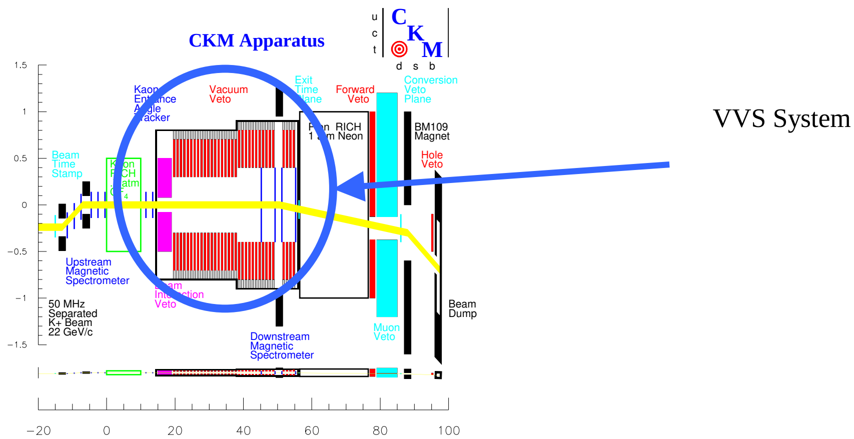
Manpower Cost Estimate CKM VVS Module Assembly

This document describes a preliminary manpower cost estimate for the production, assembly and delivery of 34 VVS modules for the CKM detector.

The CKM VVS detector is composed of 34 annular lead-scintillator veto stations housed in a 38-meter long vacuum vessel. Each annular section is azimuthally segmented into 16 sectors, with four photomultiplier tubes (PMT) instrumenting the longitudinal depth of the sector. Each sector is composed, longitudinally, of 80 layers of 1-mm lead/5-mm scintillator tiles corresponding to a longitudinal depth of 50 cm and ~15 radiation lengths. The tiles are read out by WLS fiber. In total there are ~43k tiles, ~700k fibers and ~2k PMTs. A schematic drawing of the VVS stations is shown in figure 1.

During FY02, members of TD have participated in the CKM R&D program to design and build the first VVS prototype tested in the fall '02 at Jefferson National Lab in Virginia. The VVS prototype comprised 2 azimuthal sectors in a vacuum vessel as shown in figure 2. Based on this prototype work, engineering and drafting resources from TD are contributing to the design of first prototype for the real experimental module.

The large scale of the project, the tight requirements on mechanical tolerances, vacuum performance and light yield output make this an ideal project to be cost and estimated following the production-like practices of the Engineering and Fabrication group in the Technical Division and the experience accumulated during the construction of the EMU Cathode Strip Chambers for the CMS detector.



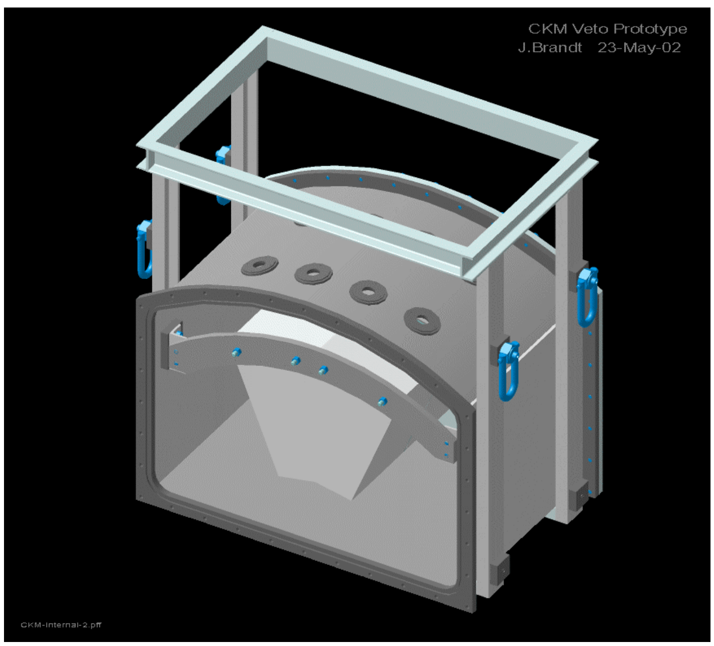


Figure 2: Engineering drawing of the 2-sector VVS prototype housed in a vacuum vessel.

