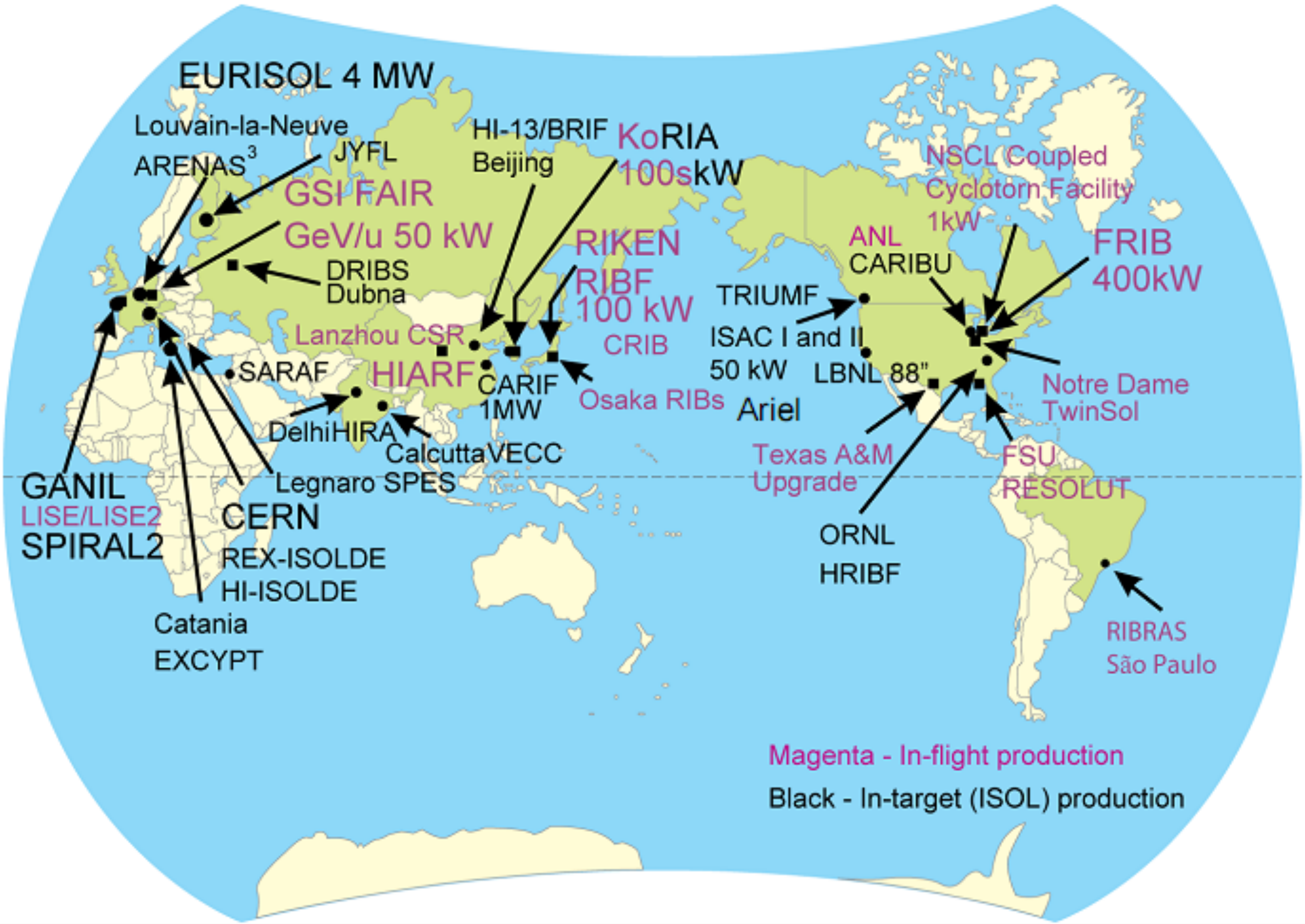
CIAE facility and future perspective
Progress of BRIF and CARIF proporsal

Weiping Liu
China Institute of Atomic Energy

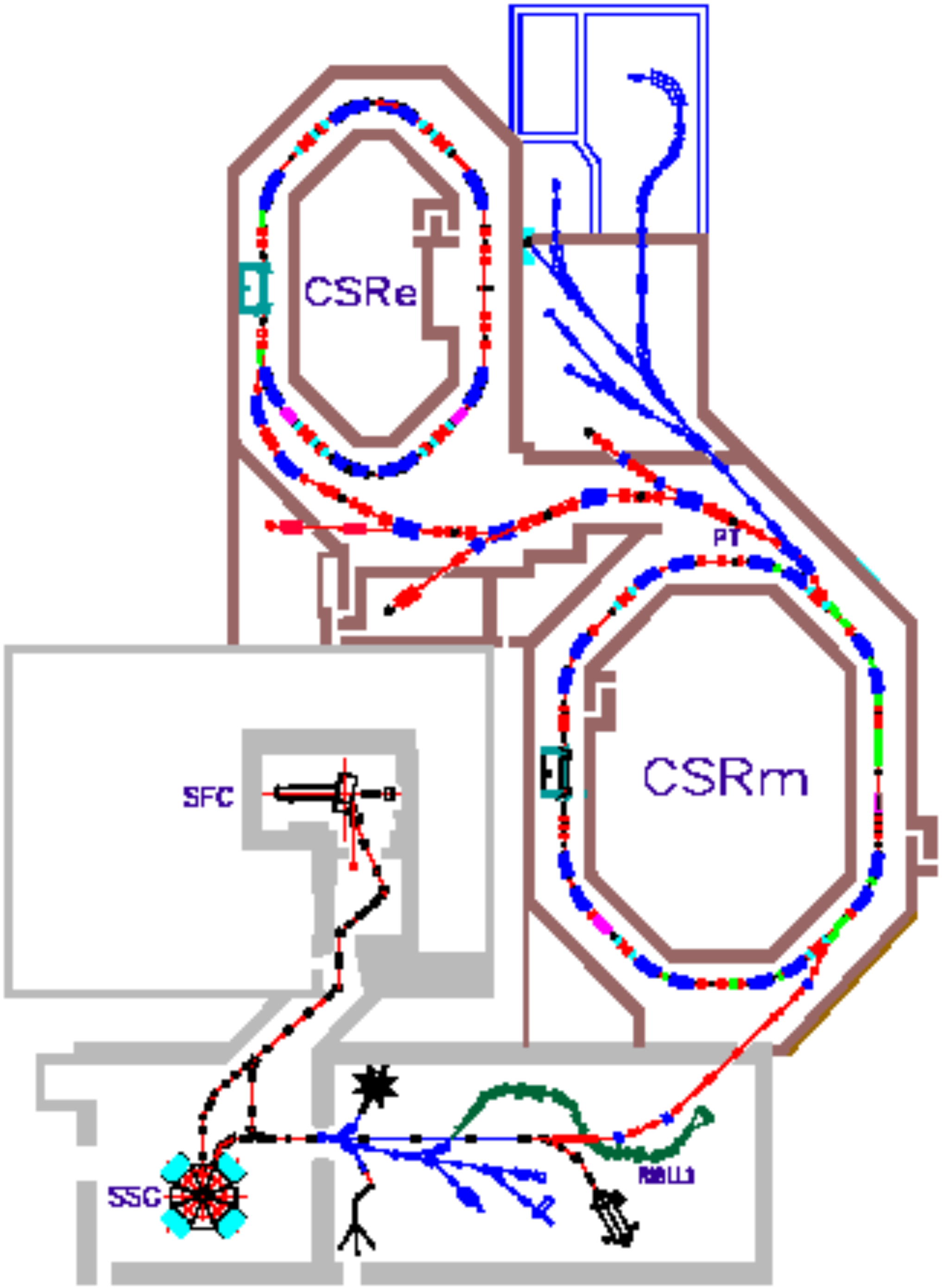
Nuclear science in the world, RCNST steering meeting
November 1, 2011, Beihang University

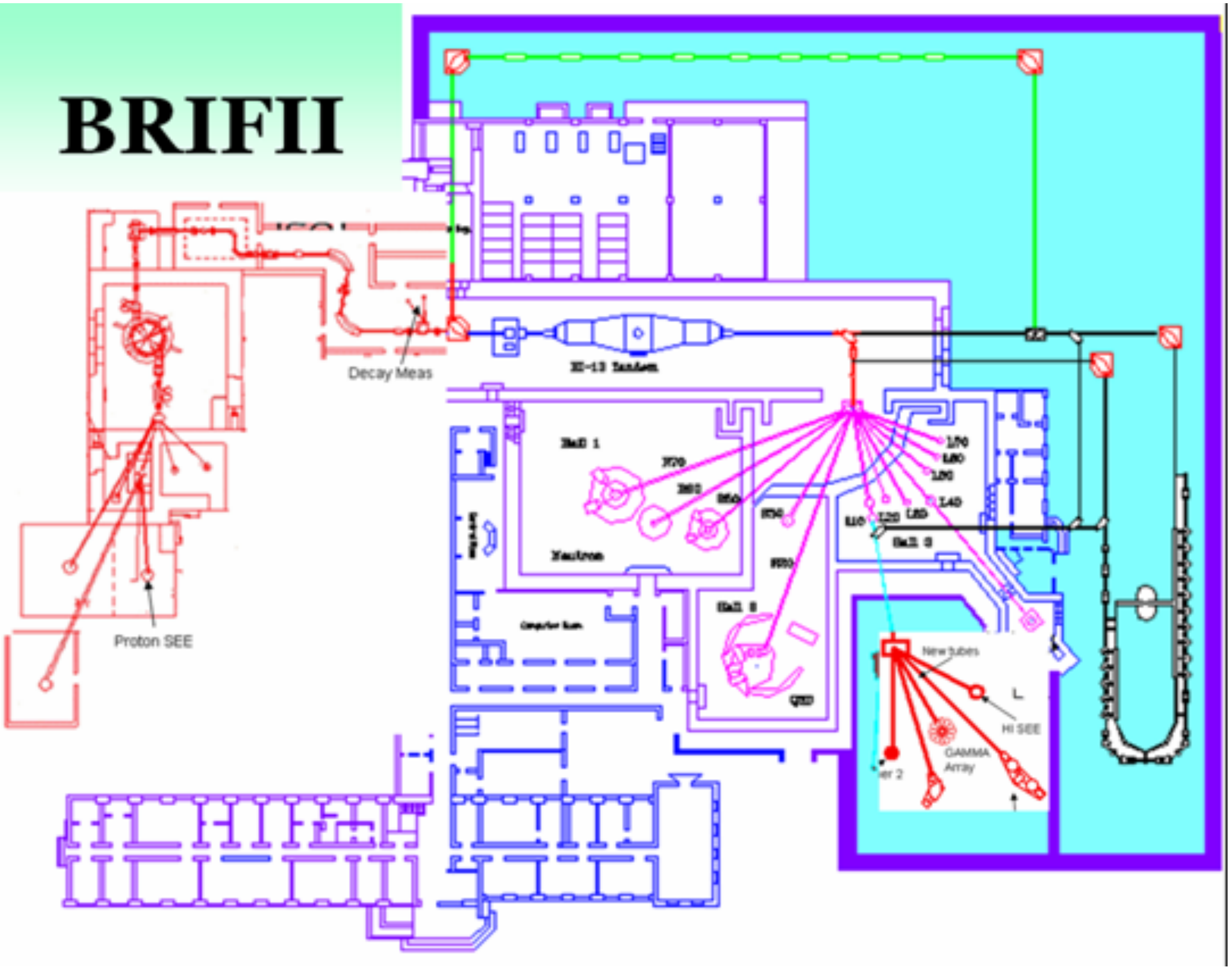
World wide RIB facilities



Brad Sherrill ISSSP August 2011, Slide 35

Current China nuclear physics facilities





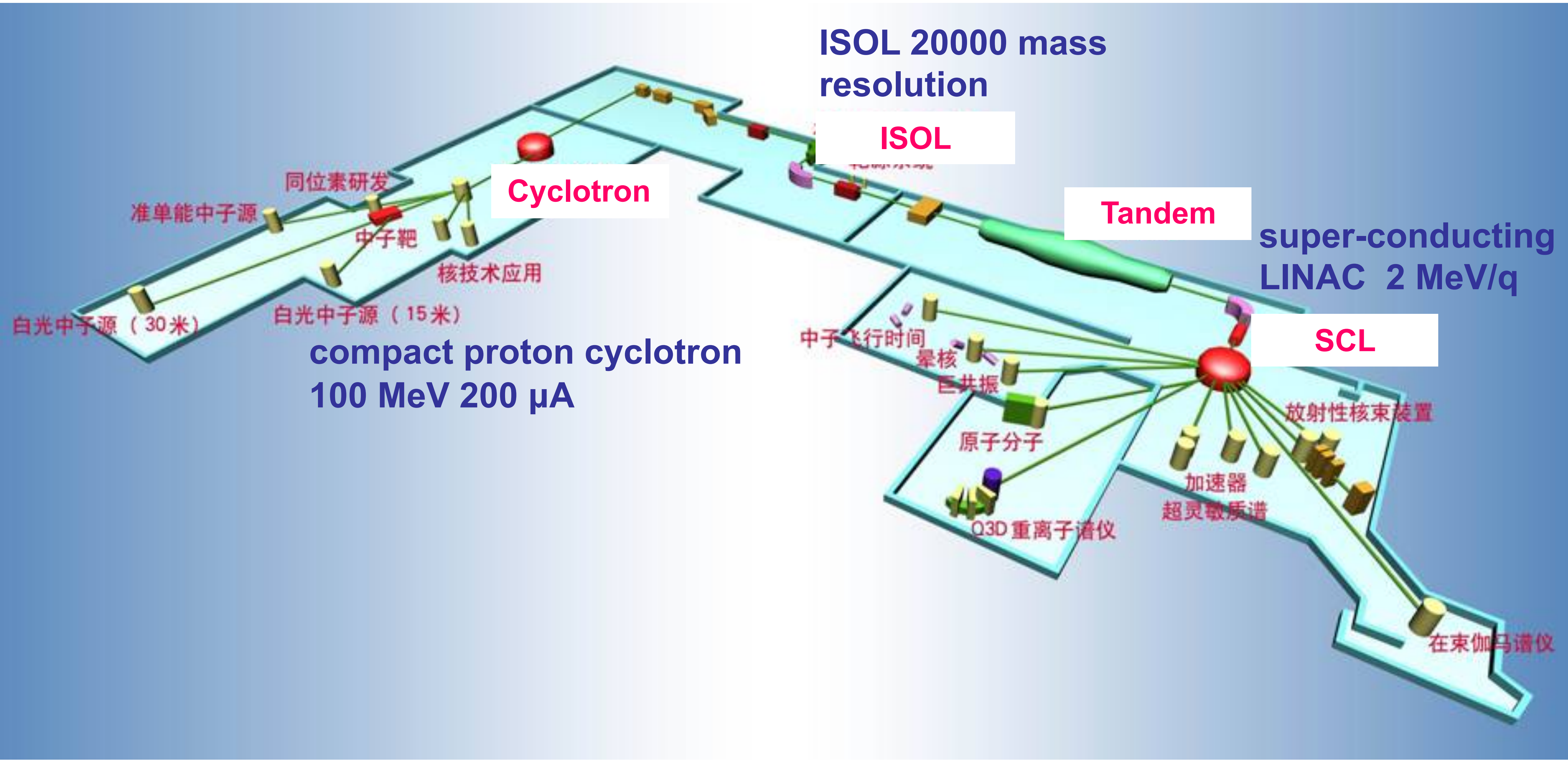
CSR, Lanzhou,
High E HI, RIB, 2008
Future: HIAF@Ordos

