Austrian Academy of Sciences

Low-energy antiprotons at CERN and at FAIR

Eberhard Widmann

International Conference on Science and Technology for FAIR in Europe 2014

Worms, Oct 15, 2014

Stefan Meyer Institute for Subatomic Physics, Vienna

Current source: AD @ CERN

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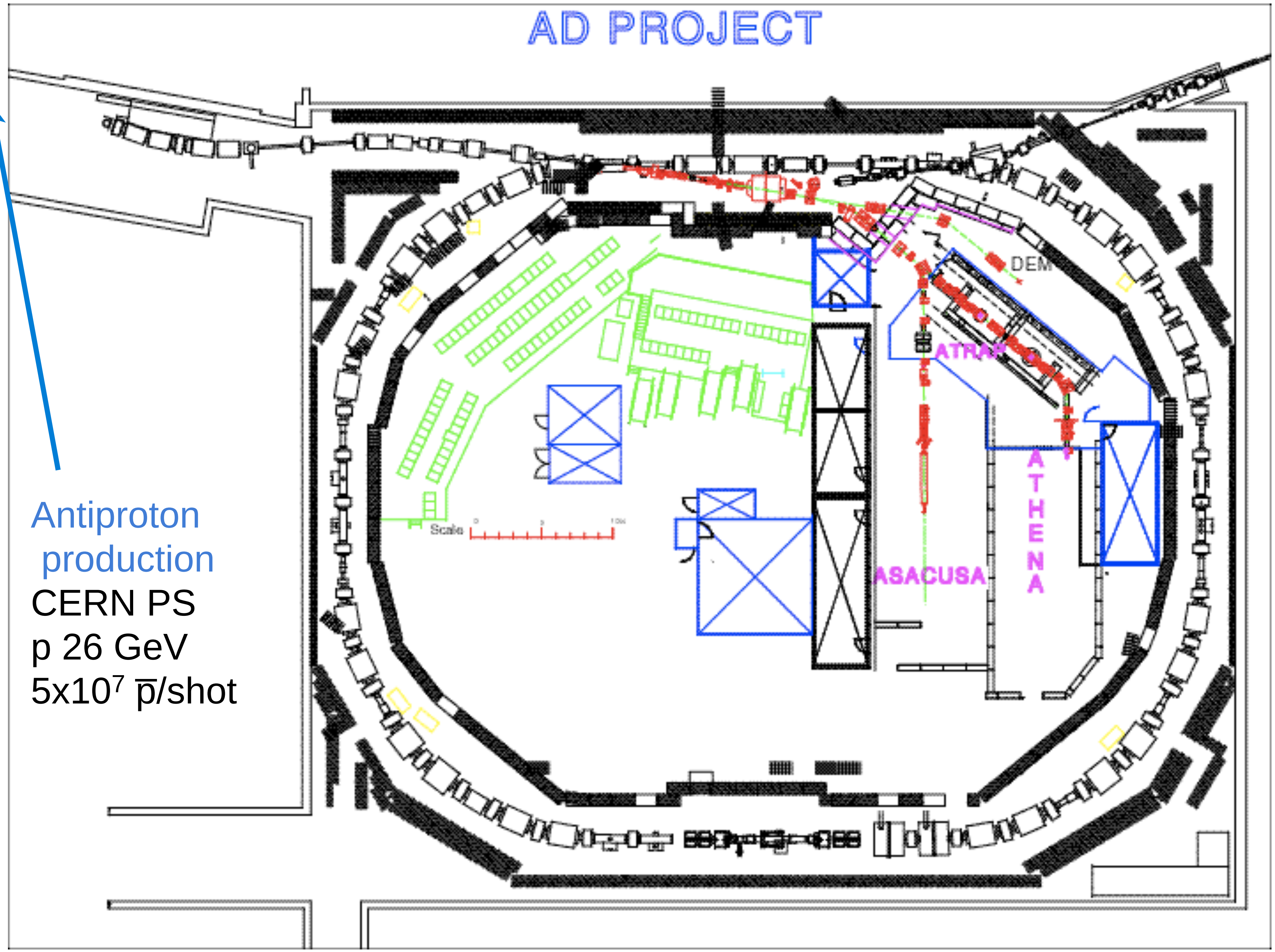


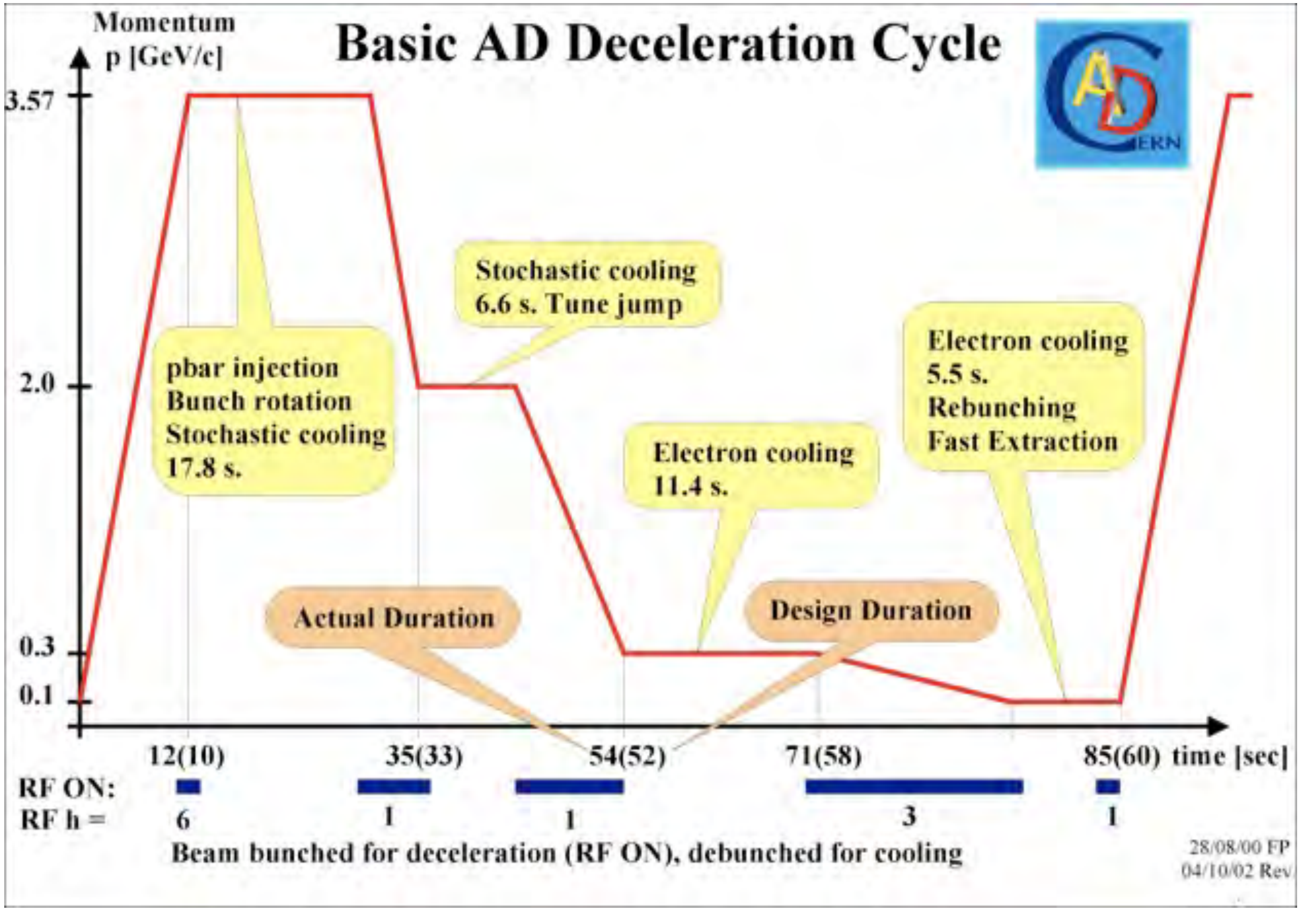
Antiproton production

CERN PS

p 26 GeV

5x10^7 $\bar{p}$/shot

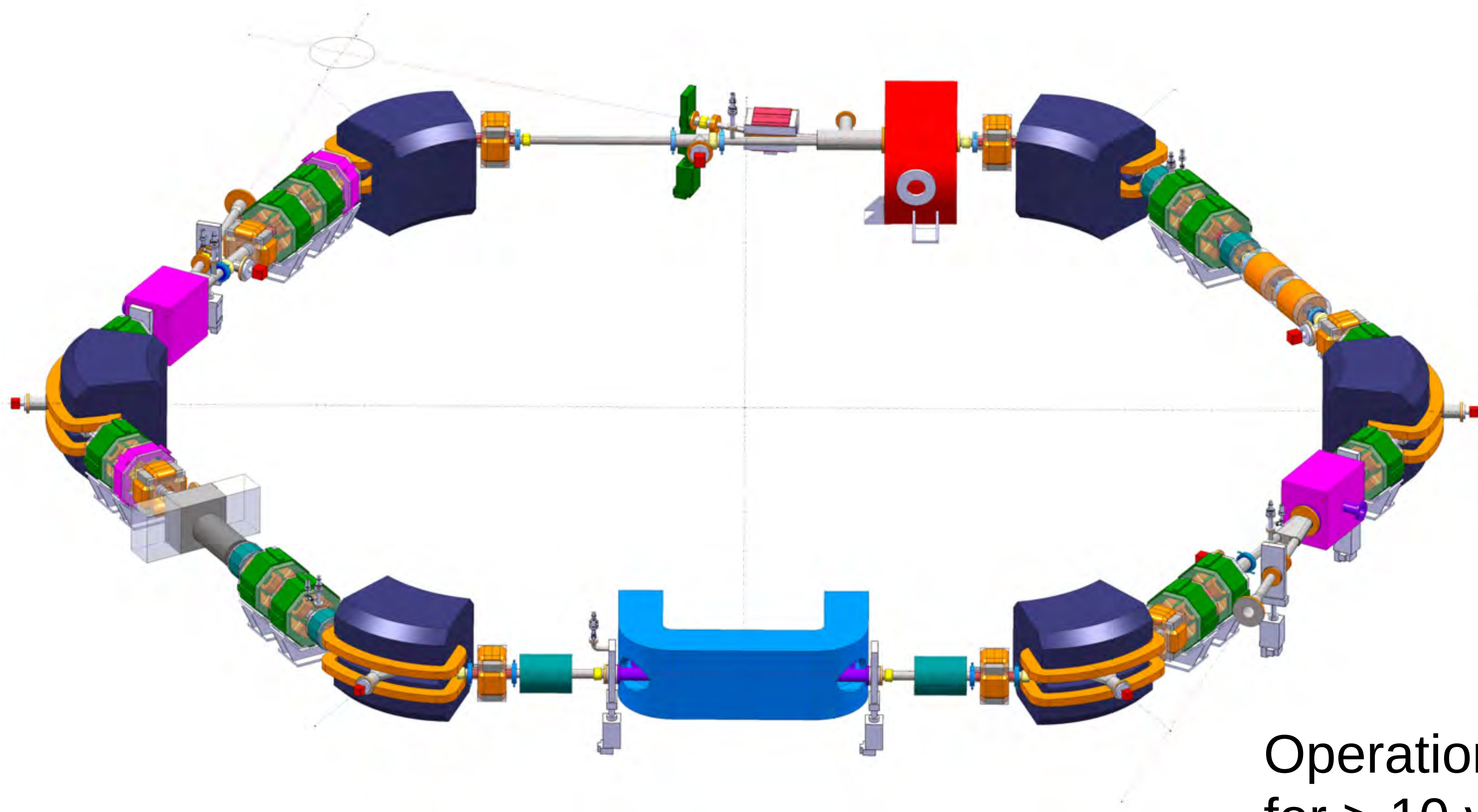
AD @ CERN: start 2000



- 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

New development: ELENA @ CERN-AD

- Decelerator after AD 5 MeV → 100 keV



Operation from 2017
for > 10 years

Energy range, MeV	5.3 - 0.1
Intensity of ejected beam	1.8
$\varepsilon_{x,y}$	4 / 4
$\Delta p/p$ of extracted beam, [95%], standard	8 ·10

