Chapter 10

Project Organisation, Responsibilities, Costs and Planning

The CMS Central Tracker Project is based on three independent but largely complementary tracking systems; the Pixel Detector, the Silicon Strip Tracker and the MSGC Tracker. There are 47 Institutions widely distributed over the world and more than 500 physicists and engineers collaborating together in a unique community to construct the central tracking system of CMS.

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10.2 Project Organisation

The Tracker project is organised according to the CMS rules described in the CMS constitution and has an organisational structure similar to that of the CMS Collaboration.

The project is governed by the Institution Board and by the Technical Board. The Institution Board is the highest decision-making body in the Tracker Project. It discusses and decides issues of financial, managerial and organisational nature and also endorses technical matters recommended by the Tracker Technical Board and proposed by the Tracker Project Manager. All Institutions participating in the Tracker Project are represented in the Institution Board. The members of the Institution Board elect their Chairperson for a term of two years.

The Tracker Project Manager, appointed by the CMS Spokesperson, heads the project and is assisted by the Tracker Technical Coordinator and the Tracker Resource Manager.

The Tracker Technical Board, chaired by the Tracker Project Manager, discusses technical and organisational matters on a regular basis and formulates proposals and recommendations to the Tracker Institution Board. The composition of the Tracker Technical Board up to the submission of the Tracker Technical Design Report, is shown in Fig. 10.1.

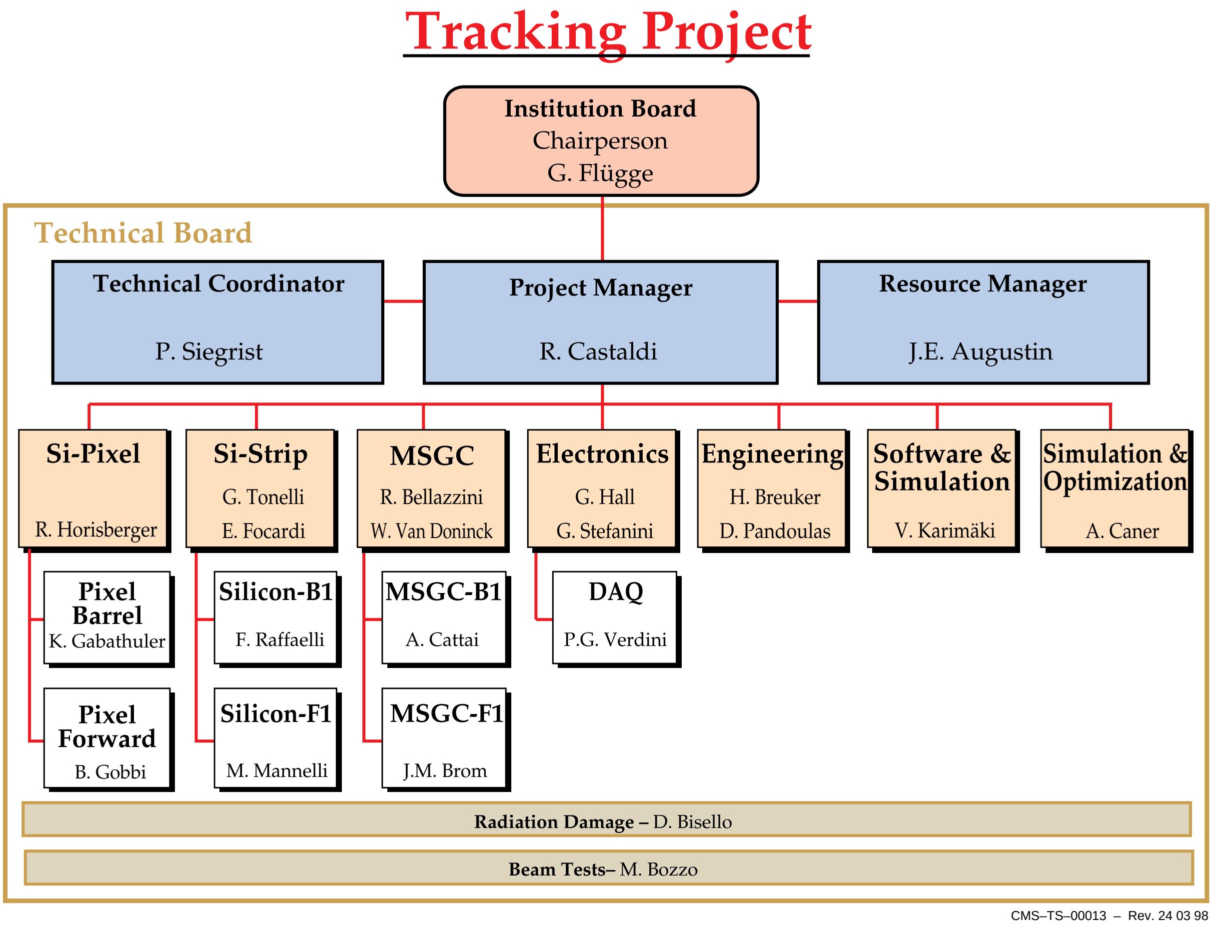

Fig. 10.1: Composition of the Tracker Technical Board in April 1998

The project is divided into a number of subprojects headed by a Coordinator assisted by a Deputy. These Coordinators and Deputies are members of the Tracker Technical Board together with the Project Manager, the Technical Coordinator, the Resource Manager and the Chairperson of the Institution Board. In addition the Coordinators of the major milestones and the Coordinators of special task forces that were needed to arrive at this Tracker Technical Design Report are also members of the Board.

This central structure is complemented by different organisations for the different subprojects. At present seven major subprojects can be identified in the Tracker; three projects for the three subdetectors (Pixel Detector, Si-Strip Tracker and MSGC Tracker) and four common projects (Electronics, General-Engineering/Integration, Software/Simulation and Simulation/Optimisation). Each of the corresponding seven communities organised by its own Coordinator assisted, as appropriate, by his Deputy meets regularly during CMS and Tracker weeks. The meetings are open to all members of the Tracker community and to CMS members in general. They are held regularly to address the most important technical issues, to compare the work of the different groups and to organise activities for the construction effort.

Several special working groups have been set up to address specific problems, to investigate different technical options and to complete prototyping activity. They are composed of groups of specialists from different institutions. Several working groups are permanent (radiation effects, test beam organisation, DAQ, etc.) and meet regularly; others are set up as task forces to study and solve specific problems.

