Relativistic Heavy Ion and Spin Physics

Sub-group of the JINR Strategy Long Range Plan International Working Group

Strategy of the Laboratory of High Energy Physics

- Locally developed document by a group of ~30 people under the coordination of R. Tsenov and after a laboratory-wide discussion (June – Dec. 2017)
- Web site (also with audio records) *https://indico.jinr.ru/conferenceDisplay.py?confId=296*, passwd: ***ask me!***

Version: March 2018

STRATEGIC PLAN FOR THE CONSTRUCTION AND DEVELOPMENT OF THE LHEP BASIC FACILITIES AND FOR CONDUCTING OF PHYSICS RESEARCH AT THESE FACILITIES, AS WELL AS AT OTHER ACCELERATOR CENTERS IN THE WORLD, FOR THE NEXT THREE DECADES

Table

No.	FOCUS AREAS AND OBJECTIVES	2017-2023	2024-2030	2031-2037	2038-2044	2045- 2051
1	Construction, start-up and operation of the NICA complex	2020 – commissioning of the basic configuration, 2023 – design configuration.	Symmetric heavy ion collisions, $L=10^{27}$ $sm^{-2}s^{-1}$. Polarized proton and deuteron collisions,	Asymmetric[2] heavy ion collisions, $L=10^{27}$ $cm^{-2}s^{-1}$. Polarized proton and deuteron collisions, $L=10^{32}$	Electron-nuclei head-on and co-moving collisions	

Relativistic Heavy-Ion and Spin Physics sub-group

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- Vladimir Kekelidze (LHEP JINR) - chairman

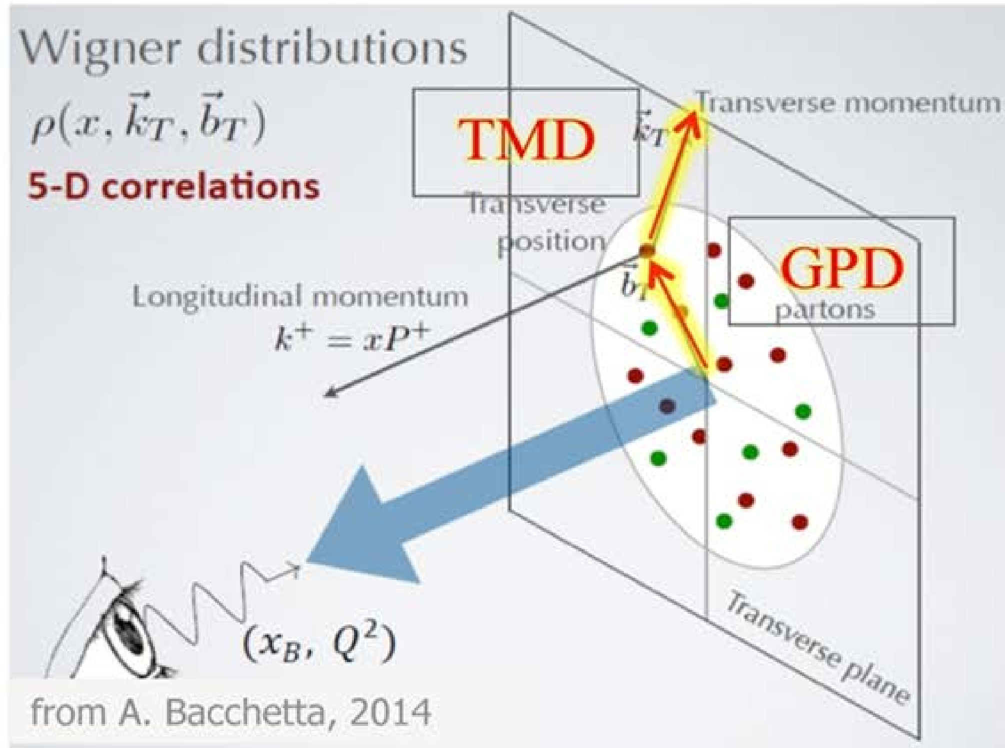
Results of our sub-group work

We have produced a concise document (8 pages) containing the physics potential and feasibility of the research directions that are worth to pursue in the following 10 – 20 years in the LHEP.
Available at: https://indico.jinr.ru/conferenceDisplay.py?confId=296, passwd: *ask me!*

