Perspective of BRIF project in CIAE

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CIAE, China institute of atomic energy
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Scope of study

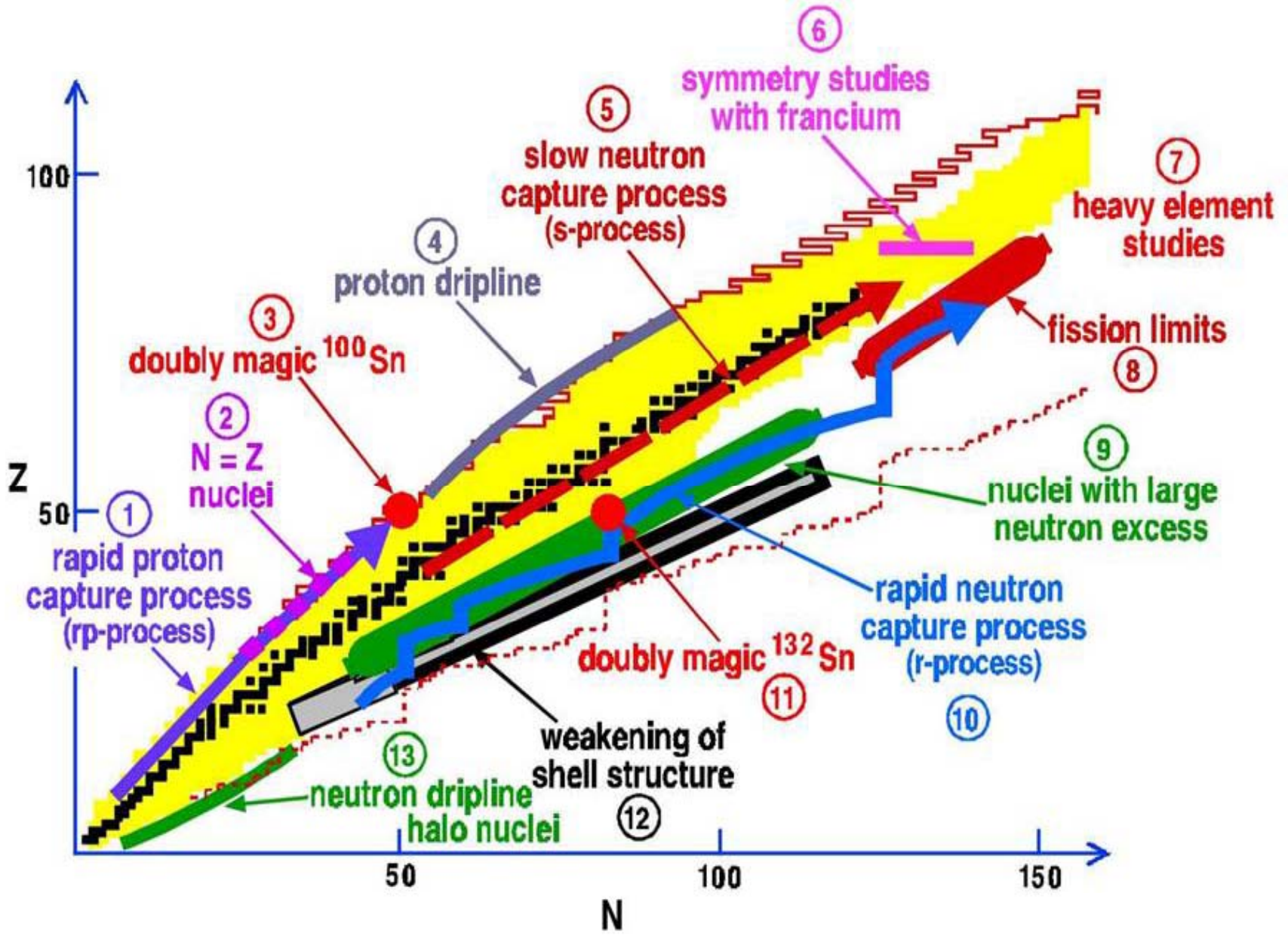
- Nuclear physics with stable nuclei
  - SHE
  - Reaction and structure
- Nuclear physics with unstable nuclei
  - Reaction
  - Structure
  - Nuclear astrophysics
- Funded by
  - MOST
  - NSFC
  - CAS, MOE, CAEA, and others

Nuclear physics activities in China: not complete!

- **Experimental**
  - **IMP, CSR, HI physics**
  - **CIAE, HI-13, BRIF, low E NP**
  - **Other: IHEP, SINAP, PKU, USTC and others**
- **Theoretical**
  - **All institutes above**
  - **PKU, THU, plus other universities**
- **Council for China-Japan Research Collaboration on Nuclear Physics established in 2007**
- **Asian nuclear physics association (ANPhA) established in 2009**
- **Summer school by PKU, NN09 by CIAE, in Beijing**

Some Experimental Highlights, not complete!

- **Physics**
  - **Reactions**
    - **around coulomb in Beijing, few tens MeV A at Lanzhou and RIKEN**
    - **SIAP: Lanzhou exp, for total cross section ^{23}Al, ^{27}P and ^{17}F, Riken exp, ^{23}Al; 2p emission in Lanzhou for CIAE**
    - **reaction ^{17}F+^{12}C at CNS and near barrier and fusion, in CIAE**
    - **PKU: ^{17}Ne, ^{16}C Lanzhou, ^{6}He and ^{8}He in RIKEN, transfer and breakup**
    - **Elastic scattering: new scaling in Lanzhou**
  - **Decay, and the PKU for beta-n, ^{21}N**
  - **In-beam gamma exp, CIAE, Lanzhou, Jilin, TU, PKU, stale nuclei**
  - **Nuclear astrophysics, indirect and direct and decay, in CIAE, Lanzhou and CNS**
  - **1st Observation of antimatter hyper-nucleus $^{3}_{\bar{\Lambda}}\bar{\mathrm{H}}$: RHIC STAR-SIAP, published in science**
- **Detector**
  - **Good collaboration in gamma array: Beijing-Lanzhou**
  - **charged particle array, Lanzhou, CIAE and PKU**
  - **PKU for beta-n decay**
  - **Neutron detection wall, Lanzhou and PKU**

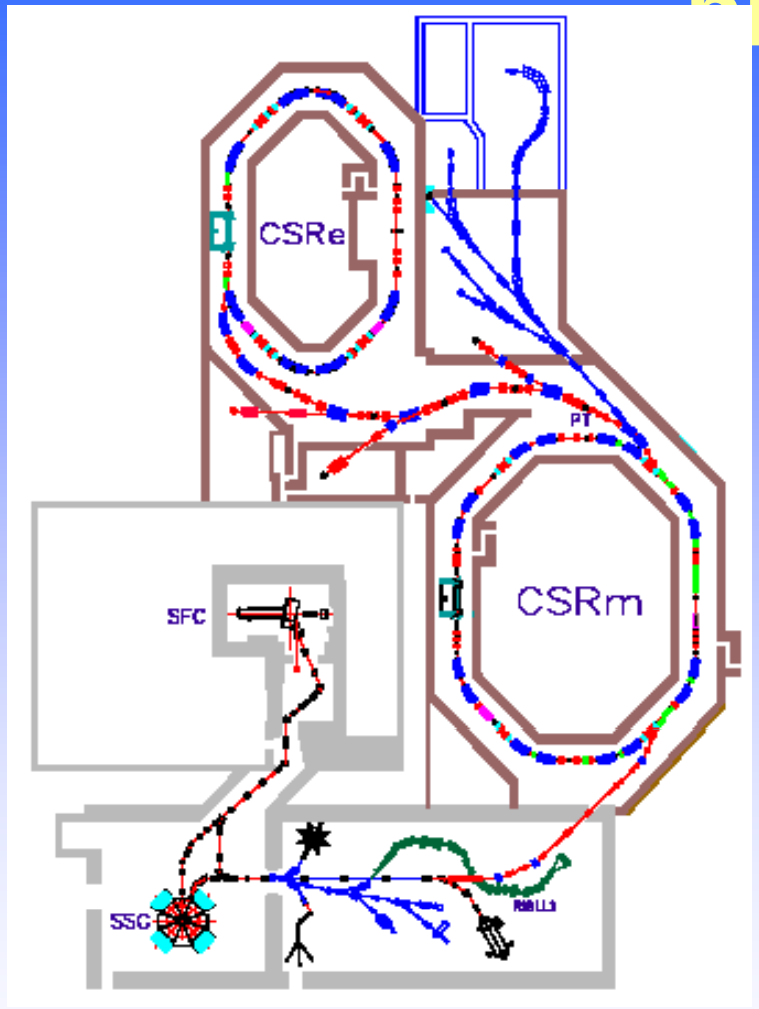

6
symmetry studies
with francium
5
slow neutron
capture process
(s-process)
7
heavy element
studies
4
proton dripline
3
doubly magic 100Sn
fission limits
8
2
N = Z
nuclei
9
nuclei with large
neutron excess
100
Z
50
1
rapid proton
capture process
(rp-process)
rapid neutron
capture process
(r-process)
10
doubly magic 132Sn
11
13
weakening of
shell structure
12
neutron dripline
halo nuclei
50
100
150
N

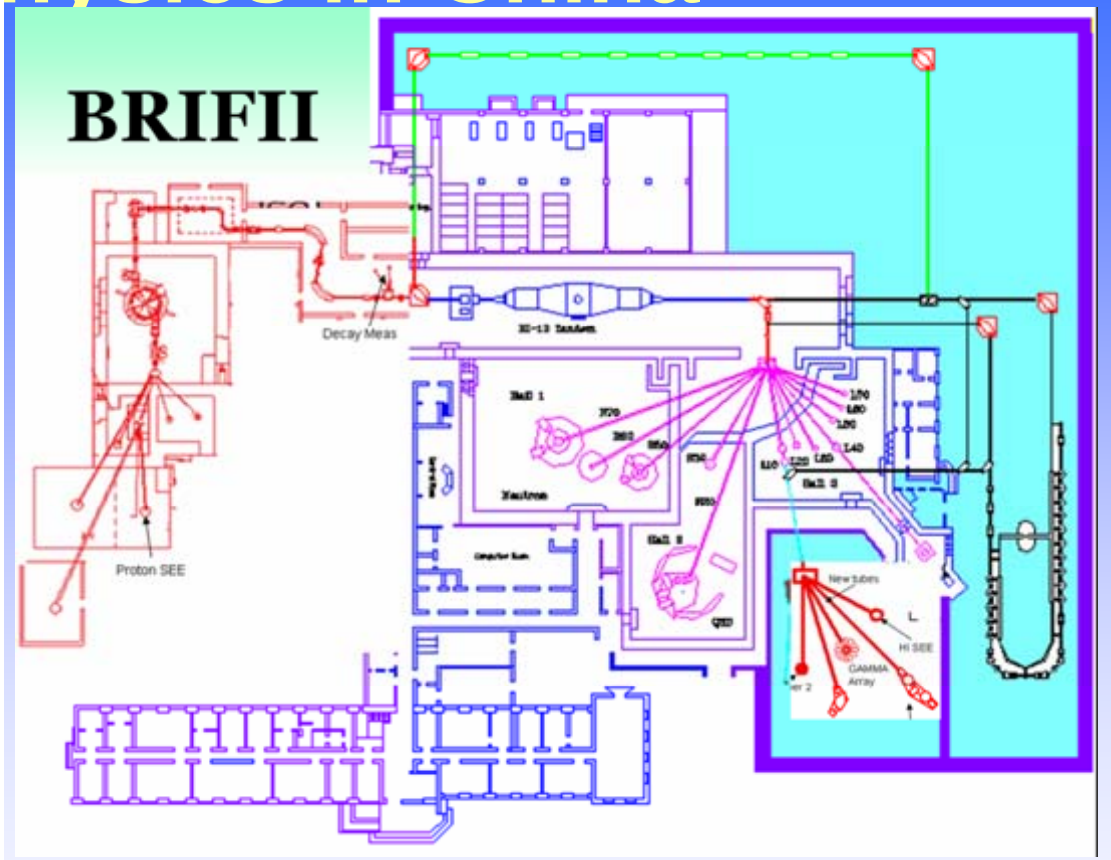
PF and ISOL

- PF
- Wide range of RIB
- In-flight selection of 1 μs
- Energy 50-400 MeV/u
- Beam purity and energy resolution is limited
- GSI, RIKEN, GANIL, etc
- Effective beam use is issue

