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

Charge radii

FS, HFS

g-factor

e^--binding

+ surface

BW effect

α, m_e

Lamb-shift

Structures

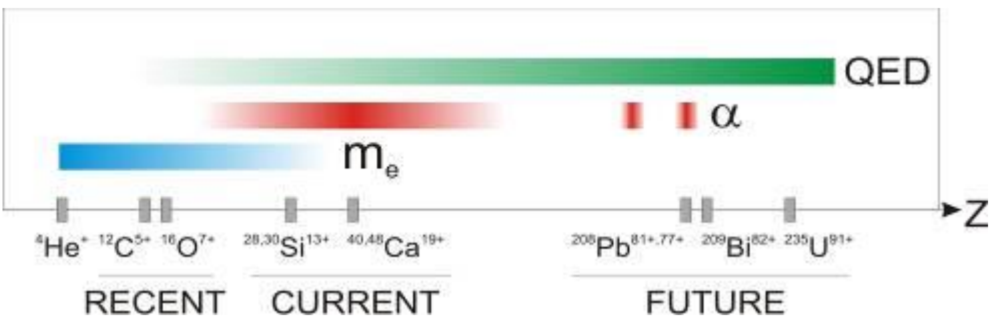
QED test

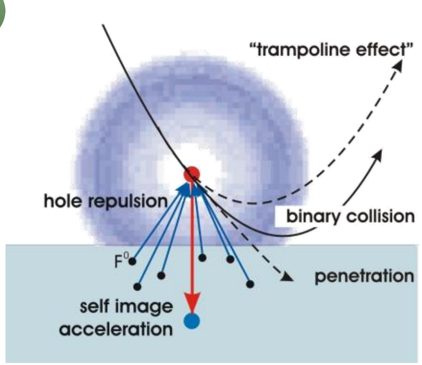
Hollow atoms

+ atoms

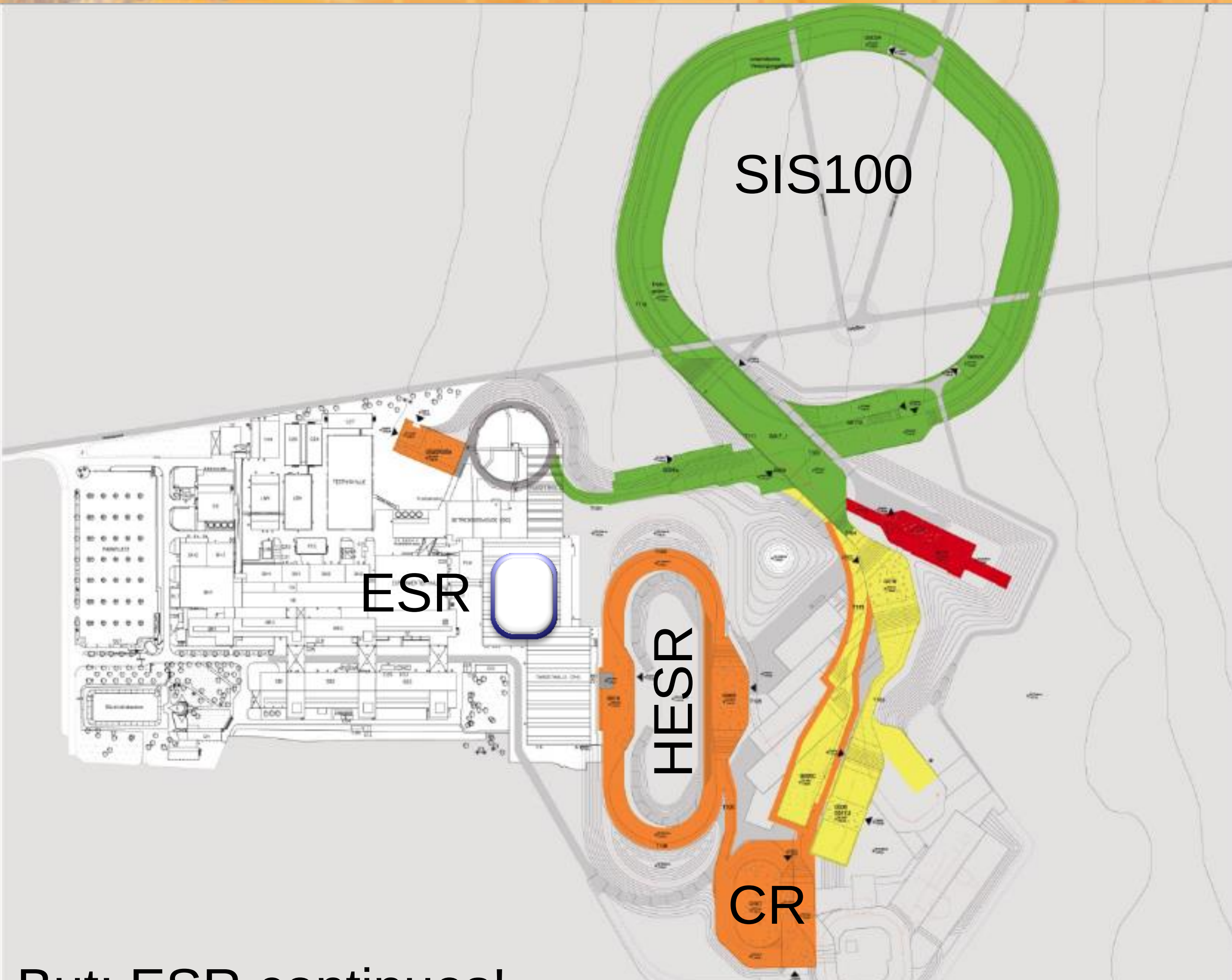
Charge exchange

Collision dynamics





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

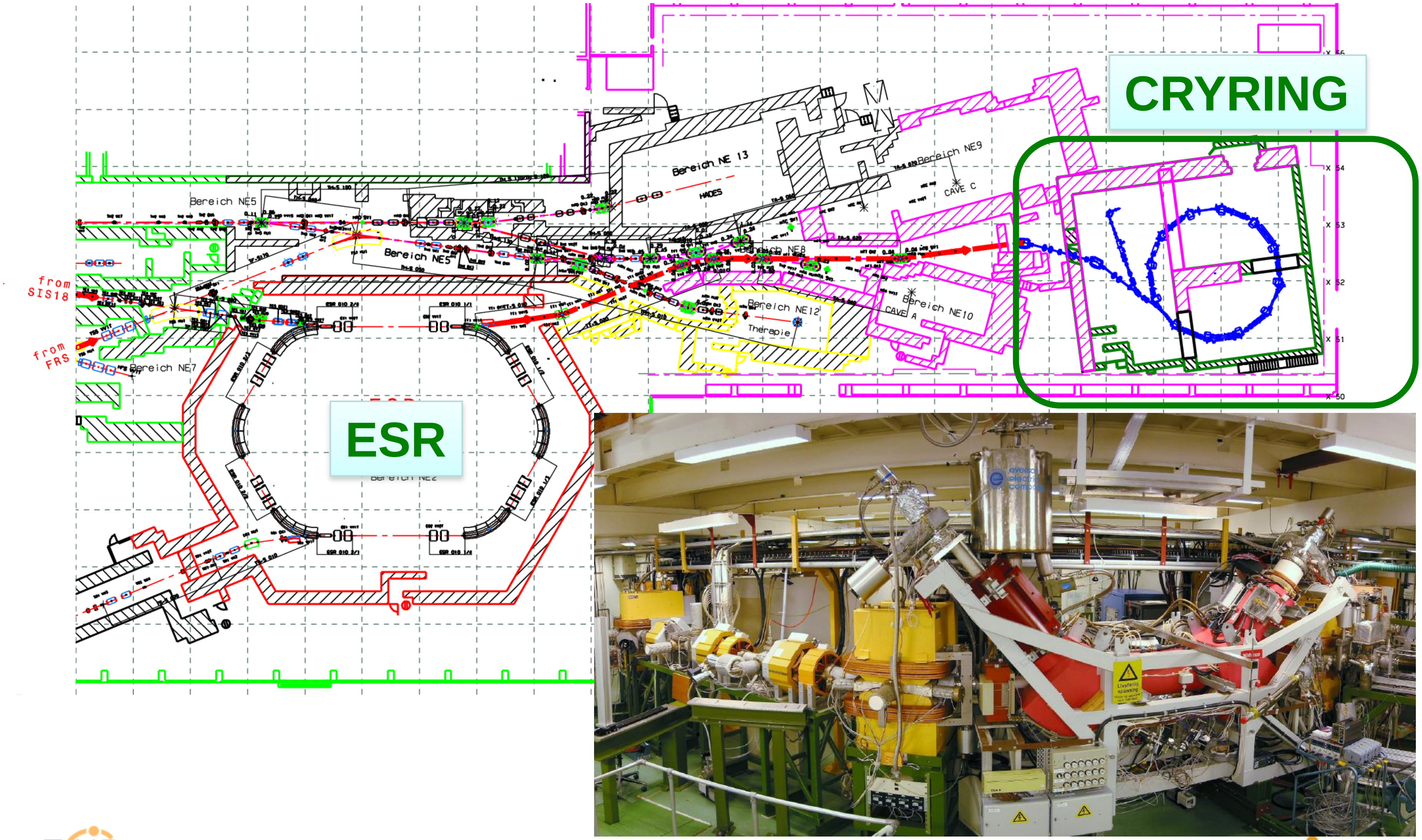
- Detectors and diagnostic systems
- FAIR type control system
- Training of operators on FAIR type system
- FAIR type safety and radiation monitoring/access system

All this with real beam!

