Update on DarkLight

Narbe Kalantarians

For the DarkLight Collaboration

Hampton Univ.

DARKLIGHT

HAMPTON UNIVERSITY

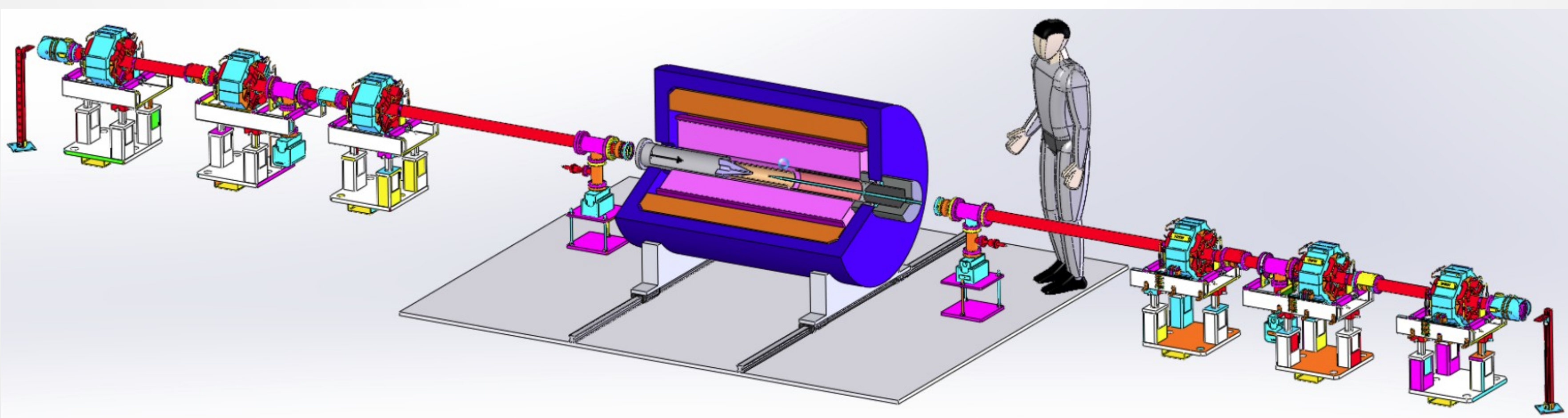
HEAVY PHOTON SEARCH

HPS Collaboration Meeting

June 4-6, 2013
Jefferson Lab

Outline

- Background/Motivation
- DarkLight Experiment
- JLab PAC Proposals
- Beam Test
- Timeline
- Summary



Overview—motivation

- A detailed understanding of dark matter is a major part of any complete description of the world
- Many experiments hint at the existence of dark matter, but no specific dark matter candidates are know
  - Possibilities include WIMPs and axions
  - And, more recently, a new “dark sector”
    - That couples to Standard Model particles via a heavy photon *A’*

The "Dark Forces" concept

A Theory of Dark Matter

Nima Arkani-Hamed,[1] Douglas P. Finkbeiner,[2] Tracy R. Slatyer,[3] and Neal Weiner[4]

[1] *School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540, USA*
[2] *Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, USA*
[3] *Physics Department, Harvard University, Cambridge, MA 02138, USA*
[4] *Center for Cosmology and Particle Physics, Department of Physics, New York University, New York, NY 10003, USA*

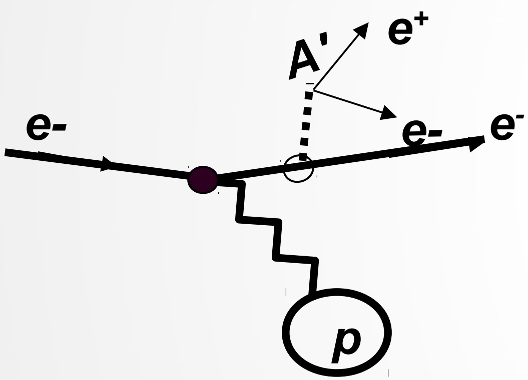
(Dated: January 20, 2009)

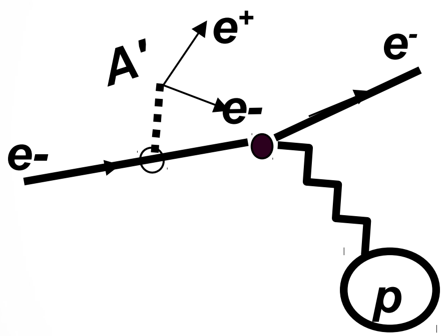
arXiv:0810.0713 [hep-ph], and others…

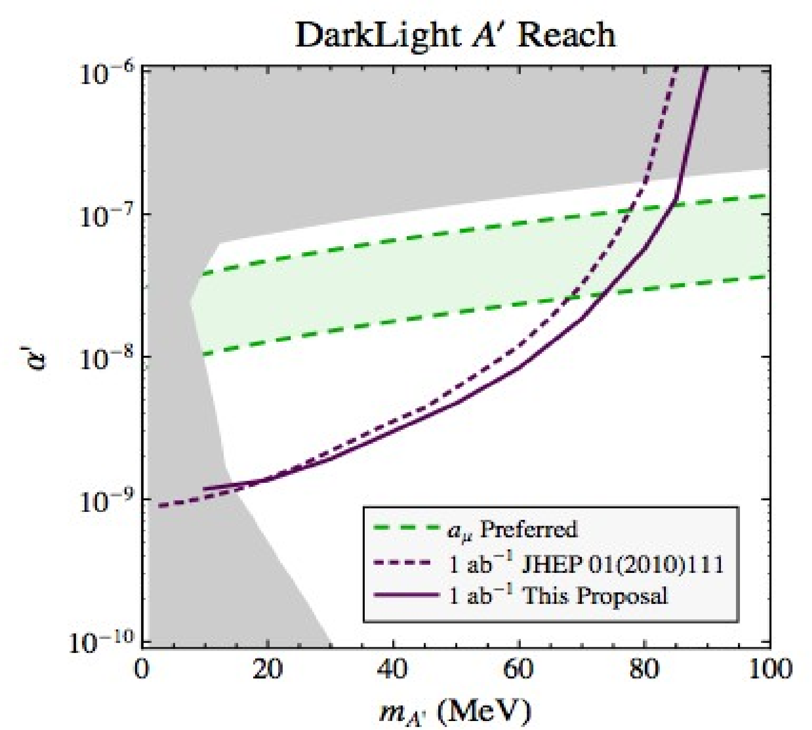
Physics

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

A Search for new light bosons using the Jefferson Lab FEL facility.







Goal: Explore e^+-e^- invariant mass spectrum using the process $e^- + p \rightarrow e^- + p + e^- + e^+$

High Intensity, Low Energy Electron Beam

Using JLab's FEL on Thick Hydrogen Gas Target

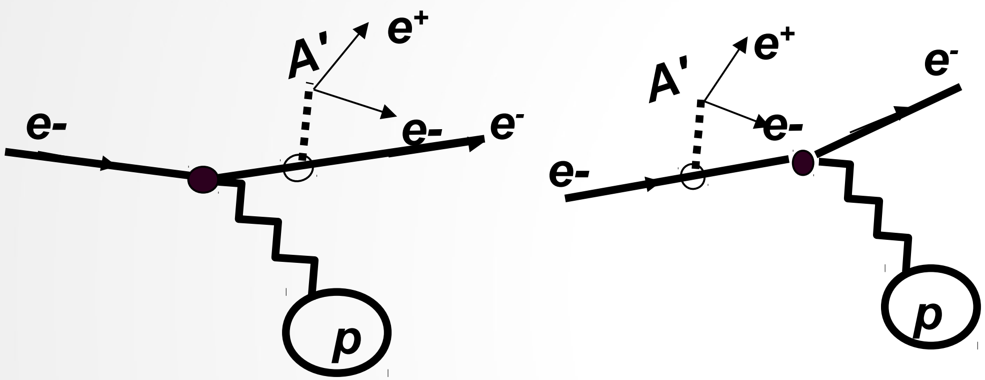
==> Luminosity: 1 ab^{-1}/month

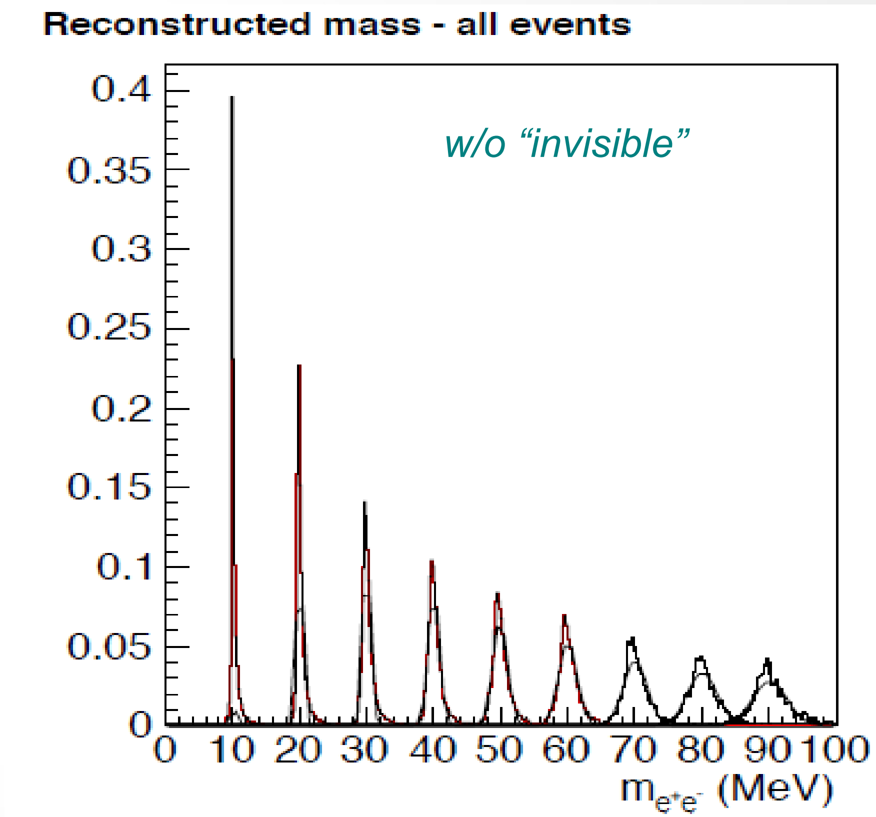
$$\alpha' \equiv \varepsilon^2 \alpha \,, \ \ (\alpha = e^2/4\pi)$$

