A Proposal for the DarkLight Experiment at the Jefferson Laboratory Free Electron Laser

Peter Fisher

Jan. 11, 2011

Collaboration

P. Balakrishnan, J. Bernauer, W. Bertozzi, R. Cowan, K. Dow, C. Epstein, P. Fisher, S. Gilad, A. Kelleher, Y. Kahn, R. Milner, R. Russell, J. Thaler, C. Tschalaer, A. Winnebeck

Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

S. Benson, J. Boyce, D. Douglas, R. Ent, P. Evtushenko, H. C. Fenker, J. Gubeli, F. Hannon, J. Huang, K. Jordan, G. Neil, T. Powers, D. Sexton, M. Shinn, C. Tennant, S. Zhang

Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606

M. Freytsis

Physics Dept. U.C. Berkeley, Berkeley, CA

R. Fiorito, P. O'Shea

Institute for Research in Electronics and Applied Physics University of Maryland, College Park, MD

R. Alarcon, R. Dipert

Physics Department, Arizona State University, Tempe, AZ

G. Ovanesyan

Los Alamos National Laboratory, Los Alamos NM

M. Kohl

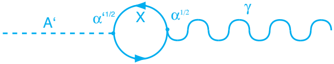
Physics Dept., Hampton University, Hampton, VA 23668 and Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606

T. Horn

Physics Dept., Catholic University of America, Washington, DC 20064

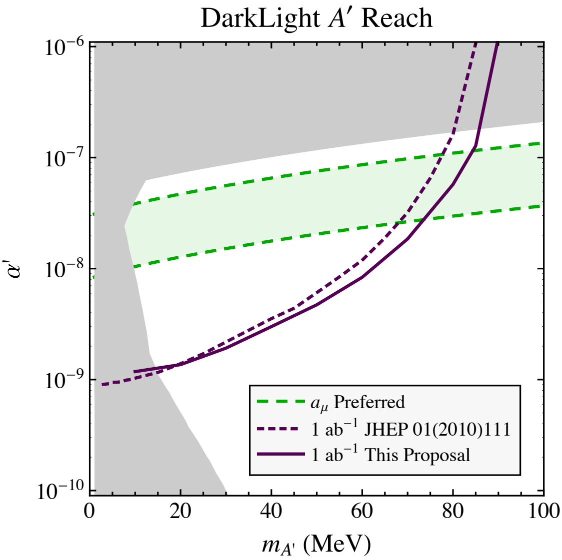
Motivation

Goal: explore $e^{+} - e^{-}$ invariant mass spectrum from 10-90 GeV using the process $e^{-} + p \rightarrow e^{-} + p + e^{+} + e^{-}$



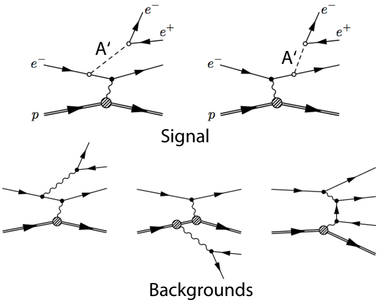
New theories of dark forces predict a dark force carrier in the mass range 0.01-1 GeV that couples like a photon via kinetic mixing.

Sensitivity



Signal and backgrounds

For $\alpha' = 10^{-8}$, the signal is 10^{-4} of the QED background processes.



For 5σ sensitivity to a peak with 1 MeV/c^2 width in the continuum e^+e^- spectrum across the 10-90 MeV mass range requires a luminosity of 1/ab.

Experimental Concept

We reduce backgrounds from other sources by requiring full reconstruction of $e^- + p \rightarrow e^- + p + e^+ + e^-$

- 1 MW 100 MeV FEL electron beam gives 10 mA or $1.6 \times 10^{17} e^-/s$
- Hydrogen gas target with areal density of $10^{19}/\text{cm}^2$
- Lepton spectrometer with momentum resolution to reach $\sigma_{m_{e^+e^-}} < 1 MeV/c^2$
- Proton detector to identify ∼2 MeV recoil proton and measure it momentum with 10% precision.

