

NUSTAR @ FAIR



Reiner Krücken
for the NUSTAR collaboration

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Technische Universität München
&
Maier-Leibnitz-Laboratory
for Nuclear and Particle Physics

NUSTAR @ FAIR



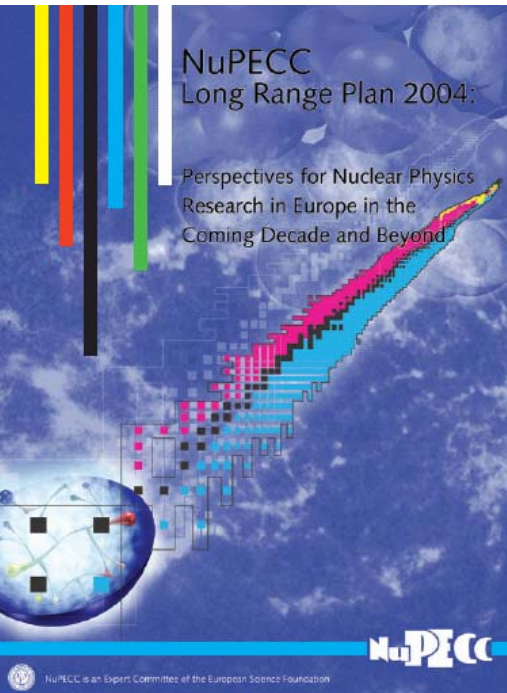
Nuclear Structure & Dynamics at the Extremes

The NUSTAR facility at the Super-FRS

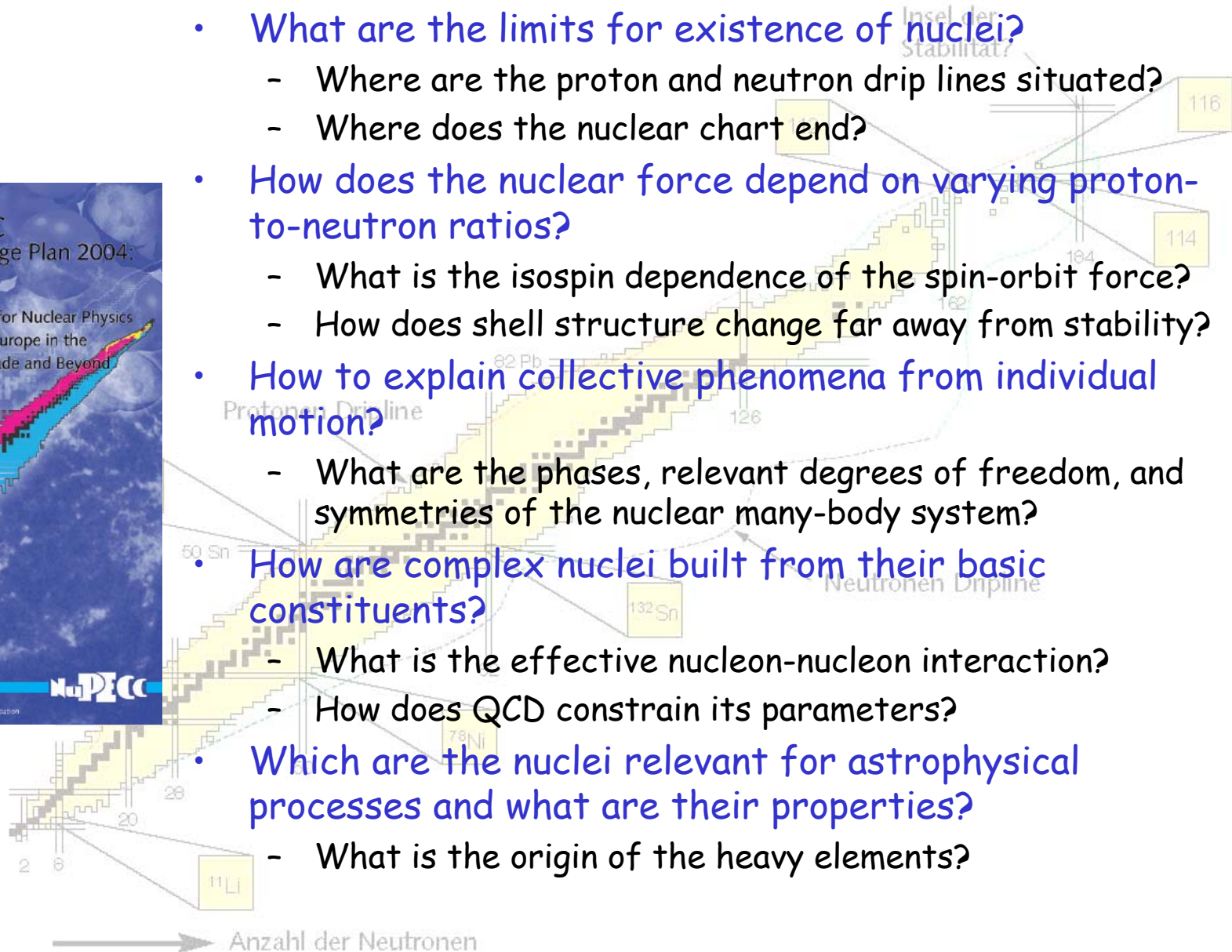
Unique Possibilities with NUSTAR

Conclusions

Long Standing Questions of Nuclear Structure Physics

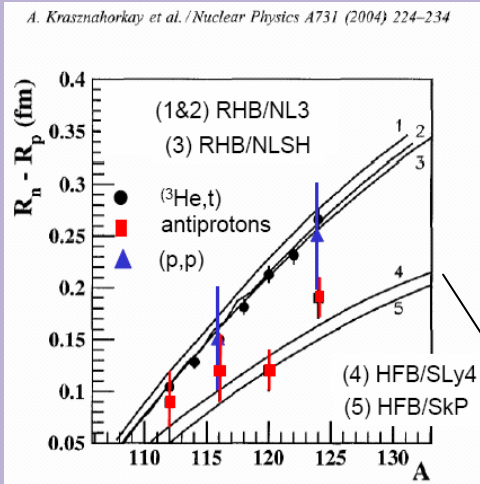


- What are the limits for existence of nuclei?
 - Where are the proton and neutron drip lines situated?
 - Where does the nuclear chart end?
- How does the nuclear force depend on varying proton-to-neutron ratios?
 - What is the isospin dependence of the spin-orbit force?
 - How does shell structure change far away from stability?
- How to explain collective phenomena from individual motion?
 - What are the phases, relevant degrees of freedom, and symmetries of the nuclear many-body system?
- How are complex nuclei built from their basic constituents?
 - What is the effective nucleon-nucleon interaction?
 - How does QCD constrain its parameters?
- Which are the nuclei relevant for astrophysical processes and what are their properties?
 - What is the origin of the heavy elements?

