Introduction of HIAF project

(High-Intensity Heavy Ion Accelerator Facility-HIAF)

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Outline

- Science of HIAF
- Accelerator aspects of HIAF
- Schedule and current status of HIAF project

Science of HIAF project

- Nuclear physics
- High Energy Density Physics
- Science based on the EIC
- Atomic physics
- Application

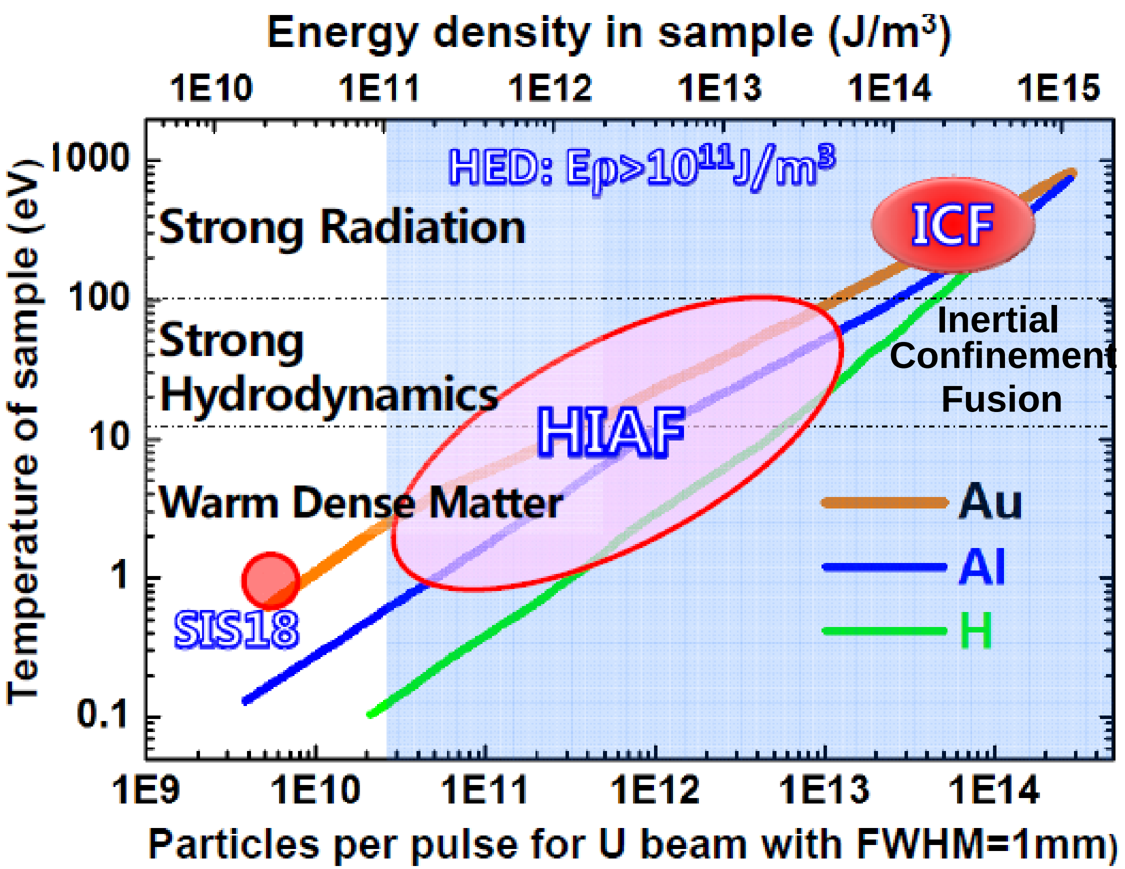
Nuclear physics at HIAF

- What are the limits to nuclear existence?
- What are new forms of nuclear matter far from stability?
- How about the quantum levels far from stability?
- What are new forms of collective motion far from stability?
- What dynamical symmetries appear in exotic nuclei?
- How were the elements from carbon to uranium created?
- How is energy generated in stars and stellar explosions?
- What is the behavior of stars and supernovae?

High Energy Density Physics at HIAF

Application of ion acc. to HEDP research

- Study the Atomic Process in Plasma
- Diagnostics of HED: High Energy Proton/Ion Radiography
- Generate HED with intense Heavy Ion Beam
- Basic Knl. Fast Ignition of a compressed fuel with H.I.B.

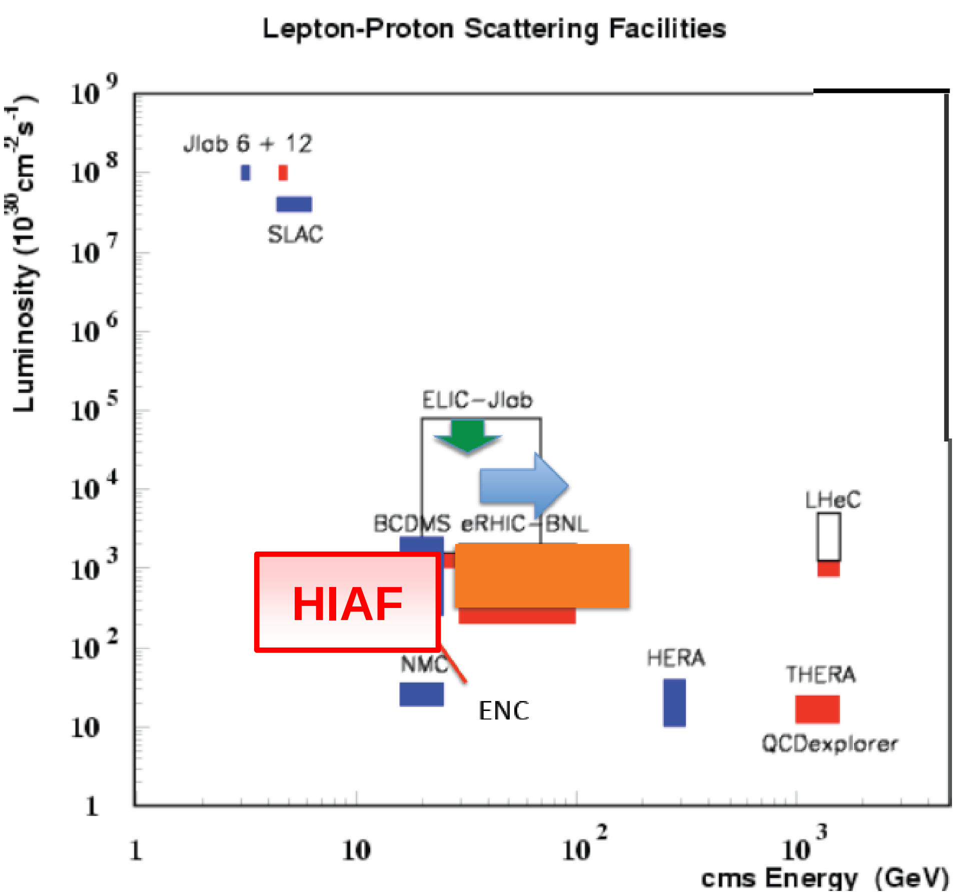


Specific energy deposition up to 0.2-2MJ/g, Target T up to 10-100eV will be possible with HIAF.

Science based on Electron Ion Collision

A High Luminosity, High Energy Electron-Ion Collider: A New Experimental Quest to Study the Sea and Glue

How do we understand the visible matter in our universe in terms of the fundamental quarks and gluons of QCD?



E (3GeV) + p (12GeV),

Polarized,

Lumi:$10^{32-33}/cm^2/s$

Atomic physics programs at HIAF

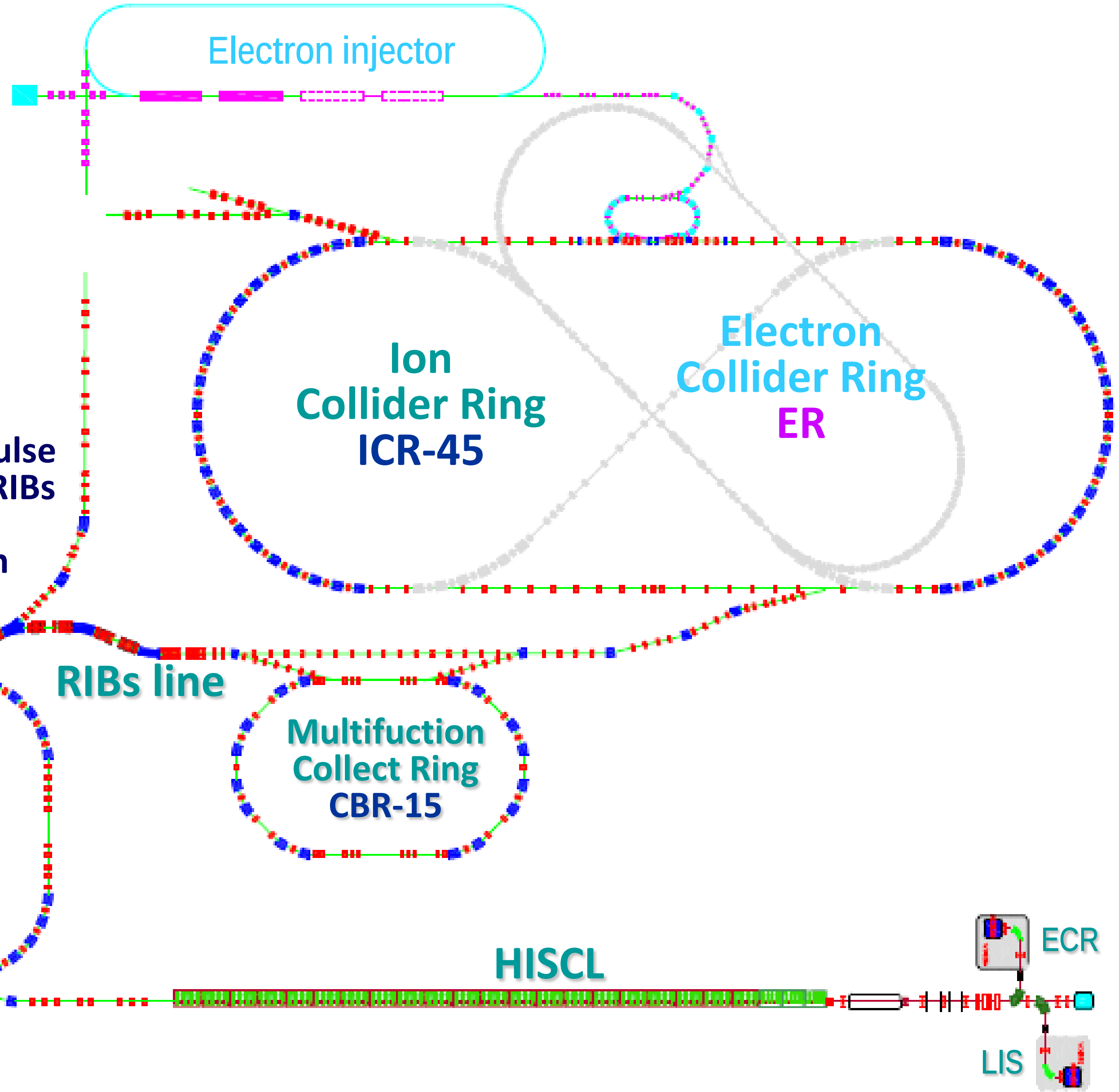
- ***Quantum Electrodynamics in strong Coulomb field—e^+e^- pair production in heavy ion collisions***
- ***Relativistic ion-atom collisions – collision dynamics at ultra short time, extremely strong electric-magnetic pulse***
- ***Precision x-ray spectroscopy at relativistic ion-atom collisions***
- ***Precision dielectronic recombination spectroscopy with stable and unstable ions***
- ***Laser spectroscopy of ions***
  - ***laser spectroscopy with radioactive ions***
  - ***laser cooling and laser spectroscopy of heavy ions at relativistic velocities***