The CKM TDR is the main document defining, at this time, the technical specifications of the VVS detector. All the technical requirements described in the CKM TDR are assumed to be valid here. In addition we make the following assumptions for the purpose of this cost estimate:

- The VVS tiles and canes of fibers are provided to the Production Factory by external sources.
- There are 16 WLS fibers in each tile. Each fiber is tacked in place with a drop of cement/epoxy.

Executive Summary

The following cost estimates have been identified and are documented here to procure VVS parts and run a 2 years production Factory at FNAL. This estimate *does not include any labor needed for the Opto-Electronics read-out* (PMTs and bases, WBSs 2.6.4.1 and 2.6.4.2 in the June 4th, 2001 CKM Proposal).

Items	Effort Level	Cost@FNAL
Materials and Services (M&S)	-	**(Jeff, please input the total M&S coming from your quote+Oleg quote+Don's quote- read next section)**
Factory Setup and Tooling	-	277 k$
EDIA Manpower	4.4 E-FTEs	594 k$
Parts Handling & Documentation	1.0 T-FTEs	70 k$
Production Manpower	19 T-FTEs	1,330 k$

Assuming an M&S cost of 3,114 k$ **(Jeff, please input the total M&S coming from the table in the next section, using (your number+Oleg's number+2049k$) = new M&S)** for the VVS (CKM TDR, WBS 2.6 & 2.2.1 with the exclusion of WBSs 2.6.4.1 and 2.6.4.2), the EDIA ratio defined as EDIA ratio ="non-touch labor"/(M&S+"touch labor") is only ~13% **(Jeff, please recomputed the ratio with the following numbers: (594+35)/(1330+35+277+new M&S))**. This probably indicates that the EDIA effort is underestimated (the comparable number for both the HCAL-CMS and EMU-CMS projects is closer to 25-30%). However some EDIA efforts (Vacuum Window, Vacuum system) are not included in this estimate and would therefore increase the EDIA ratio.

The total Labor/M&S is 59% **(Jeff, please recomputed the ratio using the following numbers: (594+70+1330)/(277+new M&S))**.

M&S Cost Estimate

The following 4 M&S cost categories are identified for the VVS detector:

Item	*Cost*	*Source*
VVS Mechanical Module	**??**	**J.Brandt/P.Olderr**
PMT Optical Assemblies	205 k$	O.Prokofiev
Everything Else but not PMTs	2049 k$	D.Goloskie
PMTs	836 k$	D.Goloskie
Total	**??**	**Jeff**

VVS Mechanical Module

The cost estimate relates to what is included in WBS 2.2.1 and 2.6.4.7 (total of 1,068 k$ in June 4th, 2001 CKM Proposal).

PMT Optical Assemblies

All quantities based on 2400 PMTs assemblies (basic quantity + 10% spares. Quotes based on existing design used on FY02 VVS Prototype. Dogbones molded in polyethylene (or polypropylene) for 12 k$/tool + 133 $/1000 pieces. All other mechanical parts machined or welded as needed for a total cost of ~187 k$. For a similar quantity of PMT mechanical supports, the CDF Plug Upgrade project spent ~120 k$ in FY95-$ (~150 k$ in FY03-$ when including a 3% annual inflation). The cost estimate in the CKM proposal (WBSs 2.6.4.4, 2.6.4.5, 2.6.4.6 and 2.6.4.8) is 129 k$. Optimization and re-engineering of the present design should reduce the estimated cost.

Everything Else but not PMTs

This corresponds to the item listed under WBS 2.6 (table 50 of the June 4th, 2001 CKM Proposal) with the exclusion of the PMT clamping system and fiber cookies (WBSs 2.6.4.4, 2.6.4.5, 2.6.4.6 and 2.6.4.8) and the PMTs (WBSs 2.6.4.1 and 2.6.4.2). The cost is estimated for the "Bicron-low" scenario.

