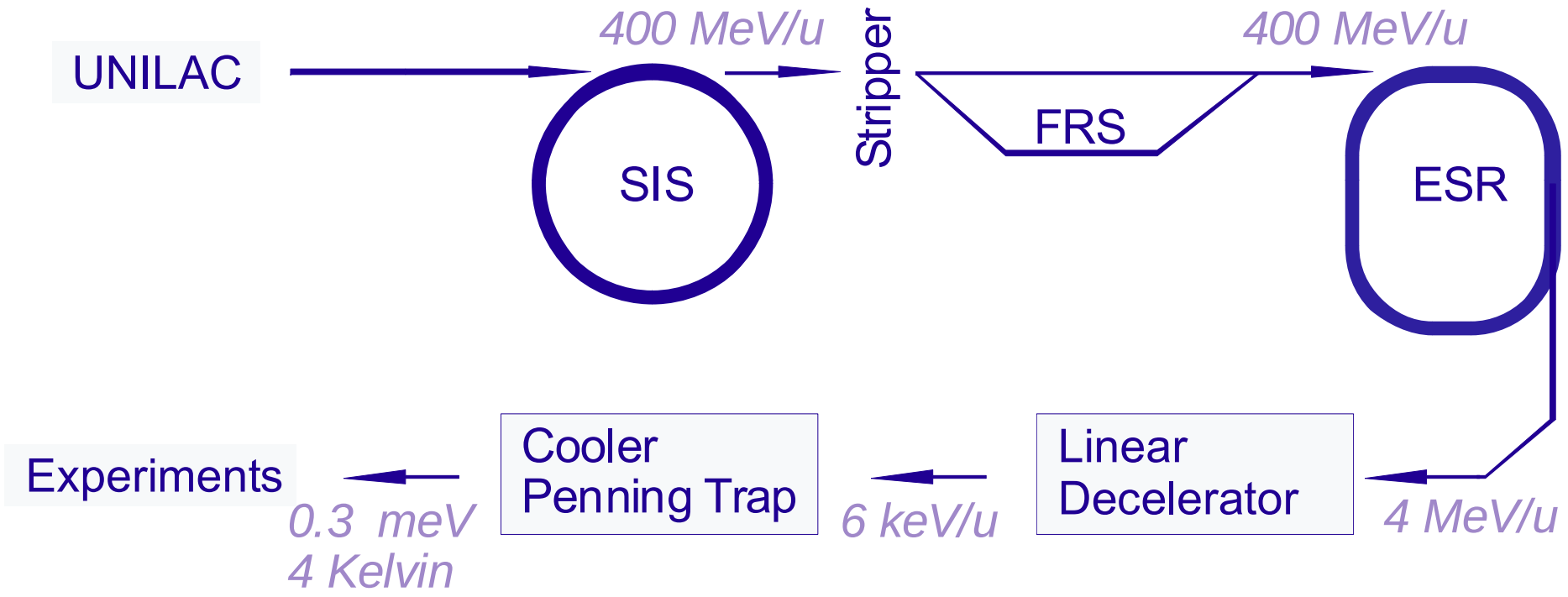
HITRAP @ GSI


UNILAC
400 MeV/u
SIS
Stripper
FRS
400 MeV/u
ESR
Linear Decelerator
4 MeV/u
6 keV/u
Cooler Penning Trap
0.3 meV
4 Kelvin
Experiments

Precision Experiments on Single Highly-Charged Ions

Test of quantum electrodynamics in extreme fields

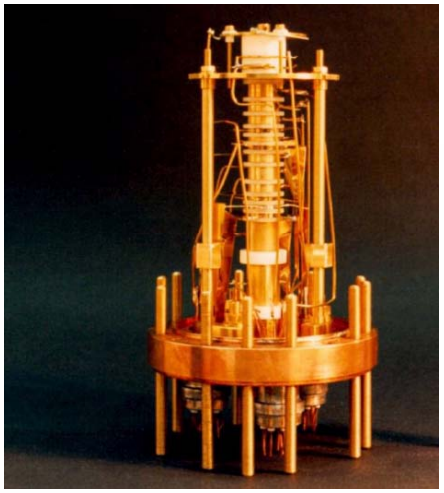
- g-factor of the bound electron
- Electron correlations and relativistic effects

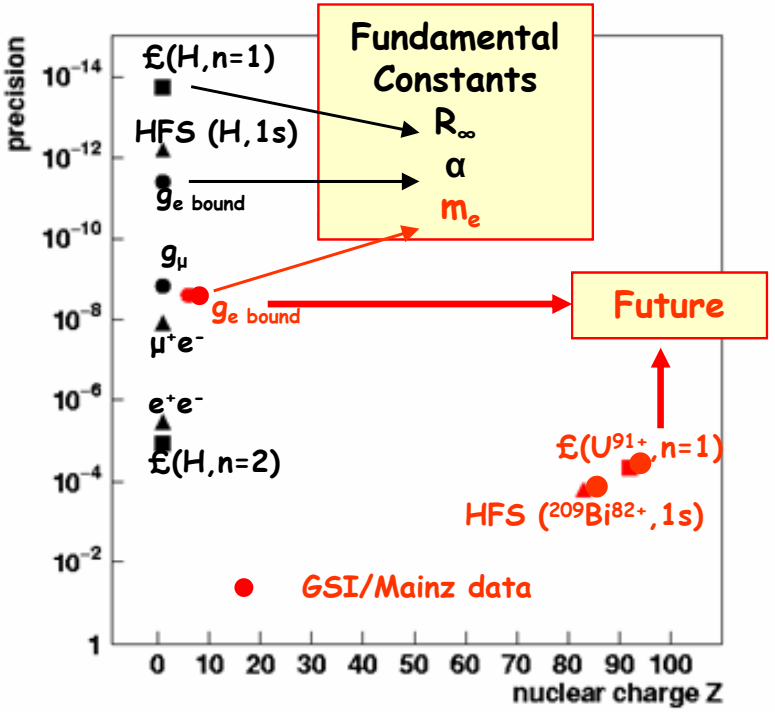
Determination of fundamental constants

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

Ultra-precise mass measurements

- Determination of atomic and nuclear binding energies





HITRAP

Spectroscopy, Reactions 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:

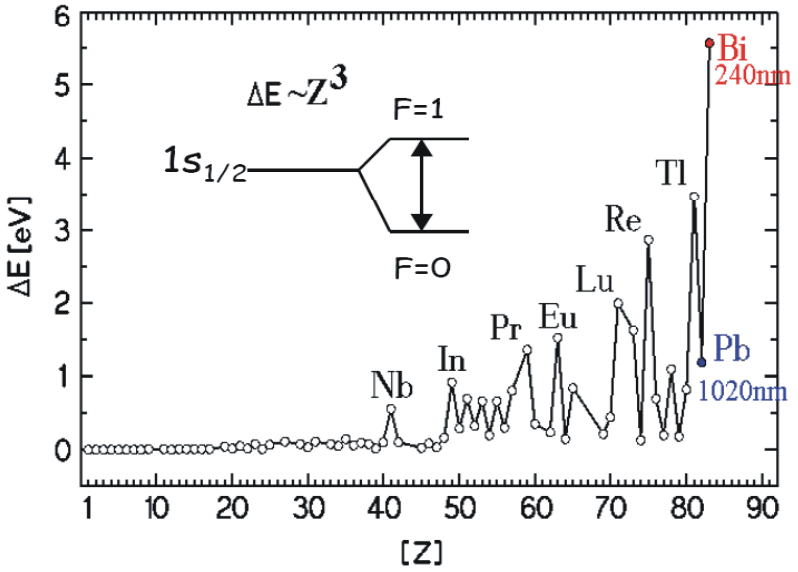
- Precision measurements of binding energies
- Isotope shift: nuclear charge radii

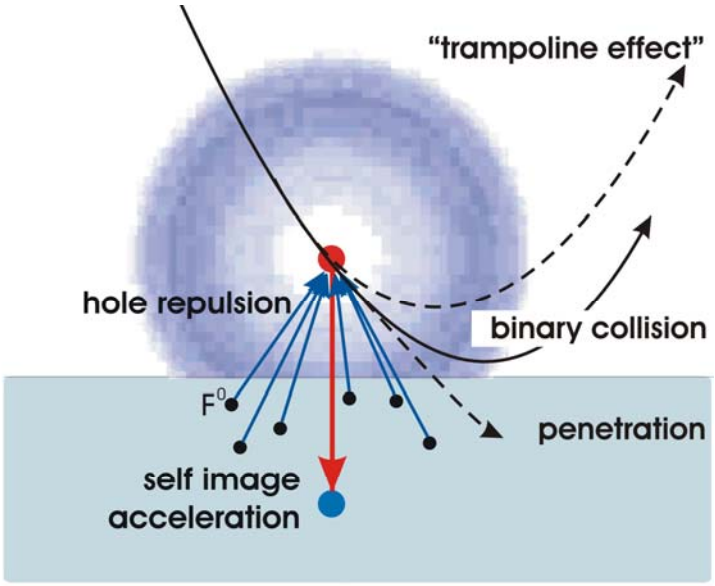
Reaction microscope:

- Studies of reaction kinematics of slow HCI

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

- Strongly inverted systems ('hollow atoms')

