PHENIX Barrel Supports

# Overview

This is an updated description of the associated cost spreadsheet and details of line items for the production of the PHENIX Barrel Shells, and the supports for the Pixel Layers. I had excluded the Stripixel (NAME?) from the previous estimate, but the Layer 4 Support Assembly is now explicitly included as it forms the support flange of the Barrel Support Shell. I have included Layer 3 Support arms in Contingency

This estimate is based on updated models provided by RJ--will include assembly drawing with this to indicate what is estimated. Some details are uncertain. In particular how the shell transitions to the Support Beam and the Layer 4 Support Plate. I have included a structure called transition ring ~$30k with tooling, and a more complicated procedure for fabricating the Support Beam ~$40k with tooling. These are balanced against a more simple to produce half shell. The 'Transition Ring' may not exist, but is a reasonable accounting of complexity. The Support Beam here is assumed to be a bonded, cored assembly. If it could be a simple machined solid laminate, its cost would reduce substantially. These points will be discussed in the sections outlining these structures.

I have included the labor rates for 'Work For Others' at LBNL--these are ~30% higher than version 0.0 of this estimate. I have also adjusted up some of the machining hours as this is a formal quote rather than estimate. As before, I have included 'switches' in the estimate that will allow you to study shifts of work from LBNL to LANL or HYTEC (sorry--coded this before IMTEC/3M, though I could change this if desired)

## Contingency Planning

The contingency here is all explicit. I have accounted for less than certain designs by including the afore-mentioned structures and their somewhat inflated estimates. The items which are explicitly labeled contingency are either iterations--hope not to spend, or increased scope (Stripixel Layer 3).

# Engineering

Significant tooling design will be required to fabricate these components. I have costed an Engineer Level 3 to assist with this (I need to verify the rate/person--this is hopefully an upper bound).

## Design for Fabrication

My input to the design represents most of the design for fabrication--change of the part geometry to make it easier/less expensive to fabricate. To date, this has been provided for free, but with no real detail work on the part of LBNL. Transition to construction will likely involve additional changes in small details, and ultimately the design of the tooling. Most of the engineering included in this estimate is aimed at that effort. It is assumed that IMTEC will follow, perhaps even carry some of this load. The number of hours included assume that an LBNL Engineer/Designer will handle most of the tooling design and oversee the fabrication/assembly.

## Oversight

I will suggest that some of the machining work be shopped out--in particular to take advantage of lower overhead for some of the parts. The spreadsheet does not include sufficient granularity to capture the remaining oversight overhead. For instance if line items get shifted to LANL/HYTEC, the engineering is taken off-project. If these options are pursued, some engineering will need to be built back in to handle the oversight. I chose not to build these into this quote as they would appear as contingency, and inflate that figure unnecessarily.

# Material Batches

These assemblies are all nominally made from M55J. In fact, the M55J material we have in stock for the Stave production could be used for much of this assembly. I believe that it will remain functional for most of 2009 as we store it at -40C. The primary limit will be 'out life.' It has only 7 days out-life after which it begins to lose properties necessary for lamination. It is possible that we can batch the cut and kit operations to still fit within that period, but I have included in base cost a new batch at standard rate (versus the cheaper rate we got for the current batch). We can discuss whether to move this to contingency or remove it alltogether.

The second material (CN60 Cloth) would be used for the 'Transition Ring' and to make a solid laminate Support Beam. If these options are chosen, this material is required. It is currently in contingency in this estimate. The FVTX will however require this material to conform to the shape of the cone. It will be in base cost for the FVTX but I've not taken much effort to homogenize contingency across both deliverables.

## Expendables

Composite material processing uses expendable bagging materials, tape, film, et-al. The material cost in each part will be the cost of these expendables (based on tool area)—not the composite cost. These are cheap by area, but large in minimum orders. We usually share these across projects.

The Stave will use excess stock from ATLAS, but the area and part count for the Barrel Shell, and the dwindling stock will likely require some material orders. I will include ~$5k for this

## Composite Batch Estimate Structure

Each batch requires some QA and tech labor to produce samples. We can save a few $k by minimizing the number of batches. Technically the material is off-spec 6mo ARO. We store at below spec temperature so can likely stretch this by another 6mo. Uncomfortable without testing thereafter. Testing would be identical in cost to the Batch Acceptance procedure below, but without the cost of a new material order.

### Material Acceptance

Assuming we keep using the current batch of M55J, approx every 6mo we should re-up its qualification. The resin is 'B-Staged, so partially cured and slowly cures during its storage, more rapidly when it is 'out' i.e. warm for cutting, so it's viscosity performance during a cure cycle can change.

Nominally we would only need to verify that the same bleed parameters continue to work--amount of bleeder, and perhaps tweaks to the cure profile (longer dwell at viscosity min temp) to assure we can still get ~58% Volume Fraction.

