DARKLIGHT @ TRIUMF ARIEL ADVANCED RARE ISOTOPE LABORATORY

Introduction

- Scientific motivation
- DarkLight – an MIT experiment at Jefferson Lab (2009-2018)

Detecting A Resonance Kinematically with eLectrons Incident on a Gaseous Hydrogen Target. (J. Thaler)

- Opportunities

Dark Matter Theories

- Idea: dark matter is very heavy and the coupling to the SM **α’** is via a light gauge boson, called the A’.
- The coupling is small because dark matter is heavy.
- Theories of dark matter predict a force carrier of mass $\mathbf{m_{A'}}$ 10 to 1000 MeV that couples like a photon via kinetic mixing.
- Could explain anomalies hinted at in muon (g-2) data.
- DarkLight was an experiment at Jefferson Laboratory, Newport News, VA conceived at MIT to look for evidence of the A’ via the process

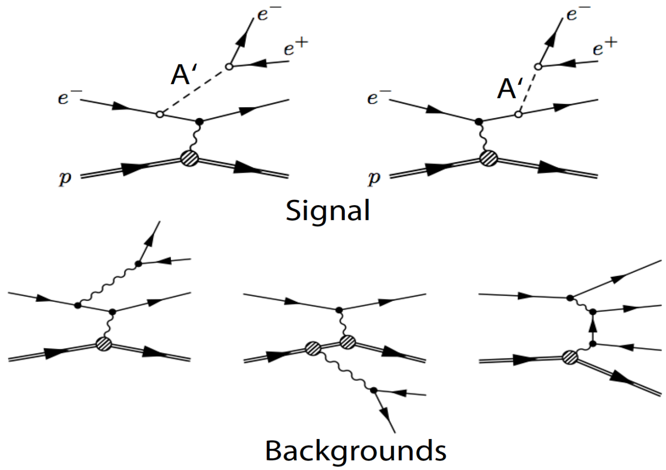
$e+p \rightarrow e' + p + A'$ with $A' \rightarrow e^+ + e^-$

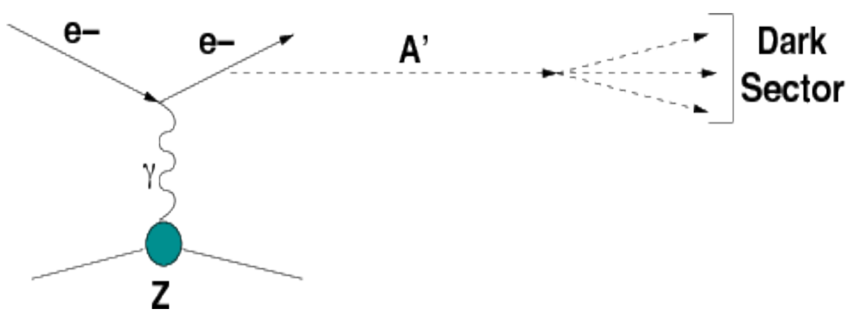
$\rightarrow f + \bar{f}$ (invisible)

James D. Bjorken *et al.*
Phys. Rev. D **80**, 075018 (2009)