- First priority in the next decade is the realization of the NICA scientific program based on:
  - Heavy ion (up to Au^{+79}) collisions at center-of-mass energy in the range 2 – 11 AGeV;
  - Collisions of transversely and longitudinally polarized protons and deuterons at center-of-mass energy up to 27 GeV

NICA scientific program

NICA Collider Luminosity in pp Collisions



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{(q+g)}$$

Transversity Momentum Distributions: TMD (x,k_T)
probe the transverse parton momentum dependence

Generalized Parton Distributions : GPD (x,b_T):
probe the transverse parton distance dependence

beam emittance ε_{nrm} , π mm mrad - 0.15 (nc

Future lines of development of the NICA accelerator complex

For beyond 2030, we have identified four directions that are scientifically promising, technically feasible, and can be seen as natural extensions of the planned NICA program:

- Upgrading of the NICA rings to obtain **asymmetric** heavy ion collisions and collisions of polarized protons with polarized deuterons and also pA and dA collisions;
- A feasibility and design study for an **electron accelerator of a few GeV** energy and, possibly, for a **high-energy photon beam**. The latter could be based, for example, on backward Compton scattering of a laser beam off a few GeV electron beam.
- A feasibility and design study for **search for the proton and deuteron electric dipole momenta (EDM)** with the NICA rings.

Future lines of development of the NICA accelerator complex (1)

New electron accelerator: The study of **ep and eA** collisions, **in particular with polarized beams**, offers the possibility of conducting numerous studies on the internal structure of the nucleons and nuclei.

Polarized beams offer the possibility to study crucial aspects of hadronic and nuclear structure beyond the reach of most of present-day facilities. **Polarized beams of deuterons** give access to a rich set of measurable structure functions.

Comparison of pp, ep and eA data → access to the multidimensional structure of the nuclei and to the mechanisms generating single-spin asymmetries in nuclear collisions.

Future lines of development of the NICA accelerator complex (2)

The **γ-p beams** may allow to study the photo-production of J/ψ and ϒ, the latter being presently studied with limited statistics or in symmetric systems such as p-p, preventing an unambiguous rapidity, and hence Bjorken-*x*, determination. Depending on the proton beam energies, these studies could **shed light on the J/ψ and ϒ formation at threshold and on the gluon structure of the nucleon**.

In addition, the production of **di-lepton pairs in eA and γA interactions** is of great interest, allowing studies of the electromagnetic interactions in the region of strong fields. The coupling $Z\sqrt{\alpha}$ is large, so conventional perturbative calculations of the processes are questionable and higher-order terms may become important.

Future lines of development of the NICA accelerator complex (3)

The NICA collider rings are very suitable for attempting measurement of the **proton and deuteron EDMs** due to the possibility of **transformation of the two storage rings into an 8-shape accelerator structure** and use of so-called **spin transparency mode**, also known as spin-frozen mode, for the spin control.

Search for the proton and deuteron EDMs could be tried after the first round of experiments with the MPD and SPD.

