Comments on the TOFr5 fabrication
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Some observations based on the TOFr5 fabrication from D&M's perspective, and some suggestions towards possible improvements to future construction, are given below. Once I added all the details needed to provide the context for the suggestions, this turned out to be long, so the suggestions were made bold to highlight the main points. For many of these suggestions there may well be solid reasons against them that I am simply unaware of, so please comment wherever this is so. I'm also hoping that this listing of problem areas spurs others involved in any kind of construction to chime in with their own suggestions for future improvements.

I need to note that some of the complications in the TOFr5 fabrication were foreseen and accepted beforehand. For example, we have been careful to include in TOFr' and TOFr5 a large number of modules that had been read-out in the STAR data-stream in all previous trays. This was done to allow studies of the long-term stability of our MRPCs, which is crucial data to have if we hope to build a ten-year TOF system for STAR. However, the 2001, 2003, and 2004 batches of MRPCs all have different dimensions, which complicates the mechanical design of TOFr5 but for a very good reason. In TOFr5, we also made special provisions for the different MRPC termination approaches to make the ToT information useful. Each TAMP+4MRPC group uses a slightly different method to better electrically terminate the MRPCs to the electronics. Some approaches involved soldering components onto the pad PCBs on the MRPCs themselves, which, especially in the so-called 'serial' approach with a big resistor on both wires of each of the 6 pairs, the MRPCs were then effectively wider than the pad PCBs. These MRPCs thus could not be installed in the inner sides in the way that this installation was originally envisioned without risking damage to these solder connections. As these termination schemes were implemented after all the mechanical components had already been fabricated, we modified the MRPC installation part of the TOFr5 fabrication plan to get around this problem. This too complicated the fabrication but it too was for a good reason, as we now depend on the ToT working for the slewing correction.

I think these kinds of foreseen complications are worthwhile and can & should continue as necessary for the next few rounds of TOFrX construction and commissioning in STAR. This is clearly the most defensible way to continue to improve upon our understanding of the major remaining design questions as we march towards the full system. Thus, I try here to concentrate only on the unforeseen complications that I've noticed, which with discussion we can perhaps avoid in future production rounds.

MRPC INNER GLASS "STAYS" AT THE SHORT EDGES

These are short plastic posts placed between the two outer glass layers in order to keep the inner glass stack in position with respect to the outer glass/PCB assembly in a direction parallel to the long axis of an MRPC. In the assembly of TOFr5 it was noticed on one chamber that these side stays were too widely placed, and the inner glass had "escaped" between these stays such that the inner glass was even with the outer glass.

This module was clearly defeated and was removed from TOFr5. A gentle shake horizontally after this module was removed resulted in all the inner glass sheets to slide completely out of this module. Such an event could also happen in the future in principle as a result of the shipping of the MRPCs or fabricated trays, The **tolerance on the positioning of the inner glass stays seems loose, or the adhesive used to keep these stays in place was insufficiently applied or is not sufficiently stable over long terms.**

TOLERANCE ON MYLAR SIZE & POSITIONING IN 2004 MRPCS

The first test insertion of the bottom assembly onto the inverted top+inner sides+MRPCs was very difficult. A quick inspection implied the problem resulted from the latest batch of MRPCs, which looked too wide. On a few extreme MRPCs, one or both mylar layers in an MRPC extended >100 mils past the neighboring PCB in either direction. Once this was noticed, these extreme cases were trimmed with a razor blade in situ. A second test-fit of the bottom assembly was noticeably easier.
Further inspection across all of the MRPCs in the latest batch revealed that the **mylar seemed to be oversized in general, and also the placement of a mylar layer with respect to its PCB was also quite loose.** In some cases, the mylar was flush with one (short) edge and extended ~100mils past the PCB on the other. In other cases, the mylar was more centered and extended ~50 mils past the PCB on both short sides. The remainder of the new batch was somewhere in between. As there are two such PCB+...+mylar+... layers in each MRPC, this tolerance affects the resulting outer dimension of an MRPC twice and independently. Before the final sealing of the TOFr5 tray, all of latest batch of MRPCs underwent mylar trimming to some extent on both short sides on both the upper and lower PCB sides. Following this, the final installation of the bottom assembly was as originally expected.

