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Exploring Confinement at CERN

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This conference note discusses an experimental programme to explore the QCD confinement phenomena at CERN with a new electron-proton and electron-nucleus collider using the existing SPS beams (optionally also the future SPL and PS proton and ions beams) and the polarised electron beam in the range of 5 to 30 GeV from a newly built Energy Recovery Linac.

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1. Preface

The past 40 years saw remarkable progress in the understanding of the strong force, both theoretically and experimentally. Quantum Chromodynamics (QCD) has been established as the theory of quark and gluon interactions. Quantitative predictions passed successfully detailed experimental scrutiny. However, this success was limited to the domain of distances much smaller than the size of hadrons, where the interaction strength becomes weak and makes perturbative calculation techniques applicable.

Despite this success, basic observables that describe the quark and gluon dynamics at the confinement scale are not predicted by QCD, notably the parton momentum distributions in the nucleon and in nuclei, and the fragmentation functions of quarks and gluons into hadrons. QCD is not complete. We do not understand the mechanism of confining quarks in nucleons and the role of quark degrees of freedom in forming atomic nuclei. We do not understand whether gluons can propagate in the atomic nucleus or whether they are confined within nucleons or even smaller constituent volumes. We do not understand the orbital angular momentum of quarks and gluons in hadrons. We do not know how "rigid" the nucleon and nuclear matter is, i.e., how easy it is to "knock" that matter by knocking one of its constituents.

Confinement phenomena have been considered as a burden rather than as research goal. The quest for understanding gave way to absorbing the lack of knowledge in phenomenological parametrisations with ad hoc parameters.

In this note, an experimental CERN programme is discussed that
(i) focusses on the study of the confinement of quarks and gluons, that
(ii) is relatively easy to implement at low cost, and that
(iii) offers R & D synergy with the CLIC development.

Particle physics programmes are are often classified as belonging to the "high-energy discovery frontier" or to the "low-energy precision frontier". What is proposed below, is perhaps better classified as belonging to the "medium-energy exploratory frontier".

2. Physics Observables

The proposed programme focusses on the exploration of the structure of nucleons and nuclei by elastic and inelastic scattering of electrons. This requires the collision of electron beams with beams of protons, deuterons, and nuclei, at appropriate energies.

The spatial dimensions to be explored range from much smaller than the size of the nucleon (with a view to connecting with the results from past fixed-target experiments and from HERA) up to the diameter of heavy nuclei, i.e., from about 0.01 fm up to 100 fm. In terms of Q^2, this means a range from 4×10^2 to 4×10^{-6} (GeV/c)^2. For the same Q^2, the independence between the electron scattering angle and the inelasticity permits a subdivision of the spatial resolution into longitudinal and transverse components.

A non-exhaustive list of physics observables that hopefully will help toward a theoretical understanding of confinement reads as follows:
(i) inclusive quark and gluon structure functions of the proton, the neutron, and of nuclei
(ii) fragmentation functions of exclusive nuclear fragments

(iii) correlations between structure functions and fragmentation functions
(iv) semi-inclusive structure functions for flavour-tagged final state particles
(v) spin dependence of structure functions and of fragmentation functions
(vi) heavy flavour production

The core of the proposed programme is to provide completely new information that is intrinsically connected with the phenomenon of confinement: what are the reactions of a struck quark that moves in vacuum as compared to the case that it moves in nuclear matter? And how do observed differences depend on the pathlength and fragmentation modes in nuclear matter?

In order to get these questions answered, it is imperative to study the distributions of all reaction products from the struck quark, up to and including nuclear fragments. This is not possible in fixed-target experiments and requires the collision of low-momentum electrons with protons and ions with rather high momenta.

More information on the proposed physics programme can be found in [1-7].

3. Machine Aspects

The upper limit of the desired Q^2 range is achieved by colliding 30 GeV/c electrons with 200 GeV/c protons. The lower limit of the desired Q^2 range is achieved in collisions where the electron is scattered at very small angles. The efficient detection of small-angle electron scattering and of nuclear fragments sets stringent upper limits on the proton beam momentum (not larger than a few hundred GeV/c which eliminates the use of LHC beams) and requires appropriate detector designs. Running with beam momenta below 30 GeV/c for electrons and also way below 200 GeV/c for protons, down to a few GeV/c), is highly beneficial.

