Spectroscopy of pionic atoms via (p, ^{2}He) reaction

Yuni N. Watanabe

University of Tokyo

Univ. of Tokyo: R. S. Hayano
Kyoto Univ.: S. Ashikaga, H. Fujioka, T. Furuno, K. Inaba, T. Kawabata, S. Matsumoto, T. Morimoto, M. Murata, A. Sakaue, Y. Takahashi, M. Tsumura, K. Watanabe
RCNP: S. Adachi, N. Aoi, G. Guillaume, K. Hatanaka, A. Inoue, C. Iwamoto, S. Noji, H. J. Ong, A. Tamii, T. S. Tang
Tohoku Univ.: Y. Matsuda
Konan Univ.: K. Heguri
RIKEN: K. Itahashi, T. Nishi
GSI: Y. K. Tanaka, H. Geissel
Beihang Univ.: S. Terashima
Inst. for Basic Science: T. Hashimoto

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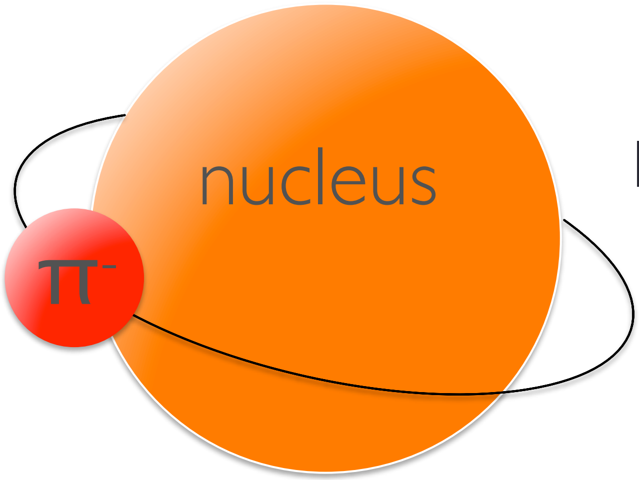
Introduction: Deeply Bound Pionic Atoms



Interaction
- EM
- Strong

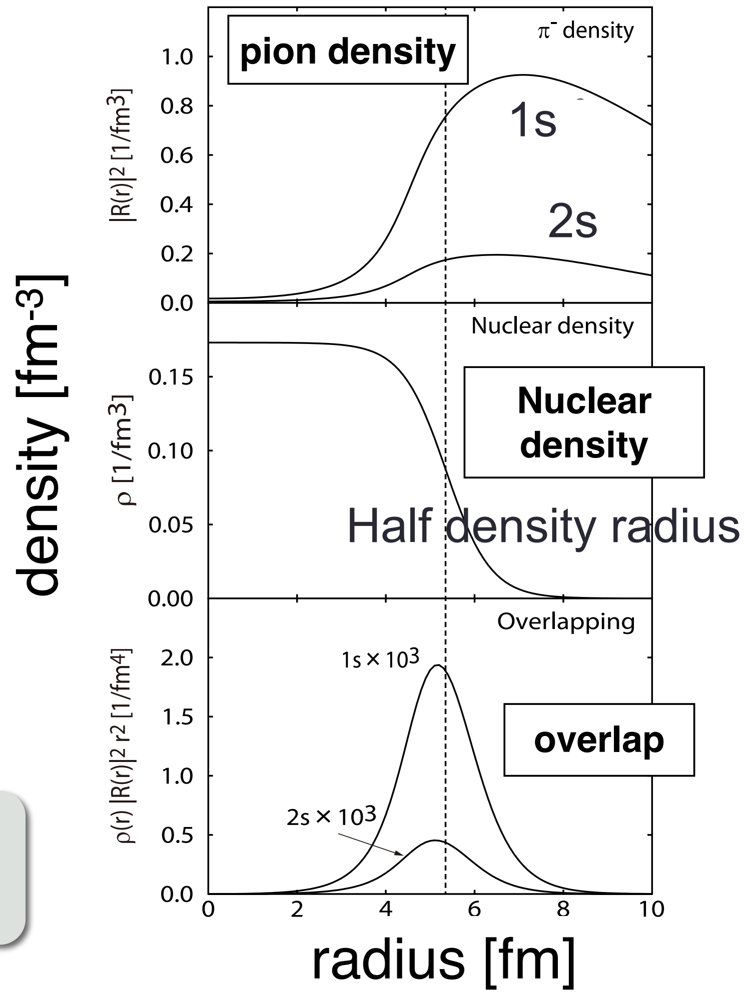
Large overlap!

→probe for QCD in finite density

s-wave optical potential

$$U_s = -\frac{2\pi}{\mu}[\epsilon_1(b_0\rho + b_1(\rho_n - \rho_p)) + \epsilon_2 B_0 \rho^2]$$

Pionic atom with ^{121}Sn



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

Physics Motivation: Chiral Symmetry Restoration

Tomozawa-Weinberg relation

$$b_1 = -\frac{m_\pi}{8\pi f_\pi^2}$$

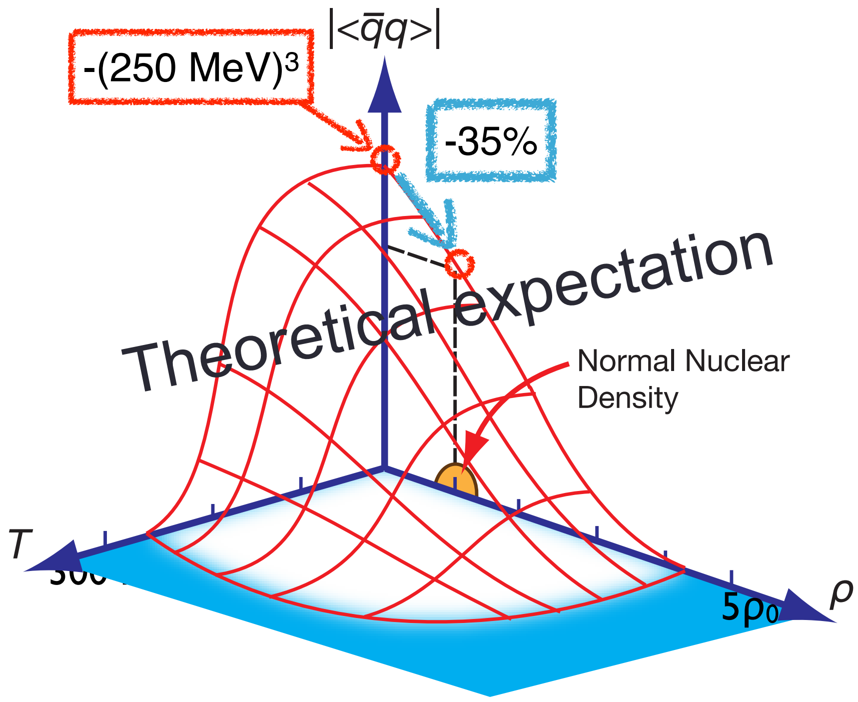
Gell-Mann-Oakes-Renner relation

$$f_\pi^2 m_\pi^2 = -2m_q < \bar{q}q >$$

$$b_1 \propto 1/|\langle\bar{q}q\rangle|$$

$$\frac{b_1^{free}}{b_{1\rho}} = \frac{|\langle\bar{q}q\rangle|_\rho}{|\langle\bar{q}q\rangle|^{free}}$$

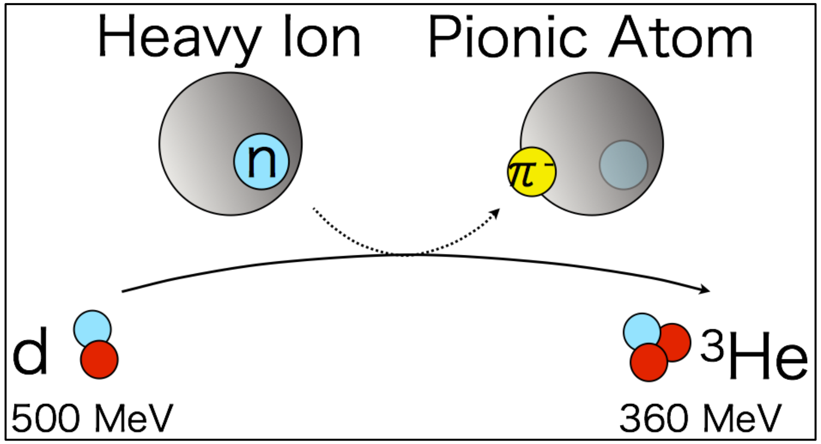
Partial restoration of chiral symmetry at finite density can be studied