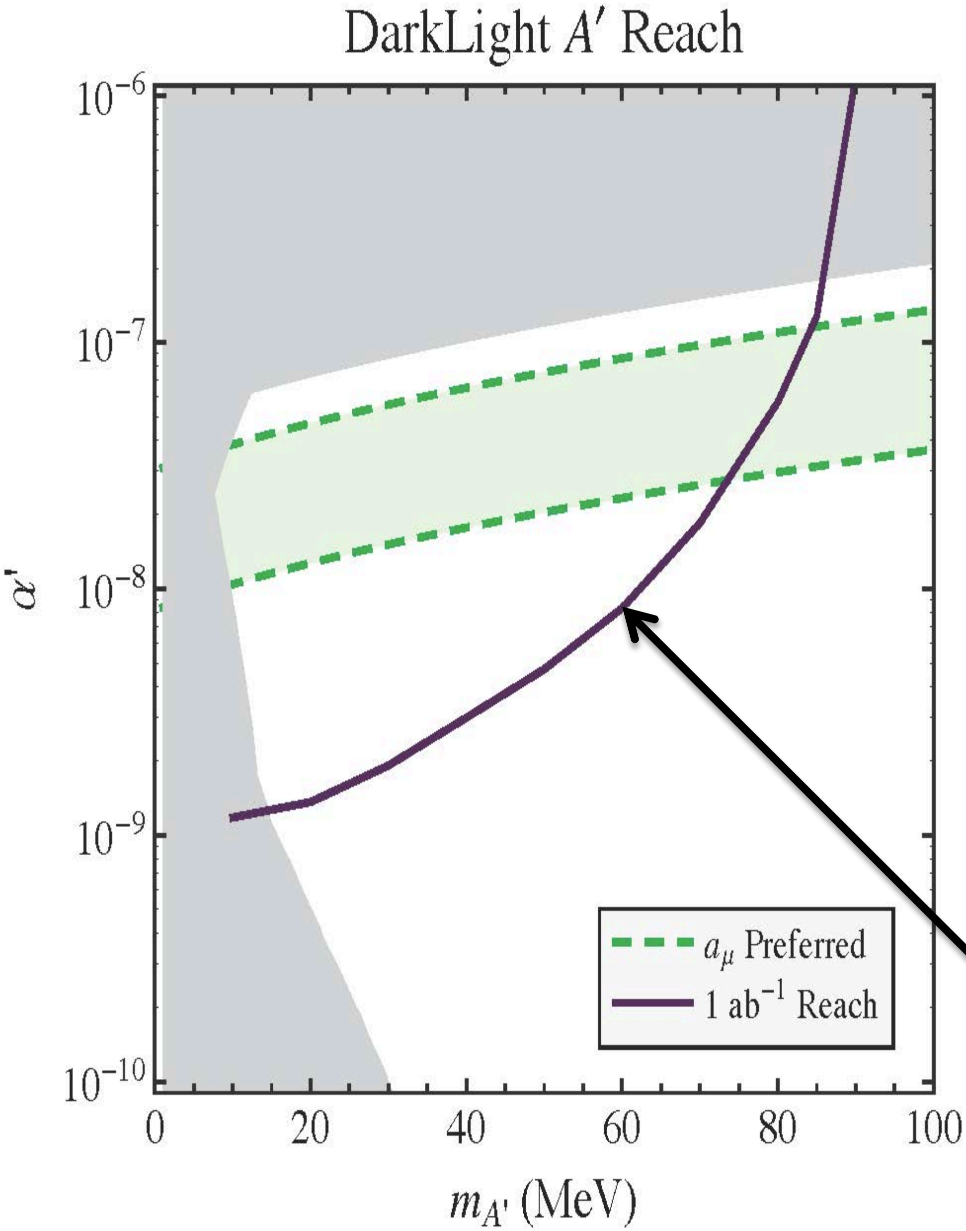
Seeking the Dark Side of the Force

- For coupling α' about 10^{-8}, the signal is about 10^{-4} of the QED irreducible background.
- DarkLight aims to measure the QED radiative process to a precision of 0.1 ppm.





- The detection of all four final-state particles (for visible decay) and their kinematic combination is highly desirable.



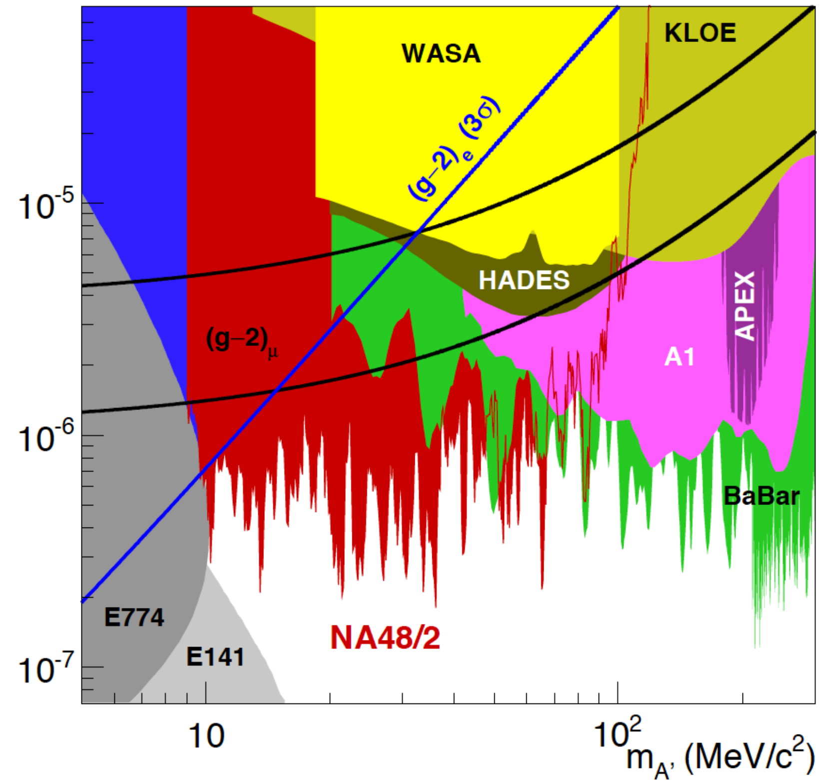
M. Freytsis, G. Ovanesyan, and J. Thaler
JHEP **1001**, 111 (2010)

