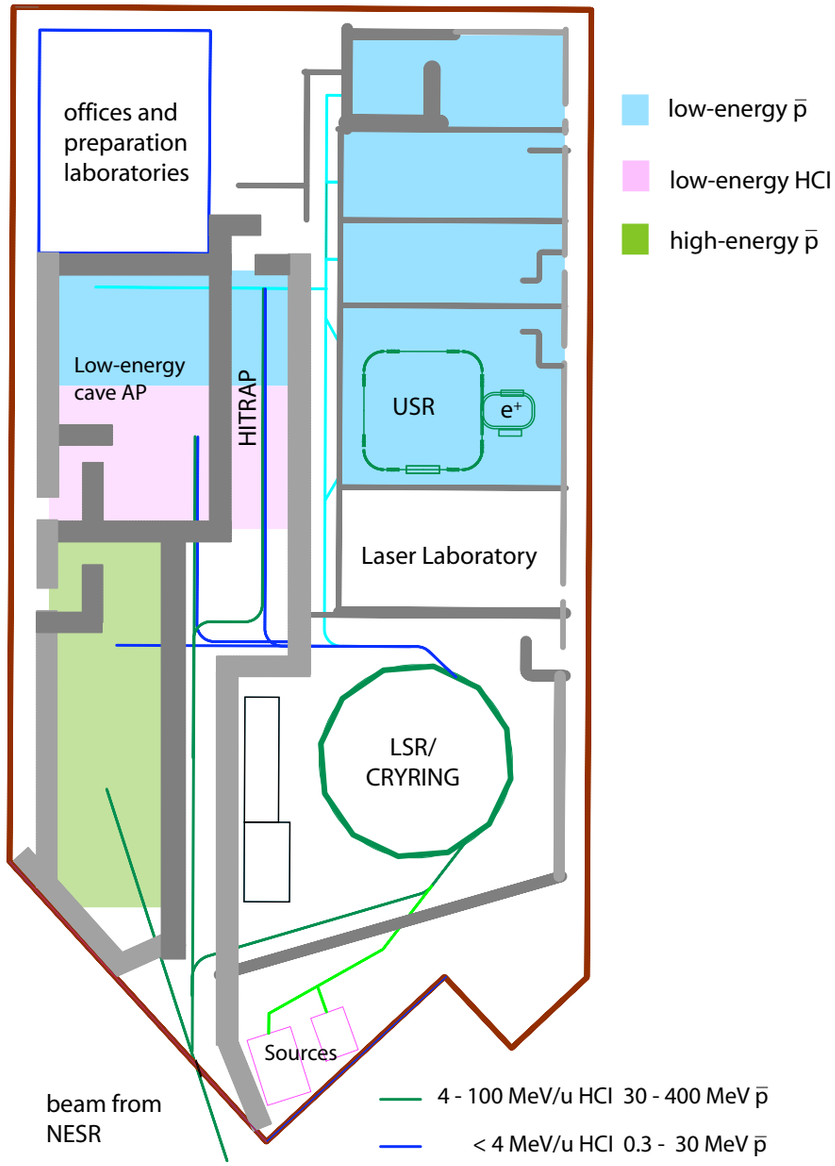
FLAIR
a next-generation facility for low-energy antiprotons



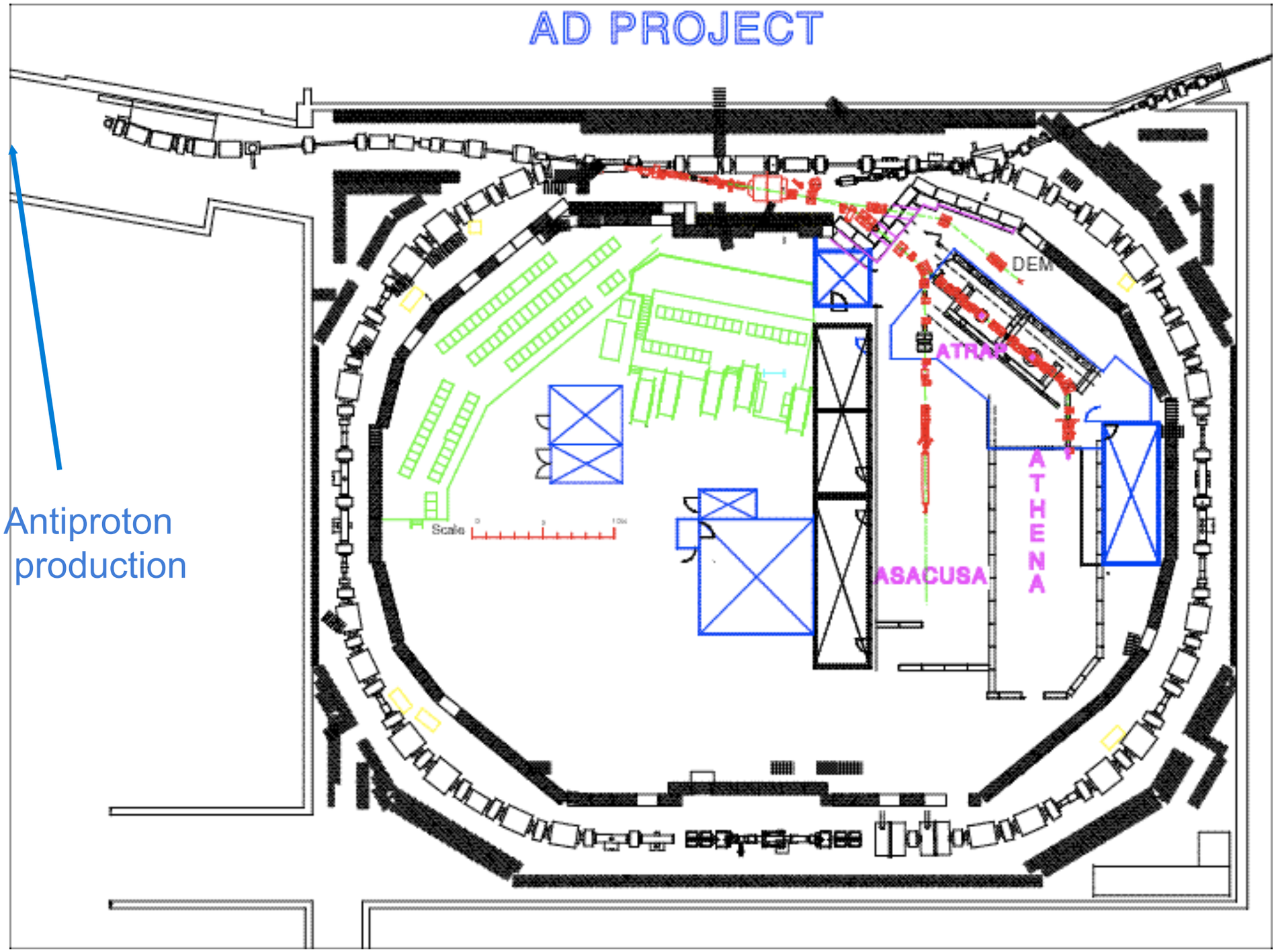
Eberhard Widmann

STORI2011

Frascati, October 14, 2011

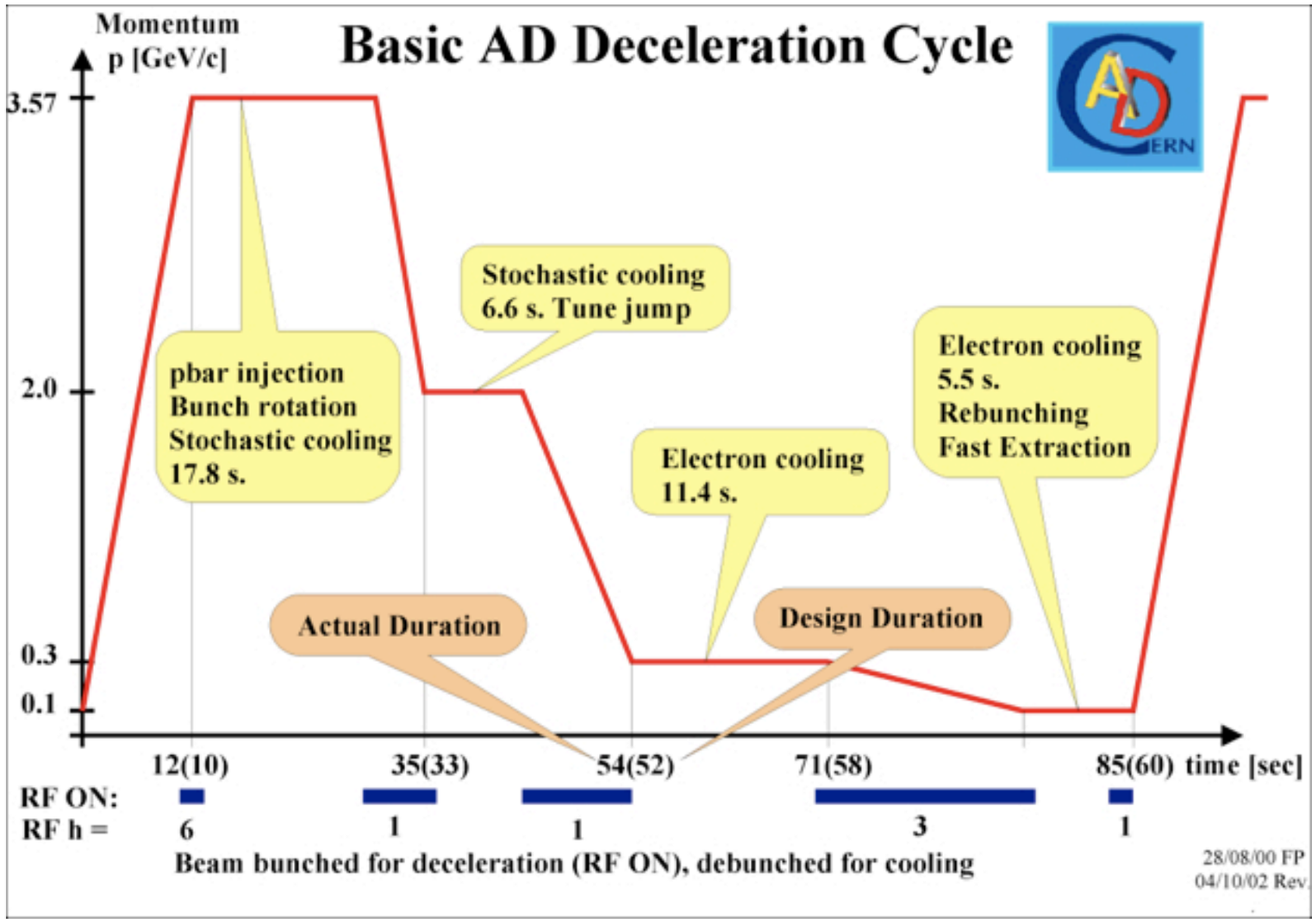
Stefan Meyer Institute for Subatomic Physics, Vienna

Current source: AD @ CERN



Stefan Meyer Institute
OAW
Austrian Academy of Sciences

AD @ CERN: start 2000



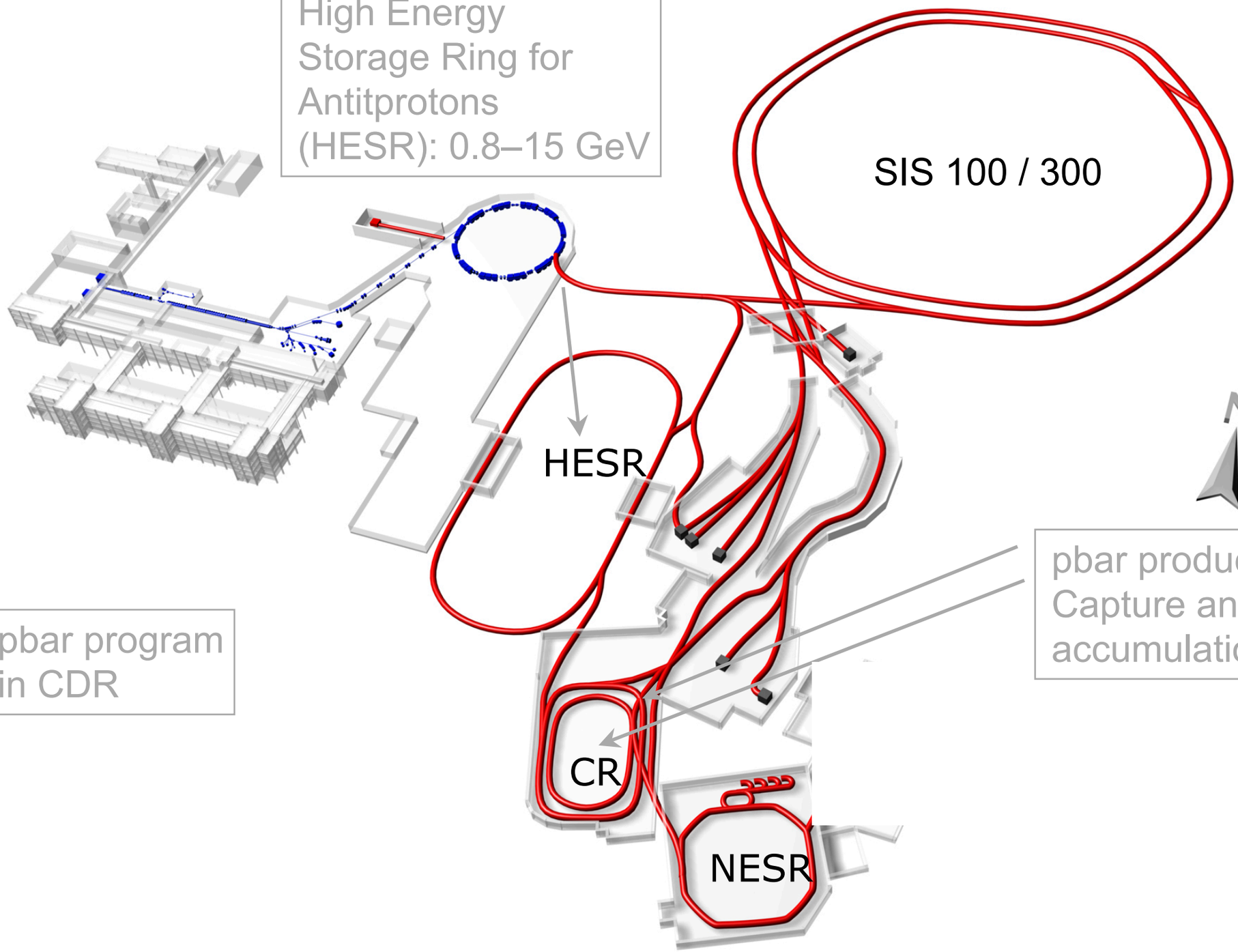
- All-in-one machine:
  - Antiproton capture
  - deceleration & cooling
  - 100 MeV/c (5.3 MeV)
- Pulsed extraction
  - 2-4 x 10^7 antiprotons per pulse of 100 ns length
  - 1 pulse / 85−120 seconds

