

DarkLight Annual Progress Report

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On Behalf of the DarkLight Collaboration

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Stony Brook University
Stony Brook, NY

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Massachusetts Institute of Technology
Cambridge, MA

TRIUMF PP-EEC Review
April 18, 2023



Stony Brook University



Introduction

- Previous PP-EEC approved DarkLight for 1300 h beam time
- Have made significant progress
 - Spectrometer and chamber design, simulation, background characterization
- Aiming for installation this fall
- Workshop organized on scientific opportunities at ARIEL e-linac
 - Proceedings published:
<https://iopscience.iop.org/issue/1742-6596/2391/1>



**New Scientific Opportunities
at the TRIUMF ARIEL e-linac**

Vancouver, Canada
May 25-27, 2022

Fundamental Physics
Innovation
AWARDS

APS
physics

GORDON AND BESSIE
MOORE
FOUNDATION

ARIEL

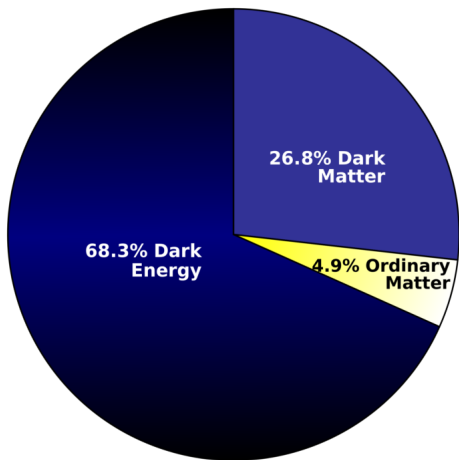
TRIUMF

Stony Brook
University

New Scientific Opportunities with the TRIUMF ARIEL e-linac

<https://meetings.triumf.ca/event/262/>

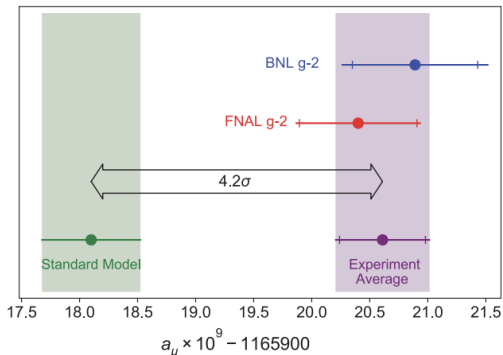
Large Phase Space To Search



- There is a lot we do not know!
- Phase space grows with complexity of model
- One either performs a broad search, or focuses on existing anomalies to illuminate the path

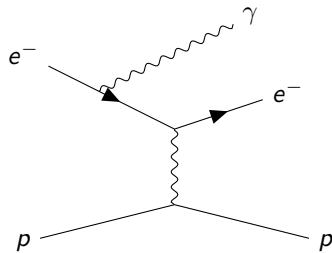
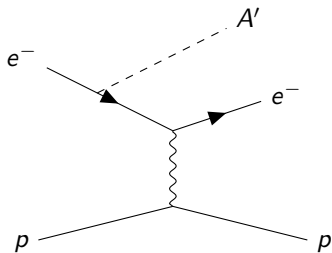
Anomalies Abound

- $(g - 2)_\mu$ anomaly (among other μ puzzles)
- Differences in standard model values between theorists calculations
- Could be indicative of BSM physics



B. Abi, *et al.*, PRL 126, 141801 (2021)

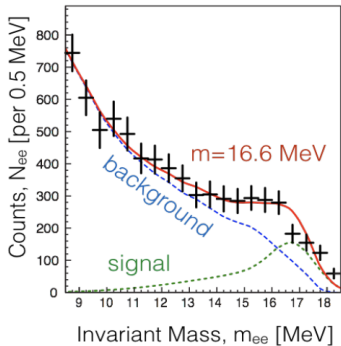
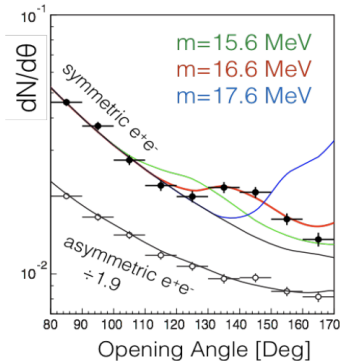
Dark Photon



- Is there a dark photon? Dark partner to the EM photon?
- Proposed by B. Holdom, Phys. Lett. B166, 196 (1986)
- Universal coupling to electric charge, but weaker by factor ϵ^2 .
- Could there be something beyond a dark photon?

