Radioactive Ion Beam Projects in Europe

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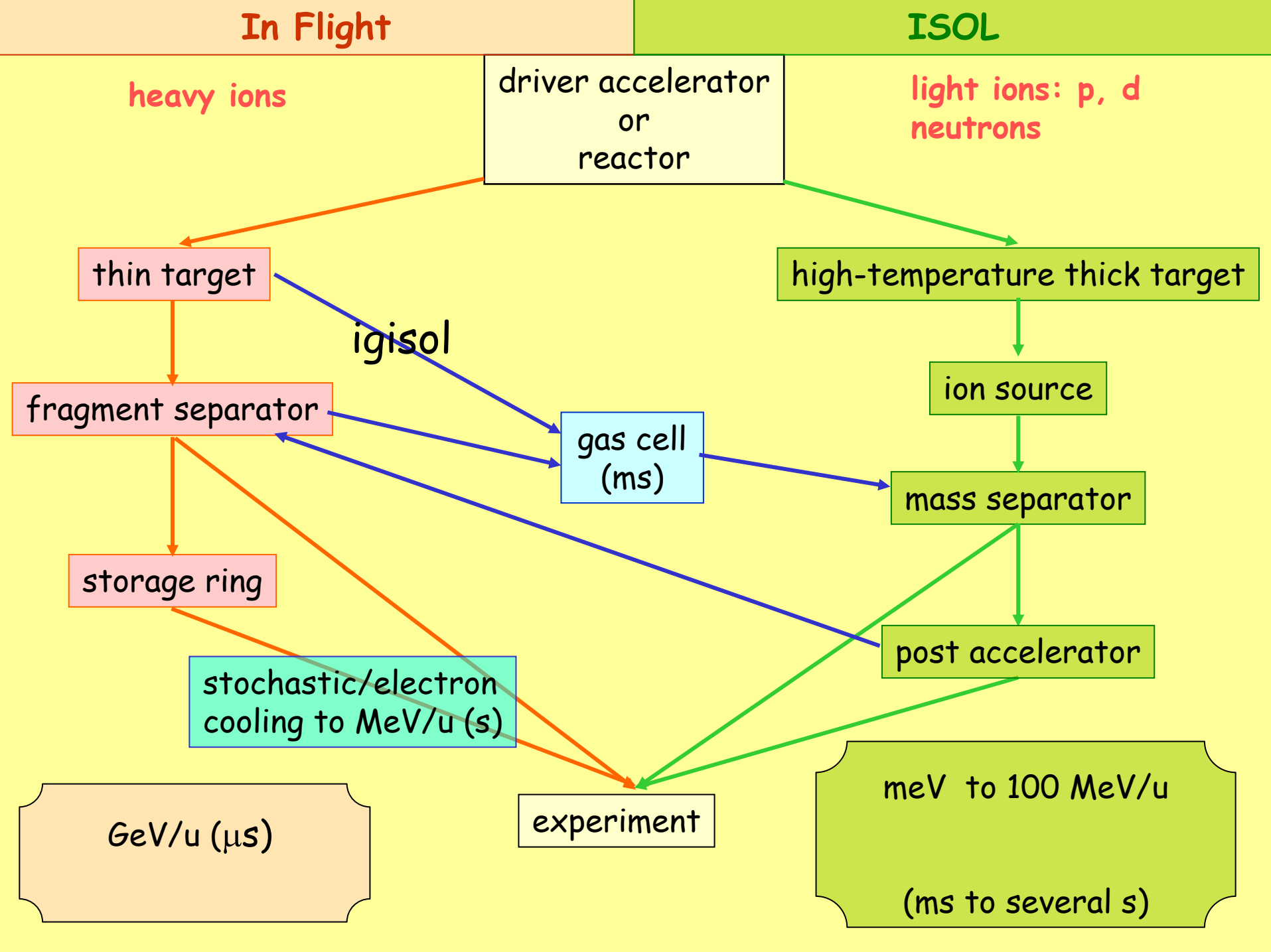
Principles of radioactive beam production

Current European Facilities

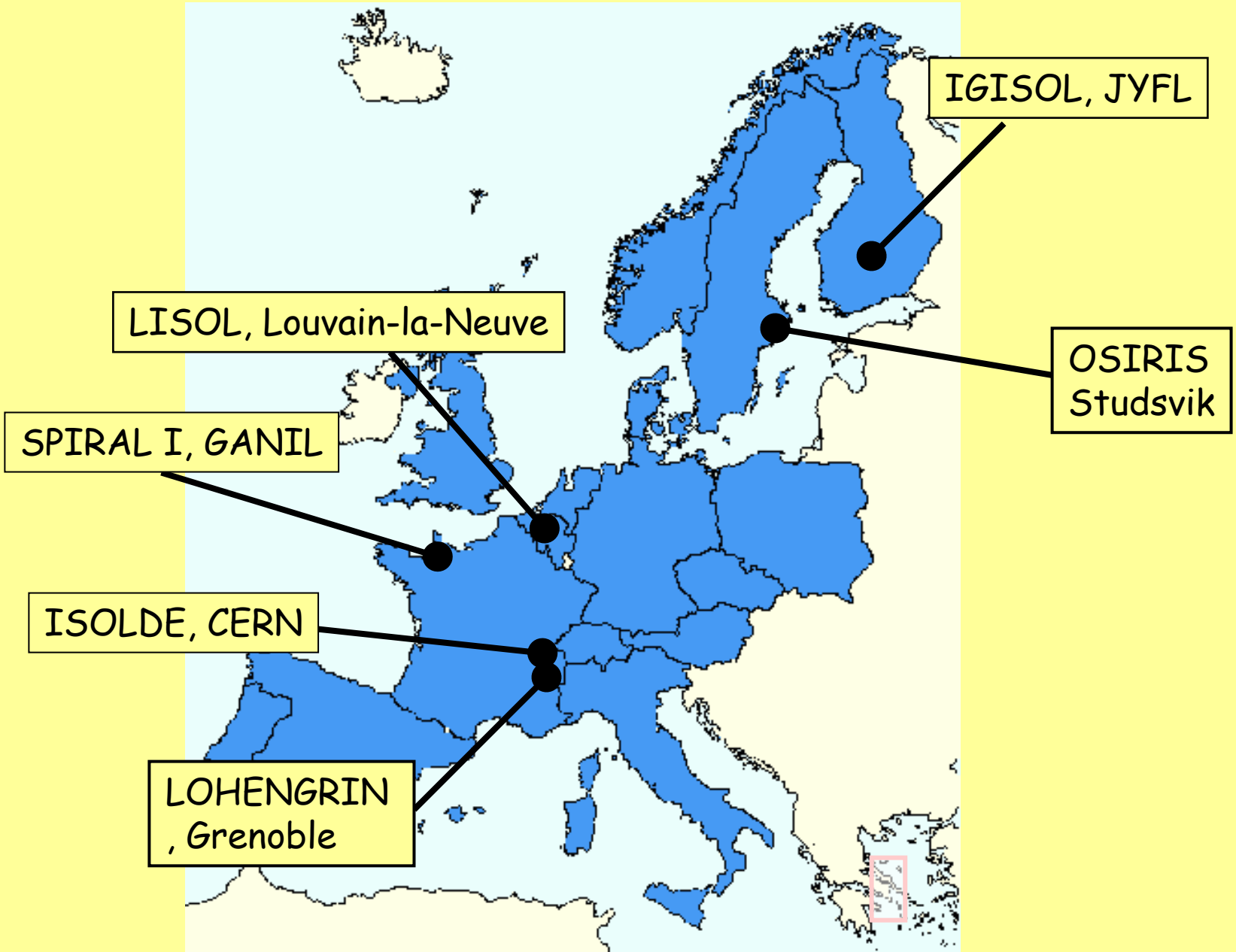
- ISOL facilities
  - Low-energy facilities
  - Accelerated beam facilities
- In-Flight Fragmentation facilities

Future perspectives worldwide

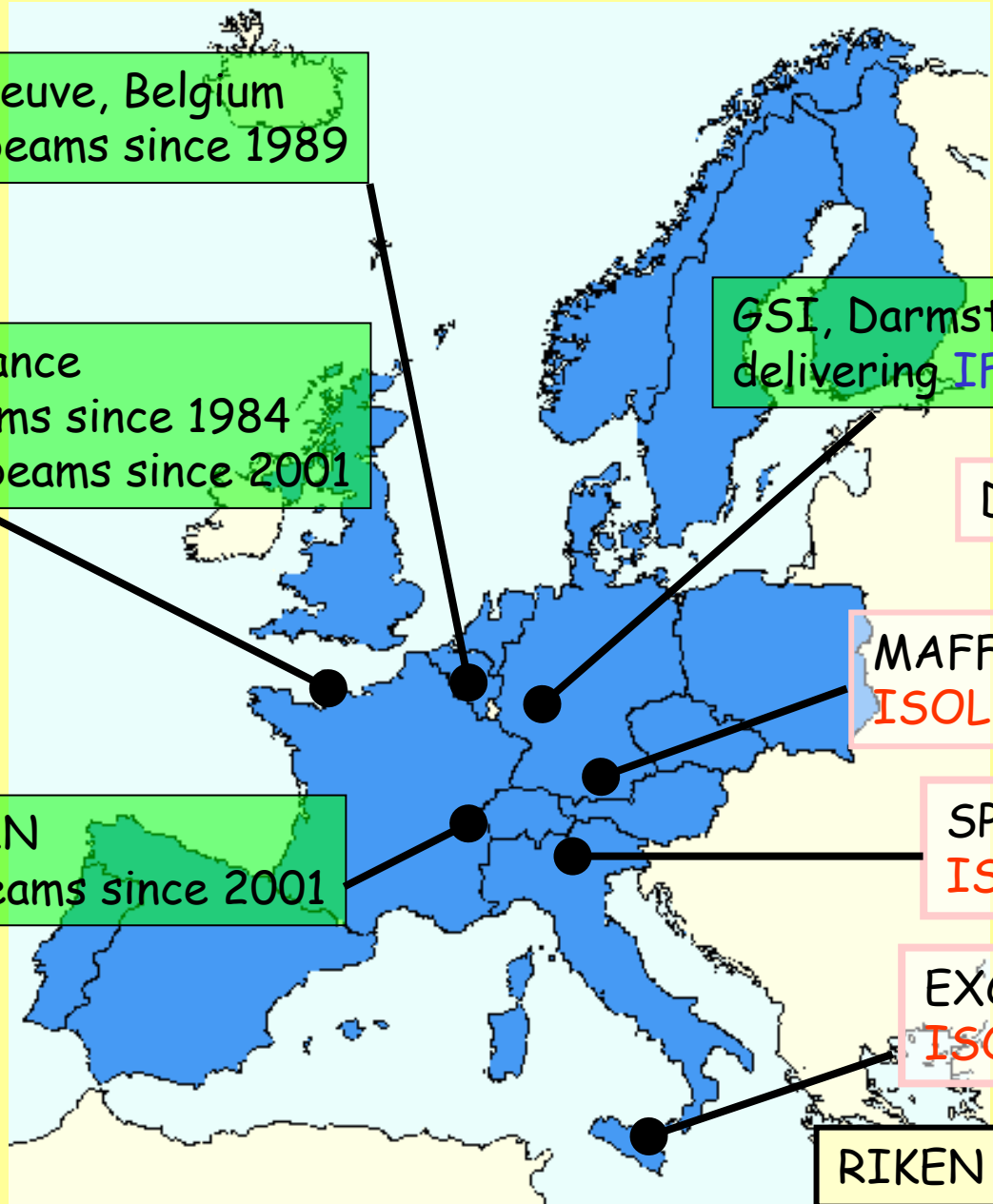
- FAIR, EURISOL
- RIKEN, RIA


In Flight
ISOL
heavy ions
driver accelerator
or
reactor
light ions: p, d
neutrons
thin target
high-temperature thick target
igisol
ion source
fragment separator
gas cell
(ms)
mass separator
storage ring
post accelerator
stochastic/electron
cooling to MeV/u (s)
GeV/u (μs)
experiment
meV to 100 MeV/u
(ms to several s)

Current low-energy RIB facilities



Energetic Radioactive Beam Facilities in Europe



CRC, Louvain-la-Neuve, Belgium
delivering ISOL beams since 1989

GANIL, Caen, France
delivering IF beams since 1984
(SPIRAL) ISOL beams since 2001

