A pre-shower detector for forward electromagnetic calorimeters

A Progress Report for the January 2014 EIC Generic R&D Advisory Committee Meeting

This project addresses the need for distinguishing neutral pions from other particles using a crystal-based electromagnetic preshower detector. The problem is universal at high energies, and is of particular interest to any Electron Ion Collider detector due to the relatively high rate of photons, electrons and positrons in the electron scattering environment. Since the previous progress report at the Advisory Committee meeting in June 2013 there has been advancement in a number of areas, and completion of the device is expected before CY 2014. The progress over the past six months consists of the following:

- prototyping of wrapping technique was finished (July)
- amplifiers board were received (July)
- data acquisition system was prepared (August)
- cosmic ray set up was completed (August)
- the MPPC readout using an LED was completed (August)
- production of wrapping for 625 crystals was finished (October)
- production of crystal array housing was finished (October)
- light covers were fabricated (October)
- crystal stacking was started (October) and finished (December)
- production of 50 light guides is in progress (will finish in December)

The exploded view of the full device from the CAD design is shown in Fig. 1. The array of 625 crystals is stacked in a square pattern of 25 rows by 25 columns. Each crystal is wrapped in a thin layer of special plastic ("Vikuiti™ Enhanced Specular Reflector") that enhances light reflectivity while preventing optical cross talk; further, it provides a small amount of mechanical cushioning. The light-tight mechanical housing for the array has dimensions that are adjustable and which are stablilized using threaded fasteners and copper shims on the corners, visible in the figure. On one side of the assembly there is a square light readout matrix consisting of horizontal and vertical fibers mounted in a transparent plate, with machined grooves to maintain the position of the fibers. The fibers lead to small, optically isolated lightguides mounted in front of the MPPC light detectors. The MPPCs (Multi Pixel Photon Counters, formerly "silicon photomultipliers") are soldered to a very compact circuitboard with four edge connectors on each of two sides that give access to the electronic pulses through demountable amplifier boards.

The current stage of the project is that the detector is complete except for a number of the 50 small lightguides, which are planned to be completed by the end of the month. Two photographs of the completed assembly are shown in Fig. 2.

Fig. 1. Exploded view of the full detector. For scale, the crystal array is 10 cm x 10 cm.

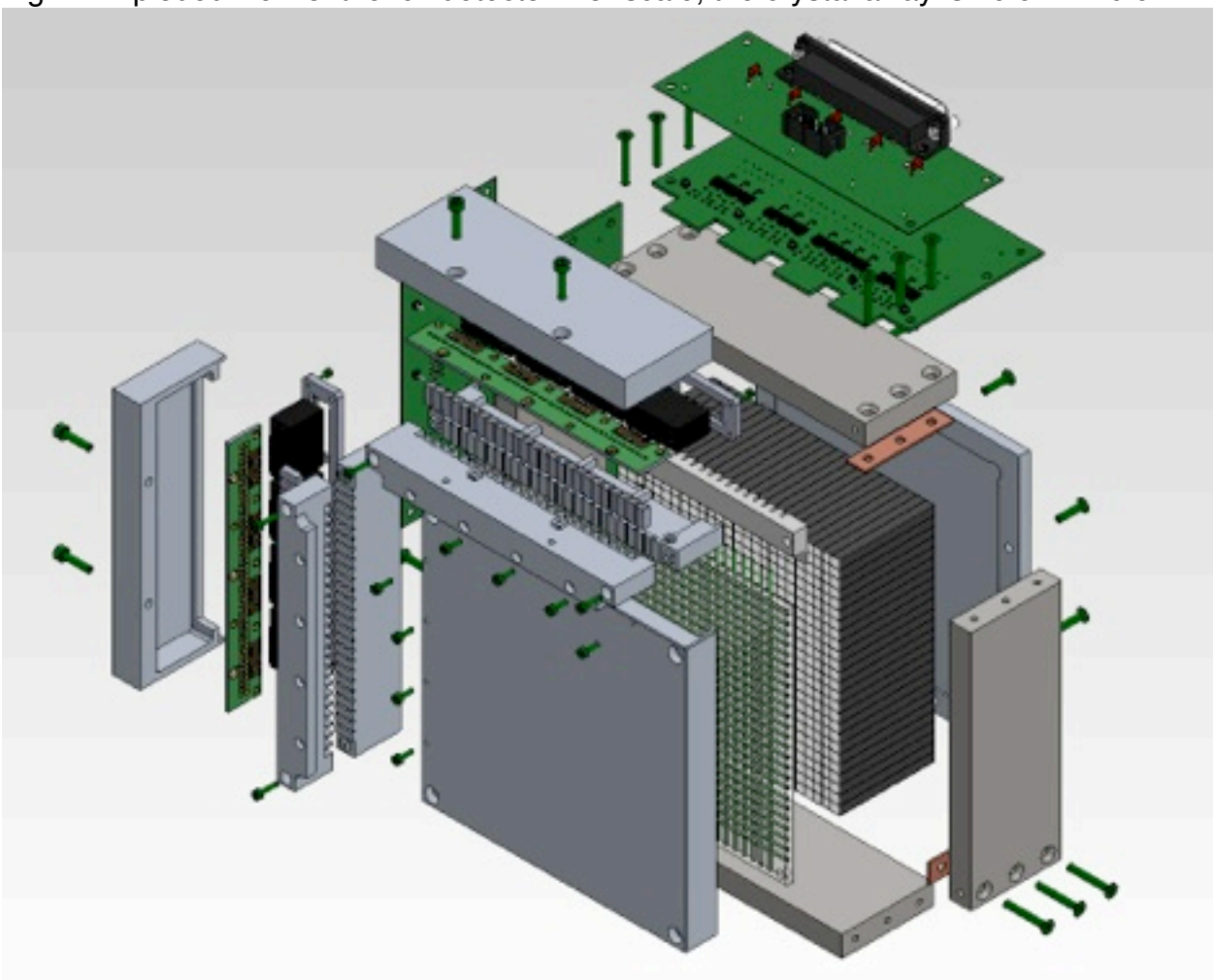


Fig. 2. Photographs of the completed assembly. Left: the completed assembly without amplifier cards. Right: the assembly including amplifier cards and cables.