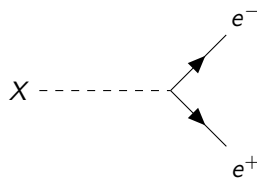
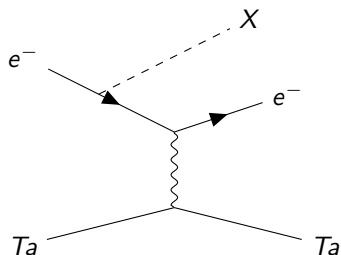
Atomki Experiment

- Signal rises and falls with proton beam energy
- Bump within acceptance, not edge effect
- Appears only for symmetric pairs, which is expected for intermediate massive particle
- Similar story for ${}^4\text{He}$ and ${}^{12}\text{C}$, different angle, same mass
- Points to proto-phobic vector boson



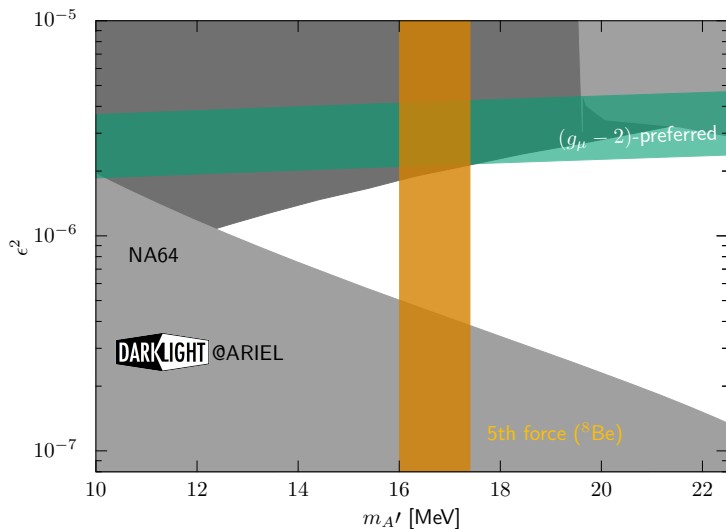
B. Fornal, Int. J. of Mod. Phys. 32 (25), 2017

Dark Boson - Measurable in an Accelerator!



- Measure the produced e^+e^- spectrum and reconstruct invariant mass
- $m(e^+ + e^-) = m(X)$
- Need a high current, low energy electron accelerator
- Sensitive to leptonic-only coupling models!

Complementarity



X17 points us to an area where we do not have lepton-based exclusion limits! If theory groups can bring $g_\mu - 2$ into better agreement with experiment, the $g_\mu - 2$ preferred band will move down in this figure.

DarkLight!

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Hampton University, US

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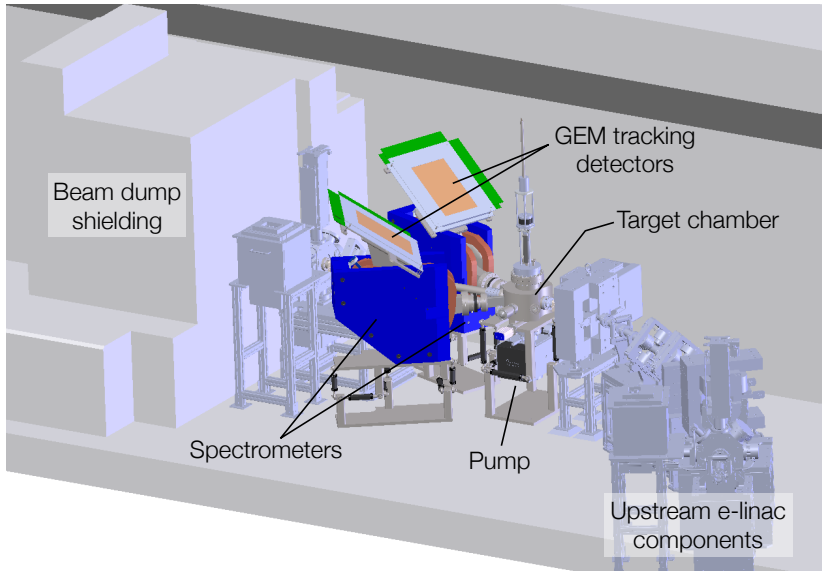
J. Martin

