Precision Spectroscopy of Pionic Atom at RIKEN-RIBF

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In-medium change of <q̄q>

D. Jido *et al.*, PLB670(2008)

In-medium Glashow-Weinberg

$$\frac{\langle \bar{q}q \rangle_\rho}{\langle \bar{q}q \rangle_0} \simeq Z_\pi^{1/2}(\rho) \left(\frac{f_\pi^t(\rho)}{f_\pi} \right)$$

f_π : pion decay constant

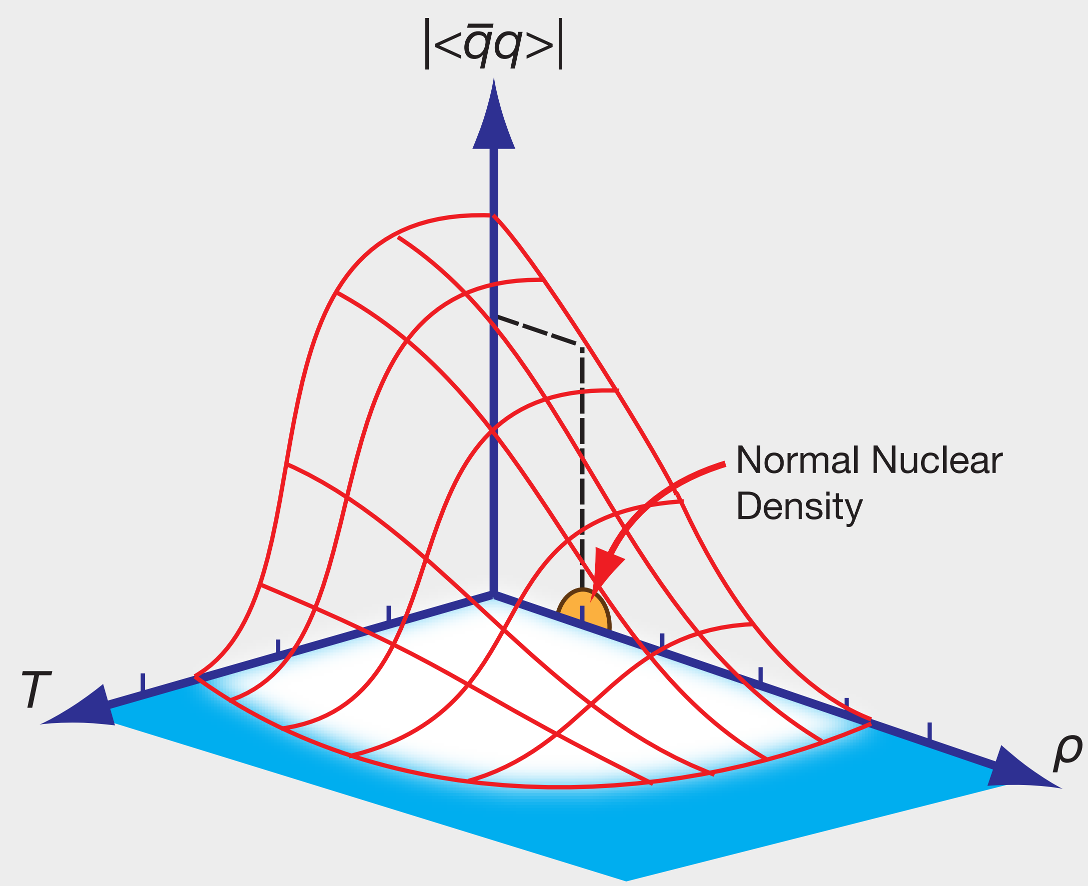
Z_π : pion wave-function renormalization

E.E. Kolomeitsev *et al.*, PRL90(2003)

In-medium Tomozawa-Weinberg

$$\frac{b_1}{b_1(\rho)} \simeq \left(\frac{f_\pi^t(\rho)}{f_\pi} \right)^2$$

b_1 : isovector πN scattering length



$$\frac{\langle \bar{q}q \rangle_\rho}{\langle \bar{q}q \rangle_0} \simeq Z_\pi^{1/2}(\rho) \left(\frac{b_1}{b_1(\rho)} \right)^{1/2}$$

