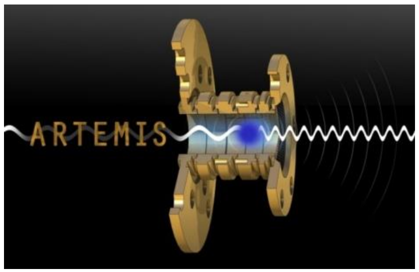
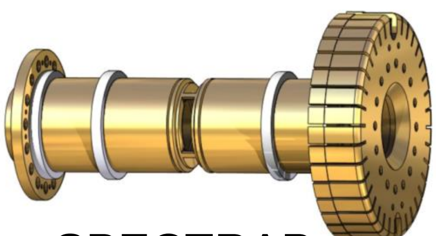
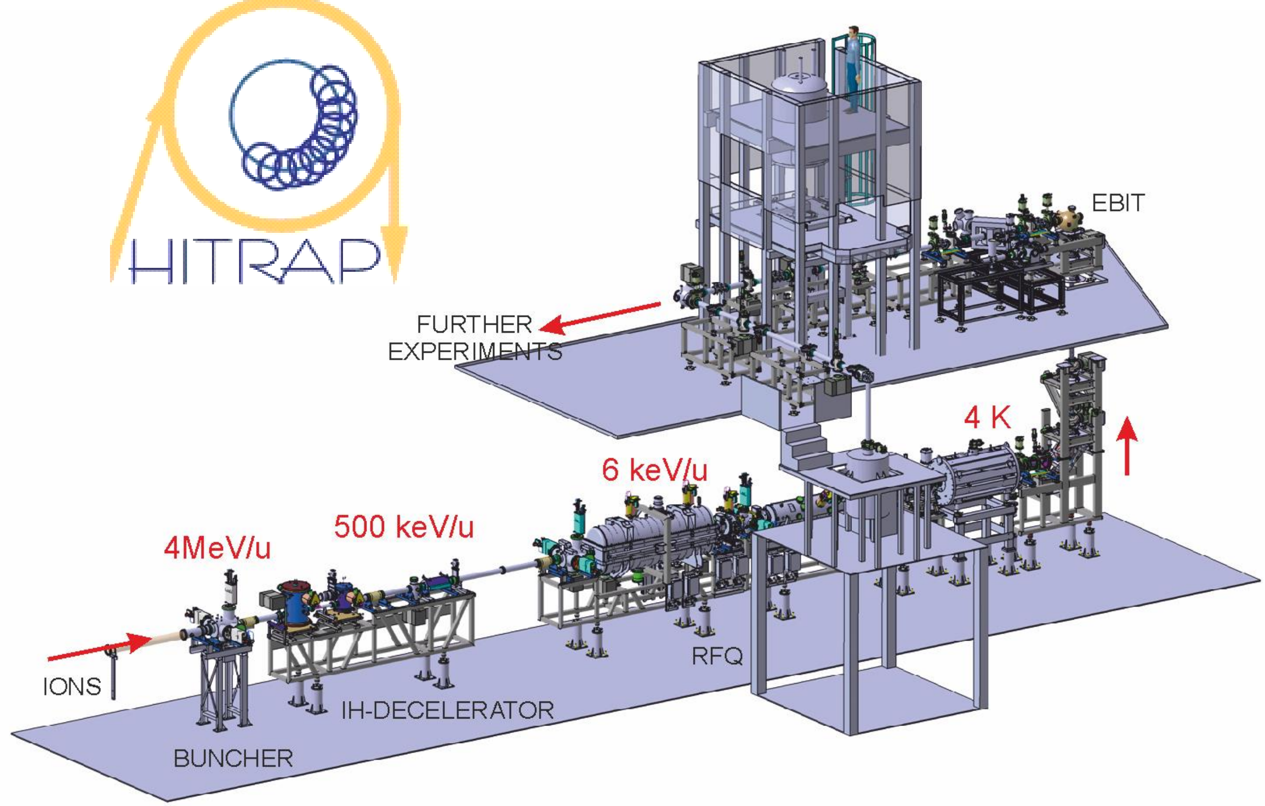
THE HITRAP FACILITY FOR DECELERATION AND TRAPPING OF HIGHLY CHARGED IONS AND ANTI-PROTONS



HITRAP



SPECTRAP



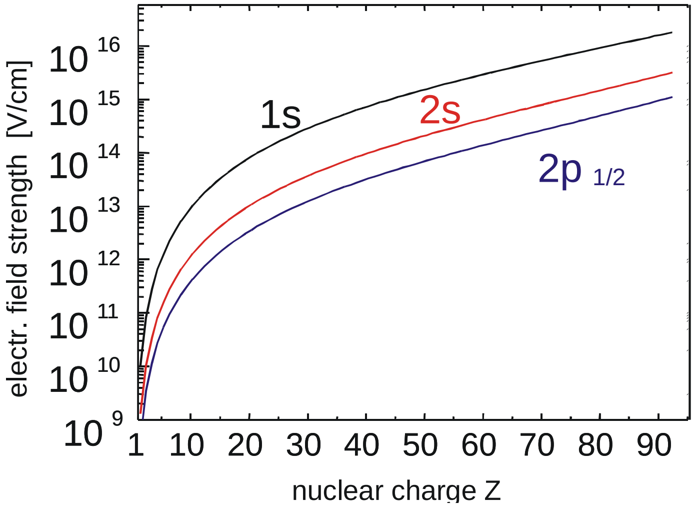
HILITE

High-Intensity Laser Ion-Trap Experiment

MOTIVATIONAL BACKGROUND

- **What makes highly charged ions (HCI) interesting ?**
- **Why do we want slow HCI?** (keV down to μeV)

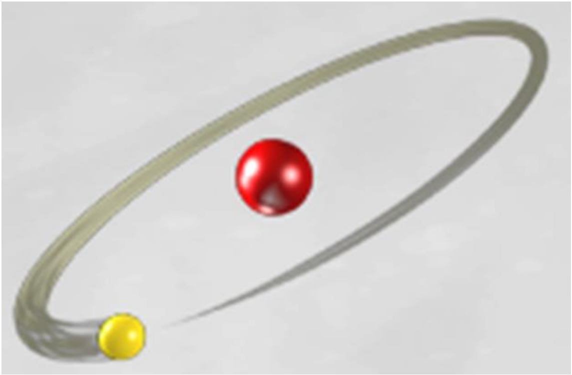
A lot of things, mainly the extreme field strength in their vicinity
-> spectroscopy, magnetic moments, reactions and collisions...



For a number of reasons, mainly for trapping and low-energy reactions
-> precision measurements, reaction microscopy,...

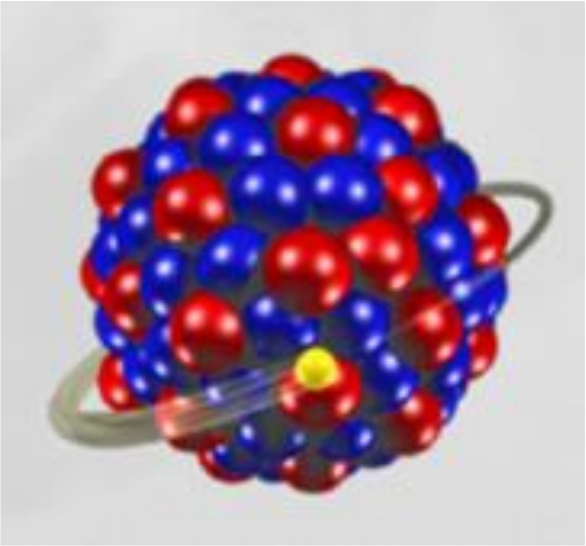
H.-J. Kluge et al.,
Advances in Quantum Chemistry **53,** 83 (2007)

HIGHLY CHARGED IONS



Hydrogen Z=1

→



Hydrogen-like ion Z=2-92 (also Z>92: unstable species)

$E < 10^{16}$ V/cm
$B < 10^{5}$ T

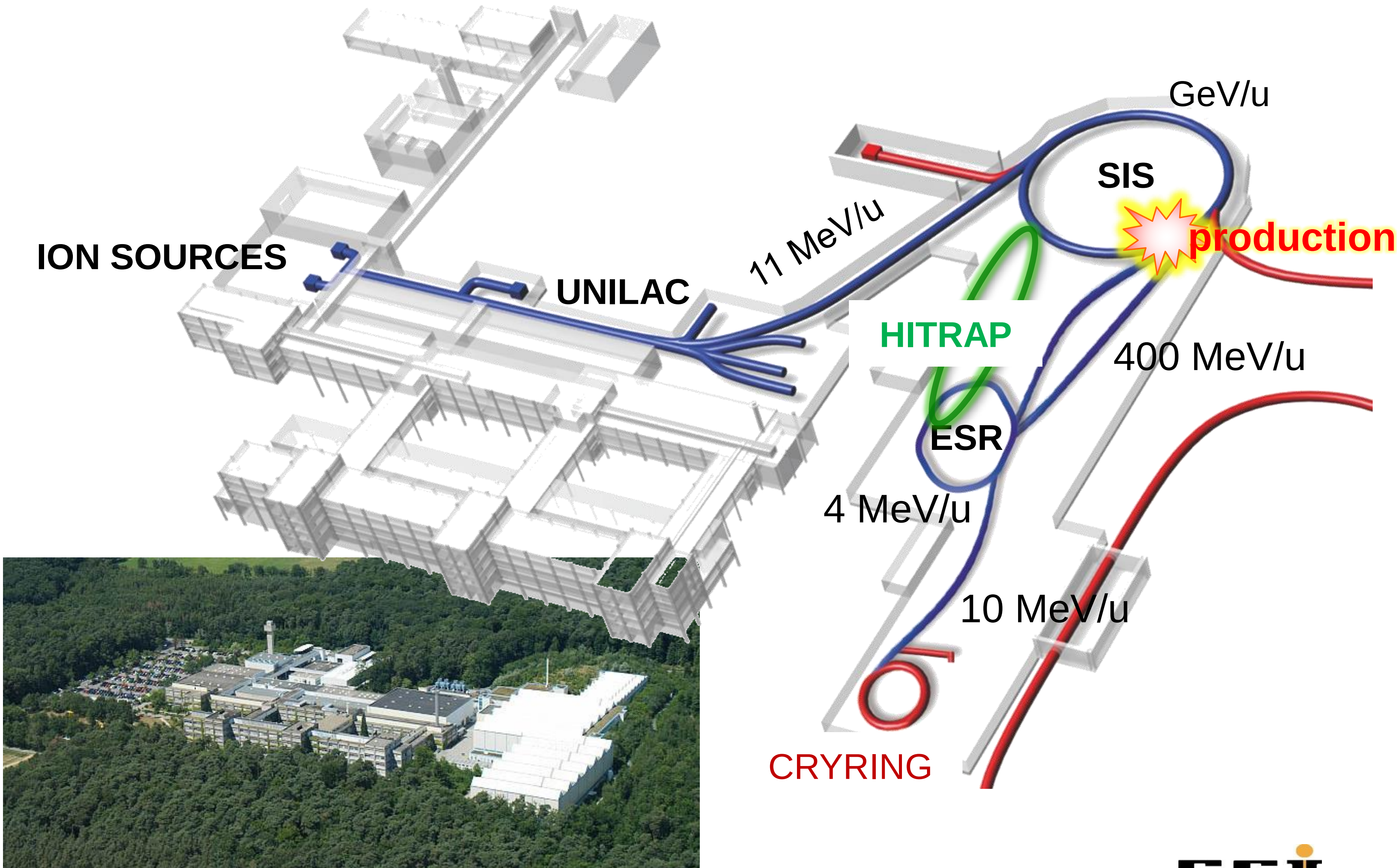
PRINCIPAL TRANSITIONS $E \sim Z^2$ ($\tau \sim Z^{-6}$)

