Strong interaction limits in antiprotonic atoms

Daniel Pęcak

Fredrik Gustafsson Tomasz Sowiński

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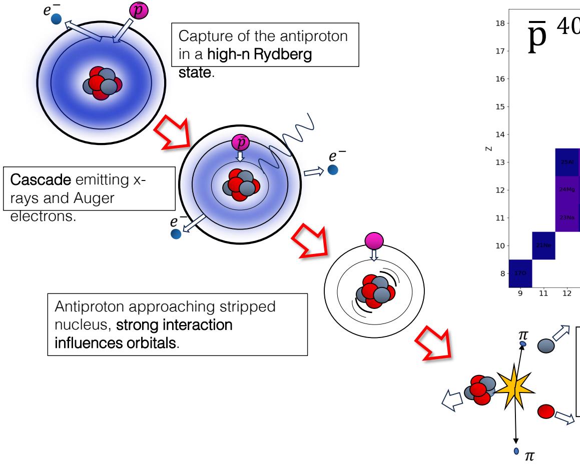
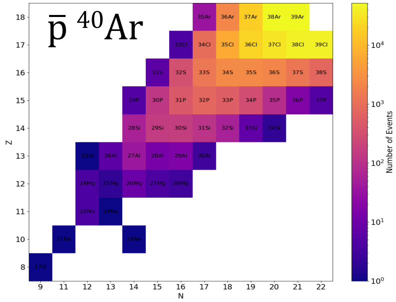
Fredrik presentation

The life of an antiprotonic atom





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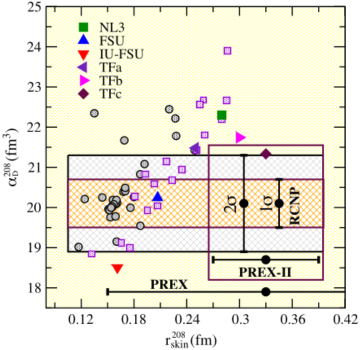


FIG. 3 (color online). Predictions from 52 nuclear EDFs for the electric dipole polarizability and the neutron-skin thickness of ^{208}Pb. Constraints on the dipole polarizability from RCNP [46,47], PREX [1], and from an updated PREX experiment assuming a 0.06 fm error and the same central value have been incorporated into the plot.

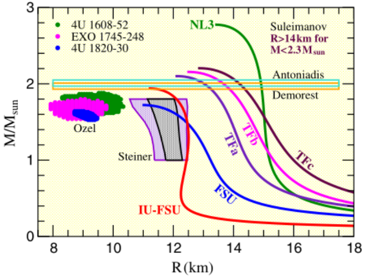
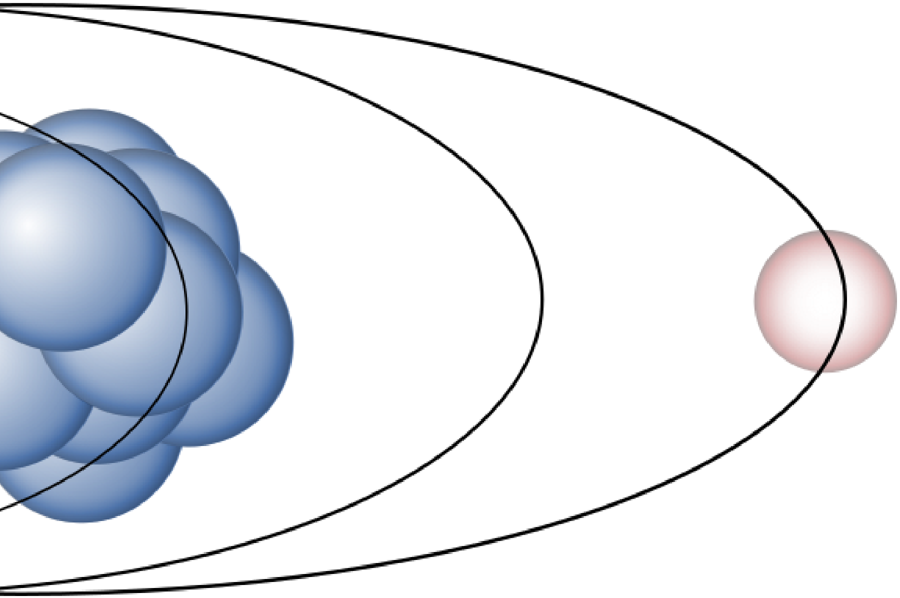


FIG. 4 (color online). Mass-versus-radius relation predicted by the six models discussed in the text.

