Faculty of Physics
WARSAW UNIVERSITY OF TECHNOLOGY

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AEḡIS EXPERIMENT

Experiments with mid-heavy antiprotonic atoms in AEgIS

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for the AEgIS Collaboration

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Experiments with antiprotonic atoms

G. Backenstoss, Antiprotonic atoms, Contemporary Physics, 1989, volume 30, number 6, pages 433-448

With the exception of antiprotonic helium only low-precision spectroscopic measurements of some antiprotonic atoms have been made

x-ray spectroscopy of “last energy level”
Sensitive to strong and coulomb interaction

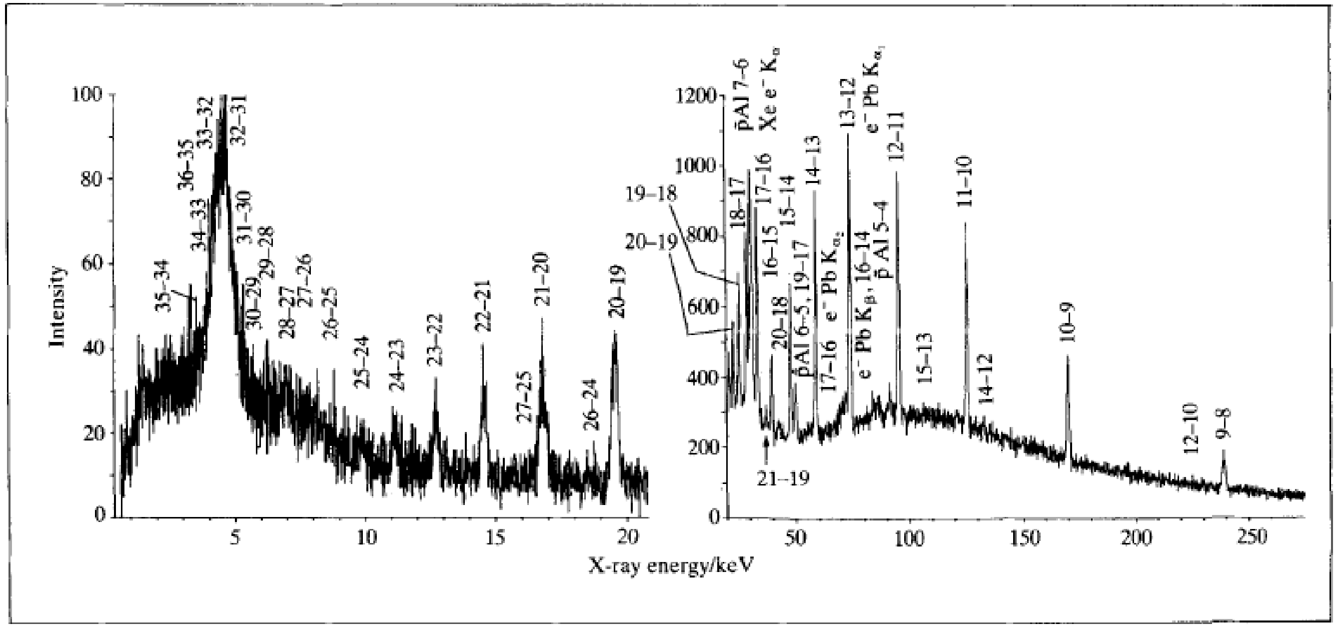

Figure 2. Antiprotonic X-ray spectrum of ^{54}Xe taken at 20 mbar with the cyclotron trap [16].

Xe x-ray spectroscopy

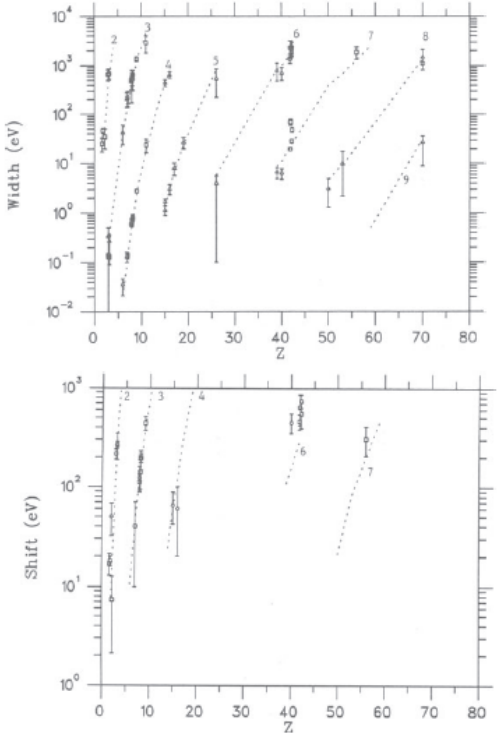

Fig. 4. Measured shifts (with reversed sign) and widths for $\bar{p}$-atoms. The dashed curve shows values calculated using the simple optical model (eq. (5)) with $\bar{a}$ = 1.53 + i2.50 fm.

C J Batty, Antiprotonic atoms, Antiproton-Nucleon and Antiproton-Nucleus Interactions, 1990

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Energy shifts, width and strong interaction

G. Backenstoss, Antiprotonic atoms, Contemporary Physics, 1989, volume 30, number 6, pages 433-448

Table 2. Typical values of strong-interaction shifts and widths of p̄ atomic levels. Measurements related to lower and upper levels of a transition are listed separately.

	Lower level (eV)			Upper level (eV)	
Nucleus	(n, l)	ε_f	Γ_f	(n, l)	Γ_i
^{4}He	2p	7·4 (5·3)	35 (15)		
^{6}Li	2p	215 (25)	660 (170)	3d	0·135 (0·016)
^{7}Li	2p	265 (20)	690 (170)	3d	0·129 (0·013)
^{14}N	3d	40 (30)	218 (75)	4f	0·136 (0·019)
^{16}O	3d	112 (20)	495 (45)	4f	0·603 (0·022)
^{17}O	3d	140 (46)	540 (150)	4f	0·731 (0·035)
^{18}O	3d	195 (20)	640 (40)	4f	0·795 (0·023)
^{19}F	3d	440 (70)	1365 (150)	4f	2·79 (0·16)
^{23}Na	3d	2080 (300)	2900 (1100)	4f	23·8 (7·4)
^{92}Mo	6i	460 (80)	1400 (300)	7j	19.5 (1.2)
^{94}Mo	6i	640 (220)	2300 (900)	5g	42.5 (9·2) keV †
^{95}Mo	6i	740 (120)	1900 (400)	5g	49·9 (19.8) keV †
^{98}Mo	6i	550 (160)	2300 (700)	5g	45·1 (10·0) keV †
^{138}Ba	7j	350 (150)	1800 (450)		

† These values have been obtained from intensity deficiencies of the $n = 7 \rightarrow n = 6$ transitions due to the Nuclear Effect discussed in Section 4.2.