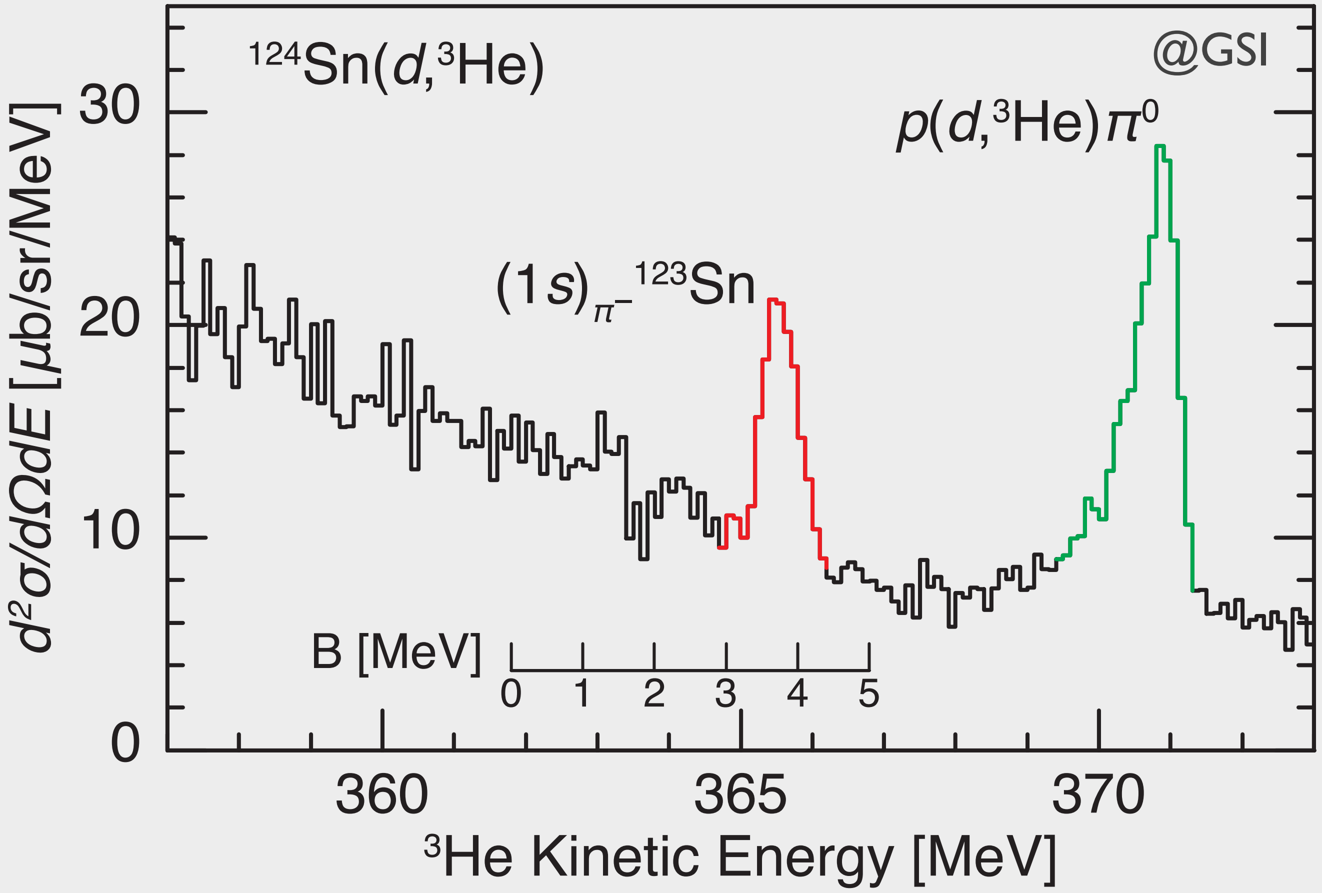
Deeply bound state of pionic atom

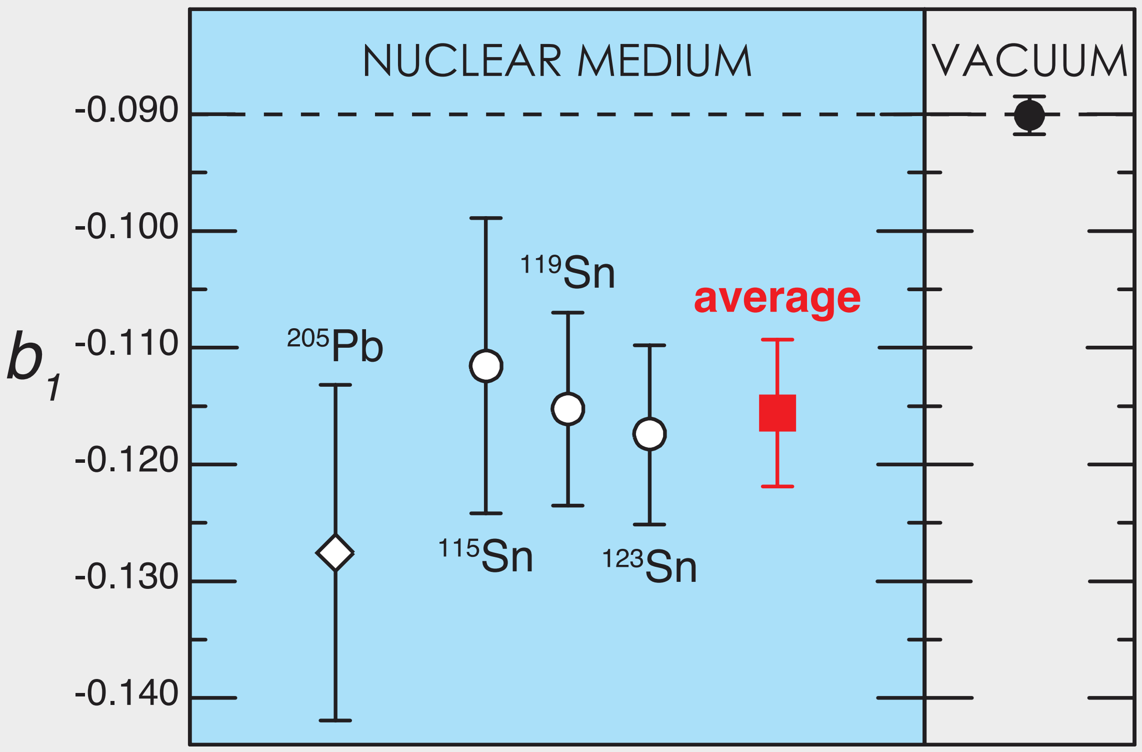
Pion-nucleus optical potential (*s*-wave)

$$V_{\rm opt} \propto b_0(\rho_n + \rho_p) + b_1(\rho_n - \rho_p)$$

isoscalar   isovector

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





piAF project at RIKEN-RIBF

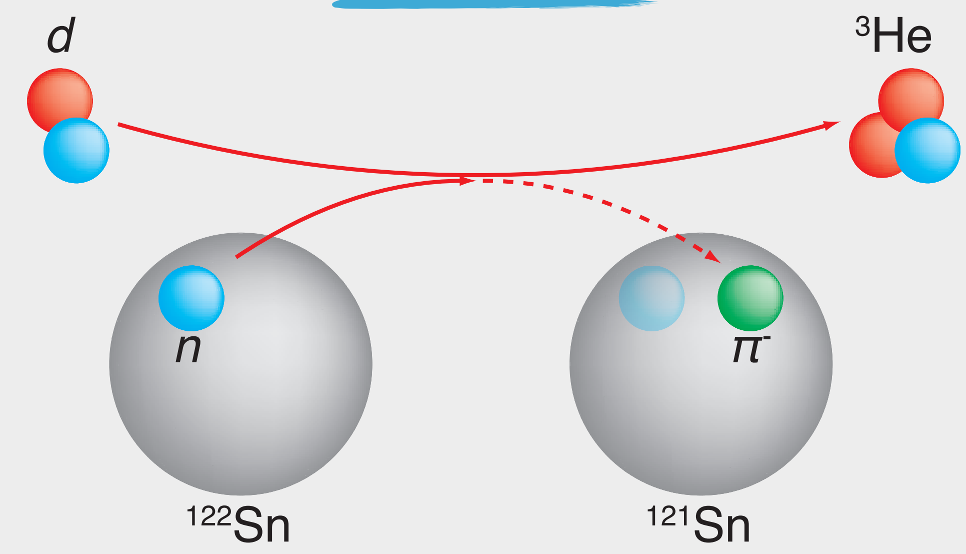
piAF: pionic atom factory

We performed the first pilot experiment of the piAF project at RIKEN-RIBF in October 2010.

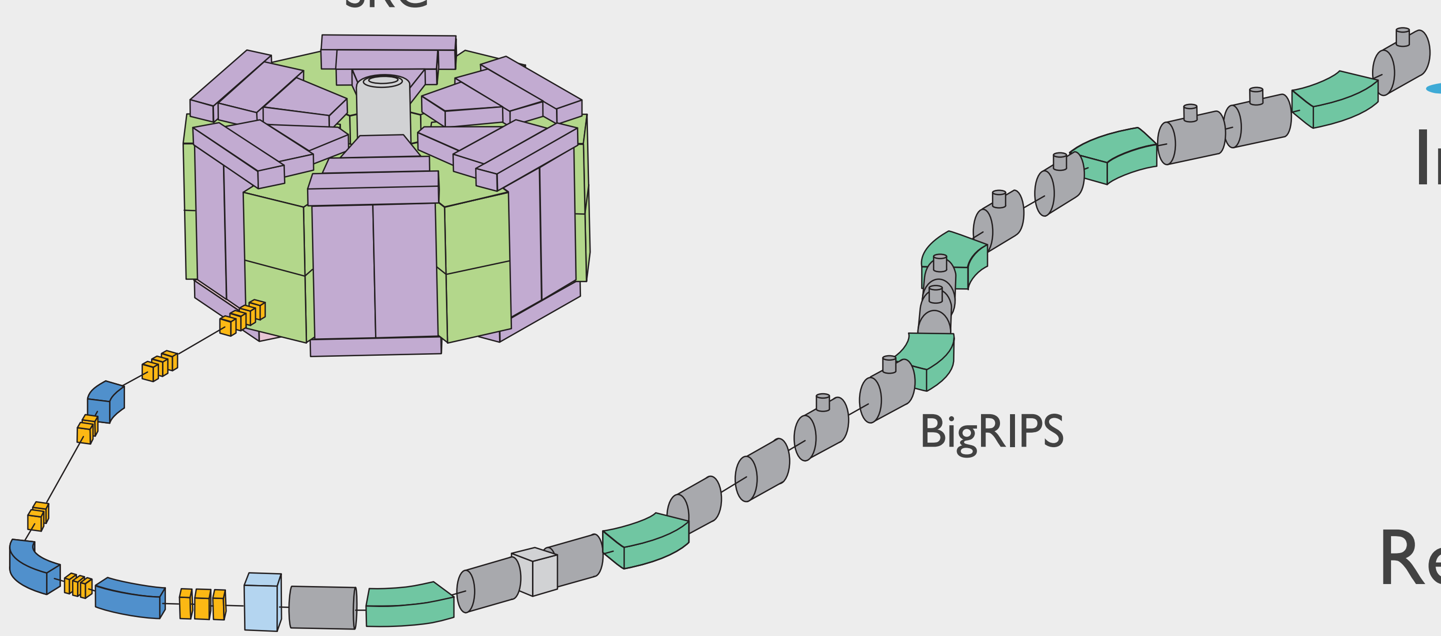
I117 2.22 m (5/2)+ EC	I118 13.7 m 2- * EC	I119 19.1 m 5/2+ EC	I120 81.0 m 2- * EC	I121 2.12 h 5/2+ EC	I122 3.63 m 1+ * EC	I123 13.27 h 5/2+ EC	I124 4.1760 d 2- EC	I125 59.408 d 5/2+ EC	I126 13.11 d 2- EC,β^-	I127 5/2+ 100
Te116 2.49 h 0+ EC	Te117 62 m 1/2+ * EC	Te118 6.00 d 0+ EC	Te119 16.03 h 1/2+ * EC	Te120 0+ 0.096	Te121 16.78 d 1/2+ * EC	Te122 0+ 2.603	Te123 1E+13 y 1/2+ * EC 0.908	Te124 0+ 4.816	Te125 1/2+ * 7.139	Te126 0+ 18.95
Sb115 32.1 m 5/2+ EC	Sb116 15.8 m 3+ * EC	Sb117 2.80 h 5/2+ EC	Sb118 3.6 m 1+ * EC	Sb119 38.19 h 5/2+ * EC	Sb120 15.89 m 1+ * EC	Sb121 5/2+ 57.36	Sb122 2.7238 d 2- * EC,β^-	Sb123 7/2+ 42.64	Sb124 60.20 d 3- * β^-	Sb125 2.7582 y 7/2+ β^-
Sn114 0+ 0.65	Sn115 1/2+ 0.34	Sn116 0+ 14.53	Sn117 1/2+ * 7.68	Sn118 0+ 24.23	Sn119 1/2+ * 8.59	Sn120 0+ 32.59	Sn121 27.06 h 3/2+ * β^-	Sn122 0+ 4.63	Sn123 129.2 d 11/2- * β^-	Sn124 0+ 5.79
In113 9/2+ * 4.3	In114 71.9 s 1+ * EC,β^-	In115 4.41E+14 y 9/2+ * β^- 95.7	In116 14.10 s 1+ * EC,β^-	In117 43.2 m 9/2+ * β^-	In118 5.0 s 1+ * β^-	In119 2.4 m 9/2+ * β^-	In120 3.08 s 1+ * β^-	In121 23.1 s 9/2+ * β^-	In122 1.5 s 1+ * β^-	In123 5.98 s 9/2+ * β^-
Cd112 0+ 24.13	Cd113 9.3E+15 y 1/2+ * β^- 12.22	Cd114 0+ 28.73	Cd115 53.46 h 1/2+ * β^-	Cd116 0+ 7.49	Cd117 2.49 h 1/2+ * β^-	Cd118 50.3 m 0+ β^-	Cd119 2.69 m 3/2+ * β^-	Cd120 50.80 s 0+ β^-	Cd121 13.5 s (3/2+) * β^-	Cd122 5.24 s 0+ β^-

