EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

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CERN-ECP-95-14

CERN - ECP / 95-14
31 July 95

# The West Area Neutrino Facility for CHORUS and NOMAD experiments ( 94 - 97 operation )

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**Abstract**

This report describes the CERN West Area Neutrino Beam line as reconstructed for the CHORUS and NOMAD experiments and provides the users with all basic hardware information.

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# Contents

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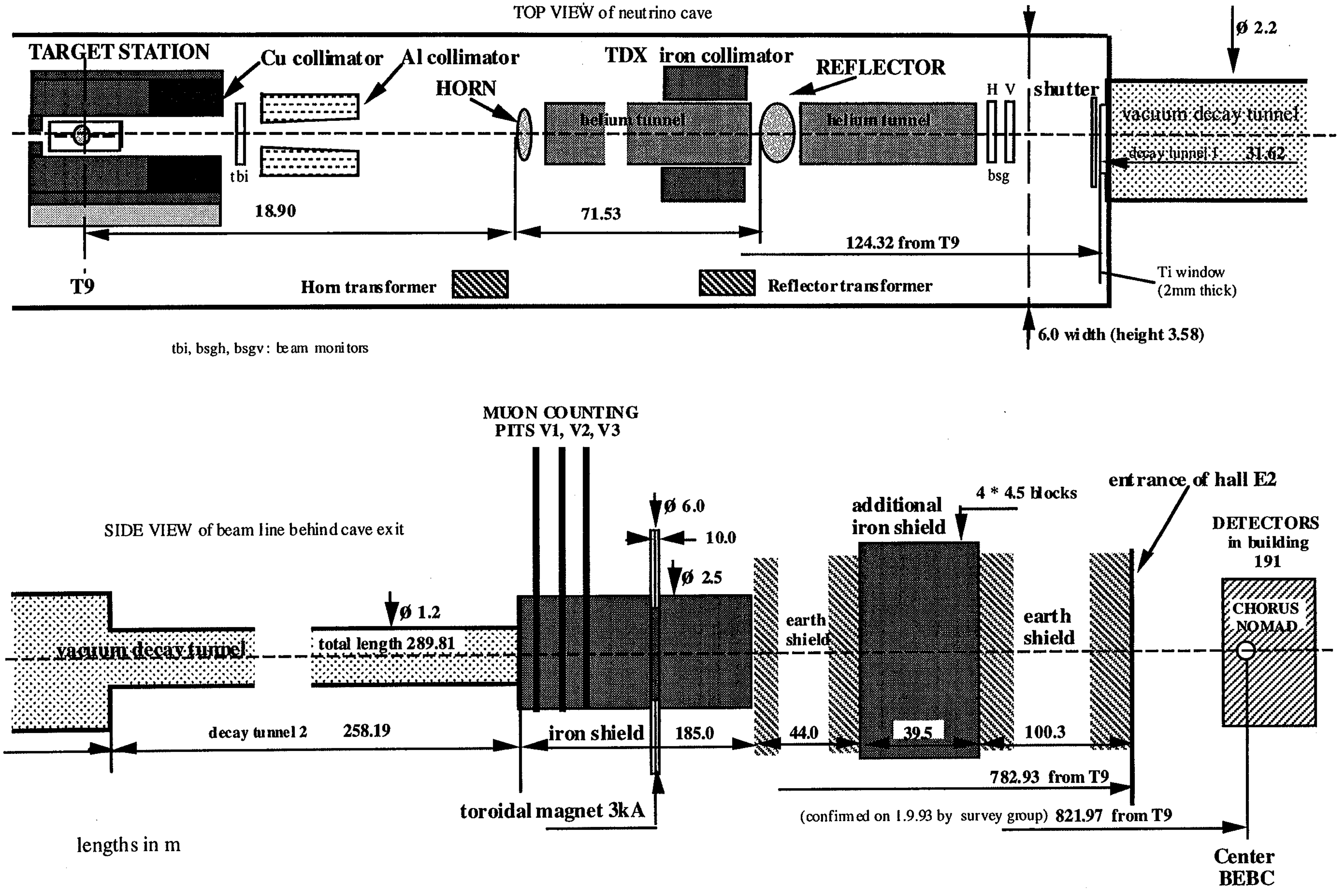



J.M. Maugain / ECP-EDN 9 october 92 (reference CERN 83-06 / H. Heijne)

[ c1 ] GENERAL LAYOUT of the NEUTRINO BEAM for the CHORUS and NOMAD experiments

[ c1 ] General layo

# Introduction

We describe the layout and all major items along the Neutrino Beam line for CHORUS and NOMAD. The reader will find in [1] the fundamental study of the " Neutrino Flux Monitoring" system which is still in use today, but in a reduced version, and many theoretical and pratical informations .

# 1. Beam layout of West Area neutrino Facility

## 1.1 Main geometrical data of WANF

The attached general layout [c1] of the neutrino beam for CHORUS and NOMAD experiments permits to list following data table :

| | |
|---|---|
| NEUTRINO CAVE<br>( T9 target to decay tunnel window ) | 124 m |
| DECAY TUNNEL | 290 m |
| IRON SHIELD | 185 m + 39.5 m added |
| EARTH SHIELD | 144 m |
| AIR | 50 m |
| T9 to center of BEBC<br>( T9 is the center of target) | 822 m |
| ========================================= | |
| T9 to center of CHARM II | 887 m |
| ========================================= | |
| T9 to center of CHORUS | 822 m |
| T9 to center of NOMAD | 838.5 m |

The target is a sequence of 11 Be rods of 3mm diameter, 100 mm long , 90 mm apart (corresponds to 2.7 $\lambda$). Point T9 is the center of the target.

( note of V. Palladino, 24/3/93 -SPS $\nu$ WBB optimization for $\nu_\mu$ to $\nu_\tau$ )

## 1.2 History of West Area Neutrino Facility

In this section, we recall the evolution of the neutrino beam since the start of the SPS operation: a precise description of the beam in the 70's and beginning of 80's can be found in [1].

The WANF area came into operation in Dec. 76 with the start of the SPS.
Until 84, two beams were run alternatively: WIDE BAND on T9 target and NARROW BAND on T11 target. The narrow band beam operation stopped in 84. The corresponding magnets were taken out of the cave in 86 and stored.

| In this period 76 till end 84, the beam is focused with horn at 100 kA + 2 reflectors at 120 kA |
|---|

**1976 >>>>** 350 Gev/c protons are used for neutrino operation,
330 Gev/c protons for antineutrino operation.
**Horn is in position A.**
**Two reflectors are in position A and B.**
Beam entry face of horn is 3.14 m from T9 .
Waist is close to beam exit face.

>>>> high flux ν beam

**in 1979** **Shielding magnet and additional 39.5m iron shield are installed** (see general layout).

Operation continues with 400 Gev/c protons.

**end of 1981** **Additional iron is installed in dump cave V0.**
**Horn is in shifted downstream by 7.95 m in position**

**Horn is in position B.**
**Two reflectors are in position A and B.**
Beam entry face of horn is 11.09 m from T9 .
Waist is close to beam exit face.

>>>> higher energy ν beam

Operation continues with 400 Gev/c protons until end 84.

| From now on til 15th of August 91, the beam is focused for CHARM II with horn at 100 kA + 1 reflector only at 120 kA |
|---|

**in 1985** **Downstream reflector is taken out.**

**1985 >>>> CHARM II** **Horn is in position B.**
**One reflector only is in position A.**
Beam entry face of horn is 11.09 m from T9.
Waist is close to beam exit face.

>>>> high ν flux beam optimized for $\nu_\mu$ e scattering

Operation continues with 450 Gev/c protons until Aug

| Since December 93 and after dismantling and refurbishment of the cave, the beam is focused for CHORUS and NOMAD with horn at 100 kA + 1 reflector only at 120 kA |
|---|

**1994 >>> CHORUS + NOMAD** **horn is shifted further downstream by 7.81 m**
**reflector is placed in downstream position B.**
**63 m helium tube is inserted in cave along the beam.**
Operation is done with 450 Gev/c protons
Beam entry face of horn 18.90 m from T9
Waist is close to beam exit

>>>> higher energy ν beam optimized for $\nu_\tau$ detection

### 1.3 Flux and rates

( extracted from V. Palladino's note of 24. 3. 93: SPS - νWBB optimization for $\nu_\mu$ to $\nu_\tau$)

From this note we extract following estimates, with values averaged per $10^{13}$ protons. They are calculated using the GBEAM neutrino beam simulation program developed inside the CHARMII collaboration.

CHARM II

- the distance of CHARM II from T9 is 887 m with detector size 3.2 * 3.2 $m^2$ area.

The calculated flux is 1.3 * $10^{10}$ ν $m^{-2}$ or 0.13 EVENTS /TON (total cross section events) and is in agreement within 5% with the measured value. The average neutrino energy measured in the experiment was about 23.8 Gev while a 25.6 Gev average ENERGY <Eν> is predicted by GBEAM. The discrepancy is probably due to the inadequate hadronic interaction generators.

CHORUS with new modified focusing conditions

- the distance of CHORUS from T9 is 822.16 m with detector size 1.3 * 1.3 $m^2$ area.
- the horn is displaced downstream by 7.81 m ( 18.9 m from T9)
- the reflector is displaced downstream by 8.04 m ( 90.4 m from T9)
- the horn current is expected to be increased to 110 kA
- the helium tube in the cave replaces 63m air by helium
  ( $\lambda(air) = 1/4 * \lambda(helium)$ —> 7% flux increase )

The calculated neutrino flux is 2.5 * $10^{10}$ ν $m^{-2}$ or 0.26 EVENTS /TON (total cross section events).
Changes are mainly due to the fact that the detector has now

CLOSER POSITION with SMALLER SIZE
—> HIGHER AVERAGE ν ENERGY

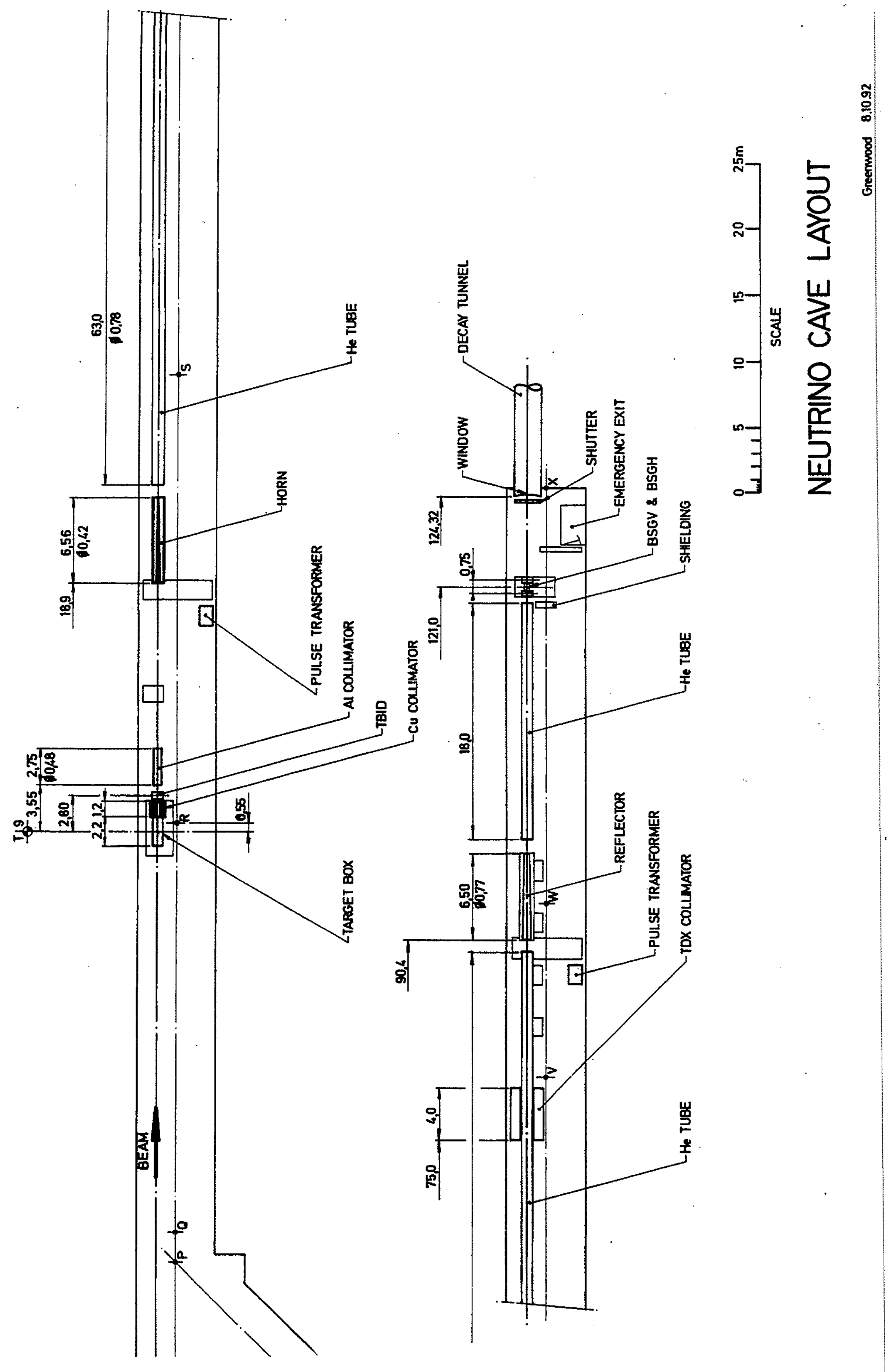
GBEAM gives **29.1 Gev** average ENERGY <Eν >. The actual energy is being measured and appears again to be somewhat lower.

Expected EVENT RATE for CHORUS

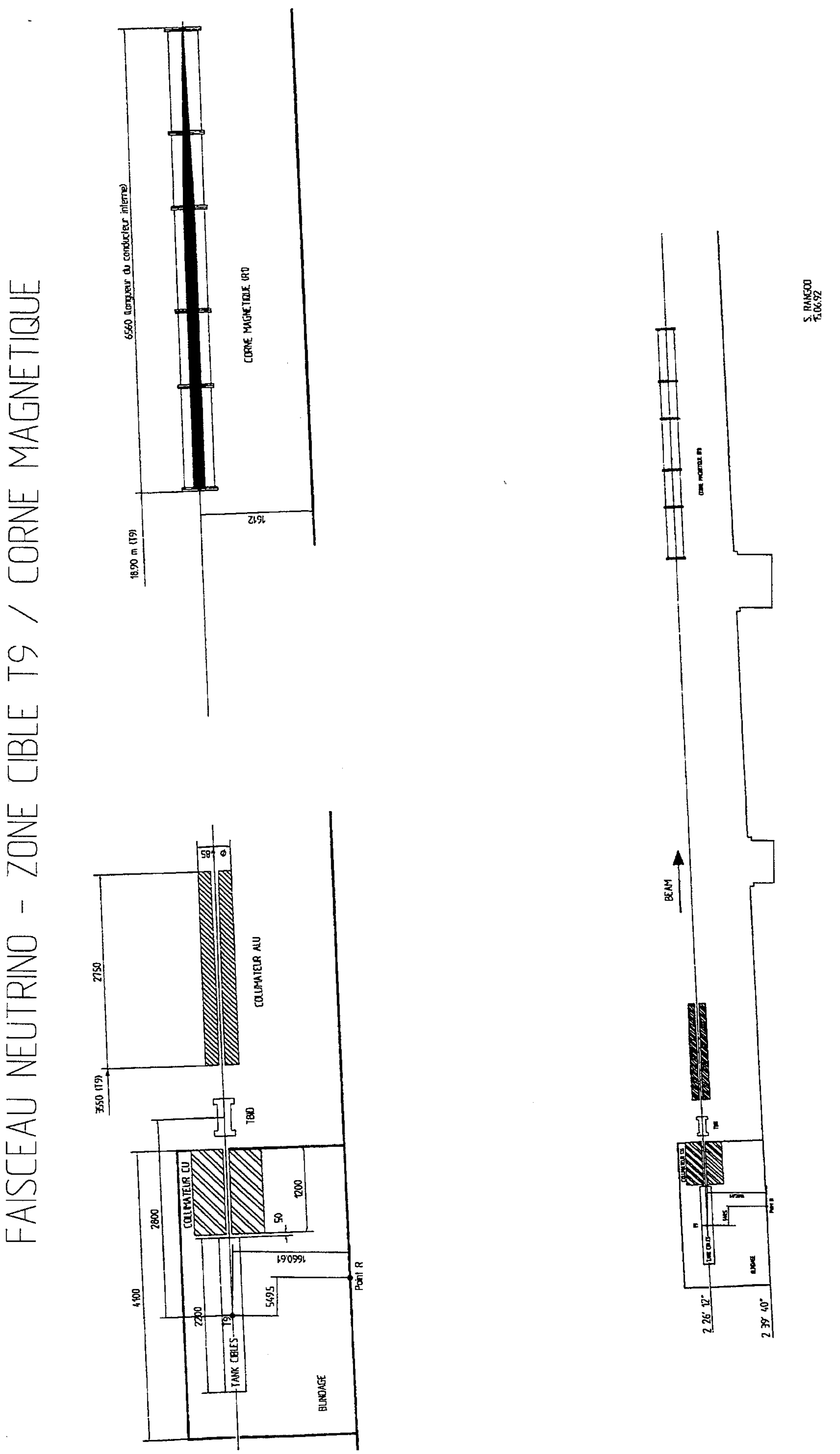
| | |
|---|---|
| target mass | 0,8 Ton |
| total numer of protons requested on target | 2.4 * $10^{19}$ |
| νμ induced CC event rate | 0.26 evts/Ton/$10^{13}$ p |
| **total number of $\nu_\mu$ induced CC evts** | **5 * $10^5$** |

### 1.4 Geometrical layout of neutrino cave and of T9 target area

The two figures [c2] and [c3] show the detailed implementation of the neutrino cave and the T9 target area after reconditioning of the cave for the production of a neutrino beam to CHORUS and NOMAD .

