H.-Jürgen Kluge

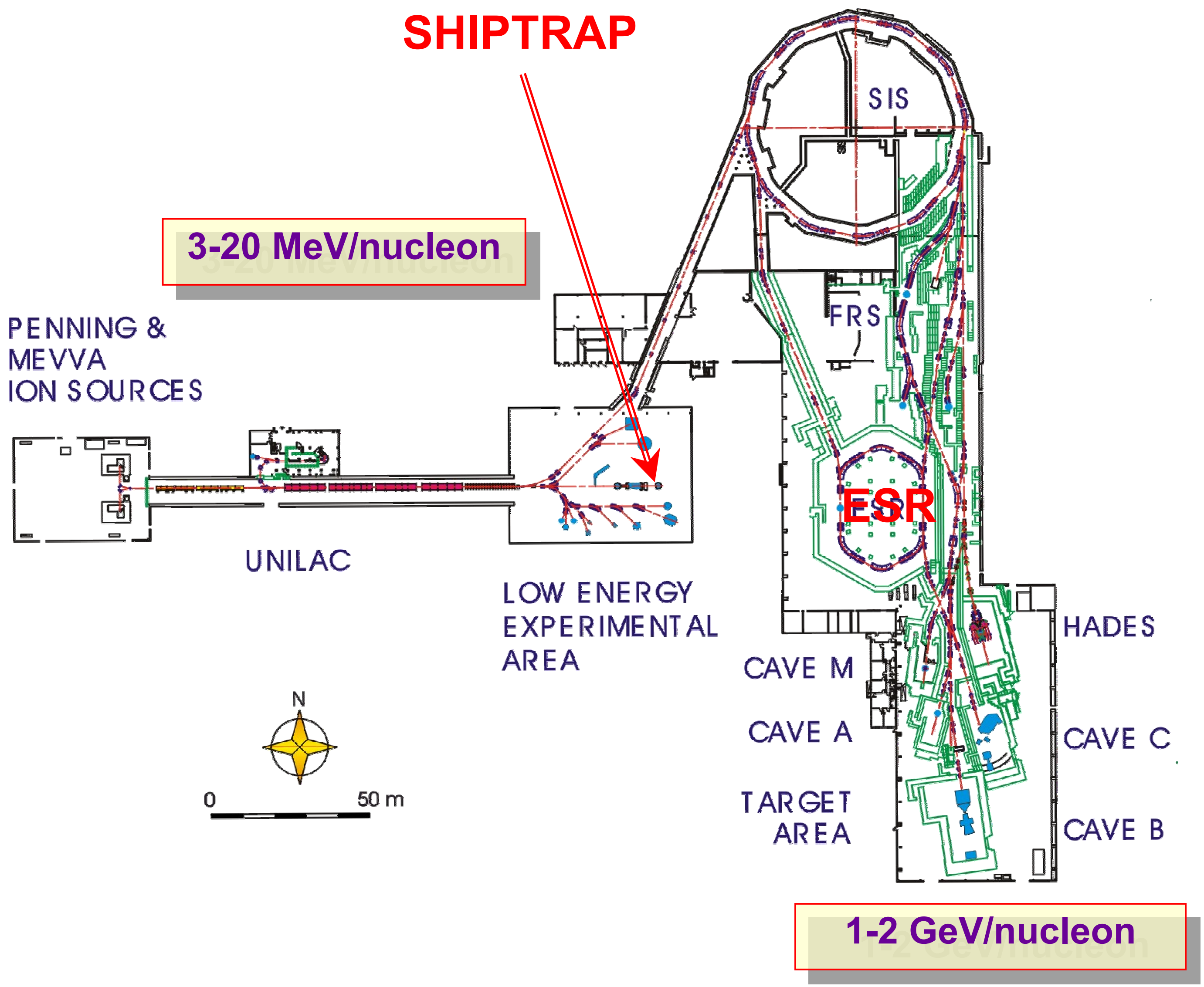
GSI/Darmstadt and Universität Heidelberg

TRIUMF, Vancouver, Canada
TITAN Workshop, June 10 -11, 2005

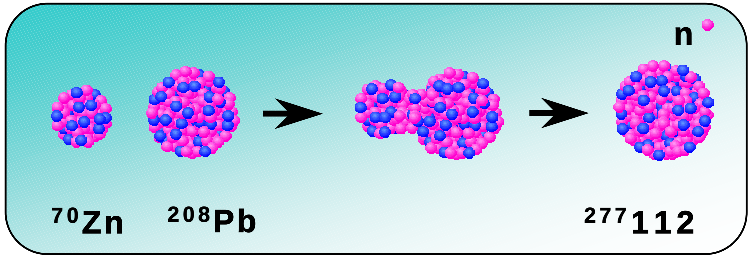
"SHIPTRAP, HITRAP and MATS: Status and Plans for ion trap projects at GSI and FAIR"

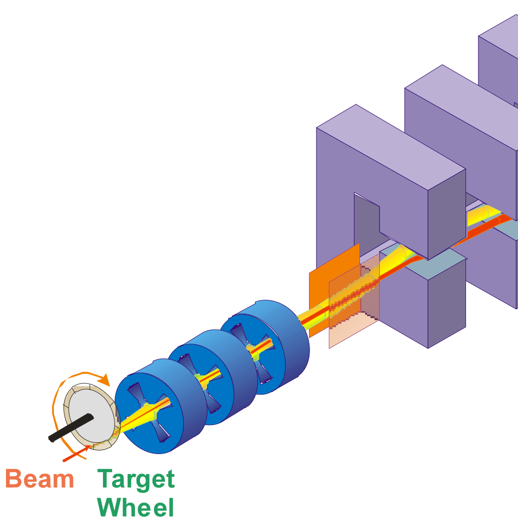
1. **Present GSI – SHIPTRAP**
2. **Mid-term GSI – HITRAP at the ESR**
3. **Future GSI – HITRAP at the NESR and MATS at the SFRS**

