A Proposal for the DarkLight Experiment[1] at the Jefferson Laboratory Free Electron Laser

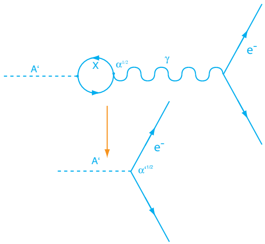
Peter Fisher, for the collaboration

June 19, 2012

[1] Detecting A Resonance Kinematically with eLectrons Incident on a Gaseous Hydrogen Target

DarkLight Goals

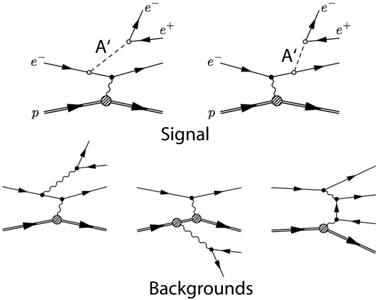
Goal: explore $e^+ - e^-$ invariant mass spectrum from 10-90 MeV using the process $e^- + p \rightarrow e^- + p + e^+ + e^-$



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. The measurement will be carried out using a magnetic spectrometer with a thick hydrogen target operating at the Free Electron Laser electron accelerator.

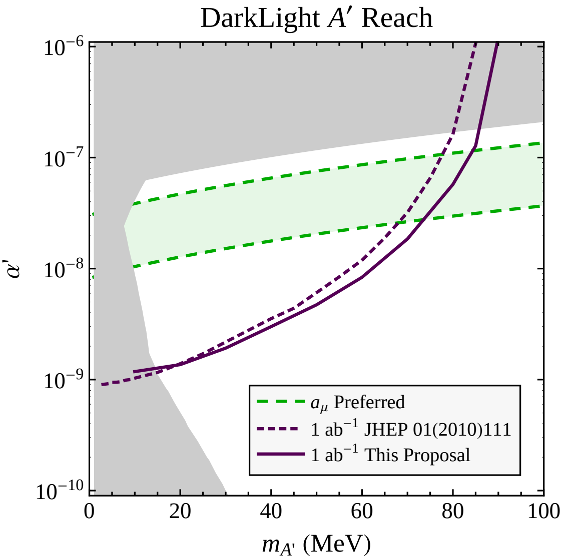
Physics Processes

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



The experiment is really the measurement of the QED background with a 0.1 ppt precision. *We believe the detection of all four final state particles and their kinematic combination is essential.*

DarkLight Goals



Progress so far

PAC35 (Jan. 2010) - Expression of interest for the DarkLight experiment

PAC37 (Jan. 2011)- Proposal requesting conditional approval to carry out beam tests at the FEL and justify proceeding with design work using DOE nuclear and high energy funds

PAC39 (June 2012)- Request for full approval so we may begin to engage the funding agencies to continue design aimed at a request for funds to construct and operate the experiment

Collaboration

DarkLight is a collaboration between groups at universities and Jefferson Lab building the detector and the Free Electron Laser group at Jefferson Lab.

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Experimental Design

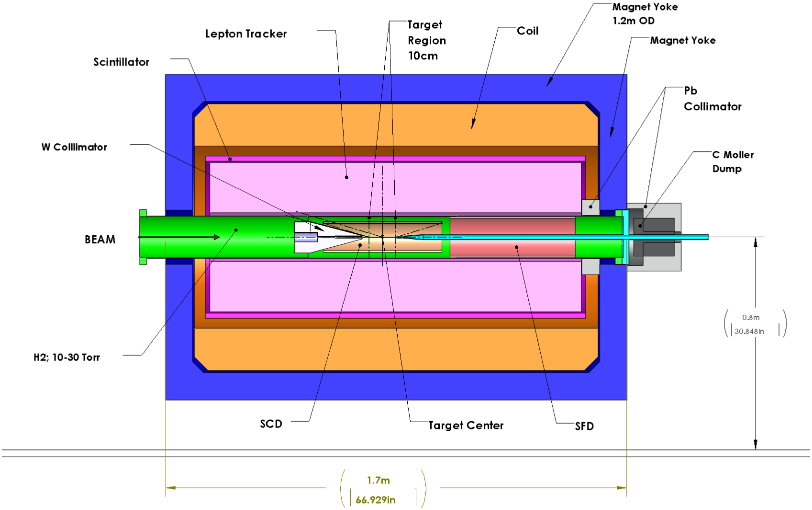


Figure: Schematic layout of the DarkLight experiment.

