Systematic studies of deeply-bound pionic atoms at the RIKEN RIBF facility

Ryugo S. Hayano (Tokyo)

for the pionic atom factory project

The team (now busy at RIBF)

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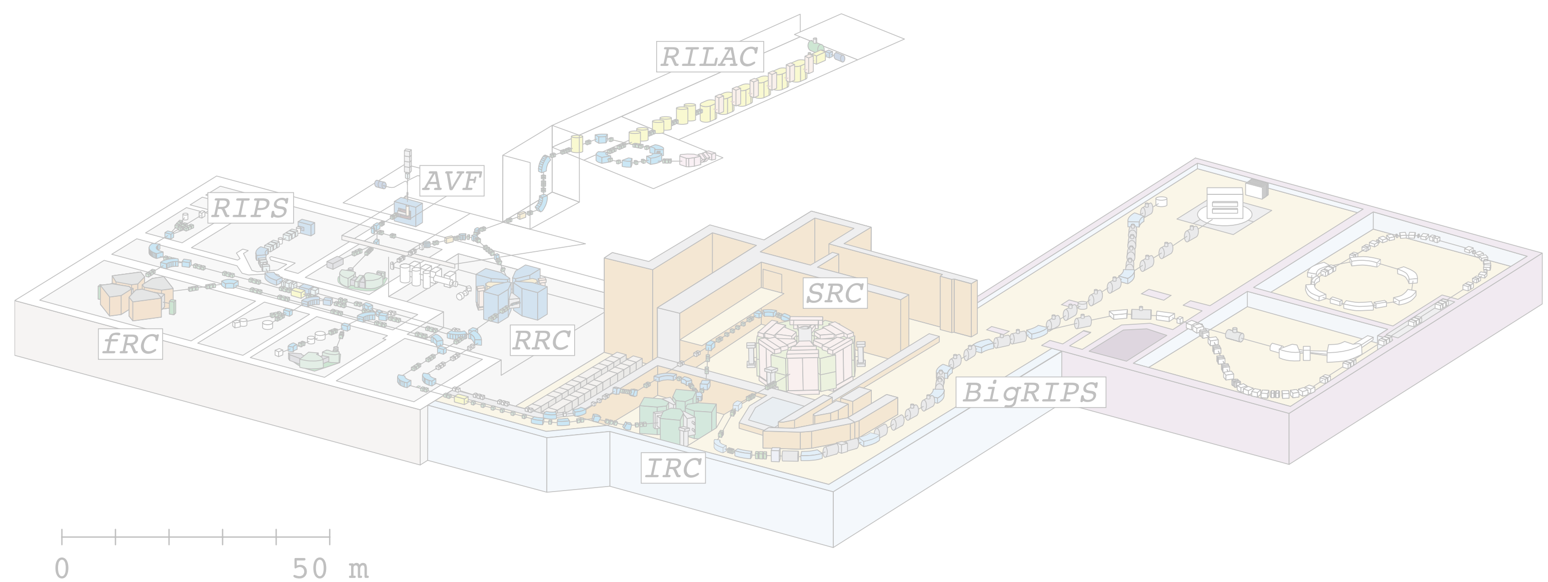
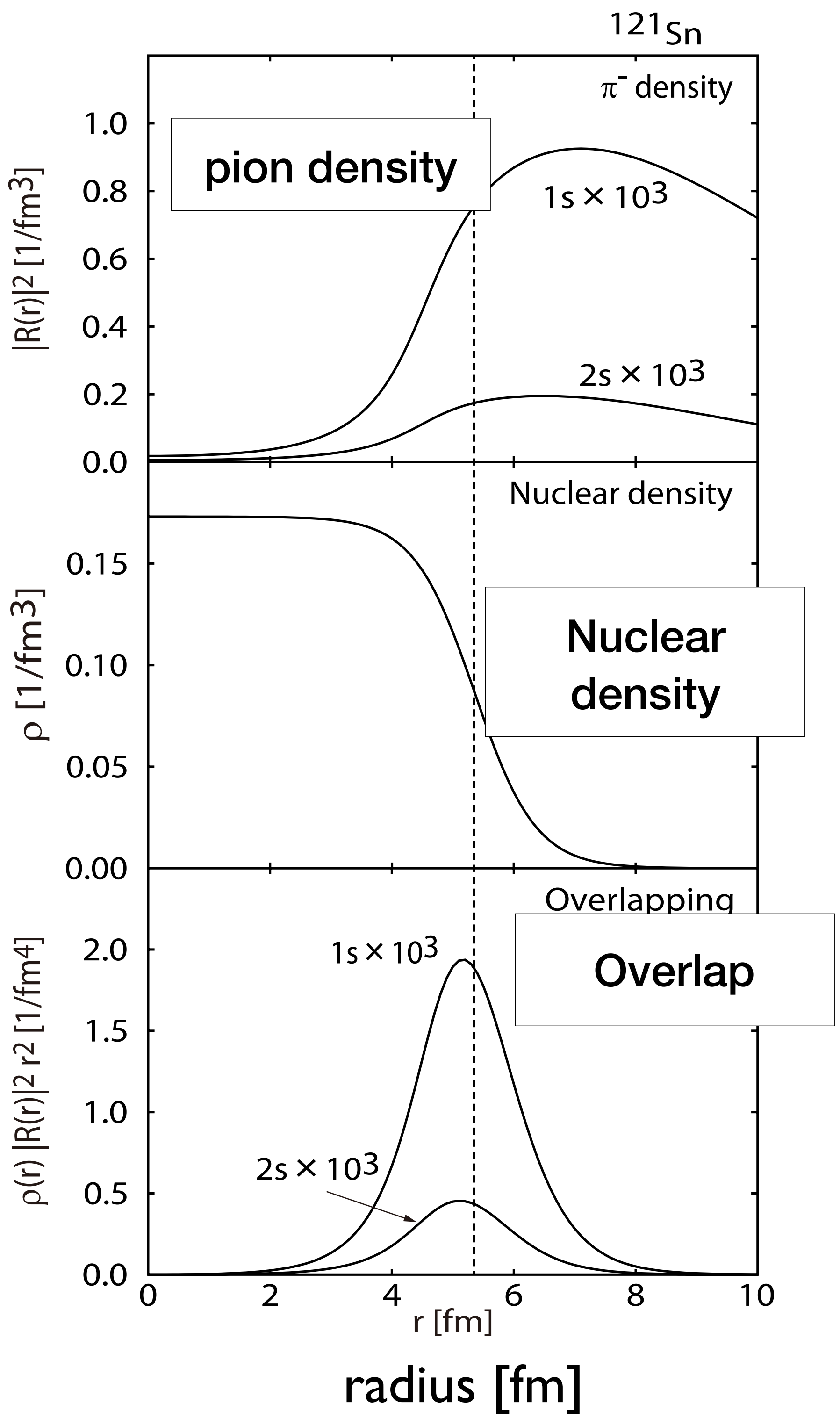


