

Status of the Super-B factory Design*

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The SuperB international team continues to optimize the design of an electron-positron collider, which will allow the enhanced study of the origins of flavor physics. The project combines the best features of a linear collider (high single-collision luminosity) and a storage-ring collider (high repetition rate), bringing together all accelerator physics aspects to make a very high luminosity of $10^{36} \text{ cm}^{-2} \text{ sec}^{-1}$. This asymmetric-energy collider with a polarized electron beam will produce hundreds of millions of B-mesons at the $\Upsilon(4S)$ resonance. The present design is based on extremely low emittance beams colliding at a large Piwinski angle to allow very low β_y^* without the need for ultra short bunches. Use of crab-waist sextupoles will enhance the luminosity, suppressing dangerous resonances and allowing for a higher beam-beam parameter. The project has flexible beam parameters, improved dynamic aperture, and spin-rotators in the Low Energy Ring for longitudinal polarization of the electron beam at the Interaction Point. Optimized for best colliding-beam performance, the facility may also provide high-brightness photon beams for synchrotron radiation applications.

1. Introduction

To achieve the design luminosity of 10^{36} in operation an ongoing effort of improvement is necessary. As part of this process new design options are explored and their effect on the design parameters studied. No individual option improves every single aspect of the machine and therefore all solutions have to be carefully compared and the solution with the overall best performance chosen. Part of this work is the study of unwanted effects, developing methods to compensate these and possibly test them in operating facilities. Based on these results design specifications and tolerances are developed. We report on the latest results of these efforts.

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2. Project Status

In December 2010 the Italian Ministry for Education, University and Research approved the SuperB project [1]. With this decision the project enters a new stage. The current conceptual design has been published in [2]. The Campus Tor Vergata near Rome, Italy was chosen as site for the facility. This was officially announced at the XVII SuperB Workshop and Kick Off Meeting in La Biodola (Isola d'Elba) Italy from 28 May 2011 to 02 June 2011. On October 7th the Laboratory Nicola Cabibbo was officially launched. The new international center for fundamental and applied physics is located on the campus of Rome Tor Vergata in Italy and will host the SuperB collider. The next goal is to deliver the engineering design report within the next year. Design construction has started.

3. Latest Design Features

3.1. Design Parameters

All calculations discussed in this paper and [2] are based on the design parameters as summarized in table I. A complete list of parameters can be found at [2].

Table I: Super-B parameters.

Parameter	HER	LER
Luminosity [$cm^{-2}s^{-1}$]	1.00E36	
Energy [GeV]	6.7	4.18
X-Angle (full) [mrad]	66	
β_x^* [cm]	2.6	3.2
β_y^* [cm]	0.0253	0.0205
ϵ_x (with IBS) [nm]	2.07	2.37
ϵ_y [pm]	5.17	5.92
Bunch length @ I=0 [mm]	4.69	4.29
Beam current [mA]	1892	2447
Tune shift x	0.0021	0.0033
Tune shift y	0.0989	0.0955
$\delta @ I_{max} [\frac{\Delta E}{E}]$	6.43E-4	7.34E-4
Lifetime [min]	4.20	4.48

3.2. IR Layout

There are currently two designs under consideration for the interaction region layout. One bases its design on vanadium permendur Panofsky quadrupoles for QD0 and QF1 for both rings ("Russian" design) as shown in fig. 1. The second utilizes superconducting air coils for QD0 and QF1 ("Italian" design). In addition a portion of the HER QD0 is laid out as vanadium permendur Panofsky quadrupole. Both solutions show good behavior for synchrotron radiation backgrounds and beam apertures. With respect to the detector solenoid compensation the latter option provides better compensation possibilities for both rings as different angles for QD0 and QF1 of HER and LER is the optimum solution.

