# Search for New Physics in $e^+e^-$ Final States With an Invariant Mass of 10-20 MeV Using the ARIEL Electron Accelerator

*The DarkLight Collaboration*

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# Abstract

The DarkLight collaboration proposes a run of 2000 hours at the electron accelerator of the Advanced Rare IsotopE Laboratory (ARIEL) at TRIUMF, initially with 31 MeV beam and 150 µA current, to search in the $e^+e^-$ invariant mass region $10-20$ MeV in electron scattering from tantalum for evidence of new physics, motivated by anomalies resulting from the muon $g-2$ determination and reported in the decays of excited $^8$Be and $^4$He (Atomki anomaly). As the energy available with the ARIEL electron accelerator increases, we envisage further requests for additional beamtime to cover all the remaining untested coupling range. It will then provide a definitive experimental constraint on the existence of a dark fifth-force carrier, proposed to explain the Atomki anomaly. If scientifically approved, the experiment can begin data-taking about 12 months after funding is made available. The experiment can form the basis for M.S. and Ph.D. theses for graduate students at collaborating universities.

# 1. Scientific Motivation

The Standard Model (SM) describes the physical universe in terms of interactions between point-like fermions (quarks and leptons), gauge bosons which mediate those interactions, and the Higgs field that provides mass to the fermions. Combined with Einstein's theory of gravity (General Relativity), this theory has been incredibly successful. The vast majority of experiments have been consistent with the SM, and no credible alternatives have been put forth.

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This proposal is motivated by the observation of SM anomalies from low energy experiments. In particular, the Atomki experiment in Hungary reports anomalies in the electromagnetic decays of excited states of the $^4$He and $^8$Be nuclei. The experiment proposed here is motivated by the conviction that any reports of possible extensions beyond the SM must be independently validated with high priority.

### 1.1 The Elusive Dark Matter

The search for an understanding of the elusive Dark Matter is one of the great scientific quests of our age. In the 1930s, astronomers first wrote of *dunkle Materie* [1]. Almost ninety years later, there is collective evidence that is substantial and consistent across seven orders of magnitude in distance scale (from about 1 kpc to 10 Gpc) that an unknown substance—dark matter—shapes the large-scale structure of the universe. It is also abundant, seeming to account for about 85% of the mass of the universe. In our current understanding, the known, uncharged particles, i.e. the neutron or neutrino, cannot be a major component of the inferred dark matter mass, and so we posit at least one as-yet unobserved new particle.

This particle must obviously interact gravitationally, but we expect it also interacts with the visible universe through other mechanisms, with coupling on the order of the weak interaction or less, in order for dark matter to be in equilibrium with other matter in the early universe.

The focus over several decades has been to look for a particular type of possible dark matter, a Weakly Interacting Massive Particle (WIMP). Thus far, no conclusive evidence for WIMPs has been found. Searches for WIMPs will continue for at least another decade. However, there is a fundamental floor on this approach due to the inability to distinguish between a neutrino-atom interaction and a WIMP-atom interaction.

A complementary experimental thrust is to search for evidence of the mediator of a new interaction between our visible world, successfully described in terms of four forces (gravity, electricity and magnetism, nuclear force and weak force), and the world of dark matter. This new interaction would constitute a fifth force. The simplest mediator widely considered is a dark photon, $A'$, that couples to the known particles via their electric charges. The searches involve experiments using particle beams delivered by accelerators to produce the mediator. This mediator decays either into (a) known, detectable particles that are sought (*visible decays*) or (b) into dark-sector particles, which are undetectable, but whose presence is deduced by observation of a large missing energy and momentum in the final-state (*invisible decays*). The results of the searches are usually summarized in terms of their ability to constrain the mediator-to-known-matter coupling strength and the mediator mass. At the Large Hadron Collider at CERN, Geneva, Switzerland, searching for evidence of dark matter is a major activity at the collider experiments.

