Measurement of $F_{2n}/F_{2p}$, $d/u$ Ratios and $A=3$ EMC Effect in Deep Inelastic Electron Scattering Off the Tritium and Helium Mirror Nuclei

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Hall A Collaboration meeting, Jun 22
Outline

- Overview and goals
- Experiment settings
- Calibrations
Overview and goals

- MARATHON finished data taking this Spring!
- Almost 30 years since last time tritium target was used
- Perform inclusive electron deep inelastic scattering (DIS) on 3H, 3He, and 2H nuclei by using Hall A HRS;
- The goal is to extract 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 at high $x$;
- We will also measure the EMC effect for 3H and 3He;
Why measure $F_n^2/F_p^2$ at high $x$

- **Testing ground for hadron structure at $x \to 1$:**
  - $d/u \to 1/2$
  - $d/u \to 0$
  - $d/u \to 1/5$
  - $d/u \to \frac{4\mu_n^2/\mu_p^2 - 1}{4 - \mu_n^2/\mu_p^2} \approx 0.42$

*slide from Jianwei Qiu*
SLAC DIS Data revisited

Bodek et al.: Non-relativistic Fermi-smearing-only model with Paris N-N potential

Melnitchouk and Thomas: Relativistic convolution model with empirical binding effects

Whitlow et al.: Assumes EMC effect in deuteron (Frankfurt and Strikman data-based Density Model)
Exploits the isospin symmetry of the \( A=3 \) nuclei \( ^3\text{He} \) and \( ^3\text{H} \). The nuclear effect difference between these should be small;

d/\( u \) extracted should be free of nuclear structure theoretical uncertainties;

First measurement of the EMC effect in Tritium;
Cross section for inelastic electron-nucleon scattering

$E (E')$ incident (scattered) electron energy; $\theta$: electron scattering angle; 
$M$: nuclear mass

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

$$
F_1 = \frac{F_2(1 + Q^2/\nu^2)}{2x(1 + R)} \quad \nu = E - E' \quad Q^2 = 4EE'\sin^2(\theta/2)
$$

$R = \sigma_L/\sigma_T$ has been measured to be independent of the atomic mass number $A$

$$
\frac{\sigma(3H)}{\sigma(3He)} = \frac{F_2(3H)}{F_2(3He)} \quad (2)
$$
Free neutron to proton structure functions:

\[
\frac{F_2^n}{F_2^p} = \frac{2R - \frac{F_2^{3\text{He}}}{F_2^{3\text{H}}}}{\frac{2F_2^{3\text{He}}}{F_2^{3\text{H}}} - R}
\]

Depends on the EMC-type ratios:

\[
R = \frac{R(3\text{He})}{R(3\text{H})}
\]

\[
R(3\text{He}) = \frac{F_2^{3\text{He}}}{2F_2^p + F_2^n}, \quad R(3\text{H}) = \frac{F_2^{3\text{H}}}{F_2^p + 2F_2^n}
\]

\(R\) has been calculated in theory to deviate from 1 only up to 1.5% by taking into account all possible effects.
MARATHON data on 3H, 3He will be of similar precision to Hall C data

A. Accardi et al.
Experiment Configuration

- **Beamline:** BCM, Raster, BPM and harps
- **Target:**
  - Solid target: C-hole, Single Carbon foil, Multi-foils, Dummy, Empty Cell, thick Al, Ti;
  - Gas target: Hydrogen, Deuterium, Helium, Tritium
- **Detector:** LHRS and RHRS: VDC, S0, GAS Cherenkov, S2, Shower

plots from Tong Su
Tritium Target

- Sealed-cell gas target

Thanks to Dave Meekins and the Target group!
Run Overview

- Run period:
  Jan 13 – Mar 5; Mar 24 – Mar 28; Mar 28 – Apr 12;
- $E=10.6$ GeV; $I=22.5$ uA
- Both HRS detect electrons;
- RHRS dipole can only stable at 2.9 GeV; RHRS stays at the highest $x$ point angle (kin16) through the entire run
- LHRS finished:
  - 10 kinematic settings:
    kin1, kin2, kin3, kin4, kin5, kin7, kin9, kin11, kin13, kin15;
  - Positron: kin0, kin1, kin3, kin5;
  - Boiling: 11uA, 16uA, 22.5uA;
  - Optics;
## Kinematic Settings

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<th></th>
<th></th>
<th>E' (GeV)</th>
<th>(\theta) (deg)</th>
<th>(W^2(\text{GeV})^2)</th>
<th>(Q^2(\text{GeV}/c)^2)</th>
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Kinematic Settings

The graph shows the good electron counts (K) for various kinematic settings. The settings are labeled as kin1 to kin16, and the data is represented by bars of different colors:

- **H3** (Blue)
- **He3** (Green)
- **D2** (Yellow)
- **H1** (Orange)

Each bar indicates the count for a specific setting, allowing for a comparison of the performance across different conditions.
Kinematic Settings

plots from Tong Su
Calibrations

BPM

Left arm BPMA pos for Fadc compared to harps

Left arm BPMB pos for Fadc compared to harps

plots from Jason Bane
**Raster**

- Traditional Raster calibration

- Fit Carbon hole by sigmod function

plots from Tyler Hague
3 BCM calibrations are performed during MARATHON, and the Receiver’s gains were stable to 1%
Dec. optics run

plots from Tong Su
Calibrations

Green is the real position;
Red is the measured position;
Plots from Tong Su
Track efficiency

- Track efficiency = \frac{\text{potential good electron events with tracks}}{\text{potential good electron events}}
- potential good electron events: pass Cherenkov sum cut and have enough energy deposit in Calorimeter

At high $x$, the event rate is same order as Cosmic rate. Cosmic dilute the track efficiency
Track efficiency

- Add cosmic cuts: good electron events have to go forward and pass central of S2
$^3\text{He}$ contamination in Tritium target

- $^3\text{He}$ fraction in Tritium target
  - Plots from Tyler Kutz

- Tritium target thickness
After 18 years, MARATHON finished data taking this Spring!

- Measure d/u at high x point;
- Measure EMC effect for tritium and $He^3$;
- Six students will graduate with this data!

Thanks to all the people!