3.3. QD0 prototype

For the QD0 design a prototype of the superconducting "Italian" design is being built. The quadrupole will have a magnetic length of 30 cm and a gradient of 96 T/m and an inner bore radius of 2 cm. Critical aspects

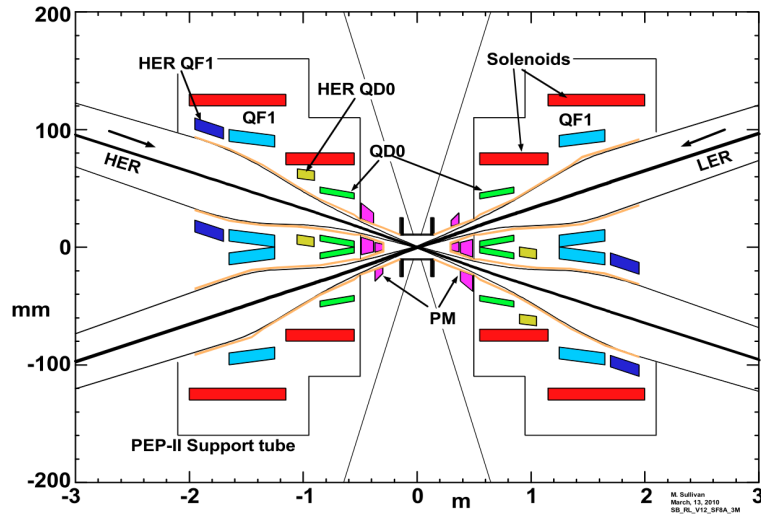


Figure 1: Vanadium Permendur "Russian" Design.

are the small space available for the SC wire and the thermal stabilization material (Cu+Al), and the small margin to quench. The prototype will help in determining the maximum gradient achievable at 4.2K and the field quality at room temperature. See Fig. 2 for a sketch of the magnet. The aluminum structure supporting

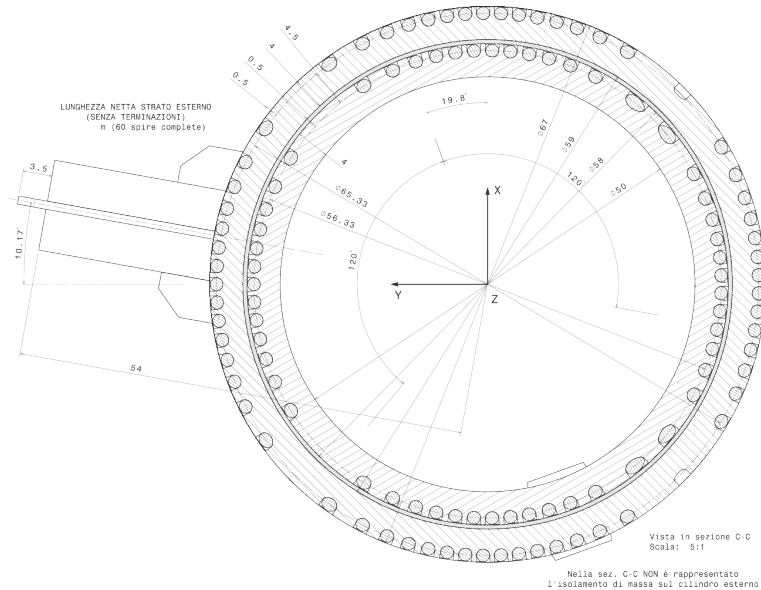


Figure 2: Construction drawing for QD0 prototype "Italian" style.

the superconducting wire has been constructed and a test winding installed in it as shown in Fig. 3.

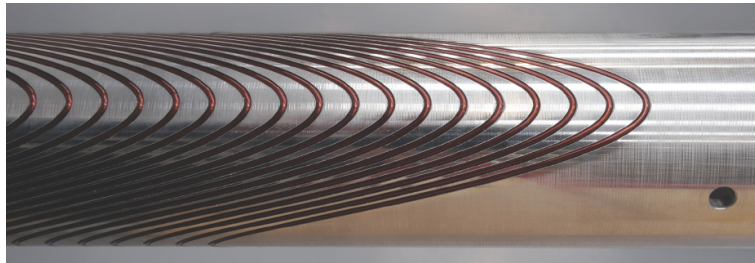


Figure 3: Picture showing the aluminum support structure with installed superconducting wire of the "Italien" QD0 prototype.