PMTs

PMTs M&S cost, copied from WBS 2.6.4.1 and 2.6.4.2. The explanation for this "mental exercise" is the following: the labor estimate presented in this document does not include any labor needed for the PMTs preparation. Since it would be inappropriate to include the PMTs M&S cost in the "*total M&S cost*" for the purpose of computing the Labor/M&S ratio or other "labor-related quantities, I have kept them separate. In the CDF Plug upgrade, the total technical manpower that went into the 2200 PMTs preparation was ~4.8 FTE (~336 k$). **Maybe Eric/Bob have re-evaluated the labor cost for PMTs ? Othrwise we will just reuse the standard percentage (46%?) of the PMT M&S cost (~836k$) to obtain an estimate of ~380 k$ for PMTs labor. But, again, I have not played with these numbers. The person that will present the VVS cost will have to sum the Assembly Labor+PMT labor to have the total labor cost for the VVS system.**

Tooling Cost Estimate

QA/QA Tooling

Existing tooling (Computer Controlled Measuring Devices) will be used for dimensional measurement of VVS Modules mechanical components, tiles or fiber diameter. The following Special Tooling will be needed for VVS Quality control procedures:

Tool	***Cost***	***Source***
VVS Module Vacuum Test	28 k$	WAG (GA)
Incoming Test on Scintillator	5 k$	WAG (GA)
Incoming Test on Fibers	15 k$	WAG (GA)

VVS Module Vacuum Test Goal:

Check vacuum integrity of each VVS, with particular emphasis on welded structures. Use large flanges (?) to seal each individual module. Cost of ~7k$ is estimated to machine large flanges (4 needed).

Incoming Test on Scintillator

Check minimum performance of molded scintillator received by Russian vendor by measuring response of small samples to standard radioactive source (i.e. response to ~1 MeV Bi^{207} electrons). PMT+DAQ+PC needed. Test performed on a batch-by-batch basis.

Incoming Test on Fibers

Measure uniformity of transmission on small samples of fibers received by Bicron (?) vendor. Test performed by fiber Scanner, consisting of UV excitation, photodiode read-out, DAQ+PC DAQ.

Production Tooling

The following Special Tooling will be needed for VVS Assembly. Although some of this tooling may already exist at various FNAL facilities, it is assumed here that a CKM VVS factory will need to reproduce all the following tools and have full control of them during the VVS production period.

Tool	***Cost***	***Source***
Jigs for Dogbones Assembly	20 k$	WAG (GA)
Dogbone Polisher	30 (5) k$	??
Jigs for Dogbones/Tiles Assembly	10 k$	WAG (GA)
Tile Storage Racks/Tables	5 k$	WAG (GA)
Lead Handling Tool	5 k$	GA
Cosmic Test Stand	30 (5) k$	GA
Module Storage Unit	34 k$	WAG (GA)
Factory Setup	50 k$	WAG (GA)
Consumables/Tooling Maintenance	80 k$	WAG (GA)

Gigs for Dogbones Assembly

Similar in scope to the jigs prepared for the FY02 VVS prototype, they would include the possibility to bend the fibers and have them cut to the proper length. 50% of the funding going to design and/or engineering, 50% to production of plastic or metal jigs.

Dogbone Polisher

Similar to the diamond polished used in many previous detector assemblies (CDF Plug Upgrade, CMS HCAL, KTEV VVS Prototype). Cost can be reduced to ~5k$ if one of the of the old polishers can be reused and engineered for CKM usage.

Jigs for Dogbones/Tiles Assembly

Not used for the VVS prototype, will greatly facilitate the insertion and glue-tacking of the Dogbones assemblies in the tiles. 50% of the funding going to design and/or engineering, 50% to production of plastic or metal jigs.

