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Estimated Cost to Mount E906

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At its October 2006 meeting, the PAC reaffirmed the approval of E906. PPD, AD, and CD were asked to develop a plan for how best to mount E906 so that credible estimates can be made of the resources required. This report is a response to that request. We were asked to consider both MWest in the Meson Detector Building and the old KTeV hall (NM4) as possible locations for E906.

We identified a small number of cost drivers and attempted to make detailed estimates for each. These cost drivers are:

- Beam line.
- Analysis magnets.
- Cryogenics (for the liquid targets).

In addition, we estimated the cost and effort required for a number of items expected to be less expensive. These included:

- Detector gas system.
- Services (water and electrical) for analysis magnets.
- Magnetic field mapping.
- Shielding.
- Services for on-detector and near-detector electronics.
- Area preparation.

Finally, we investigated other items at a level of detail sufficient to determine that they will not require significant expenditure of Fermilab funds or effort. These include:

- Detector refurbishment.
- Data acquisition electronics, software, and computing.

The total cost (without contingency) to mount the experiment in NM4 is estimated to be $1.7M, of which $1M is M&S and $0.7M is Fermilab labor. The cost to mount the experiment in MWest has a larger uncertainty, depending on the cost of the beam line, and is estimated to lie in the range $1.9M to $2.4M (also without contingency). These estimates are summarized in Tables 1 and 2 and explained in the text below. The estimates themselves can be found in the EPP document database. A list of the relevant documents is presented in Appendix A.

	NM4		Mwest	
	M&S	**FNAL Labor**	**M&S**	**FNAL Labor**
Analysis Magnets	$90,444	$48,576	$160,883	$69,976
Cryogenics (including new targets)	$181,500	$165,916	$181,500	$165,916
Gas system	$125,000	$145,040	$175,000	$145,040
Services for analysis magnets	$78,900		$115,000	
Magnetic field mapping	$22,000		$22,000	
Shielding	$50,000		$90,000	
Services for on-detector & near-detector electronics	$35,000		$40,000	
Area preparation	$52,050	$65,850	$50,000	
Detector refurbishment	$10,000	$13,920	$10,000	$13,920
PREP electronics	$20,000	$20,160	$20,000	$20,160
Total	**$664,894**	**$459,462**	**$864,383**	**$415,012**

Table 1: Detector-related cost estimates. These estimates do not include contingency or G&A.

	M&S	**FNAL Labor**
Mechanical	$255,750	$164,520
Electrical	$82,000	$81,200
Total	**$337,750**	**$245,720**

Table 2: Costs for beam line to NM4. These estimates do not include contingency or G&A.

Beam line cost estimates:

Beam to NM4

A great deal of work was done on the design of beam lines to transport high intensity charged beams to NM4 in the context of planning for the Kaons At the Main Injector (KAMI) program. For this exercise, an especially simple solution was chosen and a detailed estimate was made of the cost and effort required to reconfigure switchyard and the upstream Neutrino area enclosures. Most of this work is mechanical in nature and was estimated by David Augustine, with help from Joel Misek and a number of other members of the AD Mechanical Support Department. The estimated "electrical" labor includes 13 weeks for a two-person technician crew to reestablish the readout of beam line instrumentation. This part of the estimate has not yet been reviewed by the AD Instrumentation group.

Beam to MWest

Work has also been done in the past to determine how best to transport 120 GeV beams to Meson. The 120 GeV proton beam is larger than the 800 GeV beam for which the existing upstream Meson beam line was designed. As a result, there are substantial beam losses between switchyard and the Meson target train. These losses do not constitute a serious hazard as long as the beam intensity is low, but at the intensity required for E906, would probably result in an unacceptable level of activation inside the beam enclosures. An extensive reconfiguration of the Meson beam lines was originally envisioned as part of the "Switchyard 120" project; however this plan was dropped from the project in order to save money. A second lattice[1] was proposed with the beam requirements of E906 in mind. This design was intended to reduce the losses even more than would have been the case for the unimplemented SY120 design. As in the original design, focusing magnets would be added in the upstream end of Meson, and the Meson septa and Lambertson magnets moved downstream to enclosure M01. This would not result in enough separation between the different beams to get more than one beam through the Meson train. As noted in the SY120 Conceptual Design Report, the train would have to be modified (which would be very expensive) or moved out of the beam line. Since the train is the only location in Meson suitable for a high intensity beam dump, this would mean that all of the Meson beams would likely need to be disabled (and the beam dumped in switchyard) whenever any of the Meson area users made a controlled access.