100 keV
1 pulse every
~100 s:
average $10^5 \bar{p}$/s

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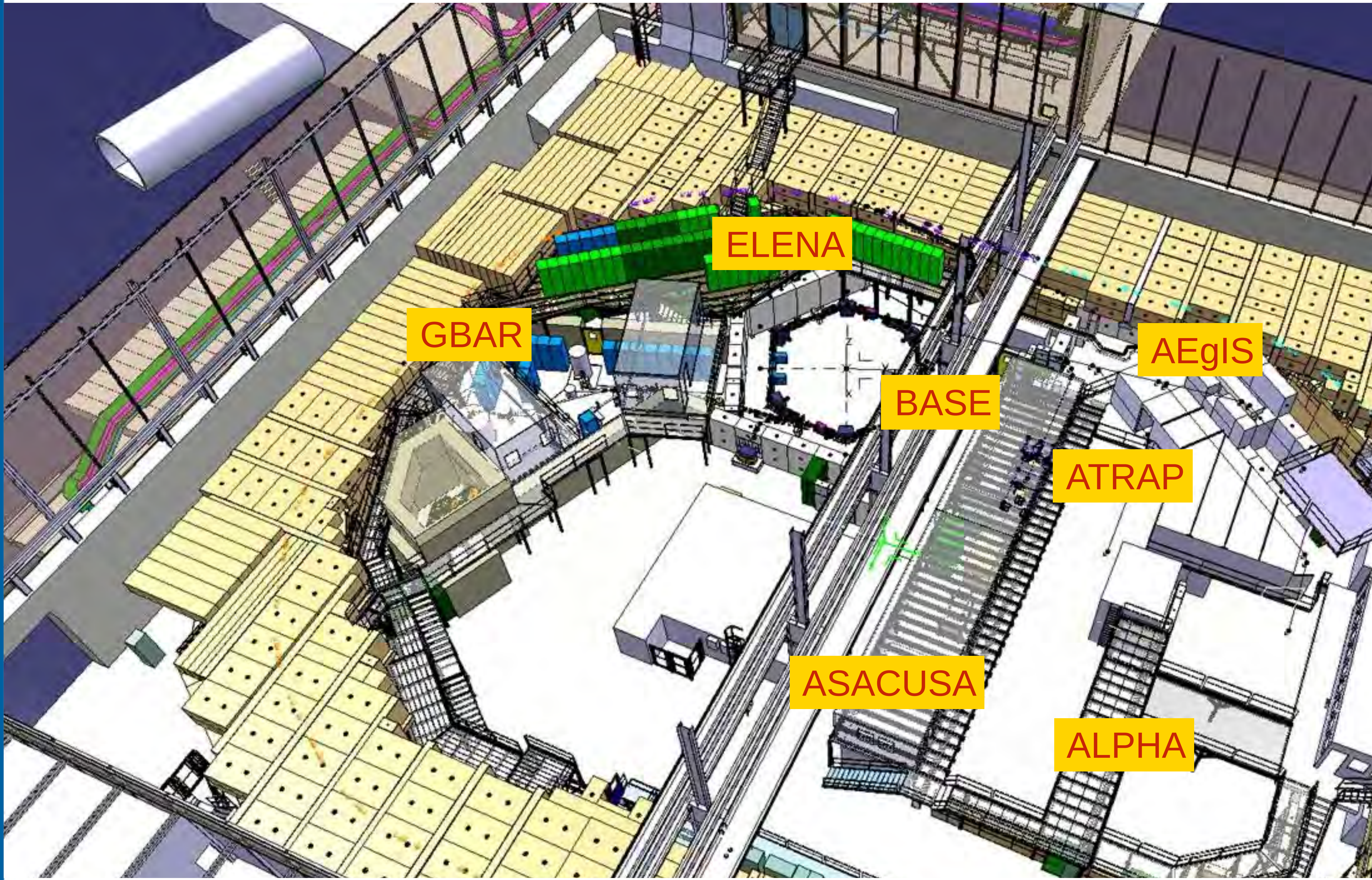
AD & ELENA area and experiments



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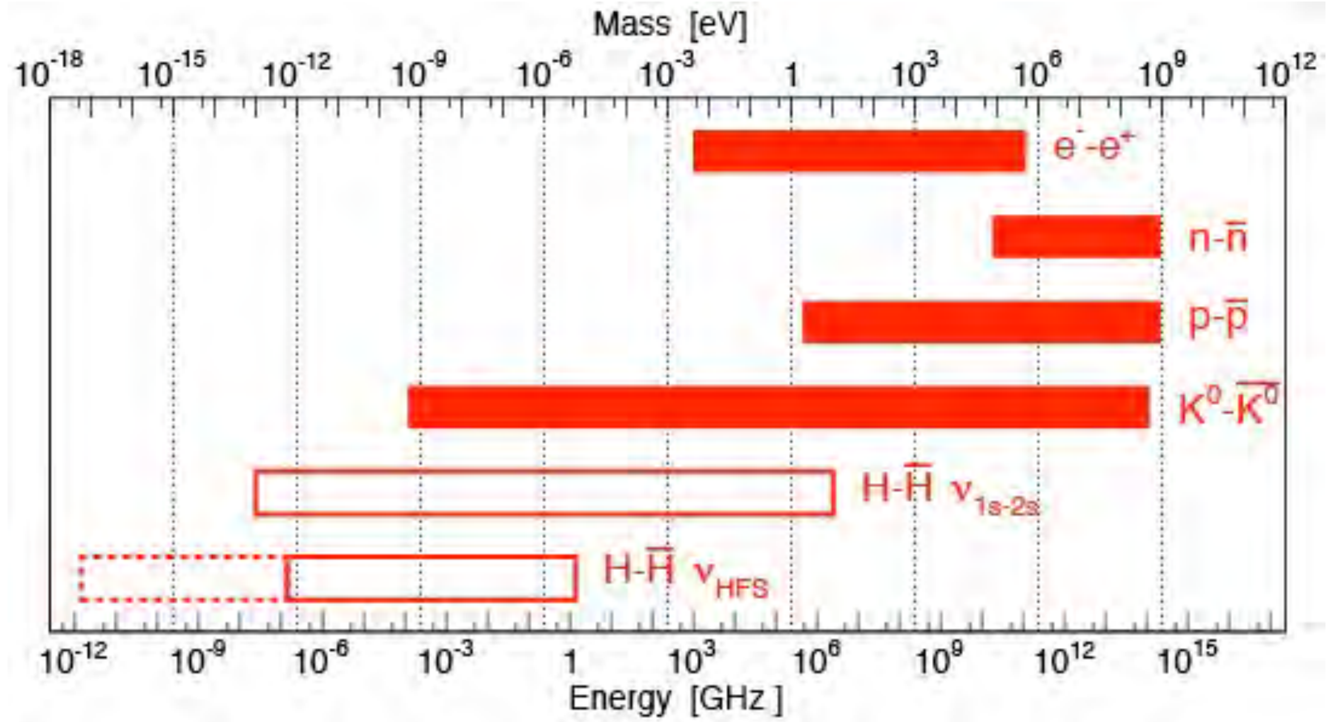
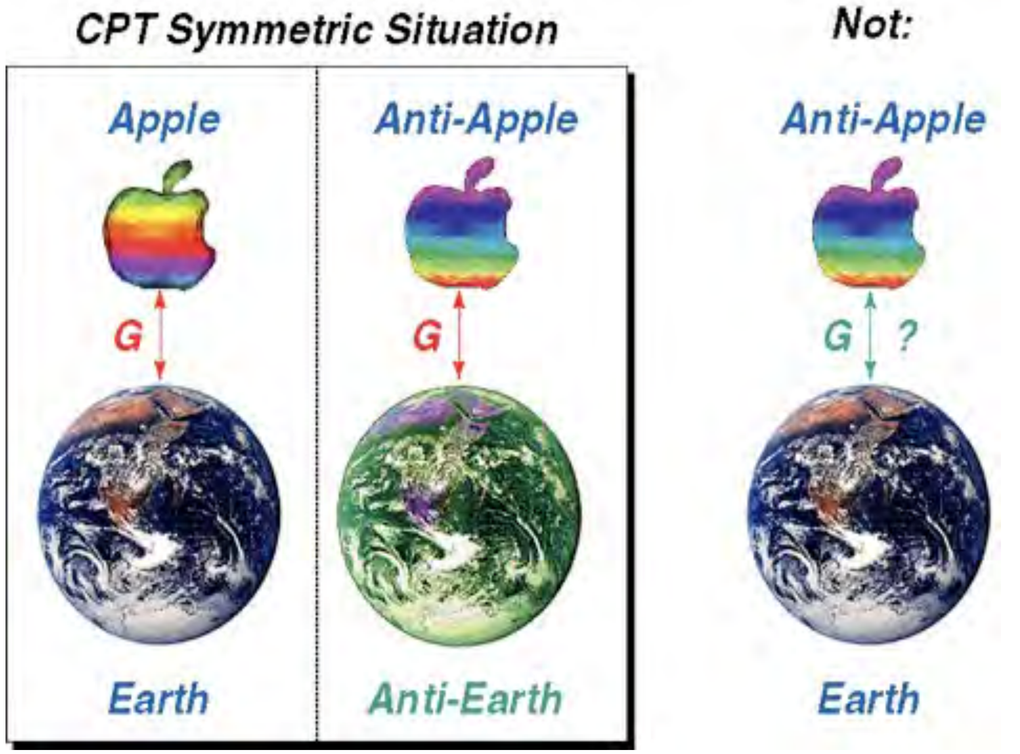
Antihydrogen: CPT and gravity

- CPT symmetry tests
  - precision spectroscopy of $\overline{H}$
  - 1S-2S, GS-HFS
    - ATRAP, ALPHA, ASACUSA, AE$\overline{g}$IS
  - Laser spectroscopy of $\overline{p}He^+$
    - ASACUSA
  - $\overline{p}$ g-factor
    - ATRAP, BASE

- Antimatter gravity
  - never directly measured
    - AE$\overline{g}$IS, GBAR, ALPHA

