Reply to TAC's review SECOND comments
on proposal PR12-10-009 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 Second comment 2:

#2) From John LeRose's recent presentation, the high field configuration of the septum magnets will significantly degrade the uniformity of the field and the optical properties. (See transparency #10 of John's presentation, Dec. 16, 2009).

We would like to re-emphasize that for APEX we use the HRS as a magnetic spectrometer with off-line optics reconstruction. This does not require the same high quality magnetic field in the septa magnet that is needed in the PREX experiment, which uses the HRS as a focusing spectrometer.

In his presentation on slide #10, John LeRose pointed out that in high field configuration, the magnet will allow central momentum of HRS, p0, up to 2.77 GeV/c and will cause a loss of uniformity: "The 'PREX' uses 2 of 3 coils and iron fillers for better field uniformity. The 'Hi' field uses all 3 coils and reaches 1.2 T at the expense of uniformity" (see http://hallaweb.jlab.org/collab/meeting/2009-winter/). However, as John emphasized in numerous discussions with us, there is no doubt whatsoever that the HRS optics could be calibrated in the same way as it was done many times before.

Below is the Comment-Reply (C-R) from the first writeup to the TAC.

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.

2 Reply to TAC Second comment 3:

#3) Regarding the proposed uncertainty of 0.1 mrad in determining the central scattering angle between the two spectrometers: The head of the JLab alignment group (Chris Curtis) states that the CMM (Coordinates Measurement Machine) tool precision is 50 um (NOT 10 um). Thus, for the center of one sieve hole 50 um will be the uncertainty. To relate it to the sieve box (which has tooling balls on the box), it will need two CMM measurements, the precision will be 50 um * sqrt(2) $\sim$ 70 um. To relate it to Q1 of the HRS, will require three

CMM measurements and 50 um x sqrt(3) $\sim$ 90 um. For the angular precision one needs to relate it to the control point in the hall, increasing the uncertainty to 0.25 mm. Since the left and right angle can not be measured just relatively, both will need to go through the corresponding control point, and the uncertainty will be about 0.5 mm. With the sieve slits about one meter away from the target, the angular uncertainty between left and right from a survey measurement with CMM will be about 0.5 mrad. This is the reason why Hall A has used the physics (elastic) process with optics study to determine the spectrometer angle. Many years of study by taking optics data with multiple settings of beam energy, spectrometer angle and spectrometer momentum, together with precision beam energy measurements led to the best determination of the HRS spectrometer angle to the uncertainty of 0.2 mrad for each spectrometer (JLab-TN02-012). The relative angle uncertainty will be 0.2 * sqrt(2) $\sim$ 0.3 mrad. With the septum magnets added, a new study with significant effort will be needed. The septa will make the optics study less flexible, since one can not easily use several different angles to control the systematics.

We emphasize again that in the present experiment, **the angle between the two detected particles is important for the mass reconstruction, but not the individual scattering angles**. The angle between the two detected particles will be obtained from the HRSs and needs as an input the angle between the two central rays. This is in stark contrast to all other experiments using the HRS, which need information about the angle between the beam direction and the central ray of each HRS. Obtaining the angle between the two central rays is much easier — it does not require relating the sieve slit to the “sieve box” and does not need to make use of the physics (elastic) process with optics study to determine the spectrometer angle.

We also emphasize that the accurate absolute value of the angle between the central rays of the two HRSs, $\theta_\pm$, is needed mainly for relating the measurements of the e^+e^- invariant mass spectra between several kinematic settings. For example, setting A and setting B will produce two spectra of e^+e^- invariant mass, which have an overlapping region. If they have accurate off-sets (better than a mass resolution) then the overlapping data could be combined. The difference between the off-sets in the angles of 0.5 mrad will correspond to a mismatch by a half of the mass resolution value. **However, even such a difference has only a small effect on the experimental sensitivity of the A'-boson search that will be obtained from these two settings independently.**

Within one measurement, e.g. “A”, the absolute value of the angle between the two central rays needs to be known with much lower accuracy. In the leading order approximation, the offset of the central angle has no effect on the mass resolution, and only shifts the invariant mass spectra by a tiny amount.

To estimate the required accuracy for the angle between two central rays let us first recall the other contributions to the angular resolution. The contribution of multiple scattering in the target (e.g. for the setting “A”) is about 1 mrad. The HRS angular resolutions are 1.0 mrad (vertical) and 0.5 mrad (horizontal). When the two effects (from the scattering and the HRS) are added in quadrature, the resolutions are 1.41 mrad (vertical) and 1.12 mrad (horizontal). It is then easy to estimate that an additional 0.5 mrad contribution to the uncertainty, due to the next to leading order effect of $\theta_\pm$, will decrease the overall resolution by less than 10%. If the next to leading order effect of $\theta_\pm$ is, for example, 1/3 of the uncertainty in $\theta_\pm$, we find that even an uncertainty of 1.5 mrad for $\theta_\pm$ will be acceptable for a single setting.

