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PRELIMINARY FEASIBILITY STUDY AND COST EVALUATION FOR AN EXPERIMENT OF NEUTRINO OSCILLATIONS AT CERN-PS

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1. Introduction

A Letter of Intent (CERN-SPSC/97-21) was presented at a recent SPSC meeting suggesting a new experiment of neutrino oscillations to be done at the PS (similar to the one already done in 1981, see Ref. 1). The idea is to reinstall the TT1-TT7 tunnels (see Fig.1) to send a high intensity proton beam to a target located at the end of TT7 beam line. The neutrino will reach Bldg. 181 where a "near detector" station is located and successively Bldg. 182 where a "far detector" is also located.

The scope of this paper is to present a first order estimate concerning the technical possibilities and a cost evaluation.

2. PS beam requirements

The PS proton beam requirements are the following:

- momentum : 20 GeV/c, which is the maximum attainable for a 1.2s repetition rate.
- total beam intensity : 3 10^{13} p/pulse which is the maximum present achievable PS intensity
- the number of cycle per supercycle of 14.4s will vary from 1 to 3 depending on the scheduled sharing with other PS users. The maximum number 3 is related to the maximum amount of losses which can be accepted into the PS machine (see Ref.2).
- the beam is fast extracted at 20 GeV/c making use of the present fast extraction in SS16 with no machine modification required. Other approx. beam characteristics will be : number of bunches = 16, bunch spacing = 131ns, long. emittance = 1eVs, bunch length = 25ns at 4 sigmas, momentum spread = 2 10^{-3} at 4 sigmas.

