Reply to TAC's comments
on proposal P12-10-009 to Jefferson Lab PAC35

PR12-10-009 Search for a New Vector Boson A' Decaying to e^+e^-

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1 Reply to TAC comment 1:

In the background estimation, several approximations/assumptions were used. Some are stated in the proposal (neglecting the effect of nuclear excitations in inelastic processes for the QED trident background calculation, used reduced-interference approximation with re-scaling, extrapolation of rates from scaling of codes), some are not clearly stated. One example is an important process was never mentioned: pi0 production, which is often a dominating process for e+ singles or e+e- pairs. The increasing of e+ singles might significantly increase the accidental rates for on-line trigger and for offline background. All assumptions in the simulations/calculations should be explicitly stated to make it possible for others to evaluate the reliability of them. ———

We have been very careful with all of our background estimates, and in the proposal we clearly state how we calculated the various backgrounds of importance. As the reviewer points out, we did not mention π^0 decays producing e^+e^- pairs and e^+ singles — however, this is because the singles rate is typically sub-dominant to the QED contribution, and the pair rate is very small. The exception is the 4 GeV setting, where π^0 decays increase the e^+ singles rate by a factor of 3 but have no impact on performance.

In the proposed settings of the spectrometers, the e^+e^- pairs have to carry most of the beam energy to reach the two spectrometer arms, which greatly suppresses the rate of such pairs from π^0's. Likewise, single positrons that carry half the beam energy represent a small fraction of the decay phase space, even for high-energy π^0's. We can obtain a simple upper bound on the e^+ singles rate from π^0's directly from the π^- rate presented in Table 2 (page 23) of the proposal. The branching of π^0 to $e^+e^-\gamma$ (1.2%) and photon conversions in the target ($\approx T/2$) contribute, but the positron spectrum is peaked at low energy due to the kinematics of the three body final state. The resulting positron rate in the acceptance of the positron arm is smaller than the QED rate in all but the 4 GeV setting, as detailed below.

Quantitative calculations of the e^+ singles rates from π^0 decay were done by A. Deur and P. Bosted for the 1, 2, and 3 GeV beam energies for the configurations of the proposed experiment. We have also computed the rate for the 4 GeV setting using code by P. Bosted described in CLAS-NOTE-2004-005. These calculations include both $\pi^0 \to e^+e^-\gamma$ and photon conversion contributions. A rate of about 25 Hz was obtained in the HRS for the 1 GeV setting, 2 kHz in the 2 GeV setting, 9 kHz in the 3 GeV setting, and 7 kHz in the 4 GeV setting. On the other hand, the rates for these settings due to QED processes are about 24 kHz, 31 kHz, 23 kHz, and 3.6 kHz respectively (see Table 2 in the proposal). The π^0 contributions are sub-dominant for all but the 4 GeV setting. Even in this last case, a factor of 3 larger e^+ singles rate does not compromise the experimental approach, as the trigger rate remains below 2 kHz and true coincidence events dominate by a factor of ~ 20 in the offline analysis.

2 Reply to TAC comment 2:

The PREX septum magnet current as it is going to be used for the PREX experiment will be in the low-current mode, which is suitable for 1.11 GeV at 5 degree, but will not work for two of the four energy settings of this proposal. This septum magnet can be re-configured to be in high-current mode by adding another set of coils, which can then reach maximum of 2.7 GeV at 5 degree. Significant work will be needed for the reconfiguration. It will also have reduced performance in resolutions and other optical properties. ———

We are aware of the need to reconfigure the septa for high energy configurations. John LeRose, who is an expert on the septa magnets, looked at this issue in some detail, and found that we only need to reconfigure the septa for the 3 and 4 GeV running, but not for the 1 and 2 GeV run settings. John LeRose also analyzed the performance in resolution and other optical properties, and found that the performance of the HRS is not degraded at higher energies. The septa magnets in high-momentum configurations are not as perfect as in low-momentum configurations, which were designed to satisfy the very stringent requirements of the PREX experiment, which uses the HRS as a focusing spectrometer. However, our experiment does not need to satisfy such stringent requirements, because we are not using the HRS as a focusing spectrometer. According to the Hall A technical coordinator, E. Folts, reconfiguration of the magnets will require up to 3 weeks.

3 Reply to TAC comment 3:

The stated accuracy of the sum of the central angle measurement of better than 0.1 mr is an ambitious goal. The achieved accuracy of angle for each HRS without septum is +- 0.2 mr in-plane (+-0.6mr out-of-plane) (JLAB-TN-02-012). Coincidence p(e,ep) reactions were also used which could improve the accuracy to about +- 0.15 mr (JLAB-TN-02-032), but it can not be used when septum magnets are used. Experience from recent experiments confirmed these results. The accuracy for the sum (two HRSs) and with the septum magnets should at least be another factor of two worse. To reach the stated accuracy, improvement with new method(s) or new instrument(s) is needed, which is possible but non-trivial.

