The 1st Nuclear Physics School for Young Scientists

Introduction to the HIAF Facility

High Intensity Heavy-ion Accelerator Facility

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Outline

- Progress and Facility Capability
- R&D on the Key Accelerator Techniques
- Experimental Setups and Major Physical Aims
- Facility Location, Budget and Time Schedule
- Perspectives of Expansion
- Summarization

Project Progress

Progress of the HIAF Project

2010 — National call for projects, and ***HIAF*** proposed by IMP

May, 2011 — Recommendation of 16 top priority projects including ***HIAF***

December, 2015 — Approval by the government and locating ***HIAF***

April, 2017 — Accomplishment of the technical assessment for ***HIAF***

2018 — Startup of the construction

The major goals identified for HIAF: exploration of the nuclear chart and study of exotic nuclear structure, synthesis of super-heavy nuclides, understanding the origin of heavy elements in the Universe, and heavy-ion applications

Physics discussion

Design Review


Technical assessment

Funding agency: The National Development and Reform Commission (NDRC)

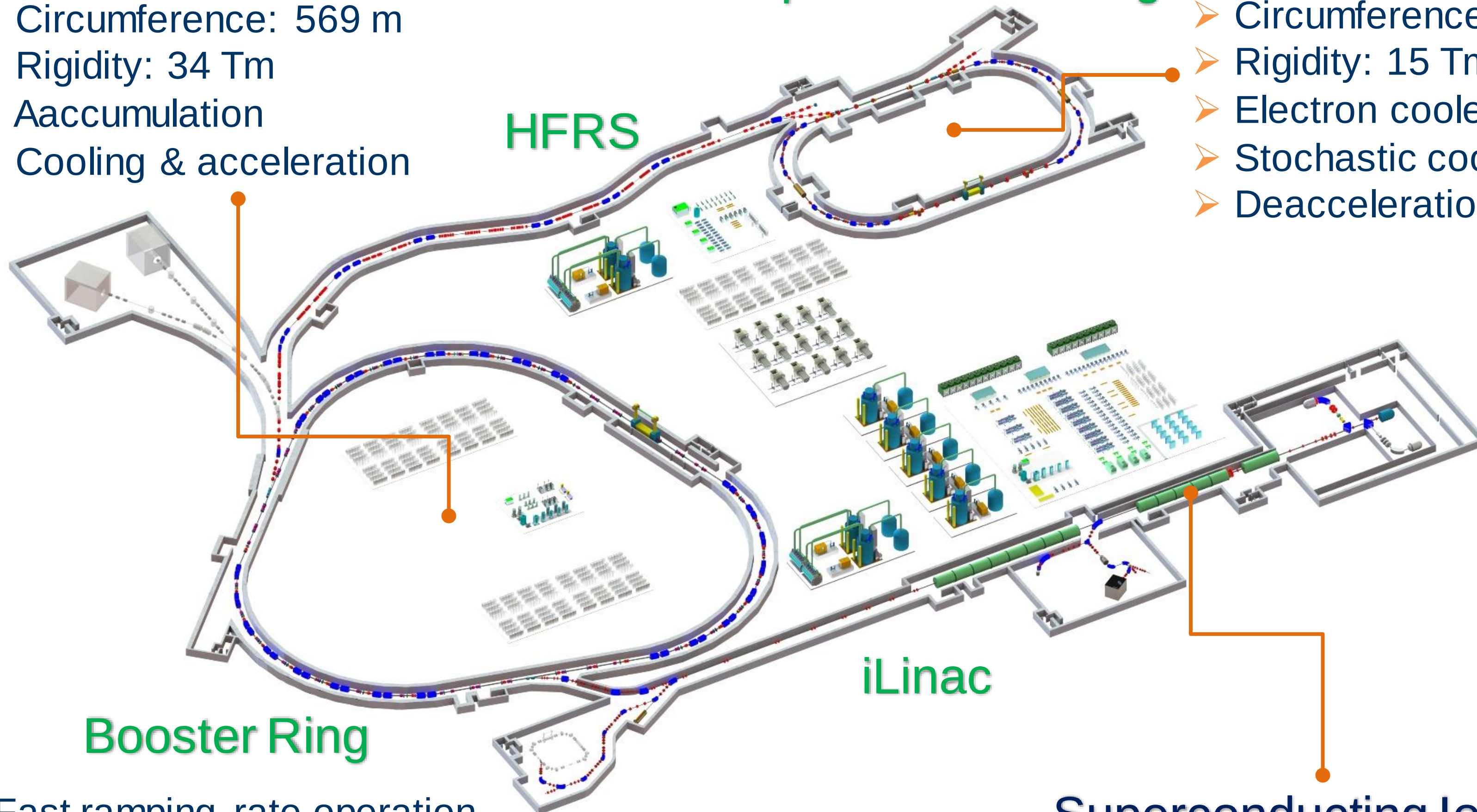
16.7亿元

Accelerator Complex

A Budget of 1.67 Billion CNY Authorized Officially

Booster Ring:
- Circumference: 569 m
- Rigidity: 34 Tm
- Aaccumulation
- Cooling & acceleration

Spectrometer Ring:
- Circumference: 270.5 m
- Rigidity: 15 Tm
- Electron cooler
- Stochastic cooler
- Deacceleration



Fast ramping rate operation

Superconducting Ion Linac:
- Length: 180 m
- Energy: 17 MeV/u (U^{34+})
- CW and pulse modes

Phase I

Scientific Drivers & Facility Capability

Scientific Goals Common to All Existing and Future Facilities

- to explore the hitherto unknown territories in nuclear chart,
- to approach the limits of beam intensities and experimental precisions,
- to open new domains of physical researches in experiments, and
- to develop new ideas and applications beneficial to the societies.

Typical Beam Parameters From the Booster Ring

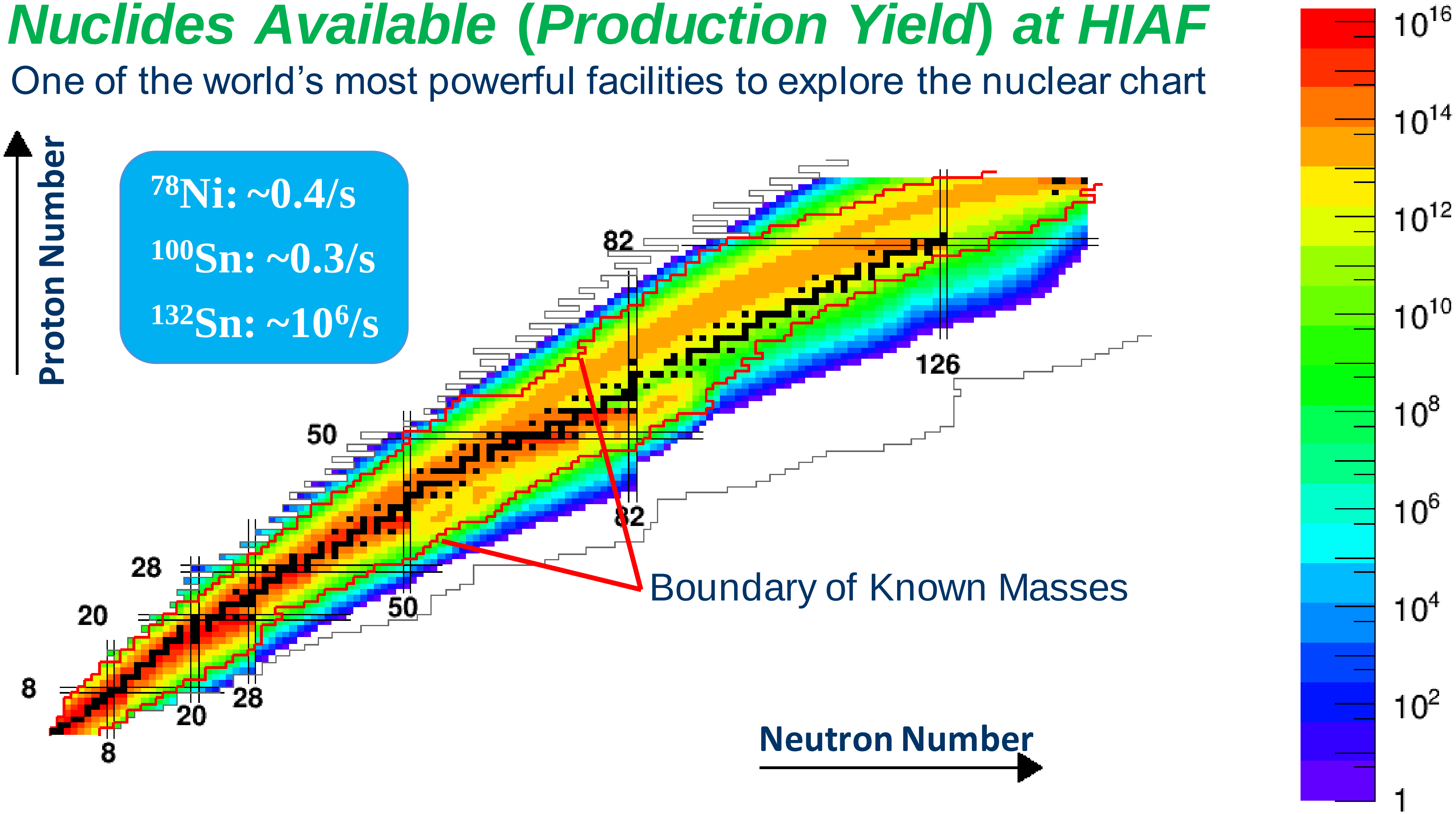
Ions	Energy(GeV/u)	Intensity (ppp)
P	9.3	2.0×10^{12}
$^{18}O^{6+}$	2.6	6.0×10^{11}
$^{78}Kr^{19+}$	1.7	3.0×10^{11}
$^{209}Bi^{31+}$	0.85	1.2×10^{11}
$^{238}U^{34+}$	0.8	1.0×10^{11}

Higher beam energies available on a tradeoff of the beam intensities

Capability of Producing Nuclides

Nuclides Available (Production Yield) at HIAF

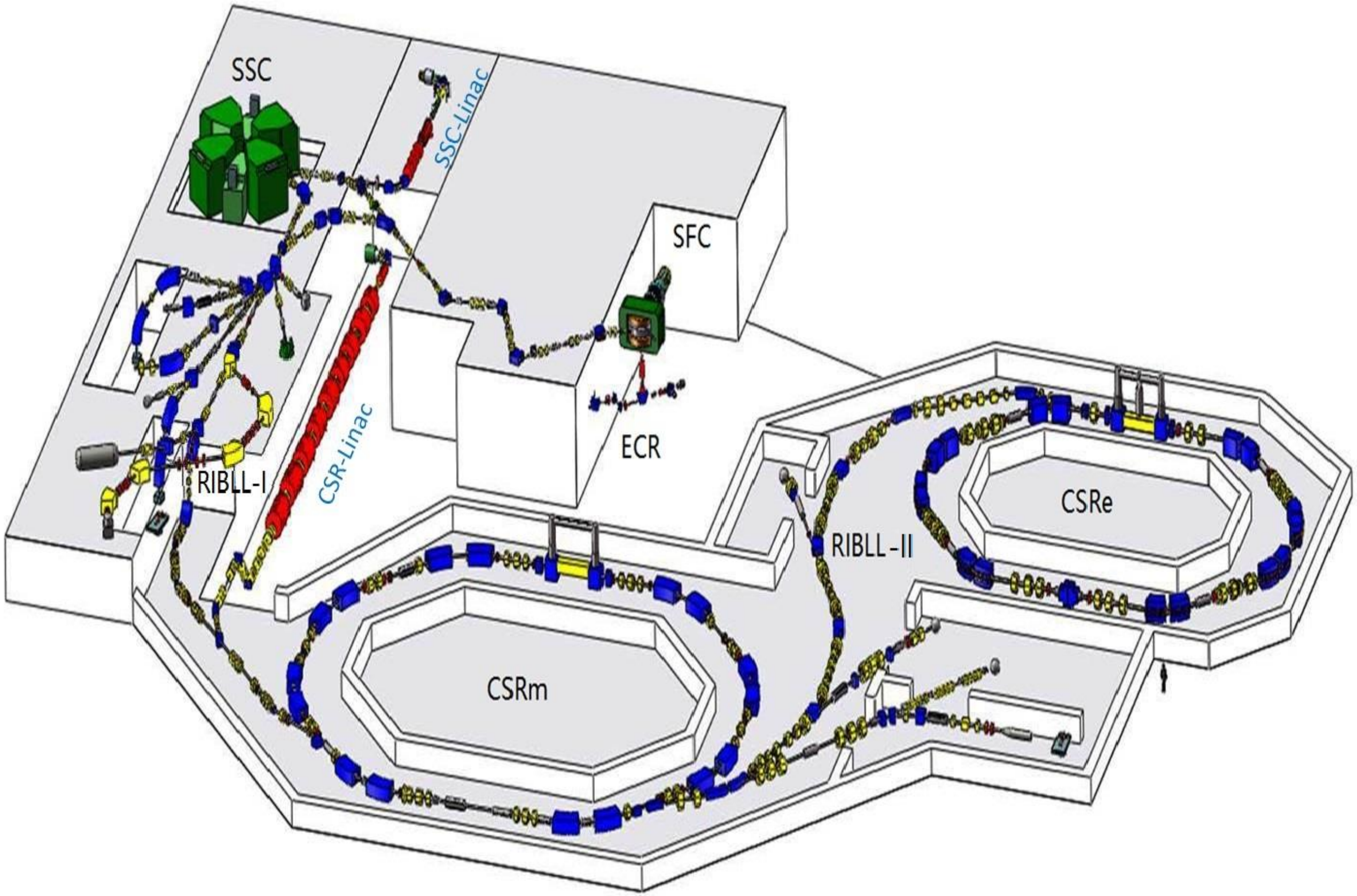
One of the world's most powerful facilities to explore the nuclear chart



Prolific sources of nuclides far away from the stability line will be provided using projectile fragmentation, in-flight fission, multi-nucleon transfer, and fusion reactions. The limits shown are the production rate of one nuclide per day, which enable the "discovery experiments"

R&D on the Key Accelerator Techniques

R&D on the Key Accelerator Techniques



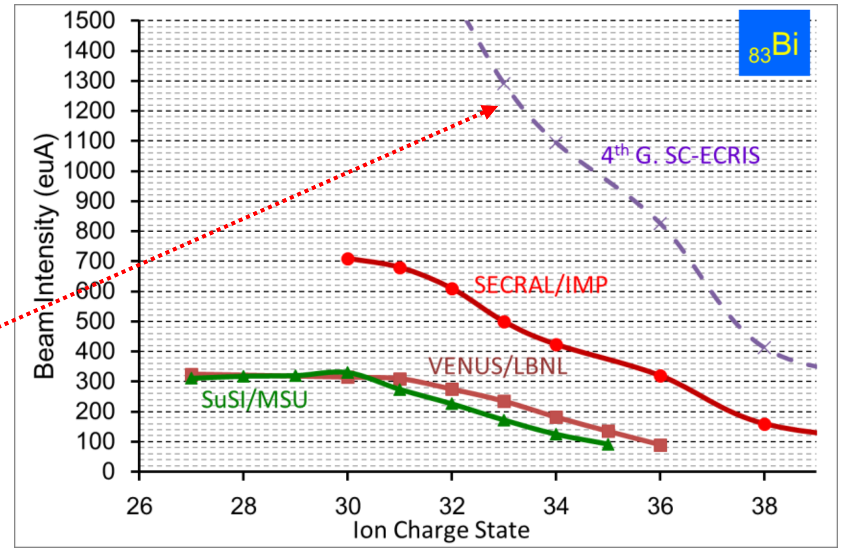
HIAF builds upon the expertise and achievements of the HIRFL

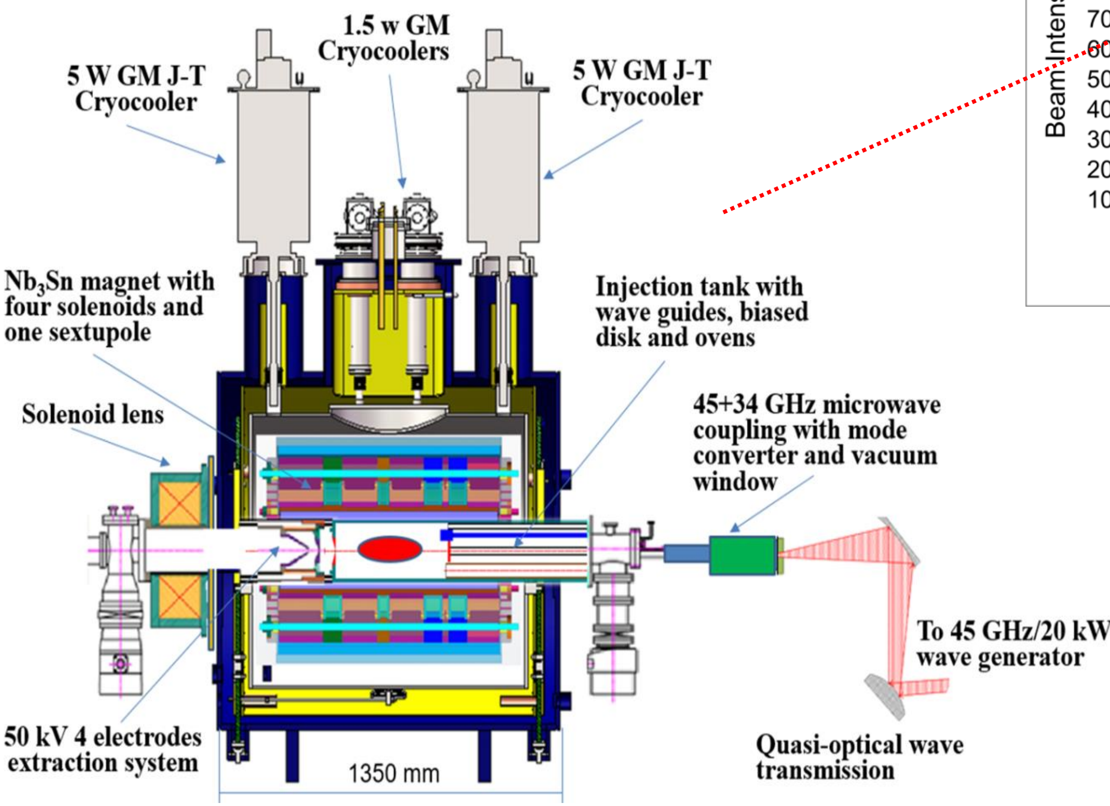
See the talk by L. J. Mao

First 45 GHz ECRIS in the World

Next-generation Type 45 GHz ECRIS

For the very heavy ion beams, such as Bi and U, the existing highly charged ion sources can not meet HIAF requirements



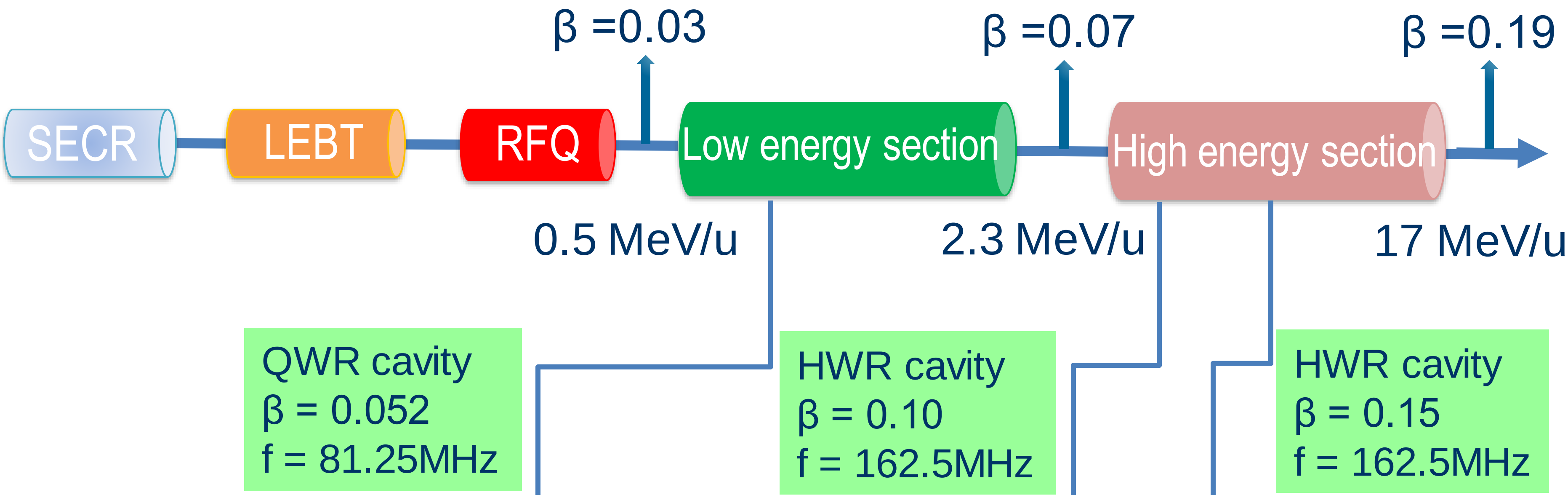


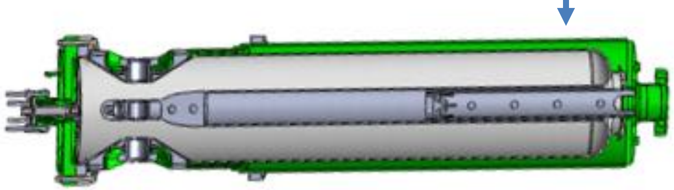
Microwave	45 GHz/20 KW
Magnet conductor	Nb_3Sn
Axial fields (T)	6.5/1.0/3.5
Sextupole field (T)	3.8@r=75 mm
Maximum field (T)	11.8 T
Magnet bore (mm)	Ø161~165
Extraction (kV)	50
Typical beam	1.0 emA U^{34+}

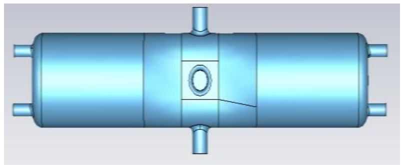
Produce intense highly-charged heavy ions

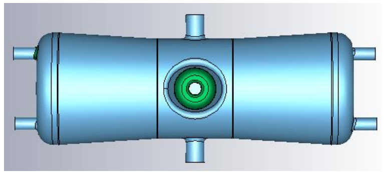
High-power Linac

SRF Cryomodule Design and Prototype Development







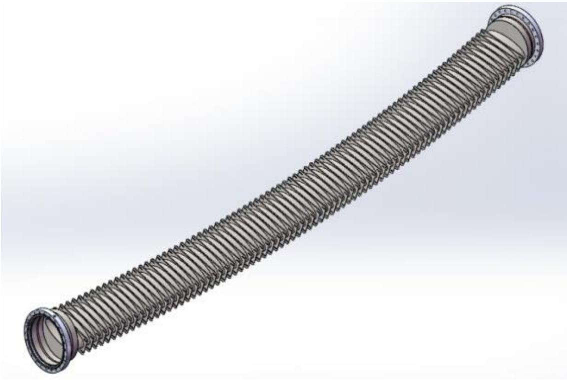


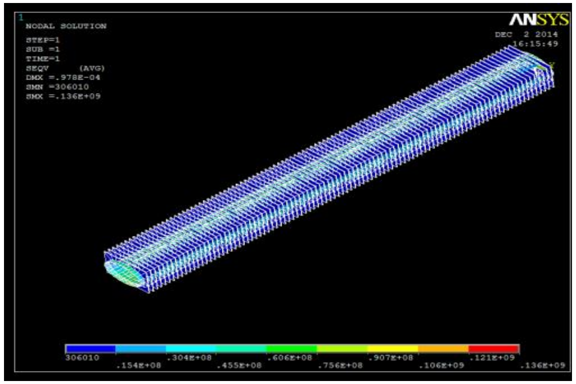
The average uncontrolled beam loss should be limited to below 1 W/m level

Thin Wall Vacuum Chamber Prototype

Prototype of Thin Walled Vacuum Chamber

Due to fast ramping rate operation of BRing, thin walled vacuum chambers are needed for all magnets in order to keep eddy currents at a tolerable level





0.3 mm chamber design

0.3 mm thick vacuum chamber prototype

- Elliptical aperture
- Stainless steel
- Rib supporters in parallel with the magnetic fields

Collimator of Dynamic Vacuum

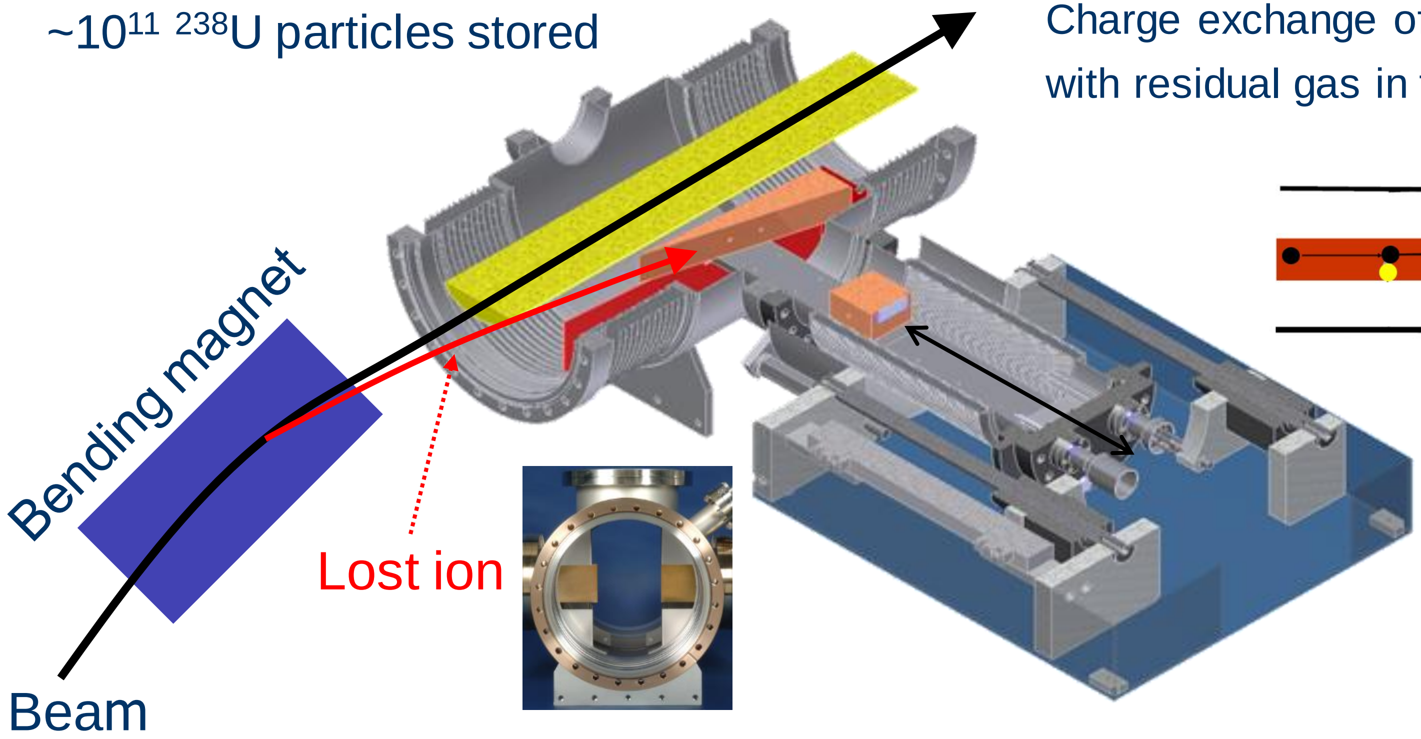
Design of Collimator for High Vacuum at Booster Ring

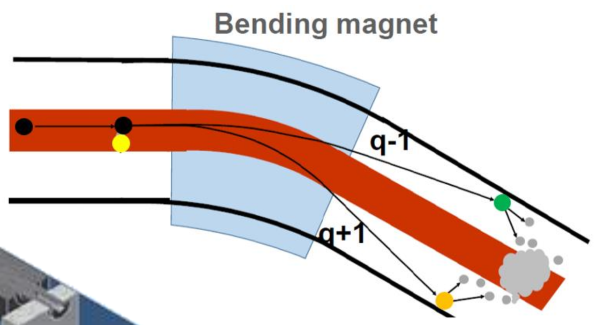
~10^{-11} mbar vacuum in Booster Ring

~10^{11} ^{238}U particles stored

Beam loss mechanism:

Charge exchange of ions due to collision with residual gas in the pipelines





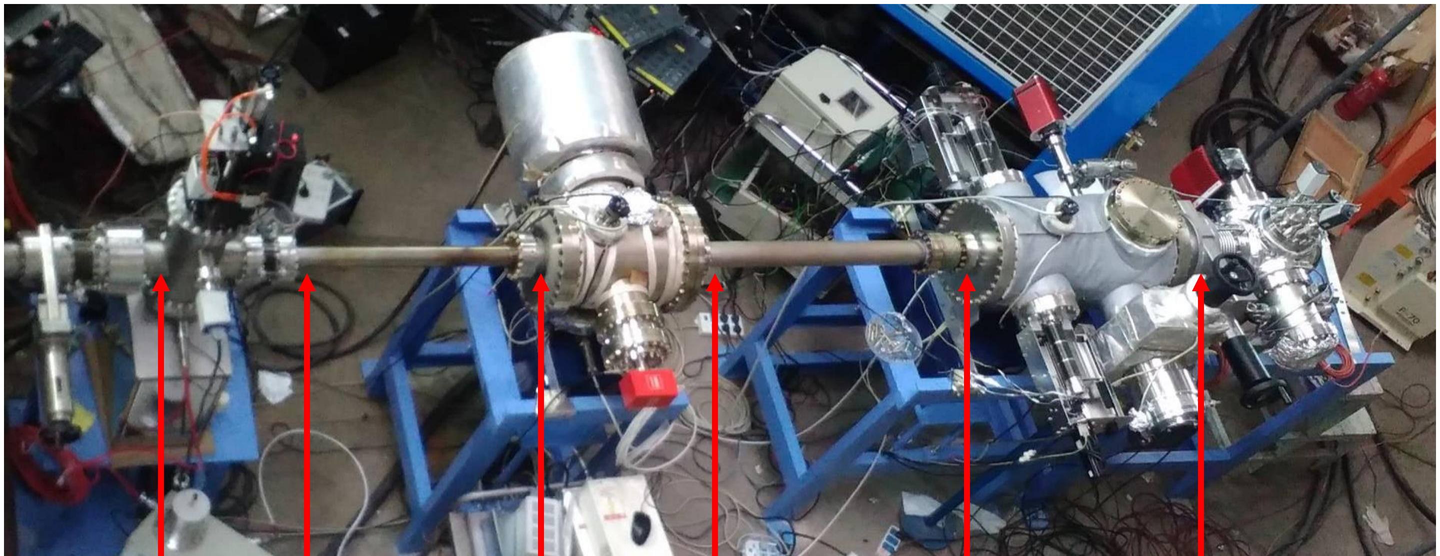
Challenges: to get near 100% collimation efficiency!

