NEUTRON DENSITY DISTRIBUTIONS DEDUCED FROM ANTIPROTONIC ATOMS

(PS209 Experiment, LEAR, CERN)

Jerzy Jastrzębski

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“Nuclei at the Limits”

Argonne National Laboratory

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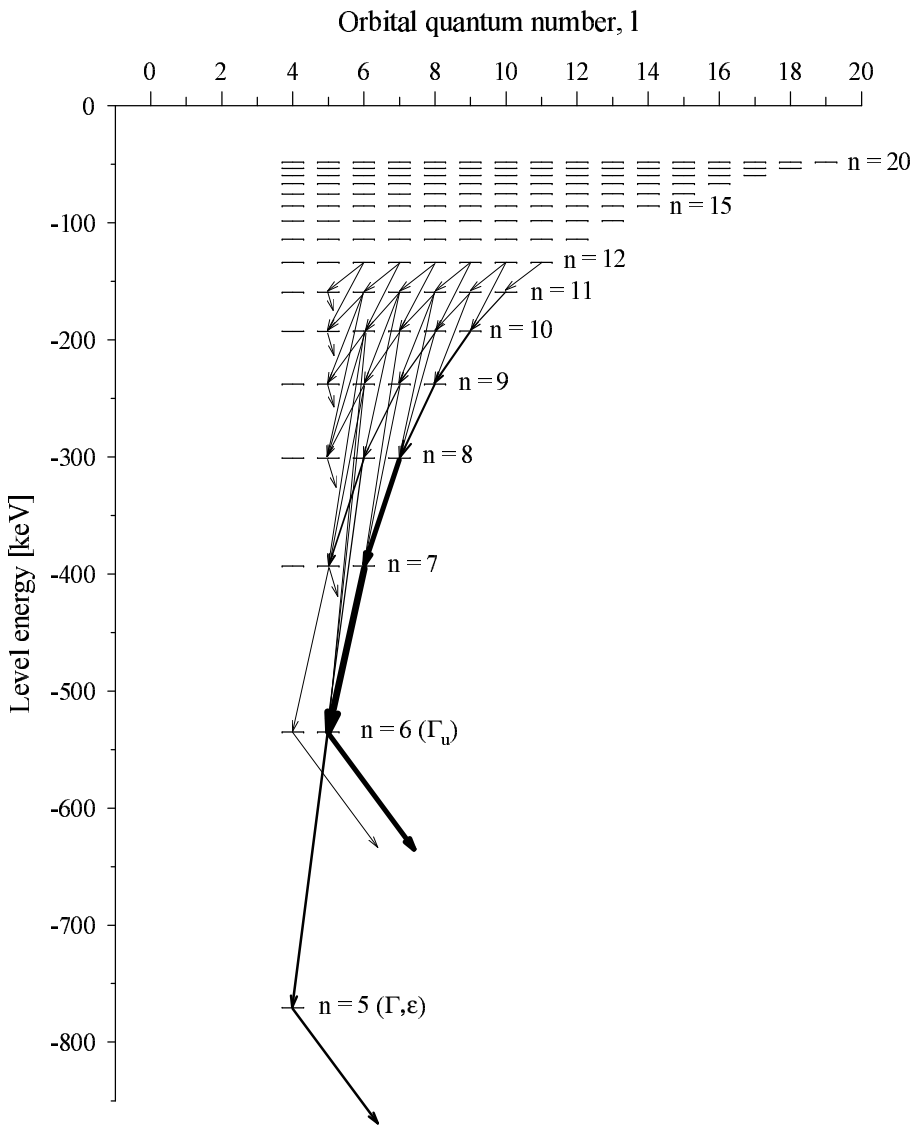
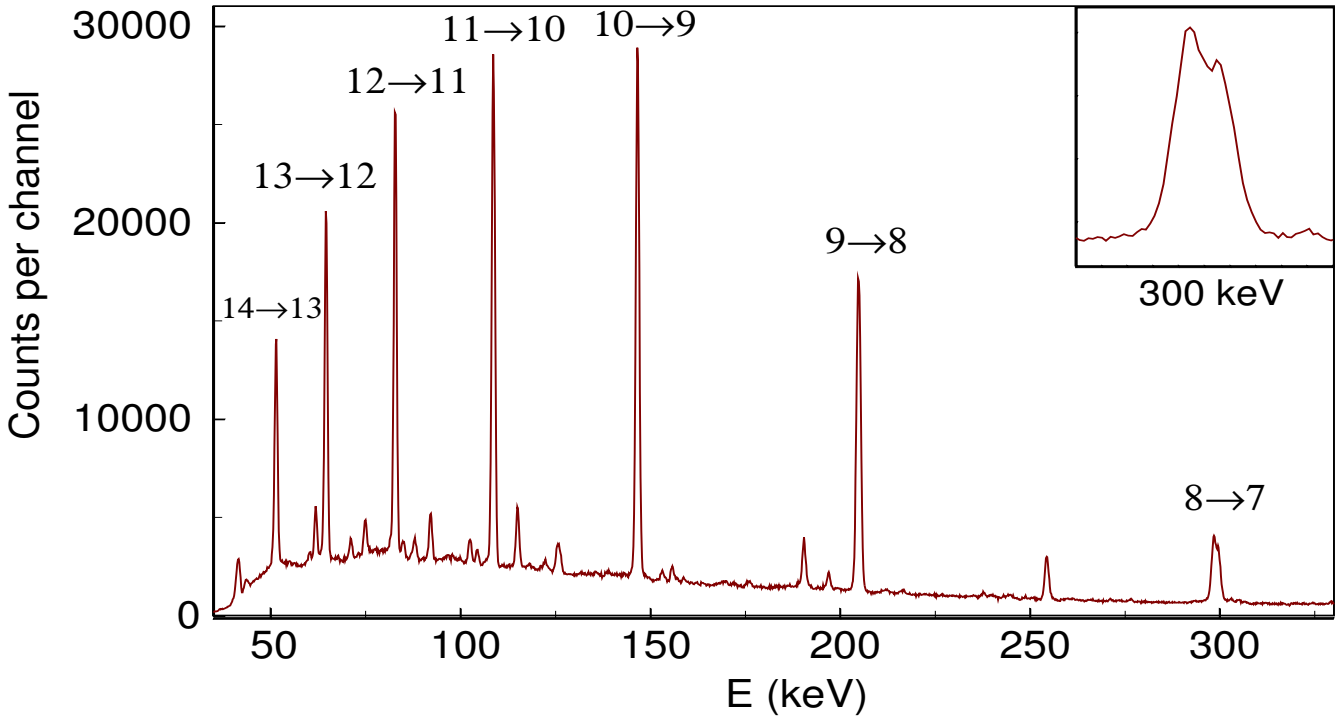
Contents:

- Antiprotonic atoms
- Radiochemical method of the nuclear periphery study
- Comparison with previous neutron rms data: “neutron skin” or “neutron halo”?
- Peripheral neutron distribution from antiprotonic X-rays
- Proton-neutron rms difference Δr_{np}
  - comparison with hadron scattering data , droplet model and mean field calculations
- Projects for unstable atoms
- Conclusions

