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The West Experimental Area at the CERN SPS

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Abstract

The West Area at the CERN SPS has recently been rebuilt to provide two versatile secondary and/or tertiary test beams, the X5 and X7, which each have been upgraded to a top momentum of 250 GeV/c. In this note we describe the design, operational modes and performance of these new West Area beams.

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1. Introduction

The West Area started operation in 1971 as an experimental area at the CERN PS with top beam momenta of 28 GeV/c. In 1975 the zone was transformed into a SPS area, providing 7 different beam lines of initially up to 200 and later up to 240 GeV/c, delivering particles to various experiments and facilities, such as BEBC and the Omega spectrometer.

In 1983 the area was rebuilt again to provide two physics beams of up to 450 GeV/c (H1), respectively 400 GeV/c (H3). The H1 beam served a large number of experiments in the Omega spectrometer with secondary beams, attenuated primary proton beams and various species of heavy ions. The successes of the Omega programme were recently summarised in [1]. One interesting variant of the H1 beam was a dedicated hyperon beam exploited for hadron spectroscopy [2]. The H3 beam served mainly a series of heavy ion experiments, ending with the WA98 experiment [3] in the 400 GeV/c lead beam. In addition the H3 beam served as a parent beam for the four West Area test beams X1, X3, X5 and X7. These were versatile tertiary beams, optimised for good quality and maximum flexibility, adapted to tests and calibrations of the LEP experiments. The top momentum was limited to 100 GeV/c for the X5 and X7 beams, 80 GeV/c for X1 and 50 GeV/c for the X3 beam, well matched to the LEP beam momenta.

When the future of CERN turned towards the Large Hadron Collider, it seemed attractive to stop the West Area altogether, thus liberating resources and space in favour of the LHC project. However, it was pointed out that without any of the West Area beams, the need for test beams by the LHC experiments themselves and for all other experiments in addition, could not be satisfied [4]. Therefore it was proposed to keep two test beams in the West Area, namely the X5 and X7, but upgrade them to a top momentum of 250 GeV/c [5], better suited to the test requirements of LHC and SPS experiments. The X5 upgrade was performed in the 1996-1997 shutdown, whereas the X7 upgrade was done a year later, after the termination of the CHORUS neutrino experiment[1].

The equipment liberated by the H1, X1 and X3 beams served both to upgrade the X5 and X7 beams and to reconstitute a stock of spare elements for other beam lines. As the X5 and X7 beams are situated on one extreme side of the West Hall, still a large fraction (≥ 70%) of the hall space could be liberated for the LHC project.

In this note we describe the design, operational modes and performance of the new West Area beams and their associated facilities. Some attention is given to the modifications of the H3 beam to make it compatible with the injection line from the SPS into the LHC, which would interfere with the shielding of the T1 primary target.

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[1] In case the X7 would be operated at a high fraction (>57%) of the H3 momentum, muons from decay of pions in the H3 beam would be transported by the X7 beam and a significant number would traverse the emulsions installed in the CHORUS experiment. To avoid an over-exposure of the emulsions, the X7 beam had to be run at very low momenta during the full duration of the neutrino experiment.

2. General organisation of the West Area

Primary protons of momentum up to 450 GeV/c are slow-extracted from the CERN SPS to two experimental zones, the North Area in Prévessin (France) and the West Area on the Meyrin site. Every SPS cycle (typically 2.58 seconds, repeated every 14.4 seconds), some $1.5{\cdot}10^{12}$ protons are transported to the T1 primary target in the West Area. Secondary particles produced by interactions in this target are momentum selected by the H3 beam - see chapter 3 - and transported to a pair of septum magnets, from which two branches emerge, that deliver up to $\approx 2.10^{7}$ particles per SPS cycle onto each of two secondary targets. From these targets, the two test beams X5 and X7 are derived, which are described in detail in chapters 4 and 5, respectively. Each of the beams can operate either in secondary or in tertiary mode. In secondary mode they can deliver up to 10^{6} particles per SPS cycle, limited only by radio-protection guidelines. In tertiary mode the maximum achievable fluxes are lower by typically two orders of magnitude, but the user has more flexibility, in particular the free choice of beam momentum and particle type.

Each of the test beams serves two main test facilities, called X5A (X7A) and X5B (X7B). As safe access conditions to the downstream (B-) area are guaranteed by a mobile dump, the upstream area can be operated with beam, while installation work is taking place in the downstream zone.
A schematic layout of the three beams H3, X5 and X7 with their respective test facilities is shown in Figure 1. Details of the test facilities are given in chapter 6.

At the end of the X5 beam, downstream of its final dump, the so-called Gamma Irradiation Facility (GIF), is installed [6]. This facility houses a strong gamma source, that irradiates large detectors (up to 3x6 m^{2}) of LHC experiments with an intense and adjustable photon flux. A small muon flux accompanying the X5 beam, tagged by scintillators and two drift chambers, is used to measure the efficiency and resolution of the detectors as a function of the photon background. A short description of the Gamma Irradiation Facility is given in chapter 7.

During the first half of 1998 a specially built prolongation of the X7 beam was exploited by the CHORUS experiment [7] for a final in-situ calibration of its detector components. The layout and special features of this prolongation are outlined in chapter 8.

3. The H3 secondary beam

The H3 secondary beam is derived from the T1 primary target. A slow-extracted primary proton beam of typically $1.5 - 210^{12}$ protons per SPS cycle impinge on one out of five Beryllium target plates, housed in a heavily shielded target box. The dimensions of the five plates (the so-called target heads) are listed in Table 1.

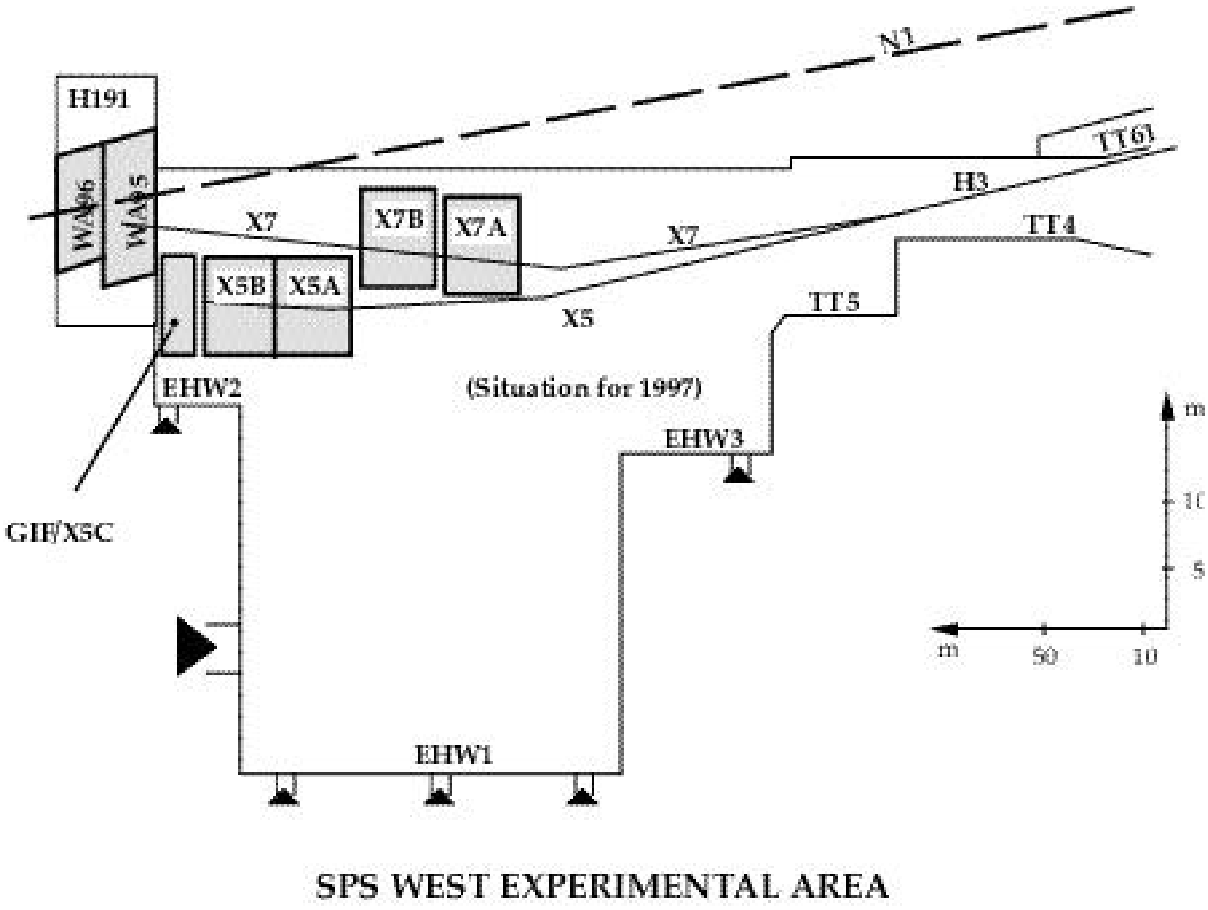

Figure 1: *Schematic layout of the West Area beams and test facilities*

Head #	**Material**	**Horizontal (mm)**	**Vertical (mm)**	**Length (mm)**
0	Empty position			
1	Be	160	2	400
2	Be	160	3	500
3	Be	160	3	400
4	Be	160	2	100
5	Be	160	2	40

Table 1: *T1 target heads*

For maximum useful secondary particle flux, a suitable compromise has to be made between particle production rate and re-absorption inside the target. Therefore, usually a target length close to the optimum (about 400 mm) is chosen, but shorter targets are preferred in case of high production rates e.g. for high-momentum positive beams.