- Huge worldwide effort to search for evidence of A’: CERN, BNL, GSI, JLab,…
- No evidence to date.
- Mass-coupling parameter space excluded at 2σ.
- However, claim from ^{8}Be nuclear decay measurements of possible 17 MeV “particle”.
- DarkLight planning to search in this mass region.
- DarkLight also planning an invisible search

5σ limit

NA-48: π^0 decay

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



J.R. Batley *et al.*
NA48 Collaboration
Phys. Lett. B **746**, 178 (2015)

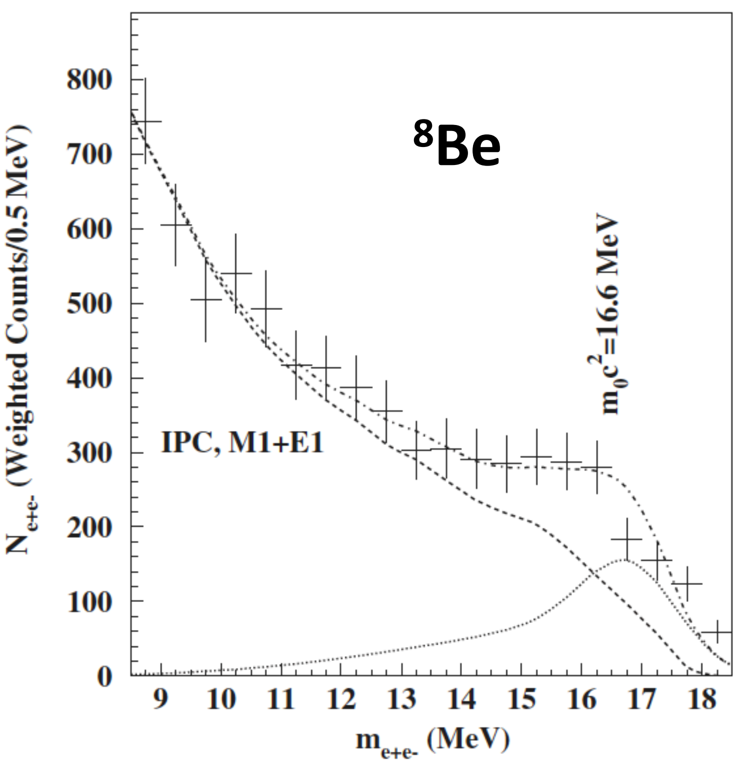
Figure 4: Obtained upper limits at 90% CL on the mixing parameter ε^2 versus the DP mass $m_{A'}$, compared to other published exclusion limits from meson decay, beam dump and e^+e^- collider experiments [15–21]. Also shown is the band where the consistency of theoretical and experimental values of muon $(g-2)$ improves to $\pm 2\sigma$ or less, as well as the region excluded by the electron $(g-2)$ measurement [2, 22].

SCIENTIFIC AMERICAN®

PHYSICS

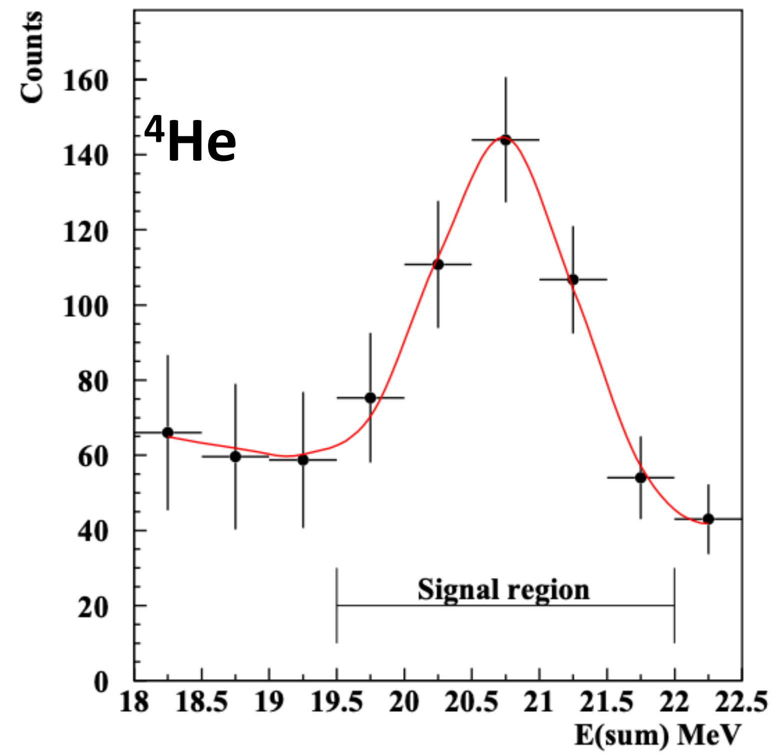
Evidence of New X17 Particle Reported, but Scientists Are Wary

