CRYRING @ ESR

heavy, highly-charged Ions stored at low Energy

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

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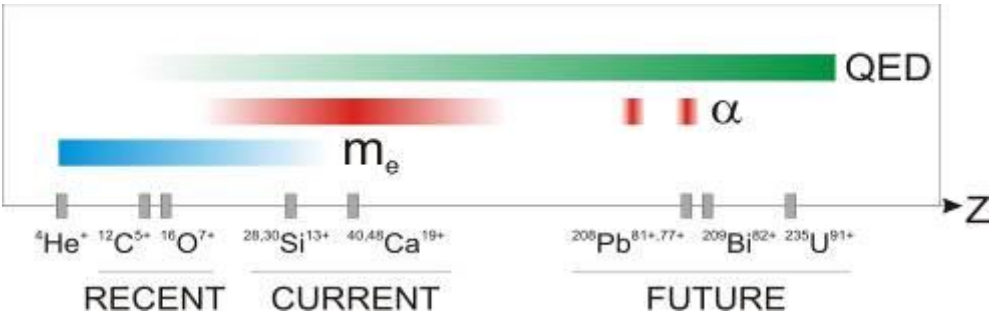
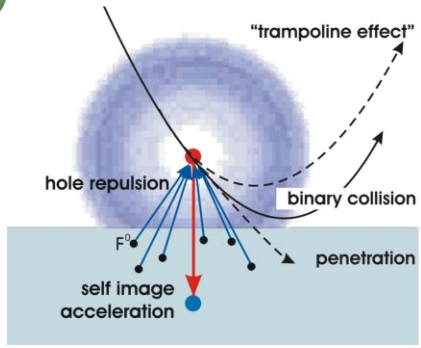
WHY?

HCI — **H**ighly **C**harged **I**ons

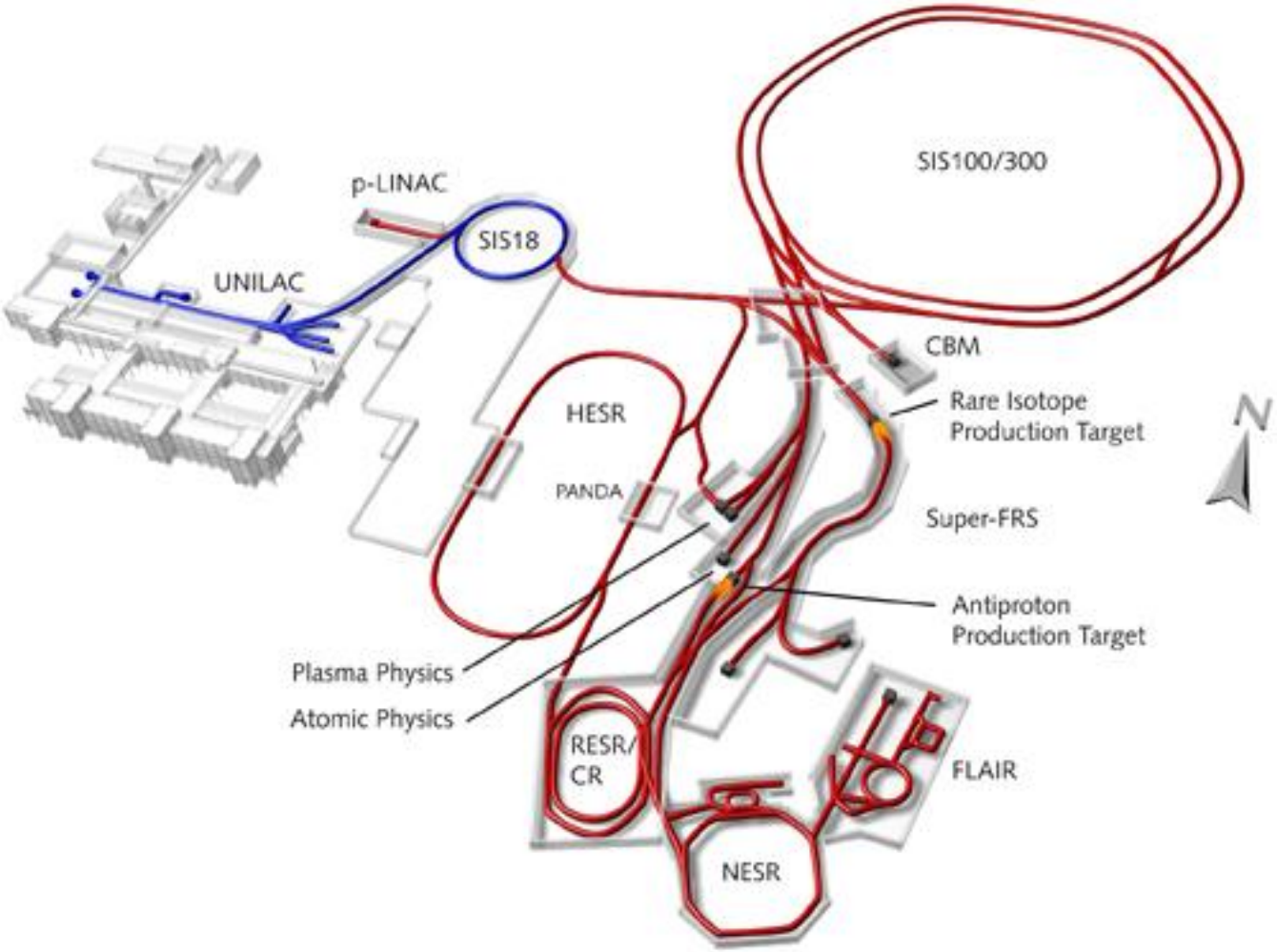
- **Elements**
  - **g-factor** — α, m_e — QED test
  - **e--binding** — Lamb-shift
- **Isotopes** — Charge radii
  - **FS, HFS** — BW effect
- **+ Matter**
  - **+ surface** — Structures
  - **+ atoms** — Charge exchange, Collision dynamics



Hollow atoms

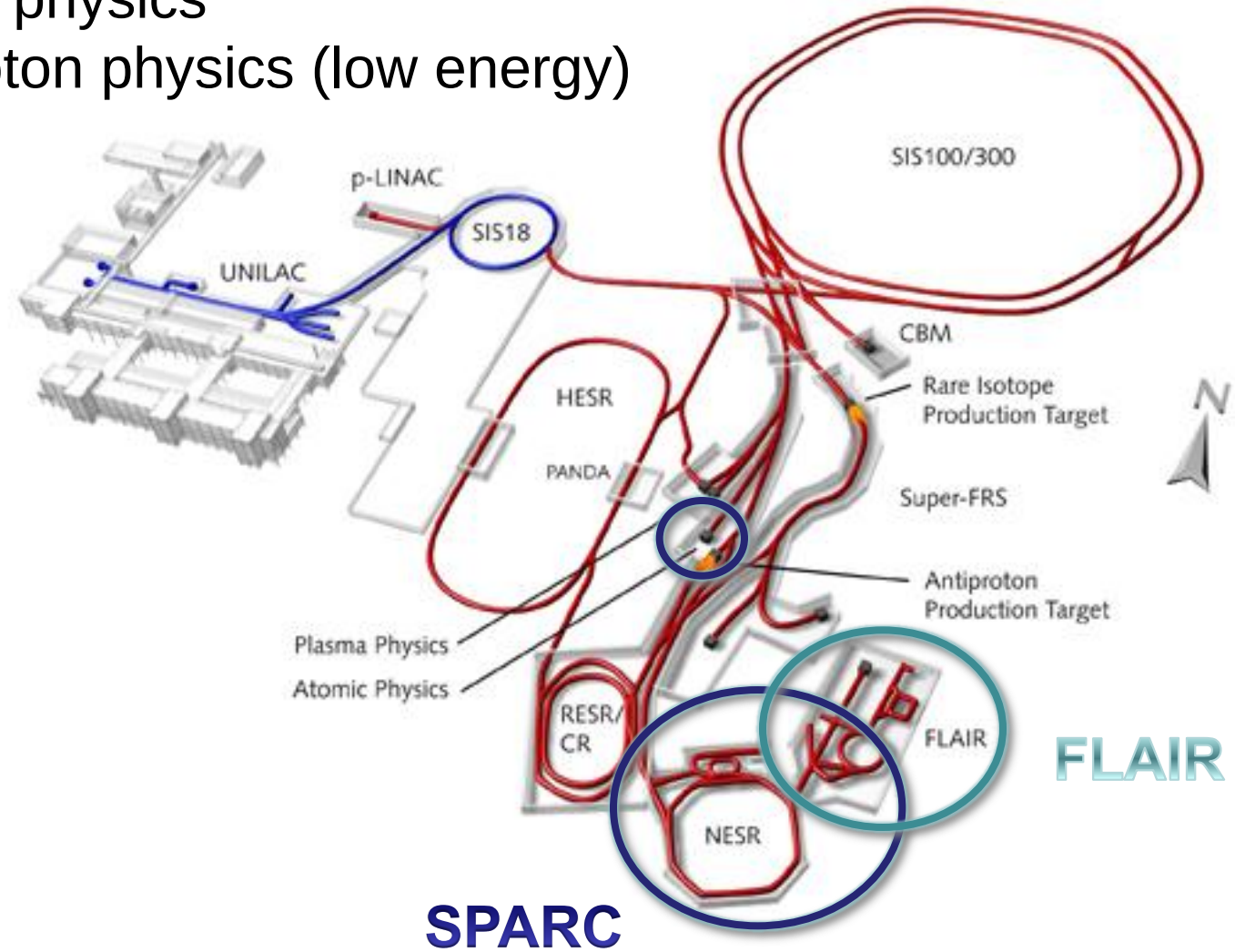


FAIR


SIS100/300
p-LINAC
SIS18
UNILAC
CBM
HESR
Rare Isotope
Production Target
N
PANDA
Super-FRS
Antiproton
Production Target
Plasma Physics
Atomic Physics
RESR/
CR
FLAIR
NESR

