MOLLER New RTP HV Driver – Requirement Document

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The probability of interaction of electrons with their spin aligned along the momentum direction (positive helicity) with matter (e.g., atomic electrons in the hydrogen atom, as in MOLLER experiment) is different than that of the interaction of electrons with negative helicity where the spin direction is opposite to the momentum direction. Since under parity asymmetry (or mirror asymmetry or space inversion) a positive helicity electron becomes a negative helicity electron, the fact that the probability of interaction is different is called parity violation. The helicity of the electron beam is reversed (or flipped) by changing the circular polarization of the laser light used to generate the electrons from the photocathode. By flipping the laser circular polarization from right-handed to left-handed, the helicity of the electron beam is reversed. At CEBAF, we are using a Rubidium-Titanyl-Phosphate (RTP) Pockels cell to achieve this fast reversal, with helicity stated selected from a pseudo-random sequence at up to 2 kHz. Linearly polarized laser light passing though the RTP crystals becomes right-handed or left-handed circularly polarized light depending on the HV applied to the RTP cell. The ultimate goal would be a perfect polarization flip, stable after the first 2% of the helicity time window, keeping all other properties (like charge and position) of the electron beam unchanged. This is achieved by carefully aligning the cell and also making sure any information that gives the real helicity is isolated from the outside world. The leakage of the real helicity signal (e.g., changing the electrical ground level) can be picked up by other devices used by data acquisition or in control of the electron beam, and can therefore create an instrumental signal that mimics and confounds the measurement of parity-violation.

RTP Pockels Cell Properties

The Pockels cell and its HV driver are a critical part of any parity violation experiment. Very careful work goes into the design and operation of the cell.

The RTP cell is made up of two crystals as shown in Figure 1. The crystals are rectangular, with exposed faces to allow passage of the laser beam. In a state with no voltage applied, the crystals have significant birefringence, and the two crystals are oriented to largely cancel this intrinsic birefringence. An applied electric field is used to create an additional birefringence within each crystal, with a total of quarter-wave birefringence used to convert the incident linear light to right- or left-handed circular polarization.

Two electrodes are mounted covering opposing faces on each crystal transverse to the laser passage direction. Grounded shield plates are mounted just slightly removed from the remaining two faces of each crystal. Each electrode can be energized to positive or negative high voltage. The electric field in each crystal results from the difference in voltage of the opposing electrodes,

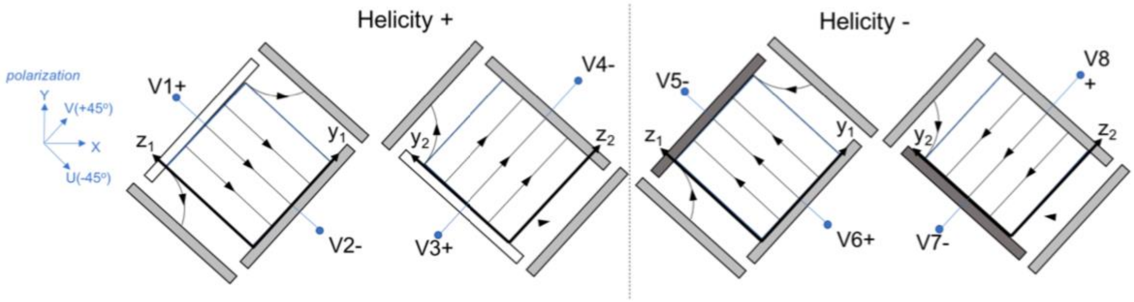


Figure 1: The RTP Cell HV scheme.

which is typically about 1600 V. The location of the electrical center of the configuration depends on the average voltage of the two opposing electrodes, which typically varies between +/- 200 V. For flexibility in functionality, the switch for each voltage should be able to hold off at least 3500 V, that is, the difference between the positive and negative HV supplies for any one electrode could be as large as 3500 V in some modes of operation. It may also be necessary to build the switch to hold off the limits of the power supply voltages, or to otherwise failsafe the switch against an over-voltage failure.

