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BISOL Facility Conceptual Design and Opportunities with extended EOS study

BISOL（Beijing-ISOL，北京ISOL): Beijing Isotope-Separation-On-Line Neutron-Rich Beam Facility

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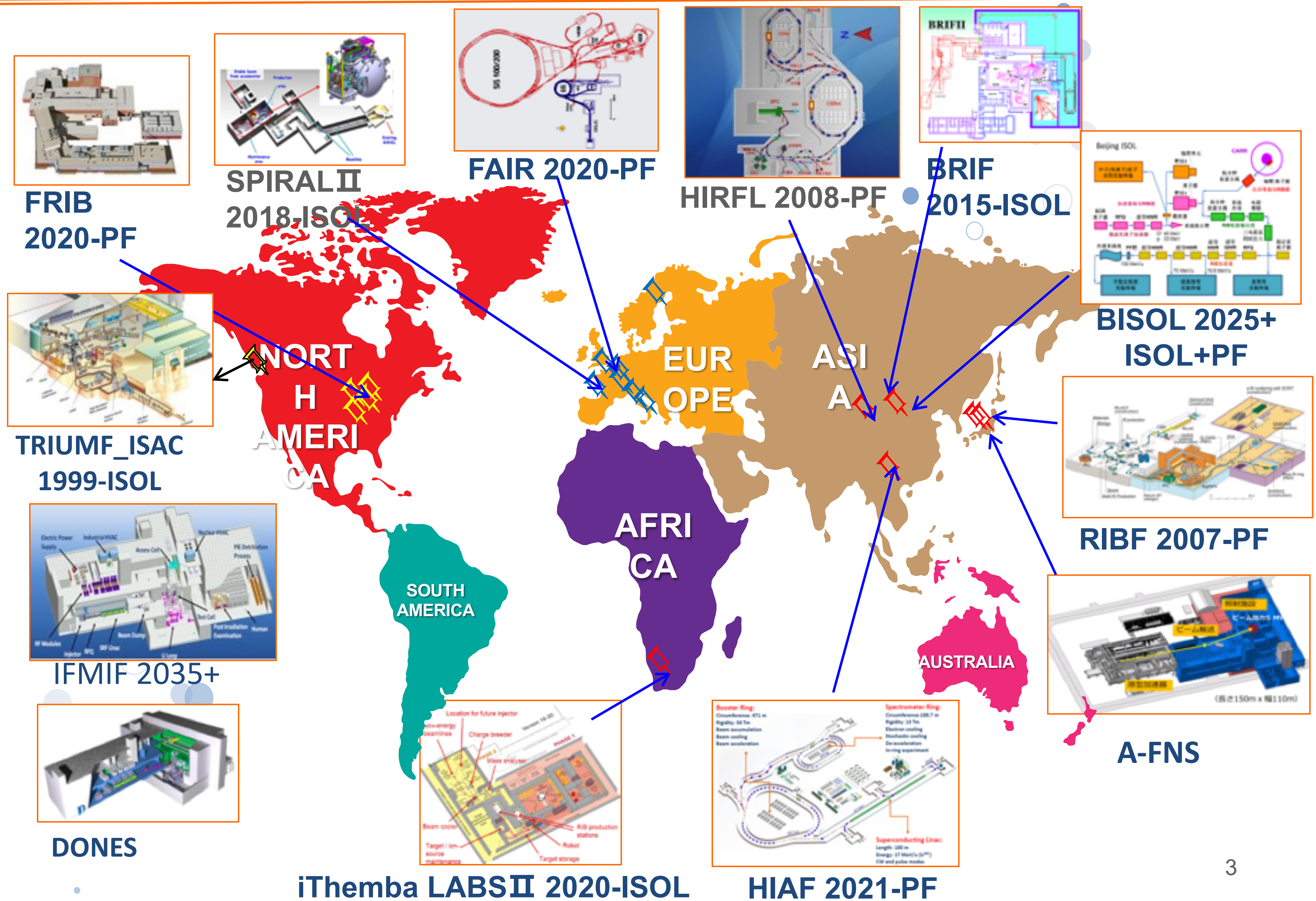
中国原子能科学研究院
中核集团 CHINA INSTITUTE OF ATOMIC ENERGY

北京大学
PEKING UNIVERSITY

Outline

- A brief history
- Background in basic and applied sciences
- Conceptual design (CD-1)
- Opportunities for EOS
- Outlooks

World-wide efforts for intense RIBs and n-sources



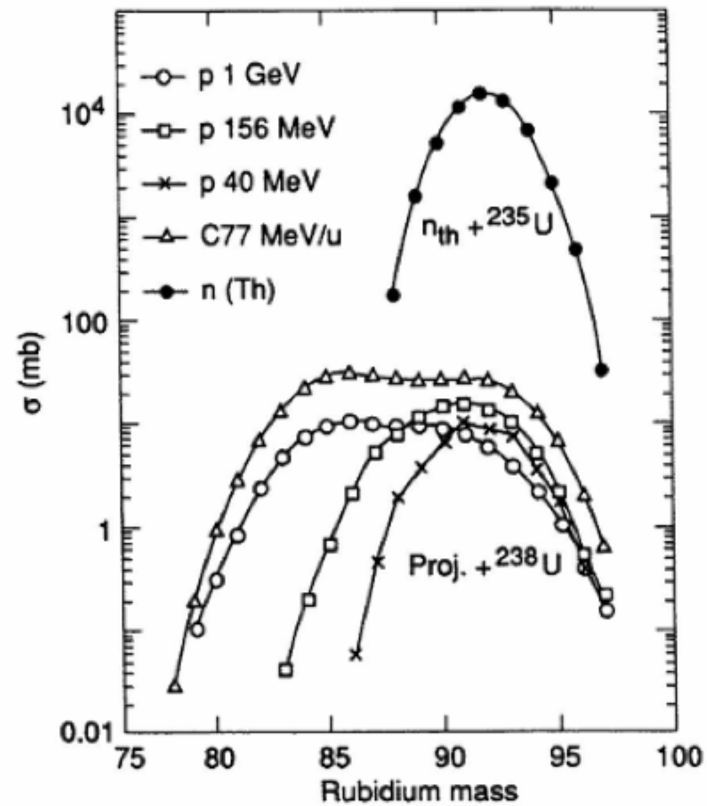
Physics and application: facility requirements

- drip line nuclear physics
  - New magic number
  - Super heavy elements
  - Astrophysical r-process
  - Multi-neutron correlation
  - New decay modes: βxn, GS neutron decay
  - Neutrino beam
  - Data of n-rich nuclei
  - Application of n-rich beams
  - …

- RIB intensity vs. the depth of study
  - >10^{-5} pps, for neutron drip line search
  - > 10^{-2} pps, for half life and mass
  - > 10^{2} pps, for direct reaction
  - > 10^{4} pps, initiative structure study
  - More intense, more precise

Combined approach

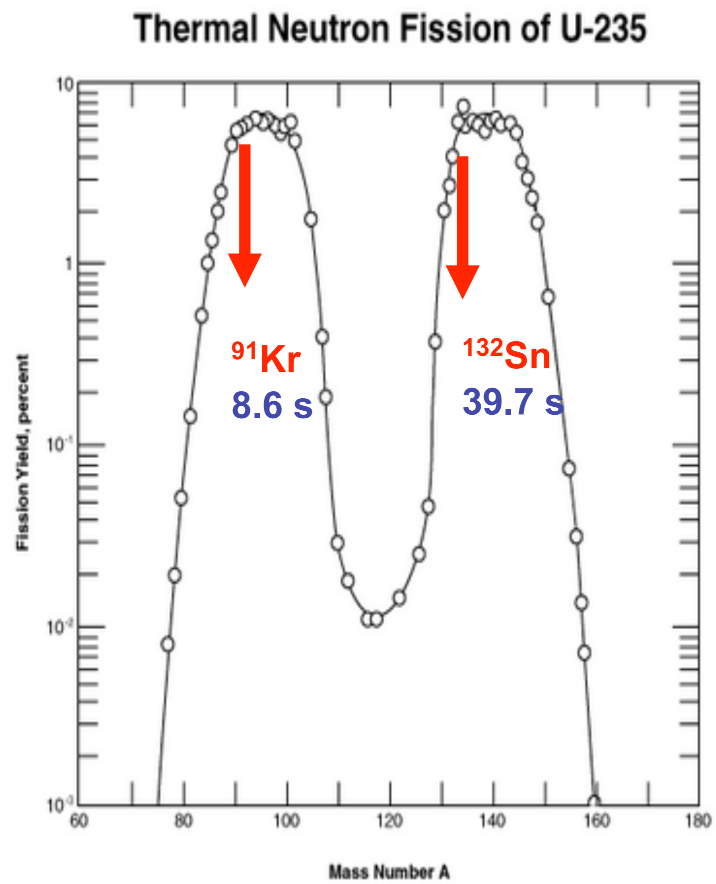
- **ISOL+PF: neutron beam from reactor or accelerator, with large ^{235}U fission cross section (585 b), easy ISOL selection of fission fragments, post acceleration, then fragmentation PF again: EURISOL, Beijing ISOL**
- **Pro and con**
  - **Pro: 5-8 more neutrons than stable beam, with cross section increase by 4-6 order**
  - **Con: re-accelerated beam intensity weaker by 2-3 order: RIBF ^{238}U 10^{12} pps ； Beijing ISOL ^{132}Sn10^{9-10} pps**
  - **The net gain: 1-2 order or more intensity of n-rich beams!**



I. Tanihata, NIM B266(2008)4067

Advantage of using reactor

- High intensity of thermal neutron: 10^{14} n/s/cm^2
- Large fission cross section: 585 barn
- Simultaneous use of reactor: only using one horizontal tube, a super spectrometer
- Reactor delivers stable n flux once it operated: a stable beam intensity



Large yield
Long half live
Easy to separate

Combined approach merit

- Merit: combination of established technique
  - Good and easy beam: long half life, high yield, normal ISOL
  - 10 pnA order beam acceleration: no limitation of space charge and difficulty of beam diagnostics
  - The techniques afterwards, e.g. fragmentation and selection: are well established
  - Less burden in PF target: lower intensity of primary beams
  - Less burden of ISOL: only select long life, high yield fission products

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Design criteria of Beijing ISOL

- **Competitiveness**: first class beam and research platform→double driver and reactor-accelerator coupling
- **Multiple purposes**: meet the user requirements ranging from basic science research to urgent applications → multi-beam, multi-energy and multi-terminal
- **Feasibility**: relatively mature but also advanced technologies → double driver to achieve high duty factor and feasibility, as well as good cost performance ratio
- **Complement to other facilities**: complement the existing facilities in China and world wide → beam varieties, detector performance and facility location

Major milestones

- ◆2011, CIAE - PKU MOU
- ◆ISOL-type RIB facility in Beijing
- ◆CARIF and ImPUF merge to Beijing-ISOL

北京大学与中国原子能科学研究院
共同推动建设 ISOL 型大科学装置的协议

中国原子能科学研究院创建于 1950 年，是我国第一个核科学技术研究机构，是我国重要的核科学技术先导性、基础性、前瞻性的综合研究基地。拥有中国先进研究堆、中国实验快堆、北京串列加速器升级工程和核燃料后处理放化实验设施等众多科技创新平台。

北京大学创办于 1898 年，是我国第一所国立综合性大学，是国家“985 工程”重点建设的大学之一。1955 年，北京大学建立了我国高校中第一个核科技专业，几十年来为国家的核事业培养了大批骨干人才。近年来，在我国核科技行业率先建立了国家重点实验室和核物理人才培养基地。

根据国际核科学技术发展的态势，以双方各自提出的 CARIF 和 ImPUF 计划为基础，共同提出在北京地区建设国际先进水平的 ISOL 型大科学装置，以此为基础建立国际一流的基础和应用研究基地。

1. 双方共同商定的目标是：在北京周边适当地区建设一个国际先进水平的 ISOL 型大科学装置。该装置瞄准核科学的重大前沿问题及核能和多学科应用中的某些关键问题，同时带动相关高新技术的发展和突破。并在合作建设运行大科学装置的过程中，形成大学和科研院所联合研究和人才培养的创新模式。

2. 为实现上述目标，双方将联合规划并提出申请，并结合各自的优势，分工开展必要的预先研究工作，包括不同方案的研究和比较；同时协同在国内国际开展广泛的研讨和咨询，以期未来提出的正式方案得到科技界的广泛认同和支持。双方均认为，始终以开放和国际化的方式推动此项大科学工程对于保障其先进性和可行性至关重要，为此将做出不懈的努力。

3. 建立规范、高效的合作机制和领导机构。由双方共同推荐和组织专家委员会，指导预先研究工作，并讨论确定最终提交国家的建设方案。同时组建负责日常工作的联合工作组，负责协调、组织和落实预先研究工作和国际国内的研讨咨询工作，并定期向专家委员会提交进展报告和建设方案草案。

4. 双方将根据各自的优势和可能的经费渠道，组织力量承担预先研究和工程建设的任务。适时推动建立联合的研究基地和队伍。根据目前实际情况，先由原子能院牵头，北大核研院参与，开展相关前期工作。

5. 双方将尽早推动国内外用户群体的建立和经常性联系。在立项和建设阶段就充分发挥用户群体的作用，听取用户群体的建议并开展广泛的合作。在装置建造过程中分阶段发挥其作用，尽早产生重要的科学研究成果。

6. 双方将大力支持和全力推动此项大科学工程相关的工作，尽快完成预先研究和方案确定，尽早向国家主管部门提出立项申请。

7. 双方已建立的北京核科学中心，将以推动此项大科学工程作为近期的工作重点。为此将调整和充实该中心的人员组成和结构，并完善日常工作机制。

中国原子能科学研究院　　北京大学

2011 年 10 月 31 日

◆ Oct. 2012, an IAC was formed

◆ Review meeting was held at PKU

◆ *"Initial Conceptual Design of the BISOL".*

- "The Committee considers the research potential of the proposed facility in both, basic as well as applied and interdisciplinary research
- as excellent and highly competitive on the world level. It promises a unique science reach in several respects
- in particular with regard to the most neutron rich exotic nuclei and the study of the astrophysical r-process."


