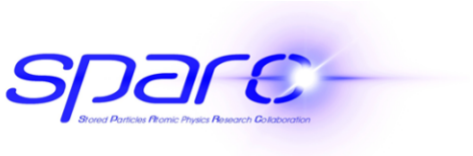
Status of the low-energy facilities for antiproton and heavy ion experiments at FAIR



Thomas Stöhlker *Helmholtz Institute Jena, GSI, & Friedrich Schiller University, Jena*
Eberhard Widmann *Stefan Meyer Institute, Vienna*

Introduction

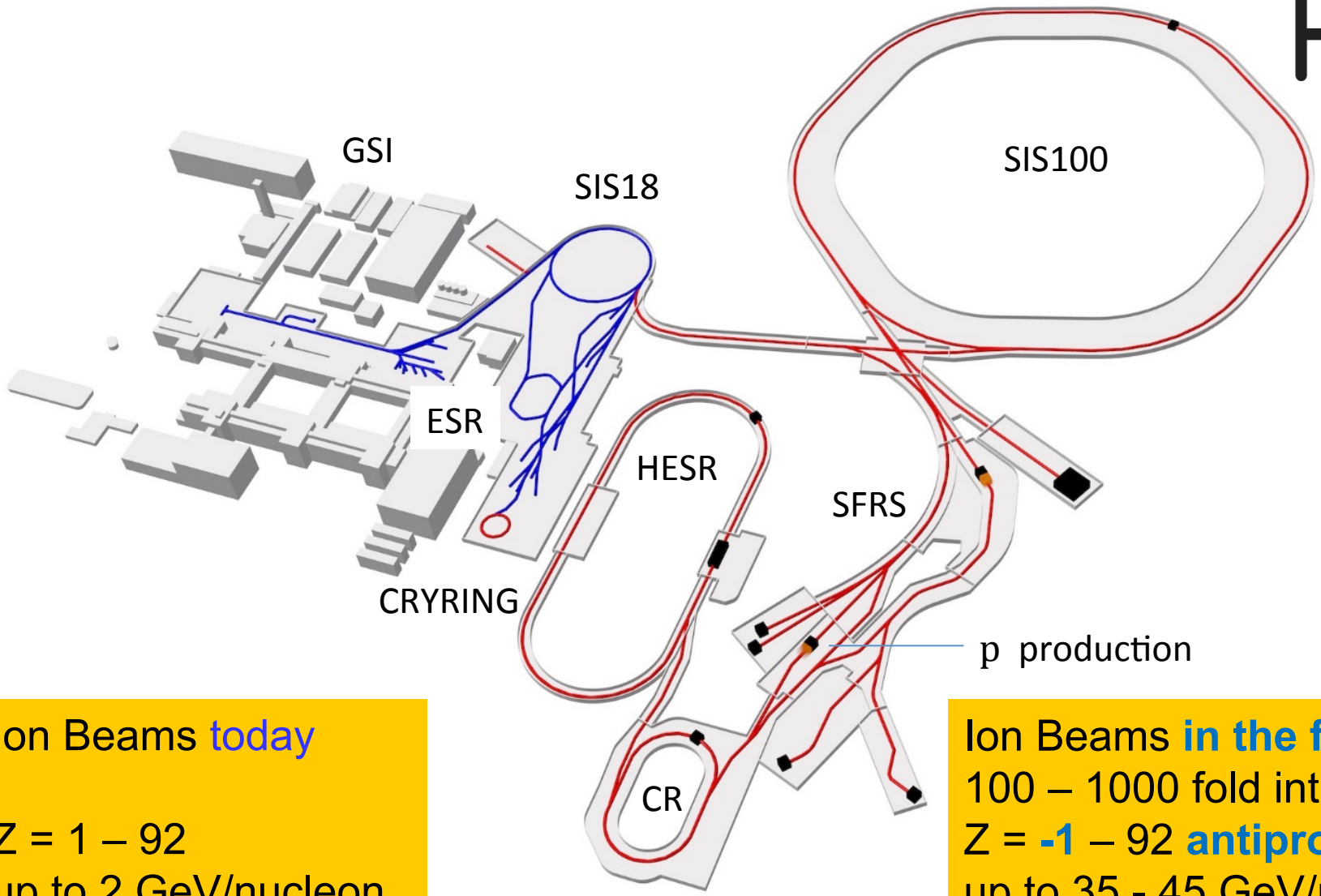
The Facilities: HITRAP & CRYRING

CRYRING: Physics Case (ions)

Novel Scheme to Connect ESR with FAIR for pbars

Summary and Outlook

The International Facility for Antiproton and Ion Research



Ion Beams today

Z = 1 – 92
up to 2 GeV/nucleon

Ion Beams **in the future**
100 – 1000 fold intensity
Z = **-1** – 92 **antiprotons**
up to 35 - 45 GeV/nucleon

FLAIR Physics Topics with Antiprotons

- **Spectroscopy for tests of CPT and QED**
  - Antiprotonic atoms (pbar-He, pbar-p), antihydrogen
- **Atomic collisions**
  - Sub-femtosecond correlated dynamics: ionization, energy loss, antimatter-matter collisions
- **Antiprotons as hadronic probes**
  - X-rays of light antiprotonic atoms: low-energy QCD
  - X-rays of neutron-rich nuclei: nuclear structure (halo)
  - pbar-p cross section, nbar interaction
  - Strangeness –2 production
- **Medical applications: tumor therapy**

Features of FLAIR

- Low-energy, high-brilliance beams for effective stopping
- High effective collision rates with USR: fully kinematic measurements
- Continuous beams: *only possible @ FLAIR*
- availability of radio-active ions offers synergies
- High energies, high intensities, slow extraction

E.Widmann, 2007

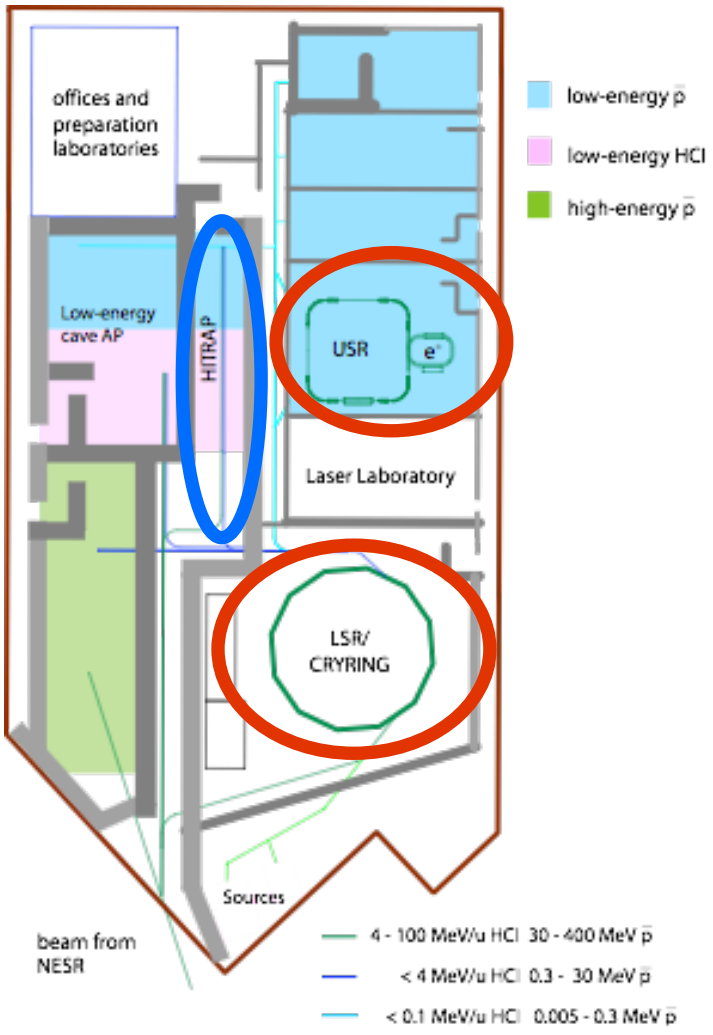
Features of a Next-generation Low-energy Antiproton Facility

Feature	*Solution*
Higher intensity	*Accumulation scheme*
Fast and slow extraction	*Coincidence experiments (nuclear physics)*
Cooled beams down to < 500 keV	*Storage rings*
Availability of pbar and RI	*FAIR*

E.Widmann, 2007

FLAIR@ FAIR - Baseline Technical Report 2005

- High brightness low energy beams
  - two storage rings with 300 keV (LSR) and 20 keV (USR)
  - electron cooling
    - ε ~ 1 π mm mrad
    - Δp/p ~ 10–4
- Storage rings with internal targets for collision studies
- Slow and fast extraction
- Ion traps
  - HITRAP facility for HCI & pbar
- Many new experiments possible
- same facilities can be used for HCI



Factor 100 more pbar trapped or stopped in gas targets than now

Introduction

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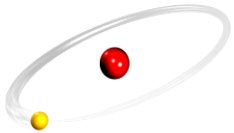
Summary and Outlook