For historic reasons, a wobbling station is available at the location of T1. This wobbling station, shown schematically in Figure 2, consists of two groups of dipole magnets upstream of the target (Bend-1_T and Bend-2_T) and one set of dipoles (Bend-3_T) downstream. By choosing suitable fields in the various magnets, background from the primary proton beam can be minimised (by dumping those protons cleanly in mobile dump collimators (TAX) in the direction of the ancient H1 beam) and clean secondary particle beams can be provided to the H3 line. If required, electrons present in the beam can be removed further downstream in the beam line by moving in a motorised 5 or 10 mm thick lead plate (absorber), thus keeping a pure hadron beam.

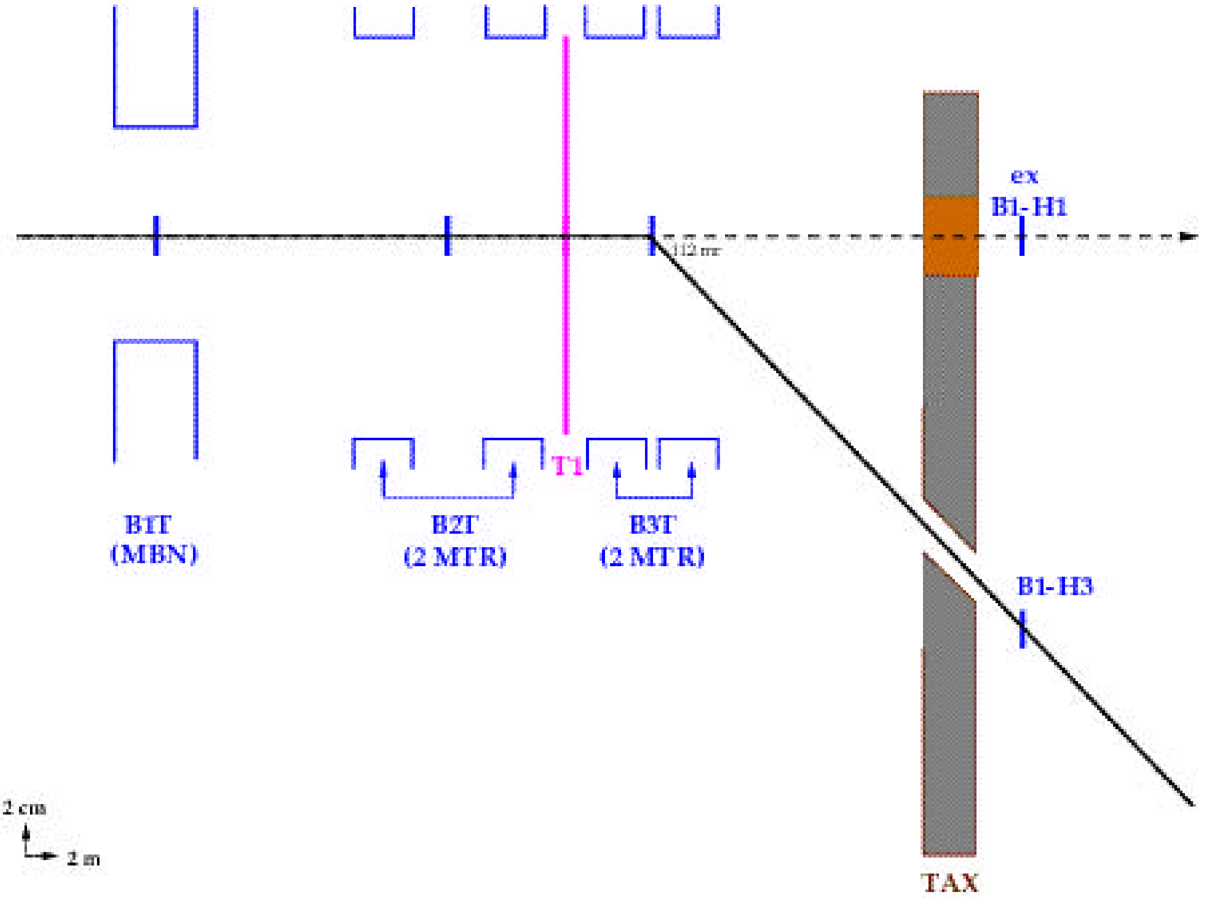

Figure 2: *Schematic layout of the T1 wobbling station*

Alternatively, by the appropriate choice of Bend-1_T and Bend-2_T strengths, the protons can be targeted almost in the direction of the H3 beam and subsequently all charged secondaries can be swept by a strong field in Bend-3_T and dumped in the massive dump collimators (TAX). Photons from the decay of π^0 produced in the target will thus travel predominantly in the direction of the H3 acceptance. Just downstream of the dump collimators a motorised 4 or 6 mm thick Lead plate ("Converter") can be brought into the beam in order to convert most of these photons into $e^+ e^-$ pairs. The H3 beam can then be tuned to transport these clean electron or positron beams via the splitters towards the secondary targets. A horizontal dipole magnet (B1) allows to compensate for any skew of the beam leaving the primary target through the holes in the TAX dump/collimators.

The H3 beam itself is a high-transmission transport system with momentum definition in the vertical plane. The optics of the beam, including (as an example) the branch towards the X5 target, is shown in Figure 3. The beam emerges from the primary target at an upward vertical slope of 43 mrad. A first group of vertical dipoles (B2) increases the vertical angle by another 42 mrad, which is compensated later by B3, situated some 400 metres further down the beam line. The optics in between B2 and B3 is calculated to have a dispersion-free beam downstream of B3. In that section one finds a vertical momentum slit (COLL4), located in a dispersive focus, that allows a precise momentum definition with an intrinsic resolution of 0.3 permille and a maximum momentum byte of about ±2%. The horizontal and vertical acceptances of the beam are about ±1.1 and ±0.5 mrad, but may be reduced by COLL2 and COLL1, respectively.

B3 is almost immediately followed by another group of 5 dipole magnets (B4), that renders the beam exactly horizontal. These dipole magnets are interspersed with quadrupoles to keep the beam free of dispersion. At the exit of B4 the beam is wide and parallel in the vertical plane, whereas in the horizontal plane it converges to a focus a few metres further downstream. Around this horizontal focus a pair of magnetic septum magnets allows to split the lower part of the beam away towards the X7 target, whereas the upper part follows a straight path towards the X5 target. The beam intensities on the secondary targets are restricted by radiation level limits and should not exceed $2\cdot10^7$ particles per SPS cycle. The overall beam intensity is controlled by the momentum slit COLL-4 and, if necessary, the horizontal acceptance collimator, COLL2. The beam at the splitter is an inverted image (at 540^o phase advance) of the beam at the vertical acceptance collimator, COLL1. Therefore, closing the upper jaw of COLL1 will reduce the flux on the X7 target, whereas the lower jaw will only affect the flux onto the X5 target. Additional 4-jaw collimators in each of the branches allow to clean the beam and reduce even further the intensity per branch, if so required.

The spot size at each of the secondary targets is measured using wire chambers located about 0.5 metres upstream of the focus at each target. The RMS widths (horizontal x vertical) are 0.7x 3.8 mm^2 for X5 and 1.0x 3.0 mm^2 for X7, essentially independent of H3 collimator settings.

The total length of the H3 beam from T1 to the X5 target is 660 metres. The maximum momentum that can be transported to the two targets is just above 250 GeV/c. The main design parameters of the H3 beam are summarised in Table 2.

The particle composition is a strong function of the beam momentum. For standard wobbling station settings, the composition can be calculated from a formula given in [8]. At –120 GeV/c, some 10% of the beam are electrons. At momenta of ≈150 GeV/c and above, electrons loose so much energy by synchrotron radiation that they are lost from the beam before getting to the secondary targets. The calculated beam composition at some typical beam momenta is listed in Table 3.

Alternatively, a special electron wobbling can be prepared or, for H3 momenta above ≈150 GeV/c, the beam can be tuned to take the synchrotron radiation loss of electrons into account. Now the hadrons are removed from the beam and the beam consists of ≥ 99% electrons.