3.4. Arc Cell Design

Over the past year two alternative arc cells have been developed. Three different versions for the HER arc cell were designed: V12 is the current version, V13 was modified to improve chromatic behavior and V14 to reduce the ring circumference. The major drivers were the optimization of emittance, dynamic aperture, reduction of chromaticity for version 13 and reduction of ring circumference for version 14. The parameters for these new lattices are summarized in [3]. A detailed description for both solutions is given in [4].

3.5. Compensation of Detector Solenoid

The detector solenoid has a strong 1.5 T field in the IR area, and its tails extend over the range of several meters. The coupling of the horizontal and vertical betatron motion needs to be corrected in order to preserve the small design beam size at the Interaction Point. Additional complications are: (1) The solenoid is not parallel to either of the two beams due to the crossing angle leading to orbit and dispersion perturbations. (2) The solenoid overlaps the innermost IR permanent quadrupoles causing additional coupling effects. The proposed correction system provides local compensation of the solenoid effects independently for each side of the IR. It includes bucking solenoids to remove the unwanted longitudinal solenoid field tails and a set of skew quadrupoles, dipole correctors and ante-solenoids to cancel all linear perturbations to the optics. The details of the correction system design are presented in [6].

3.6. Low Emittance Tuning

The ultra low vertical emittances in SuperB rings need a very careful procedure of emittance tuning, including the study of the maximum tolerable magnet errors (such as misalignments, tilts, BPM errors). To minimize the vertical emittance an orbit and dispersion as well as coupling and β -beating free steering routine has been developed. The efficiency of this routine has been studied for the SuperB lattices with MADX. The results were presented in [7]. The SuperB final focus (FF) introduces stringent restrictions on alignment of both FF and arcs. To test the applicability of this method beam studies were conducted in late 2010 at the Diamond Light Source. In this test the vertical emittance correction was compared to the standard method using LOCO. These studies are still ongoing and preliminary results were presented in [8].

3.7. Vibration Study

To establish a "vibration budget" an ongoing study investigates the effects of on beam sensitivity to dynamic misalignments. The major sources for these are expected to be the vibration of the IR cryostat. To confirm this the effects of ground motion as originally measured at LNF and later on the Tor Vergate site and the vibration of arc quadrupoles have been compared to the results for both sites. The results of the Tor Vergate site are favorable compared to the LNF site which contributed to the site choice. For this investigation ground motion

measurements at LNF site at Frascati and Tor Vergata, vibration measurement at the SLD detector at SLAC are combined with theoretical modeling. To establish the budget a maximum allowed orbit displacement at the interaction point reducing the luminosity is defined. The preliminary results are summarized in table II. These

Table II: Super-B Proposed Vibration Budget.

Element	RMS motion per element	Transfer Function (RMS sum, both rings)	RMS differential displacement at IP no feedback	RMS differential displacement at IP with feedback
Cryostat linear	$< 800 \text{ nm}$	< 0.05	$< 40 \text{ nm}$	$< 4 \text{ nm}$
Cryostat rotation	$< 2 \mu\text{rad}$	$0.02 \frac{\text{m}}{\text{rad}}$	$< 40 \text{ nm}$	$< 4 \text{ nm}$
Final focus quads, excluding IR	$< 200 \text{ nm}$	< 0.2	$< 40 \text{ nm}$	$< 4 \text{ nm}$
Arc	$< 200 \text{ nm}$	< 0.14	$< 30 \text{ nm}$	$< 3 \text{ nm}$
Total (two rings)			$< 75 \text{ nm}$	$< 7.5 \text{ nm}$

results are based on the assumption that the beam feedback achieves a 10 times reduction of motion at IP. Also the integrated RMS motion is larger than 1 Hertz. By achieving these values the relative beam motion at the IP will be within 8 nm and the luminosity loss below one percent. This work has been presented in [9].

