Physics Strategies in China

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Major Contents to be Presented

Big science: physics with big facilities → nuclear, particle and astroparticle physics

- ✓ Accelerator based experiments
- ✓ Underground experiments
- ✓ Cosmic-ray physics at high altitude
- ✓ Space experiments

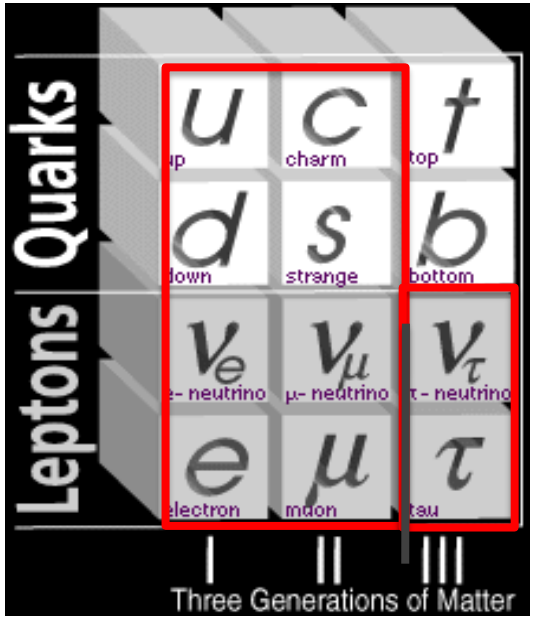
Priorities in condensed matter, optics, statistical & quantum physics and technology…

- ✓ Quantum and topological orders in condensed matter systems.
- ✓ precision measurements and manipulations based on atomic and molecular physics and quantum optics.
- ✓ Fundamentals and applications of extreme light fields
- ✓ Propagation, regulation and application of sound in complex media.
- ✓ Quantum physics for the development of information and computation technologies.
- ✓ Statistical physics for complex, finite-size systems and life science.
- ✓ Advanced light source and application.

Present accelerator-based experiments & Proposals for future facilities

Beijing Electron Positron Collider (BEPC)

- **BEPC construction: 1984-1988, operation: 1989-2004, L_{peak}=1.0x10^{31} /cm^2s**
  BESI: 1989 – 1997, **BESII: 1998 - 2004**
- **BEPC upgraded to BEPCII: 2004-2009, BEPCII** operation: **2009 to now**
  L_{peak}= 1.0 x10^{33}/cm^2s, BESIII: 2009 to now



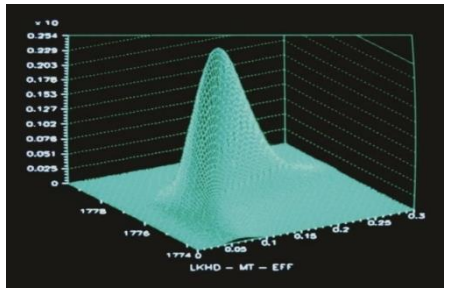
Science questions:

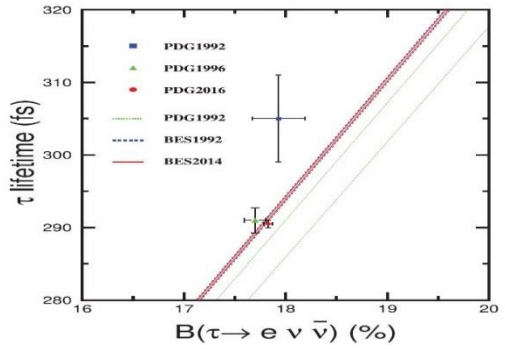
- Are there any exotic hadrons→new form of matter
- What are the structure of hadrons→ Strong interaction (QCD)
- Are there any new physics that could be observed from this high precision frontier?

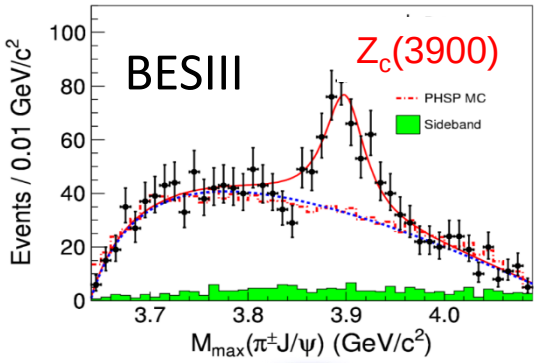
BESI measurement of τ lepton mass

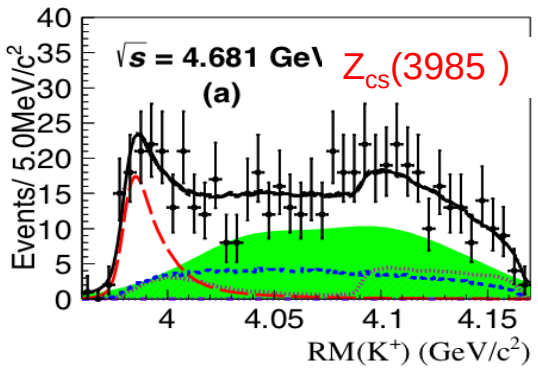
BESIII observed $Z_c(3900)$ and $Z_{cs}(3985)$

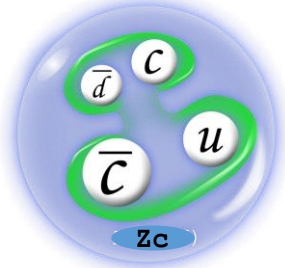
- **Measurement in 1992 achieved most precise Mτ measurements when published, validated the universality of leptonic μ-τ coupling,**