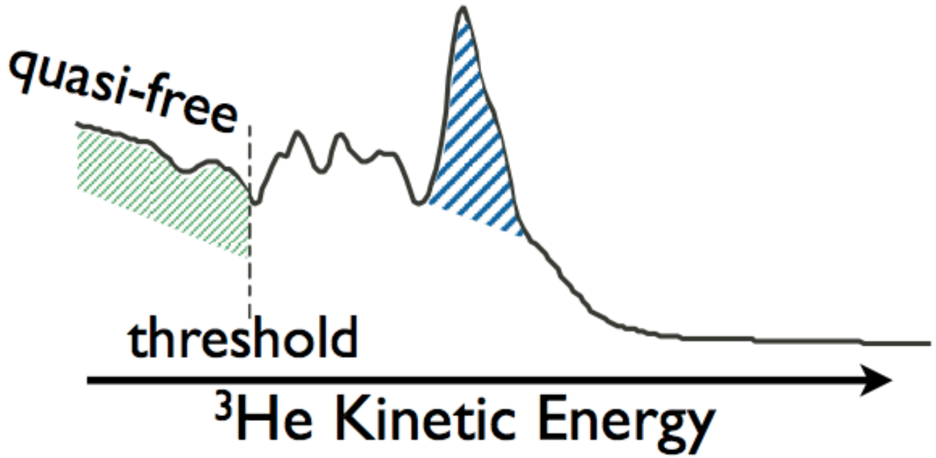
W. Weise, NPA553(93)59.

Spectroscopy via (d, ^{3}He) reactions

(d, ^{3}He) reaction



Expected Spectrum

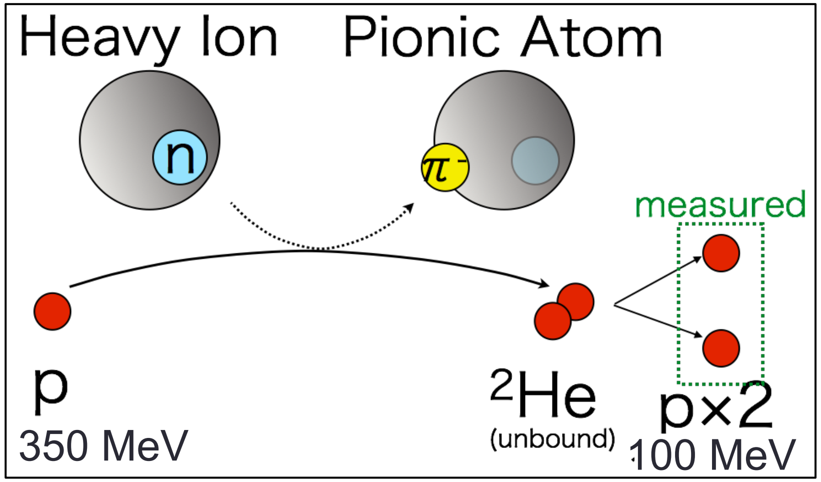


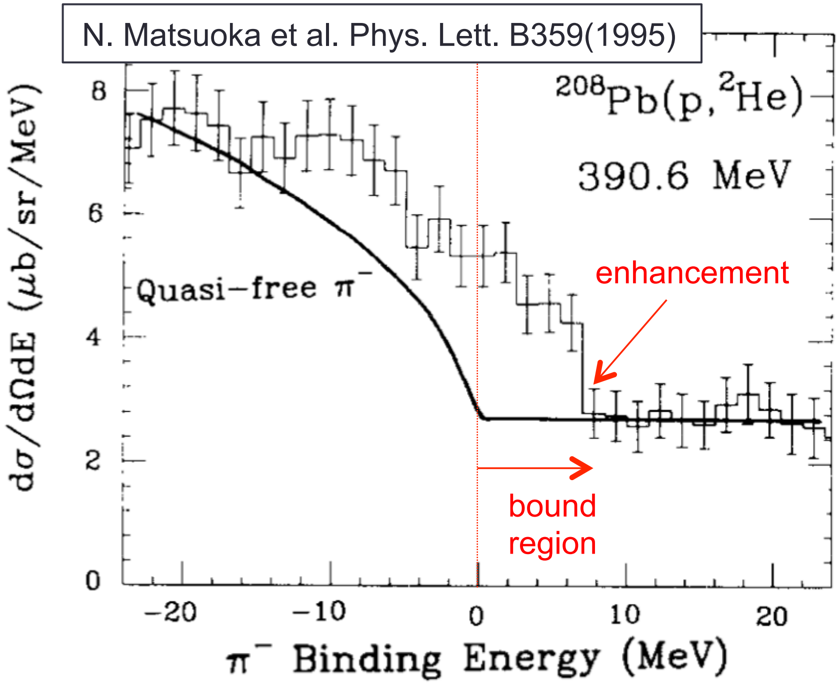
- well established method since 1996
- $^{206,\,208}$Pb, ^{116,120,124}Sn(d, ^{3}He) reactions were measured in GSI
  →partial restoration of chiral symmetry
- A systematic study on Sn isotopes in RIKEN

We are planning to use the (p, ^{2}He) reaction

Spectroscopy via (p, ^{2}He) reactions

(p, ^{2}He) reaction





Pioneering Experiment

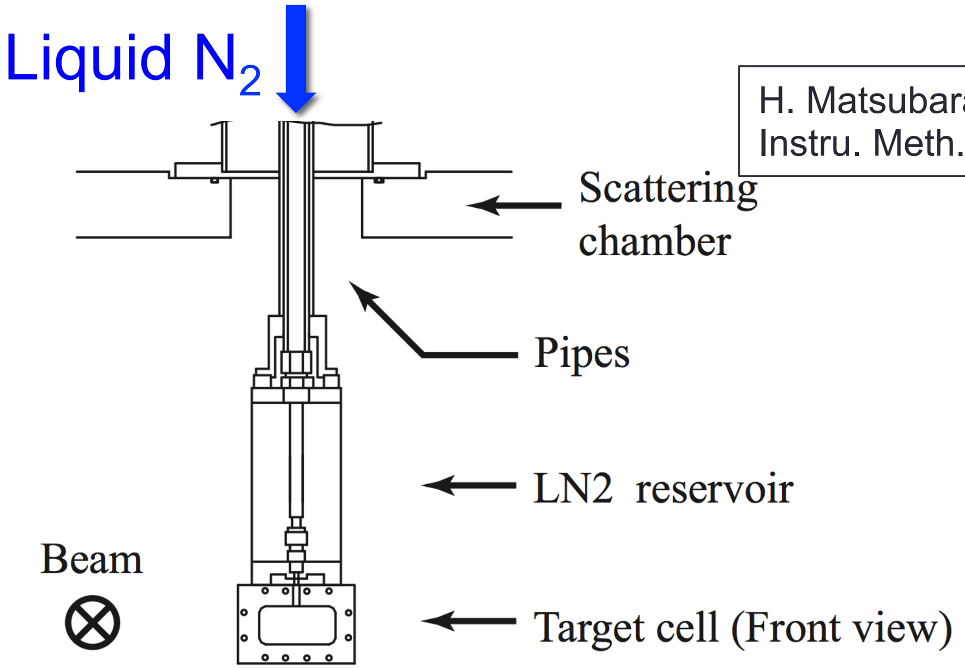
・no peak structure: poor resolution ~ 700 keV (FWHM)