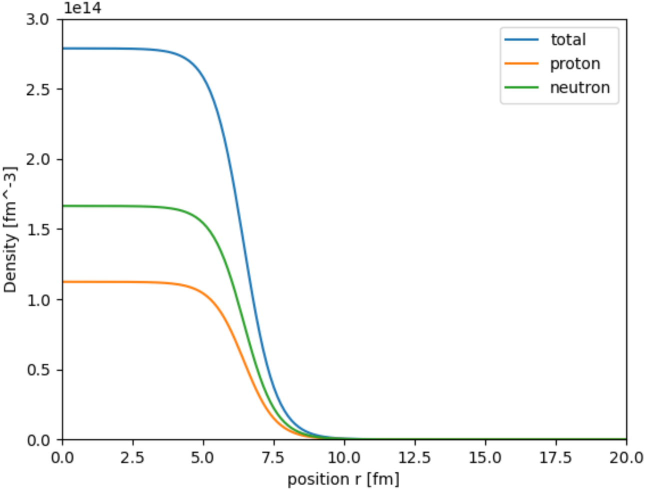
indeed from most models lacking exotic cores [54]. Shortly after, Steiner, Lattimer, and Brown supplemented Özel's study with three additional neutron stars and concluded that systematic uncertainties affect the determination of the most probable masses and radii [55]. Their results suggest larger radii of 11–12 km and have been depicted in Fig. 4

Hydrogen-like atom

	Energy scale	Length scale
	$E_n = \frac{mc^2\alpha^2}{2}\frac{A}{A+m/m_p}\frac{Z^2}{n^2}$	$a_B = \frac{\hbar c}{\alpha mc^2}\frac{A+m/m_p}{A}\frac{n^2}{Z}$
e^-	13.61 eV	0.53 Å
μ^-	2.81 keV	255.95 fm
$\bar{p}$	24.98 keV	28.82 fm