Accelerator aspects of HIAF facility

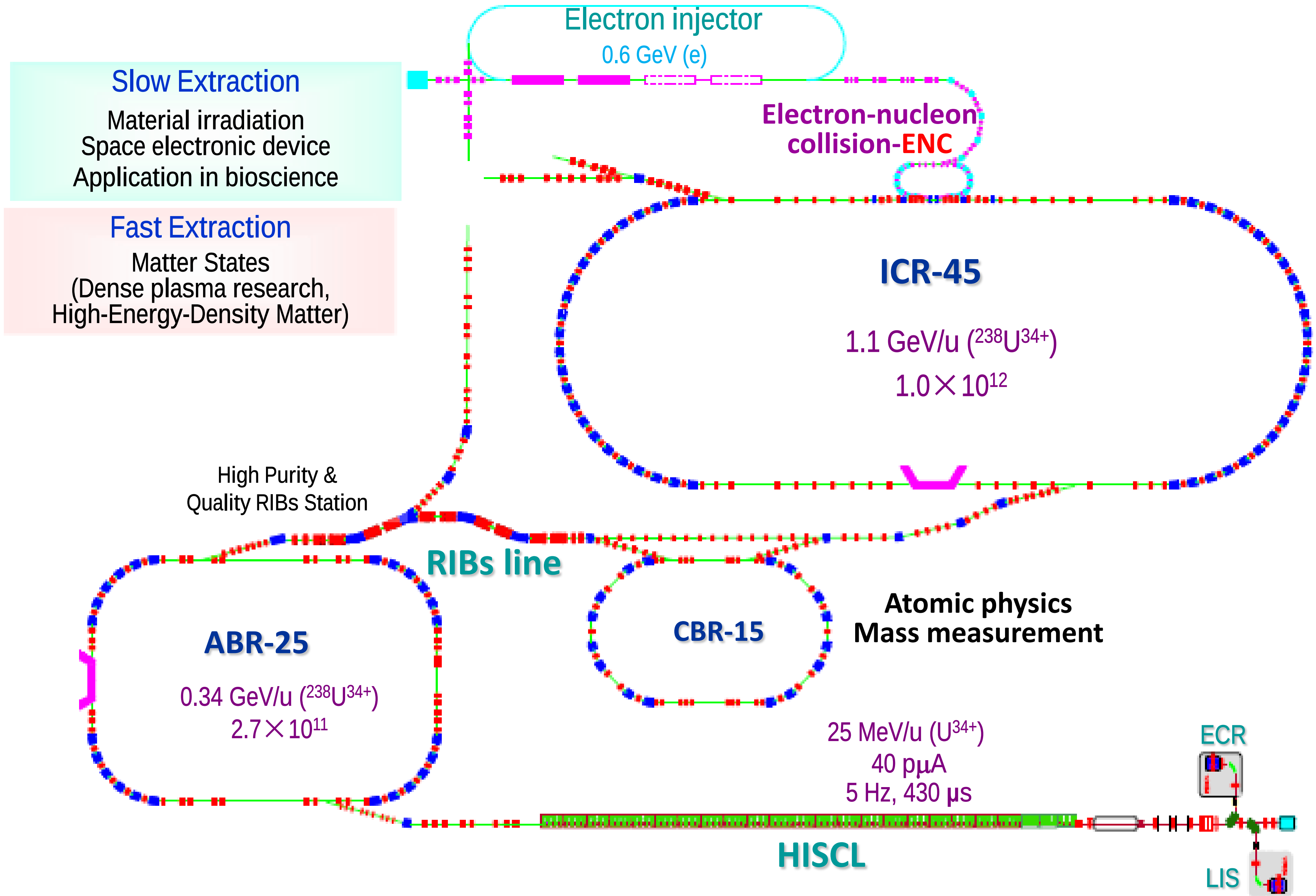
- General discription
- Dynamics design
- Technical R&D

The Layout of HIAF Complex

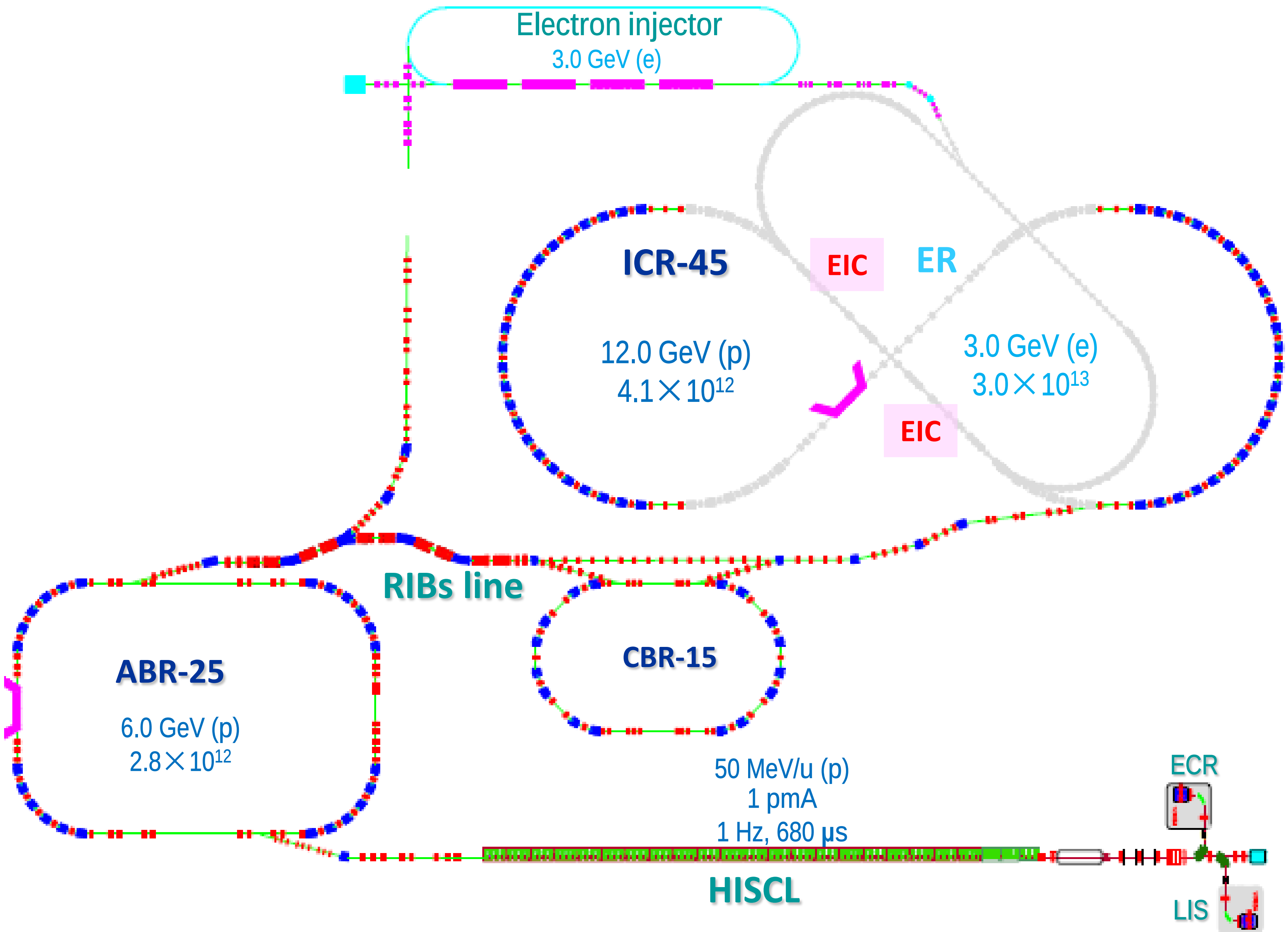
- Main Components:
  - **High intensity ion source**
  - **High intensity pulse SC-Linac**
  - **Multi-function booster and collector ring**
  - **Long straight ion collider**
  - **Figure-8 electron collider**
  - **Large acceptance RIBs line**
- Key features:
  - **High energy & High intensity & Pulse**
  - **Cooled intense primary beam & RIBs**
  - **Beam compression**
  - **Super long period slow extraction**
  - **Multi-operation modes**