In the case of the Si-strip and MSGC Trackers, where rather large communities are involved, the activity of the physicists and engineers fully committed to build and operate these detectors is organised by the Coordinator and his Deputy with the help of a Steering Committee. Both the Silicon and the MSGC Steering Committees consist, in addition to the Coordinator of the project and his Deputy, of representatives of each participating Institution and technical experts. The two Steering Committees meet regularly every 2/3 weeks. The committees monitor the project, coordinate the activities among the various groups and provide recommendations to the Technical Board and Institution Board of the Tracker.

10.3 Costs and Funding

The cost estimate for the CMS Tracker has been done in great detail, following the procedure and guidelines defined in collaboration with the Cost Review Committee (CORE). The present cost estimate has developed over the last several years and the costs were an important consideration in optimizing the design presented in this Technical Design Report.

The estimates are based on a variety of different approaches. Some of the costs of individual items have been derived from discussions and budgetary quotes with qualified industries, others are based on recent experience in constructing tracking systems and vertex detectors for experiments at CERN (LEP) and Fermilab ($p\bar{p}$ Collider).

The cost of the CMS Tracker will be borne by all institutions participating in the project. At present the participating institutes are expecting to contribute financially to the CMS Tracker as shown in Table 10.1. For most institutes the total funding has already been discussed with the corresponding funding agency. It is expected that the commitments will be made formally by all funding agencies when signing the Memorandum of Understanding (MoU) early this year.

10.4 Institutional Responsibilities

Table 10.2 provides an overview of the division of responsibilities among the institutions participating in the project. For each institution the table also specifies the proposed contribution to the total cost of the project which will be discussed and defined in separate documents corresponding to bi-(multi)lateral agreements (MoU) between CERN and the funding agencies. Codes used for the insitutes in Table 10.2 are explained in Table 10.3. Several common items of the Tracker are the responsibility of the host laboratory CERN. The global Tracker support structure is such a common item. It consists of the central support tube (CST), the endflanges, pixel and beam pipe support structures, the Tracker support brackets and special installation tooling. Further common items are the overall alignment system and part of the monitoring system. The thermal separation screen between the Silicon and MSGC volumes is a common item. CERN's responsibility also includes most of the services between the main patch panels and the underground control rooms.

Table 10.1: Funding of the Tracker project by participating institutes

Cost Estimate Reference	Deliverables	Estimated Cost (Phase II)	Austria	Belgium	CERN	Finland	France-IN2P3	Germany	India *	Italy	RDMS-Russia	Switzerland ETHZ/Universities	Switzerland PSI	United Kingdom	USA DOE	USA NSF	Totals Assigned Funding	Estimated Cost (Phase I)	Balance of Funding vs Cost of Phase I	Balance of Funding vs Cost of Phase II
2.1.1	Detectors (incl. Pre-series)	965										240	410			315	965	965		
2.1.2	Electronics (incl. Engineering	5'020	170									1'030	2'250		695	675	4'820	5'020	-200	
2.1.3	Module Mechanics	1'010										260	460		290		1'010	1'010		
2.1.4	Support Structures and Asser	480										110	140		230		480	480		
2.1.5	Monitoring	110											60		50		110	110		
2.1.6	Service Systems	655										160	280		215		655	655		
2.1	**Pixel Detector**	**8'240**	**170**									**1'800**	**3'600**		**1'480**	**990**	**8'040**	**8'240**	**-200**	**-200**
2.2.1	Detectors (incl. Pre-series)	10'845	440		1'800	200		650	450	4'400		900					8'840	8'825	15	
2.2.2	Electronics (incl. Engineering	15'605	570		2'700			850	100	5'900		1'100		1'500			12'720	12'790	-70	
2.2.3	Module Mechanics	1'120	170		175			150	50	200		100					845	880	-35	
2.2.4	Support Structures and Asser	2'400			720			150		1'100							1'970	2'320	-350	
2.2.5	Monitoring	400						200									200	400	-200	
2.2.6	Service Systems	120			120												120	120		
2.2	**Silicon Detector**	**30'490**	**1'180**		**5'515**	**200**		**2'000**	**600**	**11'600**		**2'100**		**1'500**			**24'695**	**25'335**	**-640**	**-5'795**
2.3.1	Detectors (incl. Pre-series)	13'465		590	1'335		2'530	1'525		3'590	630	370					10'570	10'755	-185	
2.3.2	Electronics (incl. Engineering	24'310		2'635	3'375		3'920	2'910		4'300	320	590		1'200			19'250	19'225	25	
2.3.3	Module Mechanics	1'940		35	270	800	50	340			95						1'590	1'630	-40	
2.3.4	Support Structures and Asser	2'640		155	620	1'200	230	395				40					2'640	2'605	35	
2.3.5	Monitoring	100			50			50									100	100		
2.3.6	Service Systems	120		5	50		20	30		10	5						120	120		
2.3	**MSGC Detector**	**42'570**		**3'420**	**5'700**	**2'000**	**6'750**	**5'250**		**7'900**	**1'050**	**1'000**		**1'200**			**34'270**	**34'435**	**-165**	**-8'300**
2.4.1	Overall Support	2'100			2'100												2'100	2'100		
2.4.2	Overall Alignment	800			600	200											800	800		
2.4.3	Service Systems	3'185			2'985												2'985	3'185	-200	
2.4	**General Mechanical Infr**	**6'085**			**5'685**	**200**											**5'885**	**6'085**	**-200**	**-200**
2.	**Tracker**	**87'385**	**1'350**	**3'420**	**16'900**	**2'400**	**6'750**	**7'250**	**600**	**19'500**	**1'050**	**4'900**	**3'600**	**2'700**	**1'480**	**990**	**72'890**	**74'095**	**-1'205**	**-14'495**

* Pending approval

Table 10.2 DELIVERABLES AND ESTIMATES VALUE (KCHF) BY FUNDING AGENCY

AUSTRIA

Ref.	Institutes	Deliverables	Assigned
2.1.2	AT1	Tracker : Pixel Detector : Electronics (incl. Engineering) Fabrication and testing of pixel electronics	170
2.2.1	AT1	Tracker : Silicon Detector : Detectors (incl. Pre-series) Purchase of silicon detectors	440
2.2.2	AT1	Tracker : Silicon Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for silicon detectors	570
2.2.3	AT1	Tracker : Silicon Detector : Module Mechanics Engineering and manufacture of silicon detector modules in a Regional Centre	170
		Total Assigned Funding	1'350

