1 Summaries of Experimental Activities

1.1 C12-10-009

An Electron Fixed-Target Experiment to Search for
a New Vector Boson A' Decaying to e^+e^-

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2 Introduction

The development of the Standard Model of particle interactions is the culmination of a century of searches and analyses with fixed-target and colliding beam experiments. Interactions with new forces beyond the Standard Model are currently limited by well-tested gauge symmetries to a handful of possibilities. One of the few remaining ways for interactions with new sub-GeV vector-like forces to arise is for charged particles to acquire millicharges, ϵe, under these forces. This occurs through a simple and generic mechanism proposed by Holdom [**?**], in which a new vector particle A'_μ mixes via quantum loops with the Standard Model photon. MeV–GeV masses for the A' gauge boson are particularly well-motivated in this context. Such sub-GeV forces are a common feature of extensions of the Standard Model, but existing constraints are surprisingly weak, with limits at $\epsilon e \lesssim (0.3 - 1) \times 10^{-2} e$.

Fixed-target experiments with high-intensity electron beams and existing precision spectrometers are ideally suited to explore sub-GeV forces by probing reactions in which a new A' vector particle is produced by radiation off an electron beam [**?**, **?**]. The A' can decay to an electron and positron pair and appears as a narrow resonance of small magnitude in the invariant mass spectrum. In [**?**], several fixed-target experimental strategies were outlined to search for new sub-GeV vector interactions.

The C12-10-009 experiment is a concrete plan for an A' search using the CEBAF accelerator and the High Resolution Spectrometers (HRS) in Hall A [**?**]. This experiment, the *A' Experiment* (APEX), can probe charged particle couplings with new forces as small as $3 \times 10^{-4} e$ and masses between 65 MeV and 525 MeV — an improvement by more than two orders of magnitude in cross section sensitivity over all previous experiments.

Fixed-target experiments of this form are particularly timely in light of a series of recent anomalies from terrestrial, balloon-borne, and satellite experiments that suggest that dark matter interacts with Standard Model particles. Much of this data hints that dark matter is directly charged under a new force mediated by an A' and not described by the Standard Model. Theoretical as well as phenomenological expectations suggest an A' mass $m_{A'} \lesssim 1\,\mathrm{GeV}$ and $\epsilon e \lesssim 10^{-2} e$.

2.1 Expected reach and impact

APEX will be sensitive to new gauge bosons with couplings as small as $\epsilon^2 \equiv \alpha'/\alpha \sim 9 \times 10^{-8}$ and masses in the range $65 - 525\,\mathrm{MeV}$ (here α (α') is the coupling of the photon (A') to electrically charged matter). This is about a factor of $3 - 35$ times lower in ϵ than existing constraints (which assume that the A' couples also to muons), and corresponds to $\sim 10 - 1000$ times smaller cross-sections.

The precise mass range probed by this type of experiment can be varied by changing the spectrometer angular settings and/or the beam energies, see the APEX plan in Figure **??**. The parameter range probed by APEX is interesting for several reasons. This region of mass and coupling is compatible with A''s explaining the annual modulation signal seen by the dark matter direct detection experiment DAMA/LIBRA, and also with dark matter annihilating into A's, which explains a myriad of recent cosmic-ray and other astrophysical anomalies. In addition, and independently of any connection to dark matter, the APEX experiment would be the first to probe A's of mass $\gtrsim 50\,\mathrm{MeV}$ with gauge kinetic mixing below $\epsilon \sim 10^{-3}$, the range most compatible if the Standard Model hypercharge gauge force is part of a Grand Unified Theory.

The importance for fundamental physics of precision searching for new forces near the GeV scale cannot be overstated.