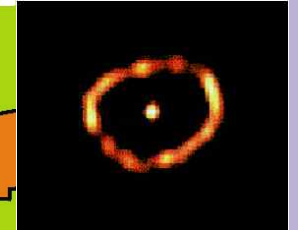
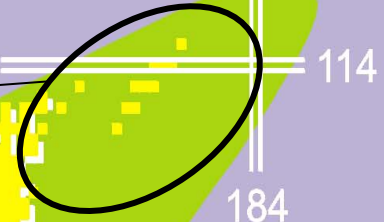
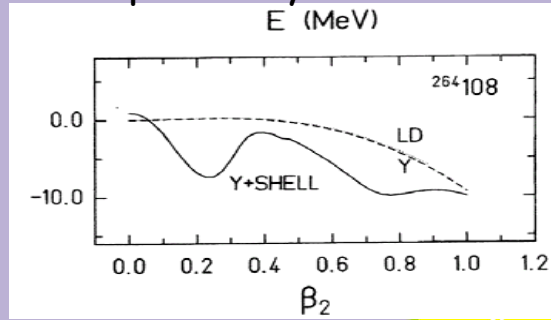


Nuclear Structure at the extremes

Neutron skins



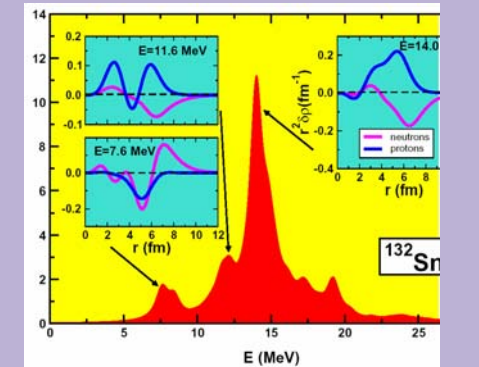
Superheavy elements



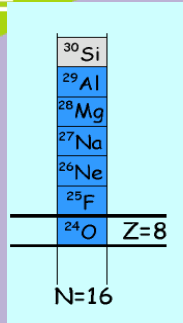
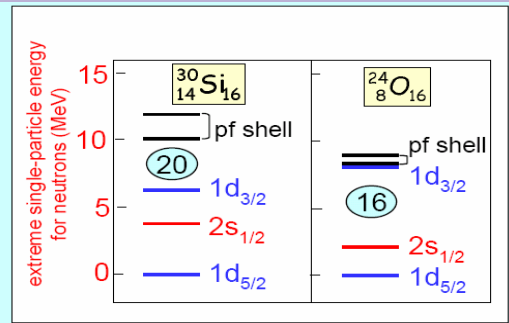
Shell quenching by diffuse surface