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I. Friščić

University of Zagreb, HR

DarkLight at ARIEL!



Several Stages of Running

- Planned upgrades and expansions to the ARIEL hall
- Phase 0
 - Minimal changes
 - Run at 31 MeV near beam dump
 - Planned run this Fall and next Spring

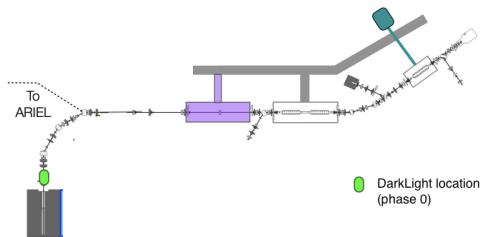


Figure from T. Planche, [ARIEL Workshop](#)

Several Stages of Running

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- Phase 1
 - Single user mode
 - Up to 51 MeV
 - CFI grant submitted, passed conceptual design review

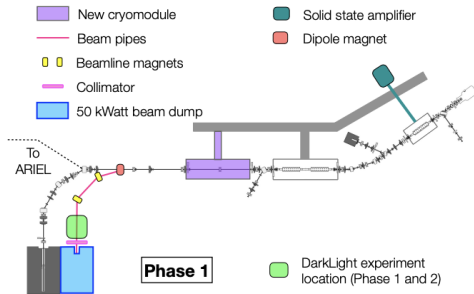


Figure from T. Planche, [ARIEL Workshop](#)

Several Stages of Running

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- Phase 2
 - Multi-User mode
 - 51 MeV

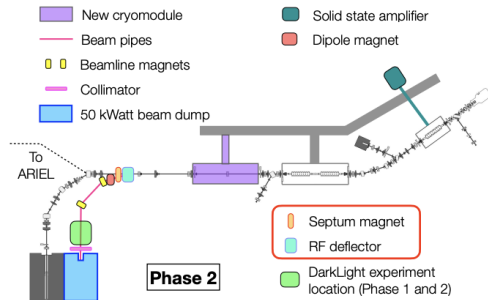
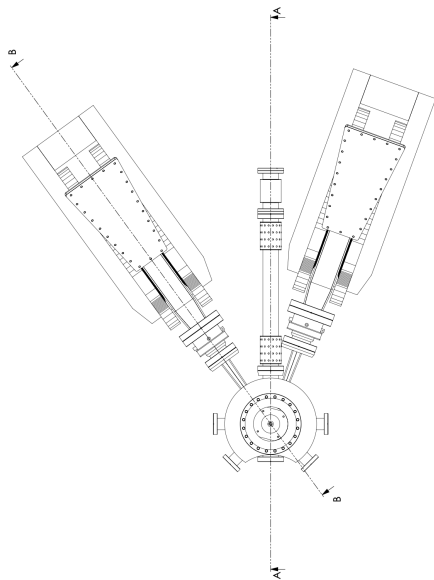


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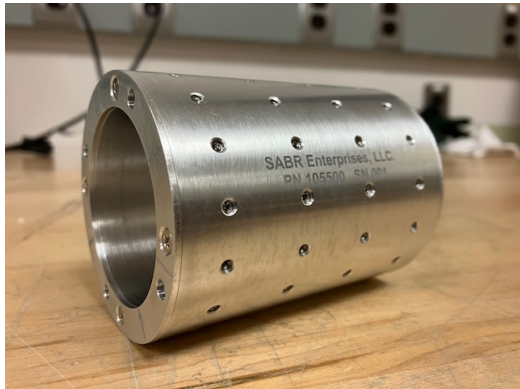
DarkLight Target Vacuum Chamber

