DARKLIGHT 1c

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

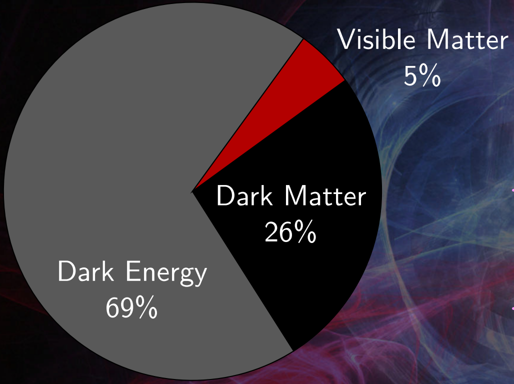
Jan C. Bernauer

JLAB PAC48 - August 2020

RBRC
RIKEN BNL Research Center

Stony Brook University

The Standard Model is just a sliver



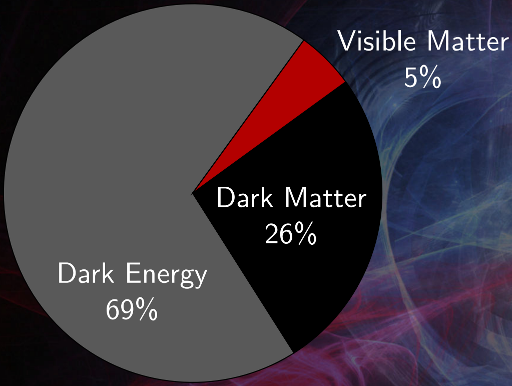
Standard Model

Something else

Search for BSM physics

- Phase space large for simple, infinite for complex models

The Standard Model is just a sliver



Standard Model

Something else

Search for BSM physics

- Phase space large for simple, infinite for complex models
- Two approaches: Cover large area – or look at anomalies
  Beryllium/Helium anomaly, $g_\mu - 2$, proton charge radius

X17

C | Physics | Technology | Community | In focus | Magazine

SEARCHES FOR NEW PHYSICS | NEWS

Rekindled Atomki anomaly merits closer scrutiny

20 December 2019

Atomki's new high-resolution $LaBr_3$ spectrometer, which will record gamma–gamma pairs from excited nuclei. Credit: Atomki

X17

C | Physics | Technology | Community | In focus

SEARCHES FOR NEW PHYSICS | NEWS

Rekindled Atomki anomaly merits scrutiny

20 December 2019

Atomki's new high-resolution $LaBr_3$ spectrometer, which will record ga
excited nuclei. Credit: Atomki

The plot thickens for a hypoth "X17" particle

Additional evidence of an unknown particle from a Hungarian lab gives to NA64 searches

27 NOVEMBER, 2019 | By Ana Lopes

The NA64 experiment at CERN (Image: CERN)

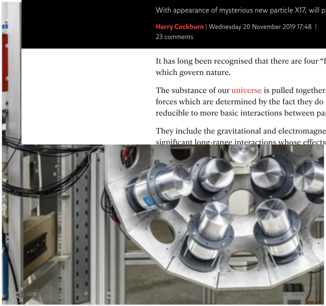
X17

SEA

Re

sc

20 D



Atomki's new high-resolution $LaBr_3$ spectrometer, which will record ga
excited nuclei. Credit: Atomki

Scientists may have discovered fifth force of nature, laboratory announces

With appearance of mysterious new particle X17, will physicists have to call time on hunt for dark matter?

Harry Cockburn | Wednesday 20 November 2019 17:48 |
23 comments

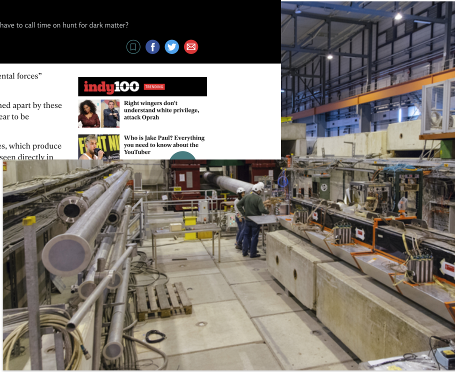
It has long been recognised that there are four "fundamental forces" which govern nature.

The substance of our universe is pulled together, or pushed apart by these forces which are determined by the fact they do not appear to be reducible to more basic interactions between particles.

They include the gravitational and electromagnetic forces, which produce significant long-range interactions whose effects can be seen directly in

The plot thickens for a hypoth "X17" particle

from a Hungarian lab gives



The NA64 experiment at CERN (Image: CERN)

X17

C Physics ▾ Technology ▾ Community ▾ In focus

SEA
Re
sc
20 D

The plot thickens for a hypoth
"X17" particle

from a Hungarian lab gives

INDEPENDENT

Support us Contribute Subscribe

NEWS POLITICS VOICES SPORT CULTURE INDY/LIFE INDYBEST VIDEO DAILY EDITION

Scientists may have discovered fifth force of nature, laboratory announces

With appearance of mysterious new particle X17, will physicists have to call time on hunt for dark matter?

Harry Cockburn | Wednesday 20 November 2019 17:48 |
23 comments

It has long been recognised that there are four "fundamental forces" which govern nature.

The substance of our universe is pulled together, or pushed apart by these forces which are determined by the fact they do not appear to be

indy100 TRENDING

Right wingers don't understand white privilege, attack Oprah

Google Translate

BBC Menú Buscar

NEWS | MUNDO

Noticias | América Latina | ¿Hablas español? | Internacional | Economía | Tecnología | Ciencia | Salud | Cultura | Video | Más ▾

Partícula X17: qué es la quinta fuerza que dicen haber descubierto científicos húngaros

Redacción
BBC News Mundo

25 noviembre 2019

Compartir

Principales noticias

"A las 8:14 era un día soleado, a las 8:15 era un infierno": los segundos apocalípticos en los que miles murieron tras la explosión de las bombas atómicas de Hiroshima y Nagasaki

