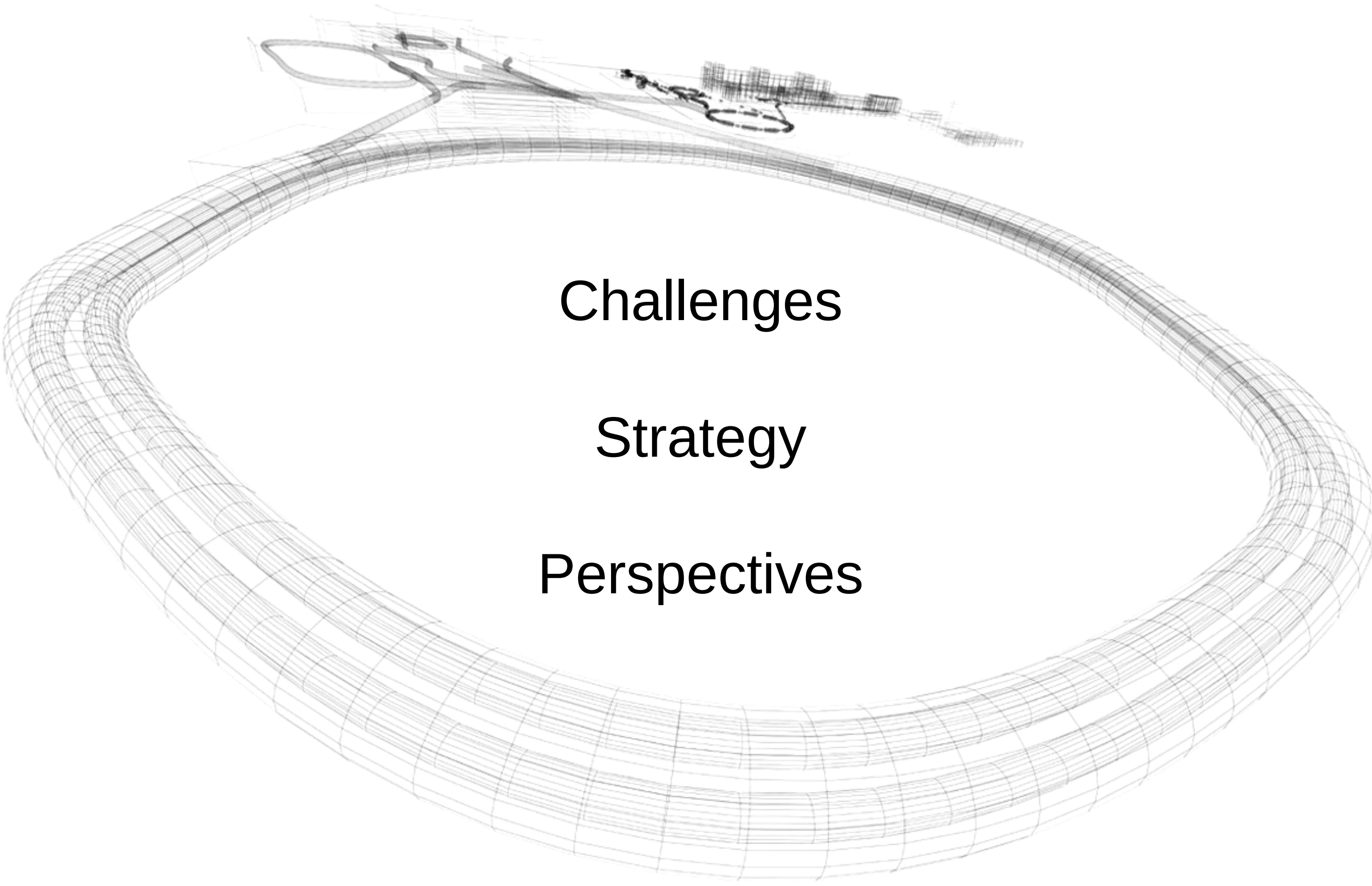
Transactinide research at GSI

Christoph Scheidenberger

GSI and JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

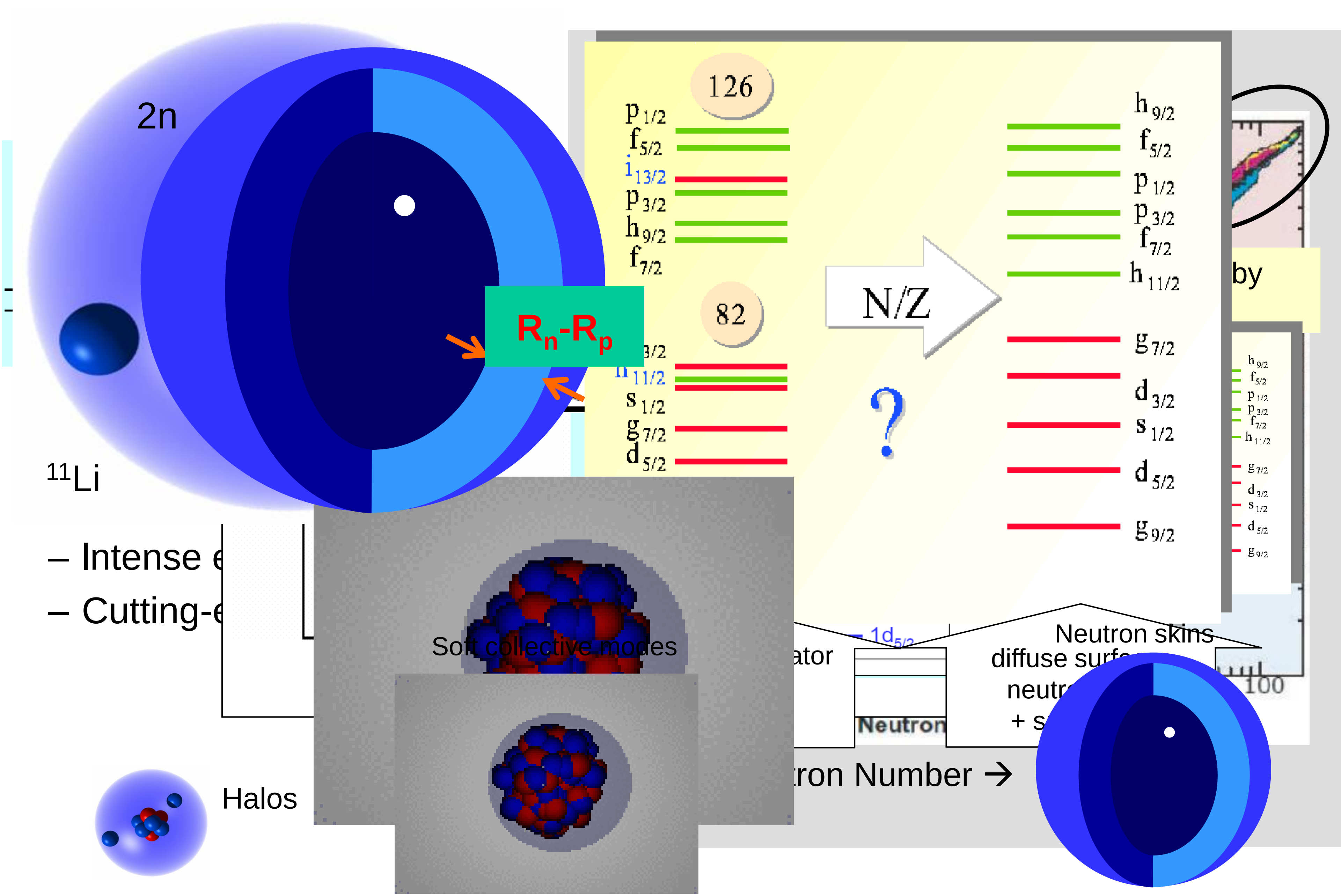


Challenges

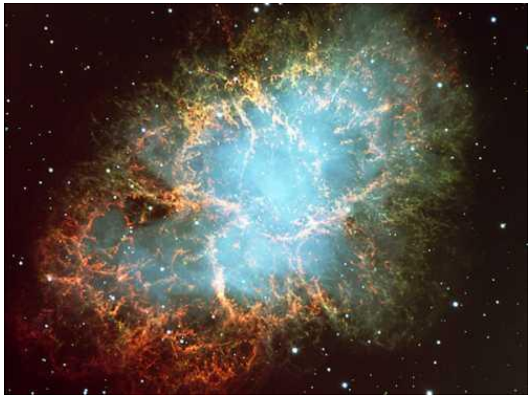
Strategy

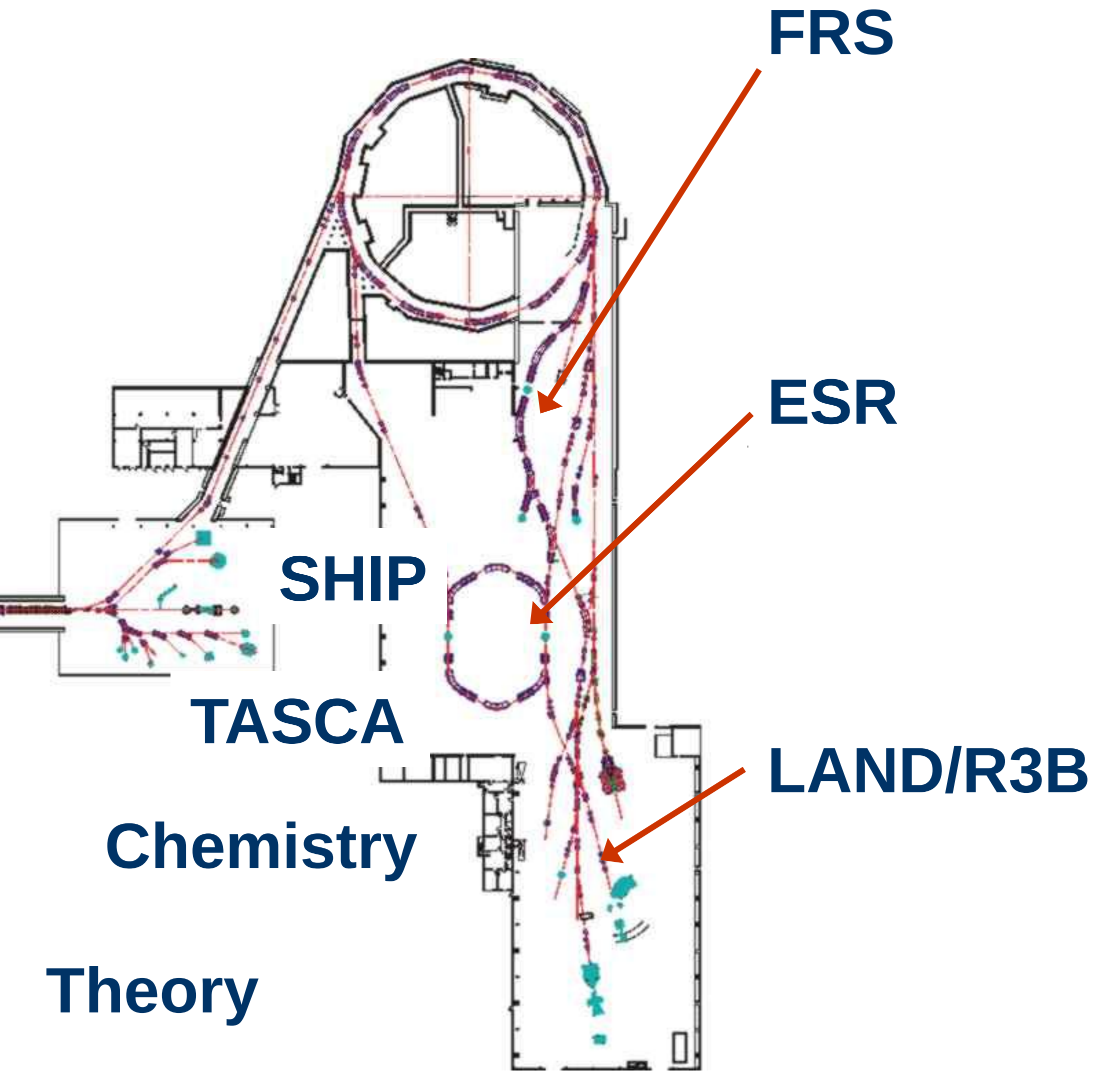
Perspectives

Nuclear structure, astrophysics, reactions, superheavy elements

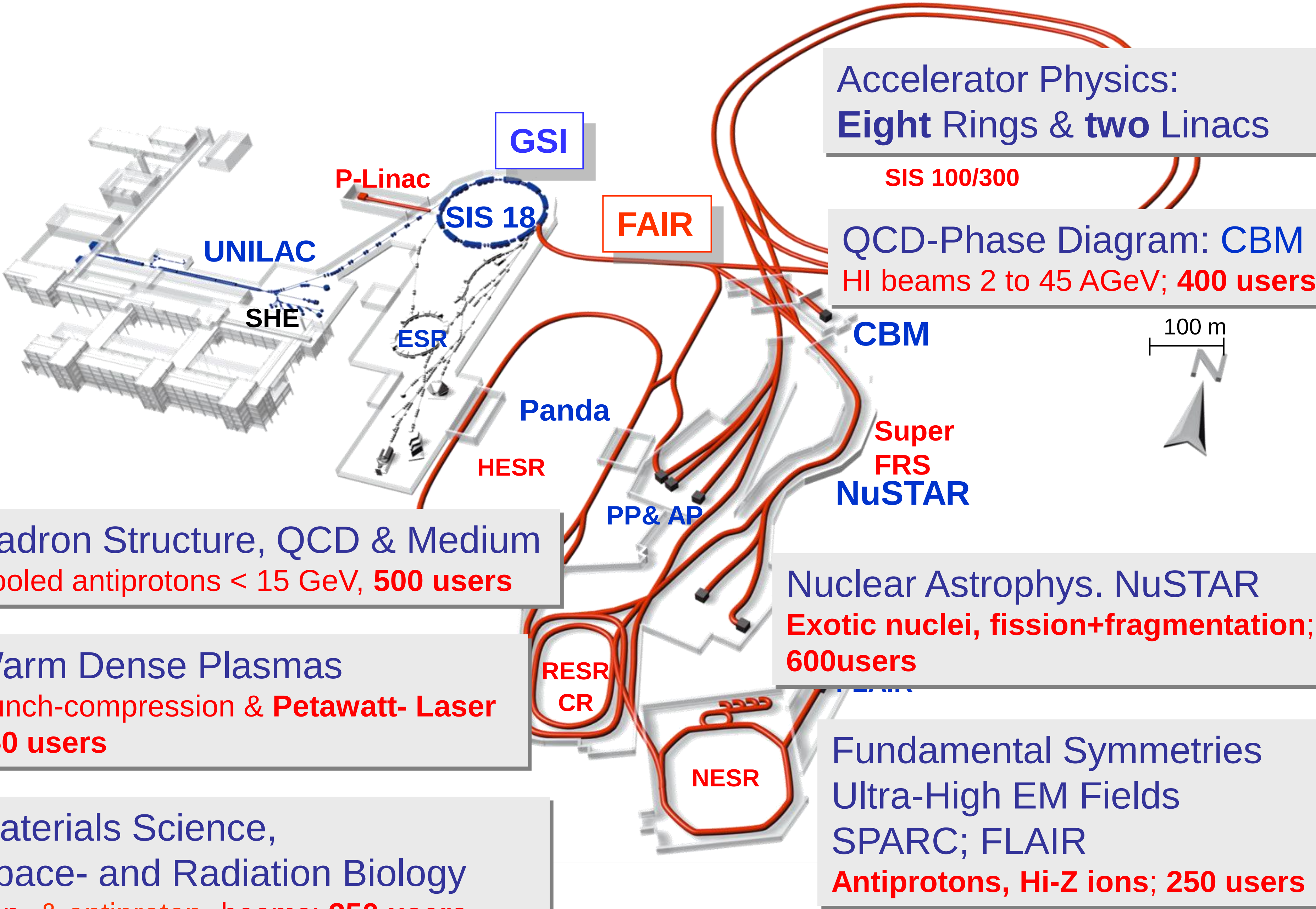


Elements and their isotopes: cosmic matter in the GSI laboratory





International Facility for Antiproton and Ion Research FAIR



Accelerator Physics:
Eight Rings & **two** Linacs

QCD-Phase Diagram: CBM
HI beams 2 to 45 AGeV; **400 users**

Hadron Structure, QCD & Medium
Cooled antiprotons < 15 GeV, **500 users**

Warm Dense Plasmas
Bunch-compression & **Petawatt- Laser**
250 users

Nuclear Astrophys. NuSTAR
Exotic nuclei, fission+fragmentation;
600users

Materials Science,