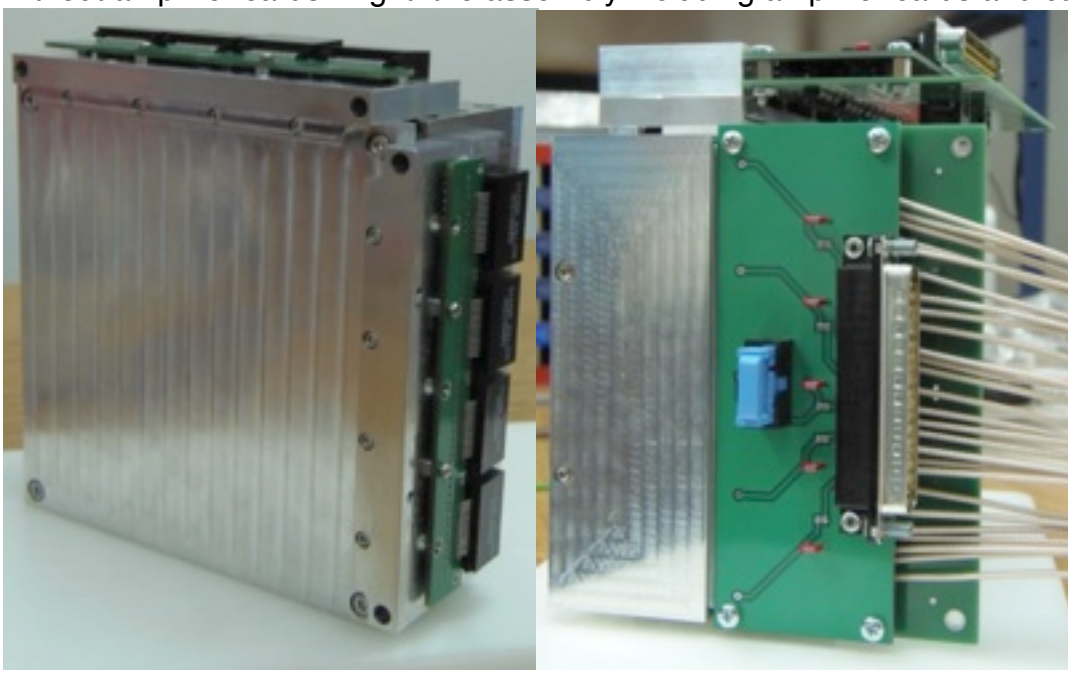


Fig. 3. A photograph of the crystal matrix with the light covers and readout matrix removed (left) compared with the design (right).