・enhancement in bound region ← contribution from bound states

→ different setup with an improved resolution in RCNP

Motivation for (p, ^{2}He) reaction

1. gas cell target of Xe isotopes in RCNP



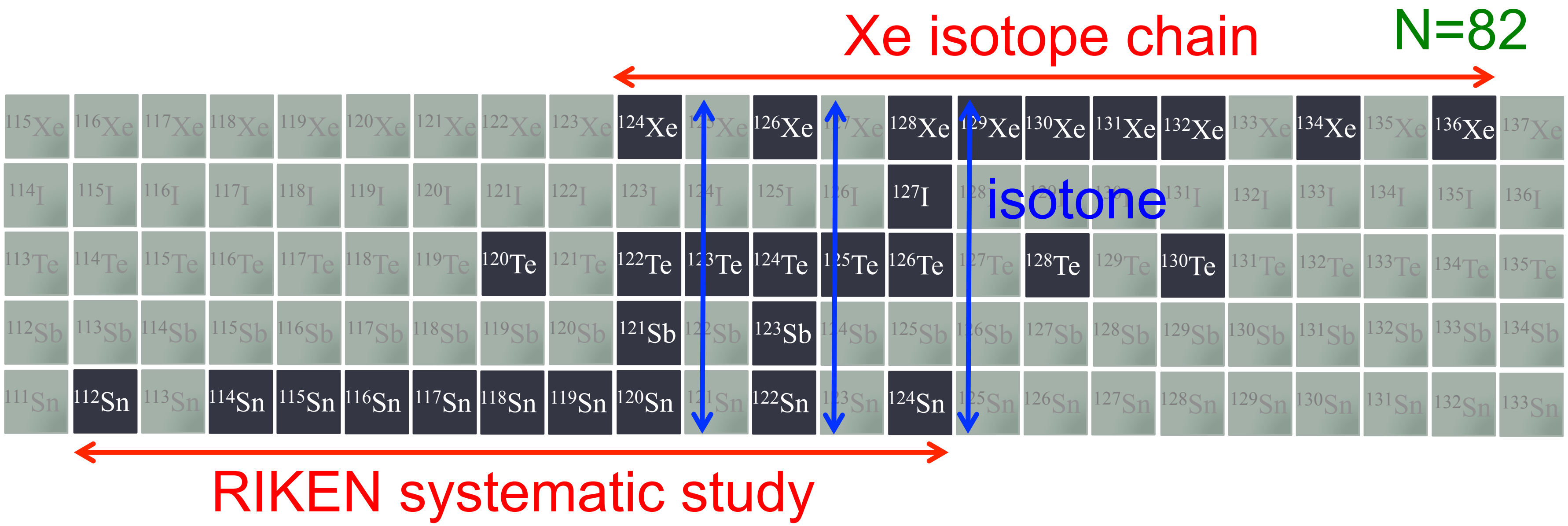
H. Matsubara et al., Nucl. Instru. Meth. (2012).

- Physics results has been reported

P. Puppe et al., Physical Review C 84 (2011)
J. P. Entwisle et al., Physical Review C 93 (2016)

Motivation for (p, ^{2}He) reaction

1. gas cell target of Xe isotopes in RCNP



s-wave optical potential

$$U_s = -\frac{2\pi}{\mu}[\epsilon_1(b_0\rho + b_1(\rho_n - \rho_p)) + \epsilon_2 B_0 \rho^2]$$

Motivation for (p, ^{2}He) reaction

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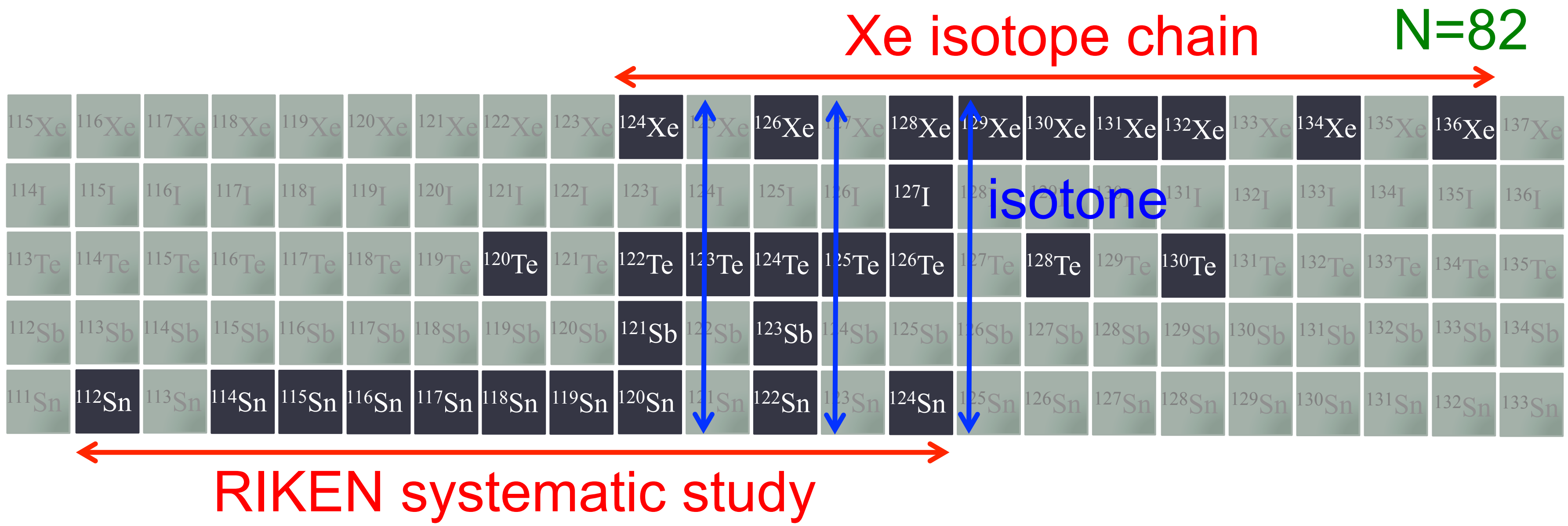


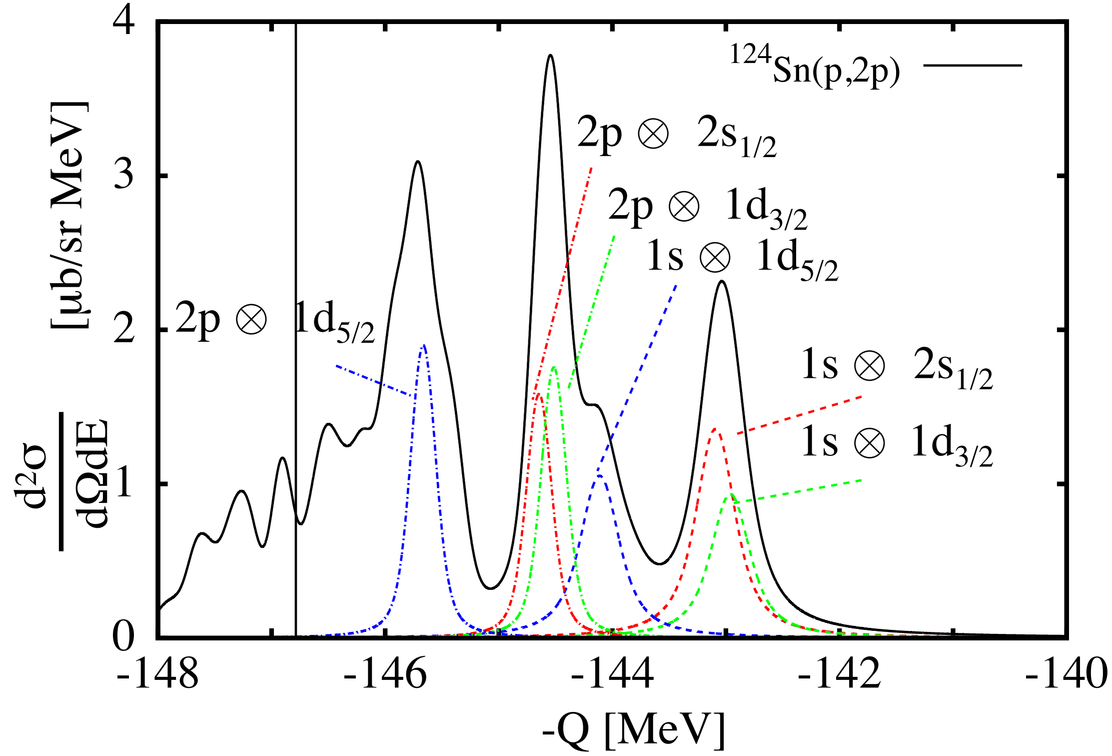
2. Future development of dispersion matching

→ resolution < 100 keV (FWHM)

