Super-FRS the Next-Generation Facility for Physics with Exotic Nuclei

Hans Geissel

Polish-German Meeting, Warsaw, November 24, 2003

- **Introduction**
- **The Superconducting FRagment Separator**
- **The Experimental Branches**

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Polish Contributions to Nuclear Structure Physics

Maria Skłodowska
*** 7.11.1867 in Warsaw**
Discovery of Polonium

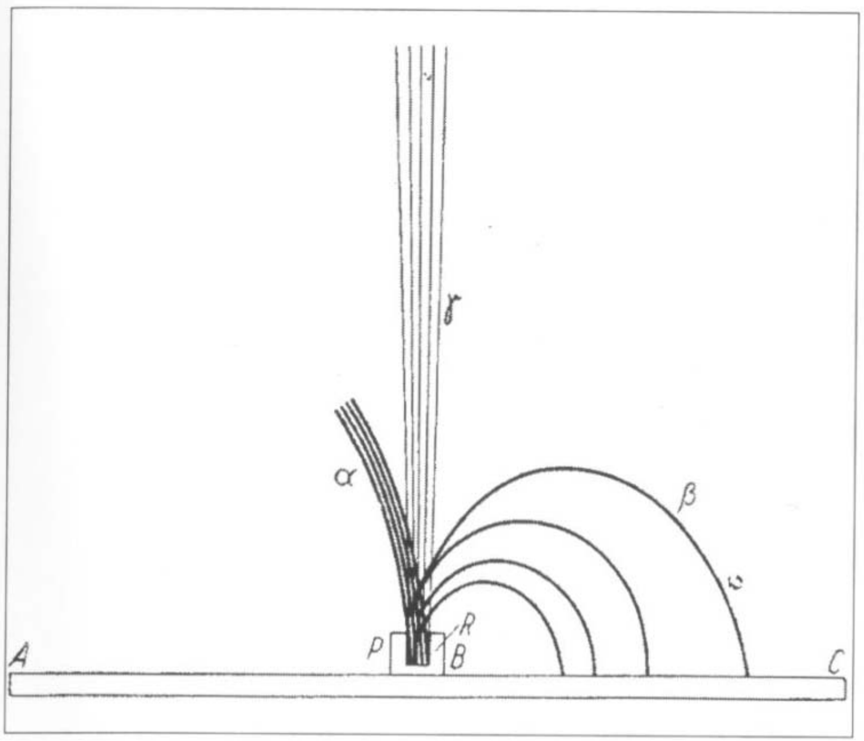
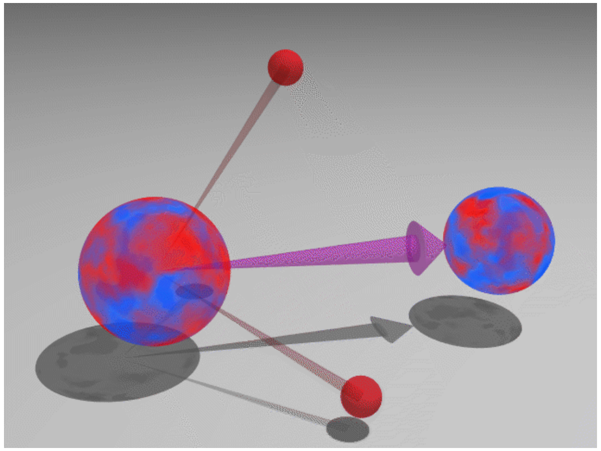


Schéma illustrant l'action d'un champ magnétique sur les rayonnements de radioactivité (Marie Curie, thèse).

The discovery of the two-proton radioactivity

Marek Pfützner
Institute of Experimental Physics
Warsaw University



Polish Collaborations in Nuclear Structure Research at GSI

- **At the UNILAC (SHIP, Online Separator)**
  Theory and experimental groups for super-heavy element research, spectroscopy of fusion products near the proton dripline and gamma spectroscopy (Coulomb excitation).

- **At the SIS18 (FRS, LAND-ALADIN, ESR)**
  From MUSIC to the discovery of 2p radioactivity
  Mass measurements
  Halo and skin nuclei
  Gamma spectroscopy (RISING)

- **At the Super-FRS**
  Low-Energy Branch: Spectroscopy (α, β, γ, p, 2p, ...)
  Ring Branch: Stored isomeric beams

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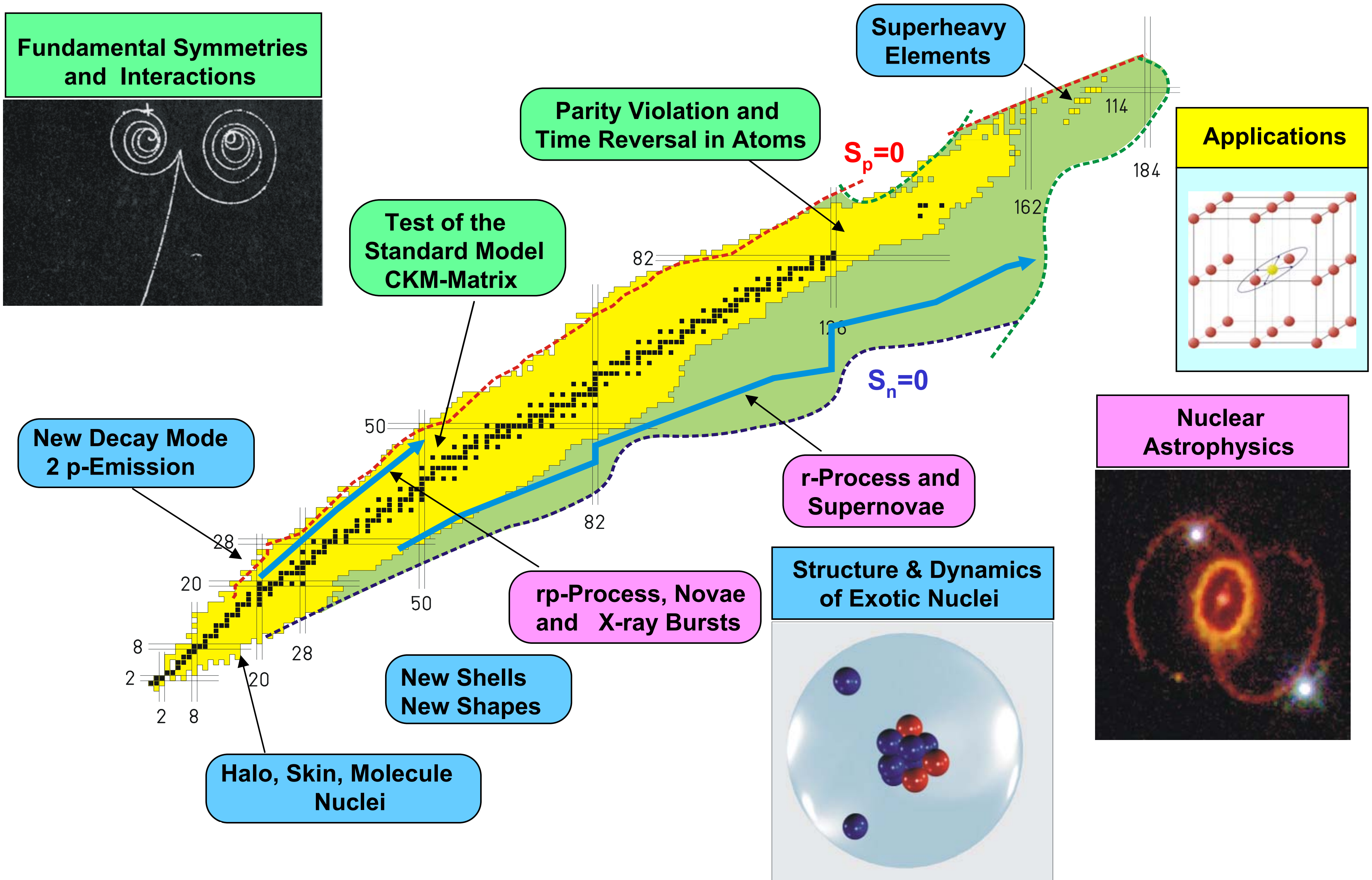
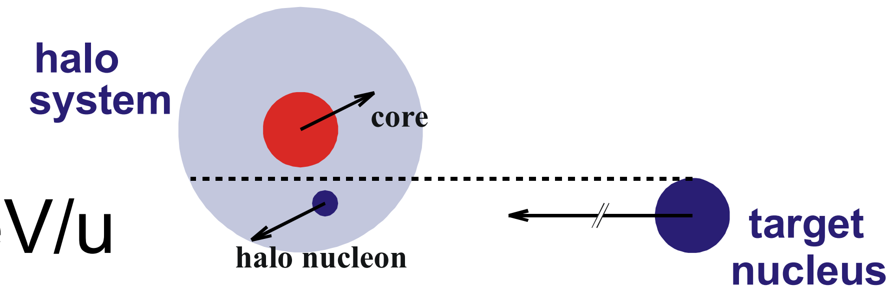
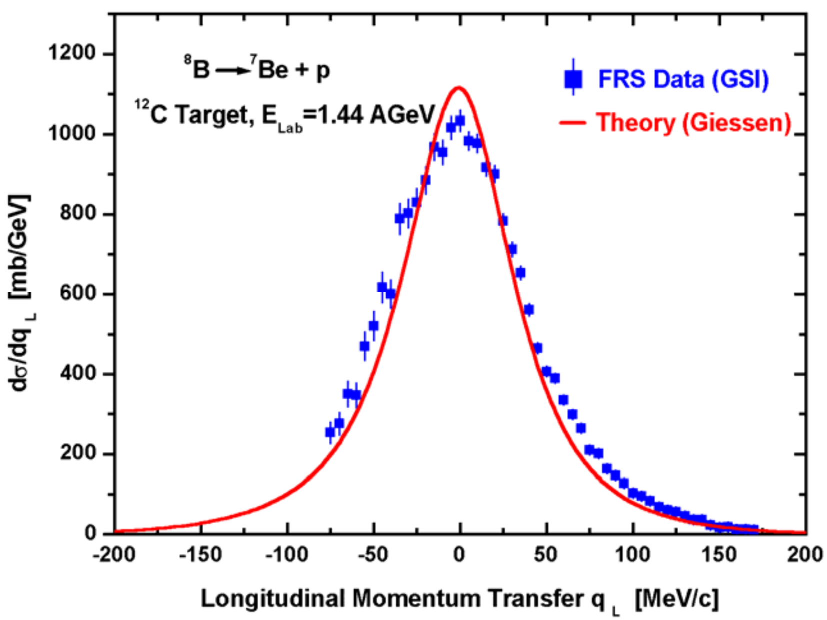
Physics with Exotic Nuclei