	H3	**X5**	**X7**
Maximum beam momentum (GeV/c)	250	250	250
Minimum beam momentum (GeV/c)	20	5	5
Dispersion at momentum slit (mm/%)	48	6.2	4.3
Intrinsic momentum resolution Δp/p	±0.03%	±0.5%	±0.8%
Spectrometer momentum resolution Δp/p	—	±0.16%	±0.22%
Maximum momentum byte Δp/p transported	±1.9%	±7.7%	±9.6%
Horizontal acceptance (mrad)	±1.1	±2.6	±3.2
Vertical acceptance (mrad)	±0.5	±0.85	±0.78
Total acceptance (μsterad)	1.7	7	12
Maximum authorised flux per SPS cycle	—	10^6	10^6
Beam length (m)	705 (T1→X5) 679 (T1→X7)	196	168
Beam height (m)	1.26	1.26 → 3.66	1.26 → 3.66

Table 2: *Design parameters of the West Area beam lines*

Momentum (GeV/c)	**$e^{\pm}$**	**$p^{\pm}$**	**$K^{\pm}$**	**p, pbar**
–120	10%	83%	5.5%	1.5%
–250	0	95.5%	4%	0.5%
+120	3.5%	59%	5.5%	32%
+160		46%	5%	49%
+250	0	15%	2%	83%
–120, e^- wobbling	>99%	<1%	—	—

Table 3: *Estimated particle composition of the H3 beam at some typical momenta*

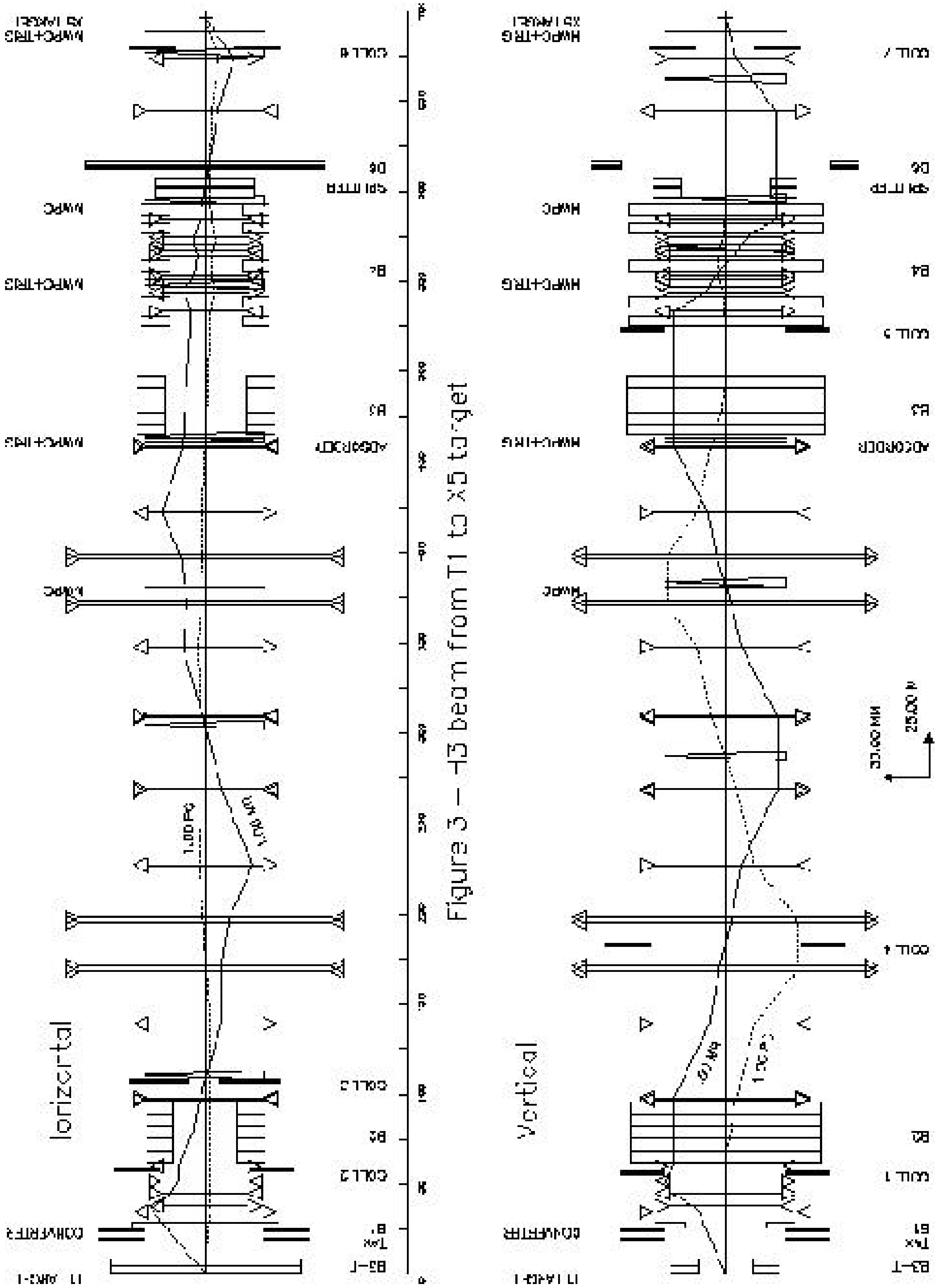

Figure 3: *The optics of the H3 beam*

4. The X5 beam

The X5 beam starts at the X5 target and transports particles to two test facilities, called X5A and X5B. Two groups of dipole magnets transport the beam into the wanted direction and, together with the (horizontal) momentum slit COLL1, they also define the beam momentum. The first group consists of 6 magnets, 3 metres long each. The two central ones and the two extremes are powered in series as B1, and the second and fifth are powered as B2. This allows to user either all 6 magnets at identical fields or only the B1 magnets at 50% higher field (with B2 switched off). The latter option is of interest when running at very low beam momenta, where a 50% higher current is easier to control precisely. Similarly the second group of dipoles is powered by two independent power supplies. B3 consists of the two outer magnets, whereas B4 is the central magnet. The optics, shown in Figure 4, contains an acceptance section with 4 quadrupoles upstream of B1, a field lense in between B1-B2 and B3-B4 (for dispersion recombination) and two more groups of quadrupoles to focus the beam at the experiment or test set-up. Four correction magnets (indicated as “Trims” in Figure 4) allow to adjust the steering through apertures and onto the test apparatus.

The intrinsic momentum resolution of the beam is about 7 permille and the maximum accepted momentum byte ±7.5%. The useful momentum range of the beam line runs from about 5 GeV/c up till 250 GeV/c. The angular acceptance is ± 2.6 mrad in the horizontal plane and ±0.9 mrad in the vertical plane.

The beam can be operated in three rather different ways, namely as a secondary beam, as a versatile tertiary beam or as a muon beam.

1. For secondary beam operation the empty target head is selected and the X5 beam is tuned to the same momentum as the H3 parent beam. The maximum allowed intensity in this mode is defined by radioprotection considerations and is 10^6 particles per SPS cycle. The momentum resolution is in this case defined by collimator settings (COLL-4) in the H3 parent beam.

2. In tertiary mode the target head defines the particle type. Three different target heads are available, namely Lead (4 mm), Copper (400 mm) or Beryllium (400 mm). Pion beams are obtained using the Copper target. Any remaining electrons (due to conversion of photons from π^o decay) can be removed from the beam by inserting a lead absorber plate (3 or 8 mm of Lead) at the location of the momentum slit. Depending on the H3 momentum, electrons can be obtained either via Bremsstrahlung of electrons from H3 in the Lead target (for H3 momenta below some 150 GeV/c) or by conversion of photons from π’s produced in the Beryllium target (for higher H3 momenta). In the latter case, TRIM1, situated immediately downstream of the X5 target, operates at full current as a sweeping magnet. Photons, unaffected by the magnetic field, continue along a straight line and convert in a converter (4 or 6 mm of Lead) downstream of the fixed collimator following the TRIM1 magnet.

