

CRYRING @ ESR

heavy, highly-charged ions stored at low Energy

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

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WHY?

HCI

Highly Charged Ions

Elements

Isotopes

+ Matter

g-factor

α, m_e

e⁻-binding

QED test

Charge radii

FS, HFS

BW effect

Lamb-shift

+ surface

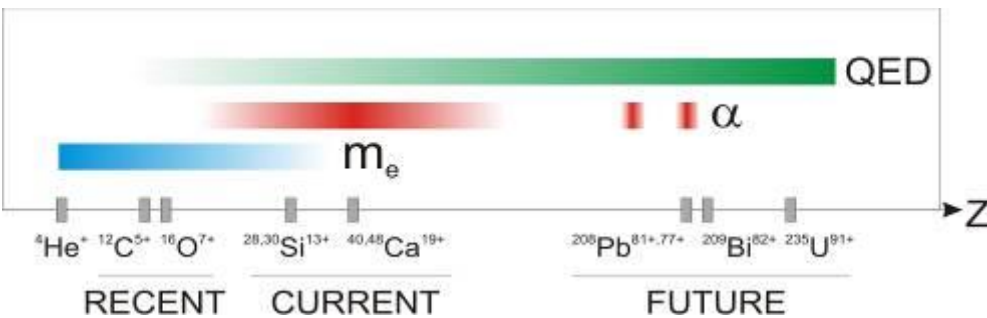
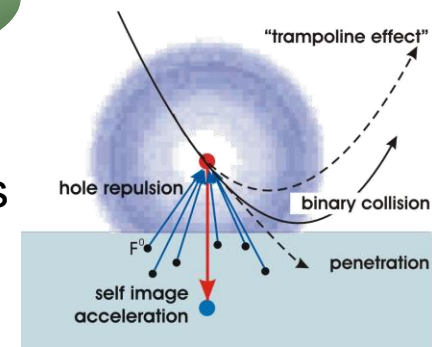
Structures

+ atoms

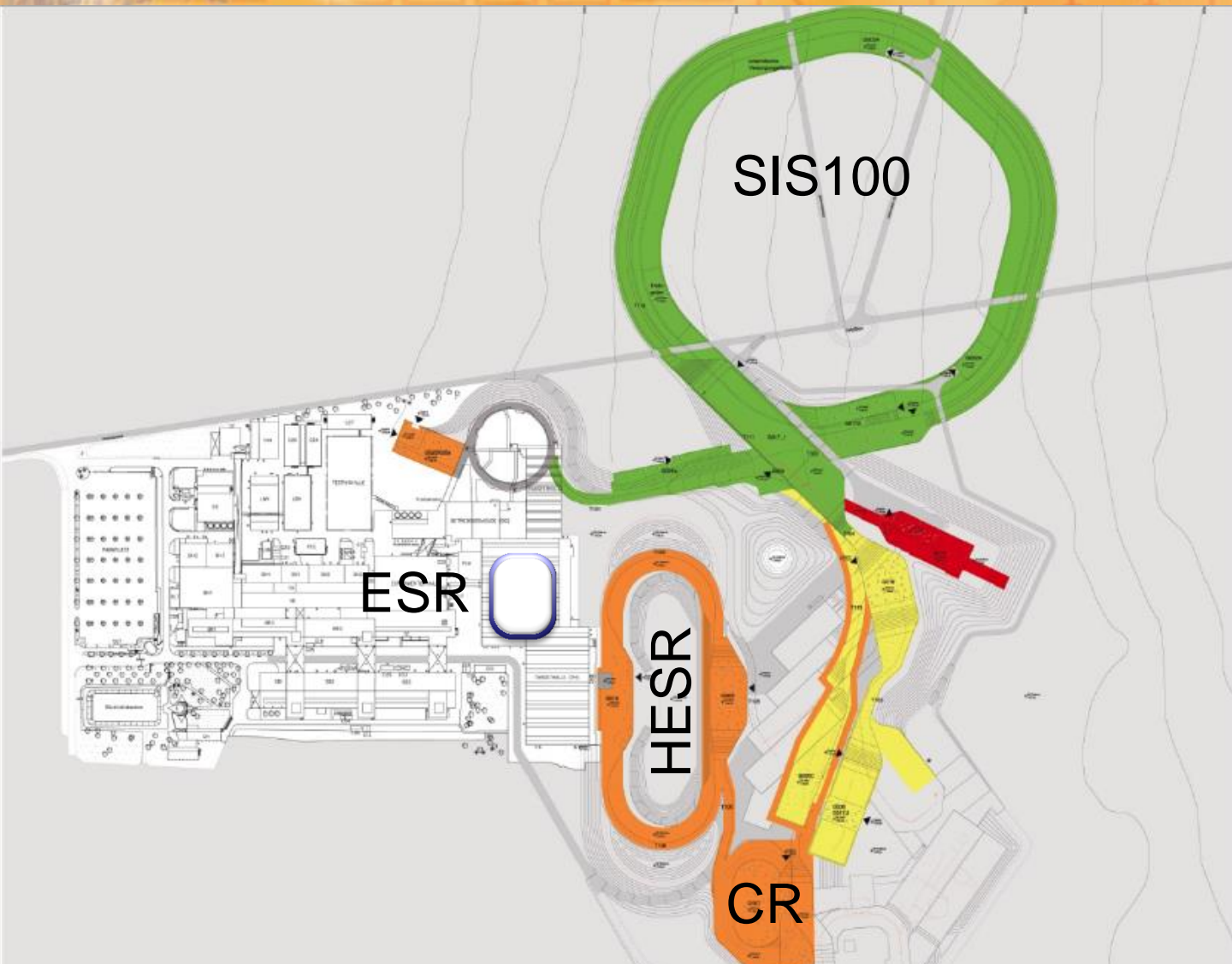
Charge exchange

Collision dynamics

Hollow atoms



The "Green Paper" – Stepwise to FAIR



-  **Module 0**
SIS 100
-  **Module 1**
*Exp. Areas CBM/
HADES, APPA*
-  **Module 2**
Super-FRS
-  **Module 3**
*Antiprotons for
PANDA
(CR, HESR)*
-  **Upgrade**

But: ESR continues!

CRYRING @ ESR

FAIR Research & Development

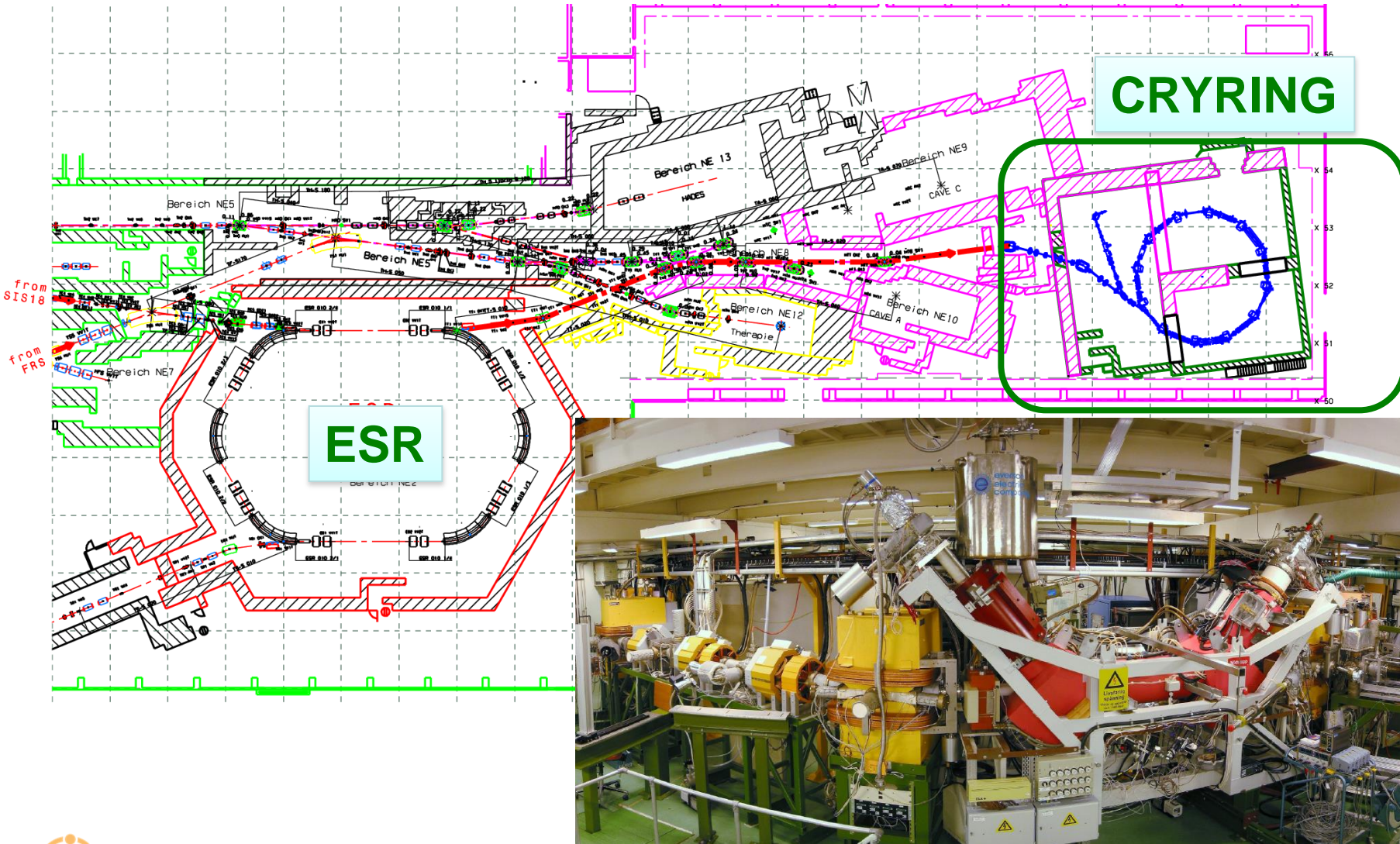
- Detectors and diagnostic systems
- FAIR type control system
- Training of operators on FAIR type system
- FAIR type safety and radiation monitoring/access system

All this with real beam!