- ISOL
- RIB near stability
- Selection time of 1 s
- Energy 100 keV to 15 MeV/u
- High beam purity
- Energy resolution same with stable beam
- TRIUMF, ISOLDE, etc
- Not so many, need target-ion source development

Two major facilities in nuclear physics in China



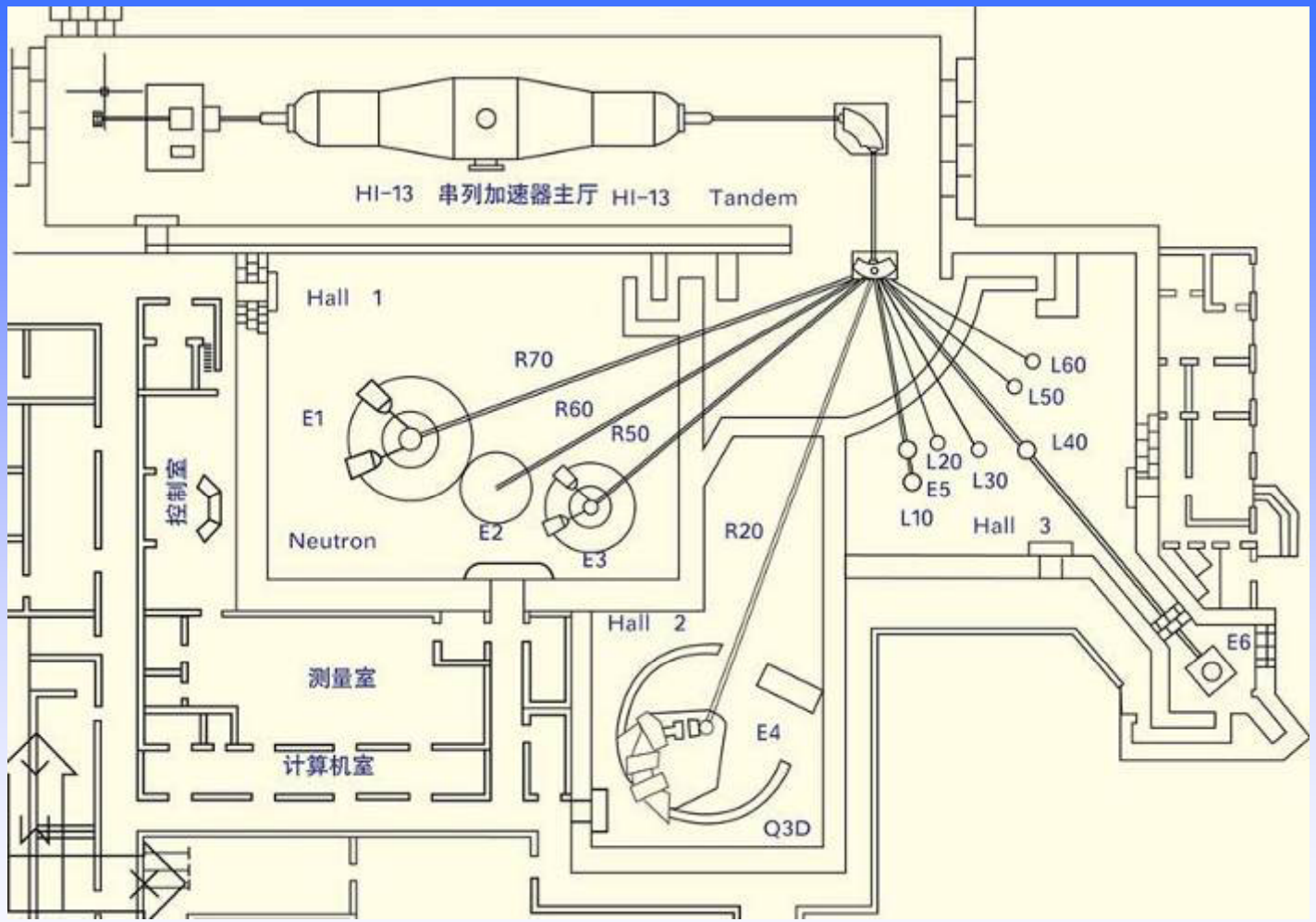


Physics : why BRIF

Intensity 1-10^{11}, energy 100 keV-10 MeV/u, RIA proposal

Physics Topics*	Reactions and Techniques	Beams	Desired Intensities [particles/sec]	Energy Range [MeV/u]
rapid proton capture (rp processes)	transfer, elastic, inelastic, radiative capture, Coulomb dissociation	^{14}O, ^{15}O, ^{26}Si, ^{34}Ar, ^{56}Ni	10^{8}-10^{11} 10^{5}-10^{11}	0.15-15
reactions with and studies of N=Z nuclei, symmetry studies	transfer, fusion, decay studies	^{56}Ni, ^{62}Ga, ^{64}Ge, ^{68}Ge, ^{67}As, ^{72}Kr	10^{4}-10^{9}	0.1-15
decay studies of ^{100}Sn	decay	^{100}Sn	1-10	low energy
proton dripline studies	decay, fusion, transfer	^{56}Ni, ^{64,66}Ge, ^{72}Kr	10^{6}-10^{9}	5
slow neutron capture (s-process)	capture	^{134,135}Cs, ^{155}Eu	10^{8}-10^{11}	0.1
symmetry studies with francium	decays, traps	^{A}Fr	10^{11}	low energy
heavy element studies	fusion, decay	$^{50-52}$Ca, ^{72}Ni ^{84}Ge, ^{96}Kr	10^{4}-10^{7} 10^{6}-10^{8}	5-8
fission limits	fusion-fission	$^{140-144}$Xe, $^{142-146}$Cs ^{142}I, $^{145-148}$Xe, $^{147-150}$Cs	10^{7}-10^{11} 10^{4}-10^{7}	5
rapid neutron capture (r-process)	capture, decay, mass measurement	^{130}Cd, ^{132}Sn, ^{142}I	10^{4}-10^{9}	0.1-5
nuclei with large neutron excess	fusion, transfer, deep inelastic	$^{140-144}$Xe, $^{142-146}$Cs ^{142}I, $^{145-148}$Xe, $^{147-150}$Cs	10^{7}-10^{11} 10^{2}-10^{7}	5-15
single-particle states/ effective nucleon-nucleon interactions	direct reactions, nucleon transfer	^{132}Sn, ^{133}Sb	10^{8}-10^{9}	5-15
shell structure, weakening of gaps, spin-orbit potential	mass measurement, Coulomb excitation, fusion, nucleon transfer, deep inelastic	^{A}Kr, ^{A}Sn, ^{A}Xe	10^{2}-10^{9}	0.1-10
(near) neutron-dripline studies, halo nuclei	mass measurement, nucleon transfer	^{8}He, ^{11}Li, ^{29}Ne, ^{31}Na, ^{76}Cu	10^{6}-10^{8} 10^{3}-10^{6}	5-10

The current Tandem lab



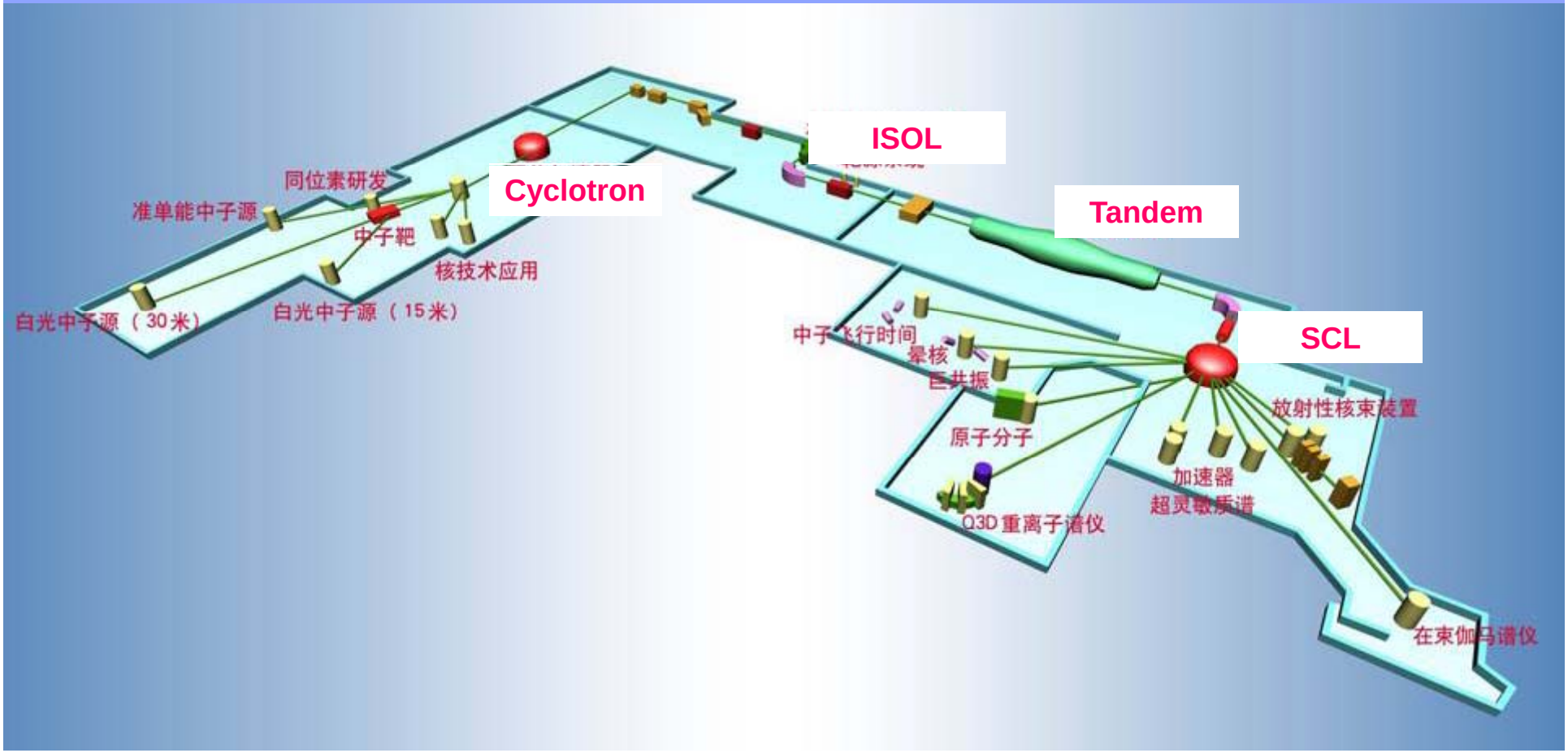
- **Beam type, only stable, few unstable in-flight**
- **Energy range, less than 15 MeV/q**

About Tandem Lab.

