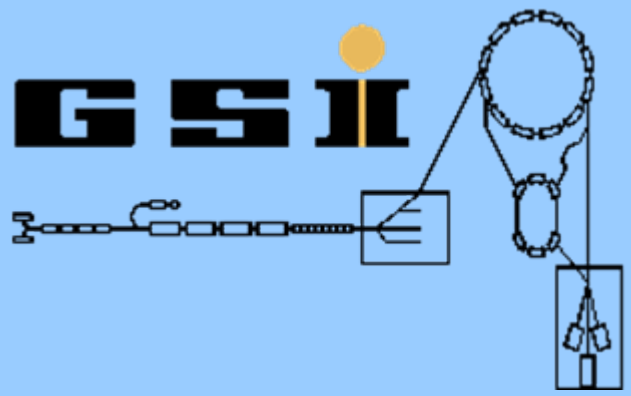
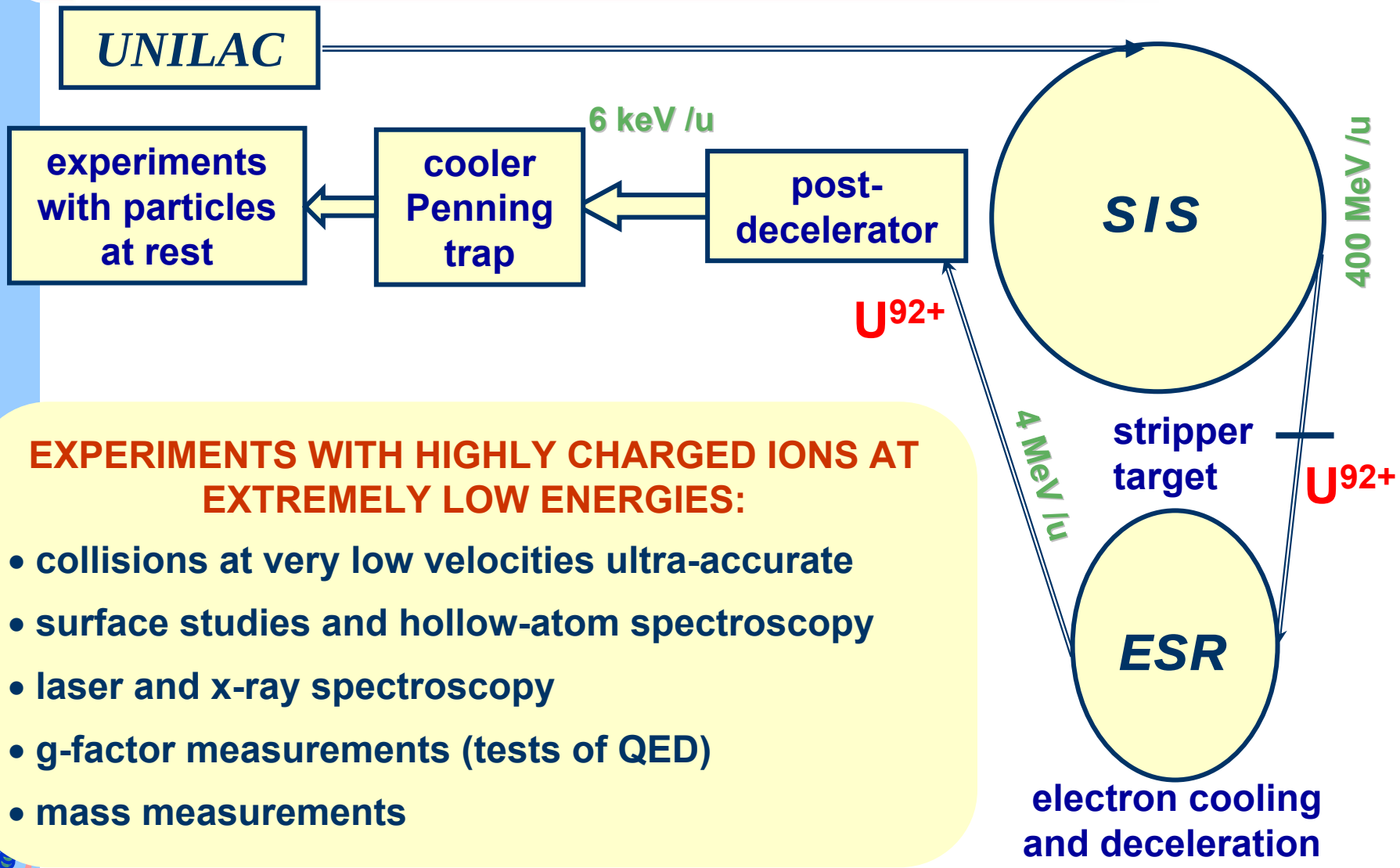
Highly charged ions at rest – The HITRAP project at GSI



Frank Herfurth, GSI Darmstadt,
for the HITRAP collaboration.

The HITRAP Project



EXPERIMENTS WITH HIGHLY CHARGED IONS AT EXTREMELY LOW ENERGIES:

- collisions at very low velocities ultra-accurate
- surface studies and hollow-atom spectroscopy
- laser and x-ray spectroscopy
- g-factor measurements (tests of QED)
- mass measurements

Precision experiments on HCI

Test of quantum electrodynamics in extreme fields

- g-factor of the bound electron
- Electron correlations and relativistic effects

Determination of fundamental constants

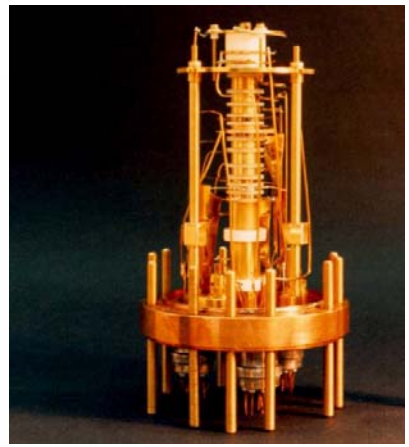
- Mass of the electron
- Future: fine-structure constant α