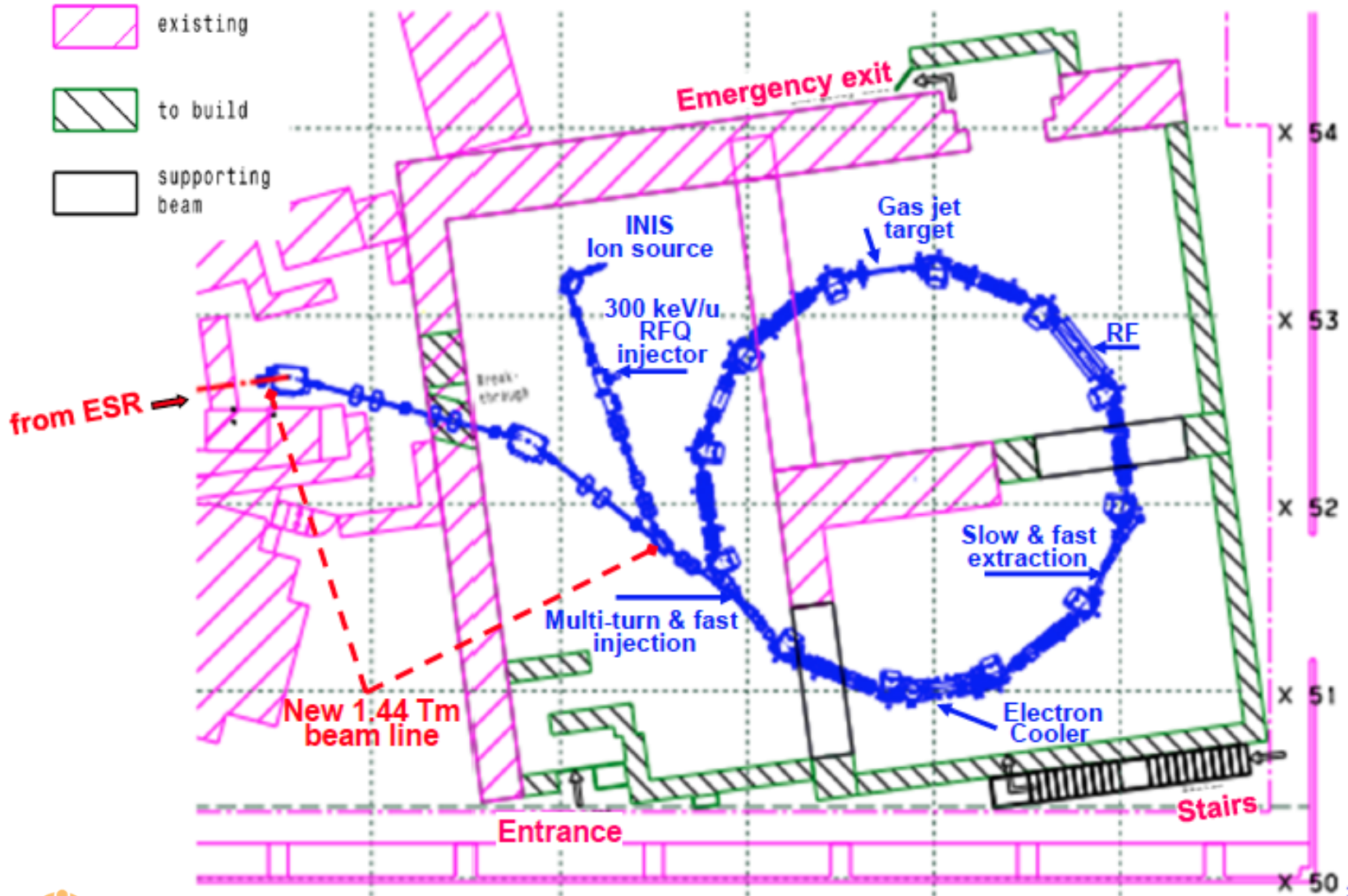
Scientific Opportunities

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

CRYRING @ ESR



CRYRING @ ESR in modified Cave B



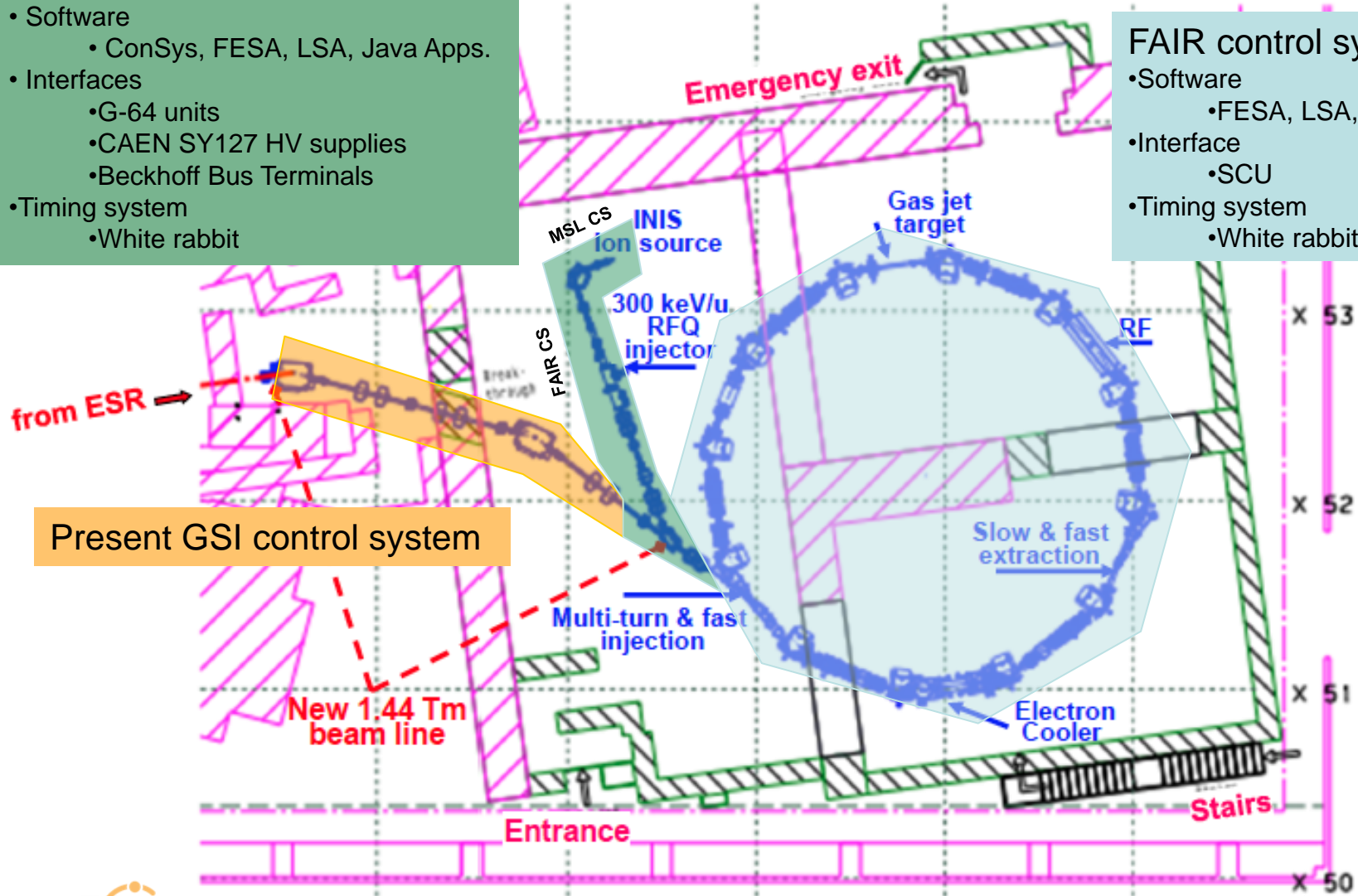
CRYRING @ ESR Control System

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

FAIR control system

- Software
 - FESA, LSA, Java Apps.
- Interface
 - SCU
- Timing system
 - White rabbit



Present GSI control system

ESR – From 400 to 4 MeV/u

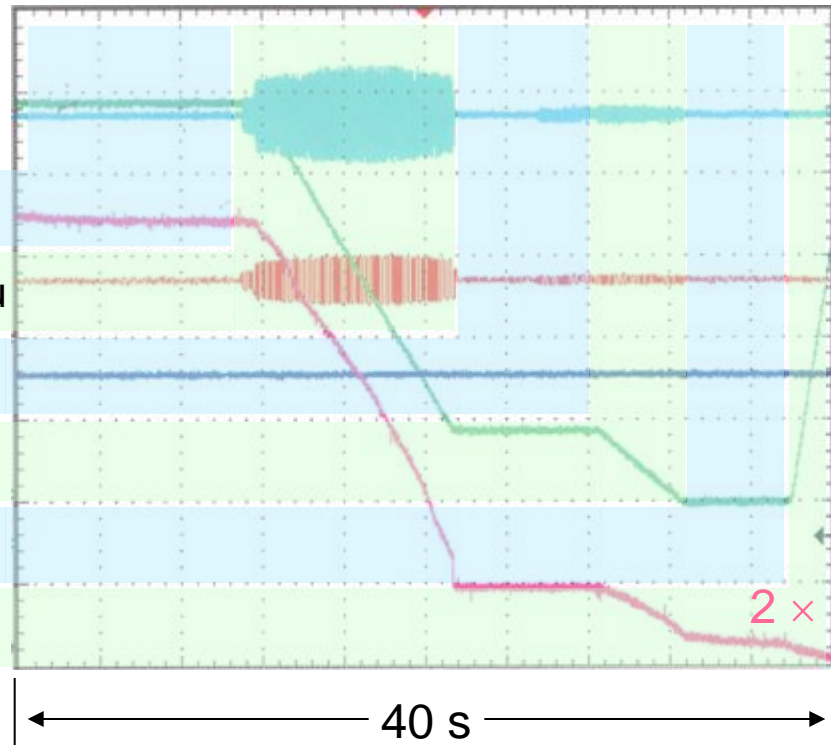
ESR – Experimental Storage Ring at GSI with stochastic and electron cooling