Cooled Heavy Ions at GSI/FAIR

hydrogen

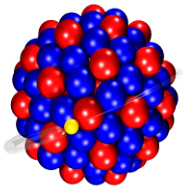


Z=1

E_b = 13.6 eV

$Z \cdot \alpha \ll 1$

uranium ion



Z=92

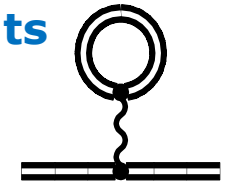
E_b = 132 keV

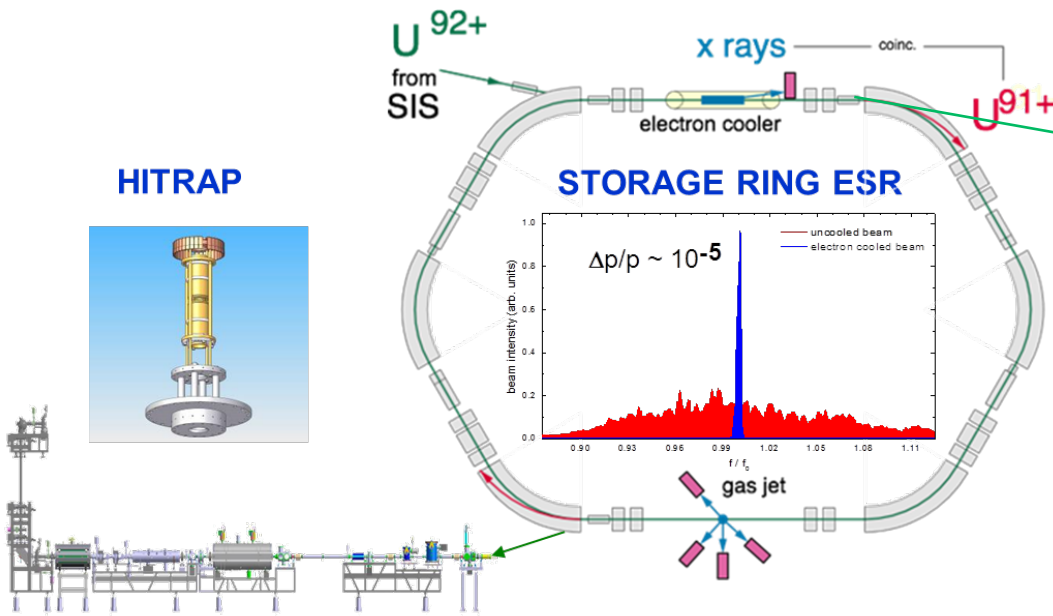
$Z \cdot \alpha \approx 1$

Strong Field QED/ Fundamental Constants

Atomic Collisions in Extreme Fields

Border to Nuclear Physics



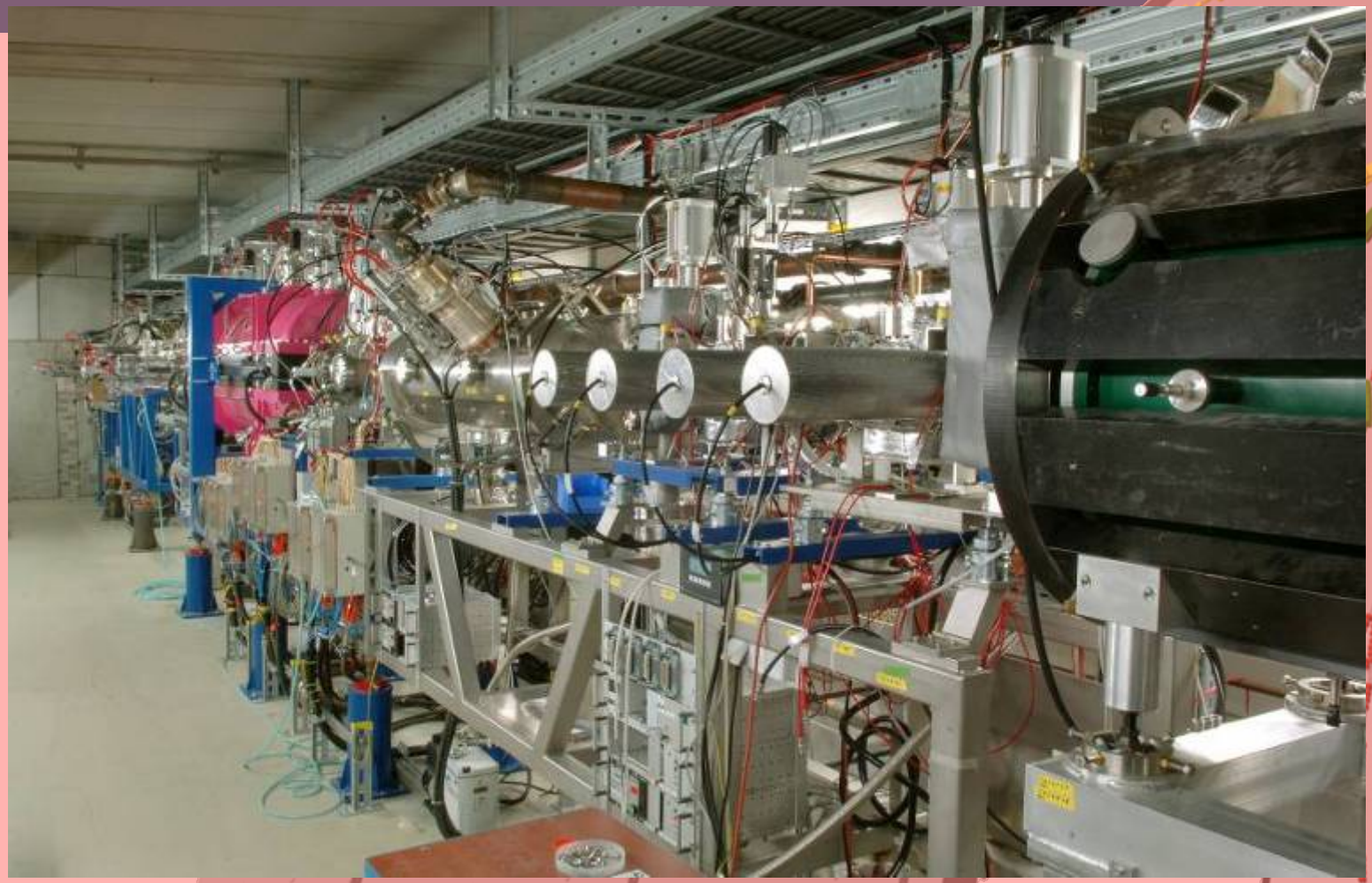


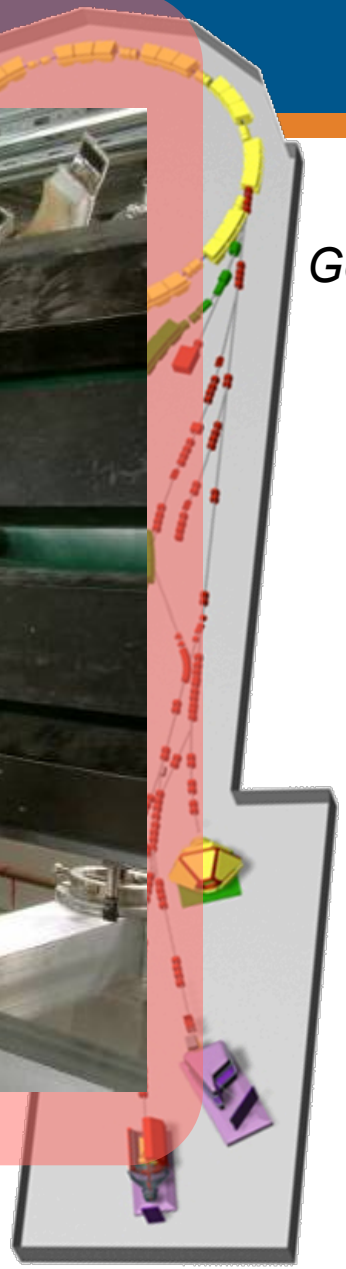
ions at rest in the laboratory

CRYRING: Swedish in-kind contribution to FAIR