BELGIUM

Ref.	Institutes	Deliverables	Assigned
2.3.1	BE1 BE2 BE3 BE4 BE5	Tracker : MSGC Detector : Detectors (incl. Pre-series) Purchase and tests of MSGC Endcap detectors	590
2.3.2	BE1 BE2 BE3 BE4	Tracker : MSGC Detector : Electronics (incl. Engineering) Purchase of components of the electronic chain for MSGC Endcap	2'635
2.3.3	BE1 BE2 BE3 BE4	Tracker : MSGC Detector : Module Mechanics Engineering of MSCG Endcap detector modules	35
2.3.4	BE1 BE2 BE3 BE4	Tracker : MSGC Detector : Support Structures and Assembly Engineering, procurement of MSGC Endcap support structures,	155
2.3.6	BE1 BE2 BE3 BE4 BE5	Tracker : MSGC Detector : Service Systems Cables, gas and cooling from MSGC Endcap detector to patch-panel	5
		Total Assigned Funding	3'420

[CERN]

Ref.	Institutes	Deliverables	Assigned
2.2.1	CERN	Tracker : Silicon Detector : Detectors (incl. Pre-series) Purchase of silicon detectors	1'800
2.2.2	CERN	Tracker : Silicon Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for silicon detectors	2'700
2.2.3	CERN	Tracker : Silicon Detector : Module Mechanics Engineering and manufacture of Silicon Detector modules at	175
2.2.4	CERN	Tracker : Silicon Detector : Support Structures and Assembly Engineering, procurement of Silicon Endcap support structures,	720
2.2.6	CERN	Tracker : Silicon Detector : Service Systems Cables and cooling from Silicon Barrel and Endcap Detector to	120
2.3.1	CERN	Tracker : MSGC Detector : Detectors (incl. Pre-series) Purchase and tests of MSGC Barrel detectors	1'335
2.3.2	CERN	Tracker : MSGC Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for MSGC Barrel	3'375
2.3.3	CERN	Tracker : MSGC Detector : Module Mechanics Engineering of MSGC Barrel detector modules	270
2.3.4	CERN	Tracker : MSGC Detector : Support Structures and Assembly Engineering, procurement of MSCG Barrel support structures,	620
2.3.5	CERN	Tracker : MSGC Detector : Monitoring Participation in Slow Controls and purchase of sensors	50
2.3.6	CERN	Tracker : MSGC Detector : Service Systems Cables, gas and cooling from MSGC Barrel detector to patch-panel	50
2.4.1	CERN	Tracker : General Mechanical Infrastr. : Overall Support Procurement of complete support system (CST, endflanges,	2'100
2.4.2	CERN	Tracker : General Mechanical Infrastr. : Overall Alignment Procurement of part of the Overall Alignment system	600
2.4.3	CERN	Tracker : General Mechanical Infrastr. : Service Systems High-voltage and low-voltage cables, gas and cooling distribution	2'985
		Total Assigned Funding	16'900

ESTONIA

Ref.	Institutes	Deliverables	Assigned
2.3.6	EE1	Tracker : MSGC Detector : Service Systems Contribution to be defined	
		Total Assigned Funding	

FINLAND

Ref.	Institutes	Deliverables	Assigned
2.2.1	FI1 FI2 FI3 FI5	Tracker : Silicon Detector : Detectors (incl. Pre-series) Purchase of silicon detectors	200
2.3.3	FI2	Tracker : MSGC Detector : Module Mechanics Manufacture and assembly of the carbon fibre structure of the "Rods"	800
2.3.4	FI2	Tracker : MSGC Detector : Support Structures and Assembly Manufacture, assembly and transportation of the MSGC Barrel wheel (4 disks and the cylinders)	1'200
2.4.2	FI2	Tracker : General Mechanical Infrastr. : Overall Alignment Procurement of part of the Overall Alignment system	200
		Total Assigned Funding	2'400

FRANCE-IN2P3

Ref.	Institutes	Deliverables	Assigned
2.3.1	FR4 FR5	Tracker : MSGC Detector : Detectors (incl. Pre-series) Purchase and tests of MSGC Endcap detectors	2'530
2.3.2	FR4 FR5	Tracker : MSGC Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for MSGC detectors, including engineering runs for MSGC ASICs	3'920
2.3.3	FR4 FR5	Tracker : MSGC Detector : Module Mechanics Assembly and tests of MSGC Endcap detector modules including mechanical elements	50
2.3.4	FR4 FR5	Tracker : MSGC Detector : Support Structures and Assembly Participation in the assembly and installation of MSGC Endcap detector modules	230
2.3.6	FR4 FR5	Tracker : MSGC Detector : Service Systems Small parts of services	20
		Total Assigned Funding	6'750

GERMANY

Ref.	Institutes	Deliverables	Assigned
2.2.1	DE1 DE3	Tracker : Silicon Detector : Detectors (incl. Pre-series) Purchase of silicon detectors	650
2.2.2	DE1 DE3	Tracker : Silicon Detector : Electronics (incl. Engineering) Purchase of read-out electronics for Silicon Detector modules	850
2.2.3	DE1 DE3	Tracker : Silicon Detector : Module Mechanics Frames and engineering of Silicon Detector modules, assembly and tests of these modules in a Regional Centre	150
2.2.4	DE1 DE3	Tracker : Silicon Detector : Support Structures and Assembly Mounting of silicon modules on the support structures	150
2.2.5	DE1 DE3	Tracker : Silicon Detector : Monitoring Participation in Slow Control and purchase of sensors	200
2.3.1	DE2 DE3 DE5	Tracker : MSGC Detector : Detectors (incl. Pre-series) Purchase of MSGC Endcap detector substrates	1'525
2.3.2	DE2 DE3 DE5	Tracker : MSGC Detector : Electronics (incl. Engineering) Purchase of read-out electronics for MSGC Endcap detector modules	2'910
2.3.3	DE2 DE3 DE5	Tracker : MSGC Detector : Module Mechanics Purchase of frames and assembly of MSGC Endcap detector modules	340
2.3.4	DE2 DE3 DE5	Tracker : MSGC Detector : Support Structures and Assembly Engineering, procurement of MSGC Endcap support structures, mounting of MSGC Endcap modules on the support structures	395
2.3.5	DE2 DE3 DE5	Tracker : MSGC Detector : Monitoring Participation in Slow Controls and purchase of sensors	50
2.3.6	DE2 DE3 DE5	Tracker : MSGC Detector : Service Systems Cables, gas and cooling for MSGC Endcap detector	30
		Total Assigned Funding	7'250

INDIA

Ref.	Institutes	Deliverables	Assigned
2.2.1	IN3 IN4 IN5	Tracker : Silicon Detector : Detectors (incl. Pre-series) Purchase of silicon detectors	450
2.2.2	IN3 IN4 IN5	Tracker : Silicon Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for silicon detectors	100
2.2.3	IN3 IN4 IN5	Tracker : Silicon Detector : Module Mechanics	50
		Total Assigned Funding	600