Ni^{28+} 400 → 30 → 4 MeV/u

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

2×10^7
ion current

40 s

$1100 \mu\text{A} \rightarrow 180 \mu\text{A} \rightarrow 25 \mu\text{A}$

ESR – From 400 to 4 MeV/u

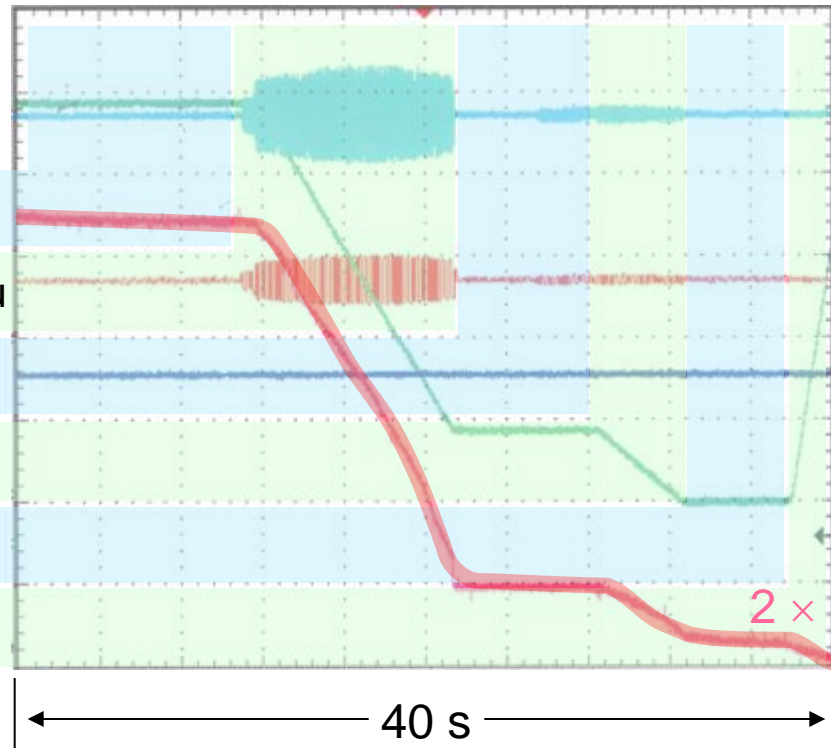
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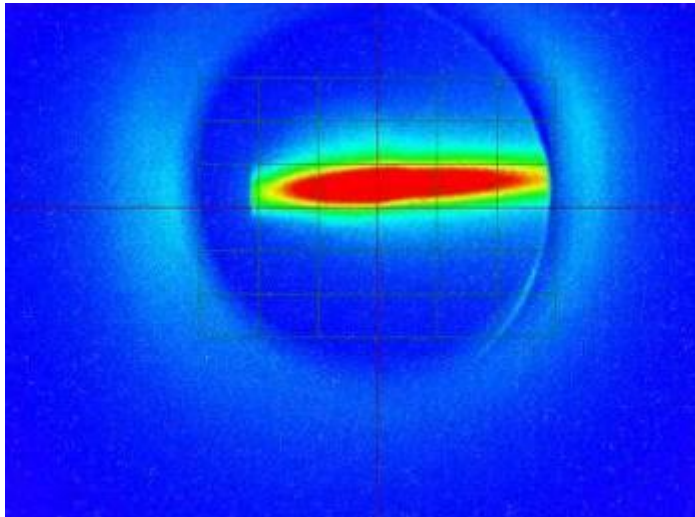
magn. dipole field