SPIRAL II
ISOL beams

REX-ISOLDE, CERN
delivering ISOL beams since 2001

HIE-ISOLDE
ISOL beams

RIA - USA

FAIR
IF beams

GSI, Darmstadt, Germany
delivering IF beams since 1990

Dubna ISOL beams

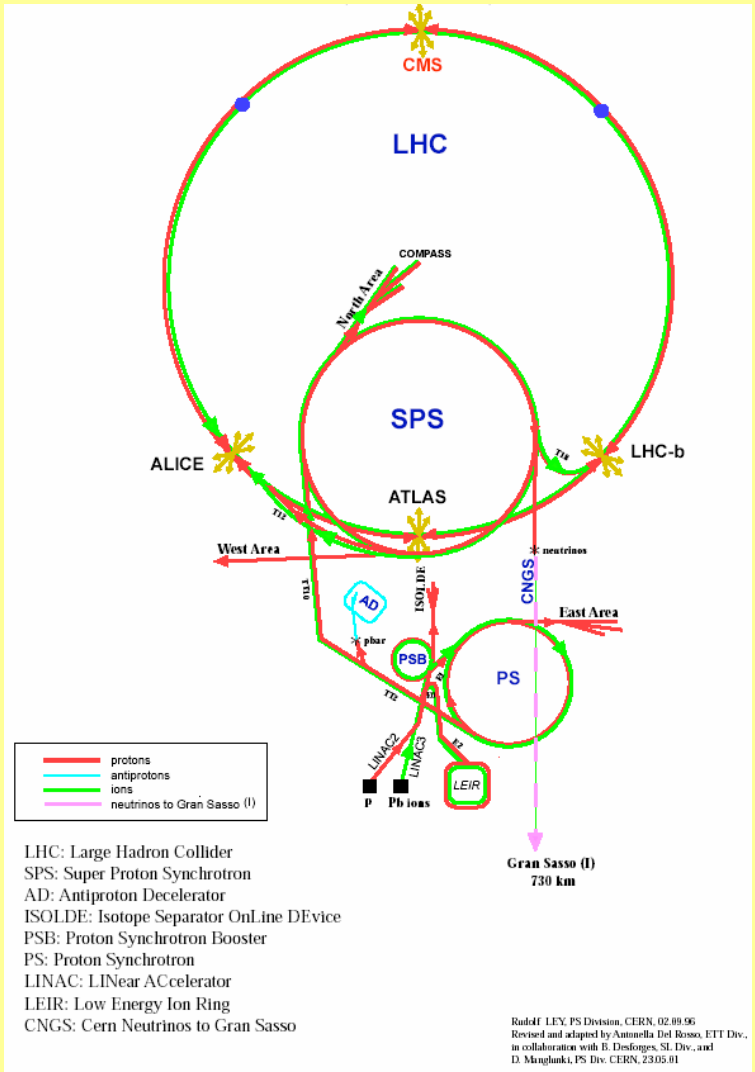
MAFF, Munich, Germany
ISOL beams

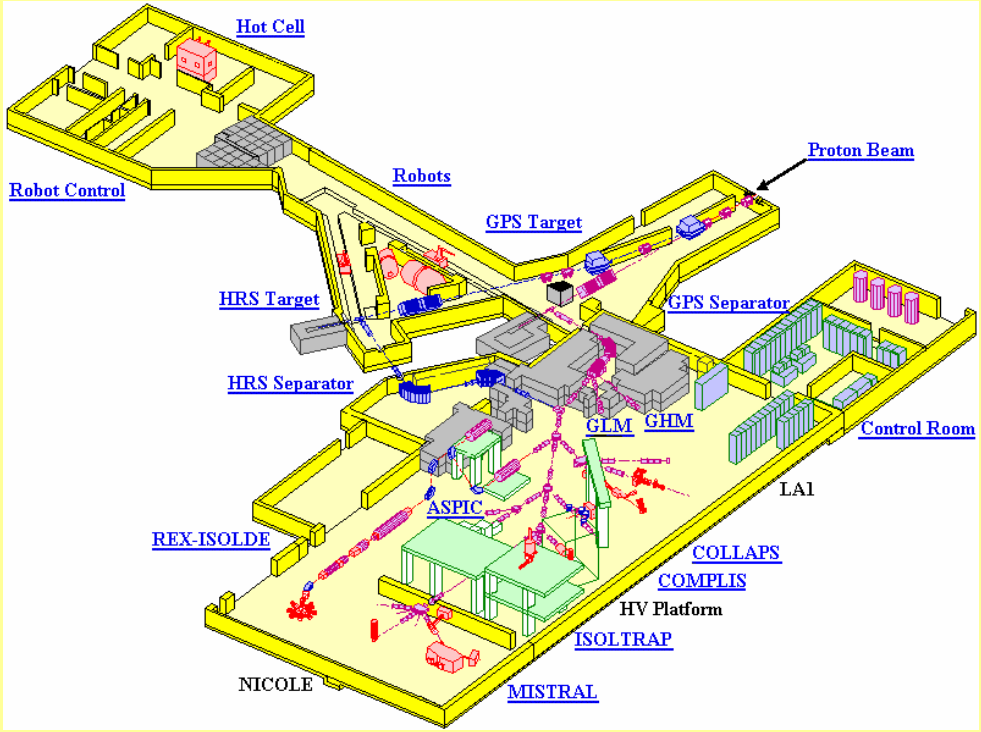
SPES, Legnaro, Italy
ISOL beams

EXCYT, Catania, Italy
ISOL beams

RIKEN - JAPAN

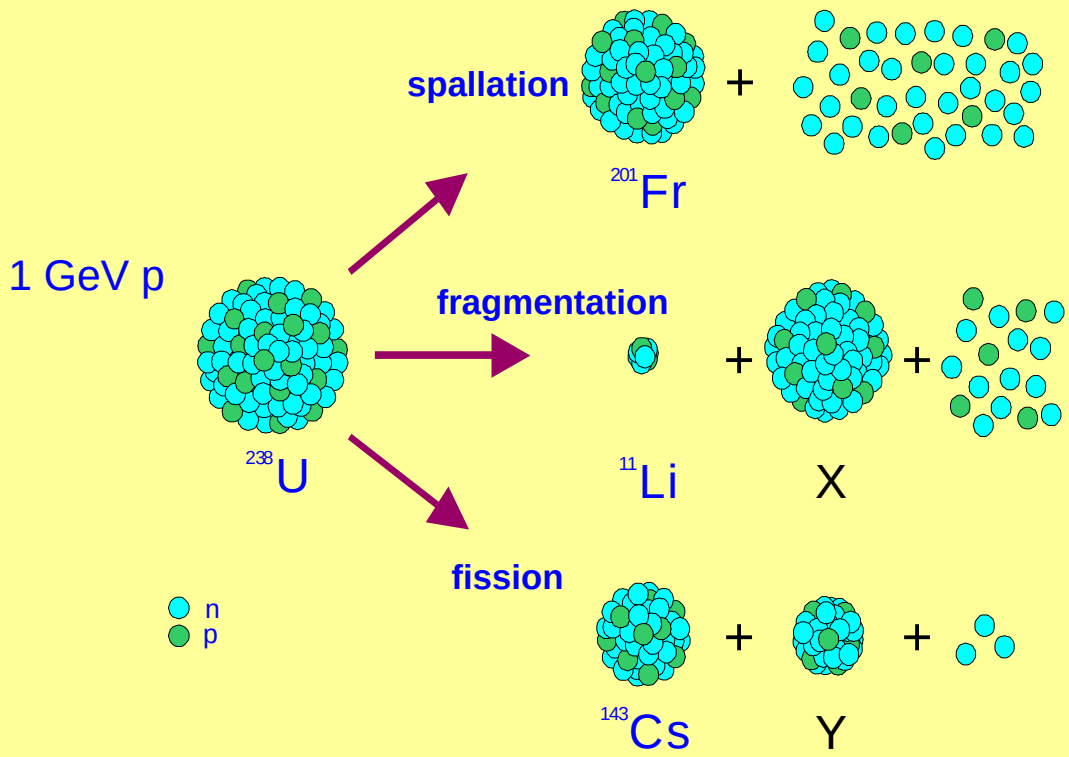
ISOLDE at CERN



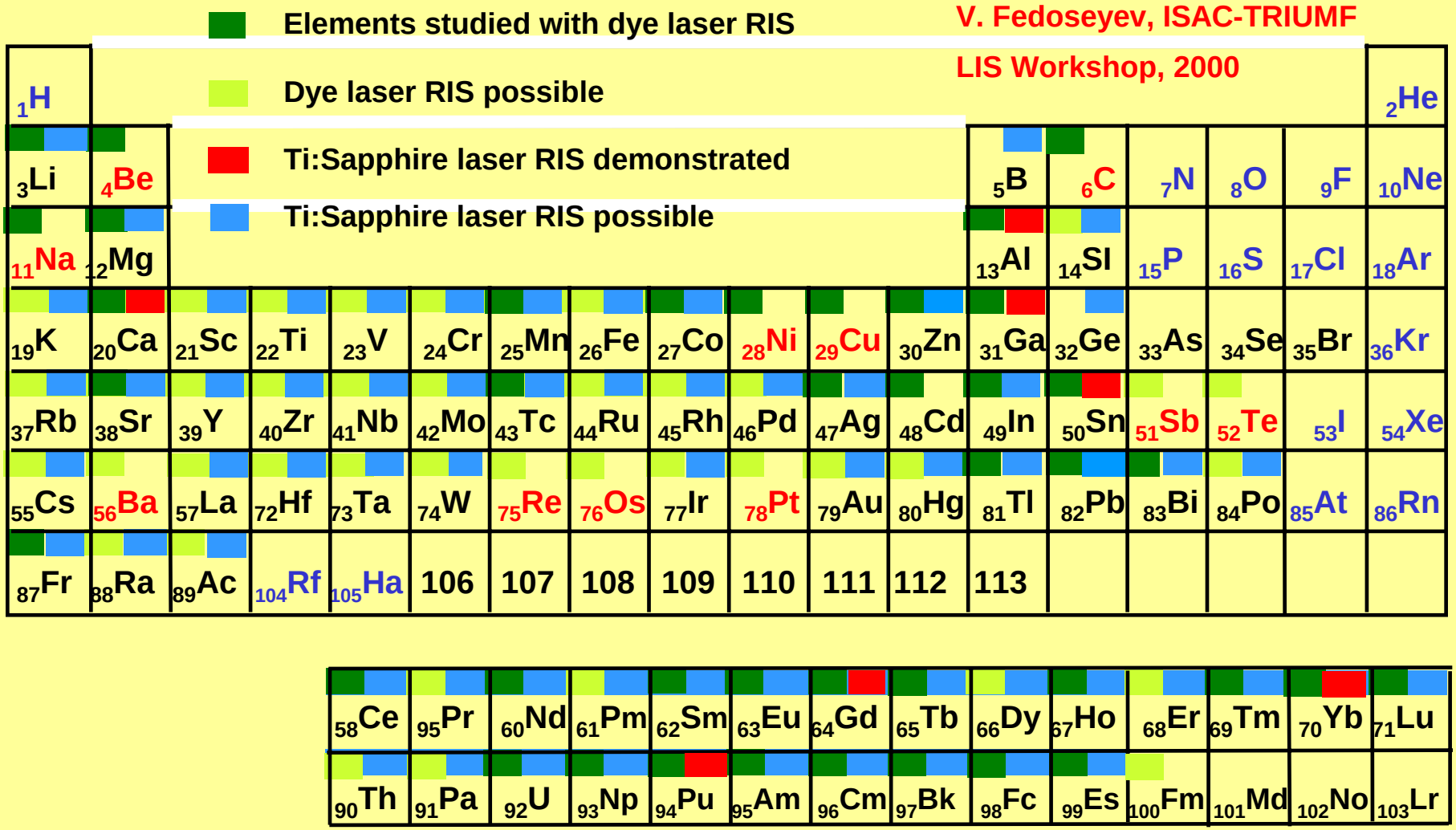


50 % PSB's protons
Two separators, push-pull mode operation
Several experimental facilities
Post-accelerator for RIBs