ITALY

Ref.	Institutes	Deliverables	Assigned
2.2.1	IT01 IT03 IT04 IT06 IT08 IT09	Tracker : Silicon Detector : Detectors (incl. Pre-series) Purchase of silicon detectors	4'400
2.2.2	IT01 IT03 IT04 IT06 IT08 IT09	Tracker : Silicon Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for silicon detectors	5'900
2.2.3	IT01 IT03 IT04 IT06 IT08 IT09	Tracker : Silicon Detector : Module Mechanics Engineering and manufacture of Silicon Detector modules at the Regional Centres in Bari-Catania, Firenze-Padova, Perugia and Pisa	200
2.2.4	IT09	Tracker : Silicon Detector : Support Structures and Assembly Engineering, procurement of Silicon Barrel support structures, mounting of silicon modules on the support structures	1'100
2.3.1	IT09	Tracker : MSGC Detector : Detectors (incl. Pre-series) Purchase and tests of MSGC Barrel detectors	3'590
2.3.2	IT09	Tracker : MSGC Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for MSGC Barrel detectors	4'300
2.3.6	IT09	Tracker : MSGC Detector : Service Systems Cables, gas and cooling from MSGC Barrel detectors to patch-panel	10
		Total Assigned Funding	19'500

RDMS-RUSSIA

Ref.	Institutes	Deliverables	Assigned
2.3.1	RU1	Tracker : MSGC Detector : Detectors (incl. Pre-series) Purchase and tests of of MSGC Endcap detectors	630
2.3.2	RU1	Tracker : MSGC Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for MSCG Endcap detectors	320
2.3.3	RU1	Tracker : MSGC Detector : Module Mechanics Engineering of MSGC Endcap detector modules	95
2.3.6	RU1	Tracker : MSGC Detector : Service Systems Cables, gas and cooling from MSCG Endcap detectors to patch-panels	5
		Total Assigned Funding	1'050

SWITZERLAND-ETHZ/Universities

Ref.	Institutes	Deliverables	Assigned
2.1.1	SW1 SW3 SW4	Tracker : Pixel Detector : Detectors (incl. Pre-series) Purchase and testing of Pixel Barrel sensors	240
2.1.2	SW1 SW3 SW4	Tracker : Pixel Detector : Electronics (incl. Engineering) Purchase and testing of Pixel electronics	1'030
2.1.3	SW1 SW3 SW4	Tracker : Pixel Detector : Module Mechanics Bump bonding and assembly of Barrel modules	260
2.1.4	SW1 SW3 SW4	Tracker : Pixel Detector : Support Structures and Assembly Construction of half-shells and assembly of Barrel modules	110
2.1.6	SW1 SW3 SW4	Tracker : Pixel Detector : Service Systems Cables and cooling system for Pixel detector	160
2.2.1	SW1 SW3	Tracker : Silicon Detector : Detectors (incl. Pre-series) Purchase of silicon detectors	900
2.2.2	SW1 SW3	Tracker : Silicon Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for silicon detectors	1'100
2.2.3	SW1 SW3	Tracker : Silicon Detector : Module Mechanics Engineering of Silicon Detector modules	100
2.3.1	SW4	Tracker : MSGC Detector : Detectors (incl. Pre-series) Purchase and tests of MSGC Forward detectors	370
2.3.2	SW4	Tracker : MSGC Detector : Electronics (incl. Engineering) Purchase of components of the electronics chain for MSGC Forward detectors	590
2.3.4	SW4	Tracker : MSGC Detector : Support Structures and Assembly Engineering, procurement of MSGC Forward support structure, mounting of MSGC Forward modules on the support structures	40
		Total Assigned Funding	4'900

SWITZERLAND-PSI

Ref.	Institutes	Deliverables	Assigned
2.1.1	SW2	Tracker : Pixel Detector : Detectors (incl. Pre-series) Purchase and testing of Pixel Barrel sensors	410
2.1.2	SW2	Tracker : Pixel Detector : Electronics (incl. Engineering) Purchase and testing of Pixel electronics	2'250
2.1.3	SW2	Tracker : Pixel Detector : Module Mechanics Bump bonding and assembly of Barrel modules	460
2.1.4	SW2	Tracker : Pixel Detector : Support Structures and Assembly Construction of half-shells and assembly of Barrel modules	140
2.1.5	SW2	Tracker : Pixel Detector : Monitoring Temperature and radiation monitoring	60
2.1.6	SW2	Tracker : Pixel Detector : Service Systems Cables and cooling system for Pixel detector, insertion tooling	280
		Total Assigned Funding	3'600

UNITED KINGDOM

Ref.	Institutes	Deliverables	Assigned
2.2.2	UK1 UK2 UK3	Tracker : Silicon Detector : Electronics (incl. Engineering) Design, develop and procure part of the front-end driver units and part of APV6 front-end chips	1'500
2.3.2	UK1 UK2 UK3	Tracker : MSGC Detector : Electronics (incl. Engineering) Design, develop and procure part of the front-end driver units and part of APV6 front-end chips	1'200
		Total Assigned Funding	2'700

UNITED STATES-DOE

Ref.	Institutes	Deliverables	Assigned
2.1.2	US03	Tracker : Pixel Detector : Electronics (incl. Engineering) Purchase and testing of Pixel electronics	695
2.1.3	US10 US13 US26 US35	Tracker : Pixel Detector : Module Mechanics Bump bonding and assembly of Endcap modules	290
2.1.4	US03 US10 US26 US3	Tracker : Pixel Detector : Support Structures and Assembly Construction of half-disks and assembly of Endcap modules	230
2.1.5	US03 US23	Tracker : Pixel Detector : Monitoring Temperature and radiation monitoring	50
2.1.6	US23	Tracker : Pixel Detector : Service Systems Cables and cooling system for Pixel detector	215
		Total Assigned Funding	1'480

UNITED STATES-NSF

Ref.	Institutes	Deliverables	Assigned
2.1.1	US17	Tracker : Pixel Detector : Detectors (incl. Pre-series) Puchase and testing of Pixel Endcap sensors	315
2.1.2	US17 US33	Tracker : Pixel Detector : Electronics (incl. Engineering) Purchase and testing of Pixel electronics	675
		Total Assigned Funding	990