Design Considerations

Table: Detector specifications for the DarkLight experiment.

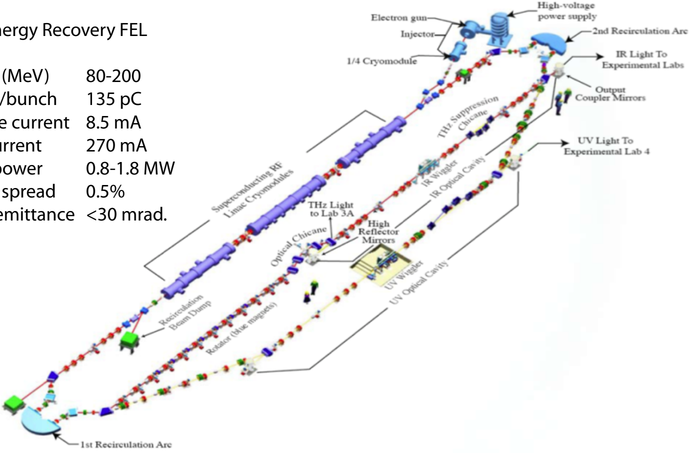
Incident electron energy	100 MeV
Luminosity	10 mA $\times$ 10^{19}/cm^2=10^{35}/cm^2-s
	1/ab per month
A' mass range	10 to 100 MeV
Scattered electron angle	25° to 165°
Final lepton energy	10 to 100 MeV
Recoil proton kinetic energy	1 to 16 MeV
Recoil proton angle	6 to 163 degrees
Experimental A' mass resolution	1 MeV
Total elastic rate within	
detector acceptance	68 MHz
QED trigger rate	1 kHz

FEL

10 kW IR/UV/THz Free-Electron Laser

JLab Energy Recovery FEL

Energy (MeV)	80-200
Charge/bunch	135 pC
Average current	8.5 mA
Peak current	270 mA
Beam power	0.8-1.8 MW
Energy spread	0.5%
Norm. emittance	<30 mrad.



Components

Four primary components:

Target - differentially pumped hydrogen target, $10^{19}/\text{cm}^2$, 10 cm long

Silicon proton detector - $\sim$3.5 cm from beam, single layer of silicon microstrip detector, measure energy and angle of recoil proton

Lepton tracker - 10-25 cm radius Time Projection Chamber (TPC), based on PANDA TPC

Magnet - solenoid provides 0.5 T to focus Møller electrons and measure lepton momentum and direction

In addition, DAQ, mechanical and electrical services.

Target

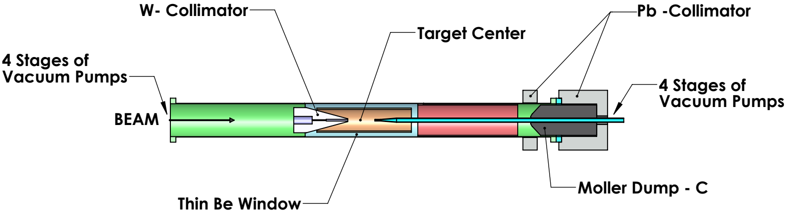


Figure: Schematic layout of the proposed DarkLight windowless hydrogen gas target.

We also have the possibility of using plasma windows to contain the target gas. This would allow larger apertures and reduce the need to differential pumping.

Table: Gas target specifications for the DarkLight experiment.

Outflow channel diameter	D=2 mm
Outflow channel length	l= 5 cm
Mach number at channel entrance	$\eta = 0.18$
Reynolds number at channel entrance	$R_e = 250$
Target pressure	$p = 12$ Torr
Target thickness	$t = 10^{19}$ atoms/cm^2
Gas outflow rate in each channel	$Q = 15$ Torr-liter/s

Silicon proton detector

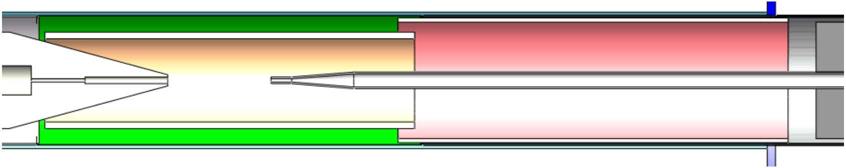


Figure: Side view of the silicon-detector system for the DarkLight experiment with the Silicon Central Detector (SCD) and the Silicon Forward Detector (SFD).