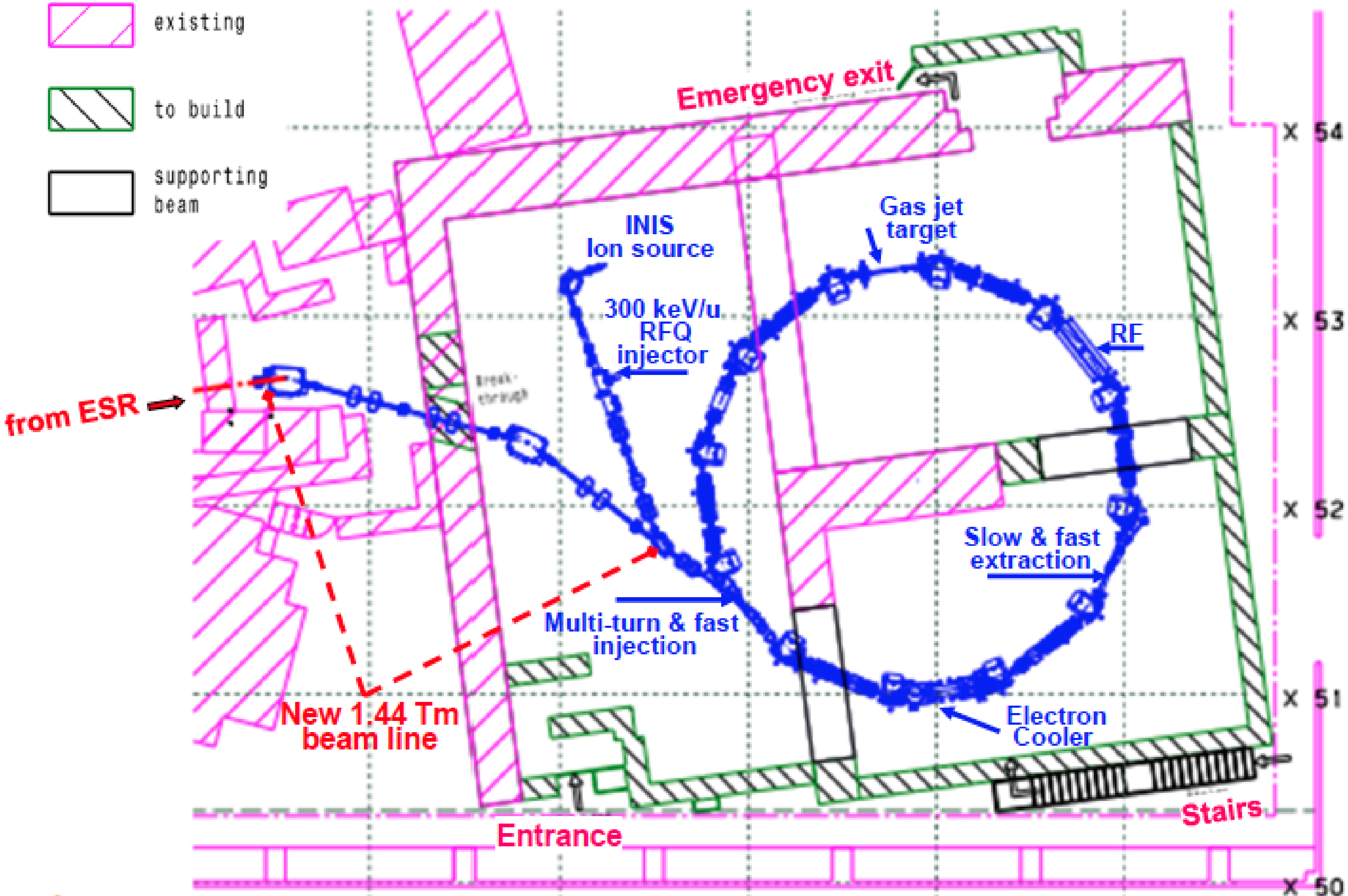
Scientific Oportunities

- 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
from SIS18
from FRS
Bereich NE 13
HADES
Bereich NE9
CAVE C
Bereich NE5
Bereich NE8
Bereich NE12
Therapie
Bereich NE10
CAVE A
Bereich NE7

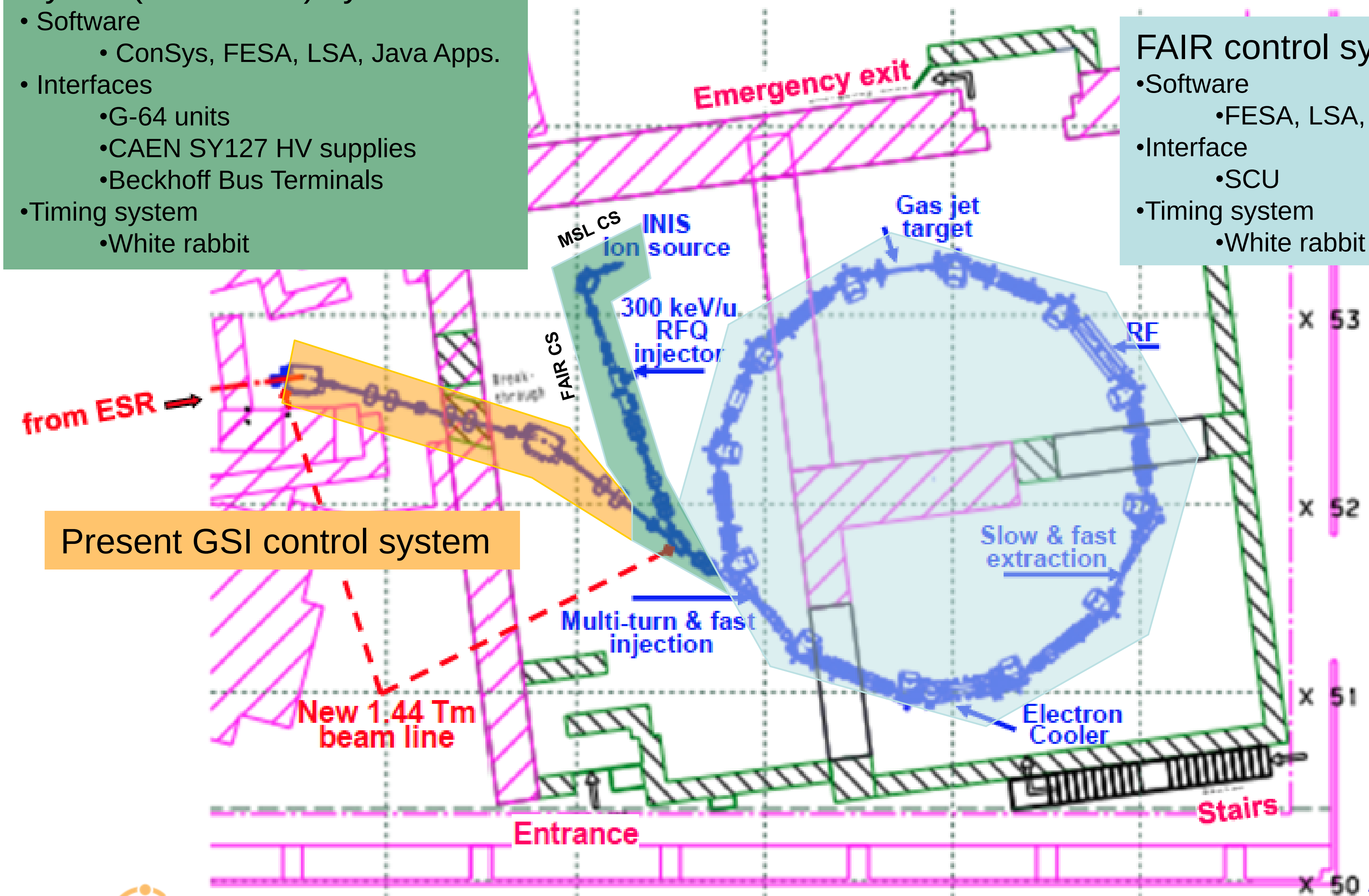
CRYRING @ ESR in modified Cave B



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



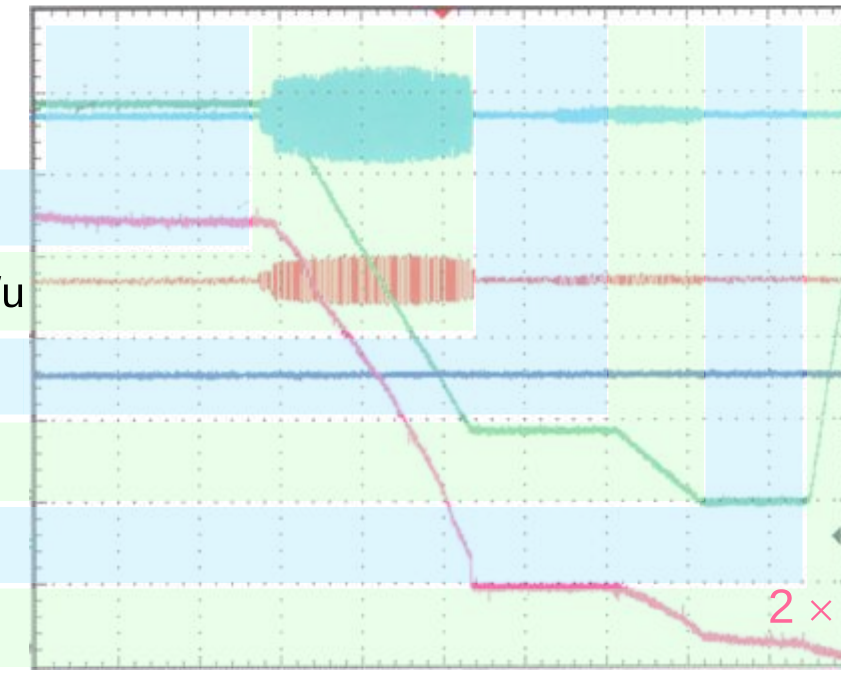
Present GSI control system

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



1100 μA → 180 μA → 25 μA

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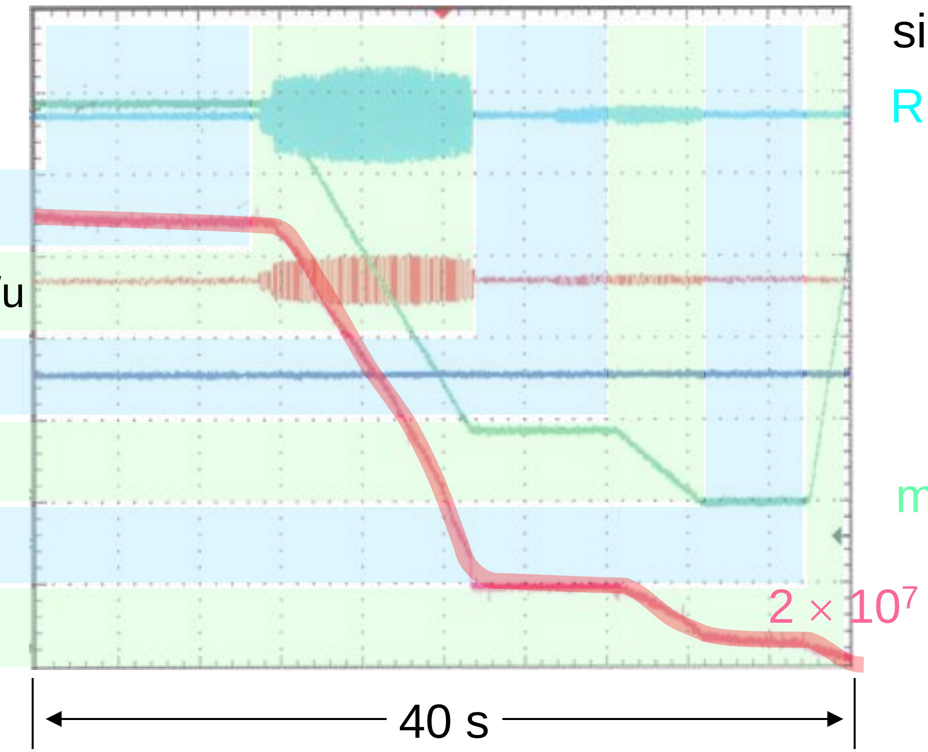


signal:

RF amplitude

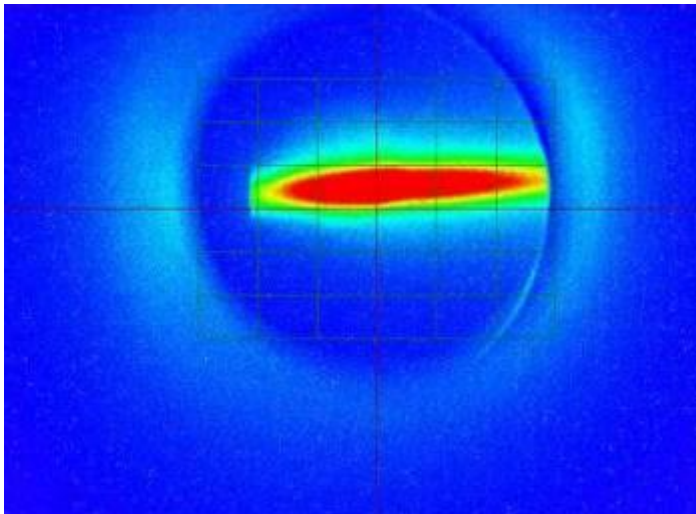
magn.dipole field

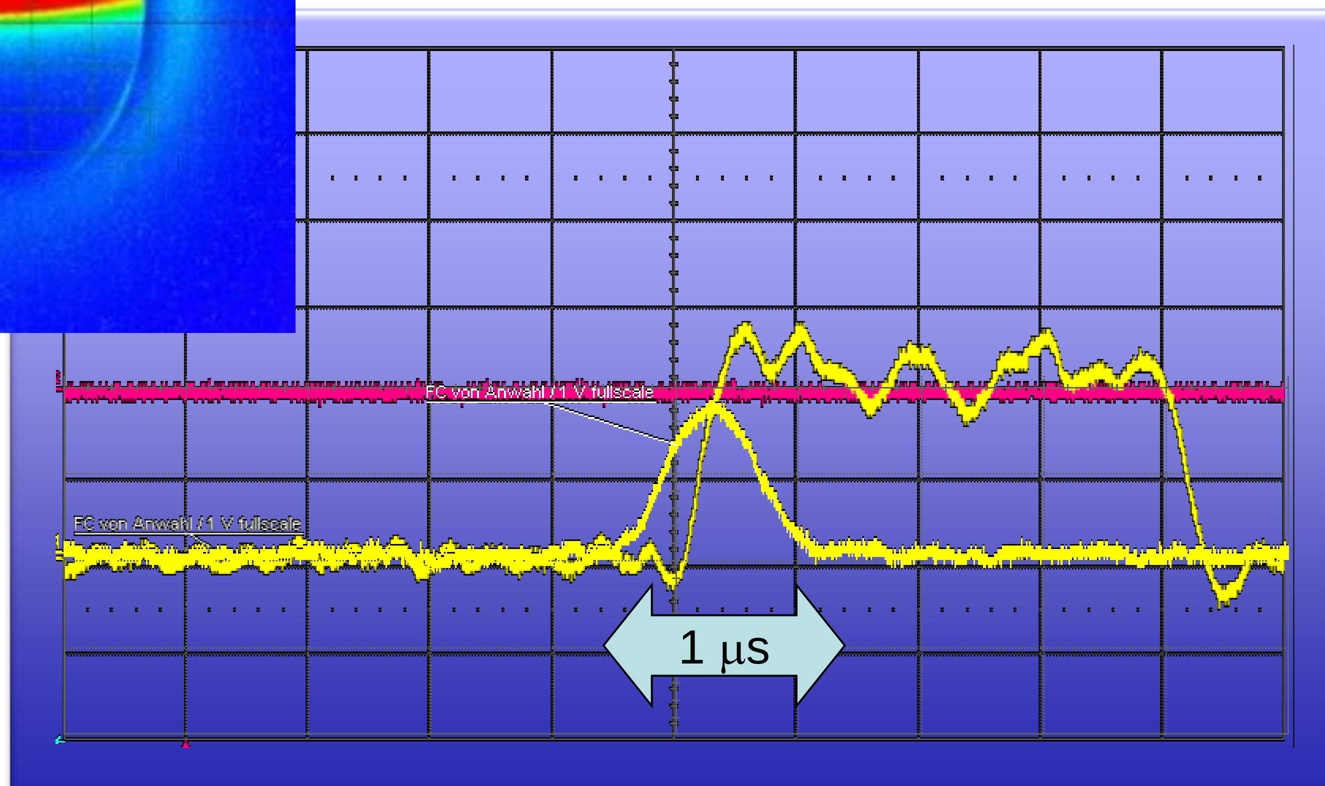
ion current

1100 μA → 180 μA → 25 μA

4 MeV/u ions from ESR

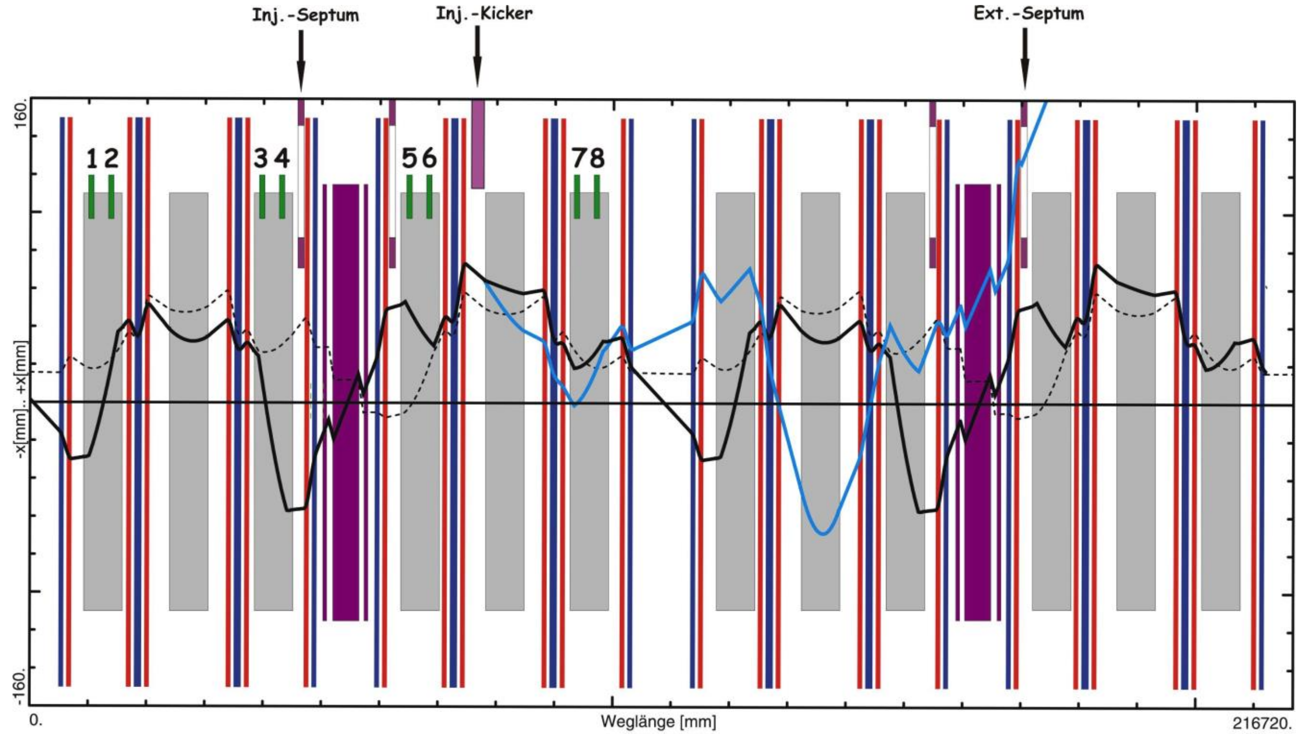
2×10^7 $^{136}Xe^{50+}$ extracted from ESR