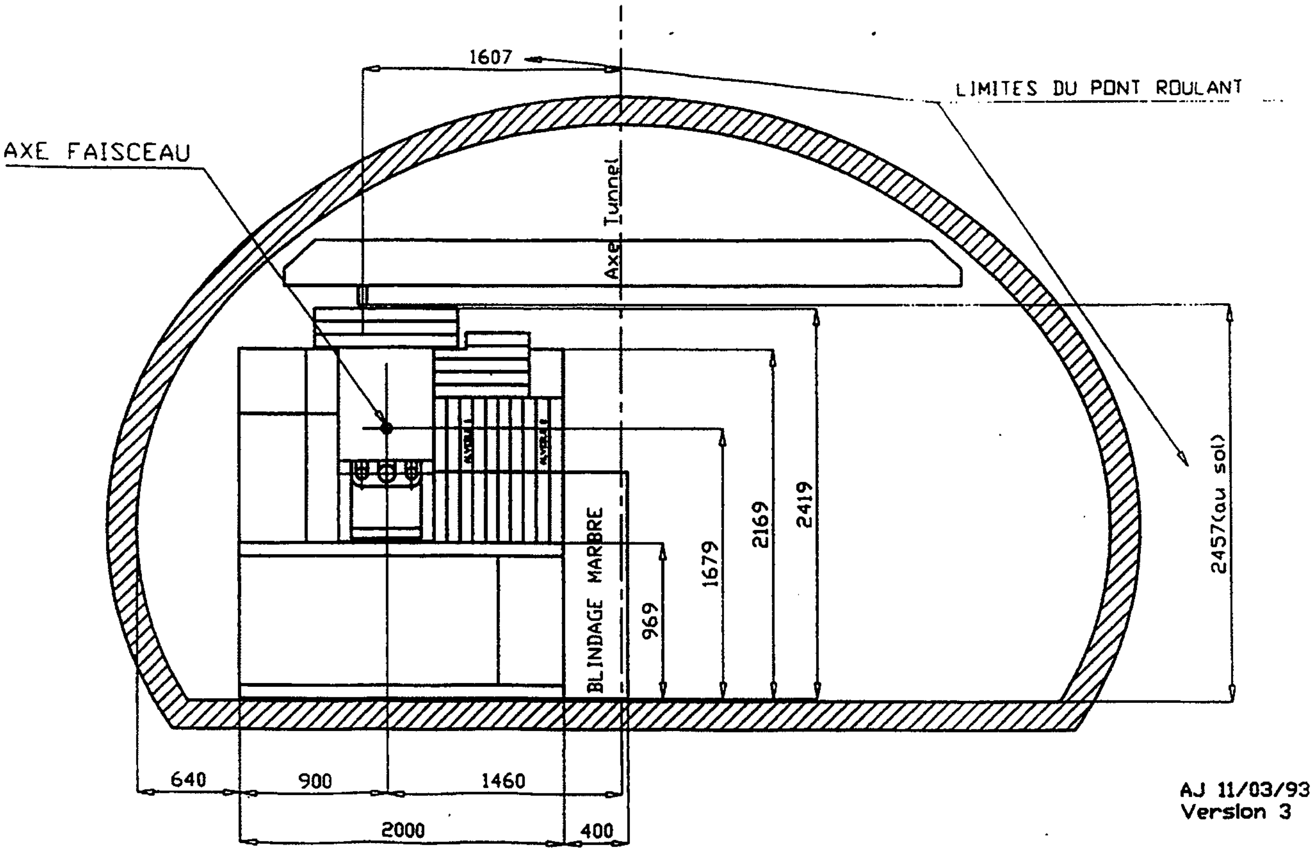



[c2] neutrino cave layout



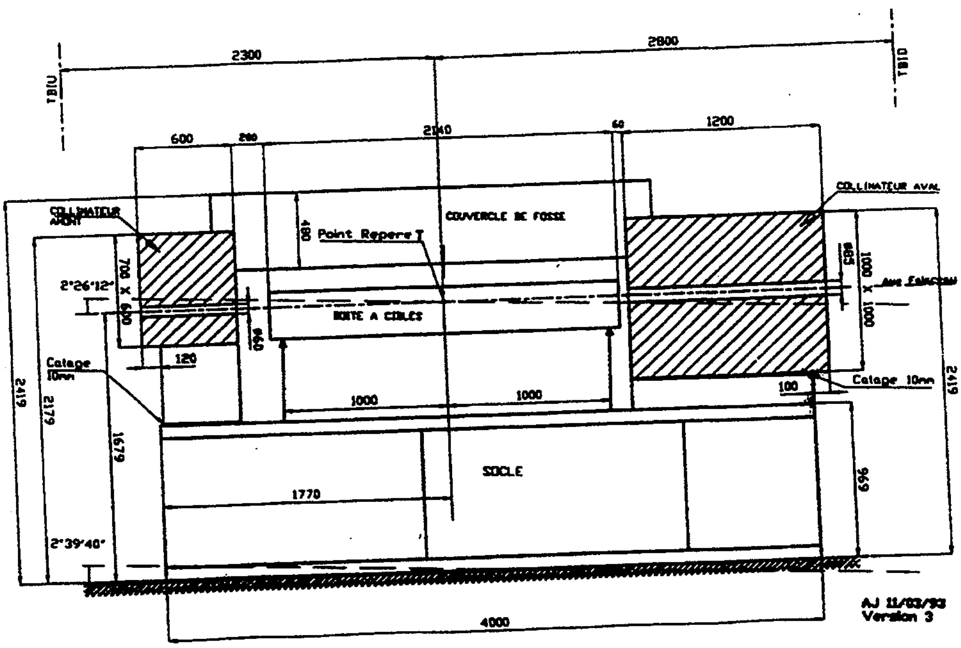

[c3] T9 target area

## CIBLE T9-VUE AVANT




## CIBLE T9-COTE PASSAGE

Toutes cotes // ou ⊥ au faisceau




[c5] Target station

## 2. NBC zone (Neutrino Beam Cave zone)

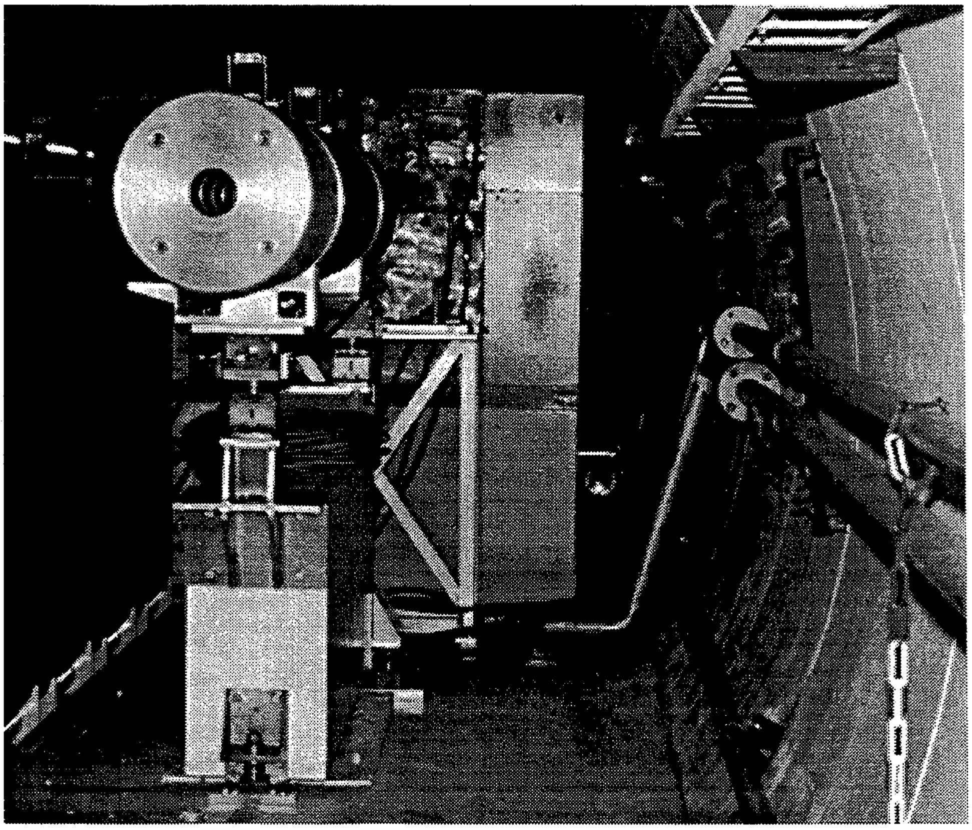
The neutrino beam cave zone includes BA7 (surface building where horn and reflector power supplies and delay lines are located), PA7 (access pit to the neutrino cave) and the Neutrino Cave itself where following equipment is located:

TARGET STATION, related monitors and copper collimator
Al collimator
Magnetic horn
Helium pipe 1
TDX large angle collimator
Magnetic reflector ( second horn)
Helium pipe 2
BSGH & BSGV ( hadron Beam Split foil Grid monitors)
Vacuum shutter
The local controls of this list of equipment are in BA7.
In the following sections, we give a brief description of these equipments.

### 2.1 T9 target constructional layout

The T9 target station has been designed and installed by the SL-BT/TA group. The 2 figures [c4] and [c5] show the main dimensions of the target box, the copper collimator and the surrounding shielding. Detailed description and related calculations can be found in [3], [4], [5] and [6].

### 2.2 Al collimator



[ c6] Aluminium collimator

The aluminium collimator ( figure [c6] ) is a machined round bar of 2850 mm length and outer diameter 490 mm ; its total weight is about 1400 kg.
On its longitudinal axis, the bored beam hole (ø 88.8 mm) is cylindrical over 1 metre, starting at the front side, and conical on the remaining part, but machined in regular cylindrical 1 mm steps (end diameter: ø 116.8 mm) resulting in an average opening angle of 8 mrad. The collimator is centered along the slope of the beam axis and its front side is at 3.55 metres from the target centre. It is placed on a manual adjustable base frame supported by a specially equipped CERN standard iron shielding block.
Support, collimator and its base frame are auto centering and can easily be removed.
The collimator is water cooled by two separate drilled circuits, one at each end, both cooling circuits being connected in parallel.
The cooling circuit of the Al collimator is connected to the same closed circuit as the Cu collimator and the secondaries of the horn and reflector pulse transformers ( see figure [c ]. The corresponding pump station is located behind the cave elevator with a heat exchanger cooled by the TF demineralised water circuit.
The total water flow is 1.5 $m^3$/h with Æp=3 bar resulting in a mean temperature of 45 ºC measured on the outer circumference at the middle of the collimator, when the total SPS intensity is 2.3 * $10^{13}$ protons for the 2 spills of the SPS 14.4s supercycle. The energy deposited in the collimator is estimated in [4] and [5] and calculations fit very well with the experimental values.

## 2.3 Neutrino magnetic horn and reflector

These elements are 2 pulsed toroidal lenses designed to focus the pions and kaons emitted from the target into a nearly parallel beam.
This beam produces muon and neutrino decay products along its 414m flight path ( 124m cave and 290m vacuum decay tunnel ), before hitting the long iron and earth shieldings needed to stop all muons.
(The undecayed parent particles and other hadronic particles are stopped in the first few meters of this iron shield).
Three measuring pits V1, V2, V3 at increasing depths inside the iron shielding are equipped to measure the muon flux distribution.

### optical design

The magnetic horn and reflector are optically designed to enhance as much as possible the neutrino flux in the detector volumes of CHORUS and NOMAD and are optimized in terms of inner and outer conductor shape by calculating the trajectories of the neutrino parent particles (pions and kaons) using the computer program GBEAM . Calculations have been done by V. Palladino.

### neutrino flux enhancement factors

The magnetic volume is confined betwen the inner and outer conductor of the element with the azimuthal magnetic induction B (Tesla) varying as B = $\mu_0$ I/2¹ r in MKSA.
The currents retained to aim at excellent reliability are :
$I_H$ = 100 kA and $I_R$ = 120 kA.

They lead to a neutrino flux peak around 29 Gev with neutrino fluxes approximately relevant to the following table:

| Neutrino energy | Enhancement of neutrino flux | |
|---|---|---|
| (Gev) | Horn only | Horn and Reflector |
| 29 | ≈ 5 | ≈ 10 |

**general design criteria**

Experience has shown that bad electrical contacts and damages along welding lines on the inner conductor were two major causes of failures, beside the problem of radiation damages to electrical insulation.

• To achieve good electrical contacts, one must keep in mind that contact pressure must not vanish when pulsing.
Concerning the horn, the inner conductor is in first approximation forced into traction when pulsed and its length tends to increase. Thus the contact pressure will only increase if the structure (end-plates + outer conductor) is stiff enough. The mounting is even done so as to force the inner conductor into compression.
Concerning striplines, the same reasoning can be applied: one pair of plates should be stiffer then the other , so that the more flexible plates move in such a way that contact pressure increases.

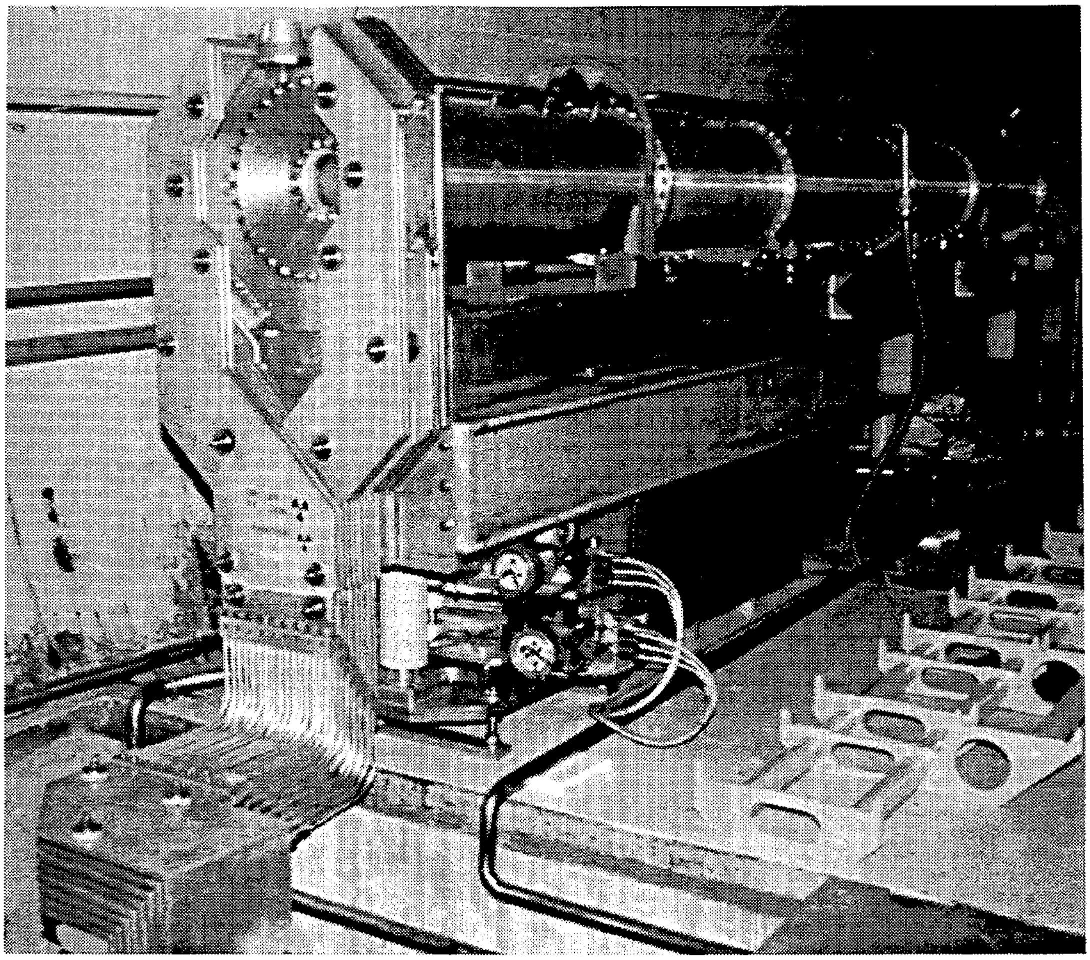
• Precise centering of inner and outer conductor is very important since the electromagnetic forces will tend to pull the conductor into center line, thus creating alternate flexion.

• Fatigue effect for 10 million alternate tractions has to be taken into account on the mechanical stress limit.

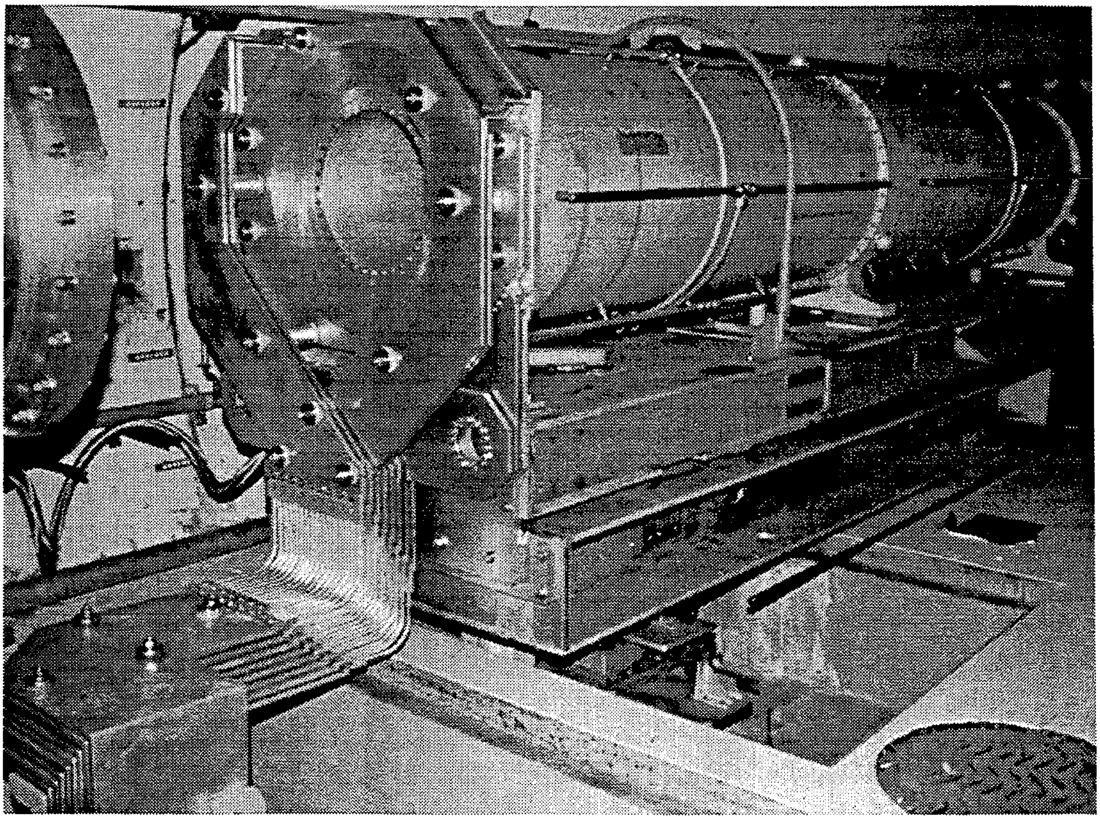
• Natural oscillating frequency of the inner conductor must remain away from the fundamental frequencies of the current pulse.

• Symmetry of revolution of the magnetic field distribution has to be as good as possible and especially on the current feeding side of the magnetic volume: one necessary basic condition to that aim is that the currents in the feeding strip-lines be equal. These currents can be measured by checking the integrated signals of field probes located between the plates of each strip-line. These probes are calibrated by successive displacement of the same reference probe in between the 4 strip-lines. With approprate tests, the strip-lines can be adjusted by machining the adequate corrections until good conditions are established (total deviation within 5%).

Next two figures [c7] and [c8] show the magnetic horn and the reflector seen from the electrical connexion side, which corresponds for both elements in the present experiments to the beam entrance side. The attachments to the flexible copper grids connected to the feeding striplines are also visible.
The flexibility of these grids allows to move the horn (or reflector) in the up/down, left/right directions as required during the alignment procedure. The copper grids are made of 16 flexible copper cables ( 50 $mm^2$ section each ) soldered with tin into the copper connexion bars. Each grid assembly is then silvered ( flush of 10 microns). Similar grids are also mounted on the secondary transformer side to compensate for misalignments of the striplines during assembling.