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

Antiprotons at FAIR

High Energy Storage Ring for Antitprotons (HESR): 0.8–15 GeV



pbar program in CDR

pbar production Capture and accumulation

Antiprotons at FAIR

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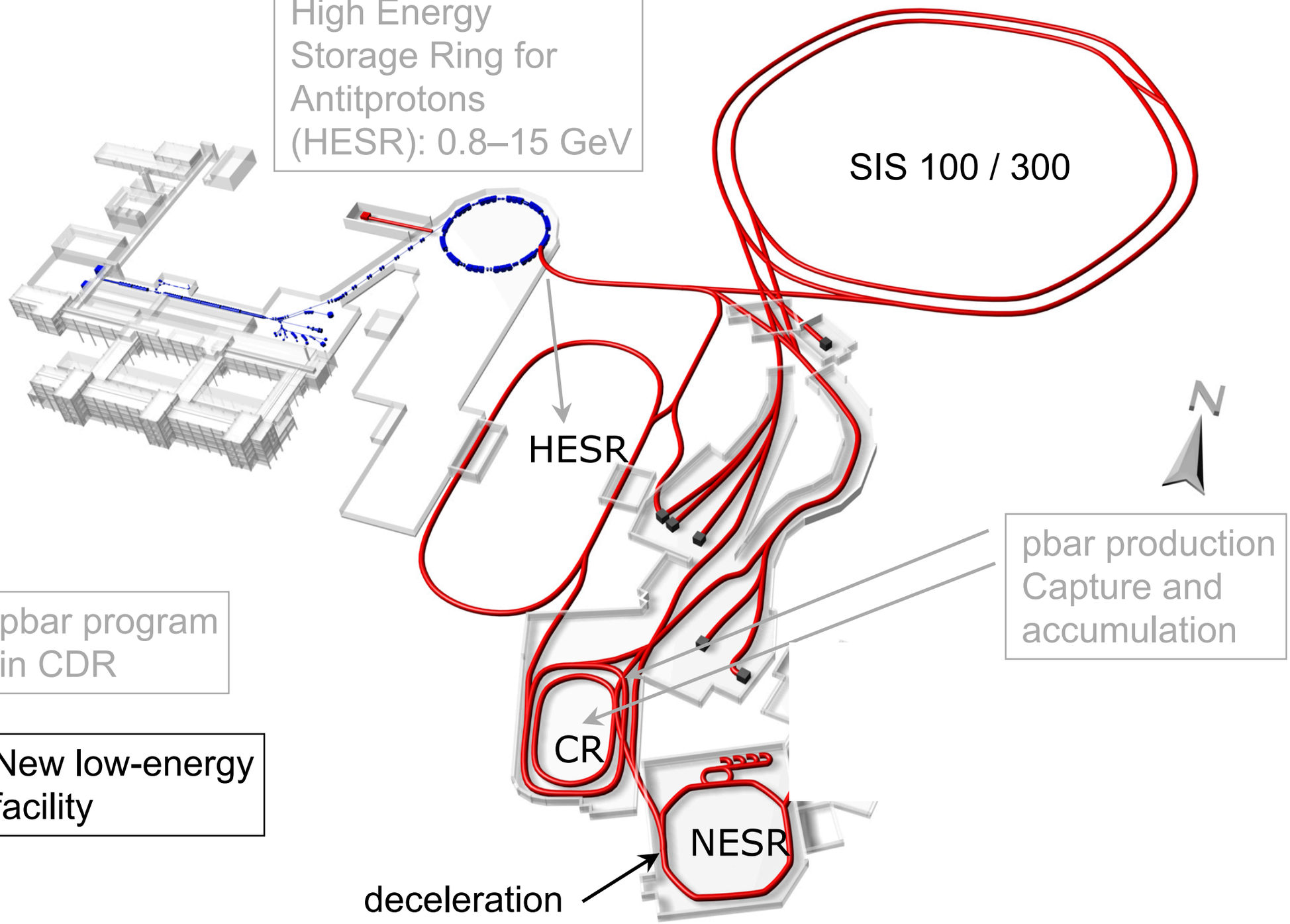

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New low-energy facility

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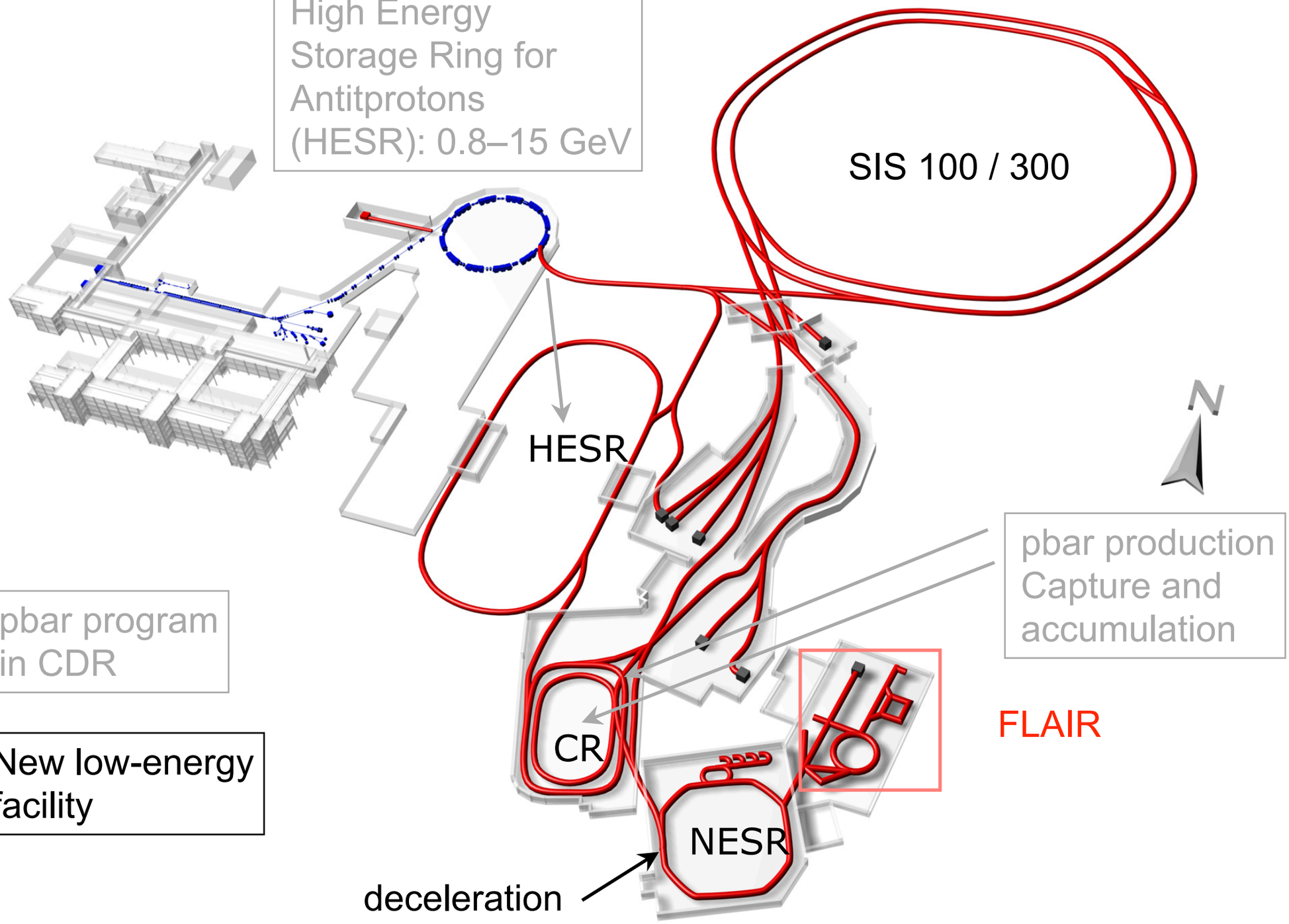

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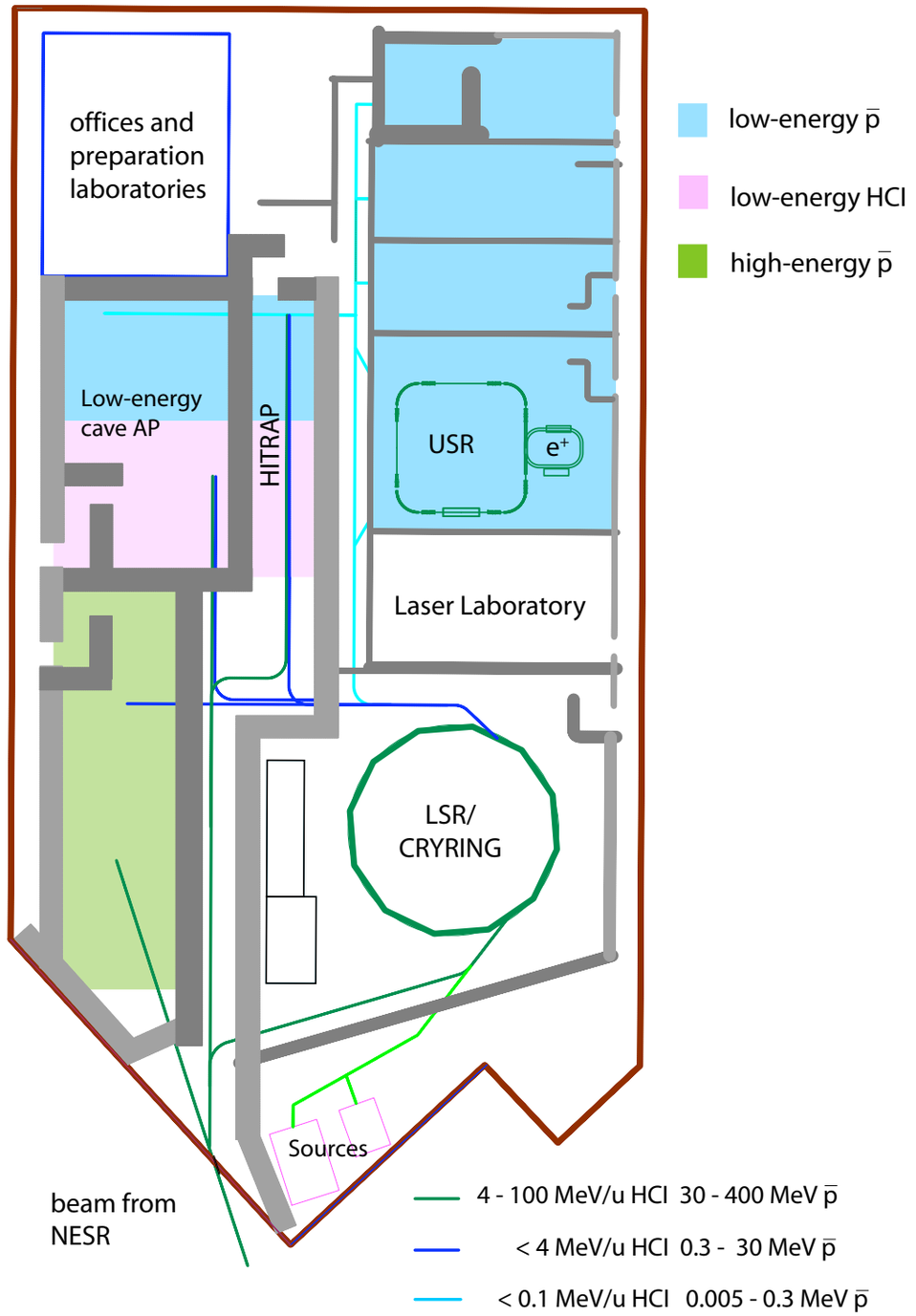
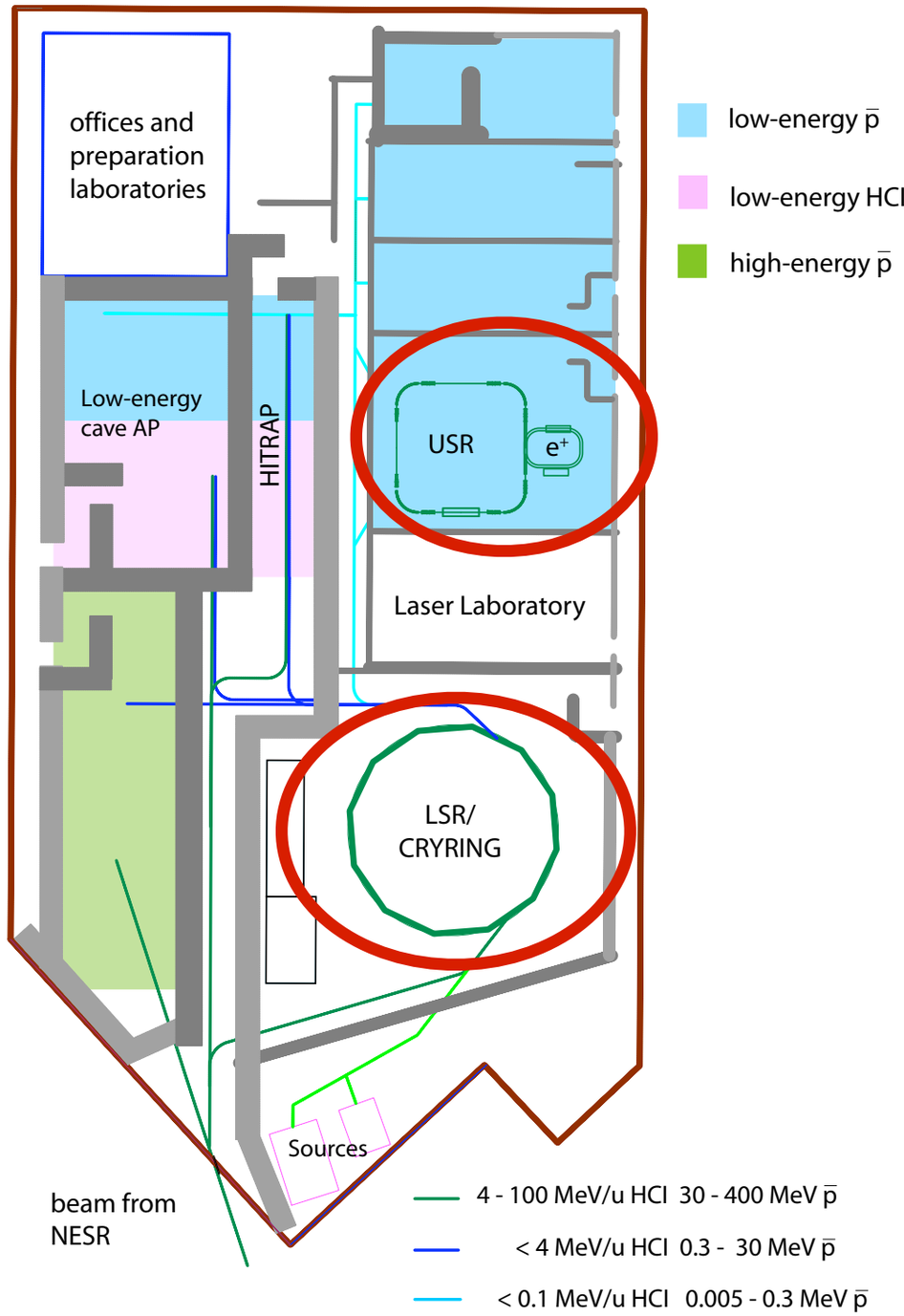
New low-energy facility

FLAIR@ FAIR - Baseline Technical Report 2005



FLAIR@ FAIR - Baseline Technical Report 2005

- High brightness low energy beams
  - two storage rings with 300 keV (LSR) and 20 keV (USR)
  - electron cooling
    - $\varepsilon \sim 1\ \pi$ mm mrad
    - $\Delta p/p \sim 10^{-4}$