HYPERFINE TRANSITIONS $E \sim Z^3$ ($\tau \sim Z^{-9}$) optical for high Z

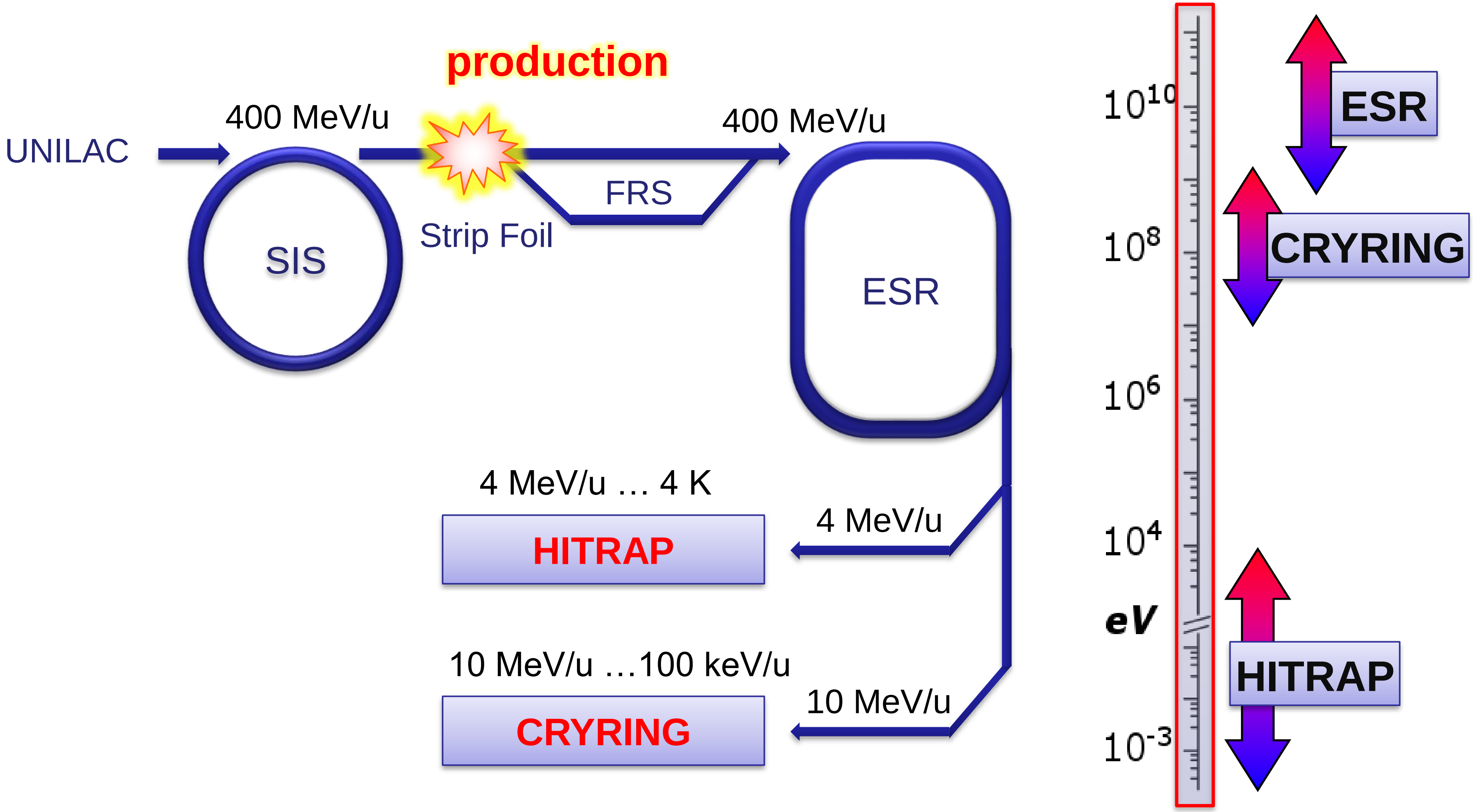
FINE STRUCTURE TRANSITIONS $E \sim Z^4$ ($\tau \sim Z^{-12}$) optical for medium Z