- PAC for all users
- 3000-4000 beam hours annually selected from 7000-8000 hours of application from more than 20 research institutes, including international ones
- Main subject
  - Nuclear data Measurement
  - Nuclear physics Basic Research
  - Application of Nuclear technology
- Main Experimental Facilities
  - Neutron Time-of-Flight spectrometer
  - Q3D heavy-ion spectrometer
  - Accelerator Mass spectrometry
  - Secondary beam line
  - Heavy-ion Micro beam facility
  - HPGe array

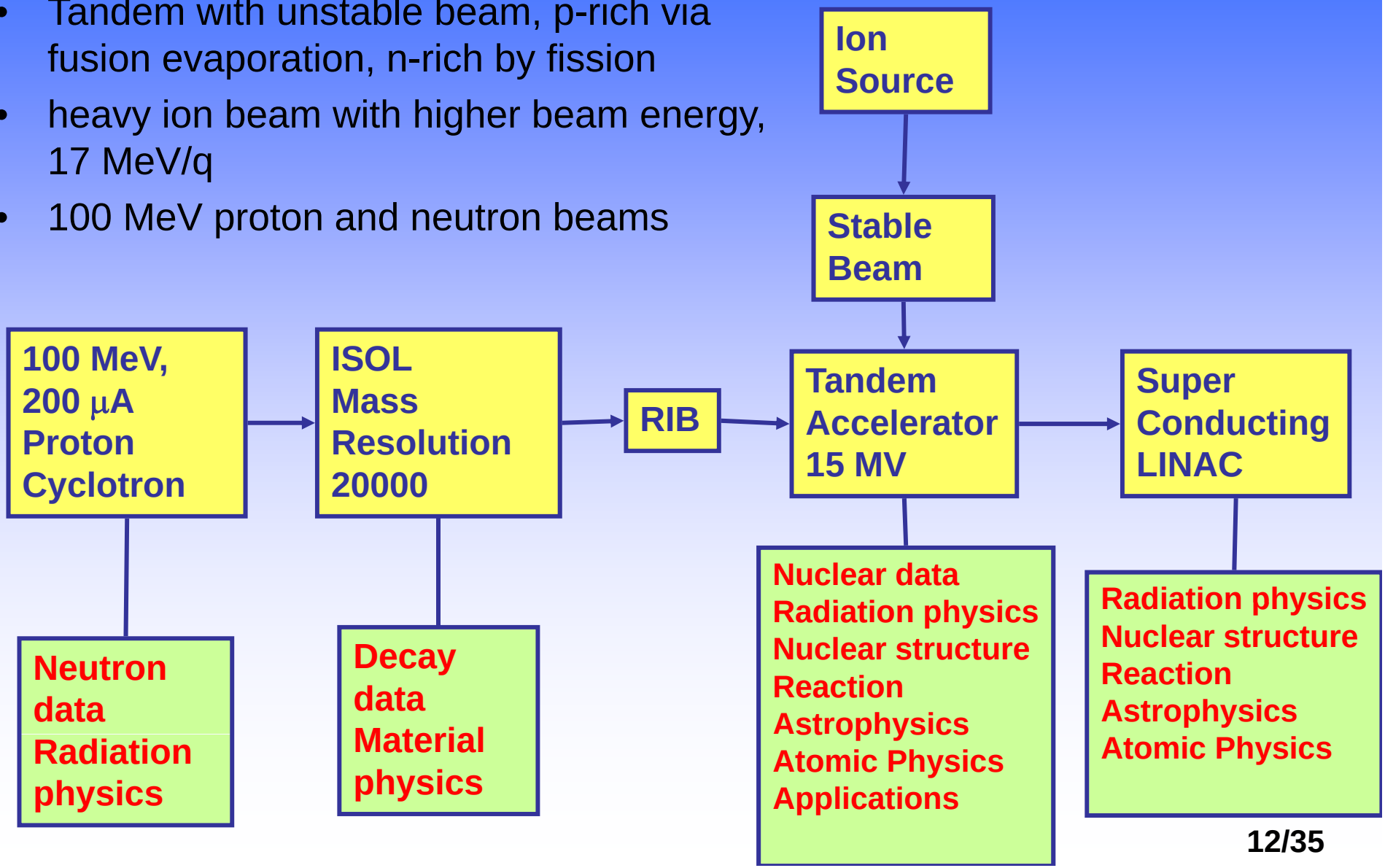
BRIF

100 MeV 200 μA compact proton cyclotron
20000 mass resolution ISOL, 2 MeV/q super-conducting LINAC
Supported in 2004, commissioned in 2012-2013

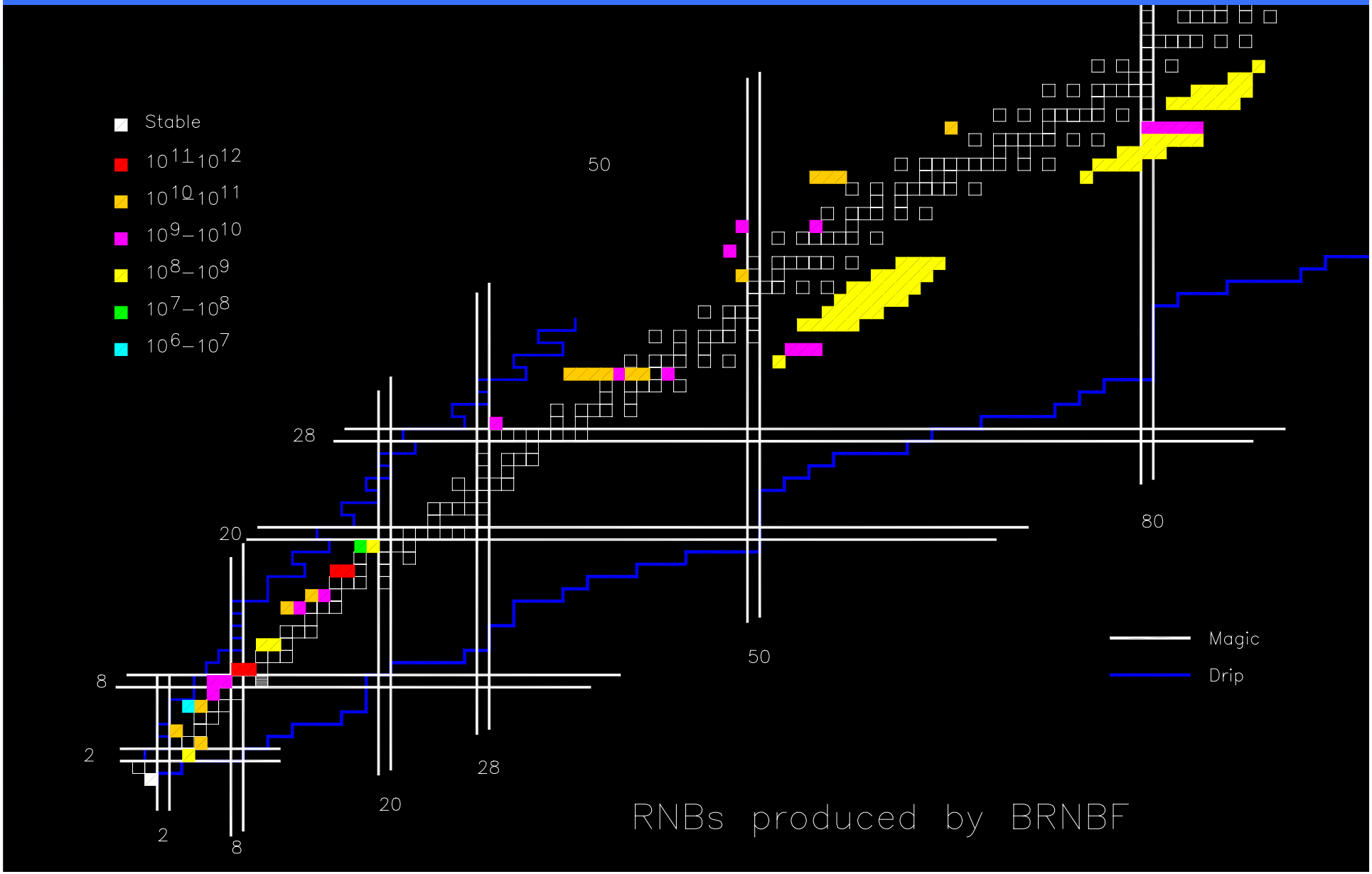


BRIF research opportunities and combinations

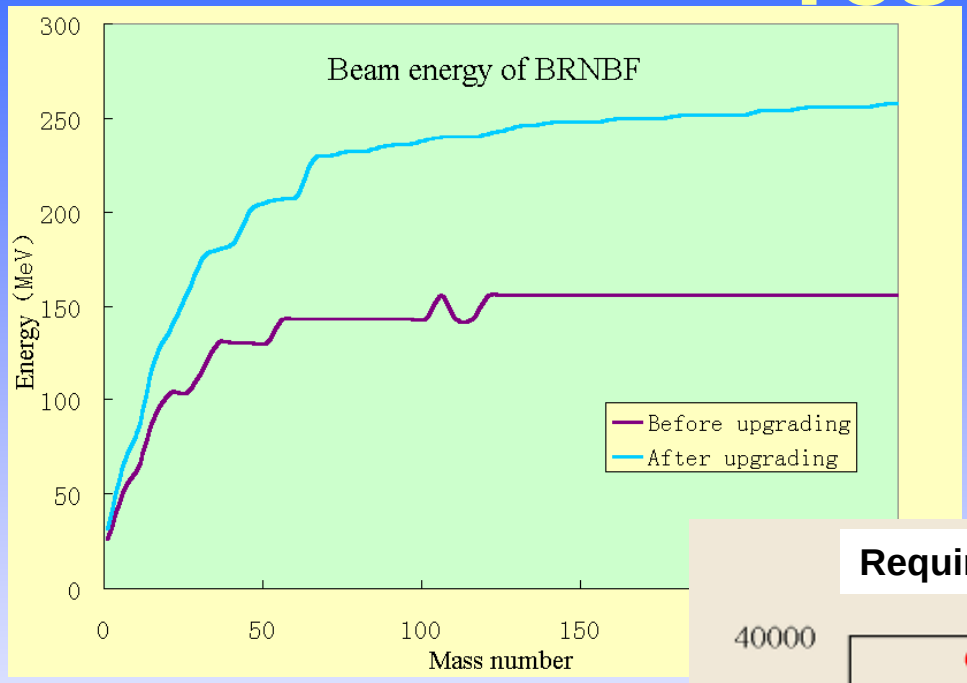
- Tandem with unstable beam, p-rich via fusion evaporation, n-rich by fission
- heavy ion beam with higher beam energy, 17 MeV/q
- 100 MeV proton and neutron beams

