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SPS Safety Chain Modification for the LHC Transfer Lines and the Long Baseline Neutrino Facility

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Summary

For the LHC two new transfer lines will be built. TI 2 leaves the present West extraction zone, while TI 8 involves the construction of a new extraction channel (East Extraction) in LSS4. In addition there is a proposal to construct a long baseline neutrino facility based on the east extraction zone. The construction of these will require significant modifications to the SPS safety chain system. The proposed modifications are given, together with the associated machine interlocks for each access area. The restrictions that will apply to access in certain areas while operation continues in others will be detailed, together with any open questions, which remain.

1. Introduction

Modifications have to be made to the present safety chain system of the SPS in order to accommodate the new restricted zones that are to be constructed for the LHC transfer. In addition there is presently a proposal to construct a long baseline neutrino facility (NGS), attached to the SPS machine [1]. This would significantly change the requirements. This note details the present knowledge of the changes to the SPS safety chain system, and is based on the assumption that the long baseline neutrino facility goes ahead.

The safety elements mentioned in this report that will be installed in the LHC transfer lines are named according to the present layout drawings for these lines [2].

2. The SPS Safety System

The controlled areas of the SPS and experimental areas are split into access zones. Each zone is bounded by interlocked doors or gates. Pairs of safety chains cover the beam and access requirements for each zone of the machine. These are the ACS/MIS chains. In each case an access chain (ACS) is paired with a beam interlock chain (MIS). There are presently 12 paired chains covering the SPS, together with the north and west experimental areas.

The state of each chain depends upon a set of safety elements, beam elements for the MIS chain and access system status for the ACS chain. Access in a given delimited zone can only be granted if the associated MIS chain is in the correct state to prevent beam. Likewise, machine interlocks can be lifted and beam put through a zone only when the corresponding ACS safety chain is in the appropriate state. The pairing of a MIS and an ACS chain is made in such a way that only one of them is allowed to be active. This is determined by the position of a key on the access console. The key cannot make the chain active unless all conditions attached to that chain are fulfilled.

There are several types of safety elements related to a particular access zone. These include:

Machine Interlocks: Beam elements that prohibit the passage of beams or high levels of radiation produced by beams, in the access zone.

Buffer Zones: In many cases a buffer zone is provided between the zone where access is permitted and zones where beam is present. In a buffer zone no access is allowed, but no beam is present.

Passive Elements: Chicanes are sometimes used to reduce the extent of the buffer zone required between access and beam zones.

Local Interlocks: These are connected to elements that may themselves form hazards to a person in a given zone. Typical hazards include those posed by high power electrical equipment and those posing a danger of oxygen deficiency or containing dangerous gasses.

Radiation Veto: In certain areas the residual radioactivity in a zone can be high enough to be a significant hazard. A veto on access is imposed until the radiation level has fallen sufficiently to allow access.

In order to achieve a sufficiently high level of security, a certain amount of redundancy is employed. There are always at least two independent active beam elements (e.g. dipole magnets) in the machine interlocks. Each element by itself will cut the beam in the case of a break-in or emergency stop. These elements are sometimes backed up by passive devices (e.g. beam stoppers) which take some time to get into the beam-in position and are not fail-safe. All of the machine interlock elements are situated upstream (beam wise) of the access zone in question. The choice and location of safety elements with respect to the access zone in question is determined not only by its ability to stop the beam, but by the radiation generated by the loss or dumping of the beam at this element being sufficiently attenuated before arriving in the access zone.

3. Modification to the West Extraction Zones for TI 2.

3.1 Present Situation

The west area of the SPS contains an experimental hall (EHW1), presently used for detector tests and a neutrino facility for the recently terminated experiments, CHORUS and NOMAD. In addition the electron beam coming from the PS, and destined for LEP, is injected into the SPS via the transfer line TT70. The different beam lines join the primary extracted beam line, TT60, in a region called the switchyard, TCC6. The test beams are derived from a target, T1, placed just at the end of TCC6. To accommodate the different access and safety requirements of these areas four different zones are defined. An additional zone (zone 1) covers the SPS ring itself. The present situation in the west area is shown schematically in figure 1. Each zone has an associated safety chain which includes all the machine interlock elements needed to allow safe access in this region. Thus zone 1 is protected by safety chain 1. In addition to the changes required for the addition of TI 2, other modifications will be needed. These are detailed in section 3.2. The zones and associated safety chains forming the west area machine interlock system are described below.