This work is balanced against a new material order. I have included the new material order in base, which includes this work. Keeping the old material would mean not incurring the cost of a new batch, but the labor is still the same.

### Material Testing

If we show that we can get the same bleed performance, we will stop at bleed studies. If the thickness varies out of statistical limits, we should re-submit a sample for material testing. This would determine the new nominal void content primarily (fiber modulus being already determined).

Would need approval from project cognizant engineer pursuant to test results before proceeding. This is more a time delay rather than cost increase.

### Iterations…

Thickness is not as important as with the staves. Iterations are not required.

## Adhesives

Hysol and the other Loctite adhesive will have generally a 6mo shelf life. Depending on schedule several batches may need to be ordered.

# Component Fabrication

The component composite parts of this production have very low part count, so there is little to benefit from any significant ‘pre-production’ where we strive to get the assembly procedure set well for production. Generally there are two identical (sometimes 4) assemblies required as deliverable. The contingency model for this will be fabrication of enough components to make 1 extra assembly of each type, e.g. 1 extra Barrel Support Shell, 1 extra Pixel Barrel Support Arm, etc. This money will not be spent in total, but allows for some errors/remaking of additional components. It would only be used in total if the first bonded assembly failed in an unrecoverable way.

## Pixel Support Components

### PEEK Bits

I have costed two different parts here. There are stave supports, and 'inserts'. I have only one drawing for an 'Insert' but assume there are several flavors, though all similar in size/form. The Stave Supports are nominally also all identical. There are a few intra-support-arm pieces, similar in form to the stave mounts which I include in the cost by an inflated number of stave supports.

I have estimated these also for the Layer 3 support. I have put them into contingency, but you may want to/need to remove this from the estimate. To do so, change the number required to '0' or delete the rows from the spreadsheet.

### Carbon Foam

These are simple parts and unlikely to require any iteration. Propose that at least the large panels from which they will be cut can all be produced up front, but with enough for whole production and any contingency parts. Trimming parts from these plates may be iterated based on assembly tolerances, but the raw stock can be completed and available for quicker iteration later of the cut-part dimensions.

### Skins

The skins for all layer supports will be laminated in 2 batches. I could even do these now if desired. The skins will be waterjet cut from these panels and later assembled via bonding to the foam cores.

## Barrel Support Shell Components

### Half Shell Skin

This is currently rather thick for the material on hand. Usually 6-8 plies per de-bulk is normal in hand layup. This laminate, barring selection of a new batch of thicker material, will require more labor to achieve regardless of tooling options.

Fabrication model is to make these as full shells and trim to shape. Contingency requires making 3 rather than 2, but this is common for ‘thin’ shells—need to develop lamination technique to avoid wrinkles. Note that this is balanced against making a ‘half-shell’ tool. A tubular tool (lathe job) will likely be less expensive than a milled half-shell tool. Making more composite parts to get the process down is likely balanced with the cheaper tooling.

Note that the decision between half-shell tooling and trimmed cylinder is where the 'Transition Ring' component enters the discussion. Going to a half-shell laminate could obviate the need for a Transition Ring, but necessarily makes the half-shell tool more risky

### Gusset Plates

The Gusset plate is a simple part to fabricate, but material intensive, as most of it is cut away. I do not have a drawing for this component so don't know its thickness well. If it is over 2mm thick, it would make more sense to order CN60 cloth rather than build the thickness with M55J.

This will be made as a flat plate, likely trapezoidal to save at least some material, then waterjet cut and later machined--flat-head bolt holes are indicated.

### Transition Rings

This will be a small but relatively complex part. The design of the transition ring will require several features in the part, the intention is to make this part complicated (and small) so that the other larger parts can be made as simple as possible. The part will only be 2-3 plies of cloth, thus only a small amount of labor. Plan for at least one iteration to get this right, and another in contingency.

The goal of this part is to put all the complex geometry features into a smaller tool which is more easily iterated, than building these into a half-shell tool, where iterations mean making completely new half-shells.

### Support Beams

The Support Beams as currently proposed may be cored structures. The intention is to make them ‘flat’. The option remains that they may vary in thickness (moment of inertia) based on load. The goal remains to keep the ‘interface’ surface (that bolted to FVTX and the Pixel/Strip layers flat and parallel to each other, simplifying those interfaces. The bond to the half-shell-skin however requires at least a part of the beam—a projected extension of the lower skin, is curved to mate well with half-shell-skin.

Keeping the above flexibility (varying core or laminate thickness to meet the design) is an option. Core essentially saves mass, but adds another tool, part, and process step. Removing the core, in lieu of a thicker laminate still requires the additional labor required to fabricate a thicker laminate. Something between the cost with full core and bonded assembly and simply excising those parts/steps/tooling is likely.