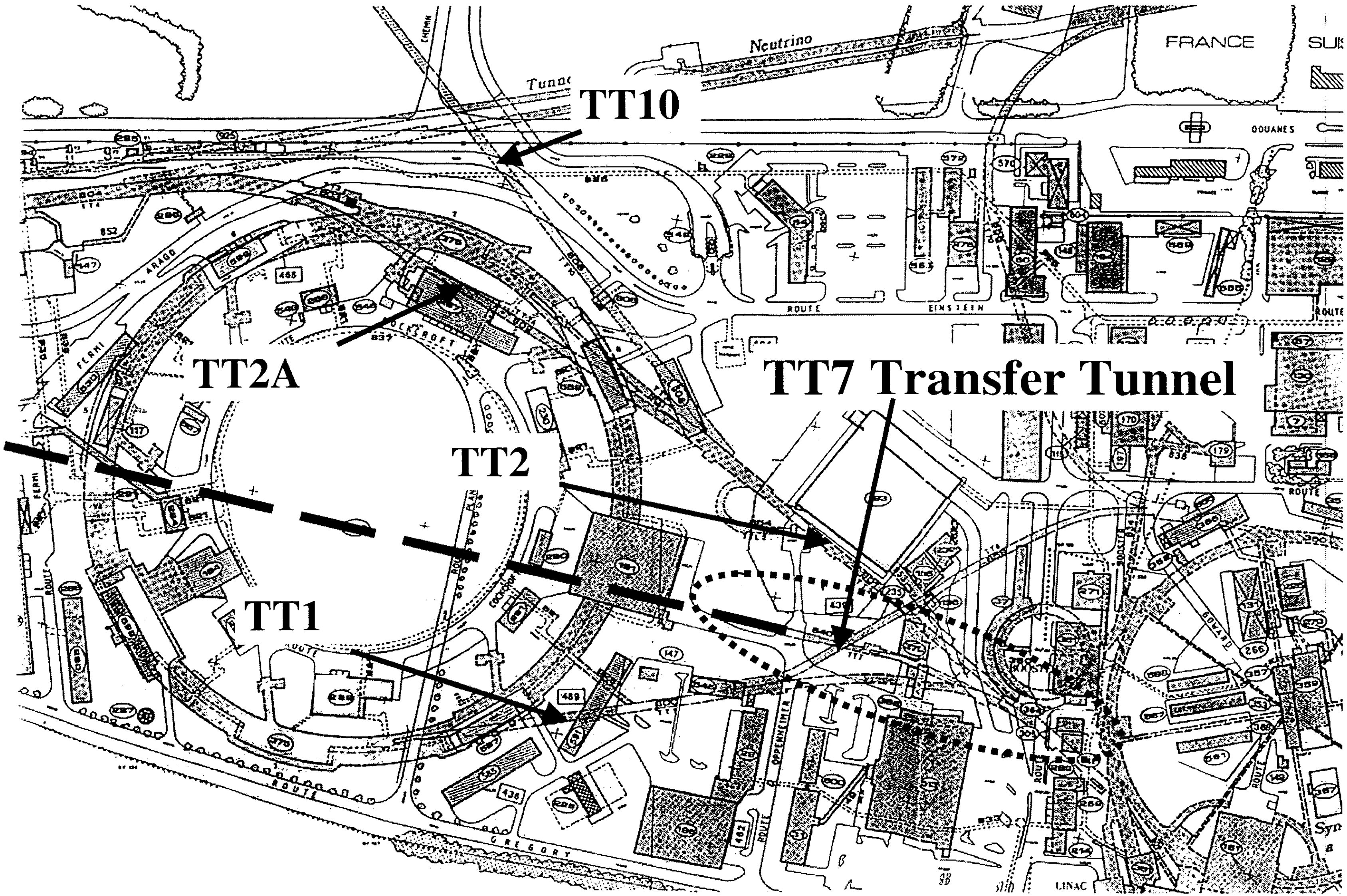

Fig.1 Neutrino Beam Line from the PS (I216)

3. Beam Layout

The beam line configuration (compatible with the present still existing tunnels) makes use of the TT1 and TT7 tunnels. These tunnels are used at present to store radioactive material. All the ancient magnets and power converters are no longer available and they will have to be replaced by other elements. The optics will also have to be consequently modified .

4. Beam optics

In the early eighties the TT7 line, see Fig.2, was used as a beam transfer line to transport high intensity proton beam to three different experiments studying neutrino physics. In the present situation, it is not possible to put back into operation exactly the same transfer line. In fact, most of the bending magnets are not available anymore, being installed in other CERN experimental areas (mainly in the SPS area).

For this reason, the overall geometry has been modified with respect to the previous version. The bending angles in the horizontal and vertical planes have been adapted to the available bending magnets, also trying to reduce the number of power converters needed, in order to reduce the overall cost of the complex.
A brief description of the different sections of transfer line is given as follows :

- TT1 line : all the bending magnets (BHZ207, HB404, HB405, HB406, HB407, HB408, HB410, HB411, HB412) perform a deflection of about 31.86 mrad toward the left. They are all connected in series and they are of type MCA. They are all available in the SPS stock. The quadrupoles (QD408, QF409, QD410, QF411, QD412, QF413, QD414) are connected in two strings : one for the focusing quadrupoles and one for those defocusing. The focusing quadrupoles are of type QFS and those defocusing are of type QD. All of them are available either in the SPS or PS stocks.

- TT7 line : the first vertical deflection is performed by three bending magnets. Two MCV (connected in series) and one MVB4 deflect the beam up by about 90 mrad. Then four MCW connected in series kick the beam horizontally by about 209 mrad. Finally two MCB connected in series reduce the first vertical deflection, generating a kick down of about 79 mrad. Five quadrupoles of type QTS are used to focus the beam on the target. Finally four MDX magnets are used as horizontal or vertical steering magnets. All the magnets are available either in the SPS or PS stocks. With respect to the previous design the entry point of the target has been moved downstream by about 4.5 m in order to install the final doublet next to the focusing point, thus reducing the beam size at the target.

The total power consumption will be about 1 MW.

In principle, the new geometry should not have any consequence on the tunnels, as far as civil engineering work is concerned. Eventually, only the small hole connecting TT1 and TT7 should be modified, but the cost for this should be negligible (about 15-20kCHF).