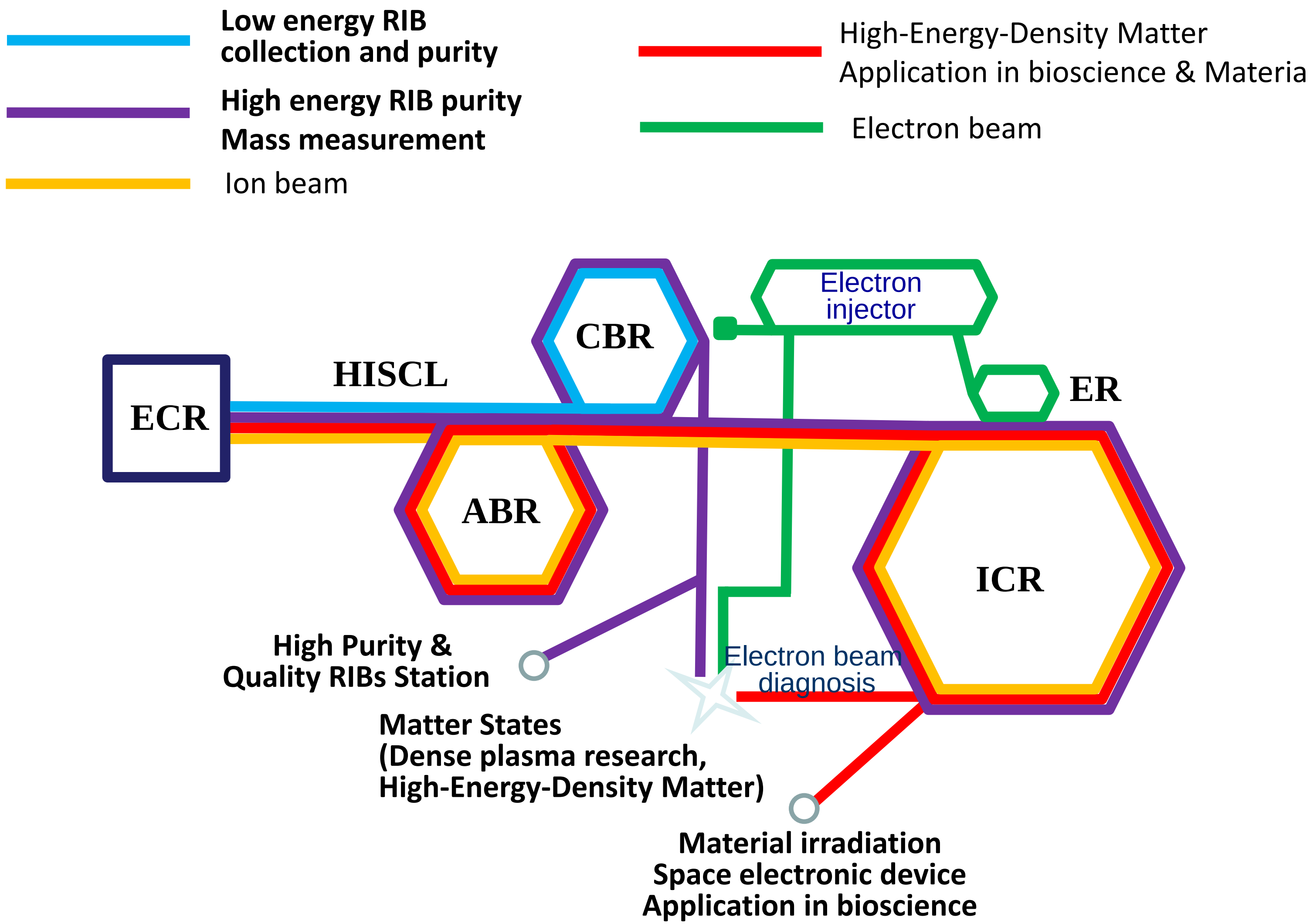
Main parameters and operation modes



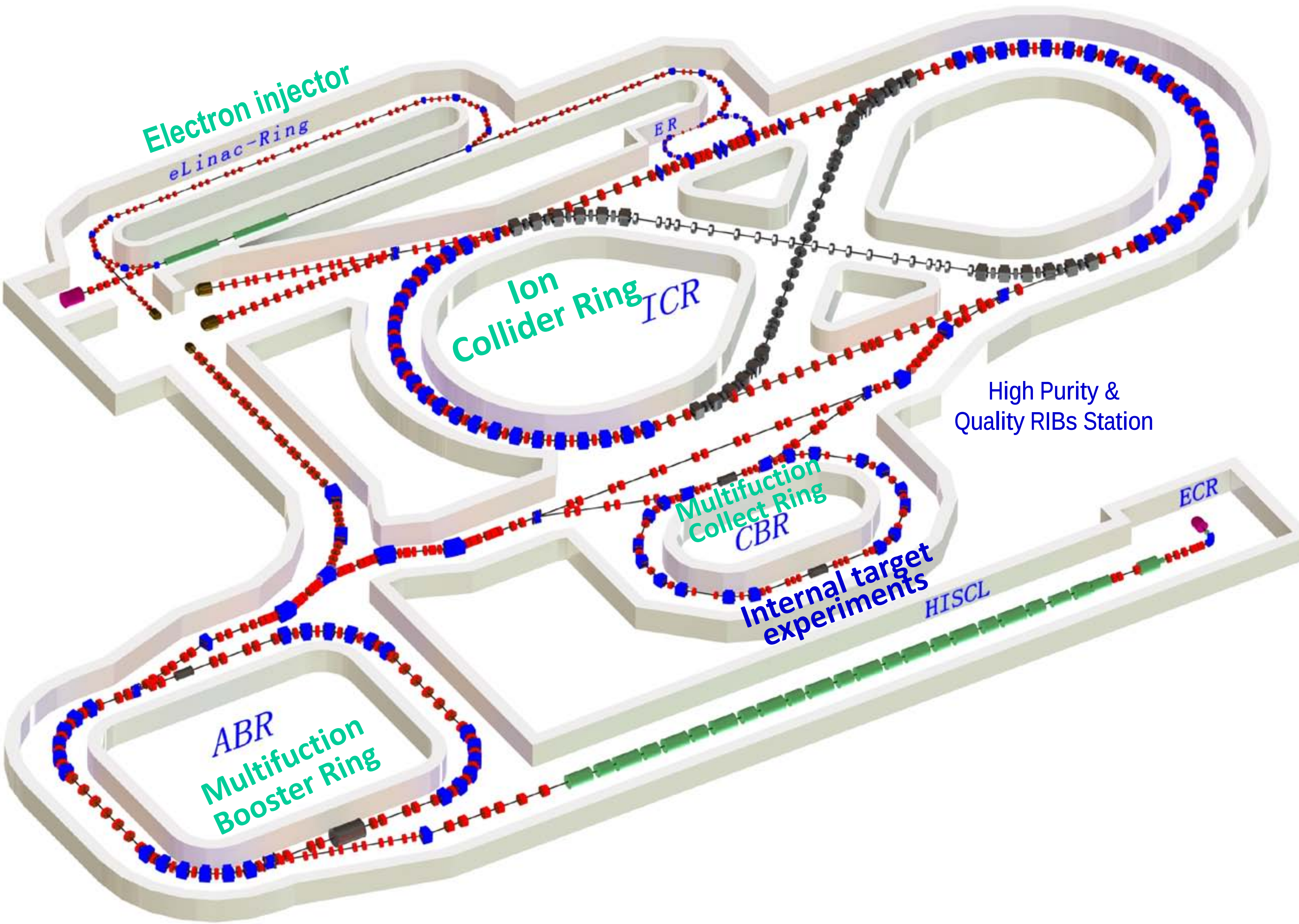
Main parameters and operation modes



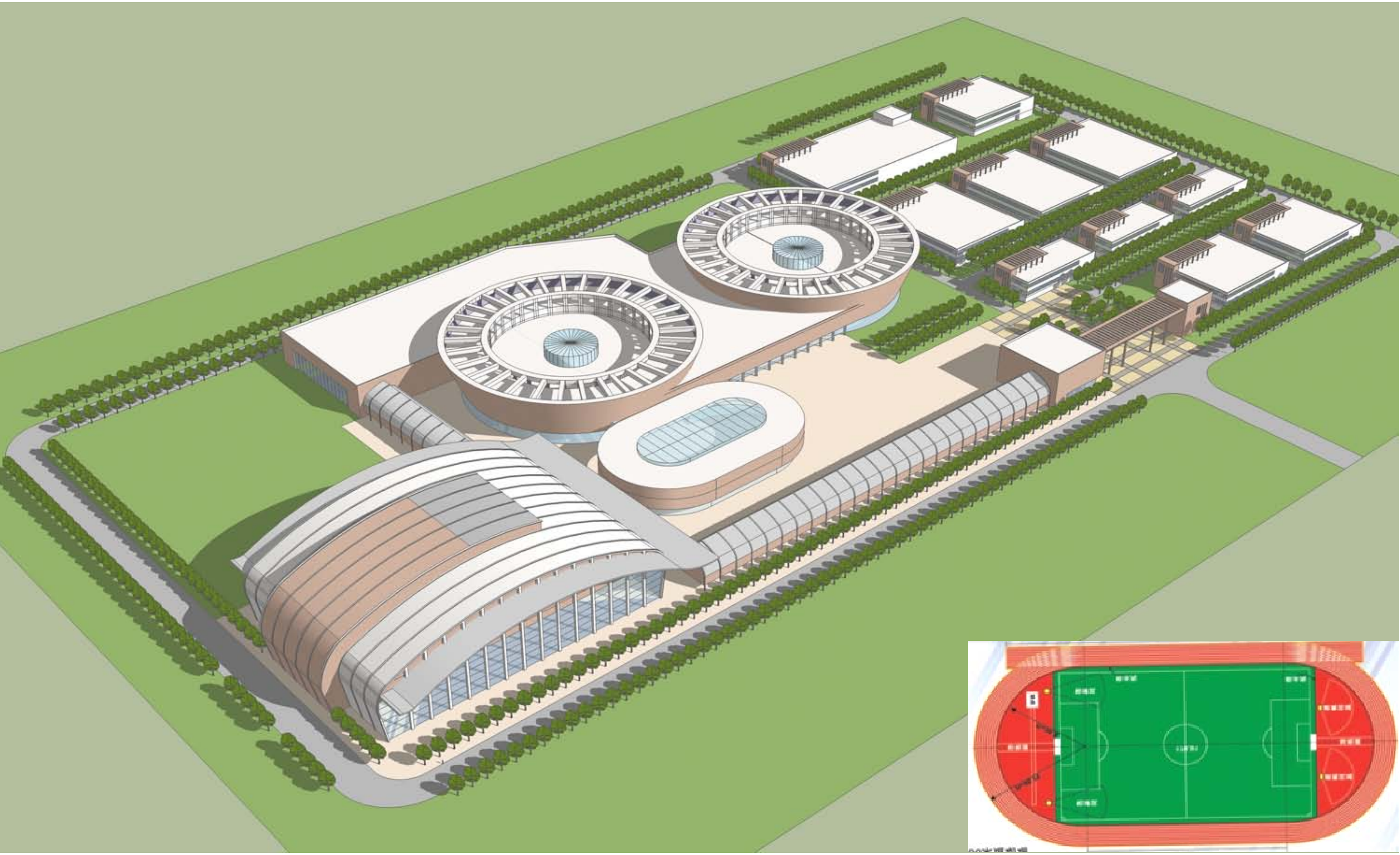
Schematic of operation modes



Main parameters and operation modes

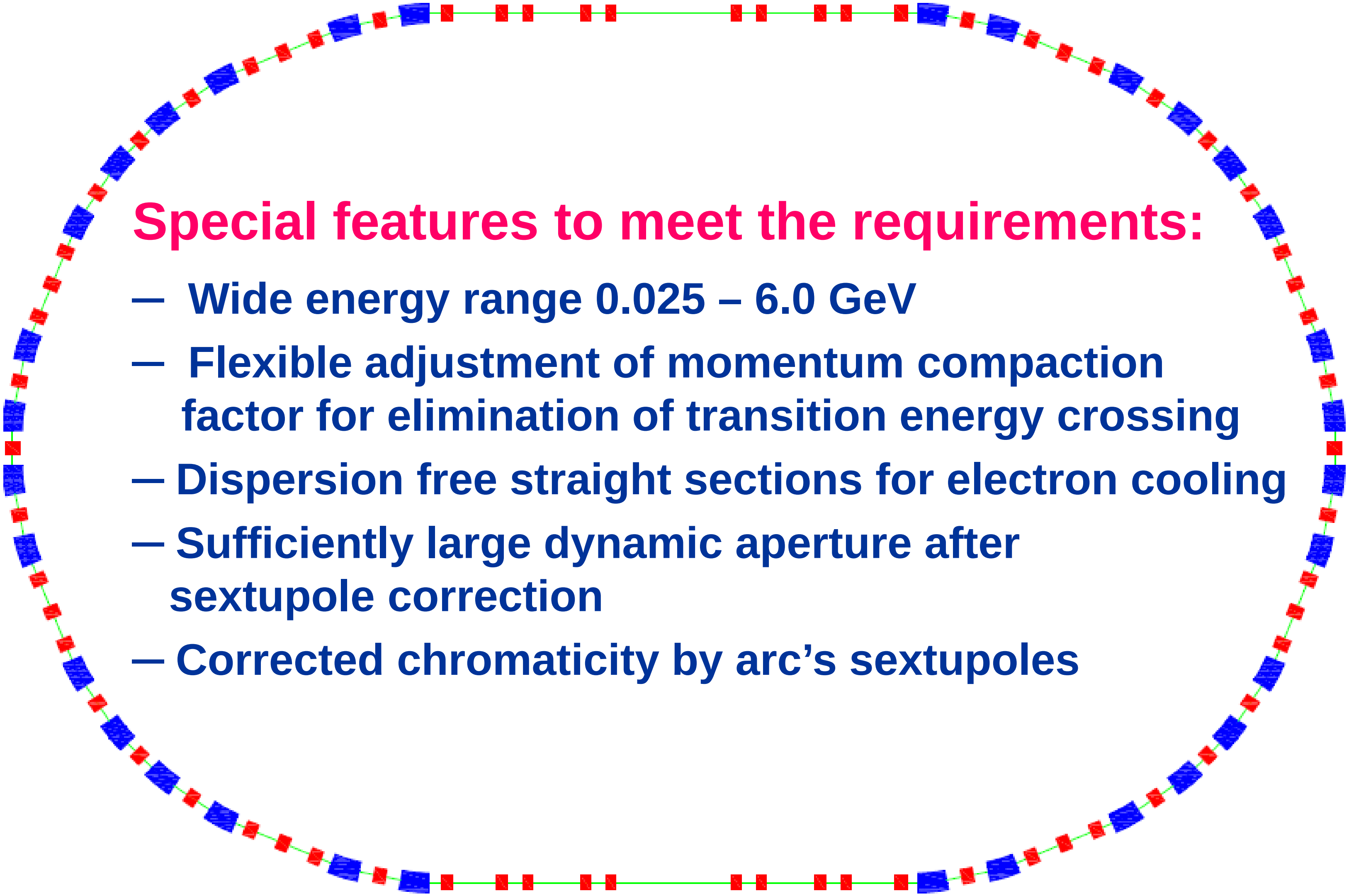


Bird view of the HIAF complex



Dynamics design of HIAF

Lattice of ABR-25

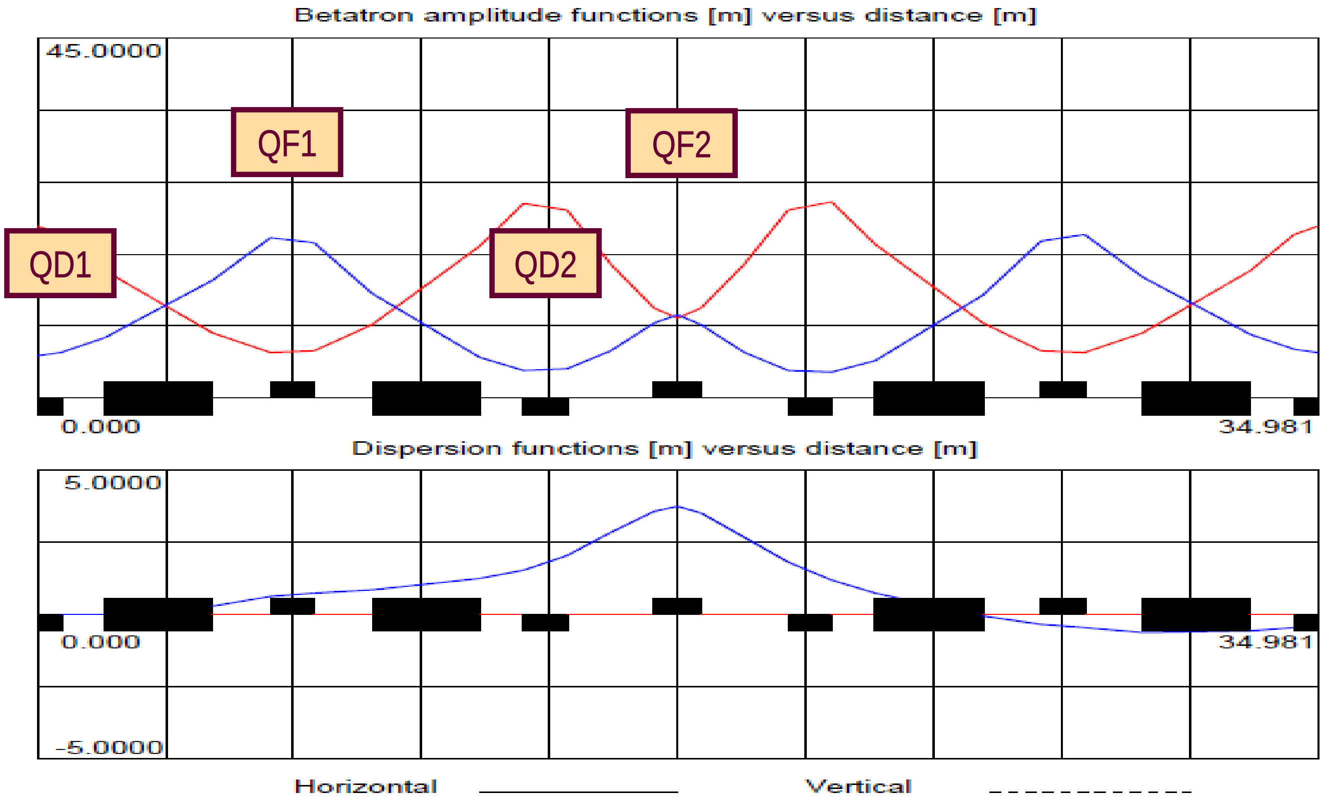


Special features to meet the requirements:

- Wide energy range 0.025 – 6.0 GeV
- Flexible adjustment of momentum compaction factor for elimination of transition energy crossing
- Dispersion free straight sections for electron cooling
- Sufficiently large dynamic aperture after sextupole correction
- Corrected chromaticity by arc’s sextupoles

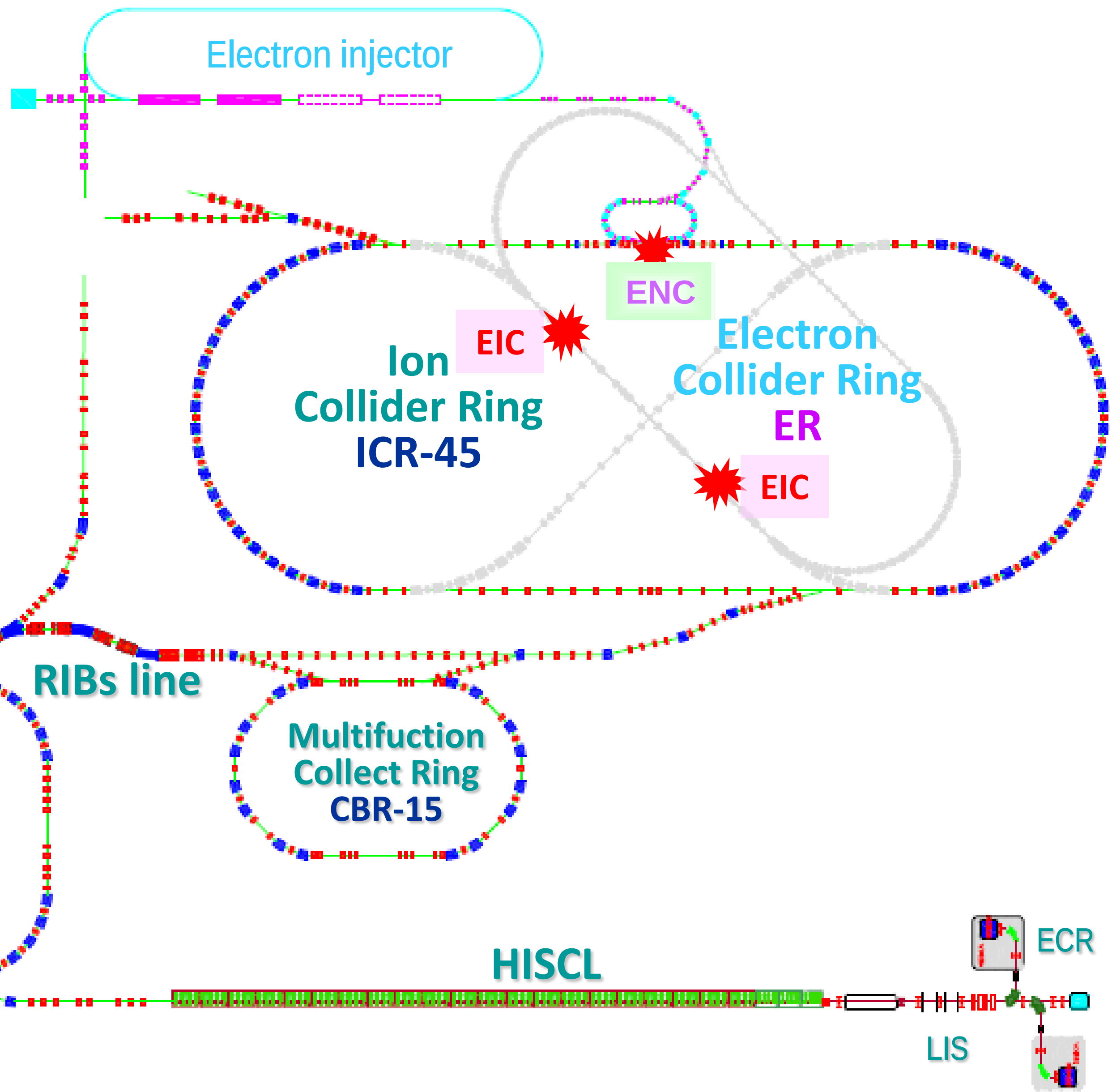
Dynamics design of ABR-25

“Resonant” magneto-optical lattice
with controlled momentum compaction factor

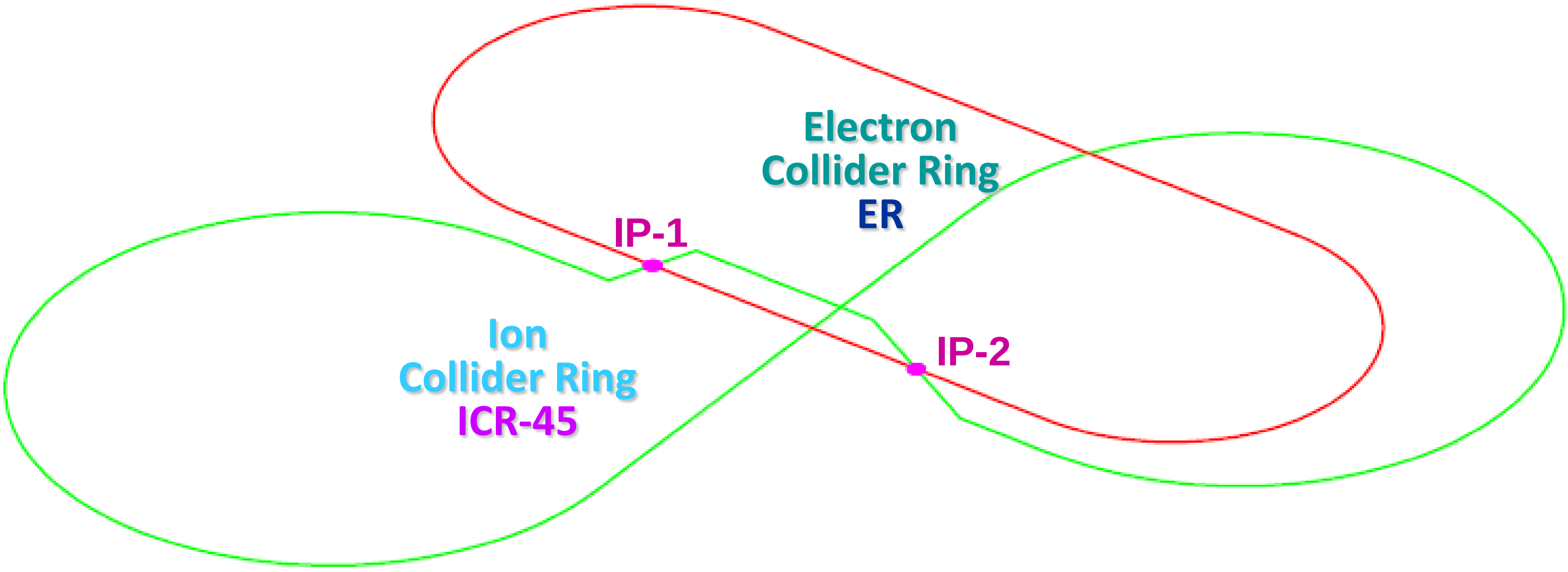


- **QF1 is placed at the point of the Beta-x function maximum.**
- **QD1 and QD2 is placed at the point of the Beta-y function maximum.**
- **QF2 is placed at the point of the Dispersion function maximum.**

ENC and EIC design of HIAF



Interaction region design of EIC



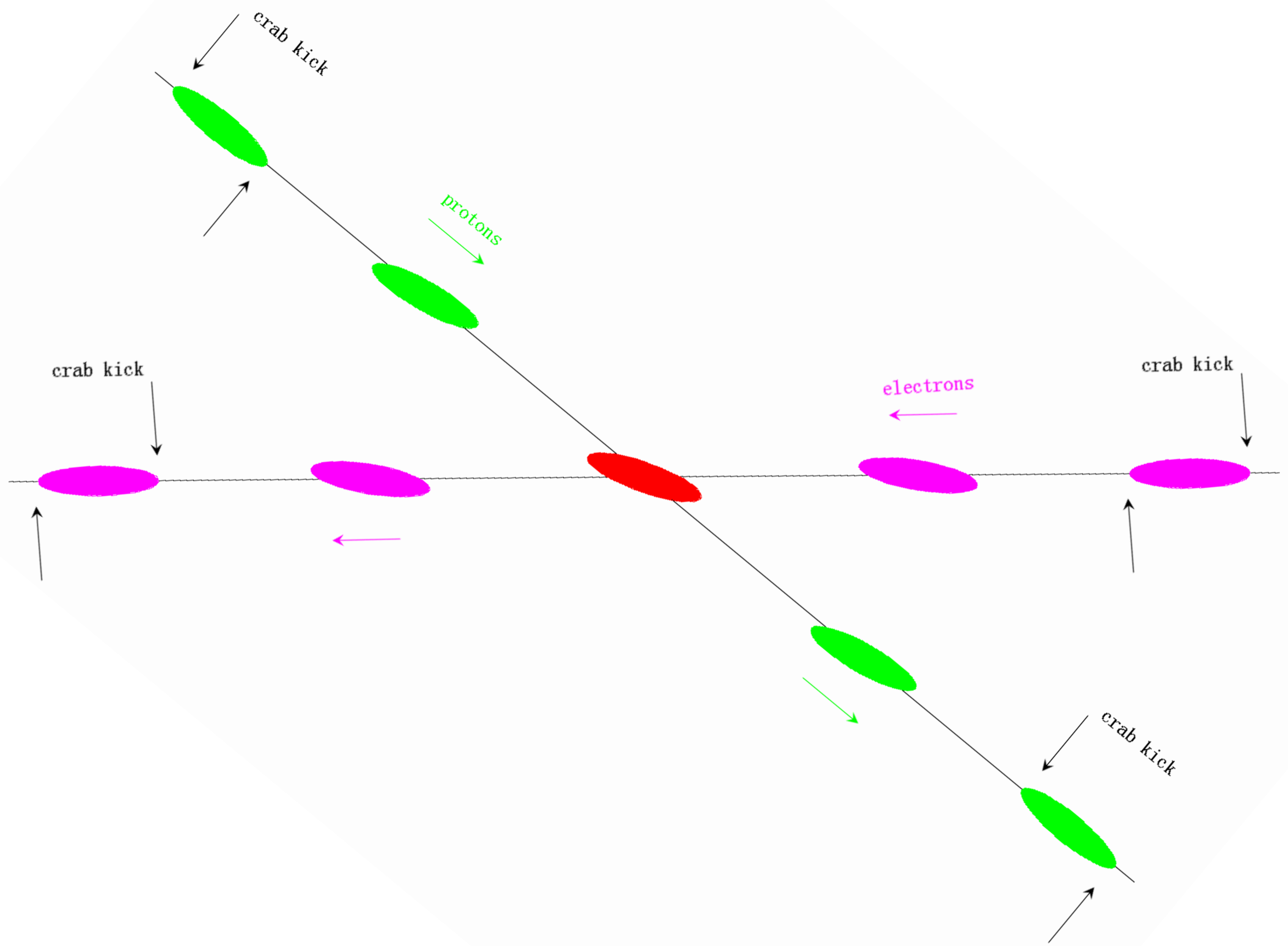
- **The ion beams execute a vertical excursion to the plane of the electron ring for collision at two interaction points (IP).**

- **Ion collider ring with Figure-8 shape**

  For **spin preservation** and
  ease of **spin manipulation** (spin rotators)

Interaction region design EIC

50 mrad crossing angle with crab cavity



'Crab Crossing' is required to compensate the luminosity reduction and to avoid parasitic beam-beam interaction due to high repetition rate.