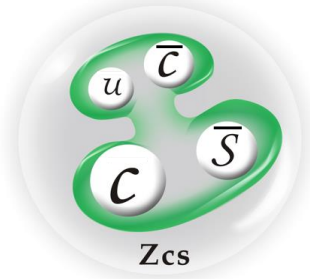






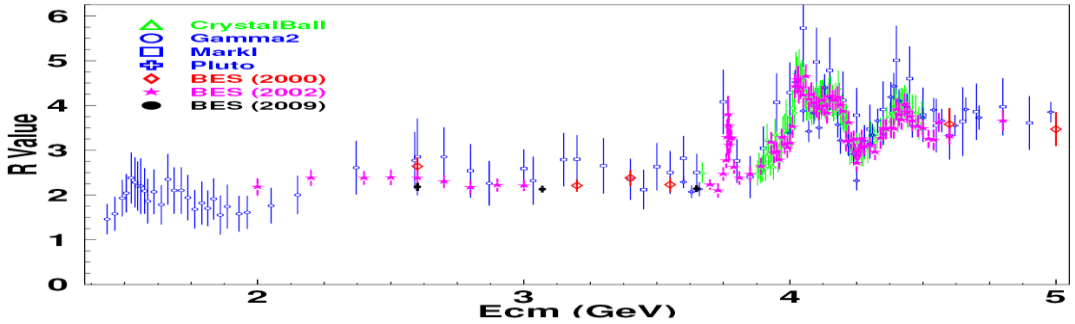


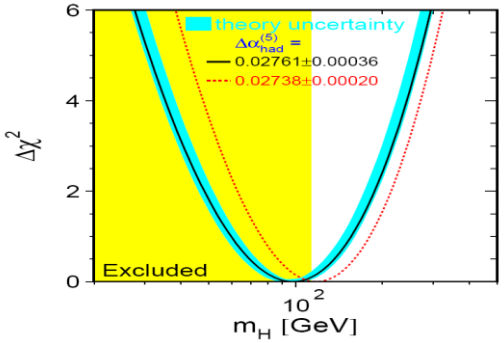




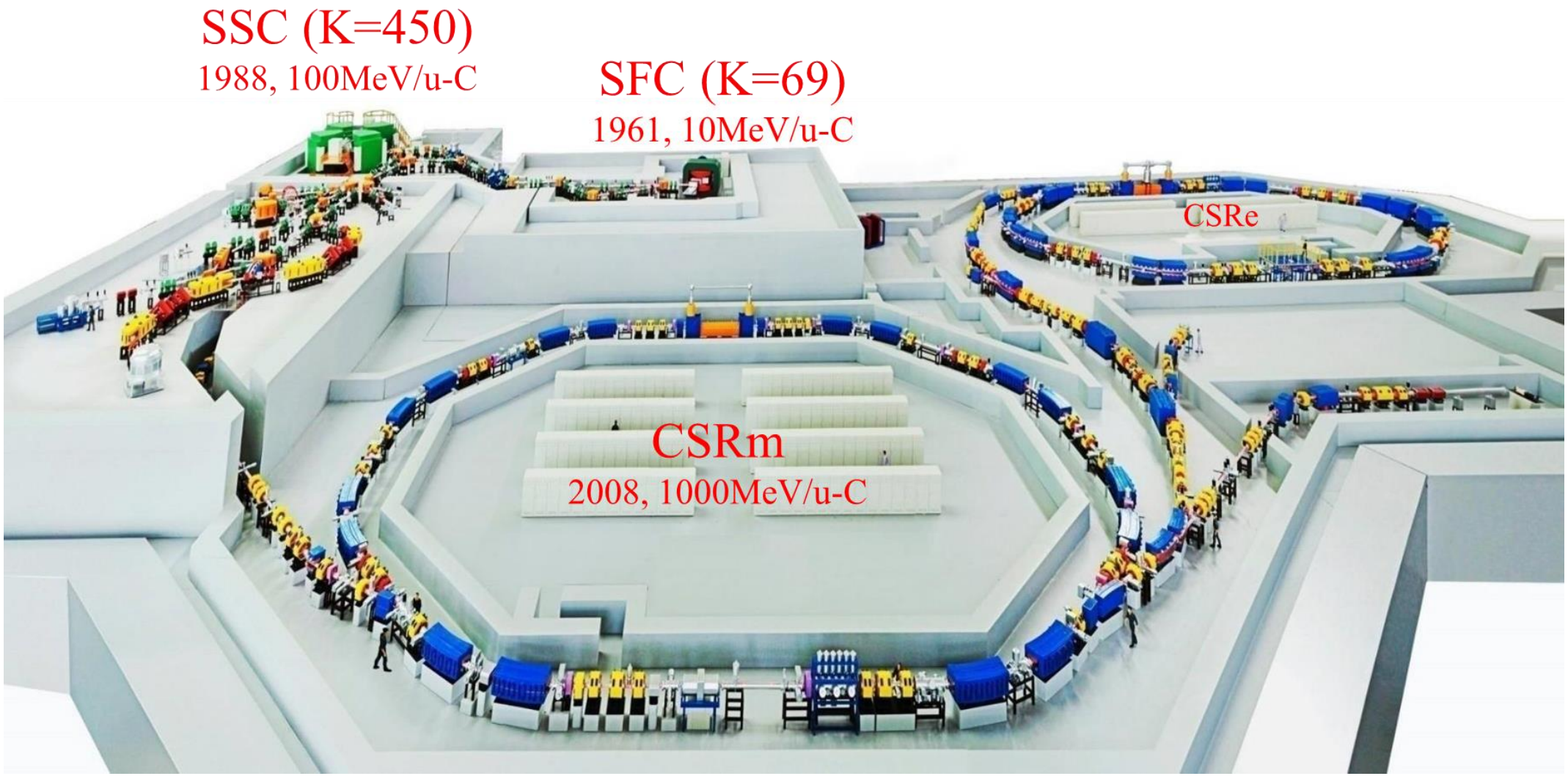
BESII measured R values in 2-5GeV energy range

- R values: one of the most fundamental quantities in particle physics. measurements reduced the uncertainties of R from ~20% to ~6%. Crucial to the estimation of Higgs mass from SM fit.





Heavy Ion Research Facility in Lanzhou (HIRFL)

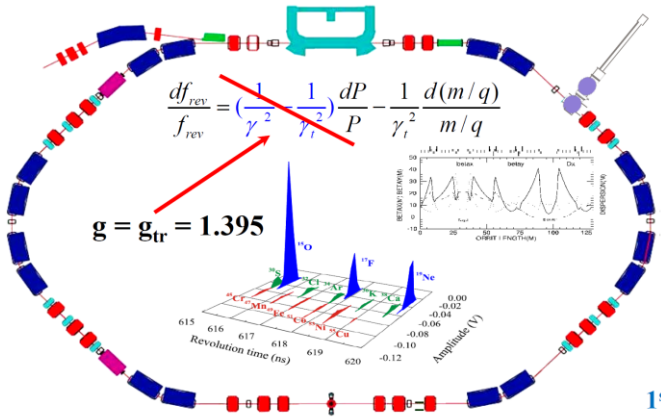


Mass measurement for short-life time nuclei in CSRe

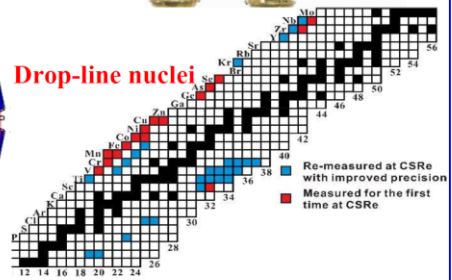
Beams: ^{58}Ni, ^{78}Kr, ^{86}Kr and ^{112}Sn

CSRe lattice: Isochronous mode

Operation mode: SECR+SFC+CSRm+CSRe, 1.5monthes/year



ΔM/M~10^{-7}



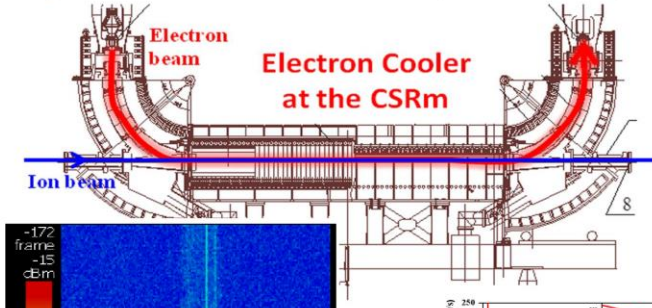
1st time measured for 16 nuclei

Precision improved for 26 nuclei

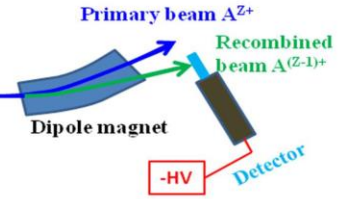
IMP,GSI,MSU,MPIK,RIKEN…

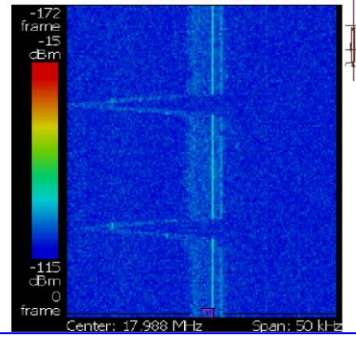
DR (Dielectronic Recombination) experiments

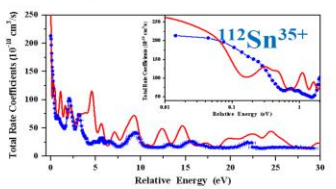
Operation mode: ECR+SFC+CSRm, Beams: C, Ar , Xe and Sn

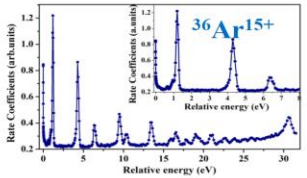


CSRm: Injection mode









DR of ^{112}Sn^{35+}, 10. 2012

DR of ^{36}Ar^{15+}, 07. 2014

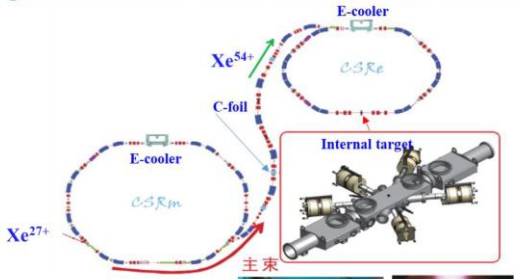
Detuning e-energy for DR cross section measurement

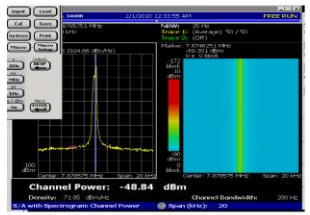
Xe^{54+} beam for internal target experiment at CSRe

Beam: Xe

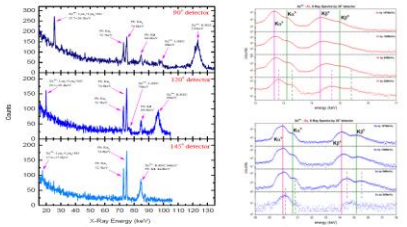
CSRe lattice: Internal-target mode

Operation mode: SECR+SFC+CSRm+CSRe





Xe^{54+}beam were cooled in CSRe at 60 ~ 200MeV/u



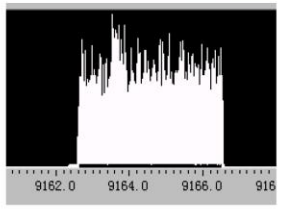
X-ray of REC processes (Jan. 2010)

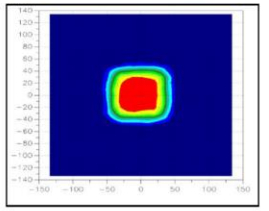
X-ray of hypersatellite lines (Oct. 2013)

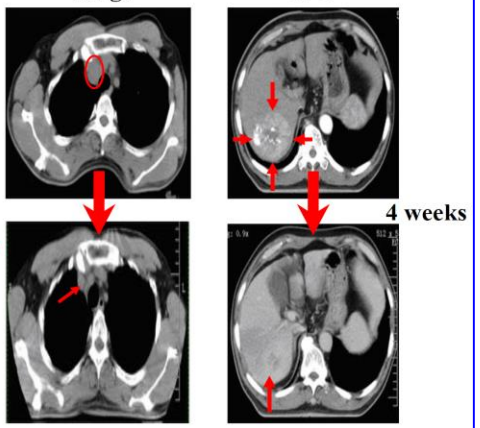
Slow extraction from CSRm for cancer therapy