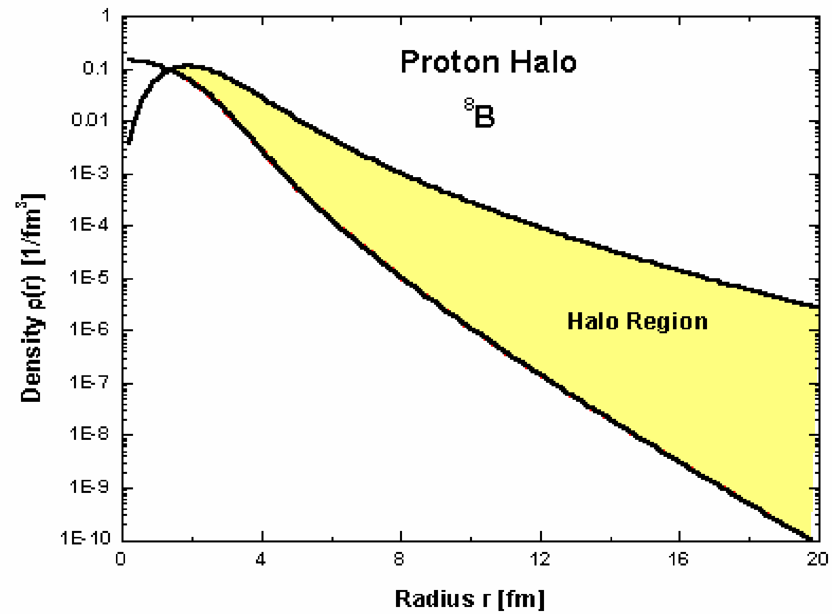


High Energies RIB →
Discovery of the Proton Halo

1500 MeV/u







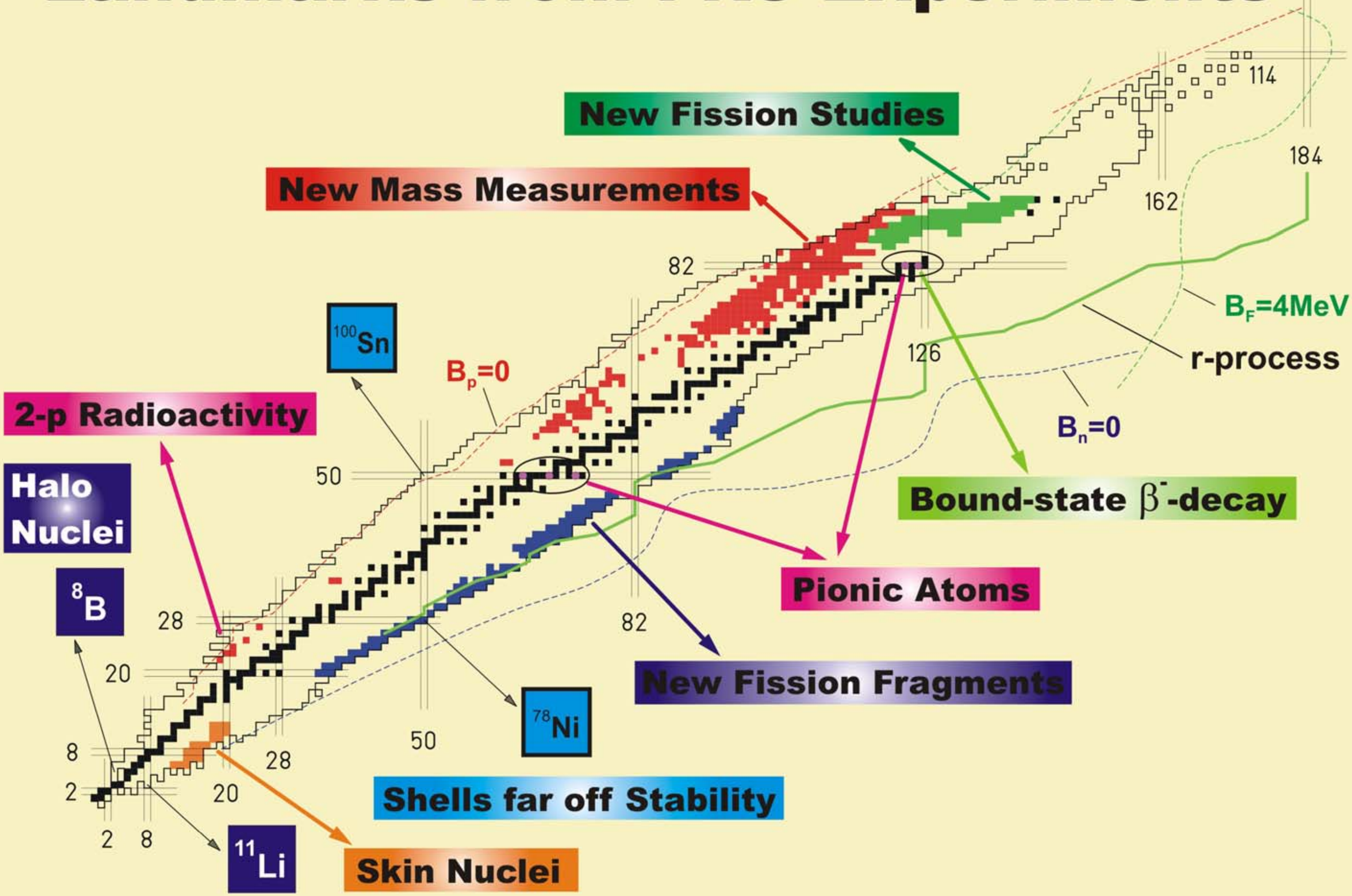
W. Schwab et al.,

Z.Phys. A350 (1995) 283

H. Lenske,

Prog. Part. Nucl. Phys. 46 (2001)

Landmarks from FRS Experiments



Limitations of the Present Facility

- Low primary beam intensity (e.g. 10^8 ^{238}U ions /s)
- Low transmission for projectile fission fragments (4-10%)
- Low transmission for fragments to the experimental areas (cave B,C) and into the storage ring ESR (a few %)
- Limited maximum magnetic rigidity
  @ FRS: for U-like fragments
  @ ESR: cooler performance and magnets
  @ALADIN, to deflect break-up fragments

Solutions→ SIS-100/300, Super-FRS, CR, NESR

- SIS-100/300 ^{238}U ions 10^{12} / s
- Large Acceptance Superconducting FRagment Separator (Super-FRS)
- Ion-optical Parameters:
- CR, NESR