Zone 1: SPS Ring

Covers access into the SPS ring itself and the initial part of TT60. It requires cutting major elements of the SPS machine (to prevent circulating beam) and the prevention of beam arriving from the PS.

Zone 4: Switchyard (TCC6)

Covers the switchyard area, the target T1, the initial part of the secondary beam line to EHW1 and a portion of TT70 to the PS. Access is possible in this region with beam in the SPS ring, but the extraction of any beam towards the west area must be prevented. The interlocked elements are shown in figure 1 and include the extraction septa, a full-beam

stopper (TED6103) and two sets of dipole magnets in the initial part of TT60. Elements of TT70 are cut to prevent beam arriving from the PS along this line.

Zone 6: Neutrino Target and Beam-line

Access in this zone is permitted with beam extracted from the SPS as far as the stopper (TED6103) in TT60. In addition to the active beam elements in the chain, there are several local interlocks concerned with the target and secondary beam line equipment.

Zone 7: Neutrino Pits

This zone contains the muon shielding for the neutrino facility. Access is allowed once the primary proton to the neutrino target is vetoed with interlocks on the fast/slow extraction kicker, together with two dipoles in the beam line (MBS6600 and MBS6601). Beams can still be extracted to EHW1.

Zone 8: West Area Secondary Beam-lines

This zone covers the experimental regions in EHW1, together with the beam-lines serving it. With access in this area beams can continue to be delivered to the other zones in the west area.

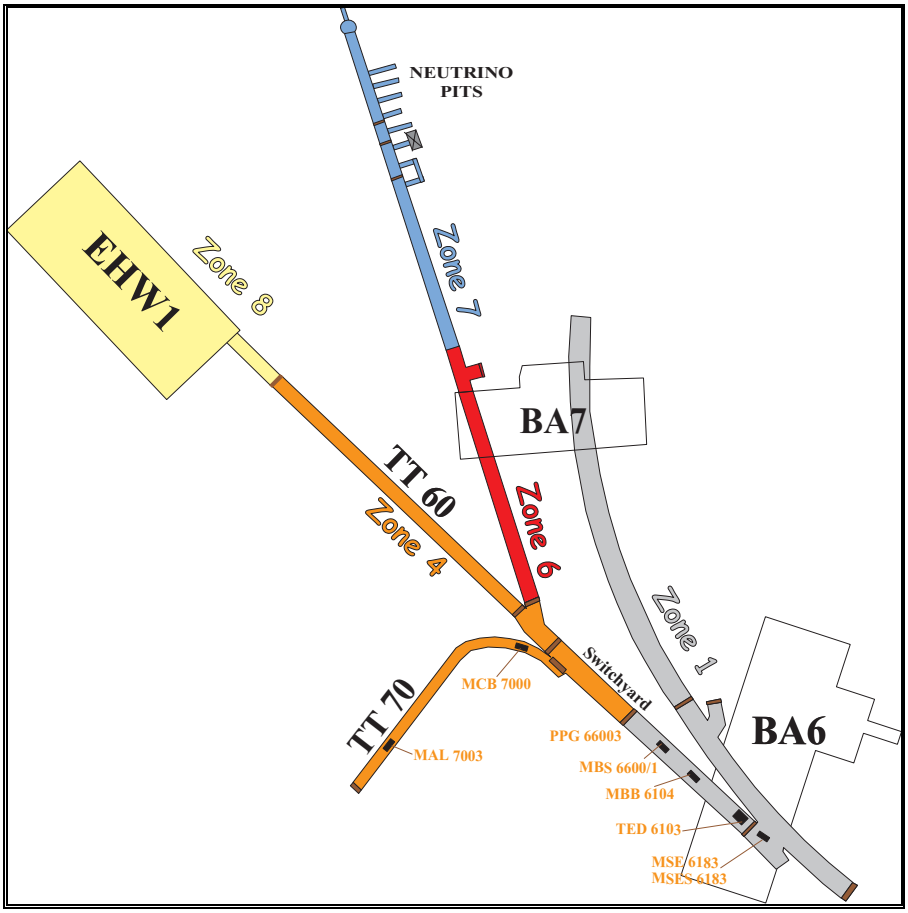

Figure 1: Present Arrangement of the SPS Access Zones in the West Extraction Area