Antiprotonic cascade in Ni

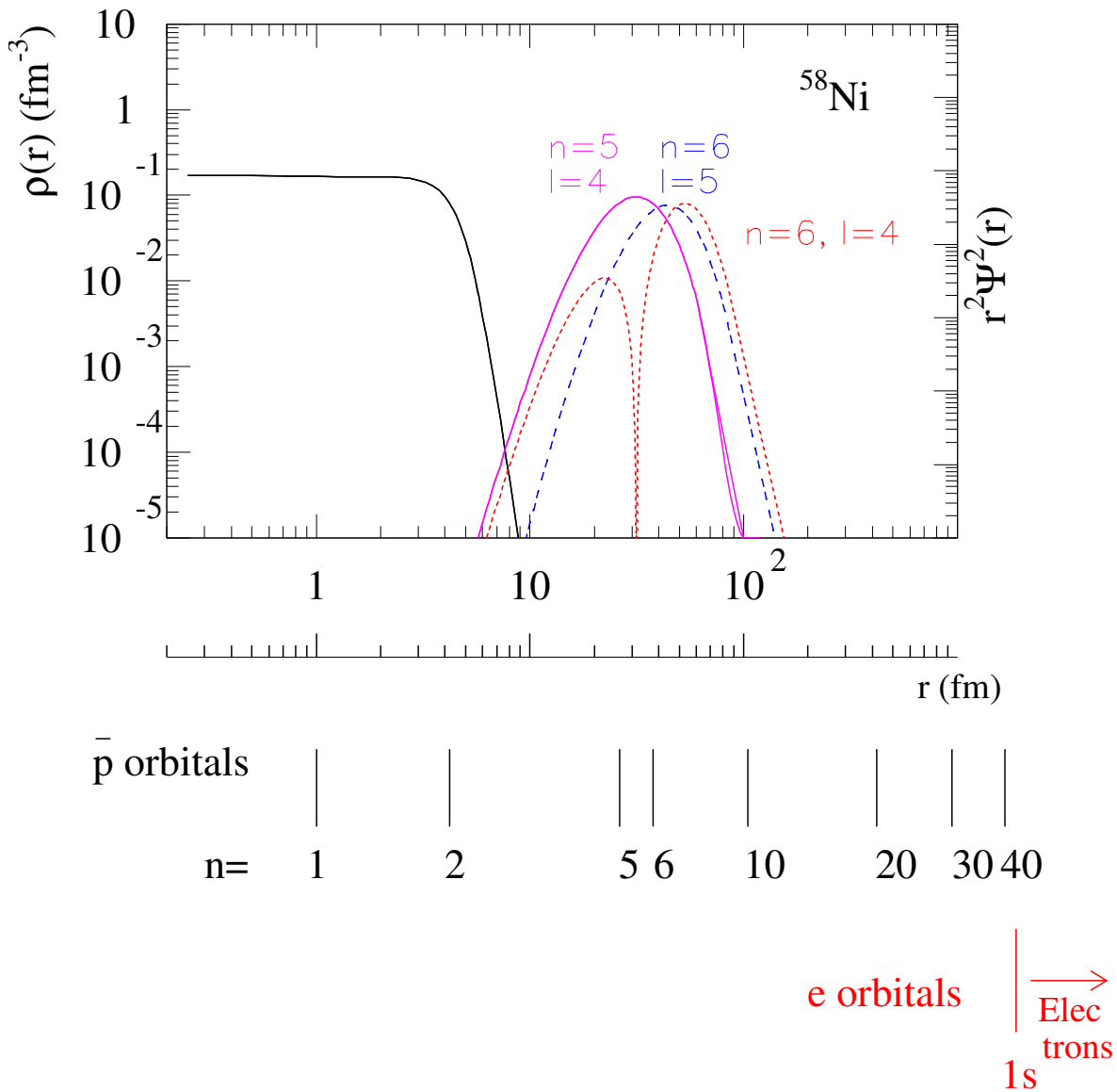


Spectrum - example

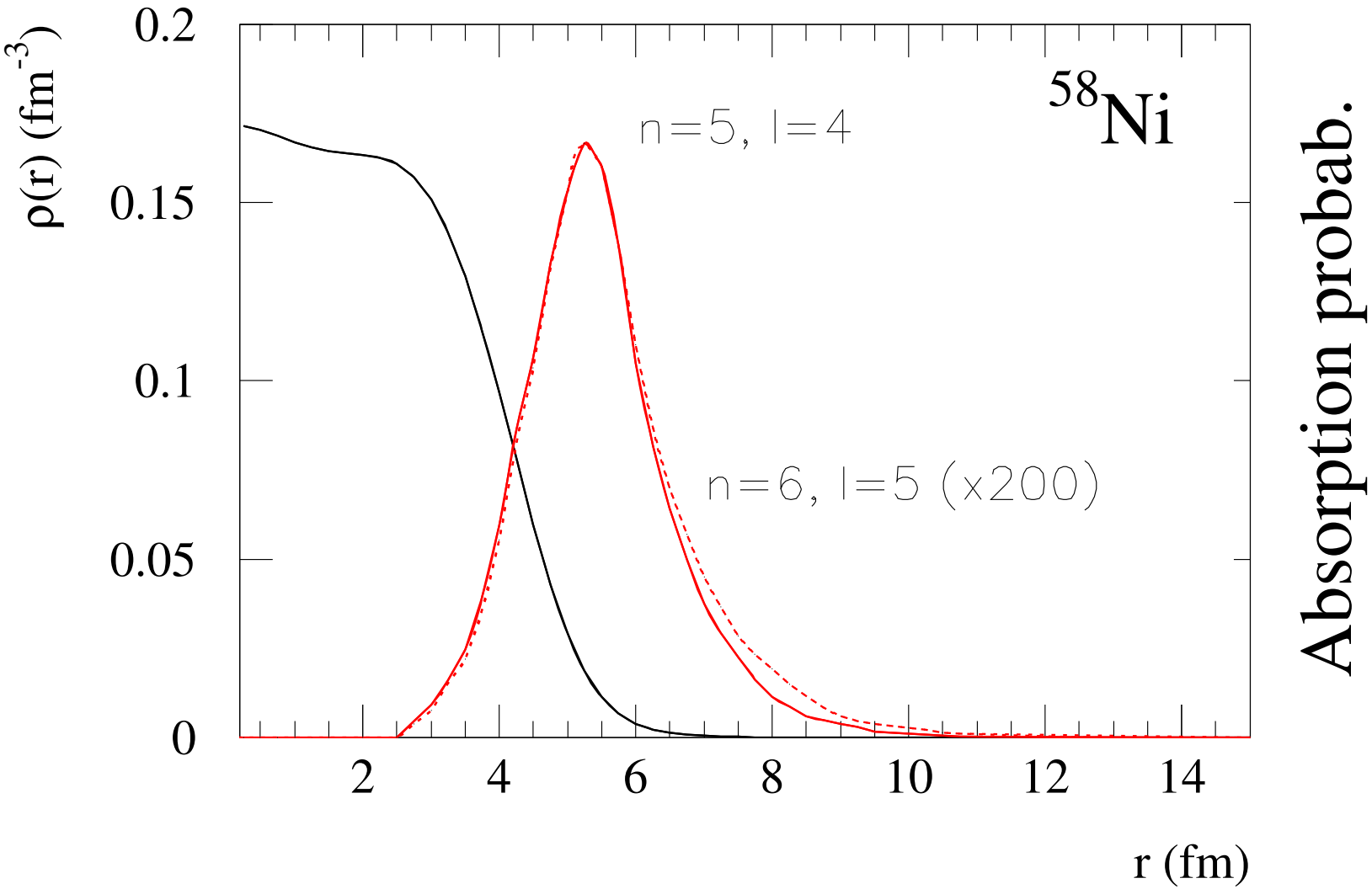


^{124}Sn

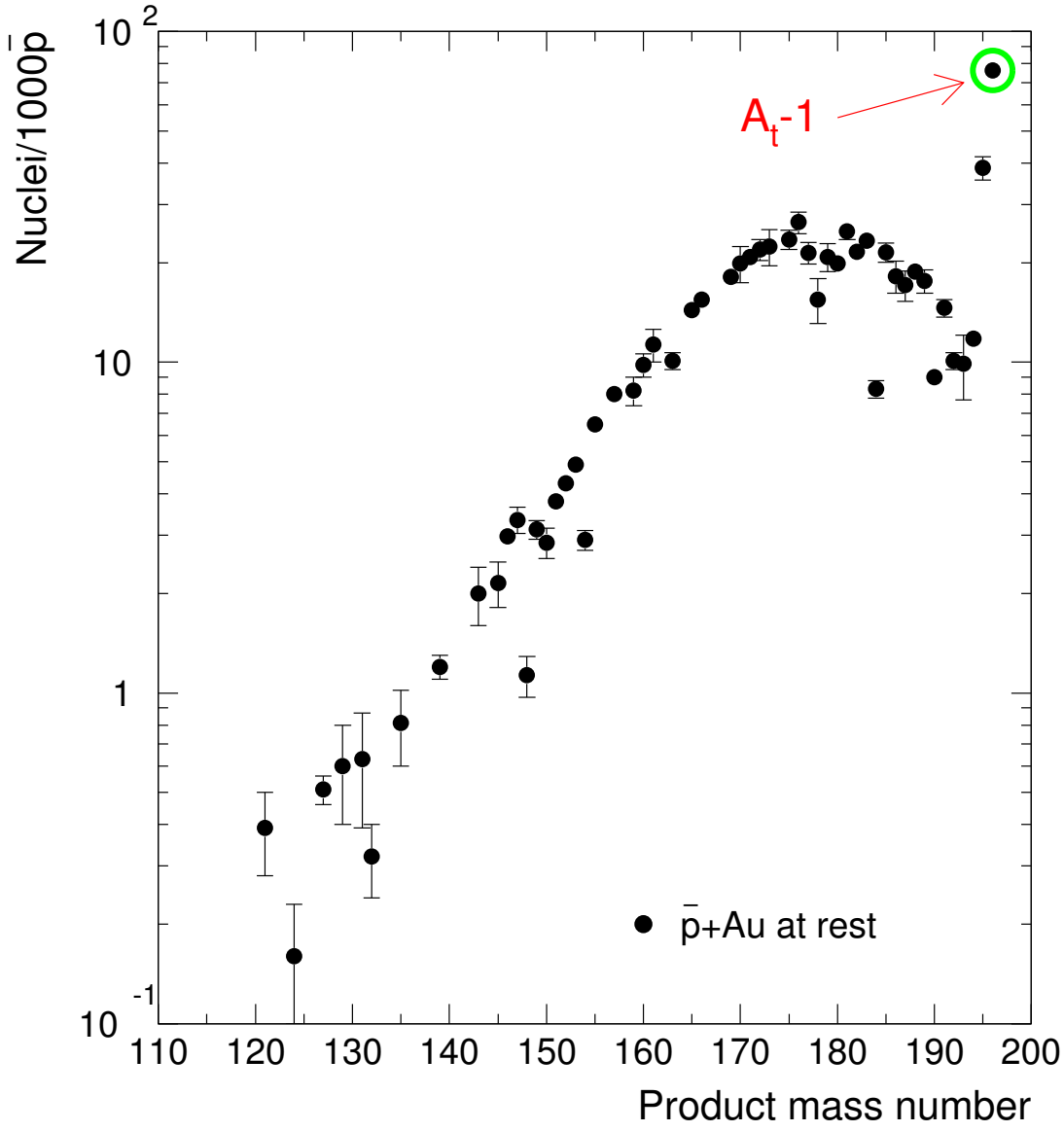
Space relations



Absorption probability

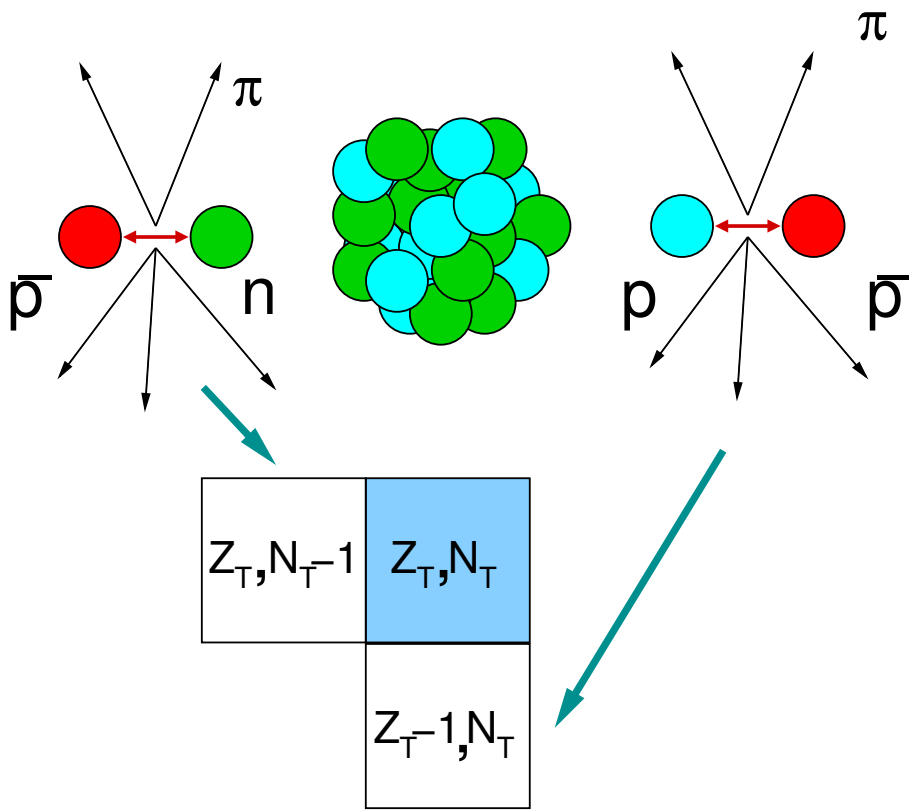