"Dark Force Detection in Low Energy e-p Collisions"
[Freytsis, Ovanesyan, Thalar: arXiv:0909.2862 (JHEP 1001;111)]

Physics Processes

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





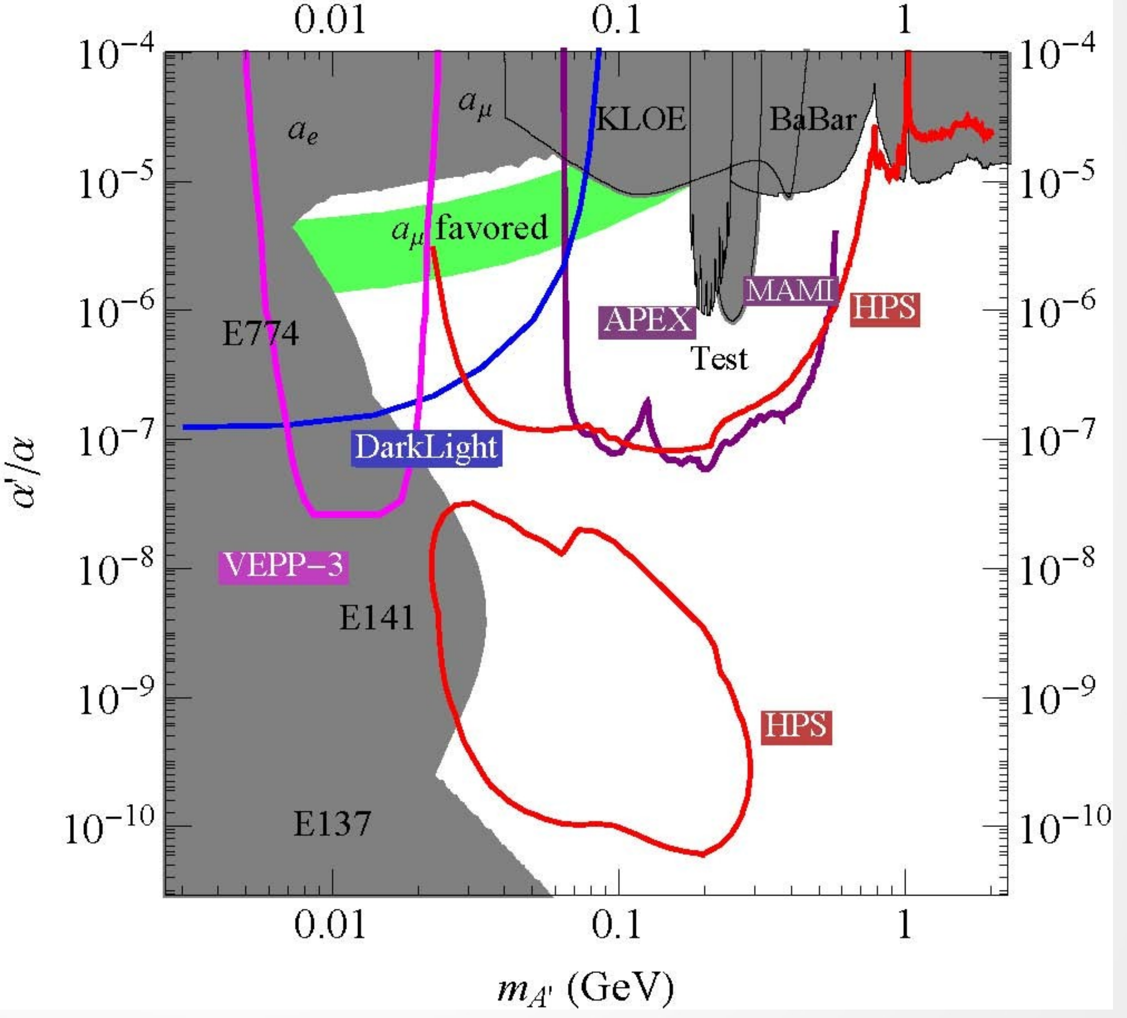
Signal:
epγ/epA', *ep/epA' ("invisible")*
Kahn, Thaler PRD 86 115012 (2102)

Backgrounds:
ep/ep, ep/epγ, ep/ep$\gamma\gamma$, epγ/epγ

The experiment is basically a measurement of the QED background with 0.1ppm precision. *The detection of all 4 final states is essential.*

Complementarity

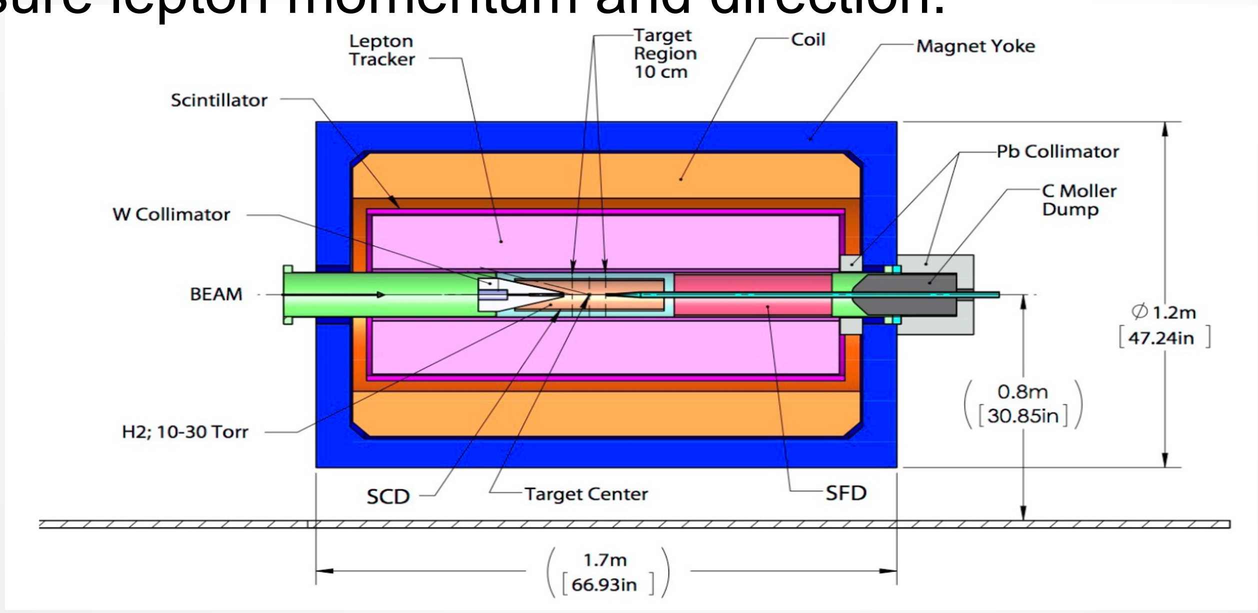
- Reach is complementary to other planned experiments
- Such as APEX and the Heavy Photon Search (HPS) at JLab CEBAF machine



DarkLight Components

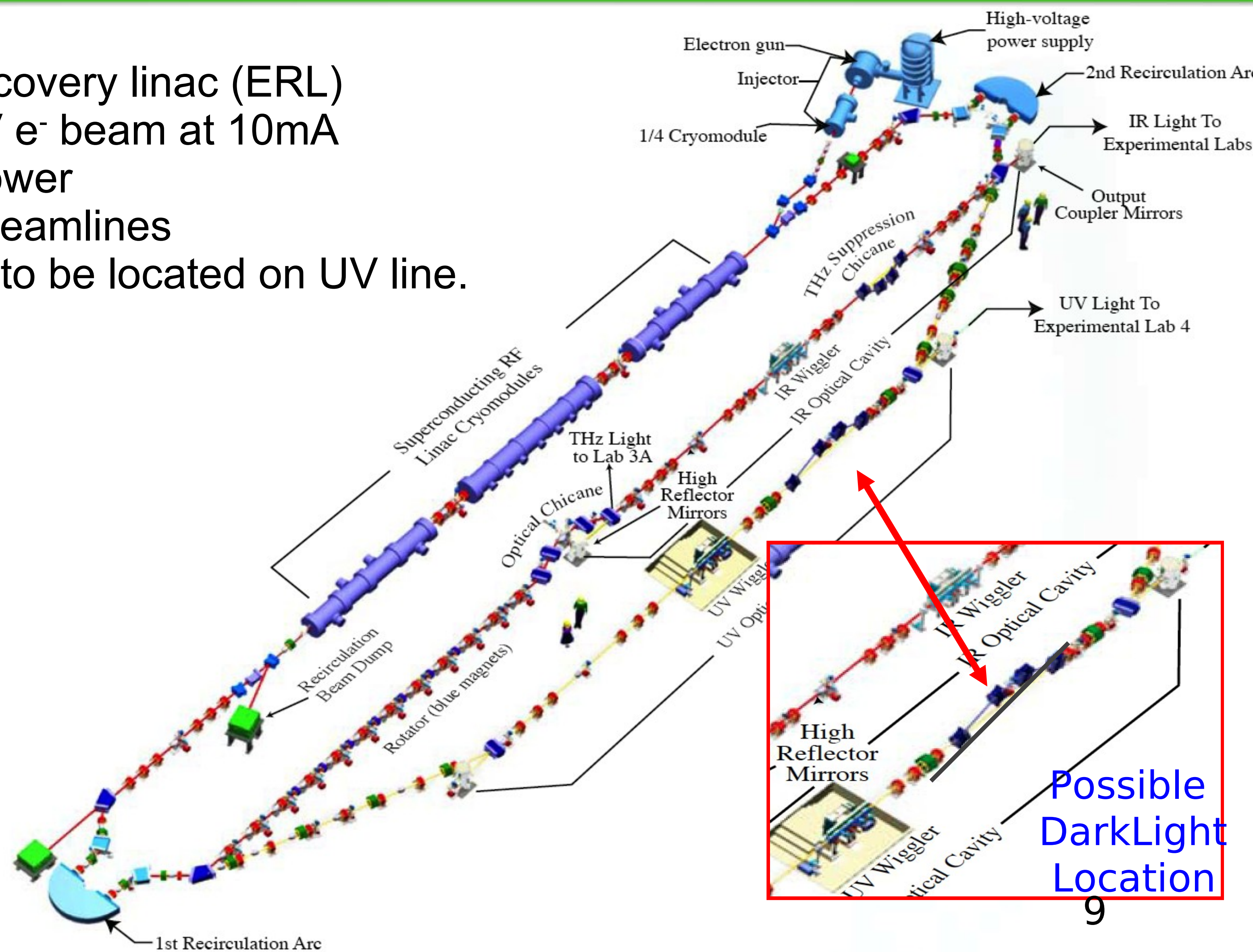
DarkLight has 4 primary components:

- Target – Differentially pumped hydrogen gas target 10^{19} atoms /cm^2, 10 cm long.
- Silicon proton detector - ~3.5 cm from beam, single layer of silicon micro-strip detector. Measure energy and angle of recoil proton.
- Lepton tracker – 10-25 cm radius cylindrical projection chamber.
- Magnet – Solenoid provides 0.5 T B-field to focus Moller e$^-$ and measure lepton momentum and direction.



DarkLight @ FEL

- Energy recovery linac (ERL)
  - 100 MeV e^- beam at 10mA
  - 1 MW power
- IR & UV Beamlines
- DarkLight to be located on UV line.



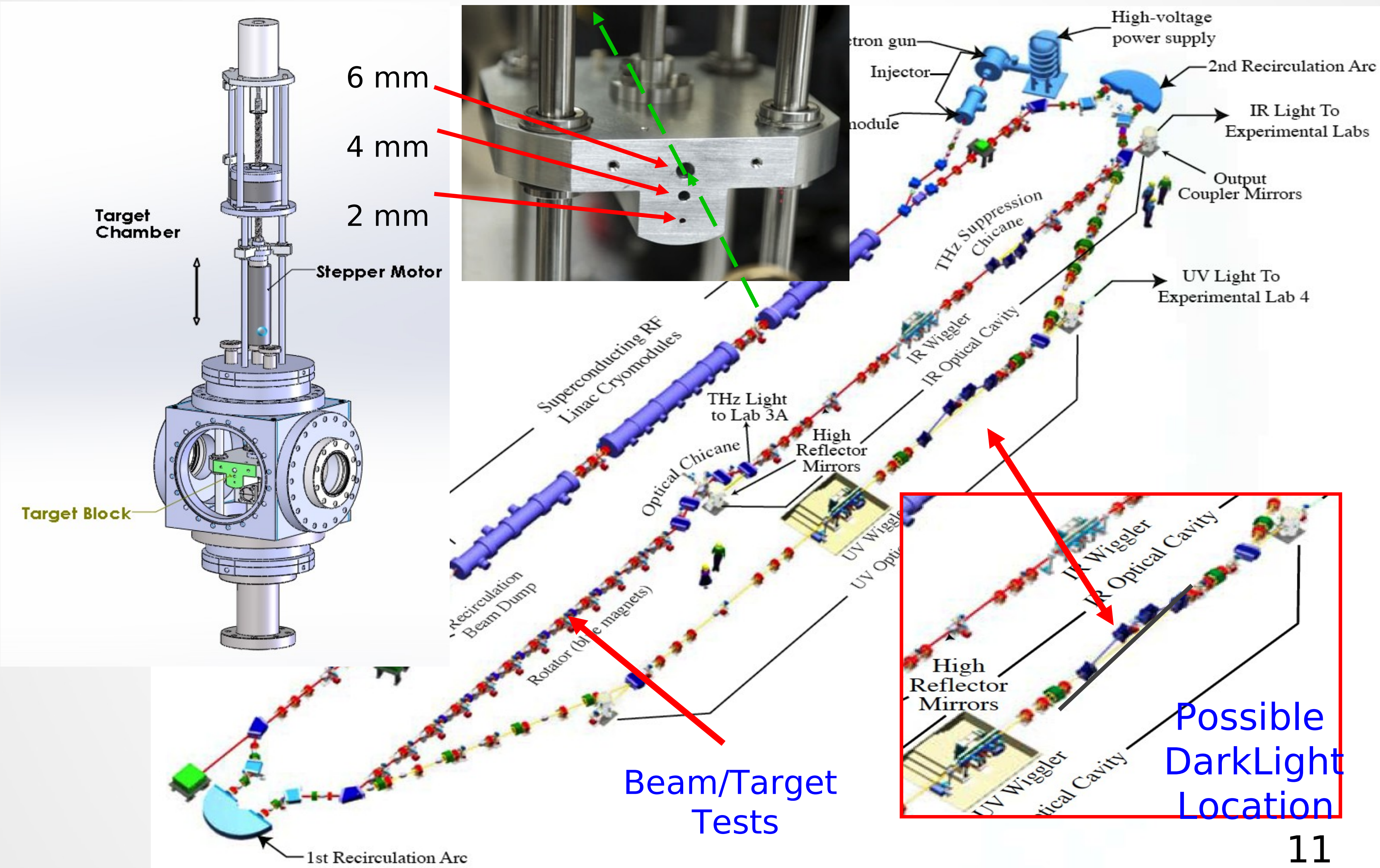
Jlab PAC Proposals

1. PAC 37: DarkLight Collaboration, PAC 37, November 30, 2010.

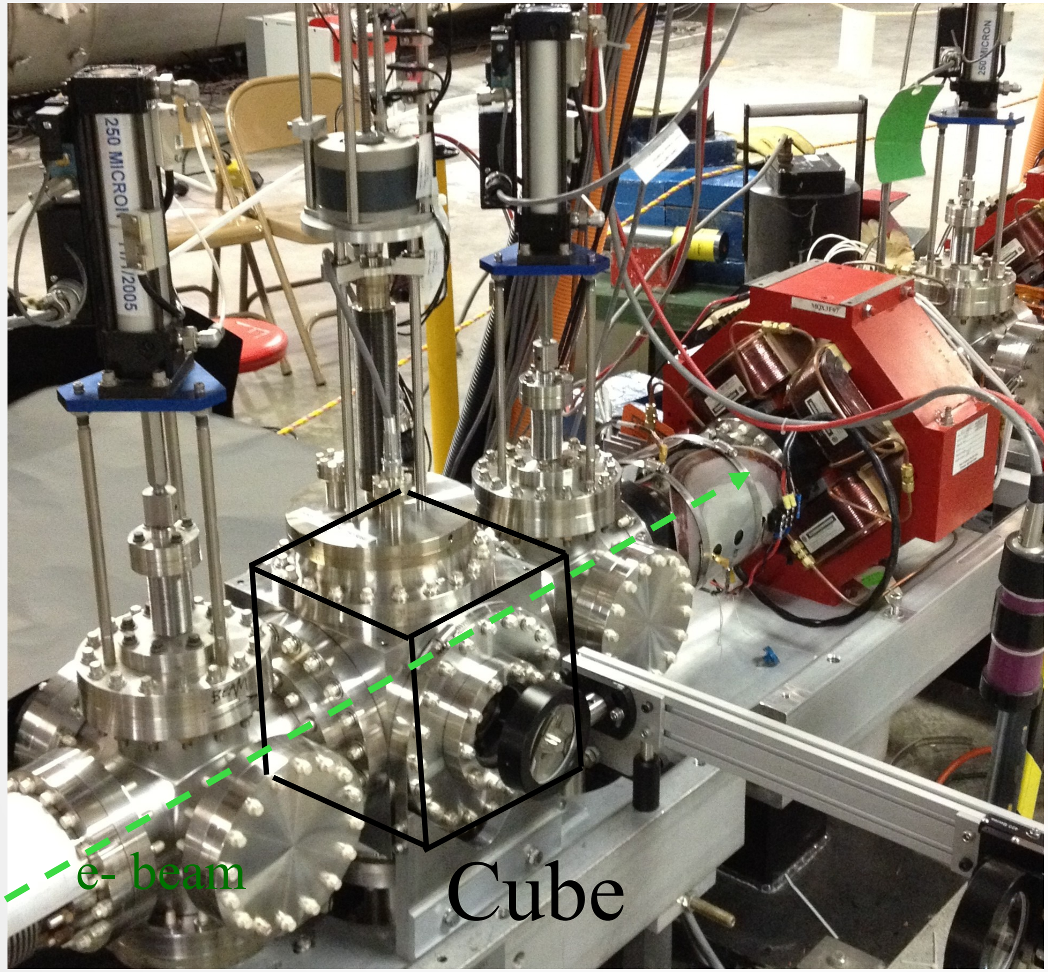
Early concept: electron beam scattering off H_2 in a windowless chamber.