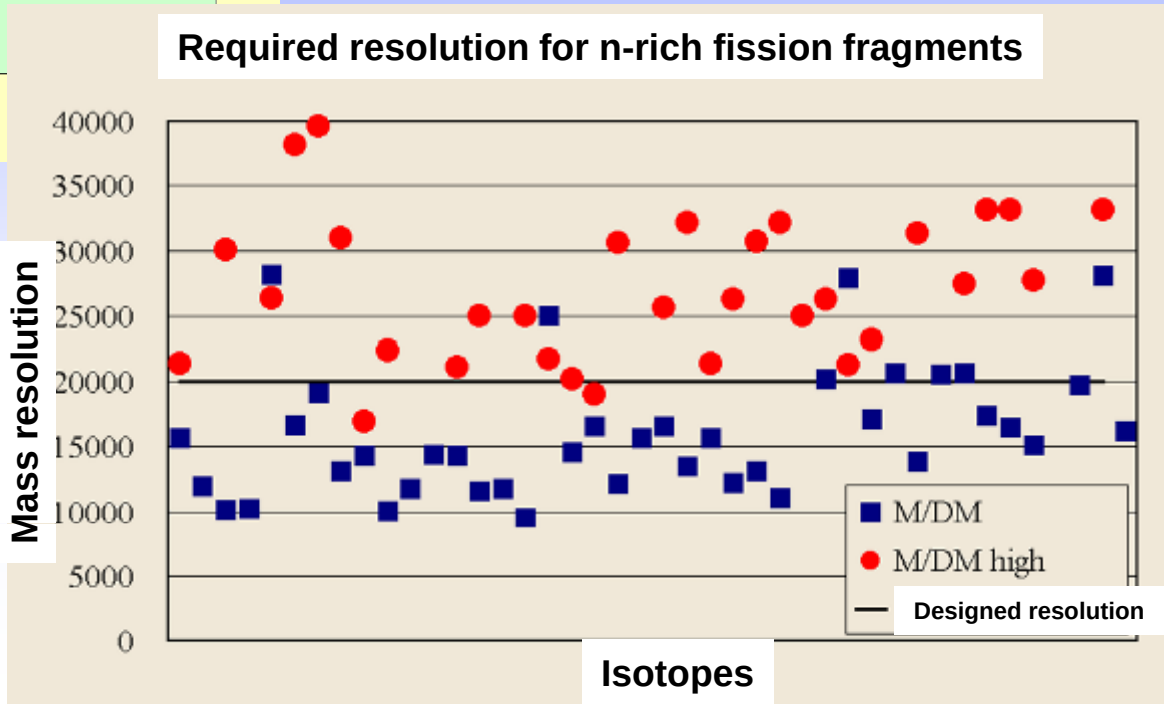


RIB intensity expected



BRIF energy and mass resolution





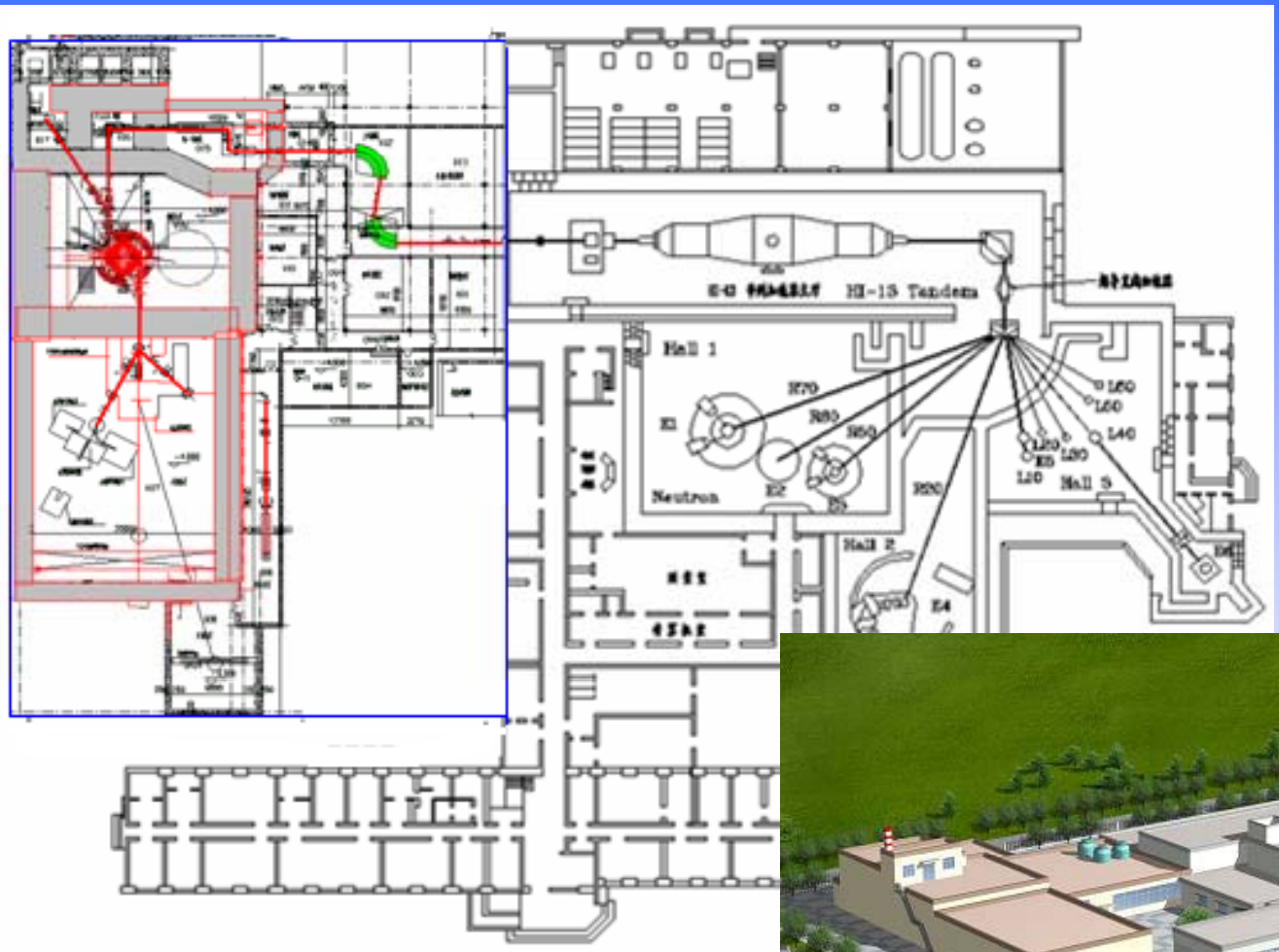
Project Milestone

- Conceptual plan approved in July 2003
- Feasibility plan ($28 M) approved in April 2004
- First budget ($20 M) come to CIAE in 2005
- New feasibility plan required in May 2006
- New feasibility plan finished in May 2007
- New feasibility plan ($54 M) approved in July 2009
- Deliver to user in 2012-2013

BRIF status in 2009

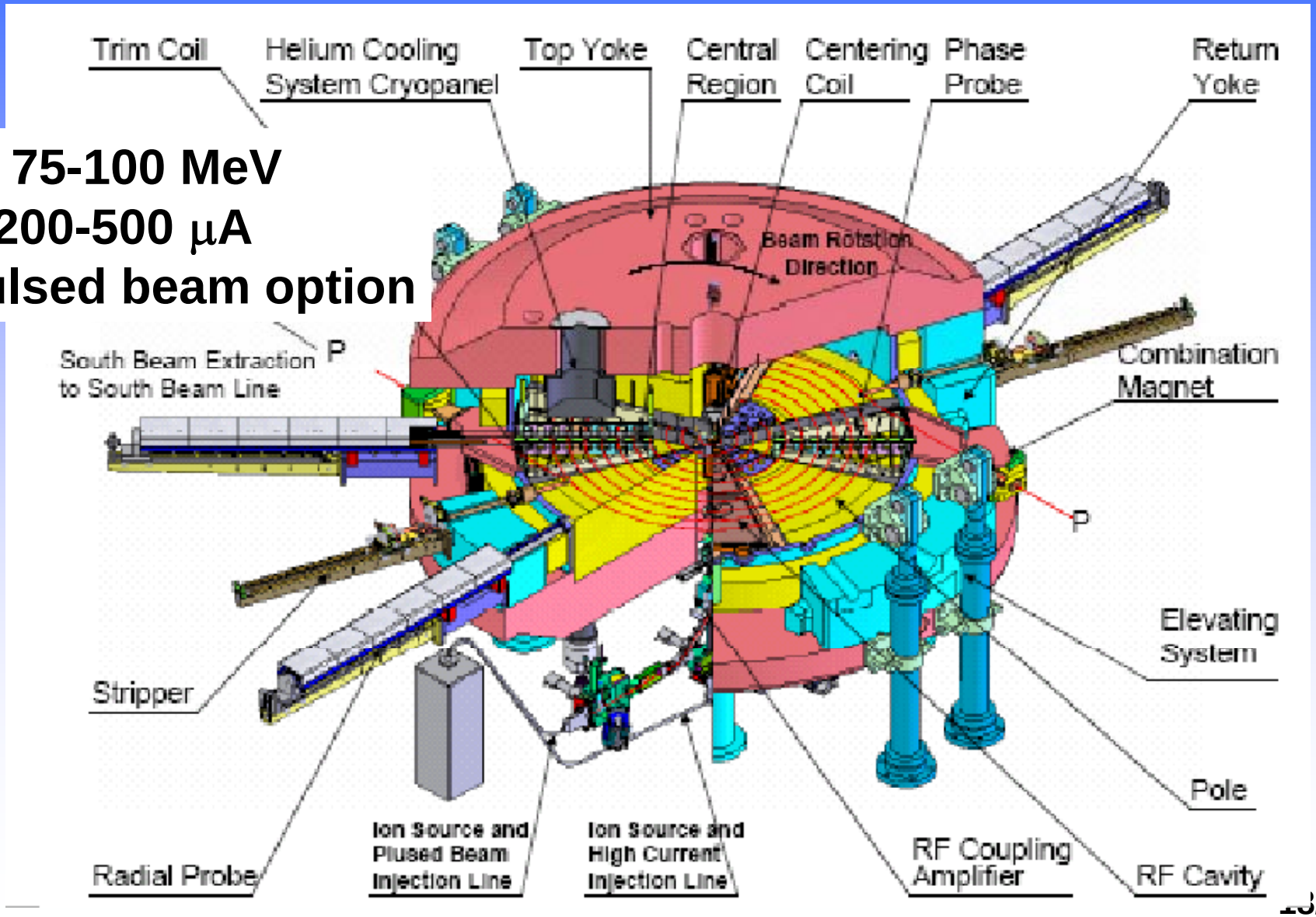
- **Cyclotron: magnet rough machining finished , fine machining started, central region test finished, all machining finished in 2010**
- **ISOL: target-source area fabricated, magnets and control machining in progress**
- **SC linac: QWR lab. finished, all the fabrication of prototype and sample tested OK**

Engineering layout



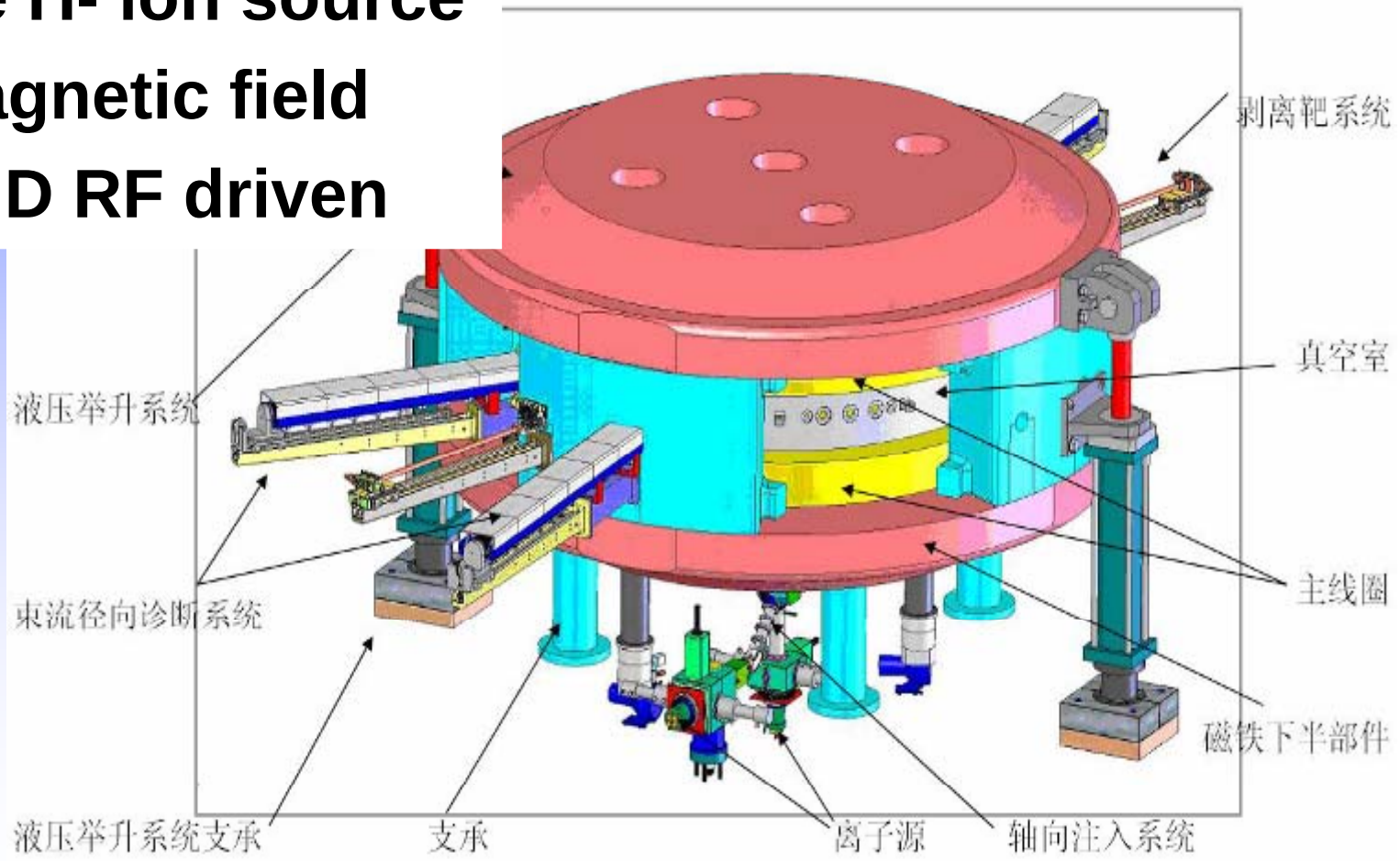
3D internal structure of proton cyclotron