Modules that are manufactured but fail simple dimensional tests (e.g. PCBs not well-aligned) need not go into the queue for HV/noise/cosmics tests! **Such a module should rather be redirected into a shorter side queue of modules that need some mechanical tweaking.** Once fixed, redo the outer dimensions tests, and if it passes these this time, now put the MRPC into pile ready for cosmics testing etc.... Since the outer dimensions tests take only a ~1 minute/MRPC compared to much longer for gas&HV&cosmics testing, such a pre-selection of modules based on outer-dimension tests should save production time overall.

Of course, such a test & feedback mechanism in the MRPC production would also insure that each resulting tested MRPC would fit perfectly in the mechanical components given agreed upon tolerances in the critical MRPC dimensions, which was the original goal of the comments in this section.

Suggest **MRPC outer dimension and square-ness measurements should be part of MRPC production QA.** The measurements of interest are (each to 5mils or better):

Height of module at all four corners of hexcell outer layers (→height of inner sides reveals)

"Total" short width at both short sides (→width of inner sides reveals)

"Total" long width at pigtail side and at other side (→interior width of the bottom assembly)

Both of these "total" dimensions are measured across the fabricated MRPC - i.e. the dimensions of the "shadow" of the module in various locations. Since these measurements are across both outer layers, these measurements also indicate square-ness & alignment of the two (practically independent) PCB+...+mylar+big glass layers.

We noticed a modules in which the two PCB assay layers were quite skewed with respect to each other. **These kinds of outer dimension measurements should be used for QA and maybe also tabulated along with any other test data as part of the module documentation shipped along with the MRPCs.**

MRPC SIGNAL PIGTAILS

problems with signal pigtail connections to pad PCBs:

In TOFr, TOFr', and as delivered for TOFr5, the MRPC signal pigtails are soldered to the PCBs and then laid down 'along-eta' onto the top of the hexcell, and a layer of 0.5" kapton tape is then laid across all six pigtail cables parallel to the long edge of the MRPC. **This kind of pigtail strain relief is not appropriate if we stay with the TOFr5-style inner sides concept.** To install MRPCs in TOFr5, it was necessary to release the outer two pigtails so that they could be laid along the long edge into the corner of the hexcell&PCB. This allowed the MRPC to slide into the inner sides.

In a few cases, **pigtail wires broke free where they were soldered into a pad PCB** - these could be fixed by re-soldering, but in general this appears to be a very fragile connection.

We should discuss **how the signal pigtails are strain-relieved where they connect to the pad PCBs**. one idea: finalize the inner sides design and hence signal pigtail routing during MRPC installation in the inner sides, bend the pigtails into the appropriate direction, and then put a dab of CAF4 where the pigtails are soldered onto the pad PCB. Other ideas?

problems with signal pigtail connectors at TAMP side:

The small two-socket connectors that connect the MRPC signal pigtails to the underside of TAMP have several problems.

We have **seen these coming loose** from these pins in TOFr, which were perpendicular to the FEE layer. In TOFr'/TOFr5, the pins were/are parallel to the FEE layer, which should help reduce this problem, but still **this connection has no strain-relief whatsoever**.

The underside of the gas box-closing layer of FEE – the F/T boards (run-3), TFEE (run-4), and TAMP (run-5) - all had/have 6 pins available for each MRPC channel inside the gas box yet we have always only used two of these pins to connect an MRPC to this FEE layer. **Why so many Pins**?

During the TOFr5 testing, several dead channels were found and each was from the same reason. Basically, the stripped wire inside these connectors was not sufficiently pressed down into the connector's teeth, hence the wire was not electrically mated with the sockets in this connector. We thus need to **make sure the wires are well-seated in these connectors**, and also **include in the module fabrication plan a simple electrical continuity test between the sockets of these connectors and the points where the signal pigtails solder onto the pad PCBs**.