Table 1. Windows in nuclear charge Z where strong-interaction effects are measurable.

n_c	Z	n_c	Z	n_c	Z
1s	1	4f	15–20	7i	55–59
2p	2–4	5g	26–30	8j	70–74
3d	7–11	6h	40–45	9k	90–92

→ Neutron skin measurements

→ Antiproton – nucleon scattering parameters at threshold

→ Annihilation

→ QGP searches in “deep” annihilations

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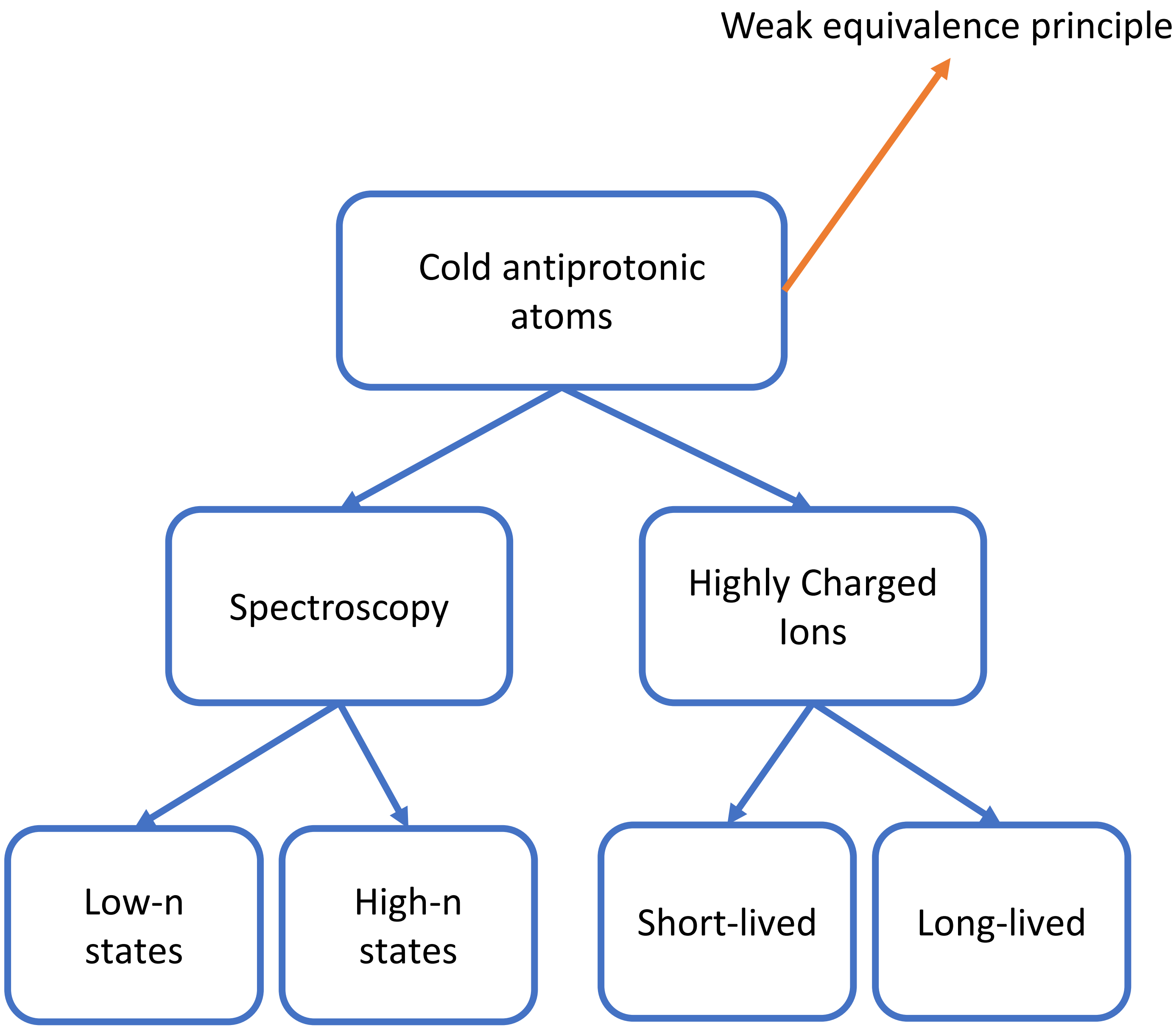
Antiprotonic atoms

- Gravity measurement
- Laser spectroscopy
- Fluorescence and x-ray spectroscopy
- Highly Charged Nuclei
- Fragments
- Atomic clocks
  - Fundamental constants
  - Atomic structure
  - Nuclear structure
  - …



