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# TOP
# A Prototype for the TOSCA Experiment

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**Abstract**

We propose to build a prototype of the TOSCA detector (TOP) as a necessary step to the development of the full apparatus.

The basic design of TOSCA consists of 6 quasi-independent modules. Each module is made of an emulsion target, followed by a silicon tracker, an optional emulsion spectrometer and electronic detectors for pattern recognition and momentum measurement. The dimensions of the target and the silicon tracker are of about $1.4 \times 1.4$ m$^2$. Mechanically, both are made of four independent quarter modules of dimensions of about $72 \times 72$ cm$^2$.

The prototype proposed here consists of a complete quarter of a module for the emulsion target, silicon tracker and emulsion spectrometer. This quarter module would be installed inside the NOMAD magnet. The prototype would be completed with re-used elements from NOMAD: electronic trackers, a transition radiation detector, electromagnetic and hadron calorimeters and muon detectors.

We argue that two months of data taking with neutrino and hadron beams would be extremely valuable to understand and optimize the design of the TOSCA detector as well as to acquire experience towards building a large scale detector. We propose to build the prototype in 1998 and 1999 and to take data for a two month period in 1999.

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# 1 Introduction

TOSCA is a proposed third generation $\nu_\mu \leftrightarrow \nu_\tau$ oscillation experiment which attempts to suppress backgrounds by almost seven orders of magnitude, while keeping a very high efficiency for signal identification [1]. It combines the ability of detecting the topological signature of the tau decays (CHORUS [2]) with a good measurement of the kinematical variables (NOMAD [3]). The concept of TOSCA is based on Monte Carlo simulations, together with the experience acquired in building NOMAD–STAR [4] and an emulsion/silicon detector operated at a 1997 PS test beam [5]. We argue that invaluable experience both to optimize the detector design and to understand and improve the performance of TOSCA would be gained by building a real scale prototype of one TOSCA quarter module, TOP (TOsca Prototype).

The TOSCA design presented in [1] consists of six quasi-independent modules, located in the NOMAD magnet. Each module consists of an Emulsion Target (ET) followed by a Silicon Tracker (ST), an optional emulsion spectrometer (ES) and electronic detectors for pattern recognition and momentum measurement. In addition, TOSCA will reuse several NOMAD detectors: electromagnetic and hadron calorimeters and the muon chambers. In order to increase the acceptance for muon identification it is foreseen to instrument the C–shaped return yoke of the NOMAD magnet, as well as the second half of the I–shaped sections of the magnet housing the hadron calorimeter.

Since each TOSCA emulsion/silicon module consists of 4 mechanically independent quarters the natural size for the prototype target (TOP) is one such quarter module. In this paper we propose therefore to construct one quarter module prototype and test it inside the NOMAD magnet using a neutrino and a pion beam in 1999. TOP comprises an emulsion target, four planes of single–sided silicon detectors providing two measurements of each of the two orthogonal coordinates and an optional emulsion spectrometer. In addition to the TOP module we plan to instrument part of the C–shaped yoke and the I–shaped sections of the magnet to study the muon identification planned for TOSCA. Some of the NOMAD target drift chambers will serve as an electronic tracker for the test. The NOMAD transition radiation detector, preshower, calorimeters and muon chambers will be used for particle identification and momentum measurement. With a mass of 50 kg, about 6,000 $\nu_\mu$ charged current events will be observed in the emulsion target during the two–month neutrino run.

With the aid of new high-speed automatic microscopes, these events can be analyzed in three months (time dominated by calibration). Despite the fact that large scale production for the most important detectors may have already started in parallel with the analysis of the TOP data, the TOP results will arrive early enough to influence the final implementation of the TOSCA detector.

This note is organized as follows. The motivations to build the prototype are discussed in detail in section 2. In section 3 the beam is described. The proposed prototype is discussed in section 4. The experience with alignment and construction are discussed in sections 5 and 6. The cost estimates and the schedule for TOP are shown in section 7. Conclusions are presented in section 8. A detailed description of cost and the schedule for construction of the different detectors are presented in appendices A and B.

