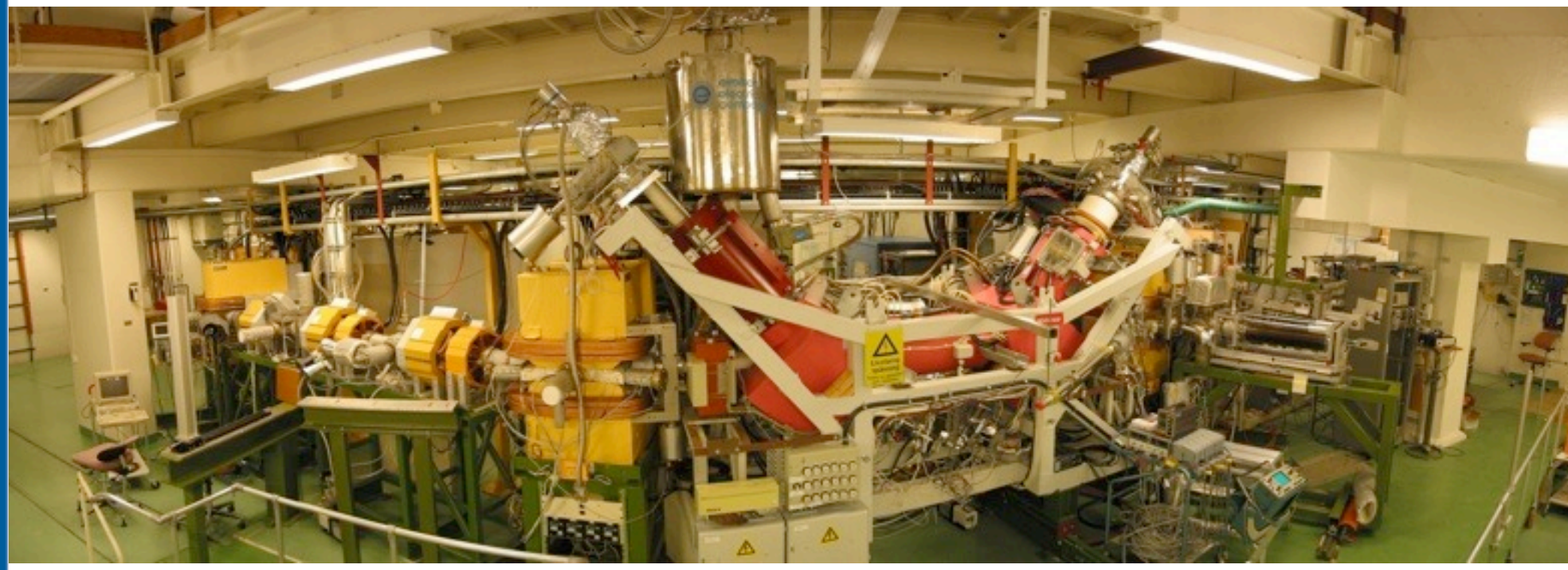
CRYRING and its role in future low-energy antiproton physics