HIGH POTENTIAL ENERGY, BUT ALSO : IONIZATION THRESHOLD $E \sim Z^2$

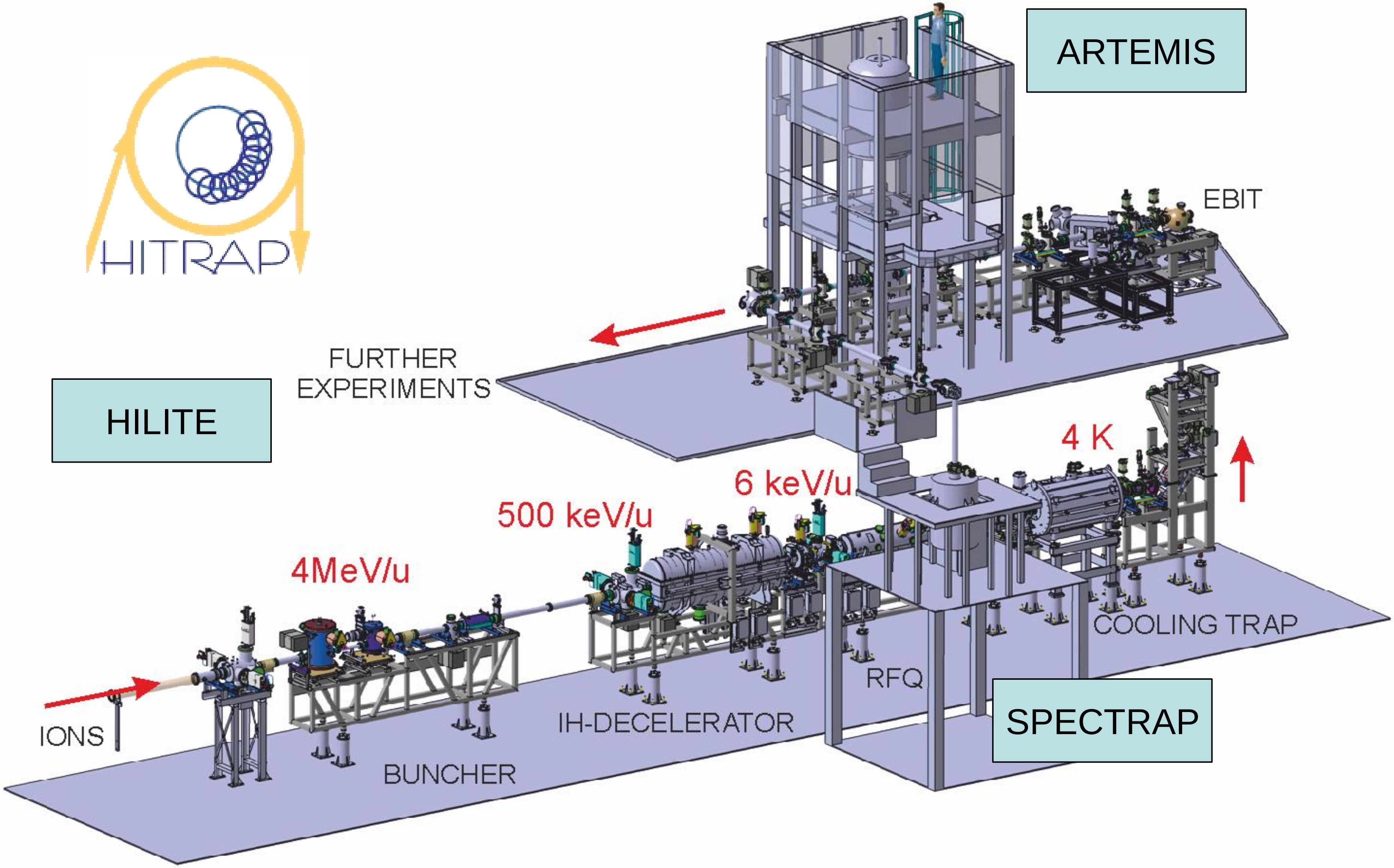
HIGHLY CHARGED ION PRODUCTION @ GSI



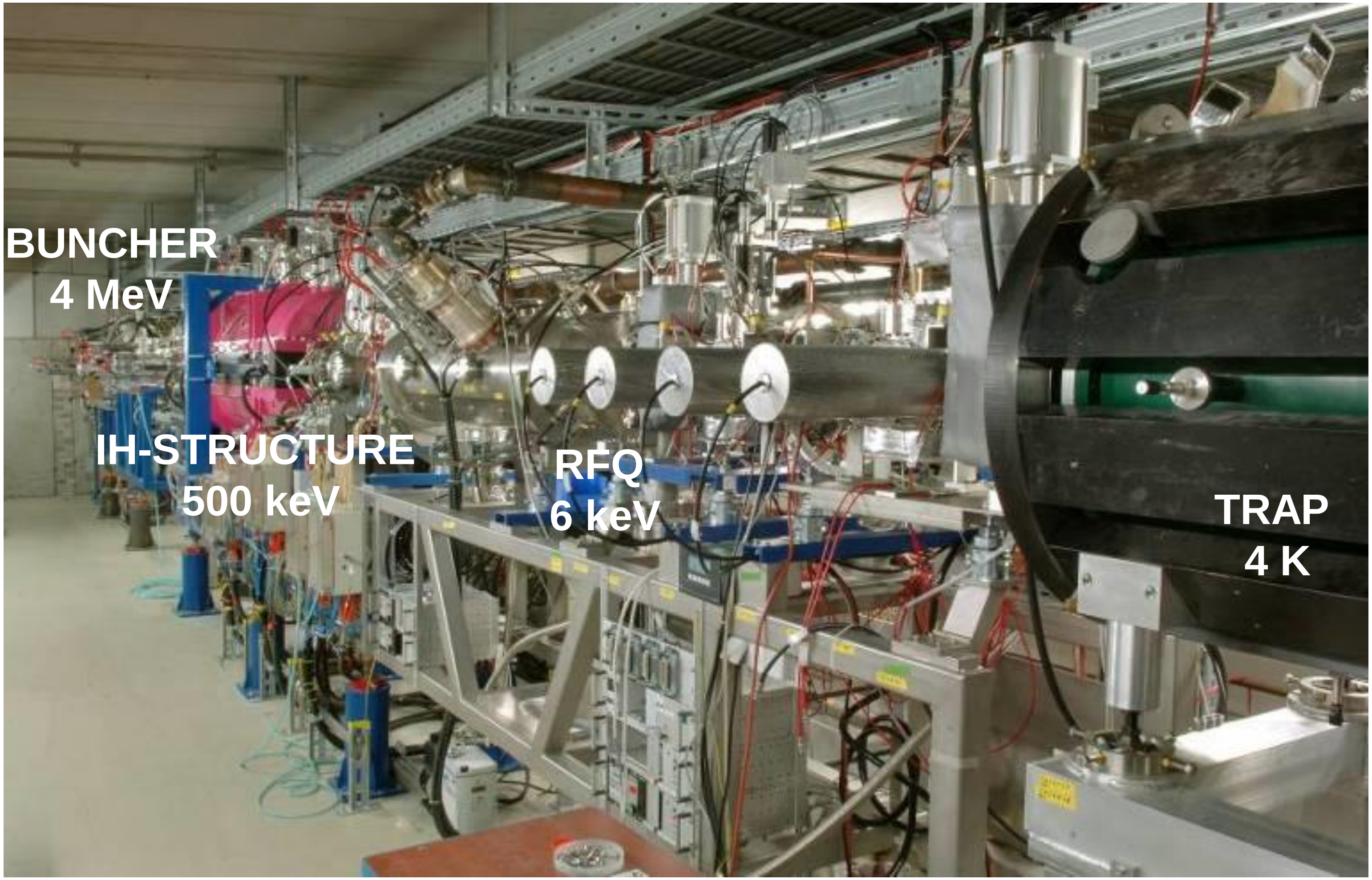
HIGHLY CHARGED IONS FOR HITRAP



HITRAP LAYOUT

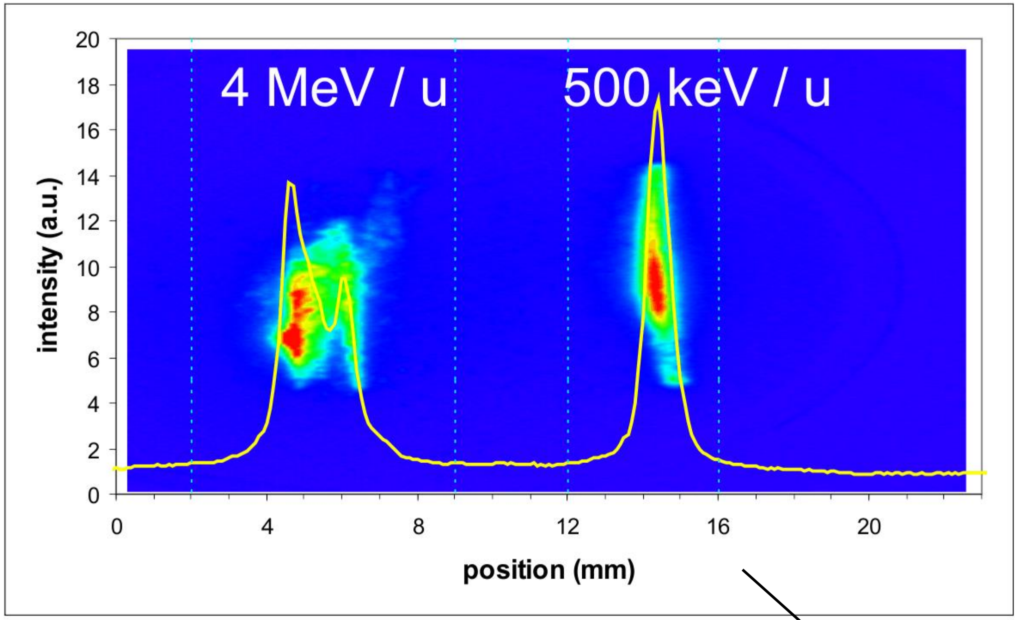


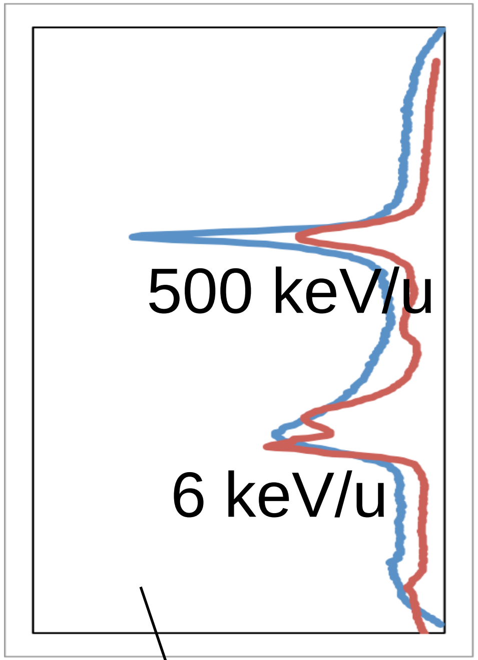
PICTURE OF THE DECELERATION STAGES

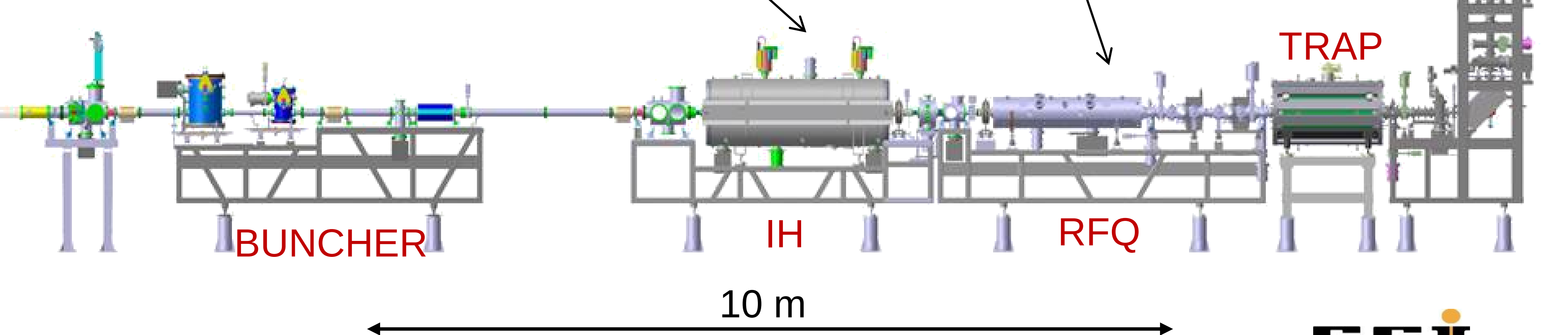


ION BUNCH DECELERATION SO FAR

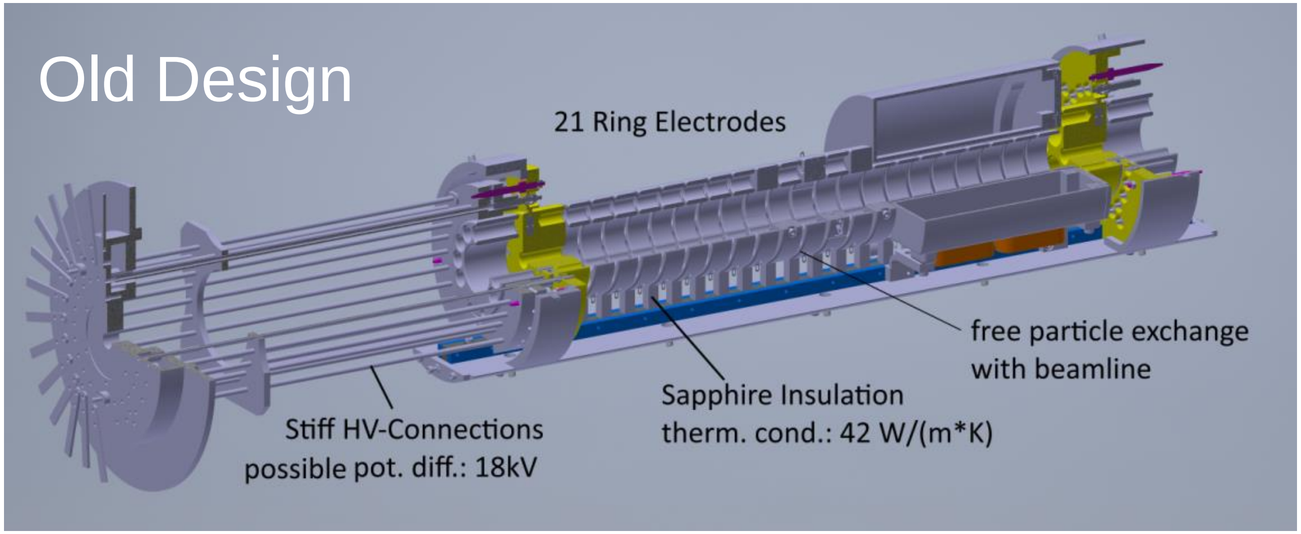
designed to work with |m/q|<3 ← HCI, anti-protons