AD experiments





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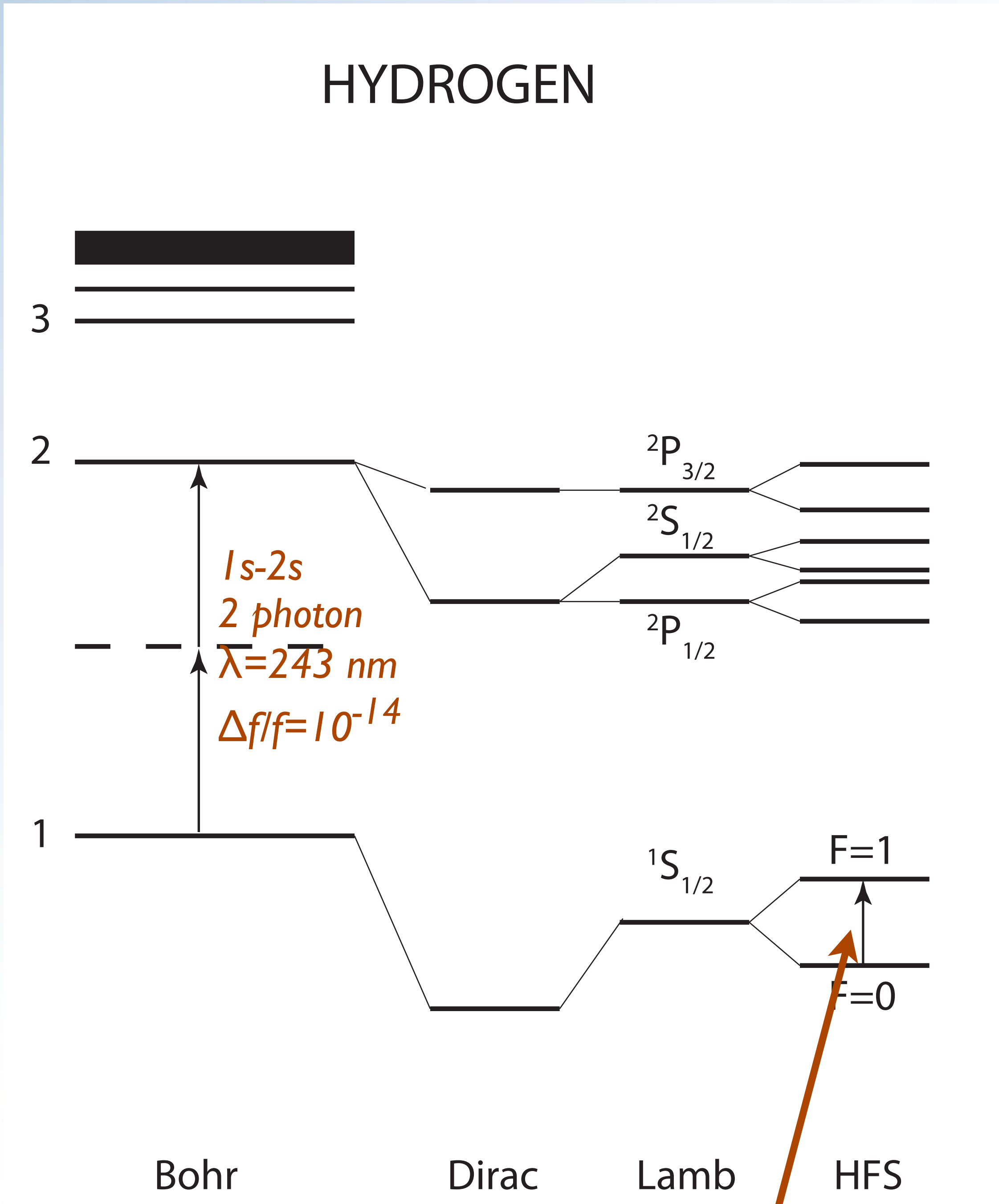
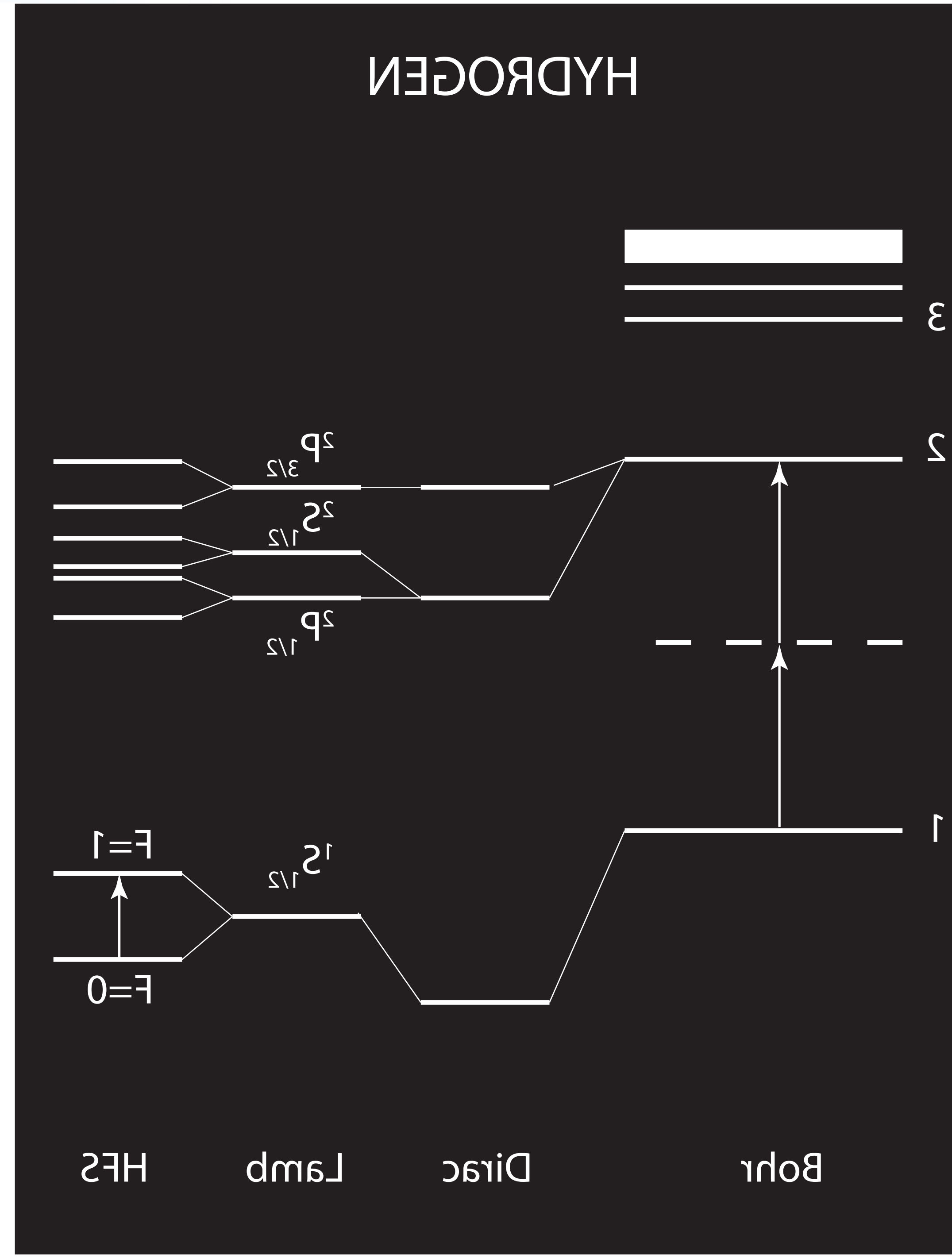
HYDROGEN AND ANTIHYDROGEN





Ground state
hyperfine splitting
f = 1.4 GHz
$\Delta f/f=10^{-12}$

ASACUSA CUSP COLLABORATION

A tomic
S pectroscopy
A nd
C ollisions
U sing
S low
A ntiprotons

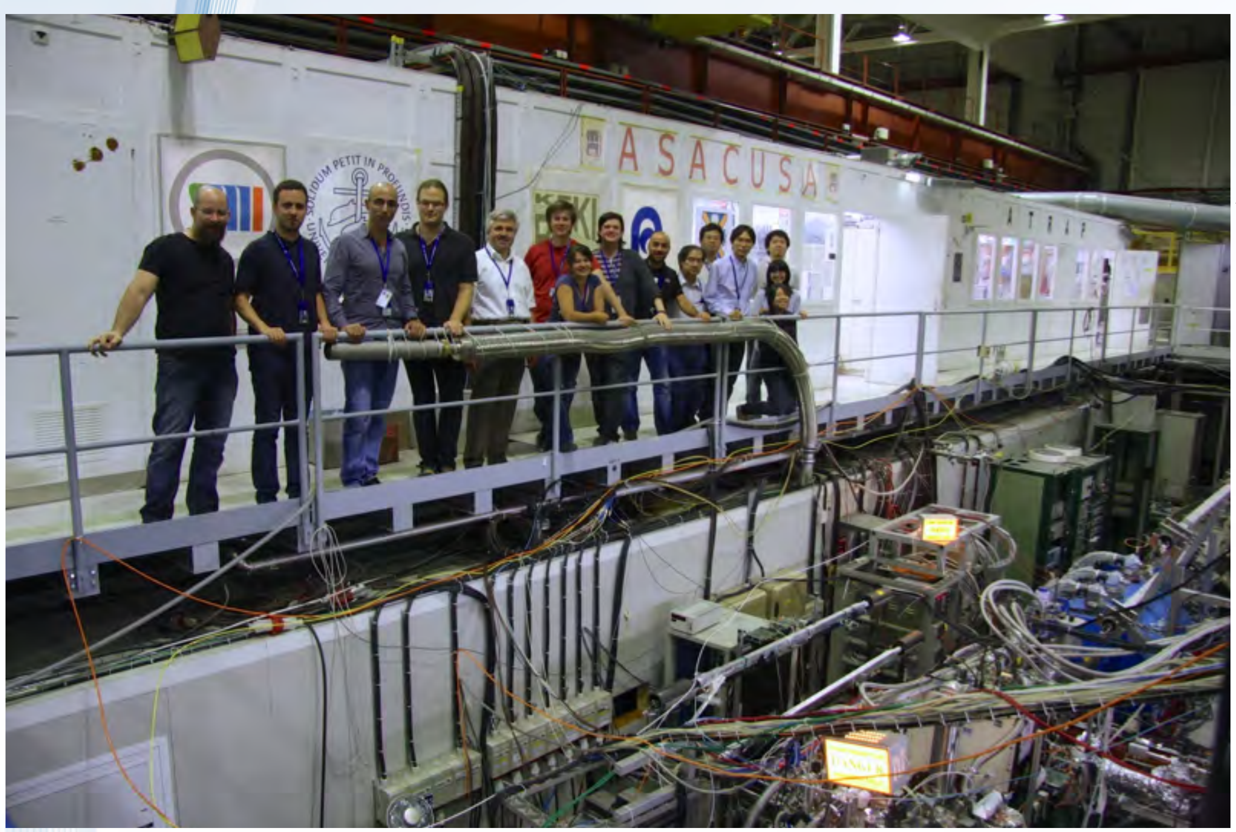
ASACUSA Scientific project

(1) Spectroscopy of $\bar{p}$He

(2) $\bar{p}$ annihilation cross-section

(3) $\bar{H}$ production and spectroscopy

The $\bar{H}$ team



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RIKEN: Y. Kanai, A. Mohri, D. Murtagh, Y. Nagata, B. Radics, S. Ulmer, S. Van Gorp, Y. Yamazaki