As these connectors are clearly prone to this problem, and because the complications to the TOFrX tray fabrication process that they have always caused (since there are 6 pigtails/module), **why can't we join all six signal pigtails onto a single 12-pin connector that mates to TAMP in just one location per module**? No changes would be needed to the lengths of pigtails or how they are attached to the pad PCBs. The change is just that one connector mates to TAMP instead of 6 small un-strain-relieved and proven failure-prone connectors → tray fabrication faster & better. Likewise, there is just one connector to mate to a test fixture at whatever point of the MRPC construction or the tray construction versus 6 very small ones → better testing is also faster. This change would also free up a lot of area on the underside of TAMP that is presently filled up with pin headers, so if we go this way it should be easy to add strain-relief to this connection, taking care of that problem with these connectors as well.

There is though an open question as to whether this suggestion would cause complications to the electrical design of TAMP to accommodate a single 12-pin connector. These could outweigh the significant fabrication and testing time savings, so we need to fully **explore the penalties & benefits of replacing the six two-socket pigtail connectors with a single twelve-pin pigtail connector** on any newly fabricated MRPCs.

TAMP-RELATED PROBLEMS

Solder pads for LV connectors placed too closely to wide edge of TAMP. Pure shorts to top assembly were quite possible. Added special cutouts to "large holes" in top assembly fab to avoid this problem. Need to move these connectors away from this edge in future trays.

Four horizontal pin-headers on one long-edge of TAMP are positioned ~3/8" too close to the edge. For these, the two-socket MRPC signal pigtail connectors cannot be installed if the neighboring Inner Side is in place. This problem was one of the major reasons that an unforeseen special "sideways" module installation procedure was required, which significantly complicated the module installation process.

If we chose to stay w/ six separate pigtail->TAMP connections per module instead of the 1 as suggested above, then these pin headers need to be either moved away from this edge or turned around.

The testing procedure done to the TAMP PCBs when these are received from the PCB manufacturer, and the testing procedure done to the TAMP boards after they are stuffed, is not documented, yet these tests are simple enough that an engineer is not required to flag suspect channels. The **TAMP test procedures should be documented** to allow less-qualified collaborators to take on the majority of the load of initial-testing the 960 fully-qualified TAMP boards needed for the full system.

INNER SIDES

This was the major step forward in the mechanical design, and TOFr5 was our first attempt at pushing this idea all the way through to a completed tray. We learned a lot about the Inner Sides idea in this way. In TOFr and TOFr', ~80 individually cut and positioned pieces of 1/4" hexcell, "sawtooths," were glued to the interior long vertical sides of the bottom assembly. This was time-intensive to fabricate

and install (several man-days, plus curing time). Also each sawtooth is placed individually, which leads to overly high tolerances on the positioning of MRPCs with respect to the tray body.

The inner sides concept first attempted in TOFr5 dramatically improves the precision on the MRPC positioning while also reducing (from several days to several hours) the time it takes to install 32 MRPCs in a tray assembly. There are two inner sides per tray that "hang" from the underside of the top assembly. The two inner sides are the same (i.e. can be machined at the same time) and run along the two long edges of the tray at ~1" in from the tray walls. The material for the TOFr5 inner sides is 1/4"-thick acrylic with outer dimensions of ~3"x90". Rectangular "reveals" in these inner sides hold the MRPCs at the correct position and angle and are machined by a Hurco machine using the DXF file produced by D&M. Thus, the loose and position-dependent tolerances on the MRPC positioning in TOFr and TOFr' via sawtooths is replaced by a scheme where each and every MRPC is positioned to ~20mils with respect to the inner sides (this 20mils is to allow for the variations in the MRPC outer dimensions, which need to be better controlled anyway, see section above), and the positioning of the inner sides with respect to the tray is just a single constant that is known to ~10 mils.

