HITRAP decelerator
and Beam Instrumentation

- Reasons to invest in slow, heavy, highly charged ions
- The HITRAP Facility
- The HITRAP decelerator status

W. Barth, D. Beck, T. Beier, M. Bevcic, E. Berdermann, 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, S. Litvinov, 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, W. Vinzenz, M. Vogel, H. Vormann, G. Vorobjev, C. Will, D. Winters, A. Wolf, O. Zurkan and the HITRAP collaboration

Univ. Frankfurt, Univ. Mainz, Imperial College London, TU Darmstadt, St. Petersburg State Univ., TU Wien, Univ. Heidelberg, Jagiellonian Univ. Krakow, MPI-K Heidelberg, KVI Groningen, Univ. Stockholm, ENS Paris, Univ. Münster

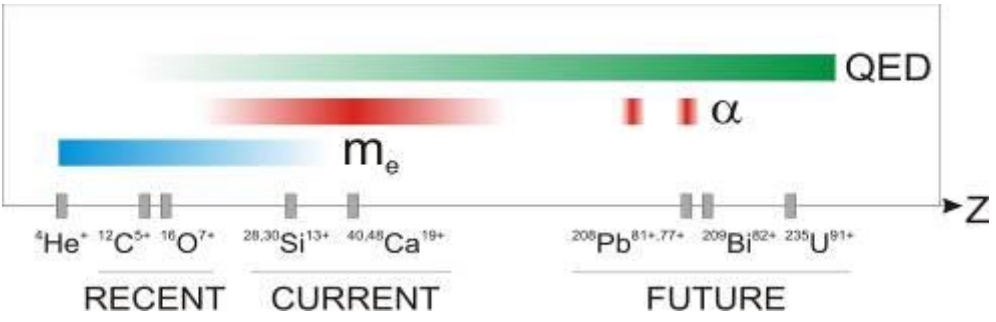
Darmstadt *Frankfurt* *Heidelberg* *Mainz* *Groningen*

WHY?

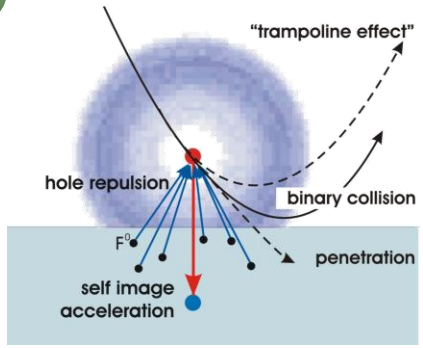
HCI Highly Charged Ions

- **Elements**
  - **g-factor** — α, m_e
  - **e--binding** — Lamb-shift
- **Isotopes**
  - Charge radii
  - **FS, HFS** — BW effect
- **+ Matter**
  - **+ surface** — Structures
  - **+ atoms** — Charge exchange, Collision dynamics

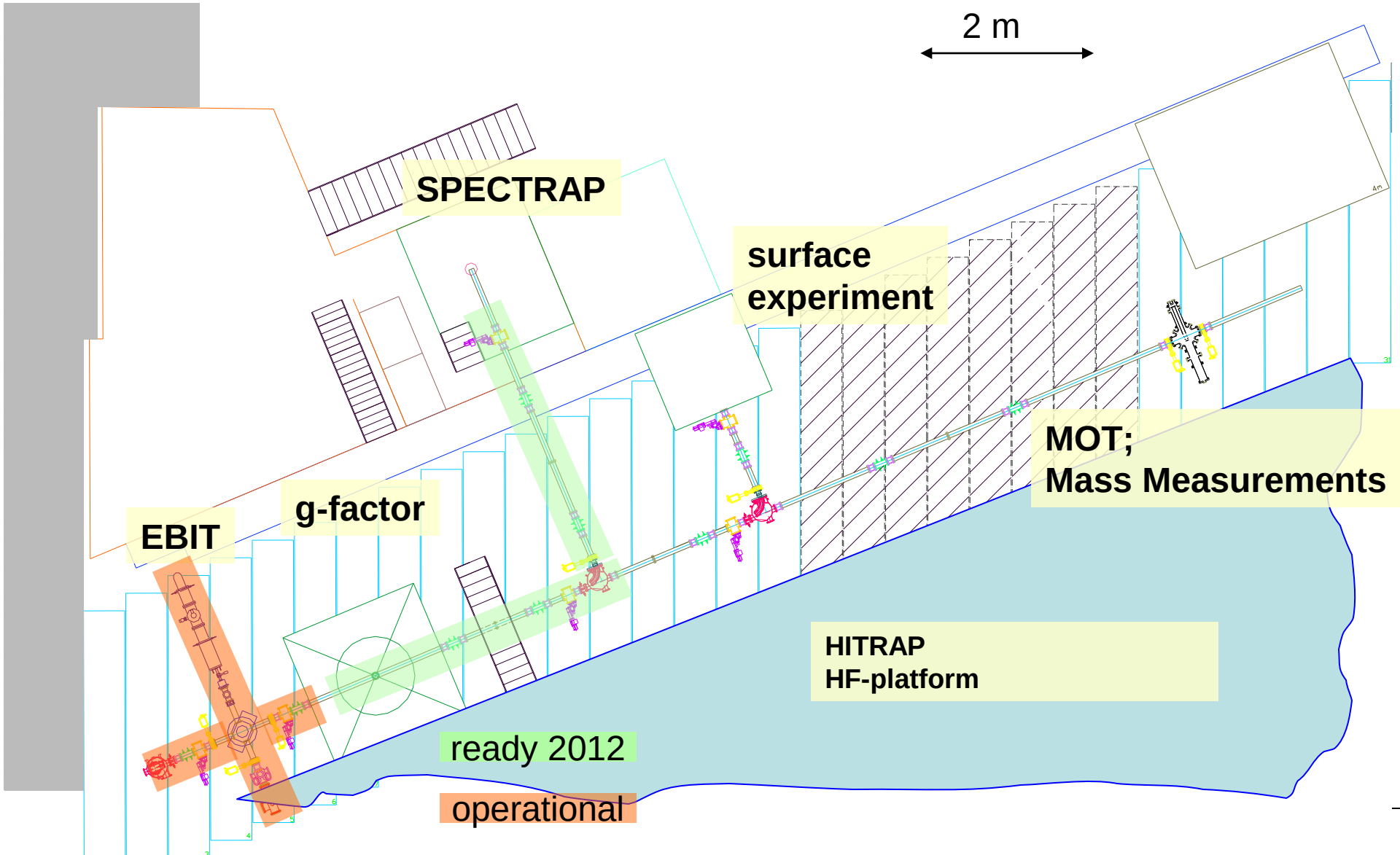
QED test



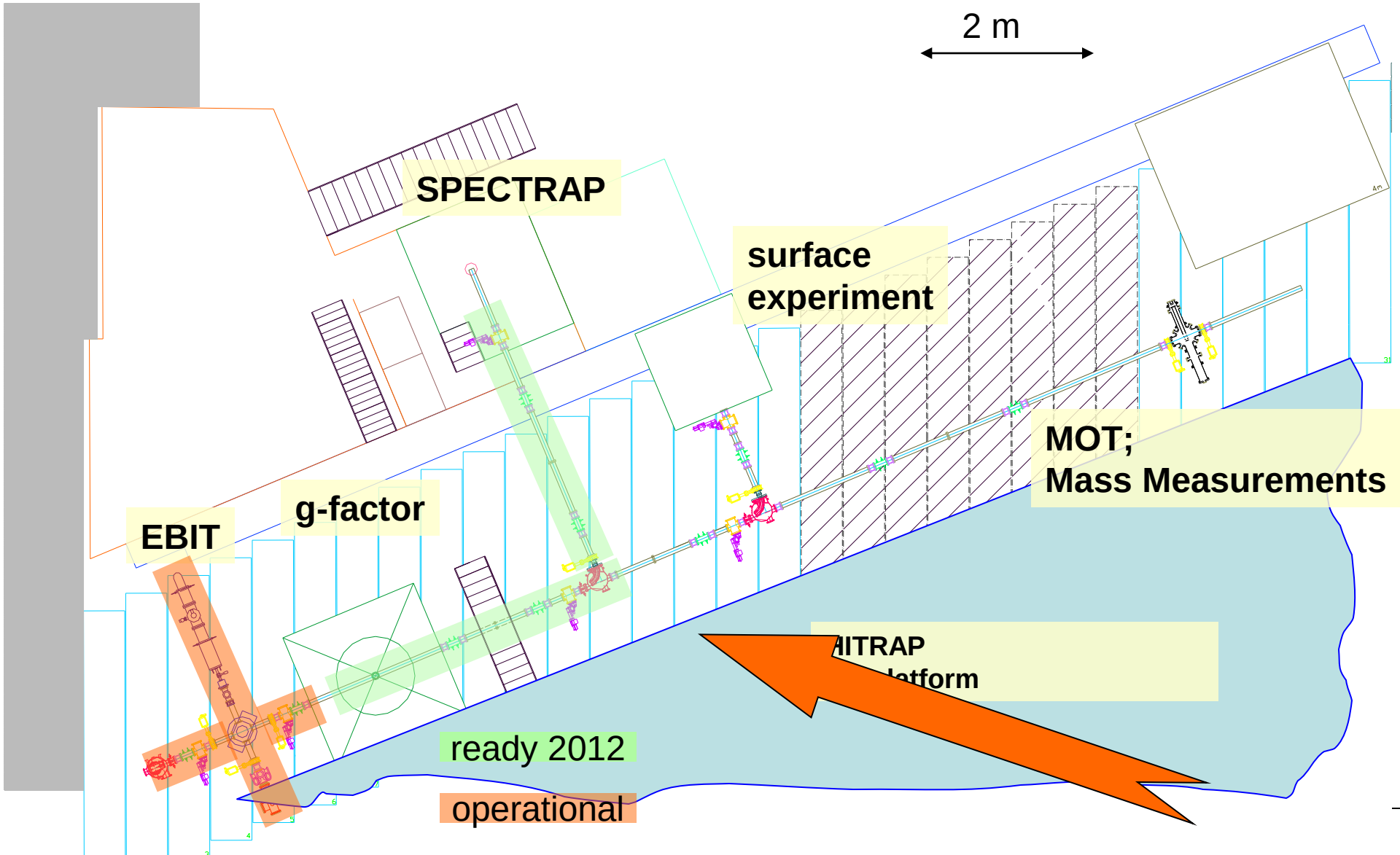
Hollow atoms



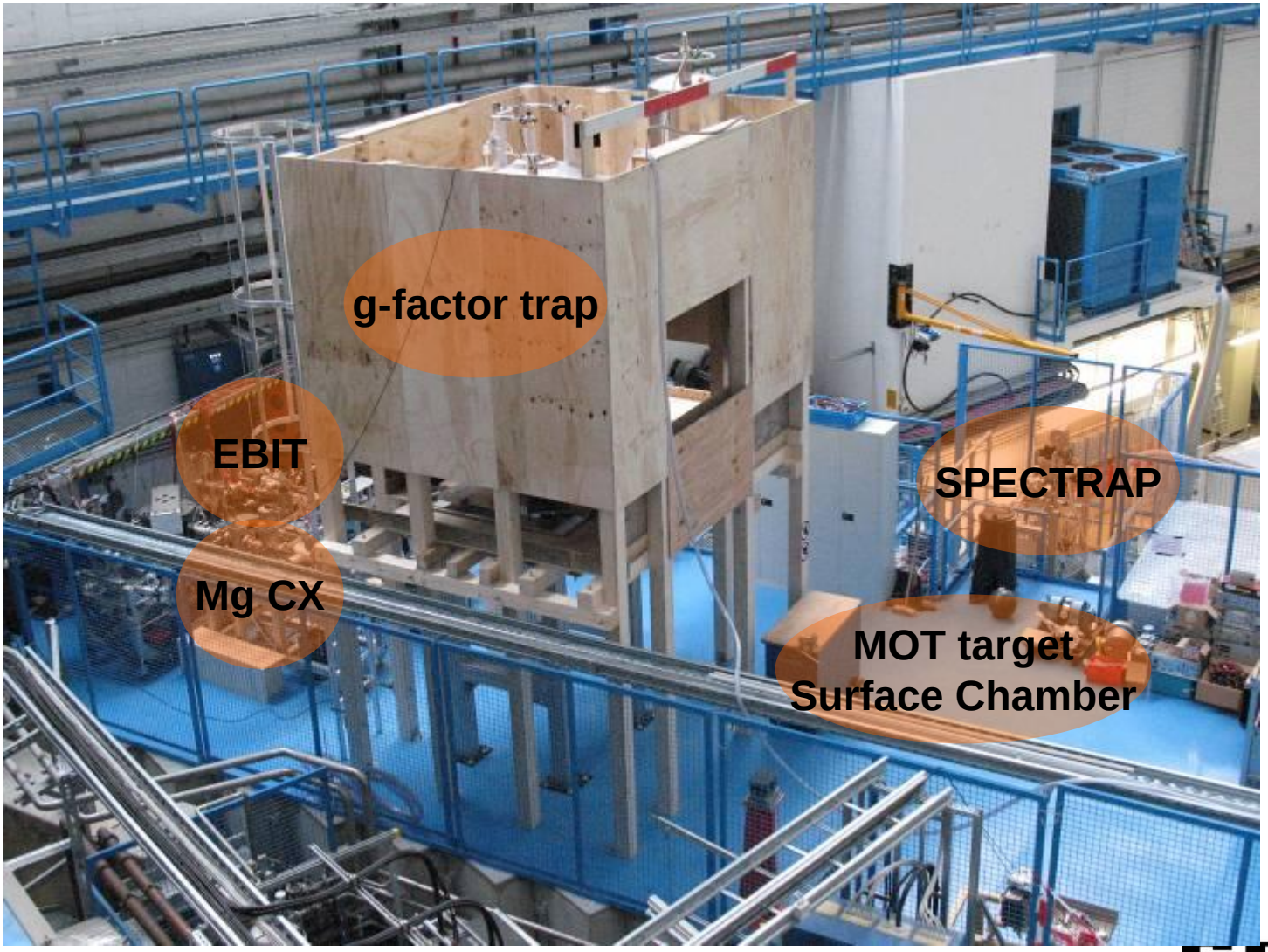
HITRAP Experimental Area



HITRAP Experimental Area



HITRAP Experimental Area

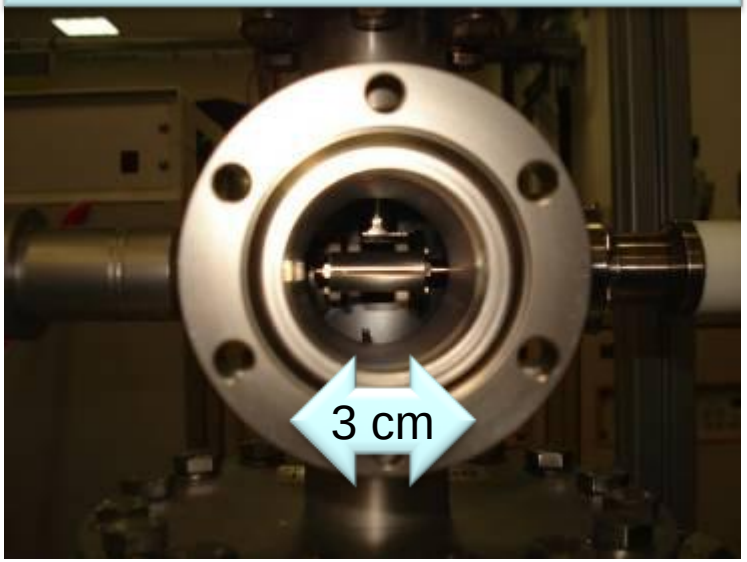


Two electron beam ion traps (EBIT)