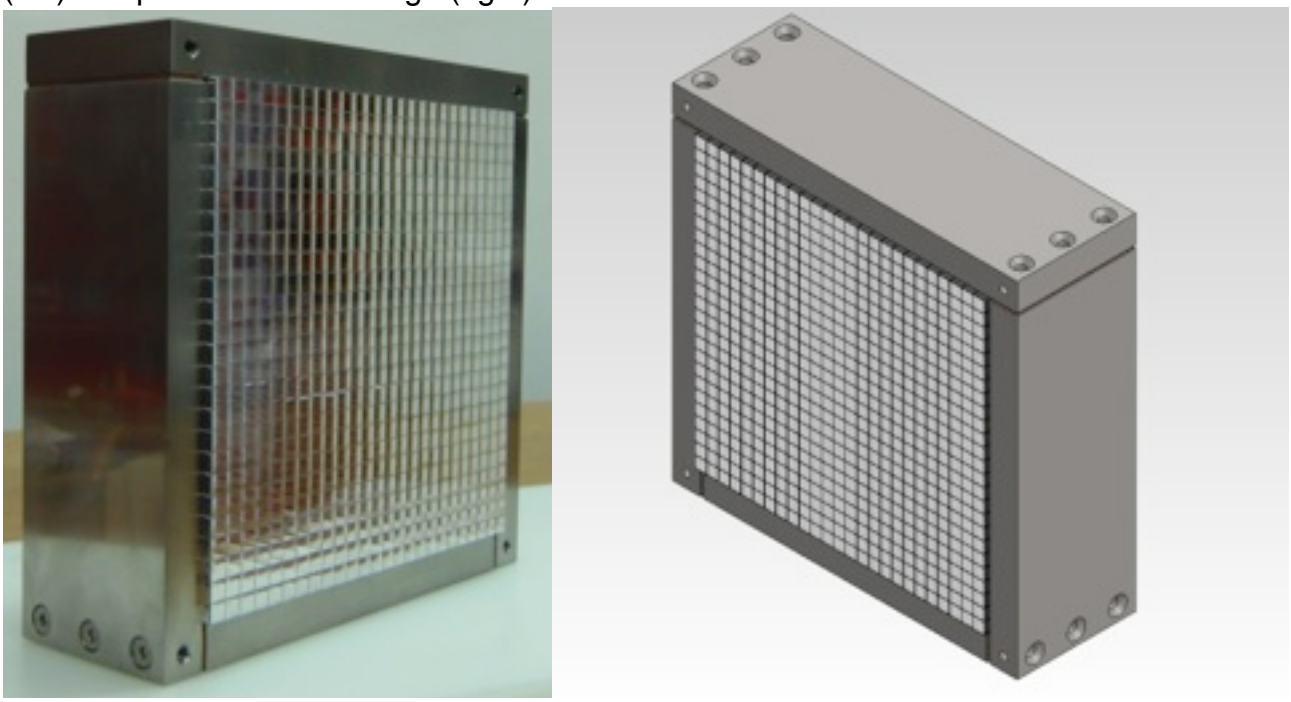
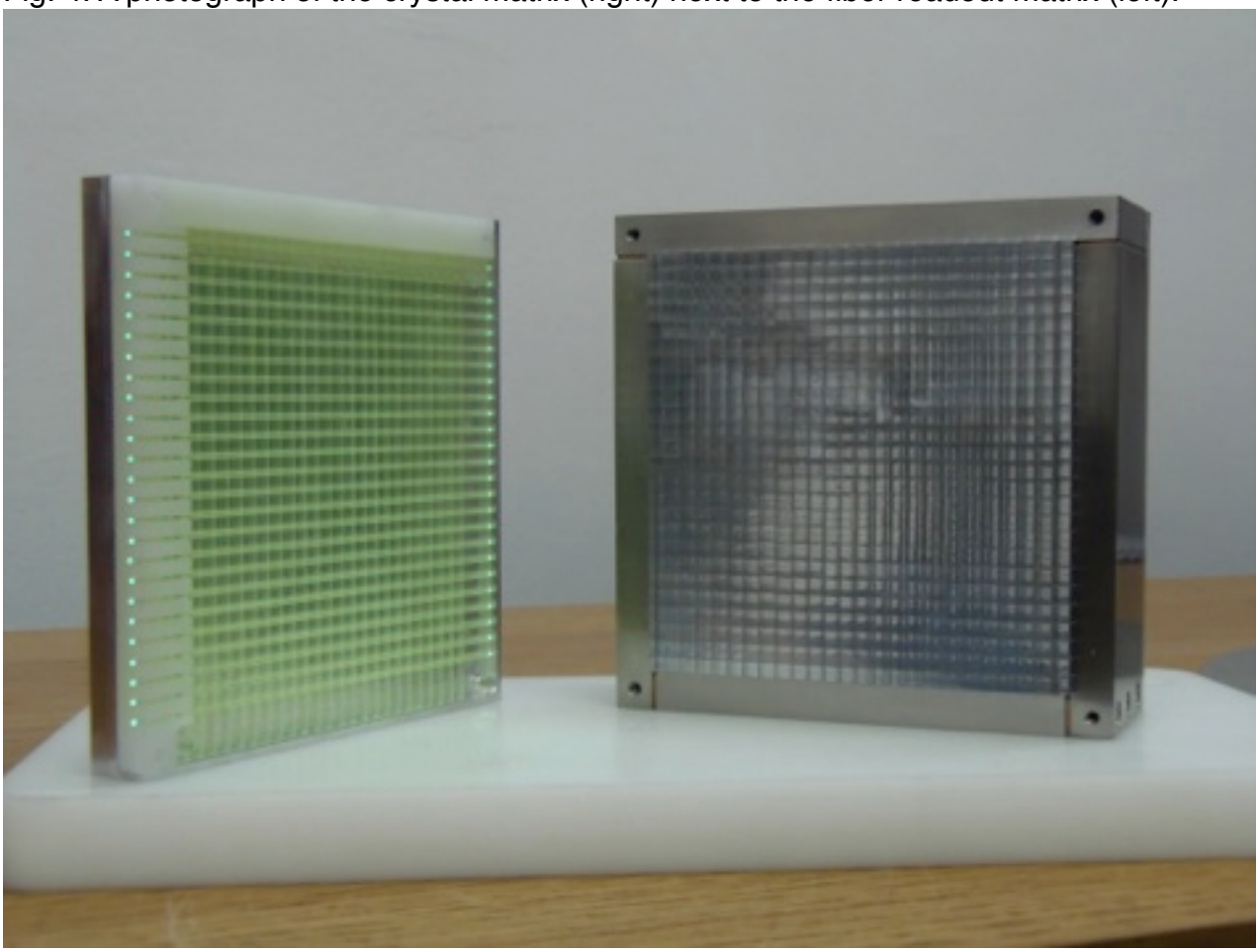


Fig. 4. A photograph of the crystal matrix (right) next to the fiber readout matrix (left).



In Fig. 3 is shown a photograph of the crystal array in its mechanical housing, but with the light cover and readout matrix removed, and a similar view from the CAD model. In Fig. 4 is shown a photograph of the crystal array next to the fiber matrix array.

All electronic components have been tested, and LED tests have been made of the light measurement chain. In addition, the data acquisition system has been thoroughly tested with all 50 channels. Therefore we do not anticipate problems in the measurements with cosmic rays, which are planned for early 2014.

Forming the reflective wrapping

The prototyping of the wrapping procedure for the crystals required some development and optimization. As mentioned above, we used a plastic sheeting called Vikuiti™ Enhanced Specular Reflector (ESR). This product claims greater than 98% specular

Fig. 5. Cutting the wrapping film to size.

reflectivity across the visible spectrum. Fig. 5 shows a photograph of the film being cut to size. Because this film is relatively stiff, it was necessary to thermally mold it into shape so as to wrap the crystals tightly. The thermal molding apparatus which we ultimately fabricated, following various prototyping efforts, is shown in Figures 6 and 7.

Aluminum blanks that have the same dimensions of the crystals were fabricated. The wrapping material was wrapped around them and they were inserted into a clamping jig with a capacity for holding 25 blanks. The wrapping was configured so that four sides were covered without an overlap of the film, with the junction between the edges of the film being located at a corner of the blank. A top plate was then attached, holding the wrapped blanks in place. The assembly was placed in an oven and heated to the optimal temperature; these steps are illustrated in Fig. 8. It was found that the rate of heating was also an important factor in achieving optimal results; following the initial prototyping stage, a new oven was purchased in order to have more rapid heating rates for the production work.

Fig. 6. The thermal molding apparatus for the plastic wrapping material. The 25 aluminum blanks are shown, together with the clamping jig. The blanks are wrapped with the film, inserted into the jig, and heated in an oven. Three examples of the final product are shown at the bottom left.

Fig. 7. The thermal molding apparatus for the plastic wrapping material. Aluminum blanks are shown wrapped with the plastic, and inserted into the clamping jig.