Presently, a ground isolation system in the injector laser room provides a chassis ground (isolated from wall ground), designed to fluctuate a few millivolts above/below wall ground, to "helicity-aware" components in the source. The existing system is often referred to as "John's ground" or "the Hansknecht ground", as it was designed by John Hansknecht. It is used for the Pockels cell voltage driver and IA driver for previous experiments. "John's ground" is used for the power supply chassis for the Pockels cell, connected to the ground terminals of each HV power supply, and carried to the Pockels cell where it is connected to the "grounded" Pockels cell plates.

The cell requires 8 independent HV levels, corresponding to the positive/negative HV on each of the 2 electrodes on each of the 2 crystals, as illustrated in Figure 1. In operation, the cell is toggled between two states, characterized by opposite polarity of the electric field on both crystals.

The RTP crystals exhibit very low piezoelectric response, which is important as it avoids a mechanical resonance associated with a fast voltage transition. The resistivity is high, total resistance across each crystal is dominated by surface resistivity and is approximately 700 GOhms. Due to their small size, the capacitance of each crystal is approximately 4 pF. In typical operation, the capacitance driven by each switch is primarily due to the capacitance of the HV cabling.

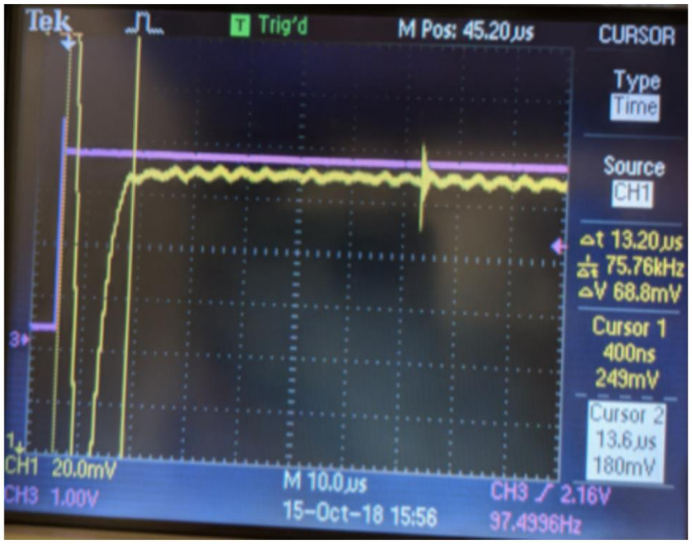
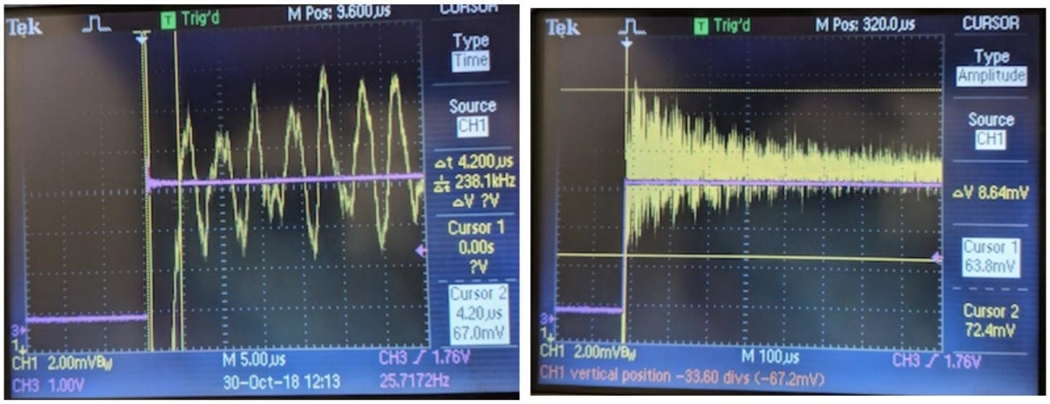


Figure 2: 13 µs transition time with <1% ringing.



(a) (b)

Figure 3: Solid state switch with 50 kOhm resistors on the HV lines to soften the transition down to 4 µs (shows 8.6% ringing)

The cell is driven with too sharp a pulse of current, the piezoelectric response drives a mechanical resonance in the crystals, which degrades the cell performance through a corresponding piezo-optical effect. Soft transitions from + to – helicity states are desired to avoid exciting these resonances and “ringing” in the cell signal. Typically, the lowest resonance occurs around 200 kHz, and we have found through operational experience that driving the cell no faster than ~10 µs keeps the ringing amplitude <1% (see Figures 2 and 3). The cell driver should be designed so the sharpness of the driving pulse reaching the cell does not excite the resonances and produce ringing.