Operation mode: NECR+SFC+CSRm

Beams: C^{6+}



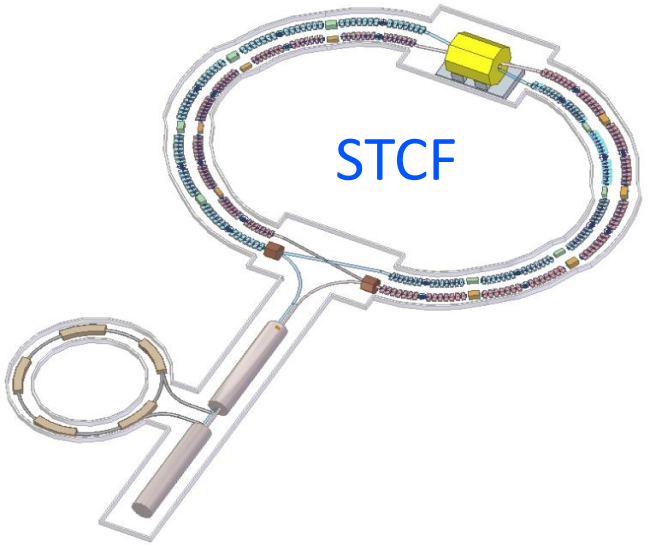




Passive beam delivery systems have been developed in the therapy terminal.

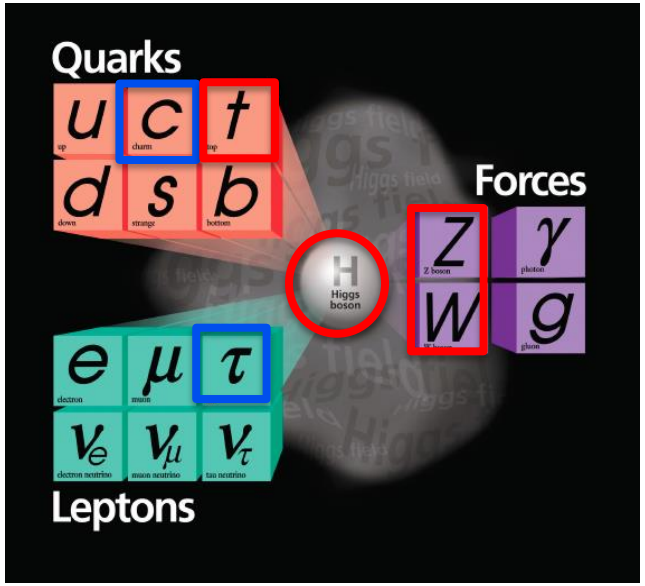
110 deep-seated tumor patients has been treated successfully.

Proposals of future facility in China

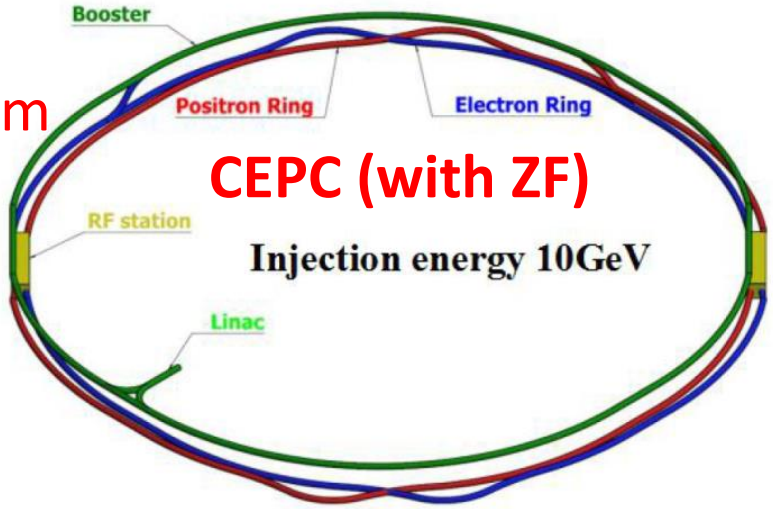


1 km

- E_{cm}: 2-7 GeV
- L: 0.5/1 $\times 10^{34}$ $cm^{-2}s^{-1}$
- Cost: 4.5 B RMB
- One of the 5 centers for HEP



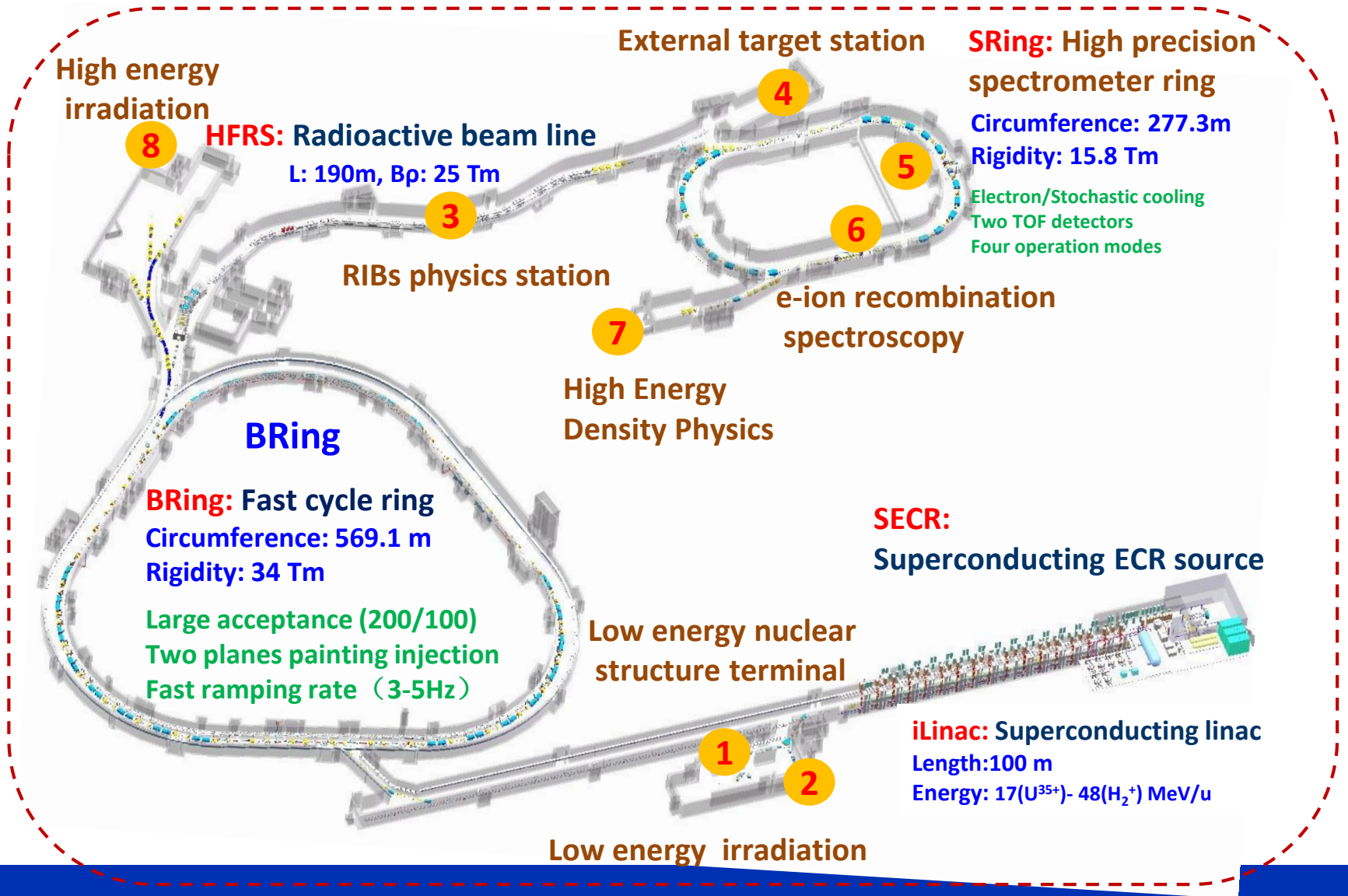
100 km



- E_{cm}: 91/240 GeV
- L: 25/3 $\times 10^{34}$ $cm^{-2}s^{-1}$
- Cost: 11.6 B CHF B (int.)
  35 B RMB (CN)
- Could be the biggest center of HEP in the world

High-Intensity Heavy Ion Accelerator Facility (HIAF)