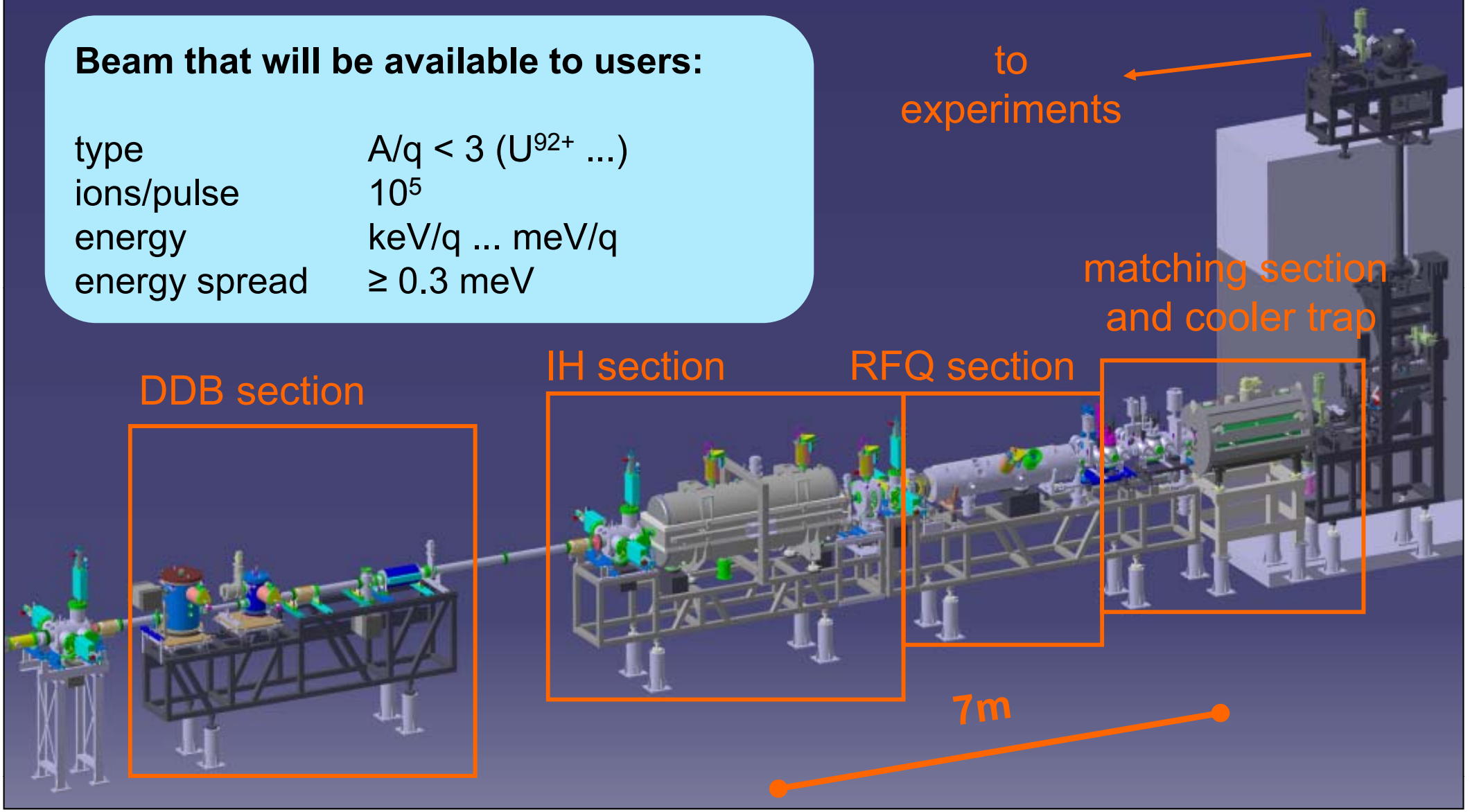




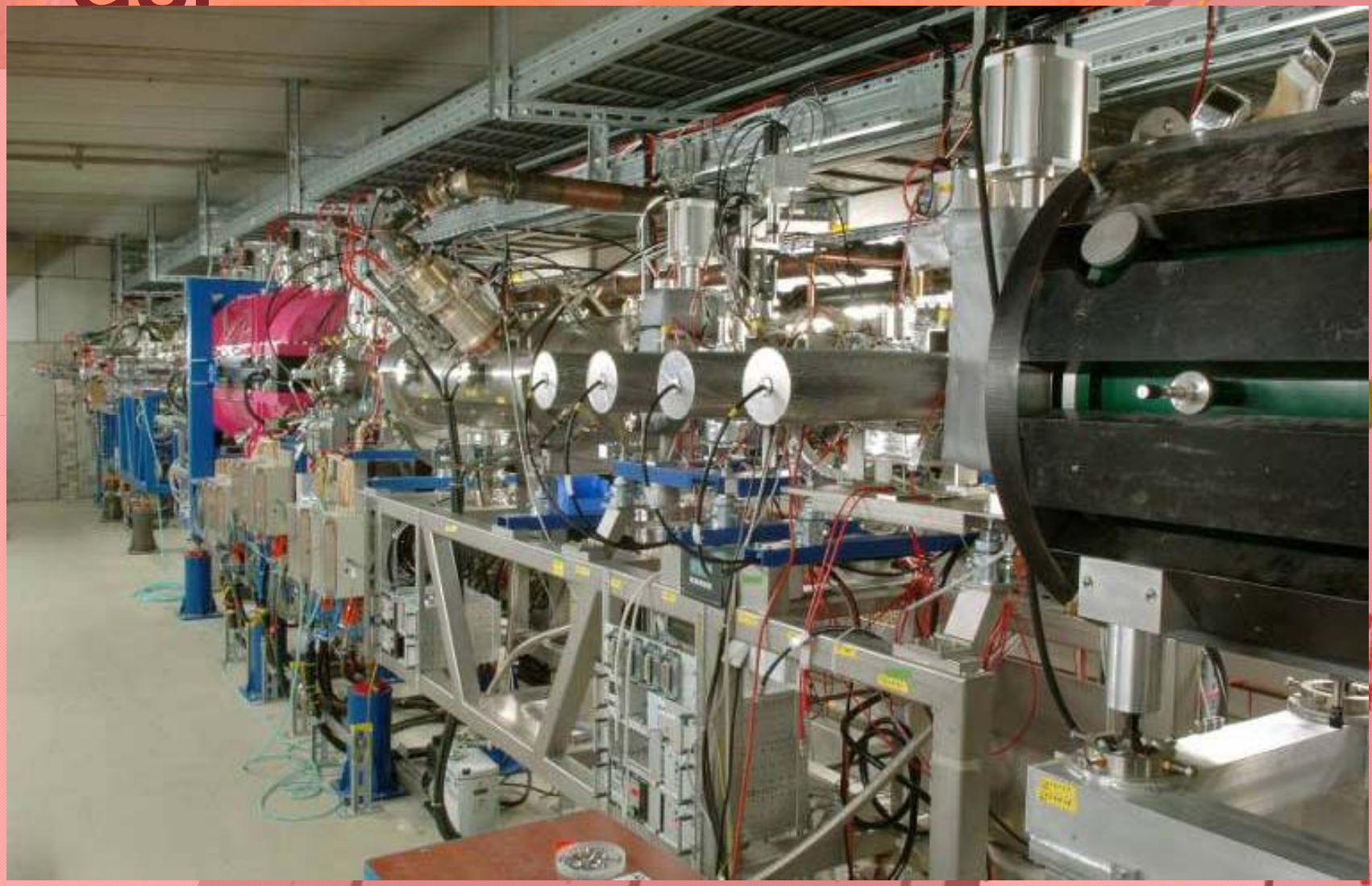
HITRAP – Linear Decelerator

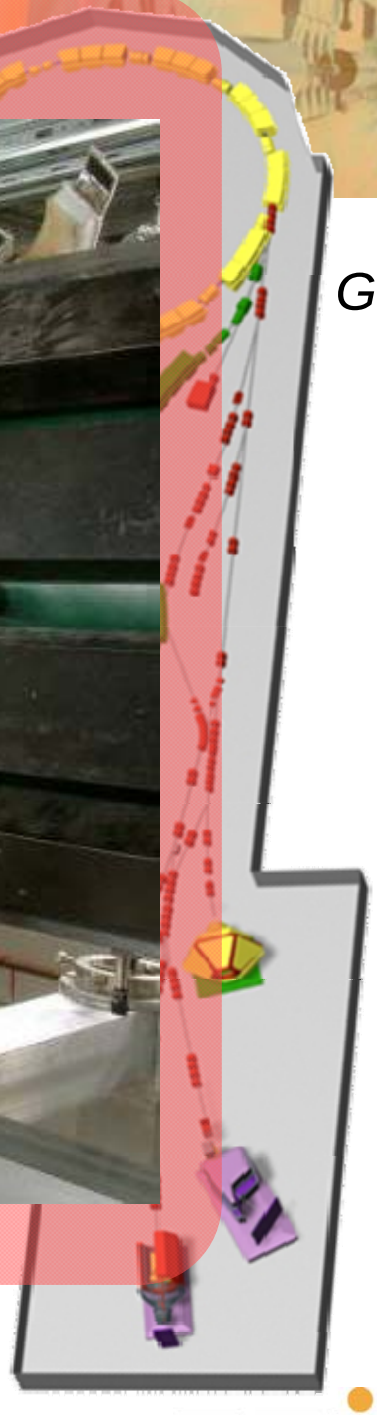
Beam that will be available to users:

type	A/q < 3 (U^{92+} ...)
ions/pulse	10^5
energy	keV/q ... meV/q
energy spread	≥ 0.3 meV



HITRAP
GSI



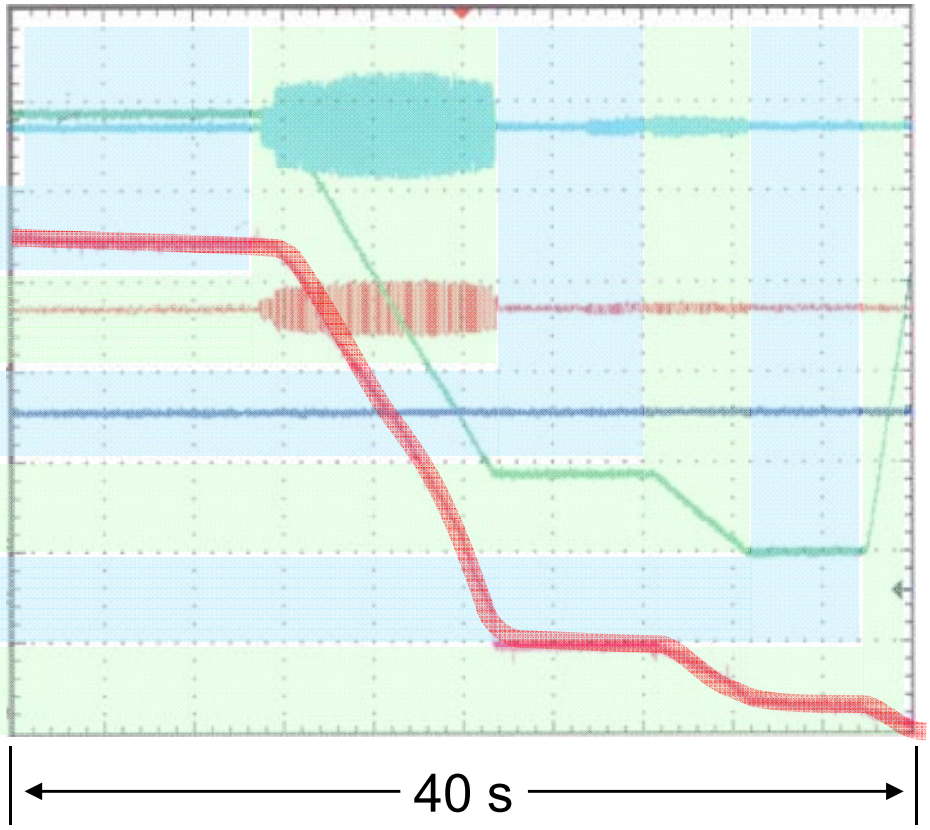


GeV/u

ESR – From 400 to 4 MeV/u

ESR – Experimental Storage Ring at GSI with stochastic and electron cooling

time (s)	**ESR cycle during recent experiment**
5..20	injection, **stoch. cooling**
3..10	deceleration 400 – 30 MeV/u
2..6	e^- cooling, rebunching
2..5	deceleration 30 – 4 MeV/u
2..5	e^- cooling, ejection
3	reset magnets



signal:

RF amplitude

magn.dipole field

ion current

HITRAP – Linear Decelerator

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ions/pulse	10^5
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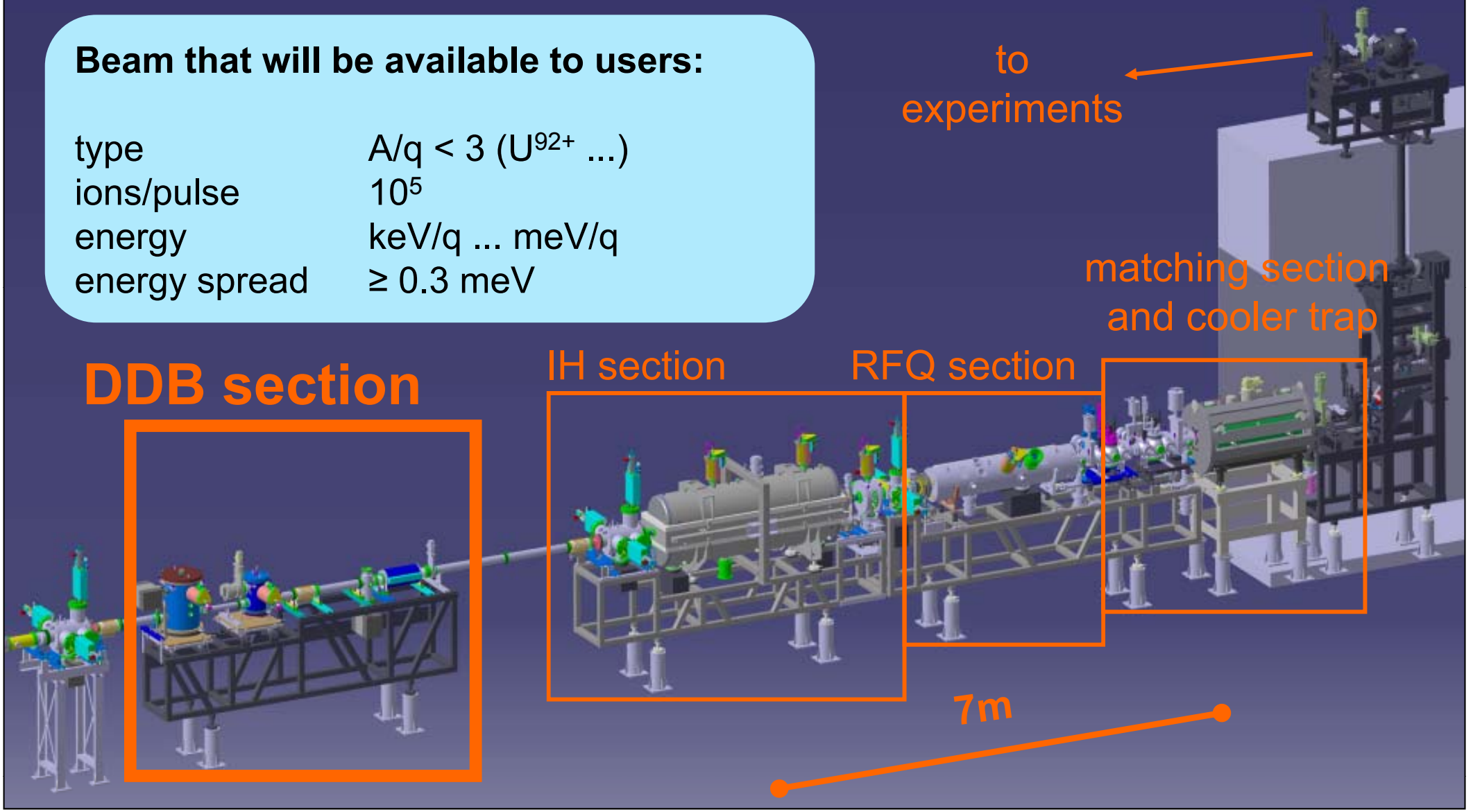
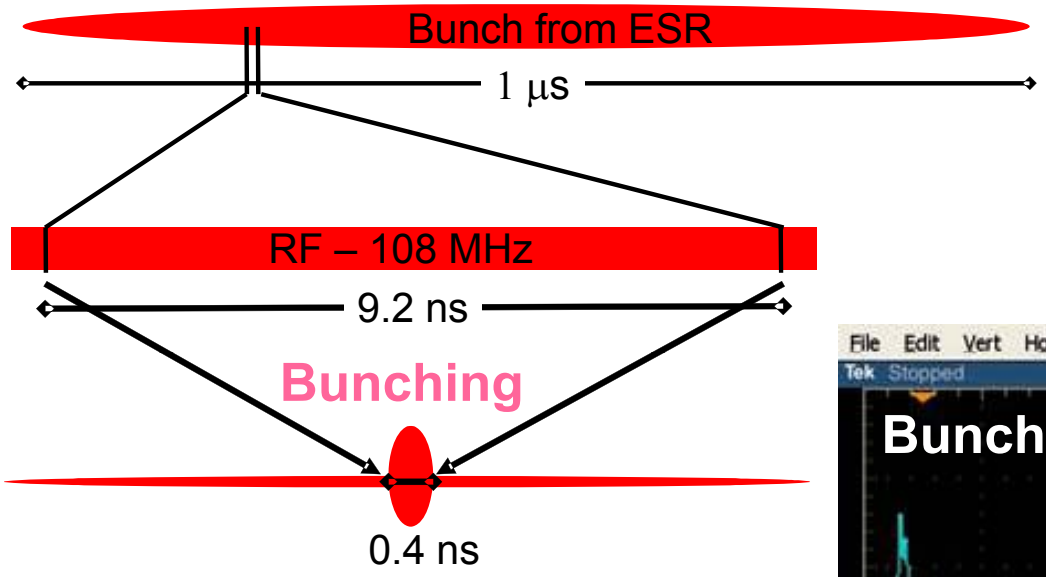
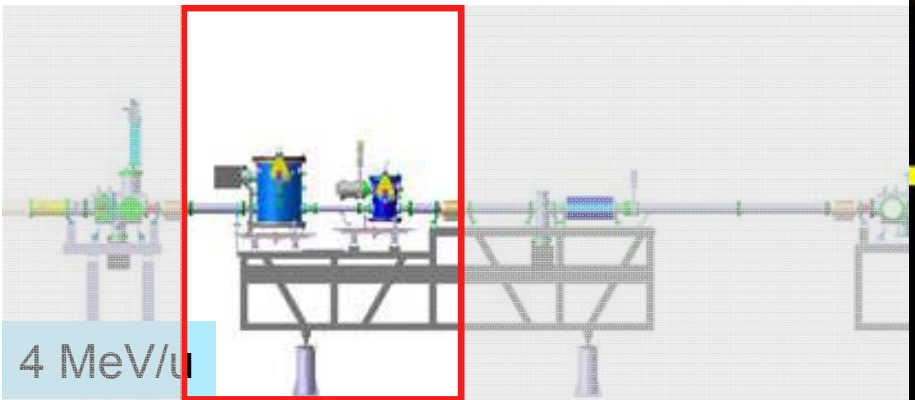
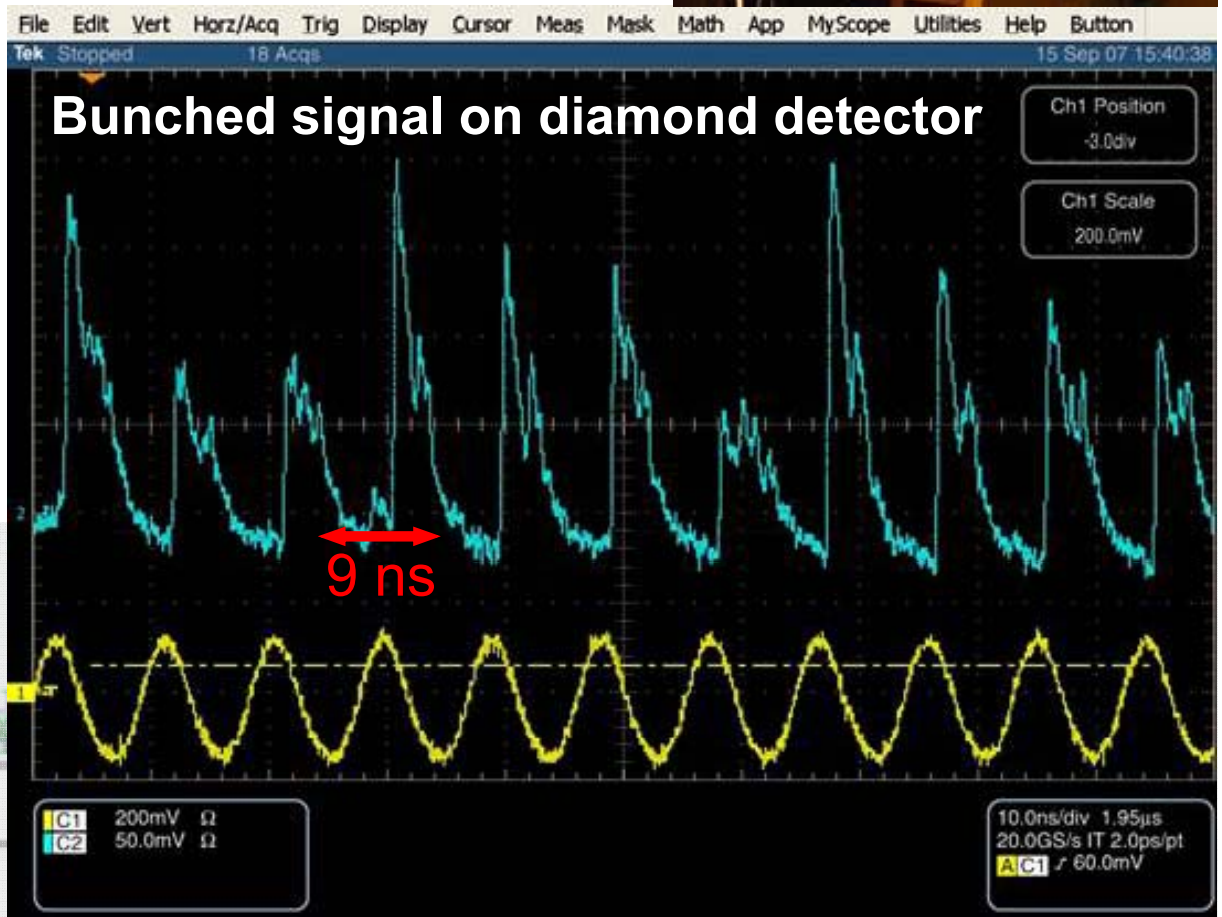