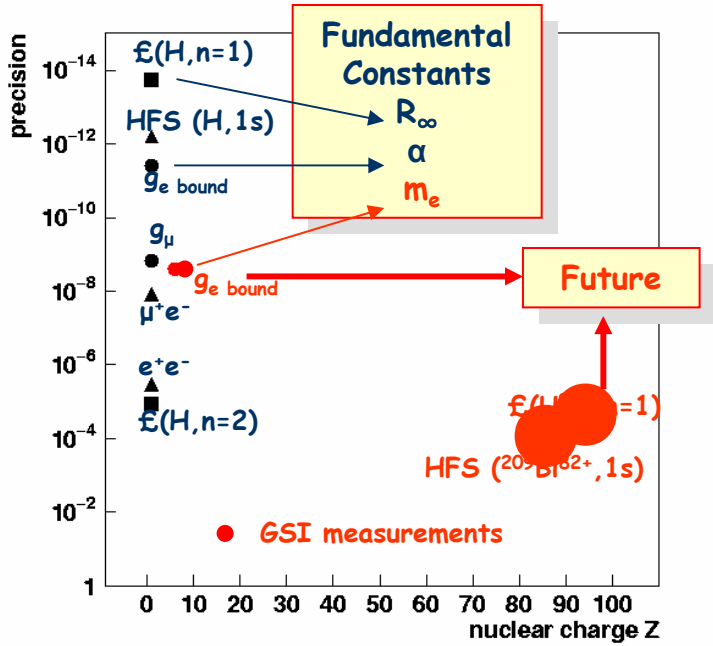
Recent highlights

- g-factor measurements on H-like carbon $^{12}C^{5+}$ and oxygen $^{16}O^{7+}$ with accuracy better than 10^{-9}

Ultra-accurate mass measurements

- Determination of atomic and nuclear binding energies

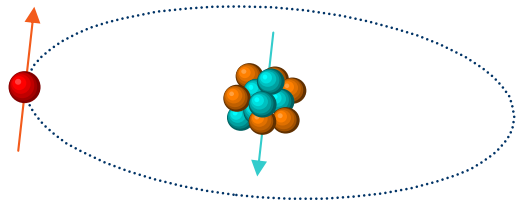




Laser- and X-ray spectroscopy, reaction and surface studies with HCI

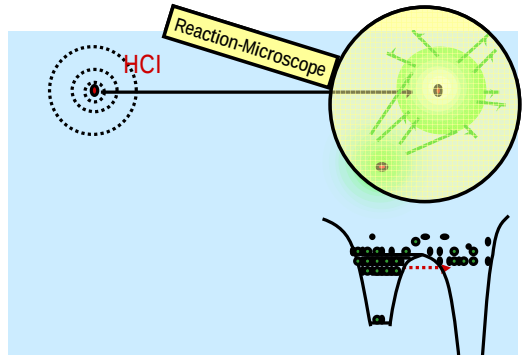
Laser spectroscopy of H-like ions:

- Nuclear properties (Bohr-Weisskopf effect)
- Atomic and nuclear polarization by optical pumping



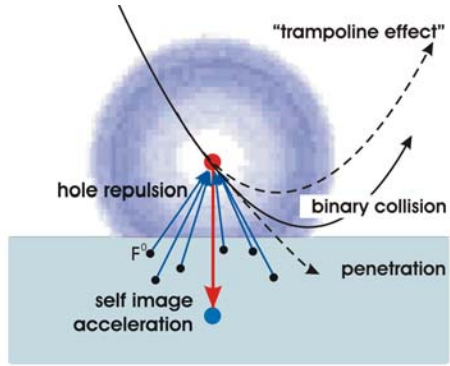
X-ray spectroscopy with HCI:

- Precision measurements of binding energies
- Isotope shift: nuclear charge radii



Reaction microscope:

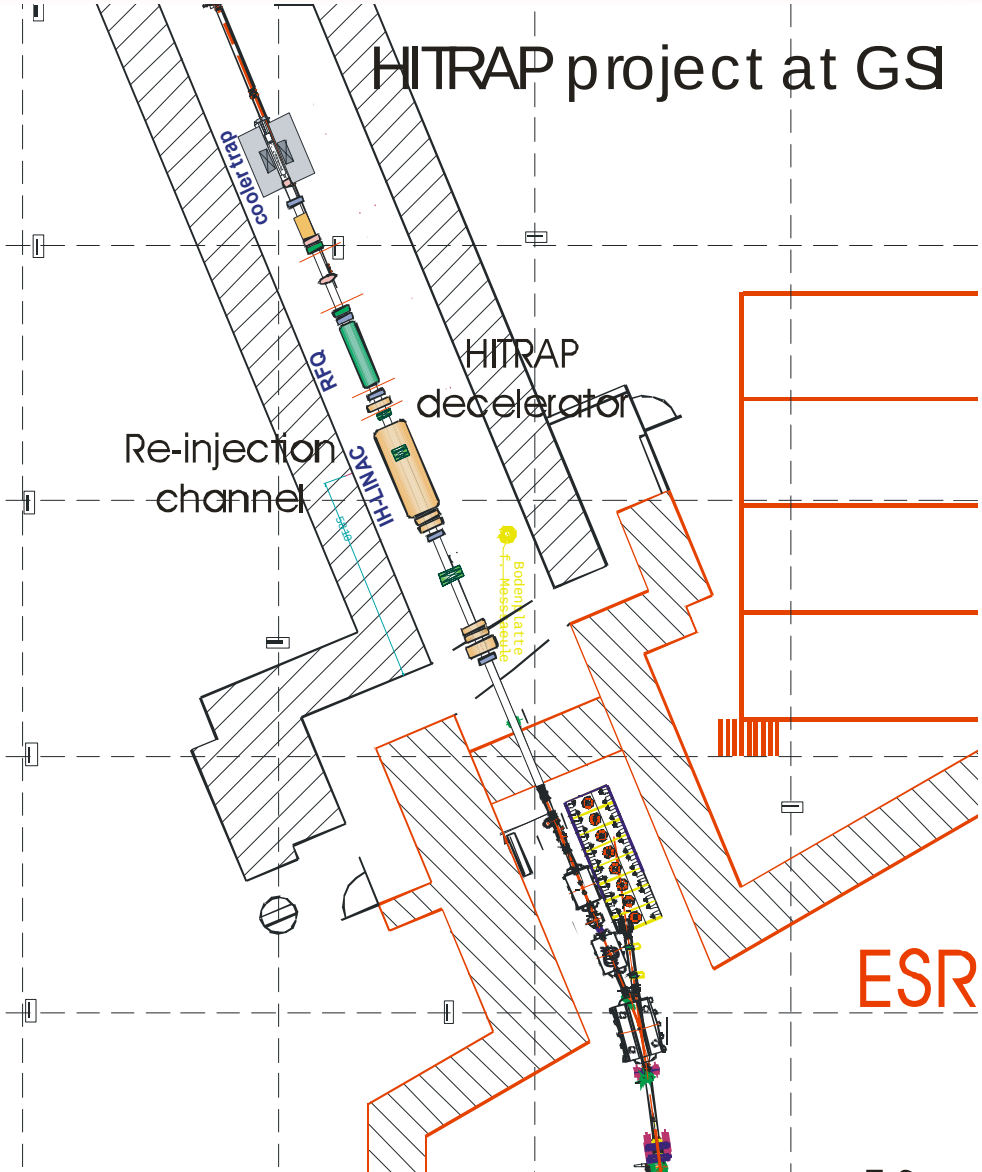
- Studies of reaction kinematics of slow HCI