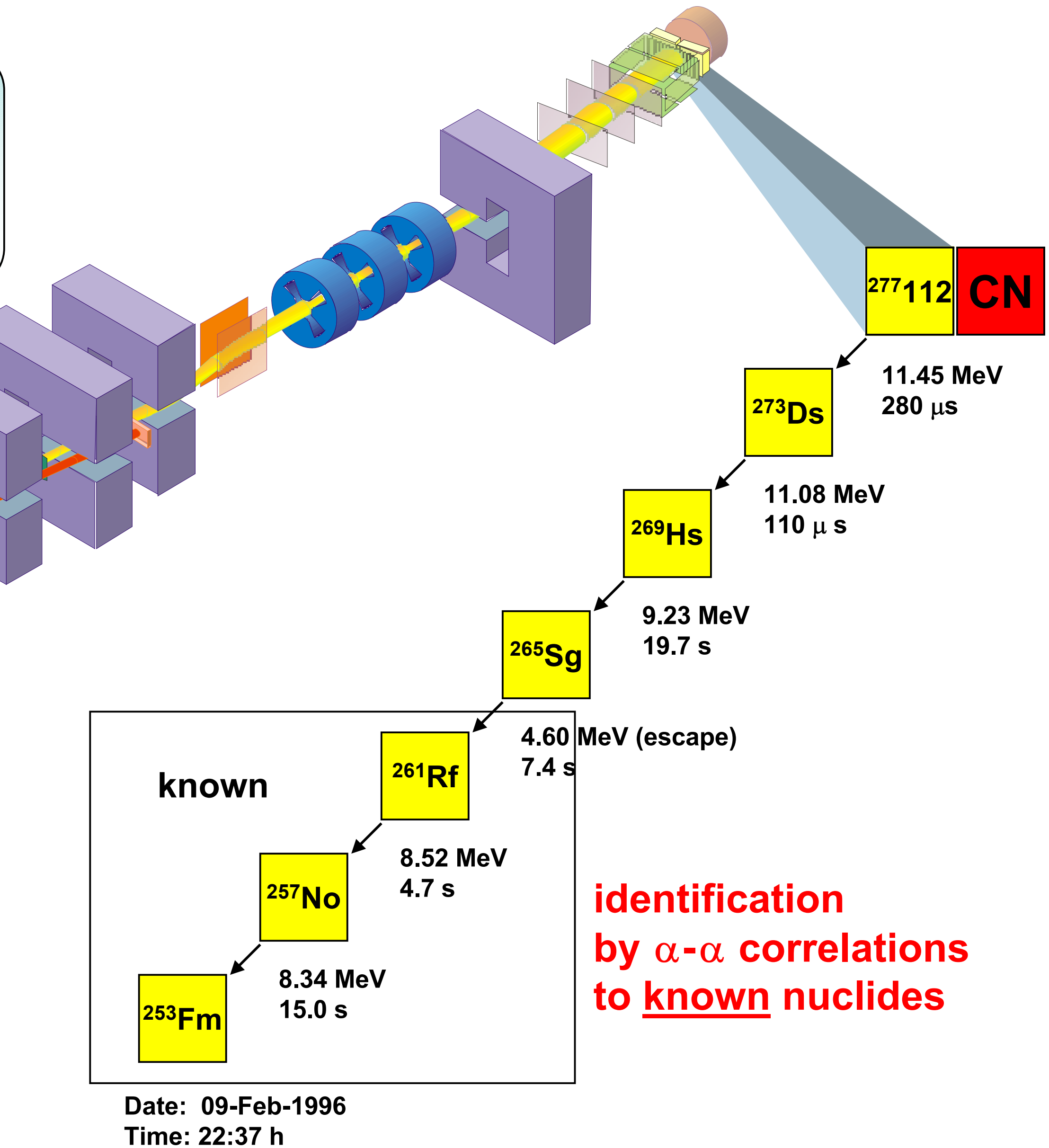
1. PRESENT GSI – SHIPTRAP



Synthesis and Identification of SHE at SHIP







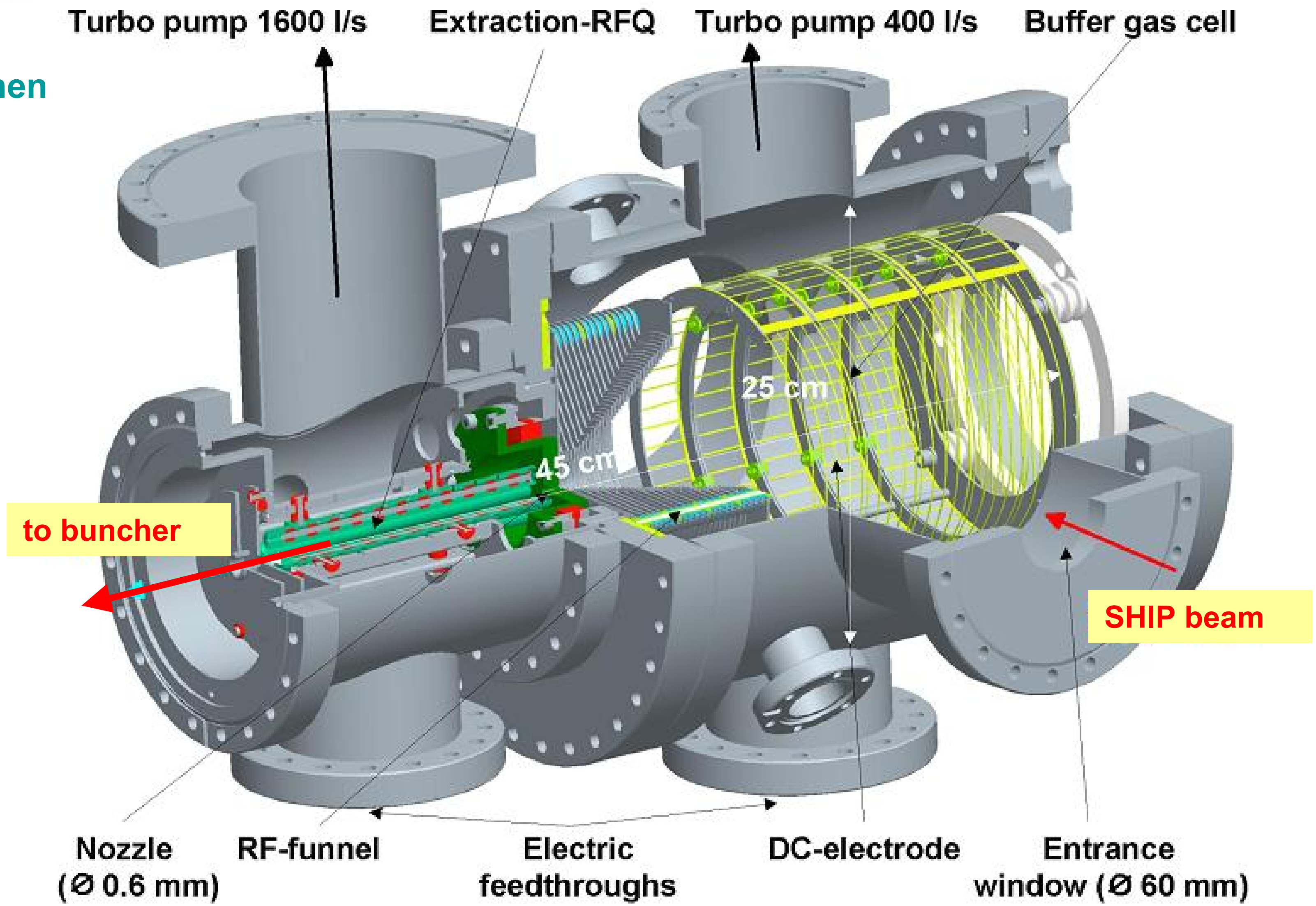
kinematic separation in flight

identification by α-α correlations to known nuclides

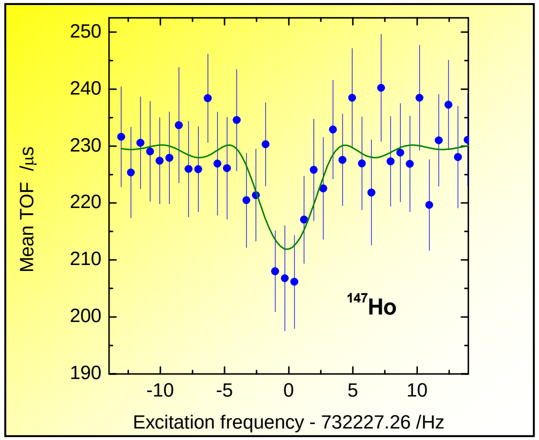
S. Hofmann et al.

