The DarkLight Experiment at Jefferson Laboratory Free Electron Laser

DARKLIGHT

Detecting **A** **R**esonance **K**inematically with e**L**ectrons **I**ncident on **G**aseous **H**ydrogen **T**arget

High Energy Physics in the LHC Era, 5th International Workshop, Valparaiso, Chile, 16-20 December 2013

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Outline

- Introduction
- Experiment Design
- Path to Realization

Introduction

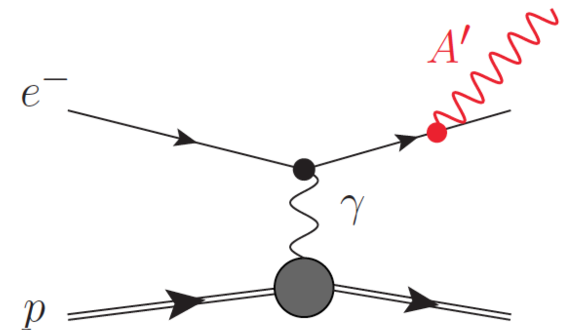
- Dark Matter theories[#] predict that TeV-scale dark matter interacts with a GeV-scale boson *A'* with a mass in the range

$$2m_e < m_{A'} < \text{few GeV}$$

and with small couplings to the standard model (dark sector).

- DarkLight proposes to search for a Dark Photon *A'* in low-energy electron-proton scattering through the process

$$e^- + p \longrightarrow e^- + p + A'\,; \quad A' \longrightarrow e^+ + e^-$$



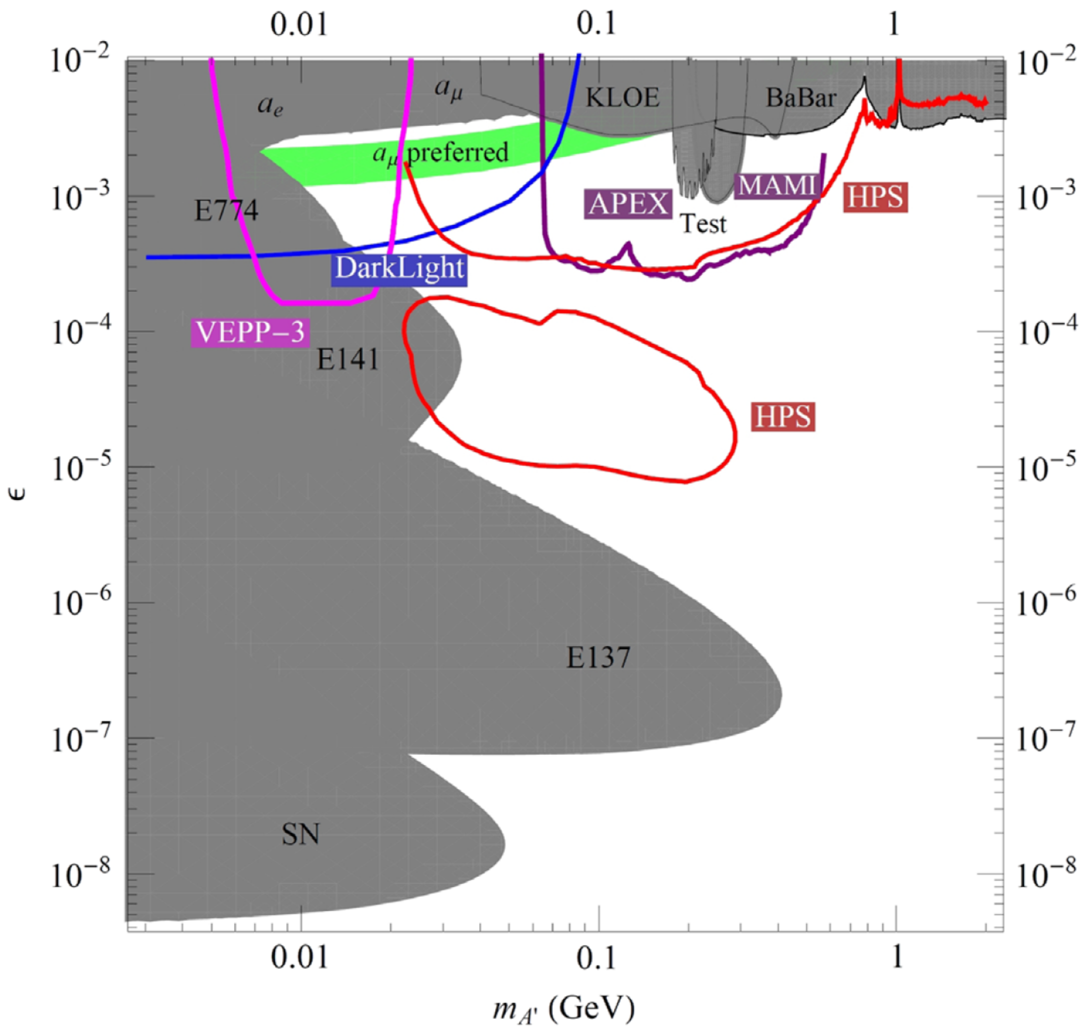
- Over the parameter space accessible by DarkLight the strength of the coupling is constrained by axion searches (beam-dump experiments) and by precise measurements of the electron (a_e) and muon (a_μ) anomalous magnetic moments.