Eberhard Widmann

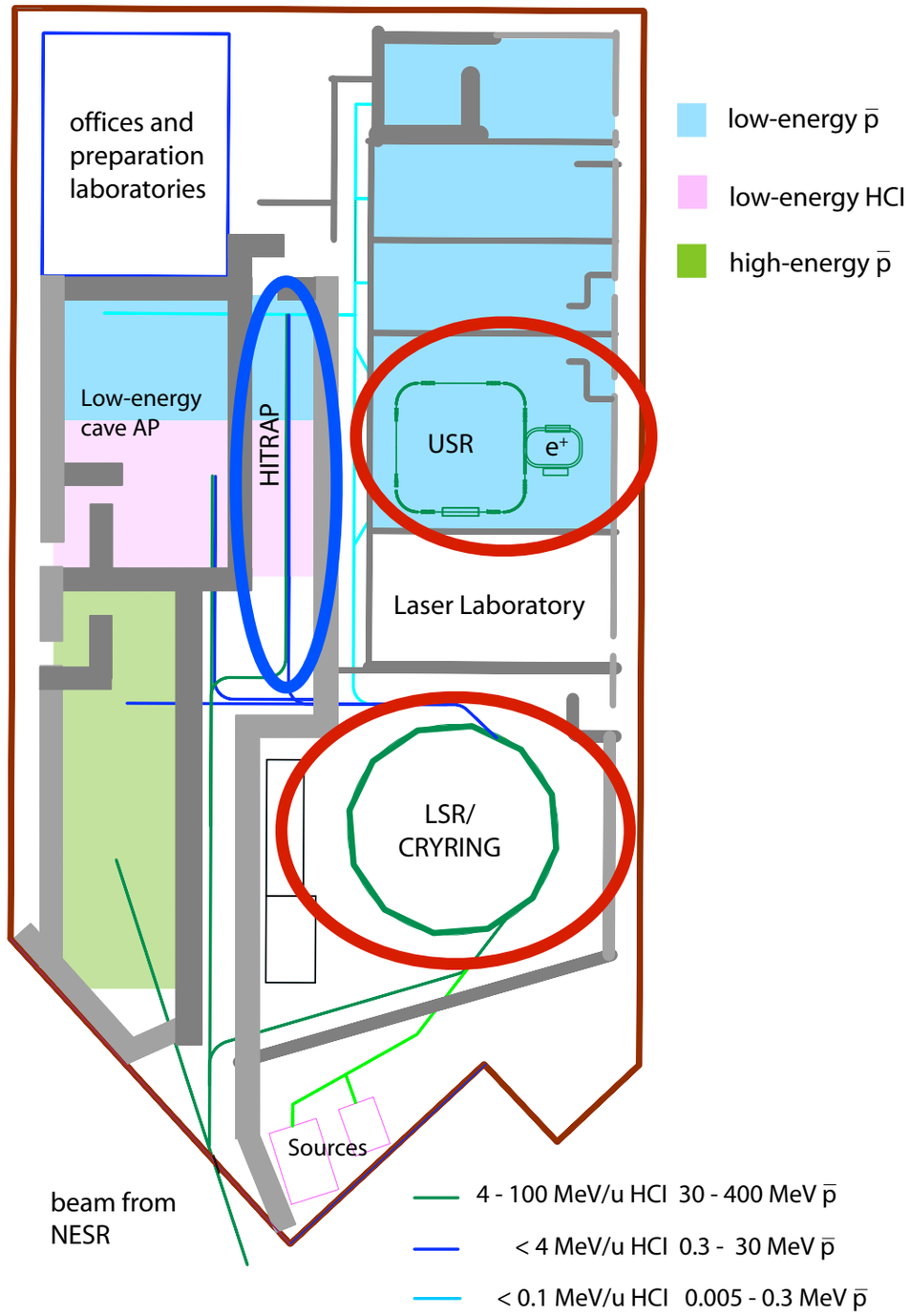
LEAP2013

Uppsala, June 13, 2013

Stefan Meyer Institute for Subatomic Physics, Vienna

FLAIR@ FAIR - Baseline Technical Report 2005

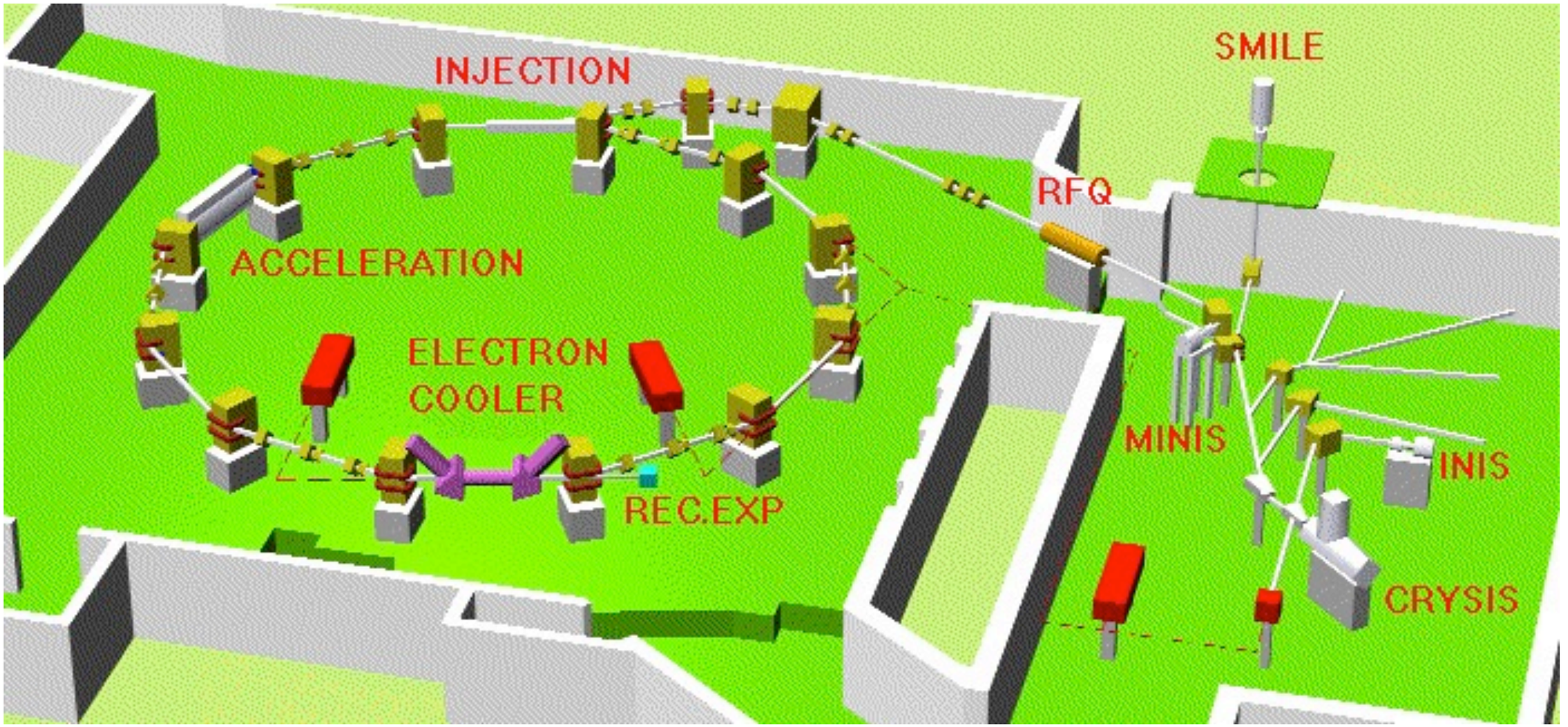
- High brightness low energy beams
  - two storage rings with 300 keV (LSR) and 20 keV (USR)
  - electron cooling
    - ε ~ 1 π mm mrad
    - $\Delta p/p \sim 10^{-4}$
- Storage rings with internal targets for collision studies
- Slow and fast extraction
- Ion traps
  - HITRAP facility for HCI & pbar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



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

Operation after ~2018

Existing storage rings of LSR type

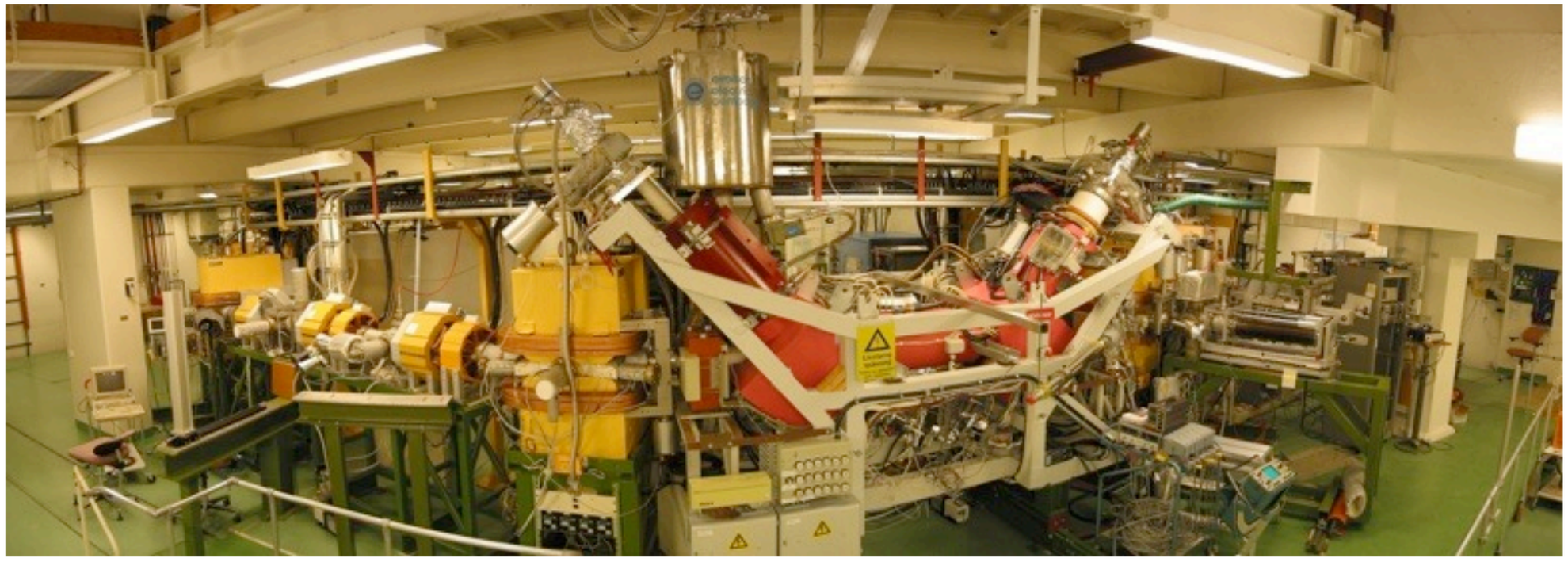


CRYRING (MSL Stockholm)