3.2 Modifications to the West Area Not Associated with LHC or NGS

Once the operation of LEP as an e^+e^- collider ceases at the end of the year 2000, the SPS will no longer be required to accelerate leptons. The transfer line TT70, which delivers electrons to the SPS will be dismantled and the equipment re-used elsewhere. As a consequence the safety elements associated with zone 4 will be modified to remove the two elements of TT70 which presently have to be cut to grant access in the switchyard area (MCB7000 and MAL7003). In addition the MSES6183 will be removed. This is a shunt

supply to the extraction septa (MSE) and is used exclusively for the extraction of positrons. The interlocked access doors within TT70 will be maintained and a buffer zone created at the SPS end of TT70, where access cannot be granted with beam enabled in the west area. The remainder of the line will be used for storage with access from the PS end. The modifications described in section 3.3 assume that these changes have been made.

The present physics programme for the west area neutrino facility (WANF) came to an end in 1998. However, there is no official decision as to the long-term future of this facility. For the purpose of the present document it is assumed that the WANF will continue to operate. Under this assumption, zones 6 and 7 will continue as presently defined.

3.3 Modifications for the LHC Transfer Line TI 2

For the purpose of the personnel safety system TI 2 will be split into two zones, separated by an inter-zone gate. The exact position of this gate has yet to be defined, but is likely to be approximately 700 m after the start of TI 2. The upstream part will be treated as an extension to zone 4 of the west area, described above. Access to this zone will therefore prevent any beam being extracted towards the west area. The lower part of TI 2 will form part of the LHC access system. Access in the nearby octants of the LHC machine, or the lower part of TI 2, will require elements in the upstream part of TI 2 to be cut. The new security elements of TI 2 are shown schematically in figure 2.

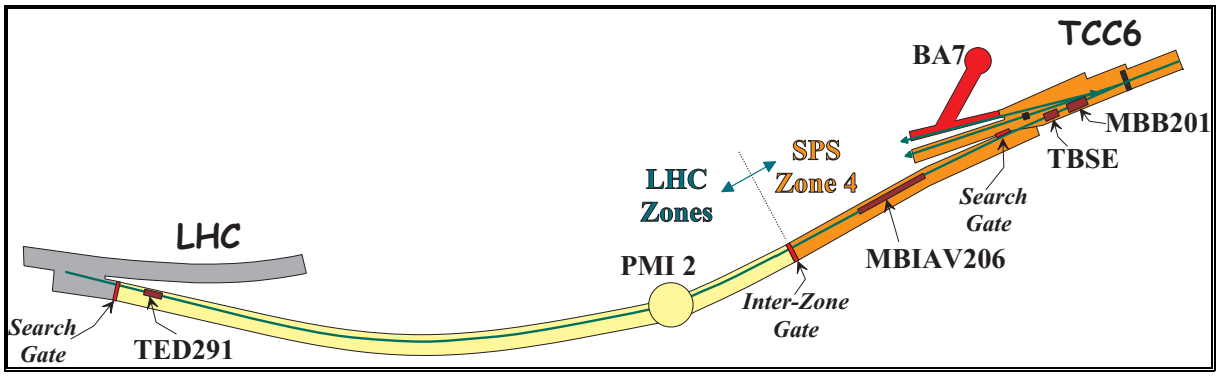

Figure 2: Schematic Layout of TI 2 Showing the Planned Security Elements

Table 1: Summary of Safety Elements and Beam Status for Access in the Upstream and Downstream Parts of TI 2.