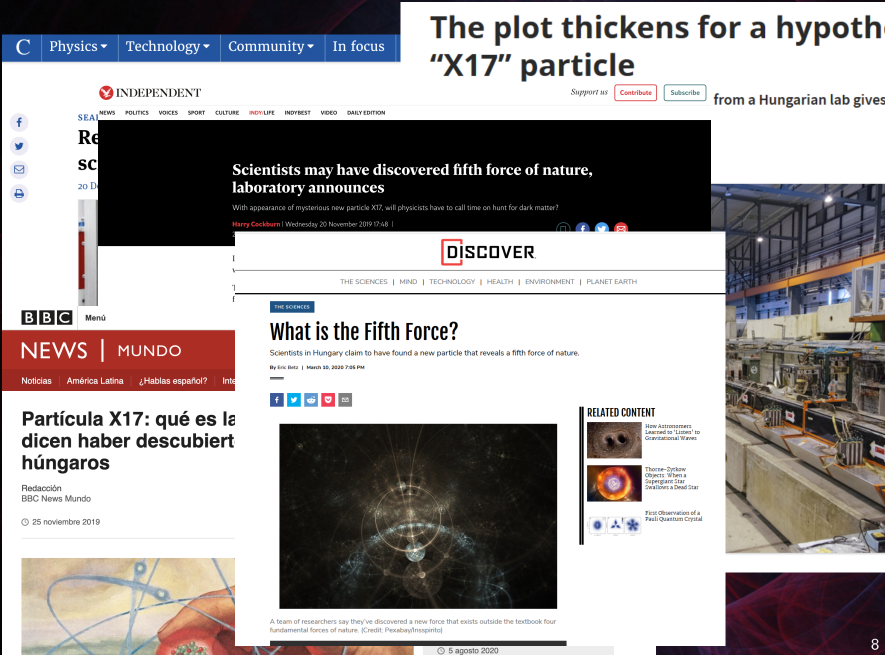
En este recorrido interactivo verás cómo ocurrieron y qué consecuencias tuvieron los dos únicos ataques con bombas nucleares de la historia. No te lo pierdas.

5 agosto 2020

Qué se sabe de la devastadora explosión en Beirut que dejó al menos 137 muertos y miles de heridos

5 agosto 2020

X17



Physics
Technology
Community
In focus
The plot thickens for a hypoth
"X17" particle
Support us
Contribute
Subscribe
from a Hungarian lab gives
INDEPENDENT
NEWS POLITICS VOICES SPORT CULTURE INDY/LIFE INDYBEST VIDEO DAILY EDITION
Scientists may have discovered fifth force of nature, laboratory announces
With appearance of mysterious new particle X17, will physicists have to call time on hunt for dark matter?
Harry Cockburn | Wednesday 20 November 2019 17:48 |
DISCOVER
THE SCIENCES | MIND | TECHNOLOGY | HEALTH | ENVIRONMENT | PLANET EARTH
THE SCIENCES
What is the Fifth Force?
Scientists in Hungary claim to have found a new particle that reveals a fifth force of nature.
By Eric Betz | March 10, 2020 7:05 PM
RELATED CONTENT
How Astronomers Learned to 'Listen' to Gravitational Waves
Thorne-Zytkow Objects: When a Supergiant Star Swallows a Dead Star
First Observation of a Pauli Quantum Crystal
A team of researchers say they've discovered a new force that exists outside the textbook four fundamental forces of nature. (Credit: Pexabay/Insspirito)
BBC Menú
NEWS | MUNDO
Noticias
América Latina
¿Hablas español?
Partícula X17: qué es la
dicen haber descubiert
húngaros
Redacción
BBC News Mundo
25 noviembre 2019
5 agosto 2020

X17

C Physics Technology Community In focus

The plot thickens for a hypoth
"X17" particle

from a Hungarian lab gives

INDEPENDENT

Support us Contribute Subscribe

NEWS POLITICS VOICES SPORT CULTURE INDY/LIFE INDYBEST VIDEO DAILY EDITION

Scientists may have discovered fifth force of nature, laboratory announces

With appearance of mysterious new particle X17, will physicists have to call time on hunt for dark matter?

Harry Cockburn | Wednesday 20 November 2019 17:48 |

DISCOVER

THE SCIENCES | MIND | TECHNOLOGY | HEALTH | ENVIRONMENT | PLANET EARTH

THE SCIENCES

What is the Fifth Force?

BBC Menú

NEWS | MUNDO

Noticias | América Latina | ¿Hablas español? | In

Partícula X17: qué es l dicen haber descubier húngaros

Redacción
BBC News Mundo

25 noviembre 2019

CNN World Africa Americas Asia Australia China Europe India Middle East United Kingdom LIVE TV Edition

SPACE + SCIENCE

A 'no-brainer Nobel Prize': Hungarian scientists may have found a fifth force of nature

By Ryan Prior, CNN
Updated 2:44 PM ET, Sat November 23, 2019

More from CNN

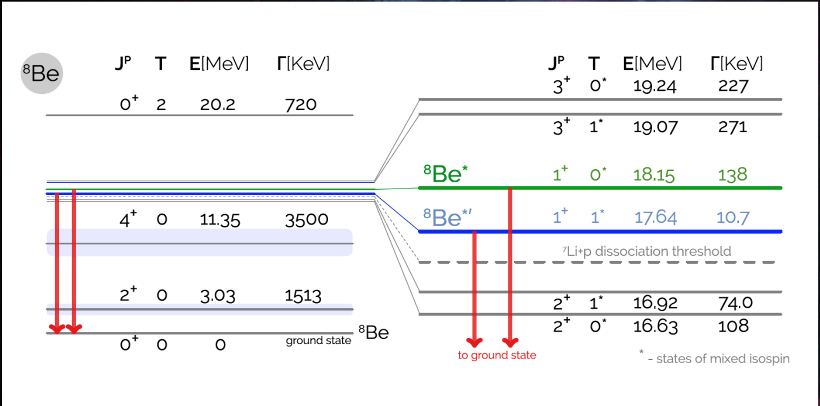
Alexis Ohanian on being married to Serena Williams and his...

5 things to know for August 6: Coronavirus, Beirut, White House...