HITRAP

GSI



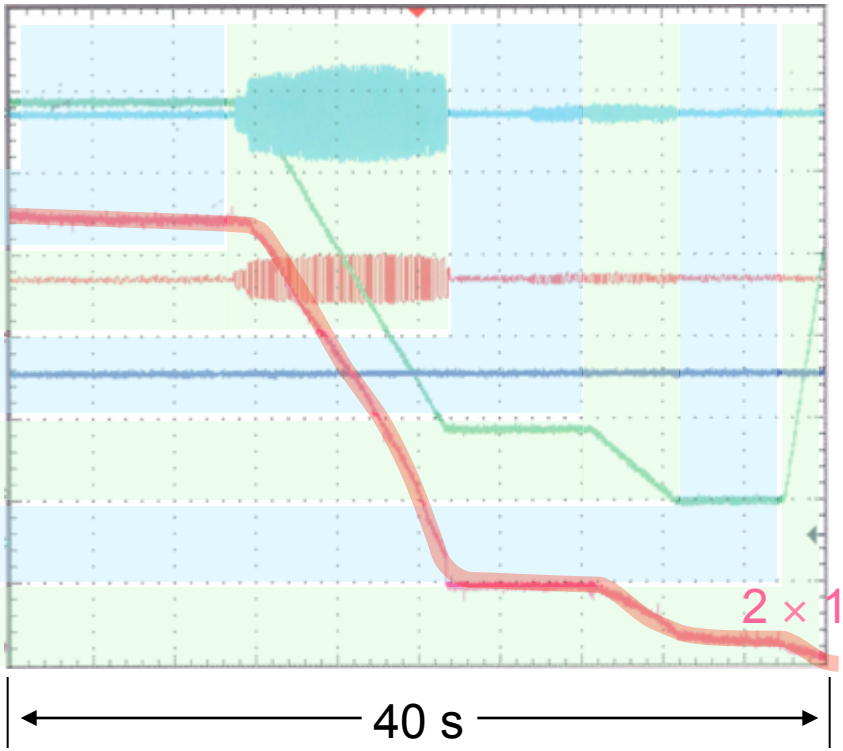


ESR – From 400 to 4 MeV/u

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

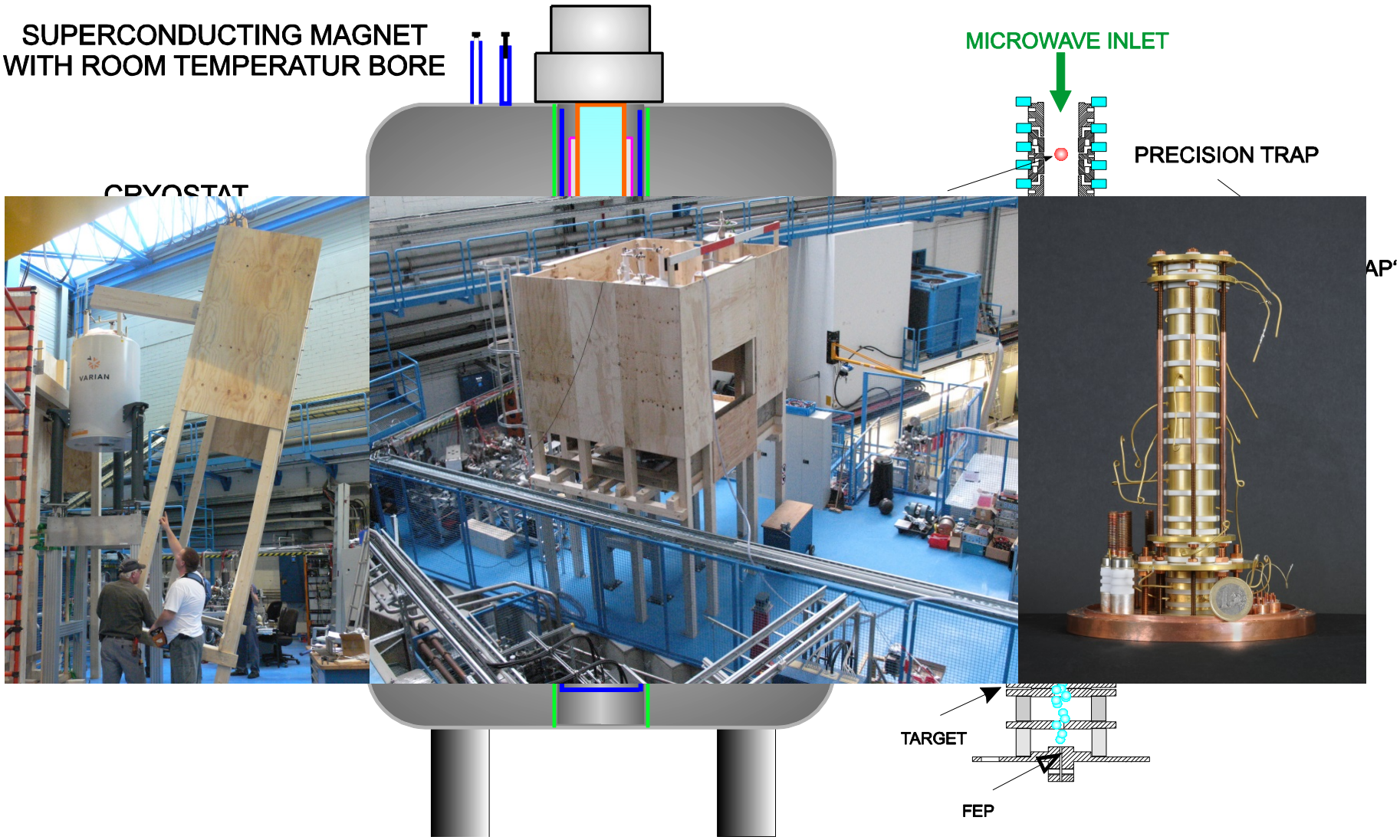
Ni^{28+} 400 → 30 → 4 MeV/u

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

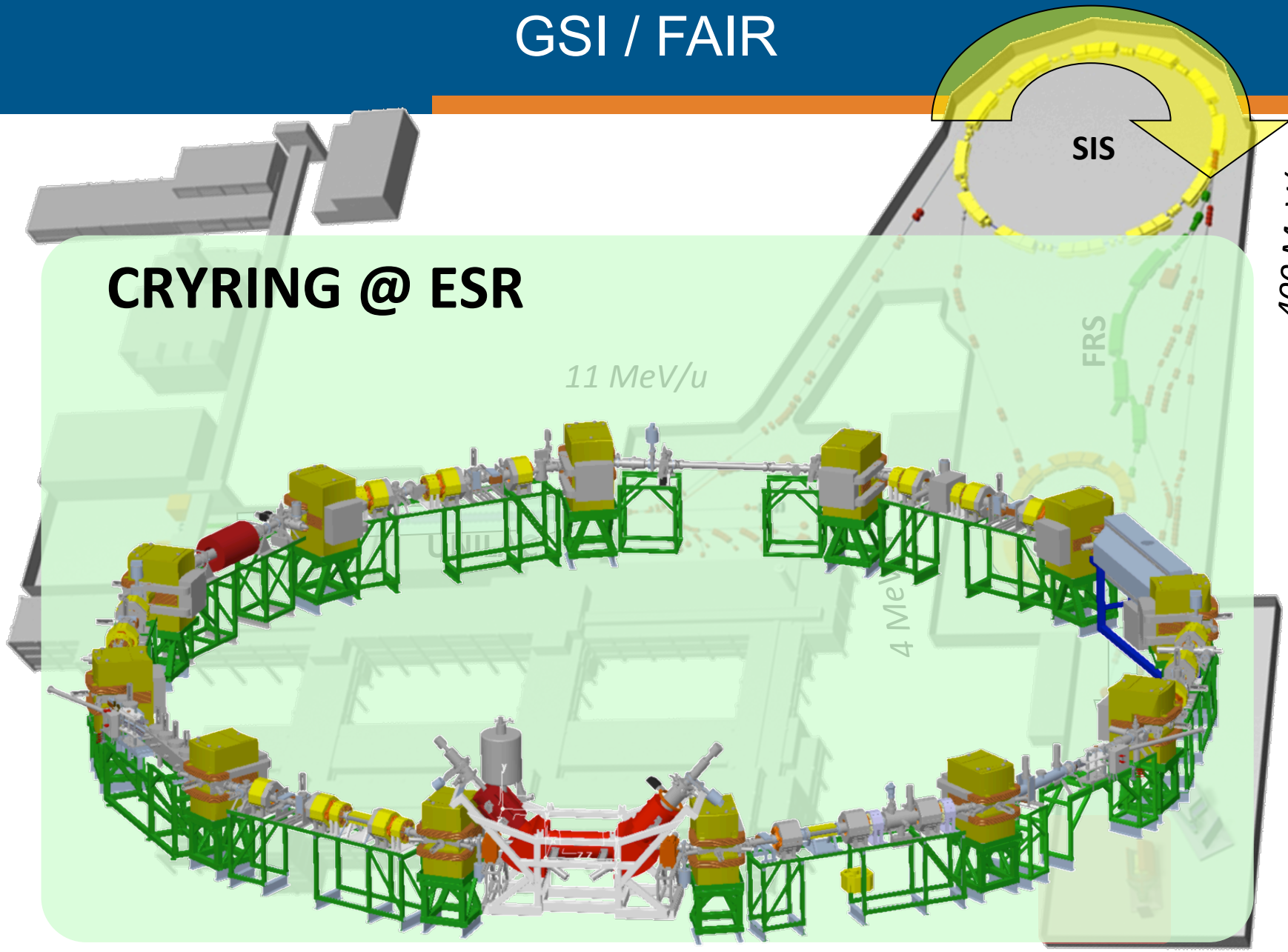


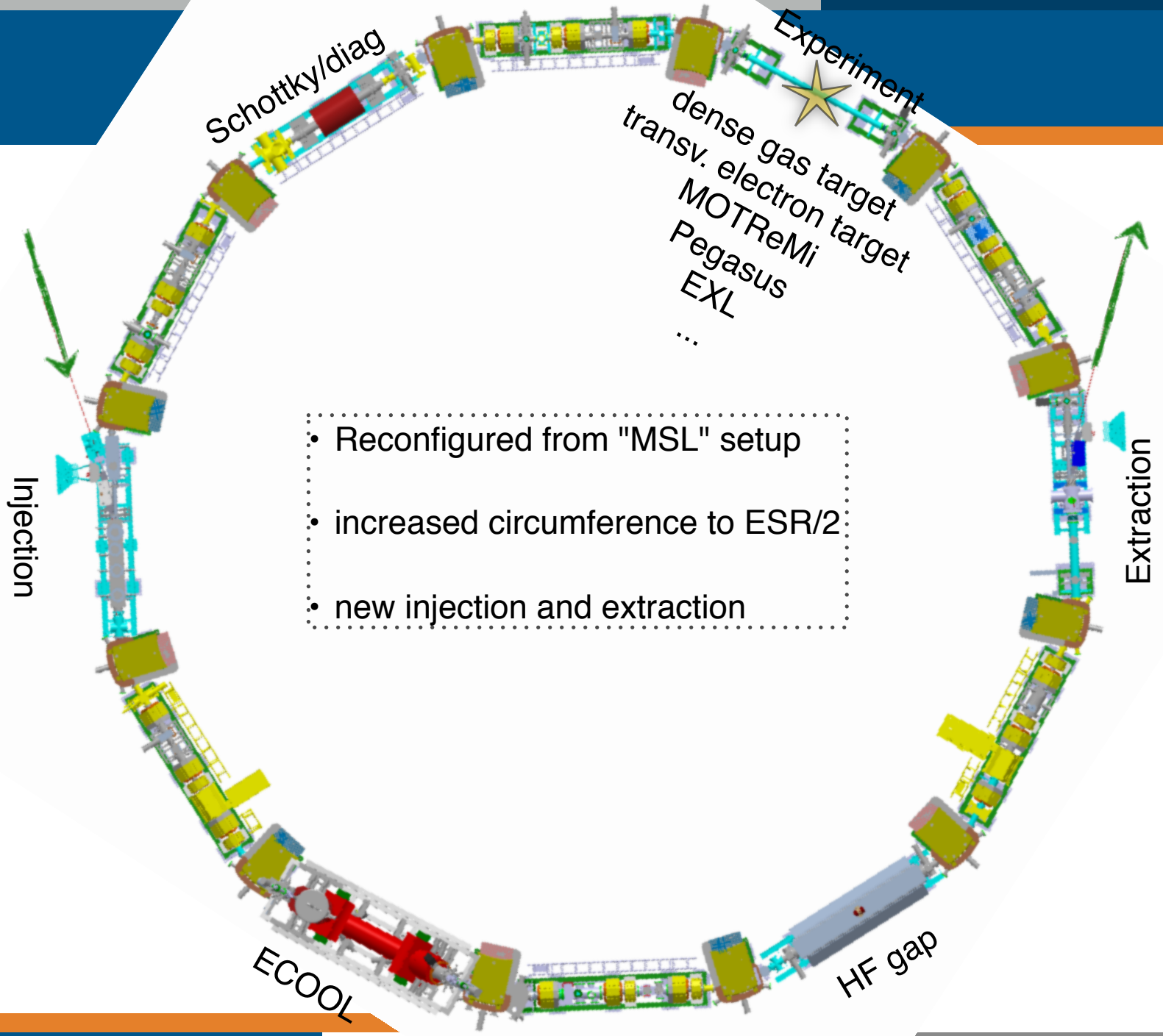
1100 μA → 180 μA → 25 μA

HITRAP: g-factor apparatus



GSI / FAIR





- Reconfigured from "MSL" setup
- increased circumference to ESR/2
- new injection and extraction