# 2 Motivations to build TOP

The test of the TOP inside the NOMAD magnet allows to study the precision with which neutrino interactions can be reconstructed using the proposed TOSCA design. In detail the objectives are:

- To study the effect of a cost–optimized emulsion target by adding thin tungsten foils.
- Address the critical issue of the alignment between the different detector elements on a real–size scale and applied directly to the detection of neutrino interactions. This includes tests of temperature stability of the emulsions in the vicinity of the silicon detectors.
- Acquire the necessary construction experience by building a full size detector module at an early stage. This requires implementation of the laboratory infrastructure needed at a later stage for the large scale production of TOSCA.

- Study details of pattern recognition and particle identification; in particular the effect of an improved muon identification at low momenta and large angles.

# 3 Beam

We propose to collect data with TOP in the SPS West Area, in the present NOMAD location, during a 2 months run at the end of 1999 SPS operation period using both the neutrino beam and the X7 hadron beam.

Running TOP in a neutrino beam is necessary to study the neutrino interaction topologies. Using the standard configuration of the West Area Neutrino facility (WANF) we should be able to collect about 6000 $\nu_\mu$ charged current interactions in the TOP 50 kg effective target mass.

There is a possibility that TOSCA may be running, rather than in the WANF, in the SPS New Neutrino Facility (NNF) presently being designed for short and long baseline neutrino oscillation searches. If approved, this facility will operate only with a fast extraction scheme providing very intense short spills of 23 $\mu$s or less. This is very different from the normal operation of the WANF with a fast/slow resonant extraction scheme providing much longer spills of 4 ms or more. It would then be extremely important to test the new read out electronics that will be necessary for the silicon tracker and for the other devices in these much more severe conditions.

The WANF has operated in the past with a fast extraction scheme, that can be put again in operation with limited effort. If it is decided that TOSCA will run in the NNF, we will request to operate the WANF with a fast extraction during a few days of the proposed running time in 1999.

The accumulation of statistics in a neutrino beam is relatively slow. Therefore we plan to complete our data set with pion interactions in the emulsion target using an SPS hadron beam. For this purpose the X7 beam in the West Area can be extended to the neutrino hall and directed into the NOMAD magnet. This will require the removal of part of the CHORUS detector. The knowledge of the momentum of the beam will allow studies on the momentum resolution to be performed.

# 4 Description of the prototype

The TOP detector shown in Fig. 1 consists of :

- An emulsion target to be built (ET),
- a silicon tracker to be partially built (ST),
- an optional emulsion spectrometer to be built (ES),
- an electronic tracker re-used from NOMAD,
- an electromagnetic calorimeter and a preshower both re-used from NOMAD,
- a hadron calorimeter re-used from NOMAD,
- muon chambers re-used from NOMAD and
- additional muon chambers to be built.

## 4.1 Emulsion Target

A quarter module of the TOSCA target is specified by a mass of about 100 kg, a thickness of about 2 $X_0$, and a cross section of 72x72 $cm^2$.

As explained in section 4.2, the silicon tracker for TOP will equip a reduced active area of $54 \times 54$ $cm^2$. Therefore it is reasonable to equip with emulsions only this area, whereas the rest could be built with dummy material with similar mass and radiation length as emulsion. In order to study other target options, a hybrid design of the emulsion target is proposed, with the insertion of thin tungsten foils, as detailed below.

The guidelines for the new target design were the following:

- achieve the main goal of the prototype, i. e. to test tracking and particle identification capabilities with a thick target and in a magnetic field;
- preserve the overall dimensions, effective mass and thickness of a TOSCA quarter module;

