Designing a Tritium Target for the MARATHON Experiment

Nick Lubinsky

Rensselaer Polytechnic Institute

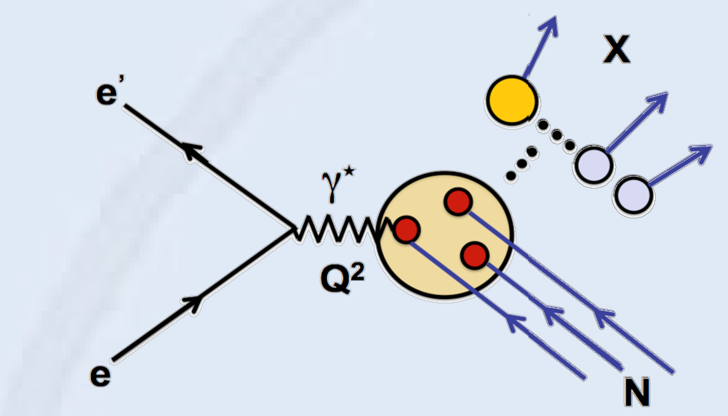
Patricia Solvignon

Abstract

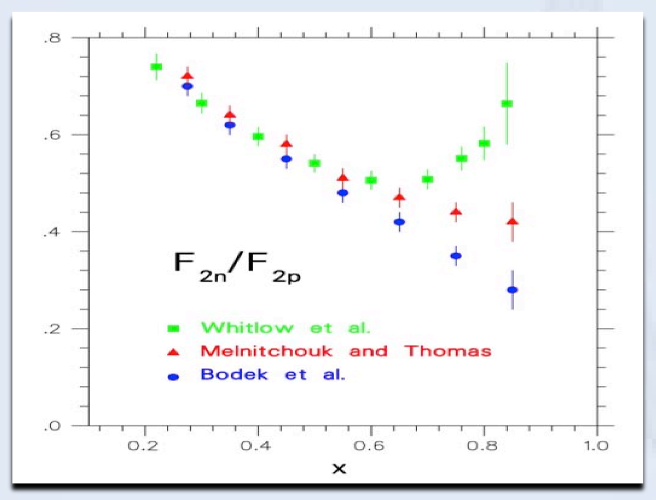
All interactions in the physical world can be broken down to four different forces; the strong force, gravity, electromagnetic force, and the weak force. The strong force is mediated by gluons acting upon quarks, antiquarks, and gluons themselves. Previously, data was obtained on the quark distribution ratio using hydrogen and deuterium. Therefore, the extraction of the neutron structure function from deuterium data depends heavily on nuclear corrections embedded in the deuteron wavefunction. Subsequently, assuming nuclear corrections are dependent only on the atomic mass, there are no better candidates for testing than mirror nuclei. This allows us to have a scattering ratio between protons and neutrons and by extension their constituent quarks, since the only difference between a neutron and proton is the interchange of an up to a down quark. Three different theoretical predictions exist from Special Unitary 6 Symmetry (SU (6)), SU (6) breaking, and perturbative quantum chromodynamics (pQCD) (the explanation of these theories are beyond the scope of this paper). The focus of this study is to devise an experiment capable of determining the distribution of quarks inside the nucleus, as well as support or refute towards one of these three predictions. Simulations were created of the tritium target with the simulation program Geant4. Specifically, collimators were designed over the target windows to minimize contamination emanating from the aluminum container, as well as to evaluate the heat deposited in the crucial elements of the target system. It was found that tungsten rectangular block collimators with a cylindrical section removed asymmetrically was particularly effective at this event biasing. Extensive work is being done on this simulation. It is shown that tungsten collimators can be just as effective at event biasing as other methods, such as magnetic displacement. This result will aid in the attainment of Jefferson Lab target safety requirements thereby allowing the next stage of target development.