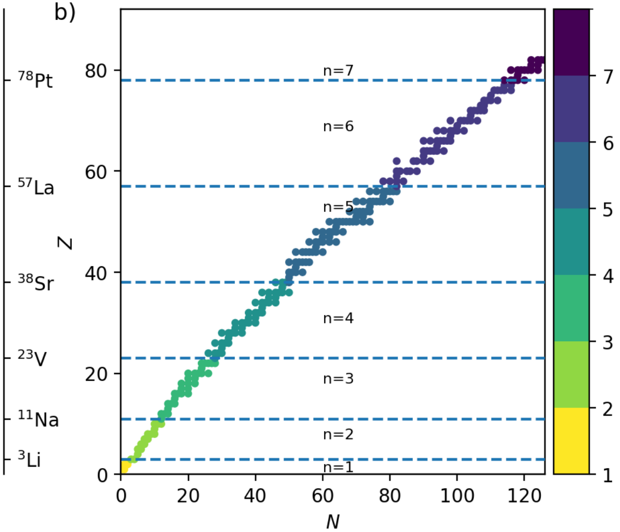
Liquid drop model



$$\rho_N(r) = \frac{N}{1 + \mathrm{e}^{(r-R)/a}},$$

$$R = 1.25\, A^{1/3} \mathrm{fm}$$

$$a = 0.5\, \mathrm{fm}$$



$$\frac{N}{Z} \approx 1 + \frac{a_C}{2a_A} A^{\frac{2}{3}}$$

$$Z = \frac{A}{2 + a_C/(2A_A)A^{\frac{2}{3}}}$$

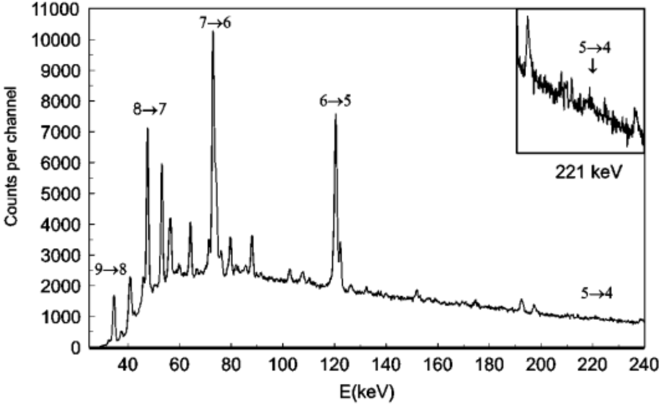


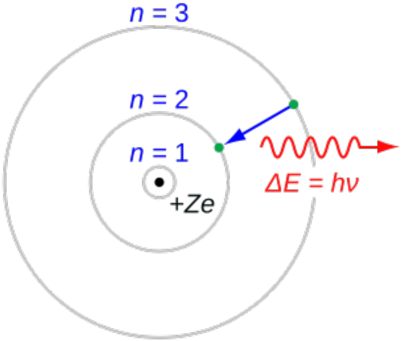
FIG. 1. Spectra of antiprotonic x rays from calcium. Upper part: spectrum from ^{48}Ca. Lower part: accumulated spectrum of all targets; the weights of the different calcium isotopes are for ^{40}Ca: 27%, ^{42}Ca: 18%, ^{43}Ca: 3%, ^{44}Ca: 24%, and for ^{48}Ca: 28% (determined from the number of antiprotons per isotope given in Table I).

Hartmann et al. PRC 65, 014306 (2001)

Experiments

- **Pb**: Kreissl, A., et al. "Remeasurement of the magnetic moment of the antiproton." Zeitschrift für Physik C Particles and Fields 37 (1988): 557-561.
- **Ca**: Hartmann, F. J., et al. "Nucleon density in the nuclear periphery determined with antiprotonic x rays: Calcium isotopes." Physical Review C 65.1 (2001): 014306.
- **Tl**: Bamberger, Andreas, et al. "Observation of antiprotonic atoms." Physics Letters B 33.3 (1970): 233-235.
- **O, Ca, Fe, Ni, Zr, Cd, Sn, Te, Yb, Pb, Bi, Th, U** Trzcinska, A., et al. "Information on antiprotonic atoms and the nuclear periphery from the PS209 experiment." arXiv preprint nucl-ex/0103008 (2001).
- **He**: Poth, Helmut, et al. "The antiprotonic x-ray spectrum of liquid helium." Physics Letters B 76.4 (1978): 523-526.
- **Mo**: Kanert, W., et al. "First Observation of the E 2 Nuclear-Resonance Effect in Antiprotonic Atoms." Physical Review Letters 56.22 (1986): 2368.

Electromagnetic transition Γ_{EM}



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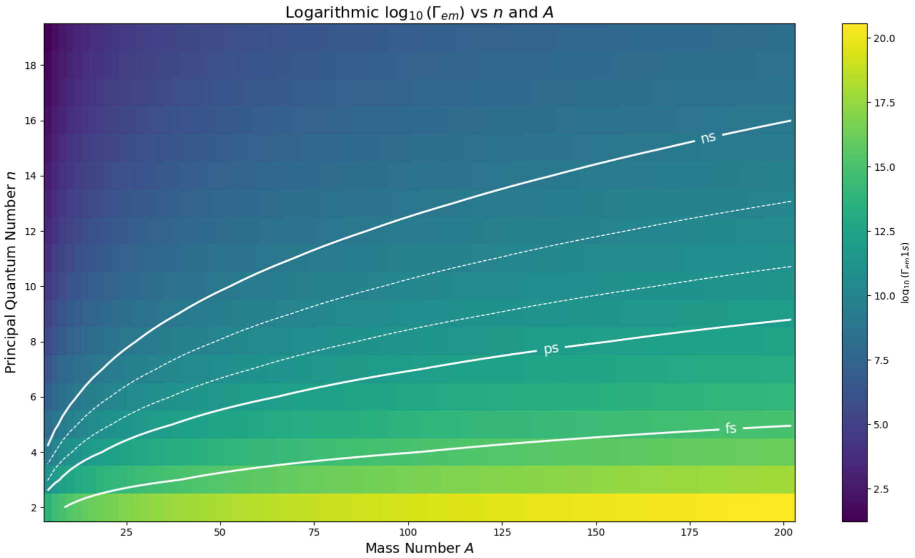
$$\Gamma_{\mathrm{EM}} = \frac{\omega^3 |d|^2}{3\pi\epsilon_0 \hbar c^3}$$

$$|d| \approx \frac{3}{2}\frac{a_0}{Z}$$

$$\Delta E = \mu c^2 \alpha^2 Z^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