2×10^7
ion current

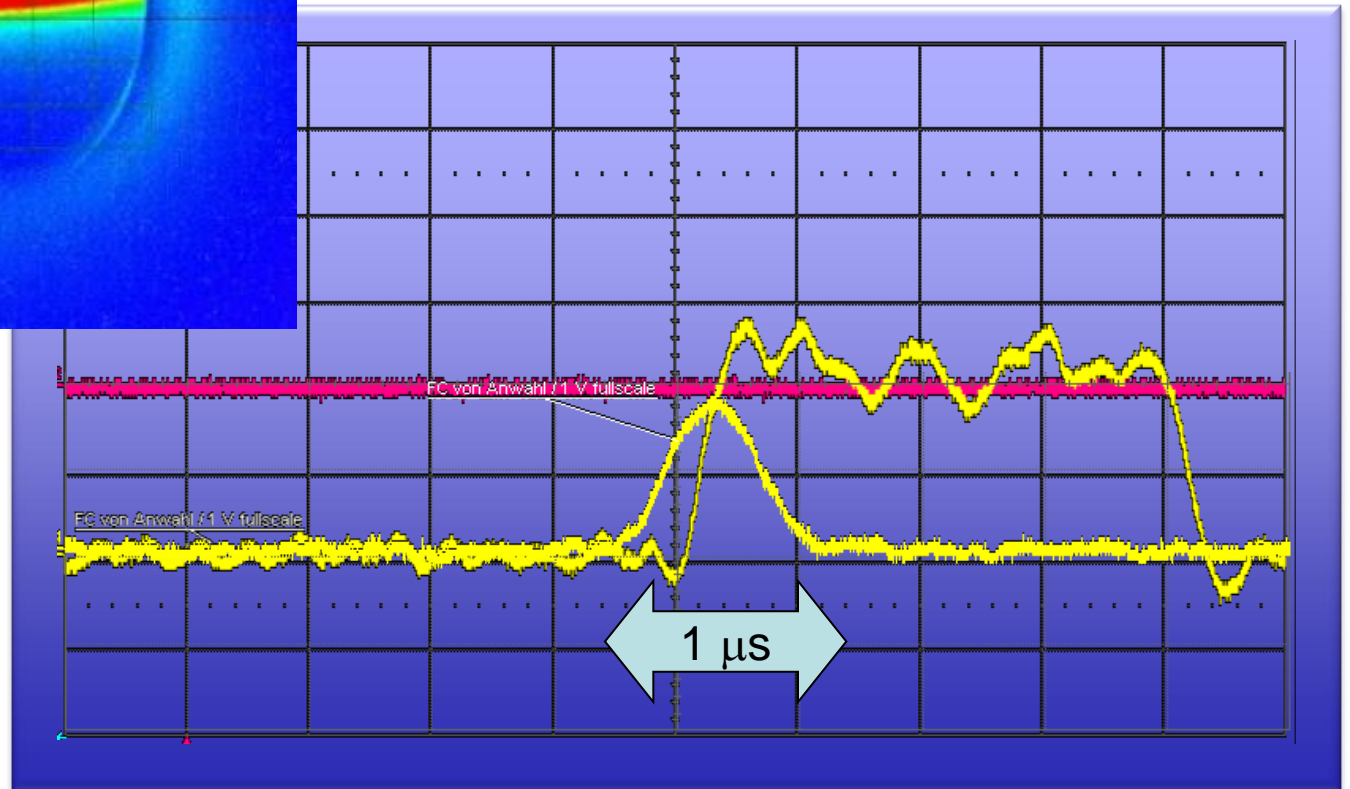
40 s

$1100 \mu\text{A} \rightarrow 180 \mu\text{A} \rightarrow 25 \mu\text{A}$

4 MeV/u ions from ESR

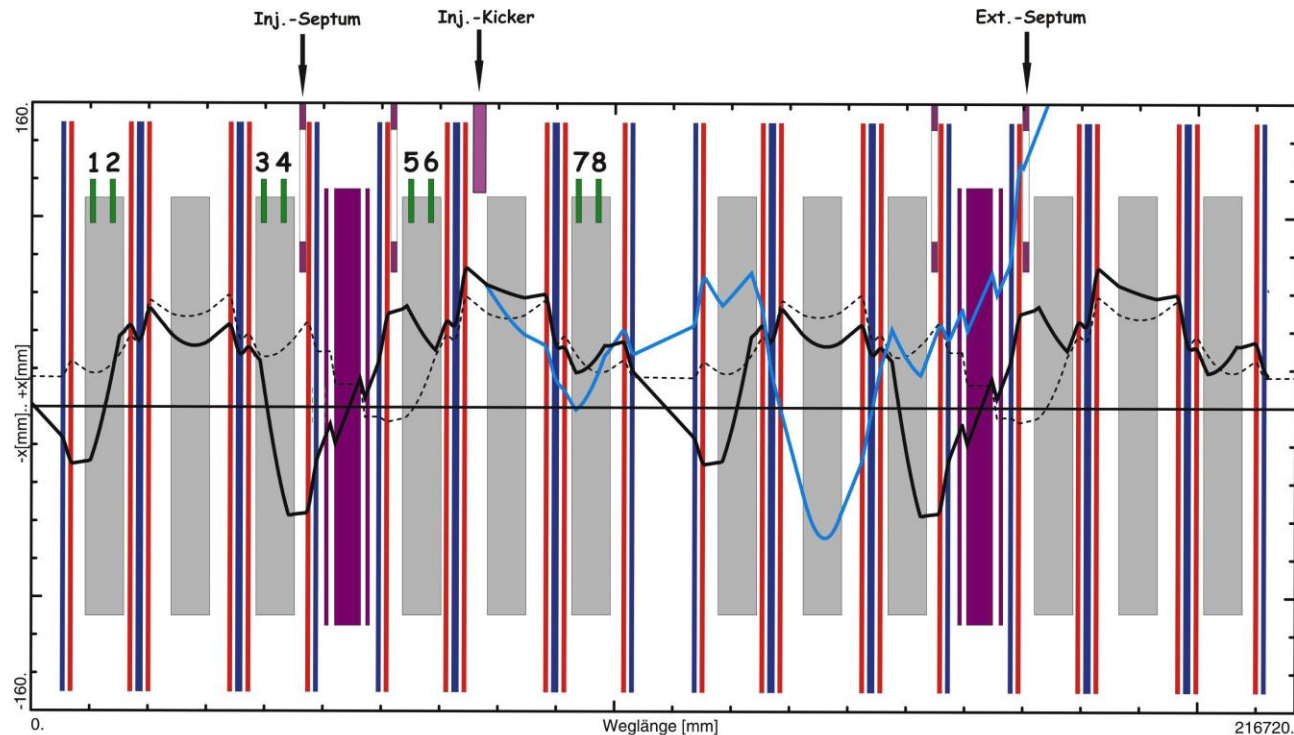


2×10^7 $^{136}\text{Xe}^{50+}$ extracted from ESR



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

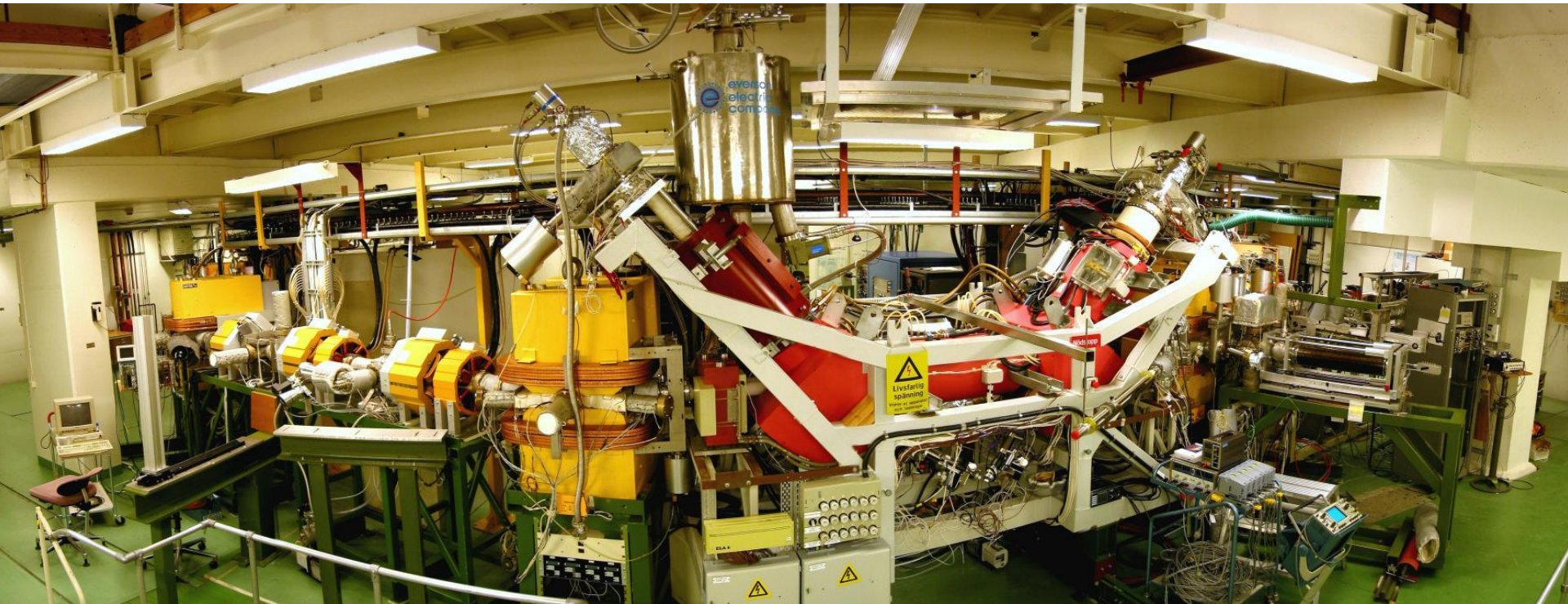
Modification of ESR for CRYRING

- 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:

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

Multiply charged atomic ions:

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

Positive molecular ions:

$H_2^+, HD^+, H_3^+, D_2^+, H_2D^+, {}^3HeH^+, {}^3HeD^+, {}^4HeH^+, D_3^+, He_2^+, LiH_2^+, D_5^+, BH_2^+, CH_2^+, NH_2^+, OH^+, CH_5^+, NH_4^+, H_2O^+, H_3O^+, HF^+, ND_3H^+, CD_5^+, ND_4^+, D_3O^+, C_2H^+, CN^+, C_2H_2^+, HCN^+, C_2H_3^+, HCNH^+, C_2H_4^+, CO^+, N_2^+, N_2^{2+}, {}^{13}CO^+, N_2H^+, C_2H_5^+, H^{13}CO^+, NO^+, D^{13}CO^+, CH_3O^+, CF^+, O_2^+, CH_3NH_3^+, CH_3OH^+, CH_3OH_2^+, H_2S^+, CD_3O^+, PD_2^+, N_2H_7^+, D_2^{32}S^+, CD_3OH_2^+, CD_3OD^+, H_5O_2^+, D_2^{34}S^+, D_3^{32}S^+, CD_3OD_2^+, {}^{13}CD_3OD_2^+, D_3^{34}S^+, C_3H_4^+, D_2^{37}Cl^+, D_5O_2^+, CH_3CNH^+, C_3D_3^+, N_2D_7^+, N_3^+, C_3H_7^+, NaD_2O^+, CO_2^+, HCS^+, C_2H_5O^+, DN_2O^+, C_2H_5OH^+, CO_2D^+, CD_3CDO^+, NO^+·H_2O, O_3^+, DCOOD_2^+, CD_3OCD_2^+, C_3D_7^+, CF_2^+, NO^+·D_2O, DC_3N^+, CD_3OCD_3^+, N_3H_{10}^+, DC_3ND^+, CD_3ODCD_3^+, H_7O_3^+, COS^+, N_2O_2^+, CH_3OCOH_2^+, D_7O_3^+, N_3D_{10}^+, C_4D_9^+, S^{18}O_2^+, ArN_2^+, H_6O_4^+, CD_3COHNHCH_3^+, CD_3CONHDCH_3^+, C_6D_6^+, PO^{37}Cl^+, H_{11}O_5^+, C_2S_2H_6^+, C_2S_2H_7^+, H_{13}O_6^+, PO^{35}Cl_2^+$

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

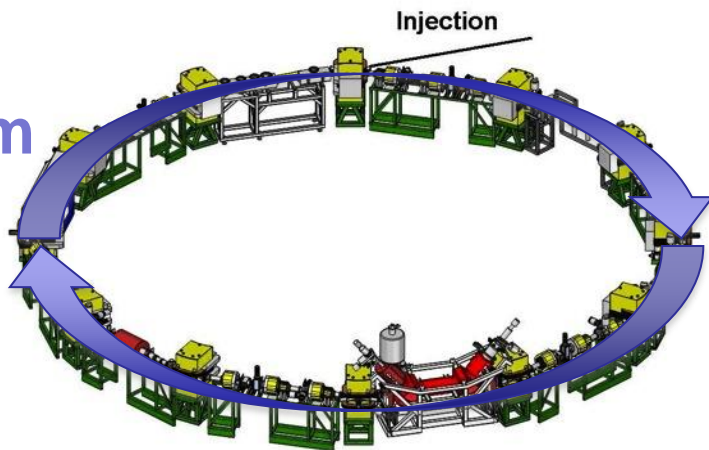
~200 different ion species

CRYRING Parameters

54 m = ESR/2



52 m



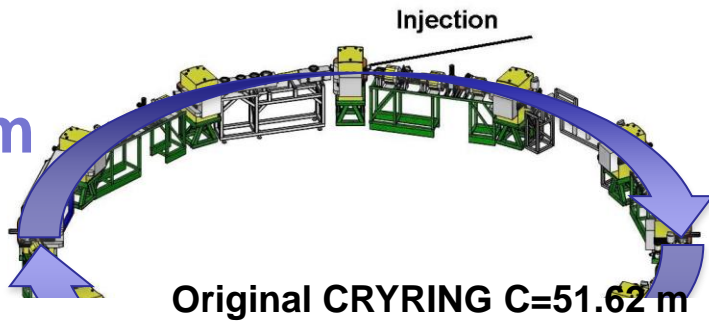
- Max. rigidity 1.44 Tm
 - 15 MeV/u U^{92+}
 - 96 MeV/u protons
- Min. rigidity ~ 0.054 Tm
 - 150 keV/u protons
- Ramping speed 1 T/s; 7 T/s

CRYRING Parameters



54 m = ESR/2

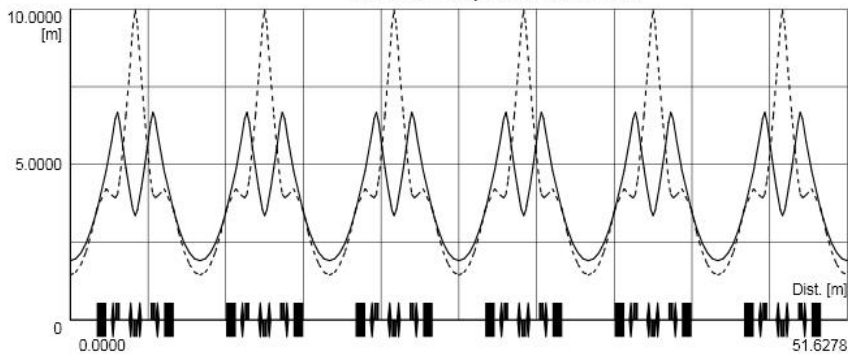
↑
52 m



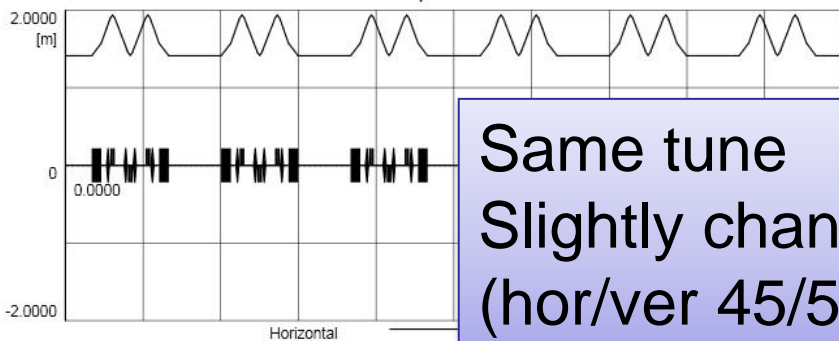
- Max. rigidity 1.44 Tm
- Min. rigidity ~ 0.054 Tm
- Ramping speed 1 T/s; 7 T/s