Radiochemical method



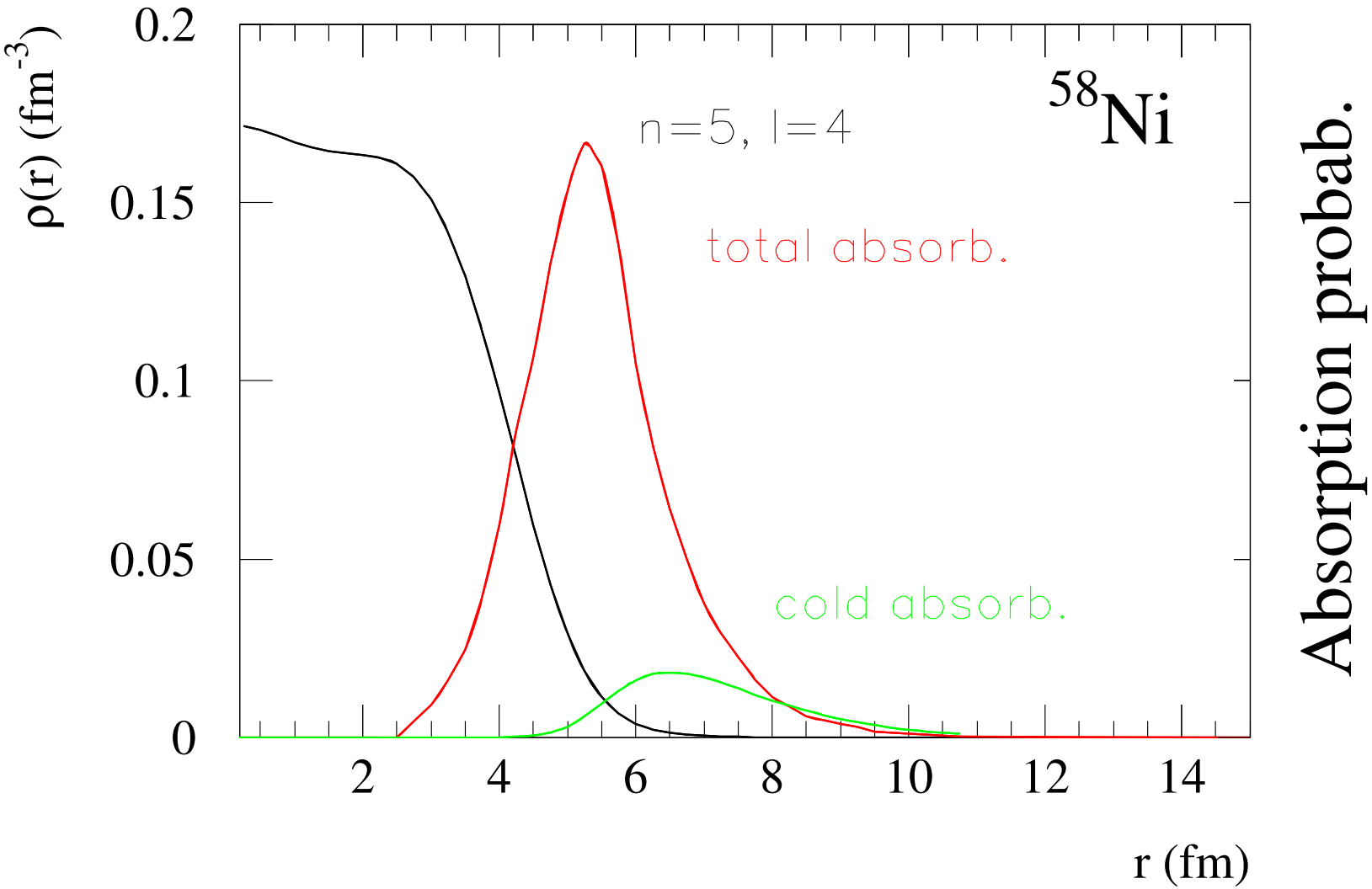
PS203

Principle of the radiochemical method

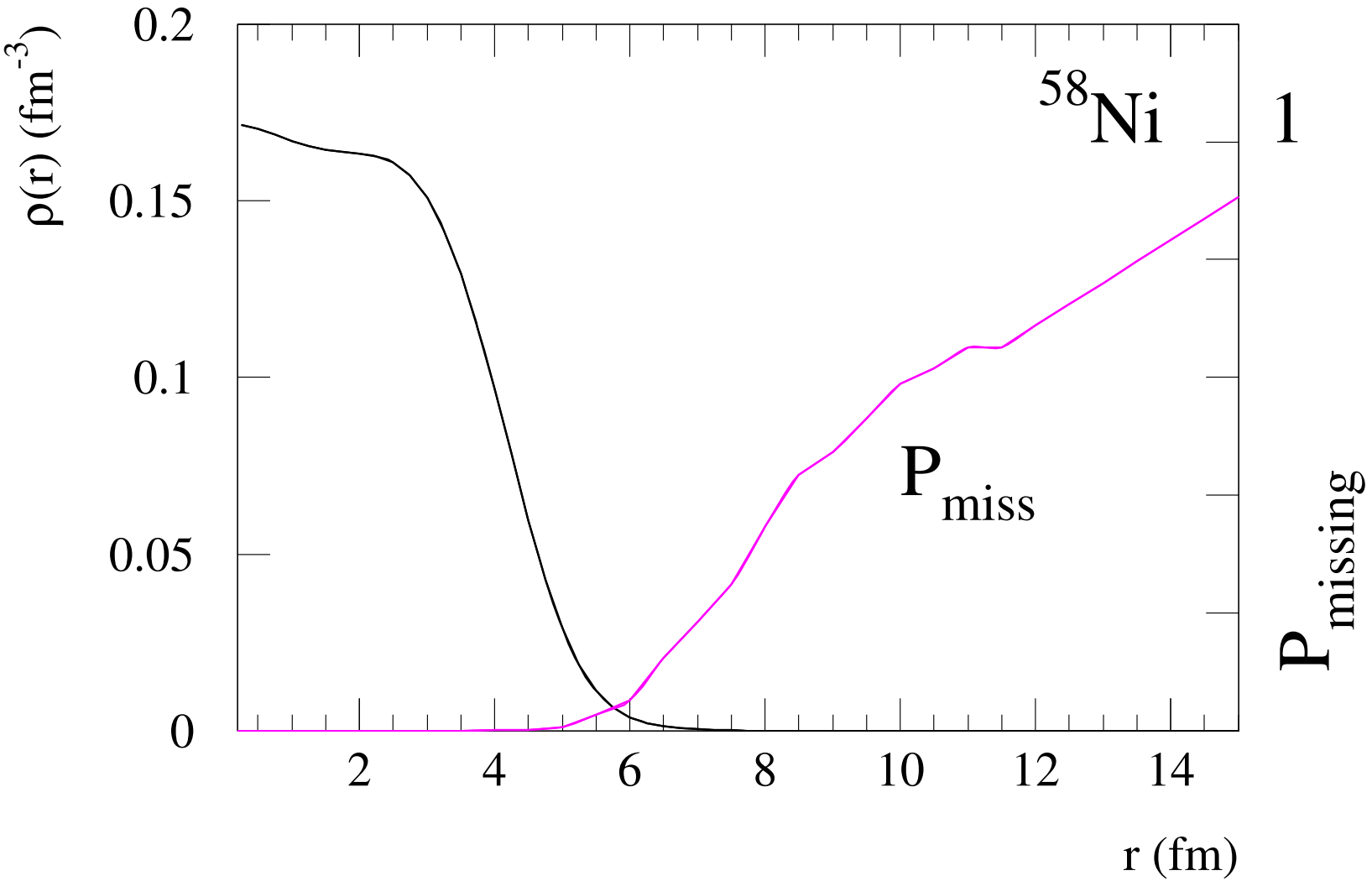


$$f_{\text{halo}} = \frac{N(\bar{p}n)}{N(\bar{p}p)} \cdot \frac{Z}{N} \cdot \frac{\text{Im}(a_p)}{\text{Im}(a_n)}$$