#: *Phys. Rev.* **D76** (2007) 083519; *Phys. Lett.* **B662** (2008) 53-61; *Phys. Rev.* **D79** (2009) 015014; arXiv:0810.5397

Parameter space for $m_{A'}$ > 1 MeV

$$\alpha' = \varepsilon^2 \alpha$$

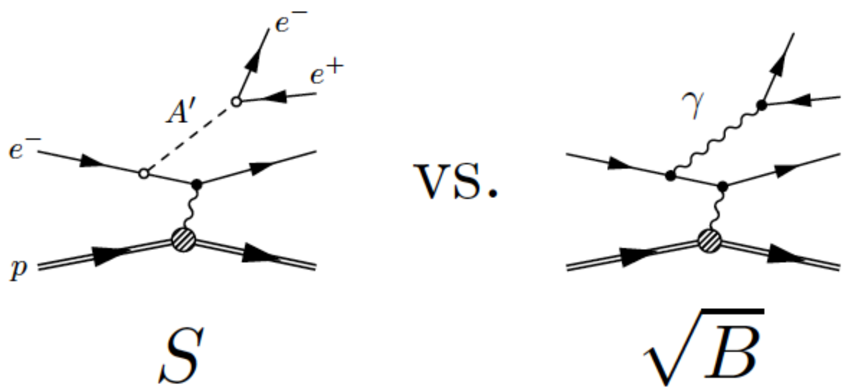
$$\alpha = \frac{1}{137}$$

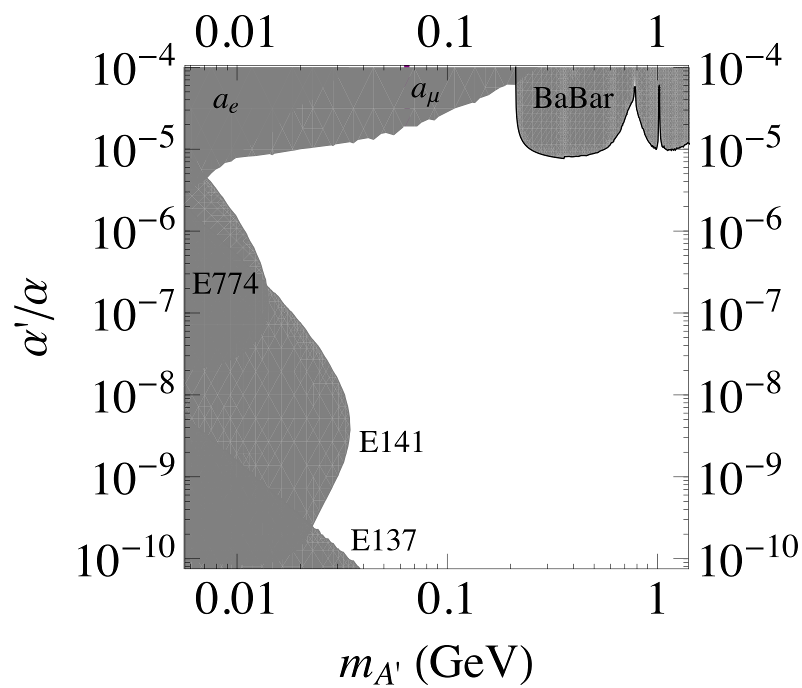


Exploration of dark sectors with existing facilities and technologies, modest experiments, and experimental cleverness. (Intensity Frontier, Snowmass2013)

Experimental Design

- Electron-Proton Scattering with a 100 MeV beam narrows the search to the 10-90 (MeV) mass range and to the e^+e^- decay channel.
- It is a background limited experiment (Looking for a Narrow Resonance on a Huge QED Background)