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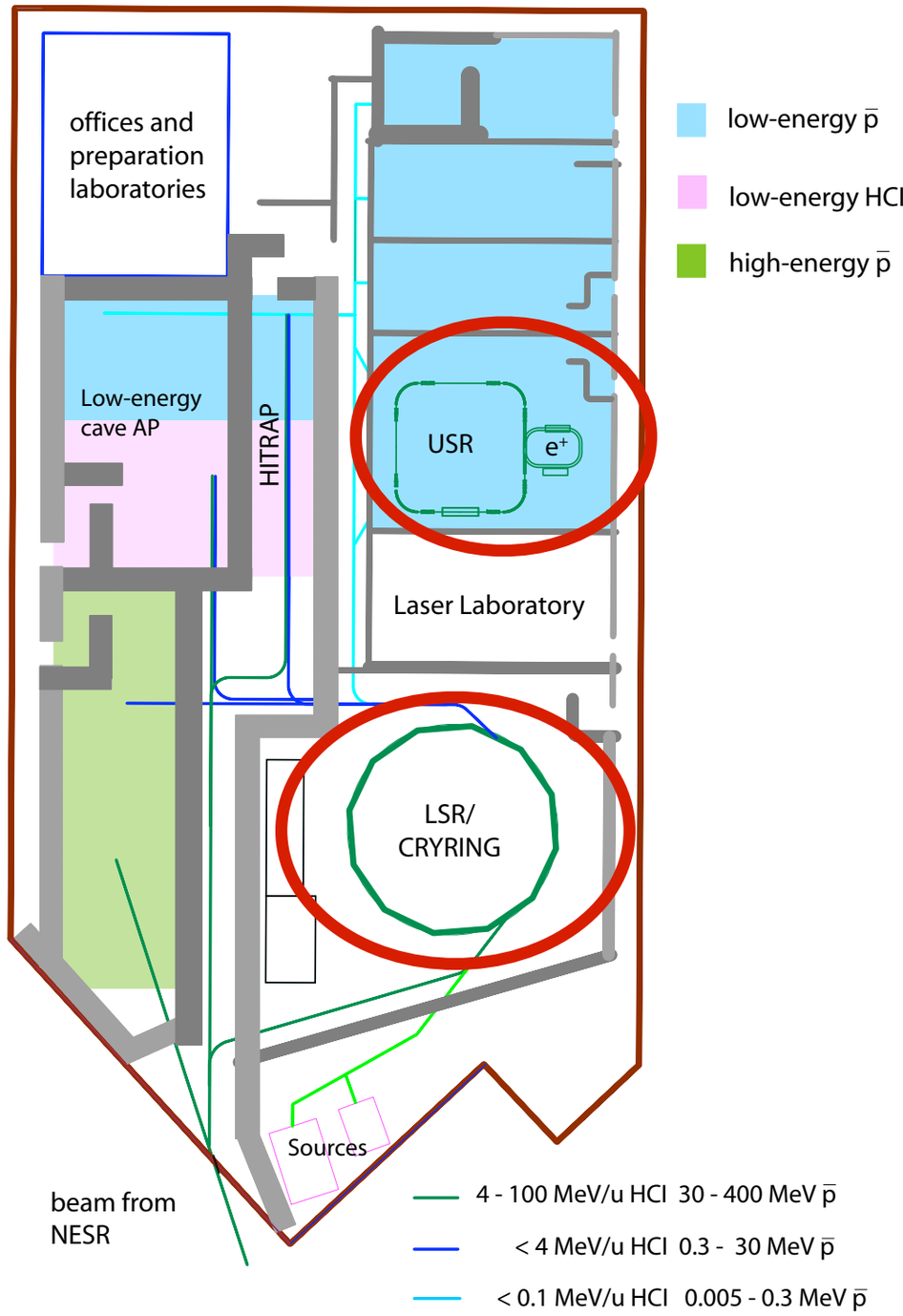

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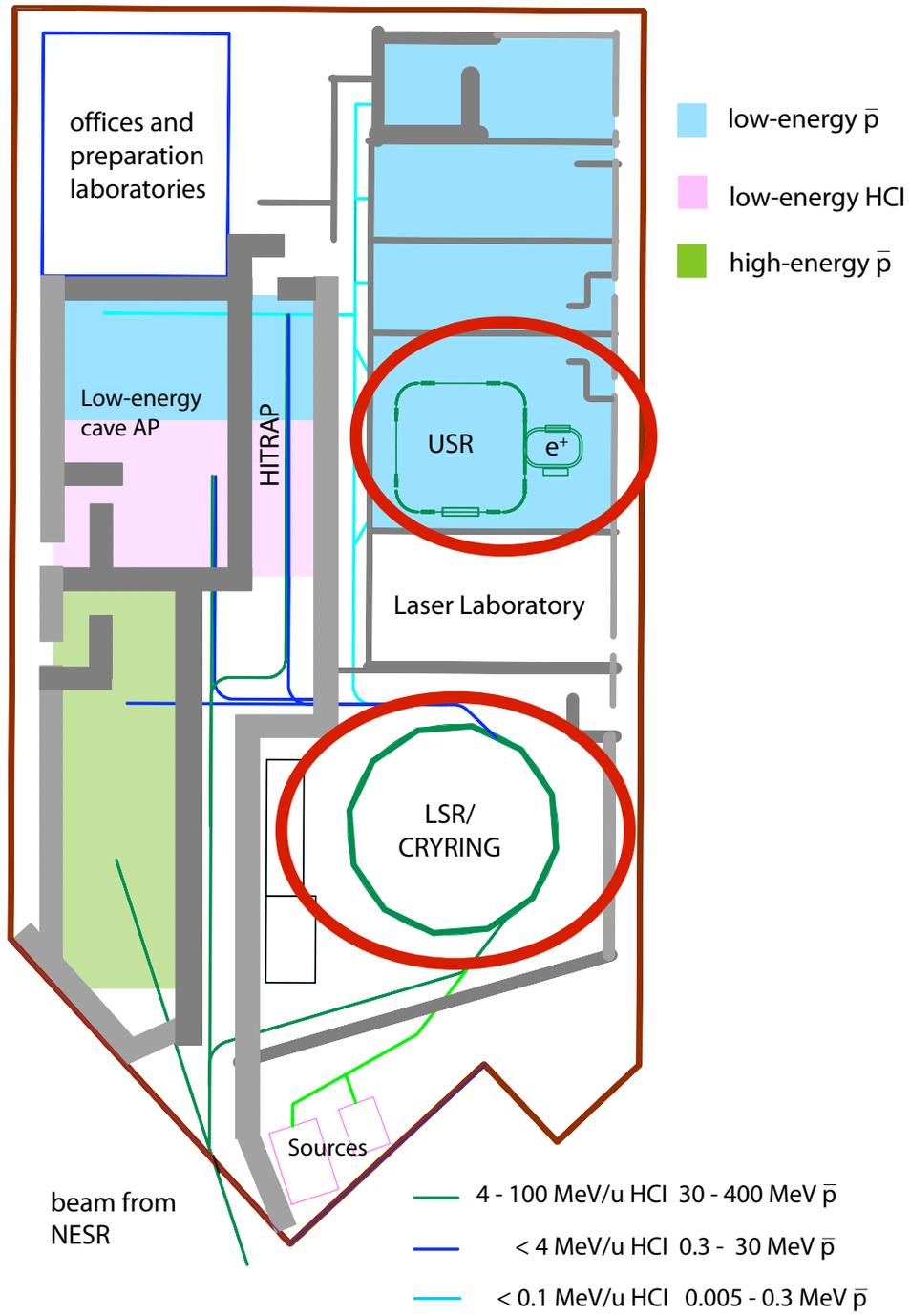

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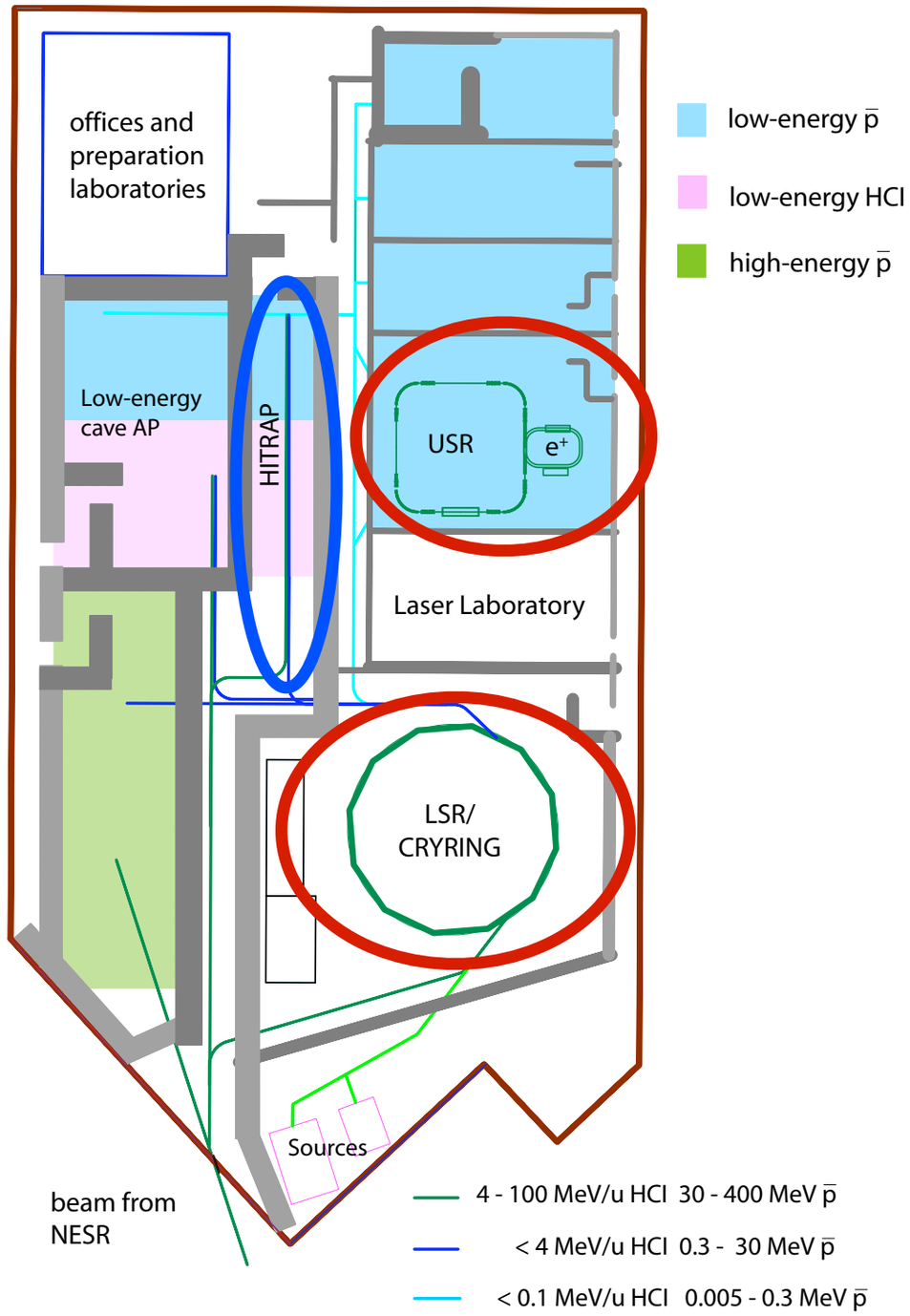

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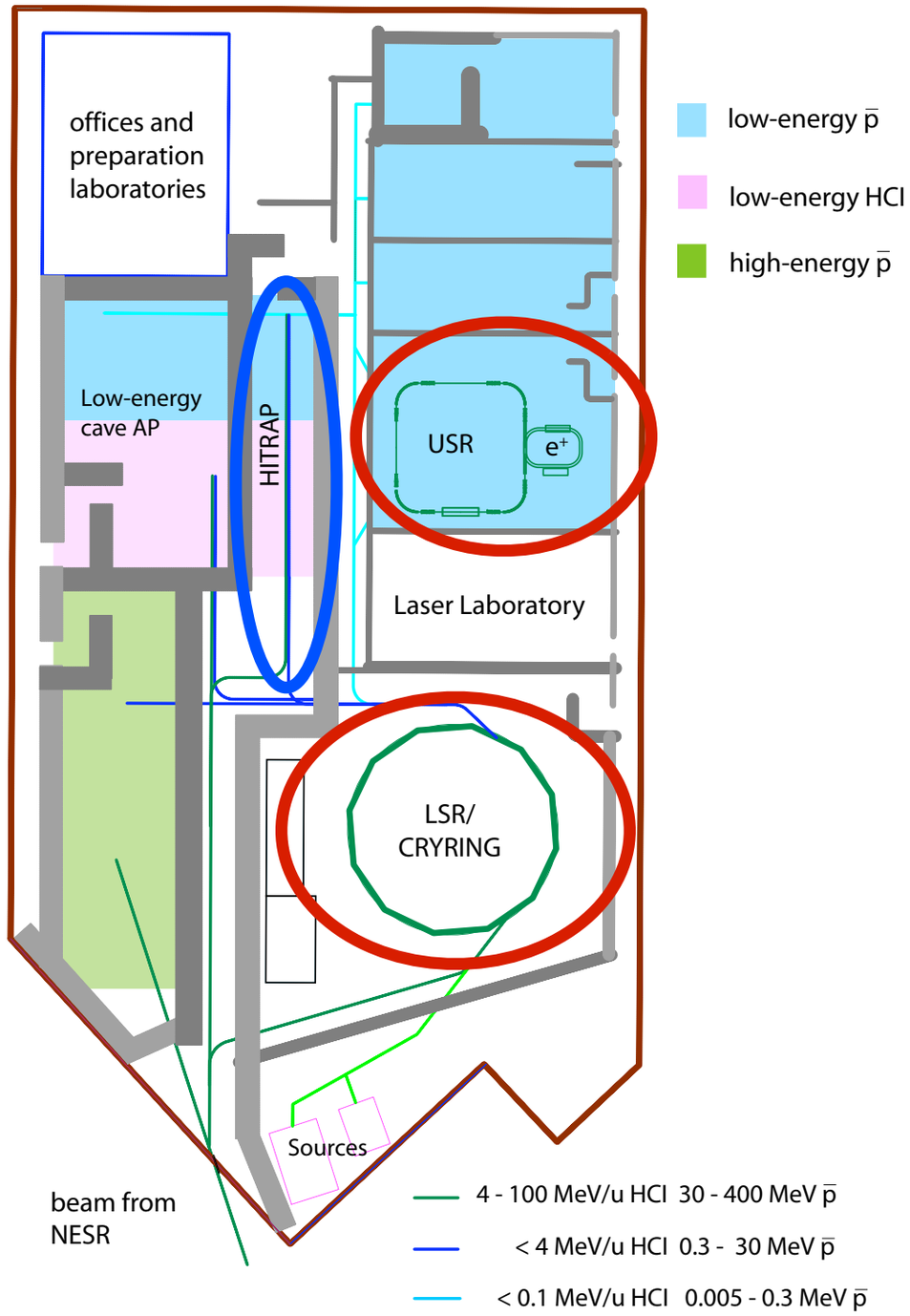

