Physics with Exotic Nuclei and Exotic Atoms at Relativistic Energies

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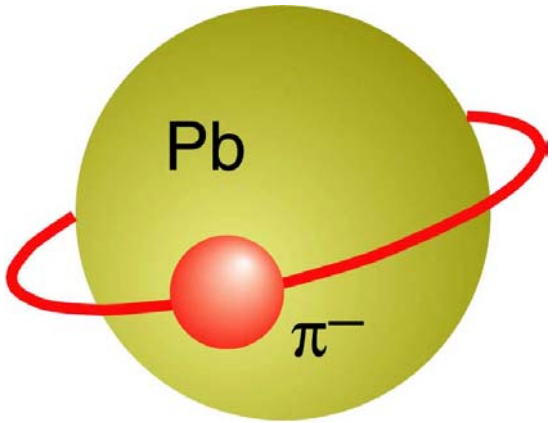
Euroschool Valencia, September 2003

- Introduction √
- Momentum Measurements, Ion Optics, Spectrometers √
- Atomic Interaction of Heavy Ions √

- **Exotic Atoms**

Discovery of Deeply Bound Pionic States in Heavy Atom



- Deeply Bound Pionic States in Pb
- Deeply Bound Pionic States in Sn
- Study of pion mass modification in nuclei
- Future experiments

JLTUG

GSI

Spectroscopy of 1s Pionic States in Pb and Sn Isotopes

M. Fujita, H. Geissel,
H. Gilg, A. Gillitzer,
R.S. Hayano, S. Hirenzaki,
K. Itahashi, M. Iwasaki,
P. Kienle, L. Maier,
M. Matos, G. Münzenberg,
T. Ohtsubo, M. Sato,
M. Shindo, K. Suzuki,
T. Suzuki, H. Weick,
M. Winkler, T. Yamazaki,
T. Yoneyama.

