Chapter 3 Design of the East Area facility after renovation

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3.1 Beamline design and layout

3.1.1 Introduction

The PS primary proton beam is slowly extracted at 24 GeV/c towards the East Area with the help of the third-order resonance technique over a typical spill length of 350 to 450 ns within 2.4 s cycles. The number of East Area extractions is usually around five to six per overall PS super-cycle of typically 40 s and depends on both users and schedule constraints, respectively. After passing both magnetic septa SMH57 and SMH61 (Fig. 3-1) in the PS, the beam enters the F61 transfer line that transports the beam either to the so-called North Targets via the lines F62 and F63 or towards T08, which serves the irradiation facilities IRRAD and CHARM. During operation of primary ion beams, only these irradiation facilities can be operated. The principle of extraction by third-order resonance and the corresponding optical elements inside the PS, such as the magnetic septa, will be kept unchanged for the new East Area operation. Thus, only a replacement of the existing magnets by laminated versions with slight optimization of the optics was chosen as the renovation baseline for F61 with changes in the layout mostly due to integration constraints and considerations for improved radiation protection. In particular, all the main horizontal bends have been replaced by reliable and robust MCB magnets, which are available with sufficient spares and can be operated in pulsed mode. The splitting option, although more efficient for operation, was dropped in 2005 for technical reasons that were hard to overcome in a reliable manner. For further details on the recent operational history of F61 and the original ideas of the renovated East Area beams, see Ref. [1].

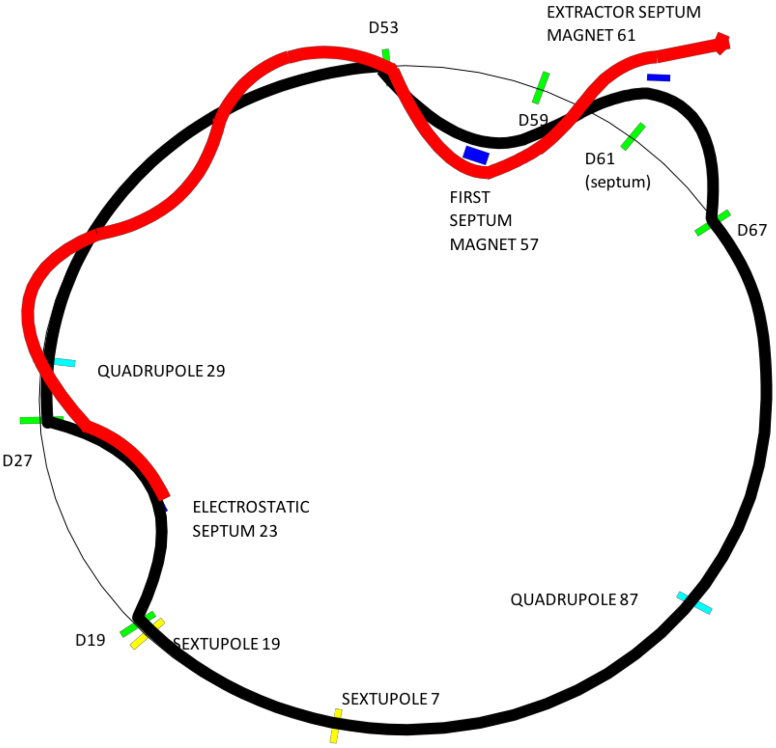


Fig. 3-1: Employed slow extraction scheme in the PS ring towards F61; courtesy: R. Steerenberg, ‘Proton Beams in the East Area’, OP course material, 2004.

3.1.2 The F61 transfer line matching section

The matching section of F61 uses a frontend of four quadrupole magnets to match the extracted beam for further transfer. As the beam is horizontally extracted and thus horizontally large, at the start, strong and compact focussing quadrupoles are required with a large horizontal aperture. While three Q74 magnets were used in the old layout, only one laminated Q74 magnet will be used in the new design (F61.MQNCL007), therefore reducing space restrictions in the very dense area between the PS main combined elements and allowing for a better spare situation for this purposely made magnet. The first quadrupole is then followed by a set of five beam stoppers that are used as safety elements during access to the zones downstream. Afterwards, a triplet of quadrupoles follows (F61.MQNEL014, F61.MQNEF021, and F61.MQNEG030), which matches the beam towards either F62 or T08.

Inside the triplet, after F61.MQNEF021, the M100 and M200 dipoles have been replaced by a single C-shaped MCB magnet (F61.MBXDH025). At full current and inversed polarity, this magnet deflects the beam towards the F6D dump position, which is required by Operation Group (BE-OP-PS) for setting up the slow extraction. In nominal operation, F61.MBXHD025 in combination with F63.MBXHD001 provides a magnetic chicane that enlarges the space between F61 and T08. This ensures enough space for the installation of two North Targets instead of one. The destination of primary proton beam is chosen with the help of F61.MBXHD033, which replaces the unreliable SMH01 splitter magnet. At zero field, the beam is transported towards the North Targets, while at full field the beam is directed towards T08.

3.1.3 Transport towards the North Target – F62 and F63

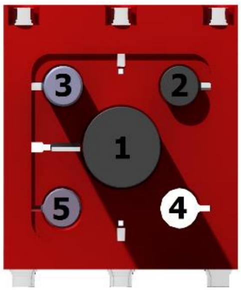
A doublet of Q120C quadrupoles is used to focus the beam on the respective secondary targets. The F63.MBXHD001 MCB-type dipoles correct the angle introduced by F61.MBXHD025, while another MCB-type dipole (F63.MBSHD005) switches between the target locations, again with field off (target A serving T09) or field on (target B serving T10/T11).

For both targets, the multi-target design chosen was introduced originally in 2014. Each target has five target heads, each with a diameter of the order of 1 cm (see Table 3-1). The layout of the target region is shown in Fig. 3-2, where the primary beam enters from the left side. In order to avoid changes in the main dipole currents and to separate initial position matching the F61 correctors from steering on the targets, another set of CR200 corrector magnets was introduced: F62.MCXCE013 for horizontal corrections and F62.MCXCE013 for vertical corrections. Figures 3-3 and 3-4 illustrate the optics configuration for beam extraction to the two different target destinations.

Figures 3-5 and 3-6 depict the beam spots for target A and B, respectively, which were calculated using the software TURTLE [2]. Table 3-2 summarizes the calculated parameters for the spot sizes on the two targets as well as the corresponding beam size on the primary dump.

Table 3-1: Multi-target configuration of the two north targets. The position of the target heads as seen in beam direction is depicted on the right side.

Head	Material	Length (mm)	Diameter (mm)	Comments
1	Be	200	10 + Al case	Electron enriched
	W	3		
2	Al	100	10	Electron enriched
	W	3		
3	Al	200	10	Hadron
4	Air	-	-	Empty
5	Al	20	10	Hadron



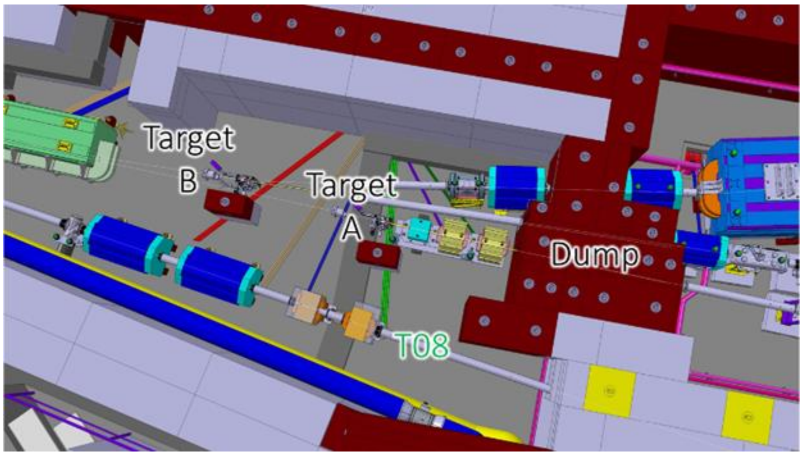


Fig. 3-2: Layout of the target region around the production targets for the T09 secondary beamline (target A) and for the T10/T11 beamlines (target B).

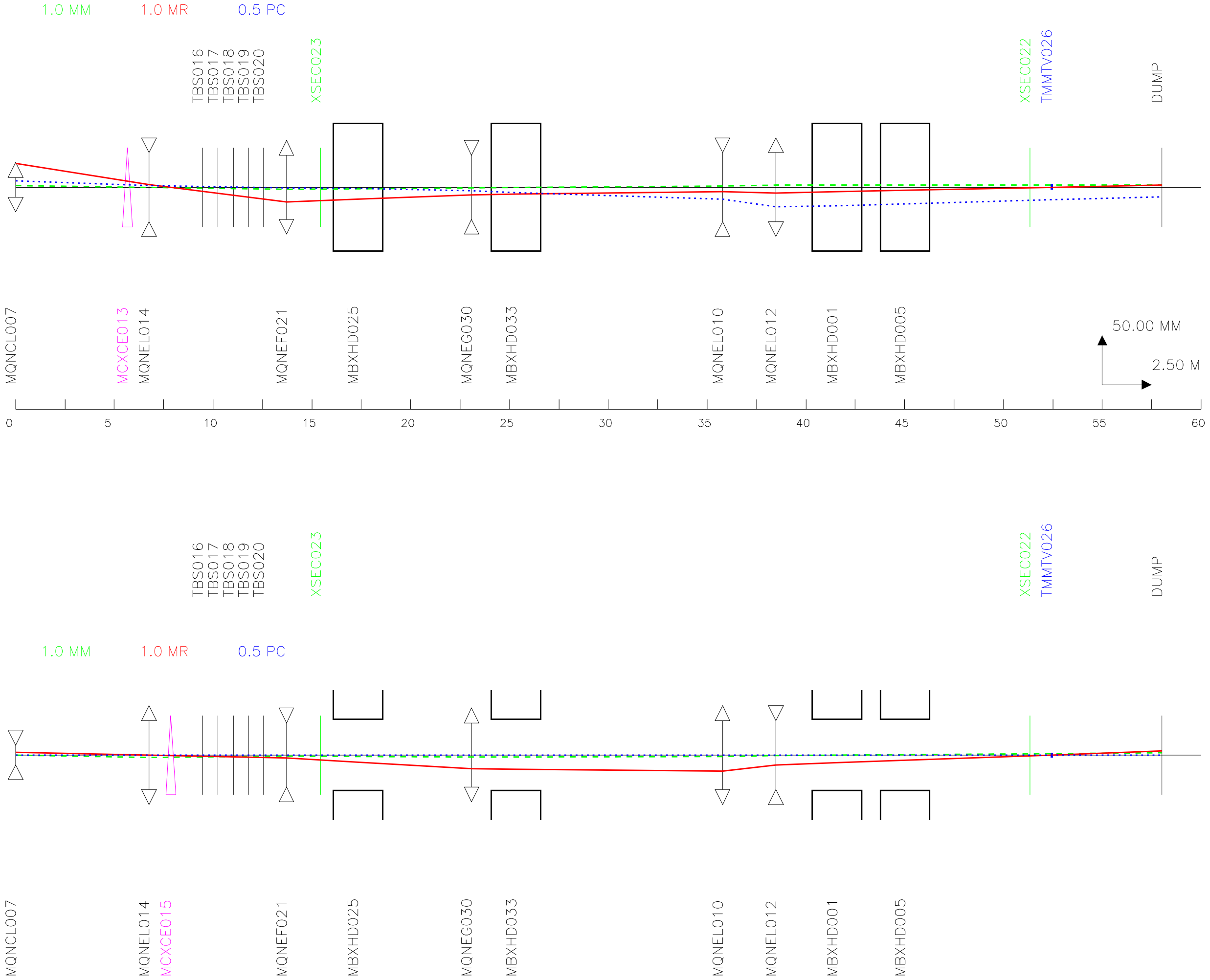


Fig. 3-3: Optics for the primary proton beam in F61/F62 from the PS extraction to target A as calculated with TRANSPORT. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane.