### 1.2 A New Low Mass Mediator

Recently, there has been a focus on a mediator of a new fifth force, beyond the SM, with mass lower than 1 GeV. Astrophysical observations and observed anomalies in measurements involving the muon and nuclear transitions, hint at this possibility. For example, the observed $3.5\sigma$ deviation between the measured and expected anomalous magnetic moment of the muon [2] can be explained by a fifth force with mass in the range 10 to 100 MeV [3]. There have been extensive searches for the dark photon, mainly through the study of $\pi^0$-decay in existing experiments, and much of the parameter space of coupling and mass that corresponds to these anomalies is excluded at $2\sigma$ [4]. However, a more general fifth force, where the couplings are no longer directly proportional to the electric charges, can not yet be ruled out.

It is straightforward to adjust the quark couplings of a fifth force to satisfy existing constraints and still allow such a force acting via lepton coupling to produce a signal. A number of recently-

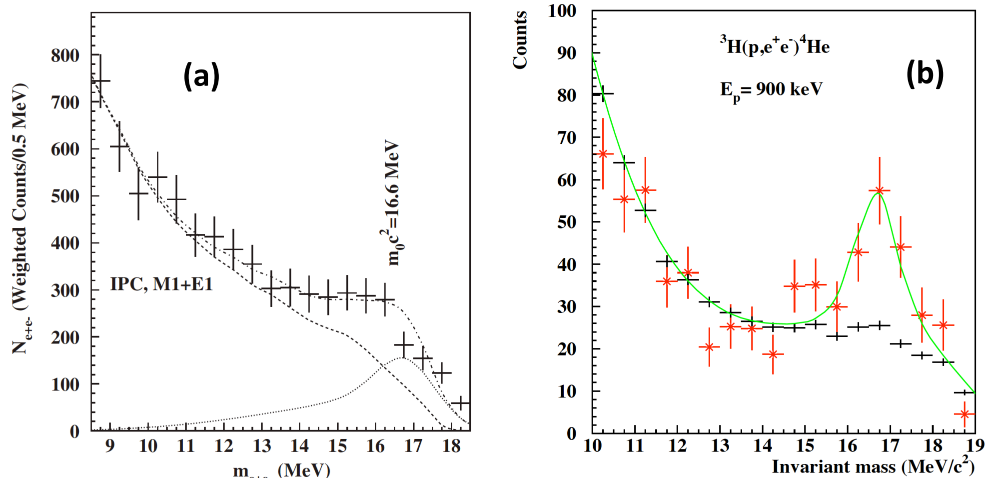


Figure 1: (a): Anomaly in $^8$Be [5]. (b): Anomaly in $^4$He [7].

reported anomalies motivate further searches for such an effect at low energies: Studies of the decays of an excited state of $^8$Be to its ground state have found a 6.8$\sigma$ anomaly in the opening angle and invariant mass distribution of $e^+e^-$ pairs produced in these transitions [5], and a similar anomaly has recently been announced in $^4$He [6, 7]. While these discrepancies may be the result of as-yet-unidentified nuclear reactions or experimental effects, they can be simultaneously explained by the production of a new boson with a mass around 17 MeV. These results have attracted great attention in the popular media [8, 9], and urgently demand independent experimental verification.

The focus of this proposal is to search for evidence of this possible new particle of mass around 17 MeV in $e^+e^-$ final-states in electron scattering from a nuclear target.

### 1.3 Alternative Interpretations and Other Searches

The primary path to reconciling the ATOMKI anomalies with other searches that exclude dark photons in that region is to consider the couplings to quark and lepton flavors independently. Feng *et al.* demonstrated that $u$ and $d$ couplings that produce protophobic or nearly protophobic interactions would satisfy all contemporary limits [10]. In light of that observation, the X17 anomaly has been interpreted in various more specific theoretical models as a new particle, a Z', axion, or other light pseudoscalar [11, 12, 13, 14].