Production reactions

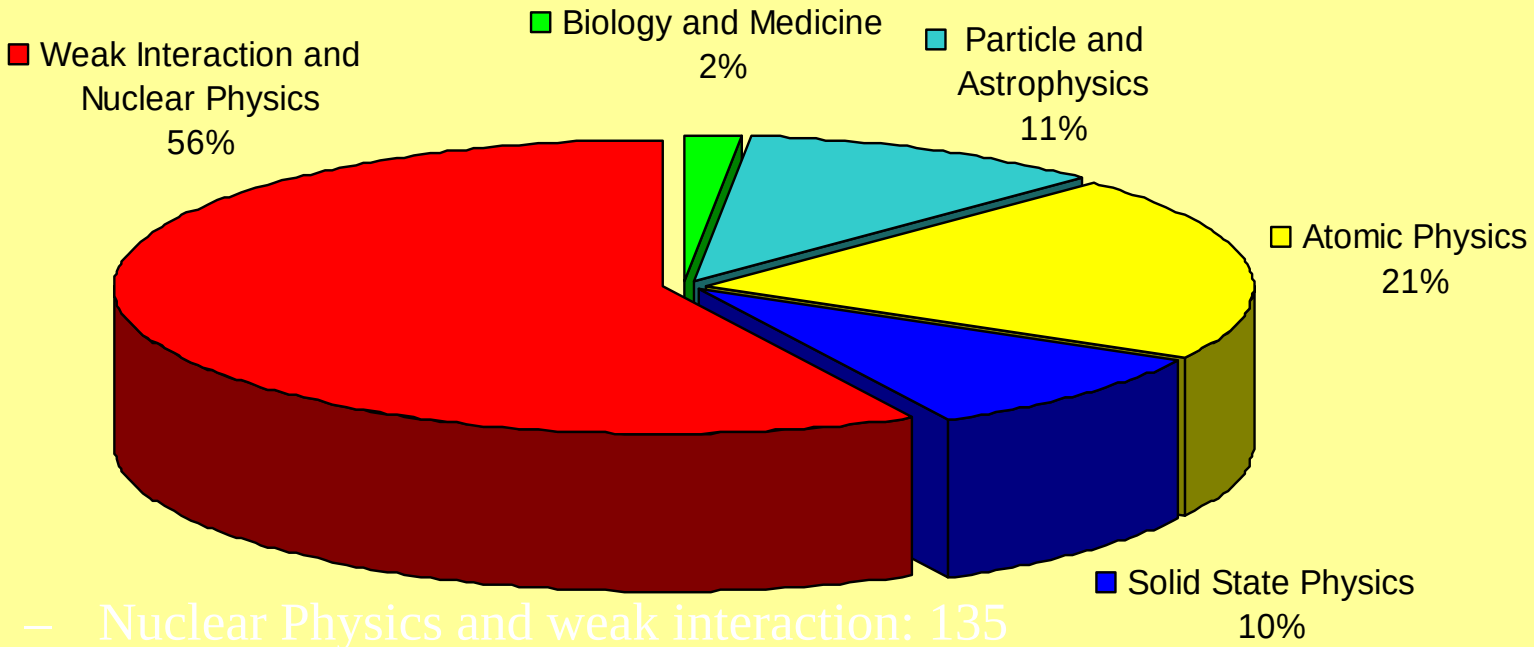


Accessibility of elements using resonant laser ion source



ISOLDE scientific programme 2004

- Delivered 320 shifts



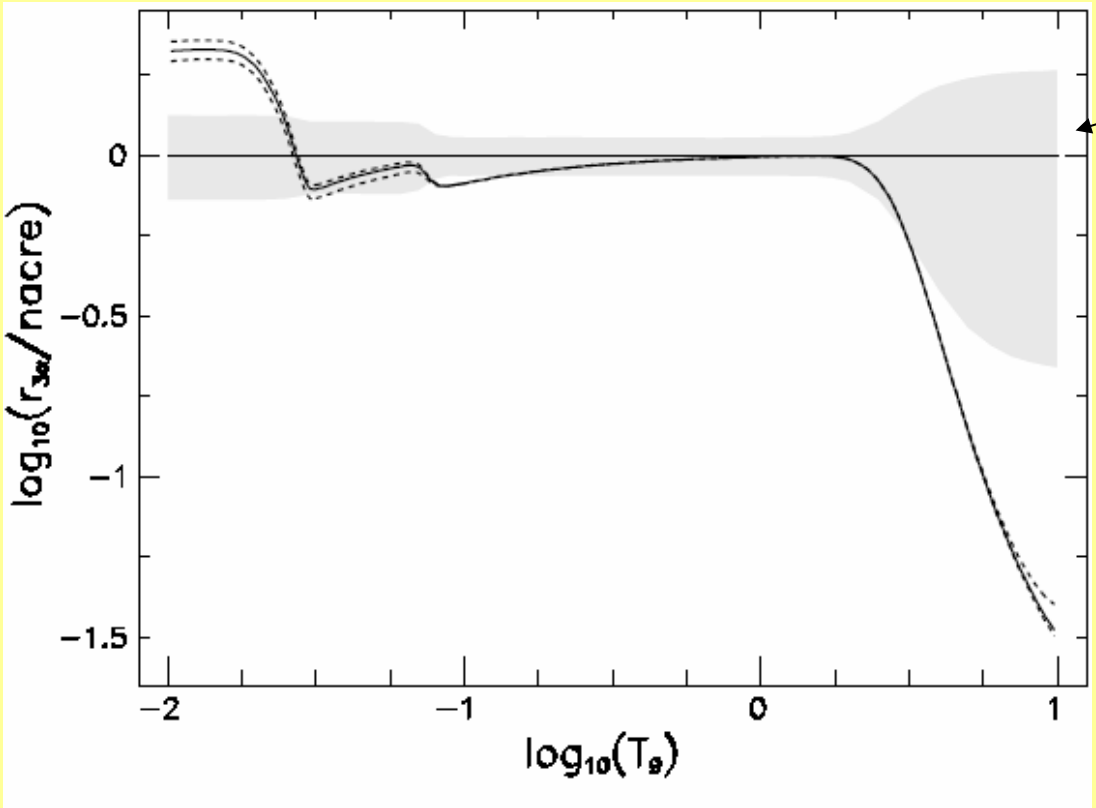
  - Nuclear Physics and weak interaction: 135
  - Atomic methods: 50
  - SSP: 22
  - + Development experiments: 30
  - + Tests and beam development: 30

"New" 3 α → ^{12}C rate vs. temperature

NATURE 433(2005)136

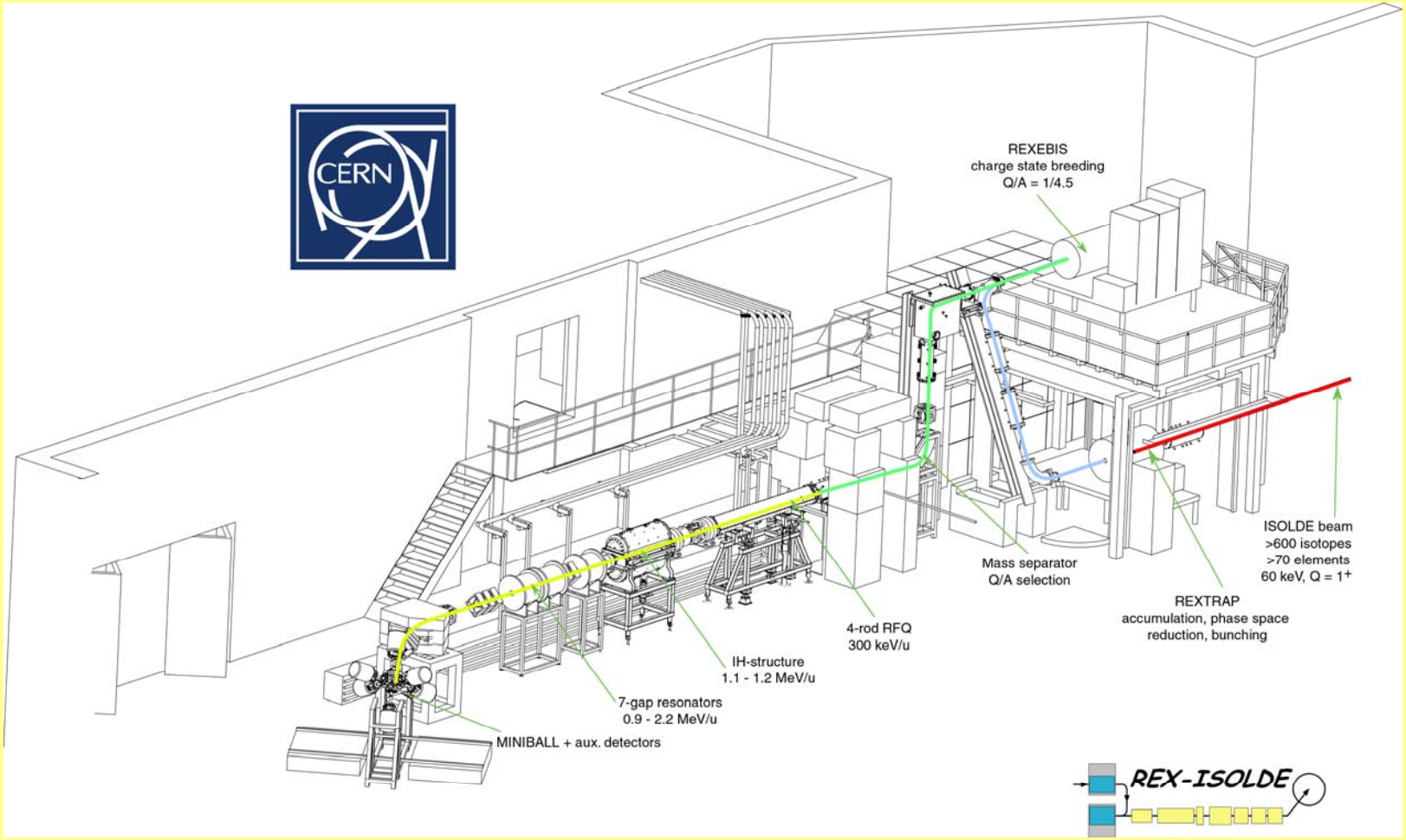
IGISOL: ^{12}N → ^{12}C* ← ^{12}B : ISOLDE