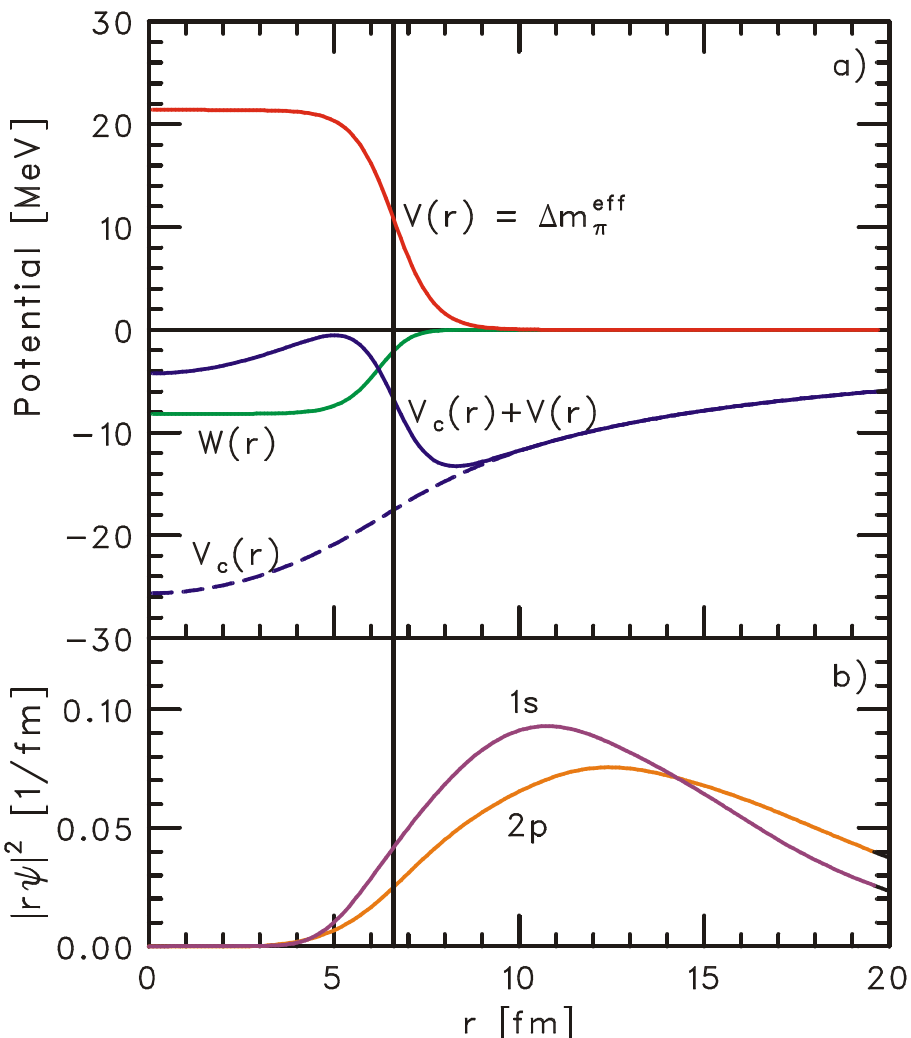
Pionic States

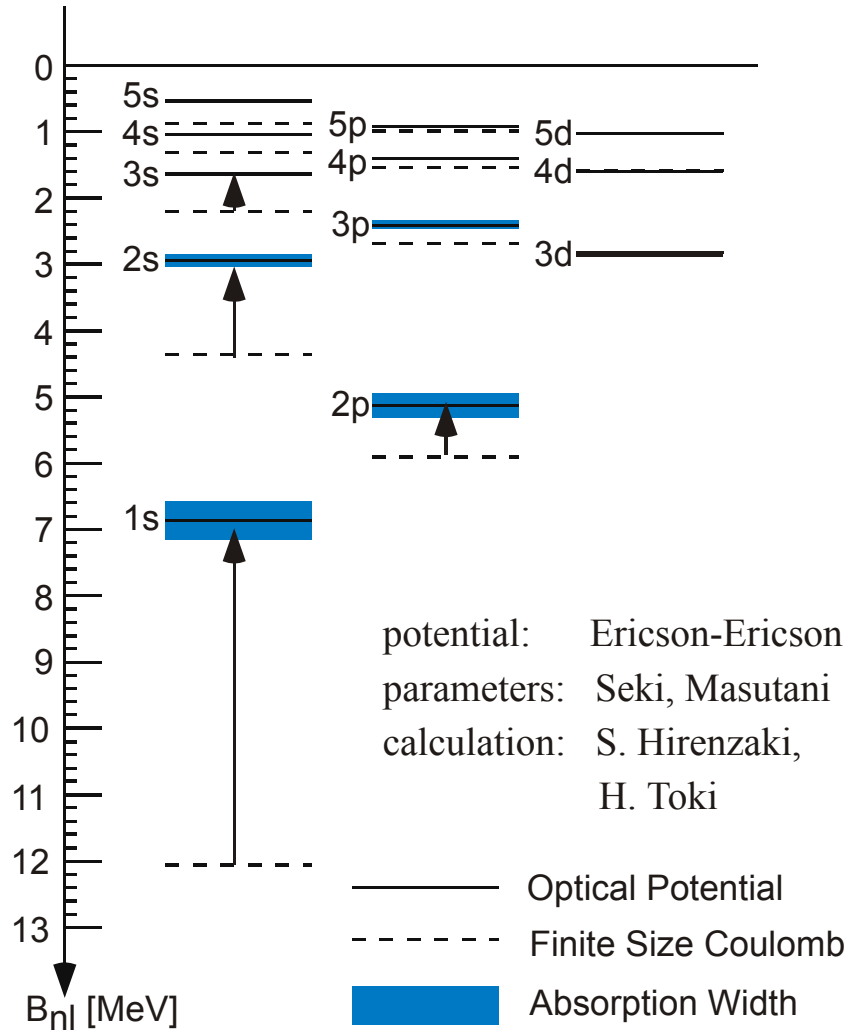
Repulsive s-wave interaction causes:

- binding energy reduced in $2p$ and $1s$ states
- width significantly reduced
- nuclear-pionic halo states

E. Friedman and G. Soff,
J. Phys. G 11 (1985) L37

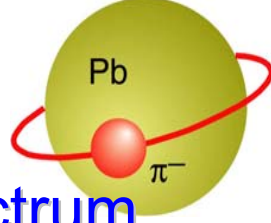
H. Toki and T. Yamazaki,
Phys. Lett. B 213 (1988) 129