- These are not limited to (p, ^{2}He), but d beam energy is not enough in RCNP

First Goal: ^{124}Sn(p, ^{2}He) reaction

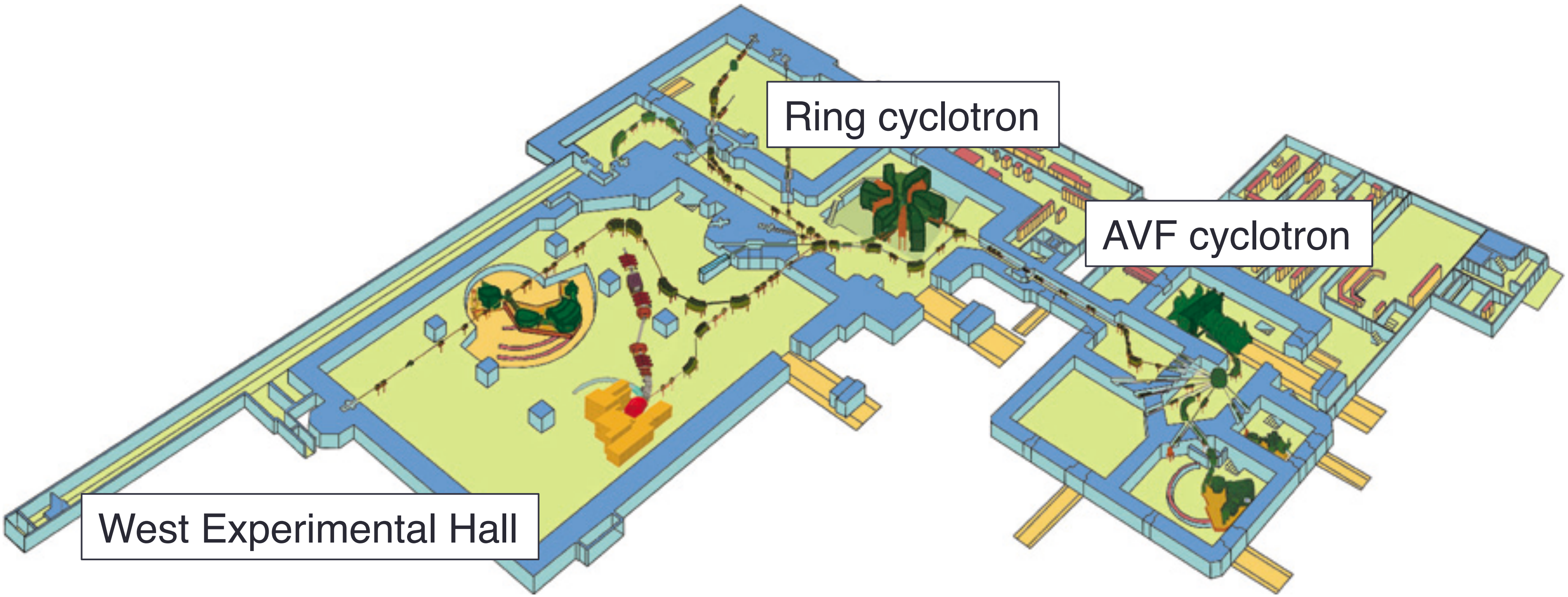
Yamagata-Sekihara et al., private communication



- ^{124}Sn: relatively large cross section in Sn isotope
- relatively good S/N ratio