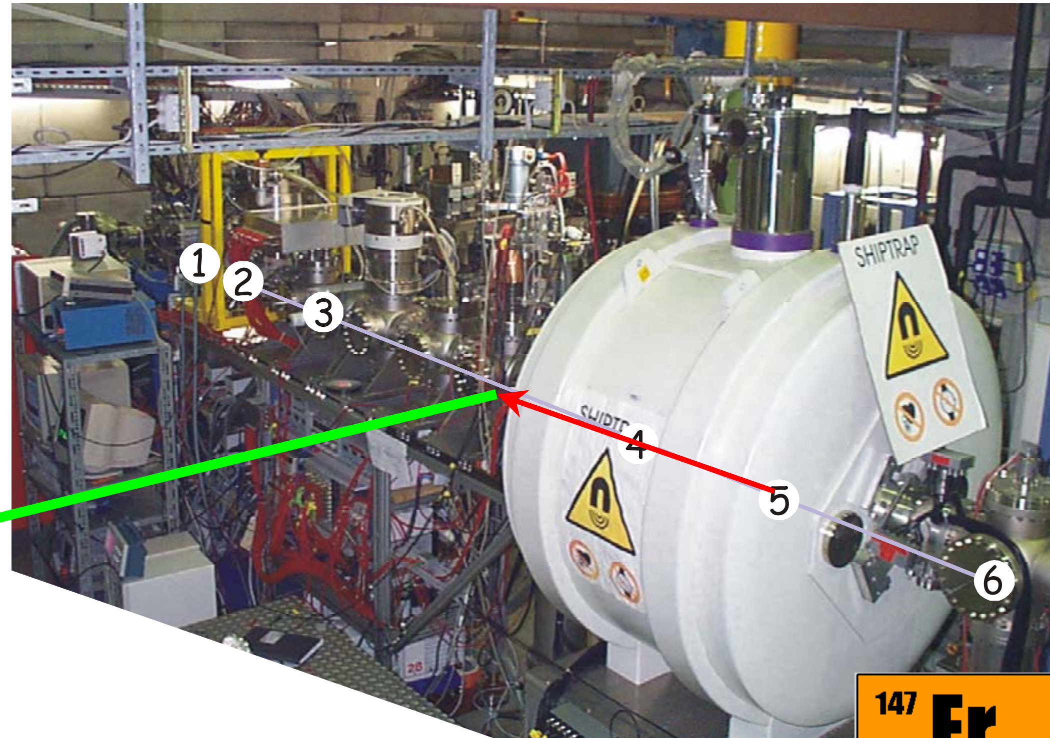
SHIPTRAP stopping cell

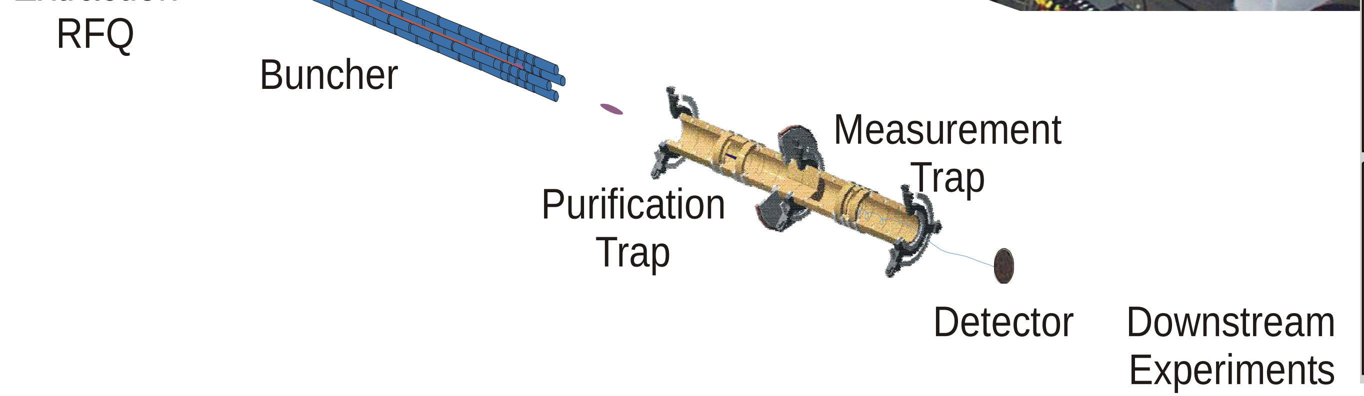
LMU
München

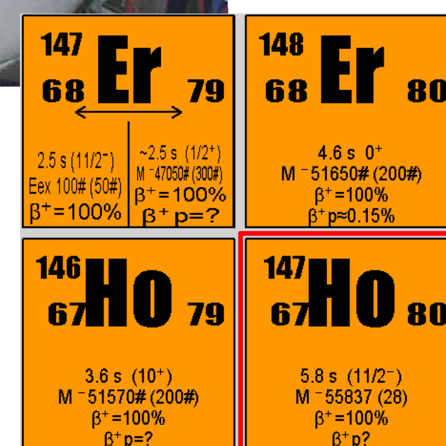


FIRST MEASUREMENTS AT SHIPTRAP: ^{147}Ho, ^{147}Er, ^{148}Er





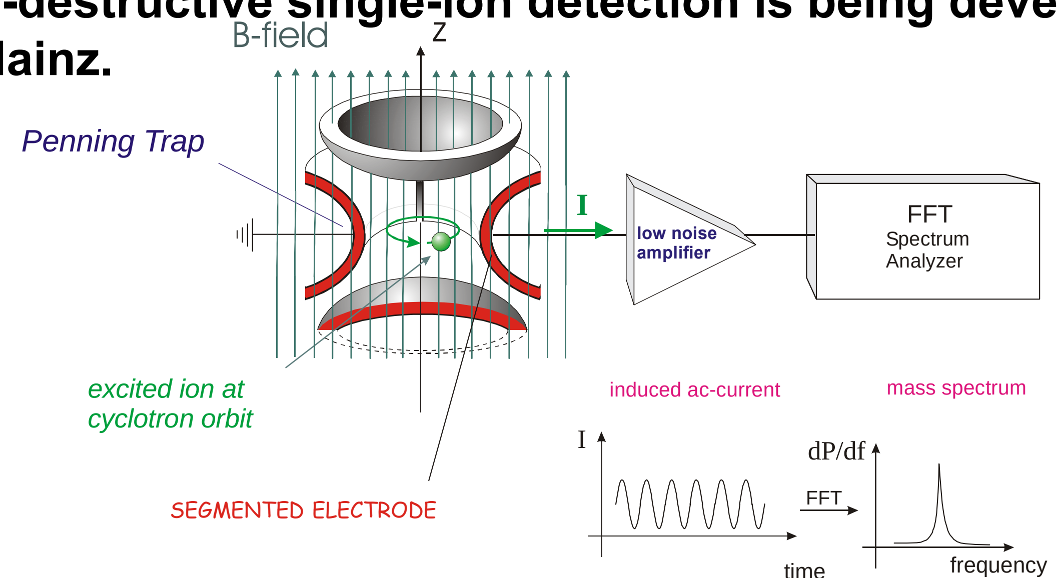




M. Block et al.

STATUS OF SHIPTRAP

- **The concept of two traps (purification and precision traps in the very same superconducting magnet) is ok. The sister trap of SHIPTRAP (JVL-Trap at IGISOL facility in Jyväskylä/Finland is producing a large number of results.**
- **SHIPTRAP needs in addition a gas cell for stopping fusion products. The gas cell is very sensitive to chemical impurities. The validity of the conceptis shown by the CPT trap at Argonne and very recently by LEBIT at MSU.**
- **SHIPTRAP needs a lot more on-line beam time for commissioning and tests.**
- **Non-destructive single-ion detection is being developed at the University of Mainz.**



Ch. Weber, K. Blaum et al.

The linear RFQ

The segmented gas-filled linear RFQ´s are essential.

Without this development, the following facilities would not work or would have strong limitations:

ISOLTRAP at ISOLDE/CERN, Switzerland

CPT at Argonne, USA

JVL-TRAP at Jyväskylä, Finland

SHIPTRAP at GSI, Germany

GANIL trap at GANIL, France

LEBIT at MSU, USA

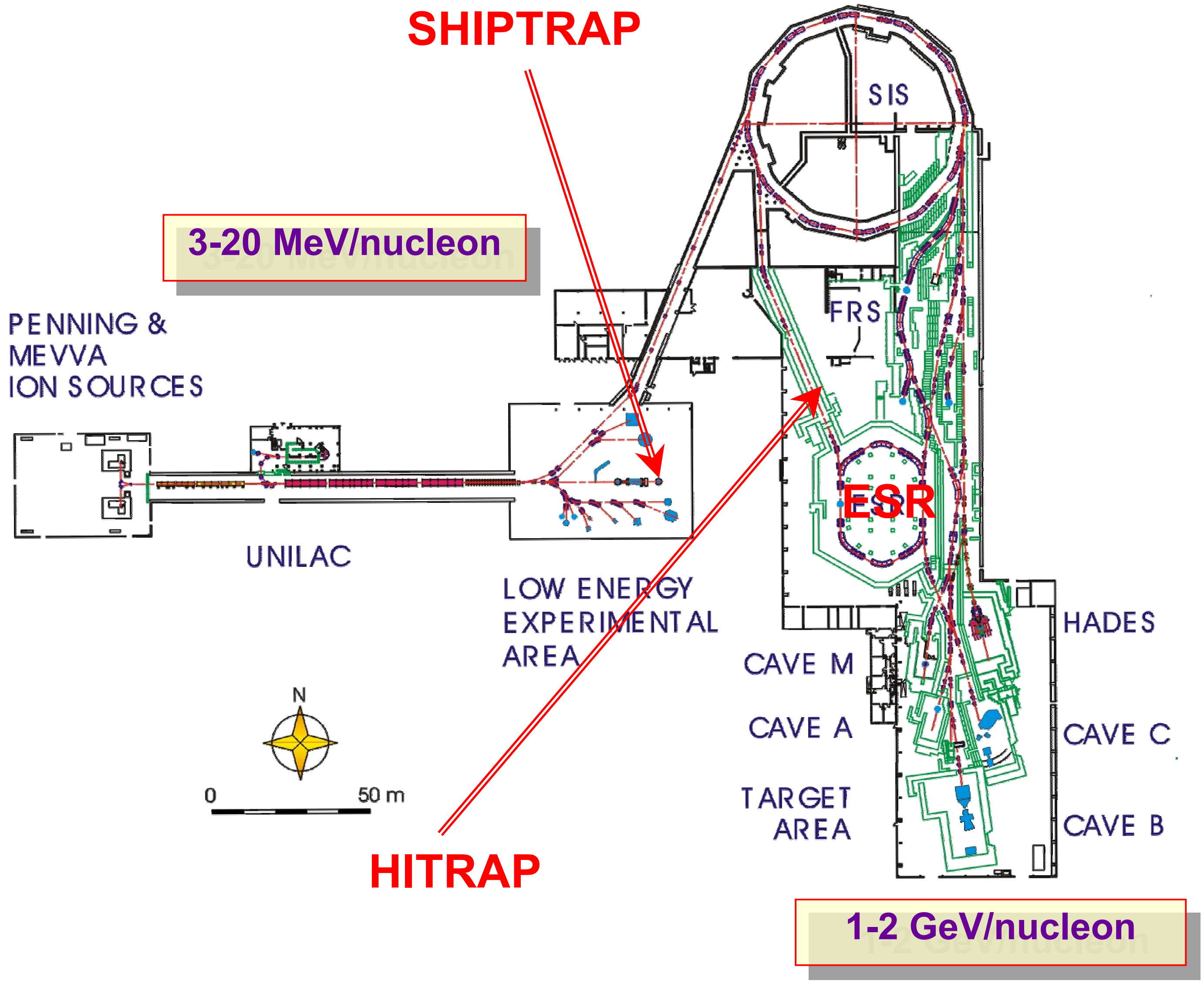
MISTRAL at ISOLDE/CERN, Switzerland

TITAN at TRIUMF, Canada

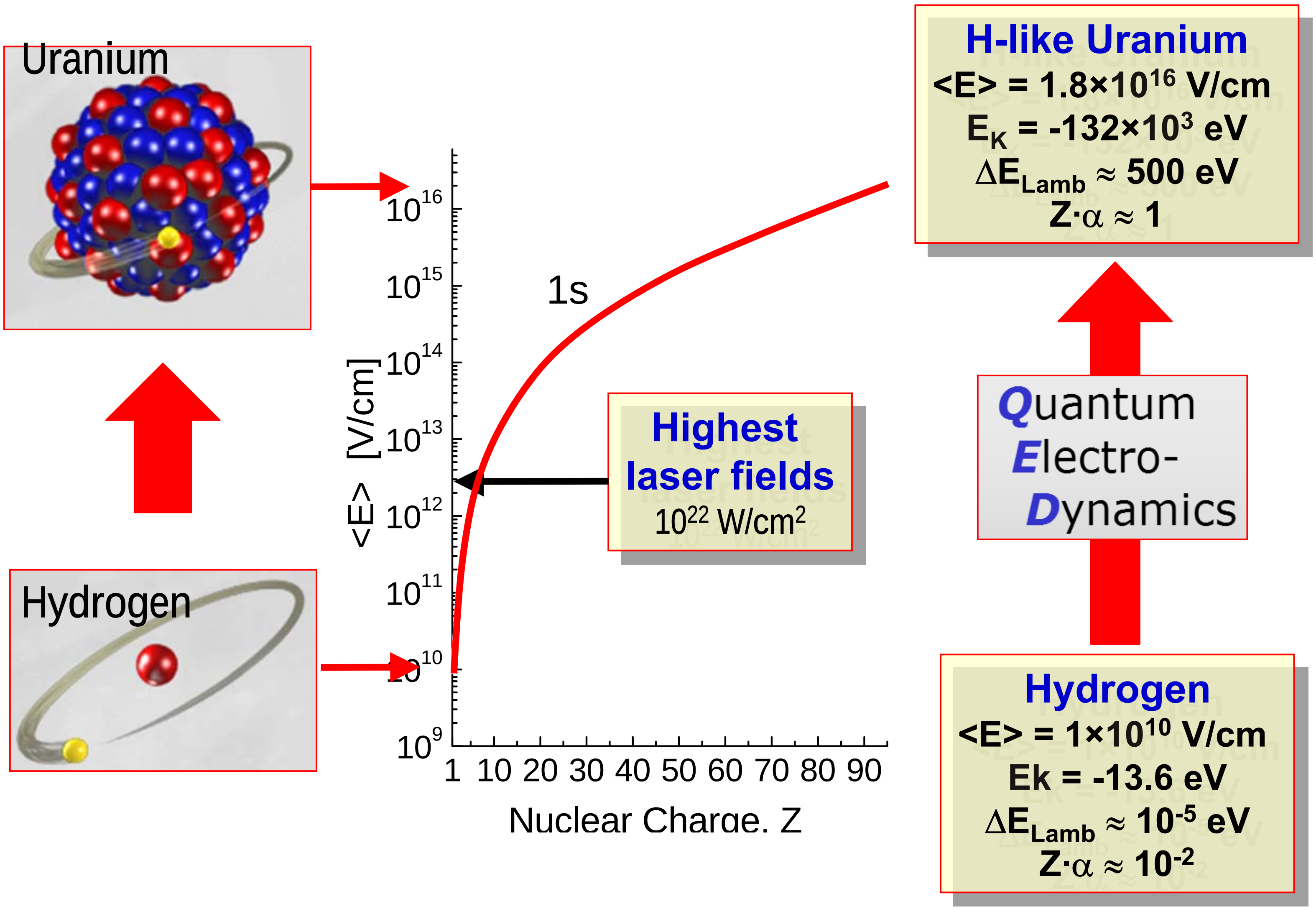
MLL-Trap at Munich, Germany


70 years of Bob Moore *
and we wish you many more bottles and years
Elke and Jürgen
and
The Trappers from GSI
remember: heaven can be on earth
* June 28, 2005

