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FEASIBILITY STUDY OF A NEUTRON TIME OF FLIGHT FACILITY AT THE CERN-PS

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This report summarises the feasibility study of a neutron time-of-flight facility at the CERN-PS as described in Refs. [1] and [2]. The idea is to extract at 24 GeV/c proton bunches (r.m.s. length ~7 ns) onto a target. The neutrons produced by spallation are directed to an experimental area located 230 m downstream through a vacuum pipe (diameter ~80 cm) making use of the existing TT2A tunnel about 7 m below the ISR tunnel.

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Introduction

This report summarises the feasibility study of a neutron time-of-flight facility at the CERN-PS as described in Refs. [1] and [2]. The idea is to extract at 24 GeV/c proton bunches (r.m.s. length ~7 ns) on to a target (a lead block of 80×80×40 cm). The neutrons produced by spallation are canalised to an experimental area located 230 m downstream throughout a vacuum pipe (diameter ~80 cm) making use of the existing TT2A tunnel about 7 m below the ISR tunnel (see Fig.1).

The report only concerns the initial phase of this project, the so-called "1st year test phase" which differs from the "final phase" essentially in the proton beam intensity requirements. In the "1st year test phase" only one bunch of $0.5\text{-}0.7 \cdot 10^{13}$ p/bunch will be extracted at 24 GeV/c (or 19 GeV/c). In the 'final phase" four bunches with total intensity of $2\text{-}3 \cdot 10^{13}$ p/pulse will be extracted, one every 50 ms, at 24 GeV/c.

The initial phase does not require any modification in the PS machine, while the final phase requires important modifications in the power supplies of the fast extraction elements (septum magnet, bumps, etc.) as well as a more refined cooling system for the lead target.

PS beam requirements

2.1 Initial phase

As described in the introduction, the proton beam characteristics of the single bunch, required in the "initial phase" are:

Number of protons: $N_b = 0.5\text{-}0.7 \cdot 10^{13}$ p/bunch
r.m.s. bunch length: $\sigma_t \sim 7$ ns
One cycle / 14.4 s

The single bunch will be obtained by accelerating the beam in only one of the four PS Booster ring working with a RF harmonic number $h = 1$. The estimated longitudinal emittance will be $\varepsilon_l \sim 1.6$ eVs. Injection will take place at 1.4 GeV into the PS machine with a RF at $h = 8$, filling only one bucket. The incoherent space charge tune shift will be $\Delta Q_H \sim -0.2$ and $\Delta Q_V \sim -0.3$. These can be considered acceptable values as some transverse emittance blow-up, of about 20-30%, can be tolerated. Transverse head-tail instabilities will be controlled with chromaticity tuning (negative below and positive above transition), transverse feedback, octupoles and *H-V* coupling. A controlled longitudinal blow-up with the 200 MHz cavity system will be adjusted to minimise longitudinal instabilities. The expected resulting longitudinal beam parameters at 24 GeV/c ($V_{RF} = 200$kV, $h = 8$) will be:

$\varepsilon_l \sim 3$ eVs
$\sigma_t \sim 14$ ns
$\sigma_p/p \sim 0.8 \cdot 10^{-3}$

