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PRELIMINARY REPORT ON BEAM FACILITIES FOR THE POST-SCIP MACHINE

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In this report we shall attempt to describe briefly the characteristics of the various beams planned for the synchrocyclotron after the Improvement Programme has been carried out.

From the users' point of view the main modifications to the machine itself will be :

1. Increase in the average internal beam from the present 1 μA to approximately 10 μA; if the extraction efficiency can be made very high it may be possible to accelerate 20 μA for extraction.

2. Increase in the extraction efficiency from the present 5% to at least 50%; this means we may well have an extracted beam of 10 μA instead of the present .05 μA.

3. Increase in the repetition rate of the machine from 54 to 466 pulses per second. This, together with the improved extraction system, will provide a macro duty cycle of approximately 80% for the extracted beam; the micro duty cycle will be 10-15% for Cee extraction and approximately 100% for the kicker coil. The Cee extraction should produce an

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external beam with an energy spread of $\leq$ 500 keV FWHM; the kicker coil should produce an energy spread of approximately 3 MeV FWHM.

NEUTRON ROOM (Internal Targets) (Figure 1)

The only major change in the present neutron room beams will be the mounting of those transport elements situated near the machine or in the shielding wall on a rail system so that they can be pulled through the shielding for repair or replacement.

1. μ Channel

The only changes to the μ channel will be the addition of one quadrupole lens at the entrance to the channel and a new beam blocker system. The particle flux increase should be given simply by the increase in the internal beam current. Thus for a nominal internal current of 10 μA one can simply multiply the particle fluxes listed in the SC Users' Handbook by a factor of 10.

2. MSS (125 MeV) Beam

The following changes will be made in this beam :

a. The present LC doublet within the shielding wall will be changed to a LC triplet making a more symmetrical transport system.

b. The present remotely-controlled collimator which has only a limited travel in one plane and is fixed in the other plane will be replaced by a new collimator having remotely adjustable gaps in both planes with increased travel. This should enable one to optimize the intensity versus resolution for a given experiment.

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c. The present beam blocker will be replaced with a rotating wheel "fail safe" blocker.

Although exact analysis of the effect of these changes has not yet been completed by the Brussels-Orsay Group, they estimate that they should result in a roughly 20% increase in π fluxes, possibly 30% for the low energy region. With a 10 μA internal beam one should obtain approximately the following fluxes at the centre of the platform (i.e. scattering target) over an area of roughly 2 cm ϕ for a momentum band of 4% $\Delta p/p$ FWHM

Energy MeV	$(\pi^- + \mu^- + e^-)$/sec
110	1.7×10^6
150	2.6×10^6
180	2.9×10^6
220	2.6×10^6
260	2.0×10^6

3. <u>Low Energy Pion Channel</u>

This channel will replace the present 70 MeV channel but will have the following improvements over the old beam:

a. Broader energy range (60-110 MeV) available due to the use of an inflector magnet at the channel entrance.

b. Much better optics due to inclusion of a remotely-controllable collimator in the middle of the channel and the addition of an LC doublet before the final deflecting magnet. The changes will give a smaller final spot size and the possibility of obtaining a beam with a smaller

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energy spread.

c. A larger acceptance increasing the intensity for a given machine current by approximately 30%.

The estimated π fluxes assuming a 10 μA internal beam are :

Particle	E_π MeV	$\Delta p/p$	Spot (FWHM)	Flux (π/sec)	Stopping rate in 1 cm CH_2
π^+	85	<5%	5 cm ϕ	10^6	1.4×10^5
π^+	85		7.5 x 4 cm	5×10^6	
π^-	105		7 x 5 cm	7×10^6	
π^-	90	5%	5 x 2 cm	5×10^6	4×10^5
π^-	60	3%	5 cm ϕ	3×10^5	

PROTON ROOM (External Target)

In designing the beam systems using the extracted proton beam the chief consideration was to achieve reasonable flexibility with a standard system of transport elements which could be rapidly moved into position. The radiation level in the machine vault is expected to be so high that the present system of positioning the elements with a transit will no longer be possible. We will therefore install a precision rail system along the axis of the extracted beam and the bending magnet and quadrupole pair will be mounted on carriages which can be quickly rolled along the rails to the desired location.

The carriage for the one-meter bending magnet will have provisions for rotating the magnet about its centre in order

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to be able to vary the beam entrance angle with respect to the pole faces, and for a limited amount of translation perpendicular to the beam axis in order to optimize the beam path through the magnet. The quadrupole pair will be mounted on a separate carriage with provision for adjusting the position of each quadrupole so as to place its magnetic optical axis along the beam axis.

The beam elements which are not common to all beams, e.g. the clearing magnet in the neutron beam, will be placed on self-aligning pins fixed to the floor or in the case of LA3 and the degrader assembly onto alignment pins on the carriage holding LA1, LA2 and the beam transformer. The beam pipes will be provided with toggle-type quick vacuum connections in order to keep the time required for beam change-over to a minimum.

I. HIGH RESOLUTION Π BEAM (Figure 2)

In designing this beam our object was to obtain the highest resolution which seemed achievable with our standard beam elements with only relative minor shimming or collimation. The rough order of magnitude we have been attempting to achieve is 200-300 keV FWHM for 280 MeV pions, however since the presently available elements were not designed for high resolution beams even this moderate goal will probably be rather difficult to achieve. The system shown in Fig. 2 is only one of several alternatives we are presently analysing; however, since its analysis is most advanced and its major features are typical of all the systems we shall discuss it. In any case the beam layout within the machine vault will remain fixed for any of these beams since the space limitations together with the desire

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for a large bending angle, minimum beam length, inclusion of an electro-static separator, and maximum useful space in the proton hall more or less determine the layout.