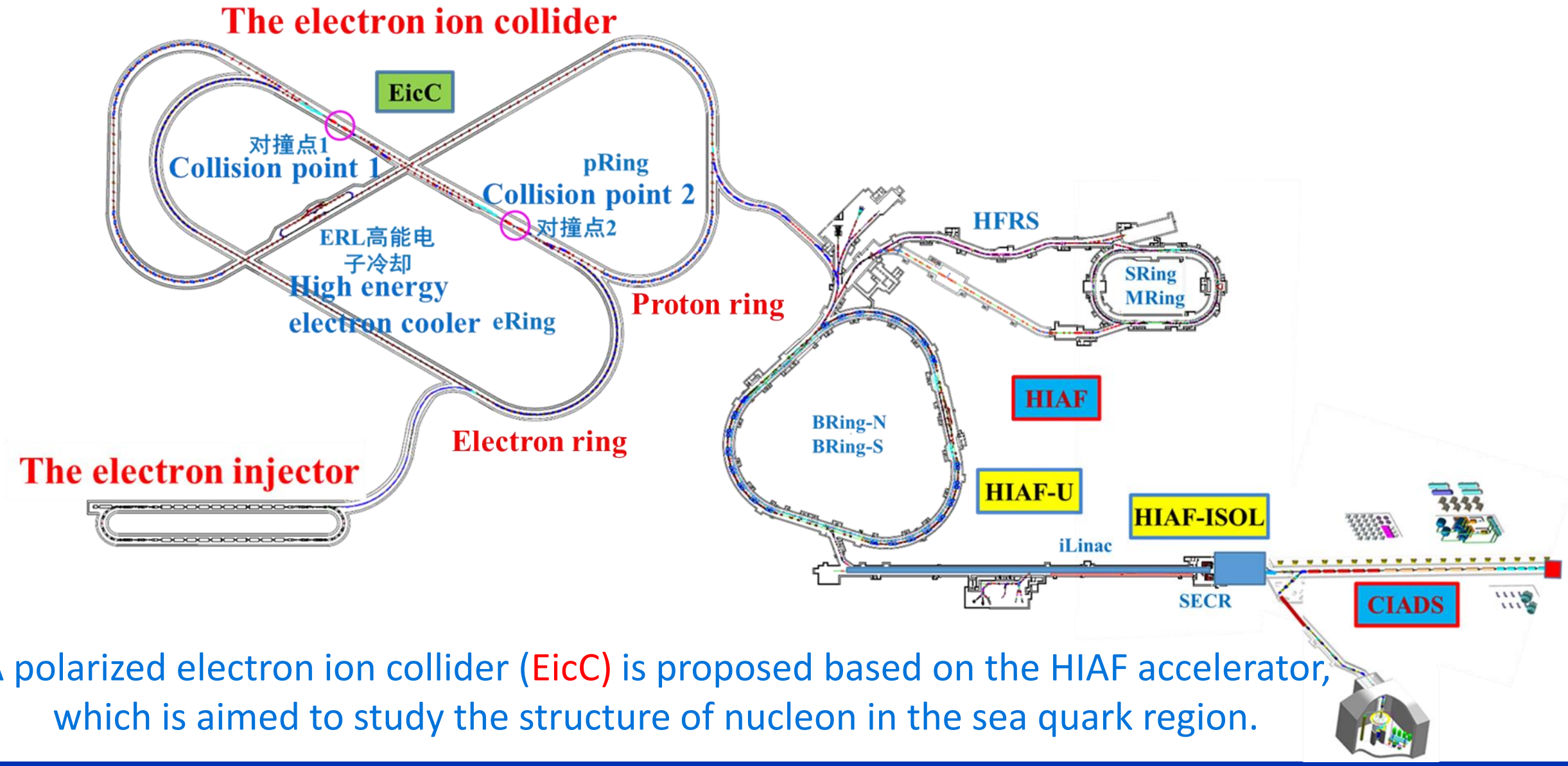
Under construction



Science motivations:

- ※ High intensity radioactive beams to investigate the structure of exotic nuclei, nuclear reactions of astrophysics and to measure the mass of nuclei with high precision.
- ※ High charge state ions for a series of atomic physics programs.
- ※ Quasi-continuous beam with wide energy range for applied science.
- ※ High energy and intensity ultra-short bunched ion beams for high energy and density matter research.
- ※ Spontaneous electron–positron pair production

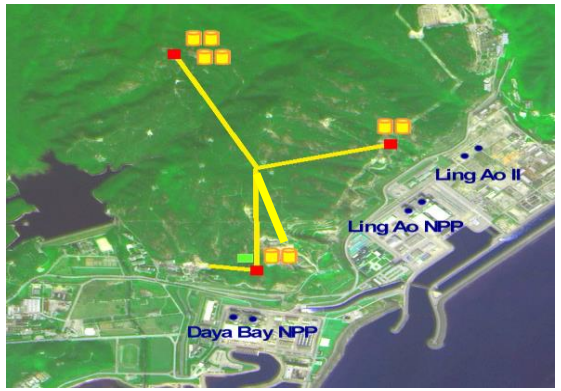
The future upgrade of HIAF

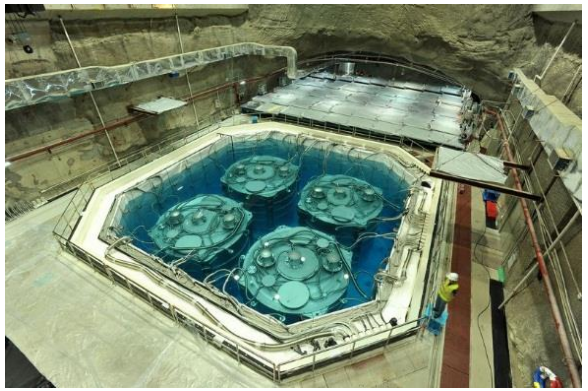


A polarized electron ion collider (EicC) is proposed based on the HIAF accelerator, which is aimed to study the structure of nucleon in the sea quark region.

None Accelerator Based Experiments

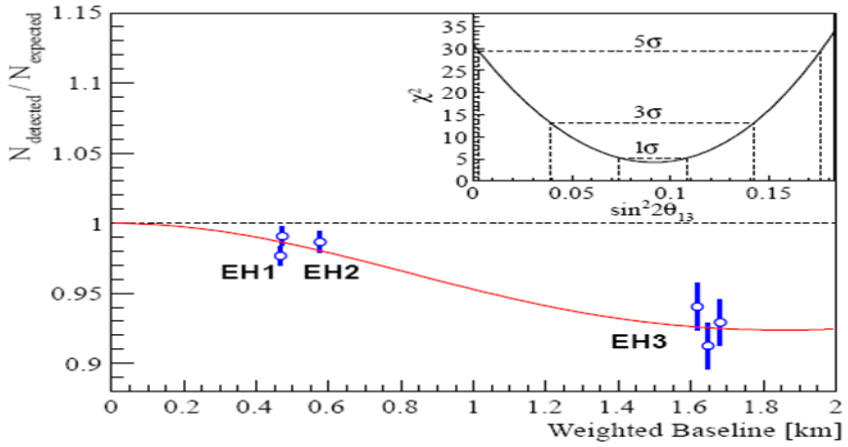
Daya Bay Reactor Neutrino Experiment (Shutdown)



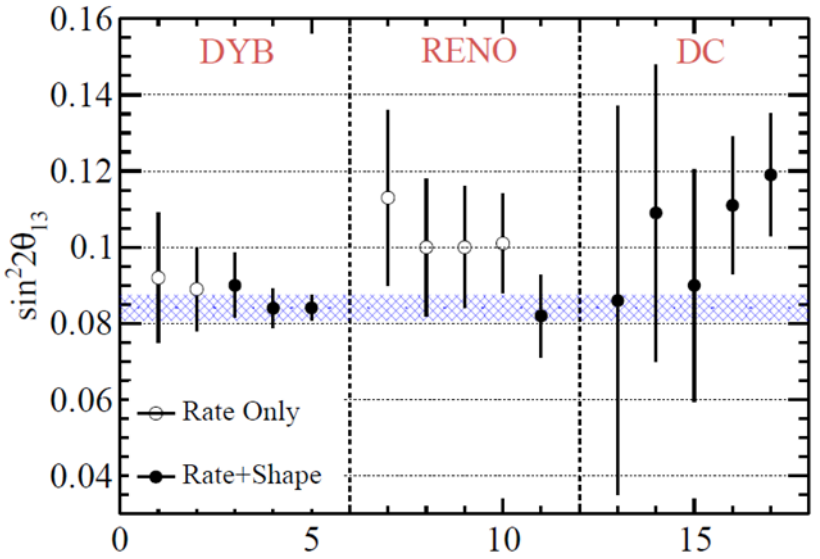


$\mathrm{Sin}^2 2\theta_{13} = 0.092 \pm 0.016(\mathrm{stat}) \pm 0.005(\mathrm{syst})$

Daya Bay: PRL 108, 171803 (2012)