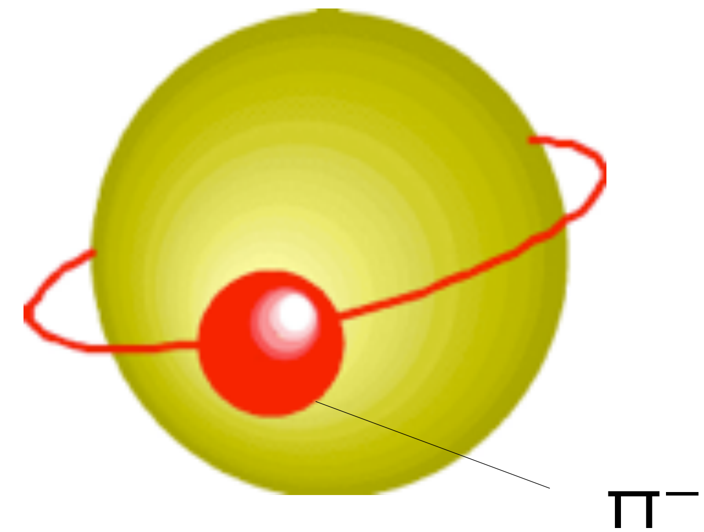
Already discussed by S. Hirenzaki

why? - chiral condensate

Deeply bound pionic atoms



Quantum bound system of meson-nucleus



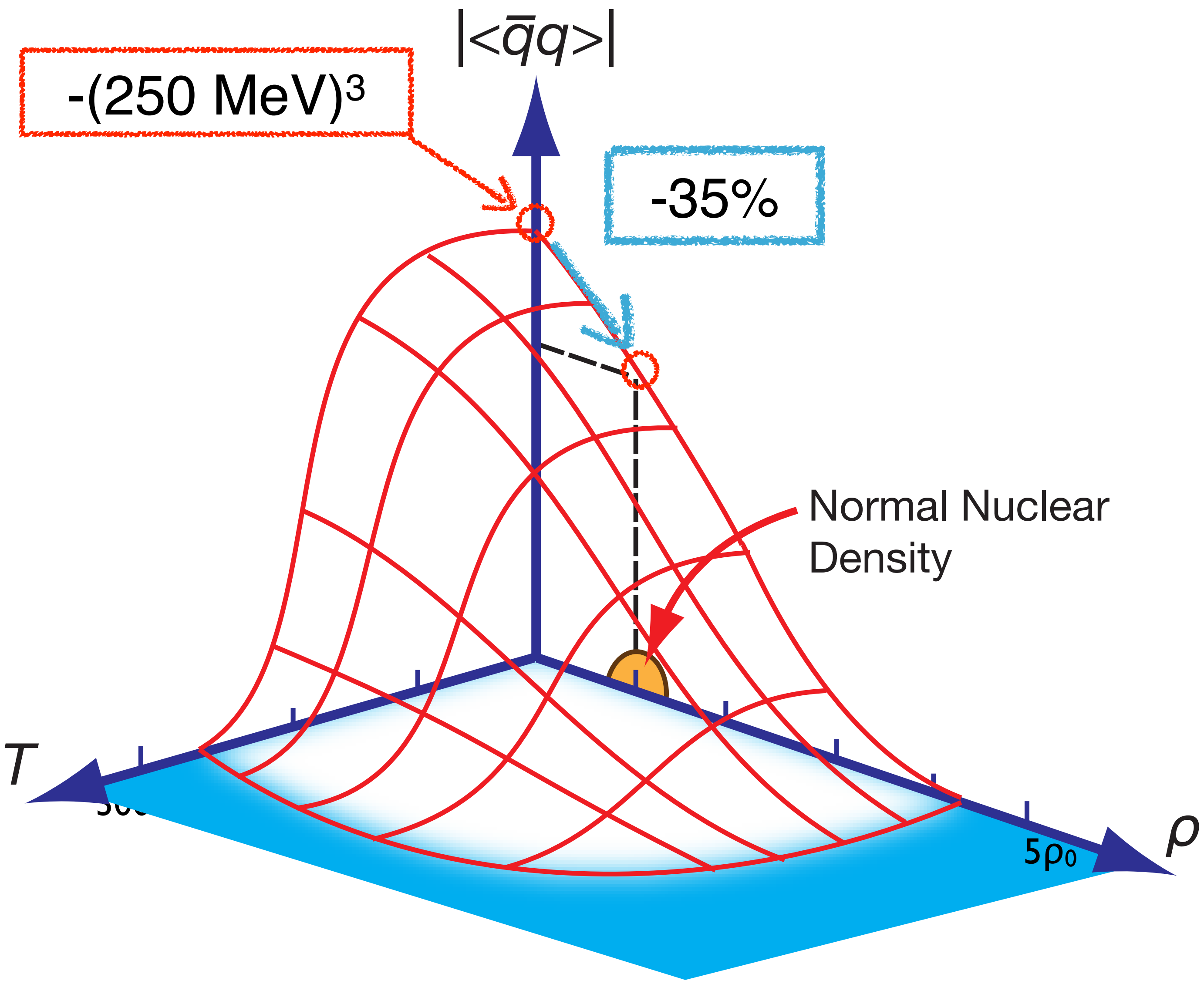
Probes ~60% of ρ_0

N. Ikeno et al., PTP126(2011)483.

Hayano, MESON 2014, Kraków

Deeply bound pionic atoms

Quantitative evaluation of chiral order parameter



Hayano, MESON 2014, Kraków

Binding energy → $\langle \bar{q}q \rangle$

pionic atom 1s energy

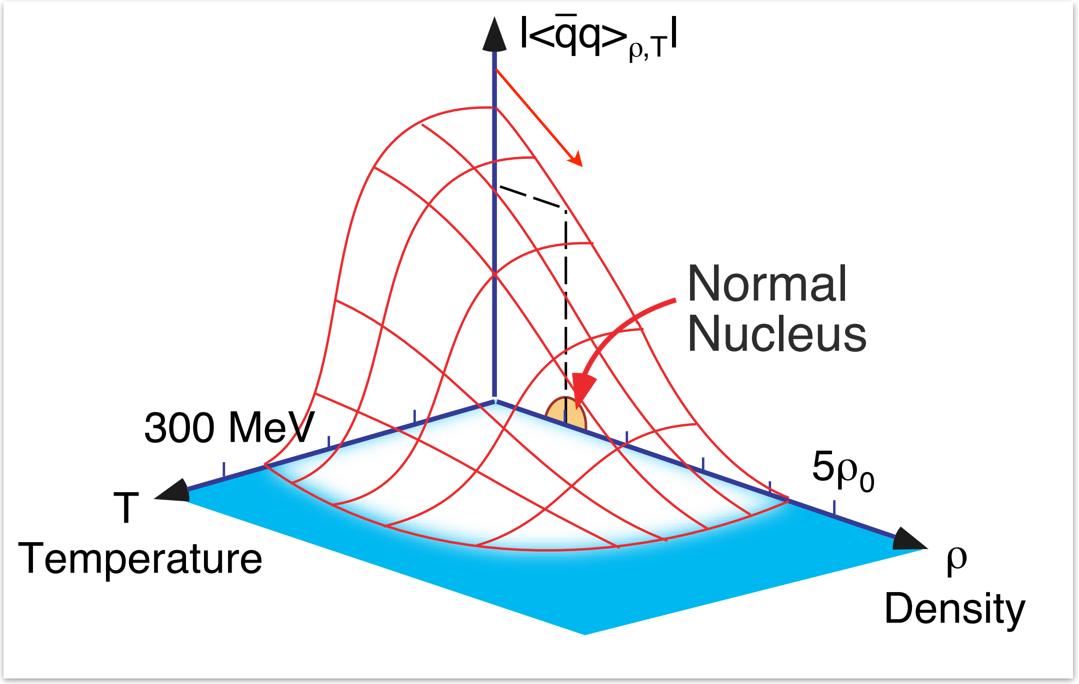
$$b_0(\rho_n + \rho_p) + b_1(\rho_n - \rho_p)$$

$$b_1 \propto \frac{m_\pi}{f_\pi^2(\rho)}$$

Tomozawa-Weinberg

Gell-Mann Oakes Renner

$$f_\pi^2(\rho) m_\pi^2 \approx -m_q < \bar{q}q >_\rho$$

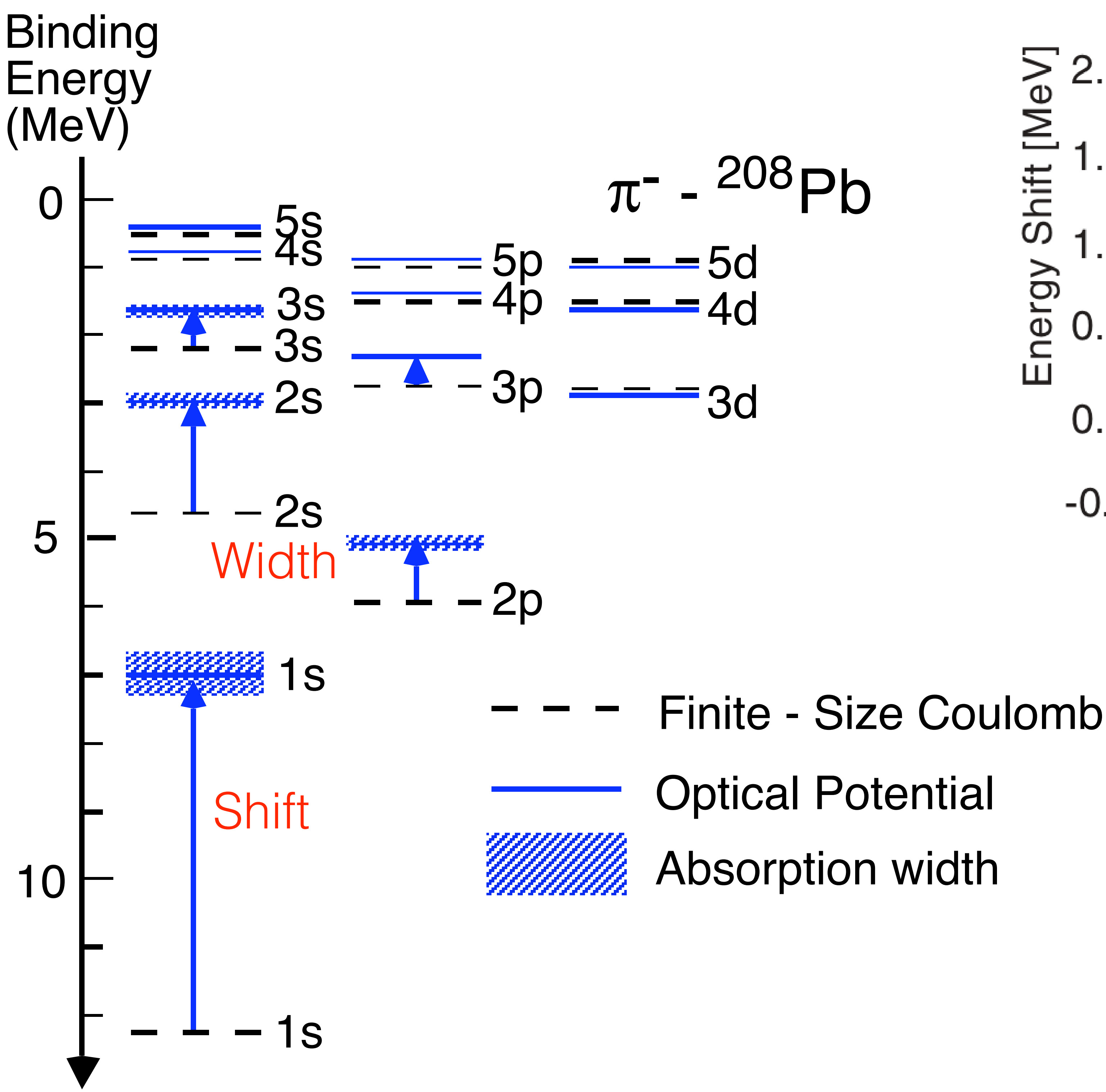


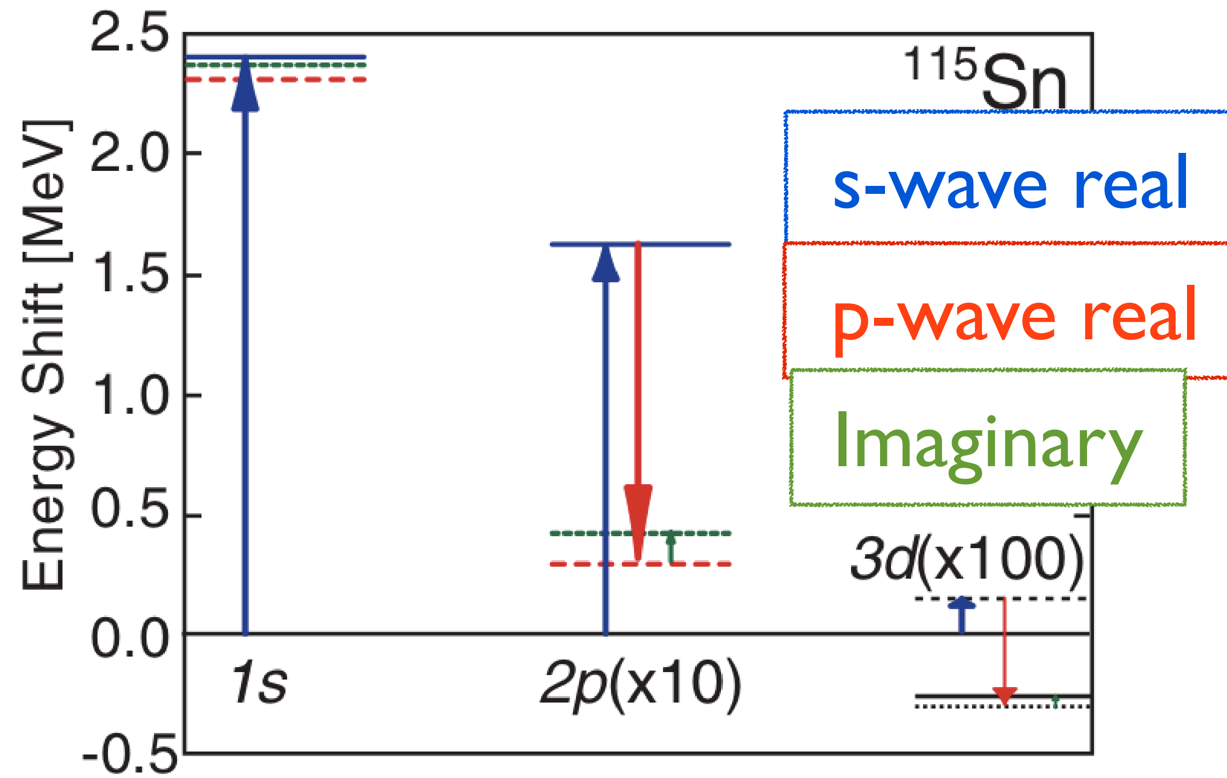
Hayano, MESON 2014, Kraków

GSI experiment (pionic Pb, Sn)