HITRAP – Double Drift Buncher







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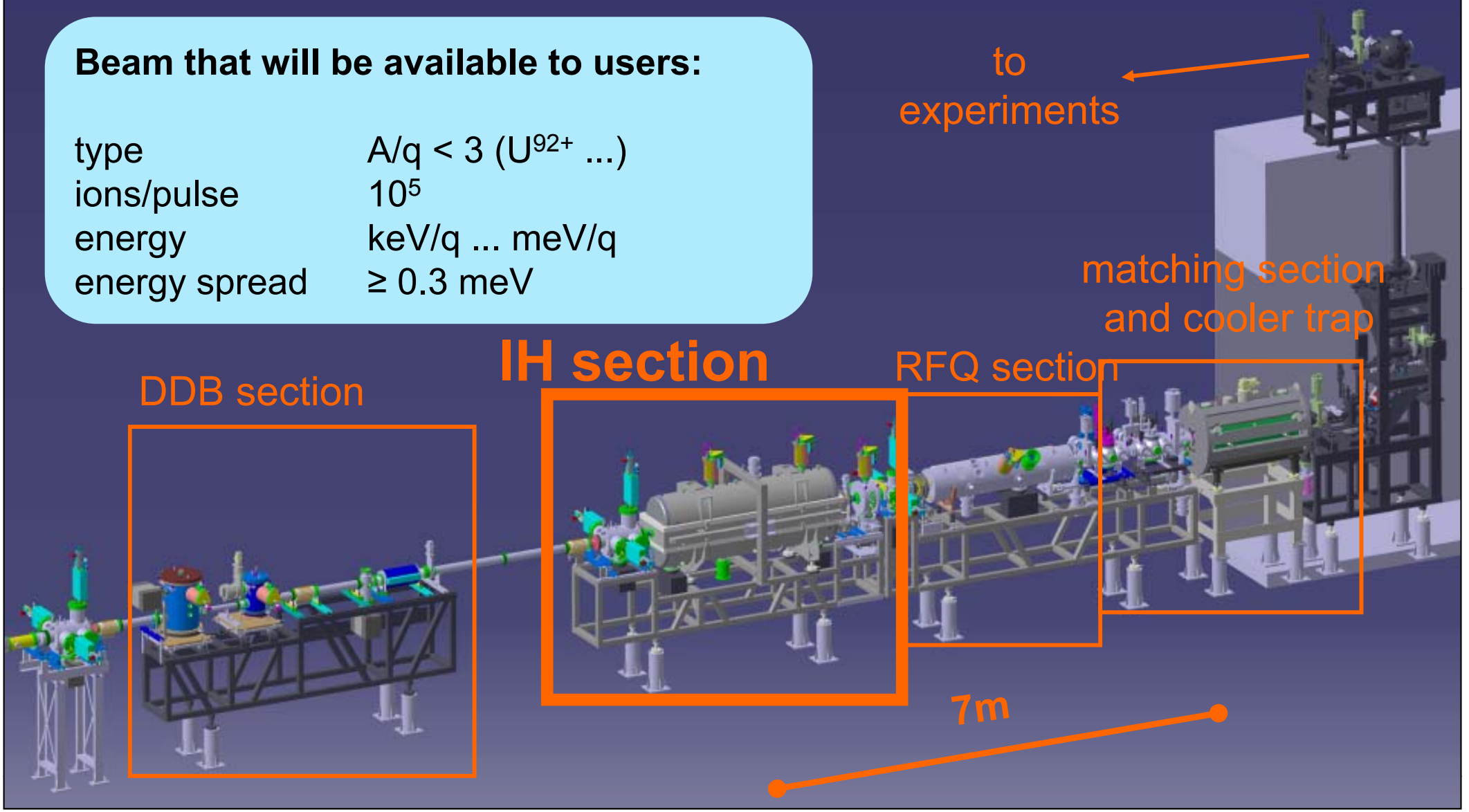
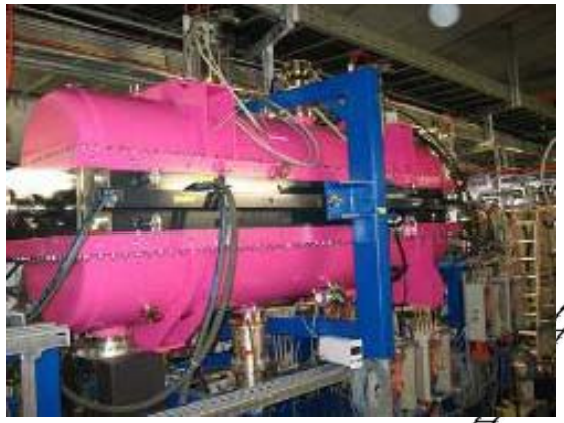
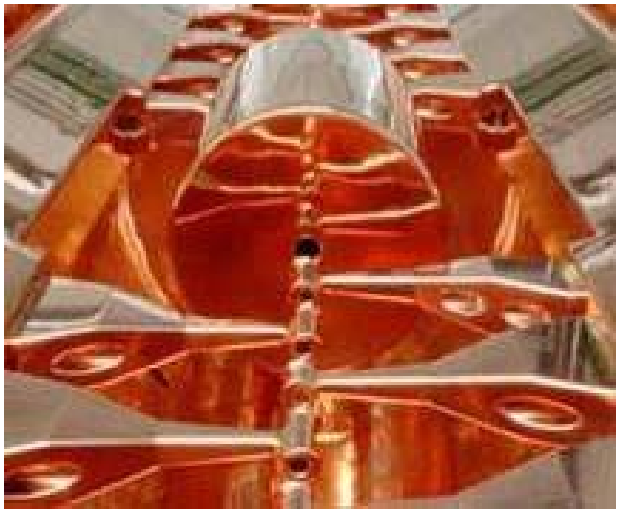


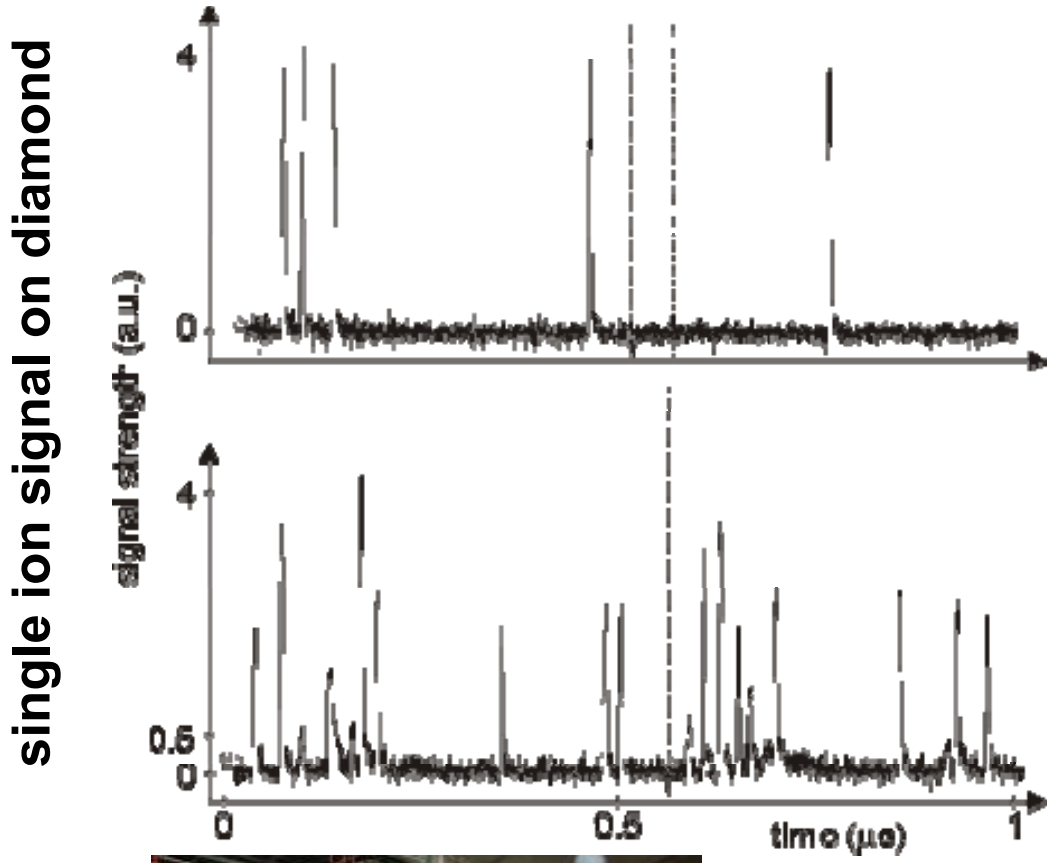
The HITRAP IH Structure

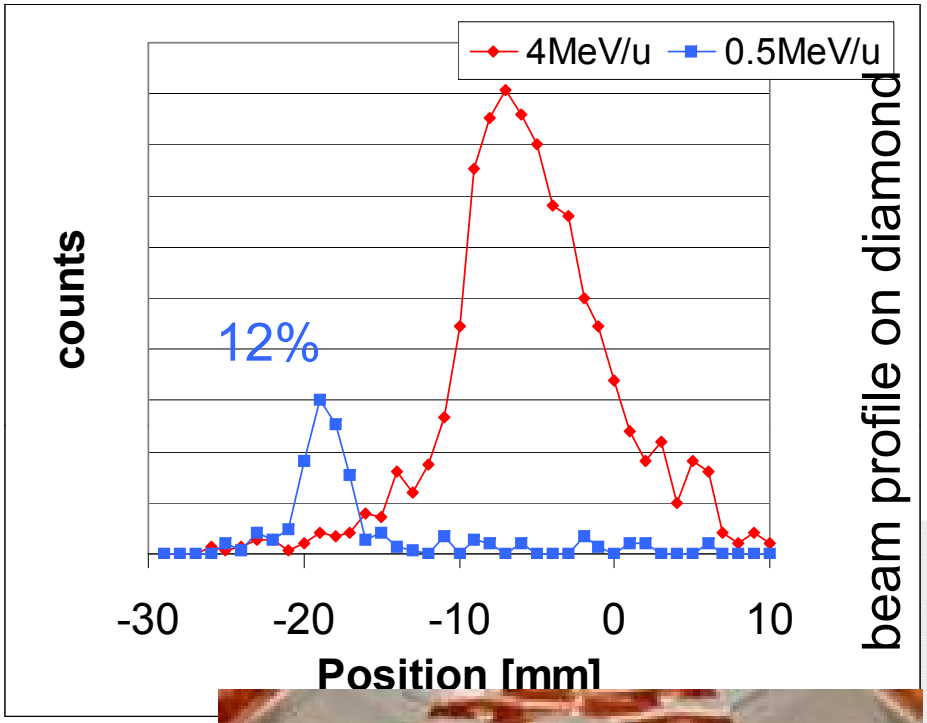


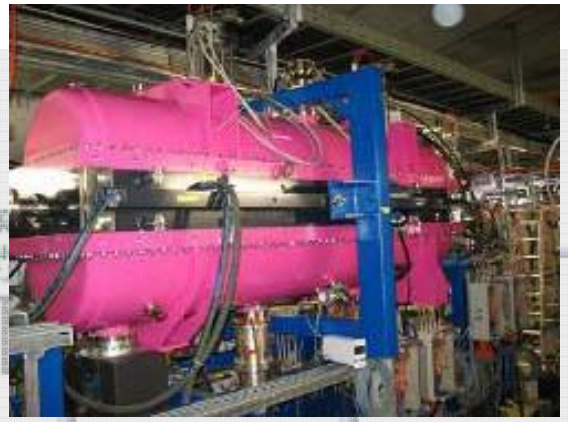


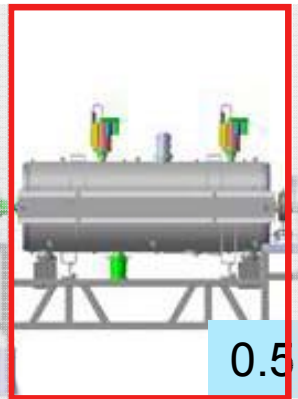
f_{rf}	108	MHz
Q_0	25800	
Z_{eff}	220	MΩ/m
E_{eff}	1.3	A/q*MV/m
Length	2.6	m
P_{rf}[1]	170	kW