Soft collective modes

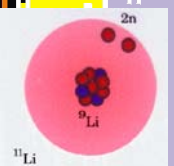


New shell gaps through residual interaction



Halos

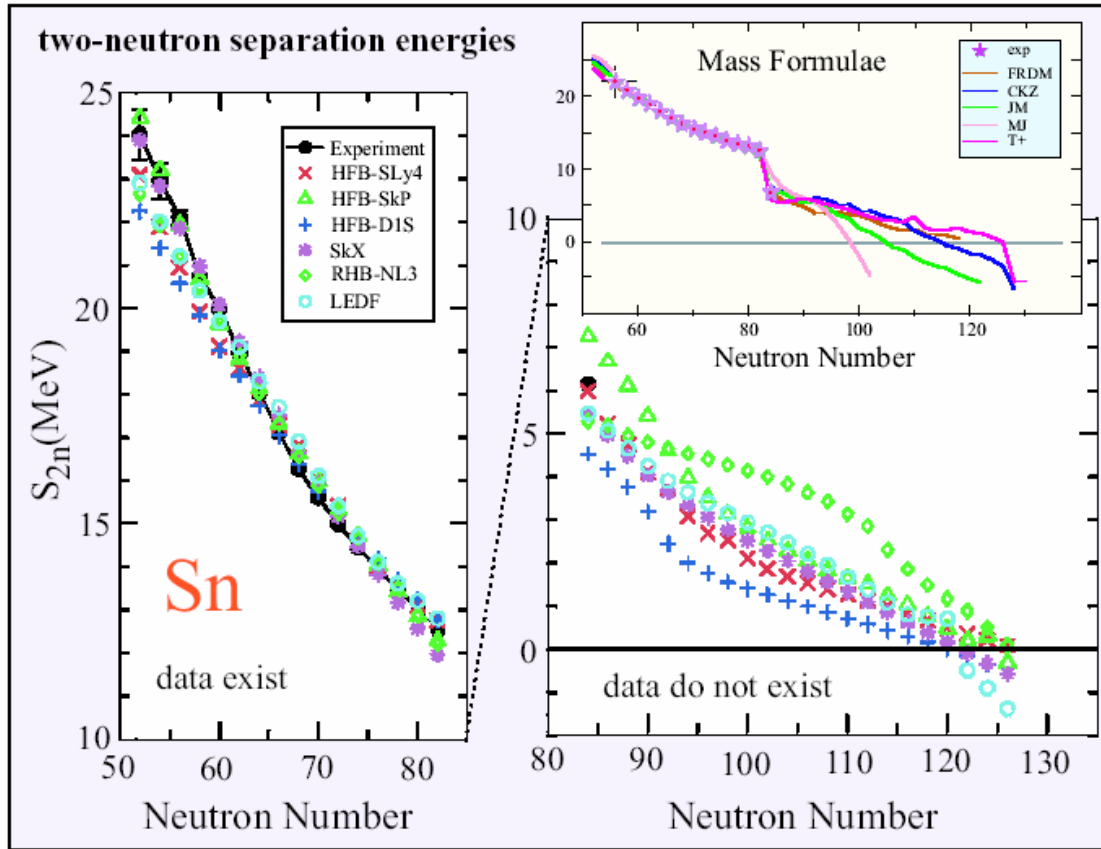
Neutron number, N



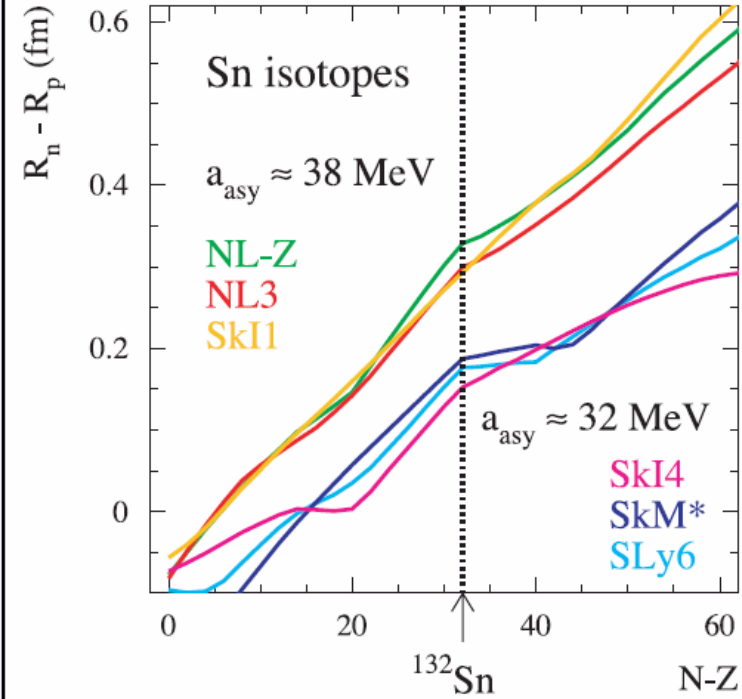
Proton number, Z

Neutron number, N

Lack of predictive power of mean-field models



from RIA Whitepaper



M. Bender, P.H. Heenen, P.G. Reinhard
Rev. Mod. Phys. 75 (2003) 122

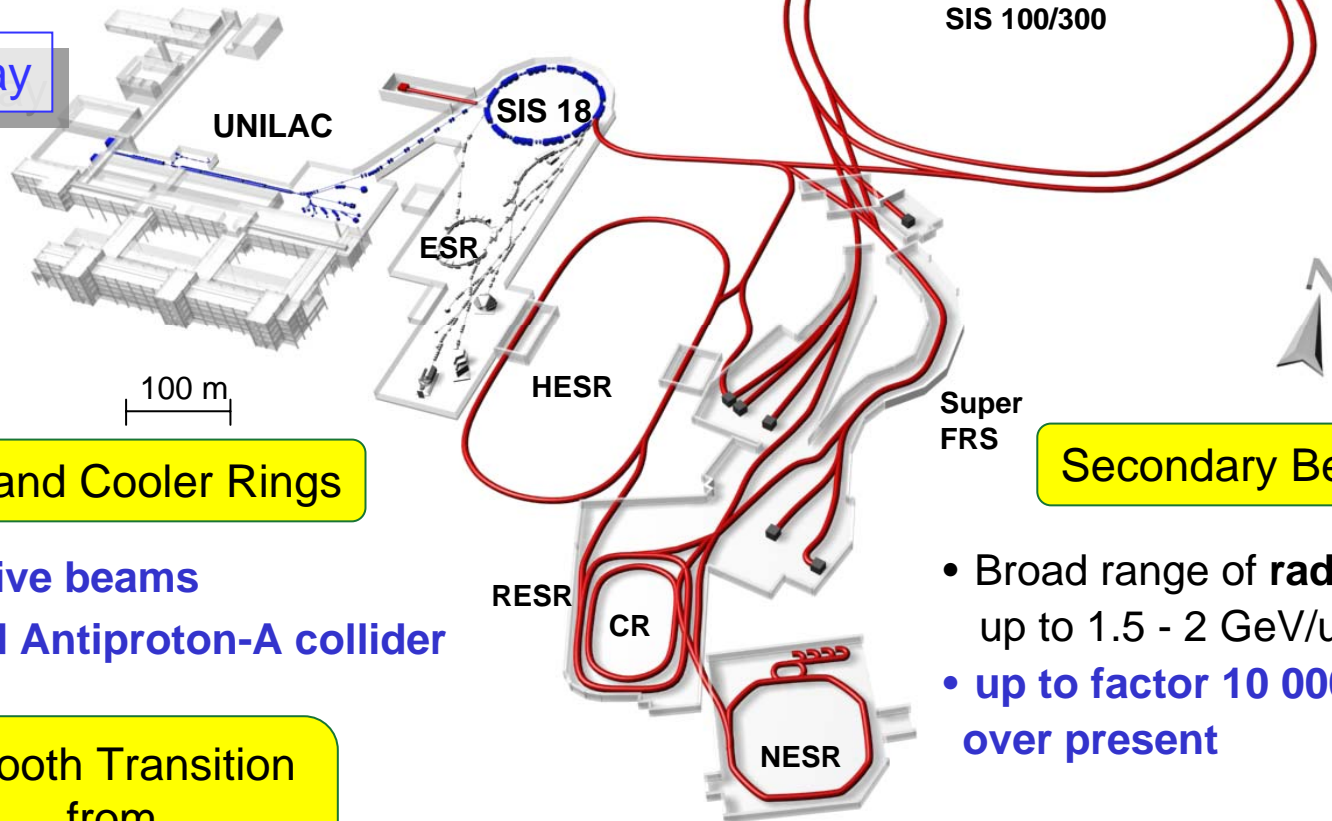
FAIR: Facility for Antiproton and Ion Research

Primary Beams

- $10^{12}/s$; 1.5-2 GeV/u; $^{238}\text{U}^{28+}$
- Factor 100-1000 over present in intensity

Future Facility

GSI today



Storage and Cooler Rings

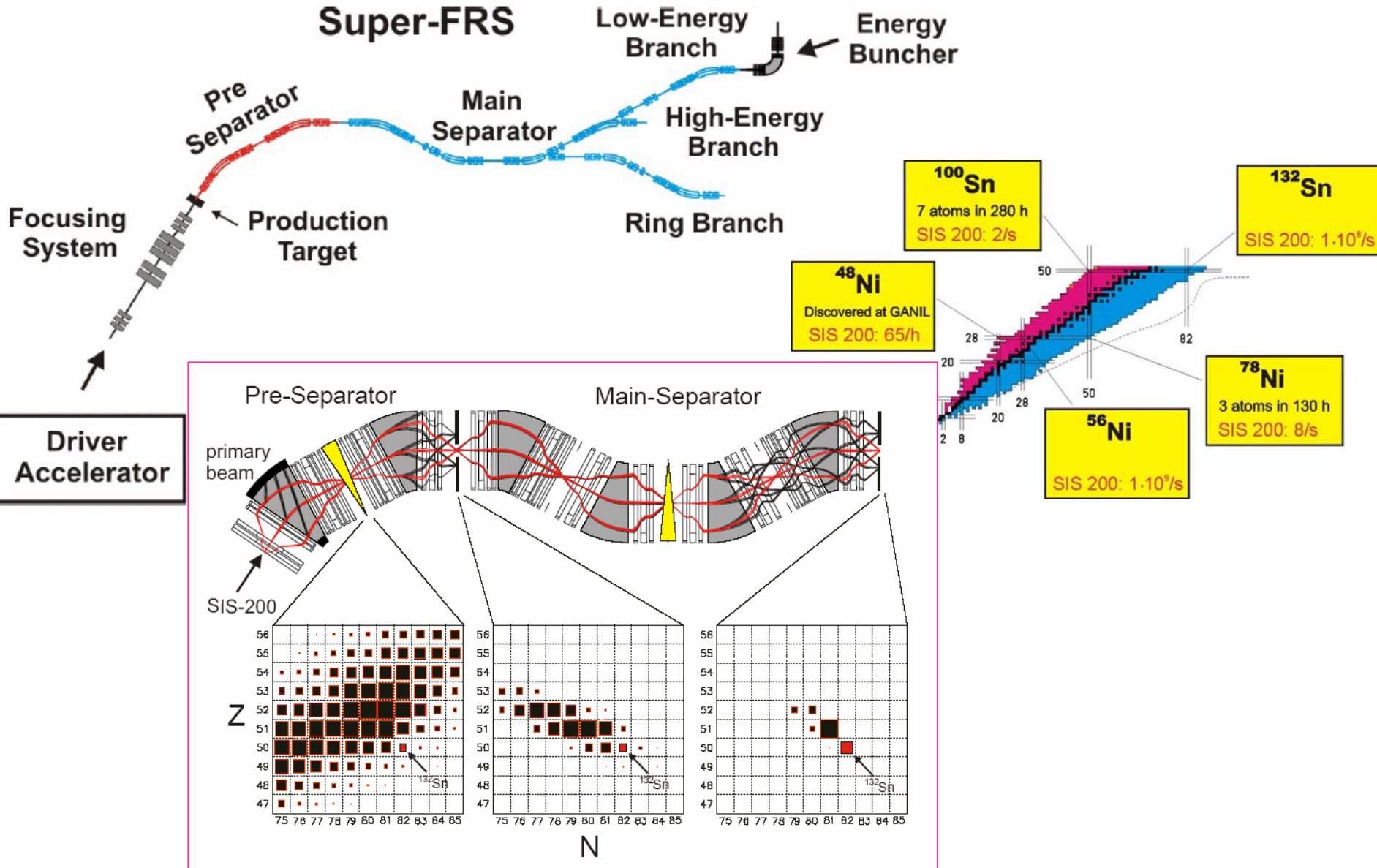
- Radioactive beams
- e^- - A and Antiproton-A collider

Smooth Transition
from
FRS to Super-FRS

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

SUPERconducting FRagment Separator



Nuclear-Structure, -Astrophysics and -Reactions Collaboration

(NUSTAR) (chairman B. Gelletly)

Projects at the Super-FRS

667 members

1.) *Low Energy Branch (LEB)*

- High-resolution In-Flight Spectroscopy (**HISPEC**)/
- Decay Spectroscopy with Implanted Ion Beams (**DESPEC**)
- Precision Measurements of very short-lived Nuclei using an Advanced Trapping System for highly-charged Ions (**MATS**)
- LASER Spectroscopy for the Study of Nuclear Properties (**LASPEC**)
- Neutron Capture Measurements (**NCAP**)
- Antiprotonic Radioactive Nuclides (**Exo+pbar**)