The TOFr5 reveals are simply rounded rectangles at the proper position and angle. **Need to optimize the shape of these reveals to allow pigtails including their connectors to more easily pass through the reveals during the MRPC installation process.**

After the reveals have been machined away, the inner sides are fragile. We want to stay with no more than a 1/4" thickness to reduce the mass inside the box. **Plan to replace acrylic with lexan.**

Enjoy a **widening of the positioning of the two inner sides if the cooling loop goes from 1/4"x1/4" square tubing to 1/4"x3/8" rectangular tubing** (see below). This should reduce stresses on the signal pigtails in tge two extreme pads on all MRPCs. However, this cannot be widened too much or we won't be able to install the teflon screws for the inner sides mounting to the lower brackets.

Need to **add a ~3/4"x5/16" slot for the 1/4" interior gas tubing near the eta-0 end.**

Two reveals of the 32 in TOFr5 are ~1/8" too high, and thus these MRPCs get blocked by the edges on the 'shoe-box' top assembly (this was another reason for the TOFr5 "sideways" MRPC installation procedure). **Need to tweak the MRPC-placement scheme so that this blocking doesn't happen and/or reduce the lip on the top assy.**

Need to **add 'mirror' holes along lower edges to the CADD drawing.**

Possibly **reduce number of points where inner sides mounts to top assembly**? Presently there are 9 upper brackets, whereas 5-6 is probably enough. Thus would allow some TAMPs to be closer together on the top assembly and hence there would a bit better geometrical efficiency per tray compared to TOFr5. If this pursued, we need to coordinate with the mechanical assembly modifications (next subsection below). There is some interest in "matching" the positioning of the lower bracket Z-positions on the top assembly to the positions of the screws that mount the top assembly onto the bottom assembly. This would make inner sides installation somewhat easier, as a standard screwdriver could be inserted through holes in top assembly to drive in the teflon screws for the inner sides.

Presently these two sets of screw locations are not matched in Z along the tray, so it takes a few minutes more to install these teflon screws.

MECHANICAL STRUCTURE

The TOFr5 mechanical assembly as fabricated at Oaks Precision is overall very good. The inner sides concept works, two layers of FEE were successfully integrated with the cooling loop and the mechanical structure of the gas box, and all FEE are enclosed in a (mechanical and RF) protective cover. These are all new improvements to the overall mechanical design. TOFr5 is also the first MRPC-based TOF tray that fits in front of a BEMC module.

There was really only one problem with the mechanical structure as delivered by Oaks. The lower edge of the (unloaded) bottom assembly of TOFr5 had 100 mils of arc presumably caused by the plug-welding of the tray feet onto the bottom assembly. This arc is smaller when the tray was fully loaded and closed, so the only downside is that it takes slightly more force to slide the tray onto a TPC rail. The concept of welded feet (used in TOFr' and TOFr5) is still good, as it reduces the number of holes through the box that would need to be gas-sealed, but I need to discuss this with Oaks and see what can be done to **reduce this bottom arc from welding** during the fabrication of all future bottom assemblies.

We intend to build four next-generation trays, four TOFr5' trays, within the next few months that will include as many improvements as possible. This upcoming production round is thus the first time that Oaks will be producing more than one TOFrX box assembly in a single fabrication round. Aspects like the tolerance on the PEM stud positioning (electronics and inner sides mounts) are so tightly controlled at Oaks (few mils) that there is no concern whatsoever with the PEM-stud model used in TOFr' and TOFr5. However, the "one-off" fabrication that we've asked of Oaks for TOFr' and TOFr5 allows certain workman-like "fitting" of the bottom, top, and cover pieces to each other during the production of a single tray. In a multiple tray production, it seems more likely that the raw components are machined in parallel. This next round of tray fabrication should thus **carefully work out with Oaks the tray-to-tray tolerances on the critical dimensions in multiple-box production runs**. The critical dimensions are the following:

Interior width of bottom assembly
Fit of top assembly onto bottom assembly (in 2 dimensions)
Position and parallel-ness of tray feet.
Flatness along length ("arc") of bottom assembly after feet are welded onto bottom assembly.

Oaks may need to jig up more than they have to achieve the same tolerances tray-by-tray in a multiple tray production as compared to the previous two single-tray fabrication rounds.

