

CRYRING @ ESR

heavy, highly-charged Ions stored at low Energy

- Why?
- Details of Installation
- Some Physics Aspects
- Schedule

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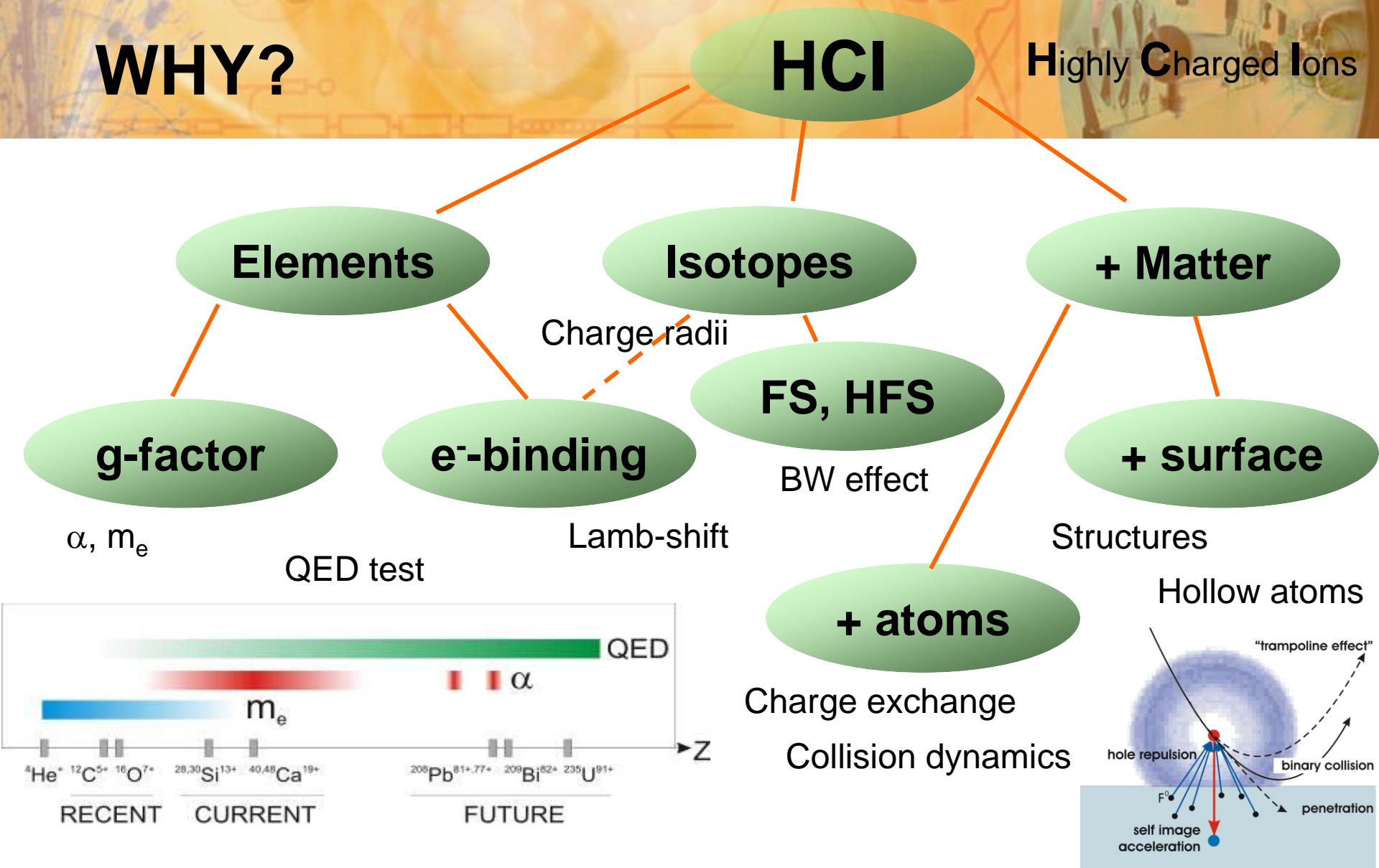
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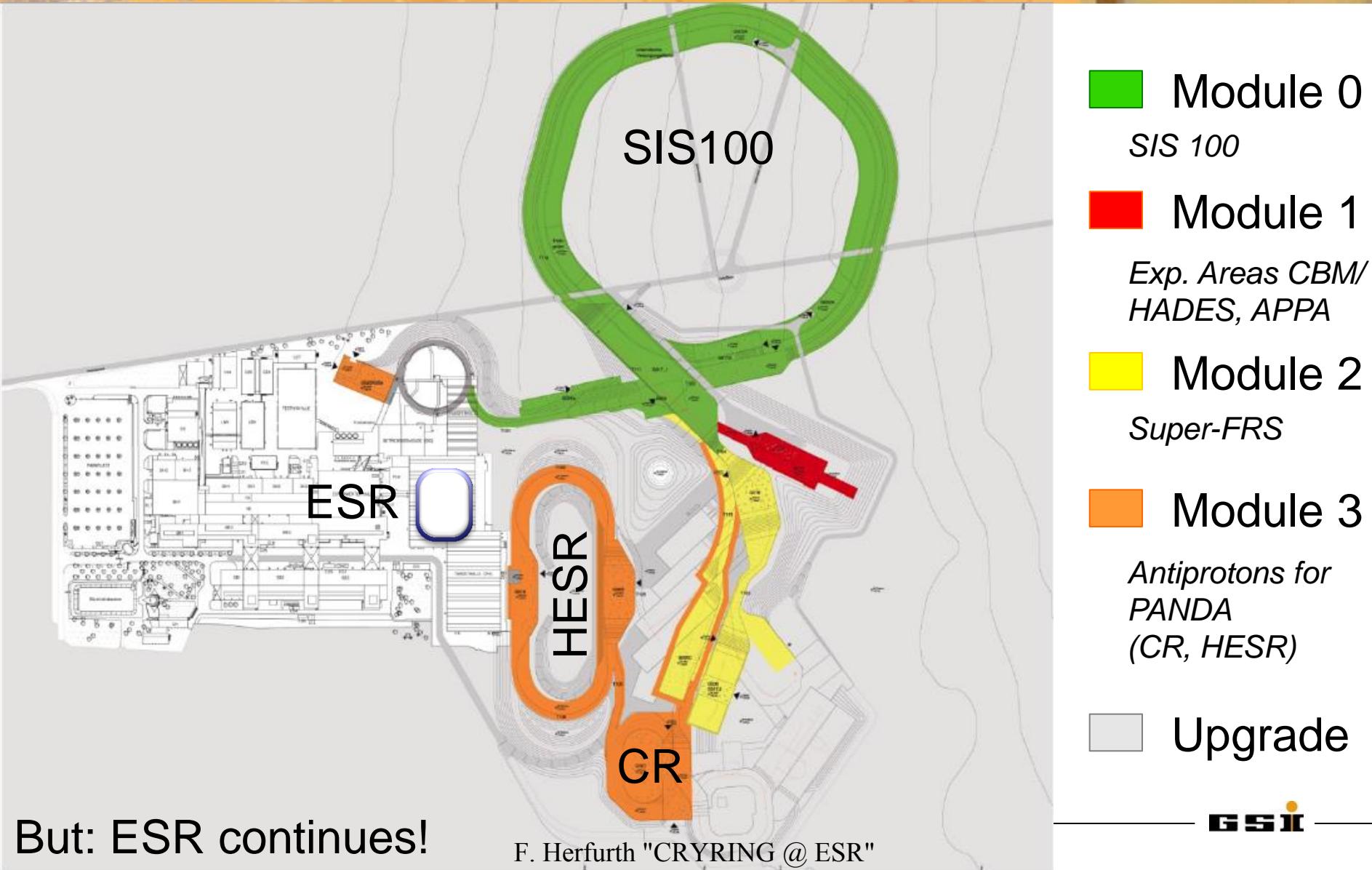
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WHY?



The “Green Paper” – Stepwise to FAIR



But: ESR continues!

F. Herfurth "CRYRING @ ESR"

CRYRING @ ESR

FAIR Research & Development

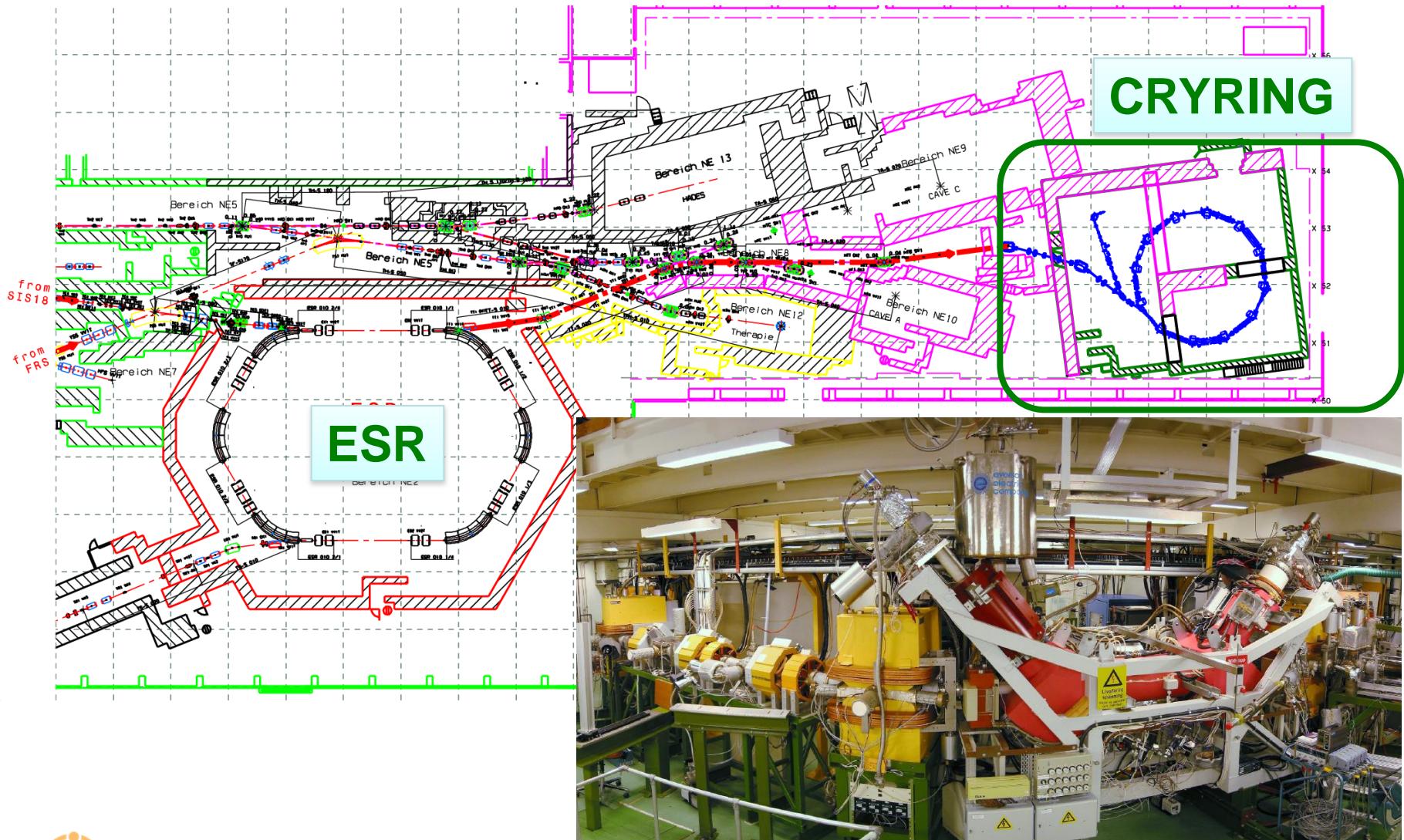
- Detectors and diagnostic systems
- FAIR type control system
- Training of operators on FAIR type system
- FAIR type safety and radiation monitoring/access system

All this with real beam!