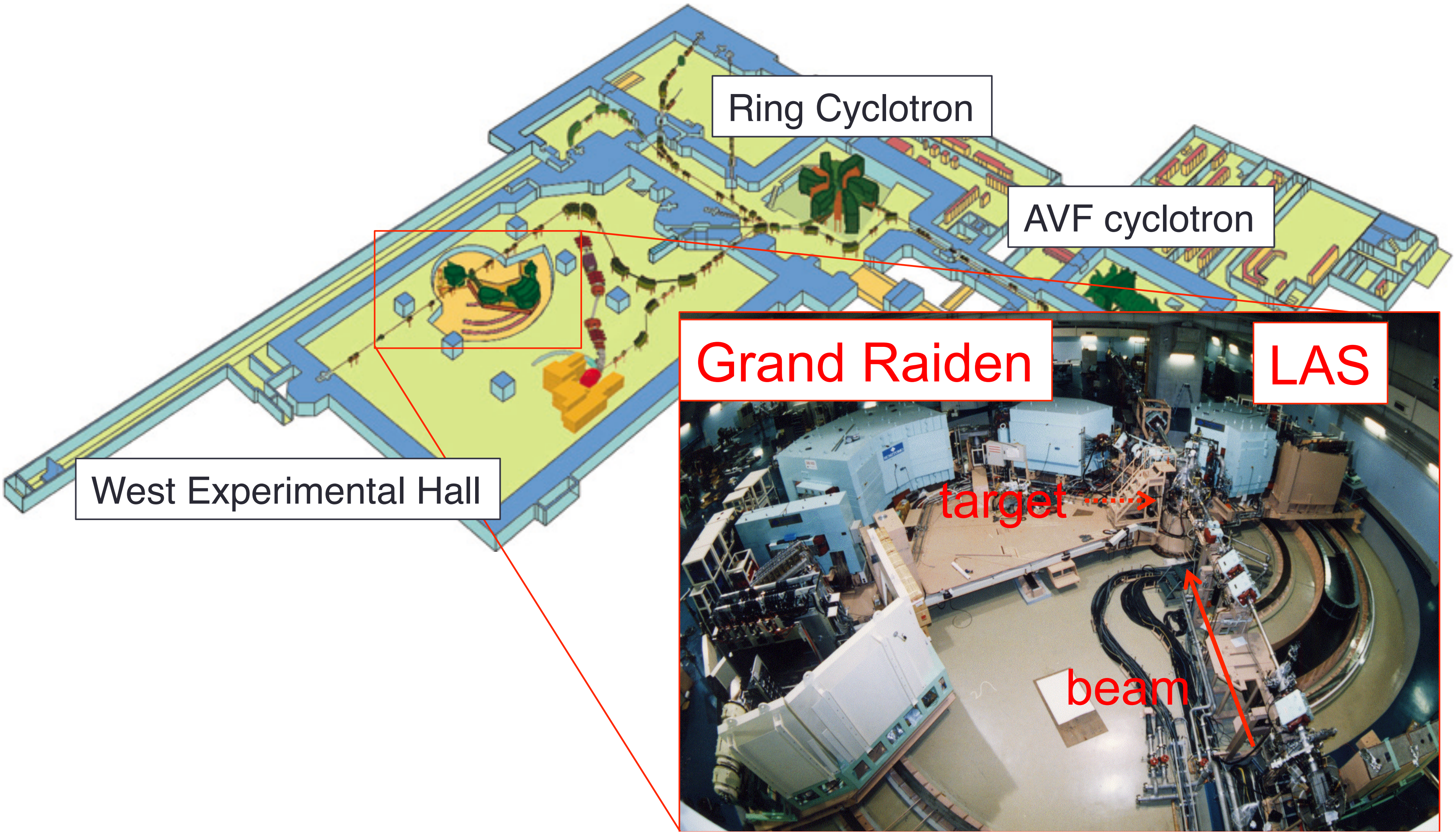
Experimental Setup

RCNP Facility

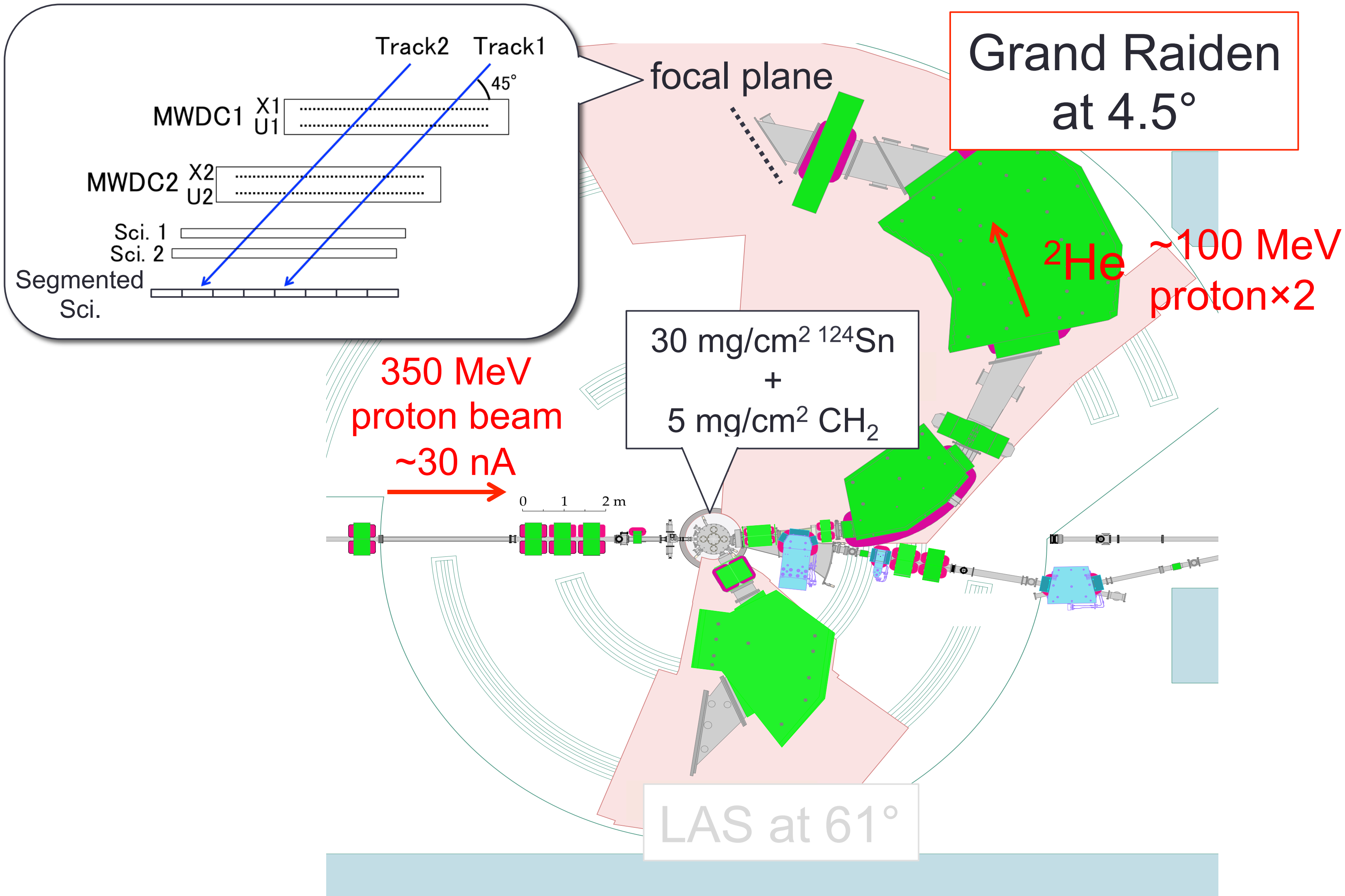


▪proton beam up to 400 MeV (⇔deuteron up to 200 MeV)

RCNP Facility

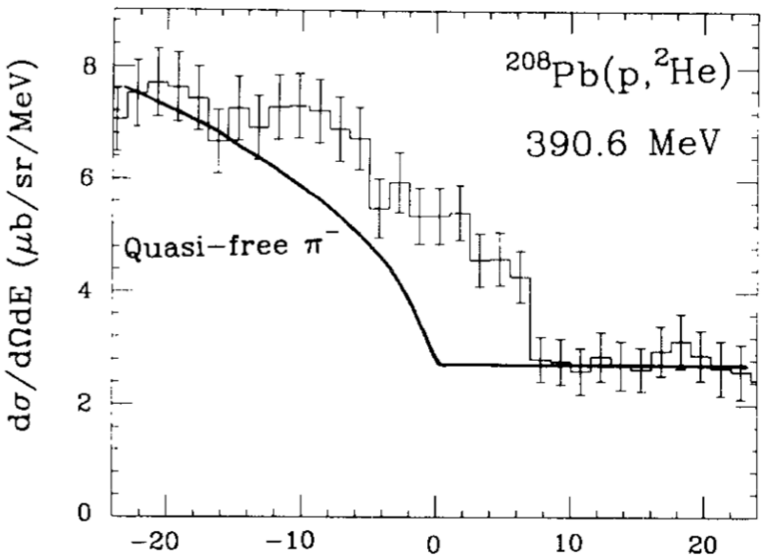


Experimental Setup: Grand Raiden

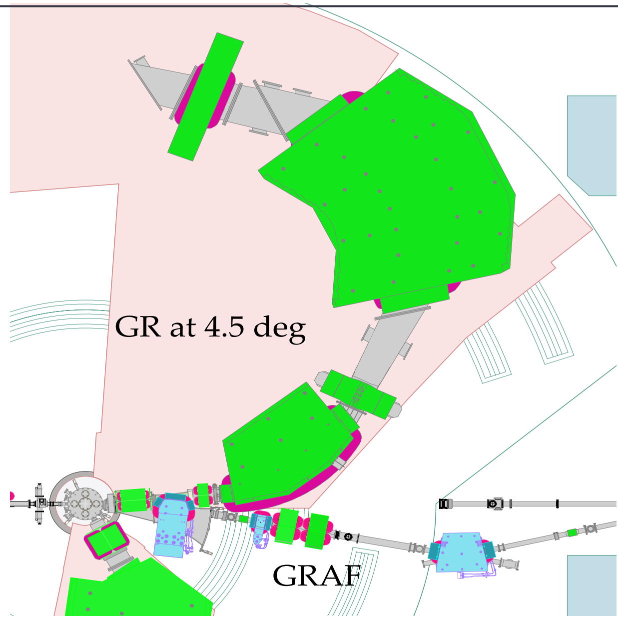


Comparison with the Previous Experiment

Matsuoka et al. : LAS at 0°



Our Setup: Grand Raiden at 4.5°



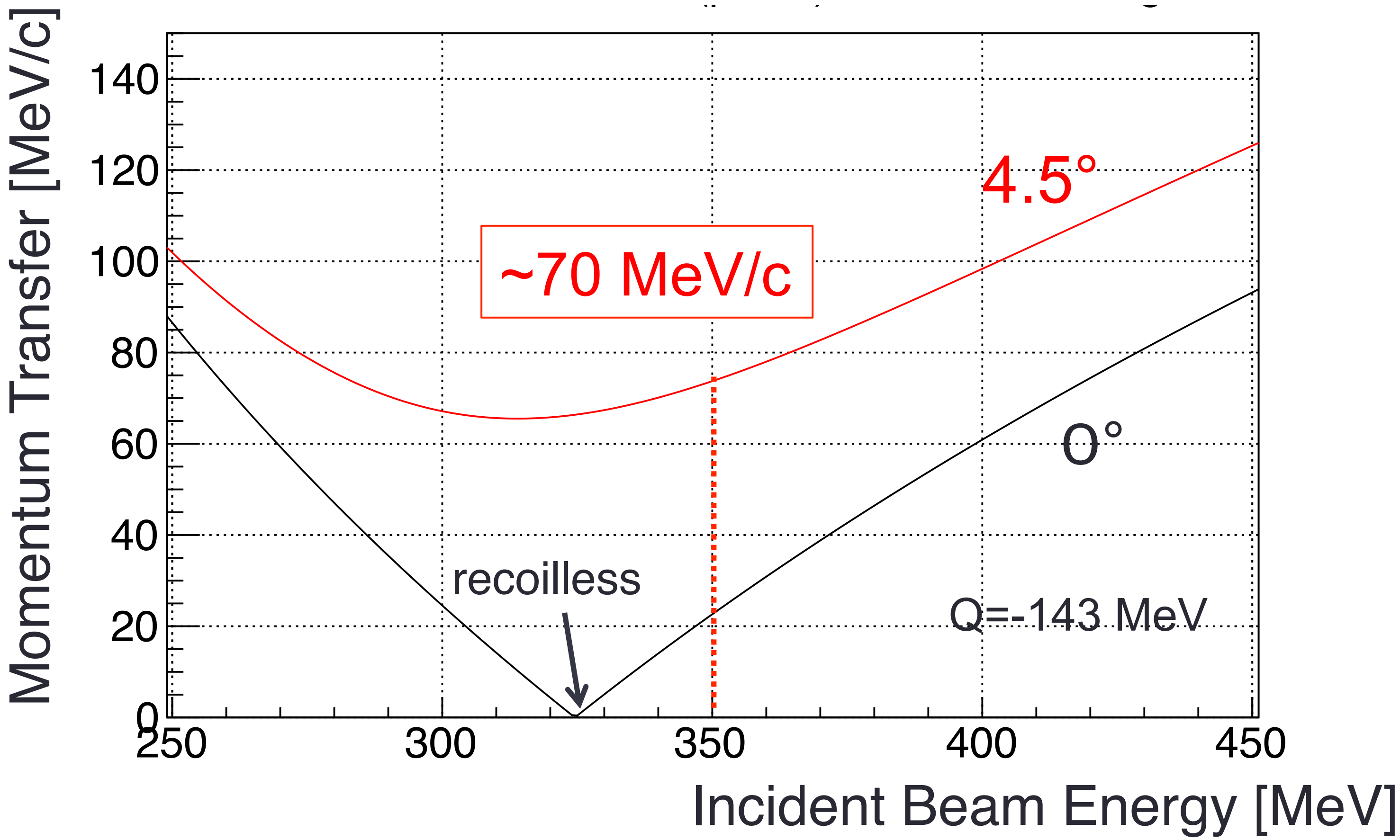
	Matsuoka et al.	Our Setup
Resolution	700 keV	200~250 keV
Acceptance	2.4 msr	~0.04 msr
Beam Intensity	0.5~1 nA	~30 nA