Tile Storage Racks/Tables

Assembly of one VVS module will require the availability of ~1300 Dogbone/Tile assemblies (or ~650 assemblies if half-way Module loading is assumed). Racks/storage units will provide the necessary buffer between the Tile Assembly operation and the VVS Module loading operation.

Lead Handling Tool

The lead is manufactured in semi-circular units weighting few kilograms each, thus allowing handling by technicians. However to prevent continued lead manipulation by personnel, a vacuum lifting unit can be modified from the CMS experiment for a small cost.

Cosmic Test Stand

A complete VVS module can undergo cosmic testing in the horizontal orientation. A setup similar to the one used for the CMS CSC project (Lab 7) can be envisioned. The setup cost ~30 k$. Refurbishing the CMS Cosmic Stand would cost ~5k$ in moving and modification costs.

Module Storage Unit

The tunnel and all the ancillary services (vacuum system, tracks, etc.) are unlikely to be delivered before the VVS Factory delivers the first assembled VVS Module. We assume that ~50% of the modules will have to find temporary storage in appropriate, movable wood boxes at a cost of ~2k$/box.

Factory Setup

This cost covers for all aspects of a factory setup like “clean” areas, cabinets, setup of working stations, setup of chemical stations (glue mixing, glue disposal) generic shelves, safety-related improvements, etc. Some of the cost could be avoided by using facilities already setup at FNAL.

Production Consumables

Includes all cost for consumables like gloves, epoxy, syringes, needles, glue mixing equipment, tooling maintenance, resurfacing of the diamond polisher every ~1k polished pigtails, etc.

Labor Estimates

All labor estimates are provided in year-FTE (abbreviated FTE). In a standard FNAL Project there are many labor categories: engineers, drafters, programmers, mechanical technicians, inspectors, electrical technicians, etc. In this simple study we will use the simplification of only two major labor categories: engineering and technical assembly labor (E-FTE and T-FTE). Finally, for technician labor we assume the standard 80% efficiency factor between paid time and actual time spent on the job.

EDIA

The following efforts will be needed in the EDIA (Engineering, Drafting, Inspection and Administration to provide all the appropriate documentation to Safety Reviews, Production Readiness Reviews, Procurement activities and Factory operations.

Activity	***Effort***	***Source***
Engineering/Drafting		
FEA and Safety Analysis	0.4 E-FTE	WAG (GA-JB)
VVS Mechanical Design (~350 dwgs)	1.7 E-FTE	GA-CMS
Tools Mechanical Design (~50 dwgs)	0.3 E-FTE	GA-CMS
Specifications for Inspections	0.2 E-FTE	GA-CMS
Specifications for Special Tools	0.1 E-FTE	GA-CMS
Inspection		
Mechanical Inspections (~5% basis)	0.4 E-FTE	GA-CMS
VVS Modules Vacuum Testing (100%)	0.3 E-FTE	GA-CMS
Administration		
US Vendors Visits and Qualifications	5 k$	WAG (GA)
Foreign Vendors Qualifications (Tiles)	10 k$	WAG (GA)

Engineering/Drafting

Full documentation of FEA and Safety analysis will take approximately 2 months of Engineer time for the first VVS module. Analysis of subsequent modules can per performed on a shorter time-scale of the order of 0.5 months/module. Assuming a total of 6 Vacuum Modules and spool pieces (DMS-VVS interfaces, Vacuum Window module, etc.) the total time estimate is 0.4 E FTE.

The total VVS system included approximately 350 Mechanical drawings and ~50 Tooling drawings. Based on the CMS charge-back history experience, it takes an integral of 10h to bring a drawing from conception to production readiness.

Inspection

Each VVS module contains ~120 individual parts (excluding fasteners and PMTs assemblies). 3 or 4 critical parts will be mechanically inspected on a 100% basis (Thompson rod holes, mid ring, end ring, etc). The remaining parts will be “sample-inspected” at a 5% rate. The total number of parts to inspect mechanically is approximately 350. Based on similar CMS experience, a mechanical part takes ~2 h for a thorough mechanical inspection.