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

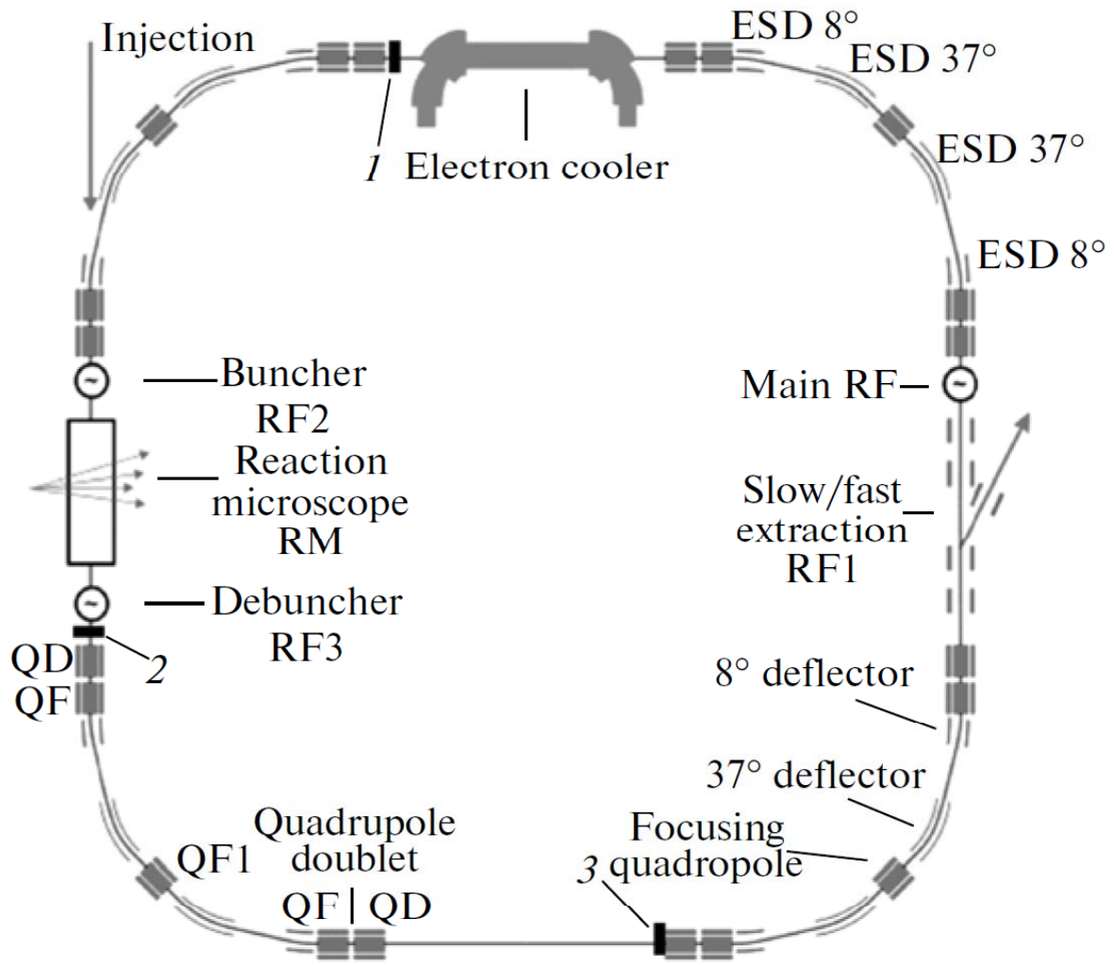
CRYRING: a perfect match for LSR

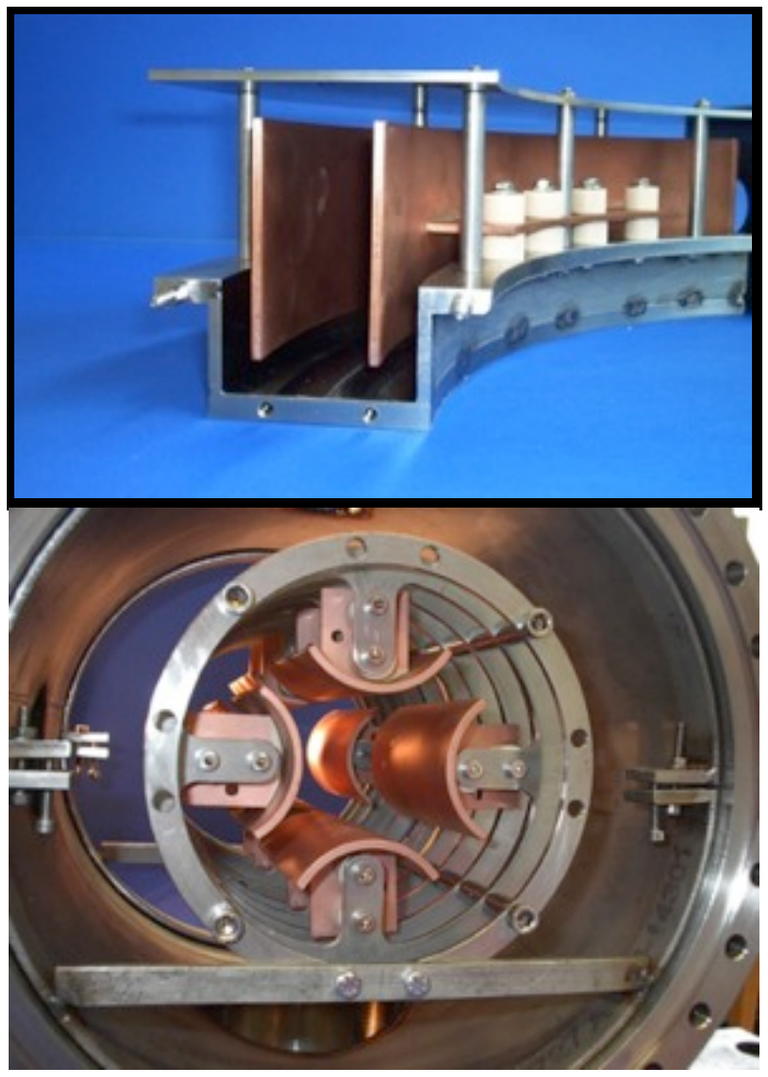
- LSR is central "working horse" of FLAIR
  - Beam delivery for HITRAP, USR, experiments
- Choice of CRYRING (MSL, Stockholm)
  - Fitting energy range, electron cooling, fast ramping, internal target, low-energy injection from ion source for commissioning
  - Expertise: MSL staff has designed & built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



available in 2012

USR: electrostatic storage ring





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

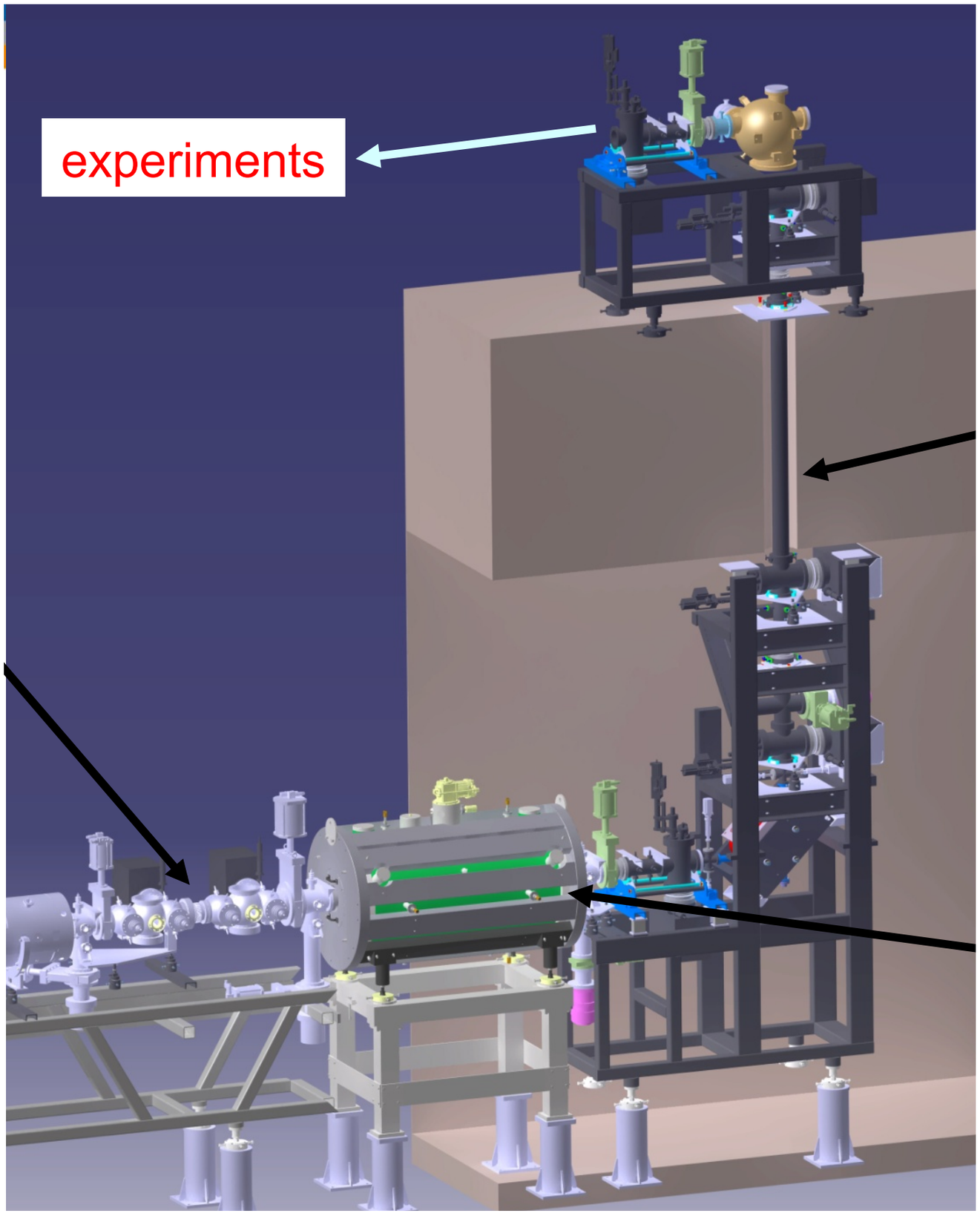
E_{min} / E_{max}	20 / 300 keV
Voltages	< ± 20 kV
number of pbars at 20 keV	$1 \cdot 10^7$