×1/60

×30~60

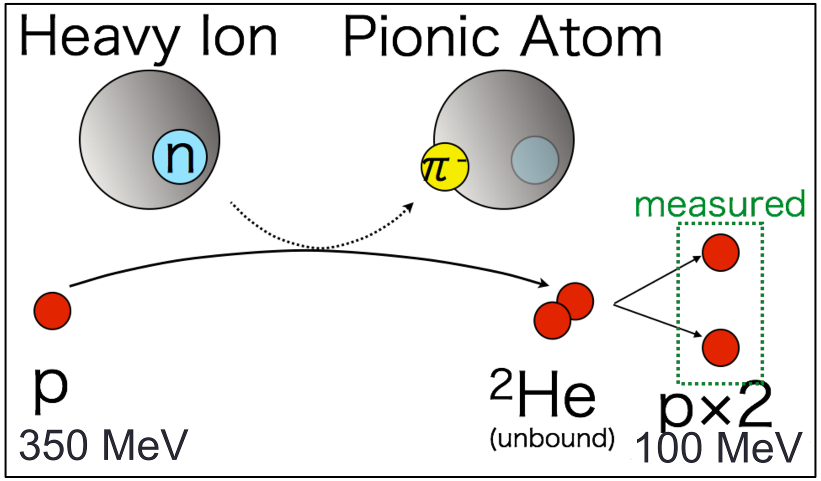
Target ~150 keV
Beam ~ 150 keV

Momentum Transfer



- small momentum transfer with a 350 MeV beam energy

There is no calibration peak

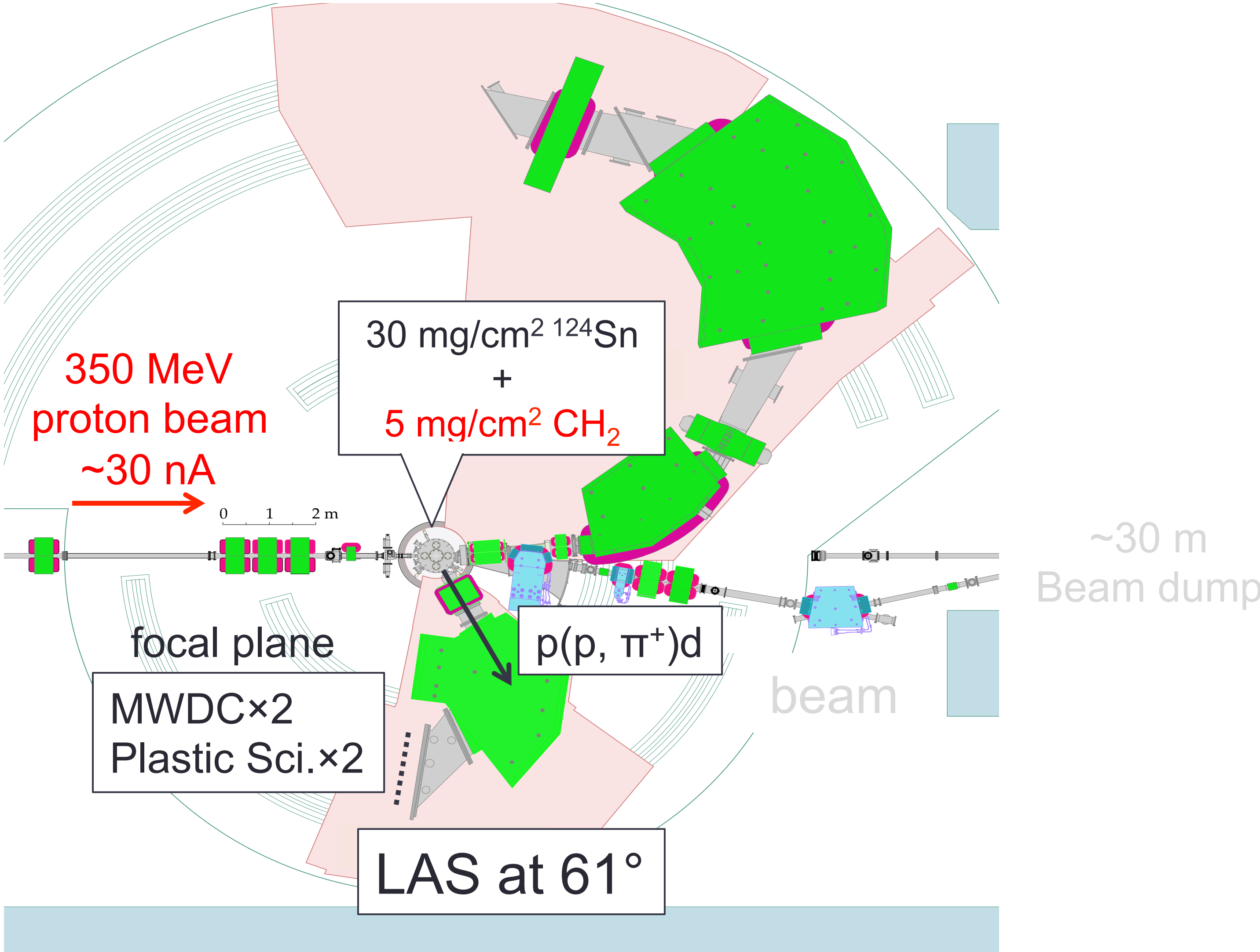


- Large energy difference between the beam and ejectile
- p(p, ^{2}He)π^0: out of acceptance
  → no in-situ calibration peak

Difficulties:

1. Beam energy fluctuation can deteriorates the resolution
   ← beam monitor by the other spectrometer(LAS)
2. Beam energy must be precisely measured
   c.f.) $Q = T_{2He} - T_{beam}$

Beam energy monitor using LAS



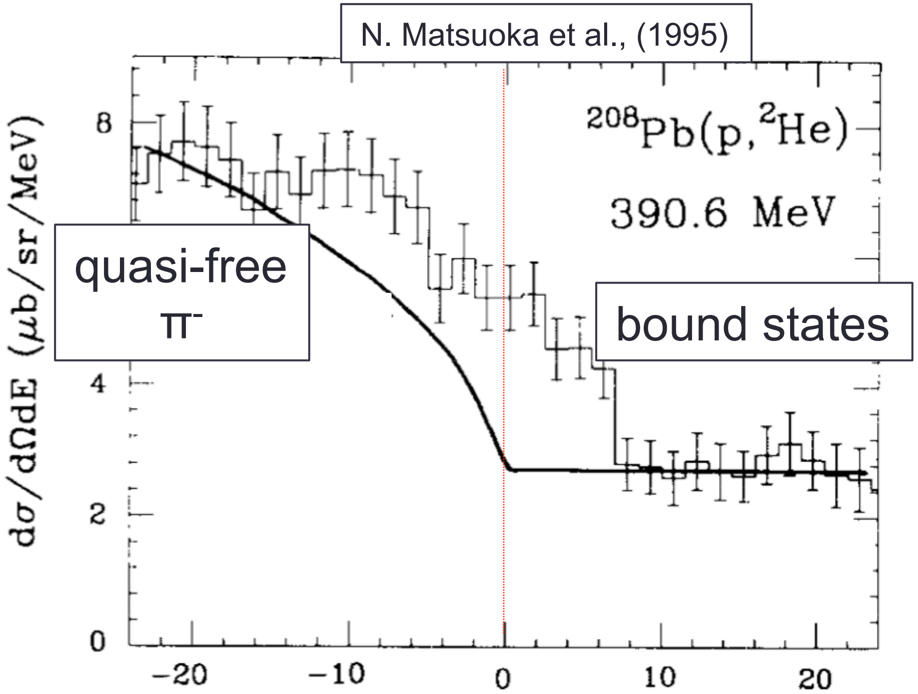
Test experiments in 2015, 2016

1. Accidental background measurement
2. Measurement of $^{12}C(p, ^{2}He)^{11}B$ reaction
3. Beam monitor by LAS
4. Beam energy measurement

