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 VTX Support Space Frame, and Barrel Supports for Layer 1 and 2. Some effort has been made to standardize on the PHENIX nomenclature for the structures named, and after recent discussion with RJ and Walt, have finalized some of the open questions from the previous estimate v0.2.

To follow the discussion, this and previous versions of this document and the associated estimates are posted at http://www-eng.lbl.gov/~ecanderssen/PHENIX in version named folders

There remain changes to be made to the production drawings, but many of the assumptions from the previous estimate have been clarified, in particular the previous inclusion of a 'transition ring' (now excluded), and a more complicated procedure for the Support Beam. Also excised from the previous estimate are vtx barrel 3 and 4 supports, however a 'new' structure which will provide the support condition of the vtx barrel 4 support is included. I will call this the 'Barrel 4 Temporary Support'.

As per the previous discussions on outsourcing some machining tasks, I have constructed the estimate so that these are more easily swapped out. I have put oversight of outsourced contracts on separate lines so that the machining can be swapped out of project cost, while maintaining some engineering oversight within the contract to manage delivery

## Contingency Planning

The contingency model here is typical to the previous estimates, though now without the extra structures. I have included extra articles/iterations where appropriate to cover manufacturing risk.

# 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--the rate qouted 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.

I have added line items to separate out machining versus engineering so that any sharing of engineering effort versus machining between LBNL/LANL/ and IMTEC can be more easily zeroed from the quote.

## 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 previous version of this estimate lumped engineering, Mech Tech and Shop labor in the line item of the deliverable. These are now expanded to separate machining and design to separate lines. M-Tech and engineering oversight will be on a separate line to indicate the minimum amount of work required to happen at LBNL.

# Material Batches

Current drawings call the material out as M55J for all structures, and the previous estimate put some CN60/EX1515 into contingency. After discussion with RJ/Walt, it is clear that the VTX Support Space Frame as an assembly in its entirety can be made from CN60. The Barrel Supports should still be made from the M55J material still on hand from the Pixel Stave production.

As the M55J has a finite shelf life, it would be desirable to fabricate now all panels required for both the Pixel and the Strip Pixel (Layer 3/4) supports. Only the laminate specification is required--shapes will later be cut from these panels so a final design is not required. They are likely all QIBS laminates, the question remains whether they are 6 or 8 ply laminates i.e. [0,60,-60)s or [0,45,90,-45]s or their variations. The choice between these is cost neutral, but decision to include the fabrication of the panels for L3/4 now isn't. I've included their cost here in base.

**Walt noticed a reference to FVTX here before**--the text has changed since, but FVTX will largely be fabricated from CN60 because of its shape. It would make sense to include in the batch order of CN60 enough material to also fabricate the FVTX shell. This is not included in this estimate, but obviously if both can be done simultaneously the 'overhead' of minimum material orders could be shared.

## 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, but only spend what's required.

## Composite Batch Estimate Structure

The following section is included for completeness. Change to all CN60 and use of the current M55J batch render most of the discussion points of the previous version moot. CN60 cloth does tend to come resin-rich, so most of the qualification steps are still required, but unlike the Pixel Staves, the overall laminate thickness need not be so well controlled. Additionally CN60 is slightly stiffer than M55J (though less strong) so more variance in void fraction and Fiber Volume fraction are tolerable.

### Material Acceptance

As any material the CN60 must go thru the standard material acceptance, though less effort can be expended on understanding Cured Ply Thickness (CPT). Depending on when we are allowed (given permission) to use the M55J material on hand, and tolerance on thickness for the Layer Support Skins, it may be required that another set of bleed studies/void fraction tests be done on that material. I will include these in base, but they can later be moved to contingency or zeroed if these panels are completed prior to project inception.

### Material Testing

This is exactly the same text as before, but should still be noted:

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

These parts are the best candidates for external machining. An explanation of the 'name' is probably in order... These are all of the Barrel Supports' inserts, the Stave Supports, and the L1 to L2 mounts (costed like a stave support)

I have costed only two different parts here. These 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 removed all L3 stave supports from this version of the estimate.

These machined components are the best candidates for shopping out. They have a large part count and can have moderate tolerances for the features that would interface to any LBNL deliverable. They are also pre-designed components so require little LBNL engineering input--other than some oversight (assuring that they are delivered)

### 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.

As an additional stipulation to the above from the previous version of this document--this should be done at LBNL. Any variation on delivered 'PEEK Bits' can be accounted for by adjustment to the Foam's thickness and cut profile, so best done in-house.

### 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

Change from M55J to CN60 reduces the labor on this part. Removal of the radial flange in the current drawing package also simplifies the tooling, however not the cost of the tool from the previous estimate--this is where the 'Transition Ring' was used to capture some of the indeterminate complexity. The tooling cost here will remain the same, but will trade later against the cost of Transition Ring.