$$\varepsilon_x = \varepsilon_y = 40\,\pi\,\text{mm mrad}$$

$$\varphi_x = \pm 40\ \text{mrad},$$

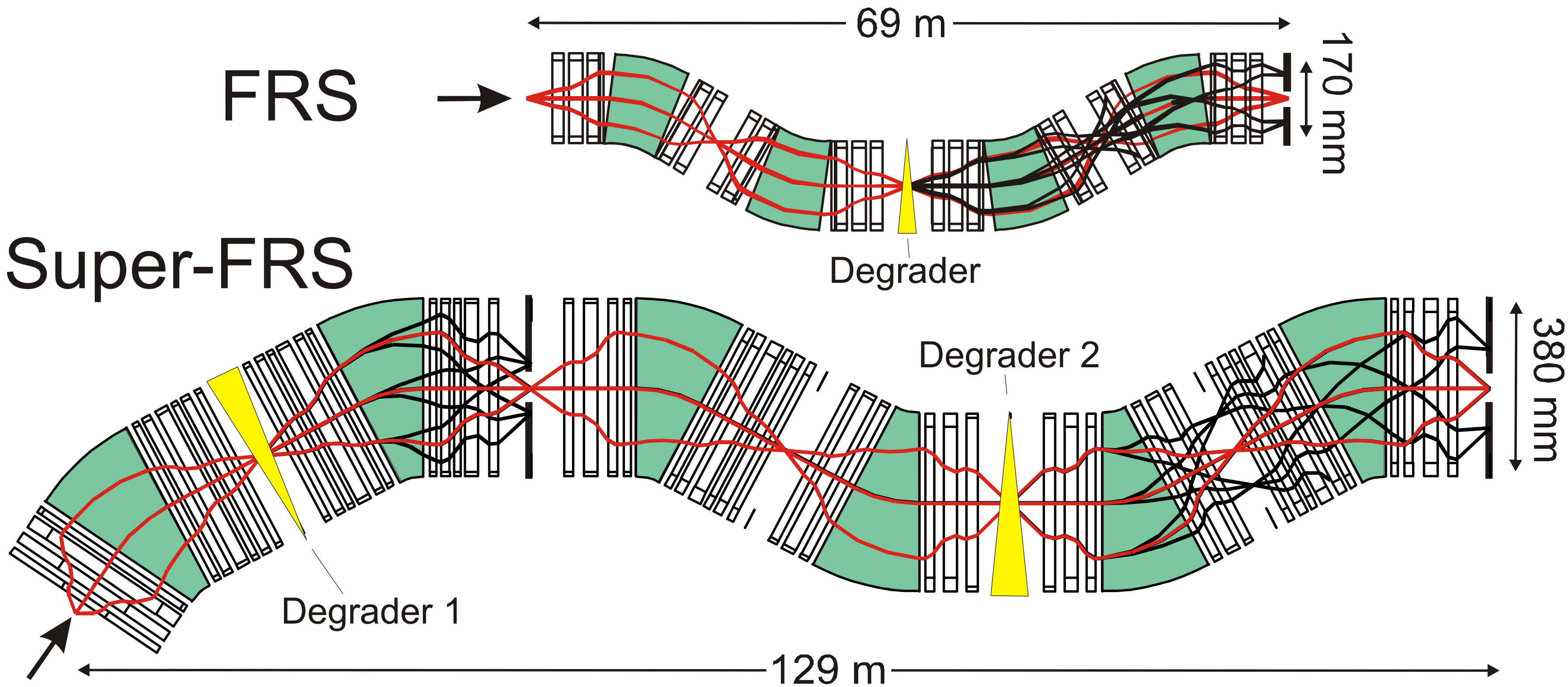
$$\varphi_y = \pm 20\ \text{mrad}$$

$$\frac{\Delta p}{p} = \pm 2.5\ \%$$

$$B\rho_{max} = 20\ \text{Tm}$$

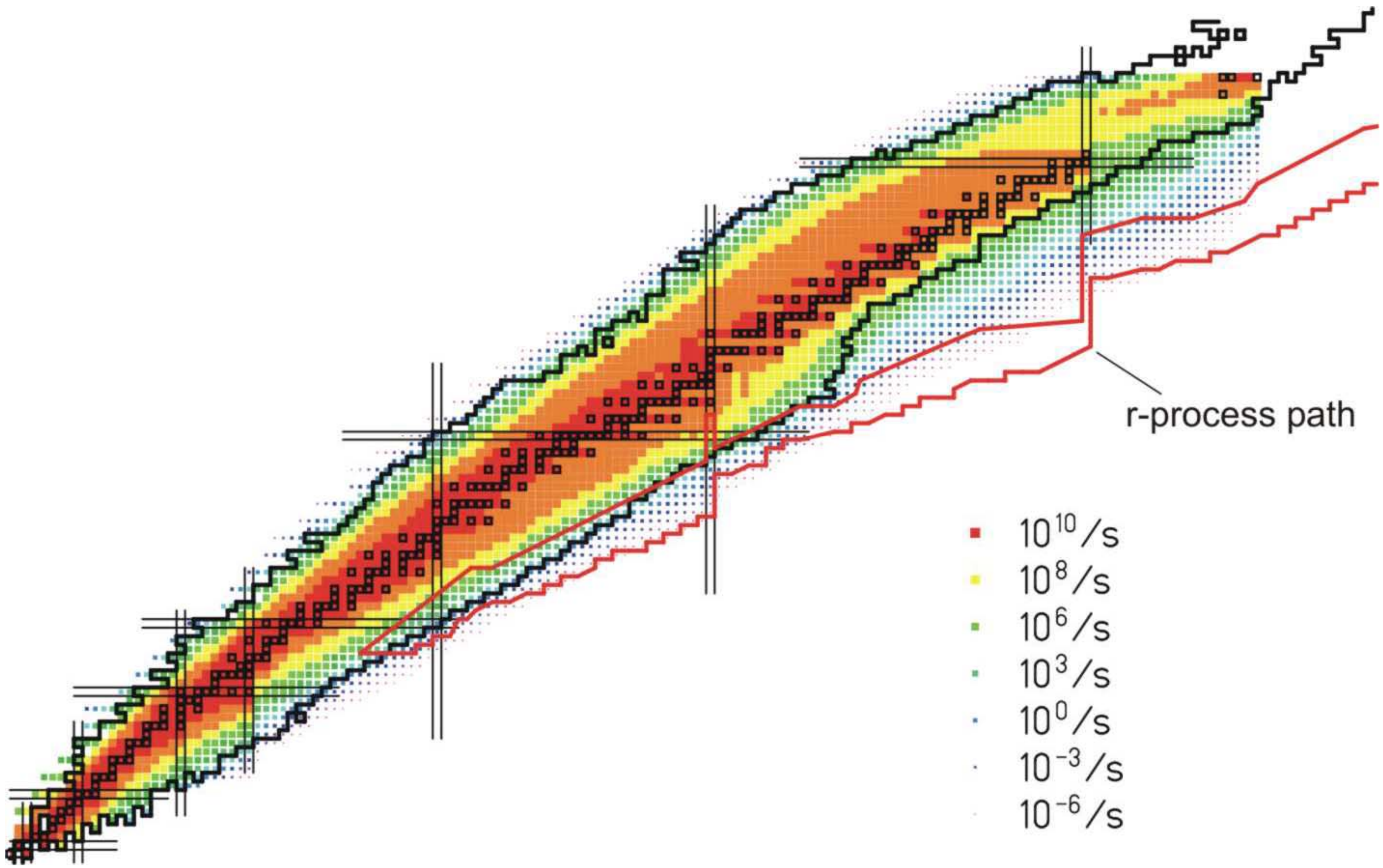
$$R_{ion} = 1500$$

Comparison of FRS and Super-FRS



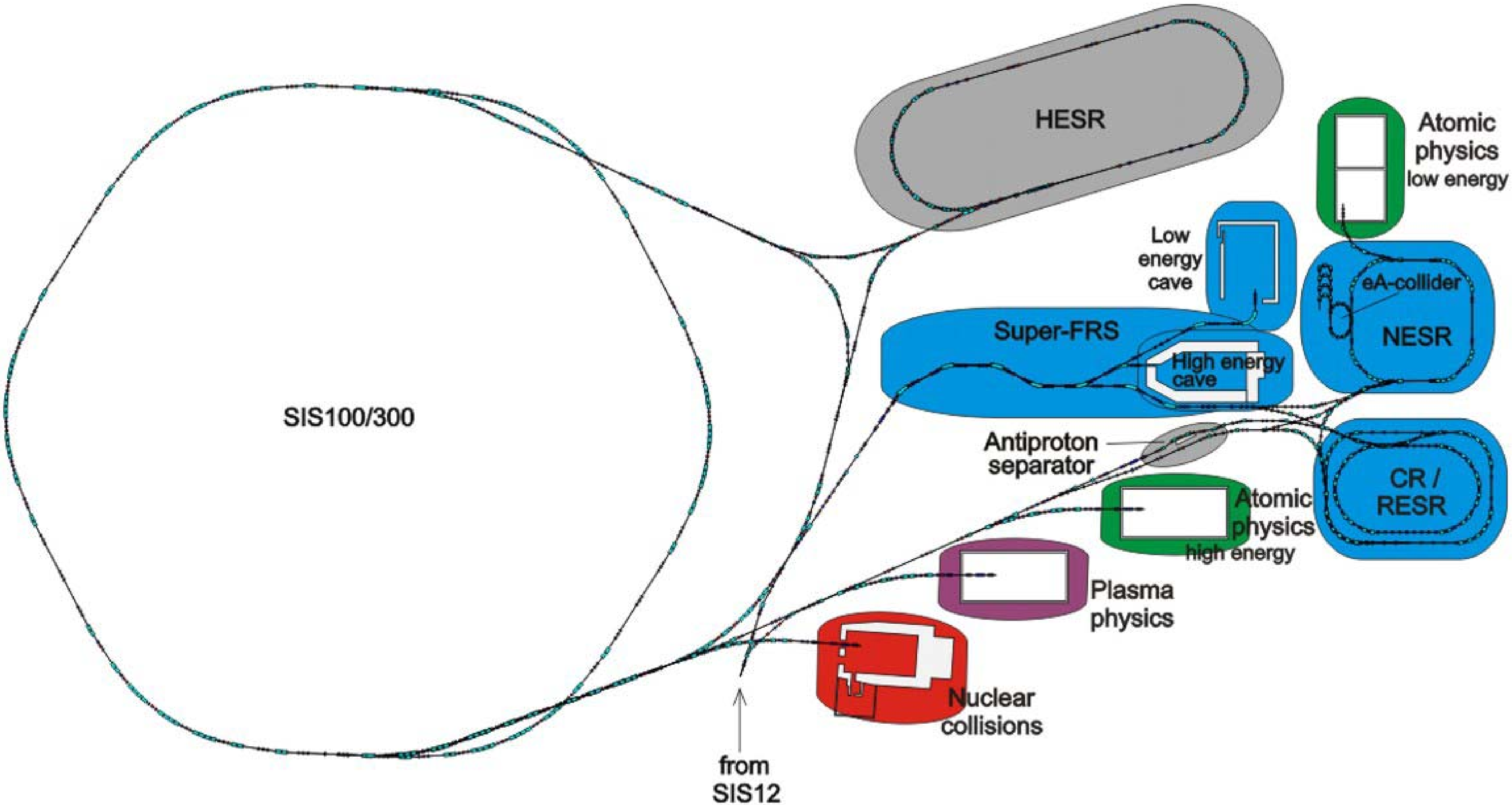
H. Geissel et al. NIM B 204 (2003) 71

The Super-FRS is ideal for Studies of r-Process Nuclei

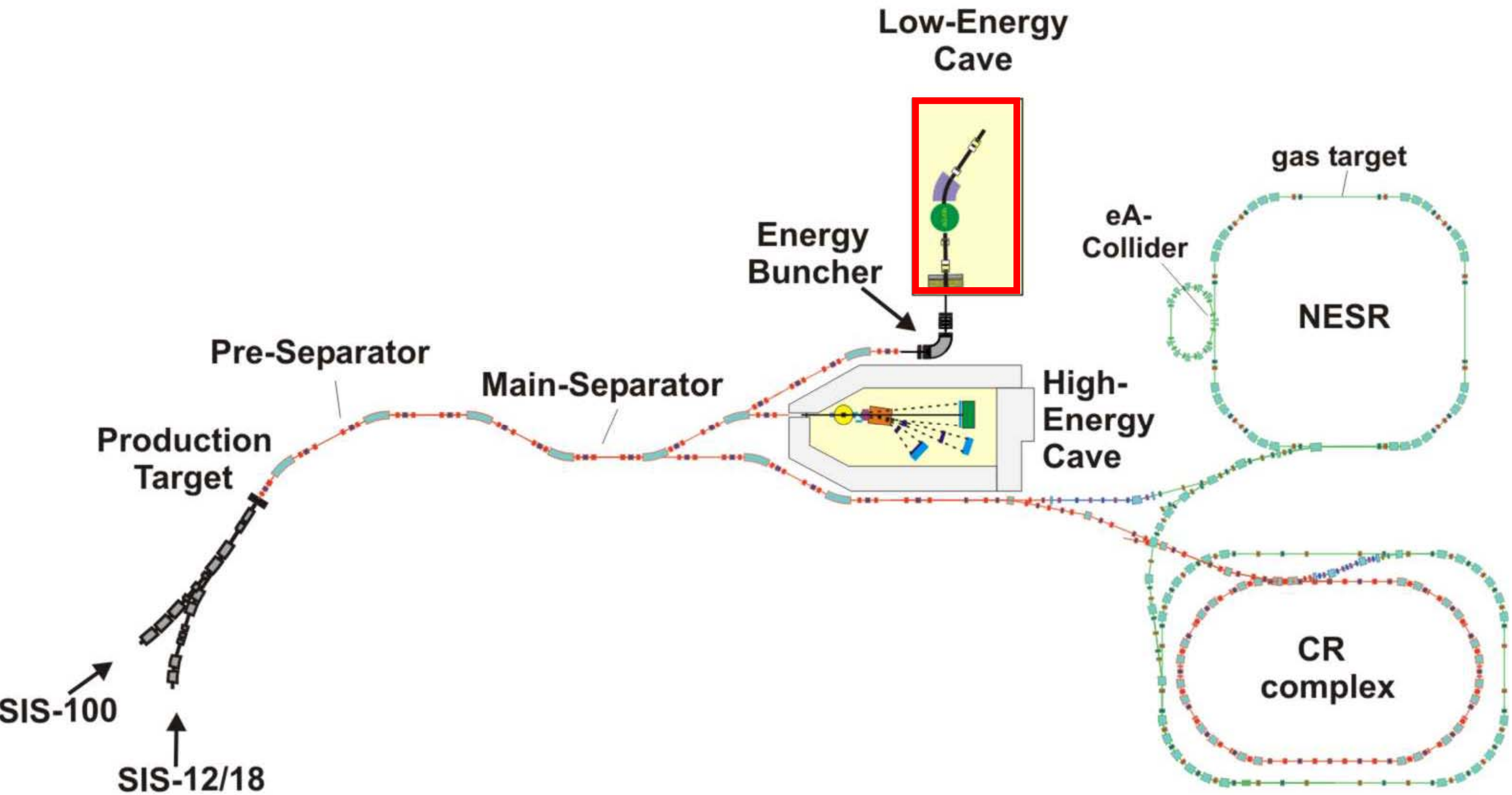


K.-H. Schmidt

The International Accelerator Facility for Beams of Ions and Antiprotons

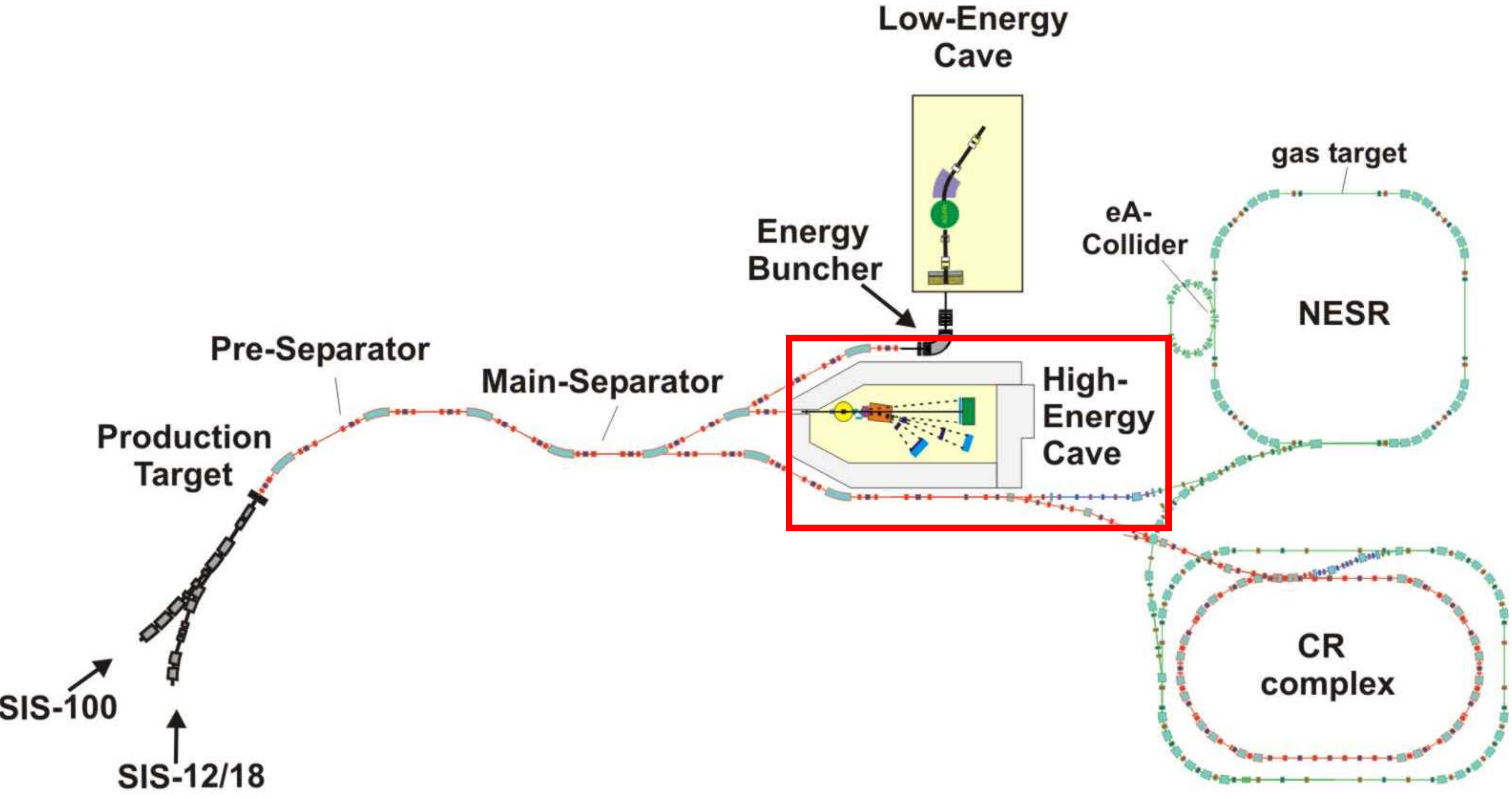


The Super-FRS and its Branches



see talk by Magda Górska

The Super-FRS and its Branches