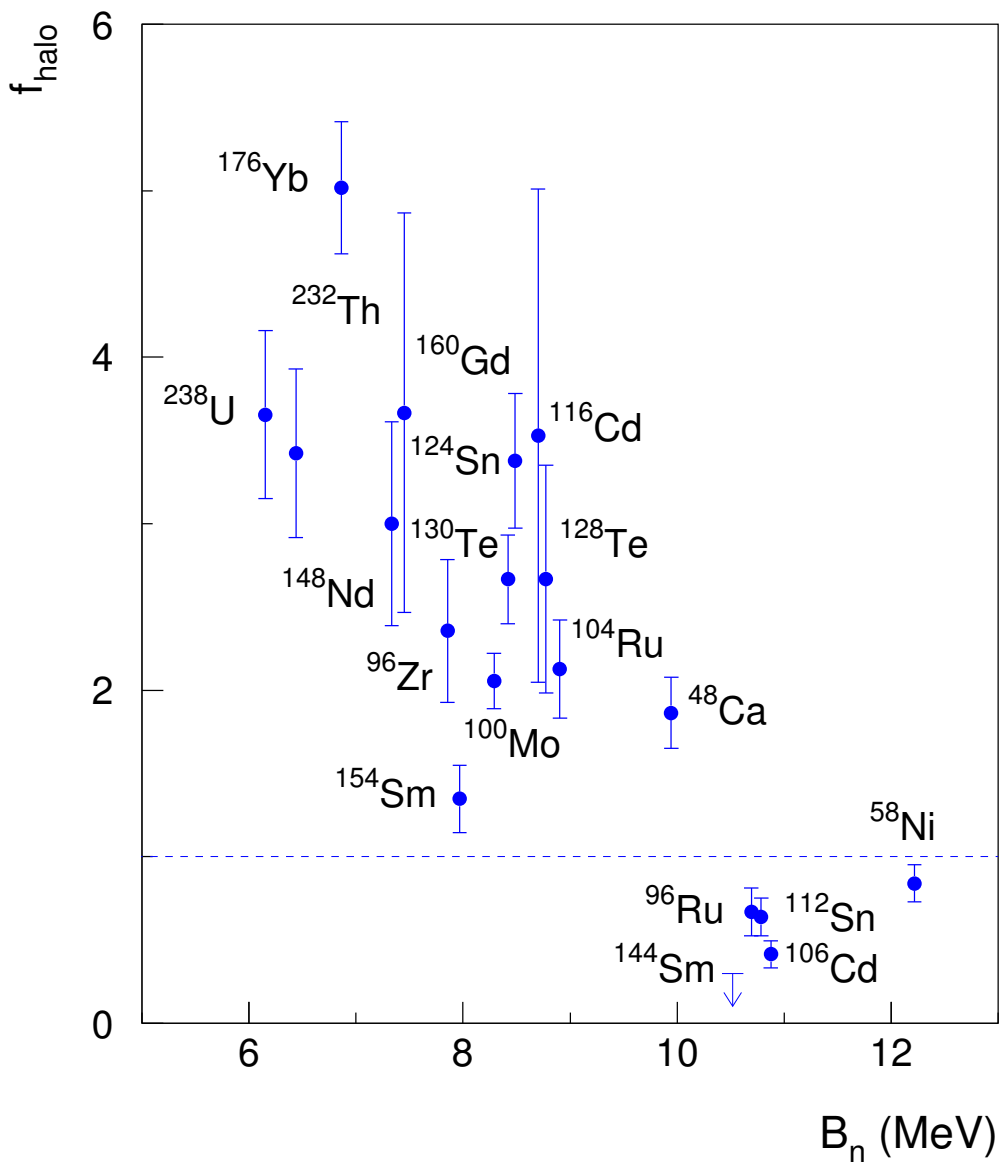
Cold absorption probability



Missing probability

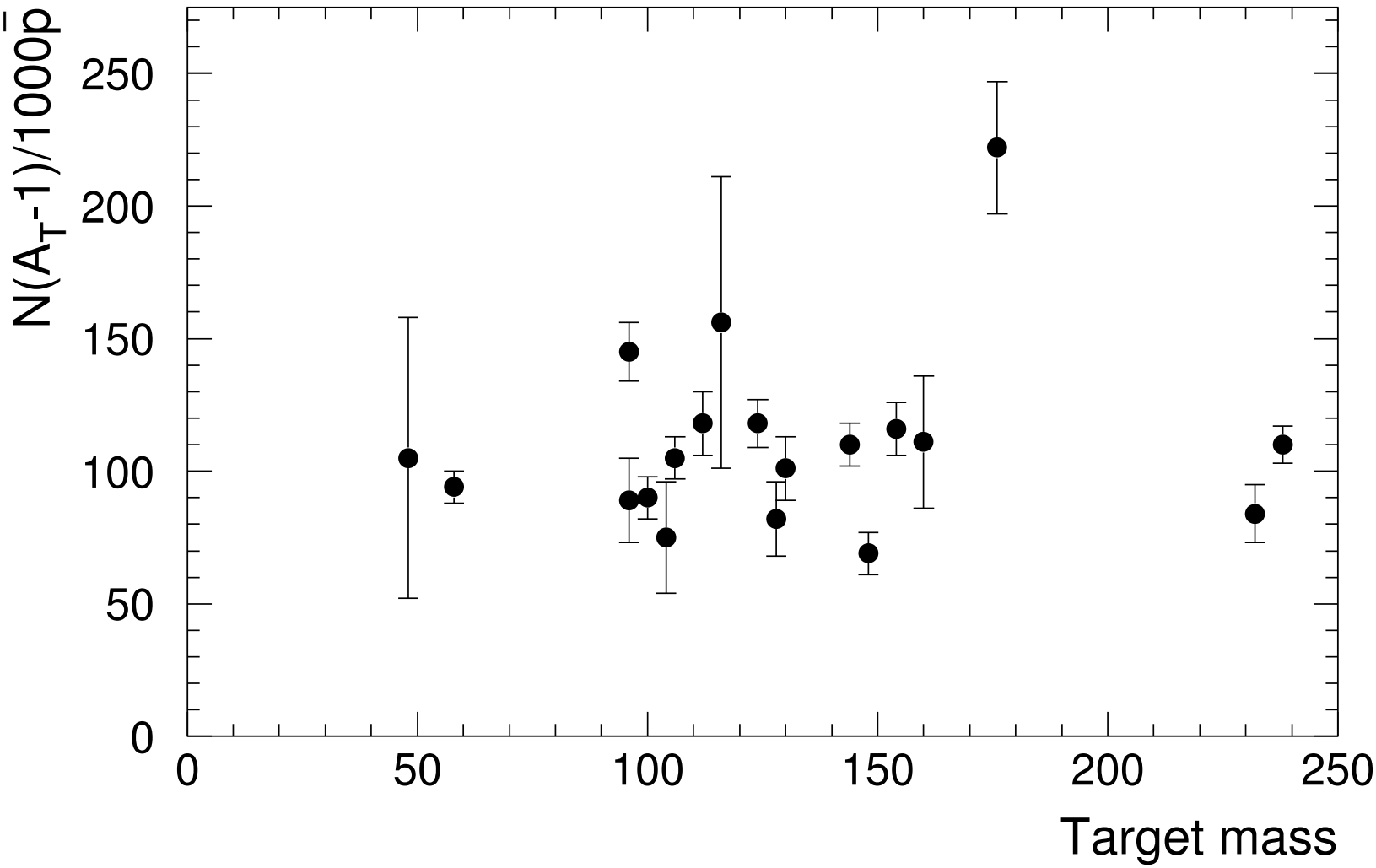


Radiochemical method – results



$$f_{halo} = \frac{N(\bar{p}n)}{N(\bar{p}p)} \cdot \frac{Z}{N} \cdot \overbrace{\frac{Im(a_p)}{Im(a_n)}}^{=1}$$

$A_T - 1$ production



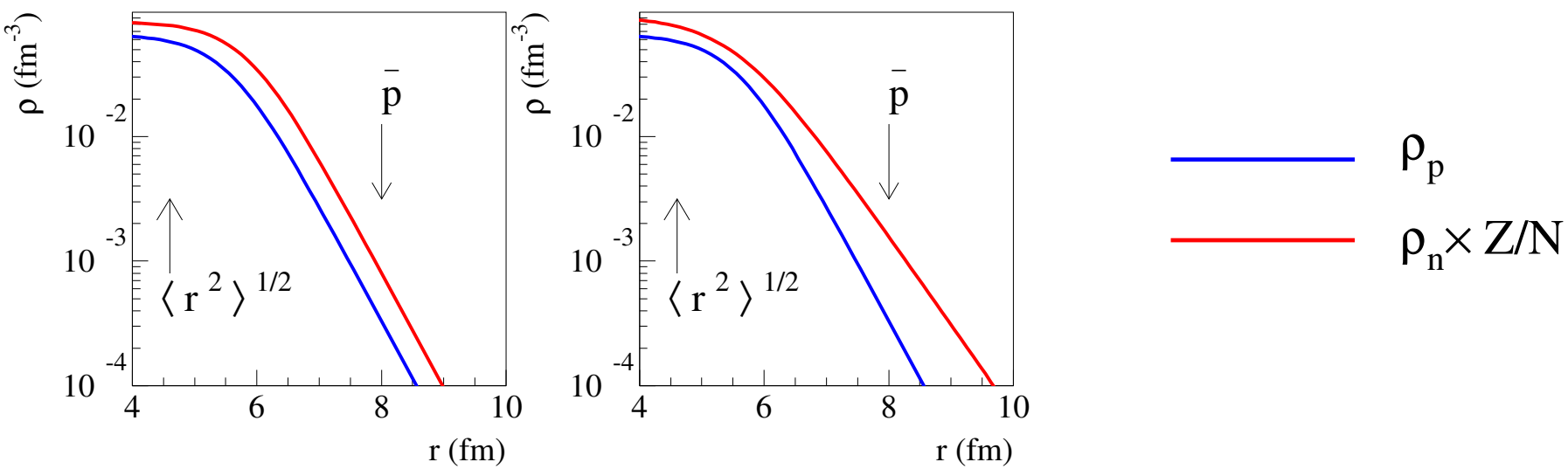
NEUTRON DENSITY DISTRIBUTION

from Δr_{np} and antiproton data

$$\rho(r) = \rho_0 \left(1 + \exp\left(\frac{r-c}{a}\right)\right)^{-1}$$

$$\langle r_n^2 \rangle = \frac{3}{5} c_n^2 + \frac{7}{5}\pi^2 a_n^2$$

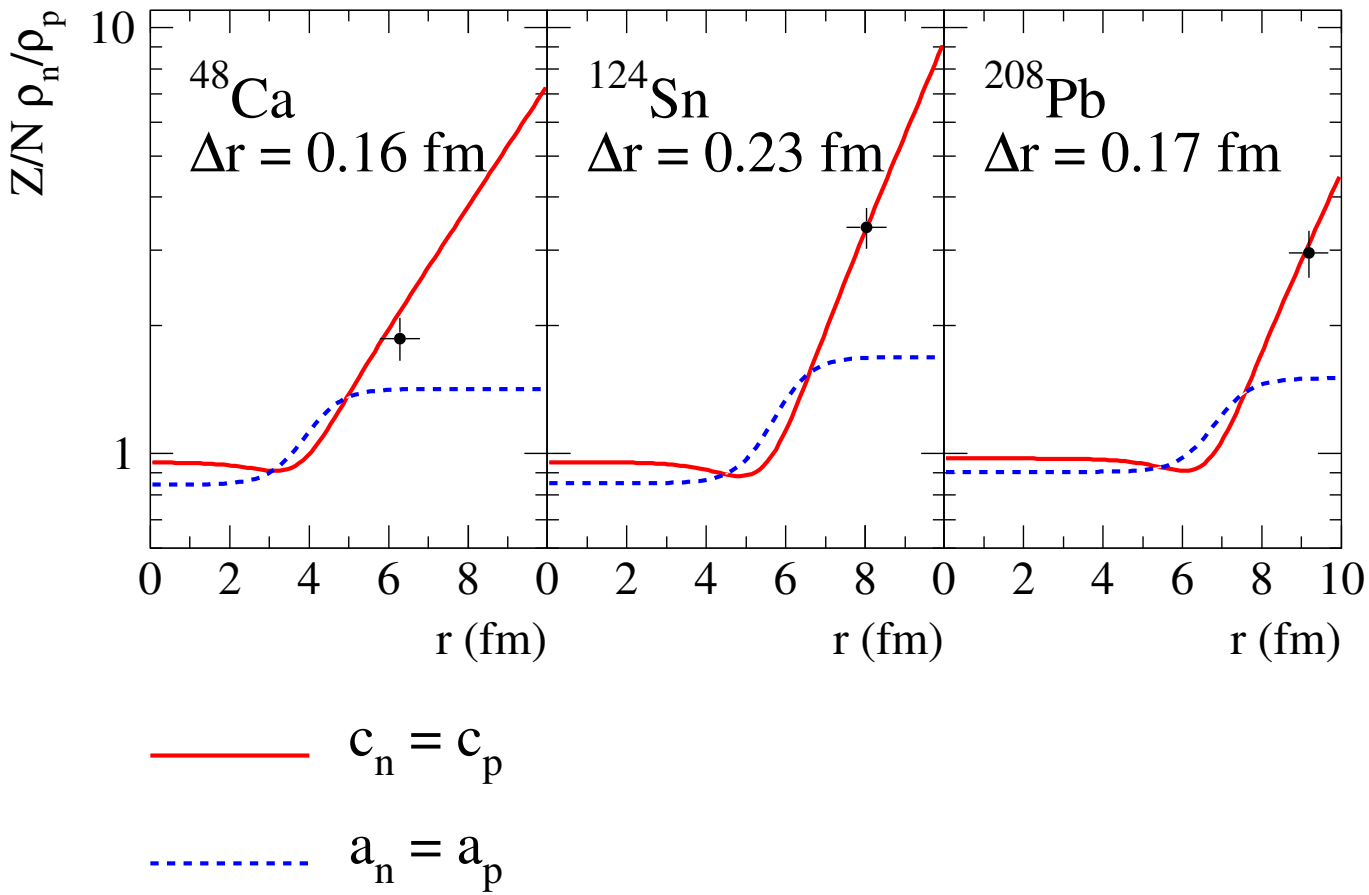
Two extreme cases illustrated by ^{124}Sn: Δr_{np} = 0.22 $\pm$ 0.03 fm



$a_n = a_p$
"neutron skin"

$c_n = c_p$
"neutron halo"

halo factor vs Δr_{np}



Conclusion: Δr_{np} caused by ”neutron halo” rather than ”neutron skin”.

Antiprotonic X-rays ...

... another tool for the investigation of the nuclear periphery: strong interaction level **widths** and **shifts** depend on the antiproton-nucleus potential:

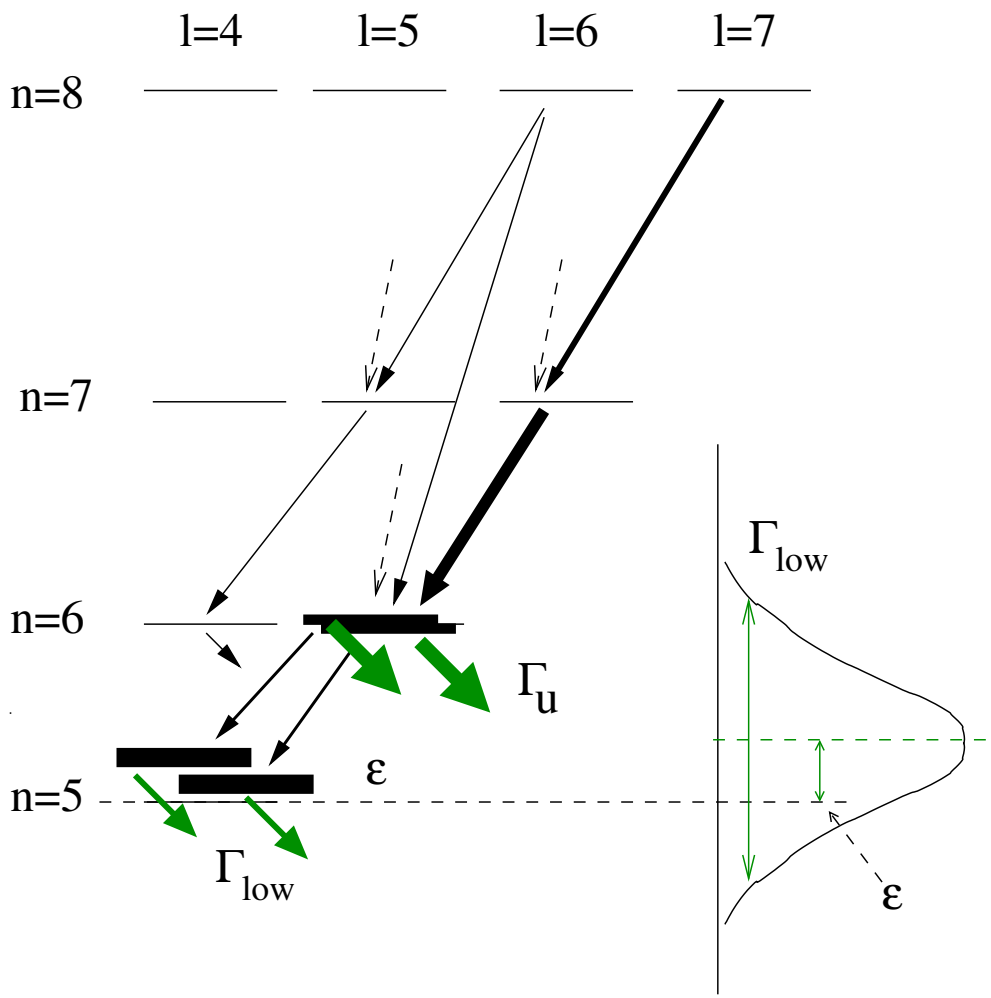
$$V_{opt} = -\frac{2\pi}{\mu}\left(\bar{a}_n\,\rho_n(r) + \bar{a}_p\,\rho_p(r)\right)$$