successfully completed some 10 years ago

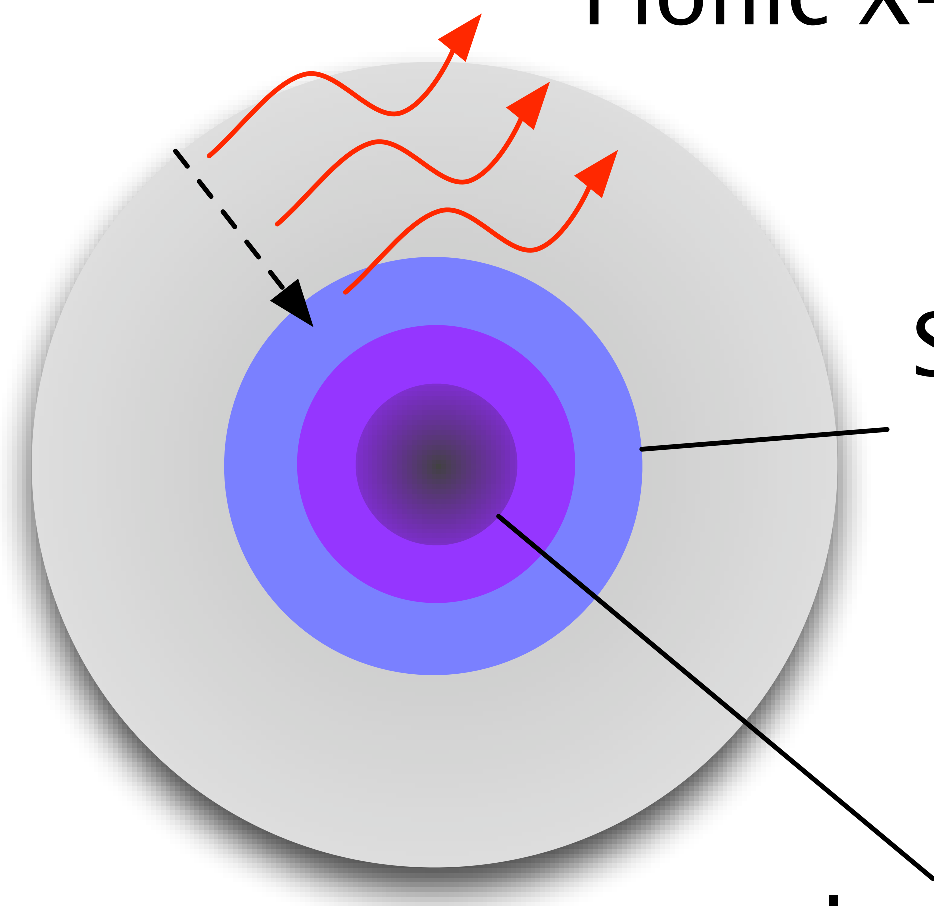
Level scheme





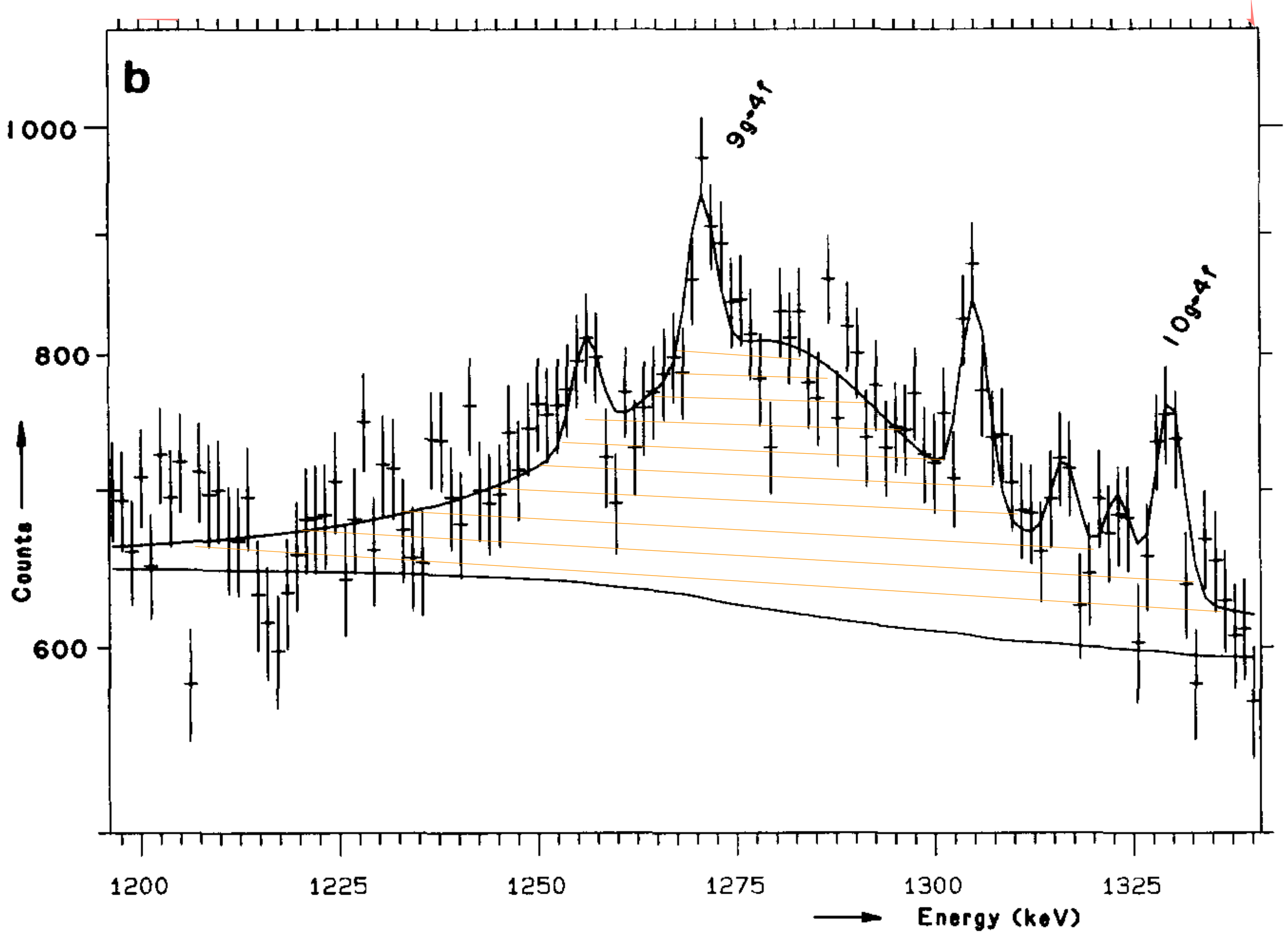
effect of the strong interaction

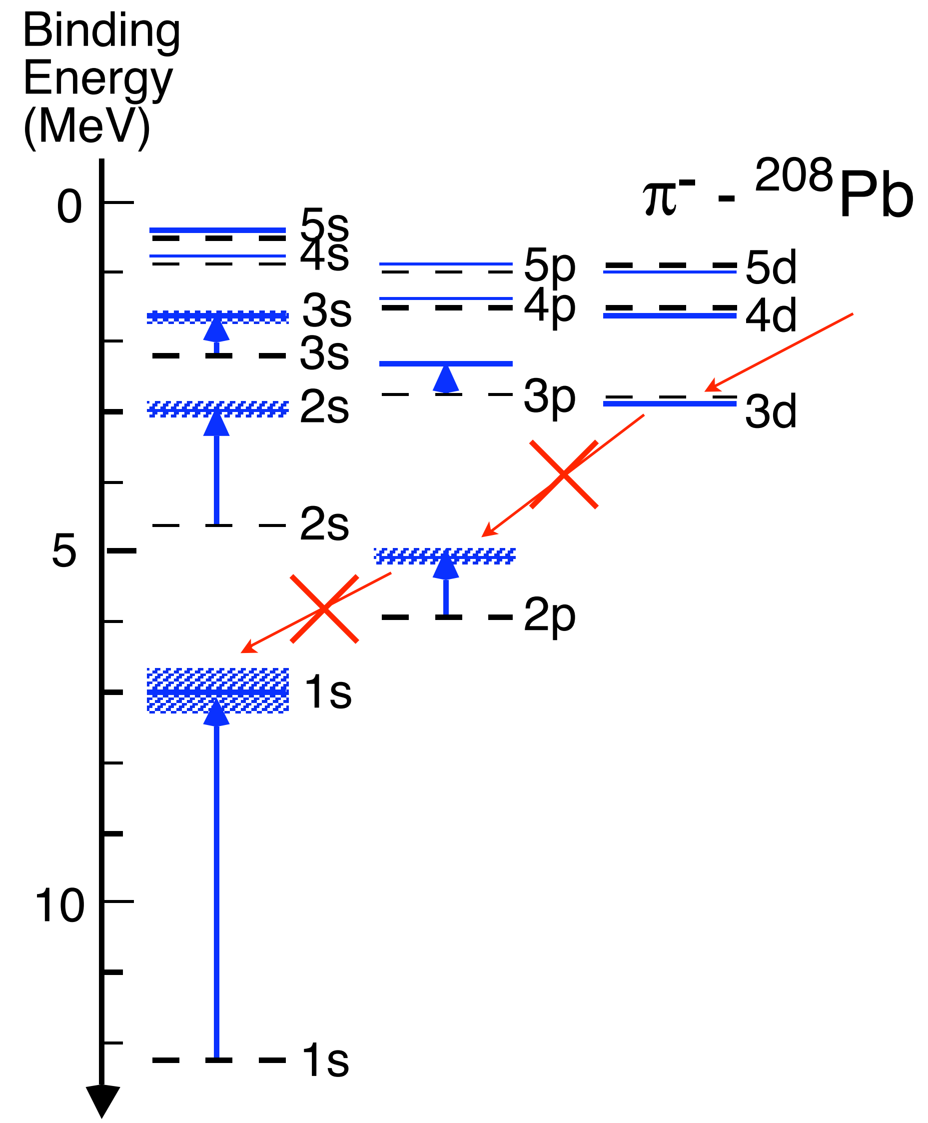
“deep” states invisible to X-rays



“last orbit”

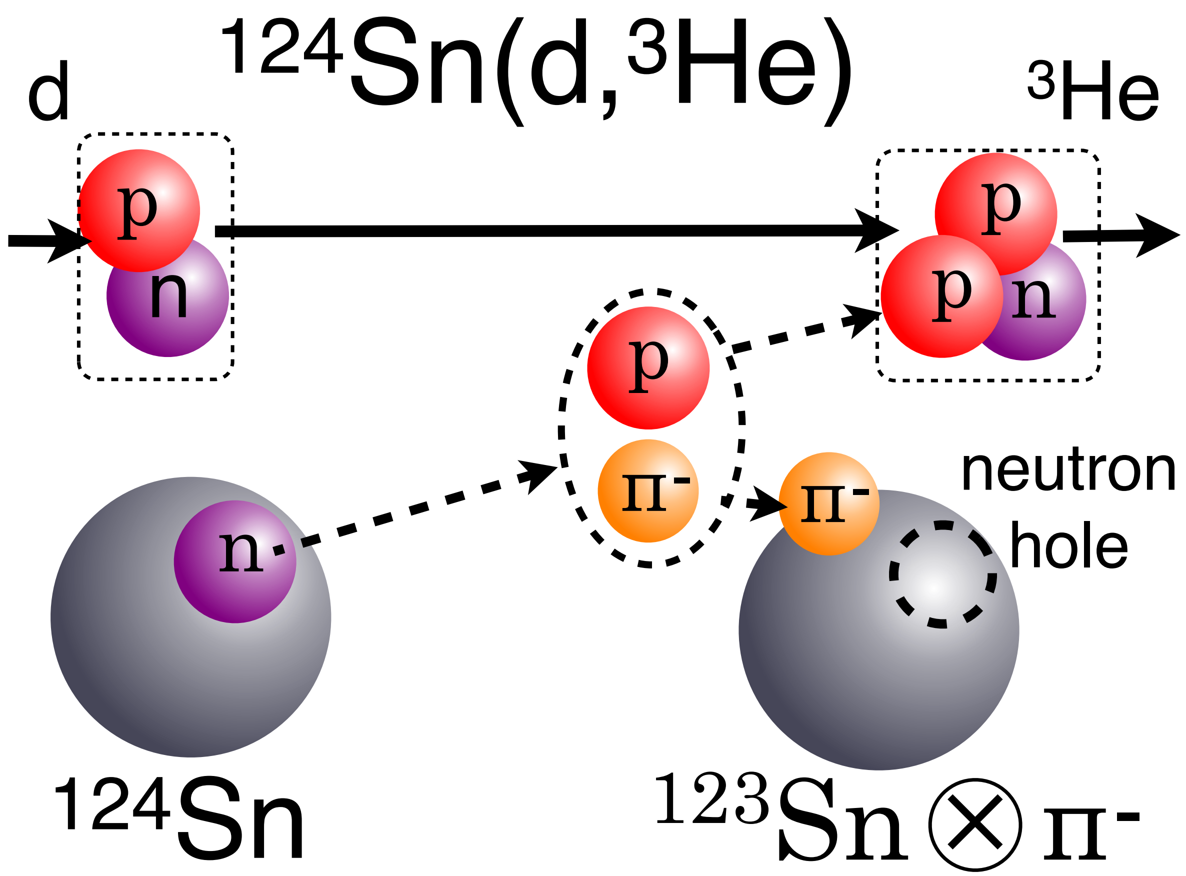
Pionic Pb, 4f→3d (“last orbit”)