Reactions with Relativistic Radioactive Beams

R3B

Experiments in the High Energy Branch of the Super-FRS

T. Aumann, H. Emling, B. Jonson

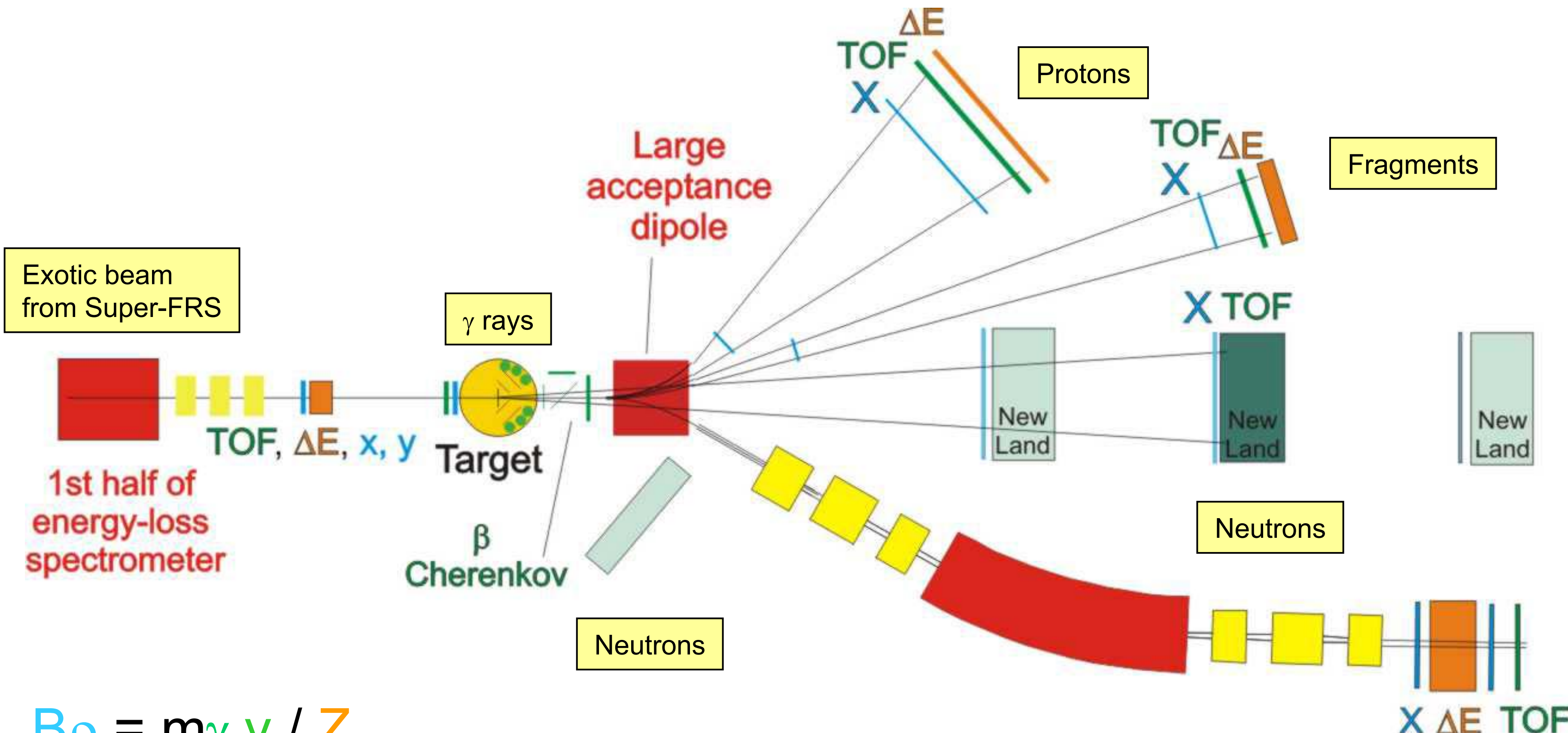
Experiments	Physics Goals
➢ knockout and quasi-free scattering	single-particle occupancies, spectral functions, correlations, clusters, resonances beyond the drip lines
➢ electromagnetic excitation	single-particle occupancies, astrophysical reactions (S factor), soft coherent modes, giant resonance strength, B(E2)
➢ charge-exchange reactions	Gamov-Teller strength, spin-dipole resonance, neutron skins
	shell structure, dynamical properties
➢ fission ➢ spallation	reaction mechanism, applications (waste transmutation, ...)
➢ fragmentation	γ-ray spectroscopy, isospin-dependence in multifragmentation