TDR in progress
see talk by O. Karamyshev

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

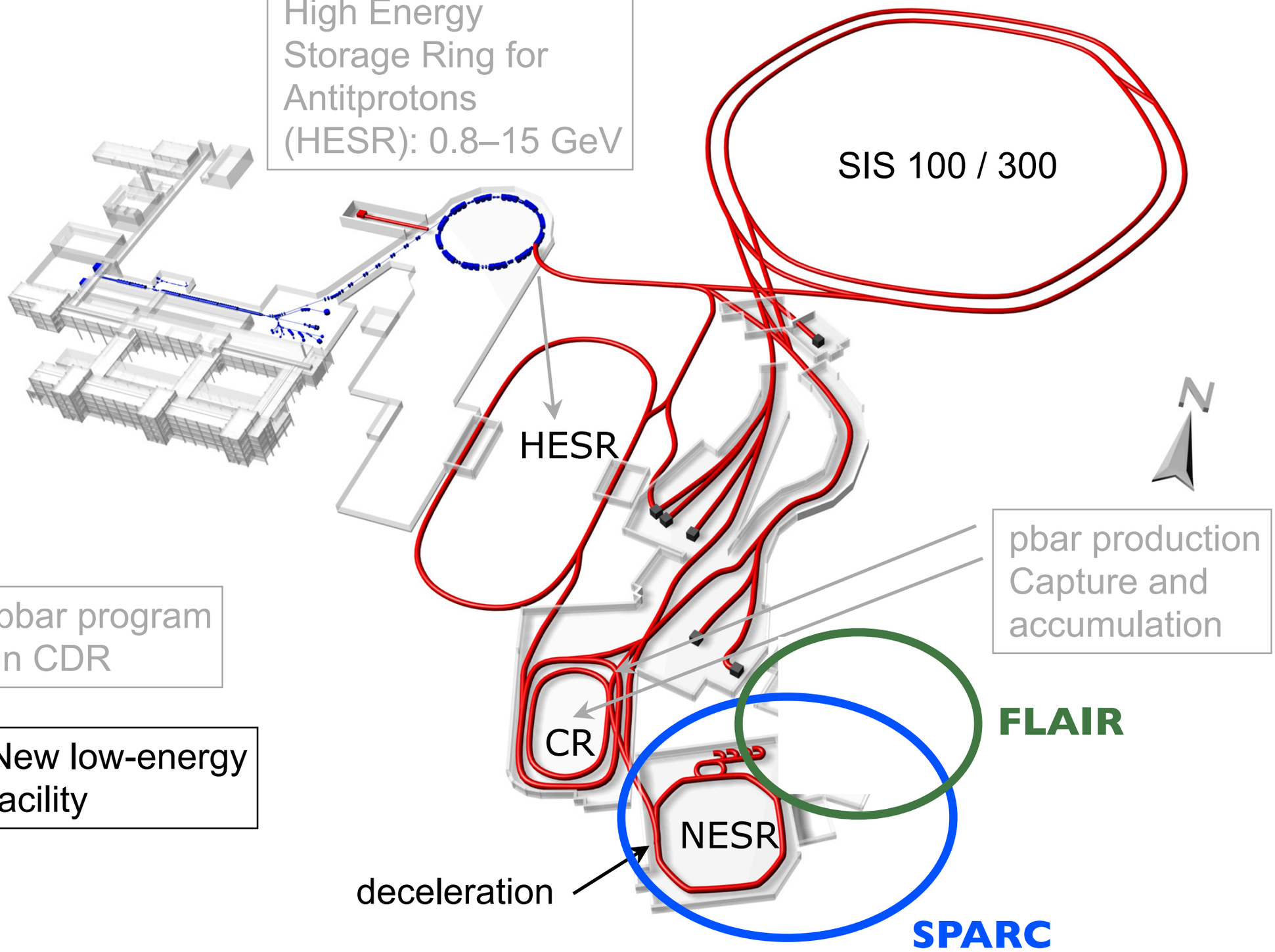
HITRAP

- 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**



Antiprotons at FAIR

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



pbar program in CDR

New low-energy facility

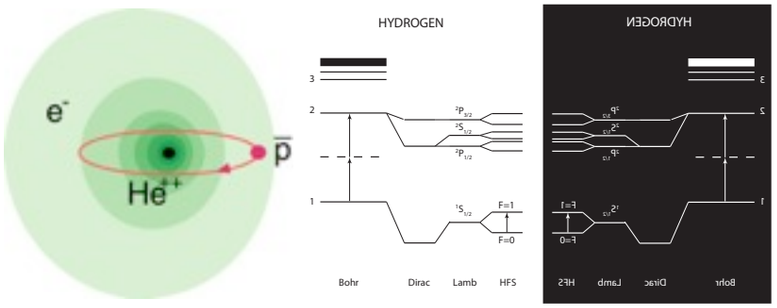
Stefan Meyer Institute

Next-generation Low-energy Antiproton Facility

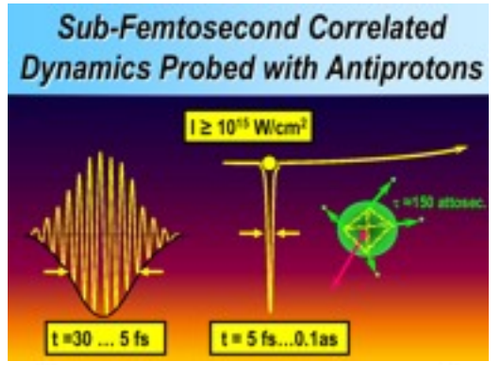
Feature	Solution
Higher intensity	Accumulation scheme
Fast and slow extraction	Coincidence experiments (nuclear physics)
Cooled beams down to < 500 keV	Storage rings
Availability of pbar and RI	FAIR

Low Energy Antiproton Physics @ FLAIR

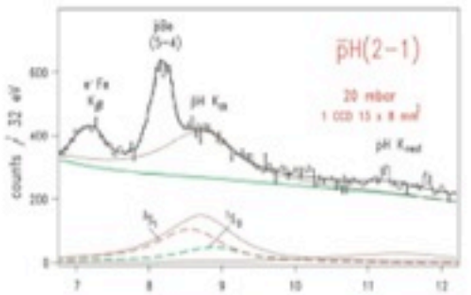
- Spectroscopy for tests of CPT and QED
  - Antiprotonic atoms (pbar-He, pbar-p), antihydrogen

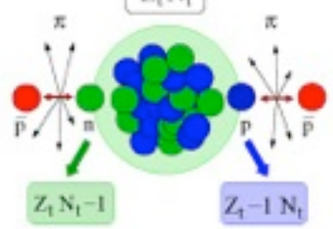


- Atomic collisions
  - Sub-femtosecond correlated dynamics: ionization, energy loss, antimatter-matter collisions

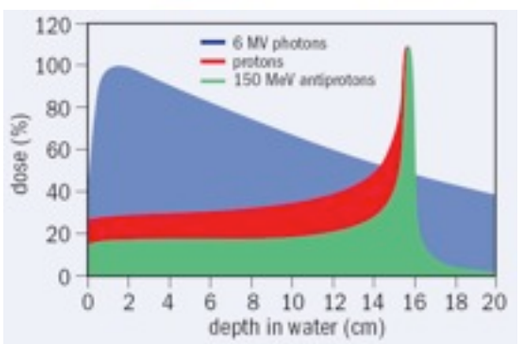


- Antiprotons as hadronic probes
  - X-rays of light antiprotonic atoms: low-energy QCD
  - X-rays of neutron-rich nuclei: nuclear structure (halo)
  - Antineutron interaction
  - Strangeness –2 production





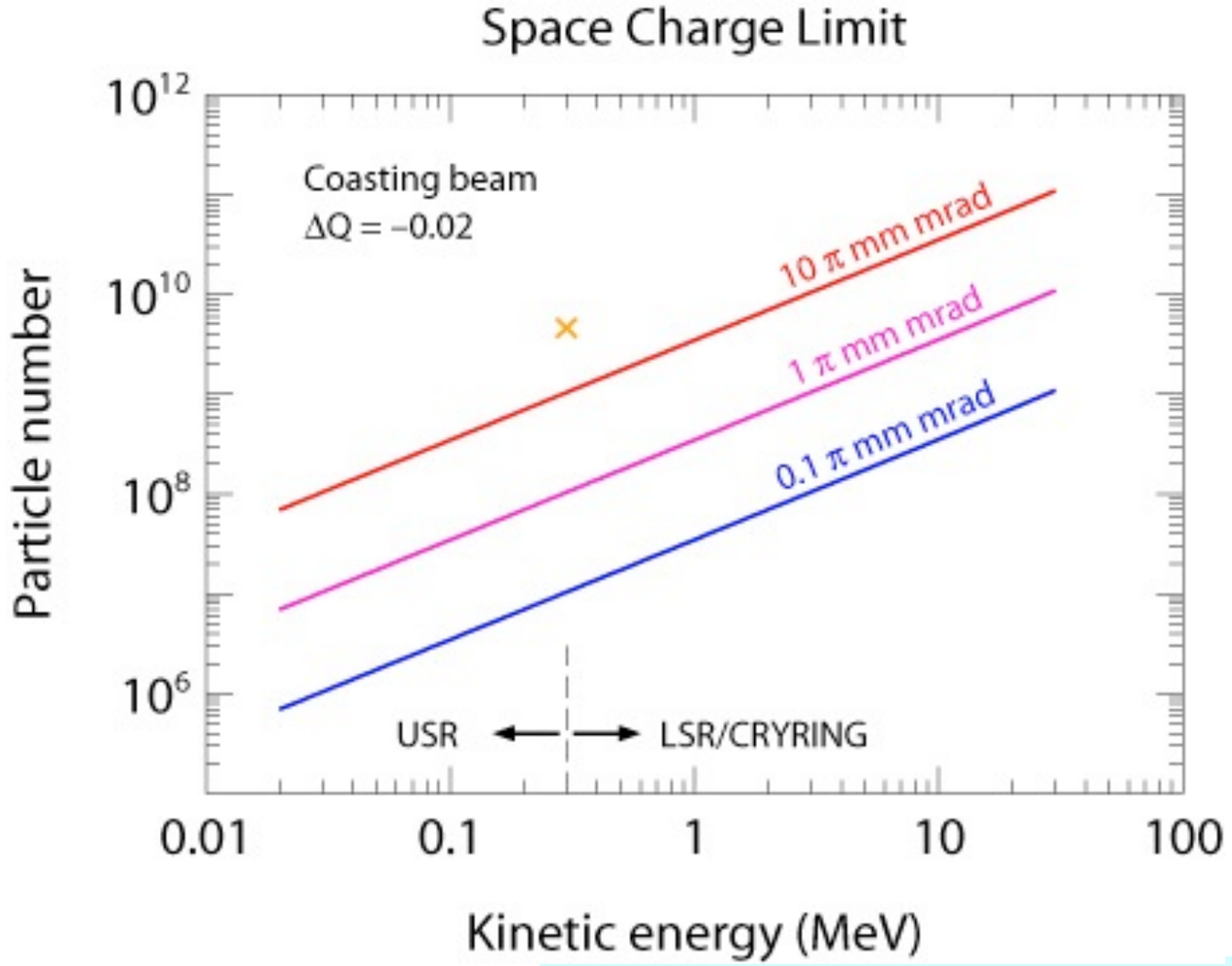
- Medical applications: tumor therapy



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

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

Assumptions: 10% of accumulated $\bar{p}$

Modularized start version of FAIR

- Modularized start version 0-3
  - founded Oct. 2010
  - construction started
- FLAIR: Module 4 with NESR, SFRS-LEB
  - additional funding of ~100 M€ needed
    - *in 2005 prizes*
- Storage rings are a core feature of FAIR