$$\bar{a}_p = \bar{a}_n = 2.5 + i\,3.4\,\mathrm{fm}$$

$$\frac{\Gamma}{2} \sim \int \mathrm{Im}\,V(r)\;|\Psi_{nl}(r)|^2\,r^2\,dr$$

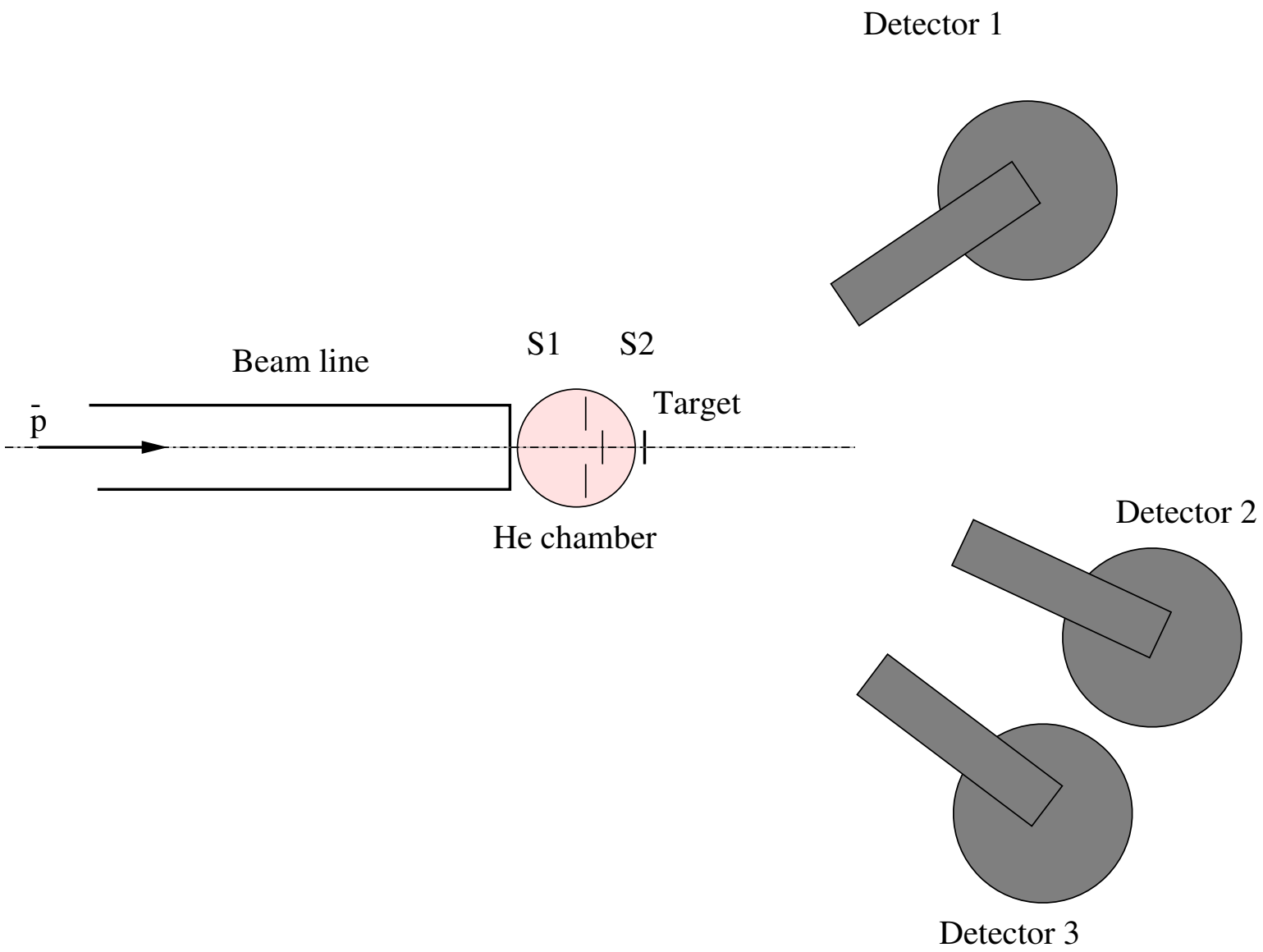
$$\frac{\epsilon}{2} \sim \int \mathrm{Re}\,V(r)\;|\Psi_{nl}(r)|^2\,r^2\,dr$$