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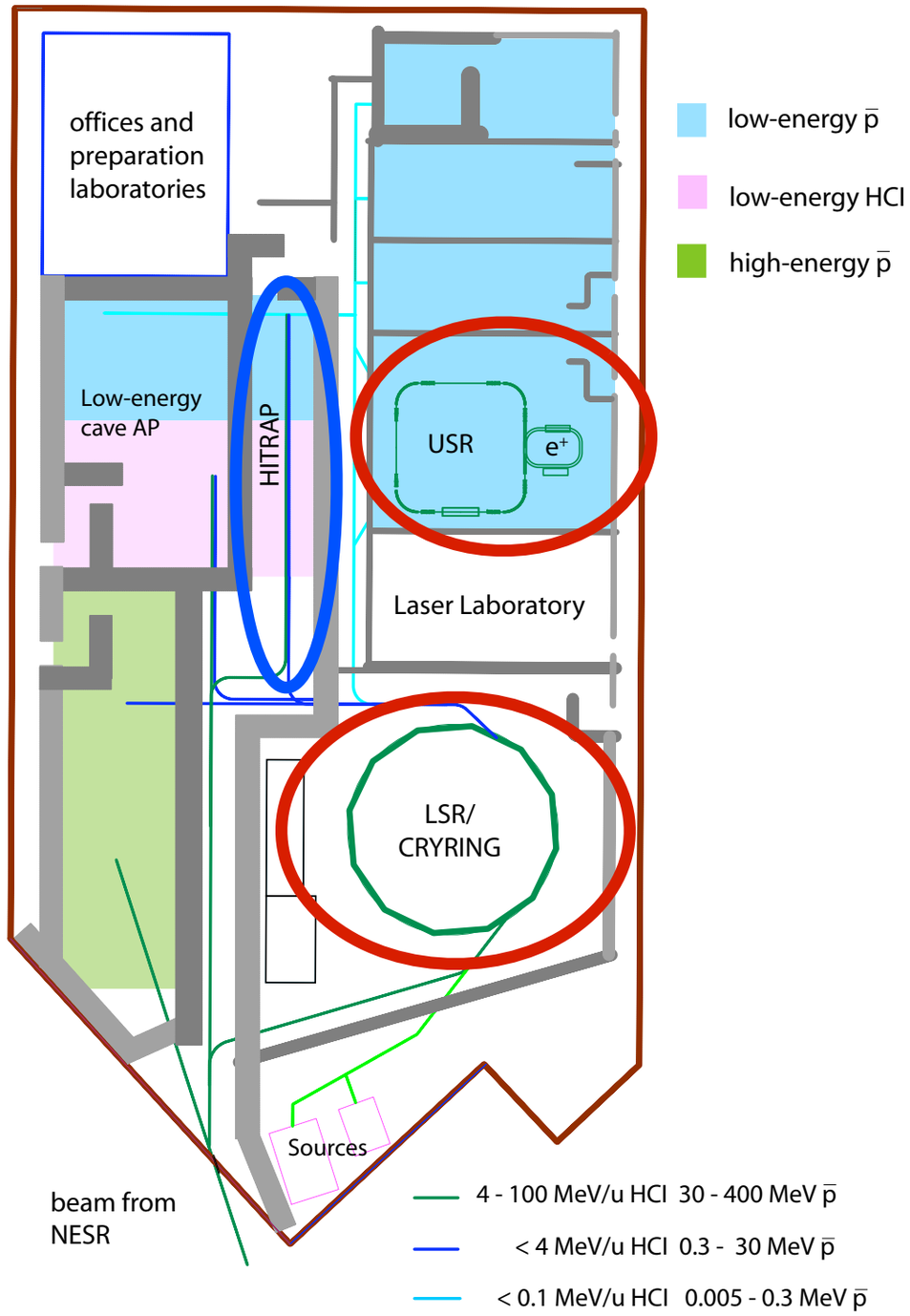

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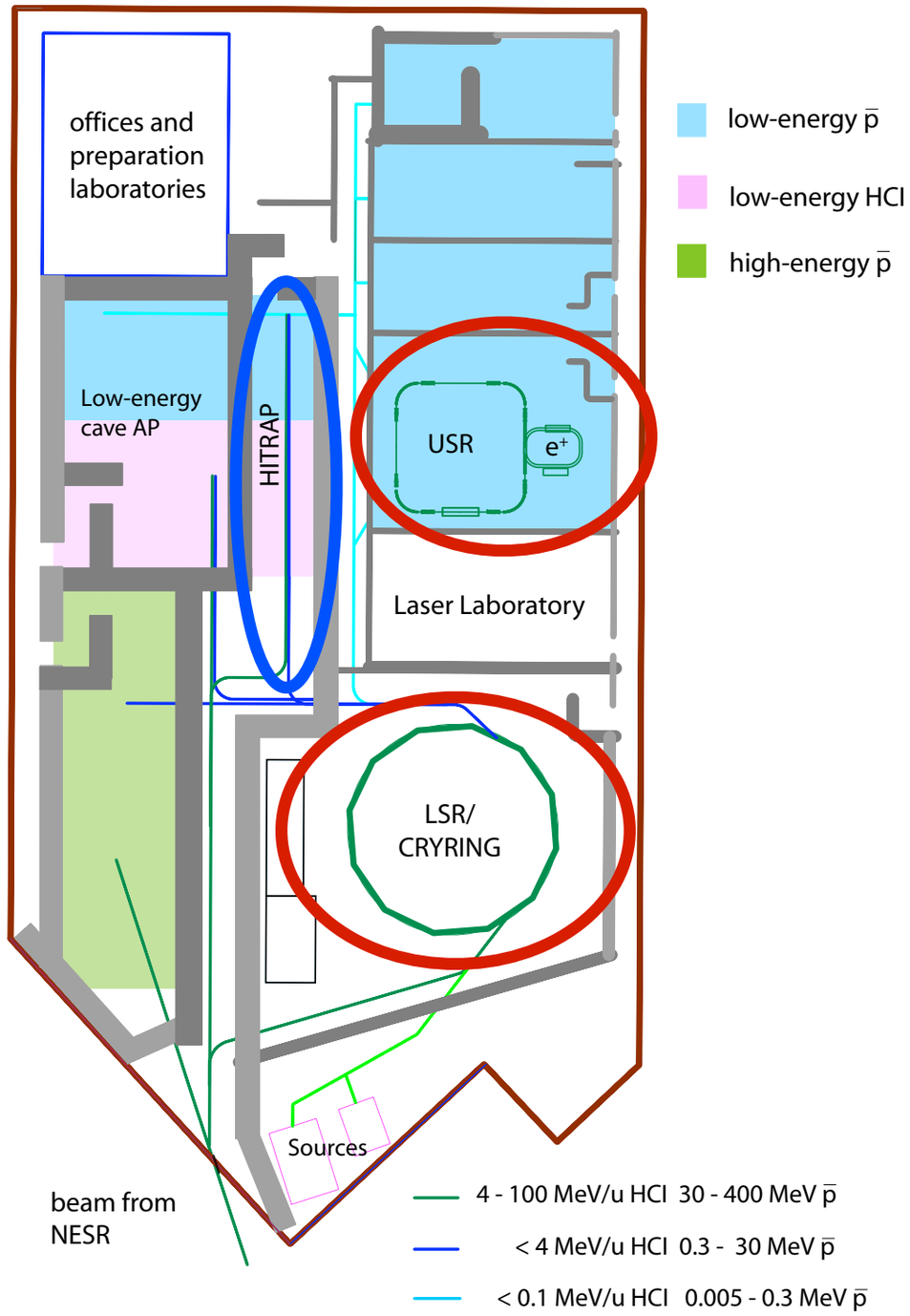
- Many new experiments possible
- same facilities can be used for HCI



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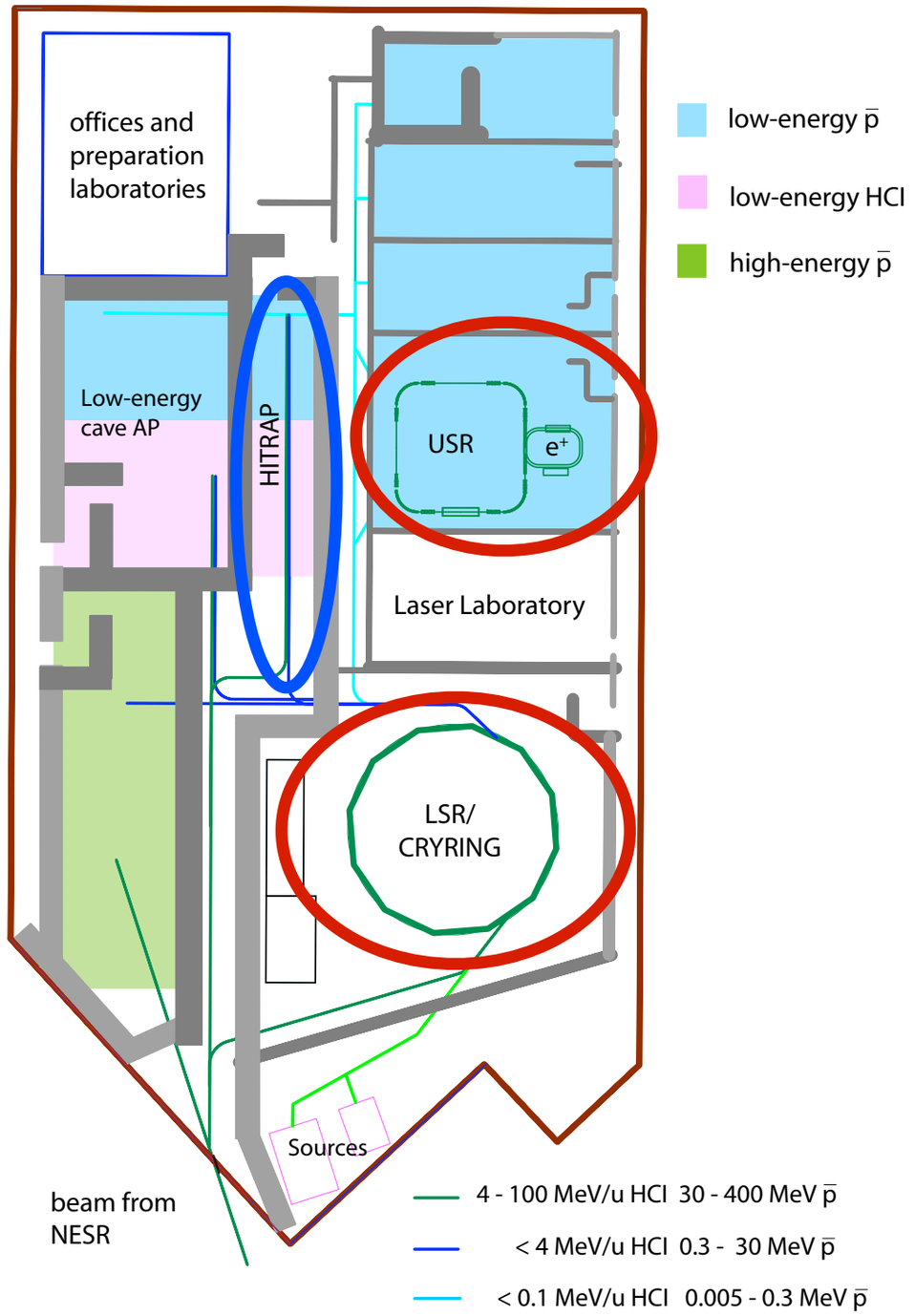

Factor 100 more pbar trapped or stopped in gas targets than now

Operation after ~2018

Low Energy Antiproton Physics @ FLAIR

FLAIR TDR - E. Widmann CAMOP - Physica Scripta 72, C51-C56 (2005)

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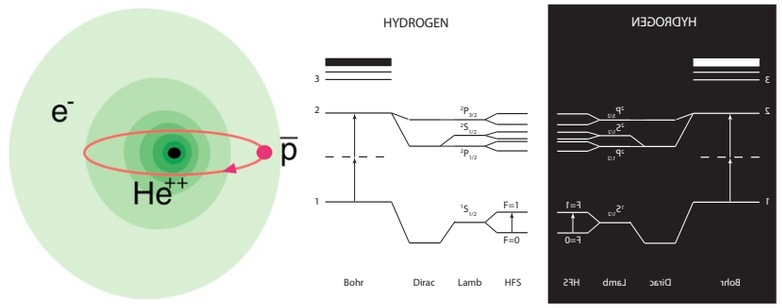
- Spectroscopy for tests of CPT and QED
  - Antiprotonic atoms (pbar-He, pbar-p), antihydrogen



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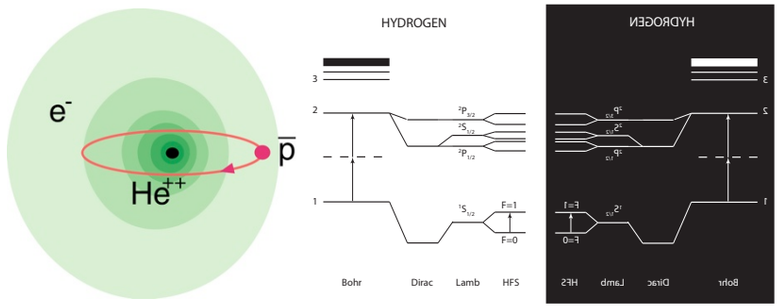

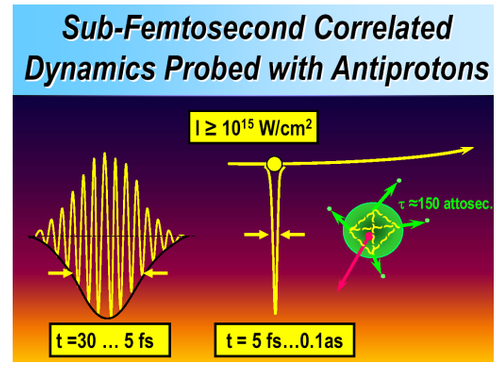

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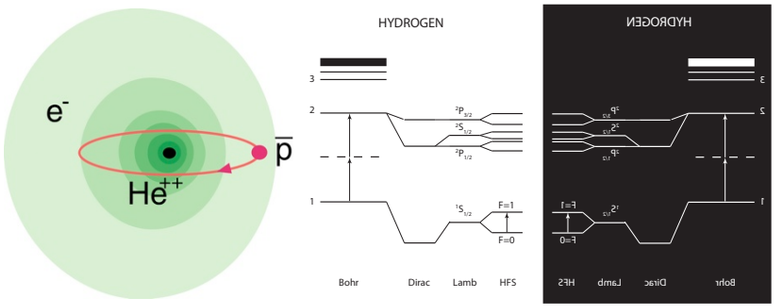

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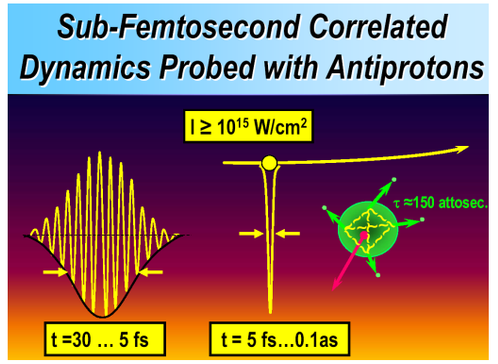

- Antiprotons as hadronic probes
  - X-rays of light antiprotonic atoms: low-energy QCD
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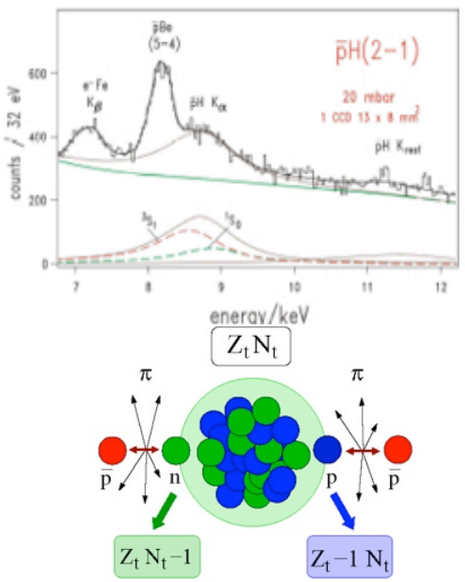
  - Strangeness –2 production