	Machine Safety Elements		**Beam Status**			
Access Zone	**Element**	**Description**	**West Area**	**Neutrino**	**TI2**	**LHC**
SPS TCC6	MSE6183	Extraction Septa	OFF	OFF	OFF	
+ TI 2	TED6103	Full Beam Stopper				
(Upstream)	MBB6104	TT 60 Dipole Magnet				
LHC	MBB201	TI 2 Dipole Pair			OFF	OFF
+ TI 2	TBSE	Beam Stopper				
(Downstream)	MBIAV206	TI 2 Dipole Chain				

Table 1 shows the modified safety elements required for access in the upstream and downstream zones of TI 2. The conditions for access in the west experimental area and the WANF remain as presently described in section 3.1. For reasons of economy it is planned to

use the same power supply for the MBB201 dipole pair in TI 2 and for dipoles in the final part of the primary beam line before the target T1. A mechanical switch will be used to connect the power supply to one or the other. The safety interlock will therefore be on the position of the mechanical switch.

For the moment it is assumed that any access in the LHC requires the transfer lines to be cut. It remains to be seen if access to distant octants of the LHC can be granted with beam permitted to the TED at the end of TI 2. This will require sectoring of the LHC ring and interlocks to prevent powering of the LHC elements in the injection octants.

It should be noted that giving access in the SPS itself would normally require elements of TI 2 (and TI 8) to be cut. These would prevent beam in the LHC being extracted and sent backwards up the transfer lines to the SPS. However, with the two-ring design of the LHC and the placement of the injection point, beams in the LHC cannot be sent backwards up the transfer lines. For this reason no interlocked elements in TI 2 and TI 8 are foreseen. As this situation is different from that found in the other CERN accelerators, it is worth explaining why, in the case of the LHC, beam cannot be extracted and sent back towards the injectors.

The LHC is a proton-proton collider, with the two beams travelling in separate vacuum chambers within the same magnets. The field polarity within one chamber is reversed with respect to the other to allow the two beams to counter-rotate. Within the insertions the two beams are brought together within the same chamber. The beam from TI 2 is injected into ring 1 of the LHC. This beam circulates clockwise round the LHC and is travelling in the wrong direction to be extracted once more from TI 2.

Beam injected from TI 8 travels in ring 2 of the LHC. It is moving in the right direction, but in a different vacuum chamber. It could be switched from ring 2 to ring 1 if the polarity of the LHC elements D1.L2, D2.L2, Q5.L2 and Q6.L2 had their polarity reversed. The beam could then be extracted up TI 2 if the polarity of the kicker, the septum and every element of TI 2 was also reversed. The reversal of the polarity of so many elements would be a major undertaking. In addition the beam cannot circulate in the LHC with these elements inverted. It would therefore have to be injected from TI 8, making 3/4 of an LHC turn, before being extracted up TI 2. As the source of beam to TI 8 would not be available with access granted in the SPS, a new 450 GeV/c source of protons would have to be built. Similar arguments apply for TI 8. Under these circumstances it is clear that there is no danger of beam from the LHC arriving in the SPS during an SPS access.

4. The Access and Safety System for the New East Extraction and TI 8.

4.1 Introduction

At present there is no extraction from the SPS in the region of LSS4. A complete set of safety chains has therefore been designed to protect all of the underground areas associated with the new extraction. In addition there is a proposal [1] to build a new neutrino facility, which would derive its beam from the new east extraction. Although not yet an official CERN project, the construction, layout and planning for this area have been made in such a way that this possibility is not excluded. For this reason the access zones have been designed under the assumption that the neutrino project goes ahead. Not building the neutrino facility would represent a major simplification, but not a modification to the system outlined.

Figure 3 shows a schematic view of the new east extraction, together with the LHC transfer line, TI 8 and the planned neutrino line, TN4. Five access zones have been defined, each one with its own set of interlocked elements. These are marked zone A-E and are described below.