There has also been some success in generating an X17-like angular correlation within the standard model through careful treatment of higher order effects. Zhang and Miller [15] suggest that form factor corrections can produce peaking structures in invariant mass, though it is not clear that this can produce the angular correlations seen in the $^8$Be experiments, and the required form factor implies an anomalously large charge radius that is not expected from microscopic calculations. More recently, it has been demonstrated that interference between leading and next-to-leading terms in the internal pair creation matrix element can produce resonant structures in mass and angular correlations [16], and that such resonant structures can also arise from consideration of other nuclear states in the matrix element [17]. Some of these studies suggest that detector acceptance effects may enhance the size of such a peak beyond the Born-level shaping effects. These predictions could be checked experimentally, but, to our knowledge, no proposals to independently investigate $^8$Be decays have advanced to operation.

We note a key indirect search of this parameterspace, the Fermilab g-2 experiment, is expected to release preliminary results in the very near future [18]. In the longer term, many experiments have been proposed, are under construction, or are currently taking data, that will directly search for dark photons through a variety of leptonic and hadronic channels. However, few can probe the mass and coupling range implied by the X17 anomalies in model-independent ways. Of those that can, LHCb, currently operating at CERN, has the shortest timeline. Upgrades currently underway are expected to extend the mass region it can reach in the subsequent run. The data collected 2021-2023 is expected to fully cover the X17 anomaly region [19]. Several other experiments will also have some sensitivity to this range in the coming decade.

A search for the X17 via low-energy radiative production and leptonic decay would permit a nearly model-independent search of the allowed mass and coupling parameter space, avoiding possible nuclear effects. If mounted in the near future, any observed resonance could then be supported by complementary measurements in different channels and configurations from other experiments as they come online in the following years.

### 1.4 Motivation for Proposed Experiment at ARIEL

Motivated by these developments, we have designed an experiment to use the 31 MeV electron beam from the e-linac driver at ARIEL as presently configured to search for the reported anomaly in $e^+e^-$ final-states in scattering from a tantalum target.

The existing exclusions on the production of dark photons can be divided into measurements observing hadronic production mechanisms (e.g. $\pi^0$ decay) and those observing leptonic production mechanisms (e.g. $e$-$p$ scattering, $e^+e^-$ annihilation). In the simplest dark photon model, the effective coupling to a new force-carrier is proportional to electric charge, so all these exclusions apply to the same parameter space, but in more generic fifth-force models [10], this restriction is relaxed.

The wider parameter space has multiple couplings—most generally an independent coupling to each flavor of quark or lepton. Since these couplings are no longer directly linked, many of the experiments which probe the $^8$Be anomaly region in the simplest dark photon model, and which depend on various hadronic couplings, no longer directly inform the coupling to electrons. Indeed, the $g-2$ and $^8$Be anomalies suggest a particle whose coupling to some quark flavors is significantly suppressed, implying a substantially reduced sensitivity in some hadronic production modes.

The strongest remaining constraints on the electronic coupling near the $^8$Be anomaly region come from measurements by NA64 [20] for small couplings, and from electron g-2 measurements for large couplings, with a key region of the anomaly region still untested. New results of NA64 [21] include a larger statistical sample and pushes the lower exclusion bound at the relevant mass up to $\epsilon^2 \approx 5 \times 10^{-7}$. First calculations indicate that the effect found in $^4$He would be compatible with a similar coupling range.

A program to fully search the available parameter space for corroboration of the $^8$Be anomaly will require both leptonic and hadronic probes: If a new particle is observed in one of these modes, it will be of utmost interest to measure all of its couplings. If it is not observed, both modes will be needed in order to definitively rule out the couplings required for the production of the new boson inside the nucleus and its prompt decay into electrons.

# 2. Experimental design and equipment

The use of the ARIEL e-linac has the benefit of allowing a relatively low beam energy, thus reducing the boost of a produced boson and opening up the small angles of these forward-going decay leptons. The experiment proposed here takes advantage of these larger angles. We propose a two spectrometer setup optimized for the anomaly region and using a thin foil target to achieve sufficient luminosities.

The proposed experiment aims to measure the process $e^-X \rightarrow e^-TaA' \rightarrow e^-Ta(e^+e^-)$ as a resonant excess of $e^+e^-$ pairs at the invariant mass of the $A'$. The produced leptons are detected by a pair of dipole spectrometers arranged asymmetrically around a fixed foil target placed in the beamline at the electron linac of ARIEL.