Vacuum testing is estimated to take approximately 2 FTE-days per module when all the operations of handling, sealing, connecting a vacuum port and checking for leaks are included.

Administration

Travel costs for production engineer(s) and procurement specialist(s) to visit US or Foreign vendors.

Parts Handling

Parts need to be handled and stored once they arrive at FNAL. Kits need to be delivered on the production floor during VVS production. In the CMS EMU CSC production experience, the typical level of effort to support a Production Factory of ~5-8 technicians was approximately 0.5 T FTE/year for the duration of the Production. Since the number of individual parts is lower in the CKM VVS case, we estimate (WAG) the need for an effort level 0.2 FTE/year for the duration of Production.

Documentation/Instructions

Dedicated personnel are responsible for the preparation and maintenance of the final Tooling Operating Procedures and Production Documentation (travelers, production floor drawings, discrepancy reports, etc). In the CMS EMU CSC production experience, the typical level of effort to support the Production Factory with documentation was 1 FTE/year. This level of effort was determined by the need to maintain and record extensive chamber measurements and performance characteristics.

The CKM VVS is not presently requiring extensive documentation on the performance of the detector modules. We estimate (WAG) an effort level of 0.3 FTE/year for the duration of the Production.

Assembly

The following list of efforts describes the amount of work estimated to produce the total number of 34 VVS modules. All the work is performed by Mechanical Technicians. As mentioned before all the work for individual tasks is estimated in a "stop-watch" approach, and the final estimate is increase by ~20% to obtain the total number of FTEs that need to be funded by the Project. We assume the production of 43,000+3,000 (7% spares) dogbones/tiles assemblies.

Dogbone Preparation	***Time Estimate/Unit***	***Total***
Fiber Cutting and Jig Loading	5 fiber/min.	1530 h
Dogbones Insertion	16 fibers/5 min.	3830 h
Dogbones Gluing	10 Dogbones/30 min.	2300 h
Dogbones Extraction and Precutting	1 Dogbone/min.	770 h
Dogbones Polishing & Visual Insp.	1 Dogbone/min.	770 h
Total		9200 h
		5.8 T y-FTE

Fiber Cutting and Jig Loading

Dogbones assembly will be performed with the help of jigs as experimented in the VVS prototype assembly. We assume a U-shaped bent fiber to avoid fiber mirroring and polishing. 8 individual fibers will be loaded in a 4x4 matrix dogbone. 4 fibers/minute can be loaded in a jig. The total number of fibers to cut and insert in the jig is 46,000 x 8 = 368,000 fibers.

Dogbones Insertion

Once inserted in the jig, the fibers have to be guided into the dogbones and the setup has to be prepared for the gluing operation.

Dogbones Gluing

This task included epoxy preparation and mixing, loading of the filling cartridges (syringes) and epoxy injection in the dogbones jigs.

Dogbones Extraction, Precutting, Polishing and Visual Inspection

Dogbones are extracted from the assembly jigs, precut to few mm from the final dimension of the polished surface, polished and given a visual inspection before being sent to the following assembly step.

Tile Preparation	***Time Estimate/Unit***	***Total***
Dogbone Insertion in Tile	8 tiles/hour	5750 h
Dogbone tack-glueing	10 tiles/hour	4600 h
Sampling Tile Testing	6 tiles/hour	100 h
Tile Storage	30 tiles/hour	1530 h

Total		11980 h
		7.5 T y-FTE

Dogbone Insertion in Tile

Dogbones are inserted in the tiles and kept in place by mylar tape. The use of loading jigs may facilitate this task.

Dogbones Tack-Gluing

This task included glue preparation, loading of the filling cartridges (syringes) and tacking of fibers in the tile grooves in few positions.

Sampling Tile Testing

0.2% of the assembled dogbones-tiles will be tested with some form of radioactive source or other testing method. This amounts to ~100 tested tiles during the course of production.

Tiles Storage

Assembled tiles are removed from the assembly jigs and stored in (cardboard) containers before being used in the module assembly process.