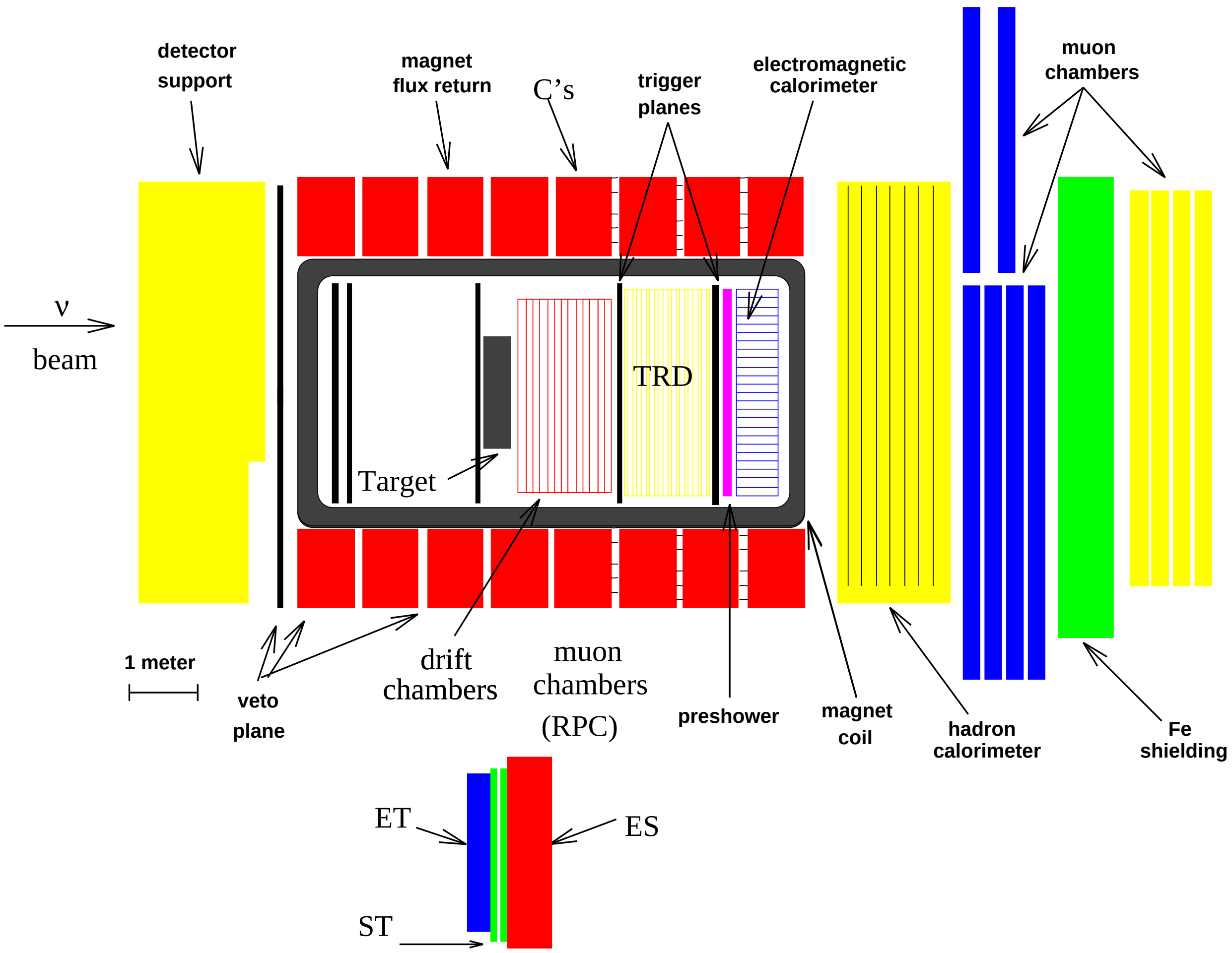


Figure 1: Schematic drawing of the TOP detector.

- since TOSCA requires full measurement of the kink topology rather than full reconstruction of the primary vertex, weaker constraints could be set on the visibility of the primary vertex. Therefore, TOP will verify whether some "degradation" of the active (visible) part of our target is still compatible with the aimed sensitivity.

It is an obvious advantage for pouring, development and scanning facilities to keep the well tested CHORUS size of emulsions. Our proposed option is to insert a number of tungsten foils between thick double coated emulsion plates. The active part of a target prototype will be of the same lateral dimensions as the fully equipped silicon tracker (54 $\times$ 54 cm$^2$). It has a suitable mass and thickness to fit the TOSCA design. The rest of the surface will be completed with dummy material.