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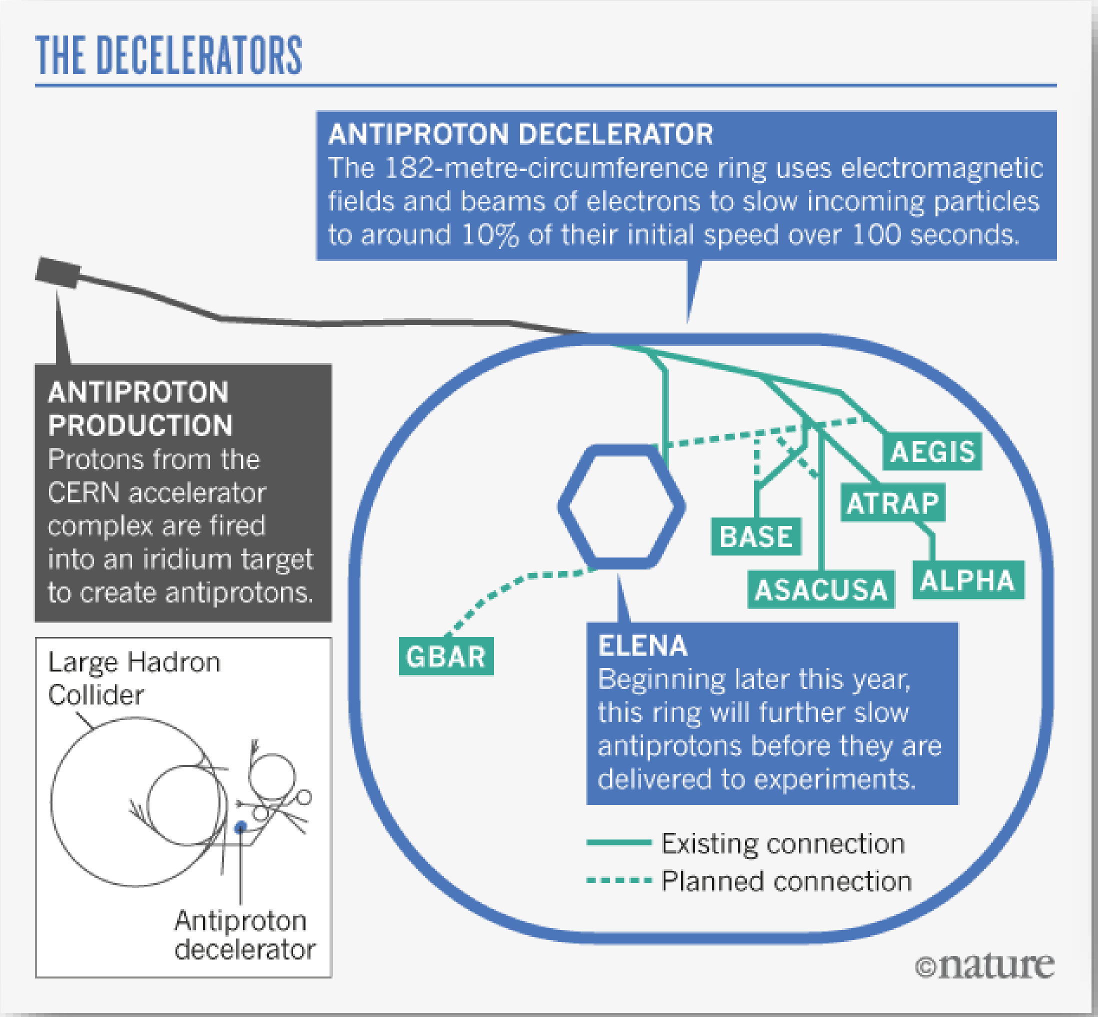
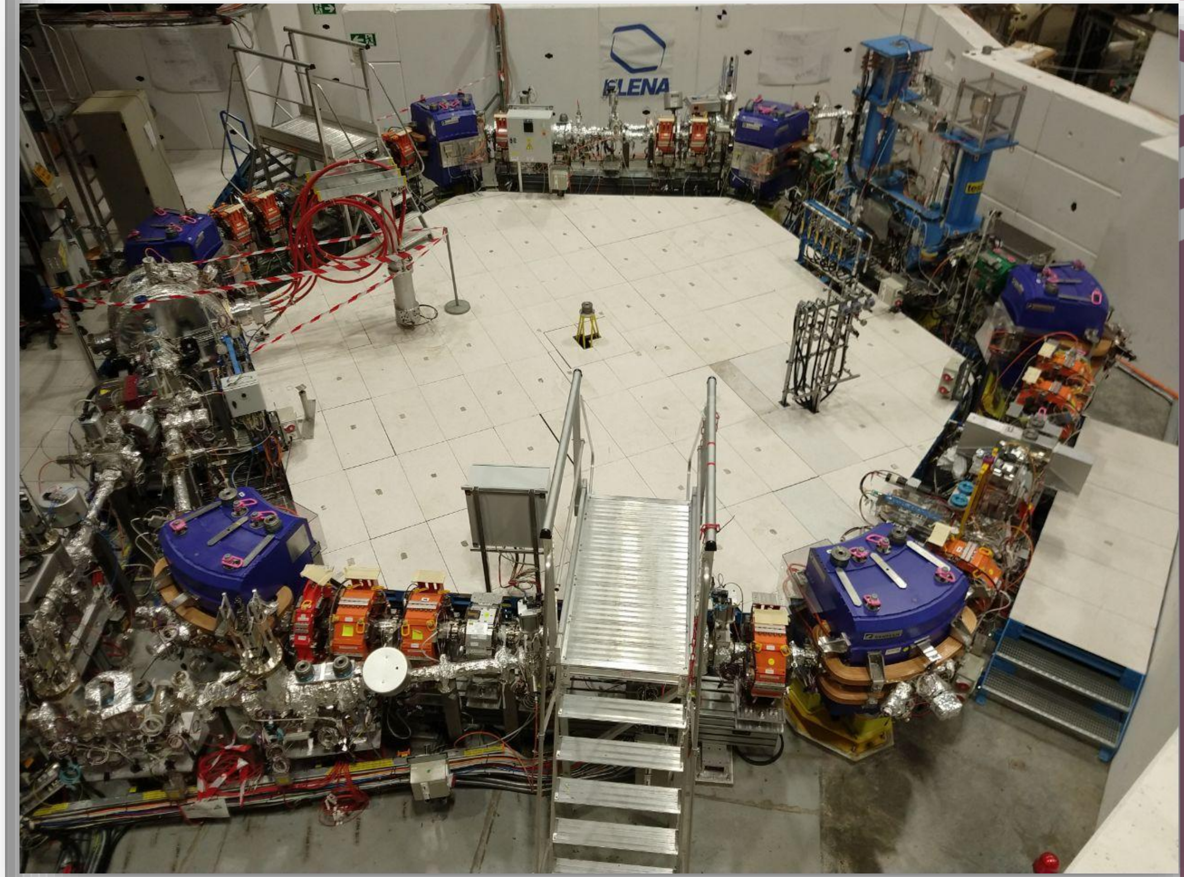
ELENA: 100 keV antiprotons