Current: Tandem HI-13
BRIF, Beijing
Low E HI, RIB, 2013

About CIAE

- China Institute of Atomic Energy
- Established in 1950, multi-disciplinary national lab for nuclear science, 30 km SW of downtown Beijing
  - Nuclear physics, Tandem
  - Nuclear fuel cycle technology
  - Nuclear reactor engineering
  - Nuclear technology application
- Project high lights
  - Fast breeding reactor CEFR critical on July 21, 2010, send electricity to grid on July 21, 2011
  - Research reactor CARR critical on May 13, 2010

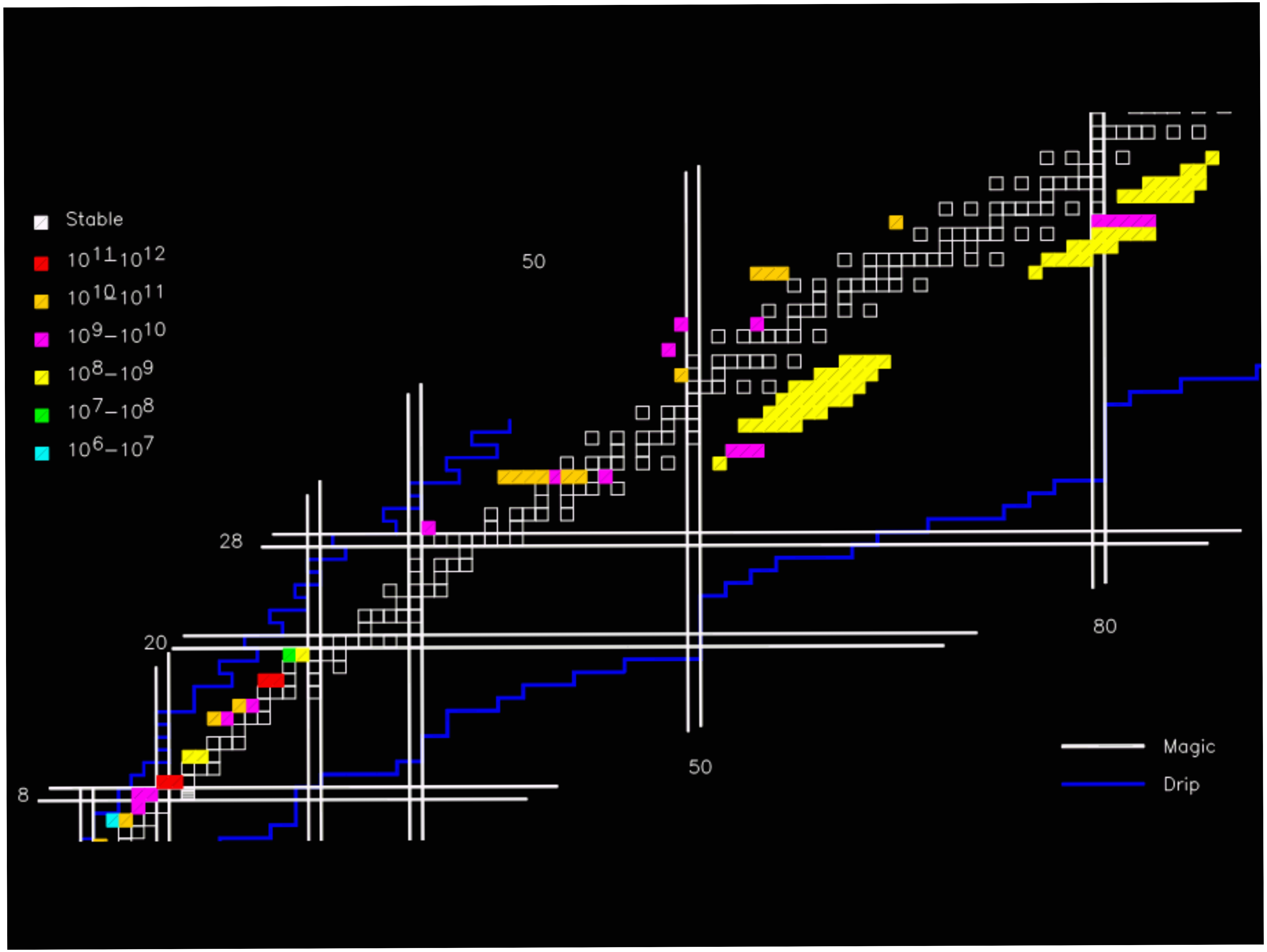
BRIF (Beijing Rare Ion beam Facility)



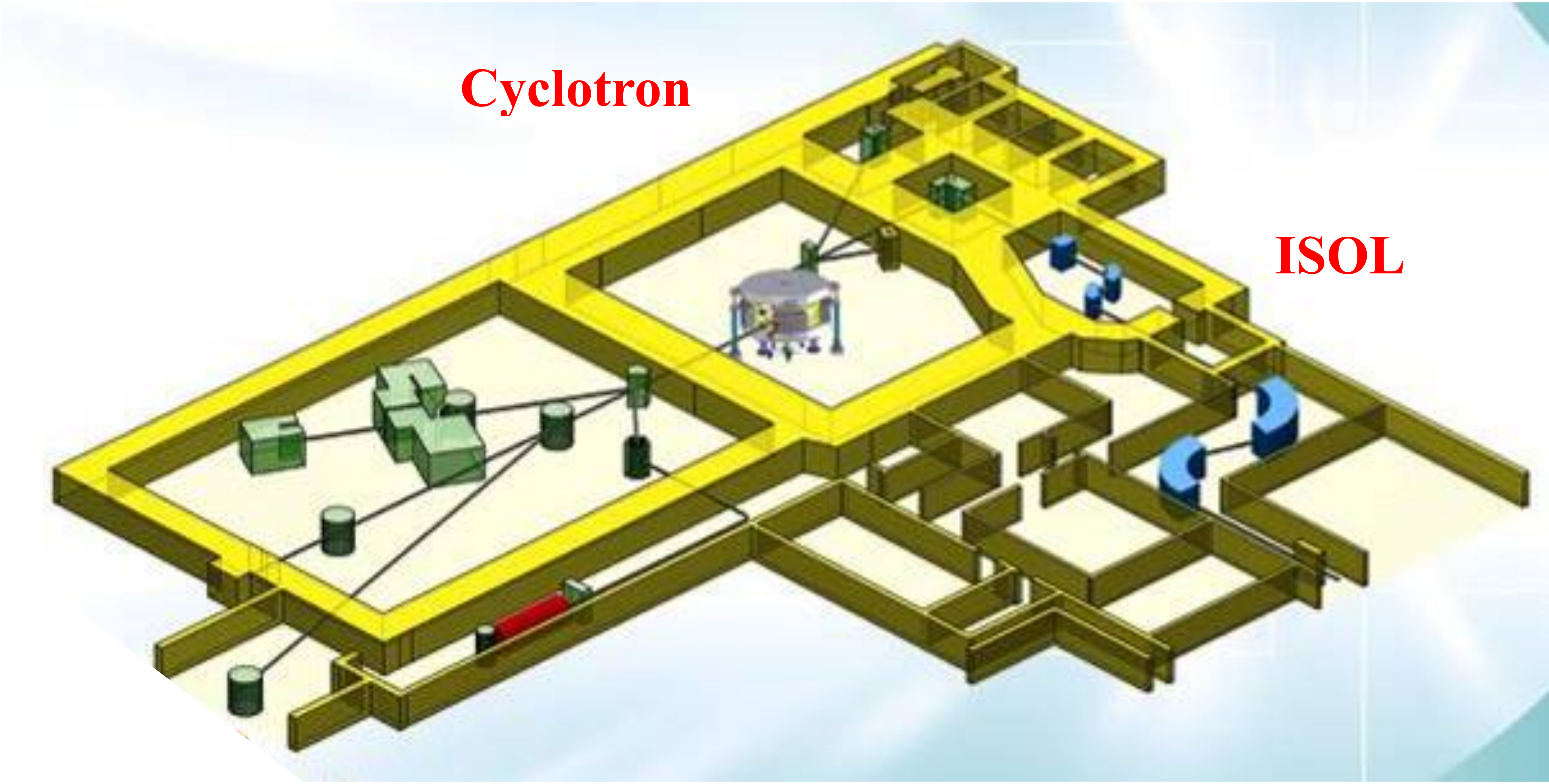
Project milestone

- Project approved in 2003
- Feasibility plan approved ($29 M) in 2004
- Revised feasibility plan got permission in Aug. 2009 ($56 M)
- Civil engineering started on April 28, 2011
- Cyclotron fabrication completed in June 30, 2011