VVS Module Preparation & Stacking	***Time Estimate/Unit***	***Total***
Mech. Components Cleaning	24 h/module	820 h
Mechanical Pre-Assembly	8 h/module	270 h
Tile/Tyvek/Lead Stacking	144 h/module	3430 h
PMT Mechanics Installation	16 h/module	540 h
Module Handling/Storage	8 h/module	270 h
Module Cosmic Testing	8 h/module	270 h
Total		5600 h
		3.5 T-FTE

Mechanical Components Cleaning

All mechanical components (~120 parts/module, excluding fasteners) will be cleaned before assembly. The Vacuum Vessel module vendor will clean and paint the inside of the Vacuum Vessel.

Mechanical Preassembly

Step to insure all mechanical parts fit together properly before tiles are used.

Tiles/Tyvek/Lead Stacking.

1280 individual tiles assembly are stacked in the VVS module. This estimate is based on the VVS prototype experience (160 tiles stacked by 3 FTEs in 6h) with a 30% increase in efficiency during real production.

PMT Mechanics Installation

Clamping the dogbones in the PMTs holders, mounting (gluing) of the PMT clear window, mounting of the PMTs housing and shields. The work is estimated at 15 min/tube, with a total of 64 PMTs/module.

Module Handling/Storage

Containers are procured from an outside vendor. Handling of a complete VVS module will take 4 h to a crew of 2 techs operating a crane.

Module Cosmic Testing

Although a physicist will probably perform the cosmic testing, setting up the module under the cosmic stand will require 8 hours of technical work.

Exercise I - Assembly Manpower Estimate "Sanity" Check

The total amount of "hands-on" manpower estimated for the full assembly of the 34 VVS modules is approximately 16.5 FTE years of technicians. As a sanity check, we compare this estimate with the manpower used for the VVS prototype at Lab 6 in June-July '02. At that time we used approximately 2 FTE for 1.5 months (June 15th-July 31st) to assemble a 2-sector VVS prototype. Scaling this up to a 16-sector VVS module, and then to the 34 modules VVS we get: 3 FTE months x 8 (increase to full VVS module) x 34 = 68 FTE years.

Although the difference is larger than a factor of 4 and appears irreconcilable on paper, it can be explained by a "Prototype vs. Production" effect of learning curves and factory efficiency.

A well-documented example showing a similar difference is the production rate of Prototyping vs. Production Assembly in the CMS EMU Cathode strip chambers project. The first prototype chamber (P2'') took 2 months to 2 technicians to be assembled back in July-August 1999, for an effort investment of 0.25 chamber/1 months of FTE. The EMU CSC production rate in the last 16 months has been 5.7 chambers/month with a 6 technicians crew, for an effort investment of 0.95 chamber/1 month of FTE. Production efficiency and learning curve effects account for an increase by a factor of 3.8 in the CSC production rate between the Prototyping and Production phases.

Exercises II - "Running" a FNAL Factory & Cost/Tile

16.5 FTE can correspond to a crew of ~5 technicians for 3 years, or ~8 technicians for two years. Technical crews of these sizes will require an effort of 0.5 T-FTE/year in Floor Management/Supervision. A running Production factory requires an effort of 0.5 E-FTE/year in Supervising Engineering. As an example, the total manpower to run a 2 years VVS construction factory at FNAL would be:

Technicians	***Effort/year***

Hands-on Manpower	8.5 Technicians
Floor Management/Supervision	0.5 Technicians
Engineers	0.5 Engineers

The total effort to run a 2-years VVS factory is therefore 19 T-FTEs and 1 E-FTE. Assuming a fully loaded cost of 70k$ for Technicians (Mech Tech II) and 135 k$ for a Mechanical Engineer (Mech. Eng. III) the manpower cost of the factory is 1.46 M$, or 31$/installed-tile. The cost of tile assembly only (Dogbones+Tile) can be scaled down and is approximately 24$/tile. Absence of full loading for the manpower cost (i.e. absence of the ~35% manpower G&A charges) will decrease the cost/tile accordingly.