Production Plan for the BTeV Muon System

The BTeV Muon Group
BTeV-doc-865

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1 Introduction

This document describes the plans for production, production testing, and production quality assurance of the BTeV muon system. The various components that need to be produced are (1) the sensor planes, which includes front-end electronics and cabling, and (2) support systems such as gas, low-voltage, and high-voltage. By far the largest task is the construction of the sensor planes, which will be built in modules at university sites (Illinois, Puerto Rico–Mayaguez, and Vanderbilt). These modules will then be delivered to Fermilab for installation. Our delivery, installation, integration, and shake-down plan (including the construction and installation of the mechanical support for the sensor planes) are described in BTeV-doc-1036

Octants mounted on octant plates are the basic installation unit of the muon system. An octant covers 1/8 of the azimuthal angle in one view, so there are 8 octants per view and 32 octants per station. Four octant plates are assembled into a wheel; two wheel make up a view.

Octant plates will be assembled at Illinois and Vanderbilt and shipped to Fermilab for installation there. A fully assembled octant plate will have all front-end electronics installed, as well as gas connections, low and high voltage cables, slow-control cables, and signal cables that are "interior" to the octant. When a octant is delivered to the C0 hall, it will only be necessary to attach it to the muon system mounting structure and make electronic, electrical, and gas connections to external devices (such as the experimental DAQ and to muon system low voltage supplies). The octant will have been fully tested prior to installation: all readout, electrical, and supply connections will have been verified at the octant assembly site prior to shipping.

For a one-arm muon system, there will be 3 detector stations, with 4 views per station, 8 octants per view, and 12 planks per octant. This results in 1,152 planks or 36,864 tubes (electronics channels). Planks range in length from 2 to 6 feet. We will build eight complete octants (96 planks, 3,072 tubes) during the pre-production stage (which we will use to shake down and evaluate our production lines and methods). During production we will make two additional views worth of planks to use as spares. These additional planks must be made at the same time to minimize the cost of the necessary parts and labor.

2 Construction overview

Muon octants will be fabricated at university sites and delivered pre-tested to Fermilab. Installation at Fermilab will involve attaching each octant to the support structure and connecting it to electrical, electronics, and gas. There are three main tasks in the construction of a octant: (1) plank fabrication, (2) front-end electronics fabrication, and (3) assembly of planks into octants.

2.1 Pre-production

In order to shake down and evaluate our production lines and methods, we will make eight pre-production octants. These octants will be fully instrumented so that we can fully debug and evaluate our testing and quality assurance program. This means that they will have a full complement of front-end electronics, gas supply lines, low and high voltage cables, slow-control cables, and readout cables. All of this "internal" cabling, as well as each of the proportional tube counters, will be tested and certified during the production process. Each of the plank production lines will fabricate planks during this pre-production stage, the electronics production process will be implemented, and the octants will be assembled at one or both of the octant assembly sites. Once the fabrication and testing of these octants is complete, we will evaluate all aspects of the process and make adjustments as necessary, and then begin the full production process of the full system.

2.2 Quantities of materials needed

The quantities of parts, planks, octants, etc., that must be acquired or fabricated are driven by the numbers listed in Table 1. For example, the total number of planks that will be installed in the base system can be determined by multiplying the planks/octant (12), octants/wheel (4), wheels/station (8), stations/arm (3), and arms/spectrometer (1), which gives 1,152. Multiplying this by tubes/plank (32) gives the number of proportional tube channels in the base system (36,864).

Manifolds, support ribs, gas connections, and Delrin inserts are all parts used to construct planks. The numbers given for these items in Table 1 are the number that will be in the base system. For example, there will be 2 Delrin inserts per proportional tube, or a total of 73,728 inserts.

The average tube length and longest tube are used in calculating the amount of tubing required. The remaining numbers in the table are important for calculating the total amount of materials (such as tubing) and parts that must be acquired/fabricated when accounting for spares, waste, mistakes, and so on. For example, the *fraction of problem planks* is our assumption of the number of finished planks that will be found to be bad by our quality assurance program (QAP). Once a plank is finished, it cannot be restrung or "rescued." If a plank is found to be bad, a new one must be made. So, if we need 100 planks, this fraction (0.1) predicts that we will have to make 110. Similarly, the *fraction of re-strung tubes* is an estimate of the number of tubes that have to be restrung because a crimp doesn't hold, the tension is inadequate (too low), or the tube doesn't hold high voltage. The *wire waste per tube strung* is the amount of extra wire required when stringing a tube (1) to make sure the wire in the tube is clean and has no kinks, and (2) to connect to the tensioning part of the stringing apparatus. The *tube safety factor* is added because we don't know what lengths of planks will be bad and have to be re-made. We will buy the stainless steel tubes pre-cut to length, and will buy extra of each length to make sure we have enough of each of the required lengths. The "2" here does not mean we will buy twice as many tubes as needed, it

