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Chapter 8

Cost and Schedule

8.1 Cost

The scope of the BTeV Project consists of the BTeV detector, the C0 Interaction Region, and the C0 Outfitting Project. In addition,there is a Project Office to manage and coordinate the three main subtasks.

8.1.1 The Detector Project

The detector project has had an aggressive R&D effort going on for several years and the basic design and scope has been stable for a least three years.The cost estimate is derived from a very detailed, Work Breakdown Structure (WBS) for each of the BTeV detector's 10 Level 2 subtasks. It includes the remaining design, prototyping, production/fabrication, assembly, transportation, installation, and integration of all components required to implement the design described above. It also includes all support systems: monitoring, calibration, and alignment systems; high and low voltage, gas systems, cooling systems; test stands and test equipment; ES&H-associated costs; and project management costs. Where designs have been available, we have used a bottoms up estimate and acquired quotes directly from likely vendors. In other cases, we have been able to identify similar systems built for other experiments and have contacted them to get their actual costs. The estimate is made in FY2005 dollars.

The cost estimate also includes contingency and estimated overhead (G&A). Contingency estimates have been carried out from the bottom up, applying higher contingencies to systems that have not had detail design work done or have significant risks or uncertainties that are still being addressed by R&D or detailed design work. Issues like exchange rate fluctuations and electronics technologies becoming obsolete have also been taken into account. A Risk Assessment has also been carried out.

Table 8.1 shows the cost estimate by subproject. The total cost for the deteector is \$129 Million (FY2005 dollars). Of this, approximately 41% of the base cost is labor and 59% is M&S. Of the approximately 700 FTE-years of labor in the project, about 325 FTE-years is faculty, research associate, and graduate student physicist labor. About 200 FTE-years of mechanical, electrical/electronics, and software engineering is required. About 175 FTE-years of technician effort is required. The contingency is 37.5%.

8.1.2 The C0 Interaction Region

Only limited design work was done on the C0 Interaction Region until recently. With the recommendation of the P5 Subpanel of HEPAP that a custom interaction region capable of high luminosity be constructed for BTeV, effort increased dramatically, starting in the fall of 2003. Since then a Advanced Conceptual Design Report for the C0 IR has been developed. Effort is now underway to develop a complete resource loaded cost and schedule based on this design. However, detailed design and interaction with vendors is required before the cost and schedule can be determined at the same level as has been done for the detector.

Table 8.1 shows the cost estimate for the Interaction Region subproject. The contingency is just a guess and is expected to be reduced as the design matures and better information is received from vendors,suppliers, and fabricators.

8.1.3 The C0 Outfitting Subproject

Although some preliminary work had been done a few years ago, design work began in earnest in the fall of 2003. Since Fermilab's Facilities and Engineering Support Section (FESS) had worked on the construction of the original C0 Collision Hall, Assembly Area, and Service Building, progress was rapid. Table 8.1 also includes the cost estimate for the C0 Outfitting.

8.1.4 Project Management/Project Office

The subprojects are managed and directed by a team that constitutes the BTeV Project Office. The size and cost of the high-level project management has been estimated both from a bottoms up (detailed specification of management tasks) method and a top down (estimate of the number of people required). The Table 8.1 also includes the cost estimate for the BTeV Project Management.

8.1.5 Cost Summary

Given the detailed nature of the estimate, the method used to assign contingency, and the results of our risk assessment, we consider the estimates of Table 8.1 to be reliable for the detector and the C0 Outfitting. Due to the state of the technical design, the C0 IR costs are less certain and are assigned a high contingency at this point.

WBS	Items	Base Cost M$	Cont. %	Cont.$ M$	Total M$
1.1	Vertex, Toroidal Magnet, Beampipe	1.78	25%	0.45	2.23
1.2	Pixel Detector	15.51	39%	6.12	21.63
1.3	RICH Detector	12.11	36%	4.32	16.43
1.4	EM Calorimeter	12.27	33%	4.09	16.36
1.5	Muon Detector	3.96	37%	1.47	5.43
1.6	Forward Straw Tracker	9.53	29%	2.77	12.30
1.7	Forward Silicon Microstrip Tracker	7.47	34%	2.54	10.01
1.8	Trigger Electronics	12.04	42%	5/02	17.06
1.9	Event Readout and Controls	12.04	34%	4.06	16.10
1.10	System Installation, Integration	6.84	51%	3.49	10.34
2.0	C0 Interaction Region	31.45	40%	12.58	44.03
3.0	C0 Outfitting	5.98	20%	1.20	7.18
4.0	BTeV Project Management	7.99	23%	1.88	9.87
	Total	138.97	36%	49.98	190.00

Table 8.1: BTeV Detector Cost by Level 2 Subtask in $M FY2005

FY05	FY06	FY07	FY08	FY09	Total
10.5	41.2	51.2	51.7	44.9	199.5

Table 8.2: Current Preliminary BTeV Funding Profile, Construction and R&D, in Million $ (then year)

8.2 Schedule

The BTeV schedule is currently expected to be limited by funding and scheduling considerations with respect to Collider Run 2, not by technical considerations. The goal is to complete the BTeV Project, including the custom IR, in calendar 2009. The current funding guidance is shown in Table 8.2. A technically limited schedule would show completion of the construction of the BTeV detector in early 2008. This would require more funding in the early years of the project.