3.8. Effect of Second Order Momentum Compaction

A longitudinal head-tail instability can appear when the momentum compaction shows a strong nonlinear energy dependency [10]. The momentum compaction can be developed as a function of energy spread δ as follows: $\alpha = \alpha_1 + \alpha_2 \delta + \alpha_3 \delta^2$. This particular instability is affected by the combination of nonlinear momentum compaction and beam impedance. To better understand its effect it was studied using the code described in [11]. It showed the behavior of an saw tooth instability as depicted in fig. 4. The following preliminary results

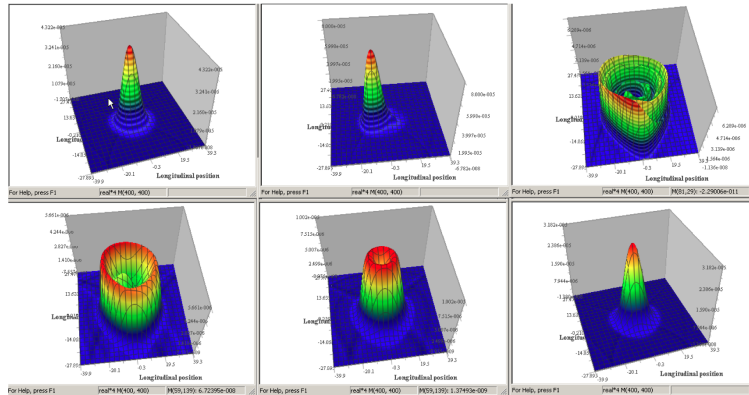


Figure 4: Simulation of head tail instability caused by nonlinear momentum compaction and wake fields. The instability manifests itself in an saw tooth behavior.

were obtained: (1) Second order term of momentum compaction may play important role in the longitudinal beam dynamics for low compaction machines. (2) There is no instability threshold for a positive value of $\frac{\alpha_2}{\alpha_1}$. (3) It is necessary to check that the second part of the momentum compaction of the Super-B lattice has the right sign, or at least is less than 0.05, if it is positive. During operation of the DAΦNE collider this behavior

has been observed in the past. With this study the effects could be understood and, more important, provide the knowledge on how to avoid it.

4. Synchrotron Light Option

The possibility of using the HER and LER storage rings as third generation light source have been investigated. As an initial step the performance of both rings were compared to state of the art facilities in operation, construction and design [5]. Both HER and LER compare favorable in this study. As a result the synchrotron light option has been made integral part of the Super-B project. A preliminary analysis was performed of the ring geometry locating synchrotron light beam lines on the LNF site at Frascati. This work is applicable to the Tor Vergata campus. This is work in progress. Adding the functionality of a light source to the project will impact other decisions.

The design parameters relevant to this study, are shown in Table III. As comparison the design parameters from NSLS II [12] and other state of the art synchrotron light sources have been added to this table. From these parameters it is obvious that synchrotron radiation generated from both HER and LER is comparable to this last generation sources.

4.1. Benchmark Results

To quantify the statement above the synchrotron radiation generated from both rings using bend magnets and standard undulators have been analytically calculated using the formalism described in [13]. A MATLAB script was used to calculate the Bessel functions and calculate flux, and brightness. To verify this setup a benchmark test was performed with a set of parameters and results calculated with an alternative code. As comparison the same calculations have been performed for other light sources to benchmark both HER and LER. For the comparison state of the art facilities in operation, construction and design are used.

4.1.1. Bend Magnet

Bend magnet radiation is parasitically generated in any collider and no change to the optics needs to be implemented. Although most third generation light sources are optimized for undulator and wiggler beam lines bend magnet sources are part of future designs and their performance optimized. The brightness for the different facilities is shown in Figure 5. The parameters used for the calculations are those in Table III. The data were extracted from the facilities web pages, CDR's and presentations. Future facilities like PEPX are not included here as no data was available for it. For bend magnets the HER and LER have the brightest photon beam.