Item	**Value**	**Item**	**Value**
Planks/octant (1 view)	12	Pre-production octants	8
Octants/wheel	4	Spare octants	16
Wheels/view	2	Fraction of problem planks	0.1
Views/station	4	Fraction of problem manifolds	0.1
Stations/arm	3	Fraction of problem support ribs	0.1
Arms (in the BTeV detector)	1	Fraction of problem Delrin inserts	0.1
Tubes/plank	32	Fraction of problem misc. parts	0.1
Manifolds/plank	2	Fraction of re-strung tubes	0.25
Support ribs/plank	2	Wire waste/tube strung (ft.)	2.5
Gas connections/manifold	2	Tube safety factor	2
Delrin inserts/prop. tube	2		
Average tube length (ft.)	4.1		
Longest tube (ft.)	6.5		

Table 1: Numbers and assumptions for the muon system. These determine the quantities of parts, planks, and octants that need to be fabricated. The meaning or derivation of these numbers is explained in the text.

means we will buy twice as many tubes as necessary to build all the bad planks, a 10% effect. These fractions and estimates are based on our experience stringing about 25 prototypes.

2.3 Pre-production and production quantities

Using the numbers in Table 1, we can calculate the number of parts, planks, and octants that must be acquired or fabricated. The resulting numbers are shown in Table 2. The calculations are based on two premises. First of all, it will be very difficult and expensive to get the assembly lines going to make planks, and to crank up production of the parts (manifolds, support ribs, Delrin inserts). Therefore, we must make all required quantities during production, and will not plan on going back and making more later. This means that all parts and materials, such as the stainless steel tubes for our proportional tubes, will be purchased during the production phase; it will not help to buy more later. Having to buy all necessary materials in advance complicates calculations of the required quantities. An example is the Delrin end plugs. We must have enough extra to account for re-stringing (the plugs usually can't be saved), enough to re-make planks that are found to be bad after they are finished, and for plugs that are found to be defective after they are made. The second premise is that if a bad plank is found after it is completed (one of the wires breaks, or has insufficient tension), it will be very difficult to save the parts used to make it. A new equivalent plank will likely have to be made with all new parts. Fortunately, because of the tests we will perform on the tubes after they are strung and before they are assembled into a plank, we do not believe this will happen very often.

	Pre-Production				**Production**					**Sum**
Item	Base	Bad Plnk	Re-string	Total	Installed	Spares	Bad Plnk	Re-string	Total	Total
Planks	96	10	0	106	1152	192	135	0	1479	1585
Tubes	3072	320	0	3392	36864	6144	4320	0	47328	50720
Octants	8	0	0	8	96	16	0	0	112	120
Gas manifolds	212	22	0	234	2535	423	297	0	3255	3489
Support Ribs	212	22	0	234	2535	423	297	0	3255	3489
Delrin End Plugs	6759	704	1866	9329	81101	13517	9504	26031	130153	139482
SS Tubing (feet)	12595	2080	0	14675	151142	25190	35424	0	211757	226432
Sense Wire (feet)	20275	2880	5789	28944	243302	40550	28512	78091	390456	419400
Crimp tubes	6759	704	1866	9329	81101	13517	9504	26031	130153	139482
Crimp wires	6759	704	1866	9329	81101	13517	9504	26031	130153	139482
Flare nuts	423	44	0	467	5069	845	594	0	6508	6975
Gas connect. tubes	423	44	0	467	5069	845	594	0	6508	6975

Table 2: Production quantities determined using the numbers and assumptions listed in Table 1.

The derivation of some of the entries in Table 2 is trivial. For example, the number of *installed* planks in the production section is simply the number of planks needed for a working detector, as calculated in section 4.2 above. The number of *bad planks* is just the number we need to build (from the *installed* and *spares* columns) times the *fraction of problem planks* from Table 1. Others are less obvious. For example, the number of *installed* Delrin end plugs in the production section is the number needed for the detector plus the number we assume will be defective (see *fraction of problem Delrin inserts* in Table 1).