The Beijing ISOL
Initial Conceptual Design Report

PKU & CIAE
2012.09

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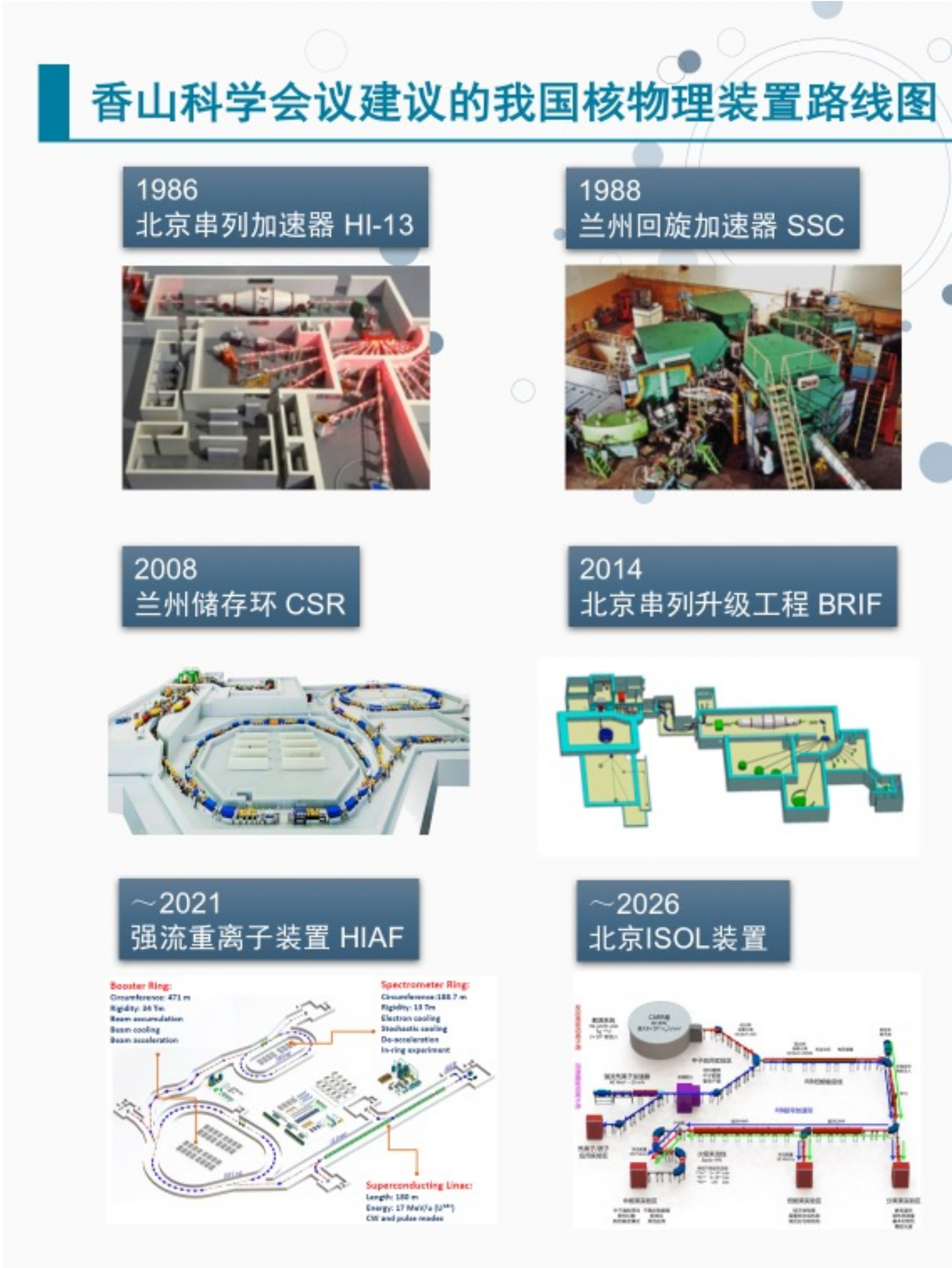
- 2013, advanced ISOL-type facility was adopted in “the national mid- and long-range plan (till 2030) of the major facilities for science and technology development”.
- Aug. 2014, a Xiang Shan Forum (503th meeting in the series) was successfully organized and a road map for major nuclear physics research facilities was established, including the BISOL as the future major facility.
- May 2016, a domestic expert meeting was held at CIAE to evaluate the preparation works of the BISOL, aiming at a proposal to the 13^{th} 5-year plan of the central government of China.



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- **May-June 2016, proposed large-scale science facilities (more than 50 proposals for all fields) were reviewed by the National Development and Reform Council.**
- **BISOL was successfully classed into the list of the preparation facilities (10+5 facilities in total).**
- **Dec. 2016, the government has officially announced the results for the 13th 5-year plan.**

特急

国家发展和改革委员会
教育部
科学技术部
财政部
中国科学院
中国工程院
国家自然科学基金委员会
国家国防科技工业局
中央军委装备发展部
文件

发改高技〔2016〕2736号

关于印发国家重大科技基础设施建设
“十三五”规划的通知

（二）深化后备项目的筹备论证。对科学意义重大、国家需求强烈、抢占科技创新制高点、预先研究较为充分并纳入综合评审的设施，加强对其设施属性、建设紧迫性、科学目标、工程目标、技术风险等的深化论证，开展国内外同类设施的对比分析，逐步形成成熟的设施建设方案。按照设施建设紧迫性、方案成熟度和财力保障状况，适时启动若干筹备论证充分的设施建设工作。“十三五”期间，设施筹备论证的后备项目包括：北京在线同位素分离丰中子束流装置，中国陆地生态系统观测实验网络，生物医学大数据基础设施，作物表型组学研究设施，大气环境模拟系统等纳入专家综合评

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- Jan. 2017, a specialized IAC meeting was held at PKU-CIAE, dedicated to the accelerator based intense neutron source, in particular the high-power target systems.
- Mar. 2017, the 1st BISOL user meeting was held at PKU, with ～150 participants and very active discussions.
- Jun. 2017, BISOL-CD-1 was finalized and evaluated by an internal committee, being ready for the next national review and the next IAC review.

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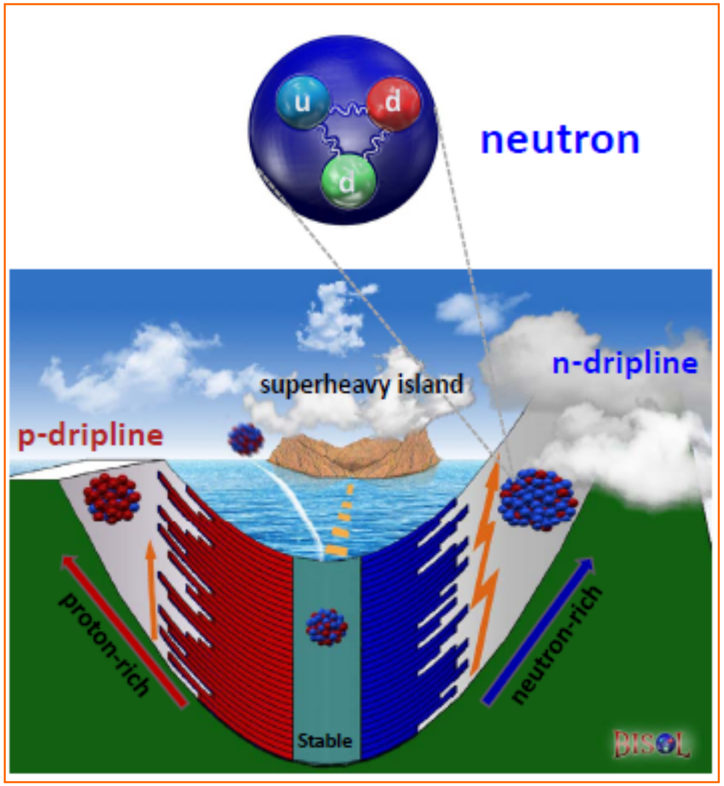
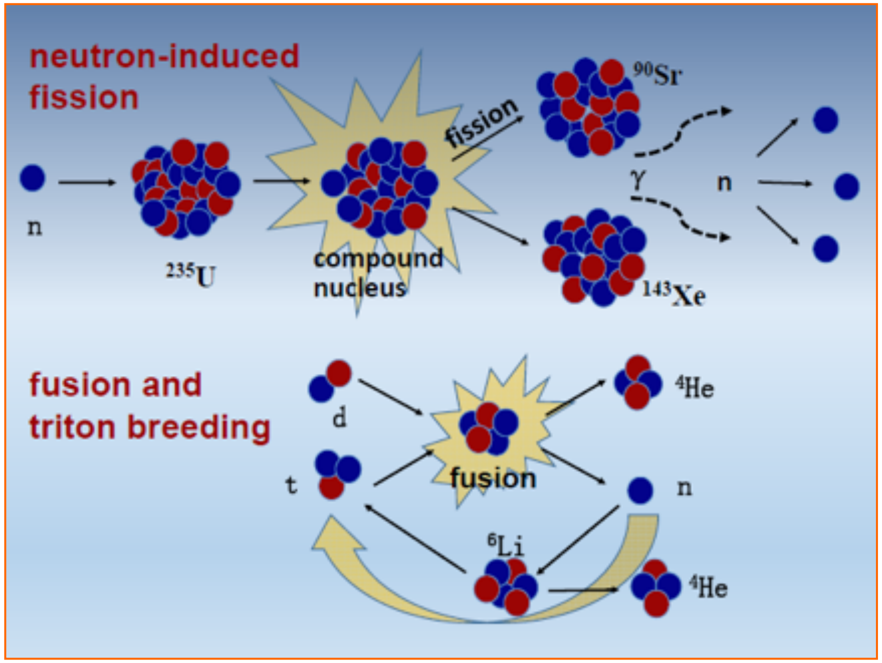
Neutron: essential for both basic and applied nuclear sciences



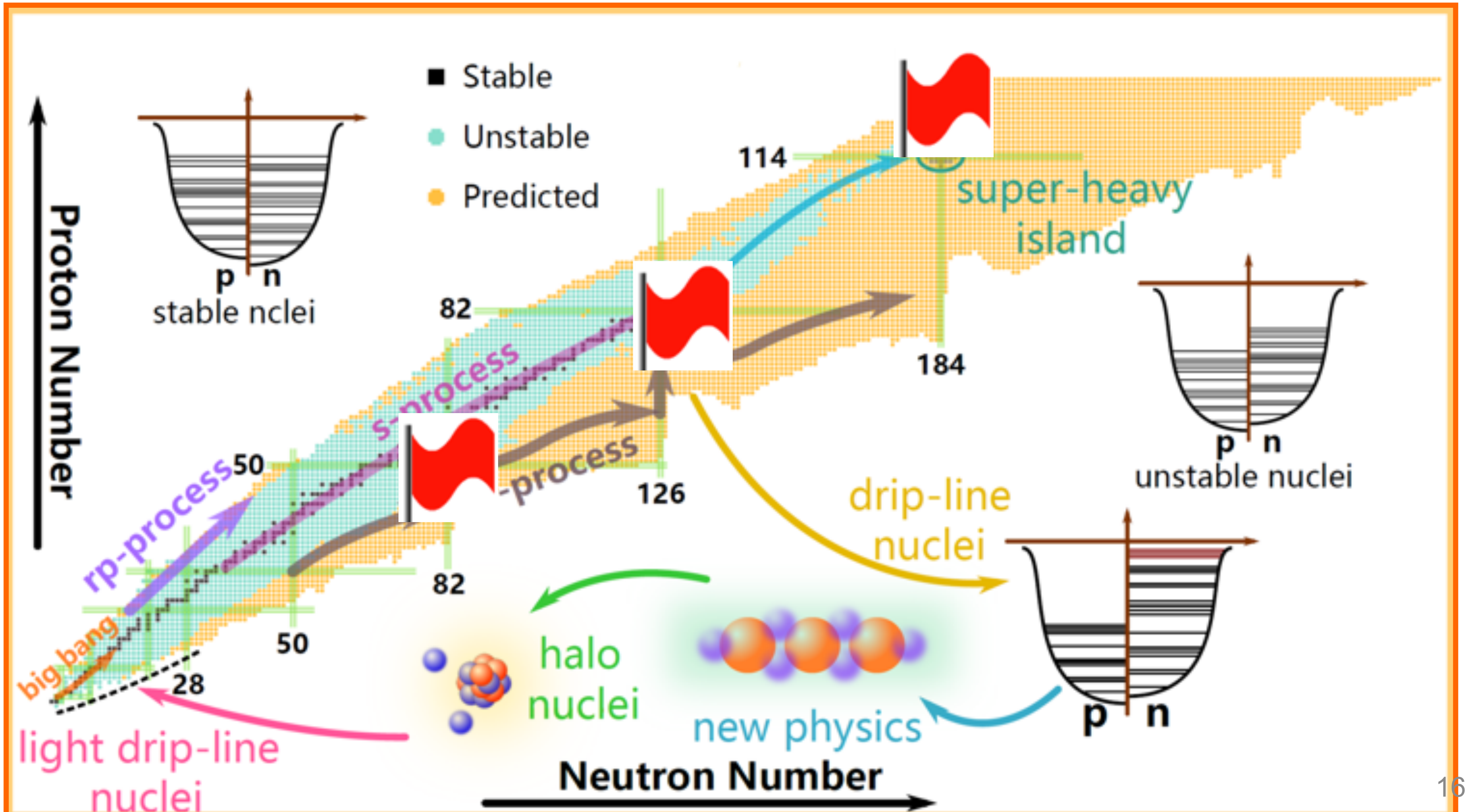
one of the two basic units of nuclide which determines the nucl-ear isospin



a main player of the fission and fusion nuclear energy systems.

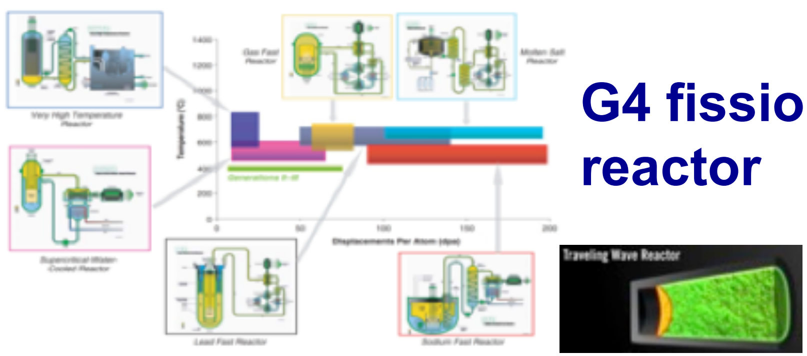
Great scientific questions at the expanded nuclear chart

- New physics at the drip-lines
- Nuclear-processes in creating heavy elements in the stars
- Ways towards the super-heavy stable island



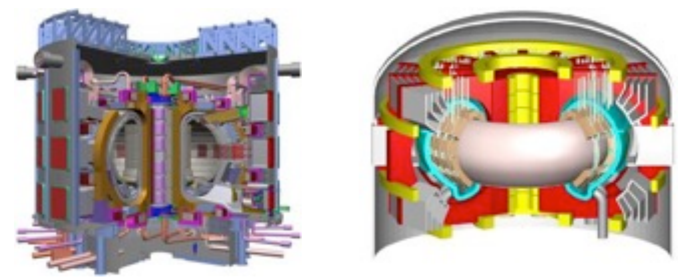
Needs for application of intense neutron beams

- Mechanism of n-irradiation damages
- Material evaluations
- Reaction data with fast neutrons

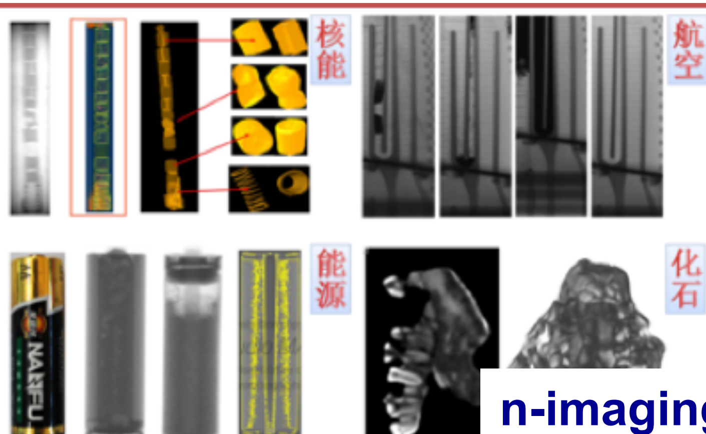


G4 fission reactor

Fusion reactor (DEMO, CFETR…)