1. Accidental background measurement

There are 2 kinds of background in (p,^{2}He) measurement

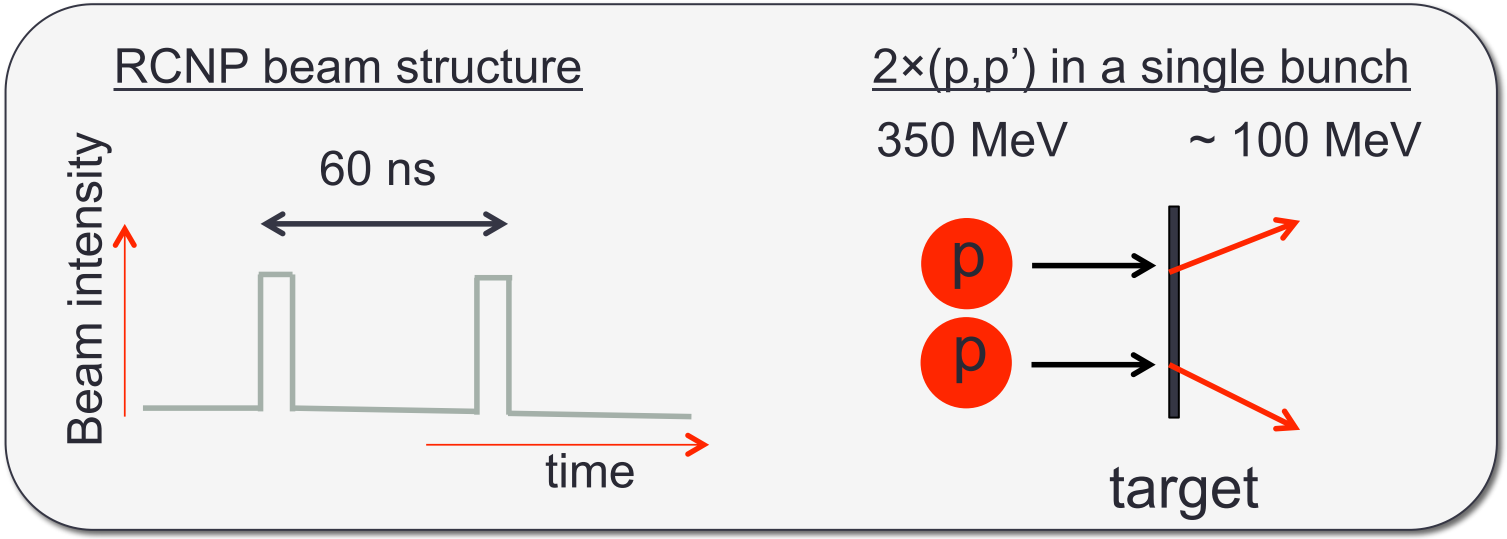
(i) ^{2}He production w/o pion



flat continuum ~ 2 ub/sr/MeV

1. Accidental background measurement

(ii) Accidental background of (p,p’) reaction

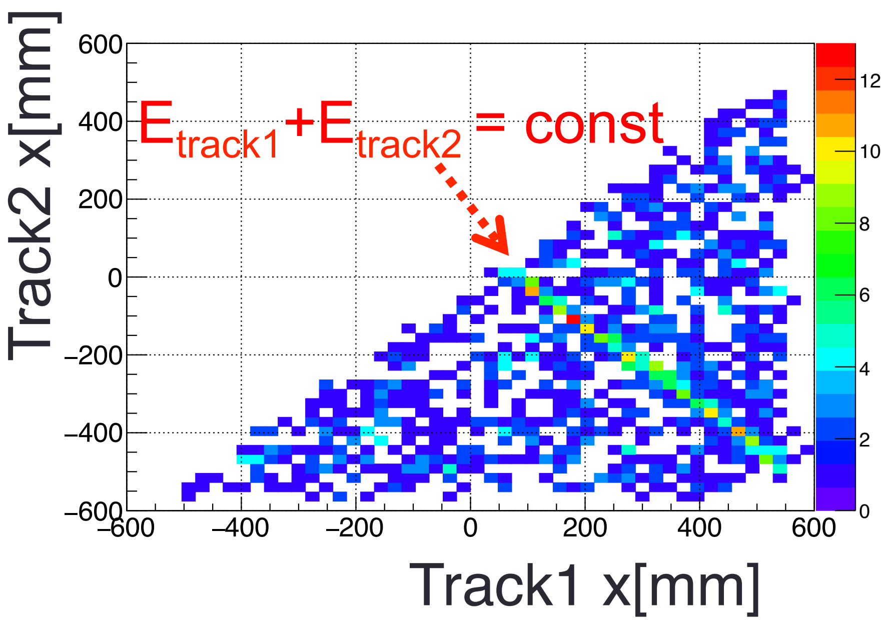


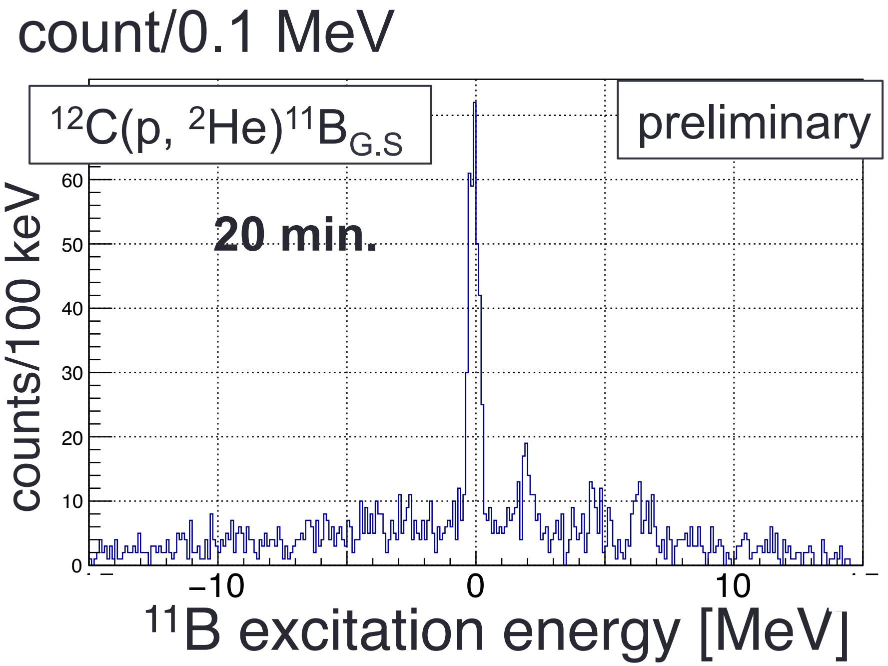
- single (p,p’) rate ~ 1.5 mb/sr/MeV
- accidental rate is proportional to (single (p,p’) rate)^2

  → accidental coincidence in our setup: 6 ub/sr/MeV

  (⇔ flat continuum: 2 ub/sr/MeV)