Interaction of slow HCI up to U^{92+} with surfaces:

- Strongly inverted systems ('hollow atoms')

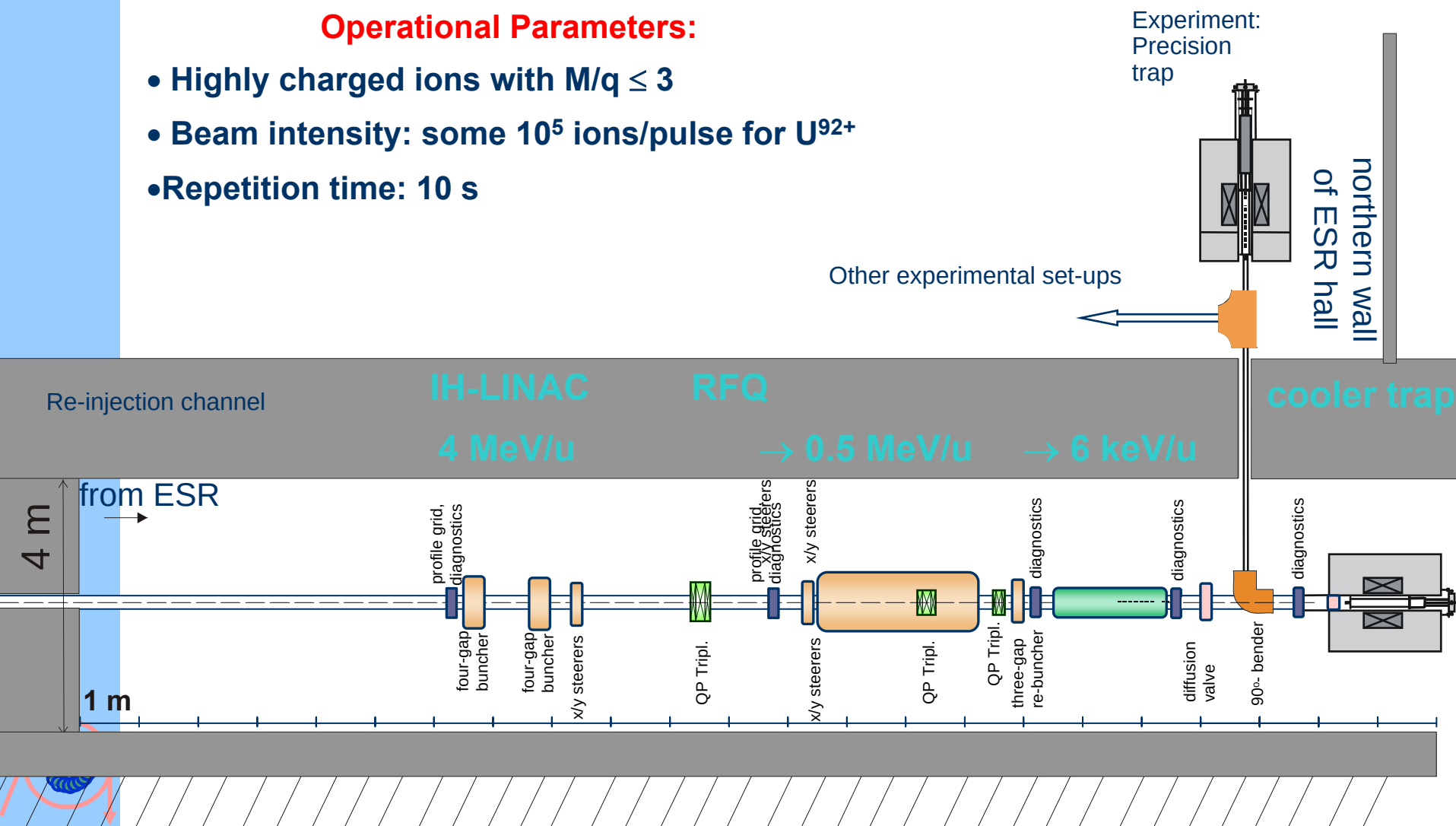
Overview


HITRAP project at GSI
Cooler trap
RFQ
IHLINAC
HITRAP
decelerator
Re-injection
channel
ESR

HITRAP

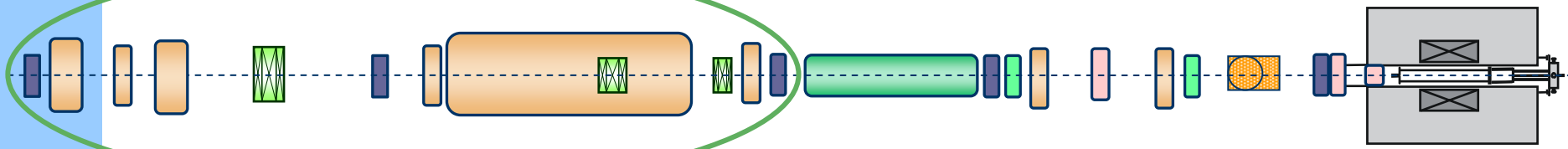
Operational Parameters:

- **Highly charged ions with M/q ≤ 3**
- **Beam intensity: some 10^5 ions/pulse for U^{92+}**
- **Repetition time: 10 s**