Due to its density, a 135 $\mu$m thin tungsten foil would give rise to about the same number of neutrino interactions as a standard double-coated emulsion (350 $\mu$m + 350 $\mu$m on 90 $\mu$m plastic base). Its hadronic interaction length is relatively lower than that of emulsion. The radiation length, however, is shorter, so that a 85 $\mu$m thin tungsten foil is equivalent to an emulsion plate.

As done in the past, pure tungsten with clean surface can be stacked in direct contact with emulsion with an easy handling of thin foils. No problem is caused by a magnetic field.

The composition of the mixed stack (pending possible refinements after Monte Carlo simulation) could be the following: 10 emulsion plates upstream, then 10 pairs of 100 $\mu$m tungsten and one emulsion plate, another 10 emulsion plates and another set of 10 pairs of 100 $\mu$m tungsten and one emulsion plate and finally 10 emulsion plates and an interface "special" plate downstream. The overall thickness will be 4.2 cm, and about two radiation lengths. The 100 kg mass will be formed by 39 kg of emulsions, 11 kg of tungsten and 50 kg of dummy target. The stack would correspond to 64 "equivalent" emulsion plates (50 kg), with 22% of neutrino interactions in tungsten. With this set–up 16% of decays will occur either in tungsten or plastic base.

## 4.2 Silicon Tracker

The silicon detector for TOP consists of 4 planes of single–sided silicon microstrip detectors each covering an area of about $72 \times 72$ cm$^2$ and providing two measurements of each of the two orthogonal coordinates.

To reduce the cost of TOP we will use the same readout chips[1] (VA1) used for NOMAD–STAR. To test the final TOSCA design we need to develop a new readout chip, so that more than one event can be read out per spill. This development begins in 1998. If the new readout chip and the new readout chain are available in time, additional ladders could be built and tested in this prototype.

TOP will provide the opportunity to test a new detector design more suitable for the future TOSCA experiment. The design of the detector has been optimized following NOMAD STAR. This optimization requires,

- good signal–to–noise ratio ($\simeq 20$),
- reasonable spatial resolution ($< 20$ $\mu$m), imposed by the emulsion scanning capabilities,
- readout pitch $> 50$ $\mu$m to reduce the number of readout channels.

We will use AC coupled, low leakage current, FOXFET biased detectors [7] whose specifications are given in table 1 and are compared to the currently used NOMAD–STAR detectors.

Building 2 m$^2$ of silicon detectors would cost about 500 kCHF. To reduce costs, TOP combines elements of NOMAD-STAR [4] (long ladders of 72 cm read out at one end with very low noise VLSI chips) with elements of the TOSCA design (thin ladders and two coordinate measurements and detectors of about $6\times6$ cm$^2$).

The first two planes will immediately follow the emulsion target (see Fig. 1). Each plane has an active area of about $72\times72$ cm$^2$. They will be made of 24 ladders, using detectors of about $6\times6$ cm$^2$ glued onto a common carbon fiber back bone (1 mm thick) and daisy-chained electrically using wire bonds.

[1] It is a commercial version of the VIKING chip [6] distributed by IDE AS, Norway.

| | NOMAD–STAR | TOP/TOSCA |
|---|---|---|
| Detector size | $33.5 \times 59.9$ mm$^2$ | $65.5 \times 61.5$ mm$^2$ |
| Active area | $32.0 \times 58.8$ mm$^2$ | $64.0 \times 60.0$ mm$^2$ |
| Readout pitch | 50 $\mu$m | 100 $\mu$m |
| Strip pitch | 25 $\mu$m | 50 $\mu$m |
| Number of readout strips | 640 | 640 |
| Depletion voltage | 60–80 V | 60–80 V |
| Breakdown voltage | $> 2 \times$ depletion voltage | $> 2 \times$ depletion voltage |
| Interstrip Capacitance | 1.2 pF/cm | $\simeq$ 1.0 pF/cm |
| Aluminum strip resistance | 31.5 $\Omega$/cm | $<$ 15 $\Omega$/cm |

Table 1: Silicon detector specifications.