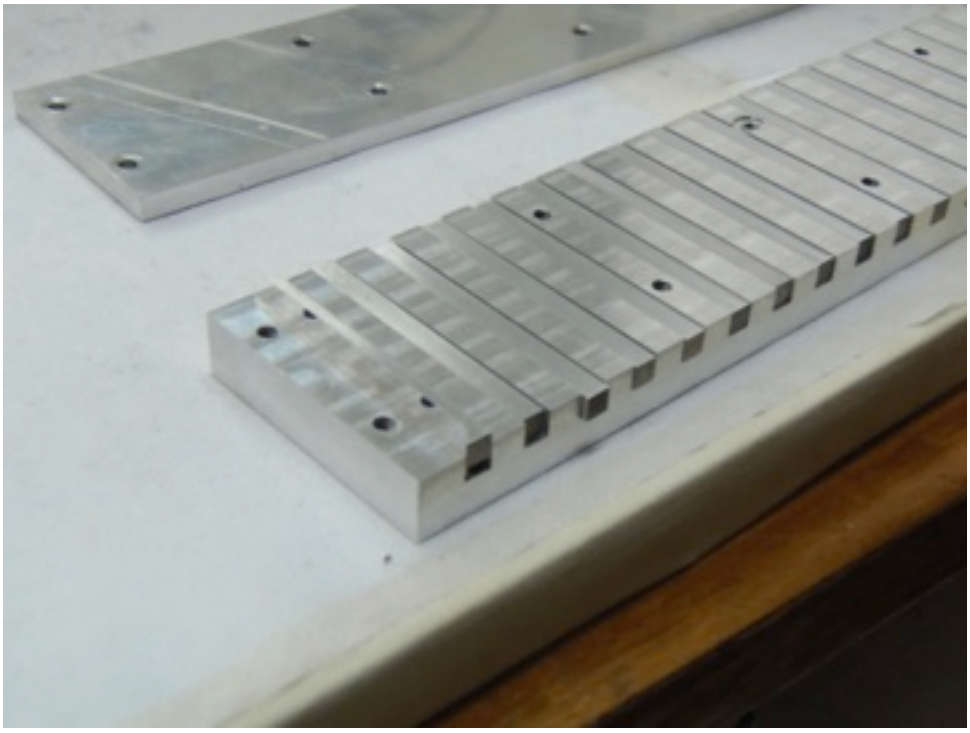
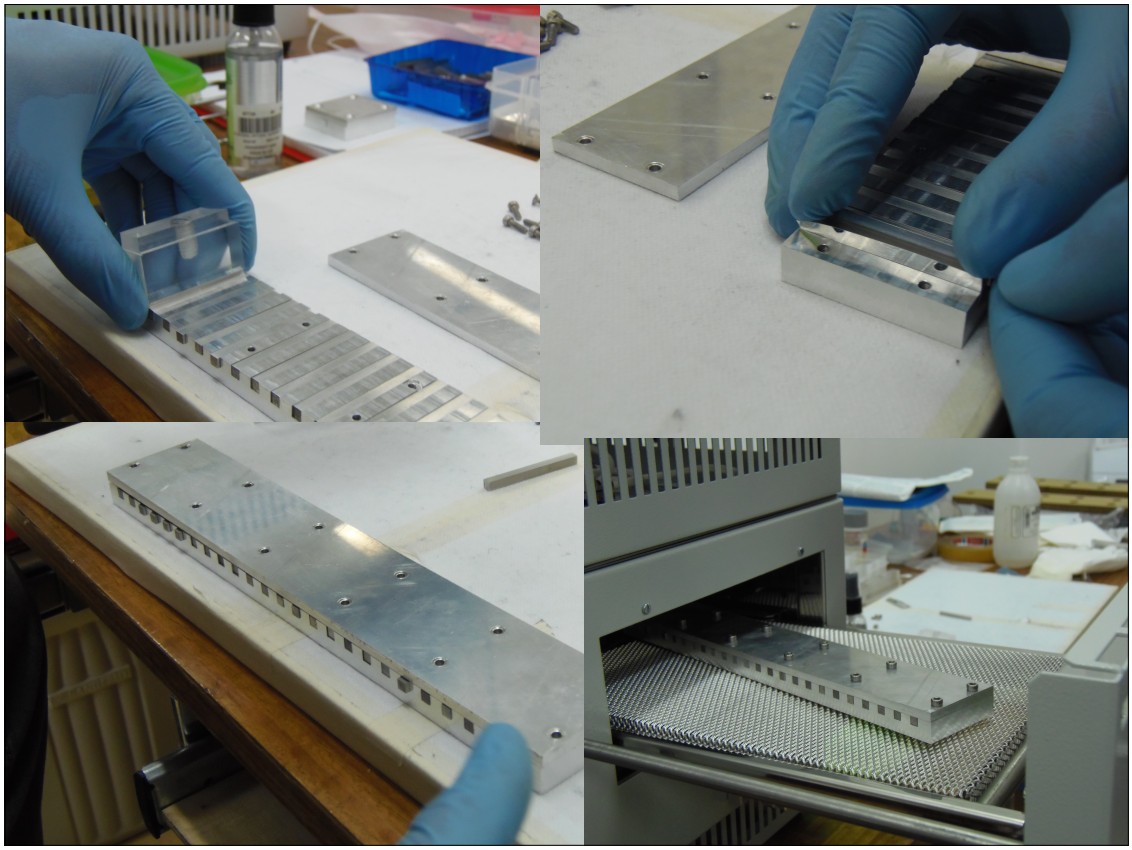


Fig. 8. Illustration of the process of wrapping the aluminum crystal blanks and inserting them into the clamping jig, then putting the assembly into the oven.



Crystal stacking

The 625 crystals were placed individually into the mechanical housing as illustrated in Fig. 9. Care was taken to continuously assess the correct width of the stack to take into account variations in mechanical tolerances of the crystals. Copper shims were used at the corners of the assembly in order to have a small amount of flexibility in the width of the array. The mechanical frame was left slightly loose during the stacking, and the cumulative width of the array was monitored. In Fig. 10 the array is seen near the completion of the stacking process (left) and after final shim optimization and tightening (right).