Involvement in external experiments

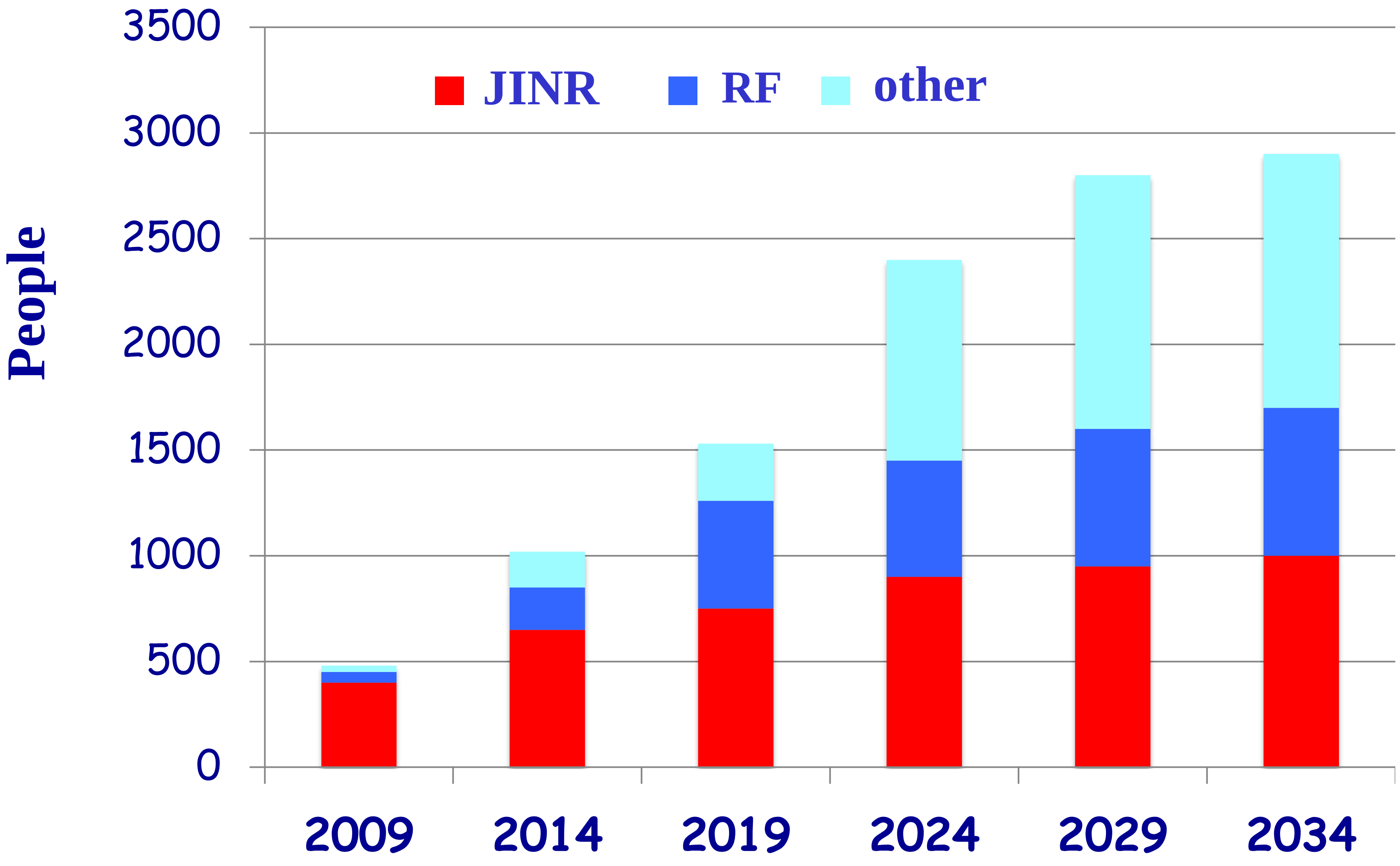
Traditionally, the HEP scientific program of JINR includes participation in experiments at accelerator centers around the world (**CERN, BNL, DESY, GSI**) that provide unique conditions to perform studies in the fields of high-energy heavy-ion physics and spin physics. **The key factor here is a mutual benefit from the exchange of new scientific information and know-how**. JINR participation will depend on the **discovery potential** of the experiments and **leading role** in them of the JINR researchers

The continuing participation in the experiments **NA61 and COMPASS at SPS, ALICE at LHC and STAR at RHIC** is of invaluable importance for preparation and realization of the physics program at the NICA complex. **Strategically important is the JINR participation in experiments at future electron-ion collider (EIC) facility to be built in US and in fixed-target experiments at FAIR-GSI.**

The JINR strategy for cooperative research at other accelerator centers should be linked closely to the **updated European Strategy for Particle Physics**, expected to be available in 2020.