HITRAP – IH Structure





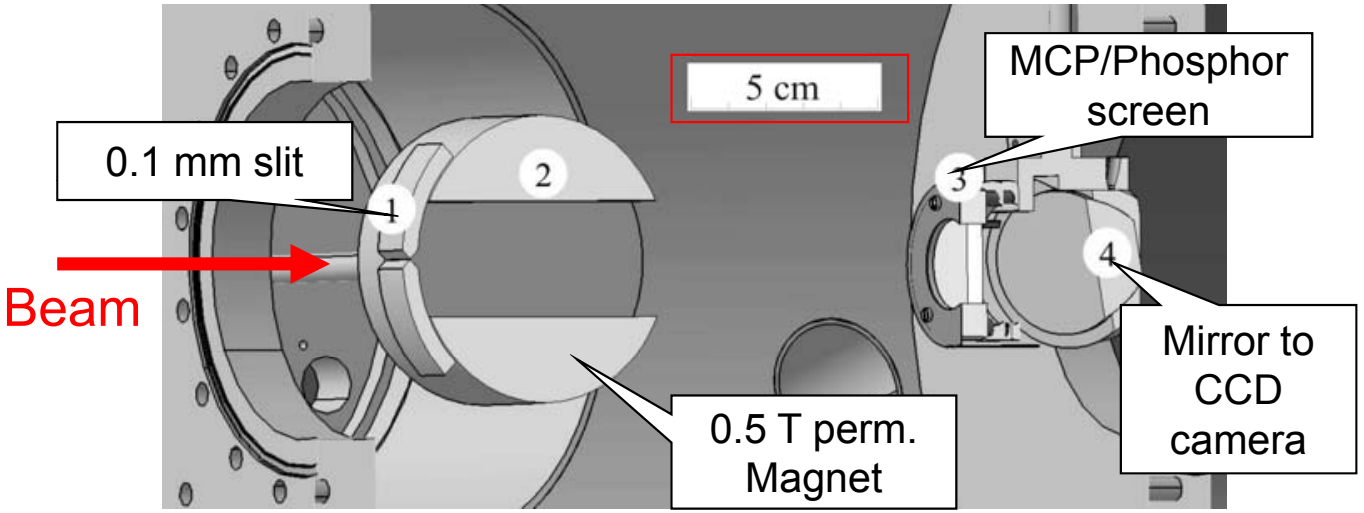




4 MeV/u

0.5 MeV/u

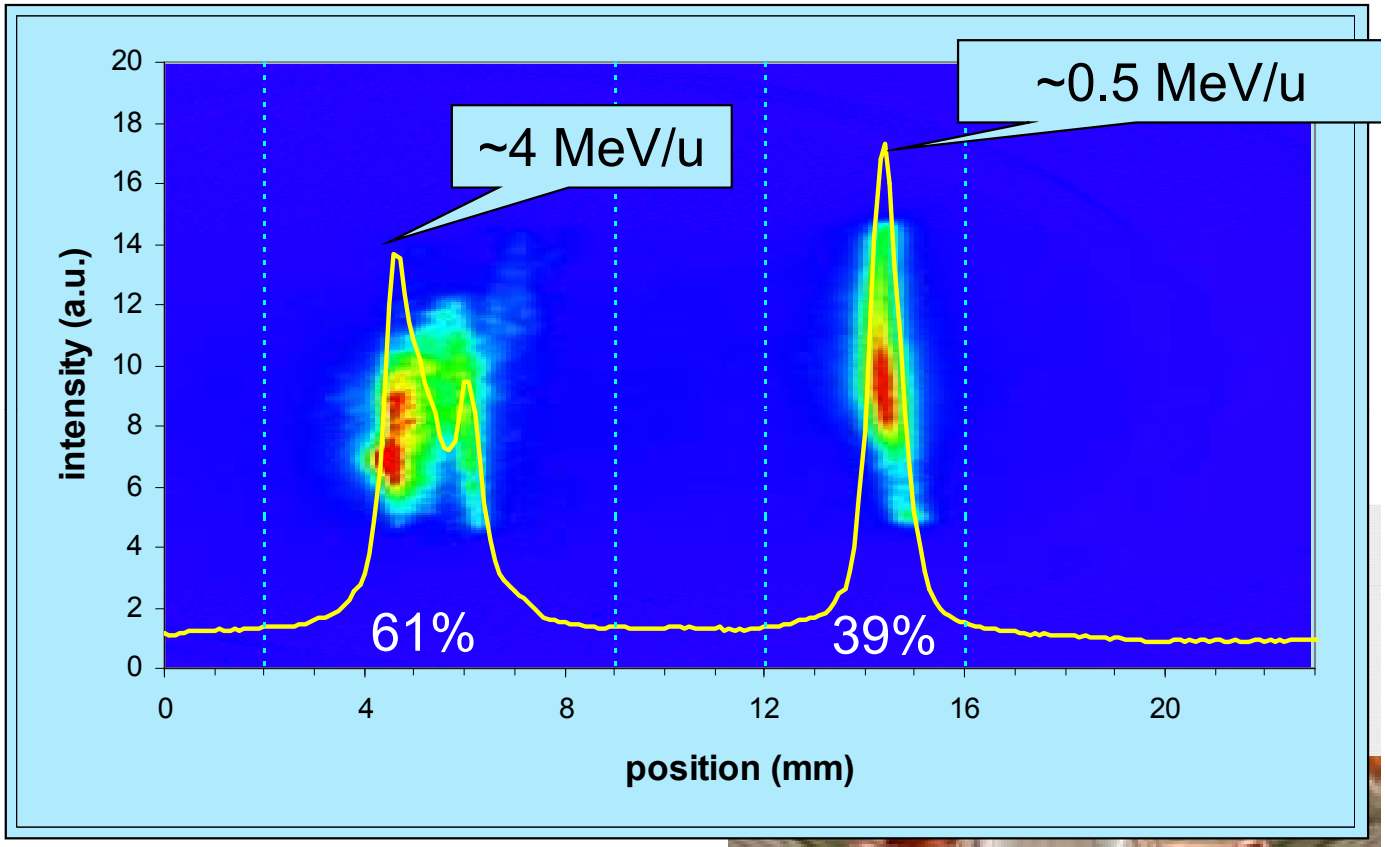
Principle of energy analyzer

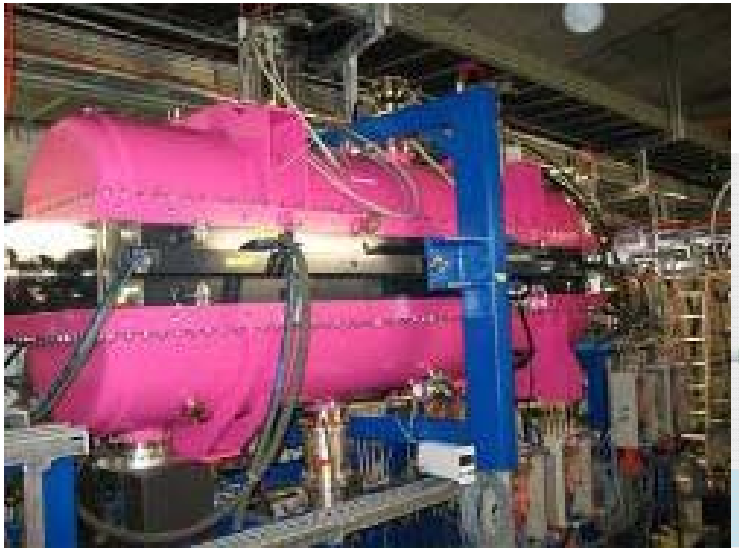


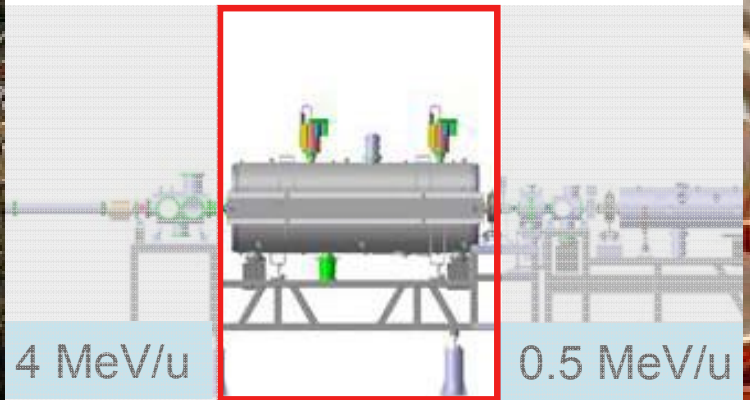
HITRAP – IH Structure

Energy spectrum IH

- Fraction of decelerated particles close to theory (55%)

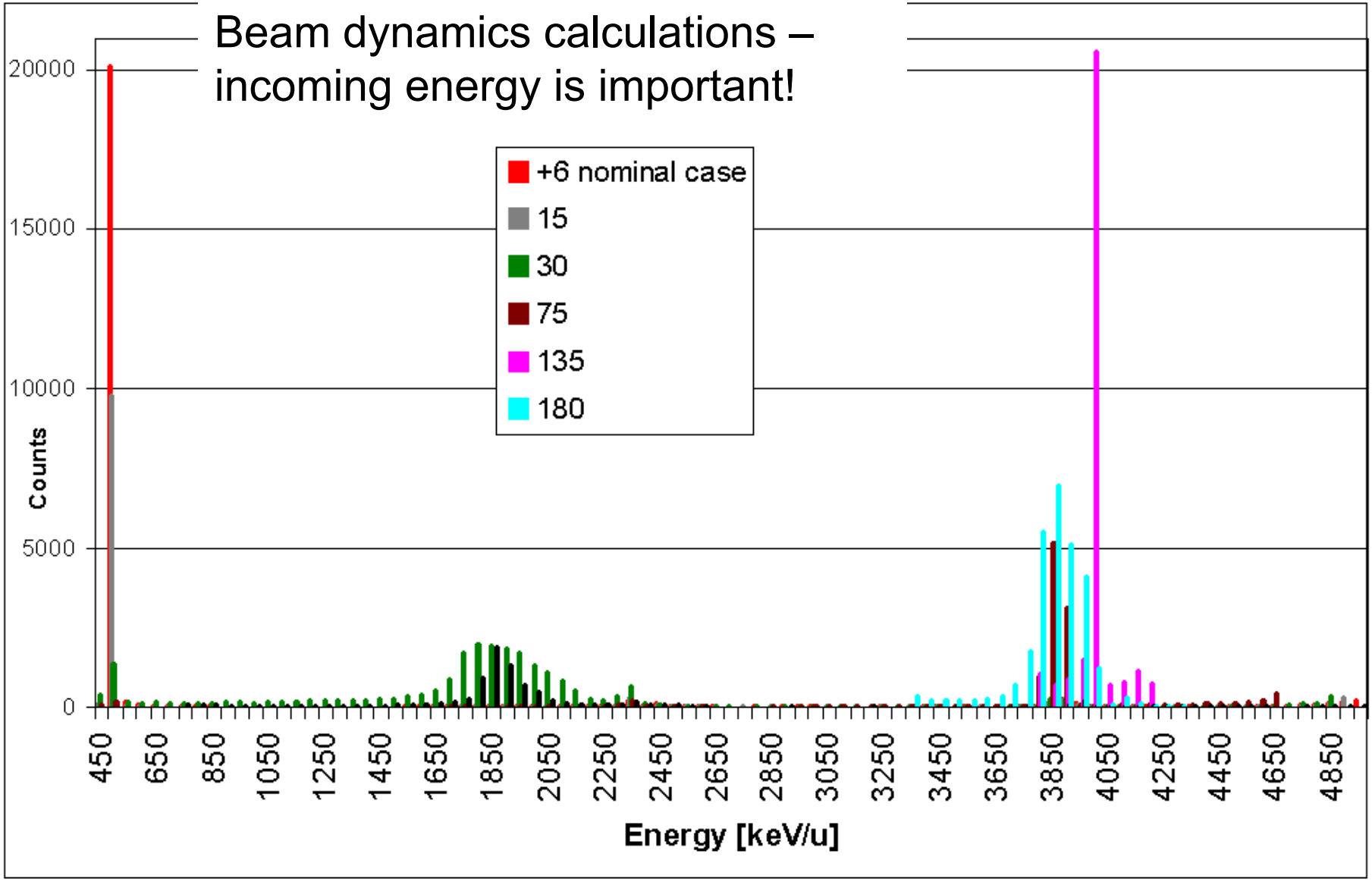






IH Structure – Energy Spectrum

Beam dynamics calculations – incoming energy is important!