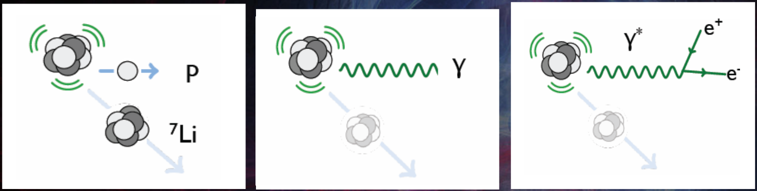
^8Be is special

Many images from arXiv:1707.09749

^8Be is special: two narrow, highly energetic states which can decay to ground state via E/M

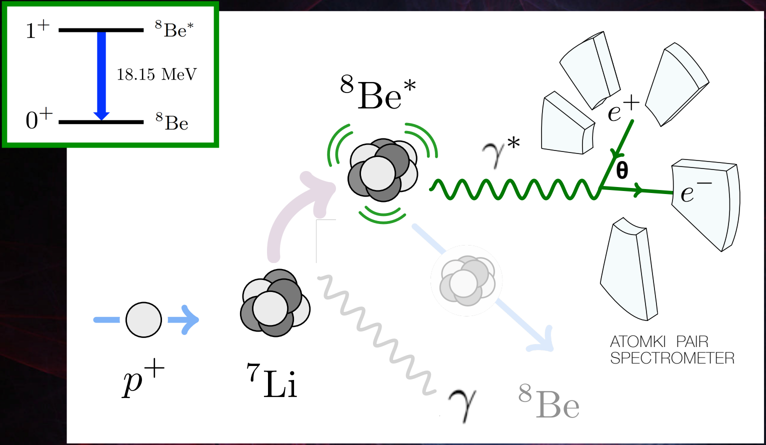


Decay modes of $^{8}Be(18.15)$



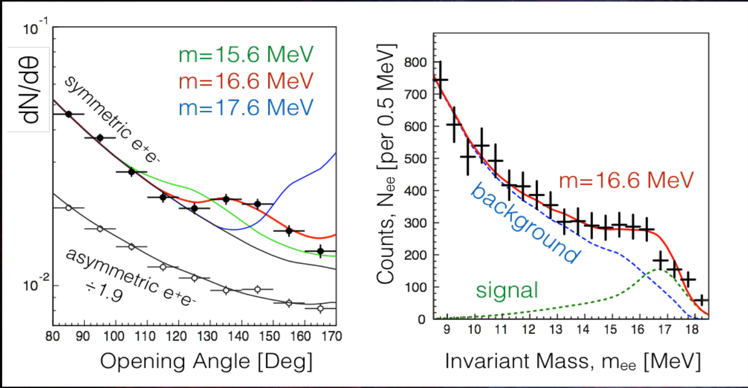
Hadronic, electromagnetic and through internal pair conversion

The Atomki experiment



1.04 MeV proton beam on ^7Li to $^8Be(18.15) + \gamma$. Followed by decay. Looked at $e^{\pm}$ pairs from internal conversion.

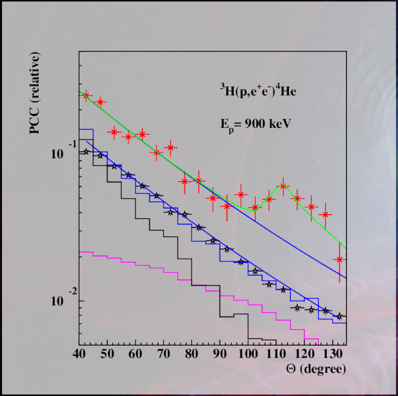
The Beryllium anomaly

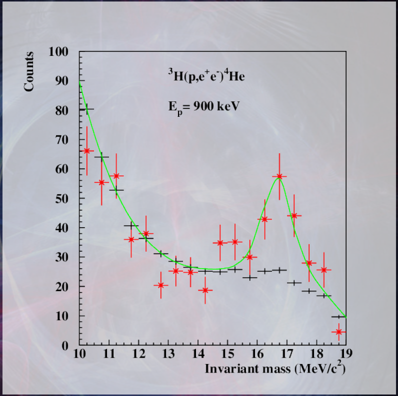


(from: arXiv:1707.09749v1, modified from PRL 116 042501 (2016))

- Feng et al. (PRL 117, 071803 (2016)): Proto-phobic force to evade current limits

New results on $^3H(p,\gamma)^4He$ arXiv:1910.10459 [nucl-ex]





- Updated experimental setup: reduced background
- Bump appears at different angle, but same mass: ^4He : 17.01 ± 0.16 MeV ^8Be : 16.84 ± 0.16 MeV

Why believe it?

- This model has $\chi^2/d.o.f.$ of 1.07, significance of 6.8σ
- Bump, not last bin effect
- Remeasured with new detector: A J Krasznahorkay et al 2018 J. Phys.: Conf. Ser.1056 012028
- Compatible masses in ^8Be and ^4He, and compatible couplings (Feng et al. arXiv:2006.01151)
- Non-linearities in Isotope shifts (King-plots), observed (I. Counts et al., arXiv:2004.11383)
  - Hard to distinguish from higher order SM effects.

Why not believe it?

- DM boson interpretation is proto-phobic to evade NA48/2 limits
  - Actually: $\frac{\epsilon_p}{\epsilon_n}$ coupling below $\pm 8\%$. Z^0 is $\sim 7\%$

Why not believe it?

- DM boson interpretation is proto-phobic to evade NA48/2 limits
  - Actually: $\frac{\epsilon_p}{\epsilon_n}$ coupling below $\pm 8\%$. Z^0 is $\sim 7\%$
- Recently, alternative processes were proposed
  - arXiv:2003.05722v3 Hard $\gamma + \gamma$ process
  - arXiv:2005.10643 Anomalous Internal Pair creation

How can we measure it at JLab?

- This particle can be produced via Bremsstrahlung, predominantly ISR off the electron.
- Measure

$$e^- \, Ta \to e^- \, Ta \, X \text{ followed by } X \to (e^- e^+)$$

- Irreducible background:

$$e^- \, Ta \to e^- \, Ta \, \gamma^\star \to e^- \, Ta \, e^+ e^-$$

How can we measure it at JLab?

- This particle can be produced via Bremsstrahlung, predominantly ISR off the electron.
- Measure

$$e^- \, Ta \to e^- \, Ta \, X \text{ followed by } X \to (e^- e^+)$$

- Irreducible background:

$$e^- \, Ta \to e^- \, Ta \, \gamma^\star \to e^- \, Ta \, e^+ e^-$$

- two spectrometers, measure e^+ and e^- in coincidence

How can we measure it at JLab?

- This particle can be produced via Bremsstrahlung, predominantly ISR off the electron.
- Measure

$$e^- Ta \to e^- Ta\, X \text{ followed by } X \to (e^- e^+)$$

- Irreducible background:

$$e^- Ta \to e^- Ta\, \gamma^\star \to e^- Ta\, e^+ e^-$$

- two spectrometers, measure e^+ and e^- in coincidence
- Best kinematics:
  - highest production rate if X takes all electron energy. Rise in CS beats all.
  - with limited and same out-of-plane acceptance, symmetric angle optimal.