A dedicated dynamic vacuum simulation software has been developed in collaboration with GSI for the optimization of the collimator design

Collimator of Dynamic Vacuum

Test of the Collimator Prototype

Test platform for desorption measurement



diagnostic chamber | pump chamber | measurement chamber

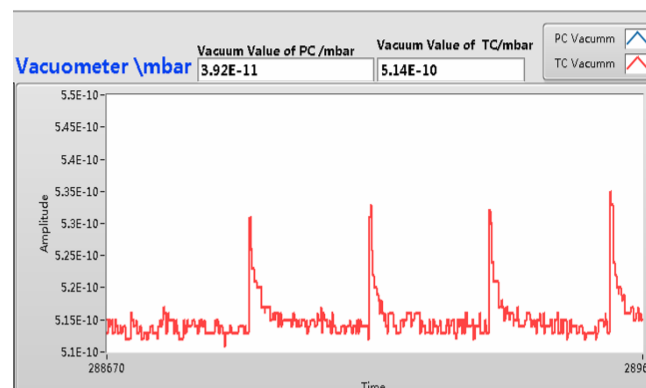
First Beam Test @CSR:

Beam: Sn^{26+}

Injection Energy:3.7 MeV/u

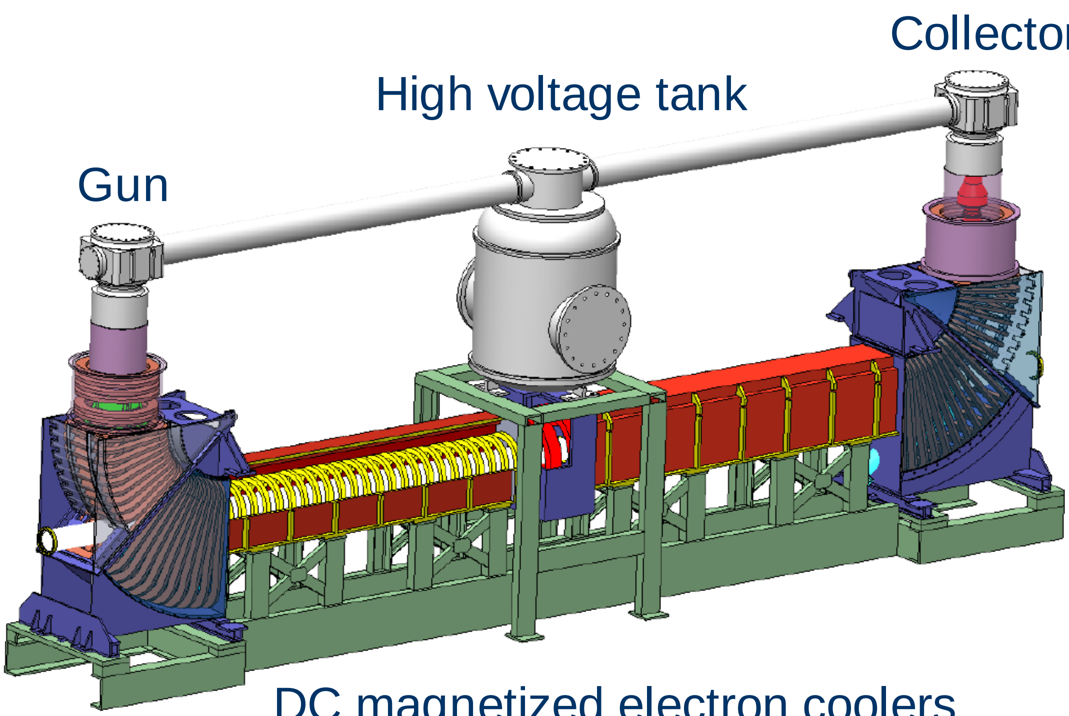
Extraction Energy:150 MeV/u

DCCT: 80 uA ($2*10^7$)



Electron Cooler

Design of Electron Coolers @HIAF



DC magnetized electron coolers

200 keV & 2 A e-cooler at Spectrometer Ring

Well-established electron cooling at existing CSR

Hollow e-beams were obtained at the coolers@CSR, which partially solve the problem of space charge effect and reduce the recombination between the ions and electrons

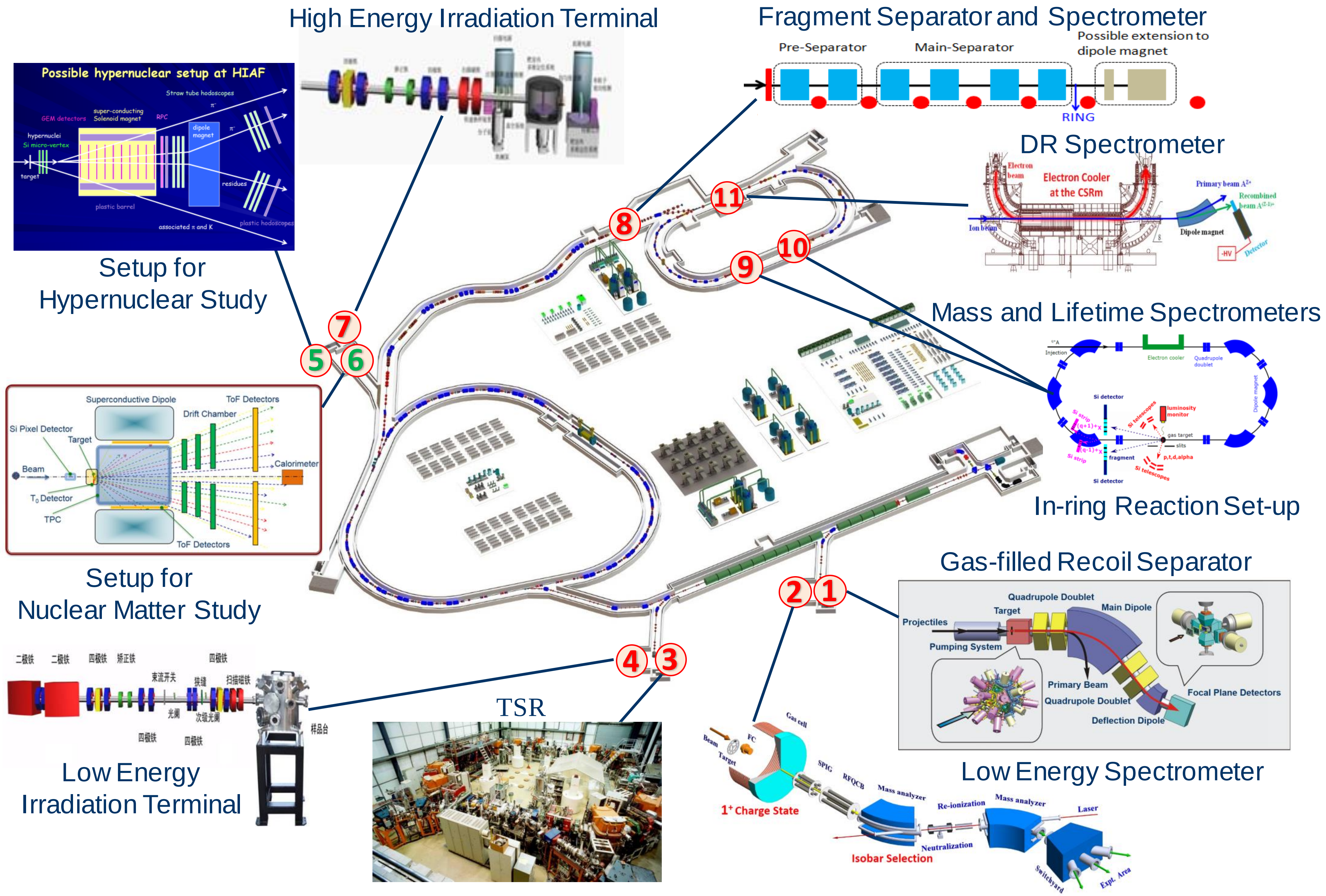
Experimental Setups and Major Physical Aims

Major Physical Aims

Major Physics

- to explore the hitherto unknown territories in nuclear chart,
- to find exotic nuclear properties and recognize the physics behind,
- to understand the origin of chemical elements in the Universe, and
- to depict the QCD phase diagram of nuclear matter

Experimental Setups



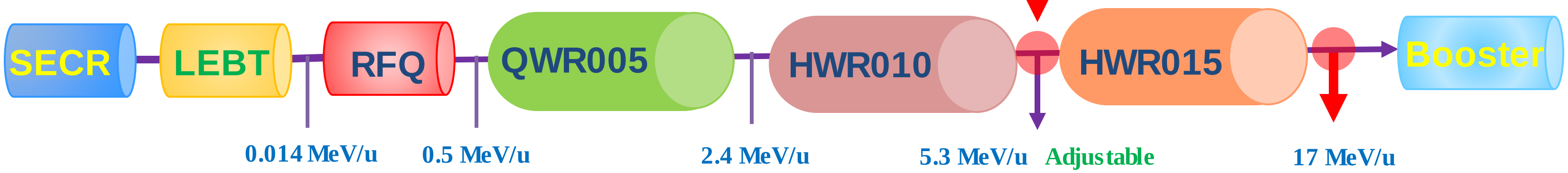
Low Energy Stations

The iLinac works in two modes:

- Pulse Mode: inject beams into the Booster and provide pulsed beams for TSR
- CW Mode: deliver intense heavy-ion beams for low-energy experiments

Ions	Energy (MeV/u)	Intensity (emA)
H_2^+	48	1.0
$^{18}O^{6+}$	36	1.0
$^{78}Kr^{19+}$	30	1.0
$^{209}Bi^{31+}$	30	1.0
$^{238}U^{34+}$	17	1.0

- Fusion Evaporation Reactions
- Multi Nucleon Transfer Reactions

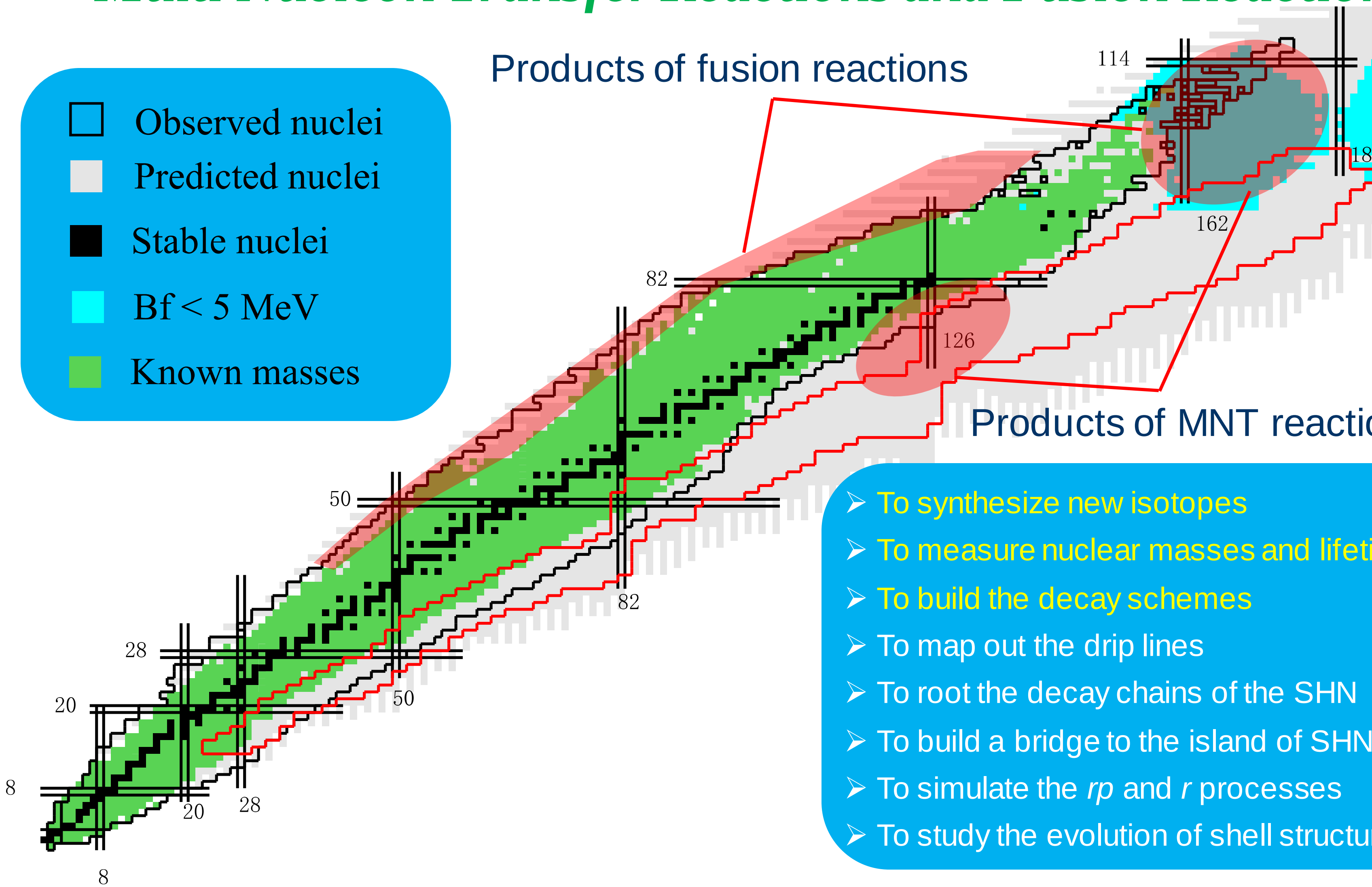


The TSR built by the Max-Planck Institute for Nuclear Physics might be moved to HIRFL and then to HIAF, to conduct investigation of nuclear structure, reactions of astrophysical relevance, and atomic physics

Eur. Phys. J. Special Topics 207, 1-117 (2012)

Experimental Layout @iLinac

Multi Nucleon Transfer Reactions and Fusion Reactions



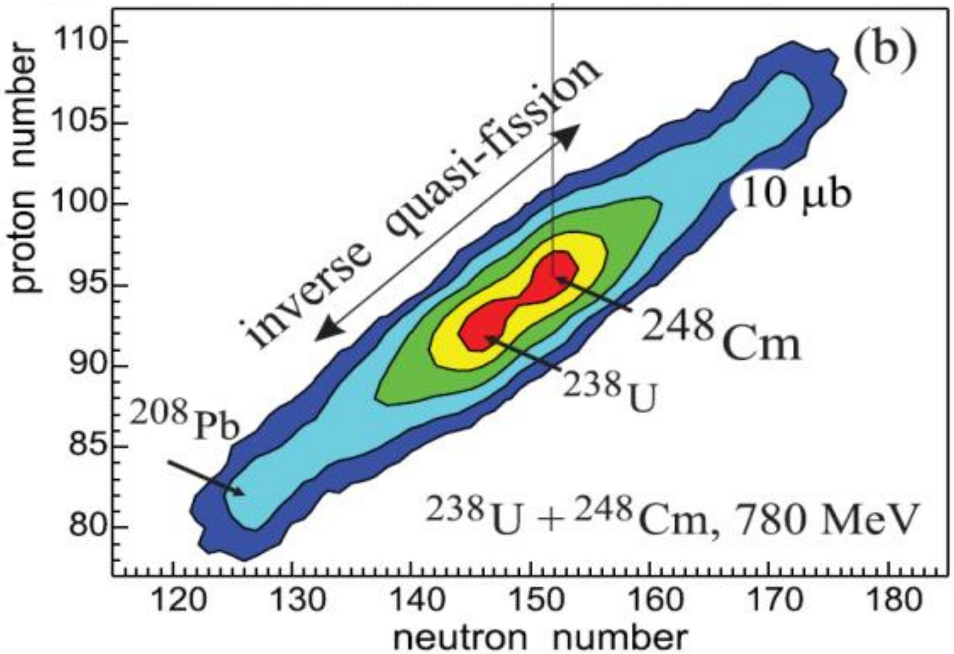
- To synthesize new isotopes
- To measure nuclear masses and lifetimes
- To build the decay schemes
- To map out the drip lines
- To root the decay chains of the SHN
- To build a bridge to the island of SHN
- To simulate the *rp* and *r* processes
- To study the evolution of shell structure

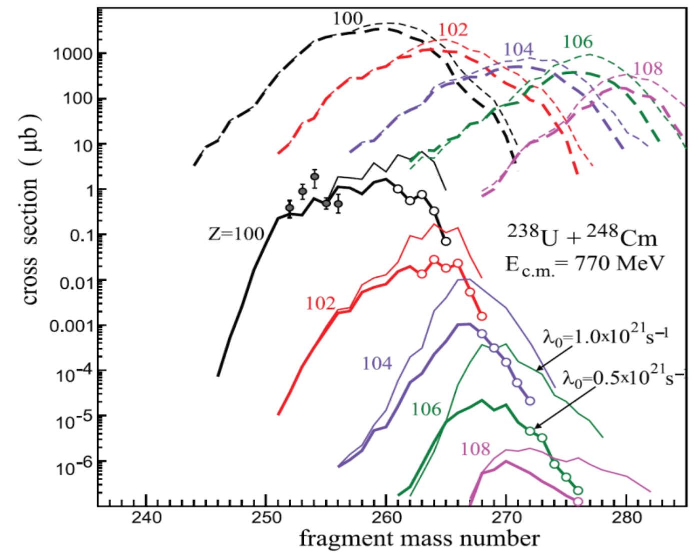
The low-energy intense beams will enable producing very n-deficient nuclei by fusion reactions and particularly heavy and super-heavy n-rich nuclei by multi-nucleon transfer reactions

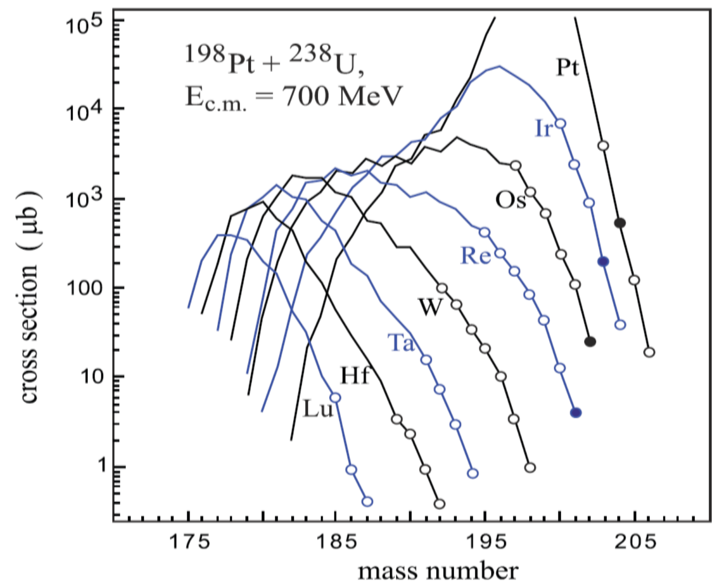
Experimental Layout @iLinac

Multi Nucleon Transfer Reactions

V. I. Zagrebaev et al. PRC 87, 034608 (2013).





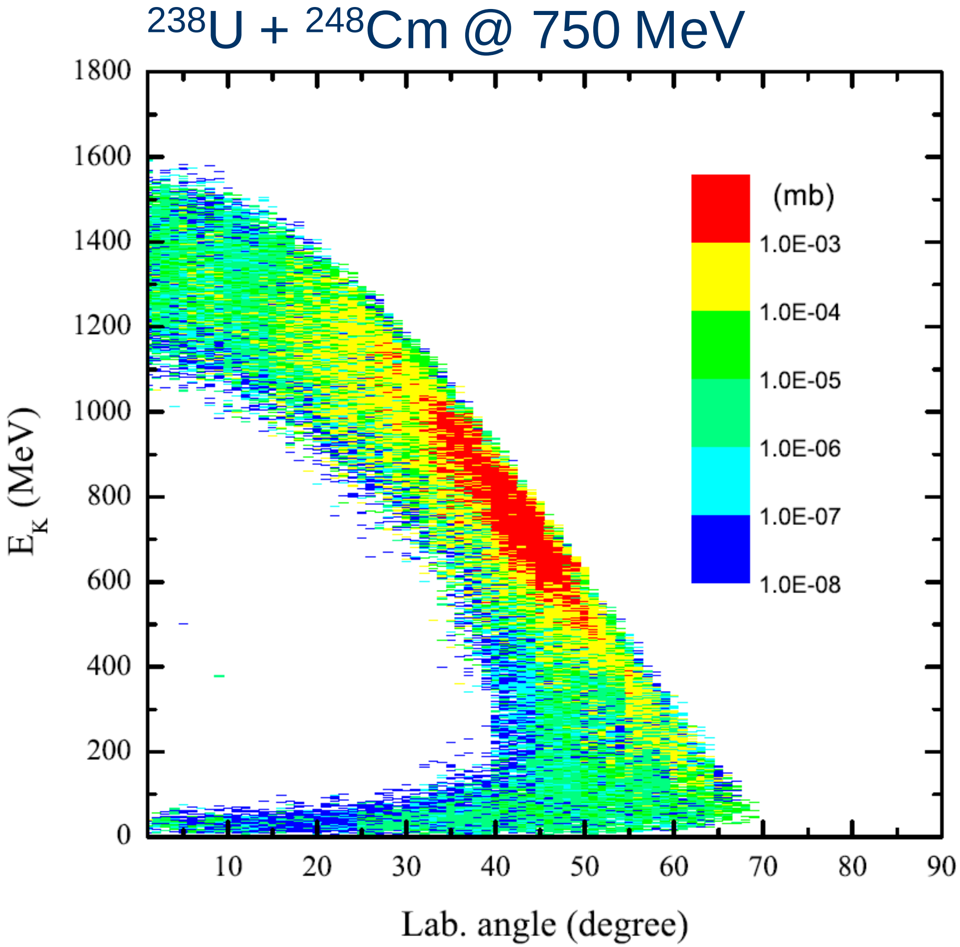


MNT reactions would be the optimum method to produce n-rich nuclei (SHN and *N*~126)

- Bridge to “the Island of Super-heavy Stability”
- Understand the *rp* astrophysical process
- Study the evolution of *N*=126 magic number

Experimental Layout @iLinac

Multi Nucleon Transfer Reactions



Very broad distributions of recoil energy and angle, and charge state!

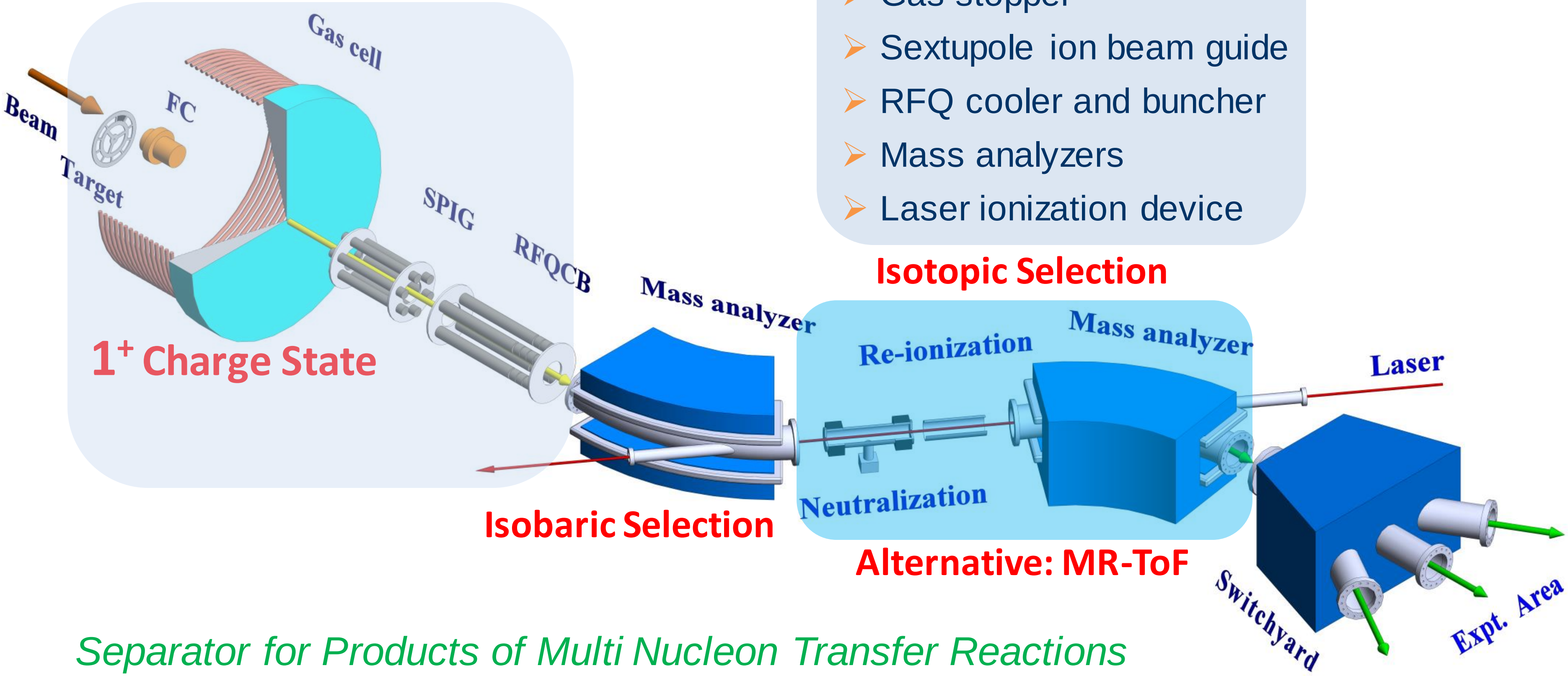
Experimental challenge: How to separate the products efficiently?

Experimental Setups @iLinac

Separation and Identification of Products from MNT Reactions

30 KV High Voltage Platform

- Rotating target system
- Gas stopper
- Sextupole ion beam guide
- RFQ cooler and buncher
- Mass analyzers
- Laser ionization device



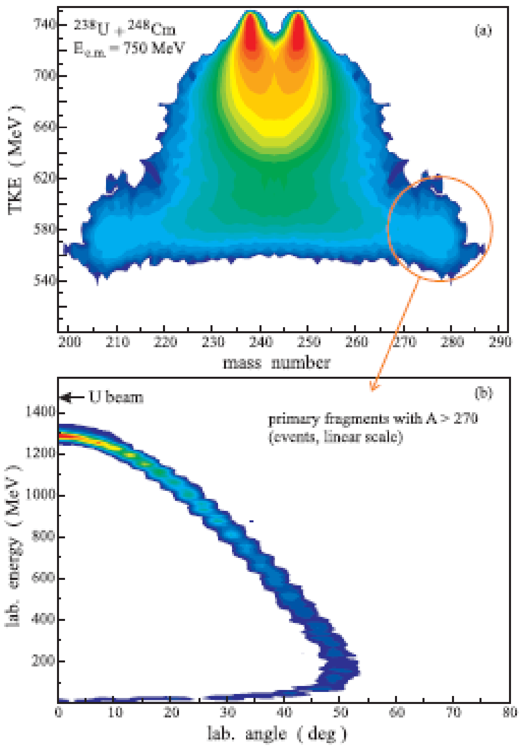
Separator for Products of Multi Nucleon Transfer Reactions

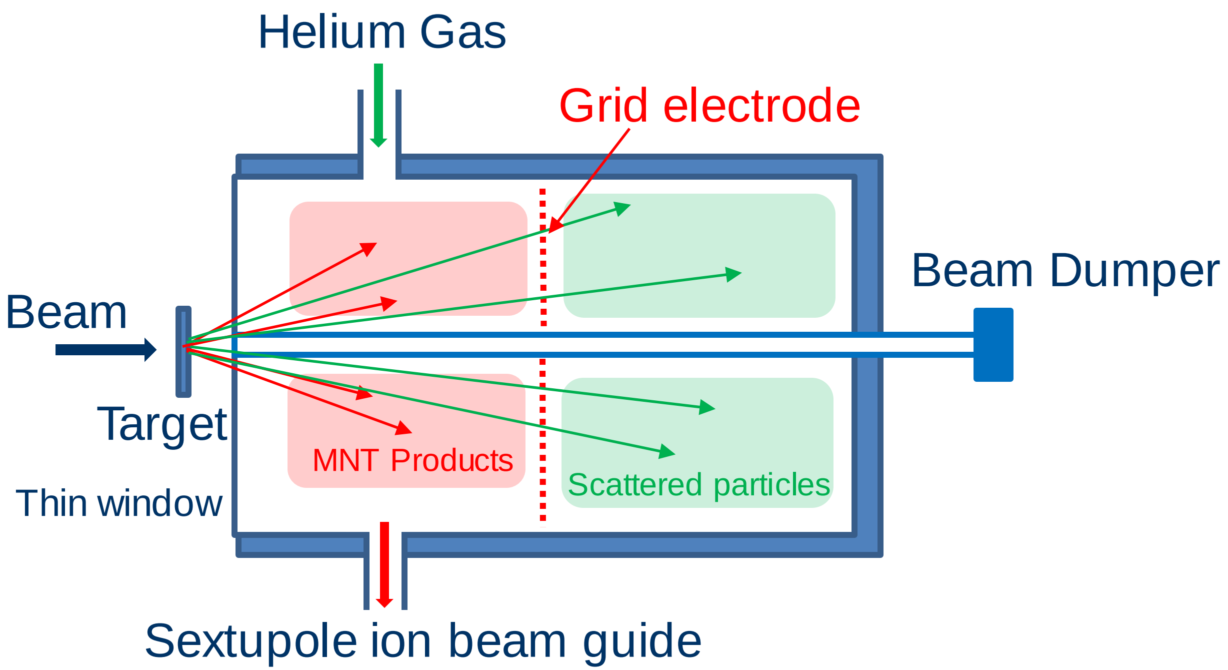
The separator provides pulsed low-energy, high-quality n-rich beams with mass and atomic numbers well identified, and then distributes the beams to various measuring apparatuses

Experimental Setups @iLinac

How to suppress the intense projectiles from elastic scattering?