3 Plank fabrication

Plank fabrication involves several steps: acquire parts and materials, fabricate parts that need to be machined, string individual proportional tubes, test them, assemble the tubes into planks and test the planks, attach electronics to the planks, and test the planks in a cosmic ray test stand. Three plank fabrication lines will be established at Illinois, Puerto Rico, and Vanderbilt.

3.1 Parts of a plank

There are 11 different parts or materials needed to make a plank, not including the electronics. Each proportional tube will be made from a thin-walled (0.01 inch thick) **stainless steel tube** (3/8 inch in diameter) with a 30 micron gold plated tungsten **sense wire**. The sense wire is tensioned to 75% of its yield point, or 150 grams. A **Delrin insert** goes in each end of the tube to electrically isolate the wire from the tube and center the wire in the tube. It also has three gas holes. A **brass crimp tube** is inserted in each end plug, the sense wire exits the tube at each end through the plug and this tube. A thicker **crimp wire** is inserted into the crimp tube after the wire is threaded through, this helps the crimp hold the sense wire in place. Completed tubes are assembled into planks, which are held together at the ends by brass **gas manifold**s (see Fig. 1). For longer planks, the tubes will also be supported along their length by brass or aluminum **support ribs**, which will maintain the spacing of the tubes. The stainless steel tubes are glued into the manifolds at each end in two stages. In the first stage, conductive epoxy is used to provide an electrical connection and a modest amount of structrural support. In the second stage, the tubes are bonded to the brass manifold with structural epoxy. The potting done in this second stage provides the bulk of the structural support and a gas seal. The open end of the gas manifold is sealed by a **circuit board** with sockets on the inside that accept the brass crimp pins, these sockets will provide the signal connection to the front-end electronics. A brass sheet is glued (with conductive epoxy) or spot welded to the outside of the brass manifold to maintain electrical continuity and RF integrity. This sheet is soldered to the Front-end electronics to provide the ground connection for the signal and HV delivery. Two flared stainless steel (or brass) **gas tubes** will be glued into holes in each manifold, these will be connected to the gas supply lines with flare nuts.

3.2 Acquisition of materials and supplies

The materials needed to build the muon system planks should all be readily available stock items with the exception of the thin walled stainless steel tubes and the sense wire. These will require some lead time in purchasing (*i.e.* roughly 3 months before delivery of the first stainless tubes). The brass (including the crimp tubes) and Delrin required are standard stock items. Once delivery starts, all parts could be in hand in a matter of months. We may decide to stretch acquisition out for budgetary reasons, however.

4 Fabrication of manifolds, support ribs, and Delrin inserts

A major portion of the work required to build the planks needed for BTeV is fabricating the gas manifolds, support ribs, and Delrin inserts (which includes inserting the brass crimp pin). These three parts require substantial machining. The Vanderbilt Science Machine Shop will do the machining of the first two parts. The Vanderbilt machine shop has the computer controlled milling systems needed to make these parts in bulk already, and can make these parts substantially cheaper than a commercial shop. Fabrication of the Delrin inserts may be done by a commercial machine shop, or may be done in the Vanderbilt shop. For this part, commercial shops may be able to compete on price.

The manifolds and support ribs will require roughly two years to make. This is also roughly how long it will take to string and assemble all the planks, so the two will proceed in tandem. It will therefore be very important that the shop work be kept on schedule, so as not to delay the manpower intensive plank stringing operations.

4.1 Tube stringing and plank assembly

Plank stringing and assembly is the most labor intensive part of the muon system construction project. We have built roughly 25 prototype planks. Based on this experience, we have produced Table 3, which breaks plank assembly into sub-tasks and estimates the time and personnel required to perform each.

The times in Table 3 are under "optimal" conditions, in which we have the parts required and the operation is running smoothly. In estimating our total required labor, we increase the total time per plank by 15% to account for inefficiencies. We also increase the time required to make the first few planks because we assume it will take some time to "ramp up" to smooth operation of the assembly lines. We assumed it would take twice as much time for each production line to make their first 3–4 planks. The total times for the pre-production and production runs are summarized in Table 4. These numbers can be divided by 3 to get the times for each institution.

Individual tubes will be strung in a stringing jig. This is a two person operation. After stringing and testing, the gas manifolds that go on each end of a plank are assembled with 32 tubes, and this assembly is then glued together. A G10 circuit board is epoxy potted onto the open end of each gas manifold. The circuit board also connects to the individual sense wires and provide the signal path to the front-end electronics. Finally, a small brass sheet is glued to the end of the brass manifold with conductive epoxy for ground conveyance and noise suppression.