Material irradiation research and tests



n-imaging

Space radiation

n-data

Applications in multidisciplinary areas

RIB Requirements

Physics problems

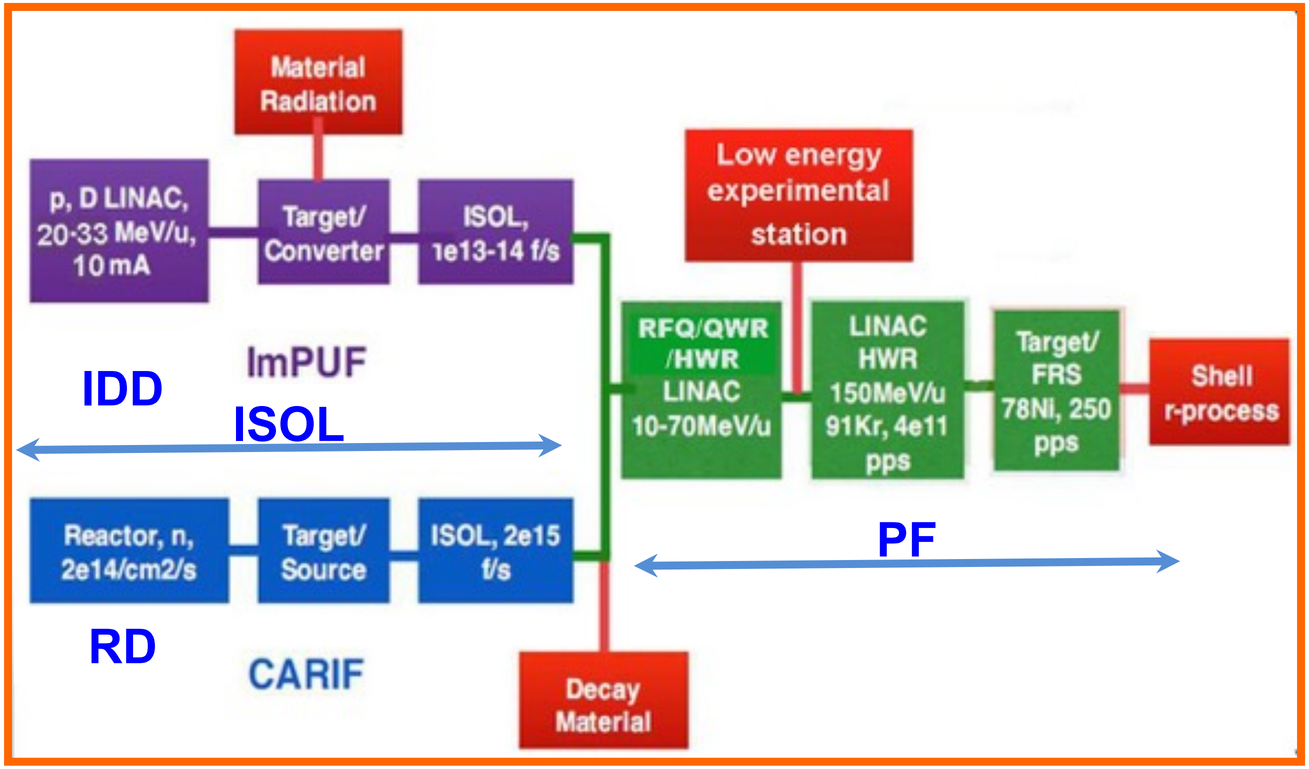
1. New phenomena
   - Ground state properties
   - Symmetry test and energy
   - Shell & magic #
   - Clustering
   - Strong couplings
2. Synthesis of SHN
   - new mechanisms
3. Nuclear astrophysics
   - rp- & r-processes

measurements	requirements	
Mass& moments	keV-MeV/u,	10^{1-3} pps
Decay	keV-MeV/u,	10^{1-4} pps
CS & momentum	MeV-GeV/u,	10^{1-4} pps
CX & Breakup	tens of MeV/u,	10^{2-4} pps
Elastic & inelastic	all energies,	10^{4-5} pps
QF Knockout	> 100 MeV/u,	10^{4-6} pps
Transfer reaction	1-50 MeV/u,	10^{5-6} pps
Fusion-fission	< 30 MeV/u,	10^{5-6} pps

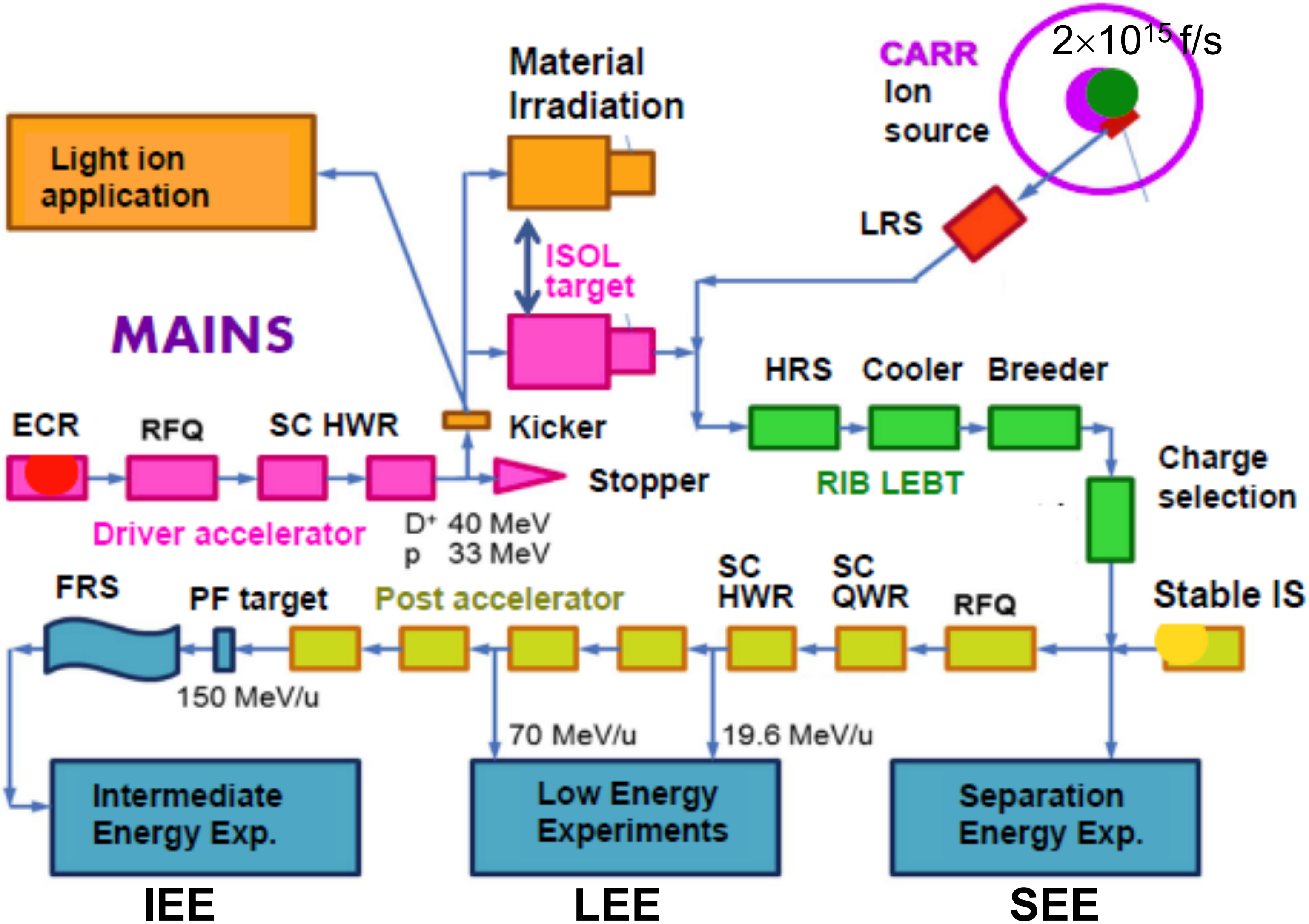
1) Mostly at LE (keV-MeV/u) and ME (~ 100 MeV/u) , but some at HE (300-1000 MeV/u).
2) RIB intensity as high as possible

Basic solutions provided by BISOL

- ◆ reactor driver (RD) + intense deuteron-beam driver (IDD)
- ◆ isotope separation on line (ISOL) + projectile fragmentation (PF)
- ◆ basic science questions + key application questions



More configurations



World Race of RI facilities

Type	Facility	Beam: Beam	Beam: Beam Power (kw)	Target(ISOL) or Beam current(PF): Direct/ Conv/ PF	Target(ISOL) or Beam current(PF): Fissions/s Beam pnA	(Post) acceleration: MeV/A	(Post) acceleration: $^{132}Sn/s$	Start
PF running	RIBF 2015	U86+	5	PF	58 pnA	345	$3*10^6$	running
PF upgrade	RIBF2	U86+	160	PF	2000pnA	345	$2*10^8$	plan
PF Const-ructing	FRIB	U76~80+	400	PF	8000 pnA	200	10^8~10^9	2020
	RISP	U77~81+	400	PF	8000 pnA	200	10^8~10^9	2019
	FAIR	U28+ 1500MeV	10	PF	30 pnA	1500	10^7~10^8	2018
ISOL Const-ructing	ARIEL	e 50MeV 10000mA p 500MeV 100mA	~100	Direct	$1*10^{14}$	5-11	$2*10^9$	2015
	HIE ISOLDE	p 1GeV 2mA	2	D&C	$4*10^{12}$	5-10	$2*10^8$	2015
	SPIRAL2	d 40MeV 5000mA	200	Conv	$1*10^{14}$	3-10	$2*10^9$	2014 2020?
	SPES	p 40MeV 200mA	8	Direct	$1*10^{13}$	10	$3*10^8$	2016
Super ISOL Planning	EUR ISOL	p 1GeV 5000 mA	4M	D&C	$1*10^{15}$	20-150	$4*10^{11}$	?
	CAF BISOL	Reactor	6M	reactor	$2*10^{15}$	>100	$5*10^{10}$	?

slide from Shegio Koyasu(RIKEN) at the C12 meeting, Tokyo, Aug. 2017

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Design concept of BISOL

1）Double drivers

① CARR：8×10^{14} n/cm^2/s）, 5 g ^{235}U； 2x10^{15} f/s

② D-LINAC：40 MeV， ~10 mA ， LLi target; 5x10^{14} n/cm^2/s

2）ISOL+PF

ISOL: m/△m～2000-20000

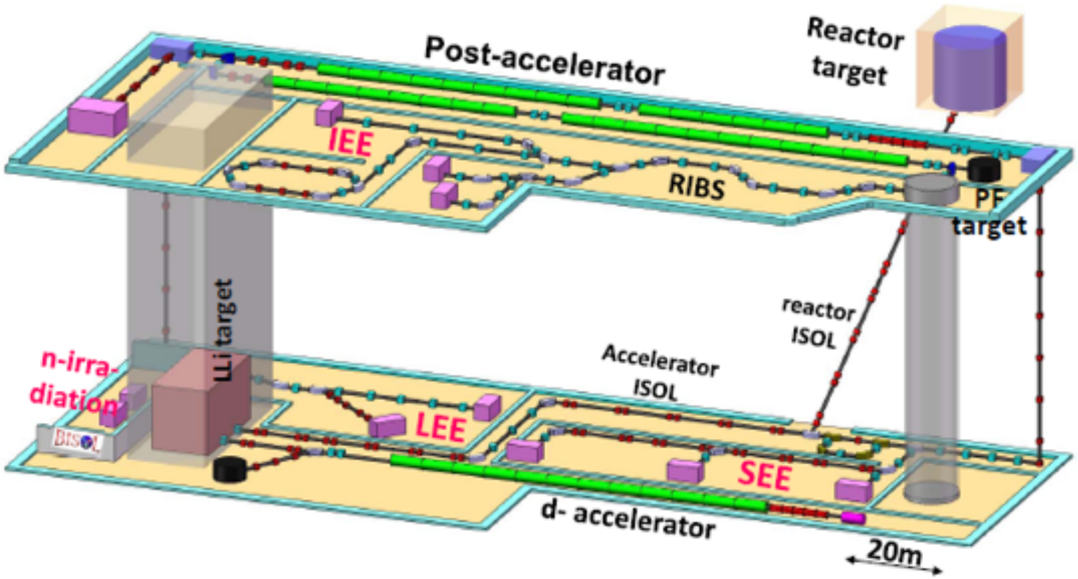
SEE: Separation Energy Experiments (~20keV/q)

Post-Acc: 20-150 MeV/u

PF separator: 7 Tm

LEE: LE Experiments

IEE: IE Experiments



3）Multiple-operation schemes

① CARR + ISOL + PA for RIB
D-LINAC + LLi for n-beam

② D-LINAC + LLi + PA for RIB

③ D-LINAC + LLi for n-beam
PA for stable beams

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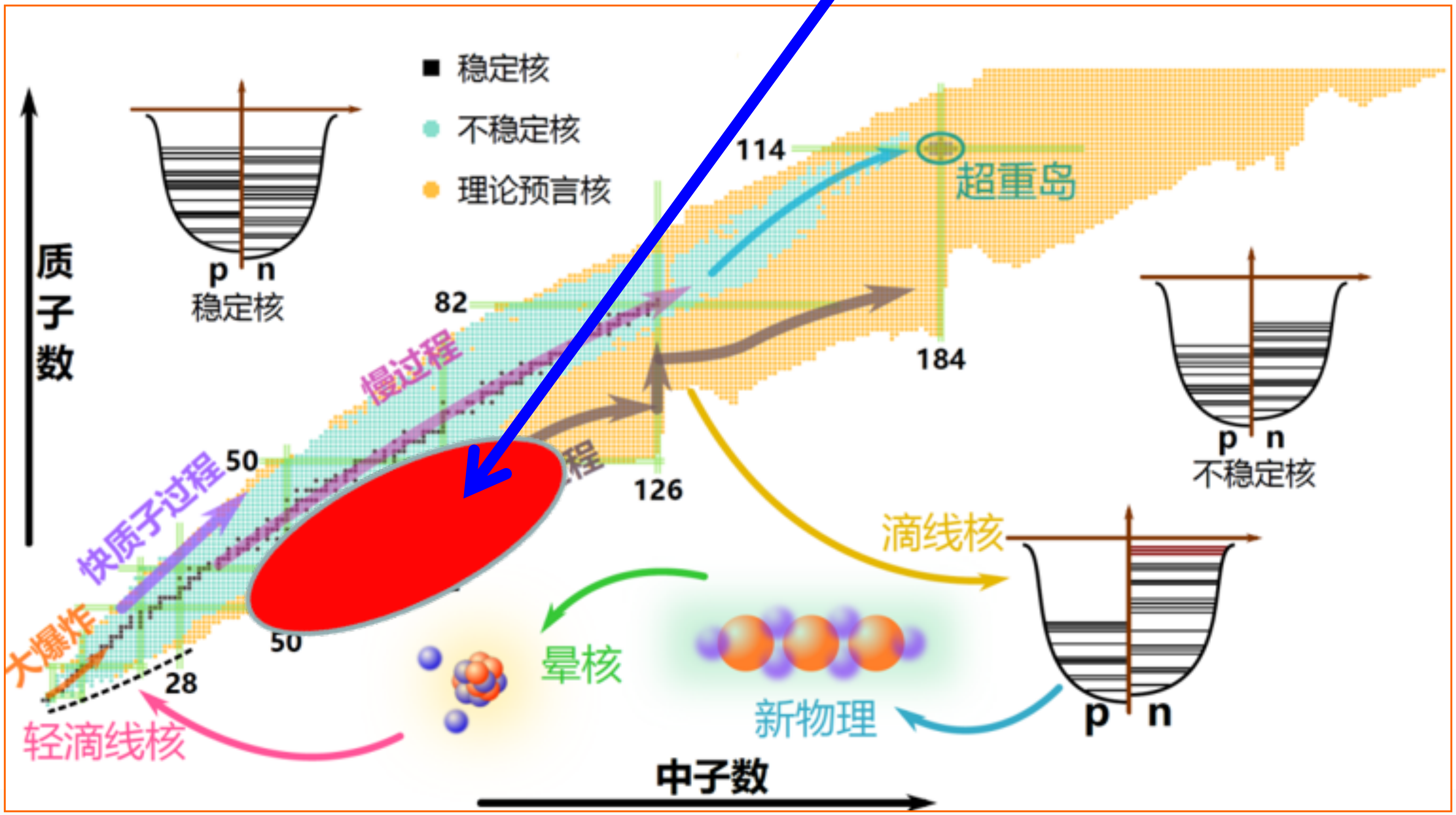
Science focus of BISOL