Luminosity consideration of EIC

		Proton	Electron
Beam energy	GeV	12	3.0
Collision frequency	MHz	500	
Particles per bunch	10^{10}	0.54	3.7
Beam Current	A	0.43	3
Polarization	%	> 70	~ 80
Energy spread	10^{-4}	3	3
RMS bunch length	cm	2	1
Horizontal emittance, geometric	nm•rad	150	30
Vertical emittance, geometric	nm•rad	50	10
Horizontal β*	cm	2	10
Vertical β*	cm	2	10
Vertical beam-beam tune shift		0.0048	0.015
Laslett tune shift		0.045	Very small
Luminosity per IP, 10^{32}	$cm^{-2}s^{-1}$	4.0	

Luminosity consideration of EIC

Guidelines:

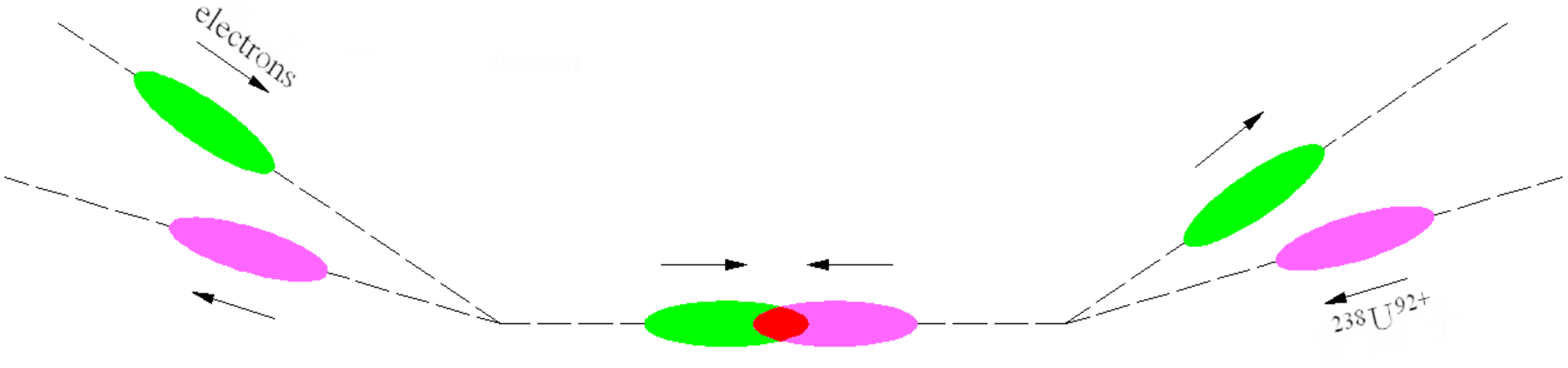
- At low energy, we assume a flat beam
- A symmetric final focusing ($\beta^*_x=\beta^*_y$)
- Assuming a little smaller emittance
- Keep Laslett tune-shift around 0.05

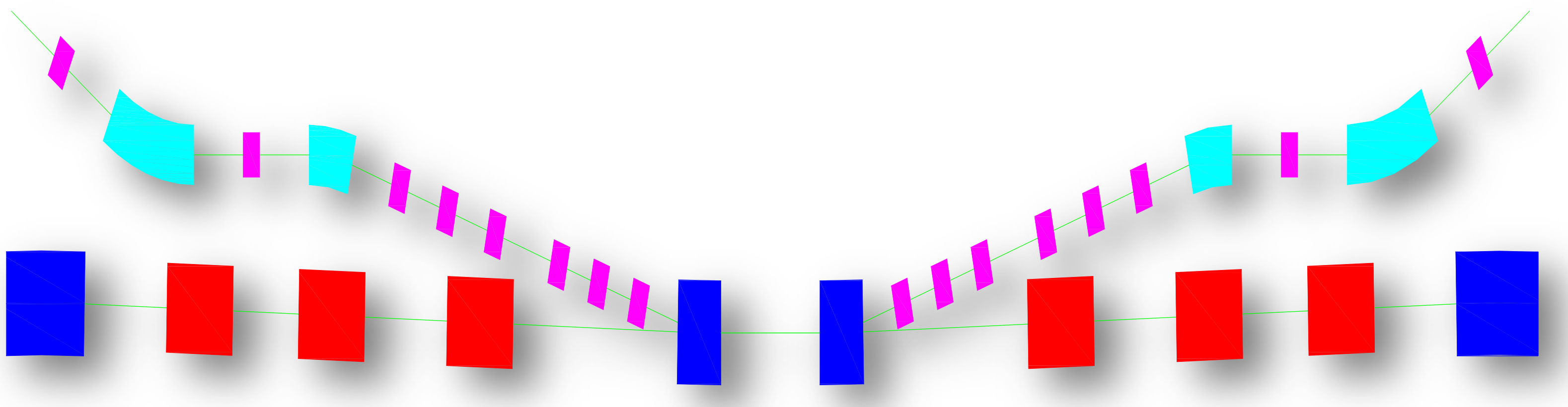
Luminosity bottom-line (3 GeVx12 GeV):

- Conservative estimate: $\sim 2\text{x}10^{32}$
- With optimization: $\sim 4\text{x}10^{32}$
- Forward-looking: $\sim 1\text{x}10^{33}$

(with lots of R&D and introducing uncertainty)

Interaction region design of ENC





Luminosity consideration of ENC

		$^{238}U^{92+}$	Electron
Beam energy		769MeV/u	500MeV
Collision frequency	MHz	54.6	
Particles per bunch		3.2×10^{6}	5×10^{10}
Beam Current	mA	2.6	437
Energy spread	10^{-4}	3	4
RMS bunch length	cm	15	4
Horizontal emittance, geometric	nm•rad	50	50
Vertical emittance, geometric	nm•rad	50	50
Horizontal β*	m	1	1
Vertical β*	m	0.15	0.15
Beam-Beam Parameter ξ_x/ξ_y		0.046/0.018	0.0019/0.0008
Laslett tune shift		0.1	Very small
Luminosity per IP, 10^{27}	$cm^{-2}s^{-1}$	2.9	

Accelerator technical-R&D

- Superconducting magnets
  - Superferric design with warm iron yoke to fulfill requirement of big aperture. Hollow tube superconducting cable coolling with supercritical He. Strong support structure to resist strong electromagnetic force.
- Superconducting linac design and prototype
  - The HISCL will utilize Half Wave Resonator (HWR) accelerating cavities operating at a frequency of 81.25 MHz and a series of prototypes are developed and the vertical test results indicate very good performance.
- Stochastic cooling
  - A novel type of 2.76 m long slotted pick-up was developed (cooperated with F. Caspers) for CSRe stochastic cooling.

Accelerator technical-R&D

- Dynamic vacuum system
  - Intensity dependent beam lossed for intermediate charge state heavy ion beams. The origin of these losses is the change of charge state of the beam ions at collisions with residual gas atoms
  - In order to suppress and control the beam loss, a dedicated ion catcher system is necessary. Two prototypes of this catcher has been developed and installed in SIS18.
- Collective beam effects
  - (Long time scale) beam-beam with crab crossing
  - Space charge effects in ABR-35
  - Electron cloud in the ion rings and mitigation

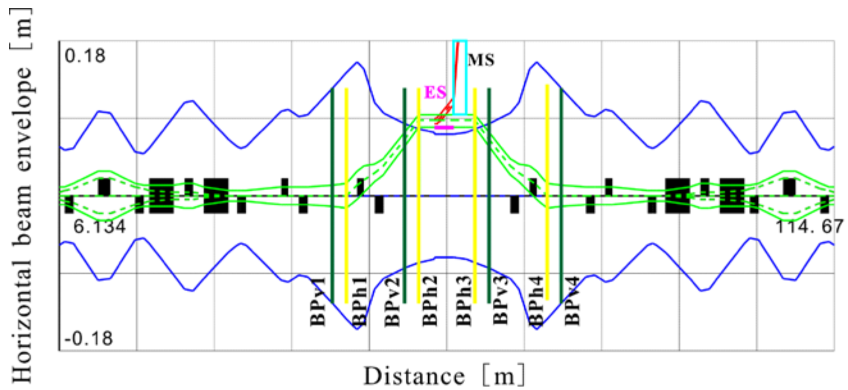
Electron cooling of HIAF

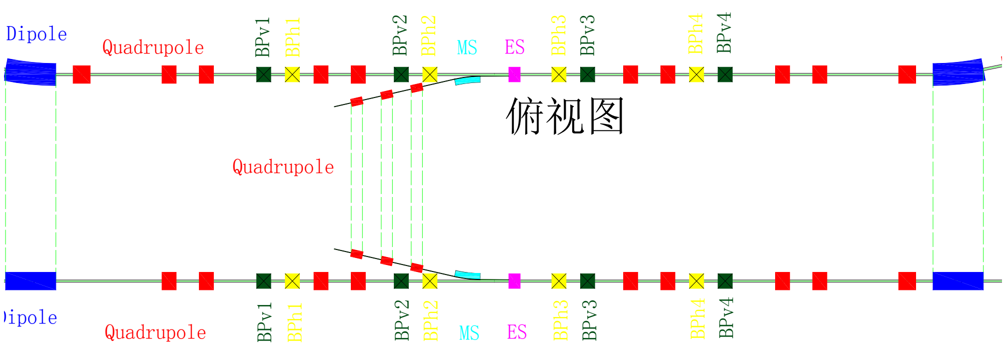
Electron cooling of ABR-25 (about 100keV)

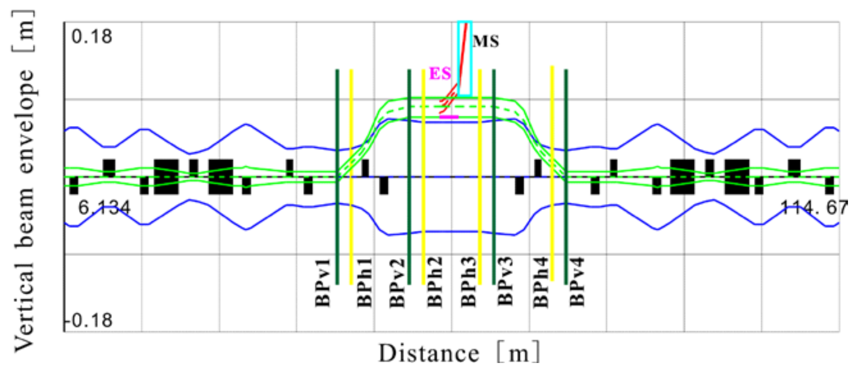
The crucial point for ABR-25 injection.

Painting + e-cooling
Injection scheme

- Large acceptance
  (500pimmmrad/120pimmmrad)
- Horizontal and vertical Painting
- Fast electron cooling







Injection components layout of Painting+e-cooling

Orbit of Painting+e-cooling injection

Electron cooling of HIAF

Electron cooling of ICR-45

- Medium energy (several hundreds keV)-U beam cooling

  To get more focused U beam for high energy and density matter research.

- High energy (several MeV) electron cooling-proton cooling

  Particularly important for preserving the collider luminosity and its lifetime by suppressing IBS induced heating.

Electrostatic accelerating apparatuses

That are used for accelerating the electron beam in all existing low energy electron cooling facility.

ERL circulator cooler

Rely on RF or SRF technology, and also photo-cathode electron source

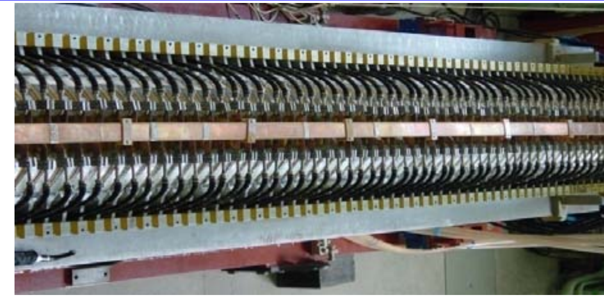
Coherent electron cooling

New concept, it has not yet been demonstrated experimentally.