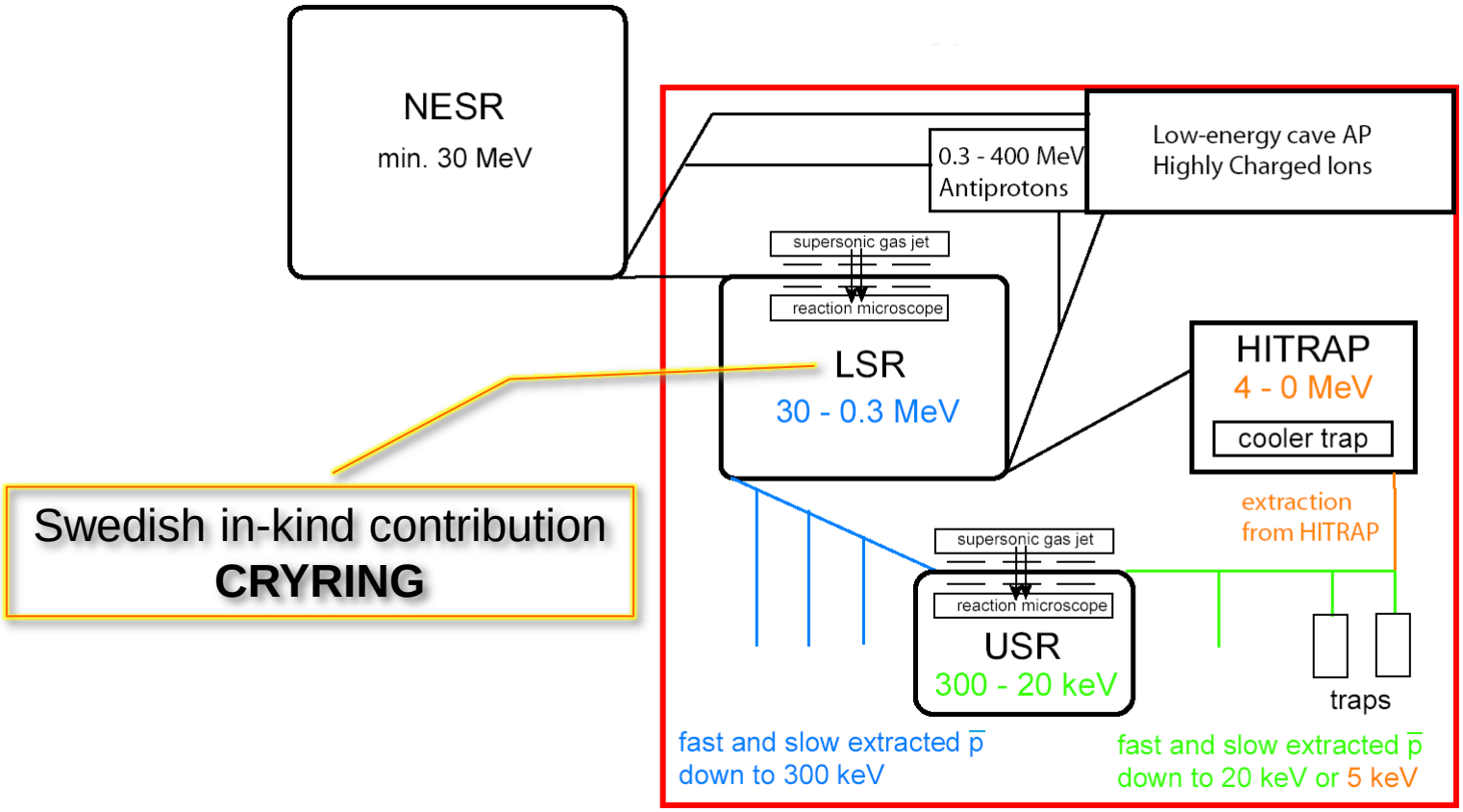
FAIR – SPARC and FLAIR

Atomic physics
Antiproton physics (low energy)



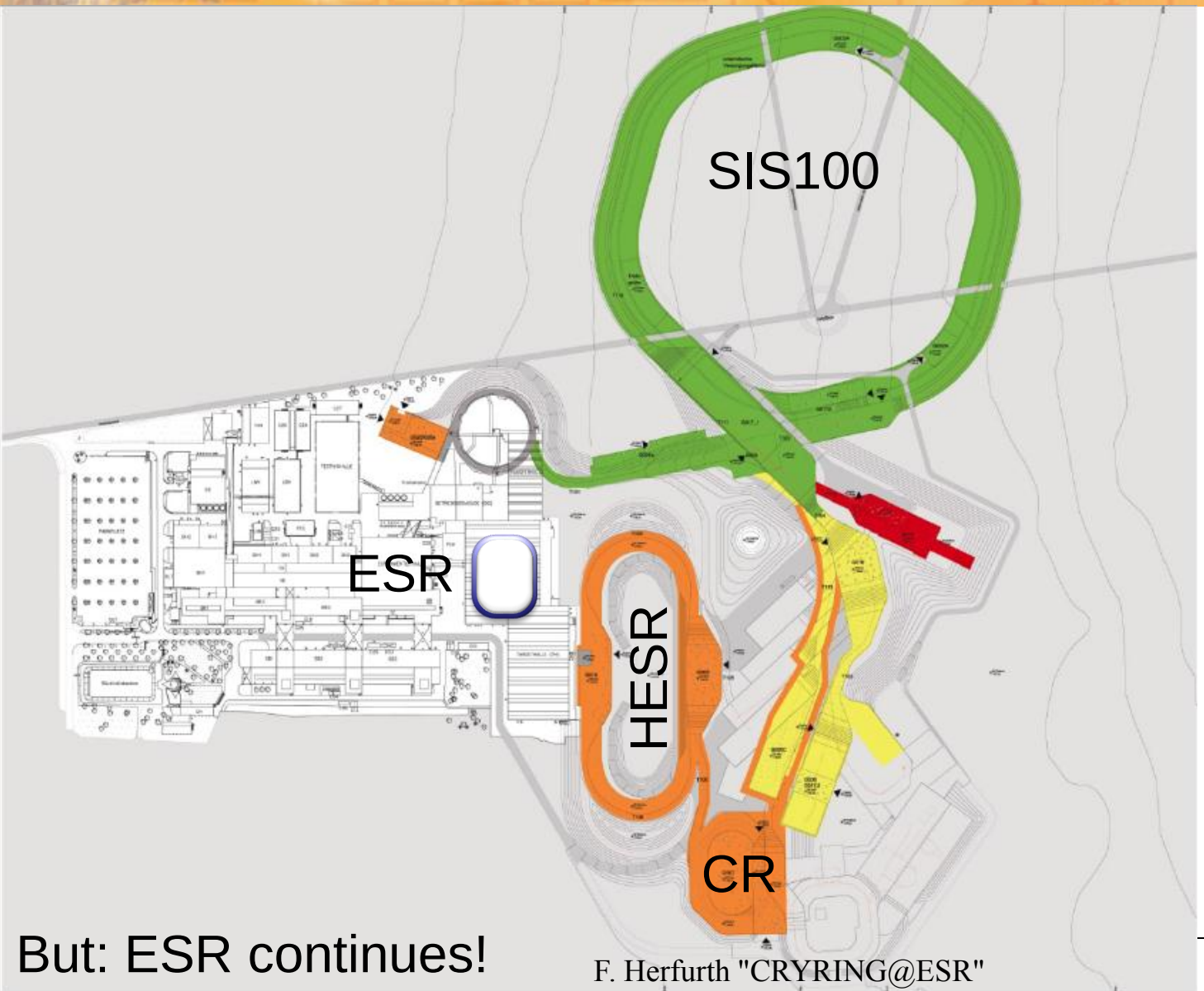
SPARC and FLAIR

Facility for Low Energy Antiproton and Ion Research
Stored Particles Atomic Physics Research Collaboration



Swedish in-kind contribution
CRYRING

The “Green Paper” – Stepwise to FAIR



Module 0

SIS 100

Module 1

Exp. Areas CBM/ HADES, APPA

Module 2

Super-FRS

Module 3

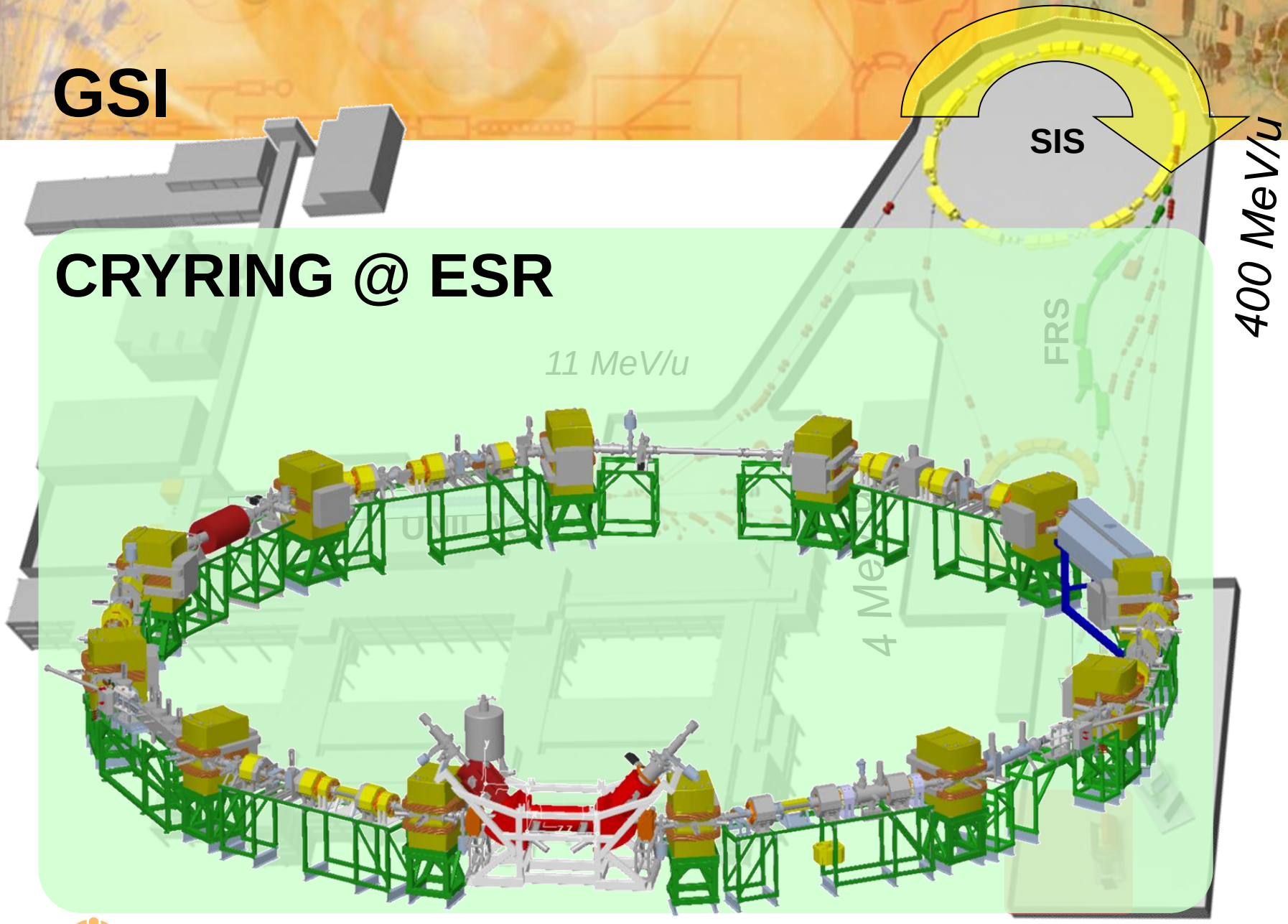
Antiprotons for PANDA (CR, HESR)

Upgrade

But: ESR continues!