Estimate is for the more costly process.

#### Base Skin

This is a ‘fully formable’ part — small flat, transition to fixed radius (bond area to half-shell-skin). Tool cost is straightforward—material plus one face machining. Layup, 2mm thick cloth.

If Core is dropped, this tool needs to become more complex to support a thicker laminate—assume that this would be approximately the cost of the ‘Top Skin’ tooling, i.e. a formed tool for only one side, rather than both

#### Top Skin

If the core thickness is optimized based on local moments, the top skin needs a more complicated shape. 10mm change in thickness is assumed, and the skin can be laid up to this profile—again, ~2mm thick cloth.

#### Core

Assumed is a varying thickness core. This can be machined after bonding to the base skin, though requires the additional step of cutting to shape, and a tool to bond it in place—not the same tool as the part, due to CTE mis-match.

No Core machining or Core, for 'thick laminate' option.

#### Bonded Assembly

This would be a vacuum bag process. The same tool required to bond the core to the base skin would be used to bond on the top skin.

This would go away for a 'thick laminate' option

# Deliverable Assemblies

The number and names of the deliverables have changed since the last version of this document. What I had previously called the 'End Plate' is now Layer 4 support, and has been moved to the 'Layer Support Assemblies' section of the estimate. I had also previously omitted the Gusset Plate, which has replaced where the 'End Plate' was in the Barrel Support Shell portion of the estimate.

The Layer Support Assemblies are all estimated together because they are similar in fabrication. All are cored assemblies with inserts, and later have stave mounts bonded to their inner radii. The tooling required and assembly procedures are all similar so each are replicated, with tooling scaled to relevant size of the component. Layer 3 is all contingency, so contingency for a failed attempt is not included. Layer 4 has no stave mounts in the drawing, so they are not included here, though assume they might appear later...

Note that the levels of contingency are based on the delivered quantity, i.e. for the Pixel Supports (4ea), contingency is ~25% which would be what it takes to make an additional assembly. For the Barrel Support Shell, it will be ~50%. This will only include tech-time, not any NRE.

## Support (panel) assemblies (all 4 layers)

These are fairly simple sandwich panel components with a moderate amount of inserts and post bonded attachments. The fabrication method for allf of these structures is similar enough that they are described here. They differ only in geometry, thus require separate tools.

All assemblies use a densified Carbon Foam Core, and some cost-equivalent material for the inserts. Costed is CF PEEK (Carbon Fiber loaded PEEK), but the drawings specify POCO Graphite. Cost per pound is similar, but Graphite limits the number of machine tools that can be used (abrasive material, so requires guarded ways).

The assemblies will be made from skins water jet cut from panels of face sheet material, pre-profiled foam core, and machined mount point inserts. First, the Core, and Inserts will be bonded to the bottom face sheet with a fixture that holds the mounts in the right location relative to each other and crudely positions the face sheet. After this first bond, the foam core will be finished machined to final thickness prior to bonding of the second skin. The second skin will be bonded using the same tool, as the base skin to core bond. The Stave mounts will be bonded in a secondary operation, referencing the inserts. There will be three tools for each assembly: Insert/Core bonding, Core-Machining Vac Chuck (perhaps just a stock vac-chuck), and Stave Mount Bond. The stave-mount bond holds the panel vertically and all stave mounts simultaneously.

### Panel Fabrication Tooling/Procedure

These Tool plates are costed as vacuum chucks with pins rather than pockets to locate parts. Each part has a different outline so needs a different chuck. The base skin is place in the chuck, located by pins. A second tool, also located by pins will place all 'inserts' on the base skin. The core can be bonded simultaneously to the base skin and held with a Caul Plate. After this operation, the Core must be machined to within tolerance (thickness) of the 'inserts' so that the second skin both hits the thickness over-dimension, and has adequate bond to the inserts. The second skin will be located by extended pins (same location as base skin), and loaded with the Caul Plate.

### Stave Mount Tooling/Procedure

The Stave Mounts are pre-machined blocks of PEEK which bond in a clevis arrangement around the thickness of the Support Arm/Ring. Feature wise, it is important to be able to remove these from the tool, as the geometry has potential to trap the part on the tooling. Proposed is a fixture which will hold all parts simultaneously. First a hoop, perhaps requiring 4-axis machining that will hold each stave mount in position via pins—note that the pins must be extractable post-bond, or they will trap the part on the tool. This hoop will be located on a plate which will locate the pre-fabricated Panels (Arm/Ring) using the inserts as reference. This will be a one-shot bond operation.

### QC and Required data

I have not included any CMM measurements of these assemblies. I'm assuming that location to within 0.1mm is satisfactory which is easily achievable via machining tolerance, but if desired, can include CMM survey of either tooling or individual components.