As far as the beam optics is concerned, it seems feasible to obtain values of the beta-functions less than 5 m on the target. Therefore, the following approx. beam sizes are to be expected on the target.

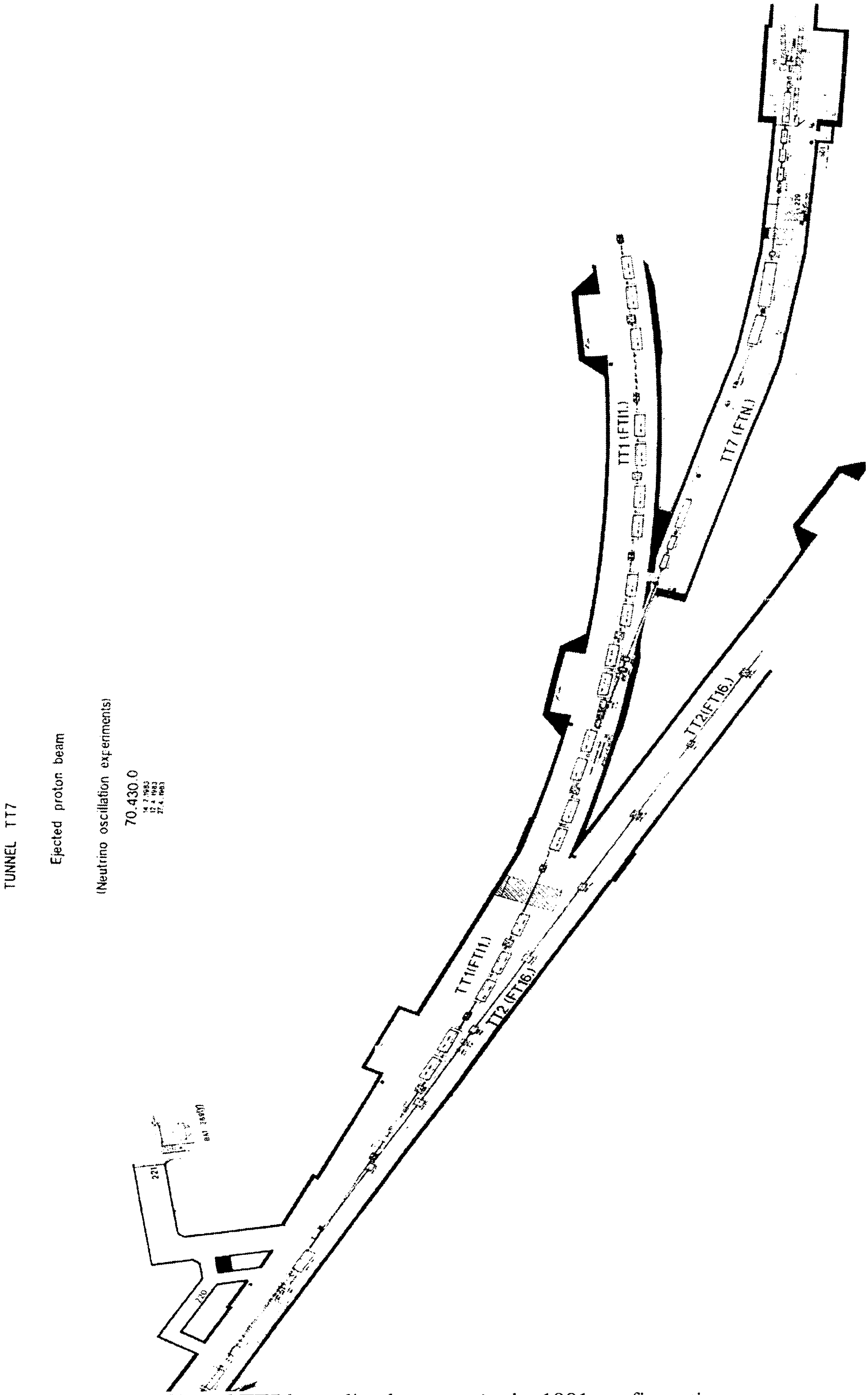

Fig.2: TT2, TT1, and TT7 beam line layout as in the 1981 configuration.