Zs.Podolyak/ Surrey
+ B. Rubio Valencia

K.Blaum Mainz
P. Campbell Manchester
M.Heil FZK
M. Wada Riken

2.) *High Energy Branch (R³B)*

- Universal Setup for Kinematical Complete Measurements of Reactions with Relativistic Radioactive Beams (**R³B**)

T. Aumann GSI

3.) *Ring Branch (STORIB)*

- Study of Isomeric Beams, Lifetimes and Masses (**ILIMA**)
- Exotic Nuclei Studied in Light-Ion Induced Reactions at the NESR Storage Ring (**EXL**)
- Electron-Ion Scattering in a Storage Ring (e-A Collider) (**ELISe**)
- Antiproton-Ion Collider: A Tool for the Measurement of Neutron and Proton rms radii of Stable and Radioactive Nuclei (**AIC**)

Y. Novikov SPNPI

M. Chartier Liverpool

H. Simon GSI

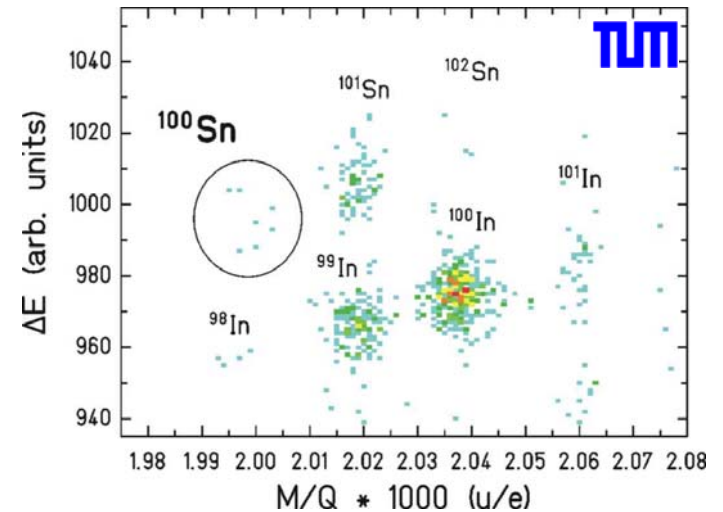
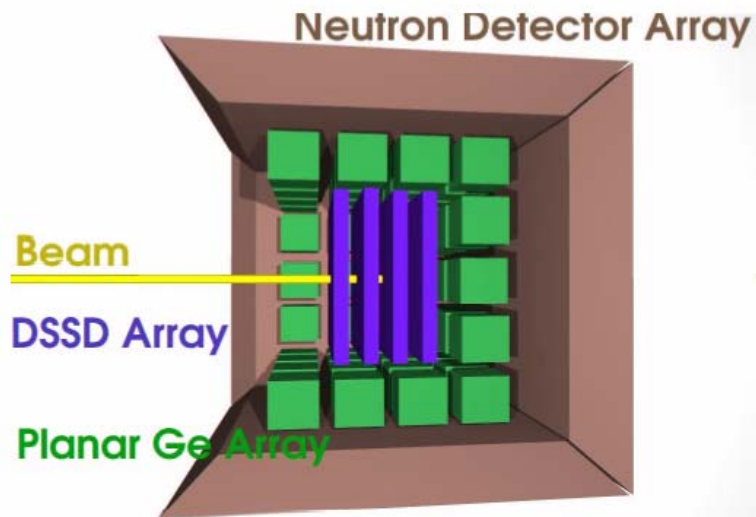
R. Krücken TUM

Unique possibilities with NUSTAR@FAIR

- Decay spectroscopy at the extremes (< 1 pps, short $T_{1/2}$) (DESPEC)
 - Decay properties, $T_{1/2}$, branching ratios, Q-values, GT strength)

„Complete“ decay-spectroscopy

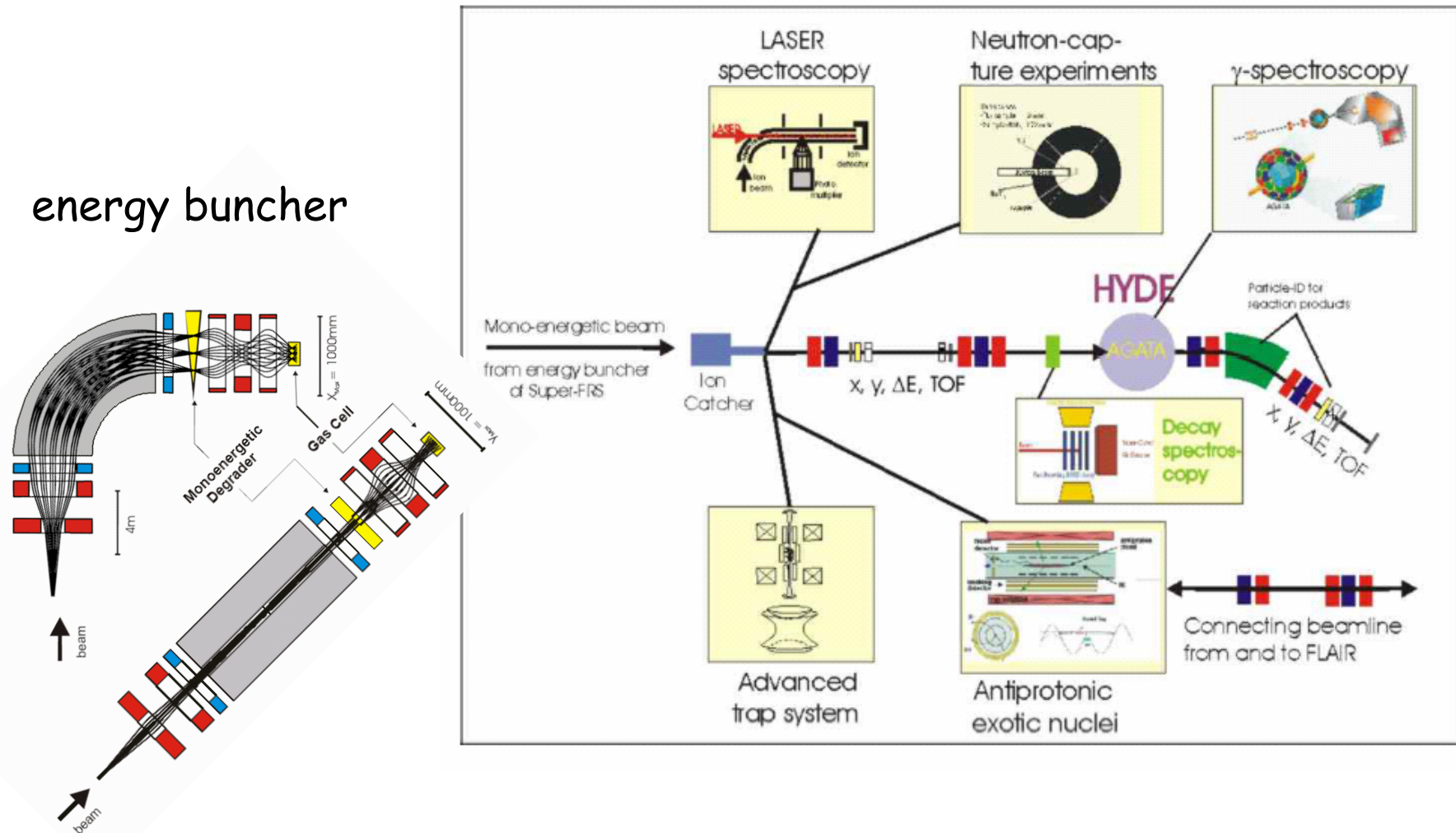
- * α , β , γ -decays
- * conversion-electrons
- * β -delayed neutrons