Space- and Radiation Biology
(Ion- & antiproton- beams; **350 users**

Fundamental Symmetries
Ultra-High EM Fields
SPARC; FLAIR
Antiprotons, Hi-Z ions; **250 users**

Requirements for GSI linear accelerators

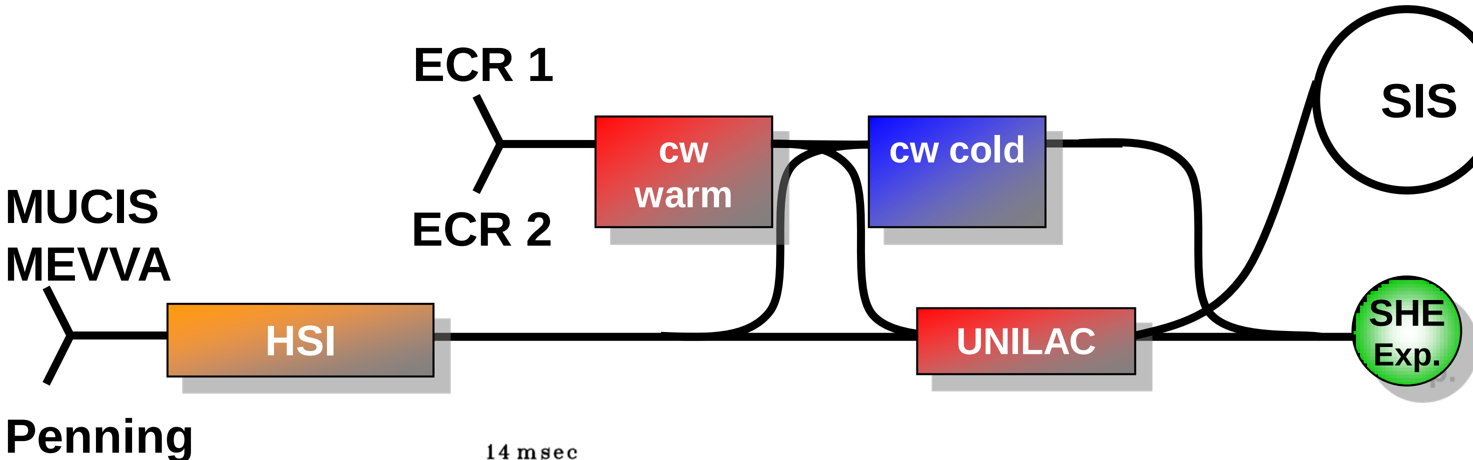
SHE experiments

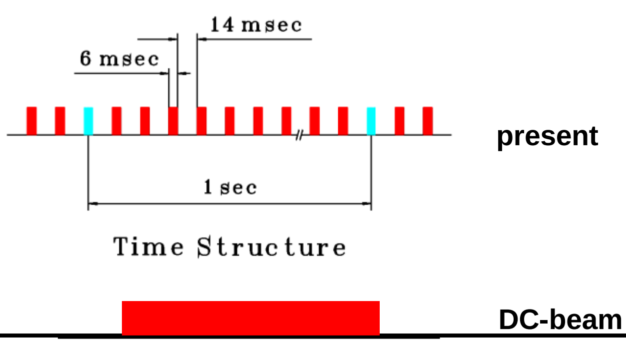
* high intensities: >1E11/ppp
* high repetition rate (50 Hz)
* high duty cycle (~100%, cw-operation, ~20 ms pulse)

Injector for synchrotrons (SIS-18, -100)

* extremly high intensities: >1E12/ppp
* low repetition rate (max. 3 Hz)
* low duty cycle (0,1%, 100 μs for SIS-18)

→ dedicated linear accelerators needed!





High beam currents

DC beams

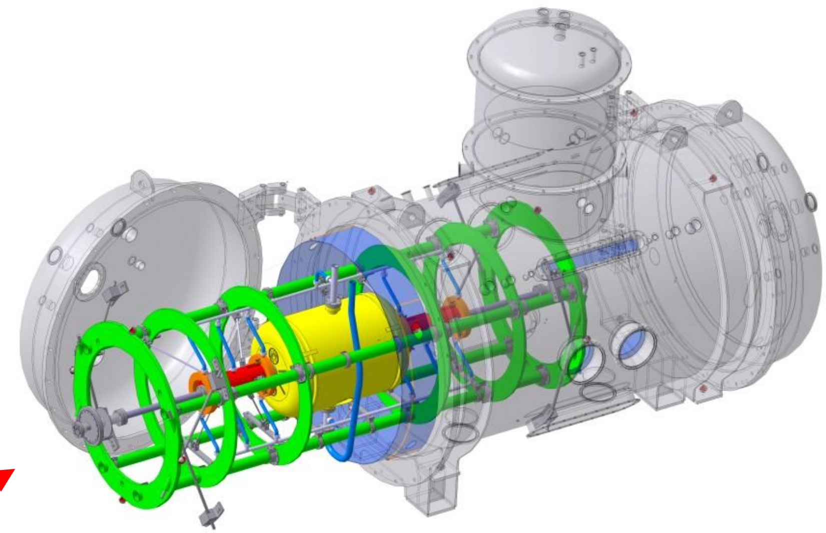
Permanent availability (300 d/year)

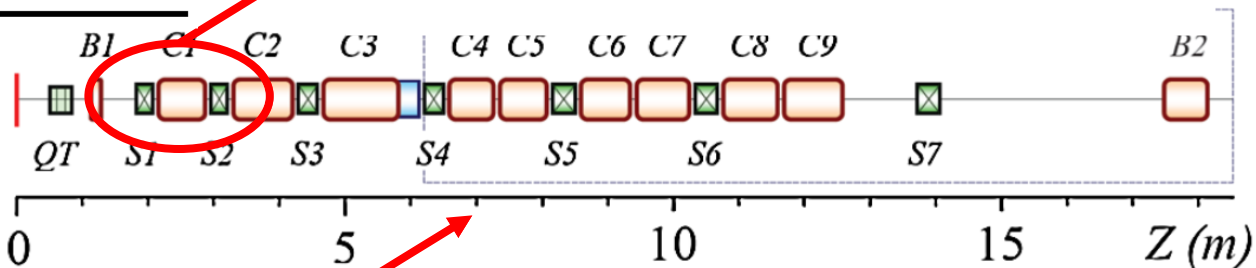
Low electricity costs

The planned superconducting cw-linac

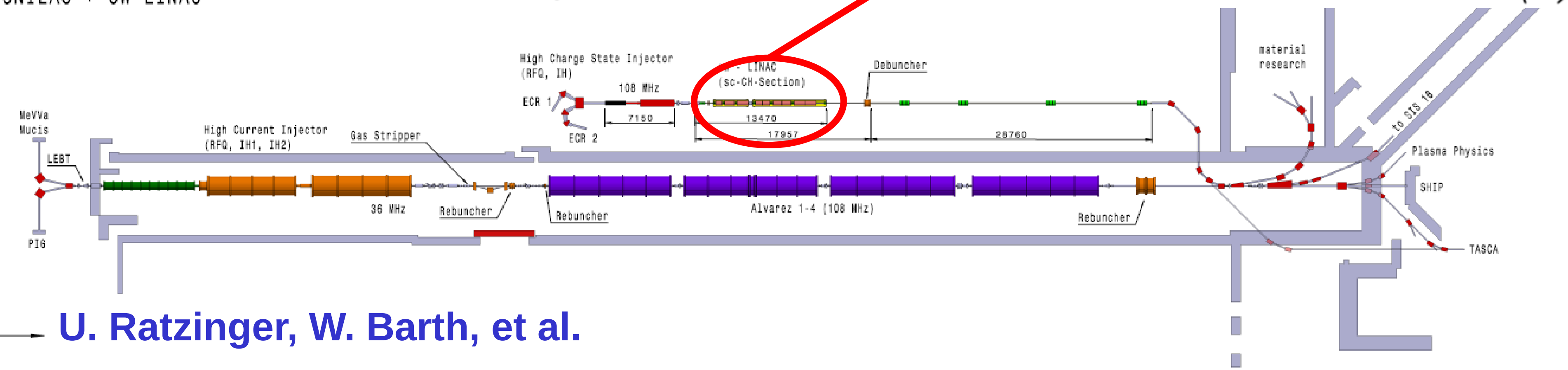
Table 1: General Parameters of the cw-LINAC