Could the mysterious particle be our window into studying dark matter?



A.J. Krasznahorkay *et al.*,
Phys. Rev. Lett. **116**, 042501 (2016)

Atomki **anomaly**



A.J. Krasznahorkay *et al.*,
arXiv: 1910.10459

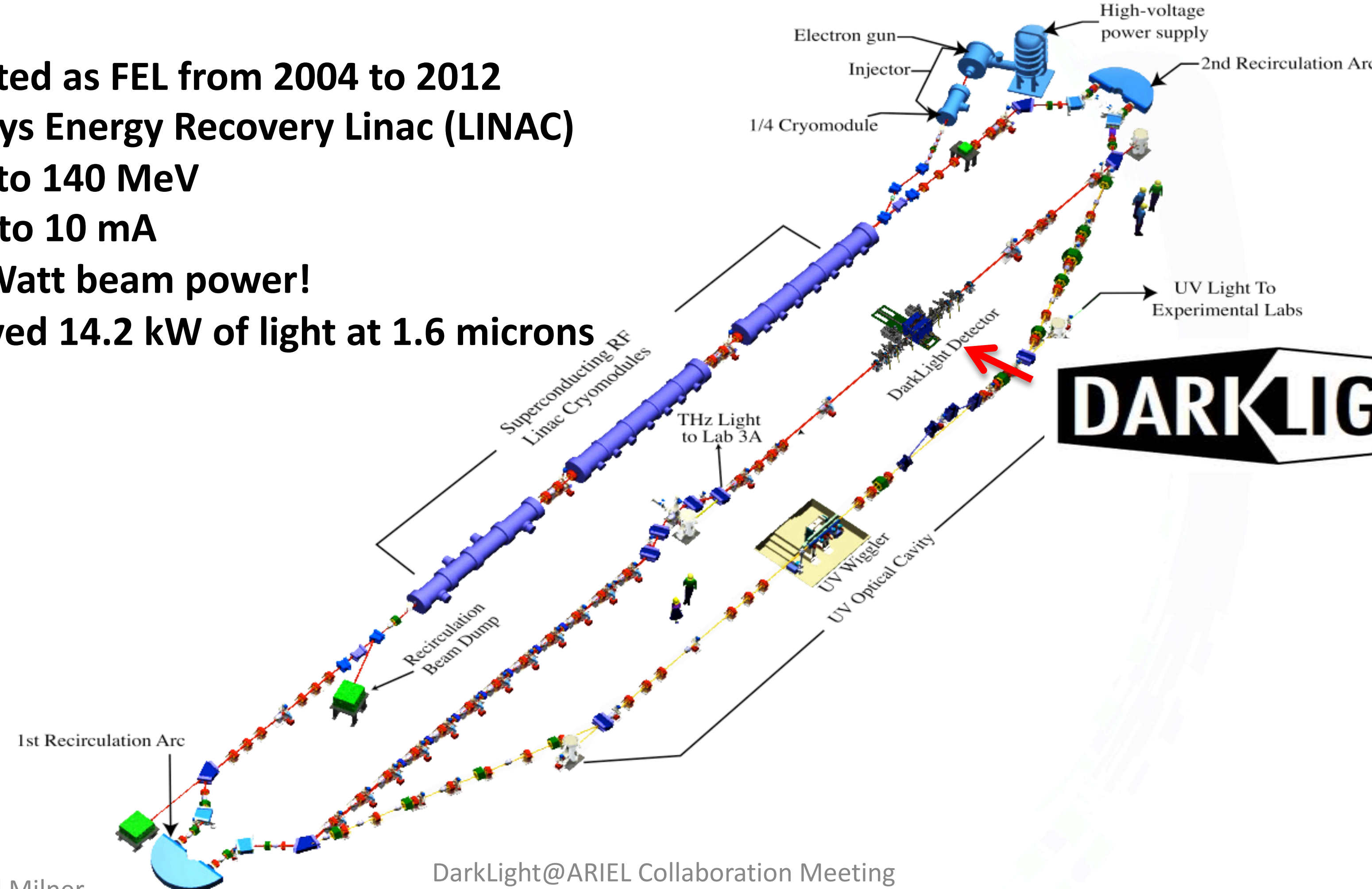
Generalized Fifth Forces

- A' exclusion limits are largely determined by π^0 decay.
- A' produced via π^0 decay requires a coupling to quarks.
- It is not difficult to construct models where the quark-A' couplings are suppressed and lepton-A' couplings are enhanced.
- For example, a vector gauge boson *X17* has been postulated which would mediate a fifth force with a characteristic range of 12 fm that would explain the Atomki anomaly.

  J. Feng *et al*., Phys. Rev. Lett. **117**, 071803 (2016)
- In this particular case, the A' gauge field is *protophobic*, i.e. proton coupling is suppressed relative to neutron coupling.
- DarkLight is well suited to look for evidence of this X vector gauge boson.
- DarkLight can also search for evidence of the invisible decay A' -> dark sector.
- Complementary to other planned measurements, e.g. LHCb.

Low Energy Recirculator Facility Layout

- **Funded by US Navy as prototype light source to shoot down missiles directed at an aircraft carrier**
- **Operated as FEL from 2004 to 2012**
- **Employs Energy Recovery Linac (LINAC)**
  - **- 80 to 140 MeV**
  - **- up to 10 mA**
  - **- MWatt beam power!**
- **Achieved 14.2 kW of light at 1.6 microns**



DARKLIGHT Timeline

- DarkLight proposal approved at JLab PAC 39 in June 2012 with "A" scientific rating for 90 days, conditional upon a successful test being completed
- Test successfully completed in July 2012
- Full scientific approval granted in May 2013
- Phase-I experiment was funded ($ 914 k) by NSF MRI July 2014 with strong support of Jefferson Laboratory