E_p 75-100 MeV
I_p 200-500 μA
Pulsed beam option

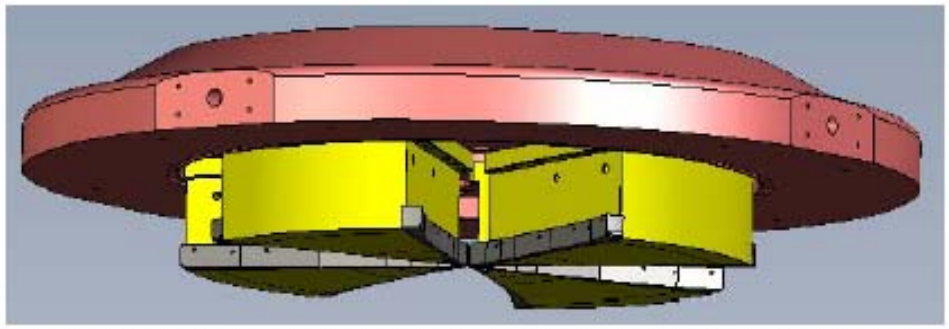


Characteristics

- **Compact design**
- **Outside H- ion source**
- **Low magnetic field**
- **Double D RF driven**

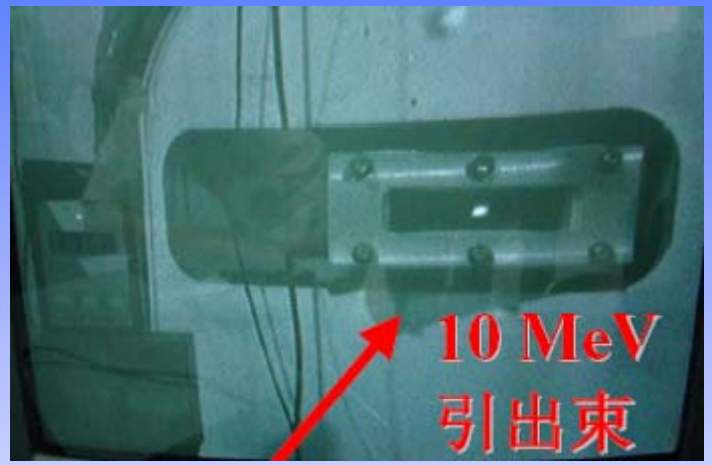


Magnet design and fabrication

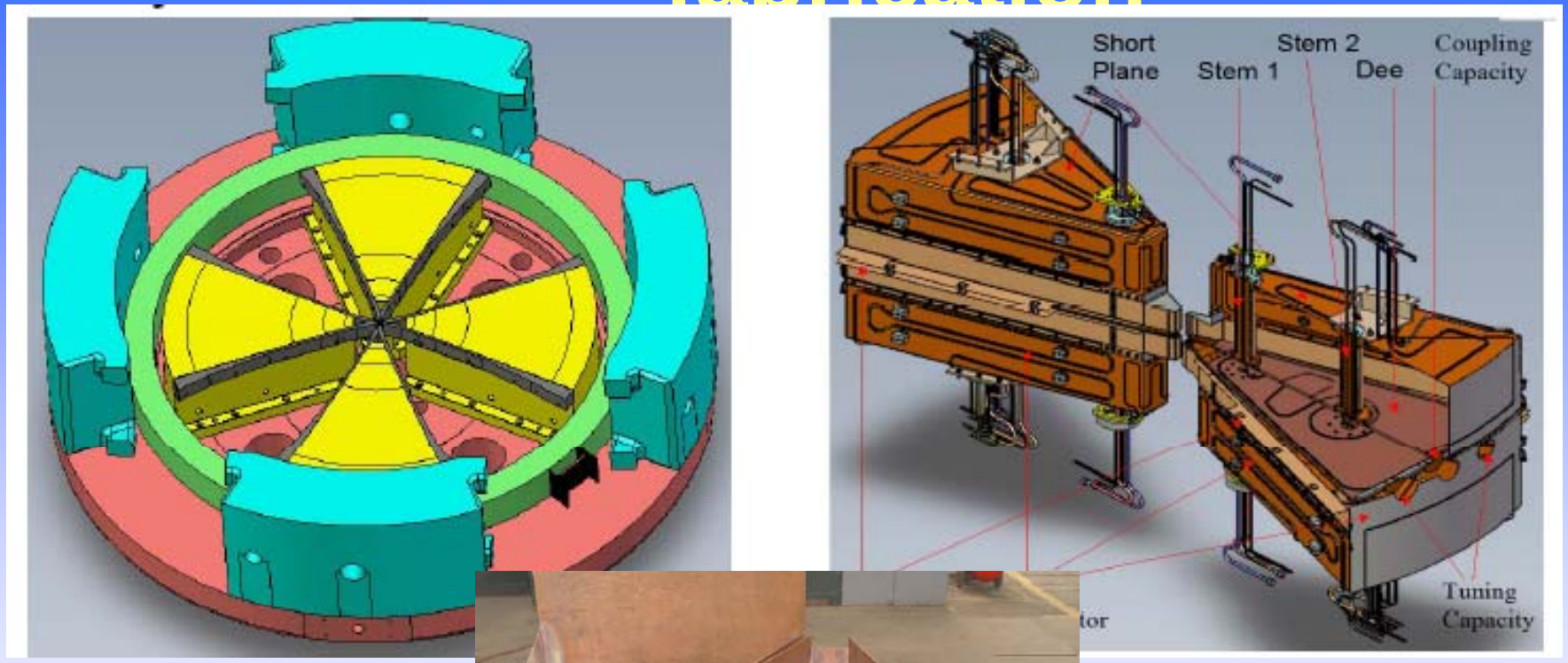


Dia.: 6160 mm
Height: 2820 mm
Weight: 435 t

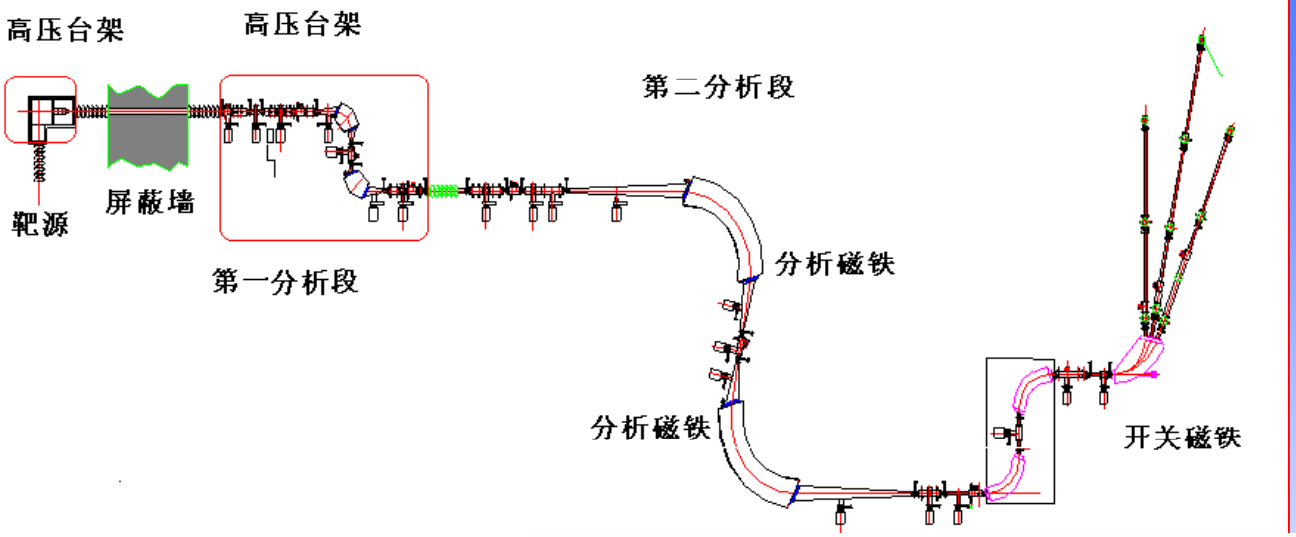
10 MeV central region test bench
10 MeV, >200 μA, proton