The determination of the central scattering angle of the HRS was not an easy task. However, this experiment needs precision information only for an angle between two central rays (between HRS-left and HRS-right). As a result, many problems related to the electron beam position and the beam direction become irrelevant. The target coordinate along the beam needs to be known to high precision. However, because we plan to use a room temperature target, the position instabilities will be greatly reduced. The distance between the two central holes in the collimators of the HRS will be measured to 10 μm accuracy by means of the CMM tool available at JLab. The distance between the collimators and each target plane will be measured by the same tool and then monitored with 50 μm precision through the optical port. In addition, we will calibrate and monitor the position of the zig-zag target using a single wire target.

4 Reply to TAC comment 4:

The VDCs in HRS were designed to run at 1 MHz uniform rate. Operationally, it has been kept under limits of 1 MHz inelastic rate and 200 kHz elastic (concentrated) rate. Running at 6 MHz will significantly exceed the operational and design limits. All possible consequences should be carefully evaluated.

As presented in the proposal, we plan to implement new front-end amplifiers for the VDC. New cards allow reduction of the gas amplification by a factor of 5-7 compared to the Nanometric cards, and about a factor of 10 compared to the LeCroy cards that are presently installed in the VDC. These new cards were constructed for the GEn experiment using the BigBite spectrometer and are able to operate at a rate of about 100 MHz in the VDC. So, we will replace the current electronic read-out of the VDC's with this existing electronics that allows for faster operation. Members of the collaboration understand this issue, and have agreed to install the electronics.

5 Reply to TAC comment 5:

The zig-zag mesh design of the tungsten target significantly reduces the multiple scattering, which is critical for this measurement. It is a challenging design. Only limited details are presented in the proposal and some parameters are given in ranges (how many zig-zag plane: 4-5? length: 5-10 cm? radiation length: 0.5-10%? wire spacing: 0.15 to 0.5 mm?). Are they corresponding to different energy settings (in this case, it should state clearly which configuration corresponding to which setting). Due to the tight requirements in resolution, angle and available space, these details are needed to evaluate the possible issues. For example, if one plane length is 5 cm tilted at 10 mr, 0.5-mm rastered beam will reach the edge of the mesh plane. The events near the edge can not be distinguished from the events hit the adjacent mesh plane and this leads to worse resolution. This will affect the stated 5-cm target vertex correlation between arms and affect the quoted additional accidental background rejection factor of 4 from vertex reconstruction. Another question is how to vary the spacing of wires: Are they different targets? Since on page 28 it stated only one target, do we need to change target for different energies? It probably is easier just to have multi targets on the ladder (need to design cooling accordingly). ———

While the conceptual target design is provided in the proposal, the proposal did not include a complete design, as many of the detailed aspects do not impact the reach of the experiment. The final specifications of the design described in the proposal will be finalized at a later date. Below, we describe in more detail aspects of the design that do impact reach, respond to the above comments, and review the precise configurations used in calculating the reach of the experiment as shown in the proposal.

We refer the reader to Figures 1 and 2 that describe the target. Figure 2 is new and was not included in the proposal. The properties of the target design that lead to an excellent mass resolution, good vertex resolution (optics), and sufficient cooling are:

- Multiple scattering from outgoing e^+e^- pairs (in particular those originating from an A' decay inside the material) must be small so as to not degrade the mass resolution. This is achieved by using wires (Tungsten) strung together to form a plane, see Figure 2. The radius of each wire is about 5–15 μm, and the spacing between the wires is sufficiently large that an e^+e^- pair coming from a prompt A' decay inside a wire misses the next wire. For example, for $m_{A'} \sim 0.2$ GeV and $E_{\rm beam} \sim 3.3$ GeV, the typical angle of the outgoing e^+e^- pair is $\sim 0.2/3 \sim 0.06$ rad. The e^+e^- pair will miss the next wire if the wire spacing is at least $10\ \mu\text{m}/\sin\theta_e \sim 165\ \mu$m (assuming a $\sim 10\ \mu$m radius wire). Smaller e^+e^- angles are obtained for lower A' masses and higher beam energies, but for the suggested run plan we never want the spacings between the wires to be less than $\sim 200\ \mu$m, and in practice they can be a factor of a few larger without affecting the reach. Note that a target foil would have worse mass