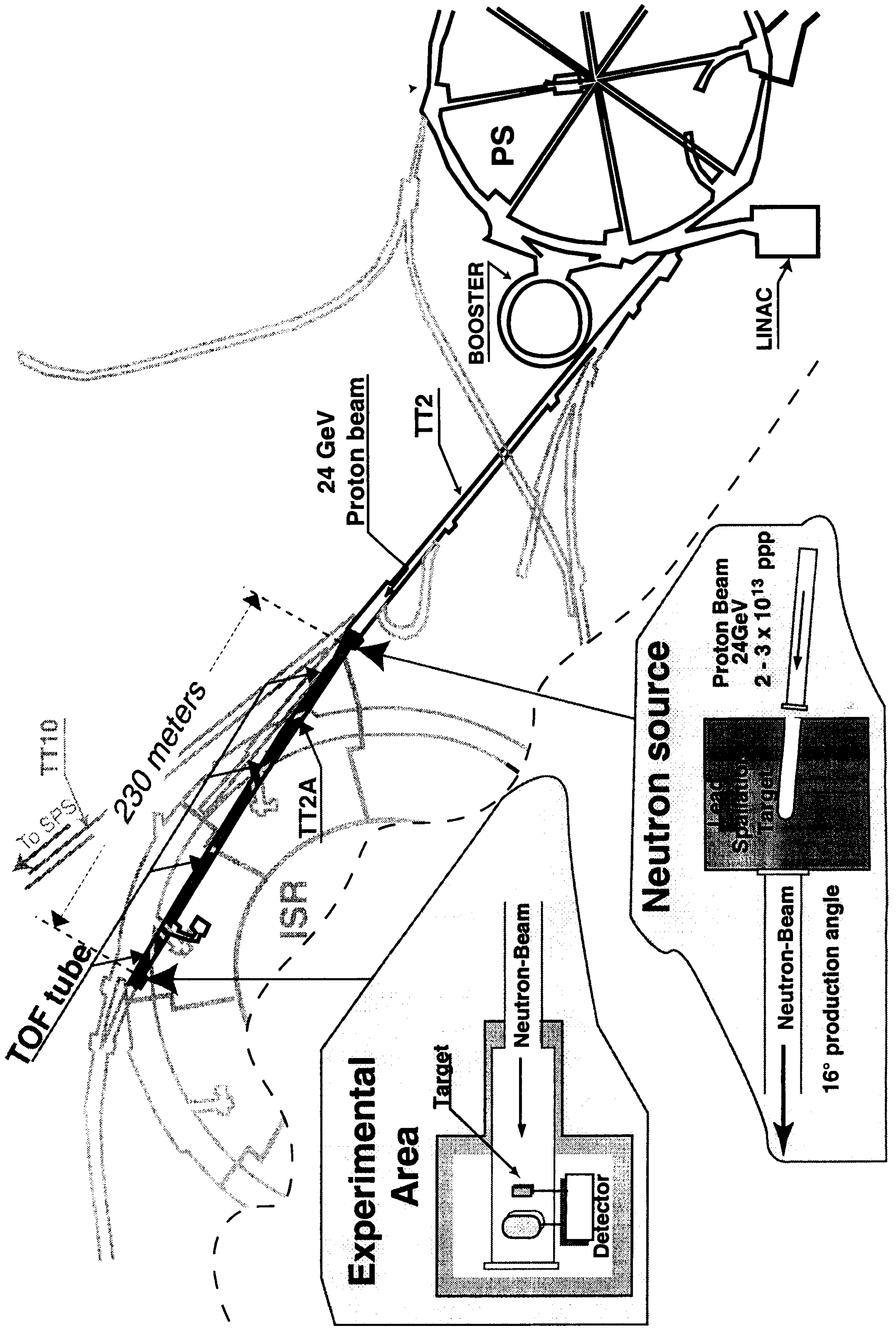
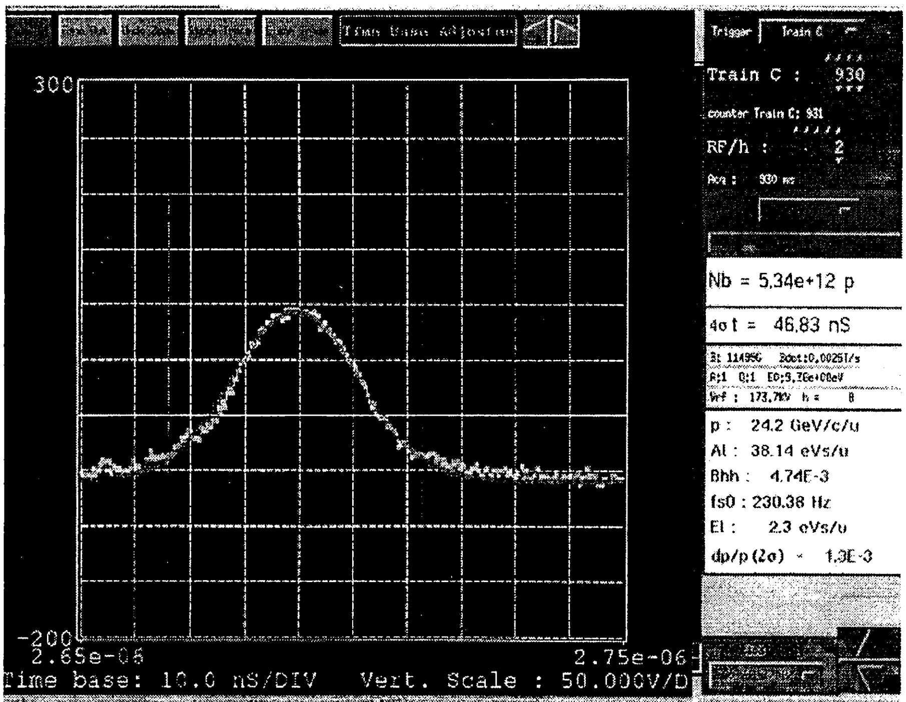


Figure.1: General layout of the experiment. The proton beam is extracted through the TT2 transfer line and hits the lead spallation target (Neutron source). After the TOF tunnel (TT2A) neutrons are detected in the Experimental Area, about 230 m from the primary target.

A bunch compression with a phase jump gymnastics will reduce, just before the extraction, the bunch length to the required value of σ_t ~7 ns. The corresponding increase of the r.m.s. momentum spread to σ_p/p ~1.6 · 10^{-3} will be still acceptable by the transfer line total momentum acceptance of ~ 8 · 10^{-3}.

Recent preliminary tests have already produced bunches with parameters close to the required ones, see Fig. 2a,b.