The BTeV detector is a forward spectrometer and is a relatively open structure with each sub-detector occupying its own space along Z, the length of the C0 enclosure. Installation can occur piece-by-piece once the experiment infrastructure is installed. The infrastructure consists of

- a large analysis dipole located in the center of the C0 Hall, centered on the collision region;
- two toroids for the muon system, located at each end of the C0 hall. Each Toroid has a hole in the center that is occupied by a dipole magnet that is needed to compensate the effect of the analysis magnet on the two circulating beams;
- vacuum pipe that contains the two beams; and
- a support structure for the Electromagnetic Calorimeter.

Instalation will begin in the summer of 2005 with the conversion of the beam around C0 to a proper straight-section from its current configuration, which it was put in so that there could be a beam abort at C0. That abort has now been moved to another sector of the Tevatron. The schedule requires the components referred to above to be fabricated in 2005 and 2006 and to be installed in C0 in various shutdowns that will occur in 2006 and 2007. After that, beginning in 2007, smaller detector components can be installed on down days and in short shutdown periods as they become available. Parasitic installation, commissioning and even pre-operations will continue until 2009. In summer 2009, another long shutdown is scheduled to install the C0 low beta optics for BTeV. During this long shutdown, the remaining detector components and the trigger and data aquisition system will be completed installed in C0, and commissioned. Dedicated running with the complete BTeV detector will begin late in 2009.

8.3 Trade Studies

The BTeV Conceptual Design Report identifies technologies for each detector component. These technologies have typically been chosen from a large number of candidates based on "trade studies." There are a variety of considerations that go into determining which technology was chosen, including

- ability to meet the physics goals for the detector component;
- cost and schedule;
- cost and schedule risk;
- robustness, operational considerations, and long term viability of the technology;
- safety considerations; and
- experience within the group with the proposed choice.

Here we list some of the key choices we made and briefly explain the reasons behind them.

8.3.1 Choice of Pixels vs Strips for the Vertex Detector

This choice was driven by the requirement to use the vertex detector in the first level trigger. The amount of computer resources needed to do the pattern recognition is a very strong function of the pixel's long dimension. In the limit where the pixel long dimension is 2 cm, it becomes a "strip." This is to be compared as opposed to the BTeV pixel's large dimension of only 0.04 cm. The computer time to eliminate fake tracks that appear using a strip system goes up by much more than an order of magnitude and the efficiency was lower. The cost and complexity of implementing a system with more than ten times as much computing is prohibitive.

8.3.2 Choice of 0.25μm CMOS for the pixel readout chip vs conventional radiation-hard technology

The cost of radiation-hard pixel readout chips was very high. Typical prototype runs cost \$250,000 and, even worse, required 8-10 months. Design runs competed with demand from military and other high priority customers. Technologies changed rapidly, with a characteristic time that was less than the elongated design cycle.

BTeV participated in a study of the radiation hardness of the commercial 0.25μ CMOS technology. This process is available from multiple vendors and has turned out to be amazingly radiation hard. With the shorter and less expensive design cycles, we have made excellent progress towards designing the final pixel readout chip. We note that the use of this technology by other HEP experiments has allowed us to share in production runs and thereby reduce development costs even further.

8.3.3 Choice of Commercial Switch and Data Highways over Custom Designed Switch for the BTeV Event Builder

BTeV needs a very high speed switch to merge data fragments from an individual event into a contiguous record for the event. We believed that no commercial switch could handle rates as high as 7.5 MHz, which is the maximum crossing frequency at the Tevatron. A review committee strongly argued that we had seriously underestimated the software development needed to support such a device and suggested that we look at commercial alternatives. A commercial solution would come with the required software and would largely eliminate these development costs. We found "custom-commercial" switches that had a reasonable chance of solving the problem but were very expensive. We studied the cost of separating the Data Acquisition into parallel highways, typically 8, and feeding them in round-robin fashion. This reduced the peak data rate into any subsystem by a factor of 8 and permitted us to use conventional network switching technology, which is inexpensive, reliable, and well-supported. This solution required each data source to be connected to each highway, or a factor of 8 more connections. It turned out that 8 times as many lower speed links did not cost any more than 1 high speed link. We have now gone to an all commercial technology. Recent reviewers have endorsed this approach because of reduced cost and complexity.