Tokyo University of Science: K. Michishio, Y. Nagashima

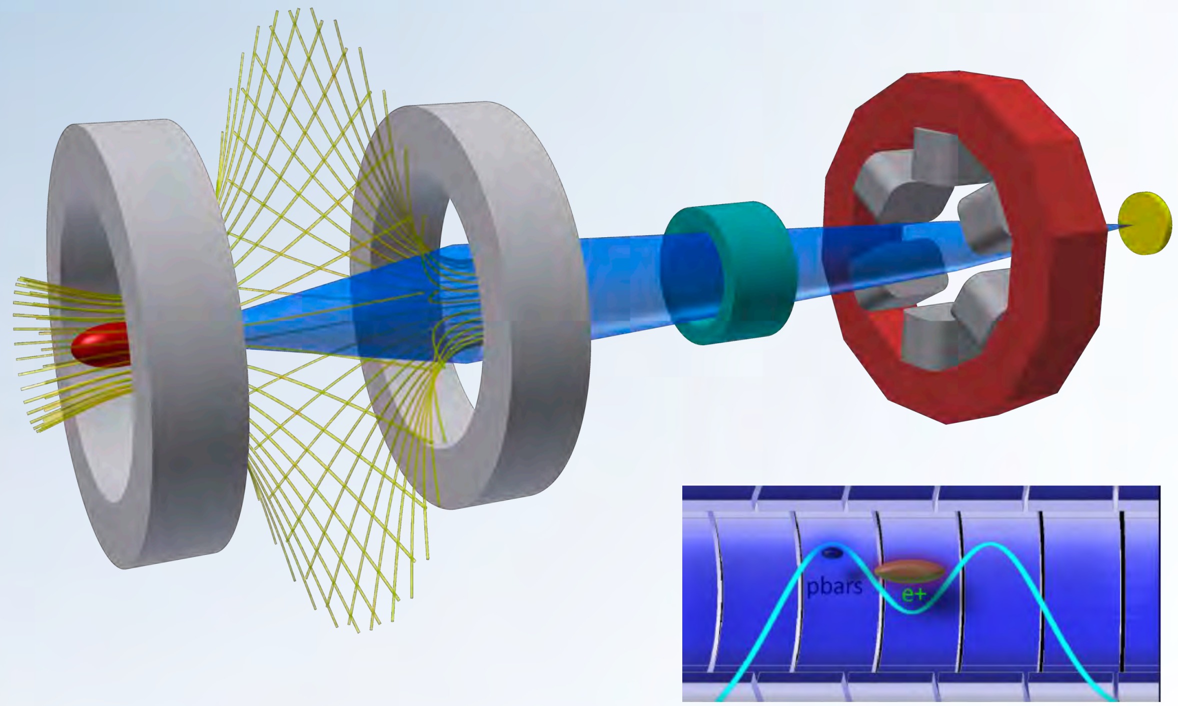
Hiroshima University: H. Higaki, S. Sakurai

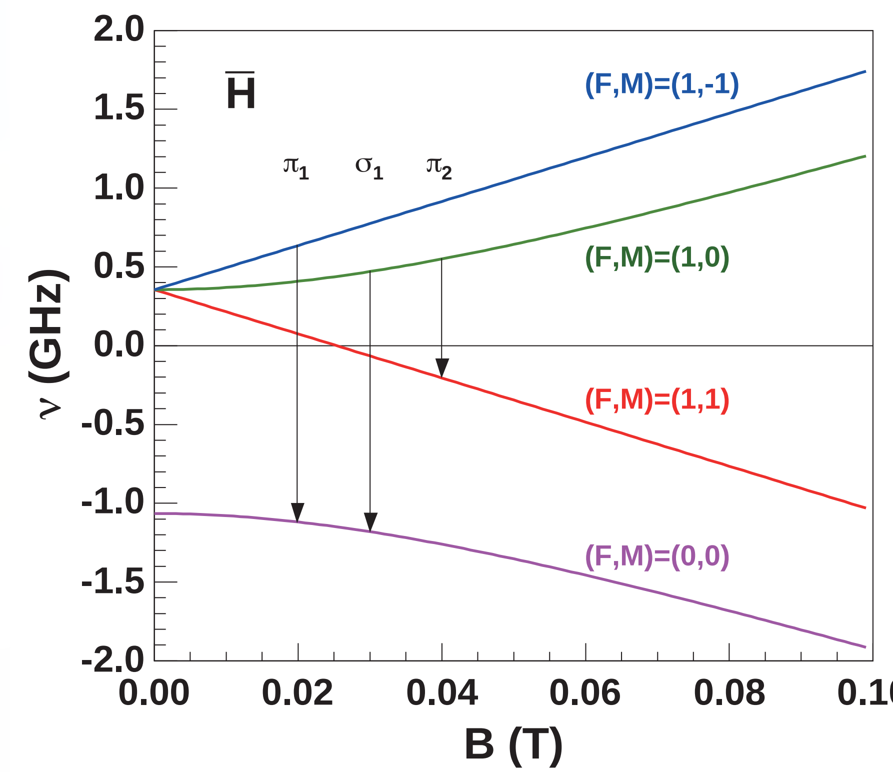
Univerita di Brescia: M. Leali, E. Lodi-Rizzini, V. Mascagna, L. Venturelli, N. Zurlo

Stefan Meyer Institut für Subatomare Physik: P. Caradonna, M. Diermaier, S. Friedreich, C. Malbrunot, O. Massiczek, C. Sauerzopf, K. Suzuki, E. Widmann, M. Wolf, J. Zmeskal

H·HFS

HFS MEASUREMENT IN AN ATOMIC BEAM





- formation in nested Penning trap
- atoms evaporate
- cusp trap provides polarized beam
- spin-flip by microwave
- spin analysis by sextupole magnet
- low-background high-efficiency detection of antihydrogen

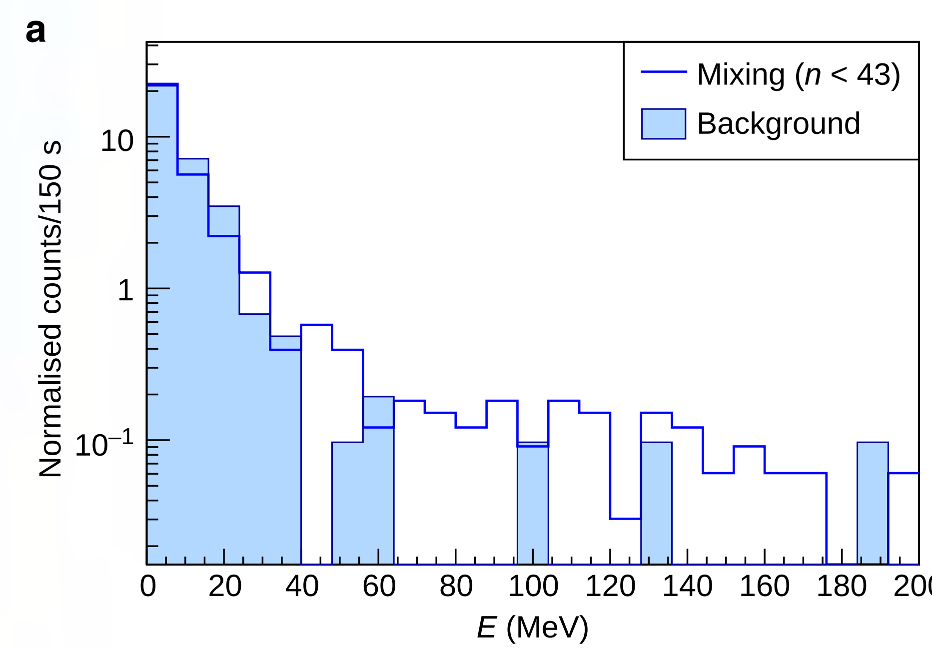
achievable resolution

- better 10^{-6} for T ≤ 100 K
- > 100 $\overline{\mathrm{H}}$/s in 1S state into 4π needed
- event rate 1 / minute: background from cosmics, annihilations uptsreams

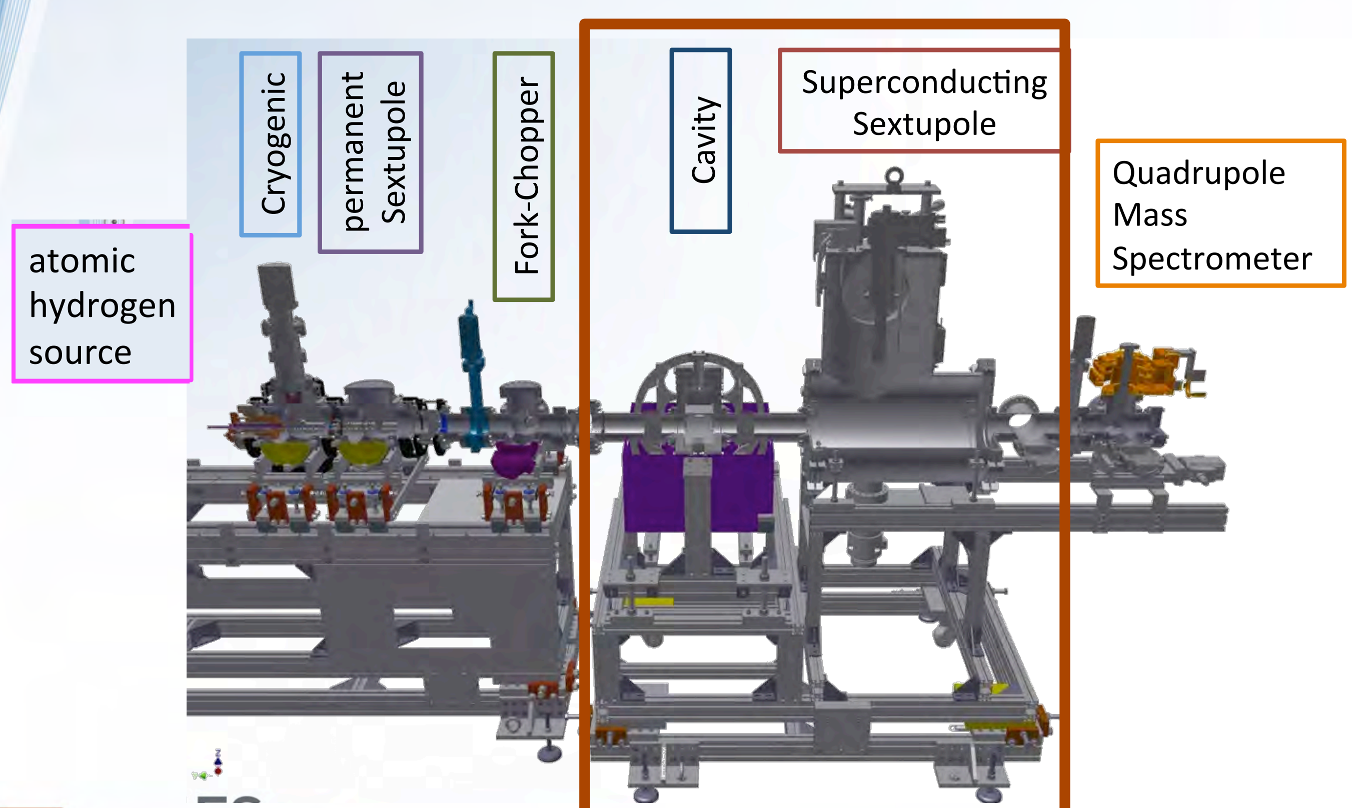
RECENT RESULTS

NATURE COMMUNICATIONS | 5:3089 | DOI: 10.1038/ncomms4089 | www.nature.com/naturecommunications