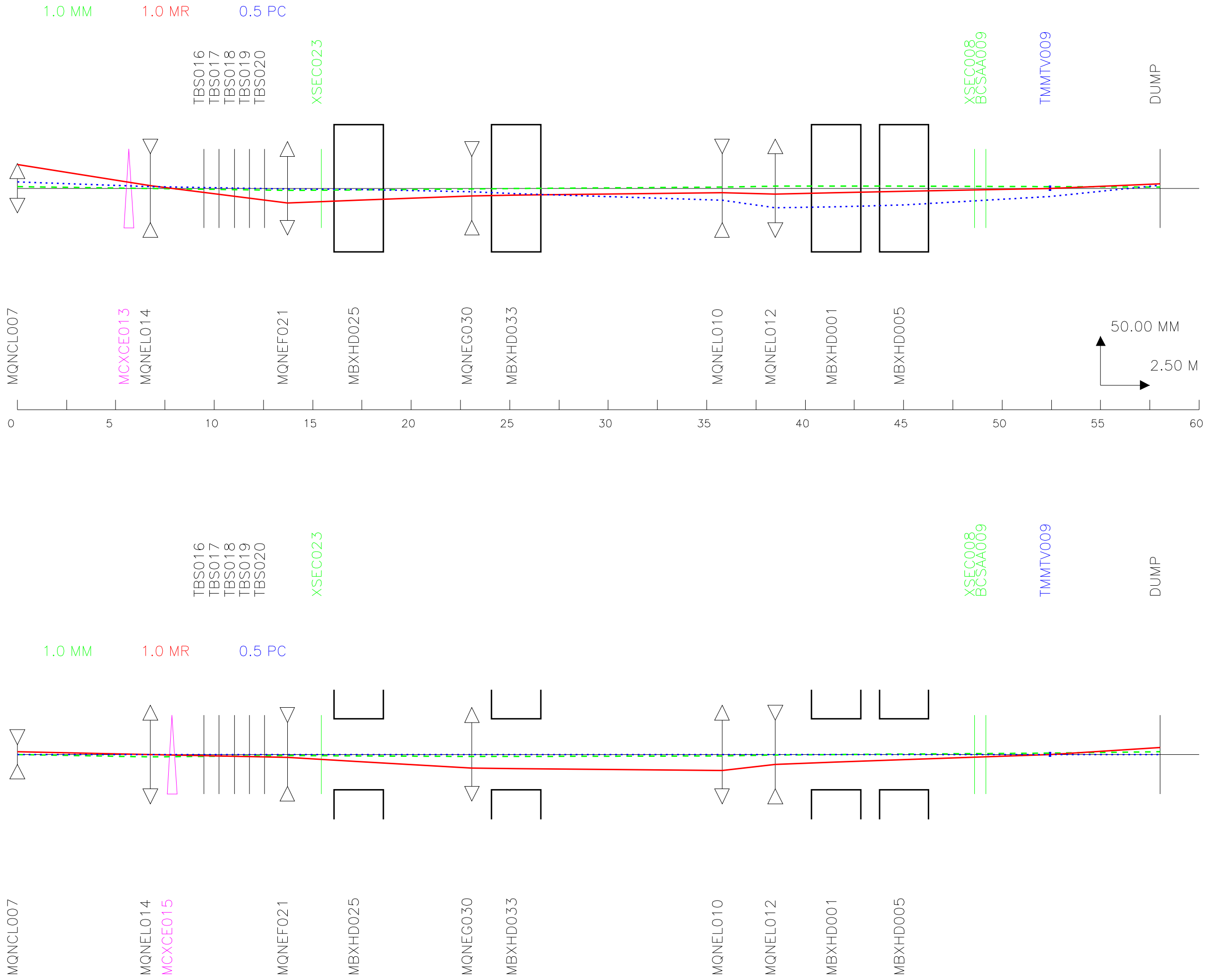


Fig. 3-4: Optics for the primary proton beam in F61/F62 from the PS extraction to target B as calculated with TRANSPORT. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane.

Table 3-2: Calculated beam spot parameters for the two targets A and B as well as the corresponding size of the beam when it enters the primary dump for destination A and B. For better comparability, the values are given in terms of the standard deviation σ and 4 σ that were found by fitting a Gaussian model to the results of TURTLE raytracing.

Location	**Plane**	**σ (mm)**	**4 σ (mm)**
Target A	Horizontal	1.7	6.9
	Vertical	0.7	2.8
Target B	Horizontal	1.3	5.3
	Vertical	0.6	2.5
Dump for A	Horizontal	1.7	7.0
	Vertical	1.1	4.4
Dump for B	Horizontal	0.9	3.7
	Vertical	1.3	5.2

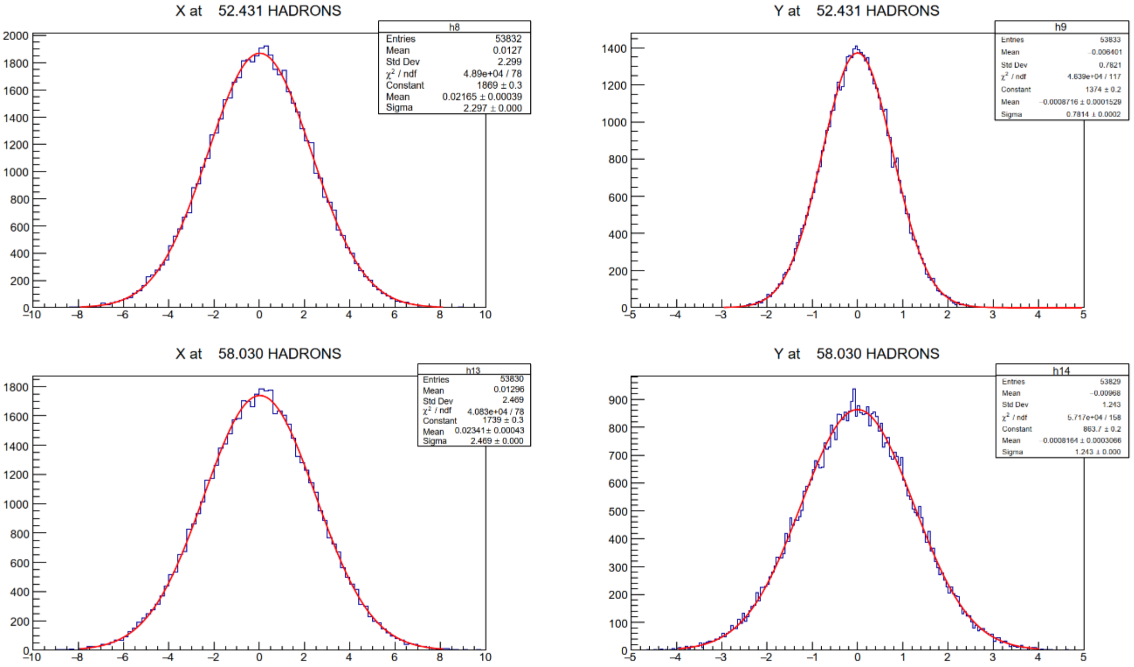


Fig. 3-5: Calculated beam spot parameters for target A (upper panels) and the corresponding spot size on the primary dump (lower panels). The left side shows the horizontal plane while the right side shows the vertical one.

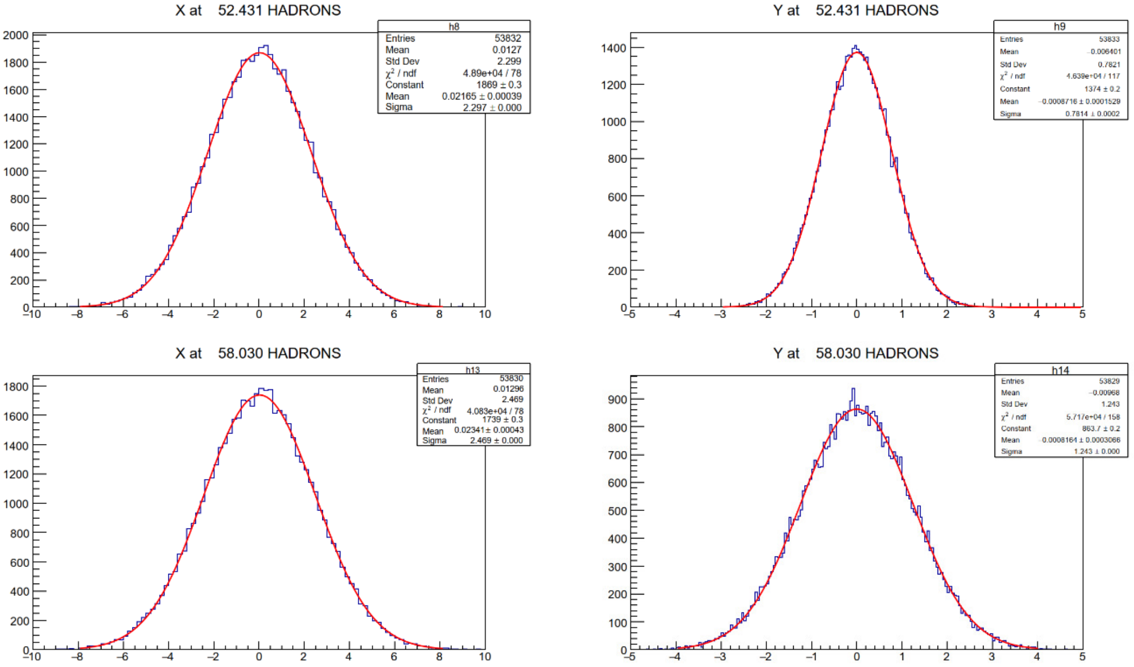


Fig. 3-6: Calculated beam spot parameters for target B (upper panels) and the corresponding spot size on the primary dump (lower panels). The left side shows the horizontal plane while the right side shows the vertical one.

3.1.4 The primary beamline T08

The primary beamline T08 serves the irradiation facilities IRRAD and CHARM. Both experimental areas were completely redone during LS1 in addition to changes in the T08 line, which are detailed in Ref. [2].

The aim of the currently discussed redesign of T08 is to keep both experimental areas unchanged, while matching the line to the newly designed primary zones at the change-over point F61.BHZ02. Furthermore, the T08 beamline has been cleared of leftover magnets due to the old T07 line and magnets have been exchanged with similar laminated models in order to respect the new pulsed powering scheme.

After passing F61.MBXDH033, the beam is bent away from the location of the north targets by an MCB-type dipole magnet and matched with the help of a first doublet of quadrupoles. Then, the beam is bent in direction of the experimental areas by a pair of MCB-type dipoles. The final focus consists of a pair of Q200 quadrupoles that allow focussing of the beam on each IRRAD experimental table, as well as on the CHARM production target. Figure 3-7 depicts the optics as an example for T08 for a focus on the second IRRAD table. Steering of the beam as well as correction of a possible angular mismatch between F61 and the T08 line are possible after introducing two sets of MDXL corrector magnets for both horizontal and vertical corrections. These magnets can also be used to shift the beam position parallel to any direction in order to cope with possible alignment mismatches of irradiation samples. In addition, a programmable function generator on the power supply of these correctors allows a sweeping of the beam on the user samples if required.

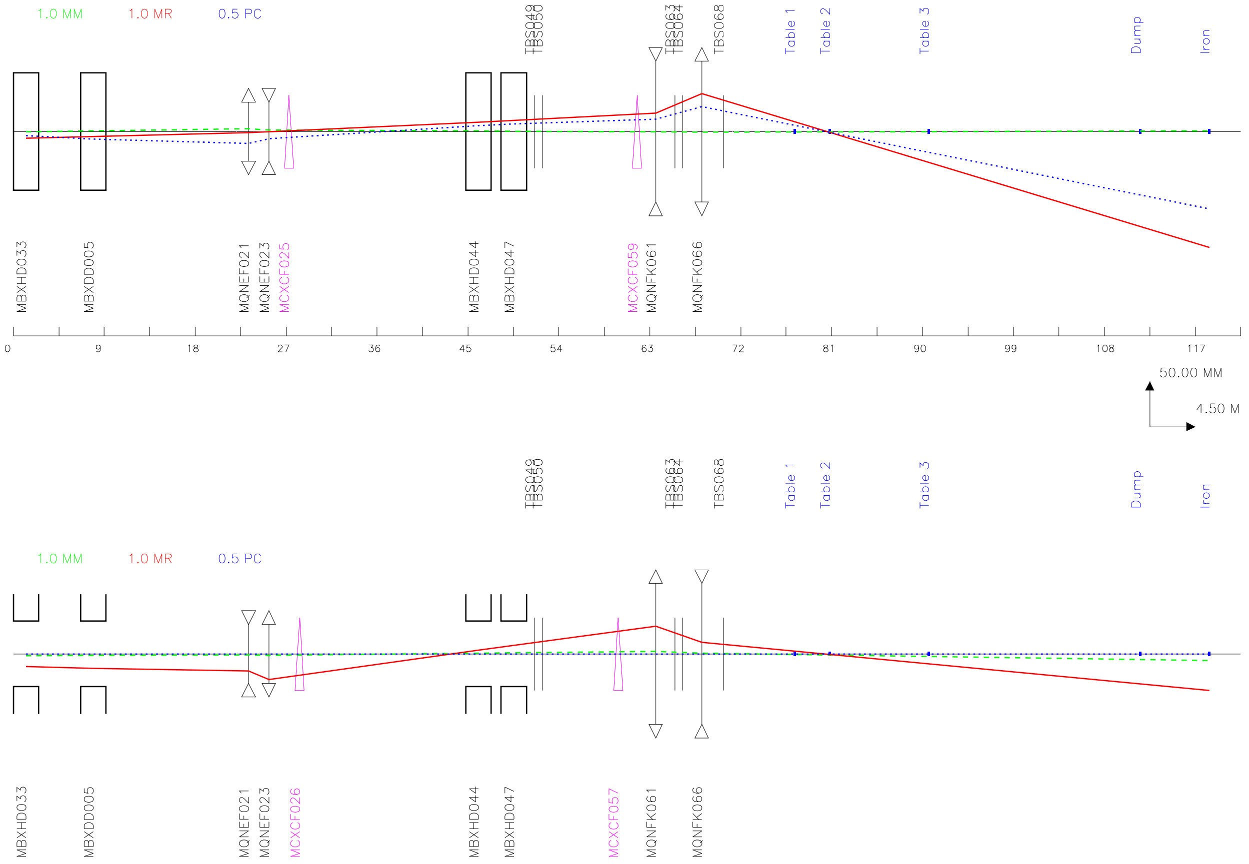


Fig. 3-7: Optics for the primary proton beam in T8 from F61.BHZ02 to the irradiation facilities IRRAD and CHARM as calculated with TRANSPORT, here exemplary for a focus on the second IRRAD table. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane.