- 10, 5, and 1 μm thick Ta foil target acquired
- 0.5 μm foil ordered
- 300 μA beam, 30 MeV \rightarrow 8 W heating
- Target ladder allows “empty space” configuration
- Design and construction underway at MIT Bates
- Characterized backgrounds in experimental hall in spring 2022



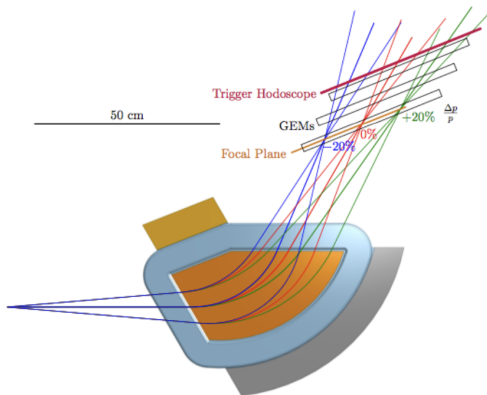
Permanent Magnets

- Permanent magnets acquired from SABR
- Incorporated in beam line optics simulation and FLUKA calculation
- Installation onto beam line planned for this fall



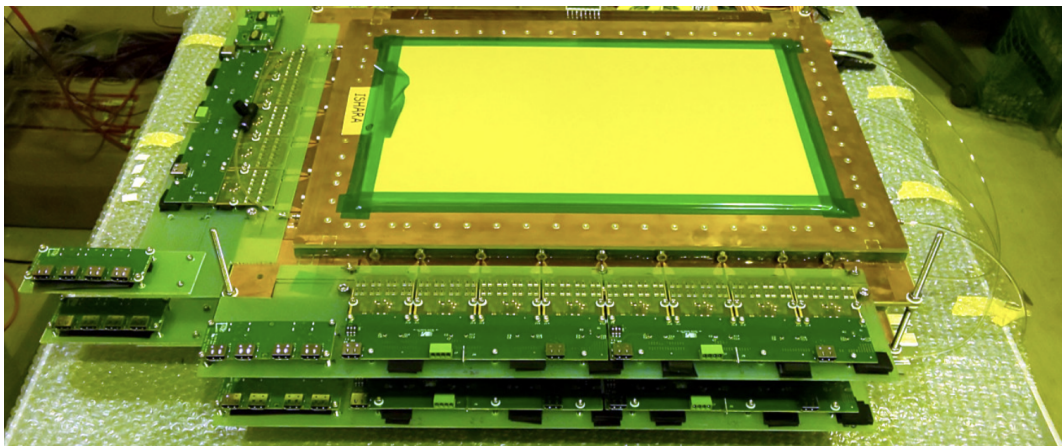
Spectrometers

- Up to 35 MeV central momentum, 0.38 T field
- $\pm 2^\circ$ in-plane, $\pm 5^\circ$ out-of-plane acceptance
- $\pm 20\%$ momentum acceptance
- Mass resolution ≈ 120 keV
- Spectrometer angles, 20° (36°) for e^+ (e^-) in Phase 0 configuration
- Final configuration work ongoing, order to be placed shortly



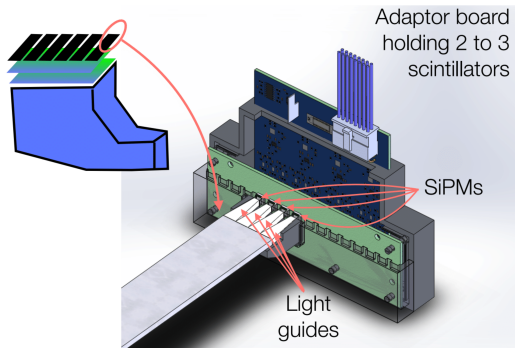
Tracking Detectors

- $25 \times 40 \text{ cm}^2$ triple-GEMs built by Hampton
- APV+MPD4 readout
- Planes constructed and already available
- Will travel to JLab next week to leak-check, HV test, and attach readout