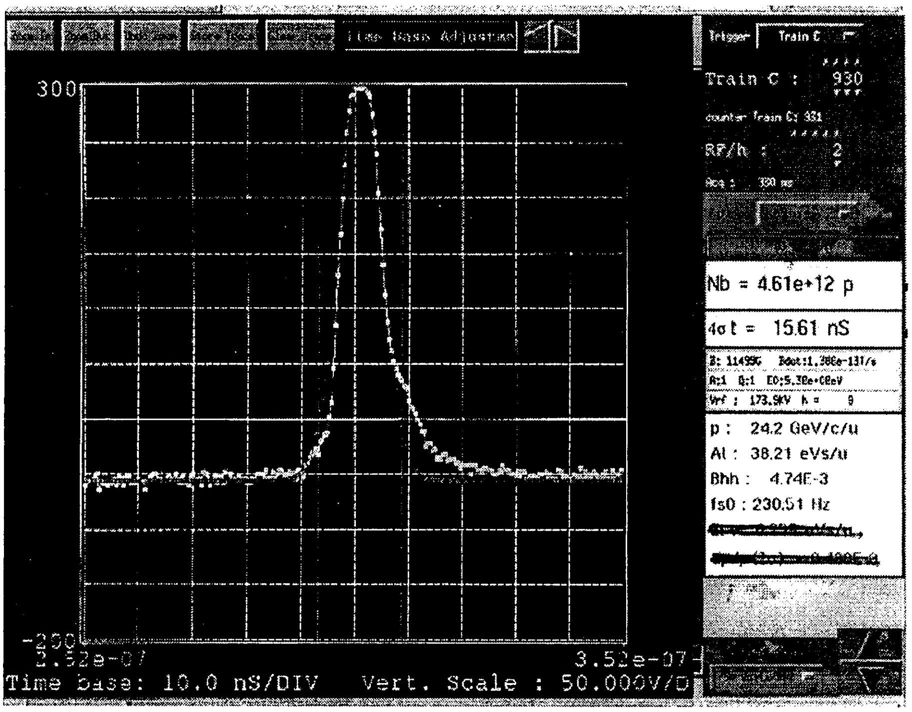


Time base: 10.0 nS/DIV Vert. Scale : 50.000V/D

Train C : 930
counter Train C: 931
RF/h : 2
Acq : 930 ms

Nb = 5,34e+12 p
4σt = 46,83 nS
B: 11495G Bdot:0,0025T/s
A:1 Q:1 E0:9,38e+08eV
Vrf : 173,7kV h = 8
p : 24.2 GeV/c/u
Al : 38.14 eVs/u
Bhh : 4.74E-3
fs0 : 230.38 Hz
El : 2.3 eVs/u
dp/p (2σ) ~ 1.3E-3

Figure 2a: A proton bunch of 0.5 10^{13} p/bunch at 24 GeV/c before bunch rotation. The r.m.s. bunch length is ~12 ns and ε_l =2.3 eVs (time base: 10 ns/div).



Time base: 10.0 nS/DIV Vert. Scale : 50.000V/D

Train C : 930
counter Train C: 931
RF/h : 2
Acq : 930 ms

Nb = 4.61e+12 p
4σt = 15.61 nS
B: 11495G Bdot:1,388e-13T/s
A:1 Q:1 E0:9,38e+08eV
Vrf : 173,9kV h = 9
p : 24.2 GeV/c/u
Al : 38.21 eVs/u
Bhh : 4.74E-3
fs0 : 230.51 Hz
[redacted]

Figure 2b: The proton bunch after the bunch rotation in phase space. The r.m.s. bunch length is ~4 ns (time base: 10 ns/div).

2.2 Final phase

The intensities for the "final phase" are subject of the results of the "initial phase". Note that after the initial phase, a possibility to increase the average number of proton to the target, which does not require any machine modifications, is to increase the number of cycles / supercycle at the expense of other users. Moreover other technical solutions without major hardware modifications could also be studied.

The solution proposed in [1] requires that the four rings of the PSB will be used to inject the four bunches into four of the 8 PS RF buckets. During the acceleration up to 24 GeV/c, problems can be expected with transverse and longitudinal coupled bunch instabilities. A phase-jump gymnastic, for bunch compression, has to be performed at each of the 4 extractions spaced by 50ms. A counter-rotation, that is a "reverse" phase jump [3], has to be performed each time to avoid phase-space filamentation of the remaining circulating bunches. The last bunch is expected to be slightly longer than the first one. Spacing the fast extractions of each bunch by 50 ms requires also important and expensive (~2 MCHF) modifications [4] in the low-level electronics of the fast kickers and in the power supplies of the septum, bumps, kick enhancement bumps and orbit correction dipoles.

The proton beam line set-up

3.1 Layout of the line

The new transfer line will be connected to the FT12 transfer line just downstream of the QDE380 quadrupole, see Fig.3. The proton beam is bent by 6 degrees to the right of the dump D3. Such a deflection is sufficient to avoid the dump. The position of the lead target is foreseen in front of the door separating the TT2 transfer line and TT10. The deflection will be produced by mean of three MCA bending dipoles, each providing a 2 degrees bending angle.

Two power supplies, previously used for the dump target D2, will be connected to the three bending magnets: the first bending will be powered alone, while the other two will be connected in series. A QFS quadrupole will be installed downstream of the bending magnets. It will provide the necessary focalisation to the beam and it will be connected in series with the string of focusing quadrupoles already present in the TT2 line.

Further downstream, two beam stoppers will be installed for an overall length of 3.2 m. A fast solution is to install the beam stoppers in air. The vacuum pipe will be terminated just upstream the two beam stoppers by means of a 100 μm thick aluminium window. Another section of vacuum pipe terminated with aluminium vacuum windows at both ends will be installed downstream of the beam stoppers. The aim of this section of beam pipe is to avoid activation of the air due to the passage of the high intensity beam. The multiple Coulomb scattering produced by the passage through the vacuum windows and the air gap should generate an emittance blow-up $\Delta\varepsilon_{H,V}$ of ~60%. The increase of beam size at the target location should not affect the neutron production. Later on, equivalent beam stoppers in vacuum may replace the present ones.