The beam consists of two magnetic spectrometers identical except for the large drift distance imposed on the first by the shielding wall. The system is designed to produce a dispersive image at the intermediate point, where a counter hodoscope or momentum slit can be used to determine the energy of the pion, and an achromatic image at the end of the system. The advantage of such a system is that one can accept a rather large momentum bite of the produced pions ($\simeq$ 2%), achieve high energy resolution by tagging them at the intermediate image and recombine them to small final spot at the position of the experimental target. The main disadvantages are the length of the complete system and the number of elements required; however, since the resolution of the system depends only upon the quality of the elements in the first spectrometer only these will need to be carefully shimmed. Since the π^+ flux will be quite high, for many experiments one will be able to use only the central region of the dispersed beam for bombarding the target, and use the second spectrometer to look at the outgoing charged particles. To facilitate such use it is planned to mount the second spectrometer arm on a rotating platform similar to that presently used with the Oxford-Göteborg spectrometer. A one-meter standard CERN electrostatic separator has been incorporated in order to remove the high flux of degraded protons present in beams using zero degree pion production. This proton contamination is very troublesome with present beam fluxes because the scintillation pulse from the proton is several times as large as that of the pion; for the new beams where the

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pion flux alone is at the limit of present counting techniques it is essential to remove the proton contamination.

At present we have carried out first and second order calculations for two systems having slightly different quadrupole settings; one system derived such as to optimize the resolution without regard to the acceptance and one so as to optimize the acceptance but with somewhat lower energy resolution. The characteristics of the π beams available with these systems are shown in Table I. However, it should be kept in mind that while we have included the second order corrections to the optics we have assumed perfect elements. In order to obtain reliable estimates for the energy resolution of the systems it will be necessary to perform ray tracing using the measured fields - since accurate field plots are not available for some of the elements this will require a fair amount of additional effort.

The beam calculations shown in Table I were made under the following assumptions :

1. An extracted proton beam intensity of 5 μamps.
2. The emittance of the extracted beam was taken from the calculated total beam envelopes since the profiles are difficult to calculate. This means we are being conservative in our estimates of the size of the proton focus; in turn our resolution figures for the assumed perfect elements are also conservative.
3. The resolution estimates do <u>not</u> include the finite spatial resolution or energy loss of the detector assembly mounted in the intermediate focus.

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4. The quadrupole lenses have been collimated to an aperture of ± 8 cm in both planes as this is approximately the good field region for the LD lenses.

As one can see from Table I even assuming perfect elements we are limited to an energy resolution in the range 300-400 keV, thus it is clear that if we wish to obtain 200 keV resolution we must use higher dispersion. Since the homogeneous field region of the one-meter bending magnet and the geometry of the extracted beam make it very difficult to obtain greater than 45° deflection inside the machine vault, we are presently investigating a beam having a second deflection immediately after the shielding wall. This should provide approximately twice the dispersion thus making it much simpler to obtain the desired resolution without extensive shimming of the beam elements.

II. HIGH FLUX Π BEAM (Figure 3)

This beam has been designed to produce a very high pion flux over a large energy range; the main objective was thus to obtain a roughly non-dispersive final image and to maximize the system's angular acceptance. The system consists of a quadrupole pair, placed as close to the production target as their saturation limits will allow, followed by two magnets deflecting the beam through equal but opposite angles of 30° in the horizontal plane and a final quadrupole pair outside the shielding wall to produce the final beam spot. Since the pions are produced at roughly 0° it is necessary to include some analysis to remove, at least partially, the large contaminant of degraded protons. The final image is made non-dispersive by equal but opposite deflections with no intermediate focus.

In principle one can vary the energy band transmitted by placing a collimator between the deflection magnets. However, because of the very limited distance (2.5 m center to center) between the magnets this is only feasible if one is willing to reduce the horizontal beam size with the consequent reduction in the angular acceptance of the system. Since we have designed another beam (No. IV) giving equally large fluxes but having an energy spread roughly half as large, this beam will mainly be of interest to those experiments needing a very high flux but being able to tolerate a very large energy spread.

The beam calculations assuming no intermediate collimation and full use of the 25 cm ϕ pole gap of the LD quadrupole lenses yields the following fluxes over a final image size of 6 x 6 cm. The extracted beam has again been assumed to be 5 μamps.

P_π at center	E_π at center	Production target	ΔE_π FWHM(1) no collimator	Flux Π^+ /sec in total band	Flux Π^+ /sec.MeV at peak
400 $\frac{MeV}{c}$	284	10 cm C_6H_{12}	≈ 5 MeV(2)	1.3 x 10^8	
400 $\frac{MeV}{c}$	284	10 cm carbon	47 MeV	2 x 10^8	4 x 10^6
300 $\frac{MeV}{c}$	191	10 cm carbon	46 MeV	2 x 10^8	5 x 10^6
200 $\frac{MeV}{c}$	104	10 cm carbon	28 MeV	5 x 10^7	2 x 10^6

(1) The shape of the energy pass band is quite asymmetric with a quite sharp cut off on the low energy side and a very

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long tail on the high energy side. We are presently attempting to remove this tail without drastically reducing the central flux.