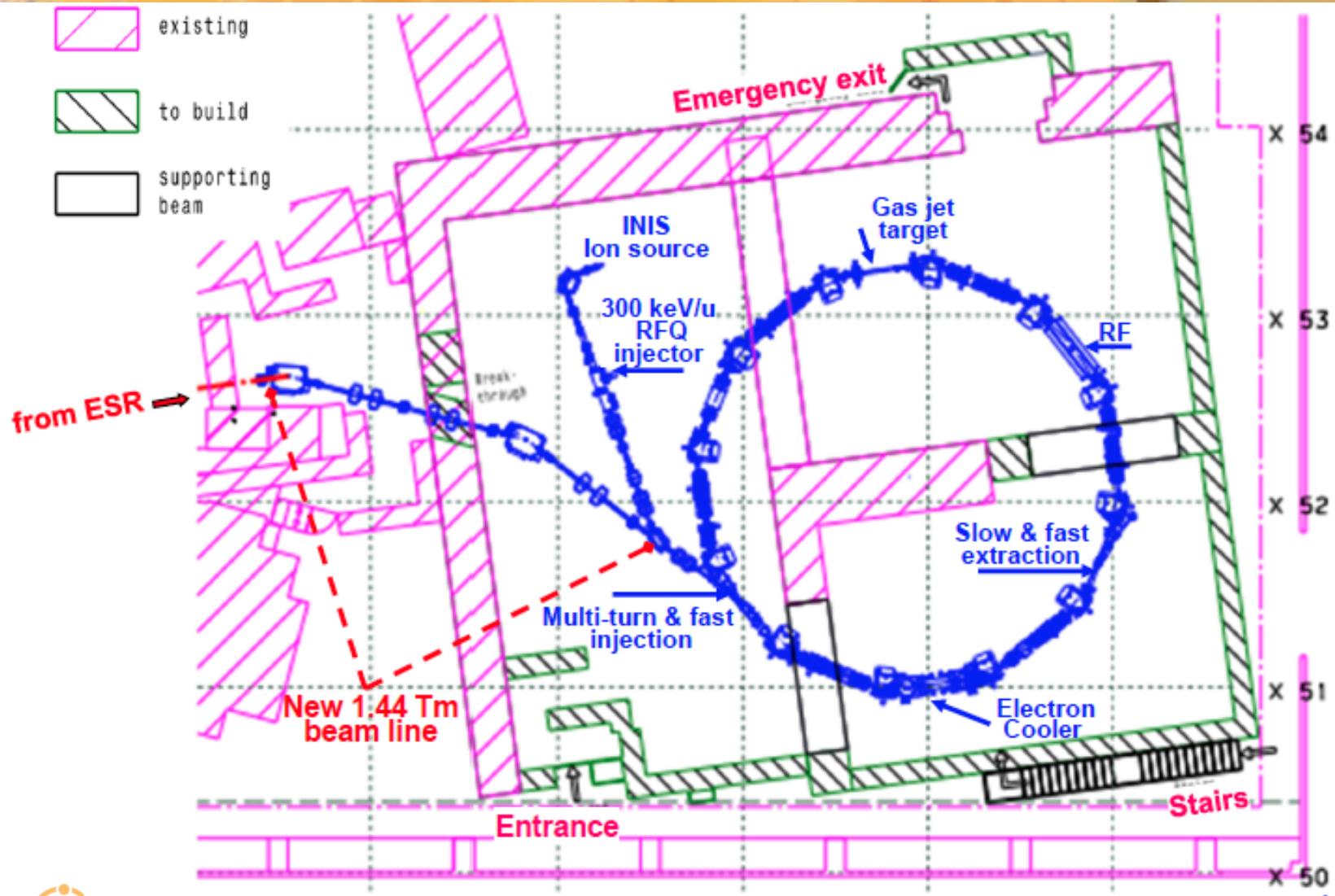
Scientific Opportunities

- Heavy, highly-charged ions as available at GSI (up to U^{92+}) at low energy $\sim 100 \text{ keV/u} .. 10 \text{ MeV/u}$ – bridge the energy gap between the ESR ($> 4 \text{ MeV/u}$) and HITRAP ($< 10 \text{ keV/u}$)

CRYRING @ ESR



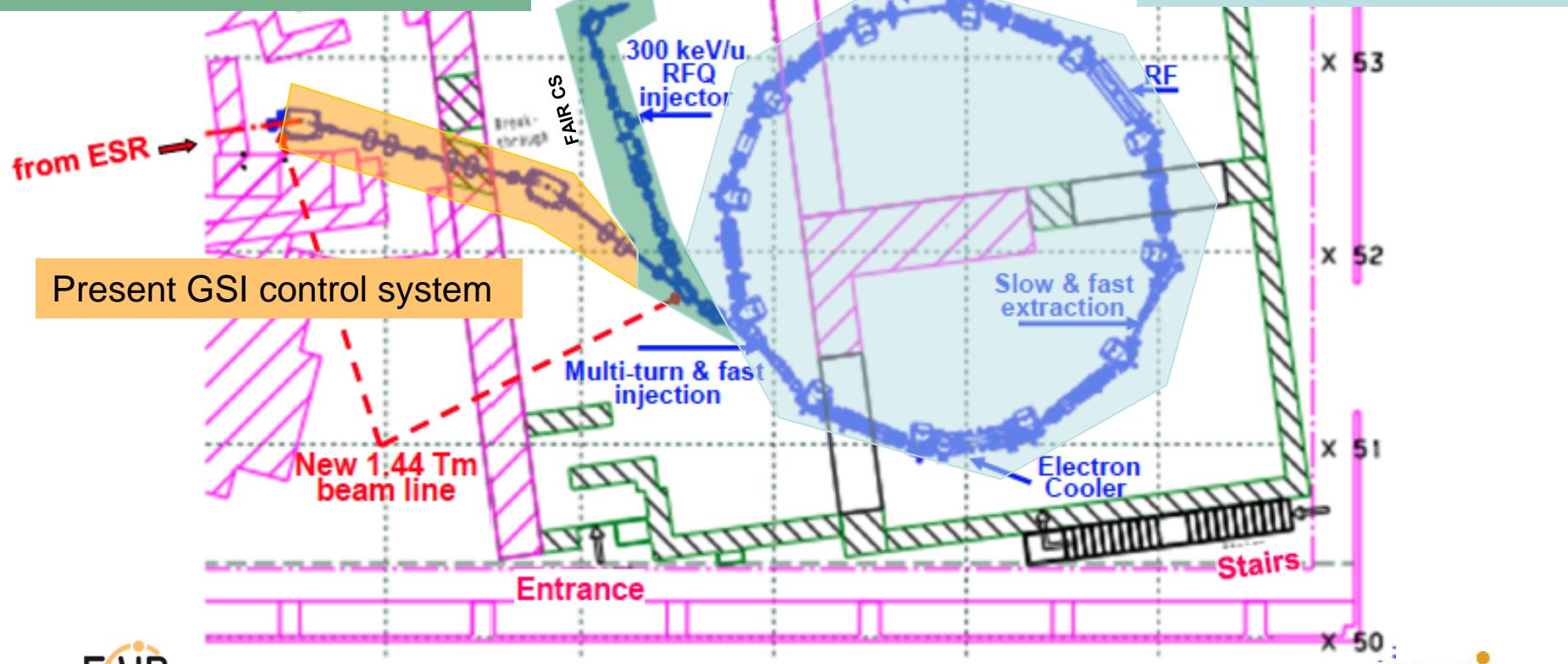
CRYRING @ ESR in modified Cave B



CRYRING @ ESR Control System

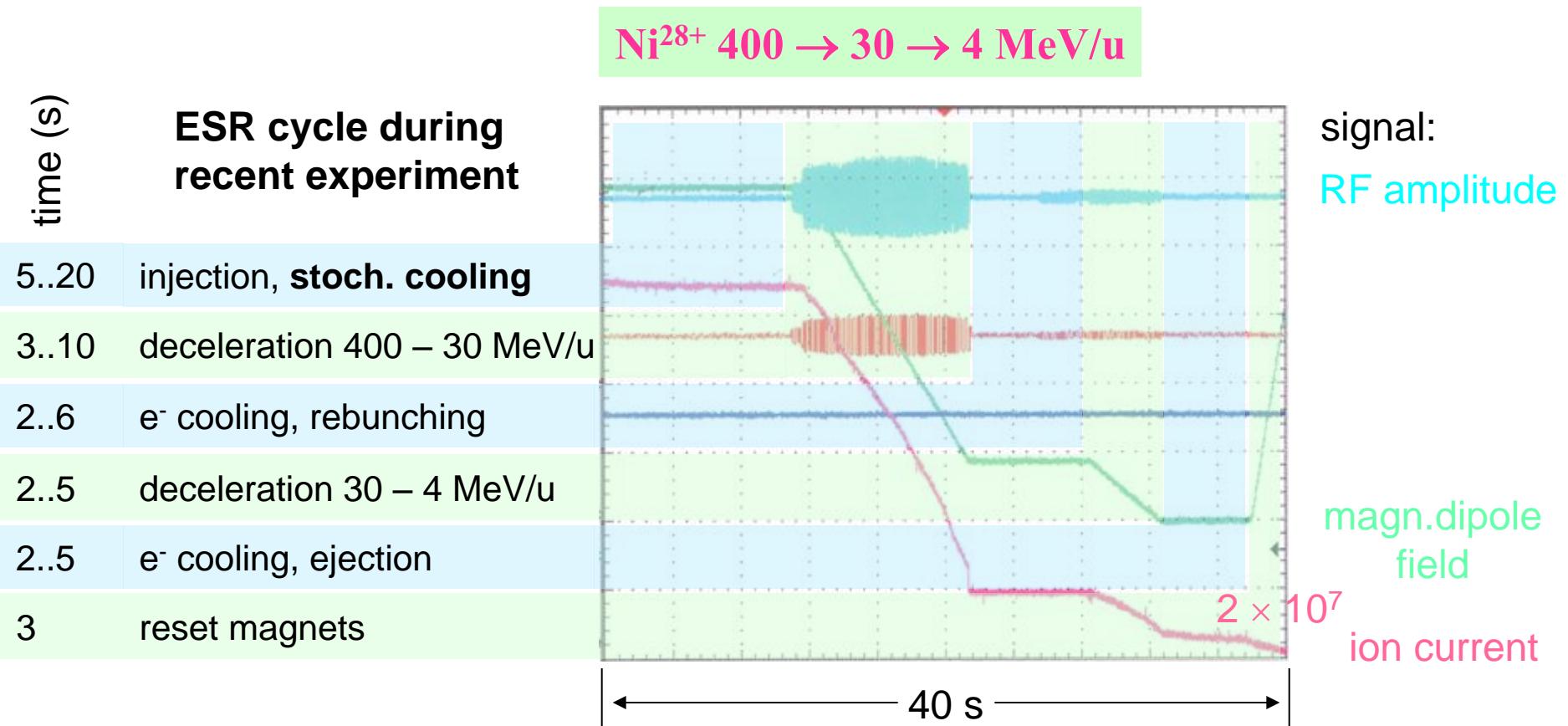
Hybrid (MSL/FAIR) system

- Software
 - ConSys, FESA, LSA, Java Apps.
- Interfaces
 - G-64 units
 - CAEN SY127 HV supplies
 - Beckhoff Bus Terminals
- Timing system
 - White rabbit