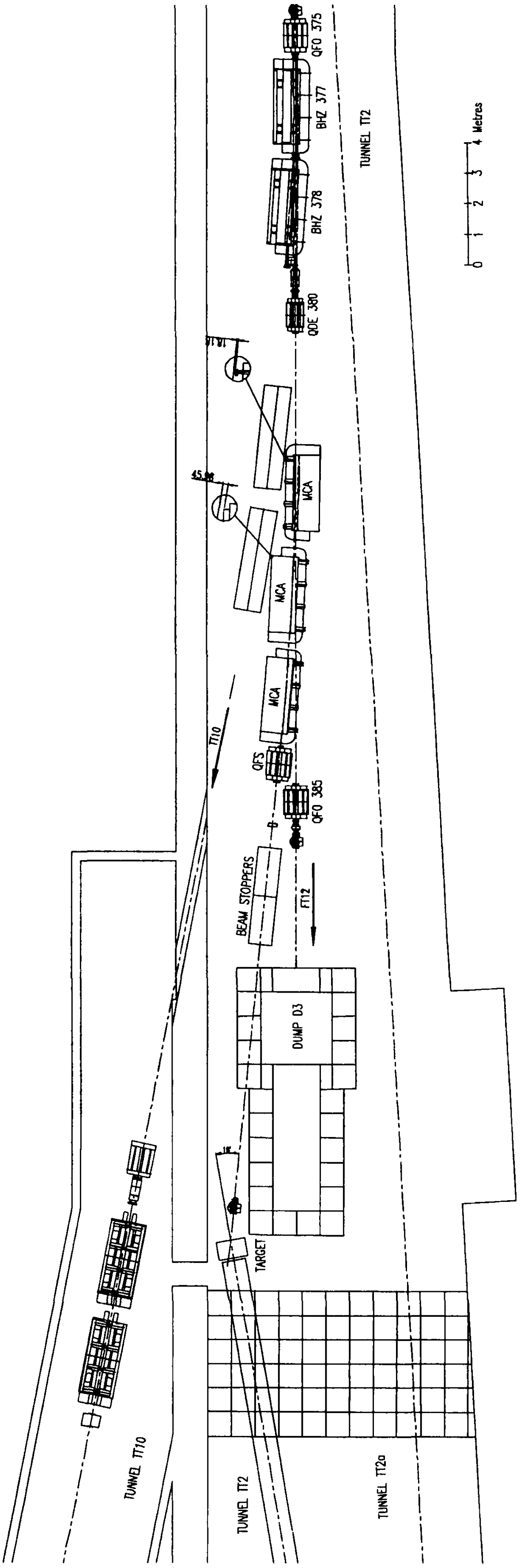


Figure 3: Layout of the new transfer line to be installed in the TT2 tunnel.

3.2 Instrumentation

A beam current transformer similar to the one installed in the FT12 line, should be installed between the quadrupole and the beam stoppers and a scintillation screen just in front of the lead target block. A wide band resistive wall pick-up should provide a bunch shape monitor.

The implementation of the new transfer line will have an impact on the existing FT12 transfer line towards the dump D3. The QFO385 quadrupole will have to be moved further downstream in order to allow the installation of the three bending magnets. Moreover, the instrumentation already present in this transfer line will have to be moved towards the dump.

Table 1 shows the list of hardware to be installed in the new transfer line.

	Description	Availability	Comments
Beam Transport	Three MCA dipoles	In stock	Max. deflection 2 degrees @ 26 GeV/c.
	One QFS quadrupole	In stock	Powered in series with the focusing string
	Vacuum chamber	To be built	
Beam Instrum.	Beam current transformer	To be purchased	Same as the one installed in FT12 line
	Scintillation screen (with TV camera)	To be purchased	Same as the one installed in FT12 line
	Wide Band pick-up	To be built	
Safety	Two beam stoppers	In stock	In air (1999)
		To be built	In vacuum (>1999)

Table 1: List of hardware to be installed in the TT2 tunnel.

3.3 Beam optics

The starting point is the standard optics for the fast extracted LHC-type beam delivered by the PS [5]. The final trimming of the beam size on the lead target has been obtained by using the strength of the QFO375 quadrupole and the position of the additional quadrupole installed in the new transfer line. With this approach, the new quadrupole does not need an independent power supply: it will be powered in series with the string of focusing quadrupoles of the TT2 transfer line. This solution should not have any impact on the pulse-to-pulse-modulation (PPM) capability of the power supply. In Table 2 are reported the beam parameters used for the computation of the beam envelope, together with the beam size on the target. In Fig. 4 are shown the optical parameters, β- and dispersion function D, of the transfer line and the evolution of the horizontal and vertical beam envelope.

