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The polarized electron-nucleon collider project ENC at GSI/FAIR

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Abstract. The ENC project attempts to realize an electron-nucleon collider at the upcoming Facility for Antiproton and Ion Research FAIR at GSI Darmstadt by utilizing the antiproton high-energy storage ring HESR for polarized proton and deuteron beams. The addition of a 3.3 GeV storage ring for polarized electrons will enable electron-nucleon collisions up to a center-of-mass energy of $\sqrt{s} \approx 14$ GeV. In such a configuration peak luminosities in the range of $L = 10^{32}$ to $10^{33} \text{cm}^{-2}\text{s}^{-1}$ are feasible. Beam-beam effects in a space-charge dominated regimes in conjunction with high-energy electron cooling represents one of the main challenges for this project. In this paper beam- and spin dynamics simulations are presented, together with the required modifications and extensions for a collision mode of the HESR storage ring and the conceptual design of this new collider complex.

1. Introduction

Up to now the only electron-proton collider ever built is the "Hadron-Elektron Ring-Anlage" HERA (DESY, Germany) [1]. Polarized electrons/positrons have been collided in HERA with unpolarized protons at a center-of-mass energy of up to 320 GeV and peak luminosities of 3 to $5 \cdot 10^{31} \text{cm}^{-2}\text{s}^{-1}$ [2]. Presently four proposals have been presented to build a double polarized electron-ion(nucleon) collider. A lepton accelerator could be added to the existing Relativistic Heavy-Ion Collider RHIC at BNL [3, 4], to the Large-Hadron Collider LHC at CERN [5, 6] and to the planned High-Energy Storage Ring HESR at FAIR [7]. TJNAF suggest to use the CEBAF facility as an injector of polarized electron into ELIC/MEIC, build a new hadron injection complex and new lepton and hadron storage rings [8, 9]. Main design objectives for the physics reach of this second-generation electron-ion(nucleon) colliders are to increase center-of-mass energy, luminosity and degree of beam polarization [10].

Beside highest possible luminosity, the high-priority goal of the ENC project is to reach longitudinal polarized electron - nucleon collisions with high polarization of up to 80% in both beams.

2. Conceptual Design

The HESR [11], primarily designed to provide antiprotons in the momentum range from 1.5 to 15 GeV/c for the internal target experiment PANDA [12], will serve as proton/deuteron storage ring. The proposed ENC concept integrates an appropriate 3.3 GeV electron ring in the HESR tunnel (Fig. 1). Center-of-mass energies of roughly 14 GeV for electron-proton and 9 GeV for electron-deuteron in head-on collisions can be provided. Pre-acceleration of protons and deuterons would take place in the planned proton linac [13] and the heavy-ion linac UNILAC [14], respectively. The heavy-ion synchrotron SIS 18 [15] would be suitable to accelerate these beams to HESR injection momentum of 3.8 GeV/c. An additional beamline from SIS18 to HESR has already been proposed for HESR commissioning with protons. For polarized proton/deuteron beams, additional equipment has to be installed in the HESR and the pre-accelerators of its injection chain to measure and preserve the beam's polarization. A corresponding scheme to accelerate and store longitudinal polarized electrons is presently under investigation [16].