BRIF intensity

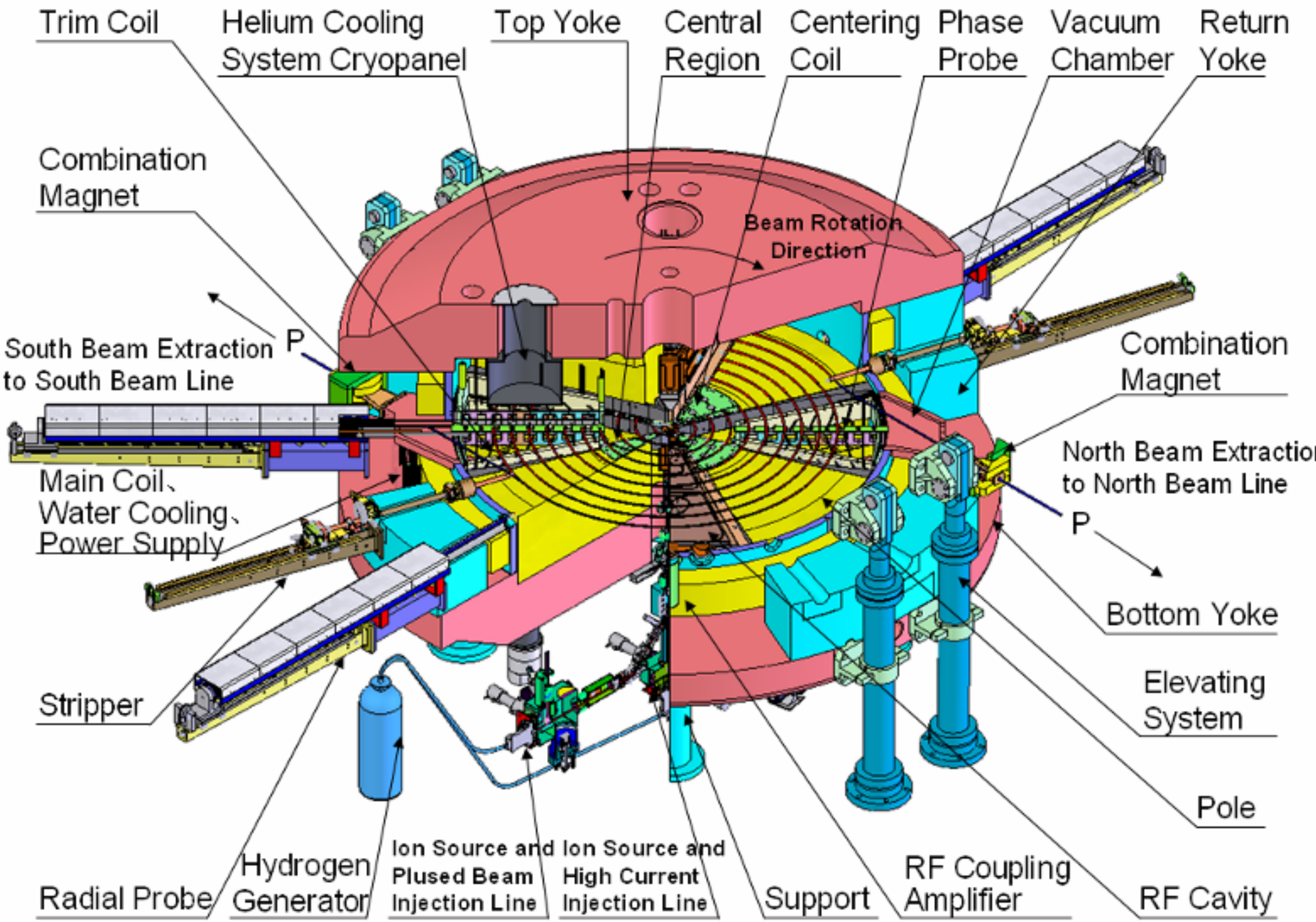


BRIF civil engineering structure



Construction site of civil engineering on July 21, 2011

H⁻ compact cyclotron structure



Assembling of cyclotron main magnets

Visiting of state chairman Hu Jintao on July 10, 2010

Cyclotron magnet arrive CIAE on September 28, 2011

ISOL progress


Magnet


Target/ion source process chamber


Target/ion source

Super conducting LINAC progress

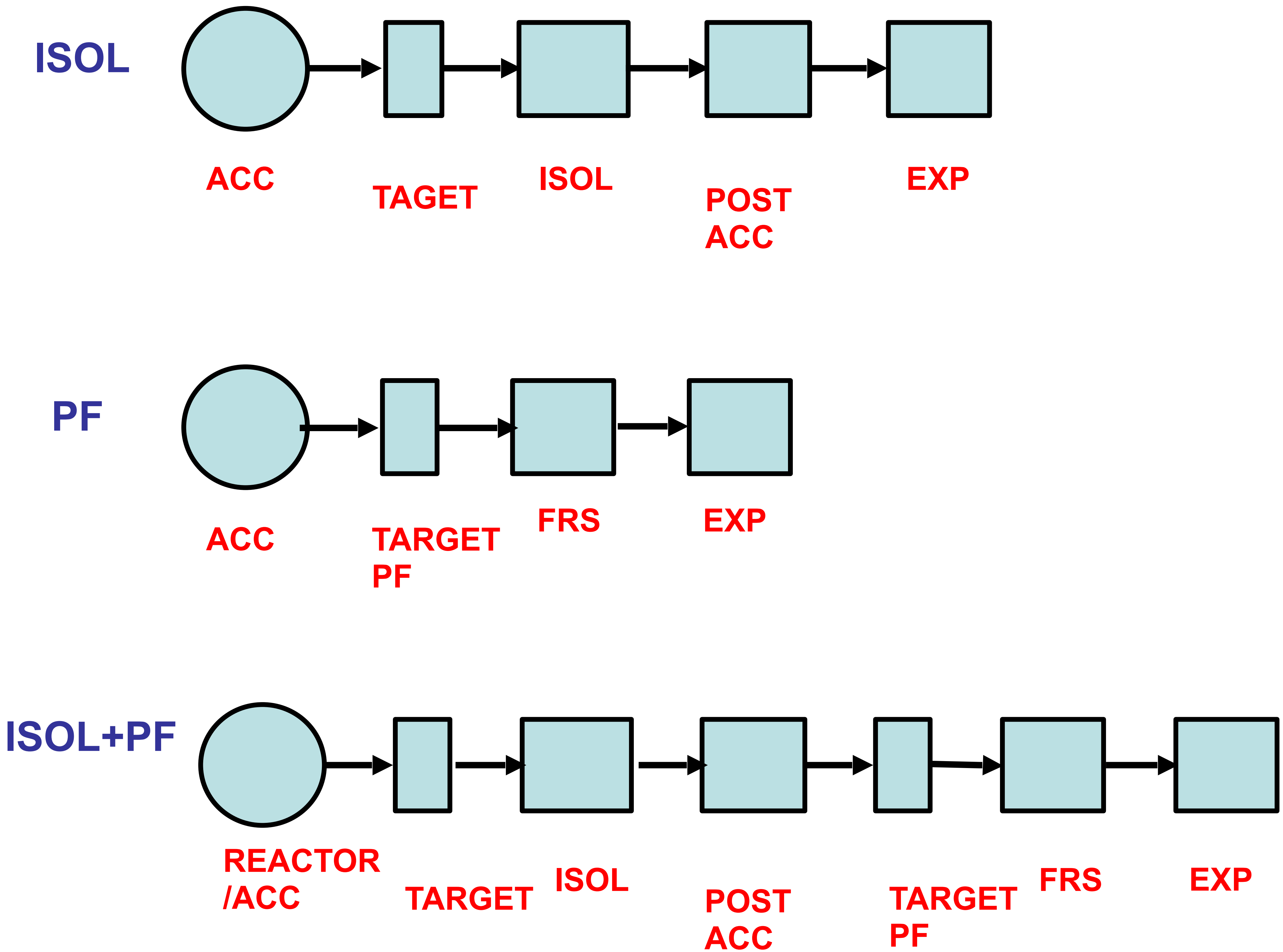
BRIF summary

- Cyclotron: magnet assembling finished
- ISOL: magnets finished, target-source in progress
- SC LINAC: cavity fabrication finished, other in progress
- Civil engineering started in April 2011, and will be finished in 1st quarter of 2012
- BRIF will be commissioned in 2013

CARIF proposal

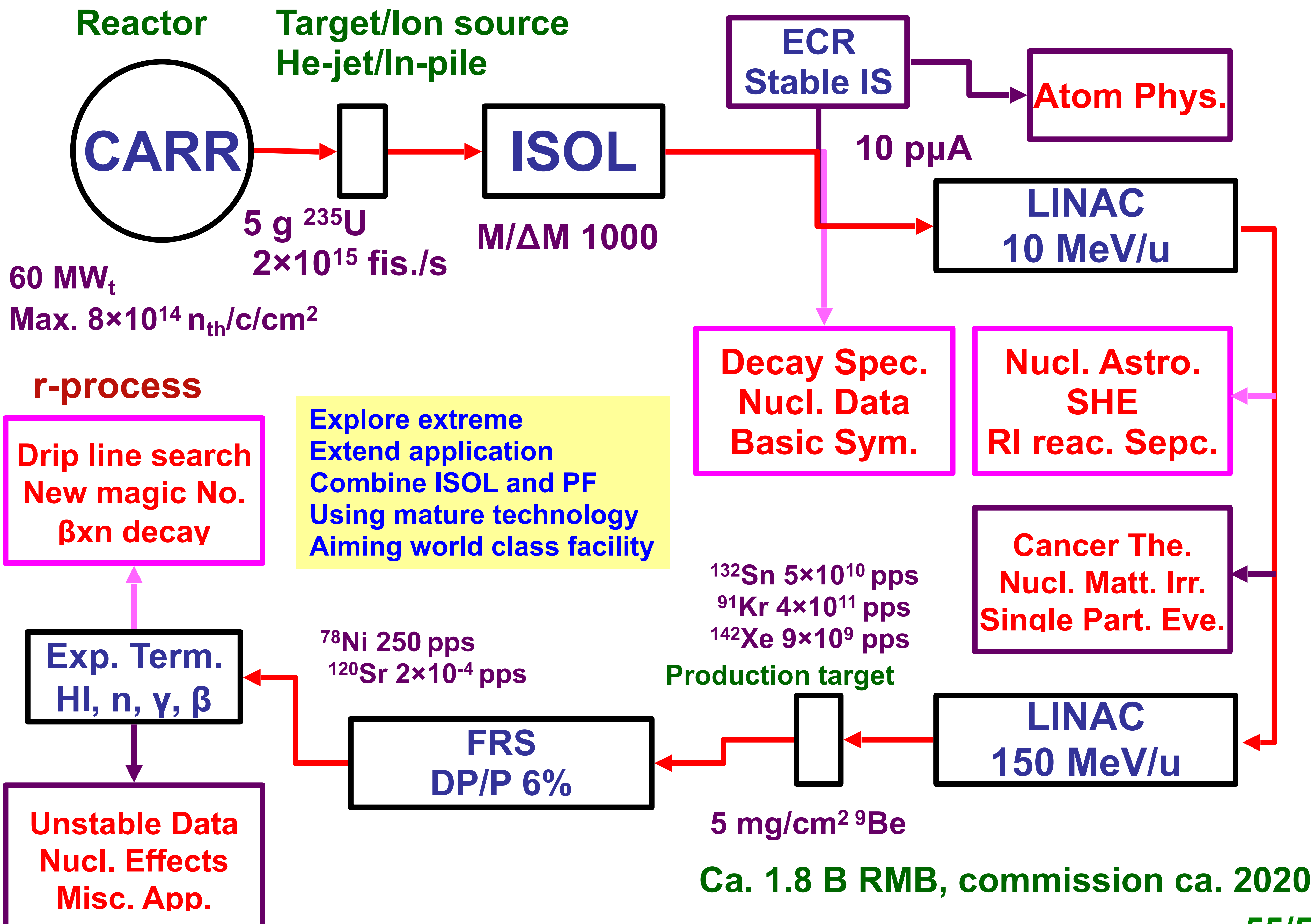
- **China Advanced Rare Ion-beam Facility**
- **Aiming at an leading facility for future (>2020)**

Comparison of production path



I. Tanihata, NIM B266(2008)4067

CARIF (China Advanced Rare Ion-beam Facility)



Combined approach

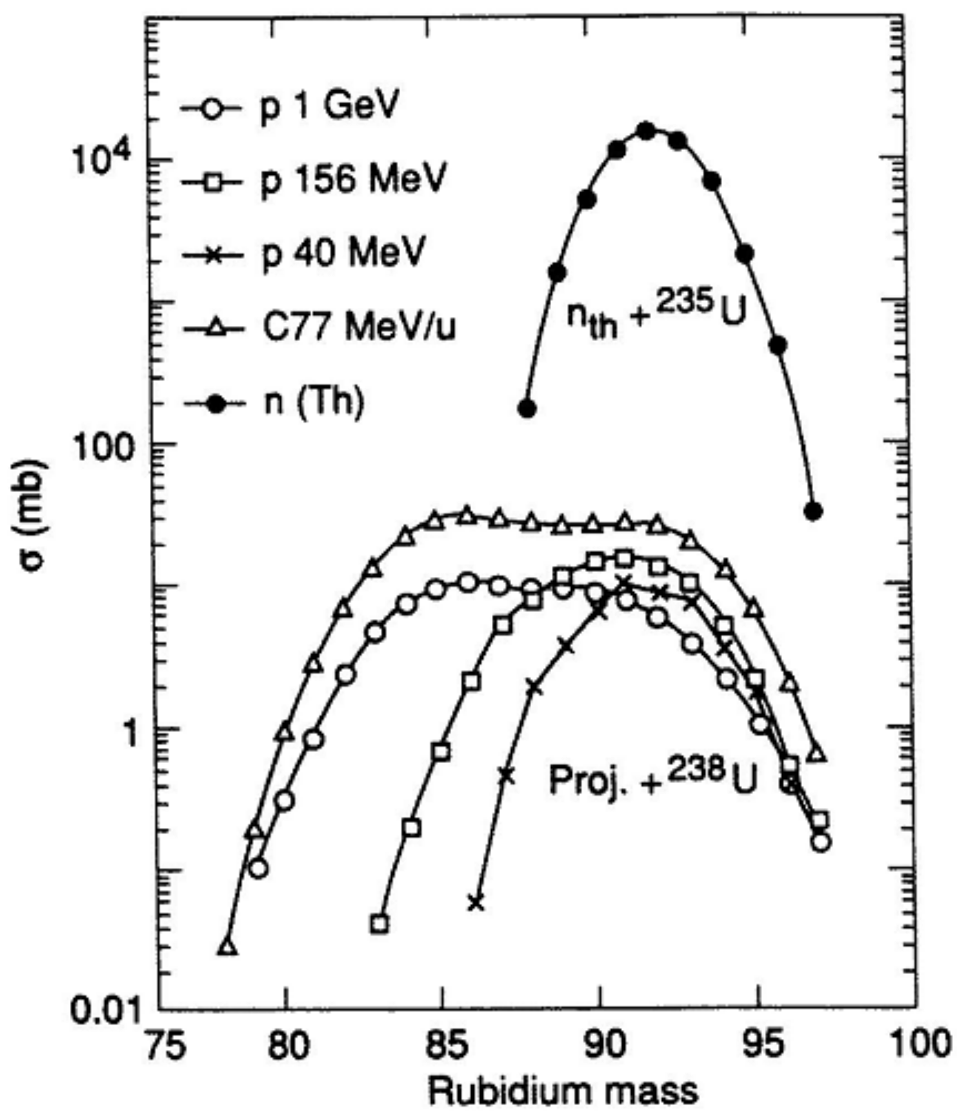
- **ISOL+PF:** neutron beam from reactor or accelerator, with large ^{235}U fission cross section (585 b), easy **ISOL** selection of fission fragments, post acceleration, then fragmentation **PF** again: EURISOL, CARIF
- Pro and con
  - Pro: 5-8 more neutrons than stable beam, with cross section increase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

I. Tanihata, NIM B266(2008)4067

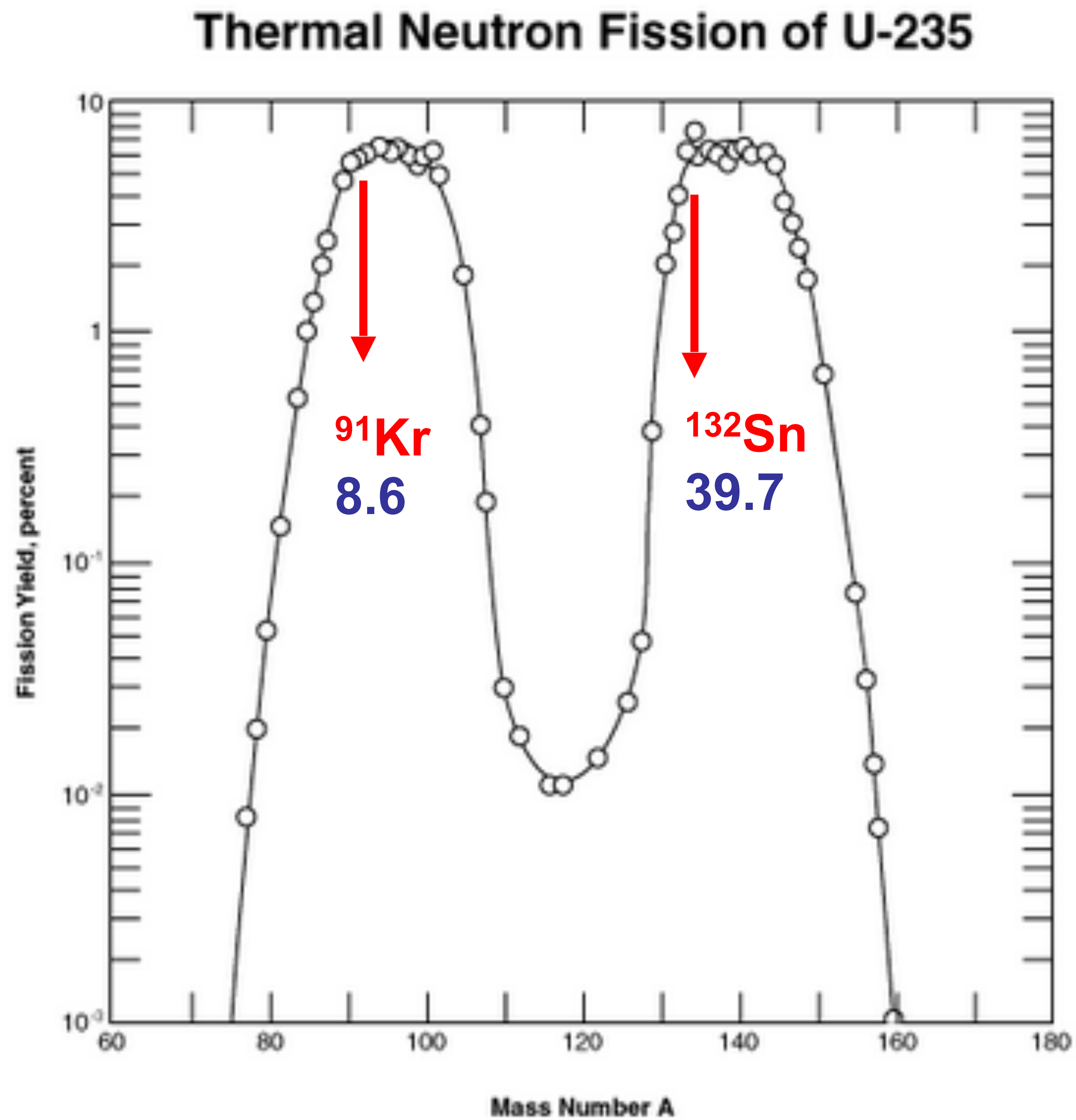
Combined approach merit

- Merit: combination of established technique
  - Good and easy beam: long half life, high yield, normal ISOL
  - Less burden of ISOL: only select long life, high yield fission products
  - 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