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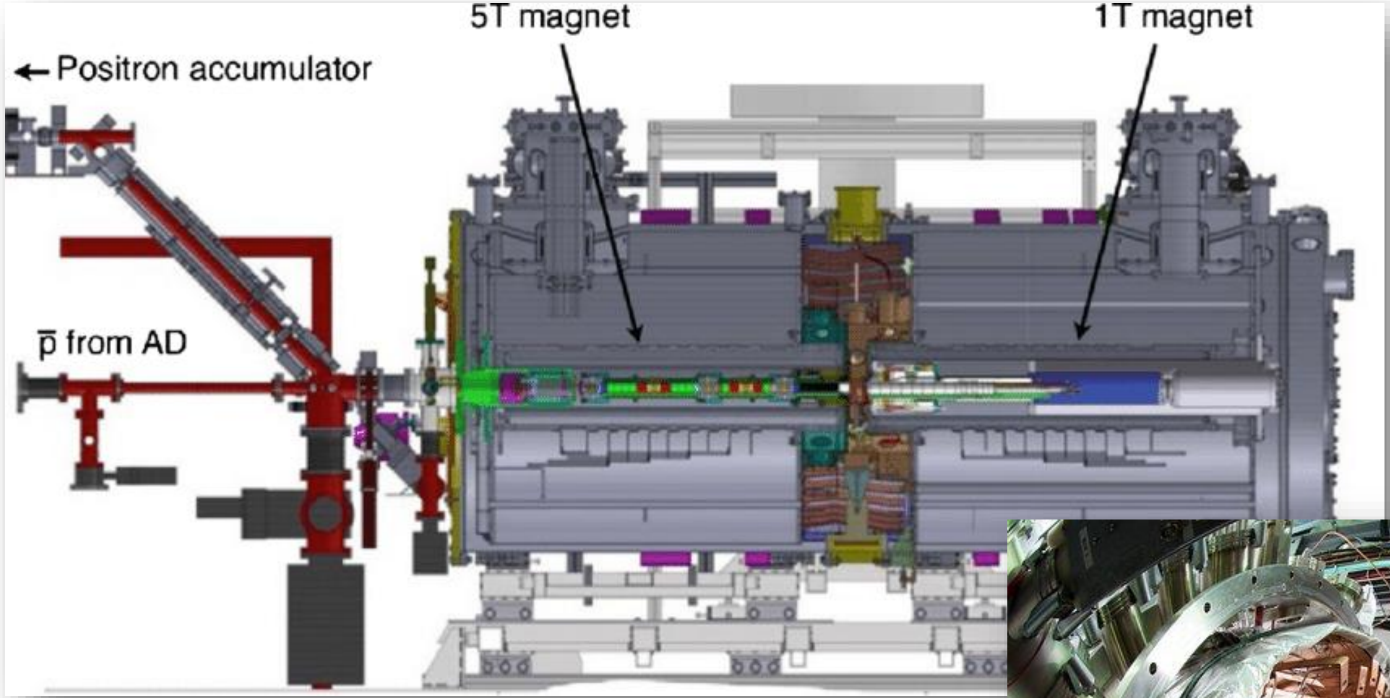
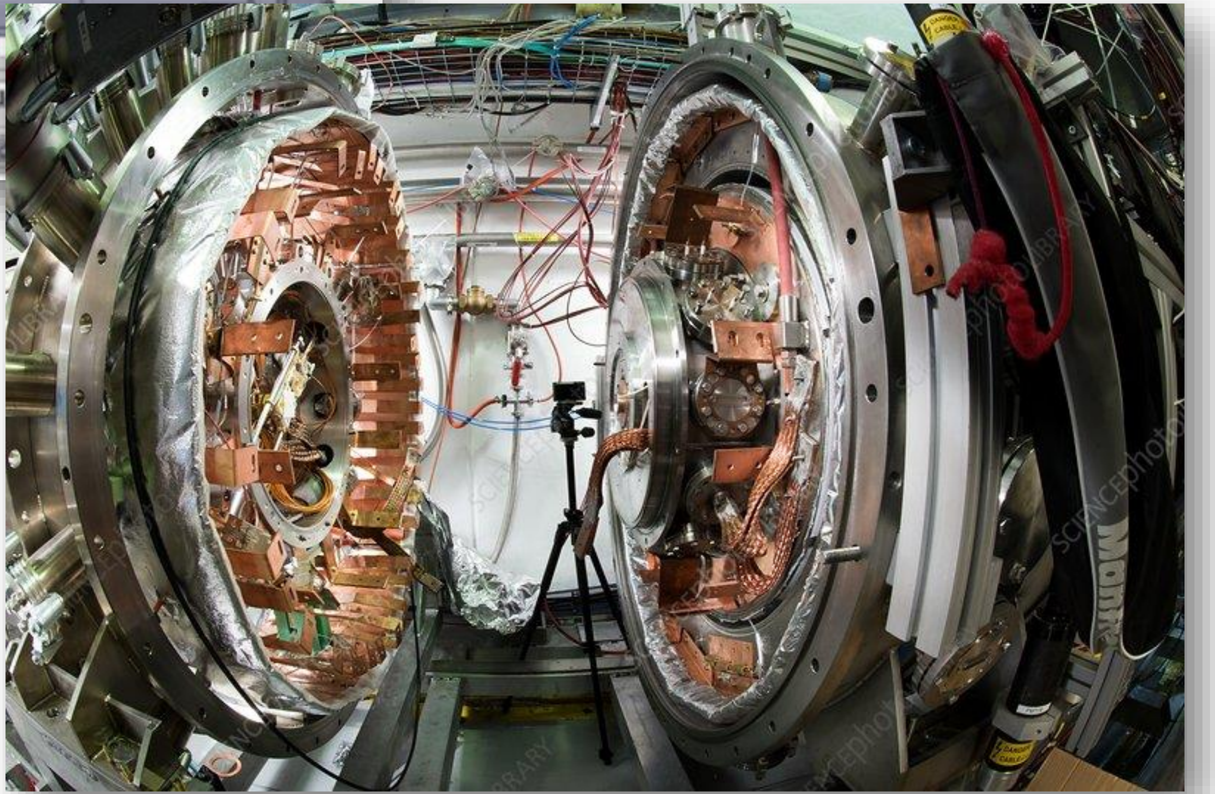
AEgIS set-up