New circumference C=54.18 m

Betatron amplitude functions

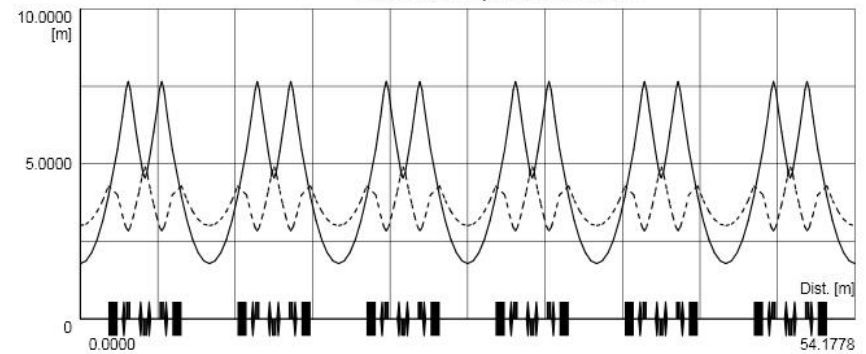


Dispersion functions

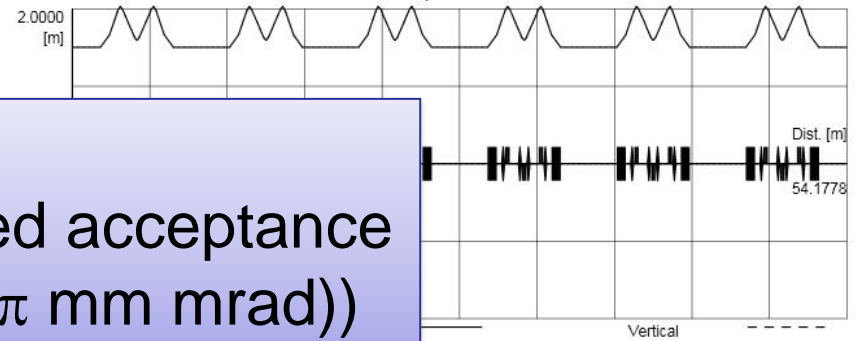


Horizontal

Betatron amplitude functions



Dispersion functions

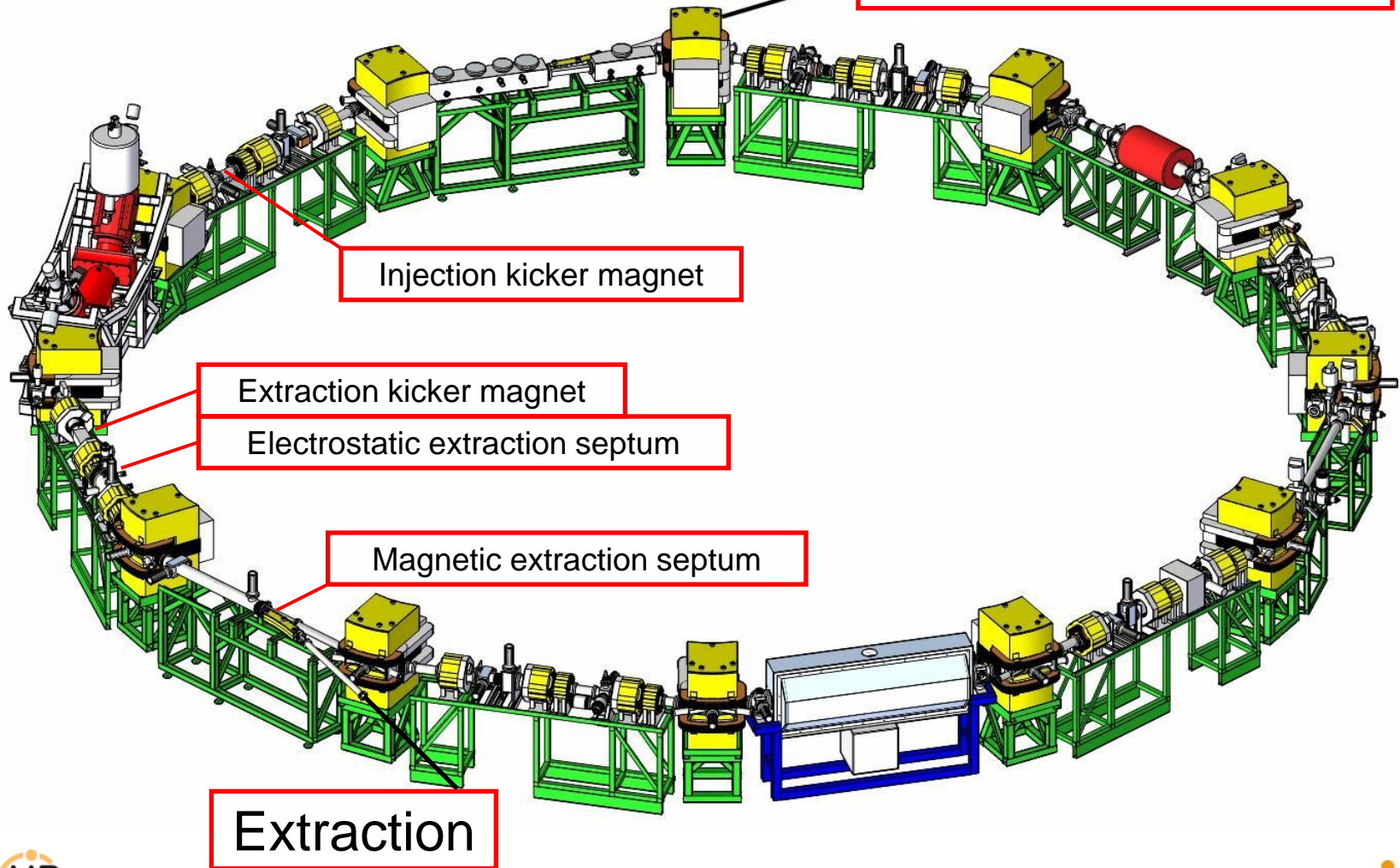


Vertical

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

CRYRING modifications toward FAIR/GSI

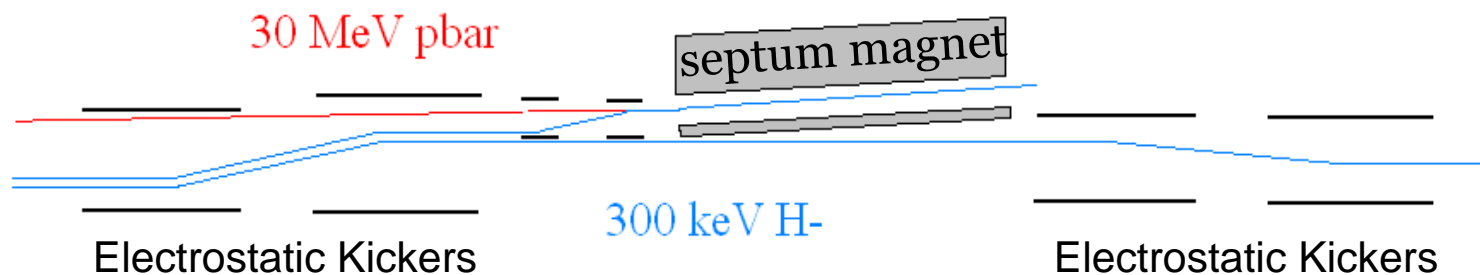
Injection ≤ 30 MeV/u



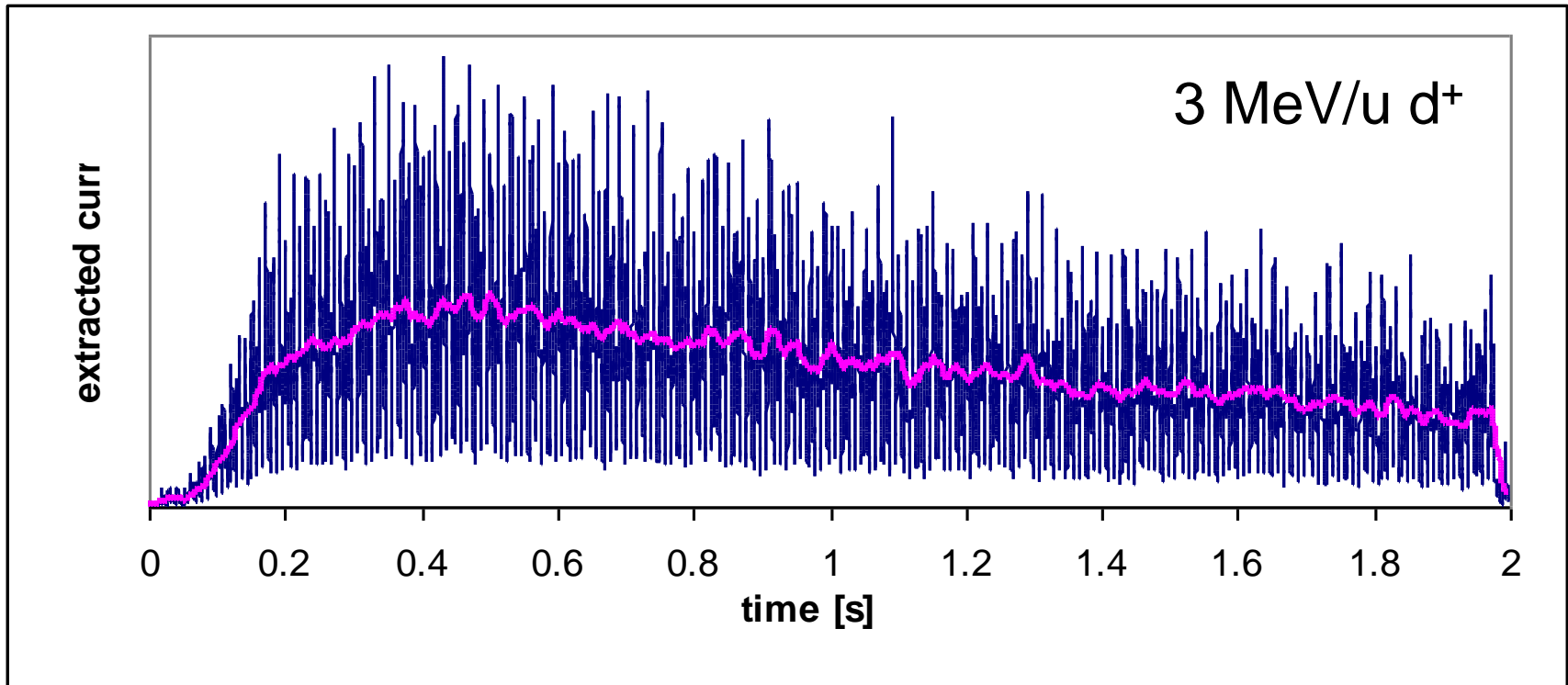
New “dual” Injection System



- Multiturn injection of slow ions (0.3 MeV/u for ions with $q/m \geq 0.25$, 40q kV for ions with $q/m < 0.25$)
- Single turn injection of fast ions ($B\rho$ 0.79 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



