Target Cell for PVDIS

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We review here basic requirements on the target cells for PVDIS. Different geometries and materials are reviewed and compared. Conclusions given here are different from the proposal.

1 Choice of Cells

There are two types of cells that may fulfill the requirement of PVDIS: racetrack-shaped (as used in HAPPEX-II) and cylindrical (“cigar-tube”) cells [1]. Racetrack cells have much better cooling flow and thus are usually more suitable for parity experiments, but are in general more difficult to make and the cell window/wall material is limited to certain materials. Cylindrical cells are easier to make and maintain and the up-stream window can be made of special materials like Be. However, it typically have less cooling flow and thus higher boiling noise.

1. Racetrack shaped
    - May have advantages when considering density affects;
    - More difficult to machine and assemble
    - less reliable (leak)
    - Minimal cell wall thickness:
        - Be: 8.8 mils (require machining)
        - havar: 1.1 mil
        - Al 7075-T6: 4.5 mils
2. Cylindrial (2” diameter)
    - Installation much easier
    - lower cost
    - more reliable and flexible
    - Minimal cell wall thickness:
        - Be: < 6 mils (require machining)
        - havar: < 1 mil
        - Al 7075-T6: < 5 mils

Because the main difference between the two types of cells are the window material/thickness and the cooling flow (density effect), we review the requirement on these two factors below.

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2 Target End Cap Contamination

The proposal calls for 3 mil-thick Be windows for the LD_2 cell and $80\times$ and $100\times$ thicker endcaps for the dummy cell. This limited the dummy cell production time (for a goal uncertainty of $\pm 0.3\%$ on A_d) to $2.2\% - 2.5\%$ of the total beam time. However, such thin Be windows are almost impossible to make. Also $100\times$ thicker endcaps will cause several side-effects, for example a highly degraded beam on the exit window of the dummy cell. Other options are havar and aluminum. But havar has very poor thermal conductivity ($\approx$ 13 W/Km at room temperature) and is easy to melt in a 85-μA beam. The possibility and effects of using Al windows are discussed below.

The endcaps of a typical target cell at JLab are made of $\approx$ 10 mil aluminum. For $G0$ a special cell was made with Al endcaps $\approx$ 5-mils thick. Assuming the same endcap thickness as $G0$, the ratio of yield from endcaps to that from LD_2 is

$$\eta \equiv \frac{N_{endcap}}{N_{LD2}} = \frac{L_{endcap}}{L_{LD2}} \times \frac{\rho_{Al}}{\rho_{LD2}} = \frac{5\mathrm{mils} \times 2}{25\mathrm{cm}} \times \frac{2.7}{0.169} = 1.62\% \; .$$

This ratio can be measured quickly using an empty target with the same endcaps as the LD_2 cell. Since aluminum has $Z = 13$, $N = 14$, the asymmetry of $\vec{e}-$Al DIS is about 4% different from A_d and will cause a 0.06% effect on the measured value, which is negligible compared to the expected statistical uncertainty. However, there exist no data on $\vec{e}-$Al DIS asymmetry and to make sure the end-cap correction is under control, the $\vec{e}-$Al asymmetry should be measured using an empty target with thick Al endcaps and the effect on measured A_d will be corrected [2]. To keep the relative uncertainty due to endcap corrections below 0.2%, we calculate here how thick the dummy target endcaps should be:

$$\begin{aligned} 0.2\quad\% \quad & \geqslant \frac{\Delta A_{endcap}}{A_d} = \eta\frac{\Delta A_{Al}}{A_d} = \eta\frac{\Delta A_{Al}}{\Delta A_d}\frac{\Delta A_d}{A_d} = \eta\frac{1/\sqrt{N_{Al}}}{1/\sqrt{N_{LD2}}}\frac{\Delta A_d}{A_d} = \eta\frac{\sqrt{N_{LD2}}}{\sqrt{N_{Al}}}\frac{\Delta A_d}{A_d} \\ & = \eta\frac{\sqrt{N_{LD2}}}{\sqrt{\lambda N_{endcap}}}\frac{\Delta A_d}{A_d} = \eta\frac{1}{\sqrt{\lambda\eta}}\frac{\Delta A_d}{A_d} = \sqrt{\frac{\eta}{\lambda}}\frac{\Delta A_d}{A_d} = 2\%\sqrt{\frac{1.62\%}{\lambda}} \end{aligned} \tag{1}$$

where λ is the ratio of the product (endcap thickness)$\times$ (production time) of dummy and LD_2 cells. Note that the statistical uncertainty $\Delta A_{d,stat} = 1/\sqrt{N_{LD2}} \approx 0.2\% A_d$ was used in the calculation. Limiting $\frac{\Delta A_{endcap}}{A_d} \leqslant 0.2\%$ we obtain $\lambda > 1.62$. If we match the radiation length of the thick dummy cell to half of the LD_2, then we need $25\times$ thicker (3.18 mm) endcaps and up to 6% of the beam time will be spent on the dummy production. For phase I (9 days production beam time) this means 12.2 hours will be spent on the dummy cell. The uncertainty on the $e-$Al PV DIS asymmetry will be $\Delta A_{Al}/A_{Al} \approx 13\%$.