G. Clemente

HITRAP – Linear Decelerator

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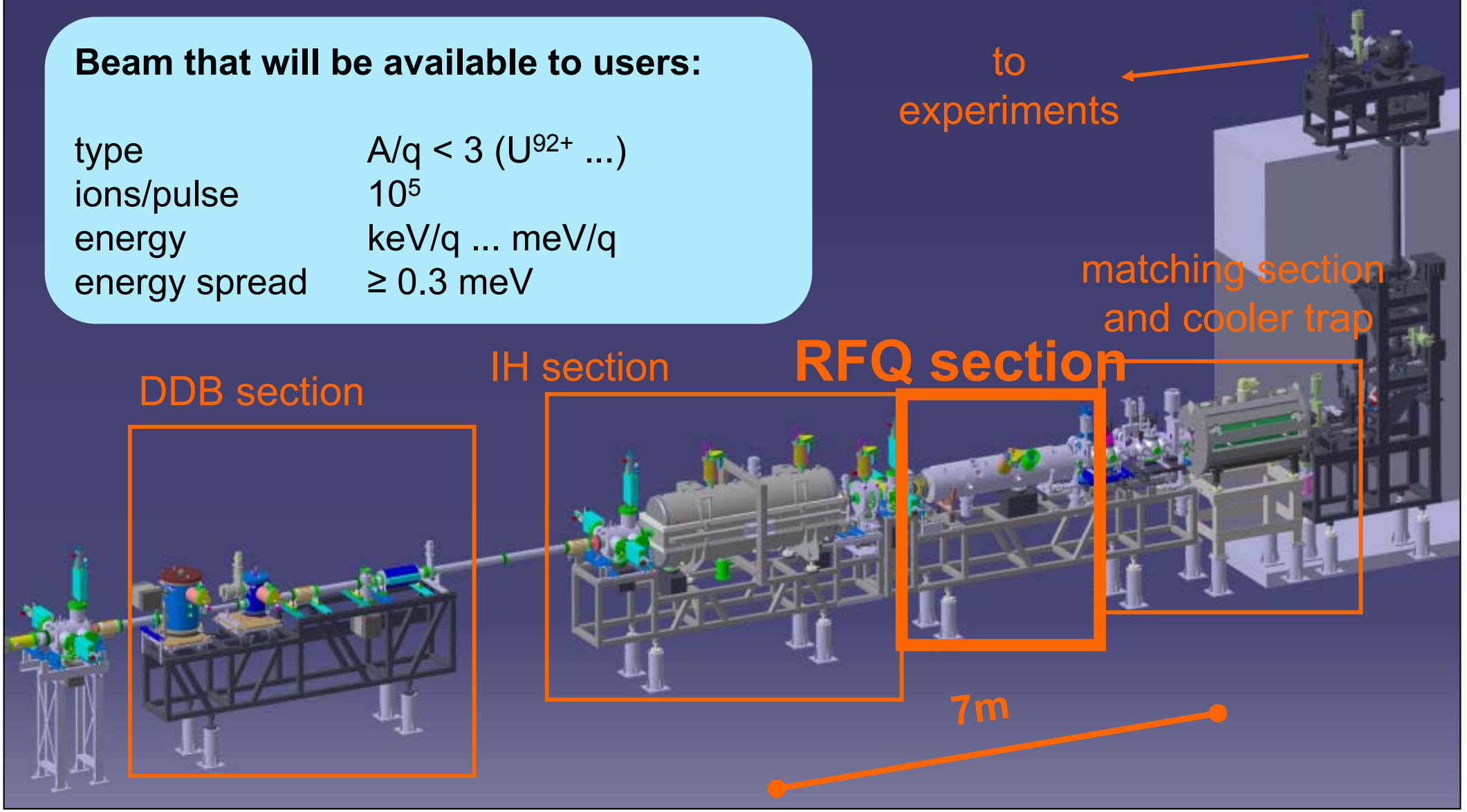
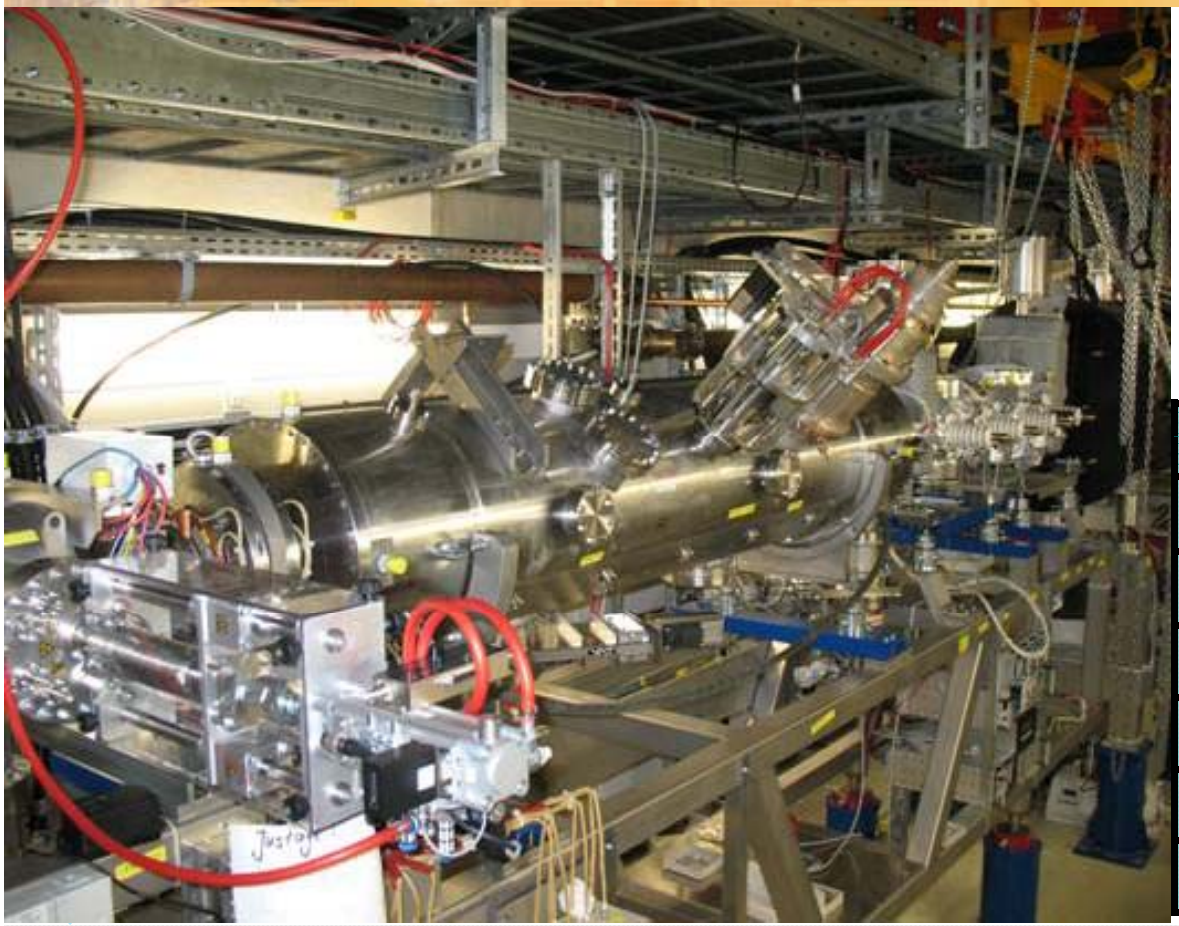
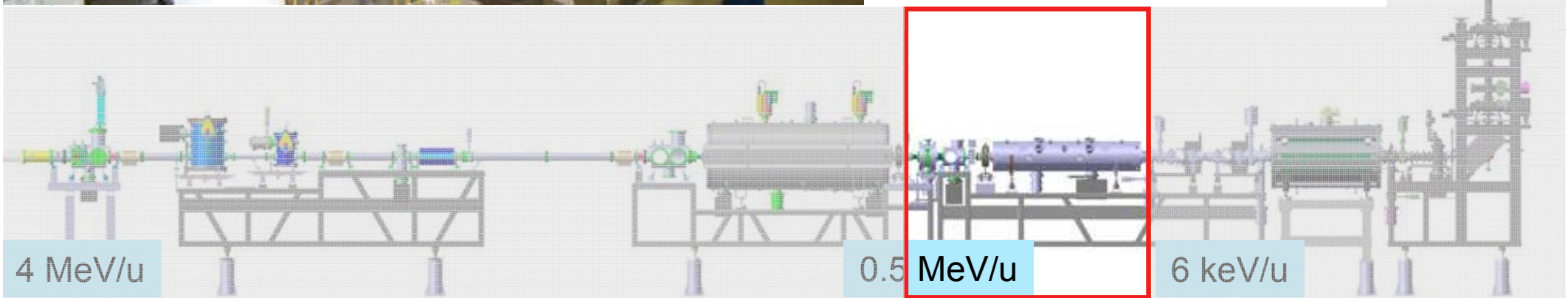


HITRAP – ReBuncher & RFQ



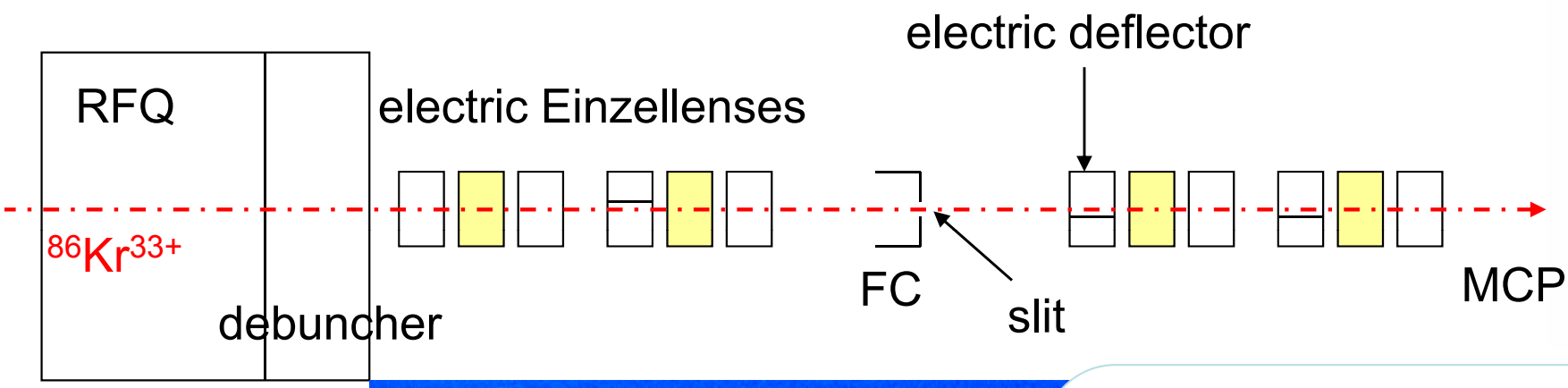
- deceleration from 0.5 MeV/u to 6 keV/u
- installed

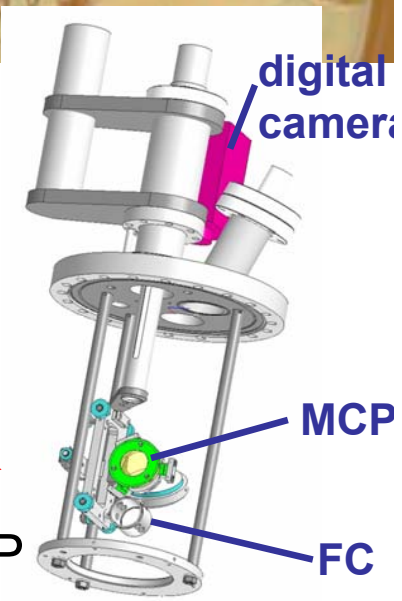
r_0	4 mm
Length	1.9 m
cells	143
stem distance	136 mm
stem width	120 mm
Z	120 kΩm
V_{rod}	70 kV



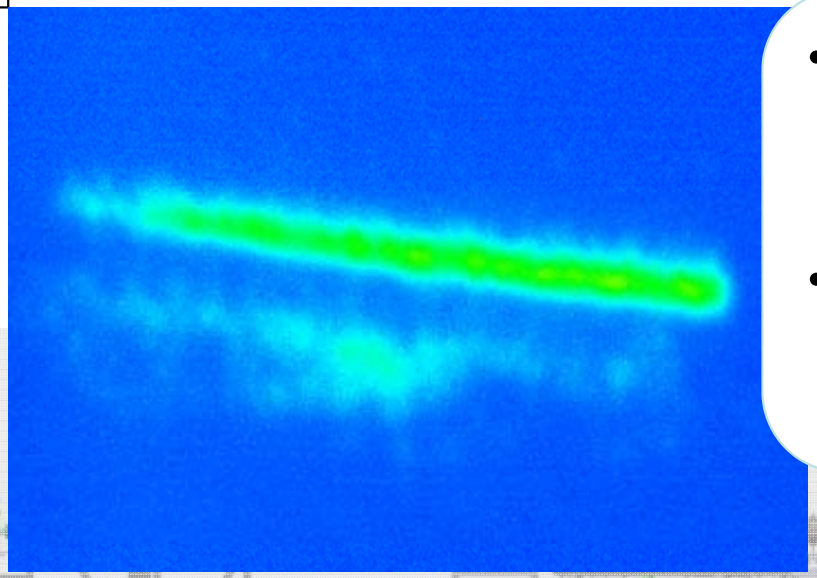
HITRAP – ReBuncher & RFQ

March 2010

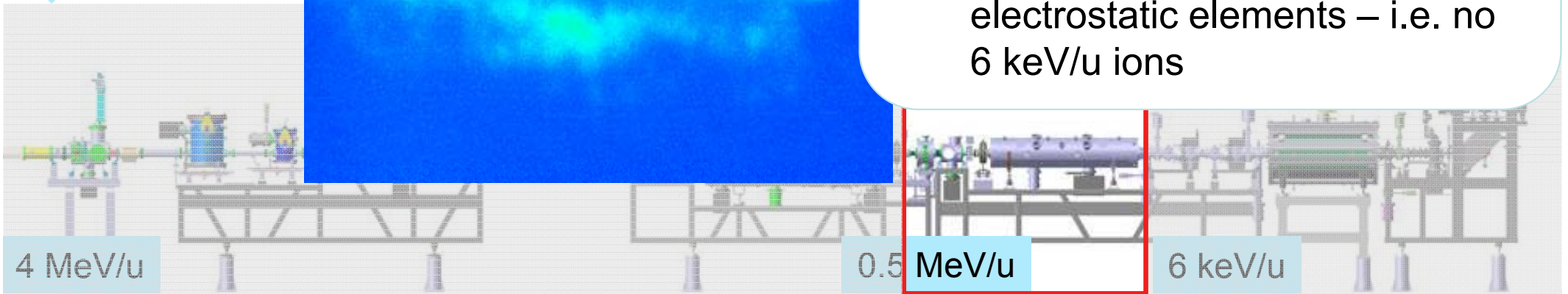




4 MeV/u



- two simultaneous spots for some settings of RFQ phase and amplitude
- no visible effect when changing electrostatic elements – i.e. no 6 keV/u ions



Commissioning Summary to Date

Two weeks/year; Beam intensity ~10^6 ions, once/minute

2007: ESR Extraction tests / Double Drift buncher comm.

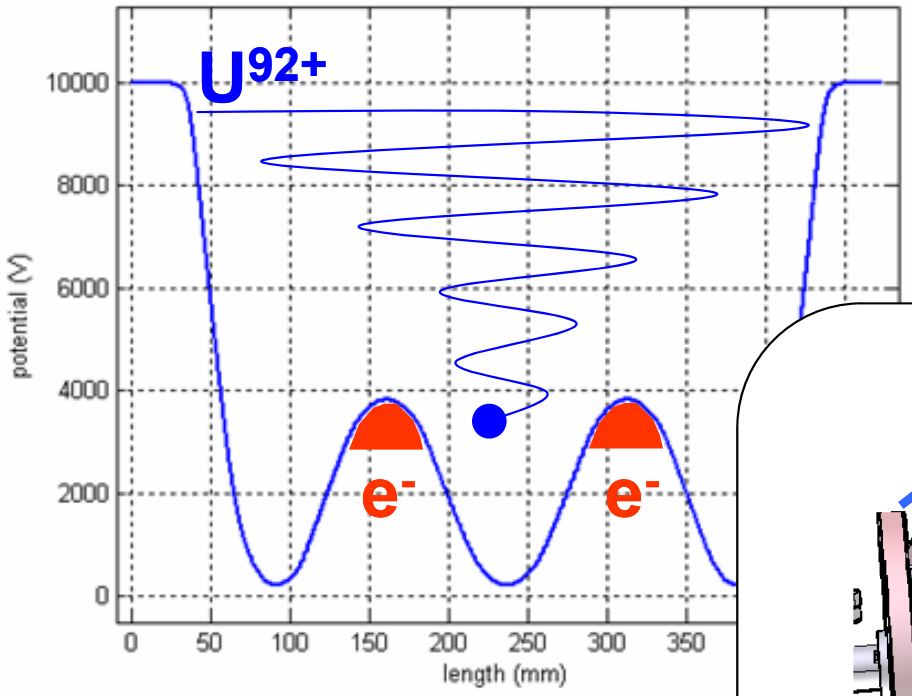
2008: DDB / IH test, first deceleration in IH seen

2009: IH retuning, RFQ mounted, Emittance measurements

2010: ESR rebunching at 4 MeV/u, 30 MeV/u mode installed,
~40% decelerated to 500 keV/u

2010: RFQ commissioning run in November

HITRAP – LEBT & Cooler Trap



- catch the ions in flight
- cool them with combined electron and resistive cooling to ~ 4 Kelvin