$$T_{1/2} (^{100}\text{Sn}) = (0,94^{+0,54}_{-0,27}) \text{ s}$$

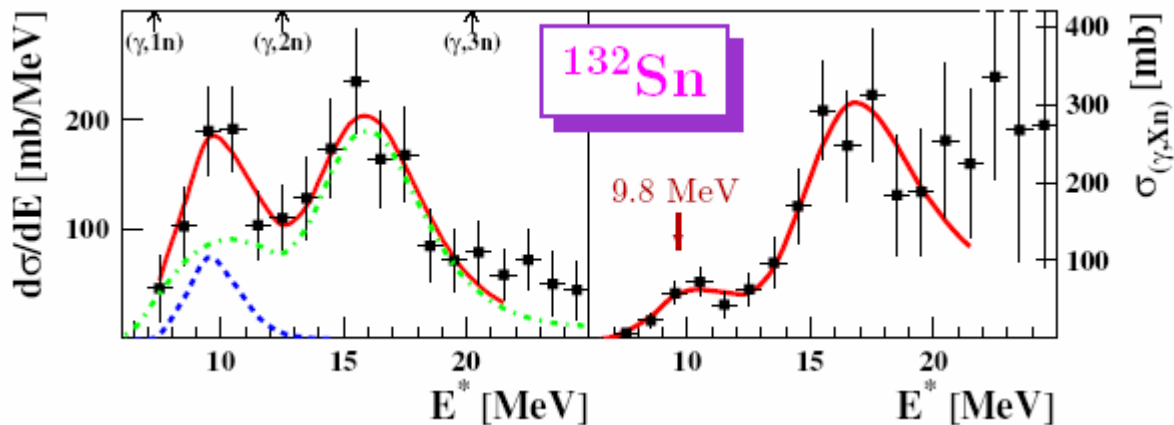
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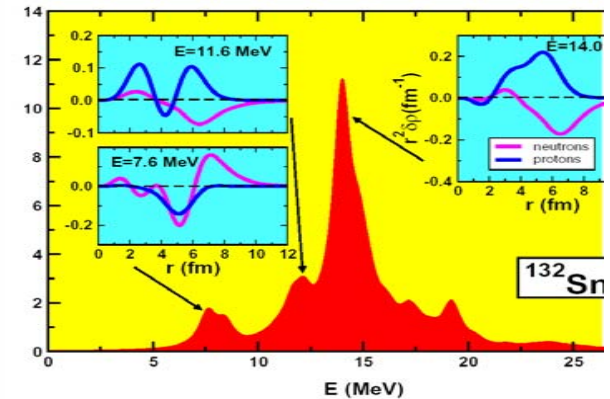
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 - Decay properties, $T_{1/2}$, branching ratios, Q-values, GT strength)
- **Kinematical complete reaction studies at the highest energies along the drip lines** (R^3B)
 - Wave functions and few body correlations (knock-out, quasifree scattering)
 - Inelastic excitations (soft modes, giant resonances)



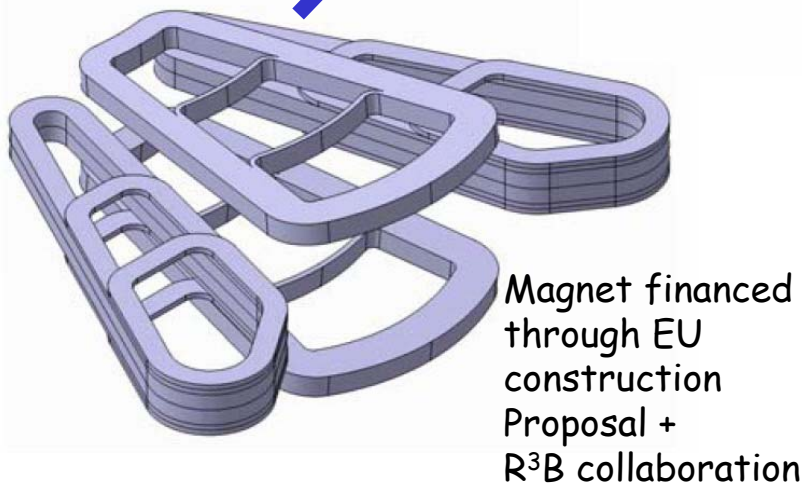
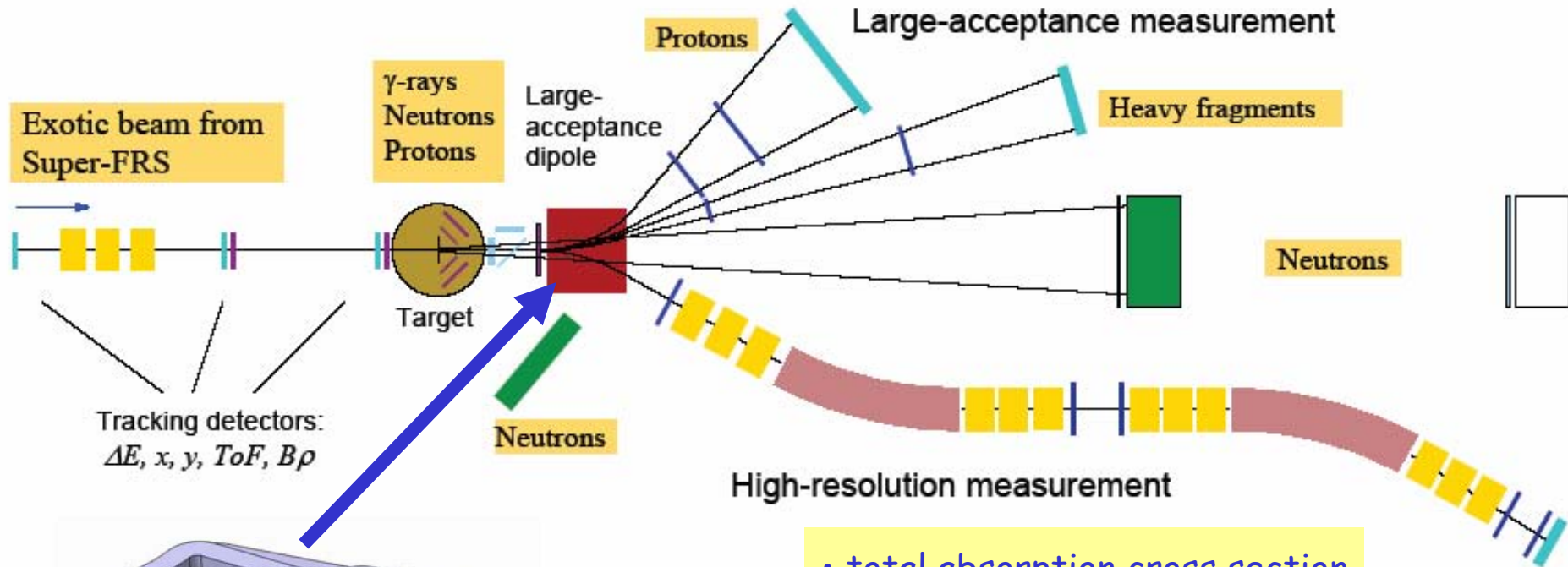
P. Adrich et al., PRL

Soft collective modes



High Energy Branch

Reactions with Relativistic Radioactive Beams (R³B)