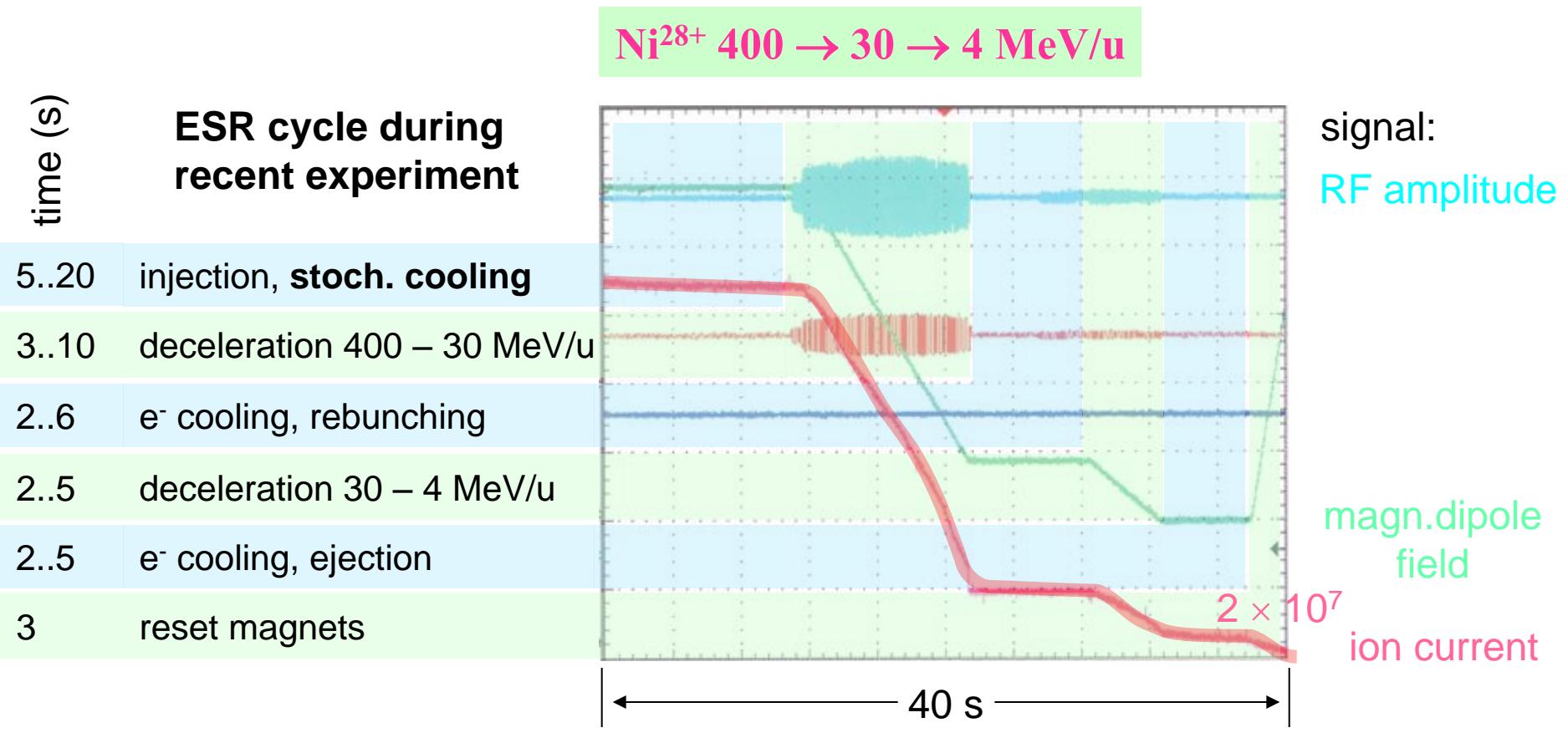
ESR – From 400 to 4 MeV/u

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

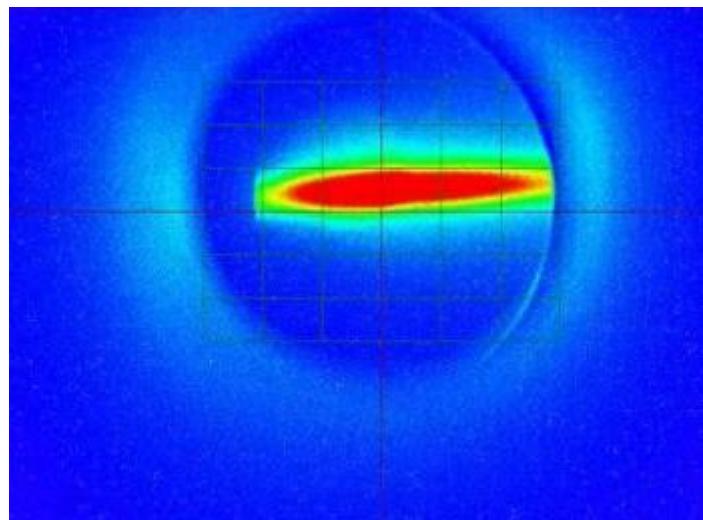


ESR – From 400 to 4 MeV/u

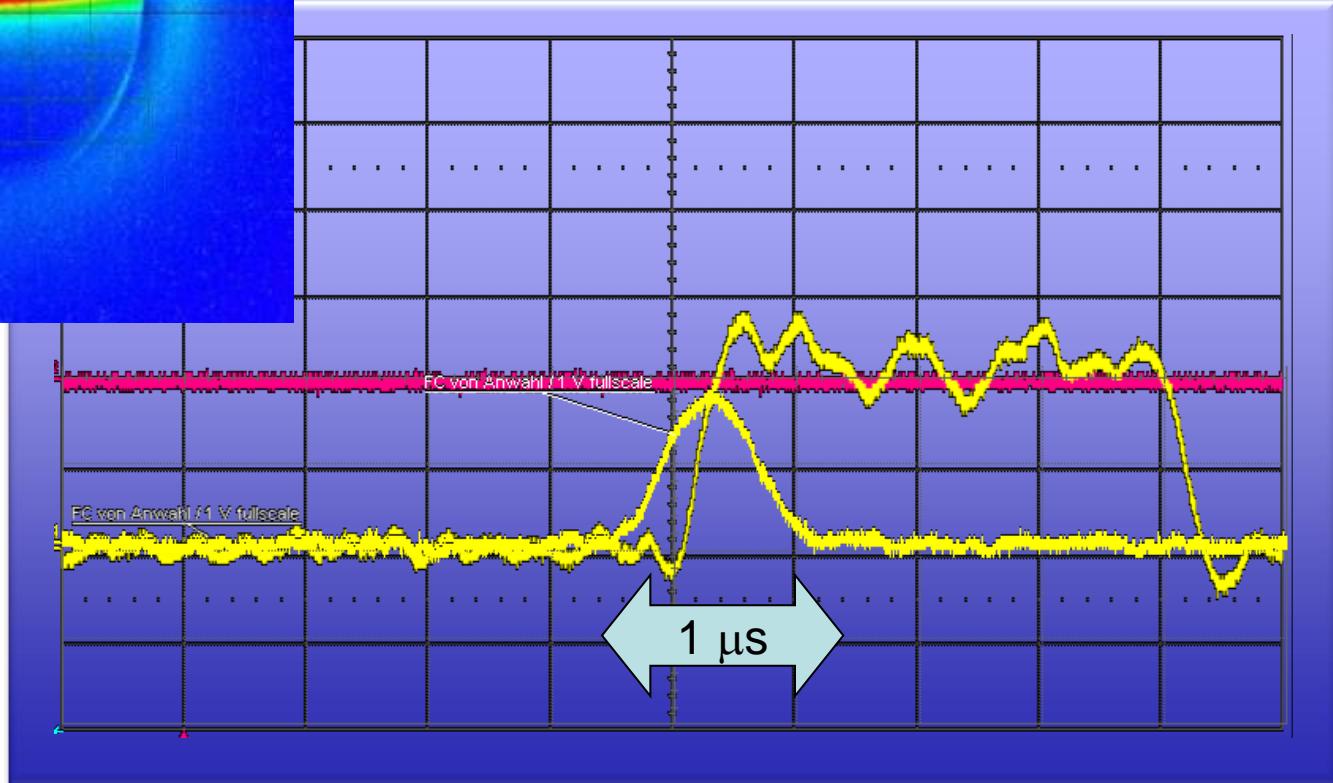
ESR – Experimental Storage Ring at GSI with stochastic and electron cooling



4 MeV/u ions from ESR

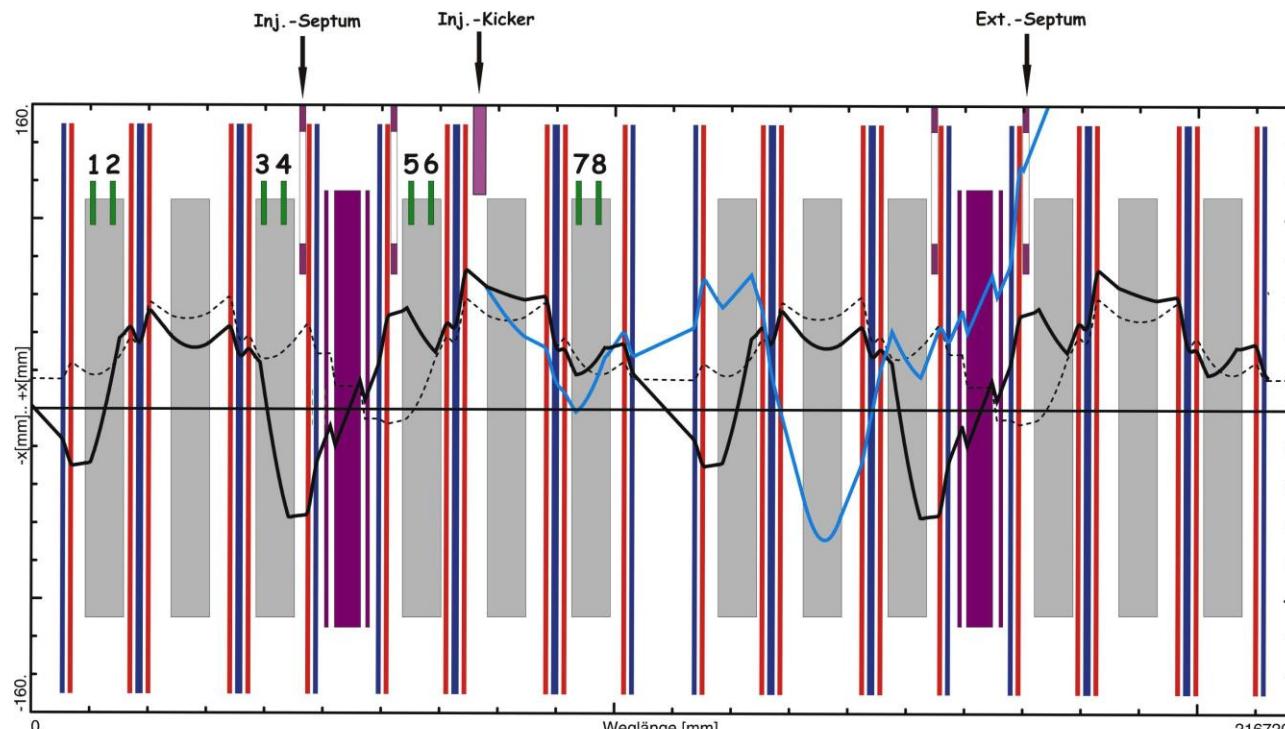


2×10^7 $^{136}\text{Xe}^{50+}$ extracted from ESR



Modification of ESR for CRYRING

- Additional Kicker
but in the mean time ...