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

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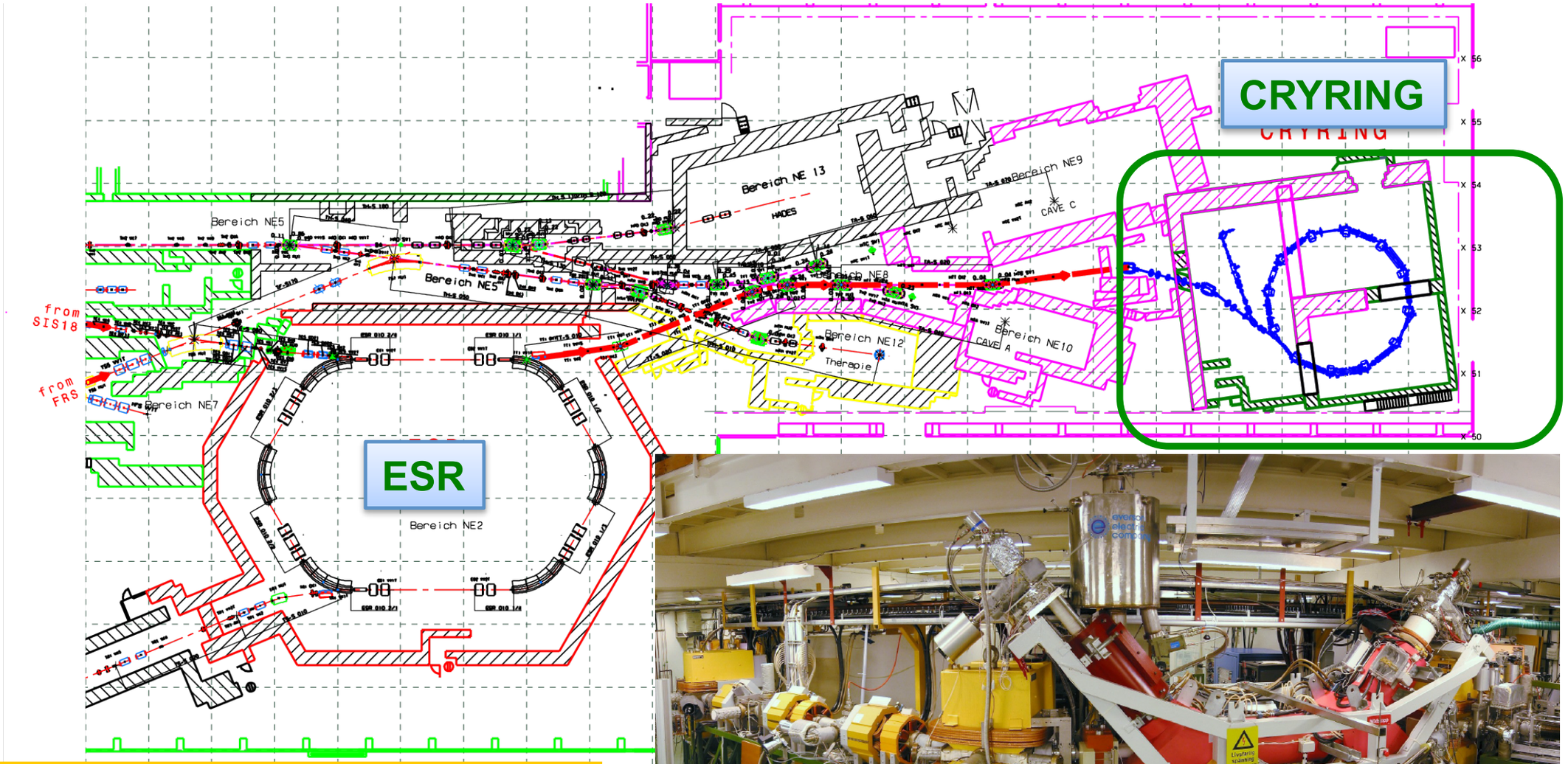
New idea: CRYRING@ESR: phase 1 of FLAIR



CRYRING has been delivered to GSI and is currently getting installed

CRYRING arriving at GSI

Physics case with HCI

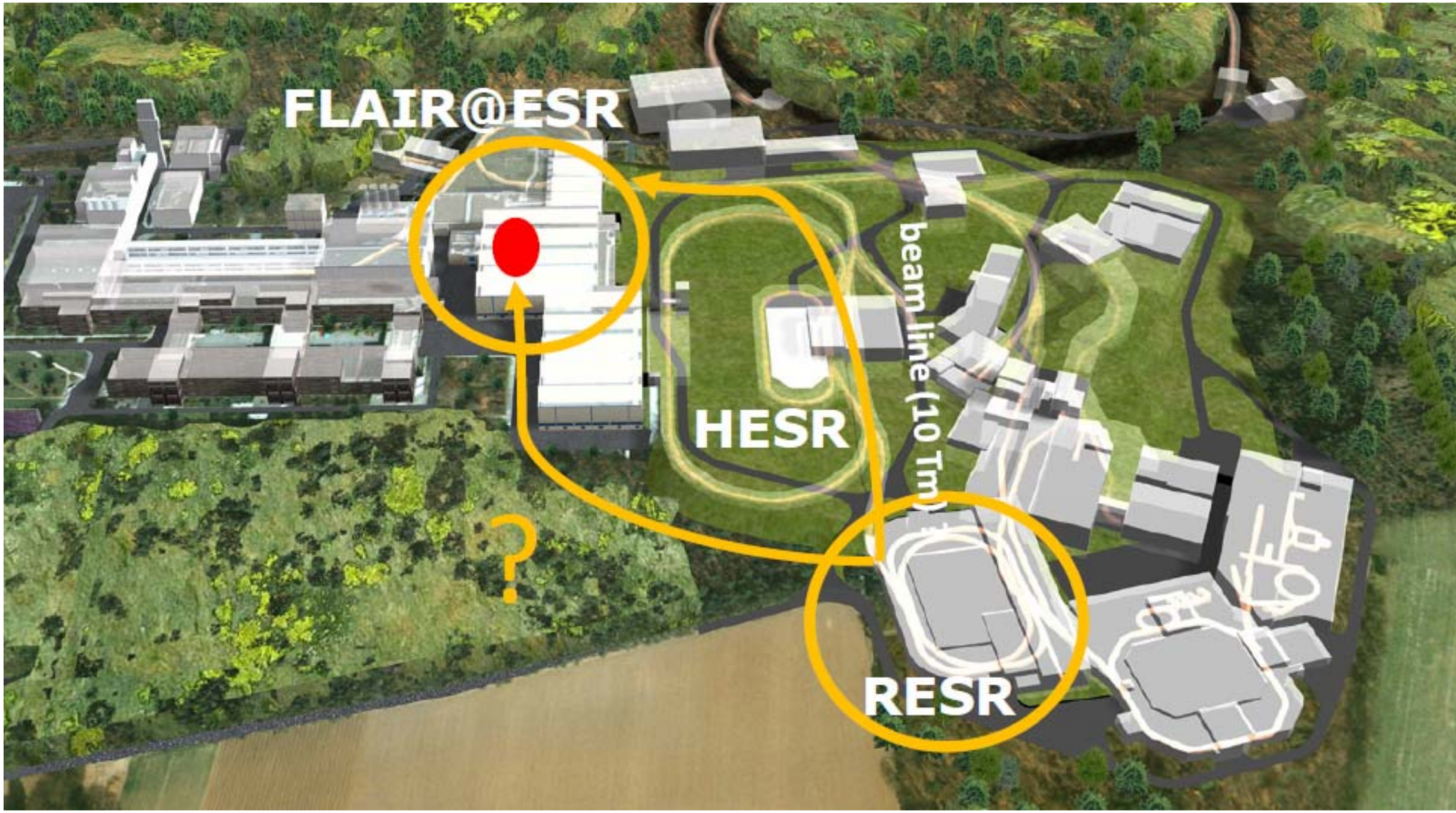
CRYRING@ESR:
A study group report

Darmstadt, July 26, 2012

Michael Lestinsky[1], Norbert Angert[1], Ralph Bär[1], Ralph Becker[1], Mario Bevcic[1], Udo Blell[1], Walter Bock[1], Angela Bräuning-Demian[1], Håkan Danared[2], Oleksiy Dolinskyy[1], Wolfgang Enders[1], Mats Engström[3], Achim Fischer[1], Bernhard Franzke[1], Georg Gruber[1], Peter Hülsmann[1], Anders Källberg[3], Oliver Kester[1,4], Carl-Michael Kleffner[1], Yuri A. Litvinov[1], Carsten Mühle[1], Bernhard Müller[1], Ina Pschorn[1], Torsten Radon[1], Heinz Ramakers[1], Hartmut Reich-Sprenger[1], Dag Reistad[3], Galina Riefert[1], Marcus Schwickert[1], Ansgar Simonsson[3], Jan Sjöholm[3], Örjan Skeppstedt[3], Markus Steck[1], Thomas Stöhlker[1,5], Wolfgang Vinzenz[1], and Horst Welker[1]