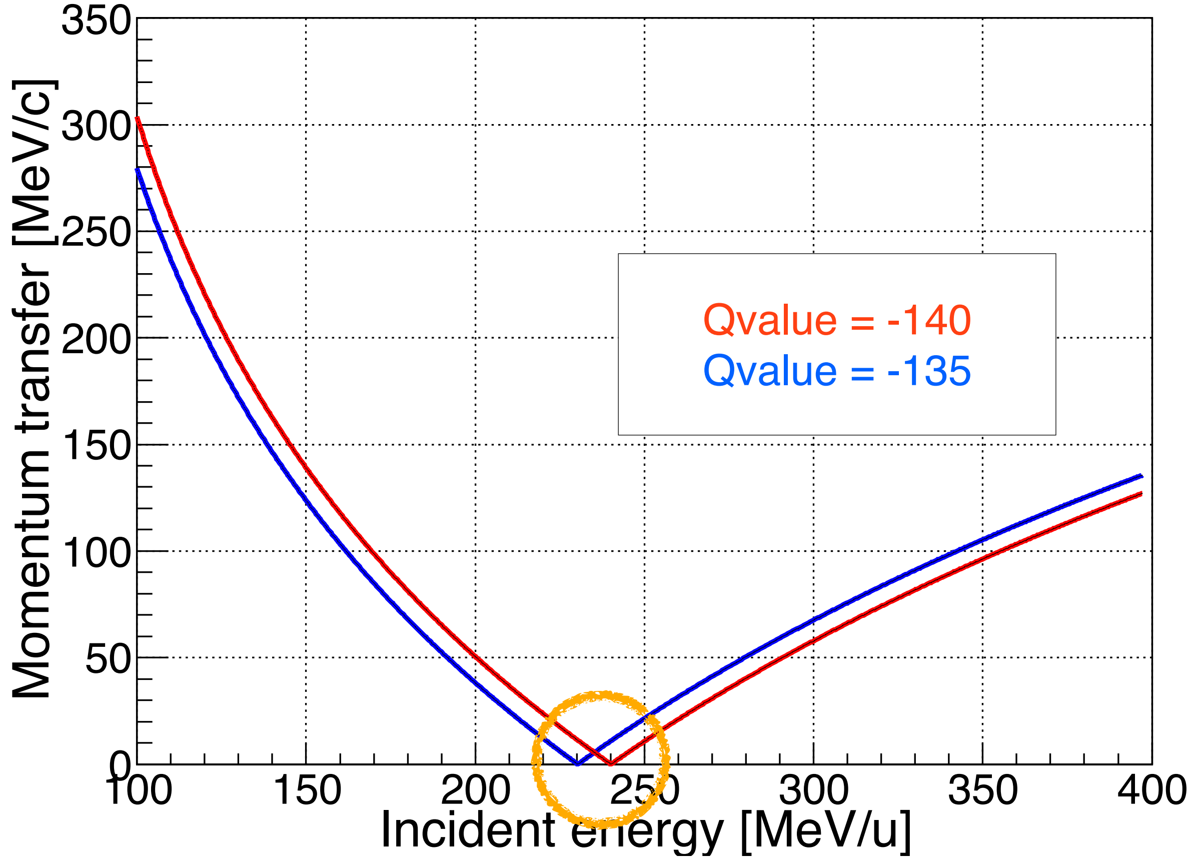




Hayano, MESON 2014, Kraków

(d,3He) reaction



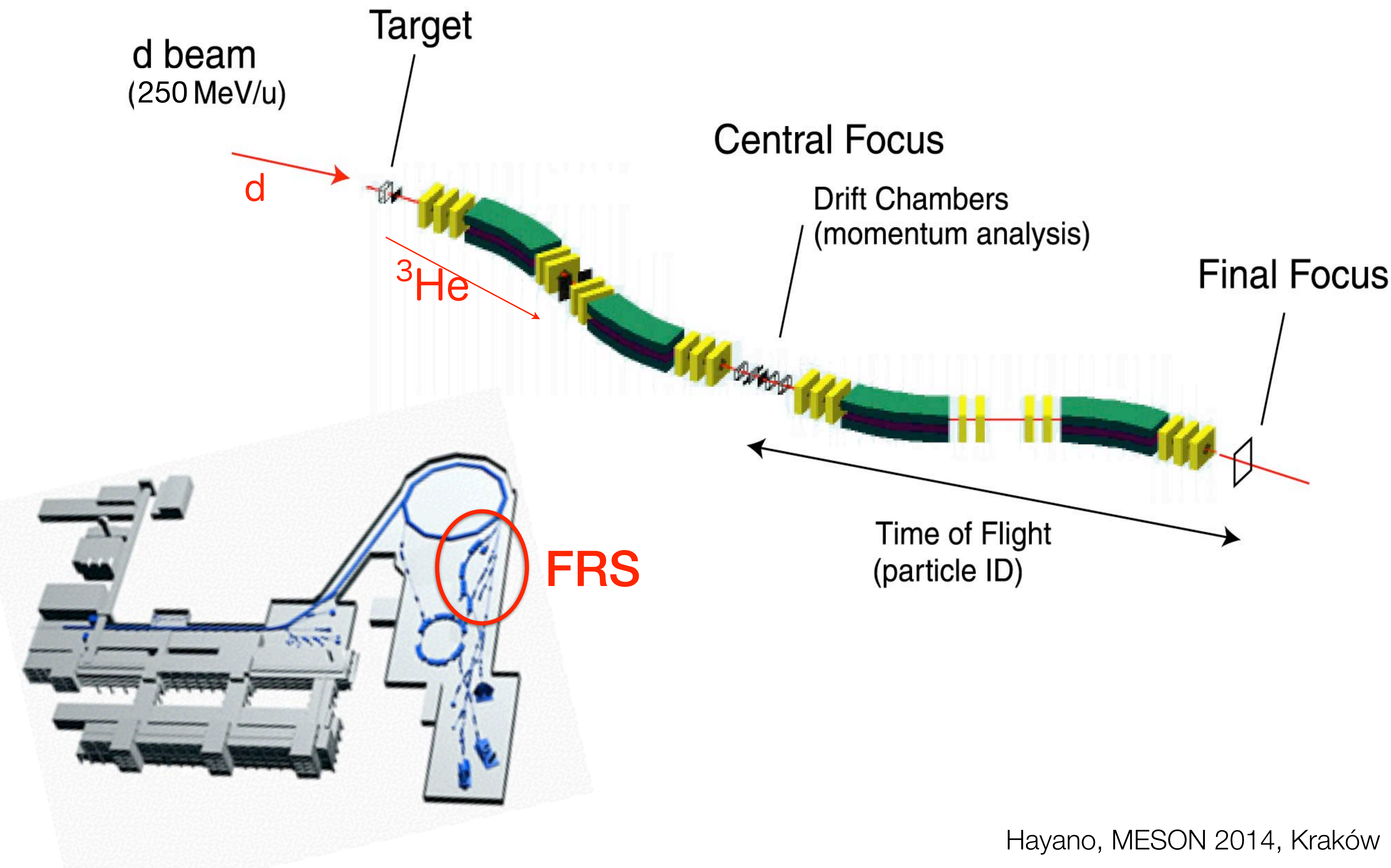


Missing mass spectroscopy

recoilless condition@250 MeV/u

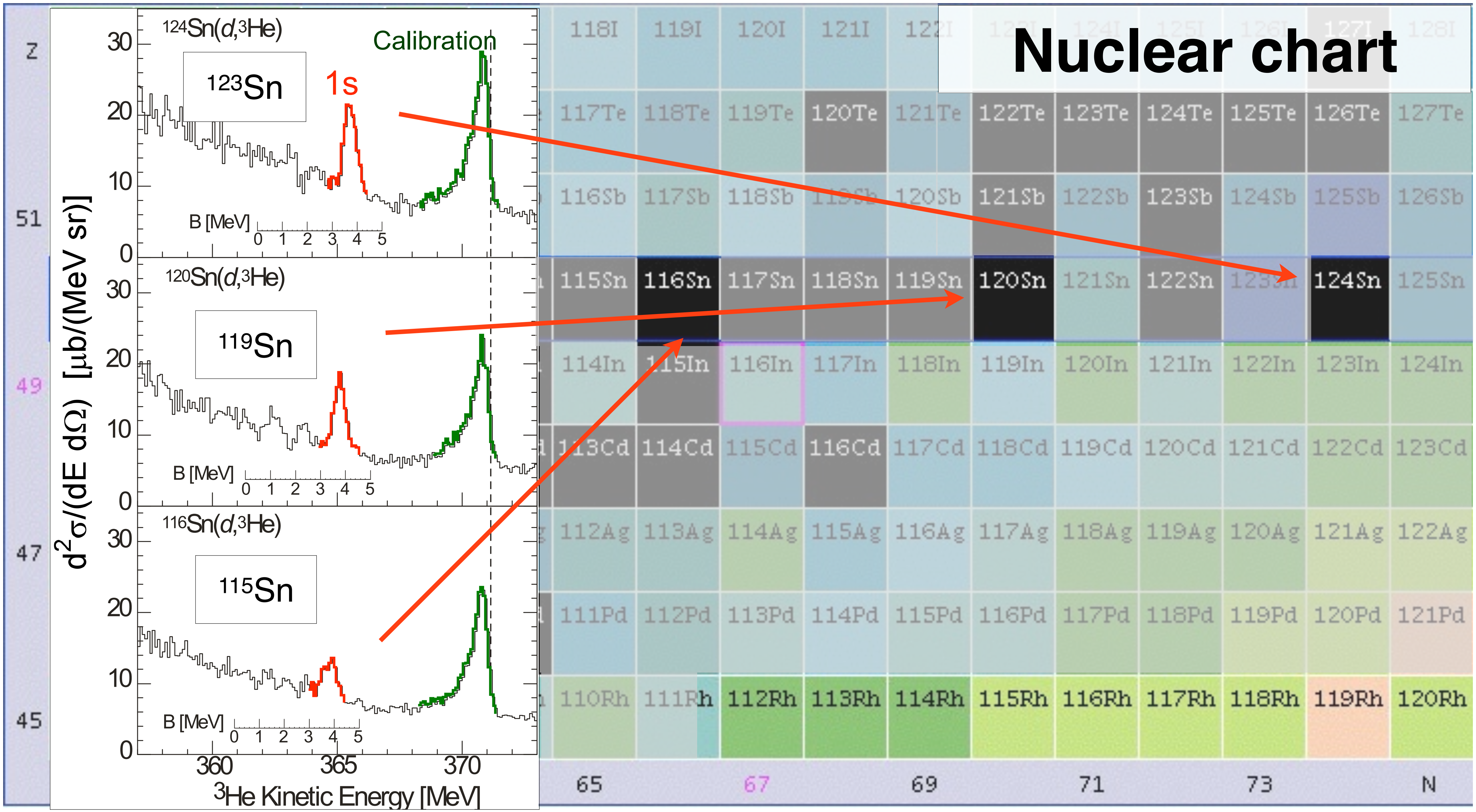
Hayano, MESON 2014, Kraków

SETUP



Hayano, MESON 2014, Kraków

Pionic Sn at GSI



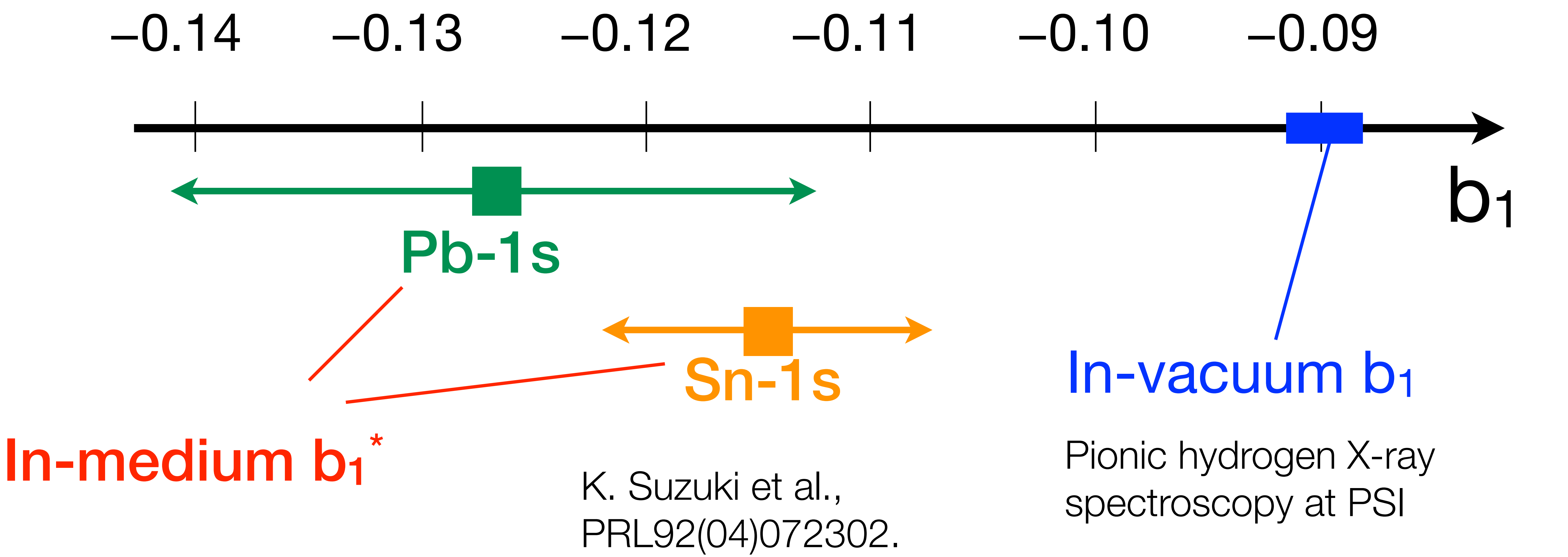
K. Suzuki et al., PRL92 072302 (2004)

NNDC,BNL

Hayano, MESON 2014, Kraków

Pionic atoms and chiral condensate

Isovector b_1 ~ 10 % error



why further measurements?

why further measurements?

b_1 precision limited by

① Experimental error (ΔBE_{1s})