Once the G10 circuit boards are in place, the front-end electronics and the interface cards are attached, and the plank is ready for the cosmic ray test stand and, if it passes our QAP, is ready to be assembled into octants.

Each site will produce one plank per day on average. This includes all testing and assembly.

4.2 Plank Quality Assurance Program (QAP)

Tests and measurements are performed at all stages of plank production as a part of our quality assurance program.

After each proportional tube is strung, it is tested for continuity and to see if it has slipped out of the crimp at either end (and is shorted to the tube walls). The wire is re-strung if a

Task (times are in hours)	**Time**	**UG**	**Grad**	**PD**	**Tech**	**Facul.**
Project management/supervision	0.50					0.5
Wash and prep tubes	0.50	0.40	0.10			
Wash and prep machined parts	0.50	0.40	0.10			
Wash and prep other parts	0.20	0.20				
QAP: Inspect parts after prep, add bar code	0.20			0.20		
String tubes, includes restringing	6.00	2.00	3.00		1.00	
QAP: Visual inspect strung tubes	0.10			0.10		
QAP: Individual tube tension measurement	1.00		1.00			
QAP: HV test in air (meas. current at 1.5 kV)	0.50	0.50				
QAP: Inspect tension/HV results	0.10			0.10		
Glue plank together	4.00		2.70	0.30	1.00	
Glue circuit board end cap to manifolds	1.20		0.90	0.10	0.20	
Glue gas connections tubes in	0.50	0.50				
Attach electronics	1.00		0.70	0.10	0.20	
QAP: Gas leak test	0.50		0.50			
QAP: Plank tension measurement	1.00		1.00			
QAP: Visual inspection	0.10			0.10		
QAP: Cosmic ray test stand, analyze data	2.00		1.00	1.00		
TOTALS	**19.90**	**4.00**	**11.00**	**2.00**	**2.40**	**0.5**

Table 3: Plank assembly sub-tasks and the labor and personnel required for each. These times are for the fabrication of one plank. UG stands for undergraduate student, PD means post-doc.

Task (times are in days)	**Time**	**UG**	**Grad**	**PD**	**Tech**	**Facul.**
Pre-prod times incl. inefficiency	337.55	67.85	186.59	33.93	40.71	8.48
Prod. times incl. inefficiency	4256.61	855.60	2352.90	427.80	513.36	106.95

Table 4: Labor required to make all pre-production and production planks.

problem is detected. Then the tube is tested to verify that it will hold high voltage (1600 Volts) in air, and the wire tension is determined by finding the resonant frequency of the wire in a uniform magnetic field when a variable frequency AC current is applied to the wire. If any tubes are out of tolerance or fail outright, they will be re-strung.

Once the tubes are glued together into planks and the G10 circuit board end is glued into place, we will retest the tension of each wire and do a leak test on the plank. If the plank passes these tests, the plank will be installed in a cosmic ray test stand and we will do plateau curves and measure efficiencies and noise rates for each tube. An inventory control system based on bar codes will be used at all points during the construction. Information such as test results, parts used, and the personnel performing the work will all be recorded in a database associated with the bar code that will be attached to each tube and to each plank. A bar code reader will be used to scan in the bar code on each plank or tube. Additional information will be entered via easy to use computer interfaces which will be tailored for each step in the process. Each front-end electronics card will also have a bar code label. Information on which electronics card is associated with which plank, and which tubes are associated with which plank, will be logged and modified as changes are made.

5 Electronics QAP

It is essential to identify electronics problems as early as possible. All fabricated ASDQ chips are tested before they are used in the circuit board assembly. The tests are well understood and were used by the University of Pennsylvania during the ASDQ vetting process for the CDF production. The expected yield and additional costs for testing are included in our cost estimate. All fabricated circuit boards must pass an electrical test at the fabricator's location. All stuffed circuit boards will be programmed at the end of the assembly process by the assembler and a power-up go or no-go will be indicated. This allows us to identify production problems early. Once assembled boards arrive at Vanderbilt, they will be placed in a fixture that mimics the electrical environment we expect during data taking. Any errors will be noted, and no boards that are less than 99% efficient will be allowed to be placed on a plank. The cards that interface the ASDQ-FPGA boards to the detector will be continuity and high-pot tested at 2000 V before being mated with the planks and the ASDQ-FPGA boards.