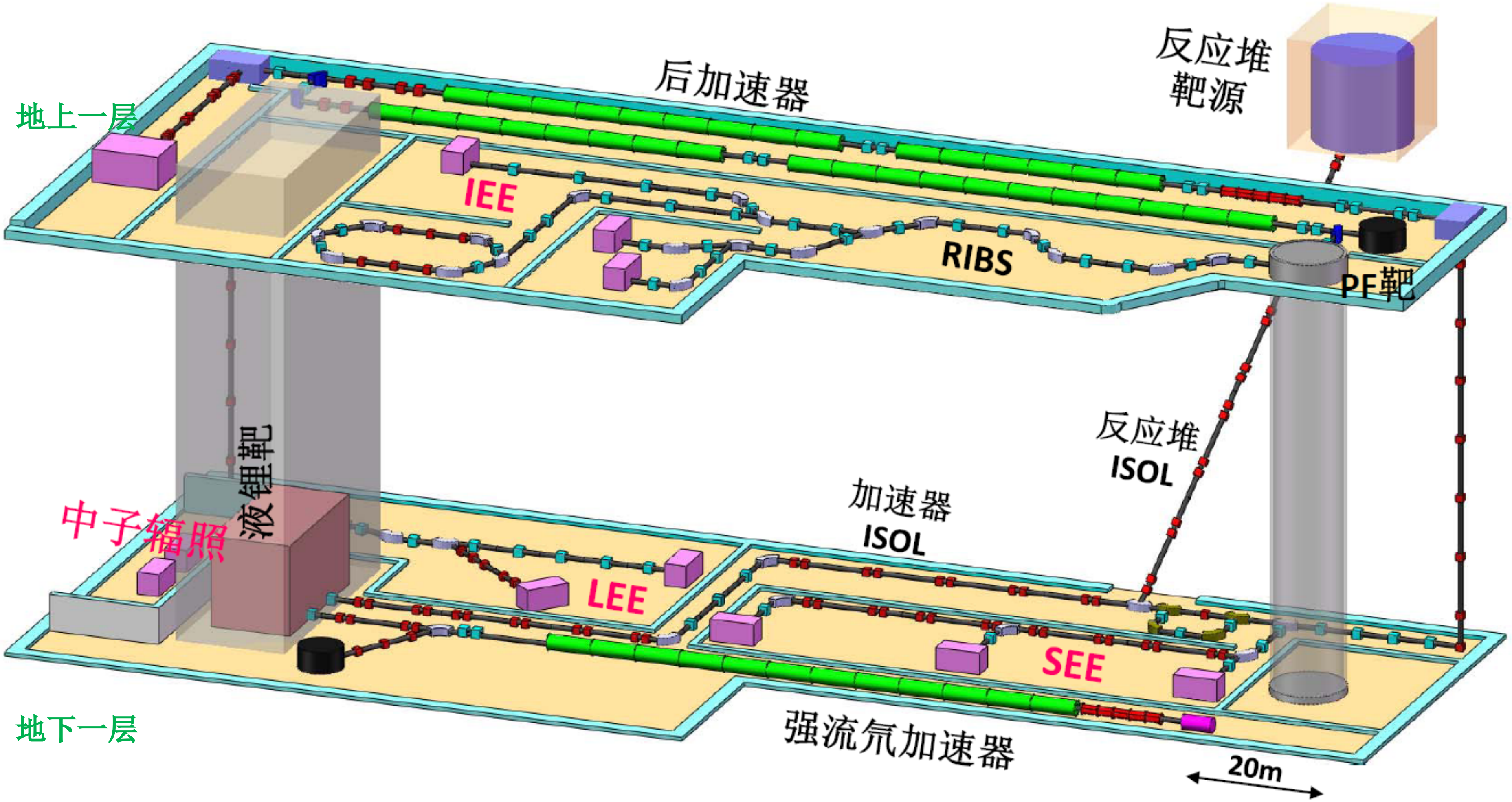


- Structure at ~ n-drip-line in the medium-mass region
- starting part of the r-process
- reaction mechanism with extremely n-rich beams

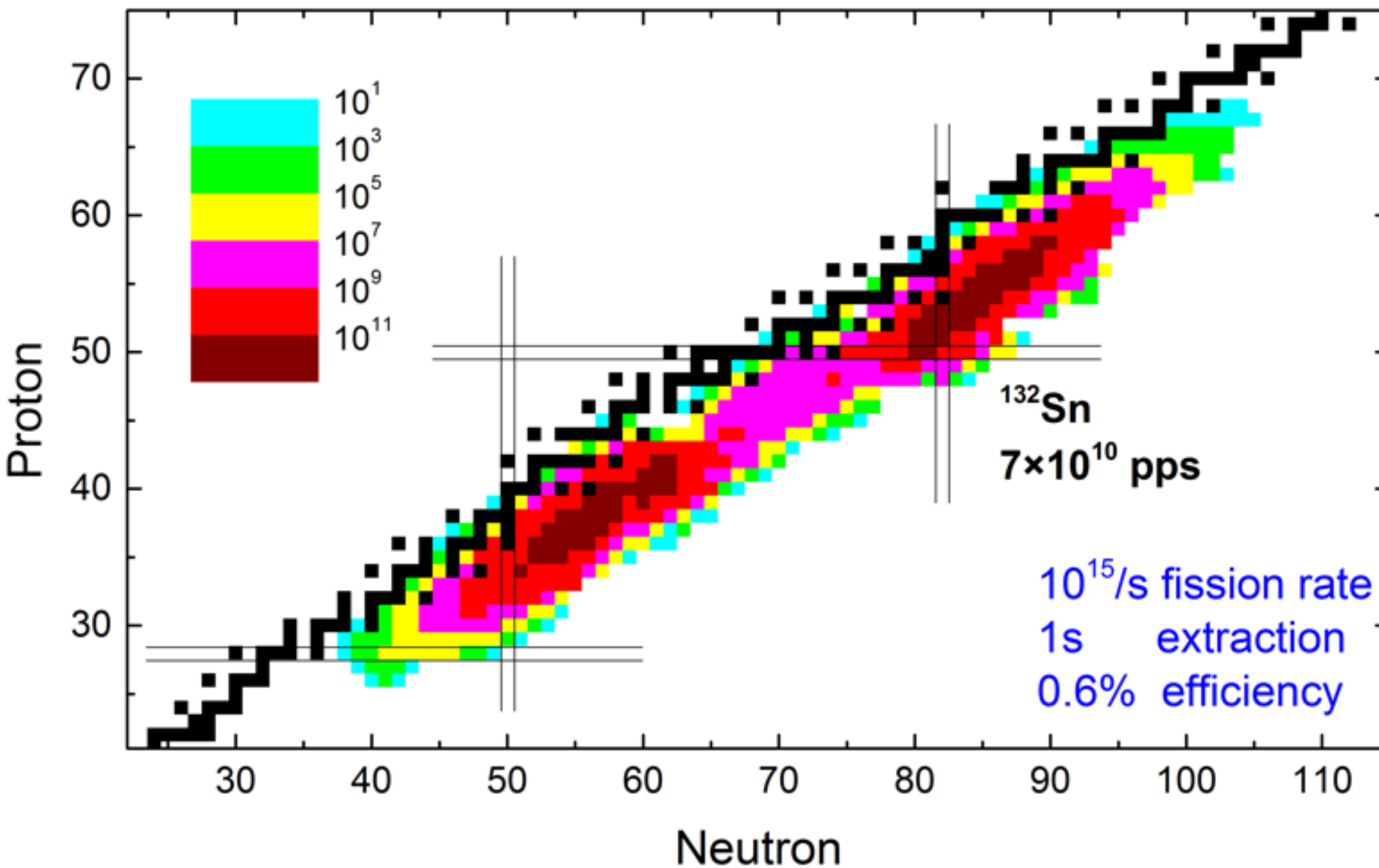
RIBs energy ranges and physics

- **20 keV range,** separated beam, SEE, for mass, decay and basic interaction studies
- **20 A MeV range (ISOL low energy), LEE,** for near barrier, SHE and nuclear reaction and structure studies
- **150 A MeV range (PF intermidate energy),** IEE, for drip line search, shell evolution and nuclear state isospin dependent studies

Beijing ISOL

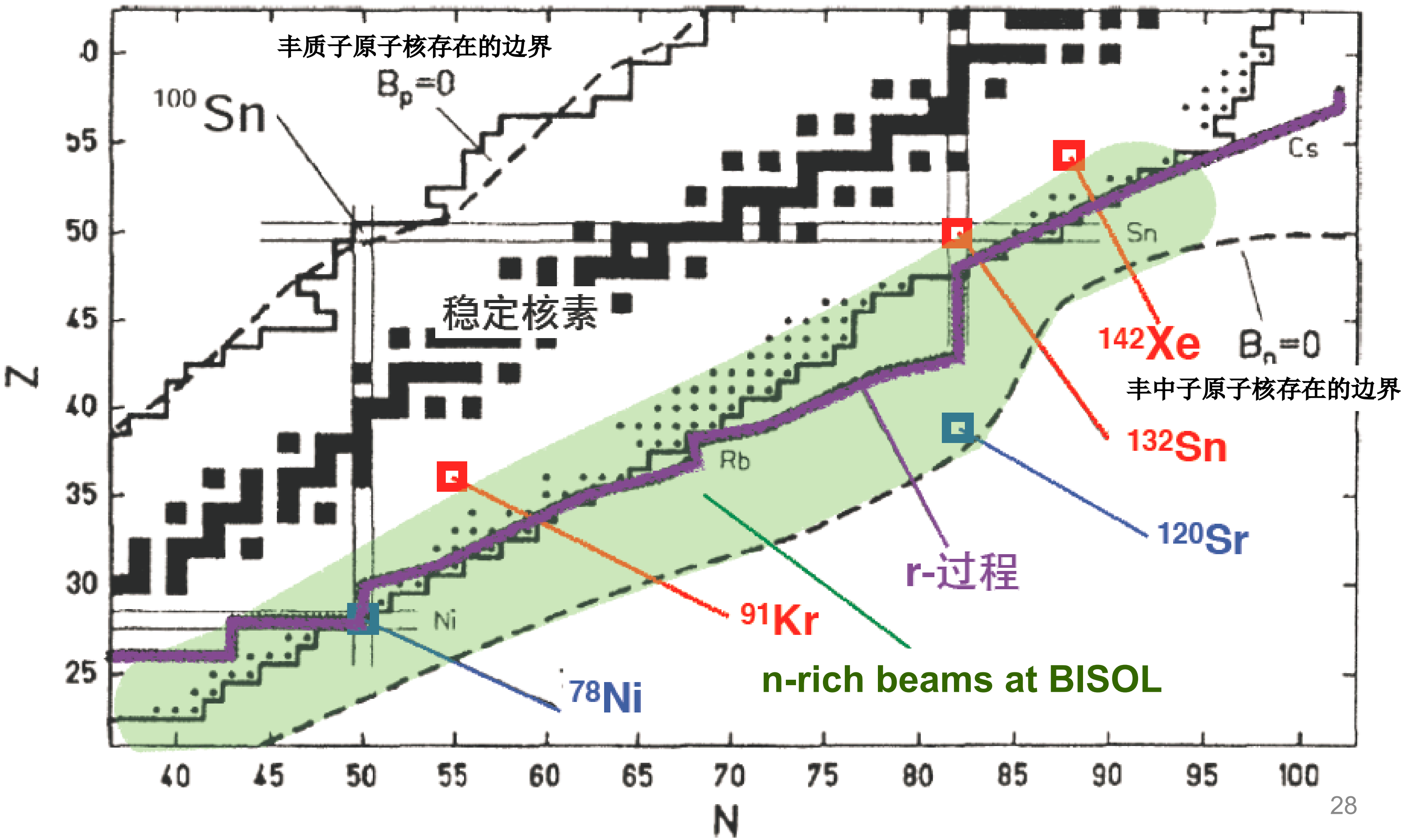


Fission products by CARR



Latest calculation by J. Su

RIB to dripline with fission beams



ISOL beam intensity

^{235}U/g	σ/b	n-flux, /cm^2/s	f /s
5	585	3×10^{14}	2×10^{15}

nuclei	Fis. yield	rate	Target +isol eff. (ref. PIAFE)	CB eff	Linac eff.	intensity
^{91}Kr	3.2×10^{-2}	6.4×10^{13}	13.0%	10%	50%	4×10^{11}
^{142}Xe	4.3×10^{-3}	8.8×10^{12}	2.0%	10%	50%	9×10^{9}
^{132}Sn	5.7×10^{-3}	1.2×10^{13}	8.0%	10%	80%	7×10^{10}
^{81}Ga	7.6×10^{-5}	2×10^{11}	8.0%	10%	95%	1×10^{9}

Latest calculation by J. Su

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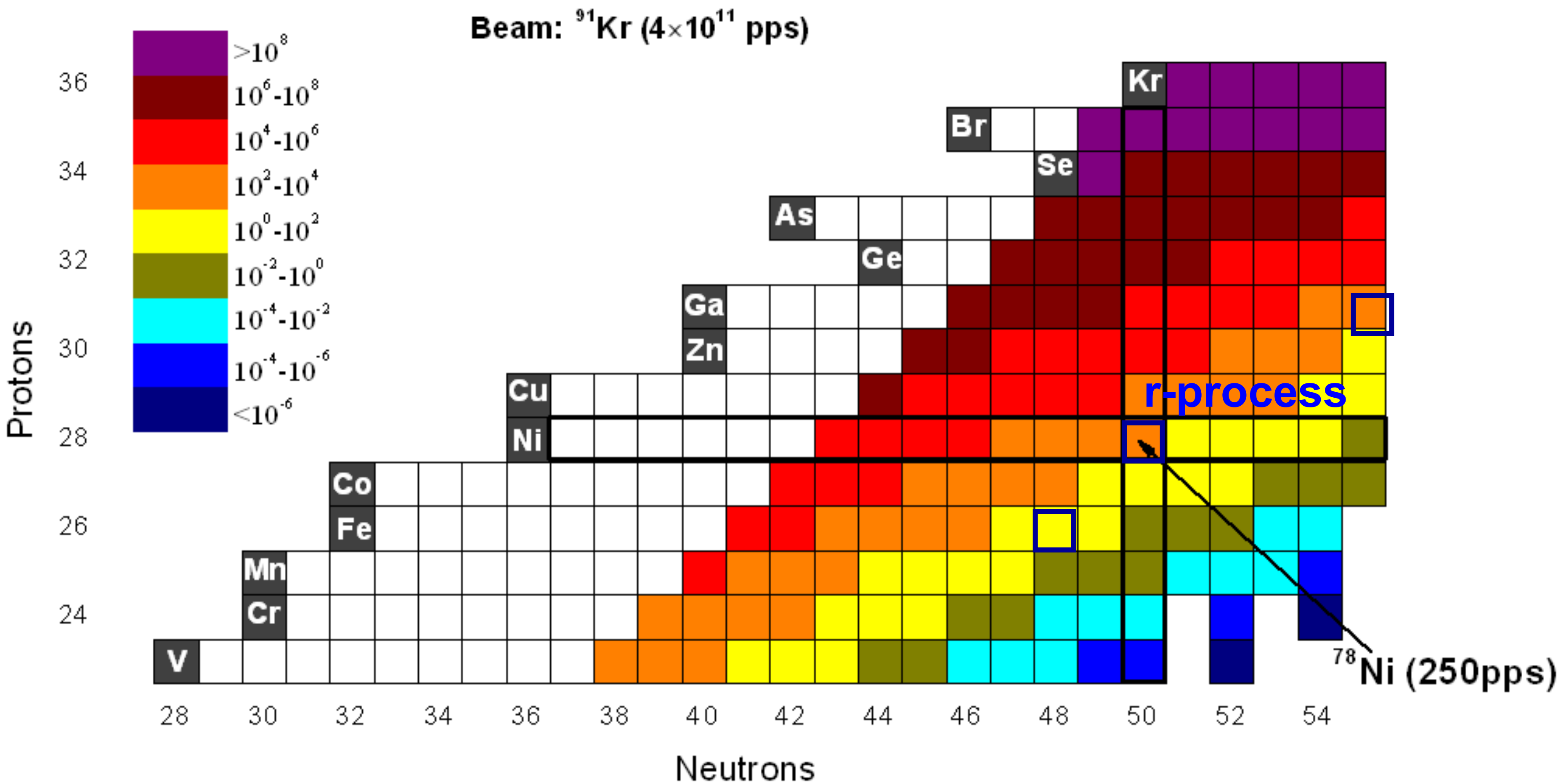
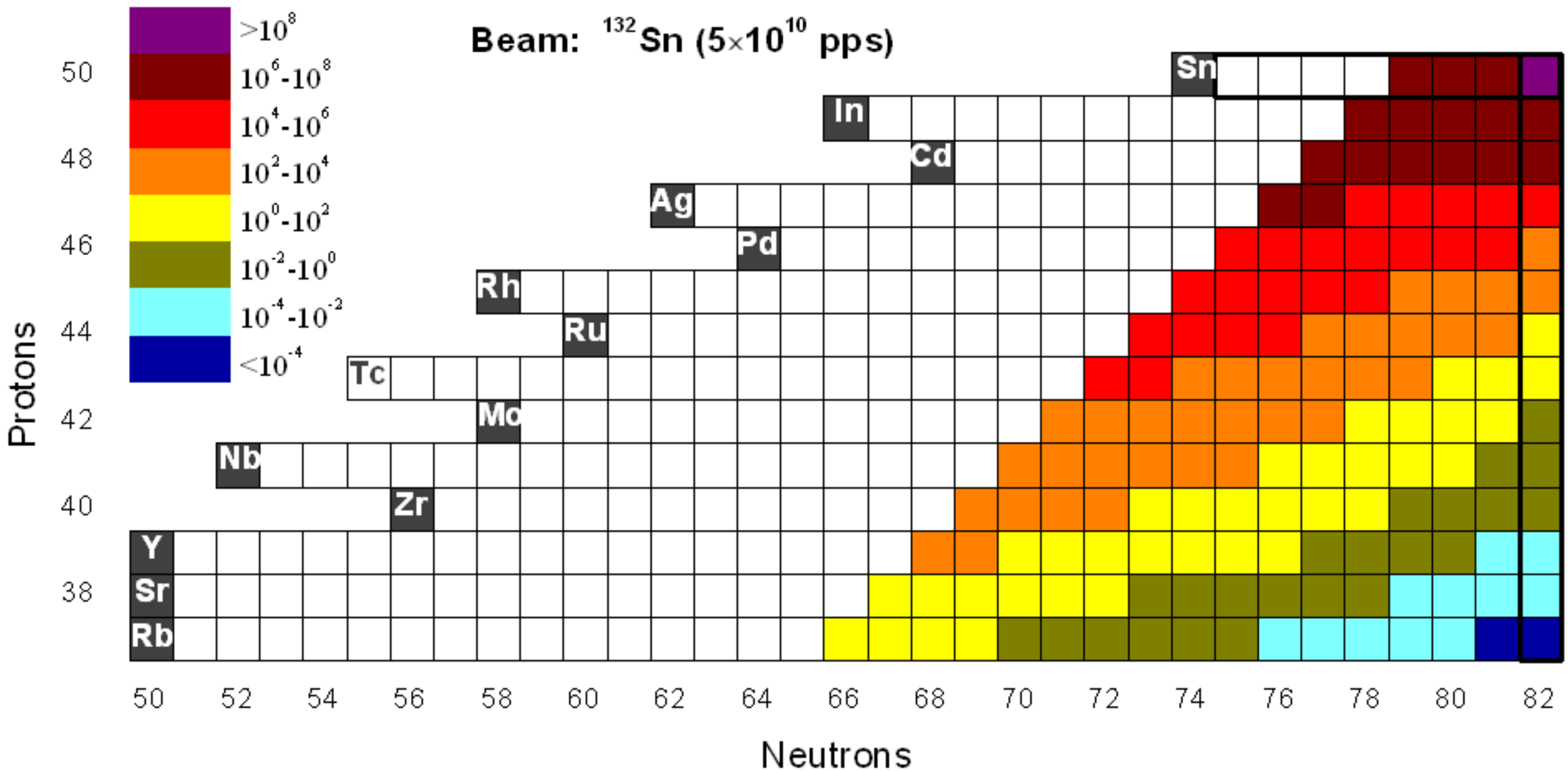
PF rates using ^{91}Kr