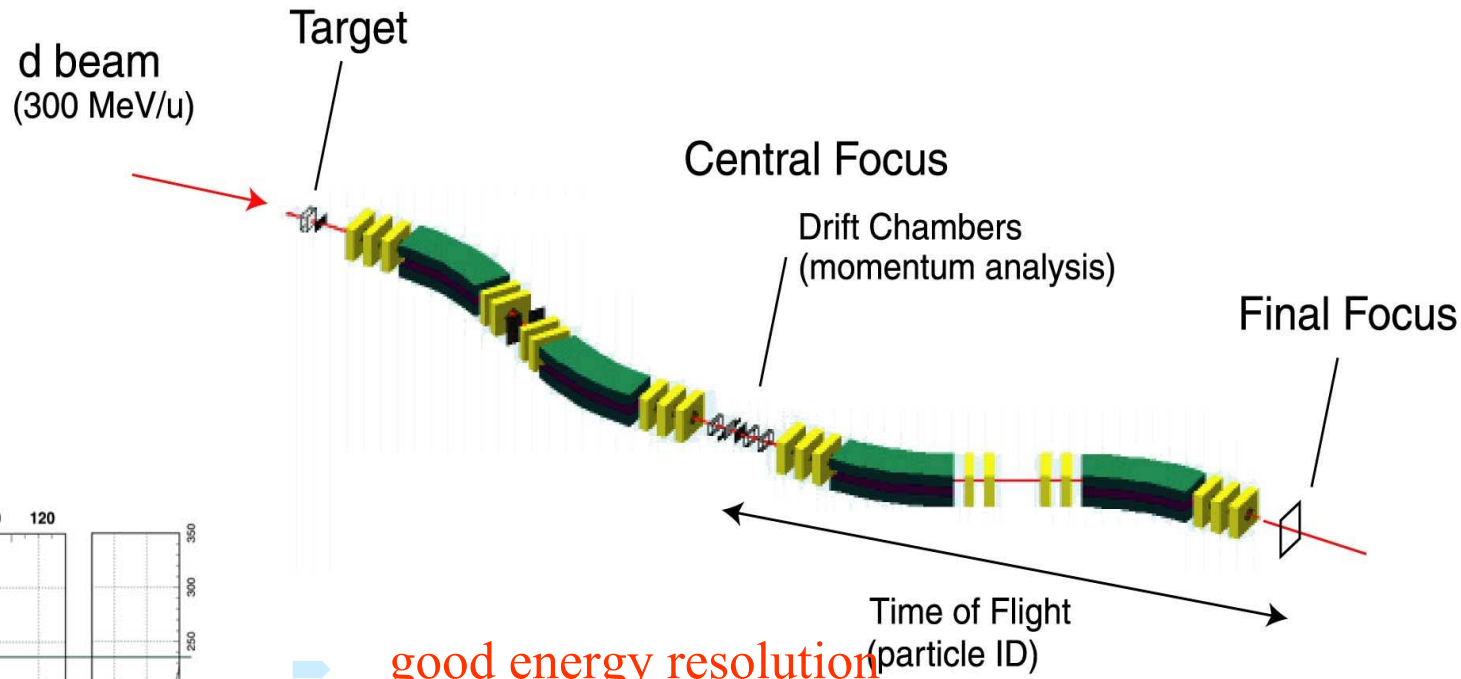


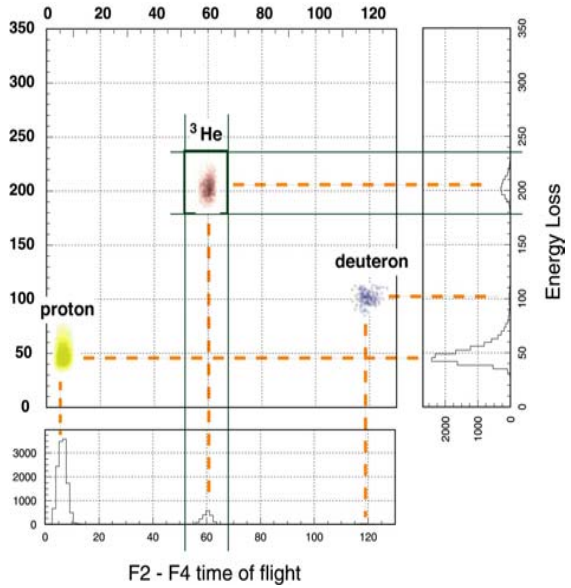


Experimental setup

^{3}He momentum measurement → excitation energy spectrum

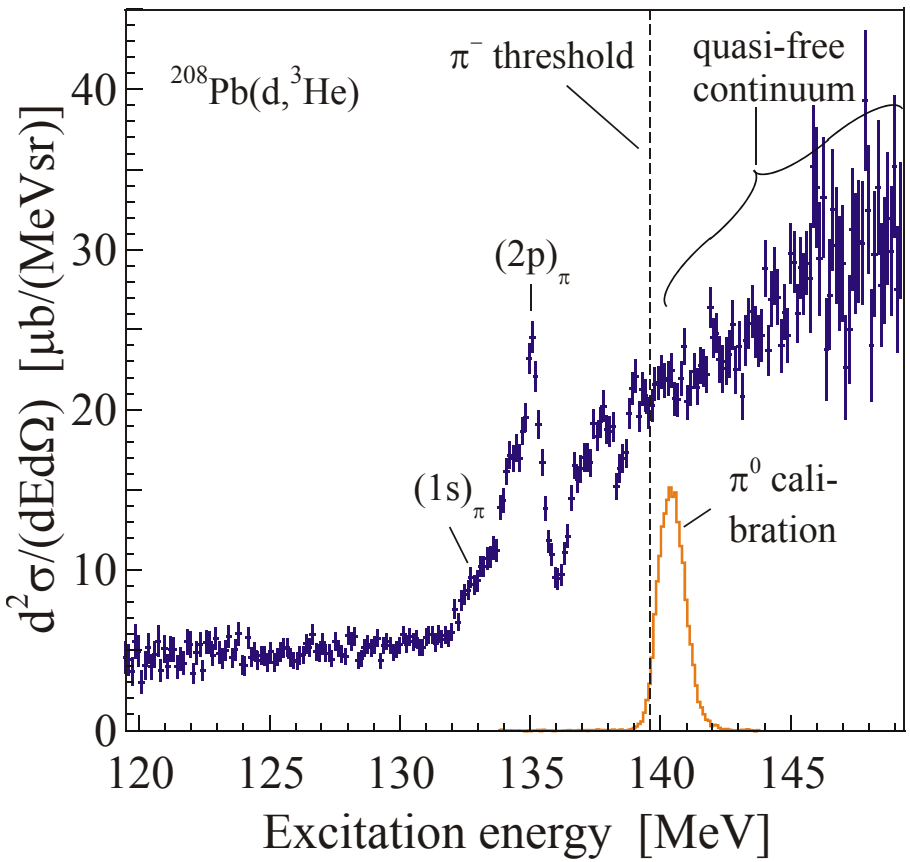






- good energy resolution
  $\delta E/E < 10^{-3}$
- high luminosity
  $L \sim 10^{30} \ldots 10^{31}/\mathrm{cm}^2\mathrm{s}$
- good background suppression:
  $(2 \cdot 10^{11} d/\mathrm{spill},$
  $10^5 p/\mathrm{spill},$
  $0.3\ ^3\mathrm{He}/\mathrm{spill})$

Discovery of Deeply-Bound Pionic States in Heavy Atoms (^{207}Pb)