Background

- Main background is NOT the irreducible one. Random coincidences between
  - radiative elastic electrons
  - positrons from (virtual) photon pair-production where e^- is missed
- Can optimize by moving electron arm backward.

Proposed setup

- 45 MeV beam, 150 μA on 10 μm tantalum foil $\longrightarrow$ about 0.3 inv. fb/s hydrogen equivalent
- Two spectrometers
  - $\pm 2^{\circ}$ in-plane, $\pm 5^{\circ}$ out-of-plane
  - Positron spectrometer at 16°, 28 MeV
  - Electron spectrometer at 33.5°, 15 MeV

Spectrometer design parameters

Kinematic var.	Acc.	Inv. mass res.	est. res. on focal plane	Error
in-plane angle	$\pm 2^\circ$	$22\ \frac{keV}{mrad}$	5mm/7cm$\rightarrow$1.4 mrad	$32\ keV$
out-of-plane angle	$\pm 5^\circ$	$5\ \frac{keV}{mrad}$	1.5°	$133\ keV$
momentum	$\pm 20\%$	$85\ \frac{keV}{\%}$	5mm/30cm$\rightarrow < 0.2\%$	$17\ keV$

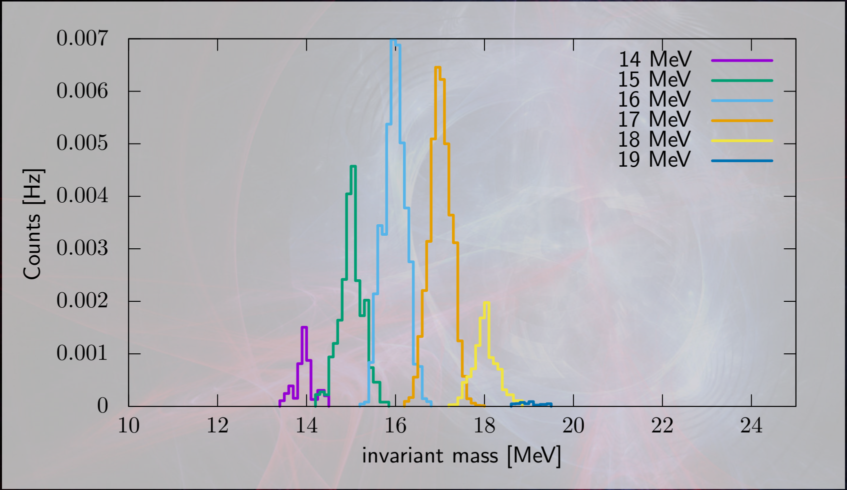
- Spectrometer can measure two quantities on first plane (position), but has additional multiple scattering for third quantity (angle)

Spectrometer design parameters

Kinematic var.	Acc.	Inv. mass res.	est. res. on focal plane	Error
in-plane angle	$\pm 2^\circ$	$22\ \frac{keV}{mrad}$	5mm/7cm$\rightarrow$1.4 mrad	32 keV
out-of-plane angle	$\pm 5^\circ$	$5\ \frac{keV}{mrad}$	1.5°	133 keV
momentum	$\pm 20\%$	$85\ \frac{keV}{\%}$	5mm/30cm$\rightarrow < 0.2\%$	17 keV

- Spectrometer can measure two quantities on first plane (position), but has additional multiple scattering for third quantity (angle)
- Simple dipole spectrometer, dispersive direction out-of-plane $\rightarrow$ out-of-plane angle is measured worst.
- Sum for two spectrometers: 194 keV, assumed 250 keV
- Have to do full simulation when realistic magnetic field is calculated.

Counting rates: X signal



Background rates

QED irreducible: 55 Hz coincidences,

Background rates

QED irreducible: 55 Hz coincidences,

... but 120 kHz e^+ singles

Background rates

QED irreducible: 55 Hz coincidences,

... but 120 kHz e^+ singles

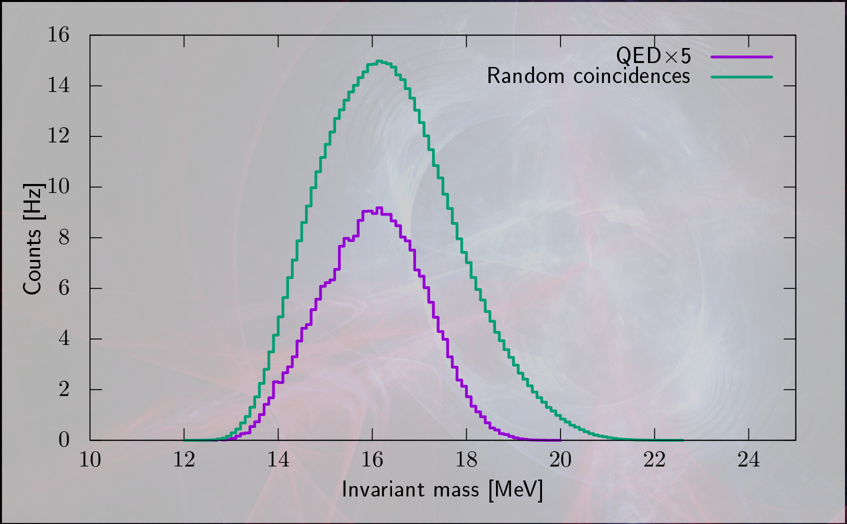
Initial state radiation e^-p: 6 MHz

$\longrightarrow$ Random coincidence rate 500 Hz

(at 1.5 GHz bunch rate)

This is the minimum trigger rate and sets the sensitivity.