Precision spectroscopy of pionic atom

Using the (d,^{3}He) reaction
near the recoilless condition
T_d = 500 MeV, ^{122}Sn target



RIKEN RIBF



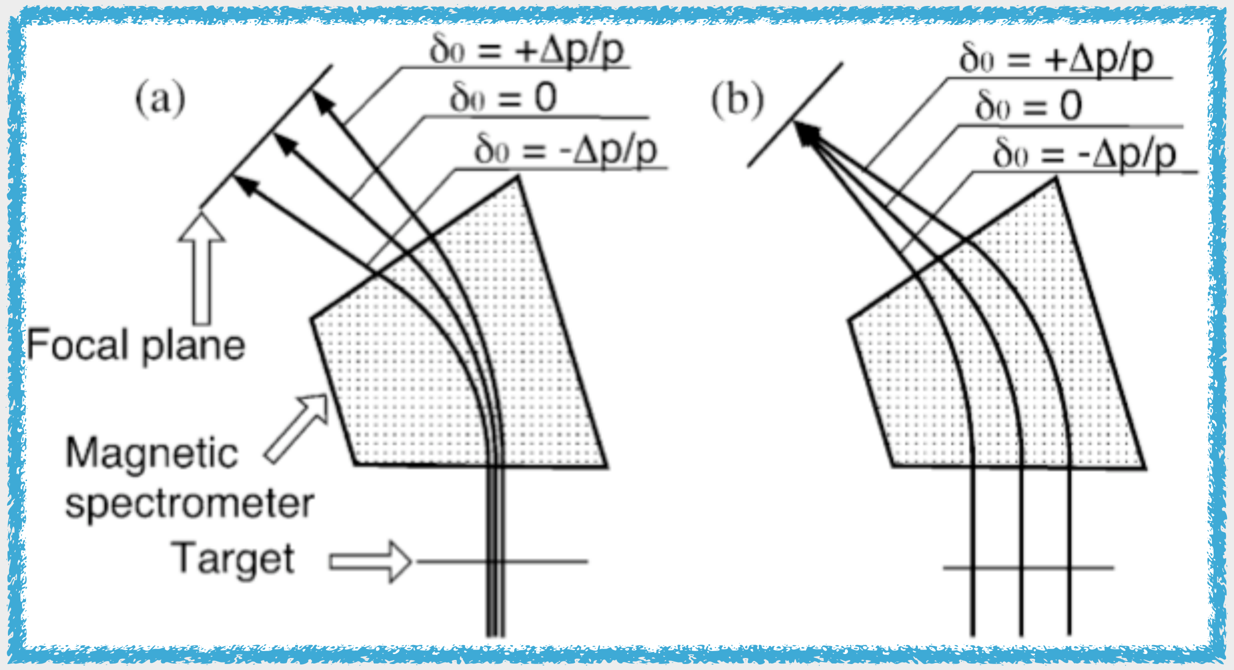
	GSI	RIKEN
Intensity	10^{11}/s	10^{12}/s
Target	20 mg/cm^2	10 mg/cm^2
$\Delta p_d/p_d$	0.03%	~~0.1%~~
Resolution	400 keV	200 keV

Dispersion matching

$$\begin{pmatrix} x \\ \theta \\ \delta \end{pmatrix} = \underbrace{\begin{pmatrix} s_{11} & s_{12} & s_{16} \\ s_{21} & s_{22} & s_{26} \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Spectrometer}} \underbrace{\begin{pmatrix} b_{11} & b_{12} & b_{16} \\ b_{21} & b_{22} & b_{26} \\ 0 & 0 & 1 \end{pmatrix}}_{\text{Beam line to Target}} \begin{pmatrix} x_0 \\ \theta_0 \\ \delta_0 \end{pmatrix}$$

Beam position at focal plane

$$x = (b_{11}s_{11} + b_{21}s_{12})x_0 + (b_{12}s_{11} + b_{22}s_{12})\theta_0 + (b_{16}s_{11} + b_{26}s_{12} + s_{16})\delta_0$$



Dispersion matching condition

$$b_{16}s_{11} + b_{26}s_{12} + s_{16} = 0$$

Matching condition

Matching condition with the target

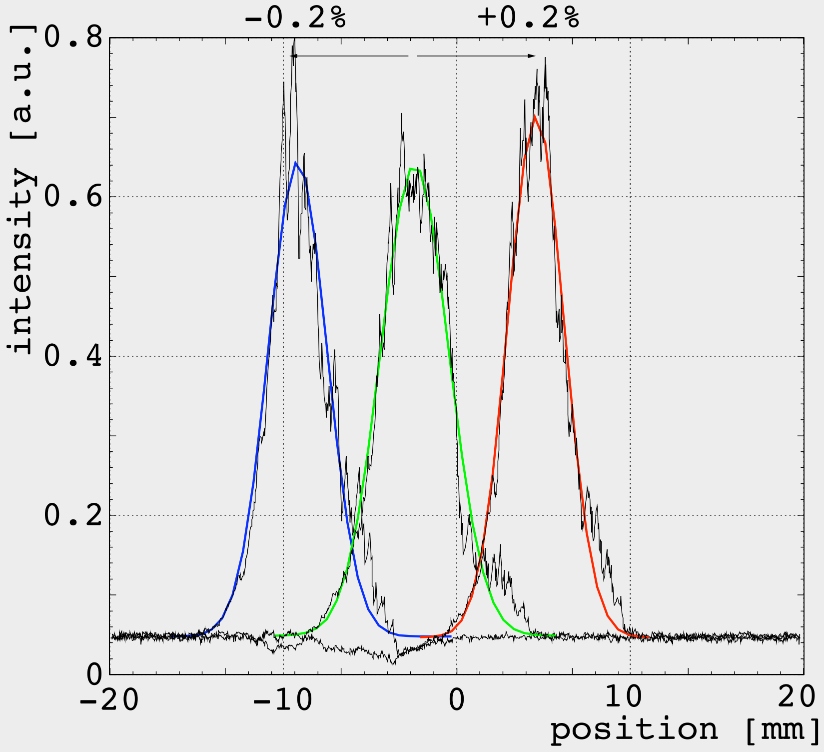
$$b_{16}s_{11} + b_{26}s_{12} + Cs_{16} = 0$$

C : kinetic factor of the $(d, {}^3\mathrm{He})$ reaction

$C = 1.3$
$b_{16} = 46$ [mm/%]
$b_{26} = 0.0$ [mrad/%]