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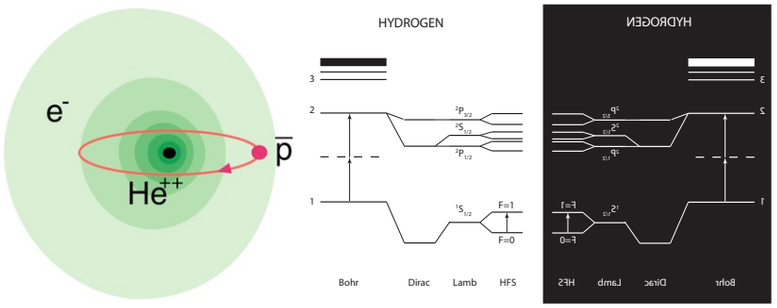

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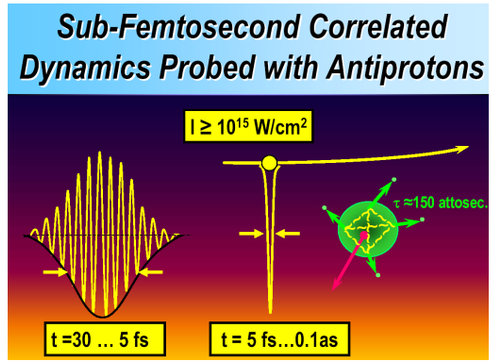

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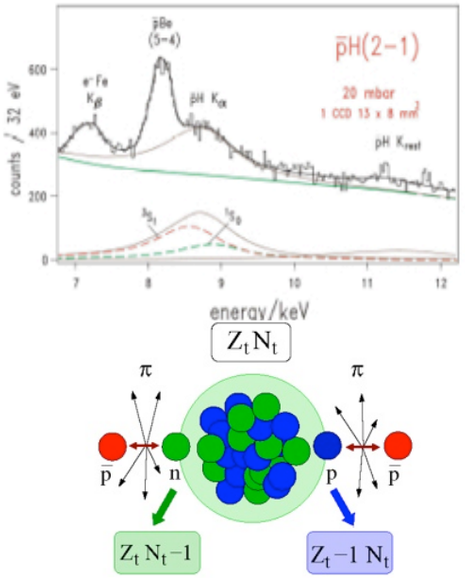
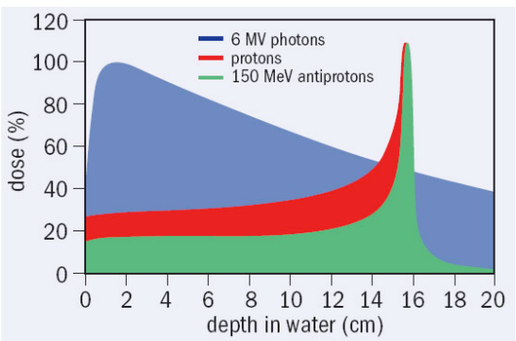
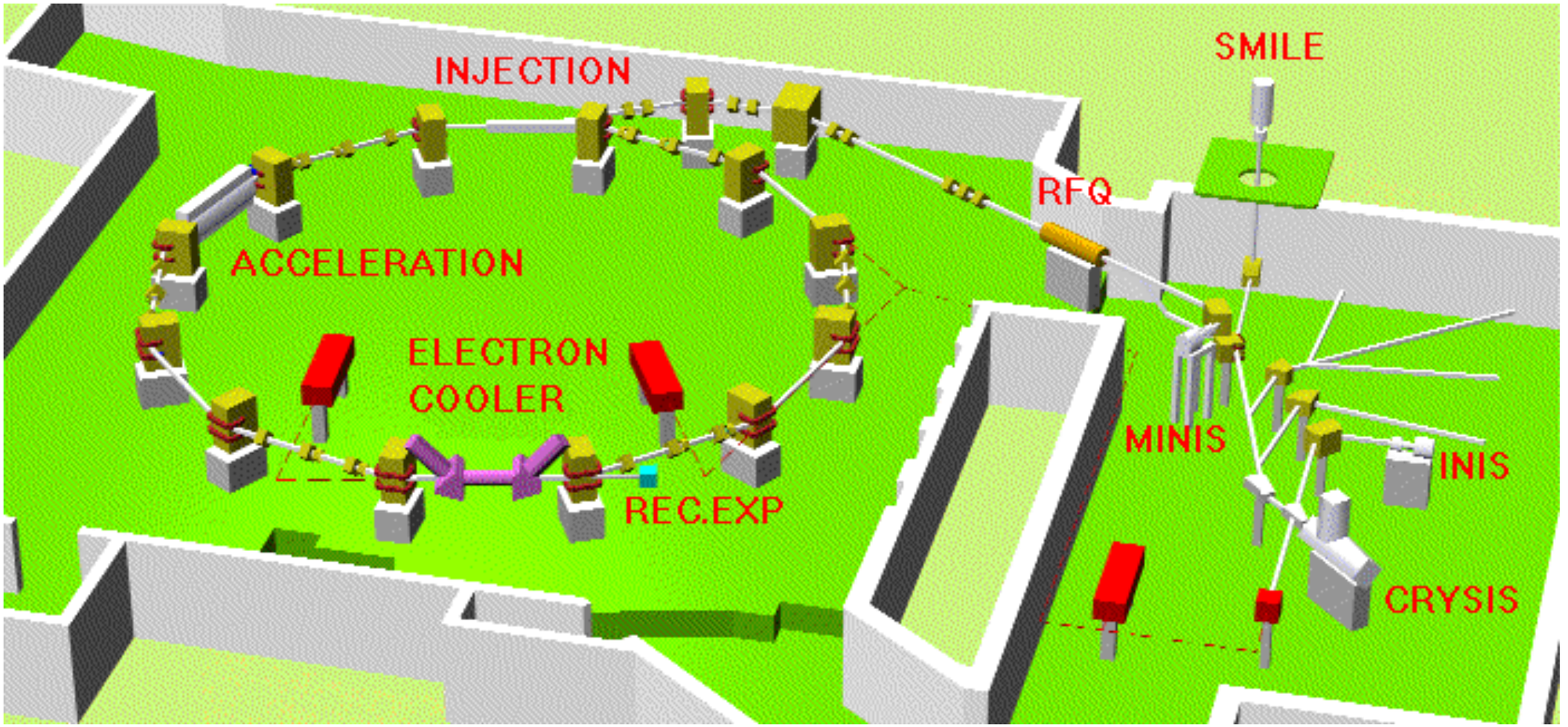


- Medical applications: tumor therapy



FLAIR TDR - E.Widmann CAMOP - Physica Scripta 72, C51-C56 (2005)

Existing storage rings of LSR type

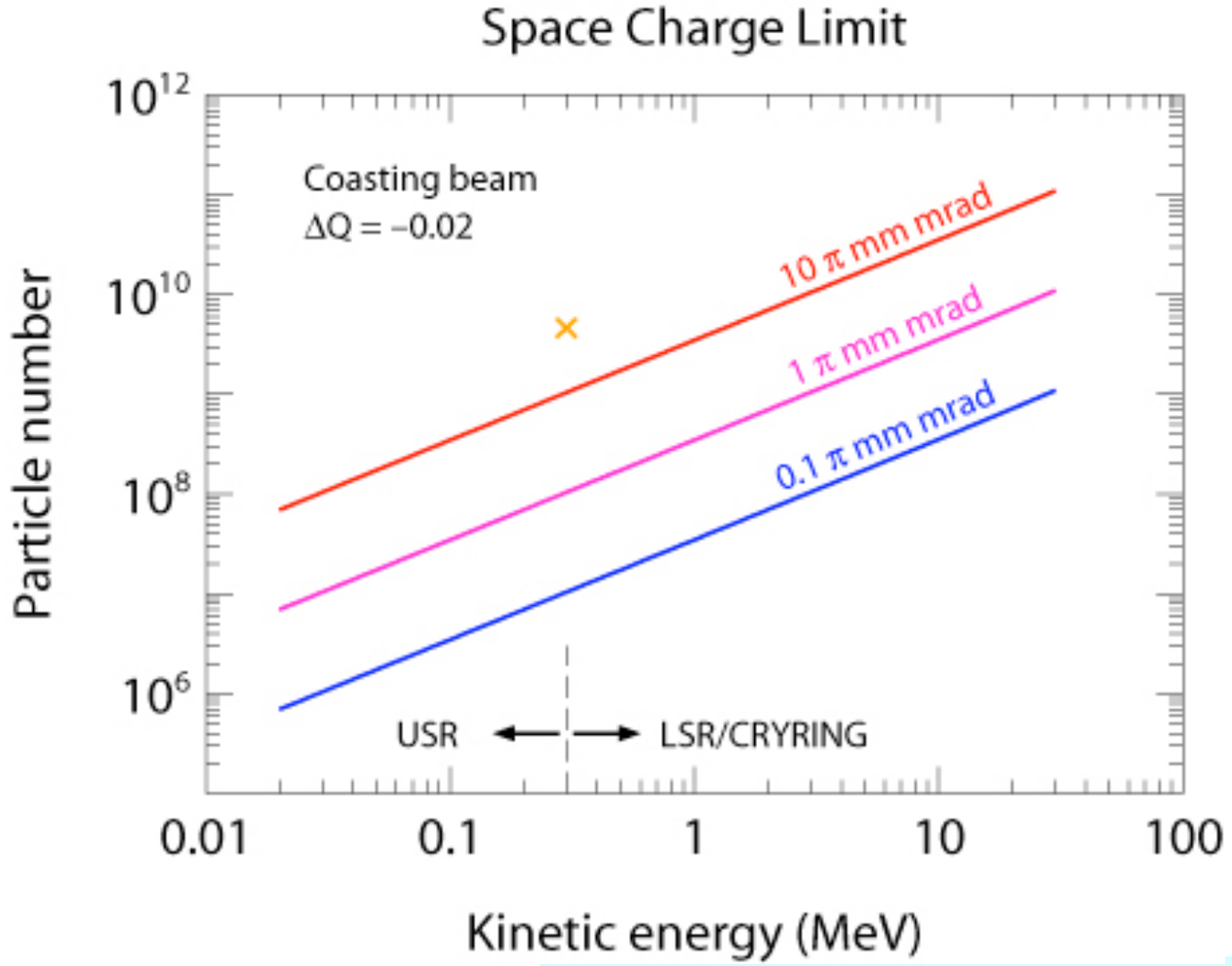


CRYRING (MSL Stockholm)

- 96 MeV – 300 keV (p)
- Circumference 51.6 m
- Will be dismantled !

FLAIR: Expected Antiproton Rates

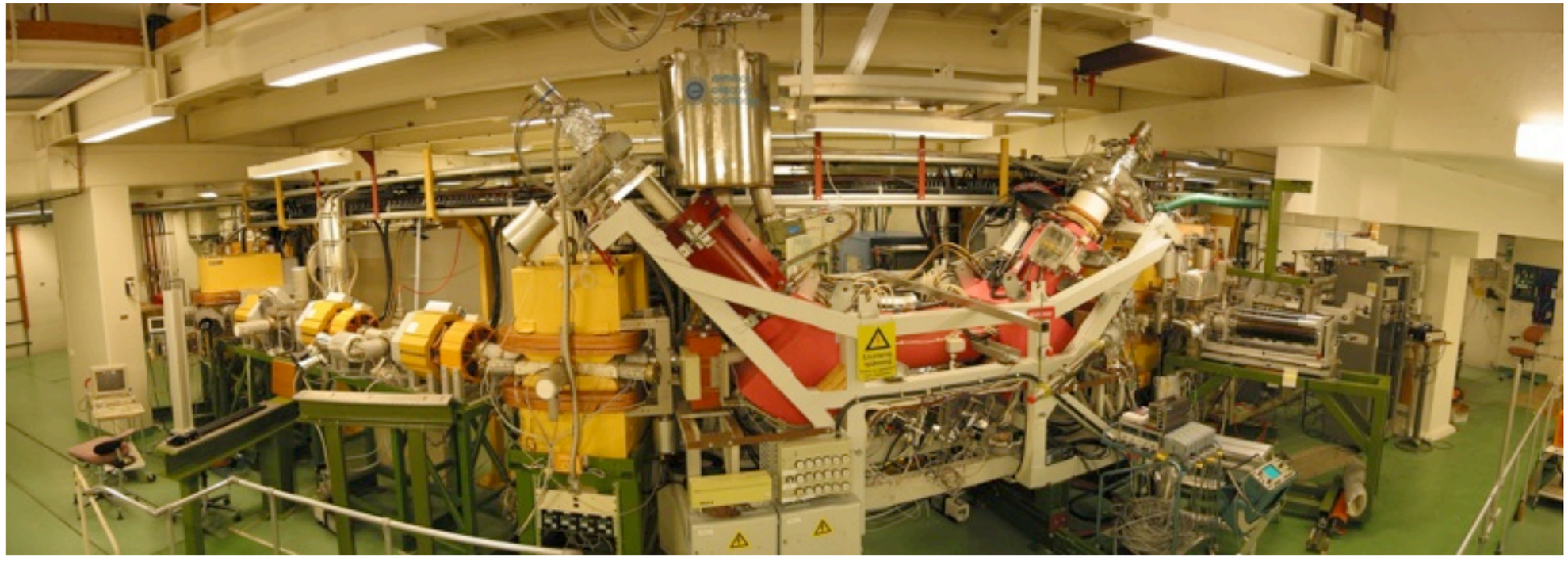
- Production: 10^8 / 4 s
- Deceleration time
  - ~ 20 s
- Limits from space charge in rings:
  - 300 keV: 3×10^6 / s
  - 20 keV: 5×10^5 / s
  - for 10 π mm mrad
  - HITRAP:
    0 keV: 1×10^6 / s
- In-ring experiments
  - Effective rates: 10^{10}– 10^{12} / s
- Phase space density much higher than AD
  - AD production rate 5×10^7 / 100 s



New estimates & test results
H. Danared, TP p. 159

CRYRING: a perfect match for LSR

- LSR is central "working horse" of FLAIR
  - Beam delivery for HITRAP, USR, experiments
- Choice of CRYRING (MSL, Stockholm)
  - Fitting energy range, electron cooling, fast ramping, internal target, low-energy injection from ion source for commissioning
  - Expertise: MSL staff has designed & built CRYRING
  - CRYRING will be contributed by Sweden as in-kind contribution to FAIR