A crude estimate of how much it would cost to implement the second design for the upstream end of Meson was made in June 2005. The estimated total was $725k. The bulk of this cost was M&S expense for rigging, pipefitting, and electrical work. A number of items (and much of the Fermilab labor) were not included in the estimate, so the total cost associated with this design is likely to be more than $1M.

Very recently, AD members of this task force have started to examine a third alternative for reducing the beam losses in Meson. In this approach, quadrupole magnets are added to the upstream end of Meson, but the septa are not moved. It appears that by running the septa at higher voltage, it may be possible to maintain enough separation between the beams so that three beams can be transported through the three holes in the Meson target train, while at the same time the size of the beam envelope is reduced enough to lower beam losses to an acceptable level. This design has not yet been fully vetted, but if it is acceptable, the cost associated with implementing it is expected to be comparable to the cost of modifying the beam line to NM4, rather than substantially higher.

[1] FERMILAB-TM-2324-AD, available as EPP-doc-219.

Detector-related cost estimates:

Analysis magnets

E906 requires two analysis magnets. The primary proton beam is dumped at the upstream end of the first magnet. Hadrons, electrons, and photons are absorbed in a water cooled copper dump. Most muons are swept out of the spectrometer by the first magnet. Muons produced at high transverse momentum to the beam are measured in an open geometry spectrometer consisting of tracking chambers, a second analysis magnet, and a muon identifier consisting of plates of steel with more chambers interspersed.

In the report that some of us prepared before the October PAC meeting, we stated that pits would need to be dug into the Meson Detector Building (MDB) floor to accommodate the analysis magnets and that the installation of the magnets would probably require the rental of a gantry crane, since both magnets would be built using 30-ton soft iron blocks recovered from the Nevis cyclotron (and previously used in MEast for the SM12 and SM3 magnets). We now realize that the beam height can be increased without increasing the cost of the beam line, so that no pits are required. We also realize that one could cut the 30-ton iron blocks into 15-ton pieces and use the 20-ton MDB crane to assemble the magnets rather than rent a gantry crane. This would also facilitate the eventual removal of the E906 apparatus. We received a budgetary estimate from Belding Walbridge (a local rigging company) of $446k to install the magnets in MDB on the MWest beam line using their gantry crane. We also estimated the cost of cutting the iron blocks and hiring riggers to install the magnets using the MDB crane. This cost was substantially lower than the Belding quote and is included in Table 1.

If E906 is located in NM4, then the KTeV analysis magnet can be used as the second spectrometer analysis magnet and only one magnet needs to be built. For this cost estimate, we assumed that the 30-ton blocks of steel used for the flux return yoke would have one end cut off to reduce their weight to 25 tons each[2]. The NM4 bridge crane could then be used to install the M1 magnet. The KTeV analysis magnet was designed to be easily relocated within NM4 and the cost estimate in Table 1 includes the amount quoted by Belding to move it.

The E906 experimenters have indicated that they plan to decrease the gap of the M1 magnet to 25 inches. We received a quote of $33.5k from Dial Machine Inc. to mill the return yoke pieces to 25 inches. However, if the gap is reduced, it will be necessary to make extensive modifications to the magnet pole tips and especially to the water-cooled copper beam dump. These modifications could cost as much as $100k. The E906 spokesperson has indicated that they will reconsider the plan to decrease the gap of M1, and will most likely change their plans to accommodate the existing gap. We have not included costs associated with reducing the gap of M1 in our estimates.

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[2] A “Poisson” simulation has verified that this will not compromise the performance of the magnet.

Cryogenics

Regardless of where E906 is located, it will require a new stand-alone cryogenics system, and new flasks and a vacuum enclosure for the liquid targets. This is because there is no existing cryogenic system in NM4 and the Meson systems are 100% utilized by other activities. The M&S cost of $181.5k in Table 1 is dominated by the price of a cryocooler and controller, but also includes costs to refurbish a table to hold and remotely manipulate the various targets. The labor includes 28 weeks of engineering and 55 weeks of technician time.