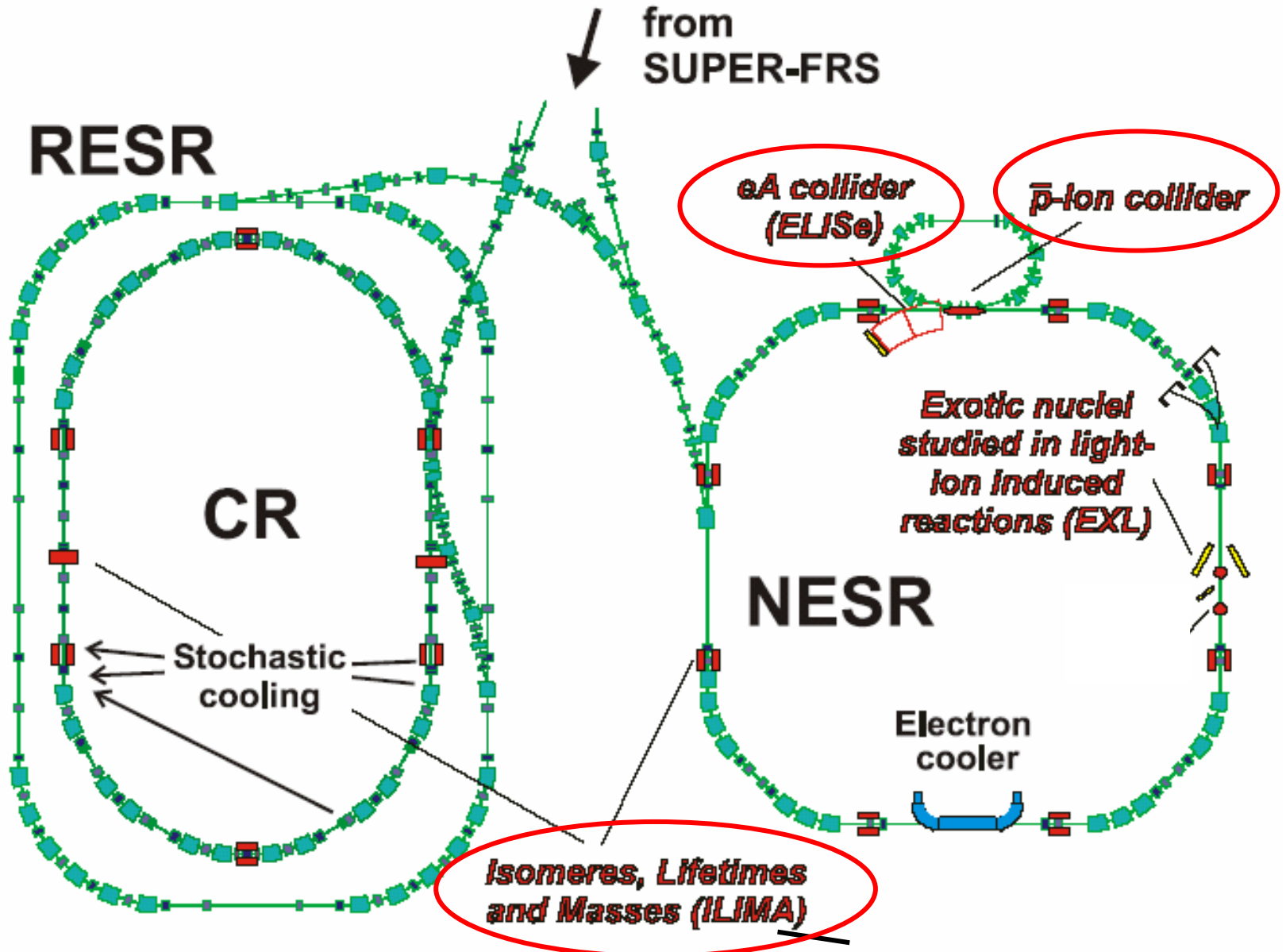


- total absorption cross section
- knock-out reactions
- quasi-free scattering
- electromagnetic excitations
- charge-exchange reactions
- fission and spallation
- projectile fragmentation

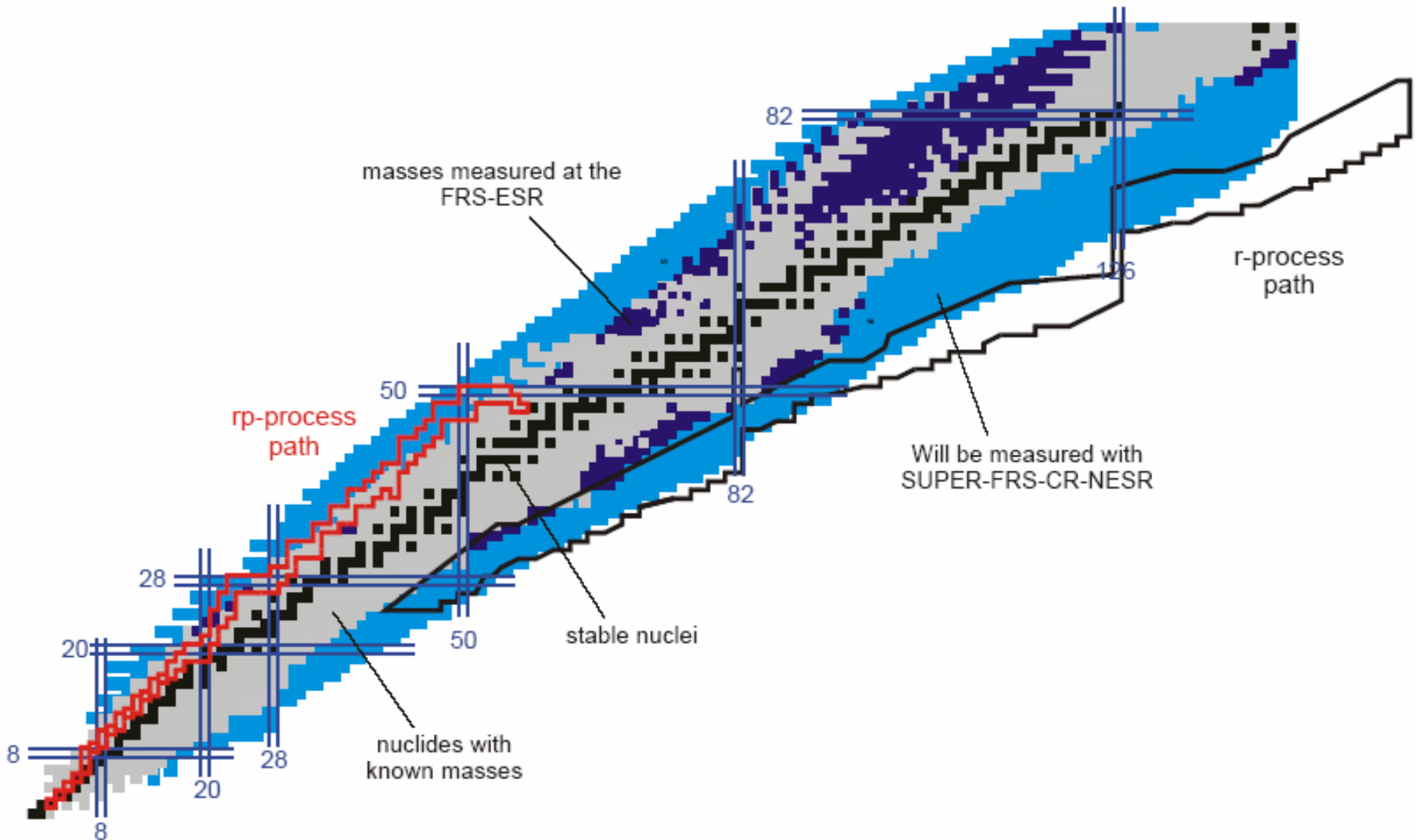
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 - Decay properties, $T_{1/2}$, branching ratios, Q-values, GT strength)
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- **Experiments with stored ions**
 - Recirculation makes multiple (10^6 s $^{-1}$) use of rare beams
 - Mass and half-live measurements with single ions (ILIMA)
 - Reaction studies from 5 A MeV to 740 A MeV (EXL)
 - (matter distributions, single-particle structure,)
 - Electron-Ion Collider (ELISe)
 - (charge distributions, inelastic scattering)
 - Antiproton-Ion Collider (AIC)
 - (radii of neutron and proton distributions)