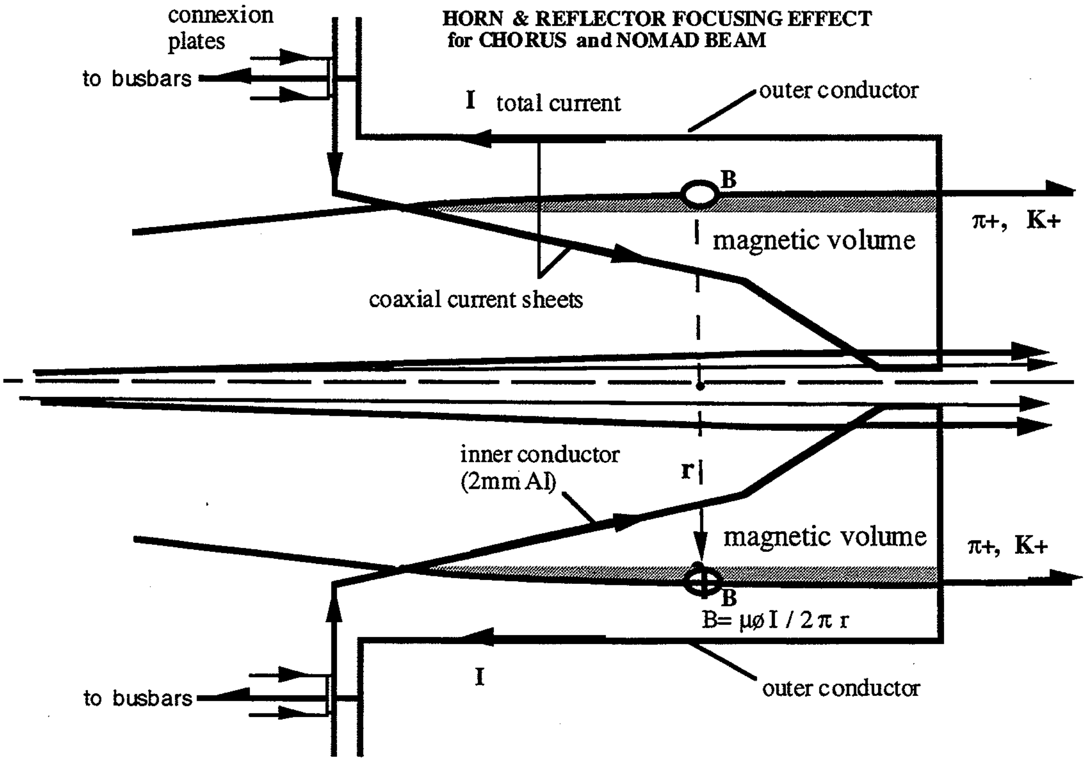


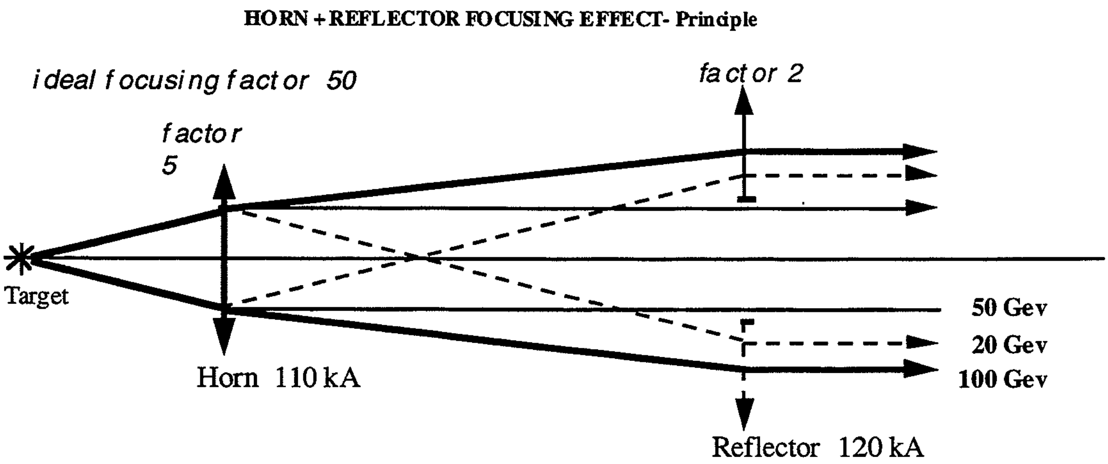
[c7] view of magnetic horn



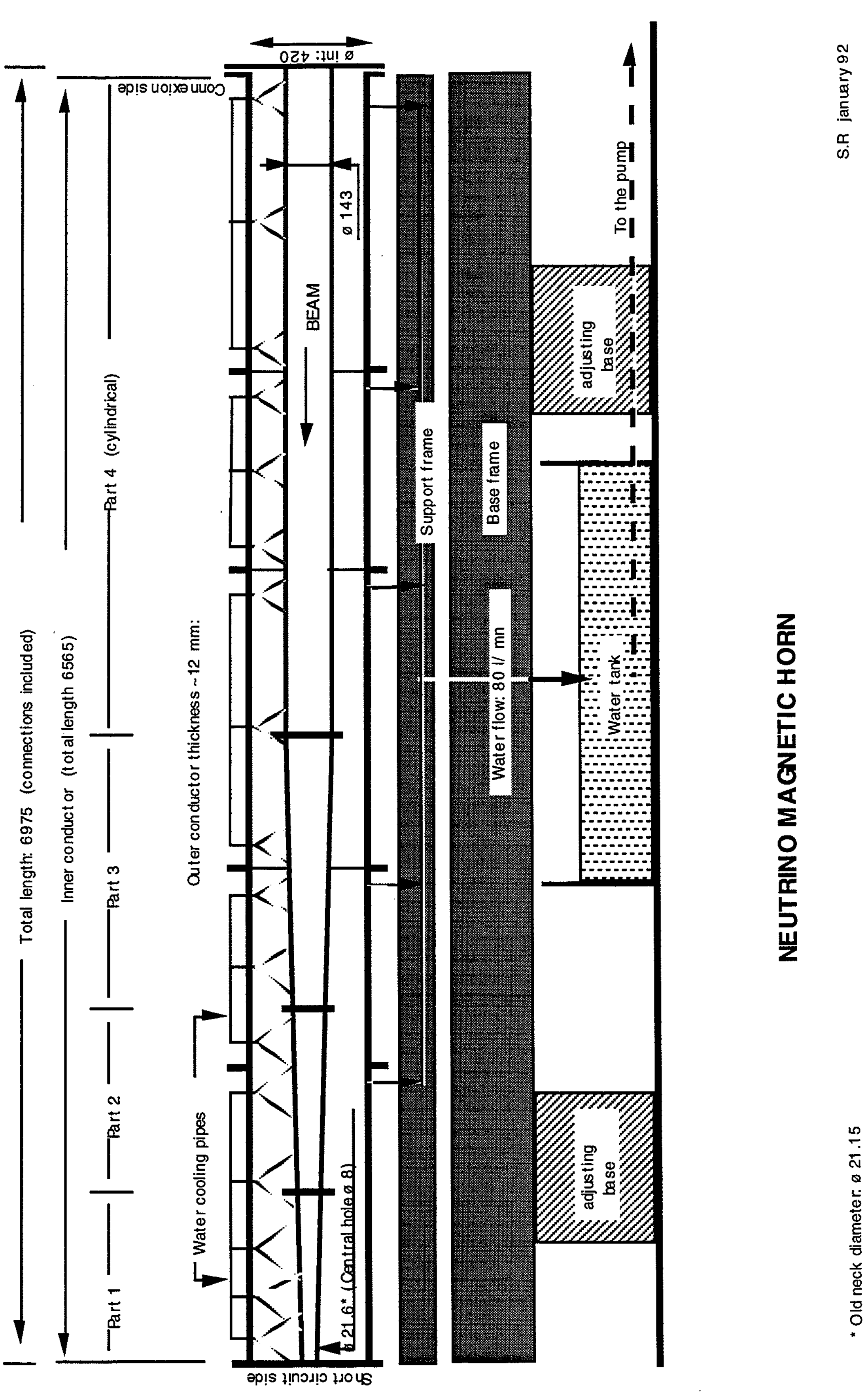
[c8] view of reflector

Following figure [c9] visualizes the focusing effect of the magnetic lenses: in first approximation, the thickness of the inner conductor can be neglected so that horn and reflector are transparent to the particles. The charged particles of the right sign are bent by the magnetic field along their path towards the detectors.




[c9]




[c10] : neutrino magnetic horn - general assembly

## mechanical construction :

### General

The mechanical design is basically identical to the one described in [7] and the principle of the construction is visible on previous figure [c10].

Modifications have been developed in order to :

- improve the electrical contacts between each conductor and the assembling method
- provide a light, strong and adjustable centering appliance using stainless steel cables to hold and precisely center the inner conductor with respect to the outer conductor
- feed the horn with the use of 4 strip-lines connected in 4 symmetricaly located points on the end plates (each strip-line is a pair of parallel plates for in and out-going current)
- keep the material thikness of the inner conductor to a minimum to reduce particle absorption loss
- avoid organic insulation material : the use of an **adapting pulse power transformer with low voltage on the horn and reflector** made it possible to work without using organic insulation materials whose limited life time constitute a very critical limiting factor in the high radiation areas.

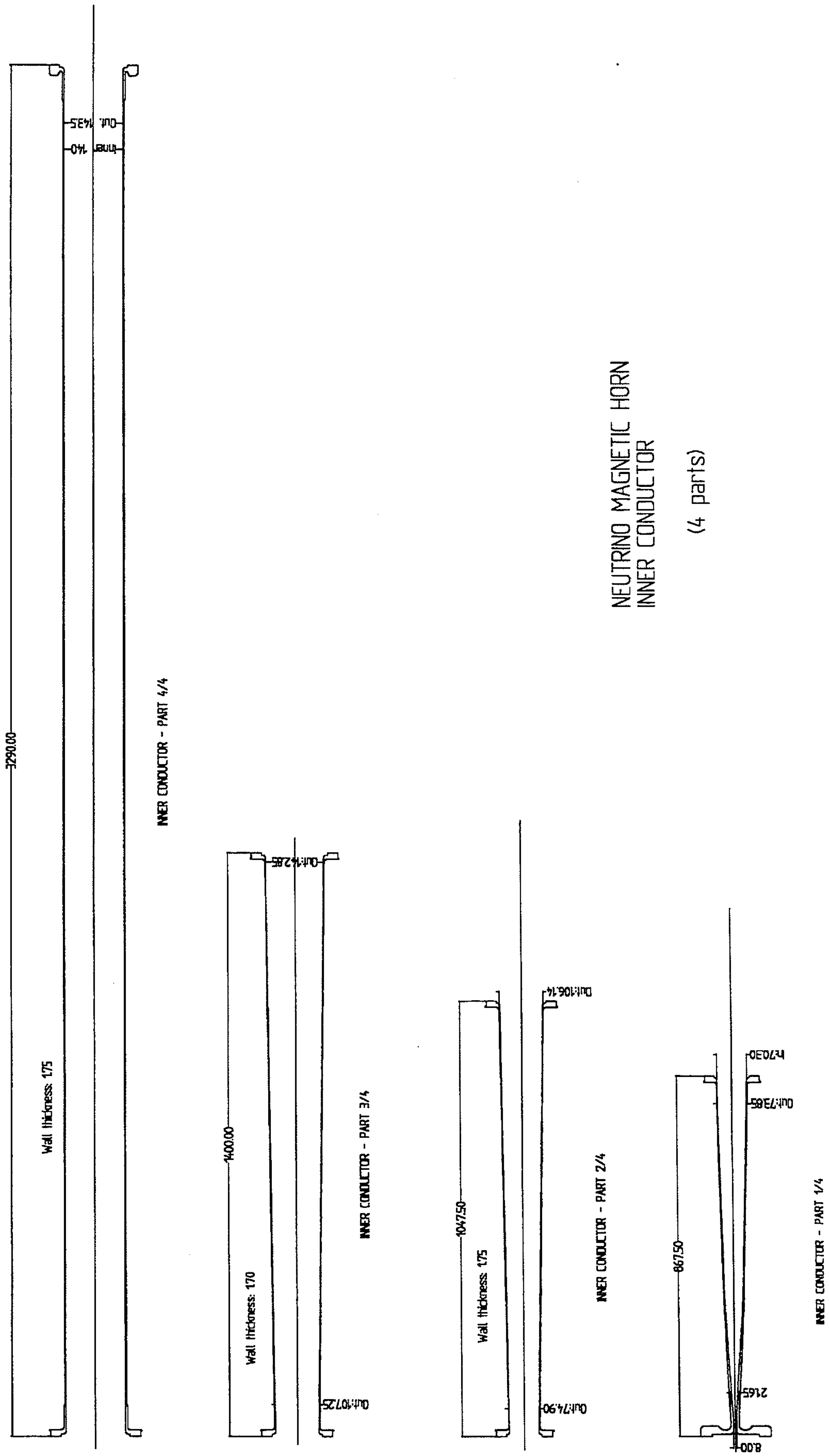
### Alignment

The attached figure [c10] shows the general assembly of the horn station.
The horn is permanently attached to a support frame. This assembly is picked up by means of 2 hooks, transported and precisely placed into position with the help of an overhead crane onto a base frame. The positioning is ensured by special vertical girders so that the support frame comes accurately into place when deposited.

The base frame is itself attached to 2 adjusting bases which are , each one, equipped with one vertical and one horizontal DC motor and corresponding position sensors. Thus remote horizontal and vertical position adjustments are possible for beam entrance and beam exit part of the horn. The possible movements are ± 3 mm for each direction with a precision of 0.01mm.
These movements are not motorised in the case of the reflector and manual adjustment in the cave is then necessary.

### Inner conductor

It is made in 4 pieces according to figure [c11]. The exit part which corresponds to the neck region is machined out of Perunal.
The entrance part is an assembly of 3 parts screwed together, each one made out of Anticorrodal 100 (metal sheets rolled and welded).
The properties of the Al alloys mentioned are summarised in the hereafter attached table; we refer to [7] as regard forces and stress calculations on the inner conductor.




[c 11 ] Horn inner conductor

| | Symbol | Perunal | Anticorrodal 100 | Units |
|---|---|---|---|---|
| Aluminum Alloy type | | ISO 7075 | ISO 6082 | |
| Metal. state | | T6 | T6 | |
| Young's modulus of elasticity | E | 72000 | 69500 | Mpa |
| Shear stress | | 330 | 218 | Mpa |
| Mechanical stress limit for $10^8$ cycles | $\sigma_{limit}$ | 162 | 102 | Mpa |
| Resistivity | ρ | 5.2 | 4.2 | μΩ·cm |
| Mass density | $m_S$ | 2.80 | 2.71 | $g/cm^3$ |
| Specific heat | $c_S$ | 915 | 935 | J/kg/°C |
| Thermal conductivity | $t_C$ | 130 | 174 | W/m/°C |

**Outer conductor**

This conductor is cylindrical with a wall thickness of 15mm and is an assembly of 5 parts screwed together, each one made out of Anticorrodal 100 (metal sheets rolled and welded). The inner diameter of the outer conductor is 420mm and is machined with a maximum ovality default of 0.2mm. Inner/outer concentricity is 0.1mm.

Centering of the inner conductor is achieved with adjustable centering appliances using stainless steel cables to hold and precisely center the inner conductor with respect to the outer conductor. Insulation of the cables with respect to outer and inner conductor is obtained with use of Arclex M glass-mica compound spacers.

**Water cooling**

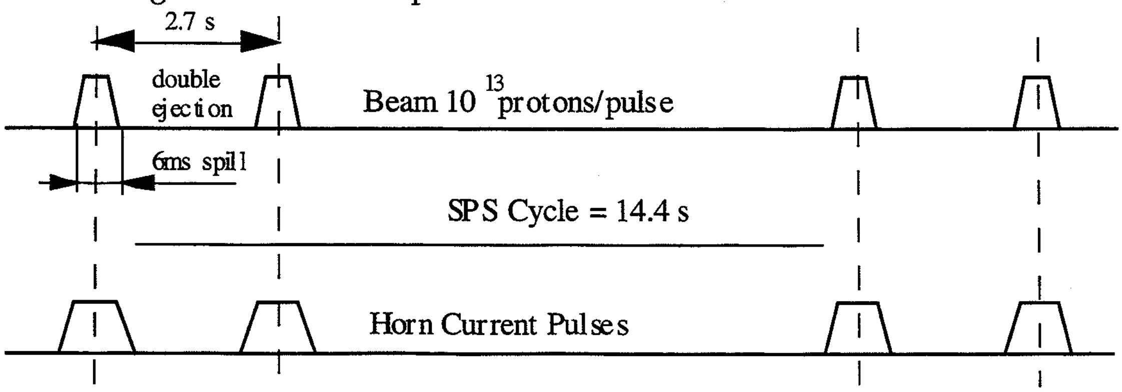
The inner conductor is water cooled by spraying continuously water onto it. The sprayers are distributed along two external pipes located on the upper part of the outer conductor, in relation with the heat dissipation along the internal conductor. The diameter of the holes of the nozzles is 1mm. The total amount of cooling water is 75l/min for respectively horn and reflector.

The water is collected by gravity into a tank located below the horn.

No special treatment of the water is applied: only the filling of the circuit is done with demineralized water.

## 2.4 Timing of extracted beam / Pulsed operation mode

Two spills of protons of 6 ms duration and 2.7 s separation are extracted from the SPS machine for each machine cycle of 14.4 s (see figure of timing sequence below). As described later, horn and reflector work in pulsed operation mode by synchronised discharge of a corresponding pulse generator. Timing pulses are available in all areas for synchronizing (for each spill ) current pulse generation and data taking to the extraction process.




[ c12 ] : SPS Timing Sequence

## 2.5 Neutrino horn & reflector electrical systems

### 2.5.1 General layout

The requirement is to produce a stable field or current in the horn and reflector during the 6ms spill extraction. To achieve this condition, the choice was made to use the current impulse produced by the discharge of a 17 cells LC delay line into a load resistance equal to the characteristic impedance of the delay line Rc = L /C = 1½.

