

INTERACTION REGION DESIGN FOR THE ELECTRON-NUCLEON COLLIDER ENC AT FAIR

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Abstract

To facilitate studies of collisions between polarized electron and protons at $\sqrt{s} = 14 \text{ GeV}$, constructing an electron-nucleon collider at the FAIR facility has been proposed. This machine would collide the stored 15 GeV polarized proton beam in the HESR with a polarized 3.3 GeV electron beam circulating in an additional storage ring. We describe the interaction region design of this facility, which utilizes the PANDA detector.

INTRODUCTION

The future polarized electron-nucleon collider ENC currently under consideration as part of the FAIR facility aims at colliding 3.3 GeV polarized electron beam with the polarized 15 GeV proton beam stored in the high-energy storage ring HESR. To achieve the projected design luminosity of $10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ a β -function at the interaction point (IP) of $\beta^* = 0.3 \text{ m}$ is required.

As part of this project, an interaction region has been designed to provide head-on collisions of the two beams. Since it is foreseen to utilize the PANDA fixed-target detector (Figure 1) for this collider, a number of boundary conditions arise:

- Preservation of the overall geometry of the proton beamline in the interaction region, including the 2 T · m PANDA spectrometer dipole [1];
- a $\pm 7 \text{ m}$ long machine-element free space between the low- β quadrupoles.

The required detector acceptance angles with respect to the proton beam direction are 0° to 5° , 25° to 155° , and 175° to 180° , which have to be kept free of any accelerator elements. The inner tracker, a 30 cm diameter, $\pm 1.5 \text{ m}$ long cylindrical detector component around the interaction point, will be removed from the central detector, and the resulting free space becomes available to be equipped with accelerator components.

The circulating beams require minimum aperture radii of $6\sigma_p$ for the proton beam, and $10\sigma_e$ for the electrons to ensure good beam lifetime and acceptable background conditions. To preserve these minimum apertures even in the presence of misalignments and closed-orbit distortions, a safety margin of 1 cm should be provided. Minimum aperture radii in the interaction region are therefore $r_p = 6\sigma_p + 0.01 \text{ m}$ for the proton beam, and $r_e = 10\sigma_e + 0.01 \text{ m}$ for the electron beam, respectively.

01 Circular Colliders

A17 Electron-Hadron Colliders

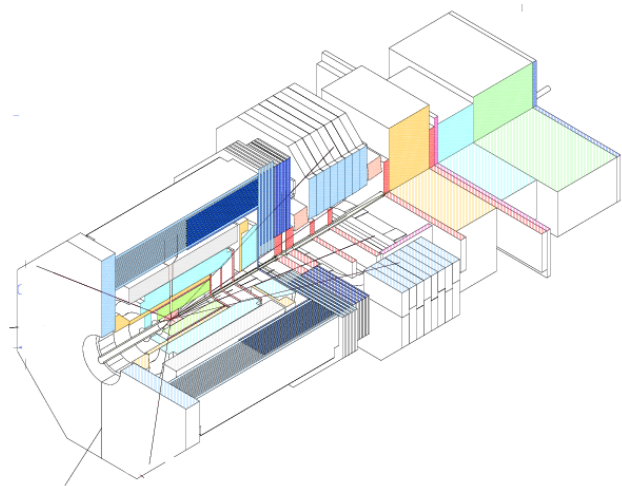


Figure 1: Overview of the PANDA fixed-target detector [1].

BEAM SEPARATION

As in any electron collider, the main challenge in designing an interaction region lies in the separation scheme. Because each beam circulates in its own dedicated storage ring, and beam energies are vastly different, beams have to be separated close to the interaction point to provide complete separation of the two beams at the entrance of the low- β quadrupoles, which are located at a distance of 7 m from the IP.

In the 30 cm diameter space freed by removal of the inner tracker around the IP, two dipoles with opposite polarity will be installed, resulting in an S-shaped geometry. Assuming an outer radius of these superconducting magnets of 15 cm, they have to be installed at a minimum distance of 32 cm from the IP to provide the required detector acceptance angle between 25° and 155° . Assuming furthermore an inner magnet radius of 7.5 cm, these dipoles must not extend beyond 86 cm from the IP in order not to interfere with the detector acceptance between 0° and 5° . These two requirements limit the length of these inner dipoles to 0.5 m.

The $l = 2.0 \text{ m}$ long PANDA spectrometer dipole with its high magnetic field of $B = 1.0 \text{ T}$ would generate roughly 55 kW of synchrotron radiation power if it was experienced by the 2 A electron beam, which is unacceptable. Due to the large transverse size of this magnet, it is virtually impossible to guide the electron beam around. Instead, the

electron beam has to be shielded from the magnetic field of this dipole, either by an iron pipe which guides the magnetic field lines around the electron beam pipe, or by a compact superconducting dipole magnet.