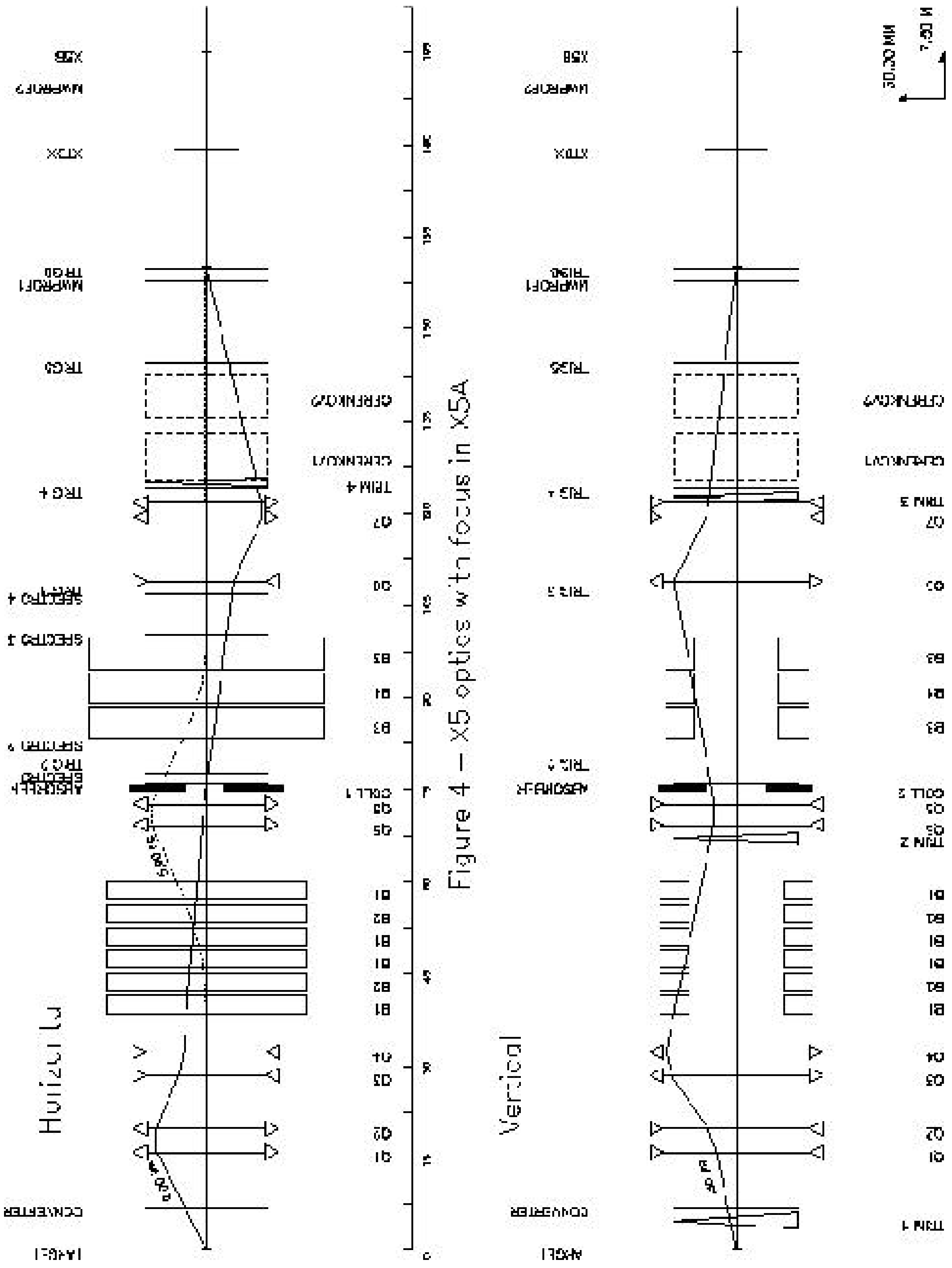

Figure 4: The optics of the X5 beam

3. Muons from decays of pions in the final straight section of the H3 secondary beam will be transported along the X5 beam, if this beam is tuned to a momentum above 57% of the H3 momentum[2]. These muons will be an unavoidable background for high-momentum tertiary hadron or electron beams. On the other hand the hadrons and electrons can be stopped in collimators or in the mobile dumps upstream of the test areas, in which case a useful flux of up to ≈ 10^4 muons per SPS cycle is available in the test facilities. This mode of operation is frequently used for tracking tests.

The X5 beam is equipped with a variety of detectors for tuning, tracking and particle identification. A scintillator counter and a wire chamber allow to monitor the beam incident on the X5 target. Five additional scintillators along the beam line allow to measure the flux in the X5 beam and to strobe the more sophisticated detectors in the beam.

Four drift chambers of the Delay Wire Chamber type [9] around B3 and B4 allow to measure the momentum of each individual beam particle to better than 2 permille. Two Threshold Cerenkov counters, 10 metres long each and filled with either Helium or Nitrogen, allow particle identification for large momentum ranges. Finally Delay Wire Chambers with 2-plane readout and 200 μm resolution are installed in each of the test facilities. Signals from these detectors are available both for the Experimental Area computers and for direct readout by the experimental teams.

At the high fluxes possible with secondary beams, the Delay Wire Chambers become very inefficient. To facilitate beam tuning under those conditions, wire chambers with analogue readout are available in each of the test facilities.

The total length of the X5 beam from the X5 target till the end of the X5B test facility is about 200 metres. Its main characteristics are listed in Table 2. A user manual for the X5 beam is available [10].

5. The X7 beam

From a conceptual point of view, the X7 beam is identical to the X5 beam. It starts at the X7 target and serves two test facilities, called X7A and X7B. It differs from the X5 beam only in the exact positions, dimensions and types of magnetic elements. Its schematic layout and optics are shown in Figure 5. The angular acceptance is ±3.2 mrad in the horizontal plane and ±0.78 mrad in the vertical plane. The intrinsic momentum resolution is 0.8 permille (a spectrometer measurement allows a precision of about 2 permille) and the maximum transportable momentum byte is ±9 %. These characteristics are very similar to those of the X5 beam.

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[2] Due to the kinematcs of the decay of relativistic pions into a muon and a neutrino, the muon carries at least 57% of the pion momentum.

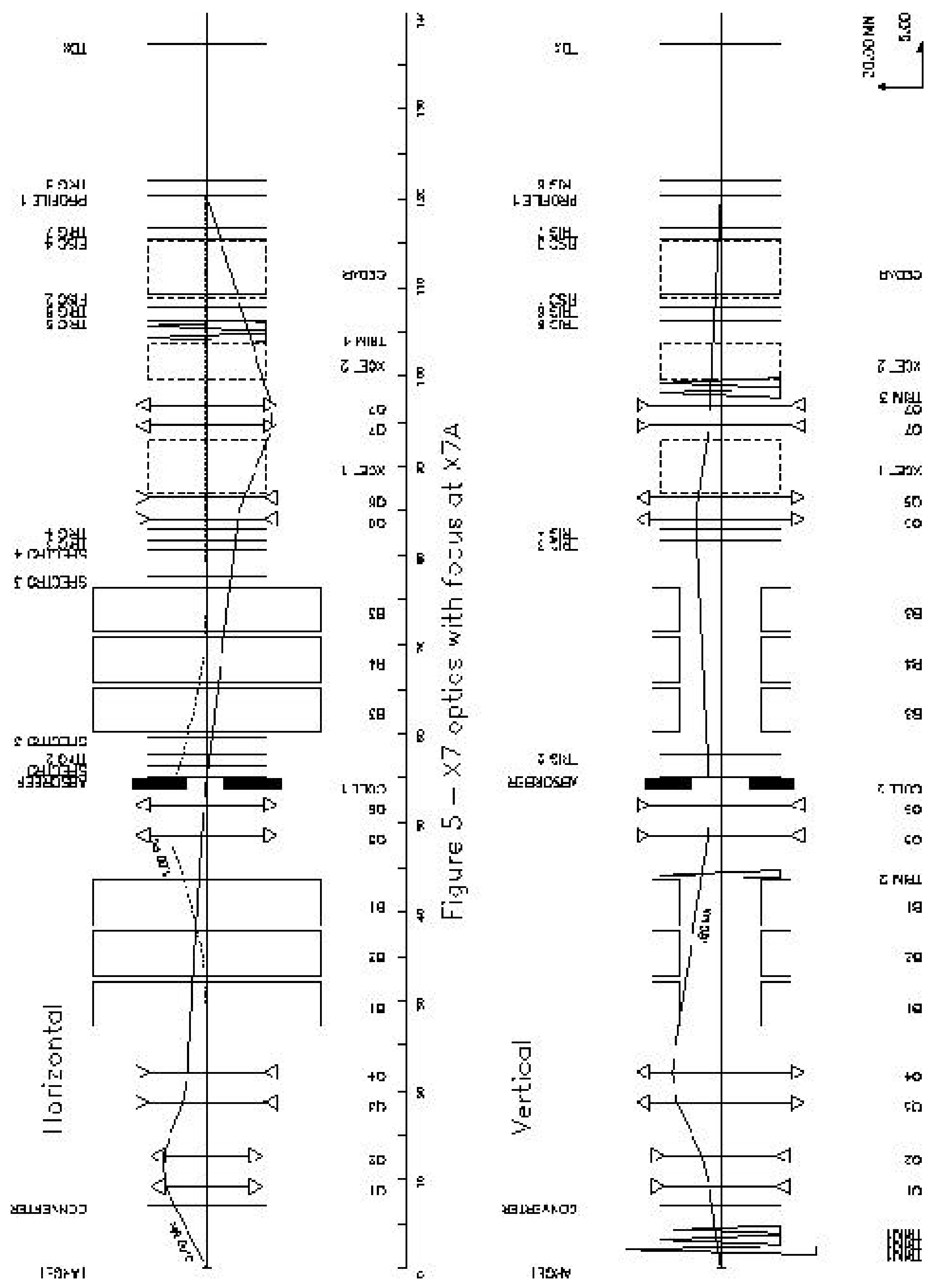

Figure 5 : *The optics of the X7 beam*

Optionally the X7 beam can be equipped with a CEDAR Cerenkov counter [11] for particle identification at high momenta, where the threshold counters are no longer selective. Note that, for good performance of CEDAR counters, the beam should be as parallel as possible. As the counter is installed close to the experiments, namely in the upstream part of the X7A test facility, there is no space for focusing downstream of the CEDAR and the beam spot will therefore be relatively wide in the test facilities, whenever the CEDAR is used.
The total length of the X7 beam from the X7 target to the end of the X7B test facility is about 170 metres. Its main characteristics are summarised in Table 2. A user manual for the X7 beam is available [12].