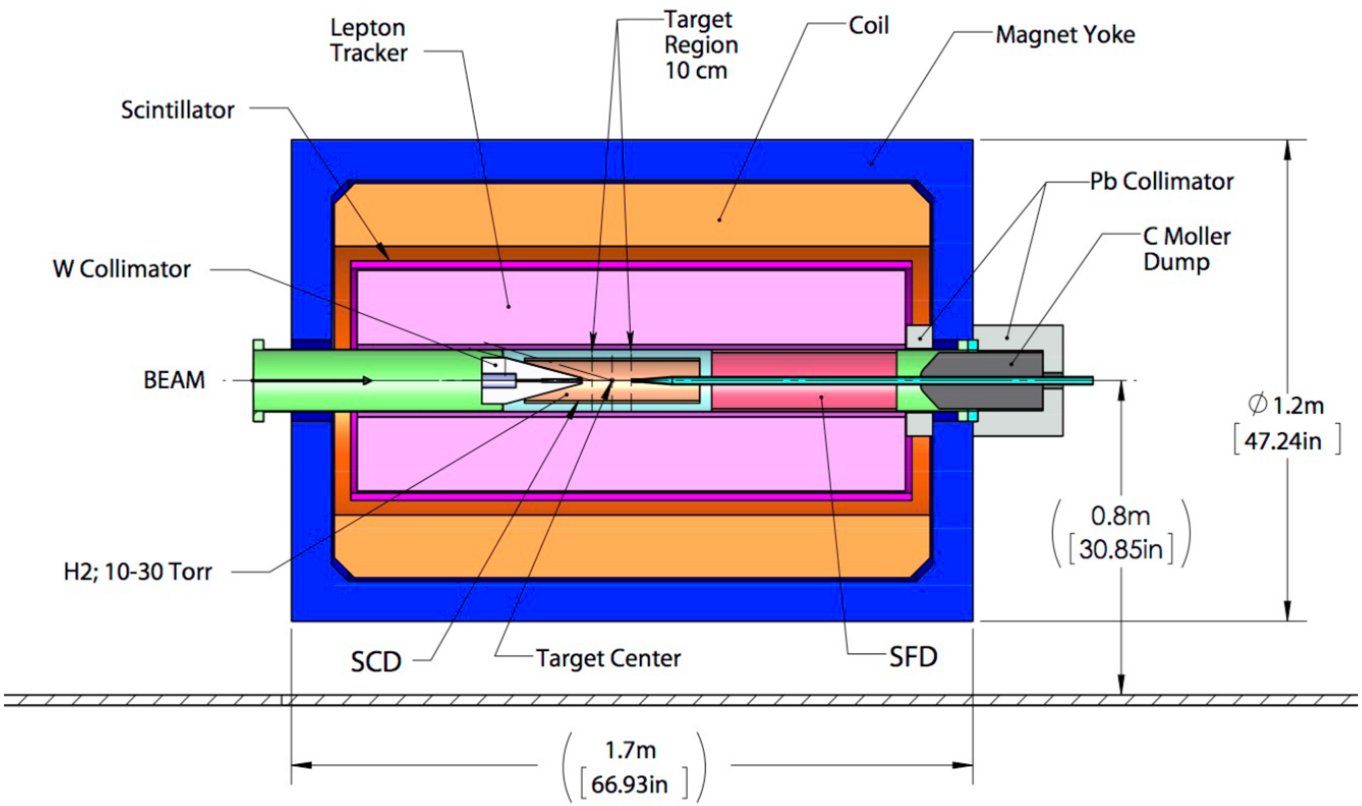


- Need: High Luminosity, Large Acceptance, Good Tracking Resolution, Full Kinematic Reconstruction amid Huge Elastic Rate