Functional requirements for HV Driver

The HV driver will consist of 8 independently controlled HV supplies, and 4 switches each toggling between HV supplies of opposite polarity.

Electrical Isolation Great care is required to maintain security of the real-time helicity signal. Both the HV switch and the HV supply should be electrically isolated in the same manner as the previous Pockels cell driver system. An isolated ground should be used for the "grounding plates" and the HV should be relative to this isolated ground.

Disabled State The driver should have an OFF state in which the driver does not process the real-time helicity signal (or, process only in an entirely electrically isolated system). In this state, the electrode voltages should ideally match ground. In any case, no switching should occur.

Physical Characteristics The switch should be small and conveniently connectorized to allow location near to the Pockels cell on the laser table (< 10" HV cabling between switch and cell). The switch should not require forced air cooling or otherwise create a source of vibration on the table.

Control systems and protections

1. Control system: the real-time helicity signal should be accepted on either optical fiber or TTL signal. Any TTL copies of real-time helicity signals should be driven only with complementary signals (this is likely part of any design using complementary switching, but also the complementary TTL signals reduce pickup of the signals).
2. Protection: The switch should not allow a short between opposite polarity HV supplies. It should hold off the applied voltage with minimal leakage current.
3. No DC operation: The switch should return each electrode voltage to ground (within <20 V or so) if the real-time helicity is removed or does not transition. A reasonable time threshold might be within about 1 s – 15 s. The switch should return to operation when the real-time helicity signal resumes operation.
4. Operation warning: A warning signal should be raised if the switch is deactivated by a removed or unchanging real-time helicity signal.
5. HV supply warning: A warning should also be raised if any voltage drops to zero, or a monitor of the voltage and/or average current should be available. This monitor should not compromise the ground isolation.

Transitions The transitions should be triggered by the real-time helicity signal, with all electrodes switching together to toggle between the two Pockels cell states.

1. Fast HV Switching: The driver should be able to change HV setpoints at 2kHz.
2. Rise time: The transition should be completed and stable (within ~1% of the final set value) within about 10 μs, including any lag time after arrival of the real-time helicity.
3. Stability: the HV value over the time window (as slow as 240 Hz, as fast as 2 kHz) should be stable within about 1% of the set point.
4. Symmetry: the transition between the two states should be as symmetric as possible, with regards to lag time, signal rise-time, total transition time, and stability after transition.

5. Limit on piezoelectric ringing: The piezo-electric ringing of the crystal upon being driven by the system at quarter-wave voltage (QWV) should have a ringing amplitude of <1% (as observed on a scope signal).

HV Supply

1. 8 HV outputs plus 2 spares for a total of 10 outputs.
2. Dynamic range: Each HV output should span at +/-2000 V. (This should be enough for QWV on a single crystal, which will be a helpful diagnostic function.)
3. Stability: The applied HV at a given setpoint should be stable within 1% at time scales of 1 week or more.
4. Control system precision: Each HV voltage should be controlled by a DAC with 16 or 18-bit resolution, for bit resolution of at least 0.1 V.
5. No manual control is needed, i.e., there is no need for HV dials.

Characterization The switch must be tested under load and measured using the optical properties of the Pockels cell.