The High Energy Experimental Setup

Reactions with Relativistic Radioactive Beams R3B

A versatile setup for kinematical complete measurements

Large-acceptance measurements

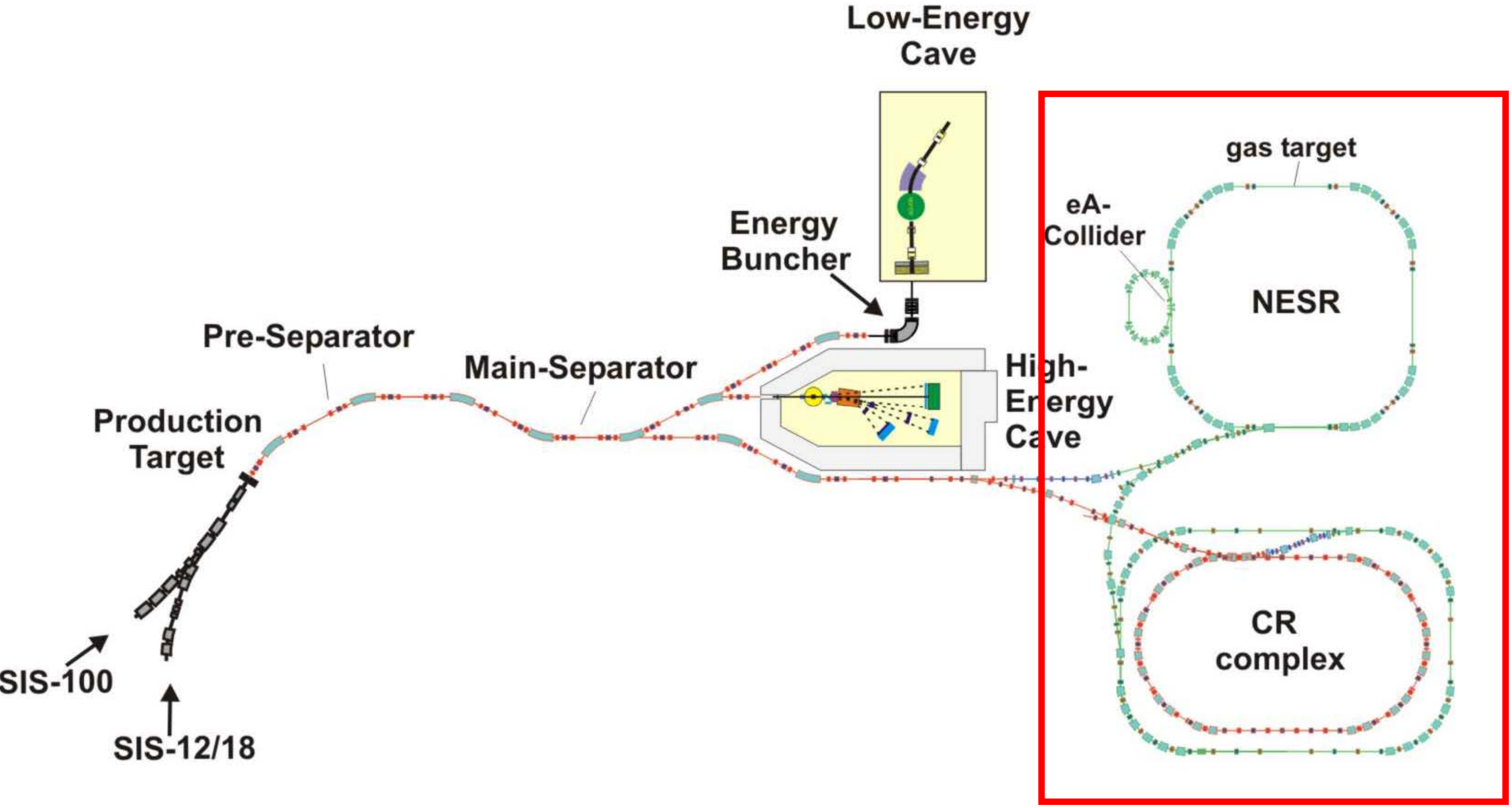


$B\rho = m\gamma\, v / Z$

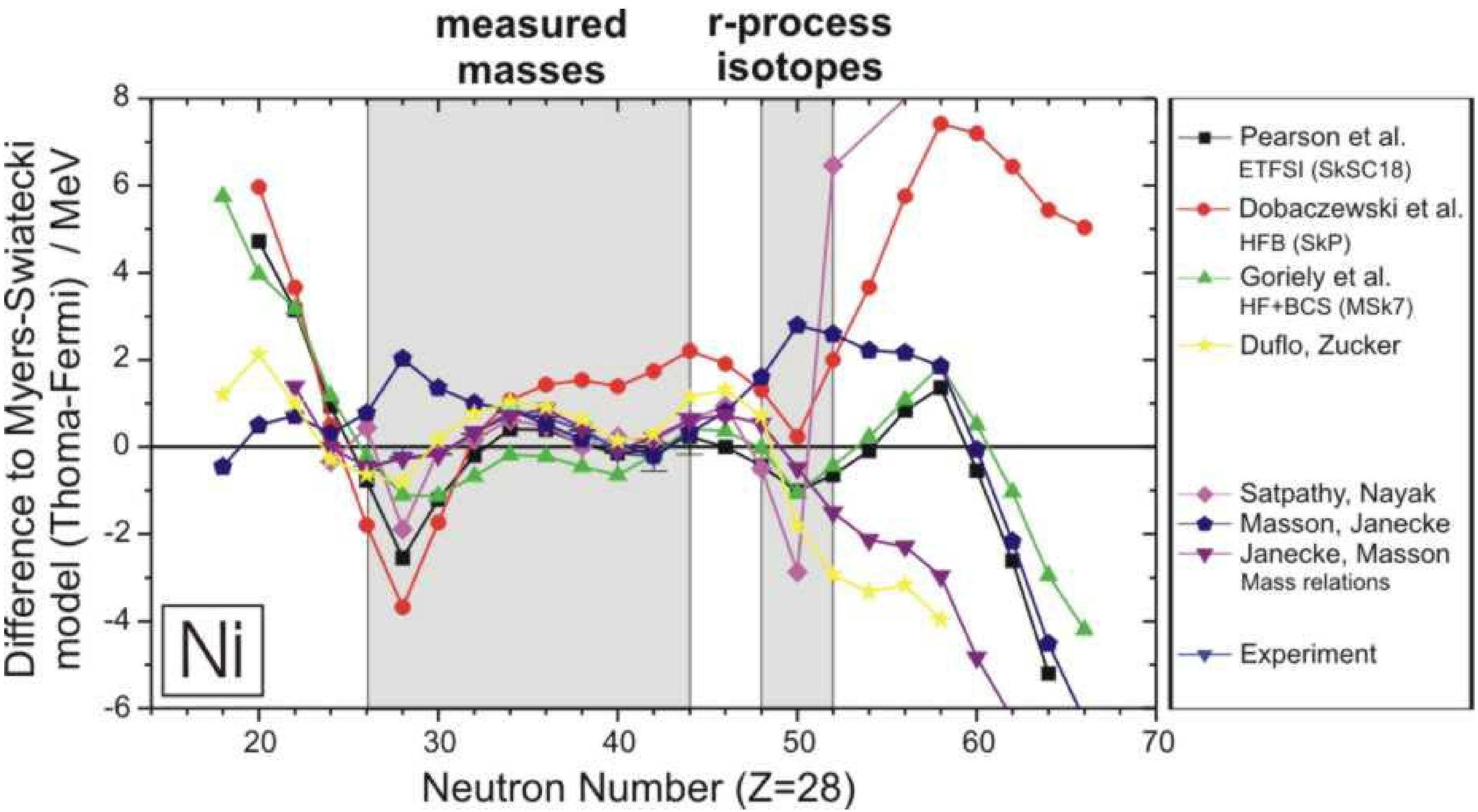
High-resolution momentum measurement

T. Aumann

The Super-FRS and its Branches



Predictive Power of Mass Models



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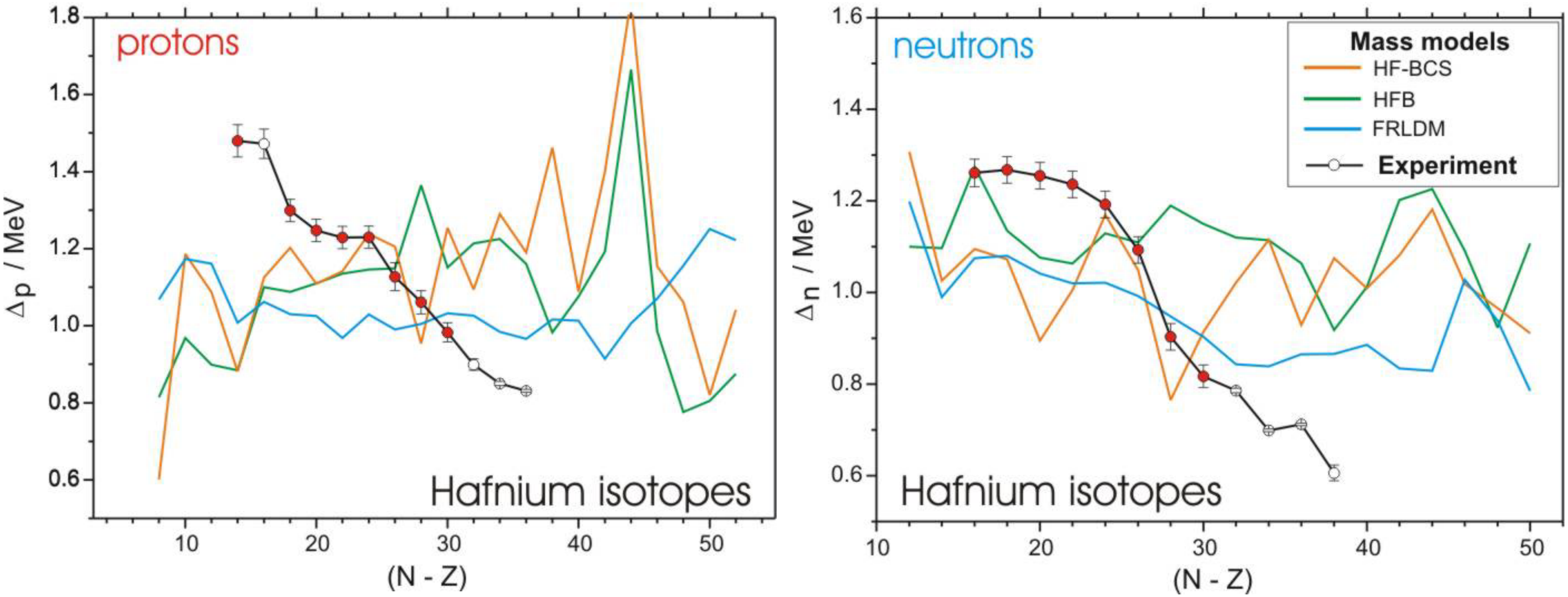
New Isospin Dependence of Pairing