4.2 Index of Underground Area Names

LSS4 : Long Straight Section 4 of the SPS
ECX4 : The part of the LSS4 cavern that is considered as part of the SPS machine.
ECA4 : The part of the LSS4 cavern, which is outside the radiation shielding and is accessible with beam in the SPS ring.
TT40 : The common part of the extraction beam line for LHC and neutrino.
TA40 : The access gallery joining TT40 to ECA4, where no beam-line passes.
TJ8 : Enlarged switchyard cavern, after TT40, where the two beam-lines are separated but are within the same tunnel.
TI 8 : LHC transfer line.
TN4 : Primary proton beam line to the neutrino target.
AGN : Access Gallery to the neutrino target zone and TN4.

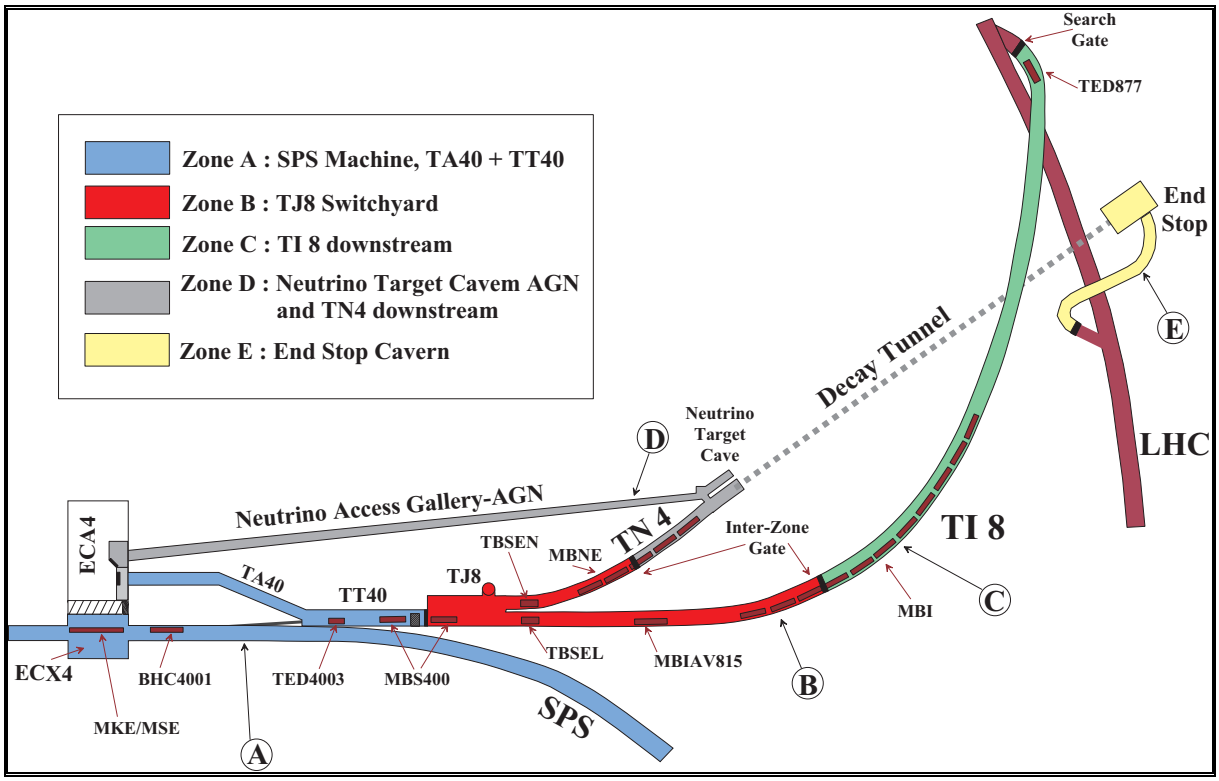

Figure 3: Schematic of the New East Extraction together with TI 8 and the Proposed Underground Areas for the Neutrino Facility.

4.3 Description of the Underground Areas and Access Zones

Zone A

This zone includes the TA40 access gallery and TT40 itself. Most of this zone is within the radiation limit of the SPS tunnel. Access can only be permitted here with no beam in the SPS machine. It can therefore be considered an extension to the SPS main ring zone (zone 1), which was mentioned in section 3.1.