$^{238}U + ^{248}Cm$



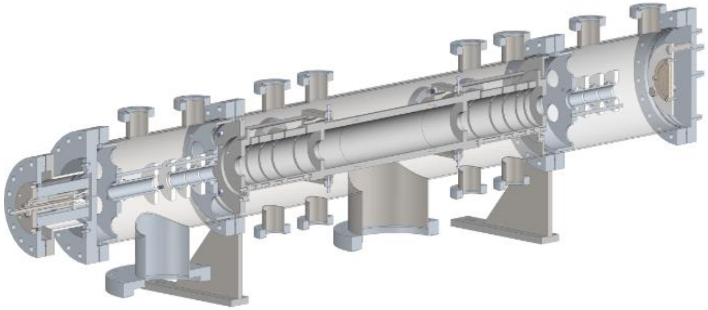


For $^{238}U + ^{248}Cm$, the kinetic energies of the target-like products are much lower than those of the scattered projectiles, and therefore their penetrating ranges in the gas cell are very different

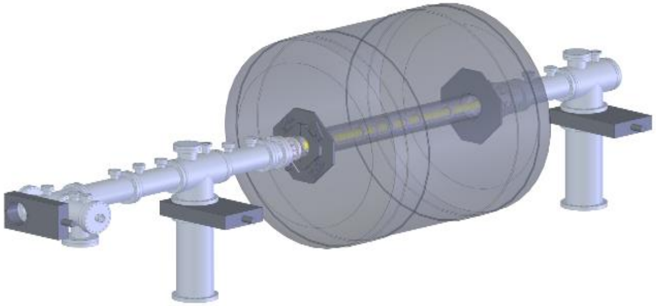
The grid electrode separates the gas cell into two parts, and the scattered projectiles deposit their major energy in the right part, hopefully reducing the plasma effect in the left part

Experimental Setups @iLinac

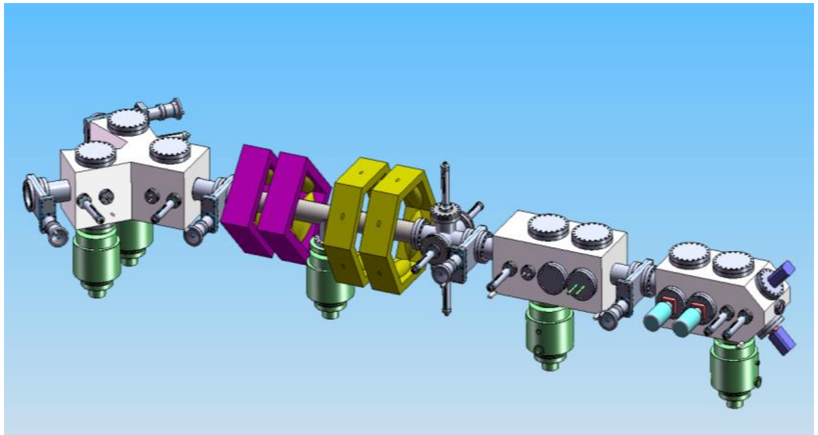
Experimental Devices Coupled to the Separator



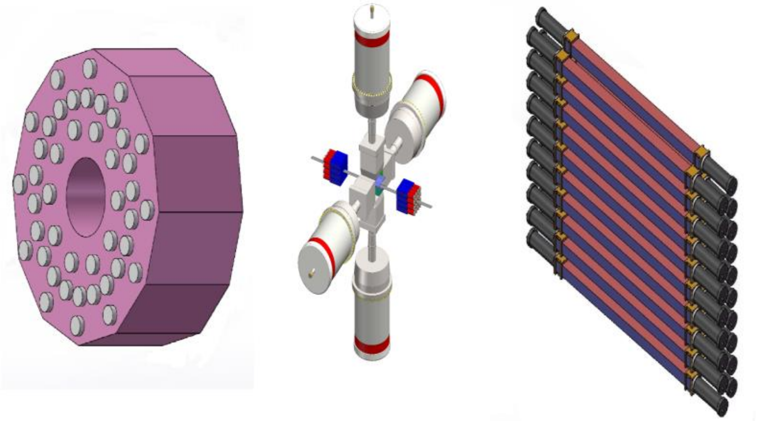
MR-ToF Mass Spectrometer



Ion Trap



Collinear Laser Spectrometer

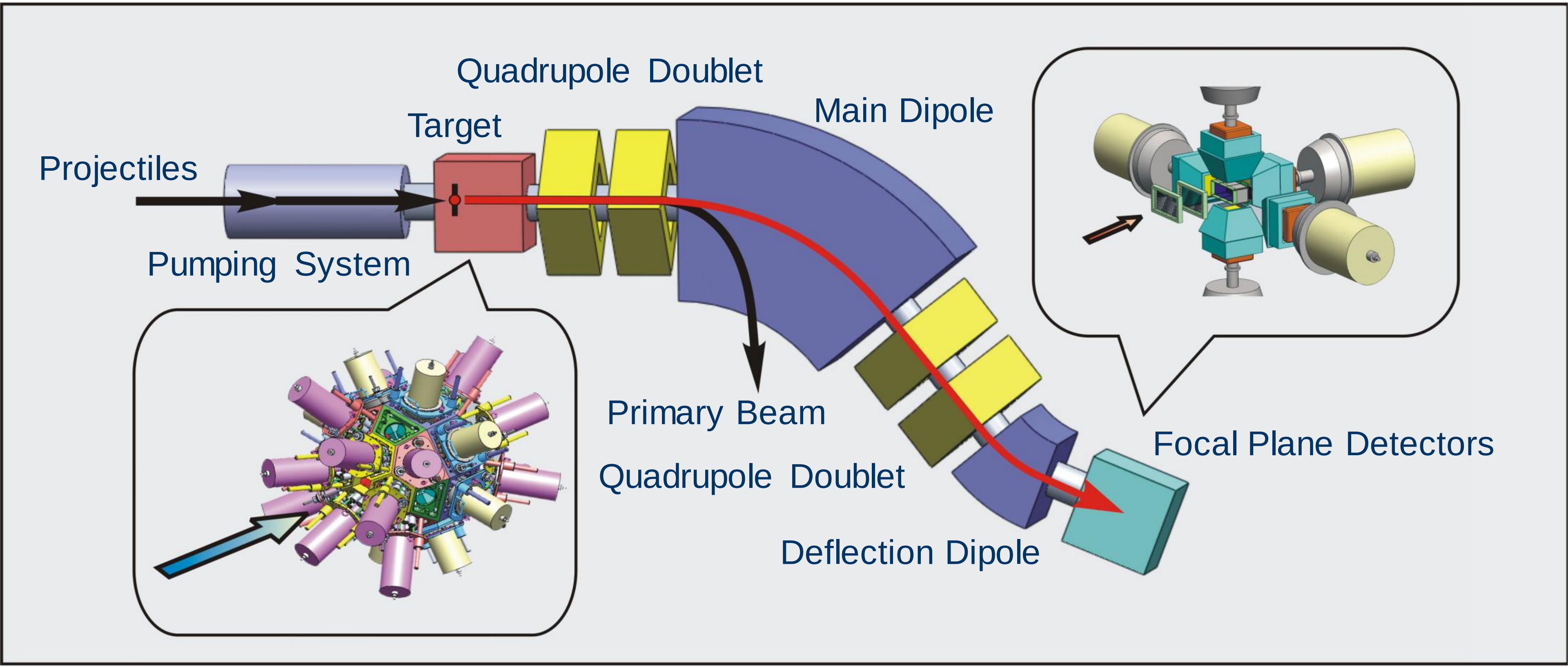


Decay Spectrometer

- For neutron-rich nuclides: Synthesis of new isotopes, study of decay properties, measurement of nuclear mass and lifetime, and determination of charge radii and nuclear moments
- For heavy and super-heavy atoms: Atomic structure (ionization potential, excitation spectra)

Experimental Setups @iLinac

Exploitation of Low-energy Fusion Evaporation Reactions



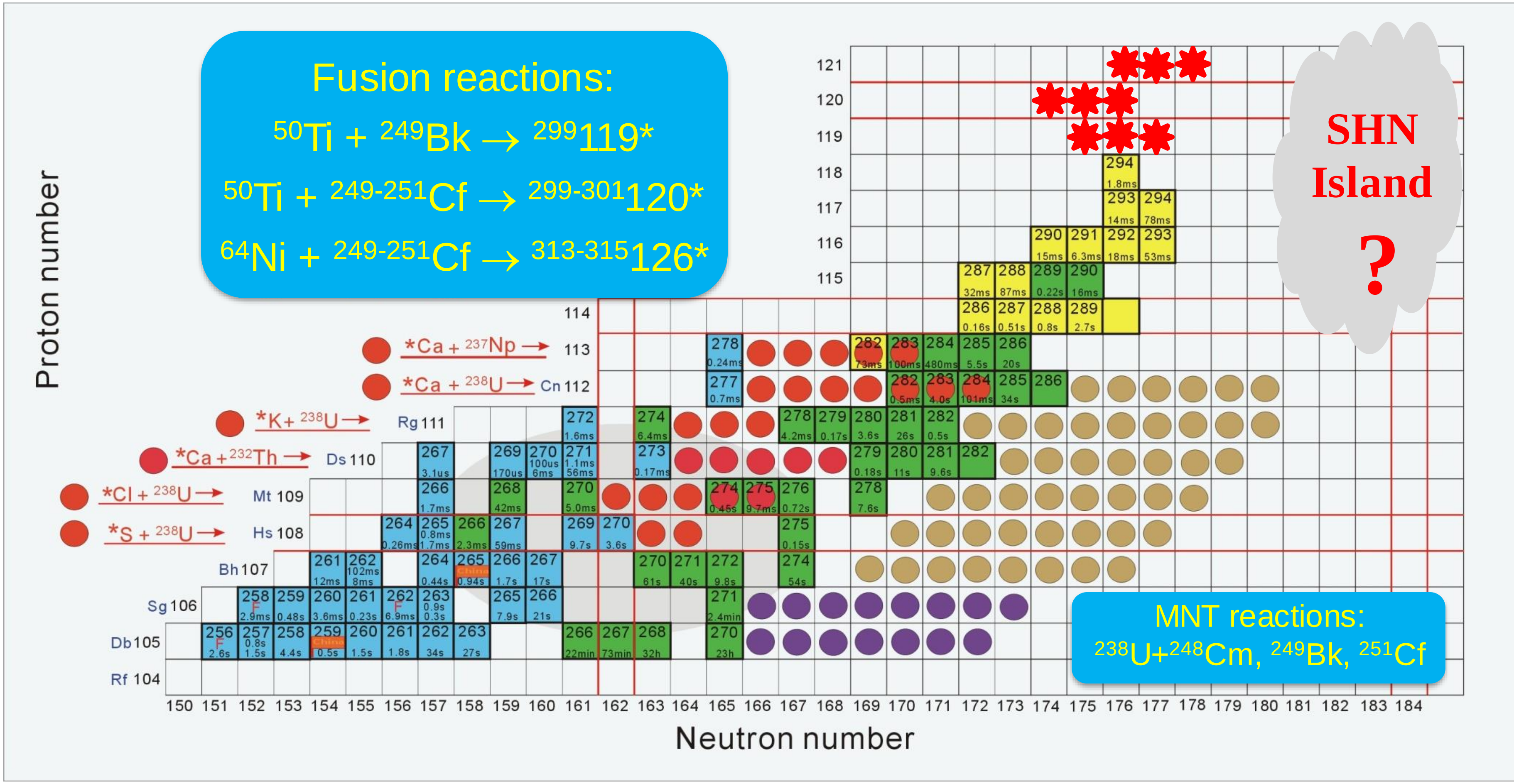
Gas-filled Recoil Separator: A fast and high-efficient separator for fusion products

By coupling with a gas cell followed by a RFQ cooler and buncher, pulsed high-quality, low-energy beams are available for mass spectroscopy and collinear laser spectroscopy

Major Physics @iLinac

Is there a limit, in terms of proton and mass numbers, to the existence of nuclei?

Unprecedented opportunities for the synthesis of new isotopes and structure studies

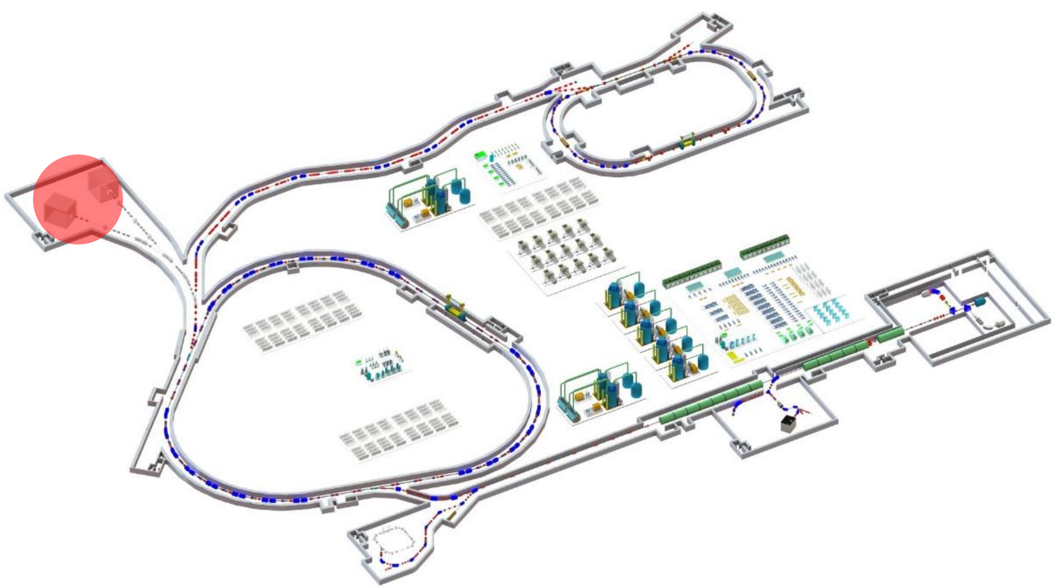


- Search for new elements and isotopes
- Bridge to the Island of Super-heavy Stability
- Measure nuclear masses and lifetimes
- Perform chemistry with the heaviest elements
- Hunt for new K-isomers
- Obtain information on the single particle states

Experimental Layout @Booster Ring

High Energy Stations

- Stable beams directly provided by the Booster
- DC-type (slow) extraction from the Booster



The high-energy stable beams are ideal to produce hypernuclei and nuclear matter

We are now seeking for financial support to build the detector systems

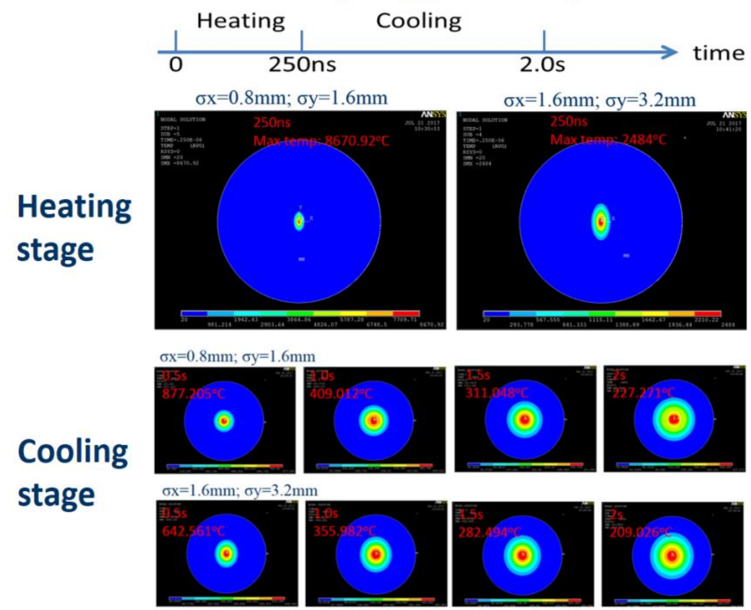
See the talks by T. Saito

Typical Beam Parameters From BRing@HIAF

Ions	Energy(GeV/u)	Intensity (ppp)
P	9.3	2.0×10^{12}
$^{18}O^{6+}$	2.6	6.0×10^{11}
$^{78}Kr^{19+}$	1.7	3.0×10^{11}
$^{209}Bi^{31+}$	0.85	1.2×10^{11}
$^{238}U^{34+}$	0.8	1.0×10^{11}

Fast extraction (pulse width 250ns/3s)

^{238}U: 800AMeV@10^{11}ppp, Carbon target



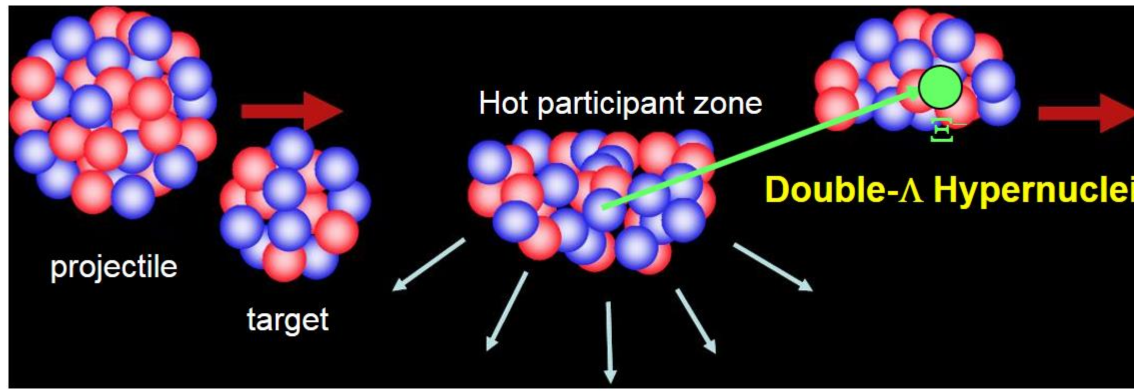
Carbon target sustainable to intense beams.

Setups and Physics @Booster Ring

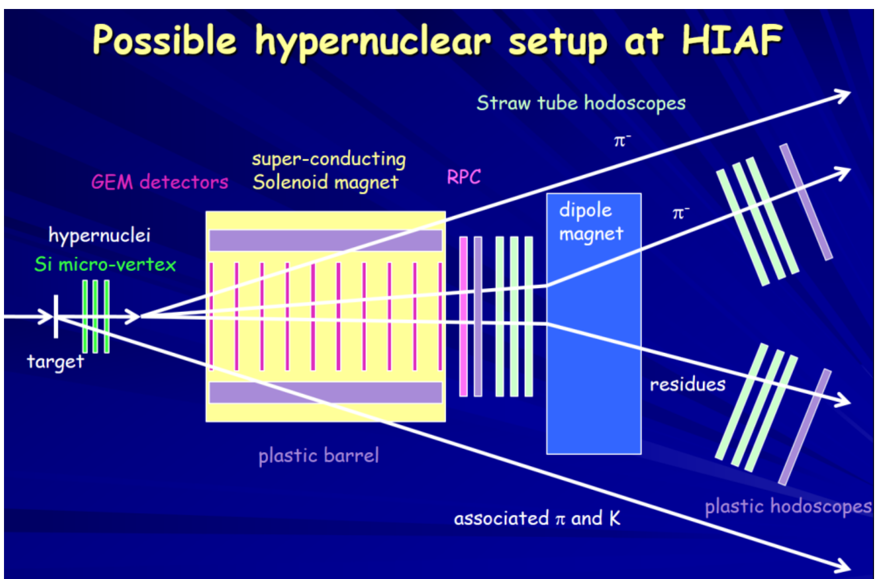
Hypernuclei with Double strangeness

- Hypernuclei are produced by coalescence of Λ in high-energy peripheral collisions
- In high-energy (>3.75 GeV/u) collisions, double-Λ hypernuclei can be produced!
- To measure the lifetime and binding energy of hypernuclei

Production threshold of Ξ^- hyperon (dss): 3.747 A GeV
Ξ^-p ->$\Lambda\Lambda$



High energy & moderate intensity



Expected reconstructed rate

- ^{20}Ne + ^{12}C at 4.25 A GeV
- Beam intensity: 10^7 /s

	Single-Λ hypernuclei	Double-Λ hypernuclei
per day	8 X 10^5	9 X 10^1
per week	6 X 10^6	6 X 10^2
per month	2 X 10^7	3 X 10^3

Cost of ~60 million CNY supported likely by CAS

Courtesy: T. Saito

Setups and Physics @Booster Ring

Open New Domain: Hypernuclei with Double Strangeness

Production of ΛΛ hypernuclei

- d + Ξ^- -> $n\Lambda\Lambda$
- t + Ξ^- -> $nn\Lambda\Lambda$
- ^3He + Ξ^- -> $^4_{\Lambda\Lambda}H$
- ^4He + Ξ^- -> $^5_{\Lambda\Lambda}H$
- ^6Li + Ξ^- -> $^7_{\Lambda\Lambda}He$
- ^7Li + Ξ^- -> $^8_{\Lambda\Lambda}He$
- ^9Be + Ξ^- -> $^{10}_{\Lambda\Lambda}Li$
- ^{10}Be + Ξ^- -> $^{11}_{\Lambda\Lambda}Li$
- ^{10}B + Ξ^- -> $^{11}_{\Lambda\Lambda}Be$
- ^{11}B + Ξ^- -> $^{12}_{\Lambda\Lambda}Be$
- ...

Decay of ΛΛ hypernuclei

- $n\Lambda\Lambda$ -> $^3He + \pi^- + \pi^-$
- $nn\Lambda\Lambda$ -> $^4He + \pi^- + \pi^-$
- $^4_{\Lambda\Lambda}H$ -> $p + {}^3He + \pi^- + \pi^-$
- $^5_{\Lambda\Lambda}H$ -> $p + {}^4He + \pi^- + \pi^-$
- $^7_{\Lambda\Lambda}He$ -> $^7Be + \pi^- + \pi^-$
- $^8_{\Lambda\Lambda}He$ -> $^4He + {}^4He + \pi^- + \pi^-$
- $^{10}_{\Lambda\Lambda}Li$ -> $^{10}B + \pi^- + \pi^-$
- $^{11}_{\Lambda\Lambda}Li$ -> $^{11}B + \pi^- + \pi^-$
- $^{11}_{\Lambda\Lambda}Be$ -> $^{11}C + \pi^- + \pi^-$
- $^{12}_{\Lambda\Lambda}Be$ -> $^{12}C + \pi^- + \pi^-$
- ...

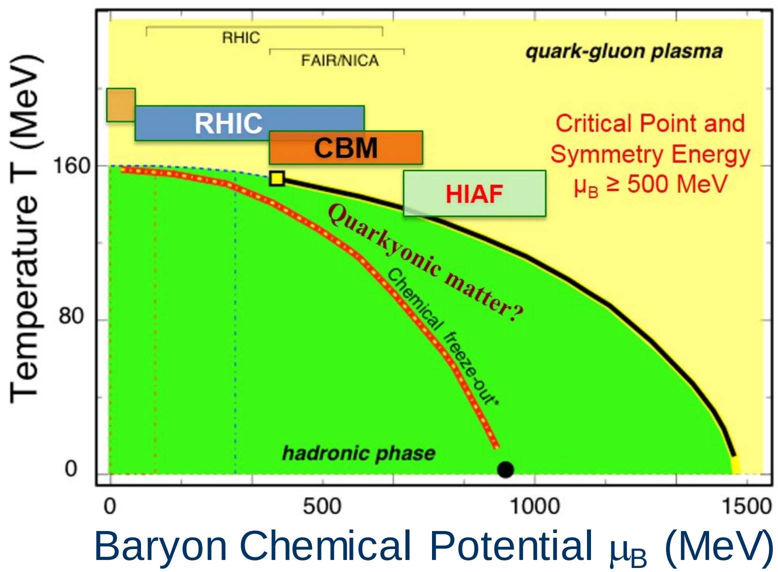
The invariant mass method is used to identify the precursor hypernuclei

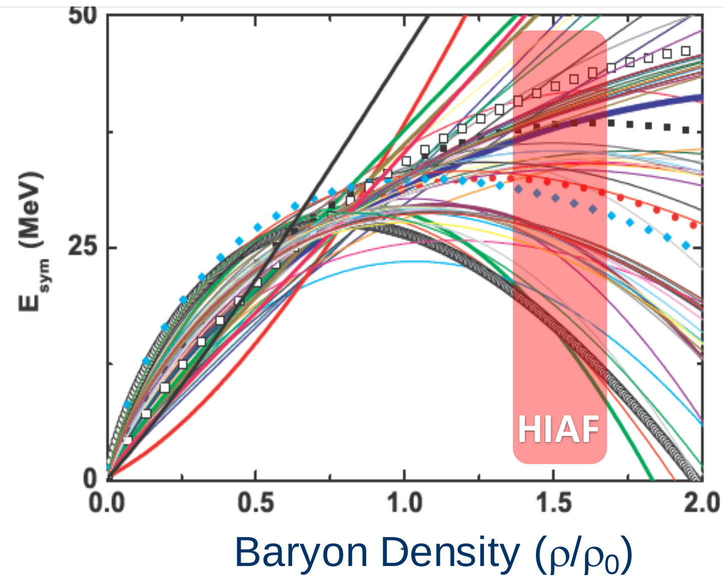
The half-life can be deduced from the distribution of the decay vertex

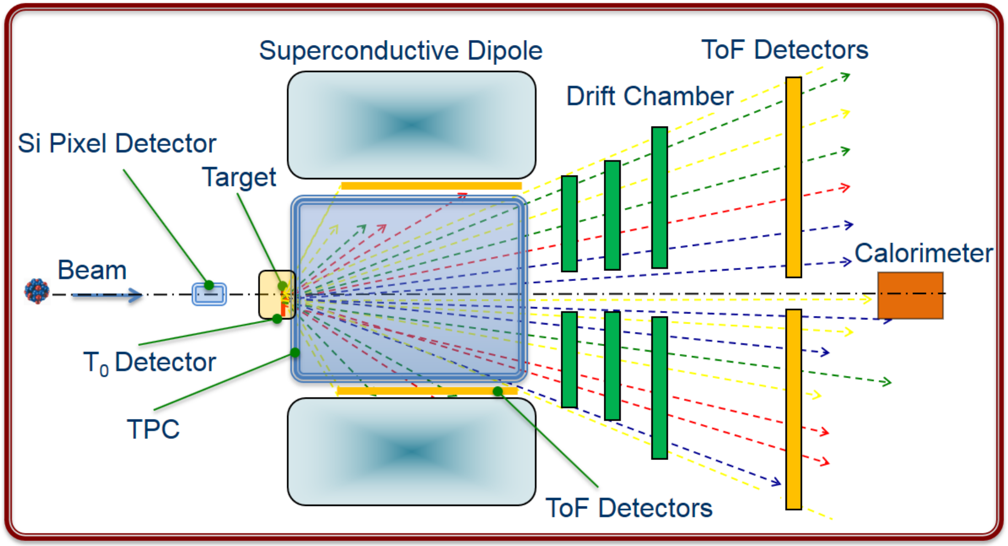
Courtesy: T. Saito

Setups and Physics @Booster Ring

Study of the QCD Phase Structure and Symmetry Energy







Cost of ~100 million CNY supported hopefully by CAS

Moderate temperature, high density nuclear matter can be produced at HIAF energies, complementary to the studies at RHIC and CBM

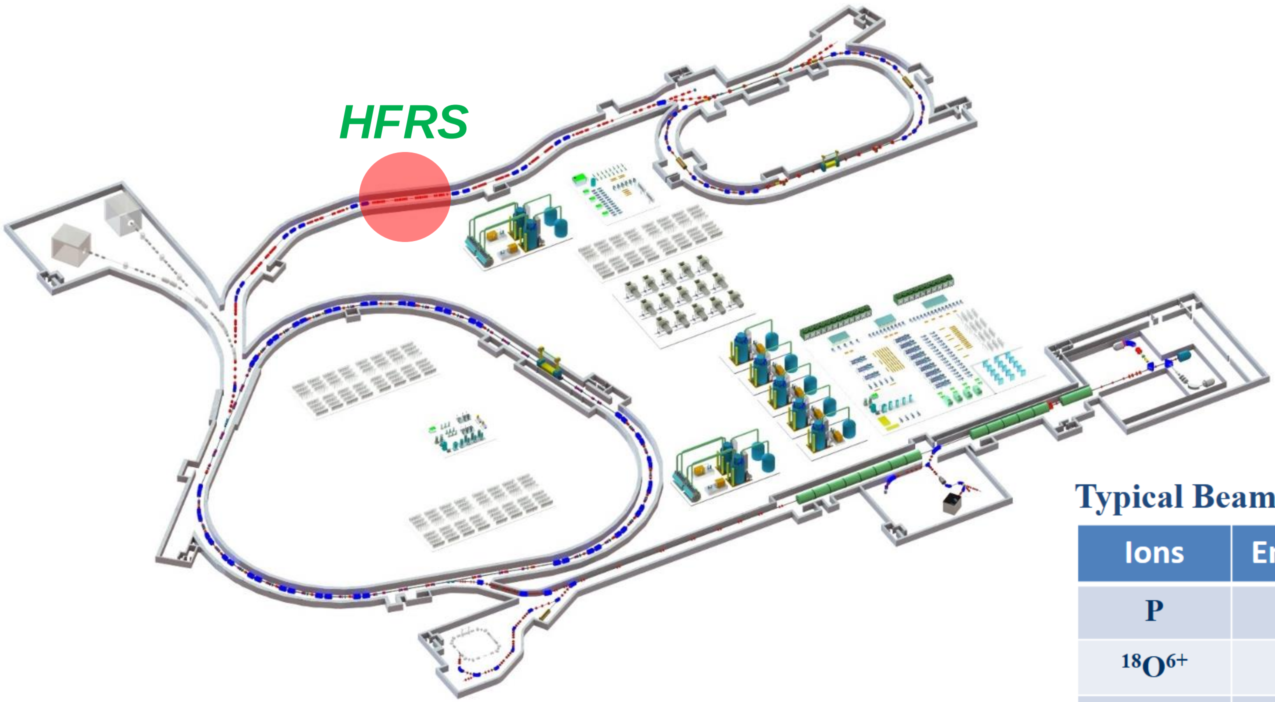
CEE Collaboration (CSR External-target Experiment) was established, including over 10 institutions in China

Courtesy: N. Xu *Science, 2011,* ***332:*** *1525.*

Experimental Layout @HFRS

High Energy Fragment Separator (HFRS)

- Radioactive ion beams are produced by HFRS
- Separator and injector for the Spectrometer Ring using fast extracted beams
- Separator and spectrometer using slow extracted beams from the Booster



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Physics @ HFRS

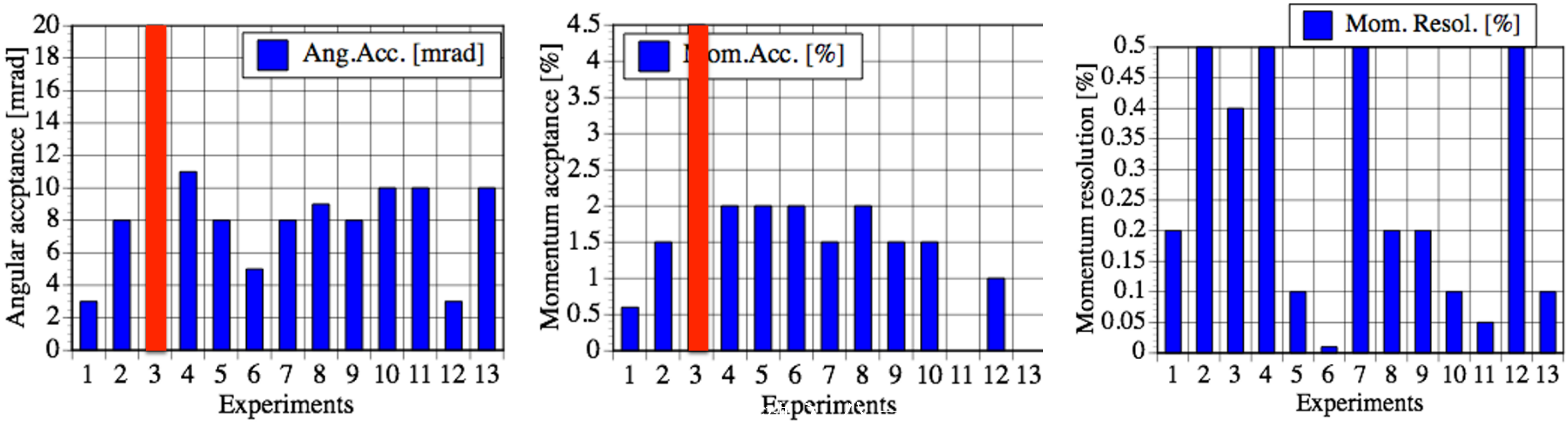
Physics Cases @HFRS

1. New isotopes in the south east of ^{208}Pb (Projectile fragmentations of ^{208}Pb and ^{238}U)
2. Neutron dripline up to Ni isotopes (Projectile fragmentations of Kr and Xe)
3. New isotopes by U fission (In-flight fission of U)
4. New isotopes using two step projectile fragmentations
5. Synthesis of neutron rich hypernuclei
6. Study of tensor interactions: a basic change in structure model
7. Particle decay in flight of unbound nuclei
8. Nuclear matter radii (Interaction cross sections)
9. Nuclear proton radii (Charge changing cross sections)
10. Charge exchange reactions and β decay of r-process nuclei
11. Nucleon excitations in nuclei
12. Giant resonance of neutron rich nuclei
13. Elastic scattering and transfer reactions
14. Spectroscopy of meson-nucleus bound system
15. …

Various experiments can be done at HFRS

Experimental Setups @ HFRS

Requirements from Physics



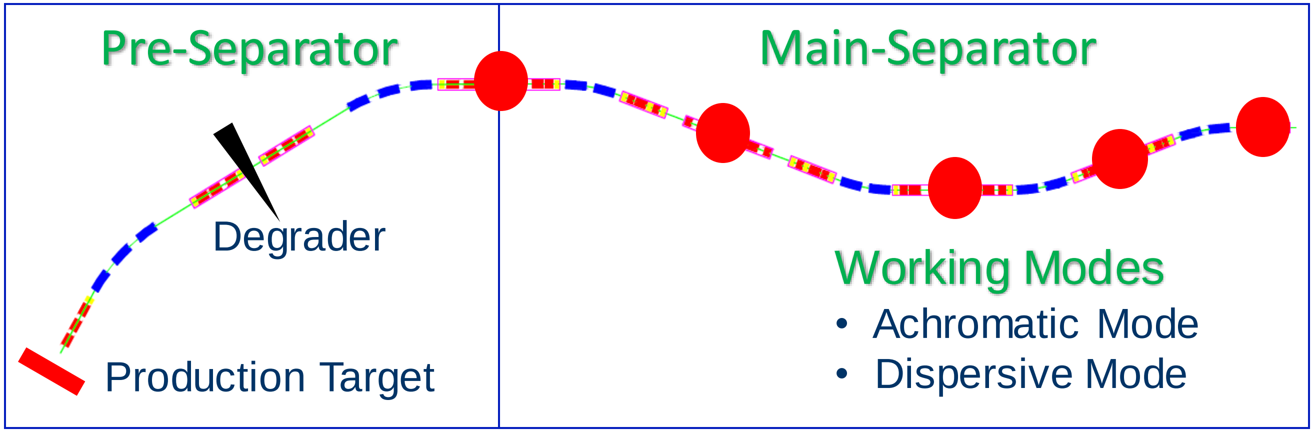
Production, Magnetic Rigidity, Agular and Momentum Acceptance, and Momentum Resolution

- Synthesis of neutron rich hypernuclei
- Nucleon excitations in nuclei
- Giant resonance of neutron rich nuclei
- Spectroscopy of meson-nucleus bound system
- …

} Bρ=25Tm

Unique Experiments at FAIR and HIAF!