GSI

CRYRING @ ESR



CRYRING @ ESR

FAIR Research & Development

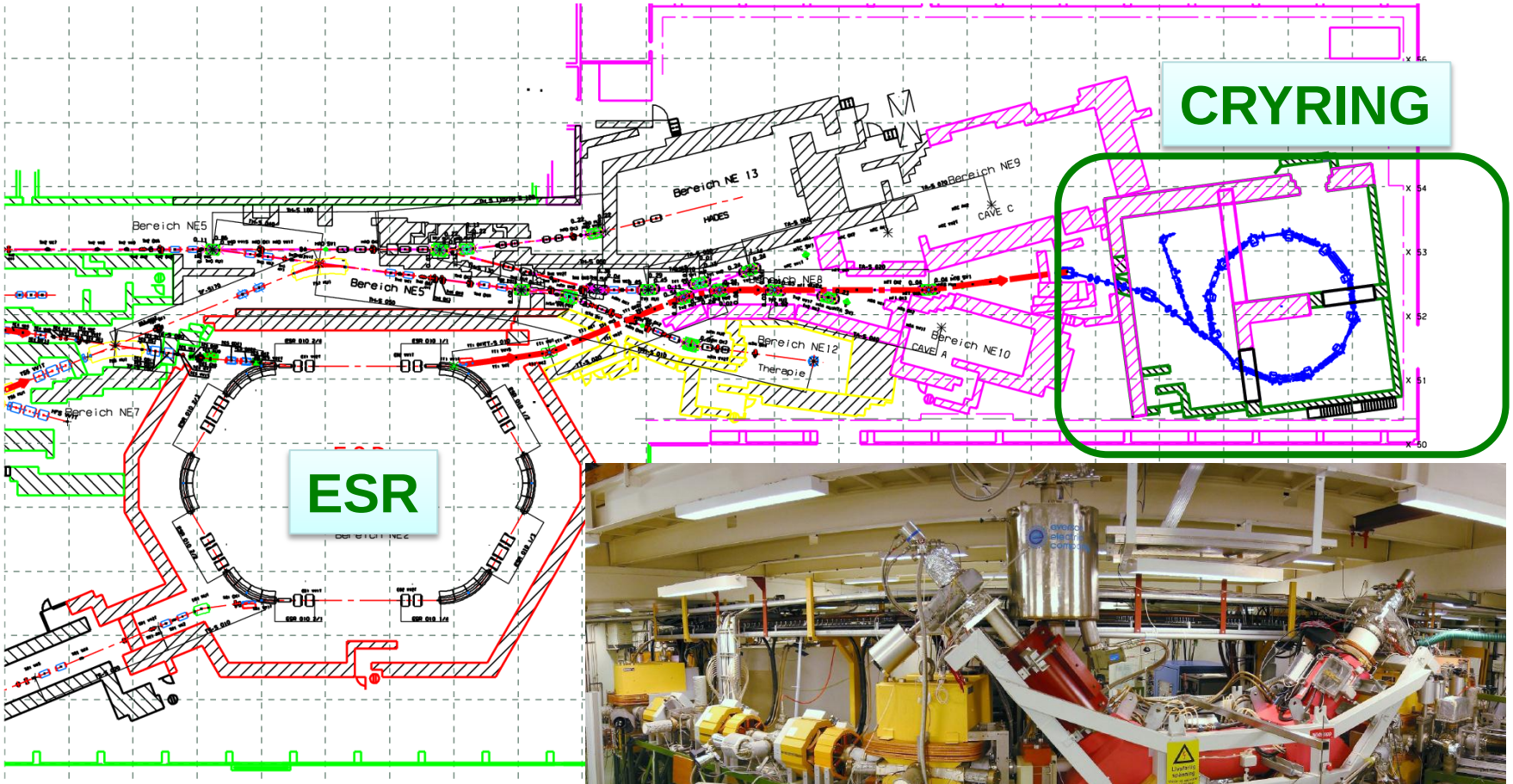
- Detectors and diagnostic systems
- FAIR type control system
- Training of operators on FAIR type system
- FAIR type safety and radiation monitoring/access system

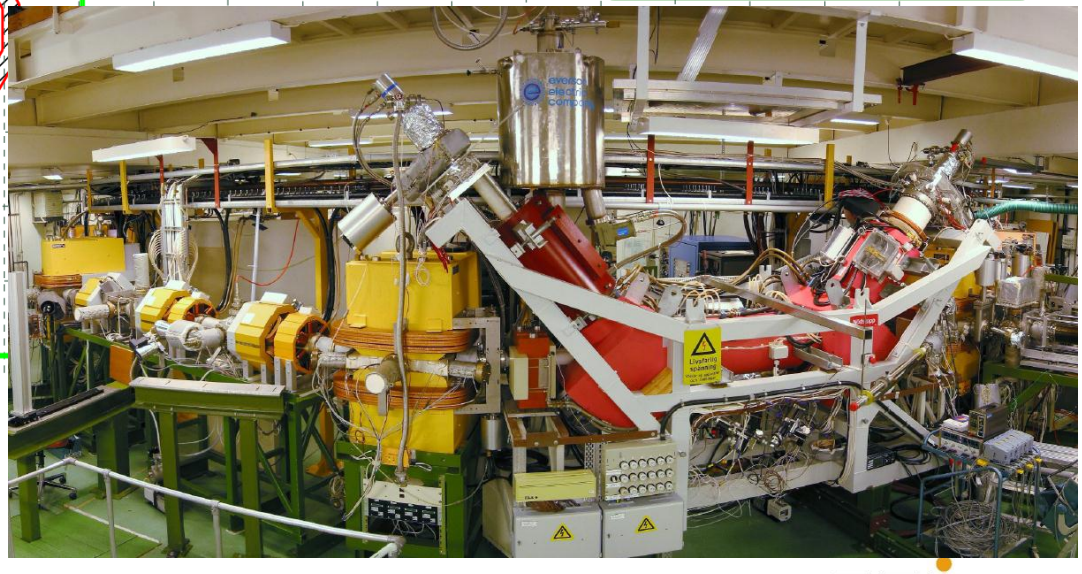
All this with real beam!

Scientific 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)

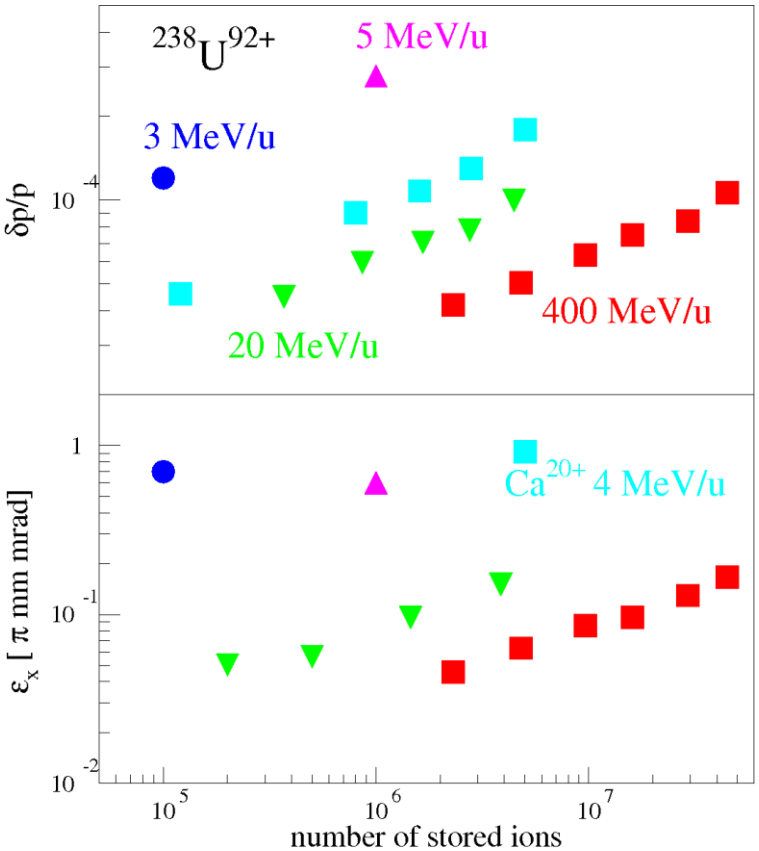
CRYRING @ ESR


CRYRING
ESR
from SIS18
from FRS
Bereich NE5
Bereich NE7
Bereich NE13
Bereich NE9
Bereich NE8
Bereich NE12
Bereich NE10
HADES
CAVE C
CAVE A
Therapie

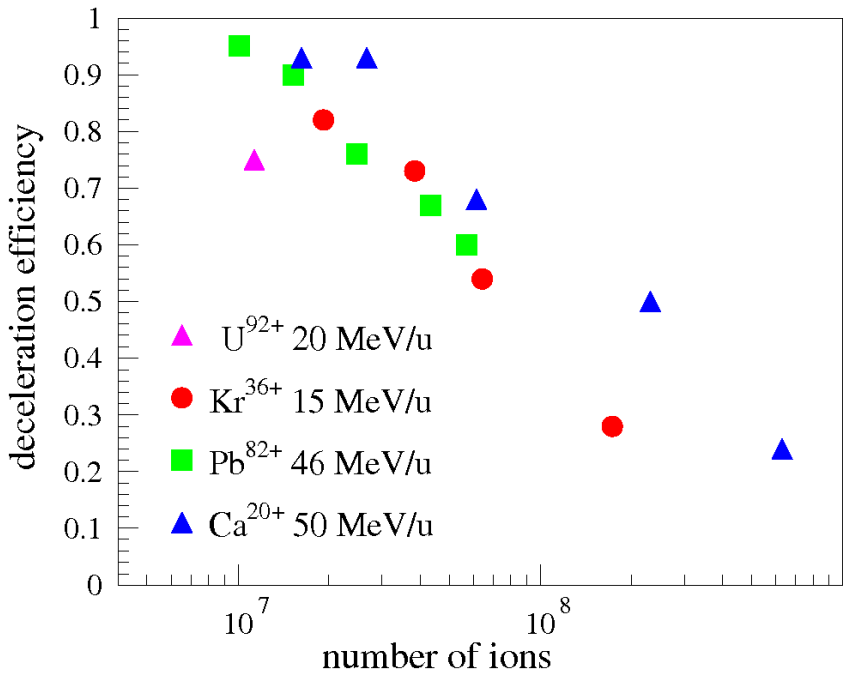


Decelerated Ions in the ESR

Equilibrium Beam Parameters after Electron Cooling



Losses increase with stored particle number



M. Steck et al.

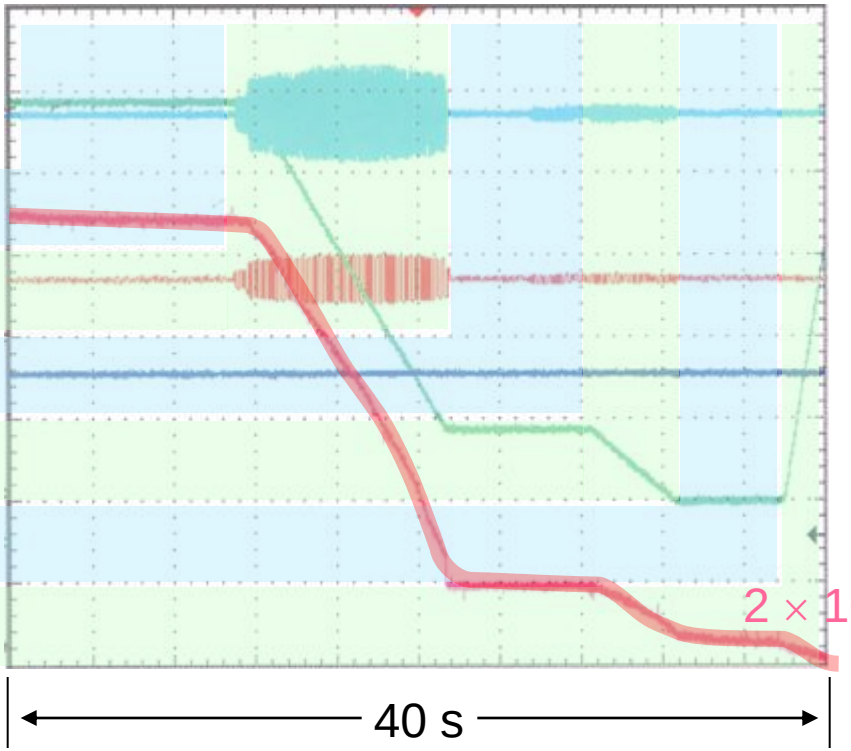
Some 10^7 decelerated ions at 4 MeV/u are realistic