Mass/Charge		1/6
Frequency	MHz	217
max. beam current	mA	1
Injection Energy	MeV/u	1.4
Output energy	MeV/u	3.5 – 7.5
Output energy spread	keV/u	+- 3
Length of acceleration	m	12.7
Sc CH-cavities		9
Sc solenoids		7





UNILAC + CW-LINAC



U. Ratzinger, W. Barth, et al.

cw-linac project

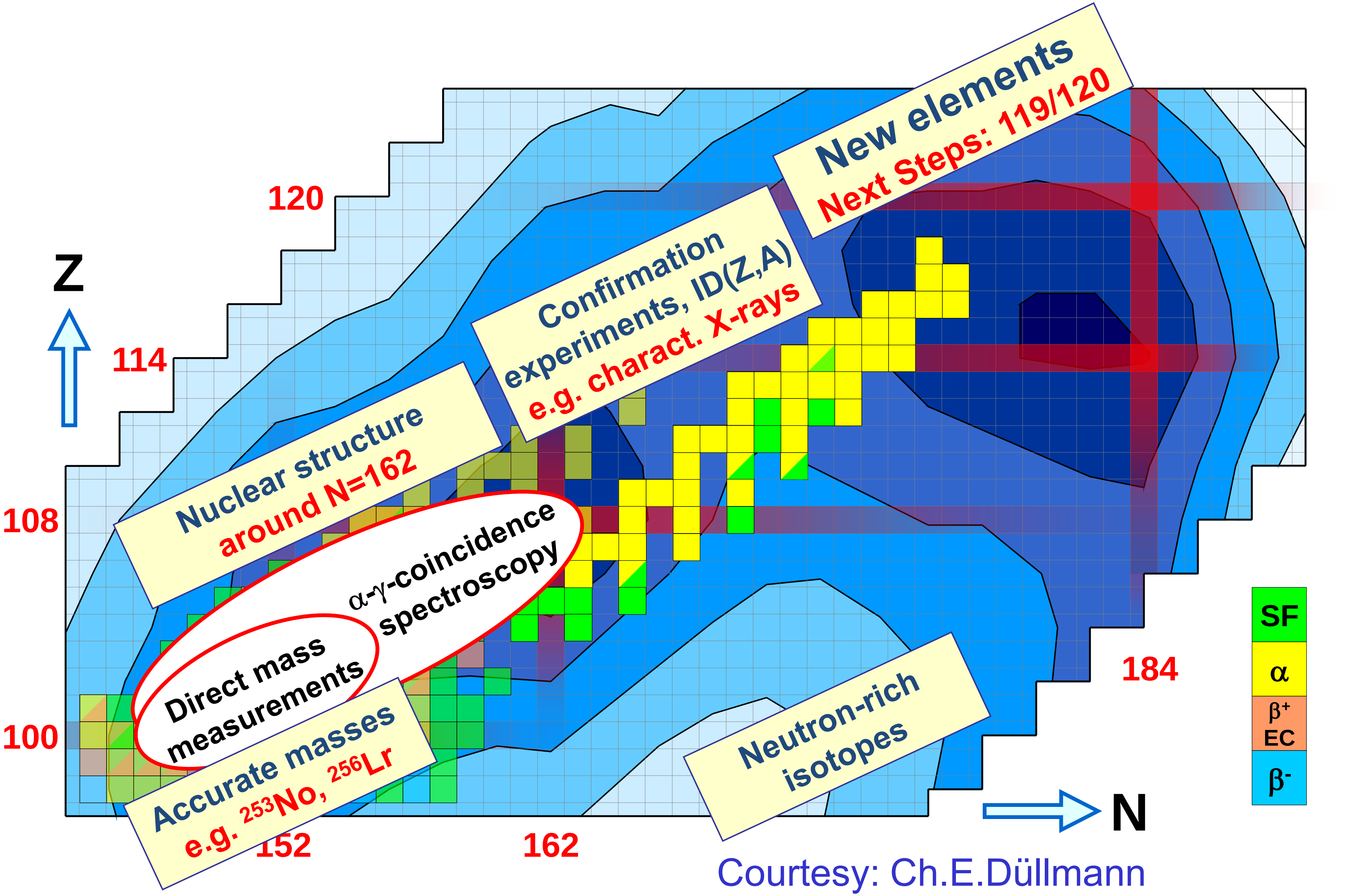
Time table:	2010-2011	Tendering & Ordering	
	2011-2013	Delivery of	5 kW amplifier 3000 ltr LHe-tank $25m^3$ He-recovery balloon
	2012-2013	1st tests (warm & cold) @ IAP (Frankfurt)	
	2013-2014	full performance tests @ GSI-HLI	
	2018-	s.c. cw-LINAC in operation for SHE research	

Project group: U. Ratzinger, et al. (Frankfurt)
S. Mikhat, L. Dahl, et al. (GSI)
W. Barth, A. Jankowiac, et al. (HIM)

Costs: Investment: 27.5 MEuro
Operation: 0.85 MEuro p.a.

Roadmap: Project recognized by Helmholtz-Association
Evaluated in 2010: „...hervorragend...“ (excellent)
R&D funded by HIM
→ on roadmap of HGF-Ausbauinvestitionen 2014-2016
→ construction 2015+ (?)

Key areas of SHE research at GSI

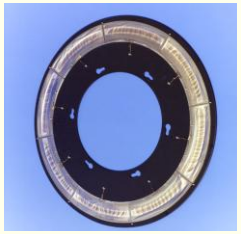


Courtesy: Ch.E.Düllmann

Key instruments for SHE studies at GSI

ECR + UNILAC

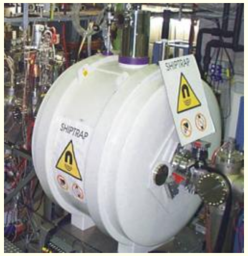
Beam



Stable targets

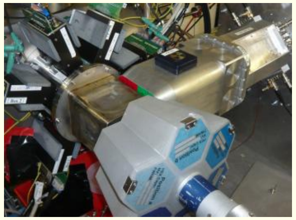
Actinide targets

SHIP

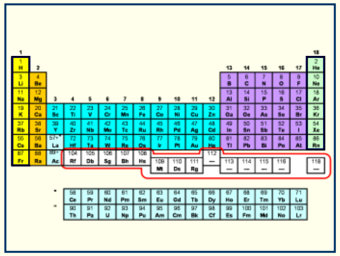


SHIPTRAP

TASCA

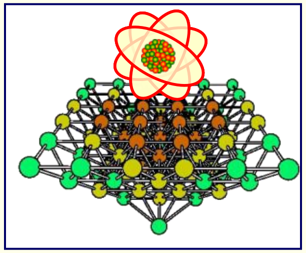


TASISpec



Chemistry

Radiochem. labs



Chemical theory

Perspectives

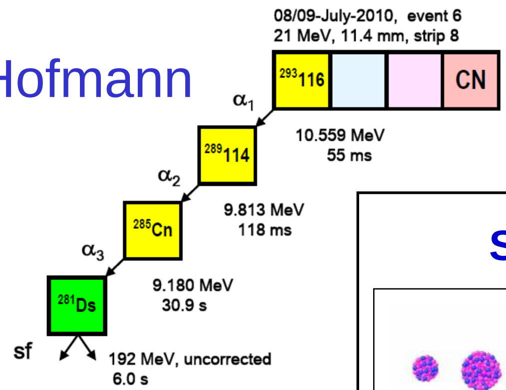
New 28 GHz ECR ion source

50% duty cycle

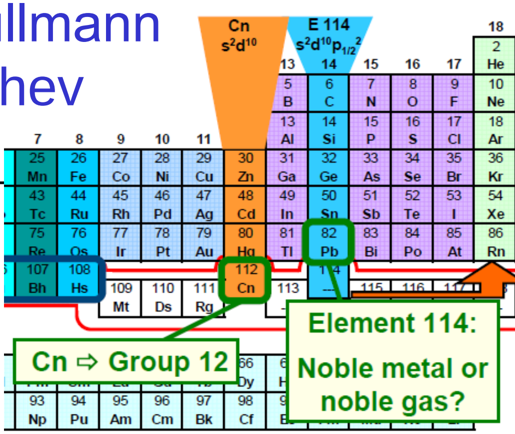
10 x higher intensity

Exemplary results

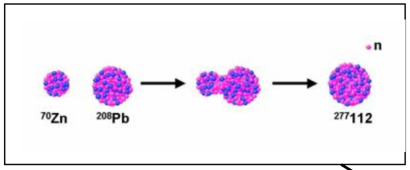
S. Hofmann



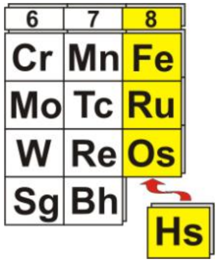
Ch.E.Düllmann
A.Yakushev
A.Türler



Synthesis



Chemistry



SHE

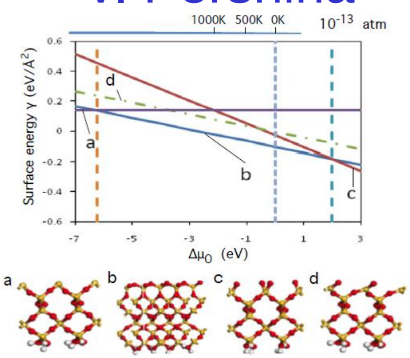
Nuclear structure

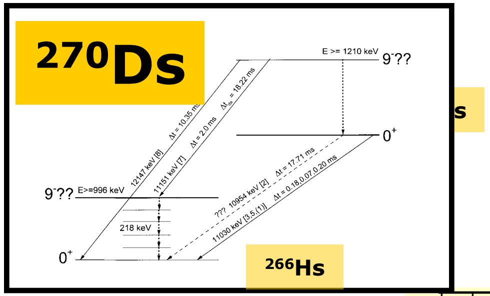
Atomic properties

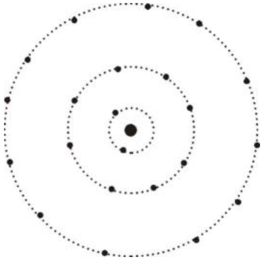
K. Eberhardt

Actinide targets

V. Pershina

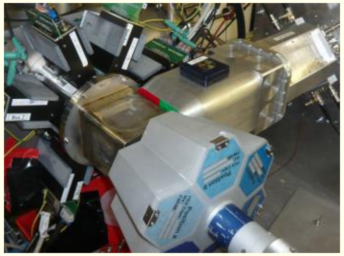






J. Even

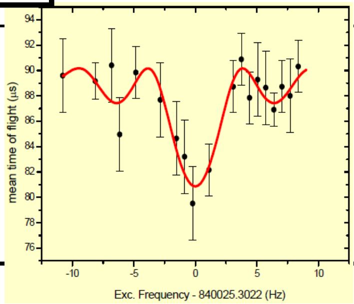
L.-L. Andersson



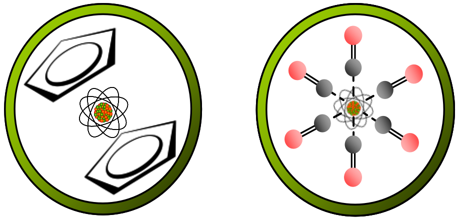
TASISpec

D. Ackermann

E. Minaya



New compounds



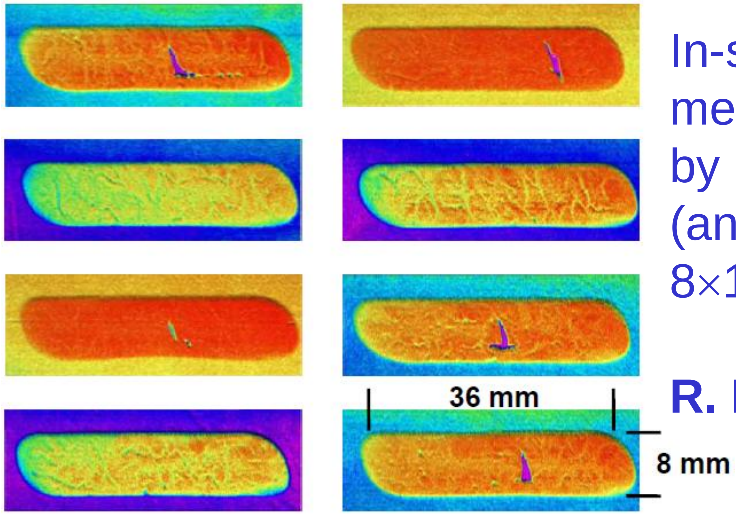
Small cross sections → long beam times, high intensities:

Ion source development

28 GHz ECR (intensity x10), new beams, enriched material

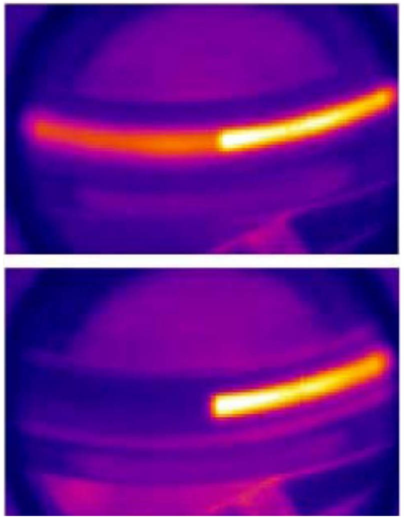
Advanced target techniques

Actinide targets – availability of isotopes, handling, safety
High-power targets – cooling techniques, new materials/compounds
Approaches – optimization, new techniques (e.g. gas jets, liquid targets?)
Analysis – in-situ, off-line-characterization, quality control



In-situ target thickness measurement of Cm targets by penetration with electrons (analysis after irradiation with 8×10^{18} ^{48}Ca ions)

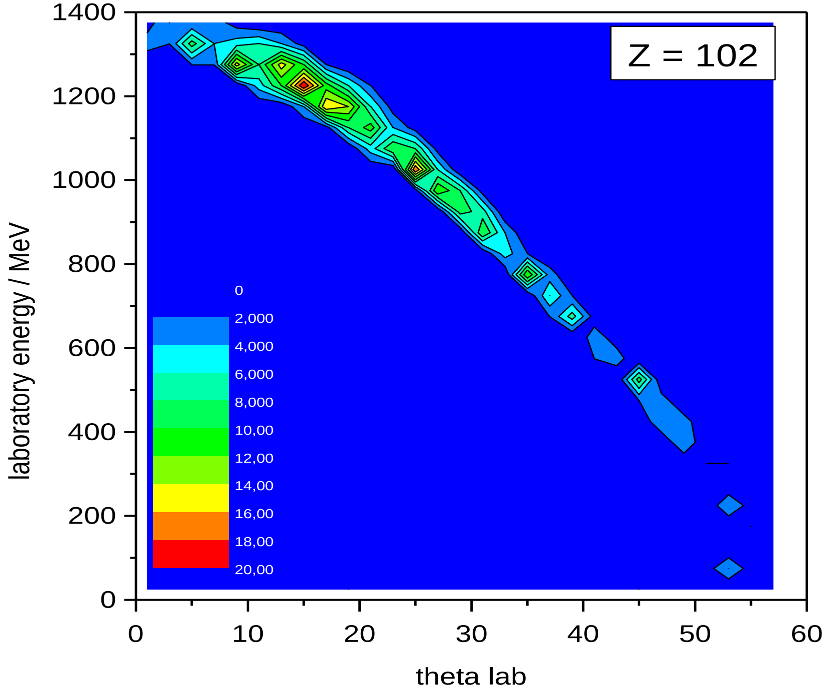
R. Mann et al.



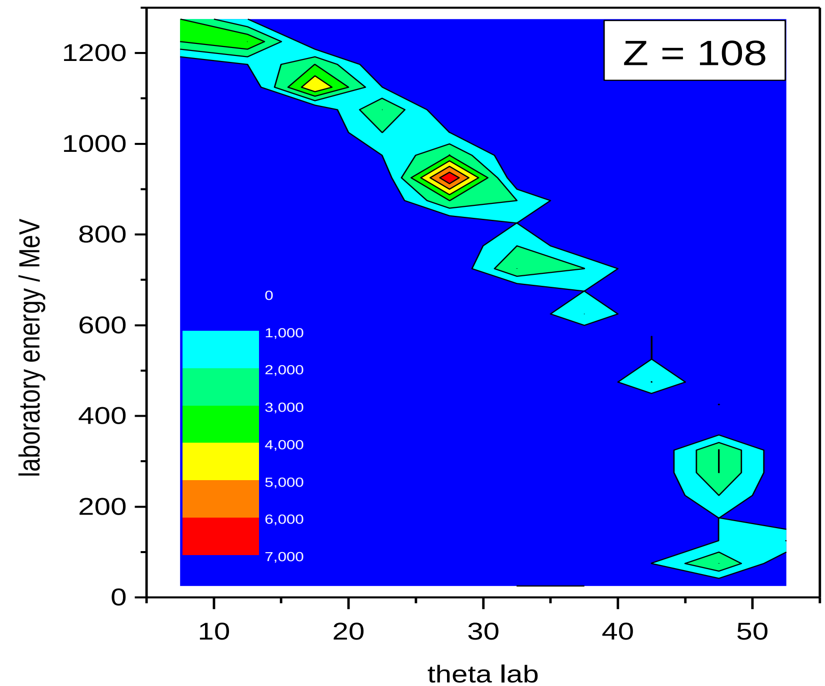
Kinematics of heavy transfer products

$^{238}U + {}^{248}Cm$, $E_{cm} = 780$ MeV

^{261}No



^{275}Hs



S. Heinz et al.

Challenge #2: new reactions

New beams!

E.g.: ^{50}Ti

Kinematical studies:

E.g.: measurement of velocity distributions for certain reactions

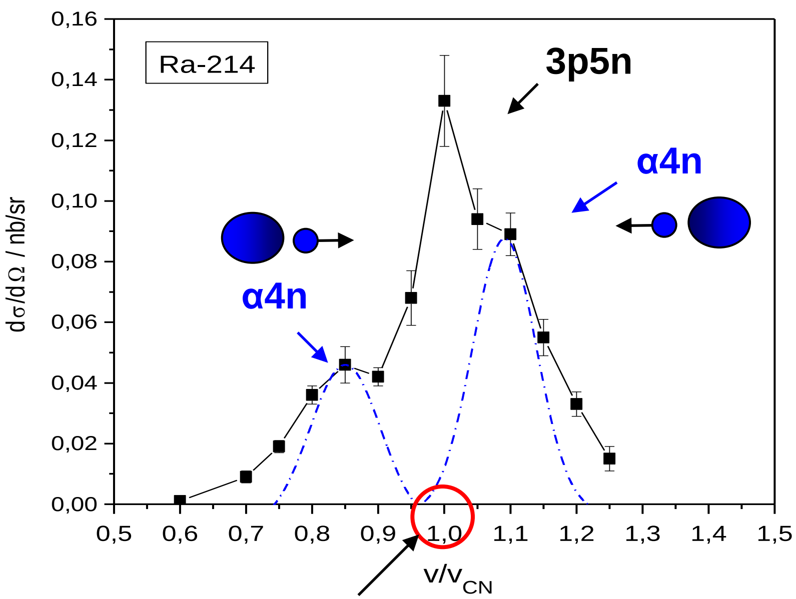
$\longrightarrow$ identification of αxn and transfer channels at SHIP

example for an αxn channel:

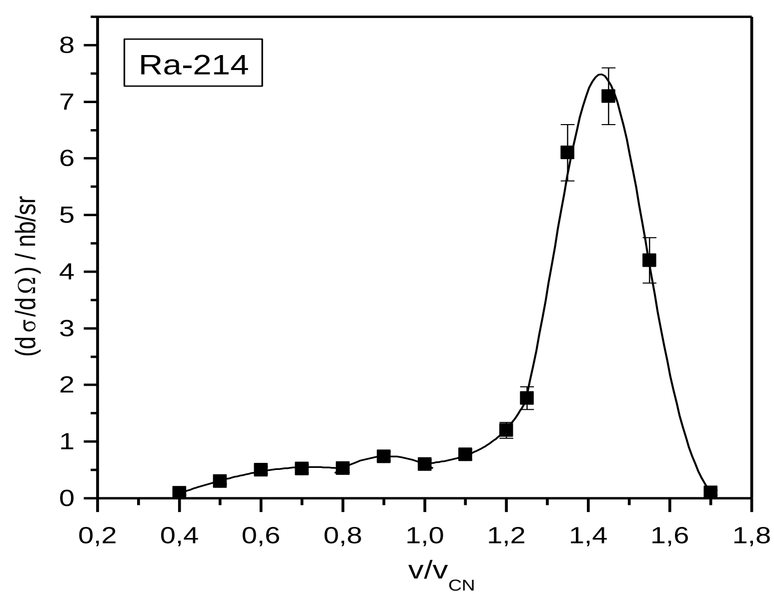
$^{25}Mg + ^{197}Au \rightarrow ^{222}Pa^*$ (E*=64 MeV)

example for a transfer channel:

$^{25}Mg + ^{206}Pb \rightarrow ^{13}C + ^{218}Ra$



compound nucleus velocity



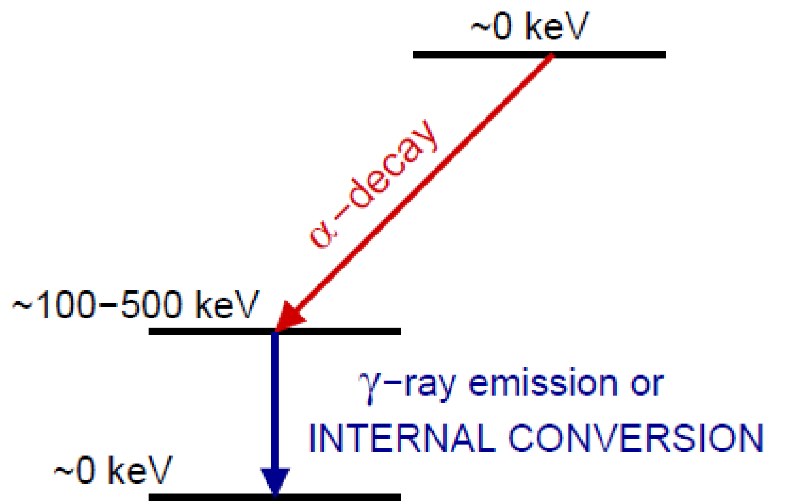
$\Delta v/v$ = 10% (FWHM)

S. Heinz et al.

Challenge #3: unambigous identification (Z,A)

1. Atomic number

characteristic X-rays



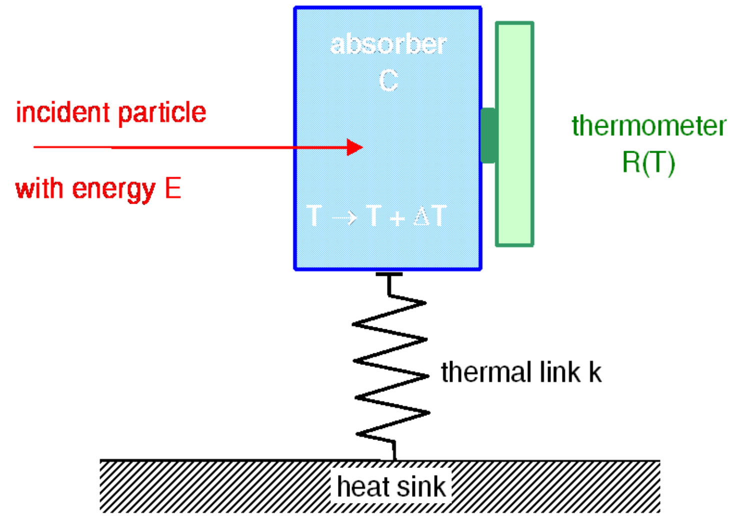
Long decay chains of odd−A nuclei!

y: D. Rudolph,
derson et al.