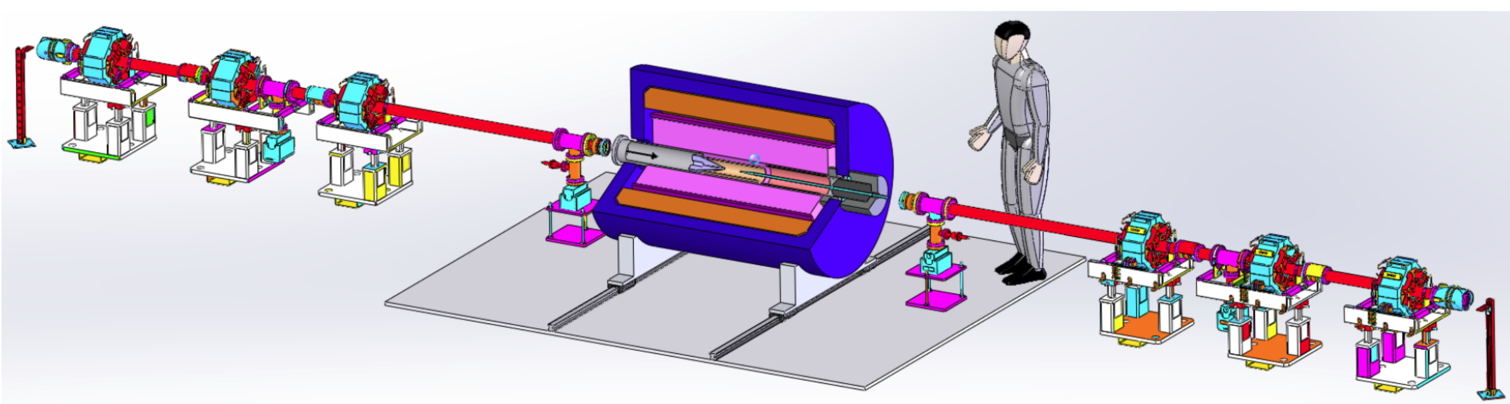
Experimental Design

- High Luminosity: need data set of 1 ab^{-1} to go beyond current limits.
  - JLab-FEL (100 mA) on an high-density Internal Gas H_2 Target ($\geq 10^{18}$ cm^{-2}) : 1 ab^{-1}/month.
- Large Solid Angle and Good Resolution for Full Kinematic Reconstruction of four-particle final states (visible decays and detached vertices) and missing mass (invisible decays).
  - Magnetic Spectrometer (~ 0.5 T) for Momentum Resolution and for Moller background.
  - Proton Detection (position, energy: 1-6 MeV) within few cm from Target.
  - Lepton Detection "4π" tracking to within 15^o of beamline.
- High Rate of Elastic Events: Triggering (sub-nanosecond scintillator trigger).