For access purposes and as safety elements, five beam stoppers have been included in the beamline, analogue to the beam stoppers in F61.

3.1.5 *Summary of beam parameters, primary destinations, and operational considerations*

The main beam parameters of the primary proton beam are listed in Table 3-3. The synoptics of destinations of the new East Area is presented in Fig. 3-8 in comparison to the old scheme. Apart from the change of using two production targets, the destination F6D has been included, for which the beam is dumped on the operational dump that will be used for set-up of the PS extraction. The old destinations DIRAC, T07, and IRRAD (old) have been already removed in LS1.

All primary lines, including T08, can be operated within the 2.4 s extraction cycles of the PS. Due to limitations in the cycled powering of large dipoles in the secondary beams, these beams can only be operated in 4.8 s cycles. Still, alternating the primary beam on the targets every 2.4 s is possible, as long as the same target destination is not programmed twice in a row. Including radioprotection constraints as well, the maximum number of T08 cycles should not exceed six per typical 45.6 s SPS super-cycle and the maximum number of cycles per target destination shall not be more than three. The total instantaneous intensity in the East Area shall not exceed 6.7 × 10^{10} protons per second. Assuming 90% efficiency and a maximum number of 340 000 super-cycles per year, this would limit the integrated yearly intensity of protons to 10^{18}.

Table 3-3: Main parameters of the primary beam.

Parameter	Value
Proton beam momentum [GeV/c]	24
Maximum # spills per typical super-cycle	6
Duration of typical super-cycle [s]	45.6
Maximum # protons per second	6.7 × 10^{10}
Maximum assumed number of days of operation per year	200
Assumed efficiency	90%
Maximum number of super-cycles per year	340 000
Maximum number of protons per year	1.0 × 10^{18}

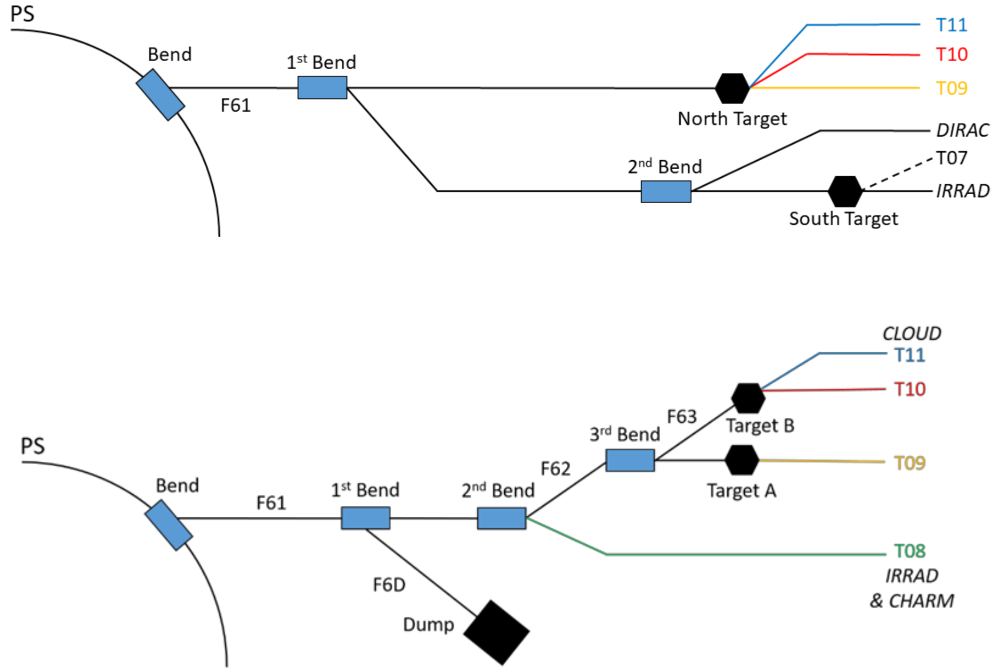


Fig. 3-8: Synoptics of the old East Area (upper panel) in comparison to the new East Area (lower panel).

3.1.6 The secondary beamlines T09 and T10

Both beamlines are based on the same concepts of secondary beams, based in the operational experience of the West Area beamlines. Hence, both beams will be discussed at the same time while differences will be highlighted when they occur. The general design aims at providing secondary beams with high selectivity of particle species, i.e. purity. In addition, the aim was to optimize for high acceptance and momentum resolution.

The beams are derived from the targets A and B under a vertical production angle in order to prevent primary protons coming into the experimental areas. The production angles were chosen to be 30 mrad (T09) and 35 mrad (T10) in order to reach the same height in the experimental areas due to the different total lengths of the beamlines. In T09, a fixed collimator (XTCX) with a cylindrical aperture of 80 mm diameter defines the initial angular acceptance and acts at the same time as passive machine protection for the magnetic elements that follow. For T10, such a dedicated fixed collimator was not deemed necessary as the beam is defined well by the primary beam dump aperture and because no equipment upstream of the dump would need protection. The non-interacting primary protons are dumped in the primary dump, while secondary particles are allowed to pass through pre-defined apertures towards T09, T10, and T11 (see also the next section). In T09, a set of two horizontally deflecting MDXL correctors can optionally be used as sweeping magnets to dump also charged secondary particles, effectively leaving only a secondary neutral beam. Just after the primary dump, a movable lead foil of 4 mm thickness can be employed to convert photons to electrons and positrons via pair production. In this mode, electron and positron beams with high purity can be reached. This option was unfortunately not possible for the T10 beam due to space and integration constraints related to the presence of the T11 line. Nevertheless, this could be a valuable future upgrade option.

The frontends of T09 and T10 consist of a triplet of quadrupoles (QFO1[1], QDE2, and QFO3) that are used to focus the secondary beam onto a horizontal collimator, COLL 3, which defines the central momentum together with the initial horizontal deflection of BHZ1 (M200L dipole). In addition to COLL3, another set of lead foils with three different thicknesses (4 mm, 8 mm, 26 mm) can be used as an absorber to filter out of the beam a certain fraction of electrons respectively positrons (50%, 75%, 99%), leaving a hadron beam of selectable purity. In between the second and third quadrupole, two collimators, COLL 1V and COLL 2H, define the vertical and horizontal acceptance of the beamline, respectively. A second horizontal M200L dipole magnet (BHZ02) is used to deflect the beam towards the respective experimental areas. Around the central collimator COLL3, two quadrupoles are used as field lenses, with the aim of eliminating the dispersion after BHZ2. The final focus consists of a triplet of quadrupoles (QDE6, QFO7, and QDE8), which focus the beam at the user location. In T10, the last quadrupole is of type Q100L in contrast to T09, where a Q200L is necessary due to the higher maximum momenta. In order to compensate the production angle of the target, a vertical M100L magnet deflects the beam with the aim of making it parallel to the horizontal floor of the experimental area. This magnet serves at the same time as a vertical corrector if necessary. For horizontal steering, a MDXL corrector can be used. For access purposes, a dedicated, movable stopper-dump exists. This dump can be also used as an effective filter for hadrons and electrons/positrons leaving muon beams of high purity, which can be optionally momentum selected with the help of BHZ02. Alternatively, the first collimator can be closed off axis to select a similarly pure muon beam.

The maximum beam momentum in T09 is 15 GeV/c and for T10 is 12 GeV/c. They differ mainly due to the larger deflection angles in T10 that are necessary to deflect the beam away from T09 as well as to compensate for the shorter length of the T10 line. Table 3-4 summarizes the calculated beam parameters for both beamlines. In addition, the T09 parameters are compared to the values of the old T09 line. Figure 3-9 depicts the optics exemplary for T09.

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[1] Due to the different equipment names, but similar functions, the physics name for the beamline elements is used in this descriptive part.

Table 3-4: Beam parameters for the future T09 and T10 beamlines. For convenience, a comparison to the old T09 values is given in addition.

Parameter	T09 (old)	T09 (new)	T10 (new)
Length up to the last element [m]	54.3	50.2	44.7
Max. momentum [GeV/c]	10	15	12
Momentum resolution	0.7 %	0.5 %	0.5 %
Max. momentum band		±15 %	±15 %
Horizontal acceptance	±4.8	±4	±5
Vertical acceptance	±4	±3.8	±3
Horizontal magnification at final focus	0.81	0.86	0.92
Vertical magnification at final focus	0.91	0.9	0.58
Max. flux per spill	10^6	10^6	10^6

3.1.6.1 Future options

In the baseline of the East Area Renovation, there are no spectrometer magnets in the T09 and T10 experimental areas, which might be a sensible future upgrade. Adding a converter and sweeping magnets in T10 would allow for high purity electron and positron beams as for T09. However, current space restrictions, especially due to the T11 beamline, do not permit this option at the moment. Figure 3-9 shows the optics for the secondary T09 beamline from target A to the endpoint/dump of the experimental area.

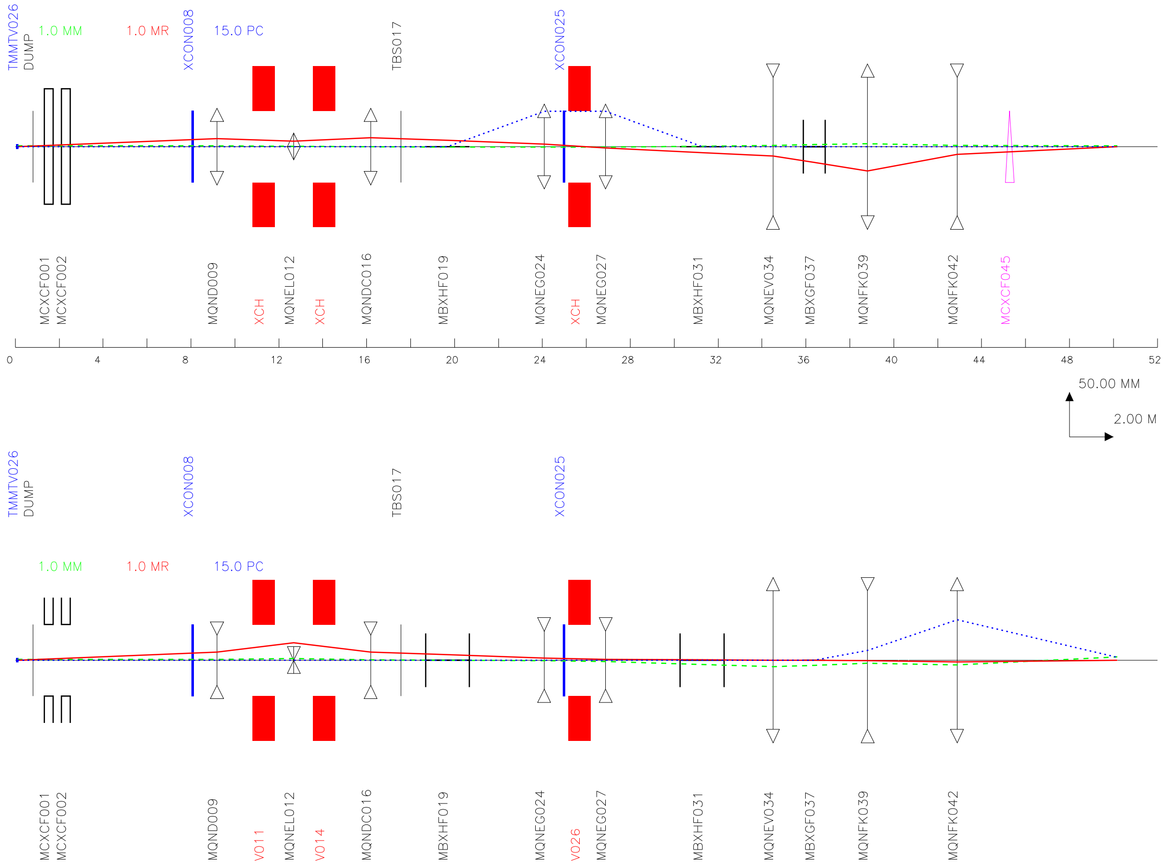

Fig. 3-9: Optics for the secondary T09 beamline from target A to the endpoint/dump of the experimental area as calculated with TRANSPORT. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane.

3.1.7 *The secondary beamline T11 for the CLOUD experiment*

The T11 beamline employs the same principles as T09 and T10, however, in a more compact form and with less elements due to the constraints of leaving the CLOUD experiment at the same place (see Fig. 3-10). The beamline shares the production target B with T10 and the initial acceptance is well defined by the primary dump aperture. The frontend and the final focus are doublets of quadrupoles in contrast to T09 and T10, where more flexibility is required. Another difference is to use only one field lens quadrupole and collimators with less control in both planes. In addition, the vertical M100L dipole was removed as it is not necessary for CLOUD. There are also no correctors in this beamline. The beam optics are chosen to provide a large spot on the CLOUD experiment by over-focusing the beam directly after the last quadrupole and hence the beam opens up again due to the large divergence.