- The OLYMPUS target was shipped back to MIT in summer 2013 and the DarkLight target was designed and constructed. It was installed at the LERF in August 2016.
- An existing 0.5 T solenoid was provided by the Stony Brook U group, refurbished at MIT-Bates and shipped to JLab in June 2016.
- Jefferson Lab Readiness Review December 7, 2015 approved run plan.
- The phase-1 DarkLight experiment was installed in August 2016 and initial commissioning took place.
- In 2017, the LERF was reconfigured for LCLS cavity testing and unavailable for experiments.
- In 2018, the DarkLight collaboration proposed a dedicated search for the X17 particle at the CEBAF Injector. Deferred by PAC.
- In October 2019, the Atomki experiment reported further evidence for X17 on ^{4}He.
- In May 2020, the CEBAF Injector experiment was resubmitted but again deferred by the PAC.
- In August 2020, DarkLight collaborators reached out to TRIUMF to explore possible interest in an experiment.
- Discussions of DarkLight@ARIEL over the last six months have brought us to this point.

Sections ☰ **The Washington Post**

Health & Science

What scientists plan to do with the most powerful electron beam in the world

Scott Windham, left, and Jason Delk work at the Thomas Jefferson National Accelerator Facility, where scientists plan to use the world's most powerful electron beam to find signs of a particle that interacts with both dark and light matter. (Judith Lowery/Newport News Daily Press via AP)

By Tamara Dietrich June 25

NEWPORT NEWS, Va. — Look around — what do you see?

A paltry 5 percent of what the universe is made of, that's what.

Most Read

1 'Then the crying stopped': Man walks into pond with 3-month-old, drowning him as others watch

2 'I can't breathe!': Walmart employees charged with fatally crushing suspected shoplifter