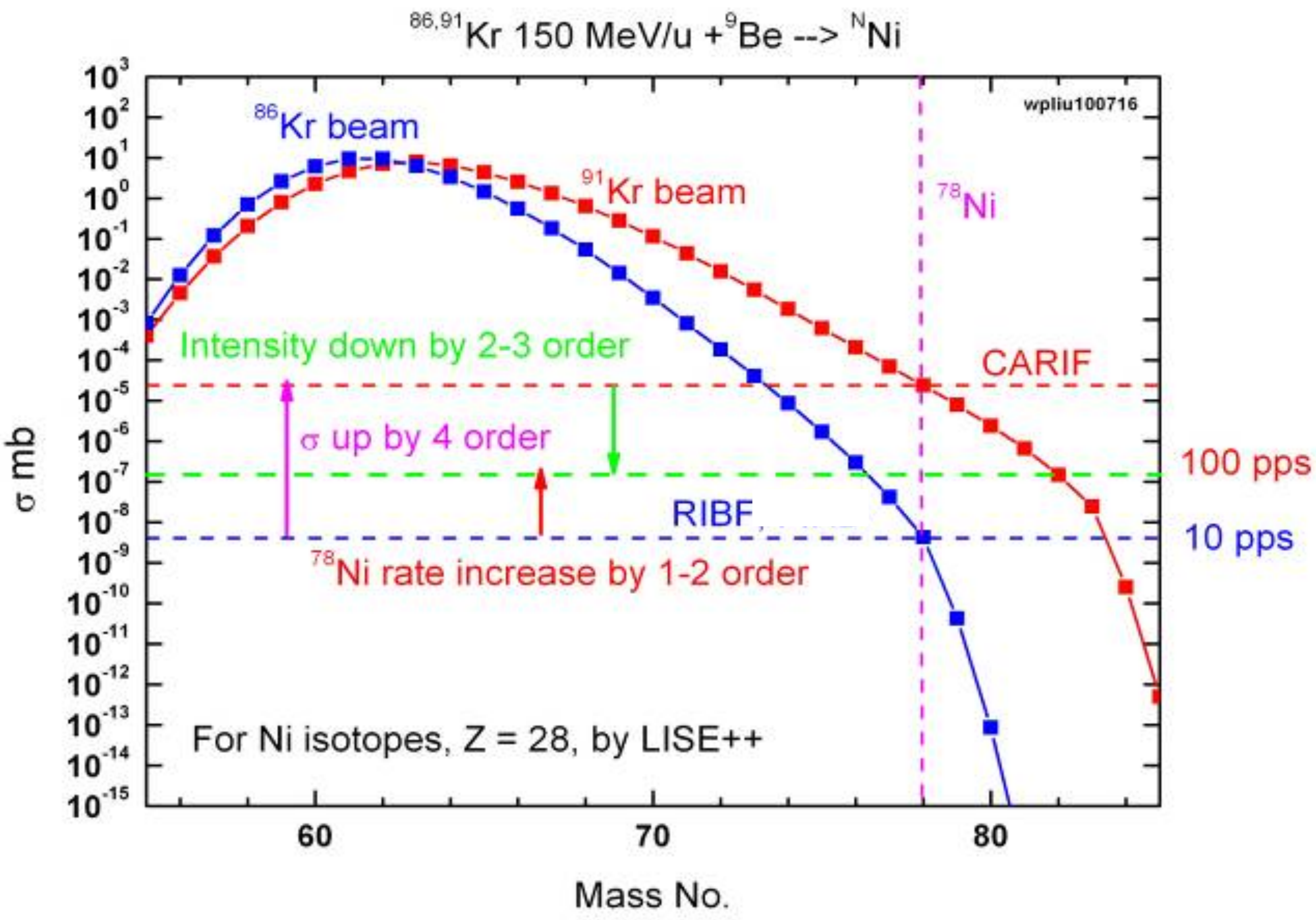
Good and easy beams



Criteria：
Large yield
Long half live
Easy to separate



^{78}Ni production by ^{86}Kr and ^{91}Kr

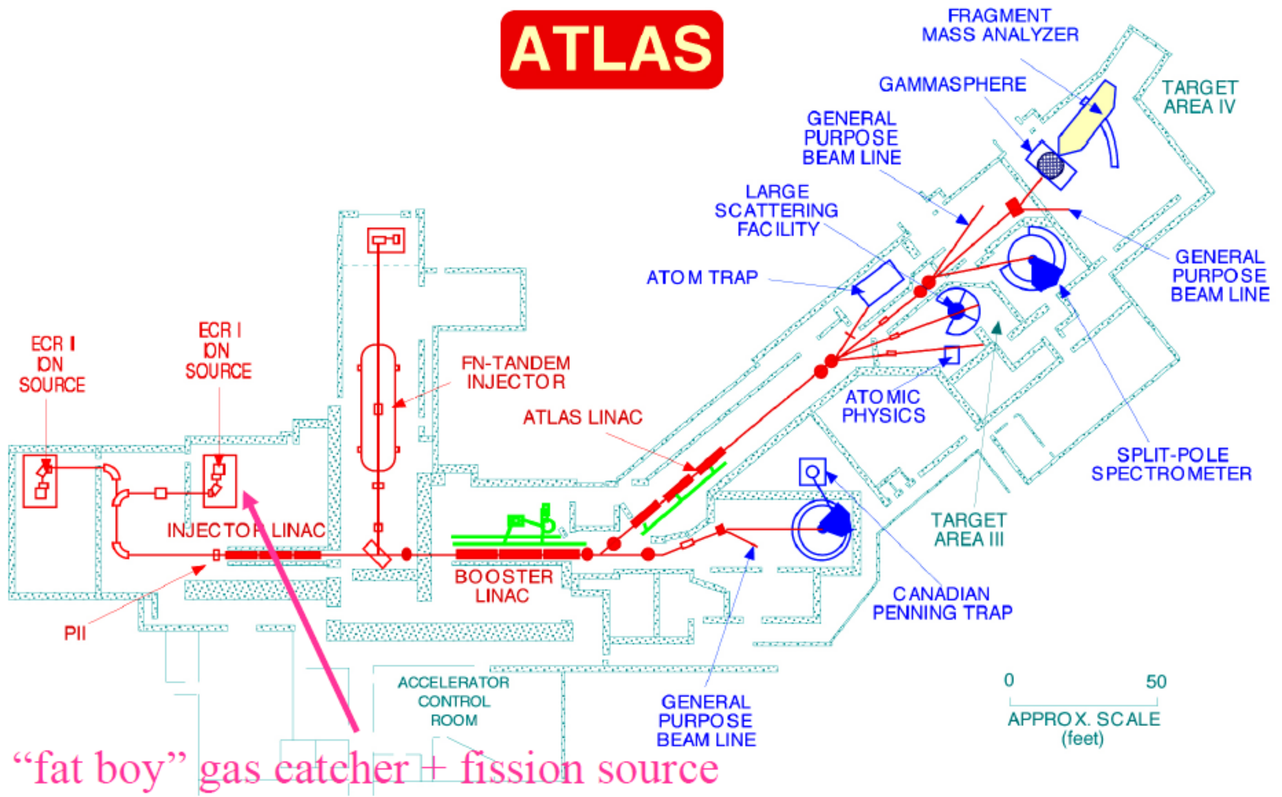


Advantage of using reactor

- High intensity of thermal neutron DC beam: 10^{14} n/s/cm^2
- Large fission cross section: 585 barn
- Simultaneous use of reactor: we only use one horizontal tube, a super spectrometer, other studies can be performed at same time
- Reactor delivers stable n flux once it operated

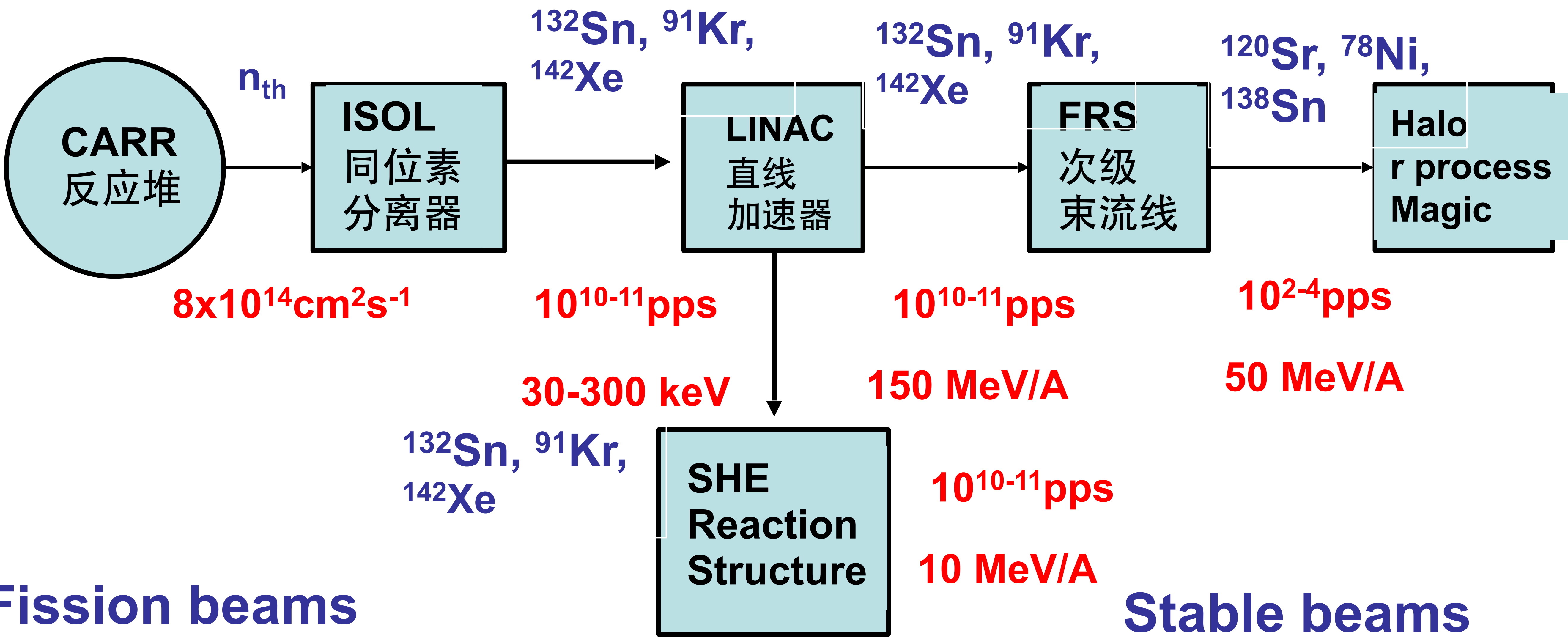
ISOL and fission facilities

- CARIBU in ANL, under construction, ^{252}Cf fission then ISOL, 10^9 f/s, ATLAS acceleration
- ORNL, separation and acceleration of ^{132}Sn to 10^5 pps, now quit user facility
- Studsvik reactor: 1 g ^{235}U and $3X10^{11}$ /cm^2/s neutron
- All showing the feasibility of ISOL post acceleration of fission fragment beams like ^{132}Sn



The CARIF concept

- **China Advanced Rare Ion-beam Facility**



Fission beams
$T_{1/2}$ N/Z
^{132}Sn, 39.7 s, 1.64
^{91}Kr , 8.6 s, 1.53
^{142}Xe,1.22 s, 1.63