$$\omega = \frac{\Delta E}{\hbar} = \frac{E_{n_i} - E_{n_f}}{\hbar}$$

Timescale of Γ_{EM}

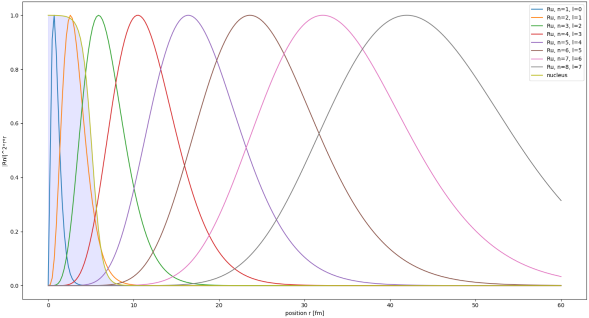


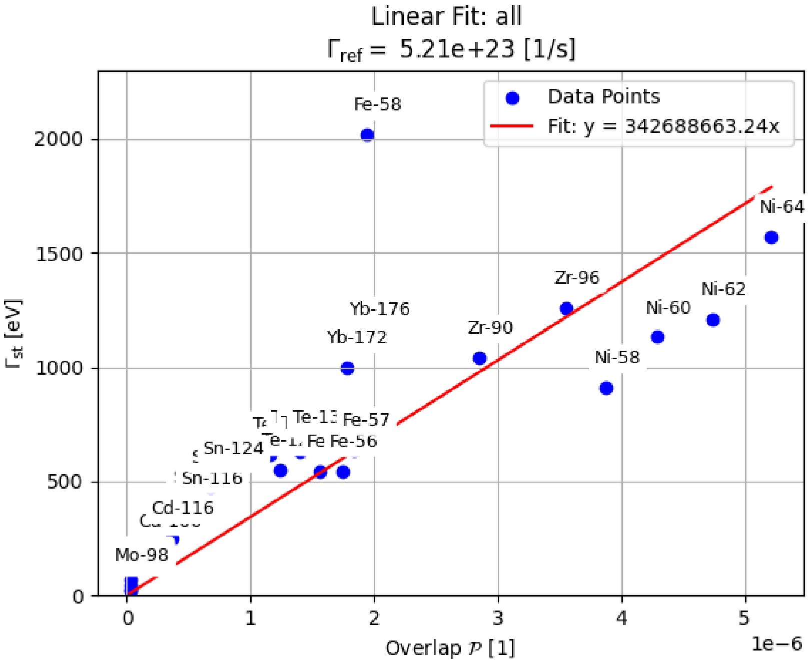
Strong interaction Γ_{st}

$$R_{nl}(r) = \sqrt{\left(\frac{2Z}{na_0}\right)^3 \frac{(n-l-1)!}{2n[(n+l)!]}}\, e^{-\rho/2} \rho^l L_{n-l-1}^{2l+1}(\rho),$$

$$\mathcal{P} = \int_0^{\mathrm{inf}} \mathrm{d}r\, r^2 \rho_N(r) |R_{nl}(r)|^2$$

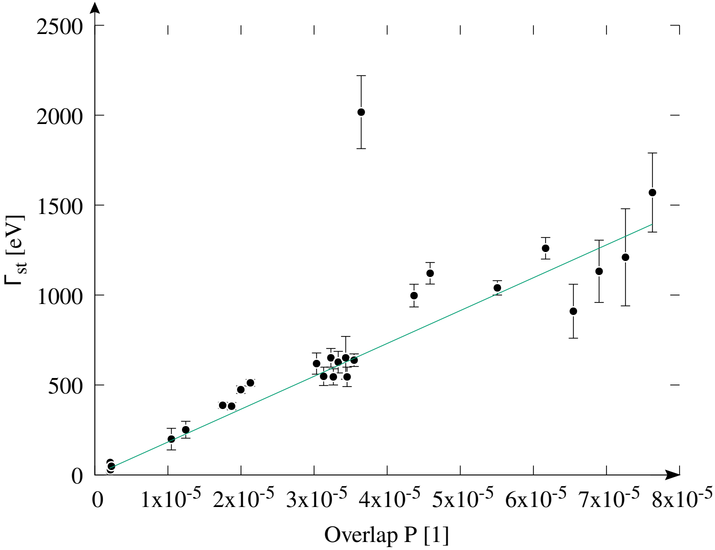
$$\Gamma_{\mathrm{st}} = \Gamma_{\mathrm{ref}} \mathcal{P}$$