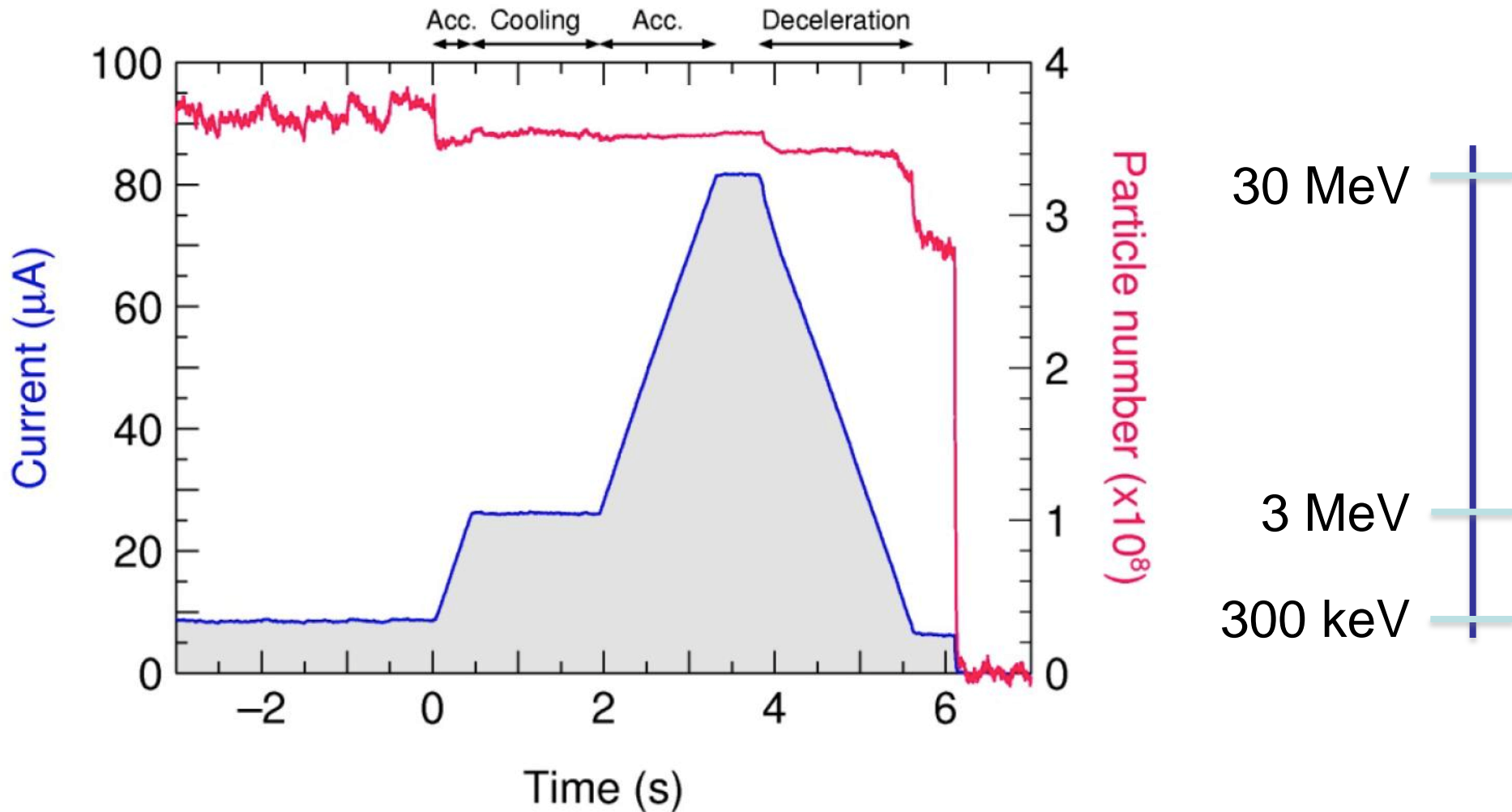
Test of Extraction



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

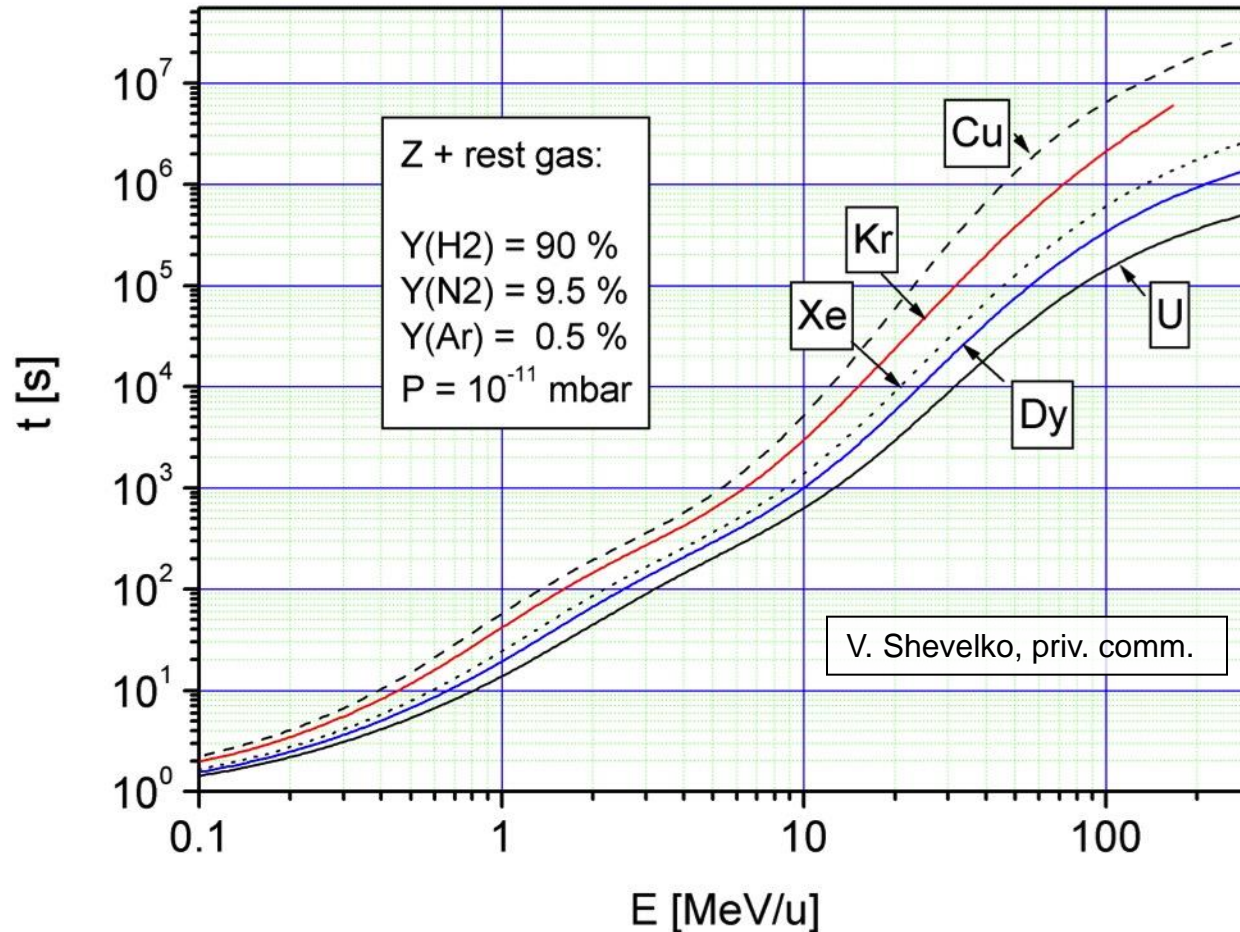
Pink - 20 ms average (no $n \times 50$ Hz)