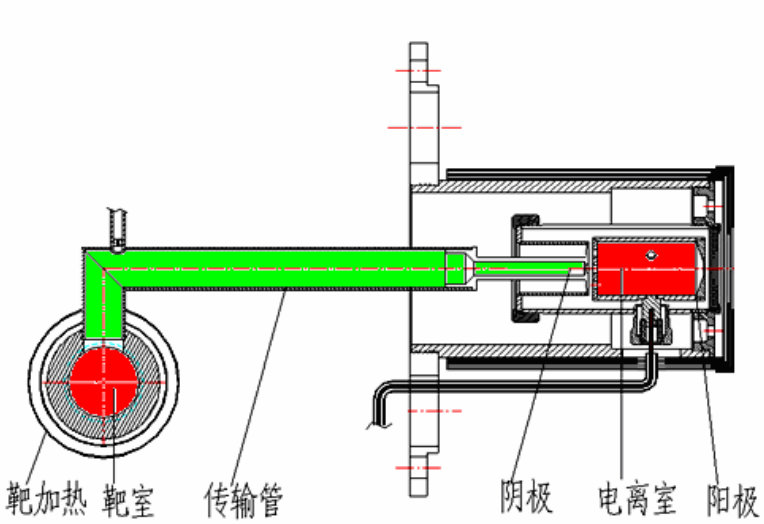


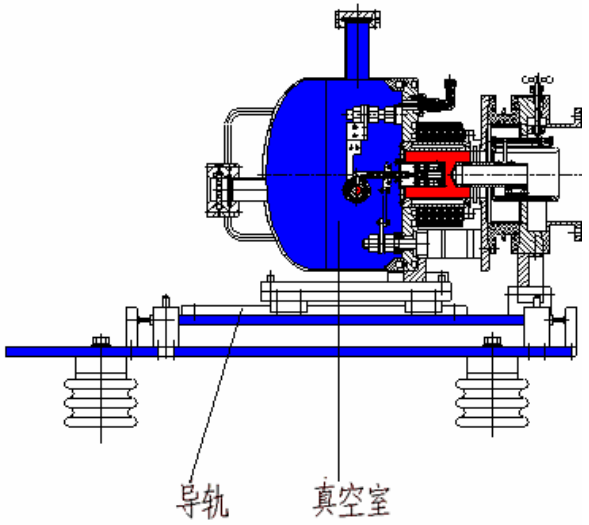
RF system design and fabrication



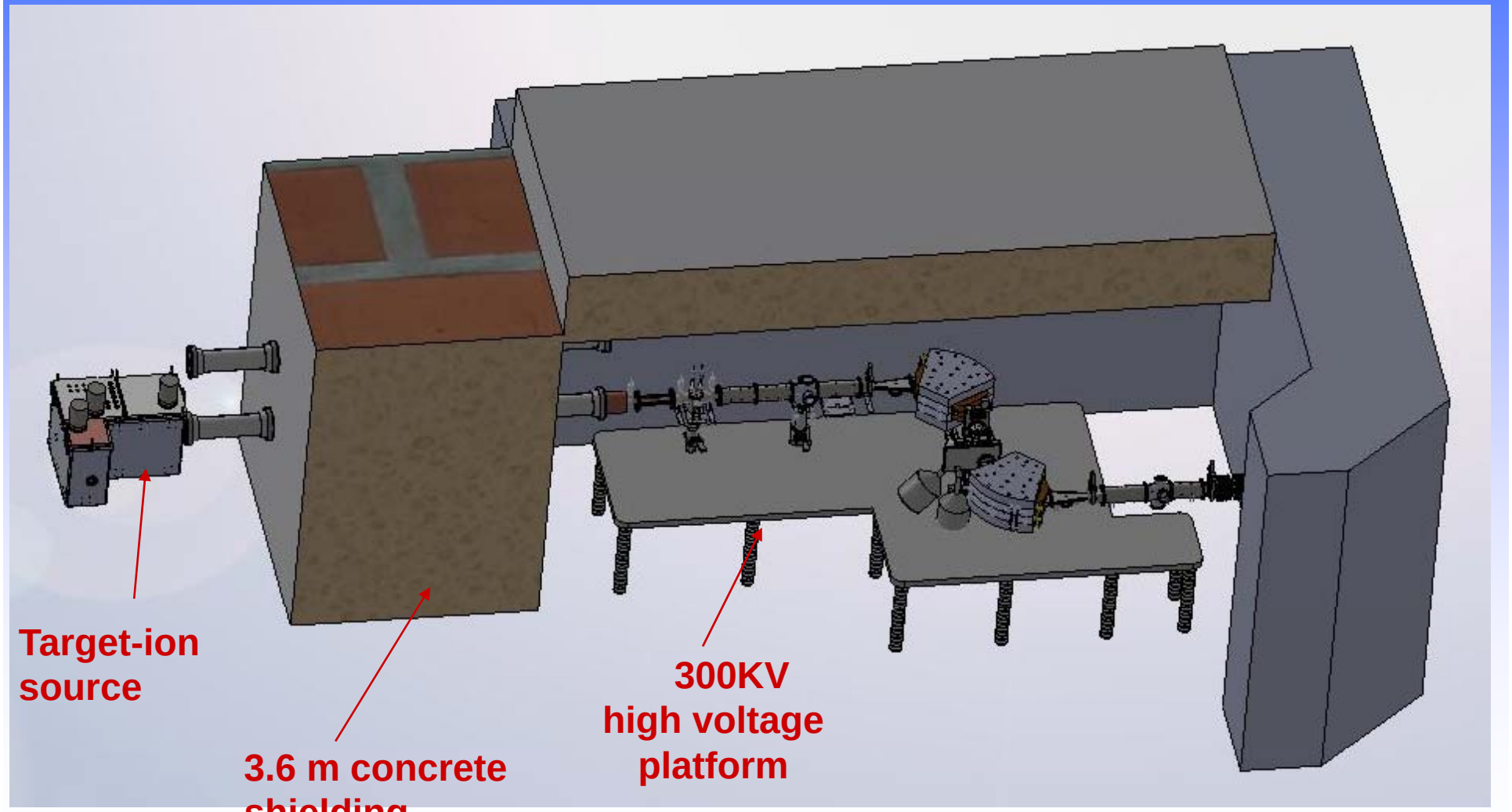
ISOL layout


高压台架
高压台架
第二分析段
靶源
屏蔽墙
第一分析段
分析磁铁
分析磁铁
开关磁铁


靶加热
靶室
传输管
阴极
电离室
阳极


导轨
真空室

Target-ion source area



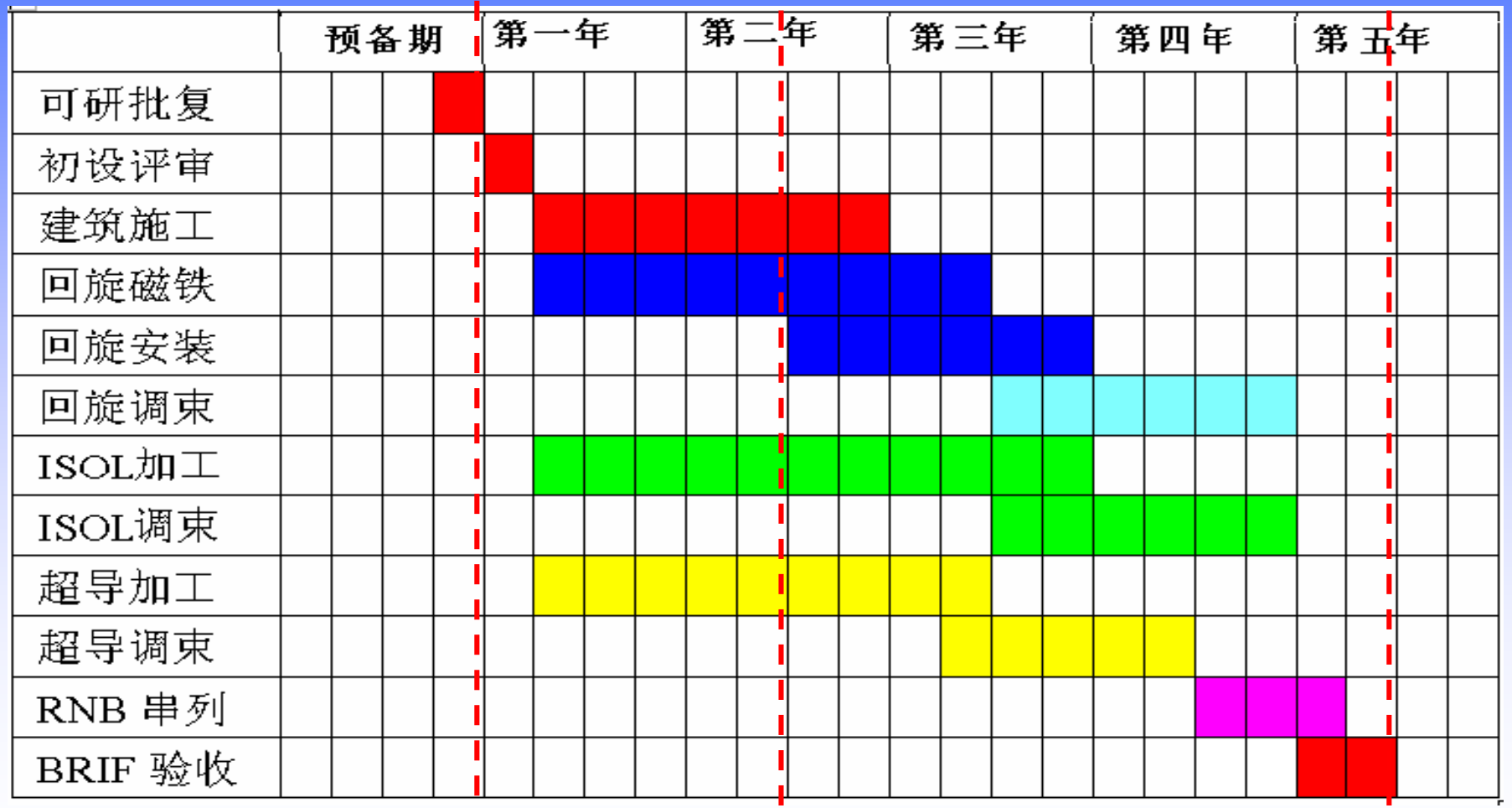
New 300 kV injection and charge exchange for Tandem

New 300 kV injection and charge exchange for Tandem

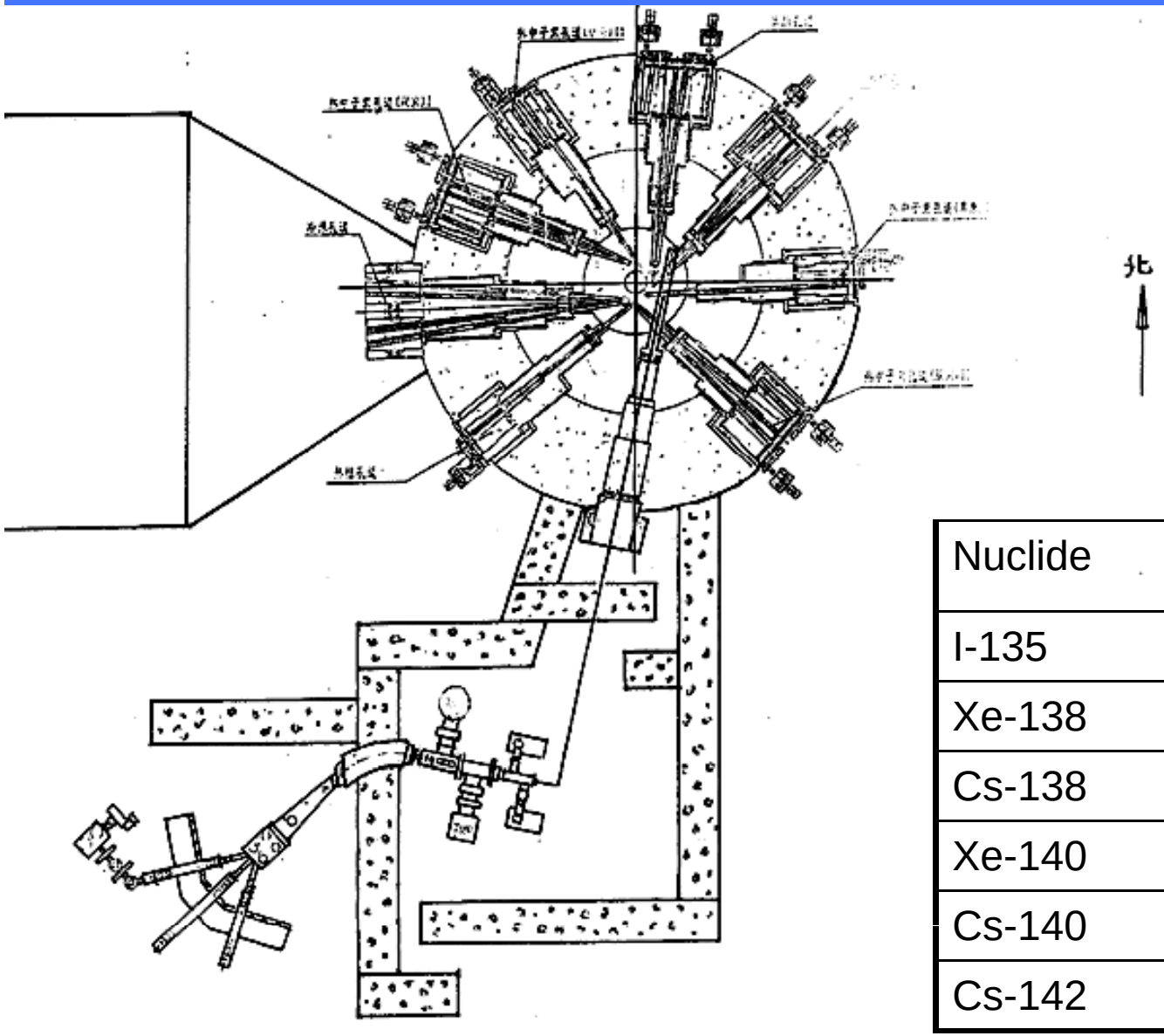
SC linac spattering, control and Cu cavity sample

SC linac spattering, control and Cu cavity sample

Timing plan


预备期
第一年
第二年
第三年
第四年
第五年
可研批复
初设评审
建筑施工
回旋磁铁
回旋安装
回旋调束
ISOL加工
ISOL调束
超导加工
超导调束
RNB 串列
BRIF 验收
T0
Now
2012-2013