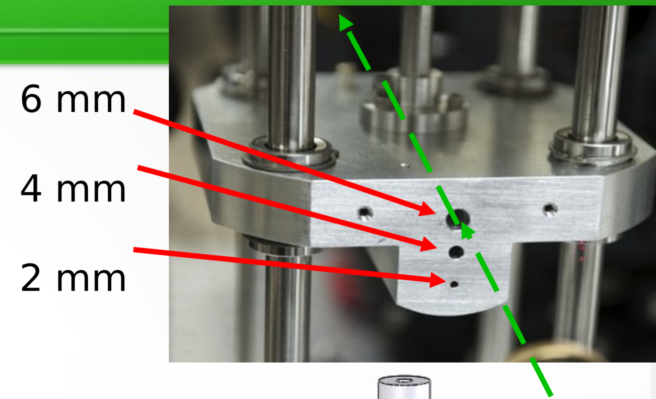
2. PAC 39: DarkLight Collaboration, PAC 39, May 4, 2012.
   - Can DarkLight identify and shield against ambient FEL Vault background radiation.?
   - Can the FEL beam be threaded through the proposed H_2 target?
   - Can beam halo be managed?
   - Are there any RF heating/effects on the target entrance/exit?

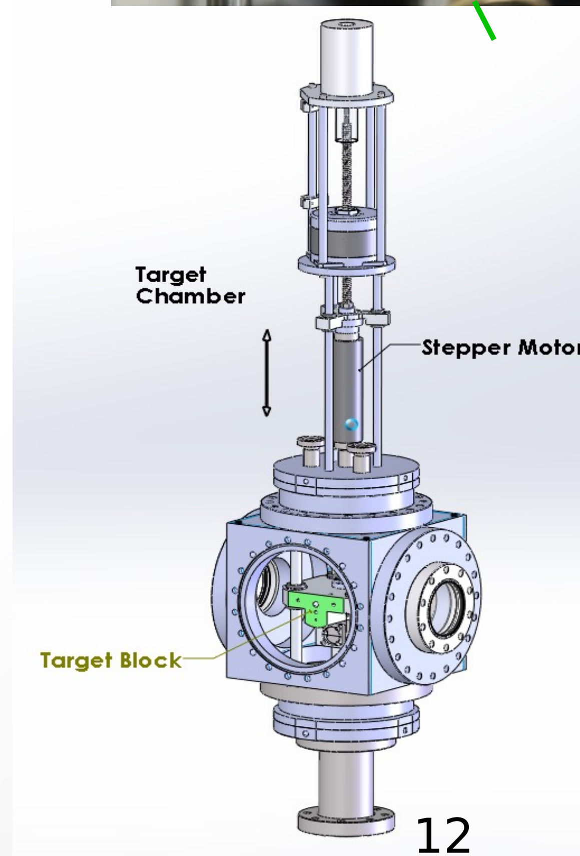
DarkLight Beam-Test



DarkLight Beam-Test





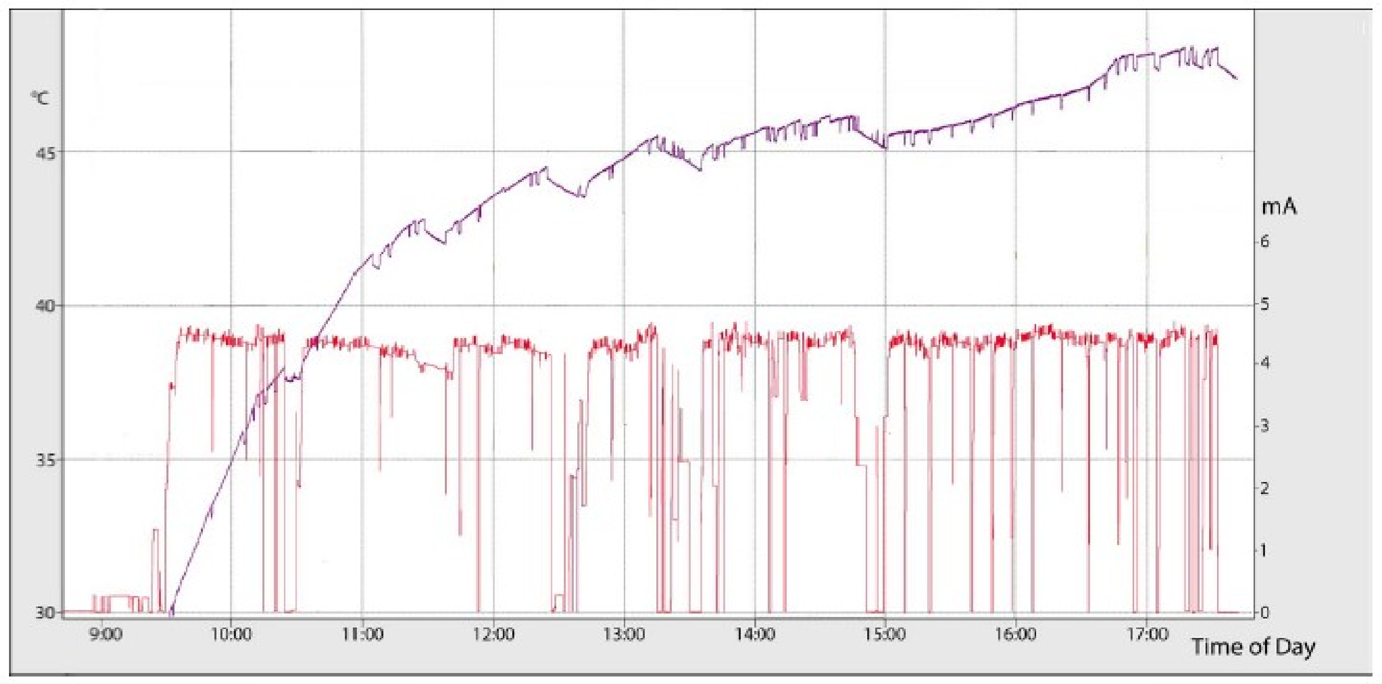


Beam-Test Results

A test e^- beam 100 MeV, 4.5 mA (450 kW power) was successfully transmitted through a 2 mm hole, 12.7 cm long, with max loss of 3 ppm for 7 hours. This showed that

- e^- beam bunch CAN be threaded through a 12.7 cm long, 2 mm hole.
- Halo CAN be minimized.
- The FEL has the stability required for a successful DarkLight experiment.
- Radiation in the vault is manageable.

arXiv 1305.0199,1305.7215, 1305.7493

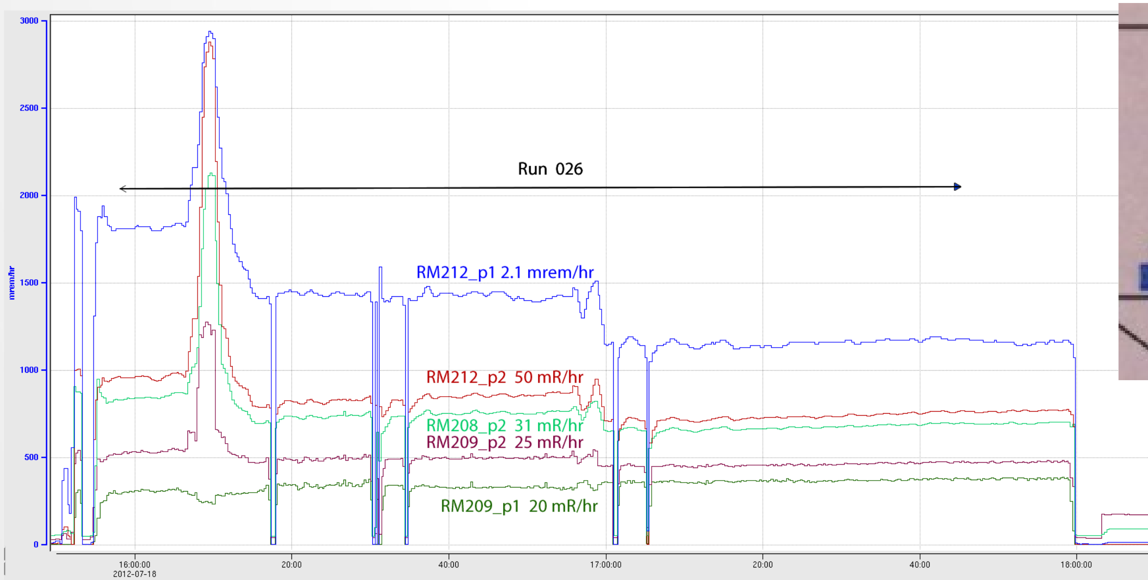


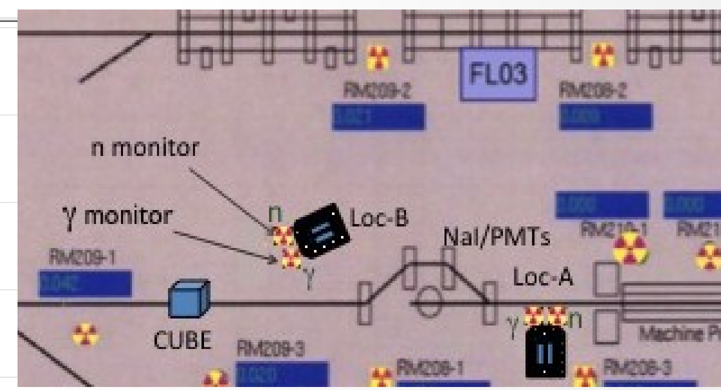
Beam-Test Results

A test e$^-$ beam 100 MeV, 4.5 mA (450 kW power) was successfully transmitted through a 2 mm hole, 12.7 cm long, with max loss of 3 ppm for 7 hours. This showed that