Fig. 9. Placing the wrapped crystals into the mechanical assembly (“stacking”).

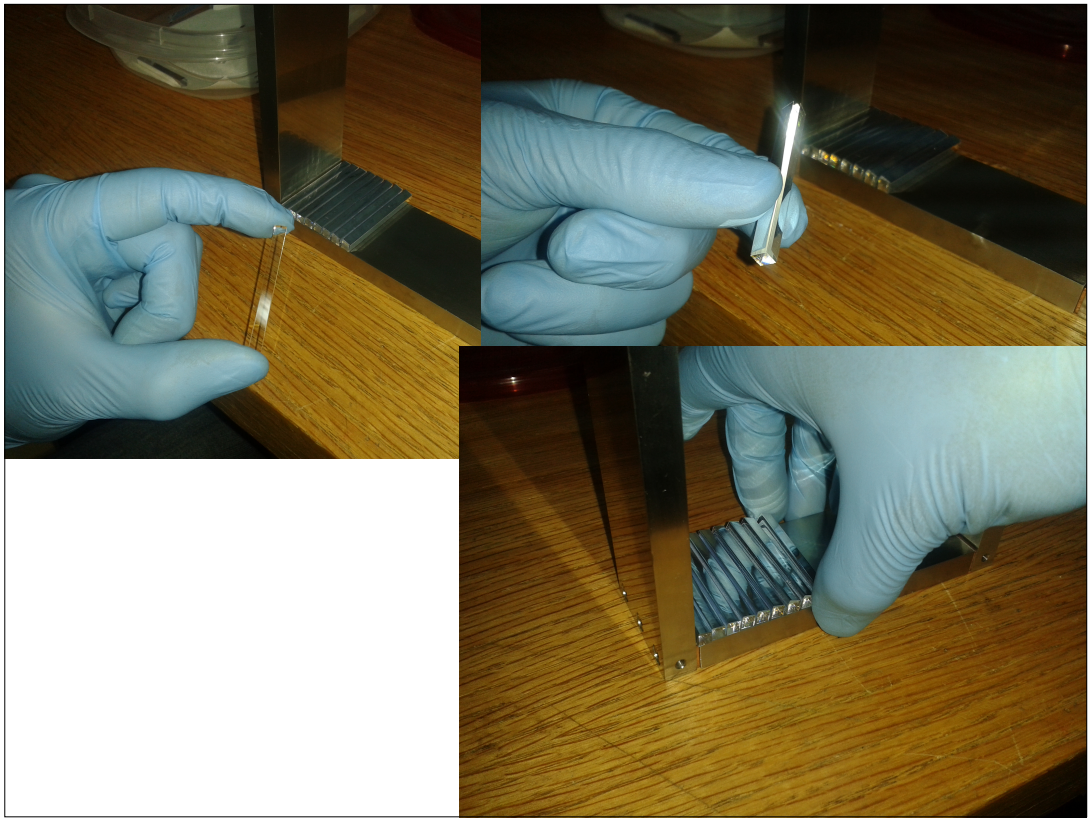


Fig. 10. Stacking procedure near the final stage, with the mechanical frame still loose (left) and following the addition of the top plate, optimization of the copper shims, and tightening (right).