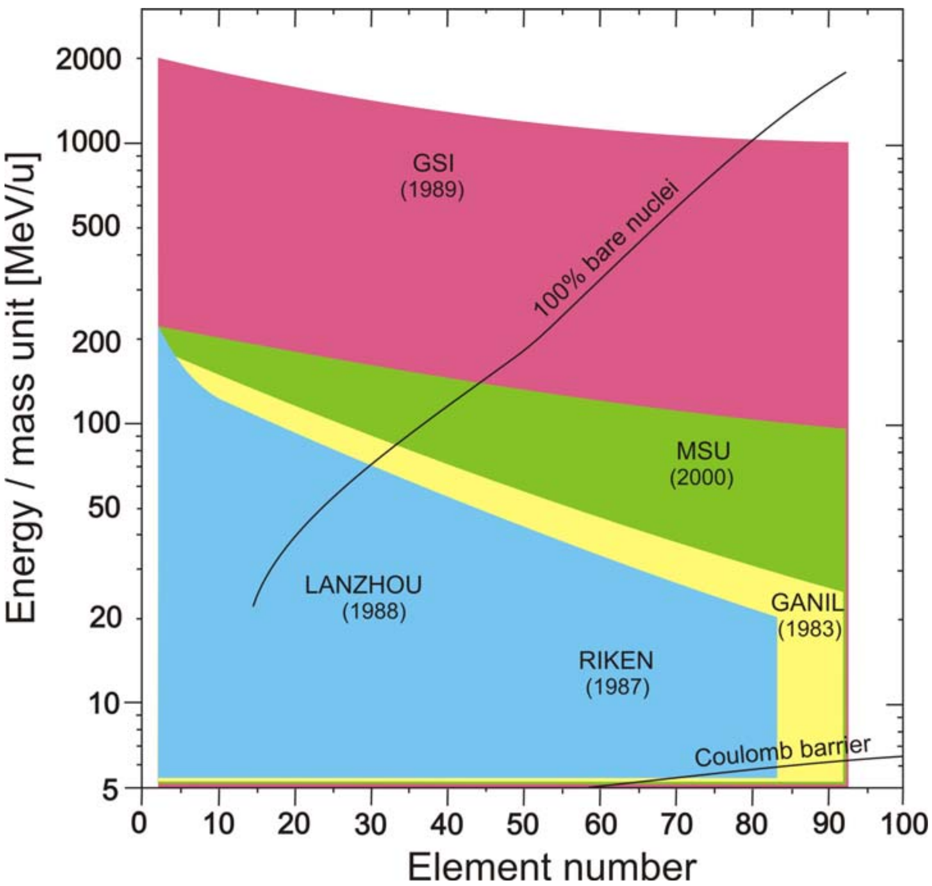
2. MID-TERM GSI – HITRAP
An ion trap facility for really highly-charged ions (q=Z, Z-1, Z-2, Z-3, …)



TEST OF HIGH-Z QED IN EXTREME ELECTROMAGNETIC FIELDS



Production of Highly-Charged and Radioactive Ions

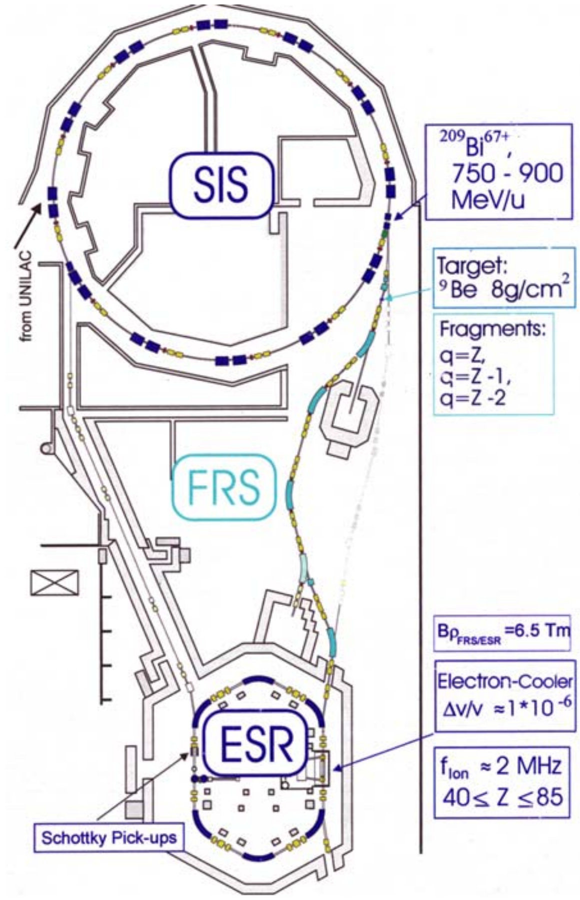


Highly-charged ions

Radioactive isotopes

High energies

Exotic systems



HCI PRODUCTION IN AN EBIT

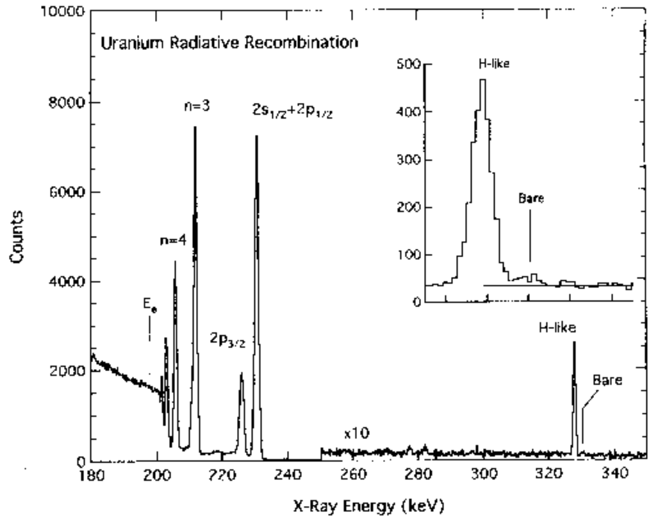
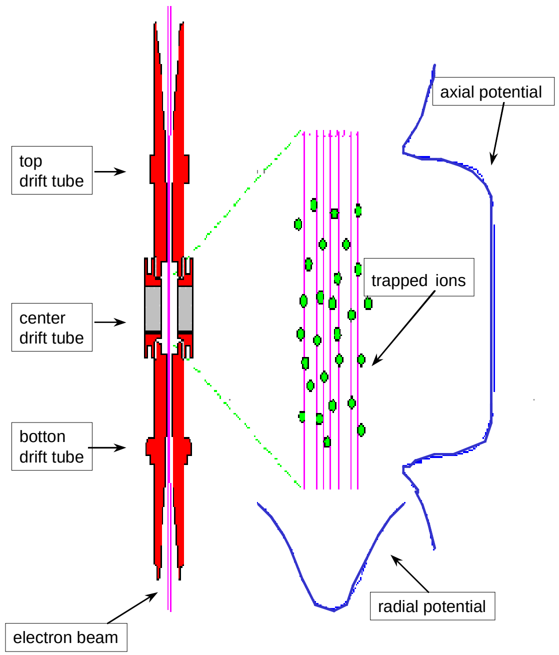
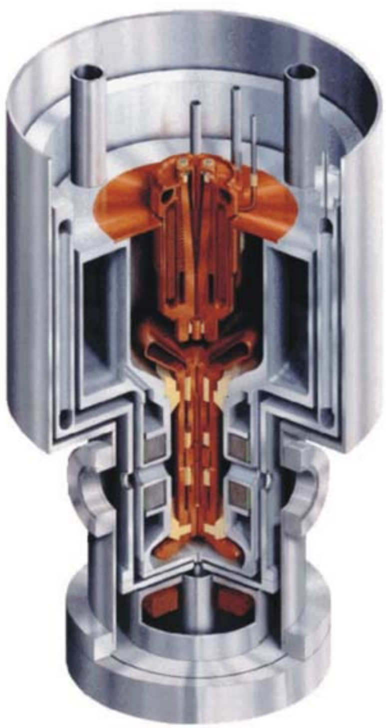


FIG. 2. Radiative recombination spectrum of uranium ions at 198-keV electron energy observed in the 40-cm^3 germanium detector. The inset shows the $n = 1$ feature from the 90-cm^3 detector; the solid horizontal line is the average background level above the peaks.