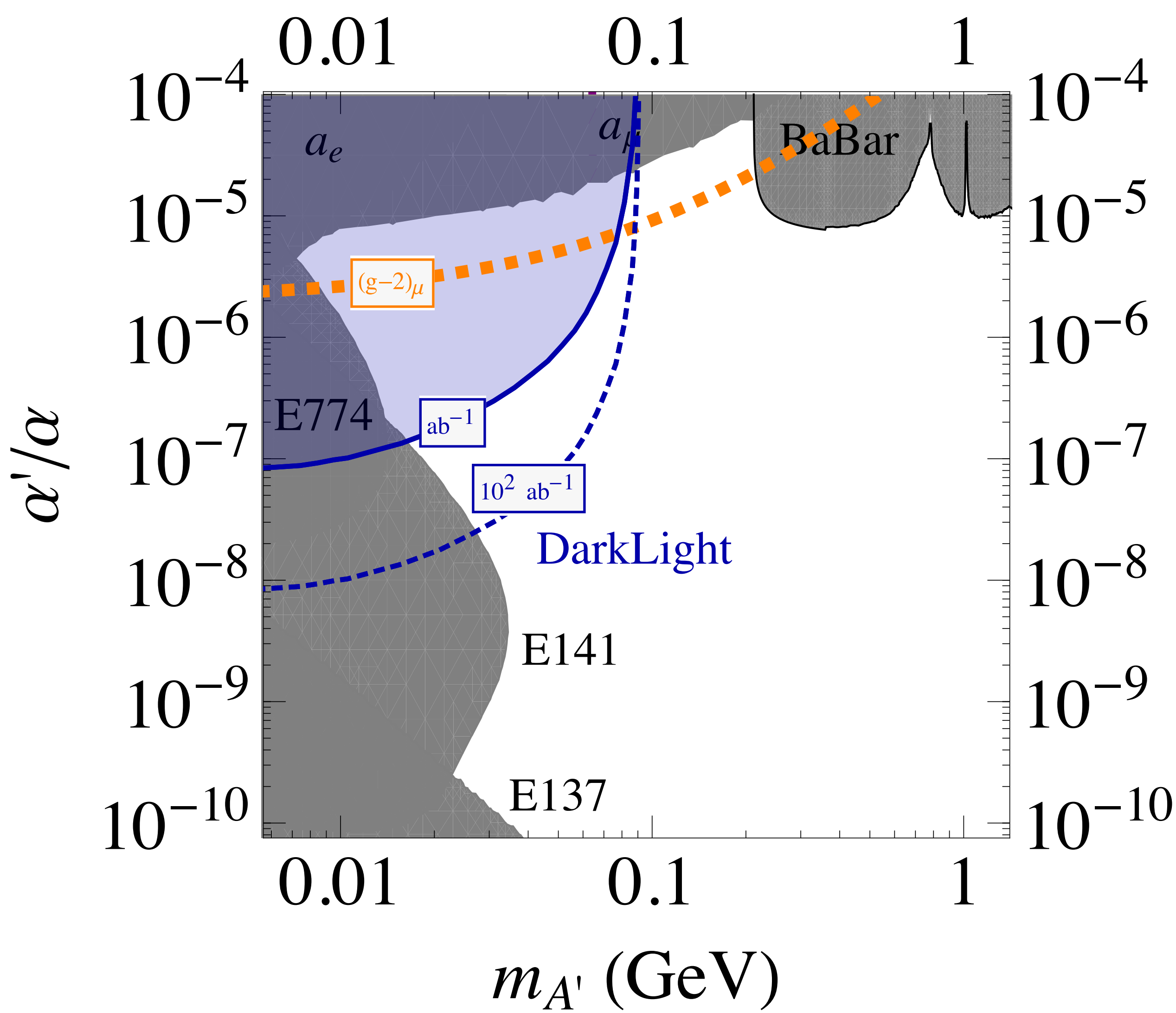
DarkLight Main Components



- Gas hydrogen target & beamline components
- Solenoidal field magnet
- Recoil proton silicon detectors
- Lepton tracker



DarkLight Reach



Path to Realization

- January 2011: DarkLight proposal presented to JLab-PAC, received conditional approval.

- Beam transmission tests in July 2012 and three papers in 2013: *Phys. Rev. Lett.* **111**, 164801 (2013); *Nucl. Instrum. Methods Phys. Res.*, **A 729**, 69 (2013); *Nucl. Instrum. Methods Phys. Res.*, **A 729**, 233 (2013).

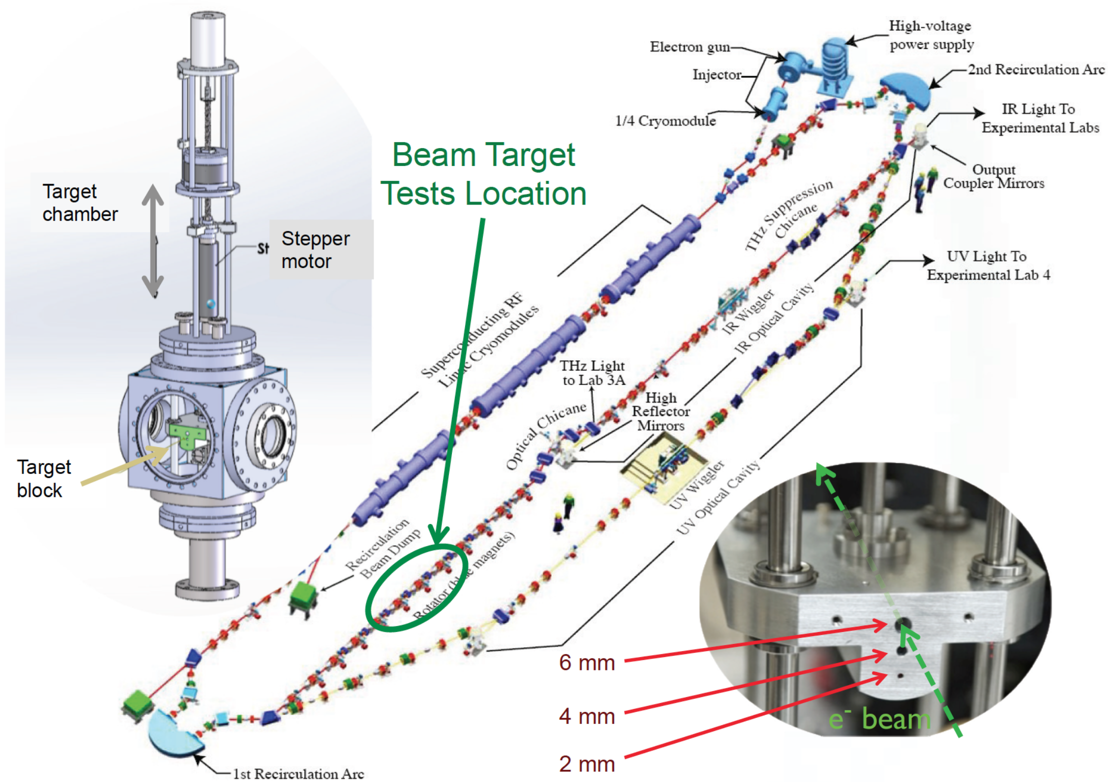
- Full approval by Jefferson Lab in August 2013.

- Community engagement : "Workshop to Explore Physics Opportunities with Intense, Polarized Electron Beam at 50-300 MeV", 14-16 March, 2013, Cambridge, MA; AIP Conf. Proc. **1563** (2013).

- Going forward:
  - DarkLight Phase 1
  - Full TDR and comprehensive review.