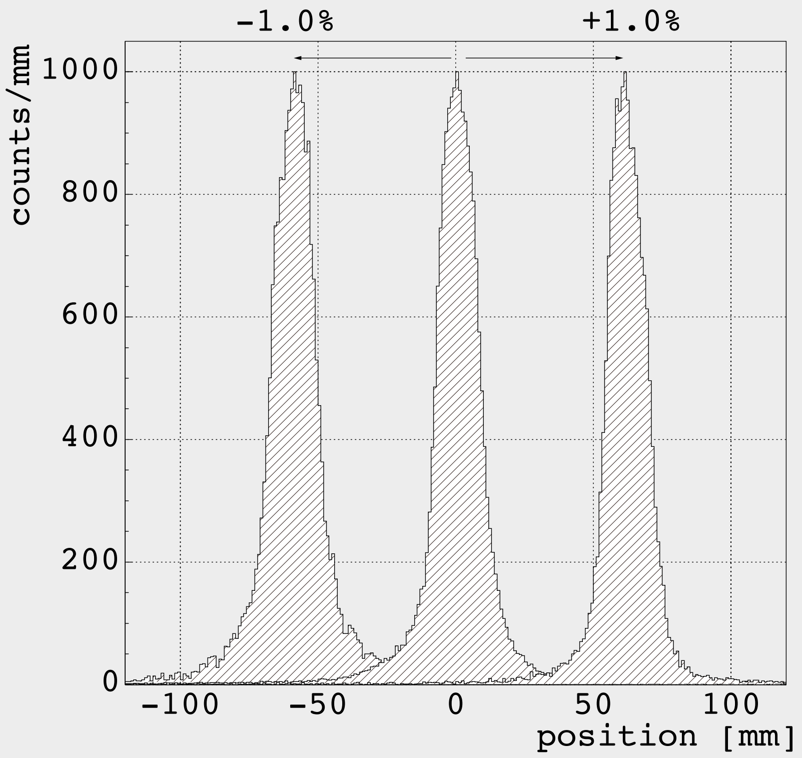
$s_{11} = -1.8$
$s_{12} = 0.0$ [mm/mrad]
$s_{16} = 64$ [mm/%]

b_{16} measurement



$b_{16} = 43.8$ [mm/%]

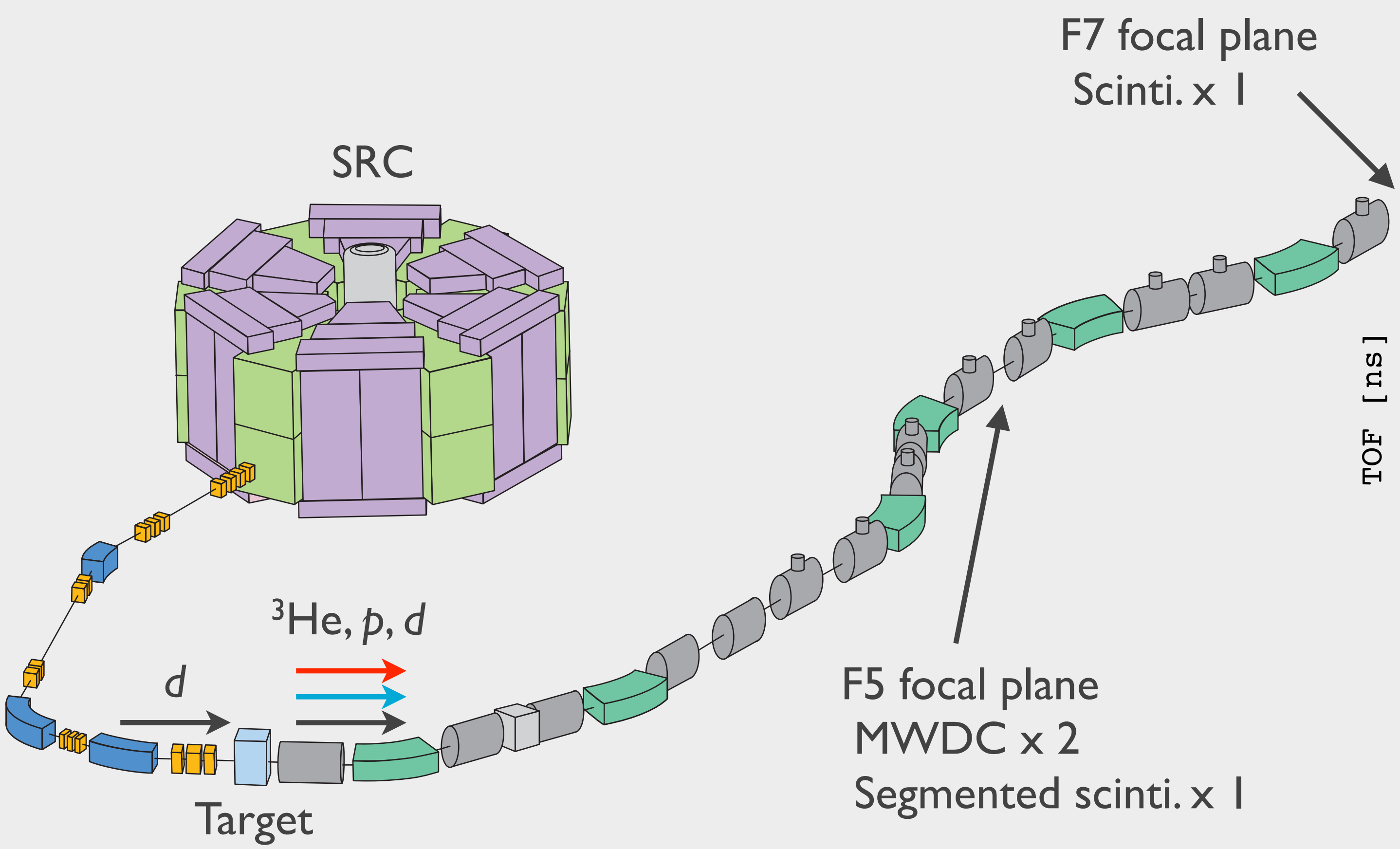
s_{16} measurement



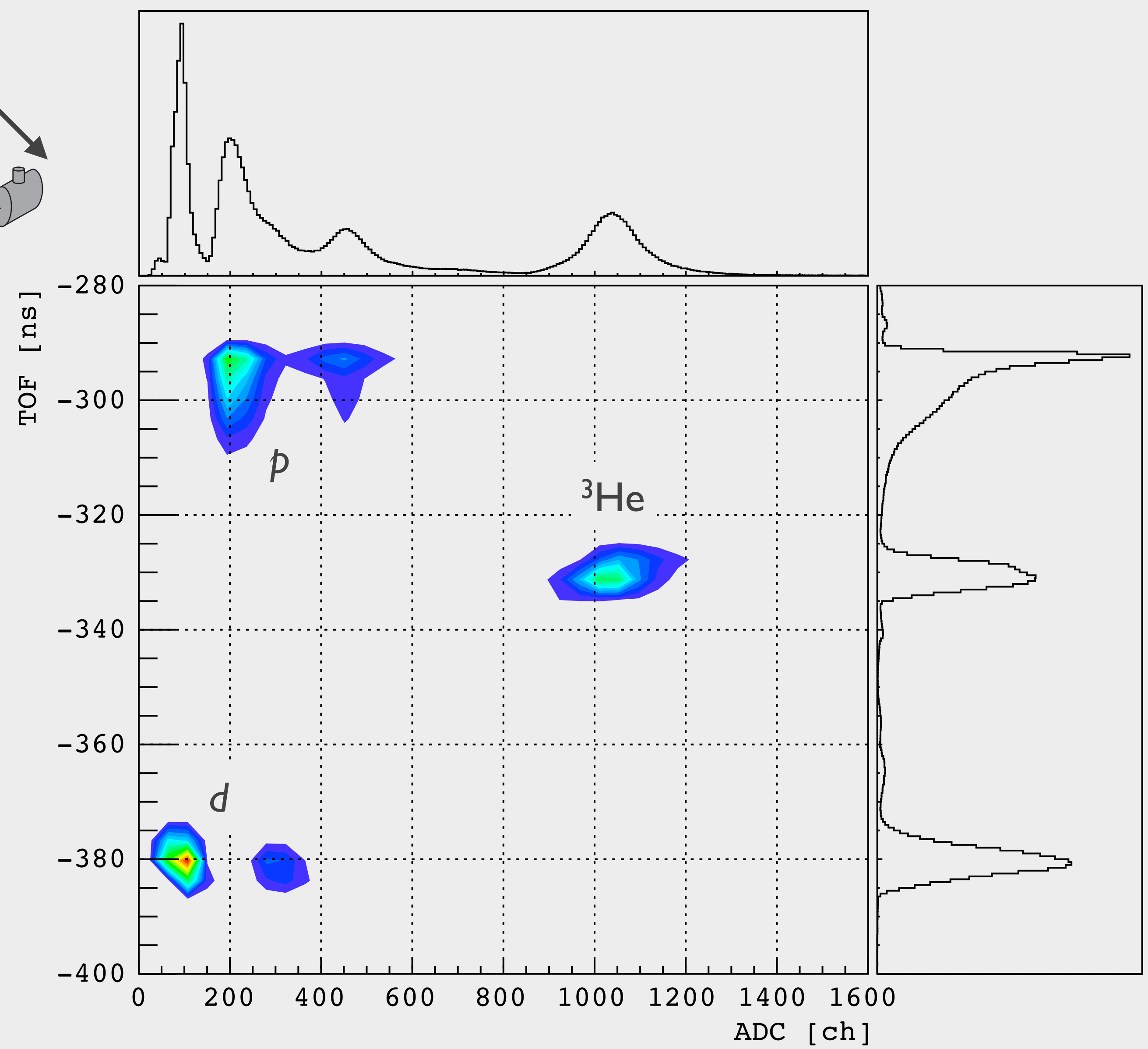
$s_{16} = 60.9$ [mm/%]