Counting rates: Backgrounds



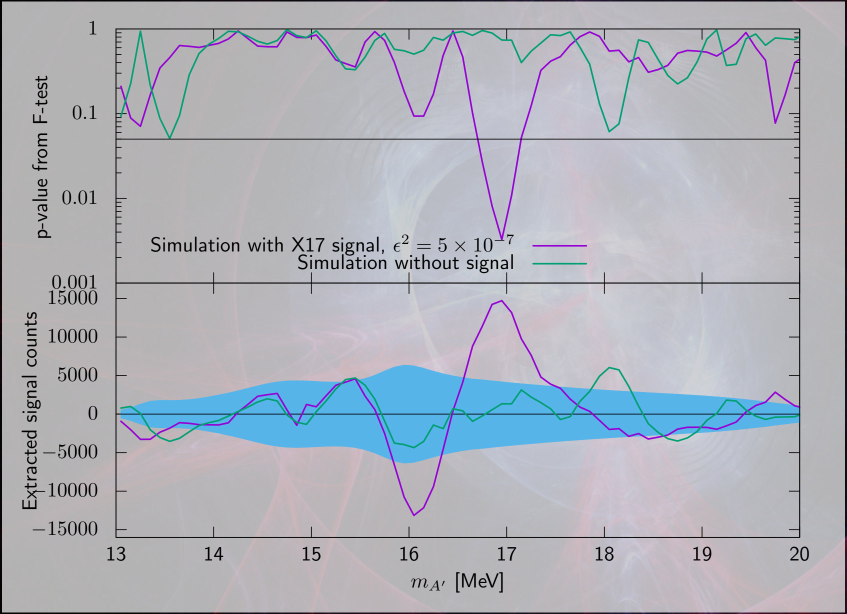
Dominated by accidental background

- Random coincidences dominate
- Scaling with instantaneous luminosity:
  - Signal $S \sim \mathcal{L}$
  - QED background $Q \sim \mathcal{L}$
  - Accidental background $A \sim \mathcal{L}^2$
  - Sensitivity $\frac{S}{\sqrt{Q+A}} \propto 1$ for $A \gg Q$

Dominated by accidental background

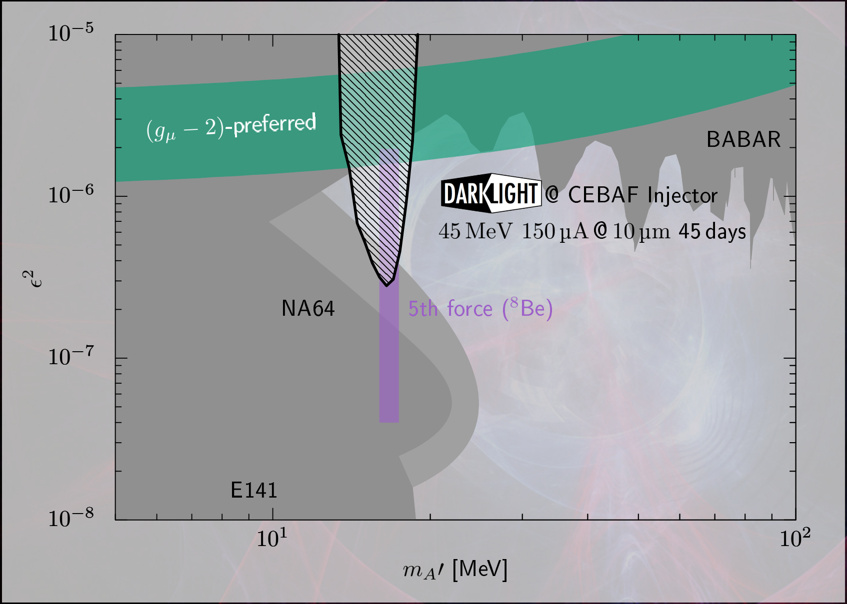
- Random coincidences dominate
- Scaling with instantaneous luminosity:
  - Signal $S \sim \mathcal{L}$
  - QED background $Q \sim \mathcal{L}$
  - Accidental background $A \sim \mathcal{L}^2$
  - Sensitivity $\frac{S}{\sqrt{Q+A}} \propto 1$ for $A \gg Q$
- Sensitivity almost independent of luminosity. Scale is set by bunch-clock / time resolution
- Out-of-time "coincidences" give accurate measure of acceptance including efficiency.

Search



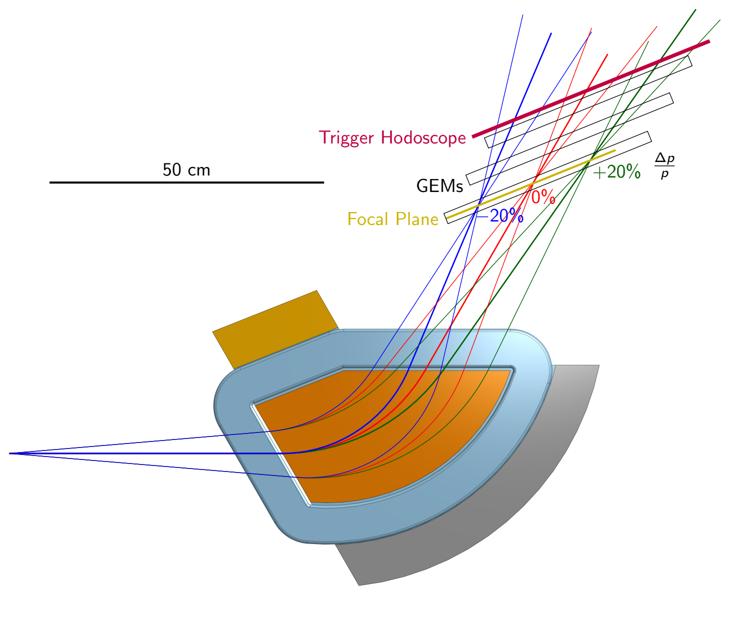
p-value from F-test
1
0.1
0.01
0.001
Simulation with X17 signal, $\epsilon^2 = 5 \times 10^{-7}$
Simulation without signal
Extracted signal counts
15000
10000
5000
0
-5000
-10000
-15000
13
14
15
16
17
18
19
20
$m_{A'}$ [MeV]

Reach

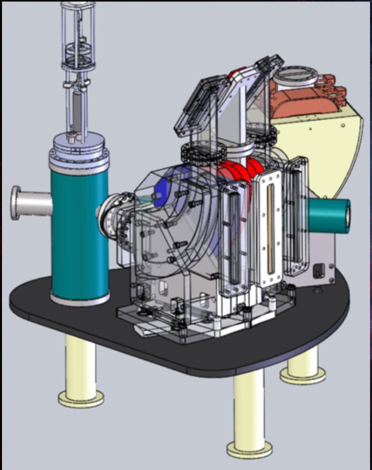


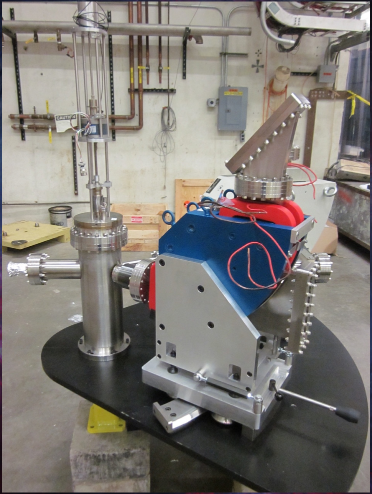
10^{-5}
10^{-6}
10^{-7}
10^{-8}
ϵ^2
$(g_\mu - 2)$-preferred
BABAR
DARKLIGHT @ CEBAF Injector
45 MeV 150 µA @ 10 µm 45 days
NA64
5th force (^{8}Be)
E141
10^1
10^2
$m_{A'}$ [MeV]