[1]GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany
[2]European Spallation Source ESS, SE-221 00 Lund, Sweden
[3]Fysikum, Stockholm University, SE-106 91 Stockholm, Sweden
[4]Institut für Angewandte Physik, Goethe-Universität Frankfurt, 60438 Frankfurt a. M., Germany
[5]Helmholtz-Institut Jena, 07743 Jena, Germany

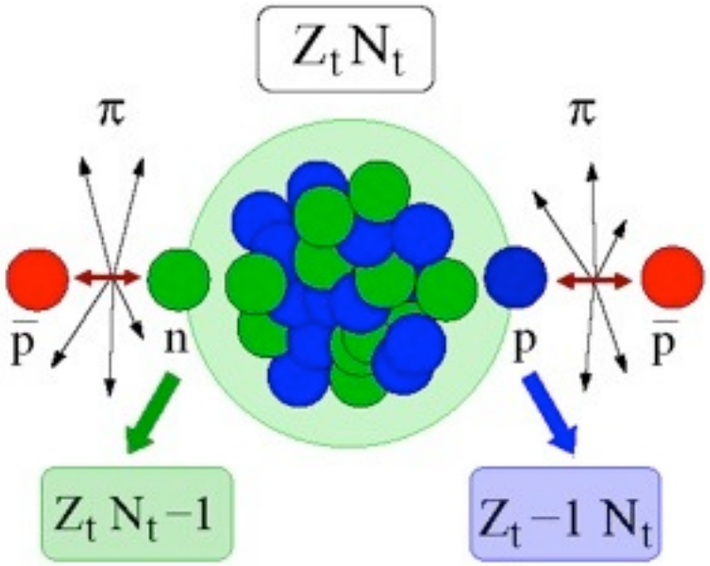
Vision: antiprotons from CR/RESR?

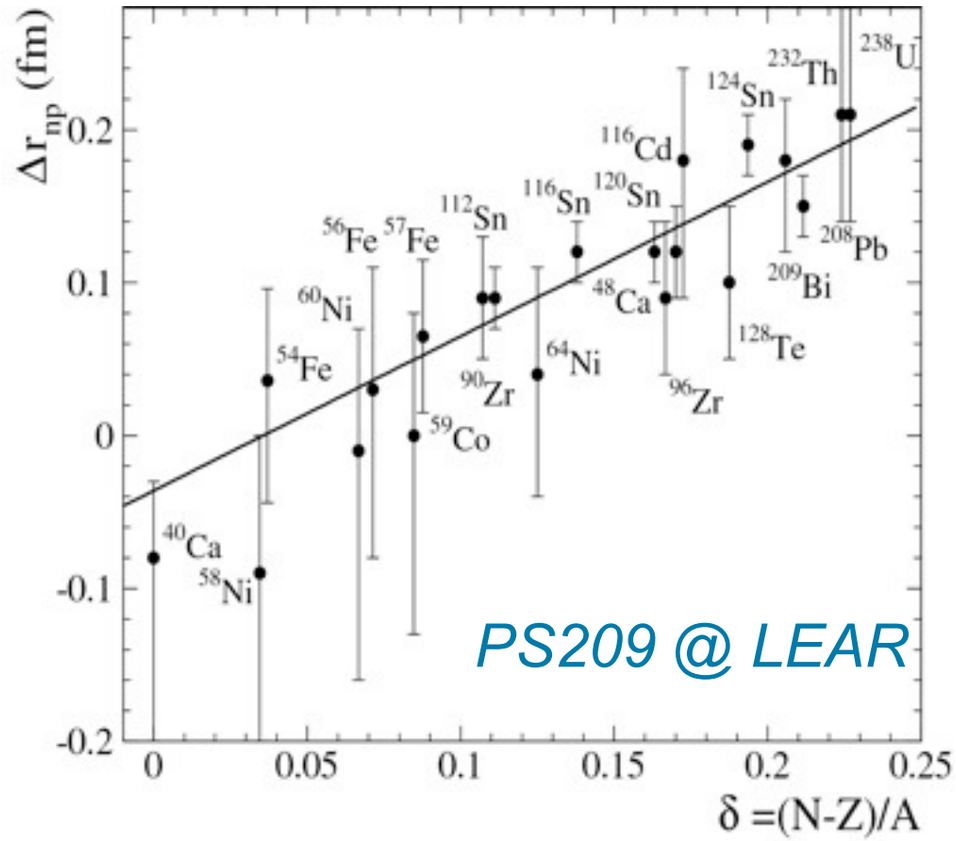


- Current ESR experimental hall could be used for full FLAIR program
  - without accumulation rates are similar to ELENA

Nuclear Periphery with antiprotonic Atoms

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



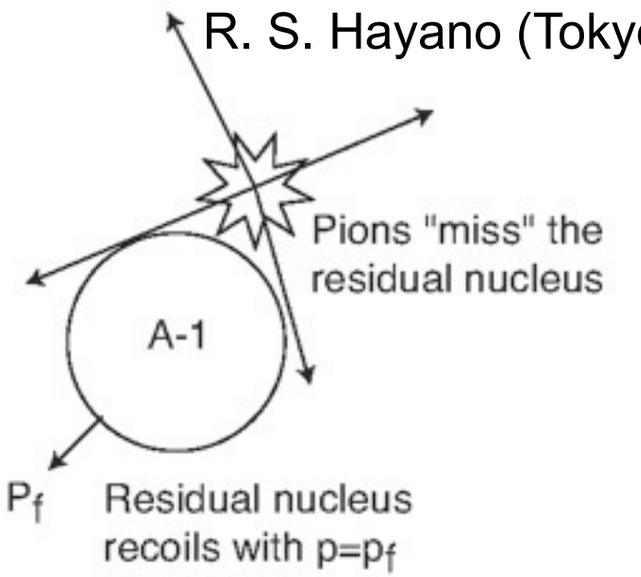


- Exotic atom formation -> cascade ->
  - Annihilation with outermost nucleons (<r>+ 2 fm)
- Measurement of neutron halo parameters
  - Radiochemical method, X-rays + model calculations
- Neutron diffuseness increases with neutron excess
- Extension to unstable nuclei interesting

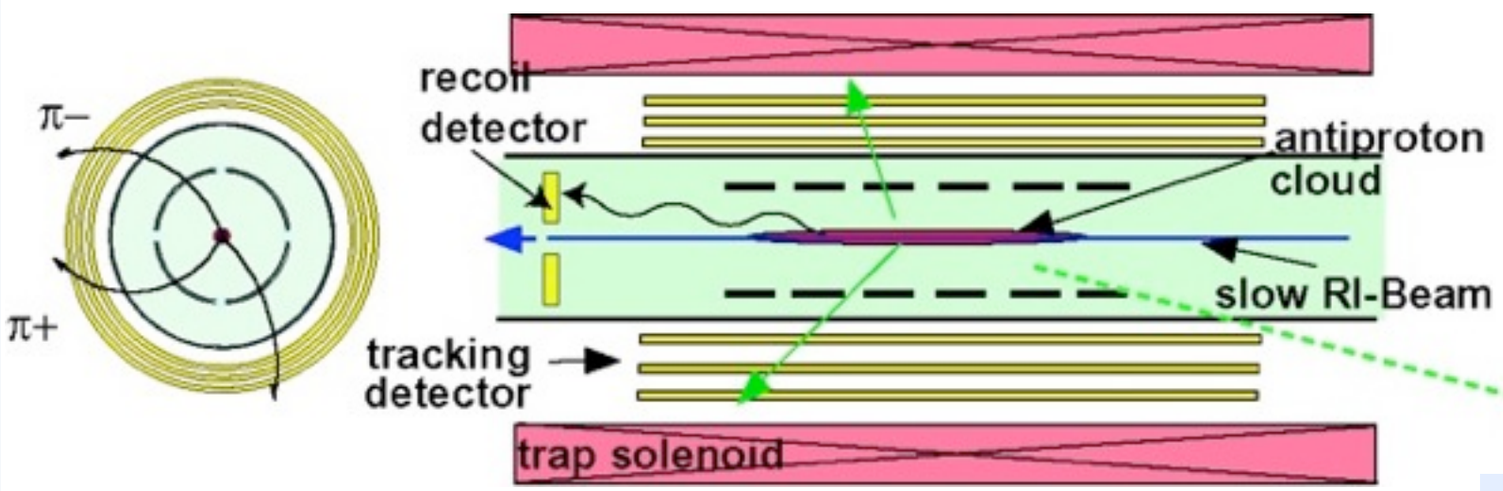
A. Trzcinska, J. Jastrzebski et al. PRL 87 (082501) 2001

pbar-RI in Traps for Nuclear Structure Study

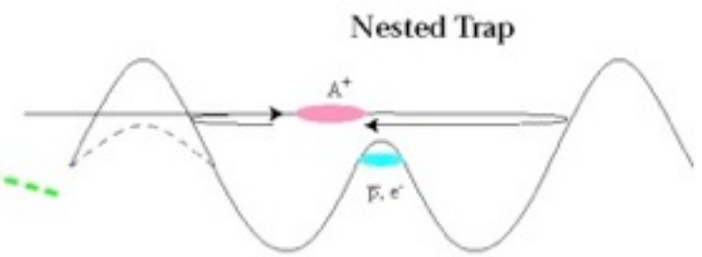
- pbar annihilates with outer-most nucleon at <r> + 2 fm