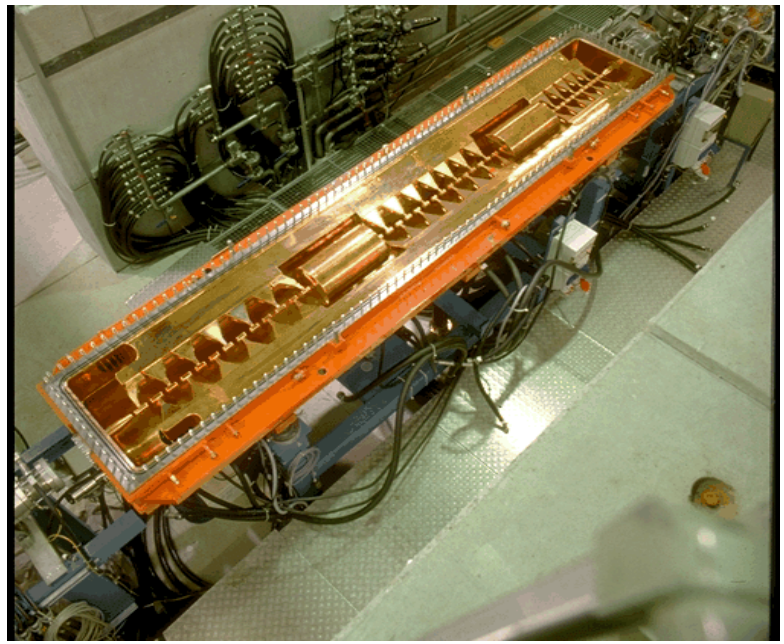
IH Structure

4 MeV/u – 0.5 MeV/u

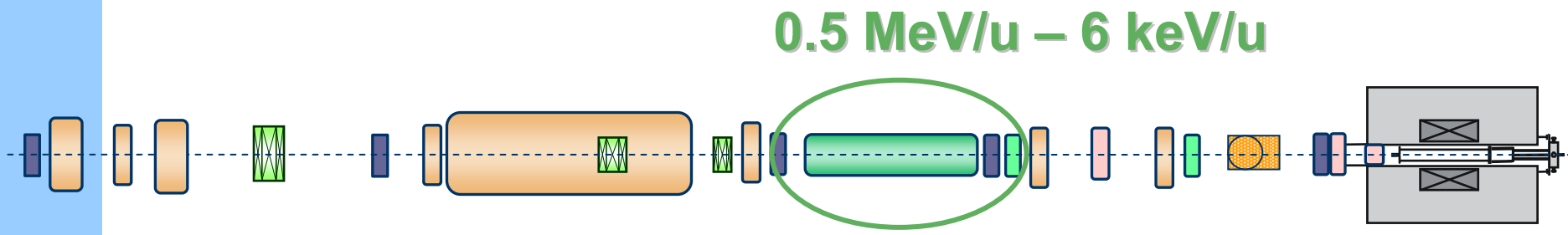


Univ. Frankfurt (U. Ratzinger)

- Ion optical simulations finished
- Tank being designed

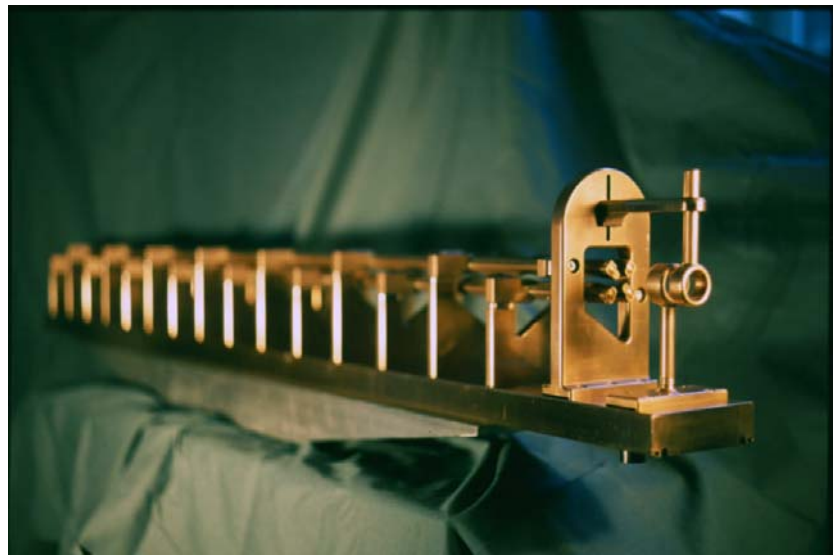


RFQ - structure



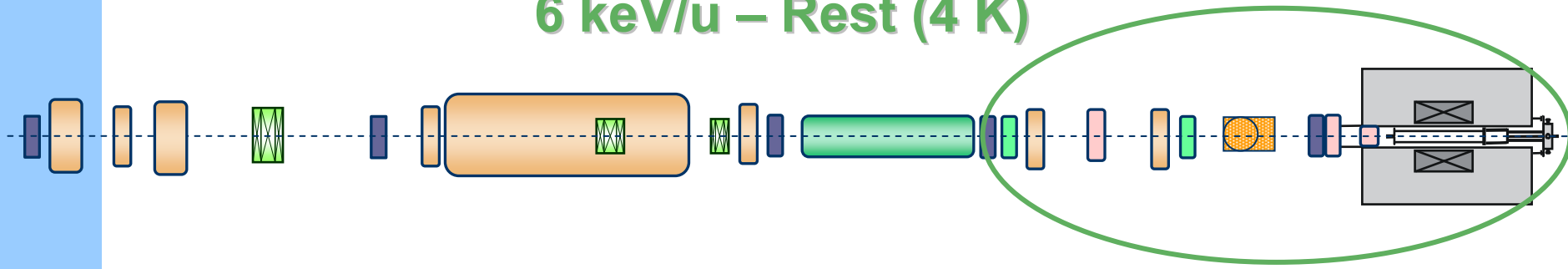
Univ. Frankfurt (A. Schempp)

- Calculations done
- Design in the last stage



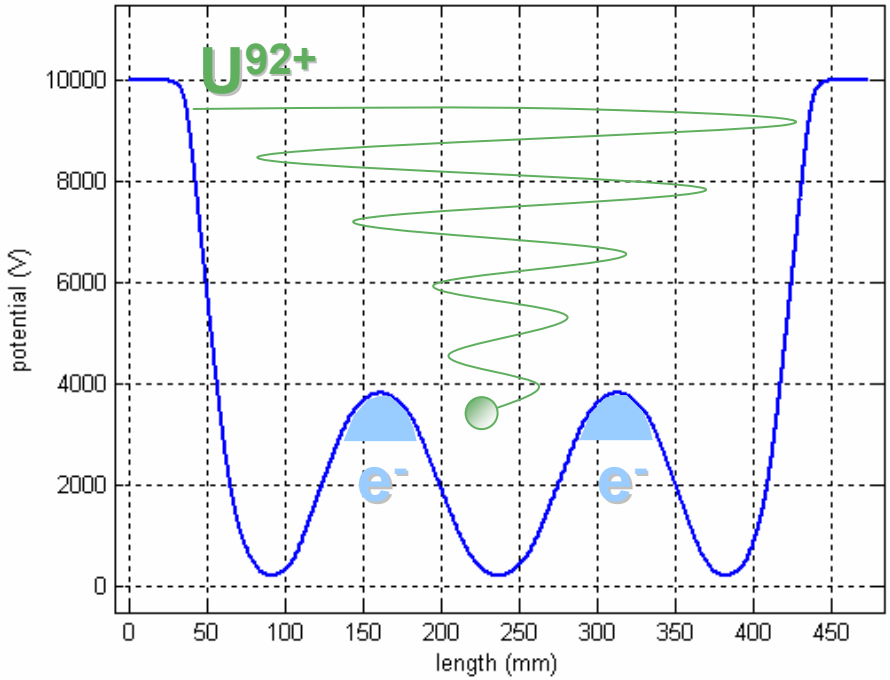
The Low Energy Beam Line & Trap

6 keV/u – Rest (4 K)