2. Mass

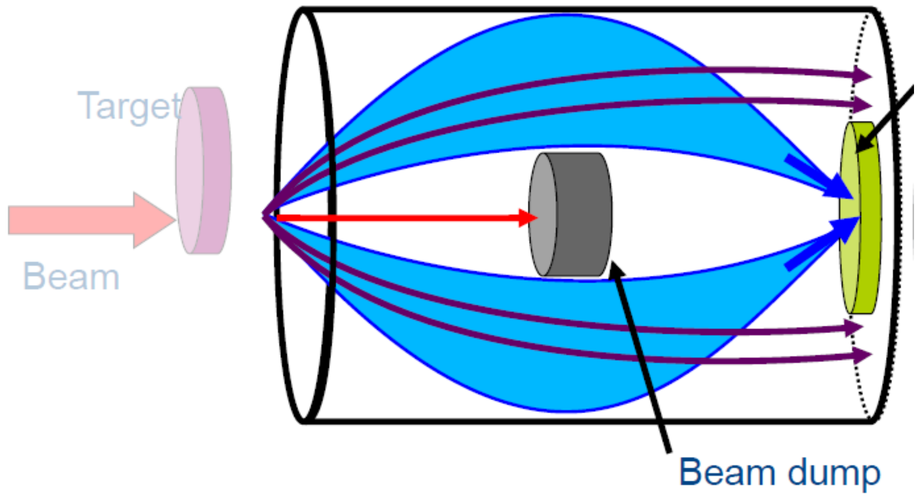
direct mass determination

* bolometer
* Pennig trap (SHIPTRAP)
* time-of-flight mass spectrometer (MR-ToF-MS)



P. Egelhof et al.

1. Mid-term project: separator for transfer reaction products



Inelastic Reaction Isotope Separator

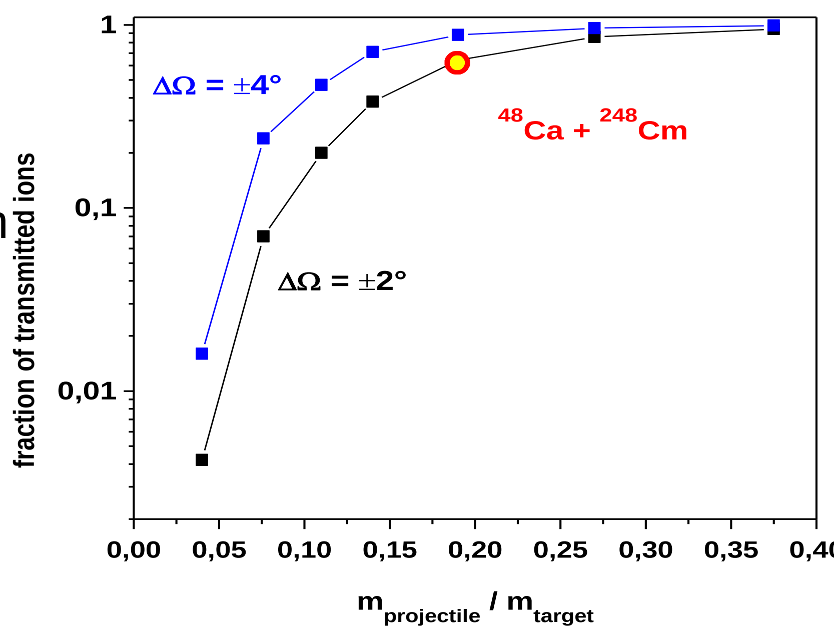
IRiS HEAVY ELEMENTS

J. Dvorak et al.

2. Mid-term project: SHIP upgrade

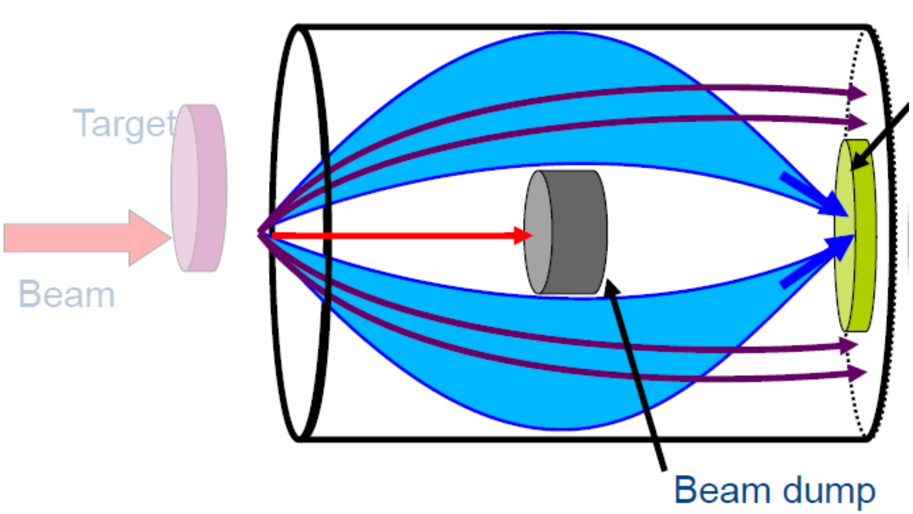
- Q'poles with larger apertures and field strength
- Shorter distance from target to quadrupoles

  → increase of angular acceptance: factor of 2
  → increase of the transmission: up to factor of 4
  → relevant for very asymmetric projectile/target combinations and for transfer reactions



Challenge #4: next-generation instruments

1. Mid-term project: separator for transfer reactions

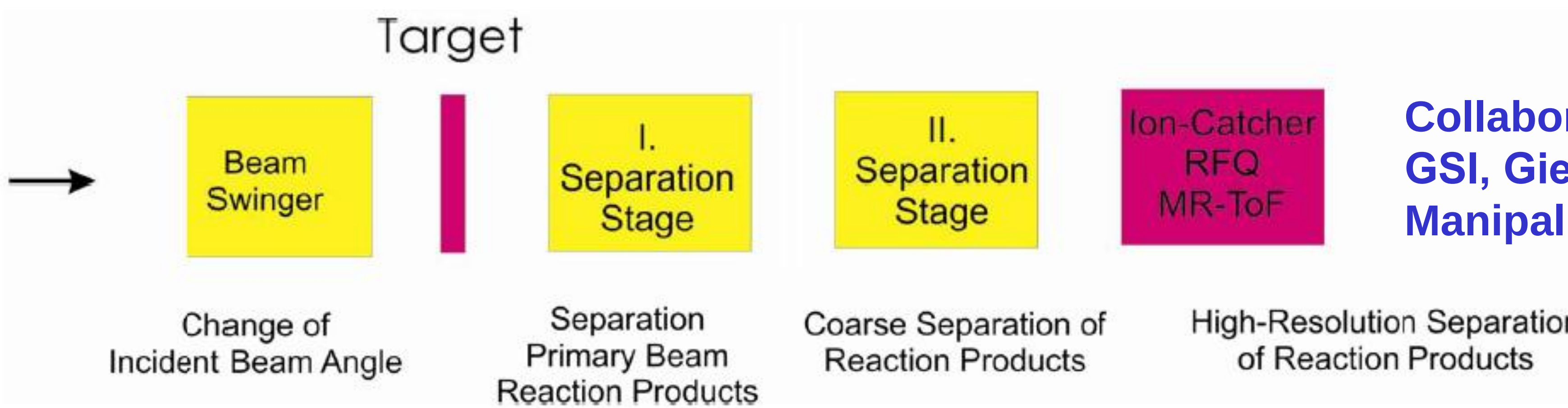


Inelastic Reaction Isotope Separator

IRiS
HEAVY ELEMENTS

J. Dvorak et al.

3. Long-term project: separator for intensities >5E13 pps

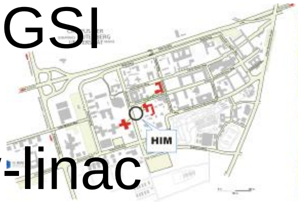


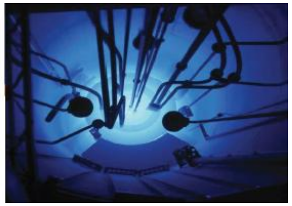
Collaboration: GSI, Gießen, Manipal

Strategic partners for SHE research at GSI

Helmholtz-Institute Mainz

Partners: University of Mainz, GSI
SHE: chemistry and physics
Accelerators: development cw-linac
Young-Investigator Group (J.Dvorak): IRiS Separator





International Graduate School

Promotes and supports structured PhD education for research associated with GSI and FAIR

Helmholtz-International Center for FAIR

Univ. Darmstadt, Frankfurt, Gießen, FIAS
A unique think tank for forefront interdisciplinary research for GSI/FAIR

International partnerships

DOE, ORNL, LLNL, Berkeley

SHE collaborators worldwide

Conclusion

Lessons

– chemical elements exist due to microscopic effects
– field of highest scientific level and interest

Challenges

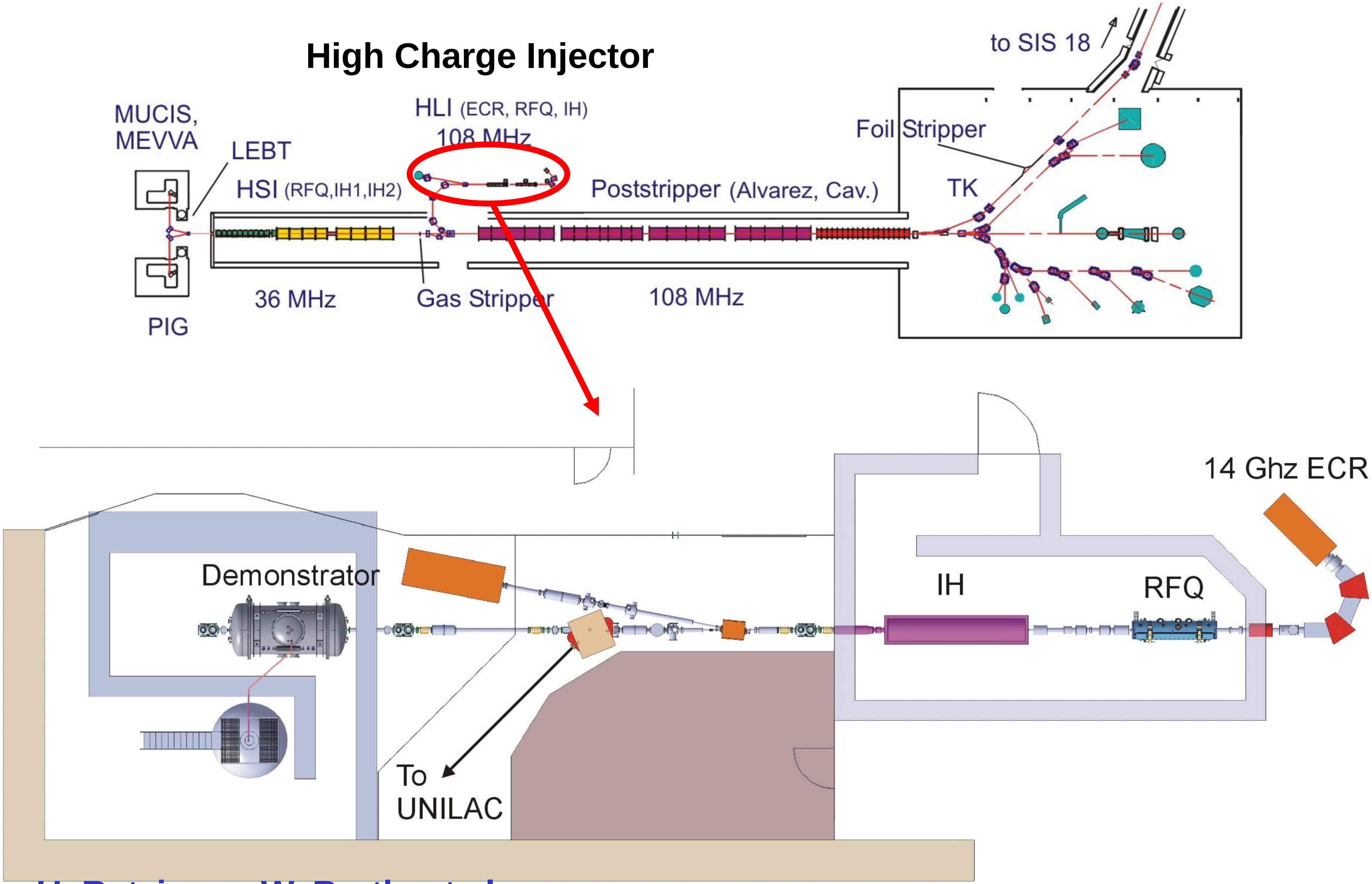
– next shell closures in nuclei and electron shells
– spherical SHE, nuclear structure
– unambigous identification
– synthesis of new elements beyond 120
– fast separation for ions with very short half-lives
– ID of ions with very long half-lives
– reactions: exploratory work needed! (transfer, reactions with radioactive nuclei)

Instruments

– accelerator and targets: highest intensities
– separators: hightest suppression
– detectors: highest selectivity and sensitivity

Thank you
for your attention!