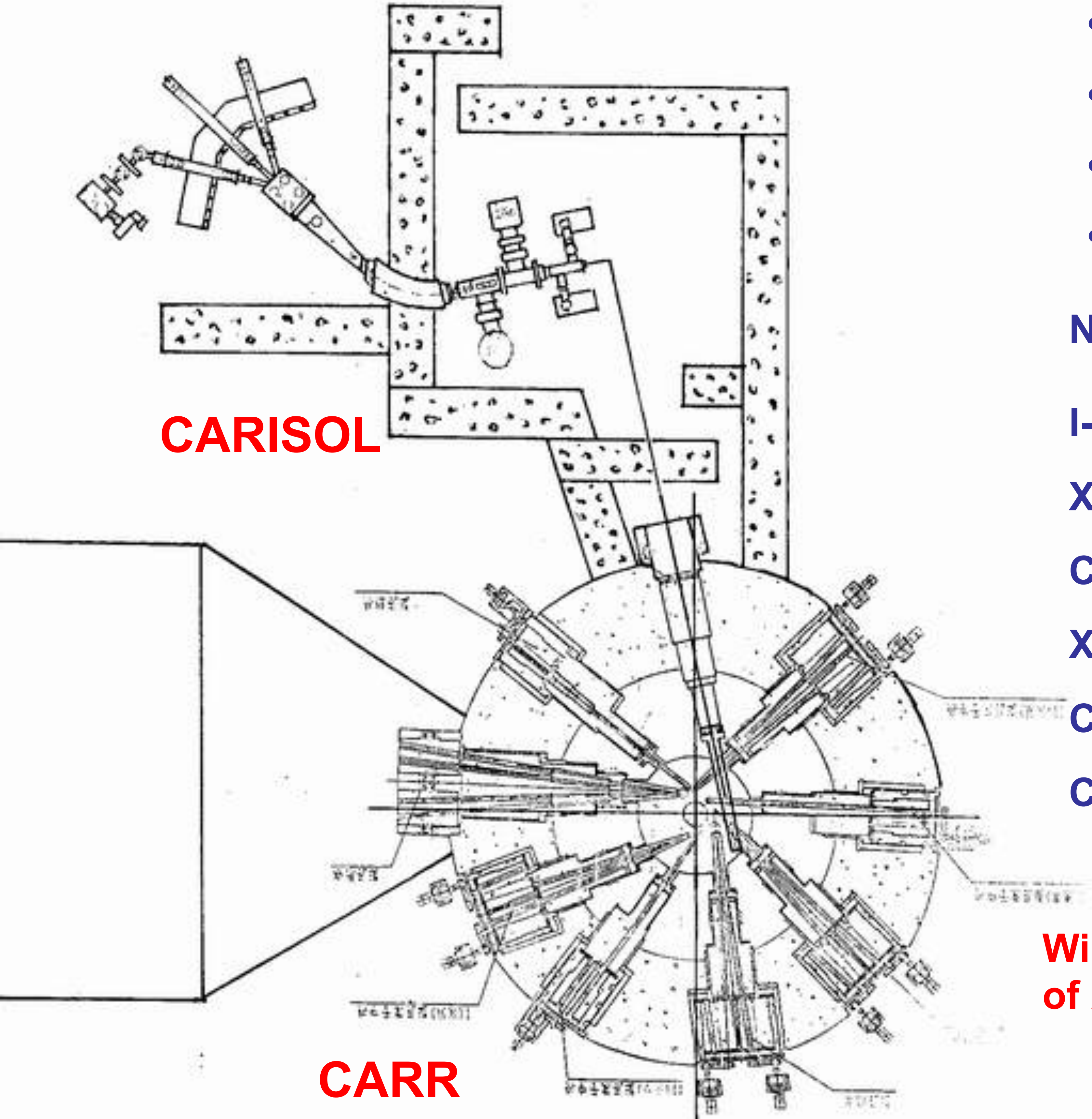
Stable beams
N/Z
^{238}U, 1.57
^{48}Ca , 1.4
^{136}Xe, 1.52

The China Advanced Research Reactor CARR

- Multipurpose, high performance
- Light water cooling, heavy water reflecting
- 60MW, neutron flux to be 8×10^{14} n/cm^2·s, one of the top level in the world
- Engineering started in 2002
- Civil engineering finished in 2005
- Reactor core finished in 2007
- First critical in May 13, 2010
- Now it make power rising and will reach full power by the beginning of 2012

Position of ISOL in CARR

CARISOL: a test bench for CARIF



- Horizontal tube
- 22 mg ^{235}U
- He-jet + ISOL
- Fission rate 7×10^{12}

Nuclide	ISOL (pps) estimation
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}

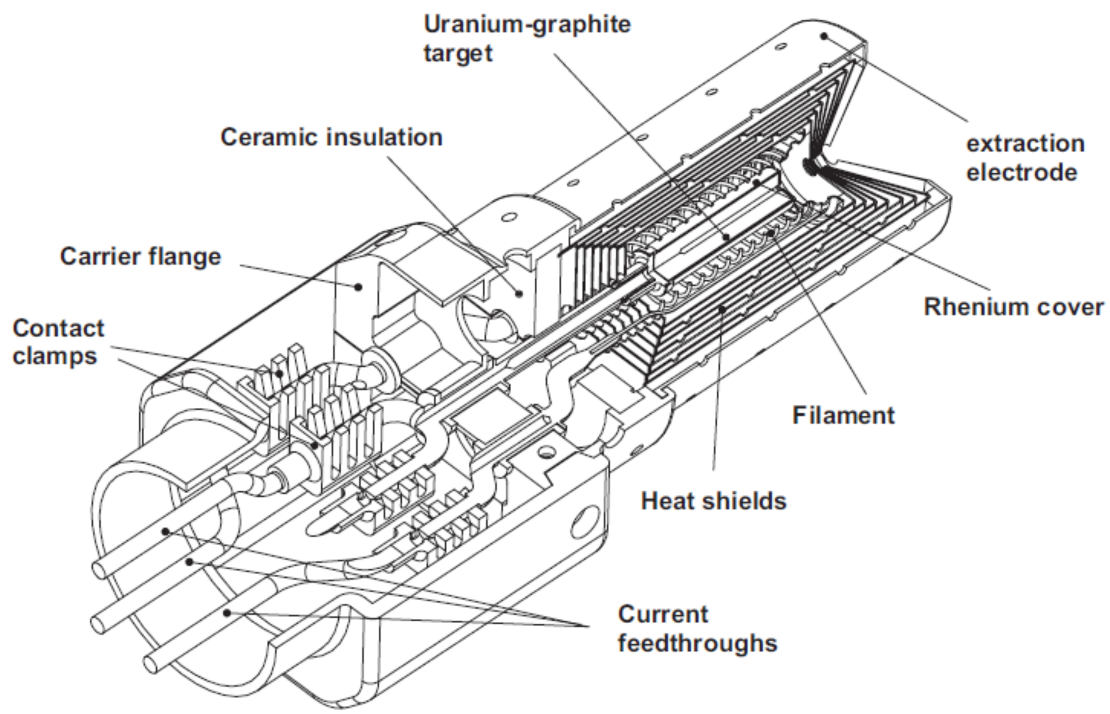
Will deliver beams by the beginning of 2012

CARISOL installed by the CARR

Research reactor in the world

- Neutron flux (horizontal,/s/cm^2)
  - ILL, 1.5X10^{15}
  - FRMII, 6X10^{14}
  - Other, 3X10^{14}
  - CARR 8X10^{14}
- Some similar proposal of RIB by reactors
  - ILL, PIAFE, France
  - FRMII,MAFF, Germany
  - All are one stage without post fragmentation
  - Only in proposal stage

Possible design of gram level ^{235}U target/ ion source



The choice for ion sources are, hot surface ion source (HSIS), resonant laser ion source (RLIS) and forced electron beam induced arc discharge (FEBIAD).

These ion sources have to be robust and reliable since the target/ion source system can only be changed during the reactor maintenance.

It is important to start the development of a target/ion source prototype as soon as possible. It is recommended to take the advantage of previous design efforts in MAFF/FRMII and PIAFFE/ILL.

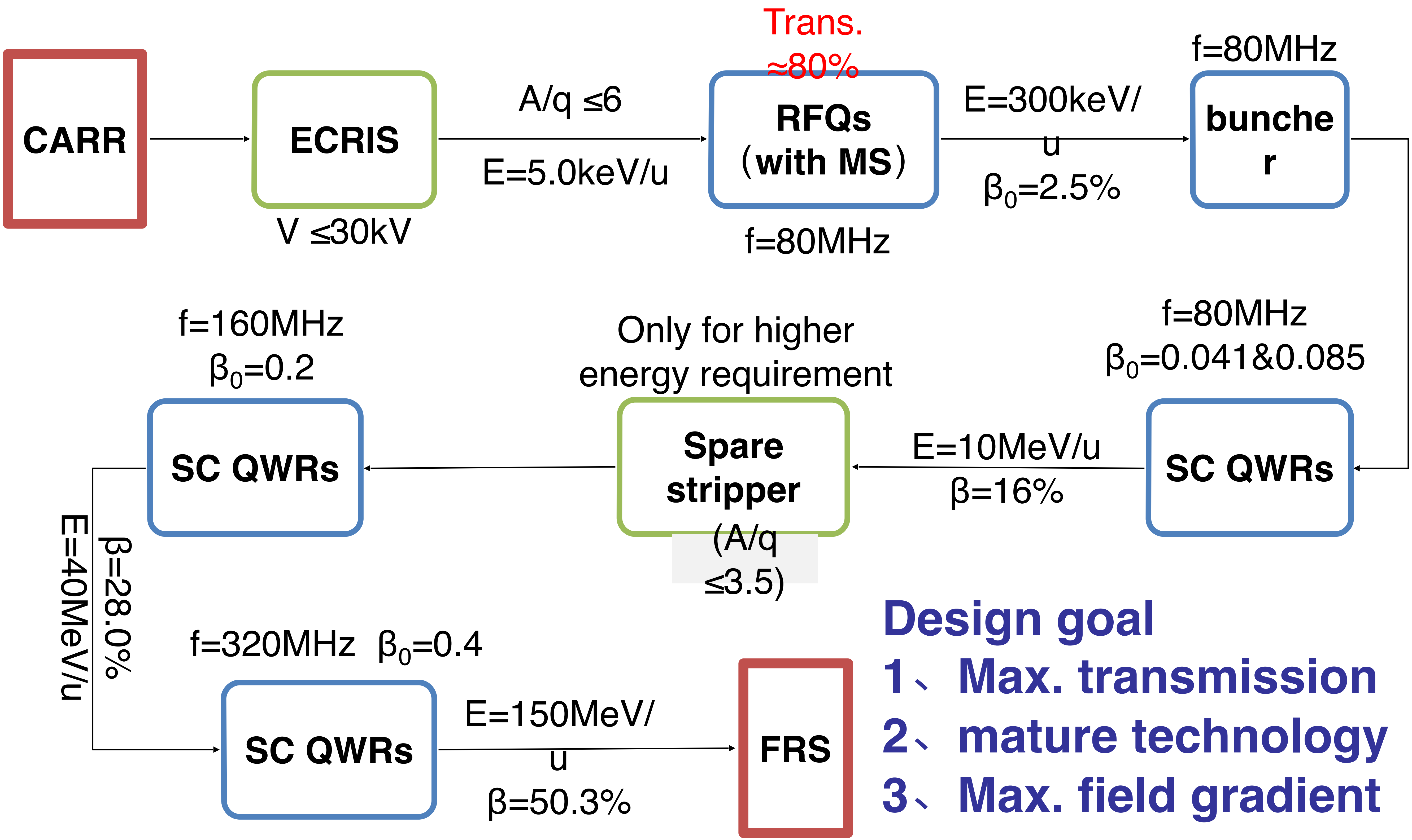
Post accelerating considerations

- It seems reasonable to keep the flexibility and beam quality of an SC linac up to 10 MeV/u in any case if this is a defined experimental energy regime and so the alternate designs could start at this energy
- Possible staging options should be discussed. The linac option gives the best alternative for flexible staging due to its modular design

Frontier of nuclear physics and RIB facility

- **Nuclear Physics: Exploring the area of extreme isospin**
  - Drip line
  - Z=30 for p-rich side
  - Z=10 for n-rich side,
  - Z>10: known isotope far from the region of shell evolution and astrophysical r-process
- **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, nuclear structure study
  - More intense, more precise
- **Current limits of RIB**
  - Low isospin of stable beams
  - Space charge limitation for intense beams