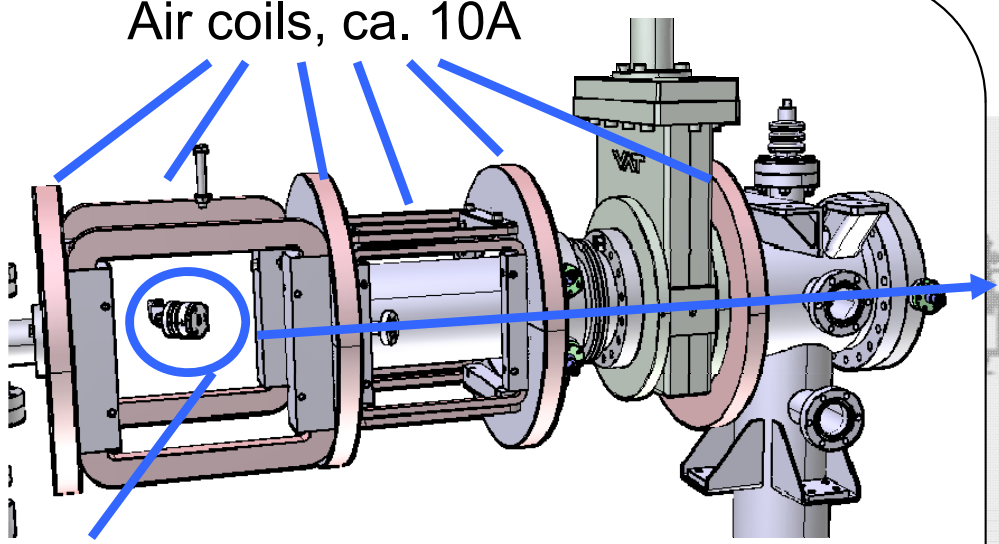
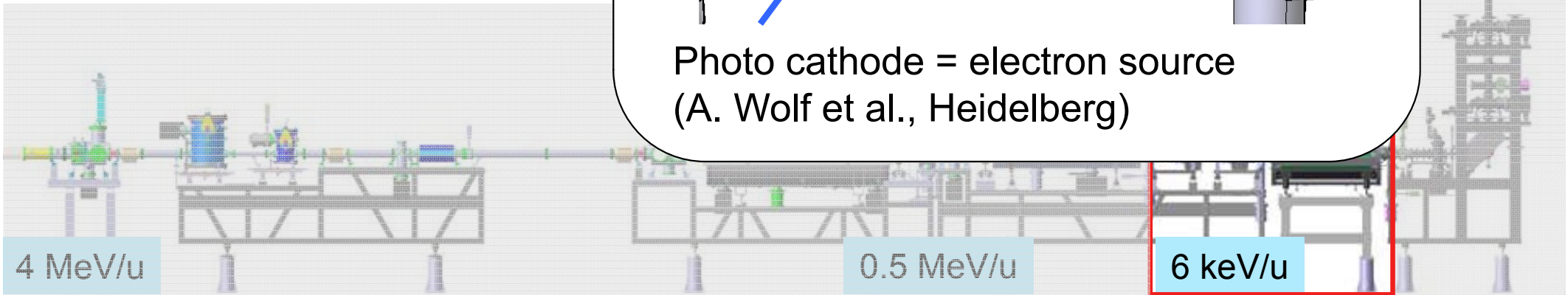
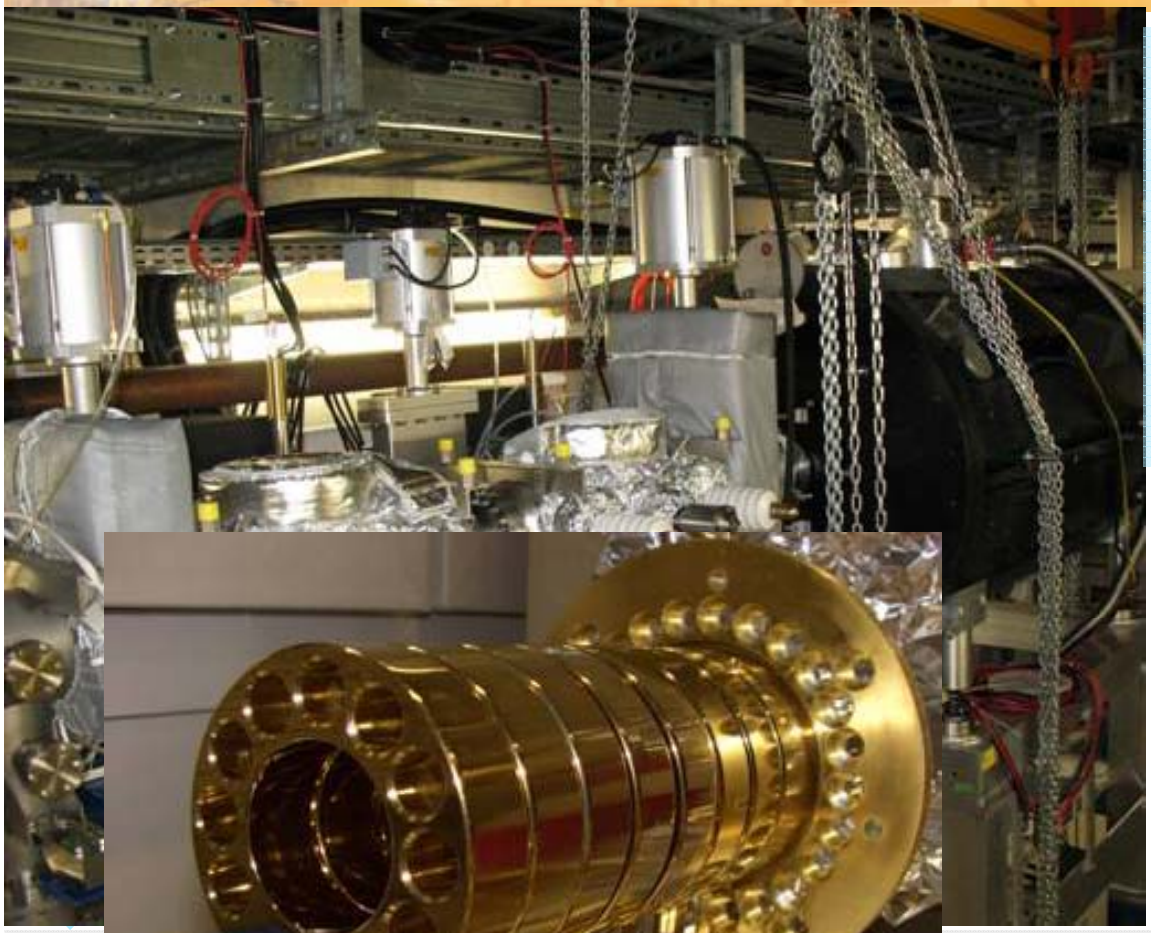


Photo cathode = electron source
(A. Wolf et al., Heidelberg)

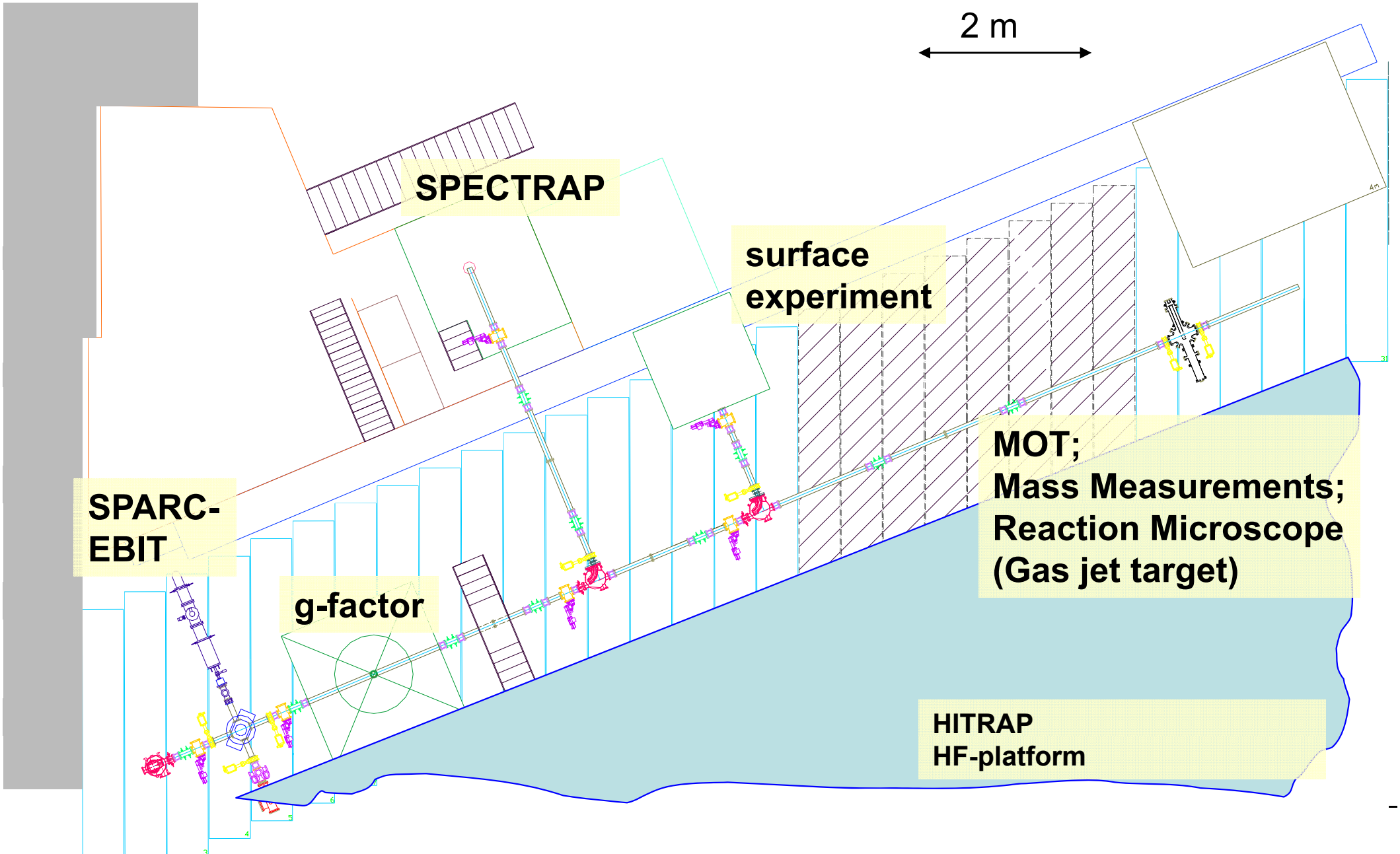


HITRAP – LEBT & Cooler Trap

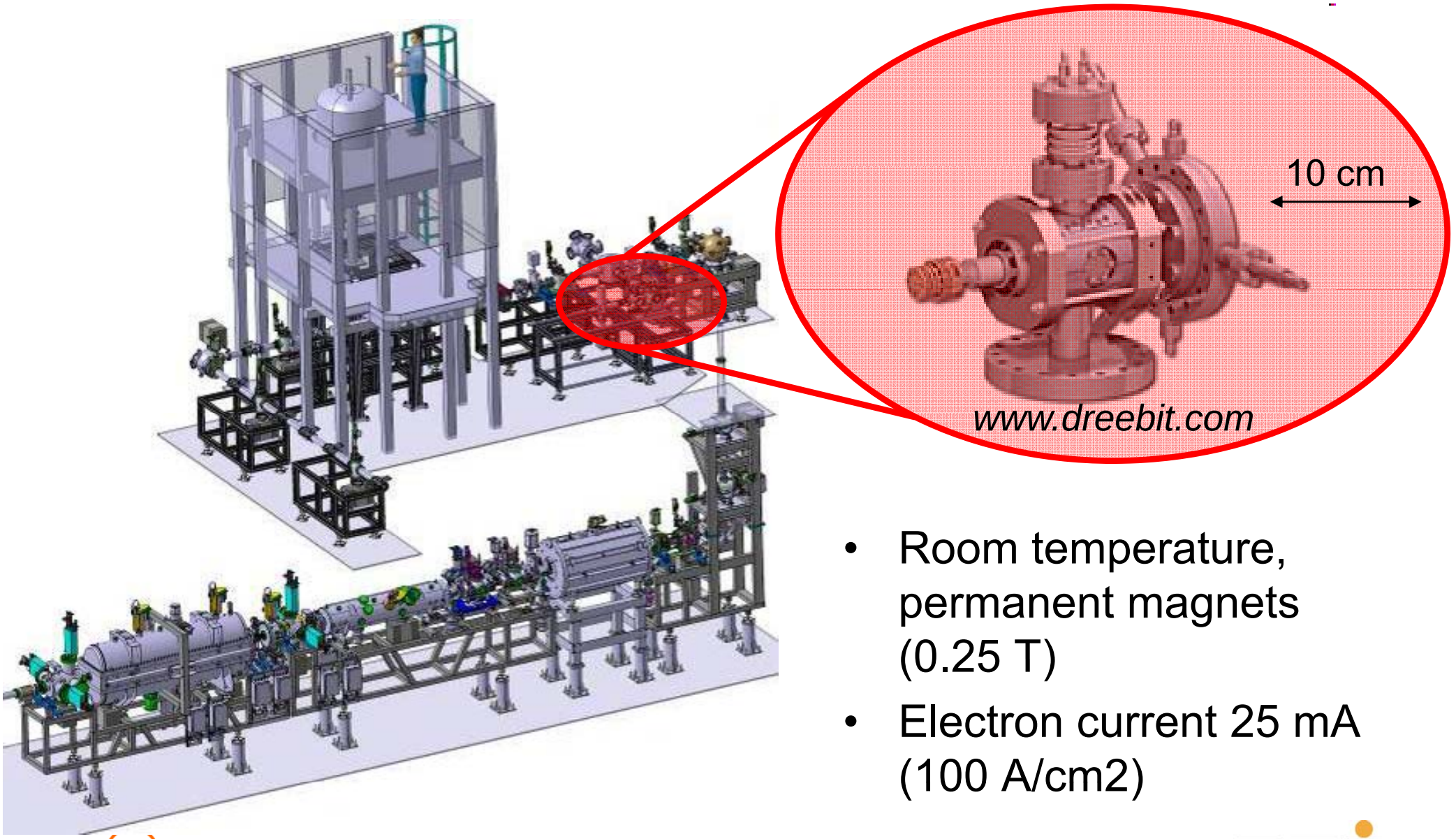


- trap installed in magnet – offline injection tests ongoing
- Extensive calculations done – resistive cooling possible but slower than expected