Silicon proton detector

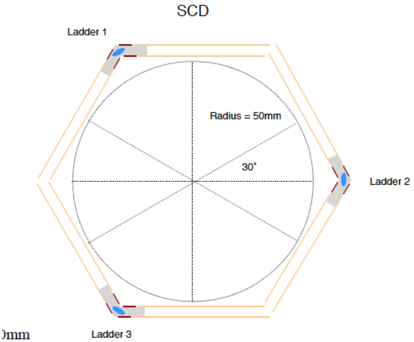


Figure: End view of silicon central detector. The silicon forward detector is similarly configured.

- Radius: 50mm
- Φ-coverage: 360°
- θ-coverage: 17° - 163°
- Number of ladders: 3
- Ladder length: 430mm
- Sensor dimensions: 56.5mm $\times$ 60.0mm / 52.5mm $\times$ 60.0mm
- Number of sensors: 28 per ladder
- Sensor thickness: 300μm

Lepton Tracker

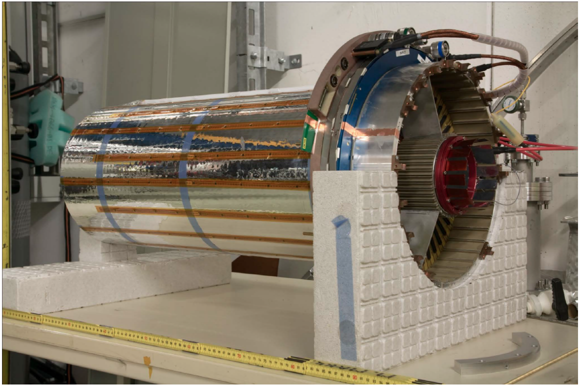


Figure: Photograph of the prototype constructed by the GEM-TPC collaboration (Bonn-Giessen-GSI-Darmstadt-TU Munich.)

Table: Characteristics of the GEM-TPC prototype.

Drift length	725 mm
Outer diameter	300 mm
Inner diameter	105 mm
Triple GEM stack	gain O(1000)
10254 channels	
Gas	Ar(Ne)/CO_2 (90/10)
Position resolution (σ)	250 μm

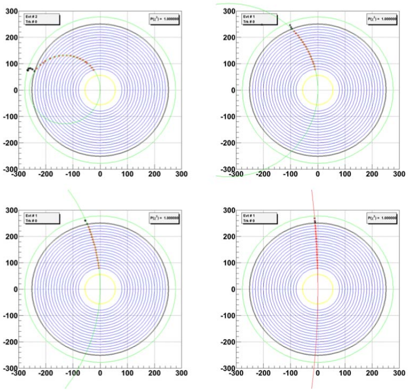


Figure: Fitted tracks using the DLG5.3 GEANT4 geometry in 70:30 Ar:CO_2 mix at with density $\rho = 0.0018$ g/cm^3 for e$^-$ momenta of 20 MeV/c (upper left), 50 MeV/c (upper right), 100 MeV/c (lower left), and 500 MeV/c (lower right). The low Z beampipe is shown in yellow, tracker layers in blue. Hits are shown as points. Hits used in the fit are colored red. Axis dimensions are millimeters. The green (red) color of the fitted circular arc indicates the signed radius returned from the Karimäki fitter is negative (positive).

Lepton Tracker Performance

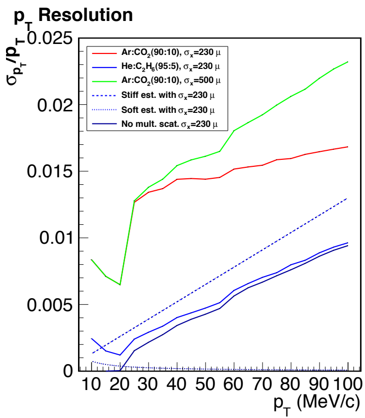


Figure: Lepton tracker momentum resolution.

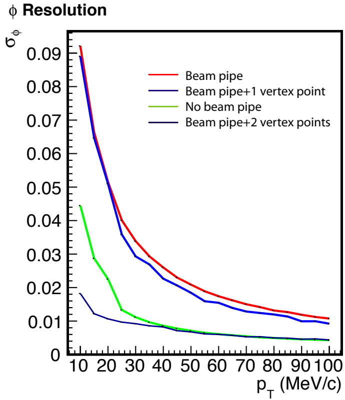


Figure: Lepton tracker phi resolution showing the impact of 1% X_o beam pipe and the improvement offered by the detection of two 10 μm point with the silicon proton detector.