(2) The energy spread in this case is determined by the ΔE of the extracted beam (assumed 3 MeV) and the spread due to energy loss in the production target.

III. NEUTRON BEAM (Figure 4)

Figure 4 shows the proposed beam layout for production of a monokinetic neutron beam via the p(d,2p)n reaction at 0°. The extracted beam, at full energy, is transported via the four quadrupoles LA1, LA2, LD1, LD2 and the bending magnet to the liquid deuterium production target. In order to be able to vary the energy of the proton beam, and hence the 0° neutron beam, we have included a degrader assembly consisting of Be blocks which can be remotely flipped into the beam so as to vary the total length of degrader in 10 cm steps from 0 to 100 cm. For each degrader length it will be necessary to optimize the two quadrupole pairs in order to produce the best beam waist at the deuterium target. For the highly degraded beams the energy spread and beam size will be rather large and one of the purposes of the first bending magnet is to attempt to clean up the degraded beam by passing it through a collimator. Whether this can be done without creating a large neutron background is, of course, questionable. The second bending magnet is used to clean the neutron beam of protons deflecting them onto the shielding wall between pipes B and C. In order to restrict the neutron production to small angles about 0° and to reduce the flux in the experimental area to an acceptable level, the C pipe will be collimated with steel collimator plugs.

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At present we have made only preliminary estimates of the neutron fluxes and energy spreads for the full energy proton beam assuming :

1. The extracted beam has an intensity of 5 μamps and an energy spread of 0.5 MeV (Cee extraction)
2. A deuterium target of length 10 cm
3. C pipe collimation of .07 millisteradian - corresponding roughly to a neutron beam of 10 cm ϕ for an experiment located 2 meters downstream from the end of the C pipe.

The neutron flux should be approximately $6 \times 10^6 \frac{\text{neutrons}}{\text{sec}}$ with a ΔE neutron ≈ 5 MeV (FWHM).

Since the intrinsic energy spread of the p(d,2p)n reaction is approximately 1.4 MeV, the full energy beam may be made more nearly monokinetic at the expense of flux by using a thinner deuterium target.

An additional use of this beam system could be to produce a variable energy proton beam in the proton hall. Here the second bending magnet would be used to deflect the degraded proton beam down pipe B. In order to reduce the proton flux in the experimental hall to the level set by Health Physics (≈ 10^8 p/sec), and to reduce the energy spread of the degraded beam, pipe B would have to be heavily collimated by plugs similar to those used in pipe C for the neutron beam. An additional collimator could be placed between the two magnets in the space occupied by the deuterium target in the neutron beam. With a double bend and two collimation systems it should be possible to produce a proton beam having a small energy spread over a fairly wide energy range.

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IV. HIGH FLUX PION BEAM (Figure 5)

This beam was originally developed to deliver a high flux of 200 MeV/c negative pions for use with the 1 meter test section of the SIN superconducting μ channel and the University of Fribourg Crystal Spectrometer. For such a system the only beam parameter of interest is the pion flux per MeV, and hence we attempted to achieve a large acceptance at 200 MeV/c by placing an extra quadrupole pair after the deflecting magnet in order to reduce the beam size before it passes through the shielding wall. In varying the lens settings so as to maximize the acceptance of the system we accidentally found a beam having a very high acceptance and a very nearly non-dispersive final image. This very useful but odd beam was achieved by setting the first lens pair so as to produce a horizontal image in the bending magnet. While this beam was developed for low energy pions the higher energy versions of it also turned out to have very large acceptance and, in fact, the pion flux delivered over the range 200-400 MeV/c is as large as that of the double bend high flux beam (No. II). Since this beam delivers the flux over an energy band roughly half as broad it should be more useful for most experiments.

The flux calculations were made assuming a 5 μamp extracted beam, full use of the 25 cm ϕ gap of the LD lenses, and a final spot collimation of 10 x 10 cm. This large final spot size was chosen so as not to artificially limit the acceptance of the system. The actual spot size depends upon how much of the wings of the pass band one is willing to sacrifice since the dispersion while small is not zero. The vertical spot size is roughly independent of the momentum and is approximately ± 2 cm. We are presently calculating the fluxes and band widths for a final spot size of ± 2 cm horizontal and vertical.

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P_π in MeV/c at band center	E_π in MeV at band center	Production Target	ΔE_π (FWHM) of band in MeV	Flux π /sec in band	Flux π /MeV-sec at band peak
			π^+		
535	413	10 cm liquid ^{3}He	0.8(1)	6×10^5	
535	413	20 cm liquid ^{3}He	1.4(1)	1×10^6	
485	365	10 cm liquid ^{2}H	1(1)	4×10^6	
407	291	5 cm liquid ^{1}H	0.6(1)	1×10^8	
390	275	10 cm C_6H_{12}	5(2)	3×10^8	
400	284	10 cm carbon	25	2×10^8	7×10^6
300	191	10 cm carbon	20	2×10^8	9×10^6
200	104	10 cm carbon	12	5×10^7	4×10^6
			π^-		
400	284	10 cm Be	25	3×10^7	9×10^5
300	191	10 cm Be	19	5×10^7	2×10^6
200	104	10 cm Be	12	1.5×10^7	1.4×10^6

(1) The energy spread for these cases is determined by the ΔE of the extracted beam, assumed to be 0.5 MeV corresponding to Cee extraction, and the spread due to the energy loss in the production target.