Stefan Meyer Institute

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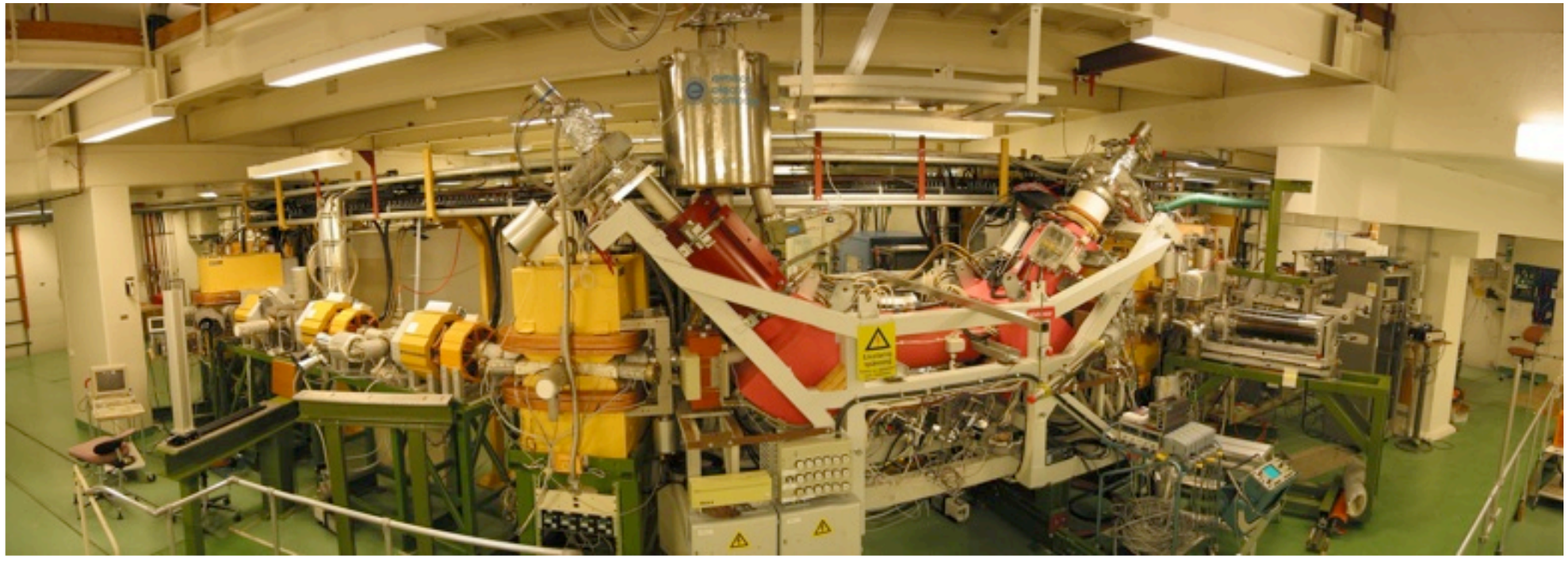
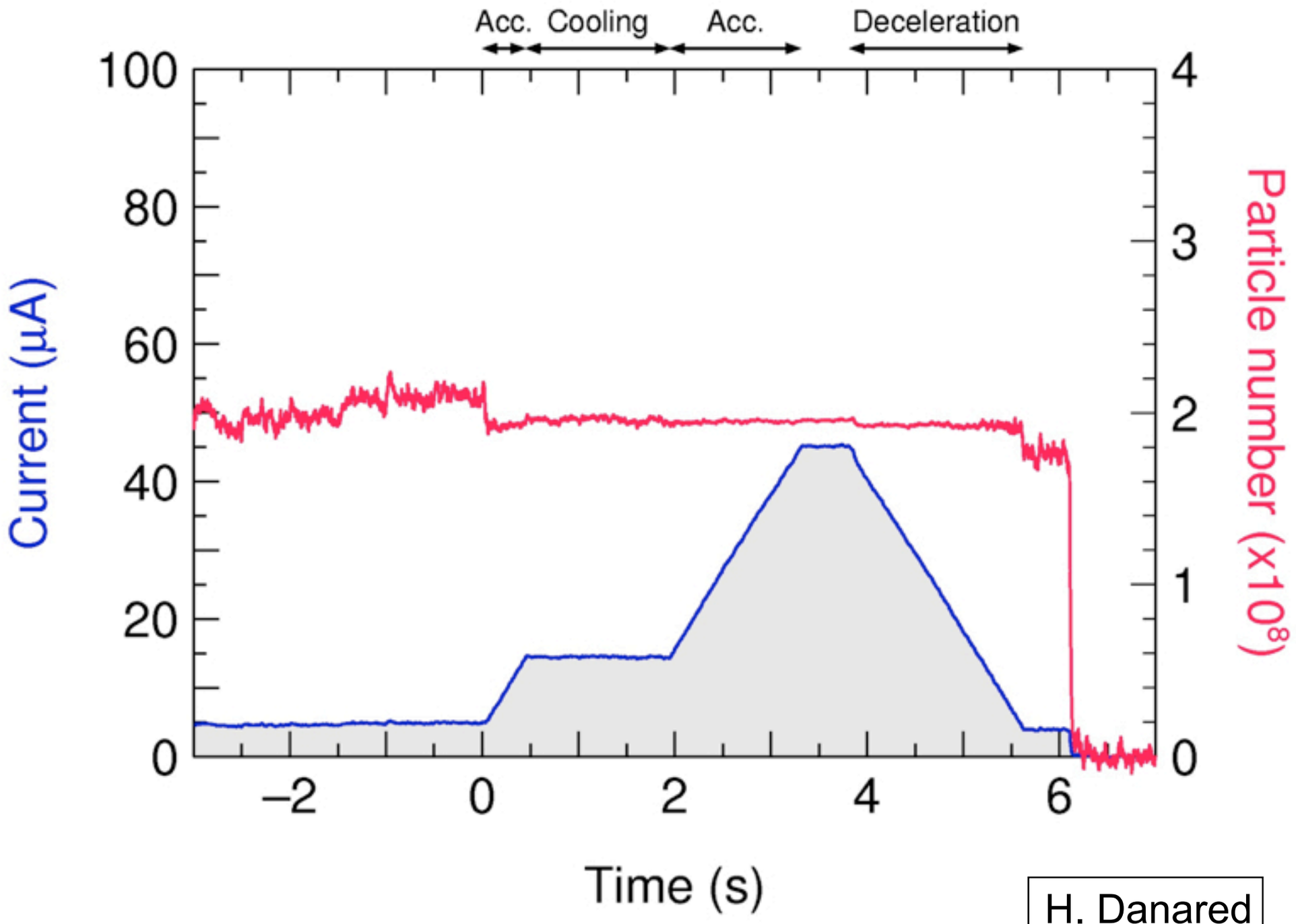


available in 2012

pbar deceleration in CRYRING

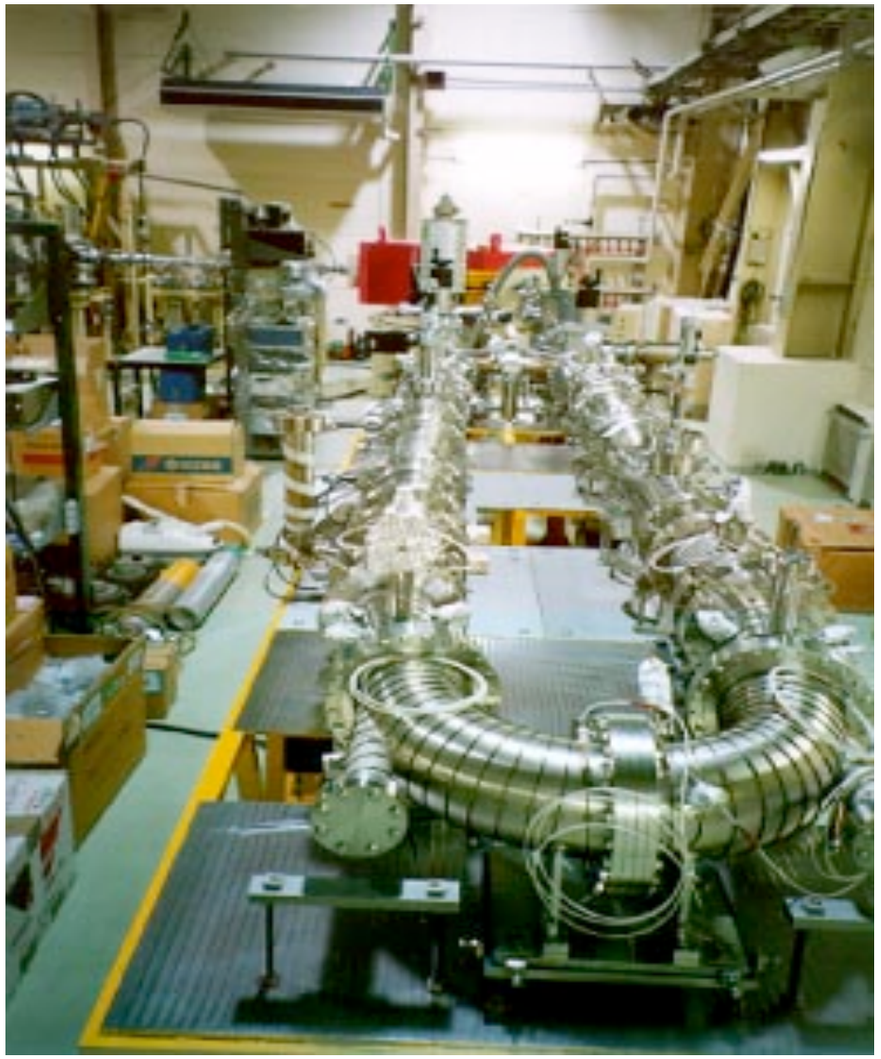


H. Danared
MSL

Stefan Meyer Institute

Electrostatic ion storage rings

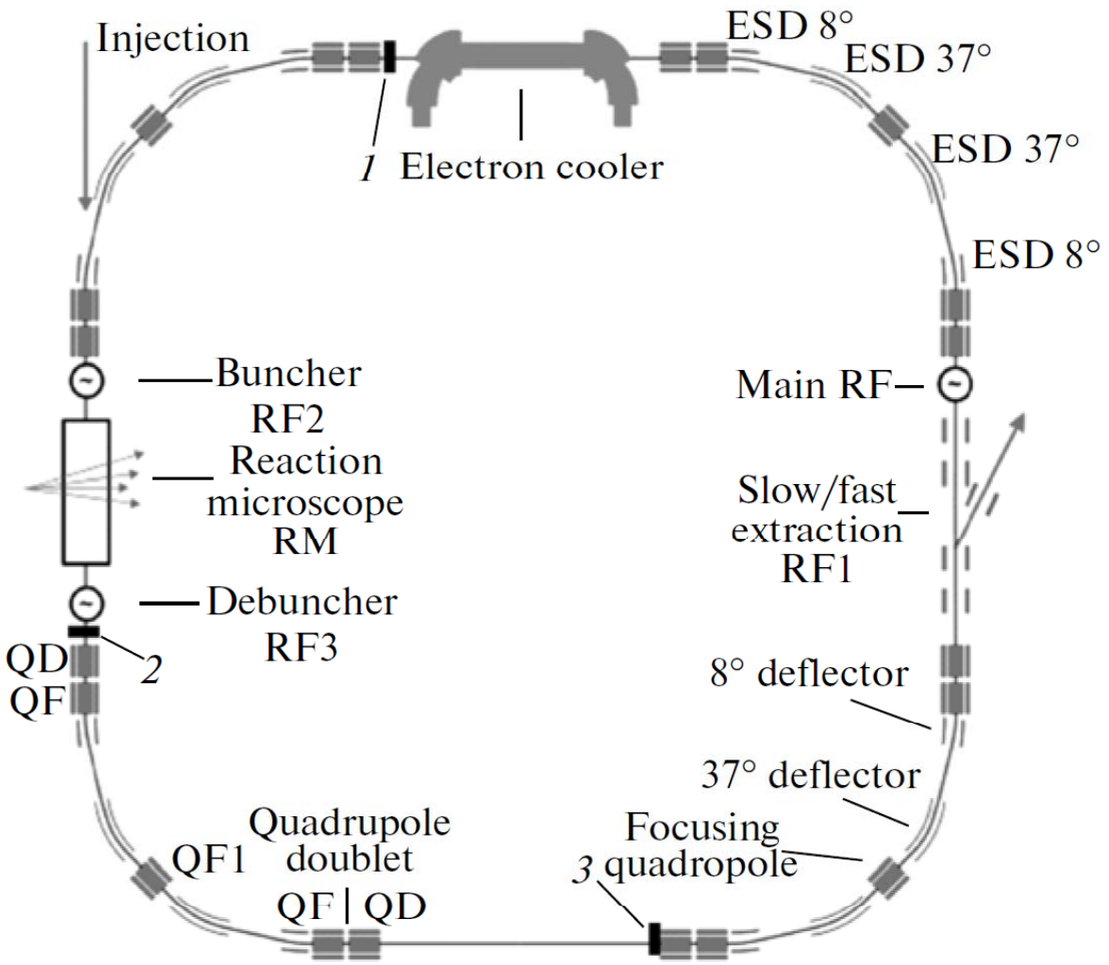
FIRST (ELISA, Aarhus)

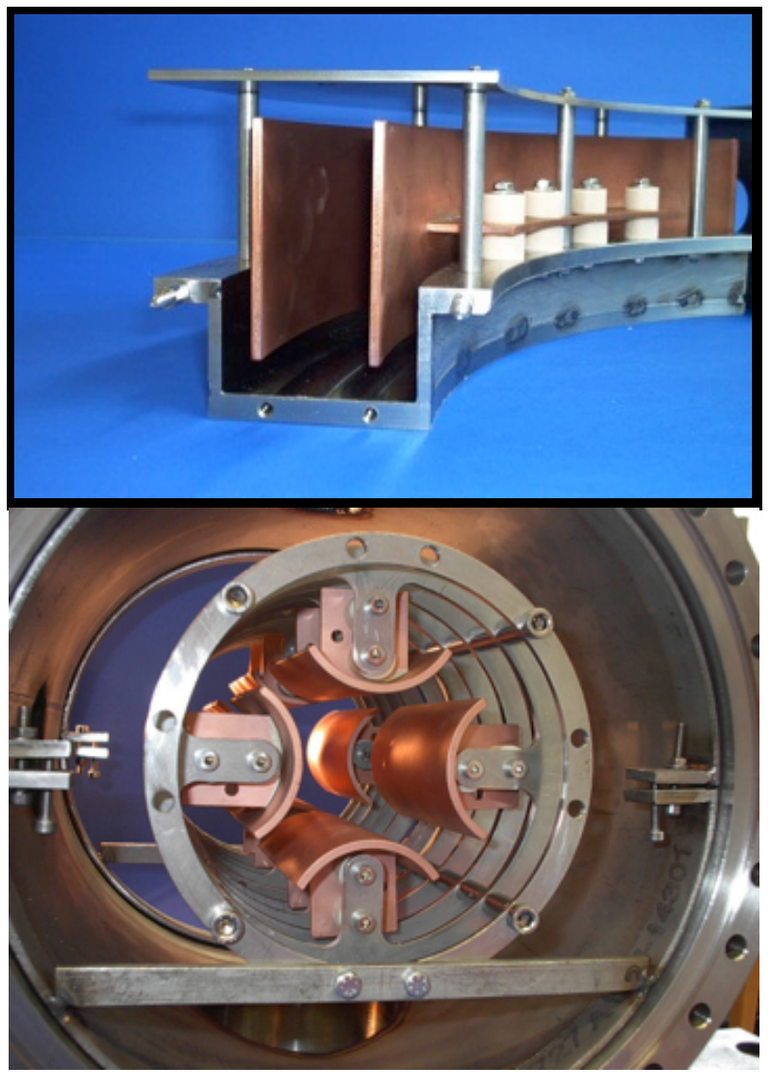


SECOND (KEK, Tanabe)