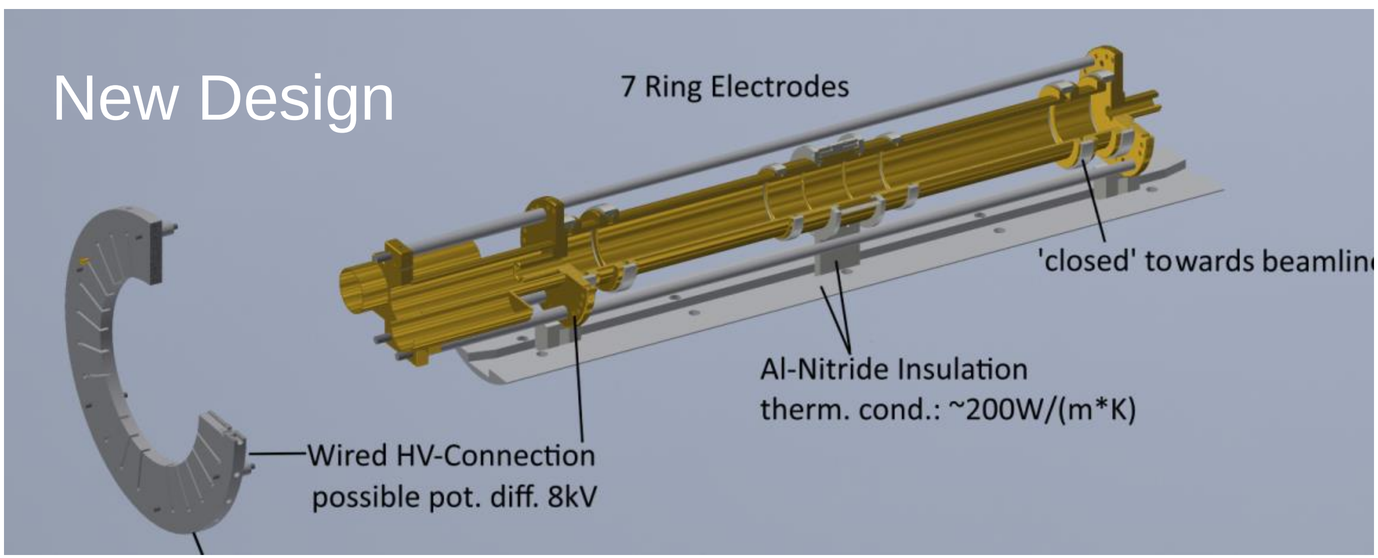




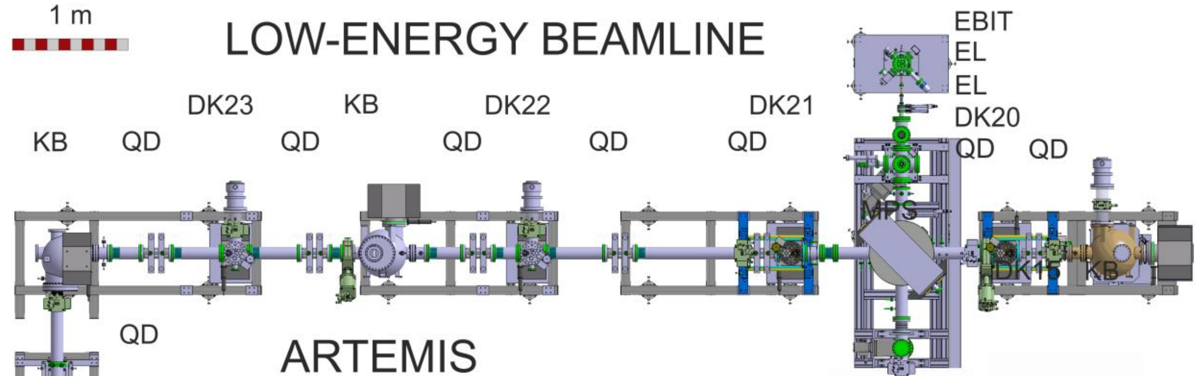


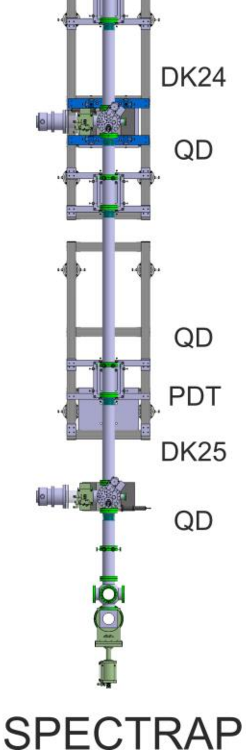
NEW COOLING TRAP UNDER COMMISSIONING

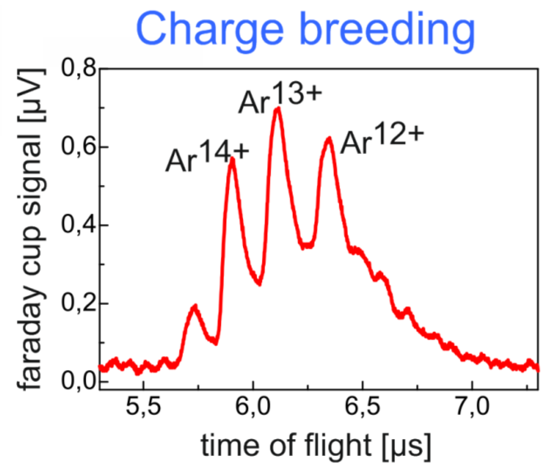




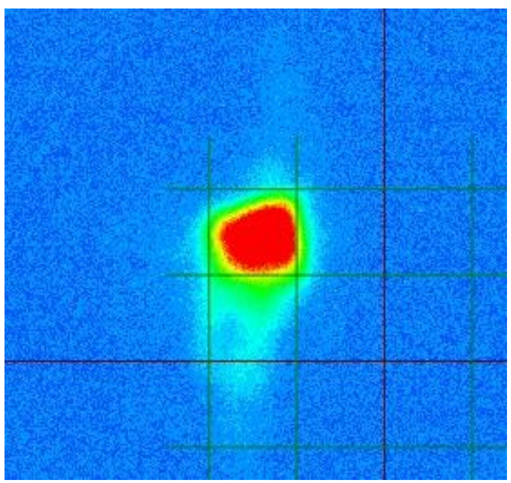
LOW-ENERGY BEAMLINE @ keV / q





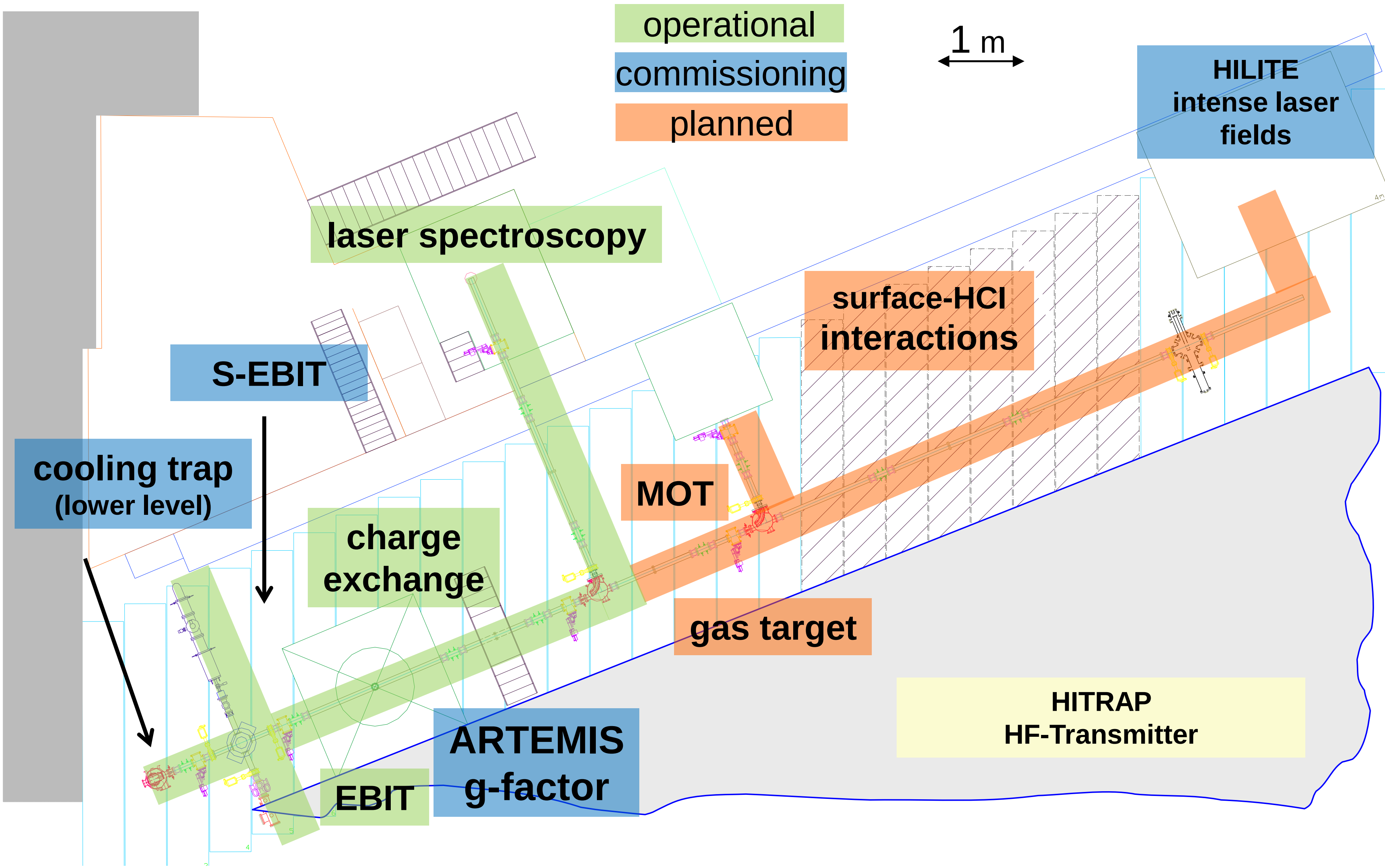


BEAM PROFILE AFTER 10m

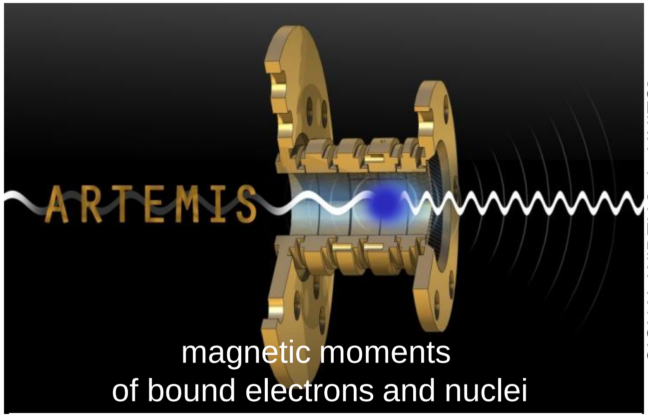


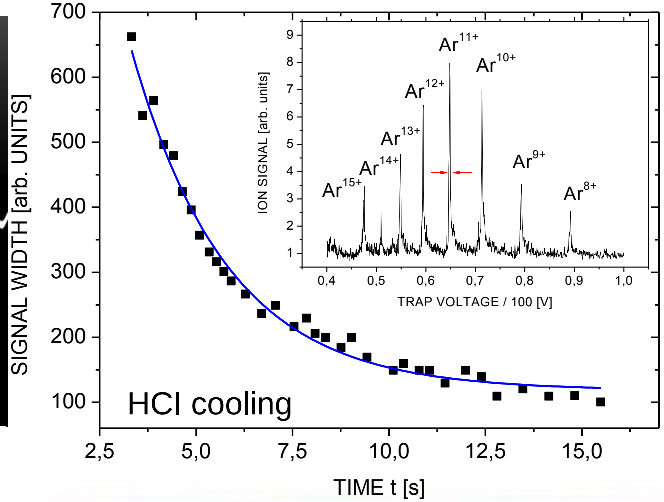
HITRAP LOW-ENERGY BEAMLINE	
beam energy	2-10 keV/q
beam size	~ 5 mm
transport efficiency	up to 95%
charge states	up to ~ 44+
ion species (DREEBIT)	Ar, Xe, Kr, O, C, K, Ca, ...

EXPERIMENTAL AREA: OVERVIEW



TRAP EXPERIMENTS

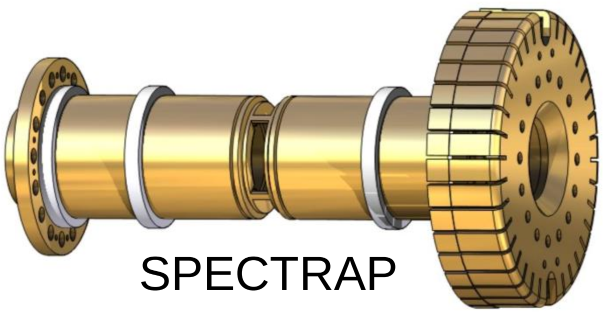