(2) As above but assuming a ΔE of 3 MeV for the extracted beam corresponding to kicker coil extraction.

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It is obvious from the preceding beam estimates that, if an extracted beam of 5 μamp or greater can be obtained from the post-SCIP machine, there will be a much heavier demand for the extracted beam than is presently the case. Thus it is essential to keep the time required for changing to and from the underground beam transport system to a minimum. In order to achieve rapid change-over it is planned to have a separate one-meter bending magnet permanently rotated and tilted into the "Isolde" position. This magnet will be mounted on a self-aligning base which can be dropped onto aligning pins set into the floor. The vacuum pipe connections will be quick connect type and, as has already been pointed out, the LA3 lens can be quickly inserted or removed.

Figure 6 shows the modified Isolde arrangement proposed by the Isolde group for the post-SCIP period. In order to keep UR 8 as a normal counting area during Isolde runs it is proposed that the target be moved into the deflected proton beam and a heavy shielding wall be installed between the target and collection areas. Although considerable effort has been expended upon arranging the required shielding so as to minimize the space loss to other users of the underground area, some loss is necessary and comments from prospective users of this area would be appreciated. In any case it seems clear, at least to one prospective user, that if the excellent extracted beam predicted by the machine group is obtained we will badly need a much larger underground area where the full proton beam can be effectively employed.

TABLE I

HIGH RESOLUTION BEAM (FIGURE 2)

P at Band Center MeV/c	E at Band Center MeV/c	Production Target	Dispersive Image			Final Image			δE_2(2) Energy Resolution 1st and 2nd Order
			$\Delta E\pi$ Band Width	$N\pi^+$/MeV-sec at Band Peak	$N\pi^+$/sec in Band	$\Delta E\pi$ Band Width	$N\pi^+$/MeV-sec at Band Peak	$N\pi^+$/sec in Band	
			High Solid Angle Alternative						
390	275	10cm C_6H_{12}	≈5 MeV(1)		6×10^7	≈5 MeV(1)		3×10^7	
400	284	10cm carbon	9 MeV	1.7×10^6	1.5×10^7	6 MeV	1.7×10^6	7×10^6	420 keV
300	191	10cm carbon	6.5 MeV	2×10^6	1×10^7	4 MeV	1×10^6	5×10^6	360 keV
200	104	10cm carbon	4 MeV	8×10^5	3×10^6	2.5 MeV	4×10^5	1×10^6	230 keV
			High Resolution Alternative						
390	275	10cm C_6H_{12}	≈5 MeV(1)		5×10^7	≈5 MeV(1)		2.3×10^7	360 keV
400	284	10cm carbon	9 MeV	1.3×10^6	1.2×10^7	6 MeV	6×10^5	3×10^6	360 keV
300	191	10cm carbon	7 MeV	1.4×10^6	1×10^7	4 MeV	8×10^5	4×10^6	300 keV
200	104	10cm carbon	4 MeV	7×10^5	3×10^6	2.4 MeV	3×10^5	8×10^5	185 keV

(1) The energy spread is determined by the ΔE of the extracted beam (assumed 3 MeV) and the spread due to the energy loss in the target.

(2) If the emittance of the improved extracted beam is equal to that of the present beam the energy resolution (FWHM) would be improved by a factor of 2.

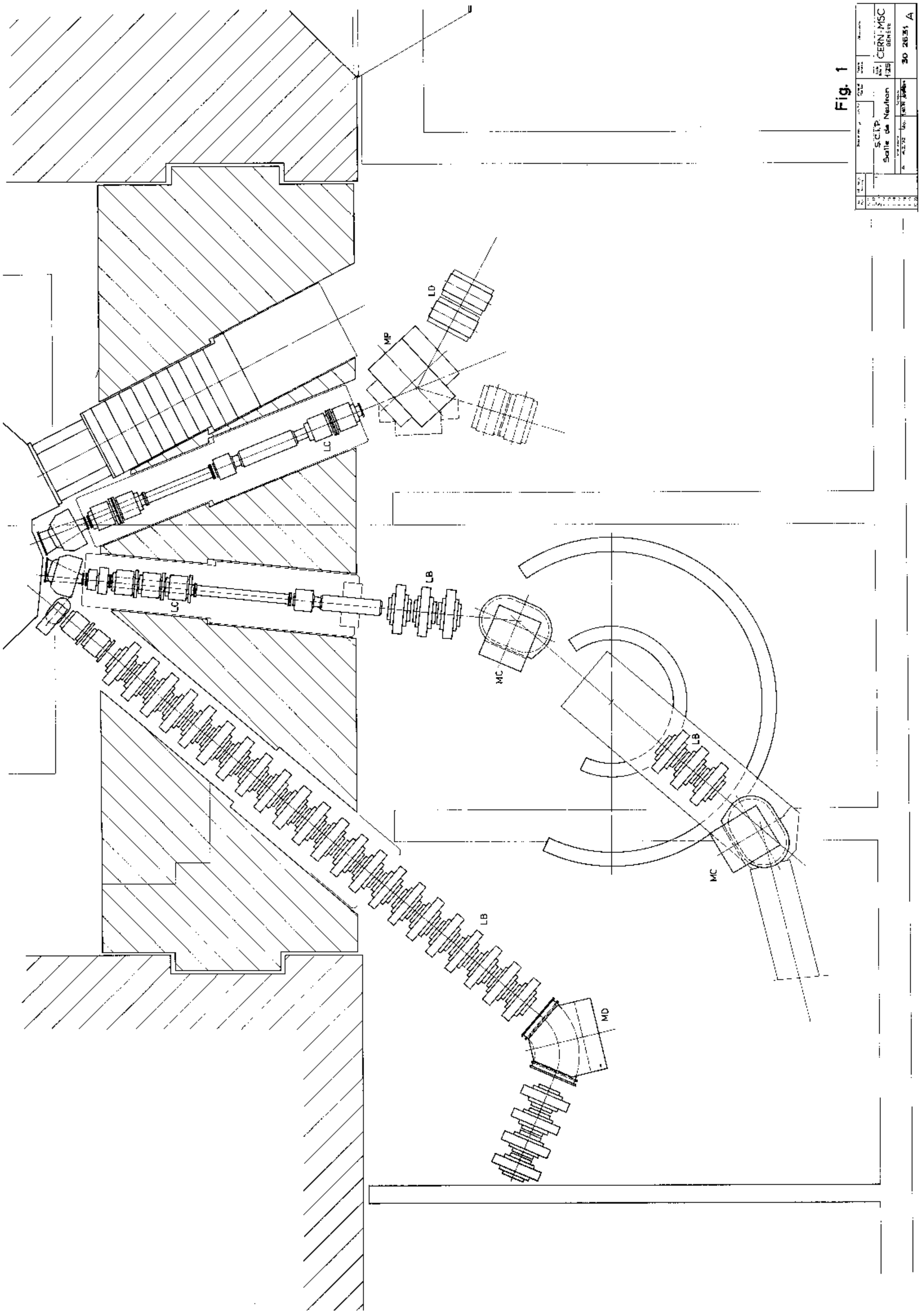
LD
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Fig. 1