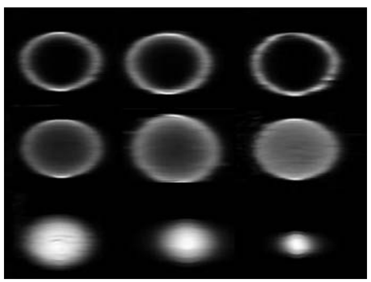
Electron cooling of HIRFL-CSR

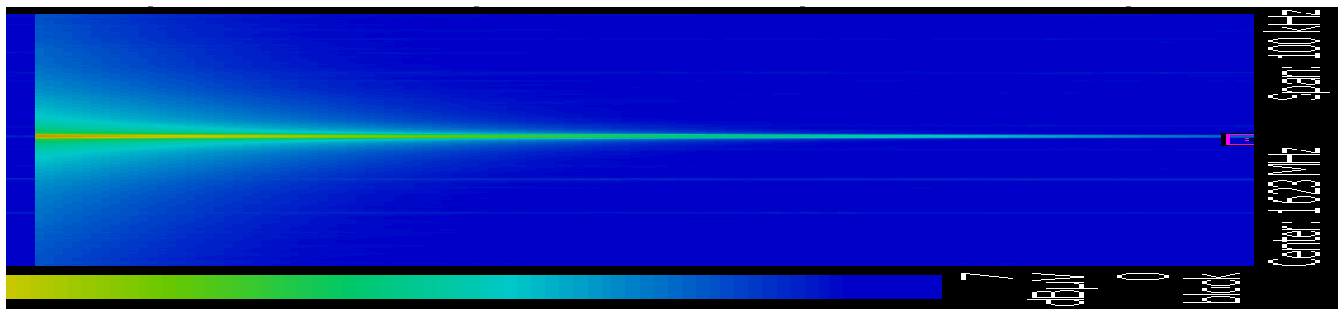
- **CSRm e-cooler**

E-energy: 4-35keV
I-energy： 7-50MeV/u
E current： 1-3A



The hollow e-beam can be obtained in both of two e-coolers to partially solve the problem due to the space charge effect and reduce the effect of recombination between the ions and the e-beam. The intensity gain factor of C beam is more than 300.

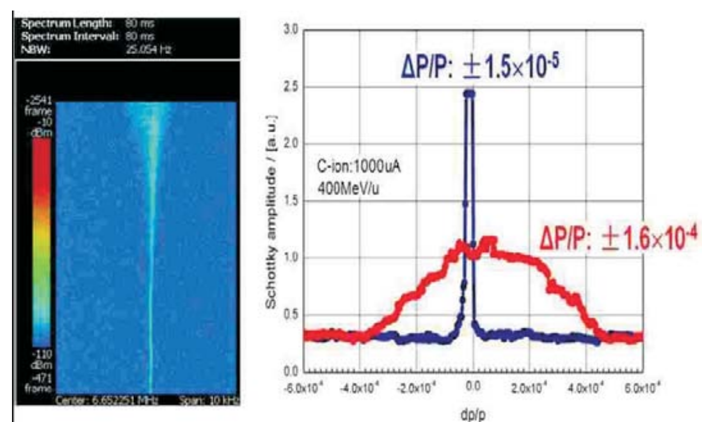




- **CSRe e-cooler**

E-energy：10-300keV
I-energy：25-500MeV/u
E-current :1-3A

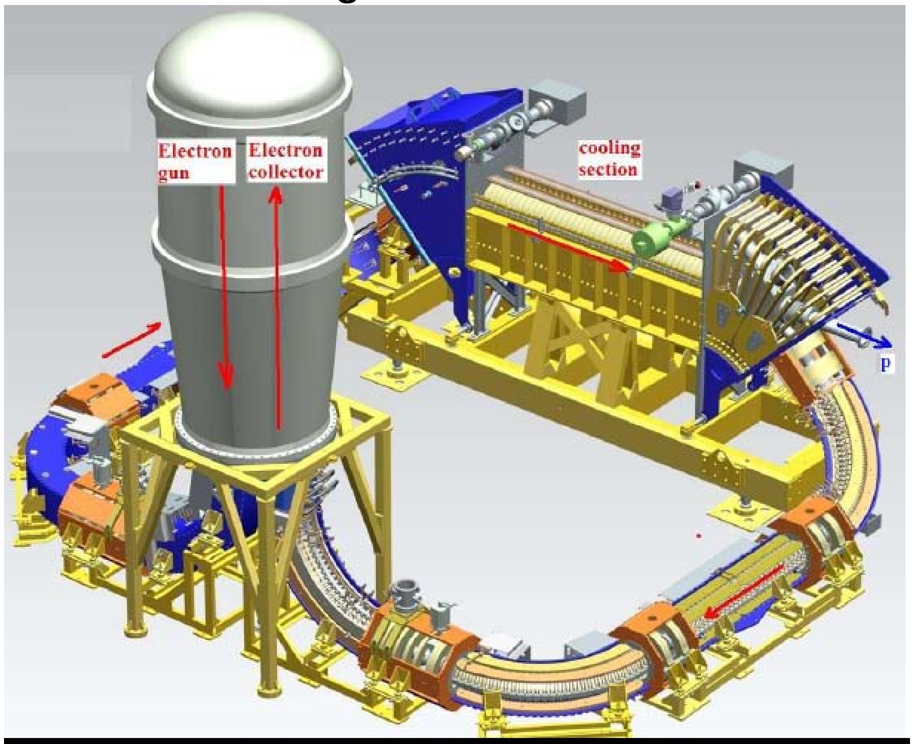
Beam momentum spread was reduced to $\pm 1.5\times10^{-5}$ from $\pm 1.6\times10^{-4}$



Electron cooling of HESR of FAIR

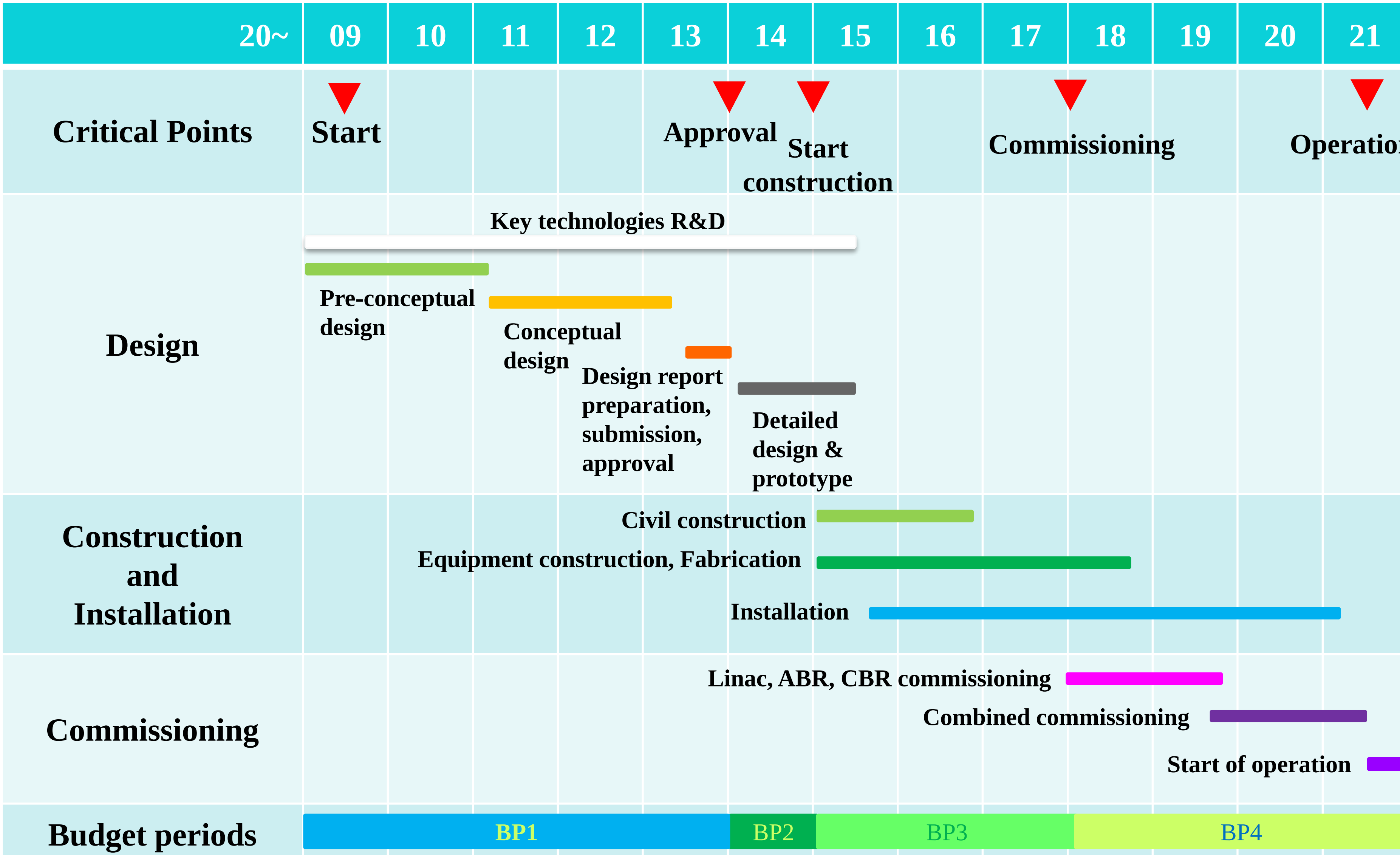
The 2 MeV electron cooling system for HESR was developed to further boost the luminosity even in presence of strong heating effects. The project is funded since mid 2009. Manufacturing of the cooler components has already finished with collaboration efforts of two institutes BINP(Novosibirsk) and FZJ(Juelich).After the first commissioning in BINP and now under assembling in COSY.

Energy Range	0.025 ... 2 MeV
High Voltage Stability	$< 10^{-4}$
Electron Current	0.1 ... 3 A
Electron Beam Diameter	10 ... 30 mm
Length of Cooling Section	2.69 m
Toroid Radius	1.00 m
Magnetic Field (cooling section)	0.5 ... 2 kG
Vacuum at Cooler	10^{-9} ... 10^{-10} mbar



Schedule and current status of HIAF facility

The project schedule of HIAF



Current status of HIAF

- The HIAF project was proposed in 2009, approved in principle by the central government in the end of the 2012 and now under conceptual design stage.
- HIAF parameters will be chosen to optimize science, technology development, and project cost.
- The final design of first stage will maintain a well defined path for future upgrade to higher energies and luminosities.
- A conceptual machine design will be completed recently and provide a base for performance evaluation, cost estimation, and technical risk assessment.