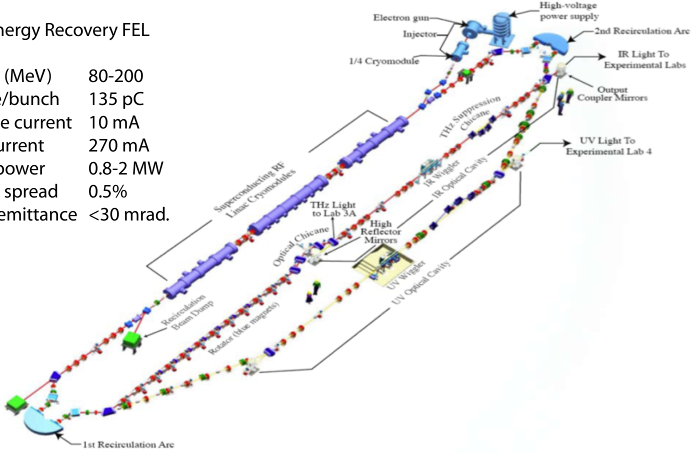
The FEL can deliver 1/ab of beam in one month of continuous running.

FEL

10 kW IR/UV/THz Free-Electron Laser

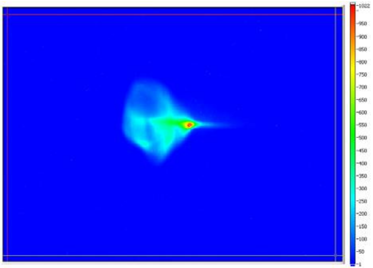
JLab Energy Recovery FEL

Energy (MeV)	80-200
Charge/bunch	135 pC
Average current	10 mA
Peak current	270 mA
Beam power	0.8-2 MW
Energy spread	0.5%
Norm. emittance	<30 mrad.



Beam halo

The FEL beam profile has a lot of structure: the core is about 50 μ and the emittance is determined by taking the 6σ spread of electrons. To date, understanding the halo has not been important for the FEL's mission. A key part of our program for the next year will be measurement and characterization of the beam halo.



Detector Concept

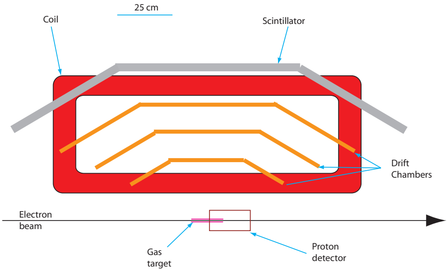


Figure: Slice through upper half of detector system. There are six toroidal coils.

- Reconstruct all final state particles and achieve an invariant mass resolution of 1 MeV/c^2 or better over the range 10 to 100 MeV/c^2.
- Toroidal magnetic spectrometer with a bending power of 0.05 to 0.16 T-m with a wire chamber tracker for the leptons, a radial TPC for proton detection and a scintillator for triggering.
- Similar in concept but smaller than BLAST used at the Bates Linac.

Target

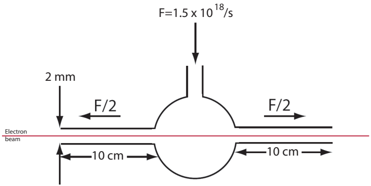
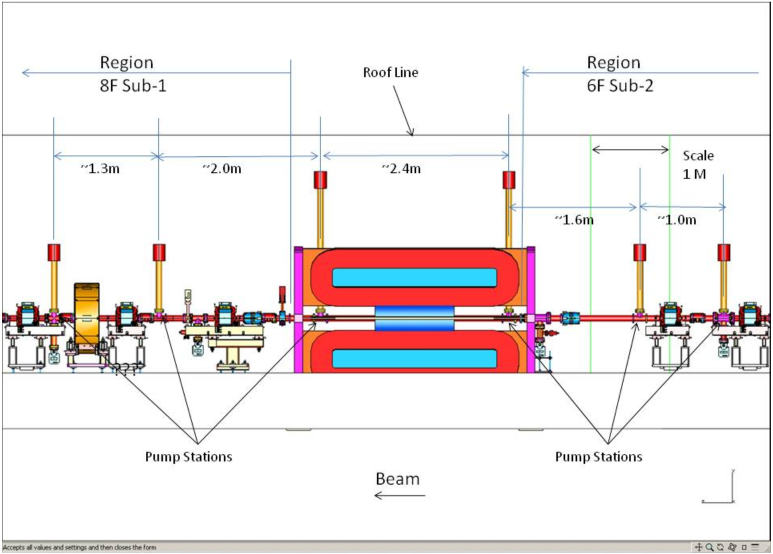


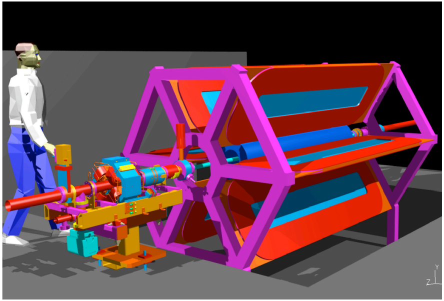
Figure: Target cell

- Density of 10^{19} protons/cm^2
- 30 μ kapton evacuated from each end into the machine vacuum.
- Exhaust pumps are located outside of the detector.