The deflection angle of the inner dipole is determined by the wall thickness of this shielding, which we assume to be $d_{\text{pipe}} = 1$ cm, together with the required apertures. With the PANDA dipole extending from $s = 3.5$ m to $s = 5.5$ m, the required beam separation at the entrance of this dipole at $s = 3.5$ m is

$$\begin{aligned} \Delta x &= 6\sigma_p(s = 3.5 \text{ m}) + 0.01 \text{ m} \\ &\quad + 10\sigma_e(s = 3.5 \text{ m}) + 0.01 \text{ m} + d_{\text{pipe}} \\ &= 6.7 \text{ cm}. \end{aligned} \quad (1)$$

The $l = 0.5$ m long inner dipole, which is centered around $s = 0.6$ m, therefore has to provide a bending angle of 30 mrad for the electron beam, corresponding to a magnetic field of $B = 0.66$ T. This already takes into account the small deflection the proton beam experiences from the same dipole.

On the opposite side of the IP, the inner dipole should be kept at the same strength to limit the synchrotron radiation power generated by this magnet. The outgoing electron beam is deflected by an additional $l = 2.0$ m long dipole, starting at $s = -3.5$ m from the IP. Its strength is scaled down from that of the PANDA dipole to $B = 0.22$ T, according to the energy ratio of the two beams. To preserve the PANDA geometry for the proton beam, this separator dipole has to be designed either as a septum magnet, or - if it is desired as an electron spectrometer magnet - the proton beam pipe has to be shielded from the dipole field by an iron pipe.

Figure 2 shows the geometry of the entire interaction region, with the PANDA dipole and the long electron separator dipole indicated as septum magnets. This separation scheme provides sufficient separation at $s = \pm 1.44$ m to allow for doubling the number of bunches in the machine from 100 to 200, which would double the resulting luminosity.

LOW- β FOCUSING

Low- β focusing of the two beams is provided by superconducting quadrupole triplets [2], starting at $s = \pm 7$ m from the IP. Figure 3 shows the β -functions through one of these triplets.

The individual magnets of each triplet are wound on a common beam pipe to minimize the required drift space in-between magnets. The radius of this beam pipe is determined by the largest rms beam sizes occurring within each triplet. Tables 1 and 2 list the parameters for each individual quadrupole magnet.

While the proton triplet with its peak magnetic field of $B_{\text{max}} = 2.7$ T requires superconducting technology, the electron triplet with its much lower peak field of $B_{\text{max}} = 0.9$ T could be realized by conventional, normal-conducting

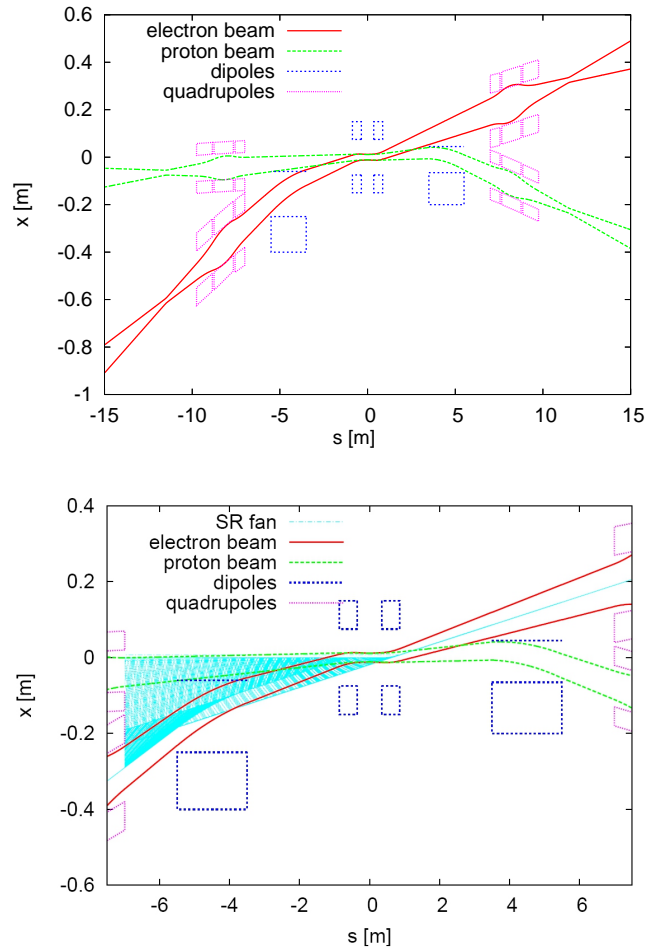


Figure 2: Top view of the ENC interaction region, with the PANDA dipole as well as the corresponding electron separator dipole indicated as septum magnets. Beam envelopes shown here correspond to $6\sigma_p + 0.01$ m for the proton beam, and $10\sigma_e + 0.01$ m for the electron beam, respectively. The lower plot shows the inner region with the synchrotron radiation fan.