Modification of ESR for CRYRING

- Additional Kicker
  but in the mean time …



Injection orbit (Δp/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

S. Litvinov

Modification of ESR for CRYRING

- Additional Kicker
  in the mean time … creative use of existing kicker

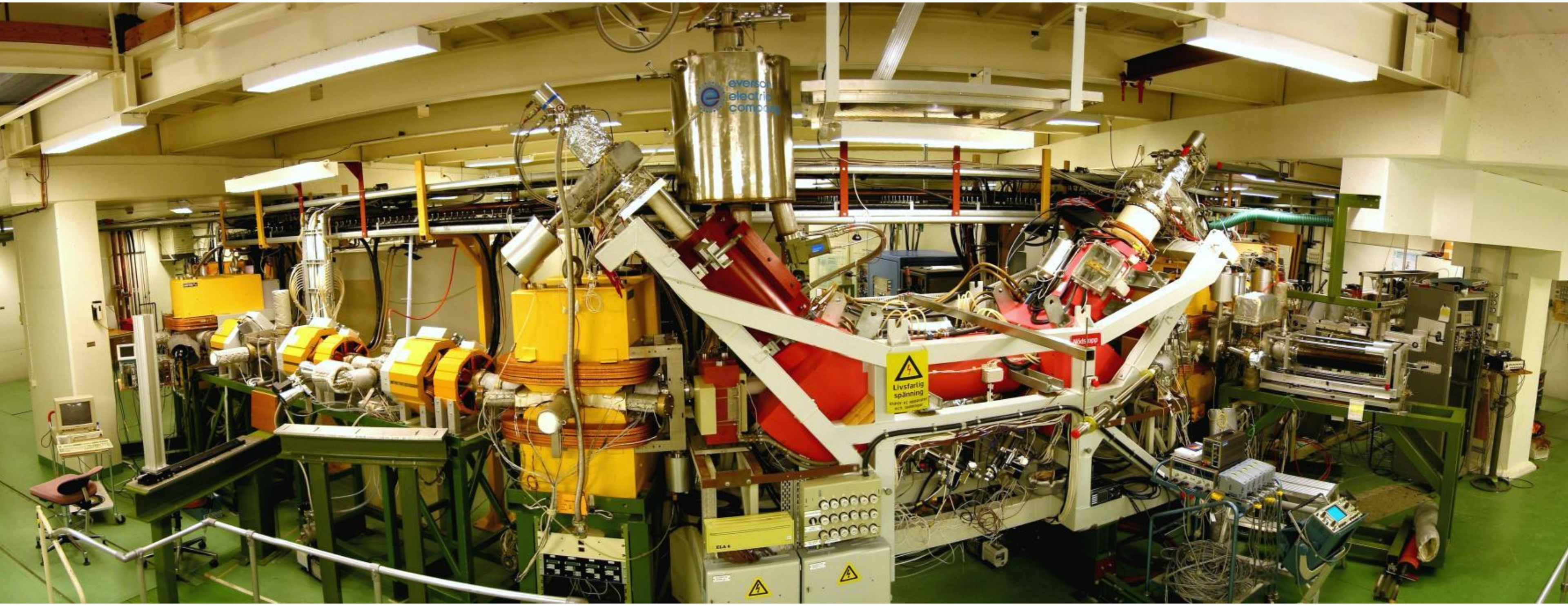
- Beam line upgrade (ESR – Cave B)
  added steering, dipoles; additional diagnostics

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

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

Positive molecular ions:
H_2^+, HD^+, H_3^+, D_2^+, H_2D^+, $^{3}HeH^+$, $^{3}HeD^+$, $^{4}HeH^+$, 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+}, $^{13}CO^+$, 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^+, $NO^+ \cdot H_2O$, O_3^+, $DCOOD_2^+$, $CD_3OCD_2^+$, $C_3D_7^+$, CF_2^+, $NO^+ \cdot D_2O$, 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^+, $H_9O_4^+$, $CD_3COHNHCH_3^+$, $CD_3CONHDCH_3^+$, $C_6D_6^+$, $PO^{37}Cl^+$, $H_{11}O_5^+$, $C_2S_2H_6^+$, $C_2S_2H_7^+$, $H_{13}O_6^+$, $PO^{35}Cl_2^+$

Negative atomic ions:
H^-, Li^-, F^-, Si^-, S^-, Cl^-, Se^-, Te^-

Negative molecular ions:
CN^-, C_4^-, Si_2^- Cl_2^-

~200 different ion species

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

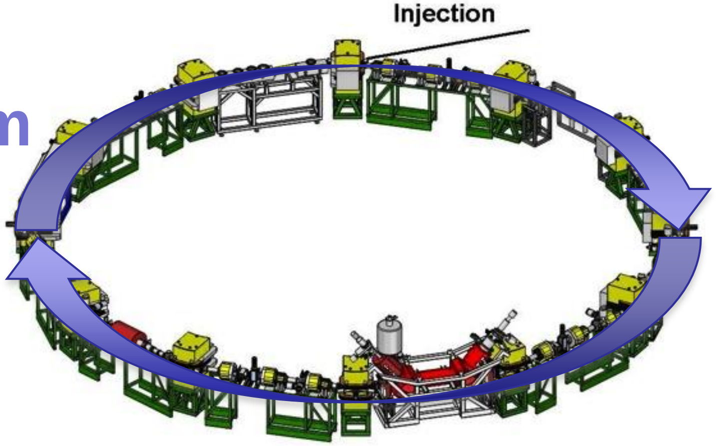
Range of total energies: 5 keV – 1.4 GeV

CRYRING Parameters

54 m = ESR/2

⇧

52 m



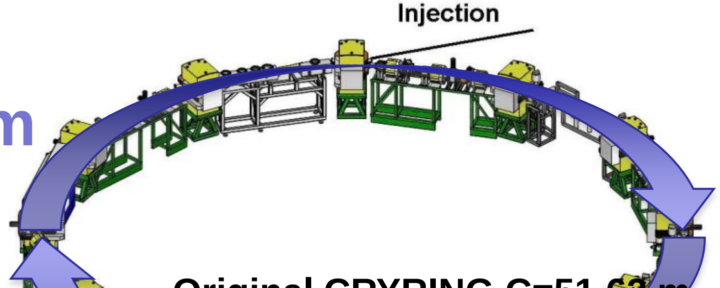
- Max. rigidity 1.44 Tm
  - 15 MeV/u U^{92+}
  - 96 MeV/u protons
- Min. rigidity ~ 0.054 Tm
  - 150 keV/u protons
- Ramping speed 1 T/s; 7 T/s