In the past the X7 beam sloped down at 6 mrad towards the centre of BEBC. At the time of the upgrade the beam was put horizontal for a number of reasons:

1. The H3 beam has been designed to have zero dispersion in the vertical plane after the exit of B4. This implies that also the X5 is dispersion free in the vertical plane. Adding a vertical bend in the branch towards the X7 target (as was the case in the past) would introduce again a dispersion that would be detrimental for the quality of secondary beams in X7[3].

2. Part of the vertical deflection was achieved by tilting the magnetic septa. The narrow gap for the straight through beam (X5) would thus be tilted as well. Its edges would reduce significantly the acceptance for the X5 branch and lead to increased beam losses on the septum.

3. The downward slope would lead to a loss of beam height of about 1.5 metres in the X7B area. This might compromise the test of large detectors, e.g. of LHC experiments.

4. It is more convenient to install and align detectors or test set-ups on a horizontal line than on a 6 mrad slope.

With this modification the X7 beam has the same beam height as the X5 beam, namely 3.66 metres above the West Hall floor. The horizontal position of the beam has not been changed.

6. The test facilities

Each beam serves two test facilities, namely X5A (X7A) and X5B (X7B). A test facility consists of an experimental area and a user barrack and may be shared by different user groups. As mentioned in the previous chapters, in each test area a Delay Wire Chamber allows to measure the positions of the incoming particles with a resolution of about 200 µm. The output signals from this chamber are delivered to a patch panel in the corresponding user barracks. Also available in the barracks are the outputs from the two threshold Cerenkov counters in each beam and from the four spectrometer Delay Wire Chambers for particle momentum measurements. The gas pressures of the Cerenkov

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[3] Note that in the past only tertiary beams were allowed in X7. The particle production process in the X7 target would in fact smear out any effects of angular dispersion at the X7 target.

counters can be adjusted by the users from their beam control terminals, which are available in the user barracks. Note that these are X-terminals connected to the public Ethernet, which is anyway available for connecting the computers of the experiments. Further facilities in each user barrack include:

1. A patch panel with TTL timing signals (1 second before the start of the slow extraction, 1 msec before the start and at the end of the extraction).
2. A patch panel with four inputs to so-called 'experimental scalers', i.e. scalers connected to the area computers, that count NIM signals from the detectors of the user groups.
3. A so-called 'Page-1' monitor, showing the actual status of the SPS machine.

The dimensions of experimental zones, user barracks and other parameters of interest are listed in Table 4.

	X5A	**X5B**	**GIF**	**X7A**	**X7B**
Useful length of beam area	17 m	11 m	3.2 m	12 m	21 m
Width of beam area	6 m	6.4 m	6 m	6.4 m	8 m
Surface of beam area	106 m^2	75 m^2	30 m^2	90 m^2	180 m^2
Standard beam height	1.26 m	1.26 m	1.26 m	1.26 m	1.26 m
Maximum beam height	3.66 m	3.66 m	3.66 m	3.66 m	3.66 m
Dimensions of barrack	28 m^2	60 m^2	88 m^2	64 m^2	80 m^2
Minimum cable length	20 m	12 m	30 m	20 m	15 m
Typical cable length	30 m	30 m	40 m	40 m	40 m
Ethernet available ?	Yes	Yes	Yes	Yes	Yes
# Experimental scalers	4	4	4	4	4
EA counter signals available	Spectro 2 XCET XDWC158	Spectro 2 XCET XDWC185	XDWC214 XDWC217 XTRI215	Spectro 2 XCET XDWC120	Spectro 2 XCET XDWC149

Table 4: *Test facility dimensions and other parameters of interest*

Transfer of data from the area computers to the user computers and vice versa is possible via Ethernet. At the end of every SPS cycle a so-called 'Standard Block' with data about beam intensities is made available for the users. A 'Non-Standard Block' with detailed status of all magnet currents, collimator settings and specific, user-dependent information can be made available on request, with a frequency typically not exceeding once per 10 minutes.

The access to the downstream areas is controlled by means of a mobile dump (TDX) located in between the two areas. Therefore installation work in the downstream area can go on during data-taking in the upstream area. This lead to the operational choice of attributing the downstream test facilities X5B and X7B to large tests of major experiments, whereas the X5A and X7A areas are reserved for smaller tests that can be (dis-)mounted within a short period of time, e.g. during the weekly 8-hour machine development sessions.

7. The Gamma Irradiation Facility (GIF)

The Gamma Irradiation Facility (GIF) [6] is a test area in which high-energy particle detectors are exposed to a particle beam in the presence of a strong background flux of photons, simulating the conditions that these detectors will suffer in their future operating environment at the Large Hadron Collider. The GIF is situated at the downstream end of the X5 test beam. The zone is surrounded by a 8 metres high and 80 cm thick concrete wall. Access is possible through three entry points, namely two access doors for personnel and one large gate for material. A crane allows to install heavy equipment into the area. A schematic layout of the GIF zone is shown in Figure 6.

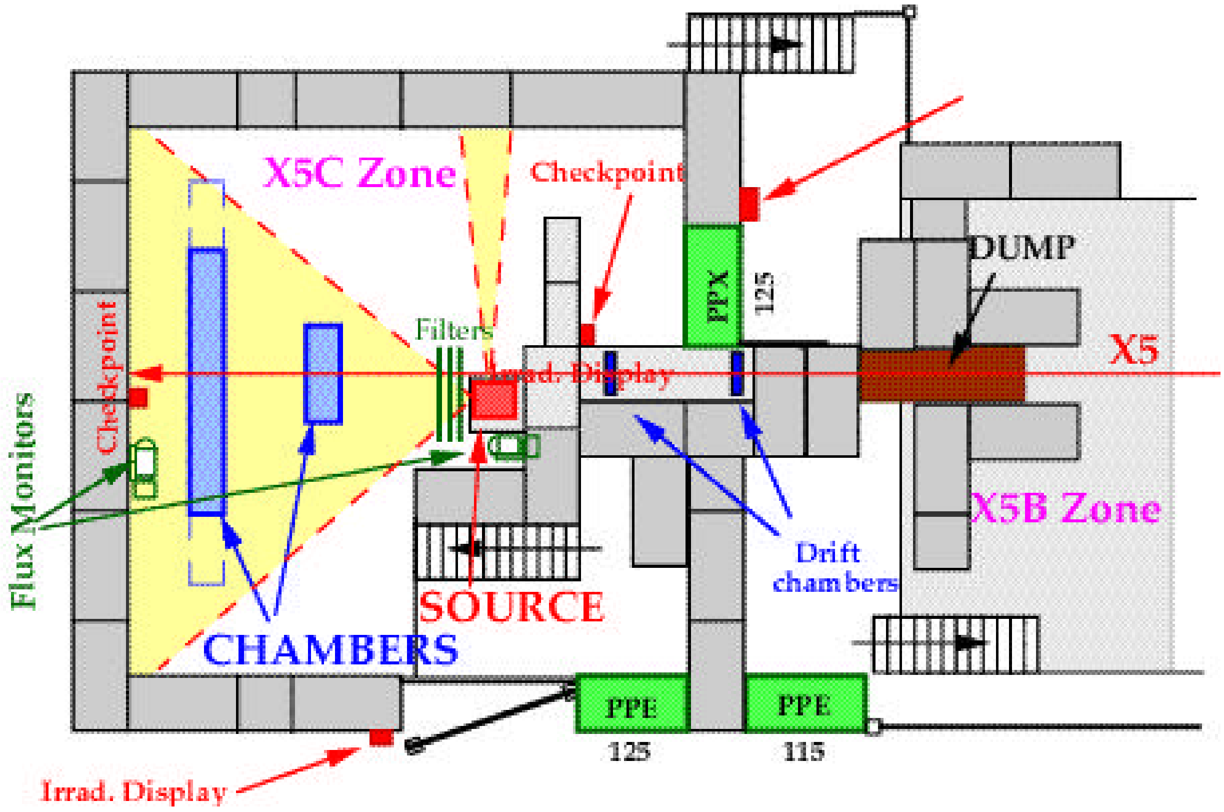


Figure 6: *The layout of the Gamma Irradiation Facility (GIF)*

The photons are produced by a strong radioactive source (irradiator). It is installed in the upstream part of the zone, 5 metres away from its downstream end, and housed inside a lead container, which includes a precisely shaped collimator, designed to permit irradiation of a 6 by 6 m^2 area at 5 metres distance from the source. A filter system, composed of four 1 mm thick lead discs of different diameters fixed at the exit face of the collimator, serves to render the outcoming flux more uniform in the vertical plane. At 4 metres distance from the source the flux on the axis is $1.8\ 10^5\ \gamma/cm^2/s$.