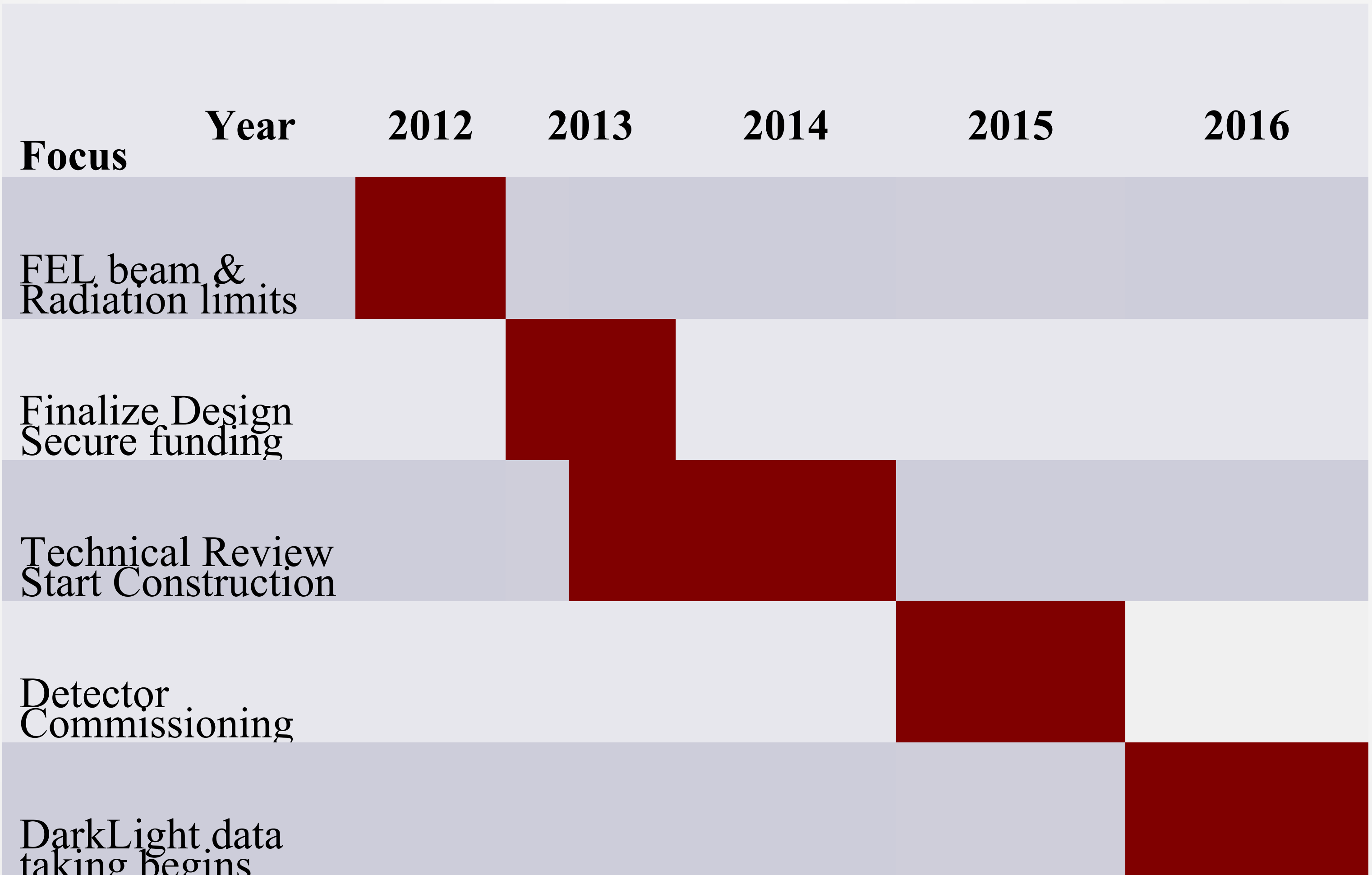
- e$^-$ beam bunch CAN be threaded through a 12.7 cm long, 2 mm hole.
- Halo CAN be minimized.
- The FEL has the stability required for a successful DarkLight experiment.
- Radiation in the vault is manageable.

arXiv 1305.0199,1305.7215, 1305.7493



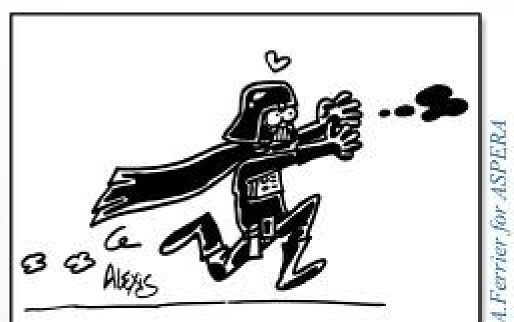


(Possible) Time-line



Summary

- The DarkLight experiment is
  - A compact magnetic spectrometer
  - Designed for detecting A’ decays to lepton pairs
  - For A’ masses in the range 10–90 MeV/c^2
- DarkLight’s reach is complementary to that of other planned heavy photon searches
- Finishing review by JLab management.
  - Will then seek funding and move to technical design and review
- Hoping for commissioning run in 2015, and data-taking runs in 2016



DarkLight collaborators

J. Balewski, J. Bernauer, W. Bertozzi, J. Bessuille, B. Buck, R. Cowan, K. Dow, C. Epstein, P. Fisher, S. Gilad, E. Ihlo, Y. Kahn, A. Kelleher, J. Kelsey, R. Milner, C. Moran, L. Ou, R. Russell, B. Schmookler, J. Thaler, C. Tschalaer, C. Vidal, A. Winnebeck
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA 02139, USA and the Bates Research and Engineering Center, Middleton MA 01949
S. Benson, C. Gould, G. Biallas, J. Boyce, J. Coleman, D. Douglas, R. Ent, P. Evtushenko, H. C. Fenker, J. Gubeli, F. Hannon, J. Huang, K. Jordan, R. Legg, M. Marchlik, W. Moore, G. Neil, M. Shinn, C. Tennant, R. Walker, G. Williams, S. Zhang Jeerson Lab, 12000 Jeerson 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
T. Gunter, N. Kalantarians, M. Kohl
Physics Dept., Hampton University, Hampton, VA 23668 and Jeerson Lab, 12000 Jeerson Avenue, Newport News, VA 23606
I. Albayrak, M. Carmignotto, T. Horn
Physics Dept., Catholic University of America, Washington, DC 20064
D. S. Gunarathne, C. J. Marto, D. L. Olvitt, B. Surrow, X. Li
Physics Dept., Temple University, Philadelphia, PA 19122
E. Long Physics Dept., Kent State University, Kent, OH, 44242
R. Beck, R. Schmitz, D. Walther
University Bonn, D - 53115 Bonn Germany
K. Brinkmann, H. Zaunick
II. Physikalisches Institut Justus-Liebig-Universitt Giessen, D-35392 Giessen Germany
W.J.Kossler
Physics Dept., College of William and Mary, Williamsburg VA 23185

Support Slides

Experimental details at a glance (1)

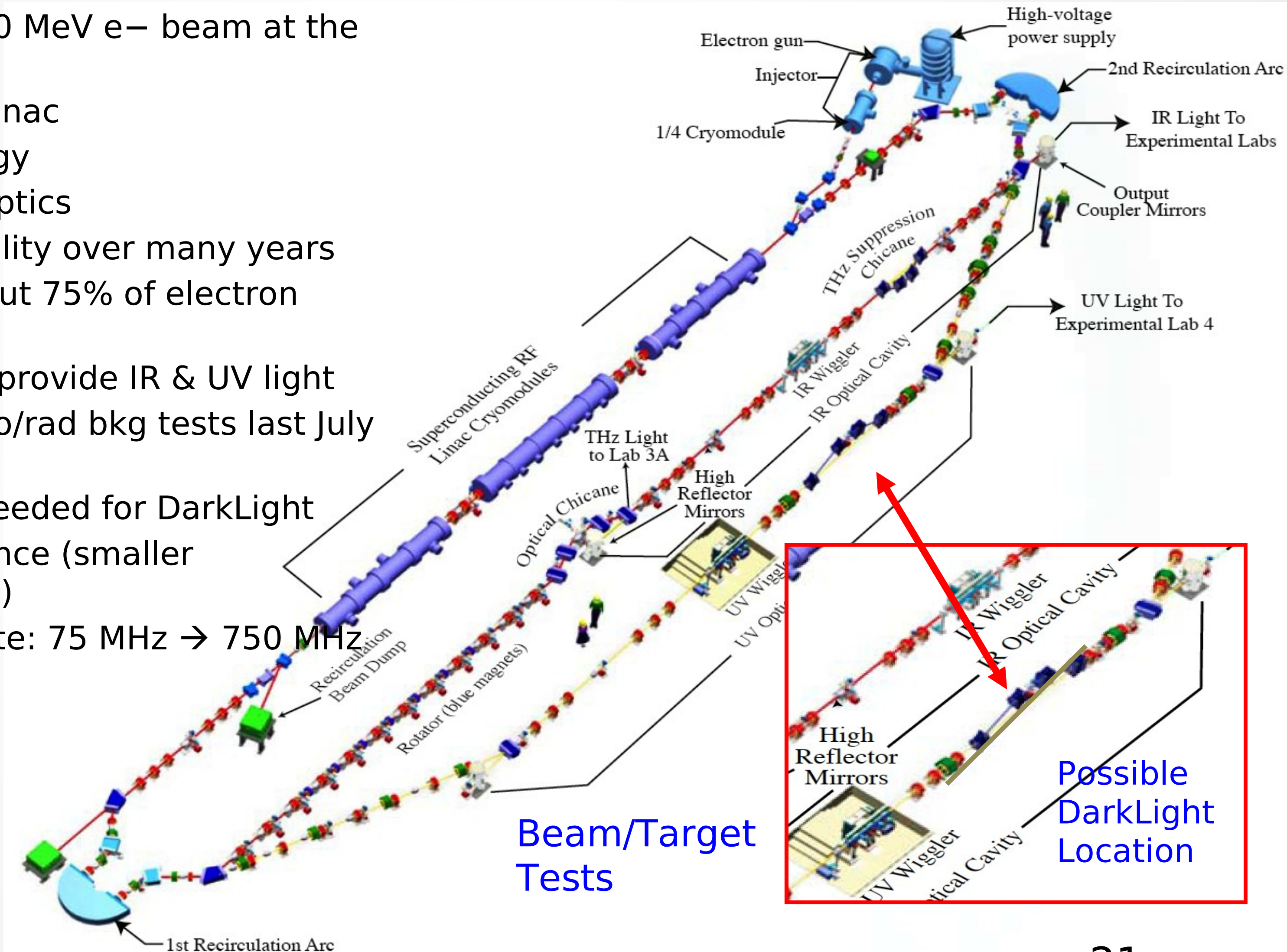
- Luminosity 6 x 10^{35} cm-2 sec-1
  - FEL beam produces 6 x 10^{16} electrons/sec
  - At 100 MeV onto 10^{19}/cm^2 target
  - 10 mA beam current
- FEL beam traverses both field and target
- Gas jet target provides point-like electron-proton interaction
- Target and tracker components in 0.5 T solenoidal magnetic field
  - Recoil proton detector
  - Silicon strips in forward direction
  - Lepton tracker
  - Trigger scintillator
- Coincident detection of scattered electron and recoil proton along with the dilepton final state