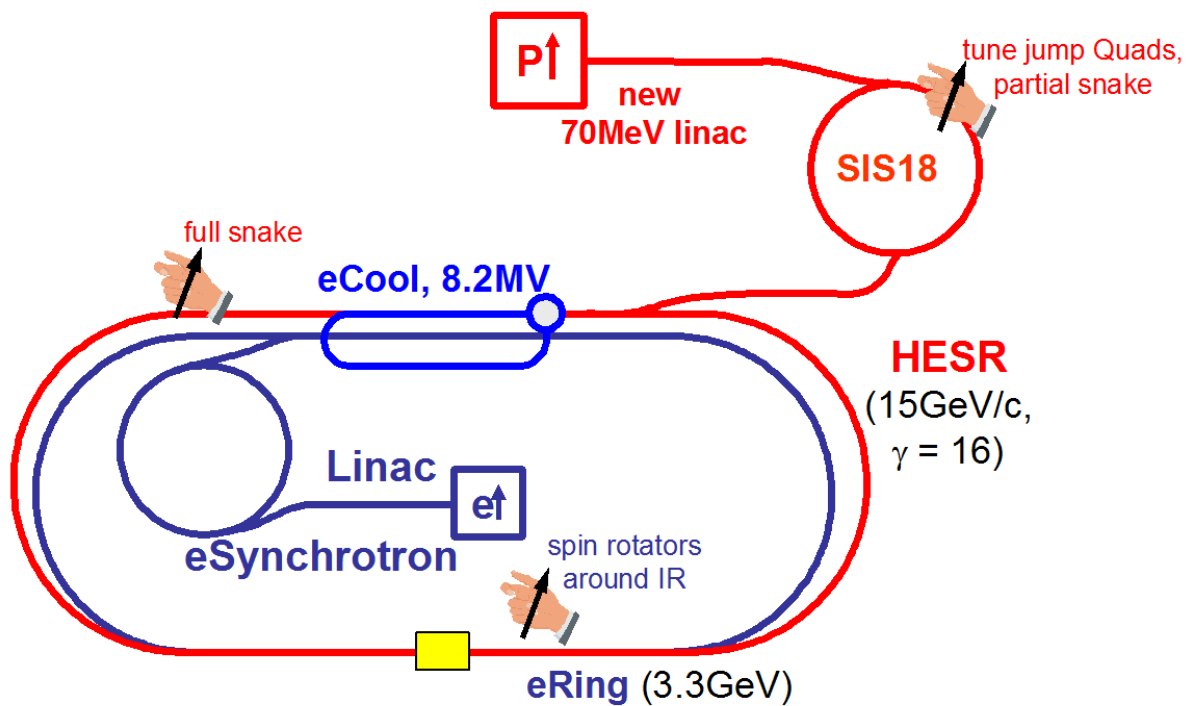


Figure 1. Scheme of ENC at FAIR for electron-proton collisions (not to scale).

Major modifications of the PANDA interaction region are required for beam collisions with high luminosity. The interaction design should include as many parts of the PANDA detector as possible, e.g., central detector and forward spectrometer. It should further guarantee back-to-back operation of the HESR storage ring in fixed target mode together with the elaborated collider mode. A conservative interaction-region design has been developed [17, 18], which is compliant with the PANDA detector setup and all experiments presently under investigation for the ENC project. The proposed concepts allow for betafuncions at the interaction point of $\beta_{x,y}^{IP}=0.3$ m and a bunch spacing of 2.88 m, which corresponds to 200 stored bunches.

The proposed electron cooler for HESR [19] is planned to be used to cool the proton/deuteron beams to equilibrium beam parameters and preserve emittance during beam collisions.

3. Beam Dynamics Simulations

Calculations of cooled beam equilibria including intra-beam scattering and beam-beam interaction have been performed using the BetaCool code [20]. The model calculations assume a Gaussian beam distribution in phase space over all degrees of freedom. For electron cooling the Parkhomchuk model [21] of the friction force was chosen and for intra-beam scattering the Martini model [22] using ring lattice functions imported from the MAD program.

3.1. Equilibrium beam parameter and luminosity estimates

Different scenarios for electron-proton and electron-deuteron collisions have been investigated to estimate maximum luminosities. In tables 1 and 2 relevant equilibrium beam parameters and luminosity estimates are summarized. The numbers in brackets are based on a scenario with an advanced interaction-region design that would allow for collisions with $\beta_{x,y}^{IP}=0.1$ m.

