Super BigBite Coordinate Detector (CDet) Review

B. Sawatzky, S. Stepanyan, C. Zorn

25 February 2014

1 Introduction

A technical review of the proposed Super Bigbite Spectrometer (SBS) Coordinate Detector (CDet) was held February 25, 2014. This is a PMT-based scintillator hodoscope designed to replace a GEM-based equivalent that was described in an early SBS program design.

This review was initiated by the SBS Project Director Mark Jones. Members of the review committee were

- Brad Sawatzky (chair)
- Stepan Stepanyan, and
- Carl Zorn.

The presentation and auxiliary documentation may be found here:
`https://hallaweb.jlab.org/wiki/index.php/Coordinate_Detector`.

2 Charge

The principle charge of the review is to confirm that the Coordinate Detector will meet the performance parameters enumerated in Table 1 of the *CDet Design Report* [1] (hereafter referred to as the "Design Report") and reproduced here:

Coordinate resolution, per plane	1.8	mm
CDet coordinate resolution	1.3	mm
Time resolution	0.8	ns
Efficiency per plane	99	%
Background rates ($E_{thr} > 3.5$ MeV)	0.4	MHz
Online occupancy	2	%
Electronic dead time (50 ns per pulse)	2	%

Table 1: Performance parameters of CDet obtained in MC simulations. (Reproduced from [1].)

Secondary goals involve an overview of the the budget and high-level parts lists presented in Table 3 of the Design Report, and providing general advice on material, design, and procedural issues that would support this project.

3 Coordinate Detector

The SBS Coordinate Detector (CDet) is a PMT-based scintillator hodoscope designed to replace a GEM-based equivalent that was described in an early SBS design. The SBS program involves very high luminosities (up to 10^{39} Hz/cm^2) coupled with large acceptance, open-geometry detector systems at moderately forward angles (e.g. 30°). The associated high rates impose requirements for fast and highly segmented sub-detectors. The two experiments that drive the performance requirements are measurements of GMn/GMp (E12-09-019), and the Proton form factor ratio GEp-5 (E12-07-109).

The proposed CDet will be constructed as 6 quasi-independent "modules" each with an area of 102 cm × 98 cm and consisting of 196 rows of 5 mm thick scintillator bars. Each row is composed of two 51 cm long bars optically isolated from each other and mounted flush with each other at the center. Each bar is independently read out using wavelength shifting (WLS) fibers coupled to multi-anode PMTs mounted along the left and right short sides of the module.

The six CDet modules will be configured in two 1×3 arrays with an active area of roughly 102 cm × 294 cm each. These two arrays will in turn be be stacked flush with each other and positioned immediately upstream of a segmented calorimeter: HCal-J in the SBS proton arm for GMn/GMp, or ECal in the electron arm for GEp-5. In both measurements the CDet is intended to provide a *vertical* hit coordinate in that arm with an accuracy of 1–2 mm. Two layers are used (rather than just one) to provide redundancy and additional background suppression analogous to wire chamber tracking detectors providing both x and x' planes. The vertical coordinate from the CDet will be combined with the lower resolution (accuracy: 6–8 mm) x, y information from the respective calorimeter to provide kinematic constraints on particle identification and track reconstruction in the other arm.

In both cases the CDet configuration incorporates a 15 cm thick polyethylene shielding block placed upstream of the scintillator bars to shield them from low energy backgrounds.

It is worth noting that neither configuration requires the CDet detector in the trigger. It is solely used during offline analysis to suppress backgrounds and refine the event selection for physics extraction. This relaxes timing and hit multiplicity constraints since TDC alignment and the tight timing cuts only need be performed offline. In both cases, the measurements also involve extracting asymmetries and/or other ratios of the detected yields. This would limit the impact of (minor) CDet efficiency and/or deadtime drifts as they should largely factor out in the final analysis.

4 Concerns and Comments

Overall the CDet design is well thought out and can likely meet the goals listed in Table 1. The following sections will discuss issues that were of significant concern to the reviewers. Formal recommendations and general conclusions follow in Section 5.

4.1 Construction/Design Concerns

There was significant discussion during the review associated with the scintillator bar fabrication plans. The scintillator bars are to be manufactured using an extrusion process with a trapezoidal cross section of 5.00 mm on one short side, 5.03 mm on the other, and 30 mm deep. Each bar will be 51 cm long and possess a 3 mm diameter hole to accommodate the WLS fiber (ref. Figure 6 in [1]). The trapezoidal shape is intended to ensure that the 30 mm axis of each bar to remain aligned with incident electron trajectories across the vertical acceptance of the full CDet stack in the GEp-5 configuration.

Hands-on experience from a CLAS member on the review panel suggests that the tolerances needed to produce a trapezoid with a 30 μm thickness difference front-to-back are not achievable with standard production methods, even if one merely hopes to average over a full stack of 196 bars. It may be possible to order over-sized bars and then machine them down to the required size, but that would incur significant additional costs.