PFrates using ^{132}Sn



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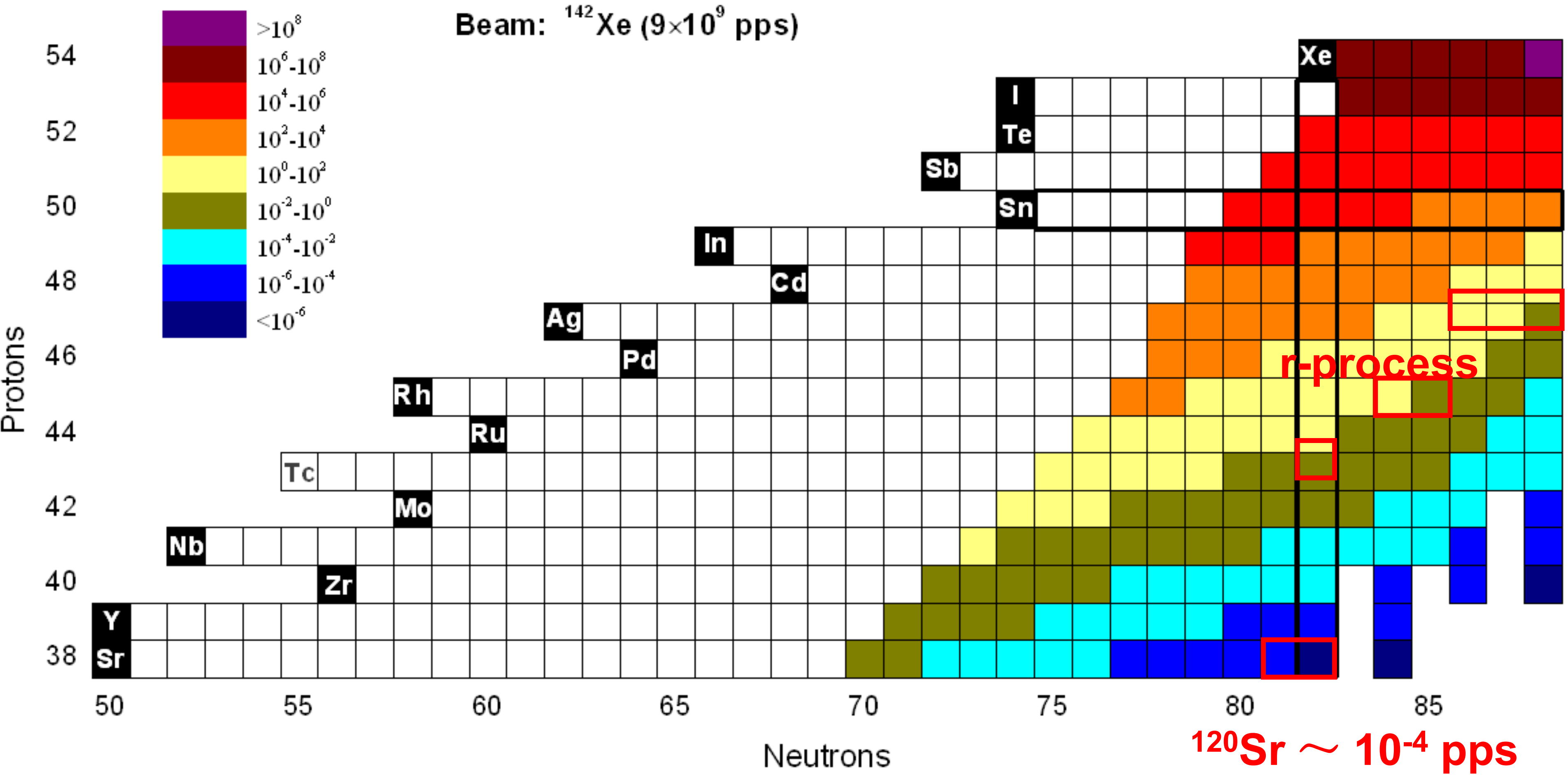
PF rates using ^{142}Xe



$^{120}Sr \sim 10^{-4}$ pps

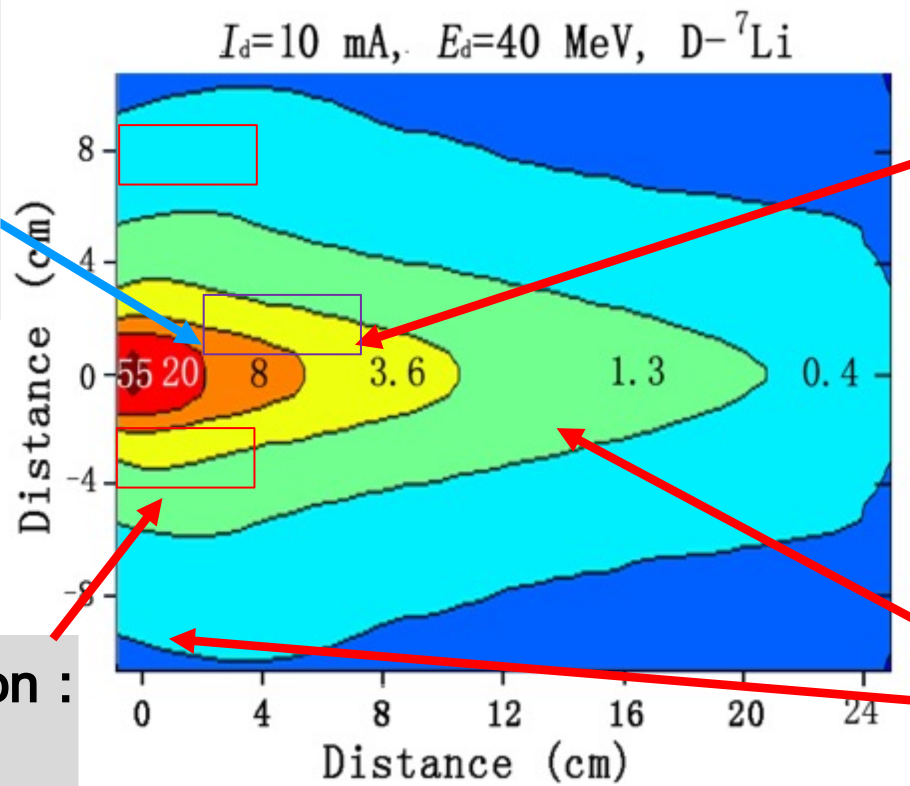
Comparison of typical RIB intensities

Facility	BISOL	EURISOL	SPIRAL2	FRIB	RIBF	FAIR
Year?	2025+	2025+	2018?	2020	2007	2020
Fission/s	$2x10^{15}$	$1x10^{15}$	$1x10^{14}$			
^{91}Kr(pps)	$4x10^{11}$	$3x10^{10}$				
^{132}Sn(pps)	$5x10^{10}$	$4x10^{11}$				
^{78}Ni(pps)	250	20		150	10	10
Drip-line ^{120}Sr(pps)	$2x10^{-4}$			$2x10^{-6}$		

BISOL n-source performances

High flux region:
- ~10-20 cm^{-3}
- 8-15 dpa/fpy
- Small sample PIE

Middle flux region:
- ~50 cm^{-3}
- > 3 dpa /fpy



Low flux region:
- Neutron data
- Detector calibration
- Imaging
- Isotope production
- ……

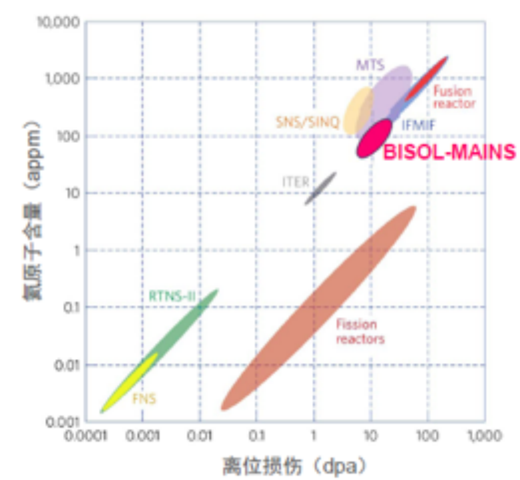
Fast neutron region:
- ~100 cm^{-3}
- 1-2 dpa/fpy
- Fission PIE

Rough neutronics calculation in pure Fe

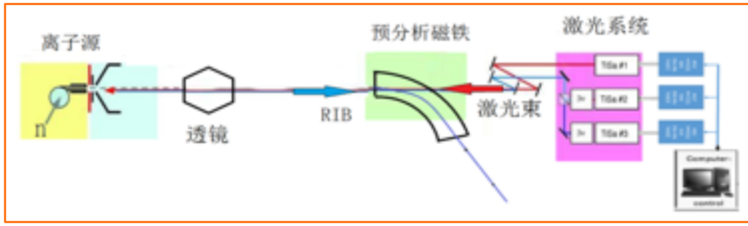
Comparison with other n-sources

	E (MeV)	ion	I (mA)	P (MW)	n	Target	S (cm^2)	Flux ($n/cm^2.s$)	V (cm^3)
IFMIF	40	D^+	2*125	10	Y	Liguid-Li	~100	$1*10^{15}$	300-500
LIPAc	9	D^+	125	1.125	No				
SARAF	40	D^+	5	0.2	Y	Solid-C		$1*10^{14}$	
SPIRAL II	40	D^+, p	5	0.2	Y	Solid-C		$1*10^{14}$	~10
BISOL	40	D^+, p	10	0.4	Y	Liquid-Li	~4	$5*10^{14}$	10~20

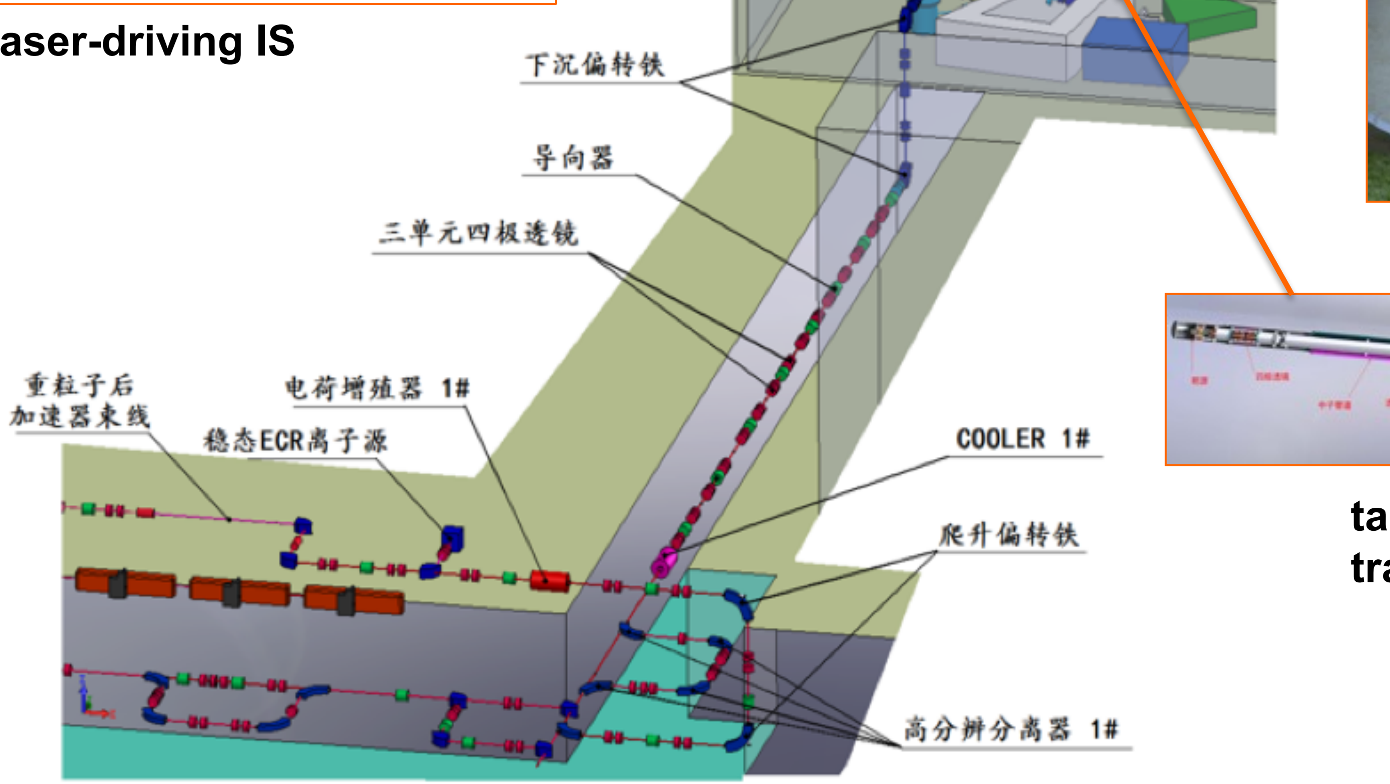
- BISOL n-source similar n-spectrum and intensity as IFMIF, \smaller irradiation volume.