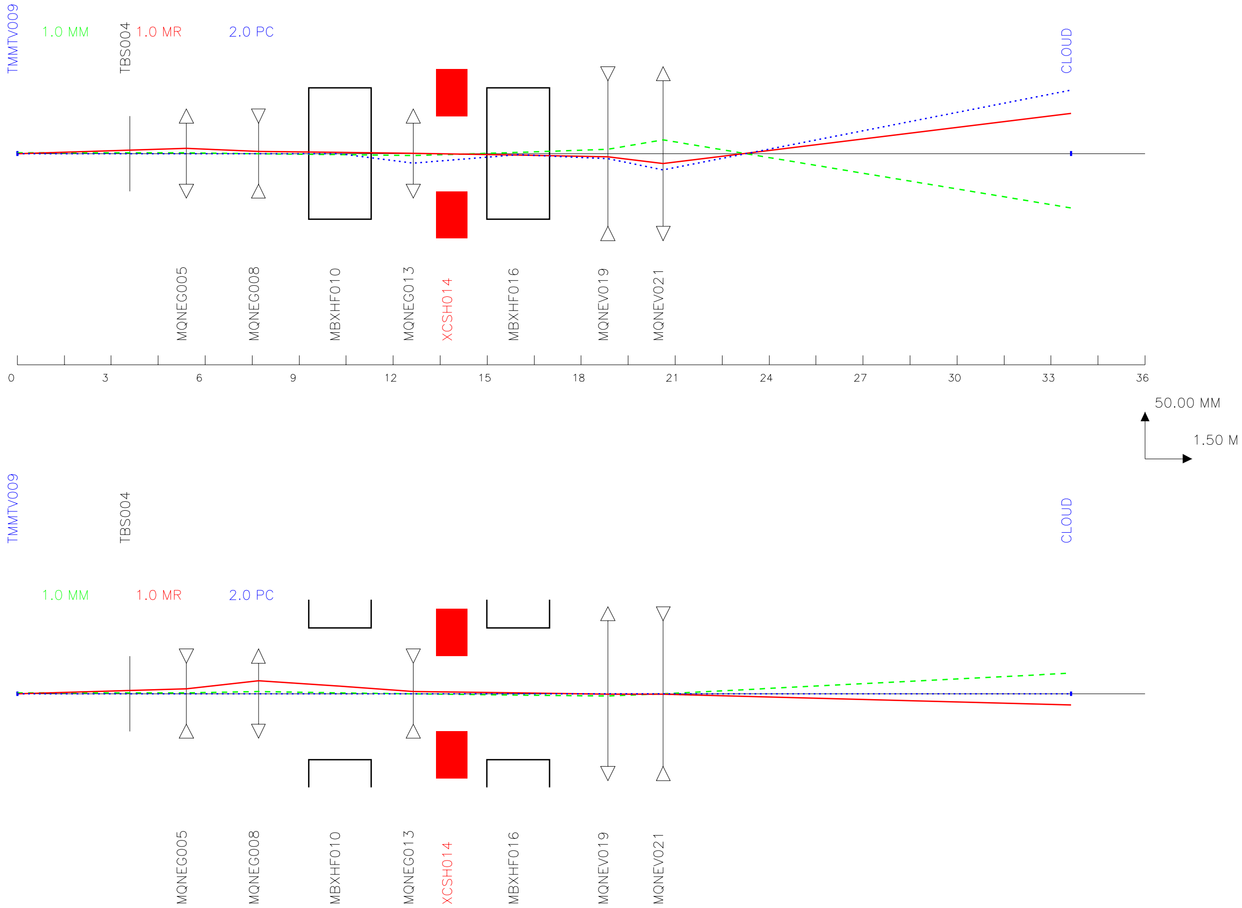

Fig. 3-10: Optics for the secondary T11 beamline from target B to the endpoint/dump of the experimental area of CLOUD as calculated with TRANSPORT. The sine-like ray is shown in red, the magnification term is depicted in green, and the dispersion term in blue. The upper part shows the horizontal plane and the lower one the vertical plane. The new layout of the East Experimental Area.

3.1.8 *Introduction*

The implementation of the new beamlines (see Section 3.1) and the application of modern safety standards (see Section 3.3) justify a major re-organization of the Building 157 hall. By extension, the proton synchrotron (PS) extraction beamline located in Building 352 has also been completely renovated. In addition, the new powering scheme of the magnets allows suppression of the need for Building 263 to host the power converters but required a major renovation of Building 251 to accommodate all of them (see Section 4.2).

Figures 3-12 and 3-13 show, respectively, the configuration of the East Experimental Area before and after renovation. Building 352 hosts the extraction line from the PS. In this area, until the wall separation with Building 157, the lines F61, F62, F6D, and the first part of the line T08 will be installed. Building 157 hosts instead the F63 line, the following parts of the T08 line, T09 T10, and T11 beamlines, and the experimental areas.

Building 157 is sub-divided into different areas. Right after the wall separation with Building 352 the *primary area* is installed; this area is further divided into three closed areas: the *target area*, the *T08b area*, and the *T08c area*. The T08 line finishes with the *IRRAD/CHARM (proton IRRADiation facility/CERN High energy AcceleRator Mixed field facility) area* that was installed during Long Shutdown 1 and will not be affected by the renovation. After the target area, the protons enter the *mixed area*, where the secondary lines start to separate. The T11 line, after the mixed area, directly enters the *T11 experimental area* hosting the Cosmic Leaving Outdoor Droplets (CLOUD) experiment. On the other side, the T09 and T10 lines share a second closed area called the *T09-10 area* before entering in the separate *T09 and T10 experimental areas*.

3.1.9 Building 352: PS extraction

The renovation in Building 352 consists mainly in installing the new F61, F62, F6D beamlines and the beginning of T08 (see Section 3.1). Moreover, services like Direct Current (DC) cabling (see Section 5.6) and the cooling network (see Section 5.2) will be renovated. In addition, F61 and T08 beamlines will be equipped with new PS standard beam stoppers (see Section 4.4) and new beam loss monitors (see Section 4.5). Figure 3-11 depicts the new layout for Building 352.

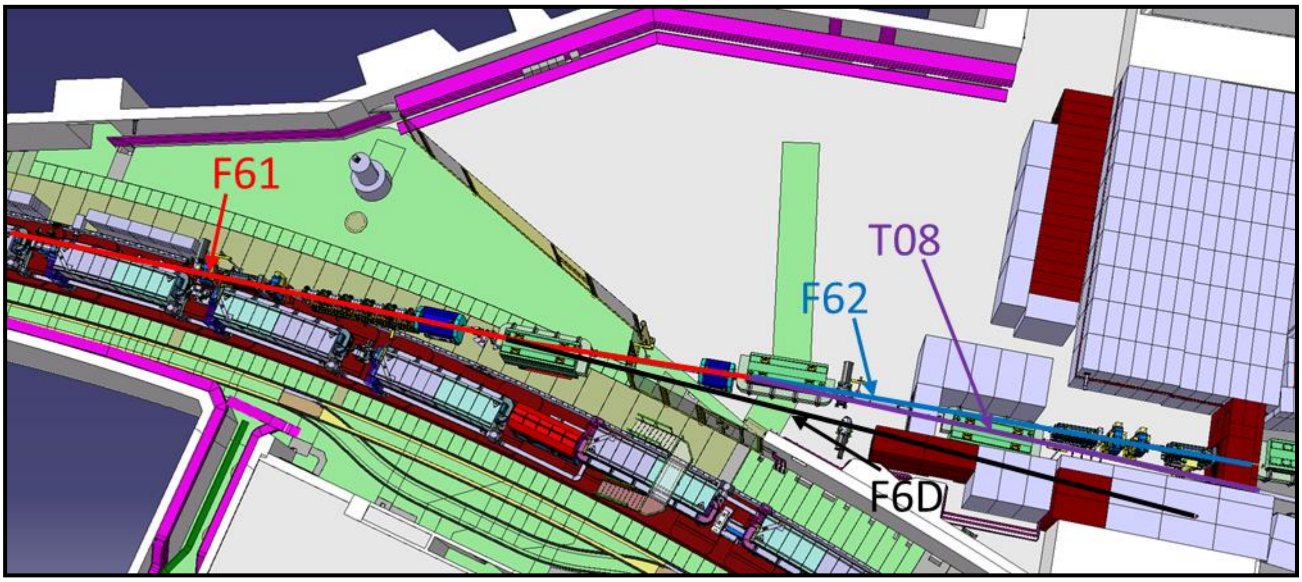

Fig. 3-11: Three-dimensional model of Building 352 after renovation.

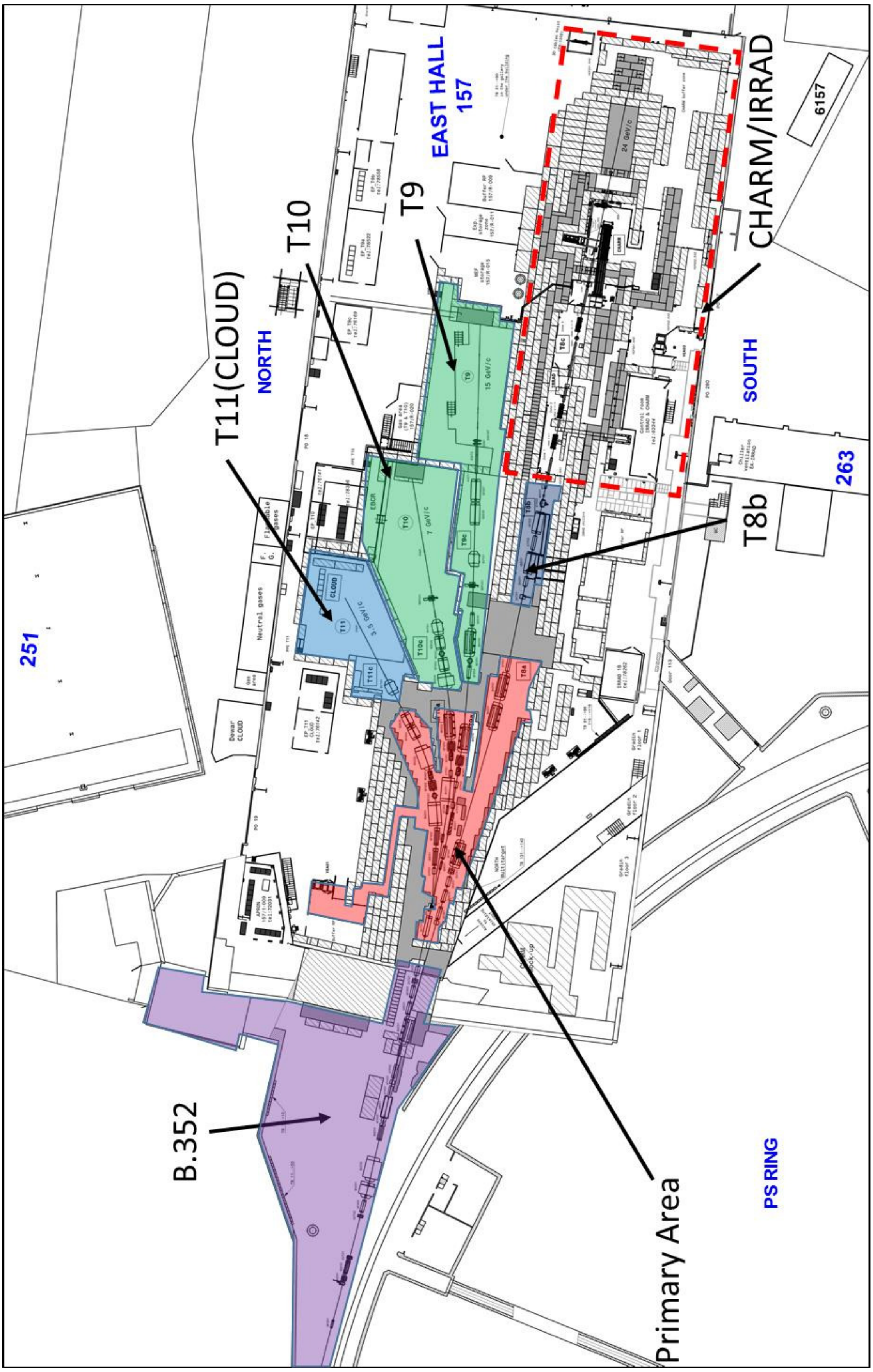

Fig. 3-12: Configuration of the East Area before renovation.