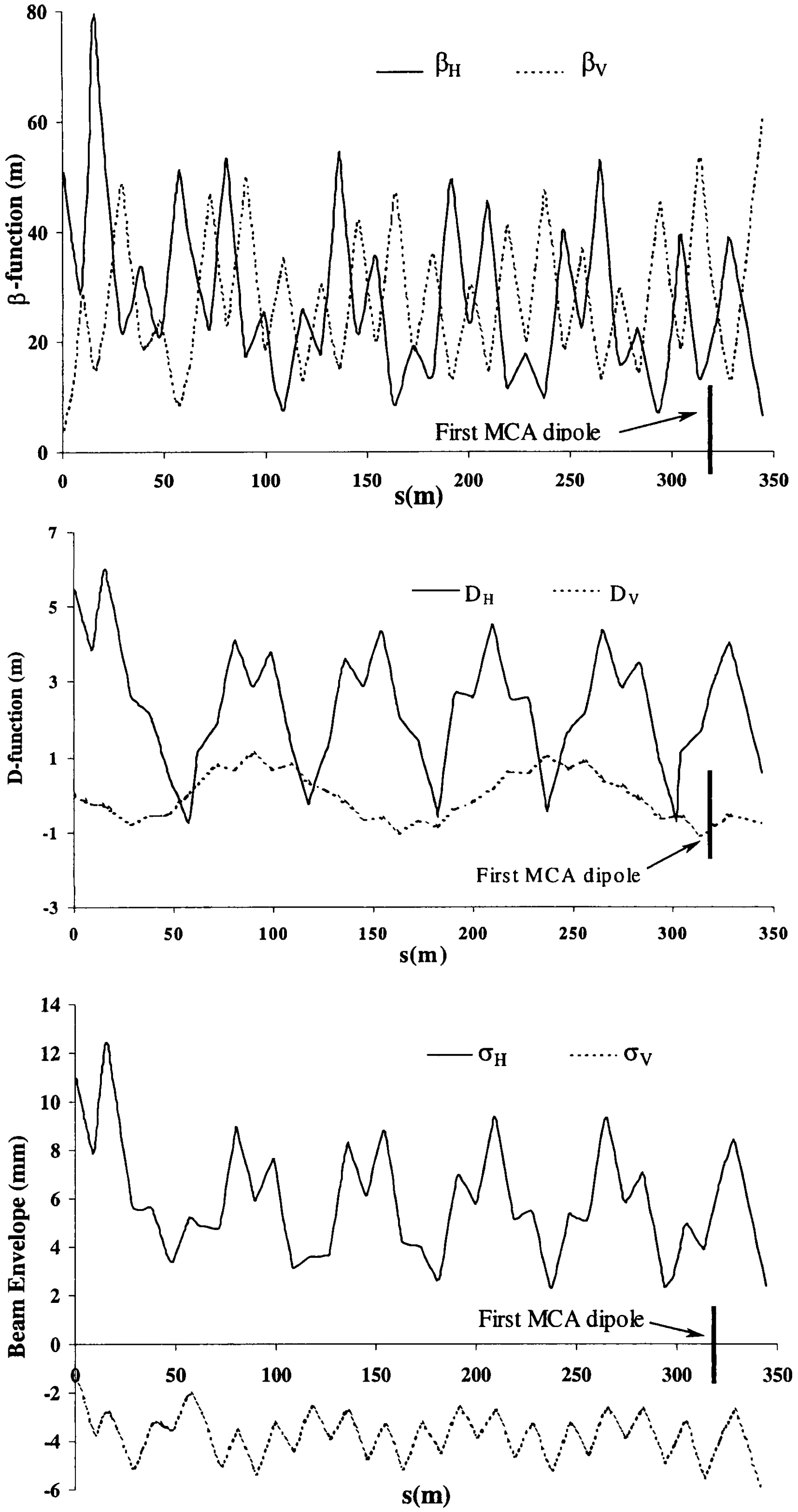


Figure 4: Optical parameters of the TT2 line from QFO105 to lead target.

Transverse Parameters		Longitudinal Parameters		Beam size on target	
$\varepsilon_H(1\sigma)$ [µm]	0.5	σ_p/p	2×10^{-3}	$4\sigma_H$ [mm]	10
$\varepsilon_V(1\sigma)$ [µm]	0.5			$4\sigma_V$ [mm]	25

Table 2: Beam parameters used for beam envelope computation and beam size on the target (including the emittance blow-up due to multiple Coulomb scattering).

Due to the modification on the location of the QFO385, the impact on the optics of the different beams sent to the dump D3 has been evaluated. The new position of the QFO385 quadrupole generates beam parameters at the dump location, which are comparable with the previous situation. However, it is foreseen to replace the section of the beam pipe downstream the scintillation screen with a new section of increased diameter.More details on these issues can be found in Ref. [6].

Lead target

The neutron production target is made of a lead block of 80×80×40 cm. About half of the 2 kW "initial phase" beam power will dissipate into the block and will require a moderate filtered air-cooling (closed circuit). With a surrounding temperature of ~20^0C the inner temperature will be ~60^0C. For the "final phase" beam (4 times the power) a more powerful cooling system is under study.

Various thermocouples will measure the target temperature to monitor any unwanted temperature increase.

Concrete blocks for radiation protection will surround the target region.

Neutron beam line set-up

The 230 m long beam pipe starting with a diameter of 80 cm, see Fig.5, will be at 16 degrees with respect to the proton beam direction in order to minimise the collection of unwanted secondary particles. Between the beam pipe and the output face of the lead target there is a gap of ~15 cm of air to facilitate the installation of the target cooling. The stainless steel vacuum window will be 3mm thick to avoid breakage. The stainless steel 304L pipe is made of 6 sectors connected by vacuum flanges. Each sector is made of various pieces welded together. Along the 230 m the diameter varies as shown on Table 3 .