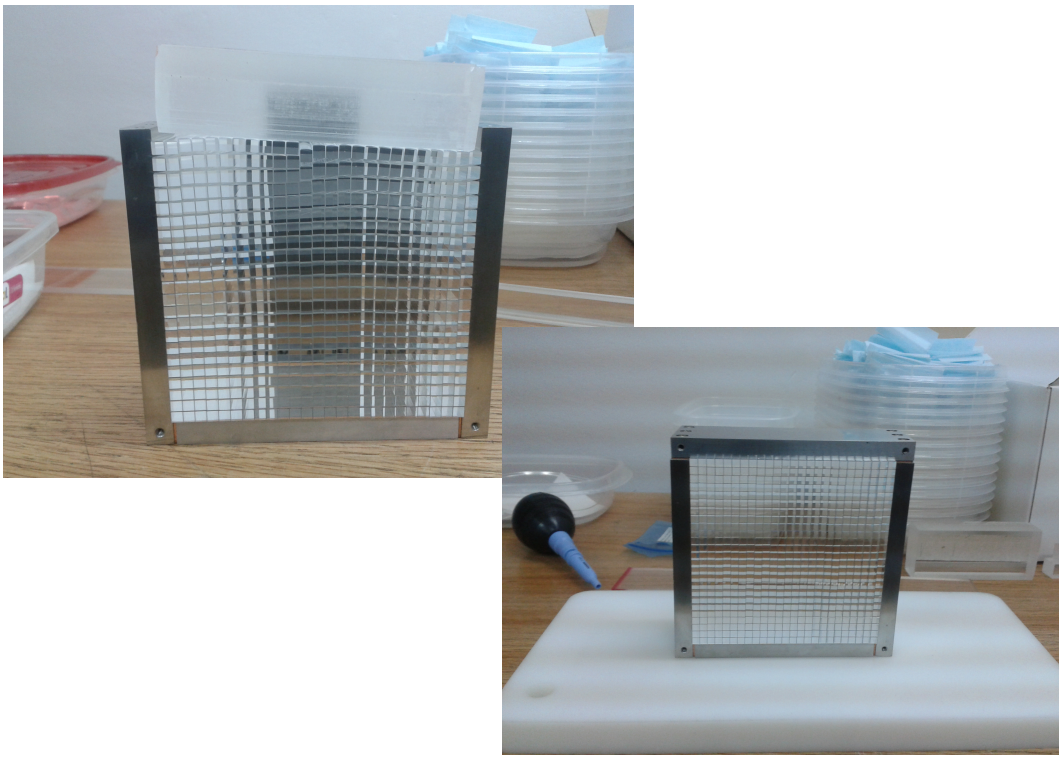
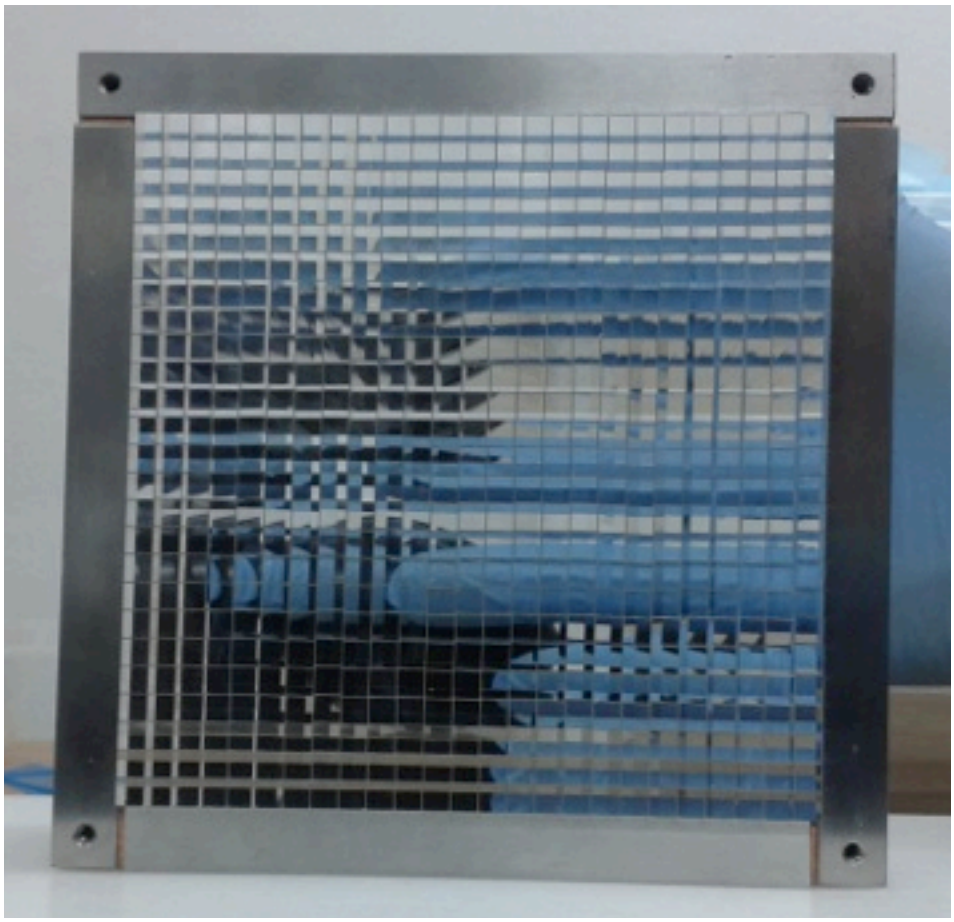


Fig. 11. Final stacked array. With a person's hand behind the crystal, there is the appearance of perfect transparency for normal incidence, while for views at an angle the apparent image is fragmented, as expected.

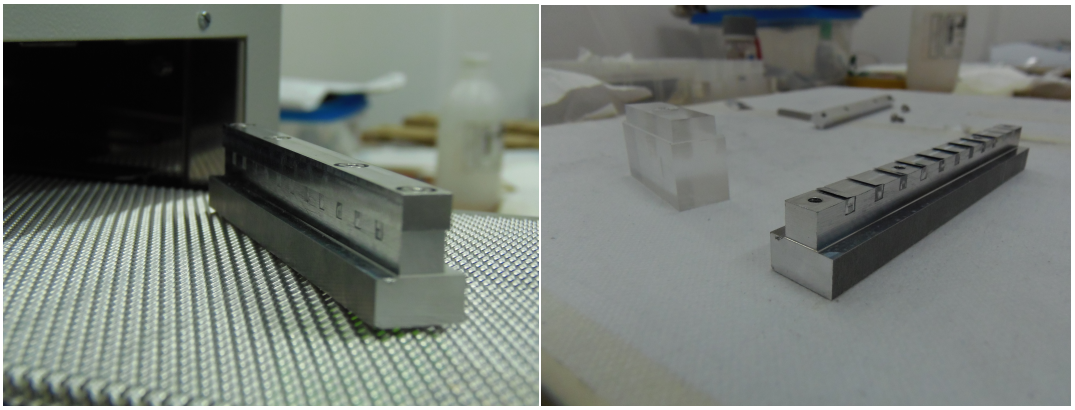


Lightguides

The lightguides are in fabrication in our plastic polishing facility. Approximately half have been completed, and the other half will be completed within two weeks. Due to their small size, the hand-polishing process has been more difficult to control, and new polishing jigs have been developed to achieve consistent results. The expertise level of the polishing technician also needs to be higher than for larger pieces which we have previously polished.

Plastic reflective wrapping has been formed for the lightguides just as it was for the crystals. Photographs of the wrapping jig are shown in Fig. 12.

Fig. 12. Fabrication of reflective film wrapping for lightguides using the same technique as for the crystals (c.f. Figures 5-8).



Mounting of MPPCs

The MPPC mounting onto the electronic boards was performed with attention to the mechanical location of the devices. To this end, a mounting tempate was machined out of plastic and the MPPCs were positioned within it. The mounting template had reference pins matching the mounting holes of the circuitboard to ensure the correct alightment alignment of the MPPCs to the lightguide assembly as well as to the mechanical frame holding the crystals. These elements can be seen in Fig. 13.

Fabrication of amplifier boards

The amplifier boards were populated with devices using the new microelectronics fabrication facility within our detector laboratory. Micro-components were positioned in place with a specialized mechanical positioner and oven-soldered to the board, as illustrated in Fig. 14. In Fig. 15 are the final amplifier boards as fabricated in our shop.