Experimental details at a glance (2)

- Performance goals
  - 1 MeV mass resolution
  - Tracking of e+/e− with K.E. > 5 MeV
  - Tracking of protons with K.E. > 0.5 MeV
- Typical signal and background rates
  - QED bkg ($\sigma \sim 10^4$ pb): 6 kHZ
  - For $m_{A'}$ = 50 MeV/c^2 (σ ¼ 10^{-2} pb): 5200 counts/day
- Issues
  - Huge QED rate
  - Pileup
  - Beam halo/heating
  - Survivability in 1 MW beam
  - Multiple scattering, etc, at low momenta (10’s of MeV/*c*)

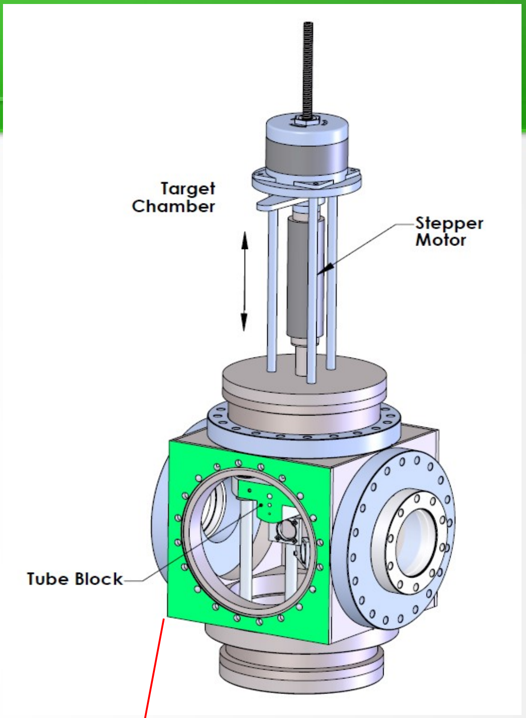
JLab FEL

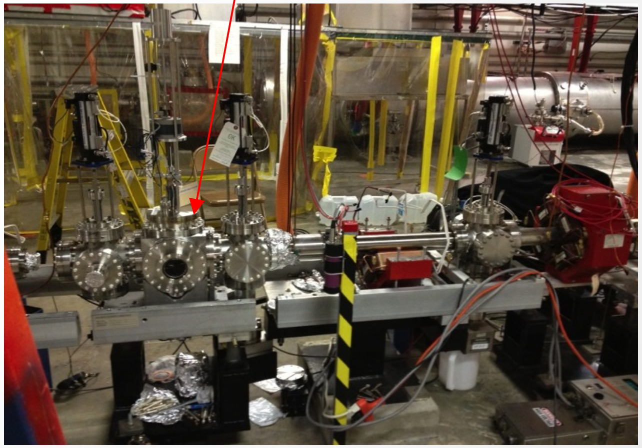
- Use the 1 MW, 100 MeV e− beam at the JLab FEL
- Energy-recovery linac
  - SRF technology
  - High-power optics
  - Proven reliability over many years
  - Recovers about 75% of electron beam energy
- Originally built to provide IR & UV light
- Beam heating/halo/rad bkg tests last July
- Some upgrades needed for DarkLight
  - Lower emittance (smaller charge/bunch)
  - Higher rep rate: 75 MHz → 750 MHz



Beam tests

- Goals
  - Show that the high-power FEL beam could pass through a 2 mm dia. Aperture 10 cm long without excessive heating or beam losses
  - To characterize photon and neutron backgrounds
  - Verify that trackers can operate in the beam/vault environment
- Setup
  - Movable aluminum block in a test cube
  - Temperature, OTR, YAG crystal monitors on cube
  - NAI/PMT and other rad counters located downstream and in vault



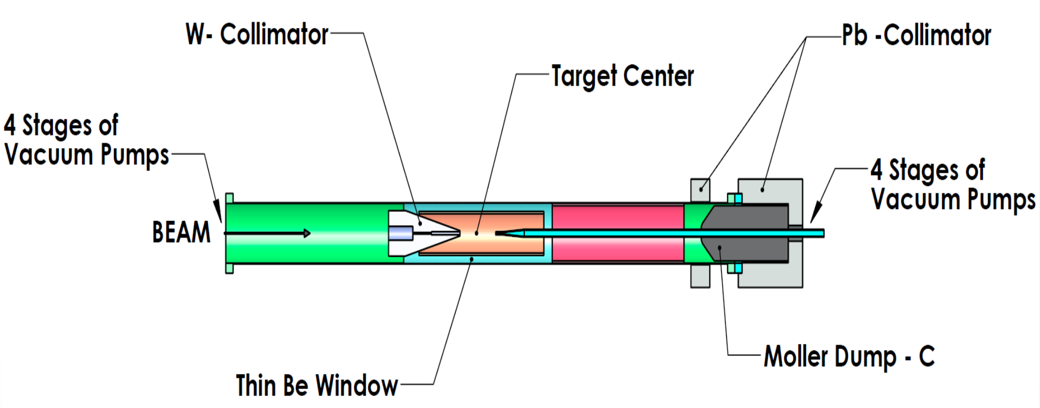


Kinematic Considerations

- Need high-efficiency detection of the 4-body final state
  - On top of a large QED background rate
- Magnetic field large enough to
  - Sweep Mollers downstream w/o entering sensitive regions
  - Provide for momentum analysis
- Detect final state proton
  - K.E. ≈ 1 –5 MeV
- Elastically scattering rates peak
  - Forward direction for electron
  - Near 90° for proton
  - In signal events w/ e+e− pair, recoil protons are at < 60°
- Limiting lepton tracking to > 25°
  - Reduces elastic rate

Target Region

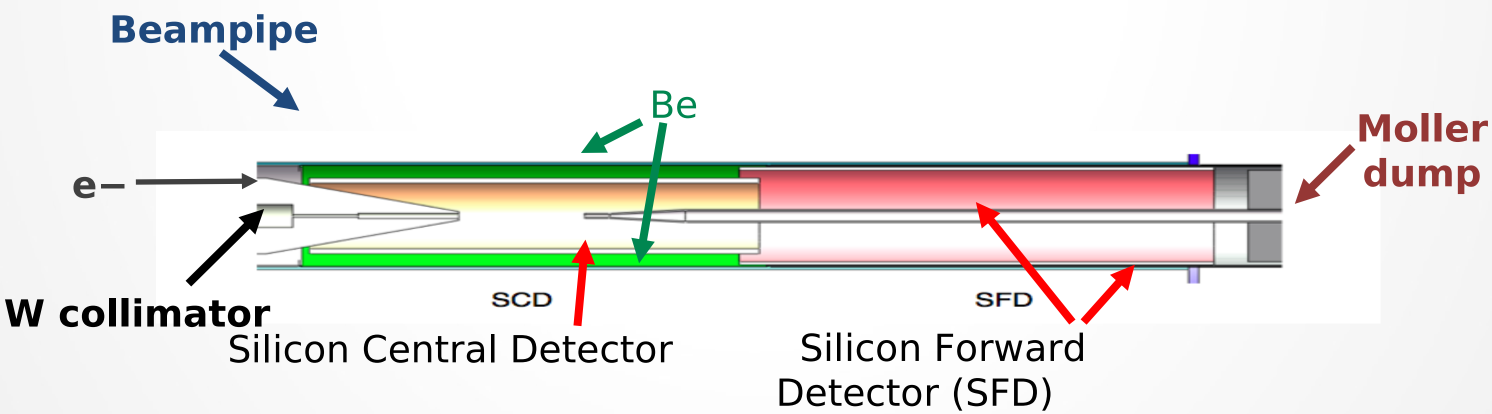
- Windowless gas target
  - Defined as volume inside beampipe
  - 10^{19} atoms/cm^2 in 10 cm long target region (12 torr)
  - Between two restrictive gas flow apertures
  - 2 mm dia., 10 cm long inlet/outlet apertures
  - And 20 mm dia, 1 m long “exhaust pipe”
  - Downstream of W collimator
- W collimator design
  - To absorb beam halo
  - Recessed to absorb backscattered halo electrons
  - Limit Rutherford-scattered electrons entering the gas volume
- Differential pumping, 3–4 stages
  - FEL vacuum 10-8 torr
  - Pumping rate 15 torr-liter/sec
- Beampipe
  - Beryllium in 25°–165° angular lepton acceptance region
- Moller dump
  - Graphite to reduce showering
  - Shielded with lead on upstream side to reduce backscatter into tracker
- Challenges
  - Control power deposition
    - beam core, halo, resistive wall heating