THIRD: Tokyo Metropolitan University

USR: electrostatic storage ring





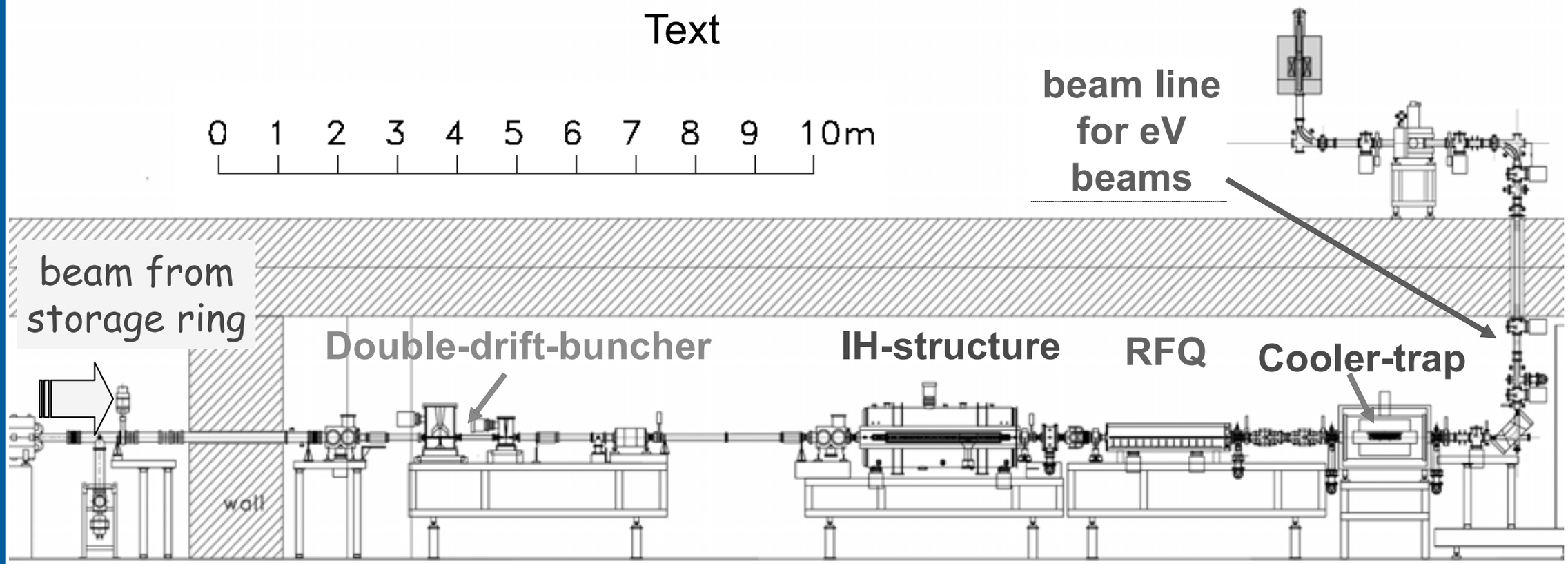
Part Phys. Nucl. Letters **8** (2011)

E_{min} / E_{max}	20 / 300 keV
Voltages	< ± 20 kV
number of pbars at 20 keV	$1 \cdot 10^7$

CSR@MPI-K Heidelberg; USR: C. Welsch Cockcroft Institute

HITRAP

- LINAC + RFQD + Penning trap for HCI and pbar
- extraction of eV beams
- precision mass measurements, reaction microscopes for collision studies, etc.
- **being commissioned for ESR@GSI**



Current status of FAIR

: Modules 0 to 3 of FAIR. Module 0: green; module 1: red; module 2: yellow; module 3: orange.

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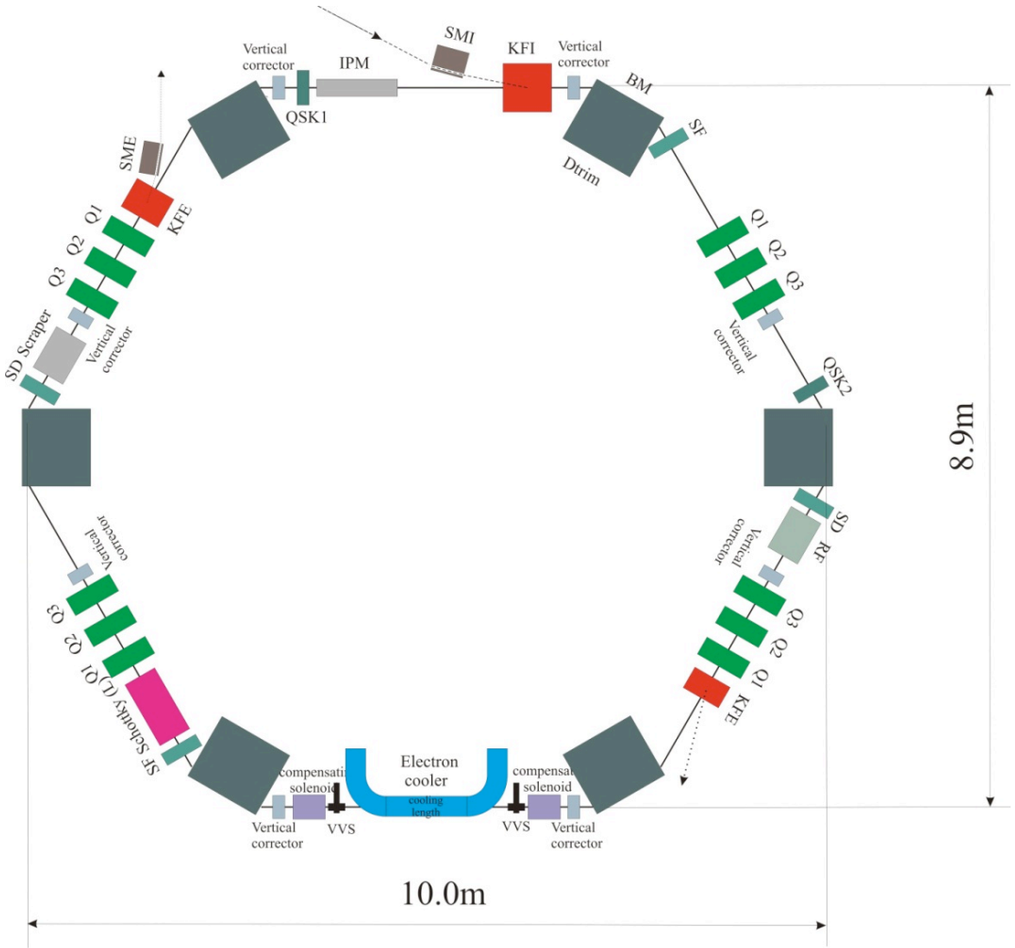
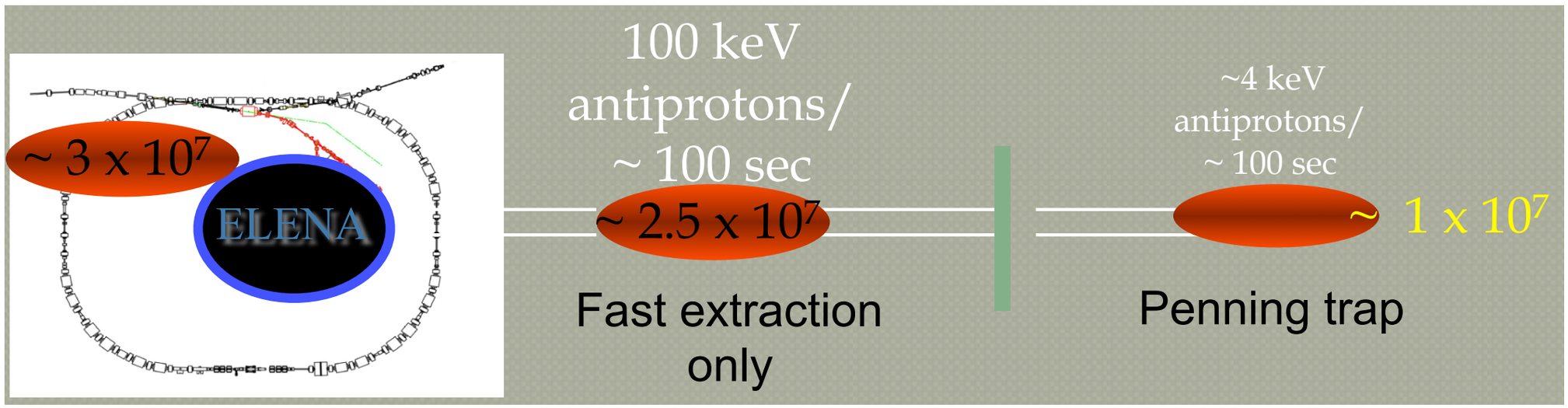
New Development I: ELENA @ CERN



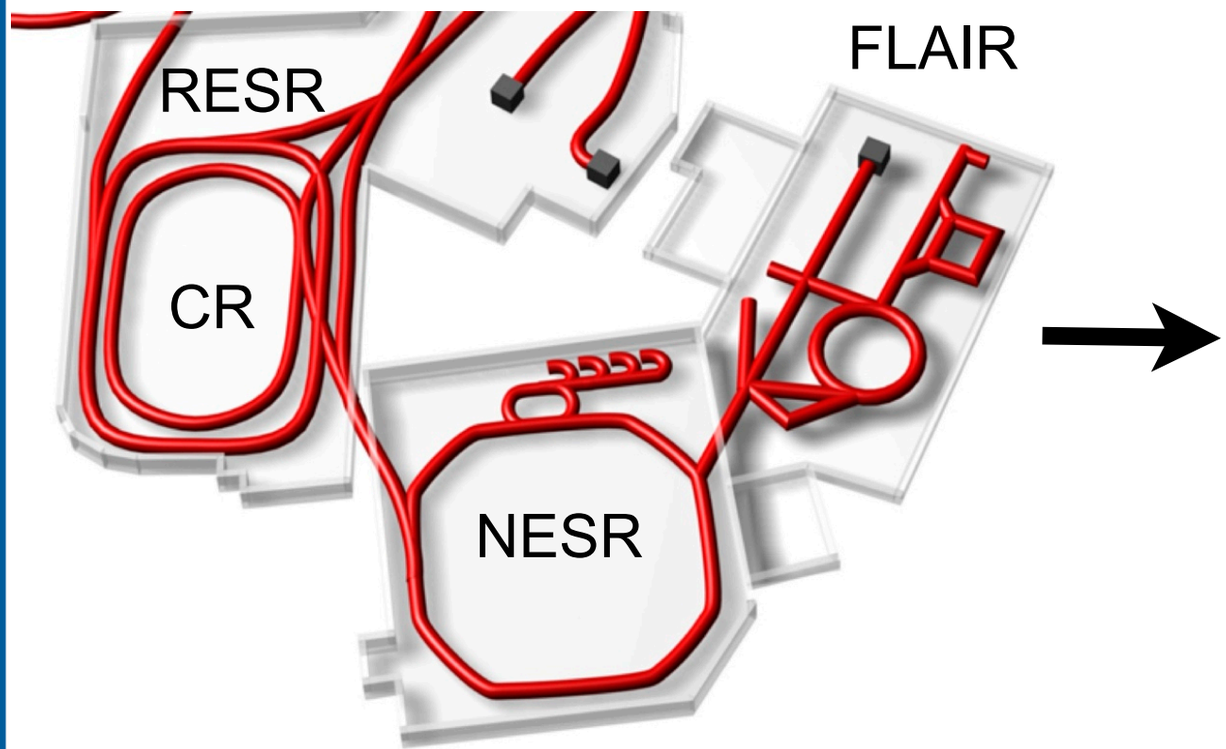
Momentum range, MeV/c	100 - 13.7
Energy range, MeV	5.3 - 0.1
Circumference, m	30.4
Intensity of injected beam	3×10^7
Intensity of ejected beam	2.5×10^7
Number of extracted bunches	4
Emittances (h/v) at 100 KeV, π ·mm ·mrad, [95%]	4 / 4
Δp/p after cooling, [95%]	10^{-4}
Bunch length at 100 keV, m / ns	1.3 / 300
Required (dynamic) vacuum, Torr	3×10^{-12}



Approved in 2011, start foreseen 2016

New Development II: RESR

- RESR in module 5, but cheap (19 M€ + small modification)
- no stacking, but decelerate in RESR
  - foreseen for AIC, needs electron cooler
  - production rate: 1×10^7 /s
  - cycle time 50-100 s
  - rates like ELENA, but ***fast extraction***