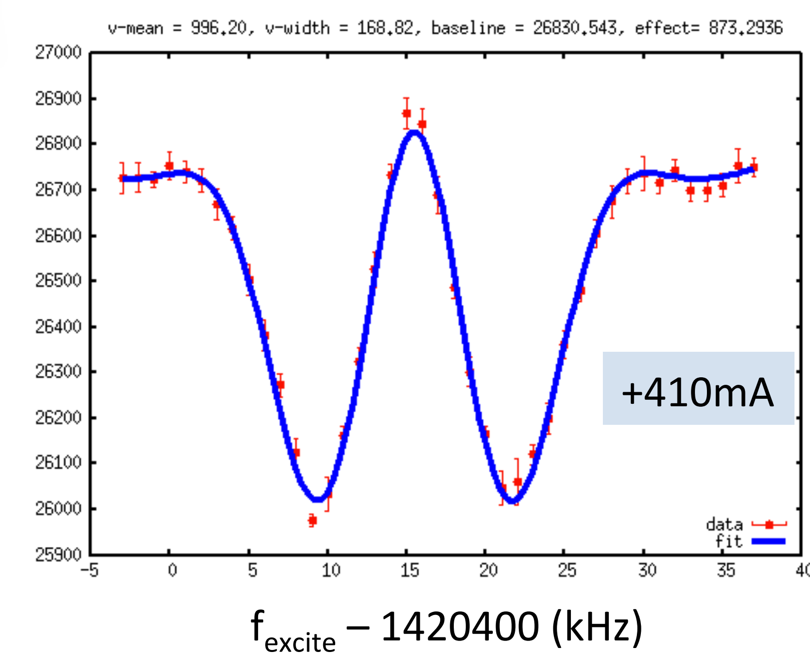
- $\bar{H}$ BEAM OBSERVED
  - n≲43: 6 events / 15 min
  - n≲29: 4 events / 15 min



- H BEAM HFS MEASUREMENT



$\bar{H}$ HFS spectrometer

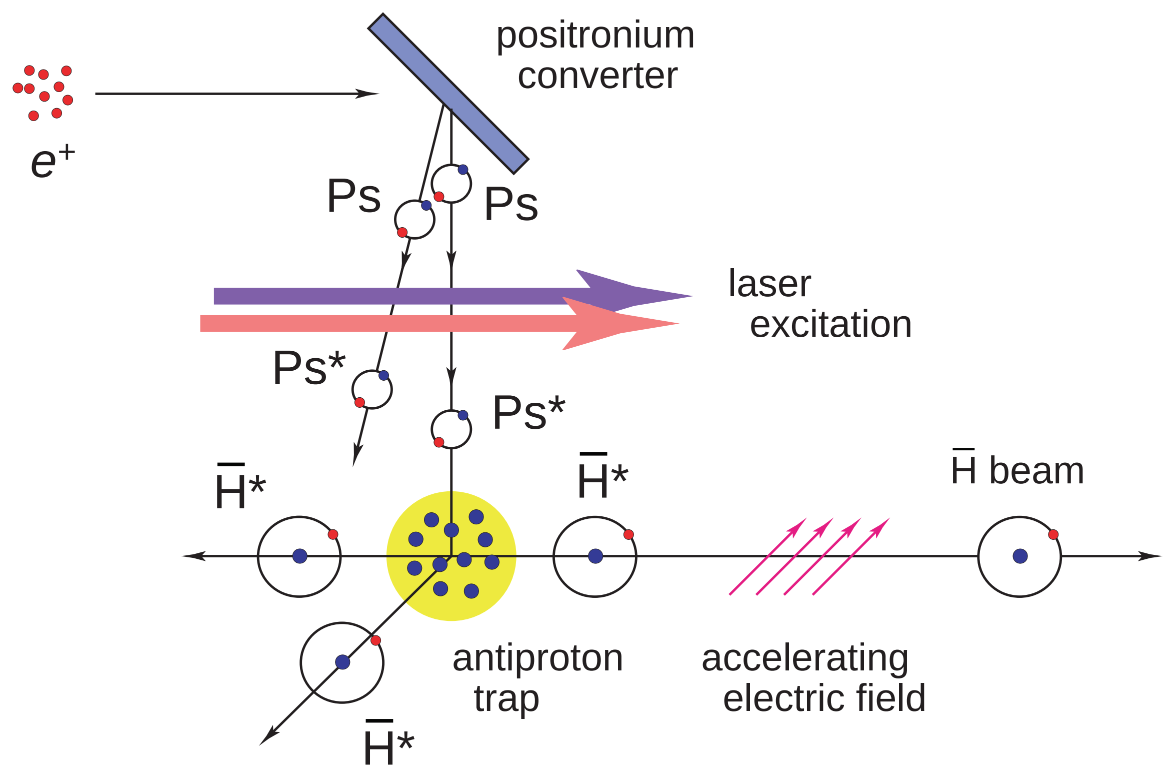


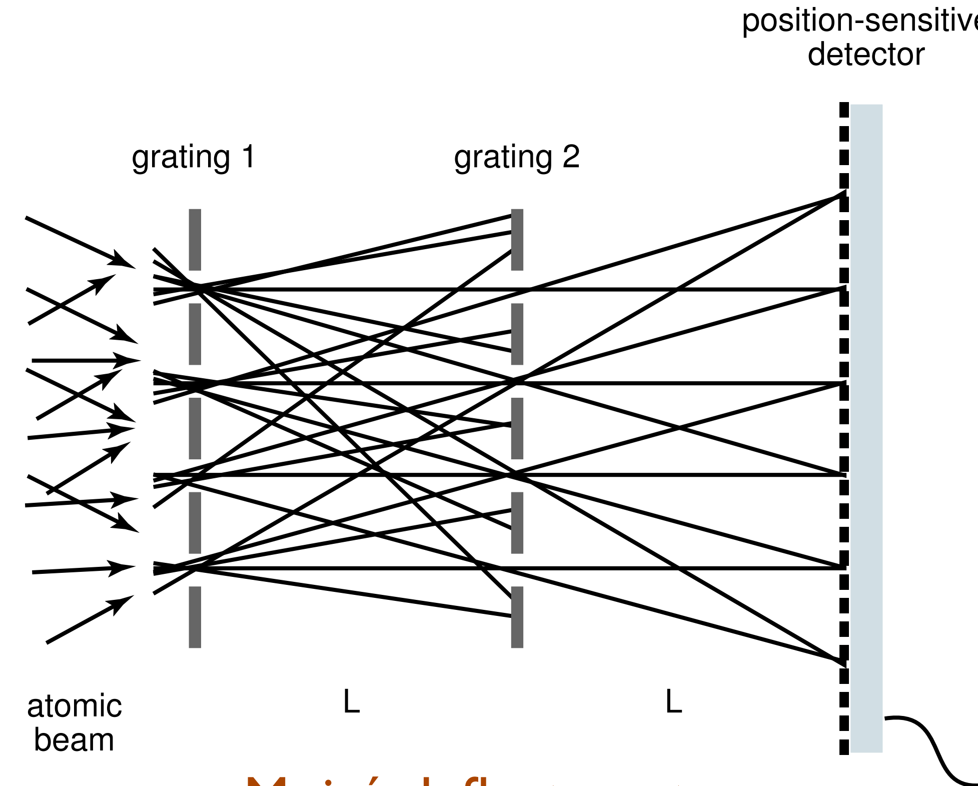
Δf/f < 10 ppb

AEgIS COLLABORATION

Stefan Meyer Institute	CERN	Czech Technical University	ETH Zurich
University of Genova	University of Milano	University of Padova	University of Pavia
Institute of Nuclear Research of the Russian Academy of Science	Max-Planck Institute Heidelbert	Politecnico di Milano	University College London
University of Bergen	University of Bern	University of Brescia	Heidelberg University
University of Lyon 1	University of Oslo	University of Paris Sud	University of Trento
INFN sections of: Genova, Milano, Padova, Pavia, Trento			

AEGIS - Antimatter Experiment: Gravity, Interferometry, Spectroscopy





Moiré deflectometer

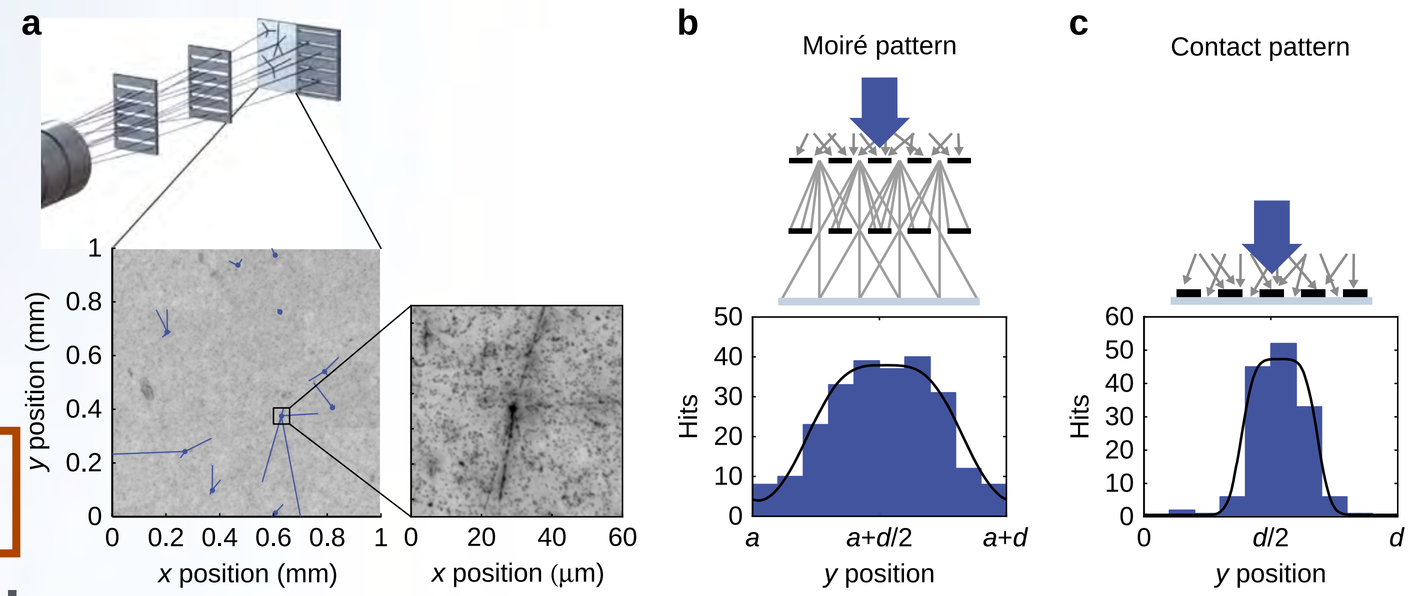
- FREE FALL OF $\bar{p}$
  - $\bar{H}$ production at 100 mK
  - resonant charge exchange with excited positronium
  - acceleration of Rydberg $\bar{H}$ by Starck effect
  - pulsed production, measure TOF & position