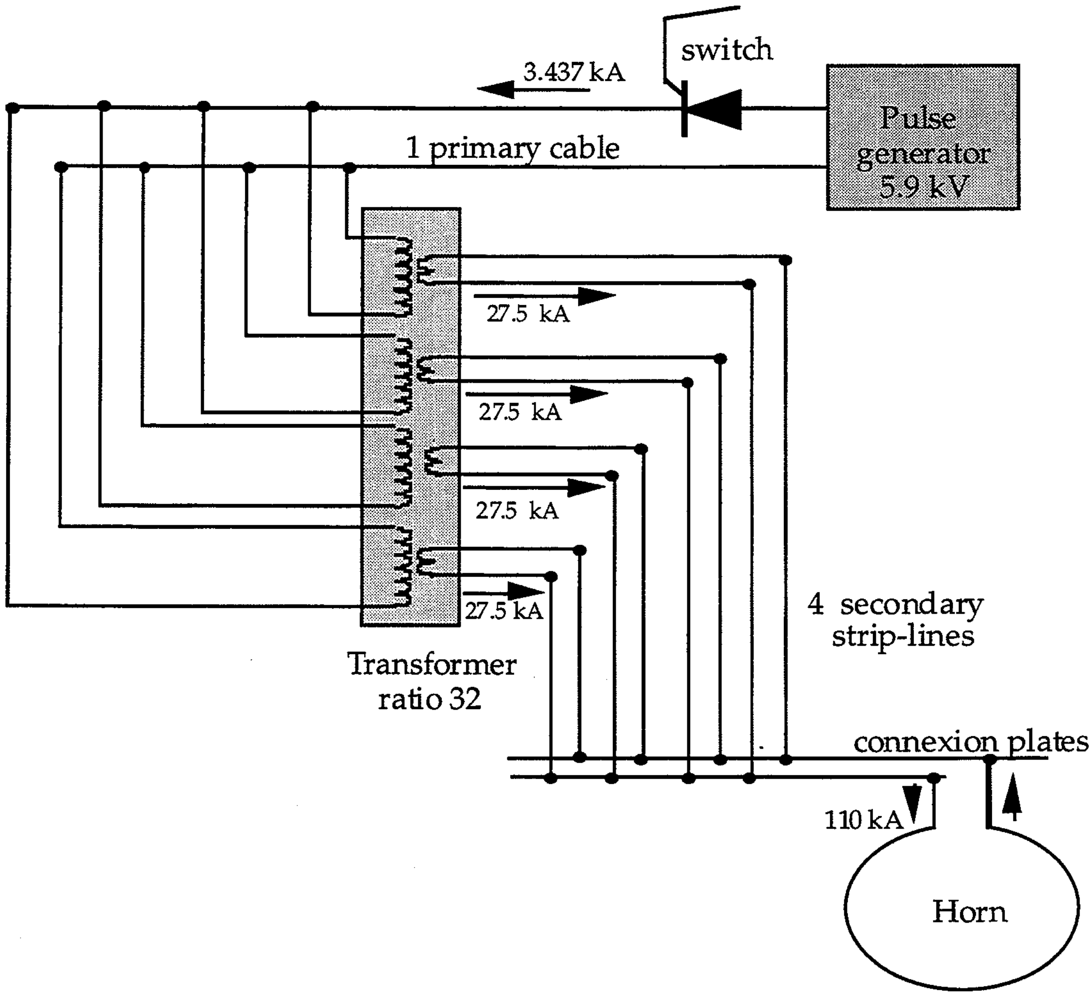
**Between load and pulse generator is inserted a pulse transformer of ratio 32 which offers following advantages:**

1.- the primary current is the load current divided by 32.
Only two thyritor switches in series are sufficient to switch the required current pulse.
One primary cable only is necessary between pulse generator and transformer, and this is useful since this distance is around 100m from the surface to the cave where the transformer is located.

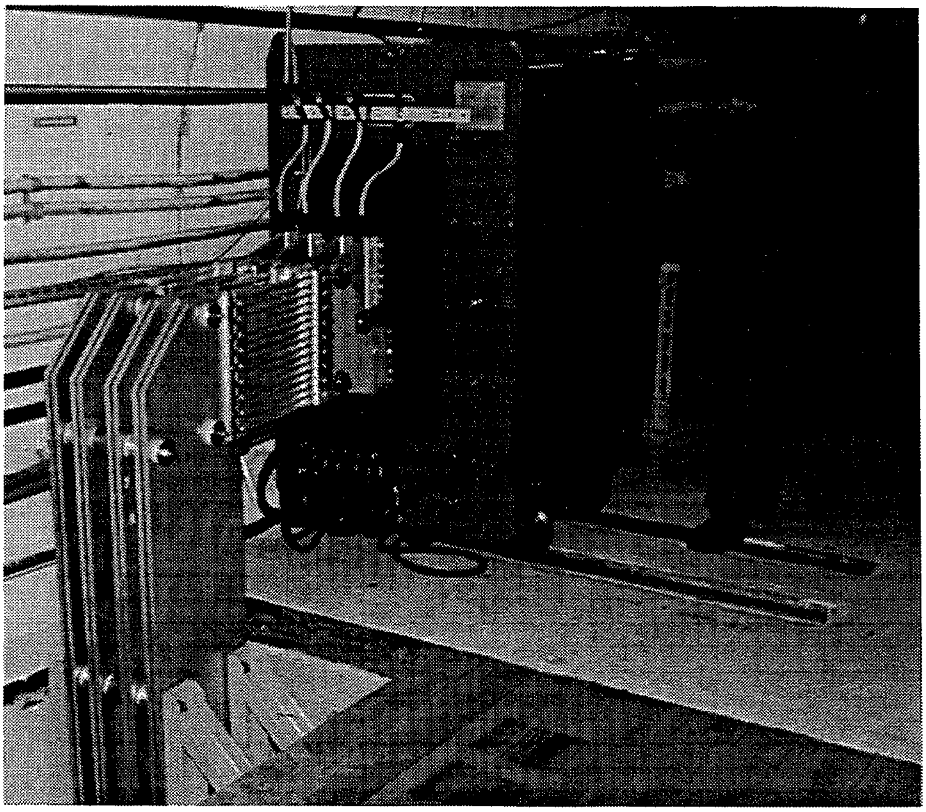
2.- the voltage on the load is low since it is the pulse generator voltage divided by 32. This factor is specially interesting, since it allows not to exceed 200V on the horn and , as already explained, allows to use radiation resistant Arclex spacers for insulation.

3.- the transformer includes in fact 4 primary coils and 4 secondary coils interleaved. The leads of the 4 primaries are mounted in parallel externally to the coil mould; the 4 secondaries are attached to 4 strip-lines connected to the horn connexion plates and this offers the possibility to tune their impedance by adjustment of the inductance of each line through correction of the width and hence the possibility to equalize the 4 secondary currents. This is used as an indirect measure of correct field distribution in the horn as already pointed out earlier.
The transformer is located in the vicinity of the horn, as much as possible outside of the high radiation areas. **In an ideal case, this transformer could be located in a separate service tunnel completely outside of the radiation area and the manual coupling to the striplines organised in such a way that it takes place in a radiaion safe area.**

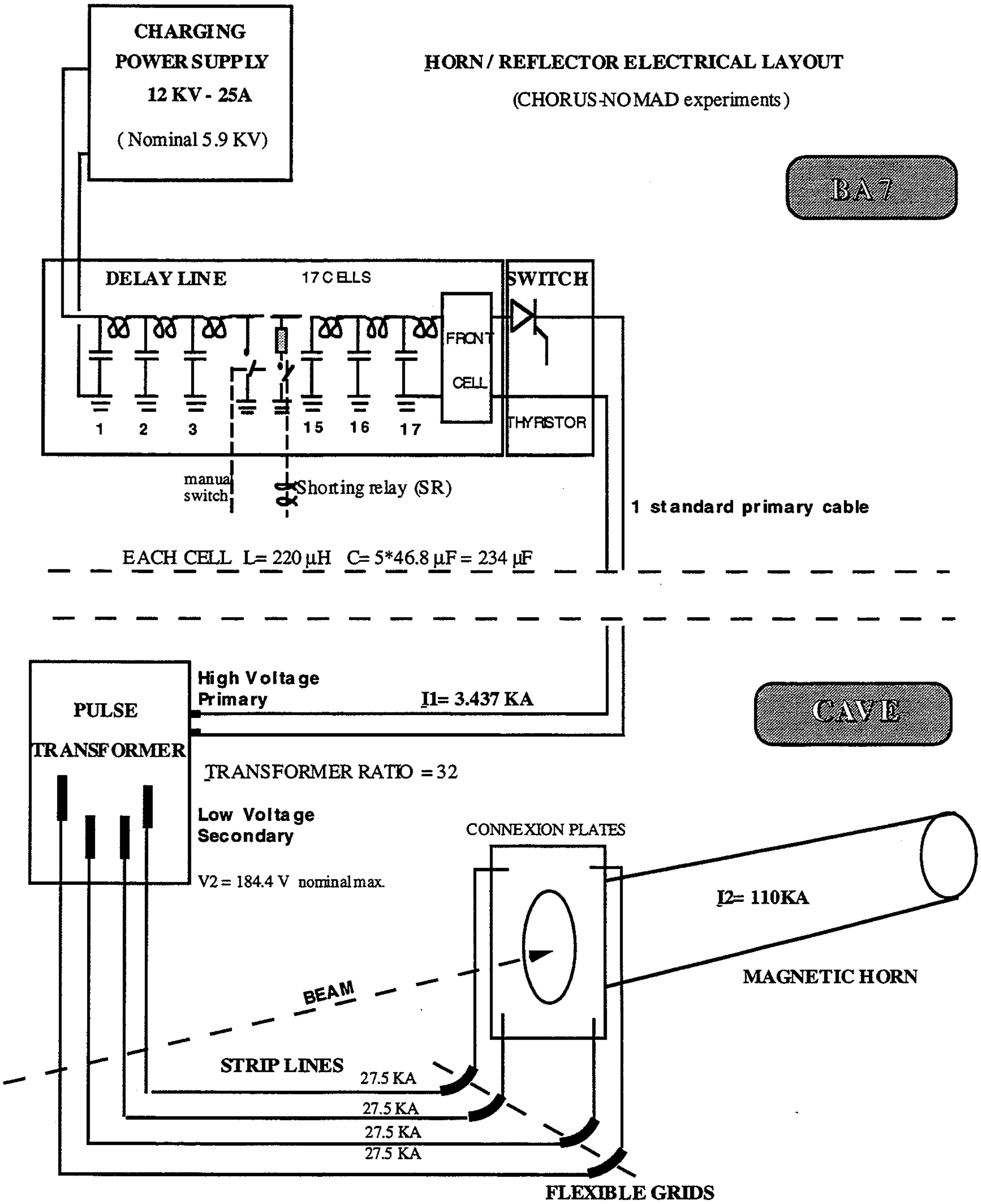
4.- the low primary current allows to insert one remote controled and motorised **polarity changer** on the power line just after the thyristor switch. It is located in a separate cabinet and remote control is possible from within the supervisor panel provided by the beam control system. This polarity changer is not shown on the drawings. The change of polarity takes one minute.
Following figures show respectively the general horn transformer circuit [c13], a view of the secondary side of the horn transformer [c14] and the electrical systems of horn and reflector[c15].
The electrical layout of the reflector is identical to the horn layout. Due to the long distance of 71.5m between horn and reflector, two independant electrical systems were almost compulsary and offer some flexibility in the operation.




[c13] general transformer circuit



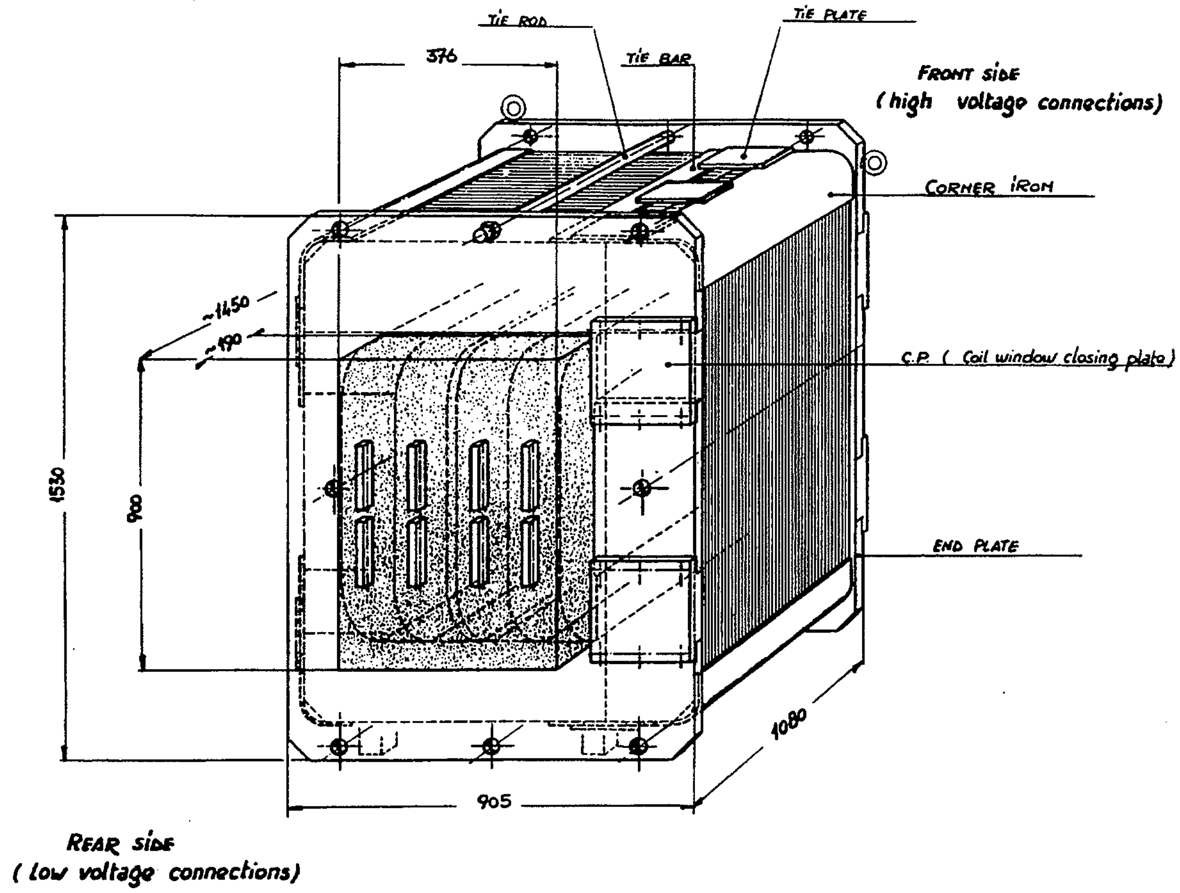
[c14] secondary side of horn transformer



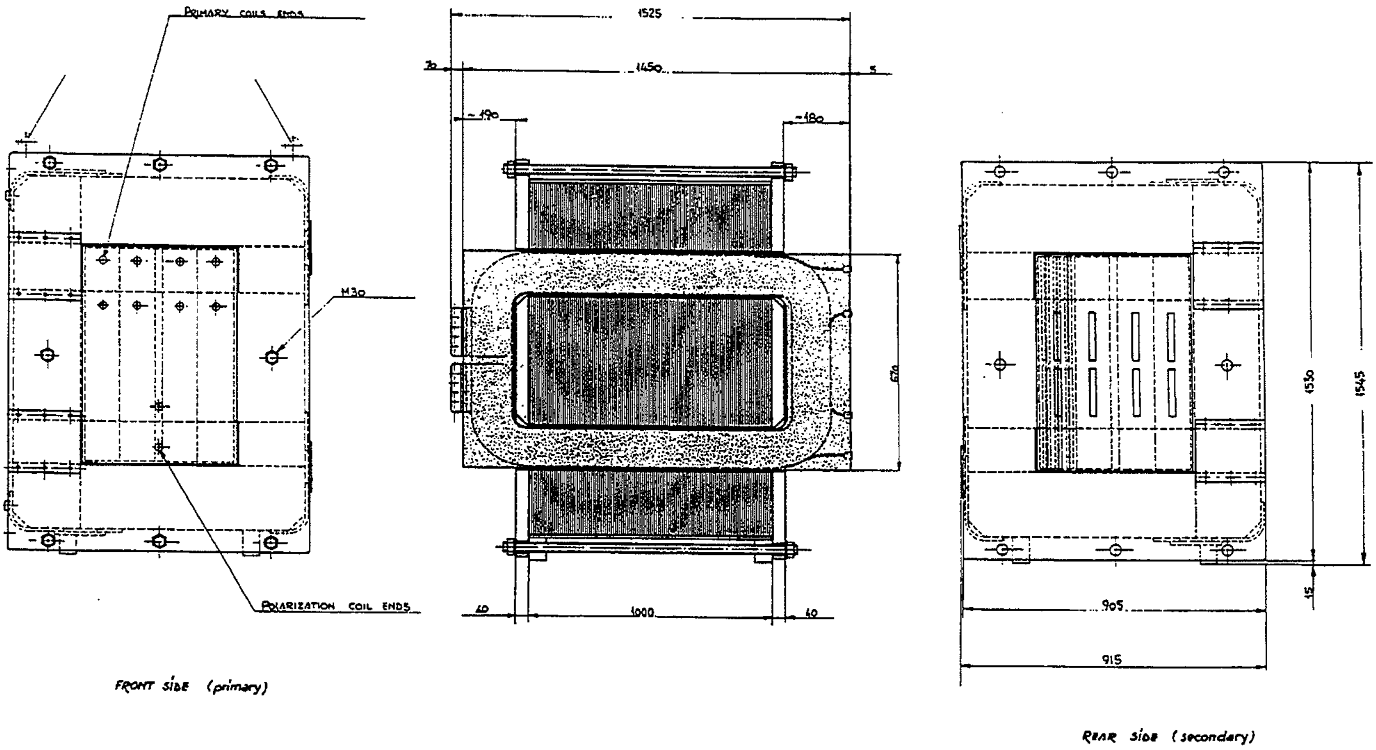

[c15] electrical systems of horn & reflector

### 2.5.2 Pulse transformer construction

The construction of 2 transformers according to technical specification [9] has ta 15 months and was achieved by TESLA Eng. Ltd in Storrington - Sussex.
The design of the windings is based on having a total stray inductance and a t resistance negligible with respect to the load. The transformer works almost short circuit mode and, therefore, the mechanical assembly has to be speci robust. For this reason, a constructional method similar to that of an accelera magnet has been chosen. Only the low voltage secondary side of the transforme watercooled. Pulse transformer assembly seen from the secondary side, coil magnetic circuit are drawn on figures [c16] and [c17].