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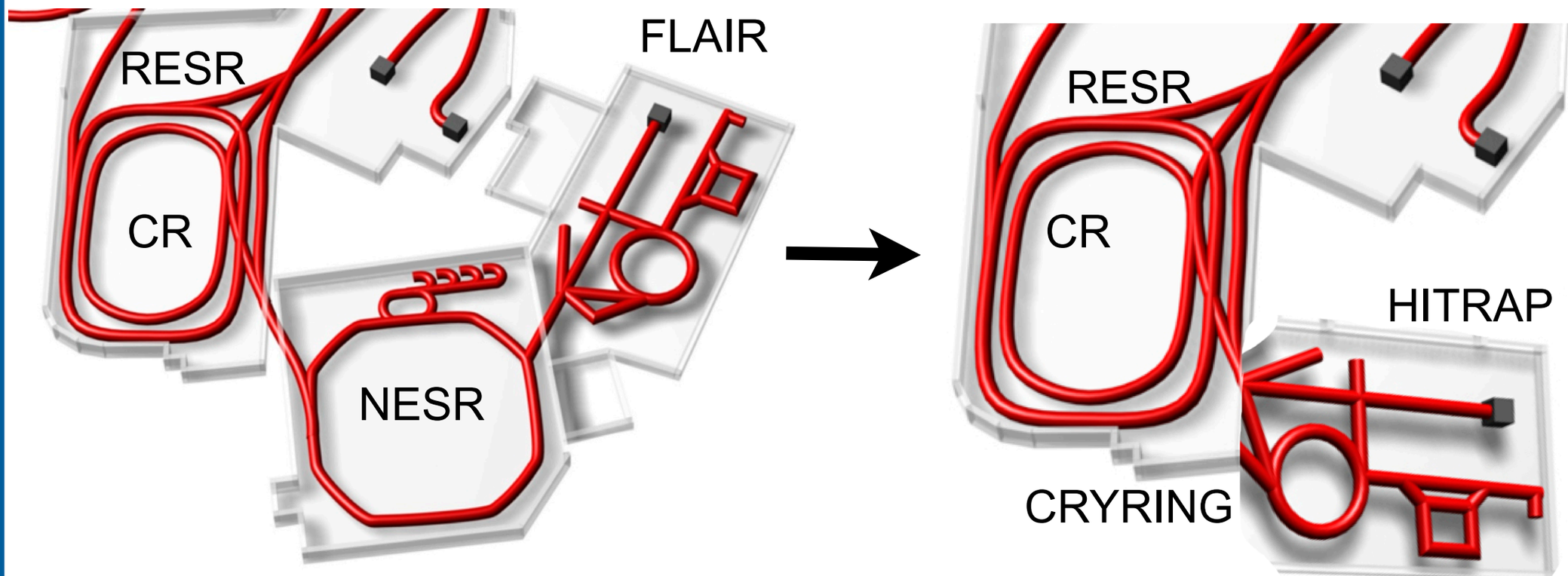
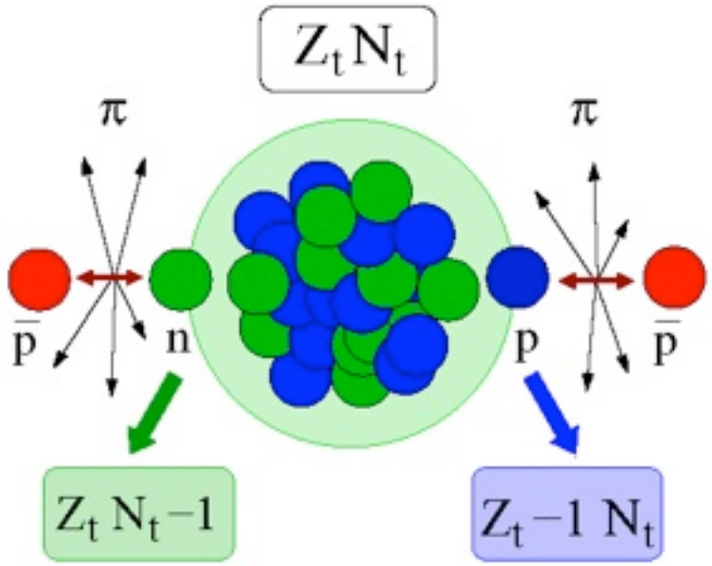
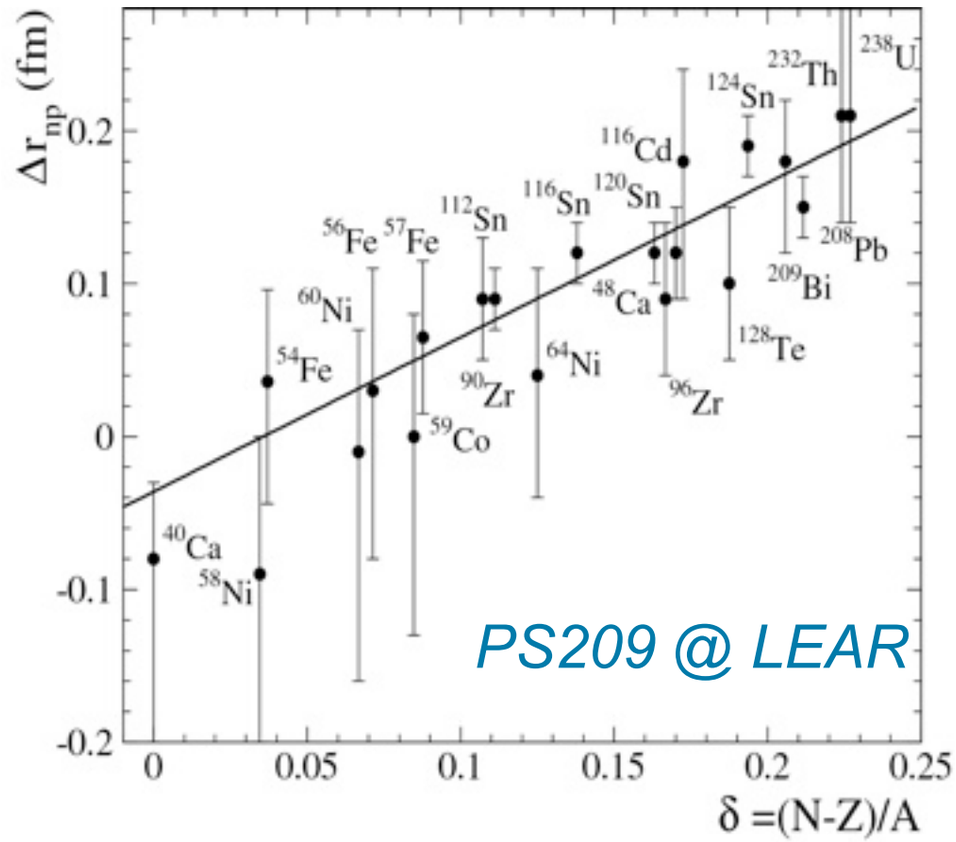
  - cycle time 50-100 s
  - rates like ELENA, but ***fast extraction***



Nuclear Periphery with antiprotonic Atoms

determination of the **halo factor** (f_{halo})



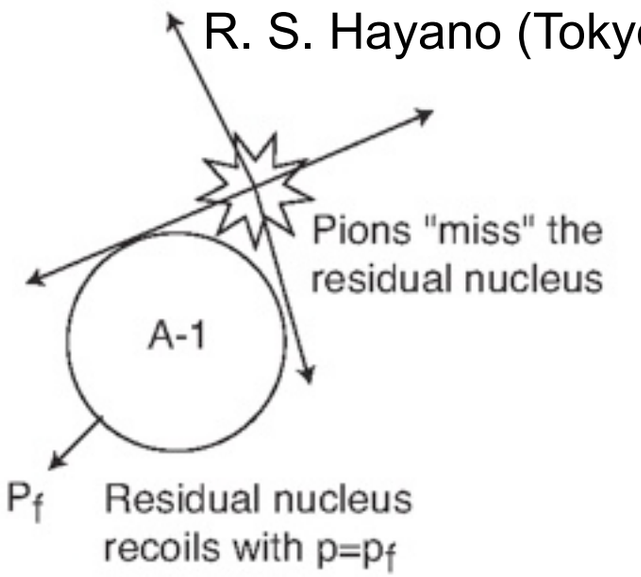


- Exotic atom formation -> cascade ->
  - Annihilation with outermost nucleons (<r>+ 2 fm)
- Measurement of neutron halo parameters
  - Radiochemical method, X-rays + model calculations
- Neutron diffuseness increases with neutron excess
- Extension to unstable nuclei interesting

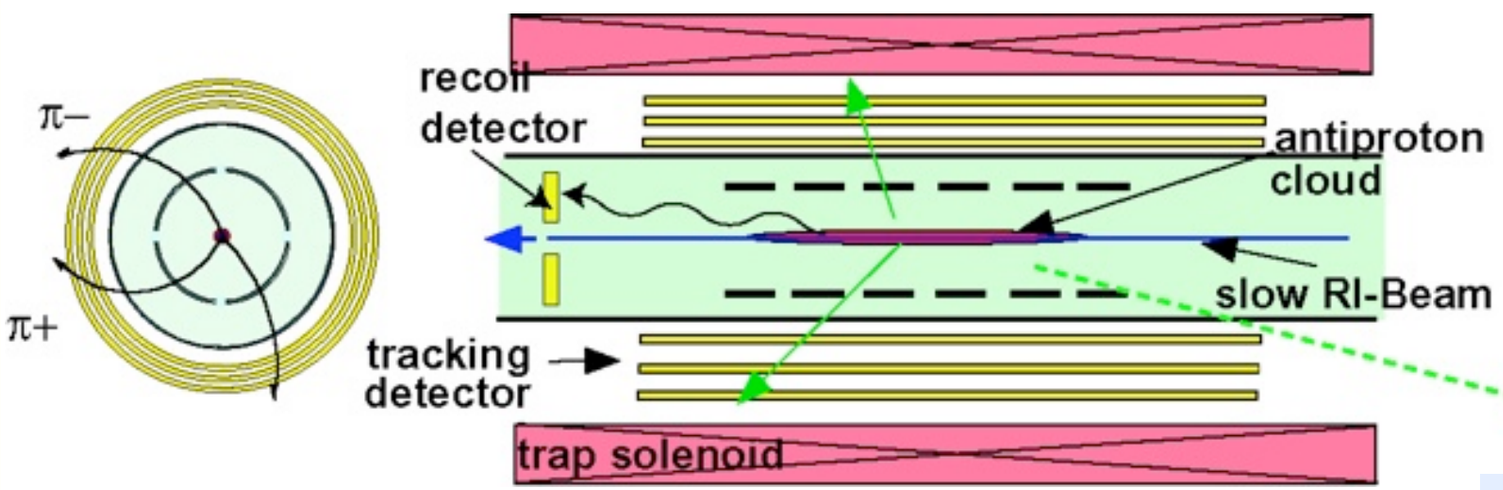
A. Trzcinska, J. Jastrzebski et al. PRL 87 (082501) 2001

pbar-RI in Traps for Nuclear Structure Study

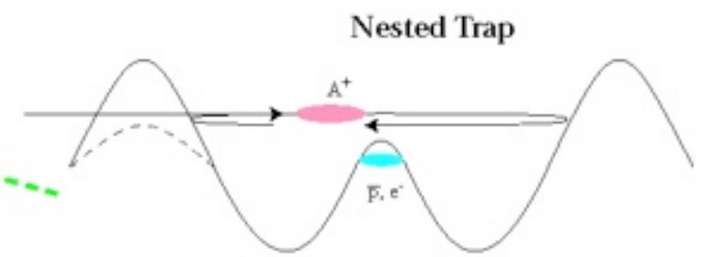
- pbar annihilates with outer-most nucleon at <r> + 2 fm



- Momentum distribution of recoil nuclei
  - Wave function of outer-most nucleon
- Charged pion multiplicity
  - Distinguish annihilation on p and n
  - Halo factors
  - Less model dependent than X-rays
- Antiprotons from FLAIR
- RI from LEB-SFRS gas catcher



M. Wada, Y. Yamazaki (Tokyo)
NIM B214 (2004) 196
Nested Penning trap

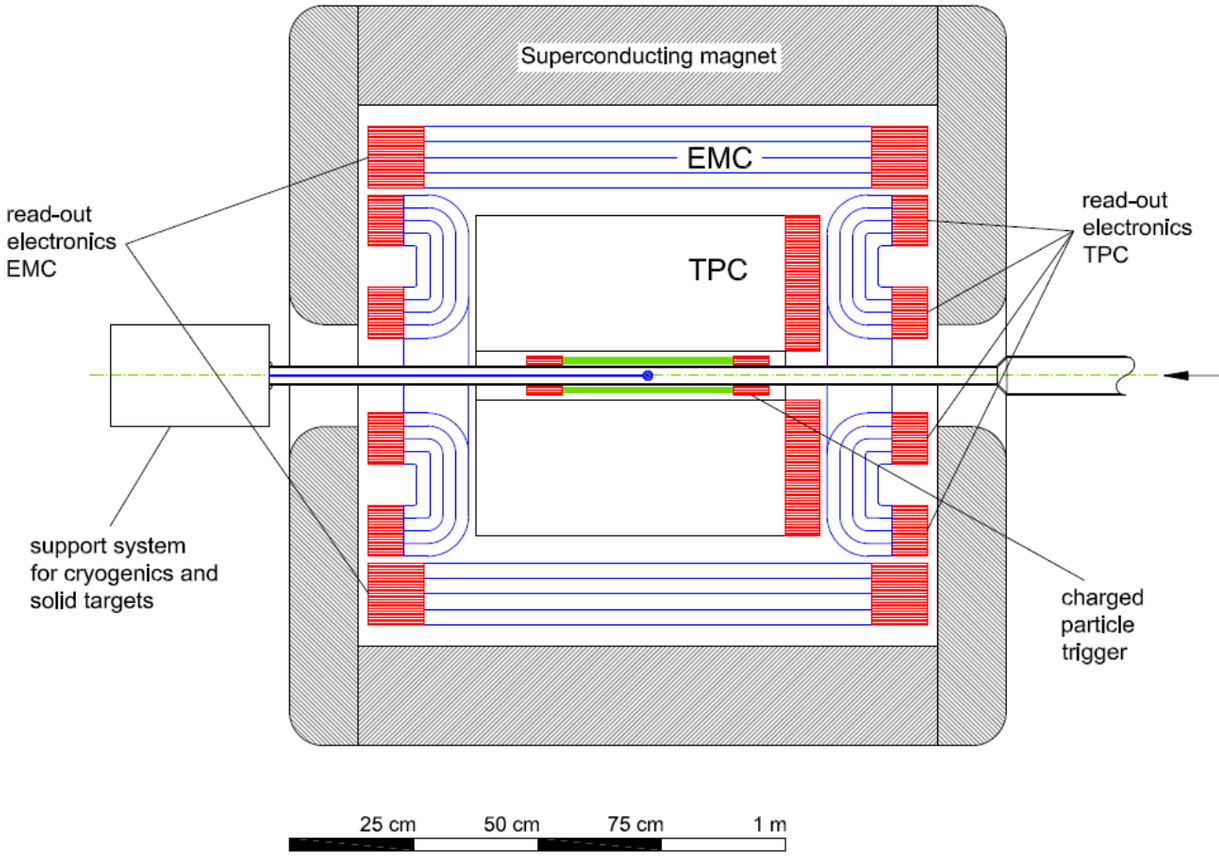


Exo+pbar

CDM: Cold, dense hadronic matter by antiproton annihilation in nuclei at rest

- Strong attraction in antikaon-nucleon interaction below threshold
  - Bound states of single and double kaons exist?
- Large cross section for production of 2 K^+ in proton-antiproton annihilation at LEAR
- re-measurement with stopped antiprotons
- 4π detector needed
  - also useful for meson spectroscopy with stopped antiprotons

J. Zmeskal et al. Hyperfine Interact 194, 249-254 (2009)



$$\bar{p} + p \rightarrow K^+ + K^+ + K^- + K^- - 0.098\,\mathrm{GeV}$$

$$\bar{p} + {}^4He \rightarrow K^+ + K^+ + [pnnK^-K^-]$$

Summary and Outlook

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Summary and Outlook

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  - Fundamental symmetries, nuclear & atomic physics
- Long-term high-precision experiments need
  - Time, Care and Particles
- CERN-AD and ELENA: Antihydrogen
  - essential for continuation of current program
- FLAIR: offers further opportunities
  - Cooled antiprotons down to 20 keV
  - higher rates (with NESR)
  - **DC beams** enable nuclear and particle physics type experiments (not possible at AD)
  - Availability of radioactive ion beams (**RIB**) offers new synergies

FLAIR Workshop 2012

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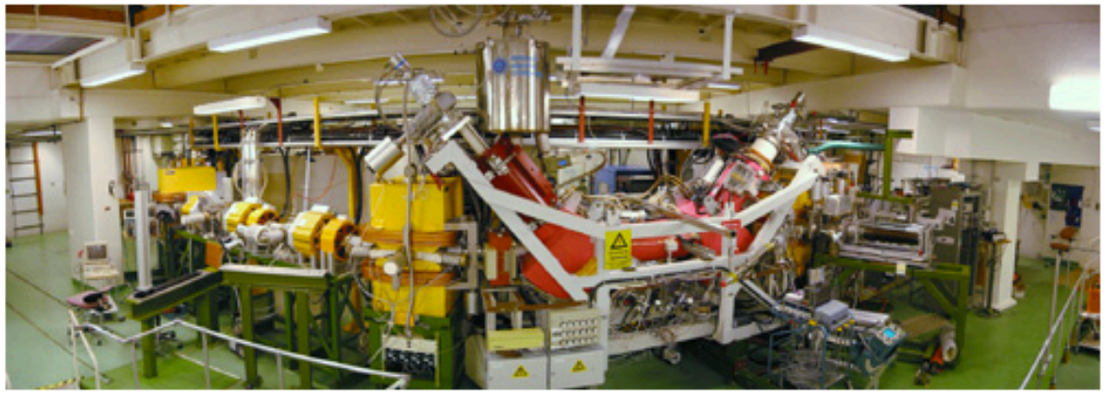
FLAIR

Facility for Low-energy Antiproton and Ion Research



This workshop is jointly organized by the **FLAIR Scientific Council**, the Max-Planck-Institut für Kernphysik **MPIK Heidelberg**, the **GSI** Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, the **Johannes Gutenberg-Universität**, Mainz, the **Extreme Matter Institute EMMI** Darmstadt, and the **Helmholtz-Institute Mainz HIM**.

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Thank you