Introduction

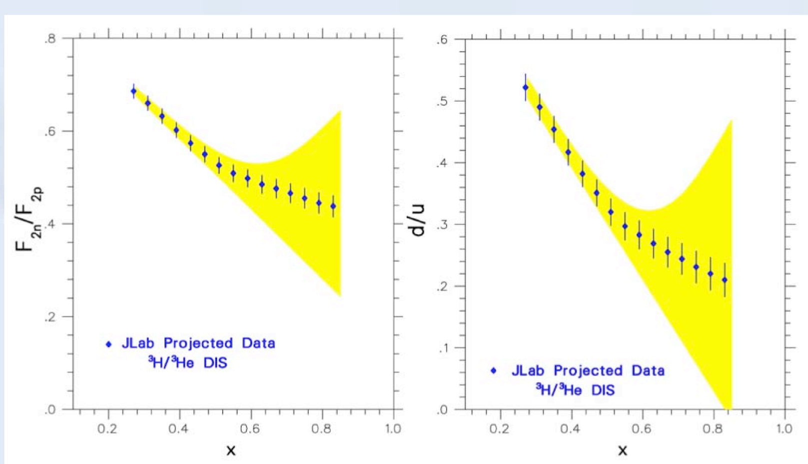
- This experiment relies heavily upon Electron-Nucleon Deep Inelastic Scattering (DIS), which is closely related to soft sphere scattering
- During an inelastic collision between an electron and a nucleon, a virtual photon is emitted. One of the nucleon's quarks then absorbs this virtual photon and subsequently the nucleon breaks apart into several other hadrons, as can be seen by this Feynman Diagram



- In the past, experiments have been run to try to determine the quark distribution ratio between protons and neutrons via hydrogen and deuterium targets. However, due to this deuteron, large nuclear corrections had to be made on the acquired data, as can be seen in the graph below



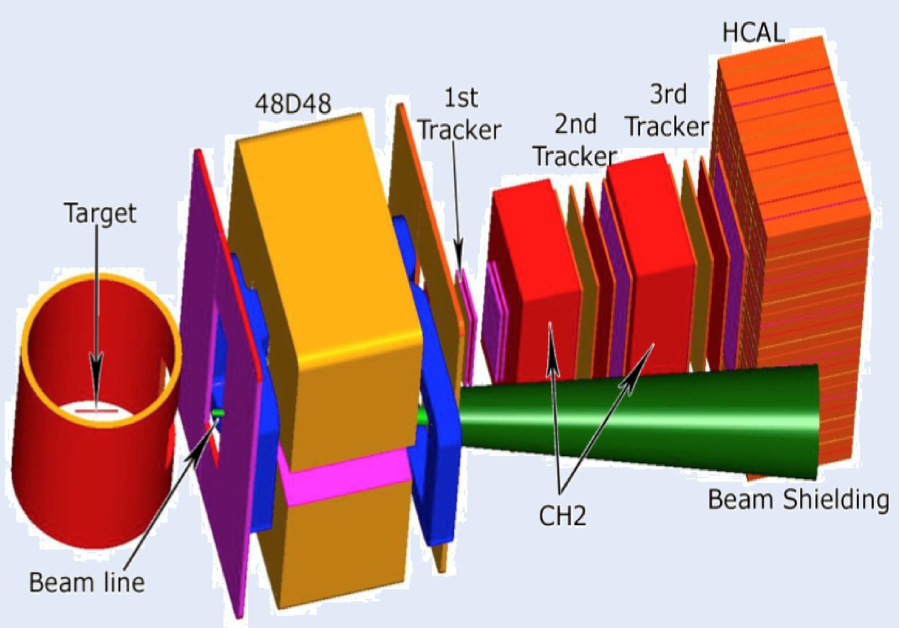
- These theories are Special Unitary 6 Symmetry (SU (6)) (green), SU (6) breaking (blue), and perturbative quantum chromodynamics (pQCD) (red)
- Therefore, the experiment was chosen to run using a tritium and helium-3 target, and then compare the results, for which predicted data is presented to the right



- Consequently, the safety requirements of the target had to be ascertained.

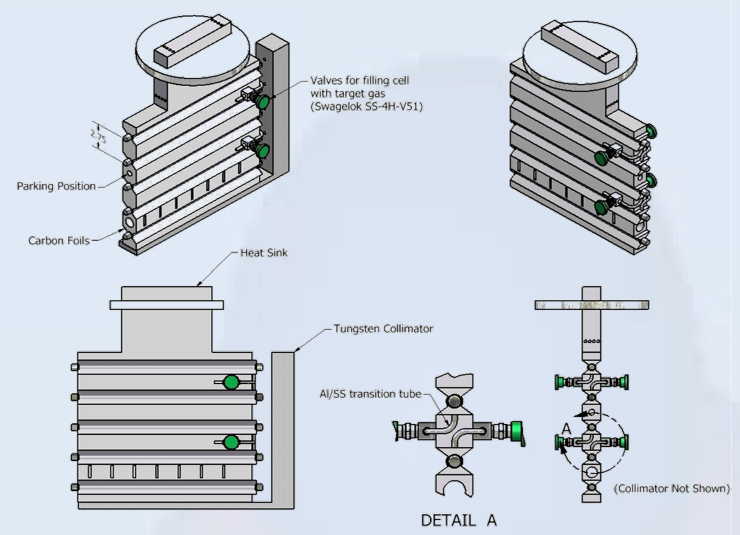
Methods and Materials

- To construct a target capable of determining the quark distributions within hadrons, several biasing factors became increasingly significant due to the design of the detector setup, as shown below



Methods and Materials Cont.