[c16] Pulse transformer : general assembly

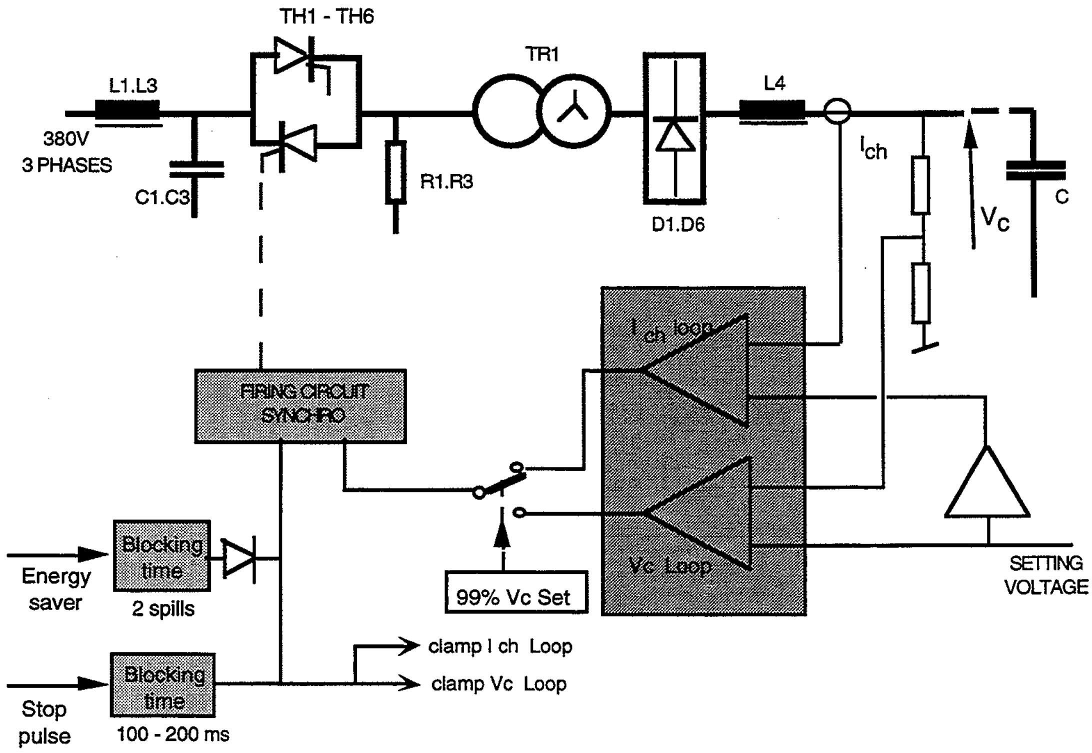



[c17] Pulse transformer ; coil and magnetic circuit

### 2.5.3 Main electrical components and data

2.5.3.1 Horn charging supply

By reception of the start pulse derived from the SPS timing system, the power supply starts charging the delay line with a constant charging current until the voltage reaches the requested preset value Vc Set. The reception of the stop pulse blocks the charging unit during the blocking time of 100 to 200 ms. The trigger pulse is expected to arrive in this time interval to fire the energy storage switching section and provoque the discharge of the delay line into the load. The preset voltage Vc Set is calculated to precisely reach the required horn current of 100 kA. The stability of the power supply enables a precision of $5.10^{-4}$.




[c18] Block diagram of horn charging supply

The voltage and current settings and the control electronics consist of two parallel senseloop working respectively in sequence:
- first during the capacitor charging phase
- and second during the voltage stabilisation phase.

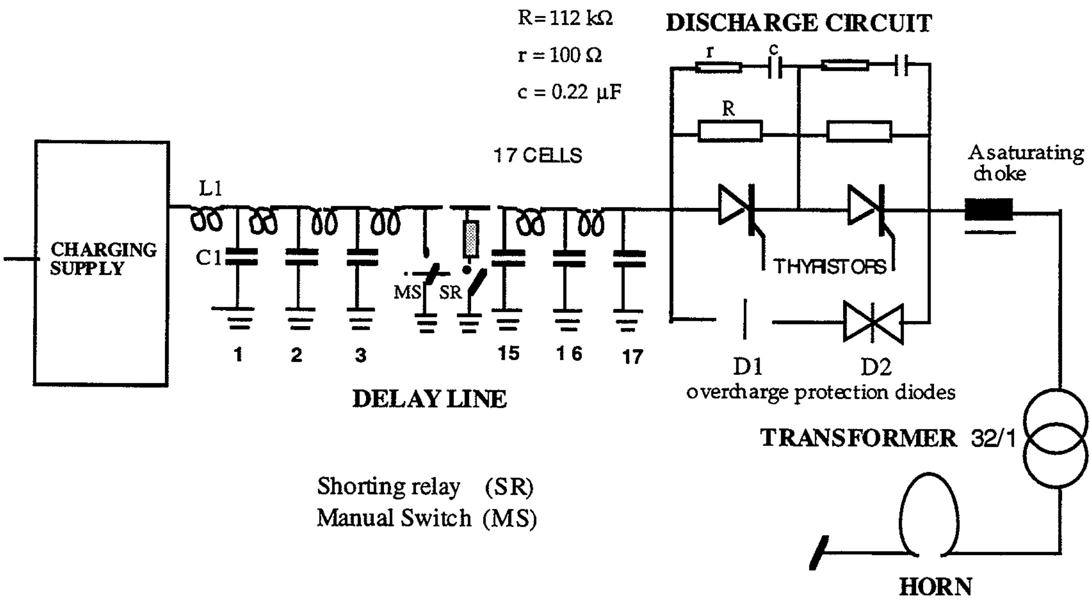
They act on the phase angle of the TH1-TH6 thyristor switch. D1-D6 is a rectifier bridge located on the secondary side of the power transformer TR1.

$$I_{ch} = \frac{Vc * C}{t}$$

$V_C$ = Voltage on capacitor
C = Capacitor of delay line
t = Charging time = [Cycle time - (Blocking Time + stabilisation time)]
$I_{ch}$ = 0 to 25 A  $V_C$ = 0 to 8 kV = f ( $I_{Horn}$ )

### 2.5.3.2 Horn delay line and discharge circuit

The current impulse is produced by the discharge of a 17 cells LC delay line into the horn. The characteristic impedance of the line is $Rc = \sqrt{L1/C1} = 1\Omega$. with $L_1 = 200\ \mu H$ and $C_1 = 200\ \mu F$.




[c19] Delay line and discharge unit

The delay lines are installed in cabinet raws in building BA7 (one for the horn and one for the reflector) as can be seen on the view below:

The discharge circuit uses 2 thyristors (TA 20.45.12 Westinghouse) in series as switching unit.
For one thyristor, the nominal forward blocking voltage is V = 4500 V.

The power dissipation for the pulse and cycle considered is 47 W, with

$$I^2t = 1{,}6 * 10^6\ A^2/s$$

$$\frac{dI}{dt} = 200\ A/\mu s$$

A is a saturating choke ( ≈ 100 μH) from TRAFOMECA (Italy) added to limit dI/dt

| Nominal inductance | Conductor / Number of turns | Saturating current | Iron section | Nominal peak/r.m.s. | Cooling type |
|---|---|---|---|---|---|
| (μ H) | | ( A ) | (cm2) | (kA) | |
| 100 | Al/(2*6) | 1000 | M6/32 | 20 | natural-air convection |

D1 and D2 are 2 identical overcharge protection diode arrangements mounted with BBC diodes DSA 27.4 and DSAS 13.2.

### 2.5.3.3 Nominal operational parameters

The parameters correspond to measured values. Inductance and resistance of the primary cables are negligible.

HORN ELECTRICAL PARAMETERS

Peak values are I = 100 kA Vc = 5.4 kV
The total capacitance installed is C = 17 * 200 = 3400 μF.
The capacitors used are a mixture of BICC and Aerovox capacitors according to following table:

| Capacitance per unit | Number of units | Nominal voltage | Stored energy | Dielectric / Impregnation/ | Dielectric stress at 4.5kV | Design lifetime | Ma |
|---|---|---|---|---|---|---|---|
| ( μF ) | | (kV) | (kJ) | Armatures | | | |
| 200 | | 4.5 | 2 | Paper(4) + polyethyl. (1)/ castor oil / High-current Al foil | Paper : 21 | $2*10^7$ | Aer USA |
| 50 | | 12.0 | | idem | | | BIC Eng |

The total inductance and the total resistance of the horn circuit seen on secondary side of the transformer are :

Lts = 1.5 μH Rts = 0.7 mΩ

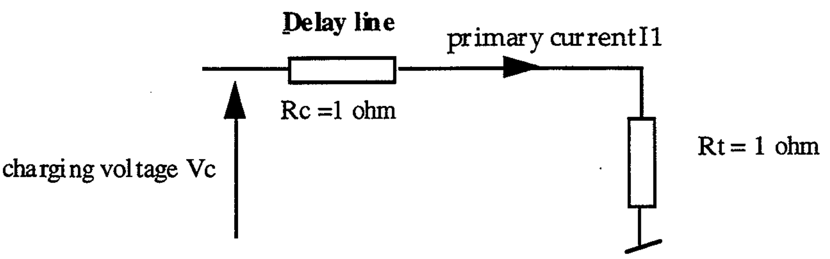
Inductance and resistance of the secondary strip-lines as well as resistance and stray inductance of the transformer are included in these values.
REMARK :
The total inductance and the total resistance of the transformer seen on its primary side are : l = 0.15 mH r = 75 mΩ

EQUIVALENT HORN PARAMETERS SEEN ON PRIMARY OF PULSE TRANSFORMER (measured values)

$I1 = 100/32 = 3{,}125$ kA

$L_t = 1.5\ \mu H * (32)^2 \approx 1{,}5$ mH $\qquad R_t = 0.7\ m\Omega * (32)^2 \approx 0{,}7\ \Omega$

EQUIVALENT CIRCUIT of DELAY-LINE and HORN



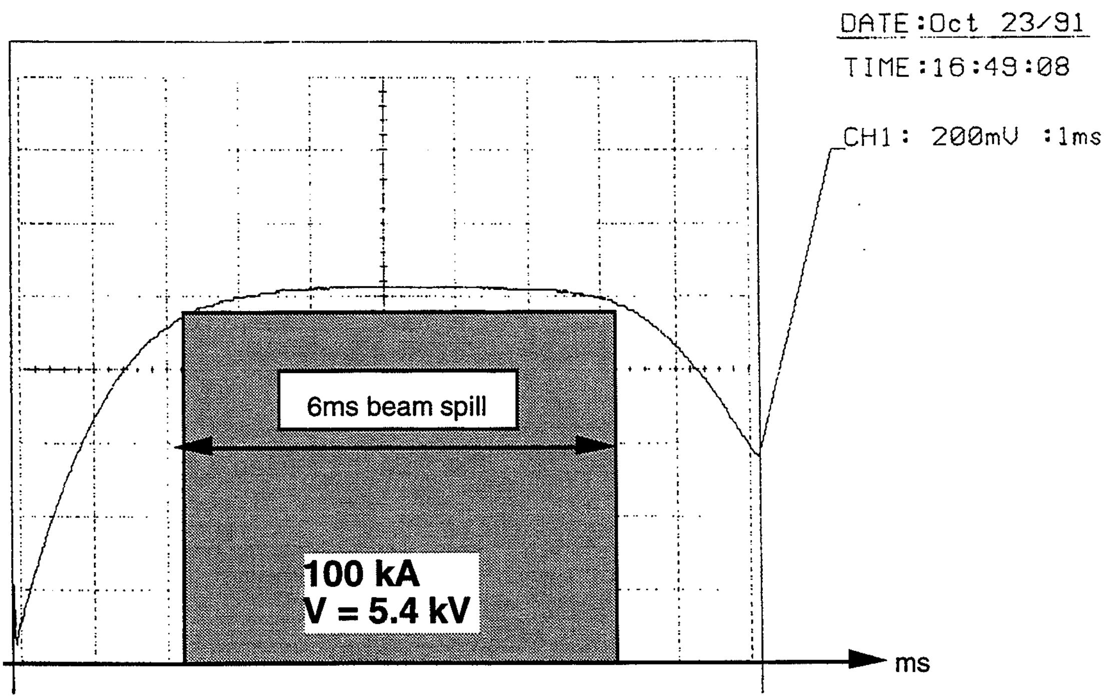

Rc is the characteristic impedance of the delay line

$V_c$ calculted = $I1 * (Rc + Rt) = 3{,}125$ kA $* 2\ \Omega = 6.25$ kV

In fact, Rt = 0.7Ω and not 1Ω.
This mismatch explains that real Vc measured = 5.4 kV at 100kA and not 6.25 kV.

ESTIMATED HORN PULSE DURATION

For one cell, $T = 2\sqrt{L1/C1} = 2\sqrt{200\ 10^{-6} * 200\ 10^{-6}} = 400\ 10^{-6}$ s
The total pulse duration for 17 cells = 17 * T : ≈ 6.8ms
The total FLAT TOP as measured on the scope at 100 kA is ≈ 6 ms for 17 cells as shown below:




Measured horn current

REFLECTOR ELECTRICAL PARAMETERS

Peak values are I = 120 kA Vc = 5.25 kV

The total inductance and the total resistance seen on secondary side of the transformer are :

Lts = 1.1 µH Rts = 0.4 mΩ

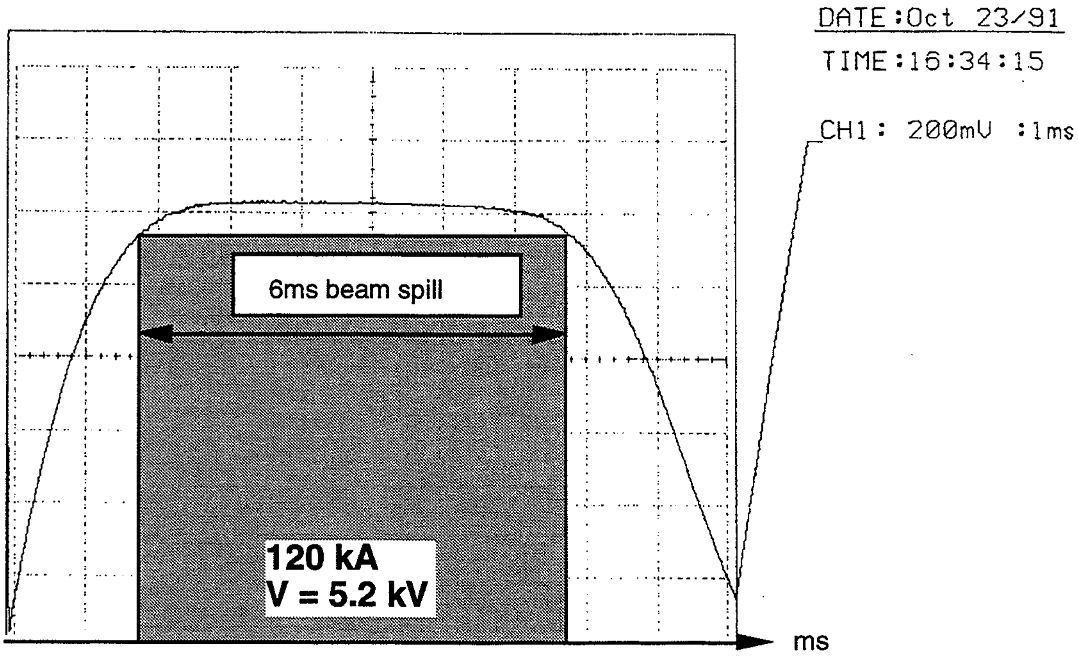
Inductance and resistance of the secondary strip-lines as well as resistance and stray inductance of the transformer are included in these values.

EQUIVALENT REFLECTOR PARAMETERS SEEN ON PRIMARY OF PULSE TRANSFORMER (measured values)

I1 = 120/32 = 3.75 kA

$L_t$ = 1.1 µH* $(32)^2 \approx$ 1.13 mH $R_t$ = 0.4 m Ω* $(32)^2 \approx$ 0.4 Ω

MEASURED REFLECTOR PULSE DURATION




Measured reflector current

2.5.3.4 Horn and reflector magnetic field

The magnetic induction varies in 1/r.

The maximum value is found on the surface of the neck at smallest radius on the inner conductor.

HORN :

For I= 100 kA at radius r= 10.8mm, the corresponding value is B = 1.85 Tesla.

REFLECTOR :

For I= 120 kA at radius r= 100.0 mm, the corresponding value is B = 0.24 Tesla.

It appears that the mechanical constraints on the inner conductor of the reflector compared with the horn are in the ratio $(0.24/1.85)^2 = 0.017$ and hence much less a problem.

2.5.3.5 Power cables between polarity changer and pulse transformer

The present electrical conditions lead to :
$I1_{rms} = 135$ A
Vc ≈ 6 kV peak corresponding to desired 110 kA.
One primary cable only is installed per system of EDF type : ROQUE ($V_N = 18$kV )
The section of the copper conductor is ≈ 100 $mm^2$

2.5.3.6 Horn and reflector interlock system

Hereafter is given the list of the hardware protection interlocks selected to ensure safe operation : they have direct action independant of the control system.

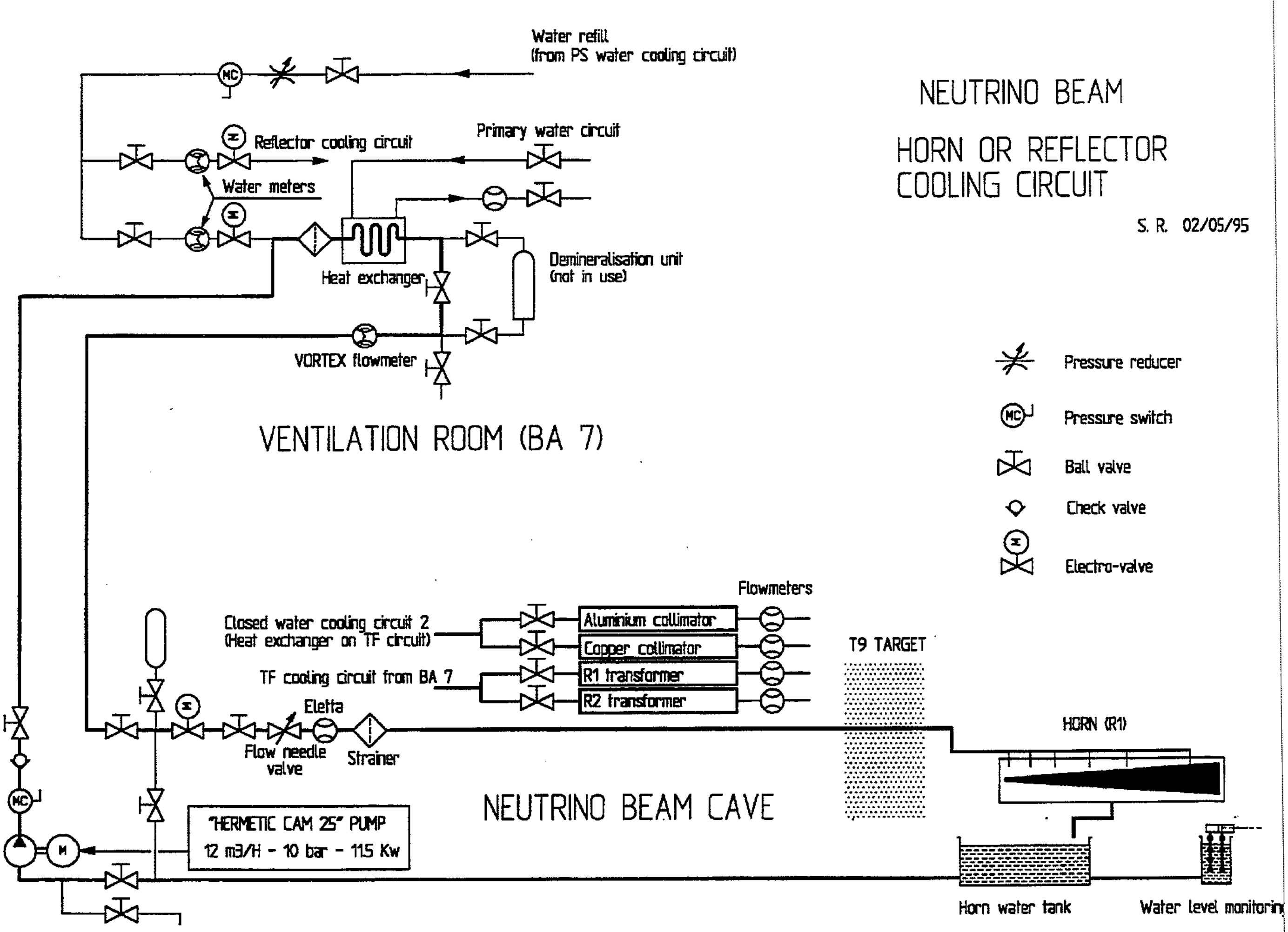
| | |
|---|---|
| charging supply : | - Cabinet doors<br>- 380 v phase failure<br>- Over current on 380v phase<br>- Output overvoltage |
| delay line | - Cabinet doors<br>- Manual switch (open or closed)<br>- Shorting relay (open or closed)<br>- Overvoltage |
| discharge circuit | - No firing<br>- Auto Firing<br>- No discharge<br>- Autodischarge<br>- Overcurrent |
| horn interlock | - Pump on/off<br>- Water exchanger primary waterflow<br>- Waterflow in horn (Vortex & Eletta)<br>- Water temperature of horn<br>- Waterflow in transformer secondaries<br>- Transformer temperature |
| cable | - Primary cable temperature |
| strip line | - Stripline current balance error |
| synchronisation | - No synchronisation of horn |

## 2.6 Horn and reflector cooling systems

The cooling systems of horn and reflector are identical as on figure [c20].