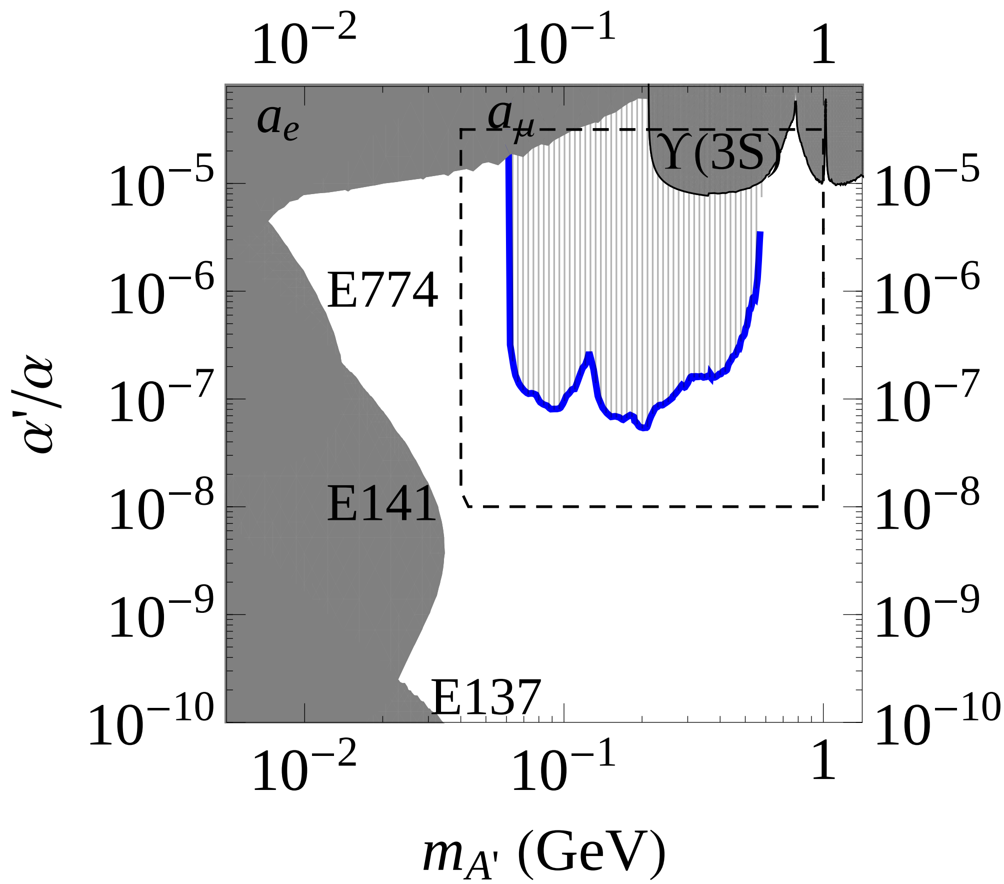

Figure 1: The reach of the APEX experiment (blue contour) and existing constraints (gray shaded regions).

2.2 Concept

In the APEX experiment, we are interested in collecting as many true e^+e^- coincidence events as possible, since the A' is expected to decay to e^+e^- pairs. A large background of such true coincidence events is expected also from Standard Model QED Bethe-Heitler and radiative trident processes, but the A' would appear as a narrow spike on top of this large Standard Model background. A further background is the accidental e^+e^- coincidences that come from two distinct scattering events, in which an electron scatters into the L-HRS from one event, while a positron scatters into the R-HRS in a second event within the timing window of the trigger. Lastly, there are both true and accidental $e^-\pi^+$ coincidence events. Rejection of these two backgrounds is key to the A' search and is achieved by means of a short trigger timing window and good particle identification (PID).

The other crucial factor in determining the sensitivity of this experiment is the optics, which determines the ultimate mass resolution of the experiment. Since we are looking for a narrow spike on top of a large, smooth QED background, excellent mass resolution is essential to achieve the best possible sensitivity to an A'. In the APEX experiment it is crucial to take into account the above considerations.