Project status

- Beamline from ESR up to the Cave is ready, fast extraction from ESR works
- Assembly of the ring is ongoing, first sections are under vacuum
- Local ion source is producing singly charged ions, transmission beyond RFQ.
- Commissioning of ring with beam early 2016
- UHV late 2016
- ESR beam ~ 2018 (depending on GSI/FAIR)
- BMBF Verbundforschung for 2015-2018 funds first set of experimental installations for AP/SPARC

Bundesministerium
für Bildung
und Forschung

CRYRING: First transfer of ions from ESR to CYRING

Introduction

The Facilities: HITRAP & CRYRING

CRYRING: Physics Case (ions)

Novel Scheme to Connect ESR with FAIR for pbars

Summary and Outlook

CRYRING@ESR: Highly-Charged Ions at Low Energies

- **Spectroscopy for tests of QED**
  - High-precision x-ray spectroscopy
    - 1s-Lamb-Shift
    - Two-Electron-QED
  - Recoil ion momentum spectroscopy
    - Highly-excited stated
  - Laser spectroscopy
  - Recombination spectroscopy with high resolution
- **Atomic collisions**
  - Sub-femtosecond correlated dynamics
  - Unexplored regime: strong perturbation Q/v
- **Nuclear Physics at low-energies**
  - exotic nuclear decay modes
  - astrophysical reactions

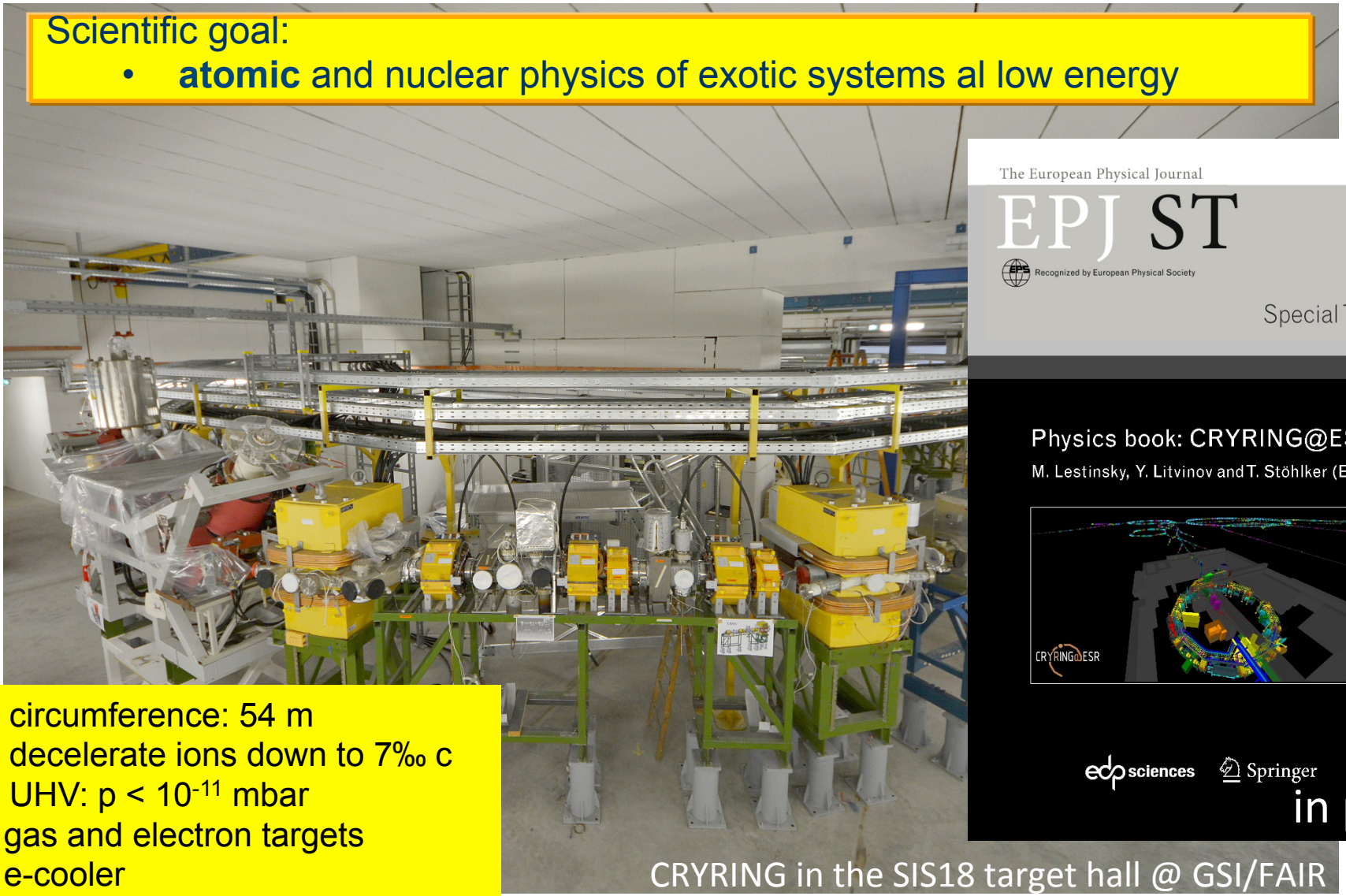
Features@Cryring

- Low-energy and electron cooled beams
- Electron cooling with adiabatic expansion
- High-luminosity for in-ring experiments
- Very fast deceleration 7 T/s
- Internal jet and electron target
- Slow extraction

CRYRING / FAIR

Scientific goal:

- **atomic** and nuclear physics of exotic systems al low energy



CRYRING in the SIS18 target hall @ GSI/FAIR

- circumference: 54 m
- decelerate ions down to 7‰ c
- UHV: p < 10^{-11} mbar
- gas and electron targets
- e-cooler
- several experiment stations

Introduction

The Facilities: HITRAP & CRYRING

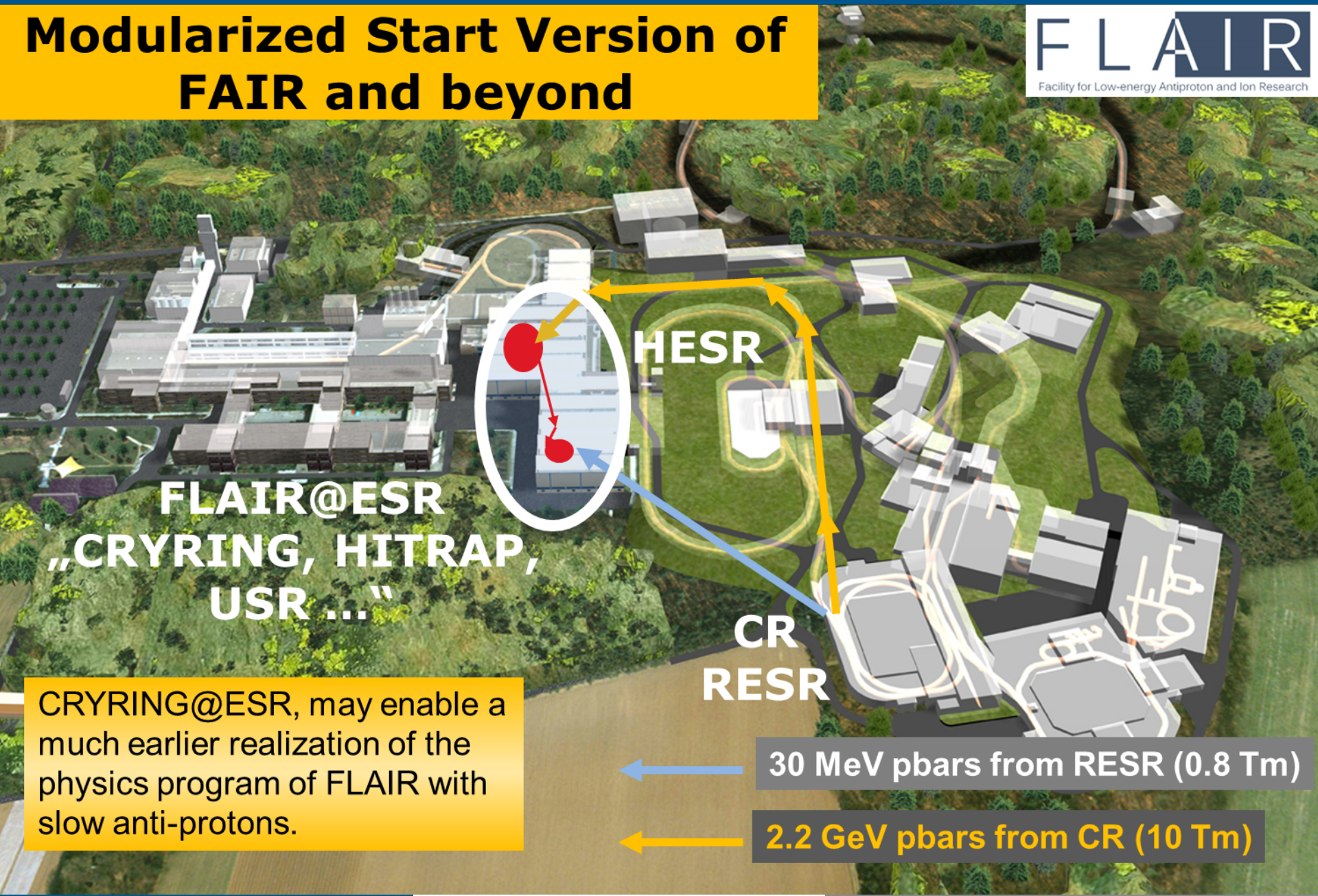
CRYRING: Physics Case (ions)