Injection orbit ($\Delta p/p = 1\%$) -----

Bumped Orbit _____

Extraction Orbit (kicker -3.5 mrad) _____

1. E01KX1 = 7 mrad

2. E01KX2 = -14 mrad

3. E01KX5 = -18 mrad

4. E01KX6 = 9.5 mrad

5. E02KX1 = -8 mrad

6. E02KX2 = 10.5 mrad

7. E02KX5 = 6.4 mrad

8. E02KX6 = -5.7 mrad

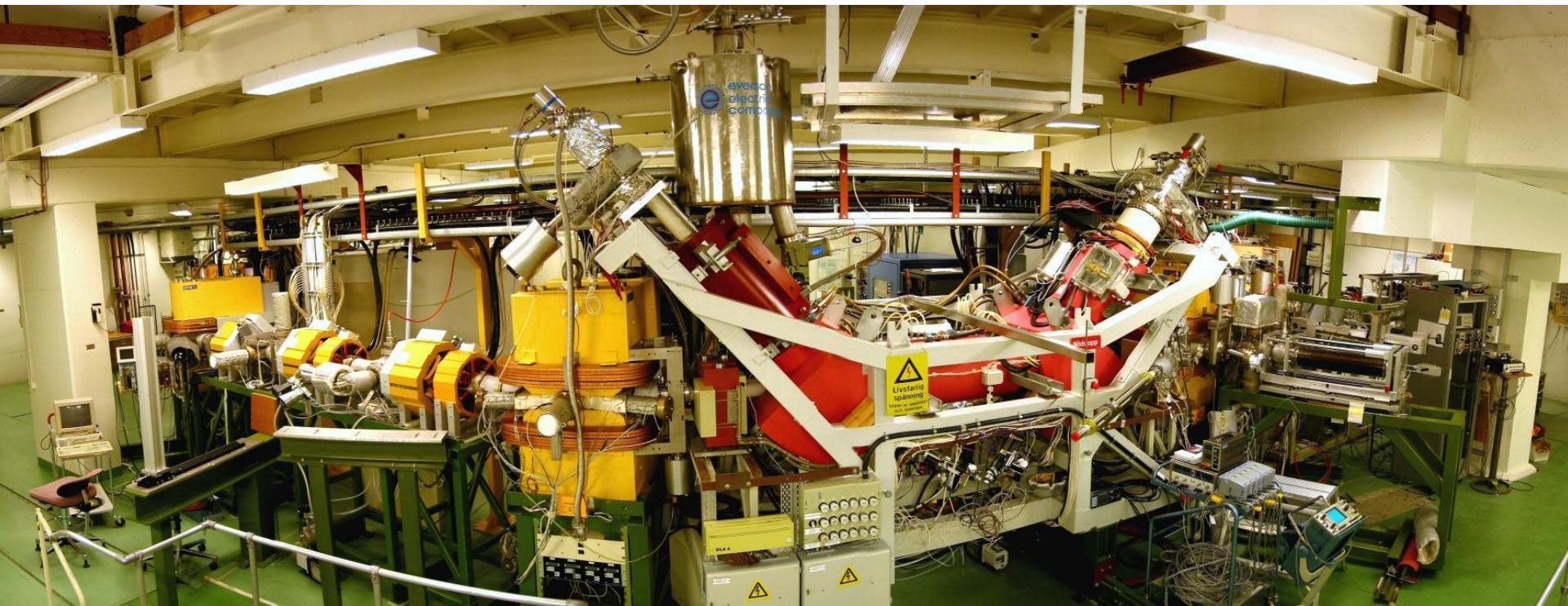
Modification of ESR for CRYRING

- Additional Kicker
in the mean time ... creative use of existing kicker
- Beam line upgrade (ESR – Cave B)
added steering, dipoles; additional diagnostics
- Synchronization ESR/CRYRING Kickers/RF
got easier by increasing the diameter of CRYRING to ESR/2

Towards a reduced cycle time

- Requires faster cooling and more flexible control system

CRYRING in Stockholm



- Successful operated from 1992 to 2010
- Dismantled and shipped to FAIR/GSI in 2012/13

CRYRING History

1985	CRYRING funded by K. and A. Wallenberg foundation
1991	First beam (deuterons)
1992-2010	CRYRING at MSL in Stockholm produces ~400 papers, 43 dissertations, 39 licentiate theses
2006	FAIR Technical report on APPA, SPARC, and FLAIR: CRYRING proposed as LSR
2009	Modularized Start Version (MSV) of FAIR: NESR, FLAIR...
Nov. 2011	Proposal for an early installation of CRYRING@ESR to GSI Science Council
Jun. 2012	"CRYRING@ESR: A study group report" submitted

Ions in CRYRING

Singly charged positive atomic ions:

H^+ , D^+ , ${}^{3}\text{He}^+$, ${}^{4}\text{He}^+$, ${}^{7}\text{Li}^+$, ${}^{9}\text{Be}^+$, ${}^{11}\text{B}^+$, ${}^{12}\text{C}^+$, ${}^{14}\text{N}^+$, ${}^{16}\text{O}^+$, ${}^{40}\text{Ar}^+$, ${}^{40}\text{Ca}^+$, ${}^{45}\text{Sc}^+$, ${}^{48}\text{Ti}^+$, ${}^{56}\text{Fe}^+$,
 ${}^{83}\text{Kr}^+$, ${}^{84}\text{Kr}^+$, ${}^{86}\text{Kr}^+$, ${}^{88}\text{Kr}^+$, ${}^{129}\text{Xe}^+$, ${}^{131}\text{Xe}^+$, ${}^{132}\text{Xe}^+$, ${}^{138}\text{Ba}^+$, ${}^{139}\text{La}^+$, ${}^{142}\text{Nd}^+$, ${}^{151}\text{Eu}^+$, ${}^{197}\text{Au}^+$,
 ${}^{208}\text{Pb}^+$

Multiply charged atomic ions:

${}^4\text{He}^{2+}$, ${}^{11}\text{B}^{2+}$, ${}^{12}\text{C}^{2+}$, ${}^{12}\text{C}^{3+}$, ${}^{12}\text{C}^{4+}$, ${}^{12}\text{C}^{6+}$, ${}^{14}\text{N}^{2+}$, ${}^{14}\text{N}^{3+}$, ${}^{14}\text{N}^{4+}$, ${}^{14}\text{N}^{7+}$, ${}^{16}\text{O}^{2+}$, ${}^{16}\text{O}^{3+}$, ${}^{16}\text{O}^{4+}$,
 ${}^{16}\text{O}^{5+}$, ${}^{16}\text{O}^{8+}$, ${}^{19}\text{F}^{6+}$, ${}^{19}\text{F}^{9+}$, ${}^{20}\text{Ne}^{2+}$, ${}^{20}\text{Ne}^{5+}$, ${}^{20}\text{Ne}^{6+}$, ${}^{20}\text{Ne}^{7+}$, ${}^{20}\text{Ne}^{10+}$, ${}^{28}\text{Si}^{3+}$, ${}^{28}\text{Si}^{11+}$, ${}^{28}\text{Si}^{14+}$,
 ${}^{32}\text{S}^{5+}$, ${}^{36}\text{Ar}^{9+}$, ${}^{36}\text{Ar}^{10+}$, ${}^{36}\text{Ar}^{12+}$, ${}^{36}\text{Ar}^{13+}$, ${}^{40}\text{Ar}^{7+}$, ${}^{40}\text{Ar}^{9+}$, ${}^{40}\text{Ar}^{11+}$, ${}^{40}\text{Ar}^{13+}$, ${}^{40}\text{Ar}^{15+}$, ${}^{48}\text{Ti}^{11+}$,
 ${}^{58}\text{Ni}^{17+}$, ${}^{58}\text{Ni}^{18+}$, ${}^{84}\text{Kr}^{33+}$, ${}^{126}\text{Xe}^{36+}$, ${}^{129}\text{Xe}^{36+}$, ${}^{129}\text{Xe}^{37+}$, ${}^{136}\text{Xe}^{39+}$, ${}^{136}\text{Xe}^{44+}$, ${}^{207}\text{Pb}^{53+}$, ${}^{208}\text{Pb}^{53+}$,
 ${}^{208}\text{Pb}^{54+}$, ${}^{208}\text{Pb}^{55+}$

Positive molecular ions:

H_2^+ , HD^+ , H_3^+ , D_2^+ , H_2D^+ , ${}^3\text{HeH}^+$, ${}^3\text{HeD}^+$, ${}^4\text{HeH}^+$, D_3^+ , He_2^+ , LiH_2^+ , D_5^+ , BH_2^+ , CH_2^+ ,
 NH_2^+ , OH^+ , CH_5^+ , NH_4^+ , H_2O^+ , H_3O^+ , HF^+ , ND_3H^+ , CD_5^+ , ND_4^+ , D_3O^+ , C_2H^+ , CN^+ ,
 C_2H_2^+ , HCN^+ , C_2H_3^+ , HCNH^+ , C_2H_4^+ , CO^+ , N_2^+ , N_2^{2+} , ${}^{13}\text{CO}^+$, N_2H^+ , C_2H_5^+ , H^{13}CO^+ ,
 NO^+ , D^{13}CO^+ , CH_3O^+ , CF^+ , O_2^+ , CH_3NH_3^+ , CH_3OH^+ , CH_3OH_2^+ , H_2S^+ , CD_3O^+ , PD_2^+ ,
 N_2H_7^+ , $\text{D}_2{}^{32}\text{S}^+$, CD_3OH_2^+ , CD_3OD^+ , H_5O_2^+ , $\text{D}_2{}^{34}\text{S}^+$, $\text{D}_3{}^{32}\text{S}^+$, CD_3OD_2^+ , ${}^{13}\text{CD}_3\text{OD}_2^+$,
 $\text{D}_3{}^{34}\text{S}^+$, C_3H_4^+ , $\text{D}_2{}^{37}\text{Cl}^+$, D_5O_2^+ , CH_3CNH^+ , C_3D_3^+ , N_2D_7^+ , N_3^+ , C_3H_7^+ , NaD_2O^+ , CO_2^+ ,
 HCS^+ , $\text{C}_2\text{H}_5\text{O}^+$, DN_2O^+ , $\text{C}_2\text{H}_5\text{OH}^+$, CO_2D^+ , CD_3CDO^+ , $\text{NO}^+\text{H}_2\text{O}$, O_3^+ , DCOOD_2^+ ,
 $\text{CD}_3\text{OCD}_2^+$, C_3D_7^+ , CF_2^+ , $\text{NO}^+\text{D}_2\text{O}$, DC_3N^+ , $\text{CD}_3\text{OCD}_3^+$, $\text{N}_3\text{H}_{10}^+$, DC_3ND^+ ,
 $\text{CD}_3\text{ODCD}_3^+$, H_7O_3^+ , COS^+ , N_2O_2^+ , $\text{CH}_3\text{OCOH}_2^+$, D_7O_3^+ , $\text{N}_3\text{D}_{10}^+$, C_4D_9^+ , $\text{S}^{18}\text{O}_2^+$, ArN_2^+ ,
 H_9O_4^+ , $\text{CD}_3\text{COHNHCH}_3^+$, $\text{CD}_3\text{CONHDCH}_3^+$, C_6D_6^+ , $\text{PO}^{37}\text{Cl}^+$, $\text{H}_{11}\text{O}_5^+$, $\text{C}_2\text{S}_2\text{H}_6^+$,
 $\text{C}_2\text{S}_2\text{H}_7^+$, $\text{H}_{13}\text{O}_6^+$, $\text{PO}^{35}\text{Cl}_2^+$

Negative atomic ions:

H^- , Li^- , F^- , Si^- , S^- , Cl^- , Se^- , Te^-

Negative molecular ions:

CN^- , C_4^- , Si_2^- , Cl_2^-

Range of energies per nucleon: 38 eV/u – 92 MeV/u

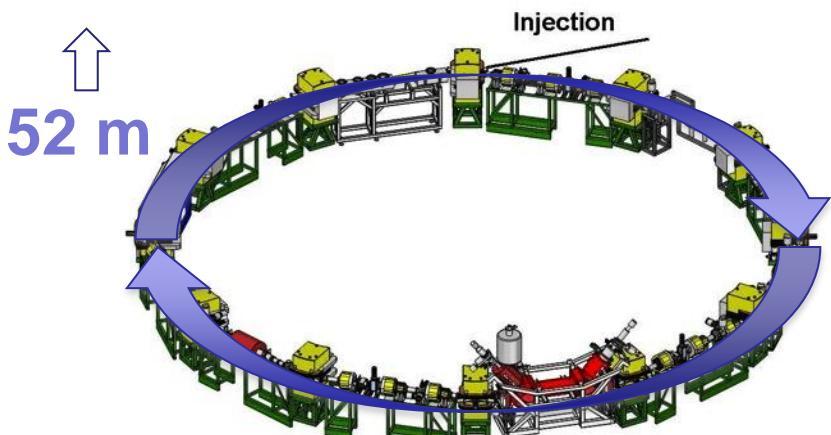
Range of total energies: 5 keV – 1.4 GeV