	QUAD. (type)	BEND. (type)	CORR.(type)	Angle [mrad] Hor.	Angle [mrad] Ver.	I [A] 20 GeV/c	I [A] 24 GeV/c	Imax [A]	Availab
TT2		BHZ207(MCB)		31.86		244	292		SPS
TT1	QD408 (QD)							500	SPS
	QF409 (QFS)							500	SPS
		HB404 (MCA)		31.86		792	950		SPS
		HB405 (MCA)		31.86		792	950		SPS
	QD410 (QD)							500	SPS
		HB406 (MCA)		31.86		792	950		SPS
		HB407 (MCA)		31.86		792	950		SPS
	QF411 (QFS)							500	SPS
		HB408 (MCA)		31.86		792	950		SPS
	QD412 (QD)							500	SPS
		HB410 (MCA)		31.86		792	950		SPS
		HB411 (MCA)		31.86		792	950		SPS
	QF413 (QFS)							500	SPS
		HB412 (MCA)		31.86		792	950		SPS
	QD414 (QD)							500	PS
TT7			HOR. (MDX)					240	SPS
			VER. (MDX)					240	SPS
	QTS.1							550	SPS
		MCV			32.50	1109	1331		SPS
		MCV			32.50	1109	1331		SPS
		MVB4			25.40	303	364		PS
	QTS.2							550	SPS
		MCW		52.25		817	980		SPS
		MCW		52.25		817	980		SPS
		MCW		52.25		817	980		SPS
		MCW		52.25		817	980		SPS
	QTS.3							550	SPS
			HOR. (MDX)					240	SPS
			VER. (MDX)					240	SPS
		MCB			39.50	321	385		SPS
		MCB			39.50	321	385		PS
	QTS.4							550	PS
	QTS.5							550	SPS

Table 1: List of hardware to be installed in the TT2/TT1/TT7 tunnels for the new neutrino transfer line.

Transverse Parameters		Longitudinal Parameters		Beam size on target	
$\varepsilon_H(1\sigma)$ [mm mrad]	$2.0\ \pi$	$\Delta p/p$	$\pm 2\times 10^{-3}$	$\sigma_H(1\sigma)$ [mm]	3.0
$\varepsilon_\varsigma(1\sigma)$ [mm mrad]	$2.0\ \pi$			$\sigma_\varsigma(1\sigma)$ [mm]	3.0

Table 2 : Beam parameters used for computation of beam envelope. The beam emittance refers to the physical value at 20 GeV/c.

5. Magnets

All magnets are recoverable from SL/EA and will come free apart from some possible moving costs.

TT1 :
2 dipoles of type MCB
7 dipoles of type MCA
3 quadrupoles of type QFS
3 quadrupoles of type QDS

TT7 :
3 dipoles of type MDX (correctors)
5 dipoles of type MCW
5 quadrupoles of type QTS

Connections to water cooling can be done with spare parts we have at CERN, to the water pipes existing along the walls. The same holds for most of the power connections inside the tunnels which still exist; some additional cost may exist on the other side to ensure the continuity up to the power supply building (see Ch.10)

6. Vacuum pipes

Not recoverable from the past experiment, the line is about 135 m long with multiple joints and some vacuum chambers are delivered inside the magnets. Estimated cost for this part is about 200 kCHF. This includes all pipes, joints, supports but not the pumps, gauges and cabling (see Ch.14).

7. Mechanics

Most of it consists of vacuum joints and supports. Possible special pieces for tanks (e.g. instrumentation) is supposed to come from the groups concerned.

Estimated total cost(excluding installation) for PS/CA-IN : 200 kCHF.