$^{208}\mathrm{Pb}\,(d,^{3}\mathrm{He}) \rightarrow {}^{207}\mathrm{Pb}_{\pi}$

T. Yamazaki et al.

Z. Phys. A355 (1996) 219

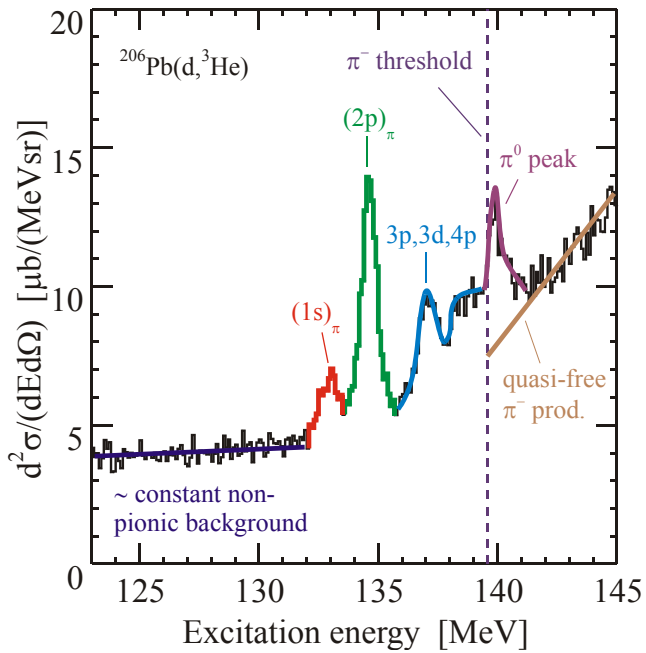
The ^{206}Pb experiment

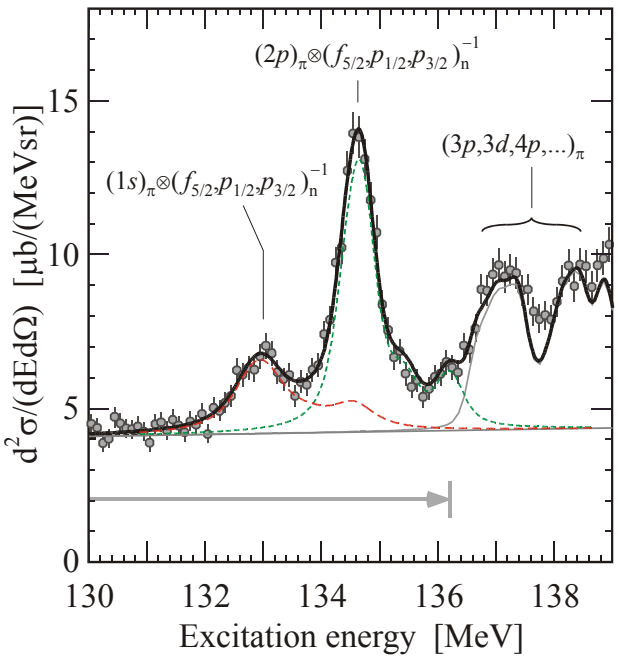
Interpreted spectrum:

- discrete bound states
- nuclear background
- free π^- production
- $p\,(d,{}^3\mathrm{He})\,\pi^0$ peak

n-holes: $3p_{3/2}$, $3p_{1/2}$, $2f_{5/2}$

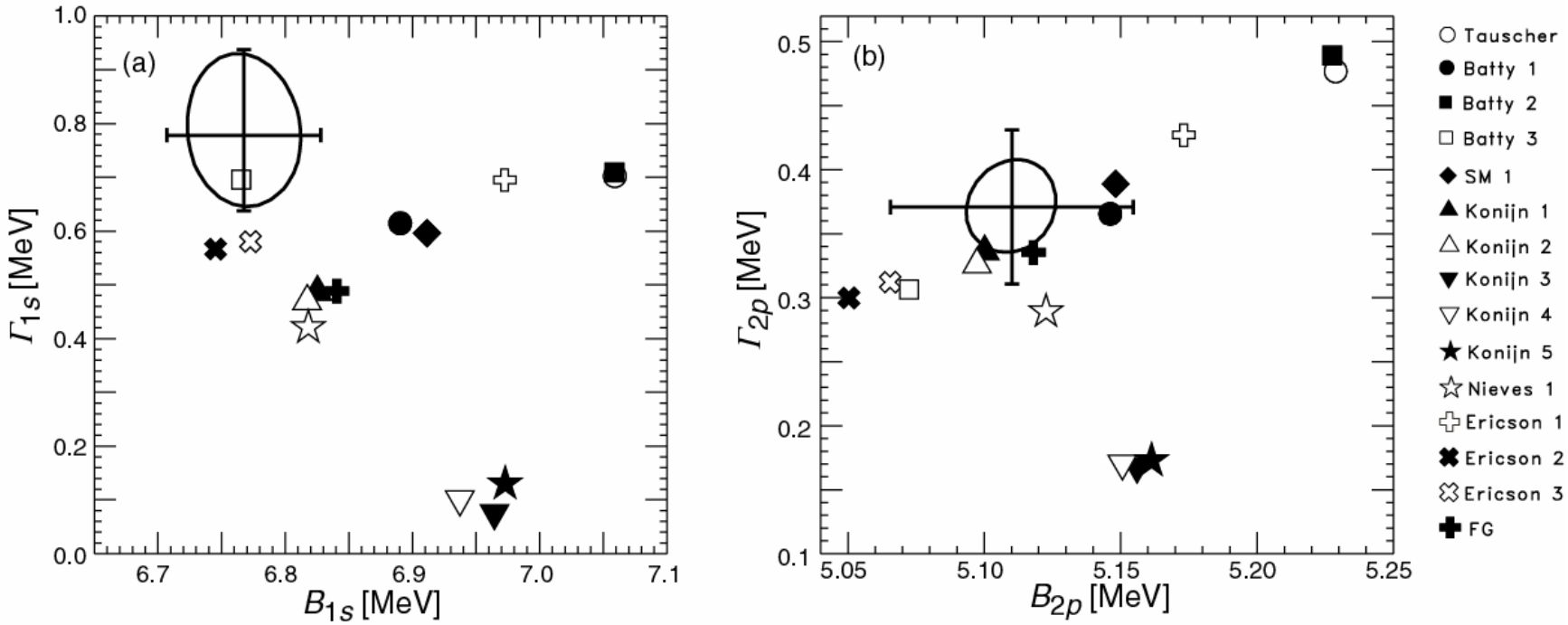
- $B_{2p} = 5.110 \pm 0.045$ MeV
- $\Gamma_{2p} = 0.321^{+0.060}_{-0.062}$ MeV
- $B_{1s} = 6.762 \pm 0.061$ MeV
- $\Gamma_{1s} = 0.764^{+0.171}_{-0.062}$ MeV