Year 2020

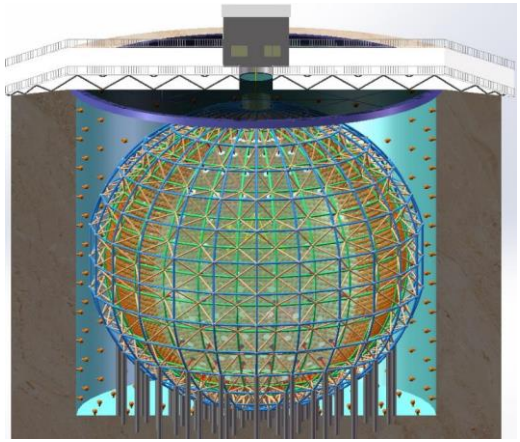


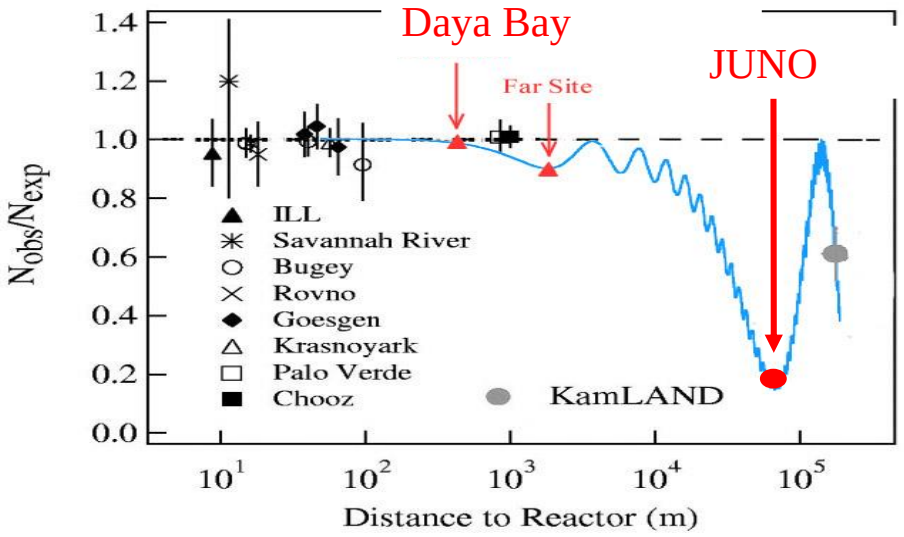
$\sin^2 2\theta_{13}$ precision improved from ~ 20% to ~ 3.4%

Jiangmen Underground Neutrino Observatory (JUNO)

A multiple-purpose neutrino experiment. Ground-breaking in 2015. Cost ~300 M USD

To be completed in 2022.



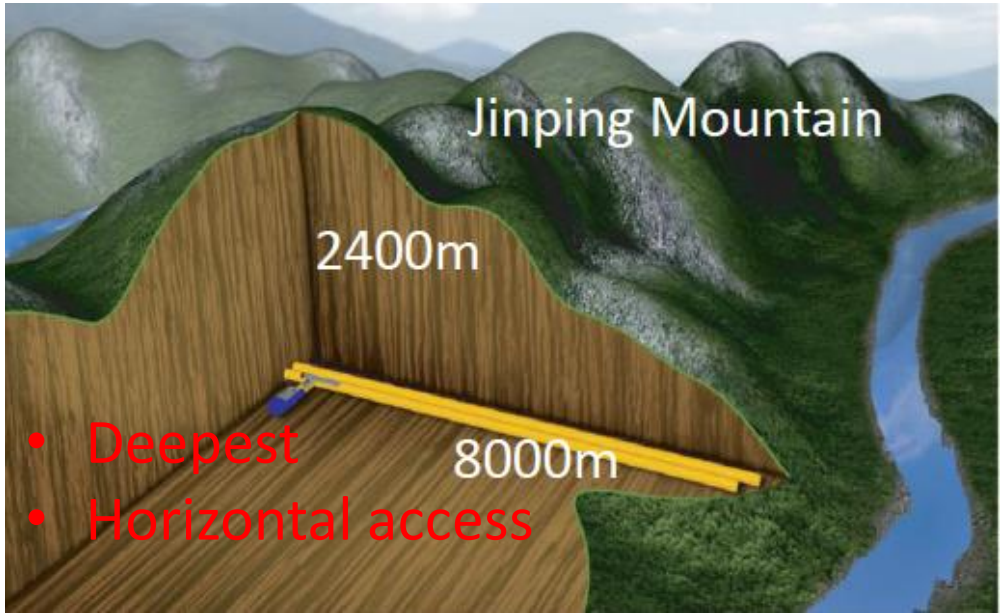


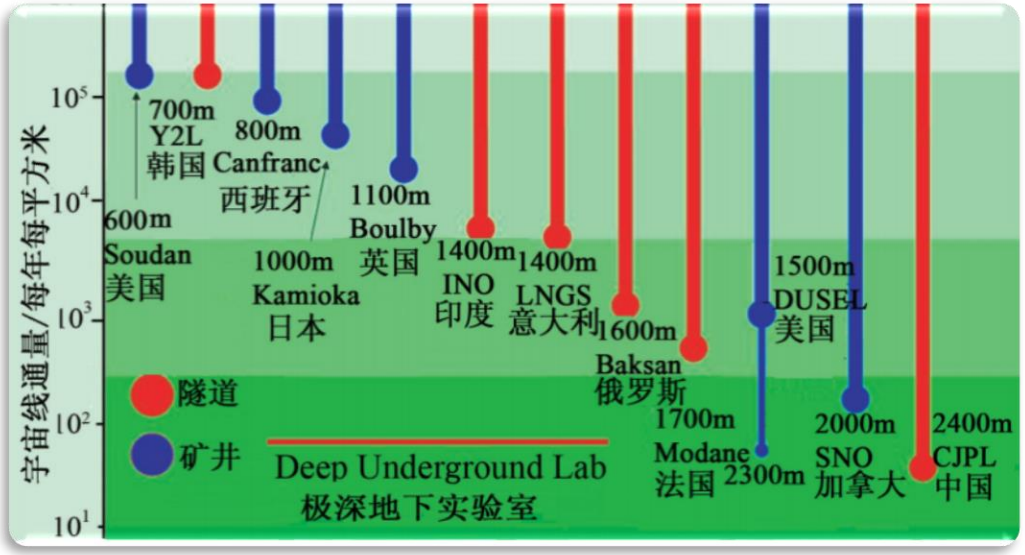
- **20 kton liquid scintillator detector**
- **3% energy resolution**
- **700 m underground**

Rich physics possibilities

- **Mass hierarchy and precision measurement of oscillation parameters**
- **Neutrinos from Supernovae, Atmosphere earth, Sun**
- **Proton decay**

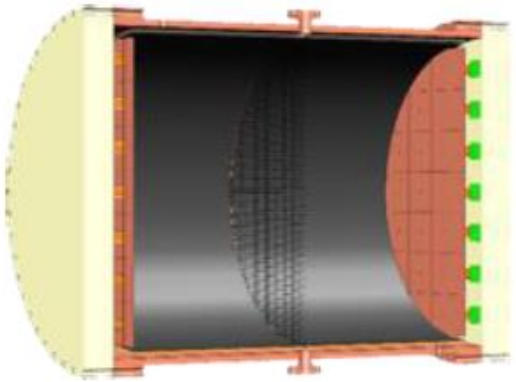
Deep Underground Laboratory in China





Particle and Astrophysical Xeon Experiment

PANDAX-xT for DM searches, PANDAX-III for 0ν2β searches

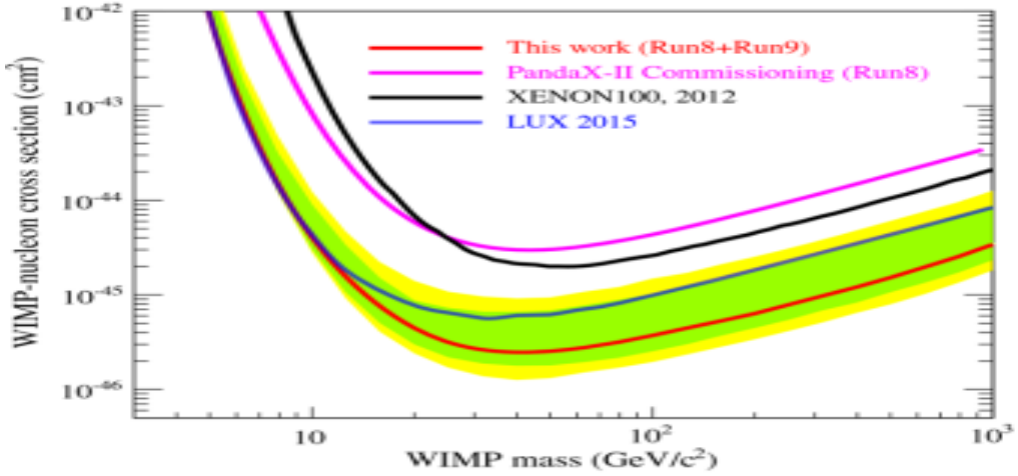


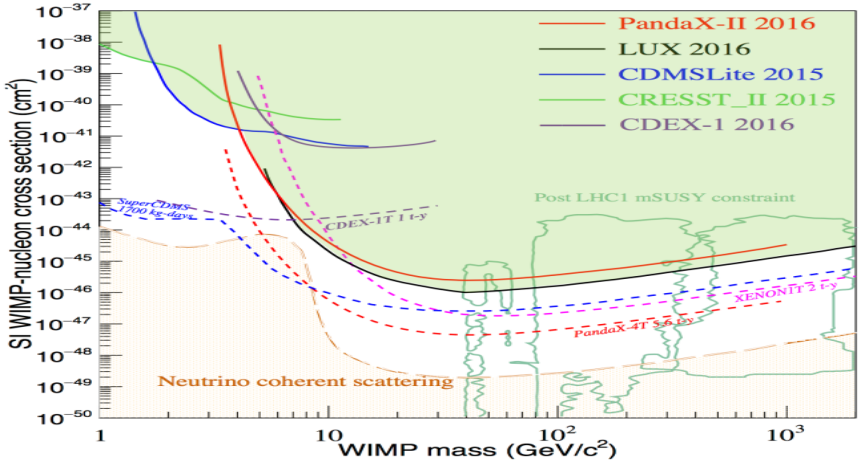
PandaX-I: 120 kg DM experiment 2009-2014

