

# CMS: Costs to Completion

## for October 2001 RRB

The estimate of the cost of the CMS detector, given in the MoU [1], is 465.7 MCHF expressed in '1995 Swiss Francs'. The evolution of the cost is outlined in Table 1 that also contains information on funding as agreed in the MoU. The current estimated cost of the sub-detectors, except DAQ that has still to submit a TDR, have been reviewed by the LHCC Cost Review Committee (CORE) and the LHCC Magnet Advisory Group (MAG, for the magnet). In Table 1 we also give an estimate of our current expectation of funding, labeled 'Income (Assured)'.

### Magnet

Until recently the cost estimate of the Magnet had been maintained at 121.9 MCHF. Furthermore, using the small reserve, extra costs had been absorbed without changing the figure of 121.9 MCHF. These extra costs comprised:

- i) 2.5 MCHF for an extra 3km of conductor needed for winding tests, and for 5km of dummy conductor needed to commission the electron beam welding line.
- ii) 1.5 MCHF for extending the period of hire of the gantry crane.
- iii) 0.5 MCHF for on-site assembly operations.

The project is now near completion. A recent detailed study of 'Cost to Complete' has been conducted and has been reviewed by the Magnet Advisory Group. The total cost is now estimated to be 124.1 MCHF. The cost has increased for the following reasons:

- i) 1.45 MCHF to cover the loss of two cables during manufacture and to provide contingency against such accidents in the future.
- ii) 0.75 MCHF increase in the cost of the winding operation.

A recent assessment of the available funds, carried out by the CMS Resources Manager, indicates that the assured funds amount to 120.9 MCHF. This leads to a shortfall of 3.2 MCHF.

### Tracker

The CMS Collaboration is building a revised design of the Tracker in which the MSGC detectors proposed in the original MoU are replaced by Si detectors. The cost estimate of the MoU design was 87.6 MCHF whereas the 'All-Si Tracker' is estimated to cost 77.6 MCHF. About 40% of this sum is expected to be committed soon, within the budget foreseen. The currently assured funding is expected to be 70.2 MCHF. This leads to a shortfall of 7.4 MCHF.

In the Amendment to the MoU [2] a contribution of 3.2 MCHF from the US DoE was expected in 2001 if US CMS cost and schedule performance allowed. This has not been possible. Furthermore 4.2 MCHF of the shortfall in the Amendment was to be cov-

ered by staging about half of the counting room electronics. This now appears to be impracticable and equivalent cost savings or additional funding has to be realized.

## Electromagnetic Calorimeter (ECAL)

The cost estimate of the ECAL, as listed in the original MoU (85.4 MCHF), was made using an exchange rate of US\$/CHF= 1.3, a rate that had been stable over several preceding years. If this assumption is still used the current estimate stands at 100.8 MCHF. The cost has increased for the reasons given below:

- i) 5.8 MCHF for crystals production: the R&D for crystals has been more difficult and more protracted than expected. More infrastructure has been required to ensure timely production of crystals especially since we essentially now only have one supplier.
- ii) 5.1 MCHF for electronics (predominantly for optical links): CMS had development contract with two companies for optical links and the estimated cost per link was about 60 CHF. Problems have occurred with the serializer chip and furthermore the manufacturer (Honeywell) has withdrawn the process. ECAL will now adopt the CERN GOL chip and first samples are being tested with encouraging results. However the cost estimate of the links is now 175 CHF/link. The system is being redesigned to run at twice the previously assumed speed in order to halve the number of links required. In this way the cost increase of the links has been limited to 4.7 MCHF.
- iii) 2.1 MCHF for the calorimeter mechanics and more complex service systems for the preshower detector.

The crystals, and some electronics, are priced in US dollars. The currently prevailing US\$/CHF exchange rate is higher than used in the cost estimate in the MoU. This leads to an increase in the project cost in Swiss Francs. A sum of 0.8 MCHF has already been spent to accommodate the higher US\$/CHF exchange rate for invoices already paid. If the future rate is set at 1.65 US\$/CHF then an extra 10.5 MCHF will be needed for future payments. It should be noted that a variation of 1 centime in the exchange rate leads to variation of 0.23 MCHF in the total cost.