② Errors in other params. (b_0, ρ_n, ReB_0...)

Improvements by

① → Higher statistics, better resolution

② → systematic study

(disentangle the QCD effects from mundane nuclear effects)

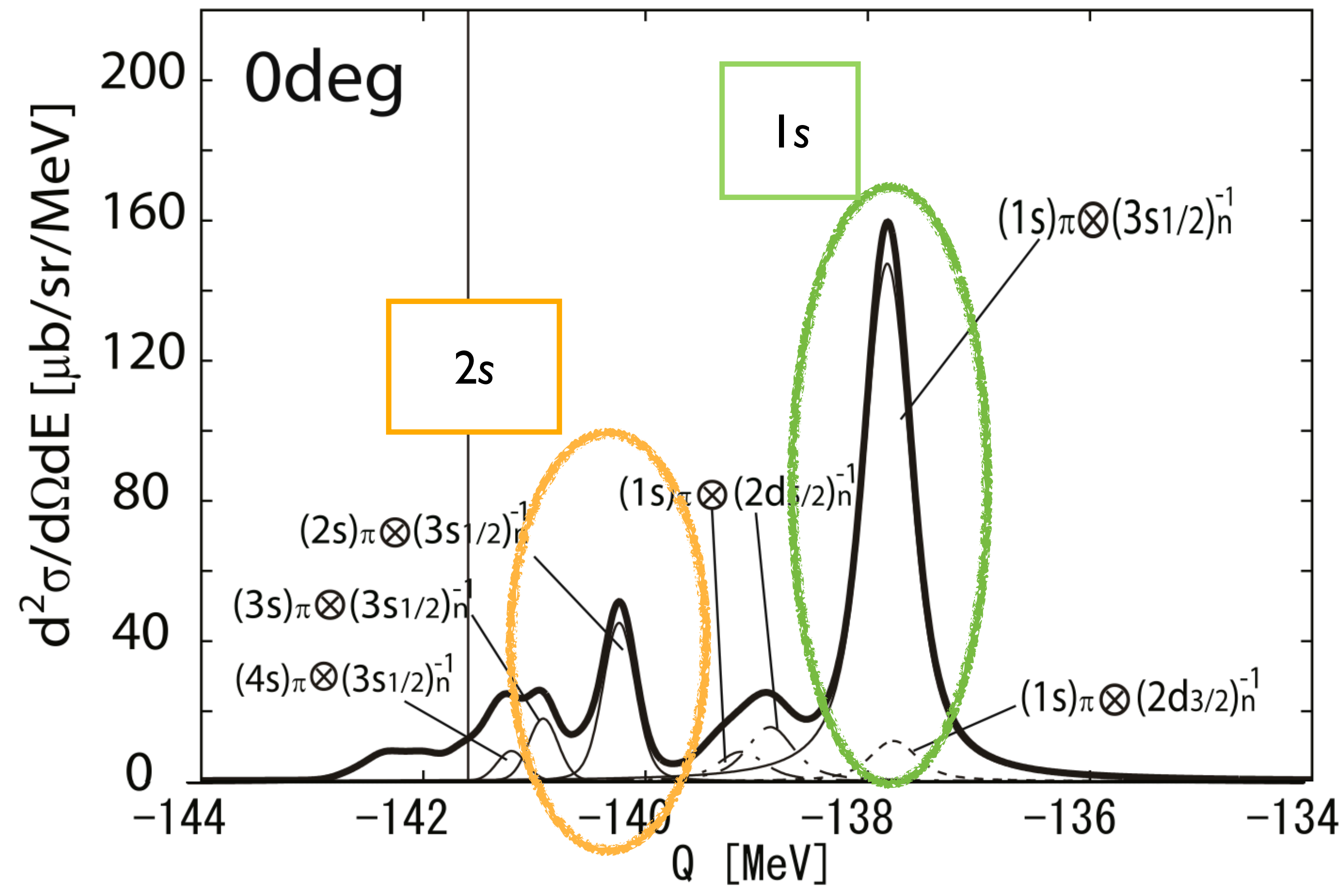
Binding Energy precision

Experimental errors

Isotope	B_{1s} (MeV)	ΔB_{1s} (MeV) Stat.	Syst.	Total
^{115}Sn	3.906	±0.021	±0.012	±0.024
^{119}Sn	3.820	±0.013	±0.012	±0.018
^{123}Sn	3.744	±0.013	±0.012	±0.018

How to improve

- σ(stat) → higher statistics
- σ(sys) → by 1s & 2s measurement

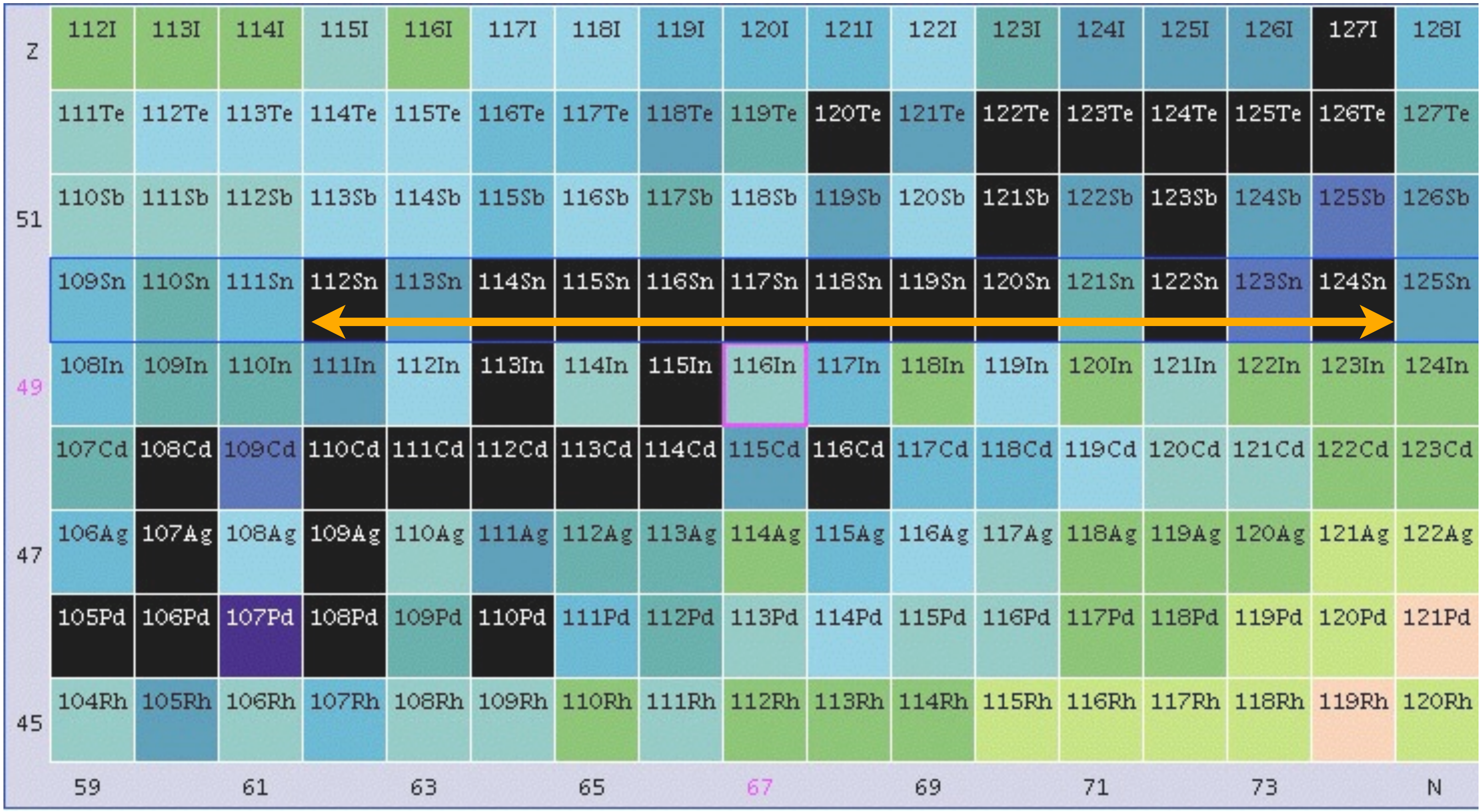


*N. Ikeno et al., Eur. Phys. J. A 47, 161 (2011)