Beam simulations indicate, that the electron cooler need a major upgrade to an electron current of 3 A at 8.2 MeV electron energy to sufficiently cool proton beams during collisions. Deuteron beam only require the design parameter of the HESR electron cooler with a 1 A electron beam accelerated to 4.1 MeV. Dedicated high-voltage storage RF systems in the frequency range from 52 to 104 MHz have to be incorporated into HESR to allow for multi-bunch operation of 100 to 200 bunches. During beam collisions an RF voltage of roughly 300 kV is sufficient to keep the beam particles inside the RF buckets.

The performed beams studies clearly showed that peak luminosities are meanly limited by space charge and beam-beam parameter in the nucleon ring. Estimates indicate that maximum luminosities above $6 \cdot 10^{32} \text{cm}^{-2} \text{s}^{-1}$ are challenging but can in principle be reached with present day technology.

More detailed studies and an advanced interaction region design are required to squeeze the betafunctor at the interaction point to $\beta_{x,y}^{IP}=0.1$ m. Especially beam separation, beam-beam parameter and chromaticity correction are main objectives to be studied in detail.

Crab crossing could further increase the performance of the proposed collider concept [23], allow for a crossing angle without loss of luminosity. Crab crossing has never been employed for hadron collisions, but it can be applied for electron-hadron collisions if only the electron bunches are tilted by the full crossing angle.

Table 1. Equilibrium beam parameter and luminosity estimates for electron-proton collisions for baseline (**advanced**) design.

	15 GeV/c protons	3.3 GeV electrons
$\epsilon_{norm.,geo.}$ [mm mrad, rms]		$\leq 2.3, \leq 0.14$
$\Delta p/p$ (rms)		$4 \cdot 10^{-4}$
$\beta_{x,y}^{IP}$ [m]		0.3 (0.1)
r_{IP} [mm, rms]		≤ 0.2 (\leq 0.1)
l (bunch length) [m]	0.27-0.35 (0.19-0.25)	0.1
n (particle / bunch)	5.4 (3.6) $\cdot 10^{10}$	$23 \cdot 10^{10}$
h (number of bunches)		100 (200)
f_{coll} (collision freq) [MHz]		52 (104)
l_{coll} (bunch distance) [m]		5.76 (2.88)
Q_{sc} (space charge)	≥ 0.05 (\geq 0.1)	
ξ (beam-beam parameter)	0.014 (0.014)	0.015 (0.01)
L (luminosity) [$\text{cm}^{-2} \text{s}^{-1}$]		≈ 2 (6) $\cdot 10^{32}$

Table 2. Equilibrium beam parameter and luminosity estimates for electron-deuteron collisions for baseline (**advanced**) design.

	15 GeV/c deuterons	3.3 GeV electrons
$\epsilon_{norm.,geo.}$ [mm mrad, rms]		$\leq 2.4, \leq 0.15$
$\Delta p/p$ (rms)		$2.4 \cdot 10^{-4}$
$\beta_{x,y}^{IP}$ [m]		0.3 (0.1)
r_{IP} [mm, rms]		$\leq 0.2 (\leq \mathbf{0.1})$
l (bunch length) [m]	0.17-0.19	0.1
n (particle / bunch)	$1.1 \cdot 10^{10}$	$23 \cdot 10^{10}$
h (number of bunches)	173	172
f_{coll} (collision freq) [MHz]		89.3
l_{coll} (bunch distance) [m]		3.3
Q_{sc} (space charge)	≥ 0.1	
ξ (beam-beam parameter)	0.013 (0.014)	0.025 (0.03)
L (luminosity) [$\text{cm}^{-2}\text{s}^{-1}$]		$\approx 0.6 (\mathbf{1.8}) \cdot 10^{32}$

3.2. Beam Bunching

To get the anticipated number of bunches, a complicated re-bunching process in combination with phase-space cooling has to be performed to minimize cooling time and beam losses. The beam would first be accelerated in one or two bunches to collision energy, using the regular HESR accelerating cavity. Since the cooling time to equilibrium parameters within 200 bunches at 15 GeV/c would take many hours, the proposed scheme is to debunch the beam after acceleration and cool the unbunched beam to the required beam equilibrium before rebunching. That would reduce the cooling time to roughly 20 min. During the rebunch procedure the storage RF systems has to be adiabatically turned on while the beam is still cooled to minimize beam losses. The required RF voltage for rebunching depends on details of the rebunch procedure and available cooling force. If the initial beam emittance before cooling is too large, one could in addition apply beam cooling at injection energy, if not limited by space-charge effects.