Silicon detectors

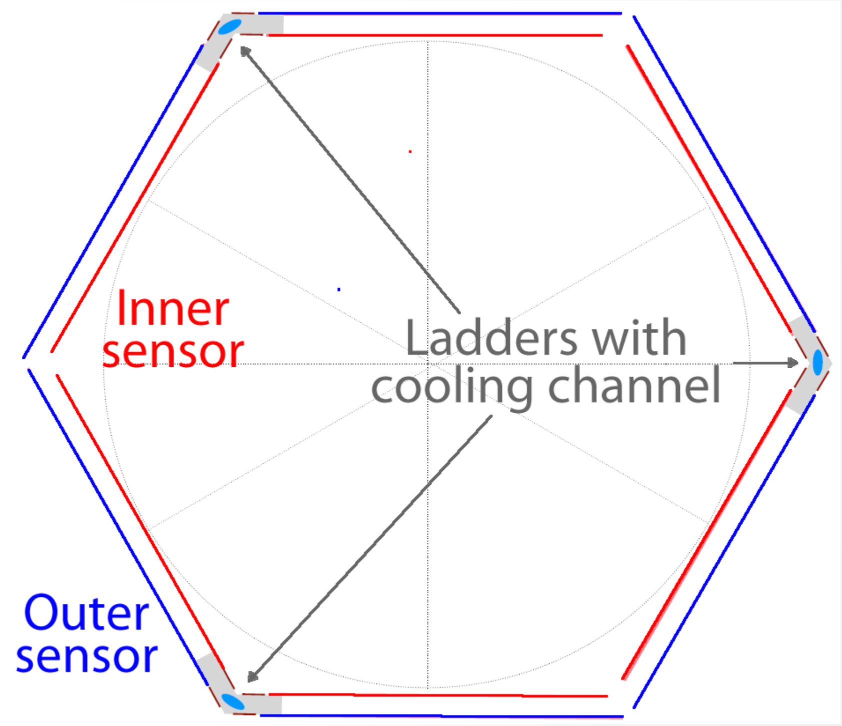
- Purpose
  - Tag the recoil proton
    - Location and energy
      - Linear response, ≈ 30% K.E. resolution
  - Hit locations of final state leptons
- Two detectors
  - Central (SCD) and forward (SFD)
  - Inside the beam vacuum
    - Similar to HERMES

- Design uses conventional single-sided, rad hard silicon strips
  - <1% radiation length
  - Low outgas rate
- Angular coverage
  - SCD 17°–163°
  - SFD 6°–19°
- Fast readout for use in trigger
  - Liquid cooled front-end electronics



Silicon detectors

- Si strips in two layers
  - Held at one edge by rigid, ceramic ladders
  - Embedded cooling tube
- Each sensor 300 µm thick
  - Total 0.65% rad. Length
  - Inner sensor for detecting recoil proton
  - Outer sensor for leptons

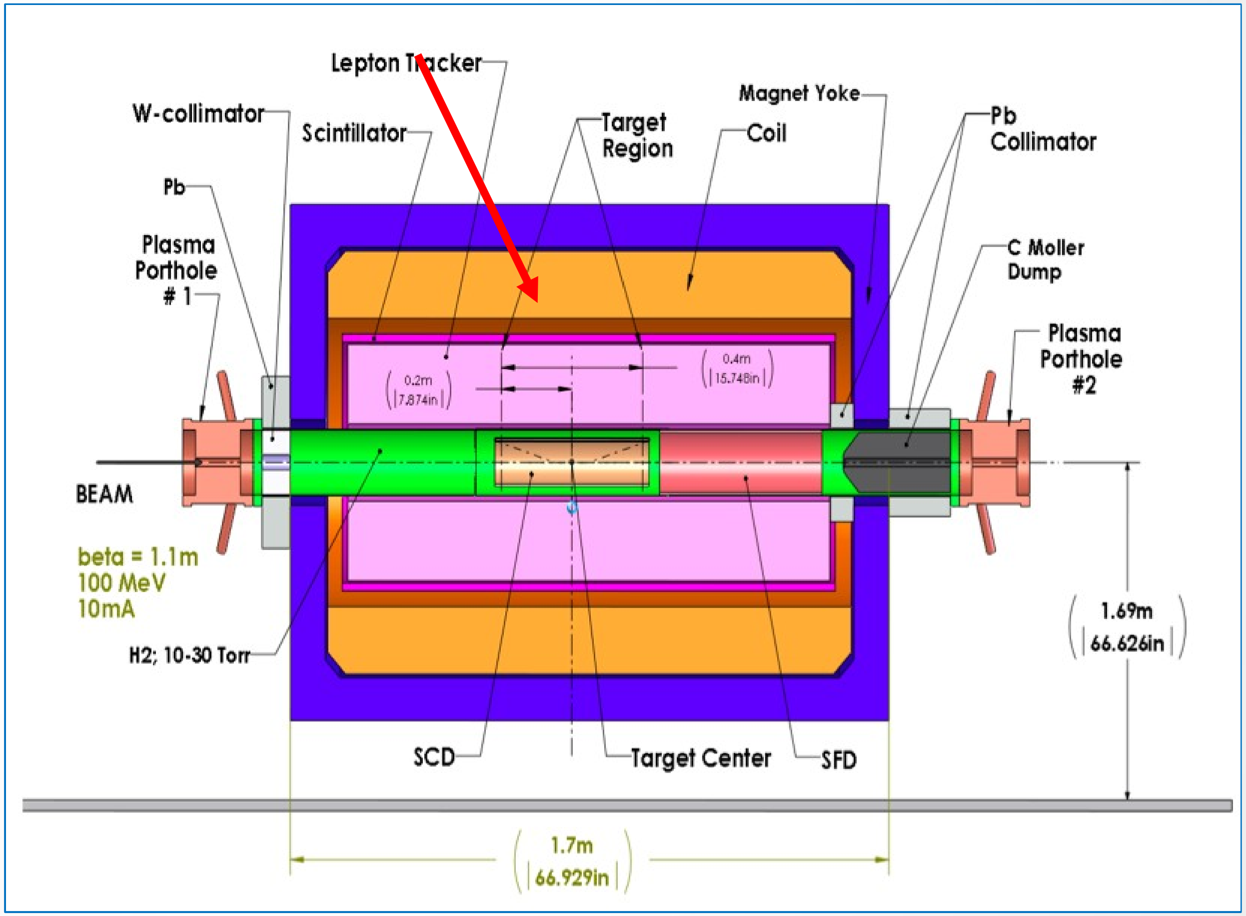


Lepton tracker

- Inside the solenoid
- Operate in high-rate environment
  - Permit long drift times
  - High channel densities
- Resolution
  - Single-hit ≈ 250 µm
  - 1 MeV average mass resol.
- Trigger at about 1 kHZ
- PANDA GEM-TPC tracker is similar in goals
  - About 60% scale of DarkLight
  - Analog event pipeline
  - Continuous operation
  - Proven technology
- Forms major part of the trigger
  – Each subsystem

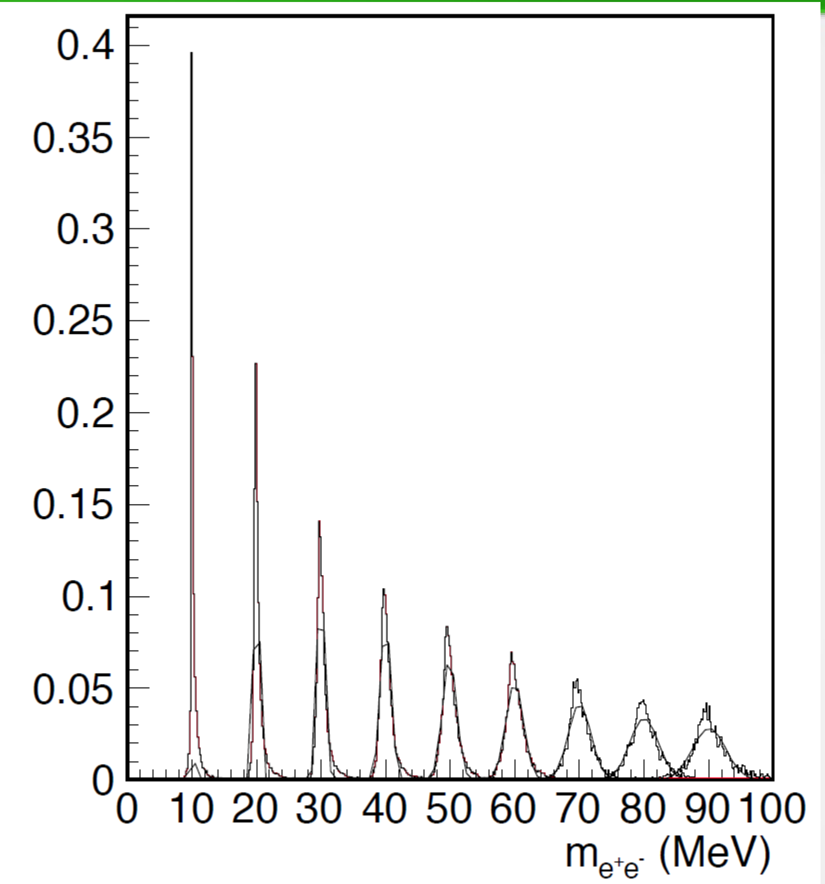
  performs prelim. event reconstruction
  - Feeds upstream for filtering