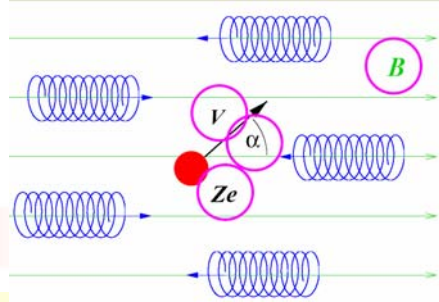


GSI/University of Mainz

- Ion optical simulations
- Trap magnet specifications defined

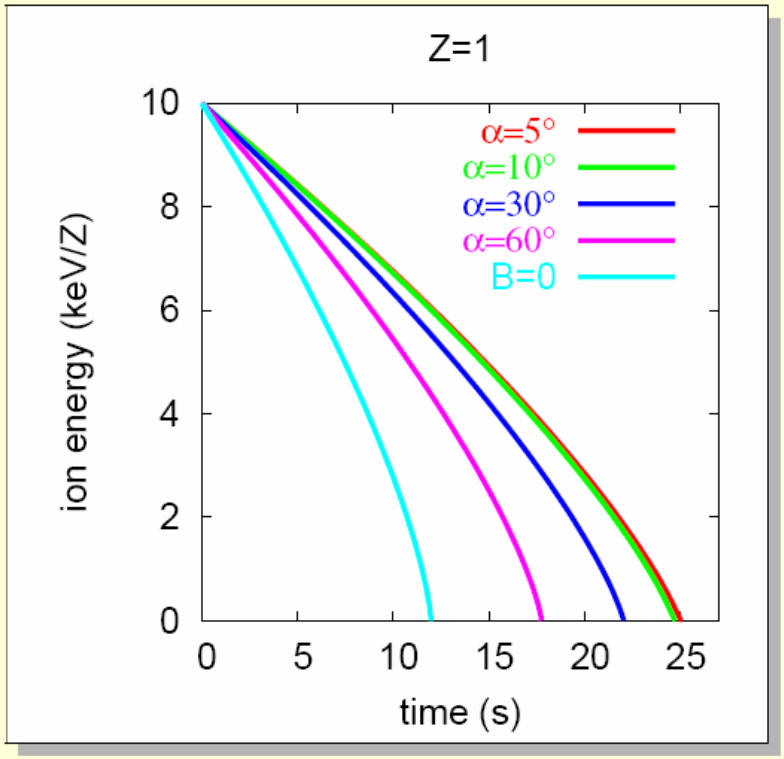


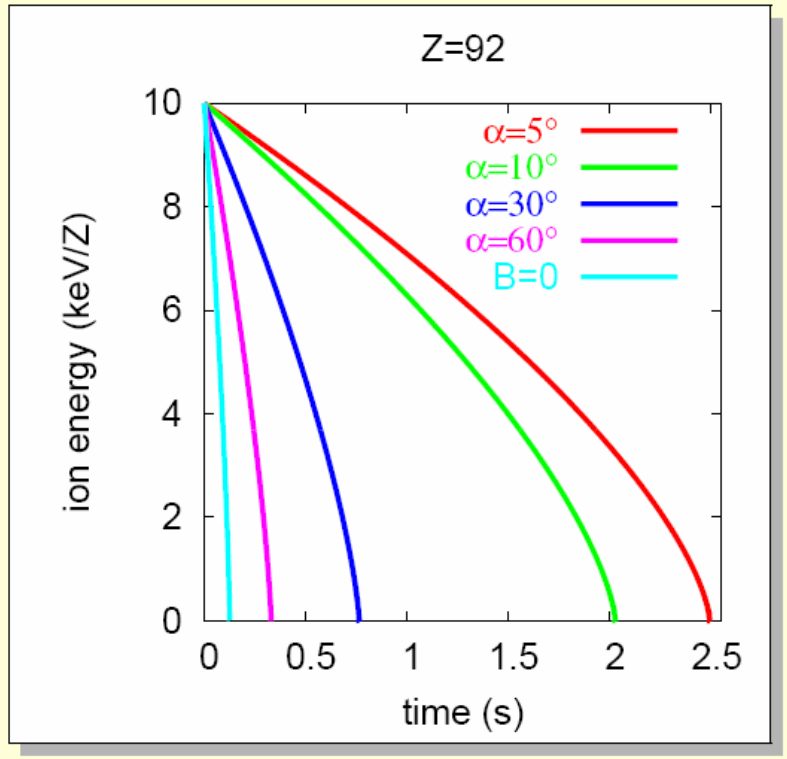
Electron Cooling of HCI



Cooling times for H^+ and U^{92+} without heating $(n_i/n_e \to 0)$

$$n_e = 10^7 \mathrm{cm}^{-3}, \quad T_e = 4\ \mathrm{K}, \quad B = 6\ \mathrm{T}$$