4. Preparation of Polarized Beams

Polarized proton/deuteron beams have to be produced in a dedicated polarized ion source, pre-accelerated in the planned proton linac or UNILAC, and accelerated to HESR injection energy in SIS18. Acceleration and storage of polarized proton in medium and high energy circular accelerator is complicated since numerous spin resonances have to be crossed. In strong-focusing synchrotron and storage rings like SIS18 and HESR imperfection and intrinsic resonances can significantly depolarize the beam. Spin resonances and preservation of polarization for protons in SIS18 and HESR has already been discussed [24, 25]. For a single Siberian snake longitudinal polarized proton beams can be prepared at the interaction point. Due to the much smaller gyromagnetic anomaly of deuterons this is not possible with reasonable technical effort for deuteron beams.

The scheme to accelerate and store longitudinal polarized electrons comprises polarized electron sources, a full energy electron injector (synchrotron or pulsed linac) and an electron storage ring. Spin lifetime under synchrotron radiation and providing longitudinal beam polarization at the interaction point are currently under investigation [16]. Spin dynamics simulations with a single Siberian snake scheme showed unacceptable short spin lifetimes in the

range of few minutes. A scenario with multiple Siberian snakes has been proposed for Novosibirsk c-tau factory project to increase spin lifetime of polarized electrons significantly [26].

4.1. Spin Resonances in SIS18

In the momentum (energy) range from 369 MeV/c (70 MeV) to 3.8 GeV/c (3.0 GeV) six imperfection resonances for protons ($\gamma G = 2, 3, 4, \dots, 7$) have to be crossed. For an acceleration rate of 1 GeV/c per 0.05 s a 3% partial snake (0.5 Tm solenoid) is sufficient to overcome these spin resonances by exciting adiabatic spin flips. Due to high super-periodicity of the SIS18 lattice ($P = 12$) only one intrinsic resonance ($\gamma G = 0 + Q_y$) occurs, where Q_y is the vertical betatron tune. The preferred correction method for intrinsic resonance depends on the vertical beam emittance [24]. For the expected normalized beam emittance in the range of few mm-mrad a tune-jump quadrupole is the adequate method to overcome intrinsic resonances [27]. A small beam emittance for efficient tune jumps and a lower acceleration rate to reduce the snake strength would be beneficial for polarized proton beam acceleration in SIS18.

For deuterons no first-order spin resonances have to be crossed up to HESR injection energy. Only one weak gradient-error spin resonance ($\gamma G = 3 - Q_y$) could lead to small polarization losses, but could easily be crossed by tune jumping.

4.2. Spin Resonances in HESR

In total 25 imperfection resonances, 50 intrinsic resonances and 50 coupling spin resonances must be overcome during acceleration in HESR. The large number of resonances in the HESR makes it very hard to apply techniques of individual manipulation of single spin resonances [28]. The application of Siberian snakes is the only option to guarantee a setup with low polarization losses during acceleration. Therefore a magnet system with combined field types has been investigated [29]. It is consisting of four RHIC-type helical dipole magnets with a maximum field of 2.5 T and a 15 Tm solenoidal field. Space for the helical dipole snake has been reserved in the straight section where the Electron Cooler is located. To reach the required 15 Tm solenoidal field the DC electron cooler in combination with its rampable correction solenoid can be used.