Section 1: Reactor target



Laser-driving IS



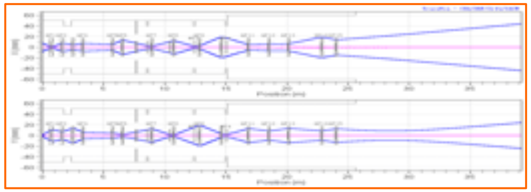
ISOL

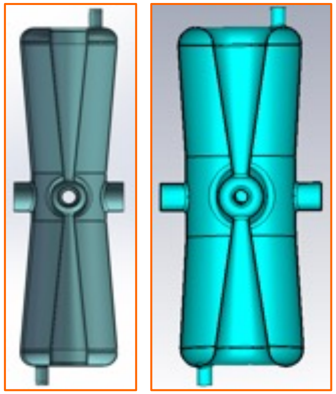
In side the reactor hall

target and transport tube

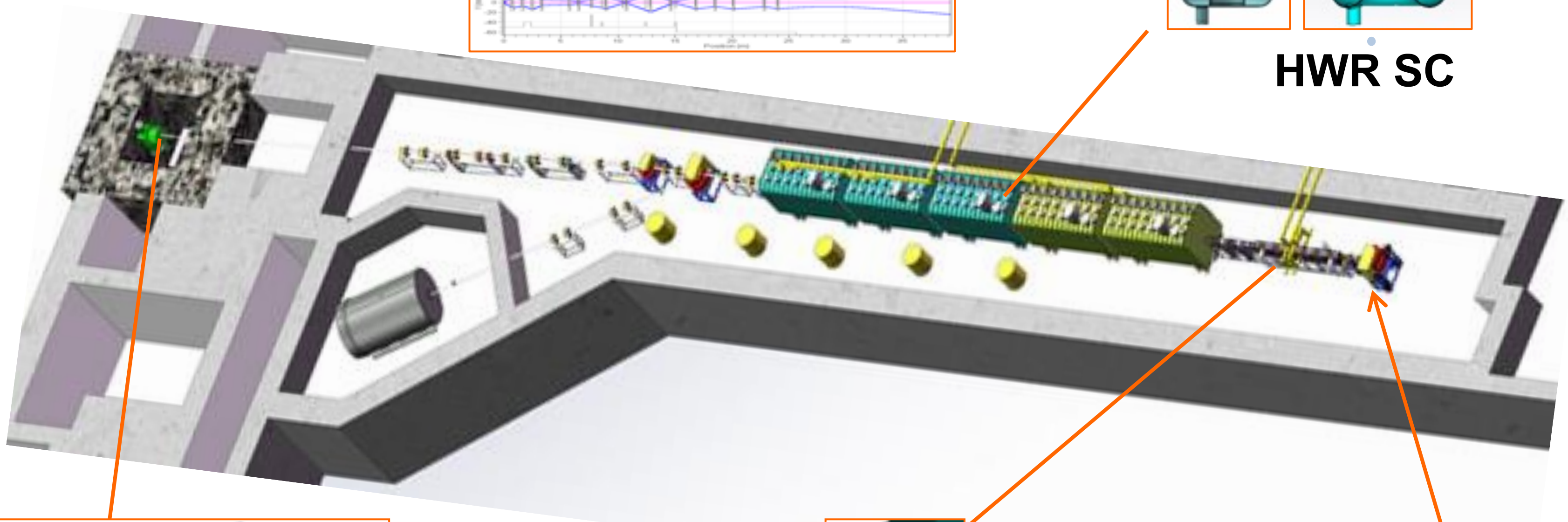
Section 2: D-LINAC

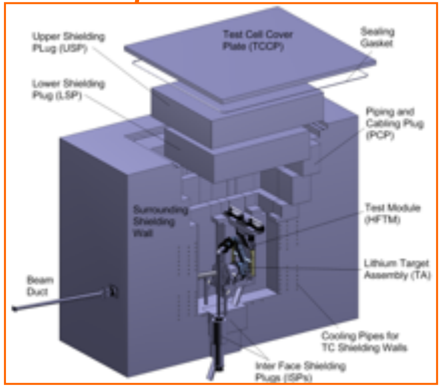
HEBT





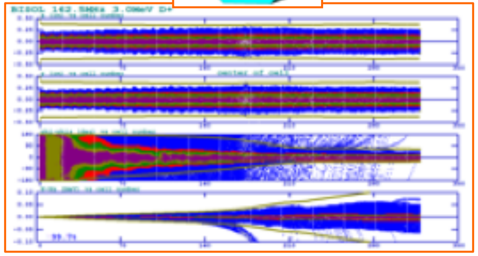
HWR SC

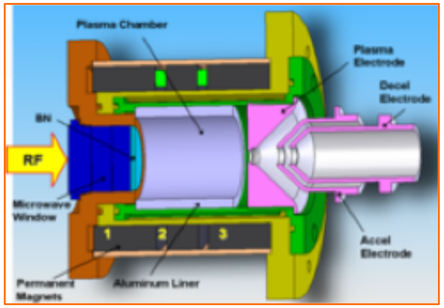




LLi target

RFQ





d-ion source

BisoL

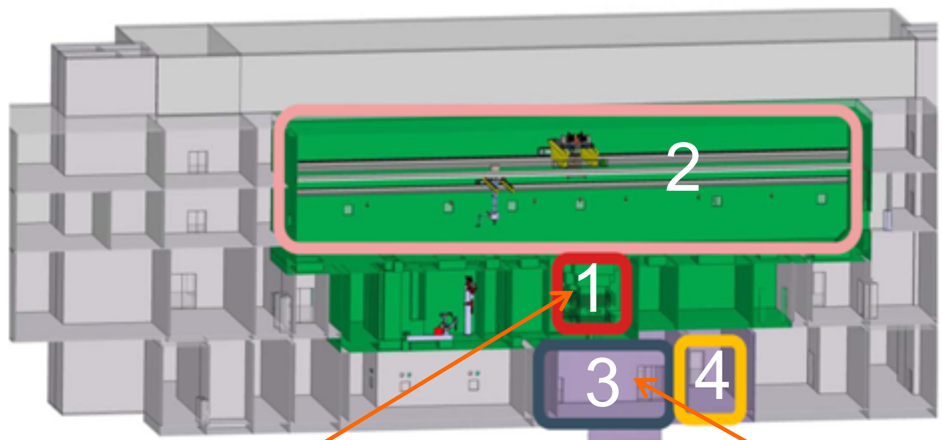
Section 3: High power target and material irradiation station

1、LLi target and irradiation unit

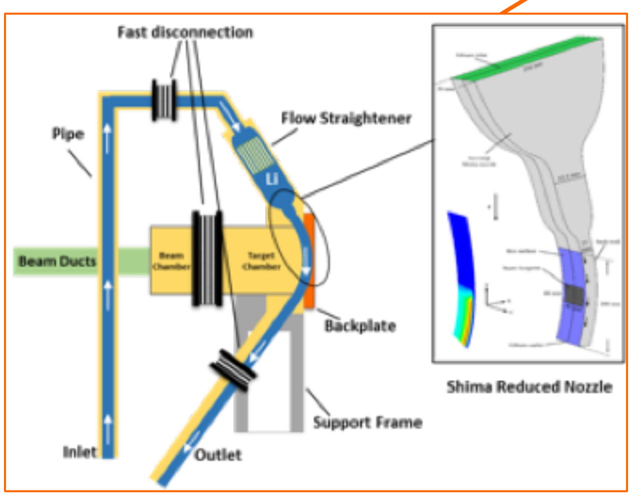
2、Maintenance and transportation

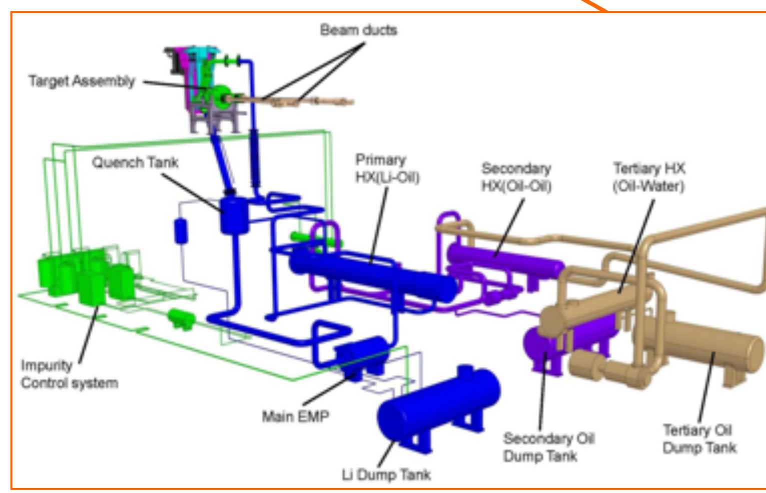
3、Li circuit and cooling

4、Wastes storage



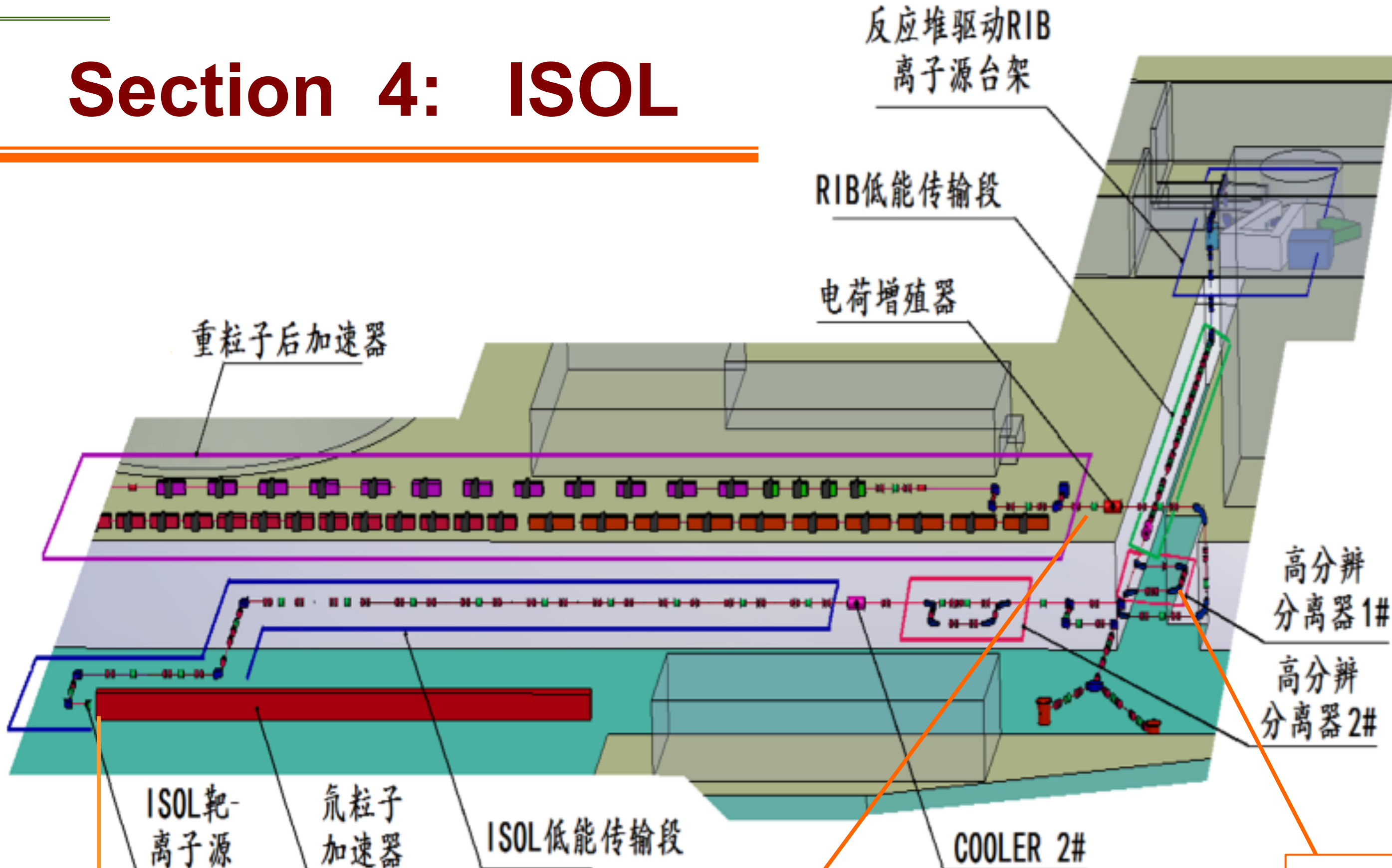
Schematic (IFMIF)

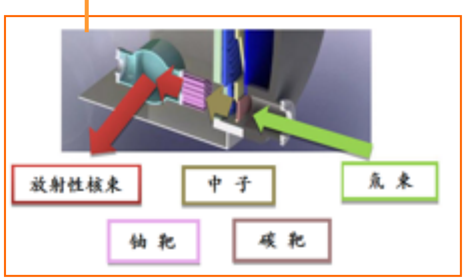




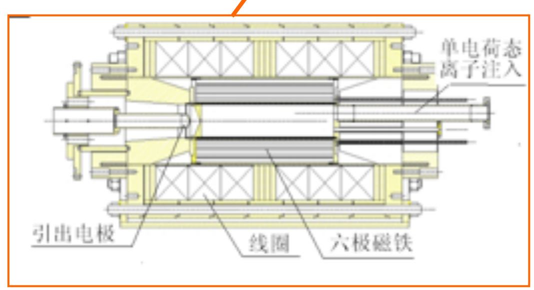
Bisol

Section 4: ISOL

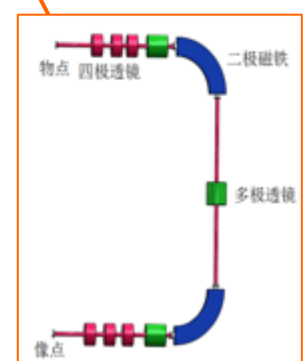




LLi target station



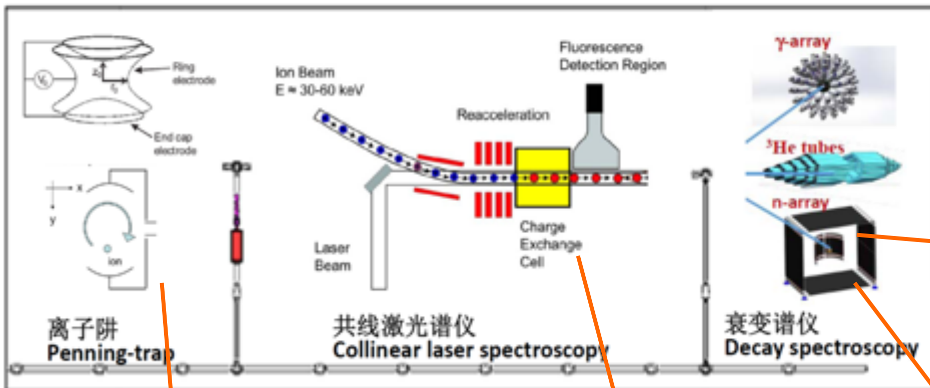
ECR charge breeder

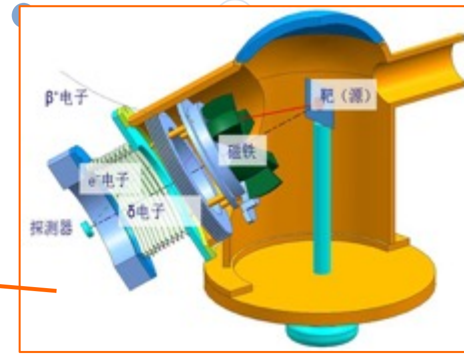


Mass separation

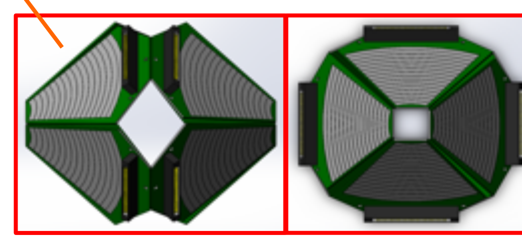
Section 5: Separation energy experiment s (SEE), at ~ 20keV/q