Novel Scheme to Connect ESR with FAIR for Pbars

Summary and Outlook

Modularized Start Version of FAIR and beyond

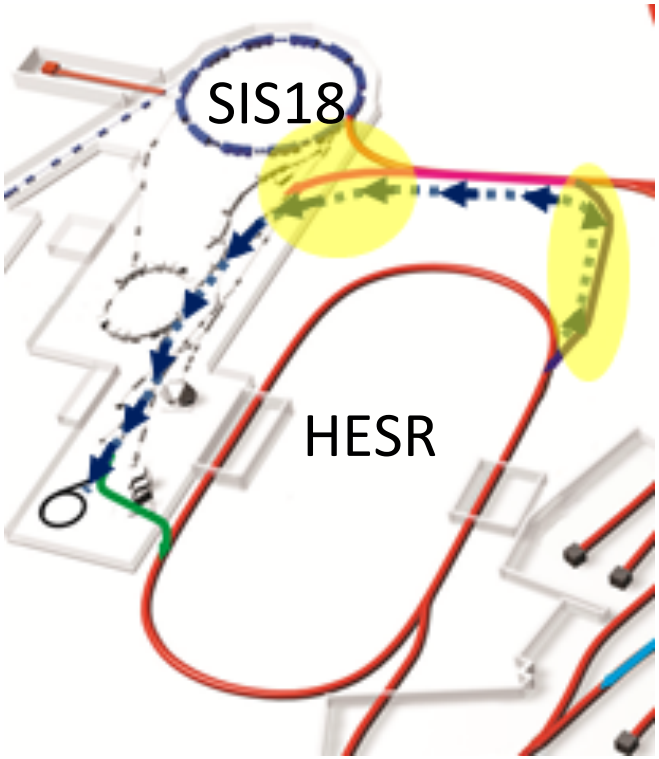
FLAIR
Facility for Low-energy Antiproton and Ion Research



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

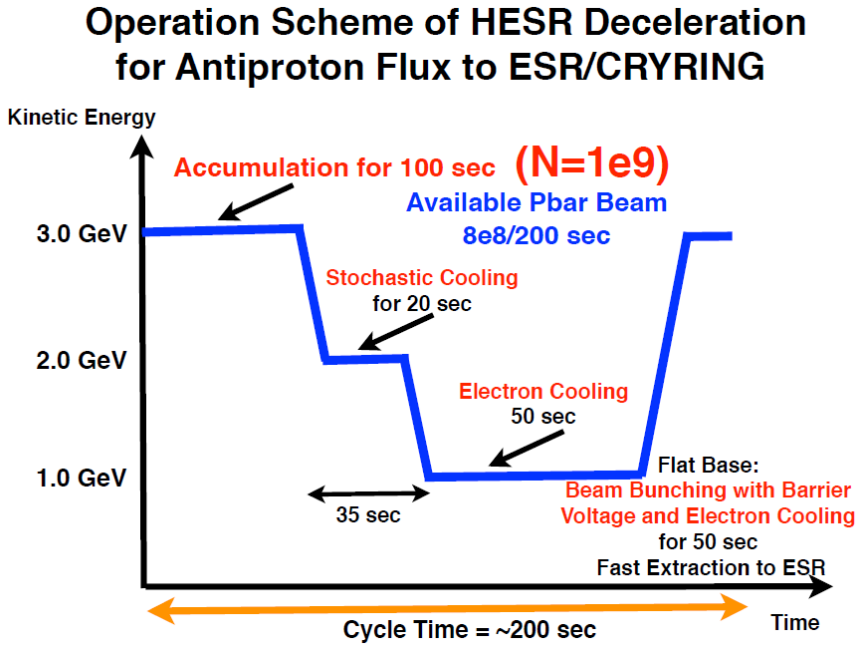
Additional Beamline to Exploit the Physics Potential of FAIR

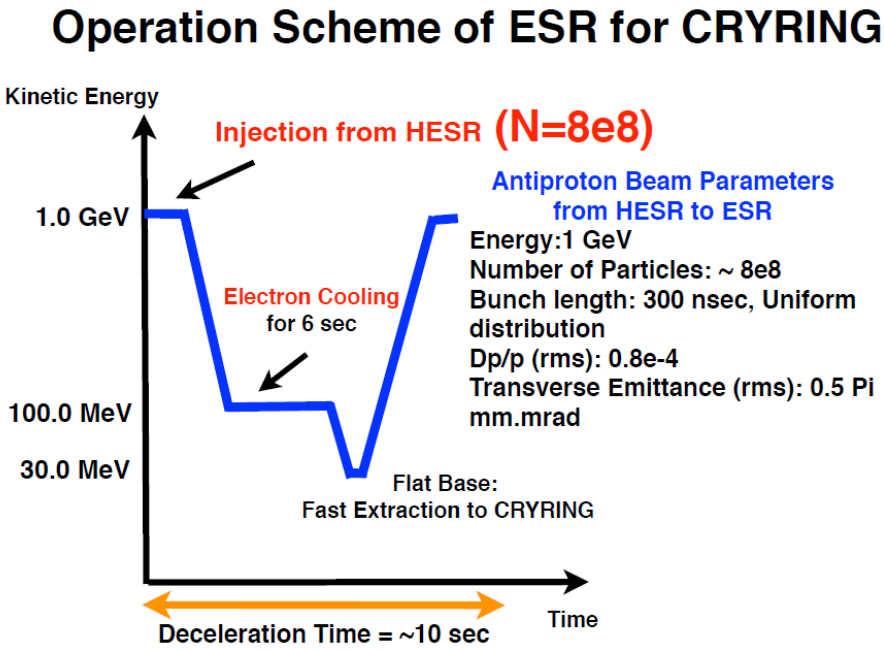
stable and exotic ions and antiprotons from HESR to ESR (not MSV)



- **Early realization of pbar @ FLAIR**
- **Exotic nuclei in storage rings**
- **Protons from SIS18 to APPA Cave**

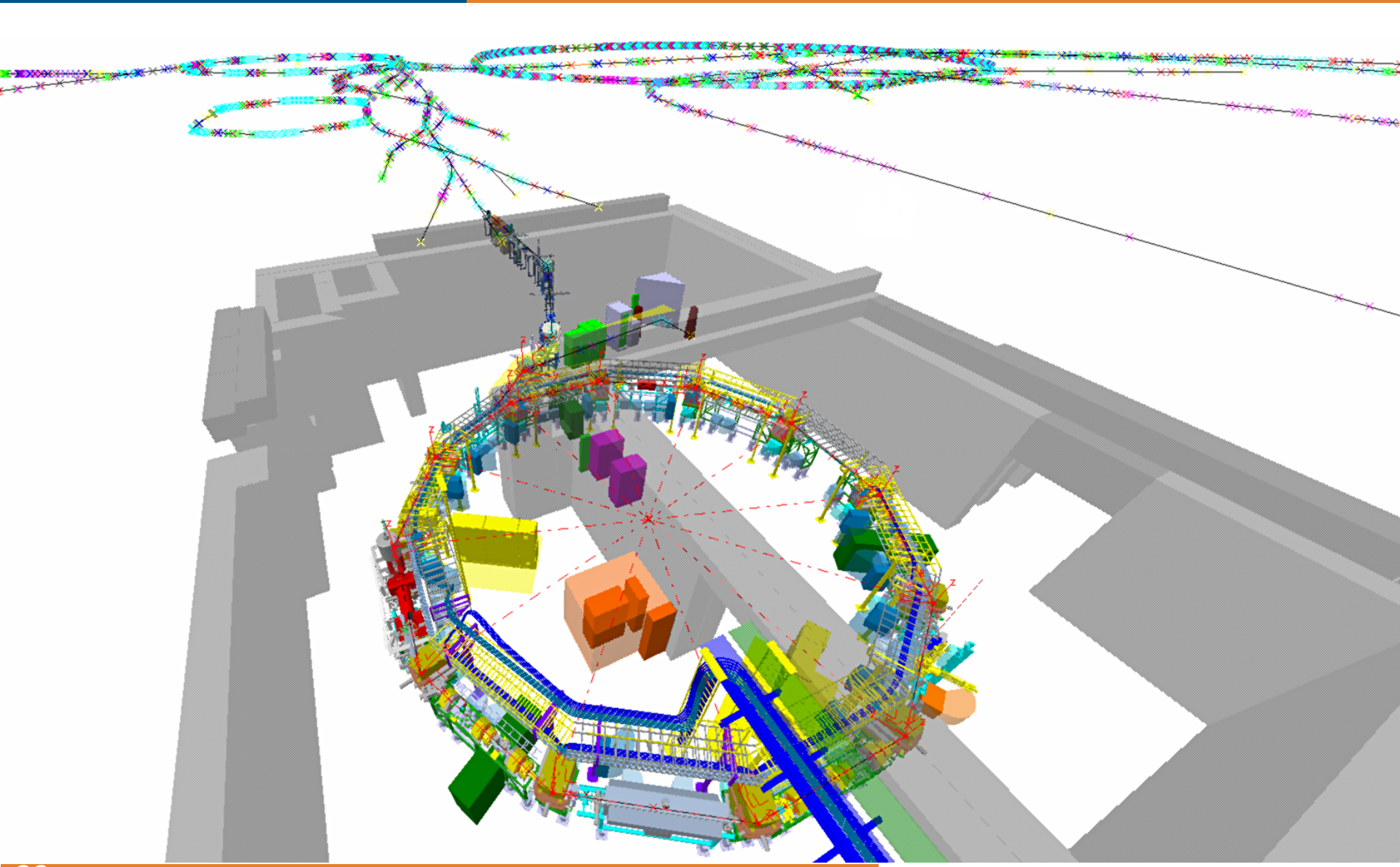
The operation scheme to provide the 1 GeV, N = 1 × 10^9 antiproton beam in the HESR





T. Katayama et al., Phys. Scr. T166 (2015) 014073 (9pp)

Thank you for your attention !



Acknowledgements

Project team: **F. Herfurth**, **Michael Lestinsky**, **A. Bräuning-Demian**, R. Bär, H. Danared, C. Dimopoulou, O. Dolinskyy, W. Enders, M. Engström, S. Fedotova, B. Franzke, M. Frey, W. Geithner, O. Gorda, L. Heyl, P. Hülsmann, A. Källberg, Th. Köhler, S. Litvinov, Y. Litvinov, J. Mohr, I. Pschorn, A. Reiter, G. Riefert, J. Roßbach, A. Simonsson, T. Sieber, J. Sjöholm, M. Steck, Th. Stöhlker, G. Vorobjev, N. Winckler, ...