- 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

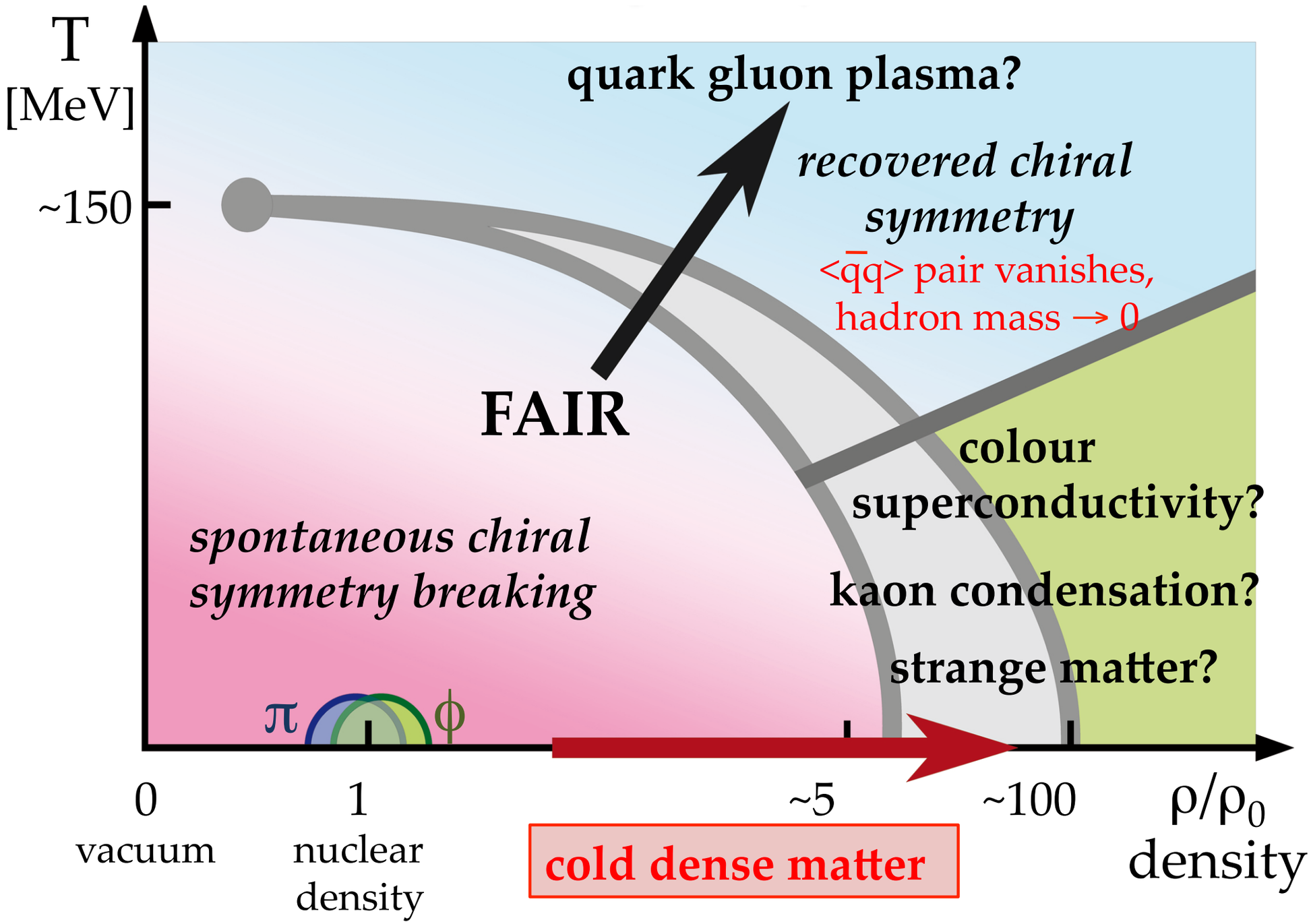


M. Wada, Y. Yamazaki (Tokyo)
NIM B214 (2004) 196
Nested Penning trap



Exo+pbar

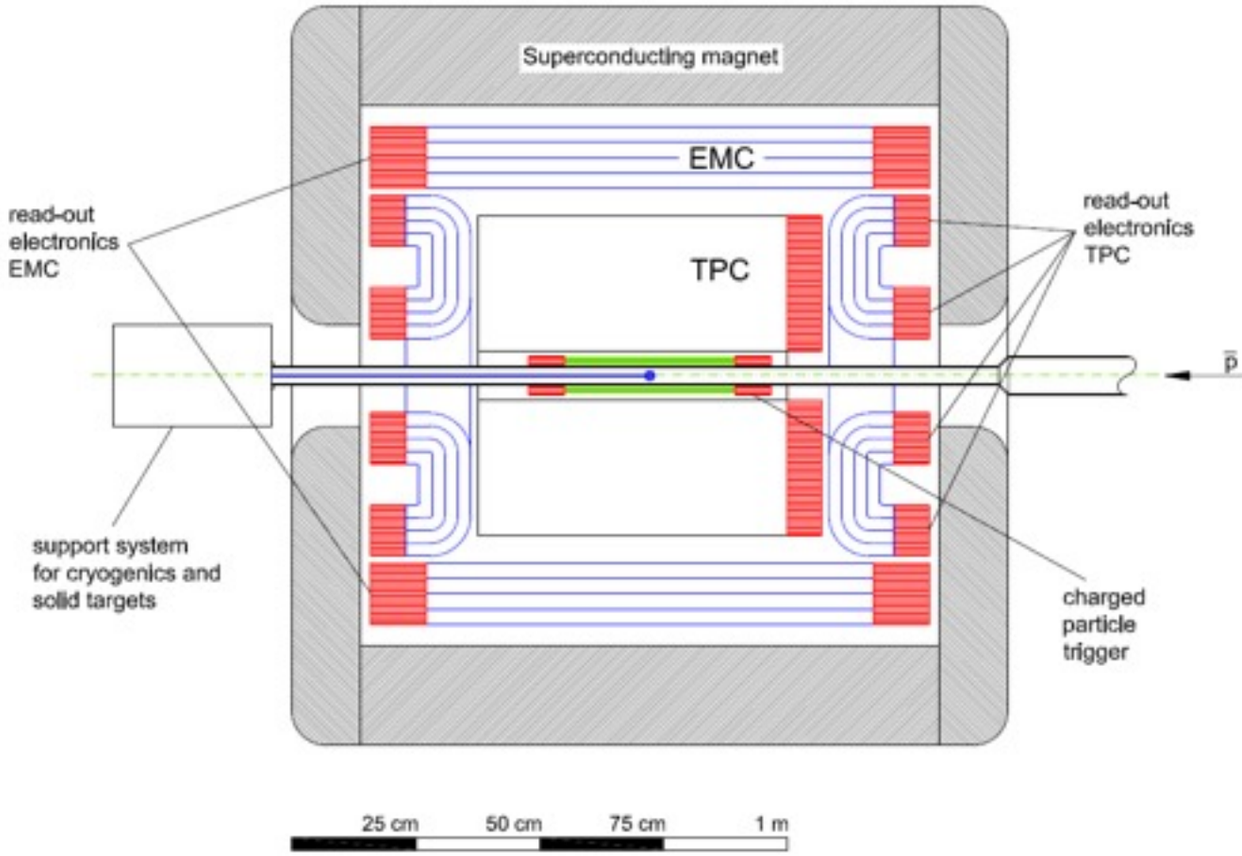
Search for strange baryonic matter



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

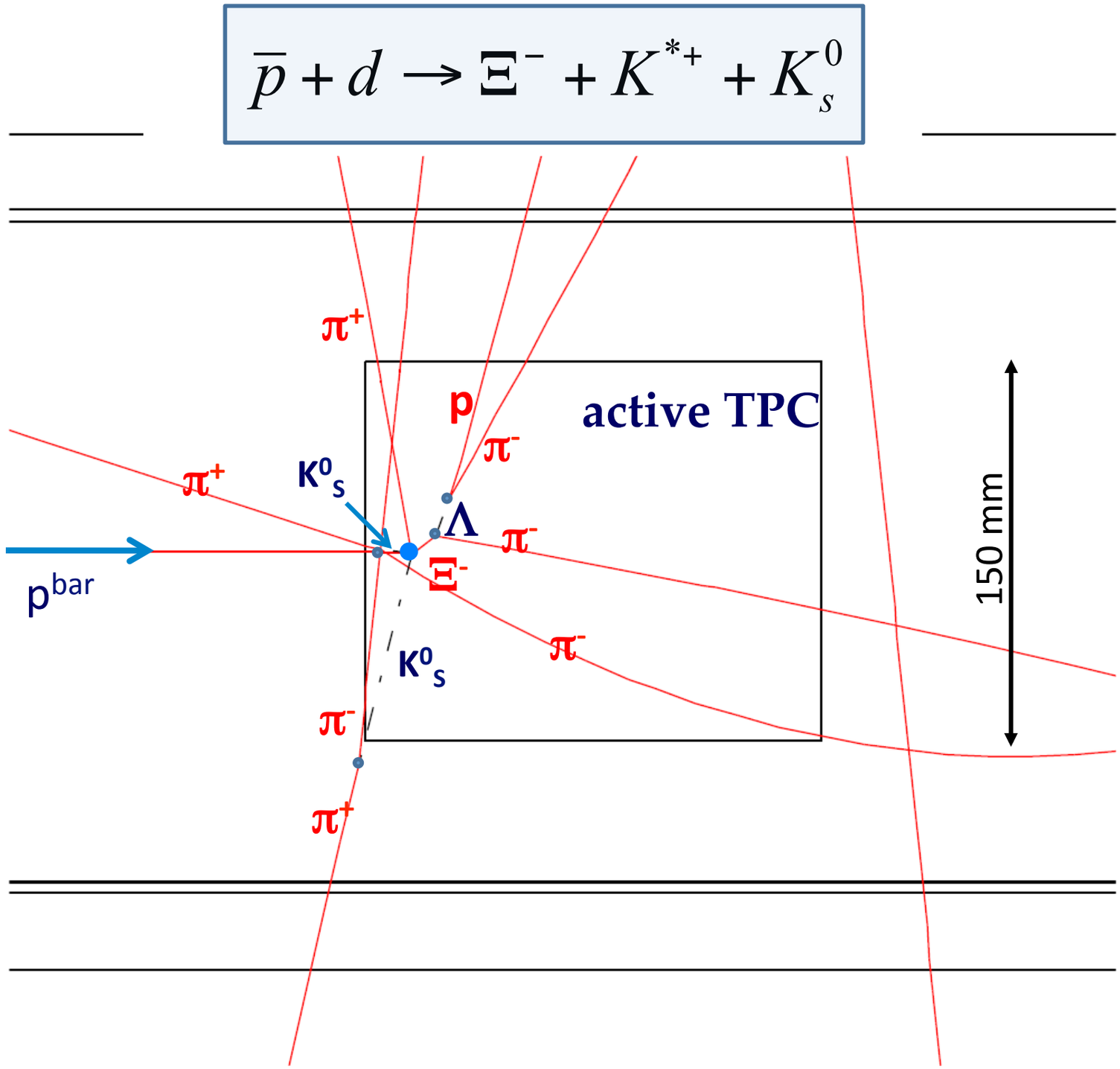
J. Zmeskal et al. Hyperfine Interact 194, 249-254 (2009)



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

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

New ideas: active TPC



Production of S=−2 baryonic statess

K. Kilian, W. Oelert, D. Grzonka
Forschungszentrum Jülich

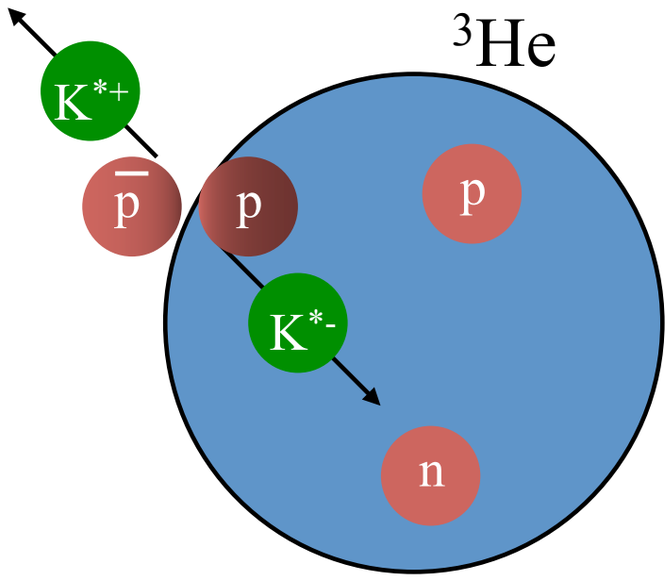
FLAIR proposal

via $(\bar{K}^*, K)$ using stopped p^{bar}

e.g. :

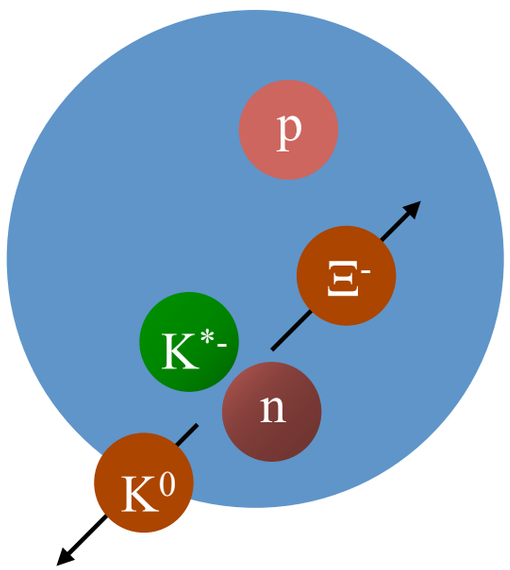
step 1 : $\bar{p}\,(p\,n\,p) \rightarrow K^{*-}\,K^{*+}$

large $\bar{p}$ stop rate on a ^{3}He target



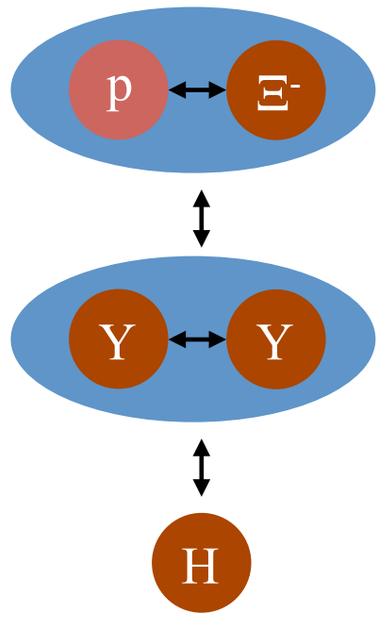
step 2 : $K^{*-}\,(n\,p) \rightarrow \Xi^-\,K^0$

very low recoil on Ξ^-
(recoil free kinematics)



S= - 2 states

low relative energy



Summary and Outlook

- Low energy antiprotons offer exciting possibilities for a variety of fields
  - Fundamental symmetries, nuclear & atomic physics
- CERN-AD and ELENA: Antihydrogen
  - essential for continuation of current program
  - getting crowded