currently: HCI production, cooling and storage for weeks
pressure ~ 10^{-16} mbar

TECHNISCHE UNIVERSITÄT DARMSTADT

RUPRECHT-KARLS-UNIVERSITÄT HEIDELBERG

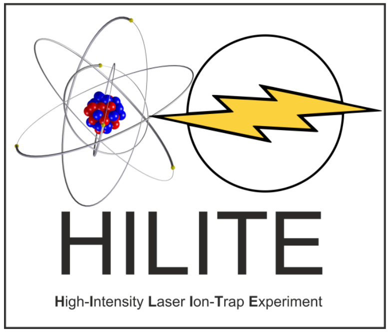


precision spectroscopy of highly charged ions

currently: upgrading

Imperial College London

TECHNISCHE UNIVERSITÄT DARMSTADT



currently: commissioning

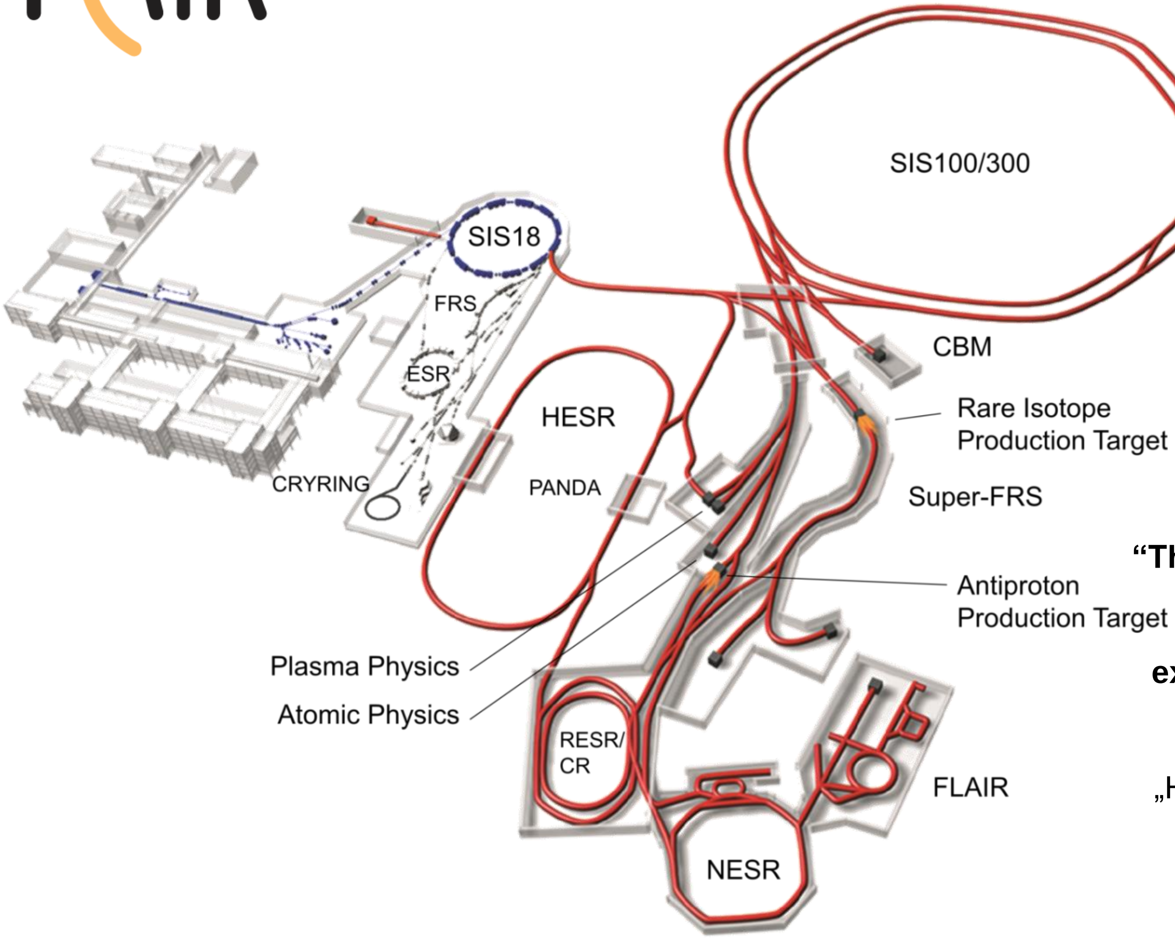
HI Jena
Helmholtz-Institut Jena

Friedrich Schiller Universität Jena
seit 1558

GSI

FAIR AND ANTI-PROTONS

FAIR = INTERNATIONAL FACILITY FOR ANTIPROTON AND ION RESEARCH



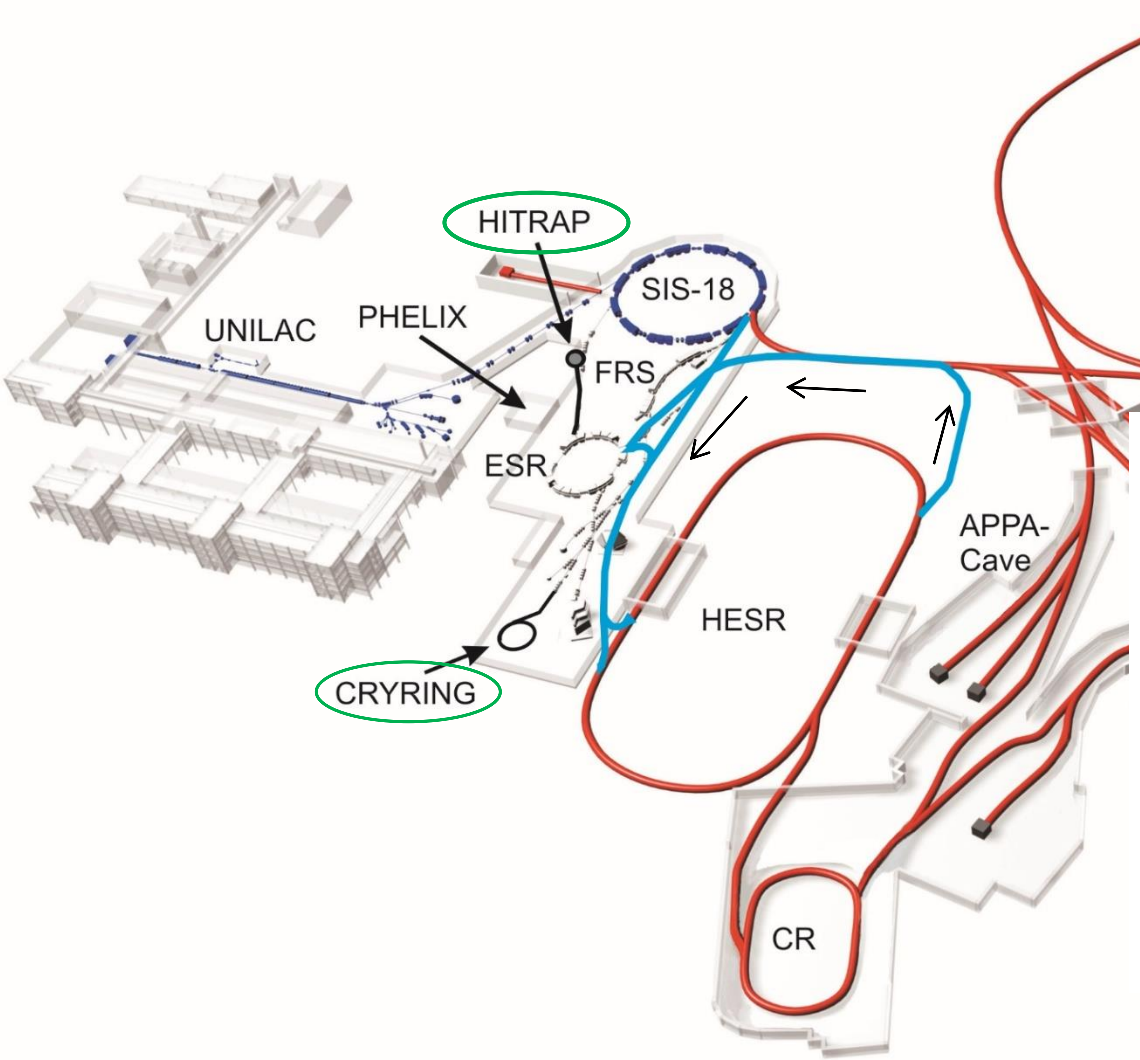
SET OF EXTENSIONS TO MAKE AVAILABLE HIGHER ION ENERGIES, INTENSITIES, and ANTI-PROTONS