Hayano, MESON 2014, Kraków

piAF @ RIBF
- what can be improved?

b_1 with better precision - longer lever arm



π-A *s*-wave interaction → $\langle\bar{q}q\rangle$

$$V_s = b_0\rho + b_1(\rho_n - \rho_p) + B_0\rho^2.$$

Hayano, MESON 2014, Kraków

b_1 with better precision - 2D coverage

π-A *s*-wave interaction → $\langle \bar{q}q \rangle$

$$V_s = b_0 \rho + b_1(\rho_n - \rho_p) + B_0 \rho^2.$$

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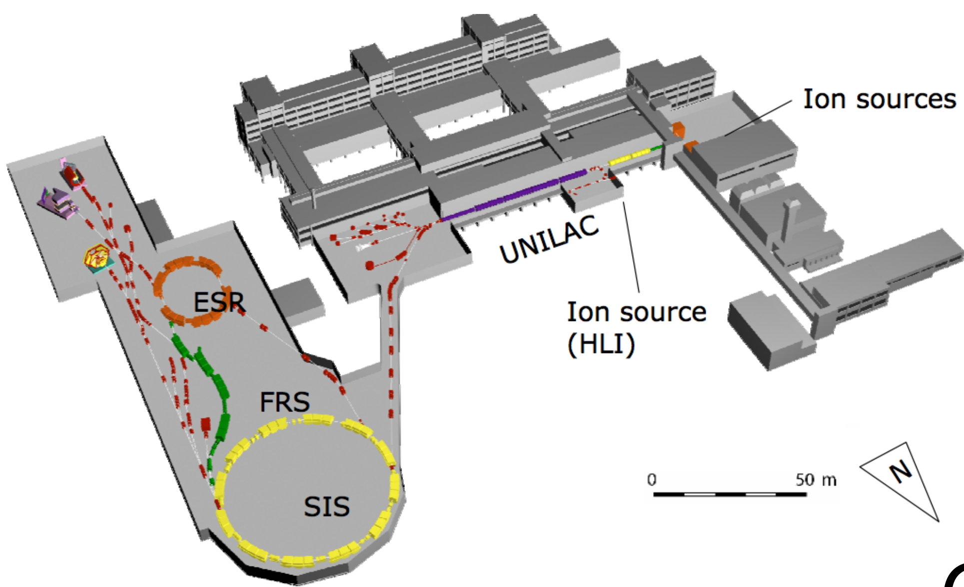
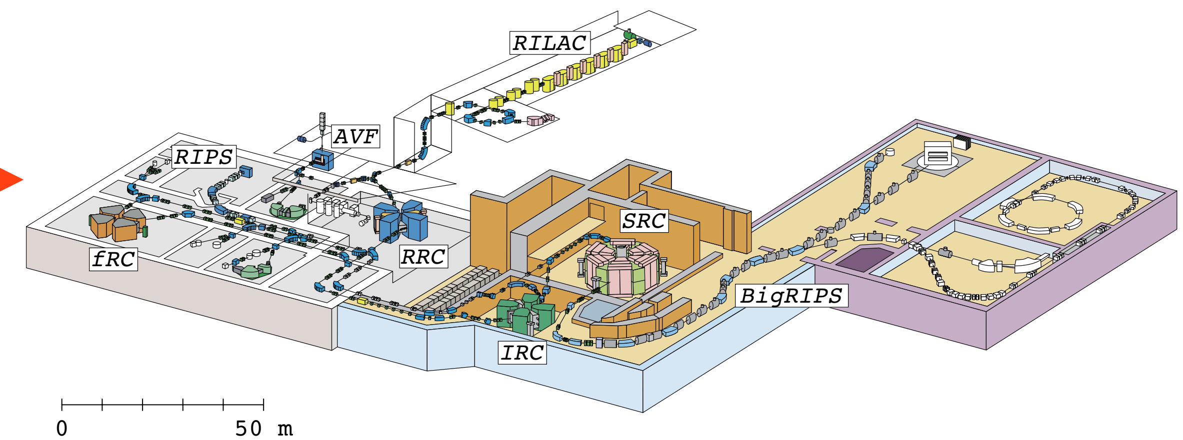
GSI and RIBF

GSI facilities



RIBF



	GSI	RIBF	
intensity	~10^{11}	~10^{12}	×50
Target	20 mg/cm²	10 mg/cm²	×0.5
angular acceptance	~10 mrad	40 / 60 mrad	×20
Δp	0.03%	0.1%	×3
resolution (FWHM)	400 keV	200~300 keV	factor 1.3 ~ 2

using dispersion matching

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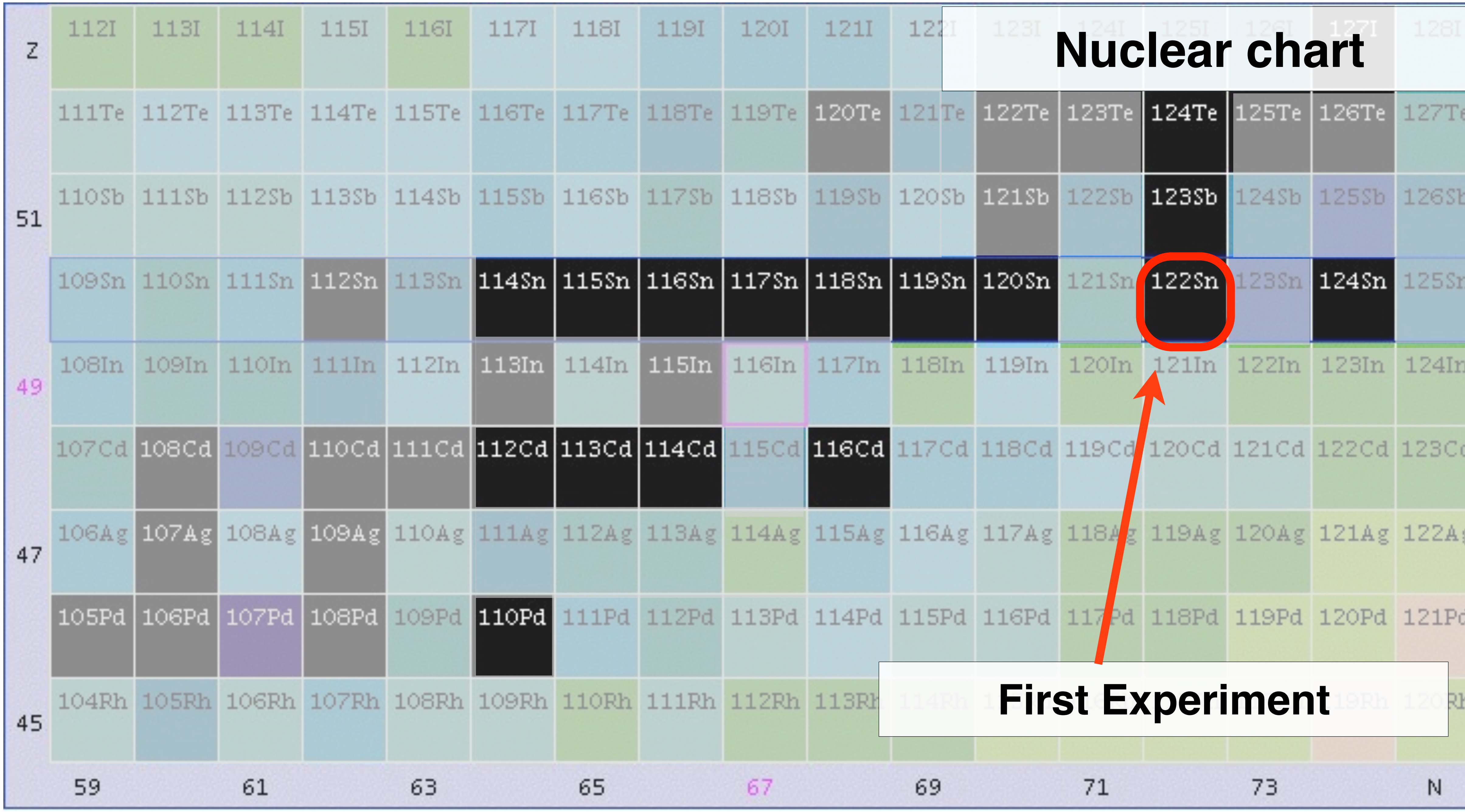
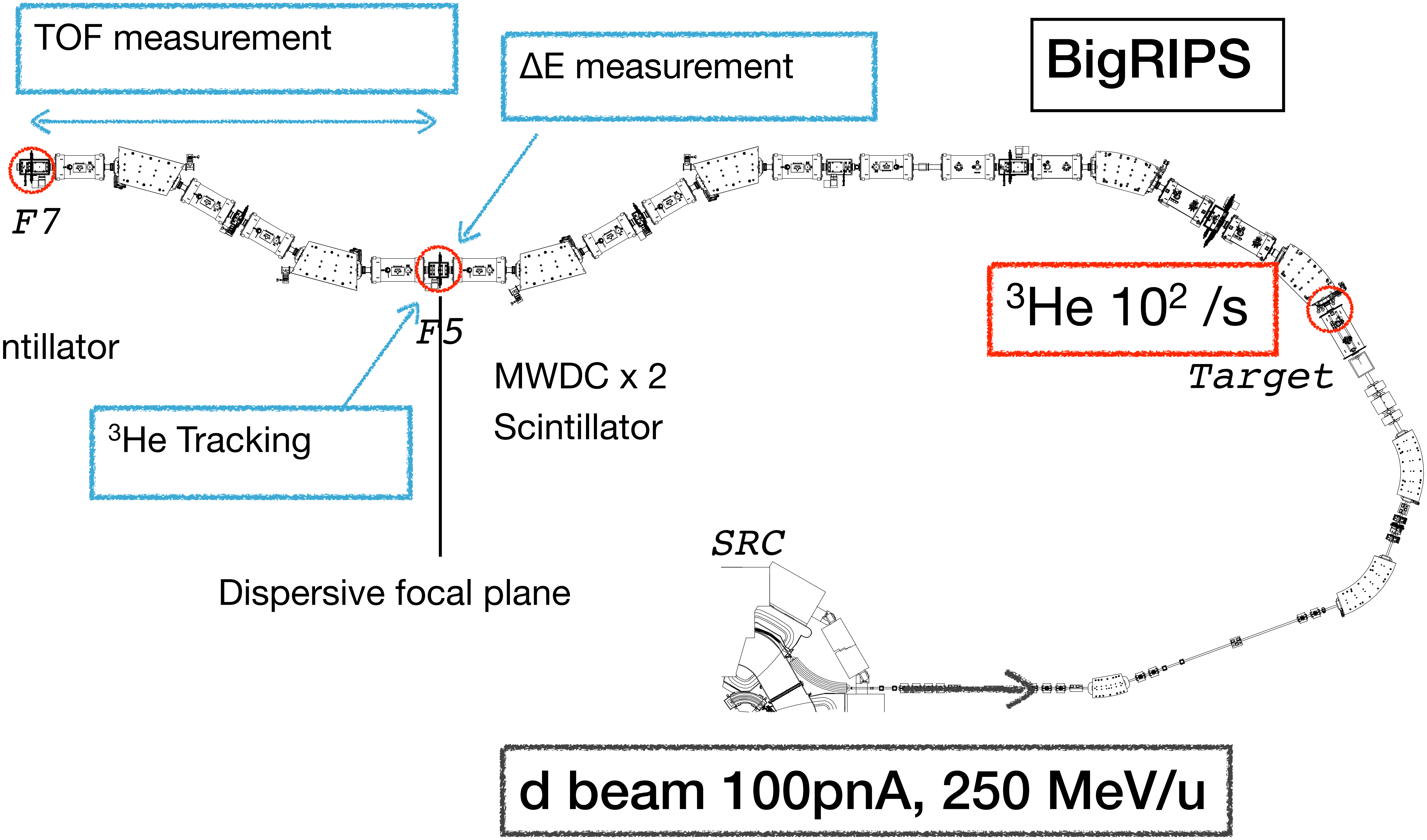
pilot experiment @ RIBF