3 Boiling Effect

The target boiling effect has two meanings. The first one is the “local boiling effect”, which is the real phase change of the liquid target. We require local boiling to be less than 5% for the proposed measurement. The second meaning is usually used for parity experiments. In this case, “target boiling” is a terminology for (1) the change in target density due to heating of the target, for example, due to deviation in beam parameters, mostly spot size; and (2) pulse-to-pulse target density fluctuation. The latter may cause a false asymmetry and will affect the measurement.

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[2] may only need to apply this correction when A_{Al} is different from the expected value

We discuss the second effect first: The measured parity-violating asymmetry of $\vec{e}$-^{2}H scattering is expected to be ≈ 100 ppm. The pulse-to-pulse density fluctuation should be controlled to under 0.05% of this value, *i.e.*, 0.05 ppm. The rate in the Luminosity Monitor is expected to be $> 10^{11}$ Hz per quartz for a 6-GeV beam, therefore it is possible to monitor the false asymmetry to a 100 ppb level [3] within each beam helicity pulse, and hence guarantee the control of the pulse-to-pulse density fluctuation to an acceptable level.

The first effect will generate a non-statistical noise ("boiling noise") in the signal which is equivalent to an additional statistical fluctuation. The rate for the proposed measurement is around $(150 - 500)$ kHz. The statistical uncertainty per beam pulse pair (33 ms H+ and 33 ms H-, hence total is 66 ms) is on the order of ± 0.01. To make sure the effect on the measured asymmetry to be negligible, the boiling noise from target should be controlled below 1000 ppm.

Tests on cylindrical target cells were performed in Nov. 2002 for both LH_2 and LD_2 [2]. Results show that for a 15 cm LD_2 cell with 2.8×2.8 mm^2 raster size (set size) and a 60 Hz fan speed, the boiling noise is ≈ 2000 ppm for 60 μA and ≈ 3400 ppm for 80 μA beam current, respectively. Although the LD_2 test was done only on a 15-cm cell, results on 4 cm and 15 cm LH_2 cells show that boiling noise scales roughly with the target length, therefore we expect ≈ 5000 ppm noise for a 25-cm long LD_2 target. This clearly exceeded our tolerance.

In 2004 boiling tests were performed on racetrack-shaped cells [3]. Results suggest a negligible (< 100 ppm) boiling noise at 70 μA current for a 20-cm long LH_2 cell with a 5×5 mm^2 raster and 60 Hz fan speed. This suggest that racetrack-shaped cell is a much better choice for PVDIS than cigar-tube cell. However, no test was performed on LD_2 cells and we will need to do boiling test before or during the commissioning to optimize the running condition. I suggest here to start the test with 4×4 mm^2 raster, 60 Hz fan speed, and a current up to 90 μA.

4 Conclusion

We choose to use a racetrack-shaped LD_2 cell with 5 mils Al for both entrance and exit windows. A dummy cell is needed with Al endcaps $25\times$ thicker than the LD_2 cell. Boiling tests should be performed before or during the commissioning to study the non-statistical fluctuation of the cell. Suggested test conditions are a raster size starting from 4×4 mm^2 (both smaller and bigger raster sizes will be tested), a fan speed of 60 Hz and a beam current varying from 30 to 90 μA.

References

[1] This section is based on Dave Meekins presentation at the collaboration meeting on Feburary 17, 2005.

[2] JLab technical Note TN-03-017, D.S. Armstrong, B. Moffit and R. Suleiman, Target Density Fluctuations and Bulk Boiling in the Hall A Cryotarget.

[3] D.S. Armstrong, presentation at the HAPPEX collaboration meeting on Feburary 18, 2005. http://hallaweb.jlab.org/experiment/HAPPEX/minutes/05Feb18/

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[3] Most of the events in Lumi are elastic. The asymmetry is in general proportional to Q^2, hence the physics asymmetry detected by Lumi is very small, of the order of < 100 ppb. Therefore the false asymmetry can be monitored to ≈ 100 ppb.