Dedicated to measure nuclear properties

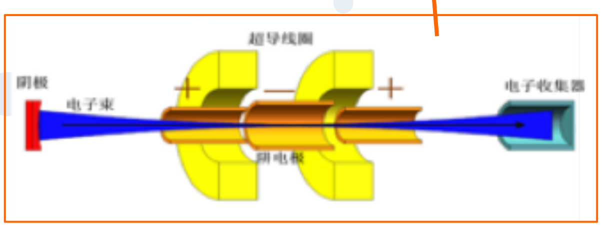




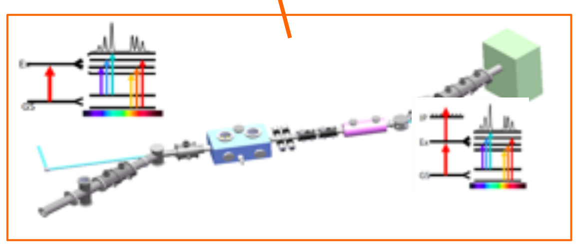
Internal conversion spectrometer



4π Si-trip array

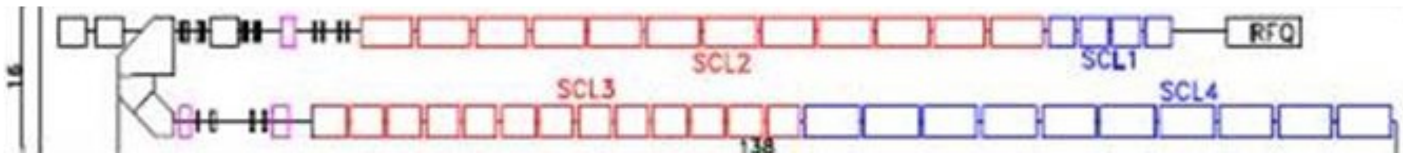


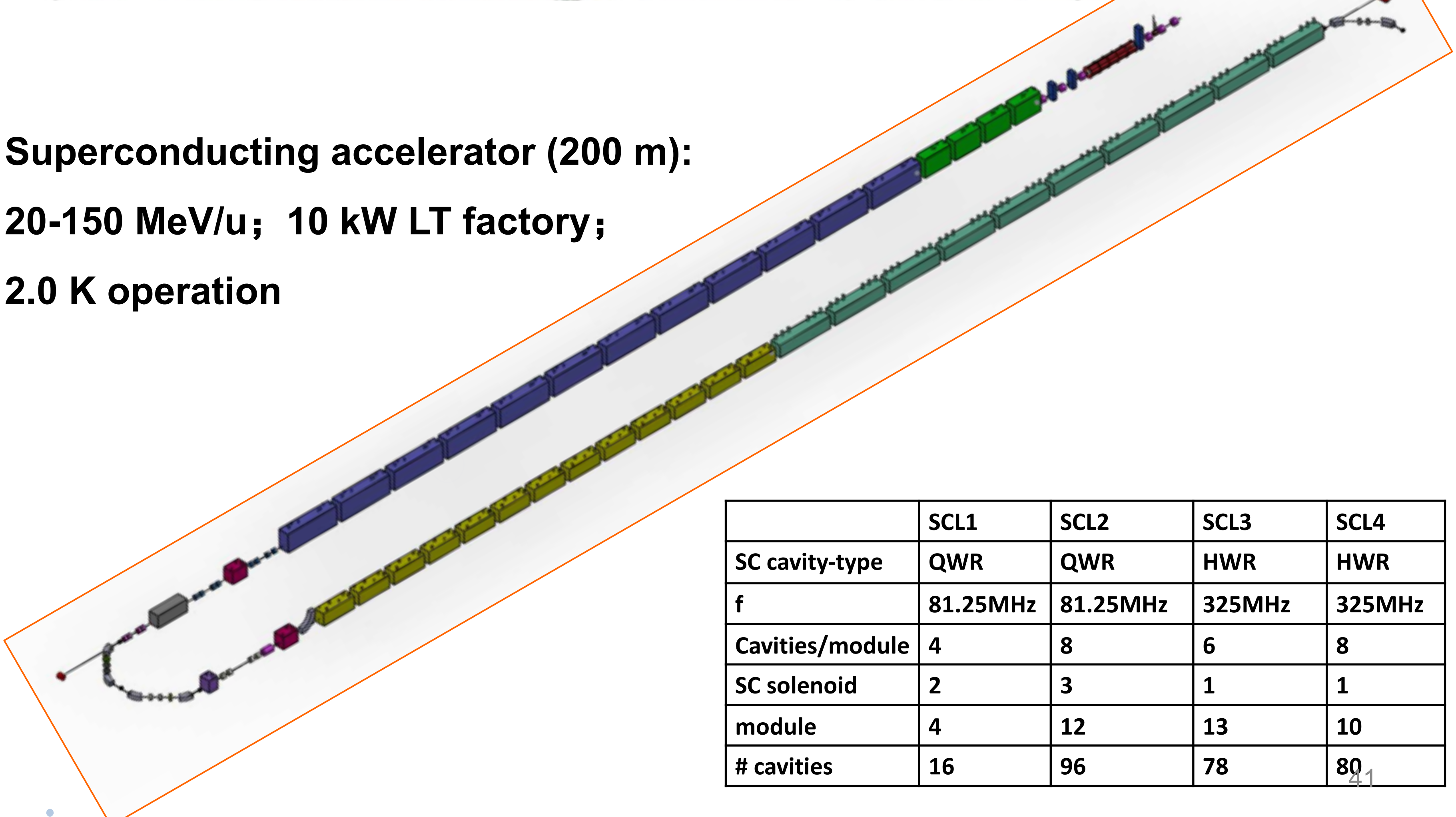
Charge breeding e-beam ion trap



Collinear resonant ionization spectroscopy

Section 6: post-accelerator





Superconducting accelerator (200 m):

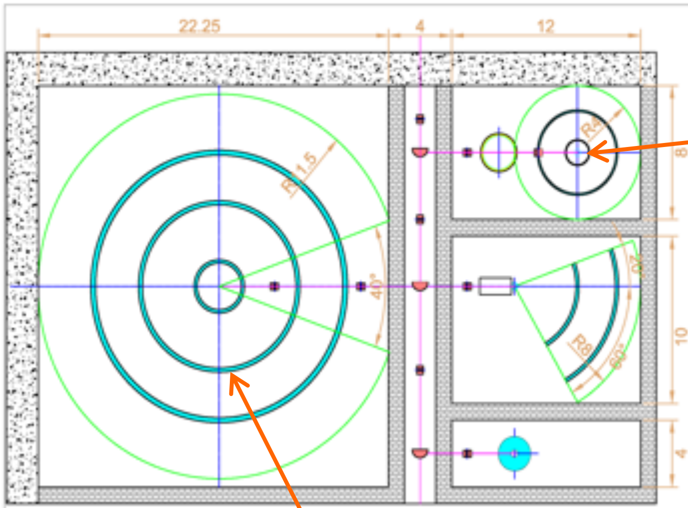
20-150 MeV/u；10 kW LT factory；

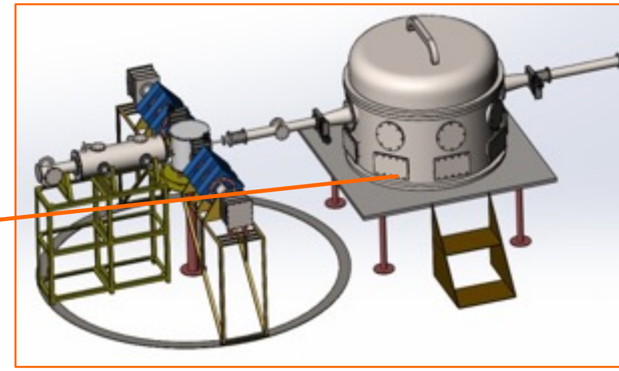
2.0 K operation

	SCL1	SCL2	SCL3	SCL4
SC cavity-type	QWR	QWR	HWR	HWR
f	81.25MHz	81.25MHz	325MHz	325MHz
Cavities/module	4	8	6	8
SC solenoid	2	3	1	1
module	4	12	13	10
# cavities	16	96	78	80

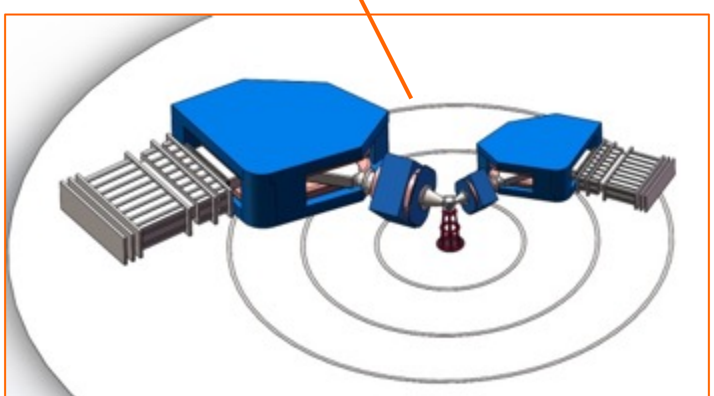
Section 7: Low energy experiments （LEE）， at ～20 MeV/u

Dedicated to LE reactions

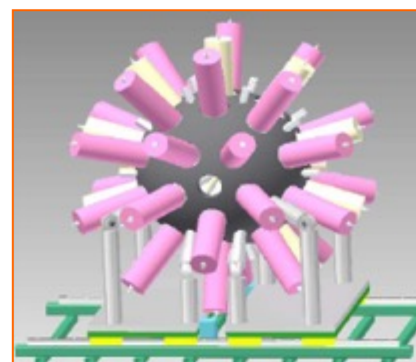




Large size target chamber with ToF



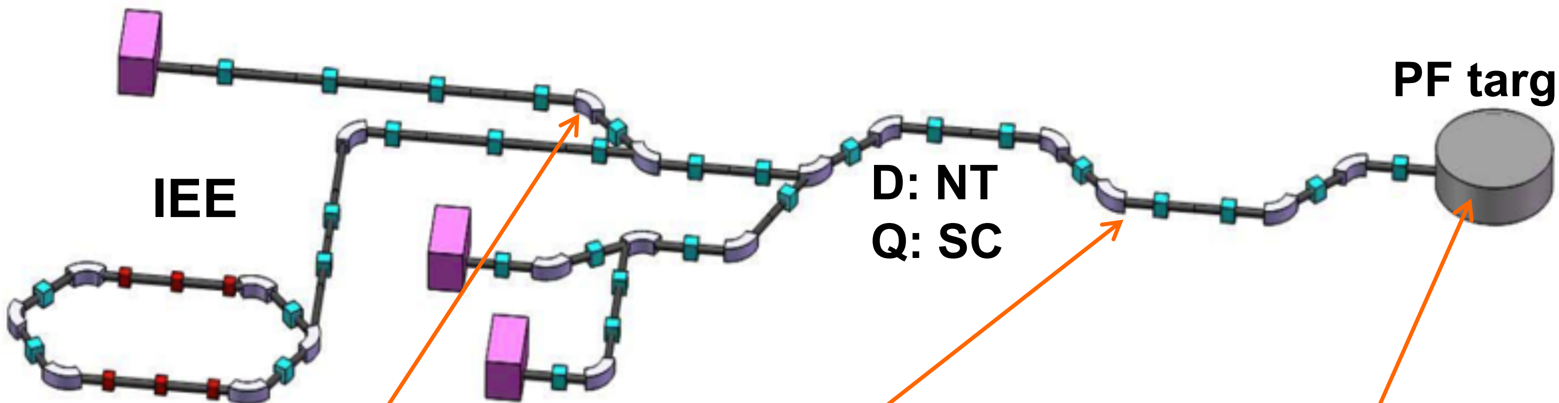
Dual-arms spectrometer

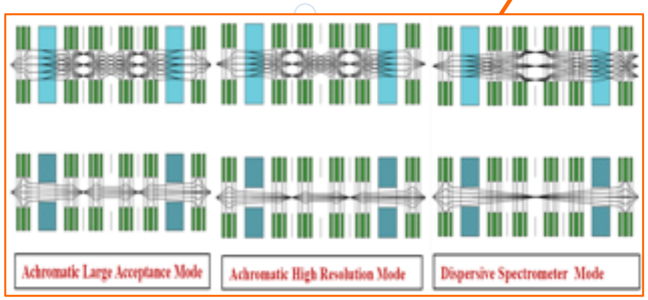


4π γ-array

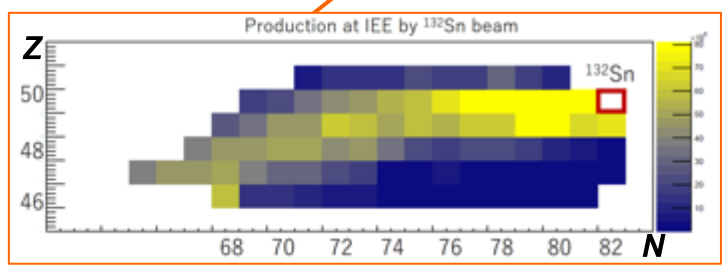
Section 8: PF separator and intermediate energy experiments (IEE), at ～150 MeV/u

Dedicated to removal reactions



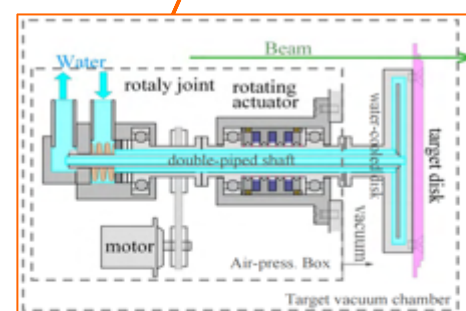


0-degree spectrometer



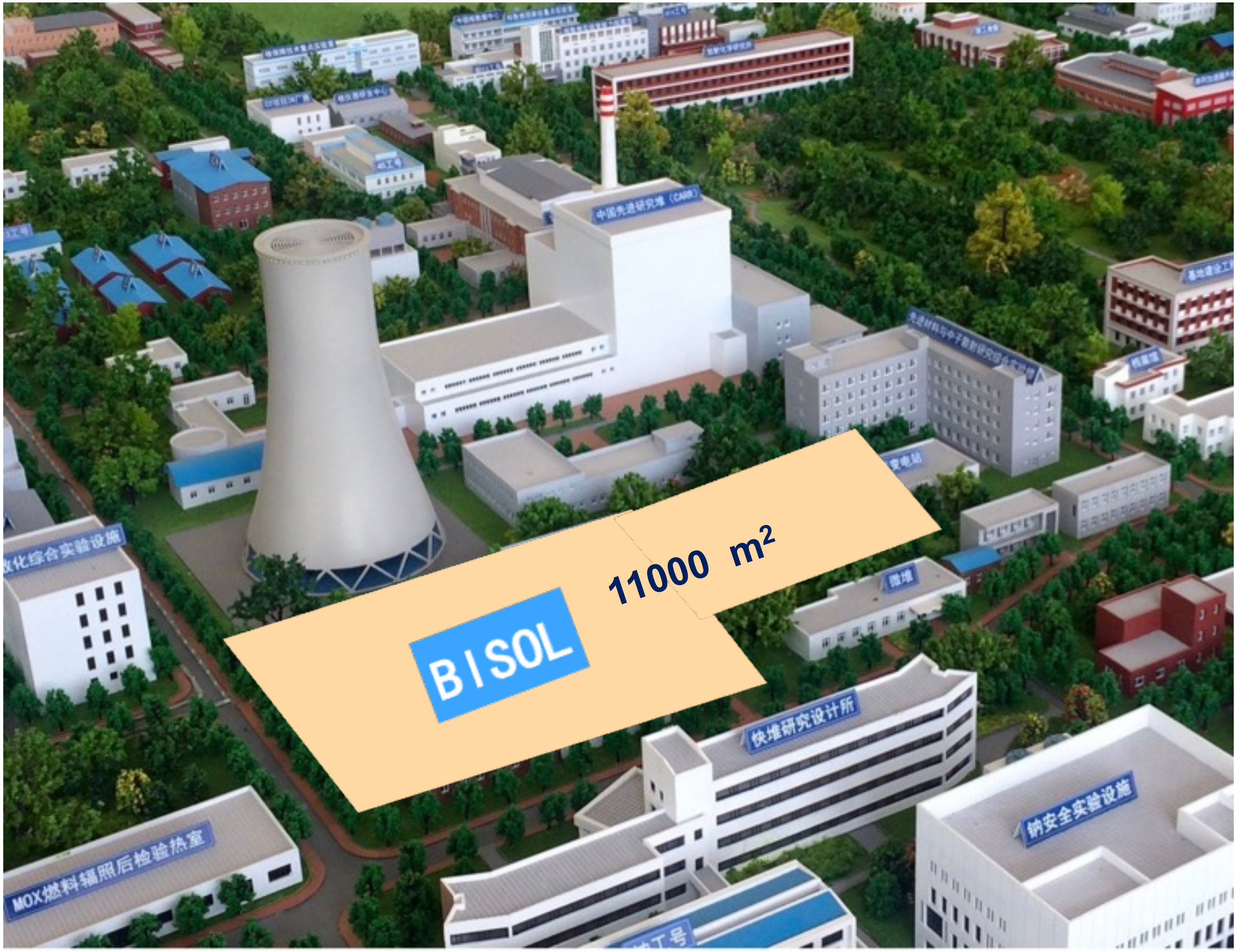
Br_{max}	$\Delta p/p$	$\Delta\Phi_x$	$\Delta\Phi_y$
7 Tm	6%	±60mrad	±60mrad