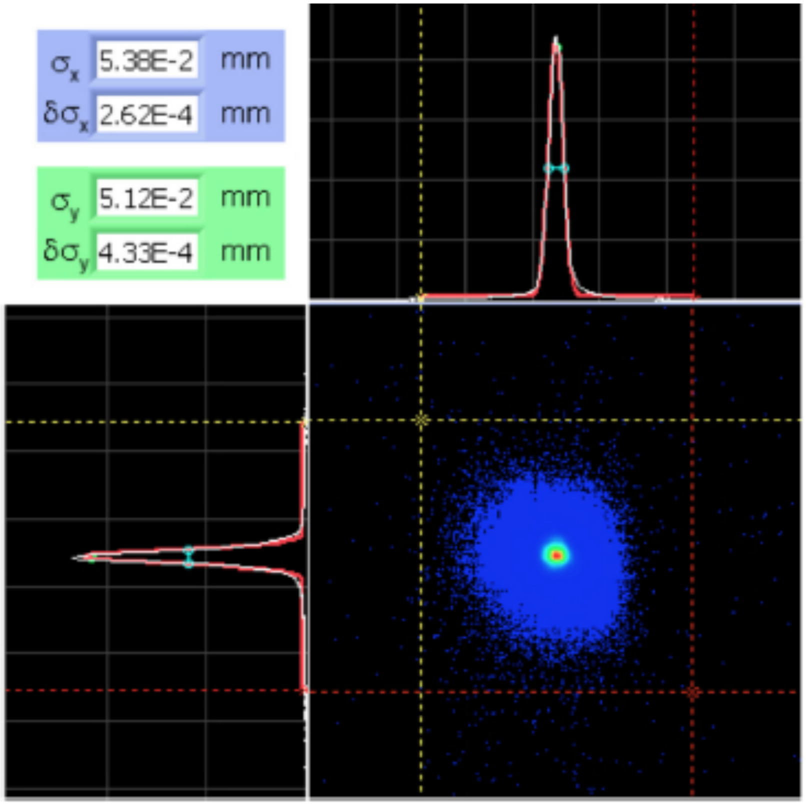
FEL Beam Transmission Test

A 100 MeV, 430 kW cw electron beam transmitted through a set of small apertures (6, 4, and 2 mm dia) in a 127 mm long Aluminum block.



- RF heating of the target region due to passage of the beam
- Background ambient radiation levels
- Radiation caused by beam scrapping along the in/out channels

FEL Beam Transmission Test



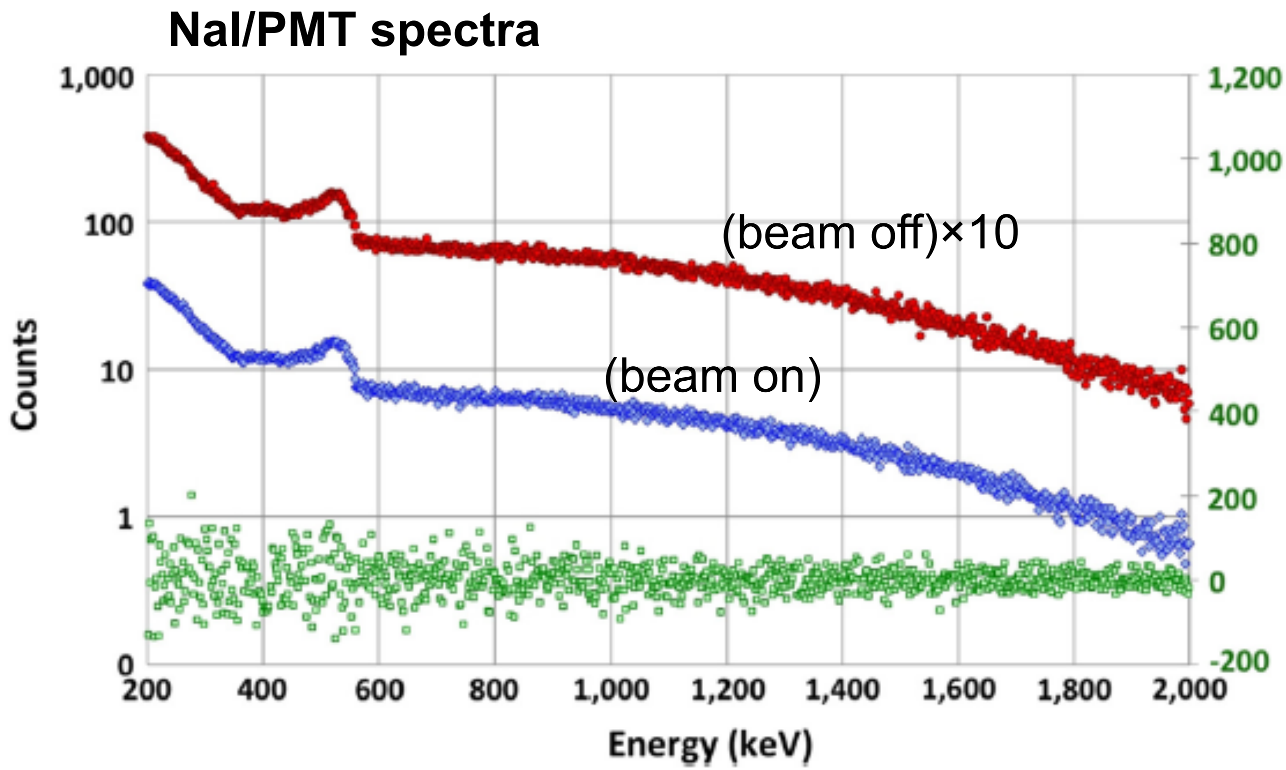
A 100 MeV spot size of 50 μm at the test aperture.