The currently assured ECAL funding is expected to be 87.8 MCHF. This leads to a shortfall of 13.0 MCHF, not including the influence of the exchange rate.

## Hadron Calorimeter

The HCAL is predominantly funded by the US. Financial difficulties in the past have been resolved by using funds freed from the US contingency. The cost has increased, by 2.6 MCHF, to 44.4 MCHF. The primary reason for the increase has been the underestimate of the forward hadron calorimeter (HF) at the time of the MoU. The final design has turned out to be more costly than expected.

The currently assured HCAL funding is expected to be 42.4 MCHF. This leads to a shortfall of 2.0 MCHF. This will be covered by reducing the longitudinal sampling in the HCAL. The physics impact is small and the LHCC has already approved the change.

## Muon Detector

The muon system consists of three distinct parts: the Drift Tubes (DTs), the Cathode Strip Chambers (CSCs) and the Resistive Plate Chambers (RPCs)

Barrel Drift Tubes: The cost has increased from 22.3 MCHF to 24.3 MCHF. The increase is due to:

- i) the complicated mechanics and the strict tolerances required. In light of this some of the firms, that had submitted offers, dropped out in the tendering process and only the more expensive ones were left.
- ii) vendor-forced migration of the TRACO chip to ATMEL 0.35  $\mu\text{m}$  process.
- iii) setting-up of a 4<sup>th</sup> chamber assembly site in Torino to ensure timely production of the DT chambers.
- iv) an underestimate of the cooling system.

CSCs: All chambers except ME1/1: The cost has increased from 23.625 MCHF to 25.2 MCHF

This project is under the responsibility of US. ME4 was staged from the beginning. The trigger electronics for the chambers were moved to the periphery to allow easier access. This led to a cost increase that essentially cancelled the savings made due to the staging of ME4. The station ME4 has two sets of chambers ME4/1 and ME4/2. It has been possible to cover the mechanics of ME4/1 within the original cost estimate of 23.635 MCHF. The 1.5 MCHF increase is the cost of the electronics for ME4/1.

CSCs: Chambers ME 1/1: The cost has increased from 4.720 MCHF to 7.6 MCHF

The cost has increased by 2.9 MCHF due to the inclusion of trigger electronics (previously overlooked and without any responsible Institute) and the move of these electronics to the periphery.

RPCs: The cost has increased from 6.955 MCHF to 11.5 MCHF

A major part of the increase (3 MCHF out of 4.5 MCHF) sits in the forward RPC system. At the time of the original MoU the forward design was not advanced and institute responsibilities were not guaranteed. Since that time Pakistani groups have joined the forward RPC project alongside the Korean groups. The forward RPCs were re-designed and repositioned on the endcap yoke disks. Furthermore, in both barrel and forward RPCs, it has only recently been possible, with the completion of the final detailed design, to reach a proper understanding of the integration and complexity of services (cooling, gas piping, cables, High and Low voltage systems). These were found to be substantially underestimated and account for 3.3 MCHF of the increase.

Alignment: The project was simplified and the cost was reduced from 3.19 MCHF to 2.70 MCHF.

The total estimated cost of the Muon detector has increased from 60.1 MCHF (MoU) to 71.3 MCHF. The currently assured funding is expected to be 58.0 MCHF. This leads to a shortfall of 13.3 MCHF.

## Trigger and Data Acquisition

Trigger: The TDR for the Trigger system was approved by the LHCC in July 2001. It has increased slightly from 12.140 MCHF to 12.335 MCHF.

DAQ: There is a continuing effort to make the design more modular and to follow the evolution of technology. The TDR will be submitted at the end of 2002. The current cost estimate of 25.4 MCHF is unchanged w. r. t. that presented in the MoU.

## Computing

The current estimate of 3.6 MCHF is unchanged w. r. t. that presented in the MoU.