8. Instrumentation

The cost of 5 scintillator screens (with video cameras), one transformer for intensity measurements and a grid system for beam position monitoring at the target is estimated to 350 kCHF.

9. Power converters

Most of the power converters for the dipoles and quadrupoles to be installed in TT1 and TT7 will be recuperated from the obsolete LEAR and WEST experimental areas. However all the converters will have to be equipped with new low level electronics, based on G64, to be compatible with the new control systems. Moreover, some converters need a consolidation (circuit-breaker replacement, DCCT, etc.) and some are simply missing due to the peculiar characteristics needed.
The consolidation of a converter foreseen for the horn cannot be precisely calculated as a fine analysis of the discharge circuit has not been done yet.

A cost estimate is shown in Table 3 below.

Line	**Magnet**	**Type**		**Consolidation**	**New Converter**
TT2	BHZ 207		new		120
TT1	HB404S	R.42N	available	20	
	HB412	R10	available	20	
	QD408S	R1	available	25	
	QF409S	R1	available	25	
TT7	MCB	R43N	available	20	
	MCV	R22	?		250
	MCW	R2B+D	available	30	
	MVB4	R1	available	25	
	QTS.1	R40N.01	available	15	
	QTS.2	R40N.02	available	15	
	QTS.3	R40N.03	available	15	
	QTS.4	R40N.04	available	15	
	QTS.5	R40N.05	available	15	
	corr H		new		70
	corr H		new		70
	corr V		new		70
	corr V		new		70
Magnetic horn				70	
Cables				150	
Sub-Total				460	650
			TOTAL		**1110**

Table 3: Cost estimate (kCHF) for power converters

- Industrial support: 1.5 my.

10. Civil Engineering

Two new constructions have to be built:

a) a building housing power converters ;
b) a decontamination cabin for the entry to the TT7 tunnel.

A refurbishment of the TT7 tunnel will be also necessary.

Power converter building

A building housing power converter should have a surface of approximately 200 m2 (19 m x 10 m) and the height of 4 meters. The false floor should have the height of 1.2 m. Its location has not been precisely fixed yet, but presumably it will be built close to Bldg.366.

The cost of the building is estimated to be 430 kCHF including: foundations, construction, false floor, ventilation (electrical heating and extraction), study.

Cost of foundations for the 2 MVA transformer located outside the building are estimated to be 5 kCHF.

Not included in the estimation: electricity (this is included in the electricity general services, see Ch. 11) and additional cost linked to the location of the building which depends on the excavations and displacement of the existing transformers. This additional expense may constitute an important part of the cost.

Approximately 6 months will be necessary to complete the works.

Manpower: 1 engineer for 2 months.

Decontamination cabin

A simple construction permitting the change of contaminated clothes will be located at the entry to the TT7 tunnel. It will be equipped with electrical heating, lighting and electrical outlet. The cabin of 3m x 2m will fit the existing passage.
The estimated cost is 10 kCHF.

Refurbishment of the TT7 tunnel

The refurbishment of the TT7 tunnel will consist of cleaning and painting of the walls and floor, as well as of the repair of the floor in the target zone. The estimated cost is 40kCHF.

11. Electricity

The electrical installation will be divided into power converter supply for the new power converter building and general services for the power converter building and the decontamination cabin.

Power converters supply

A low-voltage switchboard has been defined by the PS/PO group. The switchboard will be installed in the new building for power converters and fed from a new 18 kV / 400V, 2 MVA transformer located outside the building. The transformer will be fed from the electrical substation No. 49 in Bldg. 193, using a spare feeder of the 18 kV switchboard EMD1*49.

The following equipment has to be purchased and installed:

- 400 V switchboard
  18 kV/ 400 V, 2 MVA transformer
  100 m of the 3 x 50 cm2 Cu 24 kV cable
  48 V distribution box
  19" rack
- auxiliary cables

General services

The lighting and power for the new power converters building will require the installation of a small 400V general services switchboard which will be fed from a low-voltage switchboard in the substation No.76, Bldg.366.
The lighting and power for the new decontamination cabin will be fed from the general service switchboard in the power converters building.