The pilot experiment @ RIBF



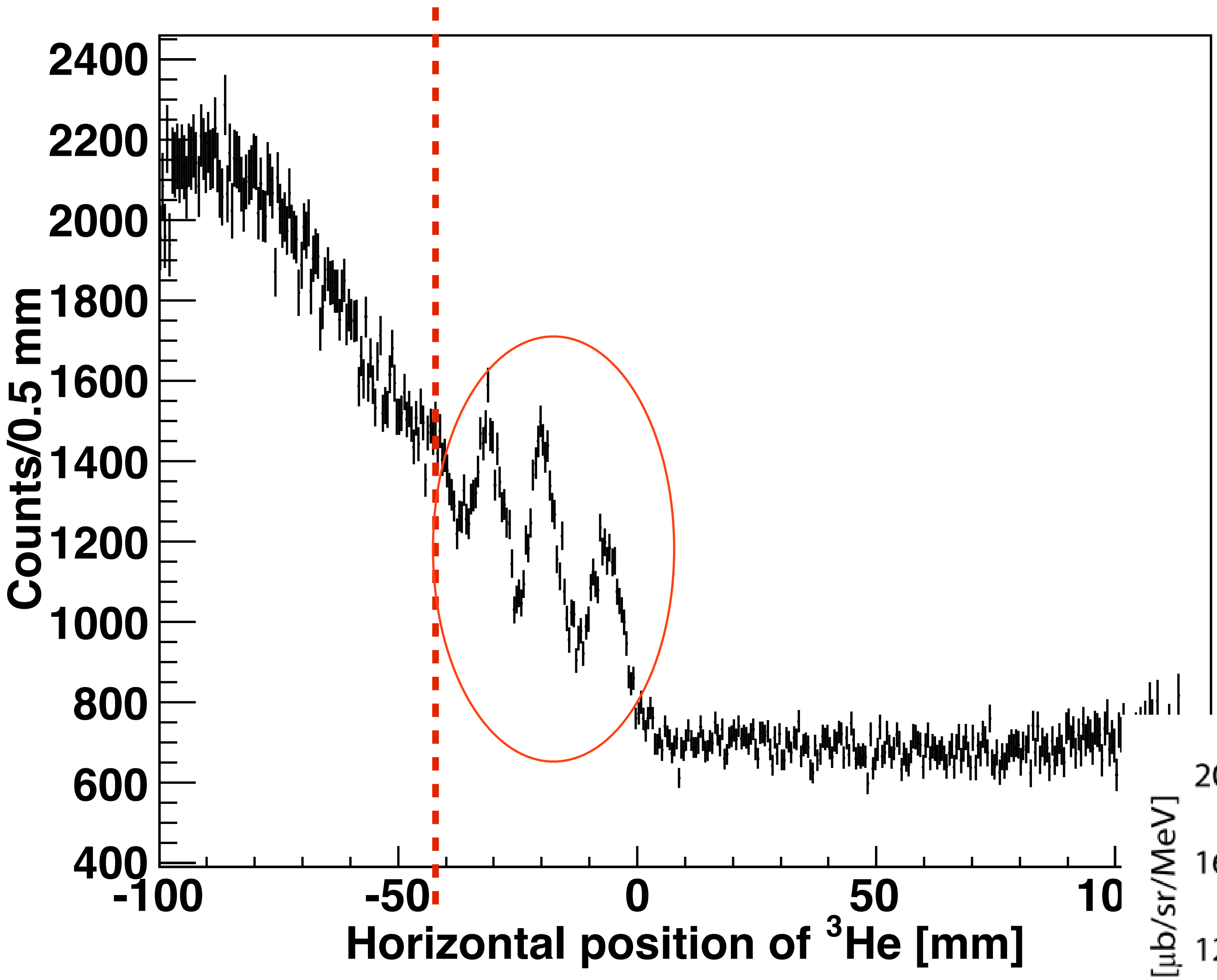
NNDC,BNL

Experimental setup

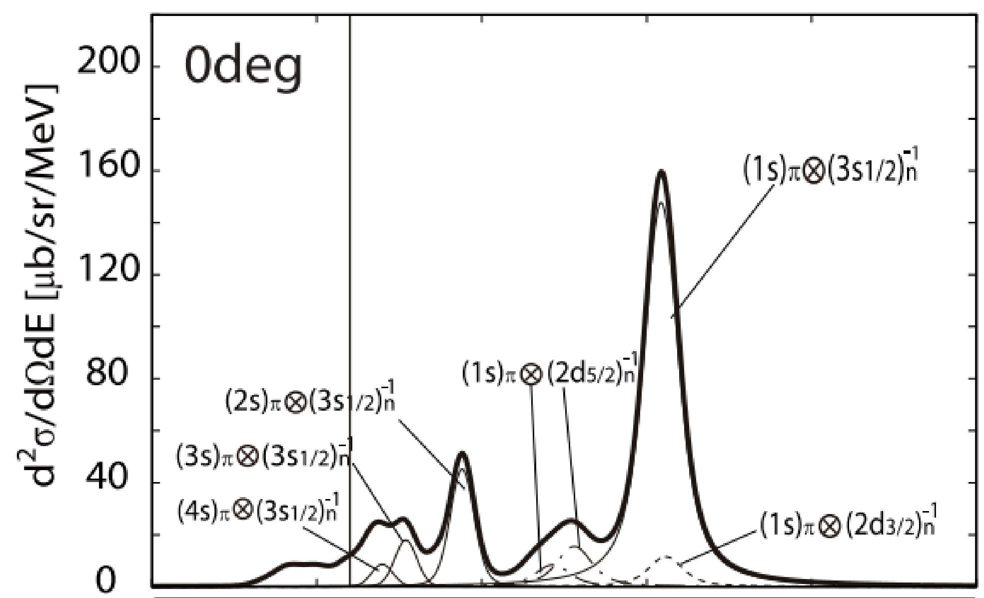


Hayano, MESON 2014, Kraków

^{122}Sn(d,^{3}He) (15 hours) - why 3 peaks?