5 Plies of CN60 Cloth versus 24 plies of M55J (with 4 intermediate debulk cycles) is a good trade on labor. Layup would be [0/90, +/-45, 0/90, +/-45, 0/90]

### Gusset Plates

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.

### Shell 'Inserts' (formerly Transition Plate)

This Transition Plate has been excised, but some of its features remain in the form of 'inserts' to provide a bolted interface to the Layer 4 Support (or its surrogate) to the half-shell skin. These inserts (really bonded components as there is no 'insertion') were not costed in the previous estimate, and are likely rather complex to interface properly to the curved form of the half shell.

These are also candidates for farming out--will add line items consistent with shopping out, but likely benefit is small due to small part count.

### Support Beams

Previous estimate was for a much more costly cored support beam. This version of the estimate assumes a plate fabricated from CN60, and later machined to include bolted interface features. Details of the transition from the half-shell skin to this part are not final. It is possible that this part may still require a 'formed tool' to keep the half shell tool simple (i.e. round).

I will assume a shaped tool for this, but a round (lathe) tool for the half shell. Opting for one or the other should be cost neutral. Most of the savings will come from removal of the Core from this part, thus a 'top skin' laminate tool, and later bonded assembly and requisite tooling.

#### Base Skin (Laminate)

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. Change from cored structure to 'thick' laminate does require some extra tooling in the form of resin dams to keep the matrix in place under autoclave pressure, as such there will be a moderate increase to the cost of this tool versus the previous estimate, but later removal of the matching tool for the no-longer-needed 'Top Skin'

#### Top Skin

This tool, and part is no longer required--some cost transfer to Base Skin for resin dam

#### Core

No Core--all tasks removed

#### Bonded Assembly (Feature Machining)

This process is no longer required, however was previously used to emplace the accurate features. As such there was a tool, and associated labor to accomplish this. Now this will be accomplished by machining. Some tooling, e.g. machine fixturing will be required and costed here in place of the bond tool. Will be renamed Feature Machining.

# Deliverable Assemblies

The deliverable here is considered to be the VTX Support Space Frame (which is modified to include surrogate Layer 4 Supports) and (Pixel) Barrel Layer 1 and 2 supports. Barrel Layer 3/4 supports are not included, however costed in the panel fabrication of Layer 1/2 supports are enough panel area to fabricate Barrel Layers 3/4; the panels being the deliverables if not exactly 'assemblies' at this juncture.

## Pixel Barrel Layer 1/2 Supports (Panel Assemblies)

These are fairly simple sandwich panel components with a moderate amount of inserts and post bonded attachments. The fabrication method for all of these structures is similar enough that they are described here. They differ only in geometry, thus require separate tools--note that while the L3/4 assemblies are now not costed here, their procedure is nearly identical--tool cost and labor should scale by their area...

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 (via the inserts) and bonds 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 placed 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 clevis arrangements 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.

Have added CMM survey of the tooling--on a separate line item. Can be moved to contingency if desired, or zeroed if tolerance discussion dictates.

## VTX Support Space Frames

The Spaceframes are composed of 5 component pieces: Support Beam (2-top and bottom identical), Half-Shell Skin (1), Layer 4 Support Surrogate. The Layer 4 Support, or in this case its surrogate, is required to provide flexural and torsional rigidity to the half shell skin of the spaceframe. It would also be required to accomplish any survey of the assembled space frame .

The Assembly tooling required is nearly identical to that of the previous iteration of this document--before there was a tool which held the 'Transition Rings' relative to the Support Beams, to which the half shells bonded. Now, the tooling simply holds multiple inserts in lieu of the transition rings relative to the support beams, to which the half shell will be bonded--change is cost neutral to the assembly...

### Support Beams

These are no longer assemblies, now are simply machined laminates, so no assembly procedure is required--will only include part prep (cleaning and bond-prep) at this stage

### Gusset Plate

As with the Support Beams, no assembly required. These will be introduced for survey if required.

### Half-Shell Skin

Now a simple half shell. Will be bonded to the pre-assembled half shell and layer 4 inserts.

### Transition Rings

These inserts bond to the half shell and provide the radial constraint via the layer 4 support/surrogate.

### 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. The arched supports will simultaneously locate all support inserts for the layer 4 support bolted joints. Finally, the Half Shell Skin will be glued to support beams, and the discrete inserts simultaneously 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

Other than the now included tool CMM surveys, it is unclear what if any final assembly survey is desirable. LBNL has a large CMM of more than sufficient accuracy, but unclear if this is required. I will include in contingency a final survey (did not before), but need to discuss scope and if desired/required...

### 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.