Zone B

The switchyard, within the cavern TJ8, is outside the radiation limit of the SPS and can therefore be accessed with beam in the SPS. However no beam can be extracted towards TT40. It should be noted that access to this area is only possible via one of the adjacent zones, zone A, C or D (see figure 3). There will be no access point within the zone itself. The upstream sections of TI 8 and TN4 will be included within this zone. This is to ensure that all safety elements for the downstream zones are within this zone, and to provide a

sufficiently long buffer zone without beam. The exact positions of the inter-zone gates connecting to zones C and D (see figure 3) is yet to be fixed. They will be determined on the basis of the arc length in each tunnel required to ensure a sufficiently low radiation level is present at the position of the gate when access is granted to the downstream zones, or a break-in or emergency stop occurs in zone C or D.

Zone C

This zone covers the downstream part of the LHC transfer line to the junction with the LHC. Access in this zone will be permitted with extraction of beam from the SPS. Two active elements and one passive element are provided for security. During access to this zone, beam can continue to be delivered to the NGS via TN 4. Note that access in this zone implies that there is no circulating beam in the LHC.

Zone D

Access to the neutrino target cave, via the AGN, can be permitted providing that no beam is transferred towards TN4. Access to this zone should therefore be possible with beam delivered to the LHC via TI 8. The downstream section of TN 4 itself is included within this zone.

Zone E

Access to the end-stop cavern has the additional requirement that access be granted in the LHC. This zone can only be accessed via the LHC. As a consequence, once access has been granted to this zone, the LHC will not be permitted to terminate access and enable beam until this zone has been cleared. Access in this zone implies no beam in TN4 as the resulting muon beam would be hazardous for personnel in this zone. In addition, access in the LHC implies no beam in TI 8. As beam is therefore not permitted in either line, the TED4003 in TT40 should be put in. In addition, two active elements are chosen for each of the two transfer lines.

4.3 Interlocked elements for the East Extraction, TI 8 and TN4

Description of Security Elements

The following list is a mixture of individual elements and externally defined interlock chains. Using these elements, the required interlock conditions for access in each of the zones A-E can be determined. These are given in table 2, together with the beam status in the other regions.

SPS OFF : Access permitted to the SPS machine. All elements of SPS chain 1 cut.
MKE/MSE : East extraction kickers and magnetic septa.
BHC4001 : 3 Dipoles situated within the SPS tunnel for the extracted beam to TT40.
TED4003 : Full-beam stopper situated within TT40 and upstream of the switch magnets.
MBS400 : Neutrino switch magnet chain.
TBSEL : Safety stopper at the beginning of TI 8.
TBSEN : Safety stopper at the beginning of TN4.
MBIAV815 : Chain of vertical bends towards the beginning of TI 8.
MBI : Main chain of horizontal bends in TI 8.
MBNE : Main chain of horizontal bends in TN4.
TED877 : Full-beam stopped situated at the downstream end of TI 8.
LHC OFF : All elements cut to allow access in the LHC machine tunnel in IP8.

It should be noted that it is planned to make use of the same power converter for the interlocked elements MBI (for TI 8) and MBNE (for TN4). This will be switched from one

chain to the other. The safety interlock will therefore have to be on the position of the switch determining the chain that is powered. In addition, for access in the end-stop (zone E), both the MBI and the MBNE chains must be cut. The interlock in this case will be on the power supply itself and independent of the switch position.

Table 2: Summary of Safety Elements and Beam Status for Access to the Zones A-E in the East Extraction, TI8 & Neutrino Region

			Beam Status					
Zone	**Description**	**Interlocked Safety Elements**	**SPS**	**TT40**	**TJ8**	**TI8**	**TN4**	**LHC**
A	SPS+TT40	SPS OFF (Chain 1)	OFF	OFF	OFF	OFF	OFF	
B	TJ8 + TI 8 upstream + TN 4 upstream	MKE/MSE, BHC4001, TED4003		OFF	OFF	OFF	OFF	
C	TI 8 Downstream	MBIAV815, TBSEL, MBI, LHC OFF				OFF		OFF
D	AGN + Target Cave + TN4 downstream	MBS400, TBSEN, MBNE					OFF	
E	End-Stop Cavern	TED4003, MBS400,MBNE, MBIAV815, MBI, LHC OFF			OFF	OFF	OFF	OFF

5. Access in the LHC.

From tables 1 and 2, the elements shown in table 3 must be cut to prevent injection into the LHC machine. To permit access within the LHC, additional elements to those shown in table 3 will be needed to prevent beam circulating in the machine itself. These elements form part of the LHC machine and are outside the scope of the present paper.