Experimental Setups @HFRS

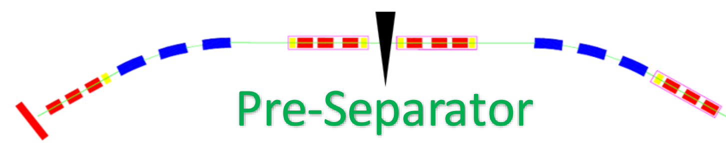


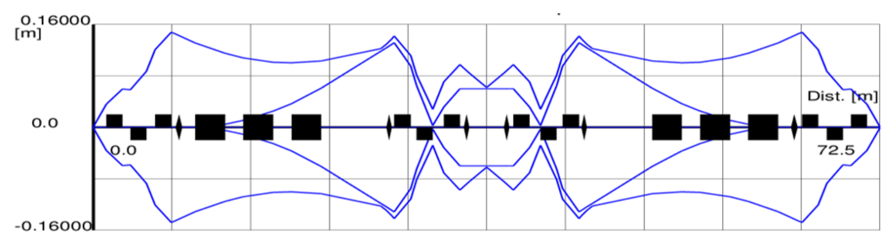
- Secondary target
- Tertiary target
- Degrader stations
- Detector systems
- Experimental areas

Separator + Spectrometer

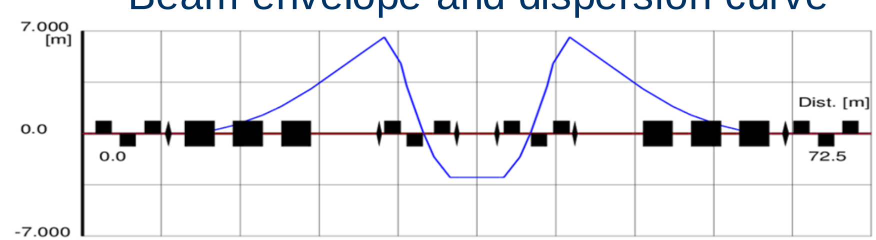
Characteristics of HFRS

Max. magnetic rigidity	25 Tm
Angular acceptance	± 30 mrad (x) ± 15 mrad (y)
Momentum acceptance	± 2.0%
Momentum resolution	750, 700, 1100
Total length	180 m



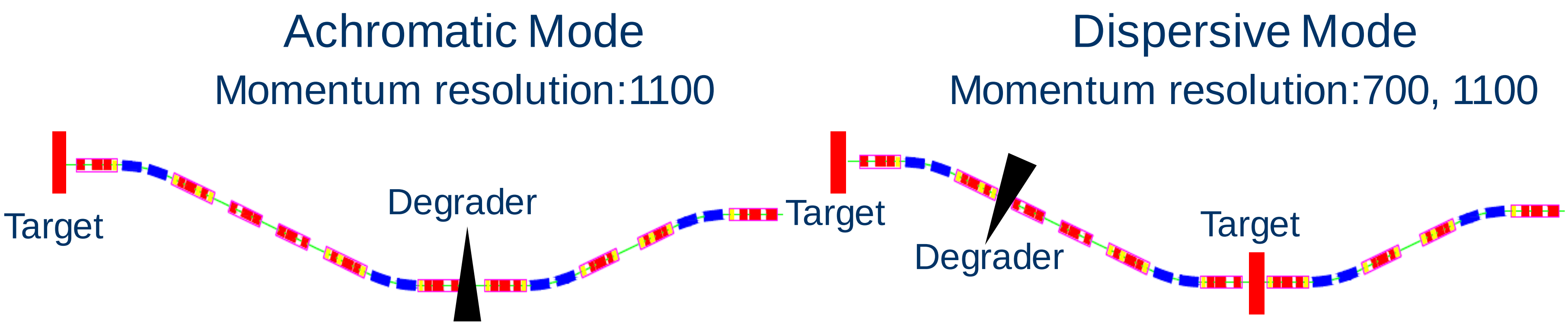


Beam envelope and dispersion curve



Experimental Setups @HFRS

Main-Separator: Separator + Spectrometer



The peculiarities of the HFRS:

- A maximum magnetic rigidity of up to 25 Tm, and thus high-energy secondary beams available with energies over 2 GeV/u
- High primary-beam suppression power and high separation power of nuclides up to *Z*=92, and fully stripped ions of all elements available
- Versatile spectrometer modes by different combinations of separator sections

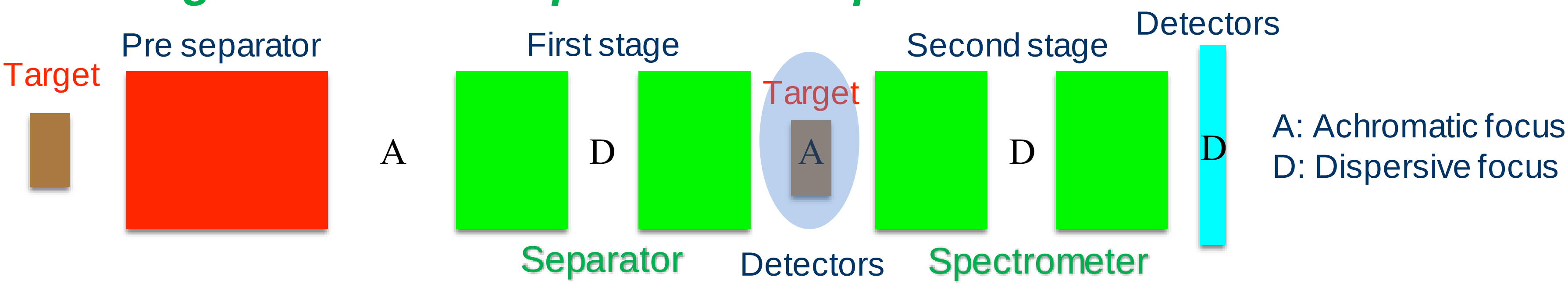
Bρ=25Tm

Unique Experiments

- Synthesis of neutron rich hypernuclei
- Nucleon excitations in nuclei
- Giant resonance of neutron rich nuclei
- Spectroscopy of meson-nucleus bound system

Major Physics @HFRS

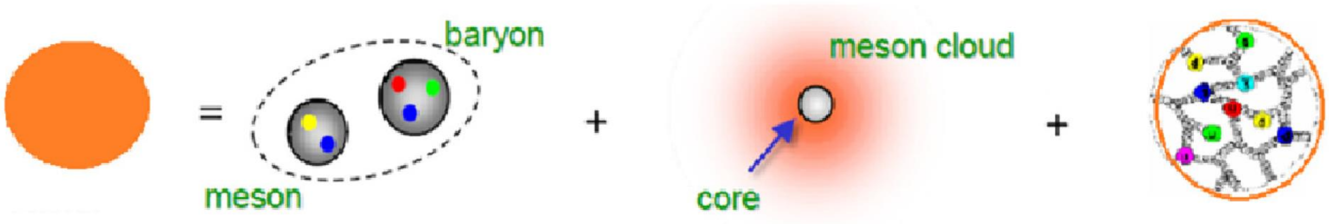
High-resolution Separator and Spectrometer



In charge-exchange reactions, Δ-resonances in nuclei can be produced

The Δ-resonance is a $\Delta S = 1$, $\Delta I = 1$ spin- and isospin-flip intrinsic excitation of the nucleon

Courtesy: H. Lenske



$$|N^*\rangle = |MB\rangle + |qqq\rangle|\pi\pi K\bar{K}...\rangle + |qqq\rangle|q\bar{q}...\rangle|gg...\rangle$$

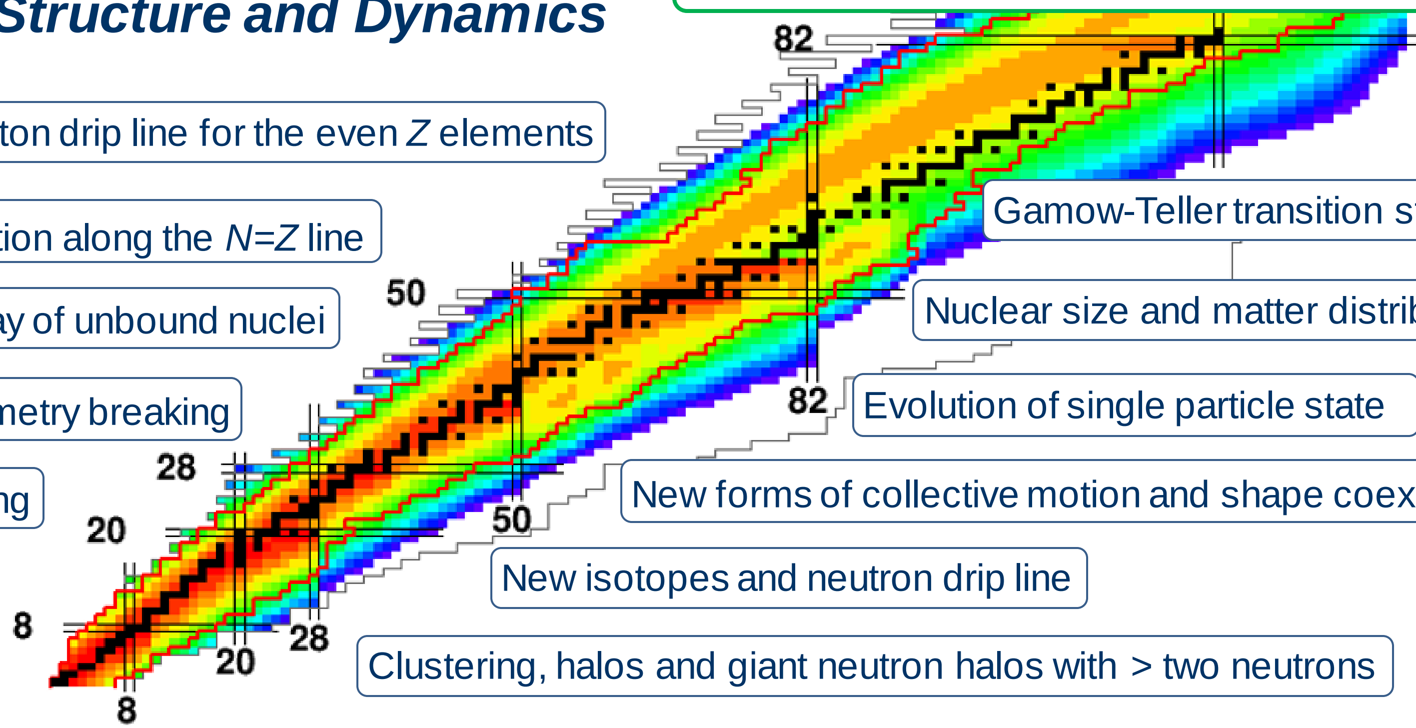
Are the masses and lifetimes of N*-resonances modified in nuclear medium? How deep is the N*-nucleus potential? What is the isospin dependence of resonance potentials? …

The setup can be extended to study of meson-nucleus bound system and neutron-rich hypernuclei

Major Physics @HFRS

To explore the hitherto unknown territories and find new phenomena

Nuclear Structure and Dynamics



- What are the limits to nuclear existence (particularly in the neutron rich side)?
- What are new forms of nuclear matter to appear far from the stability line?
- How do the quantum levels evolve into the very neutron rich regions?
- What are new forms of collective motion far from the stability line?
- What do dynamical symmetries appear in exotic nuclei (particularly along the *N*=*Z* line)?
- …

Revealing Tensor Force

The tensor forces are essential to bind nucleons together in light nuclides, but they are not treated explicitly in models such as mean field models and shell models

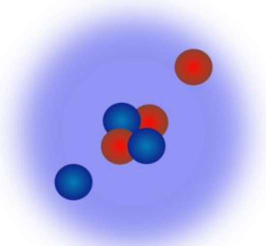
The pion interaction:

$$\vec{\sigma}_1 \cdot \vec{q}\vec{\sigma}_2 \cdot \vec{q} = \frac{1}{3}q^2 S_{12}(\hat{q}) + \frac{1}{3}\vec{\sigma}_1 \cdot \vec{\sigma}_2 q^2$$

The tensor force is as important as the central forces!

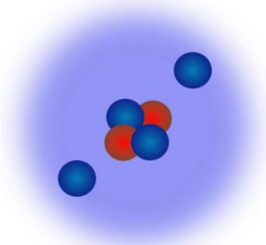
In a three-body model

^{6}Li



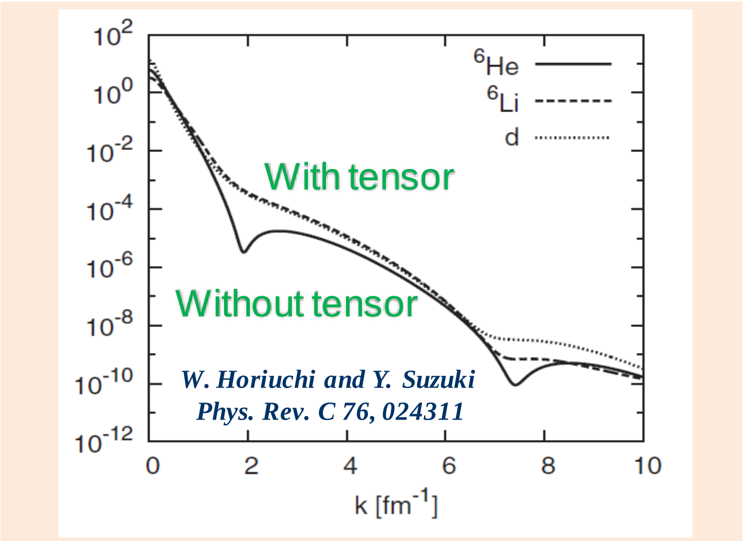
$\alpha + n + p$

^{6}He



$\alpha + n + n$

The tensor force leads to a strong correlation between a *np* pair and high-momentum nucleons in nuclei. While the high-momentum nucleon is picked up by a particle, the correlated nucleon may be emitted and measured using (*p*, *pd*), (*p*, *nd*), and (*d*, *pt*) reactions



The momentum distribution of relative motion of the two nucleons in ^{6}Li and ^{6}He, reflecting the effect of tensor forces

Proposed by I.Tanihata and S.Terashima

Nuclear Matter and/or Charge radii

Measurements of nuclear matter and/or charge radii provide the most original evidences for neutron and proton halos, neutron skins, and new magic numbers

Nucleon distributions or radii

Total interaction cross sections

Elastic proton scattering

Proton distributions or radii

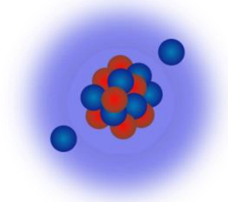
Isotope shifts

Electron scattering

μ atom

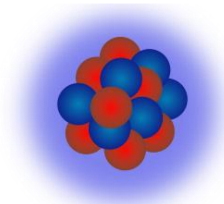
Charge changing cross sections

Halo



- Halos in heavier nuclides
- Giant neutron halos with > two neutrons
- Deformed halos
- Coupling of continuum and discrete states

Neutron distributions or radii



Skin

- Nuclear size evolution of n-rich nuclides
- New shell closures in n-rich regions
- Constrains on nuclear theories
- EOS for cold asymmetric nuclear matter

The equation of state (EOS) for cold asymmetric nuclear matter:

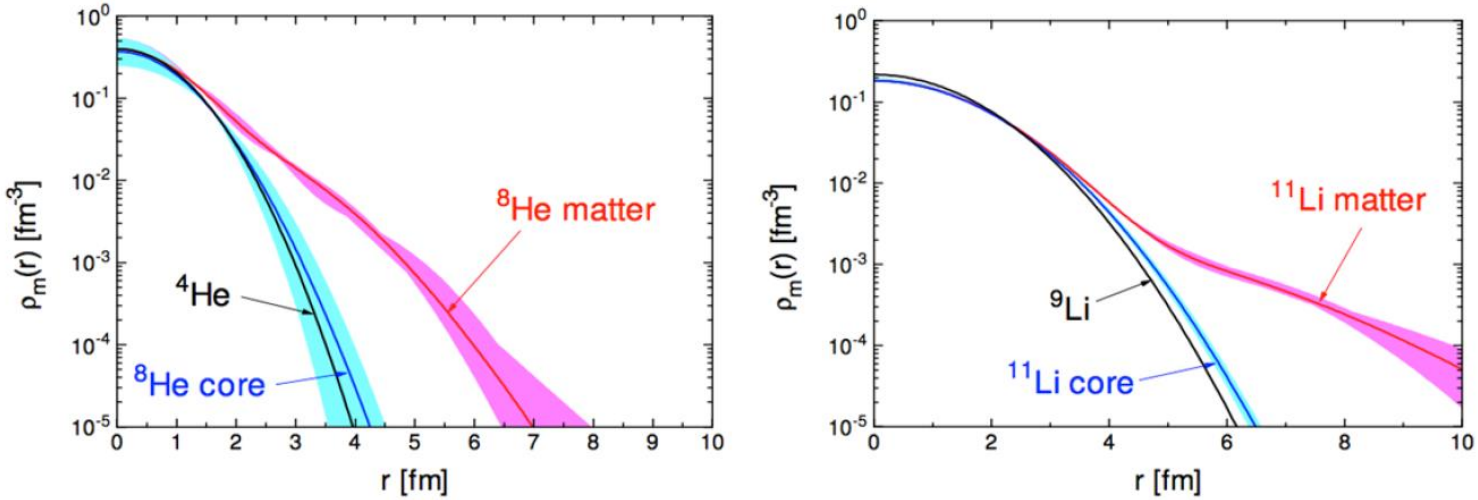
$$E(\rho, \delta)=E(\rho,0)+\delta^2 E_{sym}(\rho)+O(\delta^4) \qquad \delta\equiv(\rho_n-\rho_p)/(\rho_n+\rho_p)$$

A systematic change of neutron skin thicknesses provides sensitive constraints on the EOS, which is of upmost importance for nuclear physics and astrophysics

Low-*q* Experiments with an Active Target

Proton scattering or light particle scattering with low-momentum transfer provides crucial information on nuclear matter distribution and incompressibility of nuclide

Pilot IKAR experiments performed at FRS.



In inverse kinematic reactions using an active target, precisely measure the angular distribution in a broad angular region including the first diffraction minimum

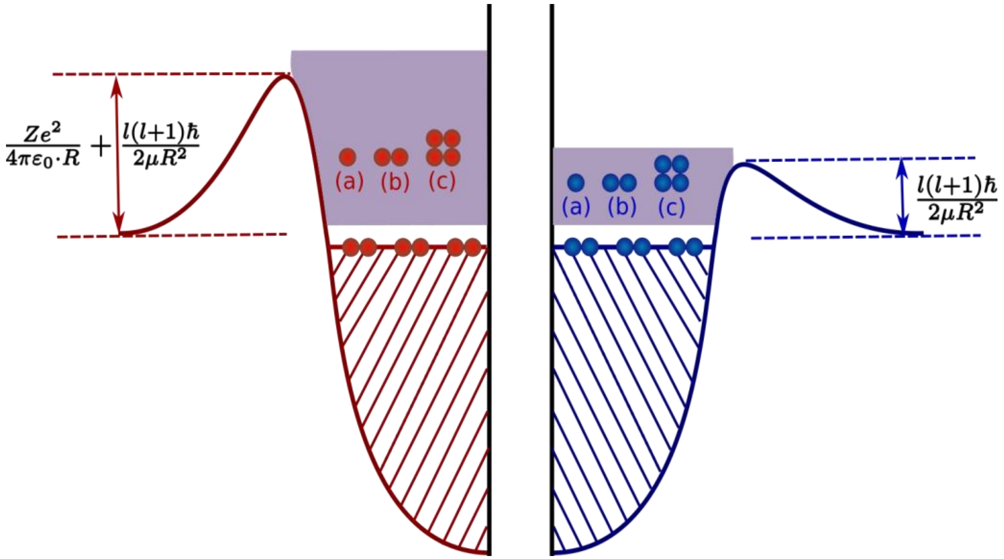
In the center-of-mass frame, proton wavelength of ~ 1 fm at an incident energy of 500 MeV/u

- Measurements of the nucleon density distribution by elastic proton scattering
- Study of the *N/Z* ratio dependence of the saturation density; the nuclear density near the maximum of $r^2\rho(r)$ sensitive to the saturation density of nuclear matter

Properties of Un-bound Nuclides

Nuclei beyond the drip-lines show interesting phenomena, and their surviving time are determined by the centrifugal and Coulomb barriers and nucleon correlations

Nucleon and cluster emissions from the ground and excited states of nuclides



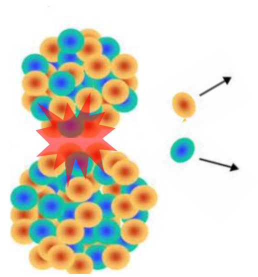
- Directly determine the drip lines
- Study the *pp* and *nn* correlations
- Understand the decay mechanism
- Study the *n-n* and *p-p* interactions
- Reveal the properties of neutron matters

The experiments can employ secondary reactions from a nearby unstable beam to produce the nuclides of interest, and the merits are relatively large cross section and low background

The in-flight decay technique coupling to inclusive measurement is most suitable for the study of particle emission of unbound nuclei with lifetimes from ~1 ps to 1 ns

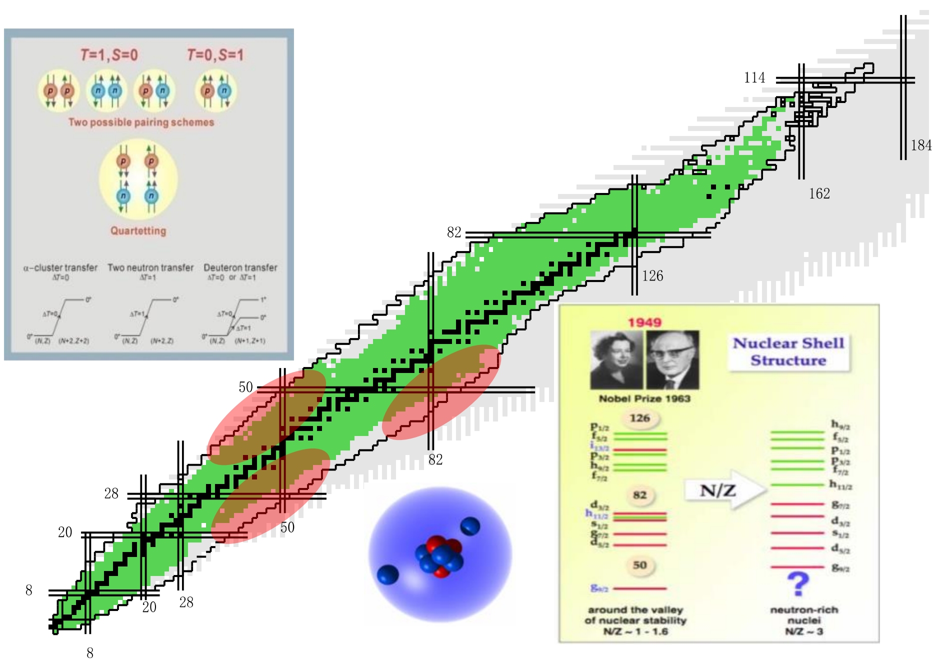
Few Nucleon Removal Reactions

In order to understand the properties of nuclides far away from the stability, it is crucial to precisely locate the position of single particle states near the Fermi surface, and to investigate the degree to which their wave functions reflect pure single-particle motion



The momentum distributions of fragments following one- or two-nucleon removal is the spectroscopic method well established, that gives knowledge on the wave function of the initial nucleons

Using very low intensity beam (~10 /s)!



Systematic study along isotopic and/or isotonic chains:

- Evolution of single particle states?
- Robustness of the shell closures?
- *T*=0, *S*=1 proton-neutron pairing?
- Coupling to the continuum?
- Heavier Halos and giant halos?
- ……

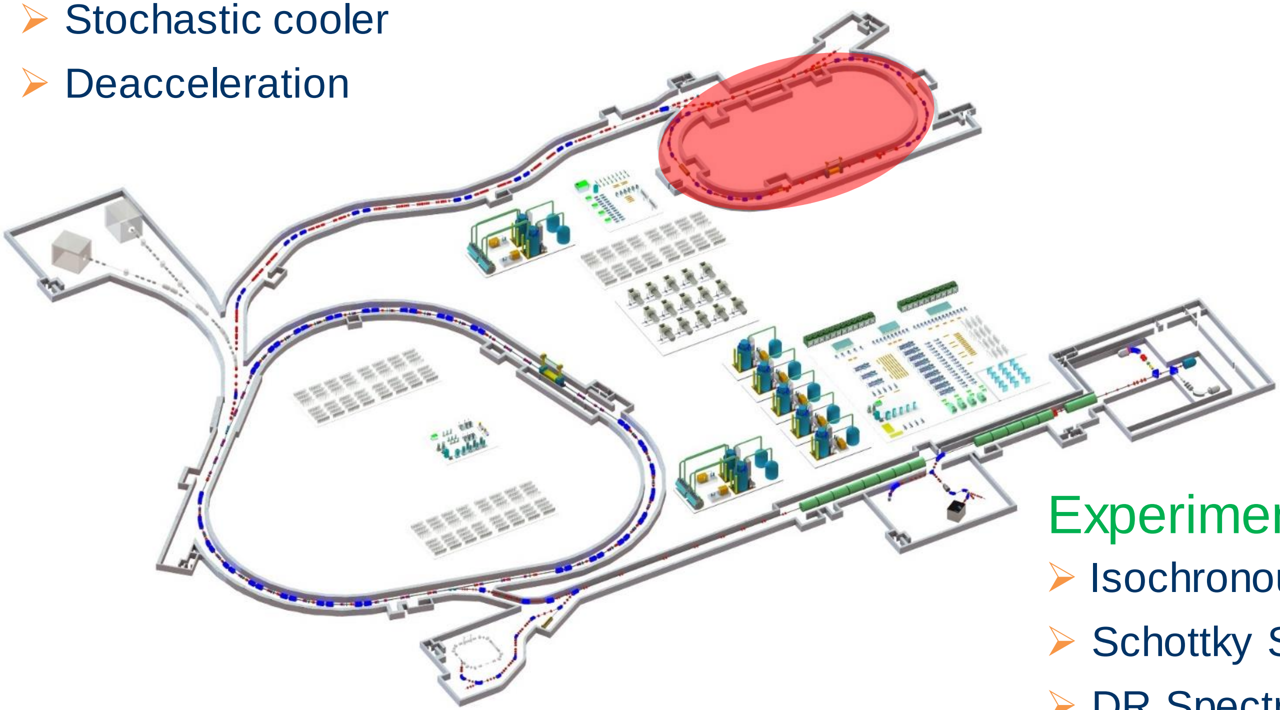
Experimental Layout @Spectrometer Ring

Spectrometer Ring: Multi Working Modes of Storage Ring

Spectrometer Ring:

- Circumference:188.7 m
- Rigidity: 13 Tm
- Electron cooler
- Stochastic cooler
- Deacceleration

With fast extracted projectiles from the Booster, HFRS produces, separates and injects the isotopes of interests into the Spectrometer Ring

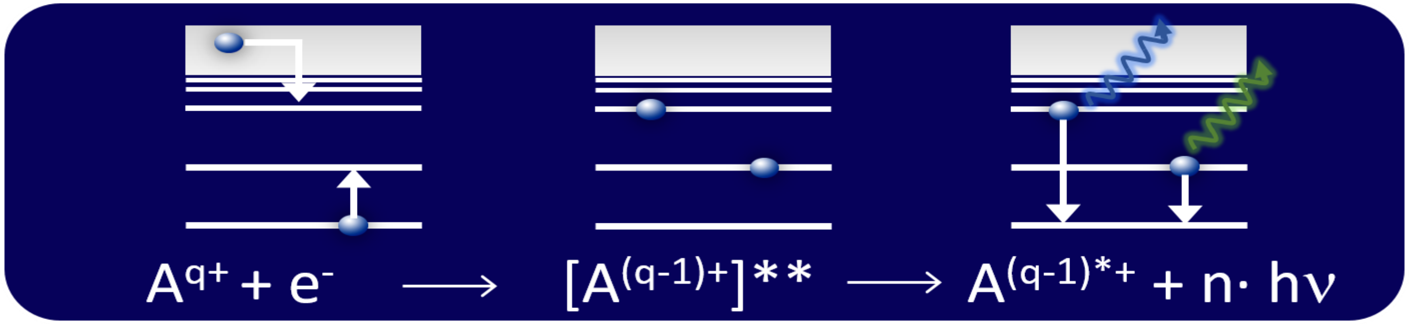


Experiments:

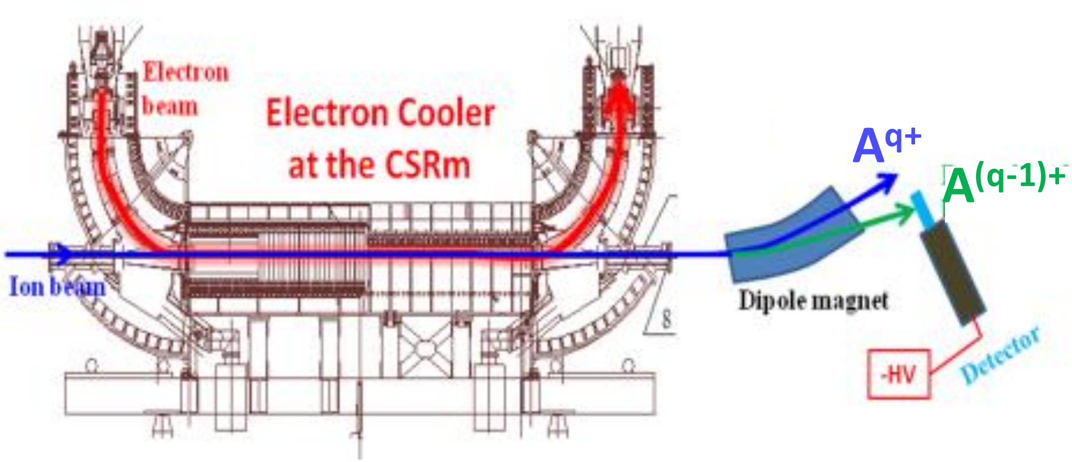
- Isochronous Mass Spectroscopy
- Schottky Spectroscopy
- DR Spectroscopy
- In-ring Nuclear Reactions
- Exotic Decay of Highly Charged Ions