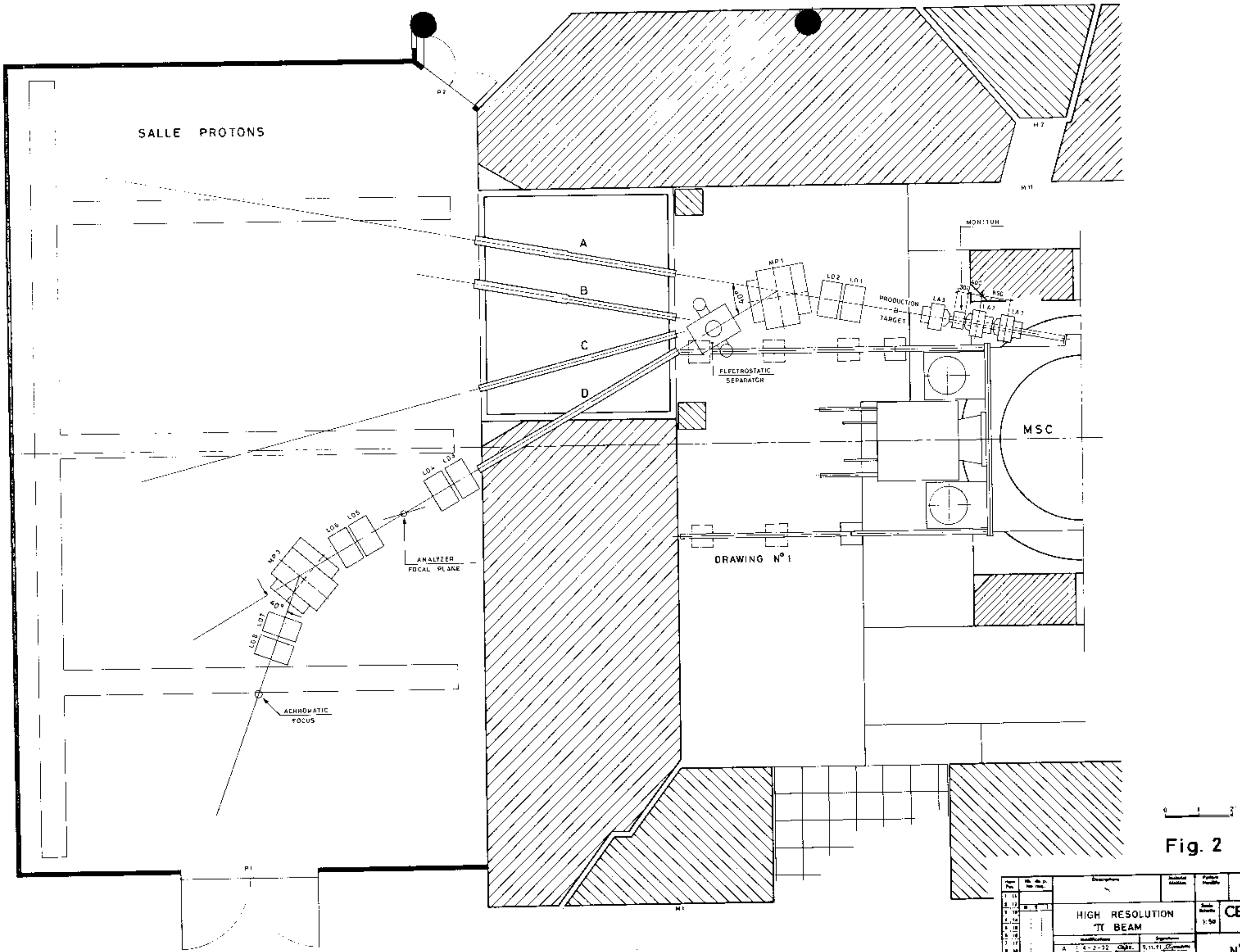

Fig. 2

HIGH RESOLUTION
π BEAM

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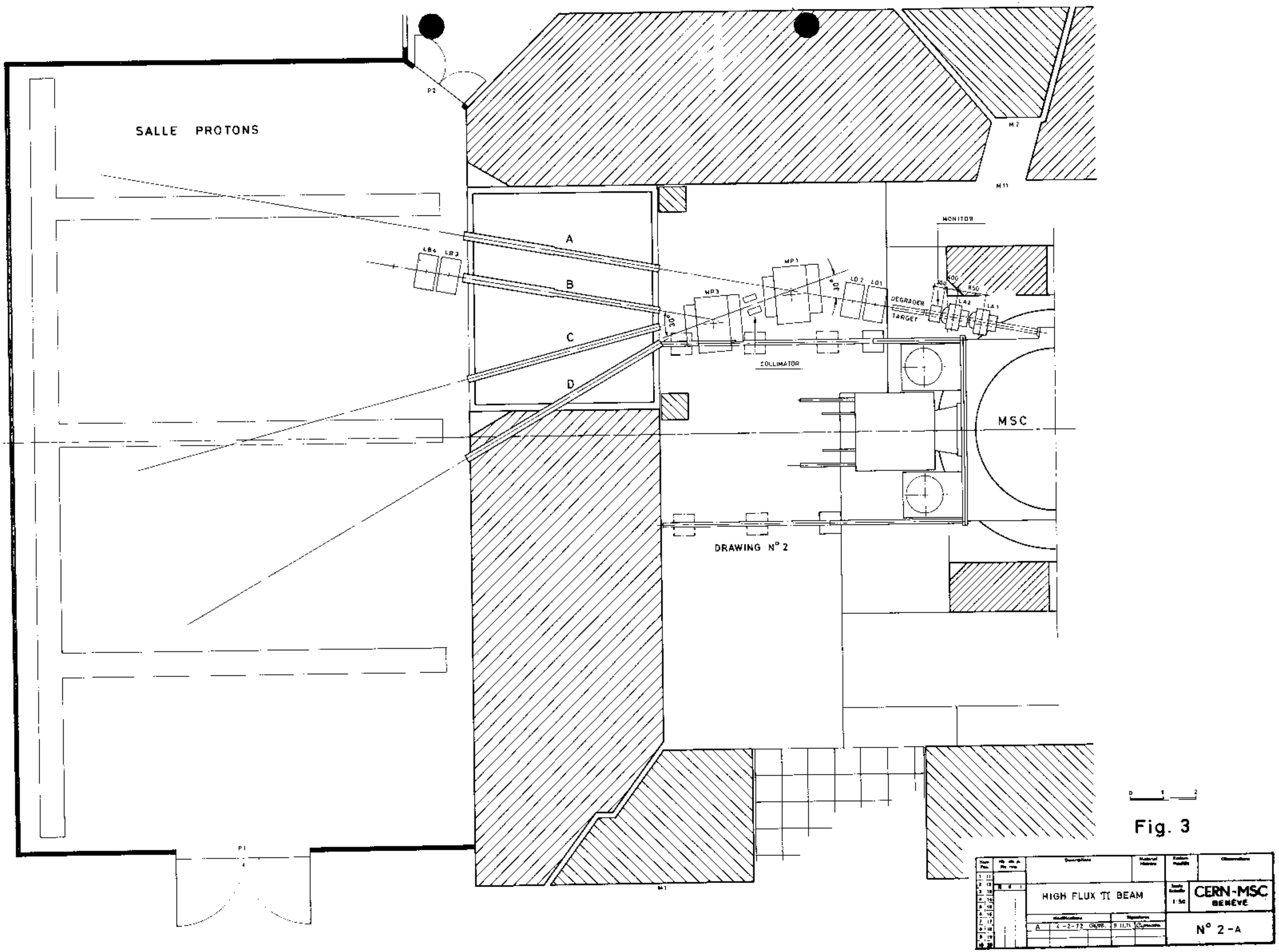
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M2
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P1