Detector gas system

Two separate gas systems will be needed for the E906 spectrometer. Some of the chambers will use a "Fermilab standard" argon-ethane-alcohol gas mixture. The balance of the chambers will use a "fast gas" mixture of CF4 and isobutane. Both are flammable gas mixtures and require mixing systems located in a gas shed as well as flammable gas sensors and a safety system. The CF4-isobutane system will probably be a closed loop system designed to recover a large fraction of the CF4. The cost estimate in Table 1 assumes that essentially none of the existing KTeV flammable gas system is reusable, and may be considerably reduced if most of the existing system can be reused. The estimate for NM4 is lower than the estimate for MWest only because a gas shed exists outside the KTeV hall, whereas a new gas shed would need to be built if E906 is located in MWest (there is not enough room in the MTest gas shed to accommodate E906).

Services for analysis magnets

The cost estimated for services for the analysis magnets in MWest assumes that existing 500kW power supplies will be used and that they will be located near the north wall of the MDB, one 500 kW supply for each magnet. The bulk of the cost is to purchase and install 150 feet of cable to carry 480V AC from MS4 to the power supplies, and 120 feet of cable to carry current to and from the magnets. $22.5k of the total is to extend LCW headers from the upstream end of MW7 to the E906 magnets in MWest.

The cost estimated for services for the analysis magnets in NM4 also assumes that existing 500 kW supplies will be used. The bulk of the cost is associated with cable to carry DC current from the power supplies in NS7 to the analysis magnets, and with DC cable to carry current from NM2 to the new quadrupole magnet in NM3.

Magnetic field mapping

If E906 is located in MWest, it will require new field maps of both analysis magnets. If the experiment is located in NM4, a new map will be required at least for the M1 magnet. In either case, the "Ziptrack" magnetic field mapping apparatus will need to be refurbished. The estimate in Table 1 comes from the MIPP upgrade proposal. No cost is included for the actual field measurement, since it is expected that this will be done by the experimenters with minimal assistance from Fermilab personnel.

Shielding

The shielding estimate in Table 1 is based on the assumption that the upstream part of E906 will be surrounded by a concrete block "cave" with 6-foot thick walls, 10.5 feet high, with a 3-foot thick roof. A total of approximately 100 B-blocks and 21 G-blocks are required for a 42 foot long cave that would cover 90% of the length of the first analysis magnet. This design concept is based on the shielding that was provided in MEast for E605 and subsequent experiments.

If E906 is located in MWest, its magnets will be configured to bend charged particle trajectories up and down. A simulation of the muon plume downstream of the experiment will be required, and an area downstream of the experiment will need to be fenced off so people are not exposed to an unacceptable level of radiation. There is a small chance that people may need to be excluded from part of MW9 (home to the AD Cryogenics Department) while beam is being delivered to E906 in MWest[3]. In Table 1, we have included $40k to represent the cost of a fenced-in enclosure downstream of E906. This is based on 1600 linear feet of 8-foot high fence. We have not included an estimate of the time required for the study of the muon plume, but this would largely be done by physicists whose time is not generally included in this type of cost estimate.

The NM4 detector hall is underground and was designed for a high intensity beam. If E906 is located in NM4, its magnets will be configured to bend horizontally, and both charges of muons escaping the beam dump will stop in earth.

Services for on and near-detector electronics

We have assumed that ten electronics racks will be required near the E906 detector. The cost estimated for E906 in NM4 assumes the racks used for KTeV will need to be relocated. The cost for E906 in MWest is slightly higher because no AC circuits currently exist where the experiment would be located (we assume that the existing panels can be reconfigured to accommodate the new circuits). We have not included any cost for new racks in MWest, since PREP has a large number of racks available. The cost of rack protection depends strongly on the type of system chosen, and on the number of parameters being monitored. The system installed for the MINOS Near Detector costs approximately $6k per rack. A simple fire-protection system without remote monitoring capability would be much less expensive. We have assumed a cost of $2k/rack for this estimate, and included $20k in Table 1.