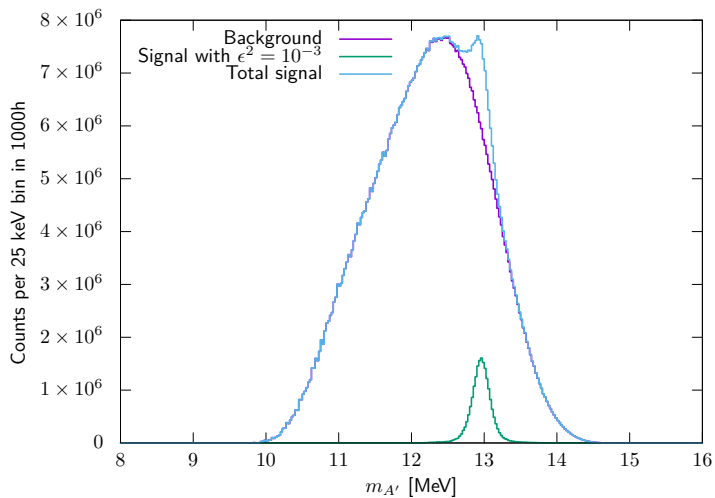


Trigger Hodoscope

- Trigger via segmented scintillator hodoscope
 - Double-ended SiPM readout
 - Design resolution < 200 ps
- Under construction at TRIUMF
- HV supply boards being tested at SBU
- DAQ development underway at TRIUMF

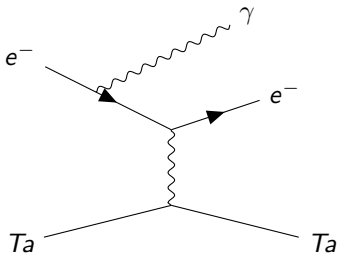


Bump Hunt

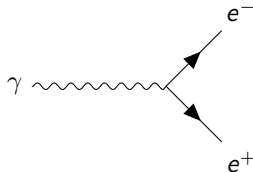


Background Processes

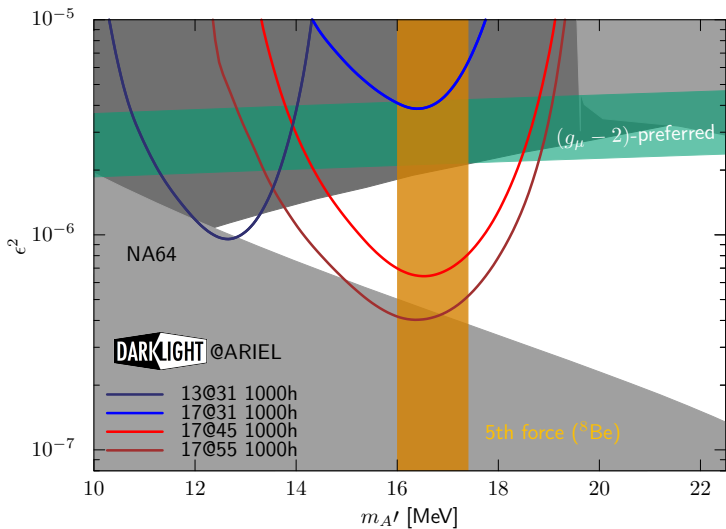
- Irreducible background
 - $X17 \rightarrow e^+e^-$ competes with $\gamma \rightarrow e^+e^-$
 - γ from scattering or radiative terms
 - e^+e^- pairs from γ scales with \mathcal{L}
- Random background
 - Any e^+ with beam e^-
 - Scales with \mathcal{L}^2



- Figure of merit for bump hunt
 - $$\frac{S}{\sqrt{B}} = \frac{p_{sig}\mathcal{L}}{\sqrt{p_{irred}\mathcal{L} + p_{rand}\mathcal{L}^2}}$$
 - Independent of \mathcal{L} at large \mathcal{L} !
 - p_{random} can be optimized by moving electron spectrometer to larger angles