HITRAP Experimental Area

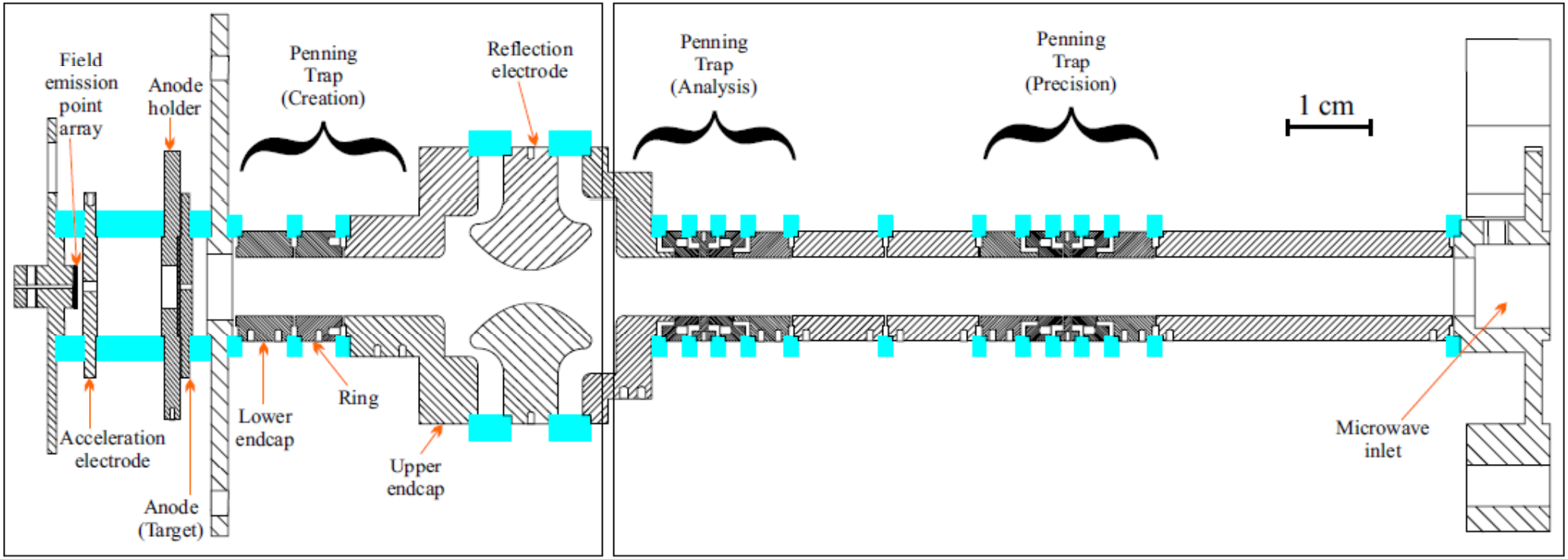


A small EBIT as Test Ion Source



- Room temperature, permanent magnets (0.25 T)
- Electron current 25 mA (100 A/cm2)

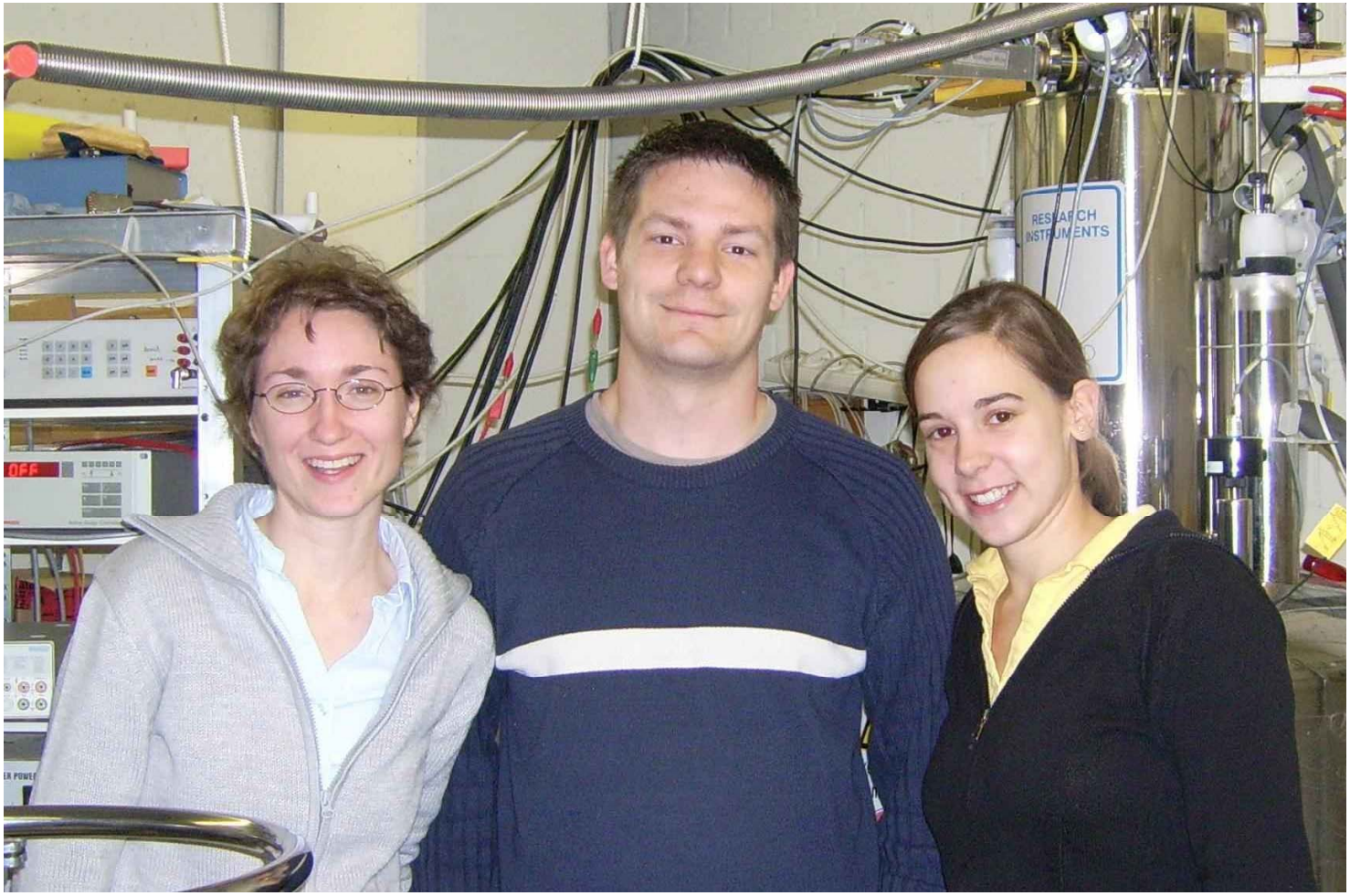
Double Penning Trap for Bound-Electron g-Factor Measurement



EBIS

Double-Penning trap setup

The lab team (before spinflip)



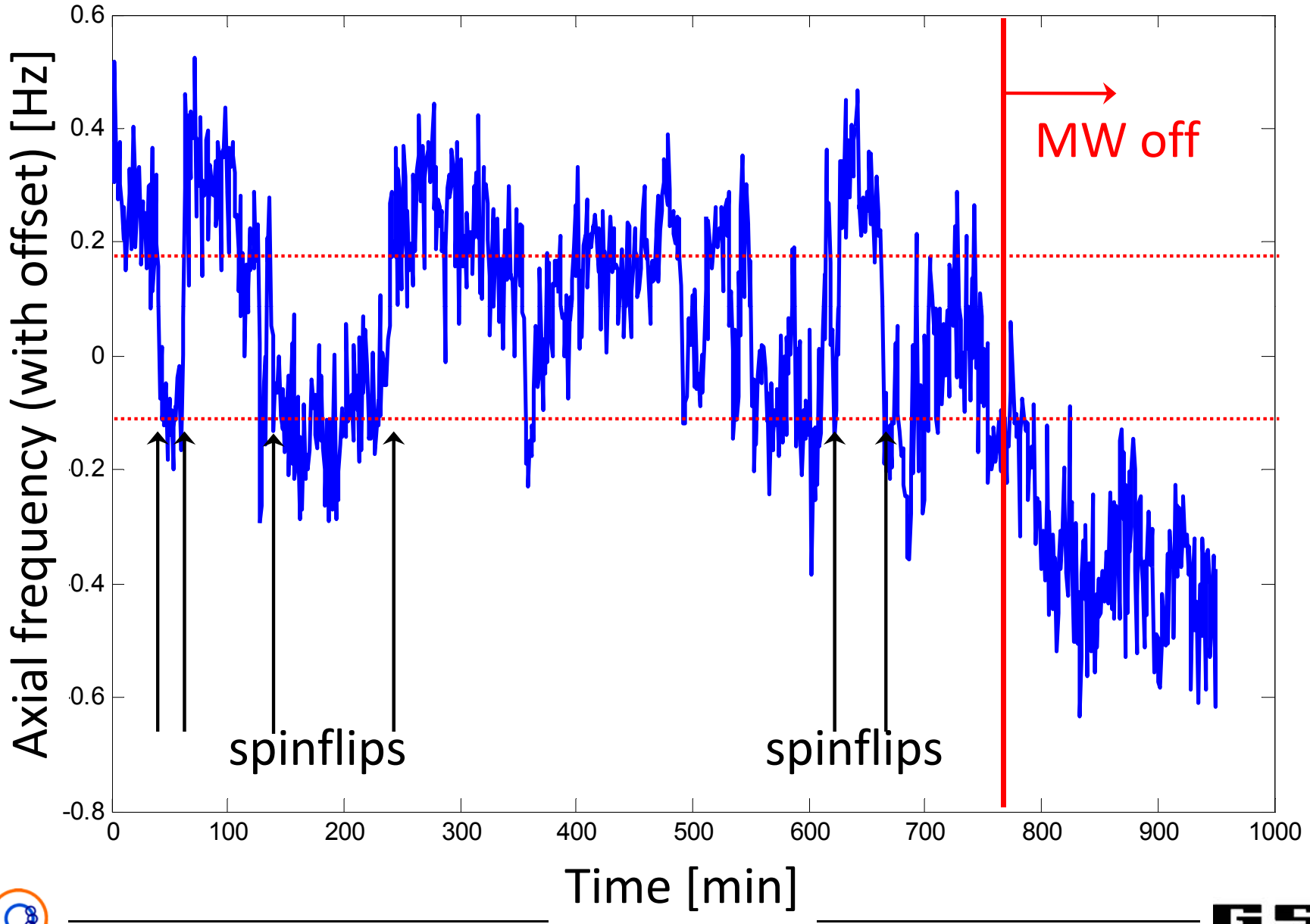
Birgit Schabinger

Sven Sturm

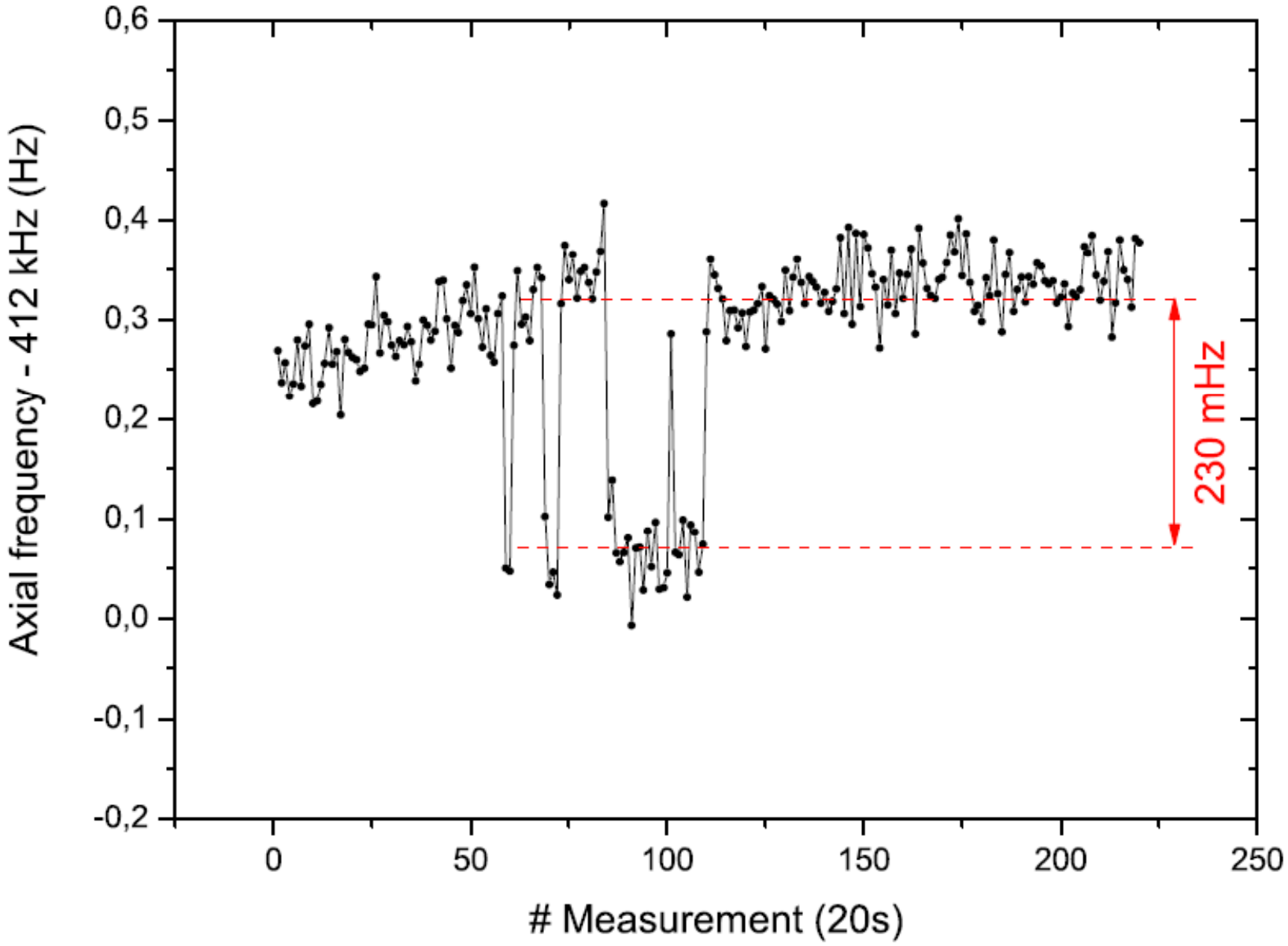
Anke Wagner

The lab team (after spinflip)