3 α



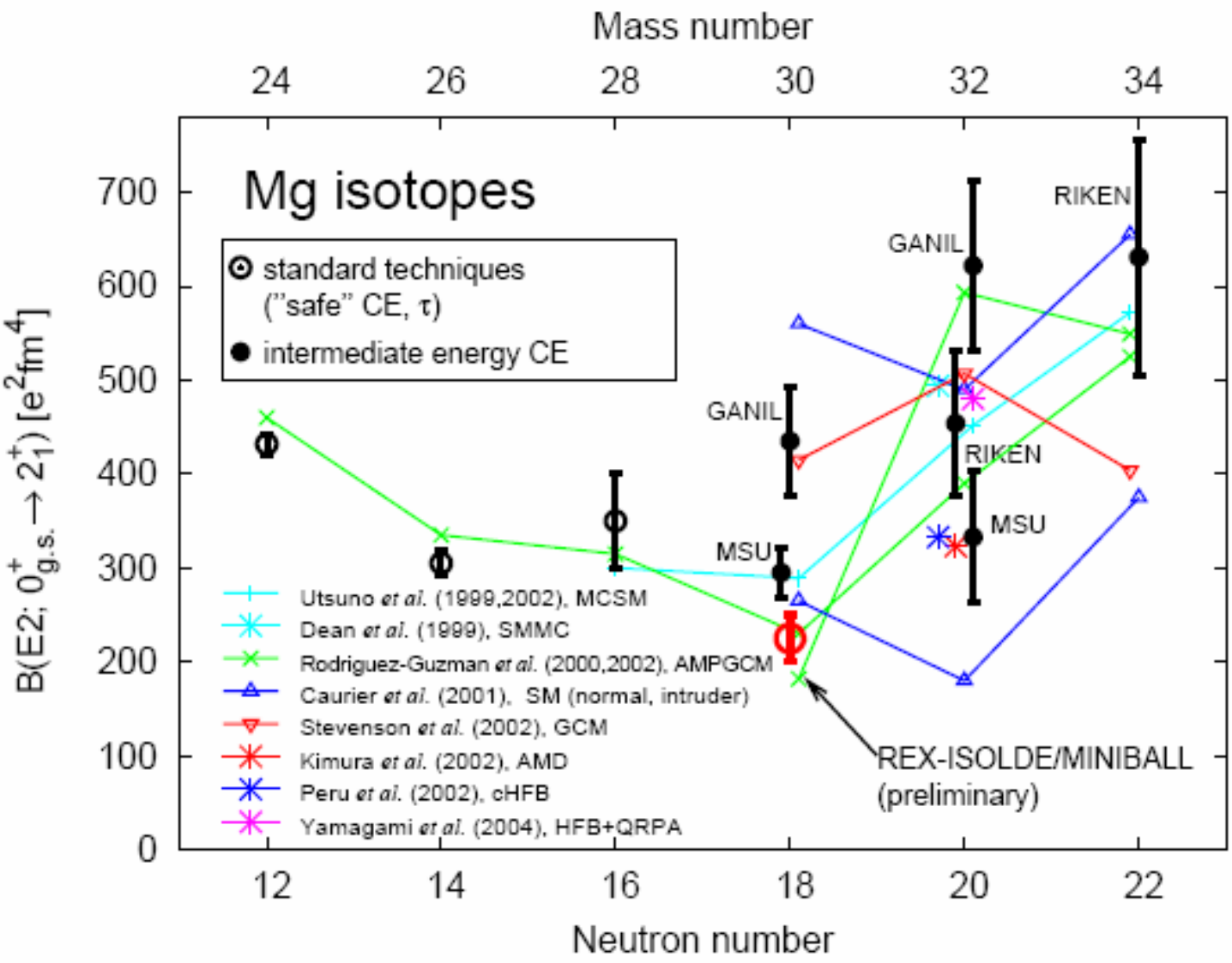
NACRE

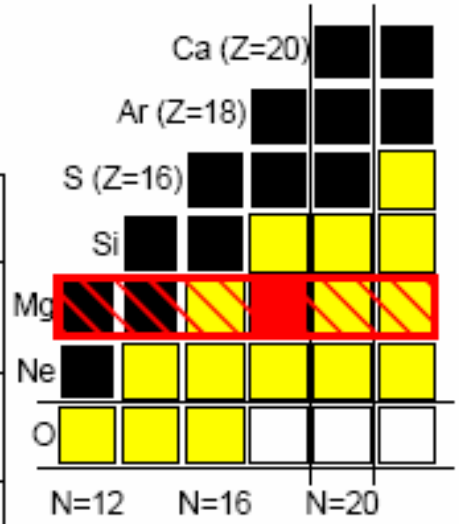
REX ISOLDE post accelerator



http://www.ha.physik.uni-muenchen.de/okester/rex/rex.html

Collectivity of the Mg Isotopes

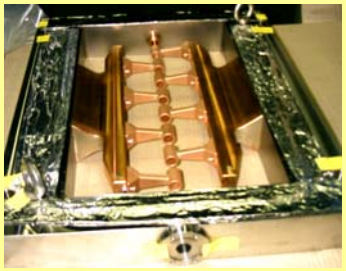




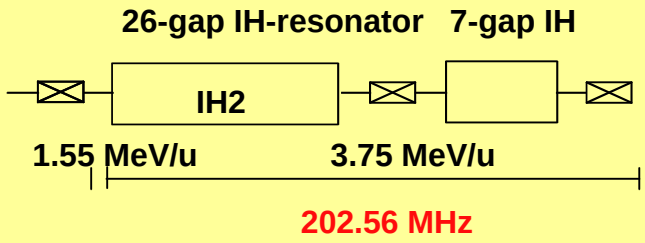
Analysis by
O. Niedermaier, MPI-K

O. Niedermaier et al.,
to be submitted

REX-ISOLDE upgrade

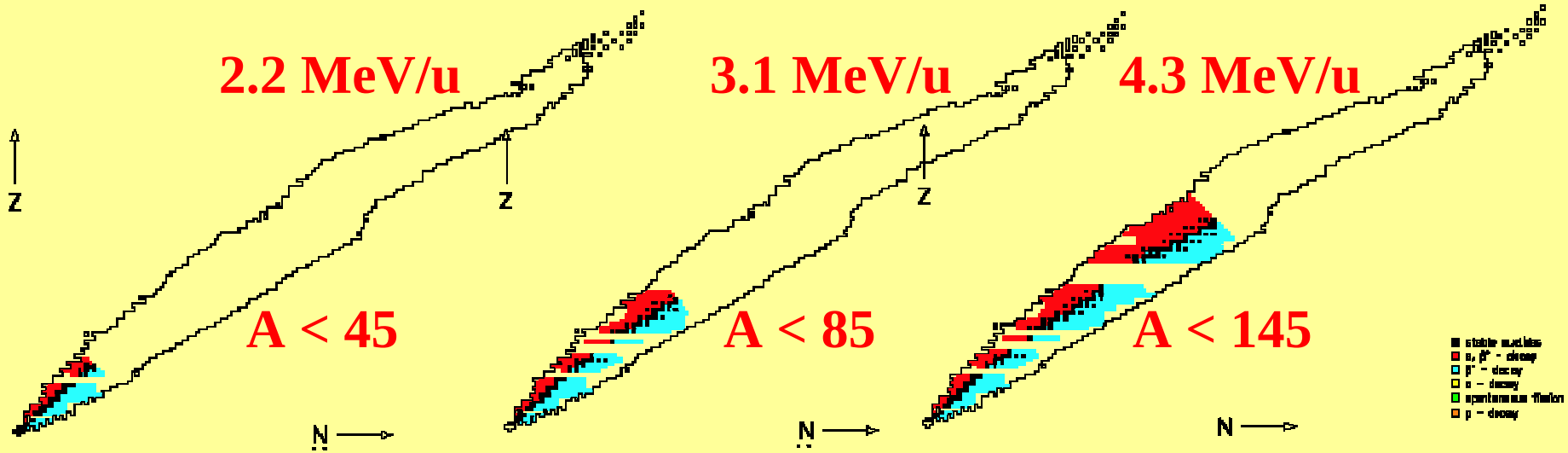


Additional 9-gap accelerating structure

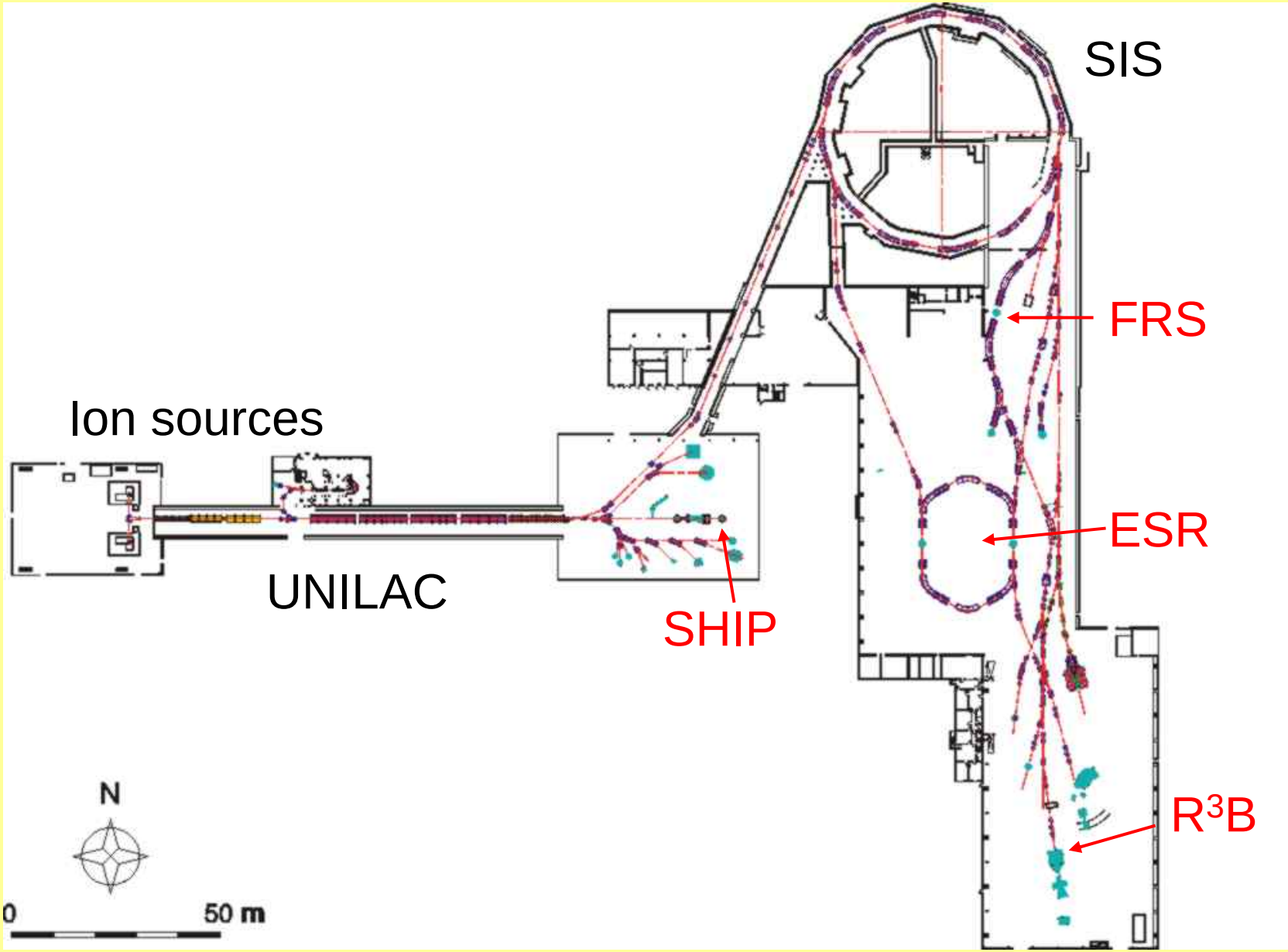


Exchange existing 7-gap with IH accelerating structures

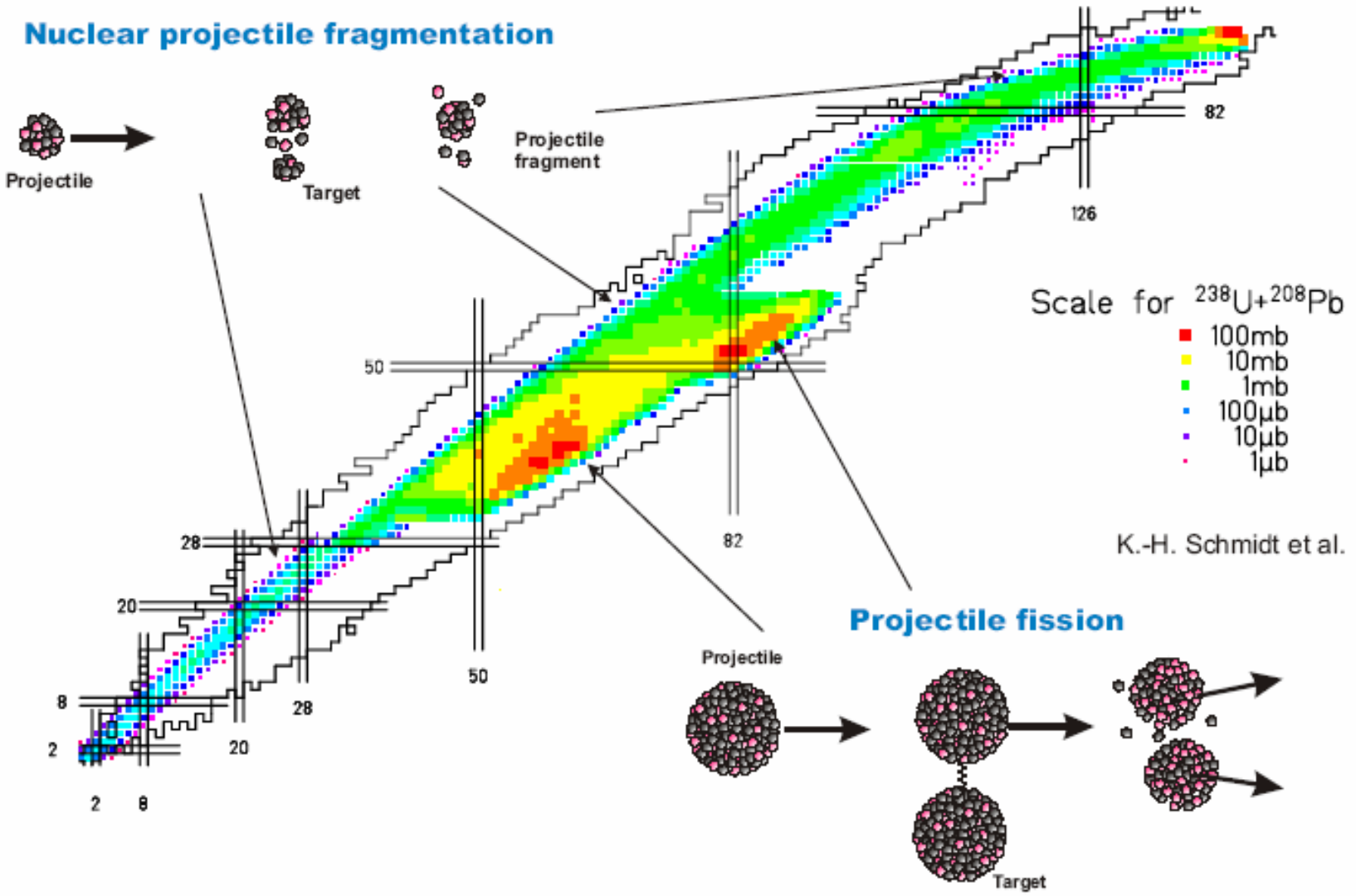
2002 → **2004** → **2006-**



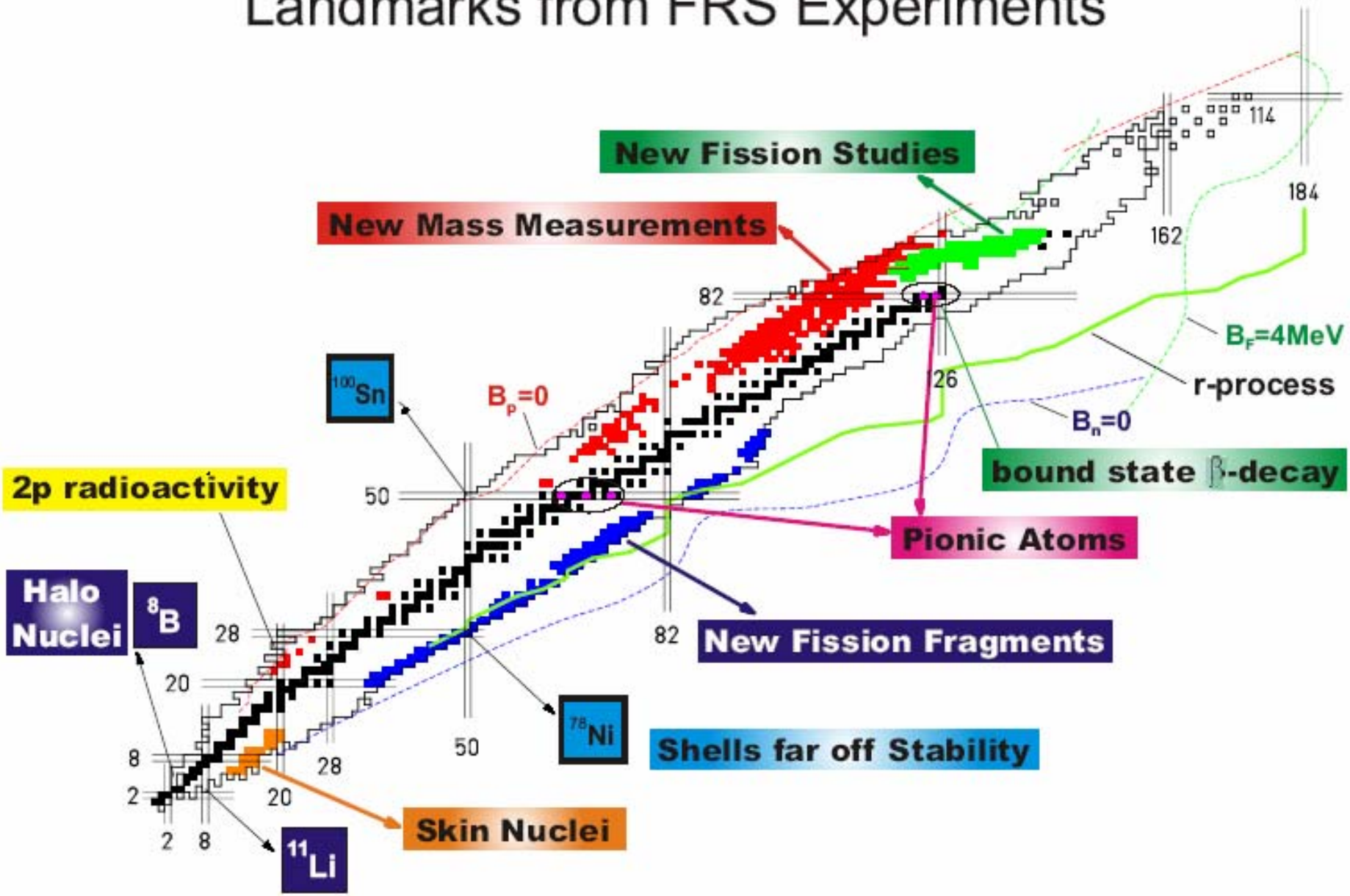
The GSI accelerator facilities



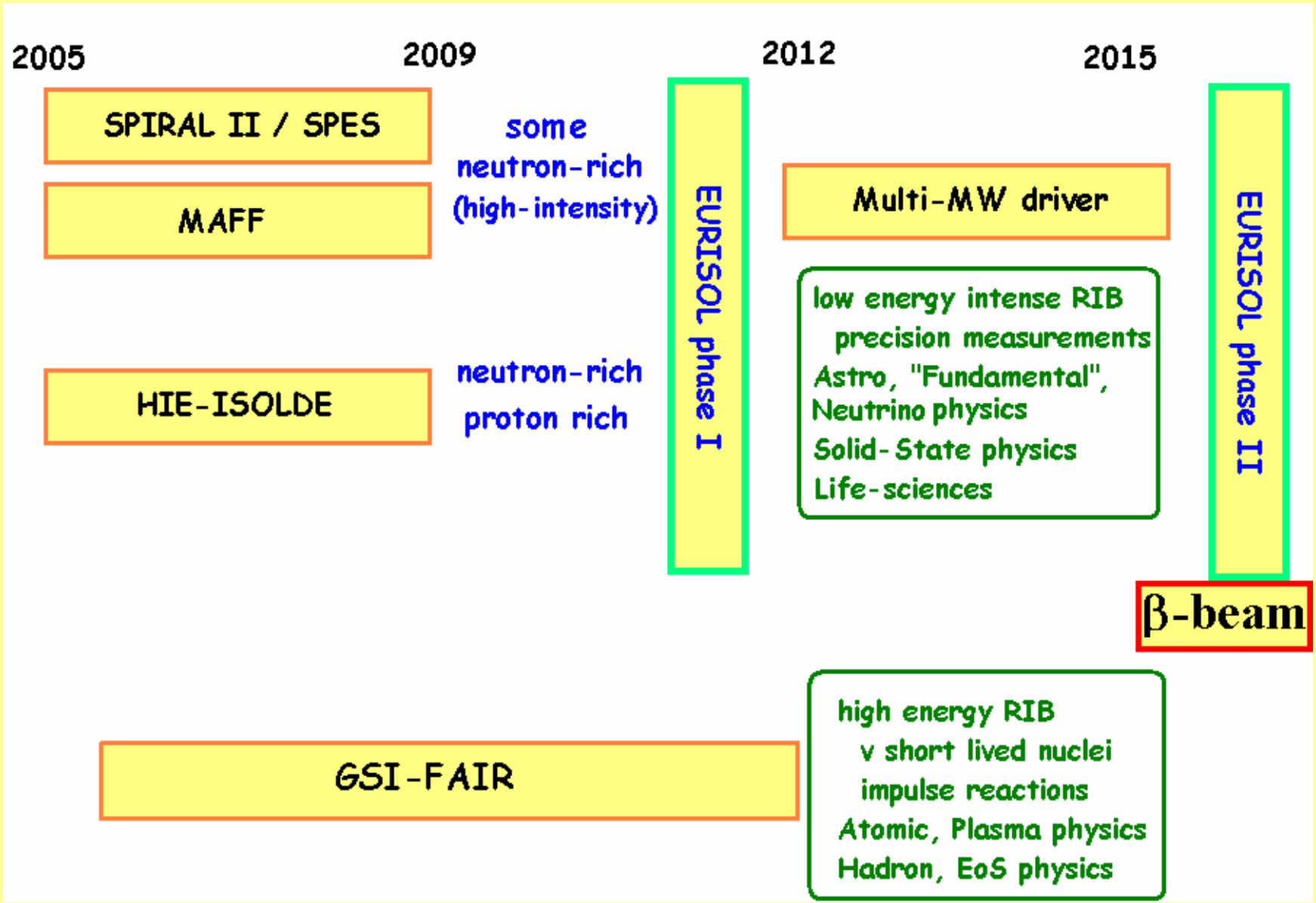
Fragments produced from ^{238}U



Landmarks from FRS Experiments

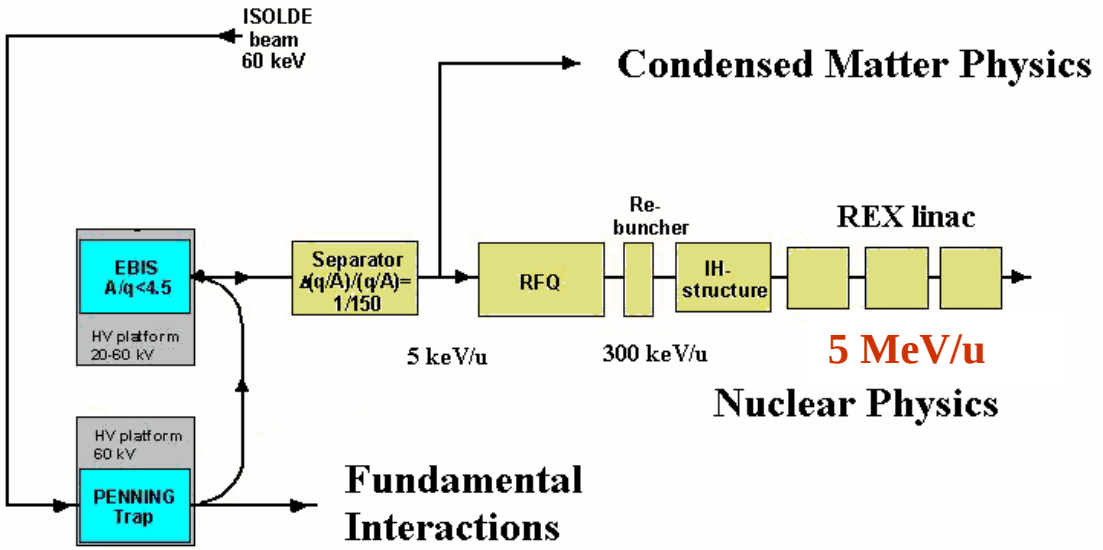


European NP Roadmap

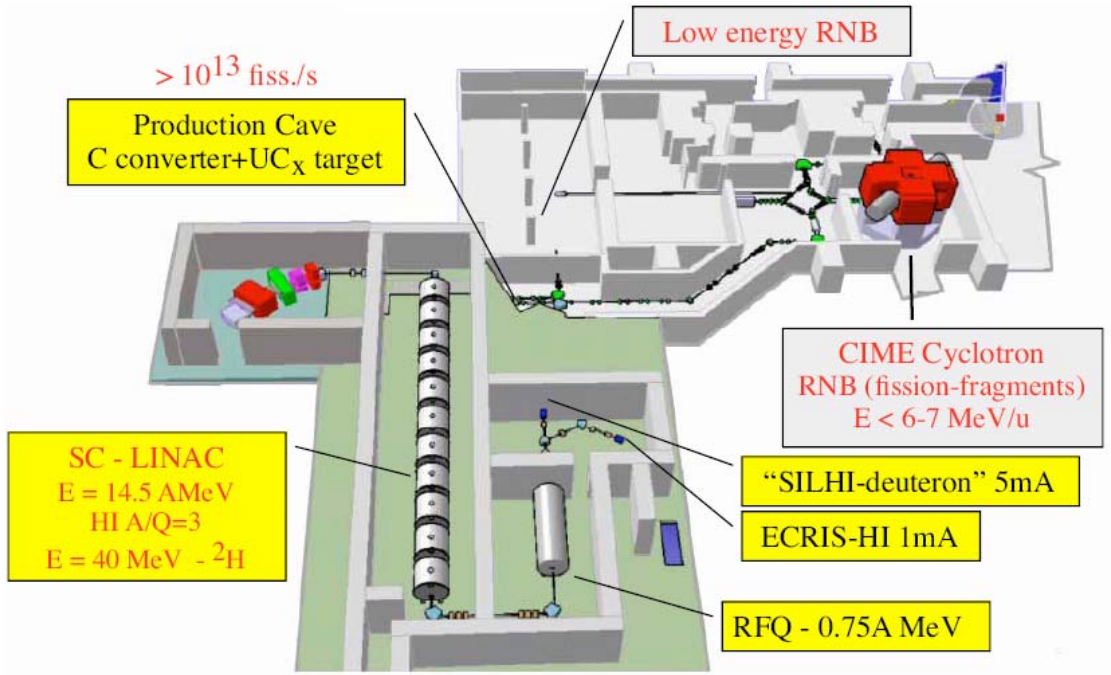


ISOL in Europe: the next 5 years

REX-ISOLDE



SPIRAL II



SPES @ Legnaro

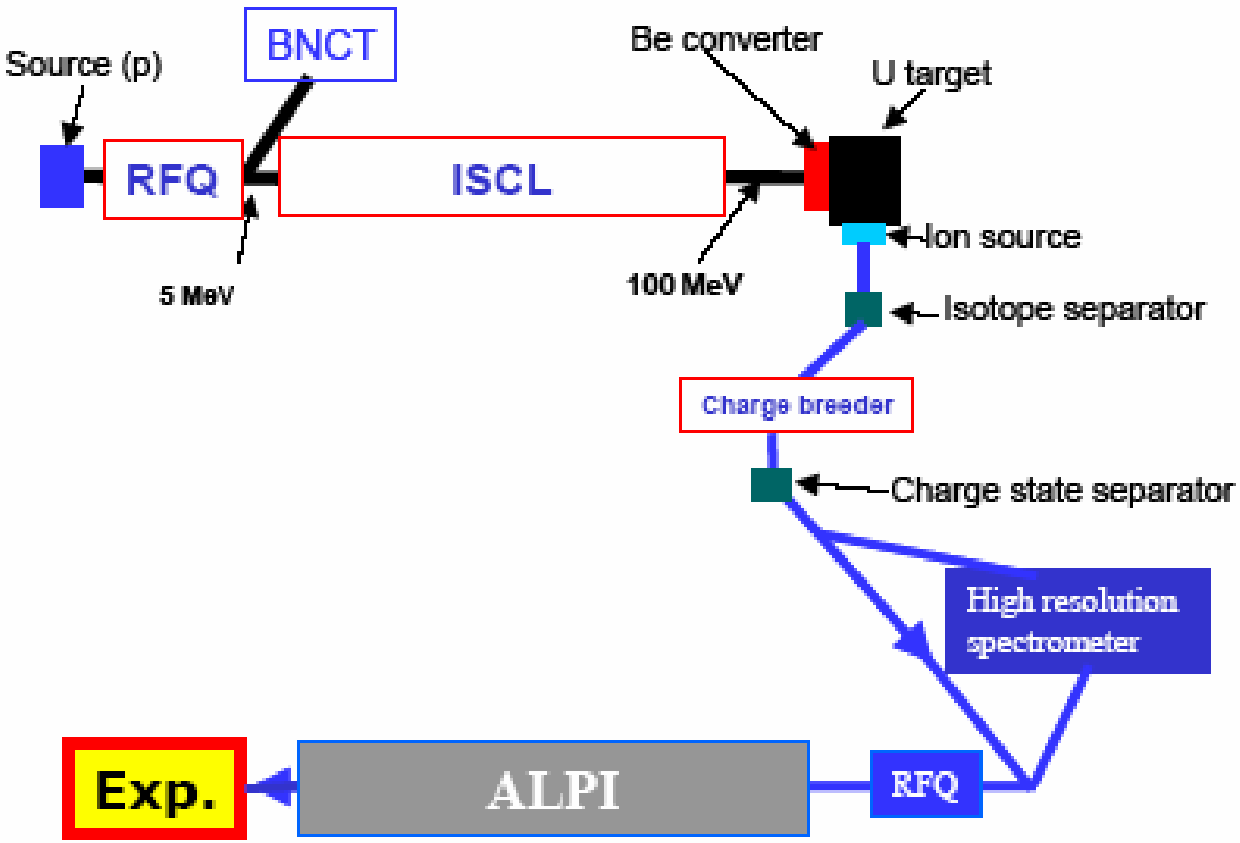