Experimental setup

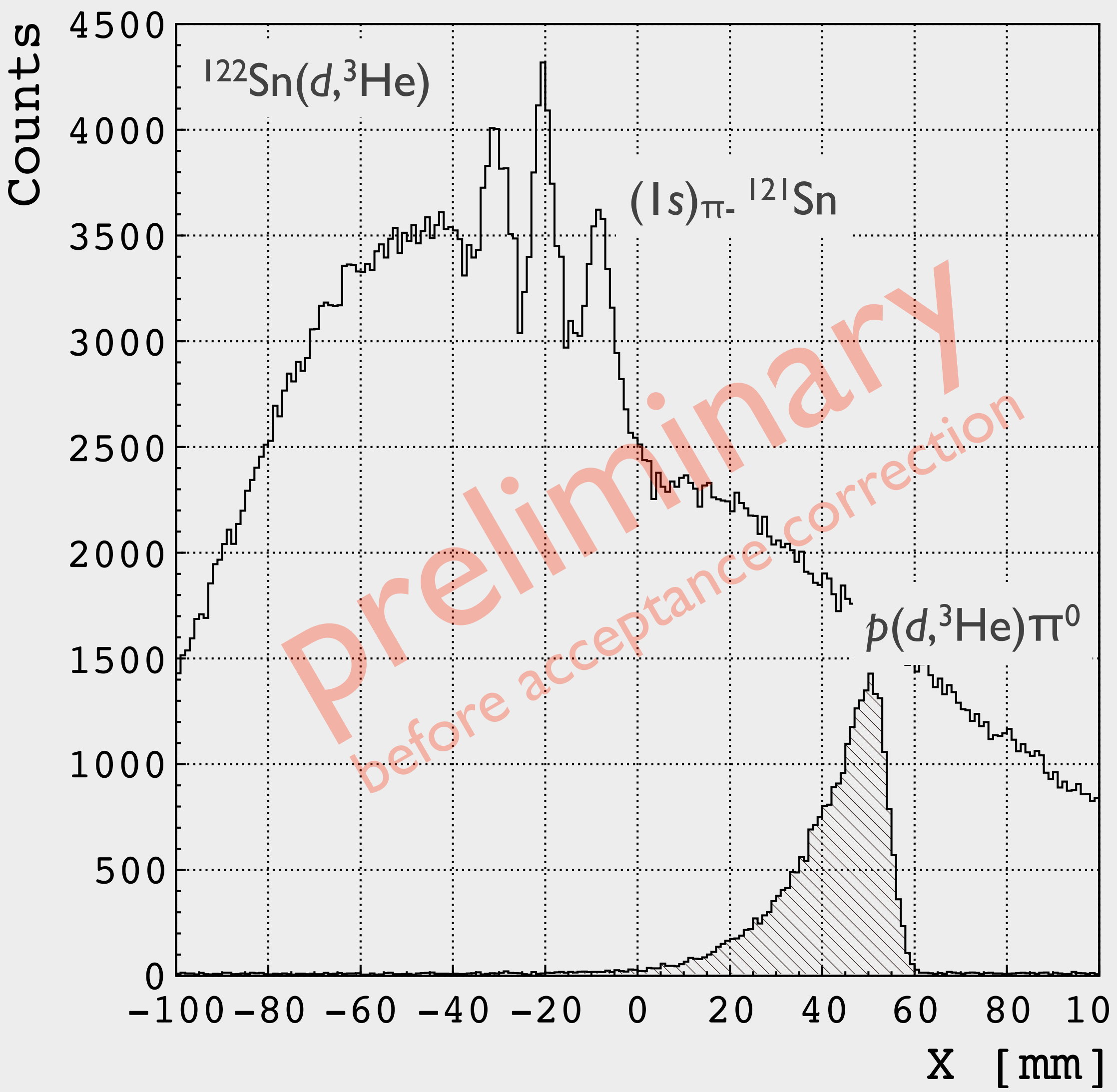
RIKEN RIBF



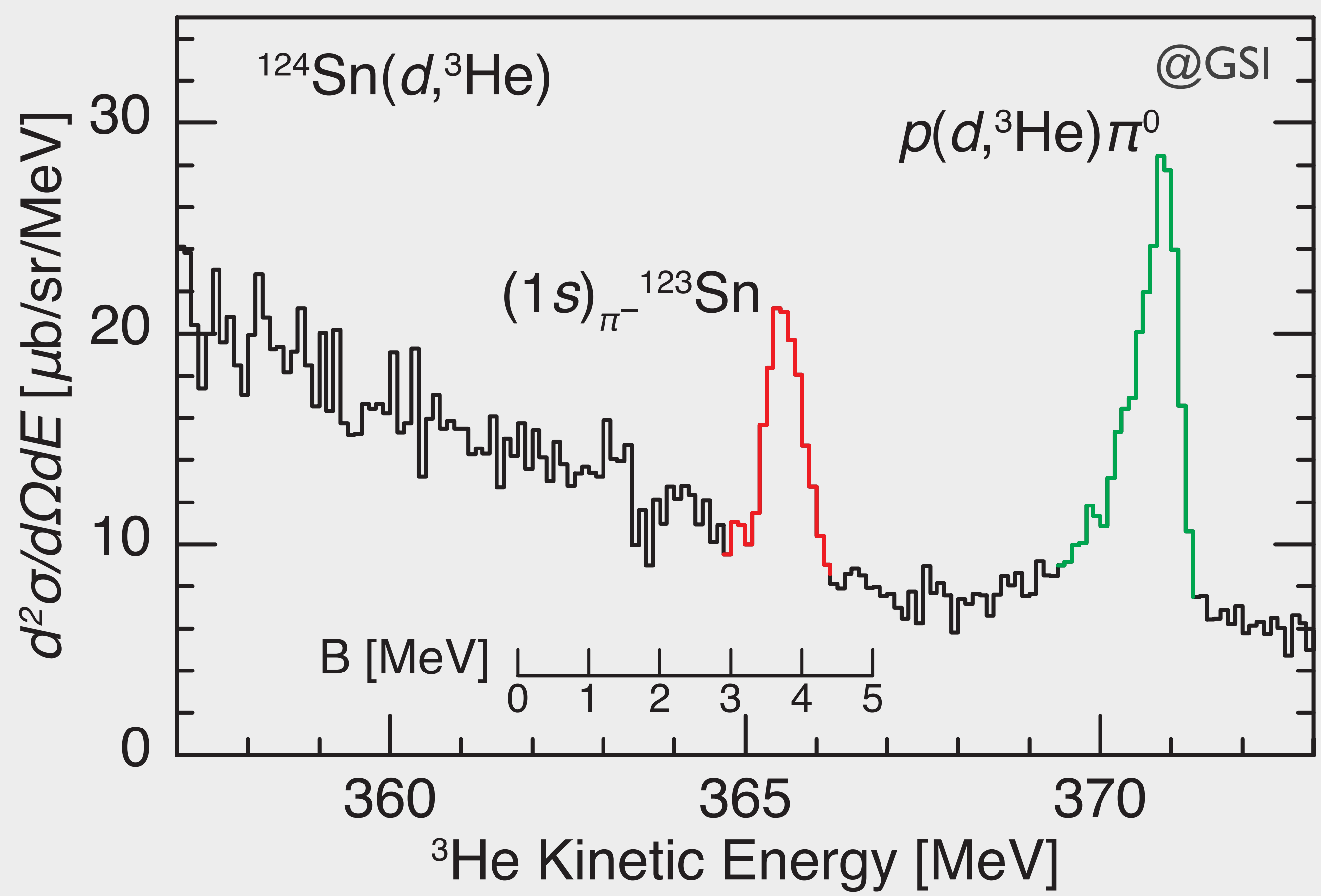
Particle identification



New data of ^{121}Sn pionic atom

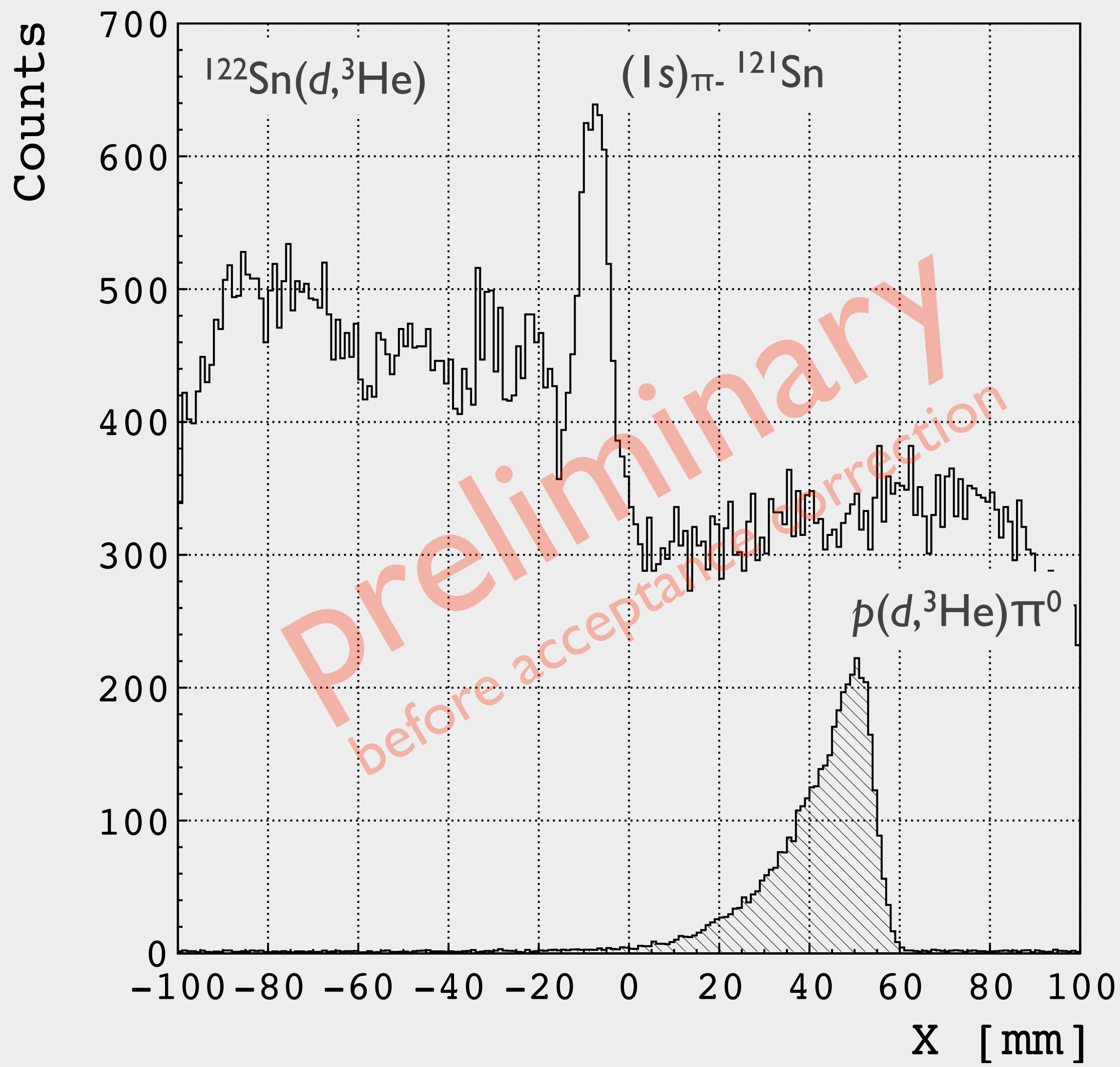