~200 different ion species



CRYRING Parameters

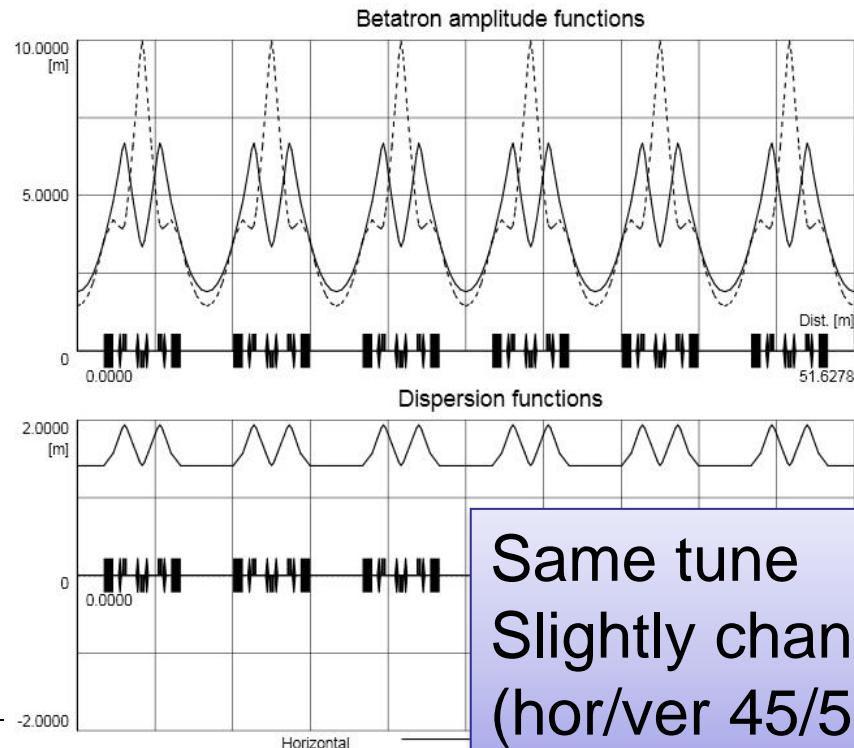
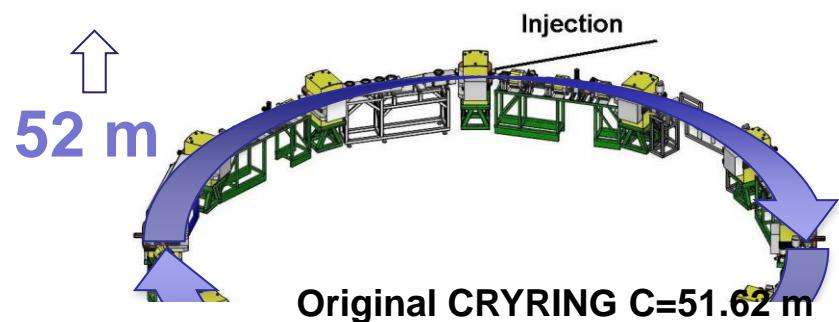
54 m = ESR/2



- Max. rigidity 1.44 Tm
 - 15 MeV/u U^{92+}
 - 96 MeV/u protons
- Min. rigidity ~ 0.054 Tm
 - 150 keV/u protons
- Ramping speed 1 T/s; 7 T/s

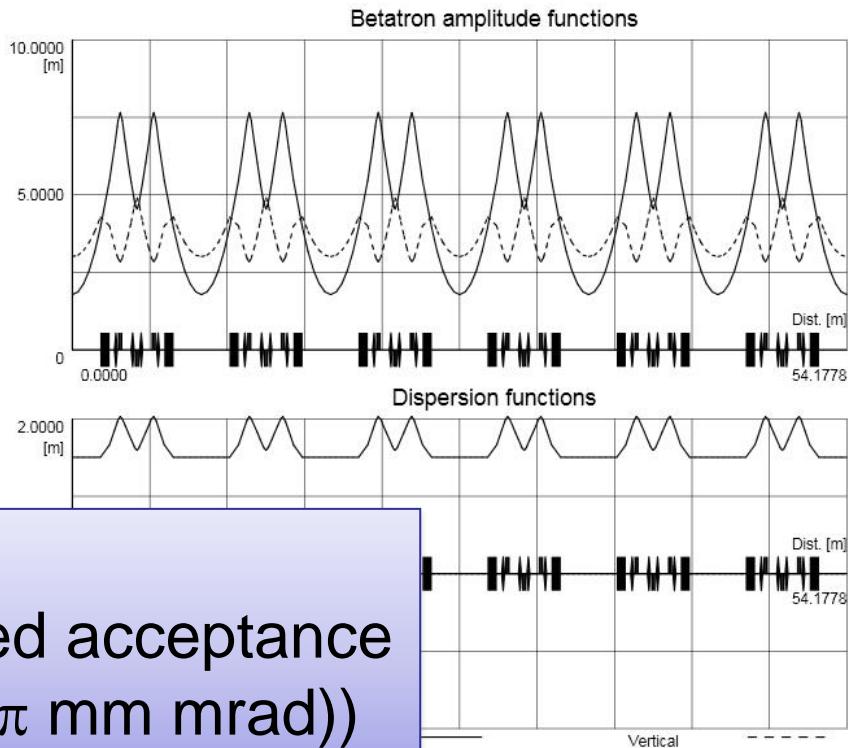
CRYRING Parameters

54 m = ESR/2



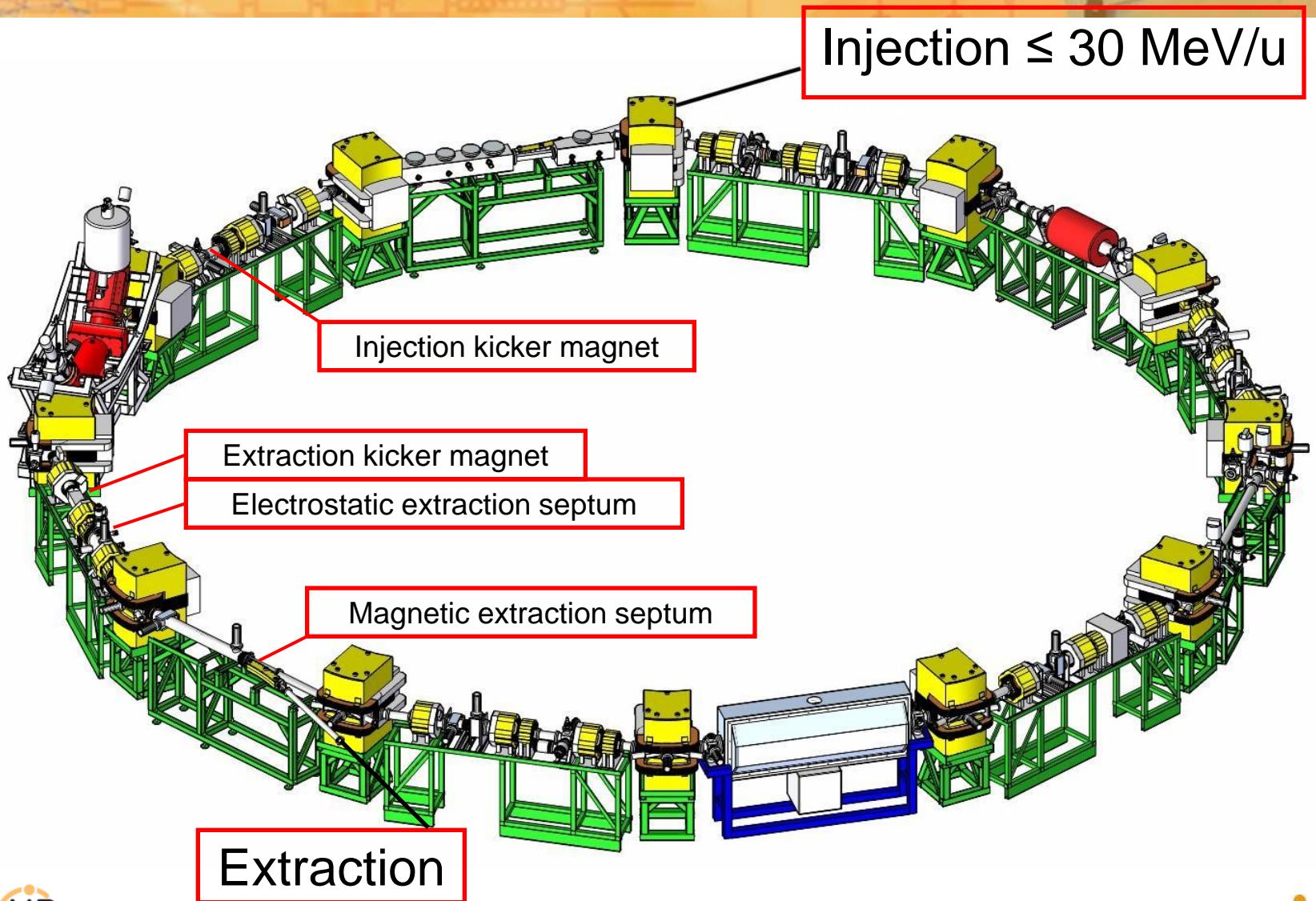
- Max. rigidity 1.44 Tm
- Min. rigidity ~ 0.054 Tm
- Ramping speed 1 T/s; 7 T/s

New circumference $C=54.18\text{ m}$



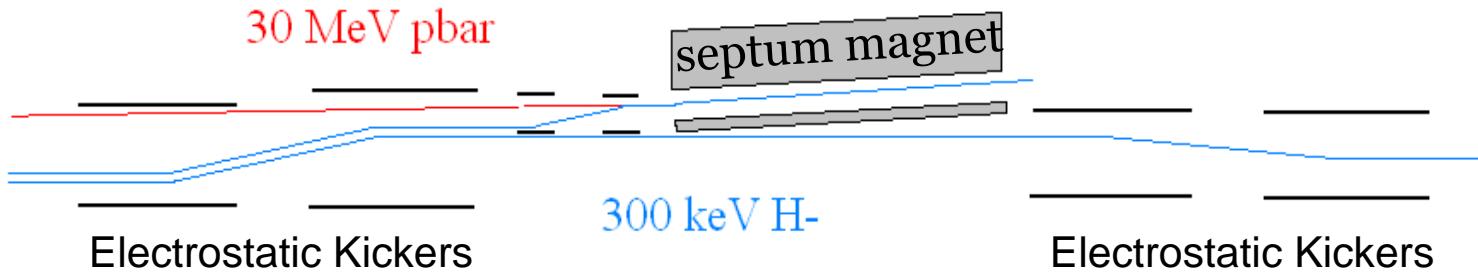
Same tune
Slightly changed acceptance
(hor/ver 45/55 π mm mrad))