The experimental programme requires a luminosity in the range from 10^{30} cm^{-2}s^{-1} to 10^{33} cm^{-2}s^{-1}. While the low luminosity is sufficient for studies of the nucleus disintegration which follows the electromagnetic perturbation, the high luminosity is necessary to measure structure functions and fragmentation functions with high statistical precision.

Electron and positron beams are equivalent for the proposed physics programme. Polarization of the electron beam is an asset, however not critical for the proposed programme.

Both ions with the highest atomic mass number and light isoscalar ions of importance. While in the e–Pb collisions the main emphasis will be on the study of the nuclear medium, the emphasis with isoscalar beams such as D, He, O or Ca will be on high-precision relative measurements of structure functions and fragmentation functions.

The basic idea is to construct at the CERN site an Energy Recovery Linac (ERL) and collide the electron beam with the proton and ion beams provided by the SPS and the PS.

Such a programme would stimulate a vigorous R &D programme on ERLs, polarized guns, e^+ production, crab cavities; and polarization and advanced cooling techniques of the ion beams. Much of this R & D would provide synergy effects with the CLIC R & D programme.

4. The future of DIS

The optimal experimental facility to conduct the confinement programme, sketched above and called hereafter iCHEEPx, is one of the five DIS experimental facilities which are presently being considered. Several technical aspects of the electron-proton and electron-ion collider in the SPS tunnel was discussed already long time ago [13]. The confinement project discussed in this note inherits from this work not only a collider name but also its several technical solutions. The other facilities are: the ENC@FAIR at GSI [9], the eRHIC at BNL [8], [10], the MEIC at TJNAF[11], and the LHeC at CERN [12] .

	ENC@FAIR (GSI)	MEIC (TJNAF)	eRHIC (BNL)	iCHEEPx (CERN)	LHeC (CERN)
E_{CM} range [GeV]	14	10-65	45-175	14-230[1]	800-1300
Peak Lumi [10^{33} cm $^{-2}$ s^{-1}]	0.2 (0.6)	14.2	9.7	1-10[1]	1-1.7
Polarisation, p,e [%,%]	80,80	70,80	70,80	0,80[1]	0,90
Adequacy of collider param. to the proposed physics programme	***	***	****	*****	***
Attractiveness to the nuclear physics community	****	****	****	****	**
New observables and new physics questions	***	****	*****	*****	***
Importance for the LHC experimental programe	*	***	****	*****	*****
Challenging accelerator R&D	***	*****	*****	*****	*****
Cost	****	****	****	*****	**

Figure 1: Evaluation of the merits of the iCHEEPx project in comparison to the other future DIS projects.

The above facilities have been discussed extensively over the last 18 years, but none of them has been approved for construction. What are the main lessons from the numerous attempts to get a future facility for the DIS physics approved?

1.The future ep(eA) collider project should be a single joint project of the LHeC (Europe) and the EIC (USA) communities and its program must be complementary to the TJNAF and FAIR programmes (the ILC-like path).

2. It should be recognized as important not only by the HEP community but, equally, by the nuclear physics community.

3. It should address new physics questions (beyond those addressed already at HERA and the fixed target program at CERN and TJNAF).

4. Its role should be recognized as essential for the model independent interpretation of the LHC experimental results and as imperative for the LHC precision measurement programme.

5. It should be challenging for the accelerator R&D.

6. It should cheap, i.e. it must maximize the physics output per cost ratio.

The main goal of this conference contribution is to make a point that the collider based on the SPS proton and ion beams and the electron beam from a newly built Energy Recovery Linac (e.g. the scaled up version of the eRHIC electron accelerator) is both optimal to study confinement phenomena and, in view of the author of this contribution, has the highest chance to be realized in the future.

An attempt to evaluate the relative merits of each of the proposed future DIS projects are presented in Fig. 1. This comparison may serve as a departure point for the discussions which, hopefully, may converge at a single world-wide project.

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