Area Preparation

An estimate was made some time ago of the cost required to clean out the KTeV hall so that it could be used as an area to test cryogenic RF modules. The cost to prepare NM4 included in Table 1 is based on that estimate. We have excluded costs associated with

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[3] This was the case during E706, which had a primary target close to the intended location of the E906 target in MWest.

removing the vacuum tanks and the CsI calorimeter as well as 75% of the cost of removing the infrastructure (raised floor, AC, etc.) in the counting house. Our assumption is that a beam pipe will be installed inside the existing vacuum tanks. We further assume that the cost of removing the CsI crystals and maintaining them in a properly controlled environment will not be borne by E906. There is no need to remove the electronics room infrastructure, but we have included 25% of that estimated cost to cover any required modifications.

The MWest area of the Meson Detector Building is currently unoccupied. The only area preparation cost that we have included in Table 1 for area preparation for E906 in MWest is $50k to outfit a trailer to be used as a control room. This assumes that an existing trailer can be used (PPD has one unused trailer at the rail head).

Detector refurbishment

E906 has asked to use the Fermilab wire chamber winding facility in Lab 6 to rewind the chambers of station 1. We expect that the cost associated with tuning up one of the moth-balled winding machines will be minimal. It will be necessary to fabricate a flat and level placement table designed to meet the needs of the E906 station 1 chambers. We have not included anything in Table 1 for this item since the cost will be depend on the details of chamber construction. It is also true that the technician team that used to operate the winding machines was dispersed long ago. Even assuming that E906 provides the labor to rebuild chambers at Lab 6, some expert Fermilab training and supervision will be required. In Table 1, we have included $10k of M&S and 6 weeks of Technical Specialist time.

Data acquisition electronics, software, and computing

E906 is an old fashioned experiment with signals stored on cables awaiting a trigger decision. For either potential site for the experiment (NM4 or MWest), the trigger and readout electronics will have to be "in the pit" near the detectors. The E906 requirements for electronics in a counting room will be modest. The experimenters plan to use a Jefferson Lab DAQ software system programmed by E906 physicists.

The E906 detectors have approximately 10000 readout channels of latched PWC wires, which they plan to readout with old “Ansley” delay cable, and preamp, amp-discriminator latch electronics from E866. In addition, the experiment has 1700 channels of drift chamber wires which they plan to readout with LeCroy 3377 CAMAC TDCs from PREP, and a few hundred PMTs which will require PREP LRS 1440 high voltage supplies and ADCs.

The needs of E906 from the PREP pool appear modest and should be easily satisfied from equipment already in the pool. A small amount of new electronics will be required for new CAMAC controllers, and perhaps some communications gear (hubs, routers, etc.). It is not clear that the old latch electronics is a viable solution. The cables are old and may be brittle; the electronics is of Columbia-Nevis vintage which in the wine analogy may now be vinegar. We have suggested to the E906 spokesperson that they should consider alternatives. We cannot easily fix this problem with PREP equipment. The division of responsibilities is beam/infrastructure to FNAL/DOE-HEP and experiment to ANL/DOE-Nuclear physics so the cost for any replacement is not an impact on Fermilab.

The experiment is in a high rate environment with >1 MHz/plane of secondary particles through the chambers. The trigger rate is low ~200 Hz and the events are tiny by today's standards (~1.5 KB). The total data volume expected is ~1TB over some years of running. Network bandwidth, data storage and computing requirements are all negligible.

In cost terms, we estimate that CD will need to provide $20k of new PREP electronics and three man-months of technical support and consulting in order to mount E906.

Appendix A: Links to other documents

Detailed Estimates

Beam line:	EPP-doc-291
Analysis magnets:	EPP-doc-293
Cryogenics:	EPP-doc-285
Detector gas system:	EPP-doc-286
Services for analysis magnets:	EPP-doc-290
Shielding:	EPP-doc-292
Services for on & near-dectector electronics:	EPP-doc-290
Area preparation:	EPP-doc-262

Other Documents

Quote for rack protection system	EPP-doc-284
Meson Beam Task Force Report	EPP-doc-222
KTeV analysis magnet	EPP-doc-267
Drawing of KTeV Hall (NM3 and NM4)	EPP-doc-264
Cost estimate for magnet pits in MWest	EPP-doc-245
June 6, 2005 Cost Estimate for SY120 Phase II	EPP-doc-224
Optics Upgrade for Switchyard	EPP-doc-219
E906 beam intensity requirements	EPP-doc-216
SY120 CDR	EPP-doc-211