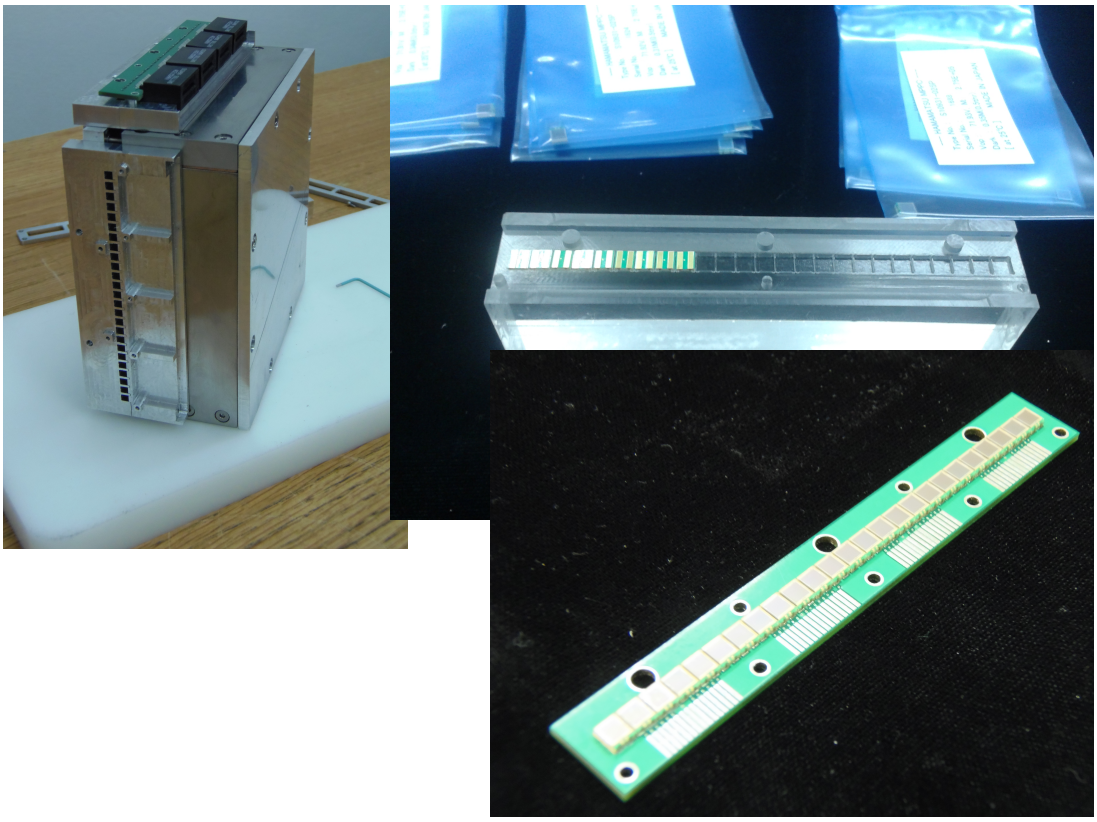
Problems and delays

We had two problems that delayed the progress of the project relative to the schedule presented in June 2013.

The first problem was that the MPPCs were delivered at the end of July, nearly two months late. This pushed the electronic testing and electromechanical assembly process to a later date than previously envisioned.

A more difficult problem was that the spindle of our 5-axis CNC mill broke in May, and the repair process in total entailed a delay of nearly four months. The delay was a combination of many effects. The mill was manufactured in Germany, and the spindle

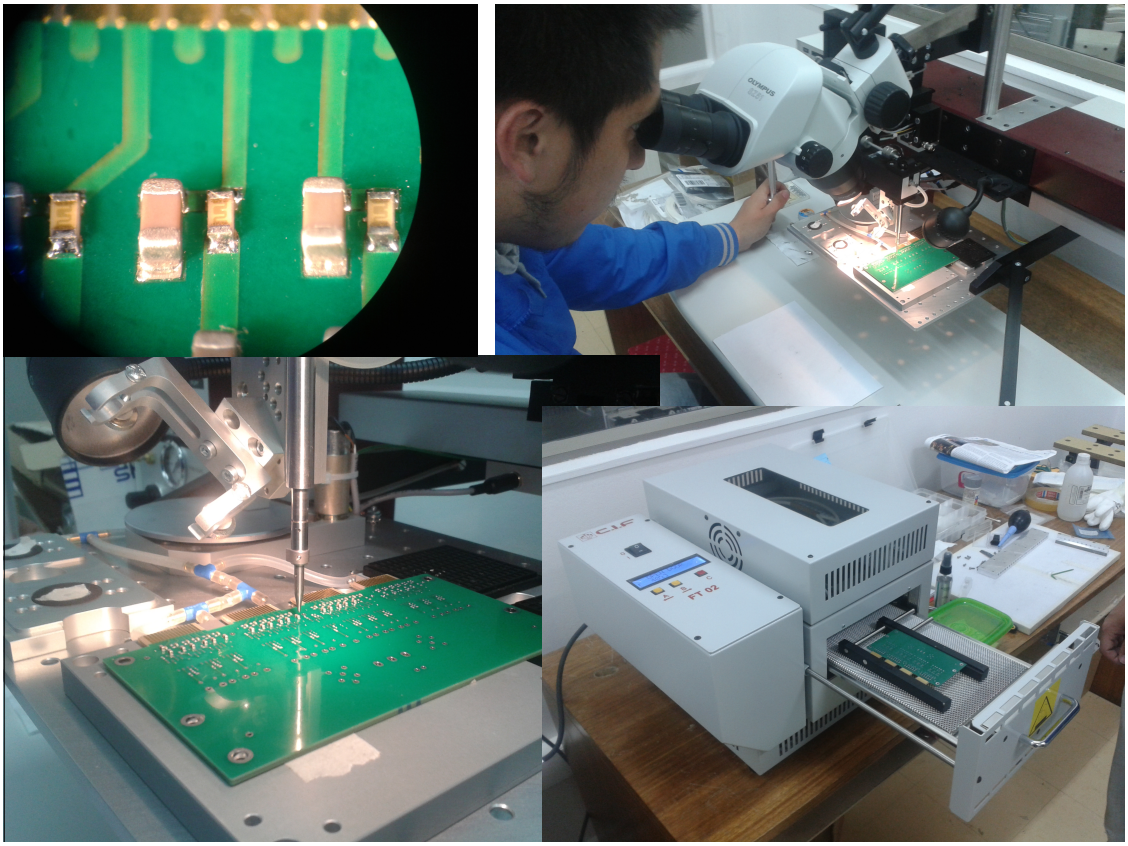
Fig. 13. Alignment of the MPPCs before attaching to the circuitboard. (upper right) The plastic alignment jig, with alignment pins matching the mounting holes in the circuit board. (lower right) The circuit board with MPPCs attached. (upper left) The circuit board mounted on the top of the device; square holes corresponding to the lightguide locations are visible on the vertical edge.