Pionic States in ^{205}Pb

PRL82(2002)02501



$$B_{1s}(^{205}\mathrm{Pb}) = 6762 \pm 45(stat) \pm 41(sys)$$

$$\Gamma_{1s}(^{205}\mathrm{Pb}) = 764^{+161}_{-141}(stat)^{+55}_{-61}(sys)$$

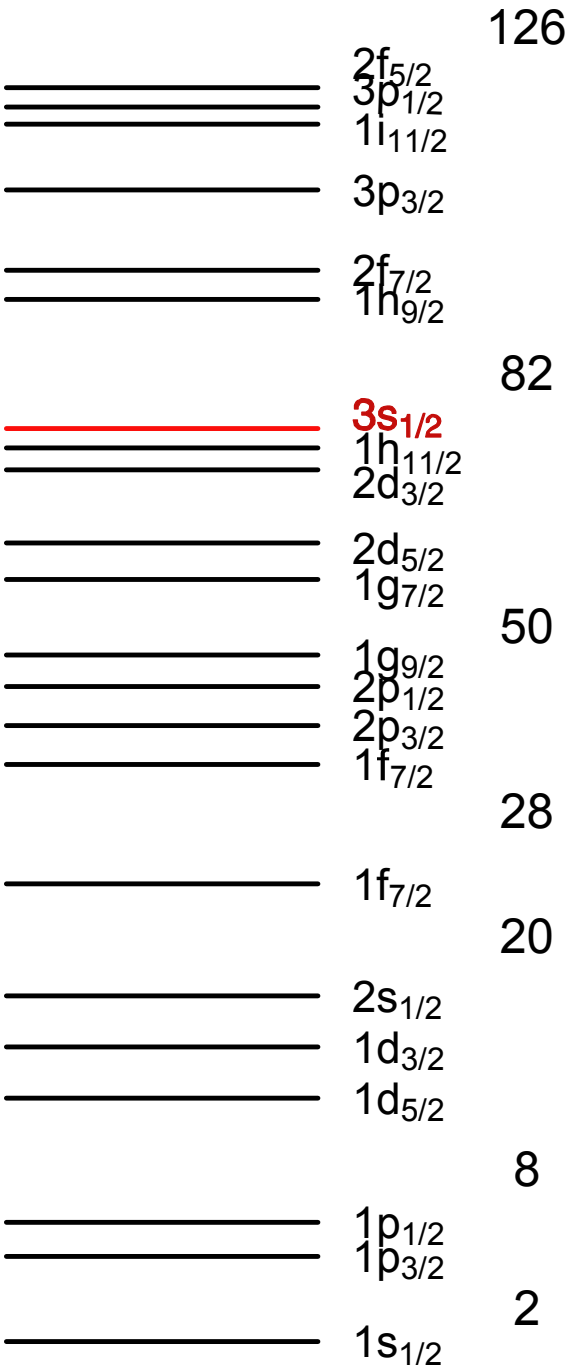
$$B_{2p}(^{205}\mathrm{Pb}) = 5110 \pm 16(stat) \pm 42(sys)$$

$$\Gamma_{2p}(^{205}\mathrm{Pb}) = 764 \pm 16(stat)^{+45}_{-49}(sys)$$

in keV

$$B_{2p}(^{207}\mathrm{Pb}) = 5110 \pm 16(stat) \pm 42(sys)$$

$$\Gamma_{2p}(^{207}\mathrm{Pb}) = 764 \pm 16(stat)^{+45}_{-49}(sys)$$



Why Sn target?