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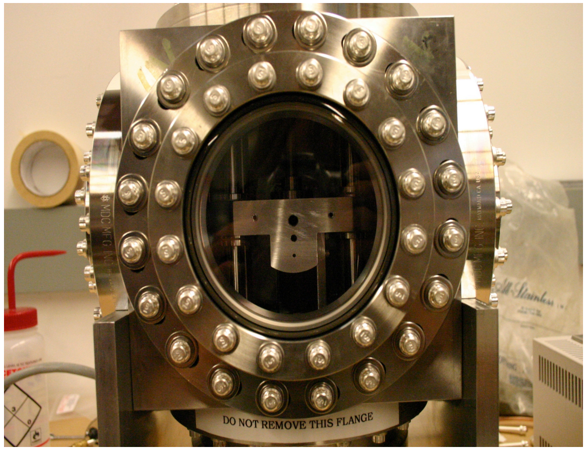
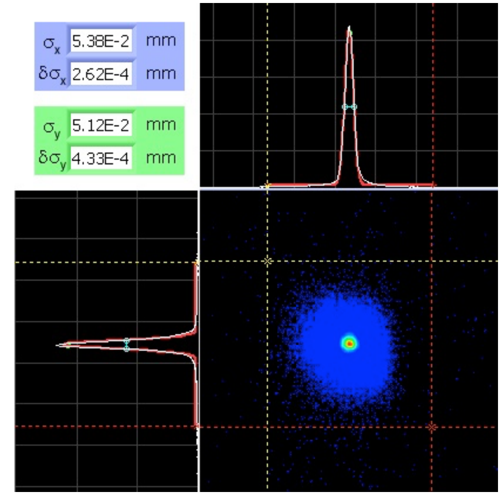
Successful DARKLIGHT beam test

July 2012



Target system designed and constructed at MIT-Bates R&E Center



- A test beam of 4.3 mA, 100 MeV (430 kWatt of e-beam power) was successfully transmitted through a 2 mm hole, 127 mm long, with a maximum loss of about 3 ppm for seven hours.
- Halo can be minimized and radiation in vault is manageable.
- The ERL has the stability required for DarkLight.
- Three papers written on test: *Phys. Rev. Lett*. **111**, 164801 (2013)
  Nucl. Instr. Meth. **A729**, 233 (2013)
  Nucl. Instr. Meth. **A729**, 69 (2013)

NSF MRI Award 2014