Table 10.3 Institute Codes in the Collaboration

Country	Code	Institute
Austria	AT1	Institut für Hochenergiephysik der OeAW, Wien
Belgium	BE1	Université Catholique de Louvain, Louvain-la-Neuve
	BE2	Université de Mons-Hainaut, Mons
	BE3	Université Libre de Bruxelles, Brussels
	BE4	Universitaire Instelling Antwerpen, Wilrijk
	BE5	Vrije Universiteit Brussel, Brussels
[CERN]	CERN	CERN, European Laboratory for Particle Physics, Geneva, Switzerland
Estonia	EE1	Institute of Chemical Physics and Biophysics, Tallinn
Finland	FI1	Department of Physics, University of Helsinki, Helsinki
	FI2	Helsinki Institute of Physics, Helsinki
	FI3	Department of Physics, University of Jyväskylä, Jyväskylä
	FI5	Dept. of Physics & Microelectronics Instrumentation Lab., Univ. of Oulu, Oulu
	FI6	Laboratory of Advanced Energy Systems, Helsinki Univ. of Techn., Helsinki
France	FR4	IReS Strasbourg, IN2P3-CNRS-ULP, LEPSI Strasbourg, UHA Mulhouse
	FR5	Institut de Physique Nucléaire de Lyon, IN2P3-CNRS, Univ. Lyon I, Villeurbanne
Germany	DE1	Humboldt-Universität zu Berlin, Berlin
	DE2	Institut für Experimentelle Kernphysik, Karlsruhe
	DE3	RWTH, I. Physikalisches Institut, Aachen
	DE5	RWTH, III. Physikalisches Institut B, Aachen
India	IN3	Panjab University, Chandigarh
	IN4	Tata Institute of Fundamental Research - EHEP, Mumbai
	IN5	Tata Institute of Fundamental Research - HECR, Mumbai
Italy	IT01	Università di Bari e Sezione dell' INFN, Bari
	IT03	Università di Catania e Sezione dell' INFN, Catania
	IT04	Università di Firenze e Sezione dell' INFN, Firenze
	IT06	Università di Padova e Sezione dell' INFN, Padova
	IT08	Università di Perugia e Sezione dell' INFN, Perugia
	IT09	Università di Pisa e Sezione dell' INFN, Pisa
Russia	RU1	Budker Institute for Nuclear Physics, SB RAS, Novosibirsk
Switzerland	SW1	Institut für Teilchenphysik, Eidgenössische Technische Hochschule (ETH), Zürich
	SW2	Paul Scherrer Institut, Villigen
	SW3	Universität Basel, Basel
	SW4	Universität Zürich, Zürich
United Kingdom	UK1	Brunel University, Uxbridge
	UK2	Imperial College, University of London, London
	UK3	Rutherford Appleton Laboratory, Didcot
USA	US03	University of California at Davis, Davis, California
	US10	Fermi National Accelerator Laboratory, Batavia, Illinois
	US13	Florida State University-SCRI, Tallahassee, Florida
	US17	Johns Hopkins University, Baltimore, Maryland
	US19	Los Alamos National Laboratory, Los Alamos, New Mexico
	US23	University of Mississippi, Oxford, Mississippi
	US26	Northwestern University, Evanston, Illinois
	US30	Purdue University, West Lafayette, Indiana
	US32	University of Rochester, Rochester, New York
	US33	Rutgers, the State University of New Jersey, Piscataway, New Jersey
	US35	Texas Tech University, Lubbock, Texas

10.5 Organisation of Construction

10.5.1 Pixel Detector Construction

Several years of development and prototyping work are still required before any mass production of the CMS pixel modules can start. The insertion of the pixel detector into CMS will occur at a very late stage after the installation of the beam pipe (spring 2005). The detector must be assembled and tested within the preceeding six months. The number of modules to be produced for the low luminosity pixel system is relatively modest; a construction time of two years, including extensive testing at various stages, should be sufficient. With the mass production of the modules starting in the fall 2002, the first lots of the final sensors and readout chips must be ordered at the beginning of 2002. During the year 2001 first pixel modules with readout chips incorporating the full column drain architecture must be fabricated and tested. Several intermediate steps will be required before reaching this goal:

1998: Design of various blocks suitable for the proposed column drain architecture. e.g. $(150\ \mu\text{m})^2$ pixel unit cell, 300 μm wide column periphery. Design of 40 MHz analogue signal driver chip.

1999: Design of complete double column of 2×53 pixels with periphery. Definition and design of Control&Interface block for the readout chip. Layout of final analogue block.

2000: Design of full readout chip.

In the years 1998 and 1999, an optimisation program for sensors with $(150\ \mu\text{m})^2$ pixels will be carried through, with special emphasis on the robustness to high voltage operation. First prototype sensors will be fabricated in the year 2000.

A procedure for large volume bump bonding must be developed, preferably in collaboration with industrial firms, to be ready in the year 2001.

First prototypes of mechanical structures for barrel and end-cap disks will be built in 1998, followed by cooling tests in 1999. The final design of the mechanical/cooling structures starts in the year 2000.

The CMS pixel system consists of three independent parts: The barrel and two end-cap disk systems. These parts will only be combined into the full pixel detector at the insertion into the centre of the CMS detector.

The complete Pixel barrel will be built in Europe by a collaboration from Switzerland (Institut für Teilchenphysik ETH Zürich, Paul Scherrer Institut, Universität Basel, Universität Zürich), Austria (Institut für Hochenergiephysik der ÖAW, Wien) and Germany (RWTH, I. Physikalisches Institut, Aachen). The pixel barrel will be assembled and tested at PSI.

The complete end-cap disk systems, including the services, are in the hands of a US collaboration centred around Fermilab, where the final assembly and test before shipment to Europe will be done. The contributing institutes are University of California at Davis, Fermi National Accelerator Laboratory, Florida State University–SCRI, Johns Hopkins University, Los Alamos National Laboratory, University of Mississippi, NorthWestern University, Purdue University, Rutgers University and Texas Tech University.

10.5.2 Si-Strip Tracker Construction

The following twentythree institutions from eight countries have signed this TDR and are committed to the construction of the Si-Strip Tracker:

RWTH I Aachen, Università di Bari e Sezione dell'INFN, Brunel University, Università di Catania e Sezione dell'INFN, CERN, ETH Zürich, Fermilab, Università di Firenze e Sezione dell'INFN, Helsinki Institute of Physics, Humboldt University Berlin, Imperial College London, Northwestern University Evanston, University of Oulu, Università di Padova e Sezione dell'INFN, Panjab University, Università di Perugia e Sezione dell'INFN, Università di Pisa e Sezione dell'INFN, Rochester University, Rutherford Appleton Laboratory, Tata Institute EHEP, Tata Institute HECR, Texas Tech University Lubbock and Institut für Hochenergiephysik der ÖAW Wien.