Nucl.Instrum.Meth.B 266 (2008) 351-356
Nature Commun. 5 (2014) 4538



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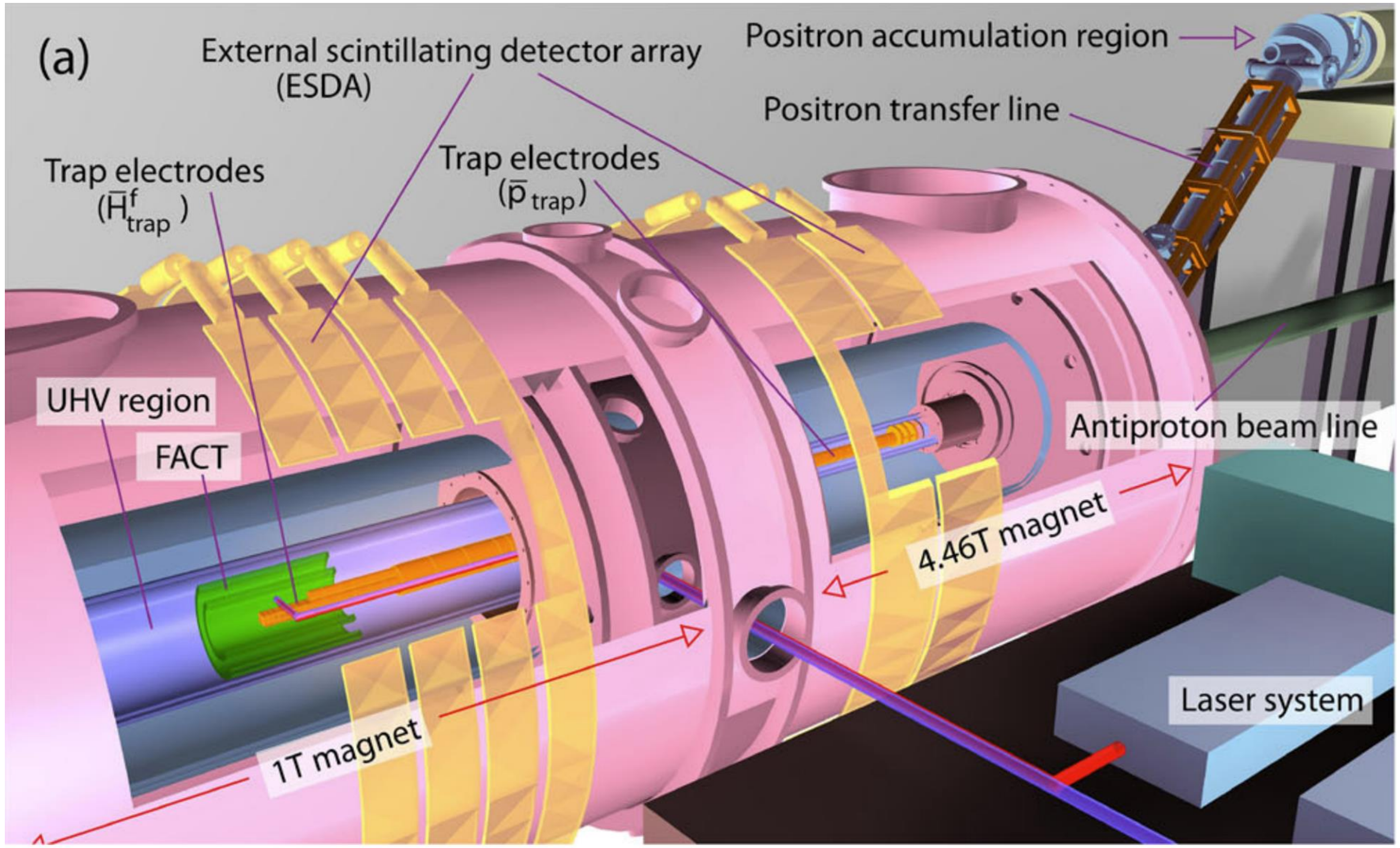
Pulsed production of antihydrogen



Direct measurement of the gravitational acceleration of neutrally-charged antihydrogen pulsed beam.

- Antiprotons from ELENA
- UHV vessel
- 5 T and 1 T Penning traps
- Laser system
- Scintillator array

AEGIS Coll., Pulsed production of antihydrogen, Commun.Phys. 4 (2021) 1, 19

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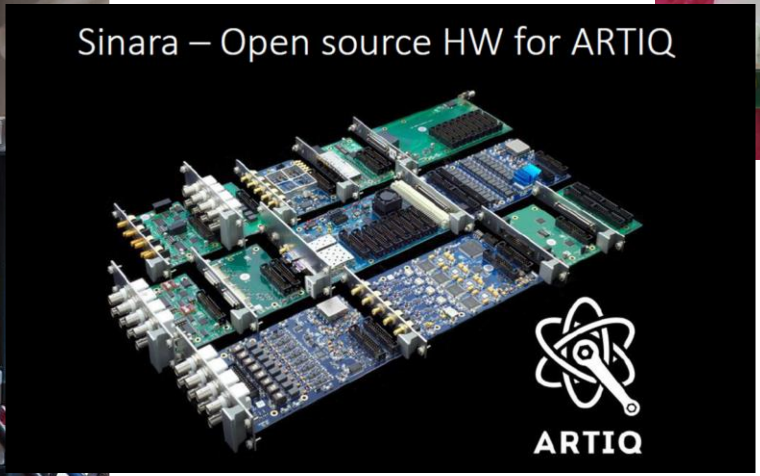
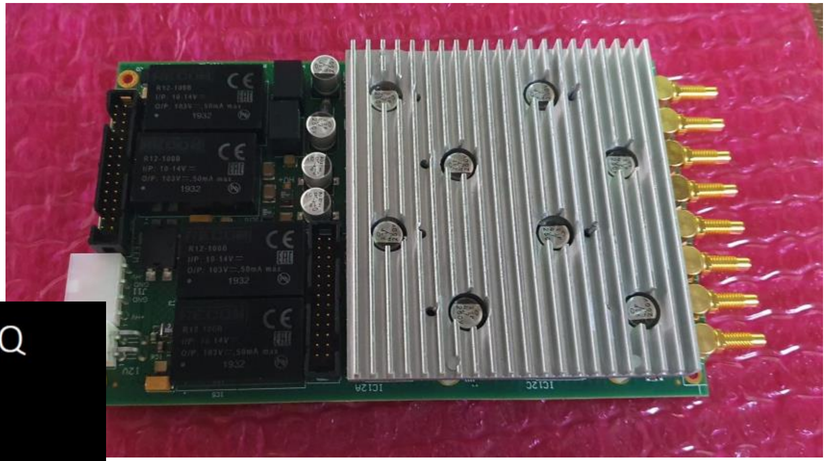
A new control system: Sinara