- Commissioning of Experiments

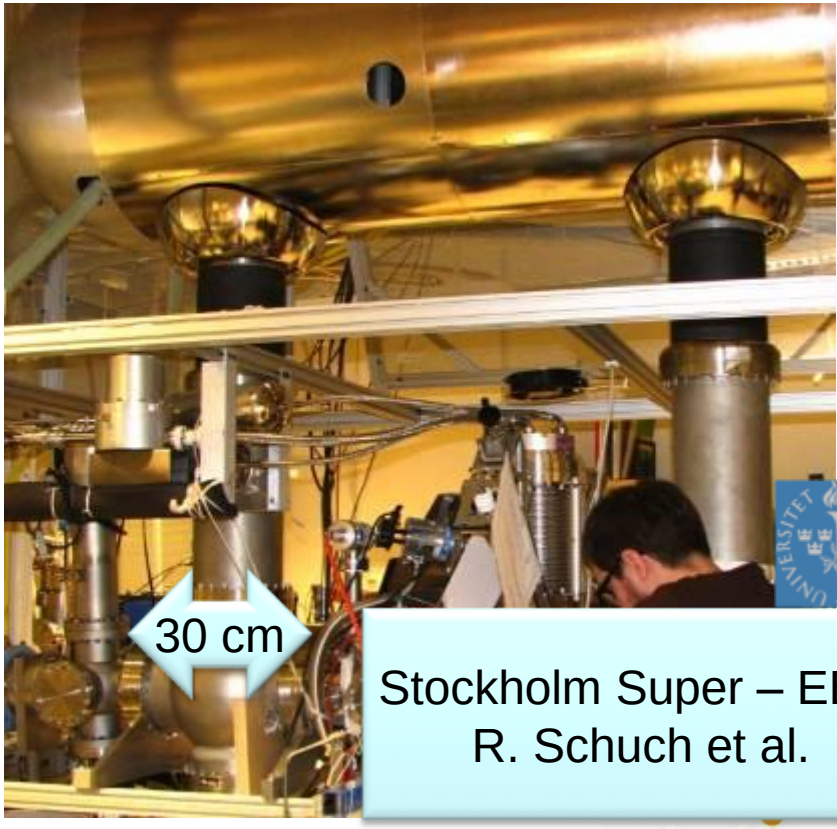
Max. electron energy 15 keV
Electron current density 100 A/cm^2
Ion capacity – 5*10^7 charges
Charge state up to Ar^{18+} or Xe^{44+}

EBIT of Dresden Type
G. Vorobjev et al.



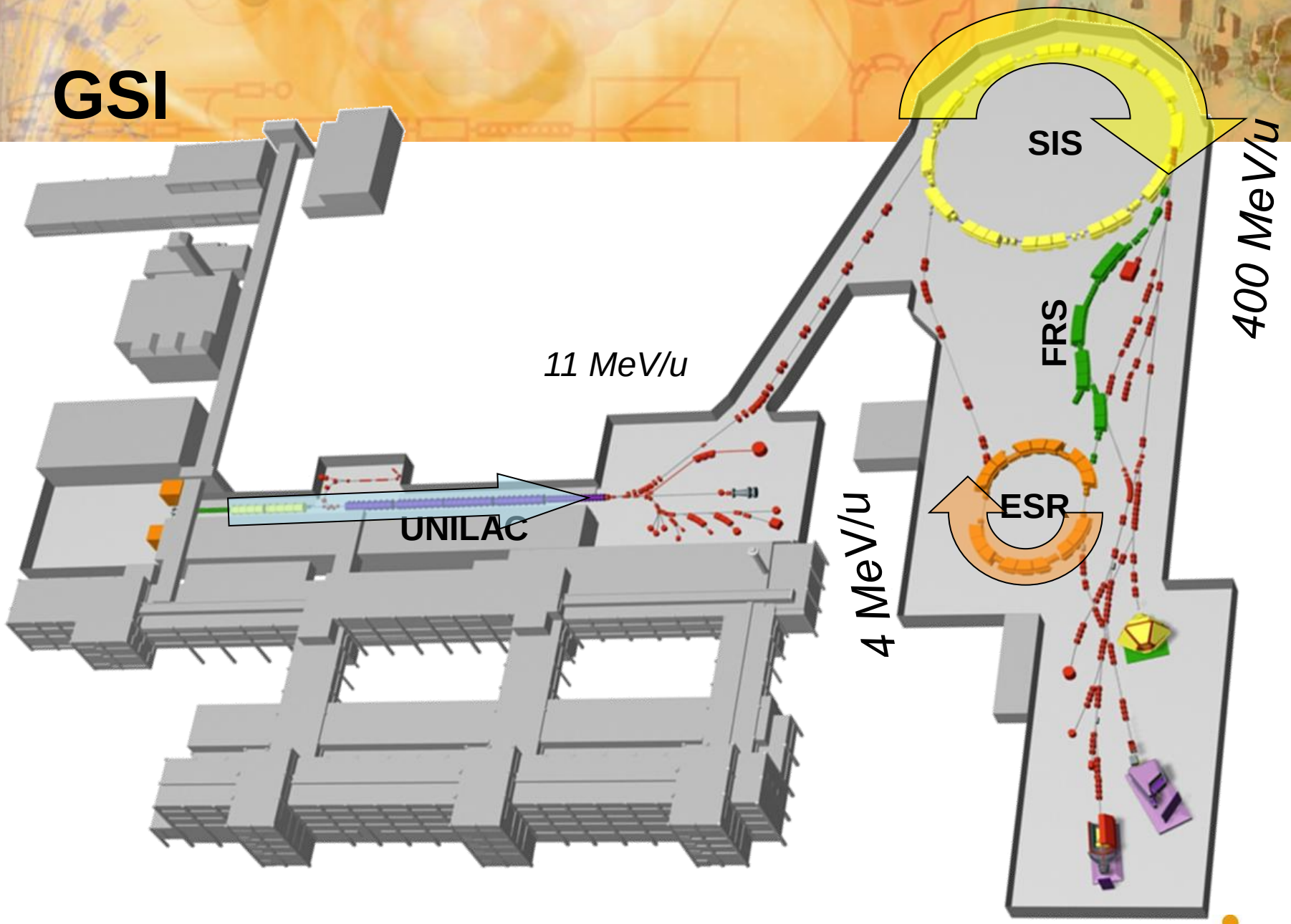
Operational, charge breeding demonstrated

Max. electron energy 260 keV
Electron current density 4 kA/cm^2
Ion capacity – 10^8 charges
Charge state up to U^{92+}

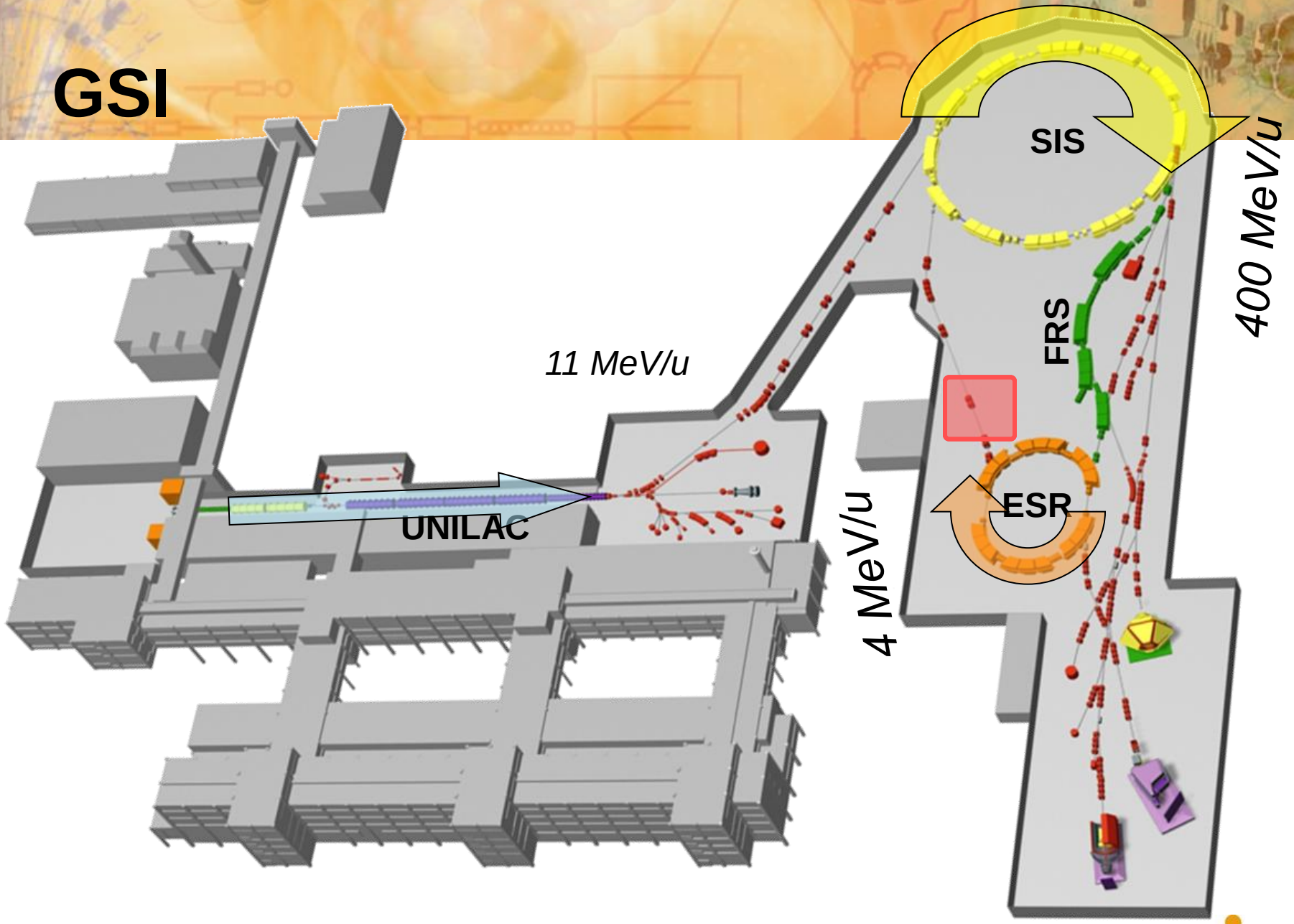


Stockholm Super – EBIT
R. Schuch et al.