Deceleration in CRYRING

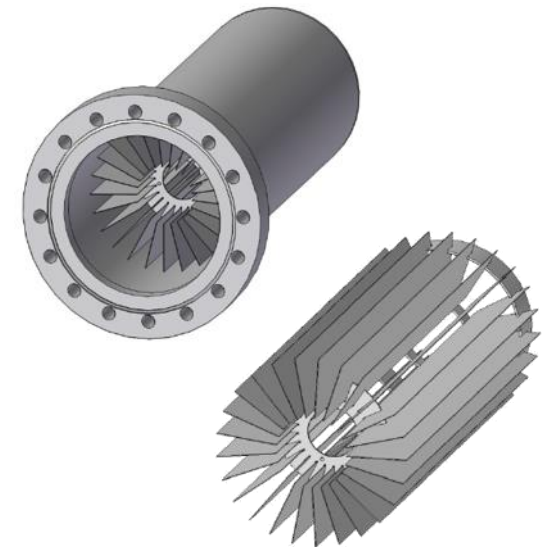


Vacuum & Beam Life Time

LIFETIMES OF BARE NUCLEUS

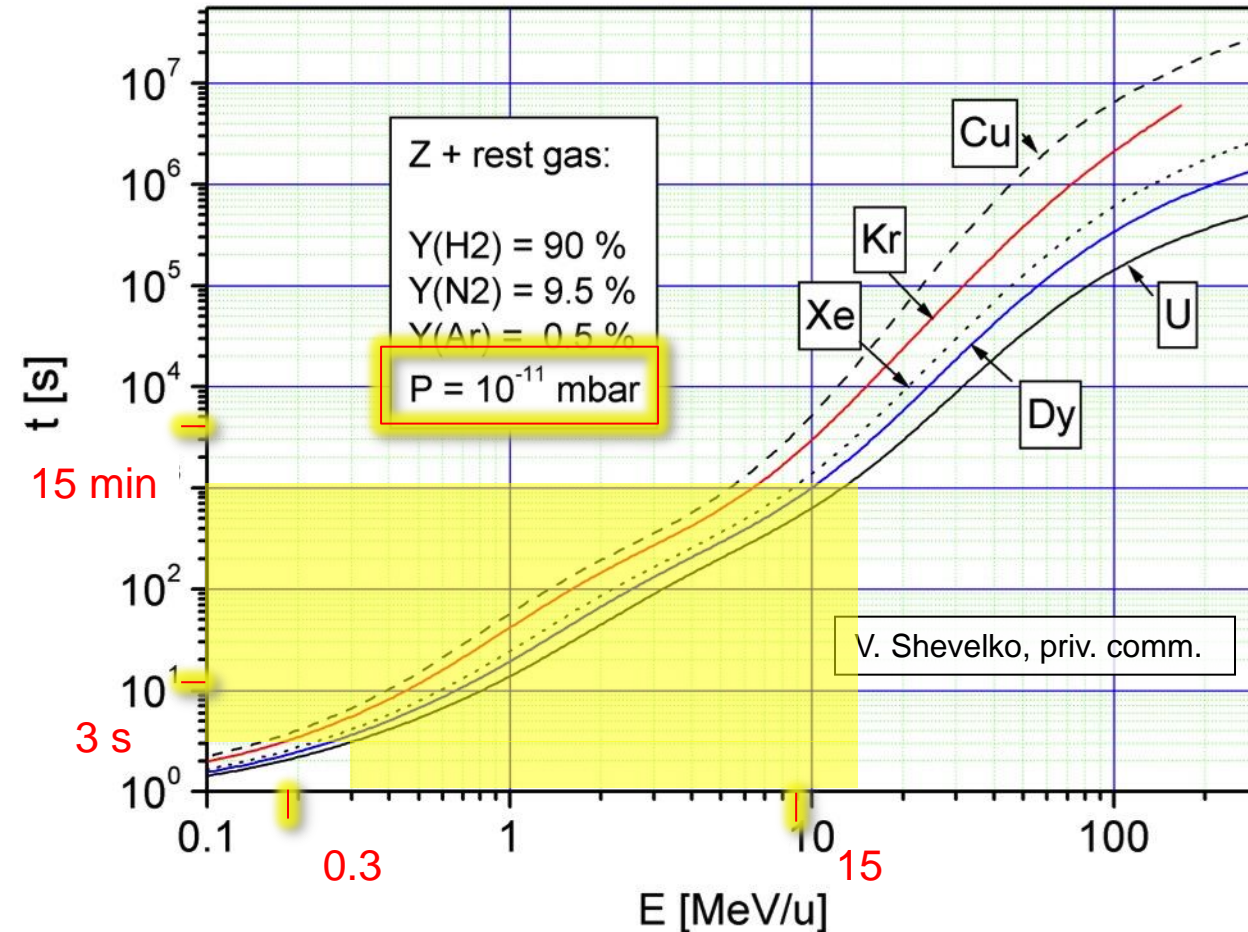


- Ion pumps
~ 10
- Cryopumps
- NEG pumps
~ 100

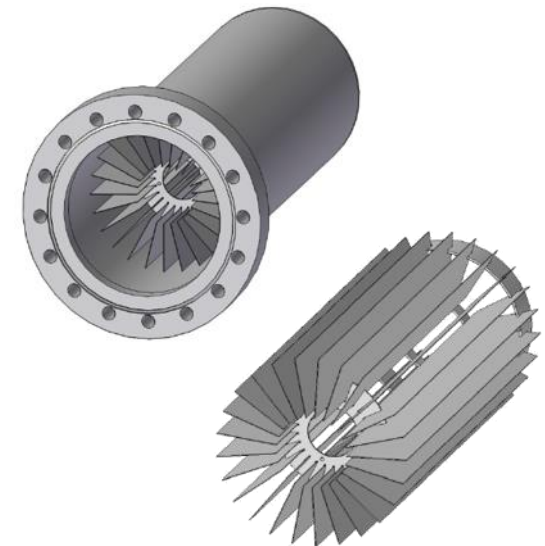


Vacuum & Beam Life Time

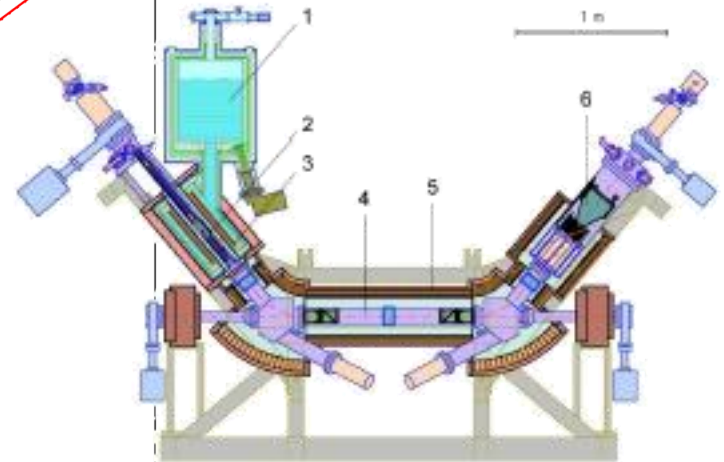
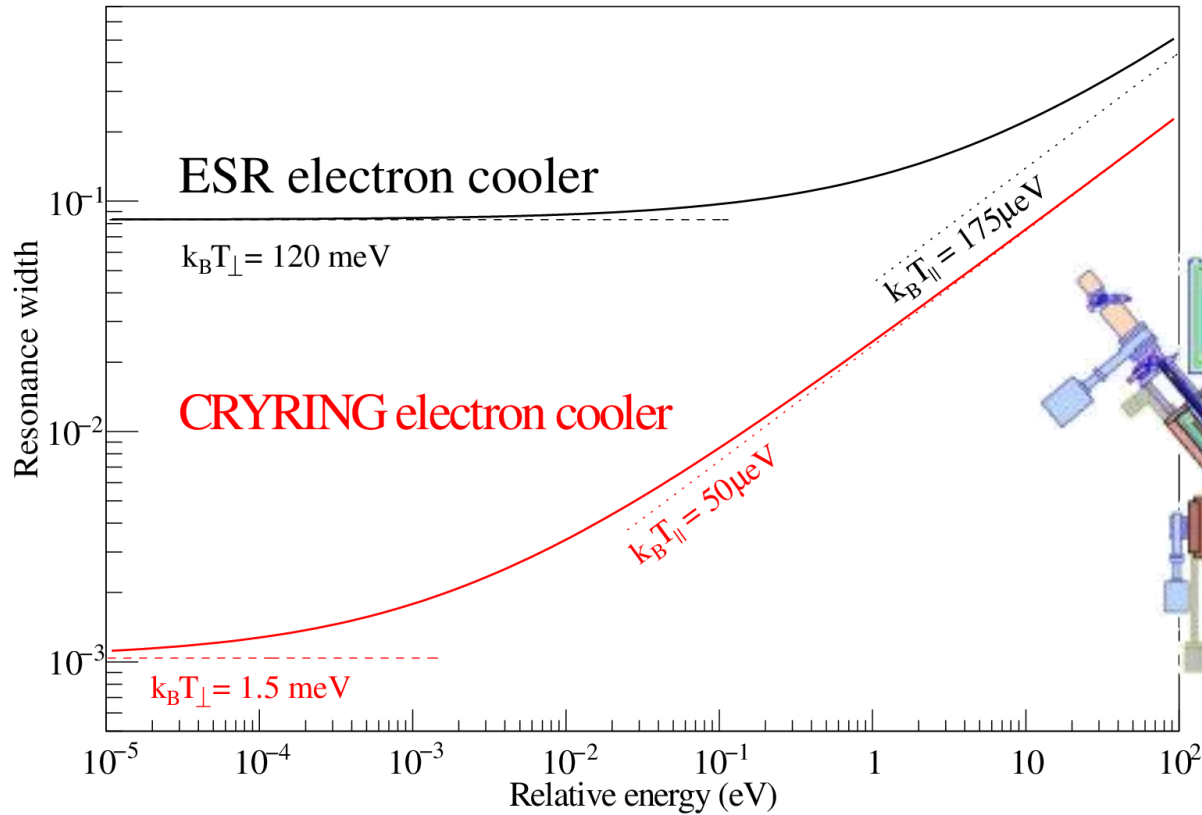
LIFETIMES OF BARE NUCLEUS



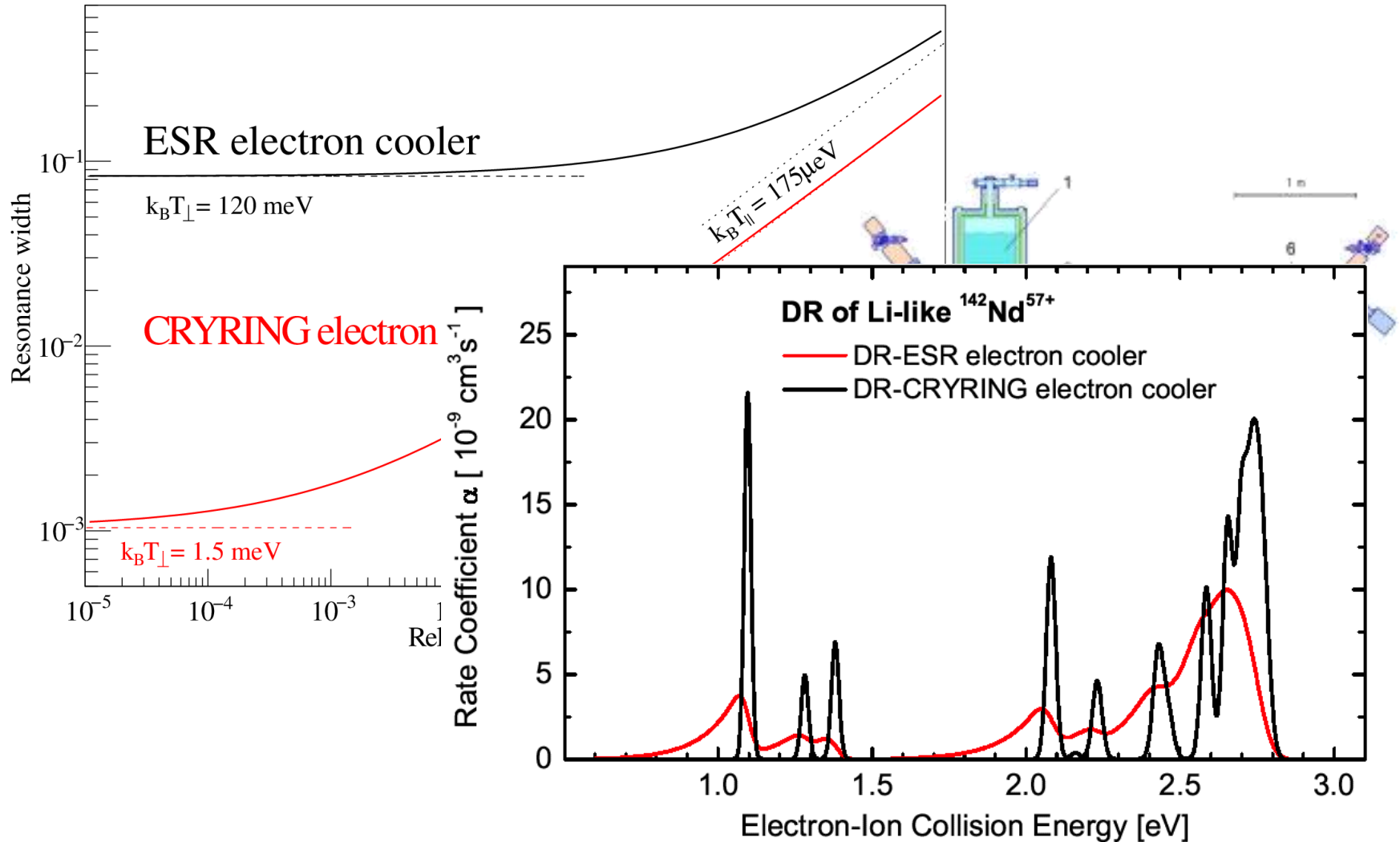
- Ion pumps
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~ 100



Electron Cooling ESR - CRYRING



Electron Cooling ESR - CRYRING



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																												
First Experiments																												

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



Documents related to CRYRING @ GSI and FAIR



LSR

Low-energy Storage Ring

Technical Design

Version 1.3

Hans Siegbahn Laboratory
Physics Department
Stockholm University
4 May 2011

CRYRING@ESR: A study group report

Dated: July 26, 2012

Michael Leventky¹, Norbert Anagnost², Ralph Bar³, Ralph Becker⁴, Martin Walter Beck⁵, Angela Braccini-Duca⁶, Hilmar Dittmann⁷, Olof Wolfgang Lindner⁸, Mats Lindgren⁹, Achim Richter¹⁰, Desmond Francis Peter Robinson¹¹, Anders Eriksson¹², Oliver Koster¹³, Carl-Martin Tam A. Lihner¹⁴, Carsten Möhl¹⁵, Bernhard Müller¹⁶, Ina Neubauer¹⁷, Heinz Rensberg¹⁸, Harald Reich-Sperger¹⁹, Dag Nilsen²⁰, Carl-Marcus Schwob²¹, Ansgar Stransky²², Jan Stokholm²³, Cristian Stoiciu²⁴, Thomas Stöckli²⁵, Wolfgang Worell²⁶, and Christl Wolf

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Infrastructure Proposal (Final and Alice Wallenberg Edition)

Infrastructure Proposal

Installation of CRYRING at GSI/FAIR for atomic experiments

Executive summary

CRYRING is a Swedish storage ring for molecules and atomic ions that has been financed by the Knut and Alice Wallenberg Foundation. It is proposed to couple CRYRING to an existing storage ring, ESR (Experimental Storage Ring), and the radioactive beam facility FRS (Fragment Separator) at the German GSI Beschleuniger für Schwerionenforschung and later to FAIR (Facility for Antiprotons and Ion Research), which is currently under construction at the same location at 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 favorable output and other unparalleled scientific opportunities for precision experiments in atomic, nuclear, and astrophysics by exploiting the capabilities of an outstanding Swedish scientific instrument.