PandaX-II: 500 kg DM experiment 2014-2018

PandaX-xT: multi-ton (~4-T) DM experiment

PandaX-III: 200 kg to 1 ton HP gas ^{136}Xe 0vDBD experiment

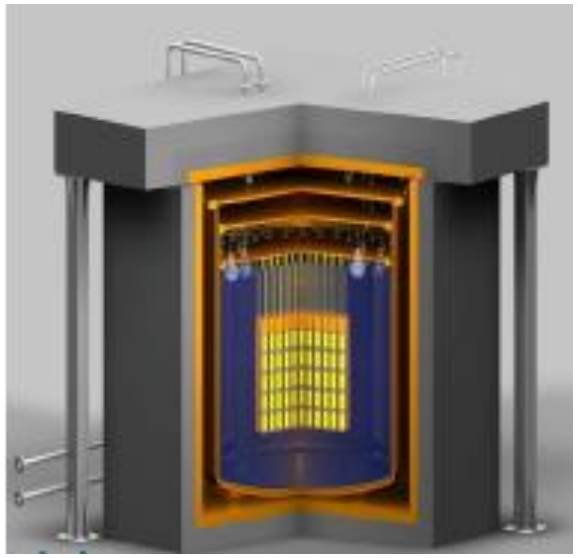




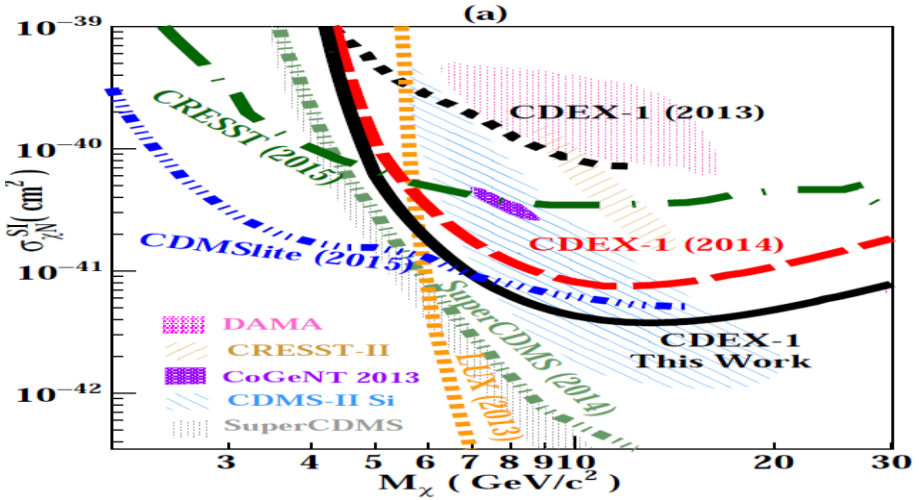
CDEX Development Stages

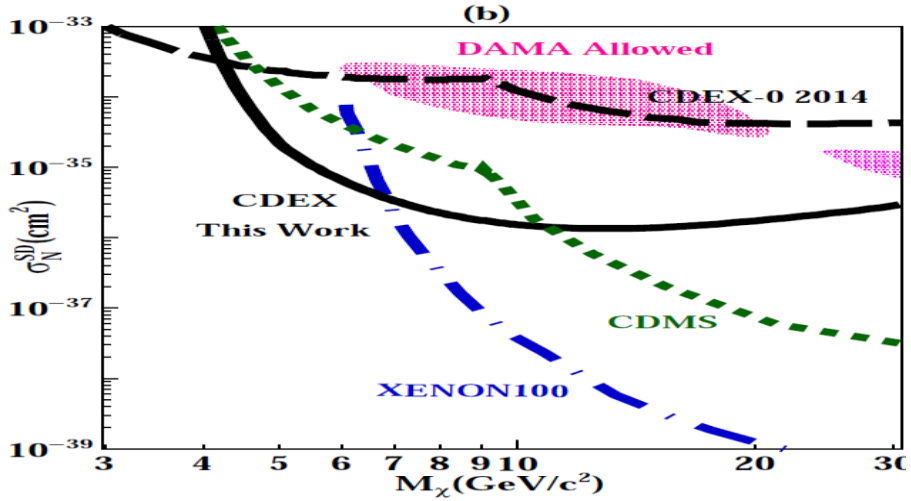
CEDX-1
1 kg Ge

CEDX-10
10-100 kg Ge



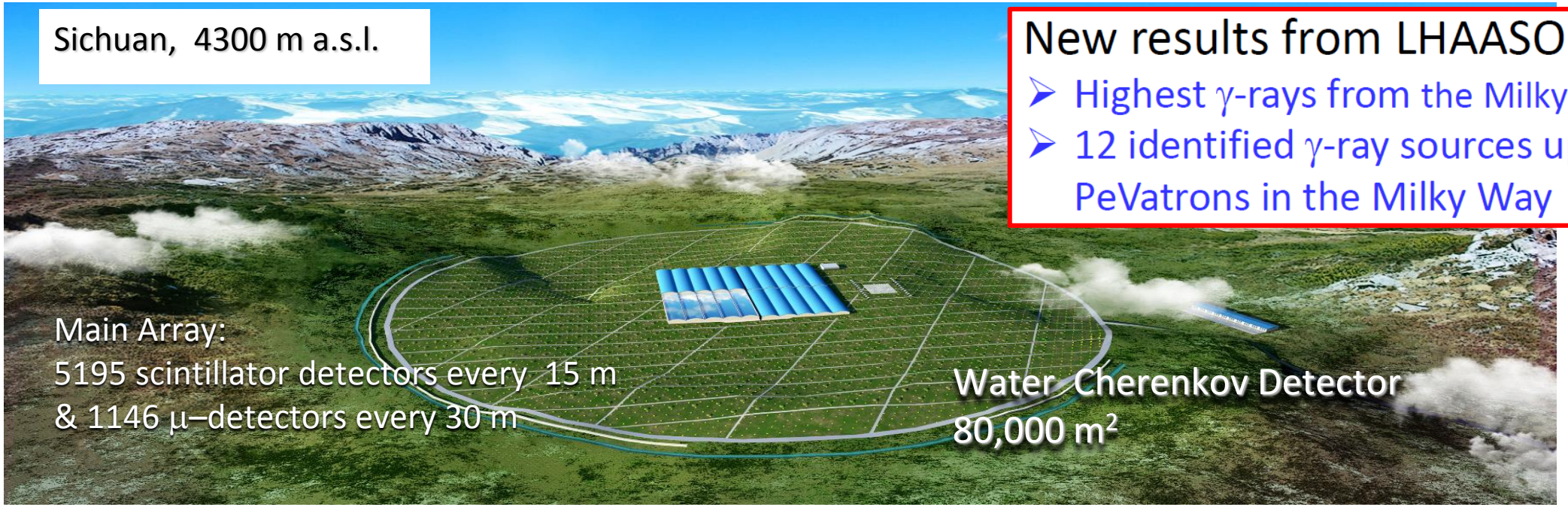
CEDX-1T
1 T Ge





Large High Altitude Air Shower Observatory (LHAASO)

- A large air shower array for cosmic-rays and γ-astronomy
- Complementary to CTA：
  - All the time, all the sky
  - Time-variant and extended sources
  - Fast indication for CTA
- Data taking started since 2019, completed installation this year