K. Suzuki *et al.*, PRL92(2004)

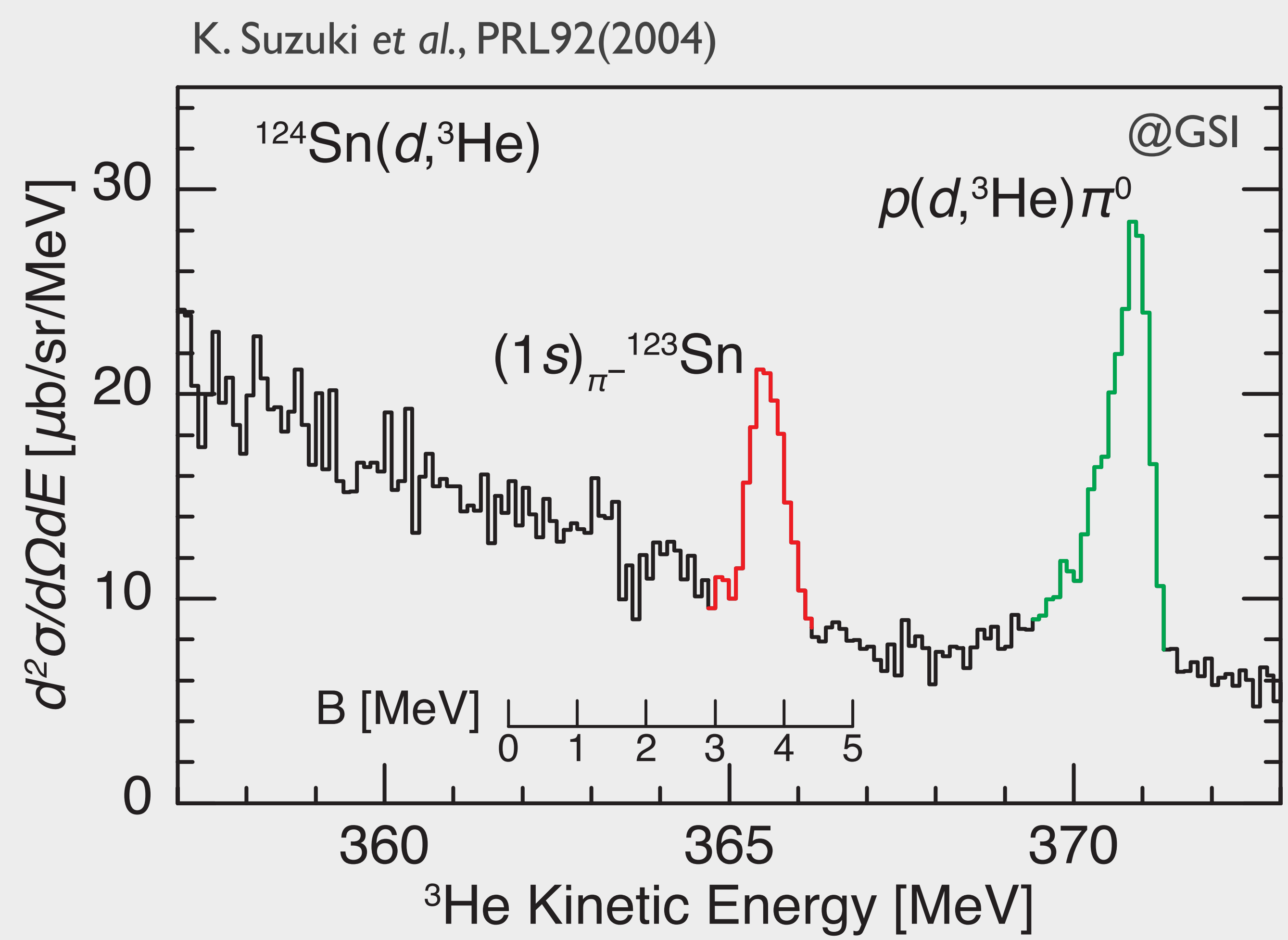


New data of ^{121}Sn pionic atom

-7 < A [mrad] < 7 A: horizontal beam angle
-9 < B [mrad] < 9 B: vertical beam angle