CRYRING Parameters

54 m = ESR/2

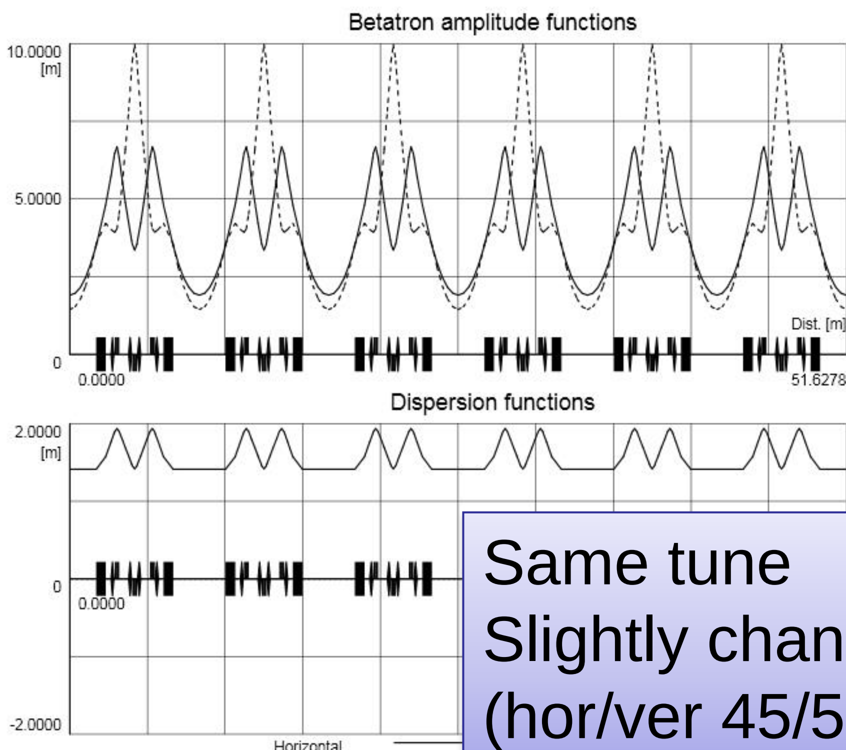
⇧

52 m

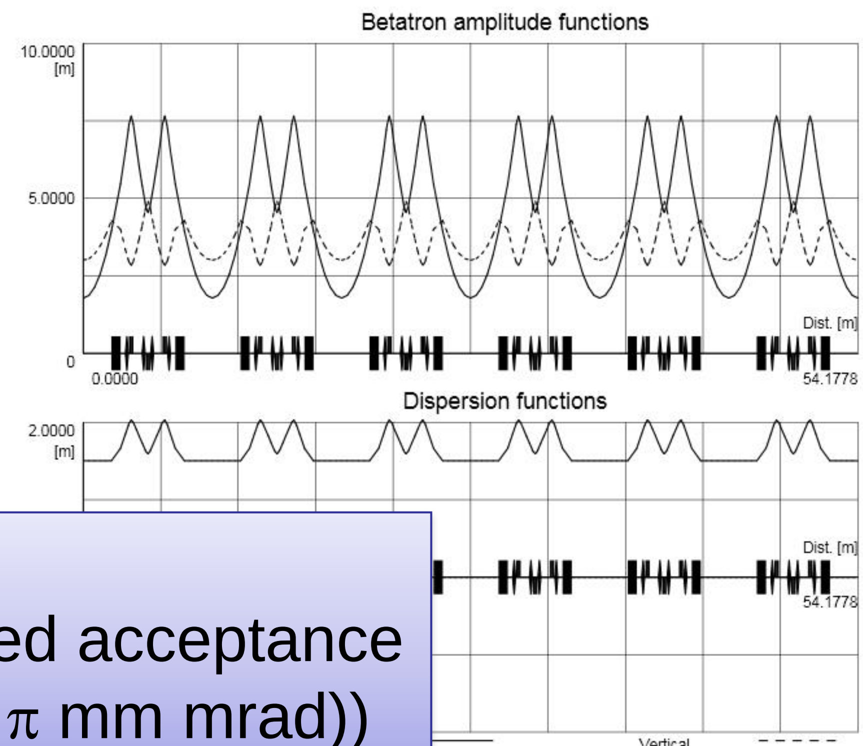


- Max. rigidity 1.44 Tm
- Min. rigidity ~ 0.054 Tm
- Ramping speed 1 T/s; 7 T/s

Original CRYRING C=51.62 m

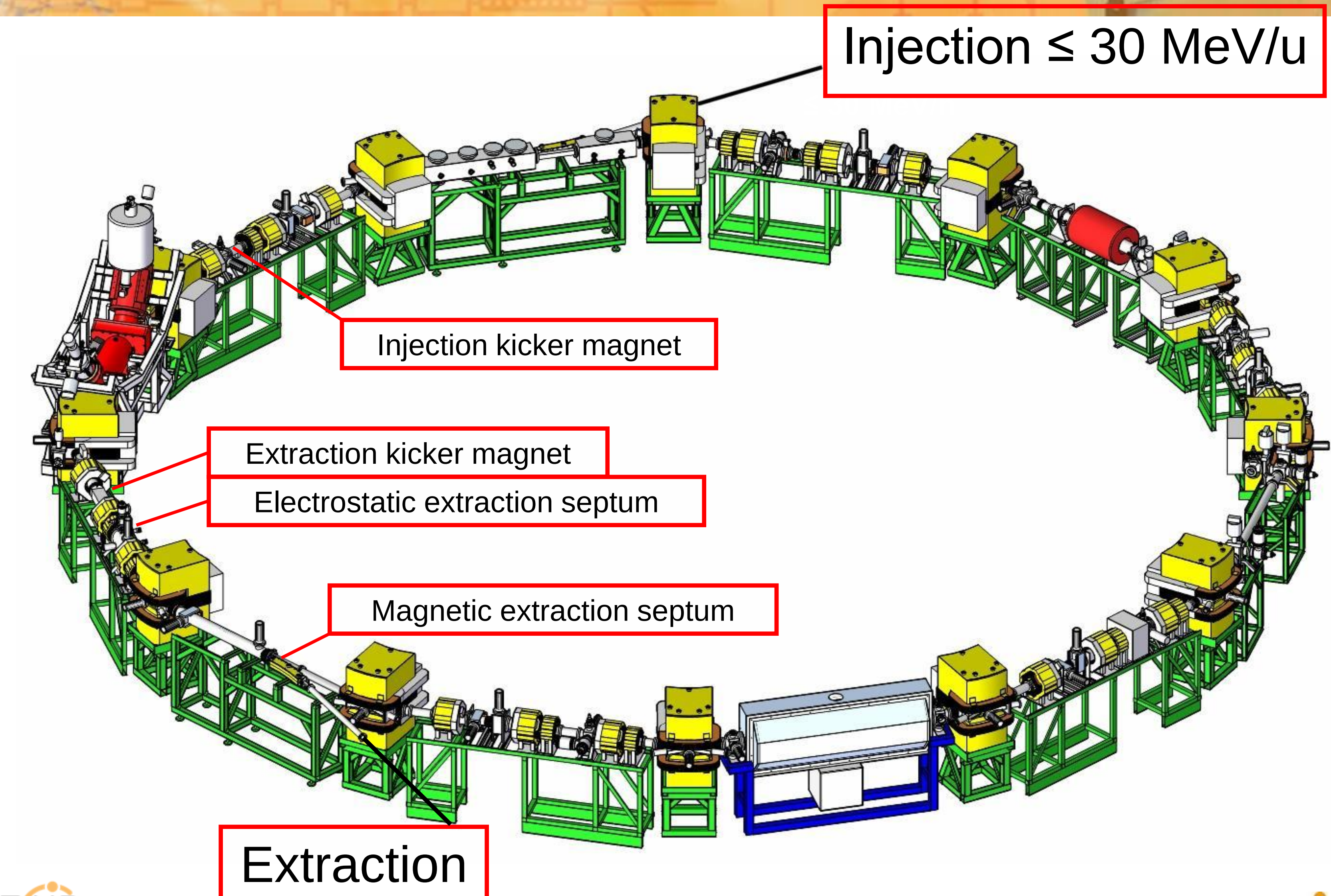


New circumference C=54.18 m



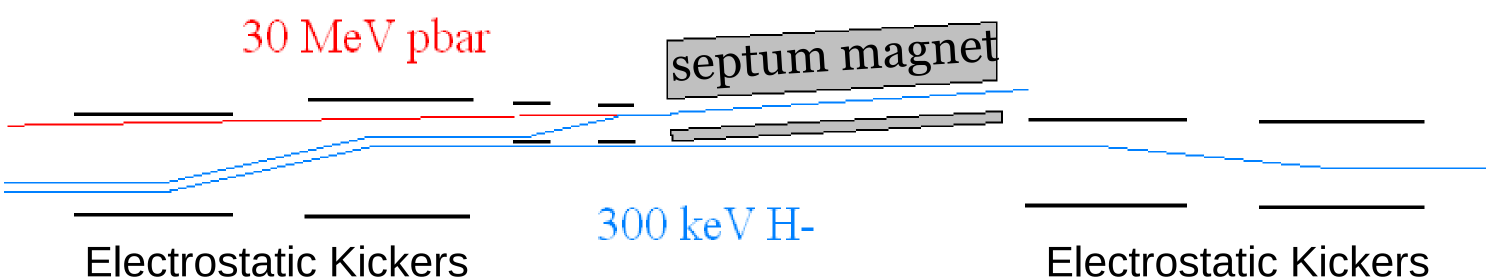
Same tune
Slightly changed acceptance
(hor/ver 45/55 π mm mrad))

CRYRING modifications toward FAIR/GSI

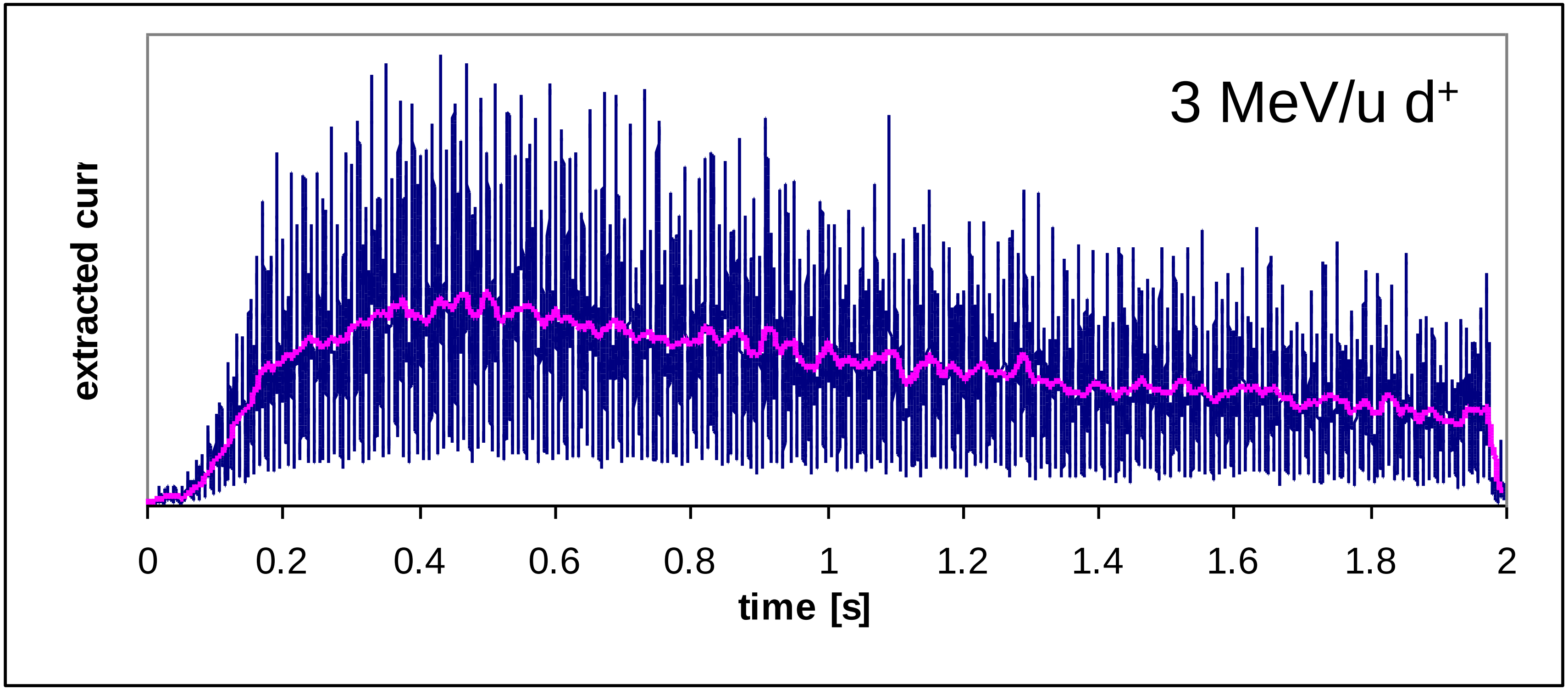


New “dual” Injection System

- Multiturn injection of slow ions (0.3 MeV/u for ions with q/m≥0.25, 40q kV for ions with q/m<0.25)
- Single turn injection of fast ions (Bρ 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