It is therefore imperative to coordinate centrally the design, specification, ordering and purchase of all critical components (sensors, front-end electronics, optical links, hybrids, power supplies). Specifications for less critical items and ancillary equipment (supporting structures, cables and connectors, off-detector electronics, cooling, alignment, control and monitoring systems) will also be centrally defined, but such items may be purchased separately by the collaborating institutes.

Given the large number of detector modules needed to equip the SST (a total of 6336 modules, 2920 single sided and 3416 double-sided, plus spares are required), it is anticipated that their assembly and test will be divided among eleven production centres (Aachen, Bari-Catania, CERN, ETH-Zürich, Fermilab, Florence, Oulu, Padova, Perugia, Pisa, Wien). The necessary components will be produced at companies and delivered to these centres, where functionality and quality checks will be done. A commonly agreed set of acceptance criteria for the components, as well as assembly, testing and quality control procedures for the modules, will be used in order to guarantee product uniformity.

Under the responsibility of a coordinator for quality assurance, each centre should be able to undertake a significant part of the production. In addition to a specialised workshop with dedicated technicians, a centre will have available a "clean area" (class 10000 will be sufficient) equipped with a 3-D measuring machine, an automatic microbonding machine and inspection facilities (microscopes, CCD cameras). Furthermore, semi-automatic probe stations, DAQ and power supply systems should be available for testing the detectors. Almost all of the production centres mentioned above are already operational.

Following their production and test, the individual modules will be mounted on the supporting structures (cylindrical panels or disks) in three sub-assembly centres (CERN, Fermilab, Pisa). These should have the metrology equipment necessary for module inter-alignment. Final assembly and survey of the barrel and end-cap detectors will take place at Pisa and CERN, respectively.

Overall assembly and survey of the entire detector will take place at CERN, where the three subunits of the SST (the barrel and the two endcaps) will be mounted together and aligned with respect to each other.

In preparation of the construction effort we foresee the following intermediate steps:

Spring	1999:	Production of final prototype and full test of barrel and end-cap detector modules equipped with the final read-out system.
Summer	1999:	Full specification of the critical elements (detectors, supporting structures, power supply, read-out electronics).
Fall	1999:	Tendering and ordering.
End	1999:	Start of the production.

The construction effort will start at the beginning of the year 2000 after the final tuning of the production chains.

10.5.3 MSGC Tracker Construction

The MSGC Tracker consists of three mechanically independent parts: the barrel and the two Forward–Backward detectors. Each of these parts is, in turn, subdivided in many subunits. In the barrel we can identify four logical and physical subunits: the MSGC module, the rod, the disk and the wheel. In the Forward–Backward regions, a smaller number of subunits has to be considered: MSGC detector modules housing four substrates and the disks. Two Super-Modules, corresponding to the two Forward–Backward regions, have to be assembled.

This high degree of modularity enables a high degree of parallelism and a much easier geographical distribution of the construction and testing work. The specification and the design of all critical components, such as MSGC substrates and electronics will be coordinated centrally. The assembly, testing and quality assurance procedures will follow a common approach but will be tailored to the specific requirements of the barrel and Forward–Backward subunits.

Before entering the full mass production phase, the MSGC community will go through the definition and exploitation of a series of pre-construction milestones:

Spring	1999:	Completion of the engineering of industrial production of the barrel and forward MSGC substrates and modules including construction of a pre-series to achieve the target price and throughput.
Summer	1999:	Production and test of final prototype, i.e. barrel and forward MSGC detector modules identical to the production ones equipped with the final read-out system.
Fall	1999:	Full specification of the final barrel and forward MSGC modules. Tendering and ordering.
End	1999:	Start of industrial production of final MSGC substrates and modules.

10.5.3.1 Barrel MSGC Construction

The complete barrel subunit will be built by the common effort of three institutes: CERN, Helsinki Institute of Physics and INFN.

A specific feature of the barrel MSGC is the industrial production of the detector modules. The participating institutions will receive from the industrial companies MSGC barrel modules already equipped with their H.V. and read-out electronics, ready for final acceptance tests before being mounted on the barrel rods.

INFN has the responsibility of monitoring the industrial production to guarantee quality levels and the observation of specifications. INFN will also be in charge of the preliminary tests on the substrate before its acceptance for mechanical assembly. We also expect to automatize and transfer to industry the substrate quality test as soon as the industrial process has reached a high degree of stability and a large statistical sample has been collected.

The final acceptance tests on the modules will be performed in all the participating institutions, roughly in proportion to the number of modules they purchase.

Massive construction of MSGC modules is planned to start at the beginning of 2000 after the final tuning of the mass production tools. Construction and test of MSGC modules will last up to the end of 2003 or the beginning of 2004. We aim at a global throughput of 5 MSGC barrel modules per day.

The manufacture of the rod and wheel components and the partial assembly of the rod, will take place in industry with Helsinki as the main responsible institute. The manufacture of the rod components will take place during 2000. The disks, cylinders and panels for the wheel will be manufactured during 2001 and early 2002.

The quality check and cabling of the rods and the wheel will take place at CERN. The CERN group also has responsibility for assembling the MSGC modules on the rods, performing the final acceptance tests, assembling the rods into the wheel and survey of the Barrel MSGC Tracker.

10.5.3.2 Forward–Backward MSGC Construction

The two super modules will be built by the common effort of eleven institutions in Belgium, France, Germany, Russia and Switzerland: ULB/VUB Brussels, Louvain-La-Neuve, Antwerpen, Mons, IPN-Lyon, IReS-Strasbourg, Aachen I and III, Karlsruhe, Novosibirsk and University of Zürich.

Germany has responsibility for the production of all mechanical elements (frames, forward disks), while the responsibility for the production and testing of the MSGC substrates will be divided between France, Belgium, Germany Russia and Switzerland. The assembly and final mounting will be done in several regional centres.

With the completion of the TDR we enter the preparation phase for a pre-series of detectors in 1999 and final production in 2000. The tooling corresponding to the design presented in this document is being set up in the regional centres for module production: Aachen, Brussels, Strasbourg, Lyon, Karlsruhe and Novosibirsk. At the same time bidding and tendering for substrates, frames and other parts needed for the module production will proceed.

Pre-series of detector modules will be built and undergo final tests in 1999, and at the same time the production of the detector elements will start in all countries involved in the Forward MSGC Tracker. At the beginning of 2000 the final production of detector modules and assembly with the final electronics will start in the regional centres.