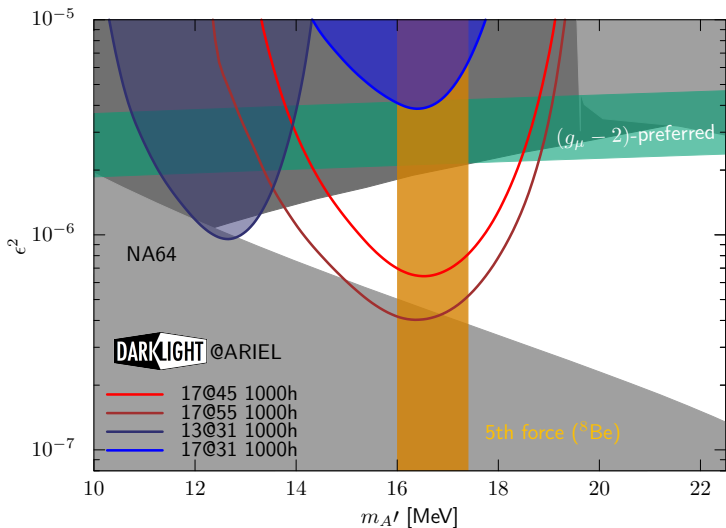


Projected Reach



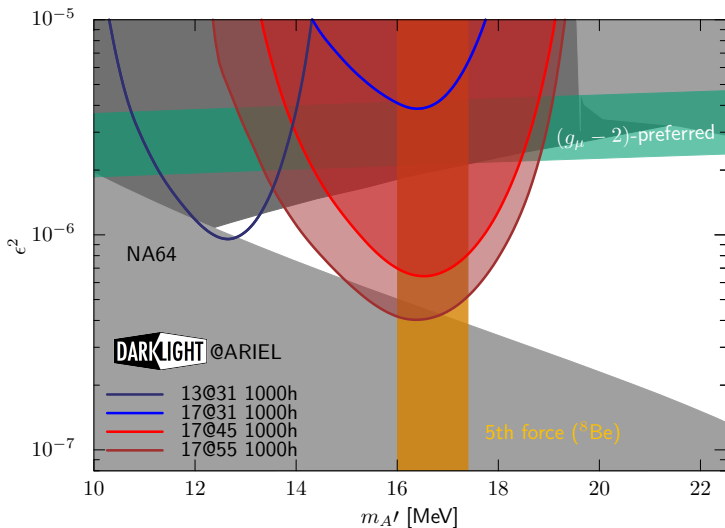
If theory groups can bring $g_\mu - 2$ into better agreement with experiment, the $g_\mu - 2$ preferred band will move down in this figure.

Projected Reach at 30 MeV



If theory groups can bring $g_\mu - 2$ into better agreement with experiment, the $g_\mu - 2$ preferred band will move down in this figure.

Projected Reach with Energy Upgrade



If theory groups can bring $g_\mu - 2$ into better agreement with experiment, the $g_\mu - 2$ preferred band will move down in this figure.

Test Run Upcoming



Moving near the beam dump in 2023. Photo Credit: T. Planche, [ARIEL Workshop](#).

The Path Forward

- Phase 0: Existing ARIEL Design
 - GEMs can be commissioned and available within 6 months
 - Trigger construction underway
 - Can begin installation and commissioning at TRIUMF this fall, 2023!
- Second cryo-module Implementation
 - Phase 1: additional cryo-module installed to reach 50 MeV beam
 - Phase 2: Septum + kicker to allow simultaneous running with ARIEL

Summary

- PP-EEC approved for 1300 h of beamtime for DarkLight
- Progress on multiple fronts in the past year
 - Finalized detector layout and experiment design
 - Submitted CFI grant and passed conceptual design review
 - Completed detailed technical review of magnets, scheduling similar review for vacuum systems
 - Secured US funding for experiment setup
 - FLUKA studies underway, used to design beam dump collimator, verifying background characterization
 - Supporting 6 undergraduates, 2 in CA, 4 in US, 1 Master student, 3 Ph. D. students, more to come!