More n-rich beam: CARRISOL



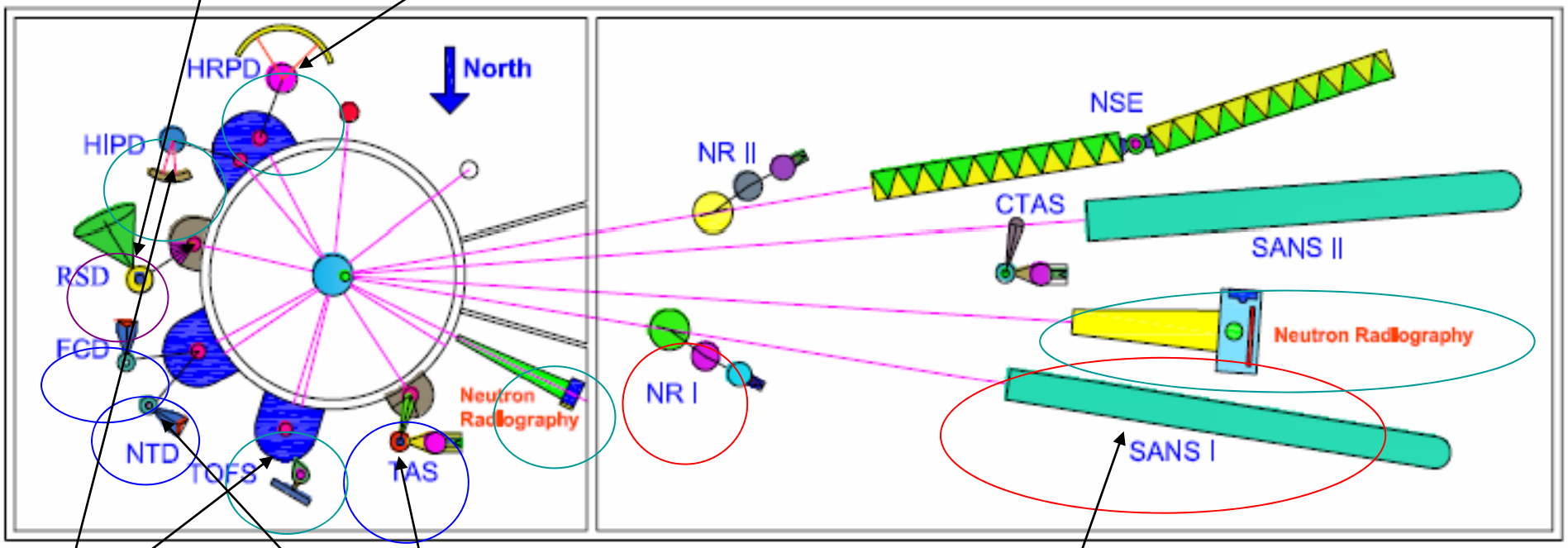
- **Horizontal tube**
- **He-jet + ISOL**
- **Neutron flux $1X10^{14}$ /cm^2/s**
- **Available in 2010**

Nuclide	ISOL (pps)
I-135	3×10^{6}
Xe-138	9×10^{7}
Cs-138	9×10^{7}
Xe-140	1.7×10^{8}
Cs-140	2.2×10^{8}
Cs-142	2.7×10^{8}

Material science via neutron scattering in CARR

Sweden

CIAE

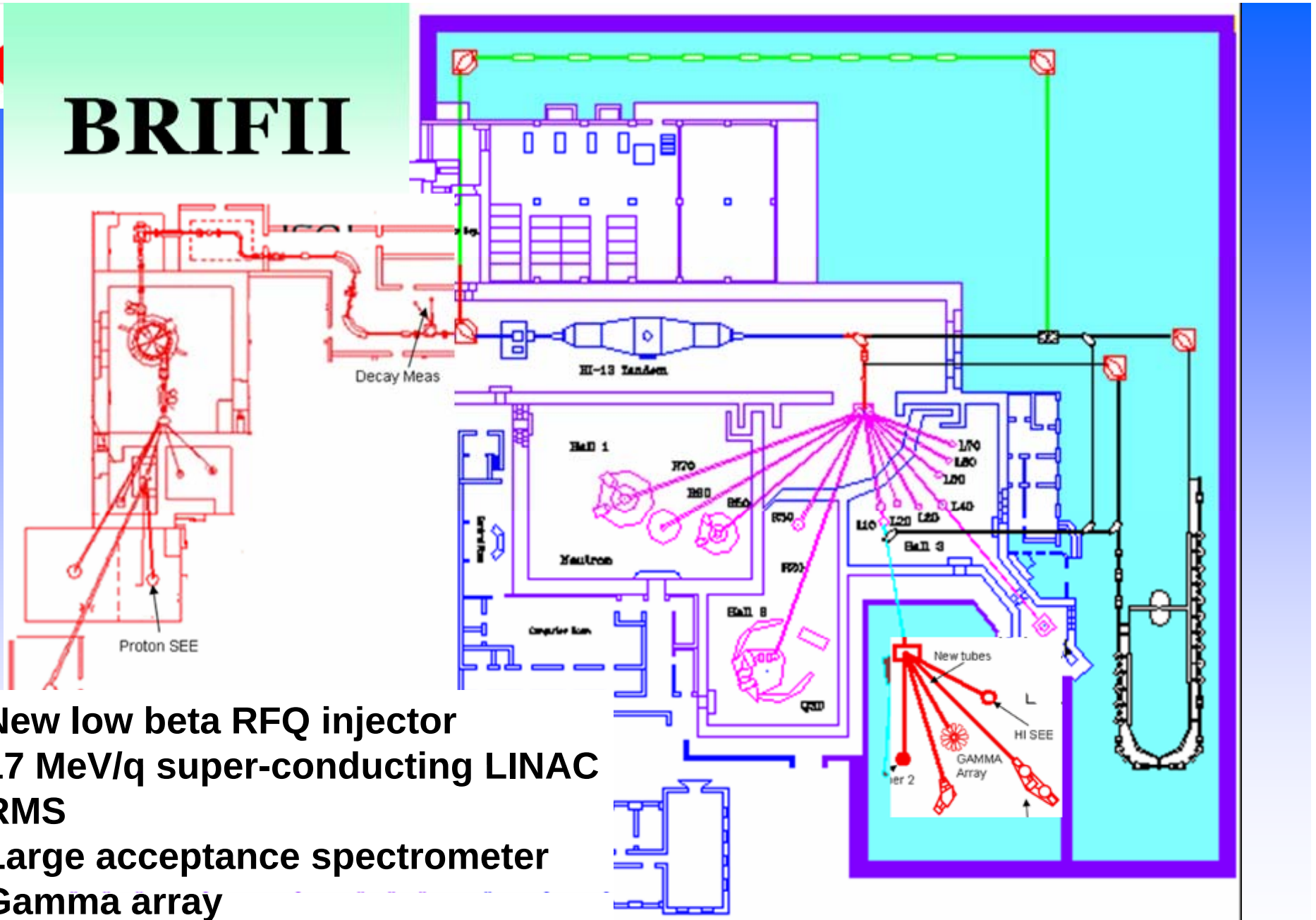


CIAE upgrade

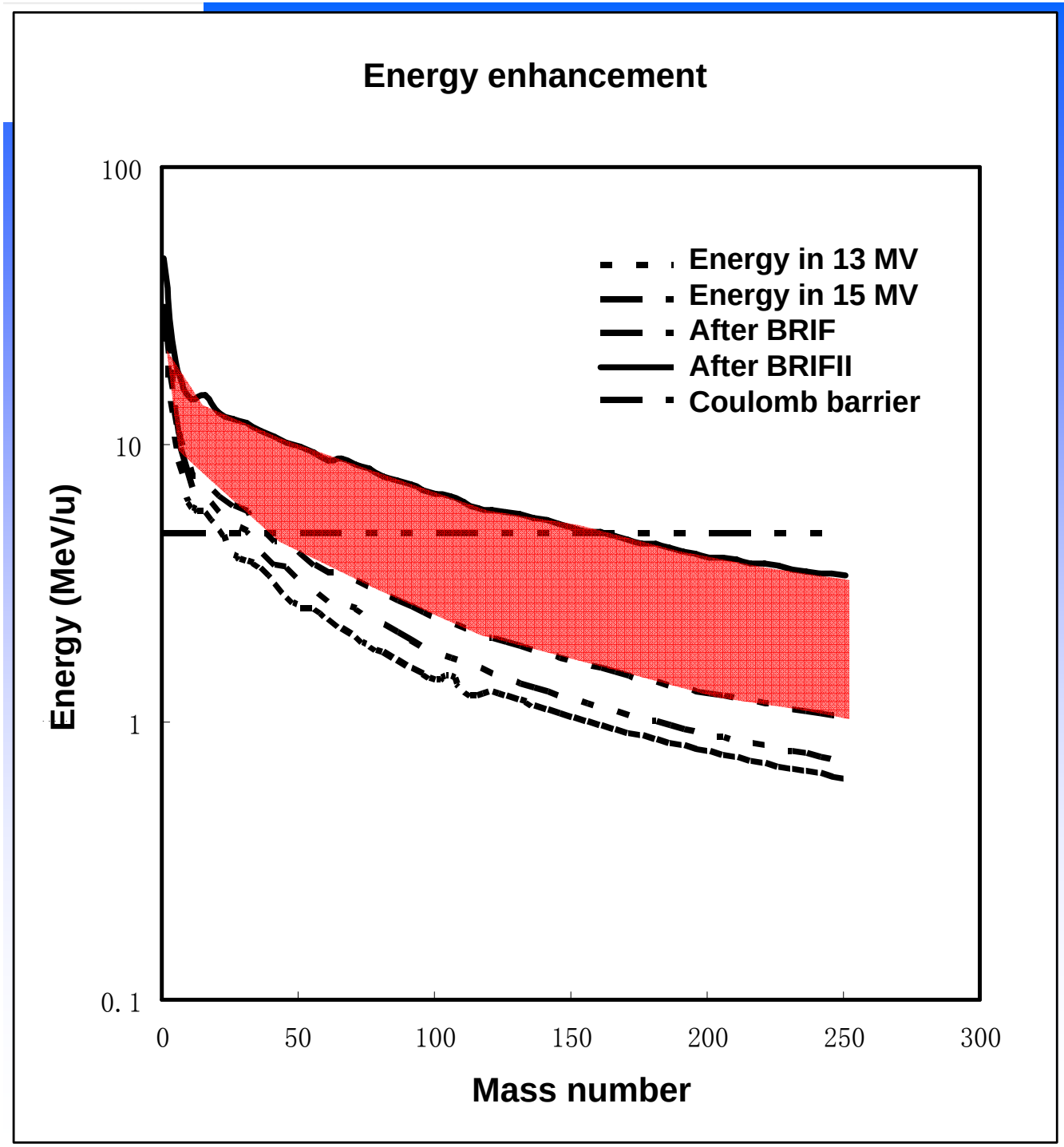
Julich

CAS-CIAE

BRIFII

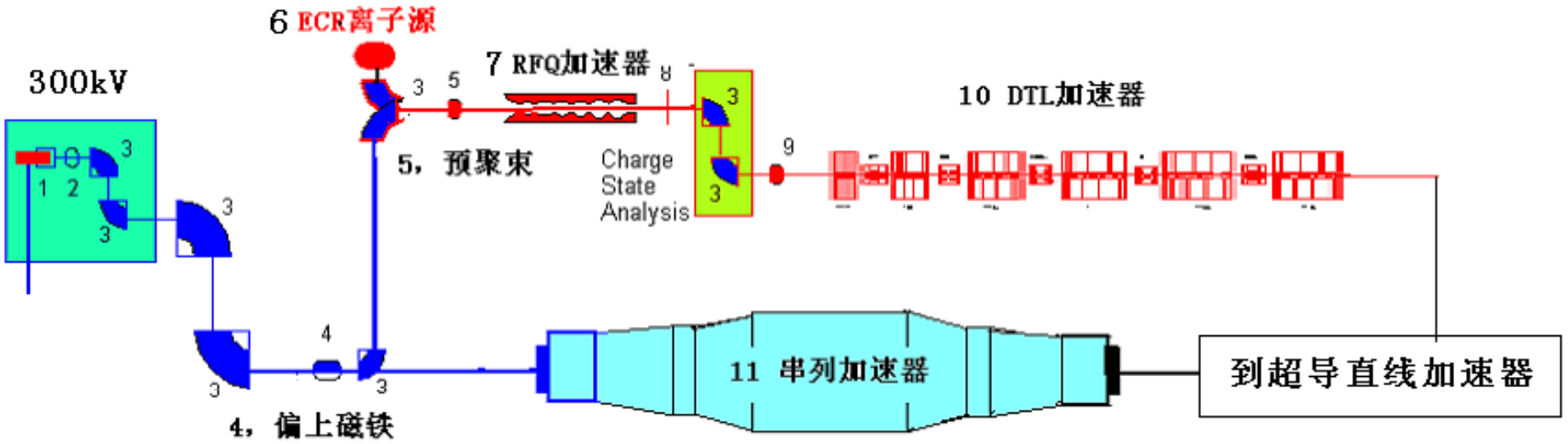


- New low beta RFQ injector
- 17 MeV/q super-conducting LINAC
- RMS
- Large acceptance spectrometer
- Gamma array
- Radiation facilities