Starting in 2001 fully assembled modules with electronics will be assembled on forward disks in the regional centres and / or at CERN.

The final assembly of Super-Modules and system tests at CERN will be due at the end of 2003 or at the beginning of 2004 so that the installation of the two completed super-modules into the Tracker can proceed in September 2004.

10.5.4 Readout and Control Electronics

The electronics required for the silicon and MSGC Trackers will, to a large extent, be common to both. The major items which are not common to both are the front-end circuits, hybrids and certain specialised items, such as the HV control components for the MSGCs. Purchasing and testing will be coordinated centrally. We foresee common purchases of the wafers containing front-end circuits followed by testing in a small number of specialised institutes or in industry, where appropriate. At present we must plan for evaluation by CMS institutes of the mixed signal front end circuits because of the specialised evaluation requirements and difficulty, and probable expense, of defining testing procedures which could be carried out in industry. However, this will be kept under review in case it should become possible once the designs are complete.

Production phases for front-end chips should extend over approximately three years with wafers delivered to CMS centres followed automatic wafer testing to identify known good die. Chips will then be distributed to CMS module production centres, some of which will be the same chip testing centres, for assembly onto hybrids and re-testing. It is not excluded that hybrid assembly could be carried out in industry but this is still under investigation. Detector module assembly will be undertaken by other centres within the collaboration, as described. All of this must be tracked and catalogued. The same institutes will evaluate both silicon and MSGC chips.

Some radiation qualification will be required which should be carried out on sample die evaluated at regular intervals using suitable laboratory irradiation facilities, plus module tests.

Optical links and Front End Drivers and Controllers will be fabricated and tested mainly in industry, followed by acceptance tests by CMS and assembly of complete units, e.g. optical receivers mounted on FEDs and FECs.

The main goal to be met before production starts is verification of the two (silicon and MSGC) front end chip designs in two radiation hard technologies and evaluation of the optical links assembled in the final form for mounting in CMS. These are expected to be completed in 1999.

The institutes contributing to the electronic design and production are Brunel University, CERN, Imperial College London, Karlsruhe, Lyon, Pisa, Rutherford Appleton Laboratory, Strasbourg, with support from CEA Saclay for DMILL developments.

10.6 Construction schedule and Planning

The planning of the construction of the CMS Tracker is integrated in the overall CMS planning. The general CMS construction planning is given in the Technical Design Report of the CMS Magnet Project. This schedule integrates the schedule for the experimental halls, the magnet, and all the CMS subdetectors including the Tracker.

Details of the construction and installation schedules of the various components of the Tracker (Pixel Detector, Si-strip Tracker, MSGC Tracker Barel and Forward–Backward, Electronics and General Mechanics and Installation) are given in Figs. 10.2 to 10.7.