Yu. Litvinov

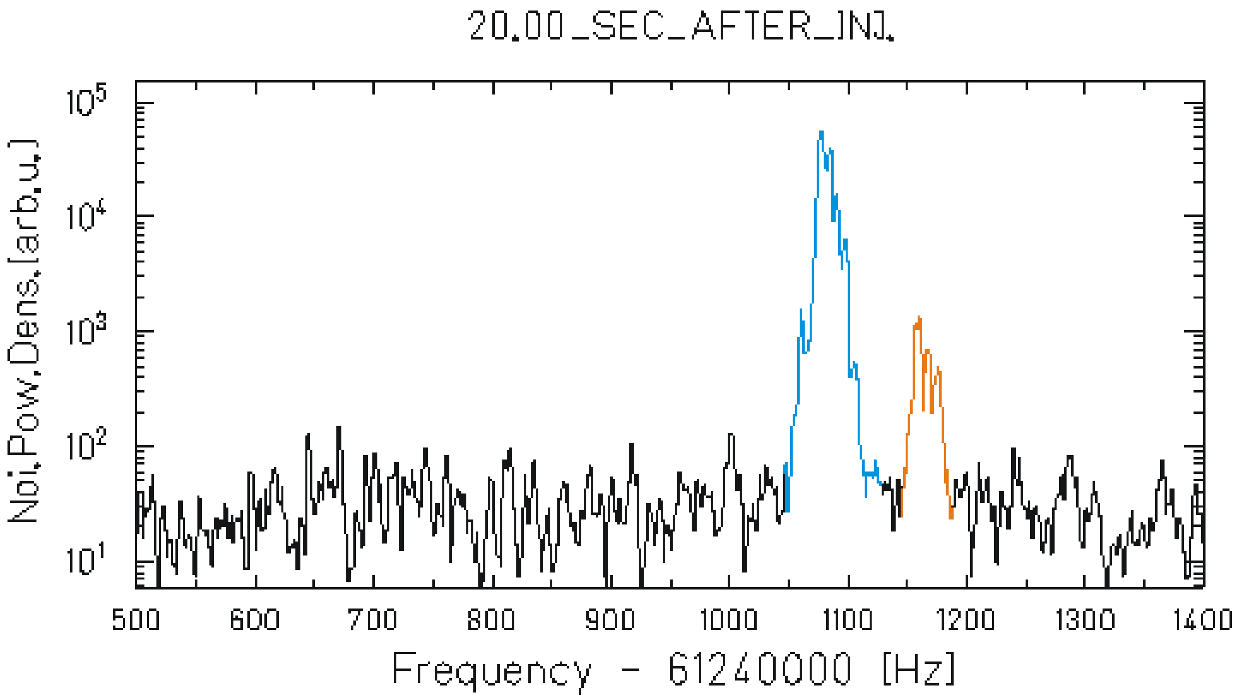
2. Pairing-Gap energy, deduced from 5-point binding difference

$$\Delta_{n5}(Z,N)=\frac{1}{8}\Big(m(Z,N+2)-4(Z,N+1)+6m(Z,N)-4m(Z,N-1)+m(Z,N-2)\Big)\cdot c^2$$

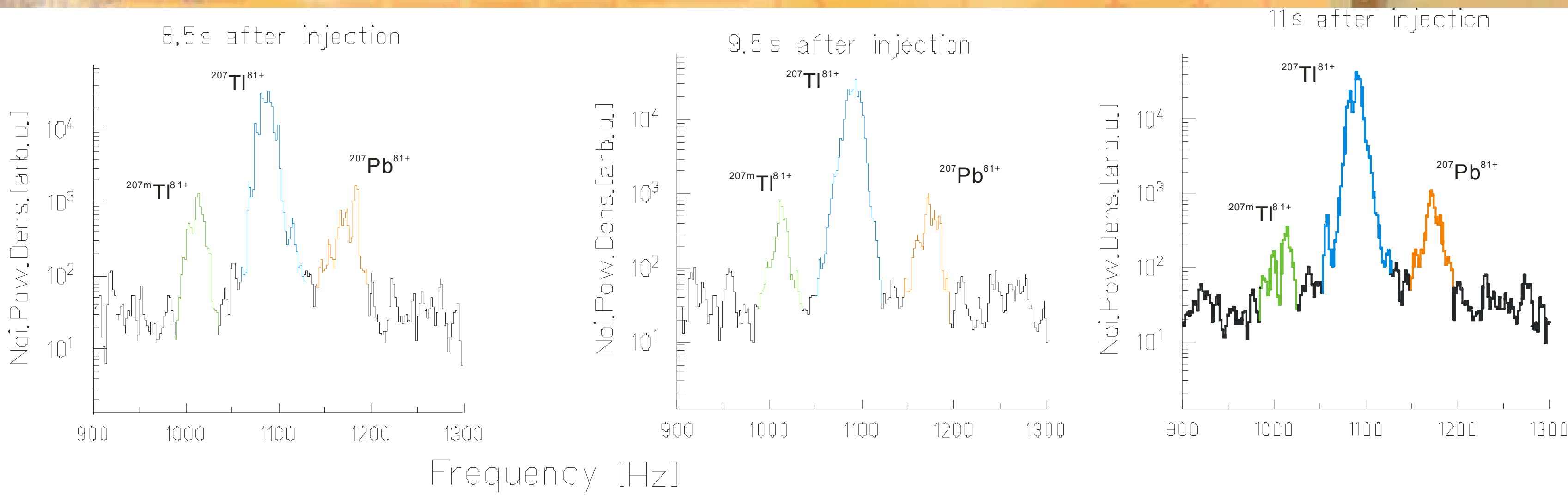
$$\Delta_{p5}(Z,N)=\frac{1}{8}\Big(m(Z+2,N)-4(Z+1,N)+6m(Z,N)-4m(Z-1,N)+m(Z-2,N)\Big)\cdot c^2$$

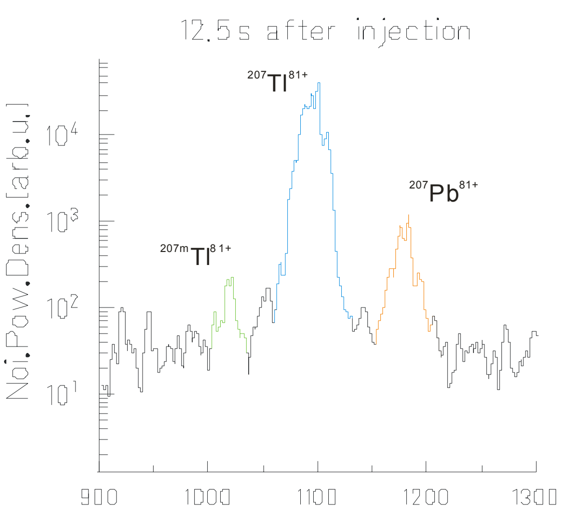


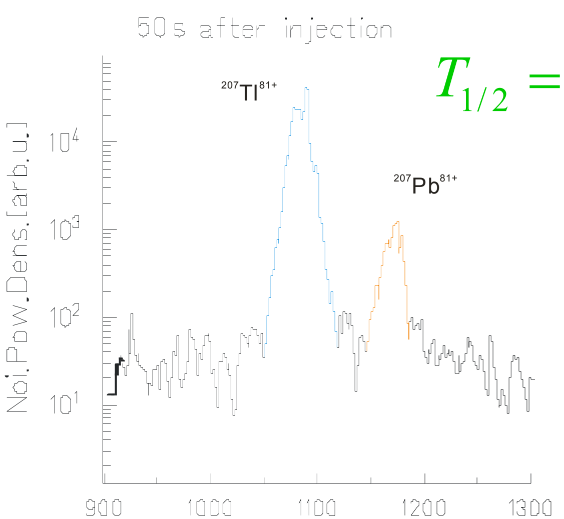
Lifetime Measurements of Short-lived Nuclei Applying Stochastic and Electronic Cooling