Table III: Parameter Table for Bend Magnet Radiation Calculation.

Param.	HER	LER	NSLS II	APS	ESRF	ELETTRA	ALS
E[GeV]	6.7	4.18	3.0	7.0	6.03	2.0	1.9
I[mA]	1892	2447	500	100	200	320	500
ρ [m]	69.6	26.8	24.98	38.96	23.62	5.55	4.81
ϵ_x [nm]	2.0	2.46	0.55	2.51	4.0	7.0	6.3
ϵ_y [pm]	5.0	6.15	8.0	22.6	25.0	70.0	50.0
γ_y [m ⁻¹]	0.33	0.54	0.05	0.101	0.10	0.50	0.74
σ_x [mm]	82.1	92.1	125	81.7	77.0	139	102
σ_y [mm]	8.66	9.11	13.4	27.0	29.5	28.0	8.20

However the offset to the other sources is smaller as the source parameters (beam emittance and divergence) are less optimized. The results for photon flux is not shown here, since it is dominated by beam current and the HER and LER will have the highest.

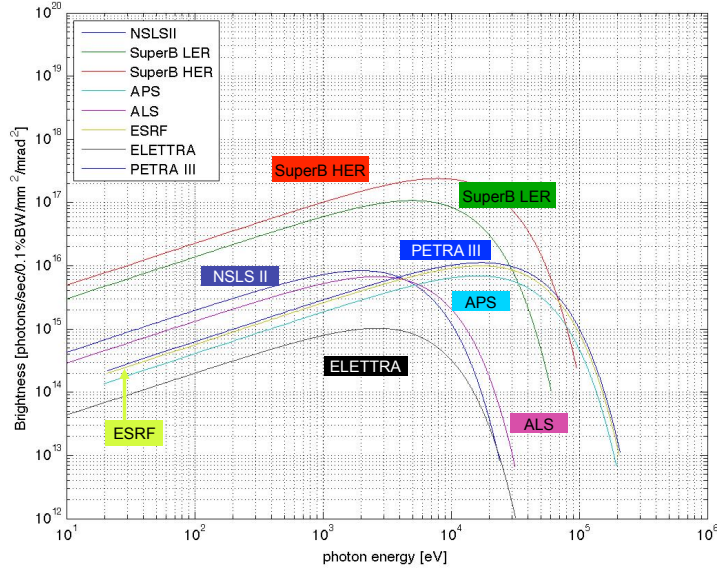


Figure 5: Brightness generated from bend magnets as a function of photon energy.

4.1.2. Undulators

The figure of merit for third generation light sources is the radiation generated from insertion devices. For this purpose the undulator radiation as documented on the same sources quoted above have been used for facilities in operation and construction. For better comparison the same device type as at NLSII was chosen for the Super-B HER and LER. Source point and device parameters are summarized in Table IV. The brightness for

Table IV: Parameter Table for Undulator Radiation Calculation.

Param.	HER	LER	NLSII	APS	PEPX	Soleil	Spring8	Petra III
Undulator	IVU20	IVU20	IVU20	U33	IVU23	U20	U24	U29
E[GeV]	6.7	4.18	3.0	7.0	4.5	2.75	8.0	6.0
I[mA]	1892	2447	500	100	1500	500	100	100
σ_x [μm]	82.1	92.1	125	81.7	22.2	3880	286	140
σ_y [μm]	8.66	9.11	13.4	27.0	7.00	8.08	6.00	5.60
σ'_x [mrad]	33.3	37.0	16.5	11.8	7.40	14.5	11.0	7.9
σ'_y [mrad]	2.1	2.7	2.7	3.3	1.2	4.6	1.0	4.1
N[1]	148	148	148	72	150	90	186	172
λ_u [mm]	20	20	20	33	23	20	24	29
K_{max} [1]	1.83	1.83	1.83	2.75	2.26	1.0	2.21	2.2
K_{min} [1]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

the undulator radiation is depicted in Figure 6. PEPX generates the highest brightness followed by HER and LER. This is a result of the high beam currents in these rings. A detailed study of the difference of source point parameter and its effect on the brightness between PEPX and the Super-B rings by considering the photon beam diffraction limit showed that the higher brightness in PEPX is generated by its lower horizontal emittance.