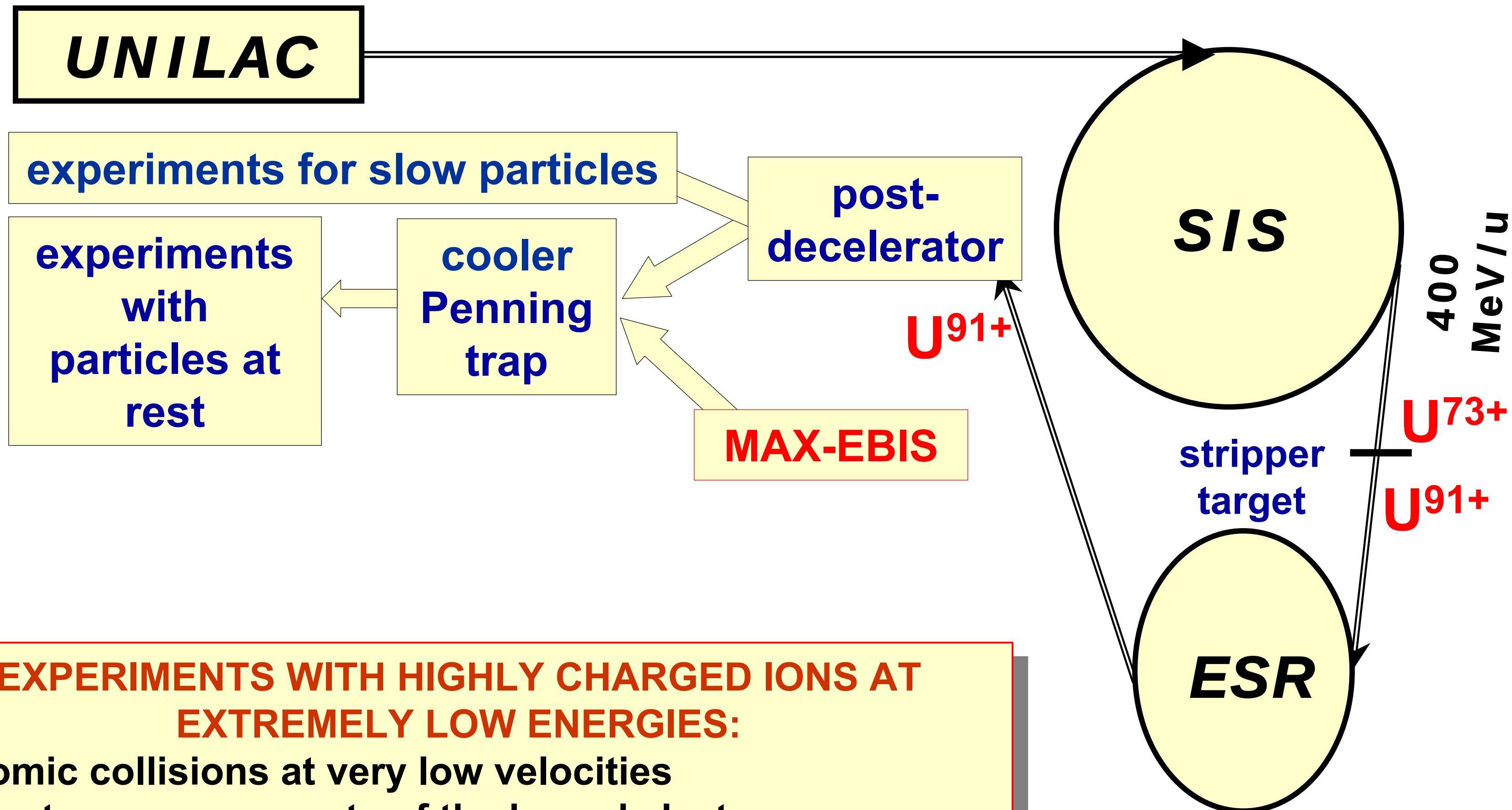


R.E. Marrs et al., Phys. Rev. Lett. 72 (1994) 4082

Evaporative cooling with Ne: $kT(U^{89+}) = 80$ eV
Space charge limit by Ne ions
$I_{electron\ beam} = 5000\ A/cm^2$
$T_{measurement} = 26$ h

$N_{U91+} \approx 2000$
$N_{U92+} \approx 40$
no extracted beam

The HITRAP Project for Highly-Charged Ions



EXPERIMENTS WITH HIGHLY CHARGED IONS AT EXTREMELY LOW ENERGIES:

- atomic collisions at very low velocities
- g-factor measurements of the bound electron
- fundamental constants
- mass measurements of extreme accuracy
- laser and x-ray spectroscopy, diamagnetic correction

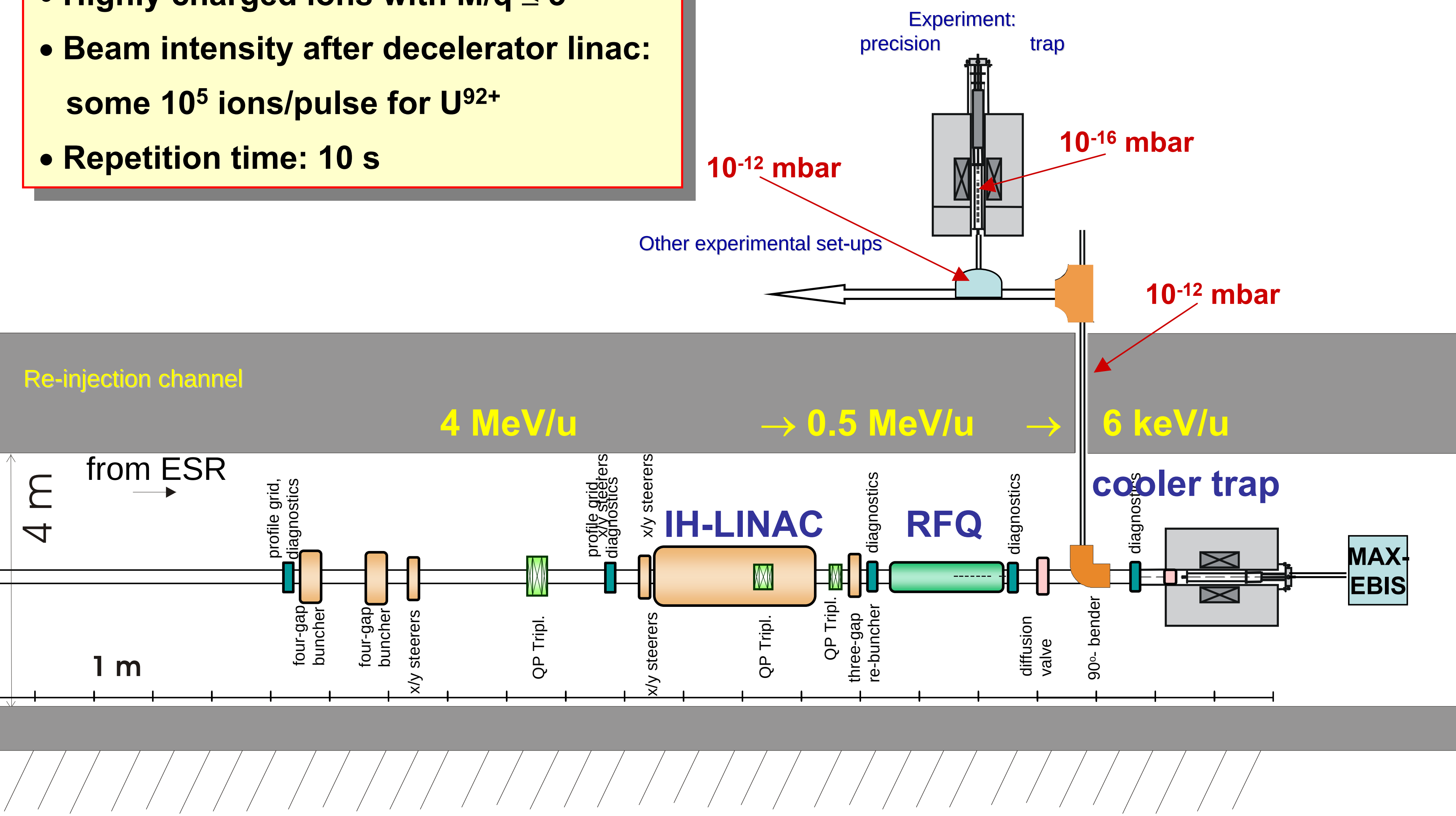
electron cooling and deceleration down to 4 MeV/u

HITRAP in the Reinjection Channel (from the side)

Operational Parameters:

- Highly charged ions with $M/q \leq 3$
- Beam intensity after decelerator linac: some 10^5 ions/pulse for U^{92+}
- Repetition time: 10 s

Ion optics of the beam line:
? magnetic – electric ?



University of Frankfurt University of Mainz

STATUS OF HITRAP

- The funds (3 M€ without personnel costs) are available for 2005-2007. Oliver Kester is the Technical Coordinator. Beside GSI the Universities of Frankfurt and Mainz play an essential role in the realization of HITRAP.