NICA staff and users

(estimation of the NICA management)



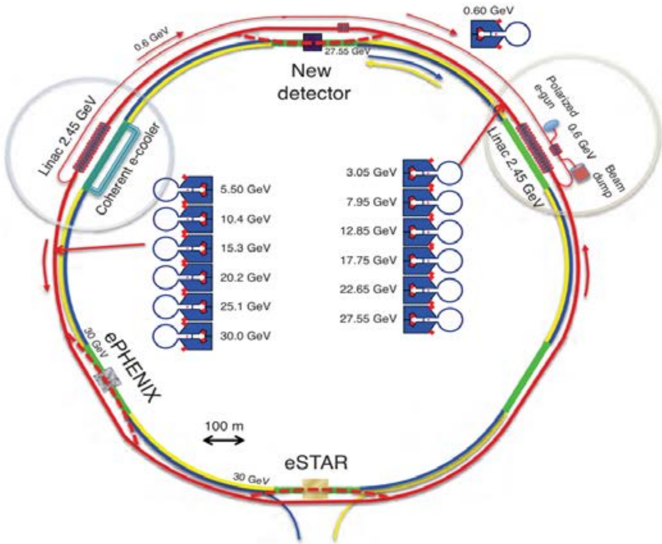
2030

We have a strategy!