observables

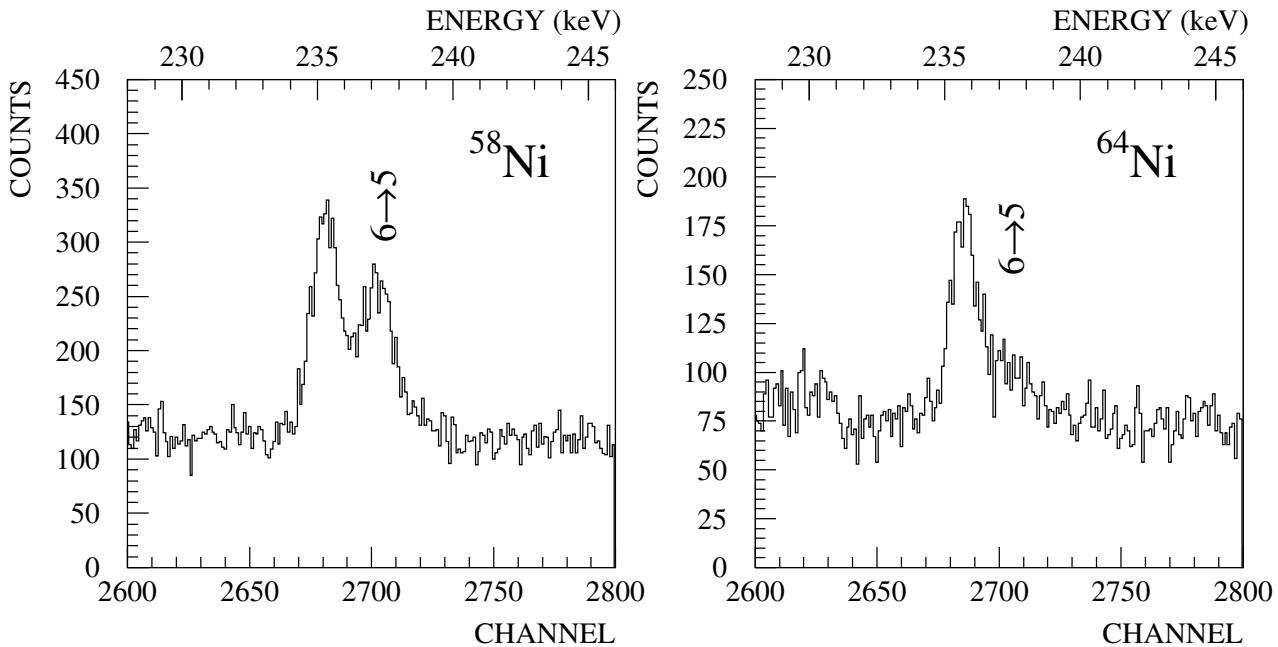


levels broadening (Γ_{low}, Γ_{up}) and shift (ϵ) measured in the experiment

Experimental set-up



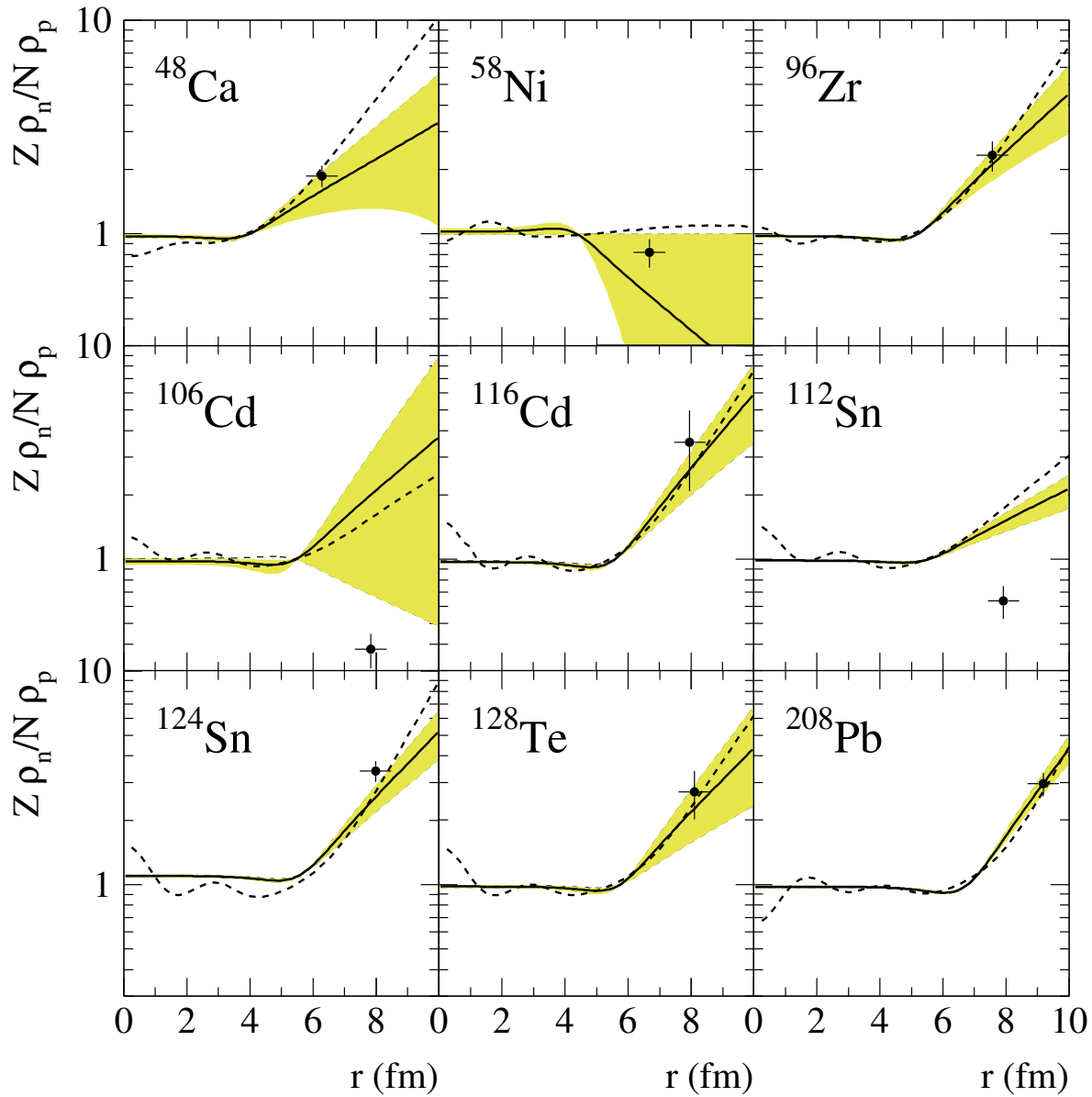
Antiprotonic X-rays



$$V_{opt} = -\frac{2\pi}{\mu}(\bar{a}_n \rho_n(r) + \bar{a}_p \rho_p(r))$$

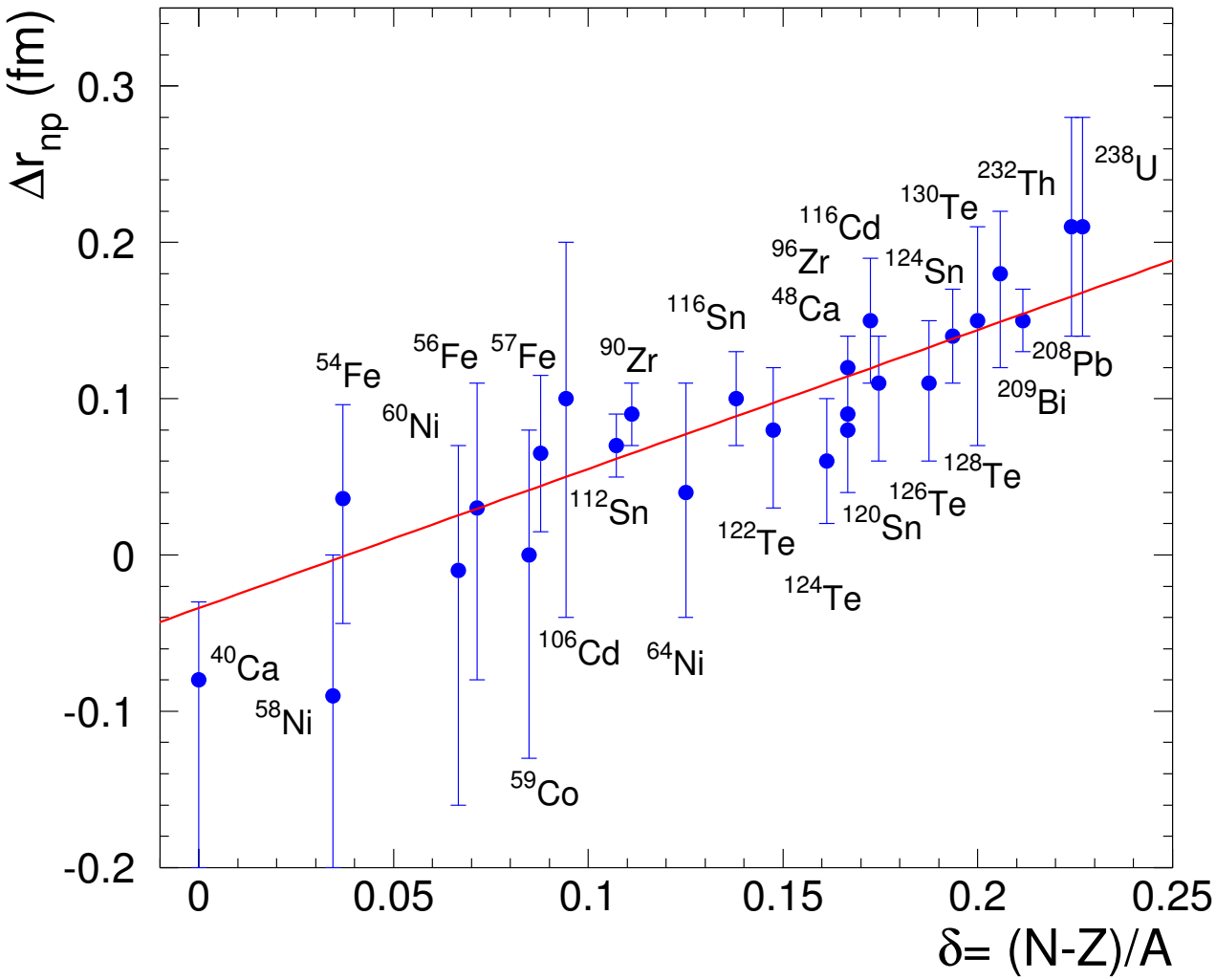
$$\frac{\Gamma}{2} = \int \mathrm{Im}\, V(r)\ |\Psi_{nl}(r)|^2\, r^2\, dr$$