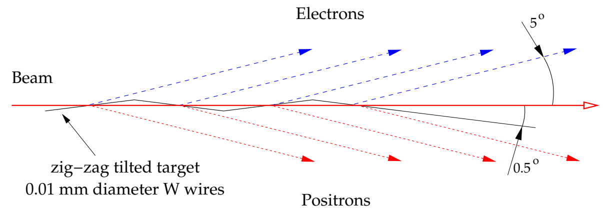

Figure 1: The top view of the tilted target. The beam is rastered over an area 0.5×5 mm^2 (the latter is in the vertical direction). The beam intersects the target in four areas spread over almost 500 mm. Pair components will be detected by two HRS spectrometers at a central angle of $\pm 5°$. Each zig-zag of the target plane is tilted with respect to the beam by 0.5° and consists of a plane of parallel wires perpendicular to the beam. This reduces the multiple scattering of the outgoing e^+e^- pair (produced in a prompt A' decay).

resolution, since then the outgoing pair *will* travel through more material.

- The beam spot along the target plane is about 0.5 cm. The vertical rastering of the beam of ~ 0.5 mm moves the beam spot ~ 5 cm back-and-forth along the target plane. By taking each plane to be at least 10 cm long, there will never be events originating from the edge of the plane, so that there will never be confusion with events coming from the adjacent wire plane. Events originating from adjacent wire planes are thus separated by a distance of ~ 10 cm, so that there is no adverse effect on the optics.

- The length of the target as well as the rastering of the beam helps to keep the target cool. As discussed in the proposal, we have checked explicitly that the radiation cooling of this target is sufficient to keep the temperature of the target below 1000 K.

Only the gross features of the design are important for evaluating a reach, so we omitted several details from the proposal. However, we now discuss a concrete design for each setting, which would achieve the sensitivity shown in the reach plot.

For setting “A”, we used two 10 cm planes, centered in the acceptance range of 4.5 and 5.5 degrees, respectively. Each plane consisted of 1000 14 μm diameter tungsten wires, with a spacing of 93 μm. The tilt of each plane is ± 24 mrad with respect to the beam line. Each beam electron passes though portions of 7 wires in each plane (i.e. total 14). Therefore each beam electron passes through 4.25% radiation lengths of Tungsten, while outgoing e^+e^- pairs only pass through one wire ($\sim 2 \times 10^{-3}$ radiation lengths of Tungsten).

For setting “B”, we used the same two 10 cm planes as for setting “A”, but centered in the acceptance range of 5.25 and 6.0 degrees, respectively. The tilt of each plane was also reduced to ± 10 mrad with respect to the beam line. Therefore, each beam electron passes though portions of 15 wires in each plane (i.e. total 30), corresponding to a total of 10% radiation lengths.

For setting “D”, the same configuration is used as for setting “B”, but the two planes are centered at 4.5 and 5.5 degrees, respectively.

For setting “C”, it is not necessary to use tilted wire planes, as we only need 0.58% radiation lengths. Instead, we used a total of 4 Tungsten foils, each 5 μm thick and oriented perpendicular to the beam line. One foil was centered in the acceptance range of 4.5 degrees. The other 3 foils were spaced 5 cm apart, with the middle foil centered in the acceptance range of 5.5 degrees.

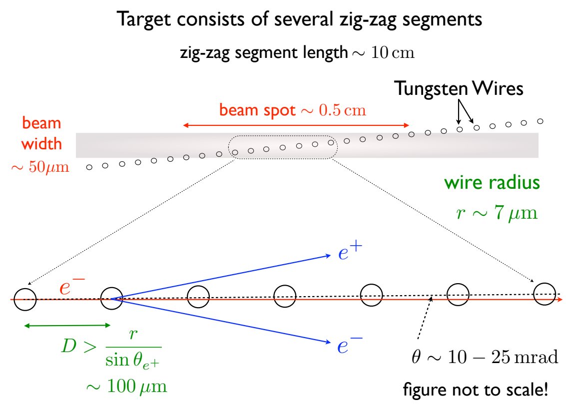

Figure 2: A schematic close-up view of the target. The figure is not to scale! The target typically consists of 4–5 zig-zag planes (although less can be used), with each plane consisting of tungsten wires strung together. Each zig-zag plane is ~ 10 cm long, and lies at an angle of $\sim 10 - 25$ mrad with respect to the beam line. The tungsten wires have a radius of $\sim 5 - 15$ μm and are spaced at a distance of $\gtrsim 100$ μm (the 7 μm wire radius indicated in the figure corresponds to the explicit radius we used for the reach plots). While each beam electron can traverse up to ~ 10 wires per plane, the production and prompt decay of an A' in a wire produces e^+e^- pairs that have an angle of $\sim m_{A'}/E_{\rm beam}$, large enough for them to miss the next wire — this greatly reduces the multiple scattering, and is the reason for not using a target foil. The beam width is ~ 50 μm, which translates into a ~ 0.5 cm large beam spot along the target plane. The vertical rastering of the beam of ~ 0.5 mm moves the beam spot ~ 5 cm back-and-forth along the target plane — this helps to prevent the beam from melting the target.