Neutrons in Shallow *s* state

$(1s)_\pi$ peak formation ⟶ large

Long stable isotope chain

⟶ Systematic study in Wide range of (N-Z)/A

Isotope shift measurement

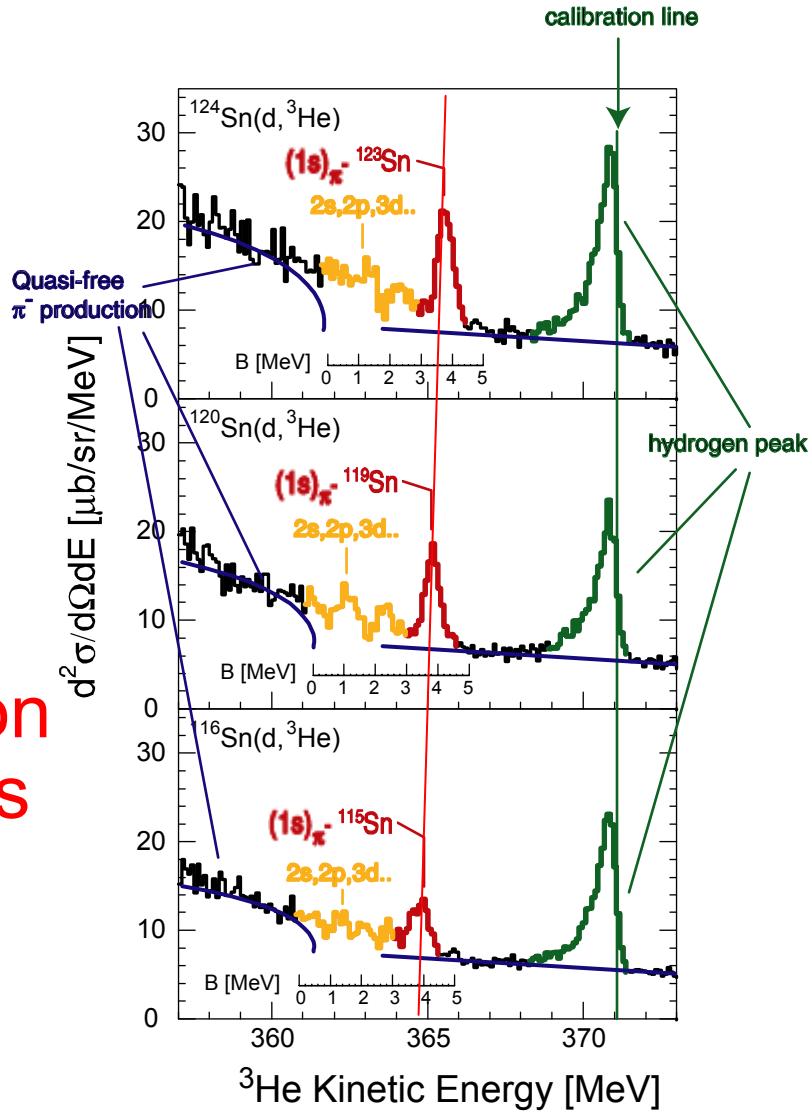
Umemoto et al. Phys. Rev. C**62**, 024606(2000)

Measured Energy Spectra
K. Suzuki et al. 2002

- Deeply bound pionic *1s* states in ^{123,119,115}Sn are clearly observed

- Monotonic shift in binding due to isotopes
- Absolute energy calibration from Mylar backing targets $p(d,^3He)\pi^0$

- Background slope from pure Sn targets



Conclusion

$$b_1(\rho)(\rho_n - \rho_p) = \frac{b_1^{\text{free}}}{1\text{-}\alpha\rho(r)}(\rho_n - \rho_p)$$