## Barrel Support Half Shells

The Barrel Half Shells are composed of 4 component pieces: Support Beam (2-top and bottom identical), Half-Shell Skin (1), Flange Transition Ring (2), Gusset Plate (2). The Layer 4 Support is required to assemble this for survey. Detailed design of transitions between these pieces does not exist--or rather is open for discussion. I will describe the assembly procedure for them and indicate where some work is needed on their geometry to allow the procedure to work. I believe the ‘money-part’ to be the Flange Transition Ring, which is really a half ring, but needs to interface to all 3 other components and will likely be the most challenging to make.

### Support Beams

The Support Beams are designed as Cored Laminates and extend beyond the End Flanges to also support the FVTX assembly. The Pixel Mounts are pinned and bolted to them, as well as perhaps the Strip Supports (may change these to be only bolted/bonded to the End Flanges?). Note that all support beams are intended to be identical—they should differ only in machining if required.

Estimate is for a cored structure, which will require additional assembly tooling to make, i.e. it will have several components, which will then be bonded together, and later machined with the mount features. Conceivably this could simply be a single, thick, laminate. Details of the transition feature which allows it to bond to the half-shell skin, Transition Ring, and Flange are lacking. I’ve assumed two shaped tools for this. Note that the actual shape is irrelavent to cost—only the depth of the shaped feature, so shape is cost neutral. Potential avenues for cost savings would be making this a single thick laminate (only one shaped tool versus 2). Depending on design requirements (performance) at least one shaped tool is required, and perhaps still a bond tool (to scab on a thick laminate to the shaped one). Details of the final design, backed up by further analysis will dictate.

### Gusset Plate

These are nominally just moderately thick flat plates. They will be water-jet trimmed to profile, with perhaps (included in cost) machined reference holes Even though these are only flat plates, as they are thick, some optimization on material usage dictates that they should be laid up to crude shape requiring some tooling. The cost of the tooling is frequently less than the material cost of the ‘drops’ from a large, thick, flat plate.

### Half-Shell Skin

This is currently a 1.5mm shell. This is 20+ plies of M55j, or 5 plies of CN60. Cutouts are included in the cost, but perhaps an optimization of material might remove the requirement for cutouts. The design change to a single skin rather than cored structure is good, but cutouts add cost

Additionally, the estimate is for a 'straight skin' rather than the formed skin (inclusion of flange-like feature). This is where the 'Transition Ring' comes in. Would like to move the complicated geometry to a smaller part, rather than the high-labor Shell.

### Transition Rings

This part is intended to be the primary interface part for the bonded assembly of the Barrel Support Shell. It must transfer all loads structurally between the half shell skin, Layer 4 Support, and support beam. It will need to have a complicated shape with ‘joggles’ to accommodate step changes in various bond thicknesses. The actual shape of the transition rings is unknown, only their general feature size and tooling depth (allowing an approximation of cost). They will require a shaped tool and likely a few iterations on laminate to achieve acceptable form. The goal of the tooling will be to require no post machining of these components.

Here, the design of the transition between Half-Shell, End-Flange, and Support Beam is critical. How the Strip Layers interface to this and either add to or detract from this interface should be decided prior to onset of production.

### Assembly Tooling/Procedure.

The Tooling required for this will be aimed at two functions: First, accurate positioning of the Support Beams relative to the Layer 4 Supports and to each other, all of which will contain critical reference geometry for the Pixel and Strip layers. Second, the tooling must adequately support bonded joints during the bond process between all of the various components.

The process I will estimate is as follows. A tool base with two arced supports will hold the Transition Support Beams in place accurately. It is unclear, though cost neutral whether I bond the transition rings to the Layer 4 Support here, use the Layer 4 Supports as part of the fixture (registration), or don't include them at all here (open to discussion). The Support Beams will then be bonded to extended tabs of the Transition Rings, still in the same fixture, with features which position the Support Beams Accurately. Finally, the Half Shell Skin will be glued to both transition rings, and some bond feature along each Support Beam, closing the structure. All of this will be done at Room Temperature.

The tooling should be limited to a base-plate, with two accurately machined half-circle plates which would register all components.

### QA/QC

As mentioned before, it is unclear whether it is important to provide CMM data for the Barrel Shells separately, or if only the final assembly with Pixel Mounts. I have not included any survey of this structure. We have a very large and capable CMM, but this might be something that you will do anyway.

### Parylene Coating

To contain any potential carbon dust or other particulate shedding of machined CFRP components. Currently I would imagine only Parylene coating the Pixel Supports which would have exposed carbon foam. The Barrel Support should either have no exposed trimmed surfaces, or most of them will be epoxy coated at the time of bonding.

## Shipping

One final shipment is planned. Cost is not negligible for both the shipper and production of adequate containers.