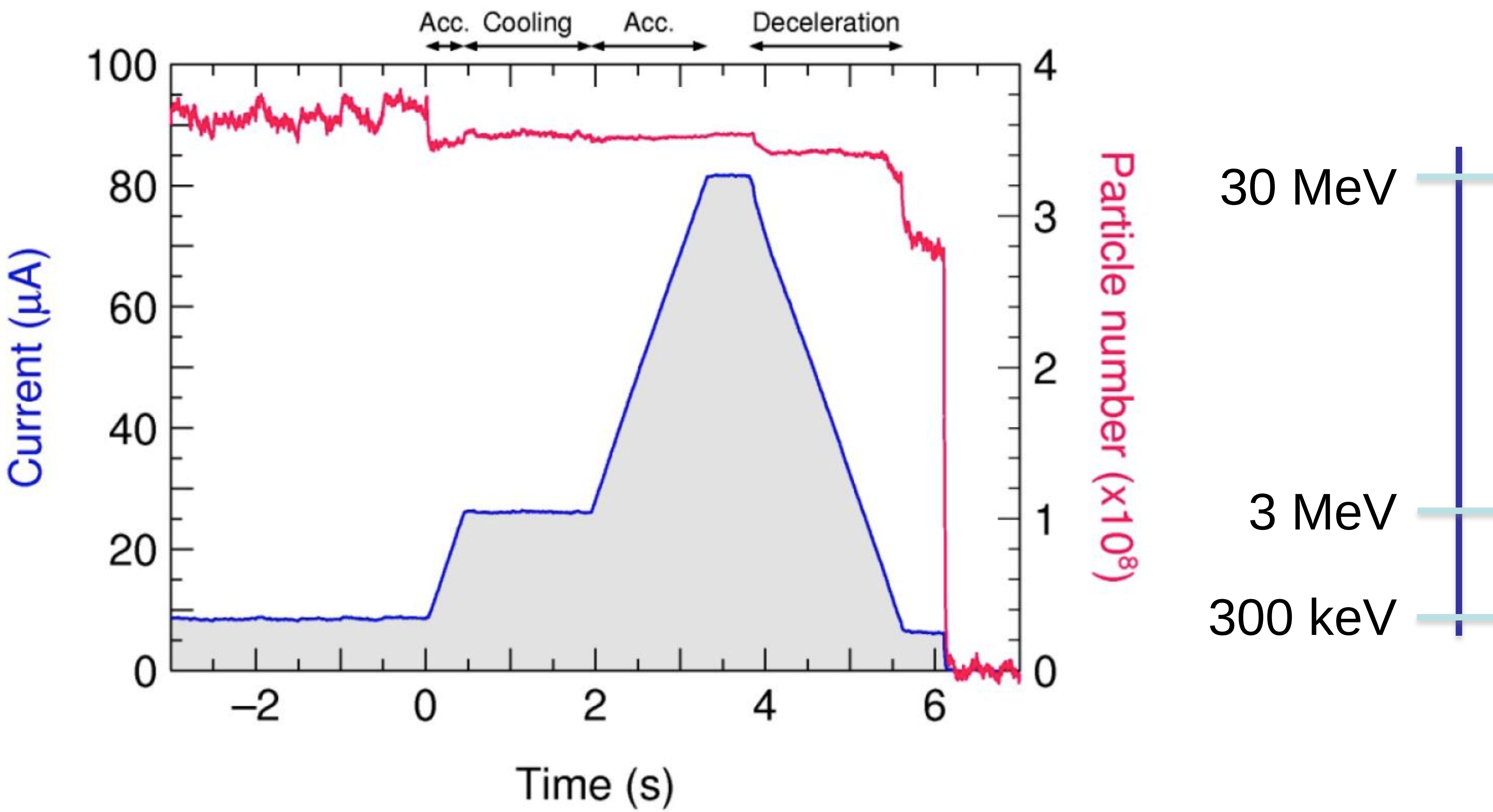
Test of Extraction



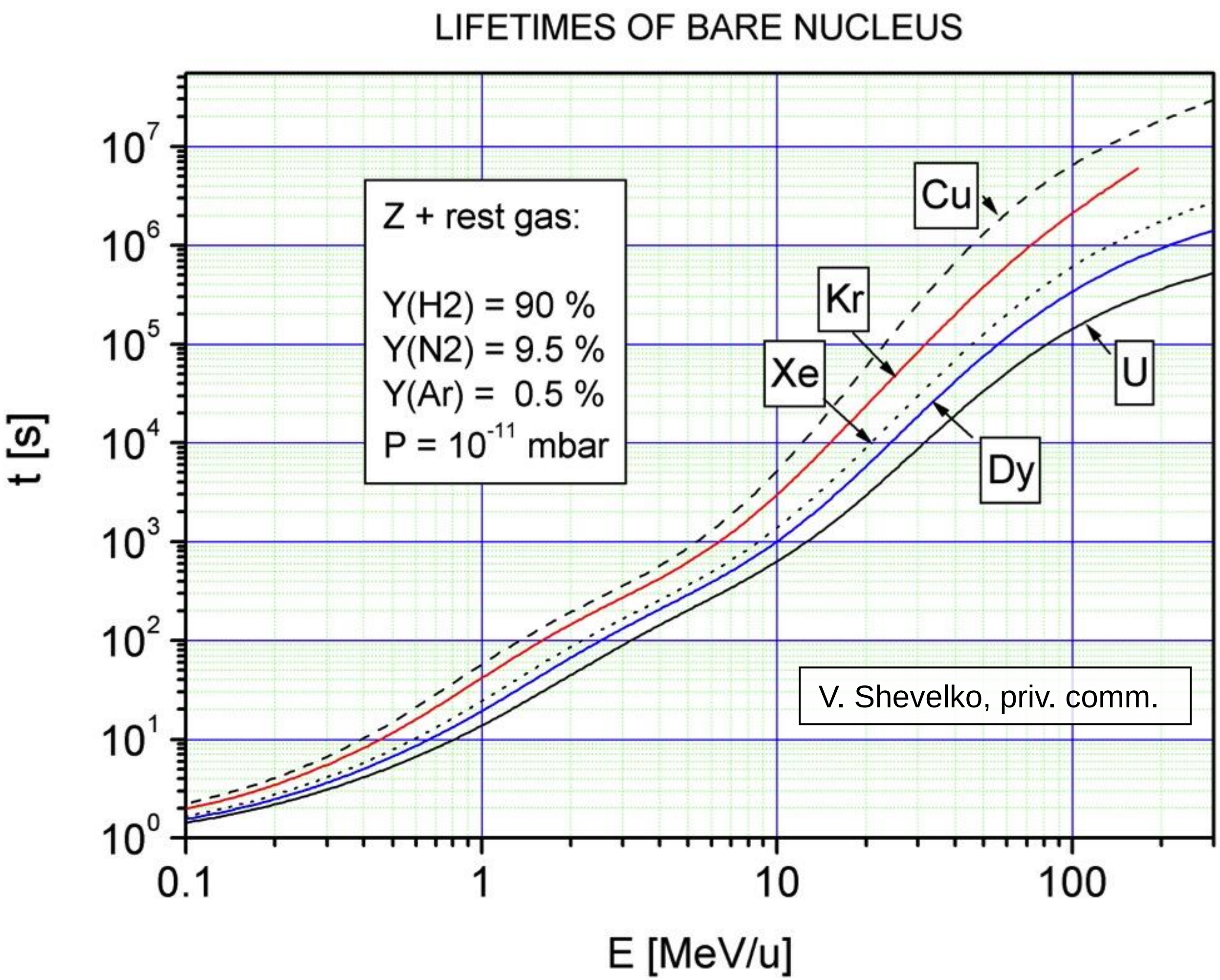
Blue - current measured on the MCP anode of the REX viewer

Pink - 20 ms average (no n × 50 Hz)