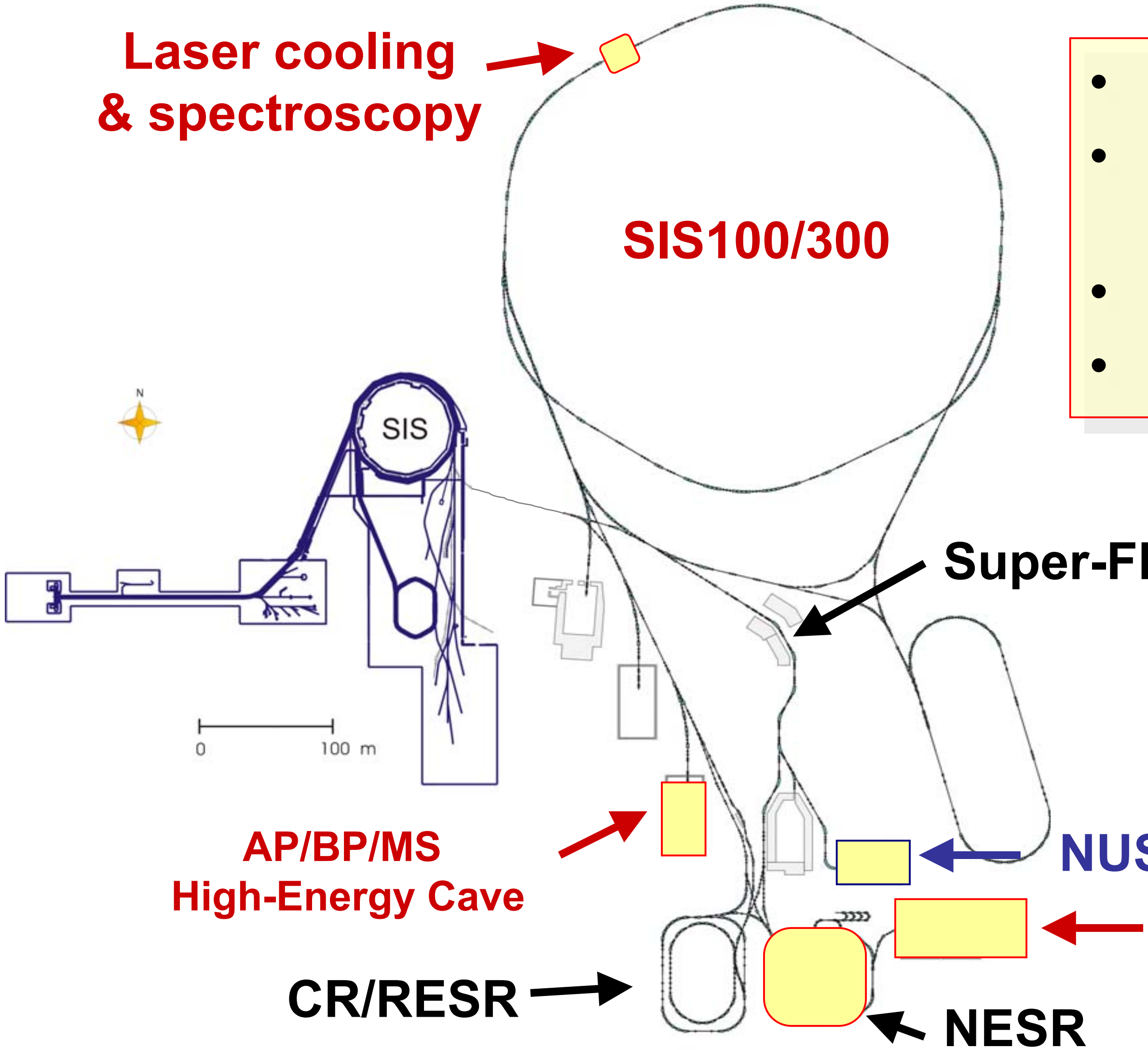
- HITRAP has got the highest marks in the evaluation of the program-oriented funding of the Helmholtz Association conducted in 2004. Since the beginning of 2005, it is one of the few mid-term projects at GSI.

- Commissioning of the facility is planned for 2007.

- A large user community is established by the EU RTD Network HITRAP:
  - g-factor of the bound electron (Mainz)
  - ultra-accurate mass measurements (Mainz)
  - recoil ion momentum spectroscopy (MPIK Heidelberg and GANIL)
  - x-ray spectroscopy (KVI Groningen, Krakow)
  - laser spectroscopy – polarization (London, Berkeley, LLNL, Texas A&M)
  - Wigner crystals (RETRAP is coming to HITRAP)

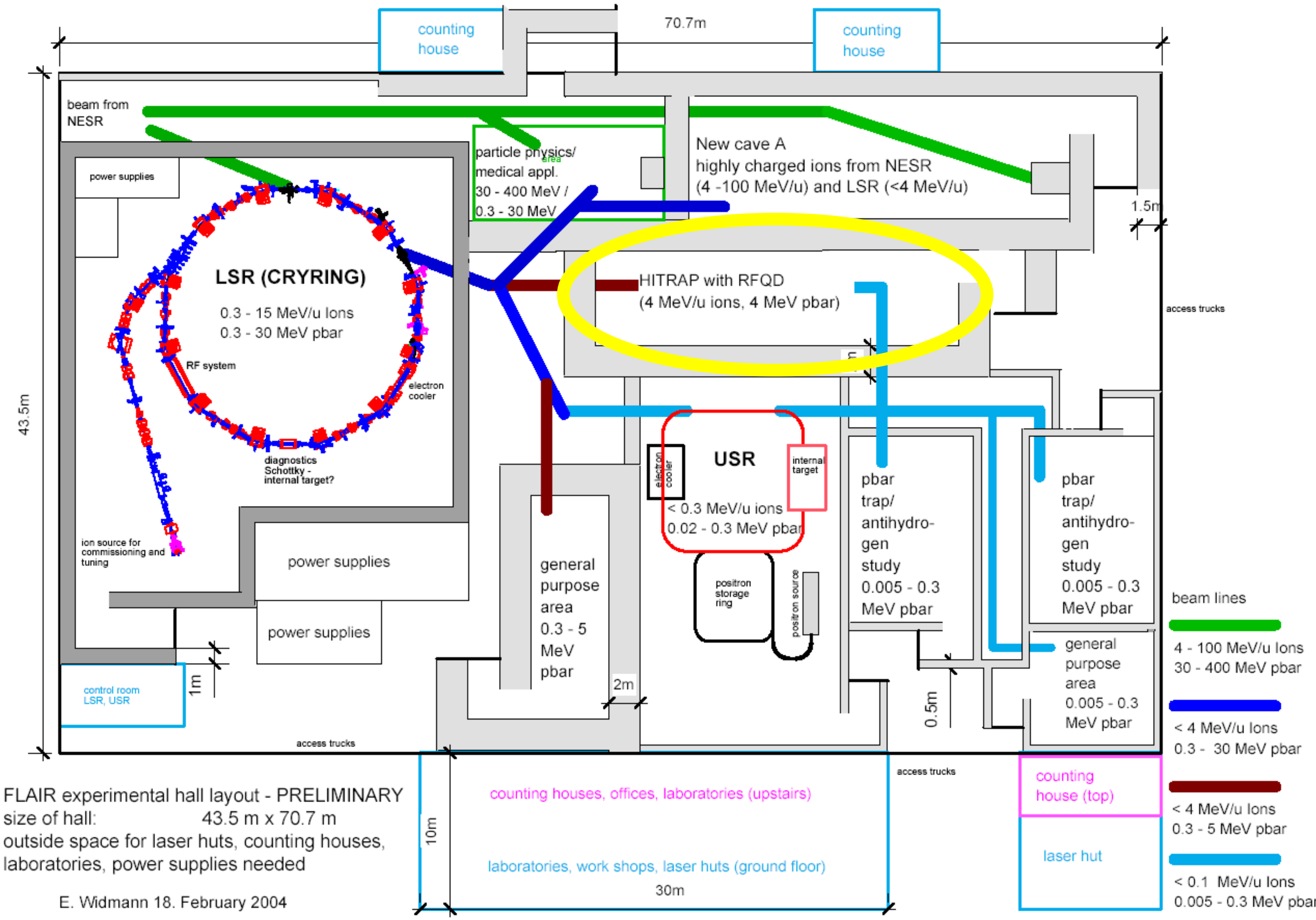
HITRAP is a user facility. New collaborators are welcome!

3. Future GSI – HITRAP at the NESR and MATS at the SFRS



- Highly-charged ions
- High-intensity radioactive beams
- High energies
- Antiprotons

FLAIR/SPARC Complex at FAIR



Expected production rate:

10^8 $\bar{p}$ every 4 sec

~ 100 x Antiproton Decelerator (AD)

($2 - 4 \cdot 10^7$ $\bar{p}$ every 85 sec)

- develop "next generation" technology
- improve performance of most present experiments
- enable experiments that are not feasible at the AD

Present $\bar{p}$ collaborations at the AD/CERN:

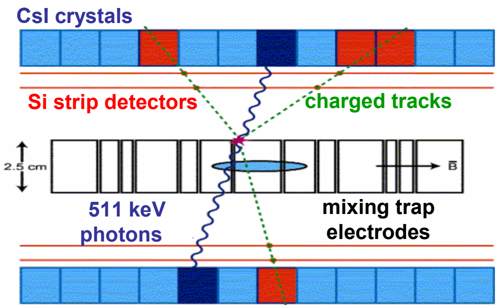
ATHENA: CPT
ATRAP: CPT
ASACUSA: structure and dynamics

GSI will provide the most intense source of antiprotons

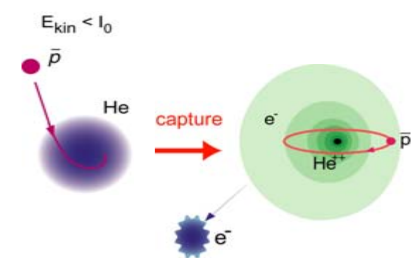
Research Topics with Low-Energy Antiprotons

EXPERIMENTS WITH ANTIPROTONS AT EXTREMELY LOW ENERGIES

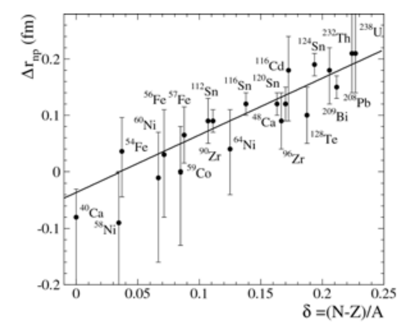
- fundamental interactions
  - CPT (antihydrogen, HFS, magnetic moment)
  - gravitation of antimatter
- atomic collision studies
  - ionization
  - energy loss
  - matter-antimatter collisions
- antiprotonic atoms
  - formation
  - strong interaction and surface effects