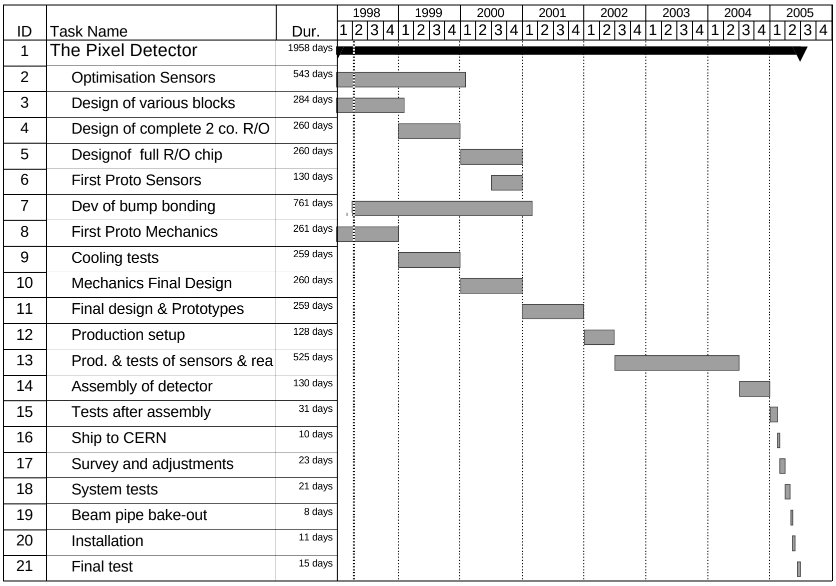

Fig. 10.2: Pixel Detector Schedule

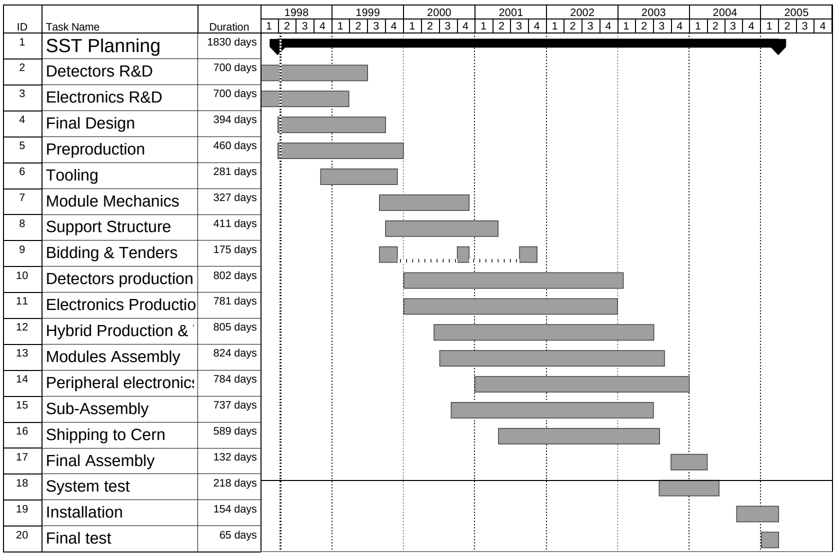

Fig. 10.3: Si-strip Tracker Schedule

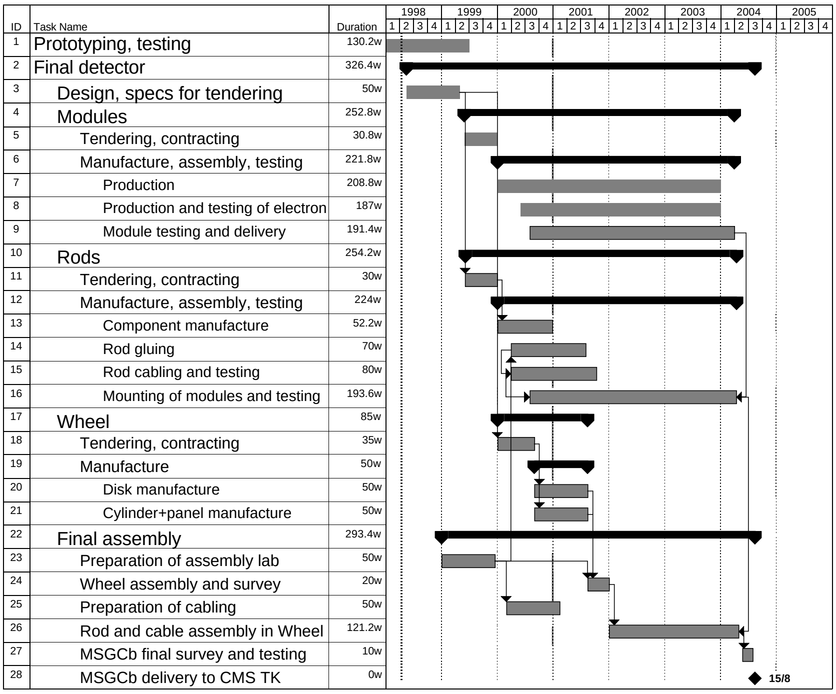

Fig. 10.4: MSGC Barrel Tracker Schedule

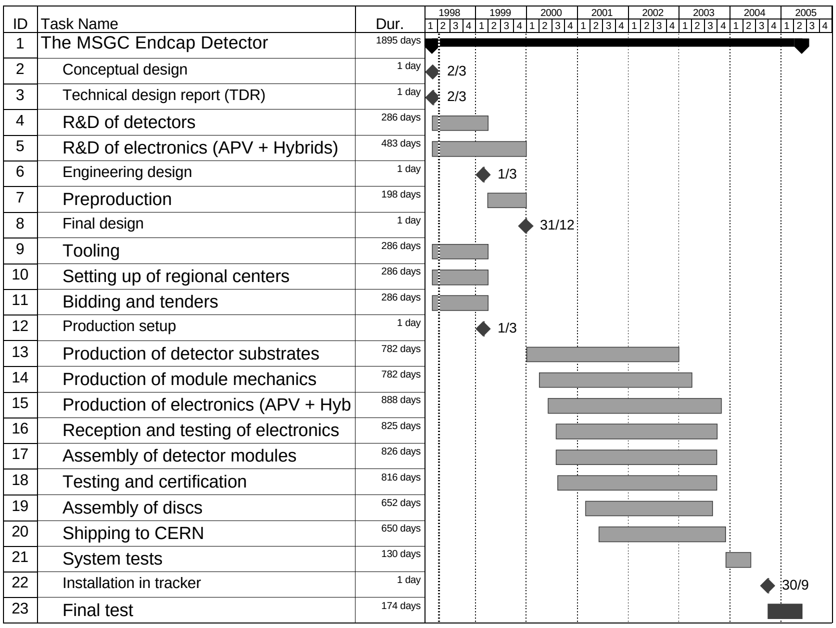

Fig. 10.5: MSGC Forward–Backward Tracker Schedule

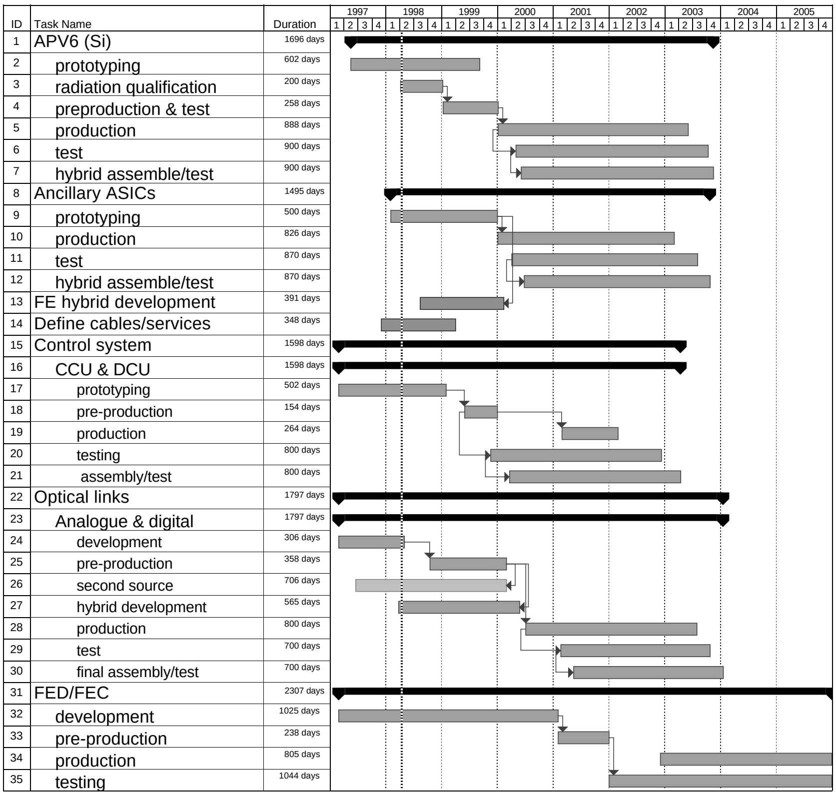

Fig. 10.6: Electronics Schedule

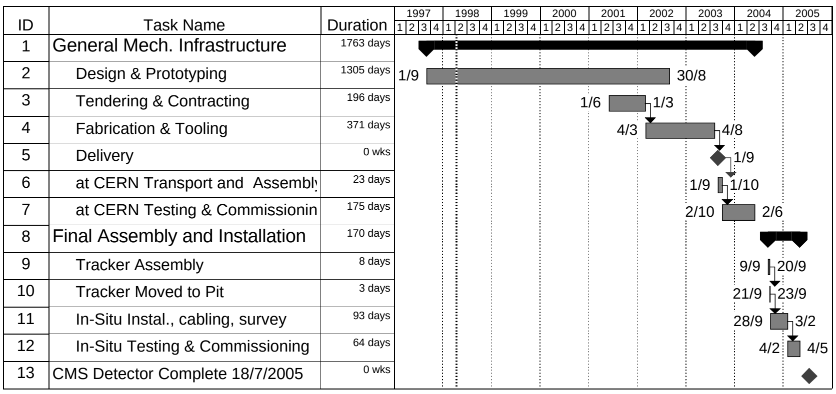

Fig. 10.7: General Mechanics and Installation Schedule