A second irradiation area has been foreseen at 90^o to the main axis. This area is defined by a separate collimator, which allows to irradiate detectors with a high flux over a smaller area, e.g. crystal calorimeters. It can be activated or isolated by means of a separate shutter. If opened, this channel provides a flux of $6\ 10^6\ \gamma/cm^2/s$ at 1 m distance from the source. The two facilities can thus operate separately or in parallel.

The Gamma irradiator is housed in a rectangular container, 400 mm each side and 900 mm high. The active element is a radioactive ^{137}Cs source of strength 740 Gbq. This isotope was preferred above ^{60}Co because of its longer half-life of 30 years and hence less variation of the photon flux over the years of use of this facility. Also its lower photon energy (662 keV/c) leads to a twice higher conversion efficiency in the detectors tested.

The source is protected by a lead shield of 140 mm thickness. The lead is contained in a 5 mm thick steel envelope. The principal collimator hole provides a conical aperture of 74 steradians solid angle. This provides a photon flux in a volume of 5 metres maximum length along the axis. A pneumatic system allows to move the source upwards into its irradiation position or to leave it in its lower, shielded, position. In case of pressure drop, the source falls naturally, by its own weight, in its protecting container.

Up to some 10^4 muons per SPS cycle from the X5 beam enter the Gamma Irradiation Facility and are tagged by scintillators and a system of two Delay Wire Chambers. The efficiency and/or resolution of detectors can thus be tested as a function of the background photon flux. Also radiation resistance measurements with and without beam are now performed on a routine basis by the big LHC collaborations.

8. The X7 prolongation to CHORUS

Every year during its main data-taking periods, the CHORUS/WA95 neutrino experiment performed in-situ tests and calibrations with a prolongation of the X7 beam into the BEBC hall [13]. With the change of vertical angle of the X7 beam, this prolongation had to be redesigned for a final calibration with pion, electron and muon beams. This calibration took place in the first half of the 1998 run.

The prolongation required the opening of the final dump at the exit of the X7B area (by crane) and the installation of a vertical dipole in the upstream part of the X7B area to bend the beam down at an angle of about 18 milliradians. After leaving the X7B area the beam passes through a narrow passage in between the X5 test facilities and the X7B user barracks. At the end of this passage a

46 mrad horizontal dipole bends the beam towards the CHORUS experiment. Finally, a vertical bend just upstream of the CHORUS experiment serves to put the beam on exactly the same axis as in the past. Two additional quadrupoles served to adapt the optics to the specific requirements of CHORUS. The layout is schematically pictured in Figure 7.

For the operation of this prolongation, secondary mode operation had to be excluded. For that purpose a series of hardware and software restrictions imposed the momentum to be less than half of the H3 secondary beam momentum and the particles to be of opposite charge of the H3 beam. With these restrictions and taking into account the total length of the beam line, pion fluxes tended to be quite low, in particular at the lowest momenta (data were taken at momenta as low as 3 GeV/c), where most of the pions decay before arriving at the CHORUS detector.

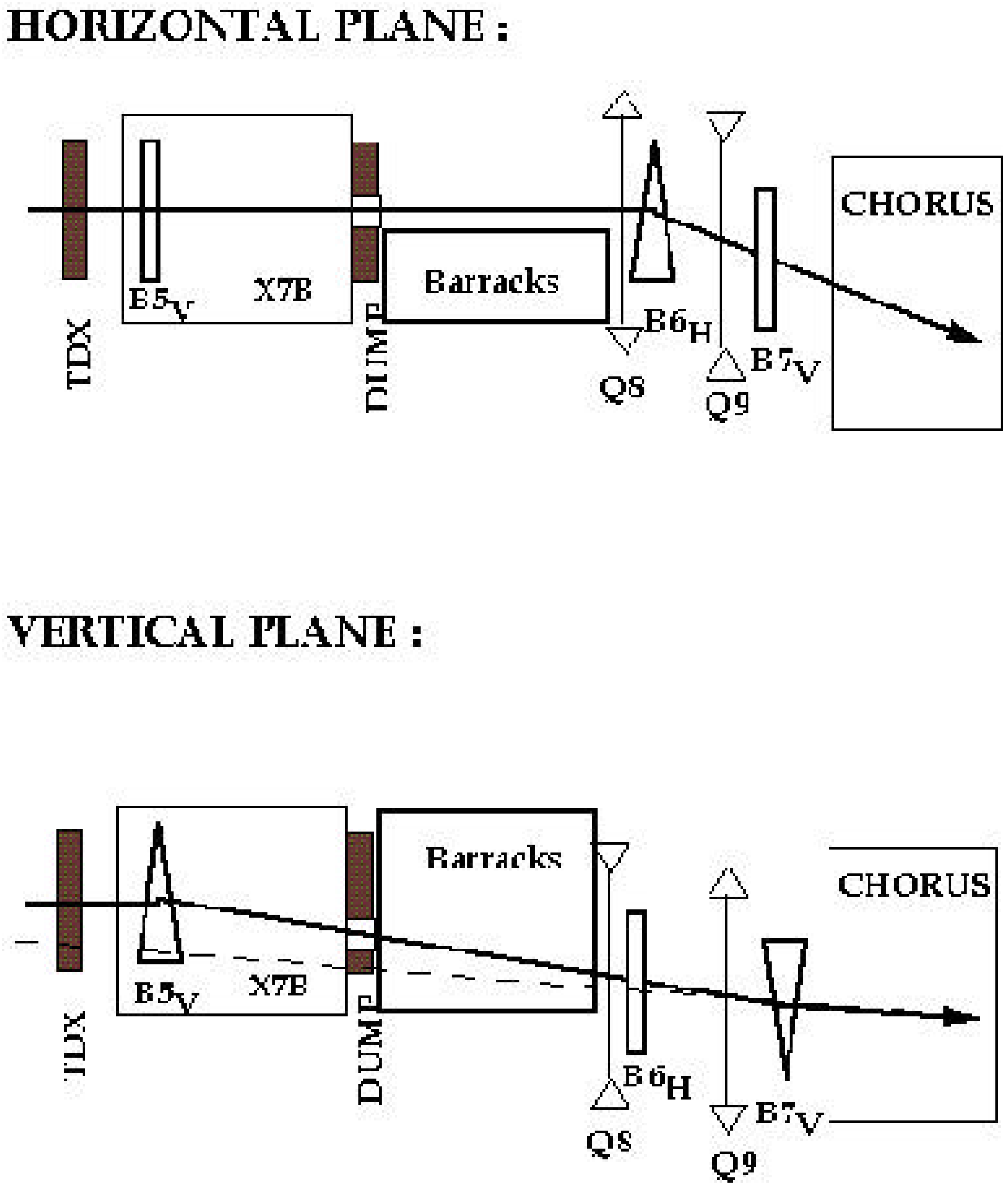


Figure 7: *Schematic layout of the prolongation of the X7 beam. The dashed line shows the old beam.*

The measured pion and electron fluxes and beam composition at CHORUS are listed in Table 5. From the π/e ratio at the experiment, the pion content at the target can be estimated. The result is consistent with >80% pions for most of the momentum range, except for momenta below 8 GeV/c where the relative pion contents drops rapidly down to <50% at 3 GeV/c.