ATHENA Nature 419 (2002) 456

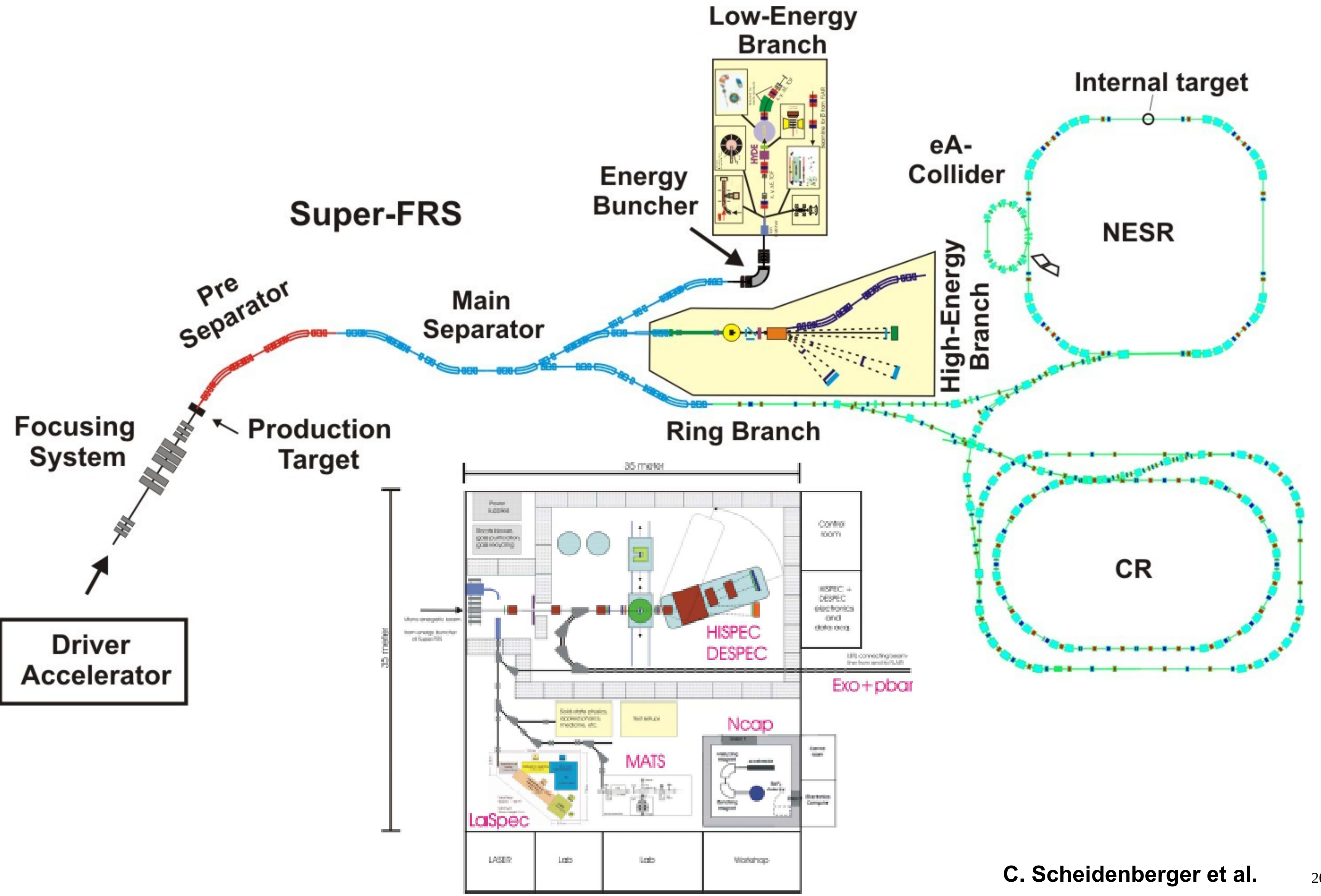


M. Hori et al., PRL 92 (2003) 123401



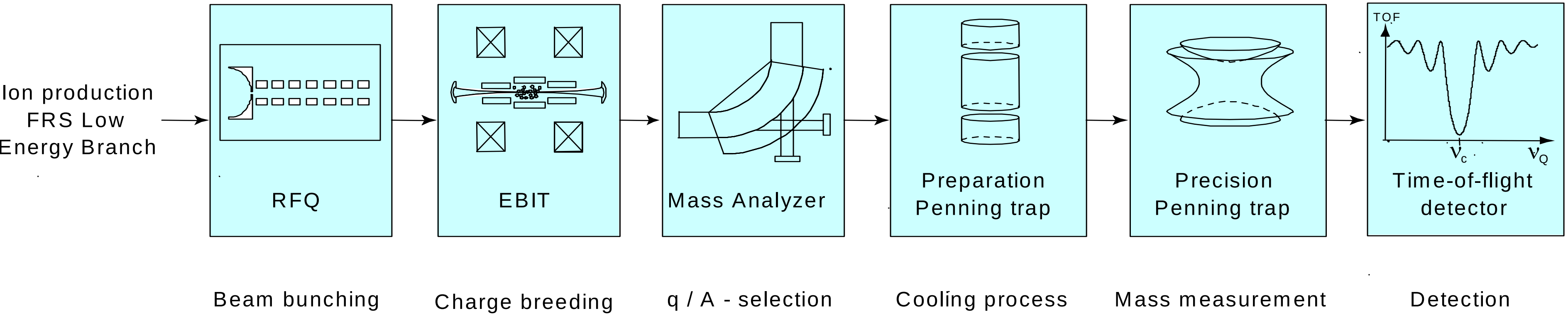
A. Trzcinska, J. Jastrzebski et al.PRL 87 (2001) 082501

SFRS – LOW-ENERGY BRANCH – MATS



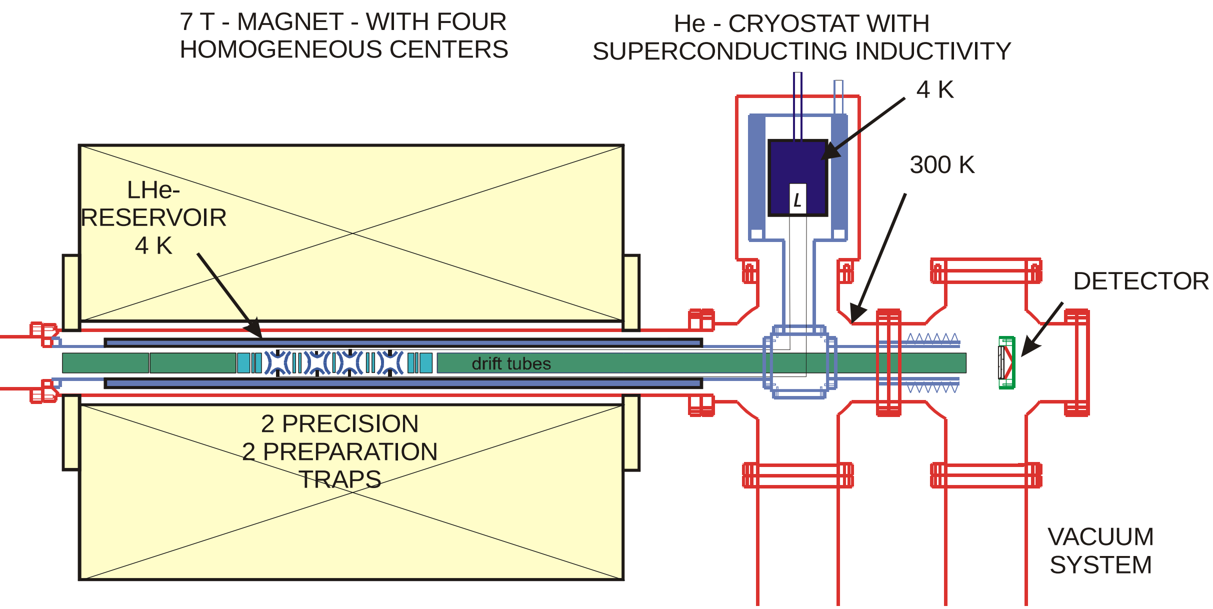
C. Scheidenberger et al.

MATS AT THE LOW-ENERY BRANCH OF THE SFRS



Concept similar to TITAN, but different production mechanism

New concept for high-accuracy mass measurements



Simultaneous storage of two ion species in two precision traps and measurement of the cyclotron frequency at the same time.

K. Blaum et al.

STATUS OF HITRAP AT THE NESR AND MATS

1999 - 2003
24 Workshops on scientific and technical aspects of the new facility

2000
Development of Facility Concept

November 2001
Submission of Conceptual Design Report (700 pages, ca. 500 authors worldwide)

June 2002
Evaluation by the German Scientific Council: Recommendation for Realization

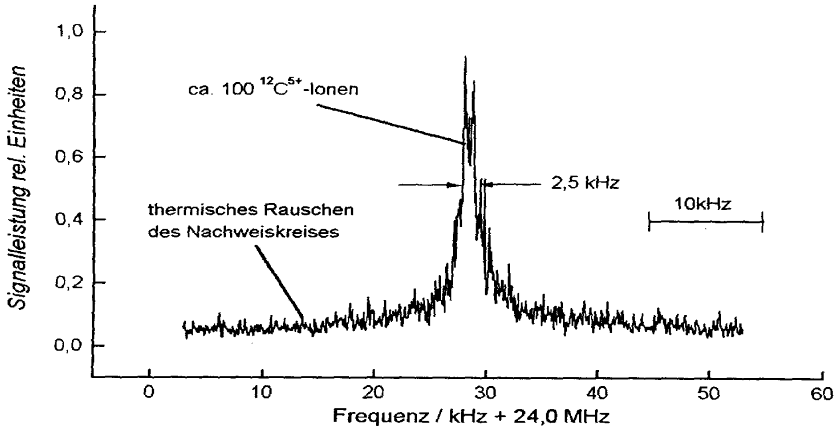
5 February 2003
Decision by the German Government to build the facility: (two conditions: 25% of funding from international sources; technical staging)

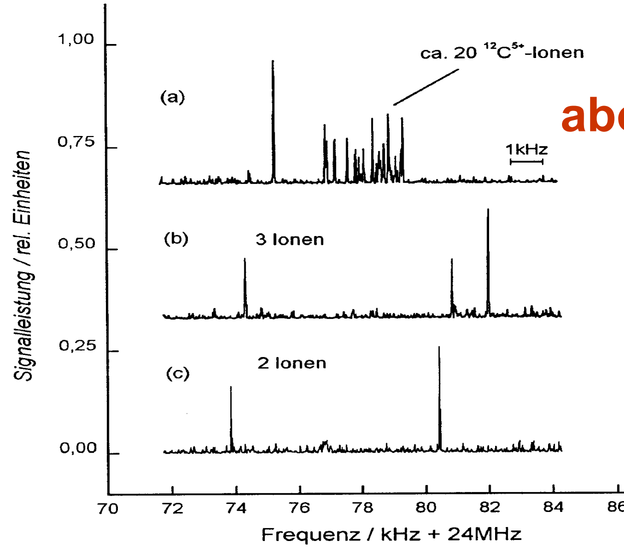
15 January 2005
Submission of Technical Proposals

March 2005
Highest Grading of HITRAP (SPARC & FLAIR) and MATS Technical Proposals

May 2005
Cost Review Committee was very satisfied with the estimated costs.