Moreover, there are several other real-world issues that will interfere with such precision alignment. The thickness of the TiO_2 coating used to improve internal light capture and to help make the bars individually light-tight has a thickness on the order of $250 \pm 120, \mu m^*$. The variance in this coating may also interfere with the angular stacking alignment. Changing the reflective material from TiO_2 to an aluminized mylar wrap, or merely thinning the TiO_2 coating will be time/labor intensive (wrapping with foil) and may significantly impact the light transport efficiency. An alternate suggestion raised in the Design Report was to use 5.00 mm × 30.00 mm bars with a rectangular cross section and use thin shims to provide the desire angular displacement. It is felt that this scheme is also unlikely to achieve the desired result for reasons similar to those listed above.

In the end, it is believed that achieving such precise angular alignment across the array is very unlikely without a large investment in time and expense. Unfortunately it is unclear what effect this will have on the CDet performance, some of the provided documentation suggests the impact may be significantly negative. For example, Figures 6 and 7 of the *Coordinate Detector Simulations* document [2] referenced in the Design Report show very different energy deposition profiles for a bar with a rectangular cross section *vs.* one with a trapezoidal cross section. Figure 1 shows a reproduction of those two energy distributions. The accompanying text in [2] comments on the significant advantages of the trapezoidal tilted-bar alignment over a rectilinear array including much better signal to background discrimination (for reasons evident in (Fig. 1)), significantly reduced hit multiplicity in the array, and (though unstated in the document) improved coordinate resolution due reduced energy sharing across adjacent bars.

The impacts of "real-world" fabrication, assembly, and alignment tolerances need to be investigated more thoroughly here to make sure that the CDet will provide the needed resolution and background tolerance even if the bars are significantly "misaligned" *vs.* the incident electron trajectory.

4.2 Scintillator Light-yield Concerns

The light yield estimates in the Design Report are likely over-estimated. The Design Report estimates ≈ 100 photo-electrons/event. Experience from CLAS suggests this may be high by a factor of 2x. This question is best answered on the bench with a prototype.

It was also noted that the pulse amplitude and timing characteristics may be optimistic. The WLS fiber has a significant re-emission time (8–12 ns) that will dominate the pulse rise time from the PMT and smear out the relatively fast scintillator response. This may require lower thresholds at the NINO discriminator and make it difficult to achieve the anticipated 0.8 ns time resolution.

*Used for the CLAS12 PCAL strips as specified by the FNAL extrusion group.

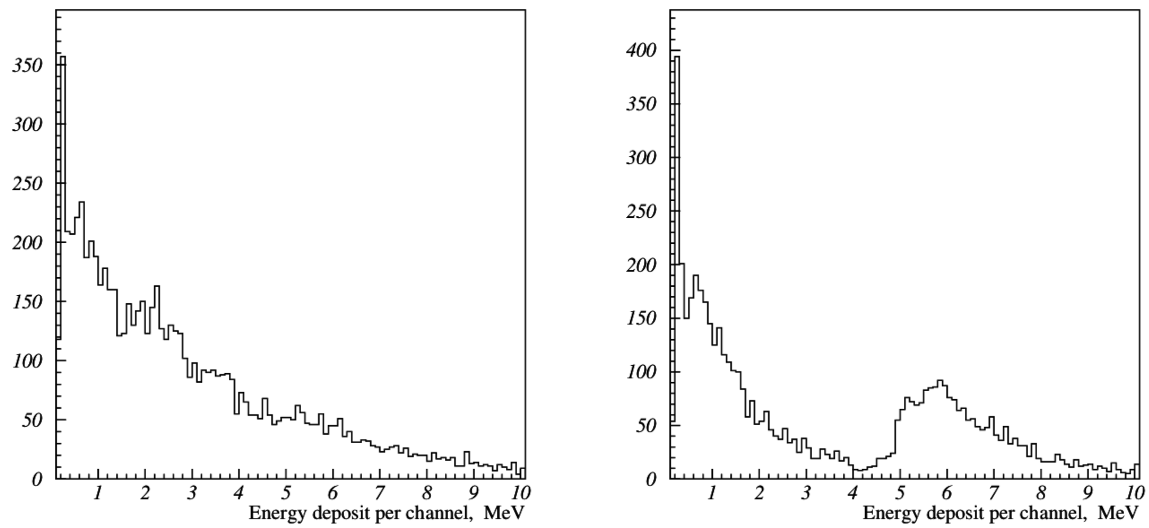

Figure 1: Averaged energy deposition in one channel for a 3 mm rectangular scintillator (left panel), and 3 mm trapezoidal scintillator (right panel). Figures reproduced from p. 4 of [2].