## Infrastructure

A major revision has occurred by adapting to the new guidelines of the host laboratory. The cost estimate has increased from 27.23 MCHF to 28.1 MCHF. The estimate for some items has gone down (1.1 MCHF for Access and Survey, 0.6 MCHF for safety systems) and for some has gone up (0.6 MCHF each for General Installation and Cooling+Ventilation, 0.7 MCHF for shielding systems and 0.8 MCHF for general manpower).

A new category has been created to cover Commissioning and Integration (C&I) that previously appeared in the gray area between Infrastructure and Maintenance & Operation.

## Commissioning and Integration

This category contains costs of

- i) additional safety and infrastructure items
- ii) actions to compensate for civil engineering delays and
- iii) items such as transport, workshop support, technician support etc. that previously used to be covered by the host laboratory.

The integral cost (up to 2006) of these items is being scrutinized by the Collaboration and currently only a preliminary figure can be given. These costs are estimated to be around 12 MCHF.

## Extra Work in SX5

This category contains additional costs due to the compressed underground phase and increased testing activities in SX5. The sub-detector related costs, amounting to 2.2 MCHF, are given here whilst the infrastructure related costs are given in the C&I category.

The sub-detector related costs are for patch panels for the barrel-ECAL and Tracker at the periphery of the yoke amounting to 1.6 MCHF and 0.6 MCHF respectively.

## Maintenance and Operation

The costs for M&O have been provided by CMS and are being evaluated by the M&O Scrutiny Group. Preliminary numbers are available for the various categories. CMS estimates for Category B costs are still incomplete and are subject to substantial change.

## Staging of Elements of the CMS Detector

Work is continuing in examining the physics impact of the staging of various elements of CMS for the first physics run in August 2006. Amongst the items being considered are: a part of the pixel system in the Tracker, the endcaps of the ECAL, a cut in the rapidity coverage of the muon trigger, the re-staging of ME4/1, starting with 50% of the full capacity data acquisition, etc. The exact detector configuration in August 2006 will depend on the ability to cover the shortfall, guided by the physics priorities. It is hoped that the situation will be clarified by the April 2002 RRB.

It should be noted that some elements of the CMS detector have already been staged until the high luminosity running. These comprise:

- i) 9.2 MCHF - ME4/2 mechanics and electronics
- ii) 1.0 MCHF - extra neutron shielding
- iii) ~ 2.5 MCHF - 3<sup>rd</sup> forward pixel disk
- iv) ~ 2.0 MCHF - 5<sup>th</sup> forward RPC layer
- v) Extra installation cost - not yet estimated.

## Summary

Table 1 summarizes the evolution of the cost and funding of the CMS detector. The total of 55.4 MCHF can be split into:

- i) 20.4 MCHF due to underfunding of the detector,
- ii) 2.2 MCHF due to extra work in SX5 arising from delays in the civil engineering
- iii) 11.0 MCHF due to the adverse US\$/CHF exchange rate, and
- iv) 21.8 MCHF due to the overrun in the detector costs

These numbers do not include the recently introduced category of C&I nor M&O. Preliminary estimates indicate that around 12 MCHF have to be added to the above value of 'Cost to Complete'.

It should be remarked that the overrun in the detector costs, caused by underestimates or items missed by CMS, corresponds to about 5% of the total cost of the detector. It should be further remarked that the evolution of the costs is not inflation adjusted.

Table 2 gives the evolution of the missing funds (shortfall). We have carried out as thorough an assessment as possible of the construction funds needed to complete the CMS detector. About half of the construction funds remain to be committed and little allowance has been made for future adverse changes. Nevertheless it should be noted that the evolution appears to be stabilizing.

Table 3 examines one possible scenario of funding of the various items discussed in this document. It is assumed that ~ 15 MCHF worth of detector items, over and above

those in the high luminosity upgrades, can be staged beyond the August 2006 date of the first physics run.