Experimental Layout @Spectrometer Ring

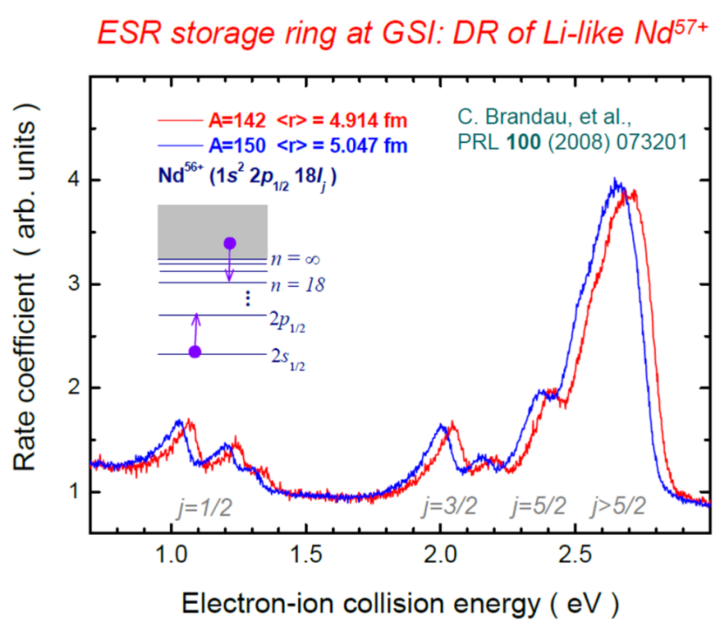
Spectrometer for Dielectronic Recombination



Dielectronic Recombination: While the ion A^{q+} captures a free electron with well defined energy provided by the electron cooler, a bound electron is excited simultaneously. It is a resonant process. The capture rates versus the relative electron-ion collision energy reflect the level structure of the highly charged atom



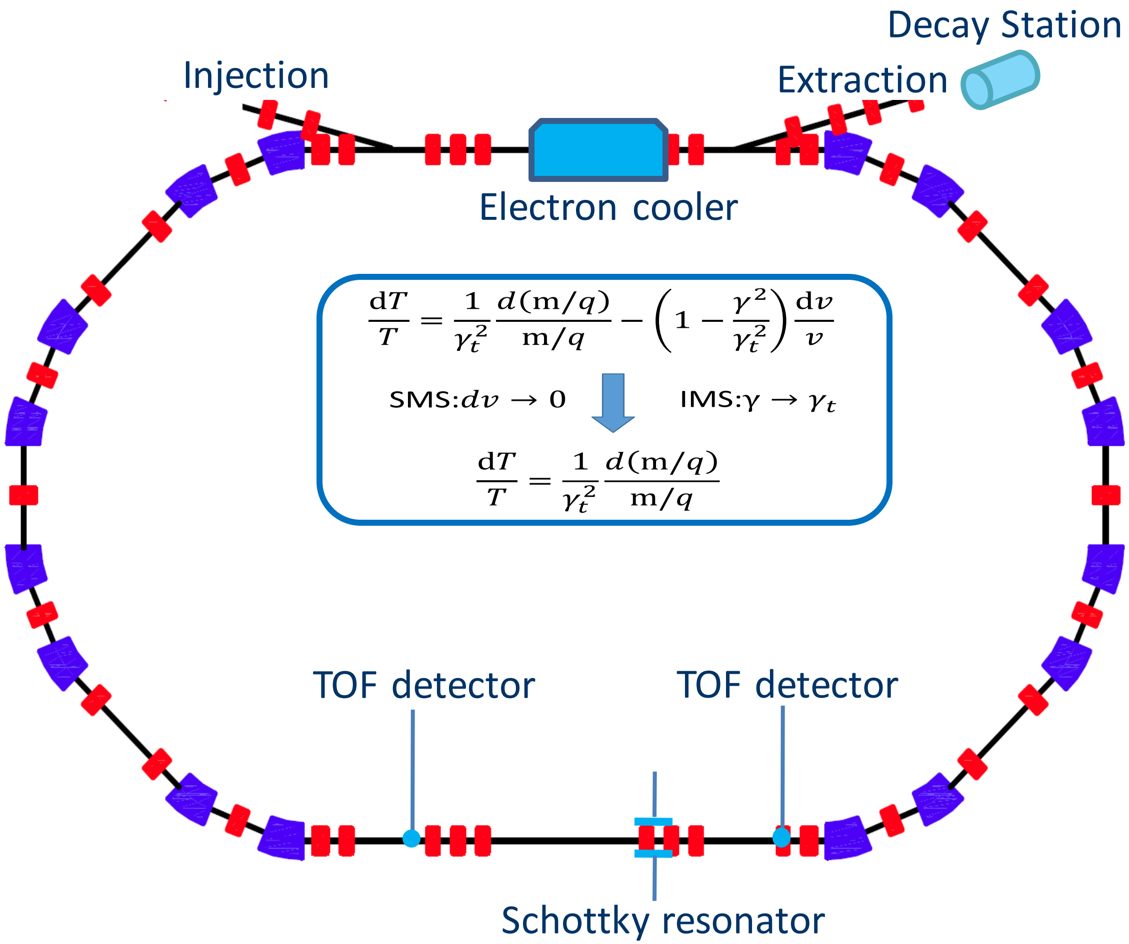
To tune precisely the electron energy and then count the recombined ions, fine or even hyperfine spectra are obtained



Recombination Rate: $\alpha(E_{rel}) \propto N(A^{(q-1)+})/N(A^{q+})$

Experimental Layout @Spectrometer Ring

Isochronous Mass Spectrometer and Schottky Spectrometer



$$\frac{dT}{T} = \frac{1}{\gamma_t^2}\frac{d(m/q)}{m/q} - \left(1 - \frac{\gamma^2}{\gamma_t^2}\right)\frac{dv}{v}$$

$$\frac{dT}{T} = \frac{1}{\gamma_t^2}\frac{d(m/q)}{m/q}$$

Isochronous Mass Spectrometer

Measurements of nuclear mass

With double TOF detectors, improve precision by velocity correction

Single ion sensitivity

Schottky Spectrometer

Measurements of mass, lifetime, and rare decay

In isochronous mode, measure masses and lifetimes simultaneously

Single ion sensitivity

See the talk by Y. H. Zhang

Development of New Techniques

New Techniques of Ring Spectrometry under Development

IMS with double ToF detectors

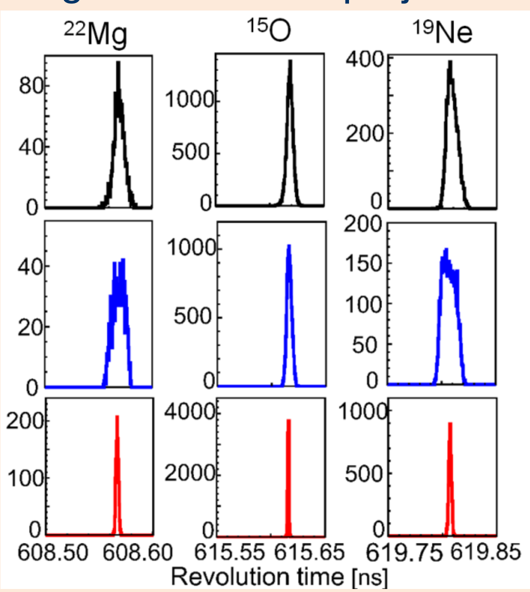
The circulating length of the stored ion is determined using the revolution time T_i and velocity υ_i :

$$L_i = T_i \cdot \upsilon_i$$

T_0 corresponding to the central orbit is obtained as:

$$T_0(L_0) = T_i + T_i \cdot \left(1 - \frac{\gamma_t^2}{\gamma_i^2}\right) \cdot \frac{L_0 - L_i}{L_i}$$

Fragments of ^{58}Ni projectiles



Measured

Simulated
with single ToF

Simulated
with double ToFs

High precision mass spectrometry!

New Schottky Spectrometry

Conventional Schottky Spectrometry:

Non interceptive resonator →
no energy loss of stored ions √
Cooling down of the stored ions→
long time of preparation ×

Conventional IMS Spectrometry:

Interceptive timing detector →
energy loss of stored ions ×
Without cooling down of the stored ions→
Very quick preparation √

Single-ion sensitive Schottky resonator working in isochronous mode of a storage ring:

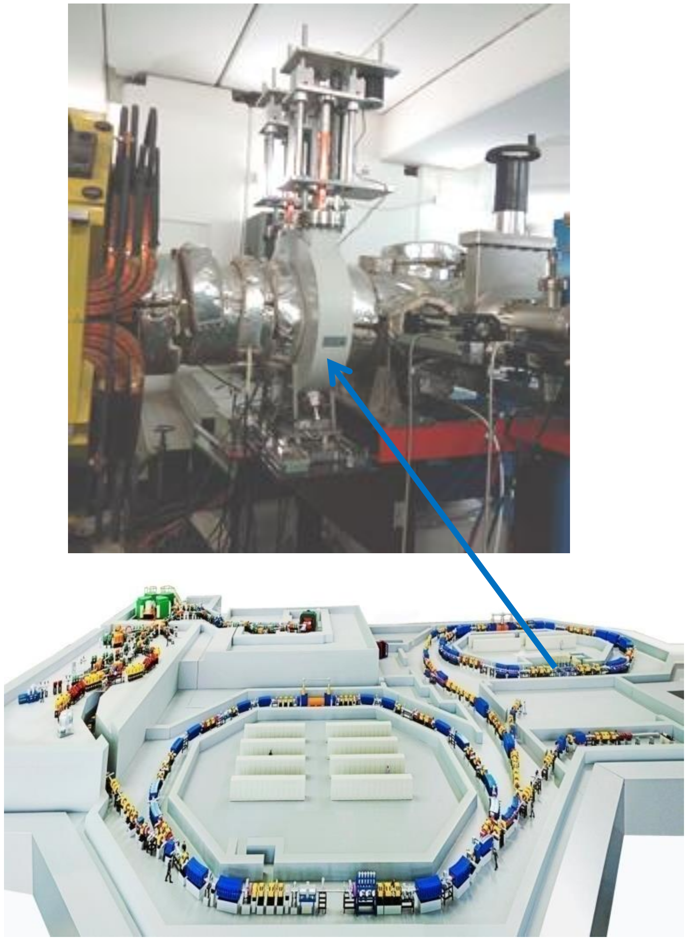
Long survival time of the stored ions √
Measure immediately after injection √
Measure mass and lifetime simultaneously!
Applicable to nuclei with broad lifetimes

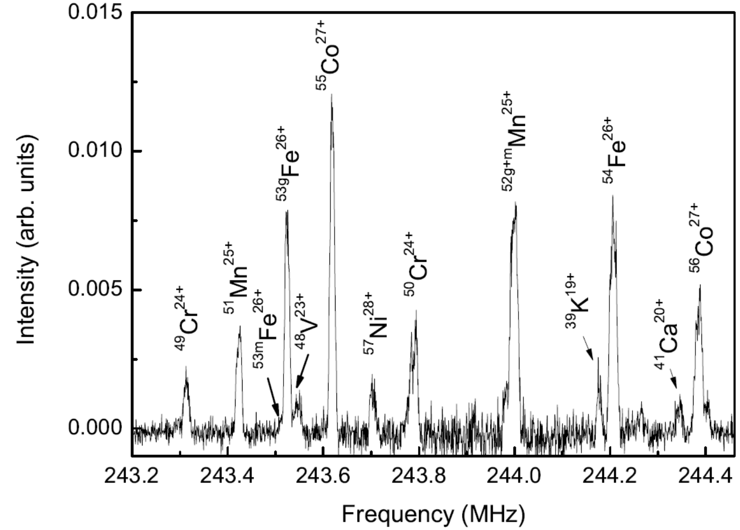
Mass and lifetime spectrometry!

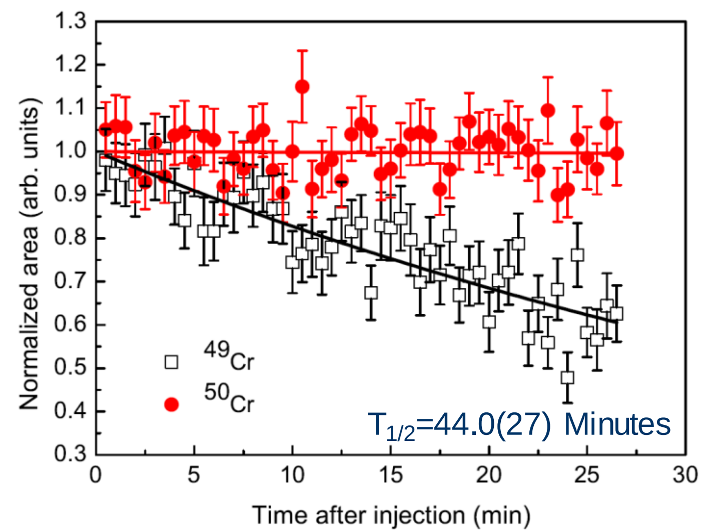
In collaboration with GSI and MPI

Proof of Principle for the Schottky Spectrometer in an Isochronous Mode

New Schottky pick-up at CSRe



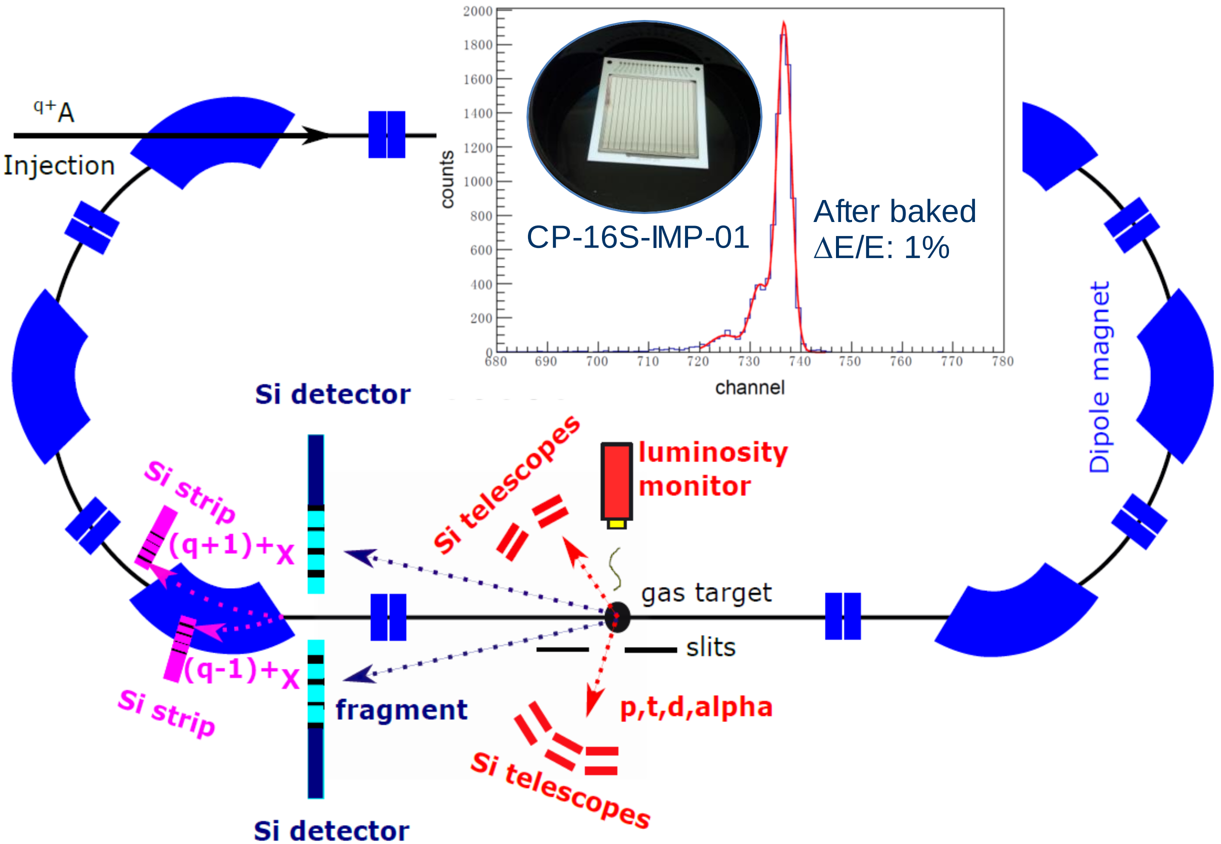




Nuclear mass and lifetime were measured simultaneously, an important proof-of-principle step.
Efforts should be devoted to developing single-ion sensitivity and then apply it to short-lived ions

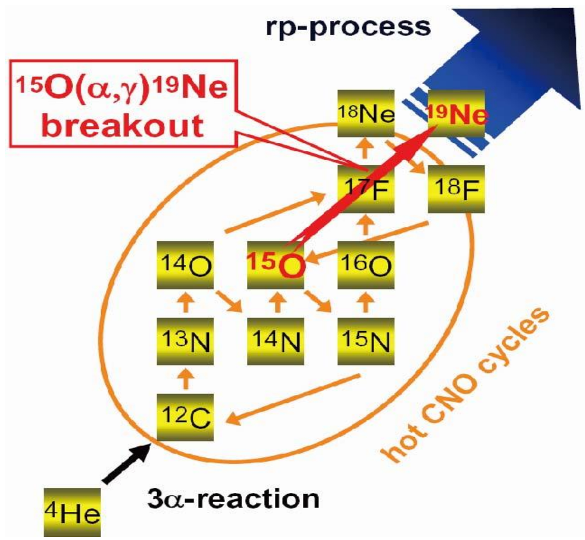
Experimental Layout @Spectrometer Ring

Setup for In-ring Nuclear Reactions



Nuclear Astrophysics:

- Simulate the *r* process
- Understand the *rp* process (waiting point, cycle and *end point*)
- Measure the key reaction rates
- Study the origin of the *p*-nuclei



$^{15}O(\alpha, \gamma)^{19}F$, $^{18}Ne(\alpha, p)^{21}Na$, (p, γ), (α, p), (α, n),(α, γ), etc.

Nuclear Reactions:

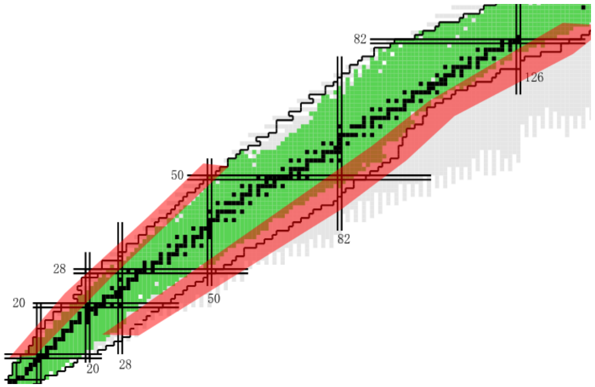
(p, p), (p, p′), (p, γ), (α, p), and (α, γ) reaction rates

Solid target and active target with ion energy compensation

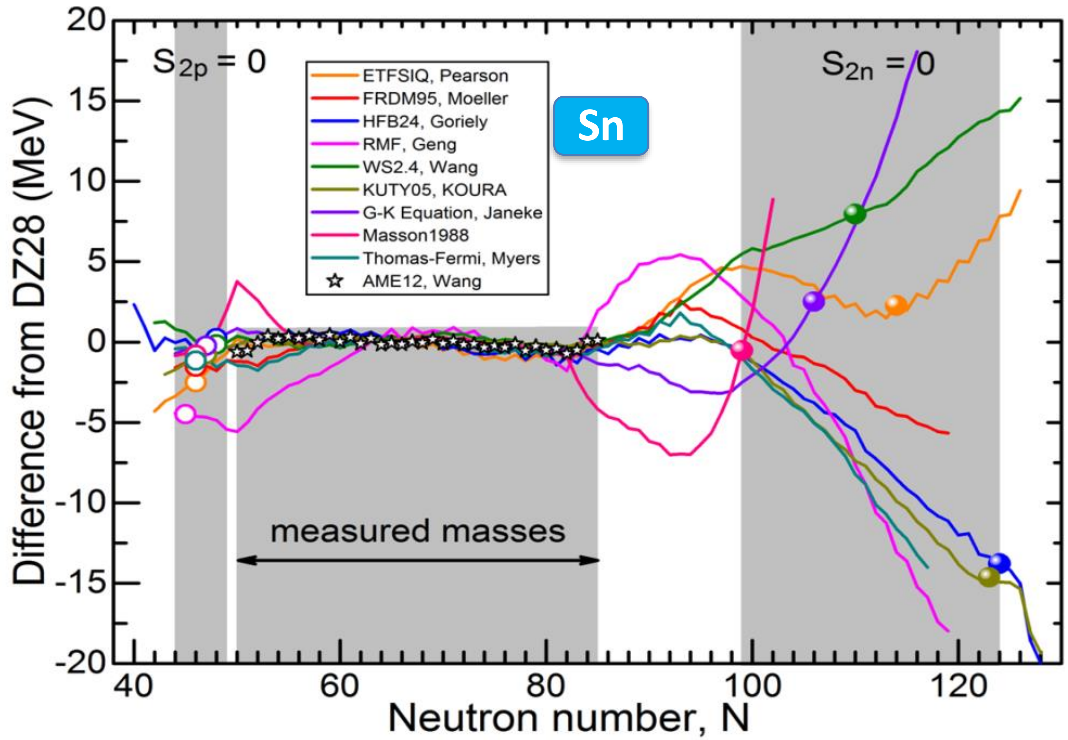
Major Physics @Spectrometer Ring

Experimental Measurements:

- **Nuclear Masses with Highest Priority**
- Nuclear Half-lives
- Exotic Decay Modes



Systematically measure nuclear masses in broad regions



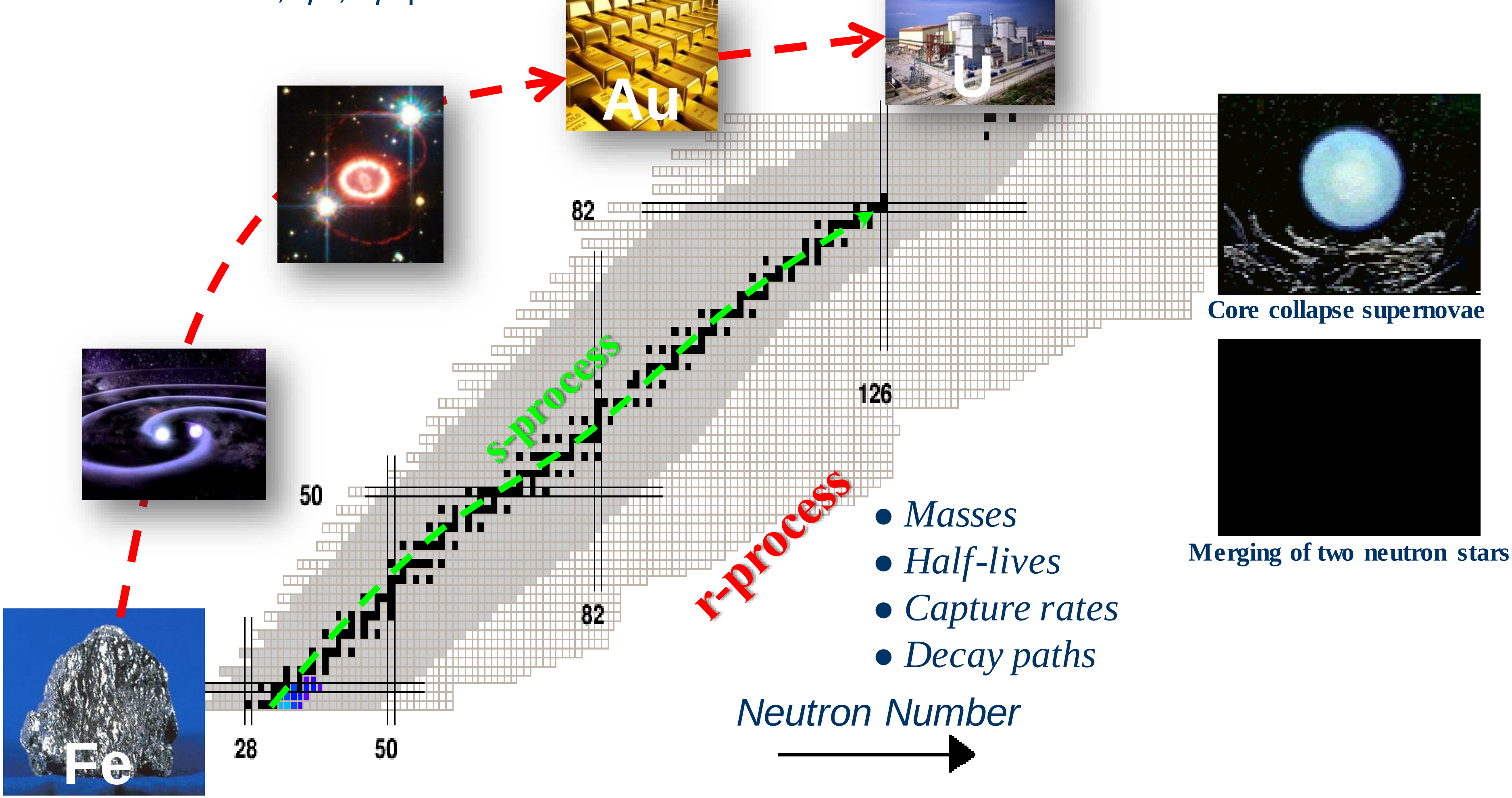
Physics:

- map out the mass surface in broad regions and determine the drip lines
- reveal the evolution of the effective interactions while changing the *N/Z* ratios
- study the quenching of the known shell gaps and development of new ones
- find out the deformation change and onset of exotic shapes along isotopic chains
- simulate the *rp* process and *r* process

Major Physics @Spectrometer Ring

How are the elements from iron to uranium produced in the Universe?

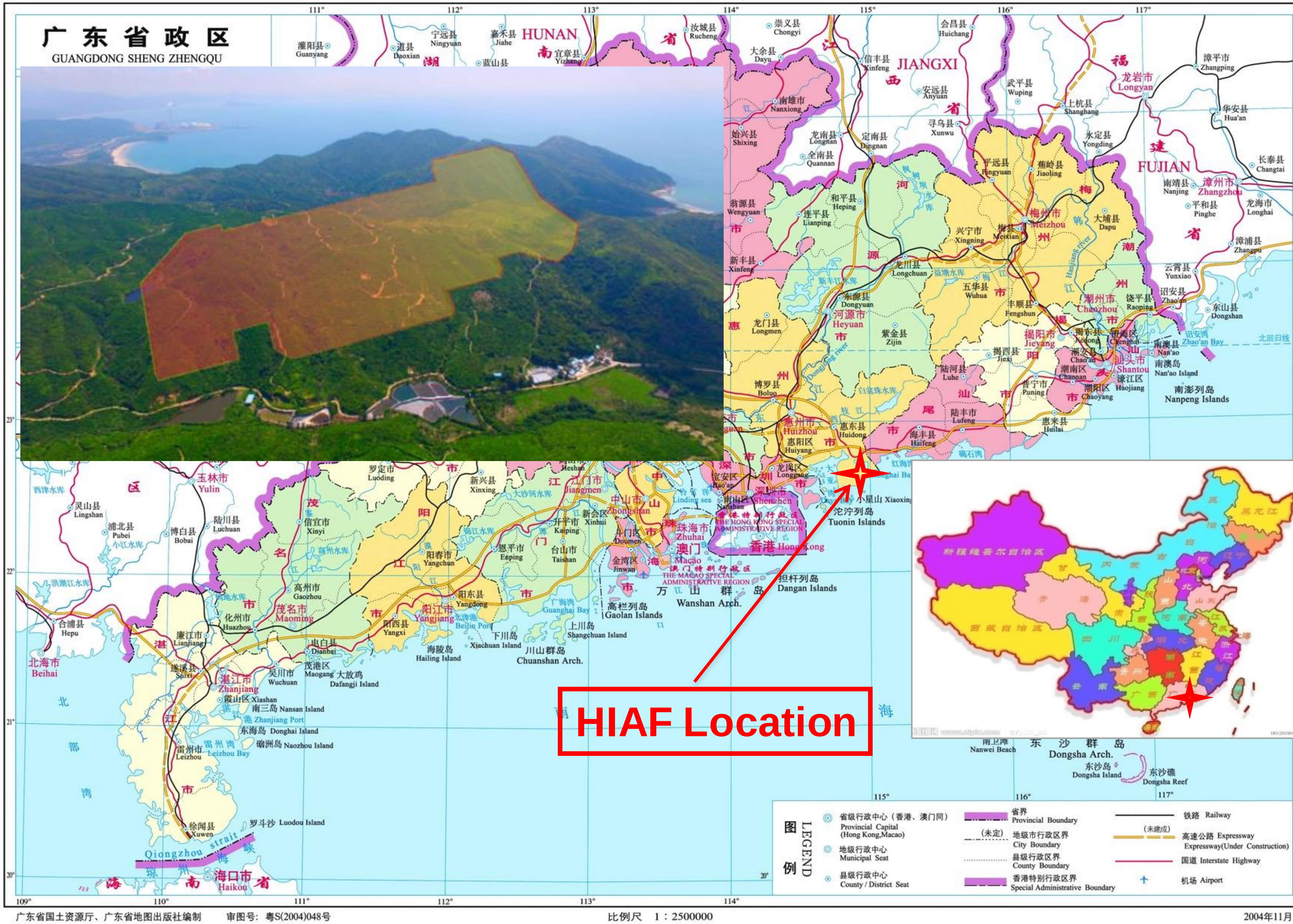
Simulation of the r-, rp-, νp-processes



By reproducing the observed abundance distribution, the network calculations with precision nuclear inputs would put constraints on the environments in which the *r*-process may happen

Facility Location

Location


广东省政区
GUANGDONG SHENG ZHENGQU
HUNAN
JIANGXI
FUJIAN
香港 Hong Kong
澳门 Macao
HIAF Location
图例 LEGEND
广东省国土资源厅、广东省地图出版社编制
审图号：粤S(2004)048号
比例尺 1：2500000
2004年11月

Location

The construction was already started, and the official announcement for the startup of construction is scheduled on Dec. 23, 2018

Location

Huizhou city and Guangdong province will cover the expenses for buying land, preparing land, building roads, building electricity and water supply stations, …

Location

About 5.0 kilometers to the downtown area of Huizhou City

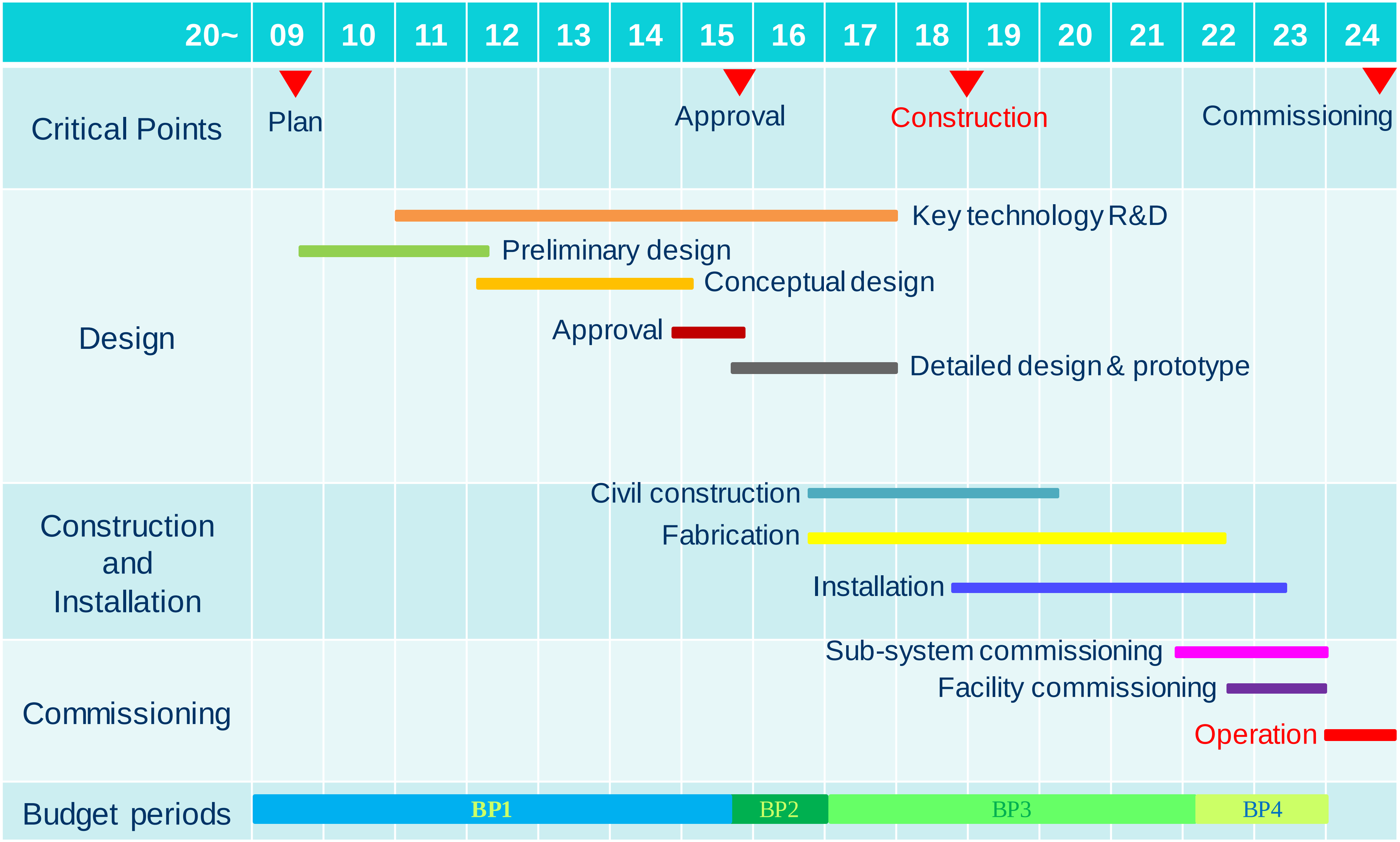
Under construction now!