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DEGRADER
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HIGH FLUX π BEAM
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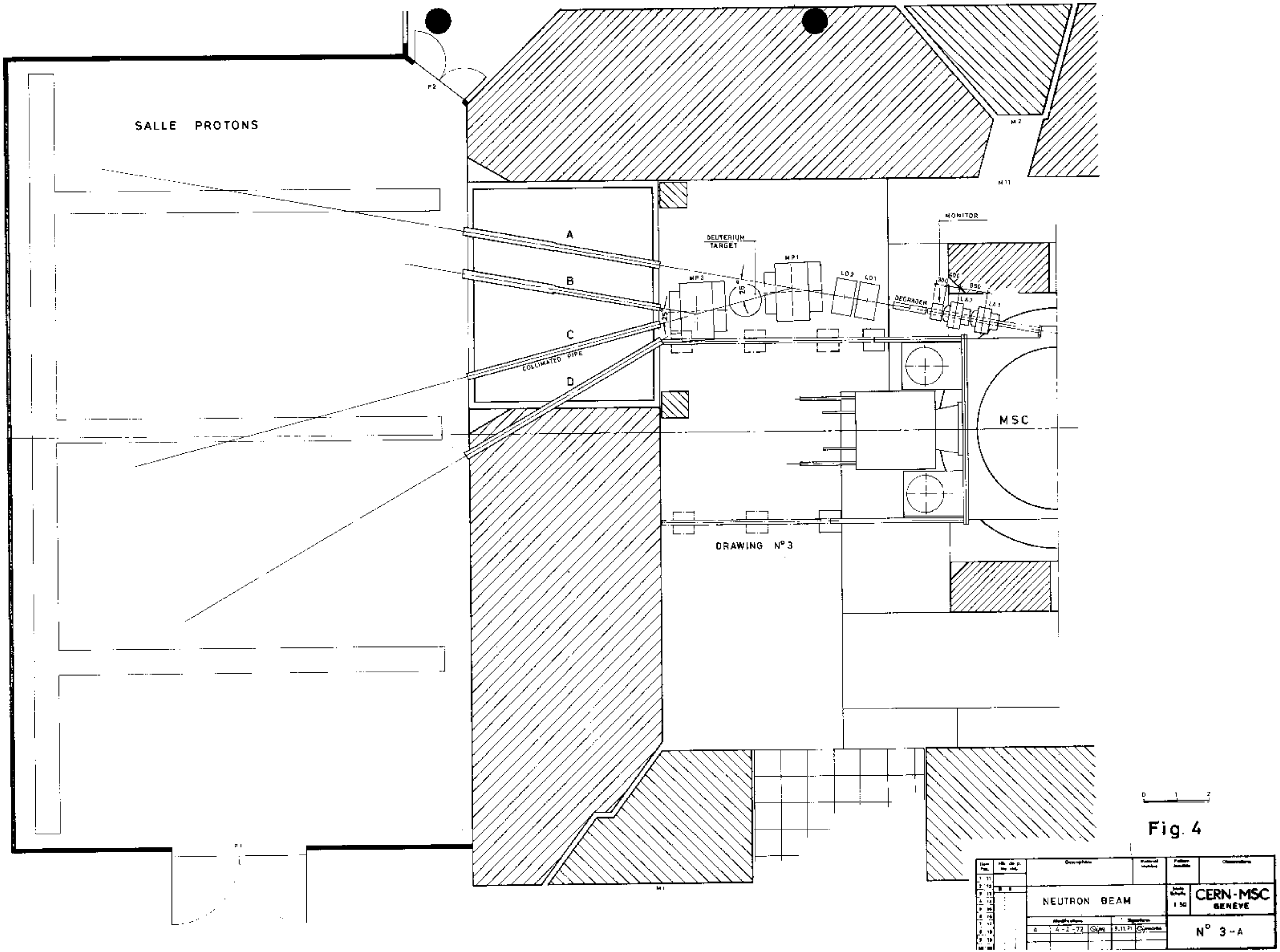
Fig. 3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LA2