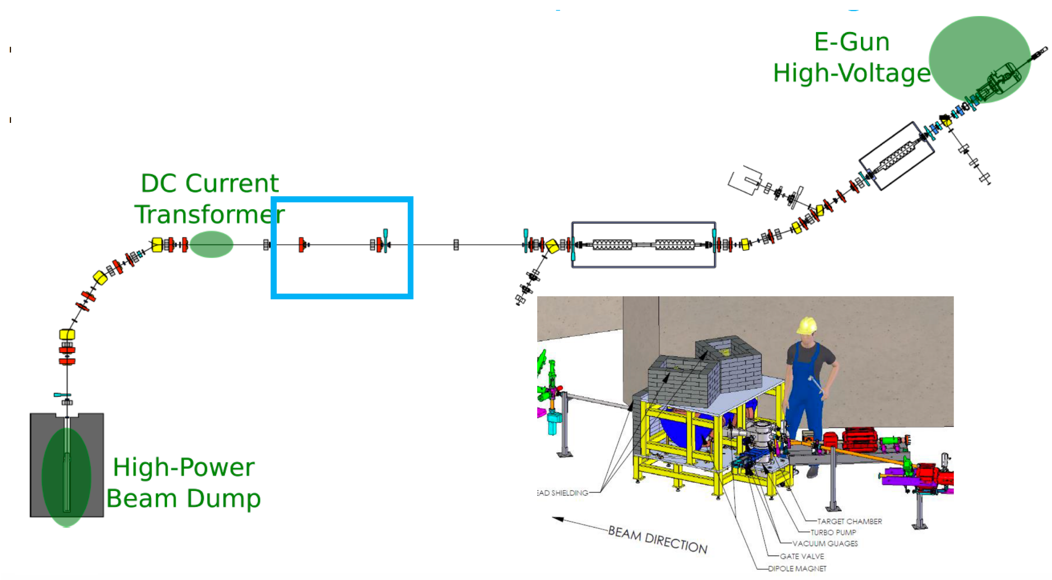


Figure 2: The blue rectangle shows the likely location of the experiment in stage 0. Also shown is a drawing of the experiment, which has an approximate footprint of $2 \times 2 \times 2$ m$^3$.

### 2.1 The Electron Accelerator

TRIUMF's existing superconducting electron linac can currently produce an electron beam of up to 31 MeV in energy and peak intensities up 3 mA. As a driver of the Advanced Rare IsotopE Laboratory (ARIEL), the e-linac delivers electrons to a photo-converter target station for the production of neutron-rich rare isotope beams via photo-fission. Recirculation of the electron beam and an increase in beam energy would offer significant, new scientific opportunities and is under consideration.

The proposed DarkLight experiment can evolve in three stages as the electron accelerator evolves:
**Stage 0:** This would require very moderate modifications to the existing accelerator and the likely location is shown in Fig. 2. The electron beam energy would be up to 31 MeV. The linac would be operated in a continuous wave mode, with a bunch frequency of 650 MHz, and an average beam current of up to 300 µA. The beam terminus would be the existing 10 kW beam dump.
**Stage 1:** Here re-circulation of the electron beam would be implemented. The experiment in fly-through configuration would be moved closely behind the cavities. In this case the beam would pass a second time through the accelerating module and reach 50 MeV. A beamline chicane would have to be installed around the experiment to separate 30 and 50 MeV beams. This mode of operation is not compatible with simultaneous beam delivery to ARIEL, because of the beam scattering through the DarkLight target.
**Stage 2:** Here a second cryo module would be added. The location of the experiment would be in the recirculation beamline opposite of the cavities. Simultaneous 50 MeV beam delivery to ARIEL and DarkLight is possible with this configuration: every other bunch would be sent to the arc, pass through the target, and then be decelerated in 'energy recovery' mode.