ESR – From 400 to 4 MeV/u

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

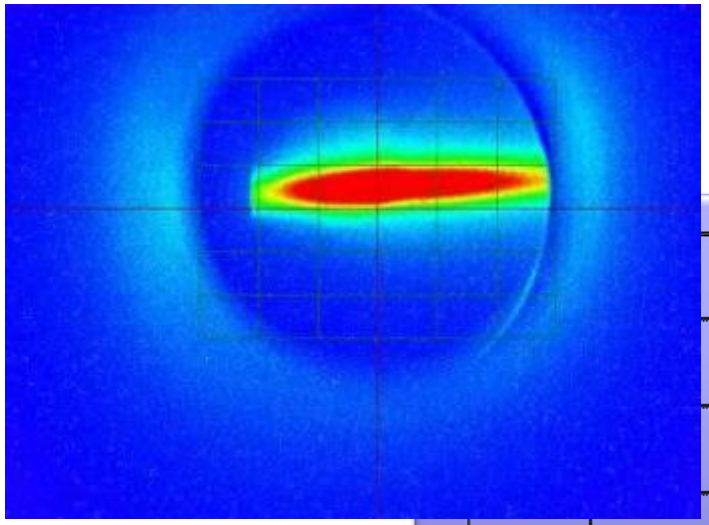
Ni^{28+} 400 → 30 → 4 MeV/u

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

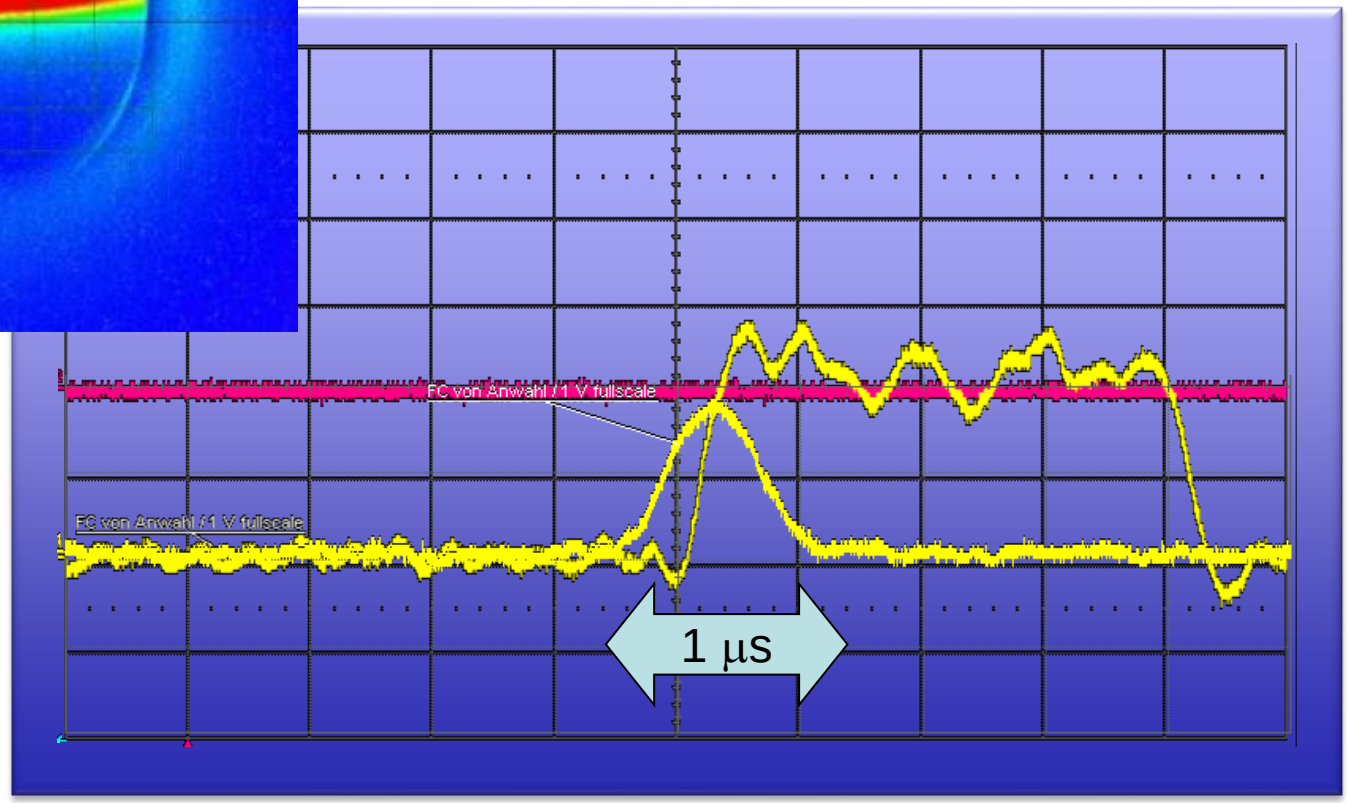


1100 μA → 180 μA → 25 μA

4 MeV/u ions from ESR



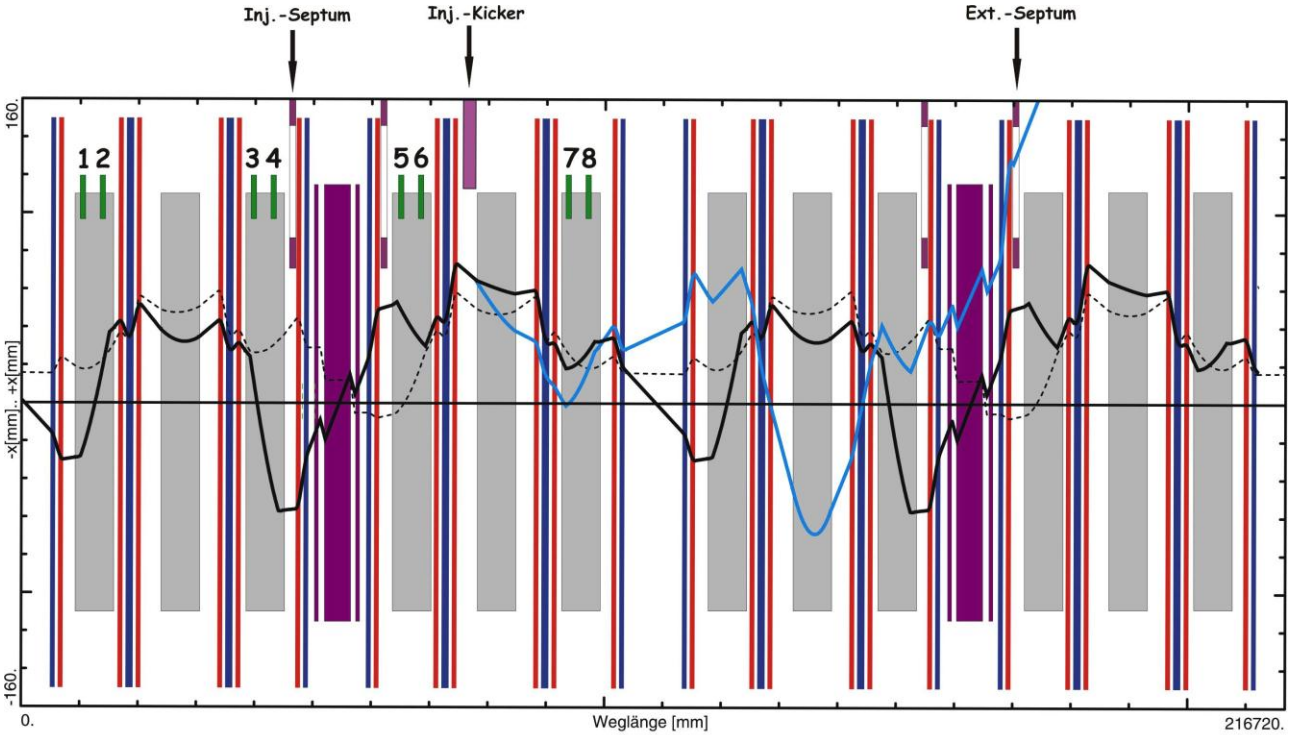
2×10^7 $^{136}Xe^{50+}$ extracted from ESR



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

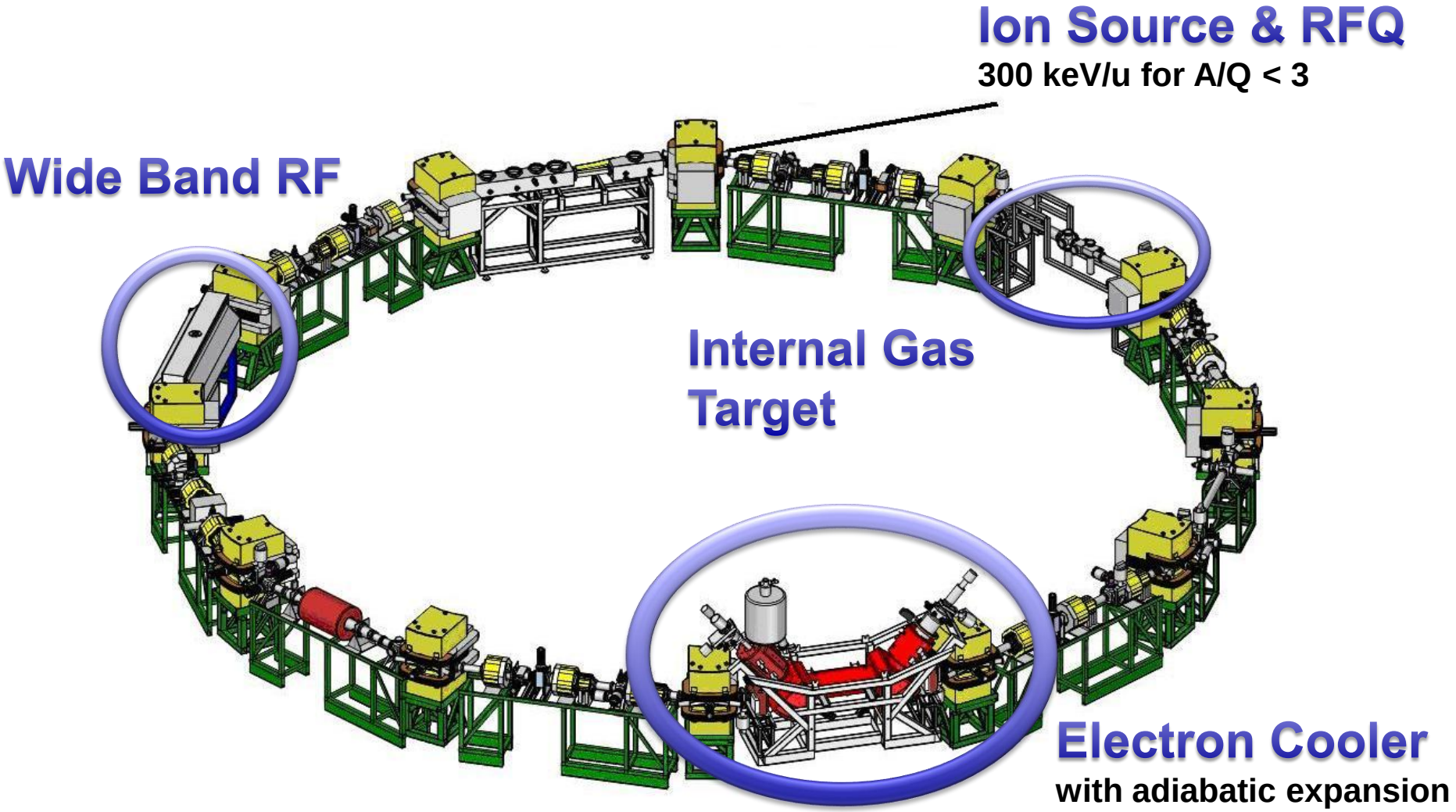
- Beam line upgrade (ESR – Cave B)
  added steering, dipoles; additional diagnostics