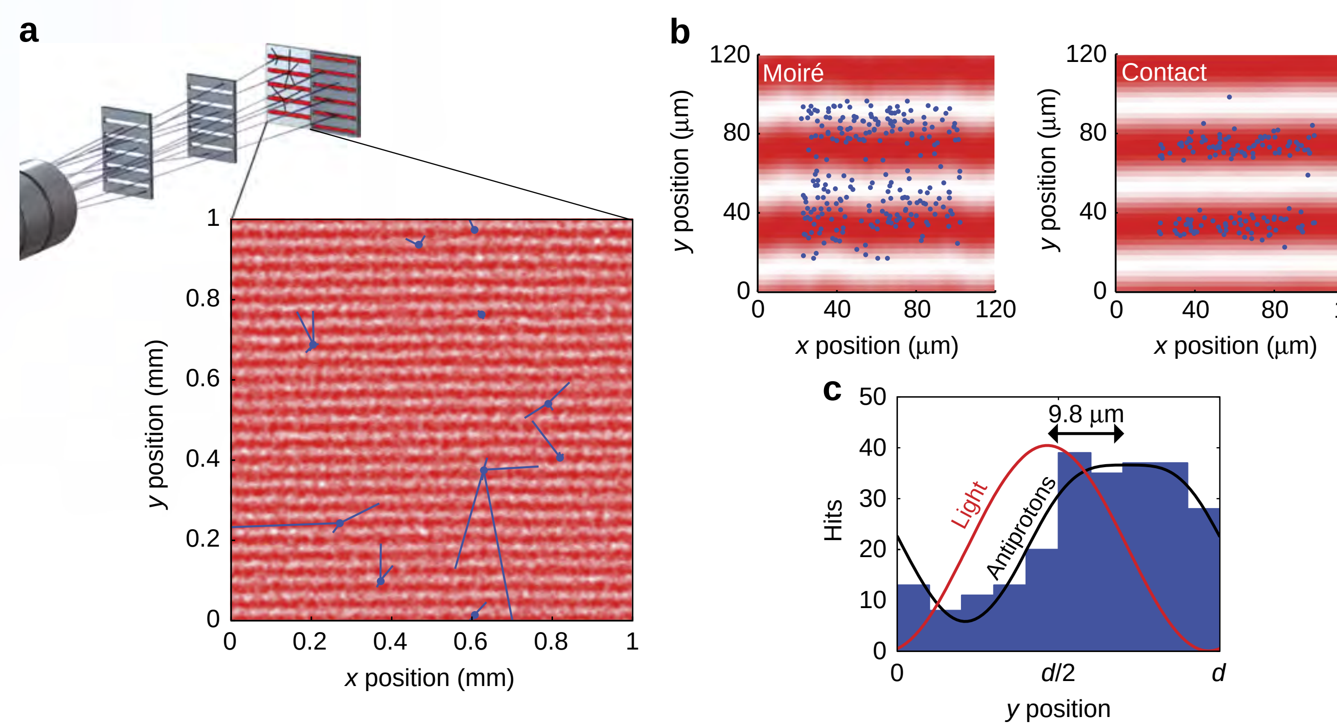
$\bar{p}$ DEFLECTOMETER RESULT

- Pattern observed
  - Shift between $\bar{p}$ and light observed

$\Delta y = 9.8 \pm 0.9(\mathrm{stat}) \pm 6.4(\mathrm{syst})\ \mu m$

  - consistent with residual B, E fields
  - sensitivity of μm reached
  - $\bar{H}$ beam case
    - velocity $* 10^{-4}$
    - distance * 40
    - Force 10^{-10}



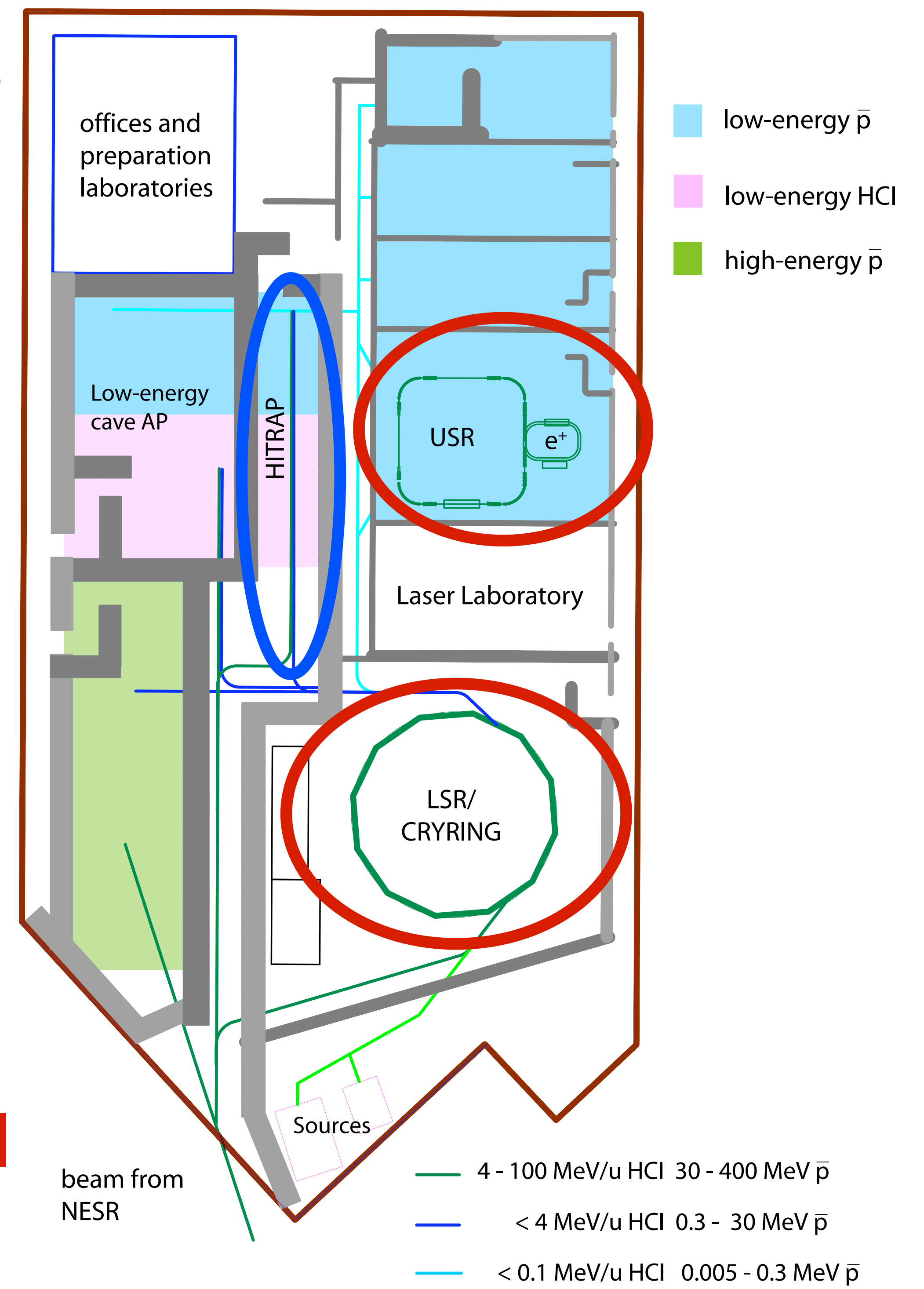


Aghion, S. et al. Nature Communications, 5, 4538 (2014)

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
    - $\Delta p/p \sim 10^{-4}$
- 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 ~2020?

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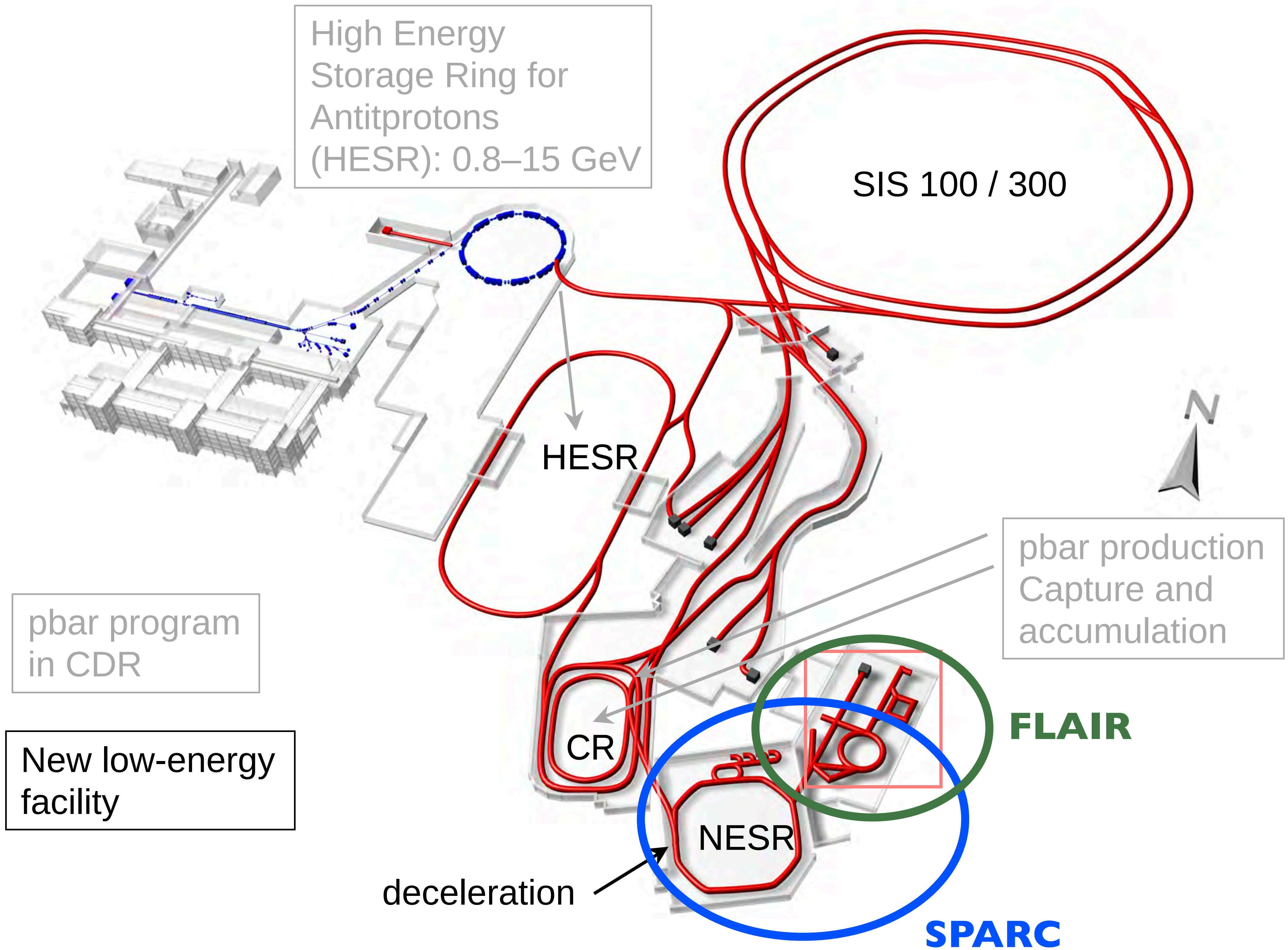
Antiprotons at FAIR