To reduce the costs we will recuperate the ladders used in the emulsion/silicon test beam, and mount them into a tray as designed for the TOSCA silicon detectors. The first prototype for this tray has already been made successfully. Each new ladder will consist of nine detectors of 100 $\mu$m readout pitch and three detectors of 50 $\mu$m strip pitch read out by existing electronics. To match the pitch of these two types of detectors we will use a pitch adapter that has already been designed. This option implies an active area with full coverage (silicon in 4 planes) of about $54 \times 54$ cm$^2$, which defines the total active area for the emulsion target. However, this option does not invalidate the testing of the mechanical design for TOSCA.

The last two planes will be made using existing NOMAD-STAR ladders which have a thick carbon fiber back bone (5 mm). 48 out of the 50 existing ladders will be reused to make two perpendicular planes of about $72 \times 72$ cm$^2$. Although NOMAD-STAR ladders are thicker than those being designed for TOSCA, this is not critical *for the second plane*. The error due to the multiple scattering is dominated by the error in the first plane, which will be built with newly designed ladders ($<$ 3 mm thick).

A new support frame will be built of carbon fiber to accommodate the four silicon planes.

## 4.3 Emulsion spectrometer

A major improvement of the TOSCA with respect to the CHORUS design is a better measurement of the kinematical variables of the events. This is made possible by using a distributed tracker, inside the magnetic field, and with large acceptance. To further improve the acceptance an emulsion spectrometer can also be used.

The emulsion spectrometer is intended to provide a moderate momentum resolution and very high–acceptance *for signal candidate events* where a kink is found. Its performance can be understood by analyzing charged and neutral current neutrino events. One can compare the momentum measurement provided by the emulsion spectrometer with the momentum measurement found by the electronic trackers, in order to *measure* the momentum resolution that can be achieved with the emulsion spectrometer. In addition, one can fully reconstruct a large number of neutrino events to understand how much the use of the emulsion spectrometer improves the reconstruction of the missing transverse momentum in charged–current interactions. The limitations from the alignment of the emulsion tracker can not be evaluated from Monte Carlo simulations.

The emulsion spectrometer will be made of 8 special plates, distributed over a lever arm of 18 $cm$, matching in dimensions the emulsion target and the silicon tracker. This emulsion spectrometer can provide a reasonable momentum resolution ($\Delta p/p \sim 15$ % at $p \sim 10$ GeV/c) in spite of the short lever arm, due to the excellent resolution of the emulsion and a precise alignment. The emulsion tracker will use the same design as the compact emulsion tracker operated at the 1997 PS test beam [5].

## 4.4 Resistive plate chambers for muon detection

In the TOP test, high momentum muons ($p > 2.5$ GeV/c) will be identified using the existing NOMAD muon system (see Fig. 1). Track segments reconstructed in the muon chambers are matched to reconstructed drift chamber tracks using established NOMAD algorithms [3]. At present, the NOMAD efficiency for muon identification drops dramatically below 4 GeV/c. In the TOSCA design good rejection of muon candidates down to momenta of 2 GeV/c or lower is essential for background rejection due to charm production. To achieve the excellent spatial coverage needed, it is foreseen to equip the downstream half of the C–shaped yokes of the magnet and the so far uninstrumented parts of the downstream I–shaped sections of the magnet with Resistive Plate Chambers (RPC) [8] .

A first test of the design is scheduled for 1998, when a small number of these chambers will be installed in the NOMAD detector to test pattern recognition, occupancies (due to the large mass of the magnet and the high neutrino flux), and the pion/muon separation power in real data taking conditions. The results from the 1998 test in NOMAD will be used to determine the number of chambers to be implemented in TOP (up to 50 chambers) and as a consequence the final design to be used in TOSCA. In the TOP test, the resistive plate chambers can be mounted in the 2 cm wide slots of the C–shaped yoke and I–shaped section of the magnet and have an area of 1 $m^2$ in the C–shaped yokes.

Resistive plate chambers are one of the simplest gaseous detectors to construct. Their operation in streamer mode is limited to a particle rate of 10 Hz/$cm^2$. This rate fits comfortably to the expected rate in the TOP detector. In streamer mode one usually employs an argon based mixture (argon 80%, iso-butane 13%, freon 6%). However it, is possible to use a non flammable mixture containing $\simeq$4% of iso-butane. A prototype chamber of 1 $m^2$ has already been built and is now being tested.