- 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

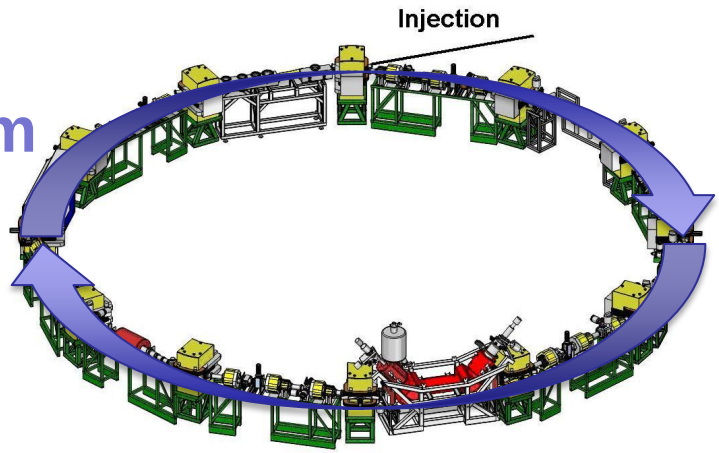
CRYRING @ MSL (Stockholm)



CRYRING Parameters

54 m = ESR/2

52 m

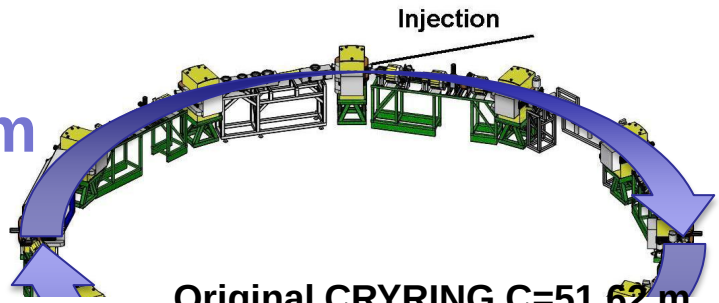


- Max. rigidity 1.44 Tm
  - 15 MeV/u U^{92+}
  - 96 MeV/u protons
- Min. rigidity ~ 0.054 Tm
  - 150 keV/u protons
- Ramping speed 1 T/s; 7 T/s

CRYRING Parameters

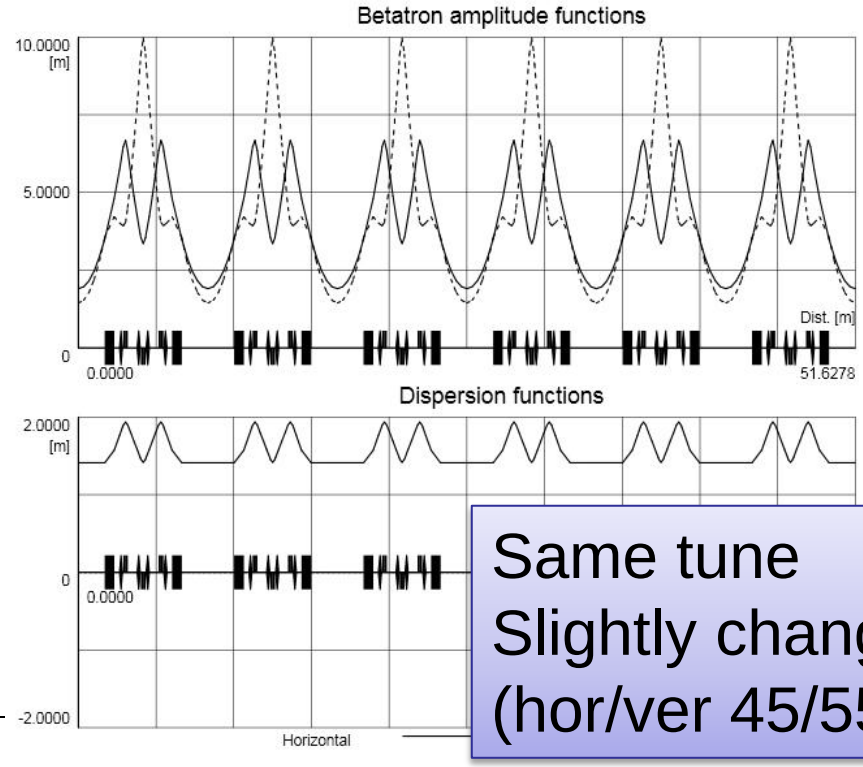
54 m = ESR/2

52 m

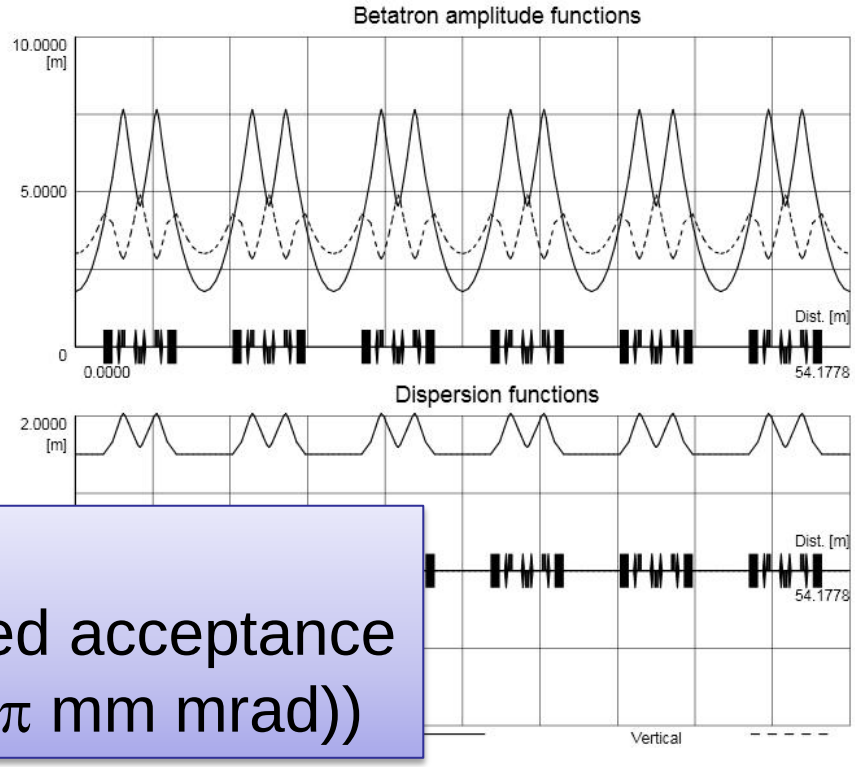


- Max. rigidity 1.44 Tm
- Min. rigidity ~ 0.054 Tm
- Ramping speed 1 T/s; 7 T/s

Original CRYRING C=51.62 m

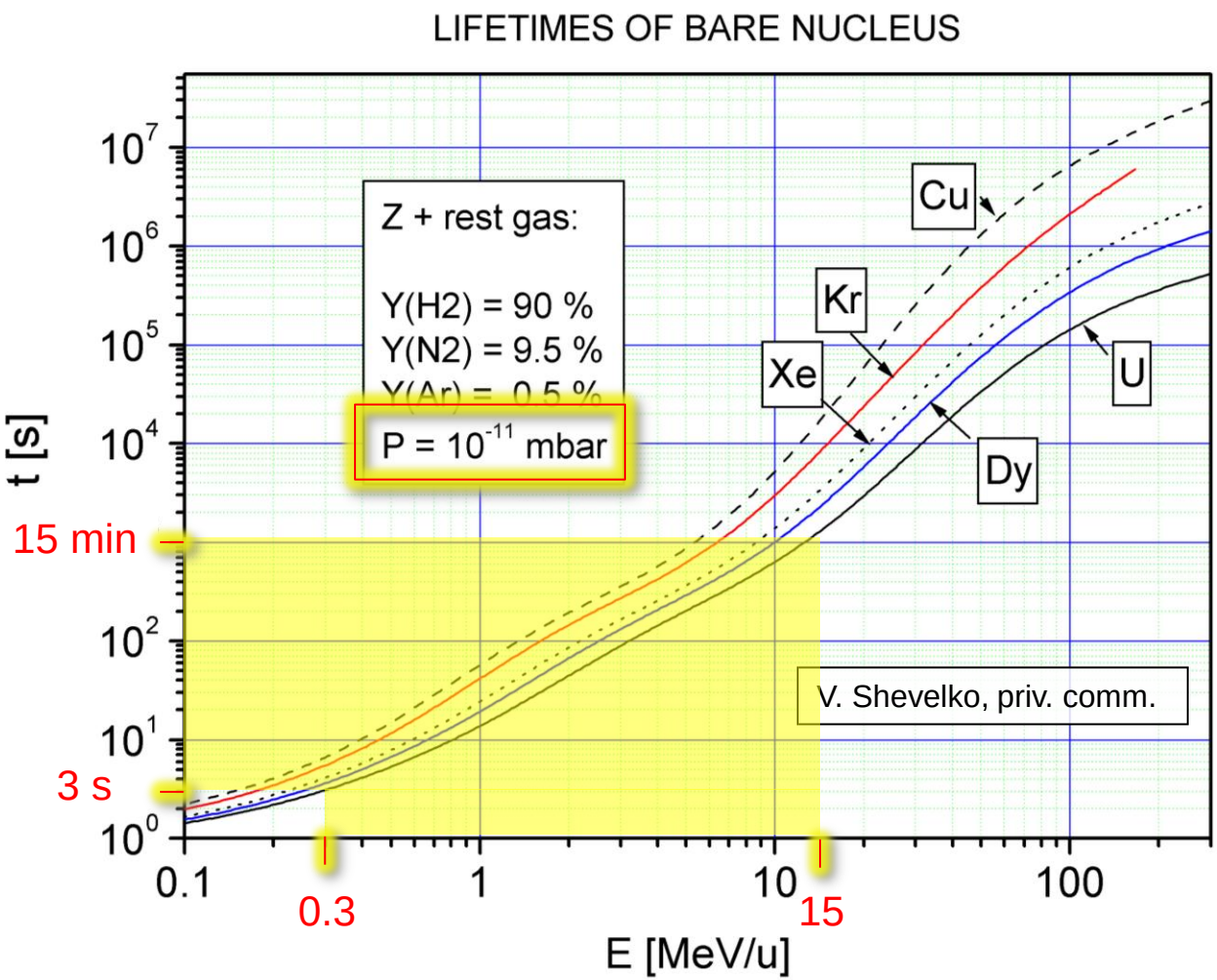


New circumference C=54.18 m

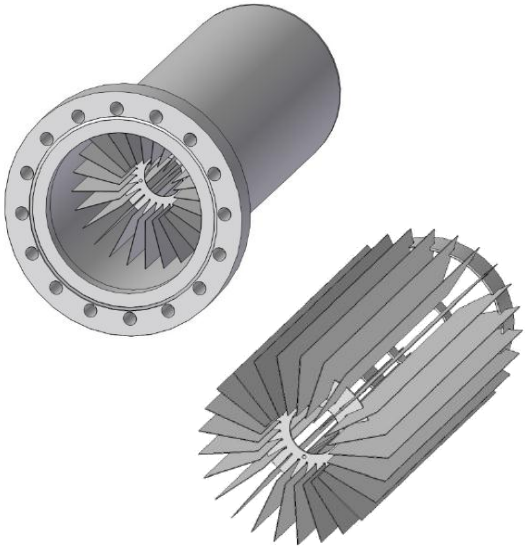


Same tune
Slightly changed acceptance
(hor/ver 45/55 π mm mrad))