For deuterons only one imperfection resonance ($\gamma G = -1$) and two intrinsic resonances ($\gamma G = -8 + Q_y, 7 - Q_y$) have to be crossed. The proposed Siberian snake can only be operated as partial snake and additional tune-jump quads have to be installed in the HESR. If the vertical betatron tune is placed close to an integer, a partial snake is in principle also suitable to overcome intrinsic resonances [30]. The challenge is to run a circular accelerator with a betatron tune close to an integer [31].

5. Conclusion and Outlook

The ENC study group aims to realize a polarized electron-nucleon collider at the upcoming FAIR facility within the next decade. Experiments with polarized beams would become available with maximum luminosities of roughly 2 to $6 \cdot 10^{32} \text{cm}^{-2} \text{s}^{-1}$. The design of an adequate lattice for the electron ring including simulations to optimization of spin lifetime is of major importance for this project. Further studies of modifications and extensions at the HESR storage ring have to be performed. Especially electron cooling of relativistic ion beams, collective effects and extensive RF bunching require detailed beam studies. Operating a collider with large beam-beam tune shift in space-charge dominated regimes is certainly the main luminosity limitation for ENC. The integration of PANDA detector, taking into account the required detector acceptance angles and the given detector geometry, further restricts beam separation and focussing in the interaction region. A crossing angle at the collision point in combination with Crab crossing could increase the performance of the ENC collider in terms of detector acceptance and peak luminosity.

Further investigations will be carried out with the goal to provide a first design report by the end of 2012.