Fig. 2.1 - Block diagram of the facility: RFQ means Radio frequency Quadrupole, BNCT Boron Neutron Capture Therapy, ISCL Independently phased Superconducting Cavity Lina and ALPI Acceleratore Linac Per Ioni

MAFF in Munich

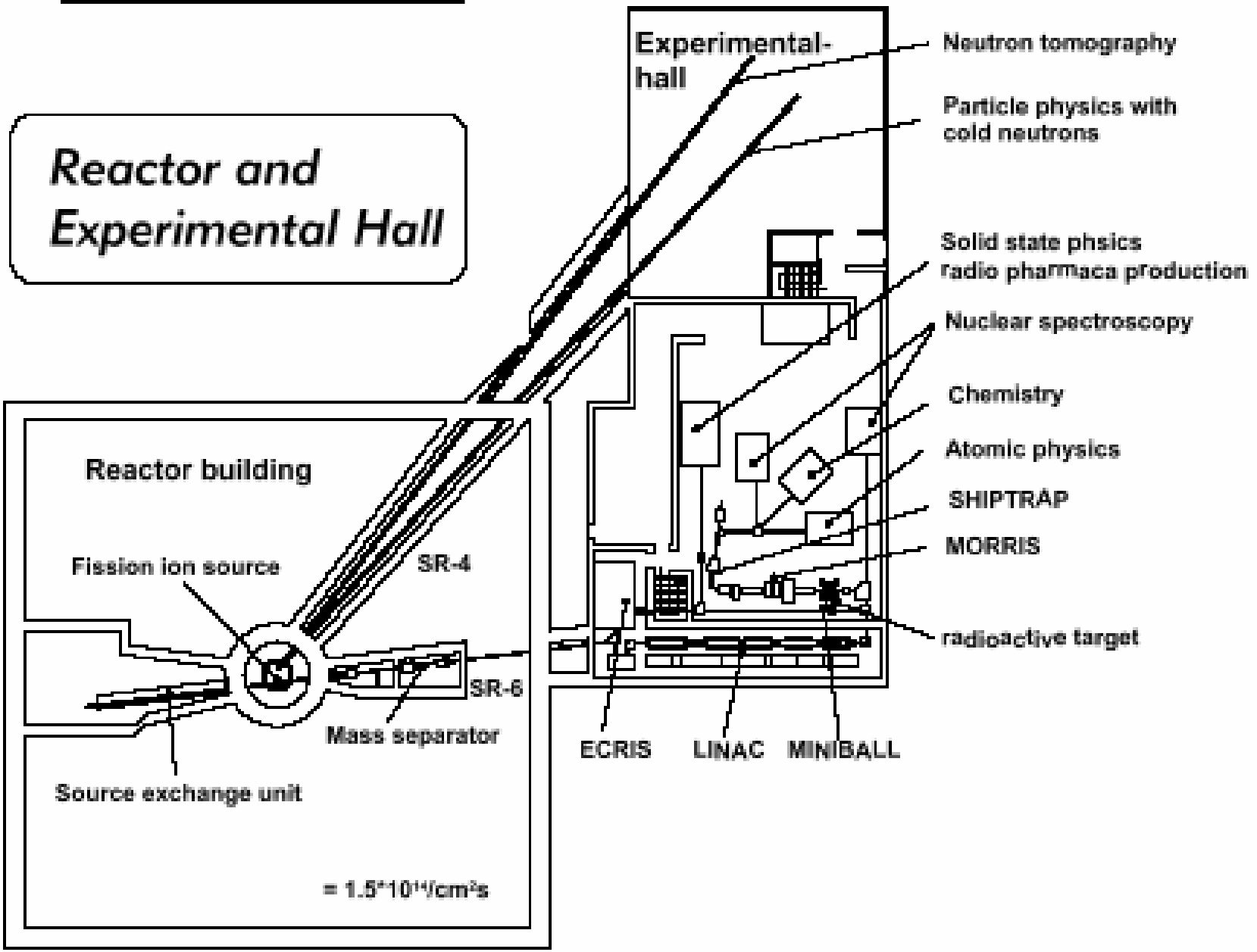


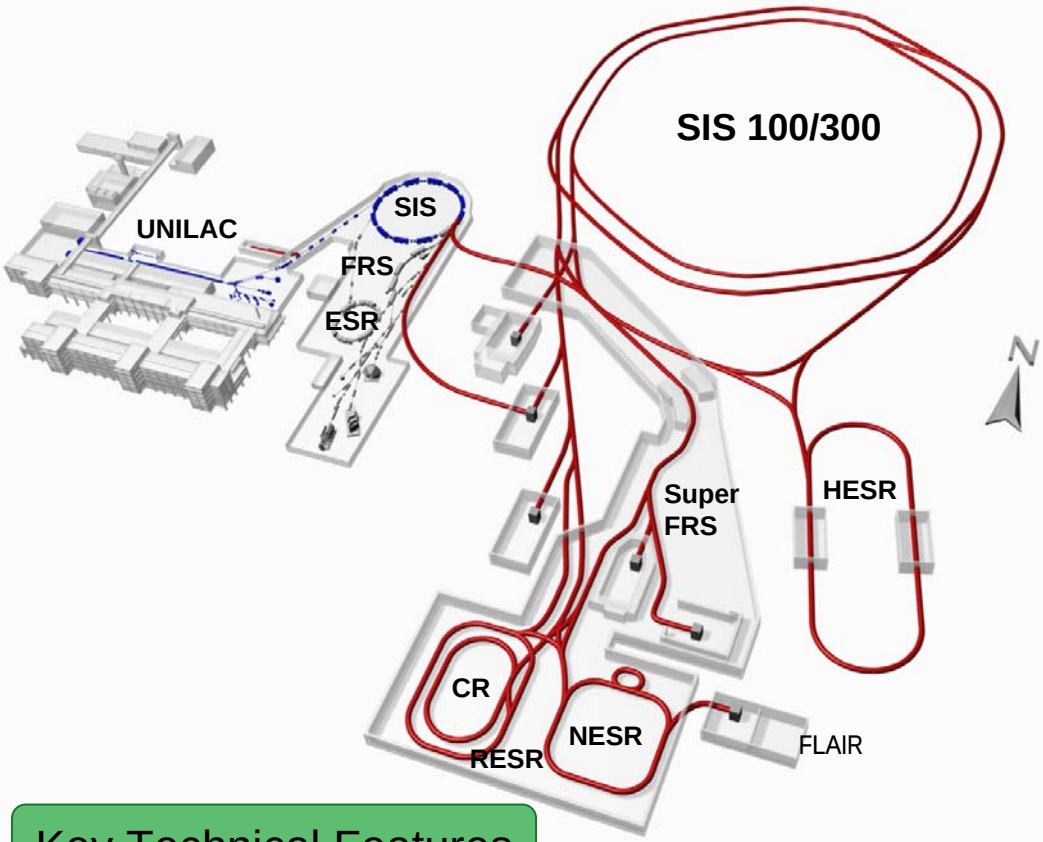
Table 1: Yields of prominent isotopes at MAFF compared with accelerator based RIB facilities. The primary beams are 10 μA of 1.15 GeV ^{12}C for SPIRAL, 2.5 μA of 1 GeV protons (or 600 MeV protons for the SC respectively) for ISOLDE and 100 μA of protons for the ISL.

Isotope	Prod. rate (s^{-1})	Half-life (s)	Release (%)	Ioniz. (%)	MAFF (s^{-1})	SPIRAL (s^{-1})	ISOLDE (s^{-1})	ISL (s^{-1})
^{78}Zn	$2.3 \cdot 10^{9}$	1.47	36	10	$\mathbf{8 \cdot 10^{7}}$	$2 \cdot 10^{6}$	$1 \cdot 10^{6}$ SC	$6 \cdot 10^{6}$
^{91}Kr	$3.3 \cdot 10^{12}$	8.6	89	15	$\mathbf{4 \cdot 10^{11}}$	$2 \cdot 10^{9}$	$2 \cdot 10^{9}$	$4 \cdot 10^{10}$
^{94}Kr	$1.1 \cdot 10^{11}$	0.2	16	15	$\mathbf{3 \cdot 10^{9}}$	$3 \cdot 10^{7}$	$4 \cdot 10^{6}$	$6 \cdot 10^{9}$