DarkLight conceptual design



Tracker performance

- Reconstruction of all four final state particles is essential for background rejection using kinematic constraints
- Momentum resolution from MC study
  - σpT/pT = 0.06 at pT=200 MeV/c
  - Scales as 1/√pT
- Yields mass resolution of 0.2–2 MeV/c2
  - Over mass range of interest

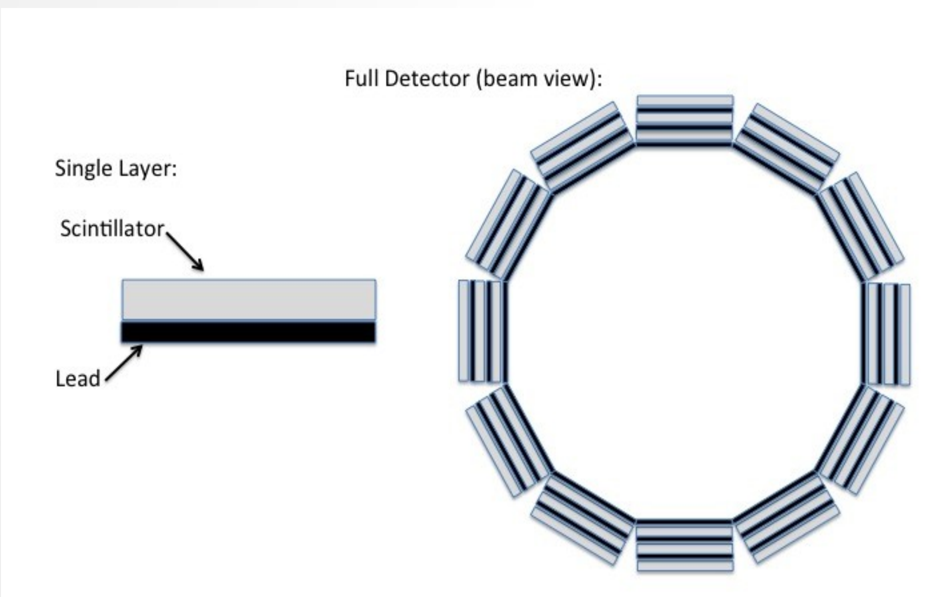


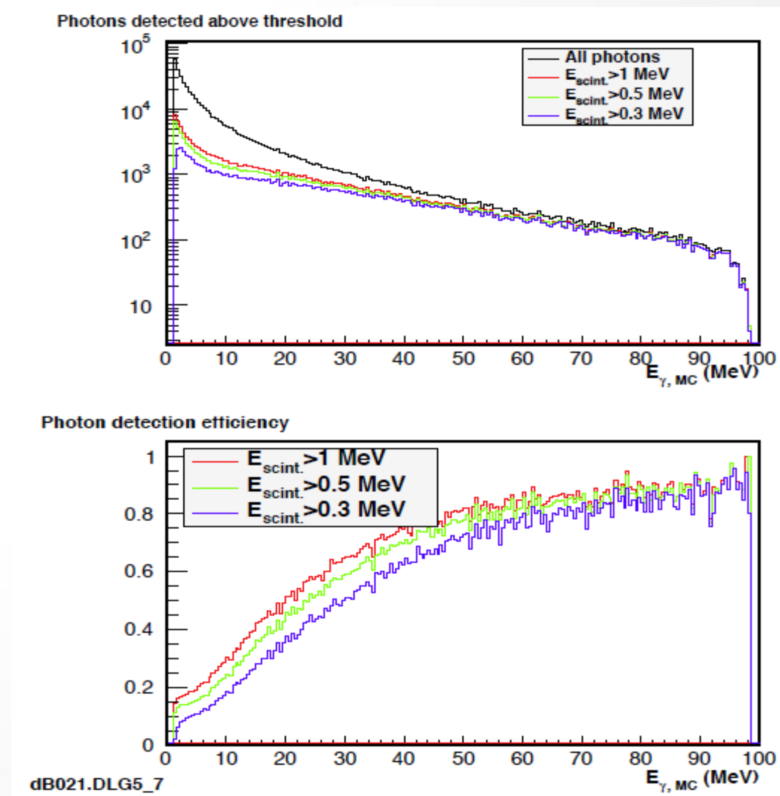
Fits to reconstructed A’ invariant mass for A’ masses from 10–90 MeV/c2

“Invisible”

Detector:

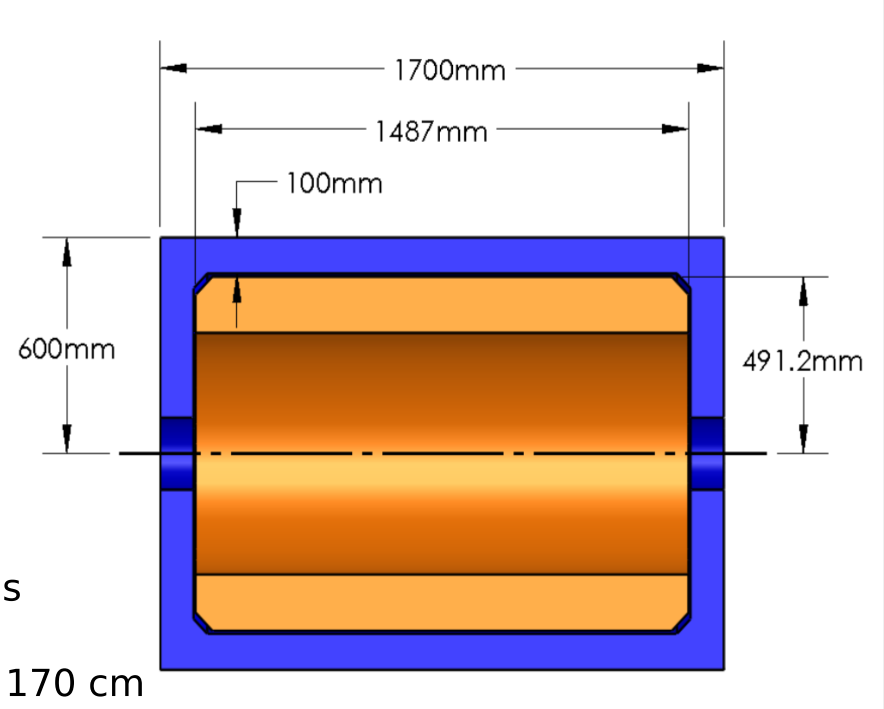
- Cylindrical Array
  60 cm (diam) x 150 cm (length)
- Composed of 10 segments (10 cm wide)
- Segment = Pb (0.5 cm thick) + scintillator (1 cm thick) x 3+
- 3 layers =/> 90% efficiency.





Magnet

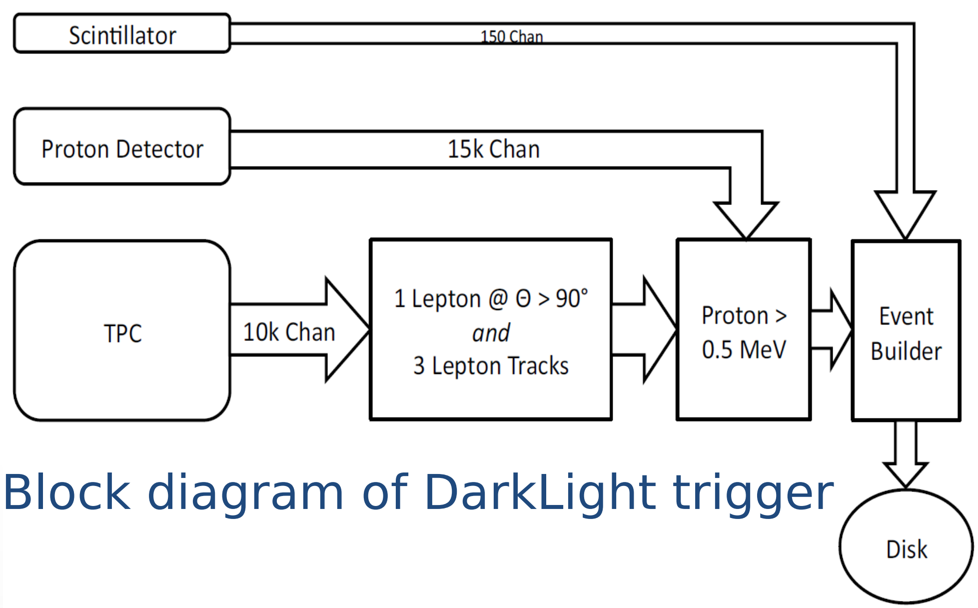
- Goals
  - Sweep Mollers and other backgrounds away from sensitive detectors
  - Provide for momentum analysis
- Nominal design
  - Solenoid, 0.5 T
    - Inner rad 33.5 cm, outer 49 cm
  - magnet to deal with backgrounds
  - Iron yoke for flux return
    - Thick enough to reduce hall backgrounds
    - Inner radius 50 cm, outer 60 cm, length 170 cm
- Water-cooled copper
  - 20 °C in, 50 °C out
  - 1300 A, 150 kW



Solenoid design (preliminary)

Trigger

- Has to handle
  - Mollers
  - e−p scattering
  - QED background
  - A’ signal events
- TPC is primary
- Data flows into trigger pipeline
  - Hit detection, charge above threshold
  - Remove channels not hit (zero suppresion)
  - Collect hits close together in position and time
    - Form simple track reconstruction
    - Helix fit, track angle and charge
  - Add timestamp
  - Package the data & send to next stage
- First trigger condition
  - One lepton at > 90°
  - Three lepton tracks total
  - 1 MHz
- Second trigger condition
  - Recoil proton
  - K.E. > 0.5 MeV
  - 10 kHz (QED irreducible backgrounds
  - This is written to disk



Block diagram of DarkLight trigger