Observation of the Short-Lived Isomer ^{207m}Tl with Stochastic Cooling







$$T_{1/2} = \frac{T_{1/2\,lab}}{\gamma} = \frac{\ln 2}{\gamma\ \lambda_{lab}} = 1.48 \pm 0.12\ s$$

$$\lambda_{lab} = 0.328 \pm 0.026\ s^{-1}$$

$$\gamma = 1.4305$$

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D. Boutin, F. Nolden

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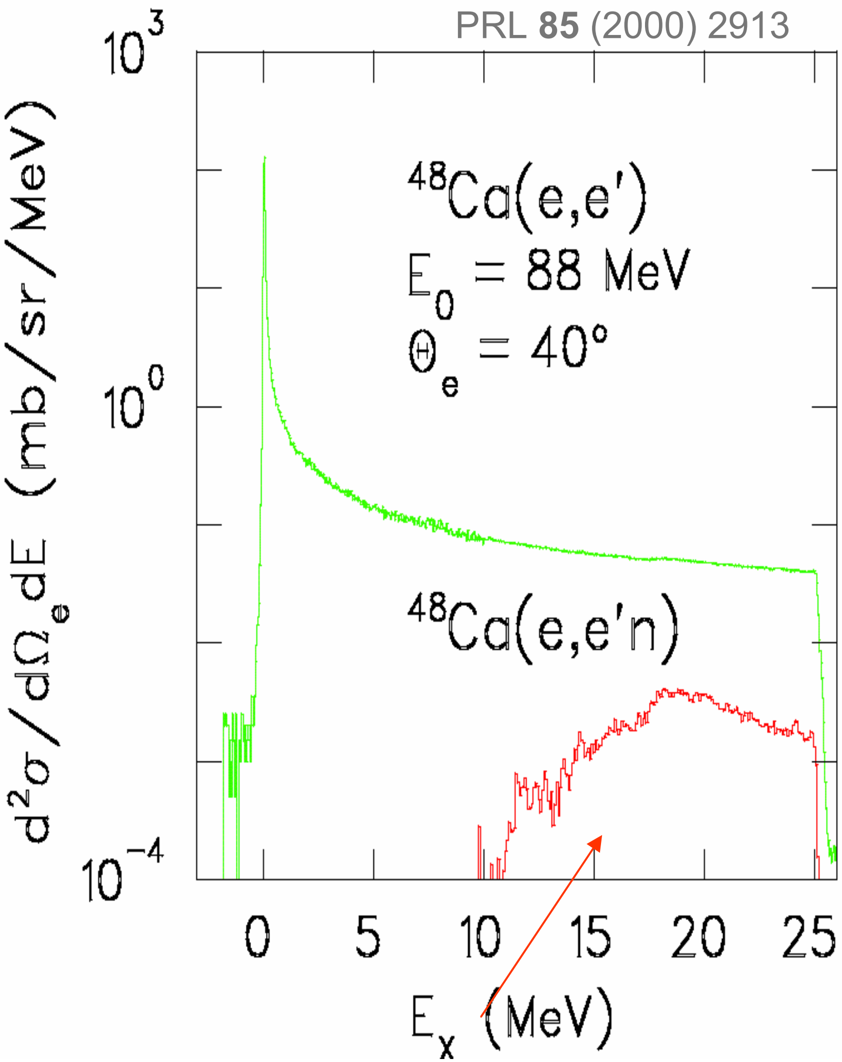
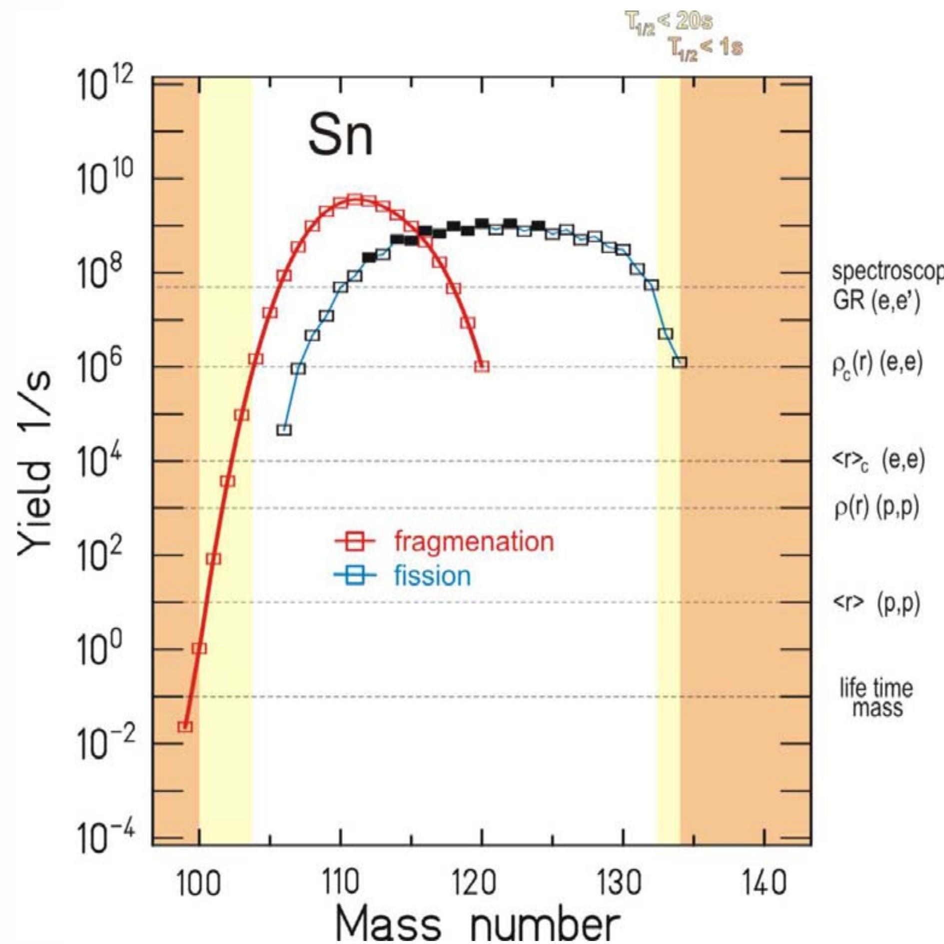
Advantage and Opportunities of eA Experiments





Coincidence with recoils

H. Simon, H. Weick

GSI

International Collaborations at the Super-FRS

- NUSTAR, 73 Council Members, 23 Countries
- Super-FRS: D(JLU), F(GANIL), JPN(Riken), USA(ANL, MSU),
- Low-Energy Branch: B, D, E, PL, SF, UK,
- High-Energy Branch: D, E, NL, S, (R3B)
- Ring Branch: D, JPN, NL, PL, S, USA

Summary

- Studies of exotic atoms and exotic nuclei will contribute significantly to the basic knowledge of matter.
- Precision experiments with stored exotic nuclei open up a new field for nuclear structure physics and astro-physics.
- The next–generation facility will present unique conditions for research and education.
- There are many technical challenges inviting especially also the next-generation scientists.