Spectrometers

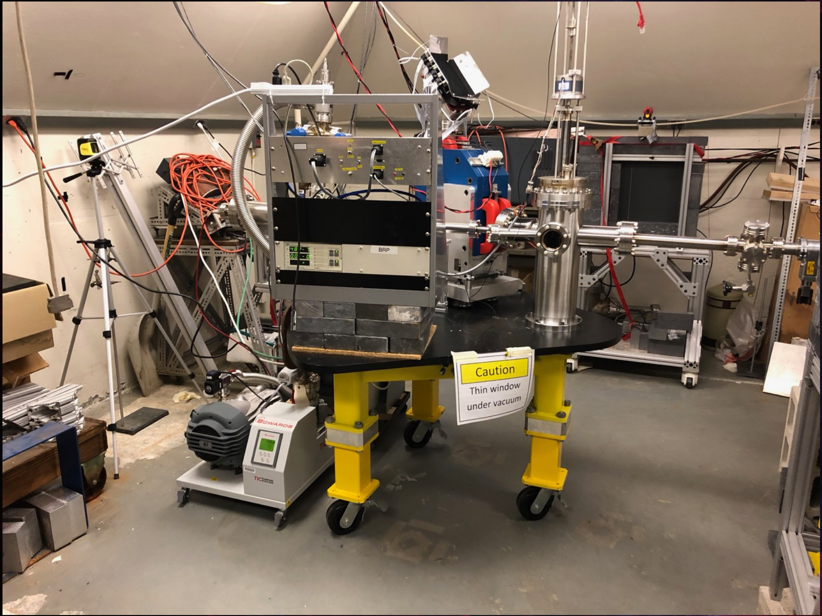


Experience: Møller at MIT HVRL

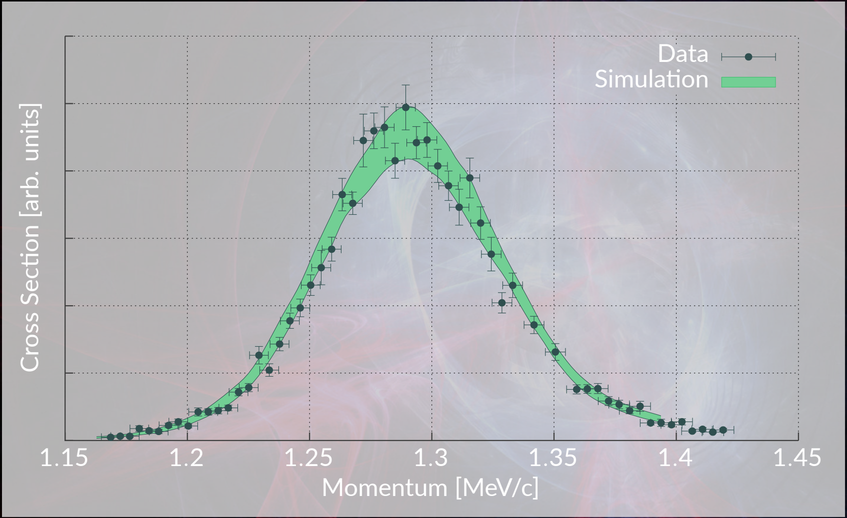




Møller experiment ran successfully



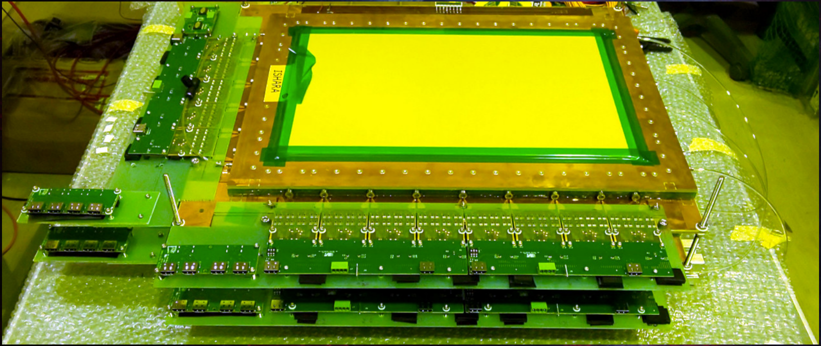
Example result



Epstein et al, Phys. Rev. D 102, 012006 (2020)

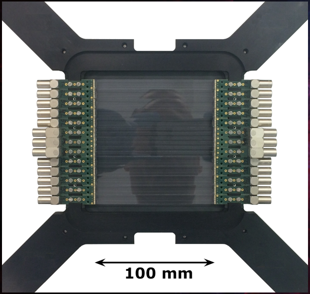
Tracking detectors

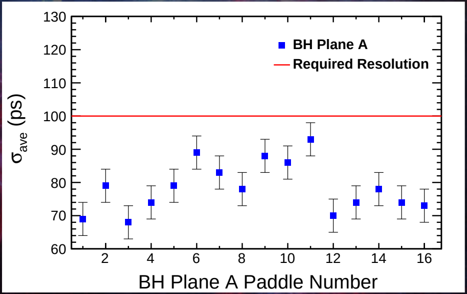
- Stack of three tGEMs, 25x40 cm, modified CERN design
- Readout via APVs and MPD4 (Same as SBS and PREX)
- Hampton group has built eight.