- Successful test followed by full scientific approval with “A” rating in May 2013
- MRI proposal based on existing solenoidal magnet provided by Stony Brook U
- $ 914,000 provided
- MIT responsible for target, vacuum, Møller dump, shipping, installation
- Hampton U responsible for GEM trackers
- ASU and Temple responsible for silicon detectors
- Cost sharing from ASU, MIT, and Temple
- Strong support from Jefferson Lab

Scientific Goals of Phase-I DarkLight
NSF MRI Phase-1

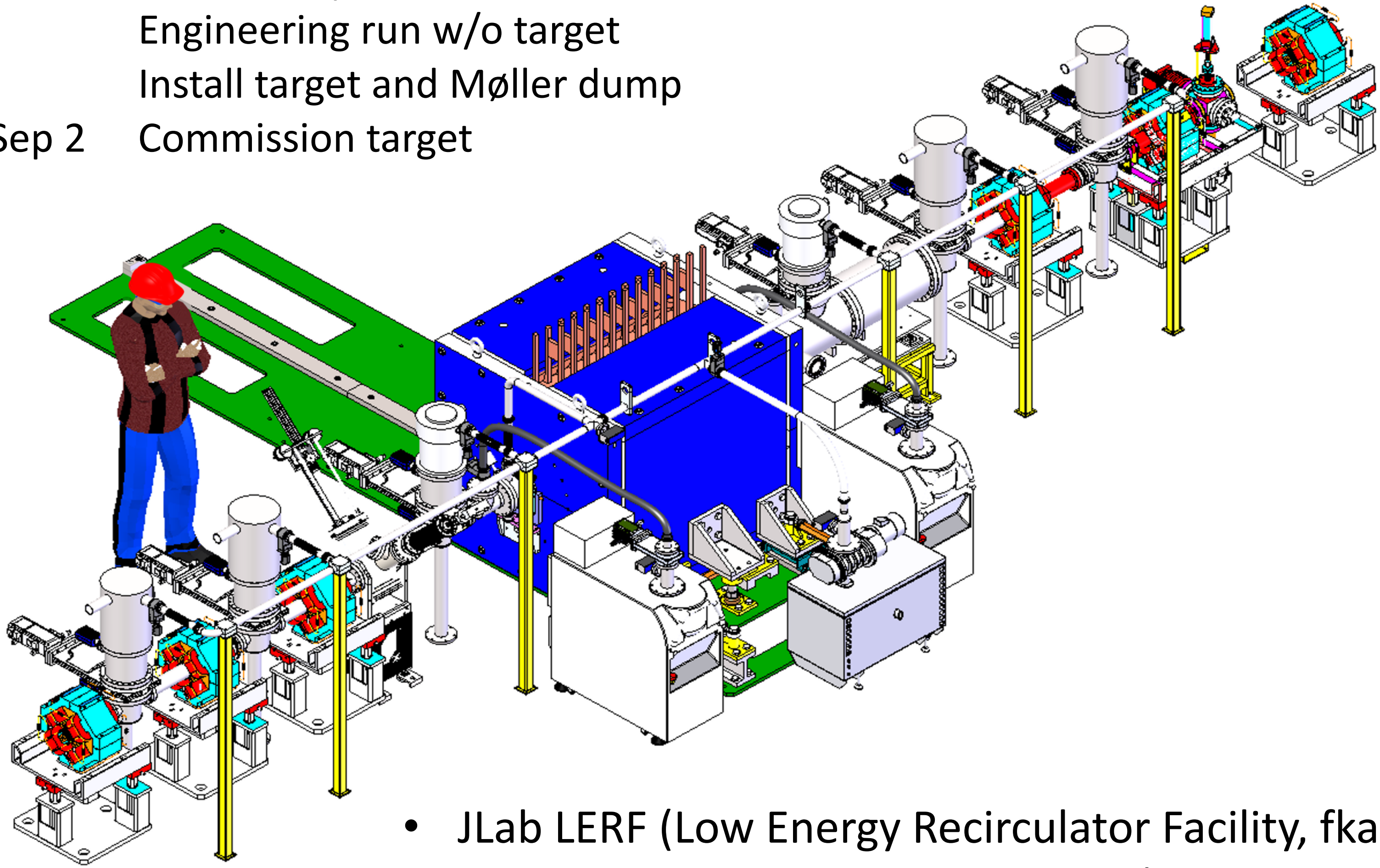
- Use 100 MeV electron beam from LERF
- Realize full luminosity: 10 mA on 10^{19} cm^{-2} of hydrogen
- Realize solenoidal magnet for complete experiment
- Realize prototype detectors and readout systems for complete experiment which enable three science goals