Cost estimate

Power converter supply

400 V switchboard for converters	52 kCHF
18 kV/ 400V, 2 MVA transformer	31 kCHF
48 V distribution box	1 kCHF
19" rack	1 kCHF
Transformer cabling	15 kCHF
Low-voltage switchboard installation	18 kCHF
General services	20 kCHF
Converter AC cabling	34 kCHF
Study	8 kCHF
Total:	180 kCHF

Planning

Equipment purchase – four months
Installation – eight weeks

Manpower

Engineer –	1 week
Technician –	4 weeks
Electrician –	4 weeks

12. Water cooling

Cooling of the magnets as well as the target will be assured by the demineralised water coming from LEAR station (Bldg. 234). This station produces 2.45 MW of demineralised water which corresponds to some 140 m3/h with ΔT=15 K (available pressure of 25 bar).

LINAC machines consume nowadays some 0.8 MW, therefore there is still 1.65 MW available for TT7 tunnel. The foreseen cooling demand for Neutrino project is the following:

185 kW	TT1 tunnel (at 24.0 GeV/c): 9 dipoles, 6 quadrupoles, 2 correctors
890 kW	TT7 tunnel (at 24.0 GeV/c): MDX(H,V), QTS(1,2), B340.1, B340.2, B340.3, BHN80, MDX(V), QTS(3,4,5)
10 kW	the target
2 kW	Magnetic horn

There is already a stainless steel pipeline inside TT7 tunnel but a connection with the existing distribution water network must be provided. A total length of some 140 m will be installed inside the TT1 tunnel and connected to the LEAR station.

The target and the magnetic horn will use the demineralised water only as a primary source of cold energy which will be used to cool down the secondary circuit (heat exchanger).

Budget

The total cost estimate for the supply of demineralised water to TT7 tunnel is given below:

- new stainless steel pipeline (140 m)	25 kCHF
- pressure reducing and by-pass valve	8 "
- cut-off valves, connections to the flexible pipes, etc.	2 "
- other	5 "
Total	50 kCHF

Remarks:
In case of higher cooling demand for LINAC's machines, the necessary missing cooling power could be supplied from Bldg. 355.

This cost estimate does not include secondary cooling circuits for the target and magnetic horn.

Manpower

Technician (study): 2 weeks
Technician (work-site supervision) : 4 weeks.

13. Ventilation

There are two zones that must be ventilated in order to maintain the indoor conditions of $t_{db} = 25°C$ and humidity < 60 %:

a) Part of TT7 tunnel to the shielding wall
b) TT7 tunnel behind the shielding wall + target cavern + decay tunnel

The first zone will be equipped with a new air handling unit which will replace the existing obsolete unit in TT1 tunnel. To the present ventilation ducts a new branch of ducts will be added in order to supply the air to TT7 tunnel. The "used" air will be then directed back to the unit (100 % re-circulation) via a transfer grill installed between TT7 and TT1 tunnels.

The foreseen modifications and cost estimate are as follows :

- replacement of the existing air handling unit in TT1 tunnel	25 kCHF
- new ducts for TT7 tunnel	15 "
- other	5 "

The second zone is already served by the air handling unit in Bldg. 366. This unit comprises the fresh air intake as well as an absolute filter allowing the recirculation and reject of the radioactive air coming from the target cavern.

However, the unit seems to be in a good condition. It will be necessary to make a complete revision and perform some tests (control and regulation system, state of the filters). Some modifications on the ventilation ducts will also be required.

For this zone the cost estimate is 10 kCHF.

Total 55 kCHF.

Remarks:

A new air handling unit must be installed while the existing shielding wall inside TT1 tunnel is dismantled.

This cost estimate does not include the replacement of the existing air handling unit in Bldg. 366. If the revision reveals that a partial or total replacement is necessary an additional cost will be added.