Add-ons

Electron-ion collider: USA projects

BNL-98815-2012-JA
JLAB-PHY-12-1652
arXiv:1212.1701



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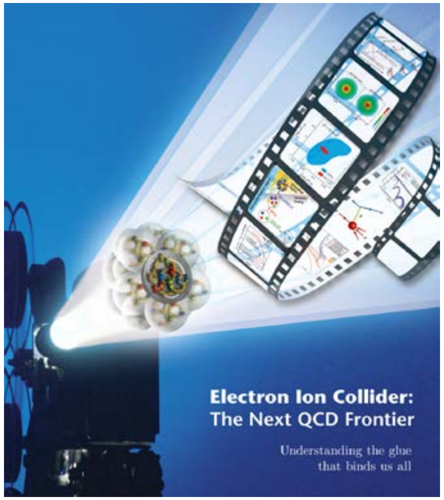
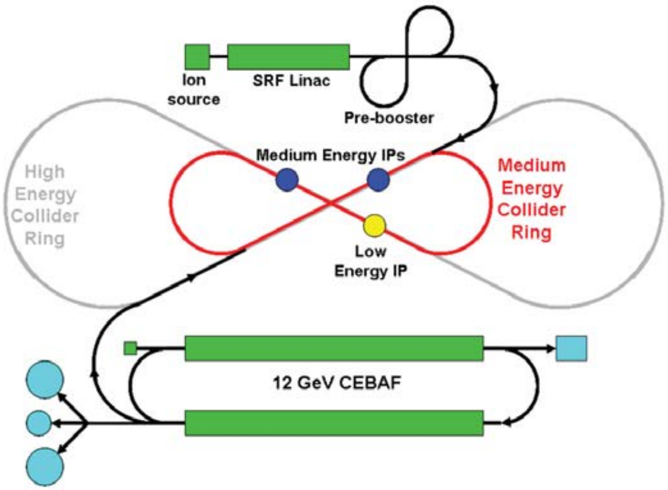
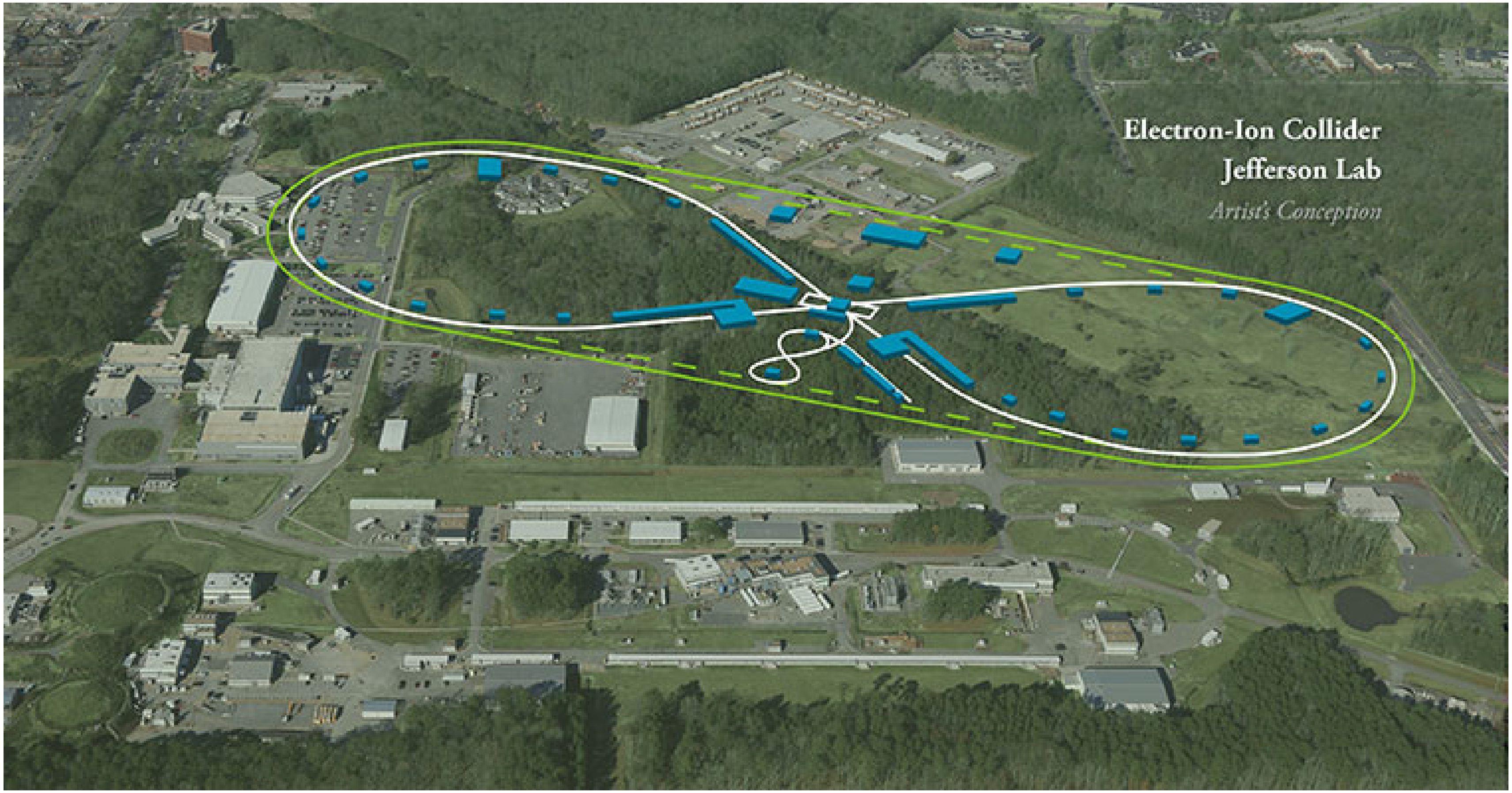




JLab

- Highly polarized (∼ 70%) electron and nucleon beams
- Ion beams from deuteron to the heaviest nuclei (uranium or lead)
- Variable center of mass energies from ∼ 20 – ∼100 GeV, upgradable to ∼150 GeV
- High collision luminosity $\sim 10^{33-34}$ cm^{-2}s^{-1}
- Possibilities of having more than one interaction region