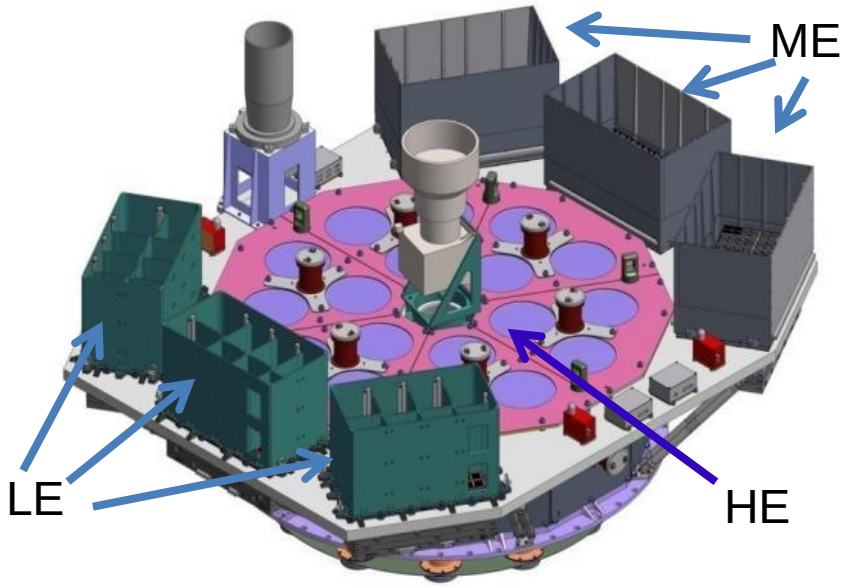
New results from LHAASO（1/2 for a year）

- Highest γ-rays from the Milky Way： 1.4 PeV
- 12 identified γ-ray sources up to ~1 PeV ➔ PeVatrons in the Milky Way

Space Experiments

Hard X-ray modulated telescope (HXMT)

- Full sky survey with good angular resolution and sensitivity
- Lunched in June, 2017



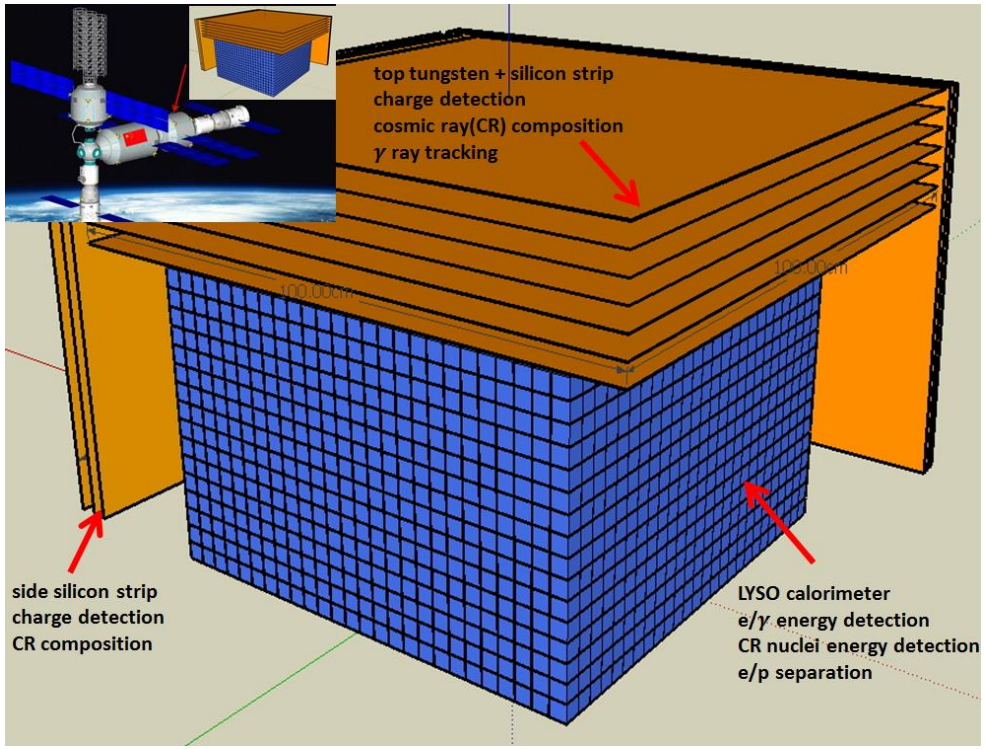
DArk Matter Particle Explorer (DAMPE)

- Cosmic-ray & gamma detector up to 10 TeV with good resolution
- Lunched in Dec., 2015

HERD to be at the China's Space Station

- Science
  - Dark matter search: γ from 100 – 10,000 GeV
  - γ-ray astronomy: GRBs, microquasars, Blazars and other transients down to 100 MeV
  - Spectral and composition measurements of CRs between 300 GeV to PeV
    - Complementary to LHAASO: directly measured composition & spectrum in space
- Status
  - Groups from China， Italy， Switzerland， Sweden,…
  - To be launch in ~2025

Acceptance & H-energy > 10X all others

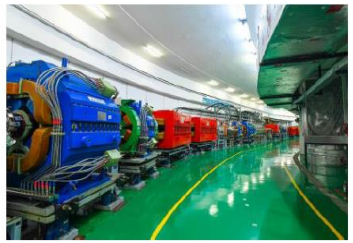


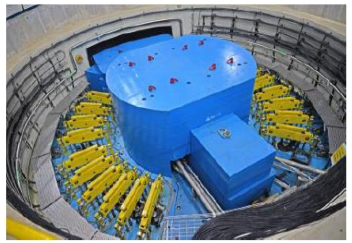
	X0(λ)	ΔE/E for e	e/p sep	e GF m^2sr@ 200GeV	p GF m^2sr@100TeV
HERD (2020)	55(3)	1%	10^{-6}	3.1	2.3
Fermi (2008)	10	12%	10^{-3}	0.9	--
AMS02 (2011)	17	2%	10^{-6}	0.12	--
DAMPE (2015)	31	1%	10^{-4}	0.3	--
CREAM (2015)	20(1.5)	--	--	--	0.2

Spallation neutron source and light sources

Spallation Neutron Source

- Smooth operation in 2020 with an efficiency > 90%.
- Power reached the design value of 100 kW
- 139 experiments last year, 60% rejection rate
- 39 user papers last year
- Upgrade plan passed the final selection
  - New target of 500 kW
  - +11 beamlines
  - Superconducting LINAC
  - Ring upgrade
- A new light source is planed next to the CSNS





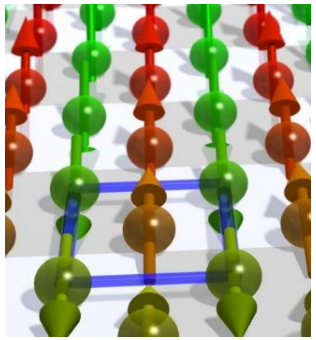
High Energy Photon Source (HEPS)

- World brightest light source: 6 GeV, 0.036nm·rad emitance, 1260m Circumference, Brilliance: >10^{22}phs/s/mm^2/mrad^2/0.1BW
- Civil Construction started in June 30, 2019, will be mostly completed in 2021
- Accelerator installation started in June, 2021
- Component production progressing well

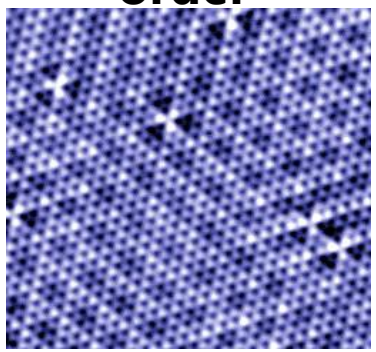
Facilities for Nuclear and Particle Physics + Particle Sources in China

Quantum and topological orders in condensed matter

Spin order

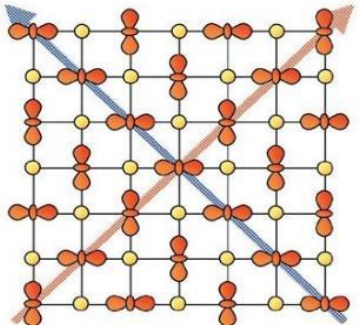


charge order

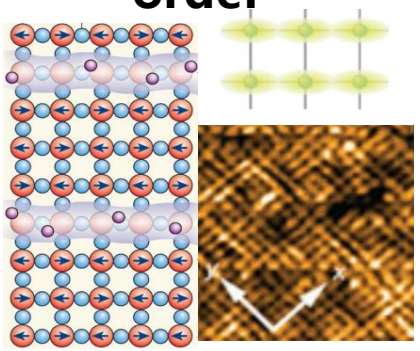


superconducting order

orbit order



nematic order



topological order

The study of quantum and topological orders in condensed matter systems:

- leads to the discovery of new materials and phenomena
- help understanding the origin of high-temperature superconductivity etc.
- helpful to material science, energy and information science including quantum computation.

Current achievement

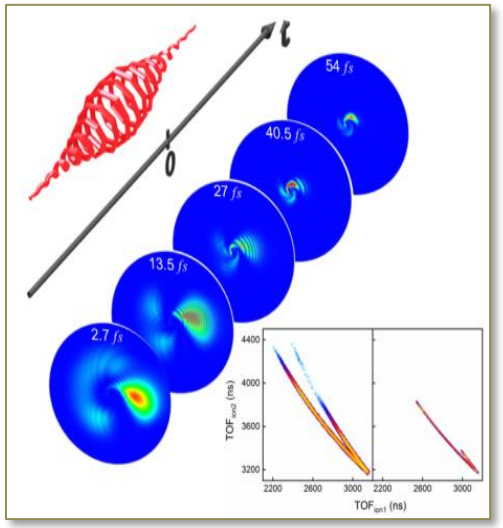
- Material synthesis and mechanism study of iron-base superconductors
- Prediction and realization of near-room-temperature hydrogen-rich superconductors at high pressures.
- Prediction and discoveries of topological insulators, Weyl semimetals, quantum anomalous Hall effect.