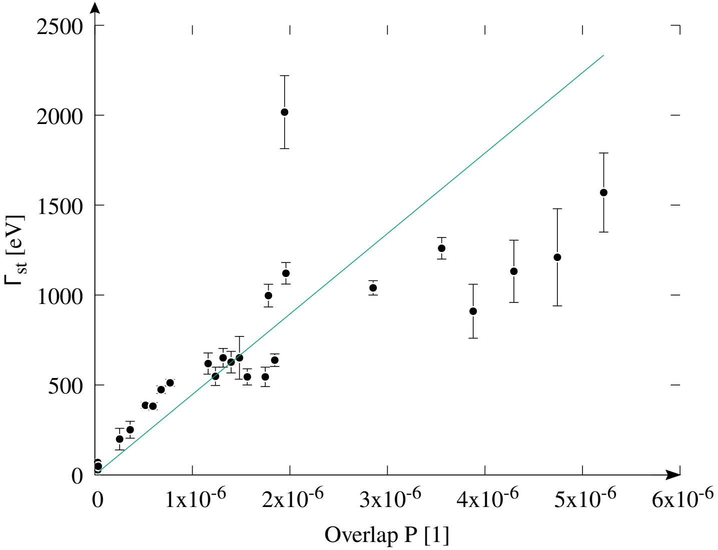
Linear Fit: all
Γ_{ref} = 5.21e+23 [1/s]
Data Points
Fit: y = 342688663.24x
Fe-58
Ni-64
Zr-96
Ni-62
Ni-60
Yb-176
Yb-172
Zr-90
Ni-58
Te-13
Fe-57
Fe
Fe-56
Sn-124
Sn-116
Cd-116
Mo-98
Γ_{st} [eV]
Overlap $\mathcal{P}$ [1]
1e−6
0
500
1000
1500
2000
0
1
2
3
4
5

$$\rho_N(r) = \frac{N}{1 + \mathrm{e}^{(r-R)/a}}, \qquad a = 1.0\,\mathrm{fm}$$

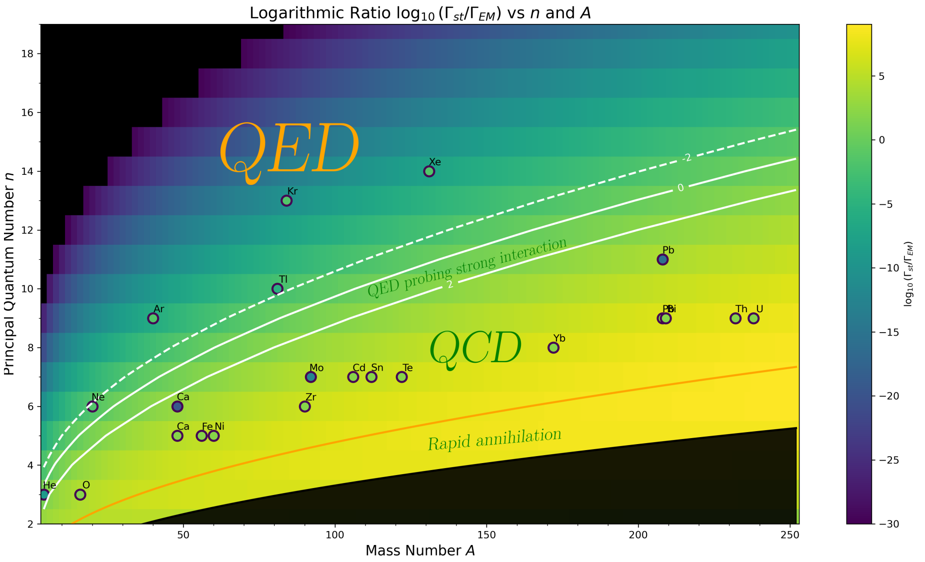


$$\Gamma_{\mathrm{ref}} = 2.75 \cdot 10^{22}\,1/\mathrm{s} \pm 5.5\%$$

$$\rho_N(r) = \frac{N}{1 + \mathrm{e}^{(r-R)/a}}, \qquad a = 0.25\,\mathrm{fm}$$



$$\Gamma_{\mathrm{ref}} = 2.1 \cdot 10^{22}\,1/\mathrm{s} \pm 7.1\%$$



Logarithmic Ratio $\log_{10}(\Gamma_{st}/\Gamma_{EM})$ vs n and A
QED
QCD
QED probing strong interaction
Rapid annihilation
-2
0
2
He
O
Ne
Ca
Ca
Fe
Ni
Ar
Tl
Kr
Xe
Mo
Zr
Cd
Sn
Te
Yb
Pb
Pb
Bi
Th
U
Principal Quantum Number n
Mass Number A
$\log_{10}(\Gamma_{st}/\Gamma_{EM})$