### Conclusions

The RRB is requested to take note of, and comment on, the numbers in this document. The CMS Collaboration will draw-up a financial plan to complete the CMS detector for the April 2002 RRB, in close consultation with the Funding Agencies.

### **References**

- [1] CMS Memorandum of Understanding, April 1998, RRB CMS-D 1998-31.
- [2] Amendment to the Memorandum of Understanding, September 2000, RRB CMS-D 2000-89.

Table 1: The Cost and Funding of the CMS Detector. All numbers are in MCHF.

	Total Cost MoU (1998)	Total Cost Sep-01	Income Current MoU	Income Assured	Missing Funds
<b>Magnet</b>	121.920	124.1	122.305	120.9	3.2
<b>Tracker</b>	87.385	77.6	73.440	70.2	7.4
<b>ECAL</b>	85.425	100.8	88.975	87.8	13.0
<b>HCAL</b>	41.775	44.4	42.820	42.4	2.0
<b>Muons</b>	60.800	71.3	61.900	58.0	13.3
<b>TRIDAS</b>	37.525	37.7	37.410	37.7	0.0
<b>Computing</b>	3.600	3.6	3.600	3.6	0.0
<b>Infrastructure</b>	27.320	28.1	27.230	24.8	3.3
<b>Sub-Total 1</b>	<b>465.750</b>	<b>487.6</b>	<b>457.680</b>	<b>445.4</b>	<b>42.2</b>
<b>Xtra Work SX5</b>		2.2			2.2
<b>Sub-Total 2</b>	465.750	489.8	457.680	445.4	44.4
<b>Xchange Rate</b>		11.0			11.0
<b>Total</b>	<b>465.750</b>	<b>500.8</b>	<b>457.680</b>	<b>445.4</b>	<b>55.4</b>

Table 2: The evolution of the shortfall in CMS. All numbers are in MCHF.

	RRB11 Oct. 00	RRB12 Apr. 01	RRB13 Oct. 01	Comments w.r.t. RRB12
Items covered using reserves in assured funds	6.2	6.2	-	Reserves are now needed to cover originally foreseen items.
Lack of Funds (excp't Tr)	8.0	8.3	10.2	+0.5 (FCS), +1.4 (Mag Russia)
Lack of Funds - Tracker	4.0	7.4	7.4	
CHF/\$ Exchange Rate	8.0	10.0	11.0	+1.0 ECAL electronics
Extra work in SX5		4.0	2.2	-1.8 moved to C&I
Overrun/Missed Items		14.6	22.6	+1.4 Muons, +5.0 ECAL, +1.8 Magnet -0.2 Infrastructure
Restore YE4, ME4/1			2.0	+0.5 YE4, +1.5 ME4/1
<b>TOTAL</b>	<b>26.2</b>	<b>50.5</b>	<b>55.4</b>	

Table 3: An example of the funding profile for the completion of the CMS detector. It has been assumed that ~ 15 MCHF worth of detector items in the category 'Completion' can be staged beyond the Aug 2006 date of the first physics run.

	2002	2003	2004	2005	2006	2007	2008	2009
Completion			11.0	15.0	14.0	8.0	7.0	
C&I	1.9	3.3	3.5	2.8	0.2			
M&O Category A	1.1	2.1	3.8	6.3	11.0	16.0	16.0	16.0
M&O Cat. B*	0.3	0.4	0.4	0.4	8.6	8.6	8.6	8.6
High Lumi. Upgrades						5.0	5.0	5.0
<b>Annual Total</b>	<b>3.3</b>	<b>5.8</b>	<b>18.7</b>	<b>24.5</b>	<b>33.8</b>	<b>37.6</b>	<b>36.6</b>	<b>29.6</b>
Present Construction	90.0	80.0	65.0	12.0	7.0			
<b>Annual Grand Total</b>	<b>93.3</b>	<b>85.8</b>	<b>83.7</b>	<b>36.5</b>	<b>40.8</b>	<b>37.6</b>	<b>36.6</b>	<b>29.6</b>

\* Category B costs – CMS sub-detectors are still evaluating these costs.