Manpower

Engineer (study): 3 weeks
Technician (work-site supervision): 4 weeks.

14. Vacuum

Layout parameters:
1) Beam pipe diameter = 140 mm
2) Length of the vacuum line =150 m
3) Number of vacuum sectors =1
4) Pumpdown time 1000 mbar to E-8 mbar =12 hours

Pumping system:
A standard solution with one pumping group (turbo + forepump) and six ion pumps (one every 25m) is proposed. Simple simulations have shown that using this configuration an average pressure of 2E-8mbar will be reached. A summary of all components is given in Table 4 below.

Objects	Price [CHF]	Quantity	Total [CHF]
Pumps			
Ion pump 400 l/s	8.100	6	48.600
Ion pump power suppl.	3.000	6	18.000
Ion pump control unit	7.000	2	14.000
Cable ion pump	10/m	6	?
Cable ion pump control	500	6	3.000
Turbo pump 600 l/s	10.000	1	10.000
Forepump	1.300	1	1.300
Control unit pump. group	3.000	1	3.000
Cable pump. group	10/m	4	?
Chassis pump. group	500	1	500
			Total Pumps: ~ 98.400 + cables
Gauges			
Penning	700	2	1.400
Pirani	700	2	1.400
Control unit TPG 300	1.000	2	2.000
Chassis	500	1	500
Cable gauge	10/m	4	?
			Total Gauges: ~ 5.300 + cables
Valves			
DN 160 CF	6200	2	12.400
Cable valve	10/m	2	?
Control valve	1.500	1	1.500
			Total Valves: ~ 13.900 + cables
Divers			
10 % on all control parts	~ 2.000	1	Total Divers: ~ 2.000
			Σ: ~ 119.600 + cables + reserve!

Table 4: Vacuum components needed for the TT7 neutrino beamline. Due to the fact that the position of the control room is not yet exactly defined the prices for cabling can only be given per meter. The price estimate is based on a control system between the "equipment" and the "equipment room" (not the control room).

15. Target and magnetic horn

The following estimate includes magnetic horn, motorized support , busbars to the power pulse transformer, local horn cooling water circuit with heat exchanger and local instrumentation.

Material Cost

Horn	180.- kCHF
Support (motorized)	70.-
Busbars	20.-
Water cooling circuit	30.-
Shielding	10.-
Instrumentation (local)	10.-
Tools (manipulation)	10.-
Target(Be rod and support)	20.-
Total Material	350.-kCHF

Industrial Support

Drawings	(1 draftsman x 2 months)
Mechanics	(2 mechanics x 5 months)

The power pulse transformer of 1981 beam will be reused.
All electrical components on primary side of pulse transformer are at the charge of the PS-PO group.

16. Radiation protection and access control

The installation of the neutrino experiment in TT7 will require the following :

The fencing around the mound at the top of the shaft must be repaired so that unauthorised access is not possible (normal fencing + locked gates). The shaft must be filled with concrete blocks (airtight) and the loading area alongside the shaft must be filled with blocks during operation of the facility.

The present entrance area (Bldg. 840/TT7) must be extended by a light building (~ 15 m2) that will be used for preparation of accesses to the target area (distribution of special dosimeters and special clothing, checking of contamination before leaving the area).

The present entrance area, the tunnel, the target area and the decay tunnel shall be refurbished (cleaning, painting of the floor and walls according to CERN standards, i.e. like other target areas at CERN (AD, ISOLDE)). The costs are already included in the cost estimate of Civil Engineering, see Ch. 10.

In order to evaluate the radiological risks involved in this job, RP has taken samples of different materials in the future beam tunnel and the target area. These samples were analysed by gamma spectrometry. Most of them reveal a specific activity that is well below the exemption limit. However, special care has to be taken if the old iron rails in the floor are to be dismounted. The specific activity level of the corresponding sample is 1.12 Bq/g for 60Co. That has to be compared with the exemption limit for this isotope of 1 Bq/g. Therefore, the rails must be considered as radioactive waste and sent to the conditioning center for radioactive material in the center of the PS ring. The cleaning of the zone will be surveyed by a RP technician who will ensure that all material leaving the zone is properly checked.