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References

- [1] Augneres J L et al. 1981 HERA - A proposal for a large electron-proton colliding beam facility at DESY *DESY-HERA Report* **81-10**
- [2] Willeke F 2006 HERA and the next generation of lepton-ion colliders *Proc. of EPAC 2006* Edinburgh Scotland <http://accelconf.web.cern.ch/AccelConf/e06/PAPERS/FRXBPA01.pdf>
- [3] Ahrens L et al. 2004 eRHIC zeroth-order design report (ZDR) *BNL C-AD Note* **142** Farkhondeh M and Ptitsyn V (eds)
- [4] Ptitsyn V et al. 2008 *Proc. of 42nd ICFA Advanced Beam Dynamics Workshop on High-Intensity High-Brightness Hadron Beams HB 2008* Nashville (TN) USA <http://www.bnl.gov/isd/documents/70346.pdf>
- [5] Burkhardt H 2008 Ring-ring layout & bypass design *Proc. of the first ECFA-CERN LHeC Workshop* Divonne France
- [6] Zimmermann F et al. 2008 LINAC-LHC ep collider options *Proceedings of EPAC 2008* Genoa Italy <http://accelconf.web.cern.ch/AccelConf/e08/papers/wepp154.pdf>
- [7] Jankowiak A et al. 2009 Concept of a polarized electron-nucleon collider utilizing the HESR storage ring at GSI/FAIR *Proc. of PAC 2009* Vancouver (BC) Canada <http://trshare.triumf.ca/~pac09proc/Proceedings/papers/we6pfp063.pdf>
- [8] Bogacz S A et al. 2008 Advances on ELIC design studies *Proc. of EPAC 2008* Genoa Italy <http://accelconf.web.cern.ch/AccelConf/e08/papers/wepp049.pdf>
- [9] Zhang Y et al. 2009 Simulation studies of beam-beam effects of a ring-ring electron-ion collider based on CEBAF *Proc. of PAC 2009* Vancouver (BC) Canada <http://trshare.triumf.ca/~pac09proc/Proceedings/papers/we6pfp067.pdf>
- [10] Litvinenko V N 2010 Future electron-hadron colliders *Proc. of IPAC 2010* Kyoto Japan <http://accelconf.web.cern.ch/AccelConf/IPAC10/papers/wexmh02.pdf>
- [11] Lehrach A et al. 2009 The high-energy storage ring (HESR) for FAIR *International Journal of Modern Physics (IJMPE)* **E 18 Issue 2** 420
- [12] PANDA Collaboration 2009 The PANDA collaboration physics performance report for PANDA: strong interaction studies with antiprotons [arXiv:0903.3905v1 \[hep-ex\]](http://arxiv.org/abs/0903.3905) <http://arxiv.org/abs/0903.3905>
- [13] Greoning L et al. 2006 The 70-MeV proton linac for the facility for antiproton and ion research FAIR *Proc. of LINAC 2006* Knoxville (TN) USA <http://accelconf.web.cern.ch/AccelConf/l06/PAPERS/MOP061.pdf>
- [14] Barth W 2006 Long term perspective for the UNILAC as a high-current heavy ion injector for the FAIR-accelerator complex *Proc. of LINAC 2006* Knoxville (TN) USA <http://accelconf.web.cern.ch/AccelConf/06/PAPERS/MOP059.pdf>
- [15] Blasche K et al. 1985 The SIS heavy ion synchrotron project *Proc. of PAC 1985 IEEE Transactions on Nuclear Science* **NS-32 No. 5** 2687
- [16] Boldt O et al. 2011 Investigation of various electron ring concepts for the ENC with regard to depolarising effects *Proc. of this conference*
- [17] Montag C et al. 2010 Interaction region design for the electron-nucleon collider ENC at FAIR *Proc. of IPAC 2010* Kyoto Japan <http://accelconf.web.cern.ch/AccelConf/IPAC10/papers/tupeb051.pdf>
- [18] Schnizer P et al. 2010 Magnet design of the ENC@FAIR interaction region *Proc. of IPAC 2010* Kyoto Japan <http://accelconf.web.cern.ch/AccelConf/IPAC10/papers/mopeb026.pdf>
- [19] Galnander B et al. 2007 Status of design work towards an electron cooler for HESR *Proc. of the Workshop on Beam Cooling and Related Topics COOL 2007* Bad Kreuznach Germany
- [20] Sidorin A O et al. 2006 *Nucl. Inst. Meth. A* **558** 325
- [21] Parkhomchuk V 2000 *Nucl. Inst. Meth. A* **441** 9
- [22] Martini M 1994 *CERN AA Report PS/84-9* Geneva Switzerland
- [23] Palmer R B 1988 Energy scaling, crab crossing and the pair problem *SLAC-PUB-4707* Stanford (CA) USA
- [24] Lehrach A et al. 2007 Modifications of the HESR layout for polarized antiproton-proton physics *Proc. of the 17th International Spin Physics Symposium SPIN 2006* Kyoto Japan *AIP Conf. Proc.* **915** 147
- [25] Bradamante F et al. 2005 Conceptual design for a polarized proton-antiproton collider facility at GSI *Report INFN-TC-05-14* [arXiv.org:physics/0511252](http://arxiv.org/physics/0511252)
- [26] Koop I et al. 2011 Longitudinally polarized electrons in Novosibirsk c-tau factory *Proc. of this conference*
- [27] Lehrach A et al. 2003 Overcoming depolarizing resonances at COSY *AIP Conf. Proc.* **667** 30

- [28] Khiari F Z et al. 1989 *Phys. Rev.* **39** 45; Huang H et al. 1994 *Phys. Rev. Lett.* **73** 2982; Bai M et al. 1998 *Phys. Rev. Lett.* **80** 4673
- [29] Lehrach A et al. 2004 Polarized beams in the high-energy storage ring of the future GSI project *Proc. of the 16th International Spin Physics Symposium SPIN 2004* Trieste Italy
- [30] Roser T et al. 2004 Acceleration of polarized beams using multiple strong partial siberian snakes *Proc. of EPAC 2004* Lucerne Switzerland <http://accelconf.web.cern.ch/AccelConf/e04/PAPERS/TUPLT190.pdf>
- [31] Huang H et al. 2007 *Phys. Rev. Lett.* **99** 154801