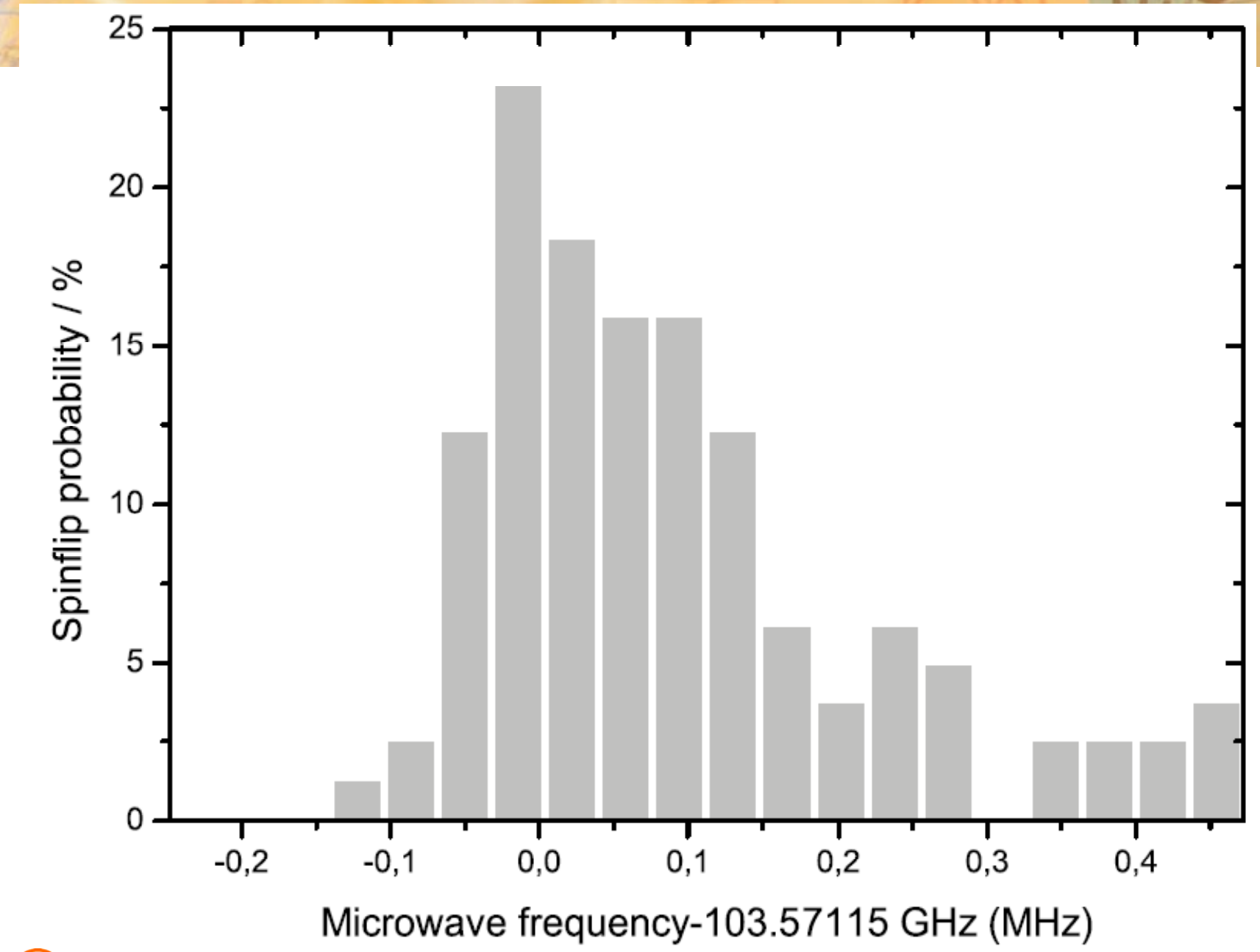
Quantum Jump Spectroscopy: First observation of spinflips with a single $^{28}Si^{13+}$ ion, 10 June 2010, Mainz



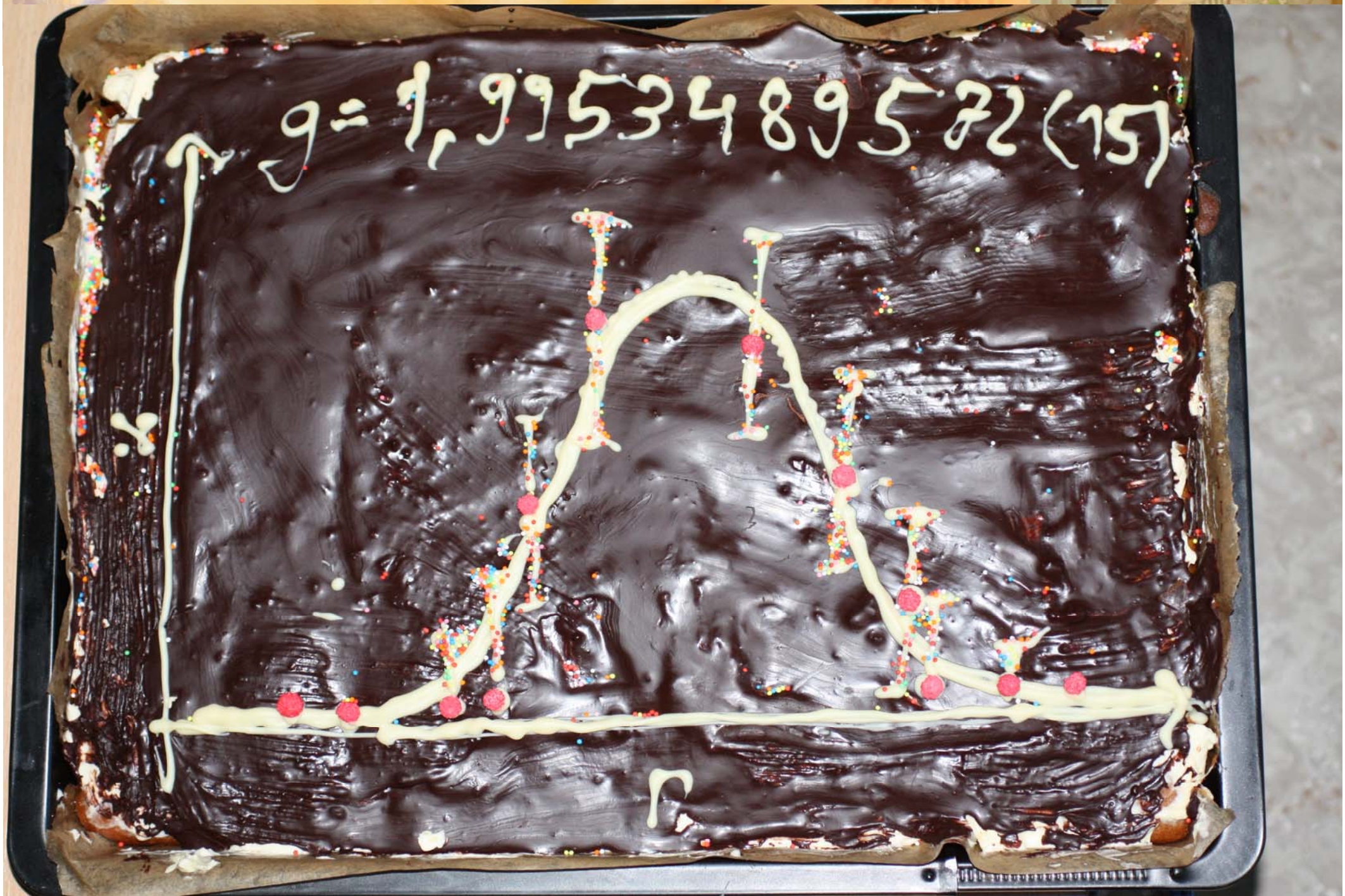
Quantensprünge eines wasserstoffähnlichen Silizium-Ions



Quantensprung-Resonanz eines wasserstoffähnlichen Silizium-Ions



Präzisionsmessung des g-Faktors an wasserstoffähnlichem Silizium-Ion

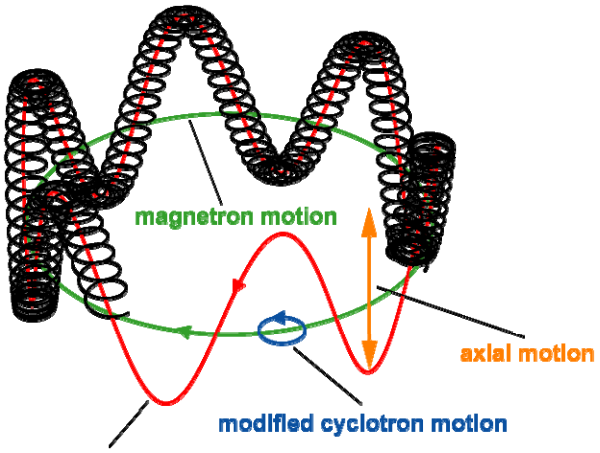


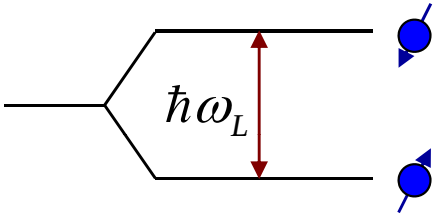
Proton / Antiproton g-Factor: Double Penning trap

$$\omega_c = \frac{q}{m} B$$

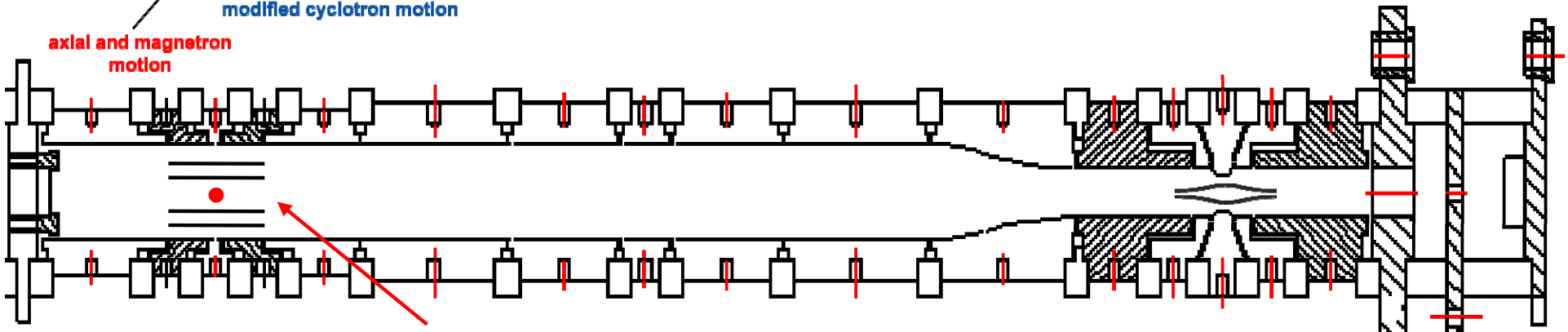
$$\omega_L = \frac{\mu \cdot B}{2\hbar} = g_p \frac{q}{2m} B$$

$$g_p = 2 \frac{\omega_L}{\omega_c}$$

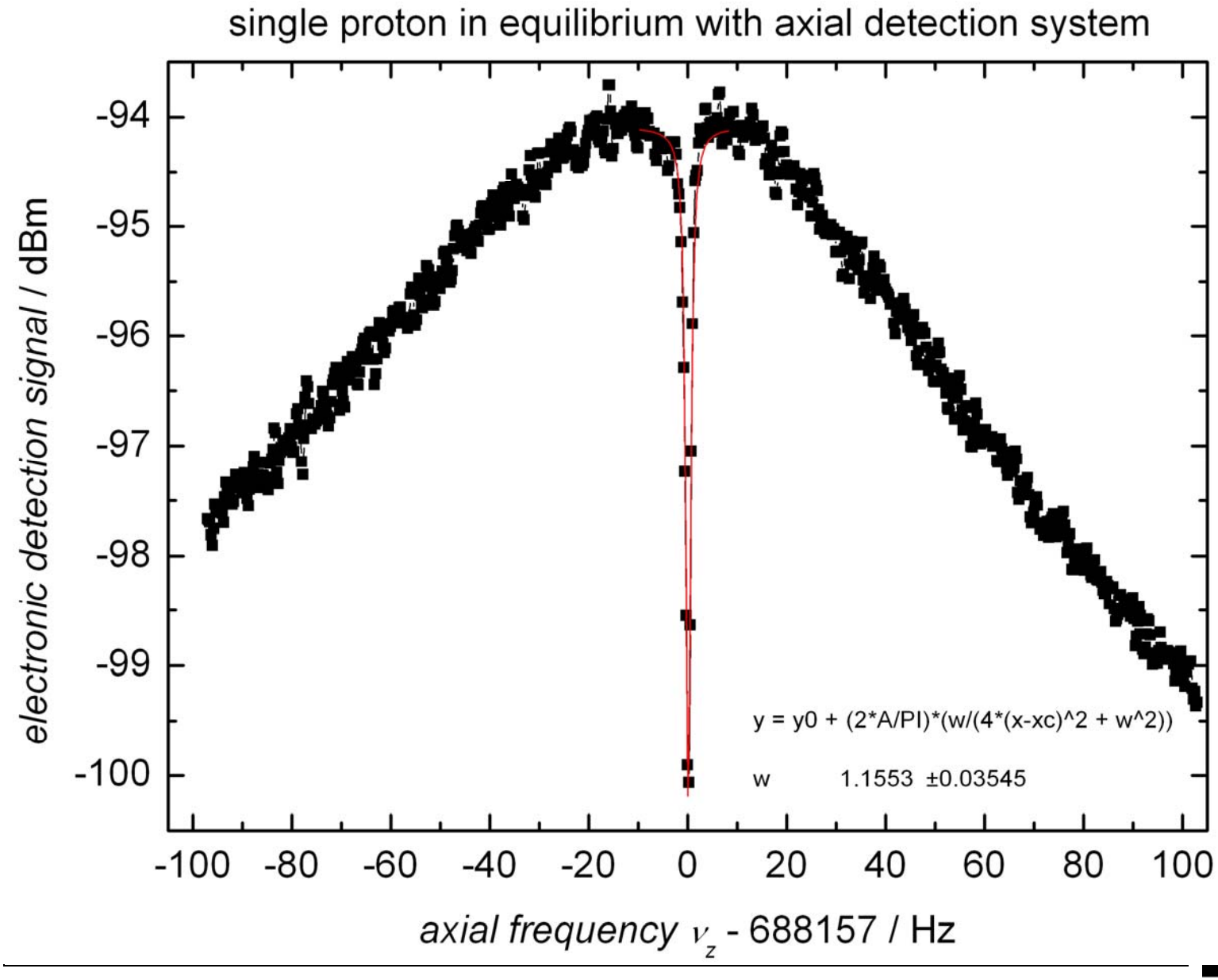




spin-state detection in analysis trap



Proton / Antiproton g-Factor: Single trapped proton at T = 4 K



HITRAP

W. Barth, D. Beck, T. Beier, M. Bevcic, E. Berdermann, K. Blaum, M. Block, A. Bräuning-Demian, H. Brand, K. Brantjes, E. Bodewits, G. Clemente, L. Dahl, C. Dimopoulou, C. Dorn, S. Eliseev, S. Fedotova, R. Fischer, P. Forck, F. Herfurth, R. Hoekstra, M. Kaiser, O. Kester, H.-J. Kluge, S. Koszudowski, N. Kotovski, C. Kozhuharov, C. Krantz, R. Lotz, M. Maier, F. Nolden, W. Nörtershäuser, F. Peldzinski, J. Pfister, W. Quint, D. Racano, U. Ratzinger, A. Sauer, A. Schempp, M. Shaaban, A. Sokolov, M. Steck, K. Stiebing, Th. Stöhlker, J. Ullrich, W. Vinzenz, M. Vogel, G. Vorobjev, C. Will, D. Winters, A. Wolf, O. Zurkan
and the HITRAP collaboration

Darmstadt *Frankfurt* *Heidelberg* *Mainz* *Groningen*