Current status of HIAF

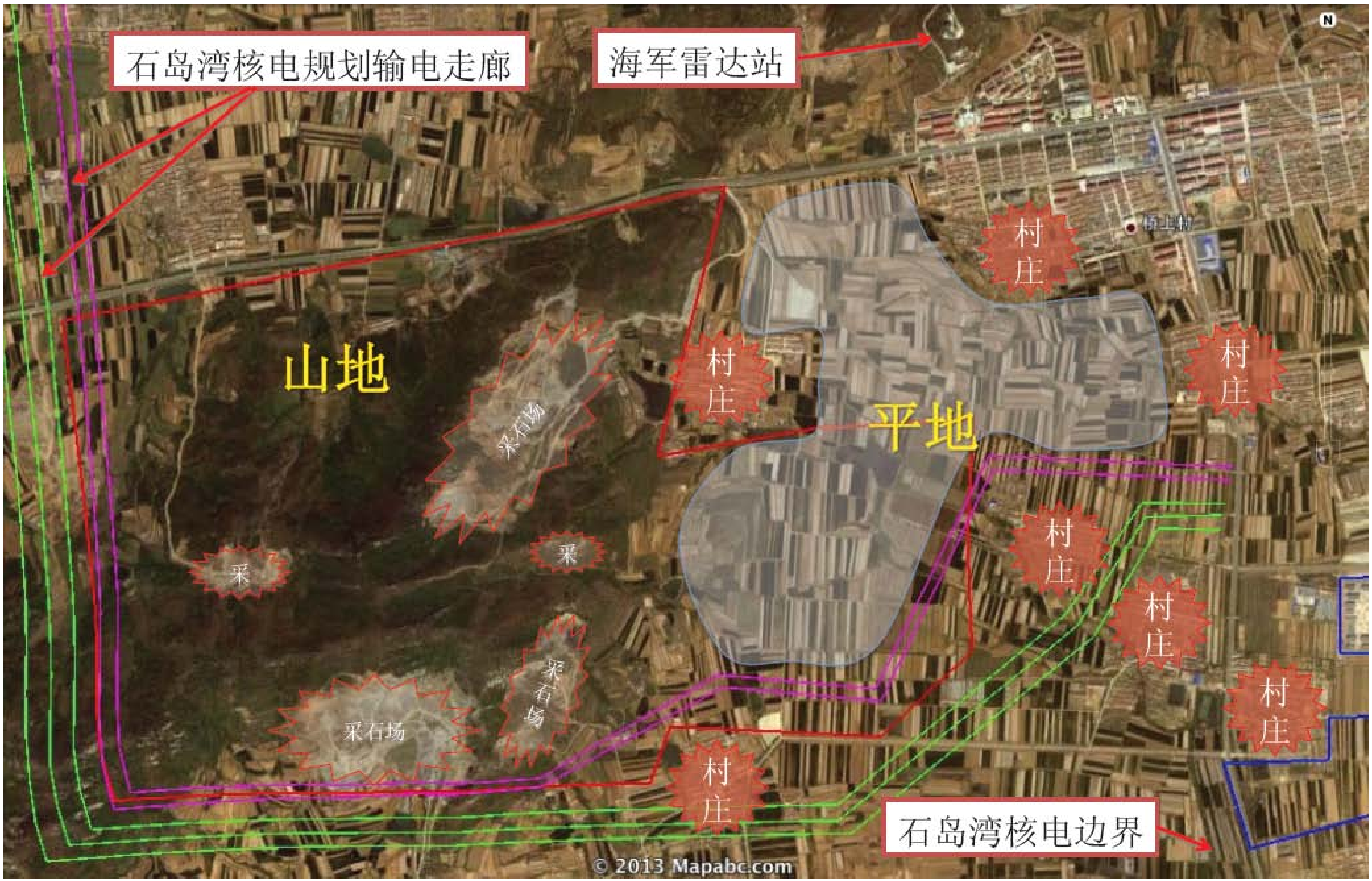
- **We seek international collaborations for key supporting technologies of HIAF.**
- **The total budget of HIAF is about $ 380 million, if the EIC cost is included , the total budget is about $ 500 million.**
- **The timing of HIAF construction depends on the design optimization and accelerator technology R&D. We hope we can start construction in the end of 2014. Project completion is expected in 2022, managing to early completion in 2019.**

Candidate site of HIAF project

— Rongcheng city of Shandong province

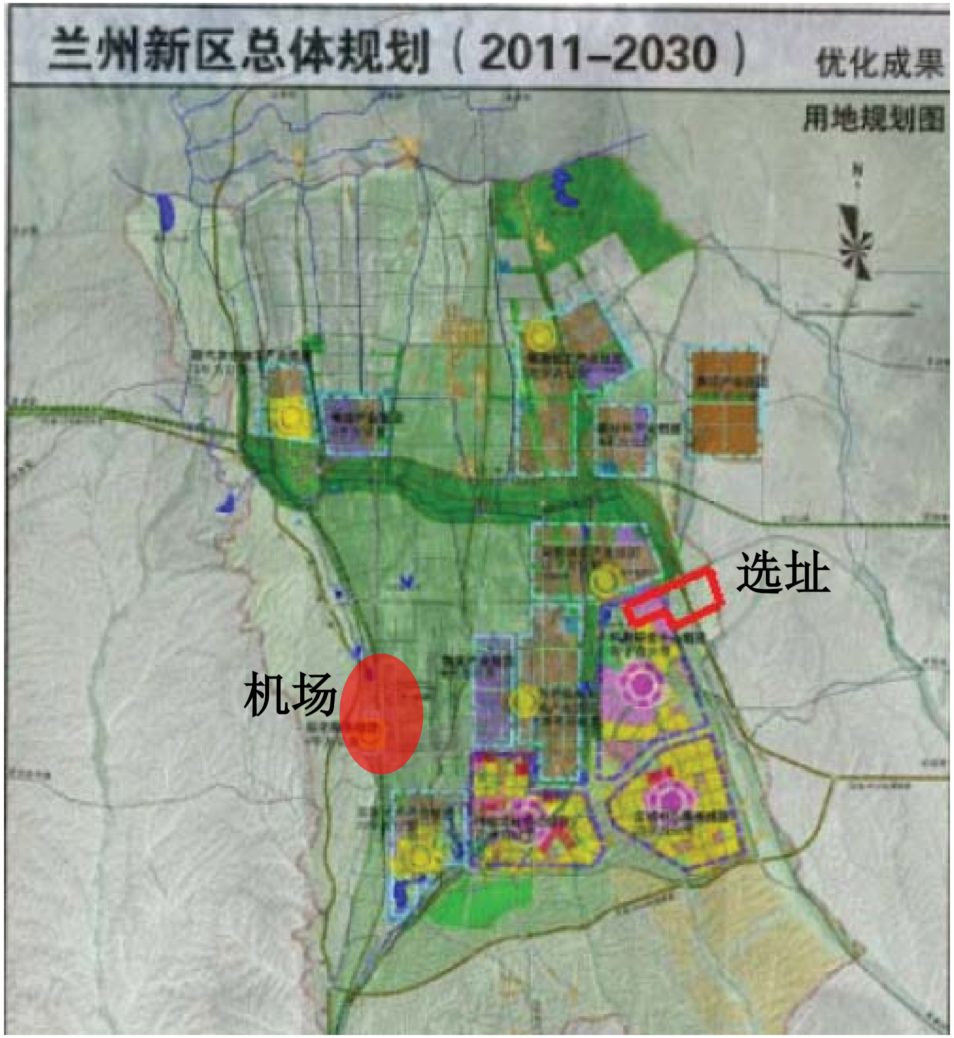
Candidate site of HIAF project

— Rongcheng city of Shandong province



Candidate site of HIAF project

— New development area of Lanzhou city



Candidate site of HIAF project

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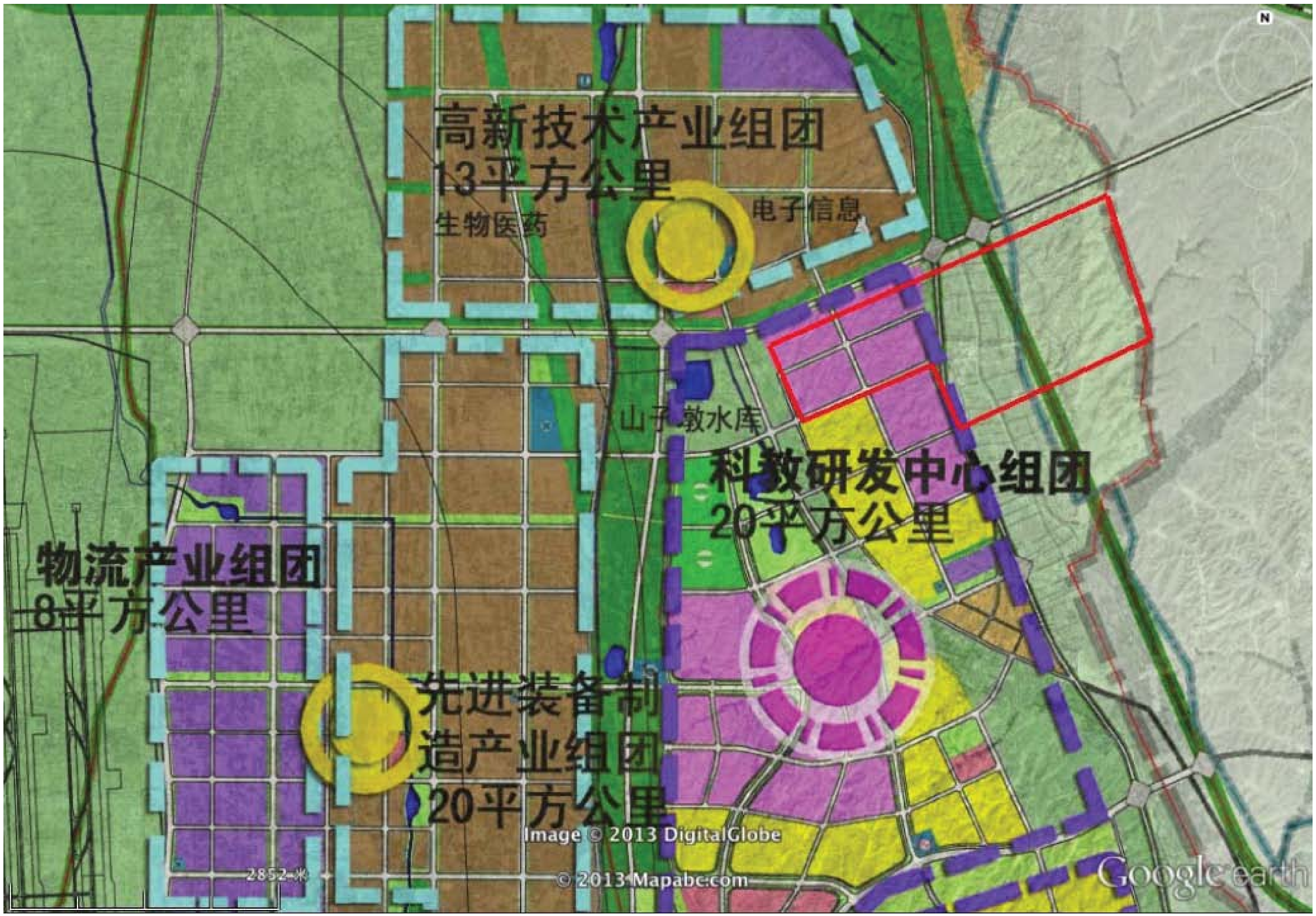
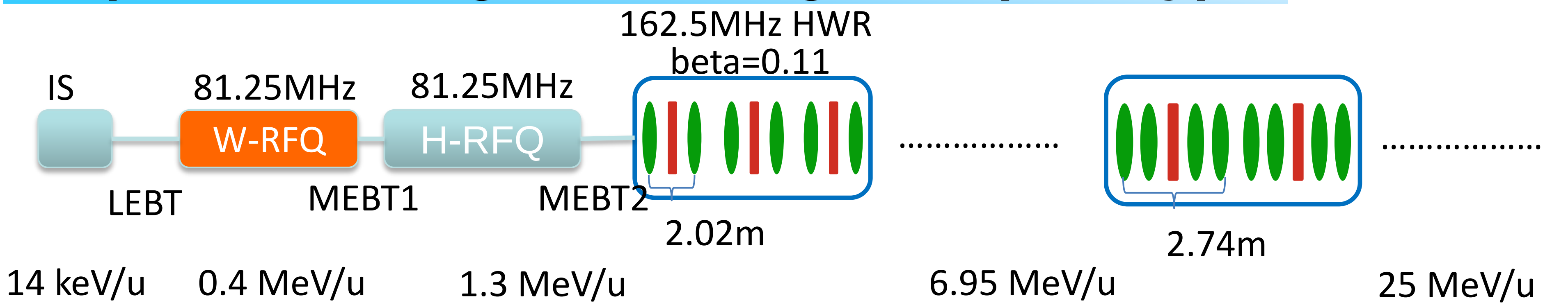


Thanks for your attention!

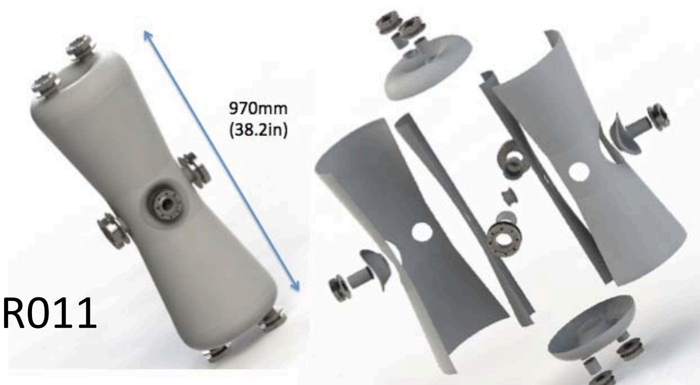
Any comments are welcome!