Figure **??** shows the layout of the APEX experiment. The central momenta of the both spectrometers are set to half of the beam energy. At such a setting the background rates are minimized. The same time most of A' events will be detected in spite of small momentum bite of the HRSs.

Our *coincidence trigger* is defined as a signal in the S2m of both the left HRS *and* the right HRS, *and* a signal in the Gas Cherenkov counters of the right HRS. The coincidence trigger based on these three signals allows us to collect true coincidence events with high efficiency and acceptable DAQ dead time. Such events are candidates for true coincident e^+e^- signal events.

The design of the target for the APEX experiment shown in Figure **??** has a number of interesting ideas

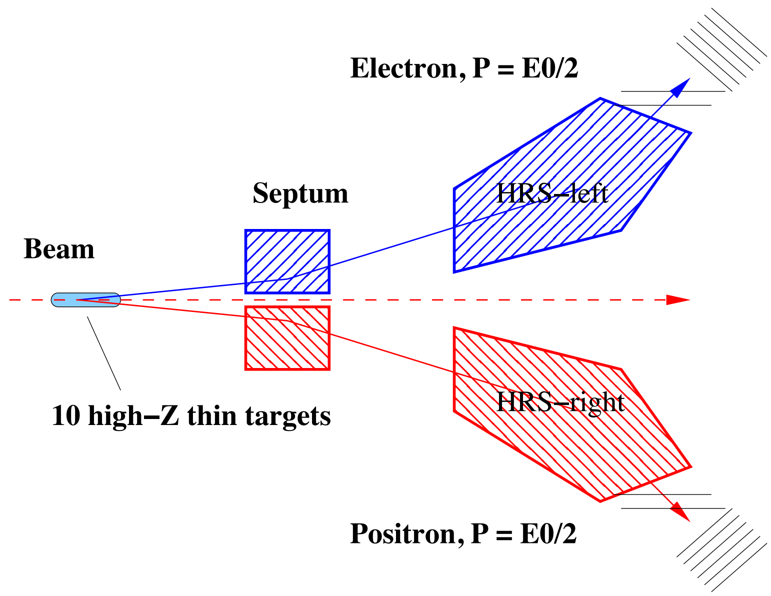

Figure 2: The layout of the APEX experimental setup.

including a concept of narrow ribbons, a tension mechanism, and alignment and calibration target sets.

2.3 PAC35 report and concerns

PAC35 conditionally approved the APEX experiment (proposal PR12-10-009). The APEX collaboration was given a test run to address some of the PAC concerns:

1. Run with the zig-zag mesh design of the tungsten target and prove that it allows the requested vertex resolution.
2. Prove that it is possible to reach the uncertainty of 0.1 mrad in determining the central scattering angle between the two spectrometers.
3. Prove that it is possible to use the gas Cherenkov counters in the trigger to help clean pions. In fact the TAC report claims that this is not possible with total rates/PMT at the level of a few hundred Hz to MHz. Also prove that the off-line rejection of 10,000:1 can be achieved.
4. Detailed description of different contributions to background and their importance (how assumptions and/or approximations can influence the predictions) and comparison with measurement.
5. Prove that a 20 ns (S0-S0) and 40 ns (S0-S0-C) can be achieved.
6. Prove that the vertical drift chambers (VDCs) can operate at a rate higher than 20 kHz/wire (that, according to the TAC report, is the maximum Hall A has operated untill now).
7. If it is possible (not obvious for a test run) it will be advisable to set the septum magnets at higher fields to prove that also at energies higher than 2 GeV it is possible to reach the uniformity of the field requested from the experiment).

3 The results of the test run and the future plans

The test run suggested by PAC35 report was prepared and realized after the PREX experiment in June 2010. The detectors were tested in all the extreme conditions expected during the APEX production run.