Electron-Ion Collider
Jefferson Lab
Artist's Conception

Electron Ion Collider in China

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DIS2018, Kobe, Japan

April 17, 2018

Electron-ion collider: China plans…

HIAF and EicC

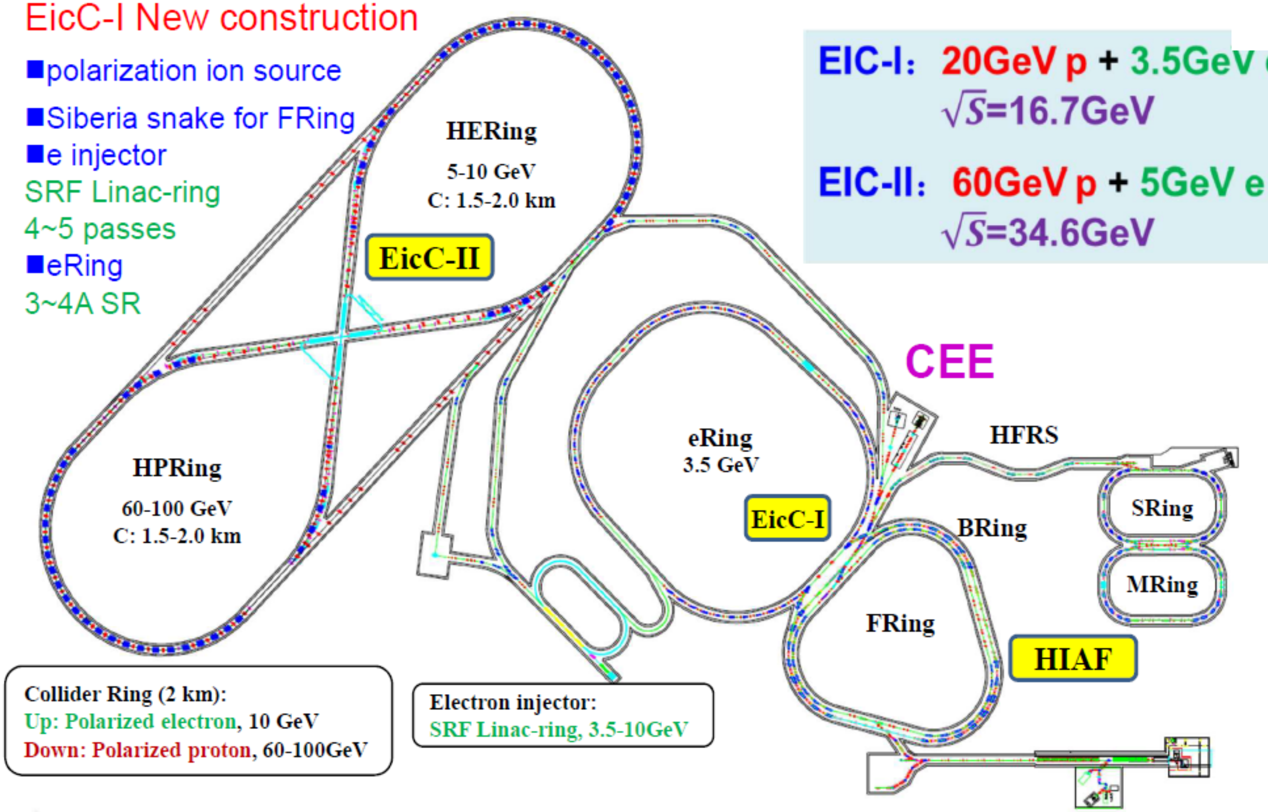
Very preliminary!