- **Science Goal 1a**: Accelerator Studies with the ERL
  - limits of energy recovery
- **Science Goal 1b**: Measurement of Radiative Møller Scattering
  - Rates depend on electron mass
- **Science Goal 1c**: Search for the A’

Charles Epstein

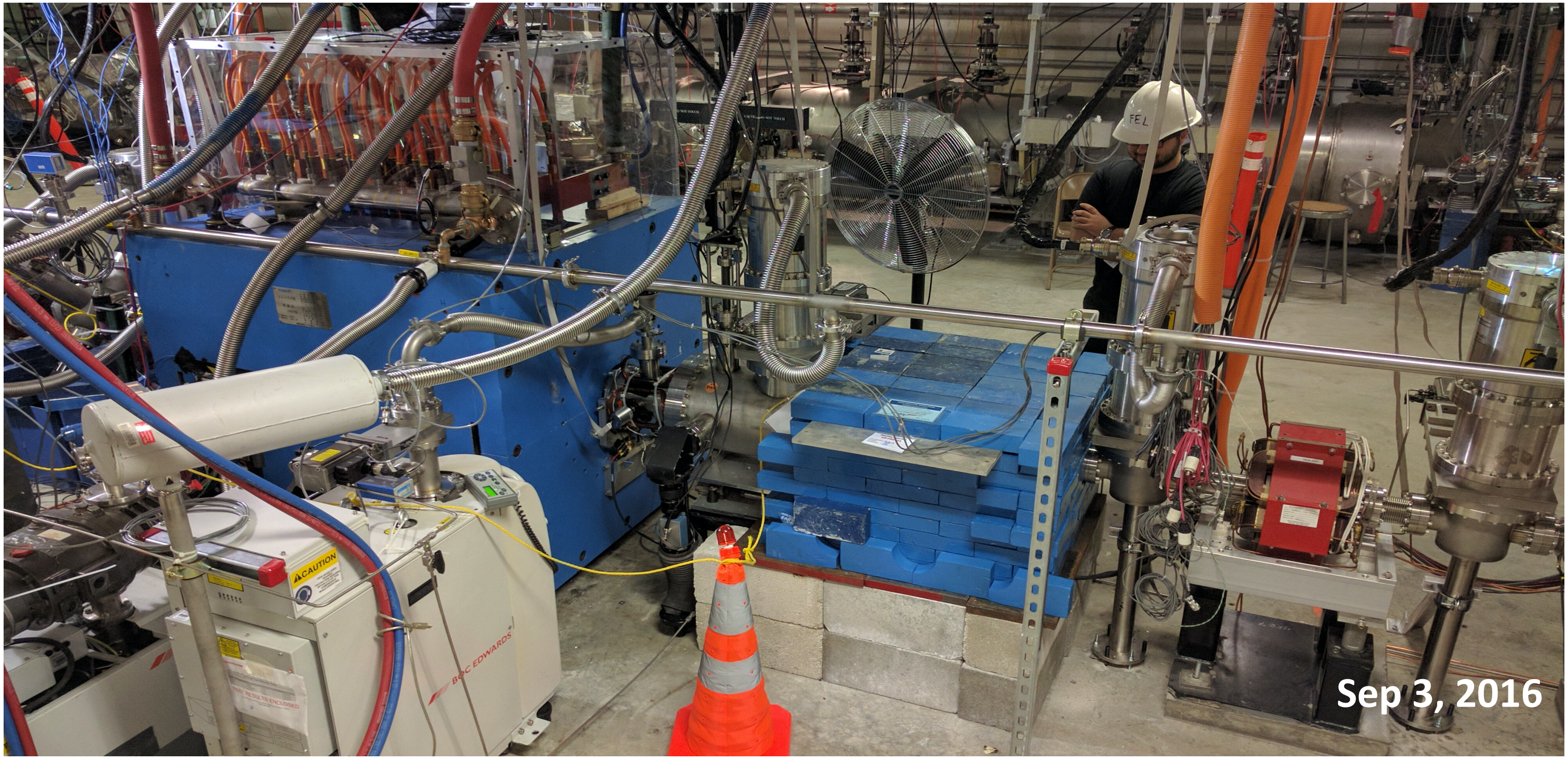
July – August 2016

- July 1-29 Phase-1 experiment installed
- Aug 1-5 Engineering run w/o target
- Aug 8-18 Install target and Møller dump
- Aug 26- Sep 2 Commission target



- JLab LERF (Low Energy Recirculator Facility, fka FEL)
- J. Balewski *et al.*, arXiv:1412.4717 (physics.ins-det)

DARKLIGHT Experiment



Target Commissioning Run

- Ran 24 hours/day for 7 ½ days. Two down periods for work on CEBAF cryo systems
- Achievements   S. Lee *et al.,* Nucl. Instr. and Meth. A **939**, 46 (2019)
  - Recovered Engineering run performance quickly and measured emittance to get match correct
  - Matched beam to solenoid
  - Could steer beam to compensate for solenoid steering
  - Gas target could run stably at 300 mTorr. No obvious effect on the beam
  - Machine ran well (RF, gun, drive laser, most diagnostics)
- Issues/Concerns
  - Target aperture limited duty cycle
  - Could not characterize halo due to losses in the target

Physics With Intense Low Energy Electron Beams

- *Proceedings of the* **Workshop to Explore Physics Opportunities with Intense Electron Beams up to 300 MeV**

  Cambridge, Massachusetts, USA March 14-16, 2013

  Edited by Roger Carlini, Frank Maas, and Richard Milner

  Published by the American Institute of Physics as AIP Conference Proceedings Vol. 1563

- **Intense Electron Beams Workshop**

  Cornell University, 16-18 June 2015

- WE-Heraeus Seminar **Physics of Energy Recovering Linacs**

  Bad Honnef, Germany October 16-18, 2017

Major Physics Thrusts

- Search for new physics BSM

  New forces

- Parity violating electron scattering

  Neutron distribution in nuclei

- Nuclear Astrophysics

  $^{16}O(e,e'alpha)^{12}C$ I. Friscic *et al.*, Phys. Rev. C **100**, 025804 (2019)

- Charge and magnetic radii of nucleon

  Proton radius puzzle

Summary

- Intense, low energy electron beams offer new scientific opportunities
  - Search for new forces which are motivated by simple extensions BSM
  - Nuclear astrophysics
  - Precision electromagnetic physics of nucleon
- There are hints that new physics beyond the Standard Model may lie uncovered at low energies:
  - Muon (g-2)
  - X17
- A programmatic search for electroproduced decays to e^+e^- with beams of energy 10 – 100 MeV is a technically straightforward and well established way to search.
- The DarkLight collaboration has developed an optimized experimental design.
- The ARIEL accelerator offers attractive electron beams to pursue such a search.

Search for New Physics in e^+e^- Final States Near an Invariant Mass of 17 MeV Using the CEBAF Injector

The DarkLight Collaboration

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(Dated: February 9, 2021)