GSI + Stockholm University
+ KVI Groningen
+ HI Jena
+ University Jena
+ Krakow University

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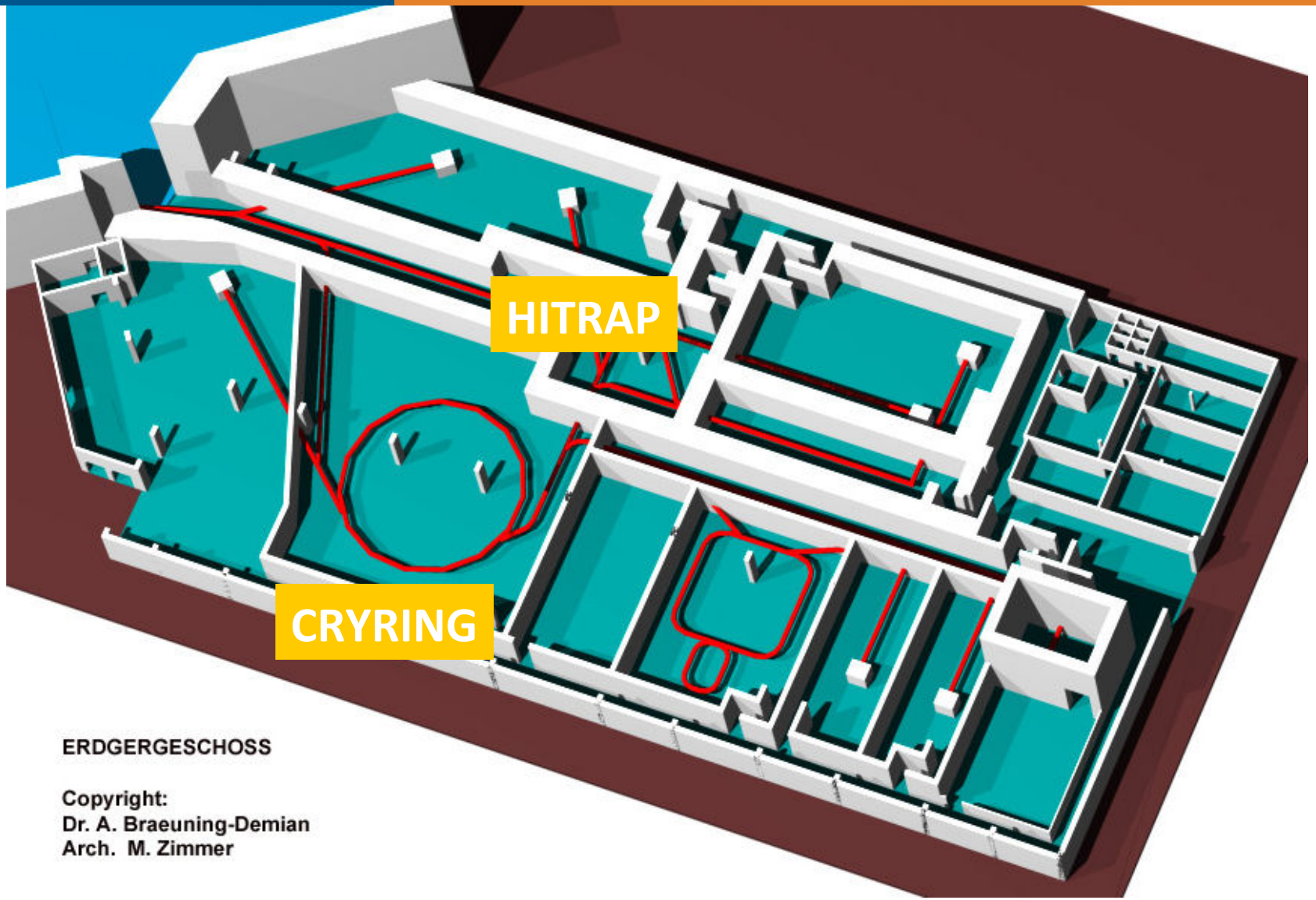
FLAIR Layout



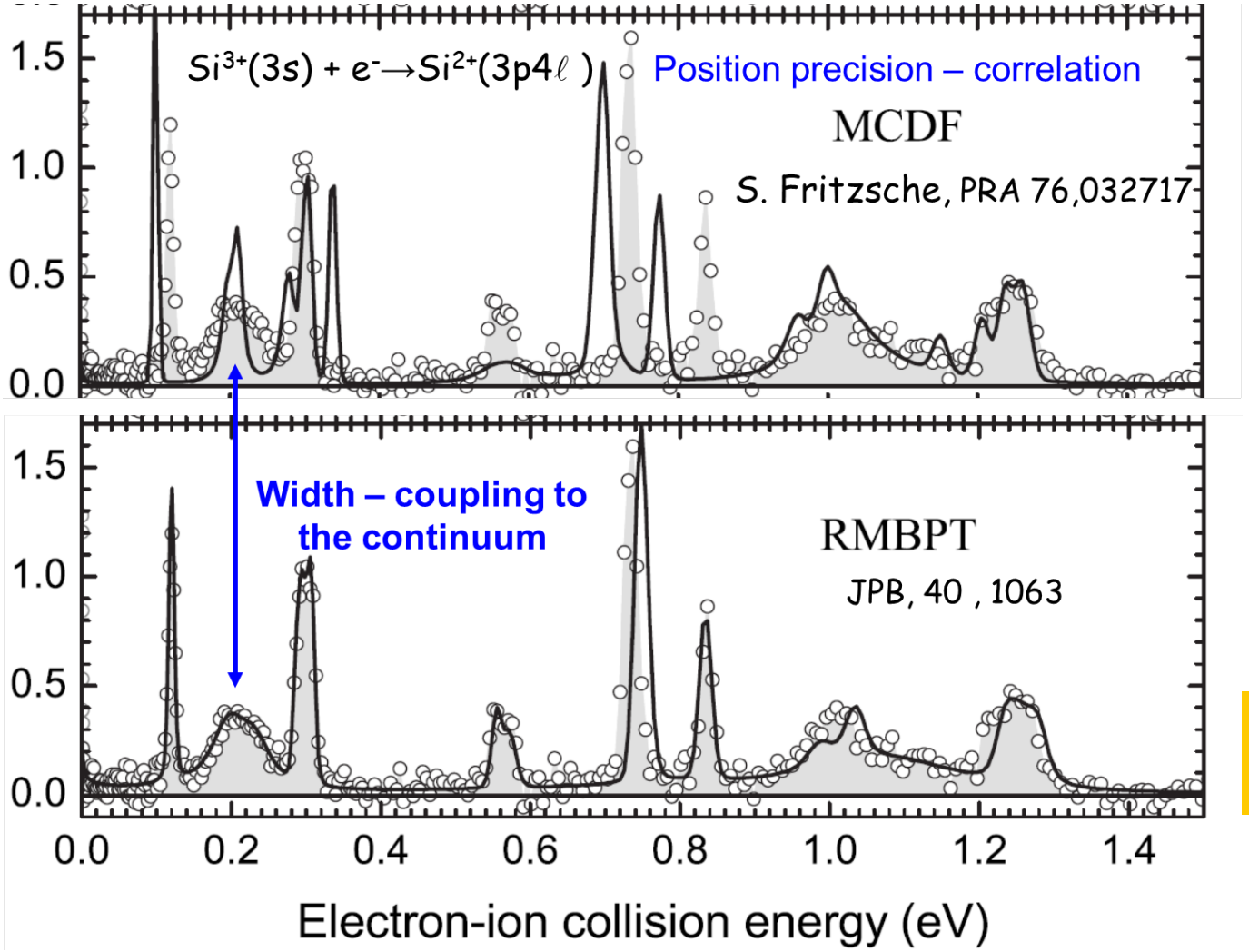
Ring parameters

Circumference	54.17 m (ESR/2)
Rigidity at injection for ions (p, pbar)	1.44 Tm (0.8 Tm)
Highest possible injection energy for p, pbar	30 MeV (capped by rad. safety)
- for $^{12}C^{6+}$	24.7 MeV/u
- for $^{238}U^{92+}$ ($^{238}U^{89+}$)	14.8 MeV/u (13.9 MeV/u)
HCI beam lifetimes	3s (300keV/u) ... 1000s (10 MeV/u)
Lowest Rigidity	0.054 Tm
Lowest Energy	Charge exchange limited
Magnet ramping (de- and acceleration)	1 T/s (4 T/s, 7 T/s)
Vacuum pressure (N_2 equiv.)	10^{-12} – 10^{-11} mbar
Beam injection	Multiturn and fast
Beam extraction	slow and fast
Ion source for stand alone operation	Yes (300 keV/u, A/q < 2.85)
Experimental areas	YR03, YR09, YRE