Each system is powered with one Hermetic pump providing 9 bar pressure. The pump is located in the cave 20m in front of the target. The water circuit is a an open circuit where the pump sucs the water from the recuperation tank of the magnetic element and sprays it on the inner conductor with a pressure of 8 bar and a total flow of 75 l/min. The water is cooled through a heat exchanger located in BA7 45m above the cave.

The flow is continuous and monitored with an electronic "VORTEX" flowmeter located in BA7 outside of the radioactive region and showing the analog flowvalue. As additional safety, the water circuit includes also an "Eletta" digital flowmeter with an open contact when the flow falls below a predefined threshold. Both flowmeters cut the power supply in case of insufficient flow.
The waterlevel in the tank is measured and triggers a warning to refill and cuts the pump and the power supply when limits are crossed.

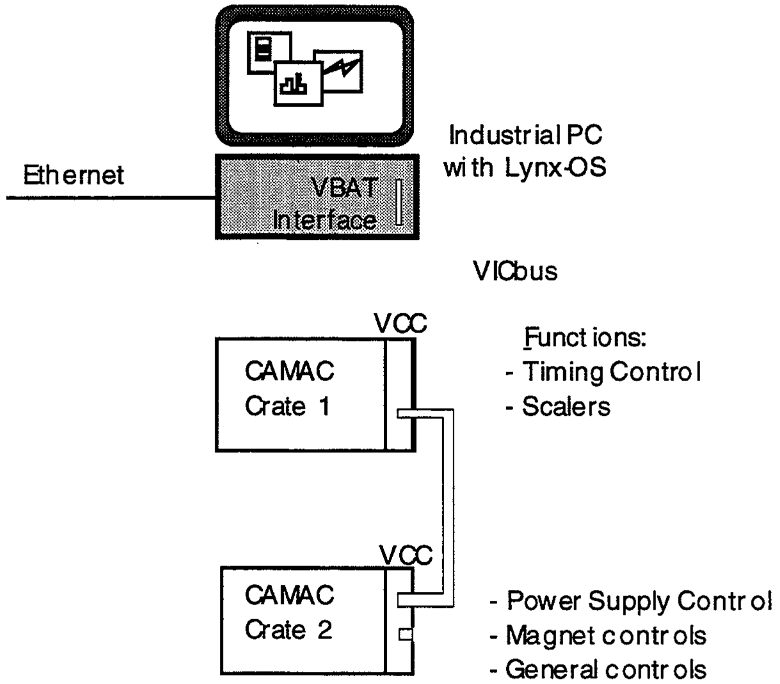



[c20] Water cooling circuits

## 2.7 Controls in NBC zone

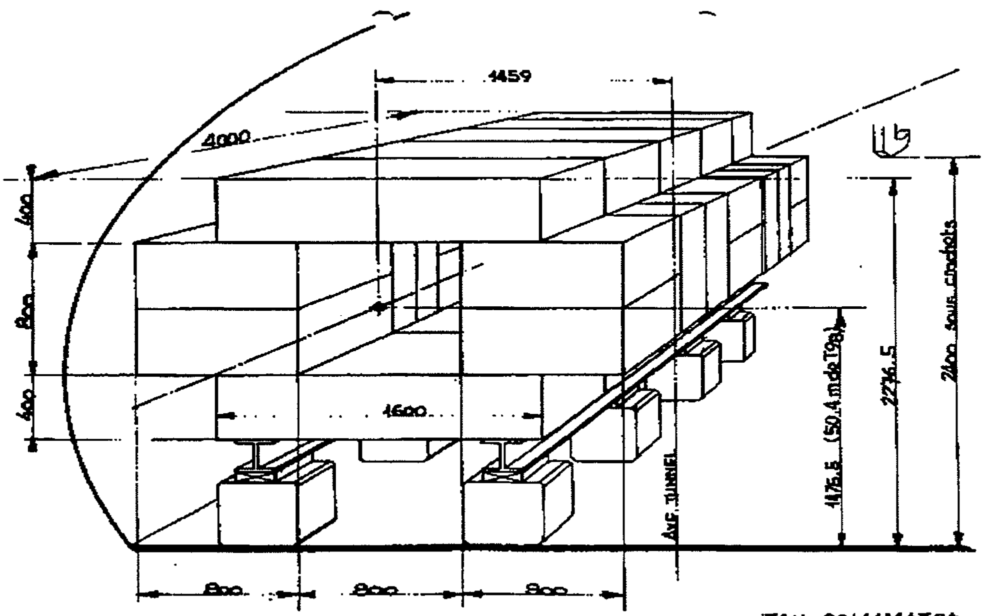
One industrial PC ( with name pcwanf01 ), connected on ethernet and located in BA7 control room, is linked to two CAMAC crates through a VIC bus. This PC is part of the WANF control system and ensures all control functions related to the NBC zone as shown on the next sketch :

**NBC system configuration**

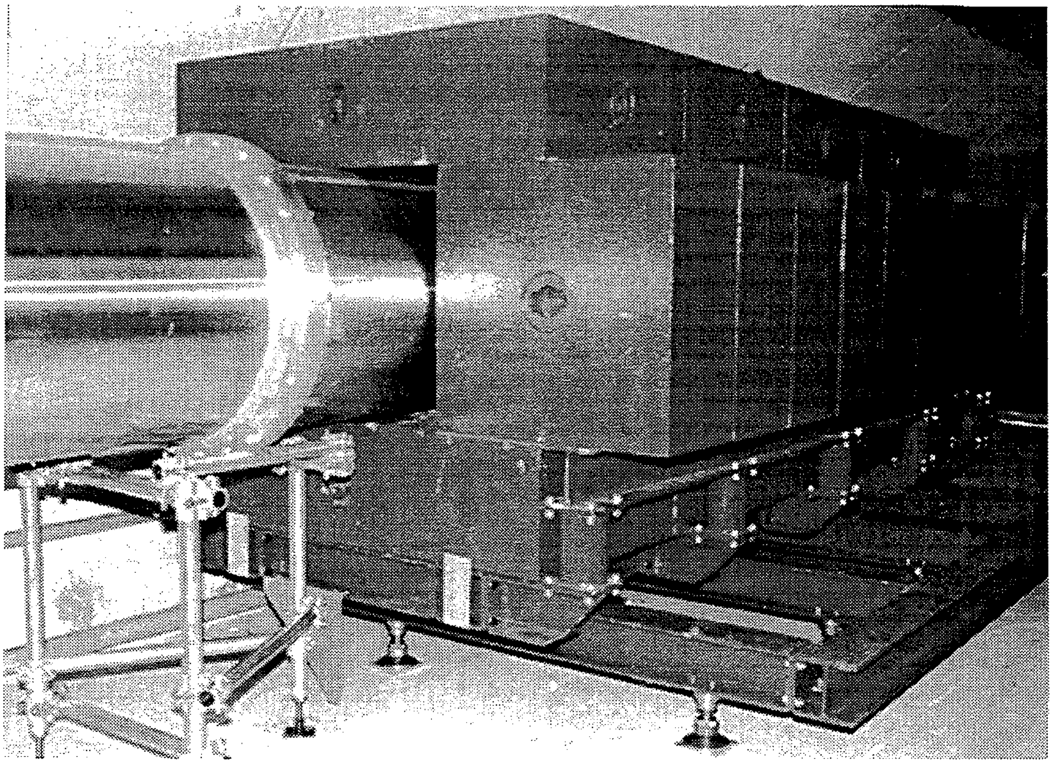



## 2.8 TDX iron collimator

Just for completenes is shown a picture of the iron collimator located 84.85m from point T9. The attached sketch shows the overall dimensions. The aim is to collimate the hadrons in order to reduce wrong sign neutrinos in the detectors induced by parents insufficiently swept away by the horn.




TDX COLLIMATOR



[c21] iron collimator TDX

## 2.9 Helium tunnel

To reduce particle absorption in air, the decision was taken to install a "helium tunnel" consisting of two parts:

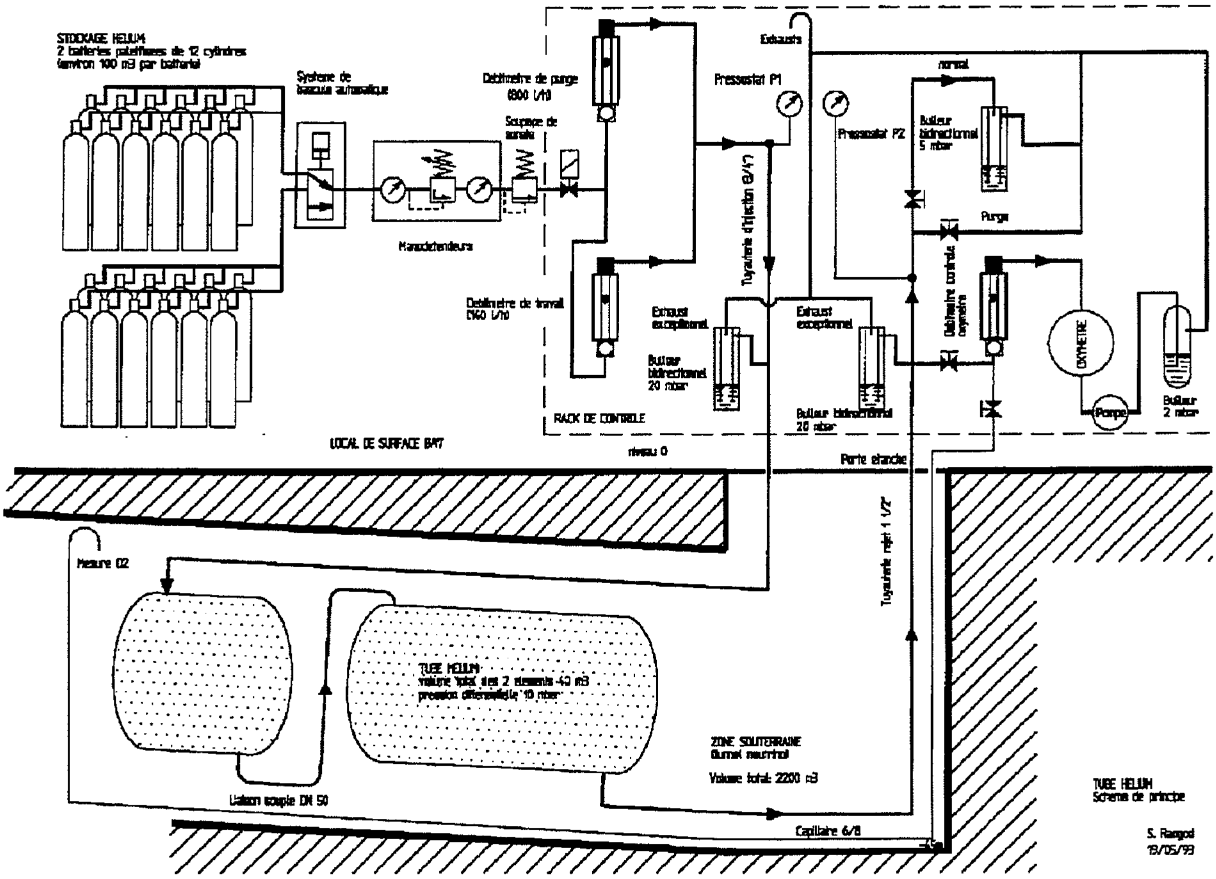
- one length of 63 metres between horn and reflector,
- the other of 18 metres behind the reflector.

(the absorption length is $\lambda$= 800m for air and $\lambda$=2500m for helium)

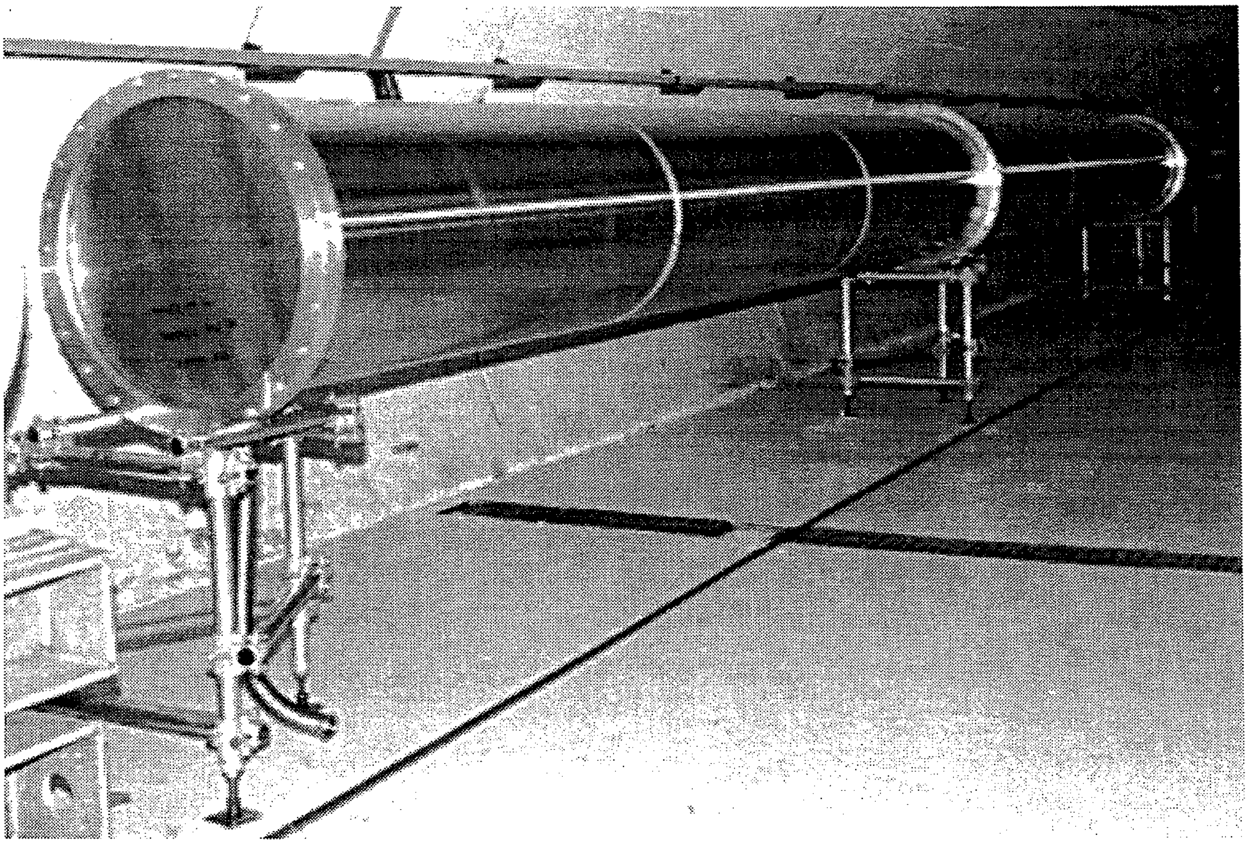
Both ends of each part are closed by a titanium window 0.3 mm thick. A flexible metallic pipe makes a connexion between the two tubes, so as to effectively represent one vessel of 40 $m^3$ volume.

The helium tube is an assembly of 14 aluminium alloy elements of the same diameter. Each element is bolted to the other and has two welded flanges with machined grooves for metallic O-ring seals.

The helium is contained in the tube at a positive differential pressure of less than 20 mbar. An oxygen analyser controls the helium concentration ; the exhaust minimum flow rate, to ensure a good precision of measurement of the He concentration, is about 30 l/h. The helium flow is controlled and adjusted by a flowmeter equipped with a needle valve as can be seen on figure [c22] showing the helium gas system. The beam entrance side of the Helium tube starting shortly after the horn is visible on figure [c23].




[c22] helium gas system



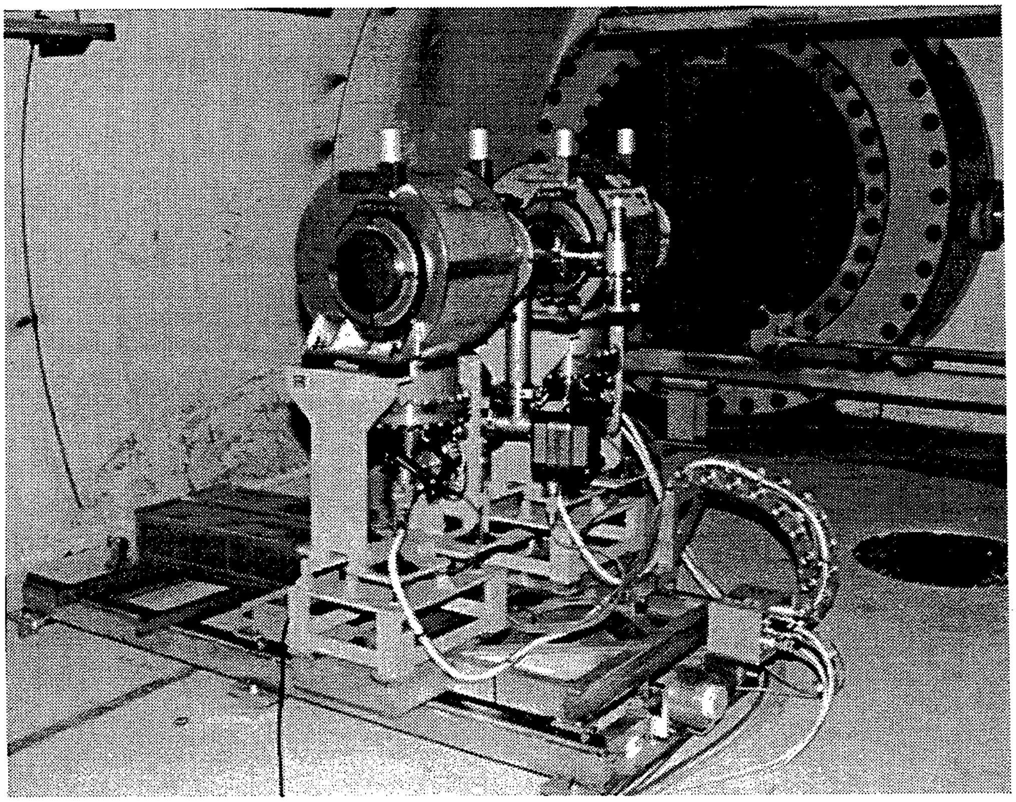
[c23] entrance of helium tube

### 2.10 BSGH and BSGV

Two BSG grid monitors BSGH (with 2 grids of 1.5mm and 5mm resolution) and BSGV (same resolutions) have been installed by the SL/BT group to measure the horizontal and vertical position and profile of the resulting beam of charged particles at a distance of 115m behind the target (see figure [c24]).