6 Octant assembly and QAP

The detector modules (octants) will be assembled from the planks at both Illinois and Vanderbilt. Puerto Rico may participate at this stage if it can be shown that shipping the octants from there is not prohibitively expensive. The planks for each module will be held together by attaching them to pre-drilled and slotted 1/8" aluminum sheets called octant plates.

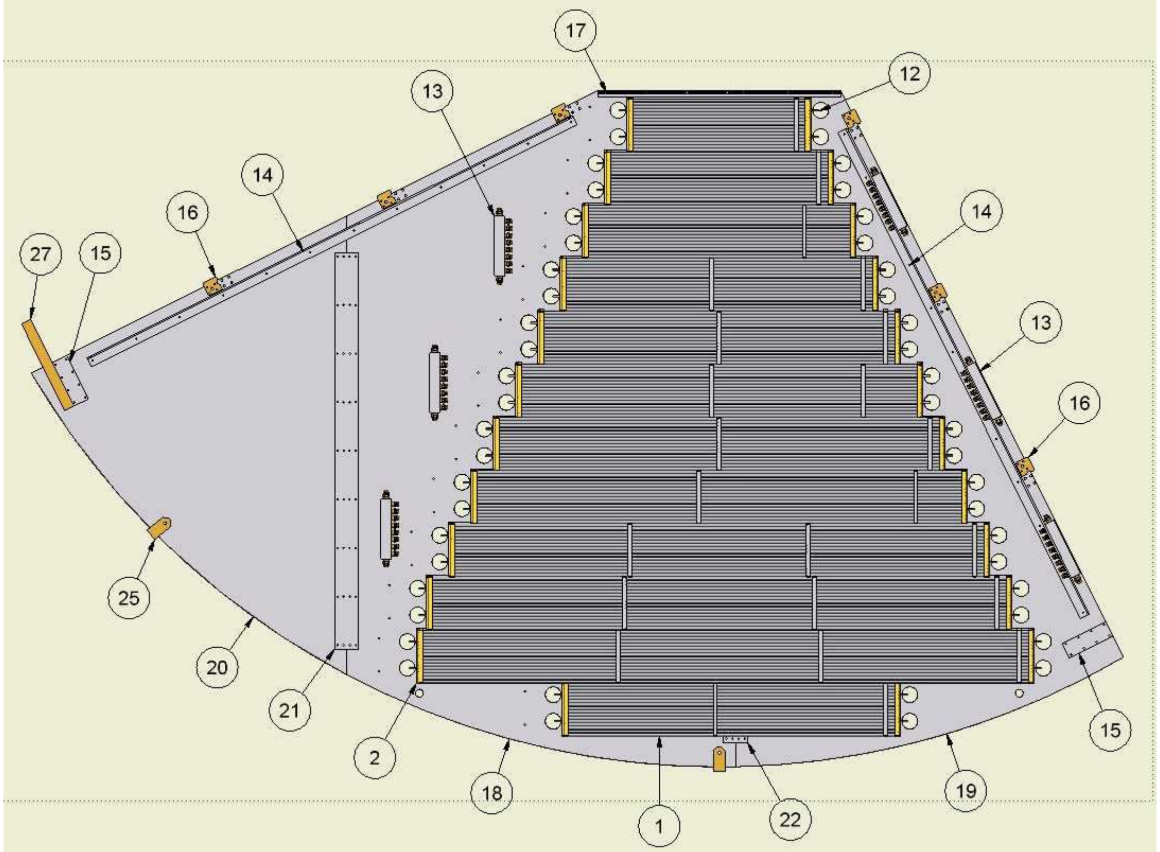

Figure 1: Assembly details of a radial octant plate. Each 1/4" thick radial plate is constructed out of three sections that are joined together using joint-bars (part 21 and 22). The blank area to the left of the tubes will be used for gas and electronics access. Gas will be distributed from three manifold assemblies (part 13). Stiffening-angles (part 14) are included to inhibit the bending of the octant plate during installation. The radial edges of this plate and adjacent plate are connected by knitting- brackets (part 15) and tie-bars (part 27).

The internal signal, gas, and HV connections will be established as the octant is assembled. These connections will be verified in an octant test stand which will provide gas, control signals, and low and high voltages to all planks in the octant. We will verify that each channel (proportional tube) is operating as expected and that it can be read out. Once complete, each octant will be packed and readied for transport to Fermilab. A portion of the octant plate which is not used for mounting planks can be removed to facilitate shipping if convenient (see Fig. 1).