### 2.2 Target

The experiment design assumes a 31 MeV $e^-$ beam provided by the e-linac of ARIEL with a current of 150 µA. It will impinge on a 1 µm tantalum foil. This produces an instantaneous luminosity of $\mathcal{L} = 5.2\,\mathrm{nb}^{-1}\,\mathrm{s}^{-1}$, i.e., $0.0275\,\mathrm{fb}^{-1}\,\mathrm{s}^{-1}$ hydrogen equivalent, and will cause a beam spread of approximately 0.5° downstream of the target. The beam will heat up the foil with about 0.4 W, which can be dissipated via radiation for practical beam spot sizes. To protect the target from accidental melting, the target will be a spinning foil disc. The system can be integrated into the accelerator fast-shutdown (FSD) interlocks to protect the accelerator in the event the disc stops spinning.

## 2.3 Spectrometers

The experiment will make use of two dipole spectrometers, with very similar magnetic characteristics, under design and to be built by MIT. The spectrometer design is similar to that of the spectrometer previously constructed for the radiative Møller scattering measurement with point-to-parallel focusing in the non-bend plane to get better resolution in the non-bend plane angle. For each spectrometer, the solid angle acceptance is 12 msr, and the momentum acceptance is ±20%. Both spectrometers will be designed to the same specifications, with ±2° in-plane, ±5° out-of-plane and ±20 % momentum acceptance.

An initial conceptual design of the spectrometers has been completed, demonstrating that the desired features are readily achievable. The two spectrometers will be operated at different currents to produce the desired magnetic fields, but share a common magnet design. They are conventional iron-core magnets with simple, planar coils. The magnet design and pole face rotations were optimized for a 0.5 m distance from target to spectrometer entrance and for post-magnet trajectories suitable for tracking with 40 cm long GEMs. The final engineering of the magnet will include detailed design optimization to increase magnetic performance, minimize size, and maximize clearance to the exit beamline. The magnet in its present configuration weighs about 950 kg. The magnets will have full fiducialization to allow for laser tracking alignment and a six-strut mechanical support system to allow for 200 µm alignment (similar to other MIT-Bates designs). We are currently in the process of finalizing a full design as the basis for generating a simulated field map to verify and optimize the achievable resolutions. The electrical needs of the spectrometer are modest, 20 A at 40 V (under a kilowatt). Air cooling is used in the present configuration.

## 2.4 Detectors

Each spectrometer will be instrumented with a focal plane detector consisting of GEM detector planes, read out via standard APV electronics. They will be provided by the Hampton University group. The GEMs are followed by a layer of scintillating paddles as a trigger detector.

**Trigger Hodoscopes:** The standard GEM readout requires a trigger signal, to be generated from the coincidence of two fast trigger detectors in the spectrometers. To reduce accidental coincidences in the trigger logic, it is important to resolve the beam bunch clock of 650 MHz, at least on the analysis level. This timing information must be provided by the trigger detector, but can be corrected by the particle path length reconstructed from the tracking detector information. However, to reduce readout dead-time, it is important to be close to the ideal timing during data-taking. The main time dispersion is generated by the momentum-dependent dispersion inside the spectrometers. We therefore propose a trigger detector made from scintillator paddles, divided along the dispersive direction into 10 segments, each read out via a photo-multiplier tube or SiPms. These segments can then be timed in individually. The scintillator paddles will be made from a standard plastic scintillator material and have a size of about 150x30x2 mm$^3$.

**GEM detectors:** Each spectrometer will be instrumented with an identical tracking detector system consisting of triple-GEM elements. Eight such triple-GEMs have been designed and built by the HU group with funding from an NSF MRI award and are being commissioned as of Spring 2021.

With an active area of 25x40 cm$^2$ the GEM detectors cover ten times more area than the 10x10 cm$^2$ GEMs used in the 2016 prototype detector[3]. The intermediate size makes the envisioned set of GEM chambers also attractive for further use in other setups.