In conclusion, the required accuracy is easily achievable.

Below is the C-R from the first writeup to the TAC.

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.

3 Reply to TAC Second comment 4:

#4) Regarding the high rate operation of the vertical drift chambers (VDCs): Due to the strong angular dependence of the cross section at small angles, the rates in the VDCs are not uniform. From the experience running at 6 degrees, they are significantly higher at the small angle side, which will make the peak rate per wire significantly worse than 74 kHz with total rate of 6 MHz. The maximum allowed for elastic 12C(e,e') was 200 kHz in earlier data, covering about 15 wires. So the maximum operated at was less than 20 KHz/wire. While changing front-end amplifiers is one part, careful study/tests should be done to assure that we understand all possible consequences when exceeding the current operation condition by a significant factor (>5).

We would like to point out that the 200 kHz rate, quoted by the reviewer, corresponds to a rate of 60 kHz/wire, because for every track several wires have a signal (on average 4.5 wires per track).

We agree with the reviewer's comment that there is non-uniformity of the event distribution in the detector. However, we disagree about the effect that such a non-uniformity has on the VDC performance. The wires of the VDC are oriented at 45° to the transverse direction, so such non-uniformity in space has little effect on the variation of the rate on individual wires. The non-uniformity in the transverse direction reduces the effective length of the wire. However, this effect is suppressed in our experiment due to the 50 cm length of the target. The effective length of the wire will be about 5 cm and the corresponding rate density is 18 kHz/cm (assuming a 6 MHz rate of tracks through the VDC), which should present no problem for the wire chamber operation with the new electronics. For comparison, the C-12(e,e') calibrations, quoted by the reviewer, were performed at 60 kHz/wire or the rate density of 12 kHz/cm using the old electronics. So we have an expected rate that is only 1.5 times larger than that measured in the C-12(e,e') calibrations, but the new electronics that we plan to install in the VDC can tolerate a rate that is 5–7 times higher.

However, we agree with the reviewer that the proposed experiment needs significantly different operation than was used before and the Test Run is needed to confirm expected performance.

Below is the C-R from the first writeup to the TAC.

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.

4 Reply to TAC Second comment 6:

#6) The recent experience with the gas Cherenkov in BigBite (during transversity experiment and d2n experiment) does not support the claim of the proponents. It showed that with a total rate/PMT at the level of a few hundred Hz to MHz, it became very difficult to use it in the trigger to help clean pions. The online pion rejection of 100:1 (1%) might be reasonable at low rates, but needs to be demonstrated with the proposed high rates. Off-line rejection of 10,000:1 will require an upgrade of the left lead-glass detectors and again study the effects of high rates.

We feel that the reviewer's arguments are not quite applicable to the proposed experiment because of the following reasons:

- The gas Cherenkov in BigBite during the transversity experiment was in the commissioning stage. Its scheme was not optimized, e.g. the PMTs were connected to the front-end electronics via 600 ns long RG58 cables. In contrast, the HRS Gas Cherenkov PMTs are connected to the front-end via 40 ns cables, which preserve the original fast signals.
- The Gas Cherenkov that we plan to use online will be in the positive polarity spectrometer, where the total rate will be on the level of 30–50 kHz or just $\sim$ 10 kHz per PMT (see the table below (which has a number 2 in the proposal) and use the 1% probability for the pion-induced signal in the Gas Cherenkov counter).

We note that the experiment does not need an off-line pion rejection of 10,000:1. Table presents the expected single rates for all kinematics, the signal rates, and the accidental background rates. Because even 10% background in the e^+e^- event sample from the accidental or the real coincidence events (other that e^+e^-) is acceptable we can estimate the required pion rejection factor. Settings "A" and "C" do not need any additional off-line pion rejection above the factor 100 from the Gas Cherenkov in the positive polarity arm, which has a low counting rate (see second bullet above). Settings "B" and "D" need additional off-line pion rejection factors of about $\sim$ 18 and $\sim$ 5, respectively. For settings "B" and "D", an additional off-line pion rejection factor of 5 is achieved by using the lead-glass in the positive polarity spectrometer arm. In addition, for setting "B", the Gas cherenkov counter in the negative polarity spectrometer easily gives