LA1
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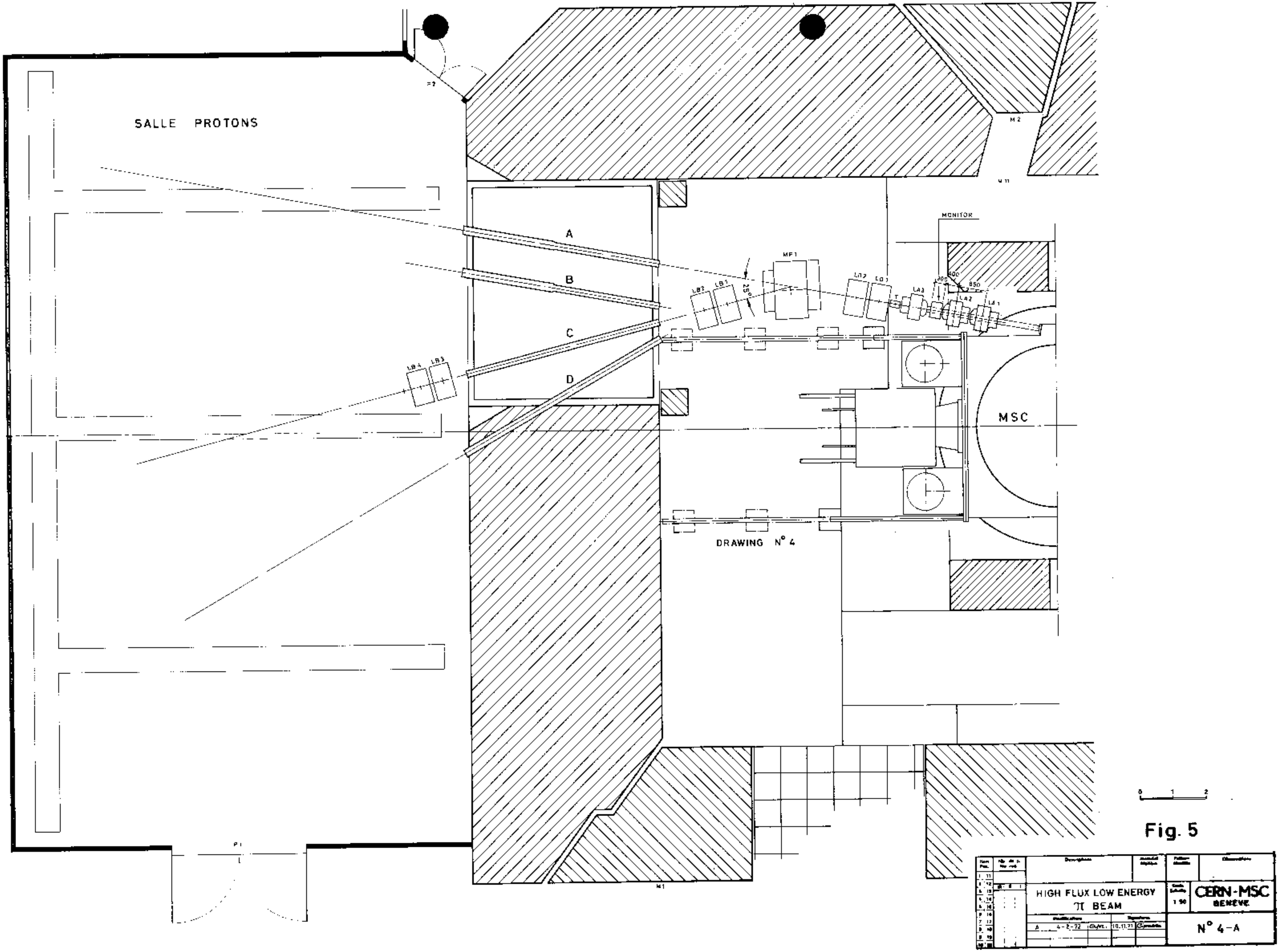
Fig. 4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HIGH FLUX LOW ENERGY
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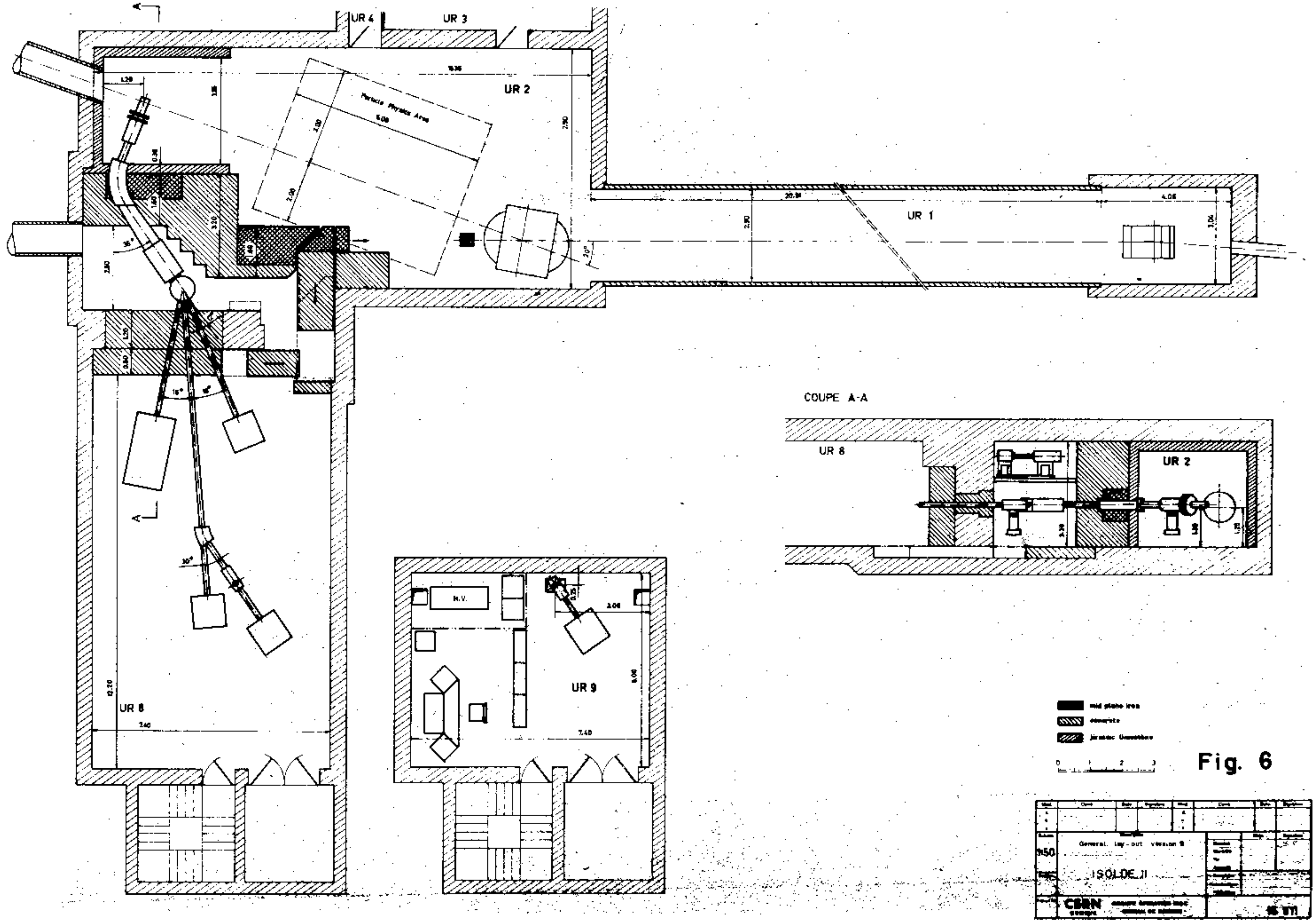
Fig. 5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1.20
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UR 8
12.20
2.40
UR 9
H.V.
3.06
8.00
7.40
COUPE A-A
UR 8
UR 2
concrete
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1
2
3
General lay-out
1:50
ISOLDE II
CERN

Fig. 6