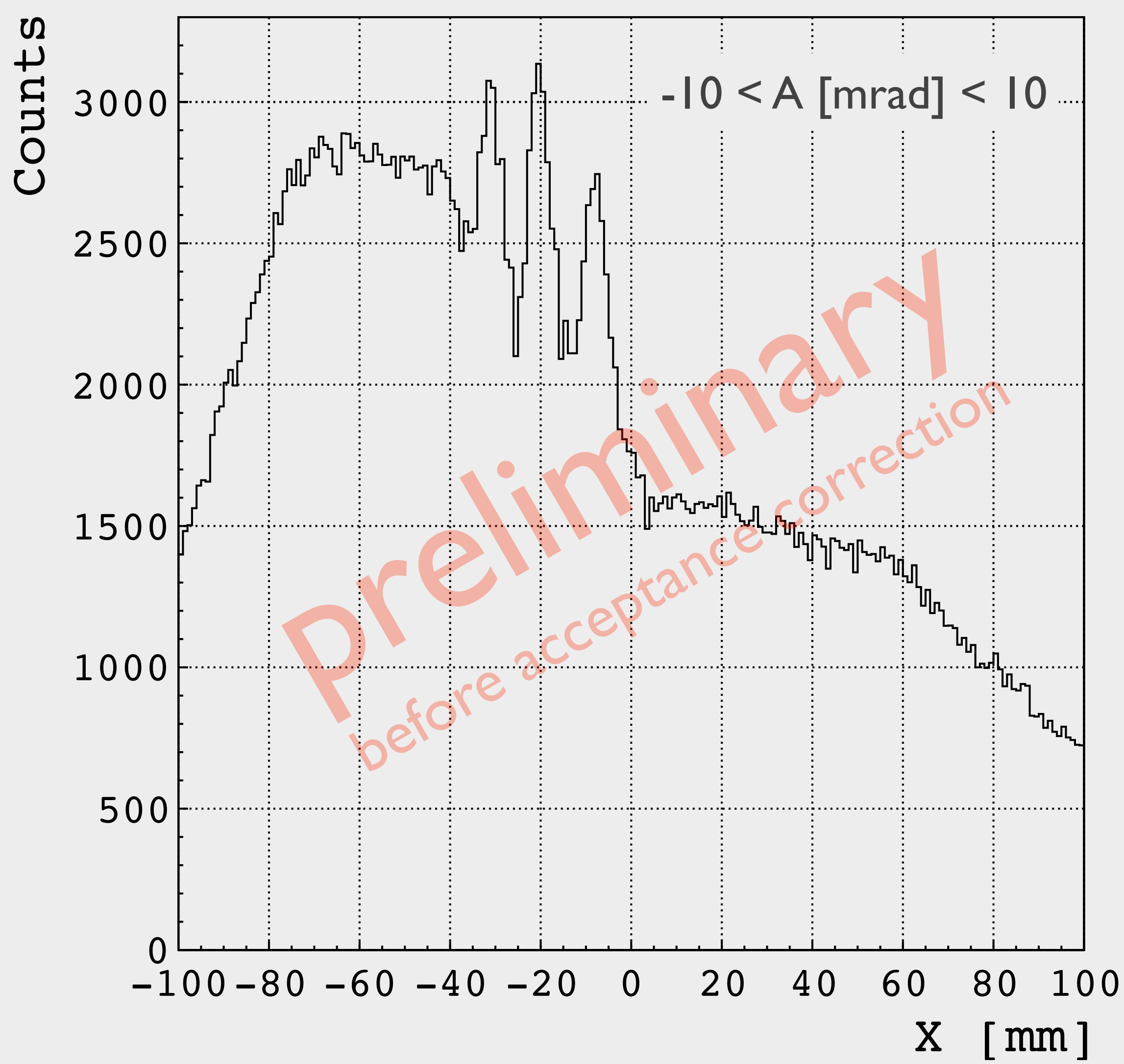
K. Suzuki *et al.*, PRL92(2004)

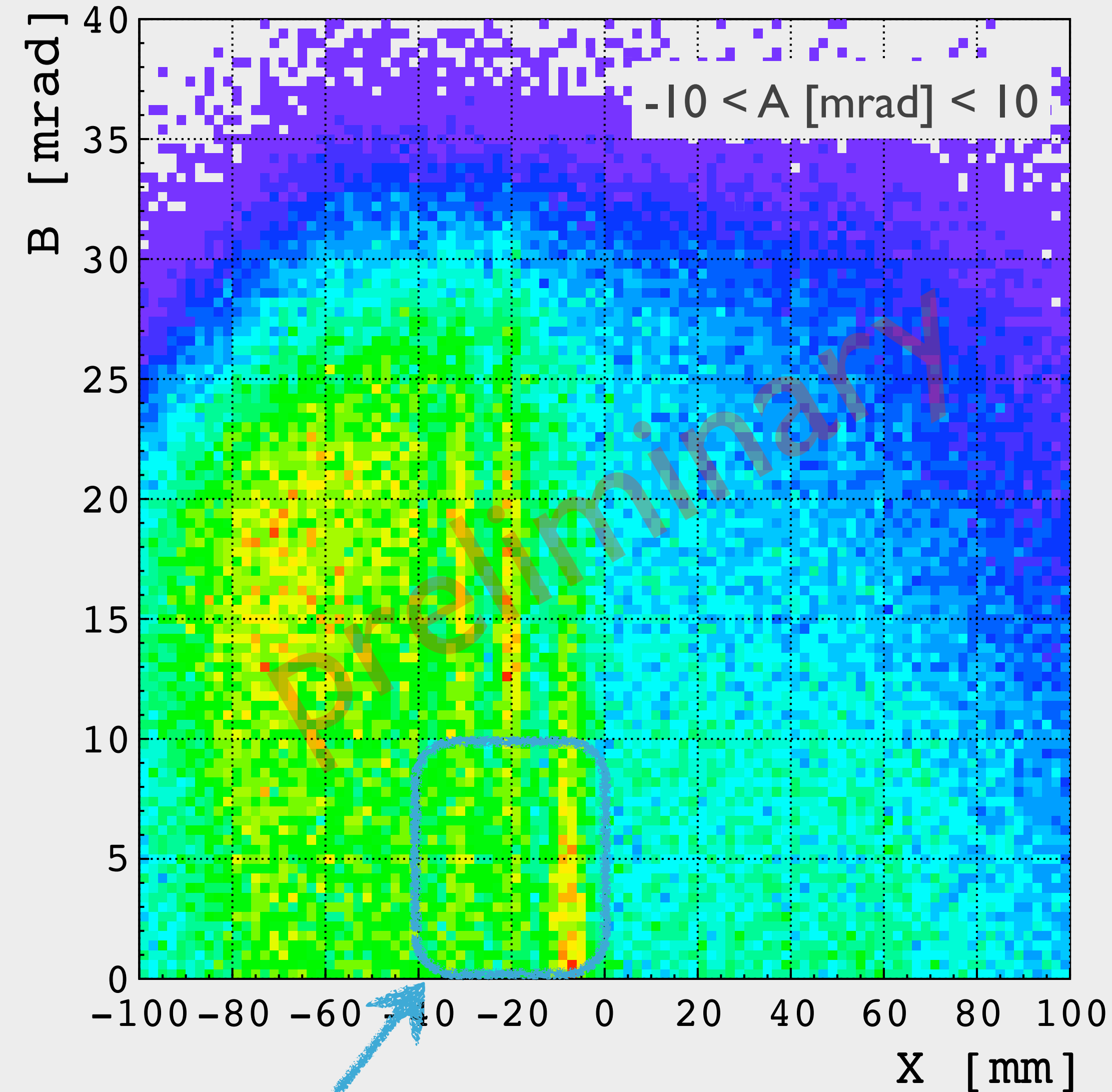


Obtained histogram with a selection of the forward reaction is similar shape to the previous GSI experiment.