EicC-I New construction

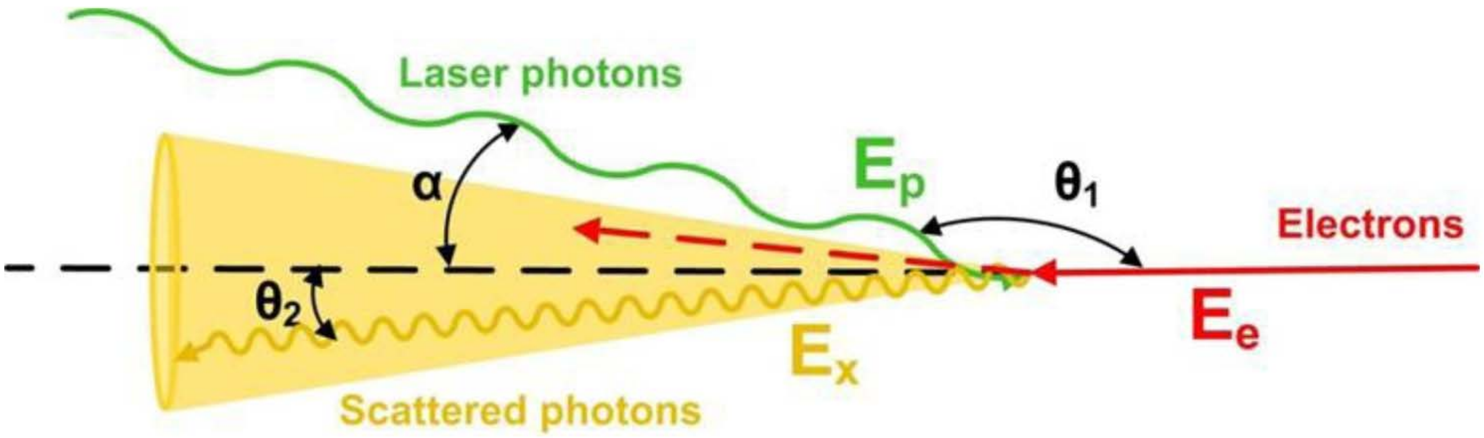
- polarization ion source
- Siberia snake for FRing
- e injector
  SRF Linac-ring
  4~5 passes
- eRing
  3~4A SR

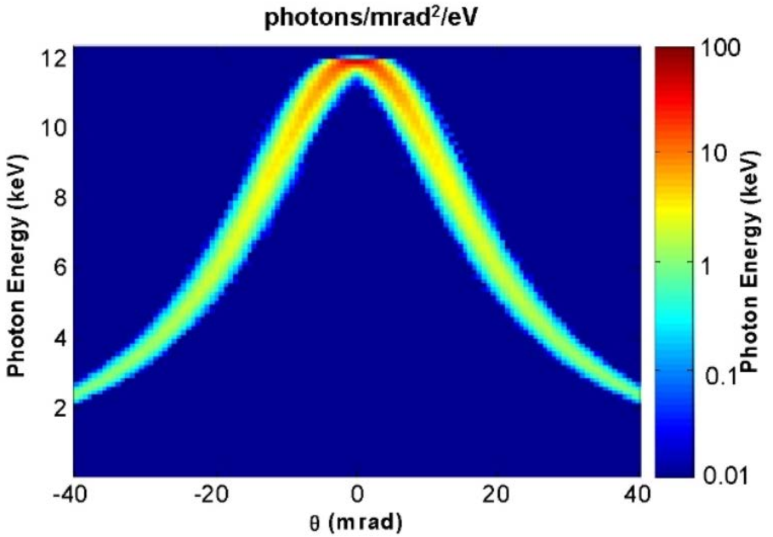
EIC-I: 20GeV p + 3.5GeV e
$\sqrt{S}$=16.7GeV

EIC-II: 60GeV p + 5GeV e
$\sqrt{S}$=34.6GeV



Backward Compton Scattering Source





ELI-NP in Romania

EUROPEAN UNION

Competitiveness Operational Programme

Structural Instruments 2014-2020

Extreme Light Infrastructure Nuclear Physics (ELI-NP)

Project co-financed by the European Regional Development Fund

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- Scientific Events
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- Visits at ELI-NP
- ISAB Meetings

About ELI-NP: » ELI in a nutshell

Extreme Light Infrastructure - Nuclear Physics facility (ELI-NP) will consist of two components:

- A very high intensity laser system, with two 10 PW laser arms able to reach intensities of 10^{23} W/cm2 in a short focus configuration, or electrical fields of 10^{15} V/m.
- A very intense (10^{13}γ/s), brilliant γ beam, ~ 0.1 % bandwidth, with Eγ up to 19.5 MeV, which is obtained by incoherent Compton back scattering of a laser light off a very brilliant, intense, classical electron beam (Ee= 720 MeV) produced by a warm linac.