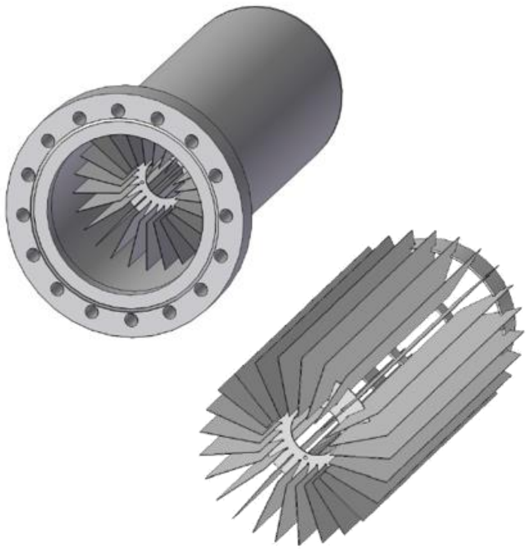
Deceleration in CRYRING



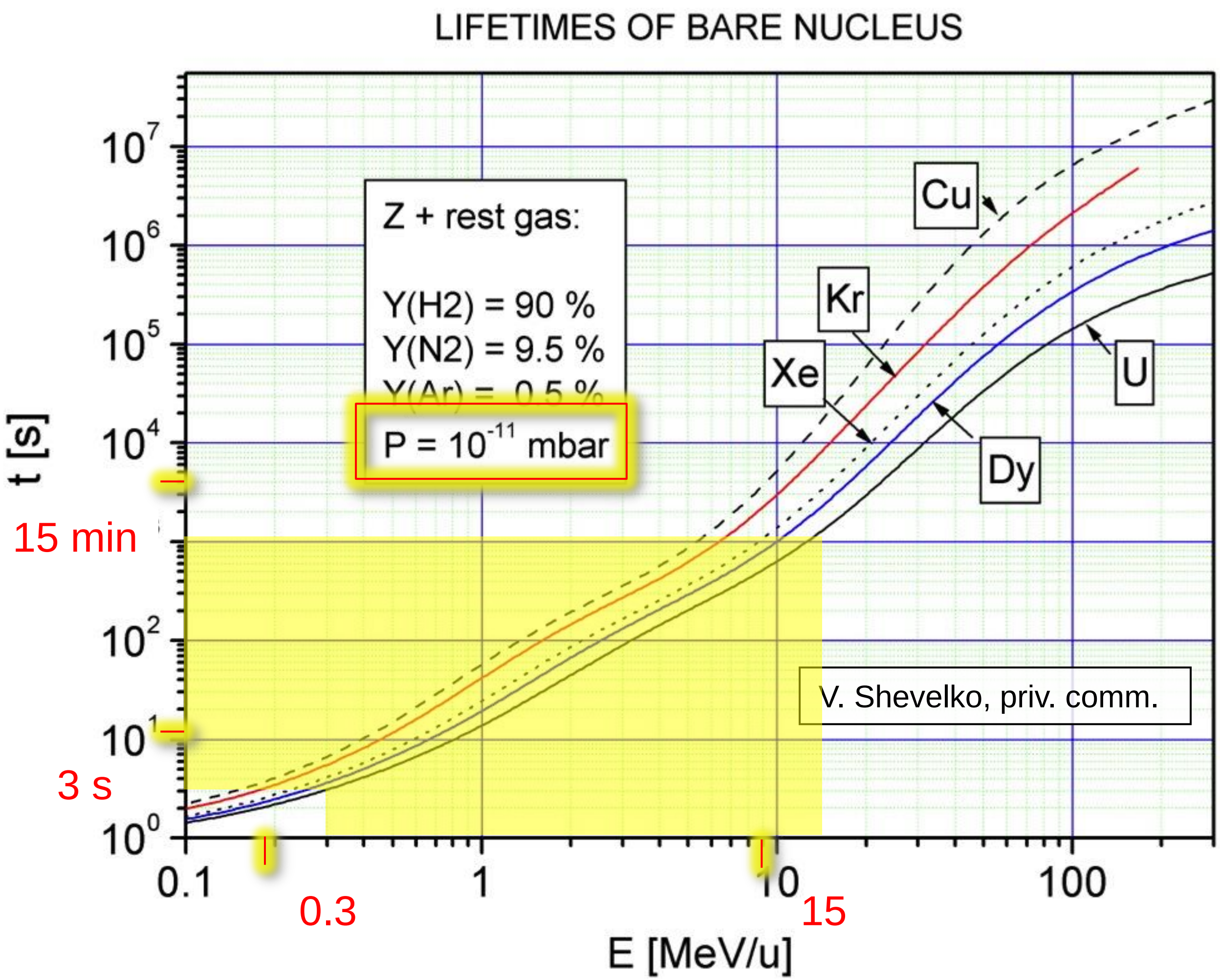
Vacuum & Beam Life Time



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



Vacuum & Beam Life Time



- Ion pumps
  ~ 10
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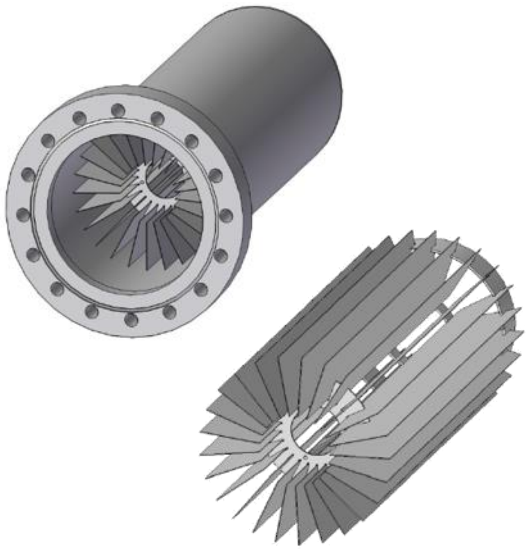
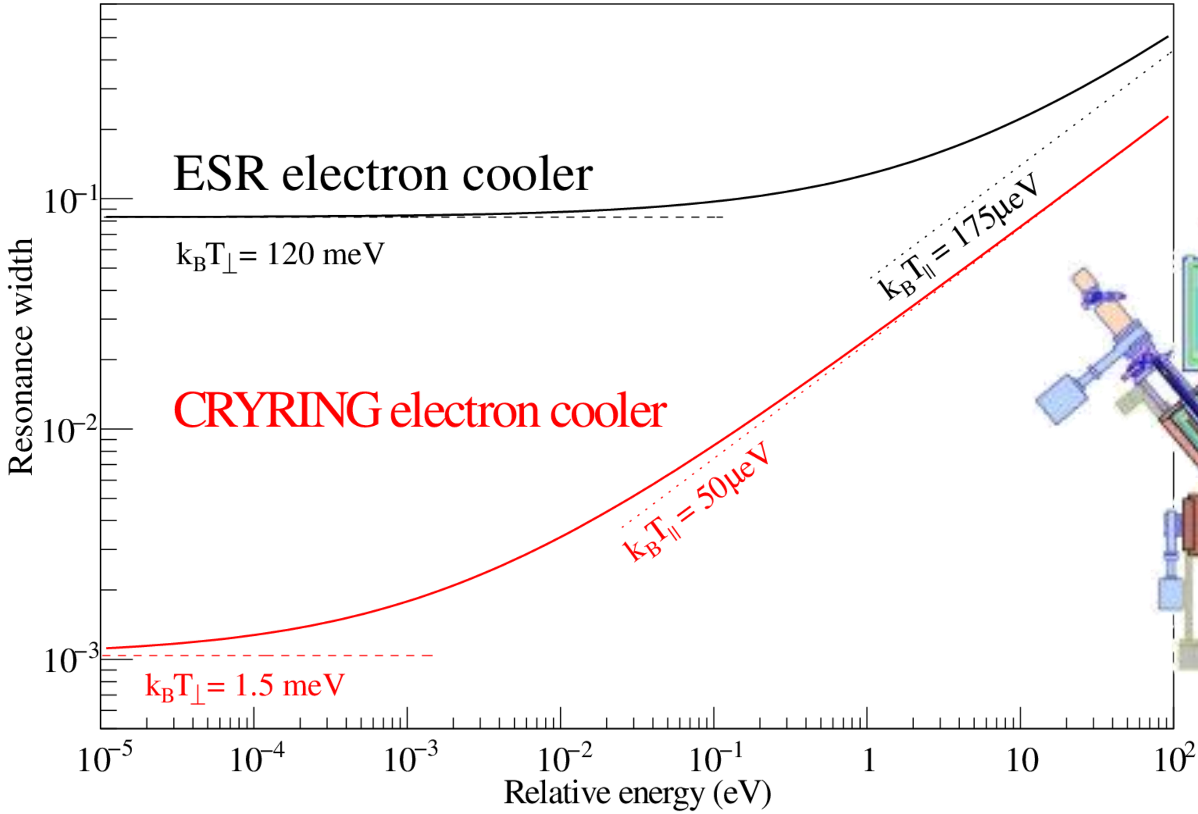
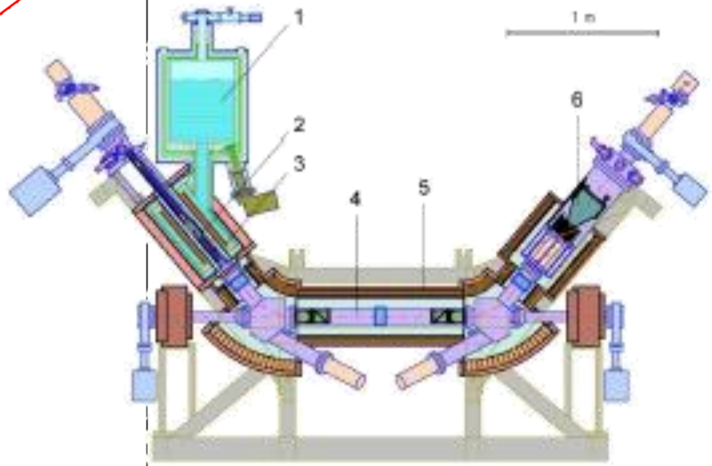
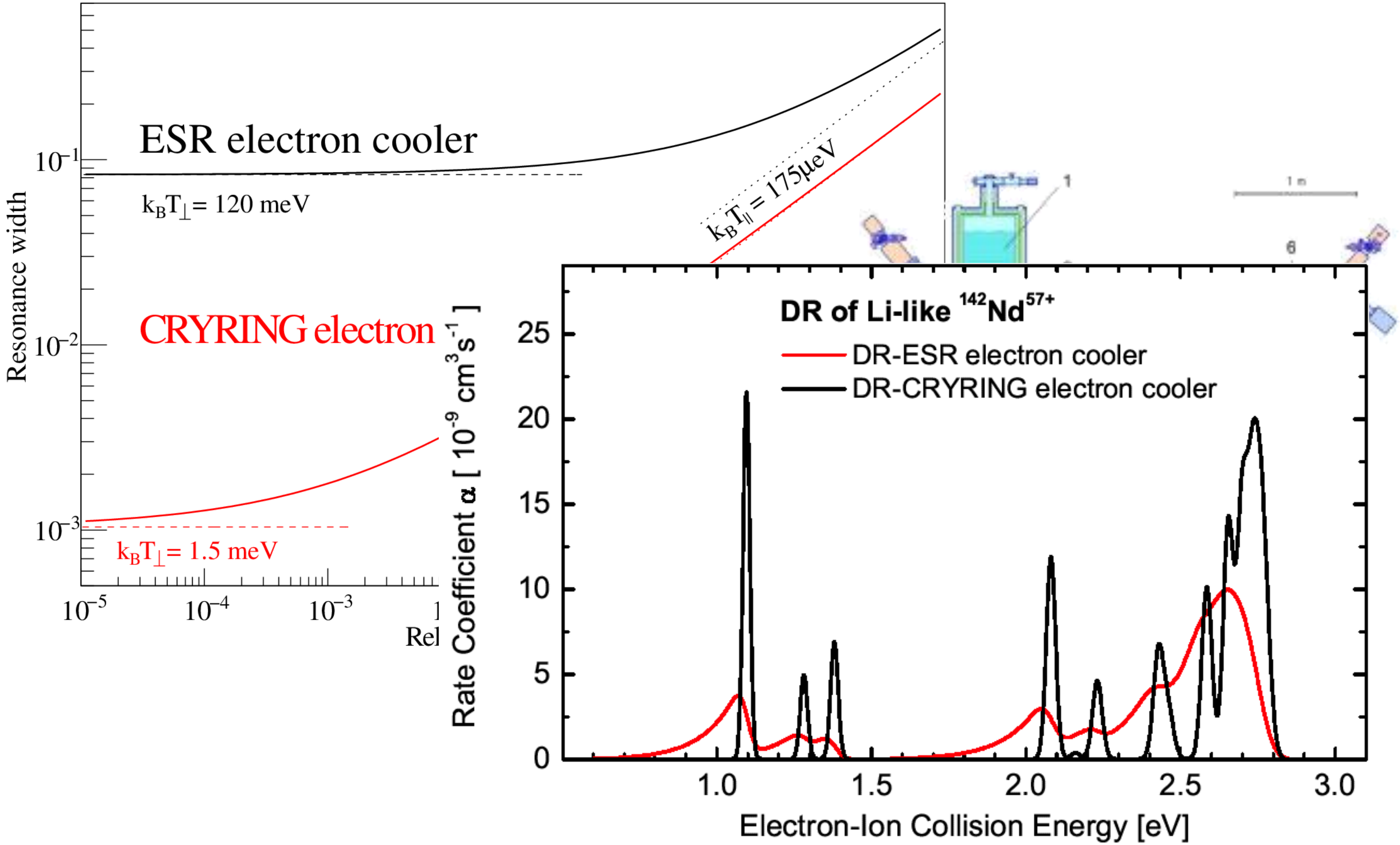