Trigger detectors

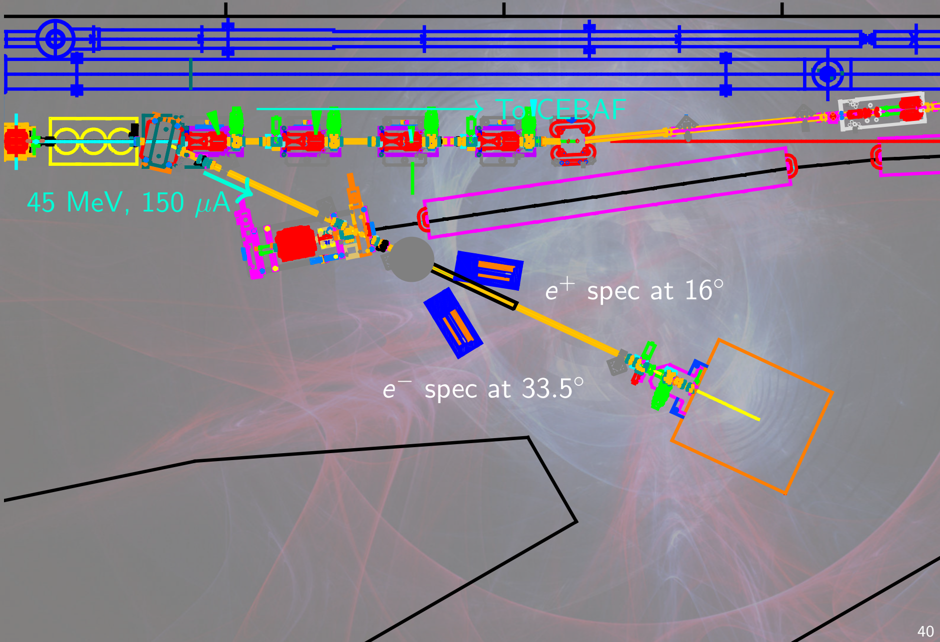
- Scintillator Hodoscope, 10 segments/spectrometer
- Needs timing resolution of < 500 ps
- MUSE beam hodoscope: 2 mm thick scintillator, SiPM readout: < 100 ps
  - Tested up to 8mm wide, 15 cm long.



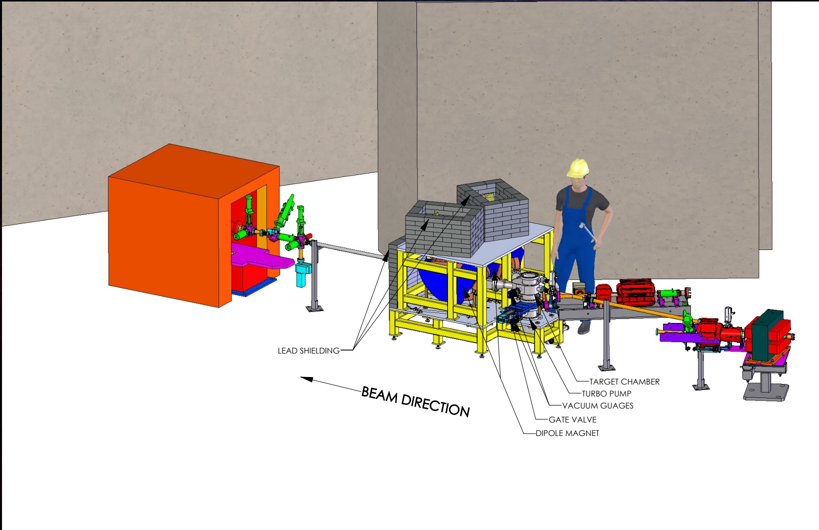


(arXiv:2007.12207)

Space requirements



3D rendering



Modifications to beamline

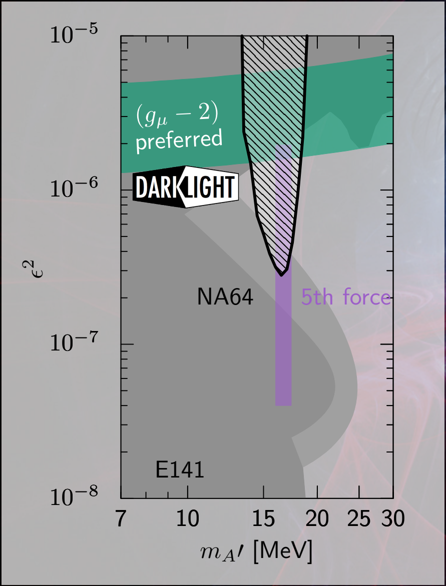
- Straight beam line segment replaced with target chamber + spool piece.
- Beam dump likely good enough, evaluating long term exposure.
- Normal operation and use of beamline for diagnostics possible with target in "out" position.

Could we run at LERF?

In principle yes, at the moment no

- Proposal was aimed at LERF, but we got guidance to look at injector, to facilitate a timely completion.
- Space should work out. Beam dump may be available.
- As of today, LERF can only achieve 32 MeV (leak). Below 40 MeV not sensible to do experiment.

Conclusion



The DARKLIGHT *Collaboration*

R. Alarcon, R. Dipert, G. Randall
Arizona State University, Tempe, AZ

A. Christopher, B. Dongwi, I. P. Fernando, T. Gautam, M. Kohl, J. Nazeer, T. Patel, M. Rathnayake, M. Suresh
Hampton University, Hampton, VA

P. Gueye
Michigan State University, East Lansing, MI

J. Grames, R. Kazimi, D. Machie, M. Poelker, S. Benson, J. Coleman, S. Frierson, C. Hernandez-Garcia, M. McCaughan, C. Tennant, S. Zhang
Thomas Jefferson National Accelerator Facility, Newport News, VA

J. Bessuille, P. Fisher, I. Friščić, D. Hasell, E. Ihloff, R. Johnston, J. Kelsey, S. Lee, P. Moran, R. Milner, C. Vidal, Y. Wang
Laboratory for Nuclear Science, MIT, Cambridge, MA

J. C. Bernauer, E. Cline, R. Corliss, K. Dehmelt, A. Deshpande
Stony Brook University, Stony Brook, NY

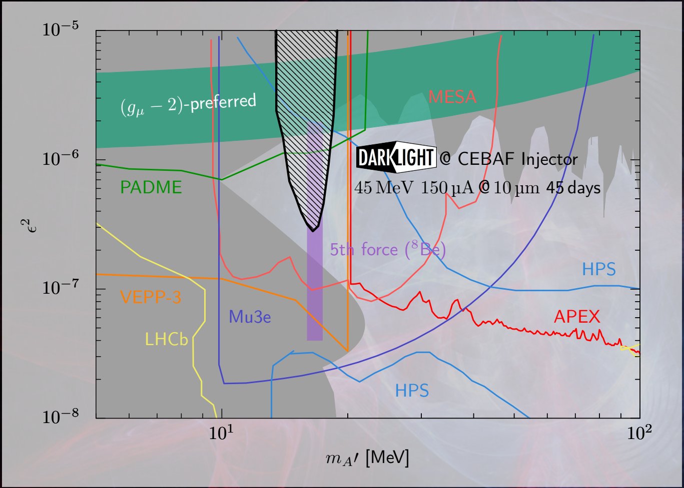
N. Kalantarians
Virginia Union University, Richmond, VA