CRYRING modifications toward FAIR/GSI

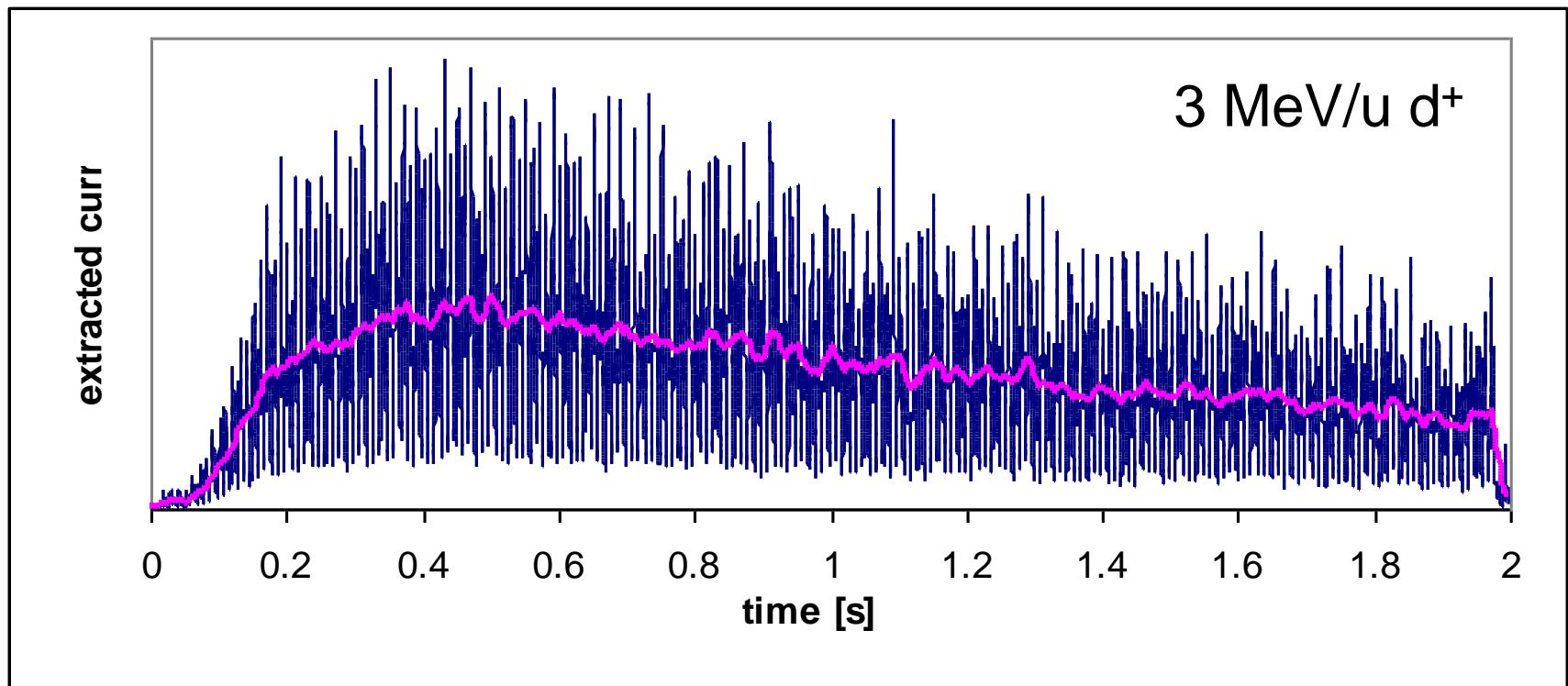


New “dual” Injection System

- Multiturn injection of slow ions (0.3 MeV/u for ions with $q/m \geq 0.25$, $40q \text{ kV}$ for ions with $q/m < 0.25$)
- Single turn injection of fast ions ($B_p 0.79 \text{ Tm}$, e.g. 30 MeV pbar) uses a *kicker magnet with switching time 280 ns in the next straight section*
- Some tweaking to reach 1.4 Tm
 - Use design limits on kicker magnet
 - Pulse the septum magnet



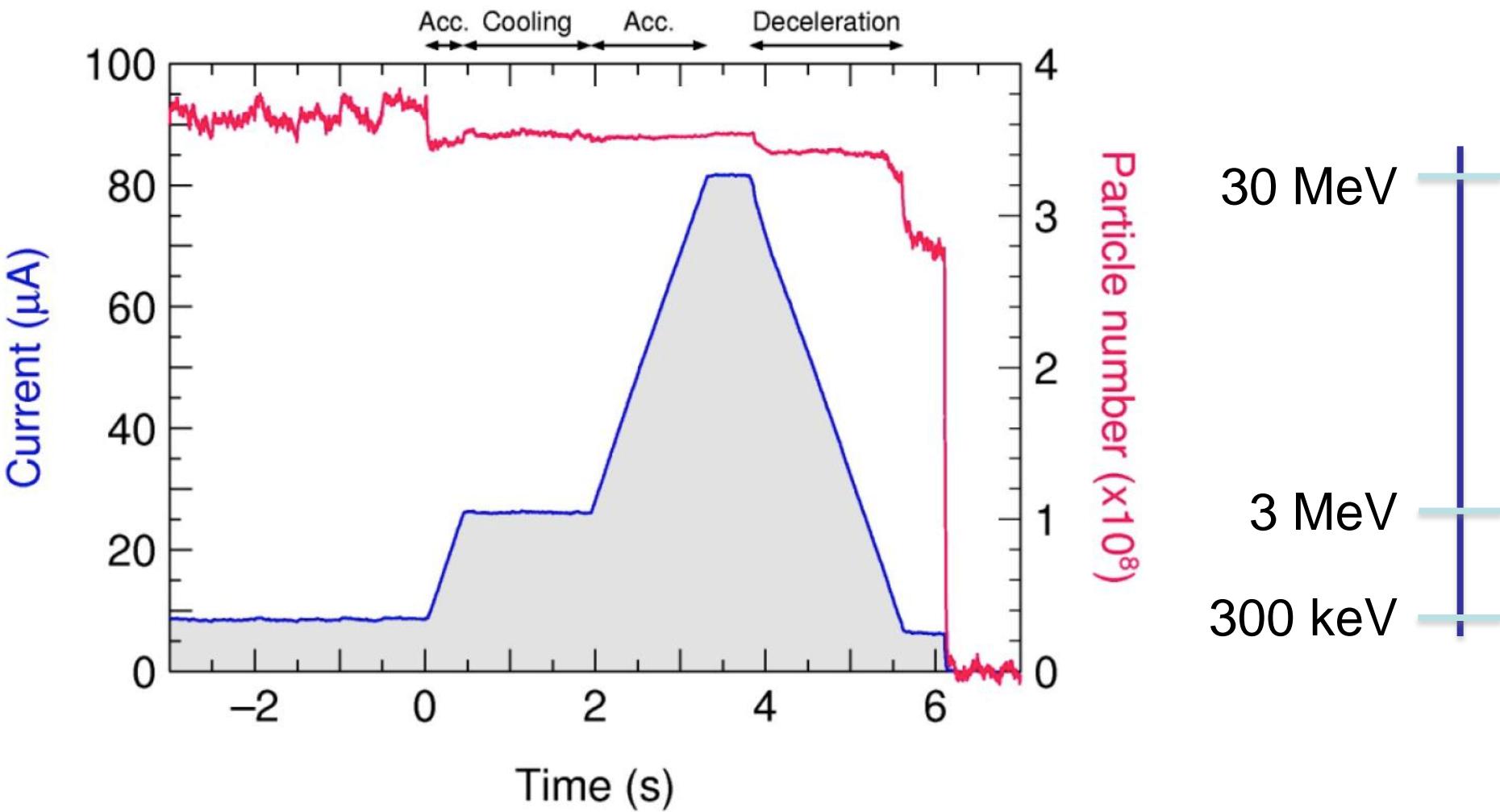
Test of Extraction



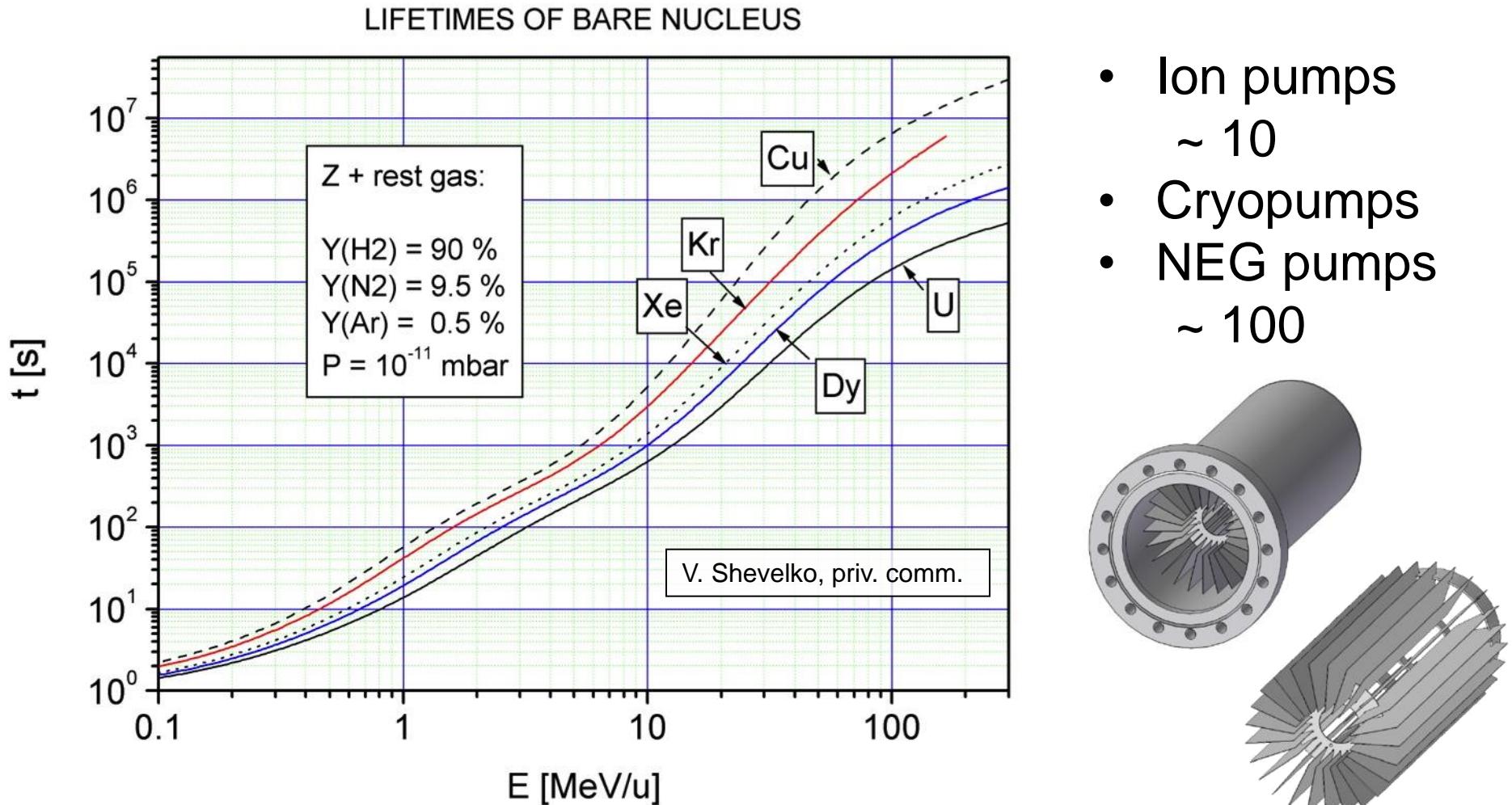
Blue - current measured on the MCP anode of the REX viewer

Pink - 20 ms average (no $n \times 50$ Hz)