Vacuum & Beam Life Time



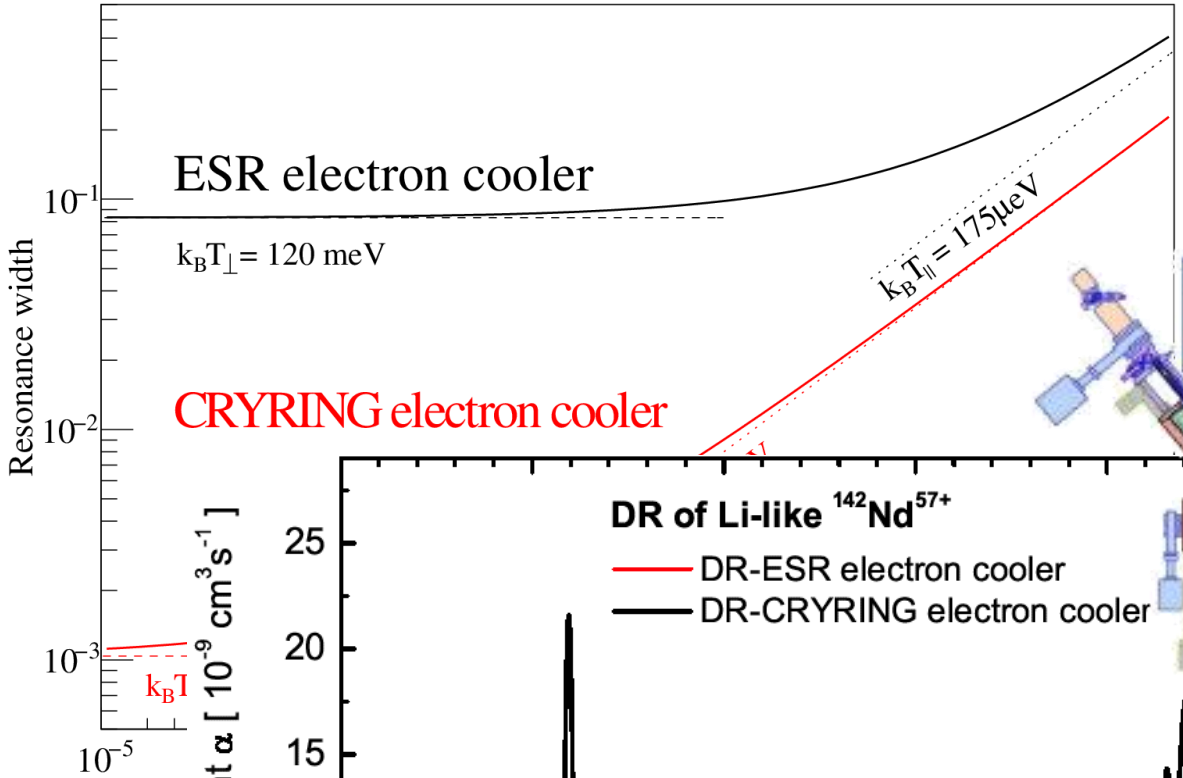
- Ion pumps
  ~ 10
- Cryopumps
- NEG pumps
  ~ 100