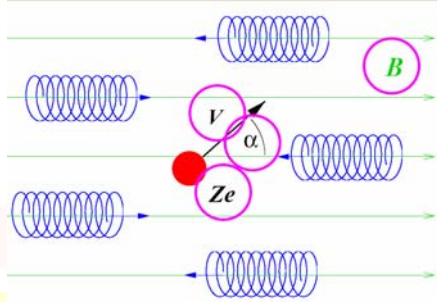




- Large variation of cooling times with α, fastest cooling for $B = 0$

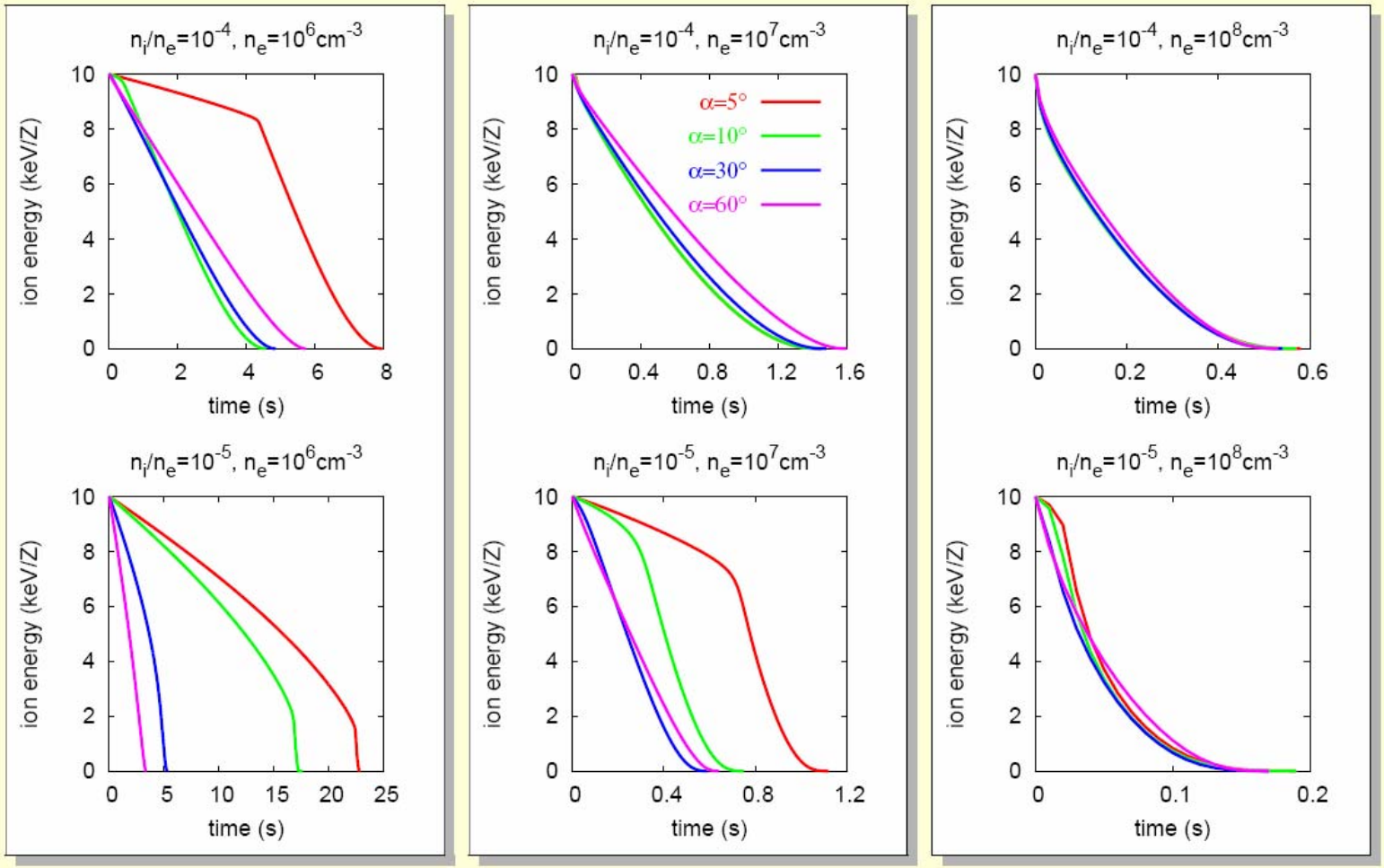
G. Zwicknagel et al.

Electron Cooling of HCl



B = 6T

Cooling times of U^{92+} at different electron densities



G. Zwicknagel et al.

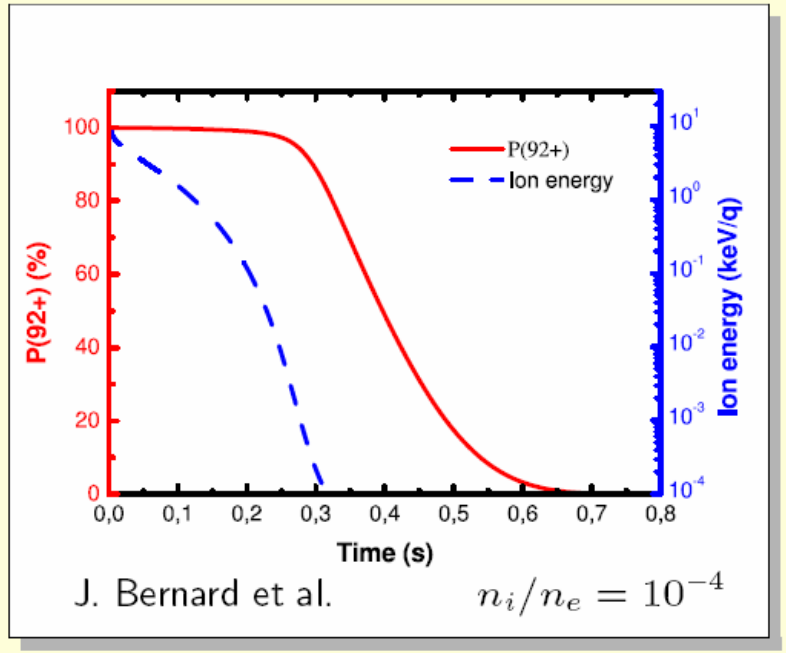
Electron Cooling of HCI

Open questions

- Cooling faster than recombination?
  - Radiative recombination rate ν_{RR} depends on $v_r \approx (V^2 + v_e^2)^{1/2}$