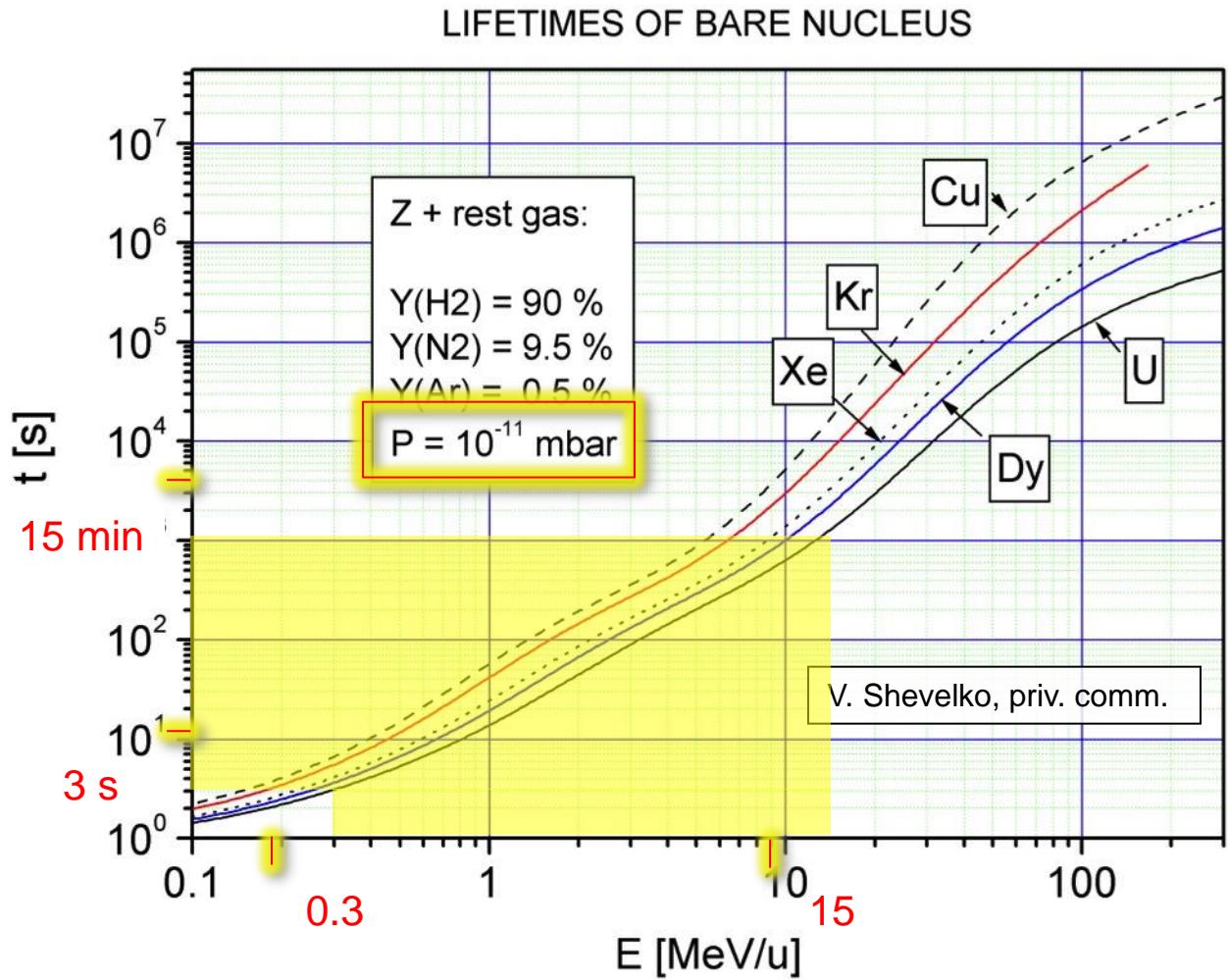
Deceleration in CRYRING



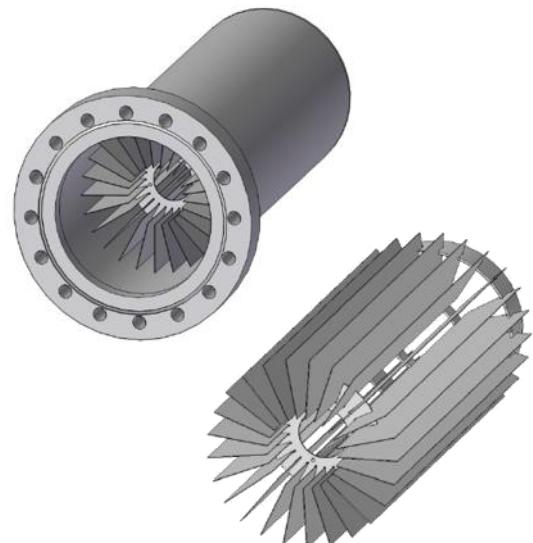
Vacuum & Beam Life Time



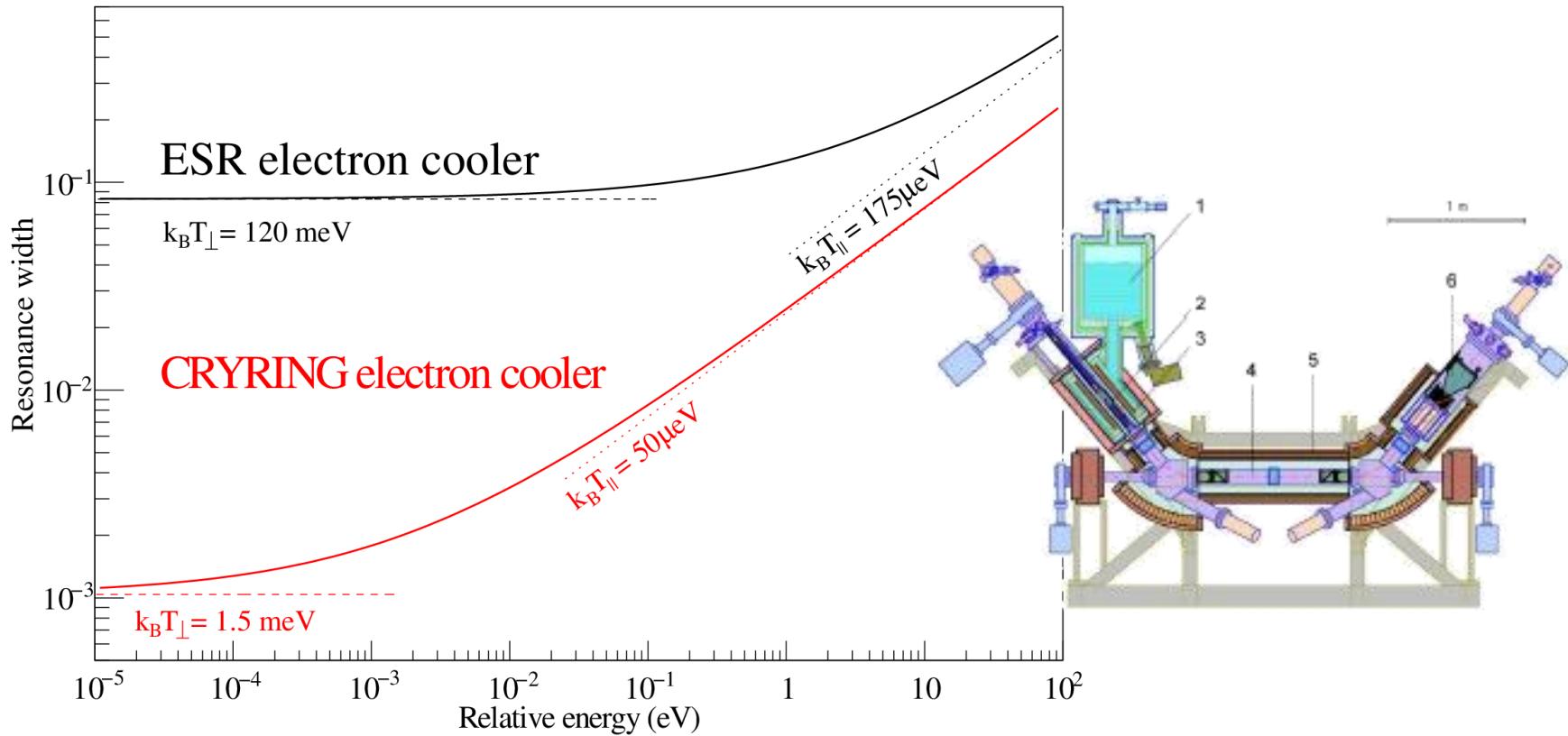
Vacuum & Beam Life Time



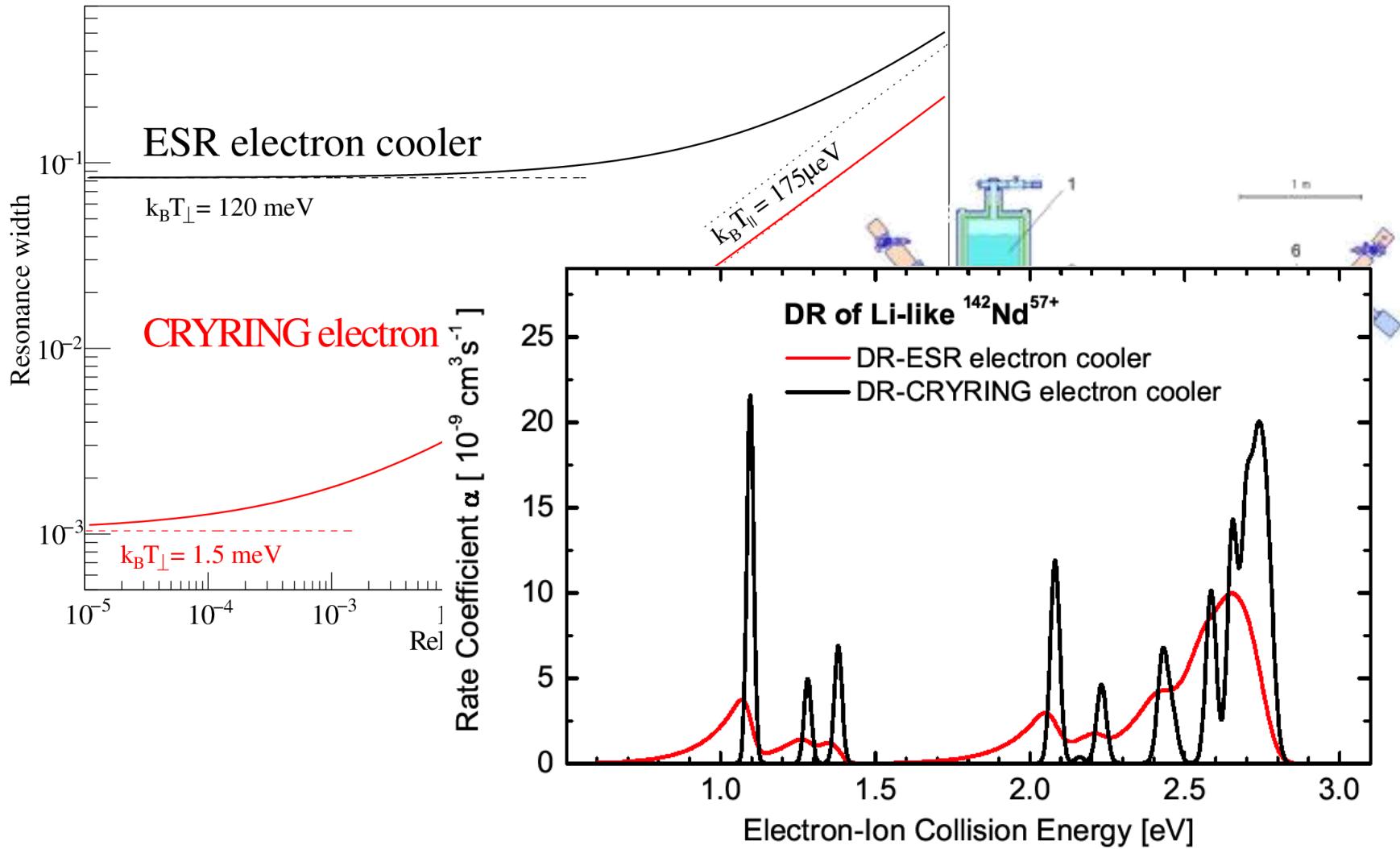
- Ion pumps
~ 10
- Cryopumps
- NEG pumps
~ 100



Electron Cooling ESR - CRYRING



Electron Cooling ESR - CRYRING



Experimental Equipment to be installed

- Schottky beam diagnostics
- Electron cooler / electron-ion merged beam experiments
- Atomic targets (**gas target**, MOTReMi)
- Transverse electron targets
- Particle, X-Ray photon, recoil ion detectors
- Cryogenic current comparator
- Slow extraction beam line



H. Beyer,¹ S. Bisbing,² C. J. Bostedt,³ C. Brinkmann,⁴ A. Breitling-Denton,¹ U. Drey,¹ T. Elbers,⁵ P. Epelbaum,⁶ M. Fiedl,⁷ C. Flory,⁸ N. Frerichs,⁹ D. Fritsch,¹⁰ A. Gieseler,¹¹ K. Glasmacher,¹² E. Goettz,¹³ S. Grönfeld,¹⁴ L. Hahn,¹⁵ J. Heinz,¹⁶ A. Gambetta,¹⁷ S. Higemoto,¹⁸ M. Holt,¹⁹ A. Hora,²⁰ R. Huber,²¹ P. Jauernik,²² C. Karbachow,²³ A. Kästberg,²⁴ M. Leibholz,²⁵ D. Linnemann,²⁶ S. Lohmann,²⁷ B. Marin,²⁸ J. Madsen,²⁹ A. Müller,³⁰ T. Nielsen,³¹ G. Pootas,³² K. Rehrer,³³ M. Reinhard,³⁴ B. Schöppen,³⁵ K. Schötz,³⁶ M. Schulz,³⁷ V. Shabestany,³⁸ A. Smirnov,³⁹ J. Stachowiak,⁴⁰ O. Skopold,⁴¹ R. Sonnabend,⁴² U. Spühler,⁴³ K. Stöhlting,⁴⁴ D. Strickland,⁴⁵ A. Sudarshan,⁴⁶ E. Taborek,⁴⁷ M. Trusinali,⁴⁸ S. Tretiakov,⁴⁹ L. Uzhurman,⁵⁰ M. Walker,⁵¹ C. Weber,⁵² J. D. E.A. Warden,⁵³ R.J. Wessels,⁵⁴ et al.