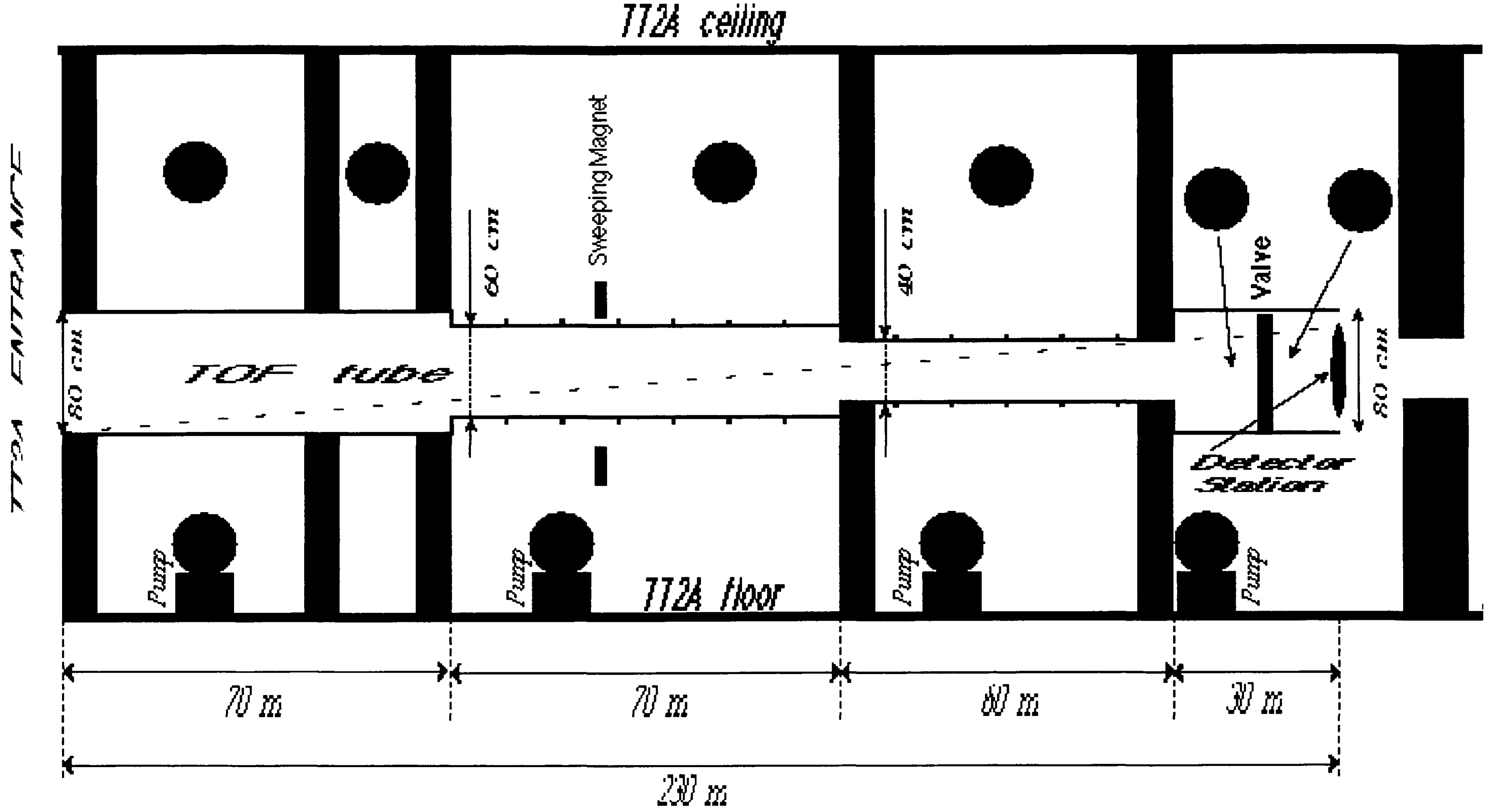


Figure 5: Schematic view of the TOF tube.

sector number	length [m]	ext. diam. [mm]	thickness [mm]	flange type in/out
1a	7.5	812.8	8.0	DN800/DN800
1b	62.5	812.8	8.0	DN800/DN630
2	70	609.6	6.0	DN630/DN400
3	60	408.0	4.0	DN400/DN400
4a	27	812.8	8.0	DN400/DN800
4b	3	812.8	8.0	DN800/DN800

Table 3. Mechanical dimensions of the various sectors of the vacuum chamber.

The variable diameters will allow collimation of the neutron beam at various places as shown in Fig. 5.

A DN800 vacuum valve will be installed between Sectors 4a and 4b (see following chapter on vacuum). The "last window" at the end of sector 4b will be a fast open vacuum door to install the sample under study (neutron capture, fission, etc.) with associated detectors and electronics.

In Sector 2, a (permanent ?) bending magnet, with an integrated field of ~1Tm, will eliminate the secondary charged particles coming from the lead target.

After the detection station, a special area of ~3 m length with concrete shielding and neutron chicanes is foreseen for trapping the neutrons and protect the detection station from back-scattered neutrons.

Vacuum

The required vacuum pressure of 1 millibar will be obtained in ~10 hours, by installing in each of the first five Sectors, 1a to 4a, a single stage 16 m^3/h primary pump. In the last Sector 4b, a 500 m^3/h pump will reduce the pumping time to few minutes, to minimise waiting time and beam time.

Civil engineering

As the TT2A tunnel is not a straight line, to maximise the length of the vacuum pipe it will be necessary to drill a ~21 m long tunnel of a diameter of ~1 m, through the wall between the ISR part of TT2 and TT2A (see Fig. 6).