Budget

Items (1st phase)	Cost
iLinac	360
Booster Ring	350
Beam line	50
Experimental setups	380
Cryogenics	80
Civil construction	350
Contingency	100
	1670 (Central government)
Infrastructure & deficiency	1000 (Local government)
Total	**2670**

Unit: Million Chinese Yuan (one U.S. dollar ≈ 6.5 Chinese Yuan)

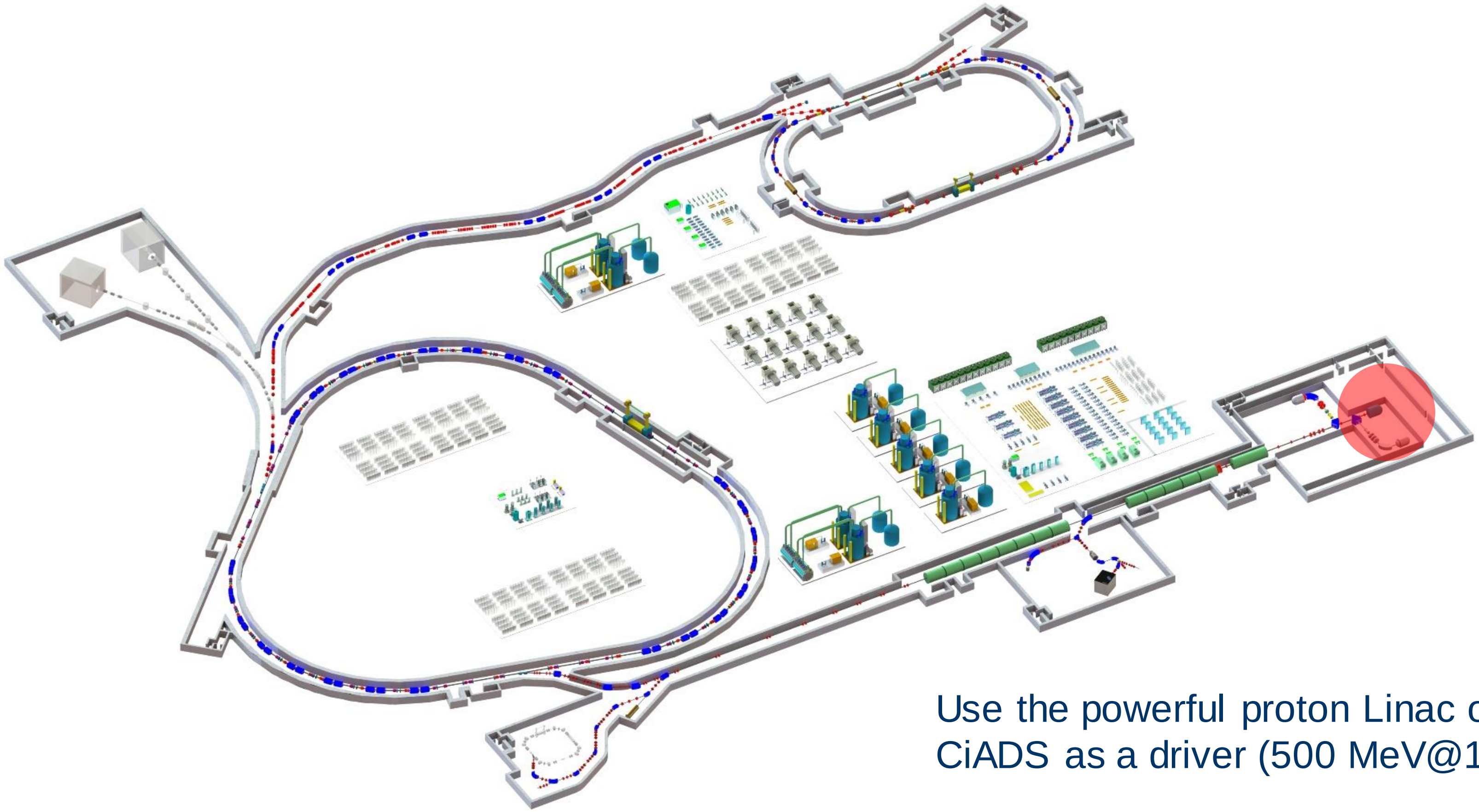
Time Schedule



The groundbreaking ceremony of HIAF is scheduled in December, 2018

Perspective of Expansion

To develop an ISOL-type facility by combing the CiADS facility



Use the powerful proton Linac of the CiADS as a driver (500 MeV@10mA)

Phase II

Summary

HIAF is one of the two storage-ring based facilities for radioactive ion beam physics (FAIR and HIAF) in the world, complementary to other future heavy-ion research facilities

HIAF will potentially incorporate with an ISOL source driven by a high energy powerful proton Linac, and consequently HIAF can turn into the first “full featured” facility capable of producing RIBs using target spallation, projectile fragmentation, in-flight fission and even the hybrid method

Domestic and international collaborations are expected to play a key role in defining the physical program and building the detector systems

Acknowledgment

IMP: X.D.Tang, Zh.Liu, W.X.Huang, Z.G.Gan, J.Yang, X.Ma, Y.H.Zhang, M.Wang, X.C.Chen, X.L.Tu, Z.Y.Sun, J.S.Wang, M.L.Liu, B.Ding, Y.L.Tian, …

Beihang University: I.Tanihata, B.H.Sun, S.Terashima, …

Beijing Normal University: F.S.Zhang and K.Zhao

Peking University: Y.L.Ye, F.R.Xu, …

CIAE: C.J.Lin, …

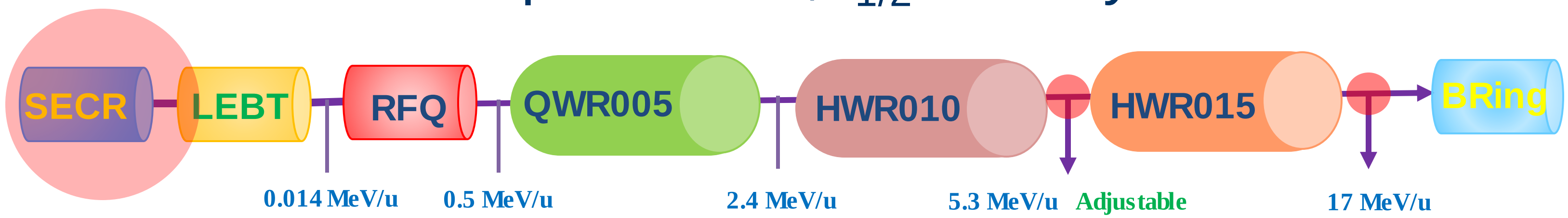
CNS: S.Kubono

GSI: Y. Litvinov, T. Saito and C.Scheidenberger

Thank you for your attention!

Feasibility for Acceleration of Heavy Long-lived Beams

Example: ^{243}Am, $t_{1/2}$=7360 years



Assuming beam intensity of 10^{12} particles/s

In the sections of superconducting cavities: beam loss < 0.01%

For an experiment of 100 hours: 0.01% beam loss in the cavities,

Resulting in total radioactivity of about 100/s, distributed in about 100 meters.

In the injecting section from ion source into the front-end RFQ: beam loss ~1%

For an experiment of 100 hours: 1% beam loss in the injection point,

Resulting in total radioactivity of about 10^4/s, severe contamination!

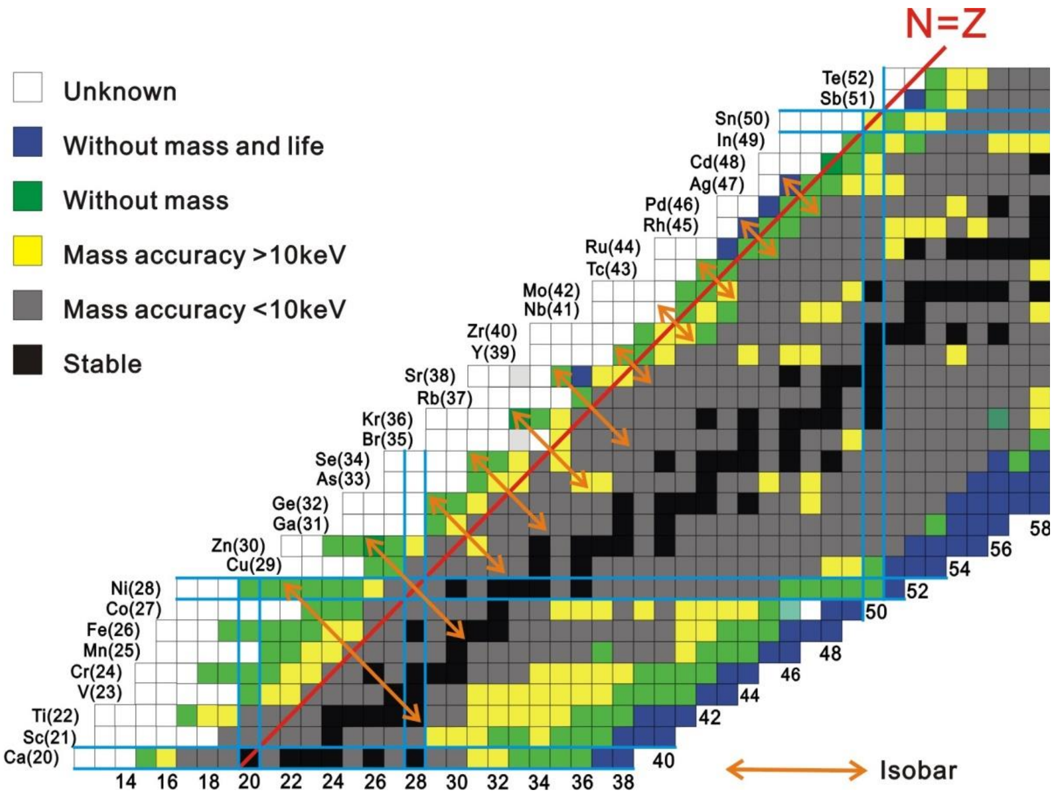
Also the ion source is badly contaminated!

Solutions:

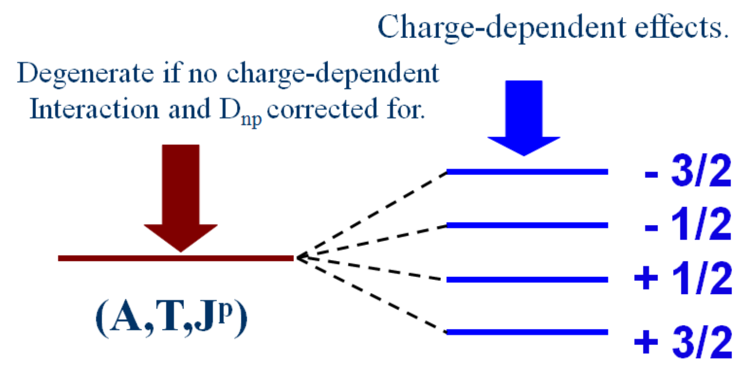
To replace the inner cavity of ion source and injecting device after experiment.
To use the ISOL ion-source technique to deal with the radioactivity.

Physics @ HIAF-Linac

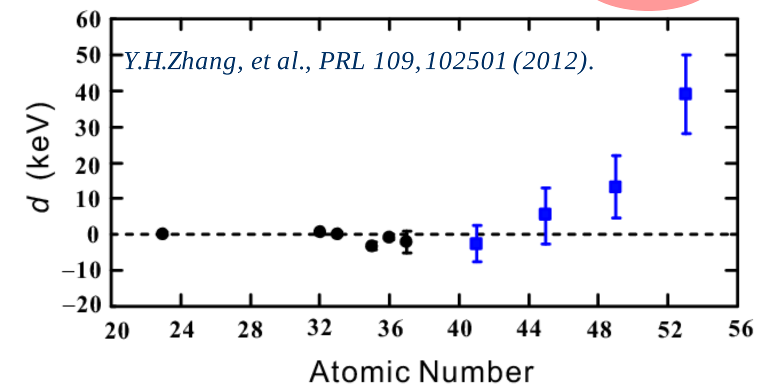
Physics along the N=Z line



Test the Isospin Multiplet Mass Equation



$$M(T,A,T_3) = a(T,A,) + b(T,A)T_3 + c(T,A)T_3^2 + d(T,A)T_3^3$$



- Understanding of the *rp* process path and end point.
- Shape evolution for the nuclei along the *N=Z* line.
- Study of the isospin symmetry breaking and its mechanisms.
- Search for the new form of *n-p* paring.
- Precision tests of the shell model around ^{100}Sn.

Complementary to the related researches at the high-energy branch.

Bound-state β decay of $^{205}Tl^{81+}$

Understanding of the solar pp neutrinos

LOREX project: ^{205}Tl in lorandite at Allchar mine is used for long-time detection of solar pp neutrinos with the by far lowest threshold of netrino energy of 52 keV.

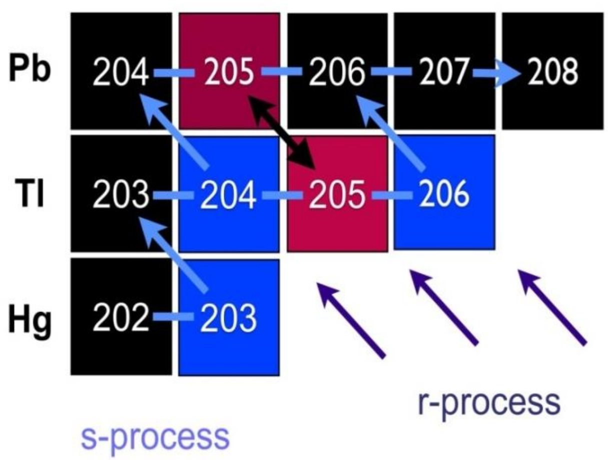
The neutrino caputure cross section σ_{ve} can be deduced from the half-life of bound-state β decay of $^{205}Tl^{81+}$.

LOREX: $^{205}\mathrm{Tl} + \nu_e \rightarrow {}^{205}\mathrm{Pb}^* + e^- \Longrightarrow <\Phi_{\nu_e} \cdot \sigma_{\nu_e}>$

↕ Share common M_{if}

β_b decay: $^{205}\mathrm{Tl}^{81+} \rightarrow {}^{205}\mathrm{Pb}^* + e^- + \widetilde{\nu}_e \Rightarrow \sigma_{\nu_e}$

Understanding of the abundance of ^{205}Pb



$$N(^{205}Pb)/N(^{204}Pb) = P(^{205}Pb)/P(^{204}Pb) \times T(^{205}Pb)/T_G$$

$N(^{205}Pb)/N(^{204}Pb)$	$P(^{205}Pb)/P(^{204}Pb)$	$T(^{205}Pb)/T_G$
$\sim 10^{-3}$	~ 1	$\sim 2.5 \cdot 10^{-3}$
in inter-stellar media	s-production ratio	lifetime raio of the Galaxy

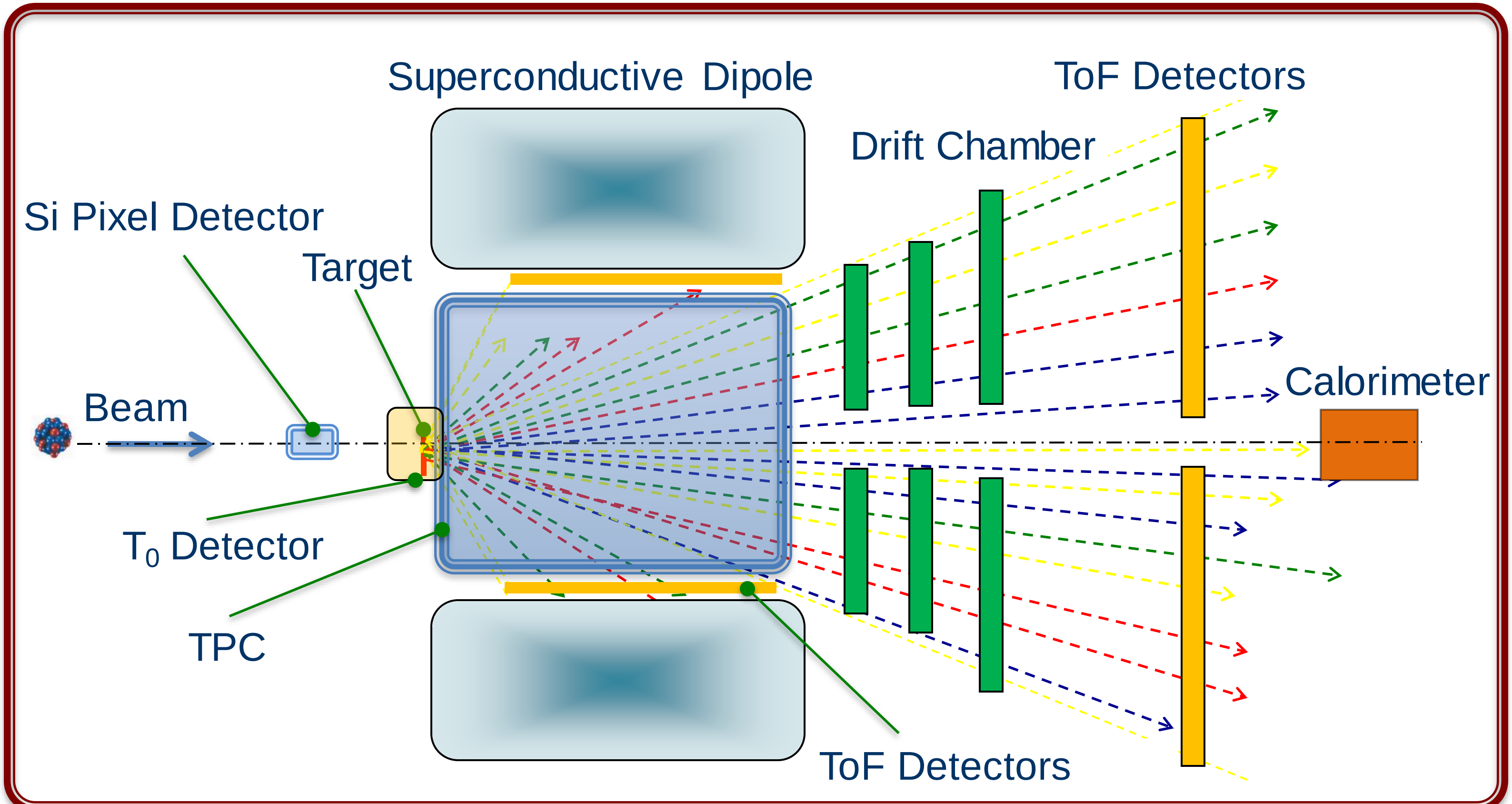
In the s-process enviroment:

^{205}Pb is strongly reduced by free electron capture.

The mean lifetime of ^{205}Tl is determinde by $\lambda_{\beta b}$ of bare ^{205}Tl.

Is ^{205}Pb counter-balanced by the β_b decay of bare ^{205}Tl?

CEE Concept



技术亮点 1) 微像素定位探测器 (华中师范大学)

自主研制 2) 高计数率高精度飞行时间探测器 (清华大学、中国科学技术大学)

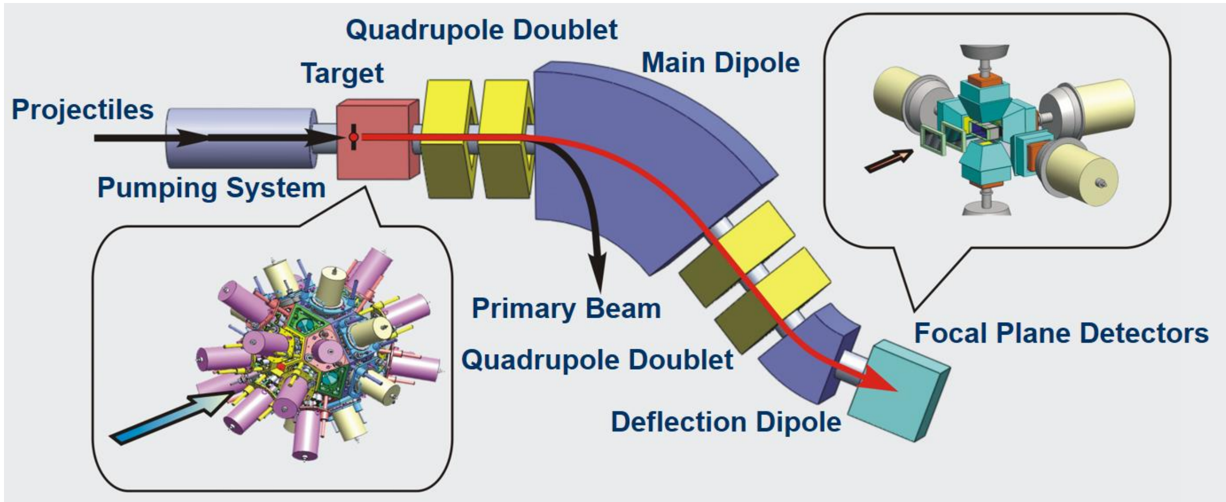
3) 高精度三维径迹探测器 (中科院上海应用物理所)

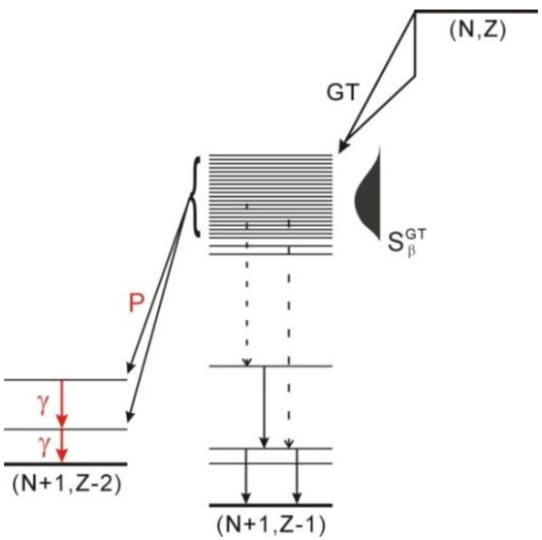
4) 新型数据获取系统 (中国科学技术大学)

5) 大接收度超导二极磁铁 (中科院近代物理所)

Day One Experiment @ HIAF

Synthesis of New Isotopes ^{143}Er, ^{157}Yb and ^{153}Hf





Beta-delayed proton decays.

Devices: The superconducting iLinac.

The Gas-filled Recoil Separator.

Reactions： $^{40}Ca + ^{106}Cd \rightarrow ^{143}Er + 3n.$

$^{58}Ni + ^{92}Mn \rightarrow ^{157}Yb + 3n.$

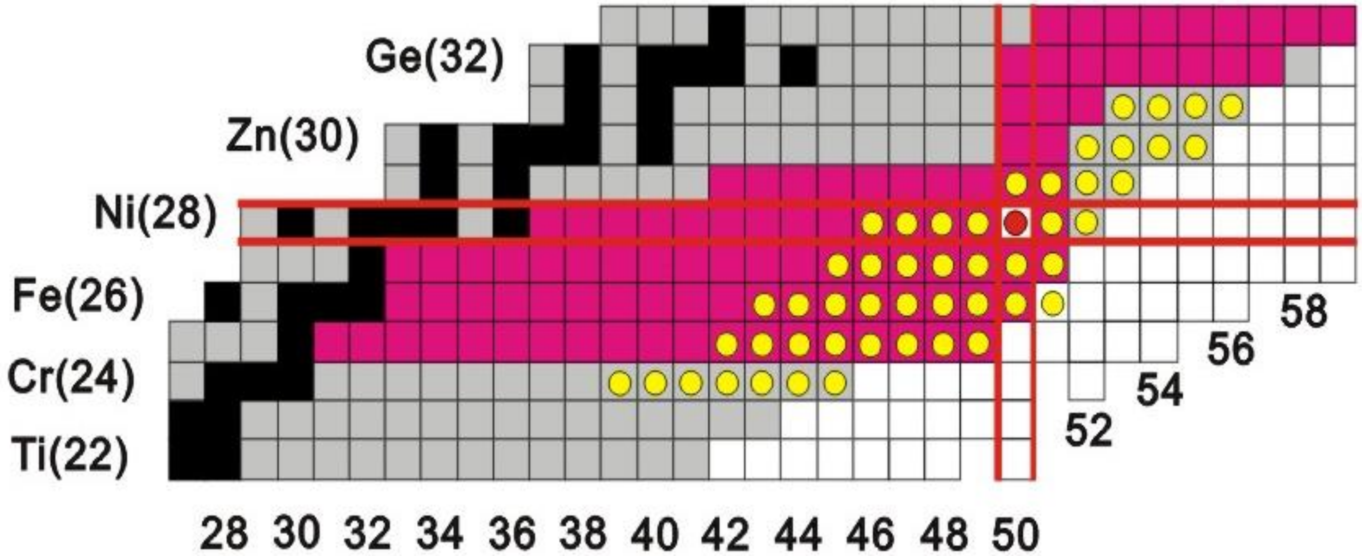
$^{54}Fe + ^{102}Pd \rightarrow ^{153}Hf + 3n.$

Expected cross sections: 20~300 nb.

Expected half-lives: 100~300 ms.

Day One Experiment @ HIAF

Mass Measurements of N-rich Nuclides around ^{78}Ni



Production: Fragmentation of Projectile ^{86}Kr Using the HFRS.

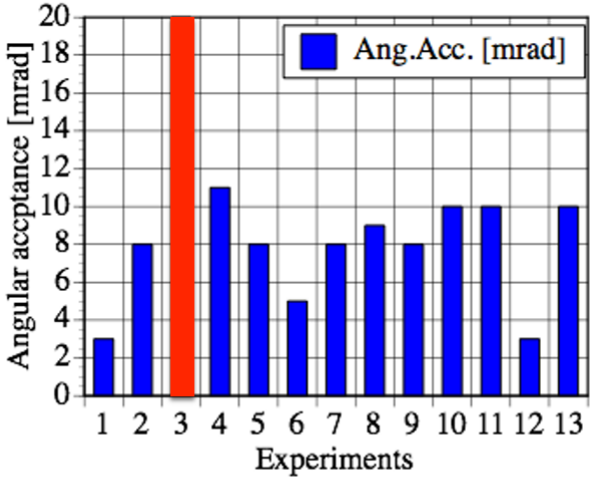
Measurement: The Isochronous Mass Spectrometer with Double ToF Detectors.

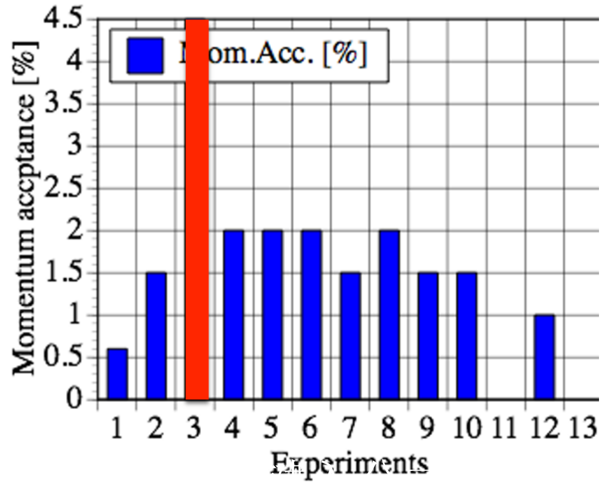
Systematically measure nuclear masses with a precision of ~ 50keV, and deduce one-neutron and two-neutron separation energies.

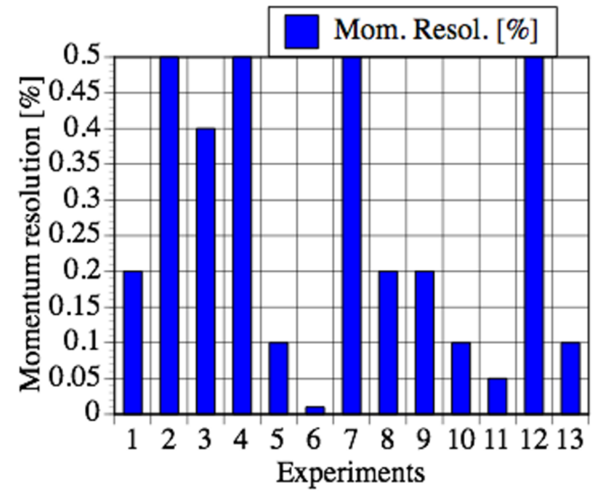
Study the evolution of the *N*=50 shell closure and Simulate the r-process.