Accelerator pre-R&D

Superconducting Linac design and prototype



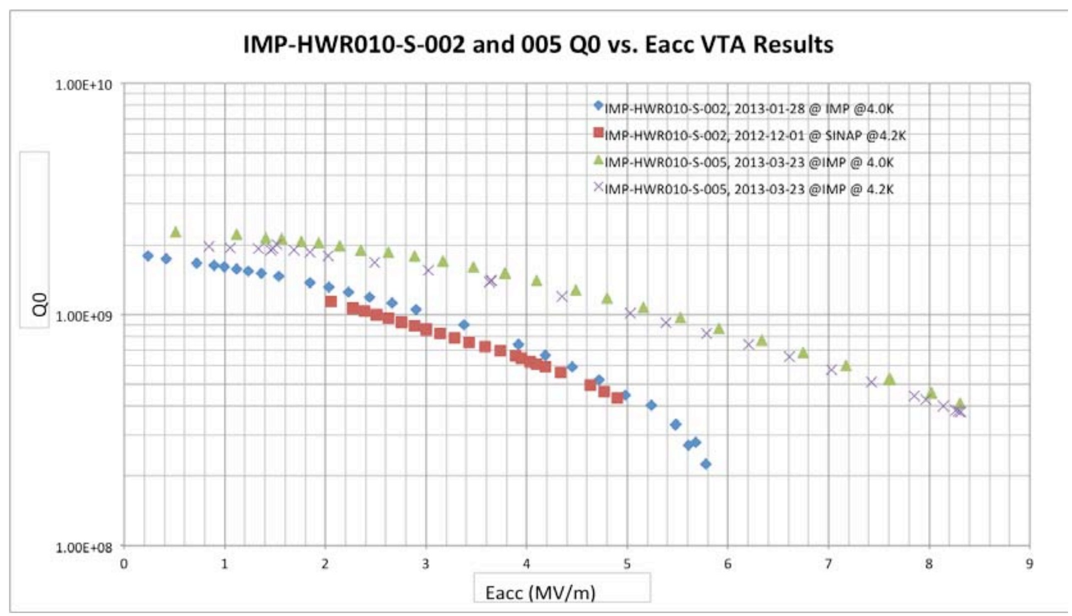
T-HWR011



EM model

Exploded View

S-HWR

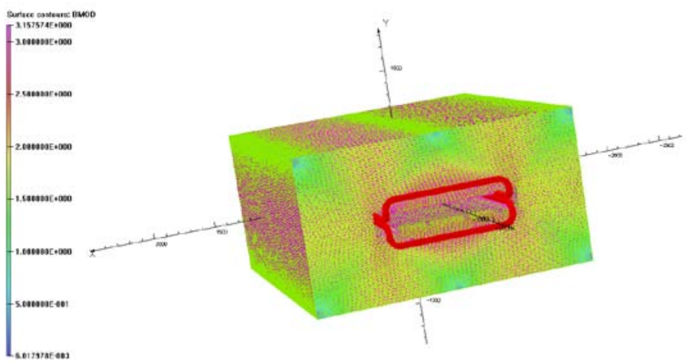


Accelerator pre-R&D

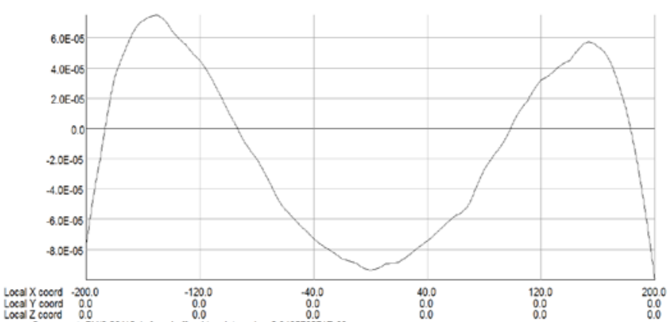
ABR-35 Superconducting Dipole

Central field	*2.25 T*
Useable aperture	***220mm ×120mm***
Max. ramp rate	2.25 T/s

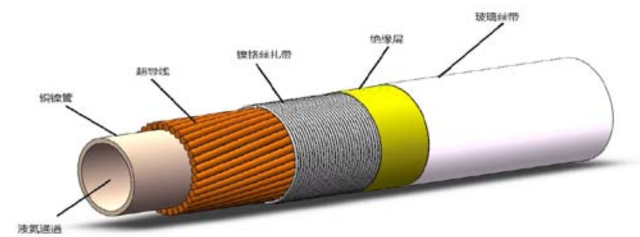
- ✓ Superferric design with warm iron yoke to fulfill requirement of big aperture；
- ✓ Hollow tube superconducting cable coolling with supercritical He ；
- ✓ Strong support structure to resist strong electromagnetic force



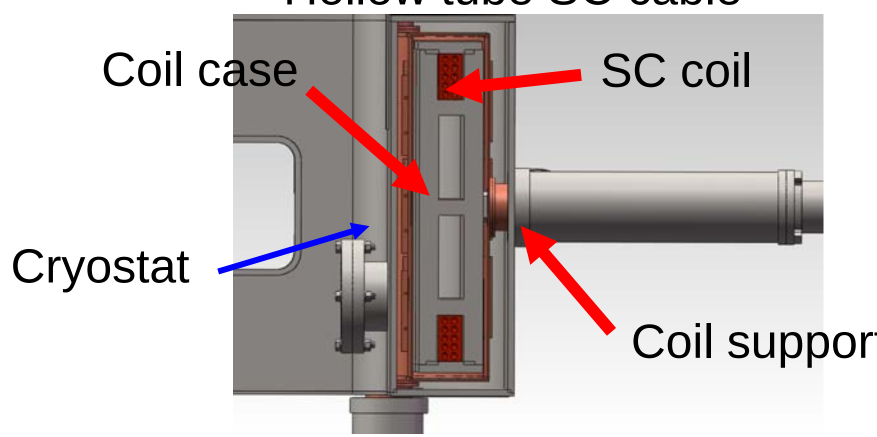
Field distribution in iron yoke



Horizental field homogeneity



Hollow tube SC cable



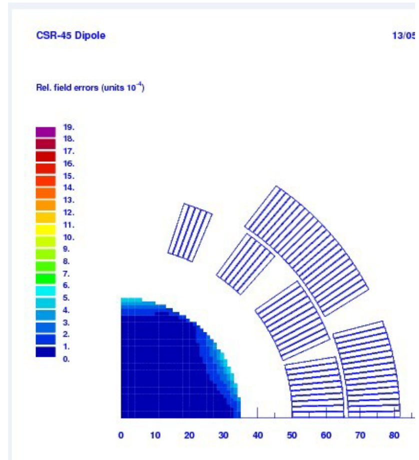
SC coil and Cryostat

Accelerator pre-R&D

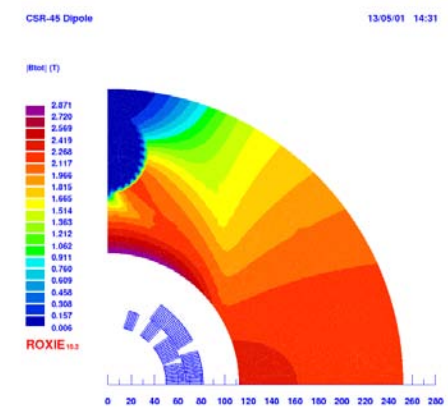
ICR-35 Superconducting Dipole

Central field	***6 T***
Useable aperture (6×10^{-4})	Φ70mm
Ramping rate	<1 T/s

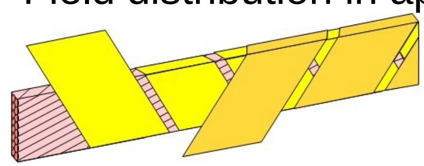
✓ Cosθ type coil with Rutherford cable;
✓ Cooled with supercritical helium (4.5K);
✓ The cold mass consists of a superconducting coil, a reinforceing shell, cold iron yoke, etc;
✓ G10 post used as cold mass support;

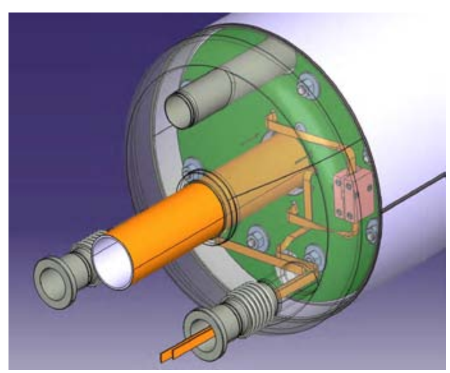


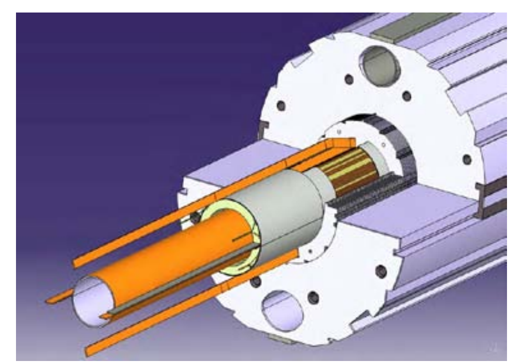
Field distribution in aperture



Field distribution in iron yoke


Rutherford cable


Cold mass assembley

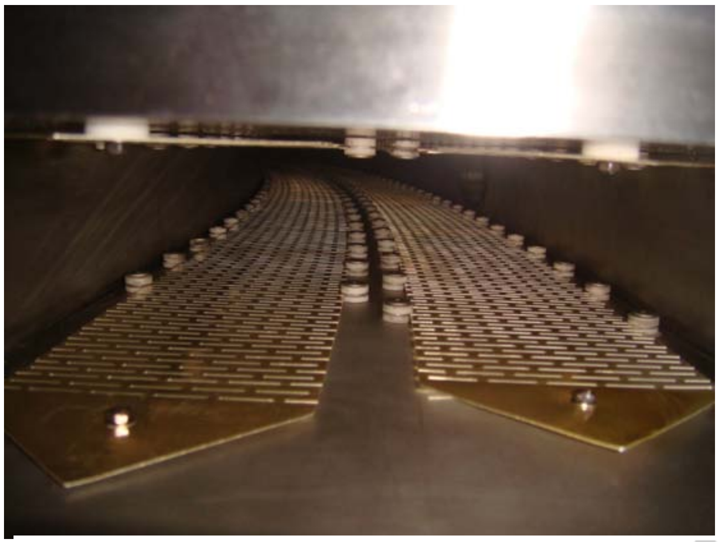

SC coil, collar and yoke

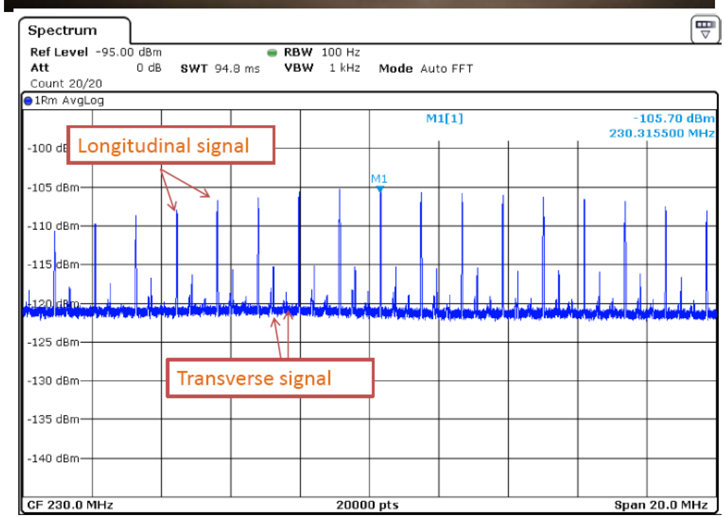
SIS 300 prototype

Accelerator pre-R&D

Stochastic cooling

– A novel type of 2.76 m long slotted pick-up was developed (cooperated with F. Caspers) for CSRe stochastic cooling.





The beam test ($^{117}Sn^{50+}$, 253 MeV/u) results show it is a perfect structure for CSRe stochastic cooling.

Two e-coolers were equipped in CSRm and CSRe respectively. In CSRm e-cooling is used for beam accumulation at the injection energy of 7~25 MeV/u, while in CSRe e-cooling is used to compensate the growth of beam emittance during internal-target experiments or to provide high quality beams for the high precision mass measurements of nuclei. The hollow e-beam can be obtained in both of two e-coolers to partially solve the problem due to the space charge effect and reduce the effect of recombination between the ions and the e-beam.

an intensity gain of 300

In April of 2009, a 400 MeV/u C-beam of current of 1000 eμA was stored and cooled in CSRe and the beam momentum spread was reduced to $\pm 1.5\times 10{-}5$ from $\pm 1.6\times 10{-}4$ with e-cooling.[17, 18]. Figures 25 and 26 show the beam momentum spread and the beam size of the C-beam before and after cooling in CSRe. After e-cooling the C-beam shrunk sharply in size and the beam emittance was reduced down to 0.03 p mm mrad.