4.3 Pixel Gain Non-uniformity

The Collaboration has done a thorough job of testing and sorting the 602 surplus maPMTs to identify the 168 best performers and build a catalog of the (relative) pixel gains. The "first-cut" criteria for selecting suitable maPMTs allowed for a $\pm 50\%$ pixel-to-pixel variation in gain. Such a gain variation across the pixels in a single maPMT would translate into a proportionate variation in the effective threshold. That could drive up to a 10x pixel-to-pixel variation in trigger rates (up to 2 MHz/bar) based the on rate *vs.* threshold plots in the Design Report.

The Collaboration should tighten those selection criteria significantly and verify that they still have sufficient maPMTs for their needs. Note that they may need to relax the 14/16 good-pixel/PMT criteria as well to ensure good uniformity across the device. As mentioned, the Collaboration has the necessary data to do this in hand. Given the large pool of maPMTs to pull from it is *not* anticipated that tightening the selection process will pose a major problem.

4.4 Threshold/Rate Concerns

Many of the aforementioned concerns directly impact the rates seen by the CDet array. The Monte-Carlo simulations predict 0.4 MHz per bar with a threshold of 3.5 MeV. The reviewers feel it is probable that these rates are underestimated. Increased rates at the factor of 2 level can likely be absorbed without major problems, factors of 4+ will start to have a significant impact on the experiment.

Note that increasing the threshold on the discriminator cards only affects the rate seen by the front-end electronics. The PMTs, however, still experience the full load. A 0.5 MeV particle will still induce a 5–6 photo-electron response in the PMT. If the low energy backgrounds do rise to the 8.5 MHz/pixel (140 MHz integrated over the device) as suggested in Figure 3 of the Design

Report, then the maPMT may transition into continuous current mode. Pile-up and/or rate-induced DC bias will impact the effective discriminator thresholds and complicate efficiency and deadtime analysis.

Anything that can be done to increase the plausible overhead of this system before falling back on beam current reductions should be pursued.

4.5 Minor Concerns / Comments

This section enumerates some minor issues, suggestions, and questions that could not be pursued during the formal discussions.

- Gain calibration of 2352 channels was not addressed in the Design Report. CDet efficiencies, resolutions, and rate issues are all coupled to getting the gains and thresholds set optimally.
- The Design Report identified research showing that the radiation hardness of Y11 WLS fiber was suitable for this application. However, the fiber identified in the presentation was **BCF 91A**. The Collaboration should confirm that the chosen fiber is still sufficiently rad-hard.
- The neutron flux off the LD_2 target in the GMn/GMp configuration may have a significant impact on backgrounds in the CDet due to *np* scattering in the 15 cm CH_2 shield block. (Unclear from the MC simulations available to the reviewers.)
- Replace the high-current blue indicator LED on the level-translator modules with a low power equivalent in any new production runs. The blue LED is a significant fraction of the power draw in the existing cards.
- The cost tables called out 2400 m of scintillator and 2600 m of WLS fiber. Those numbers seem to be significantly larger than needed (baseline quantity is roughly 1200 m $\approx$ 2352 bars $\times$ 0.51 m).
- Power supplies for the level translator cards are not in the cost tables.
- Hall B has some spare scintillator and WLS fiber that could be used for studies and prototypes.
- Hall D has some fiber assembly experience and special hardware to help assembly at PMT interface.

5 Summary & Recommendations

As noted, the reviewers feel CDet design is generally well thought out and can likely be made to meet the goals listed in Table 1. However, the system will be running close to its design limits, even under the likely optimistic conditions described in the Design Report, and there a few rate-related issues that have the possibility of imposing major performance problems. The formal recommendations are directed at detecting and avoiding such surprises

1. Evaluate the sensitivity of the CDet performance to variations in the scintillator bar alignment using MC simulations. Earlier MC results (Fig. 1) suggest the alignment impact may be quite large. It is very unlikely that $\approx 50\,\mu$m tolerances are achievable without a significant increase in cost. The dead area between the bars due to TiO_2 layers and non-uniformities in bar thickness should also be evaluated. (Sect. 4.1)

2. Continue with plans to build a fully functioning prototype assembly of a scintillator stack with maPMT readout. Verify the light yield, pulse height characteristics, measured timing response, and pile-up/DC-bias issues that may arise under very high-rate conditions. These data should be fed back into the simulations to ensure the goals in Table 1 can be met. Take advantage of materials and expertise available from Halls B & D. (Sect. 4.1, 4.2, 4.4)

3. Re-evaluate the existing data on pixel gain non-uniformities and ensure that there are sufficient PMTs to meet the CDet needs. (Sect. 4.3)

6 References

References

[1] L. Pentchev and B. Wojtsekhowski. The concept and main characteristics of the pmt-based coordinate detector (*CDet Design Report*). Available at `https://userweb.jlab.org/~bogdanw/CDet_V3.pdf`, January 2014.

[2] M. Jones and L. Pentchev. Coordinate detector simulations. (Reference [6] in the *CDet Design Report*). Available at `https://userweb.jlab.org/~jones/SBS/CDreport_dir_aug15/CDsim.pdf`, June 2013.