Results: ρ_n/ρ_p



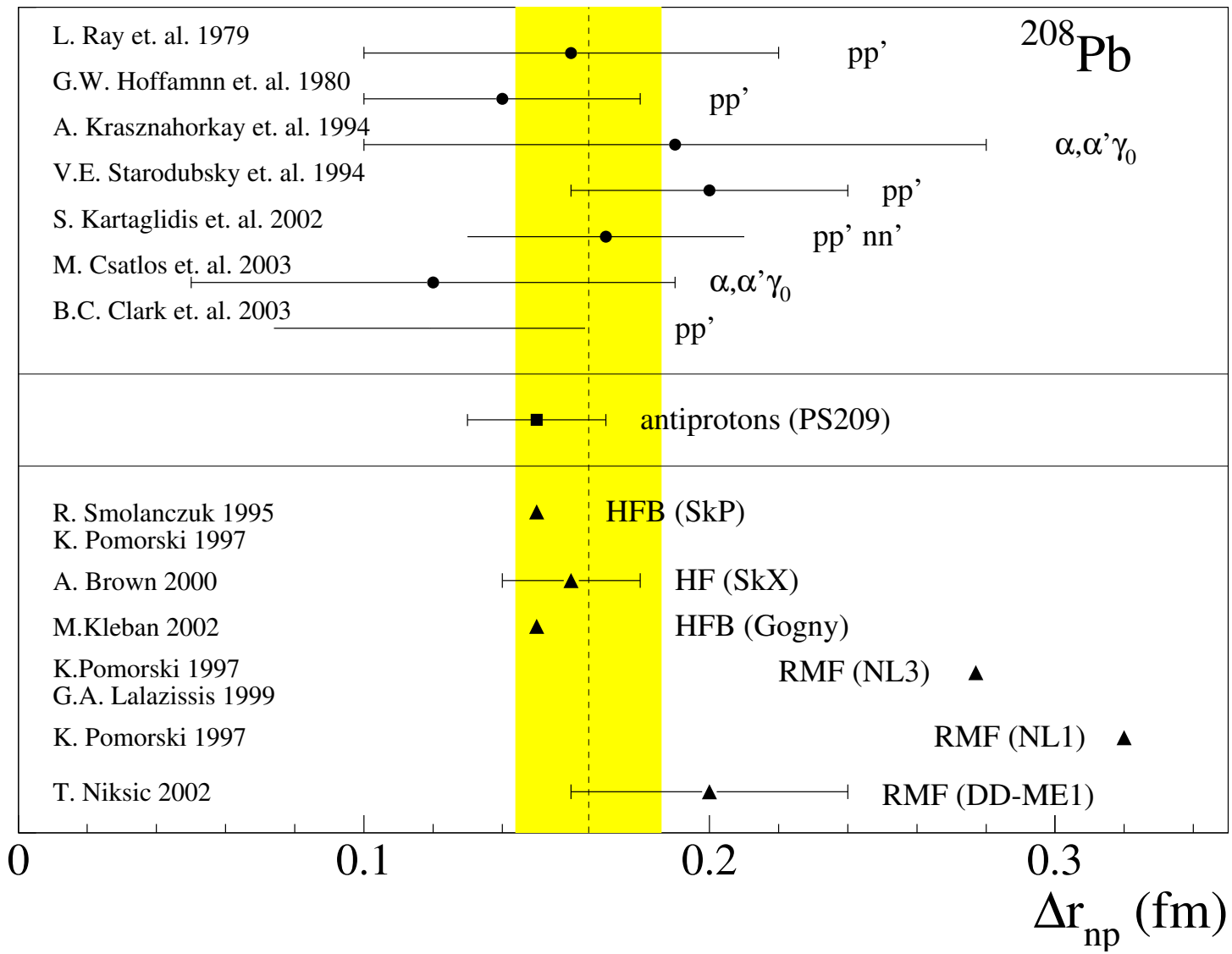
Systematics of Δr_{np}

determined from PS209 data

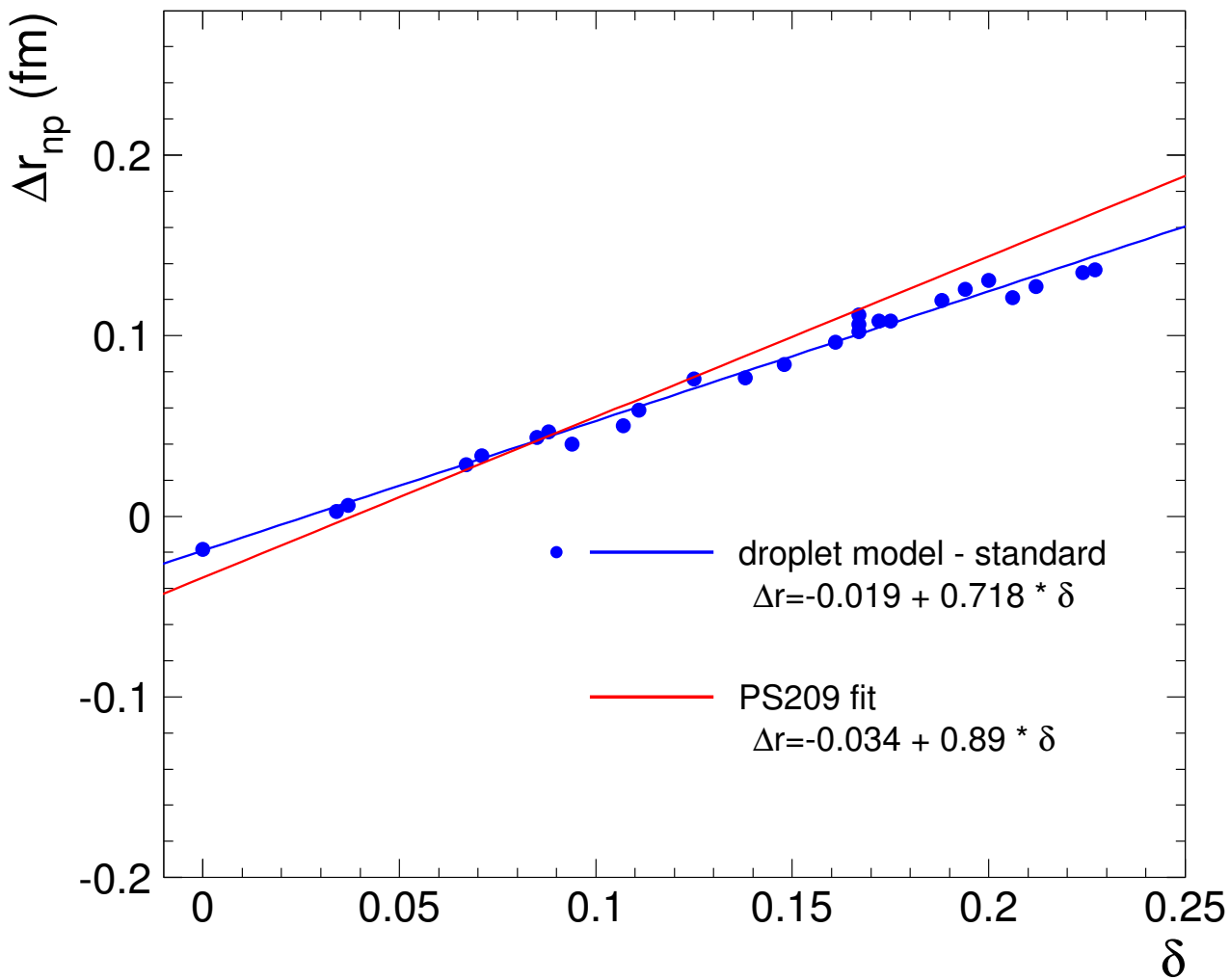


$$\Delta r_{np} = (-0.03 \pm 0.02) + (0.90 \pm 0.15) \cdot \delta \text{ fm}$$

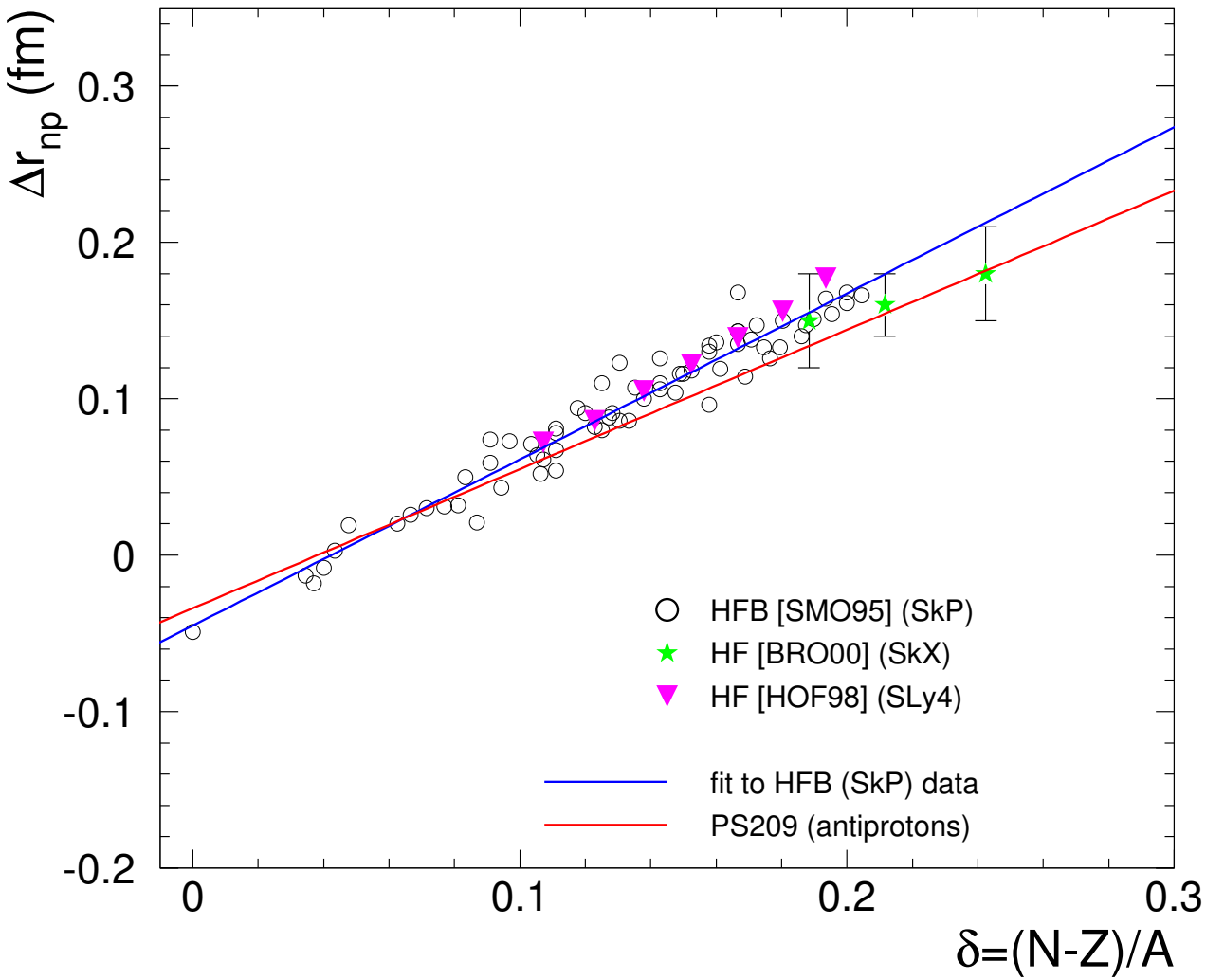
^{208}Pb


L. Ray et. al. 1979
pp'
^{208}Pb
G.W. Hoffamnn et. al. 1980
pp'
A. Krasznahorkay et. al. 1994
α,α'γ0
V.E. Starodubsky et. al. 1994
pp'
S. Kartaglidis et. al. 2002
pp' nn'
M. Csatlos et. al. 2003
α,α'γ0
B.C. Clark et. al. 2003
pp'
antiprotons (PS209)
R. Smolanczuk 1995
K. Pomorski 1997
HFB (SkP)
A. Brown 2000
HF (SkX)
M.Kleban 2002
HFB (Gogny)
K.Pomorski 1997
G.A. Lalazissis 1999
RMF (NL3)
K. Pomorski 1997
RMF (NL1)
T. Niksic 2002
RMF (DD-ME1)
0
0.1
0.2
0.3
Δr$_{np}$ (fm)