Linac design



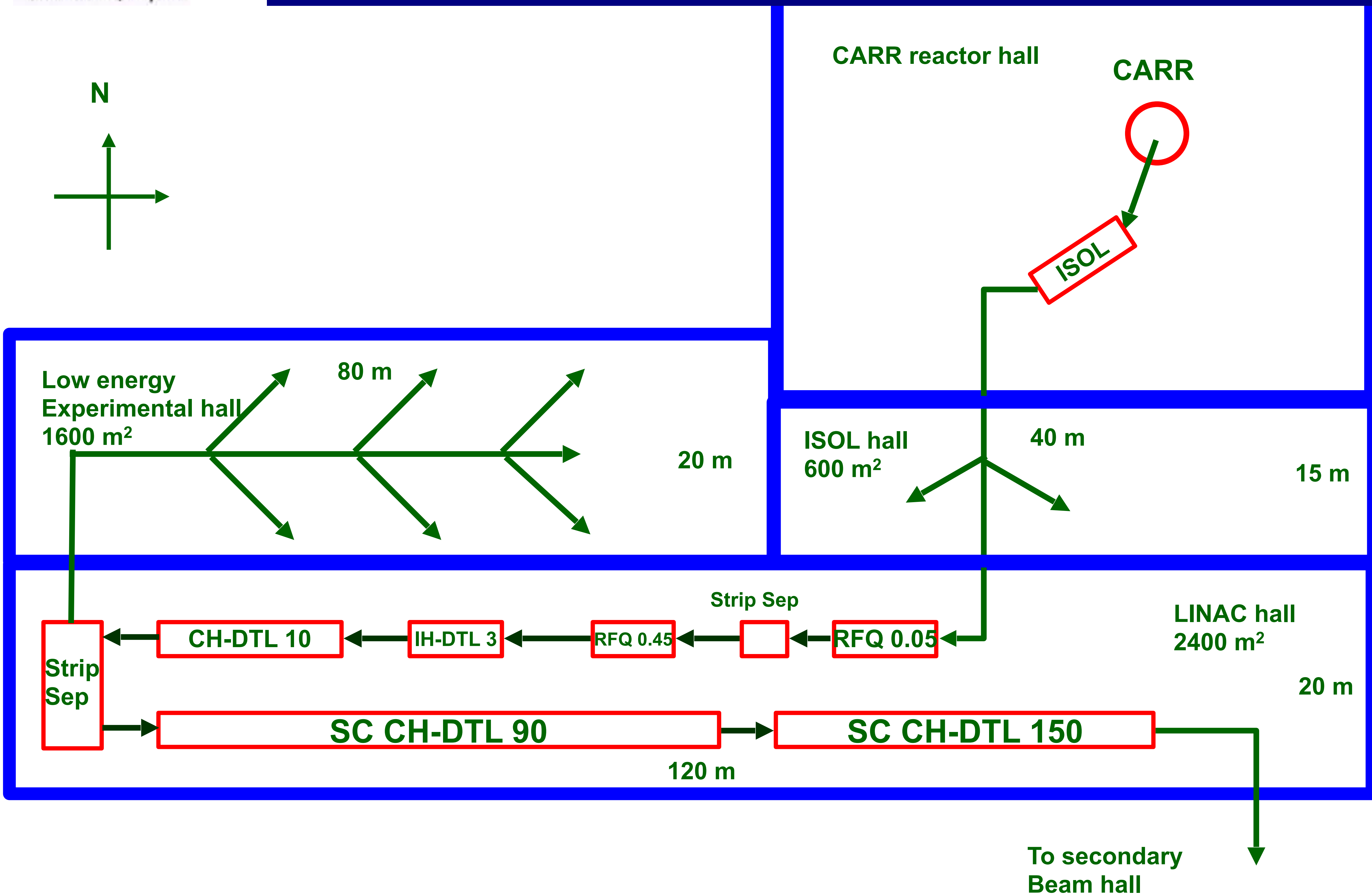
Design goal

1、 Max. transmission

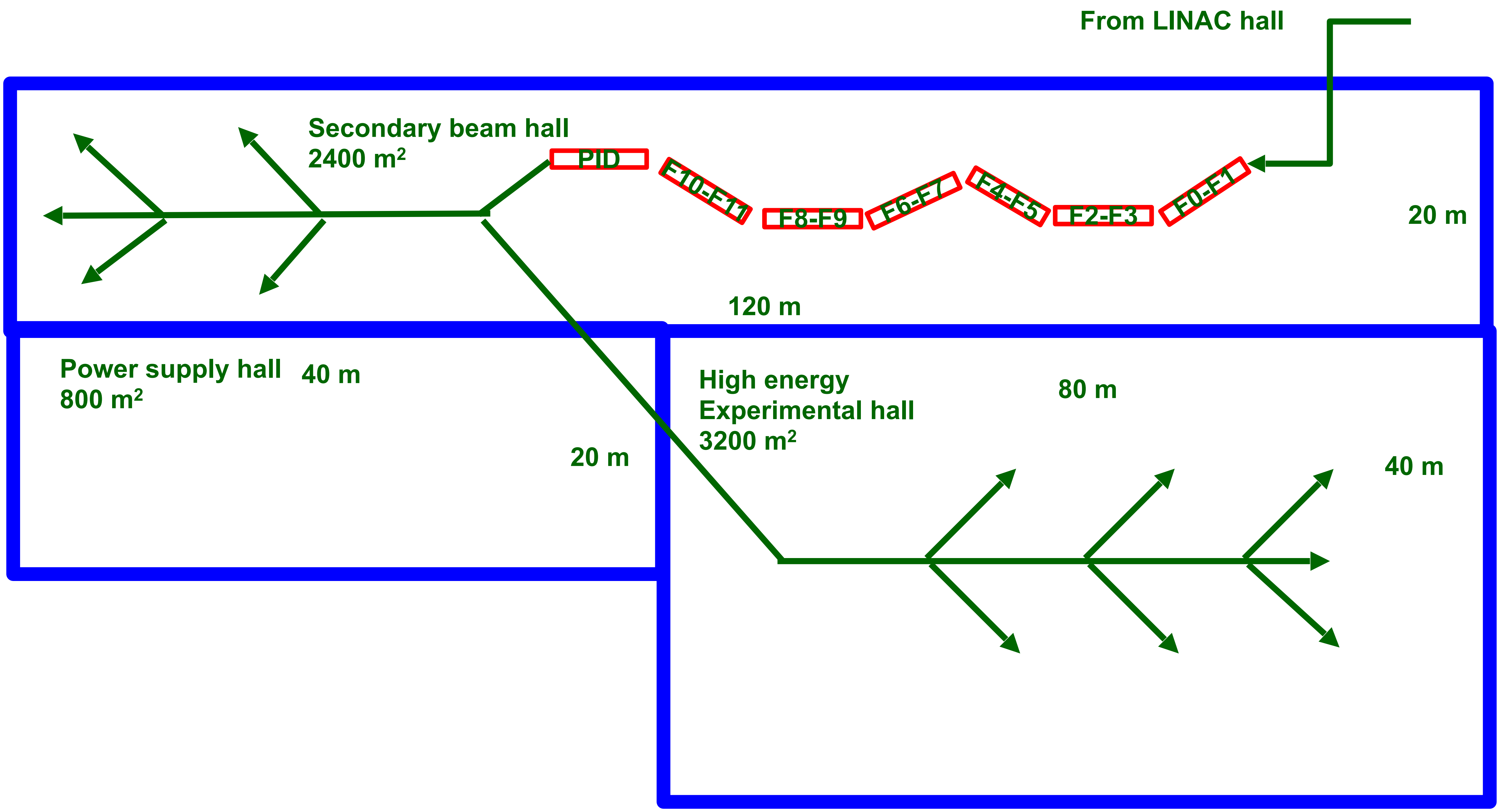
2、 mature technology

3、 Max. field gradient

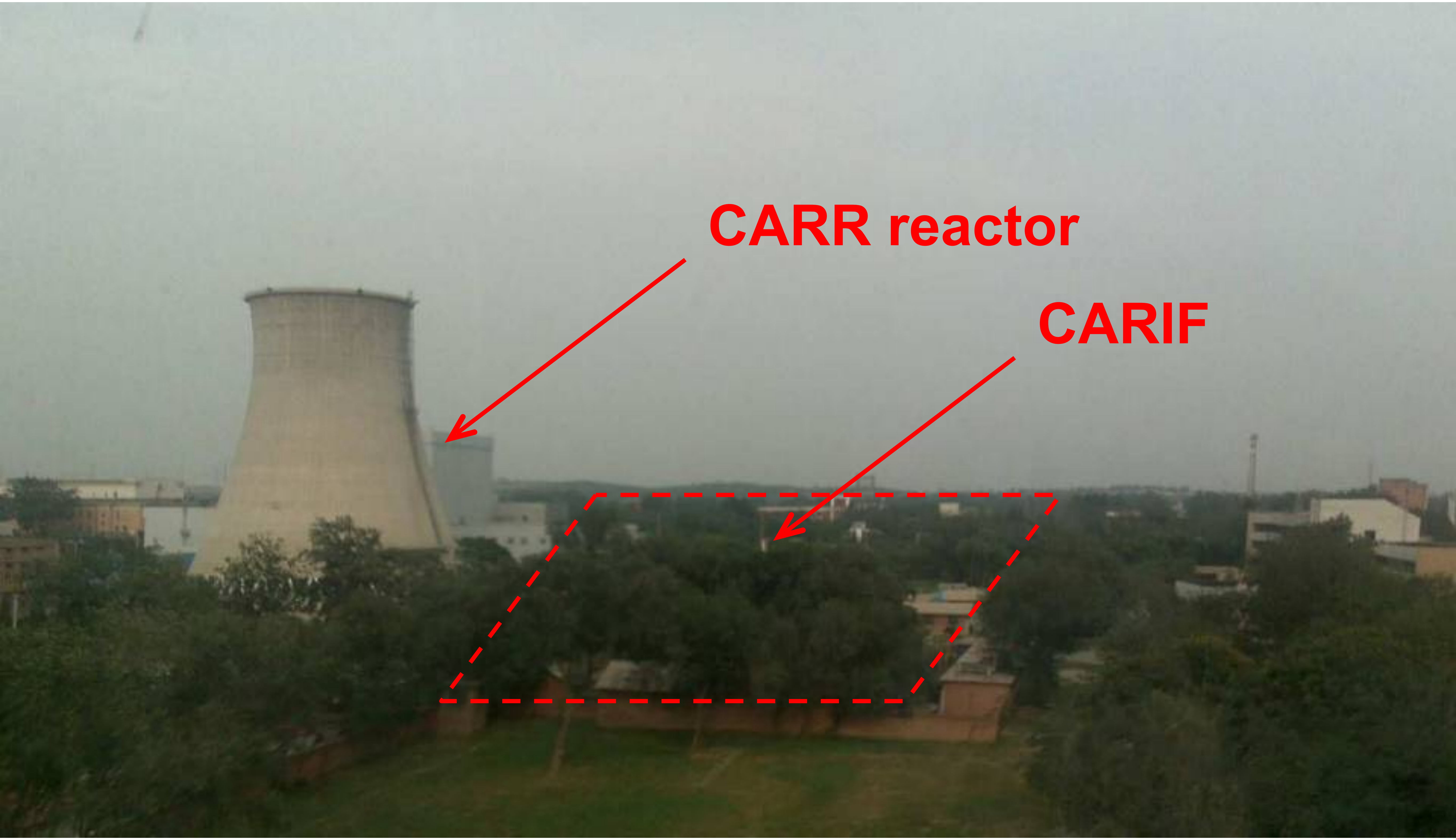
Target/ion and LINAC layout



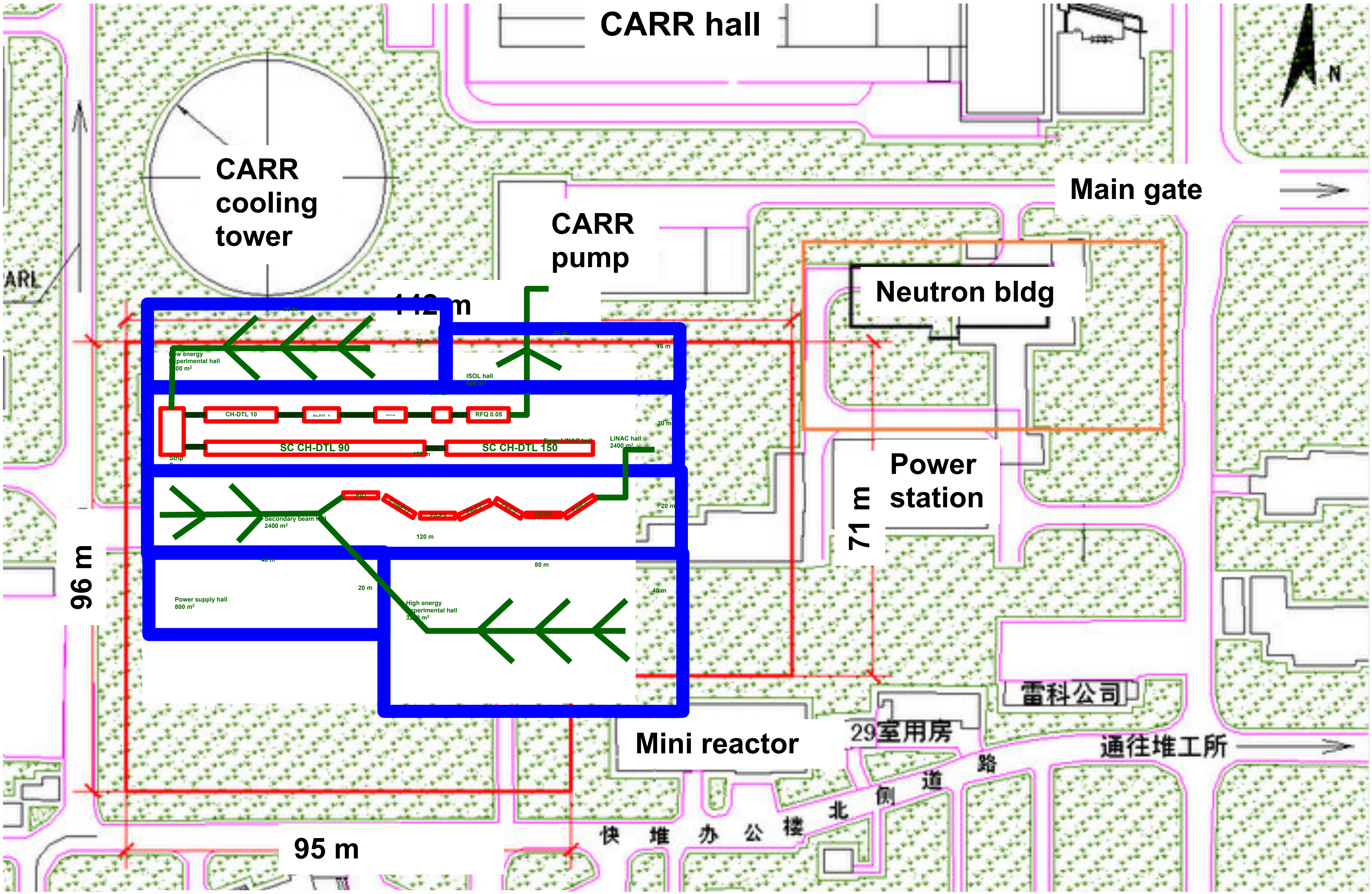
High energy experiment halls



The location of CARIF



The space allowed for CARIF



Total space: 12455 m²

CARIF RIB intensity estimates

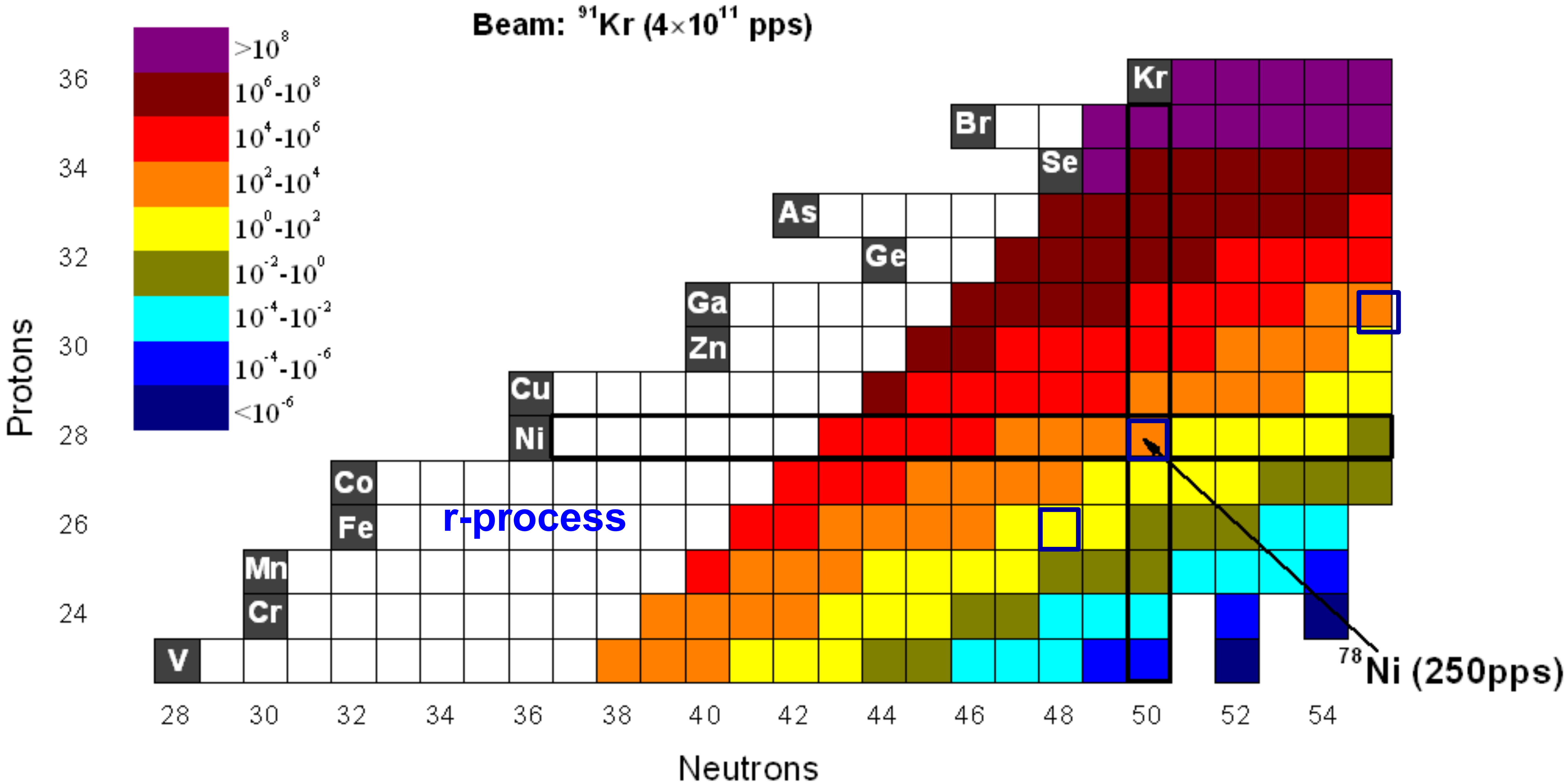
^{235}U, g	Xsec, b	N flux, $/cm^2/s$	Fis. rate, /s
5	585	3×10^{14}	2×10^{15}

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	5.9×10^{-3}	1.2×10^{13}	9.0%	10%	50%	5×10^{10}

CARIF fission rates

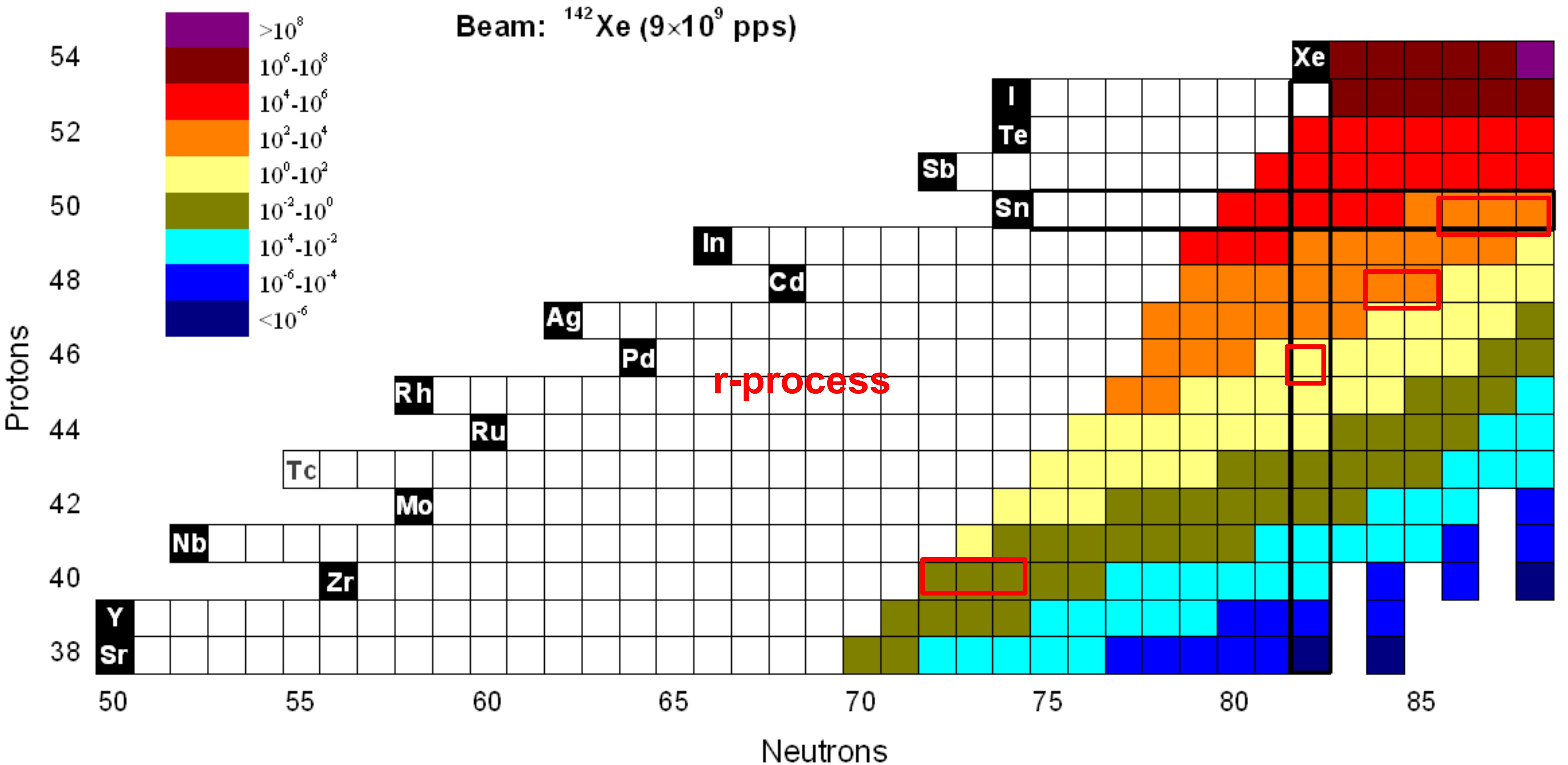
	CARIF	CARIBU	SPIRAL2	ARIEL	SCRIT
Fission rates	$2X10^{15}$	10^{9}	10^{14}	$5X10^{13}$	10^{11}
Remarks	Reactor neutron, ^{235}U of 5g	^{252}Cf spon. fission	Accelerator neutron, ^{238}U of 280g	Photo fission of ^{238}U	Photo fission of ^{238}U

RI with ^{91}Kr beams



^{78}Ni 250 pps, the possibility to make transfer reactions for r-process

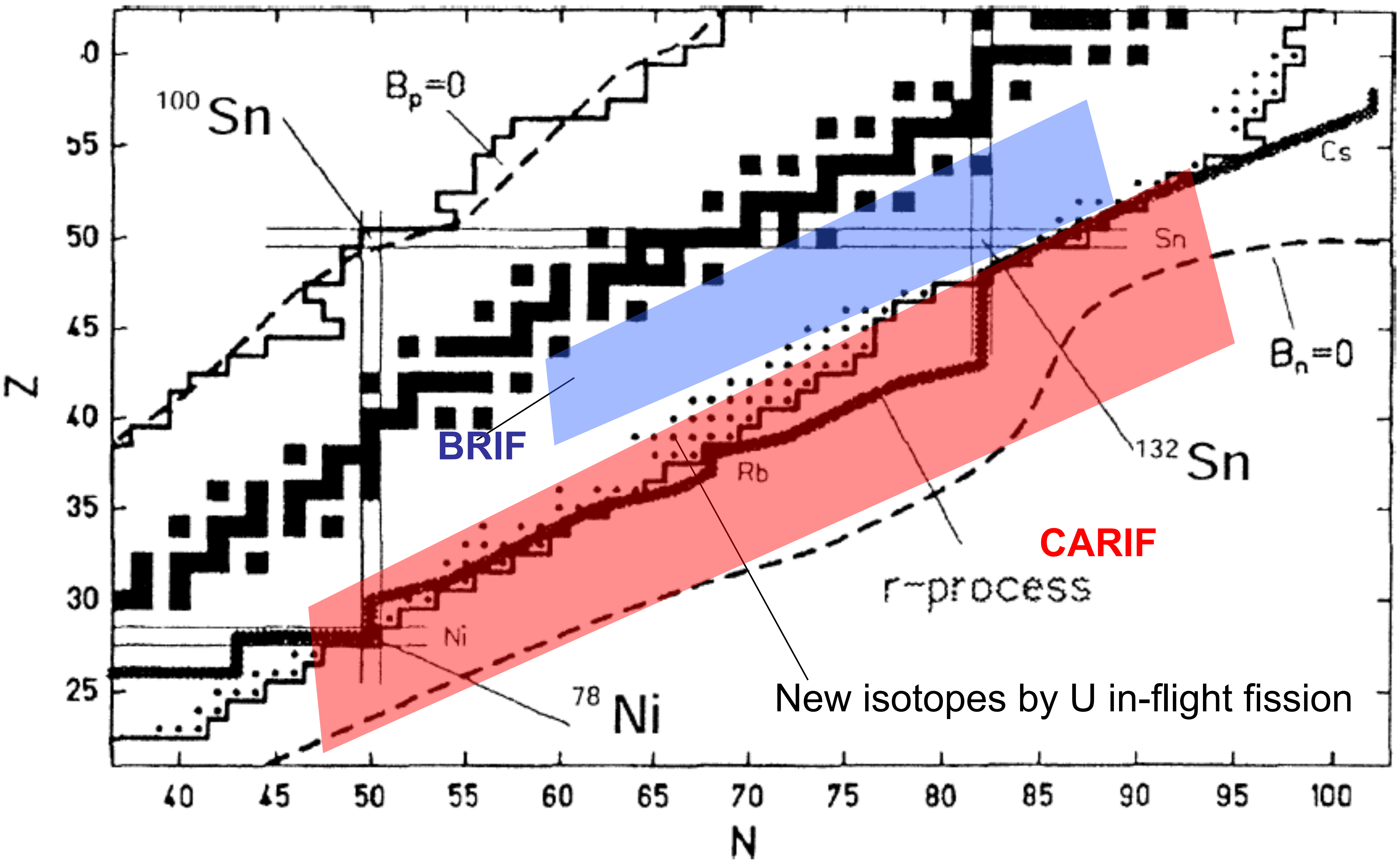
RI with ^{142}Xe beams



r-process nuclei to 10^2 pps, can make in-direct (n,g) and decay

Drip line nuclei ^{120}Sr to 10^{-4} pps, the possibility to explore neutron drip line

Physics potential



S. Kubono / Nuclear Physics A 693 (2001) 221–248

Remarks from RIF11-2 for CARIF