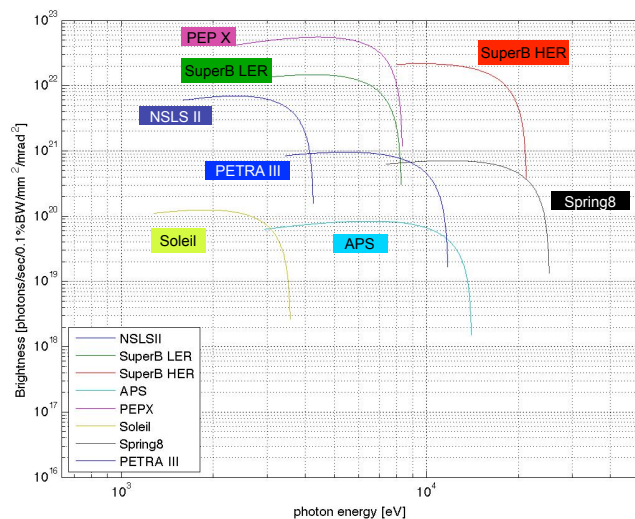


Figure 6: Brightness as a function of photon energy for different reference undulator radiation calculated for benchmarking different facilities.

4.1.3. Source Parameter Optimization

A brief study to optimize the brightness in the HER was conducted, the result is plotted in Figure 7. By reducing the HER energy and beam coupling (from design 0.25% to 0.1%) the beam emittance is reduced. This gain is unfortunately mostly canceled by the change of the diffraction limit as the calculation show, since to achieve the same level of brightness as in PEPX the horizontal emittance would have to be significantly reduced.

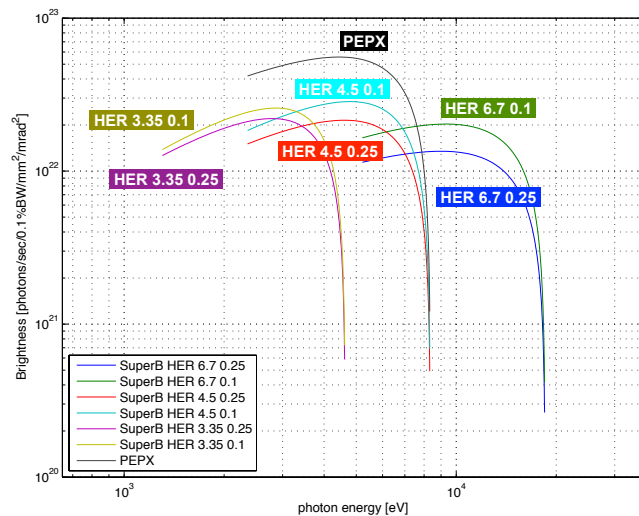


Figure 7: Brightness as a function of photon energy for different energies and coupling values of the HER in comparison to PEPX baseline design.

4.2. Beam Line Layout

When using the Super-B rings as a synchrotron light source one has to plan for additional space for the photon beam lines and user space. This is significant as collider facilities are usually located underground for radiation protection purposes whereas third generation light sources are surface installations.

4.2.1. LNF Site at Frascati Rome

During the study the LNF site near Rome was the primary choice. This site demands an underground installation as the surface area is already mostly occupied. In addition the ring dimensions partially exceed the LNF boundaries. This investigation was aimed to understand where and with what length photon beam lines could be placed within the LNF boundary. An overview is shown in Figure 8. It shows the planned Super-B tunnels with injector. Added to these are the contour lines with distances from the source point in 25 meter steps to a maximum of 150 meters. Only bend magnet source points from the outer ring were used. the upper portion of beam lines originate from the LER the lower from the HER. Figure 9 is a magnification of the



Figure 8: All possible bend magnet photon beam line location with different contour lines showing the distance to the source point.

lower left area. As the picture indicates a set of HER beam lines with different length could be located there completely within LNF boundaries. The same contour line legend of Fig.8 applies.