Target


Region
8F Sub-1
Roof Line
Region
6F Sub-2
~1.3m
~2.0m
~2.4m
Scale
1 M
~1.6m
~1.0m
Pump Stations
Pump Stations
Beam
Accepts all values and settings and then closes the form

Toroidal magnet



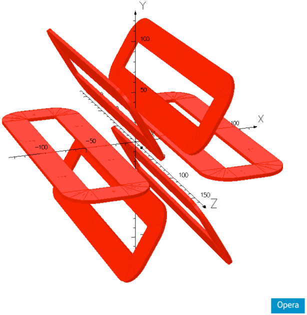


Figure: Toroidal magnet located in the FEL wiggler pit on the UV line. The bending power is 0.05-0.32 T-m. There are several options: water or nitrogen cooled or superconducting. For the configuration shown the acceptance loss is about 13%.

Proton detector

- BONUS design will detect protons and measure their momenta to about 20% precision.
- BONUS type RTPCs have successfully measured recoil proton momenta down to about 1 MeV in high rate environments.

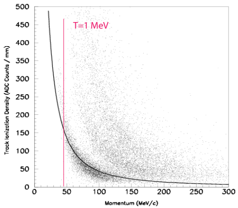
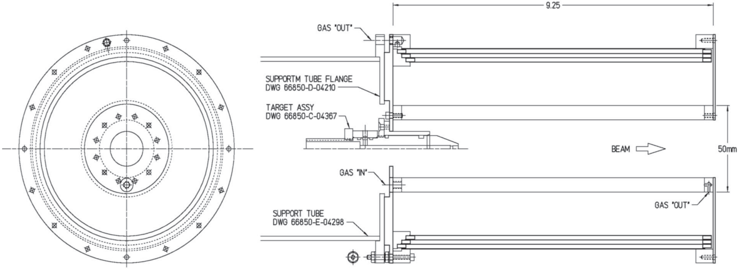


Figure: dE/dx measured by BONUS in the eg6 experiment.

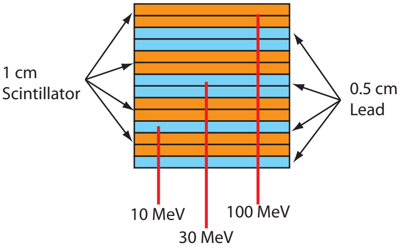


Tracking system

Figure: A drift chamber octant of BLAST.

- 25 layers, 25-50 cm from target, 15^o to 180^o
- Open cell geometry, 1 cm cell size
- Helium based gas, He:C_4H_{10}, 80:20, $X_o = 800$m
- For $\sigma \sim 100\mu$ and $\int \vec{B}_\perp \cdot d\vec{l} = 0.5$ T-m, can tolerate 0.01 X_o before MS dominates position resolution

Trigger scintillator

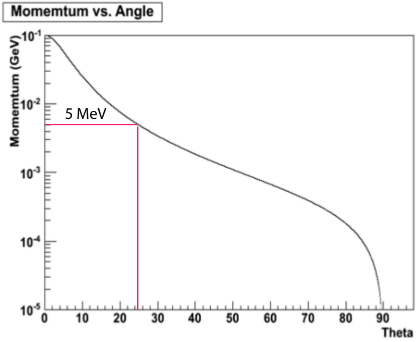


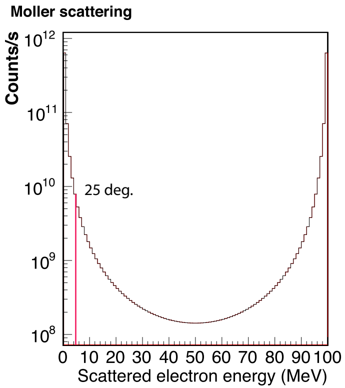
Scintillator covers $25^o < \theta < 165^o$and provides a fast trigger for three final state leptons.