TABLE I. Wakefield power and beam transmission losses.

Run	Aperture mm	P_B (W) W	P_W (W) W	P_H (W) W	I_{ave} (mA) mA	Beam loss ppm
1	6	0.33	0.08	0.5	3.84	1.3
2	4	0.52	0.10	0.9	3.93	2.1
3	2	1.95	0.50	2.9	4.25	6.8
4	2	1.09	0.50	1.2	4.23	2.8

A 100 MeV electron beam (4.3 mA, 0.43 MW) can be passed indefinitely through a 2 mm diameter aperture of 127 mm length with an average beam loss of about 3 ppm (± 20%).

FEL Beam Transmission Test



Average beam loss and radiation backgrounds

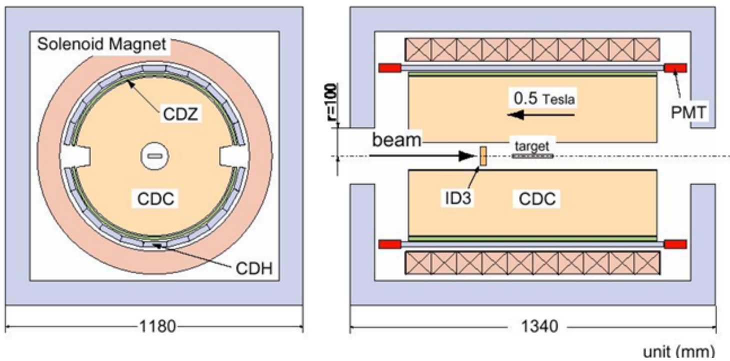
Run #	Aperture diameter (mm)	Run duration (min)	Average beam loss (ppm)	Neutron dose rate at Loc. B (rem/hr)	Photon dose rate at Loc. B (R/h)
1	6	22	1.3	0.24	13
2	4	30	2.1	0.43	19
3	2	124	6.8	1.32	75
4	2	413	2.8	0.58	60

DarkLight Phase 1

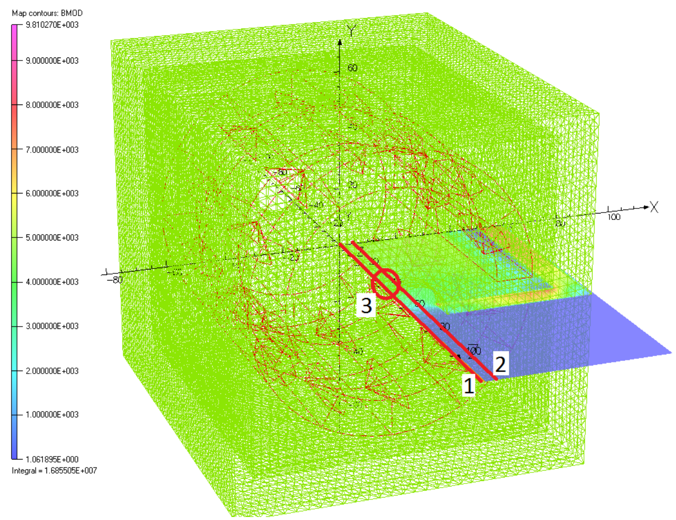
- Results from the Beam Test completed the JLab scientific approval process (June 2013).
- Opportunity for a Phase 1: coupling of an existing 0.5 T solenoidal magnet (BNL) with available internal target systems (MIT-Bates) and prototype detector systems.
- Phase 1 would allow:
  - Studies of beam-target interactions and their effect on energy recovery, and the magnet's effect on beam optics.
  - Studies of Moller generated electrons (dump).
  - Measurements of elastic *ep* scattering over a fraction of the available solid angle.
  - Searches for multi-leptons final states.
  - Tests of auxiliary detectors to further extend the experiment's reach.