^{97}Rb	$3 \cdot 10^{10}$	0.17	10	80	$\mathbf{2 \cdot 10^{9}}$	$5 \cdot 10^{8}$	$3 \cdot 10^{8}$	$7 \cdot 10^{9}$
^{132}Sn	$7 \cdot 10^{11}$	39.7	89	10	$\mathbf{6 \cdot 10^{10}}$	$6 \cdot 10^{6}$	$8 \cdot 10^{7}$ SC	$1 \cdot 10^{10}$
^{142}Xe	$5.2 \cdot 10^{11}$	1.24	7	25	$\mathbf{1 \cdot 10^{10}}$	$6 \cdot 10^{7}$	$2 \cdot 10^{8}$	$4 \cdot 10^{10}$
^{144}Xe	$9.3 \cdot 10^{9}$	1.15	7	25	$\mathbf{2 \cdot 10^{8}}$	$1 \cdot 10^{6}$	$5 \cdot 10^{6}$	$2 \cdot 10^{10}$
^{144}Cs	$4.3 \cdot 10^{11}$	1.0	47	80	$\mathbf{2 \cdot 10^{11}}$	$2 \cdot 10^{10}$	$3 \cdot 10^{10}$	$6 \cdot 10^{10}$

Future RNB facilities

Location	Driver	Post-accelerator	Fragment separator	Type of facility
GSI –FAIR	synchrotron, heavy ions: 1.5 A GeV	-	'Super-FRS'	In-Flight
EURISOL	protons, 1 GeV, 1-5 MW	CW Linac, up to 100 *A* MeV	-	ISOL
USA: RIA Rare Isotope Accelerator	900 MeV protons heavy ions: 400 *A* MeV, 100 kW	Linac up to 8–15 A MeV	4-dipole Separator	ISOL, In-Flight
JAPAN: RIKEN RIB Factory	Ring-cyclotrons up to 400 *A* MeV (light ions); up to 150 *A* MeV (heavy ions)	-	3 fragment Separators storage & cooler rings	In-Flight