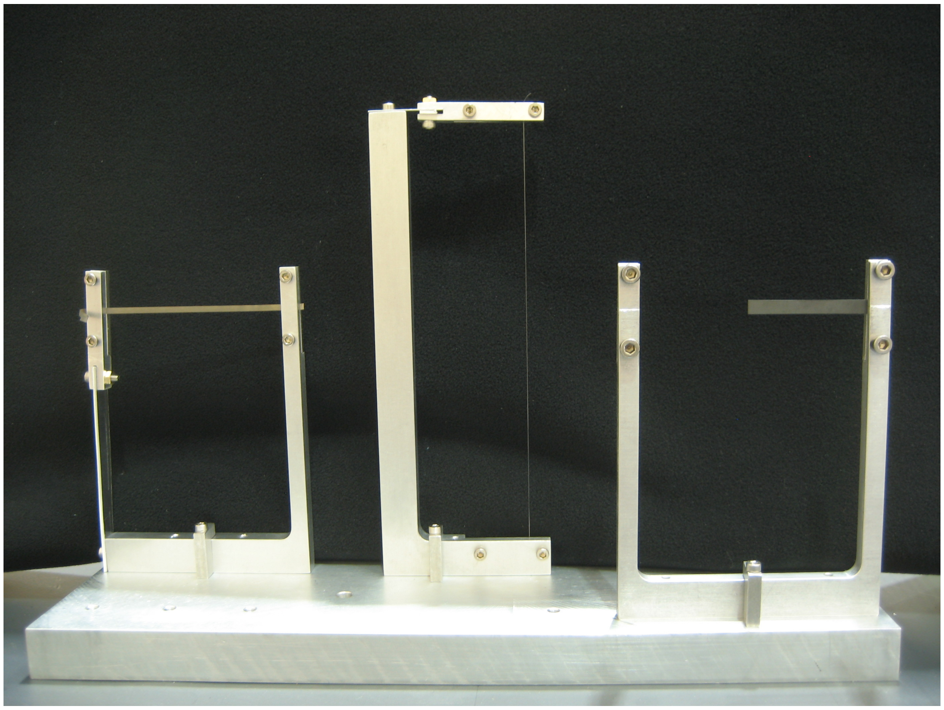

Figure 3: The components of the target for the APEX experiment.

The data was analyzed and preliminary results were presented at the A'-boson workshop [**?**] at JLab in September 2010. Its web page has the reports on each subsystem of the experiment and data analysis. The observed detector performance was found to be in compliance with the APEX requirements. Several results of general interest for the Hall A collaboration are: a 15 ns coincidence time window, a 5 MHz rate capability of the VDC chambers, a target with a set of narrow ribbons for reduction of the multiple scattering, and an observation that pion rate for small angle configuration with 2.2 GeV beam is much lower than one could calculate using the commonly used code by Wiser.

The updated proposal was resubmitted to the PAC37 on December 1, 2010. The e^+e^- data collected during the test run will be analyzed for a possible signal of the A' boson in the mass range 170-240 MeV. The sensitivity of this test run data goes well beyond the currently existing constraints in this mass range, but is well below that achievable in the full APEX experiment and, of course, also covers a much smaller mass range.

References

[1] B. Holdom, *Two U(1)'s and Epsilon Charge Shifts*, *Phys. Lett.* **B166** (1986) 196.

[2] J. D. Bjorken, R. Essig, P. Schuster, and N. Toro, *New Fixed-Target Experiments to Search for Dark Gauge Forces*, *Phys. Rev.* **D80** (2009) 075018, [`0906.0580`].

[3] M. Reece and L.-T. Wang, *Searching for the light dark gauge boson in GeV-scale experiments*, `0904.1743`.

[4] A New Proposal to Jefferson Lab PAC35: Search for a New Vector Boson A' Decaying to e^+e^-, "http://hallaweb.jlab.org/collab/PAC/PAC35/PR-10-009-Dark-Matter-Search.pdf."

[5] The Workshop "Searching for a New Gauge Boson at JLab", September 20-21, 2010,"http://conferences.jlab.org/boson2010/index.html."