Co-Spokespeople: Jan C. Bernauer (SBU/RBRC), Ross Corliss (SBU), Peter Fisher (MIT), and Richard Milner (MIT)

Backup slides

$\longrightarrow$backup slides$\longleftarrow$

Reach in comparison



- Mu3e: Commissioning in 2021
- MESA: Did not include random coincidences, post 2022
- VEPP-3: Schedule not known
- LHCb: Run 3, rejection for proto-phobic force not clear

LERF running

August 2016 running established:

- Operating windowless hydrogen gas target
- Møller dump concept validated
- Effect of solenoid on LERF beam observed, explained and compensation scheme developed
- No showstoppers encountered

Papers have been written on

- The windowless hydrogen gas target Nucl. Instrum. Methods Phys. Res. A, 939 (2019), pp. 46-54

Scintillator trigger

Several issues were raised:

- Thickness: Both considerations of timing resolution and background insensitivity push for a thinner scintillator. We have specified a thickness of 2 mm in the proposal.
- Timing resolution: A timing resolution of below 500 ps is adequate for the experiment. The design used at MUSE achieve sub 100 ps time resolution with SiPM readout.

Target cooling

- The beam deposits about 4 W in the target foil.
- Experience at Mainz with running small electrical motors in vacuum:
  Spinning the foil technically straightforward, eliminates the risk of accidental melting.

Spectrometer design

- Conceptual design finished.
- Based on expertise building the radiative Møller experiment at MIT.
- Full magnetic field calculation is in progress.
- Once the experiment is approved, high priority to completely specify the spectrometer design.

Detector resolutions

- Geant4 simulations are in progress.
- In-plane angle and momentum is measured using the first layer of the GEM, minimizing the effect of multiple scattering.
- Out-of-plane angle measurement will be affected, being studied.
- To estimate the reach, we assumed resolutions easily achieved even with naive spectrometer designs and coarse detectors.

Backgrounds in detectors I

- Detailed Geant4 simulations must include the detailed mechanical design, background rates from e+/-, photons, neutrons etc.
- Experience of successfully simulating and measuring these backgrounds from the July 2012 test at the LERF.
  - For example, the giant dipole resonance is the main process for generating neutron backgrounds.
  - Extensive Geant4 simulations of the DarkLight-1a configuration that involved detailed tracking of low energy particles. This was essential to the design of the Møller dump that was successfully validated in August 2016 running.

Backgrounds in detectors II

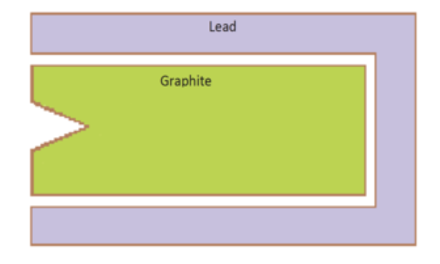
- Shielding to reject line-of-sight background trajectories from the target region to the detectors
- Collimator system to minimize particle trajectories hitting the magnets
- Minimized material thickness on the outside of the magnet bend so elastic scattered electrons can escape and are not rescattered.
- Photon background only affects the trigger rate, but not the background rate, because they will not produce tracks in the tracking detectors.

Beam dump

- The issue of a post-running radiation hazard due to activation of the beam dump during an extended running period will be looked into, in consultation with the JLab radiation control group.
- Initial findings indicate that it's likely that beam dump is useable.
- In case it's not, building of replacement beam dump is straight forward. See next slide.

6kW (40 MeV x 150 μA) beam dump

(Cite & Yilmaz, AIP Conf. Proc. 1722, 030001)



- Graphite core
  - low-cost
  - lower x-ray and neutron yield
  - $E_C = 110$ MeV for carbon
- Lead shielding
- Cone shaped entrance to redirect secondary electrons

- Fluka simulation yields:
  - few keV γs at edge of carbon, easily shielded by the lead
  - absorbed dose at the edge of carbon is low
- G. Fallon at MIT: estimate based on iron core, found a radiation level $<$ 1mr/hr when shielded with 20 cm of lead. Dominant activation product: Mn-54.

Conclusion: Beam dump for DL-1c is technically straightforward.

DARKLIGHT timeline (end of 2015)

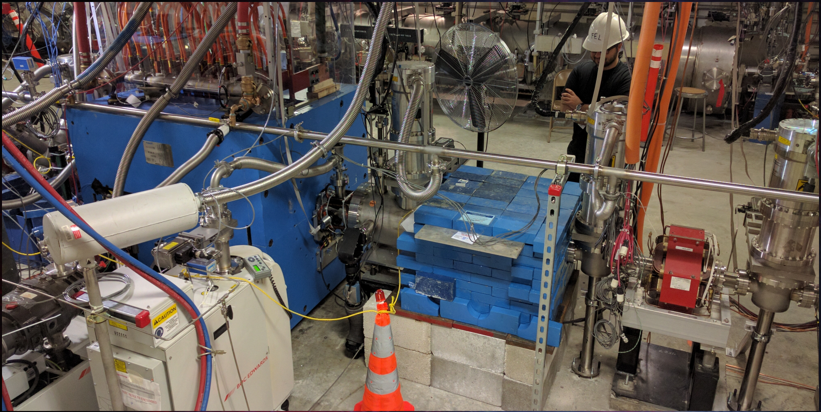
Phase 1: R&D, funded

- Will run at Jefferson Lab's LERF (fka. FEL)
  - 1a: First internal target/solenoid in an ERL (2016)
  - 1b: First measurement of radiative Møllers at 100 MeV (2016)
  - 1c: Prototype with reduced acceptance (2017)

Phase 2: Full experiment

- Simulation / design work for full experiment still in progress.

DARKLIGHT



- Search for A', via $e + p \to e' + p' + X$
  $X \to e^+e^-$ (visible) or $X \to (f^+f^-)||\ldots$ (invisible)
- Record all outgoing visible momenta $\to$ thin target

DARKLIGHT timeline (mid 2018)

Phase 1: R&D, funded

- Is run at Jefferson Lab's injector, LERF and MIT's HVRL
  - 1a: First internal target/solenoid in an ERL (2016)
  - 1b: First measurement of radiative Møllers at 2.5 MeV (2018)
  - 1c: Test of 17 MeV fifth force (2019)

Phase 2: Full experiment

- Simulation / design work for full experiment still in progress.