8.3.4 Choice of $PbWO_4$ crystals for the EMCAL

We began with 3 options that were sufficiently radiation hard. Lead scintillator did not meet our resolution requirements. Liquid Krypton was deemed by the Fermilab Particle Physics Division (PPD) to be operationally unacceptable for the C0 Collision Hall. Tests we performed at Protvino demonstrated that lead tungstate satisfied our resolution requirements and were sufficiently radiation hard to survive in the BTeV environment.

Because of the high cost of lead tungsate,we did a series of studies to determine the physics "payback" of various angular coverage. Studies with BTeVGEANT showed that the physics payback is slight after 200 mr angular coverage and the cost of the detector doubles if one extends the coverage from 200 mr to 300 mr, which is the full angular acceptance of BTeV.

8.3.5 Choice of single-sided silicon for the forward microstrip tracker

The use of double-sided silicon strips at first appeared attractive from the standpoint of minimizing the material in the detector. However, experience from the construction of the silicon strip detectors for Fermilab Run 2 revealed many difficulties at achieving good yield that led to schedule delay. Single-sided detectors are now commodity items. After a review of the effect of the extra material, we decided that a single-sided system could meet the requirements of BTeV and would be less costly and have smaller cost and schedule risk.

8.3.6 Choice of Photon Detector for the RICH Gas Radiator

Cherenkov photons produced in the gas radiator in the wavelength region between 280 - $\sim$650 nm need to be detected efficiently and their position needs to be measured to an accuracy of 0.5 mr requiring square pixels no larger than 6 mm^2. There are two feasible technologies that can be used. One utilizes the "Hybrid Photo-Diode," (HPD) a device, produced by DEP in the Netherlands, that converts photons to electrons on a photocathode and then accelerates them through 20 keV where they are detected in a pixelated silicon detector. The signal is approximately 5000 electrons.

An equally usable system can be made from Multianode Photo-Multiplier Tubes (MAPMT) produced by Hamamatsu. This device is simply a pixelated photomultiplier tube that produces a signal proportional to the gain, typically on the order of 10^5 electrons, when the applied voltage is about 900 V. We had chosen the HPD system originally because it offered to yield about 20% more Cherenkov photons and was significantly less expensive than the MAPMT's. This was judged to offset the greater difficulty of detecting the smaller signals and using a 20 kV high voltage system. The MAPMT was improved about one year ago by greatly reducing a rather large inactive border. The price for the MAPMT also was lowered. Our simulations show that now both systems would record almost identical numbers of Cherenkov photons. Since there is only one manufacturer for each device we have left open the choice of which photon detector to ultimately purchase until we can obtain final quotes for each system. In Sept. of 2000 both systems had comparable costs. By March 2004 the rapid rise in the Euro with respect to the US dollar has made the HPD based system about $1 M more costly than the MAPMT based system. We have developed electronics for both systems. Mechanical designs, support systems etc. have been worked out for both photon detectors. Since the MAPMT is easier to operate and now cheaper we have changed to this photon detector for our baseline.

8.3.7 Choice of a liquid radiator particle identifier to provide particle identification at low momentum

Identifying low momentum kaons is very important for flavor tagging of the other B for CP violation and mixing studies. Unfortunately the gas radiator RICH system is incapable of separating kaons from protons below track momentum of 3 GeV/c. A proposal by the late T. Ypsilantis was to use a thin aerogel slab as a radiator in front the gas and to use the gas photon detector system to detect the photons. LHCb has, in fact, adopted this solution. Our simulations showed that this system would not provide adequate separation as the large radius aerogel rings, populated by approximately 10 Cherenkov photons would be swamped by the many gas rings with approximately 60 photons. Our simulations looked promising before we included the many electrons produced by photon conversions in the beam pipe and other material.

We then developed an alternative system using a 1 cm thick liquid C_5F_{12} radiator in front of the gas, but with a dedicated photon detection system using 5000 3 in diameter photomultiplier tubes placed along the sides of the gas volume.

8.3.8 General Approach to Selection of Components for the C0 Interaction Region

R&D on accelerator magnets and supporting components is time-consuming and expensive. We have chosen to use standard components wherever possible. In particular, Fermilab has worked on the development of the LHC low beta quadrupoles. With some modifications to the cryostat, this design will be used for the IR. Since tooling and expertise exist, this will cost less and take the less time than any other solution that can achieve the requirements set for the IR. Similarly, standard Fermilab interlocks, instrumentation, controls, and power supplies will be used wherever possible.