## 3. Vacuum decay tunnel

The total length of the vacuum decay tunnel is 289.9m ( see figure [c1] )
The volume to pump is 412 $m^3$ . One trochoidal pump from Leybold-Heraeus with 400 $m^3/h$ capacity is constantly in operation during the runs and ensures a vacuum pressure of 0.5 Torr . It is located on the surface in BA7 with a second identical pump on stand-by.
The decay tunnel is closed on the neutrino cave side by a 2mm thick Titanium window. For safety reasons and to protect against a possible implosion risk, one has installed a motor driven vacuum shutter ( in fact a thick circular steel plate ) which is positioned in front of the Titanium window when someone needs access into the cave and which is automatically driven out of the beam when run conditions are established. This shutter is interlocked with the access conditions in the cave and is visible on the picture below behind the BSGH and BSGV monitors.



[c24] BSGV and BSGH in front of the shutter

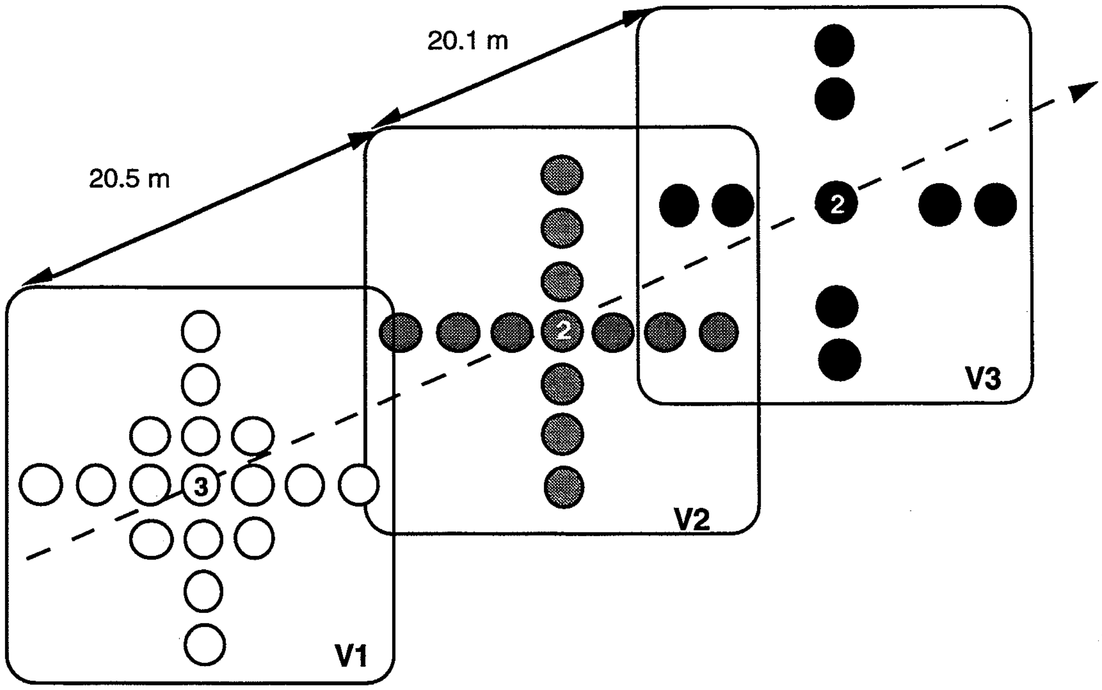
## 4. NFM zone

<u>Introduction</u>
Muon counters in the form of silicon diode detectors are used as in past experiments [1] to monitor in intensity and distribution the muon flux in the iron shielding inside

3 pits (V1, V2, V3). These 3 pits are sufficient to fulfill the following goals:

- tuning of the primary proton beam (through monitoring of the resulting muon beam)
- measurement of the muon flux and thereby indirect measurement of the ν flux
- monitoring of the horn and reflector currents

The distribution in space of the silicon detectors in the 3 pits is shown below:




Muon counters in use

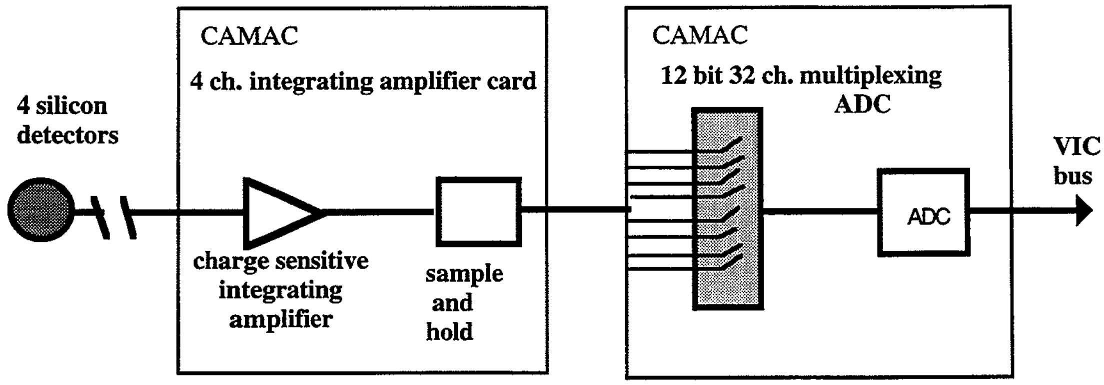
| | length in m | number of muon counters |
|---|---|---|
| air gap in pit V0 | 2 m | |
| iron shield in front of V1 | 4.42 + 6.0 | |
| air gap in pit V1 | 2.65 | 19 + 5 in cal-box |
| iron shield in front of V2 | 20.52 | |
| air gap in pit V2 | 0.98 | 14 + 5 in cal-box |
| iron shield in front of V3 | 20.15 | |
| air gap in pit V3 | 1.05 | 10 + 5 in cal-box |

63 counters are installed in total including calibration and reference boxes; 43 have a fixed position as shown on the sketch. Two counters are mounted on top of each other in the center position of V1,V2 and V3. One fixed additional counter is mounted on the wall in V1.
Each pit is equipped with one moveable calibration box including 5 calibration counters. These calibration boxes are used to do regular beam scans which provide muon flux distributions in addition to those measured with the fixed counters. The movement of the calibration box in each pit is done with 2 d.c. motors (horizontal and vertical) and the positions are read by incremental encoders.

One reference box including 5 reference counters is placed manually in front of one of the calibration boxes during access.

Electronics

The current through the Si diode structure due to the electron-hole pairs generated by the crossing muons is integrated to measure the muon flux according to following priciple:



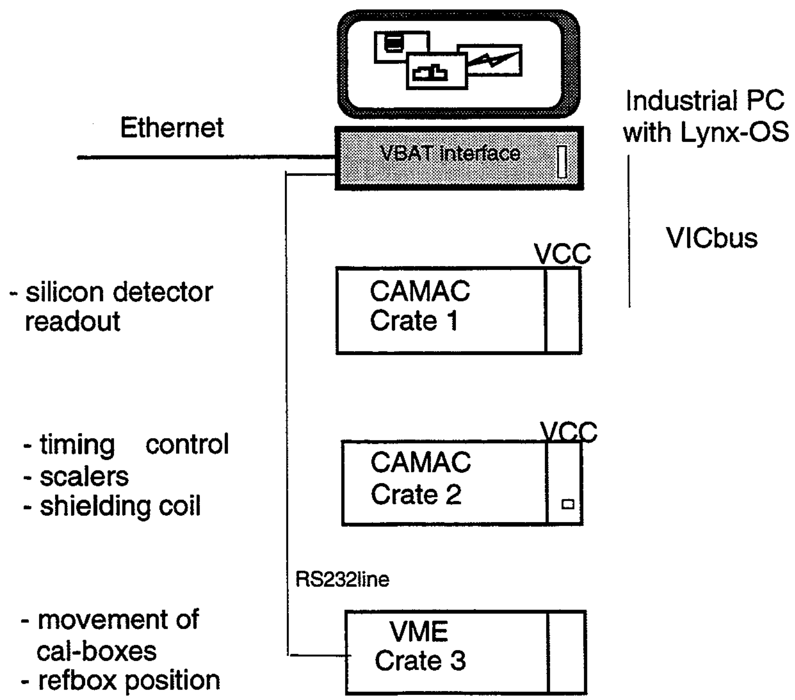

The silicon detector readout is performed in a CAMAC crate located in NFM hut 294. The crate is equipped with 16 charge amplifier integrator cards (4 channel input type) and two 32 channel multiplexing ADC card. [10]

Controls

One industrial PC (with name PCwanf02), connected on ethernet and located in the NFM hut (Building 294), is linked to 2 CAMAC crates through a VIC bus and to the VME movement crate through a serial RS232 line. This VME crate has control of the movements of the 3 calibration boxes in the 3 pits.

The PC is part of the WANF control system and ensures all control functions related to the NFM zone as shown next:

**NFM system configuration**



## 5. Shielding magnet

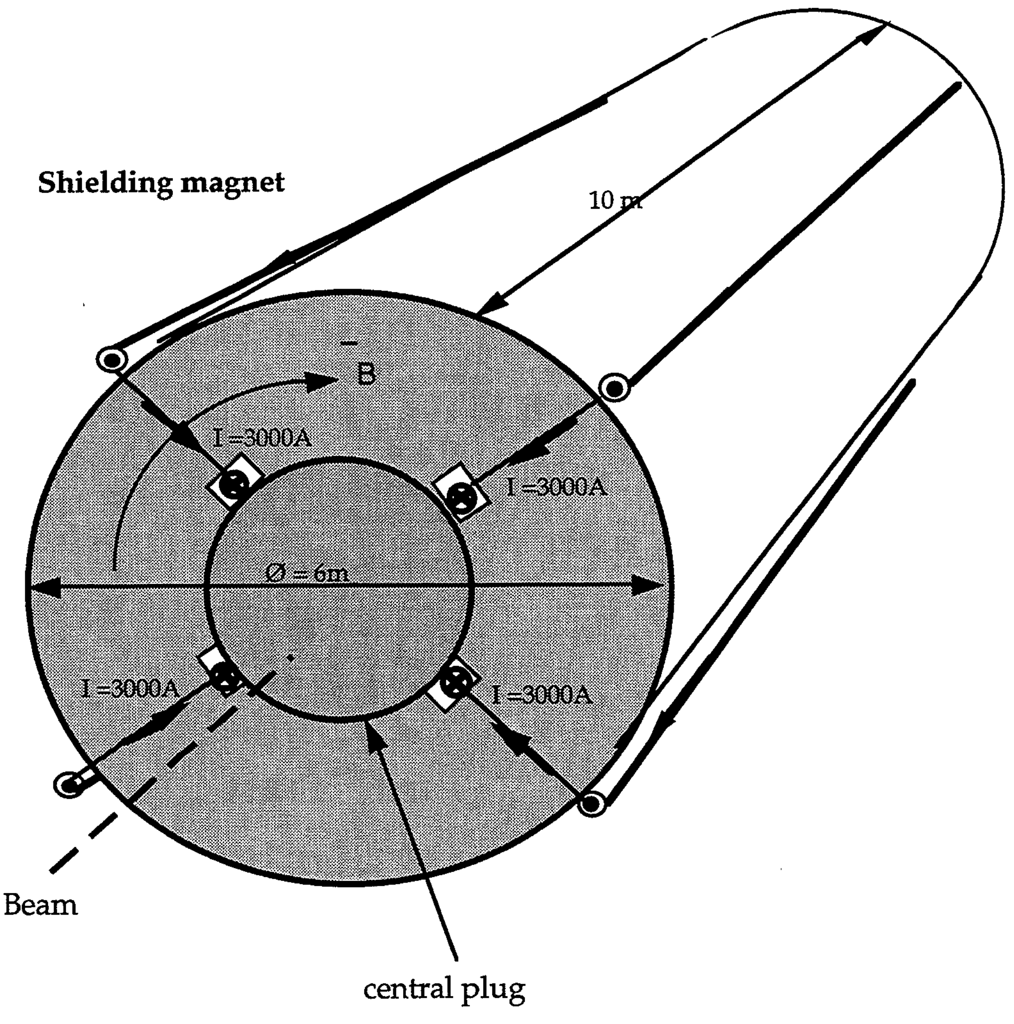
The 10m long toroidal magnet is described in [1] and is located in pit V5. It has an outer diameter of 6m and an inner diameter of 2m, the central 2m diameter iron core being field free.The total bending power for CHORUS and NOMAD operation is 7.2 Tm corresponding to a 3kA excitation current.

The 5V power supply is located in hut n° 846 on the surface, as well as the ventilation system used to force an airflow along the conducting bars of the magnet. This system constitutes a ventilation loop with partial addition of external air.

The temperature of the coil is monitored in several places with Pt 100 probes.

The polarity corresponds to neutrino mode, i.e. positive muon background is focused into the additional shielding, whereas negative background is swept out and away from the detectors.

The shielding magnet (figure [c25] below) has been installed in 1979 together with the 39.5m additional iron shield located downstream of building 274. These additions were necessary to reduce the muon background in the detectors in view of the 450 Gev subsequent operation.




[c25] Shielding magnet

# 6. Distribution of timing and direct beam signals

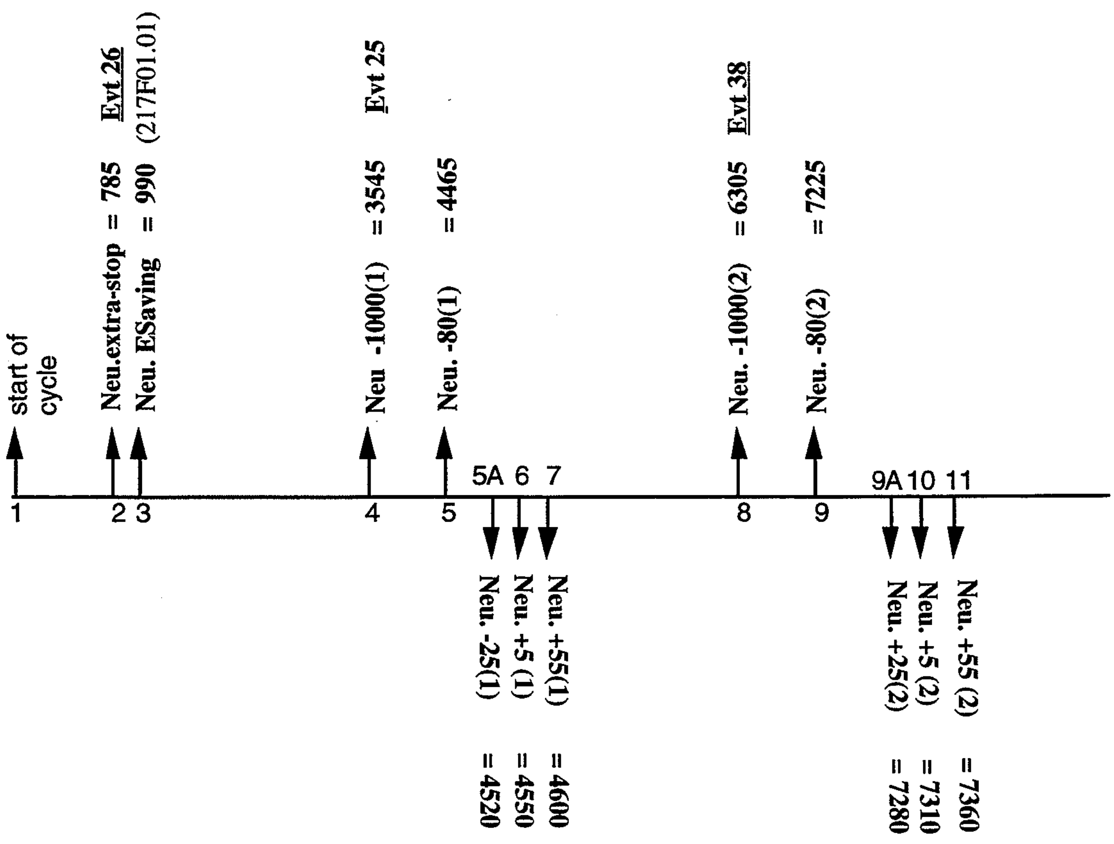
## 6.1 Timing signals

The SPS timing system (G64 crate attached to the timing line of SPS) makes available in BA7 the following list of pulses numbered from 1 to 11 according to the attached chronogram [c26] : (values are given in ms with respect to the start of cycle)

| | | | |
|---|---|---|---|
| **1** | **Start of cycle** | **= 0 ms** | |
| **2** | **Neu.extra-stop** | **= 785** | **EVT 26** |
| **3** | **Neu. ESaving** | **= 990** | (21.7F.01.01) |
| **4** | **Neu -1000(1)** | **= 3545** | **EVT 25** |
| **5** | **Neu. -80(1)** | **= 4465** | |
| **5A** | **Neu. -25(1)** | **= 4520** | |
| **6** | **Neu. +5 (1)** | **= 4550** | |
| **7** | **Neu. +55(1)** | **= 4600** | |
| **8** | **Neu. -1000(2)** | **= 6305** | **EVT 38** |
| **9** | **Neu. -80(2)** | **= 7225** | |
| **9A** | **Neu. -25(2)** | **= 7280** | |
| **10** | **Neu. +5 (2)** | **= 7310** | |
| **11** | **Neu. +55 (2)** | **= 7360** | |

Neutrino beam timing diagram

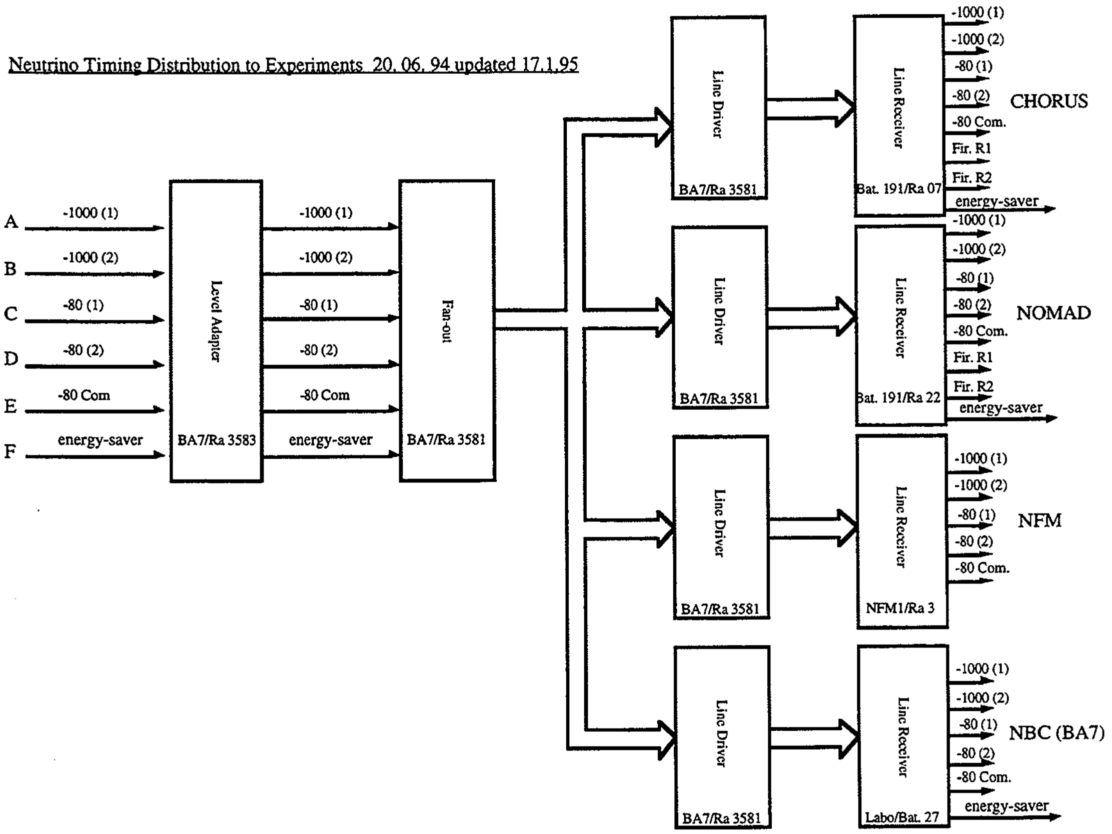
15.11.94 updated 25.4.95




[c26] Chronogram of timing pulses

As said previously, timing pulses are made available in all areas for synchronizing (for each spill ) equipment and data taking to the extraction process. These pulses are all derived from BA7 (except for users in BA6). This place was chosen as the central

distribution point for all timing pulses sent to the beam line users (figure [c 27 ]).
A special energy-saving pulse from SPS has been added in 94. This signal is a warning that no beam is accelerated and avoids pulsing horn and reflector during useless cycles.