https://github.com/sinara-hw/meta/wiki and https://m-labs.hk/artiq/





https://github.com/sinara-hw/HV_AMP_8CH/wiki

Fast HV amplification for the trap electrodes

Characteristics:

- 8 channels
- +-200 V range
- 1 MHz
- 50R output impedance
- Overtemp protection
- quick output disconnect controlled via EEM using OptoMos to limit the noise

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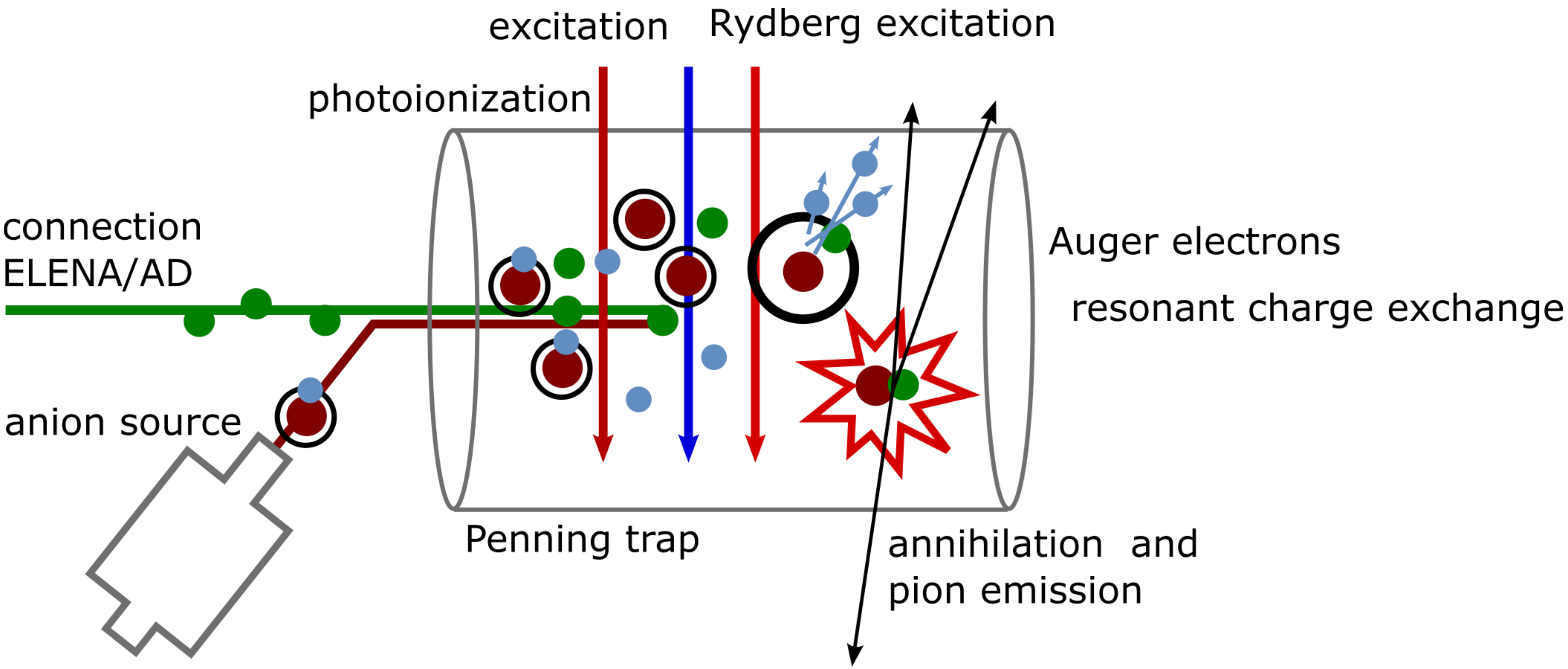
Scheme of production of pulsed and cold antiprotonic atoms