## 4.5 Remaining detectors

To study backscattered particles some of the NOMAD drift chambers can be kept upstream of the emulsion target. Downstream of the emulsion spectrometer, there are electronic trackers. A reasonable simulation of the performance of the TOSCA electronic tracker can be achieved by using sixteen of the NOMAD drift chamber modules. The total lever arm will be about 2 m in a magnetic field of about 0.4 T. This scheme is similar to that of the TOSCA proposal, a 1 m–long tracker operating in a 0.7 T magnetic field, therefore it can be used to study track efficiency, momentum resolution and hit occupancy in the tracker. To provide electron identification the NOMAD drift chambers will be followed by the NOMAD transition radiation detector, preshower and electromagnetic calorimeter. Following the electromagnetic calorimeter, outside the coil, there is an equipped iron–scintillator hadron calorimeter (about 10 interaction lengths) followed by NOMAD muon chambers.

### 4.6 Trigger and data acquisition

Trigger and data acquisition systems will be used in a similar way as in NOMAD. The data acquisition system has to be modified to incorporate the additional readout channels from the silicon detectors and the resistive plate chambers.

The total number of readout channels in the silicon tracker is 48000. Part of the hardware used in the emulsion/silicon detector operated at the 1997 PS test beam will be used to read the additional 15360 channels due to the addition of the second plane.

The resistive plate chambers will be read out with TDC modules from the NOMAD drift chambers not used for TOP.

The time needed to incorporate the necessary software changes in the data acquisition system is shown in Table 7 of appendix B.

## 5 Alignment of emulsion, silicon and electronic trackers

The construction and operation of the TOP detector will provide the necessary experience needed to build and align the TOSCA detector. The different elements composing the detector must be precisely interfaced, which implies a delicate mechanical alignment and a thorough understanding of the possibilities of further software alignment.

To improve the accuracy of the extrapolation of tracks onto the emulsion, the silicon tracker will be placed as close as possible to the emulsion target ($\simeq 10$ mm). The prototype will allow to test the long term stability of the mechanical alignment and more generally the optimization of the TOSCA detector as planned in [1].

# 6 Experience in building a large scale prototype

The design of TOSCA, which involves an increase of the CHORUS target mass by a factor of three, implies challenging developments in the technology of nuclear emulsion handling as well as in the emulsion scanning, to cope with at least $5 \times 10^6$ neutrino events.

TOSCA relies on very fast and highly efficient scanning, made possible by combining the newest technology in automatic emulsion scanning with excellent predictions of the impact points of the tracks in the emulsion. This performance will be well understood by analyzing just half of the 6,000 neutrino events obtained with the prototype in 1999.

Additional challenges will arise from the construction of a large silicon tracker. New groups willing to participate in the construction of this tracker could create the necessary infrastructure needed for a large scale production which will begin immediately after the construction of the TOP. This is very important for the silicon tracker, because the construction of TOSCA overlaps partially with the silicon production intended for LHC.

# 7 Costs and schedule

The estimated costs for the TOP detector are given in Table 2. The second column, displays the expected costs assuming the re-use of detectors described in the third column. The R&D and pre–production of the new readout chip and the new readout chain for the silicon detectors require an additional 150 kSF.

The detector will be ready around August 1999 provided we can place orders as early as June 1998. Scanning results are expected for early 2000.

# 8 Conclusion

We request two months of neutrino beam in 1999 to test a prototype having dimensions similar of the basic building block of the TOSCA detector. Initial tendering can start in early 1998 and it is feasible to have the prototype ready by mid 1999. We also request transport of the X7 hadron beam to the neutrino area.

| Item | Price (kSF) | Saving Option |
|---|---|---|
| emulsion target & emulsion spectrometer | 160 | emulsion/tungsten |
| silicon tracker | 175 | use NOMAD-STAR & emulsion/silicon test beam detectors |
| Electronic tracker | - | use NOMAD-DC |
| TRD | - | use NOMAD TRD |
| calorimeter | - | use NOMAD ECAL |
| $\mu$ detector & resistive plate chambers | 50 | use NOMAD $\mu$ chambers |
| Mechanics & Infrastructure | 100 | - |
| Total | 485 | - |

Table 2: Estimated costs for the TOP detector.