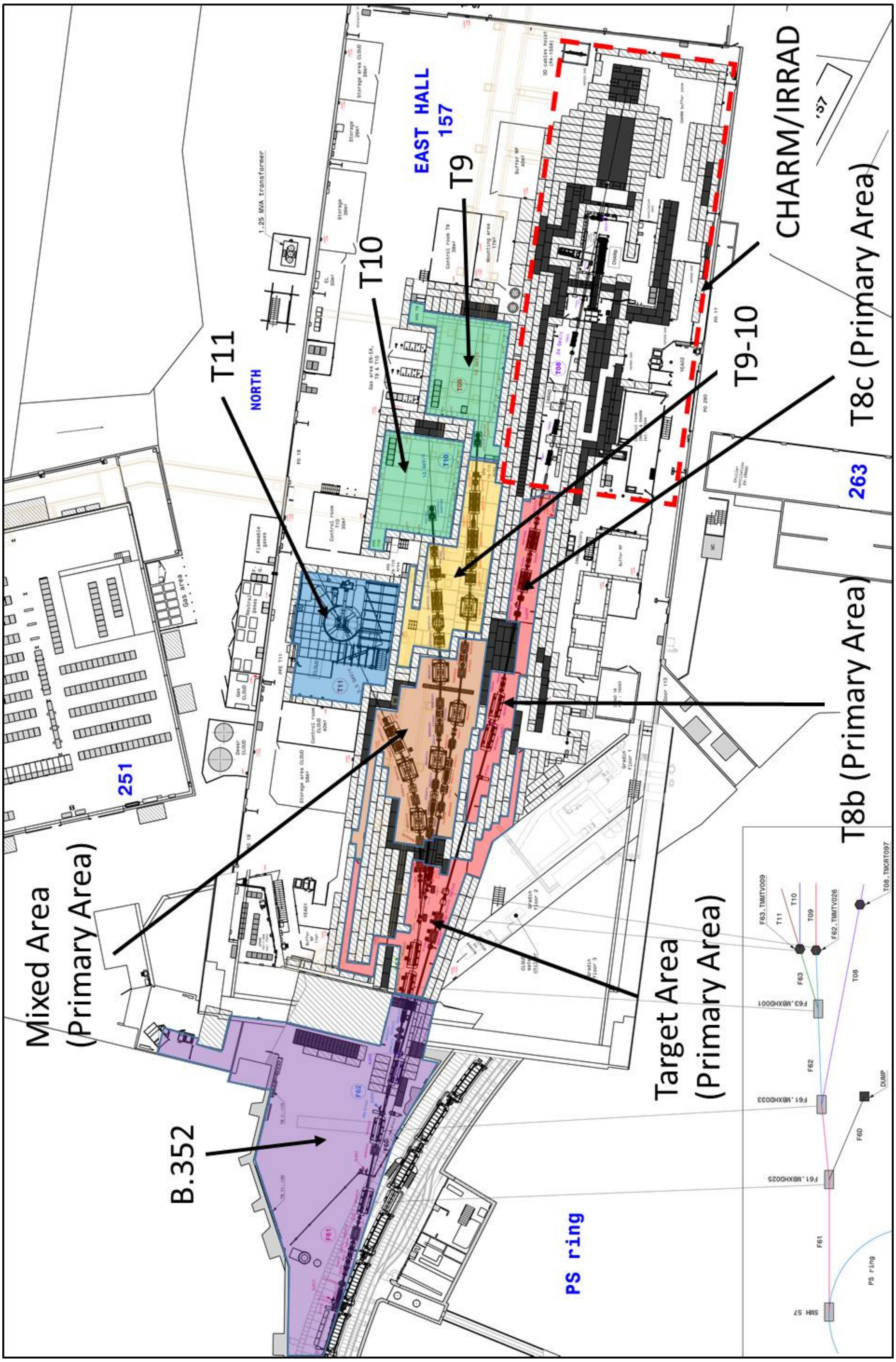

Fig. 3-13: Configuration of the East Area after renovation.

3.1.10 Building 157: Experimental facility

3.1.10.1 Primary area

The goal of the new layout of the primary area after renovation is to improve the general safety, in particular to minimize the radiation levels in each controlled area. For this reason, the target area has been reduced thanks to a new cast iron dump located in between the target area and the mixed area, which stops the residual primary particles coming from the interaction of the PS protons beam with the targets. All the primary areas will be airtight, and a dedicated ventilation system will keep the internal pressure of the primary areas lower than the atmospheric external pressure, so that any contaminated agents are kept inside the area (see Section 5.4).

The primary area is composed of three sectors: the target area, T08b, and T08c (see Fig. 3-14 and Fig. 3-15). These, in particular the targets area, will be the most radioactive zones in the East Area, due to the interactions of the PS primary beams with the two targets. Due to the high level of radiation, a shielding roof in concrete and cast iron is required, and the total height of the whole shielding will be limited to 8 m (height of the overhead cranes).

Inside the target area, magnets, targets, the fixed collimator (XTCX), and the stopper dump will be equipped with a mechanical plug-in support to suppress the need for alignment in situ when the replacement of an equipment is needed [2]. Although alignment is the most time-consuming task in this area, it will greatly reduce the exposure of workers to radiation.

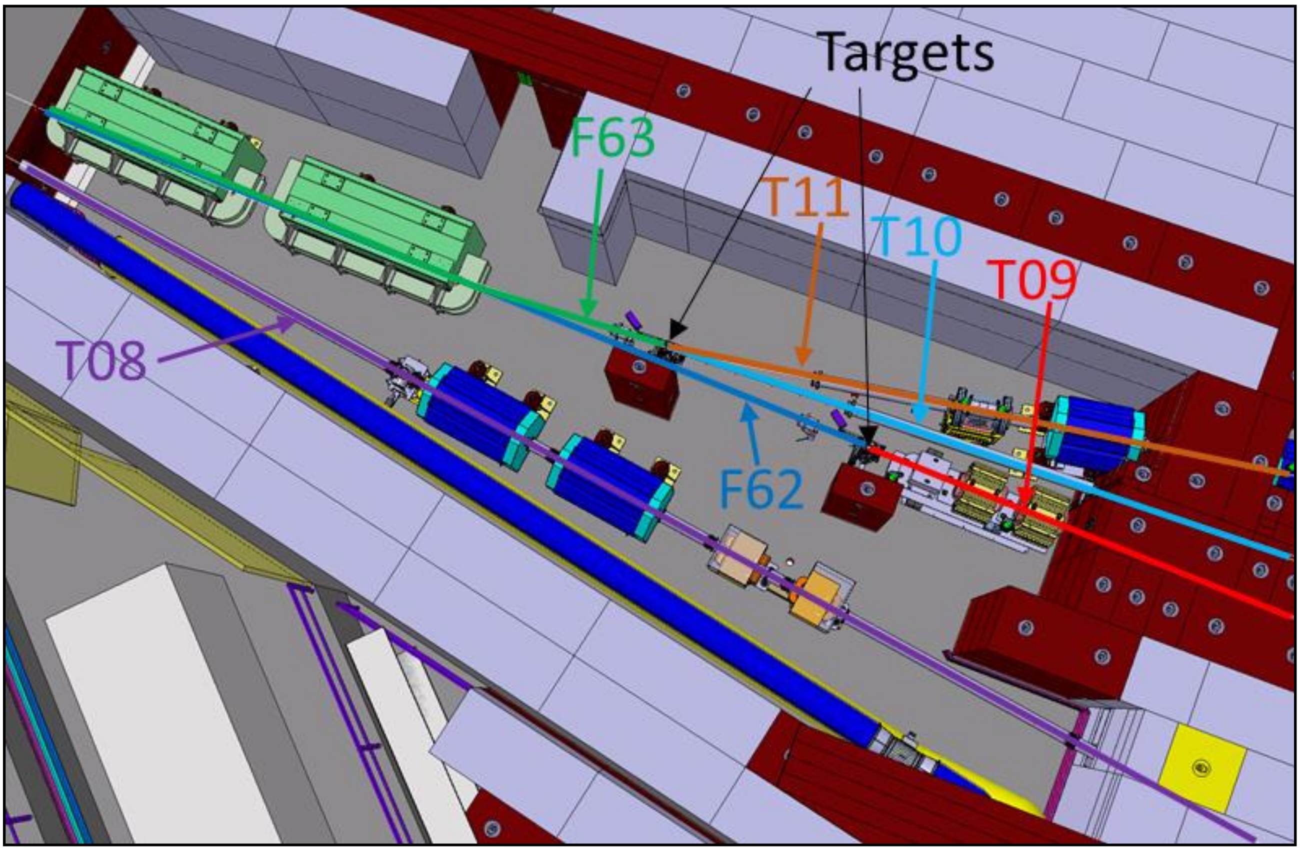

Fig. 3-14: Integration 3D model of targets area.

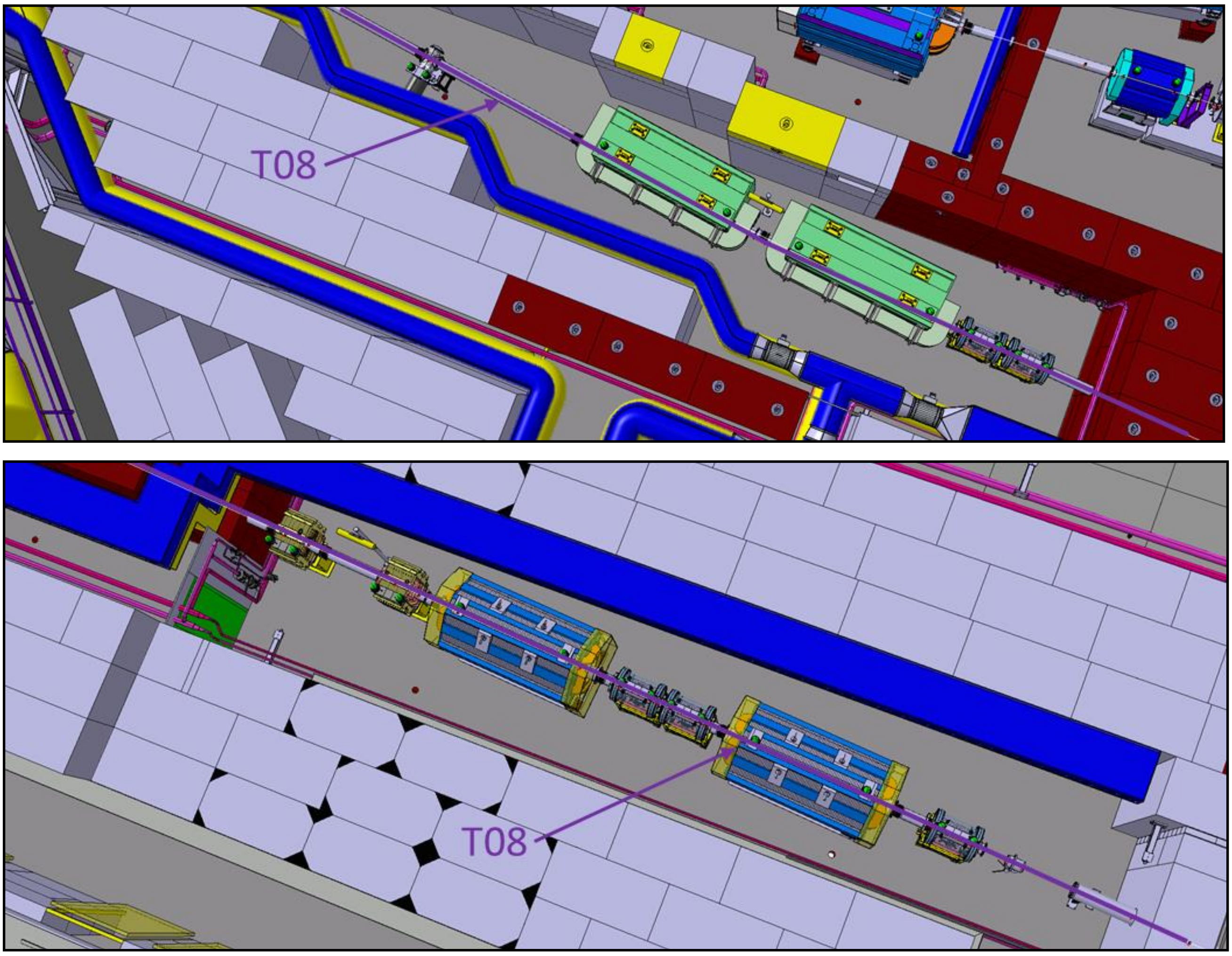

Fig. 3-15: T08b (top) and T08c (bottom) primary areas.

3.1.10.2 Mixed area

This new zone (see Fig. 3-16) is just downstream of the target area and it hosts the three secondary beams (T09, T10, and T11). Because there is a low radiation level in this area, a thinner concrete shielding roof is sufficient for safety protection. All the equipment is integrated on standard supports. The expected residual radiation dose rate does not justify the installation of a plug-in system. All the secondary beamlines have a vertical angle (production angle) in this area.

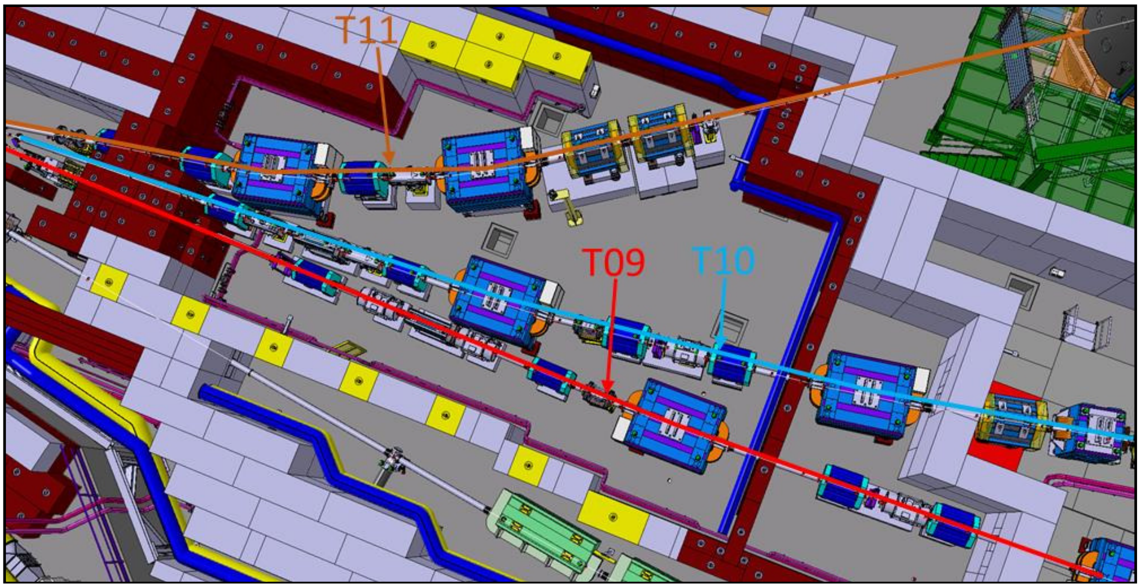

Fig. 3-16: Mixed area after renovation.