Ring Branch

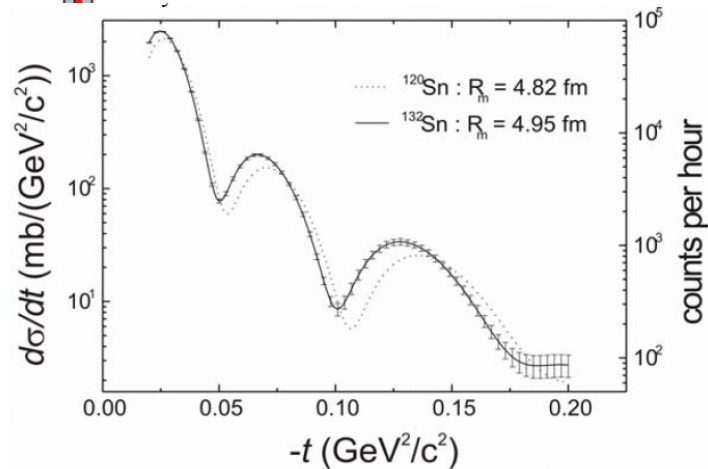
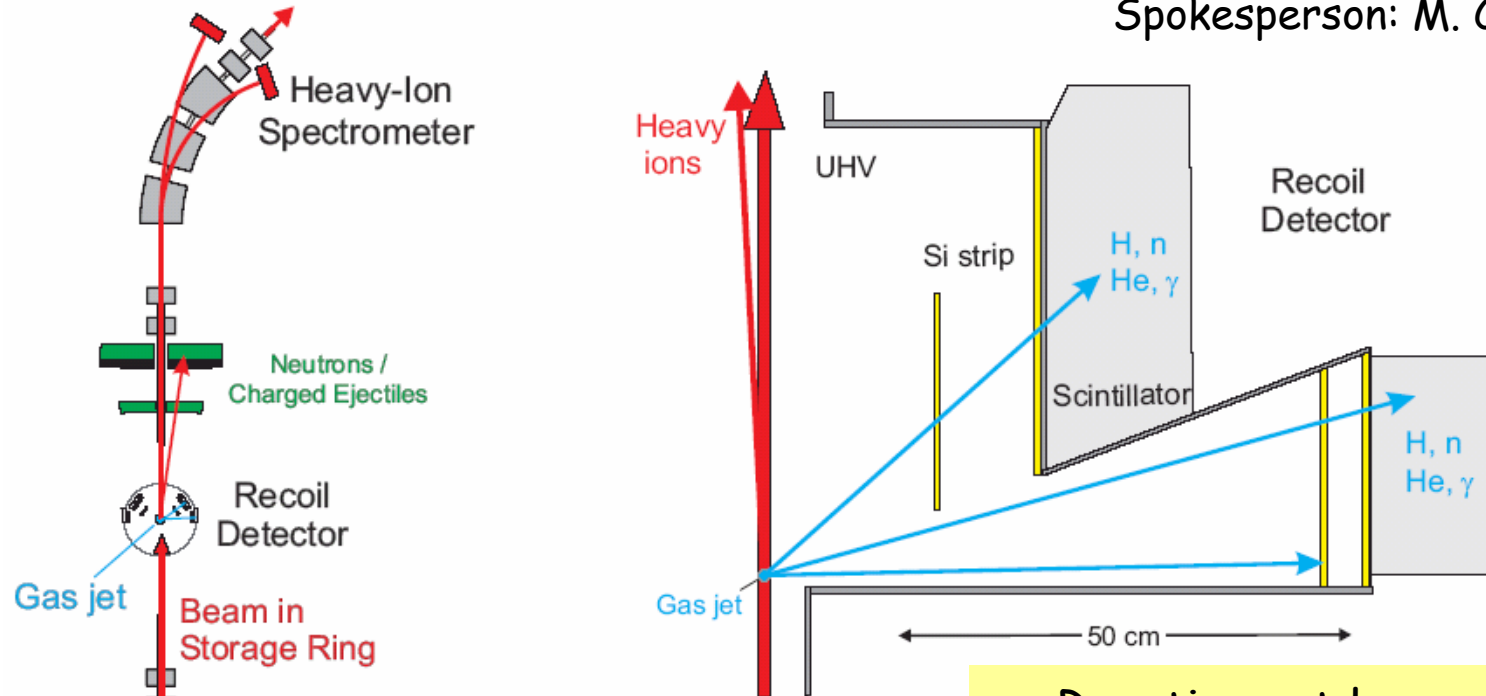


ILIMA mass (and $T_{1/2}$) measurements



Exotic nuclei studied in light-ion reactions at the NESR storage ring (EXL)

Spokesperson: M. Chartier

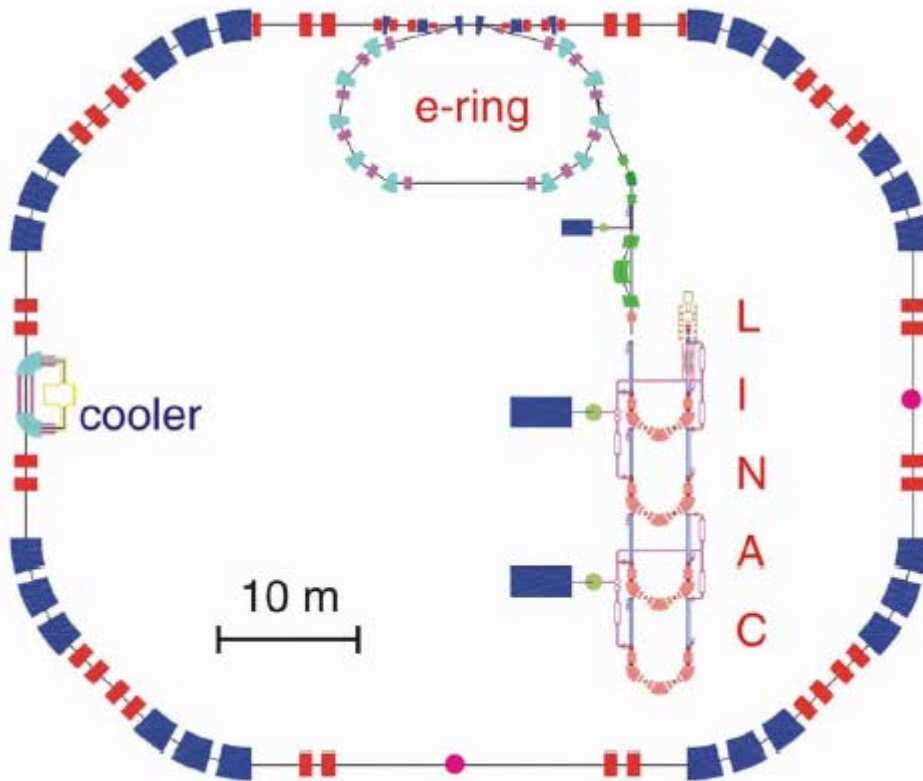


Reactions at low momentum transfer:

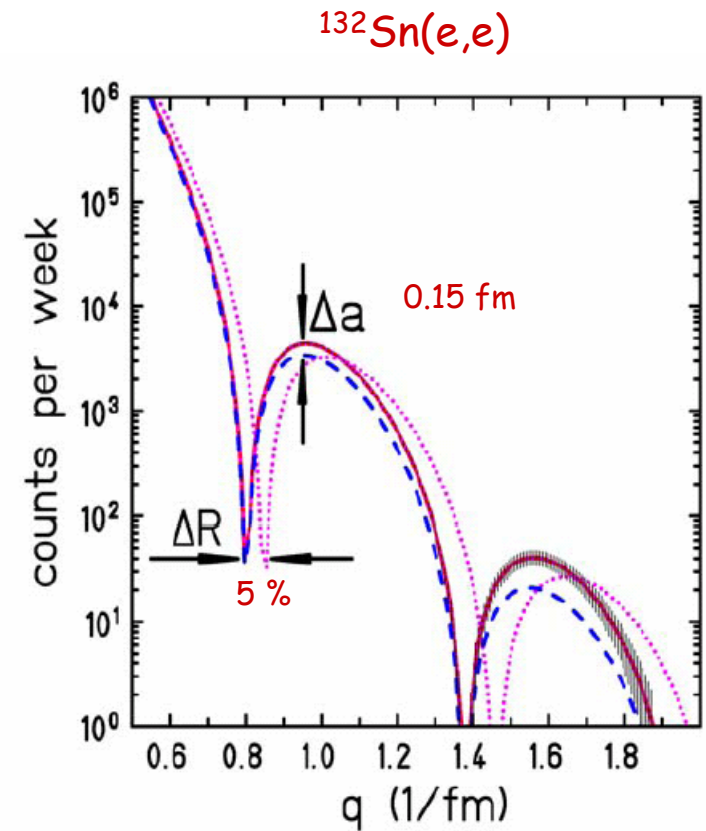
- Elastic Proton-Scattering
- Quasi-free scattering
- Transfer Reactions
- Charge-exchange reactions
- etc.

Electron-Ion scattering in a Storage Ring (eA collider) (ELISE)

Spokesperson: H. Simon



- charge densities from (e,e) scattering
- collective modes via (e,e') scattering
- single-particle structure from $(e,e'N)$ reactions

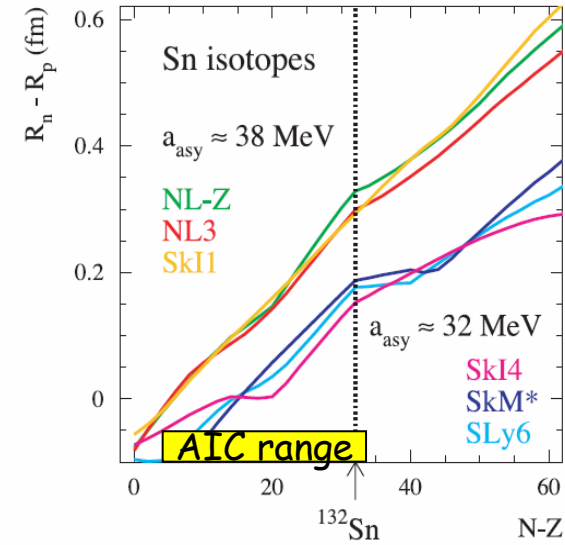
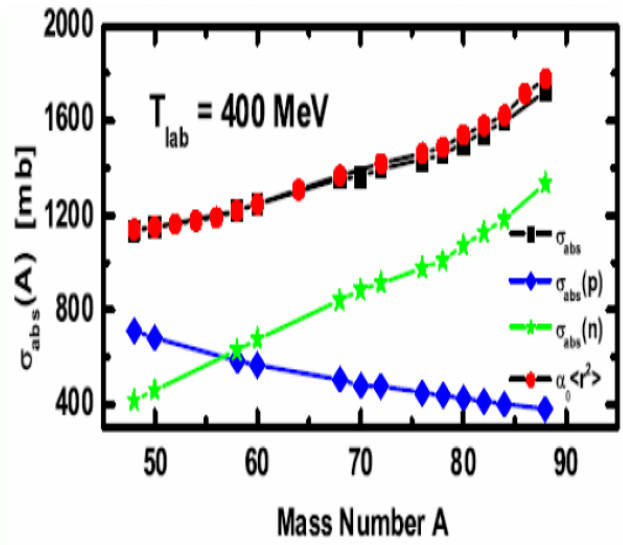
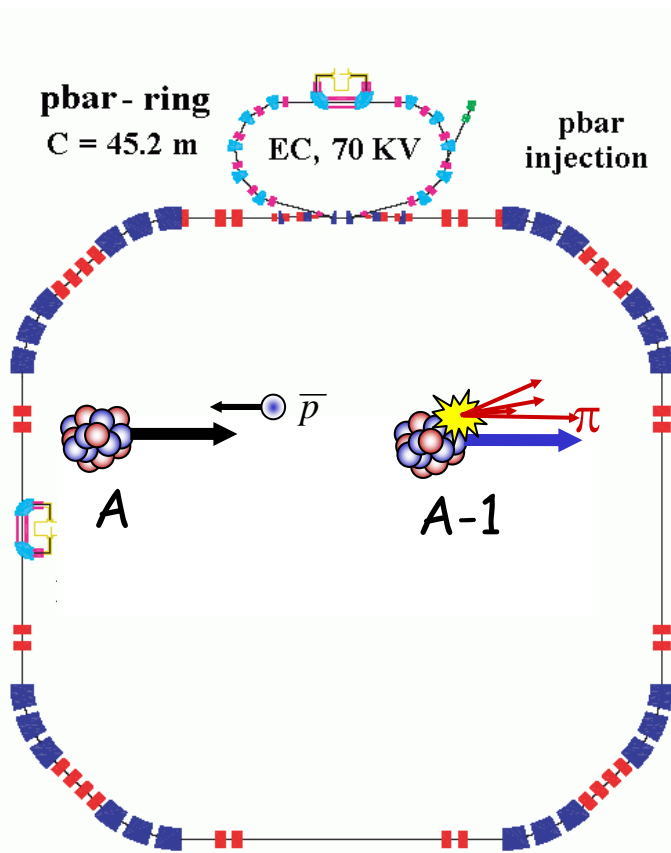


Simulation for 1 week

Antiproton Ion Collider (AIC / pbarA)

Spokesperson: R. K.

Project Manager: P. Kienle



P. Kienle, Nucl. Instr. Meth. B 214 (2004) 193

- antiproton-ion collisions at high energies measures r_n/r_p and $(r_n - r_p)/r_{n+p}$
- across long isotopic chains (e.g. $^{104}\text{Sn} - ^{134}\text{Sn}$)
- test of isospin dependence of effective interaction
- in combination with elastic electron scattering data absolute radii are measured

The aims of NUSTAR @ FAIR

- **Nuclear Structure Physics:**
 - Isospin dependence of effective nuclear interaction
 - Modification of shell structure far off stability (new magic numbers)
 - New effects near the driplines (halos, skins, soft modes, ...)
 - Relevant symmetries, structural evolution, role of phase transitions
 - **Towards a unified description of nuclear structure and dynamics**
- **Nuclear Astrophysics Studies:**
 - reactions relevant for nuclear astrophysics (direct & indirect)
 - properties of nuclei participating in nucleosynthesis (M , $T_{1/2}, \dots$)
 - nuclear structure far off stability and its effect on stellar processes
 - **Towards the understanding of the origin of the heavy elements**
 - **Towards probing stellar objects and phenomena** based on the understanding of nuclear physics together with precise astrophysical observation
- **Nuclear Reaction studies**
 - Investigate reaction dynamics for RIB production, spallation, ADS
 - Dynamics in systems with weakly bound nucleons (halos, correlations)
 - **Towards a unified description of nuclear structure and dynamics**
- **The NUSTAR collaboration works towards an optimal facility and physics program (theory & experiment) to achieve these goals**