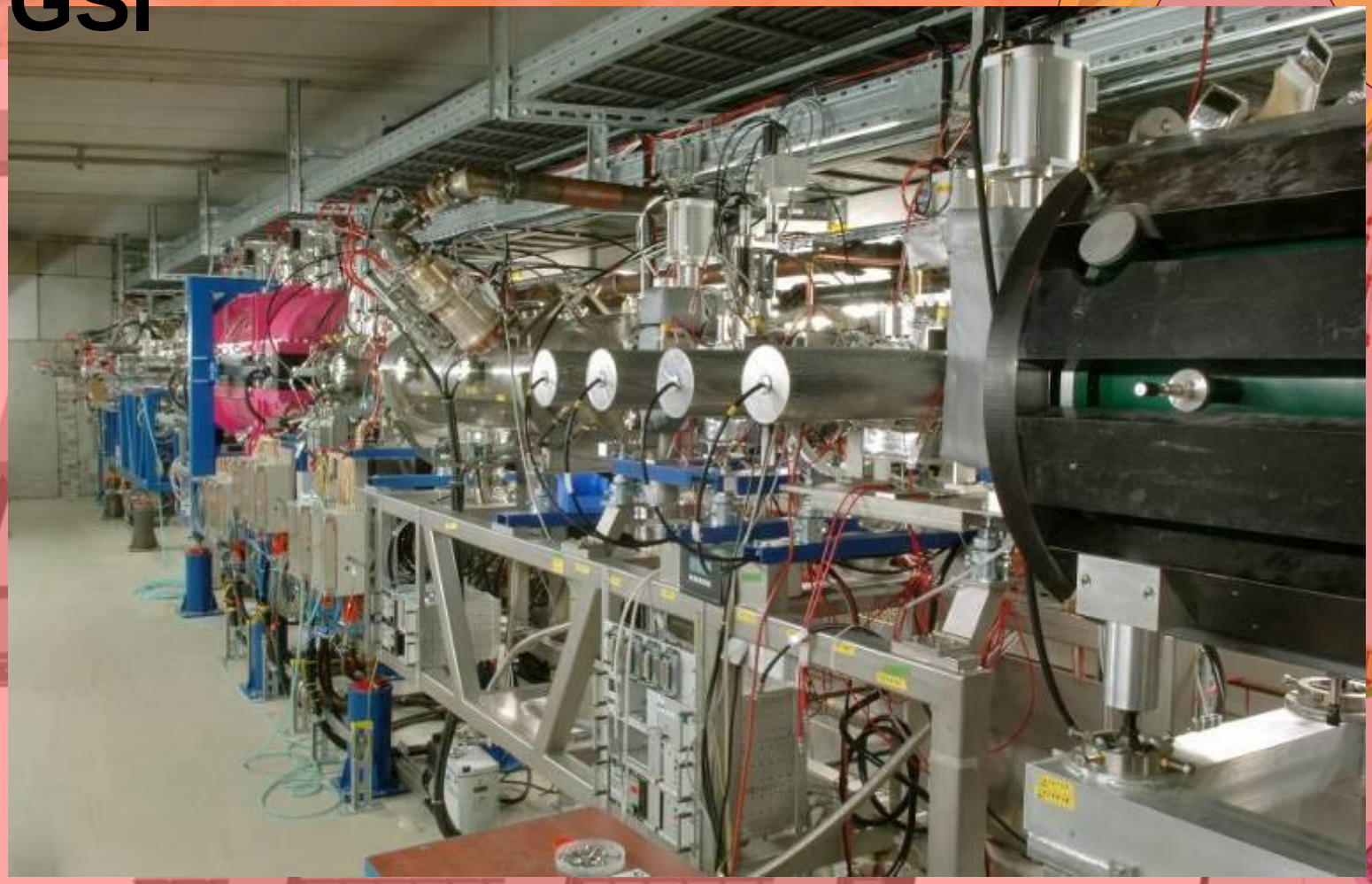
GSI



GSI

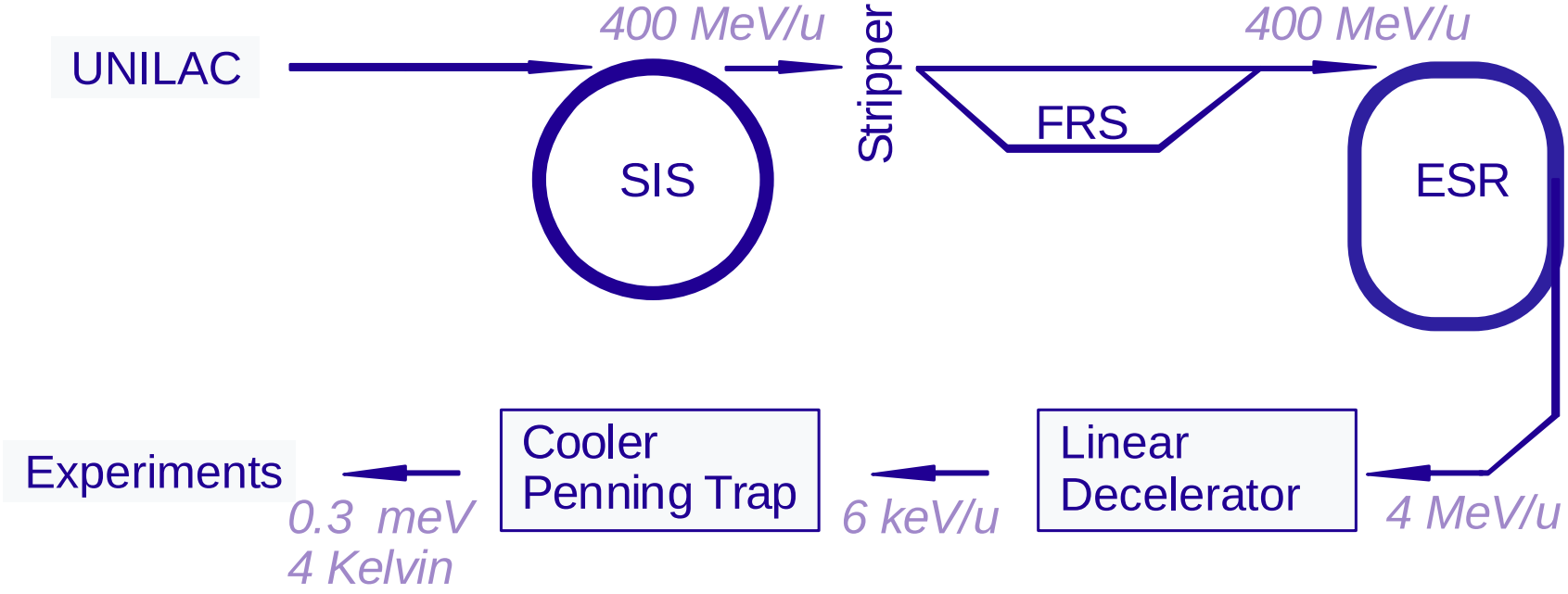


HITRAP @ GSI



400 MeV/u

HITRAP @ GSI



Beam that will be available to users:

type	A/q < 3 (U^{92+} ...)
ions/pulse	10^5 (@ FLAIR 10^6 p-bar)
energy	keV/q ... meV/q
energy spread	≥ 0.3 meV

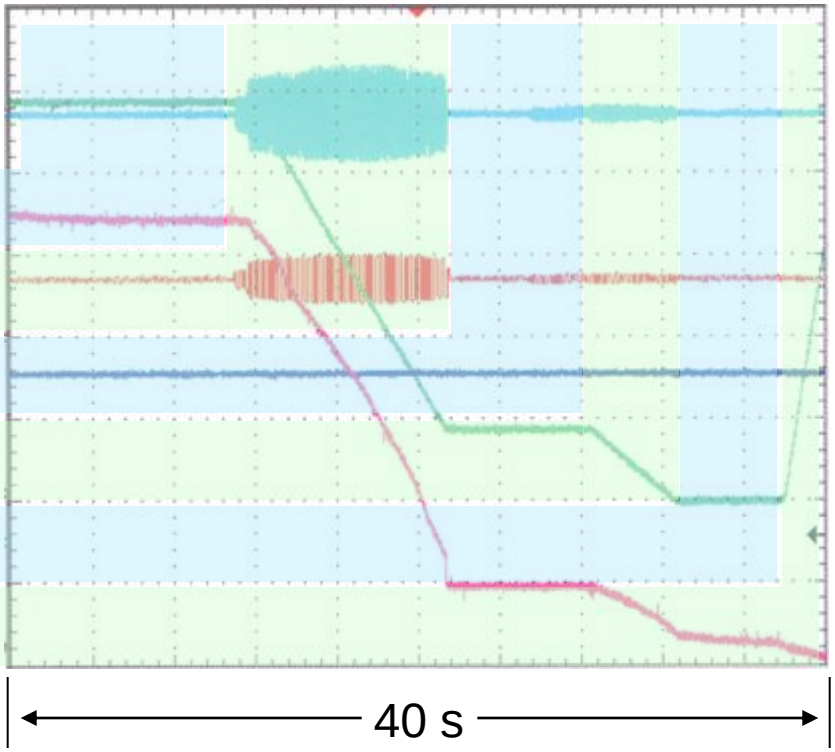
Test Ion Source - EBIT:

Up to bare K
Any element (charge breeding)
10^5 per pulse and second

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

ESR – From 400 to 4 MeV/u

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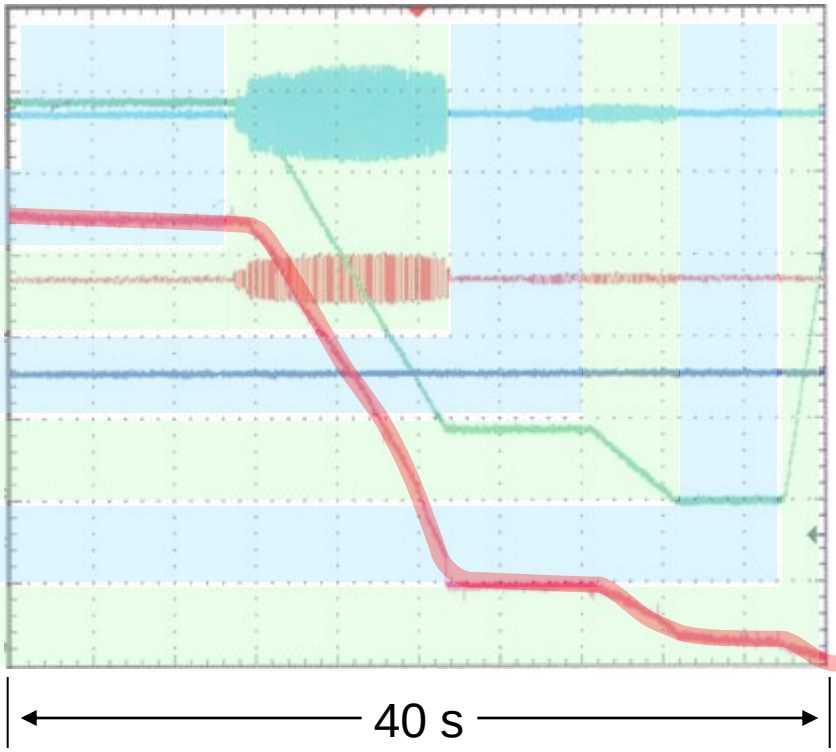


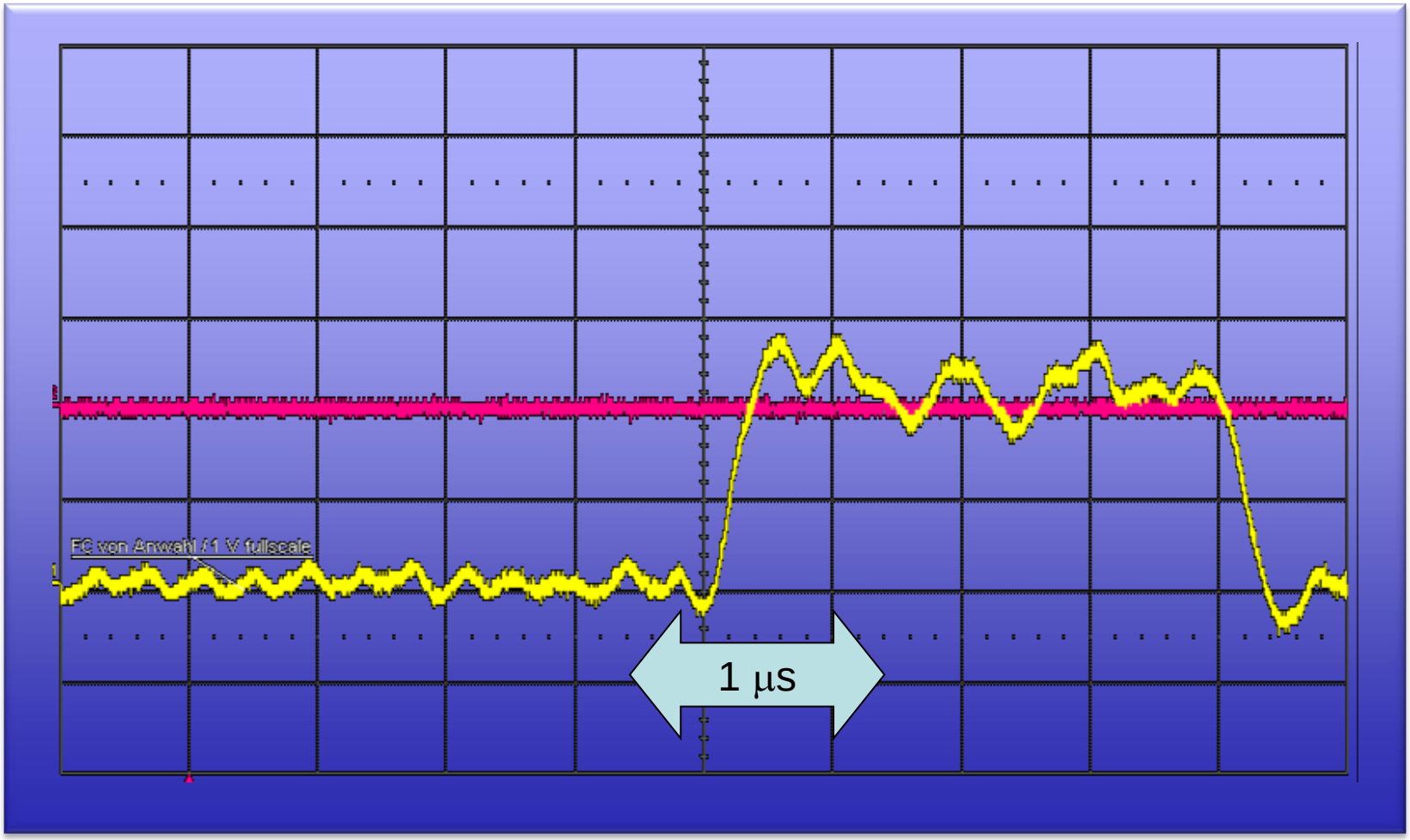
signal:

RF amplitude

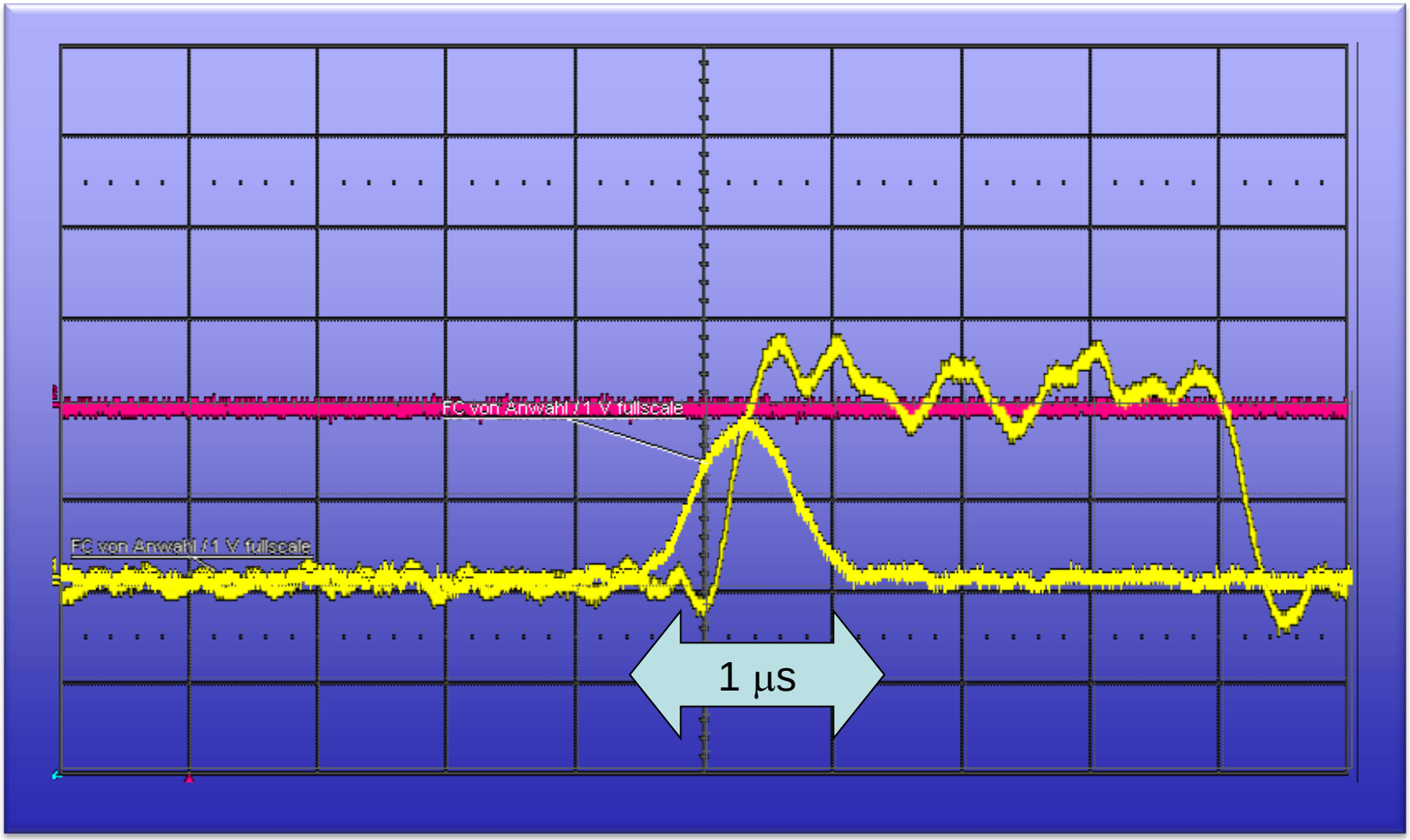
magn.dipole field

ion current

Ions ejected from ESR



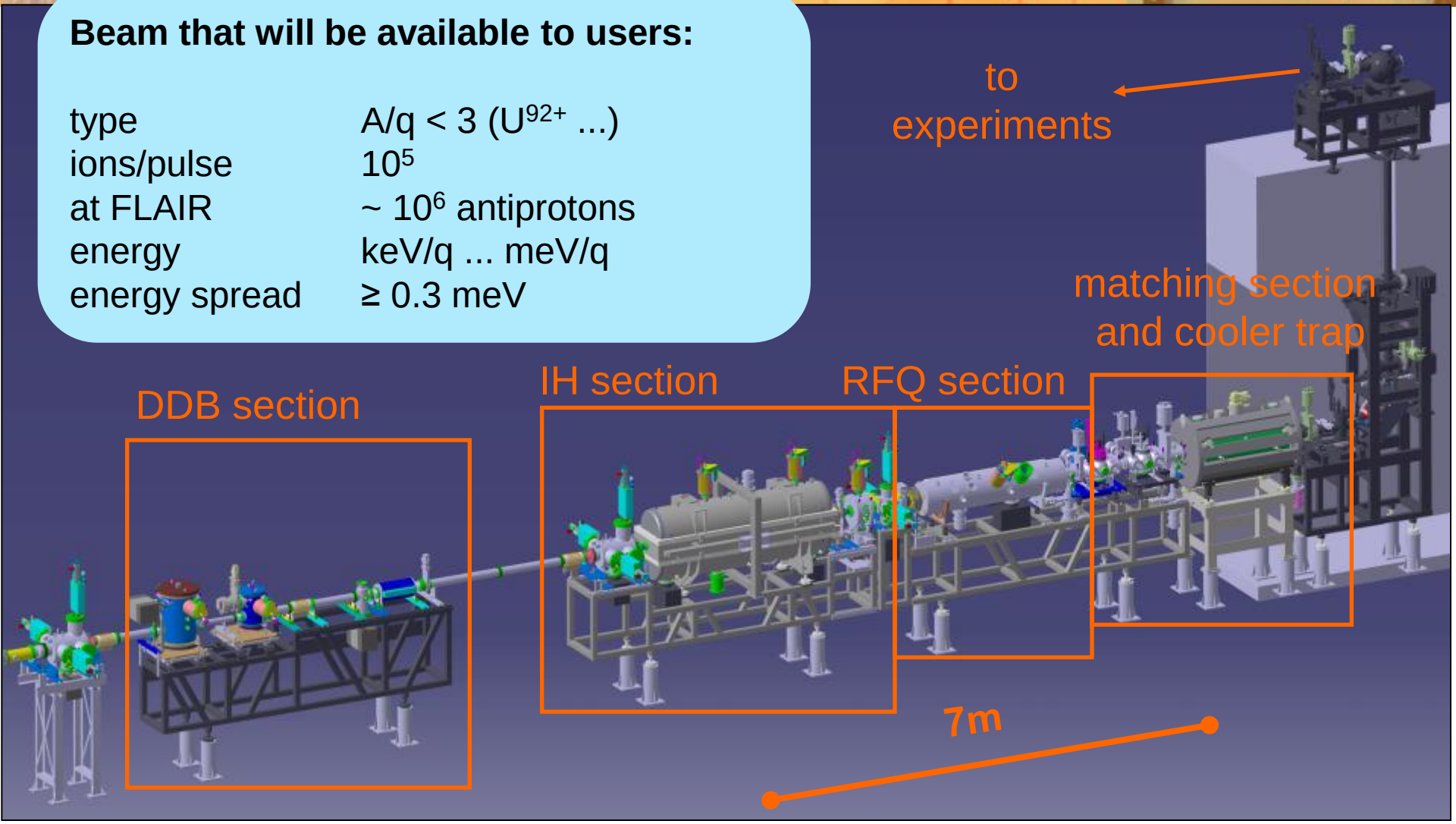
Ions ejected from ESR



HITRAP – Linear Decelerator

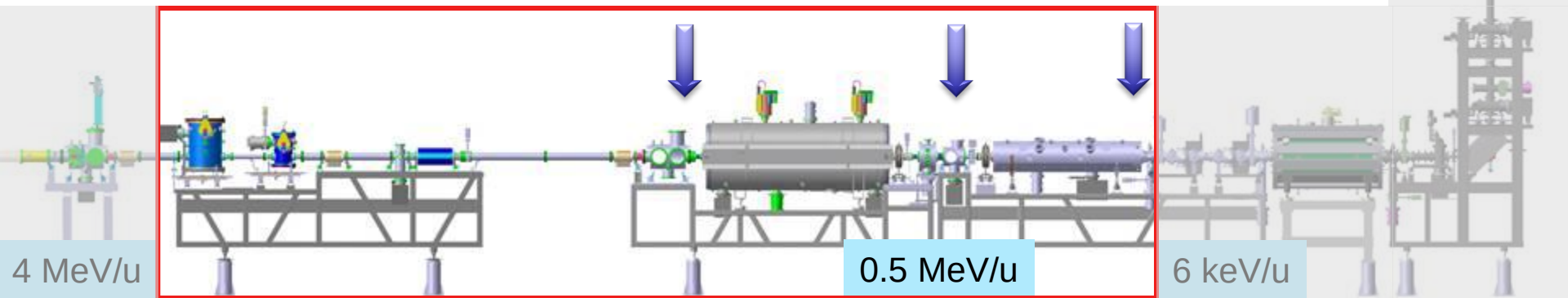
Beam that will be available to users:

type	A/q < 3 (U^{92+} ...)
ions/pulse	10^5
at FLAIR	~ 10^6 antiprotons
energy	keV/q ... meV/q
energy spread	≥ 0.3 meV



Challenges

- Never done before!
- 1 ion pulse with only 10^6 ions every 30 to 60 seconds
- “Normal” Linac diagnostics not well suited
- Unexpected behavior of decelerating accelerator



Capacitive Ring Pick-Up

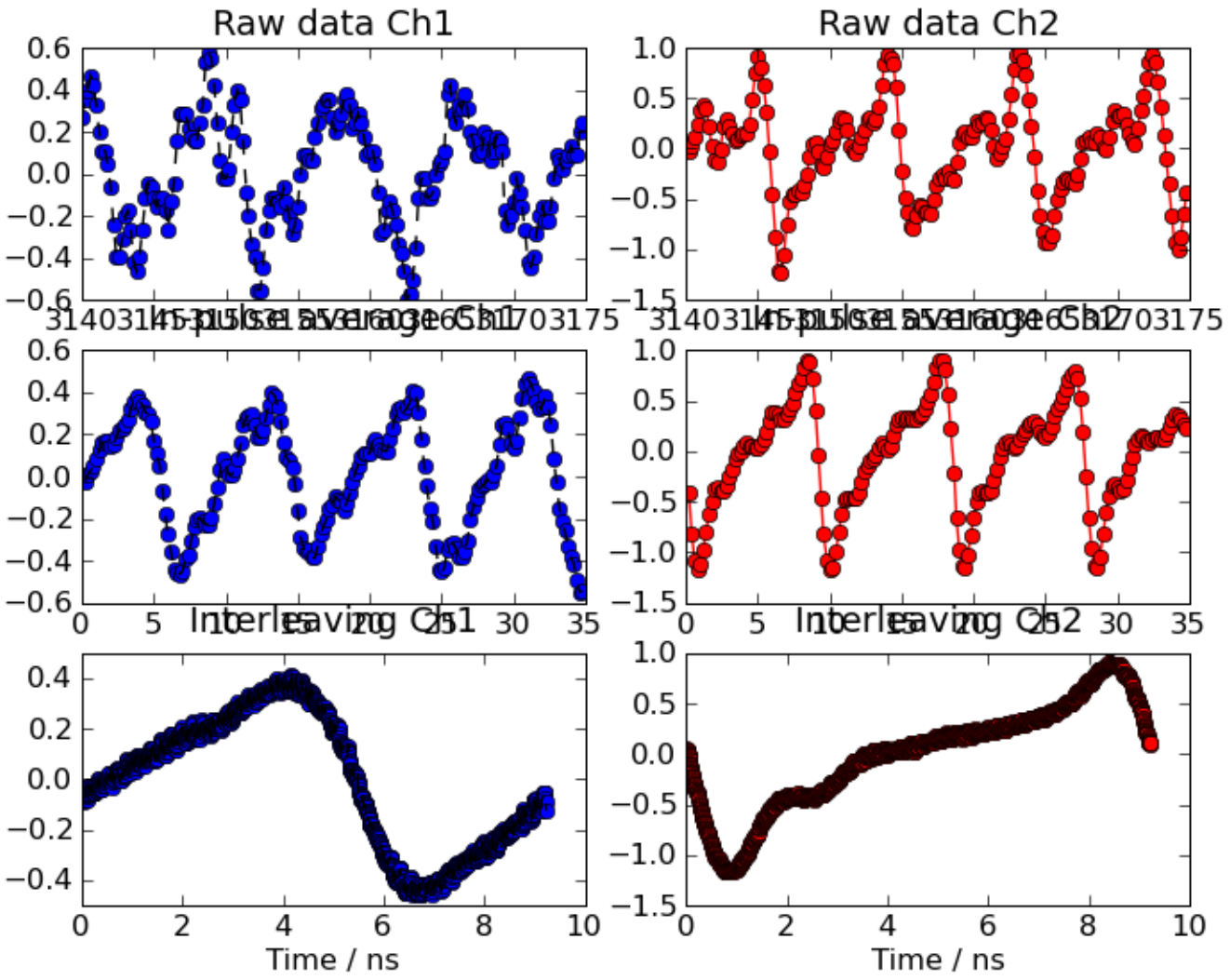
Signal Processing

:

Raw data

In-pulse average

Interleaving

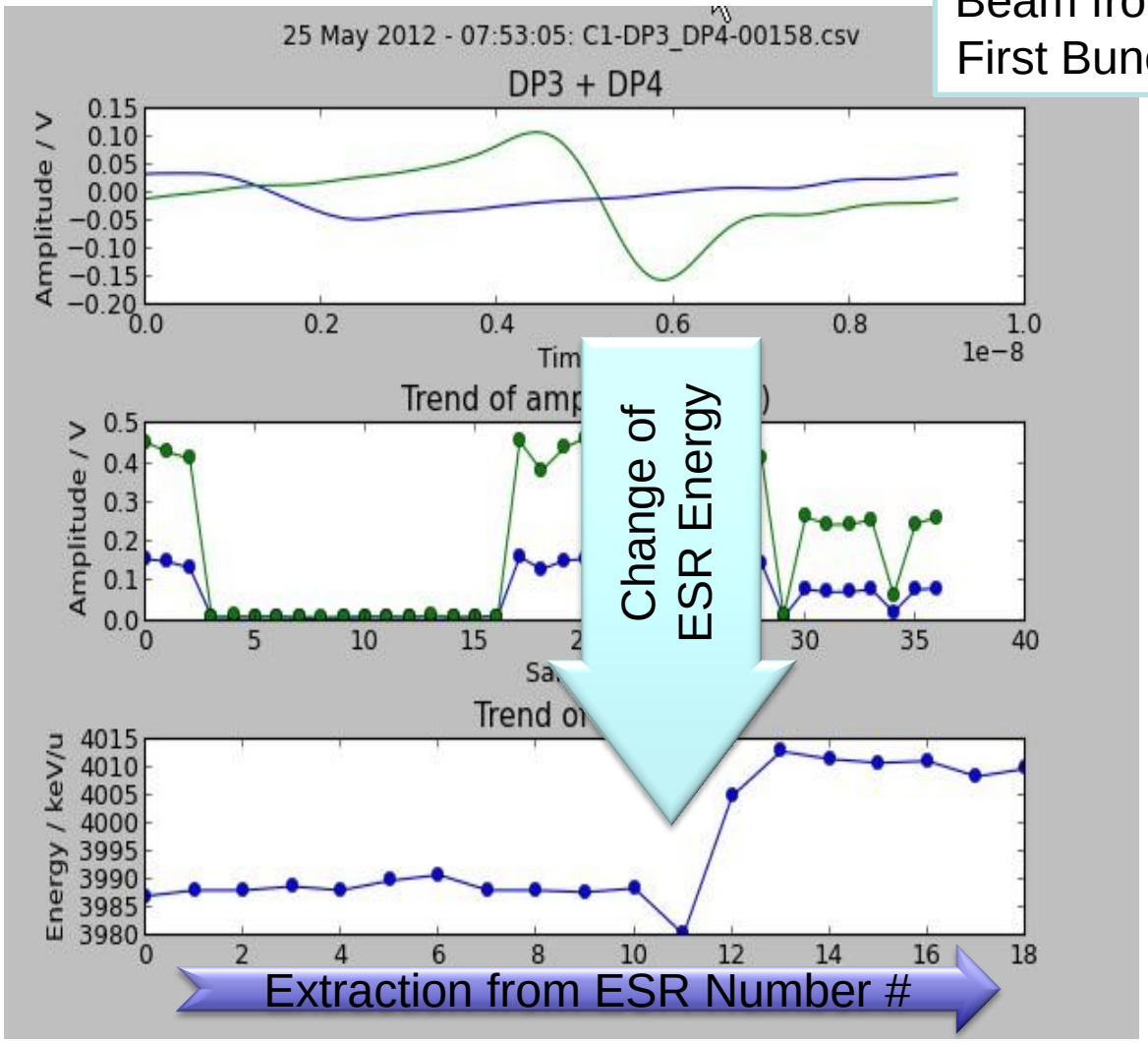


A. Reiter, C.M. Kleffner, and B. Schlitt

Capacitive Ring Pick-Up

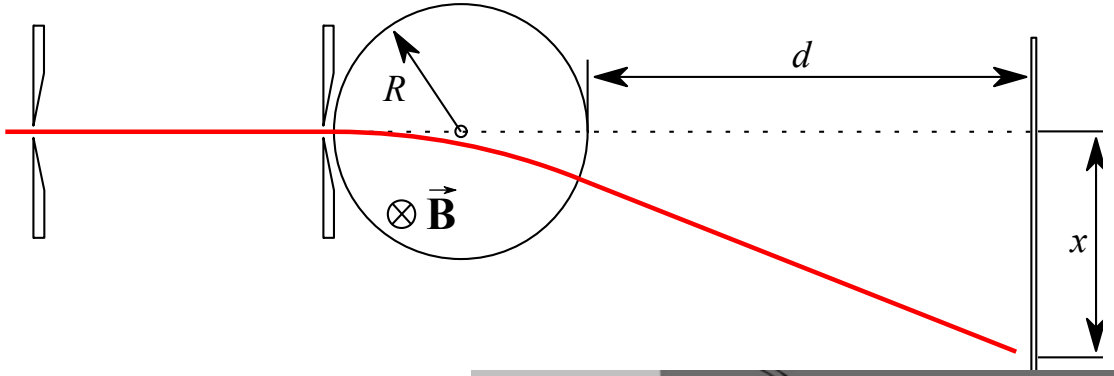
Time-of-Flight Energy Measurement

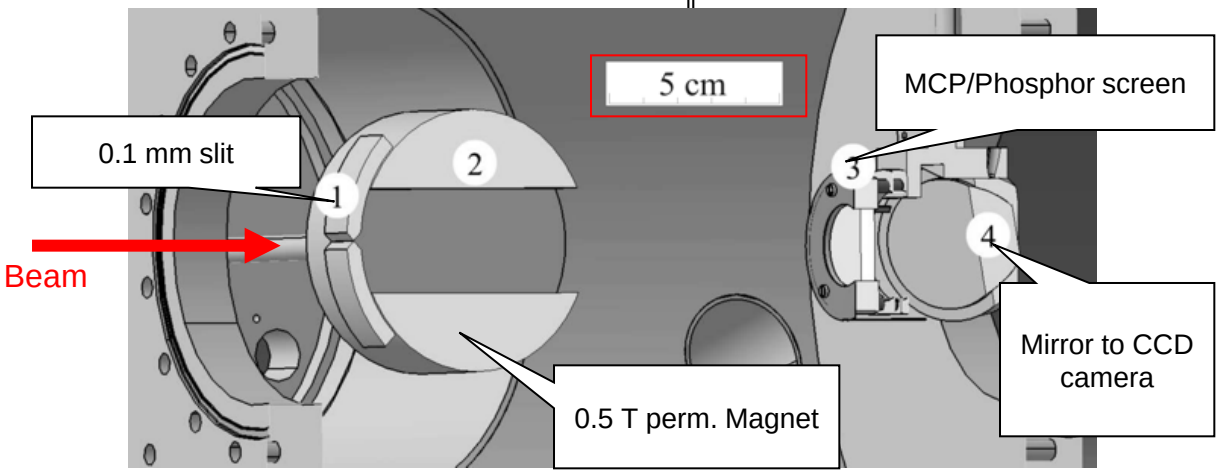
Beam from ESR,
First Buncher ON

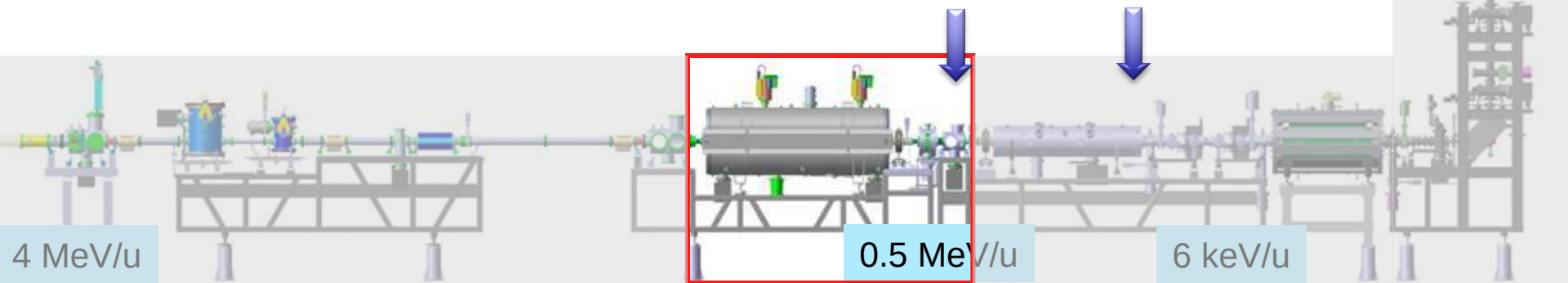


- Precise Energy measurement
- Bunch shape analysis
- Reproducibility of settings from ESR