Experimental Setups @ HFRS

Requirements from Physics







Production, Magnetic Rigidity, Agular and Momentum Acceptance, and Momentum Resolution

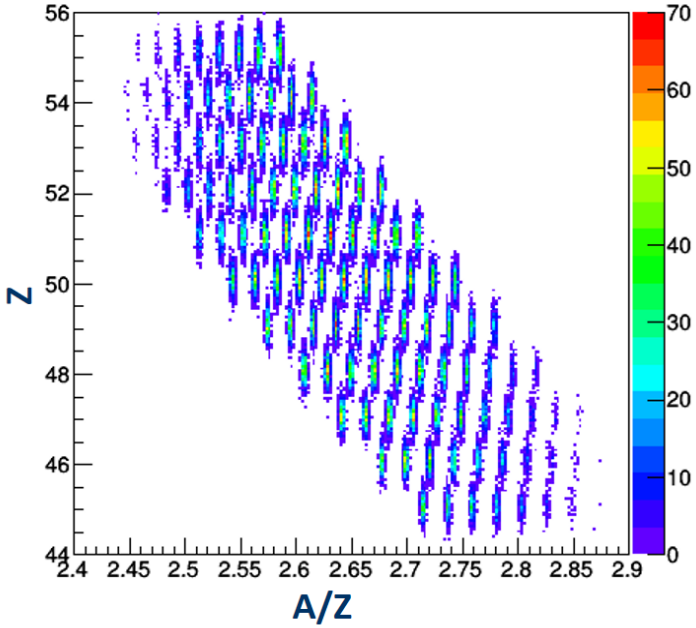
- Synthesis of neutron rich hypernuclei
- Nucleon excitations in nuclei
- Giant resonance of neutron rich nuclei
- Spectroscopy of meson-nucleus bound system
- …

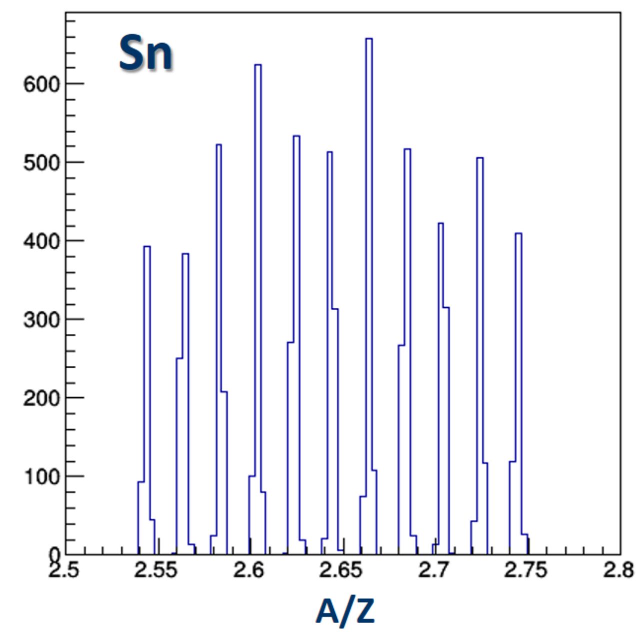
} Bρ=25Tm

Unique Experiments at FAIR and HIAF!

Experimental Setups @ HFRS

Capability of Particle Identification





Detector performance: Time resolution: 20 ps (single), position resolution: 0.2 mm, and energy resolution: 1.0 %

The peculiarities of the HFRS:

- It has a maximum magnetic rigidity of up to 25 Tm, and thus high-energy secondary beams are available with energies over 2 GeV/u
- It provides high primary-beam suppression power and high separation power of nuclides up to *Z*=92, and also provides fully stripped ions of all elements
- It provides versatile spectrometer modes by different combinations of separator sections

Revealing Tensor Force

The tensor forces are essential to bind nucleons together in light nuclides, but they are not treated explicitly in models such as mean field models and shell models

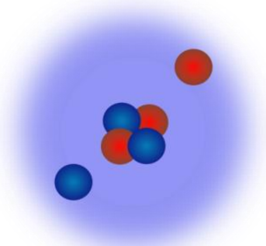
The pion interaction:

$$\vec{\sigma}_1 \cdot \vec{q}\vec{\sigma}_2 \cdot \vec{q} = \frac{1}{3} q^2 S_{12}(\hat{q}) + \frac{1}{3} \vec{\sigma}_1 \cdot \vec{\sigma}_2 q^2$$

The tensor force is as important as the central forces!

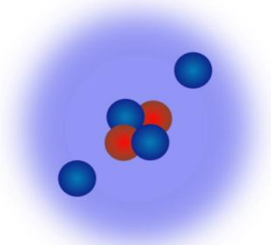
In a three-body model

^{6}Li



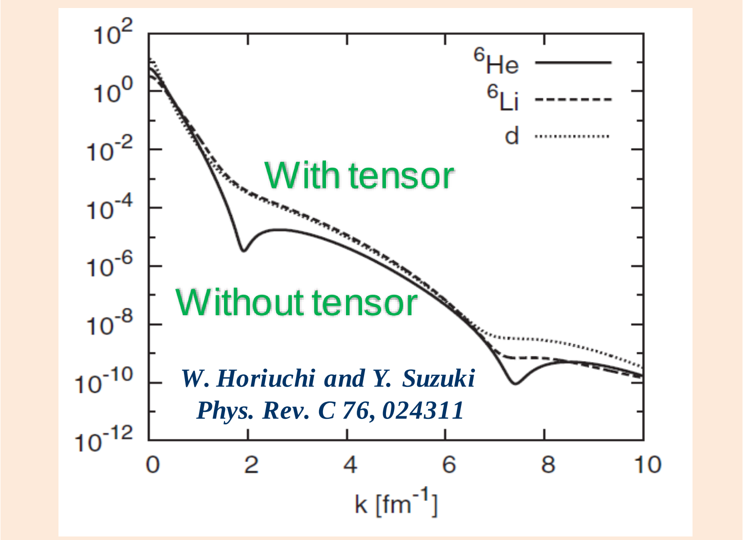
$\alpha + n + p$

^{6}He



$\alpha + n + n$

The tensor force leads to a strong correlation between a *np* pair and high-momentum nucleons in nuclei. While the high-momentum nucleon is picked up by a particle, the correlated nucleon may be emitted and measured using (*p*, *pd*), (*p*, *nd*), and (*d*, *pt*) reactions



The momentum distribution of relative motion of the two nucleons in ^{6}Li and ^{6}He, reflecting the effect of tensor forces

Proposed by I.Tanihata and S.Terashima

Nuclear Matter and/or Charge radii

Measurements of nuclear matter and/or charge radii provide the most original evidences for neutron and proton halos, neutron skins, and new magic numbers

Nucleon distributions or radii

Total interaction cross sections

Elastic proton scattering

Proton distributions or radii

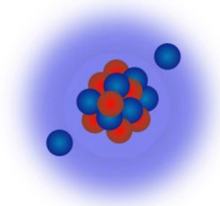
Isotope shifts

Electron scattering

μ atom

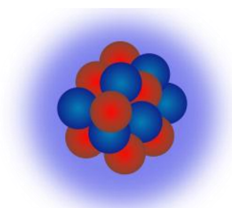
Charge changing cross sections

Halo



- Halos in heavier nuclides
- Giant neutron halos with > two neutrons
- Deformed halos
- Coupling of continuum and discrete states

Neutron distributions or radii



Skin

- Nuclear size evolution of n-rich nuclides
- New shell closures in n-rich regions
- Constrains on nuclear theories
- EOS for cold asymmetric nuclear matter

The equation of state (EOS) for cold asymmetric nuclear matter:

$$E(\rho, \delta)=E(\rho,0)+\delta^2 E_{sym}(\rho)+O(\delta^4) \qquad \delta \equiv (\rho_n-\rho_p)/(\rho_n+\rho_p)$$

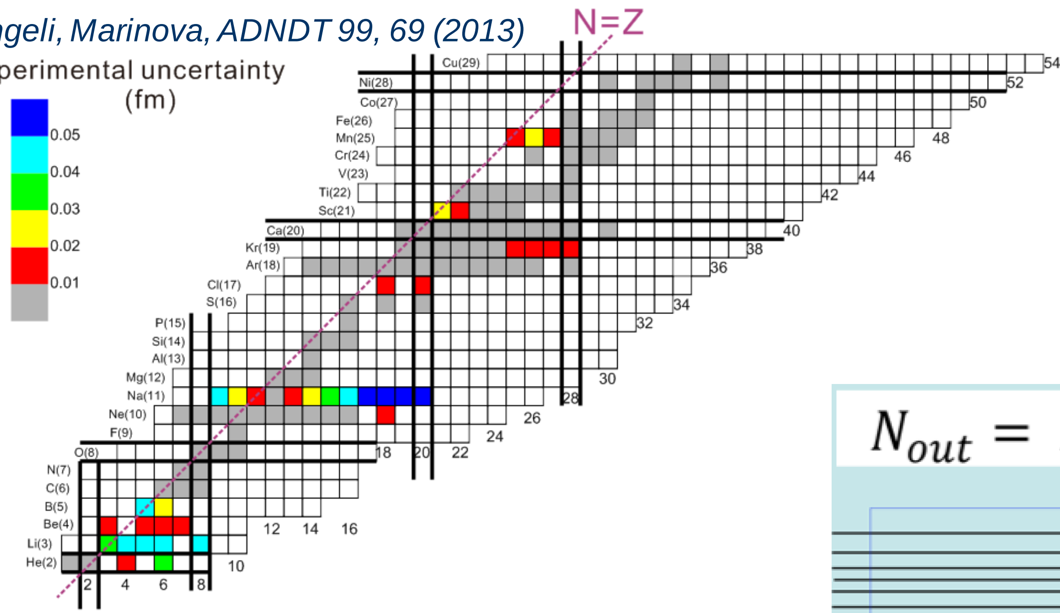
A systematic change of neutron skin thicknesses provides sensitive constraints on the EOS, which is of upmost importance for nuclear physics and astrophysics

Nuclear Matter and/or Charge radii

A New Approach for Determining Nuclear Charge Radii

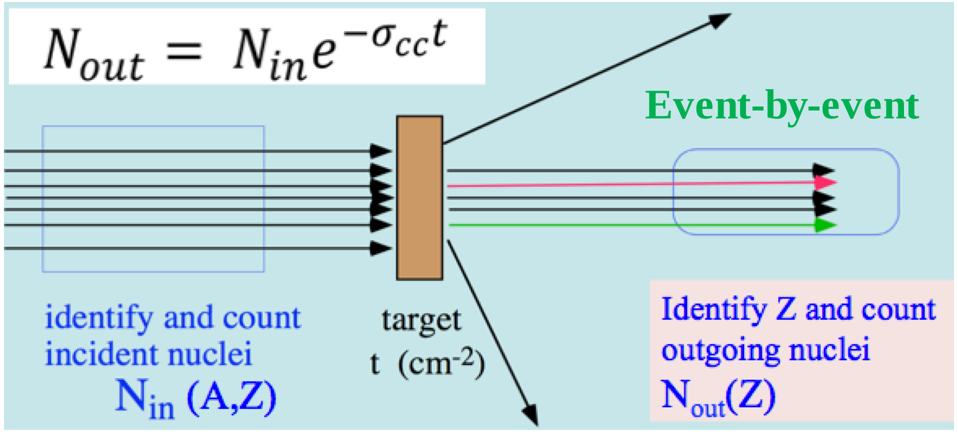
<u>C</u>harge <u>C</u>hanging <u>C</u>ross <u>S</u>ection (CCCS) Measurement at Relativistic Energies + Glauber Model

Angeli, Marinova, ADNDT 99, 69 (2013)



Charge radii:

- ➢ electron scattering
- ➢ μ atoms
- ➢ K X-ray isotope shifts
- ➢ optical isotope shift



CCCS at high energies:

- ➢ Weak energy dependence
- ➢ Clean reaction mechanism
- ➢ Statistic, $N_{in} > 10^5$

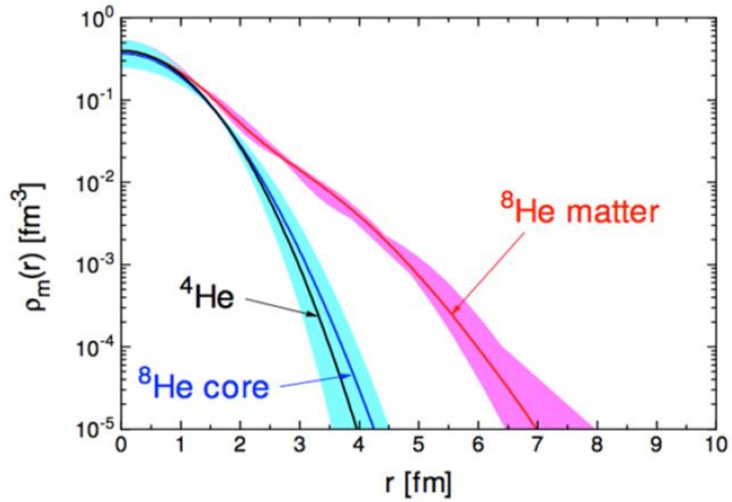
At high energies, CCCS, reflecting interaction probability between the valence protons and the target nuclide, is sensitive to the proton distribution in the projectile nuclide. Analogous to the total cross section measurement, nuclear charge radii can be deduced from the CCCS

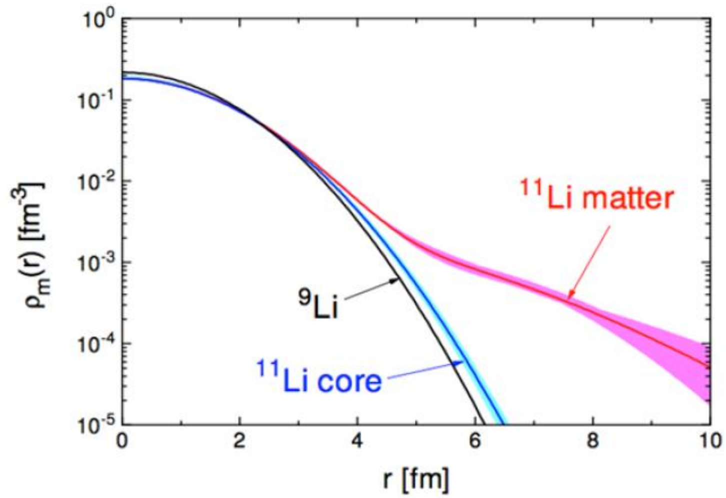
Proposed by B.H.Sun and I.Tanihata

Low-q Experiments with an Active Target

Proton scattering or light particle scattering with low-momentum transfer provides crucial information on nuclear matter distribution and incompressibility of nuclide

Pilot IKAR experiments performed at FRS.





In inverse kinematic reactions using an active target, precisely measure the angular distribution in a broad angular region including the first diffraction minimum

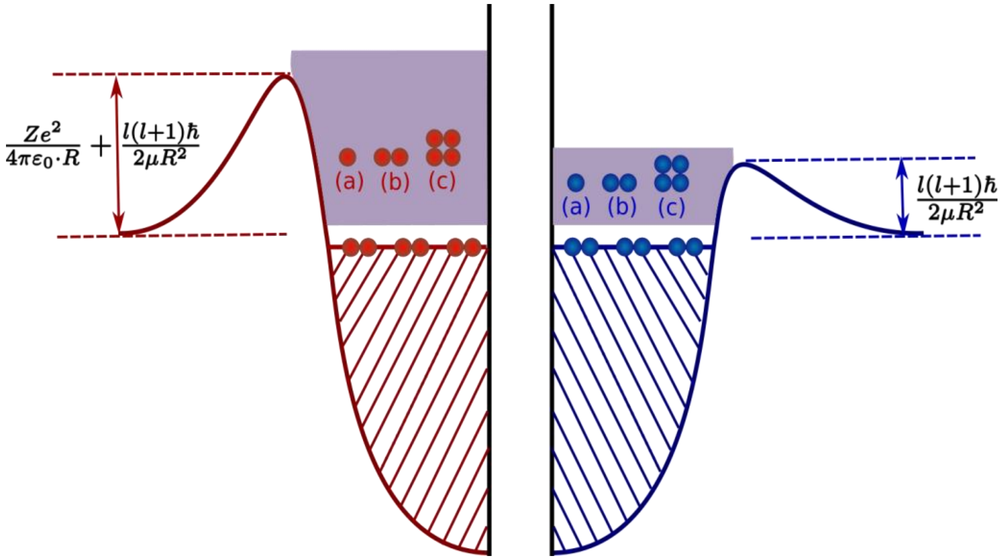
In the center-of-mass frame, proton wavelength of ~ 1 fm at an incident energy of 500 MeV/u

- Measurements of the nucleon density distribution by elastic proton scattering
- Study of the *N/Z* ratio dependence of the saturation density; the nuclear density near the maximum of $r^2\rho(r)$ sensitive to the saturation density of nuclear matter

Properties of Un-bound Nuclides

Nuclei beyond the drip-lines show interesting phenomena, and their surviving time are determined by the centrifugal and Coulomb barriers and nucleon correlations

Nucleon and cluster emissions from the ground and excited states of nuclides



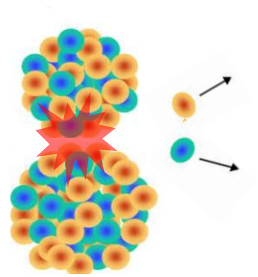
- Directly determine the drip lines
- Study the *pp* and *nn* correlations
- Understand the decay mechanism
- Study the *n*-*n* and *p*-*p* interactions
- Reveal the properties of neutron matters

The experiments can employ secondary reactions from a nearby unstable beam to produce the nuclides of interest, and the merits are relatively large cross section and low background

The in-flight decay technique coupling to inclusive measurement is most suitable for the study of particle emission of unbound nuclei with lifetimes from ~1 ps to 1 ns

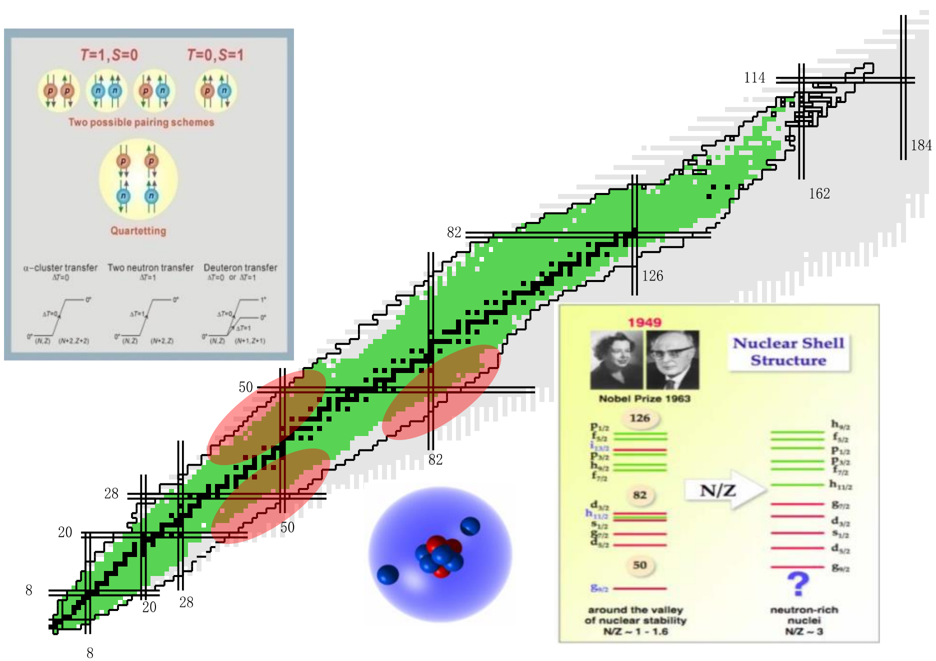
Few Nucleon Removal Reactions

In order to understand the properties of nuclides far away from the stability, it is crucial to precisely locate the position of single particle states near the Fermi surface, and to investigate the degree to which their wave functions reflect pure single-particle motion



The momentum distributions of fragments following one- or two-nucleon removal is the spectroscopic method well established, that gives knowledge on the wave function of the initial nucleons

Using very low intensity beam (~10 /s)!

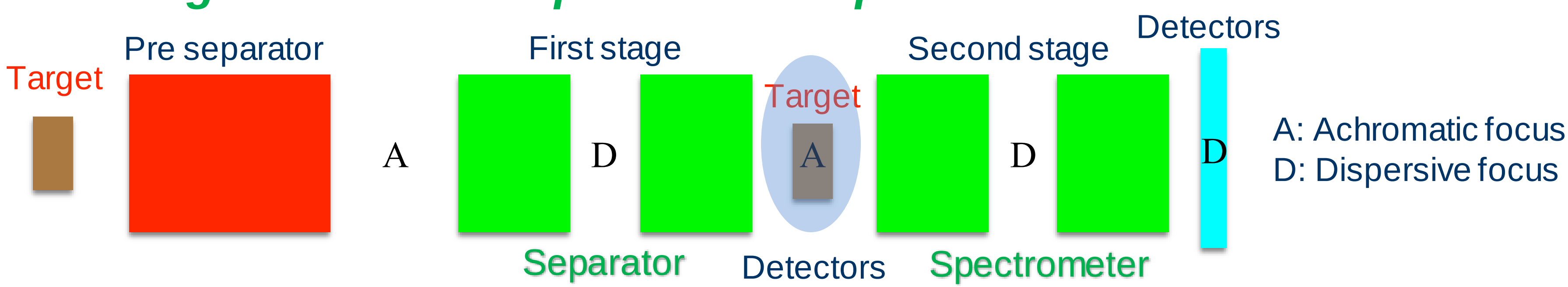


Systematic study along isotopic and/or isotonic chains:

- Evolution of single particle states?
- Robustness of the shell closures?
- *T*=0, *S*=1 proton-neutron pairing?
- Coupling to the continuum?
- Heavier Halos and giant halos?
- ……

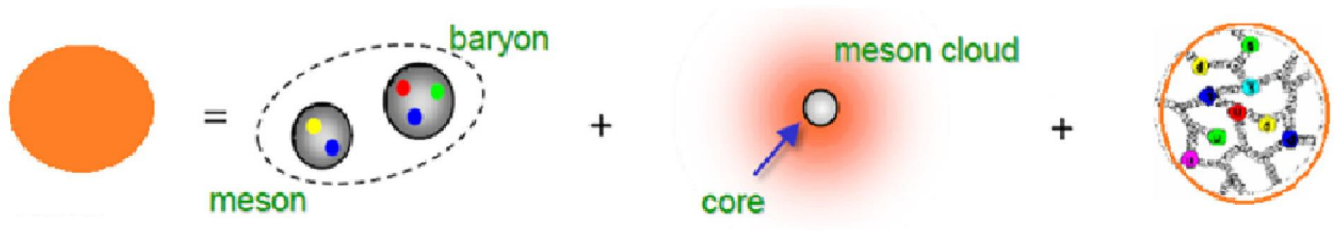
Charge Exchange Reactions

High-resolution Separator and Spectrometer



- At low energies: to measure the distribution of the Gamow-Teller transition strengths (B_{GT})
- At high energies: to study nucleon excitations in nuclei hitherto studied in (near) stable nuclei

Courtesy: H. Lenske



$$|N^*\rangle = |MB\rangle + |qqq\rangle|\pi\pi K\bar{K}...\rangle + |qqq\rangle|q\bar{q}...\rangle|gg...\rangle$$

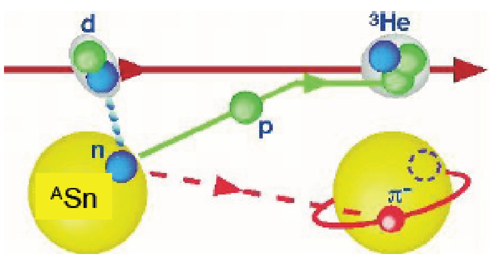
Are the masses and lifetimes of N*-resonances modified in nuclear medium? How deep is the N*-nucleus potential? What is the isospin dependence of resonance potentials? …

The setup can be extended to study of meson-nucleus bound system and neutron-rich hypernuclei

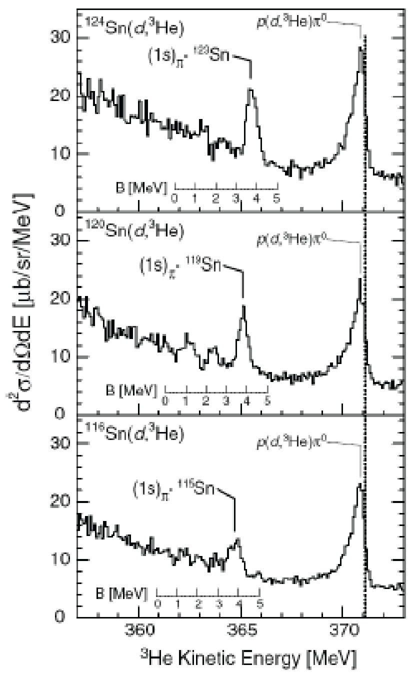
Spectroscopy of Mesonic Atoms

The masses of u and d quarks are nearly 2 orders of magnitude smaller than nucleonic masses, produced by spontaneous breaking of chiral symmetry for massless quarks subject to the strong interaction

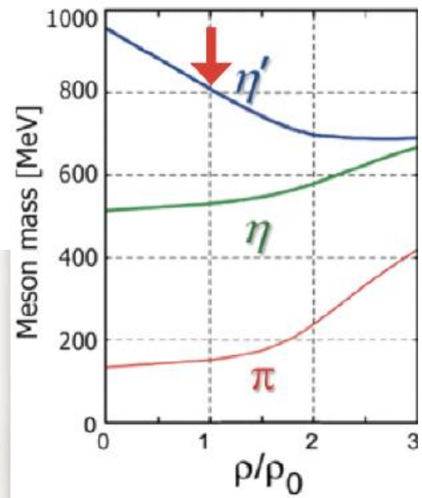
The properties of bound mesonic states in heavy atoms are related to the meson-nucleus interactions, and can contribute to the understanding of the QCD vacuum structure



- Pion-nucleus interaction
  → binding energy, width, mass shift
- Difference of s-wave potential
  → restoration of chiral symmetry?
  → reduction of chiral order parameter f_π ?
- Partial chiral restoration in nuclear medium
  → well-defined quantum states
  → normal nuclear density



H. Geissel et al., Phys. Rev. Lett. 88 (2002) 122301
K. Suzuki et al., Phys. Rev. Lett. 92 (2004) 072302



η′ bound nuclei and η bound nuclei

(p, d), (d, ^{3}He) or (p, ^{3}He) reactions
Method: missing mass spectra

The experiments:

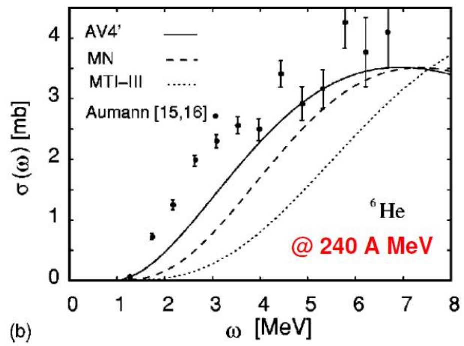
✓ Look for the existence of the states
✓ reveal modification of meson properties inside nuclear matter

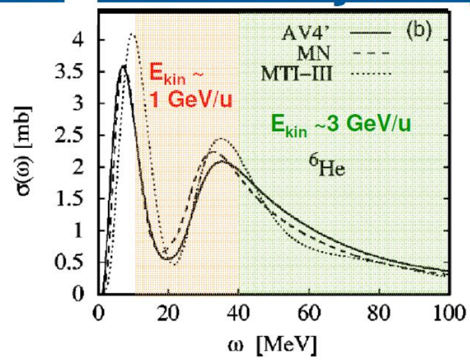
Giant resonance of neutron rich nuclei

High excitation energies

Example: dipole strength distribution in very heavy n-rich systems

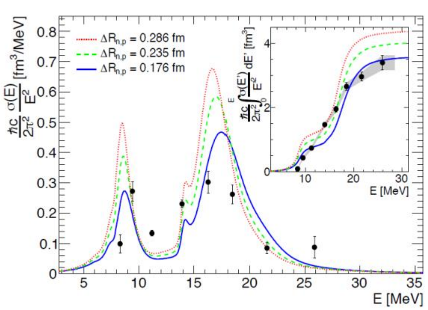
Core vs. neutron skins & halos → density / asymmetry





S. Bacca et al.
PRL **89** (2002) 052502
PRC **69** (2004)057001

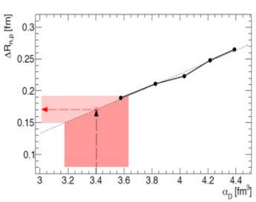
Access to EOS (density dep. of symmetry energy)

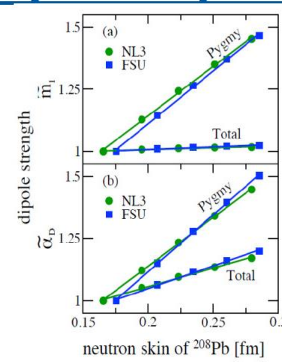


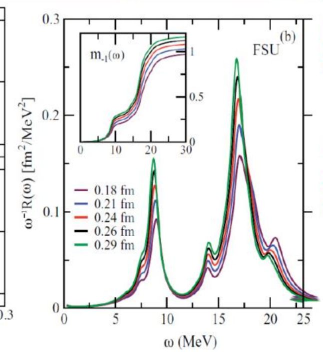
$$\alpha_D = \frac{\hbar c}{2\pi^2}\int_0^\infty \frac{\sigma(E)}{E^2}dE$$

D. Rossi et al.
PRL **111** (2013) 242503

skin thickness ^{68}**Ni**
0.175(21) fm







Pb chain &
N=126 isotones

~1 A GeV →

bare ions
fragment
identification

J. Piekarewicz, PRC **83** (2011)034319

Courtesy: T. Aumann

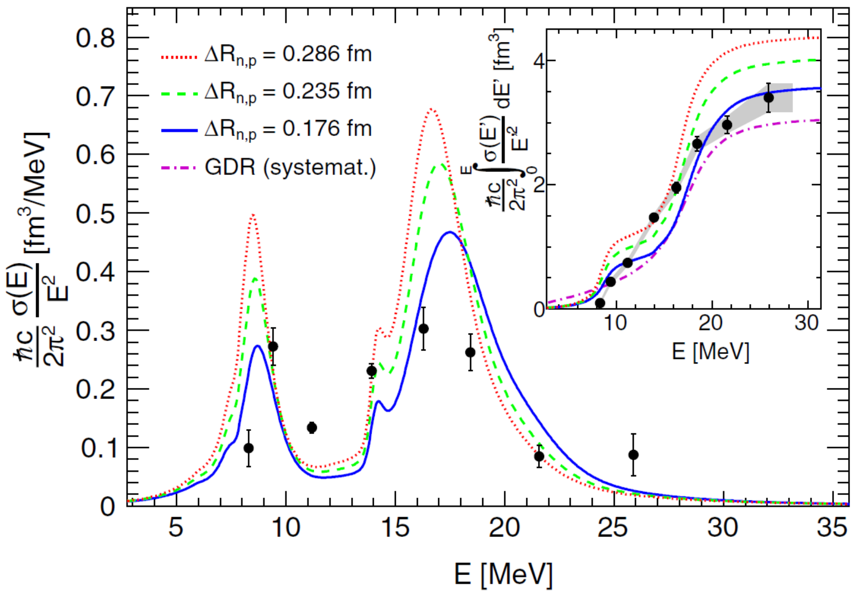
Giant resonance of neutron rich nuclei

A systematic change of neutron skin thicknesses provides sensitive constraints on the EOS, which is of upmost importance for nuclear physics and astrophysics

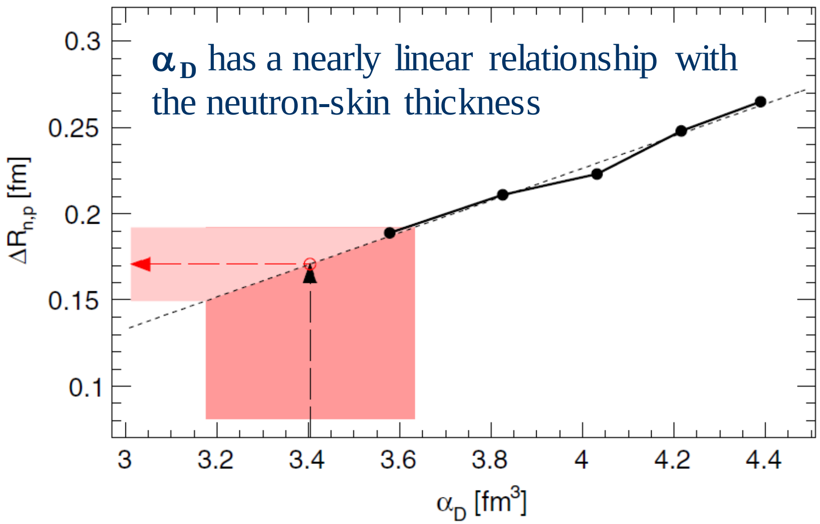
- The low-lying E1 strength (PDR) in n-rich nuclei constrains the neutron-skin thickness
- The α_D is a robust and less model dependent observable to extract neutron-skin thickness

The electric dipole polarizability: $\alpha_D = \frac{\hbar c}{2\pi^2} \int_0^\infty \frac{\sigma(E)}{E^2} dE,$