The radioactive material that is presently stored in the decay tunnel of TT7 has to be taken out, transported to and stored in a safe area. The same holds for the ancient neutrino horn that is still present in the target area. The amount of radioactive material is 400 m^3 stored in containers of 1 m^3. Presently, there is no charge made by the transport service for moving such material. If this changes, costs amounting to about 30 kCHF have to be reserved just for the transport. For the future storage of the material several solutions are under study and we hope to find the most cost efficient one. Presently, the construction of a new storage building is under discussion. After this construction, we might find space for the material of TT7 without additional costs. The worst case scenario, i.e. the construction of new storage space would require an investment of about 150 kCHF (750 CHF/m^2).

The ventilation system in the target area and the decay tunnel shall be separated from the one of the beam line tunnel. In addition, the ventilation system of the target area and the decay tunnel must be in a closed circuit. Estimates of the expected levels of radioactivity in the area are presently being made, but only the decay time to be imposed before access can be allowed will depend on the exact levels predicted. The specific activity in the air will be surveyed when the ventilation is in its closed cycle mode as well as in its release mode (radiation monitors for the ventilation system).

The cooling water system of the horn shall be a closed circuit. In particular it is not permitted to drain off the water without a previous control of its specific activity.

The RP surveillance system for the experiment will use several monitors and the total costs for this installation will amount to 90 kCHF.

Summary:

The costs due to the demands of radiation protection are already partially taken into account by Civil Engineering. Depending on the circumstances, the rest of the costs will range between 90 kCHF (minimum, only monitoring) and 270 kCHF (including worst case scenario for the storage of the radioactive material).

Access control

The TT1 and TT7 areas will be part of the present TT2 primary zone, while the target/horn area will be considered as a separate primary zone.
The total cost of the installation will be 210 kCHF ,which added to 270 kCHF bring the total cost for the radiation protection to 480 kCHF.

17. Controls

Almost all the controls for magnets and instrumentation will be located in the PS-MCR using a standard interface made by 3 DSC's, net, CATV, NAOS, etc.
The total cost will be about 150 kCHF.

18. Experimental Area

Buildings 181 and 182 for the location of the "near and far detectors" are essentially still available. The underground of Bldg. 181, where the "near detector" will be located, is presently occupied by pillars supporting the floor where LHC magnets are being tested. These pillars could be replaced by horizontal beams in order to free the underground space. Cost estimate : 50 kCHF.

19. Survey

Survey activities are foreseen as following :

- installation of a reference frame
- tracing of the beam and the various elements
- alignment of about 30 elements
- alignment of the target and horn

All these activities should be executed by a team of three persons (one of these for the follow-up of the project and the calculations).

The total cost is essentially manpower: 0.5my

20. Summary and Conclusion

In Table 5 there is a summary of the cost list.

This is not a design report, but a preliminary feasibility study. Many items should be revisited (e.g. target cooling), some costs could not be precisely quantified (e.g.. : cabling, manpower, etc.) and some have probably been forgotten.

However,

1) the project is technically feasible ;

2) taking into account a contingency of ~15%, the total cost should be less than 5 MCHF.

3) the installation time should last about two years overlapping a normal PS shutdown.

Item	Cost (kCHF)
Beam line installation (vacuum ch., machanics	420
Instrumentation	350
Power converters	1110
Civil engineering	485
Electricity	180
Water cooling (for magnets)	50
Tunnel ventilation	55
Vacuum	120
Target and horn	350
Radiation protection and access control	480
Exp. Area (Bldg 181 modif.)	50
Controls	150
Subtotal	**3800**
Manpower (industrial support) approx.	400
GRAND TOTAL	**4200**

Table 5 : Cost summary

Acknowledgements

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