This infrastructure will create a new European laboratory with a broad range of science covering frontier fundamental physics, new nuclear physics and astrophysics as well as applications in nuclear materials, radioactive waste management, material science and life sciences. For the realization of ELI-NP we envisage the following two principles as guideline:

- a staged realization of ELI-NP
- a flexible design of the ELI-NP facility.

ELI-NP will allow either combined experiments between the high-power laser and the γ beam or stand-alone experiments.

ELI-NP in Romania

- ELI-NP @ World Exhibition Astana 2017
- ELI-NP Management Team
- Implementation Progress
- ELI-NP Public Tender Procedure
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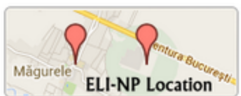

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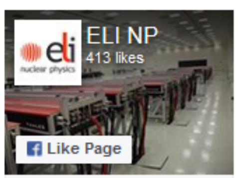

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alone experiments.

The γ beam will have unique properties in world wide comparison and opens new possibilities for high resolution spectroscopy at higher nuclear excitation energies. They will lead to a better understanding of nuclear structure at higher excitation energies with many doorway states, their damping widths, and chaotic behaviour, but also new fluctuating properties in the time and energy domain. The detailed investigation of the pygmy dipole resonance above and below the particle threshold is very essential for nucleosynthesis in astrophysics. In ion acceleration the high power laser allows to produce 10^{15} times more dense ion beams than achievable with classical acceleration. The cascaded fission-fusion reaction mechanism can then be used to produce very neutron-rich heavy nuclei for the first time. These nuclei allow to investigate the N = 126 waiting point of the r-process in nucleosynthesis. With this type of new laser acceleration mechanism very significant contributions to one of the fundamental problems of astrophysics, the production of the heavy elements beyond iron in the universe can be addressed. According to a recent report by the National Research Council of the National Academy of Science (USA), the origin of the heaviest elements remains one of the 11 greatest unanswered questions of modern physics. The γ beam also opens many new possibilities for applications. The γ beam itself can be used to map the isotope distributions of nuclear materials or radioactive waste remotely via Nuclear Resonance Fluorescence (NRF) measurements. At lower energies around 100 keV the high resolution of the beam is very important for protein structural analysis. In addition it will be produced low energy, brilliant, intense neutron beams and low energy, brilliant, intense positron beams, which open new fields in material science and life sciences. The possibility to study the same target with these very different brilliant beams will be unique and advance science much faster.

The high power laser allows for intensities of up to 10^{24}W/cm^2. Here very interesting synergies are achievable with the γ beam and the brilliant high energy electron beam to study new fundamental processes in high field QED. The use of the very high intensity laser and the very brilliant, intense γ beam will achieve major progress in nuclear physics and its associated fields like the element synthesis in astrophysics and many new applications or even to observe in fundamental physics the first catalysed pair creation from the quantum vacuum. In the field of basic nuclear physics, a better theoretical understanding of compound nuclear resonances in comparison with much improved experiments will also lead to better models for the element synthesis in astrophysics. Compared to former γ facilities, the much improved bandwidth is decisive for this new γ beam facility. Several experiments, like the parity violation experiment, only become possible due to this much better bandwidth. The large majority of γ beam experiments will profit proportionally from the better bandwidth, because the widths of the studied nuclear levels are significantly smaller than the width of the beam. Thus the ratio of "good" γ quanta within the nuclear linewidth compared to the "bad" γ quanta outside, which undergo Compton scattering and cause background in the detectors, will be significantly improved. Besides a wide range of fundamental physics projects also a variey of applied research will be enabled at ELI-NP. The project to develop techniques for remote characterization of nuclear materials or radioactive waste via NRF will gain large importance for society in Europe. It may even turn out that a detailed in-situ characterization of partially used reactor fuel elements may result in producing more usable energy in reactors for the same amount of radioactive waste. On the other hand also the new production schemes of medical isotopes via (γ,n) may also reach socio-economical relevance. The new types of neutron sources and positron sources may reach large importance in material and life sciences.