Answers to Q12

From Steve M.

The HV Bus forms a continuous loop around the CPA Array with many connections between CPA Panels.

On a CPA Panel, HV is connected to the resistive panel with 1 inch square brass blocks which contact both sides of the resistive panel and are connected with machine screws and belleville washers. There is an 8-fold redundancy in getting the HV from the topmost or bottommost CPA module to the middle modules – 4 connections from the top and 4 from the bottom. The HV Bus on the 50 CPA Panels in an array is connected by jumpers between Panels top and bottom. If 1 jumper becomes broken, there is no interruption of HV since the HV Bus forms a loop. If 2 jumpers break, then loss of HV occurs and can befixed by adding a second HV Feedthrough (HV connection donuts will be installed on both ends of the CPA Array but only 1 Feedthrough will be initially installed. The second feedthrough can be installed after cryostat is full if needed. Some additional redundancy compared to ProtoDUNE will be accomplished by moving the HV Bus vertical sections inside the CPA frames. This means that the middle resistive panels of the 2 end CPA Panels will have several sources of HV - the Bus itself through the brass blocks and the 4 jumpers at each resistive panel interface.

Addressing redundancy:

a - add HV Bus sections of cable and jumpers to the other side of the CPA (currently the HV Bus cables are mounted on only 1 side) Would add material but not significantly more labor to CPA production.

b - strengthen the jumpers between CPA Panels and use ring lugs instead of fork connections. The ring lugs make connection a little harder, but this was done for ProtoDUNE and was not too difficult - it means completely removing the machine screw in the brass block and reinstalling it thru the ring lug to make the connections connections at the top and bottom when linking Panels and Planes.

From Glenn H-S.

* Most connections already have some form of redundancy, including the HV bus, as discussed in detail below.

    * HV bus:

        * The loop topology of the HV bus completely mitigates any single break in HV bus.

        * Various double-break scenarios on the HV bus have been considered. (See https://indico.fnal.gov/event/14079/contribution/0/material/slides/0.pdf) In all but one special case the resistive paths through the cathode and CPA field shaping strips limit the voltage discrepancy to <~1 kV, and the E-field distortion is localized near the field shaping strips. (N.B. This assumes surface resistivity < ~30 Mohm/square.) In the event of a break at the top and bottom of a gap between CPA planes, the feedthrough on the opposite end of the CPA can be used to bias the entire CPA array correctly.

    * The risk of a human forgetting to make an HV bus connection is mitigated by the installation testing procedure: as each CPA is connected in the cryostat the resistance of the circuit is measured with a HV ohmmeter and compared to the expected resistance as part of the QA. This test confirms correct connections for every connection except the very final connection that completes the HV bus loop.

    * Adding more connections to each HV bus connection is possible. Currently there are 48 CPA-plane to CPA-plane connections that must be made at 12 m height inside the cryostat: one at each of the 24 boundaries between CPA planes in each of the two full CPA arrays. If each connection is doubled, then a loose end on a redundant wire could not be detected by the ohmmeter QA method. The benefit of decreased risk of multiple wire breaks after successful connection must be weighed against the increased risk of a loose wire from a missed connection.

* Connections to field shaping strips and field cages:

    * There are four resistive paths from the HV bus to the field shaping strips on each CPA panel - two on each side, with the FSS on each side connected through the top and bottom profiles - which mostly mitigates any any single or double disconnection. One disconnected board would cause ~ 750 V change in FSS voltage on that CPA; 2 would cause ~ 1.5 kV change. (N.B. This assumes surface resistivity of the cathode and FSS is <~30 Mohm/square.) The distortion of the field would be localized near the FSS.

    * Similarly,there are two resistive paths to any top or bottom FC from the frame shaping strips, and two resistive paths to any endwall from the HV bus. Similar comments apply as for the HV to FSS path.

* Connections to the field cage terminations:

    * There are two resistive paths from the last profile of each endwall to the termination on the APA.

    * There is a single resistor board connecting the last profile of each top and bottom field cage to the termination on the APA, but the connection is made with two redundant braids with extra strong ring connectors. It is easier to visually inspect this connection compared to the HV bus connections.

* Concerns:

    * If the surface resistivity of the cathode and FSS are increased to ~1 Gohm/square or more, then the alternate paths through cathode and FSS have resistances equivalent to multiple stages of the field cage divider, with the result that a double break scenario becomes more serious.