Beam energy enhancement

Full SC Linac for BRIFII

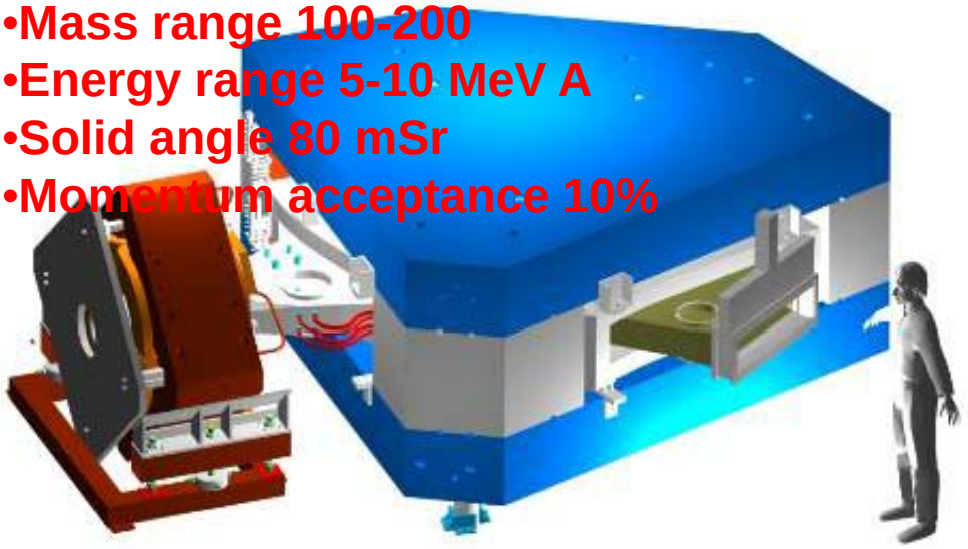


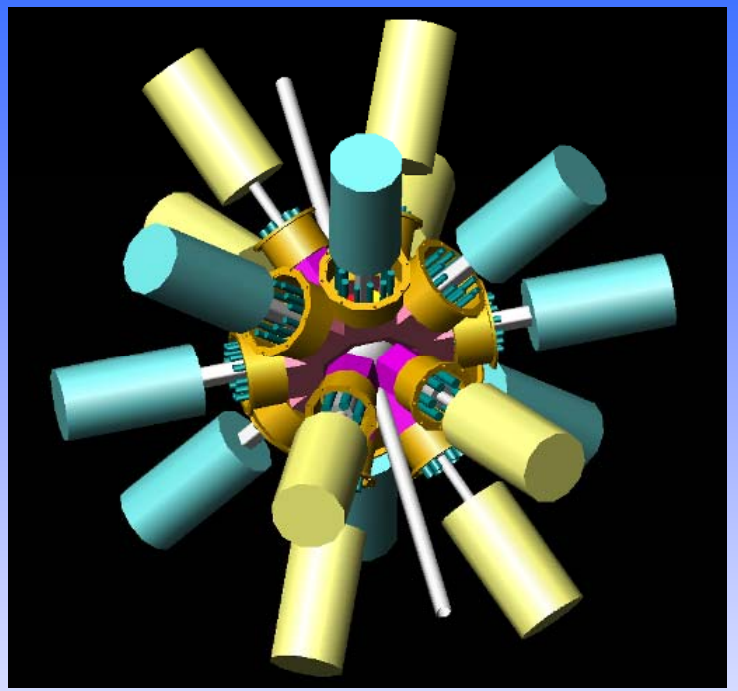
1，RNB离子源，2，在线ECR离子源，3 分析磁铁，4，偏上磁铁　5，预聚束　6 ECR离子源

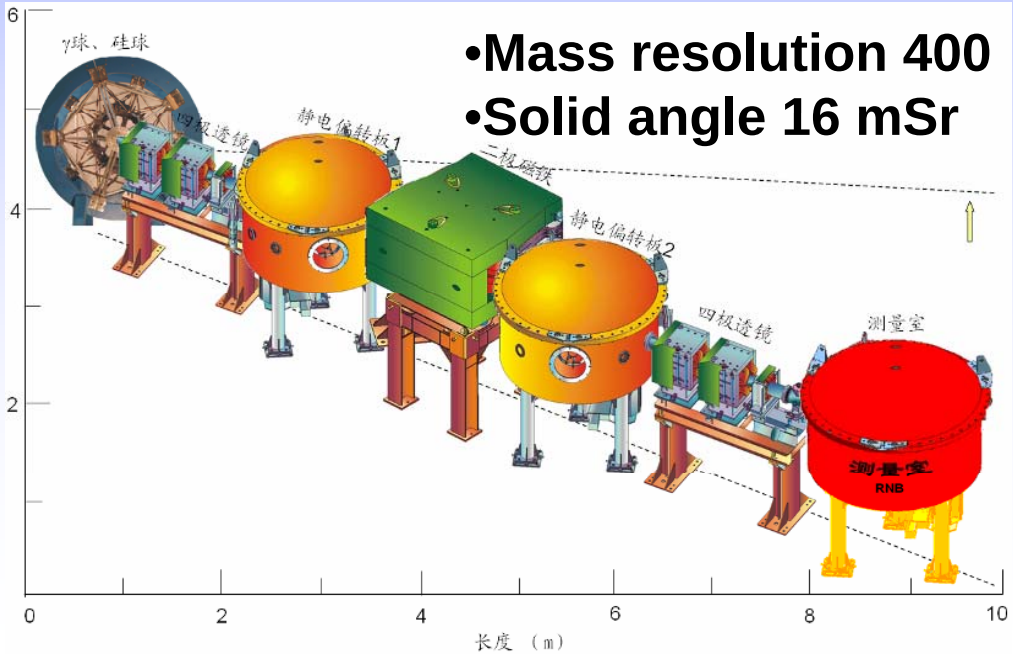
7 RFQ加速器　8，剥离器　9 聚束器　10 DTL加速器　11 串列加速器

Experimental terminals

- Mass range 100-200
- Energy range 5-10 MeV A
- Solid angle 80 mSr
- Momentum acceptance 10%





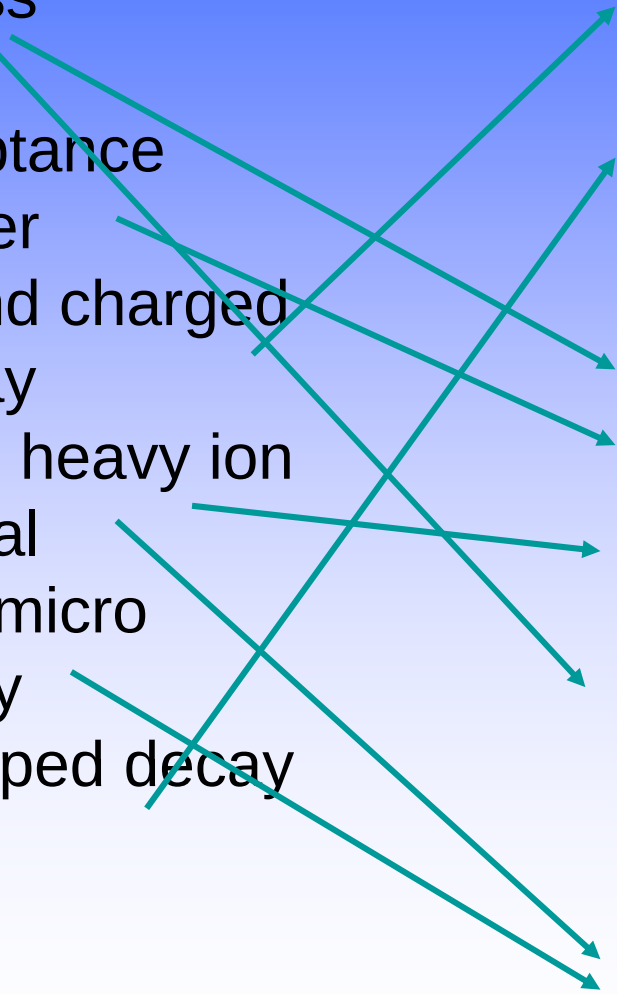


- Mass resolution 400
- Solid angle 16 mSr

- 10XBGO Segmented clover
- For 100 keV efficiency 30 %, resolution 6 keV
- Charged particle 70 %

Research opportunities

- Recoil mass separator
- High acceptance spectrometer
- Gamma and charged particle array
- Proton and heavy ion SEE terminal
- Heavy ion micro beam facility
- Fully equipped decay setup



- **Systematic study of shell evolution**
- **New decay modes**
- **Properties of medium mass neutron rich nuclei**
- **Nuclear astrophysics**
- **Mechanism of SHE**
- **Broaden the traditional study by energy**
- **Novel experimental approach, gamma-recoil coin**
- **Space applications**

World existing ISOL facilities

Facility location	Driving beam intensity	ISOL Mass res.	Post Acc. RIB Intensity	Upgrade Year
BRIF, Beijing	Cyc. p 100 MeV 200 μA	20000	Tandem+SCB 17 MeV/q, 2013 10^{6-11} pps	BRIFII 34 MeV/q, 2017
ISAC, Vancouver	Cyc. p 500 MeV 100 μA	10000	Linac 6.5 MeV/u 10^{8} pps	New e-linac driving 2015
Louvain	Cyc. K30 p 30 MeV 200 μA	LISOL	Cyc. K110 0.6-1 MeV/u	
SPIRAL, Caen	Cyc 95 MeV/u HI	ISOL	Cyc K265	SPIRAL II, 2013 SC Linac 40 MeV d
ORNL, Oak Ridge	Cyc. K105 p or α	1000, 20000	Tandem 25 MV, 4-12 MeV/u, 10^{5-6} pps	
ISOLDE, Geneva	Syn. p 1.4 GeV 2 μA	1000, 10000	Linac 0.3-3 MeV/u, 10^{11}pps	10 MeV/u
TRIAC, Tokai	Tandem 20MV p 3 μA HI, 15 MeV/q	1200	Linac, 0.17-5 MeV/u	Will be moved somewhere
EXCYT, Catania	Cyc K800 HI	ISOL	15-MV tandem	
RIKEN	Photo induce fission by 150MeV, IkW e	ISOL	Collide with e by SCRIT	Install in 2010
JYFL, Jyvaskyla	Cyc. K130, p 1μA, HI	IGISOL Many terminals		

Conclusion

- **Nuclear physics in China developed rapidly, driving by CSR, BRIF projects**
- **BRIF and BRIFII will open up exciting research opportunities**
- **We would like to collaborate with Asia research groups and labs to take their full research potential and to do cooperative effort in dealing with experimental and technical challenges**