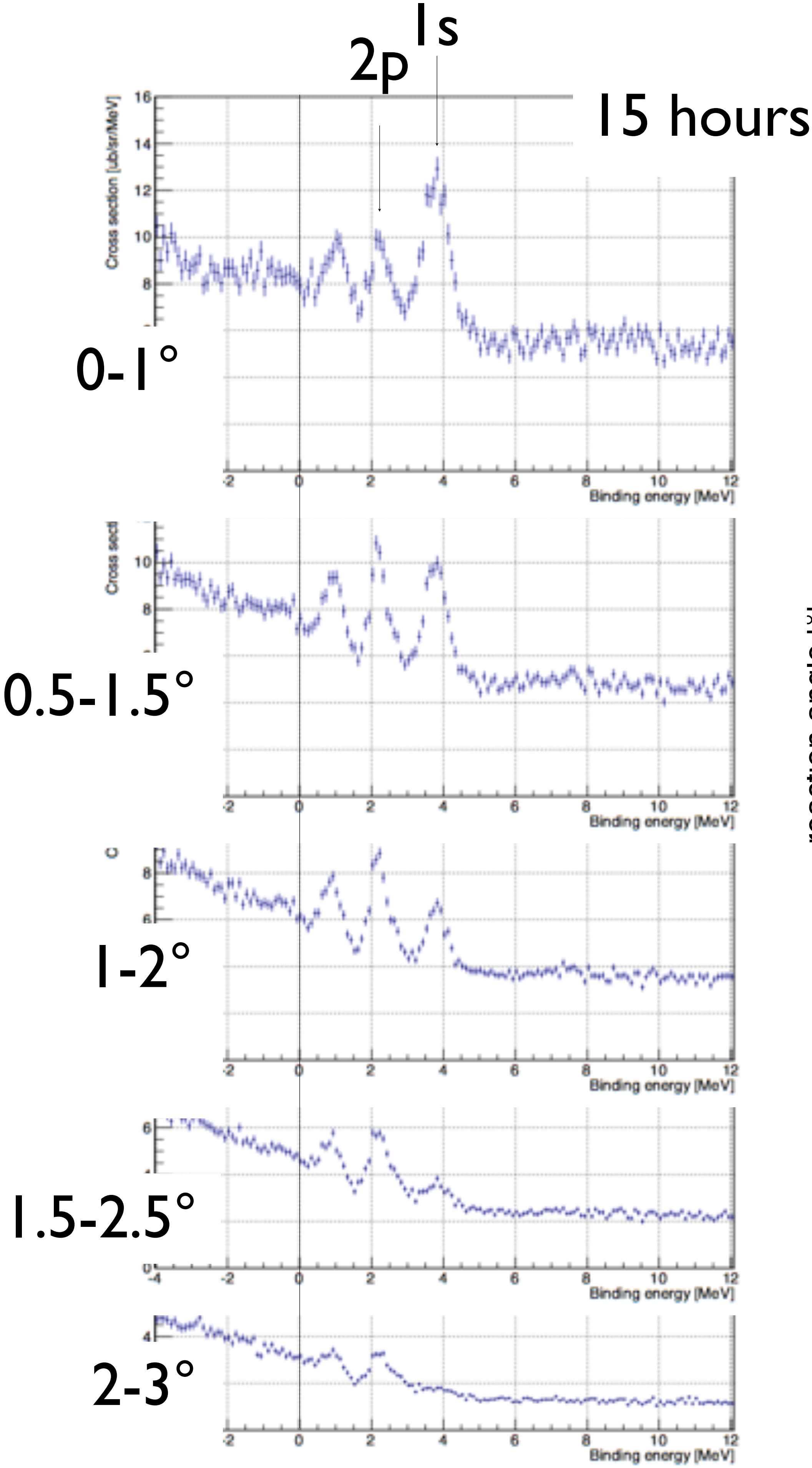


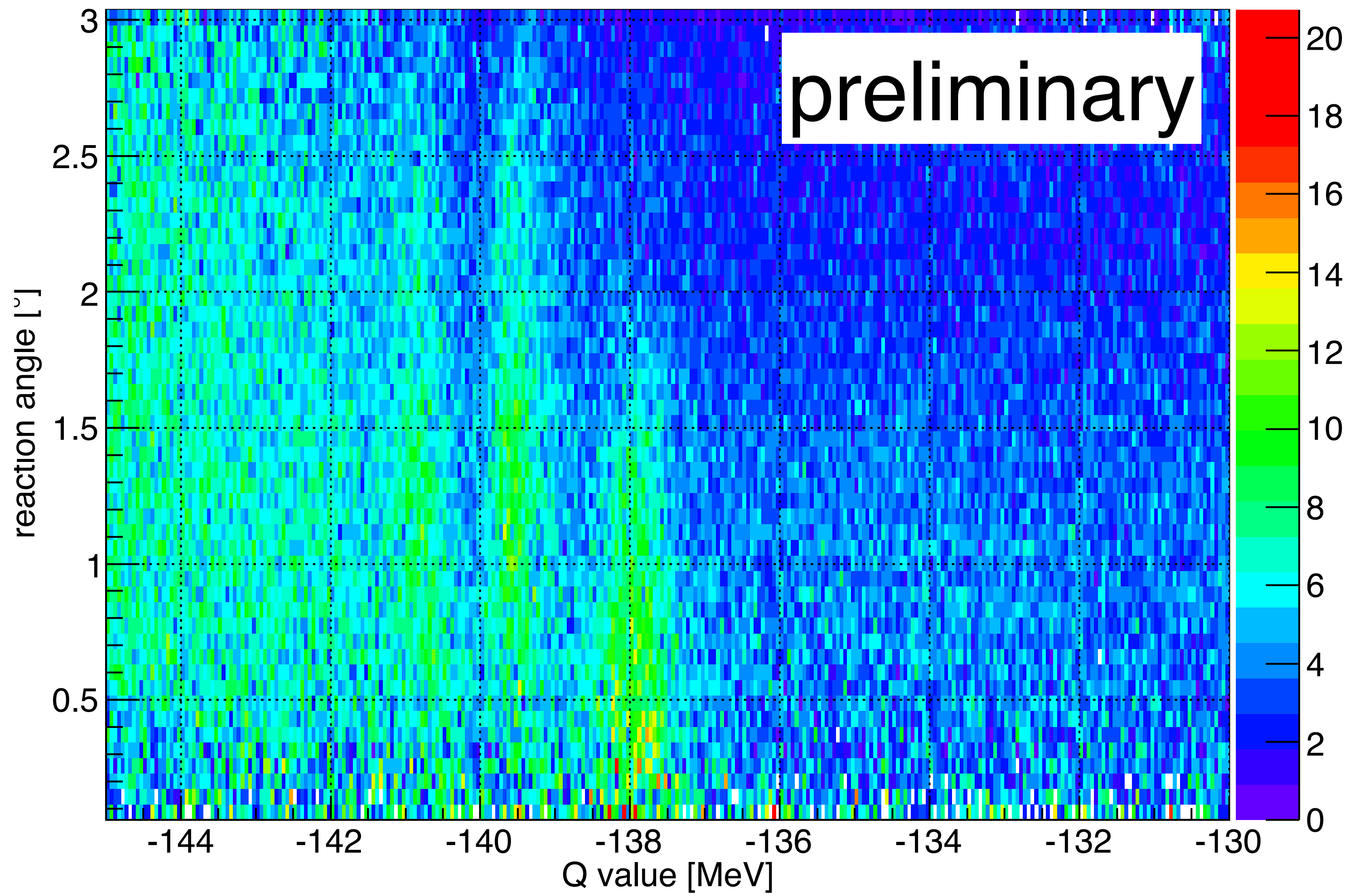
quasi free π threshold



*N. Ikeno et al., Eur. Phys. J. A 47, 161 (2011)

angular distribution!

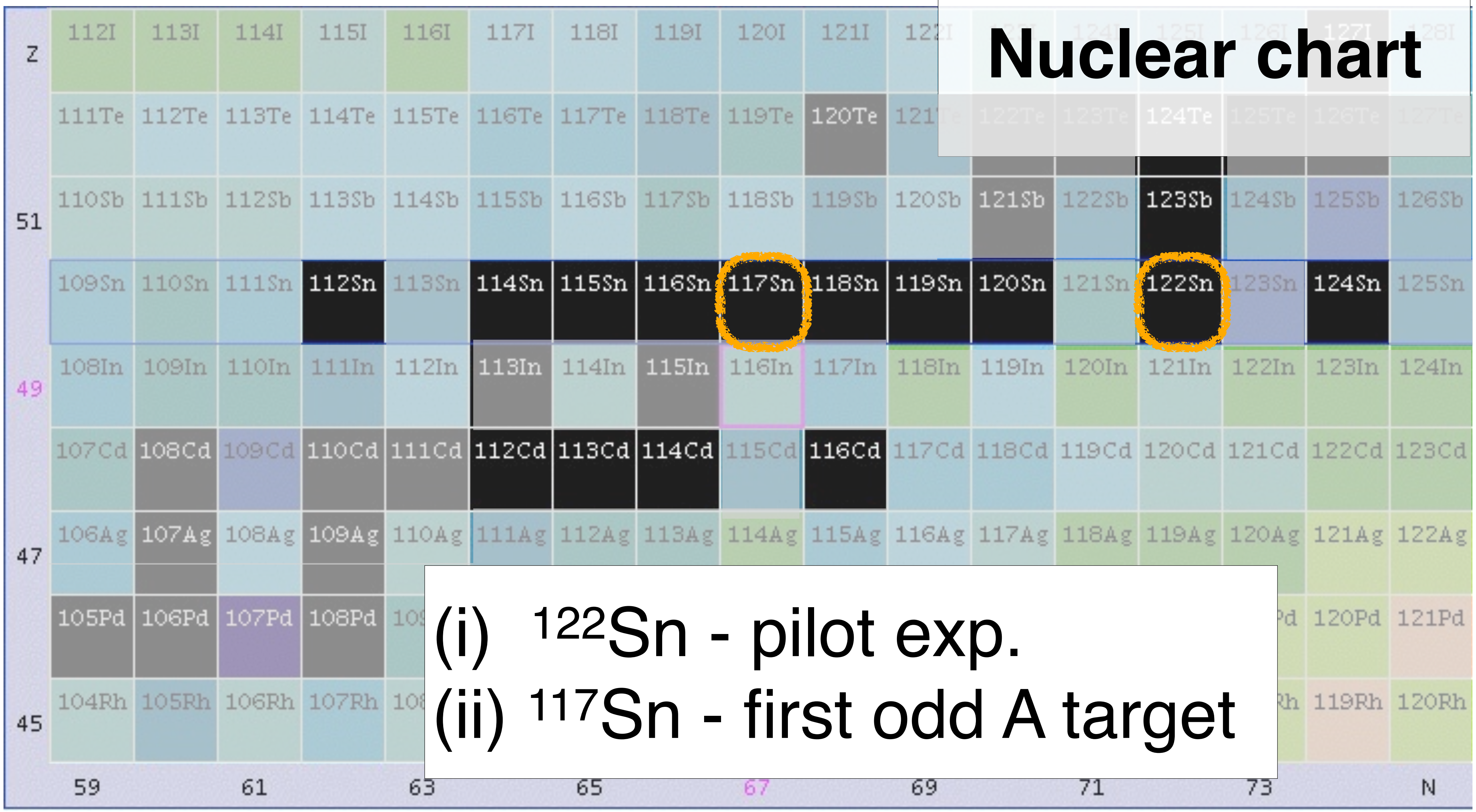




ongoing @ RIKEN RIBF

About to start at RIBF

systematic study of pionic nuclei in isotope / isotone chain

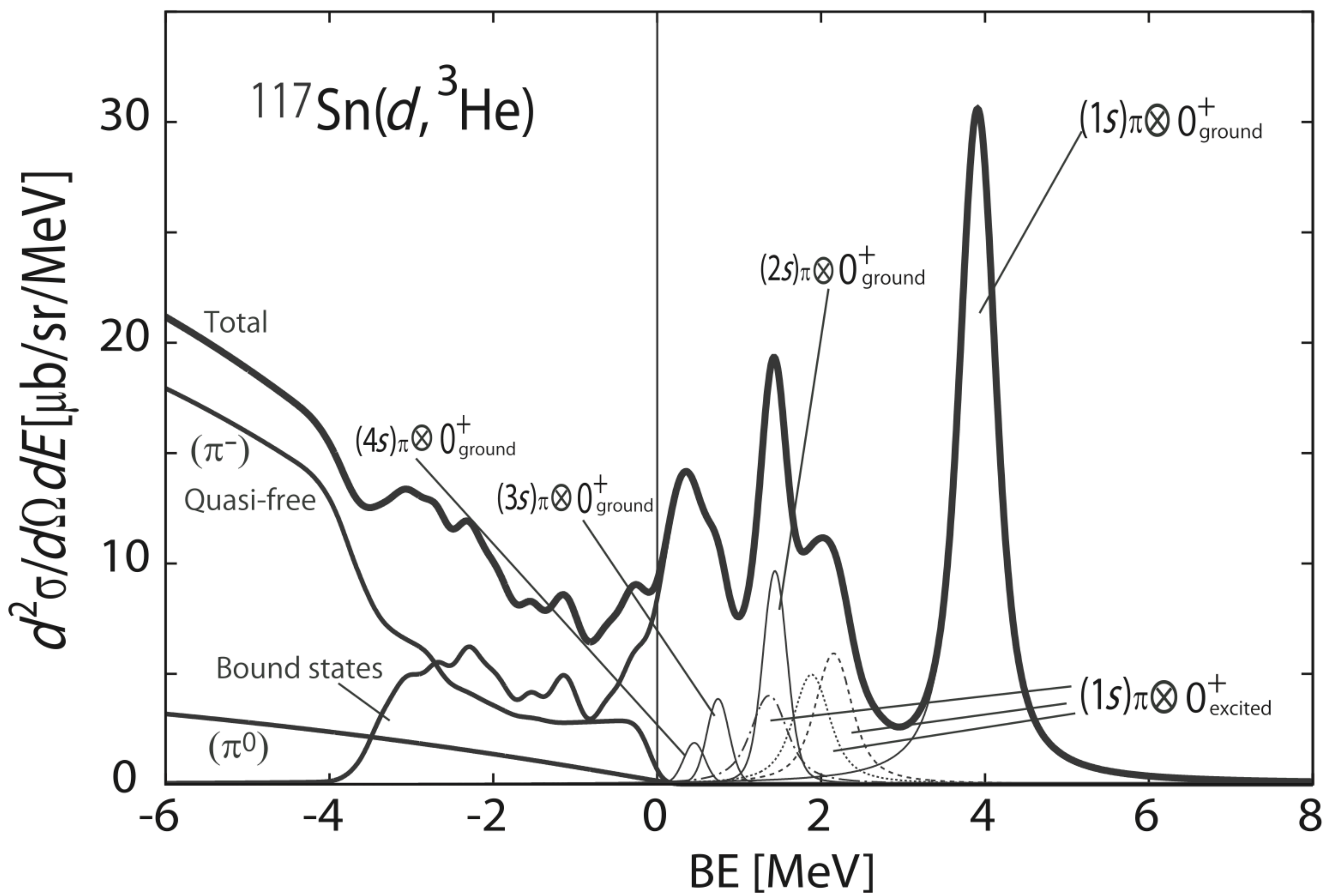


(i) ^{122}Sn - pilot exp.
(ii) ^{117}Sn - first odd A target

NNDC,BNL

Hayano, MESON 2014, Kraków

Measurement of π-^{116}Sn



*N. Ikeno et al., Prog. Theor. Exp. Phys. 2013, 063D01 (2013)

future prospects & summary

Future experiments

- Unstable Sn
  - Try Inverse reaction
    (unstable beam on an active D_2 target)
  - proof of principle experiment (stable beam) in a few years
- Isotones at RIBF
- High resolution x-ray measurements of light pionic atoms
  - use TES borometers
  - pionic ^{3}He & ^{4}He 1s shift & width, with <10 eV resolution, planned at PSI this fall

Summary

- Spectroscopy of pionic atoms - powerful tool to study partial restoration of chiral symmetry
- Ongoing
  - ^{122}Sn(d,^{3}He) - high quality data 1s, 2s, 2p, …
  - ^{117}Sn(d,^{3}He) - first "even-A" pionic 1s, 2s, …
- Future
  - isotones
  - unstable pionic atoms using inverse kinematics
  - high precision X-ray spectroscopy of light (^{3}He, ^{4}He, …) pionic atoms using TES borometers