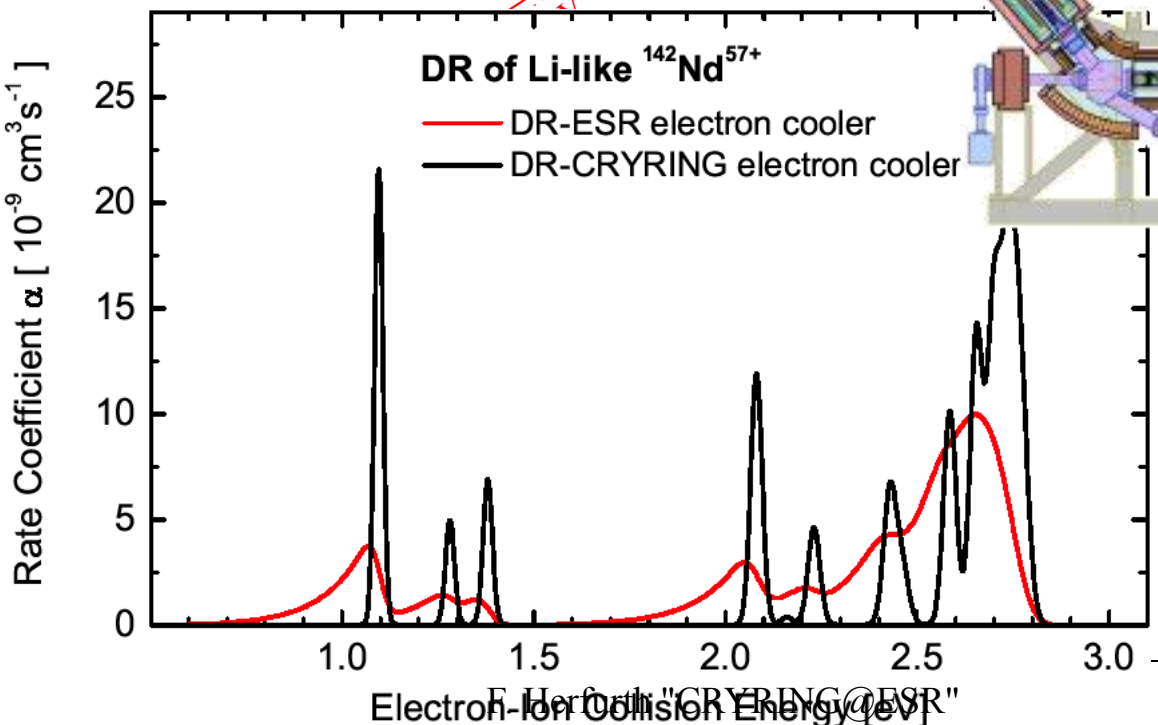


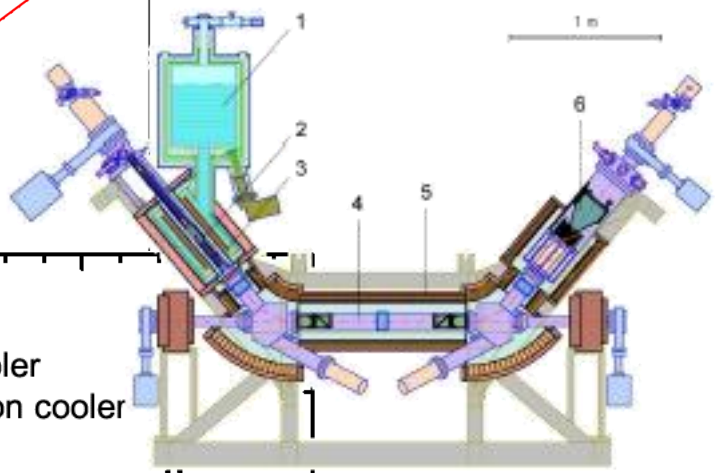
Experimental Equipment to be installed

- **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

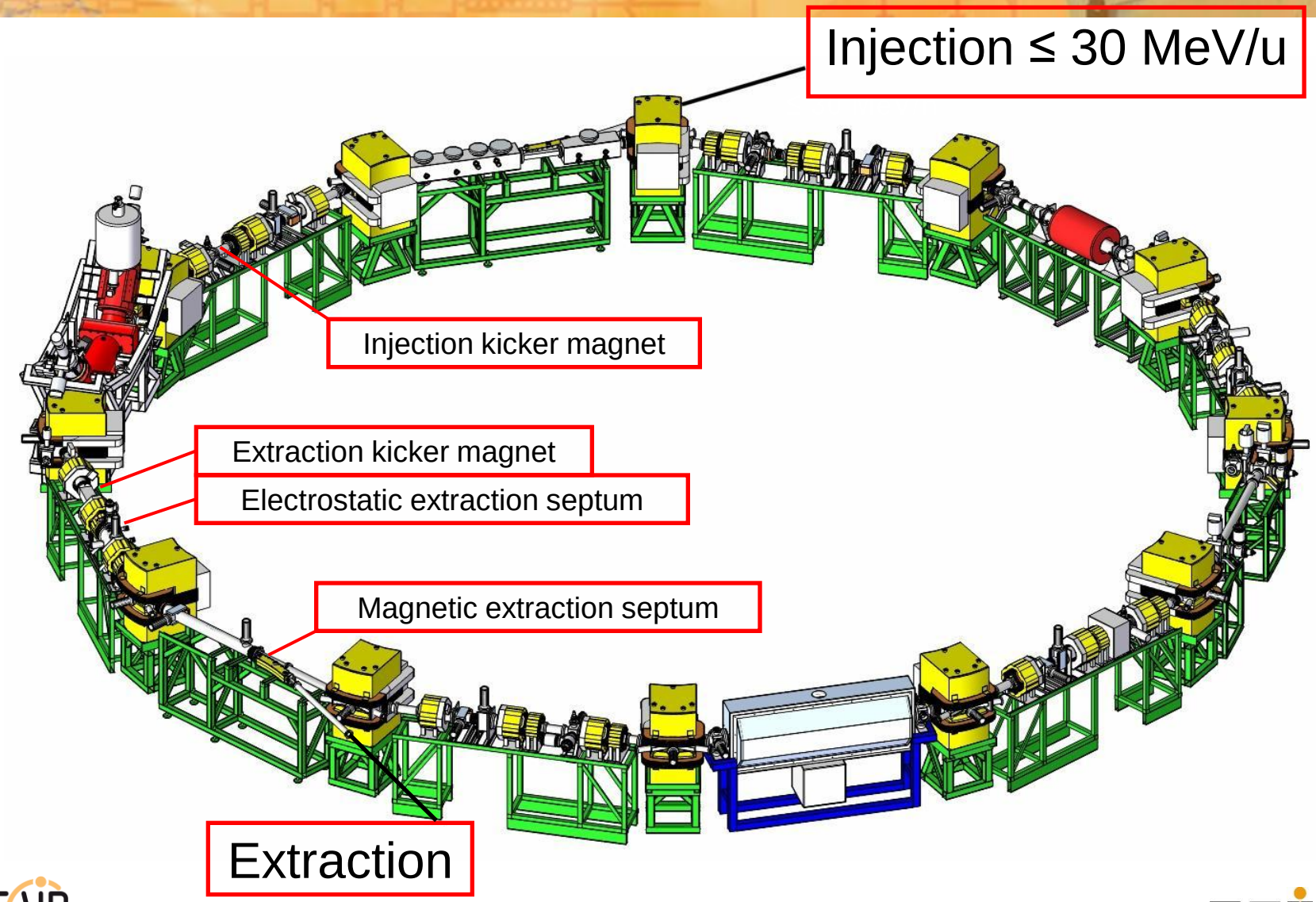
Electron Cooling ESR - CRYRING





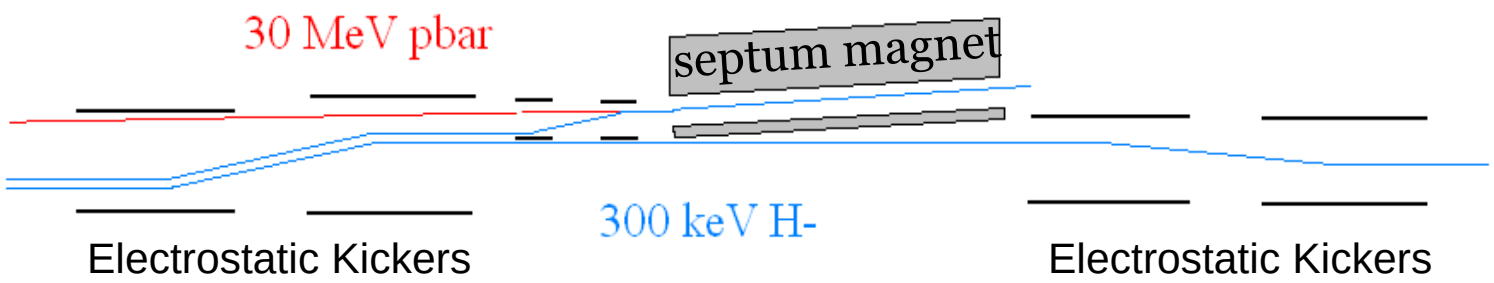


CRYRING modifications toward FAIR/GSI

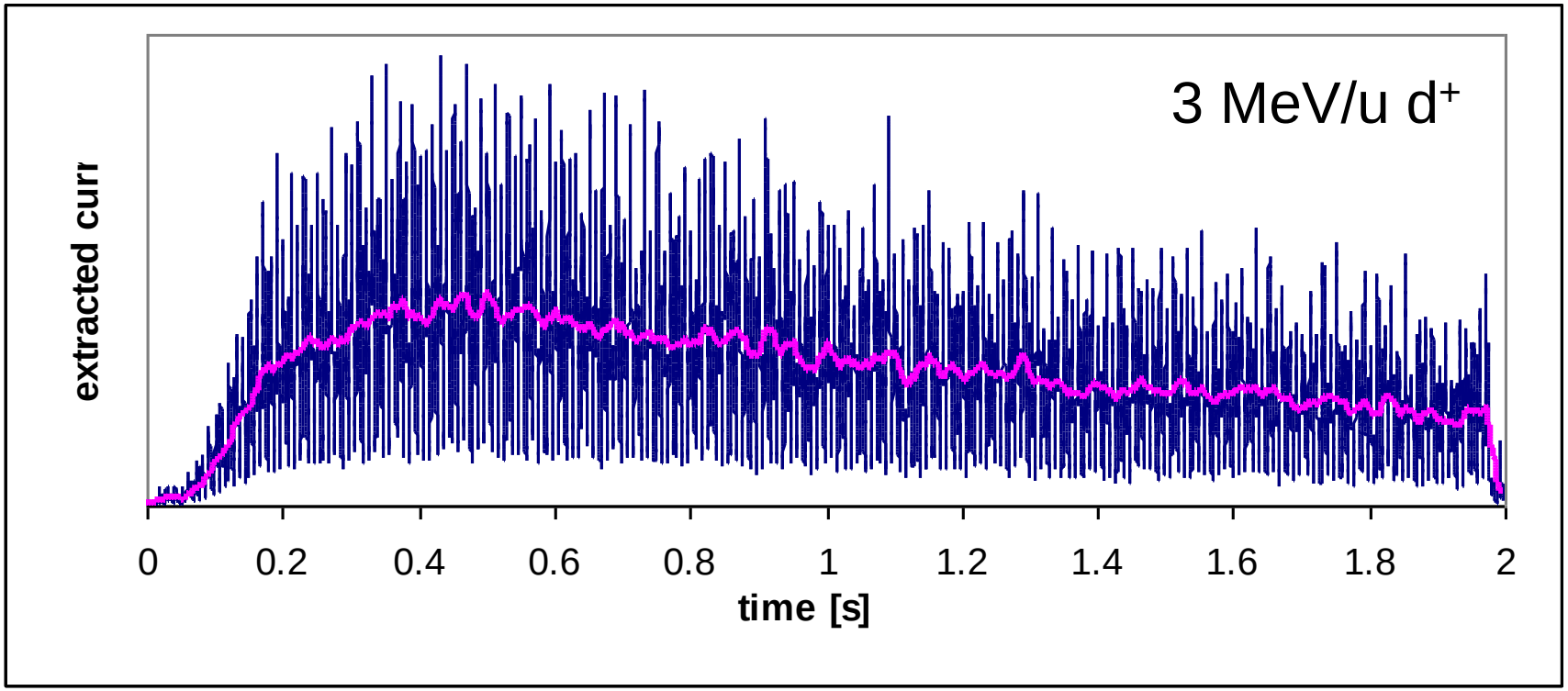


New “dual” Injection System

- 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



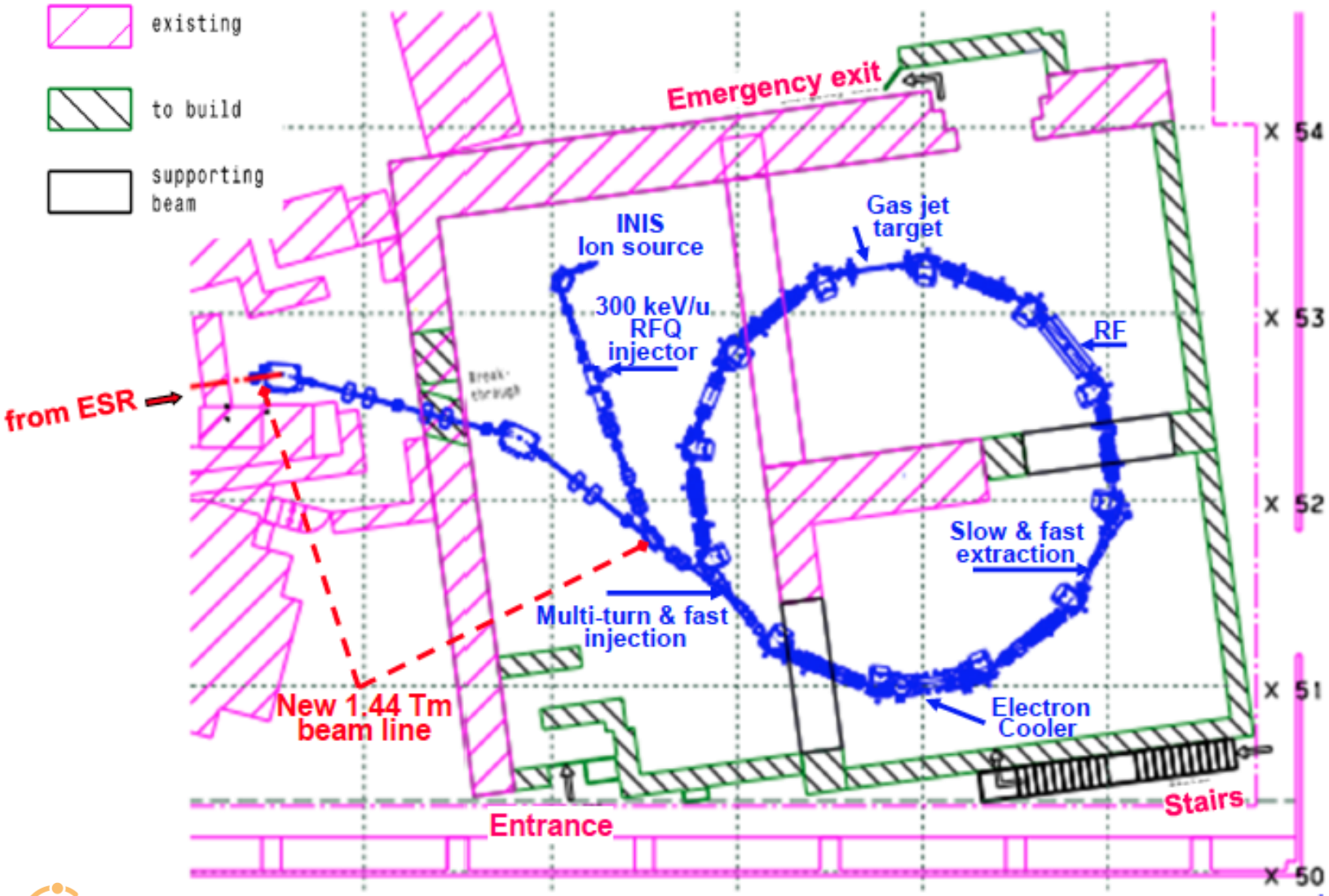
Test of Extraction



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

Pink - 20 ms average (no n × 50 Hz)