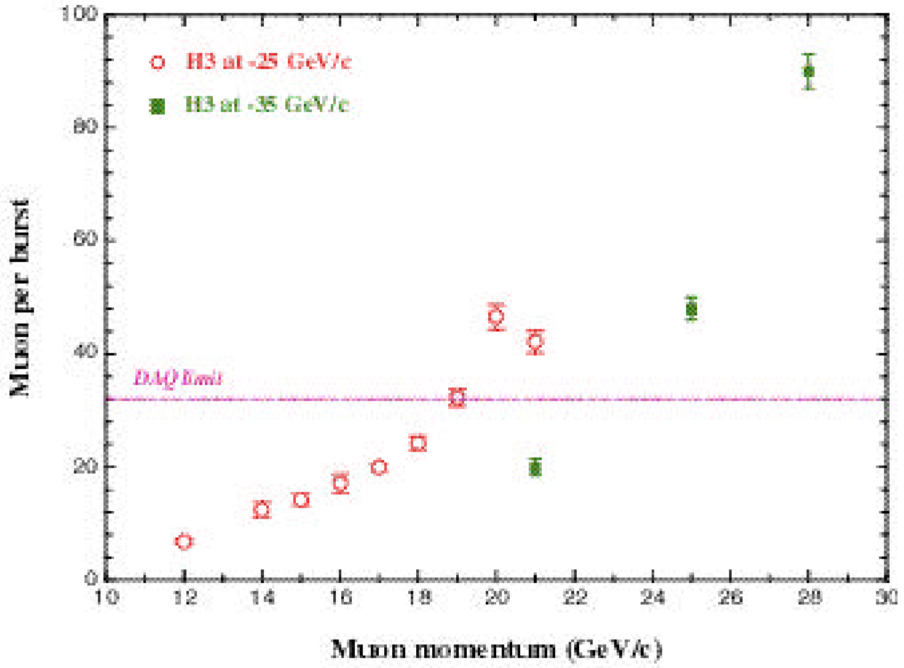
Beam mode	**Collimator setting Coll 1, 2**	**Momentum (GeV/c)**	**Average rate per SPS cycle**	**Fractions (%) hadron / e+**
Copper target No absorber	±10, ±20 mm	+3	0.3	10 / 90
	±10, ±20 mm	4	1	20 / 80
	±10, ±20 mm	5	3	30 / 70
	±10, ±20 mm	6	5	40 / 60
	±10, ±20 mm	8	10	65 / 35
	±10, ±20 mm	10	15	75 / 25
	±10, ±20 mm	15	20	82 / 18
	±10, ±20 mm	20	25	90 / 10
	±10, ±20 mm	25	30	>98% / 2%
Lead target	±10, ±15 mm	10	500	1 / >99
Lead target	±10, ±15 mm	25	800	1 / >99

Table 5: *Fluxes measured in a 10x10 cm^2 size counter at the CHORUS experiment. Typical intensities on the X7 target were about 1.5 10^7 particles per SPS cycle.*

A second part of the CHORUS tests consisted of tests and calibrations with muon beams. For this run, the X7B dump had to be closed again and the H3 beam was tuned to ≈1.25 times the required momentum of muons incident of the X7B dump. Note that on average the muons loose about 4 GeV in the 2.4 metres of iron and 1.6 metres of concrete in the dump. Muon fluxes ranged from 40 muons/burst at –21 GeV/c to 5 per burst at –12 GeV/c, as indicated in Figure 8.

9. Operational aspects and control software

Like all beams in the SPS experimental areas, the West Area beams are operated by a control tree program written in the Nodal language[14]. Nodal is a program language written originally for Norsk Data computers. Recently it has been emulated in C on Unix systems [15]. The control programme allows to select and monitor magnet currents, collimator positions, to move targets, absorbers, converters and dumps and to operate the beam instrumentation. It allows the creation, loading and manipulation of beam files (lists of magnet currents and collimator positions), changes of beam momentum and particle type. Many actions are available to the users, but certain actions (e.g. modification of layout descriptions, definition of beam control privileges) are restricted to the experimental area operators and/or EA physicists.



- Muons from π^- decays in between $B4_{X7}$ and the final dump are momentum-analysed by $B6_{X7}$ (46.714 mrad), behind the dump
- Rates are measured as coincidence of T1 and 10x10 cm^2 counter at the entrance of the CHORUS detector

Figure 8: *Muon fluxes as observed in CHORUS*

The control of the X5 and X7 beams is normally restricted to the main user teams as defined in the SPS Fixed Target Programme. The H3 beam is strictly under control of the EA physicists and the experimental area operators. This is imposed by password protection on the magnet power supplies and dump and collimator motors. The only exception relates to those collimators in the H3 beam, which allow to reduce the flux on the individual secondary target of the main user in question. This facility is vitally important during changes from tertiary mode to secondary mode and vice versa. In case of tertiary mode, the H3 acceptance collimators can be left open, whereas for secondary mode, they have to be closed until the intensity has decreased to below 10^6 particles per SPS cycle. A special programme has been written to guide the users in this task.9

Whenever a user wants to take access to his experimental area, he can prepare safe conditions from his beam terminal. Once the conditions are safe, access can be granted and safety is guaranteed by the normal access interlock hardware. Every person entering the area has to take a key and keep this until he or she leaves the area. As soon as the access is terminated and all keys are back, the user can switch on the beam. Only when an area has been put in free access (i.e. access is possible without taking a key), the experimental area operators have to be involved for enabling beam conditions again after a search of the area.

10. Performance of the beams

The West Area can be operated under a number of different conditions. The H3 beam can be run as a direct charged secondary beam from the T1 target or as an electron beam from conversion of photons from π^o decay. The X5 and X7 beams can be operated as secondary beams or as tertiary hadron, electron or muon beams.

The H3 beam is essentially unchanged with respect to the past. The only modifications concern the splitter layout and the alignment of the branches towards the X5 and X7 targets. As this alignment could now be optimised for two beams, rather than for four, the effective transmission to the X5 and X7 targets has improved by more than a factor of two, leading to a somewhat reduced need of protons onto the T1 target.

In tertiary modes the fluxes are similar to those measured before the upgrade. The secondary beam operation is a new feature, which allows better momentum definition, higher fluxes and smaller spots than tertiary mode. In most cases the limit on flux comes from radiation level restrictions, rather than from particle production and acceptance of the beam line.

In Figures 9 and 10 we list the measured fluxes of the X7 beam per 10^7 particles incident on the X7 target for a H3 beam momentum of –120 GeV/c, one of the more frequently used conditions. For electron beams the momentum slit was set to ± 1% (±5 mm), for the hadron beams to ± 4% (± 20 mm). The hadron contamination in electron beams under these conditions is 1% or lower over the full momentum range, whereas at high negative momenta the muon component is quite important (more than 50% at –100 GeV/c). For positrons (produced from a negative secondary beam) the hadron contamination ranges from 2% at low momenta via some 5% at +50 GeV/c up to about 30% at 100 GeV/c). The hadron beams contain a significant electron component, in particular at momenta below 50 GeV/c. This electron component can be reduced by a factor of 4-40, by introducing a 3, resp. 8 mm thick lead absorber into the beam. The purity of electron and hadron beams is shown in Figures 11 and 12.

The tertiary hadron fluxes do not depend very strongly on the secondary beam momentum, as long as this is at least some120 GeV/c. However, for high or positive beam momenta the tertiary electron beams are of poor quality and low flux, as the electron content in the secondary beam is suppressed.

The fluxes and beam composition in the X5 beam are very similar to the ones in X7.