International Accelerator For Ions and Antiprotons
FAIR (2007-2014)



Primary Beams

- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- 2(4)x10^{13}/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 35 GeV/u
- up to 90 GeV protons

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

Storage and Cooler Rings

- Radioactive beams
- e^- – A (or Antiproton-A) collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons

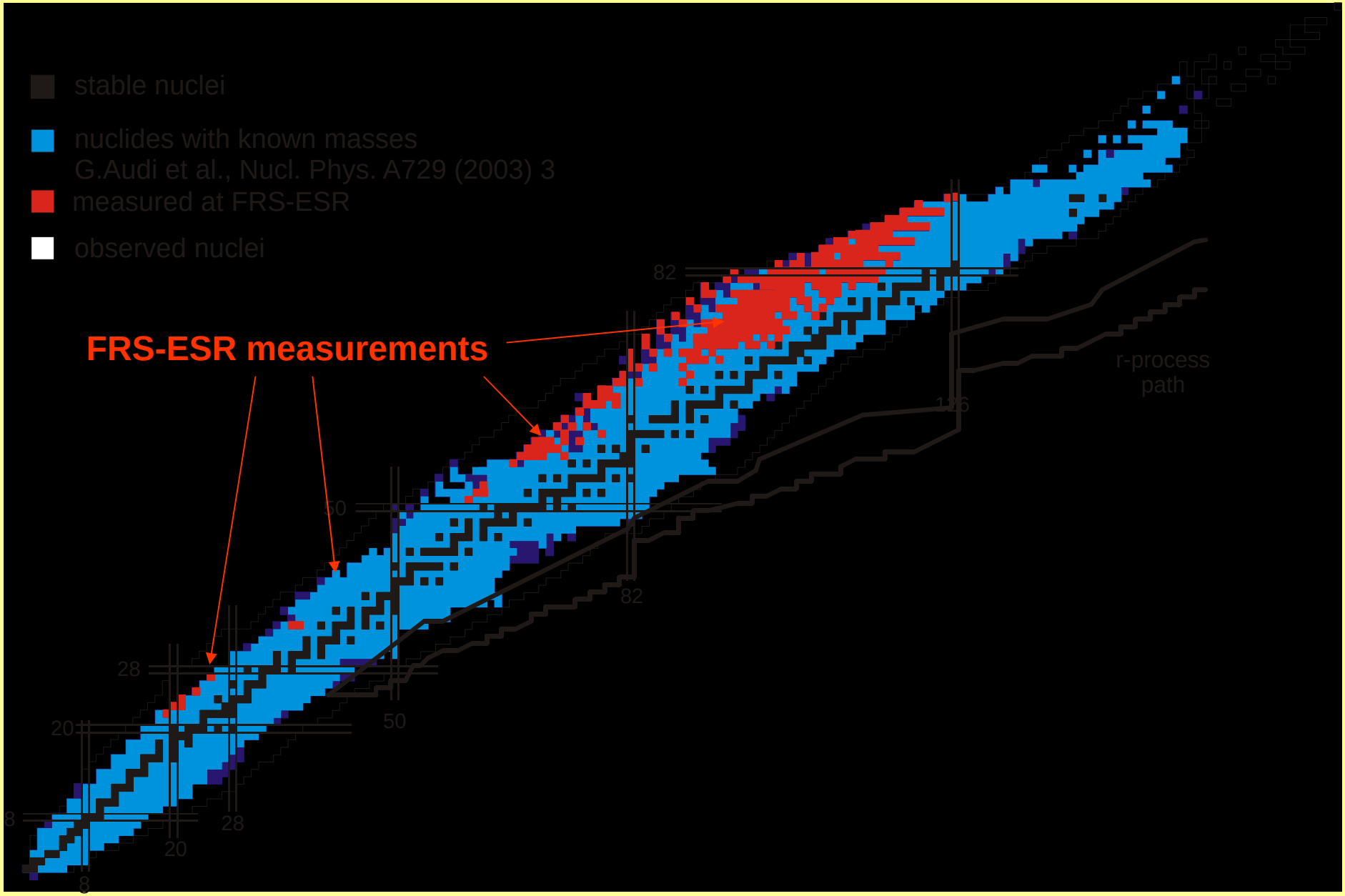
Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets

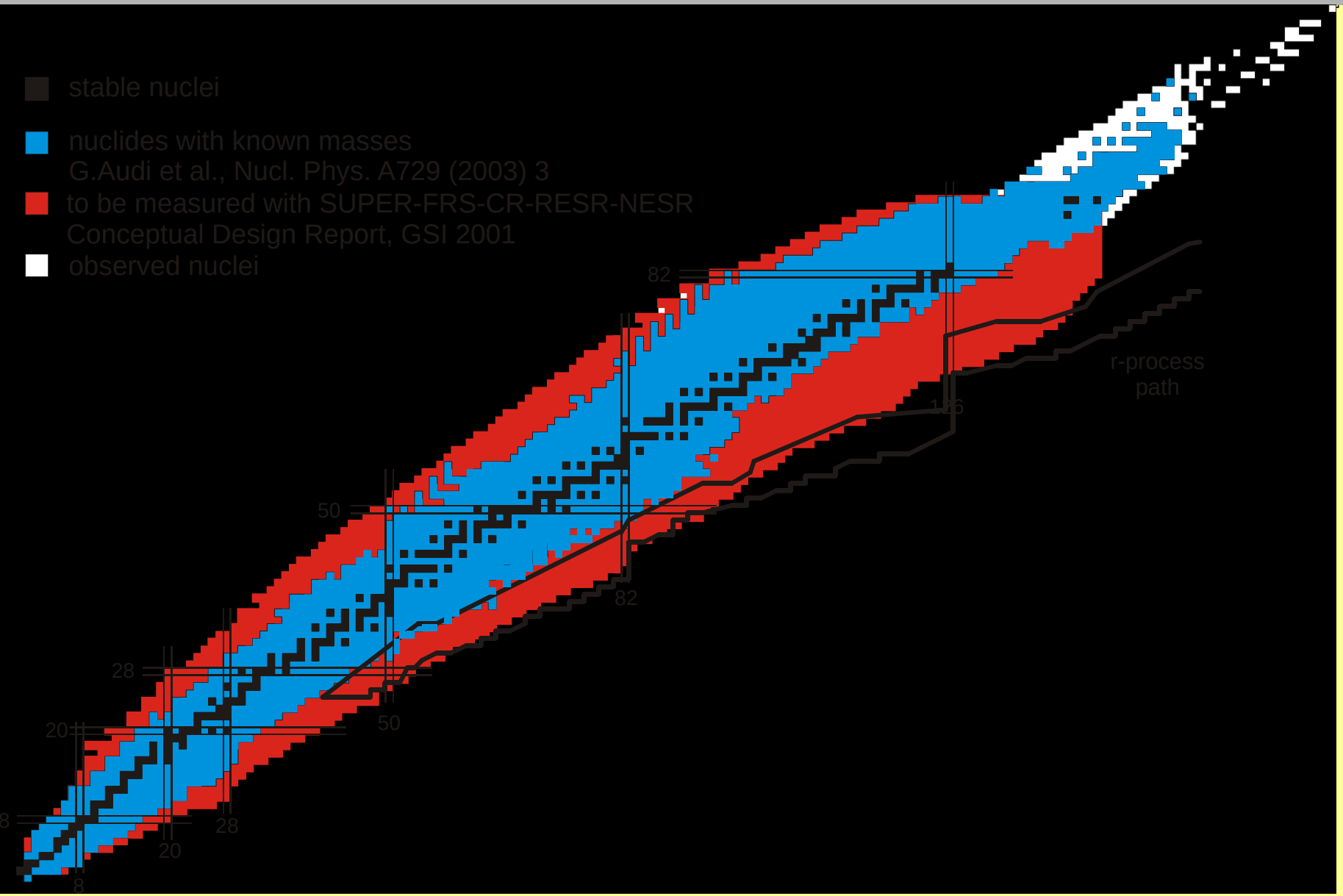
Five Scientific Pillars

- **Nuclear Structure Physics and Nuclear Astrophysics with RIBs**
  - Structure of exotic nuclei far off stability;
  - Nuclear synthesis in stars and star explosions;
  - Fundamental interactions and symmetries
- **Hadron Physics with Antiproton Beams**
  - Quark gluon structure and dynamics of “strong” interacting particles;
  - Origin of the confinement and mass of hadrons
  - Transversity measurement via polarized antiprotons and pol. protons
- **Physics of Nuclear Matter with Relativistic Nuclear Collisions**
  - Studies of hadronic matter at high densities;
  - Phase transitions in quark matter;
  - Properties of neutron stars
- **Plasma Physics with highly Bunched Beams**
  Bulk matter at very high pressures, densities, and temperatures
- **Atomic Physics and Applied Science**
  - Highly charged atoms
  - Low energy anti-protons
  - Laser cooling

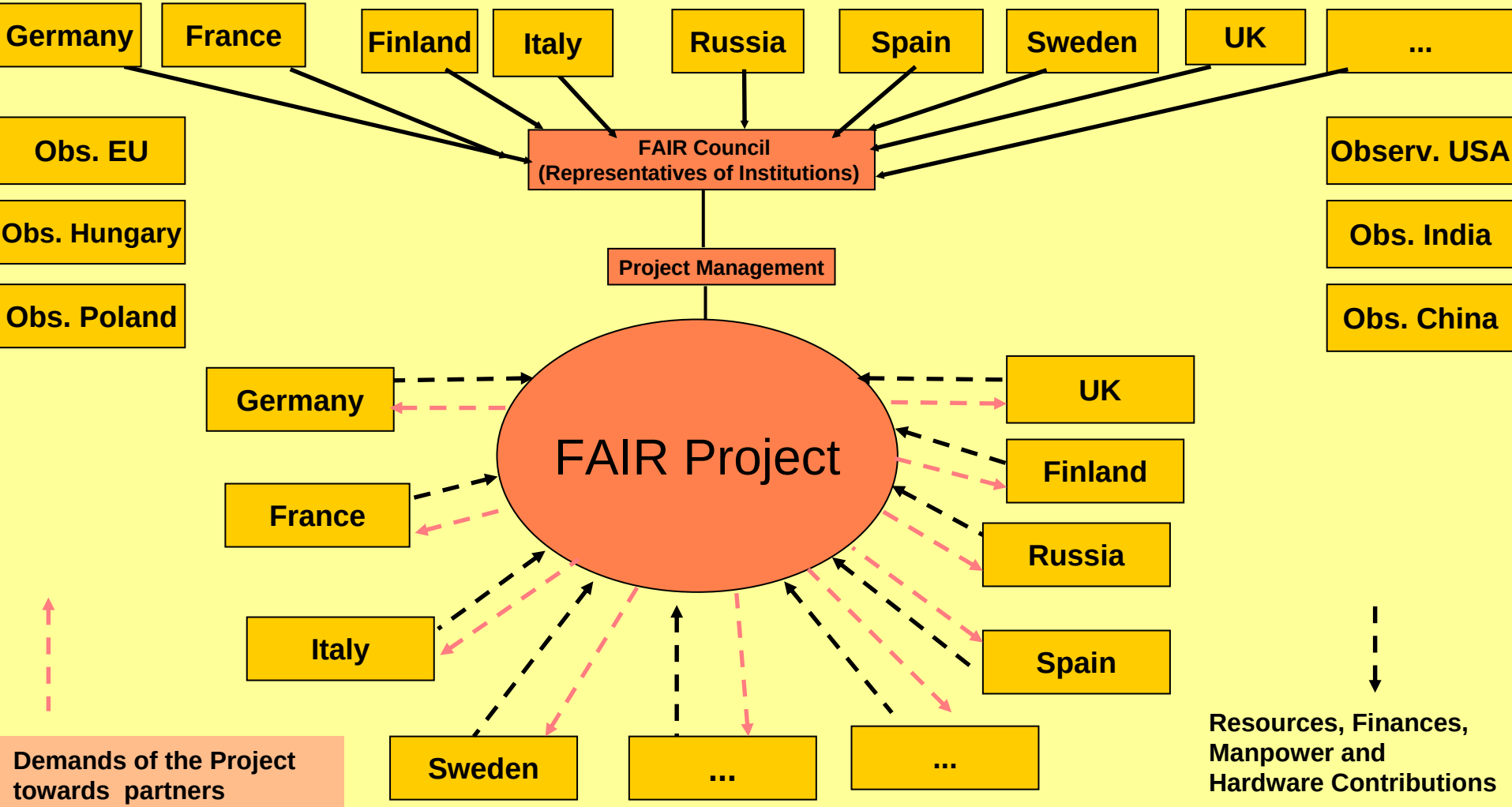
Present knowledge of nuclear masses



Mass measurements at the International Accelerator Facility for intense beams of ions and antiprotons at GSI