The GEM chambers have been built as triple-GEM detectors with a standard two-dimensional readout structure with 400 $\mu$m pitch between strips. The front-end electronics are based on APV

[3]Originally built by the Hampton group for the OLYMPUS experiment through an NSF/MRI award, these detectors were used in the DarkLight Phase 1a commissioning at the LERF and are also in use at MUSE.

front-end cards and Multi-Purpose Digitizers (MPD) of the latest generation (APV4.1 and MPD4.0), very similar to the system used previously at OLYMPUS and DarkLight Phase-1a, and presently at MUSE. The construction follows the so called NS2 scheme, and it is the first implementation for a GEM detector optimized for low-energy nuclear physics. A system of GEMs+APVs+MPDs has recently been mass-produced at a larger scale for the Super-Bigbite Spectrometer (SBS) construction at Jefferson Lab.

The existing GEMs can be tested and commissioned with cosmics within 9-12 months. The required MPD and APV electronics are 100% compatible with those used at SBS and in PREX. Since operation of the proposed program at ARIEL and of ULQ2 and the SBS program in Hall A may likely not all occur at the same time, no additional electronics are needed.

**DAQ, trigger electronics and slow control:** The signals of the trigger hodoscope will be used discriminated via suitable CFDs (e.g. Mesytec MCFDs) and the subsequent discriminated signal recorded via a FPGA-based TDC. The firmware of the FPGA will allow us to generate triggers from coincidences in very small coincidence windows, typically not possible with off-the-shelf coincidence units. These small windows are required to identify coincidences on the level of individual bunches, minimizing the recorded background. The FPGA also allows us to easily adjust the timing of individual trigger paddles, as the particle path length through the spectrometer, and thus, time offset from the vertex, depends on the momentum.

The GEMs will be read out via APV25 ASICs and MPD4 readout boards provided by the Hampton group. We envision a VME crate per spectrometer to house the MPD4 and CFDs and the FPGA trigger module.

### 2.5 Resolutions

We analyzed the initial conceptual design of the magnetic spectrometer system to determine the resolution. The magnetic field was calculated using ANSYS Maxwell. The field map was then used in a GEANT4 simulation to trace particles through the magnet system, without material scattering effects, to determine the simulated focal plane. We placed the virtual detector package with the first detector plane in the focal plane and a second plane 8 cm higher.

Assuming perfect resolution in the detector planes, we can then find the transfer function of the magnetic system. The detector system measures the focal plane coordinates $x$ (dispersive) and $y$ (non-dispersive) as well as the slopes $dx$ and $dy$. We can determine a series of functions $f(x, y, dx, dy)$ to calculate the target parameters $\Theta$ (out-of-plane), $\Phi$ (in-plane), and $p$.

We parametrize the function as a polynomial, $f_i = \sum_{a,b,c,d} \alpha_{a,b,c,d} x^a \cdot y^b \cdot dx^c \cdot dy^d$ and find the parameters $\alpha_{a,b,c,d}$ using a fit to simulated tracks, with strong restrictions on allowed combinations of $a, b, c, d$. For $\Phi$ and $p$, we find that they predominantly are determined by the focal plane position $x, y$, with small improvement of the resolution if $dx$ or $dy$ is included. $\Theta$ is predominantly given by $dx$. This is the expected behavior for a dipole spectrometer.

We then add multiple-scattering effects in the detector, assuming 0.5% radiation length for each plane of the detector. The multiple scattering effects rapidly degenerate the precision of $dx$ and $dy$, strongly affecting the extraction of $\Theta$. In the next step, we also enable multiple-scattering in the target, assuming a 1 $\mu$m thick tantalum foil target.