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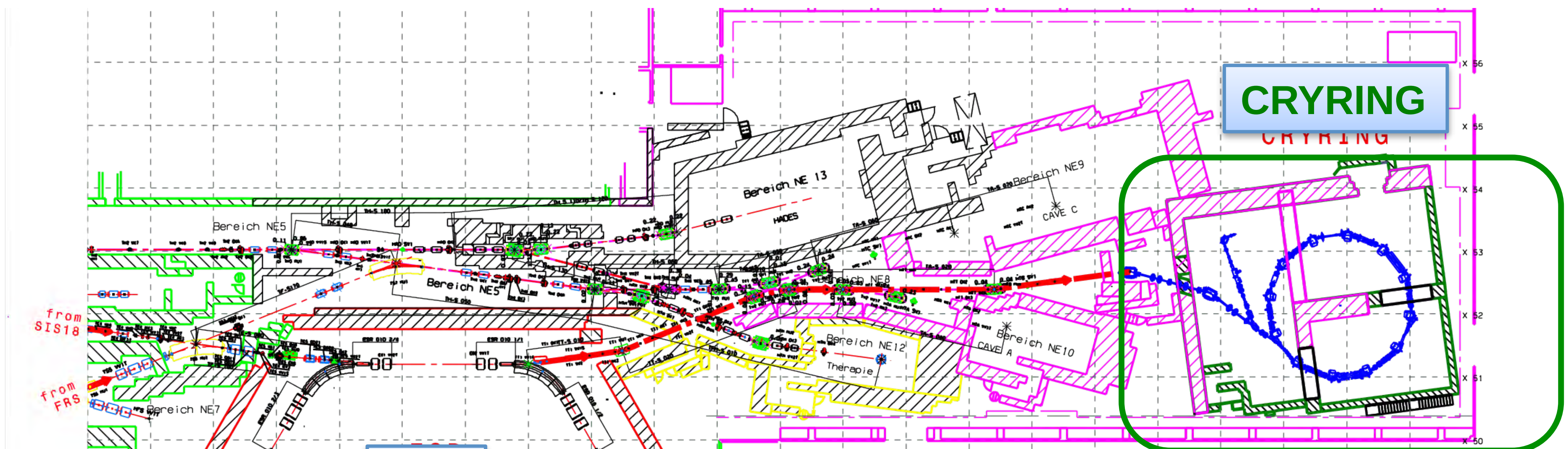
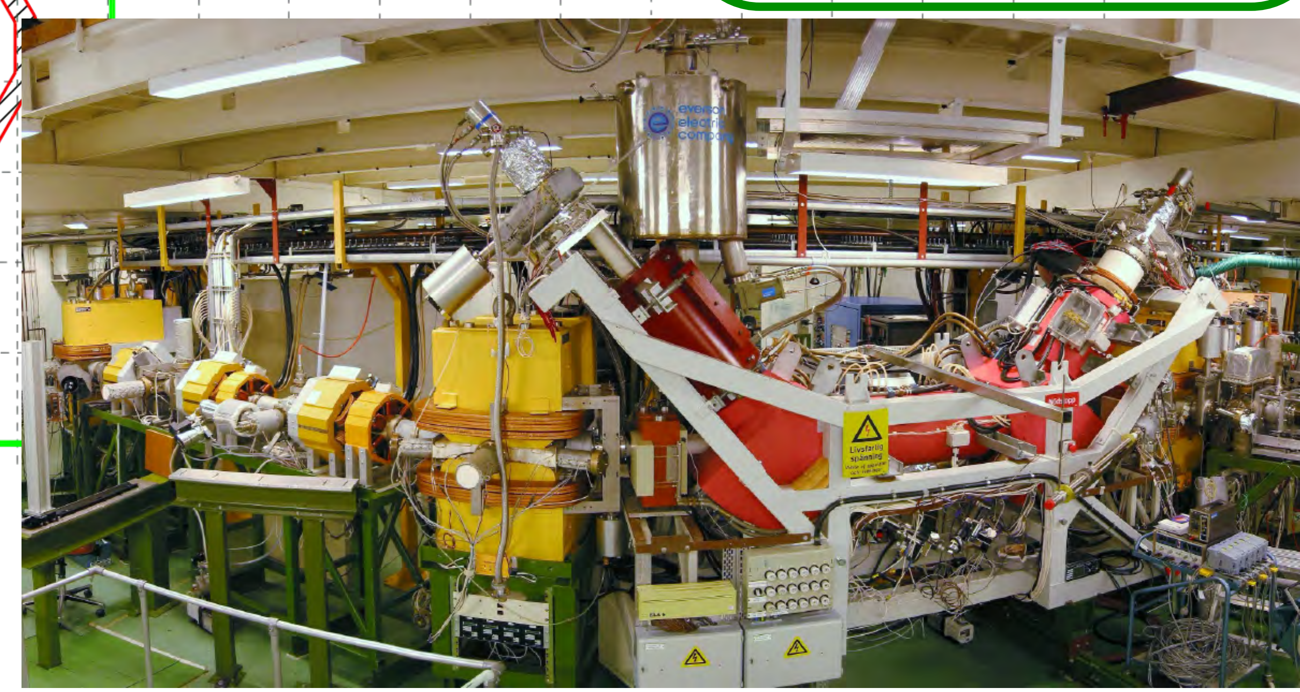
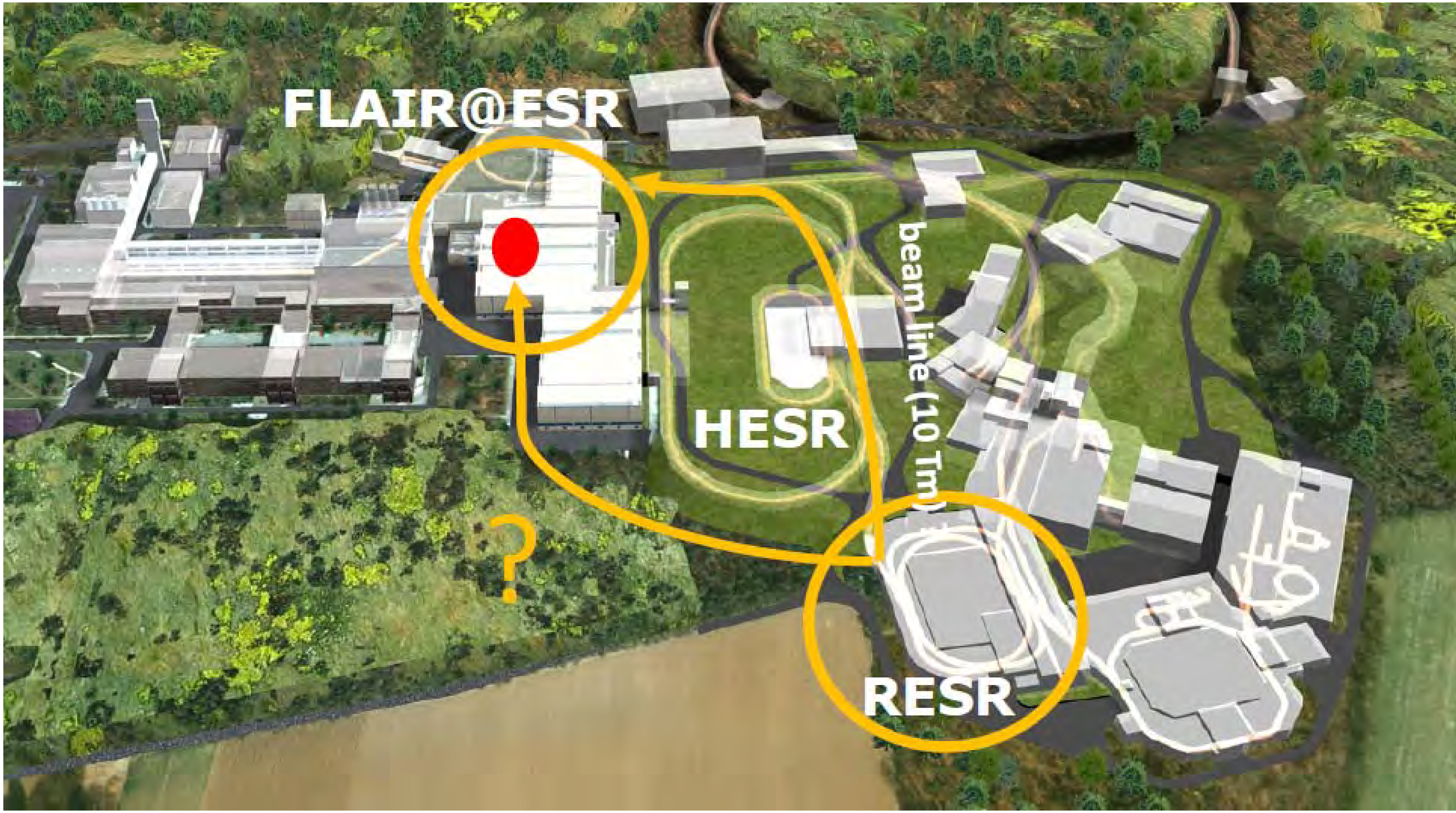
CRYRING@ESR: phase 1 of FLAIR





CRYRING has been delivered to GSI and is currently getting installed

Vision: antiprotons from CR/RESR?



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

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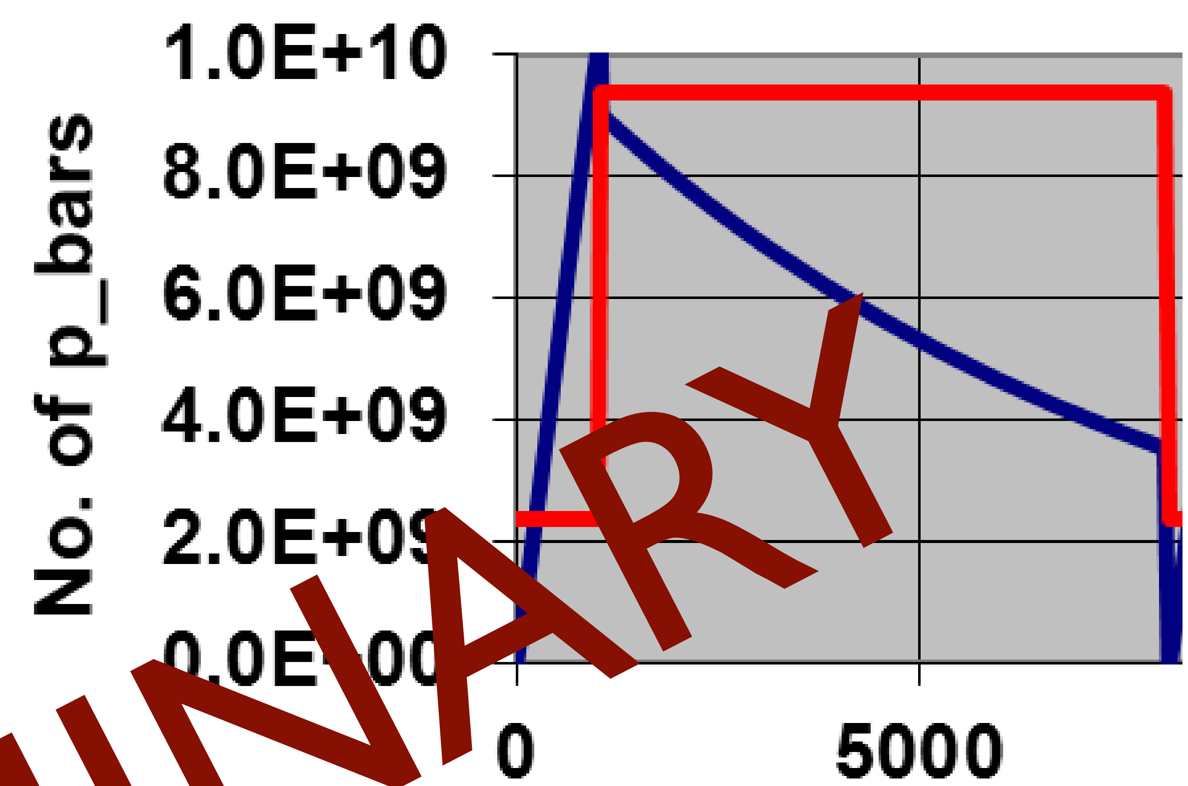
Scenarios: $\bar{p}$ rates in MSV from HESR