was a specialty part manufactured by a different company. Replacement of the part by manufacturer representatives was required. Clarification of whether the repair would be covered by warranty required more than one month, because staff at the manufacturer were unavailable and apparently internal decisions were needed for this determination. Further, the exact nature of the failure was initially unclear and it required remote diagnosis by the manufacturer. The work was ultimately not covered by the warranty, and funds had to be identified for the very expensive repair, which exceeded all budget allowances for maintenance of the device. Funds were eventually identified through descoping of other ongoing projects and altering travel funding sources, all of which required time to negotiate and implement. Once the funds were identified, there were substantial additional delays in scheduling the manufacturing representative's visit from Germany to Chile for the repair and required training. In the end there were also substantial delays in shipping the new spindle to Chile, which required coordination with customs as well as with the representative's visit.

The delay incurred by the loss of availability of the mill was primarily in the fabrication of the mechanical frame and the fiber mounting frame, and thus in the initiation of the stacking process. Some of the delay was offset by outsourcing machining to other shops.

Fig. 14. Positioning of micro-components on the amplifier board using the new microelectronics fabrication facility within our detector laboratory. Following placement of components, oven soldering is performed as shown in the bottom right photograph.



Schedule and future

We believe we can finish the assembly and initial testing of the device, and start cosmic ray tests, by the end of February. We expect to have preliminary data from these tests by the end of March.

We are not submitting requests for more funding at this time. However, we envison requesting additional funds in the summer 2014 cycle, if it occurs as planned. Among other work, we hope to perform beam tests of the device at a test facility location still to be determined.

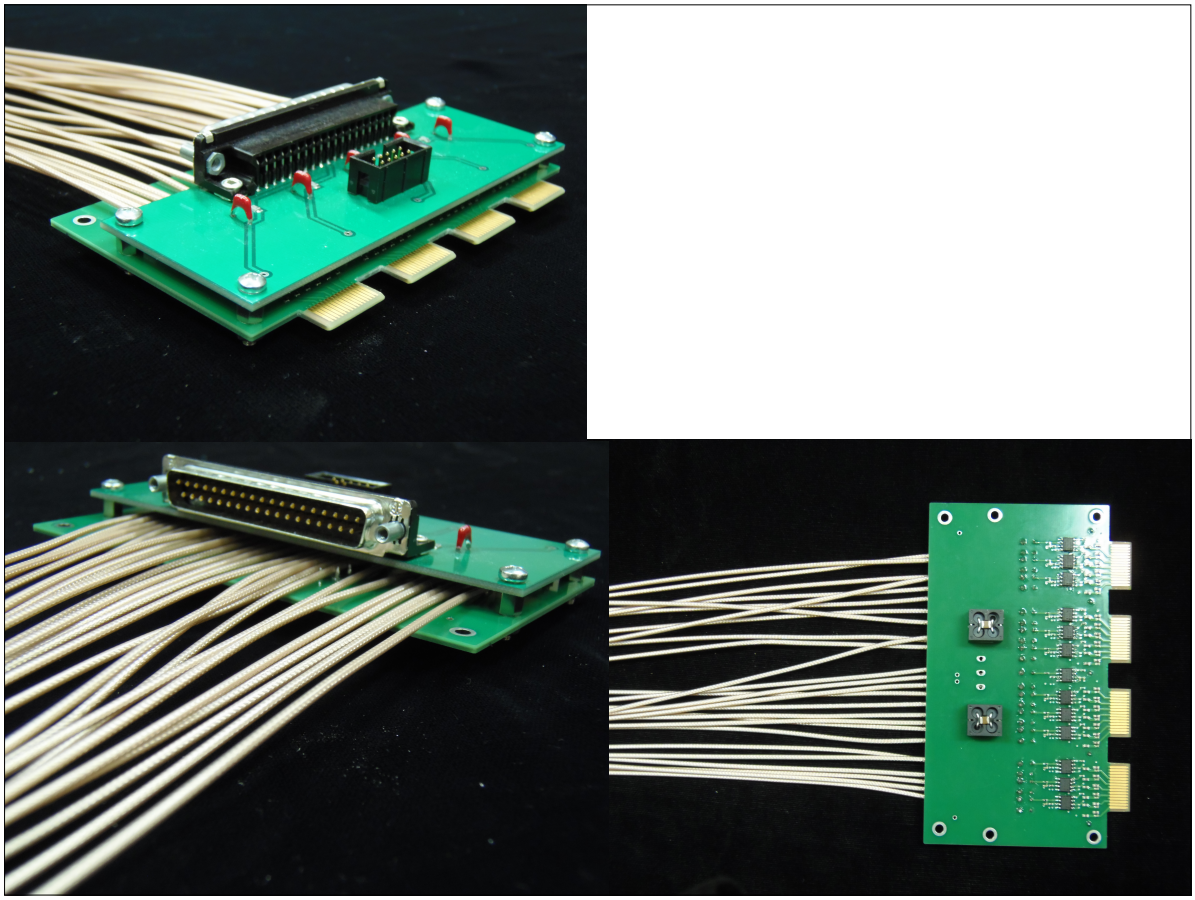



Fig. 15. The finished amplifier boards.