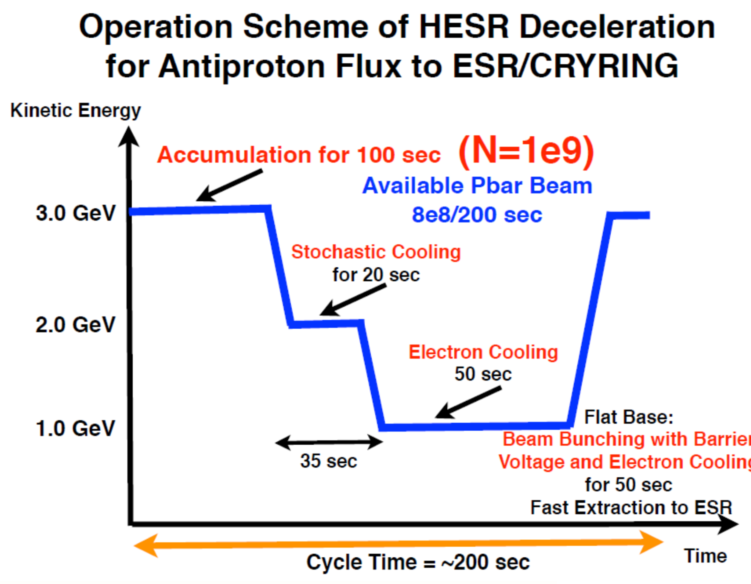
"The high intensity of secondary beams produced will make it possible to […] extend the physics programme of HITRAP to novel experiments with trapped radioactive ions and, of course, with trapped antiprotons."

„HITRAP: A facility at GSI for highly charged ions ", H.-J. Kluge et al., Advances in Quantum Chemistry **53,** 83 (2007)

GSI

CONCEPTS FOR ANTI-PROTONS AT ESR AND HITRAP





T. Katayama et al., Phys. Scr. T166 (2015) 014073

SUMMARY

HITRAP Decelerator

- Deceleration from production to 6 keV/u achieved
- Trapped offline-ions, trapped electrons, electron cooling
- Efficient low-energy beam transport to experiments
- Next step: new cooling trap, HCI beam times in 2018/19
- Intended to also work with anti-protons @ FAIR

Current Experiments

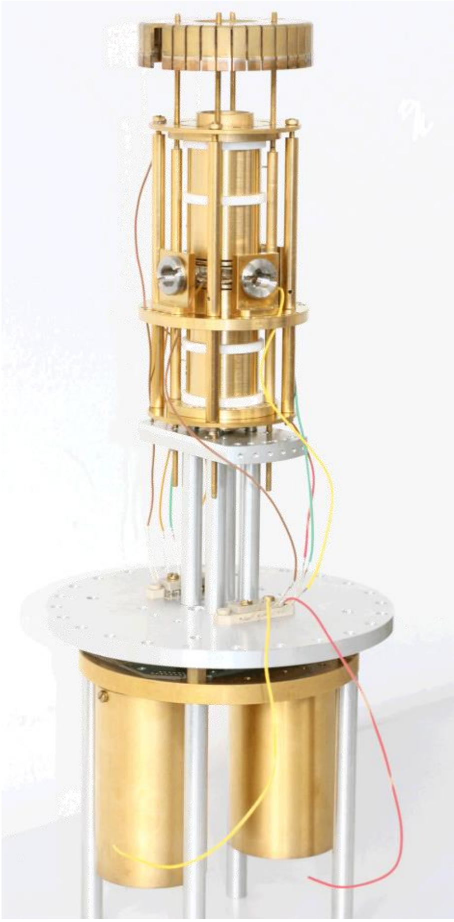
- ARTEMIS: HCI storage and cooling, operational
- SPECTRAP: mK ion crystals for cooling of HCI, upgrade
- HILITE: offline measurements, commissioning

THE FAIR FACILITY UNDER CONSTRUCTION

THANK YOU

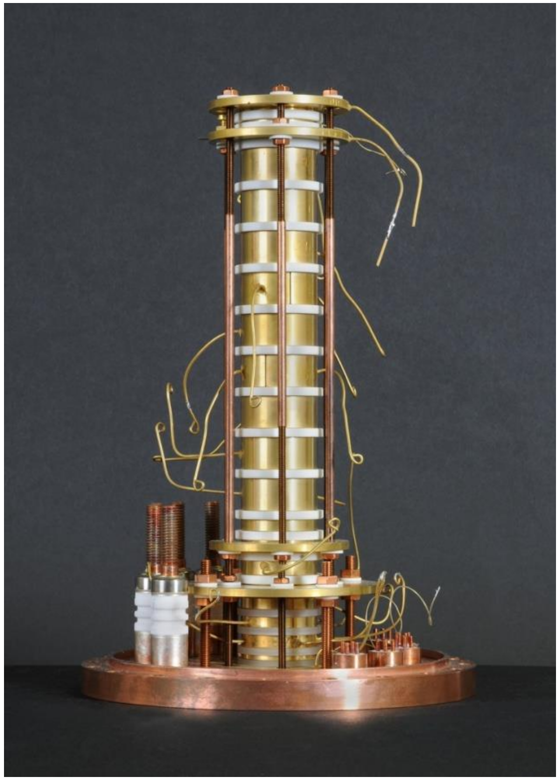
PENNING TRAPS AS COMMON DENOMINATOR

SPECTRAP



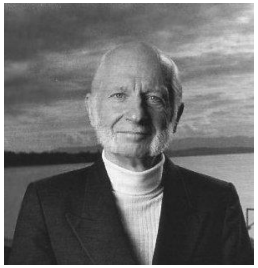
+

ARTEMIS



Frans Penning (1936)

John Pierce (1949)



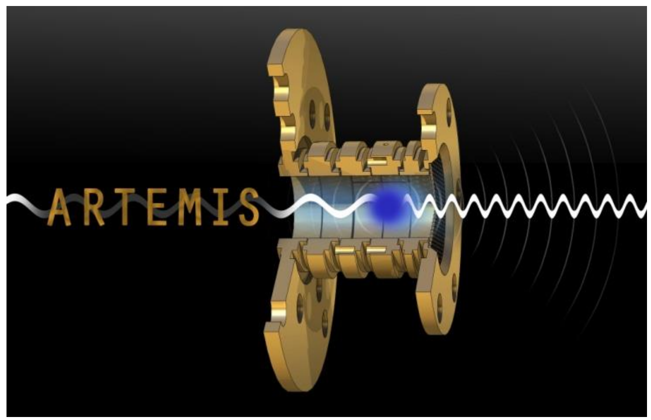
Hans Dehmelt (1961)

HILITE

ARTEMIS

double-resonance spectroscopy of highly charged ions

aim: magnetic moments (g-factors) of bound electron



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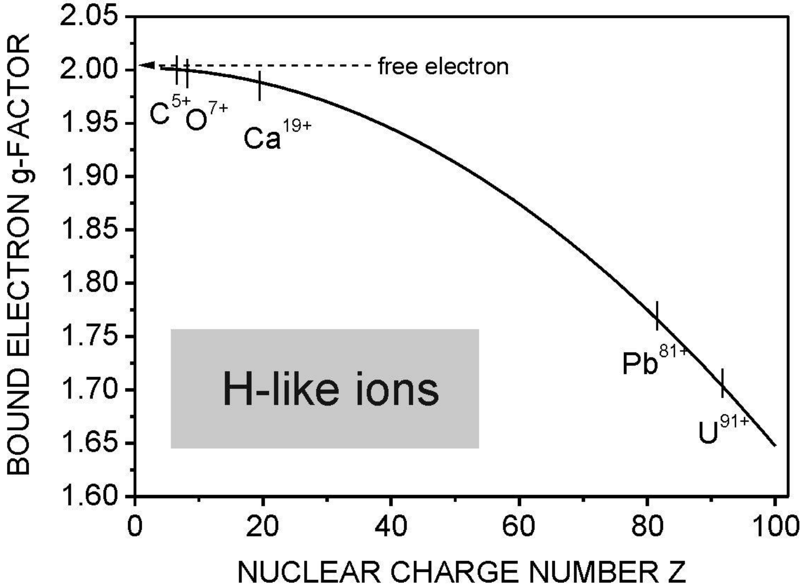
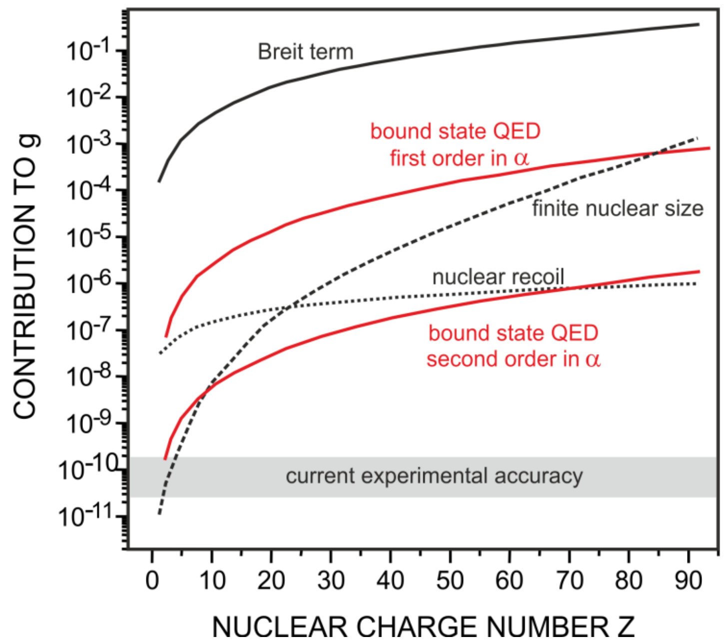
ELECTRON IN EXTREME FIELDS: MAGNETIC MOMENT