Other interventions will be:

i) Drilling of a 20 cm hole, 4 m long, through existing shielding blocks in D3 dump, for the proton beam to the lead target.
ii) To arrange the area nearby the lead target: a) cutting a corner in the present door between TT2 and TT10, next to D3, to provide more space; b) opening of a new door (80 cm wide) in the TT2-TT10 wall, 2 m upstream the present one which will be filled with shielding.
iii) Construction of airtight concrete cave enclosing the target.
iv) Construction of a similar airtight cave on the TT2A side of the shielding wall, to house the condenser of the target cooling circuit.
v) Some yet undefined modifications for the counting room

Heavy handling and transport

i) Dismantling and rebuilding the 5 m wall between TT2 and TT2A to allow the passage of the 80 cm beam pipe as well as the air cooling pipes of the lead target.
ii) Installation of various equipment (bending magnets, quads, beam stoppers, lead target, etc.) on the PS side of the TT2 line as well as some minor modifications in the shielding blocks around D3.
iii) Retrieval of existing concrete blocks around the CERN site and installation of these blocks for the beam pipe supports as well as five collimator walls in TT2A.
iv) Removal of TARC lead blocks presently stored in TT2A.

Cooling and ventilation

Again to maximise the length of the vacuum pipe and as the TT2A tunnel elevation is rising in the last part and to provide the installation of the shielding downstream the experimental area, it will be necessary to remove part of the obsolete ventilation ducts in the ceiling of TT2A.

The air cooling system of the lead target will require the installation of a 10kW water-cooled condenser downstream the TT2-TT2A wall.

Access control

No modifications will be required in the present access control system concerning the TT2 line (from the beginning of TT2 up to the shielding wall). This area will stays as it is now a ''primary zone'' with limited and MCR controlled access.

NB: <u>Access to this TT2 area (e.g. lead target) implies turning off all the beams having the SPS or AD as destination. Consequently access will only be possible during the scheduled machine shutdown or in case of major failure periods.</u>

Concerning TT2A, the tunnel will be divided in two parts (see Fig.6):

- The first part, from the entrance door A1 to door A2, will be considered as a secondary beam area and thus integrated in a PS Secondary Beam Access Control System (one access point -PPE A1- and one ''end of zone'' grid -PPX A2-). The access to this area will be under control and responsibility of the experimental team. Any normal access procedure to the first part of TT2A requires to turn off the power supplies of the three MCA bending magnets and to insert the two beam stoppers in the TT2 beam line. Consequently the proton beam will not hit the lead target anymore and will be sent on the D3 dump.

- The second part delimited by the three access doors and one grid (cableway): A2, A3, A4 and G1 will be considered as a PS Primary Beam Area without access facilities (no access point). The doors and the grid will be permanently locked once the area is empty. An emergency exit system will be available on each door and on the grid.