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Project Timeline

	2012				2013								2014															
	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Clearing Cave B																												
Reconstruction of Cave																												
Disassembly of CRYRING at MSL																												
Transport to GSI																												
Preparation of Components for reassembly																												
Reassembly at ESR																												
Fast beam ejection at ESR																												
Commissioning with RFQ injector																												
First tests of FAIR Diag. & Controls																												
Commissioning with ESR beam																											slow extraction	
First Experiments																												

- All ring components have been delivered
- Cave and component preparation ongoing



Documents related to CRYRING @ GSI and FAIR



Version 1.2

Hans Siegbahn Laboratory
Physics Department
Stockholm University
6 May 2011

CRYRING@ESR:
A study group report

Thannhauser, July 26, 2011

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Infrastructure Proposal

Installation of CRYRING at GSI/FAIR for atomic experiments

Executive summary

CYTRING is a Swedish storage ring for molecular and atomic ions that has been financed by the Knut and Alice Wallenberg Foundation. It is proposed to couple CYTRING to an existing storage ring, ESR (Experimental Storage Ring), and the radioactive beam facility FRIB (Facility for Rare Isotope Beams) at the German GSI Beschleuniger für Schwerionenstrahlung and laser to FAIR (Facility for Antiprotons and Ion Research), which is currently under construction at the same location as GSI. This scenario provides access to a very large number of stable and short-lived stored highly-charged ions at low kinetic energies. Such conditions are world-wide unique and offer unparalleled scientific opportunities for precision experiments in atomic, nuclear, and astrophysics by exploiting the capabilities of an outstanding Swedish scientific programme.

Introducción

The aim central to this proposal is to merge the radiocarbon date facility PRS [1] of GSI/FAIR, at ESR [2], and the Secondary storage ring CRYRING [3] into a combined facility, The East and Alice Wallenberg Foundation has funded, working in IPB, the construction of CRYRING at the Max-Planck-Laboratory, Garching.

The building blocks of visible matter in the universe are atoms, consisting of negatively charged electrons, positively charged protons and neutral neutrons. The latter two form atomic nuclei. If electrons are present, the formation of

atoms and nuclei visible under electrically neutral earth. Rather, in contrast, such atoms in a plasma and ions — are electrons to be equilibrated.

ef. matter becomes
number of electrons
to become electrically
prepared and to
using magnetic
well-defined trajectory
tube. Ion storage
infinite account
times are having
residual gas streams
radioactivities are

In addition electric or motorized valves can also be selected. These valves can be connected to the ring for a storage tank instrument, which has been used quite successfully.

acceleration, and
There are a
particle circula-
important use in
using acceleration
ring. Classify re-
buses. Cooling
stated particles
trajectory and
extremes of the
particles are [

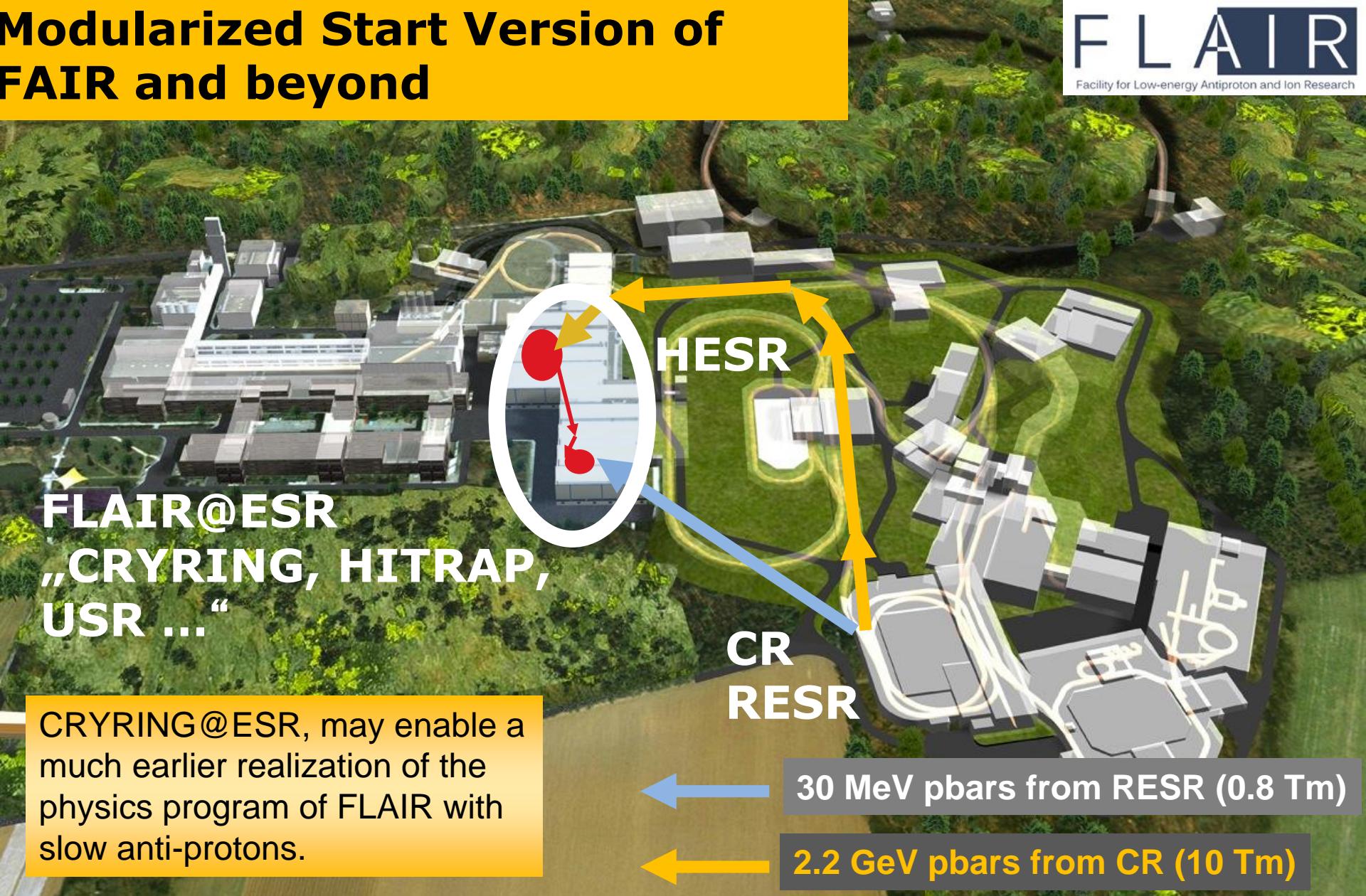
Physics book
CRYSTALLOGRAPHY

This section is an early reading sample and is not representative of the complete test.

H. Heyen,¹ S. Bishop,¹ C. J. Howe,¹ D. Chmelar,¹ A. Brattinga-Demire,¹ T. Hoy,² T. Hirschfeld,² P. F. Daniell,² M. R. Johnson,² N. A. Bernick,² D. Hoch,² A. Schlesinger,² E. Ronai,² S. Schlesinger,² J. L. Hart,³ J. G. Parker,³ A. Gundersen,³ S. H. Grimes,³ M. Field,⁴ A. Heintz,⁴ K. Kopp,⁴ J. P. McNamee,⁴ C. Asbury,⁴ A. Edling,⁴ M. Lovelock,⁴ S. Lamm,⁴ J. W. B. Studd,⁴ S. M. Moore,⁴ E. Mandelbaum,⁴ A. Miller,⁴ T. Nelson,⁴ G. Pashley,⁴ K. Reznick,⁴ J. Schlesinger,⁴ S. Schoppeck,⁴ K. Schmitz,⁴ M. Schulz,⁴ V. Shabot,⁴ A. Simonow,⁴ J. Strober,⁴ D. Steppich,⁴ K. Sonnenburg,⁴ U. Spillmann,⁴ E. Stoeckli,⁴ D. Strober,⁴ A. Sulzberger,⁴ K. Thibert,⁴ J. Tissir,⁴ S. Trockenboeck,⁴ L. Uchermann,⁴ D. S. Vandevert,⁴ J. Walker,⁴ C. Weber,⁴ D. J. A. Weston,⁴ D. J. Weiss,⁴

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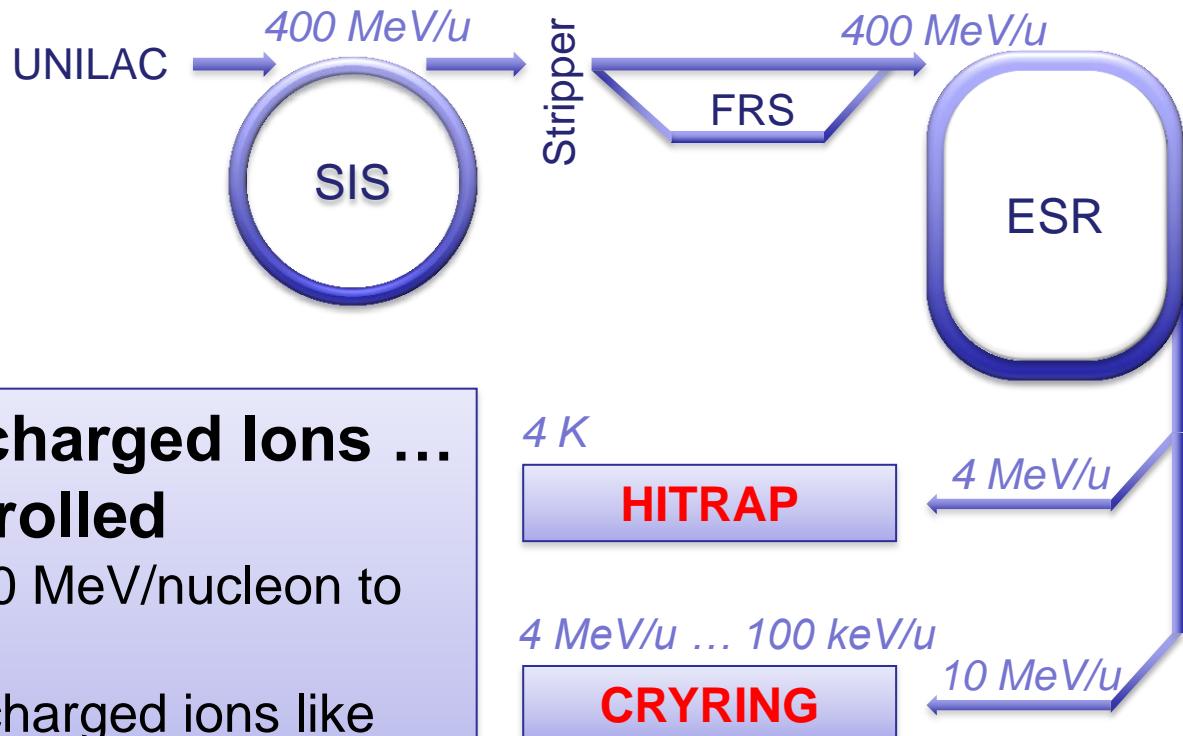
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