$$\nu_{RR} \propto \frac{n_e}{v_r} \sim \frac{n_e}{T_e^{1/2}}$$

  - ▶ Recombination has to be calculated simultaneously with $V(t), T_e(t)$

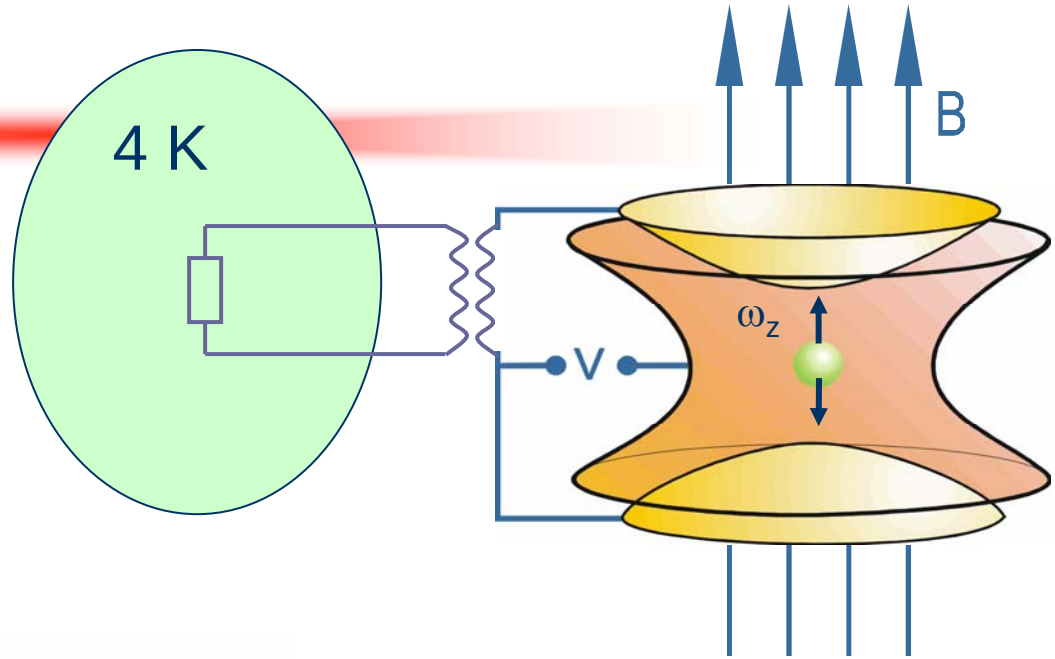


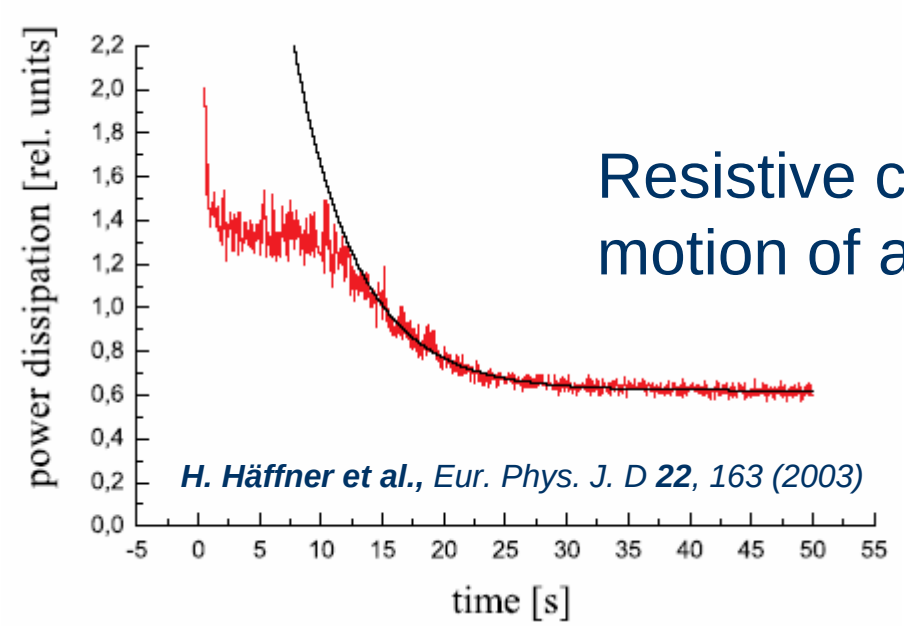
J. Bernard et al. $n_i/n_e = 10^{-4}$

- Instantaneous, isotropic thermalization?
  - Ion energy is transfered anisotropic to $v_{e,\perp}, v_{e,\parallel} \rightarrow T_{e,\perp}, T_{e,\parallel}$
  - Isotropization rate ν_{iso}: $\frac{d\vec{T}_{e,\perp}}{dt} = \nu_{iso}\left(T_{e,\parallel} - T_{e,\perp}\right), \quad \nu_{iso} \sim \frac{1}{\bar{T}_e^{3/2}}$