Introduction

The idea central to this proposal is to merge the radioactive beam facility FRS [1] of GSI/FAIR, its ESR [2], and the Swedish storage ring CRYRING [3] into a combined facility. The Knut and Alice Wallenberg Foundation has financed, starting in 1992, the construction of CRYRING at the Hans Siegbahn Laboratory in Stockholm. In the following the general ideas and principles of storage rings are contrasted, before the advantages and opportunities of the current project are discussed in greater detail.

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

atoms and molecules is possible. Such a process in a plasma and ions – can electrons to be captured.

Storage rings of matter become sources of electrons prepared and co-located with well-defined type, for 5000 particles.

In addition to atomic or molecular ions can be used as a storage ring to store ions, with fundamental or scientific goals.

There are a number of important issues in using accelerators. Firstly, the beam is stored in a ring, and the particles are cooled and stored in a ring, and the particles can be

Andreas Hahn (Hahn@GSI.de)

Physics book CRYRING@ESR

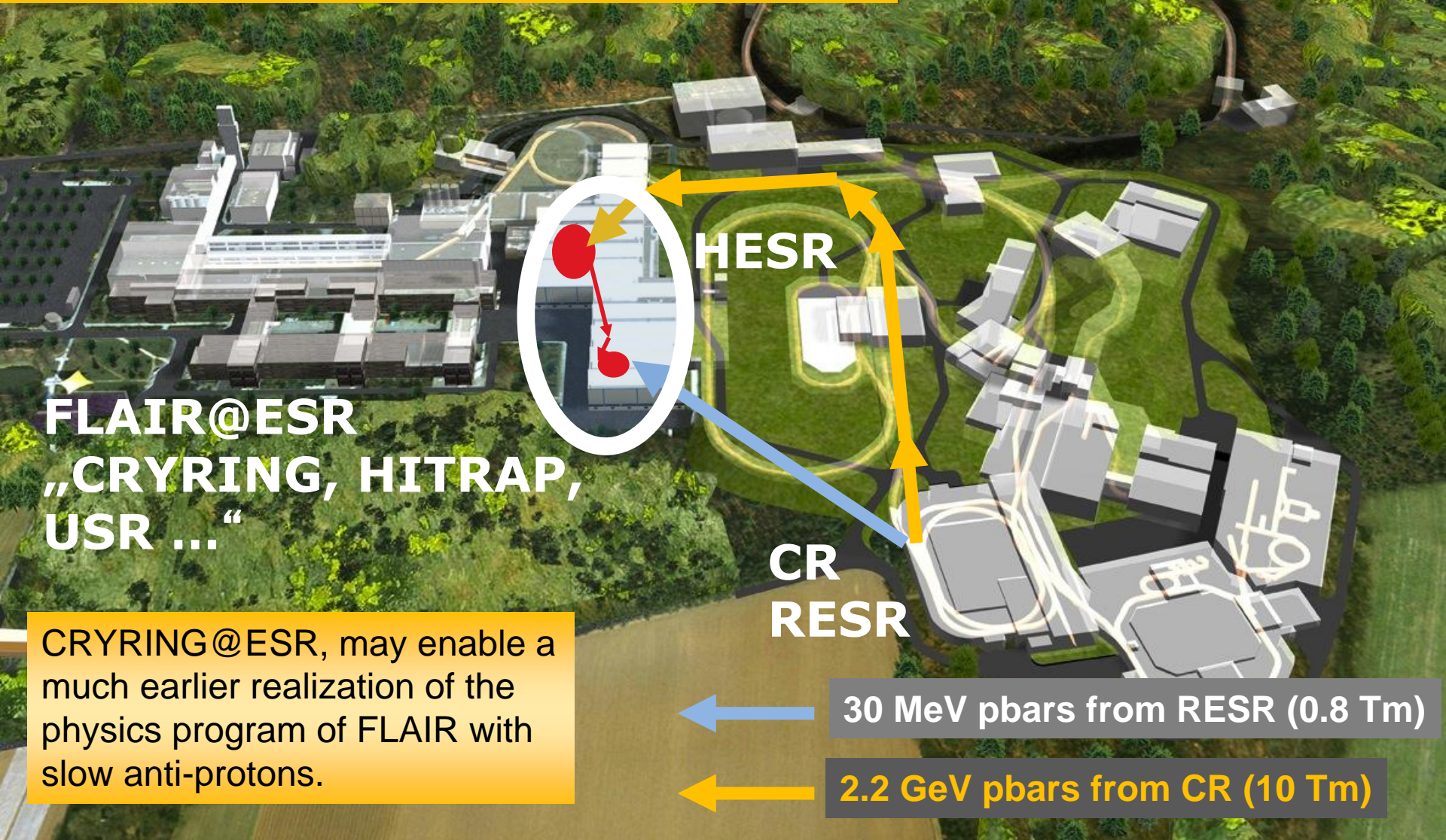
This book is an early editing stage and is not authorized by the respective institutions.

H. Beier,¹ S. Blümel,² C. J. Bostedt,³ A. Brückner,⁴ A. Bunting-Denton,⁵ L. Boy,⁶ T. Dierker,⁷ P. Engel,⁸ M. Fuchs,⁹ S. Fuchs,¹⁰ S. Fuchs,¹¹ D. Fischer,¹² A. Fuchs,¹³ E. Fuchs,¹⁴ S. Fuchs,¹⁵ S. Fuchs,¹⁶ S. Fuchs,¹⁷ A. Gumberg,¹⁸ S. Hagmann,¹⁹ M. Hahn,²⁰ A. Hahn,²¹ K. Hahn,²² P. Hahn,²³ C. Hahn,²⁴ A. Hahn,²⁵ M. Leventky,²⁶ O. Lindner,²⁷ S. Lindner,²⁸ A. Lindner,²⁹ K. Lindner,³⁰ A. Lindner,³¹ T. Lindner,³² G. Lindner,³³ K. Lindner,³⁴ S. Lindner,³⁵ S. Lindner,³⁶ M. Lindner,³⁷ N. Lindner,³⁸ A. Lindner,³⁹ J. Lindner,⁴⁰ D. Lindner,⁴¹ S. Lindner,⁴² U. Lindner,⁴³ K. Lindner,⁴⁴ J. Lindner,⁴⁵ A. Lindner,⁴⁶ K. Lindner,⁴⁷ E. Lindner,⁴⁸ M. Lindner,⁴⁹ S. Lindner,⁵⁰ T. Lindner,⁵¹ L. Lindner,⁵² M. Lindner,⁵³ C. Lindner,⁵⁴ D. Lindner,⁵⁵ J. Lindner,⁵⁶ J. Lindner,⁵⁷ et al.

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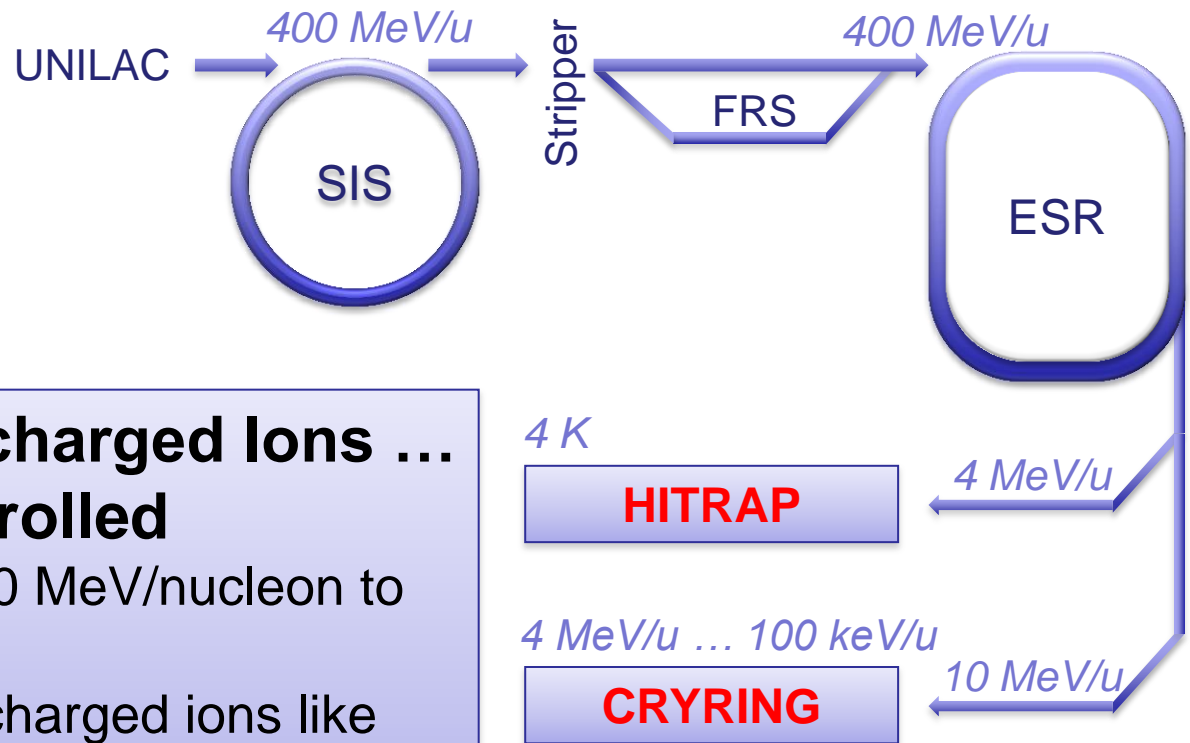
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