Beam position vs beam angle

A: horizontal beam angle
B: vertical beam angle

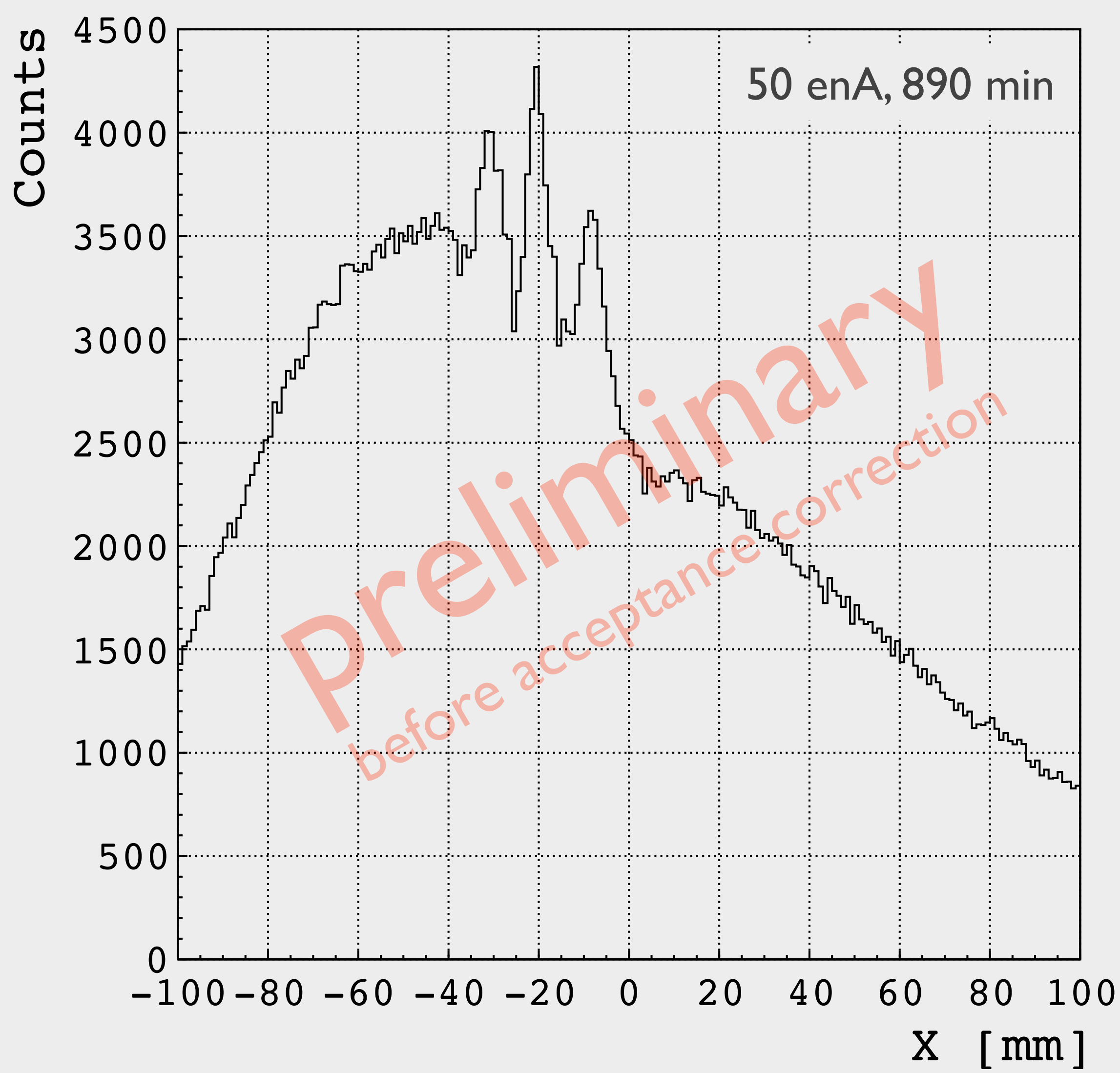




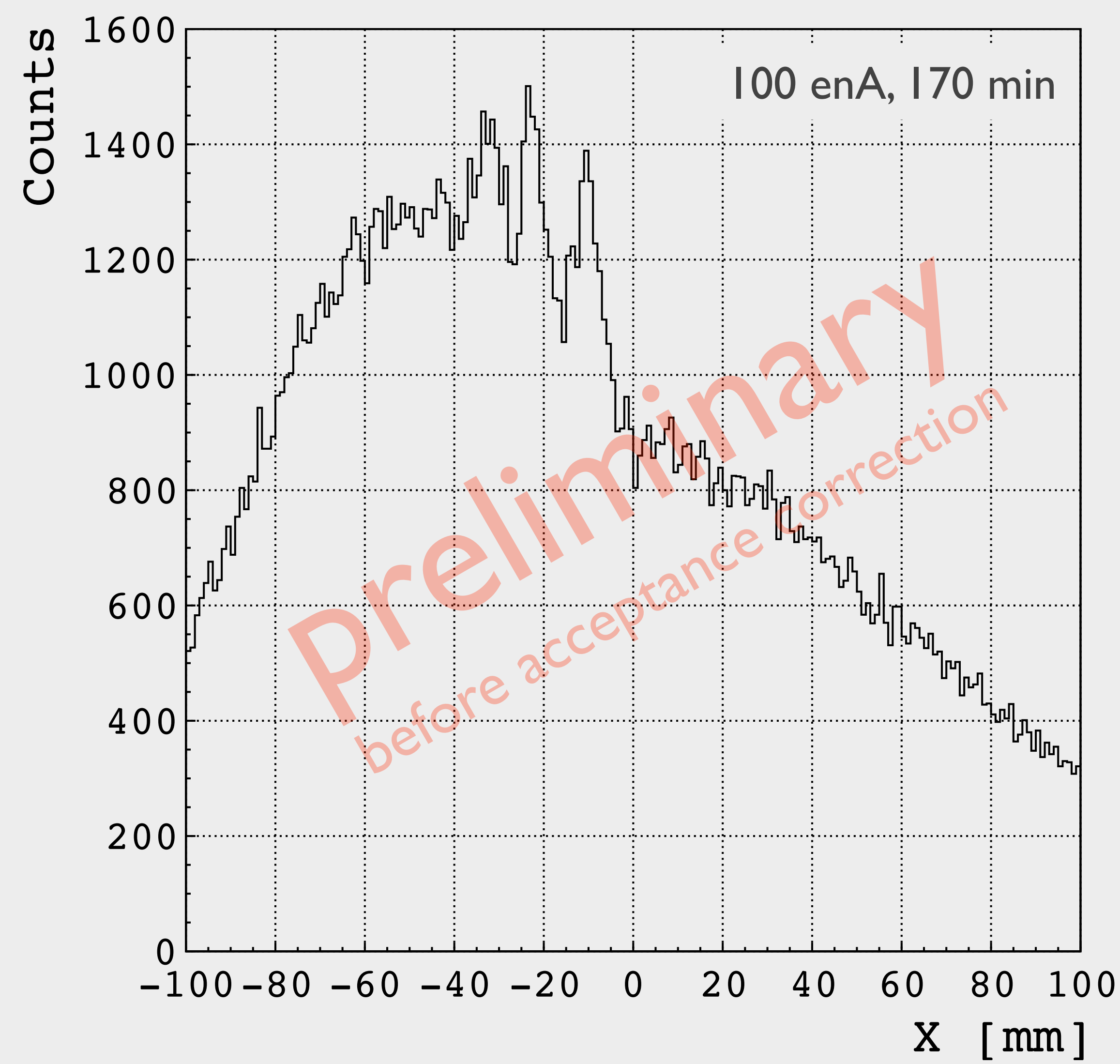
1s state is dominant for the forward emittion angle.

Evaluation of dispersion matching

1mm-strip target



Full target



Resolution of the full target is comparable with that of the strip target.
However, there is room for improvement to achieve 200 keV resolution.

Summary

1. We performed the precision spectroscopy experiment of the pionic atom at RIKEN-RIBF in October 2010.
2. The dispersion matching was realized. However, there is room for improvement.
3. We observed the deeply bound 1s state (and others) of the ^{121}Sn pionic atom.
4. Future plans
   - To deduce the binding energy and the width of the deeply bound state.
   - Improvement of the dispersion matching for the next experiment.

piAF collaboration (October 2010)

S. Itoh, G.P.A. Berg, H. Geissel, R.S. Hayano,

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