Table 3: Safety Elements in the Transfer Lines for Access within the LHC Machine

Transfer Line	**Interlocked Safety Elements**	**Description**
TI2	MBB201 TBSE MBIAV206 TED291	Horizontal Dipole Magnet Pair in TCC6 Safety Stopper in TCC6 Vertical Dipole Chain in TI2 Full-beam stopper
TI8	MBIAV815 MBI TBSEL TED877	Vertical Dipole Chain in TI8 Horizontal Dipole Chain in TI8 Safety stopper in TI 8 Full-beam Stopper

The present layout of the transfer lines specifies a beam stopper at the downstream end of each line. These will allow beam to be sent down the transfer lines without injection into the LHC. They are not presently required to fulfil the need for three independent interlocked

elements. However it is planned to split the LHC into sectors from an access point of view. This will allow machine testing over certain zones, including the access tunnels with beam, to be carried out while access is given in other sectors of the machine. The details of the conditions required for sectoring the LHC have not yet been specified, but the two beam stoppers at the end of the lined will certainly be used. Additional elements of the LHC will need to be cut to prevent the injection of beam into the LHC. The two beam stoppers will also play an important role during machine commissioning. For these reasons they are included in the list of safety elements in table 3.

6. Conclusion

The safety elements and access zones for the LHC injection lines together with the proposed NGS facility have been defined. Within each zone the exact positioning of interlocked doors and search zones remains to be clarified. The present scheme attempts to minimise the interference between access in one area and operation in another. Some questions remain to be clarified:

- The dipole chain MBNE for the neutrino facility and the chain MBI in TI 8 share a power converter. Two separate levels of interlocks will have to be provided on this power converter. For access in either zone C or D (or the LHC) the interlock will be on the position of the mechanical switch determining which magnet chain is connected to the converter. If access is granted in both zone C and D, or in zone E, the switch is not sufficient and the power converter itself must be interlocked off. The way in which this can be achieved requires investigation.
- The stoppers at the end of each LHC transfer line are not presently required for access in the LHC. They could, however, be used as an extra level of security. In addition they will be used as part of a scheme to allow beam in the transfer lines with access granted in certain areas of the LHC. Additional elements in the injection regions of the LHC will then needed to prevent injection into the LHC.
- The positioning of the safety stoppers in TI 8 (TBSEL) and especially in TN4 (TBSEN) require definition. In the case of the TBSEN, very little space is available in the line.
- There are no 'test' modes defined at present. These would, for example, allow the powering of certain safety elements during machine start-up.
- The position of the search gate in TI 8, separating zone B from zone C remains to be defined, as does a similar door separating zone D from zone B in TN4. The positions will be determined on the basis of radiation levels at the gate for the worst case scenario, i.e. with beam being lost at the last interlocked element upstream of the gate.
- The defined zones should cover the intermediate situation during the construction phase of the LHC. For TI 2 the situation is clear. Access to the downstream part of the transfer line and into LHC is allowed without perturbing the west area physics programme. For the new east extraction area the situation is less clear. Although access can be granted in the LHC itself and in the lower part of TI 8 without stopping beam to the long-baseline neutrino facility, access into the upper part of TI 8, cannot. The installation of a significant portion of TI 8 will therefore perturb the operation of the NGS. The situation can be clarified only when the planning for the civil engineering, TI 8 installation and NGS operation are known in more detail.

7. References

[1] *'The CERN neutrino beam to Gran Sasso (NGS): conceptual technical design'*, ed. K. Elsener, CERN-98-02, 1998.

[2] CDD Drawing No.: LHCLSI__0001, LHCLSI__0002, LHCLSI__0003 & LHCLSI__0004.