The international FAIR project and its members

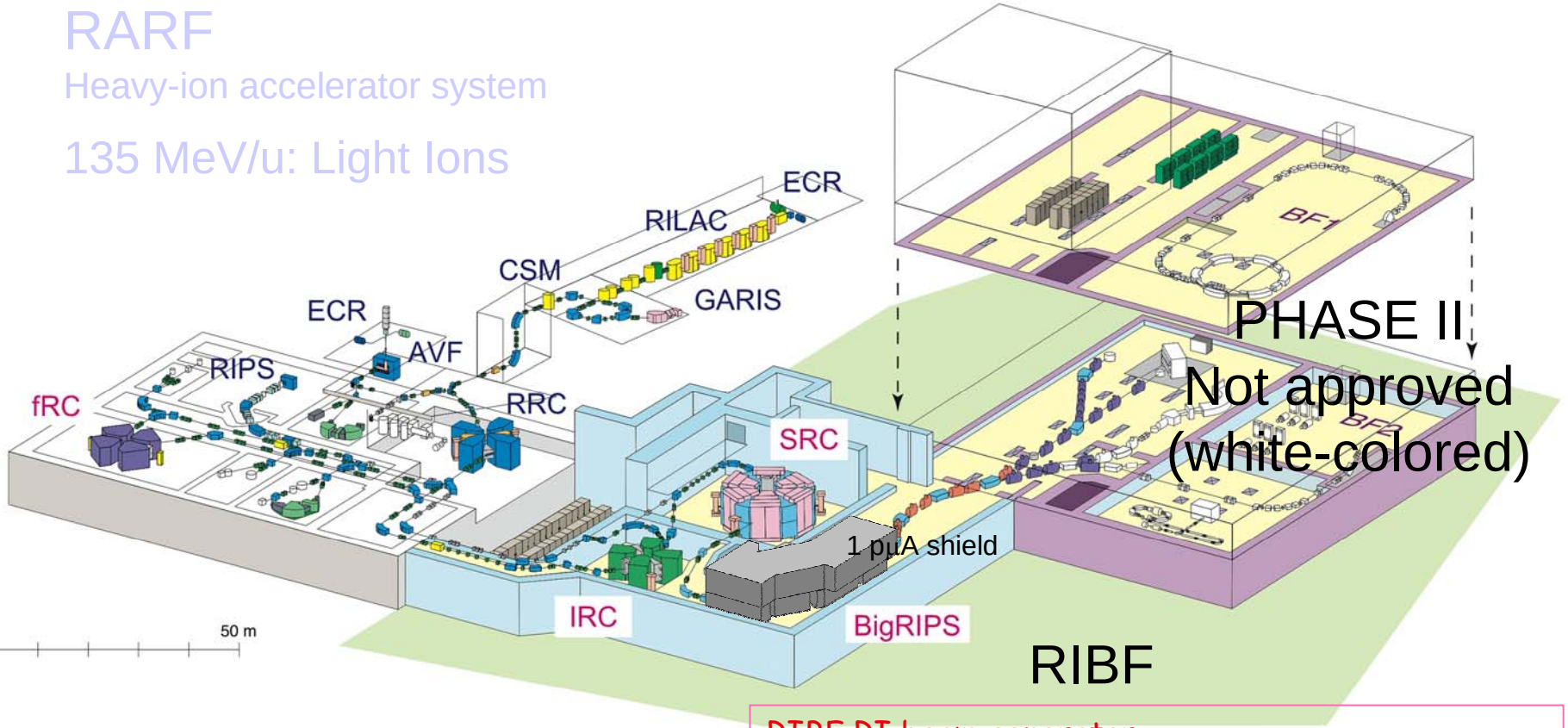


RIKEN Layout of RARF/RIBF

RARF

Heavy-ion accelerator system

135 MeV/u: Light Ions



PHASE II
Not approved
(white-colored)

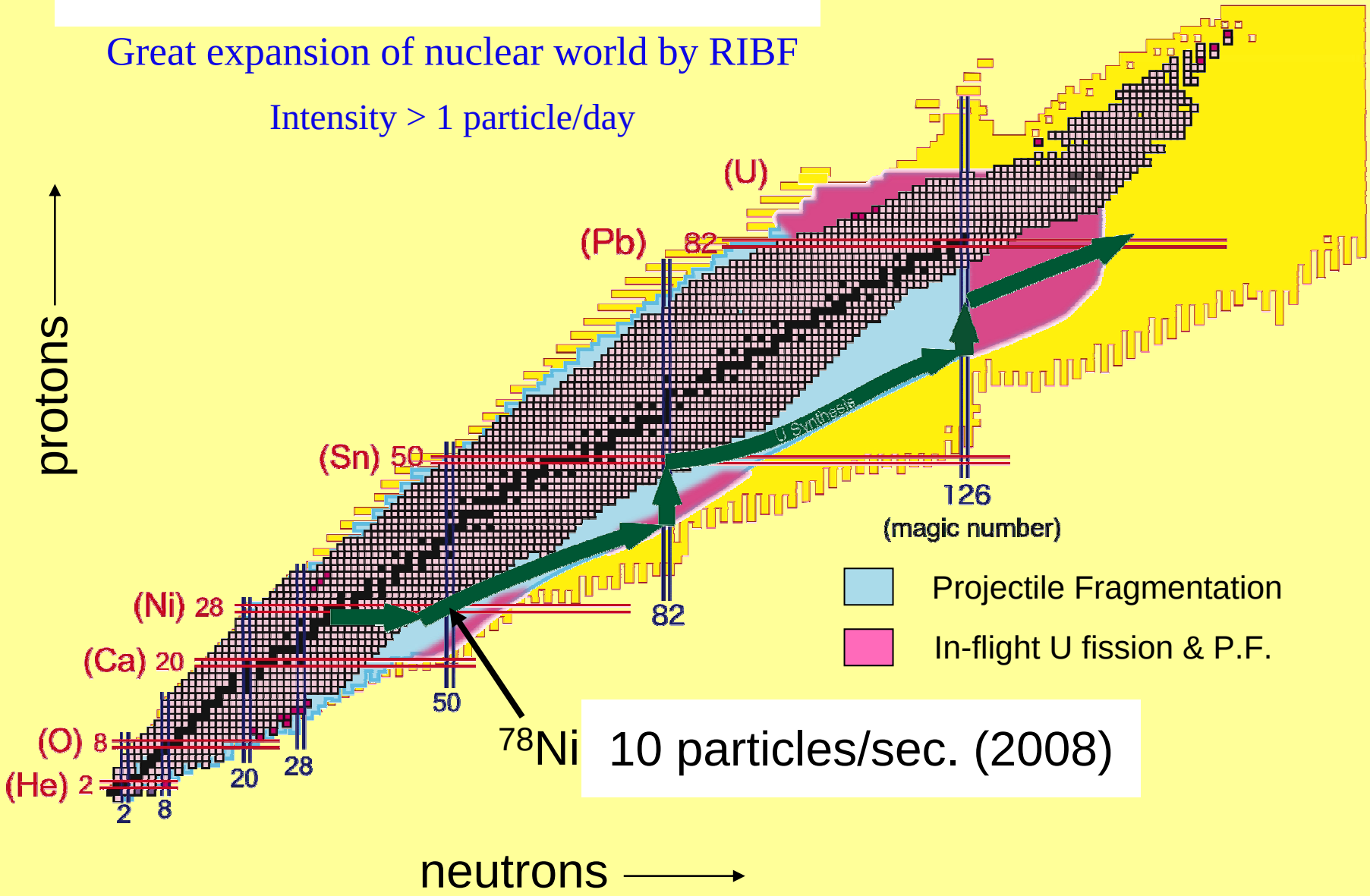
RIBF

PHASE I
350 MeV/u: All Ions

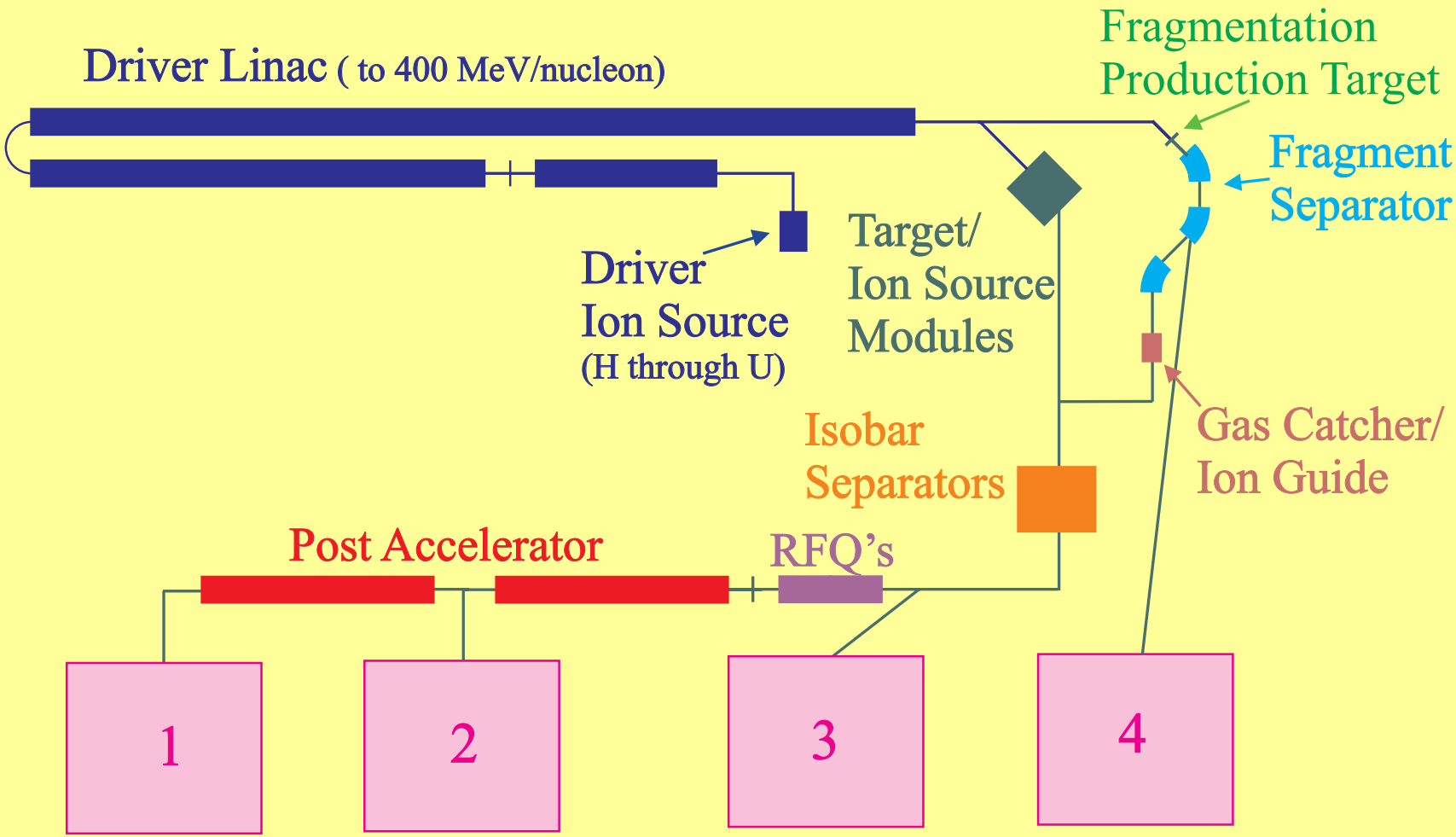
RIBF RI beam generator
featuring superconducting ring cyclotron (SRC)
and superconducting projectile fragment separator
(BigRIPS) will be commissioned in 2006.

Great expansion of nuclear world by RIBF

Intensity > 1 particle/day



USA RIA Layout



Experimental Areas:
1: < 12 MeV/u 2: < 1.5 MeV/u 3: Nonaccelerated 4: In-flight fragments

Summary of facilities and plans

Current facilities

Europe:	In-Flight – GSI, GANIL
	ISOL – REX ISOLDE, SPIRAL I
N-America:	In-Flight – NSCL at MSU
	ISOL: ISAC I at TRIUMF
	HRIBF at Oak Ridge

Future facilities

Europe:	SPIRAL II, SPES, MAFF (n-rich)	
	HIE-ISOLDE (all bems)	
		FAIR
		EURISOL
Japan:	RIKEN facility	
N-America	ISAC II	RIA