Future goals

- Discover new quantum and topological orders, manipulate these orders.
- Solve the mechanism of high-temperature superconductivity.
- Develop experimental techniques for precise growth, measurement and control

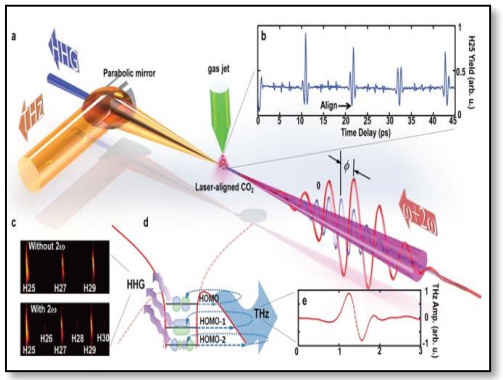
Precision measurement and manipulation based on atomic, molecular physics and quantum optics

Explore the physics of complex interaction through precise measurement and control of the electronic states of atoms and molecules at a new level of space (sub-angstrom) and time (atto-second), to promote and improve scientific understanding and control ability of matter.



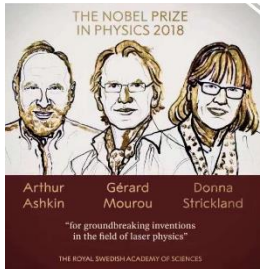
Main research fields and key scientific problems

- Multibody correlation quantum effects of warm dense matter and highly charged ions
- Ultrafast dynamics of non-equilibrium electronic states of atoms and molecules and their clusters
- New states of cold atomic and molecular gases and their precise measurement and control
- Spectral precision measurement technology, theory and application
- Quantum cavity photo-mechanics, strong-coupling cavity quantum electrodynamics
- High-energy photon quantum optics and high-frequency entanglement sources



Extremely strong light field

Extremely strong light is a field of science that studies light field and its interaction with matter under extreme conditions such as very short time, very small space, very narrow spectrum, very high intensity and very low temperature.



Main research fields and key scientific problems

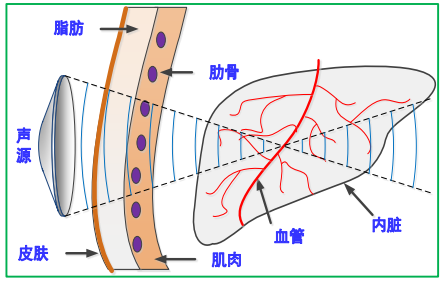
- New extreme optical field preparation and multi-dimensional precision control in space, time and frequency domains
- New extreme optical materials and devices: focus on the development of deep subwavelength scale optical field local and on-chip photonic devices
- Physics of the interaction of light with atoms, molecules, clusters, plasmas, and condensed matter under extreme conditions
- Application of extreme light field in precision measurement: focus on optical clock, precision measurement and ultra-high resolution spectroscopy techniques

Propagation, regulation and application of sound field in complex media

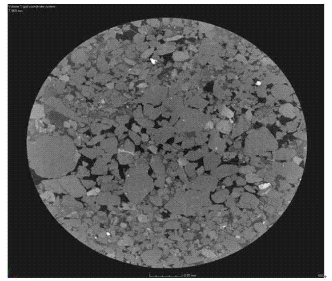
Main research fields and key scientific problems

- Study on transmission mechanism and law of extremely low frequency acoustic signal in seawater medium
- Three-dimensional effect caused by sea floor, water undulation effect, sea-air interaction and mechanism of Marine environmental noise
- Propagation law of acoustic waves in complex formation structure, and multi-scale large-scale simulation
- The acoustic artificial structure can control the low frequency acoustic waves, and the small scale material can control the large scale acoustic waves
- Study on the biological mechanism of ultrasound neuroregulation and its regulatory mechanism in the intervention and treatment of brain diseases

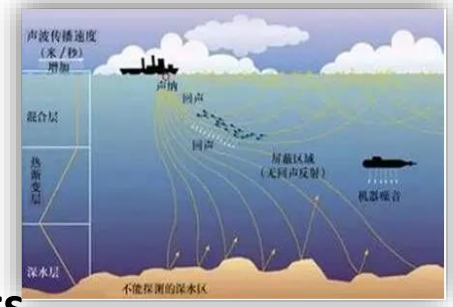
Medical ultrasound



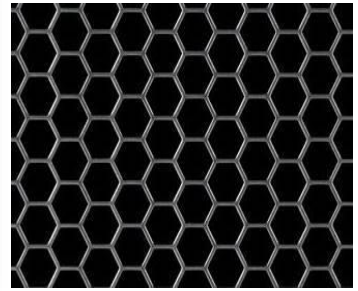
Digital core



Underwater acoustic detection



Acoustic artificial structure



Development of quantum communication and computation

Main research fields and key scientific problems

- **Research on security and reliability of quantum communication technology;**
- **Theory and experiment of scalable solid-state quantum computing;**
- **The application of quantum entanglement in condensed matter and its relation with quantum gravity theory;**
- **Quantum sensitive detection of single spin and single-molecule level structure analysis and imaging;**
- **Quantum inertial systems and quantum measurements beyond classical limits;**
- **Fundamental problems of quantum mechanics based on information theory**

Statistical physics for complex, finite systems and life science

Main research fields and key scientific problems

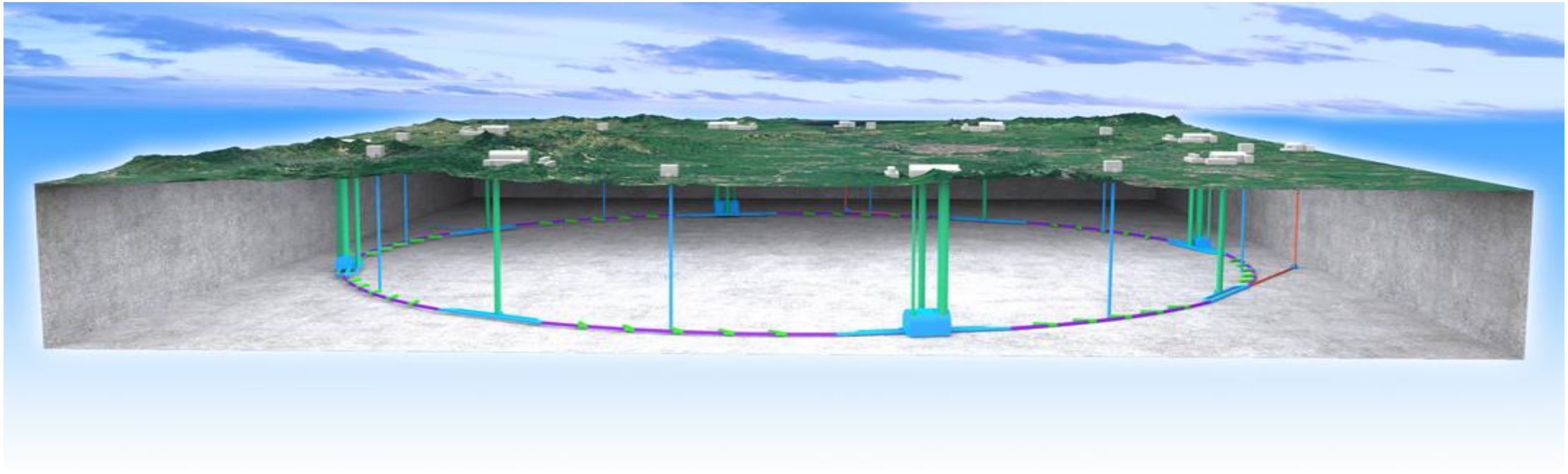
- Theory and experimental methods for soft condensates and living systems
- Finite System Thermodynamics and Micro/Nano Scale Heat Transfer, Thermal Cycle Power - Efficiency Optimization Problems
- Statistical physics of water science
- Maximum entropy principle and fluctuation theorem, spin glass, neural network and the statistical physics of the block system

Extra slides

Proposal for future facility

Circular Electron Positron Collider (CEPC) as a Higgs factory

- **The idea of a Circular e+e- Collider(CEPC) followed by a Super proton-proton collider(SPPC) was proposed in Sept. 2012, and quickly gained the momentum in IHEP and in the world**
  - ⇨ Looking for Hints@e^+e^- Collider ➔ If yes, direct searches@pp collider
  - ⇨ The tunnel can be re-used for pp, AA, ep colliders up to ~ 100 TeV ➔ compatibility study needed now



Proposal for future facility
Super Tau-Charm Factory (STCF)

- Center-of-mass energy coverage : **2-7 GeV**
- Peaking luminosity > **0.5×10^{35} $cm^{-2}s^{-1}$** at 4 GeV
- **Potential** to increase luminosity and realize beam polarization