High power separator



PF Target & cooling

Location for BISOL in CIAE



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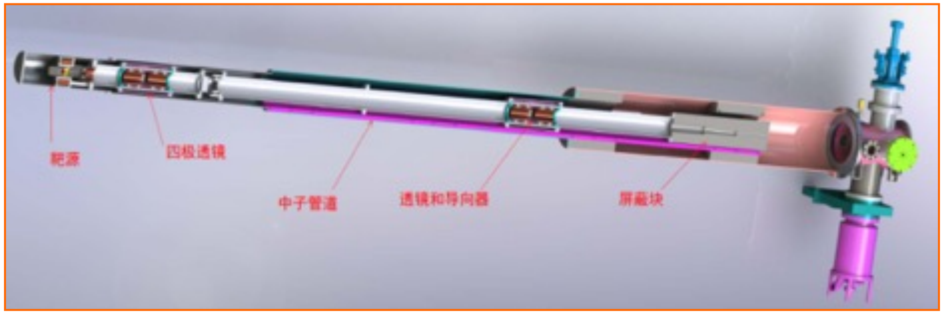
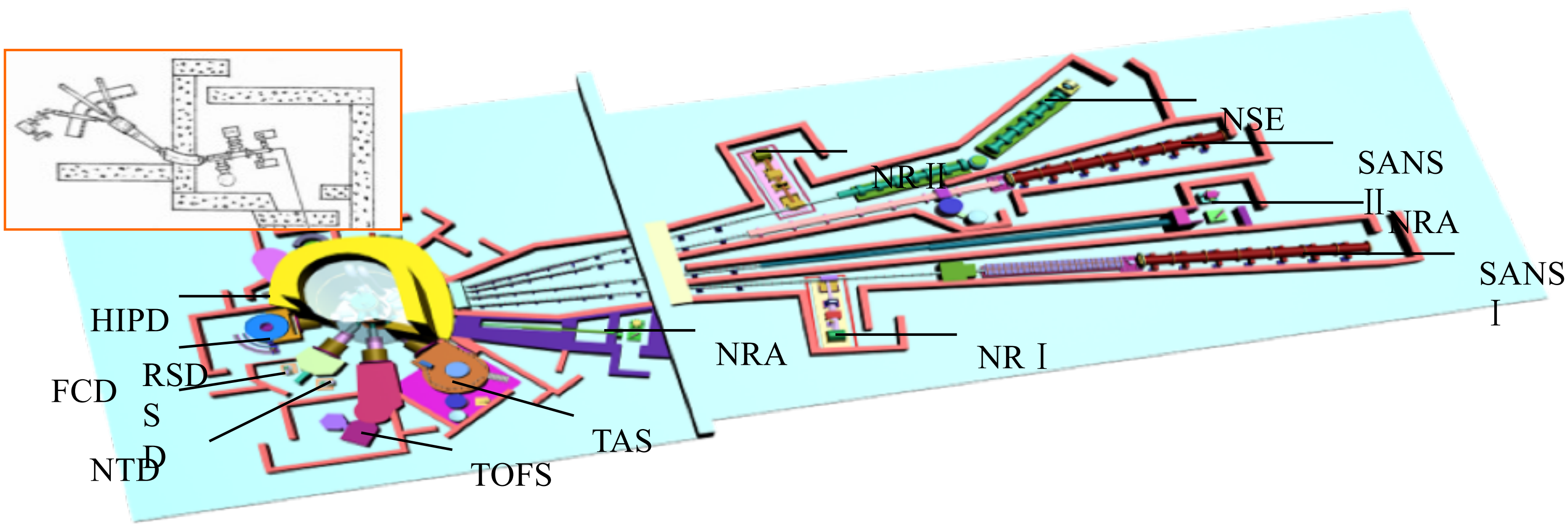
Existing CARR in CIAE

- 60MW, neutron flux 8×10^{14} $n/cm^2 \cdot s$
- Engineering started 2002
- First critical May 2010
- Reach full power May 2012
- First experiment Aug. 2012
- Stable operation since 2015
- ISOL for NP installed

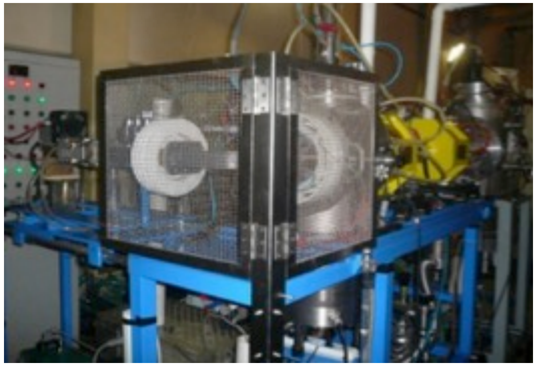
Bisol

Present R&D at CARR

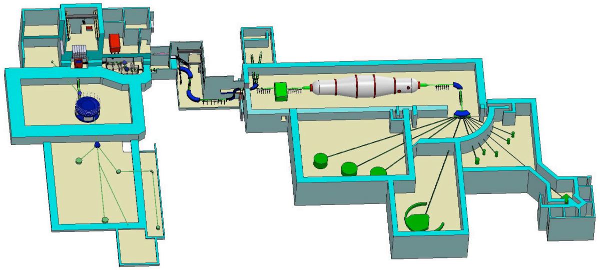




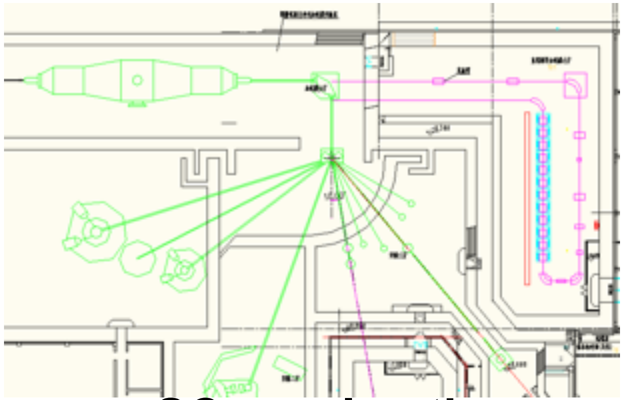
Existing accelerator technology at PKU and CIAE



2.45GHz ECR D-IS
at PKU



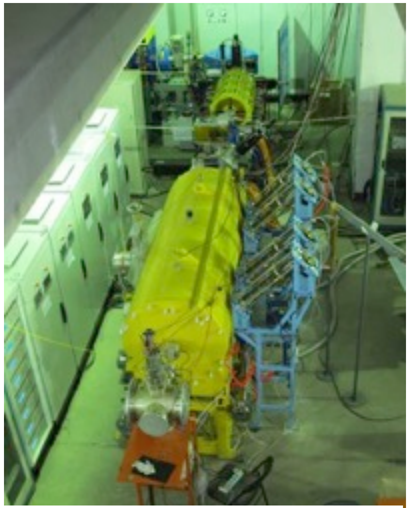
ISOL-type BRIF
at CIAE



SC acceleration
at CIAE

Intense D-accelerator
at PKU

2 x 9 cells SC
accelerator at PKU



RFQ accelerator
made by PKU

BisoL

Outline

- A brief history
- Background in basic and applied sciences
- Conceptual design (CD-1)
- **Opportunities for EOS**
- Outlooks

Opportunities for EOS

- Intense middle n-rich ^{132}Sn like beams from 20-150 MeV/u, $5x10^{10}$ pps
- Much extremely n-rich beams near drip line for new and/or precise M, $T_{1/2}$, P_n, and ng
- Much more n-rich beams like ^{78}Ni for extreme neutron skin study, $\sim 10^{2-3}$ pps, 150 MeV/u
- Near more input and instrumentation idea!

Bisol

Outline

- A brief history
- Background in basic and applied sciences
- Conceptual design (CD-1)
- Opportunities for EOS
- **Outlooks**

BisoL

- BISOL, in combination of the ISOL production through either the high-intensity deuteron beam driver or high thermal neutron-flux from the reactor, together with re-acceleration of RIBs up to projectile-fragmentation energies (i.e. ~150 AMeV), promises the most intense RIB capabilities in the medium mass region.
- Availability of accelerator-driven high-flux neutrons, produced with an intense beam of 40MeV deuterons, provides for a wide spectrum of applied research over a range of energies, in particular for unique materials research relevant to next generation fission and fusion reactors.
- Facility cost is applied 3.5 B RMB (～500M USD) plus the infrastructure & manpower investment by domestic goverment. The timetable is not clear yet but we expect a completion time in 2025-2030.

- **BISOL will be user facility and cooperation between the major institutes & universities is highly welcome**

THANK YOU FOR YOUR ATTENTION!

Websites:

http://sklnpt.pku.edu.cn

http://www.ciae.ac.cn

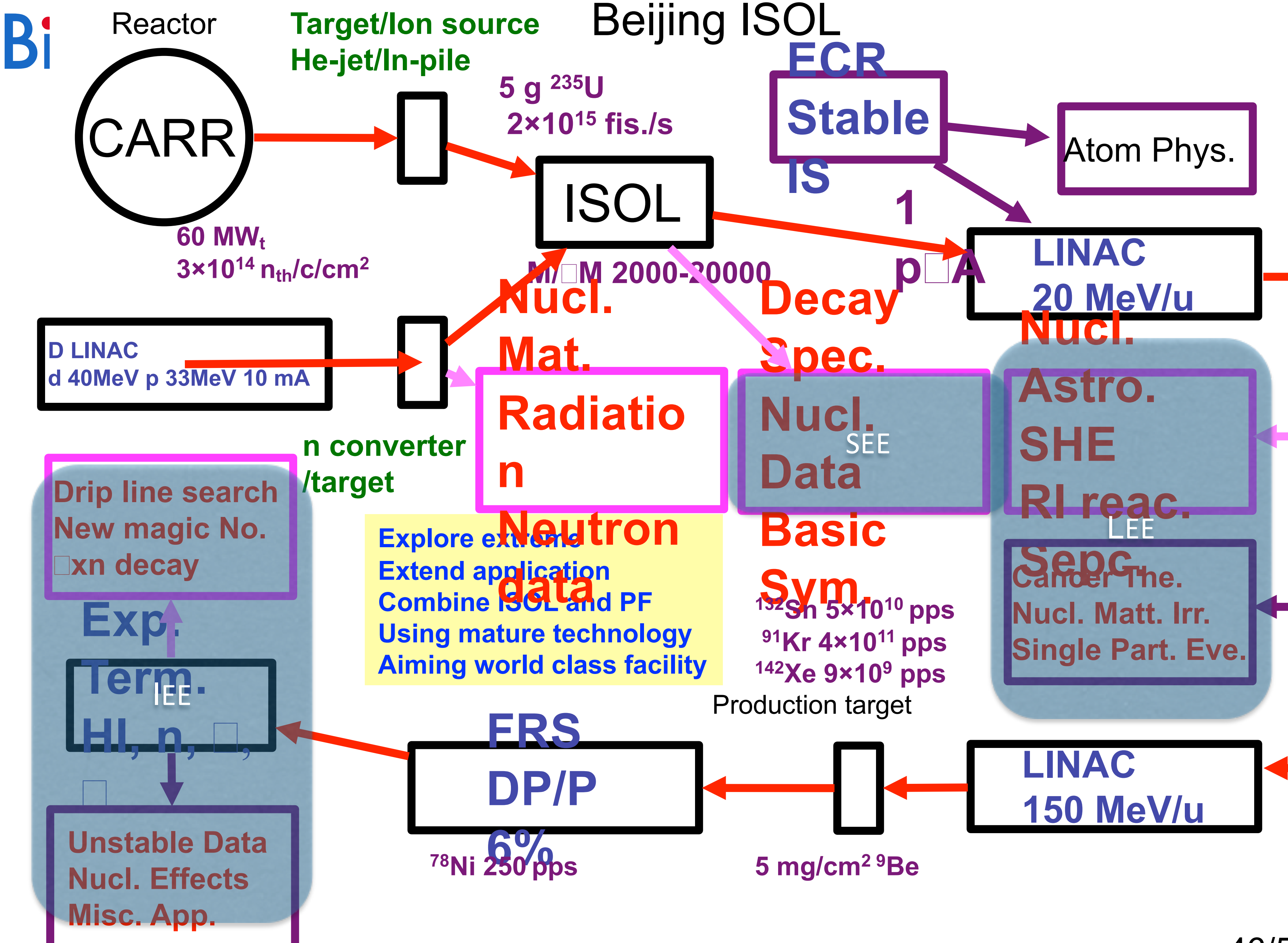
My email: wpliu@ciae.ac.cn

Fission beam intensity estimates

^{235}U, g	□, b	N flux, /cm^2/s	Fis. rate, /s
5	585	3×10^{14}	2×10^{15}

nuclei	Fis. yield	rate	Target +isol eff. (ref. PIAFE)	Charge eff	Linac eff.	intensity
^{91}Kr	3.2×10^{-2}	6.4×10^{13}	13.0%	10%	50%	4×10^{11}
^{142}Xe	4.3×10^{-3}	8.8×10^{12}	2.0%	10%	50%	9×10^{9}
^{132}Sn	5.7×10^{-3}	1.2×10^{13}	8.0%	10%	80%	7×10^{10}
^{81}Ga	7.6×10^{-5}	2×10^{11}	8.0%	10%	95%	1×10^{9}

Beijing ISOL



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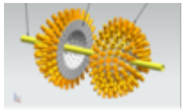
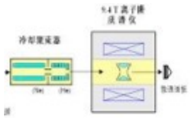
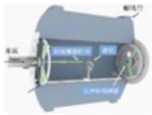
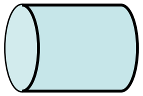
Beijing ISOL detector map

Det	MAS	LAS	BGA	BTP	BDA	BSD	CLIB	BGD
Fig								
Full Name	multiple application spectrometer	Large solid-angle spec	gamma array	Trap	decay array	solenoid	collinear laser-ion beam	general purpose detector
Measured quantity	Reaction, astrophysics	Reaction	Structure	Mass	Half life, branching ratio	Reaction, astrophysics	nuclear moments	Identification, reaction
Physics example	Shell evolution Reaction rate	SHE mechanism				Shell evolution Reaction rate		Shell evolution Drip line
Intensity, pps	10^3-10^5	10^2-10^4	10^2-10^4	10^{-1}-10^2	10^{-2}-10^2	10^2-10^4	10^2-10^4	10^{-4}-10^3