- "CARR Reactor in CIAE offers the opportunity for a unique world leading rare ion beam facility (CARIF). CARIF would provide the highest fission fragment intensity ever achieved. The use of high energy post accelerator via secondary fragmentation will make neutron-rich ion beams not available elsewhere.
- This will be ideal facility for studying the astrophysical r-process nuclei nowhere else available for understanding of origin of elements. In addition, it will enable unprecedented opportunity to explore the structure and dynamics of nuclei at limit of existence of nuclei. It will be the most cost effective approach taking the advantage of existing research reactor.
- Timely approval of CARIF will ensure a competitive proposal relative to the other existing and planned facilities in world including EURISOL.
- This facility would provide Chinese research community a world-leading platform at home for nuclear physics research and applications, and would attract a large international user community. "

Summary

- BRIF will be a unique ISOL facility and will be commissioned in 2013
- CARIF will be a very cost effective facility, based on the commissioning CARR research reactor
- The combination of advanced idea and feasible technique in CARIF will result the extremely intense neutron-rich beam, possibly 1 order higher than current facilities, by the year of 2020
- We will further optimize the design our CARIF proposal with the ImPUF proposal in PKU, in order to build up an leading and flexible ISOL based nuclear physics facility in Beijing (CIAE-PKU MOU Oct. 31, 2011) , collaboration with RCNST and other labs will be welcome!