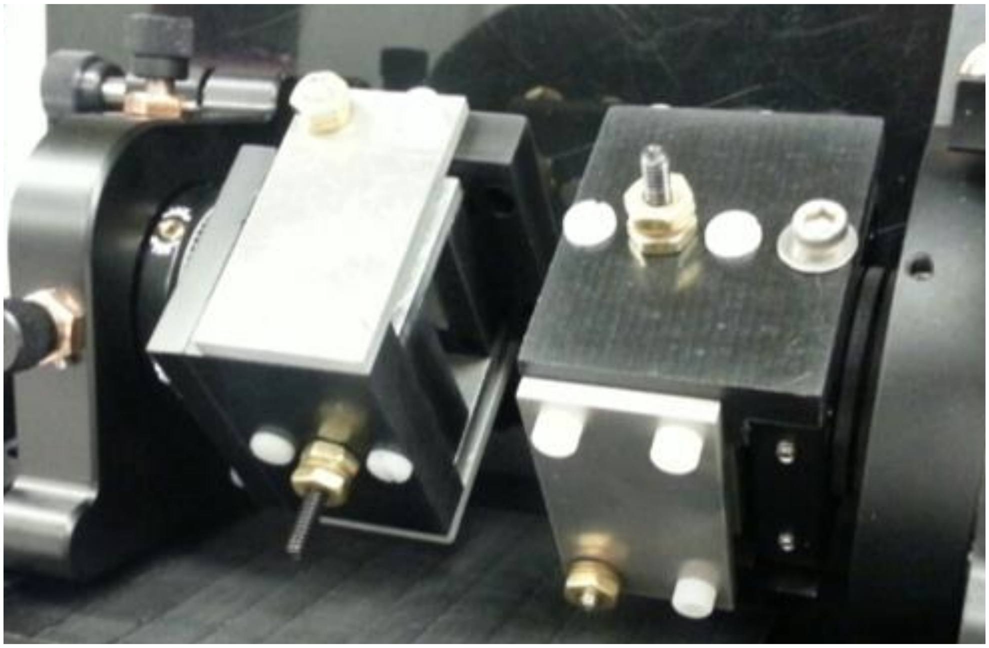


Figure 4: RTP Cell mounting with two crystals.

Existing HV Drivers

1. Existing Dragon LED 8HV System: this is HV driver in used right now at CEBAF. It was designed and built by Caryn Palatchi (UVa). Figures 4, 5, and 6 show the RTP cell, HV Switch, and its HV driver.

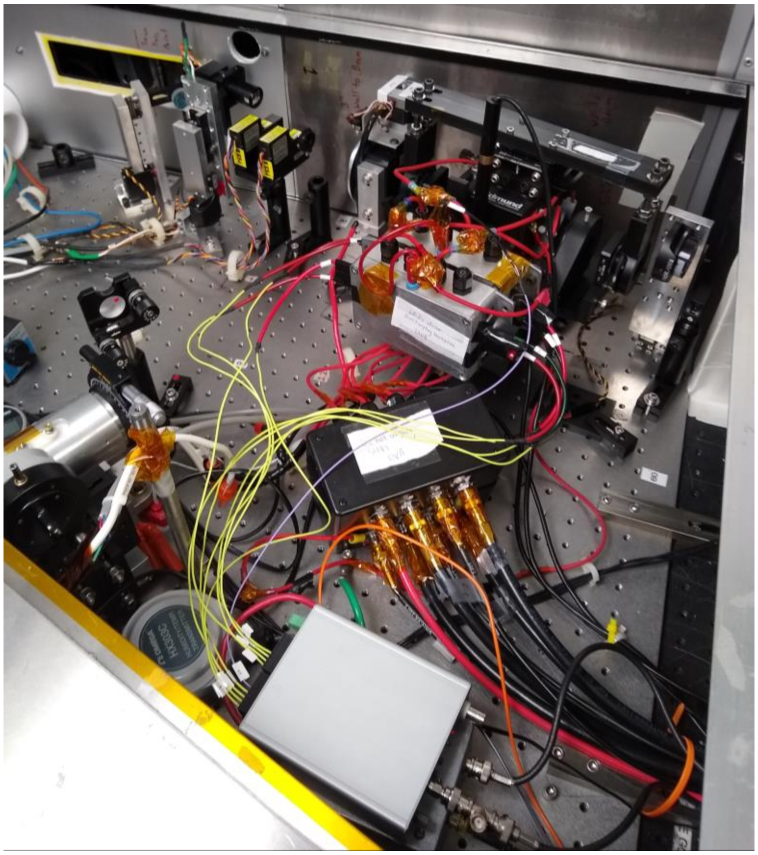


Figure 5: The RTP Pockels cell installed at CEBAF laser table with its HV Switch and connections.