Droplet model vs PS209 results



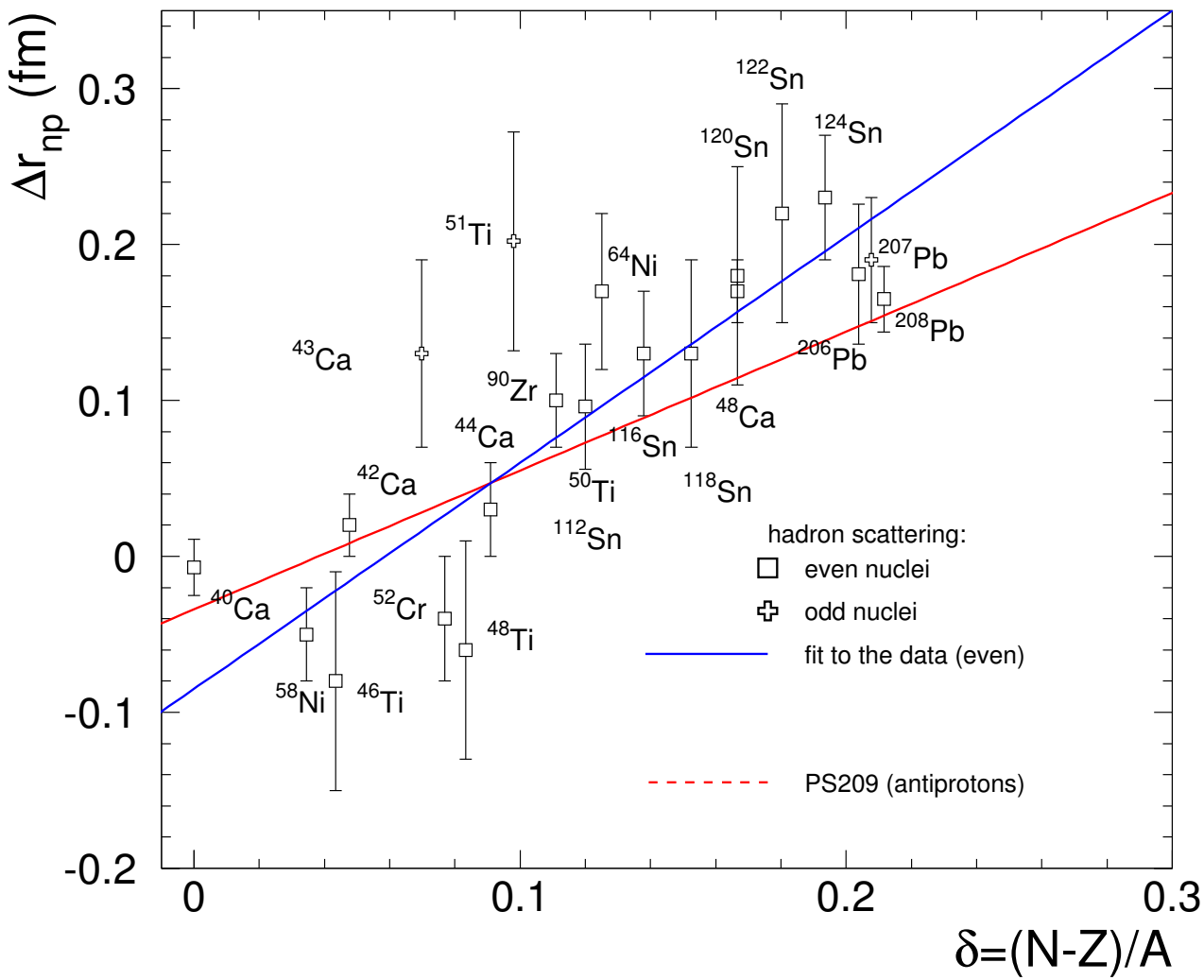
Δr_{np} from theoretical predictions



Δr_{np} = (-0.05 +/- 0.01) + (1.06 +/- 0.08) * δ fm

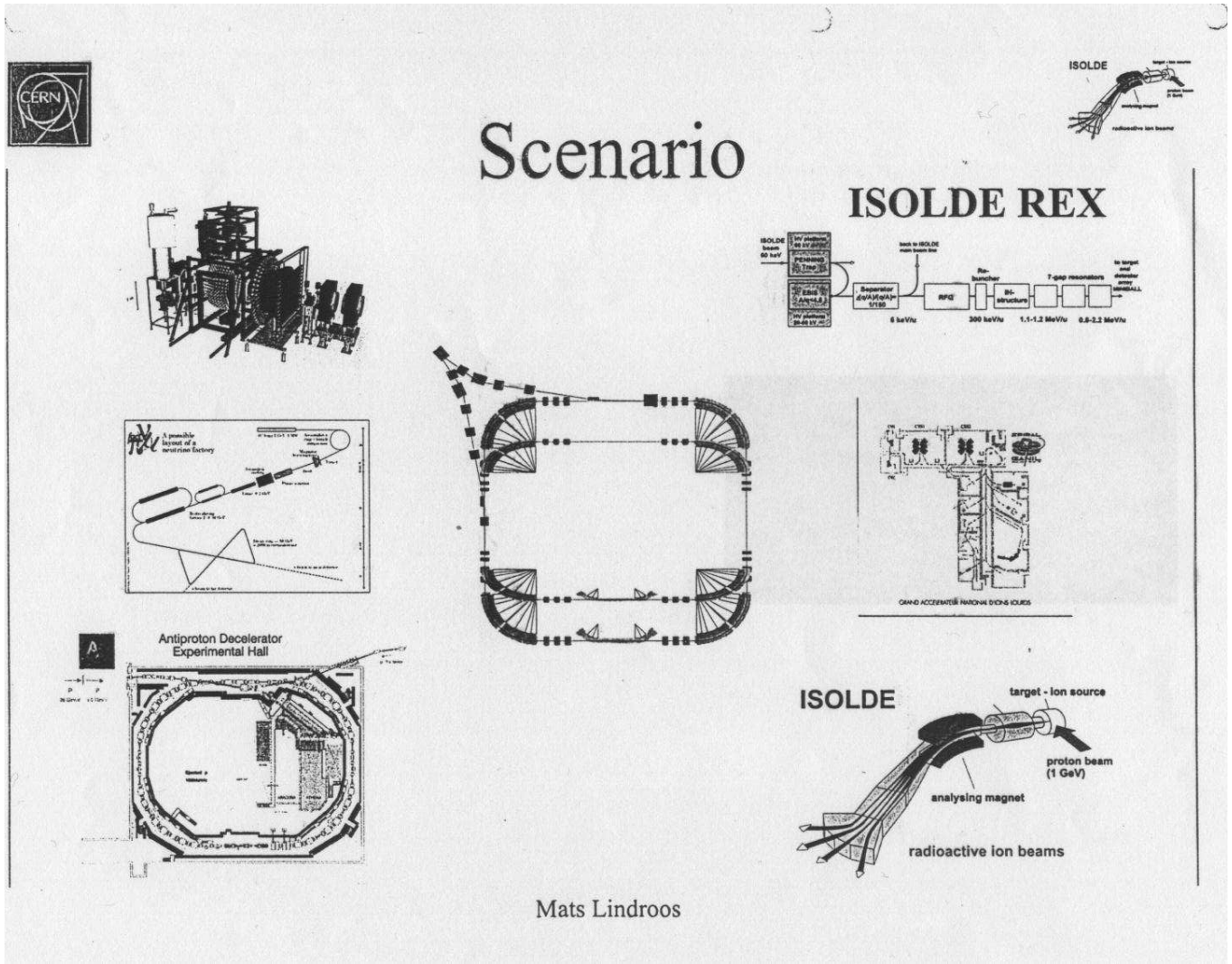
Δr_{np} = (-0.03 +/- 0.02) + (0.90 +/- 0.15) * δ fm

Δr_{np} from other experiments



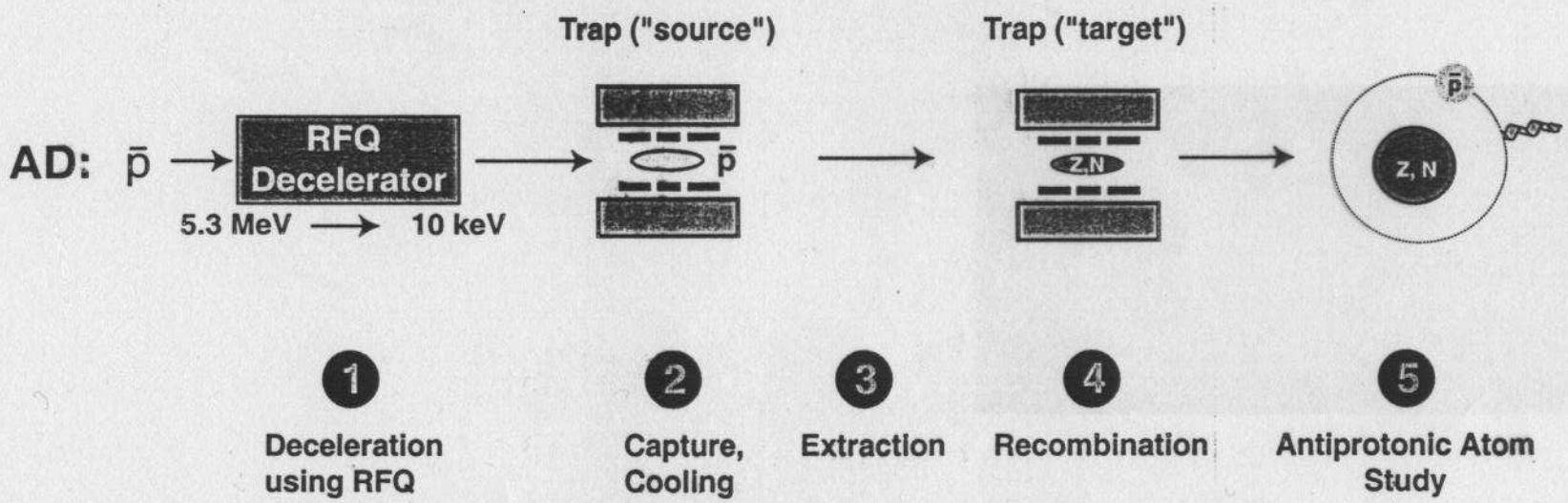
Δr_{np} = (-0.09 +/- 0.02) + (1.45 +/- 0.12) * δ fm

Δr_{np} = (-0.03 +/- 0.02) + (0.89 +/- 0.15) * δ fm



presented by M.Lindroos at “CERN Antiproton-radioactive beams meeting”, 22nd February FEB 2001

OPTION D: RFQ + Trap + Re-extraction (0 - 60 keV)



presented by R.Landua at "CERN Antiproton-radioactive beams meeting", 22nd February FEB 2001

FLAIR

FLAIR

A Facility for Low-energy Antiproton and Ion Research

Letter of Intent for the Future Accelerator

Facility for Beams of Ions and Antiprotons at Darmstadt

February 23, 2004

FLAIR – layout

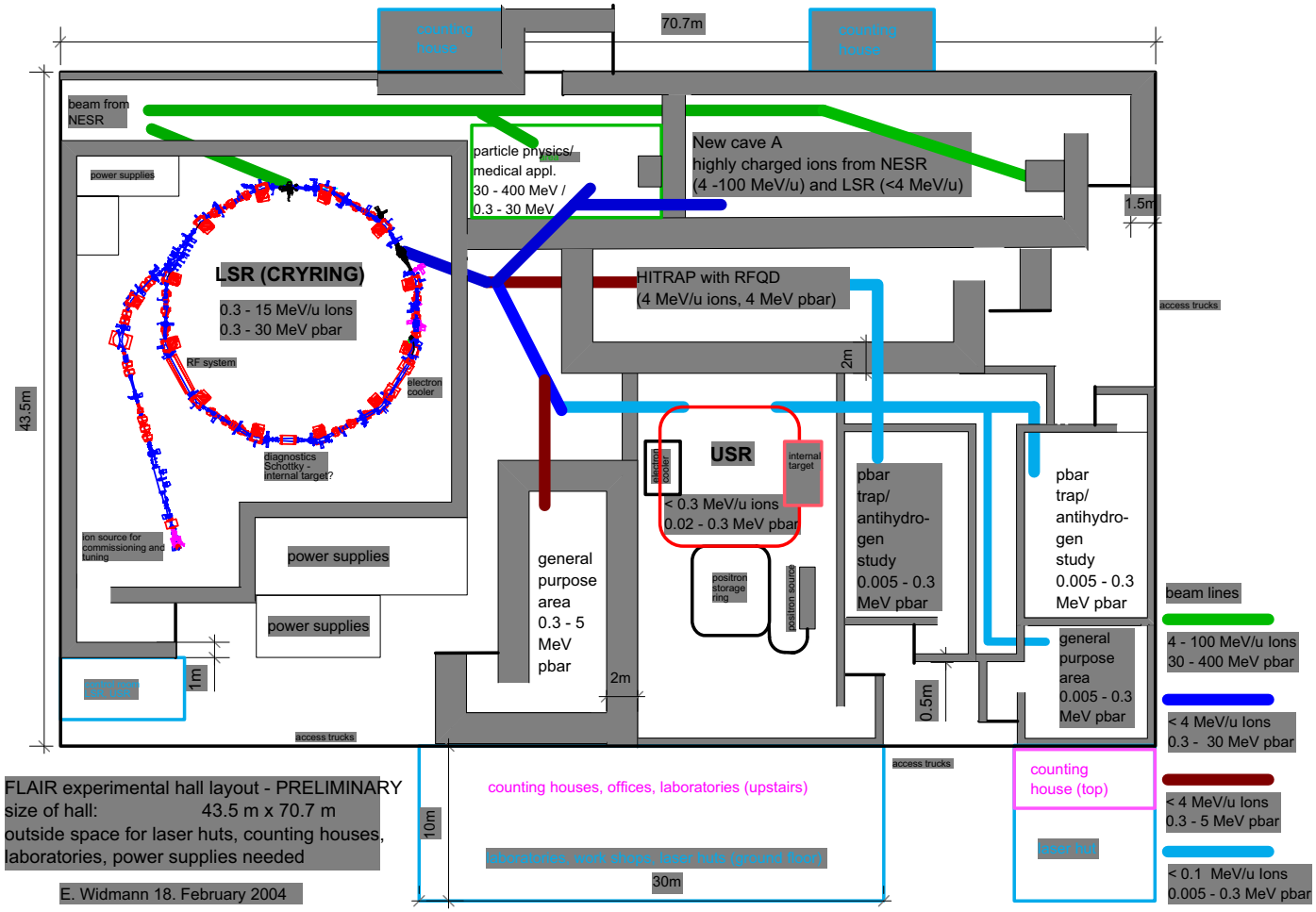


Figure 15: Preliminary layout of the low-energy antiproton and heavy ion facility.

Summary & conclusions:

1. Two experimental methods using antiprotonic atoms were employed to investigate the properties of the nuclear periphery
   - radiochemical method ρ_n/ρ_p at r_{ch}+2.5 fm
   - widths and shifts $\rho_n + \rho_p$ at r_{ch}+1.5 fm
2. Experimental data were interpreted using 2pF model of the nuclear periphery.
3. Previous determinations of $\Delta r_{np} = \langle r_n^2 \rangle^{1/2} - \langle r_p^2 \rangle^{1/2}$ compared with results of radiochemical method indicate a ”halo type” neutron distribution in neutron rich nuclei.

Summary & conclusions (continuation):

4. Neutron distributions deduced from widths and shifts – a linear relationship of Δr_{np} vs $\delta = \frac{N-Z}{A}$.
5. Hadron scattering data:
   - excellent agreement for ^{208}Pb;
   - hadron data: slope of $\Delta r_{np}(\delta)$ larger than for antiprotonic data.
6. Theory: HFB, thermodynamical consideration, droplet model — in agreement with antiprotonic data.

PS209 Collaboration

Warsaw University

Heavy Ion Laboratory

T. Czosnyka, J. Iwanicki, J. Jastrzębski, M. Kisieliński, P. Lubiński, P. Napiorkowski, L. Pieńkowski, A. Stolarz, A. Trzcińska

Institute of Exeprimental Physics

K. Gulda, W. Kurcewicz

Technical University, Munich

T. von Egidy, F.J. Hartmann, B. Ketzer, R. Schmidt

Physics Departament, Silesian University, Katowice

B. Kłos

Sołtan Institute for Nuclear Studies

Kulpa, R. Smolańczuk, S.Wycech

Group Photo