Demonstrator: test bench at GSI

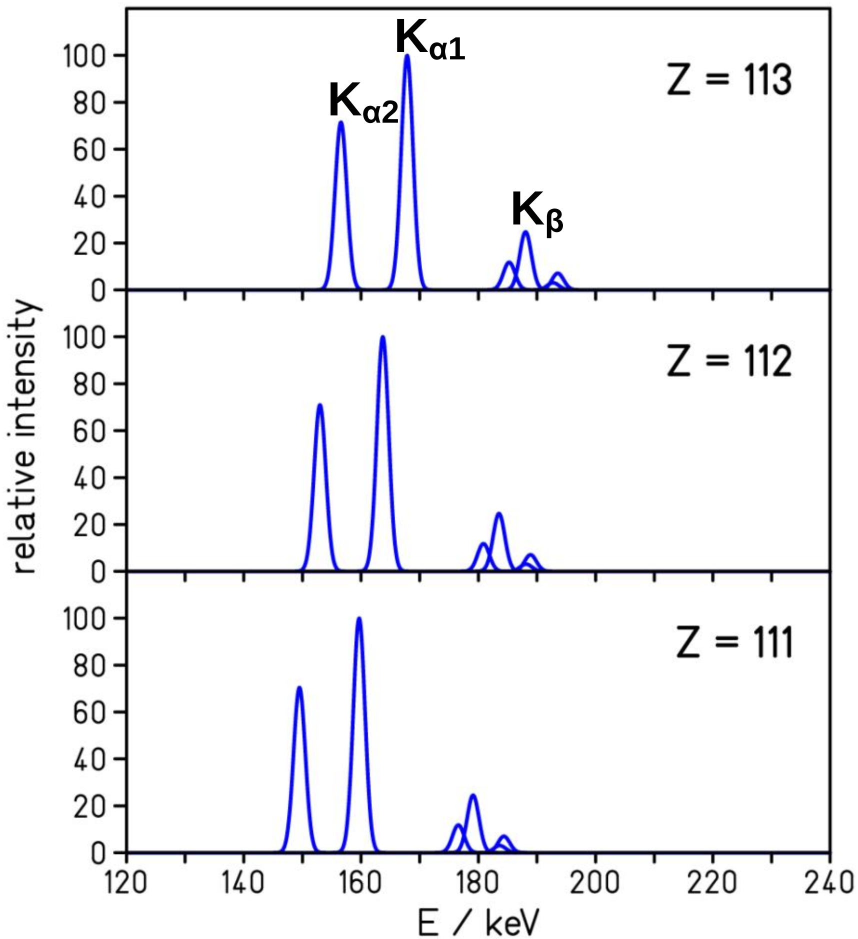


U. Ratzinger, W. Barth, et al.

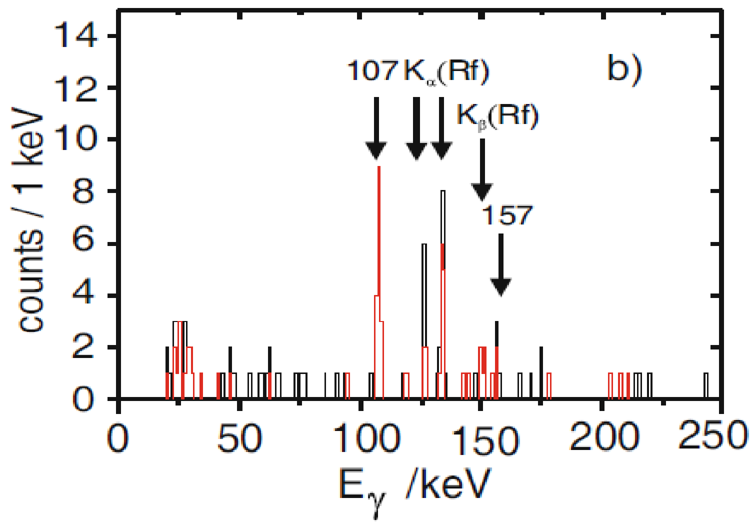
Scientific strategy for SHE research at GSI

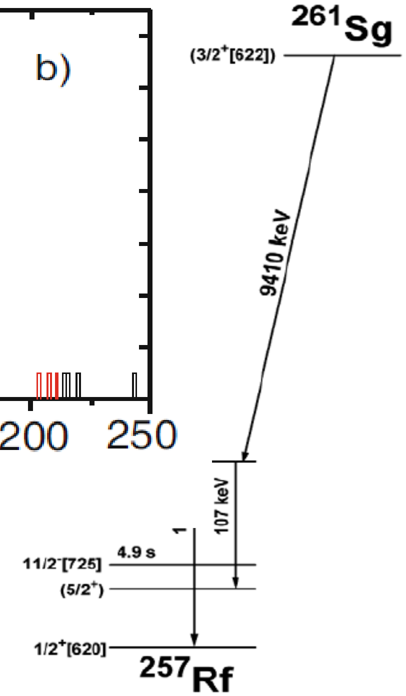
1. Synthesis of new elements, confirmation experiments, new n-rich isotopes
   - SHE synthesis: search for new elements 119 and 120, and beyond 120
   - Reaction studies, e.g. multi-nucleon transfer, cold and hot fusion,
   - Extension of SHE-Island (north-east, south-west)
   - Direct Z determination through observation of X-rays
   - Direct A determination with bolometer, mass spectrometer or new A/q separator
2. Physical and chemical studies of SHE
   - Detailed study of deformed and spherical „islands“
   - Chemical properties of element 114
   - New compound classes of lighter transactinides, organo-metallic compounds
   - Nuclear spectroscopy, decay studies, direct mass measurements, atomic and nuclear theory
3. Next-generation linac, separators and instruments
   - s.c. cw-linac
   - next-generation separator
   - novel detectors, electronics,...

Challenge #3: Z-identification via characteristic X-rays

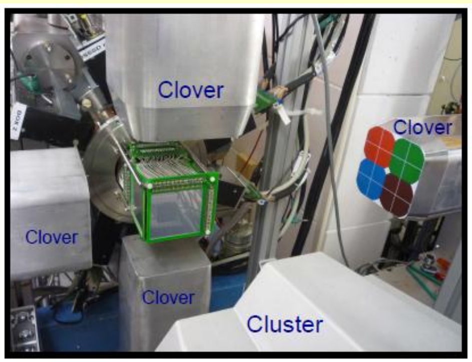


T.A. Carlson et al., NPA (1969)





B. Streicher et al., EPJ A (2010)



TASISpec setup

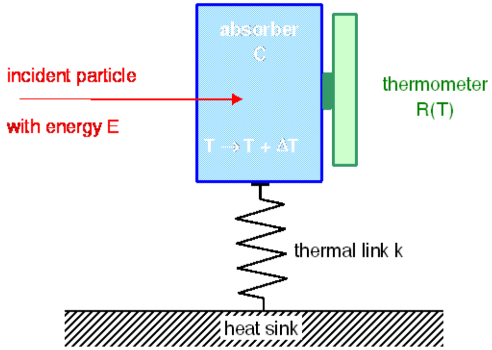
Experiment planned:

Ca + Am → 115

D. Rudolph, L.-L. Andersson, et al.

Challenge #3: A-determination by bolometers

Detection principle:



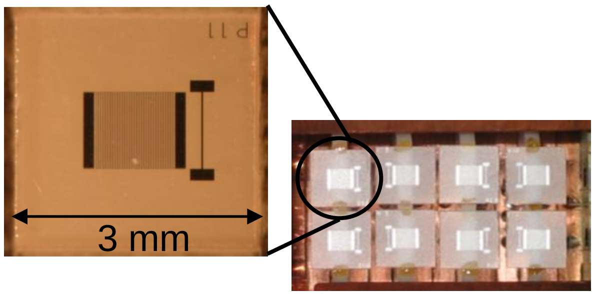
$\Delta T = E/C \sim E/T^3$

⇒ low operating temperatures

⇒ potential advantage in
- energy resolution
- energy linearity

Detector design:

sapphire absorber +Al TES thermistor array (12 x 6 mm^2) operated at 1.4 K



Detector performance:

- excellent energy resolution (~10x better as conv. Si detector)
- no pulse height defect

for ^{238}U, E = 360 MeV/u ⇒ $\Delta E/E = 1.1 \times 10^{-3}$

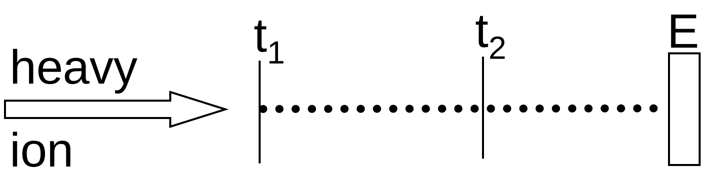
for ^{238}U, E = 0.09 MeV/u ⇒ $\Delta E/E = 4.4 \times 10^{-3}$

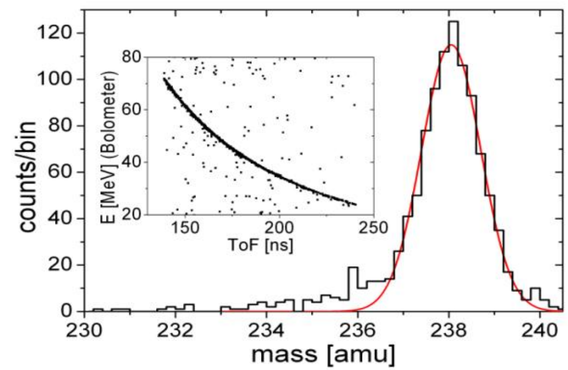
Mass identification:

E/TOF measurement

⟹ mass identification

example: ^{238}U, E=80...300keV/u

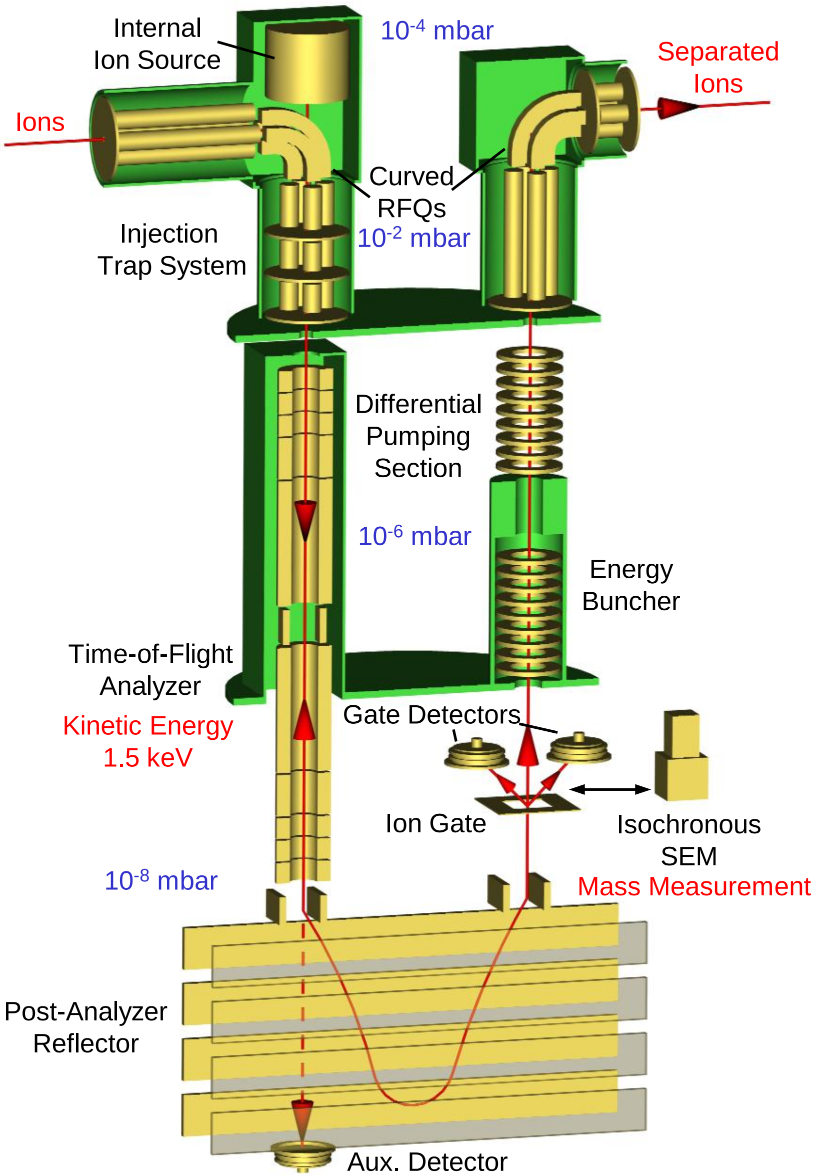


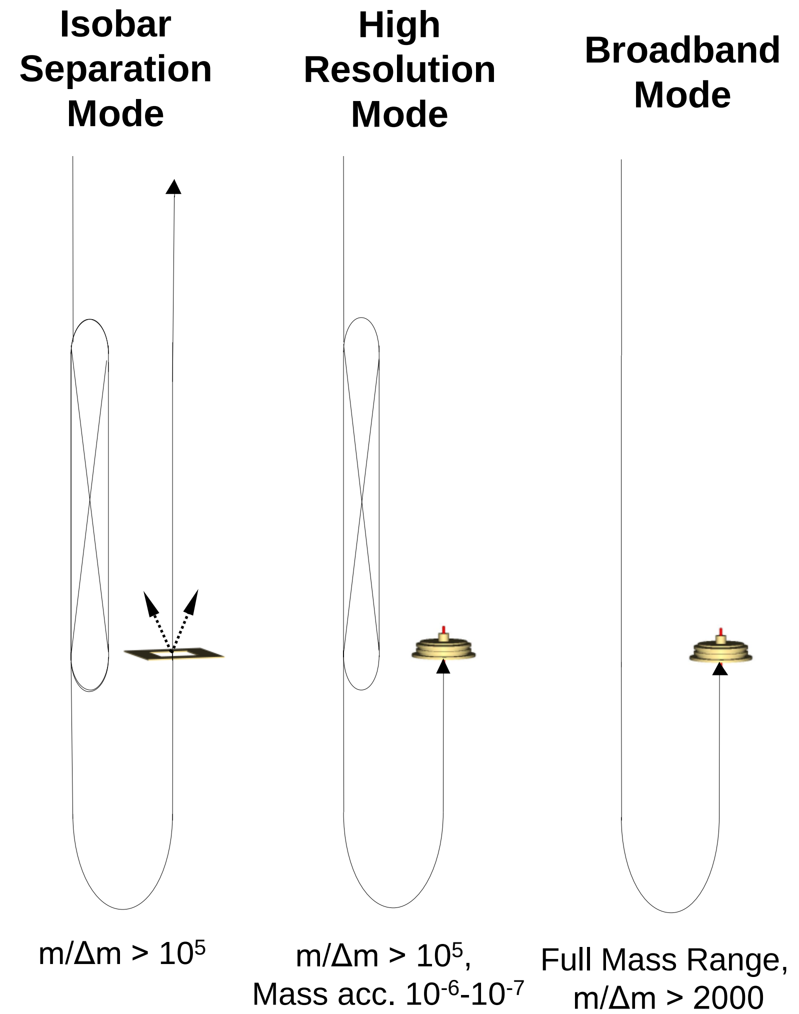


for ^{238}U: Δm(FWHM) = 1.53(5) amu

P. Egelhof et al.

Challenge #3: A-determination by mass spectrometer





W.R. Plaß et al., NIMB 266 (2008) 4560

Challenge #4: next-generation instruments

Long-term project: separator for intensities >5E13 pps

high intensity beam

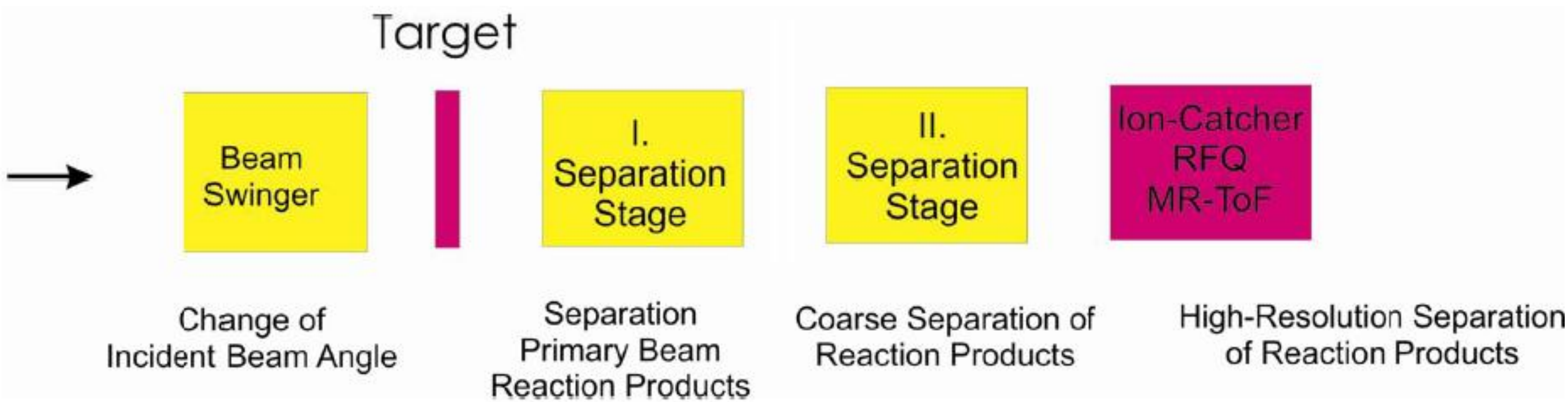
beam pre-paration and cleaning

high power target

2-stage separator

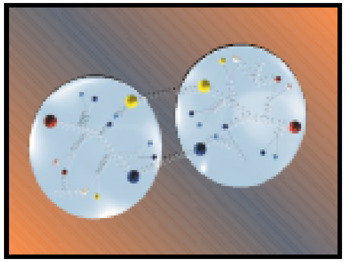
A/q - separator

detectors, instruments, chemistry, ...



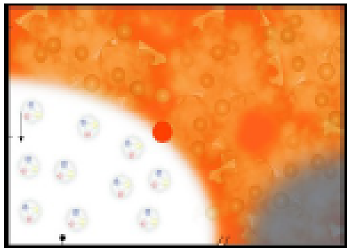
Collaboration: GSI, Gießen, Manipal

HIC for FAIR – research pillars



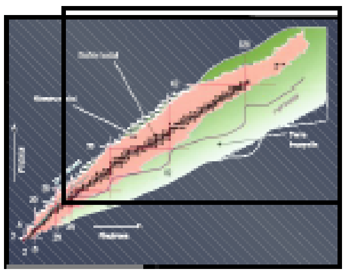
Hadron Structure and Dynamics:
COSY, SIS, FAIR
+ Theory

PANDA



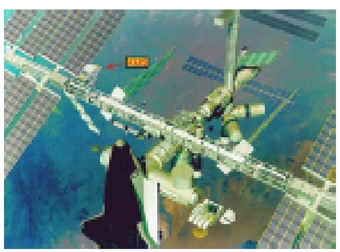
Nuclear and Quark Matter:
SIS, CERN, RHIC,
NICA, FAIR
+ Theory

CBM



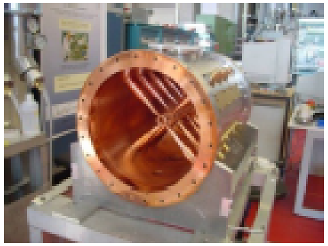
Exotic Nuclei and Nuclear Astrophysics:
UNILAC, SIS, FAIR
+ Theory

NUSTAR



From Fundamentals to Applications:
UNILAC, PHELIX, ESR,
SIS, FAIR + Theory

APPA



FAIR high-tech foundations:
Accelerator Development
High Performance Computing

HIM – The New Helmholtz Institute Mainz

HELMHOLTZ | GEMEINSCHAFT

Helmholtz-Institut Mainz

GSI

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

HIM Director: Frank Maas

Helmholtz Institute Mainz (HIM)

3 Junior Research Groups
-
-J. Dvorak (IRiS)
(currently on leave of absence)
-

THEORY Floor

International Guests Programme

MAM	**EMP**	**SPECF**	**SHE**
Symmetry of Matter and Antimatter	*Hadron Structure with electomagn. Probes*	*Hadron Spectroscopy and Flavour*	*Stability and Properties of Superheavy Elements*
			Chemistry | *Physics*
			CED | **N.N. (Successor D. Rudolph)**

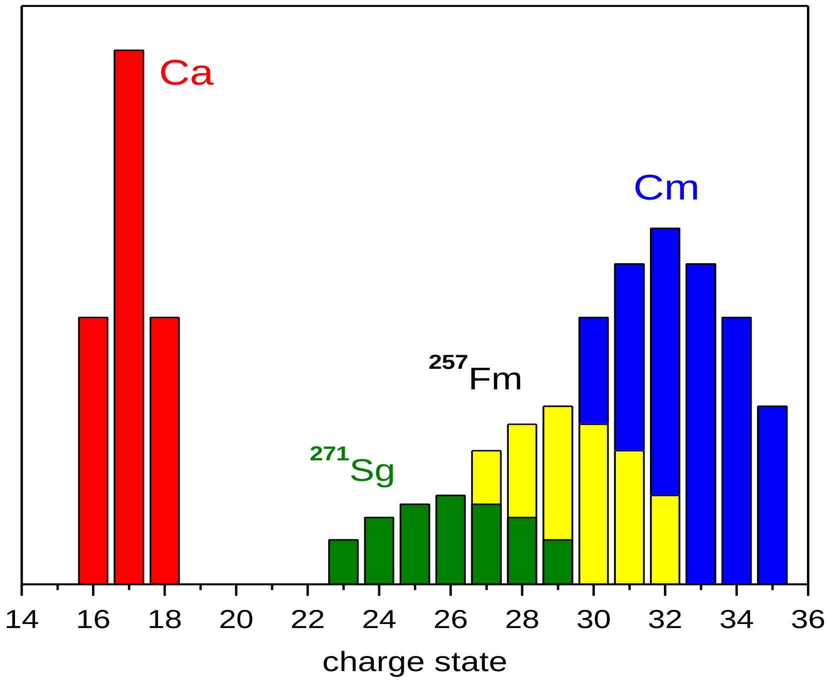
ACID *Accelerators and integrated Detectors* — **Toward a dedicated cw LINAC for SHE; ...**

Administration

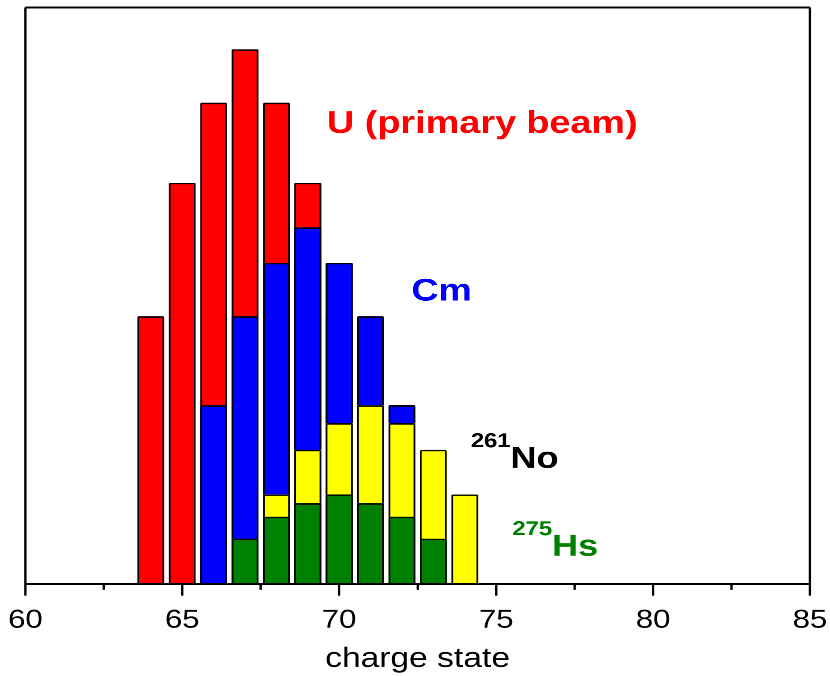
JG|U **At Mainz University (Institutes for Nuclear Physics, Nuclear Chemistry, Physics): 30 Full Time Equivalent (FTE) Personnel in Workshops and Laboratories**