	QP1	QP2	QP3
length [m]	0.55	1.1	0.9
k [m^{-2}]	-0.8755	1.0545	-0.9063
β_{max} [m]	242.5	350	330
inner radius [m]	0.0505	0.0505	0.0505
gradient [T/m]	-43.8	52.7	-45.3
B_{max} [T]	2.21	2.66	2.29

Table 1: Magnet parameters of the proton low- β quadrupole triplet. This triplet starts at $s = \pm 7$ m from the interaction point. We assume a drift length of 10 cm between individual magnets.

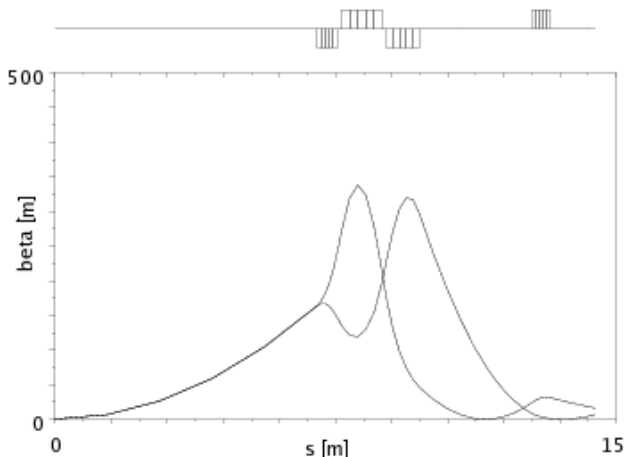


Figure 3: β -functions for a low- β triplet. The interaction point is at $s = 0$; a 4th magnet is shown to illustrate the matching into a periodic FODO structure. We assume identical focusing schemes for both beams in either direction.

	QE1	QE2	QE3
length [m]	0.55	1.1	0.9
k [m^{-2}]	-0.8755	1.0545	-0.9063
β_{\max} [m]	242.5	350	330
inner radius [m]	0.0775	0.0775	0.0775
gradient [T/m]	-8.755	10.545	-9.063
B_{\max} [T]	0.75	0.90	0.77

Table 2: Magnet parameters of the electron low- β quadrupole triplet. This triplet starts at $s = \pm 7$ m from the interaction point. We assume a drift length of 10 cm between individual magnets.

quadrupoles. However, a superconducting quadrupole triplet at such a low field is most likely more compact, especially when installed in a common cryostat with the proton triplet, thus reducing the required transverse beam separation. Assuming that these quadrupole cold masses can be built with an outer radius not exceeding twice the beam pipe radius, the separation scheme describe would be sufficient.

SYNCHROTRON RADIATION

The three dipole magnets acting on the 2 A electron beam generate a considerable amount of synchrotron radiation that has to be taken into account. Each of the two 0.5 m long inner dipoles with its magnetic field of 0.66 T generates $p = 6.0$ kW of synchrotron radiation power, at a critical photon energy of $E_c = 4.8$ keV. The corresponding numbers for the 2 m long electron separator dipole with $B = 0.22$ T are $P = 2.7$ kW at a critical photon energy of $E_c = 1.6$ keV.

These critical photon energies are low enough that the photons cannot penetrate the detector beam pipe. However,

the total heat load of $P = 14.7$ kW has to be dealt with by specifically designed absorbers, which likely have to be water cooled. These absorbers need to be designed such that excessive gas desorption is avoided, for example by a NEG-coated ante-chamber.

POSSIBLE MODIFICATIONS

The design described in this paper could be considerably relaxed by a number of modifications:

- The synchrotron radiation power generated by the two inner dipoles can be reduced by simultaneous lengthening and weakening of these magnets, at the cost of detector acceptance;
- lowering the electron beam energy by 440 MeV, to 2.86 GeV, would considerably lower the synchrotron radiation heat load;
- the electron beam emittance can be reduced by a factor of 3, while simultaneously increasing β^* for the electrons, to reduce the required electron triplet apertures at the cost of an increased, but still realistic, beam-beam parameter of $\xi_e = 0.045$;
- either the electron or the proton low- β triplet could be moved somewhat further away from the interaction point, thus providing significantly more transverse space for the two cold masses due to the large separation angle of 70 mrad, without increasing the required beam separation at $s = \pm 7$ m.

SUMMARY

We have developed a design of an interaction region for the electron-nucleon collider ENC at FAIR, taking into account the required detector acceptance angles and the given geometry of the PANDA detector. In this interaction region beams are focused down to $\beta^* = 0.3$ m at the interaction point, thus providing a luminosity of $L = 1 \cdot 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$. Since the separation scheme developed here provides sufficient separation already at a distance of $s = \pm 1.44$ m from the IP, the number of bunches could potentially be doubled from 100 to 200, thus doubling the luminosity to $L = 2 \cdot 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$.

ACKNOWLEDGMENTS

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REFERENCES

- [1] The PANDA collaboration, W. Erni et al., Technical Design Report for the PANDA Solenoid and Dipole Spectrometer Magnets, arXiv:0907.0169
- [2] P. Schnizer et al., Magnet Design of the ENC Interaction Region, these proceedings