6 Reply to TAC comment 6:

The right HRS has better PID for electrons/positrons than the left HRS. The stated offline pion rejection rate of 10,000 was barely reached on the right HRS at low rate (< 100 KHz) when PMTs in good shape and not quite reached on the left HRS. Will need upgrade of the lead-glass detector in the left arm to reach the required goal. How the very high rate (up to 6 MHz) will affect the performance should be evaluated.

The Gas Cherenkov counter (GC) of the HRS is practically blind to pions with momenta below 4 GeV/c. Only 1% of pions will be signaled in the GC. This means that the actual rate in the GC from pions is just 25 kHz (see Table 2 in proposal), which presents no problem for the trigger and off-line analysis. The lead-glass calorimeter will have signals from all pions. However, this detector is well segmented (48 PMTs in the first layer and 80 in the second layer), so the 6 MHz rate corresponds to about 200–400 kHz in an individual PMT and readout channel. Such a rate does not present a problem for the pion rejection efficiency. In addition, as e^- rates are large compared to π^- rates, PID in the left HRS is not critical. Regarding the right HRS, even a significant (10%) contamination of the event sample by pions has very little effect on the projected results.

7 Reply to TAC comment 7:

A trigger with tight timing window of 20 ns for overlapping left S0 with right S0 and 40 ns for overlapping left gas Cherenkov and right gas Cherenkov is challenging, in particular, with very high rate up to 6 MHz. The current hardware sum for gas Cherenkov does not satisfy the requirement. PMTs need to have relatively uniform performance and some PMTs may need to be replaced to reach this goal. Gain matching needs to be done very well, which may require additional beam time for calibration. Some other issues (such as double pulsing) seen in some recent experiments need to be resolved. ---

The main trigger for this experiment is given by a coincidence between signals from the two arms, constructed as follows. We require coincident signals from the two S0 scintillator counters (S0-Negative and S0-Positive) within a timing window of 20 ns, and in addition a coincidence between the scintillator counter signals and the *positron arm* Gas Cherenkov counter (GC) within a 40 ns time interval. The GC counter in the electron arm is not used in the trigger.

Note that we are going to use only one GC (in the positive arm) for the trigger logic. The highest expected rate in this GC is about 50 kHz (see reply to comment 6 and Table 2 in the proposal). The S0 counters in each arm will be used with one particular PMT (for trigger purposes), so the arrangement of a 20 ns timing window presents no problem. We disagree with the reviewer's assessment of the hardware performance. The NIM electronics allow for timing windows as short as 5 ns. We performed experiments with such small timing windows with the Mott polarimeter detectors at JLab injector. The gate for the GC was proposed to be 40 ns because this detector has 10 PMTs. These PMTs have a small spread of internal delay on the order of or less than 10 ns, which already means that a 40 ns gate could be used without any problem. In addition, this spread could be compensated for by the cable delay to 2 ns accuracy.

8 Reply to TAC comment 8:

Wire-mesh with spacing will lead to non-uniform target thickness pattern at the micro level (coupled with raster frequency). The effect of the non-uniformity on the accidental suppression using coincidence time should be evaluated. ---

We would like to emphasize that individual target planes are designed and angled in such a way that each beam electron passes through several wires ($\sim$ 15 wires, depending on their separation). This can be done while allowing for the outgoing e^+e^- pairs to traverse only one wire. This means that the fractional variation of the target thickness along the transverse direction of the beam line (along the rastering directions) is at most $\sim 5\%$. Figure 2, shown in reply to TAC comment 5, illustrates this in more detail.

9 Reply to TAC comment 9:

While extensive optics data base exists for the HRS, there will only be very limited optics data for the PREX septum. For the septum needed for this measurement, new optics study will need to be carefully planned. Since the target will not be in the center, but will be significantly shifted in z and phi, optics there will be less well known and resolutions will be worsen. The design of a new pair of septum magnets should have careful study of optics to satisfy the high demand of this measurement.

The beam spot is well-localized at a particular point along the z-direction. The accuracy is limited by the beam size, which is about 50 μm. This leads to about a 5 mm beam spot (in the z-direction), which is sufficiently small. We will also have in situ optics calibration. J. LeRose already prepared a typical plan for optics calibration, which has been included in our proposed run schedule.

10 Reply to TAC comment 10:

Beam energies of 1.1 and 3.3 GeV are not standard. They will require special setup which precludes highest energies to other halls.

We are aware of this, but during the first year of running this should not be a problem because Hall A will often be the only hall taking beam. Moreover, the precise beam energies used for the "C" and "D" settings are flexible, so they can likely be adjusted to accomodate simultaneous experiments in the other halls.