Status: Summer 2015

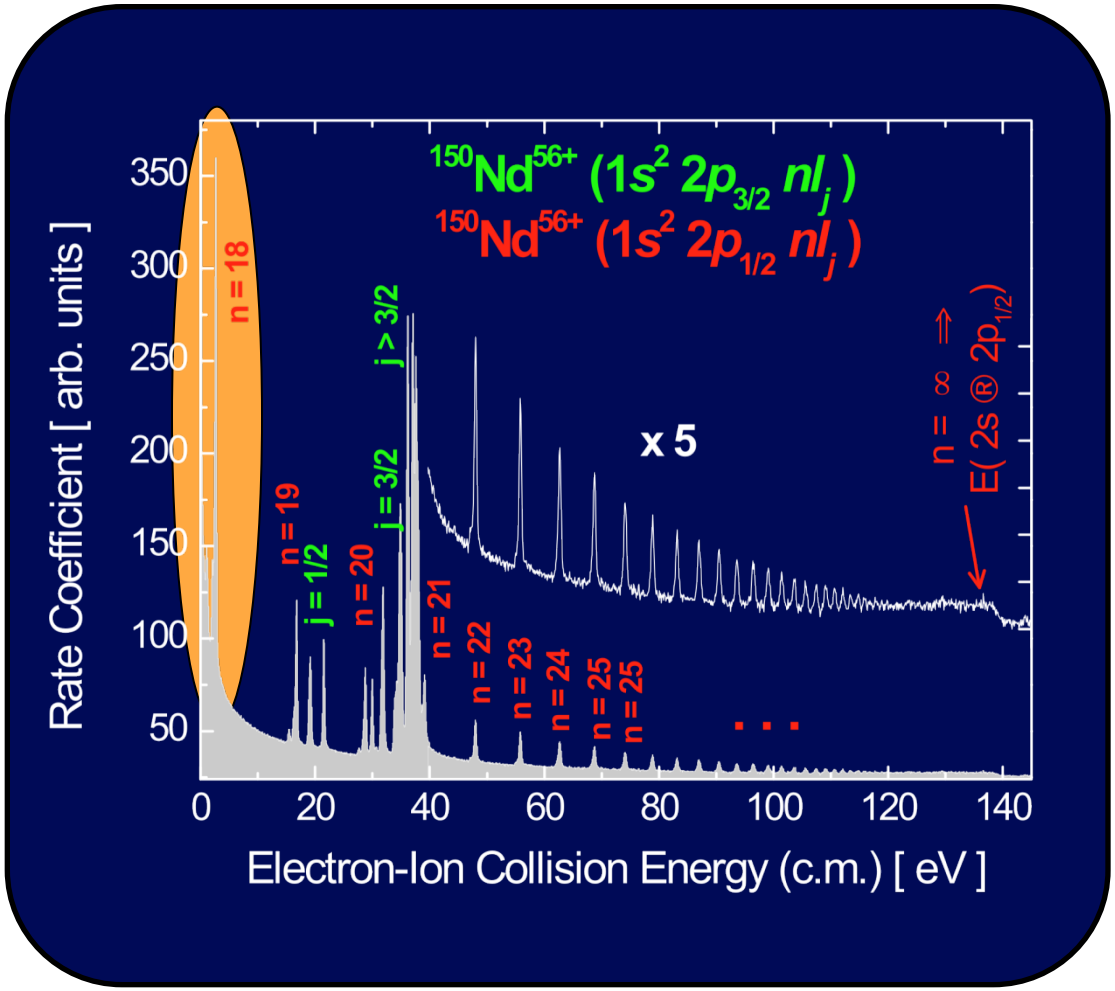
CRYRING: Stockholm

High Resolution DR Resonances as measured at CRYRING/Stockholm



Provided by Reinhold Schuch

Low-Energy DR Spectrum of Li-like Neodymium ($^{150}Nd^{57+}$)

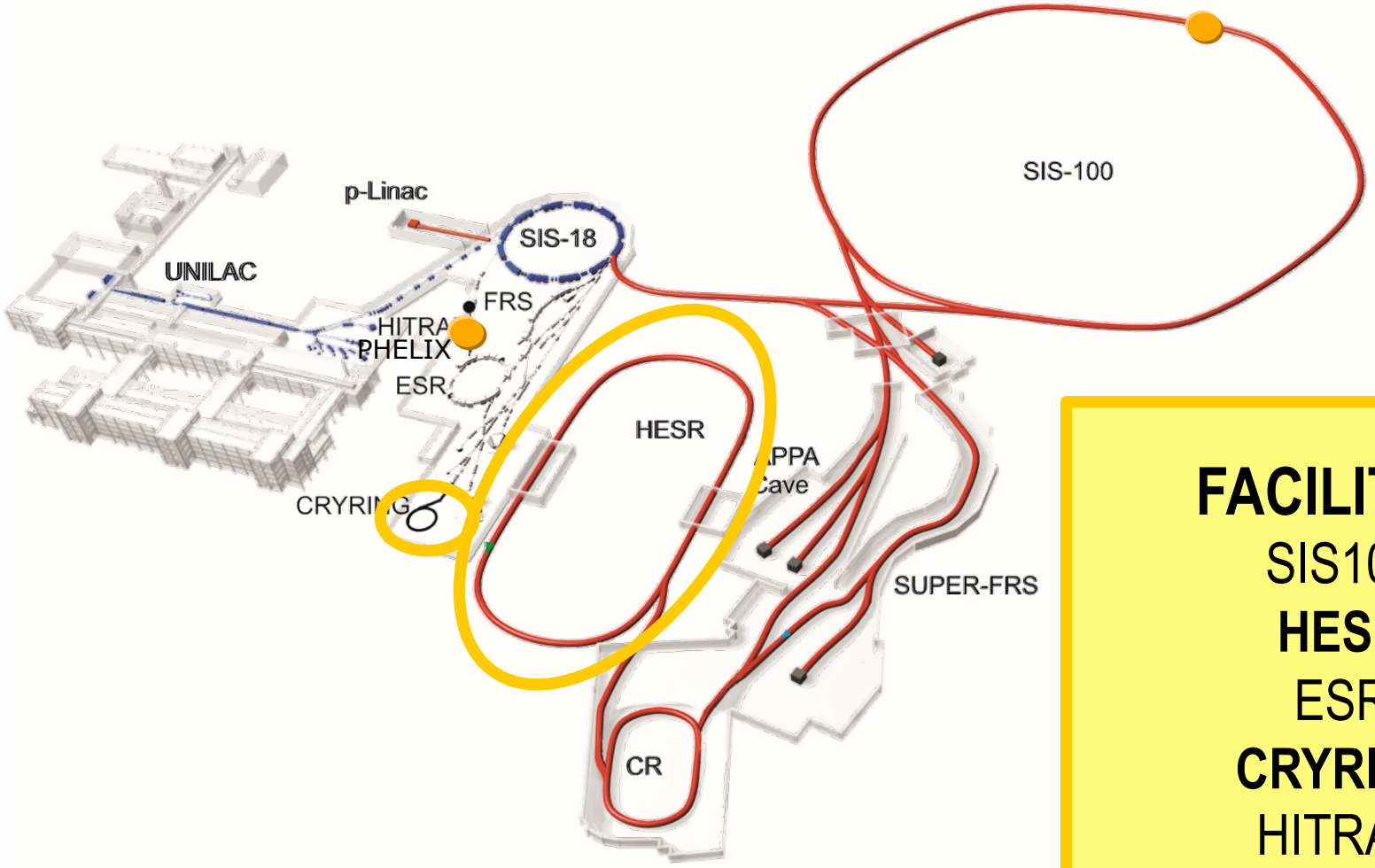


– the possibility of the ful
candidates of interest (
2008).

- The energy-sharp resonant f
tensity of associated beam a
of different isobars, atomic m
The unique signatures of DR

- **Nuclear size effect**
- **Hyperfine splitting**
- **Lifetimes of excited atomic states**
- **Isotope purification scheme**