Settings	**A**	**B**	**C**	**D**
Beam energy (GeV)	2.302	4.482	1.1	3.3
Central angle	5.0°	5.5°	5.0°	5.0°
Effective angles	(4.5,5.5)	(5.25,6.0)	(4.5,5.5)	(4.5,5.5)
Target T/X_0 (ratio[a])	4.25% (1:1)	10% (1:1)	0.58% (1:3)	10% (1:1)
Beam current (μA)	80	80	80	80
Central momentum (GeV)	1.145	2.230	0.545	1.634
Singles (negative polarity)				
e^- (MHz)	4.5	0.7	6.	2.9
π^- (MHz)	0.64	2.20	0.036	2.50
Singles (positive polarity)				
$\pi+$ $[p]$ (kHz)	640.	2200	36.	2500.
e^+: QED (kHz)	31.	3.6	24.	23.
e^+: π^0 decay (kHz)	2	7	0.03	9
Total e^+ (kHz)	33.	10.6	24.03	32.
Trigger/DAQ				
Accidental trigger[b] (kHz)	3.55	0.47	2.93	3.33
True coinc. trigger (kHz)	0.65	0.09	0.36	0.6
Total trigger (kHz)	4.20	0.56	3.29	3.93
Offline Signal & Background Rates				
Trident (Hz)	610	70	350	530
Two-step (Hz)	35	15	5	75
Accidental Background[c] (Hz)	74	3.8	72	47

[a] The listed total target thickness is split between two sets of wire mesh planes, located at different z to produce the two indicated effective angles. The numbers in parentheses denote the ratio of target thickness at the larger effective angle to that at the smaller effective angle.

[b] Trigger: Coincidence with 20 ns time window between S0-N (assuming pions are rejected by a factor of 100) and S0-P signals.

[c] Dominated by e^+e^- accidental rate. We assume pion rejection by a factor of 10^4 in offline cuts (as shown below much lower factor is needed), a 2 ns time window and additional factor of 4 rejection of accidentals from the target vertex. Further rejection using kinematics is expected, but not included in the table.

another pion rejection factor of ~ 4, which is sufficient to achieve the desired total rejection of pions. We can thus easily suppress the rate of accidental coincidence events by a sufficient amount.

In addition to the accidental coincidence events, there are real coincident events between an e^- and π^+. The production of pions is mainly due to real and quasi-real photons and the resulting rates are presented in Table. The real coincidence events of type $e'\pi^+$ are due to the virtual photons, whose flux is lower than the flux of the real plus quasi real photons by at least a factor of 300. This background will be suppressed by a factor 100 already on the trigger level by means of the Gas Cherenkov counters (in the positive polarity spectrometer). For the settings A, C, and D, the remaining background will be below the 10% level of the e^+e^- event rate. For setting B, an additional rejection factor of ~ 10 will be obtained by using analysis of the lead-glass counter.

The Test Run will be very useful for experimentally checking the considerations above.

Below is the C-R from the first writeup to the TAC.

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 the table), 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.

5 Reply to TAC Second comment 7:

#7) The current setup has significant mismatching in time/gain for the PMTs of the gas Cherenkov. Recent data from PVDIS showed multiple peaks in the timing spectrum of the Cherenkov sum (for one spectrometer) spread to over 60 ns. Careful re-alignment of time peaks and gain matching will be needed. As for the S0 timing match, due to the large active area covered with only one PMT, a position dependent time difference needs to be taken into account, in addition to other contributions (electronics, time-walk, ...). However, 20 ns (S0-S0) and 40 ns (S0-S0-C) probably are achievable, but need careful preparations.

The transit time (delay) in the 5" PMT used in the Gas Cherenkov counter is about 50-60 ns under nominal operational conditions. Due to variation of the High Voltage setting, U, this time could vary by 5-10% because it is proportional to $1/\sqrt{U}$. Therefore, the maximum expected variation should be below 10 ns. The claim by the reviewer that the observed variation is over 60 ns is most likely due to the difference in the delay lines for signals propagating to the TDCs, or difference between the TDC offsets, or some data analysis problem. However, these offsets have nothing with the hardware differences, which should be considered in the trigger logic.

Regarding the S0 timing, the factors mentioned by the reviewer were included in our analysis, as well as the variation of the particle trajectory length from the target to the S0 counter. One possibility to additionally reduce the contribution of the counters, which is easy to re-analyze because the S0 has only two PMTs per spectrometer, will be with a mean-timer and the constant-fraction discriminators.

Below is the C-R from the first writeup to the TAC.

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 the table). 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.