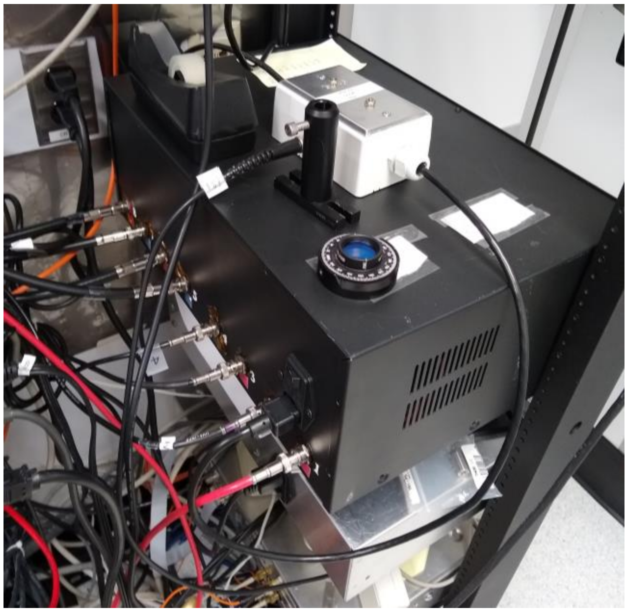


Figure 6: RTP Pockels cell HV supply used at CEBAF laser table.

2. 2019 Design: a protype was designed and built at Jefferson Lab. However, there were issues with isolation and overheating when running at 2 kHz HV reversal.

3. 2023 New Design: JLab should aim to construct a new design with similar functionality to the existing HV opto-diode currently in use, as described above. Not all components are still available, so some modifications may be required. Some specifications above are also not satisfied by the existing switches.

More technical details about the RTP Cell HV drivers can be found here:

https://wiki.jlab.org/ciswiki/index.php/New_RTP_HV_Driver

More Design Recommendations

1. Make extra spare channels in the event one breaks. Maybe 2 extra HV positive and 2 extra HV negative with opposite helicity signals so any of the 4 HV +/- pairs could be swapped.

2. Instead of SHV cables with HV and isolated ground shielding, use (a) a triax cable with GND, isolated GND, and HV or (b) an extra SHV cable that carries isolated GND, with GND shielding and SHV cables with HV and GND shielding.

3. Separate the LED’s that are on for helicity + from the LED’s that are on of helicity – to prevent optical leak-through.

4. Make everything small (including the HV housing) and put it all on the laser table.

5. Use plastic boxes for keeping isolated GND isolated along with metal boxes as an E&M shield preventing helicity pickup – hybrid plastic/metal casing.

6. Note that RC buffer can live inside LED box, there's no need for a separate box to just hold an RC buffer.

7. Perhaps put 2 HV's (HV+ and – sources), 2 RC buffers, and the LED box all in one box, make 4 such boxes, driven by the driver circuit. Make spare boxes that are easily swapped in. Make them small and stackable perhaps.

8. Put all 8 HV's, 8 RC buffers, and the LED box and the driver all in one box very close to the cell.

9. For the driver logic circuit that outputs 8-9V to the LEDs, there's no need to keep the channels for the KD*P, but maybe make it so that there are a few extra channels in case one fails (maybe 2 extra hel+ and 2 extra hel-).

10. For the driver logic circuit, it may be desirable to have it apply 9 V to the LED's instead of 8 V.

11. Want the output cables connecting to the cell to be as short as possible.

12. Want the output cables to be dis-connectable from the cell without disturbing the cell.

13. The output cables are currently connected to the cell with terminals, washers, nuts on set screws connected to electrodes inside the cell.

14. We like the rubber pull apart dis-connectable HV plugs John has on the table for the KD*P.

15. There's no need to put an AC/DC converter inside the HV box, it just needs some sort of 12V DC source that's stable and separate from GND and which provides sufficient power.

16. RC buffers could be added to the 12 V input power for the HV sources for stabilization.

17. We don't demand the IGES HV boxes, other boxes could be used with better voltage stability as long as the current output/wattage is similar.

18. Perhaps Variable Vled: 7-9 V (remote control of this?)

19. Perhaps Variable t_{end}, R_1 for each of 8 HV's (pots, remote control of this?)