- Leftover from PANDA
  - few 10^9 per 60 min
  - decelerate & transfer to ESR
    - T. Katayama: 100s, 80% eff.
  - average 5×10^5/s
  - 5×10^7/s every 100 s
    - similar to AD-ELENA
  - fast or *slow* extracted



D. Prasuhn

- Low-energy $\bar{p}$ production: full use of HESR
  - CR 13 Tm
  - ESR 10 Tm but above transition energy
  - deceleration needed to avoid loss: HESR
  - T. Katayama:
    - start with 10^9 $\bar{p}$ (stacking for 100s)
    - deceleration to 30 MeV in HESR&ESR: 8×10^8 $\bar{p}$ /100 s
    - max. 10^{10} $\bar{p}$ (stacking for 1000s): similar average rate

PRELIMINARY

Low Energy Antiproton Physics @ FLAIR

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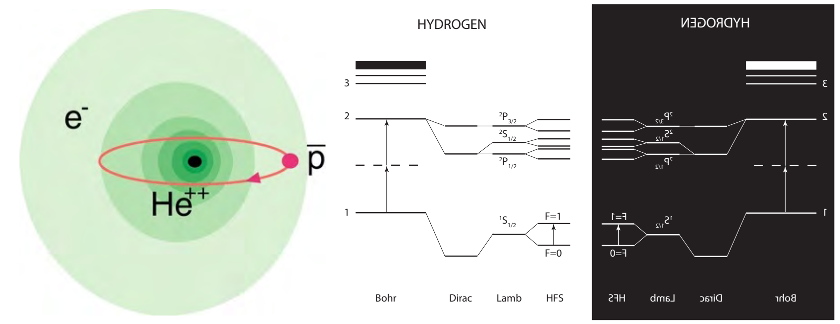
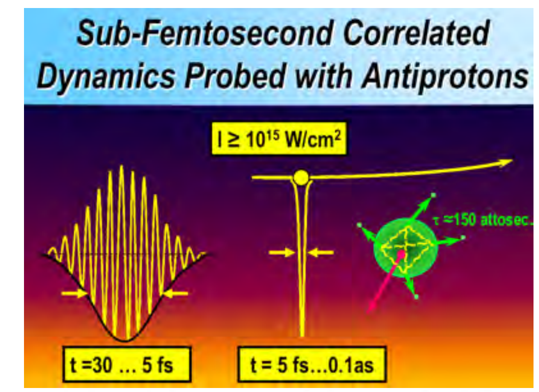
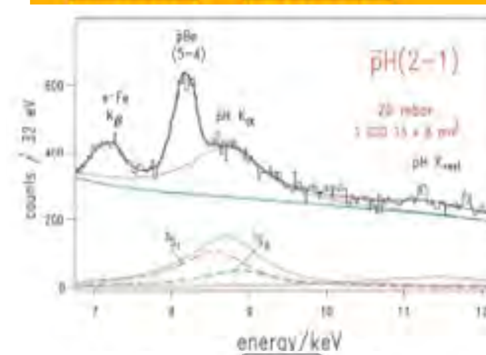
FLAIR TDR - E. Widmann CAMOP - Physica Scripta 72, C51-C56 (2005)

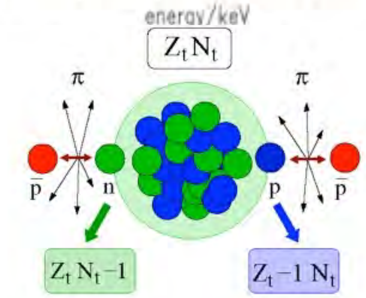
Low Energy Antiproton Physics @ FLAIR

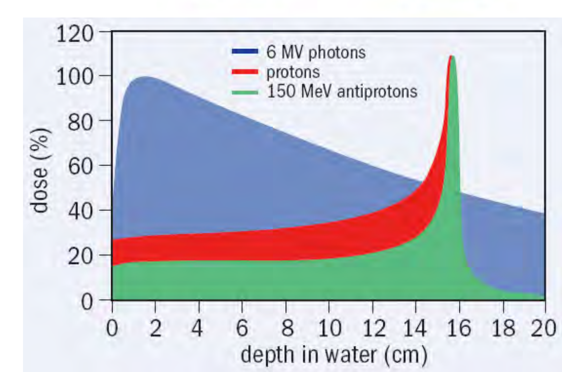
- Spectroscopy for tests of CPT and QED
  - Antiprotonic atoms (pbar-He, pbar-p), antihydrogen
- Atomic collisions
  - Sub-femtosecond correlated dynamics: ionization, energy loss, antimatter-matter collisions
- Antiprotons as hadronic probes
  - X-rays of light antiprotonic atoms: low-energy QCD
  - 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)

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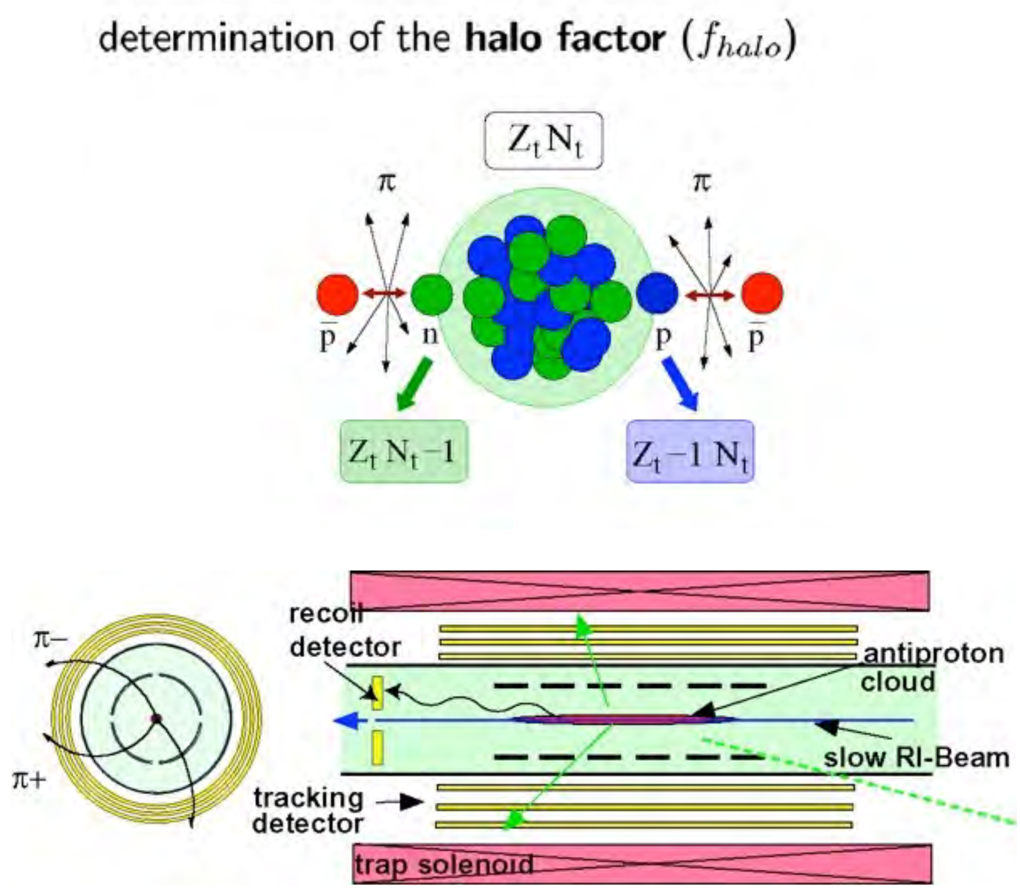
FLAIR day-1 experiments

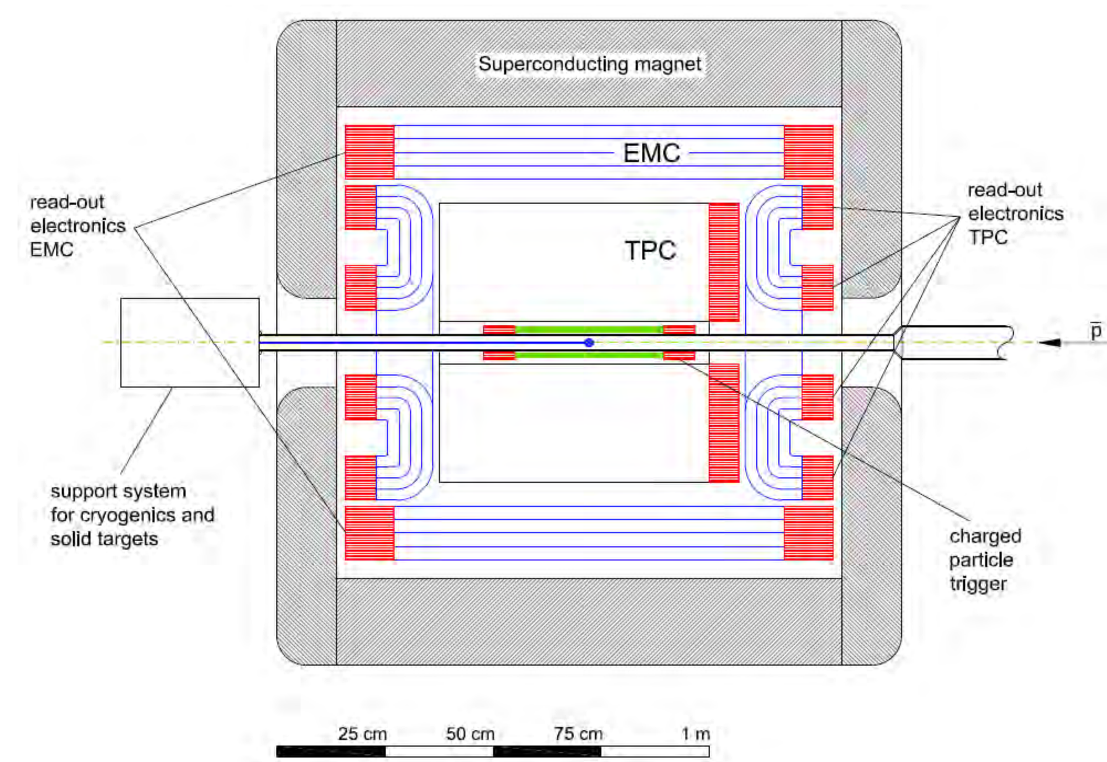
unique at FLAIR: slow $\bar{p}$ extraction → hadron physics

- $\bar{p}$ as probe of nuclear structure
  - halo structure of RI
  - nested Penning trap



M.Wada, Y.Yamazaki
NIM B214 (2004) 196

- hadron physics with stopped $\bar{p}$
  - search for (deeply) bound baryonic matter with strangeness −1 and −2
  - needs 4π detector



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

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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 available from CRYRING
    - nuclear and particle physics type experiments (not possible at AD)
  - Availability of radioactive ion beams (RIB) offers new synergies
    - requires independent beam line from (S)FRS
  - Cooled antiprotons down to 20 keV (with USR)
  - higher rates (phase 2, with RESR)
- 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

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Bundesministerium für Wissenschaft, Forschung und Wirtschaft

ERC Advanced Grant 291242
HbarHFS
www.antimatter.at
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