Status of JLab MARATHON Experiment

Measurement of $F_2^n/F_2^p$, $d/u$ RATios and $A=3$
EMC Effect in Deep Inelastic Electron Scattering
Off the Tritium and Helium Mirror Nuclei

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For the JLab Hall A Collaboration

Hall A Collaboration Meeting
January 24, 2018
Overview of the Experiment

• MARATHON is measuring NOW! electron deep inelastic scattering (DIS) from 3H, 3He and 2H nuclei using the Hall A Spectrometer Facility of JLab.

• The experiment will extract using a novel method, which exploits the isospin symmetry of the A=3 nuclei, the ratio of the neutron to proton structure functions $F_2^n/F_2^p$, and the ratio of the proton $d/u$ quark distribution functions.

• The forthcoming results are expected to be almost free of nuclear structure theoretical uncertainties that dominate the previous SLAC results (extracted from proton and deuteron DIS measurements).

• MARATHON will also measure the EMC effect for 3H and 3He. The expected A=3 EMC data are considered crucial for the understanding of the effect.
Electron-Nucleus Inelastic Scattering

- Cross section for inelastic electron-nucleus scattering \([E \ (E')]\): incident (scattered) electron energy, \(\theta\): electron scattering angle, \(M\): nuclear mass] in terms of nuclear \(F_1\) and \(F_2\) structure functions:

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

\[
R = \frac{F_2M}{F_1\nu} \left(1 + \frac{\nu^2}{Q^2}\right) - 1
\]

\[
\nu = E - E'
\]

\[
Q^2 = 4EE' \sin^2(\theta/2)
\]

- Ratio \(R\) has been measured to be the same for proton, deuteron and all other nuclear targets. Cross section ratio for two nuclei, say 3H and 3He, becomes equal to ratio of their \(F_2\) structure functions.

\[
\left[ \frac{d\sigma(3H)}{d\Omega dE'} / \frac{d\sigma(3He)}{d\Omega dE'} \right] = \left[ F_2(3H) / F_2(3He) \right]
\]
Friedman, Kendall, Taylor
Nobel 1991

$F_{2n}/F_{2p}$ extracted from $p$ and $d$ DIS using a Fermi-smearing model and a non-relativistic $N-N$ potential

Data in disagreement with $SU(6)$ prediction: $2/3 = 0.67$!

High momentum quarks in $p(n)$ are $u(d)$ valence quarks

There are no high momentum strange quarks in $p$ and $n$

Sea quarks dominate at small $x$

Data consistent with di-quark model by Feynman and others
Nucleon $F_2$ Ratio Extraction Revisited

**SLAC DIS Data**

Whitlow: Assumes EMC effect in deuteron (Frankfurt and Strikman data-based Density Model)

Melnitcouk & Thomas: Relativistic convolution model with empirical binding effects

Bodek: Non-relativistic Fermi-smearing-only model with Paris N-N potential
CJ (CTEQ-JLab) Recent Calculations

A. Accardi et al.
**$F_2^n / F_2^p$, $d/u$ Ratios and $A_1$ Limits for $x \to 1$**

<table>
<thead>
<tr>
<th></th>
<th>$F_2^n / F_2^p$</th>
<th>$d/u$</th>
<th>$A_1^n$</th>
<th>$A_1^p$</th>
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<td>1/5</td>
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$A_1$: Asymmetry measured with polarized electrons and nucleons. Equal in QPM to probability that the quark spins are aligned with the nucleon spin.

$A_1^p, A_1^n$: Extensive experimental programs at CERN, SLAC, DESY and JLab (6 GeV and 12 GeV Programs)
EMC Effect for $A=3$ Mirror Nuclei

Hall A data on $^3$H, $^3$He will be of similar precision to Hall C data
MARATHON Projected Data (Proposal)
Nucleon $F_2$ Ratio Extraction from $^3$He/$^3$H

- Just perform DIS from $^3$He and $^3$H. Binding of nucleons in the two nuclei is of same nature. Differences between bound and free nucleons in the two nuclei is calculable, summarized, for their ratio, by some parameter $R^*$ (W. Melnitchouk et al.).

- If $R = \sigma_L / \sigma_T$ is the same for $^3$He and $^3$H, measured DIS cross section ratio must be equal to the $F_2$ structure function ratio as calculated using $R^*$:

$$
\frac{\sigma_{^3\text{He}}}{\sigma_{^3\text{H}}} = \frac{F_{^3\text{He}}^2}{F_{^3\text{H}}^2} = R^* \frac{2F_p^2 + F_n^2}{F_p^2 + 2F_n^2}
$$

- Determine nucleon $F_2$ ratio using $A=3$ DIS cross section data and $R^*(\approx 1)$ from theory:

$$
\frac{F_{n}^2}{F_{p}^2} = \frac{2R^* - F_{^3\text{He}}^2 / F_{^3\text{H}}^2}{2F_{^3\text{He}}^2 / F_{^3\text{H}}^2 - R^*}
$$
JLab Hall A High Resolution Spectrometers

(For MARATHON: both used for electrons)