Ion charge states at zero degree

$^{48}Ca + ^{248}Cm$, E_{cm} = 209 MeV

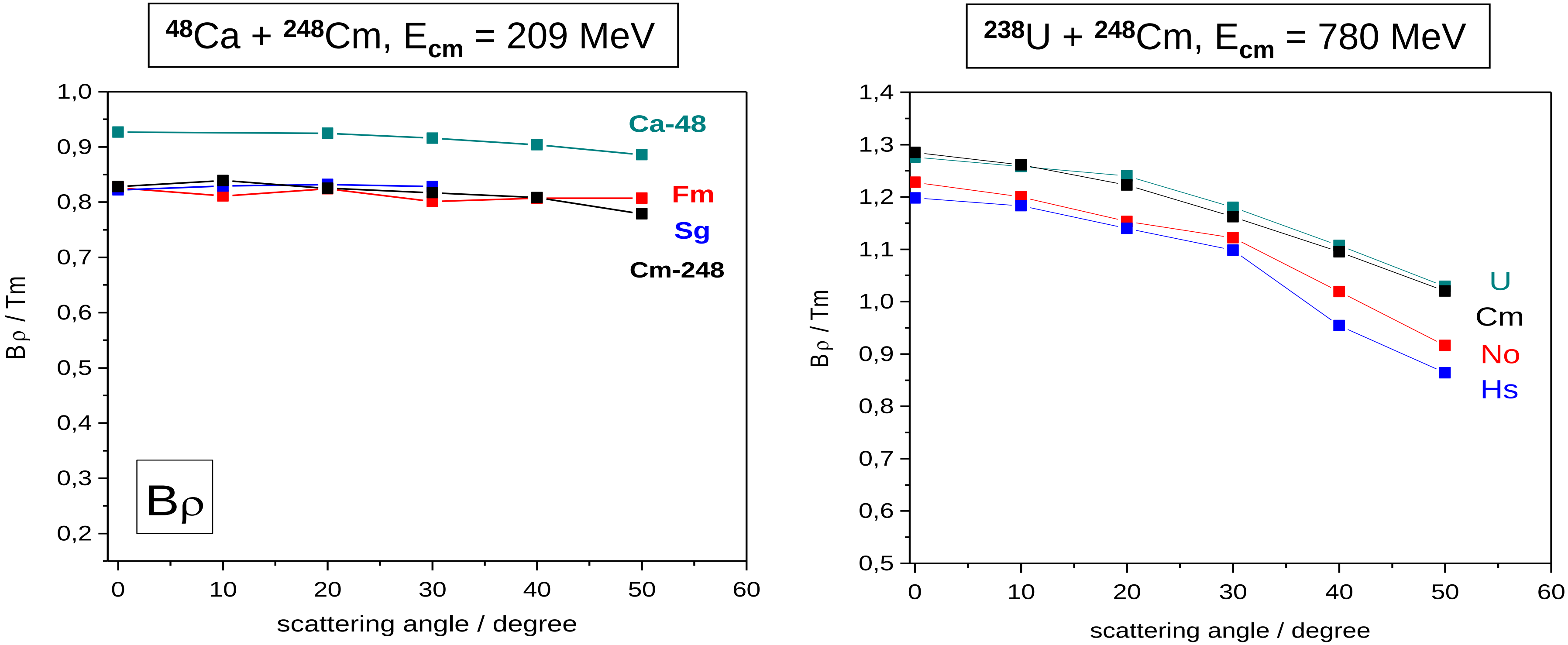


$^{238}U + ^{248}Cm$, E_{cm} = 780 MeV



S. Heinz et al.

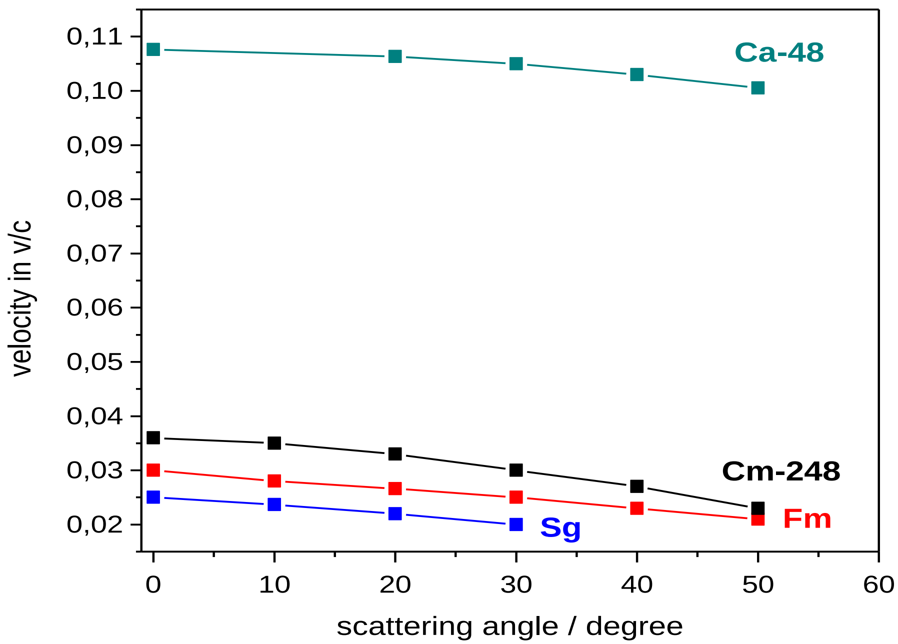
Bρ – values in vacuum



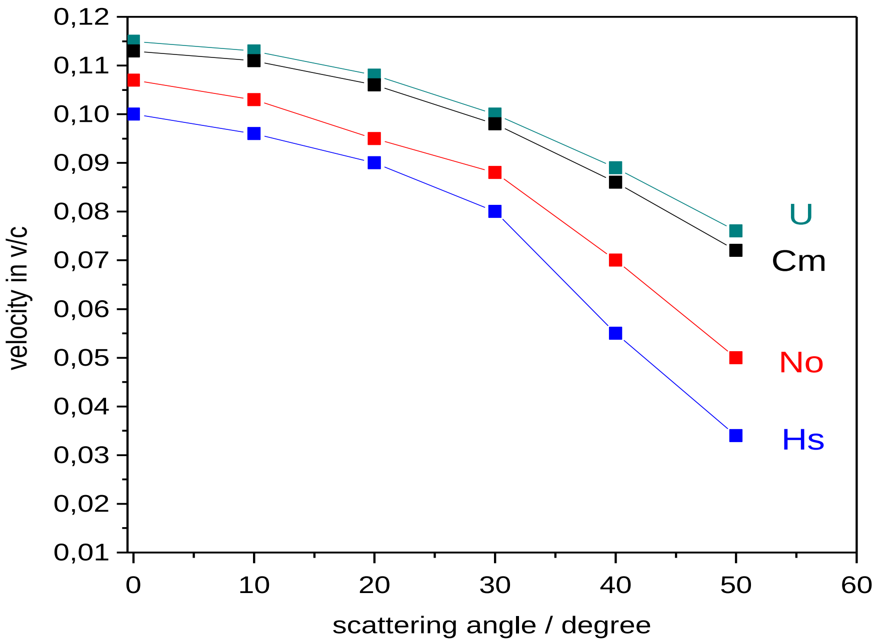
S. Heinz et al.

Ion velocities

$^{48}Ca + ^{248}Cm$, E_{cm} = 209 MeV

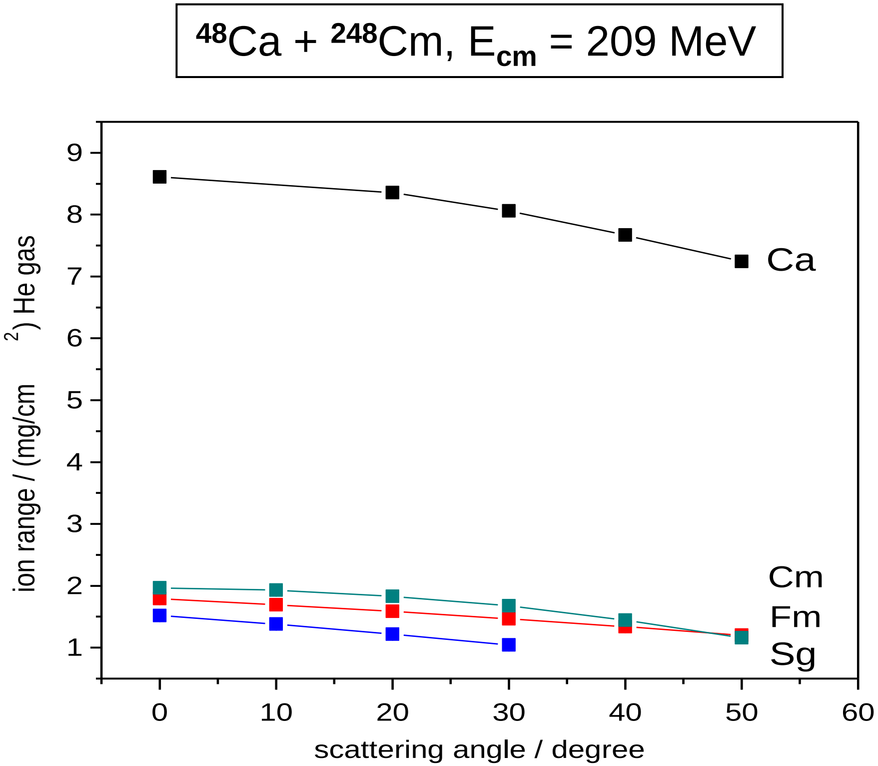


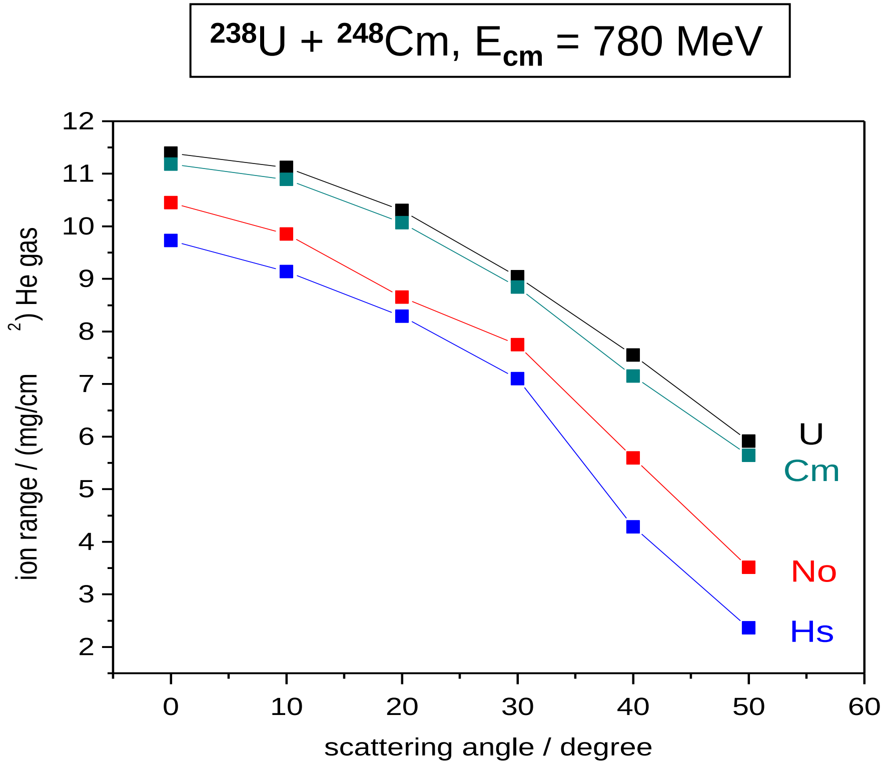
$^{238}U + ^{248}Cm$, E_{cm} = 780 MeV



S. Heinz et al.

Ion ranges in 1 bar He gas





S. Heinz et al.