Giant dipole resonance of n-rich nuclei: a precise determination of neutron skins



Inverse energy-weighted dipole strength for ^{68}Ni. Inset: Experimental dipole polarizability

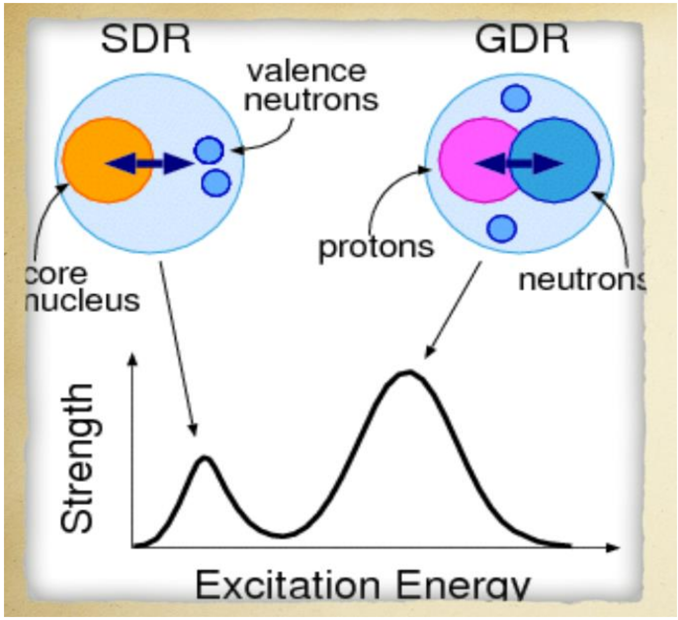


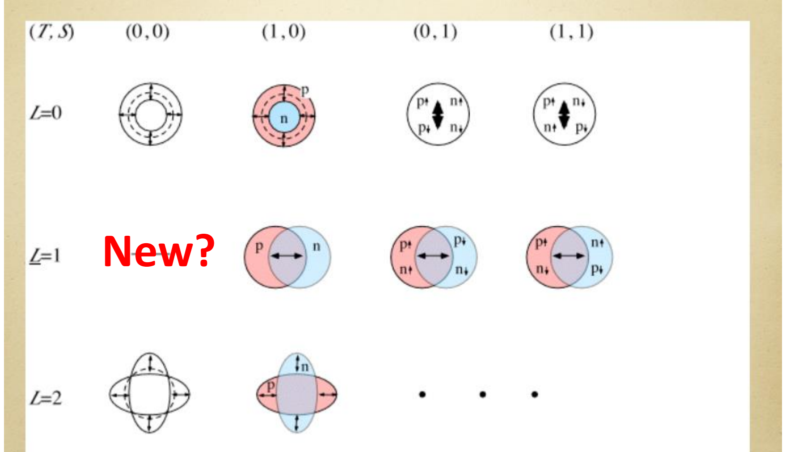
Correlation between neutron-skin thickness and dipole polarizability in ^{68}Ni

D. Rossi et al. PRL 111, 242503 (2013)

Giant resonance of neutron rich nuclei

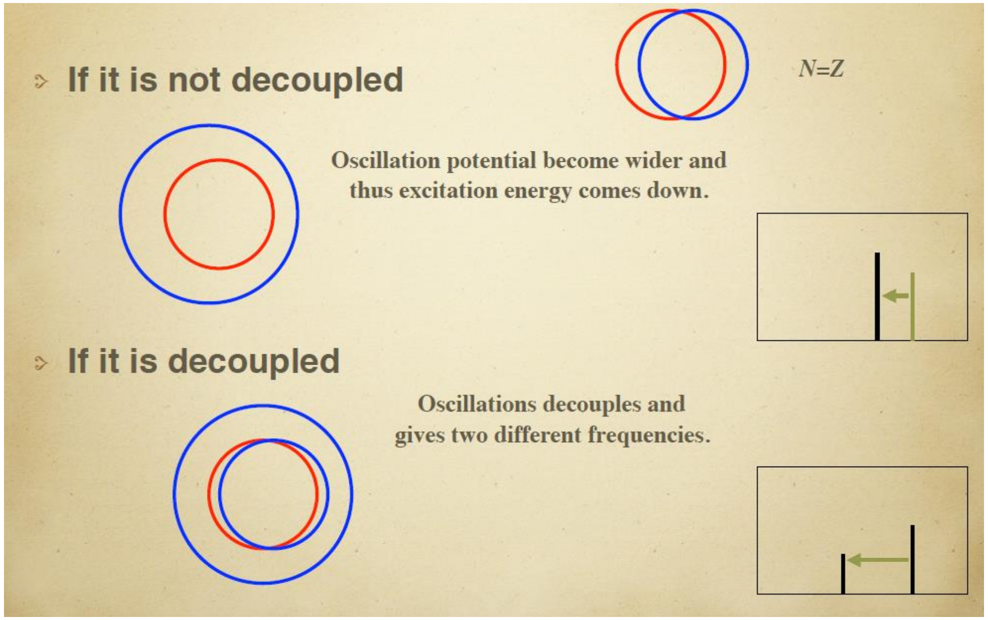
Radioactive beams of energy higher than 1-2A GeV provide new opportunities to study giant resonances in asymmetric nuclei including a new mode (isoscalar E1)





Giant resonates in macroscopic view

Is a neutron skin decoupled from the core?



High-power Linac

SRF Cryomodule Design and Prototype Development

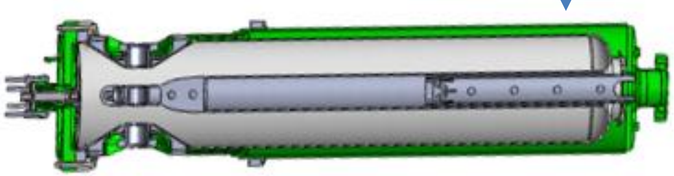
SECR → LEBT → RFQ → Low energy section → High energy section →

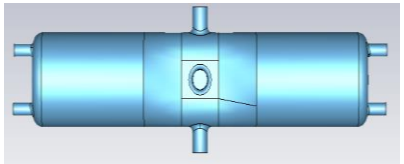
β =0.03 (0.5 MeV/u) | β =0.07 (2.3 MeV/u) | β =0.19 (17 MeV/u)

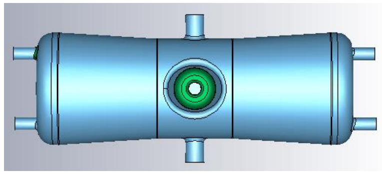
QWR cavity
β = 0.052
f = 81.25MHz

HWR cavity
β = 0.10
f = 162.5MHz

HWR cavity
β = 0.15
f = 162.5MHz





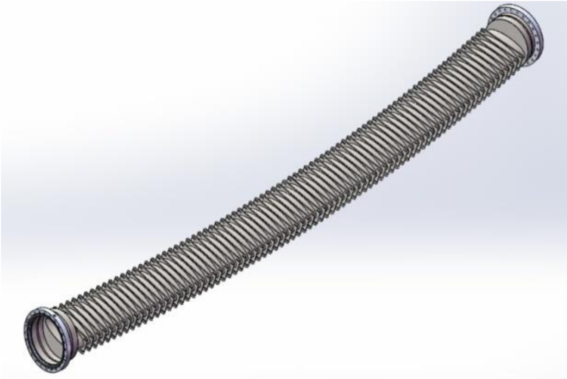


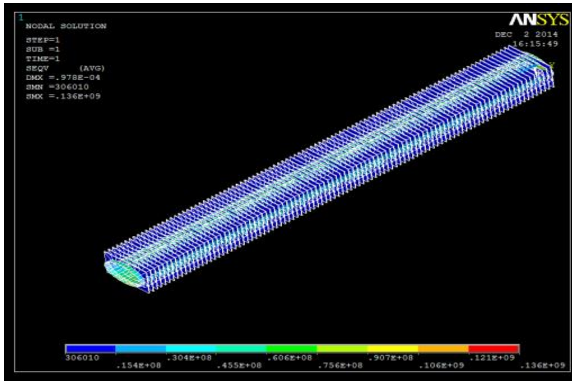
The average uncontrolled beam loss should be limited to below 1 W/m level

Thin Wall Vacuum Chamber Prototype

Prototype of Thin Walled Vacuum Chamber

Due to fast ramping rate operation of BRing, thin walled vacuum chambers are needed for all magnets in order to keep eddy currents at a tolerable level





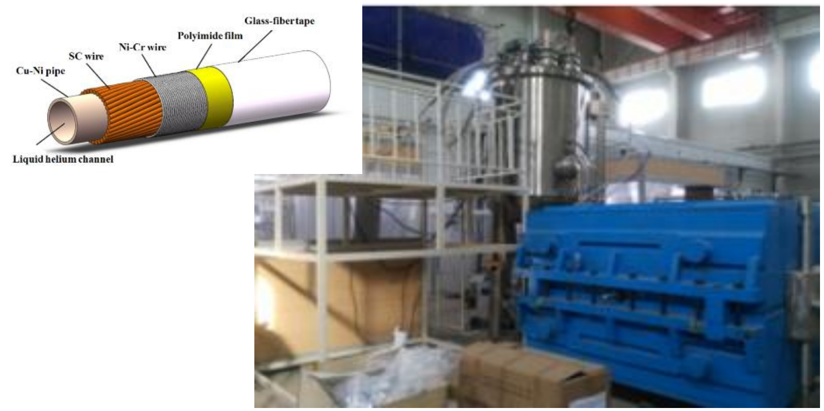
0.3 mm chamber design

0.3 mm thick vacuum chamber prototype

- Elliptical aperture
- Stainless steel
- Rib supporters in parallel with the magnetic fields

Superconducting Magnets

Prototype of Superconducting Magnets



HIAF prototype dipole based on nuclotron-type cable

US FRIB, 8-9T superconducting solenoids 80 sets completed

ADS linac, 5T SC solenoids 26 sets completed

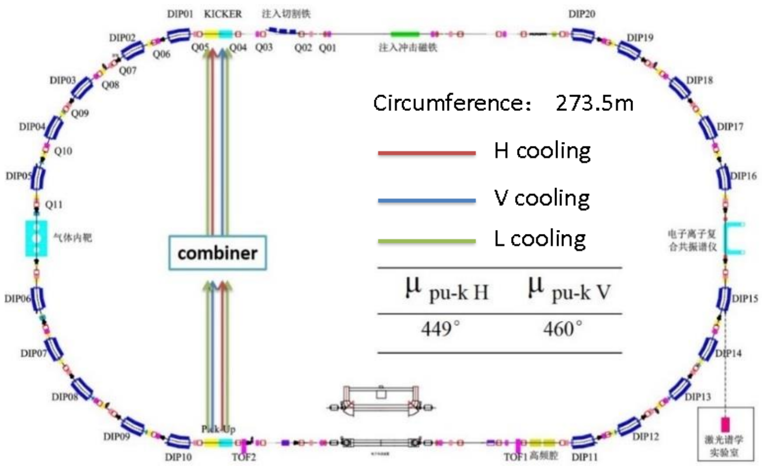
LHe-free 7T, 3×10^{-7} @1 cm^3

SECRAL II magnet

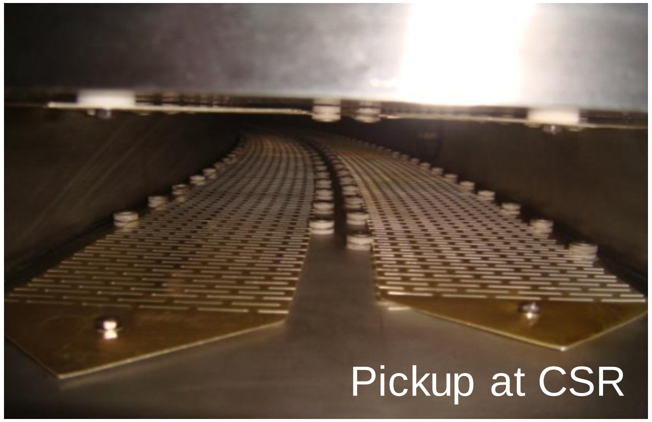
Stochastic Cooling

Prototype of Stochastic Cooling Device

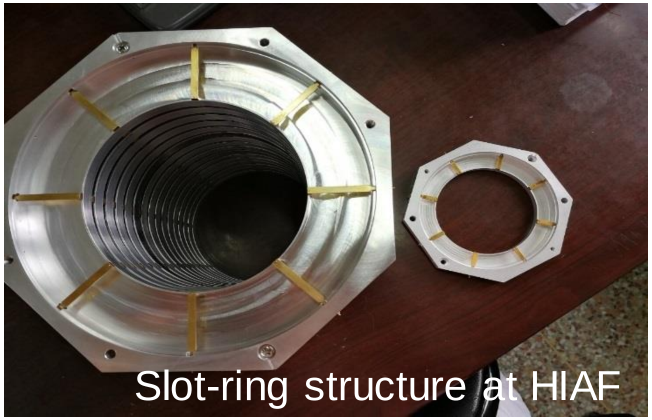
A novel type of 2.76 m long slotted pick-up was developed (in cooperation with GSI) for stochastic cooling. The key components were fabricated and installed in CSRe



Pickup and kicker



Pickup at CSR



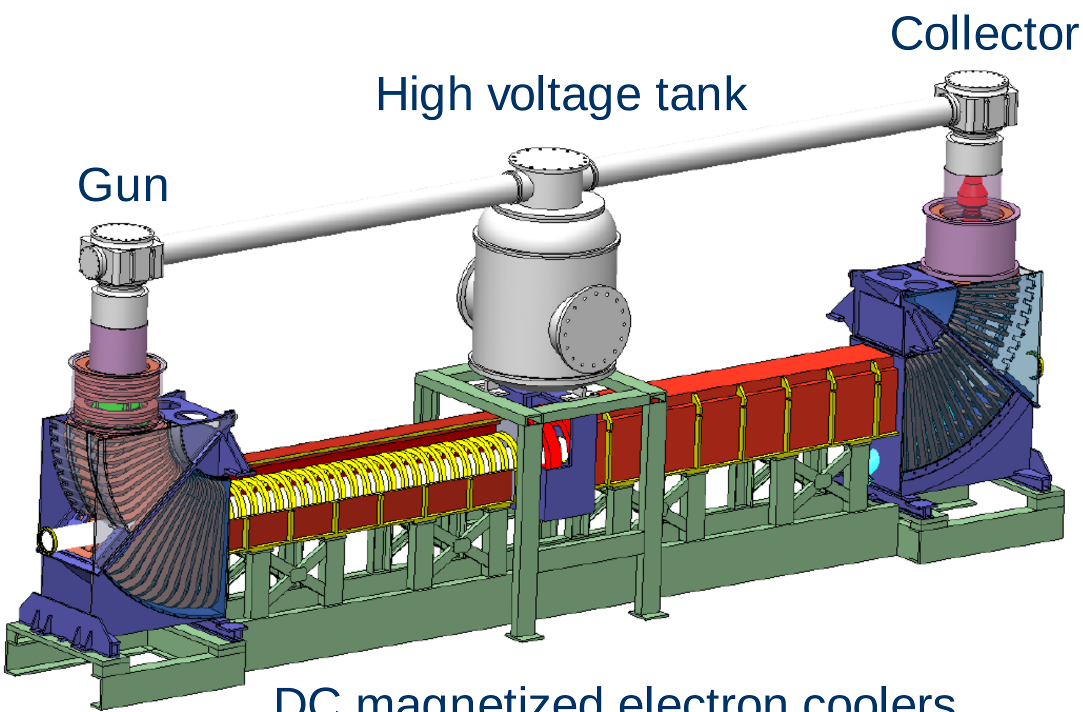
Slot-ring structure at HIAF

Before cooling	Δ p/p: $\pm 4.0\times10^{-3}$ εx/εy: 30 π mm·mrad
After cooling	Δ p/p: $\pm 2.5\times10^{-4}$ εx/εy: 5 π mm·mrad
Cooling time	<1.2 s

The beam test (253 MeV/u $^{117}Sn^{50+}$) results show that it is a well-suited structure for stochastic cooling at HIAF

Electron Cooler

Design of Electron Coolers @HIAF



DC magnetized electron coolers

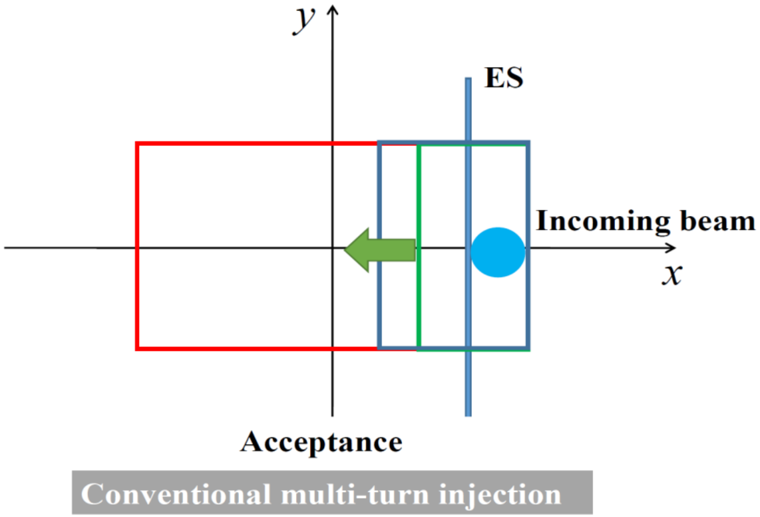
200 keV & 2 A e-cooler at Spectrometer Ring

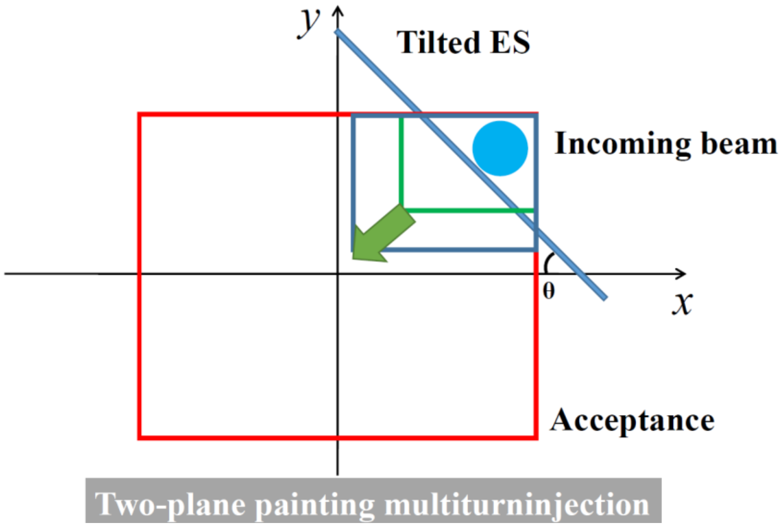
Well-established electron cooling at existing CSR

Hollow e-beams were obtained at the coolers@CSR, which partially solve the problem of space charge effect and reduce the recombination between the ions and electrons

Two Planes Painting Injection

Simultaneous injections in H and V planes using **tilted septum**





Ions	Energy (MeV/u)	Injection current（emA）	Plane	Injection turns	Single injection
$^{238}U^{34+}$	17	2.0	H	33	3.3×10^{10}
			V	16	1.6×10^{10}
			H+V	**150**	**2.0×10^{11}**

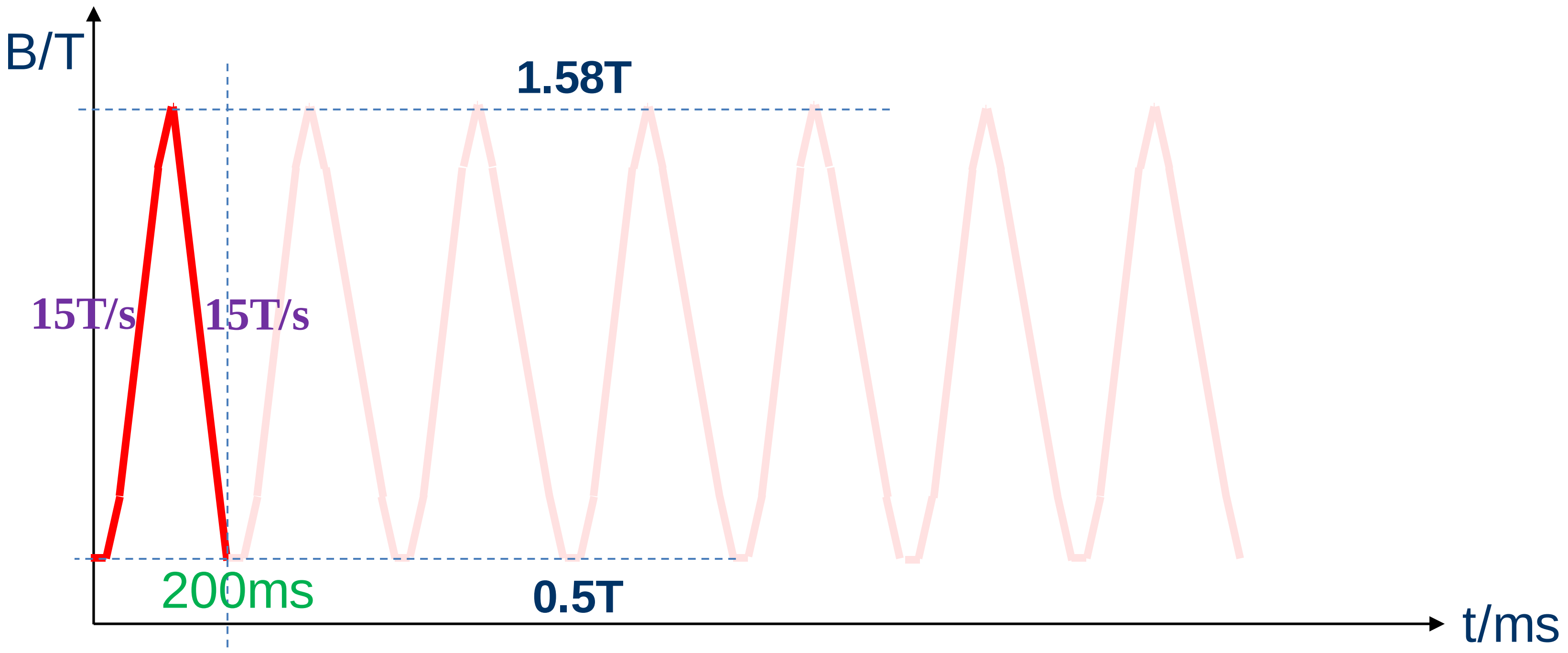
Conclusions:

The beam intensity could reach 2.0×10^{11} from simulation results, nearly 10 times over the conventional single-plane injection

Fast Ramping Rate

Fast ramping rate mode of BRing

Due to **space charge** and **dynamic vacuum** effects, ions stored should be launched to high energy as soon as possible



Repetition rate：5-10Hz

Perspective of Expansion

Build a ring to produce bunched heavy-ion beams of short pulse and high power for HED physics, and then add a high-energy electron ring for e-A collisions

Properties of the High Energy Density Matter
Electron Ion Collisions

U+U Collision (Decay of the Vacuum)

Develop merging beams of bare Uranium

An ISOL-type Facility

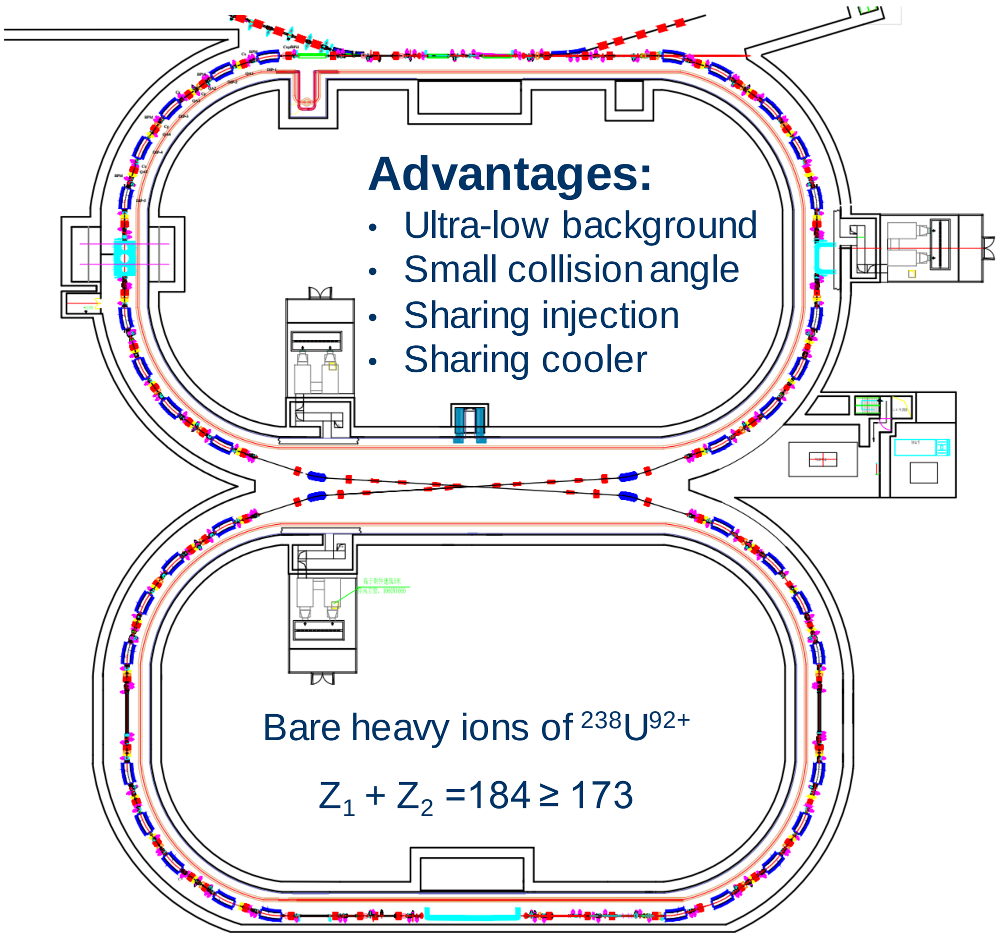
Use the powerful proton Linac of the CiADS as a driver (500 MeV@10mA)

Phase II or III

Ion-ion Merging Facility

First Ion-ion Merging Facility in the World

"8" shape of two rings



➢ Decay of the Vacuum (U + U collision)

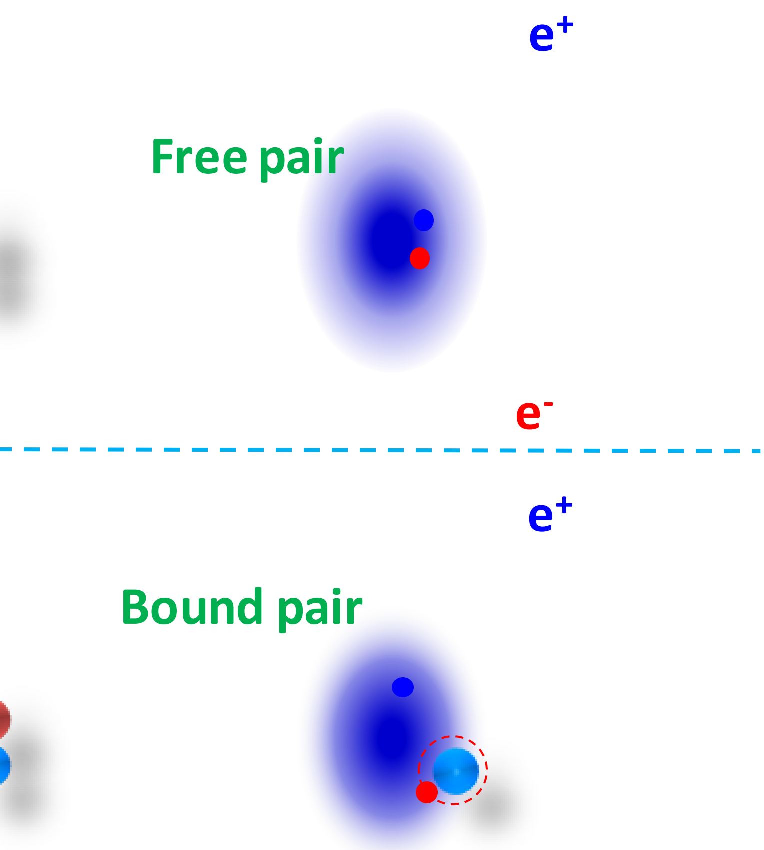
Merging beam parameters

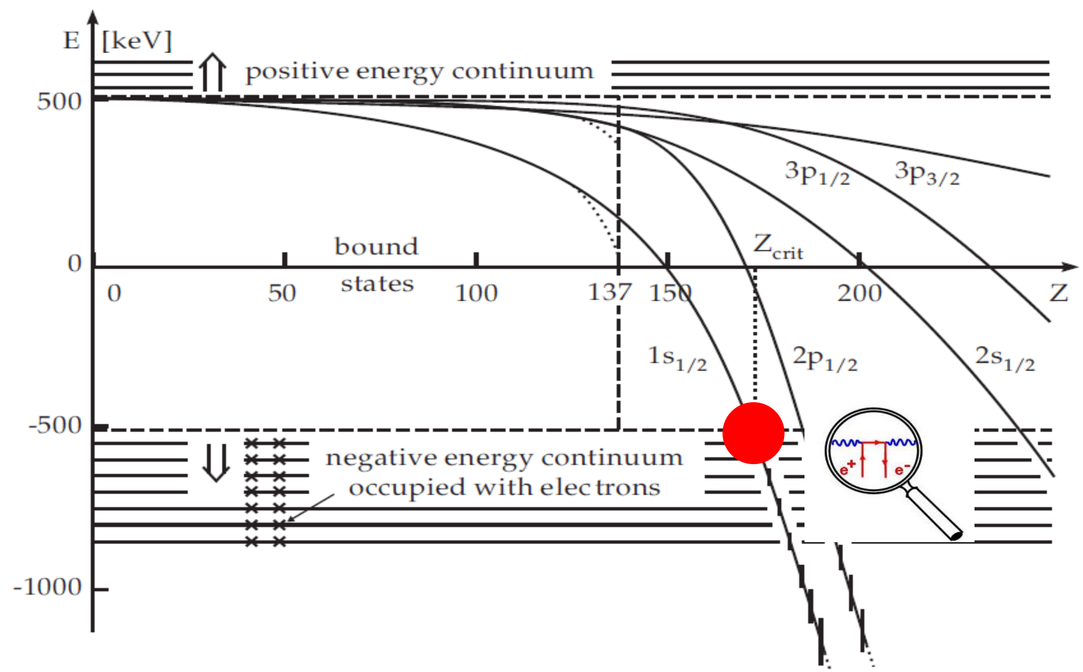
Parameter	Value
Ion	$^{238}U^{92+}$
Energy (MeV/u)	637(800)
Circumference (m)	483.8
Frequency (MHz)	0.50(0.52)
Crossing angle (°)	6.8
C.M energy (MeV/u)	6(8)
Particle number	**$7(8)\times10^{10}$**
$\varepsilon_{x,rms}/\varepsilon_{y,rms}$ (π mm mrad)	1/1
β^*_x/β^*_y(m)	1/0.03
$\sigma_{x,rms}/\sigma_{y,rms}$ (mm)	1/0.173
Laslett tune shift	-0.1(-0.077)
Hourglass factor	0.9
Luminosity($cm^{-2}s^{-1}$)	**$4.4(5.4)\times10^{23}$**

U + U Collision

Decay of the Vacuum (Theoretical prediction)

In heavy ion collision, super atoms might be formed instantaneously. If the atomic number ($Z_{projectile}+Z_{target}$) is larger than 173, a critical electric field is realized. Under the circumstance, the bound electron states dive into the negative continuum and the vacuum is excited and consequently the positron-electron pair is produced





Ideal experiment: merging beams of fully striped Uranium ions