3.1.10.3 T09-10 area

This new zone is located just downstream of the mixed area and contains the last magnets and other equipment of the secondary beamlines, as illustrated in Fig. 3-17. The benefit of creating this zone in both T09 and T10 experimental areas is that the users of the experimental areas will not be in proximity to the beamline equipment, reducing personal electrical shock risks. In addition, maintenance in this area can be done while the beam is circulating in the T08 and T11 beamlines.

The T09-10 area does not require roof shielding, thanks to the low radiation levels. The floor of this zone is fully covered with 1.2 m standard concrete blocks to compensate for the beam height (around 3 m from the floor of the building). The vacuum pumps for the T09 and T10 beamlines are placed in this area to limit exposure to radiation of the maintenance teams.

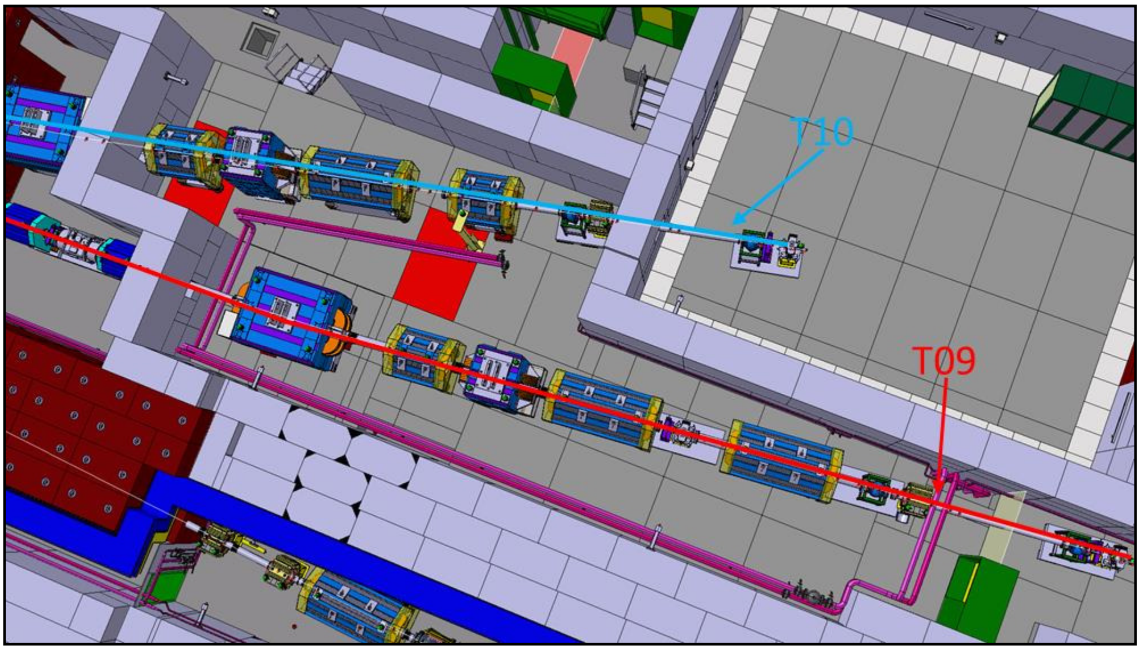

Fig. 3-17: T09-10 area.

3.1.10.4 Experimental areas: T09, T10, and T11 (CLOUD)

The T09 and T10 experimental areas are designed as general-purpose test zones. The new layout of the experimental areas takes advantage of strong experience from past operation (see Fig. 3-18). Consequentially, the design of this layout focuses on the safety and convenience of the users.

The major improvements in the T09 and T10 experimental areas are the following.

i) Same beam height in T09 and T10.

ii) Separation between users and machine services (cables, gas piping).

iii) Quantity and type (16 A, 32 A) of power sockets increased.

iv) New standard signal cable patch panels between the experimental areas and the control room.

v) New racks for a gas patch panel inside T09 and T10.

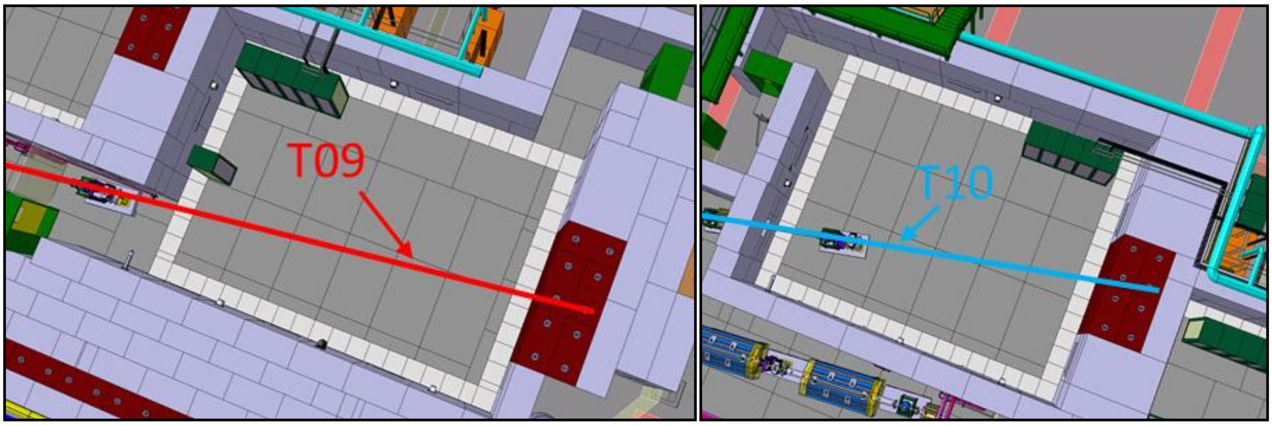

Fig. 3-18: T09 (left-hand side) and T10 (right-hand side) experimental areas.

The T11 experimental area (Fig. 3-19) will continue to host the CLOUD experiment. In addition, this area will profit from the enhancements of the renovation project in the following aspects.

i) Increase of the surface of the experimental area (layout of the platforms upgraded accordingly).

ii) The CLOUD storage area will be moved closer to its control room.

iii) The chiller used by the experiment will be relocated on the other side of Building 157 to suppress the noise disturbance.

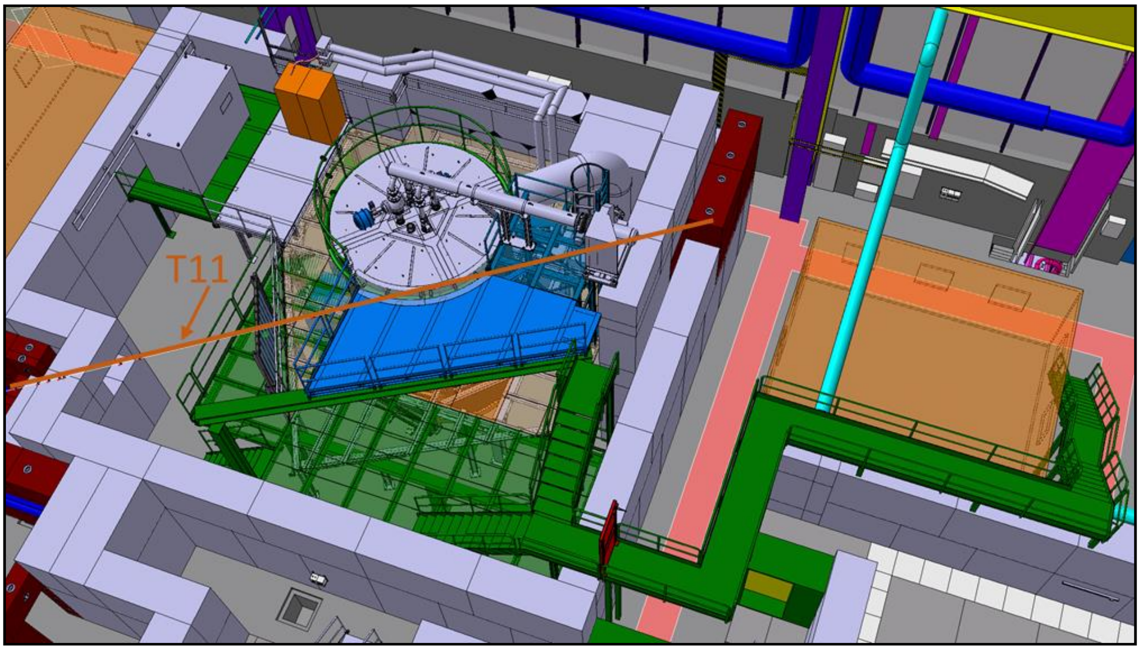

Fig. 3-19: T11 experimental area hosting the CLOUD experiment.

3.1.11 Building 251: Power converter facility

Building 251, which hosts all the power converters, will be renovated to accommodate the new configuration and requirements of the future beamlines.

The existing power converters have become less reliable and will be replaced by different types of modern SIRIUS power converters, including SIRIUS S, 2P, 4P, and 4P + (see Section 4.2). Since these new power converters have different characteristics (weight, size) compared to the old ones, the structures on which these converters are installed, the electrical supply system, and the cooling system must be redone during the renovation (see details in Fig. 3-20 and Fig. 3-21).

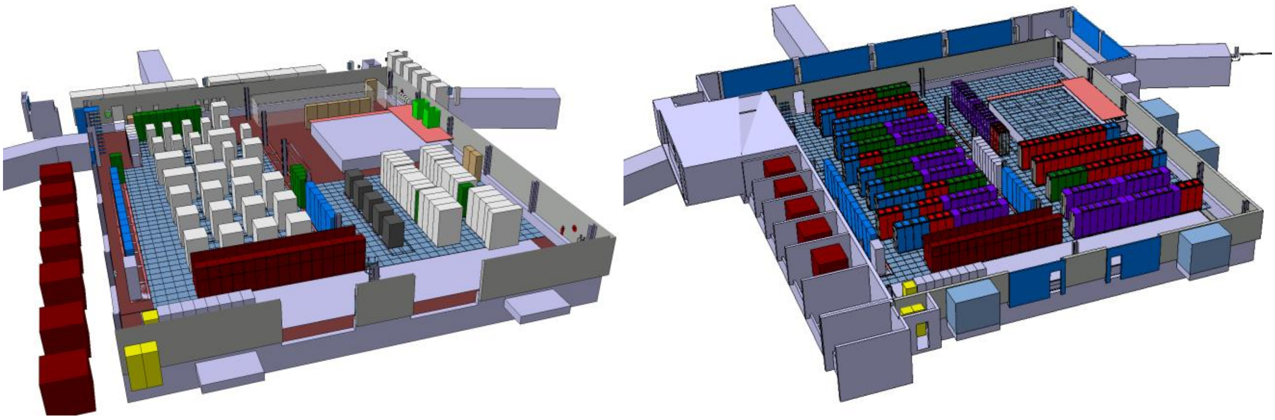

Fig. 3-20: Configuration of Building 251 before (left) and after (right) renovation.

Furthermore, the poor state of the existing false floor and the difficulty of accommodating all the new power converters and services, led to the decision to instal a new false floor in the building. The concept for the new layout of Building 251 can be found in Fig. 3-21.

In particular, the following actions will take place during the renovation in LS2.

i) Renewal of the false floor to support all the power converters.

ii) New cooling network and ventilation dedicated to the power converters.

iii) Renewal of the electrical infrastructure to provide AC current to the power converters.

iv) Re-organization of the DC cabling to connect the power converters to magnets in Building 157.