FAIR-MSV: APPA Facilities



FACILITIES

SIS100

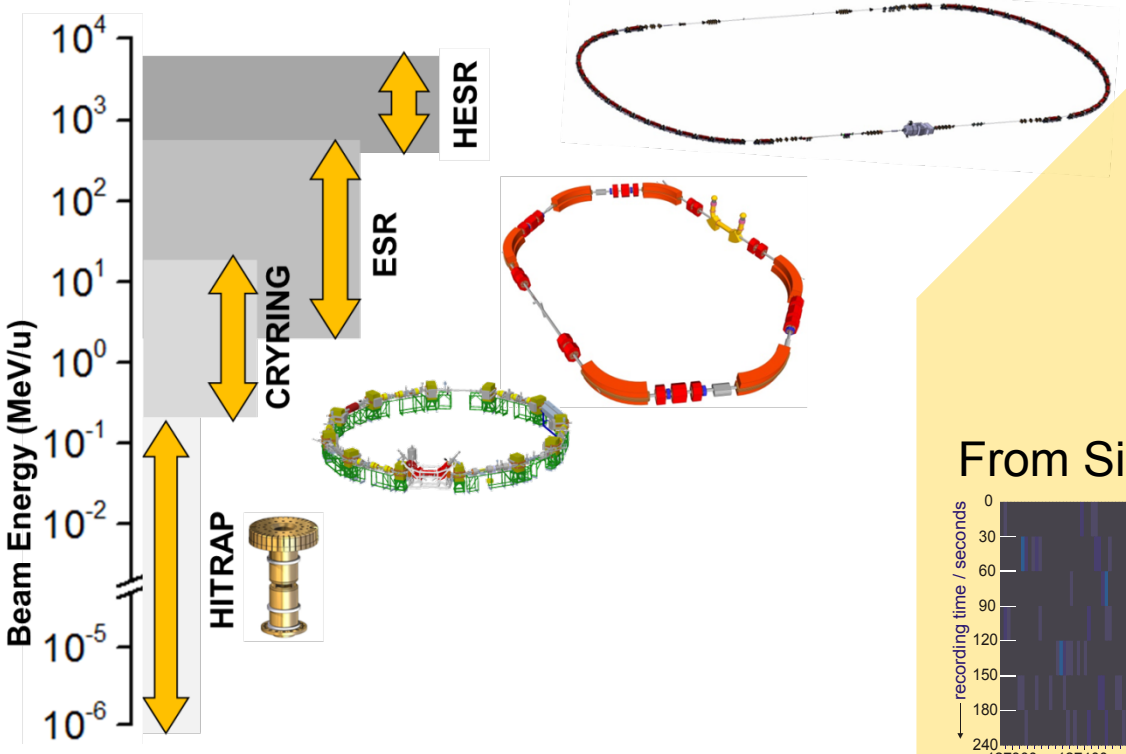
HESR

ESR

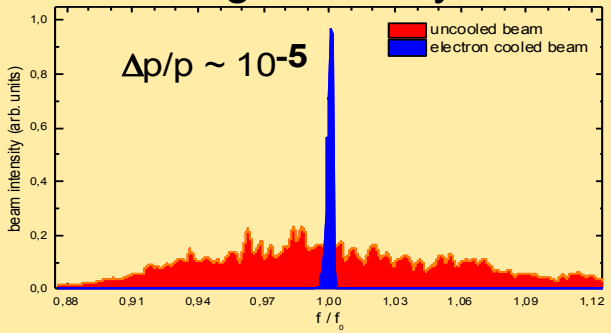
CRYRING

HITRAP

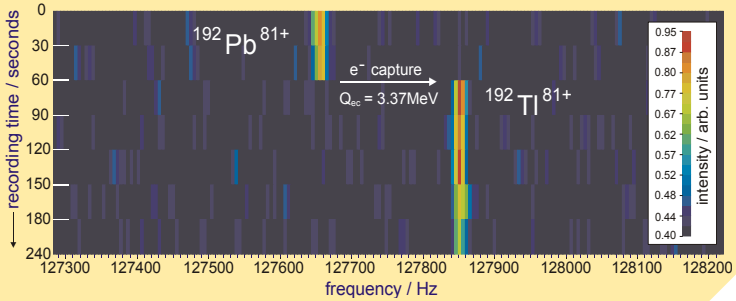
Beam Facilities / Trapping & Storage



Cooling: The Key for Precision



From Single Particles to Highest Intensities

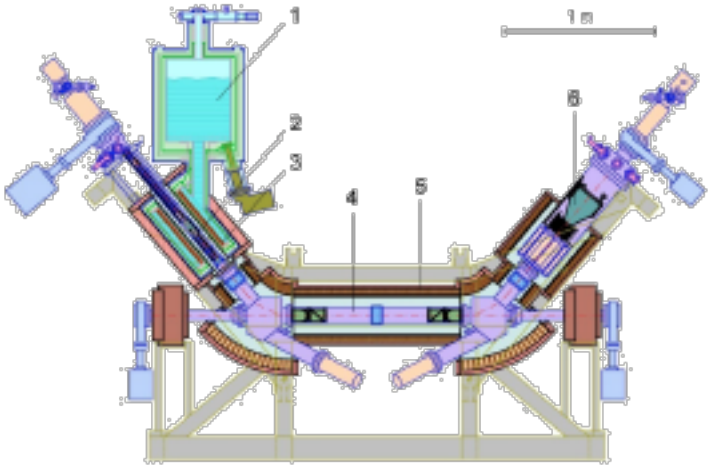


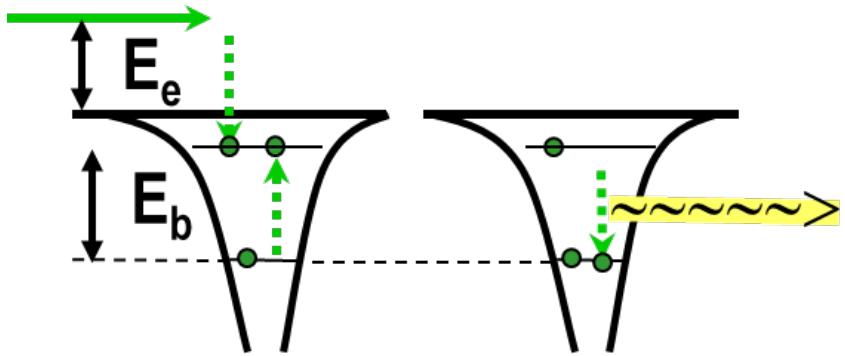
Physics Case

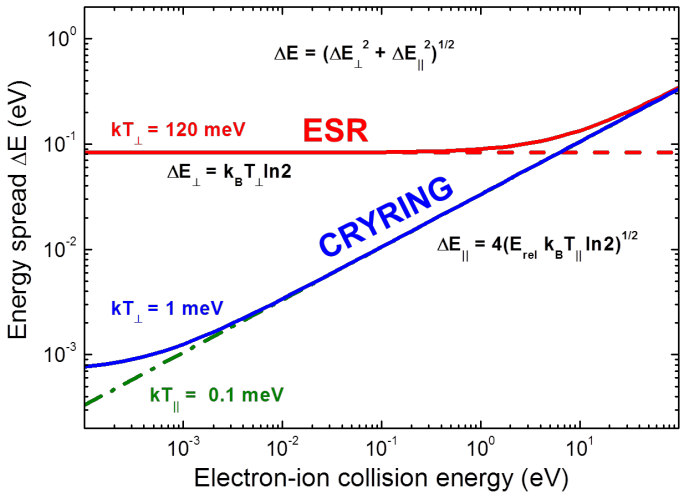
- Precision tests of QED
  - 1S Lamb shift
  - Electron binding energies
- Supercritical fields
- Electron spectrometry
- Reaction microscopes
- Dielectronic recombination
- Search for NEEC process
- Astrophysical capture reactions
- Transfer reactions

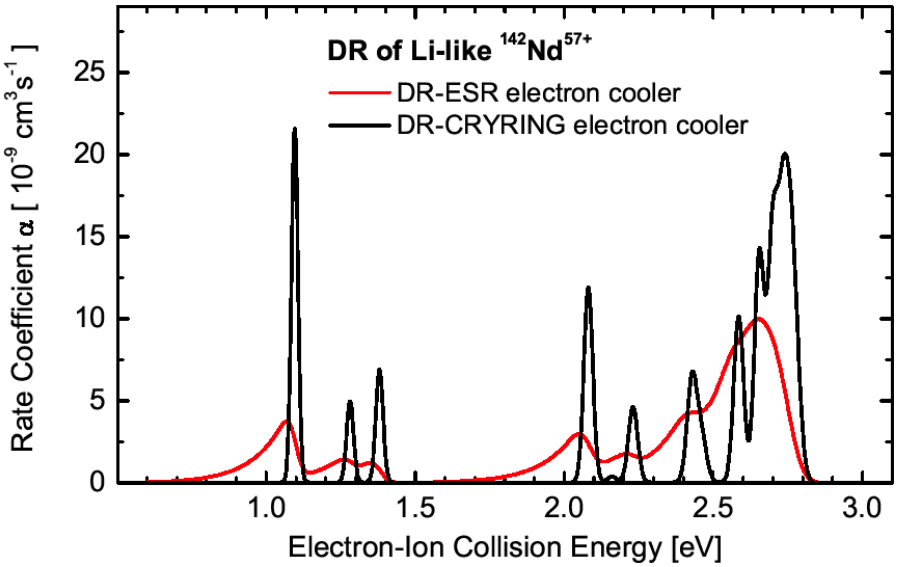
Dielectronic Recombination at CRYRING

CRYRING Electron Cooler → About two orders of magnitude higher resolving power









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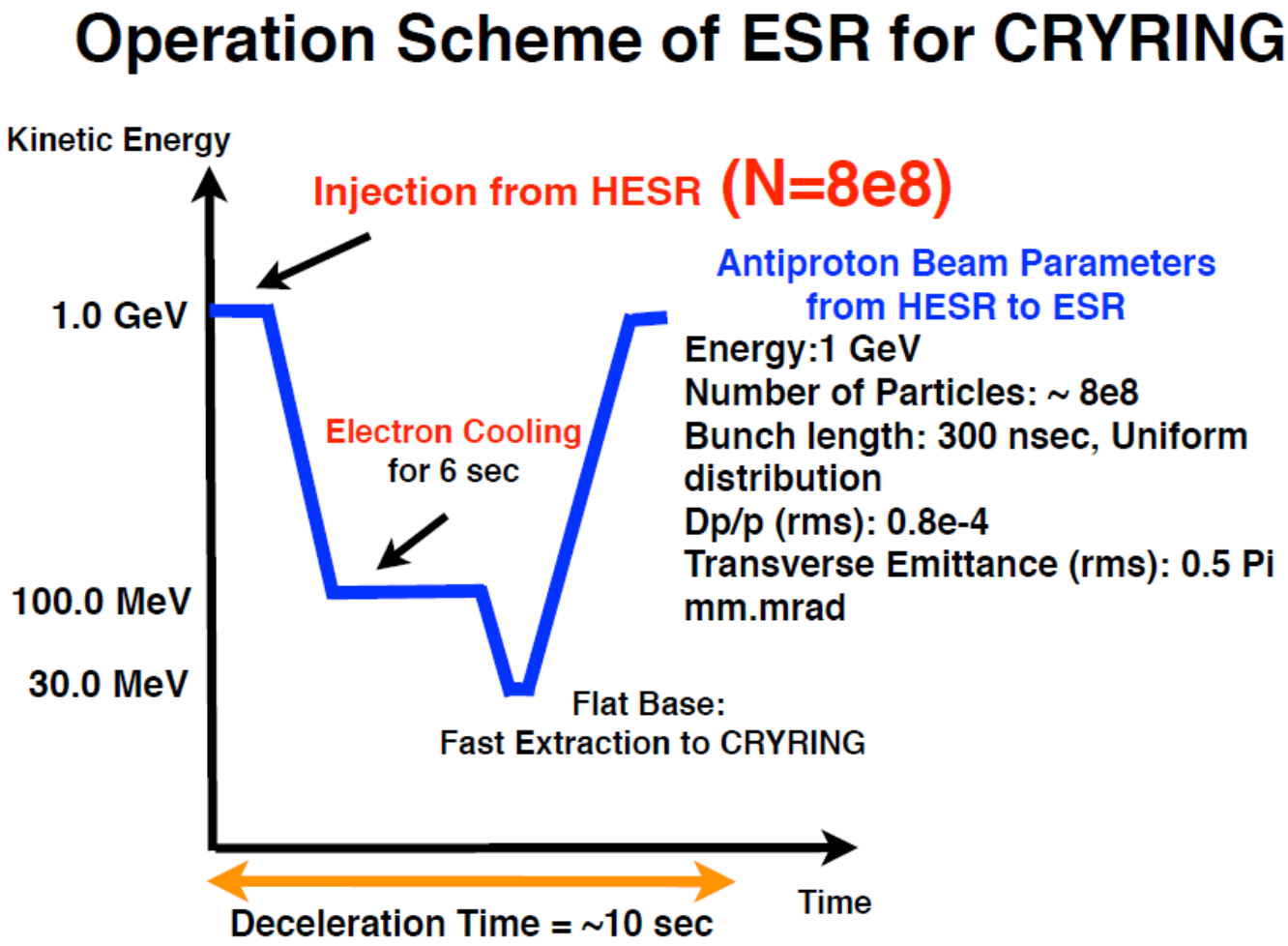

T. Katayama