Electron Cooling ESR - CRYRING





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


Physics book
CRYRING@ESR

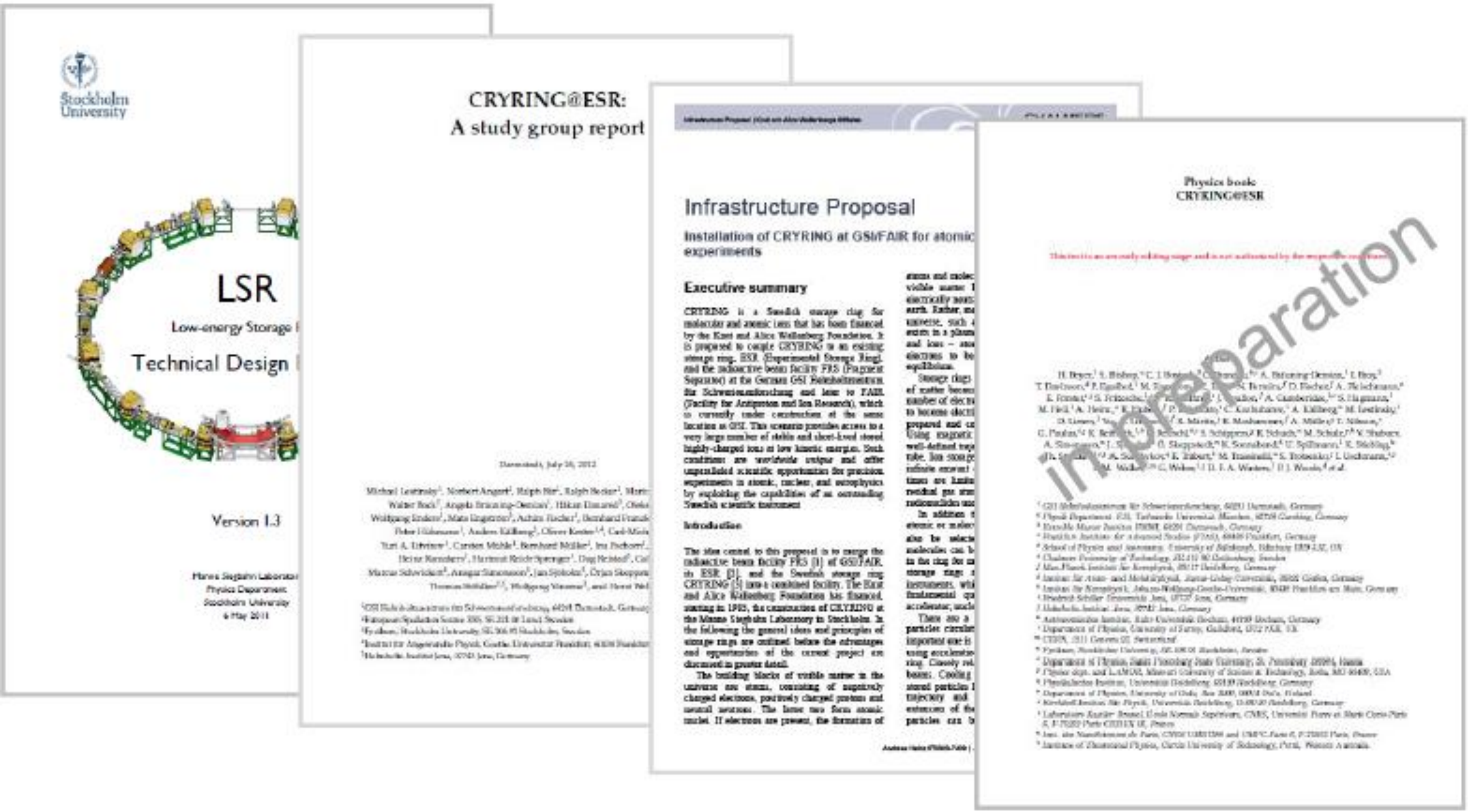
in preparation

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																												

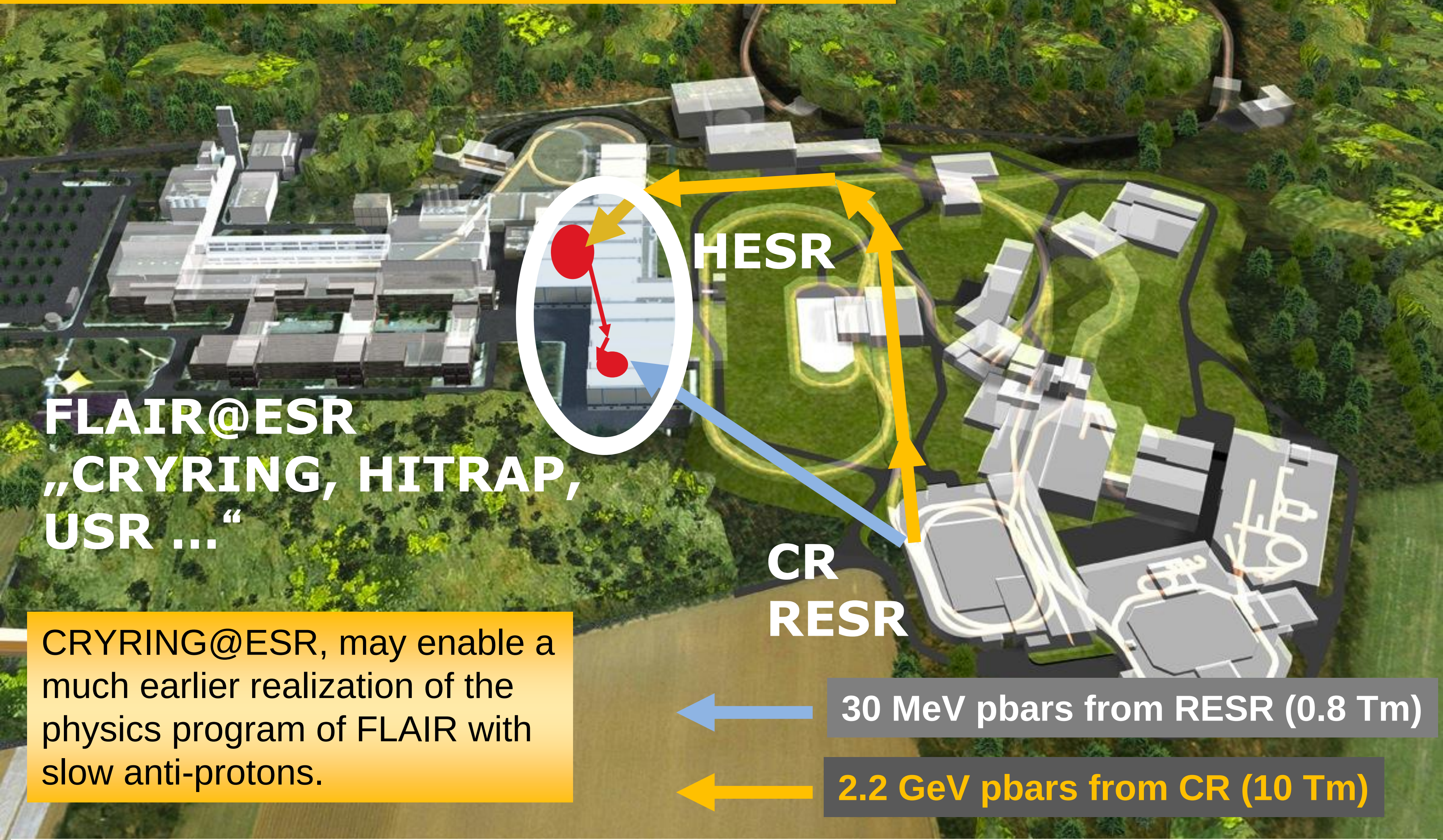
- All ring components have been delivered
- Cave and component preparation ongoing

Documents related to CRYRING @ GSI and FAIR



Modularized Start Version of FAIR and beyond

FLAIR
Facility for Low-energy Antiproton and Ion Research



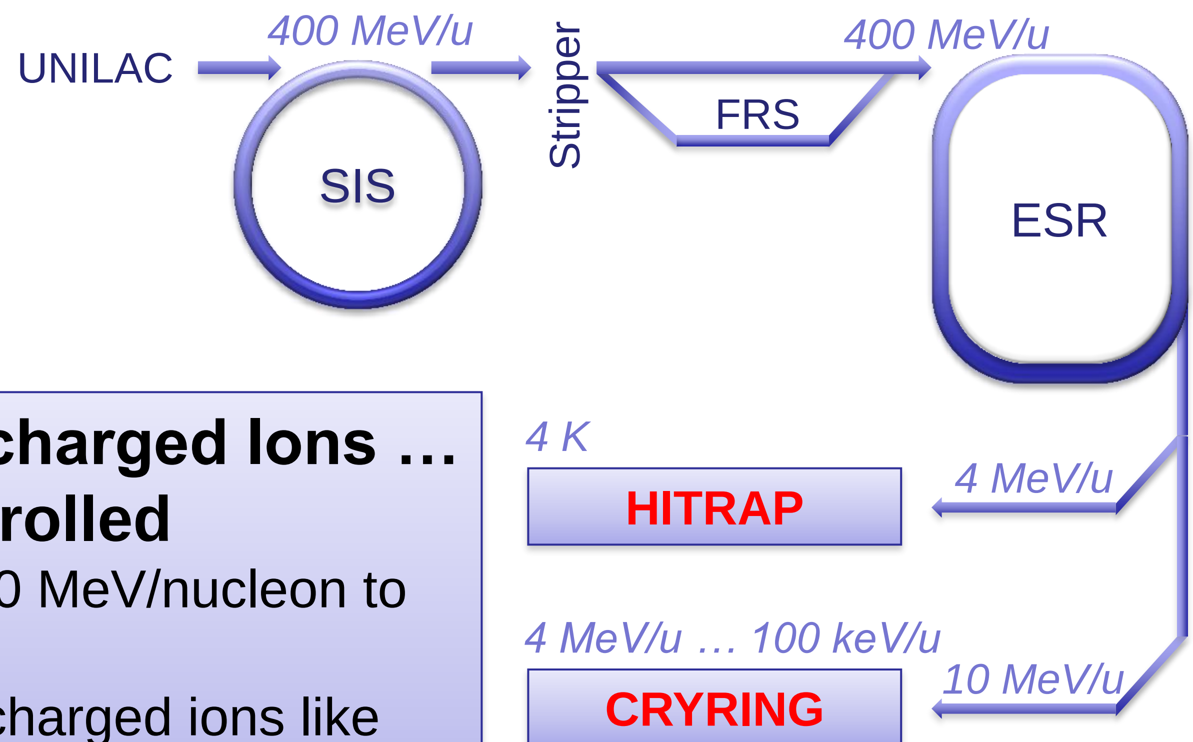
CRYRING@ESR, may enable a much earlier realization of the physics program of FLAIR with slow anti-protons.

30 MeV pbars from RESR (0.8 Tm)

2.2 GeV pbars from CR (10 Tm)

CN DE ES FI FR GB GR IN IT PL RO RU SE

Slow, Heavy, Highly Charged Ions @ GSI/FAIR



Slow, heavy, highly charged Ions … stored and well controlled

- Energy range between 10 MeV/nucleon to sub eV/Ion
- 10^5 to 10^7 heavy, highly charged ions like U^{91+}
- Low energy antiprotons in the future