G. Zwicknagel et al.

Resistive cooling

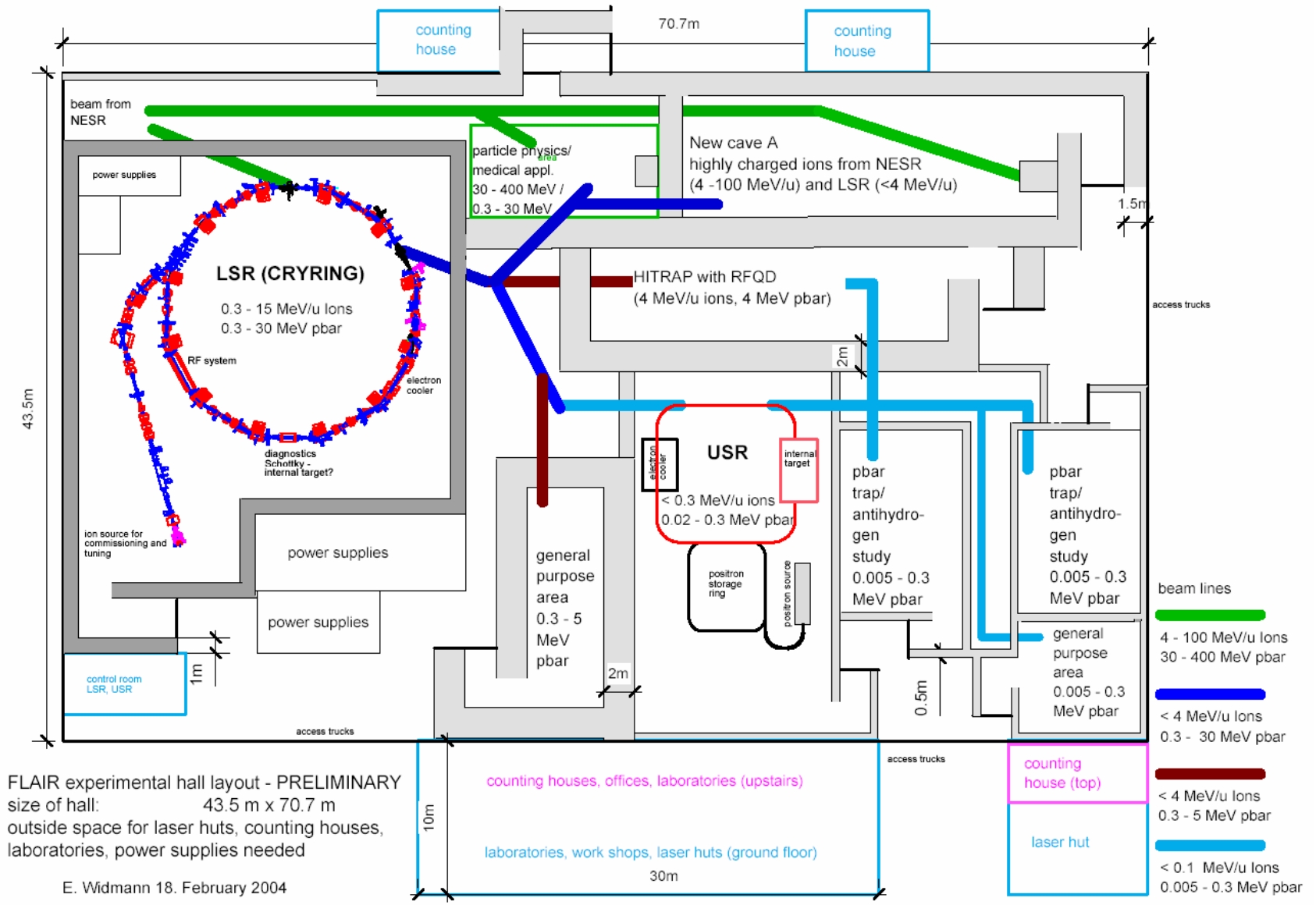




H. Häffner et al., *Eur. Phys. J. D* ***22****, 163 (2003)*

Resistive cooling of the axial motion of an ion cloud (30 $^{12}C^{5+}$)

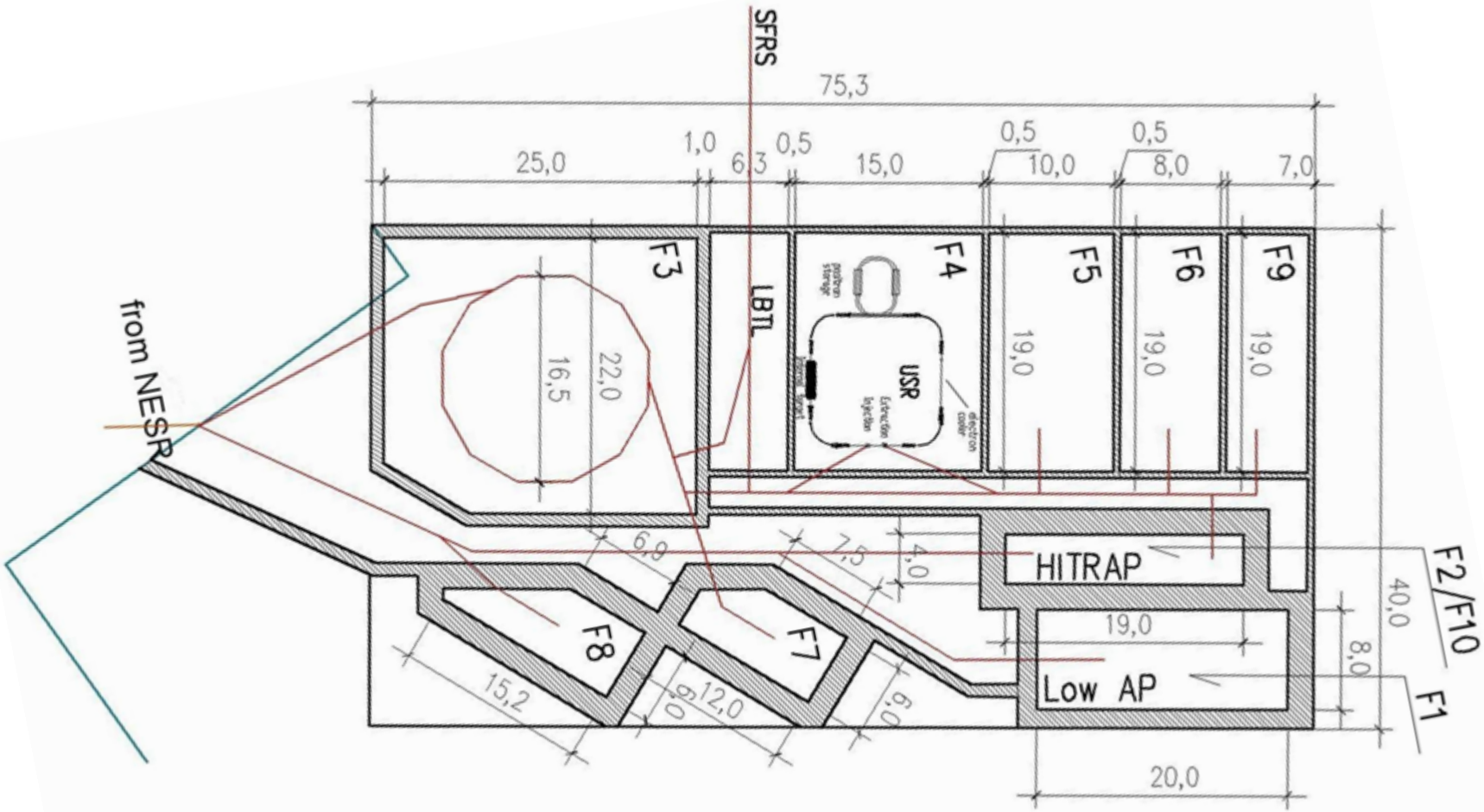
HITRAP @ FLAIR



FLAIR experimental hall layout - PRELIMINARY
size of hall: 43.5 m x 70.7 m
outside space for laser huts, counting houses, laboratories, power supplies needed

E. Widmann 18. February 2004

HITRAP @ FLAIR



- Technical proposal for FLAIR and SPARC submitted
- PAC meeting ongoing

Timeline

- Nov. 2001 – Oct. 2005: HITRAP EU RTD Network
- Oct. 2002: HITRAP proposal
- Dec. 2002: HITRAP workshop
  - positive scientific rating, however, Technical Design Report requested
- Oct. 2003: Technical Design Report
  - with detailed financial plan
- Dec. 2003: Technical Design Report rated positively
- May 2004: evaluation of HITRAP within the HGF program 'Large-Scale Facilities for Photons, Neutrons and Ions (PNI)'
  - excellent ratings
- Oct. 2004: Recommendation of the HGF Senate includes HITRAP for additional funding.
- Jan. 2005: Start of construction.

The HITRAP Collaboration

J. Alonso[1], W. Barth[2], A. Bechtold[3], T. Beier[2], K. Blaum[1], M. Block[2], G. Bollen[4], L. Dahl[2], S. Djekic[1], P. Forck[2], G. Gruber[2], F. Herfurth[2], C. Kitegi[3], H.-J. Kluge[2], C. Kozhuharov[2], A. Krämer[2], G. Maero[2] S. Minaev[3], W. Quint[2], U. Ratzinger[3], H. Reich-Sprenger[2], D. Rodríguez[2], A. Schempp[3], S. Schwarz[4], S. Stahl[1], T. Sun[4], T. Valenzuela[1], J. Verdu[1], W. Vinzenz[2], M. Vogel[1], C. Weber[2], G. Werth[1]

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