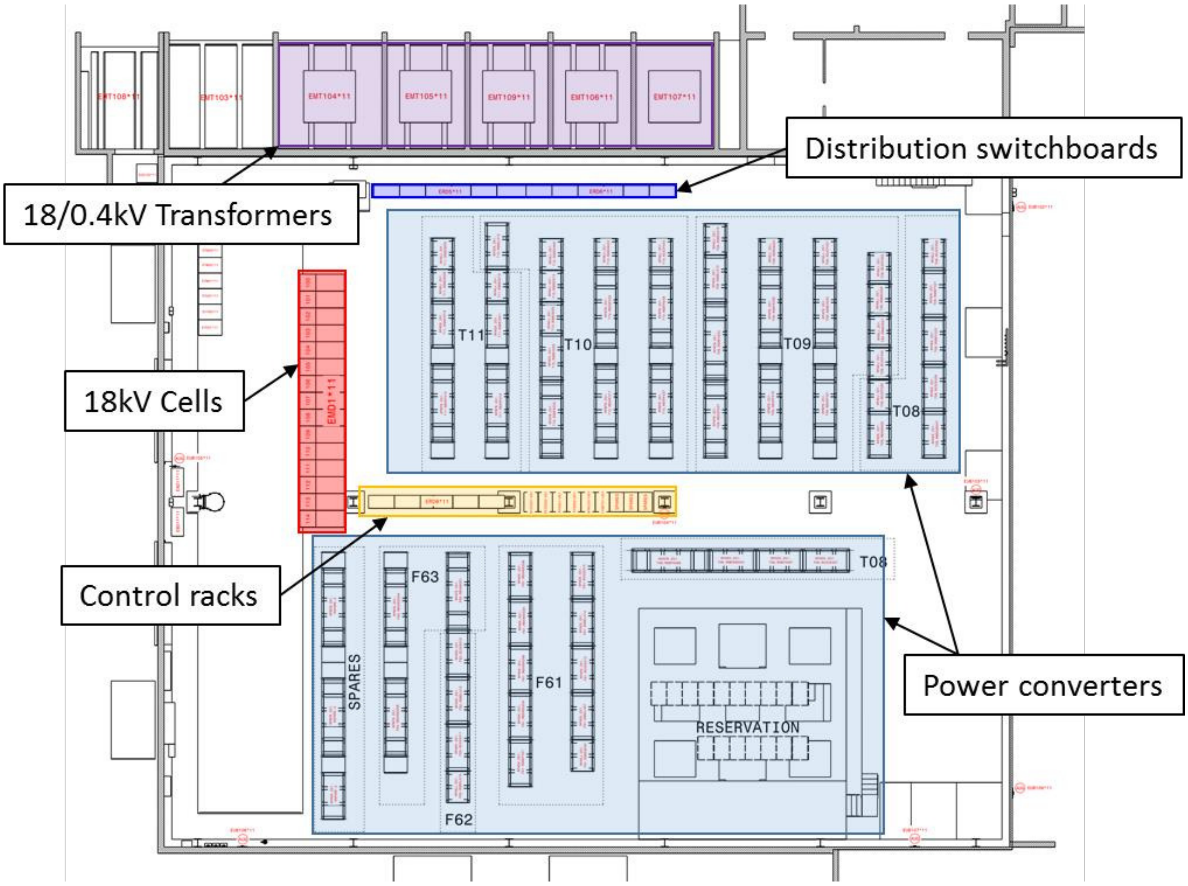

Fig. 3-21: Future layout of Building 251.

3.2 Energy savings

One of the objectives of the East Area Renovation Project is to reduce the energy consumption of the facility. This section summarizes the various measures taken to achieve an operational experimental facility with low energy consumption.

3.2.1 The magnet power supply chain

The most substantial change induced by the renovation in terms of energy will be the modification of the powering mode of the magnets. The new power converters, of type SIRIUS, conceived at CERN by the Electrical Power Converters Group, will be able to operate the new laminated magnets in pulsed mode. Equipped with capacitor banks, the SIRIUS converters will also be able to recover temporarily the inductive energy stored in the magnetic field of the magnetic components, as shown in Fig. 3-22 and reuse it for the next cycle. Those recovering units reduce the root mean square (RMS) current requirements of equipment upstream of the electrical supply network and eliminate the voltage fluctuation of the CERN general electric grid, thus simplifying it and decreasing the losses.

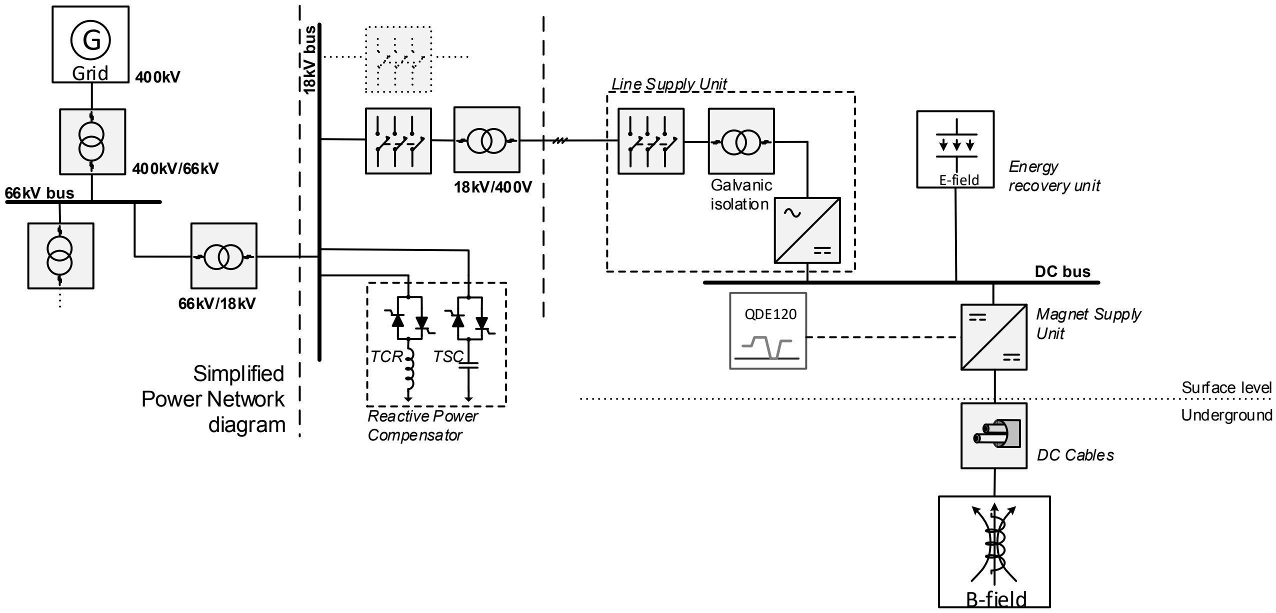

Fig. 3-22: Overview of the magnet power supply chain.

Today, the magnets are turned on at the start of the physics run and, if no major issue occurs, are never turned off, even when no beams are being extracted towards the East Area. Bearing in mind that the beamlines today count 54 magnets, which in theory only need to be generating a magnetic field for 2.25 seconds (which equals to 5 extractions) per supercycle[2], significant energy saving can result from a compatible magnet and powering scheme. Such a cycled mode gives the opportunity to only feed the required magnets to extract and direct the particles towards one of the four experiments.

Furthermore, a lower electricity consumption will significantly decrease the power losses and thus the related dissipated heat, having consequently also a direct influence on the energy consumption needs for the water cooling and air ventilation systems and therefore on their installation and operational units.

Even though it is impossible to predict the number of extractions occurring in a future physics run, an estimated electricity consumption can be calculated based on the number of extractions which took place in 2017. Based on retrieved current data of the 2017 physics run, the electricity usage before renovation (6786 MWh) was calculated. Compared to the estimated consumption in cycled mode (1028 MWh), a potential saving of more than 80% can be demonstrated.

In addition, while power converters still consume electricity in maintaining stand-by mode, a future remote control by the operators allows us to completely switch-off the equipment during long periods of inactivity.

3.2.2 Air ventilation

Currently, air ventilation systems are present in the main experimental hall and the irradiation facilities[3] on beamline T8, ensuring thermal comfort and an adequate air quality inside the hall as well as a dynamic confinement (preventing the activated air from escaping) for the highly radioactive areas. Building 251, adjacent to the Building 157 hall and housing the power converters, is also equipped with a heating and

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[2] The supercycle of the PS accelerator lasts for 45.6 seconds and depicts the distribution of the particle bunches from the accelerator towards the related experiments (nTof, AD, IRRAD, CHARM, …) and the Super Proton Synchrotron accelerator.

[3] Highly radioactive areas are covered with thick (up to 6 metre) concrete walls allowing for the presence of the users inside the hall during beam operation.

ventilation system providing heating during winter and fresh air ventilation that partly removes the heat dissipated from the converters during warmer periods.

The air ventilation’s energy consumption in the experimental hall is mainly due to the heating needs during cold months. During the hotter months, the heating is turned off and thermal comfort is uniquely assured by ventilation. Heating in the East Area and at CERN in general is provided by a central plant producing, by means of gas combustion, super-heated water (SHW) which is distributed to the concerned infrastructures located on the various CERN premises.

The cladding of the main hall is currently far from optimal when compared to today’s environmental and safety standards, causing over the year an increase in air ventilation needs. Civil engineering works have therefore been included in the project. By refurbishing the cladding and the roofing with more modern and better performing insulated materials, associated thermal losses significantly decrease.

Detailed thermal studies of today’s and the post-renovation situation have been conducted [4]. From this study, the following results have been found; the peak losses occurring during the coldest month (January) will drop from 811 kW to 245 kW, the annual thermal energy consumption will decrease by 65% together with a 65% decrease of the related gas consumption.

The project also includes a modification in the disposition of the radioactive areas, similar to the one performed for IRRAD/CHARM in LS1. Thus, introducing new specific air handling units to the primary [5] and a new ventilation system to the mixed beam area (see Fig. 3-23), leads to a total of three dedicated ventilation systems for those areas. In addition, to ensure a dynamic confinement, they compensate the dissipated heat from the magnets, which will decrease due to the above described cycled operation mode. Related thermal energy savings will amount to 75%. However, at the same time, the electricity consumption for the primary areas must cover an increase of 42% (from 11 MWh to 19 MWh) due to the required additional units.

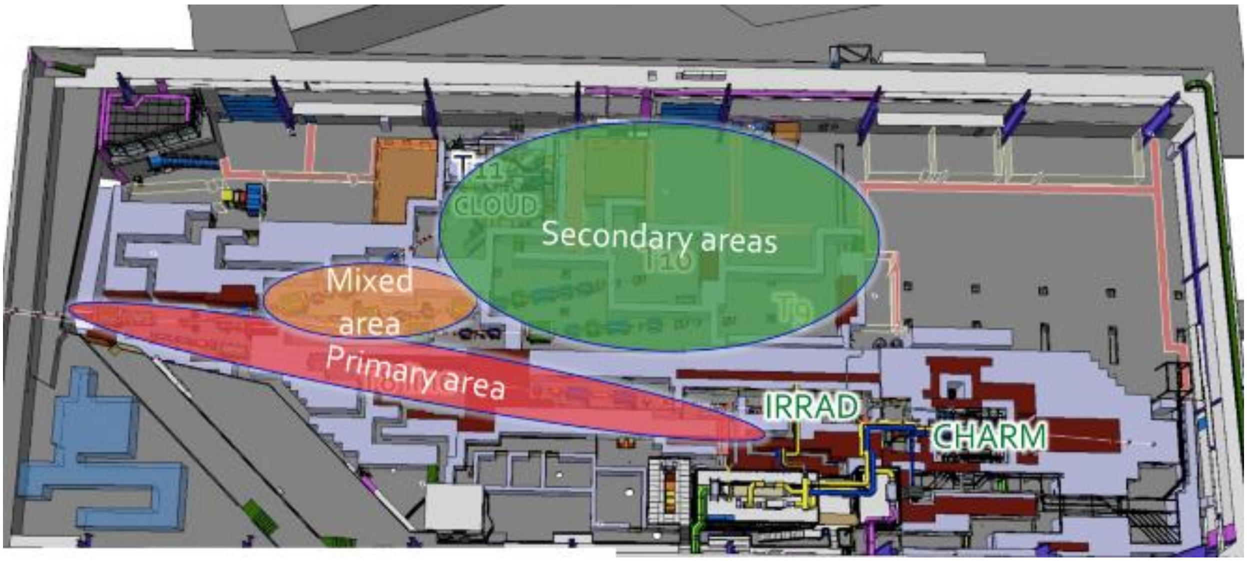

Fig. 3-23: Layout of the new radioactive zones.

Finally, the power converter building will see a 96% reduction in cooling needs (from 955 to 63 MWh). The substantial decrease is related to the fact that the new power converters will be water cooled after renovation. The ventilation will only have to compensate 15% of the total heat dissipated from the converters, while it is 100% today.

3.2.3 Water cooling

The last major energy consumer of the East Area is the water-cooling systems designed to cool the magnets and, after the renovation, the power converters, given that they dissipate up to 85% of the energy they consume.

As mentioned previously, the cycled mode will significantly reduce the heat dissipation of the magnetic components and the power converters. Based on the power losses calculated for the electricity consumption of the magnets and the power converters, the cooling needs can be easily retrieved. The annual cooling needs will massively drop from 4162 MWh to a mesmerizing 369 MWh (91% decrease).

Heat from East Area magnets and power converters is mainly absorbed by the demineralized water circuit, passed to cooling tower water, and ultimately released to the atmosphere. The cooling tower is a heat exchanger (air/water) of open wet type, meaning it partially evaporates and thus consumes the circuit's raw water to bring its temperature down.

As for the electricity consumption, which is predominantly caused by the water pumps generating the required water flow inside the circuit, a corresponding decrease will be observed. Due to a careful pump selection, the number of pumps in operation can be reduced from two to one. Combined with the fact that the new pump differential pressure will be reduced from 24 to 12 bar and the water flow will be 275 m^3/h instead of 300 m^3/h, the corresponding electricity consumption will also drop from 4246 to 1597 MWh, consequently saving 76% in energy consumption.

3.2.4 Conclusion and outlook

As a result, the total energy consumption will decrease by 81% after renovation and for the thermal energy consumption (heating and cooling needs combined), a saving of 82% will be attained, as illustrated in Fig. 3-24, which compares the energy flows by type (cooling, heating, electricity) before and after consolidation.