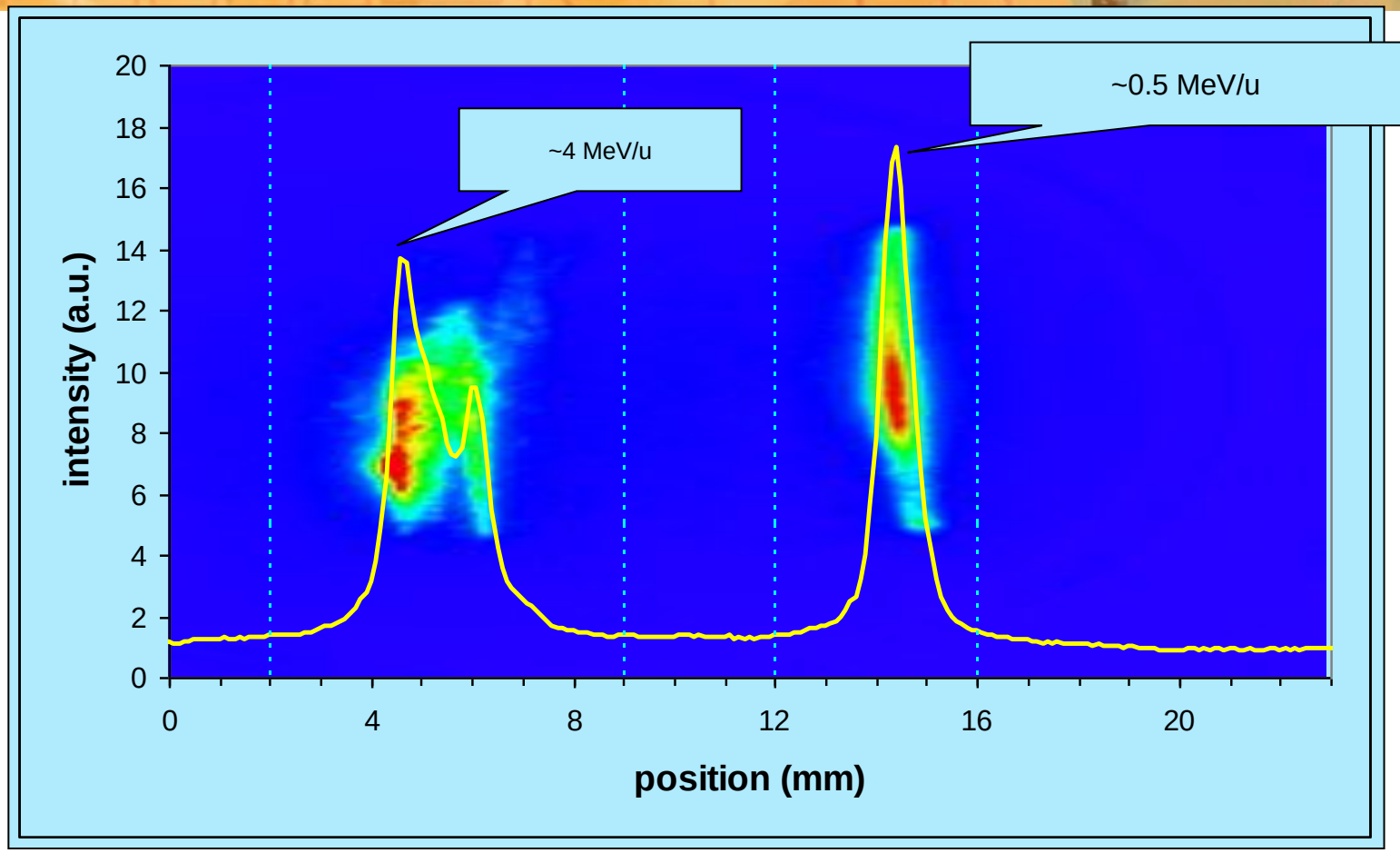
One Shot Energy Analyzer



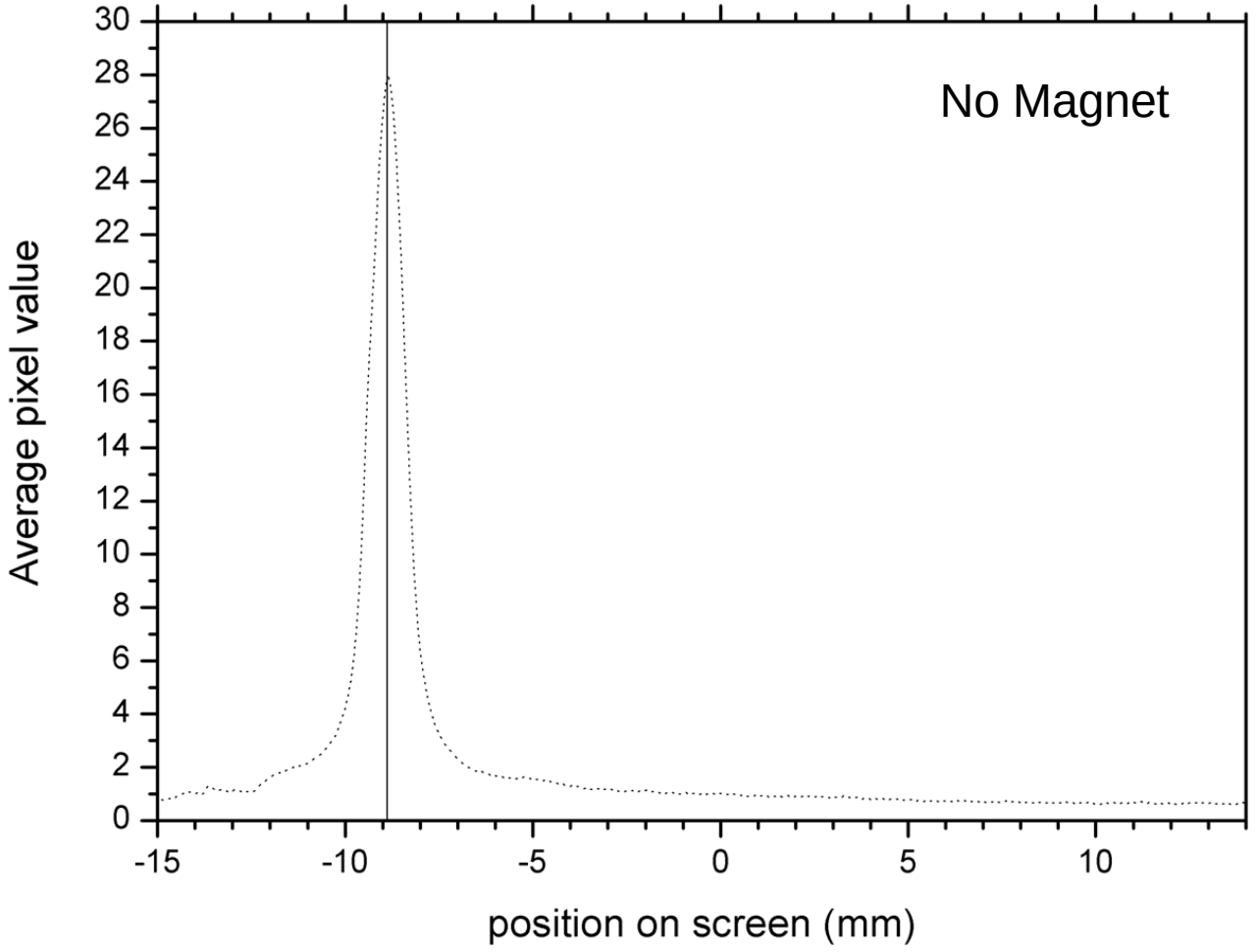




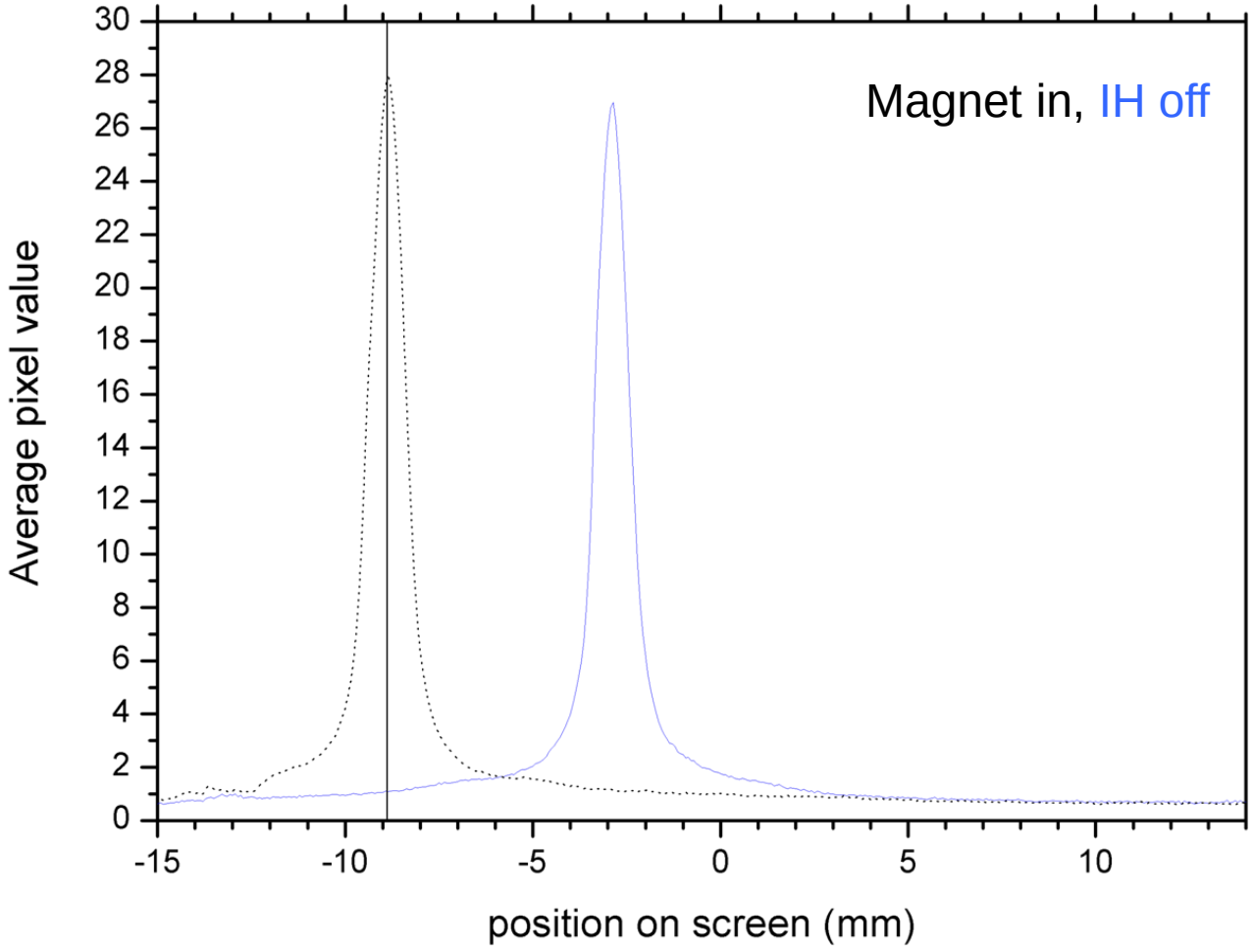
Decelerated Ions after the IH



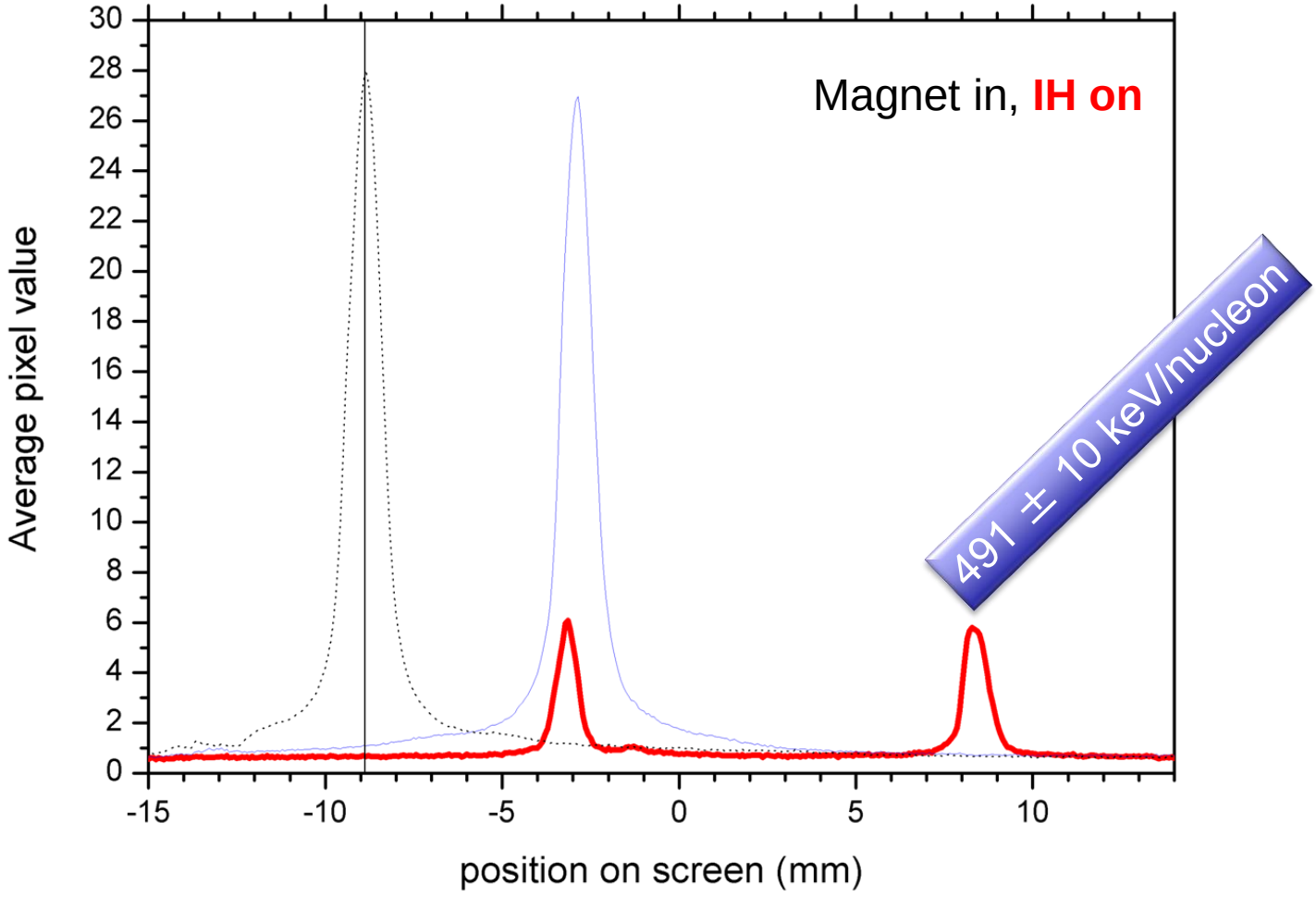
IH Energy Measurement



IH Energy Measurement



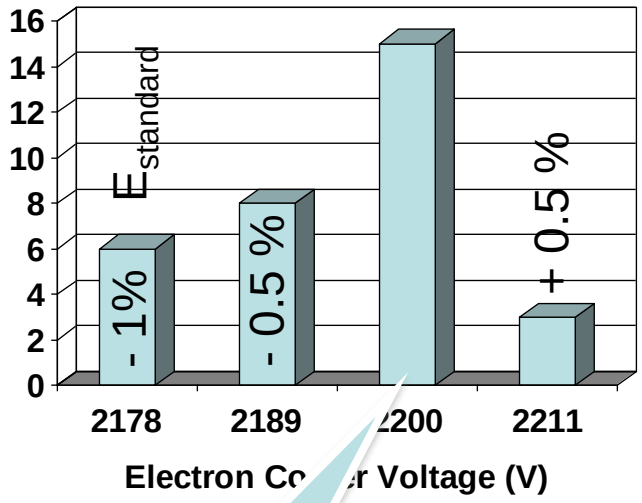
IH Energy Measurement



Input Energy Acceptance of IH

Deceleration Efficiency (%)