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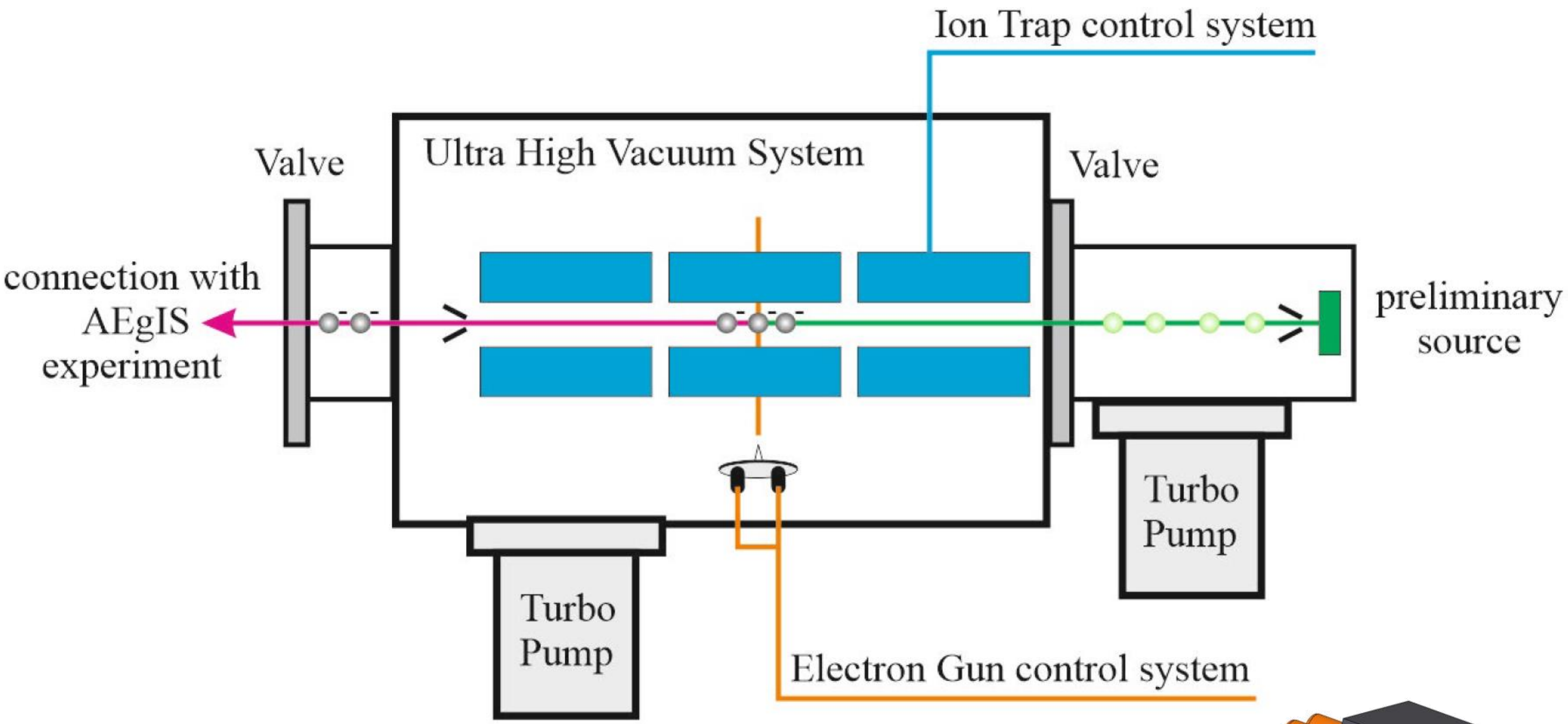
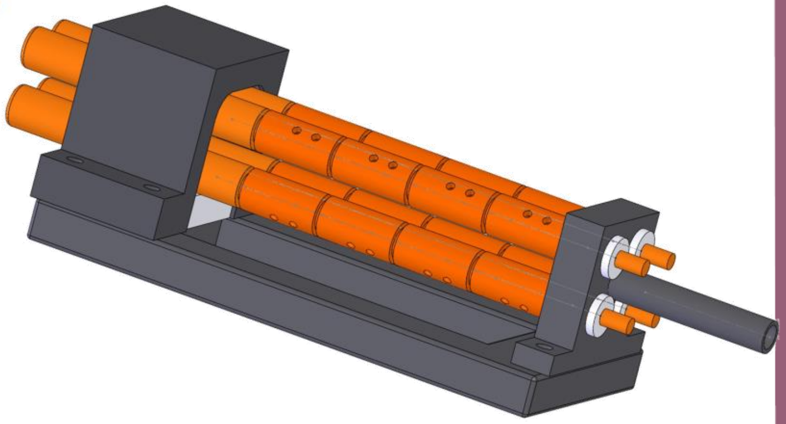
Anion source I: charge transfer collisions





Charge transfer reaction as a source of anions:
Two step production starting from H_2
$H_2 + e \rightarrow H^+ + H^-$
$H^- + A \rightarrow A^- + H$

L. Kłosowski and M. Piwiński , private communications

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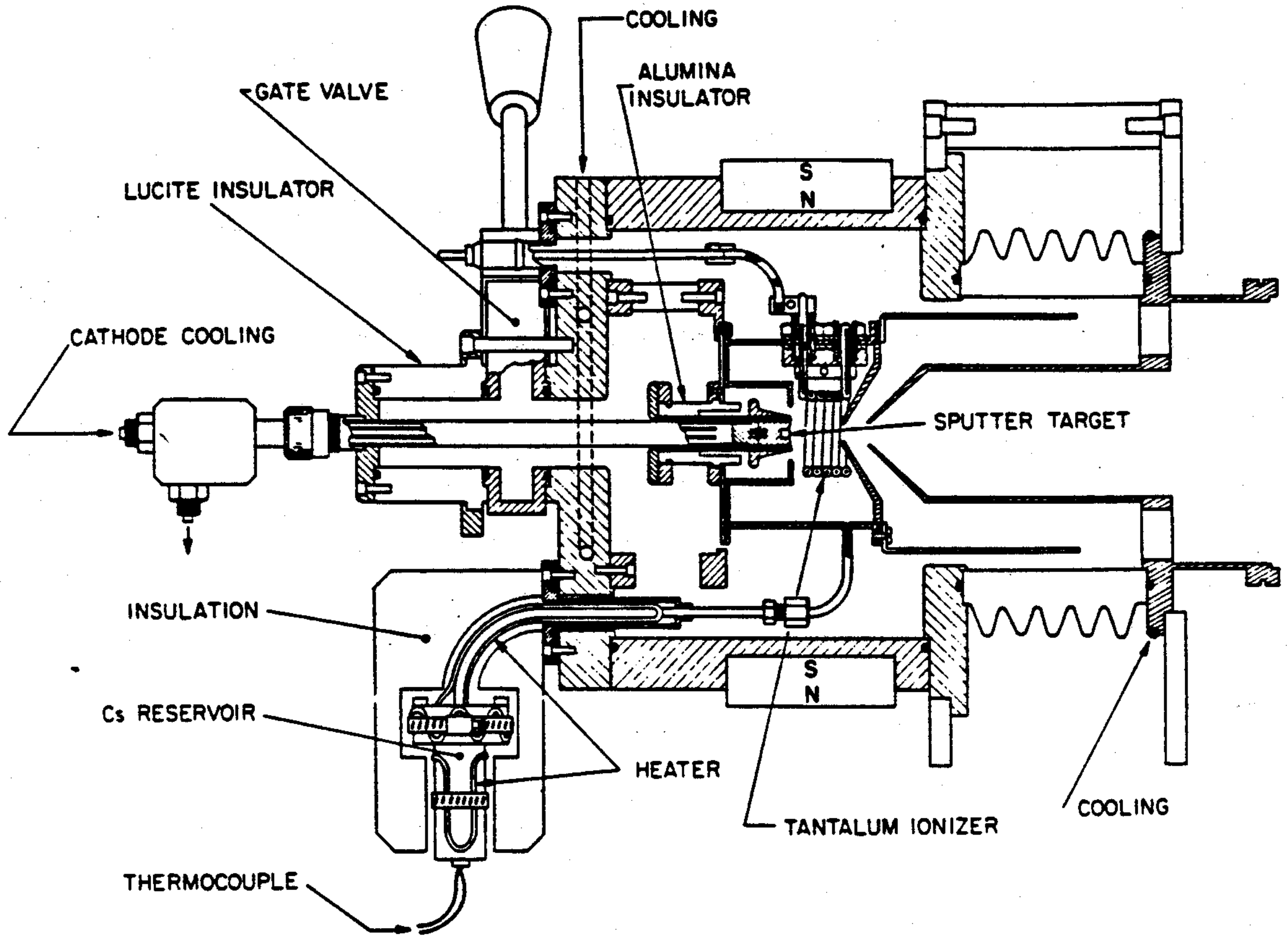
Anion source II