Simulating the detector response for events from a suitable $A'$ generator, we can simulate the full chain from $A'$ production, track propagation through the spectrometer, detection, and reconstruction of track parameters at the vertex from the detector measurements. Using this track information, we can then form the invariant mass of the coincidence tracks to find a realistic mass resolution. For the 45 MeV setup, we find mass resolutions around 150 keV and for 55 MeV, a resolution around 170 keV, while the two 31 MeV settings are slightly better with around 120 keV. The natural decay

Table 1: Background rates for the proposed settings.

| Setup | Irreducible QED | Singles $e^+$ | Singles $e^-$ | Random coinc. |
|---|---|---|---|---|
| 13@31 | 9.1 Hz | 30.2 kHz | 3.6 MHz | 168 Hz |
| 17@31 | 0.83 Hz | 18.2 kHz | 751 kHz | 21 Hz |
| 17@45 | 11.2 Hz | 32.3 kHz | 2 MHz | 98 Hz |
| 17@55 | 71.4 Hz | 45.1 kHz | 8.5 MHz | 589 Hz |

line width of the $A'$ is $O(1/3 \cdot \alpha\epsilon^2 m_{A'})$, i.e. the observed line width is completely dominated by the spectrometer resolution.

### 2.6 Count Rates

We estimate count rates for $A'$ signal and irreducible QED background using the Mainz generator [22]. The high luminosity leads to additional background from random coincidences. In this case, the positron spectrometer detects a positron from the irreducible QED background, however the corresponding electron has kinematics that are not detected by the electron spectrometer – the expected rate for this to occur is significantly higher and typically in the tens of kHz. The coincidence condition is then fulfilled with a second scattering reaction in the same time window, producing an electron in the electron spectrometer acceptance. The dominant process is elastic scattering with internal radiation. The corresponding rates were estimated via the OLYMPUS generator [23].

For coincidences times longer than the bunch spacing, the time window is given by the time resolution of the spectrometers. When individual bunches are resolved, however, a further increase in time resolution has no benefit, as all scattering events from one bunch essentially happens at the same time – the bunch length is too short to resolve below that. For the rate estimate, we assume that we can resolve the 650 MHz bunch frequency, requiring timing resolution of O(0.5 ns).

Table 1 gives the expected background rates for the two setups at 31 MeV beam momentum, aiming at a $A'$ mass of 13 (13@31) and 17 MeV (17@31), as well as two settings aimed at 17 MeV with possible future beam energies of 45 (17@45) and 55 MeV (17@55). As can be seen, for the proposed kinematics and beam conditions, the random coincidence background dominates. It is important to note that this background scales with $\mathcal{L}^2$. The figure of merit (FOM) is given by the number of signal events divided by the square root of the background events. Thus, for luminosities in which the accidental coincidence background dominates, the FOM is independent of $\mathcal{L}$ and only scales with the measurement time. The reach is not improved with a further increase in instantaneous luminosity.

### 2.7 Projected Reach

The acceptance of the experiment dominate the background signal shapes, making the irreducible background and random coincidences similar. We therefore estimate the total background by scaling up the irreducible background according to the expected rates. The reach is calculated by integrating the background over the expected signal width ($\pm 1.7\sigma$), and calculating $\epsilon^2$ so that the signal would be bigger than a $2\sigma$ fluctuation of the background.

Note that for smaller $\epsilon^2$, the background and total signal are visually indistinguishable. However, the statistical uncertainty in the measured background becomes very small, and deviations are still detectable if the shape of the background below the peak is understood.

Since random coincidences dominate the background, the pure random background will be very accurately measured by the experiment itself by mixing electron and positron spectrometer data from different events. This mixing destroys all correlations between the spectrometers, generating a pure sample of the random coincidences. Since, in principle, every combination of events $i \neq j$ can be used, the statistics grows quadratically with the recorded number of events.

Figure 3 shows the achievable reach for the four settings assuming 1000 h beam-time each.