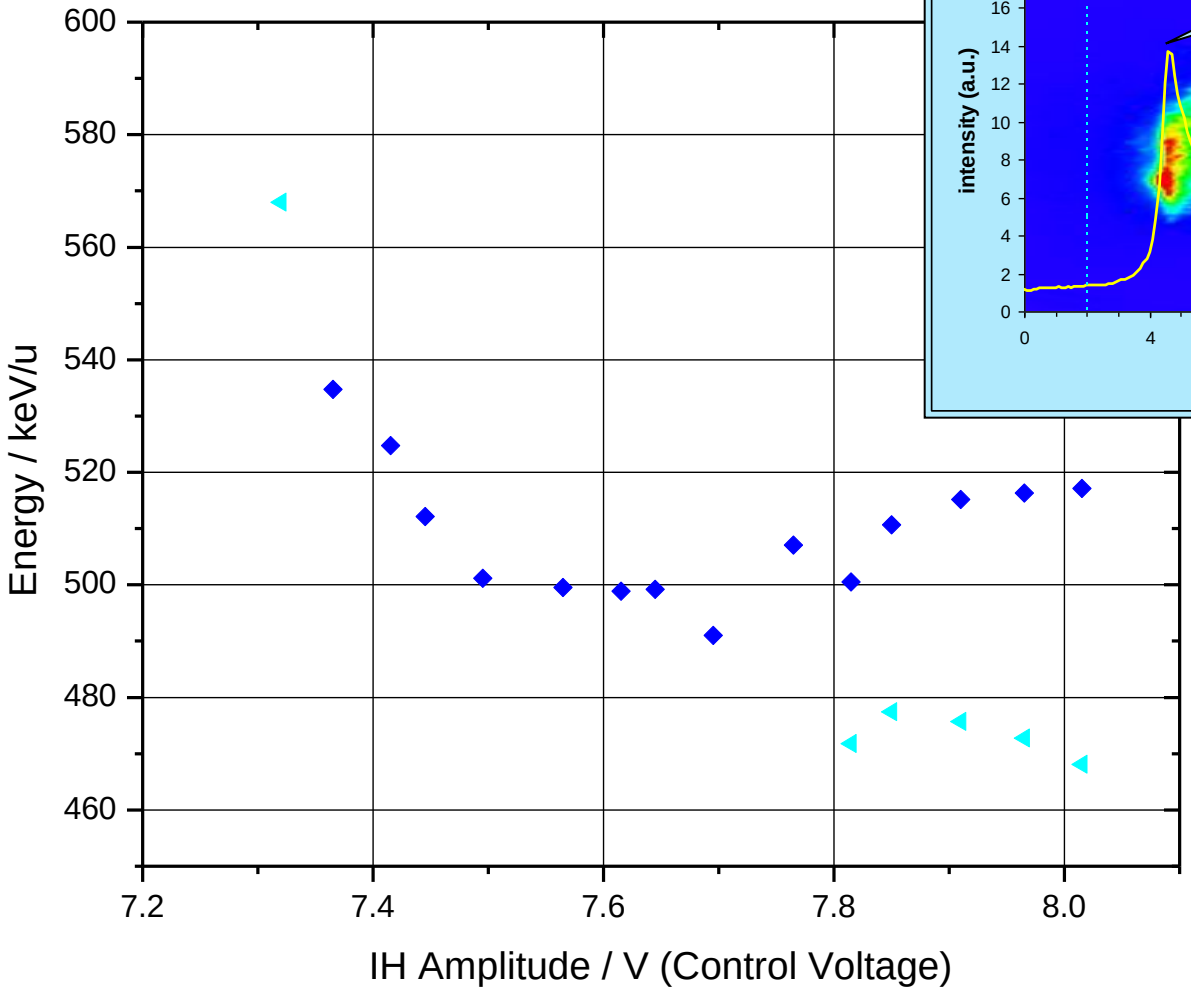
(rough, preliminary data of 2011)

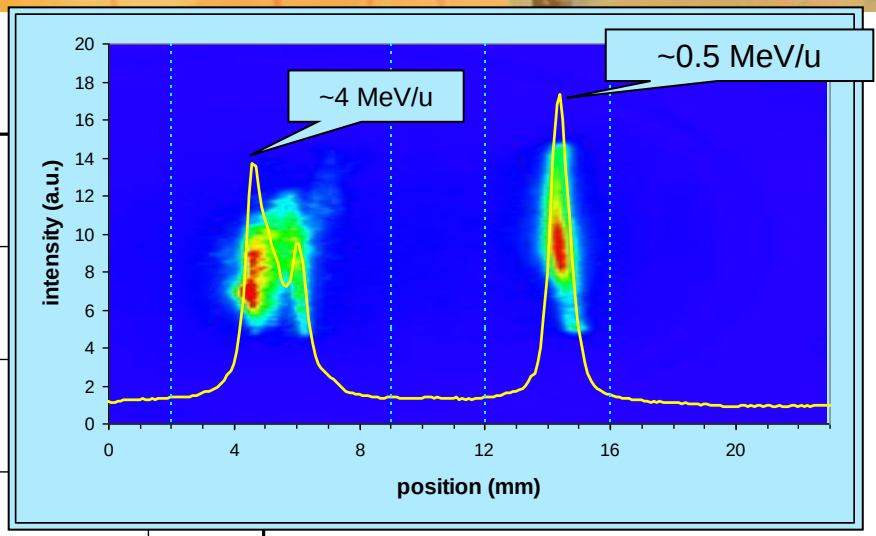


4024 keV/nucleon

Deceleration in the IH structure

Position of low energy peak vs. IH Power

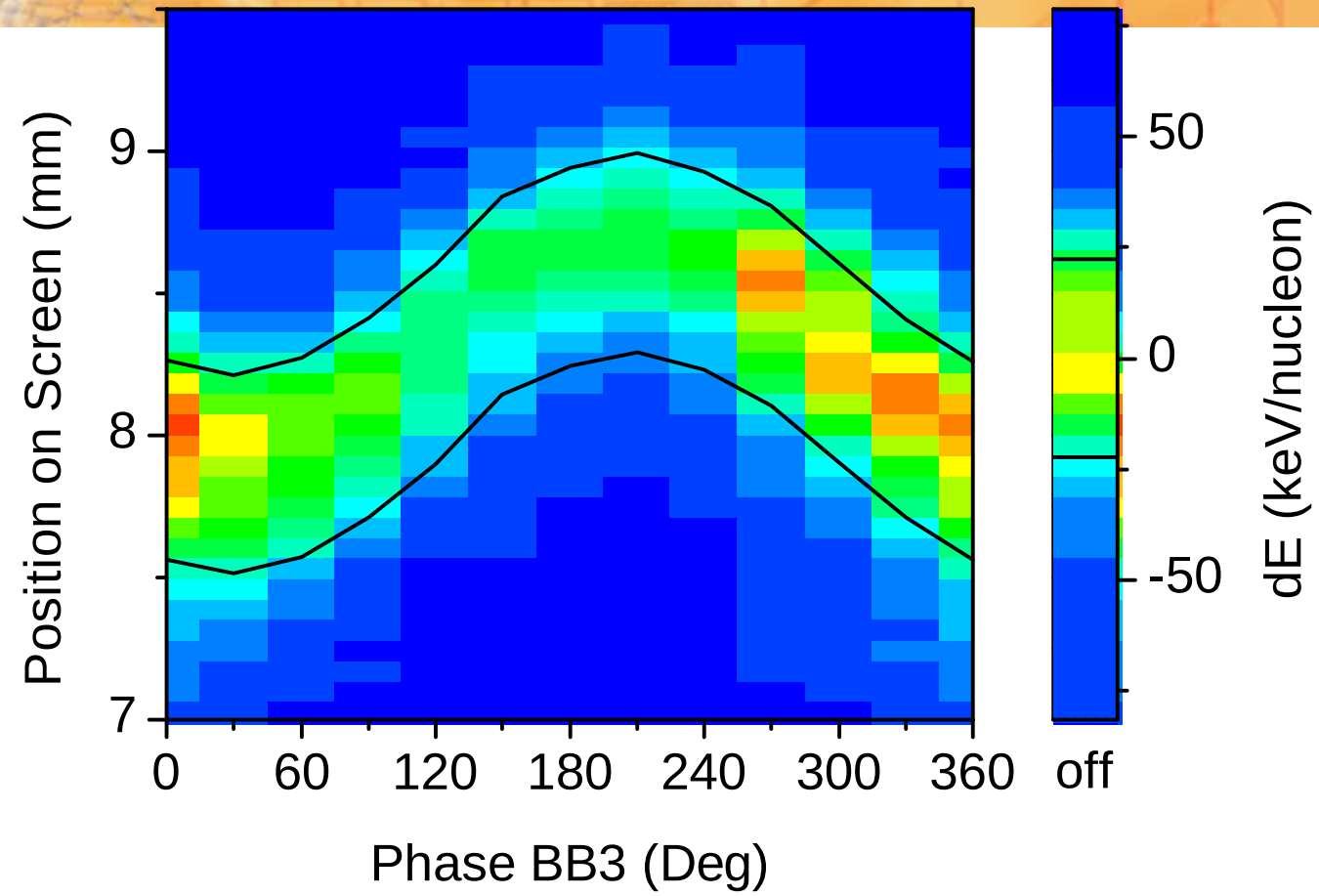


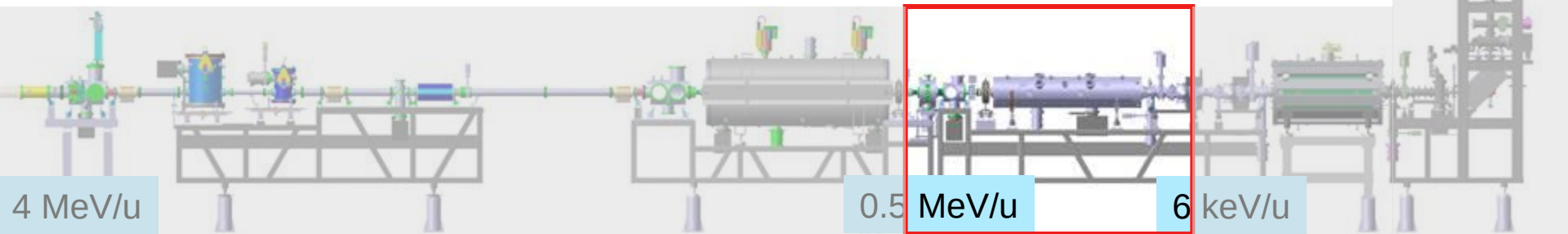


Scanned Power Range:
125 … 165 kW

Theo. Value for $^{84}Kr^{34+}$
144 kW (7.55V)