[ c27 ]

### 6.2 Direct beam signals

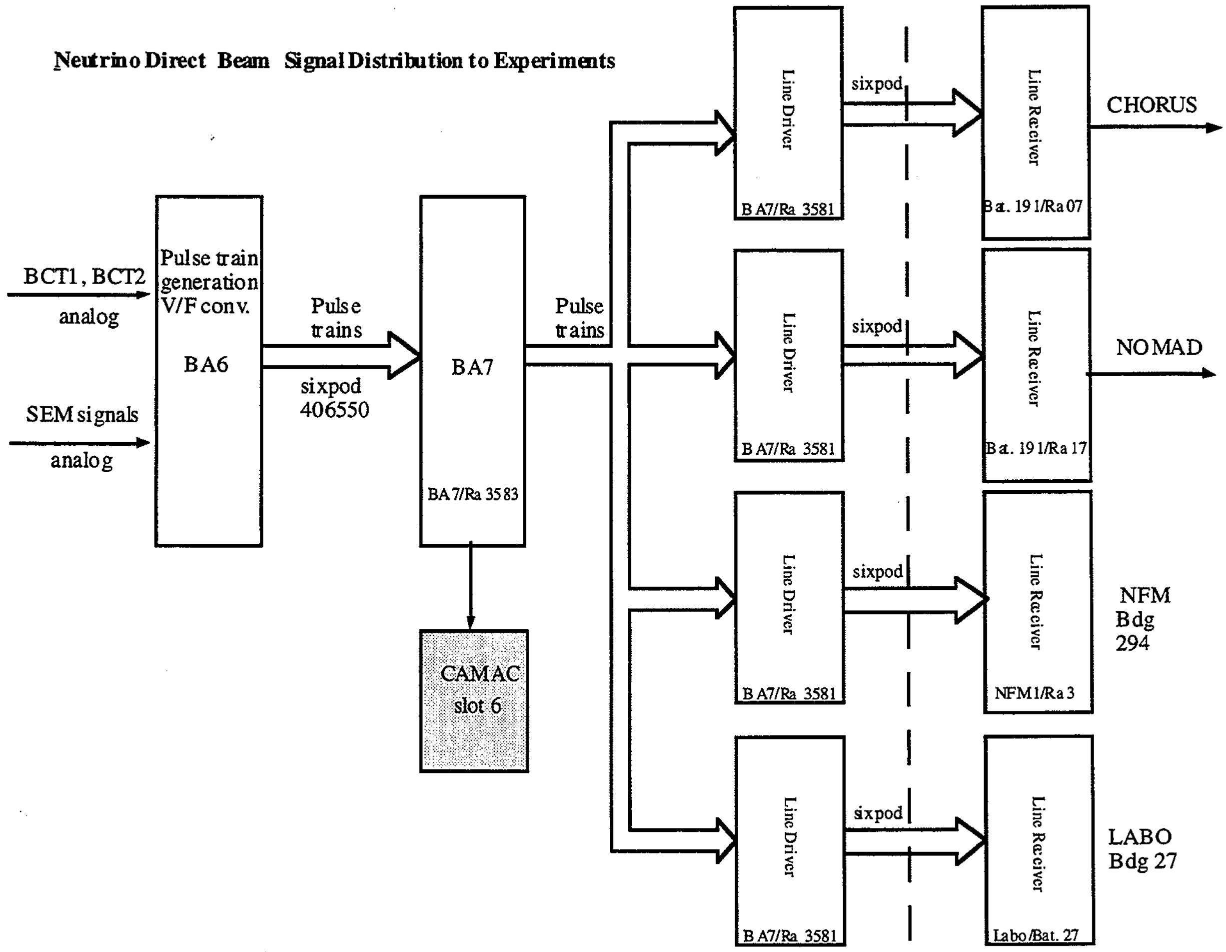
For historical reasons and to remain safe in data taking with respect to network failures, the decision was taken to keep the direct distribution to the experiments of 12 signals related to the quality of the primary proton beam and targetting.
A list of these signals is given below as connected on the sixpod cable in BA6 and read in slot 6 of the BA7 Camac crate :

| twisted pair in sixpod | scaler in slot 6 | |
|---|---|---|
| 1* | | $BCT_{sps}$ analog spill signal with scope display in BA7 |
| 2 | ch 1 | Beam current $BCT_{sps}$ as N x 10**10 protons uncalibrated but normally correct to ±2% ( also transmitted to NFM ) |
| 3 | ch 2 | Upstream split foil LEFT in TBIU in front of target |
| 4 | ch 3 | Upstream split foil RIGHT in TBIU |
| 5 | ch 4 | Upstream split foil UP in TBIU |
| 6 | ch 5 | Upstream split foil DOWN in TBIU |
| 7 ** | ch 6 | HALO1 in TBIU |
| 8 ** | ch 7 | Total UPSTREAM in TBIU |
| 9 ** | ch 8 | HALO2 in TBID behind target |
| 10 ** | ch 9 | Total DOWNSTREAM in TBID |
| 11 | ch 10 | Beam current $BCT_{cave}$ as N x 10**10 proton protons |
| 12 | | Calibration train (Fixed frequency signal) |

* : retransmitted with horn signal, reflector signal and beam simulation pulse to CHORUS and NOMAD as video picture through the TV network and to Building 27.

** : secondary emission monitors unnormalized charge signals

The pulse trains generated in BA6 are sent to BA7 and to the beam-line users according to figure [c 28 ] below:




[ c28 ]

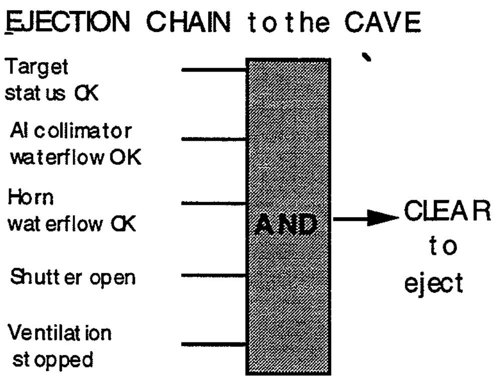
The direct beam signal sixpod in BA6 includes :

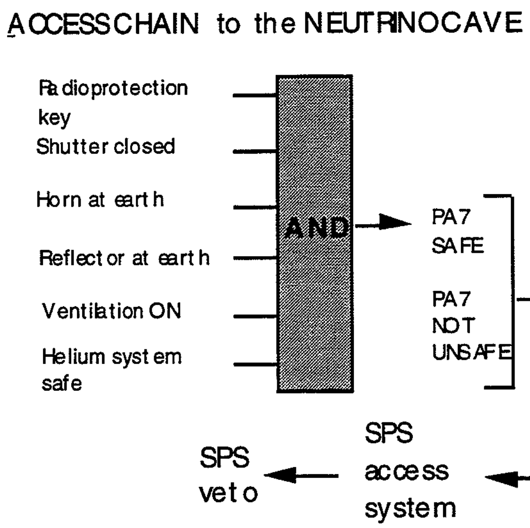
- the analog signal of the spill ($BCT_{SPS}$) sent from BA6 and received in BA7

- the 11 data pulse trains generated in BA7 (~ 150ms after the spill) and retransmitted to CHORUS and NOMAD.

## 7. Access interlock chain / ejection interlock chain

Access to the neutrino cave or authorisation to eject the beam into the cave are conditions which are subject to the clearance of following interlock chains:



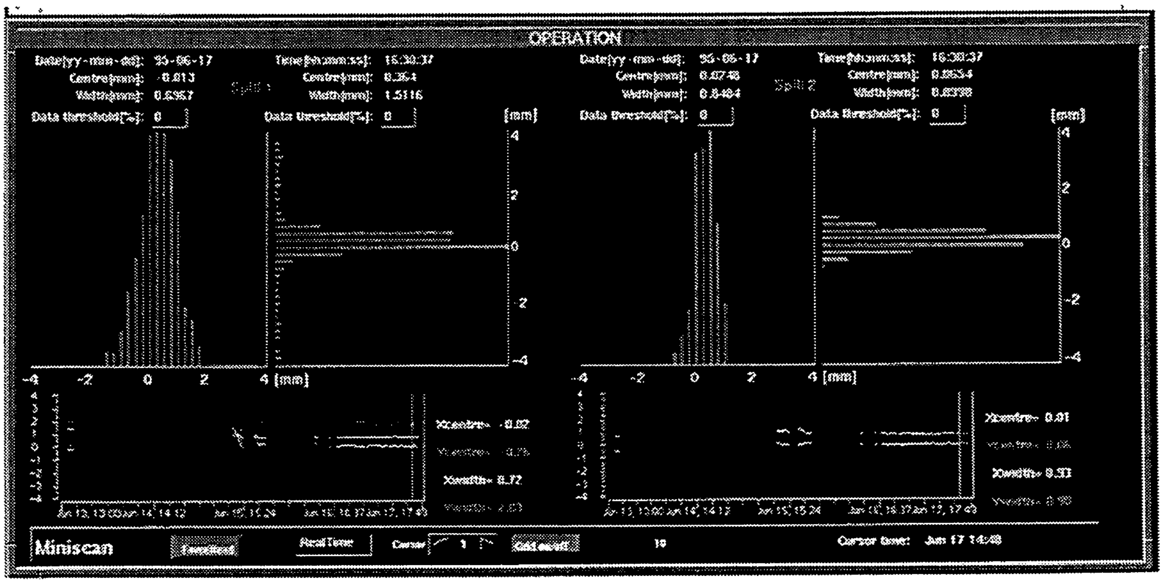




## 8. Beam monitoring

We summarize hereafter the instrumentation used for beam tuning:

- Two beam current transformers BCT1 and BCT2 from SL/BI group are installed along the primary proton beam line to monitor the absolute proton beam flux, the first one just after the ejection scheme at the entrance of the external proton beam line, the second being located in the neutrino cave. All secondary beam data are normalized to the number of protons per spill measured with one BCT.

- Two miniscannners measure once per hour the horizontal and vertical proton beam distribution in front of the target. Each moveable wire scans the beam from - 4mm to + 4mm. A typical miniscan result appears on next figure [c29] separated for spill1 and spill2 :




[c29] Typical miniscan result

- Targetting (see [13]) is monitored with secondary emission monitors (SEM's) located in 2 instrumentation boxes TBIU and TBID:
  <u>TBIU in front of the target includes :</u>
  - one BSPH for measurement of the horizontal position of the proton beam
  - one BSPV for measurement of the vertical position of the proton beam

- one BSH (plate with hole) to measure the halo of the beam
- two BSI to measure the proton beam intensity

TBID behind the target includes :

- one BSH (plate with hole) to measure the halo of the secondary beam
- two BSI to measure the secondary beam intensity

- BSGH and BSGV located in front of the entrance of the decay tunnel (already mentioned in 2.10)
- Fixed muon counters in pits V1, V2, V3 give the instantaneous flux mapping in the pits, whereas one moveable calibration box in each pit enables, beside calibration of the fixed counters, to measure the position and distribution of the corresponding muon beam averaged over a given number of spills.
  Figure [c30] on next page shows a "Factory Link" panel with, amongst other data, the results of a beamscan in the 3 pits for spill 1.

## 9. Beam line control system

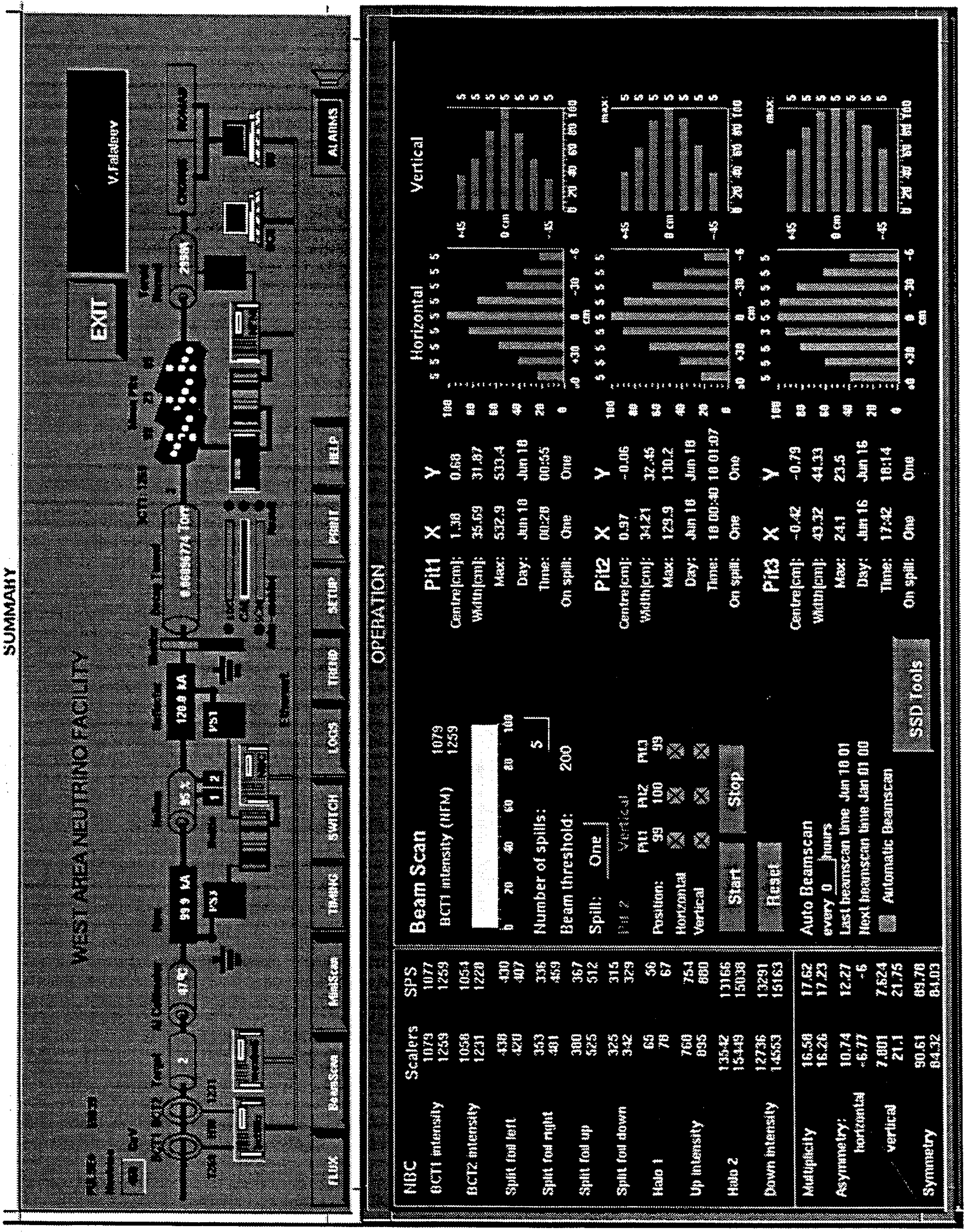
One major development has been the introduction of a new Control System by the ECP-CO group (former controls team set up and headed by W. Von Rüden with D. Myers and two visitors J. Yang and H. Butler ). A description is given in [11] and [12]. This system is based on the industrial controls package, Factory Link, and has greatly improved and facilitated the tuning of the beam-line as well as the operation. It is now fully operational and proves to be highly satisfactory.
All the data are transmitted to the experiments and, since beginning of 95, collected to the beam data disk.

## 10. Conclusion

After completion of the CHARM II physics programme in October 91, the neutrino cave has been entirely dismantled. This particularly difficult cleaning work in the highly radioactive cave started in February 92 and was finished in June 92.
The refurbishment of the cave and of the 3 muon pits V1, V2, V3 began in January 93 and ended in September 93, shortly before the start of the first beam test for CHORUS and NOMAD which took place in October - November 93.
One full year of operation has since then been achieved in 94 and physics program is scheduled to continue until end of 97.

## 11. Acknowledgements

Many groups have collaborated to rebuild the new neutrino beam-line :
SL-BT, SL-BI, ST-CV, ST-HM, TIS-RP, AT-SU, ECP-CO, ECP-EDI and ECP-ESI (former ECP-EDN). We would like to thank all who provided us with help or advise and, in particular, W. von Rüden and the CO group who equipped the beam line with this very efficient and user friendly new supervision system. We thank also for the continuous support given to this project by P. G. Innocenti, F. Bourgeois and P. Lazeyras.




[c30] Beamscan panel