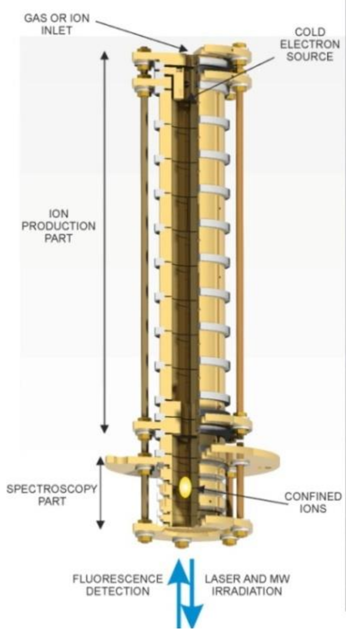


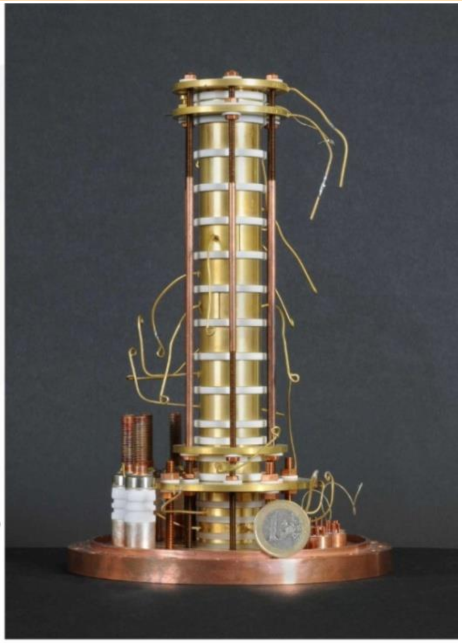


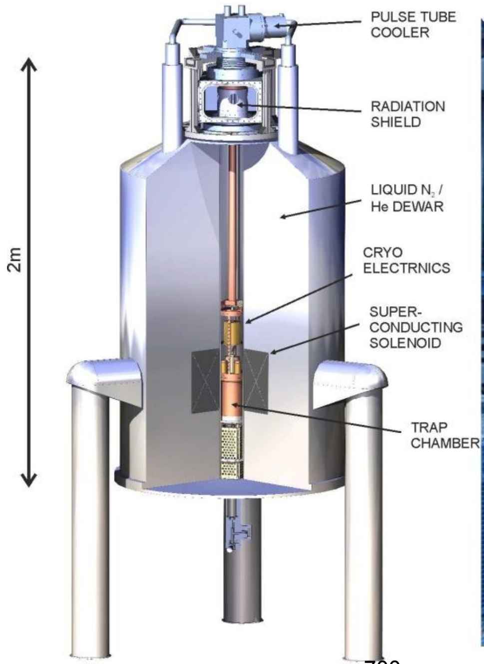
Apart from relativity, significant contributions to *g* come from QED and the nucleus

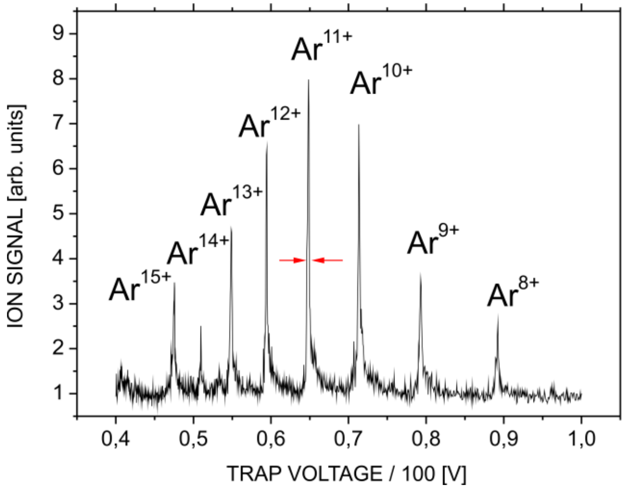
Test of QED in strong fields, higher-order Zeeman effects,
Nuclear information in absence of shielding,...

ARTEMIS

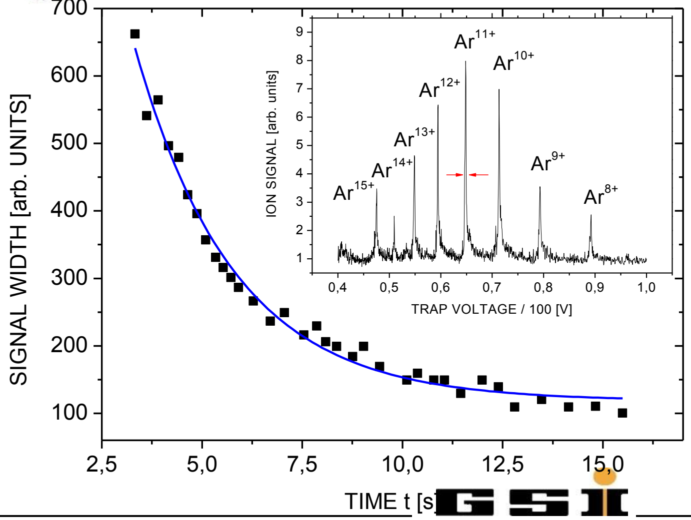






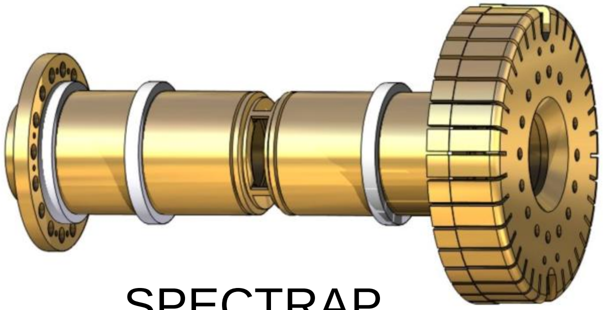


currently:
in-trap ion production and cooling
storage time: weeks
pressure ~ 10^{-16} mbar



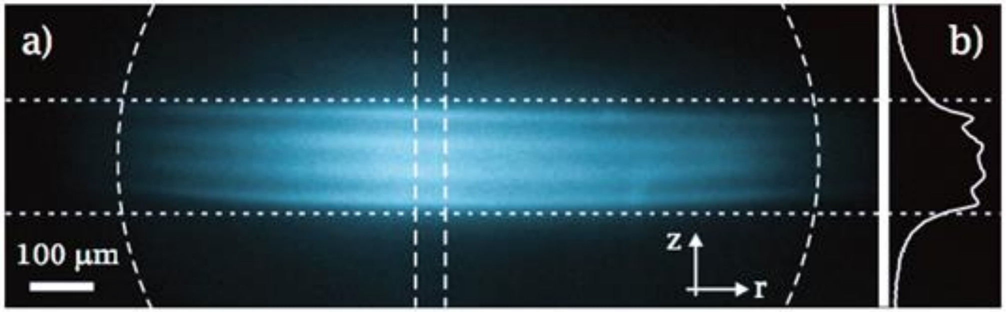
SPECTRAP

optical spectroscopy of highly charged ions
aim: FS and HFS transition energies and lifetimes in HCI