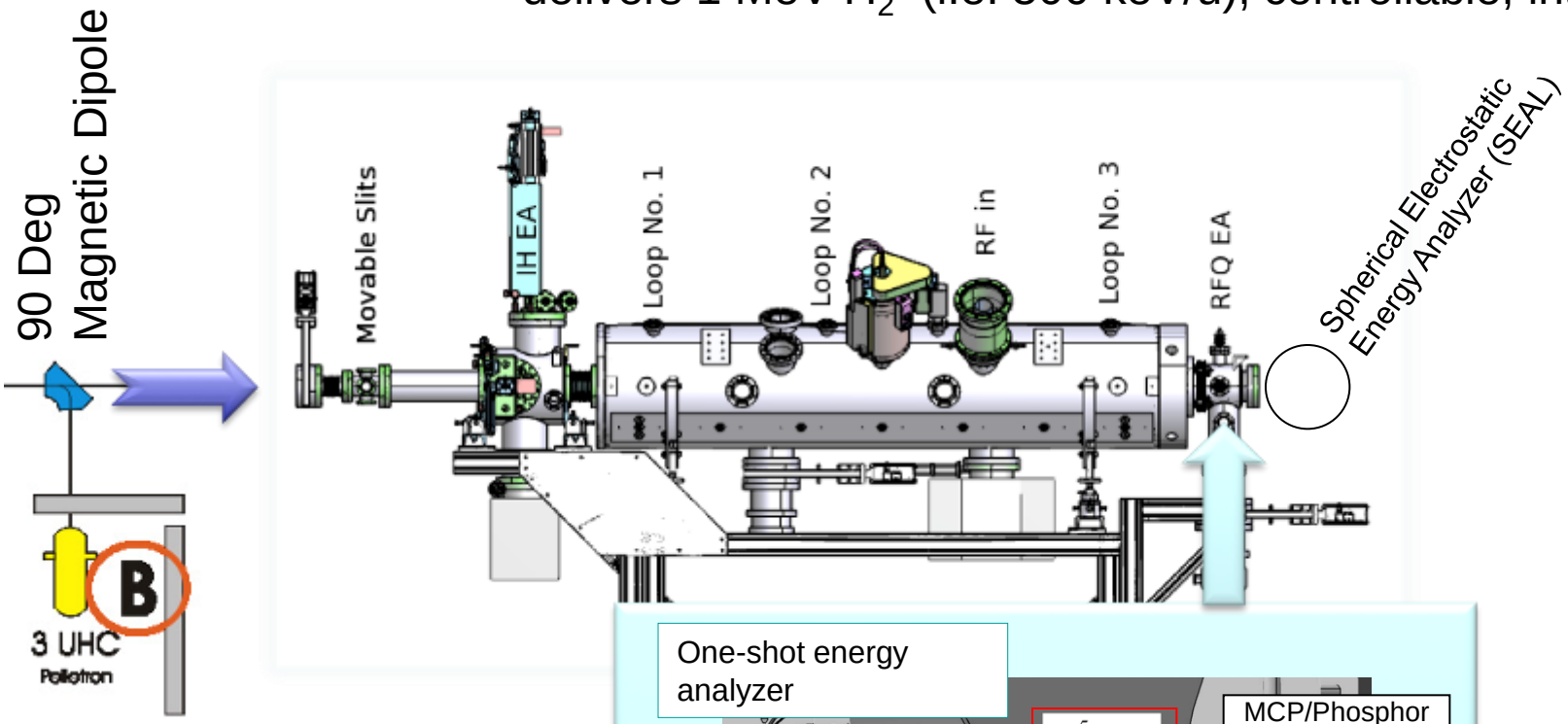
Rebuncher between IH and RFQ



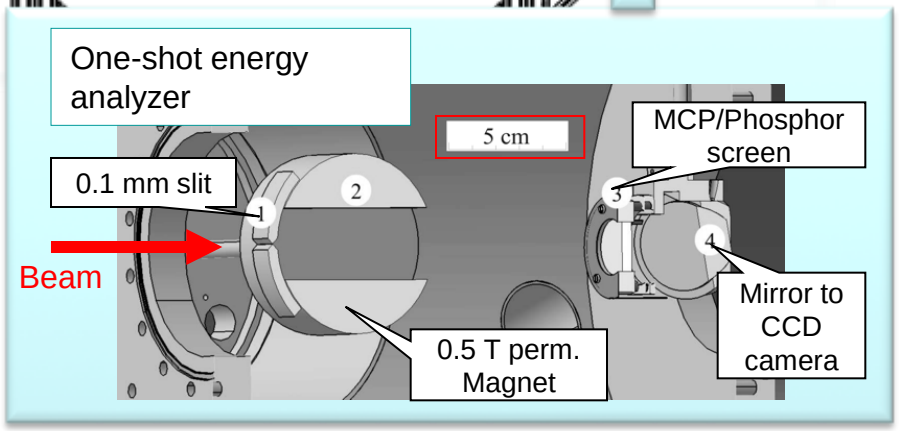


RFQ Test at 3 MV Pelletron

delivers 1 MeV H_2^+ (i.e. 500 keV/u); controllable, intense



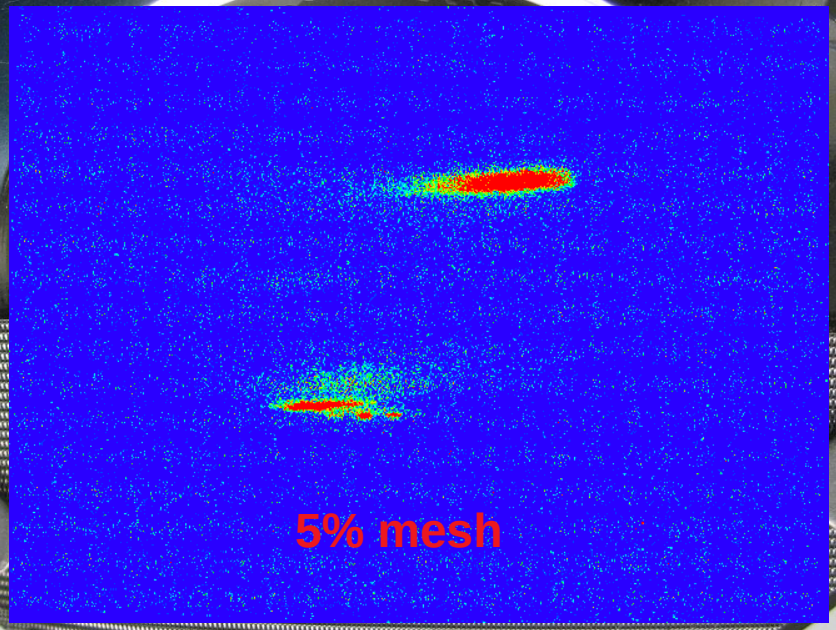
Max-Planck-Institut für Kernphysik



RFQ EA mcp wearing sunglasses

the non decelerated beam signal gets 20 times weaker
because our detector is wearing sunglasses

RFQ EA mcp wearing sunglasses



the non decelerated beam signal gets 20 times weaker
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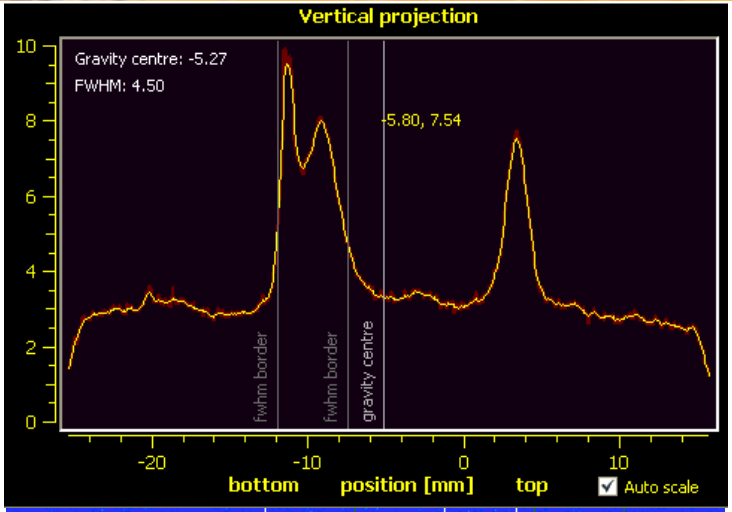
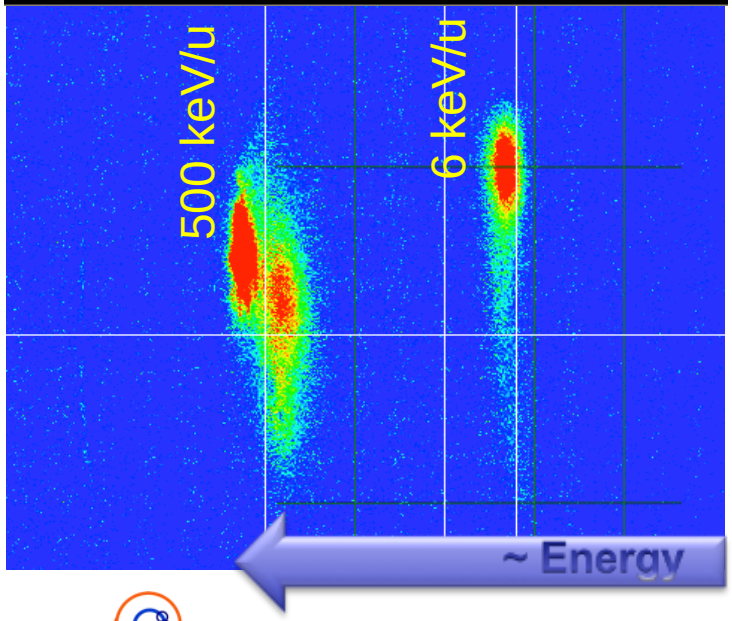
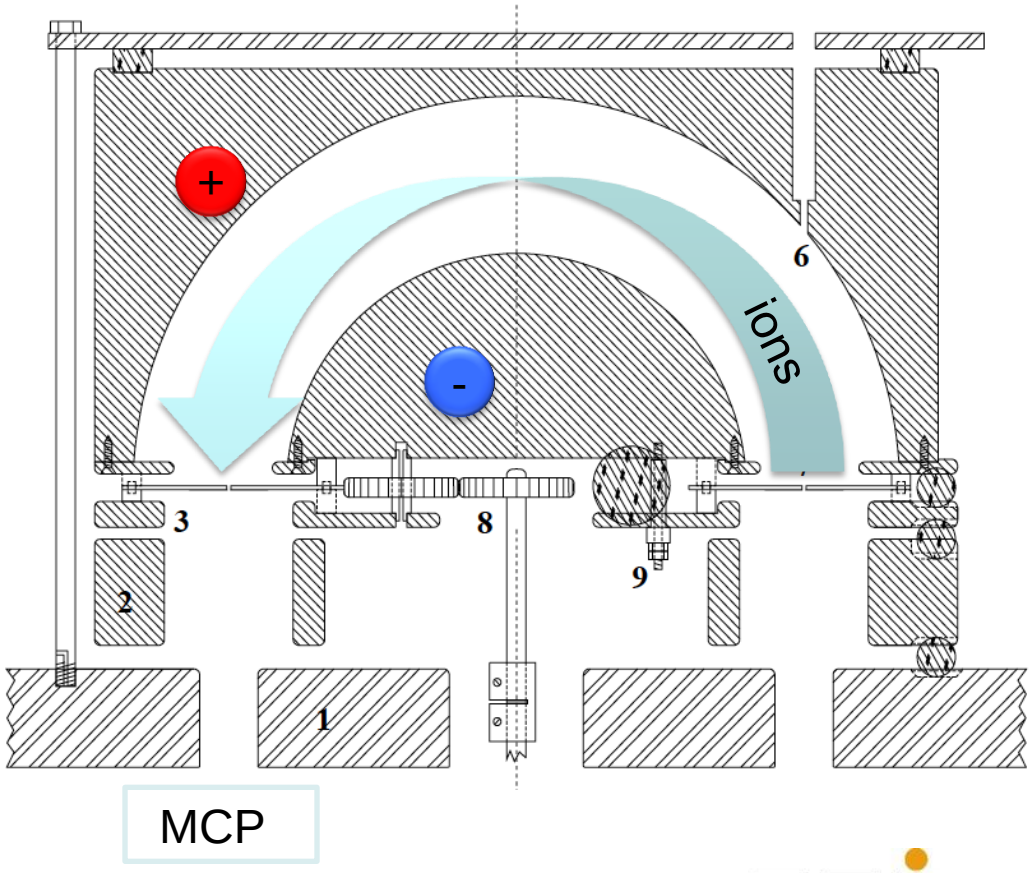
The RFQ decelerates (off-line!)

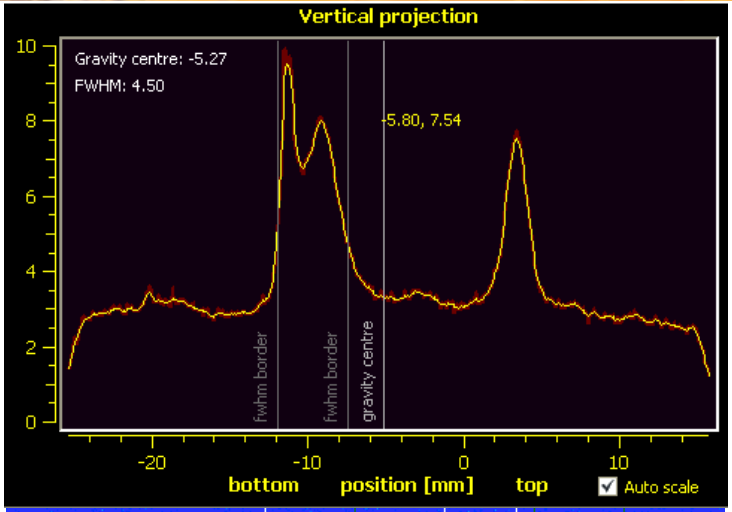


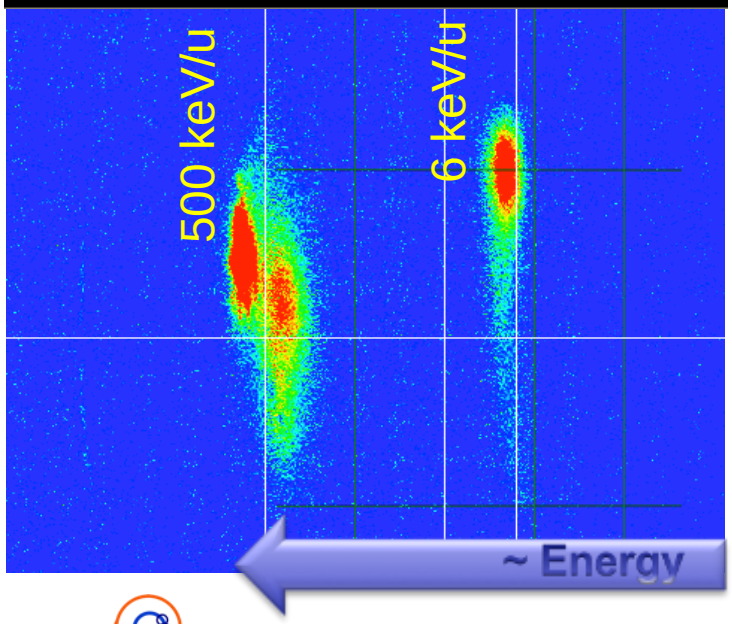


Energy of decelerated beam
(behind electrostatic analyzer)

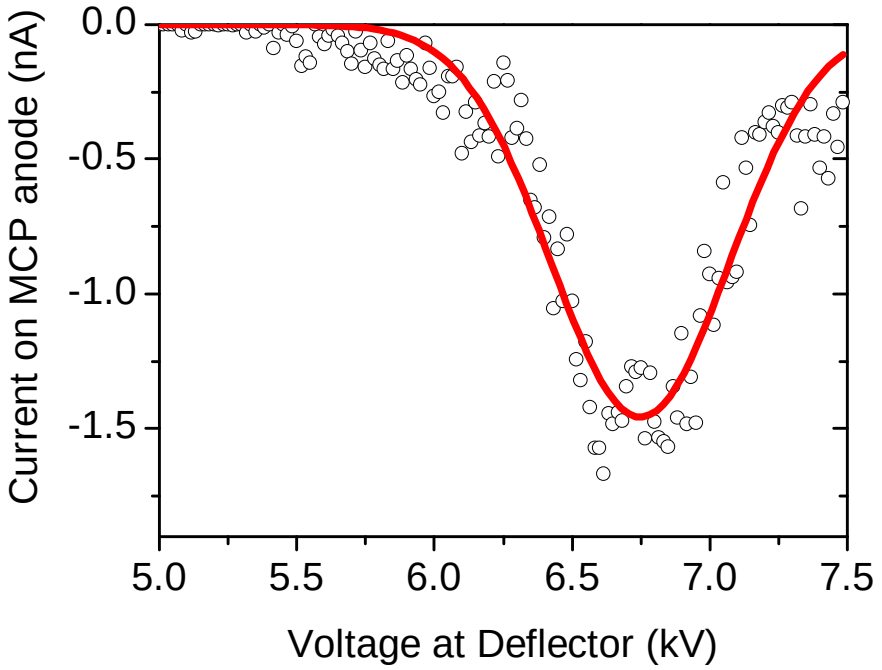


The RFQ decelerates (off-line!)