- Requiring one lepton with $\theta > 50^o$ gives a rate of 10 MHz from QED backgrounds
- Requiring two additional leptons in 10 ns window gives 1.2 MHz
- Requiring two negative and one positive lepton gives 0.9 kHz.

Moller scattering

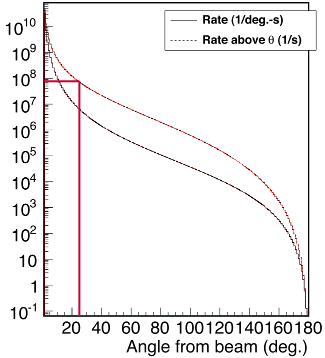
The Moller singles rate with $\theta > 25^o$ is 6×10^{11}/s, all below 5 MeV. Occupancy drive the 25 cm closest tracking element. For 1 cm^2 cells, the rate is 500 MHz, so we are considering a 50 G solenoidal sweeper magnet inside the toroid.

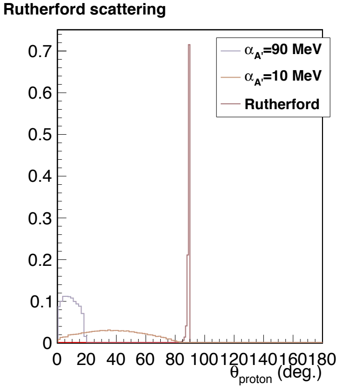




Rutherford scattering

The integral rate above 25^o is 70 MHz, for an occupancy of 500 KHz. The proton detector extends from $5^o < \theta < 85^o$ to miss most of the recoil protons.





Invariant mass resolution

- Multiple scattering is the dominant contribution to the momentum resolution.
- 1 MeV/c^2 invariant mass resolution requires less than 1% of a radiation length of material along the lepton trajectory.
- With two 1 mm precision points from the RTPC, we can tolerate 5% of a radiation length.

We plan to investigate GEM trackers outside the RTPC to achieve to provide these points.

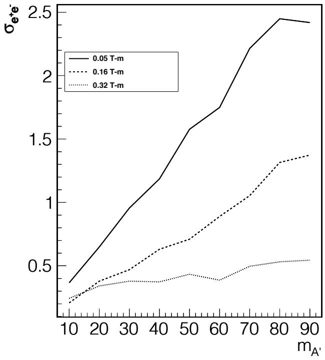


Figure: Pair mass resolution for different field settings. The resolution is calculated using a GEANT4 simulation of the track and a swim fit through the calculated magnetic field.

Collaboration

Our current collaboration has a long history in this kind of experiment and the necessary expertise to carry out this experiment

- MIT operates the Bates Research and Engineering center and has experience in toroidal spectrometers (BLAST and OLYMPUS), internal targets and drift chambers.
- The Jefferson FEL group is heavily involved, along with the group that built the BONUS detector.
- Maryland has extensive experience in beam characterization at the FEL.
- ASU led the design of the BLAST toroid.

We have the expertise can execute this experiment given sufficient resources.

Resources

Resources will be required as follows:

- Develop FEL beam: optics development, halo and background studies, emittance measurements, and dedicated test runs to produce the intense, focused, low-halo beam required to pass through the target.
- Support simulation, design and engineering of the experiment: 12 man-months of engineering (mechanical, electrical, and vacuum) and about 12 man-months of drafting will be required to bring DarkLight from CD-0, through CD-1 to CD-2.
- to develop the required FEL 100 MeV electron beam: equivalent of 30 days running assuming 100% efficiency
- An integrated luminosity of 1/ab at two different magnetic field settings. In terms of FEL running time, this translates to 60 days at 100% efficiency.

Timeline

- PAC37 January 2011
- Beam development begins March 2011
- Resources for technical design become available Fall 2011
- Technical review Summer 2012
- DarkLight construction begins Fall 2012
- DarkLight data taking begins 2015

Request to the PAC

This is an challenging experiment, but the measurement is important. The extensive use of the FEL to provide continuous beam over long periods is unusual for Jefferson lab and we will need to work with the lab and agencies to gain access to the FEL for the time we need to design the experiment. In parallel, we will develop the experimental design and plan for a Technical Review in Summer 2012.

We request the PAC endorse the scientific goal and general approach of the experiment so we may move ahead with the agencies to secure the necessary resources to develop the FEL beam and design the experiment.