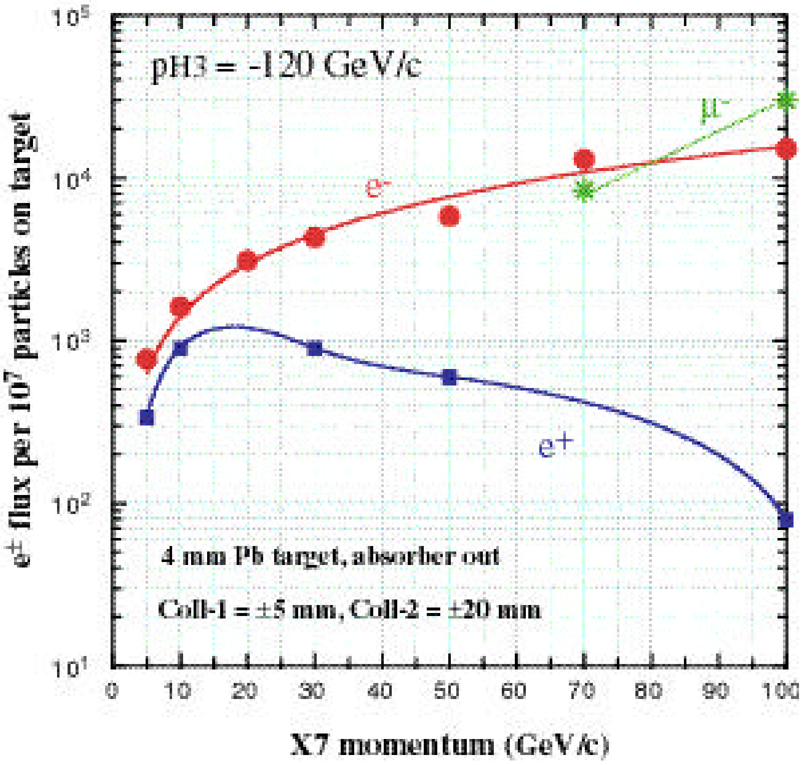


Figure 9: *Electron flux in the X7 beam for* p_{H3} *= –120 GeV/c*

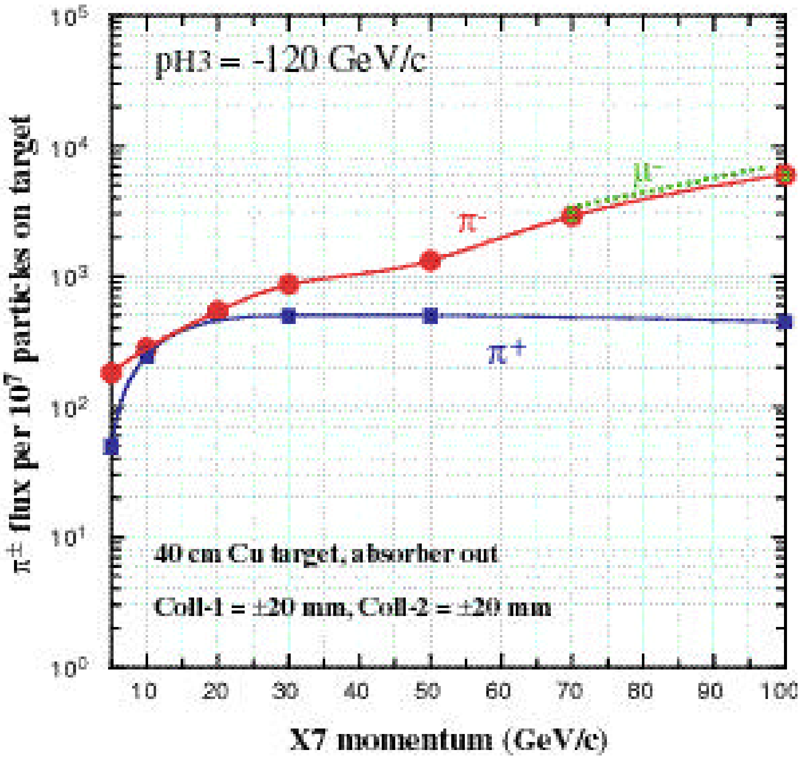


Figure 10: *Tertiary hadron flux in the X7 beam for pH3 = –120 GeV/c*

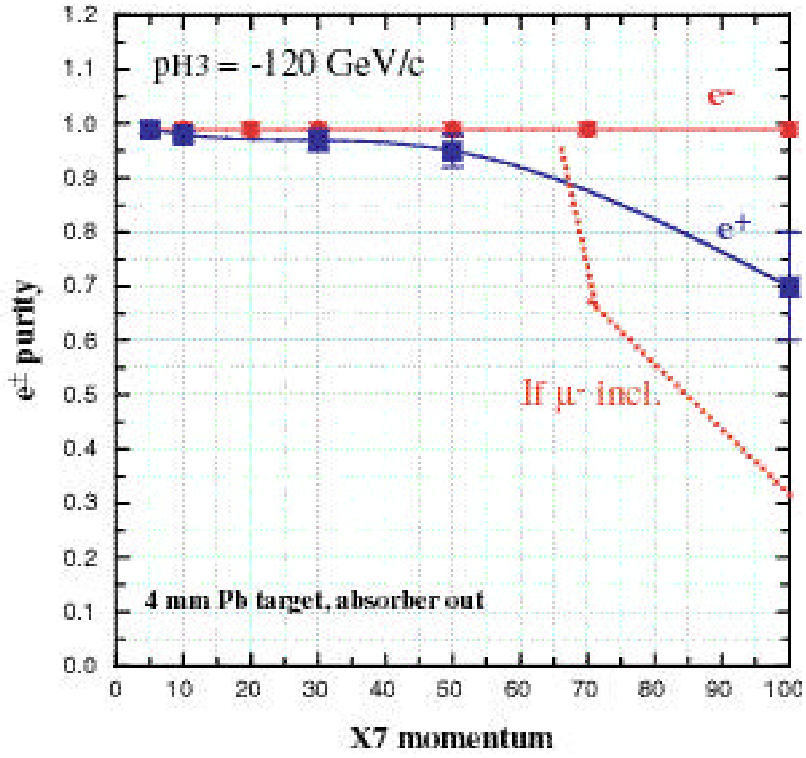


Figure 11: *The purity of tertiary electron beams from a secondary beam at –120 GeV/c*

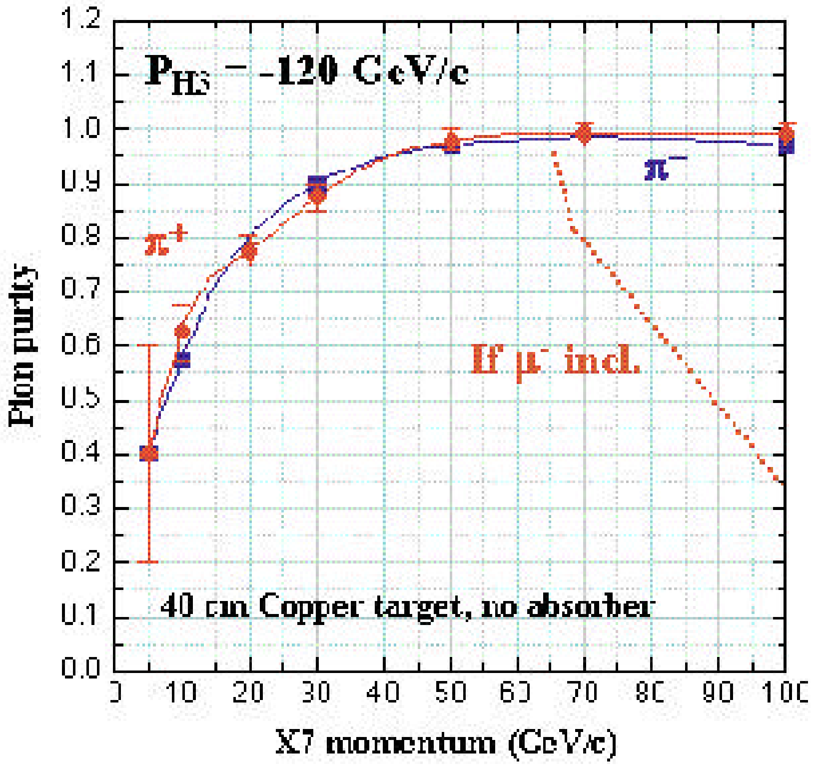


Figure 12: *The purity of tertiary hadron beams from a secondary beam at –120 GeV/c*

11. The West Area in the LHC era

In order to make space for the passage of the transfer line TI2 for the injection of protons into the Large Hadron Collider (LHC), the West Area primary target T1 will have to be dismantled. A new target will have to be installed in a new location, displaced downstream by about 12 metres and sideways by about 1.56 metres with respect to the present T1 position. This work will take place in the winter shutdown 2000/2001 or possibly already in 1999/2000.

Figure 13: *Overview of the implications of the displacement of the T1 target (not to scale)*

The wobbling magnets upstream of the target will have to disappear for lack of longitudinal space. In fact the wobbling station is only of limited use, since the H1 secondary beam line has been dismantled[4].

As a consequence of the T1 displacement, more than 500 metres of the H3 beam will have to be displaced sideways to the North side of the tunnel TT61. Schematically the whole project is pictured in Figure 13. The layout of the front end, up to the TAX, is exactly preserved, apart from the fact that the TAX mobile dumps are replaced by fixed dumps of TCX-type. Downstream of the TCX, the acceptance defining section has to be shortened by about 12 metres. From then on the optics and layout of the beam line can remain unchanged till the top end of the tunnel TT61. The old bends B3 and B4, that provided a 80 mrad vertical bend, can be aligned such that (without longitudinal displacements) the beam can be made to arrive at the entrance of the splitters in exactly the same position and at the same angle as before. For this purpose, 4 out of the 5 dipoles of B4 and B5 are tilted. The central dipole will be installed horizontally and powered separately and be of different type with bigger gap size to preserve the acceptance of the beam. This allows independent control of the beam steering in the horizontal and vertical plane. This new layout also optimises easy access to the primary target zone via the secondary beam tunnel TT61. However, it requires a displacement of the wall opposite the entrance gate.

With this layout the performance of the beam should remain essentially unchanged and the co-existence of the West Area with the injection line into LHC is guaranteed. This allows therefore the LHC experiments to perform tests and calibrations during the construction period of their detectors.

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[4] The only option lost due to the suppression of the wobbling station is the special electron wobbling, providing pure electron beams (up to some 150 GeV/c) from conversion of photons from π^o decays.

The absence of a wobbling station will in fact simplify somewhat the operation of the West Area, though at the small cost of loosing the pure electron beams for momenta below 150 GeV/c.
The T1 displacement project and its implications are described in more detail in reference [16].

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