One of the most important features of TOSCA is its modularity. The construction of the TOP detector, made of a quarter-module emulsion target and many available NOMAD detectors will optimize the design of the TOSCA detector and allow the evaluation of its performance, providing essential experience towards the construction and operation of a large scale detector.

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# Appendix

# A Detailed cost estimates for TOP

## A.1 Cost of the emulsion target and spectrometer

For the emulsion target one needs 100 kg of total mass consisting of:

- 50 kg of “dummy” material,
- 39 kg of emulsions,
- 11 kg of tungsten.

For the emulsion spectrometer one needs:

- 8 special sheets of emulsion

| Item | Unit Price (SF) | Quantity | Total (kSF) |
|---|---|---|---|
| Emulsions ($54 \times 54$ cm$^2$, 350 $\mu$m $\times$ 2) | 2450 | 50 | 123 |
| Special sheets ($54 \times 54$ cm$^2$) | 670 | 10 | 7 |
| Tungsten ($36 \times 72$ cm$^2$, 100 $\mu$m ) | 500 | 20 | 10 |
| Development costs and material | 220 | 60 | 13 |
| Miscellaneous | - | - | 7 |
| Total | - | - | 160 |

Table 3: Cost of the emulsion target and spectrometer.

## A.2 Cost of the silicon detector tracker

For the silicon detector one needs

- 240 detectors to be ordered and tested,
- support frames to be designed, built and tested,

- upgrade the existing assembly machine,
- modify the existing survey machine.

| Item | Unit Price (SF) | Quantity | Total (kSF) |
|---|---|---|---|
| Silicon detectors | 15/cm$^2$ | 0.86 m$^2$ | 130 |
| Mechanics | - | - | 45 |
| total | - | - | 175 |

Table 4: Cost of the silicon tracker.

### A.3 Cost of the resistive plate chambers

Each of the 50 resistive plate chamber has,

- an area of 1 m$^2$,
- 32 readout channels with a pitch of 26.8 mm,
- the interstrip gap is 2 mm.

## B Detailed schedule for the TOP detector

The schedule for the emulsion target and spectrometer is given in Table 6.

The schedule for the silicon tracker is based on previous experience in building the NOMAD–STAR and the emulsion/silicon detector used in the T9 test beam. The full installation is scheduled for august 1999. However, if the beam is available earlier the schedule can be adapted.

The schedule for the resistive plate chambers is given in Table 8. We foresee to build four chambers a month.

| Item | Unit Price (SF) | Quantity | Total (kSF) |
|---|---|---|---|
| Melamine-phenolic plates | $30/m^2$ | $2\times75$ $m^2$ | 4.5 |
| Aluminum/Copper foil for readout (25 $\mu$m thick) | 20/kg | 50 kg (a roll) | 1.0 |
| Honeycomb panels | $120/m^2$ | 75 $m^2$ | 9.0 |
| Makrolon plates | $50/m^2$ | 75 $m^2$ | 3.8 |
| Aluminum bars | 0.45 | 200 | 0.1 |
| Aluminum plates | $15/m^2$ | $2\times50$ $m^2$ | 1.5 |
| Mylar sheets | $15/m^2$ | 75 $m^2$ | 1.1 |
| Electronics (estimated) | 12/channel | 1600 channels | 19.2 |
| High voltage connectors | 30 | 100 | 3.0 |
| Gas connectors male & female | 10 & 8 | 100 & 100 | 1.8 |
| Gas unions | 4 | 100 | 0.4 |
| Copper gas pipes | 1.5/m | 200 m | 0.3 |
| Miscellaneous (screws, glue, isopropyl alcohol, copper tape) | - | - | 5.0 |
| Total | - | - | 49.2 |

Table 5: Cost of the resistive plate chambers.

Table 6: Schedule for the emulsion target and spectrometer.

Table 7: Schedule for the silicon tracker.

Table 8: Schedule for the resistive plate chambers.