THE NEED SINGLE ION: COULOMB INTERACTIONS OF $^{12}C^{5+}$ IONS



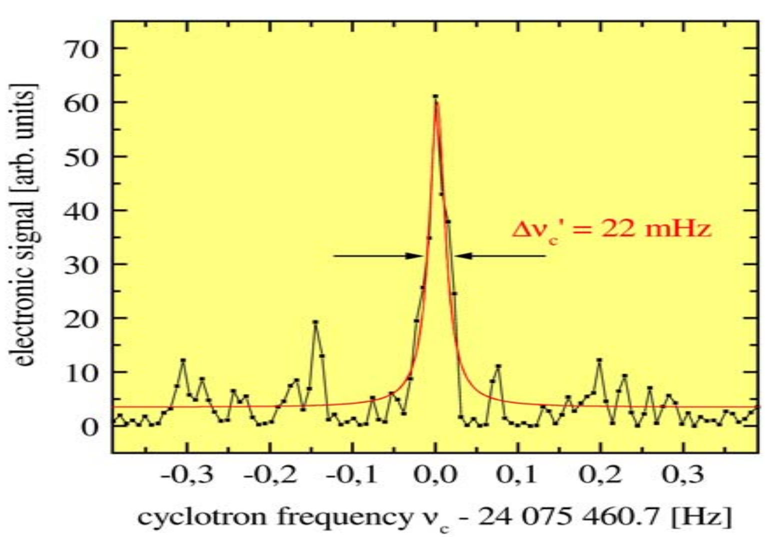


about 20 ions

3 ions

2 ions

1 ion



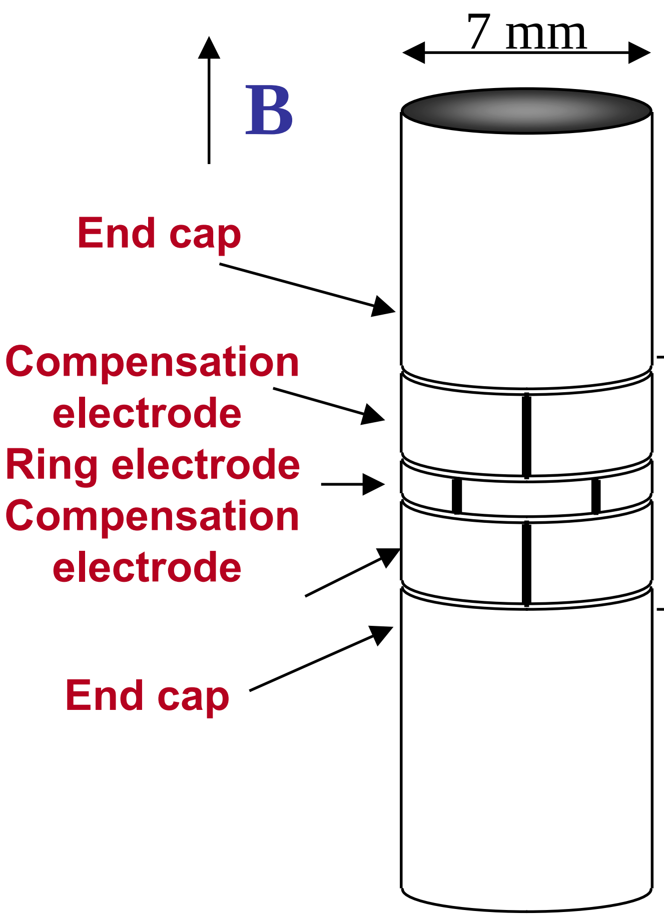
Coulomb interactions and relativistic shifts cause line broadening

With 100 ions present in the trap, the resolving power is only 10^4.

With one ion present in the trap, a resolving power of 10^9 is achieved.

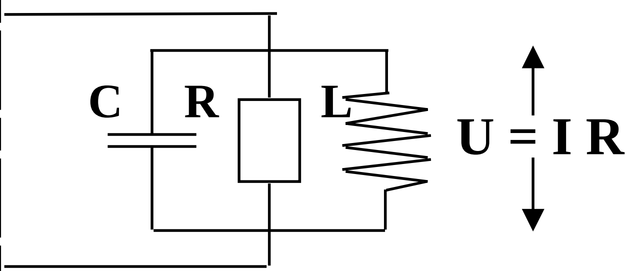
Cooling is required for eliminating relativistic mass shifts.

RESISTIVE COOLING IN CYLINDRICAL PENNING TRAP



induced image currents:
kinetic energy of trapped ions is dissipated in tuned circuit (T = 4 K)

$\nu_z = 350$ kHz



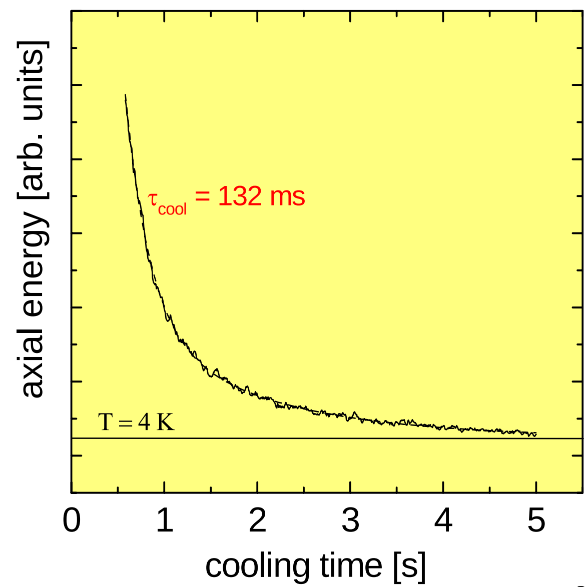
$dE_{ion}/dt = P_{cool} = -I^2R$

$R = Q\omega_z L$

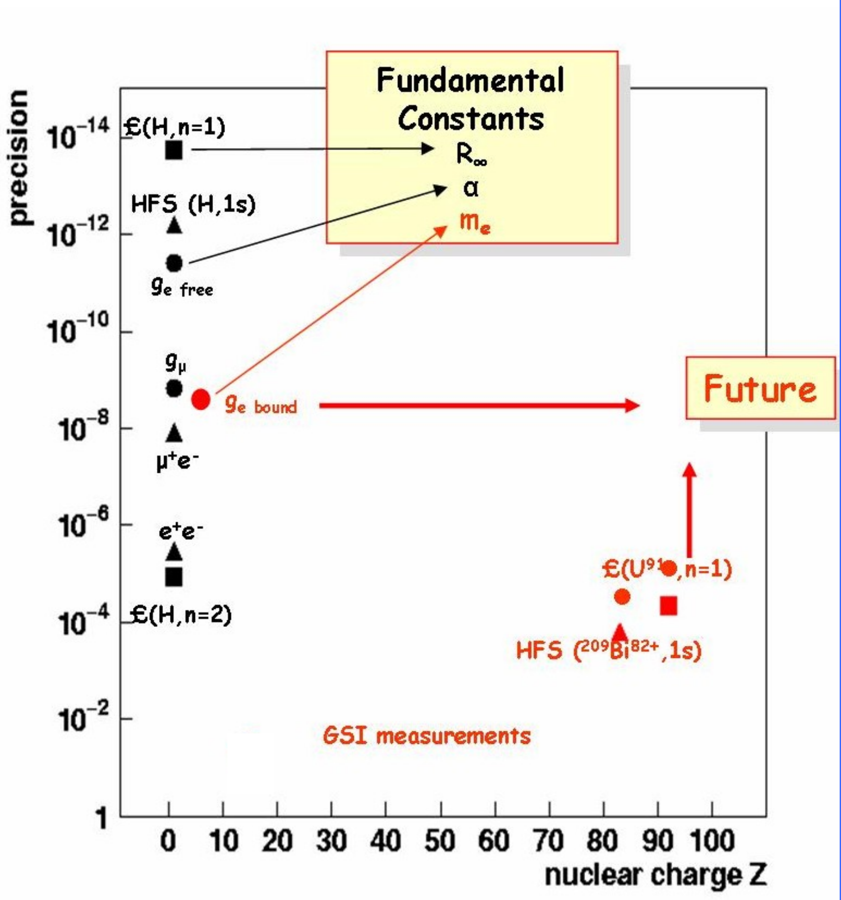
$\Longrightarrow \tau_{cool}$

Resistive Cooling of $^{12}C^{5+}$ to 4 K

- final temperature: T = 4 Kelvin



SUMMARY



Atomic physics at accelerators is a rich field of research

Storing and cooling is the key to precision

Effects of extreme electromagnetic fields can be investigated

Highly-charged ions are test grounds for fundamental interactions

Highly-charged ions offer a new access to the determination of fundamental constants

Atomic physics techniques offer model-independent information on nuclear ground state properties. Hyperfine fields of highly-charged ions can be calculated very accurately.