Magnet

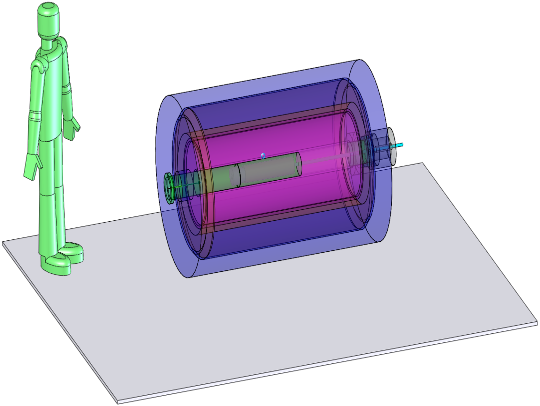


Figure: Preliminary engineering concept of the solenoidal magnet.

Magnet is a normal conducting copper coil solenoid with 0.5 T center field (able to reach 1 T) with an iron return yoke.

Some important rates

Item	Rate
Tracks in the TPC	68 MHz
Tracks with $\theta > 50^\circ$	10 MHz
+ 3 leptons from common vertex	1.2 MHz
+ positive track	0.9 MHz
Proton above 1 MeV	30 MHz
Readout rate from a single pad	100 MHz
Sparse rate from single pad	100 kHz
Irreducible QED events	1 kHz

Table: Various DarkLight inclusive and data rates.

Invariant mass resolution

For a decay to two massless particles with p_1 and p_2 and opening angle θ_{12}

$$m = \sqrt{2p_1 p_2 \left(1 - \cos\theta_{12}\right)}$$

For example, $A' = 50\mathrm{MeV}/\mathrm{c}^2$, $K_{A'} = 10\mathrm{MeV}$ and $\theta^*_{12} = 60^\circ$: The uncertainty is given by

$$\begin{aligned} \sigma_m &= \sqrt{\left(\frac{\partial m}{\partial p_1}\sigma_{p_1}\right)^2 + \left(\frac{\partial m}{\partial p_2}\sigma_{p_2}\right)^2 + \left(\frac{\partial m}{\partial \theta_{12}}\sigma_{\theta_{12}}\right)^2} \\ &= \sqrt{0.29\sigma_{p_1}^2 + 2.37\sigma_{p_2}^2 + 112.5\sigma_{\theta_{12}}^2} = 0.40\mathrm{MeV}/\mathrm{c}^2 \end{aligned}$$

Multiple scattering dominates the mass resolution in this energy range.

Data Acquisition

We have developed two concepts for DAQ: one with a hardware based trigger and one with a software based trigger. Both techniques rely on the rejection of elastic scattering and selection of vertices with two e$^-$ and one e^+. The rate of irreducible QED events is 1 kHz, so we expect to write events with a rate of 10 kHz.

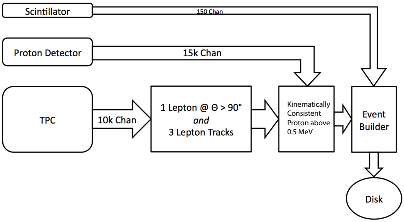


Figure: Trigger pipeline for TPC data.

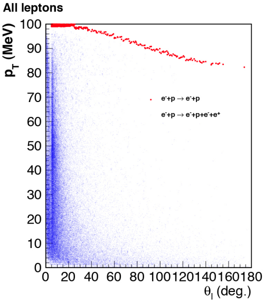


Figure: Red points show elastic events, blue points show irreducible QED events.

Beam test - July 15-22 at the FEL

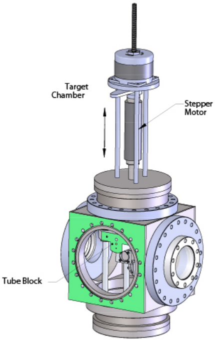


Figure: Schematic of the 6 cross target chamber. Three beam tubes are also shown inside the chamber. The tube block is driven by a stepper motor to move in and out of the e-beam.