- FLAIR: offers further opportunities
  - continuous $\bar{p}$ beams already in phase 1
    - nuclear and particle physics type experiments (not possible at AD)
  - Availability of radioactive ion beams (RIB) offers new synergies
    - requires close location to LEB branch of SFRS
  - Cooled antiprotons down to 20 keV (with USR)
  - higher rates (phase 2, with NESR)
- Major components of FLAIR are ready or will be soon
  - CRYRING can play a major role in future experiments with (continuous) beams of slow antiprotons

FLAIR Community

- Austria (SMI Vienna, TU)
- Canada (TRIUMF, York)
- Denmark (Aarhus U)
- France (P. & M. Curie, Paris)
- Germany (Berlin, GSI, Frankfurt, LMU München, Giessen, MPI Heidelberg, U Heidelberg, Jülich, U Mainz)
- Hungary (Budapest, Debrecen U, ATOMKI)
- India (Kolkata)
- Italy (Brescia, Firenze, Genova)
- Japan (Tokyo, Saitama (RIKEN))
- Netherlands (Amsterdam U)
- Poland (Warsaw U, Soltan Inst., Cracow)
- Russia (Moscow, St. Petersburg, Troitsk)
- Sweden (Stockholm U, Manne Siegbahn Laboratory, Uppsala, ESSS Lund)
- United Kingdom (Belfast, London, Liverpool, Swansea)
- USA (Albuquerque, Harvard, Texas A&M, Tallahassee, Rolla)

Spokesperson E.W.
2012 -> K. Blaum (MPI-K HD)

BTR 2005: 49 institutions, 144 scientists, 15 countries,
needs redefinition: currently 45 institutions, 93 scientists. 15 countries