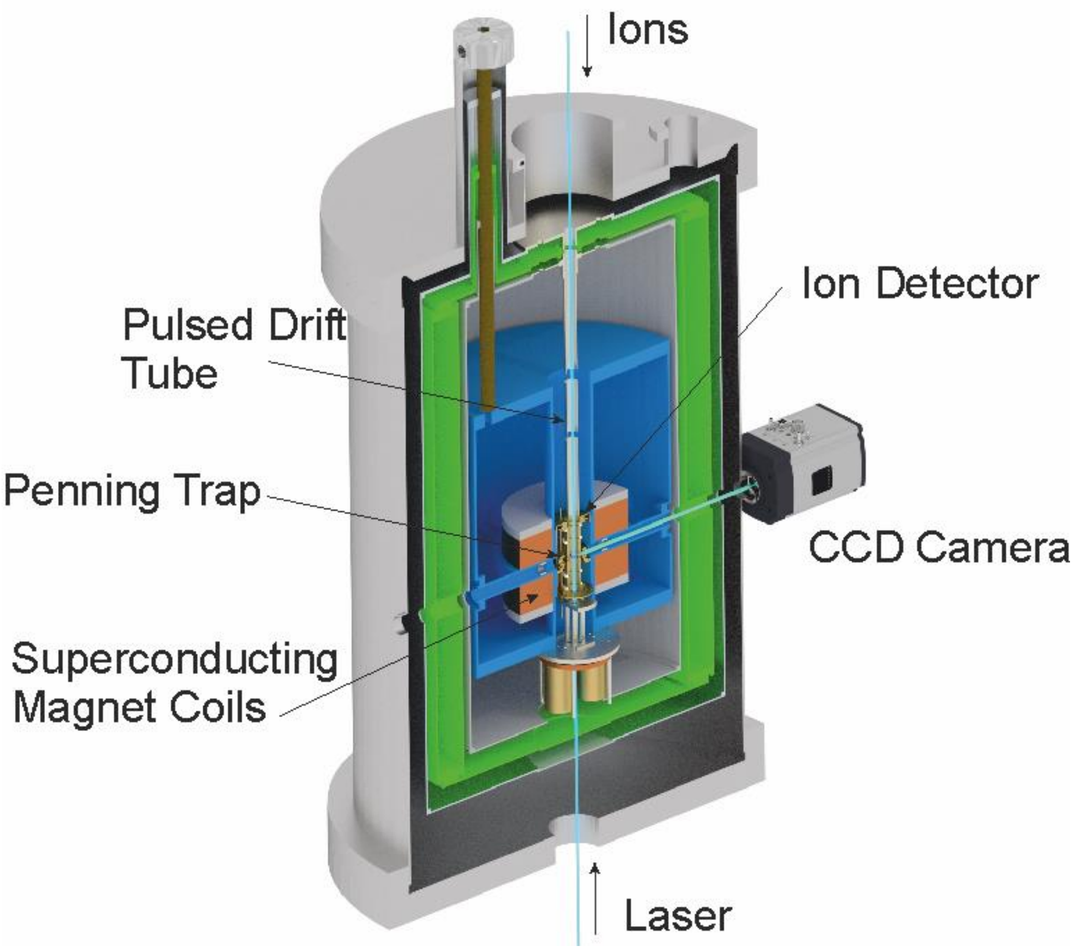


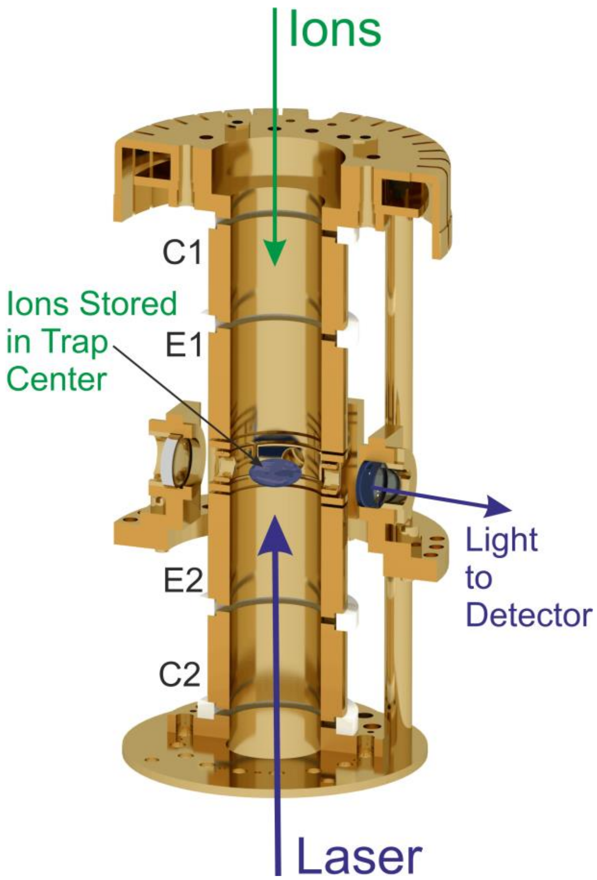
SPECTRAP

HERE: ION CRYSTALS FOR SYMPATHETIC COOLING



SPECTRAP SETUP





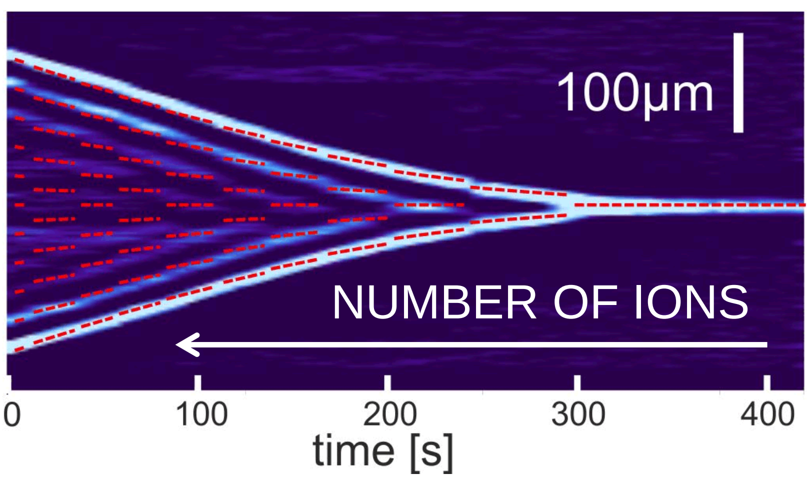
Z. Andelkovic et al., PRA **87** (2013) 033423

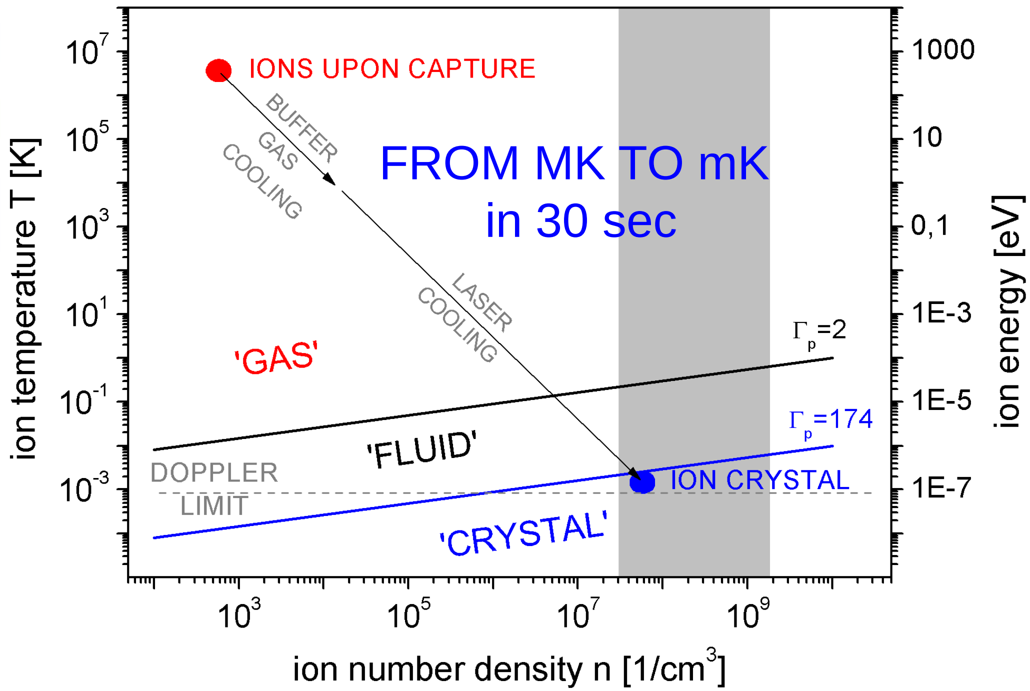
ION CRYSTAL PRODUCTION

Mg^+ CRYSTAL: $N \sim 10^4 - 10^5$

T. Murböck et al., PRA **94**, 043410 (2016)

SHELL STRUCTURE:





Application:
Sympathetic Cooling
of HCI

High-Intensity Laser Ion-Trap Experiment (HILITE)

aim: provide well-defined ion targets for high-intensity lasers,
non-destructive reaction analysis

HILITE

High-Intensity Laser Ion-Trap Experiment

HELMHOLTZ GEMEINSCHAFT

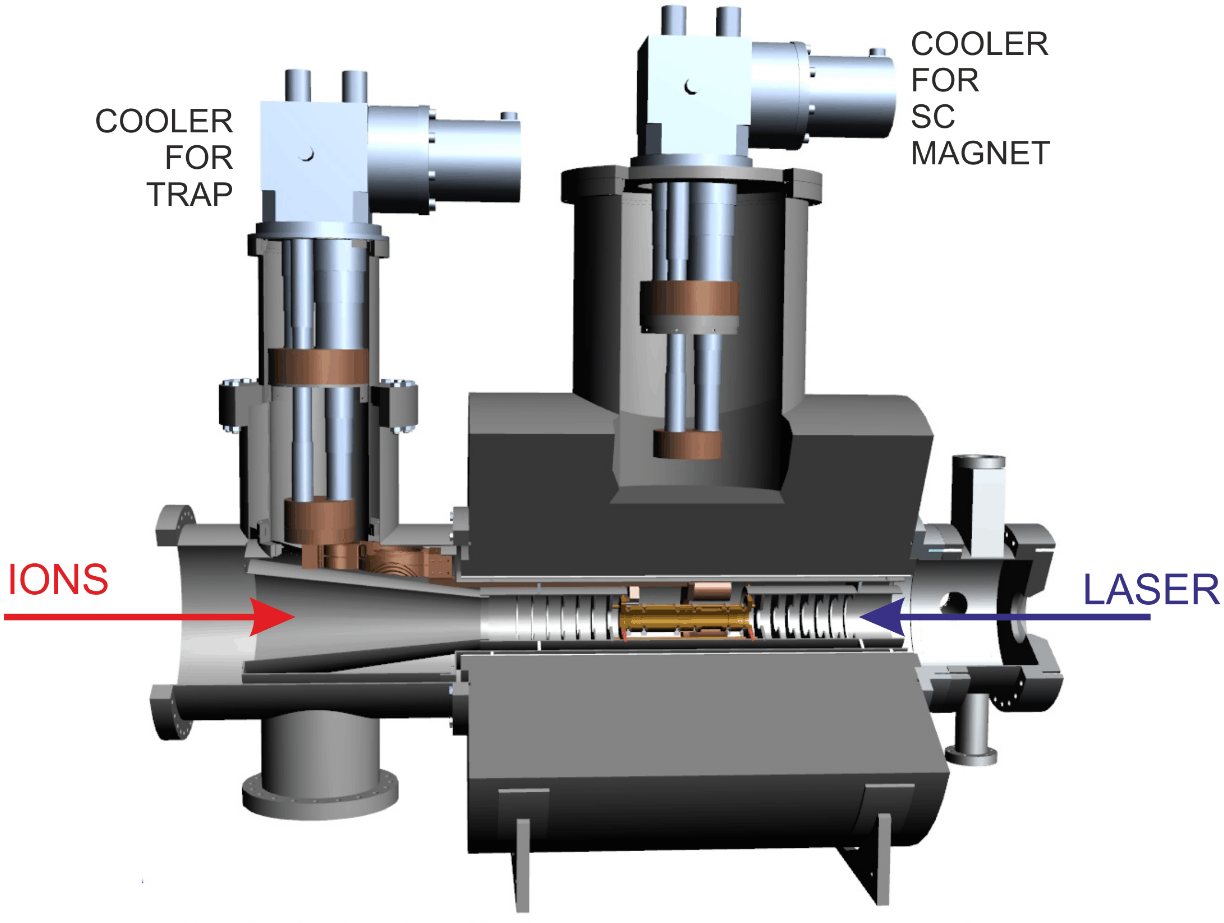
Helmholtz-Institut Jena

Friedrich Schiller Universität Jena

seit 1558

HILITE SETUP

Penning trap in a dry superconducting magnet:
high operation stability, high resolution, yet easy transport and flexible use



TRAP:
4 Kelvin
0...6 Tesla

Control over ion cloud
Position
Density
Shape
Composition

HILITE

some examples:

(non-linear) ionization processes:
cross sections X^{a+} to X^{b+}

highly charged ion reactions e.g.
electron capture from residual gas

fragmentation studies e.g.
fullerene stability

laser diagnostic
focal position, intensity,
beam parameters