Electron Spectrometer

Detector Hut

Hadron Spectrometer

Q2

Q3

Dipole

Q1

DETECTORS
Cherenkov, Calorimeter,
2 Scintillator planes, and
Drift Chamber set

Beamline

Scattering Chamber

11 GeV Beam - Tritium/Helium targets

DETECTORS
Cherenkov, Calorimeter,
2 Scintillator planes, and
Drift Chamber set
3H, 3He, 2H, 1H Gas Cells of Tritium Program
(See Hall A Tritium Wiki, Dave Meekins)
Today’s Status of MARATHON

- Experiment has been running since January 12.
- Currently taking data with the Left-HRS, which has been checked out and calibrated.
- We have high statistics data for 3H, 3He and 2H for $x = 0.22$-$0.62$ (7 pts), and for 1H for $x = 0.22$-$0.30$ (3 pts).
- The Right-HRS has had problems with its dipole. As of this morning it appears to be stable at $E' = 2.9$ GeV, which is the momentum required for the lowest-rate, highest-$x$ point ($=0.82$) of the proposal.
- There are problems with the motor motion of the Right-HRS. May have to move it to large angle(s) “manually”.
- PRELIMINARY results (not to be shown) indicate that the deuteron/proton and triton/helion cross section ratios are, at low $x$, consistent with expectations.
MARATHON High Voltage Monitoring (Example)

LHRS Cherenkov HV sum
MARATHON Scaler Rate Monitoring (Example)

Cherenkov Scaler Sum (1-5): Kin 11

(Data for different gas targets)
Left HRS Scintillator Hodoscope Performance

s0 ADC vs s2 ADC (CK,E/P and TRK1 cuts,T1 trigger)

Entries: 305647
Mean x: 737.1
Mean y: 1052
Std Dev x: 343.6
Std Dev y: 396
Integral: 3.049e+05

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Left HRS Scintillator Performance

s0 ADC (CK,E/P and TRK1 cuts,T1 trigger)
- Entries: 305647
- Mean: 1052
- Std Dev: 396.4
- Underflow: 1
- Overflow: 487
- Integral: $3.052 \times 10^5$

s2 ADC (CK,E/P,and TRK1 cuts,T1 trigger)
- Entries: 305647
- Mean: 738.6
- Std Dev: 347.1
- Underflow: 167
- Overflow: 98
- Integral: $3.054 \times 10^5$
Left HRS Cherenkov Performance

CK sum ADC(E/P and TRK1 cuts, T1 trigger)

Entries: 406581
Mean: 4243
Std Dev: 2527
Underflow: 0
Overflow: 1981
Integral: 4.046e+05

CK sum ADC(E/P and TRK1 cuts, T2 trigger)

Entries: 322504
Mean: 5333
Std Dev: 1528
Underflow: 0
Overflow: 1980
Integral: 3.205e+05
Left HRS Calorimeter Performance

E/p(TRK1 cut, T1 trigger)

- Entries: 3149492
- Mean: 0.306
- Std Dev: 0.3001
- Underflow: 4.385e+04
- Overflow: 1380
- Integral: 3.104e+06

E/p(CK and TRK1 cuts, T2 trigger)

- Entries: 344875
- Mean: 0.9418
- Std Dev: 0.2649
- Underflow: 5005
- Overflow: 331
- Integral: 3.395e+05
Left HRS - Origin of Events Along the Target

`, target(CK,E/P and TRK1 cuts,T1 trigger)`,

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Left HRS – Empty Target Run
Focal Plane coordinates

FP $\theta$ VS x(CK,E/P and Trk1 cuts, T1 trigger)

Entries: 13032
Mean x: -0.03514
Mean y: -0.007163
Std Dev x: 0.2937
Std Dev y: 0.05239
Integral: 1.303e+04

FP $\phi$ VS y(CK,E/P and Trk1 cuts, T1 trigger)

Entries: 13032
Mean x: 0.003509
Mean y: 0.003876
Std Dev x: 0.03125
Std Dev y: 0.027
Integral: 1.3e+04
Events from Target Cell End Caps
Proposal Kinematics 7  x = 0.46

Empty/He3 = 1.5 % ± 0.1 %
Empty/H3 = 2.0 % ± 0.2 %
Empty/D2 = 0.6 % ± 0.0 %

|VertexZ|<10cm
Kin7, θ = 25.59

Empty Target
Summary-Thanks

- MARATHON has been **RUNNING** with the Left HRS for 11 days, taking low- and medium-x data ($x = 0.22-0.62$).
- Currently checking out the Right HRS (R-HRS), which has had problems with its dipole. Hope to be stable and use it to take low-rate, very high-x data ($x = 0.82$).
- We have about 55 days to go (after 18 years!).
- Offline analysis will start soon, after the R-HRS checkout.

**THANKS TO:**
- THE OUTSTANDING STUDENTS OF THE TRITIUM FAMILY AND THE GMP/DVS COLLABORATIONS;
- THE OUTSTANDING POSTDOCTORAL ASSOCIATES OF THE TRITIUM FAMILY AND THE GMP/DVS COLLABORATIONS;
- Wally Melnitchouk, Roy Holt, Dave Meekins, and Doug Higinbotham for their invaluable contributions;
- All the Accelerator and Hall A Scientific and Technical Staff of JLab.
$R = \frac{\sigma_L}{\sigma_T}$ Measurements

SLAC/CERN data show that the ratio $R = \frac{\sigma_L}{\sigma_T}$ is the same for all nuclei within experimental errors.