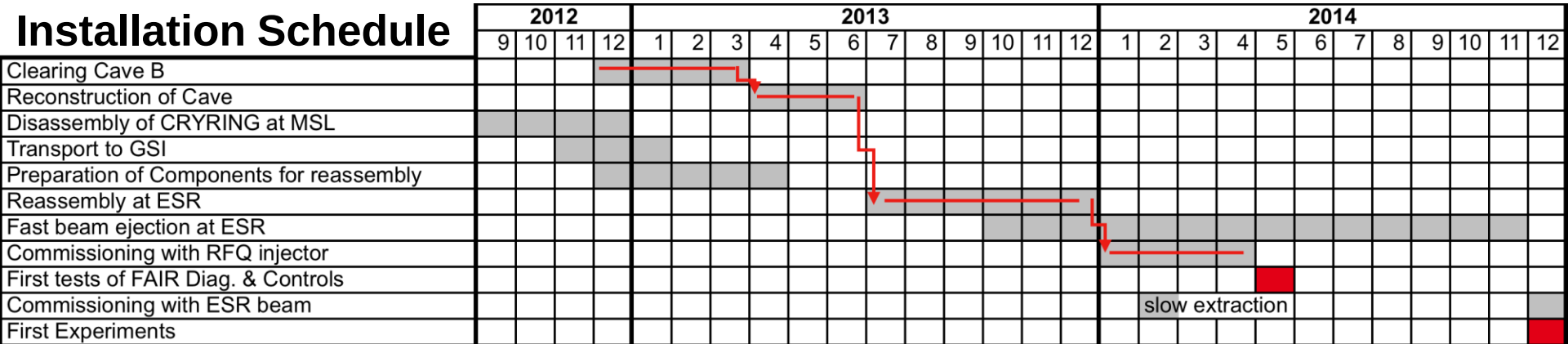
CRYRING @ ESR in modified Cave B



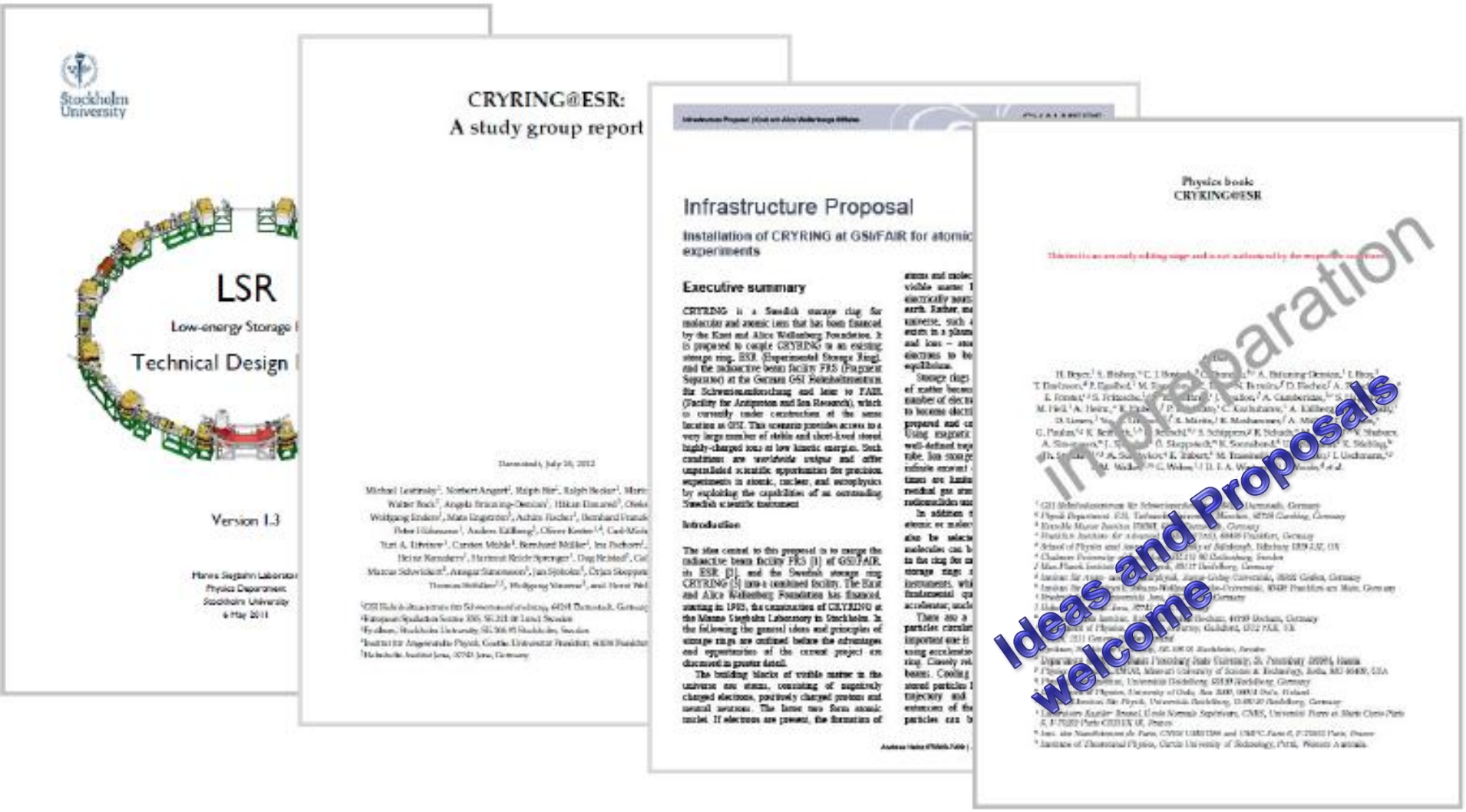
Timeline

1985	**CRYRING funded by K. and A. Wallenberg Foundation**
1991	First beam (deuterons)
2006	FAIR Technical Report on APPA, SPARC and FLAIR: CRYRING is proposed as LSR
1992 - 2010	CRYRING at MSL in Stockholm produced ~ 400 research papers, 43 dissertations, 39 licentiate theses
Nov - 2011	Proposal of early installation and combination of ESR and CRYRING
Jun - 2012	CRYRING @ ESR: A study Group Report
Oct - 2012	Positive response from GSI
Nov - 2012	Evaluation by the ECE of FAIR scheduled

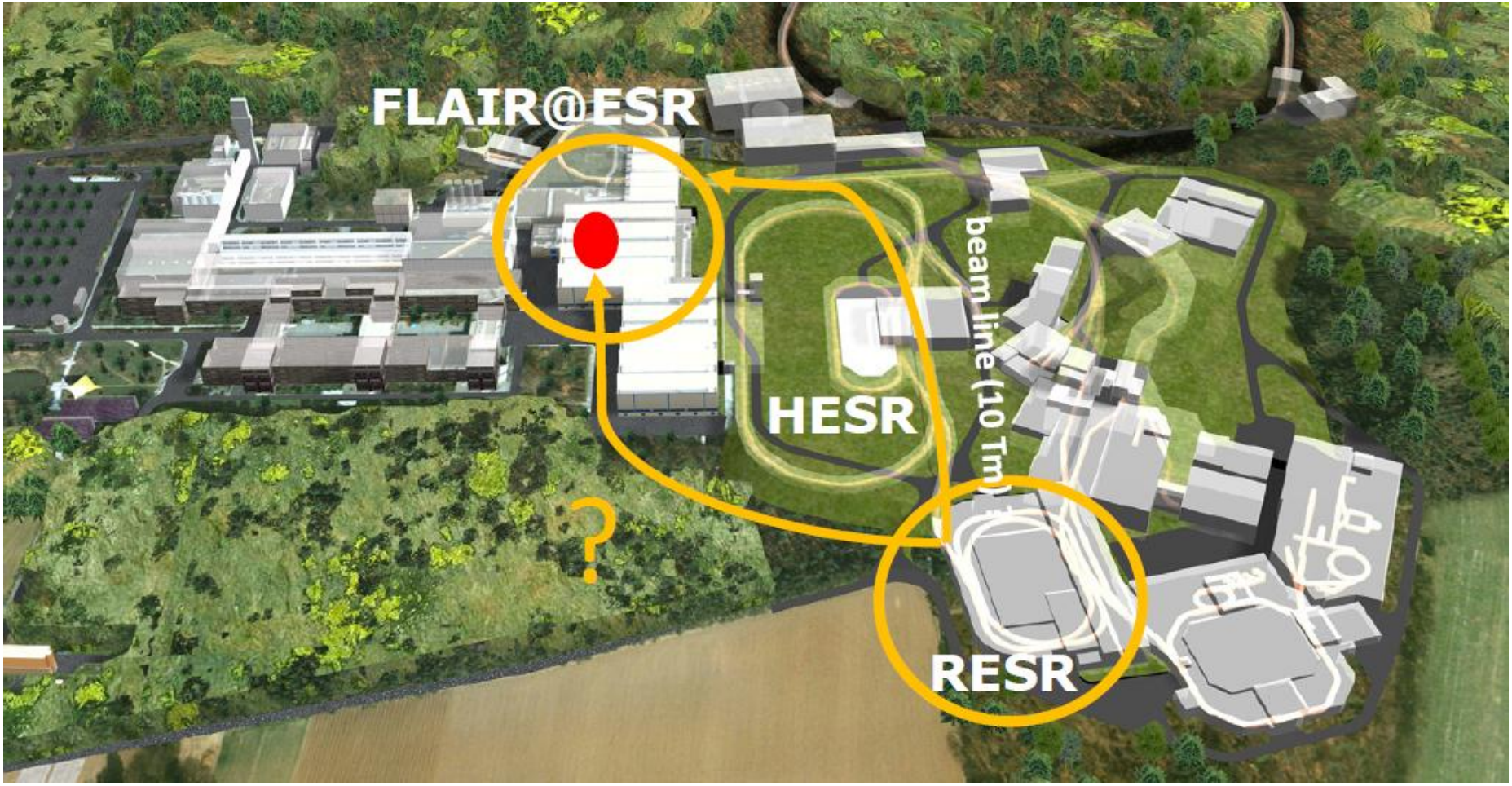
Installation Schedule



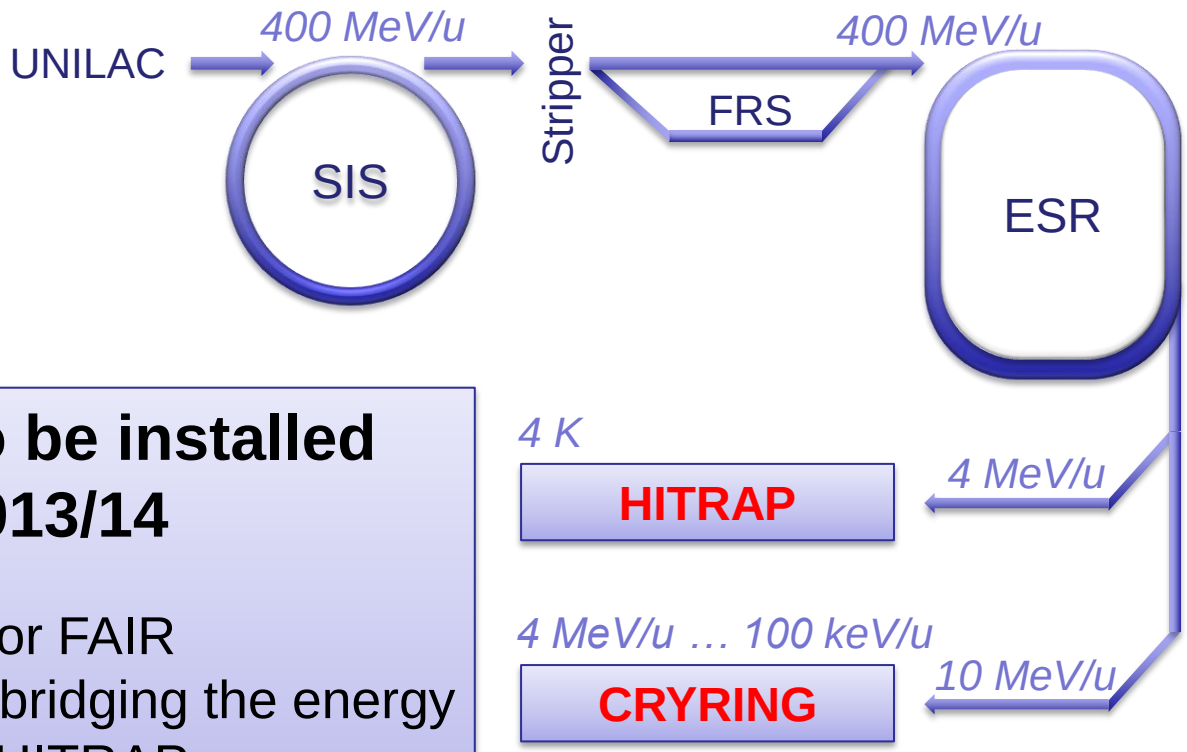
Documents related to CRYRING @ GSI and FAIR



Vision: Antiprotons from CR/RESR



Summary



CRYRING planned to be installed behind the ESR in 2013/14

- Perfect testing ground for FAIR
- Rich scientific program bridging the energy gap between ESR and HITRAP
- Decelerated antiprotons are an option for the future