UHMW polyethylene strips are 2x3 separate pieces per tray, and somewhat tricky to install correctly after feet have already been welded onto the bottom assy. **Consider U-shaped plastic extrusions (2/tray)** that can be spot-glued into place. This could result in a much faster installatio of this component with no loss of functionality or additional cost.

MECHANICAL DESIGN OF ON-BOARD ELECTRONICS

As in the 3 previous years, D&M has tried to keep current with the mechanical aspects of the electronics design and fabrication, but during TOFr5, D&M found out about changes that were made to mechanical design aspects of the electronics when it was too already late to discuss. The cooling loop design that the engineers preferred was not discussed until after both the TAMP and TDIG boards had already been ordered. Thus, D&M had to scramble to again bend to match the electronics design at any cost. The result was ~1" projective gaps in eta (i.e. gaps in our geometrical efficiency in eta) after every 4th MRPC to allow the support of the cover assembly in a sane way given the cooling loop design, and to allow the lower brackets to install on the underside of the top assembly for the inner sides. The wide footprint of the cooling loop (~0.5") on the top assembly complicated the design of the top assembly and the supports for the cover assembly, as well as the positioning of the inner sides. Also, mistakes in the hole pattern in the produced TAMP and TDIG boards (the silly 10mil non-symmetry of the 8 “side holes”) resulted in complications in the tray design and construction that could quite easily have been avoided. D&M will continue to carefully keep the details on the current mechanical design available for review or revision as the group sees fit. I simply ask that it be recognized that the mechanical aspects of the electronics design must match exactly to the mechanical aspects of everything else, and this requires coordination in equal measures from both sides of this interface.

Suggest **both D&M and EEs are required to make available drawings that indicate the mechanical aspects of any new designed component.** We clearly need better communication throughout the group on the mechanical aspects any newly produced electronics boards. To be useful, the drawings for circulation should indicate

the outer dimensions of the board.,
the hole pattern with respect to any corner, including diameters, tap instructions etc
the position and dimensions of the fiducial,
(the region on this board where components are and mechanical components should not be)

Such drawings should be circulated *before* any boards are produced. D&M should then be required to review the drawing(s) and provide any integration comments and/or make any necessary revisions to the tray mechanical design to insure that these boards will fit in a way both sub-groups find acceptable.

COOLING LOOP DESIGN

Tests indicate TOFr5 cooling loop would be consistent with 100% efficient for heat removal from the on-board electronics if an un-perforated cover assembly would be used. This is the case even though the temperature of the cooling water used for these tests was "high" (31 deg C in the tests versus 24 deg C in STAR). Thus, the cooling loop may be over-designed. This may be good overall because the present design has some significant drawbacks, and we might well be able to take care of these yet still retain a sufficient heat-removal efficiency. In TOFr5's cooling loop, heat flows through significant thicknesses of aluminum shims, thermally conductive plastic strips (7 and 11 mils), and some thermally conductive grease, before reaching the ¼” square copper tubing that carries the water. These deal layers hinder efficient heat flow and contribute to inactive mass of the detectors that produces secondaries that we don’t want. Copper as the tubing material is highly thermally conductive but has a radiation length that is a factor of >6 more than Aluminum tubing of the same thickness, at a cost of

only a factor of 2 in thermal conductivity. We must reduce the total interaction and radiation lengths of the mechanical structure related to the heat removal system via a **simpler design of this cooling loop**.

How about a 1/4x3/8" rectangular Aluminum loop? Besides removing the dead-weight layers mentioned just above, the smaller footprint on the top assembly would give more breathing room to improve the arrangement of various pieces in the mechanical design (upper and lower brackets, inner sides position etc). The smaller footprint would also allow more room for components on TAMP and TDIG, or more space for traces (whichever the EE's prefer). The smaller thermal conductivity of aluminum compared to copper might well be compensated by the more efficient thermal path that results from the (taller) rectangular loop. The present Al and plastic shims and grease layers are simply there in TOFr5 to mechanically build up the height from the ¼" width of the square copper tubing to the required TAMP to TDIG inner distance of 7/16" (set by connectors). We would be better off removing this dead weight and filling up that same space with flowing water.