Magnet for Phase 1

Used in BNL-E906, presently at Stony Brook, available to DarkLight



Maximum Magnet Flux	5	(kGauss)
Number of Turns	216	(turns/coil)
Maximum Current	2250	(A)
Voltage	73	(V)
Power Consumption	165	(KW)
Cross-section of Conductor	$20 \times 20 \times \phi\ 8$	(mm)
Resistance	28	(mΩ)
Length $\times$ Width $\times$ Height	$1380 \times 1180 \times 1180$	(mm)
Weight	7.2	(t)

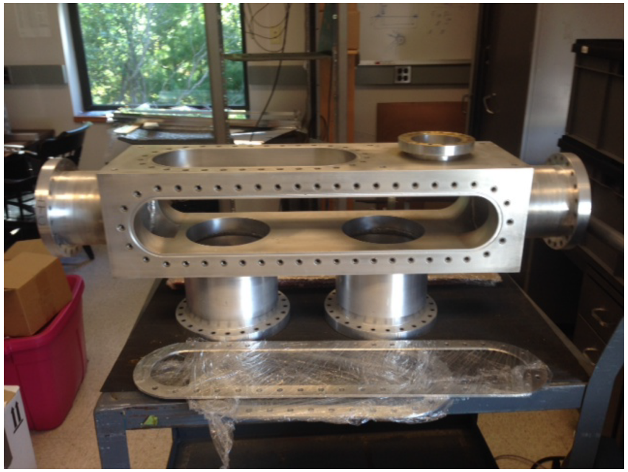


- Opera calculated fields being used in simulations.
- Can be engineered to accommodate internal target and prototype detectors.
- Plans underway to move it to Bates, map it, and condition it for Phase 1.

Phase 1 Internal Target System

OLYMPUS Target Cell

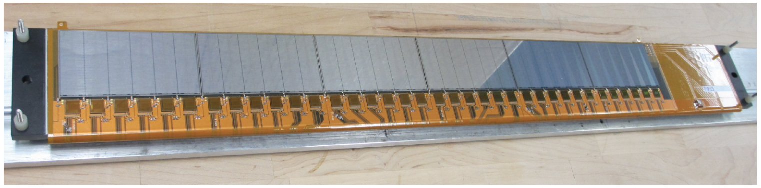
IUCF CE-25 Scattering Chamber



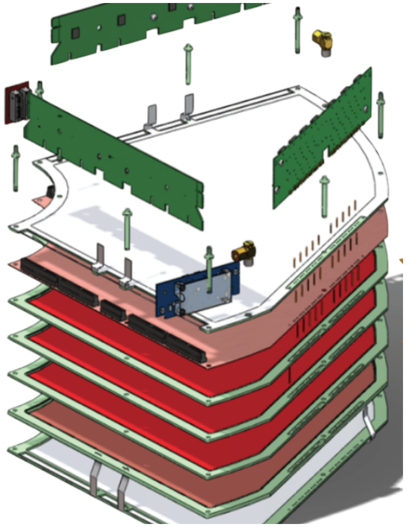
- Both systems, and their infrastructures, are at the MIT-Bates R&E Center, technical cornerstone of the DarkLight experiment.
- Funding being sought to fully engineer and construct modifications needed for a complete internal gas target system including detectors integration.
- It will also include complete design (simulations) and building of a Moller dump.
- Goal is to operate close to DarkLight design luminosity: 6×10^{35} $cm^{-2}s^{-1}$.

Phase 1 Proton & Lepton Detectors

Proton: Si strip detectors



Lepton Tracker: Triple-GEM detectors



- Standard single-sided, 300 μm thick, array of Si strip detectors mounted inside the scattering chamber.
- Array of triple-GEM detectors covering most of the available solid angle.
- Significant expertise within collaboration in construction and operation of these detectors.
- Final dimensions being optimized through simulations.
- Funding being sought to build these prototype detectors for Phase 1.

DarkLight Status

- Engaging US funding agencies and collaborators to secure funding for target engineering with existing magnet and implementation of prototype detectors.

- Goal is to carry out Phase 1 measurements in 2015.

    - Measurements would be guided by a complete simulation of the experiment and include elastic scattering with the allowed A' search.

- In parallel, collaboration working on a Technical Design Report of the full experiment for a full proposal for the experiment and operation of the FEL for tests and data taking.

- Collaboration is working through the approval process with JLab and funding agencies.

DarkLight Collaboration

Arizona State University
University of California, Berkeley
University of Bonn, Germany
Catholic University of America
College of William and Mary
University of Giessen, Germany
Hampton University
Jefferson Laboratory
Los Alamos National Laboratory
University of Maryland
Massachusetts Institute of Technology and Bates Research and Engineering Center
Temple University
Stony Brook University
Yale University