1. Compatibility of the electron beam and DarkLight target cell: the electron beam must pass through the target cell and we need to ensure the beam can be steered accurately through the cell.
2. Characterization of the beam halo: the high power of the beam means the beam halo may cause backgrounds if not properly mitigated. As a start, DarkLight needs to characterize the beam halo.
3. Detector backgrounds: in order to design the detector, DarkLight needs to understand the backgrounds from the beam and machine.

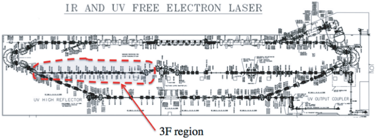


Figure: JLab FEL Facility and the location (3F) for the intended DarkLight experiment.

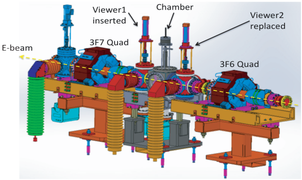


Figure: Drawing illustrating the assembly with two beam-viewer systems and the target chamber installed. The optical imaging system for the chamber viewer and halo monitor are not shown.

Figure: Six way cross installed in FEL IR line.

FEL Hall Background Measurements

We have carried out a series of measurements in the FEL hall during machine operation using NaI detectors and BF_3 detectors (provided by JLab RadCon).

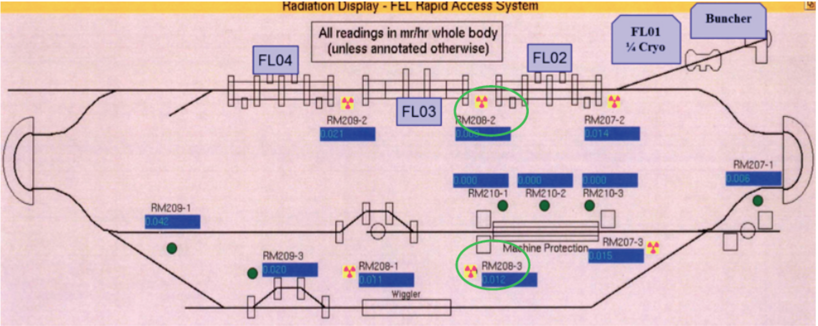


Figure: Locations of FEL RadCon monitors.

Figure: Detectors located downstream of SixWay cross for beam test.

Preliminary conclusions:

- Dose ratio of neutrons to photons: 20:80.
- Total photon flux: $10^{6-7}/\text{cm}^2$-s in hall
- Measured photon rate inside 2" Pb: $6{,}000/\text{cm}^2$-s
- 6" water shield reduces neutron flux by 10^2.

Measurements will continue during the beam test. We believe the attenuation of the yoke and coil of the magnet will reduce the photon background to a very manageable level.

Technical Design Process

The technical design of the DarkLight detector is being carried by the collaboration through the MIT Bates Research and Engineering center.

We have detector design meeting to carry out the design and first level cost analysis. This information is being collected in a Technical Design Working Document (TDWD). The design and costing has the significant support of the R& E Center engineering and technical staff as well as the DarkLight physicists.

We have a weekly meeting of the DarkLight collaboration to plan the experiment, beam tests and simulations. Our recent meetings have focussed on the beam test and FEL beam background measurements. The FEL team is a strong presence in these meetings.

Our aim is to complete the TDWD by Fall and develop it into a Technical Design Report (TDR) for use in working with the agencies to fund the construction and operation of the experiment.

The Path Forward

- Presentation to PAC39 June 2012
- Initial test run July 2012
- Seek FY2013 funds for technical design
- Technical review summer 2013
- DarkLight construction begins Fall 2013
- DarkLight detector commissioning begins in 2015
- DarkLight data taking begins 2016

Collaboration Responsibilities

The collaborating institutions have considerable expertise in all the technologies in DarkLight:

Temple - silicon proton detector

JLab FEL - High current ERL design/operation, Beam/Optics diagnostics

Bonn and Giessen - lepton tracker TPC and readout

University of Maryland - beam diagnostics

MIT, MIT Bates R&E Center - trigger, DAQ, integration, target, magnet power supply

ASU - magnet and power supply

Request to the PAC

DarkLight is a collaboration between the JLab FEL and the institutions designing the DarkLight detector to study the process $e^- + p \rightarrow e^- + p + e^- + e^+$ at beam energies around 100 MeV to search for dark forces.

We request approval of DarkLight. This will allow us to complete the design and Technical Design Working Document and allow us to begin to engage with the DOE NP and HEP, NSF and overseas agencies.