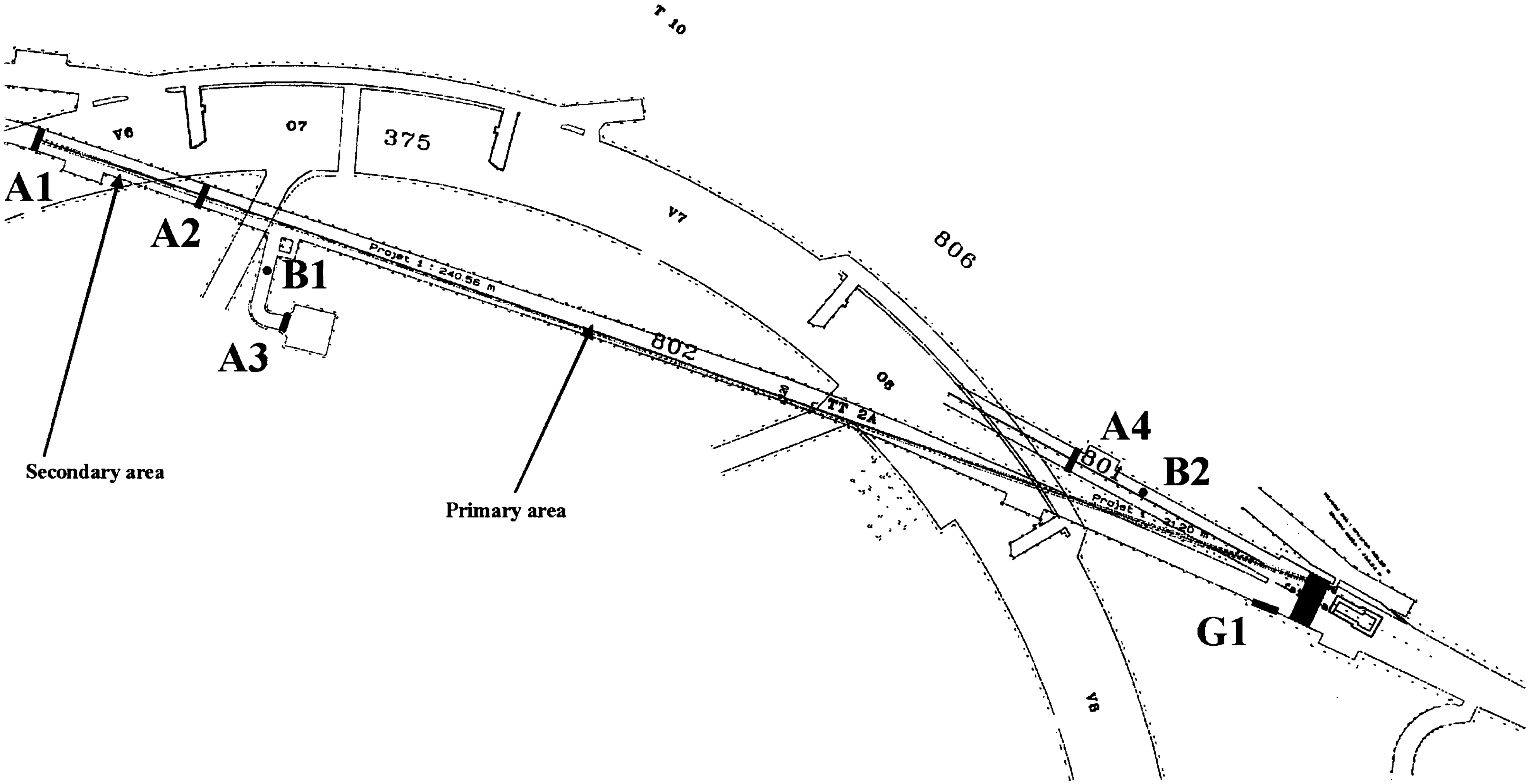


Figure 6: Top view of TT2A tunnel with neutron beam pipe position.

Any planned access to the second part (occasional in this area, for example vacuum problems) requires turning off the power supplies of the three MCA bending magnets and to insert the two beam stoppers in the new transfer line towards the lead target. To enter the area, the access will be given only through the PPX A2 grid (using one unique and specific key usually located in MCR). At the end of the intervention, the search of the area will have to be made by specialised personnel, e.g. MCR operators in charge of "arming" the "search boxes" B1 and B2 and locking all doors.

NB: Any emergency procedure (door forced) from/to the first or the second part of TT2A implies stopping the extraction of the beams in the TT2 tunnel, turning off the power supplies of the three MCA bending magnets and inserting the two beam stoppers in the TT2 beam line.

The A2 door should be made airtight to separate the ventilation between the two parts of the TT2A tunnel.

For industrial safety, not for radiation, the vacuum valve between sector 4a and 4b will close at each access in TT2A.

More details on radiological issues can be found in Ref. [7]. These include radiation levels around the target, in the TT2A tunnel and in the ISR sectors above TT2A, activation of the air in TT2 and TT2A as well as activation of the target.

Cost and time schedule

A preliminary cost estimate list is shown in Table 4. The total work planning can be divided in two parts.

The first part concerns essentially the proton beam line modification, the drilling of the hole in the TT2 shielding wall and the lead target installation in the TT2 tunnel. As this area is inside the PS machine, these activities must completed during the annual machine shutdown (about three months from December to March). The second part, dealing with the vacuum pipe and the experimental area installations in TT2A, can be done, in a period of about five months, in principle at any time during the year. The two parts can be executed in different order.

PRELIM. COST ESTIMATE (kCHF)		1st part	2nd part	Σ
Handling & transp.	Dismant. and rebuild. of 4.5 m wall	15		
	Inst. concrete blocks for shield. & support		45	
	Retrieval blocks around CERN		15	
	Subtotal	**15**	**60**	**75**
Target area	Target ventilation	30		
	Blocks, doors, support, etc.	30		
	Subtotal	**60**		**60**
Access Control	Cables		45	
	Electronics, doors, grids, etc.		130	
	Subtotal		**175**	**175**
Civil engineering	TT2-TT2A Tunnel excavation (20 m, 1 m)		200	
	Drill. 20 cm hole, 4 m long in concr. blocks	10		
	TT10-TT2 new door and wall mod.	20		
	Counting room modif.		20	
	Subtotal	**30**	**220**	**250**
TT2A vacuum Pipe	Pipe 60x0,4+70x0.6+100x0.8 meters		100	
	Supports		40	
	Vacuum conn. 10x		5	
	Windows		20	
	Welding		90	
	Preparation		30	
	Perman.magnet		50	
	Subtotal		**335**	**335**
Vacuum	Pumps 5x16 m^3/h		30	
	Pump 1x 500 m^3/h		50	
	Valve 1xDN800		75	
	Measurment, interlock,ctrl, manpow.,etc		20	
	Cables		15	
	Flanges + fab.		40	
	Subtotal		**230**	**230**
TT2 Instrumentation	Screen, TV	40		
	Transformer	25		
	Pick up + cable	35		
	Subtotal	**100**		**100**
TT2 beam line	Beam stoppers 2x		130	
	Beam pipe Y	150		
	Transport, cables,etc.	30		
	Subtotal	**180**	**130**	**310**
Counting room	Electricity		50	
	Wall		20	
	Climat.		20	
	Pipe end		20	
	Subtotal		**110**	**110**
Cables	Magnets, timings, radioprotection,..	50		
	Subtotal	**50**		**50**
	GRAND TOTAL	**435**	**1260**	**1695**

Table 4: Cost estimate.

Conclusions

The project is technically feasible.
The cost is estimated to be ~1.7 MCHF, without contingency.

Starting the work in TT2A (2nd part) in April 1999 and completing the work in TT2 (1st part) during the 1999-2000 shut-down, the experiment could take data starting from April 2000.

Acknowledgements

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