Additional operational improvements can be implemented. Firstly, by switching off equipment such as power converters while not in use (e.g. during technical stops). Secondly, replacing the water pumps of the water-cooling circuit can provide additional savings as they will be oversized after the renovation [3]. Finally, a renovation of the power converter building, which was constructed around the same period as the main experimental hall and shows, today, the same insulation issues, should be considered.

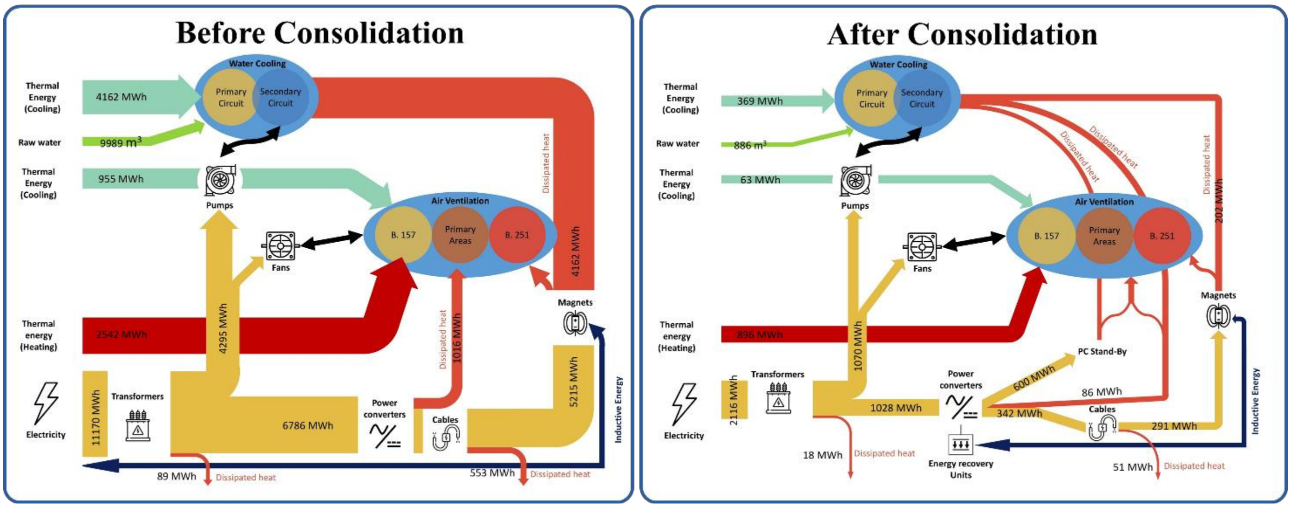

Fig. 3-24: Summary diagrams of estimated energy consumption before and after renovation.

3.3 Impact on radioprotection and general safety

3.3.1 Introduction

The design, construction, commissioning, operation, and eventual dismantling of the East Area comply with the standard CERN safety rules and applicable regulation. Following an initial risk assessment 0, the project was classified as a project with major safety implications and will thus need a safety clearance from the CERN safety authority before the facility is operated.

This section describes the main safety checks to be performed throughout the lifecycle of the project. This work is continuously documented in the safety file of the facility and will be issued before the first beam extraction to the East Area.

3.3.2 Impact on radioprotection

3.3.2.1 Air activation

The design goals for the ventilation system of the East Area renovation project are the following.

i) The committed effective dose due to inhalation has to be less than 1 µSv for a 1 hour long access.

ii) The effective dose to the reference group for members of the public should be less than 1 µSv per year, from combined prompt radiation (sky shine) and from releases to the environment.

The methodology to obtain the radionuclide concentrations, the annual release to the environment, and the resulting annual effective dose to members of the public is based on the weighting of track-length spectra in air, obtained by FLUKA Monte Carlo simulations [8][9] with a dedicated set of air activation cross-sections [10][11] , taking the time evolution, the characteristics of the ventilation circuit, and the beam parameters [11] into account and finally applying conversion coefficients from released activity to effective dose, computed with the dedicated Monte Carlo integration program EDARA [12]. A detailed description of this methodology, including the location of the reference group, can be found in Ref. [13].

3.3.2.1.1 Primary zone

The ventilation system for the primary zone will provide dynamic confinement with a forced air extraction rate between one and ten air renewals per hour. A flush of the primary zone resulting in 3 volume exchanges is mandatory before granting access to the primary zone.

All releases from the ventilation system of the primary zone to the environment will be monitored by a dedicated ventilation monitoring station [14]. The release point will be a dedicated chimney above the roof of the East Hall.

Based on these conditions, an air activation study has been performed [15]. The effective dose to the reference group for members of the public from releases of airborne radioactivity to the environment will be less than 0.2 µSv per year. The committed effective dose due to inhalation will be well below 1 µSv for a 1-hour long access. Therefore, both design goals with respect to the air activation for the primary zone will be achieved.

3.3.2.1.2 Mixed zone

A dedicated air activation study has been performed for the mixed zone [16], investigating both dynamic confinement and static confinement configurations.

The release from the mixed zone is negligible with respect to the target zone, even for dynamic confinement.

The committed effective dose due to inhalation was calculated by integrating over the 1-hour exposure time after a cool-down period of 30 minutes without flush before access as a function of the air exchange rate. Even for static confinement, the committed effective dose due to inhalation is far below 1 µSv for a 1-hour long access. In addition, it is also negligible with respect to external exposure due to residual radioactivity.

Therefore, the connection of the mixed zone to the primary ventilation system (V1, V2, and V3) is not required for radiation protection purposes, although a minimal airflow has to be ensured (see Fig. 3-25).

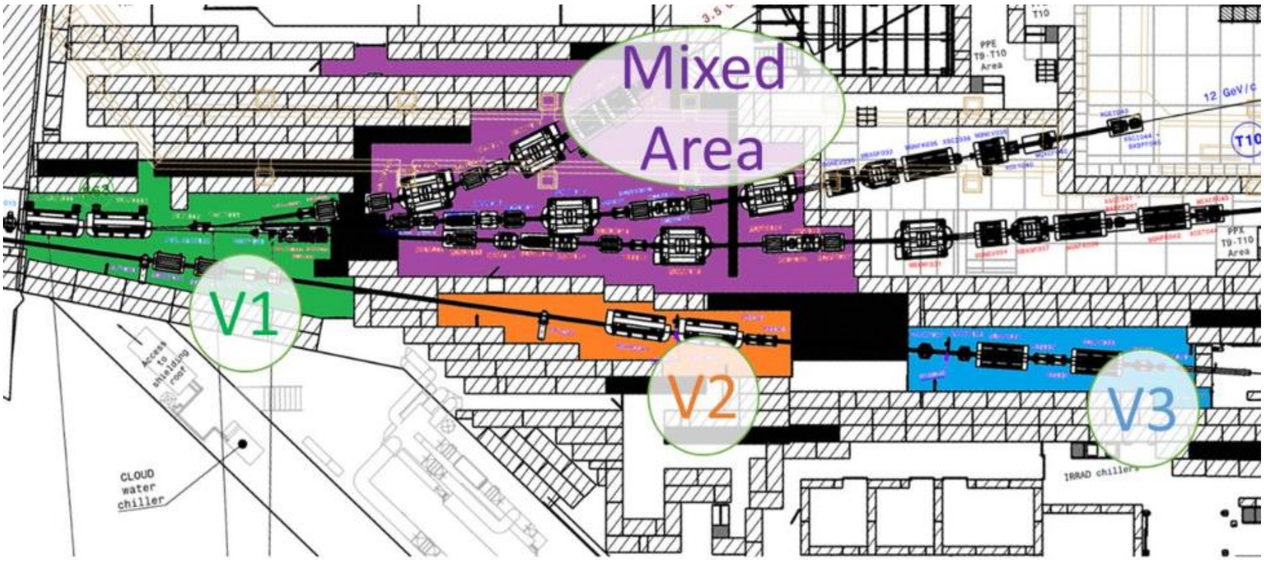

Fig. 3-25: Location of the primary zone bunkers (V1, V2, and V3) and the mixed area.

3.3.2.2 Water activation

Activation of the water used for the cooling of equipment, such as magnets, will radiologically only be significant in the primary zone. Following best practices in water circuit design in radiation areas, the water circuits for the primary zone shall be separated from the water circuits of the other parts of the East Hall, including the mixed zone. The water circuits for the primary zone can be connected with the one for IRRAD and CHARM since these two facilities also receive primary beam (see Section 5.2). All water circuits will be equipped with sampling points that allow the extraction of water samples for radiological analysis.

3.3.2.3 Radiation protection aspects of the access system

The primary zone will be classified at least as a Limited Stay Radiation Area due to the residual radiation levels [17]. Therefore, a Radiation Protection veto has to be implemented at the access point that grants access to the primary zone, as is the case today [18]. The access system also has to verify that the flush of the primary zone (see Section 5.8) has been completed before granting access to the primary zone. The access to the mixed zone is excluded from this requirement.

3.3.3 Impact on conventional safety

3.3.3.1 Electrical design report for the capacitors

The new SIRIUS power converters in Building 251 include energy storage units that consist of capacitors that recover the energy sent to the magnet at every pulse. These capacitors can in total store an energy of 10 MJ. The design of the power converter included an in-depth investigation of the failure mechanisms to assess the damage that could be caused by a failure of these systems and take measures to reduce the probability of occurrence of such events. In addition, collective measures should be taken to supress any risk to the teams working near the converters (see Section 4.2).

3.3.3.2 Structural validations

The general renovation of Building 157 requires a careful study of the structural resistance of the facility. Starting from the slab load capacity to make sure that, during all the phases of the worksite until the final configuration, no overloading happens. The assembly of shielding blocks itself needs to be validated both in its static resistance and in its stability in case of earthquake.

3.3.3.3 *Access systems*

The primary area size has been reduced to limit the need to access the most radioactive area so a new zone, called the mixed zone, has been created. Similarly, a new zone called T09-10 has been created to suppress the unnecessary access to beamline to the users working in the experimental areas (Fig. 3-26).

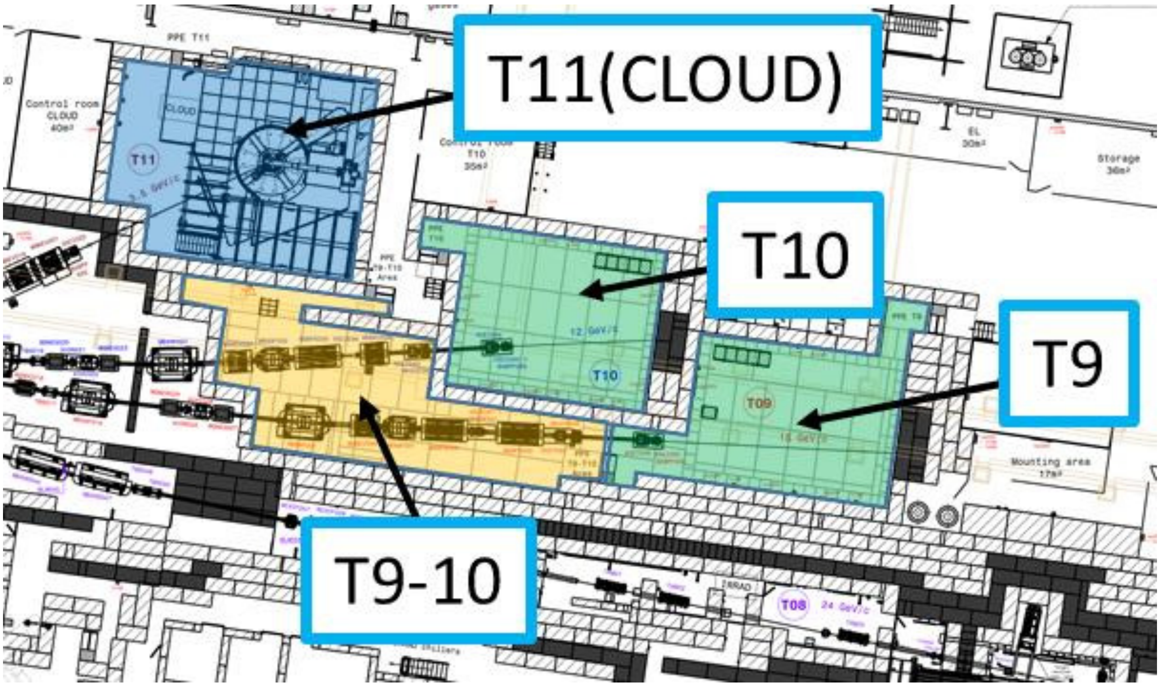

Fig. 3-26: View of the experimental areas (T09, T10, and T11) and the T09-10 area.

These changes will be integrated into the new access system to only allow access to the various areas in safe conditions: link between access mode and the new ventilation, beam stoppers protecting downstream areas, RP Veto, etc. (see Section 5.8).

3.3.3.4 *Gas systems*

The new gas system will follow the applicable standard, especially regarding flammable gases. Atmosphere EXplosible (ATEX) areas will be defined and proper systems implemented, such as ATEX ventilation (see Section 5.10) and gas detection systems (see Section 5.9).

3.3.3.5 *General safety checks*

Throughout the lifecycle of the project, mandatory checks will be performed. For instance, design validation by the relevant experts or safety acceptance when equipment is manufactured or/and installed.

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