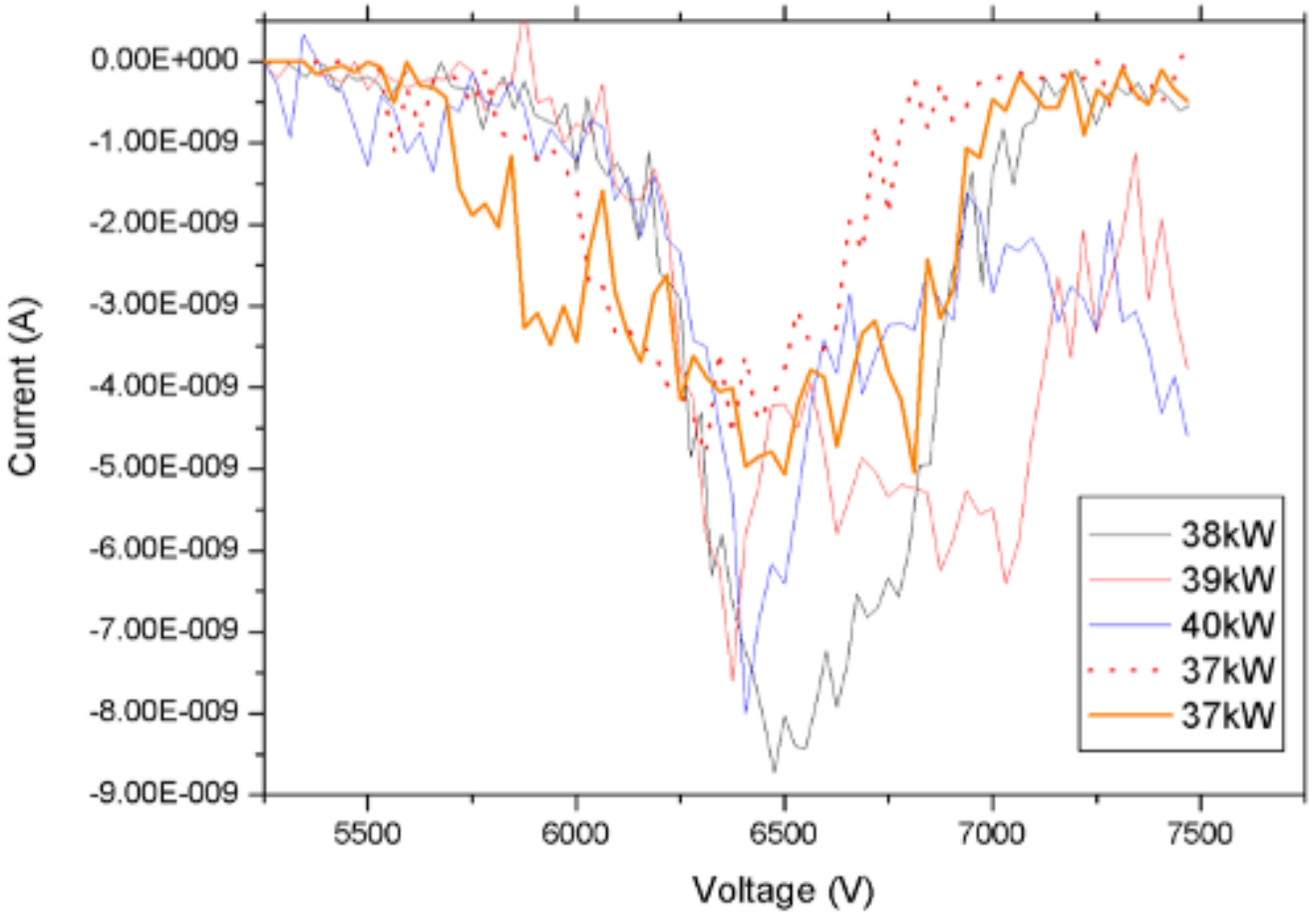


Energy of decelerated beam
(behind electrostatic analyzer)

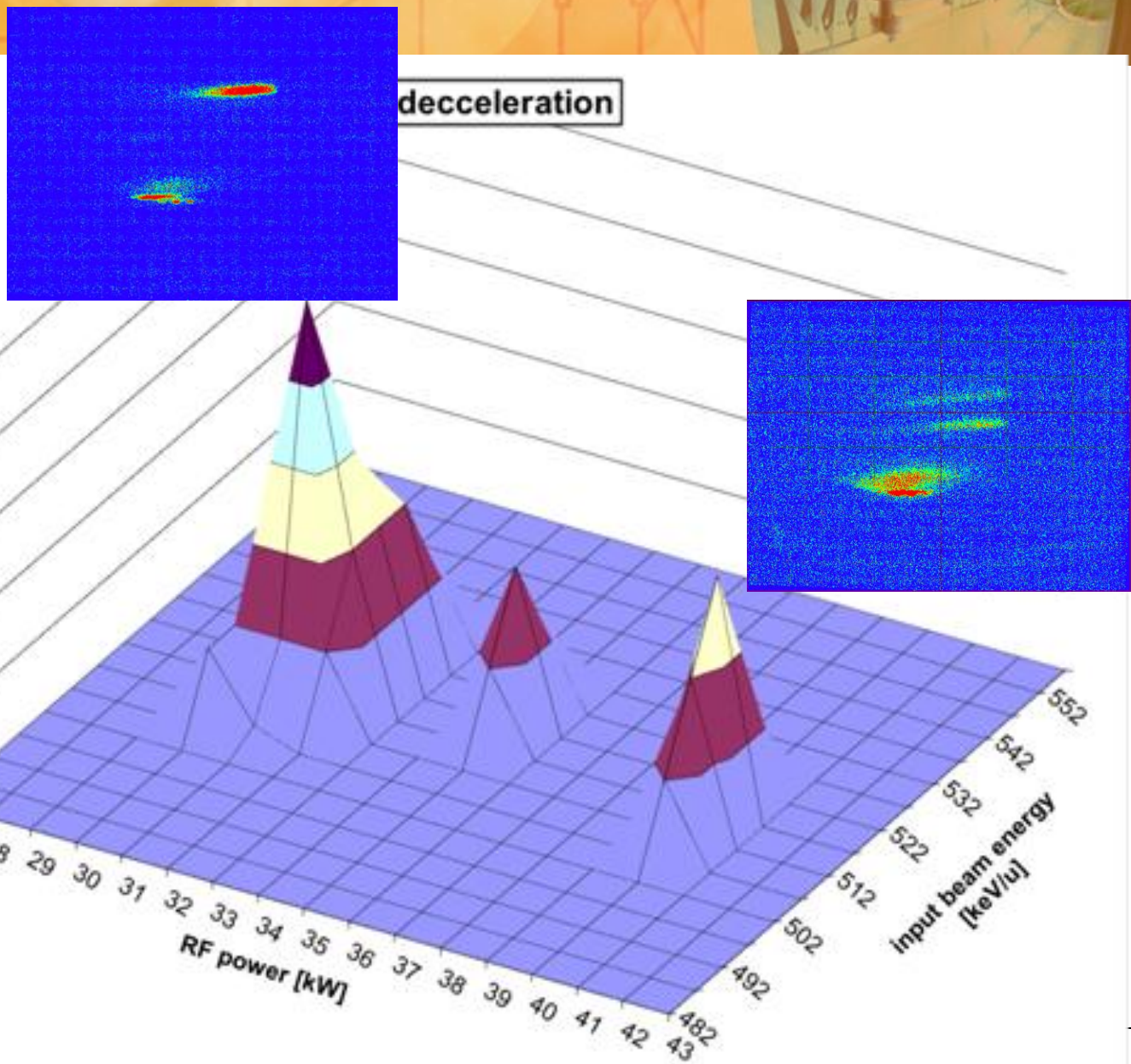


RFQ Deceleration (off-line)

Energy spectrum at different RF power levels (37 to 40 kW)

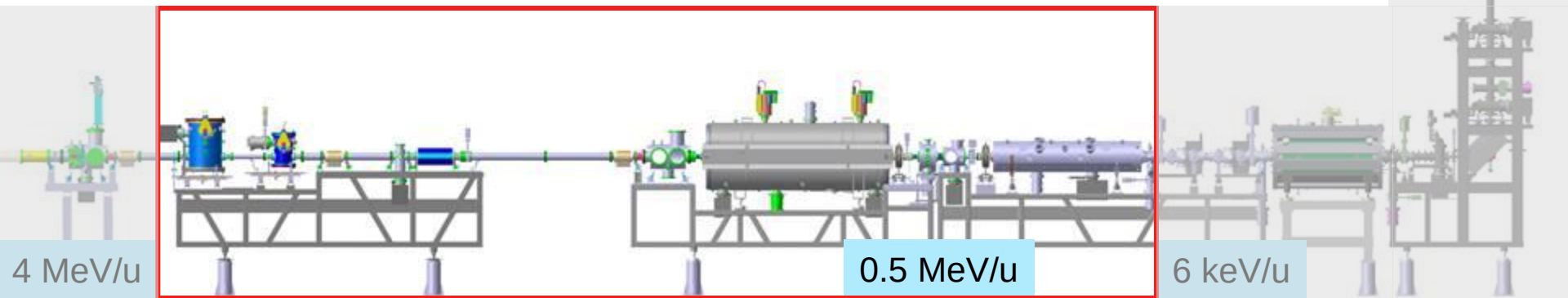


Acceptance of RFQ does not fit to IH beam.

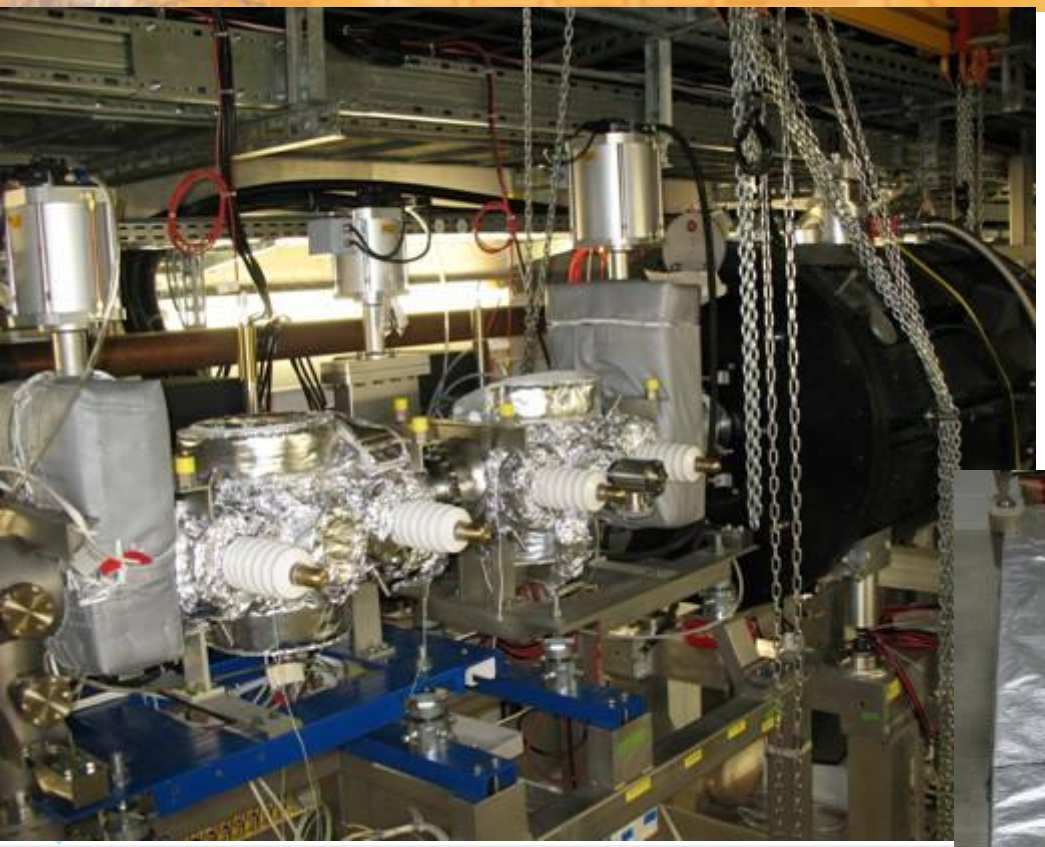


NEXT steps for Decelerator

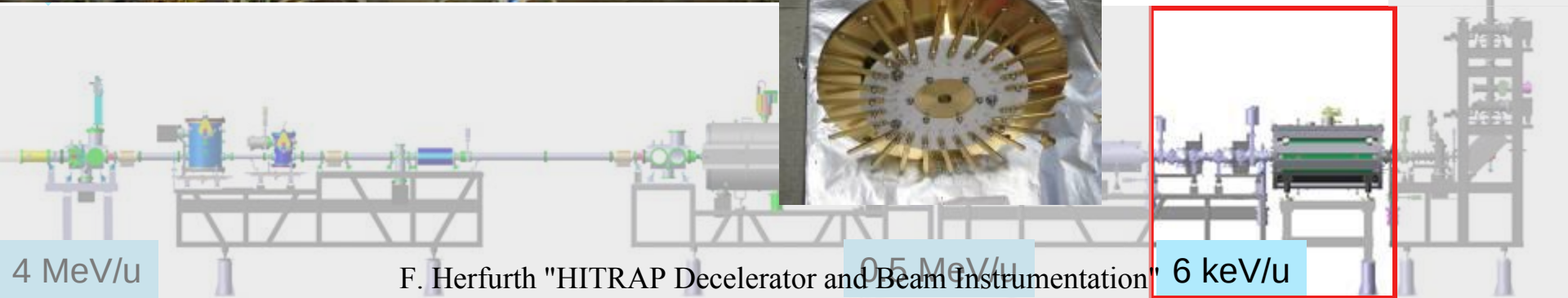
- Proof of principle with present RFQ
  - Beam time end of May – No 6 keV/nucleon beam …
- Redesign of RFQ electrodes to match IH results
  - Ion optical design ongoing (S. Yaramyshev)
  - Redesign mechanical structure for better alignment
- Discussion of new decelerating structure (IH-II)
  - Achieve wider energy acceptance



HITRAP – LEBT & Cooler Trap



- Electrodes installed, cabled
- Magnetic field tested
- Electron injection tested
- Test ion source mounted
- Electronics installed
- Extensive calculations (PIC, GPU) done



Summary

- ESR operates reliable down to 4 MeV/u
- Deceleration in HITRAP to 500 keV/u commissioned
- RFQ offline test at MPI-K Heidelberg done

- Matching IH/RFQ ongoing,
  new set of RFQ electrodes under construction

- Offline test cooler trap
- Pilot experiments with EBIT ions

- Future at FLAIR: Deceleration of p-bar