Alternative path: Middleton’s scheme as a source of anions

Bombarding with Cs^+ a sputter target a high intensity beam can be formed and separated in a magnetic spectrometer.



R. Middleton, Nucl. Instr. And Methods **214** (1983) 139

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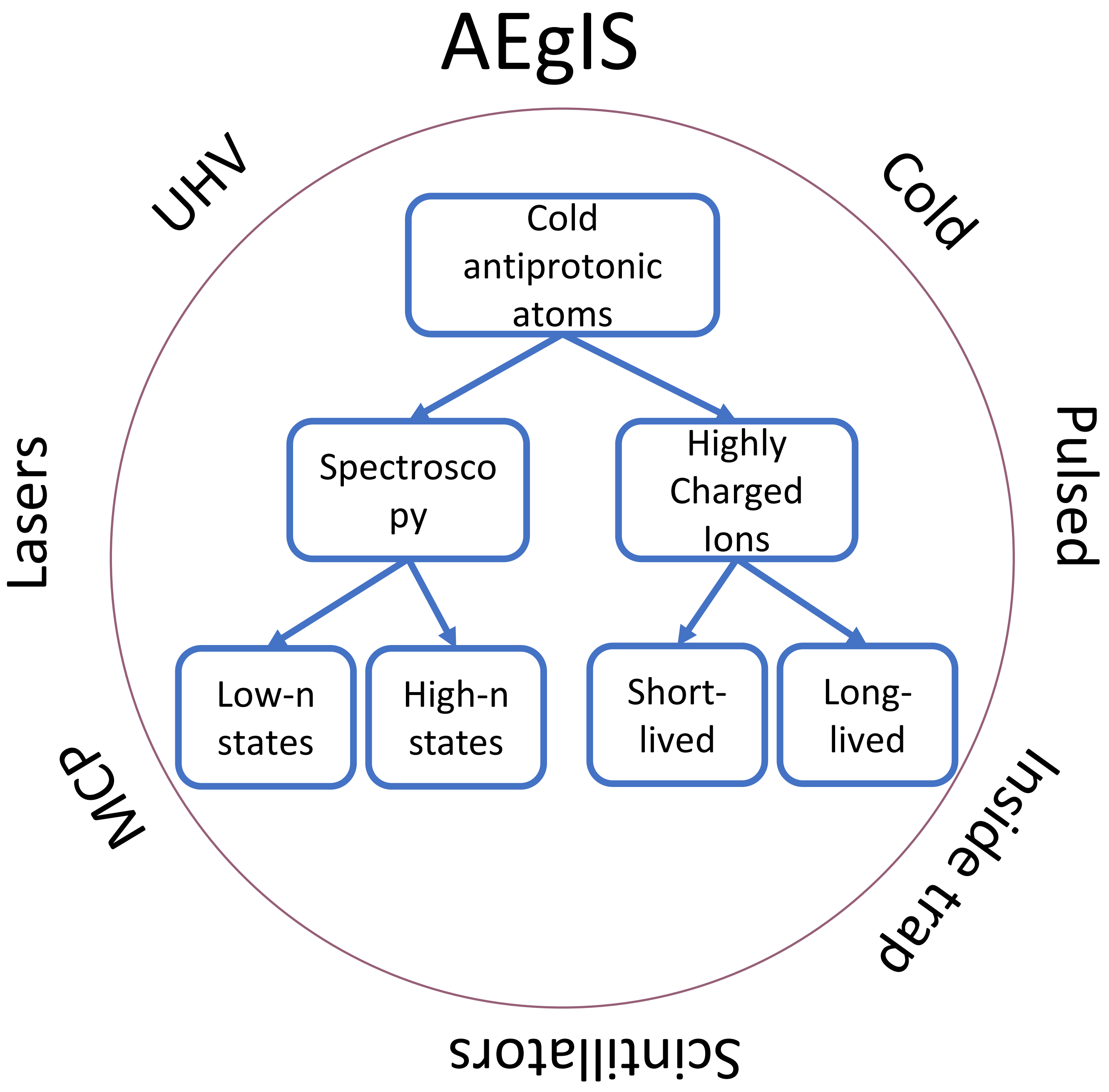
We propose:

1. Precise laser spectroscopy of Rydberg antiprotonic atoms
2. Trapping of cold highly charged radioisotopes produced after annihilation of antiprotons on the surface.



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University of Milano

Politecnico di Milano

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University of Oslo

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University Paris-Saclay and CNRS

University of Pavia

Czech Technical University, Prague

University of Trento

Warsaw University of Technology

Stefan Meyer Institute, Vienna

ETH Zurich

INFN Sections of Genova, Milano, Padova, Pavia, Trento

Raman Research Institute