- Specifically, the contamination from the end caps where the beam enters the pressure tank full of tritium is very prominent in the data. Using the software Geant4, many simulations were prepared using different designs of tungsten blocks to cut out interfering aluminum events, as can be seen in the target diagram



- The collimators were tested and compared between the aluminum events allowed without them, and the aluminum events with them. Same goes for tritium events, as depicted below

Results

- Thus far several independent tungsten collimators have been run across various angles from the detector that were determined to be critical angles where the designs play a critical role
- From my data, an integral was calculated on the events that hit the detector, one for the downstream aluminum collimator, one for the upstream aluminum collimator, and one for the tritium events
    - Events were weighted by the cross section and luminosity
- This integral was then divided by the number of total events, to provide a rate in Hertz. The data collected is tabulated here:

Collimator Shape	Angle	Tritium Rate (Hz)	Aluminum Window Rate (Hz)	Energy Deposited in Collimator
No collimator	20 degrees	2009.33	4378.35	--
No Collimator	30 degrees	More Results Underway	More Results Underway	--
Bar	20 degrees	2026.85	4393.67	19.2 TeV
Bar	30 degrees	257.797	792.032	More Results Underway
Cylinder	20 degrees	More Results Underway	More Results Underway	More Results Underway
Cylinder	30 degrees	More Results Underway	More Results Underway	More Results Underway
Block with Removed Section	20 degrees	More Results Underway	More Results Underway	More Results Underway
Block with Removed Section	30 degrees	More Results Underway	More Results Underway	More Results Underway

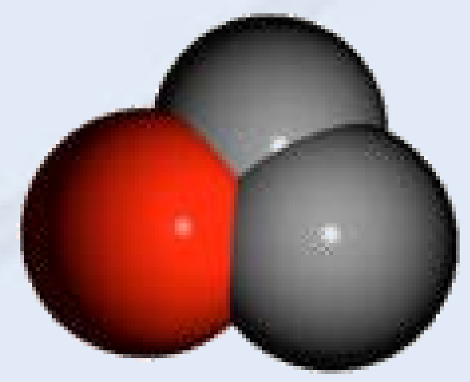
- Thus far, 3 shapes were designed and implemented at varying distances from the target
    - One of these was a simple bar of tungsten
    - Another shape was a hemi-cylinder
    - Last was a rectangular block with a cylindrical chunk removed asymmetrically
- We are still in the process of simulating the events

Analysis

- From the data, the results thus far are inconclusive and are undergoing extensive revision and testing
- Those collimators that have an increase in rate are overzealously thin; multiple scattering is occurring off the collimator and punching through to the detector
- Energy depositions need further study
- Further safety requirements include reducing tritium density and increasing target window thickness
- These results could be improved upon as these were estimates due to constricted simulation run time, so approximations were put into place, such as removing secondaries to save computational power

Conclusion

- To summarize, many experiments have been run to determine the quark distribution within the proton and neutron that used deuterium and hydrogen
- As deuterium relies heavily on theoretical calculations, this experiment will compare the mirror nuclei of tritium and helium-3 to determine the quark distribution with little nuclear effect corrections
- This requires safety outlines to be met, of which window collimators were designed
- Extensive testing is still underway
- The results could be more accurate as computation time was of the essence
- Energy deposition requires further study at this point in time
- With these collimators, the tritium events can be collected faster
- Further research can be done using this target into deep inelastic scattering, Bjorken x>1 inelastic scattering, and elastic scattering, just to name a few options



Acknowledgements

Thanks to the Department of Energy, SLAC's Geant4 software, Thomas Jefferson National Laboratory, my mentor Patricia Solvignon, SULI supervisor Lisa Surles-Law, the Tritium Safety Review Committee, and good friend Miles Price.

References:

[1] M. Petratos, "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 Experiment (MARATHON)" *Tritium Target Safety Review*, pp. 1-29, June 2010.

[2] E.J. Beise, B. Brajuskovic, R.J. Holt, W. Korsch, T. O'Connor, G.G. Petratos, R. Ransome, P. Solvignon, B. Wojtsekhowski, "Conceptual Design of a Tritium Gas Target for Jefferson Lab" *Tritium Target Task Force* pp. 1-19, May 2010.