Electron Scattering

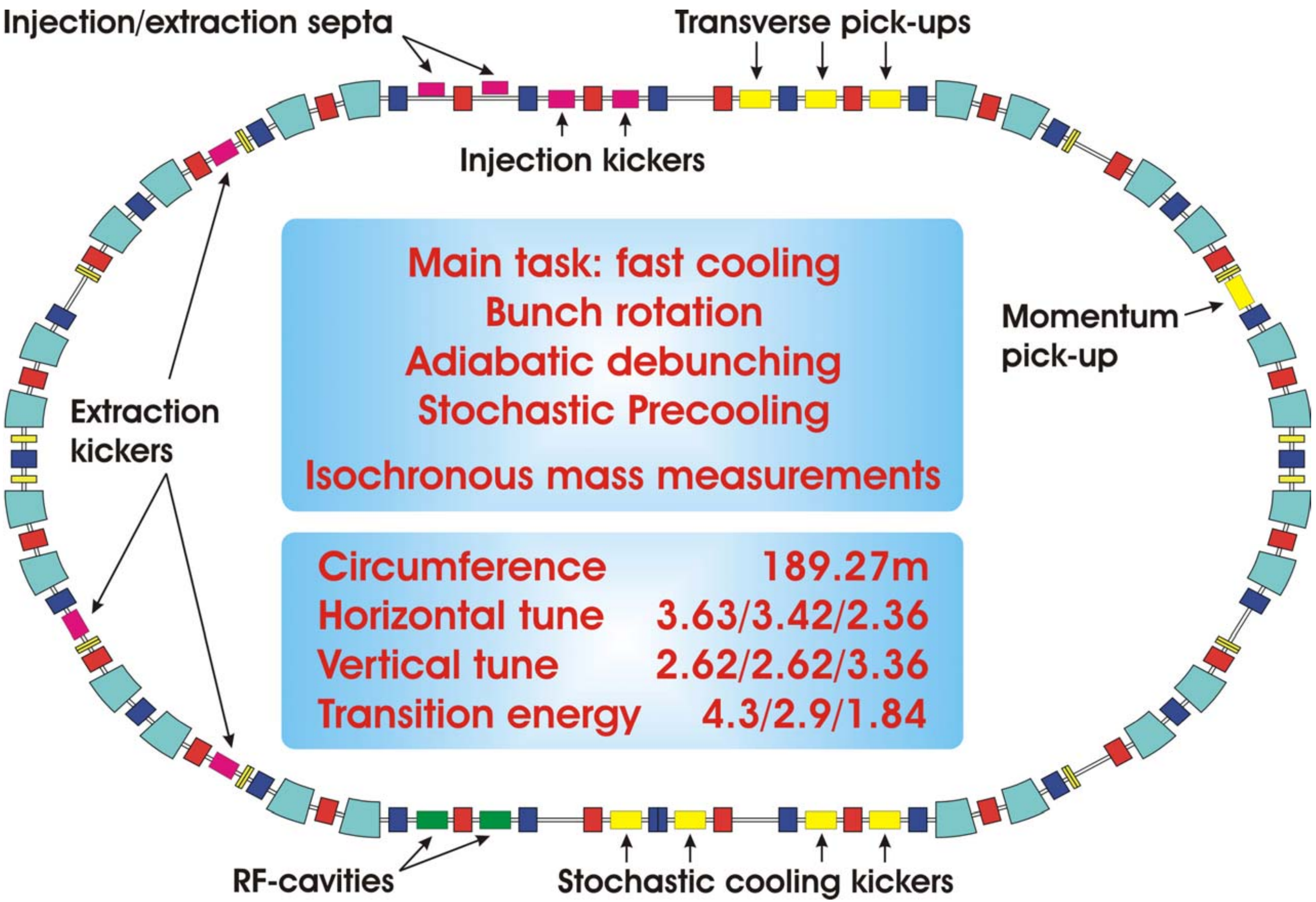
Conventional

- **Point like particle**
- **Pure electromagnetic probe**
  $\Rightarrow$ formfactors F(q)
- **F(q) transition formfactors**
  $\Rightarrow$ high selectivity to certain multipolarities

eA collider

- **Unstable nuclei**
- **Large recoil velocities**
  $\Rightarrow$ full identification (Z,A)
- **Kinematics**
  $\Rightarrow$ 4π - geometry, small angles complete kinematics
- **Bare ions**
  $\Rightarrow$ no atomic background

Layout of the CR Lattice



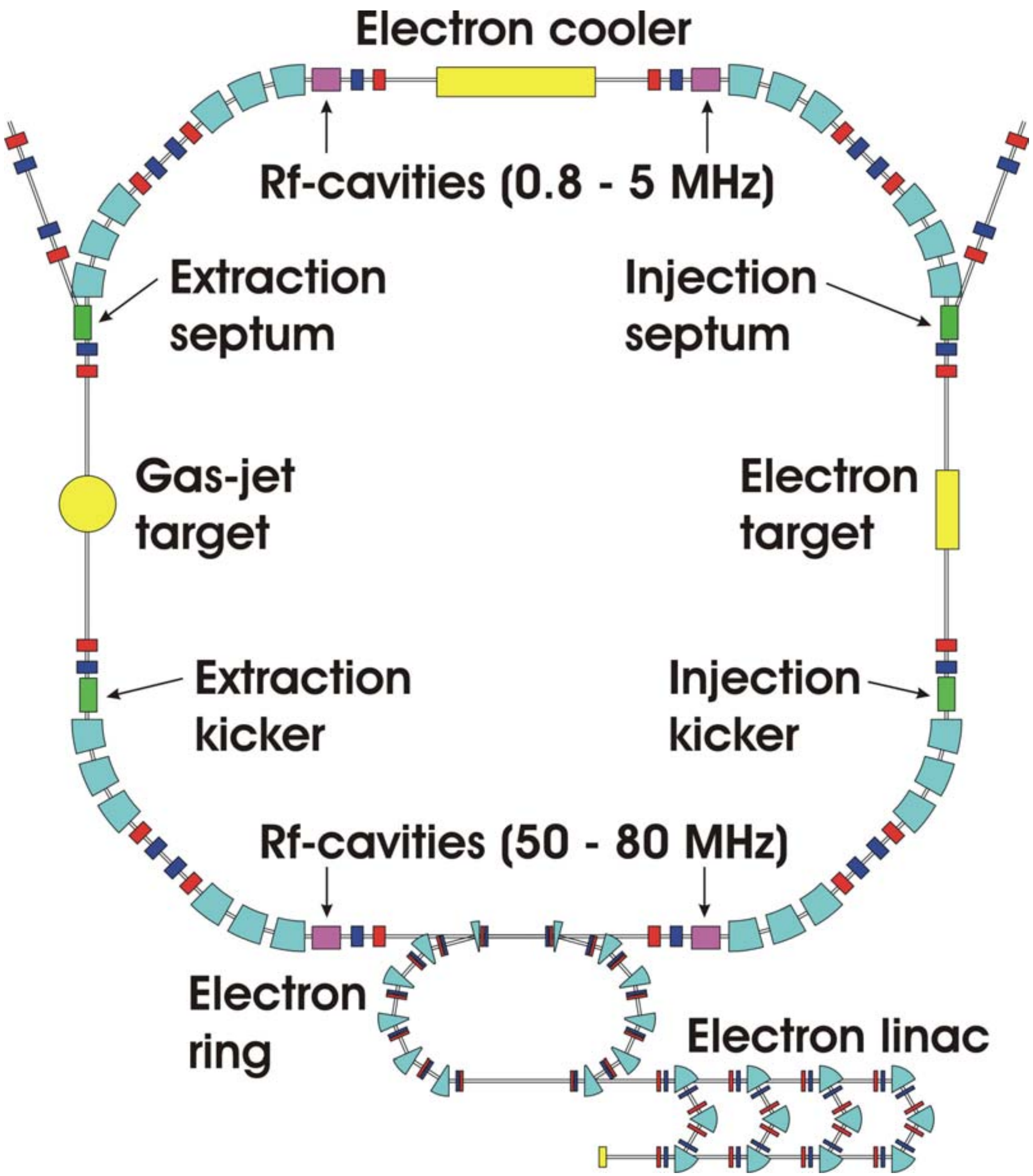
Main task: fast cooling
Bunch rotation
Adiabatic debunching
Stochastic Precooling

Isochronous mass measurements

Circumference	189.27m
Horizontal tune	3.63/3.42/2.36
Vertical tune	2.62/2.62/3.36
Transition energy	4.3/2.9/1.84

Lattice designed by A. Dolinskii

Layout of the NESR Lattice



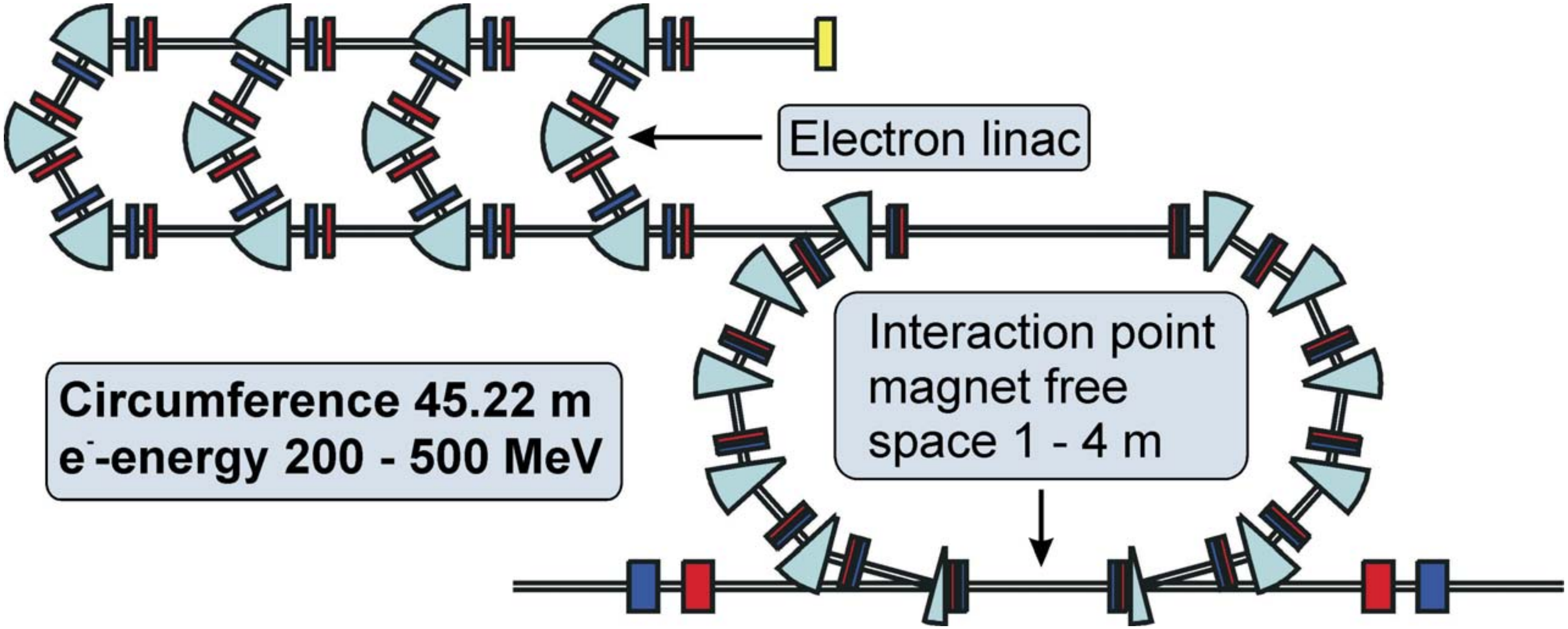
<u>Tasks</u>

In-ring-experiments at

- Gas-jet-target
- Electron target
- Electron ring

Deceleration to energies < 100 MeV/u

The Electron Ring



Horizontal/vertical emittance [mm mrad]	0.05
Momentum spread [%]	± 0.018
Horizontal tune	3.8
Vertical tune	2.8
Luminosity [cm^{-2} s^{-1}]	~ 1×10^{28}