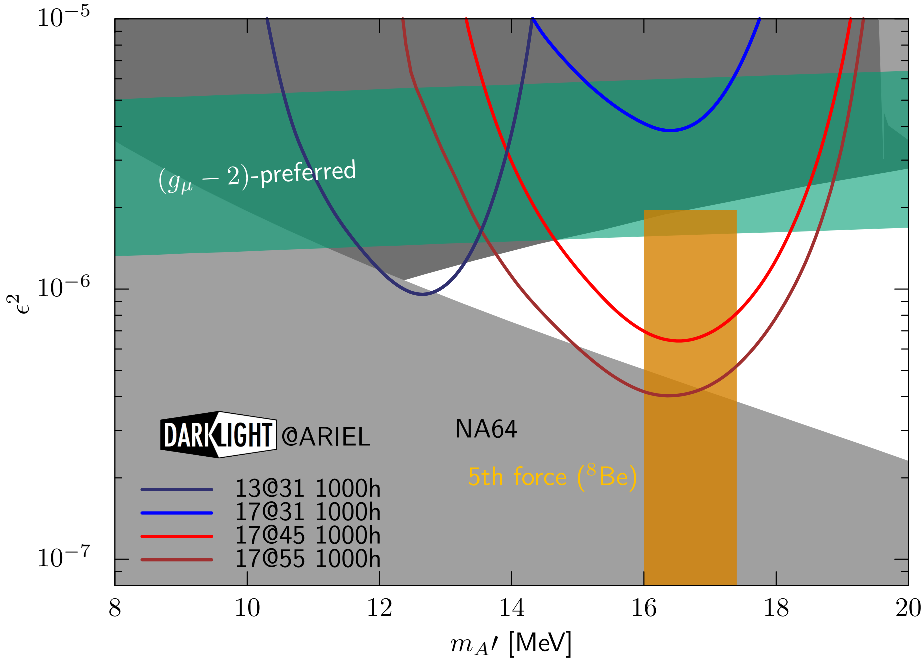


Figure 3: The projected reaches on a linear plot for three separate data taking runs: 13@31 (dark blue) – a 1000 h run at 31 MeV optimized for $m_{A'} = 13$ MeV; 17@31 (light blue) – a 1000 h run at 31 MeV optimized for $m_{A'} = 17$ MeV; 17@45 (light red) – a 1000 h run at 45 MeV optimized for $m_{A'} = 17$ MeV; 17@55 (dark red) – a 1000 h run at 55 MeV optimized for $m_{A'} = 17$ MeV. Light gray areas are excluded by other experiments sensitive to a lepton coupling. The dark gray area is excluded by electron g-2 only.

# 3. Collaboration Responsibilities, Budget and Readiness

The major tasks involved in the proposed experiment are listed in Table 2. The magnetic spectrometers, target system, and scattering chamber with vacuum system and controls will be the primary responsibility of the MIT group. The GEM detectors and GEM readout will be carried out by the Hampton University group. Stony Brook University will take care of the data acquisition and slow control system. A consortium of Canadian institutions (Saint Mary's University, TRIUMF, University of Manitoba, and University of Winnipeg will design, construct, and provide readout electronics for the trigger hodoscopes and take care of integration with the ARIEL machine.

Table 2: Major tasks and responsibilities for the proposed experiment.

| Task | Lead Group |
|---|---|
| Magnetic spectrometers | MIT |
| Target and Scattering Chamber | MIT |
| GEM detectors | Hampton U |
| Data Acquisition | Stony Brook U. |
| Trigger hodoscopes | TRIUMF, UW, and SMU |
| Integration with ARIEL | TRIUMF, UofM |

The estimated funds to construct the equipment, including spectrometers (165 kUSD), target chamber (50 kUSD), detectors (50 kUSD) and electronics (45 kUSD) total 310 kUSD. Funding at Hampton University for the GEMS existed from the NSF Phase-1 MRI award and was used to produce eight triple-GEMs. While they are partially committed elsewhere presently, there are sufficient GEMs to mount this experiment. We expect to be ready to begin commissioning within about twelve months after funding becomes available.

# 4. Beam Time Required

Subject to approval and funding availability, we propose to take data for 2000 hours starting in 2022, at the electron linac of ARIEL at a beam energy of 31 MeV with 150 μA current using the double spectrometer configuration and search in the $e^+e^-$ invariant mass region of 10-20 MeV. We propose to spend 1000 h optimized for a mass of 13 MeV and 1000 h for a mass of 17 MeV.

We additionally request 300 h for background studies and commissioning of the spectrometers. It is best if these runs are scheduled in separate distinct periods.

# 5. Data analysis

All data analysis will be performed at the collaborating institutions.

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