The Solution: spectator proton tagging $\rightarrow$ select low-momentum part of d wave function and tag motion of struck neutron

The BoNuS Experiment

Gas
Electron
Multiplier

Thin Al-Mylar Window

Thin Al-Mylar Cathode

Drift
Region

3 GEMs

Readout pads
and electronics

ϕ , z from pads
 r from time

dE/dx from charge
along track (particle ID)

BoNuS - Preliminary Results and Future

Spin Structure Functions at large x

Hall A

CLAS

Results and Future

Proton

CLAS12

Deuteron

Huge number of data points on g_1 , $g_2, \dots$

X

Similar for deuteron...

...with impact on PDFs

$$g_1(x, Q^2)_{pQCD} = \frac{1}{2} \sum_q e_q^2 [(\Delta q + \Delta \bar{q}) \otimes (1 + \frac{\alpha_s(Q^2)}{2\pi} \delta C_q) + \frac{\alpha_s(Q^2)}{2\pi} \Delta G \otimes \frac{\delta C_G}{N_f}]$$

NLO fit by Leader, Stamenov and Siderov, including both CLAS data and new COMPASS data on the deuteron

The Spin Structure Function g_2

Hall C

Hall A

Moments: Spin Structure Functions

Twist-3 Matrix
element d_2

Higher Twist

$$\Gamma_1(Q^2) = \mu_2(\ln Q^2) + \frac{\mu_4(\ln Q^2)}{Q^2} + \dots; \quad \mu_4 = \frac{M^2}{9}(a_2 + 4d_2 + 4f_2)$$

twist-2, targ. mass

$$d_2(Q^2) = \int_0^1 x^2 [2g_1(x, Q^2) + 3g_2(x, Q^2)] dx$$

twist-3

$$f_2(Q^2) M^2 S^\mu = \frac{1}{2} \sum_q e_q^2 \langle N | g \bar{\psi}_q \tilde{G}^{\mu\nu} \gamma_\nu \psi_q | N \rangle$$

twist-4

Higher Twist contribution to g_1

Duality

Long Distance Physics:
hadronic observables

Asymptotically Free Quarks:
regime of pQCD

Famous Hall C Data

Duality - New Results from Hall C

Alekhin NNLO

MRST NNLO

MRST NNLO with Target
Mass Corrections (Barbieri)

Example: Proton Structure Function F_L

Duality in SSFs

Hall A

P. Solvignon et al., PRL 101, 182502 (2008)

Hall A

Target mass corrections
were applied on PDFs

Duality in SSFs (CLAS) $1 < W < 2 \text{ GeV}$

New Data on the EMC Effect

$A(e,e')$ at 5.0 and 5.8 GeV in Hall C

Targets:

H, ^2H ,

^3He , ^4He ,

^9Be , ^{12}C ,

^{63}Cu , ^{197}Au

Isoscalar correction

Coulomb correction

A or ρ -dependence ?

SIDIS

- By detecting the leading hadron in the final state together with the scattered electron, we can:
 - tag the flavor of the struck quark
 - select hard sub-processes through high p_T (12 GeV)
 - Measure p_T , ϕ dependence of PDFs (higher twist)
 - Learn about the 3-dimensional structure of the nucleon:
 - Transversity
 - Spin-momentum correlations (Sivers function, Boer-Mulders function, “pretzelosity”)
 - Learn about new fragmentation functions (Collins)

Unpolarized Results (CLAS):

$$H_2 = \sum_q e_q^2 q(x) \otimes D(z) \quad Q^2 = 2.4 \text{ GeV}^2$$

$\langle \cos\phi \rangle$ vs p_T

Unpolarized Results (Hall C):

Closed (open) symbols reflect data after (before) events from coherent ρ production are subtracted

Good description for p and d targets for $0.4 < z < 0.65$

$$\sum_q e_q^2 q(x) D_{q \rightarrow M}(z)$$

factorization

$$\frac{D^-}{D^+} = \frac{4-R}{4R-1}$$

$$R = \frac{N_{\pi^+}}{N_{\pi^-}}$$

(Deuterium data)

Polarized Results - CLAS

$$A_1 \propto \frac{\sum_q e_q^2 g_1^q(x) D_1^{q \rightarrow \pi}(z)}{\sum_q e_q^2 f_1^q(x) D_1^{q \rightarrow \pi}(z)}$$

p_T dependence of $\pi^+ A_{LL}$ can be explained by broader k_T distributions for f_1 compared to g_1

E-05-113 with CLAS and longitudinal target

Study semi-inclusive pion production, TMDs and Collins fragmentation function as well as DVCS

$$h_{1L}^\perp H_1^\perp$$

Expected Precision for
sin ϕ and sin2 ϕ moments
of target SSA

60 days ($P_H=75\%$)

uses 2π inner
calorimeter for
 γ/π^0 coverage

Huge Program for 12 GeV: p, d, ^3He targets,
detect π 's, K's, ...; transv. + long. SSAs, DSAs,...

E-08-015 with CLAS and transverse HD ice target Study Spin-Orbit correlations in Semi-Inclusive DIS and Sivers distribution function

25 days ($P_H=75\%$ $P_D=25\%$)

Potential to add to
world data on g_2 and A_2

E06-010: Target Single-Spin Asymmetry in Semi-Inclusive $n^\uparrow(e, e'\pi^{+/-})$ Reaction on a Transversely Polarized ^3He Target

- First measurement of the neutron Collins and Sivers asymmetries in SIDIS.
- High density polarized ^3He target.
- Run in Hall A from 10/24/08-2/5/09.
110 shift workers, 7 Ph.D. students.

Summary

- There are huge number of interesting topics in (SI)DIS to pursue in “our little corner” of the kinematic plane
- Jefferson Lab has produced scores of high precision data on SFs and PDFs (TMD and integrated, especially at large x), moments, higher twist and duality, and nuclear effects
- Jefferson Lab at 12 GeV (in 5 years) will complete the 3-dimensional quark picture of the nucleon for $x > 0.1$