STSG does not allow systems that include copper tubing to connect to the TPC's water skid for chilled water. The EEMC uses copper tubing for cooling and has thus set up its own private cooling water system using an off-the-shelf water recirculation unit. TOFr5 has no choice but to set up a similar (hopefully smaller) system before the upcoming run. Another advantage of going to an aluminum loop would this be that the growing TOFrX systems in future years would be allowed to rejoin STAR chilled water (hence there would be one less major ancillary system that we have to do completely ourselves).

We need to **do a temperature test of the kind done for TOFr5 with a rectangular Al cooling loop**. We need to evaluate the efficiency of this thermal path with respect to the total electrical power dissipation on TOFr5' as in the TOFr5 temperature tests.

PRE-SEAL TESTING

The time required to open a sealed tray, fix an internal problem, clean up the defeated sealant, test-close and retest, final-seal, cure, and retest is huge compared to the time it takes to solve problems inside the tray if caught before all of the final sealing steps. It is only recently during the TOFr5 construction that some specific electronic tests have been identified that seem to indicate suspect read-out channels without the need for a sealed tray, perfect gas quality, high & low voltage, etc… This kind of pre-final-seal-testing would make the fabrication of final-sealed and high-quality trays much easier... We should further refine these kinds of tests, and hopefully pick one or two very general but effective ones, and then make these a standard part of the tray fabrication process.

The kinds of pre-seal tests tried for tofr5 were the following two. Ted can fill us in the technical details that I gloss over here - this is more a 'users' perspective...
-"Air Core Transformer test", a pulser is connected through the gas box to a loop of wire tied to a similar and parallel loop in a HV bus. This floods the interior of the gas box with RF waves. One can use a scope probe to pick off the signals from the preamp pins outside the box. The resulting signals on the scope are very, very messy. There is even some indication for 'nodes' in these EM modes inside the box. Anyway, in no way can one compare signals even in neighboring channels of the same MRPC... This method seemed to correctly find a few problem channels but this test only looks at signal side of

an MRPC pad pair. The requirements to perform this test are that the bottom assembly is in place with respect to MRPCs (otherwise no EM modes inside the box and the approach doesn't work), LV is on the TAMP boards, and the MRPC signal pigtails are connected to the underside of the TAMPs. The MRPCs don't need HV and the gas volume can just be air. So, for this test the pro's are that it's relatively easy test to perform, and capable of locating problem channels on signal side. The con's are that the signals are messy and cannot be compared to each other, so it's more difficult to define quantitative test and Q&A procedures for production. Also the termination side of the MRPCs isn't tested.
-"Time Domain Reflectometry test" seemed to be a much better test. Here pulser signals were run through a tiny board (Ted can explain) which strobes both the signal and termination pads directly and again a scope probe is used to pick signals off of the preamp inputs on both sides. This test seemed much more precise as far as indicating sick channels (3 were located and fixed - see MRPC signal pigtails section above). Typically every channel in a given TAMP board looked the same as all the other channels in the same TAMP,[1] except for the apparently sick channels.

I was so impressed about how many specific fabrication failure modes could be caught well before tray sealing that I'm optimistic that these tests can be improved in precision and made more automated and simpler to operate. Such tests can and should also be performed as part of the standard Q&A during the MRPC module fabrication – they do not require high voltage nor good gas and thus are both sensitive to a number of MRPC and signal path problems but are also very, very quick to perform. We should **develop a full "pre-seal test suite" and get this suite of tests involved during both the MRPC fabrication in China as well as the final tray fabrication in the US** after the MRPCs have been shipped.

[1] In TOFr5, each TAMP board has a different implementation for the MRPC-termination fix to the ringing seen in the analog signal in run-4. Since we now depend on a good measurement of this width, this ringing cannot be allowed. We test 7 different approaches for a new STAR MRPC termination scheme in 7 of the 8 TAMP positions of TOFr5. These approaches all appear to kill the ringing, with different effects on e.g. the rise-time of the signal at the preamp. Thus, in this pre-seal test, the 24 channels in each TAMP should look similar, but channels from different TAMPs can look very different in either or both the signal and termination sides.