4.2.2. Campus Tor Vergata Rome

With the decision in favour for the Tor Vergate site the space constraints discussed in the previous section are relaxed. This site is located about 4 kilometers from the original area of LNF. The preliminary results of the ground motion measurements show less activity at this site. A first sketch of the accelerator design at Tor Vergata as originally planned for the LNF site is shown in Fig. 10.

5. CONCLUSIONS

With the approval by the Italian government the project is moving from the conceptual to the technical design phase. With the establishing of the Laboratory Nicola Cabibbo at the Campus Tor Vergata as the future site

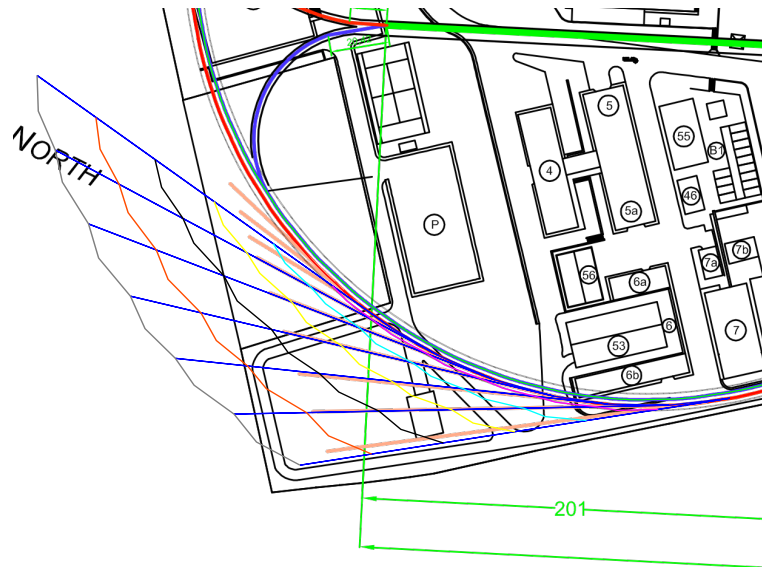


Figure 9: Area of possible HER beam lines which would be located within LNF boundaries. The contour line legend of fig.8 applies.

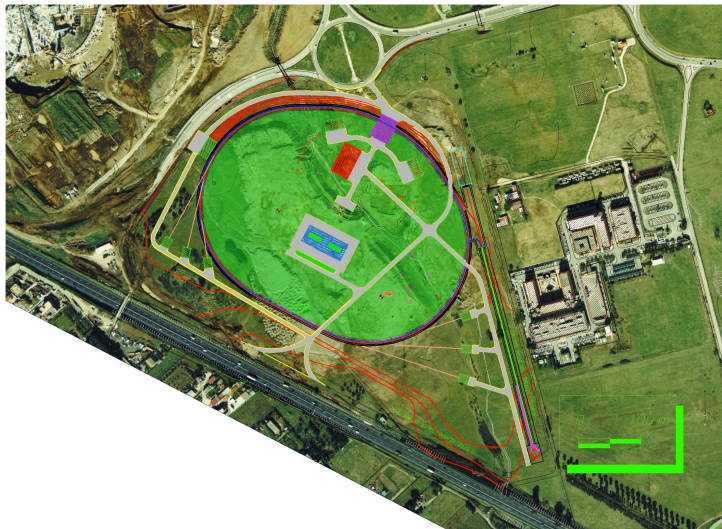


Figure 10: Design option of the SuperB collider at the Campus Tor Vergata near Rome.

of the SuperB facility a large step has been taken towards the realization. The collaboration with other funding agencies, through MOU, is in its final phase. Construction plans will follow soon.

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