CARIF progress: domestic

- 2010
  - January, first internal discussion
  - June, plan submitted to CAEA and then to NDRC
  - July and after, plan presented in community
  - November, NDRC evaluation
- 2011
  - June, NDRC rank 18th, not in 1st stage plan, but allowed to be resubmitted in 2012

CARIF progress: international

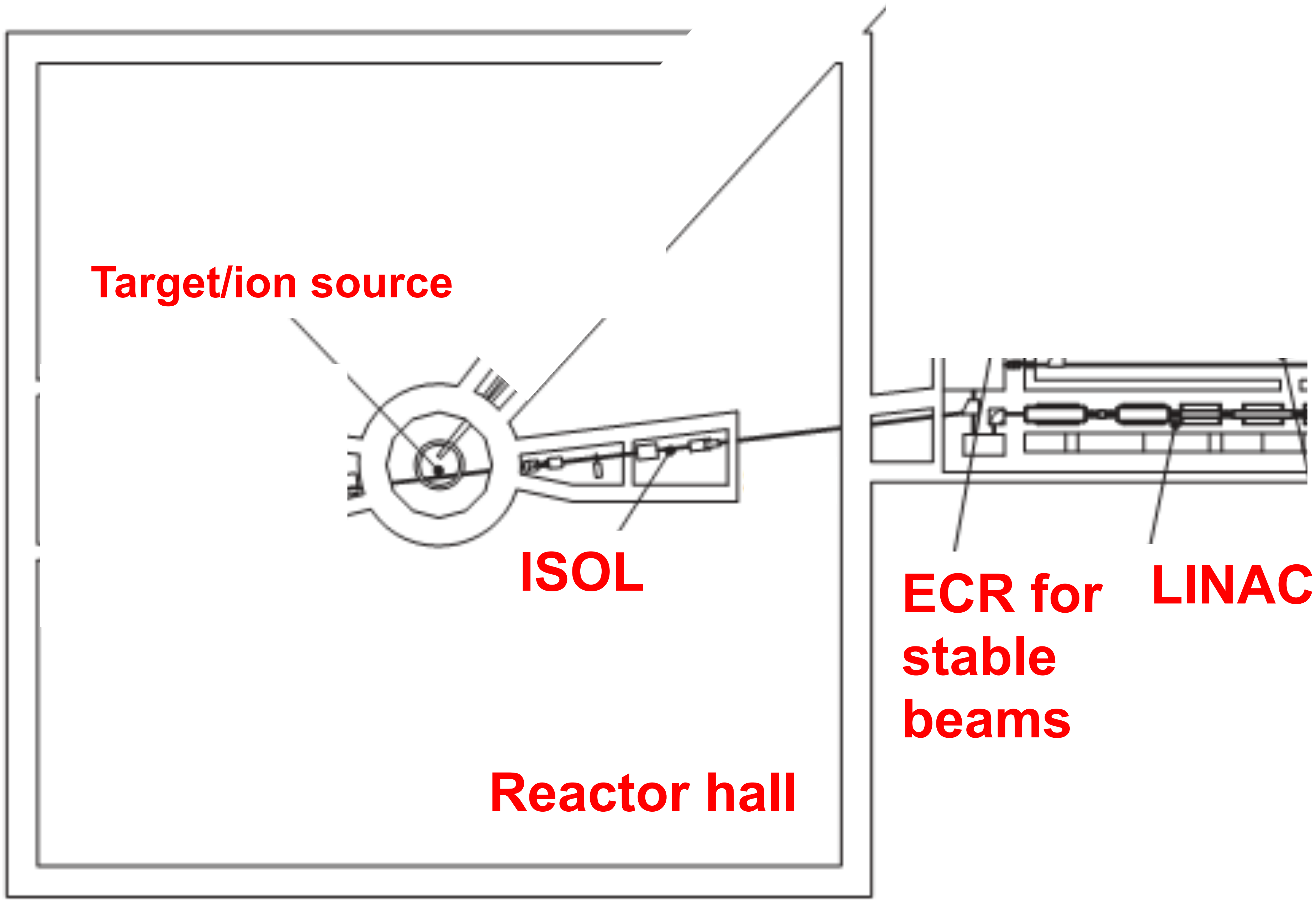
- 2010
- Jan., idea discussed in RCNP
- July, report in WG9/IUPAP, Vancouver, cited by B. Fulton in INPC2010 invited talk
- Oct., presented in ANPhA meeting Seoul
- 2011
- Mar., RIF11-1 workshop
- Visit of CARIBU and FRIB in July. 27-28
- RIF11-2 in Oct, 20-21

Wednesday July 7 2010

Session 5: New Facilities and Instrumentation
Chairs: M. Borge (Spain)
R. Tribble (USA)

08:00-08:30	S. Nagamiya (J-PARC) *Overview Hadron Facilities*
08:30-09:00	B. Fulton (University of York) *Present and Future RIB Facilities*
09:00-9:30	J. Jowett (CERN) *Facilities for the Energy Frontier of Nuclear Physics*
9:30-10:00	N. Smith (SNOLAB) *Developments in Underground Facilities*

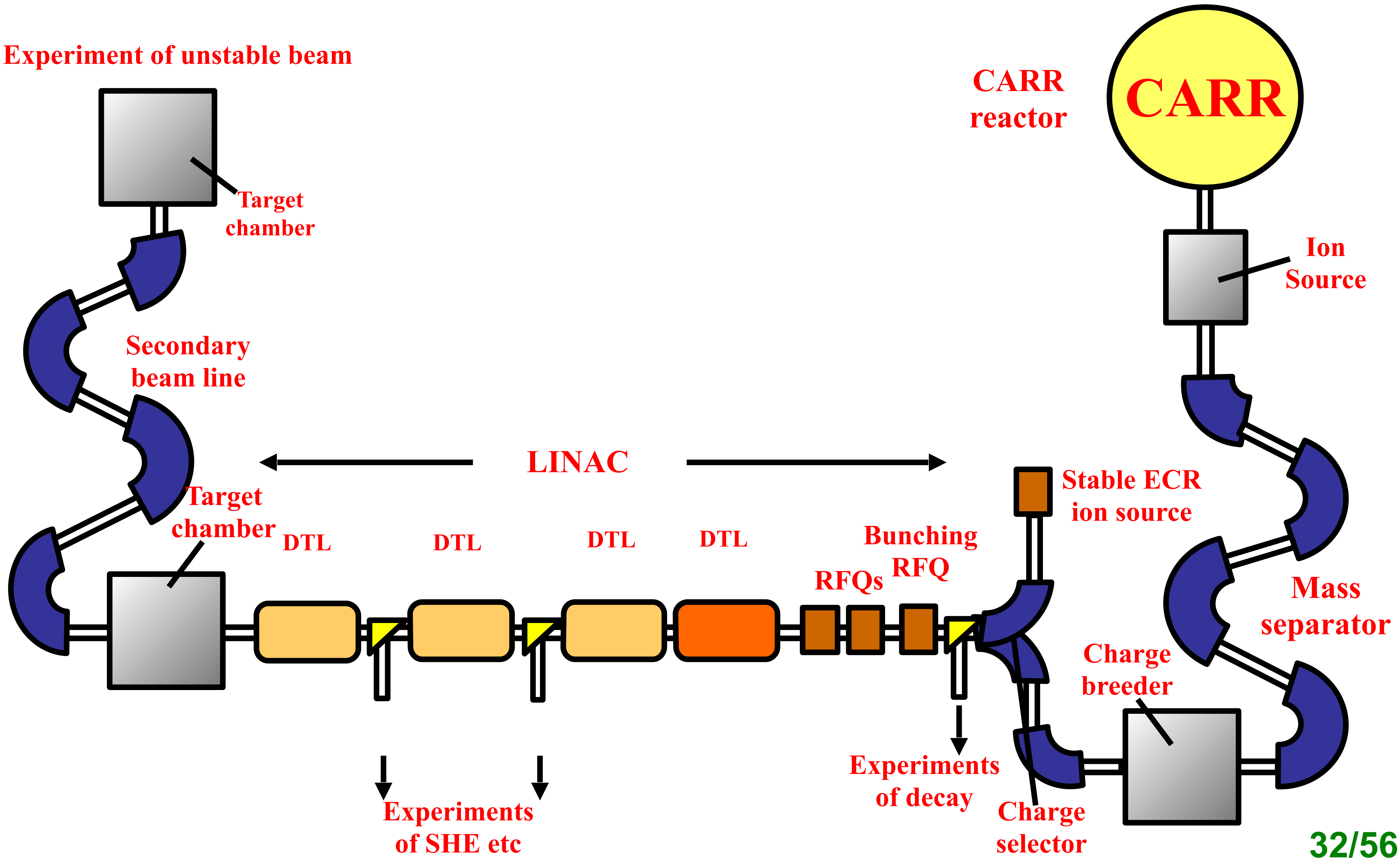
CARR-ISOL coupling



CARIF schedule

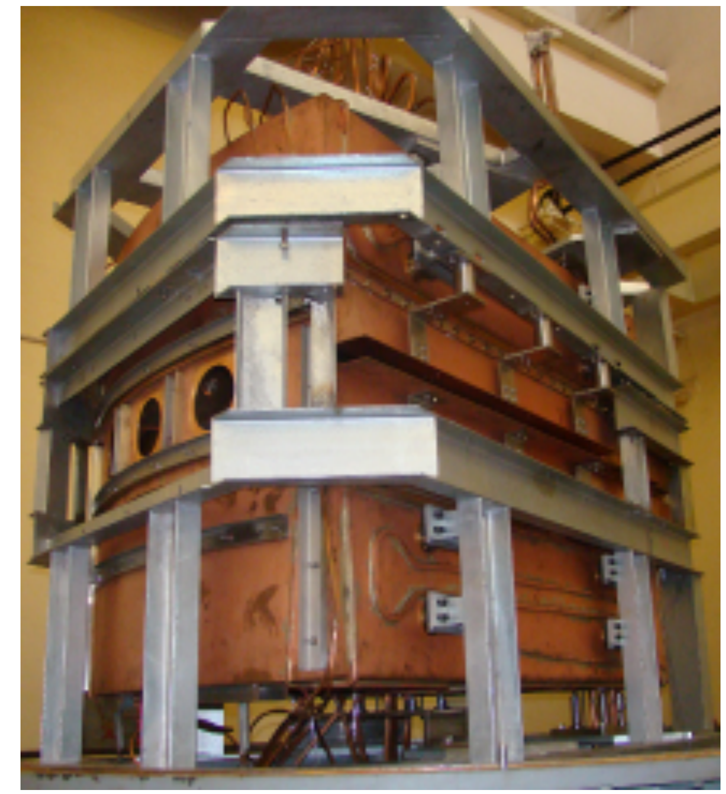
	T0	+1	+2	+3	+4	+5	+6	+7	+8
R&D	—	—	—						
Plan		—	—						
Phys. Design			—	—	—				
Eng. Design				—	—	—			
Civil					—	—	—		
Fabrication					—	—	—	—	
Tuning						—	—	—	
Commission									—

CARIF design



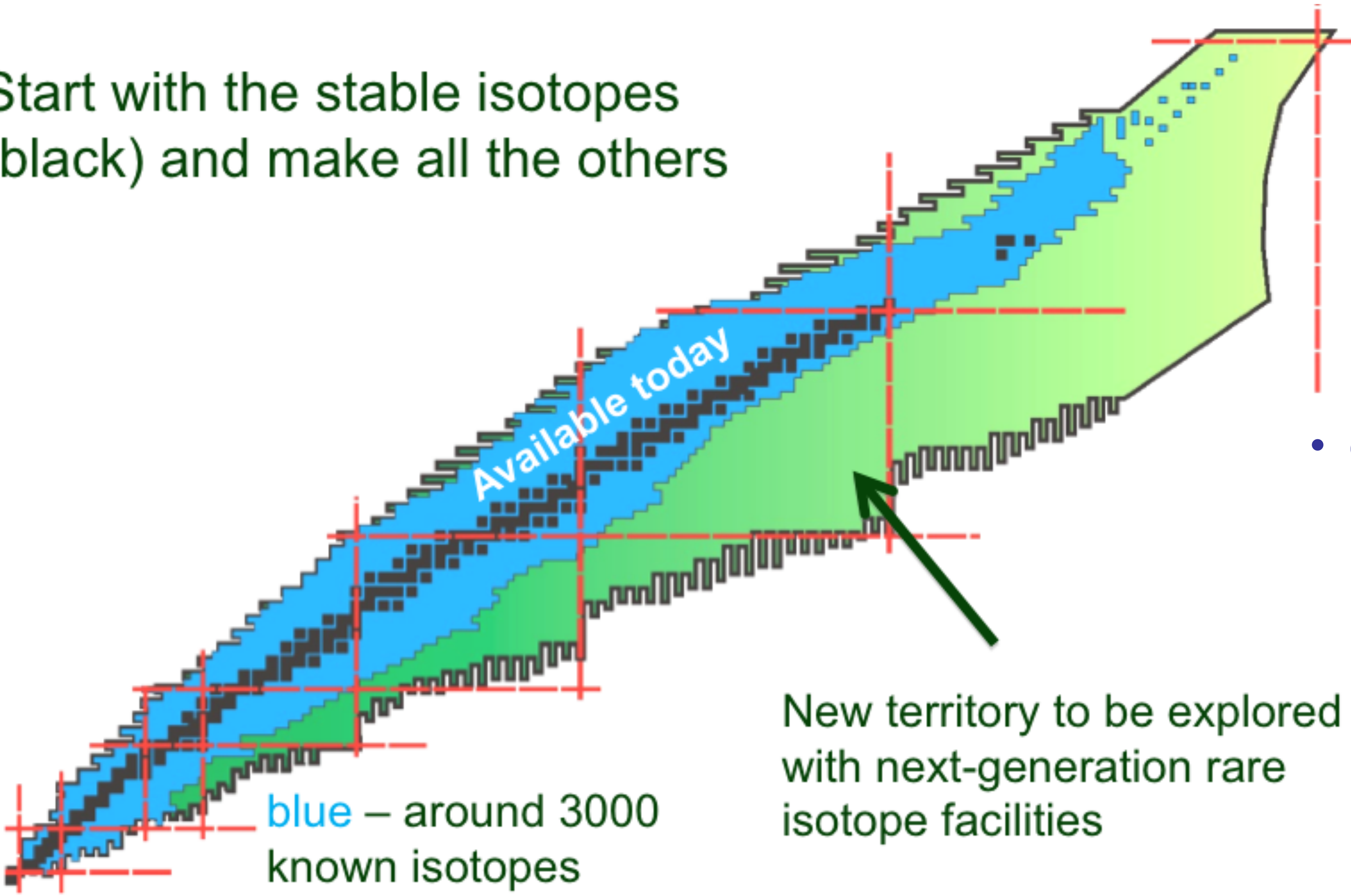
Cyclotron intermediate progress

- The main magnet in assembly stage
- Two main magnet coils
- Two 100kW RF power supplies tested
- The vacuum chamber and elevating system tested

Physics frontier: neutron rich side

Start with the stable isotopes (black) and make all the others



blue – around 3000 known isotopes

New territory to be explored with next-generation rare isotope facilities

- drip line nuclear physics
  - New magic number
  - Super heavy elements
  - Giant halo structure
  - 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

Brad Sherrill ISSSP August 2011,

ISOL and PF

- ISOL
- For precise physics with high quality beams
- Advanced target and ion source technology needed
- ISAC, REX-ISOLDE, HRIBF, SPIRAL2 etc
- BRIF

- PF
- For physics of extreme iso-spin
- Using in-flight separation method
- MSU, GANIL, CSR, RIBF, FRIB, and FAIR

- ISOL+PF
- Considered in SPIRAL2, KoRIA and EURISOL
- Proposed in CARIF

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Construction site in October, 2011