2. Measurement of $^{12}C(p, {}^2He)^{11}B$ reaction

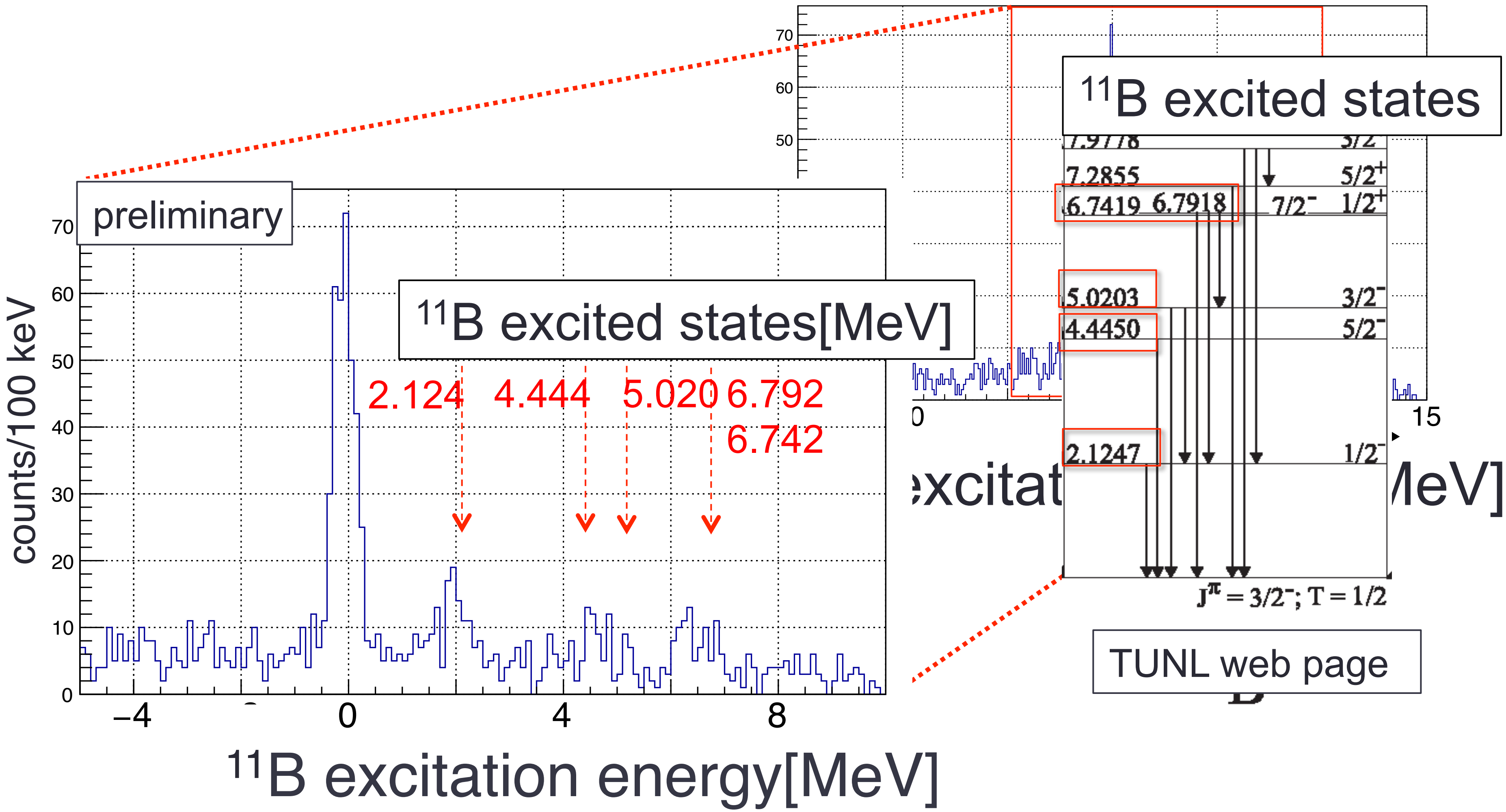




- $E_{track1}+E_{track2}$ = const
- $^{12}C(p, {}^2He)^{11}B_{G.S}$ was observed

First observation of (p, ^{2}He) reaction in Grand Raiden!

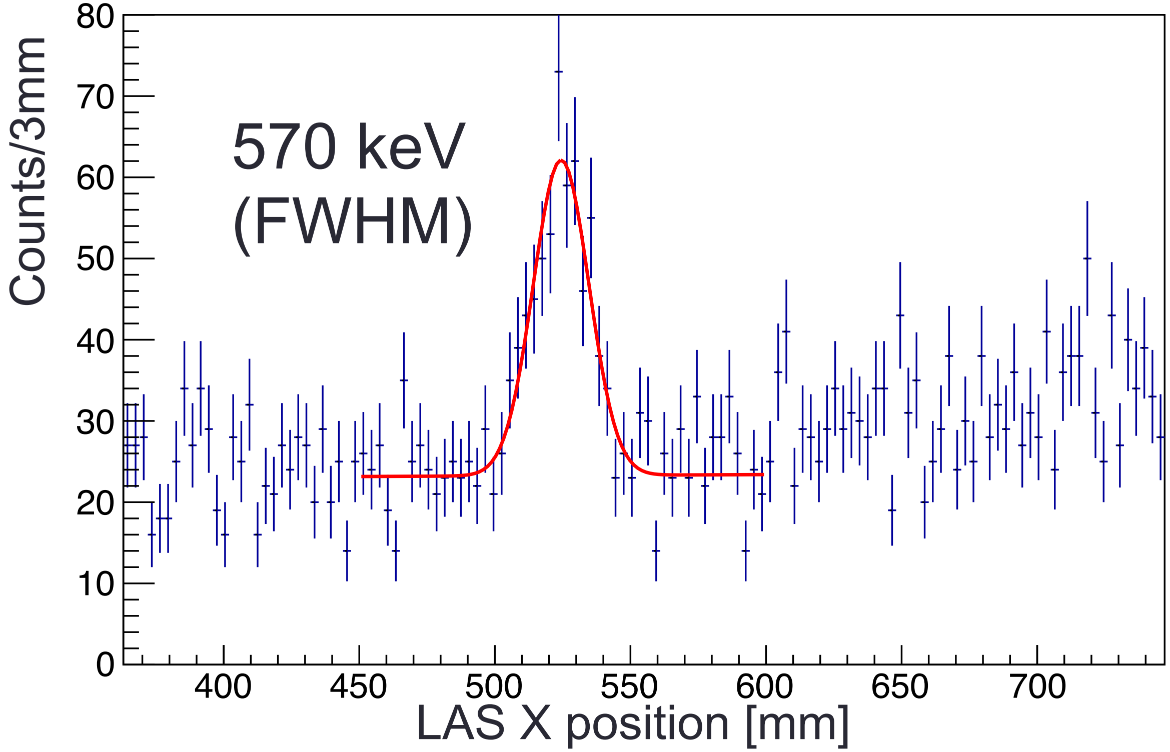
2. Measurement of $^{12}C(p, {}^{2}He)^{11}B$ reaction



3. Beam monitor by LAS

p(p, π^+)d reaction:

E_{beam} change of 1 MeV ⇔ E_π change of 600 keV



- Count rate ~ 1 Hz for our experimental setup (30 nA, 5 mg/cm^2 CH_2)
- Eneryg resolution of π^+ ~ 600 keV

⇔ Beam energy is monitored by 100keV for every 100 sec

4. Beam Energy measurement

Error of beam energy → error of bound states energy
(1MeV → 300keV)

Principle of the measurement

①$p(p,\pi^+)d$
②$d(p,\pi^+)t$
③$Pb(p,p)$

beam energy	p_1/p_3	p_2/p_3
391 MeV	0.2272	0.3068
392 MeV	0.2279	0.3074
393 MeV	0.2286	0.3082

p_1/p_3 and p_2/p_3
↓
Beam energy

4. Beam Energy measurement

Setup (1) CH_2 target, GR@4.5°

- $p(p,p)p$
- $p(p,d)\pi^+$ (forward deuteron in C.M. frame)
- $p(p,d)\pi^+$ (backward deuteron in C.M. frame)

Setup (2) CH_2 target, GR@8°

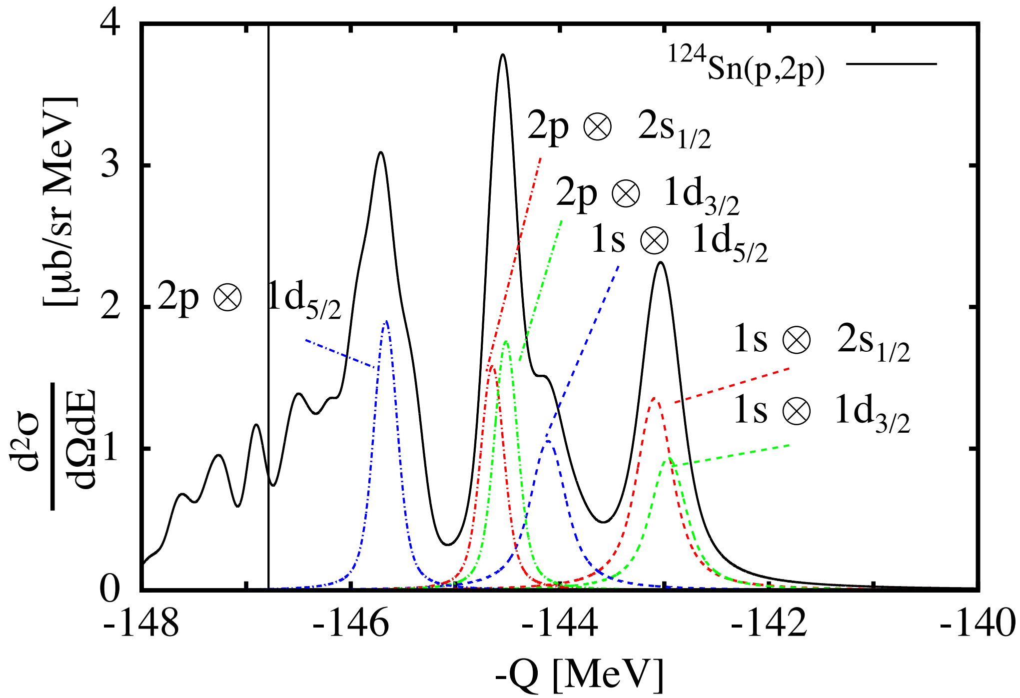
- $p(p,\pi^+)d$
- $^{12}C(p,p')$
- $^{12}C(p,d)$

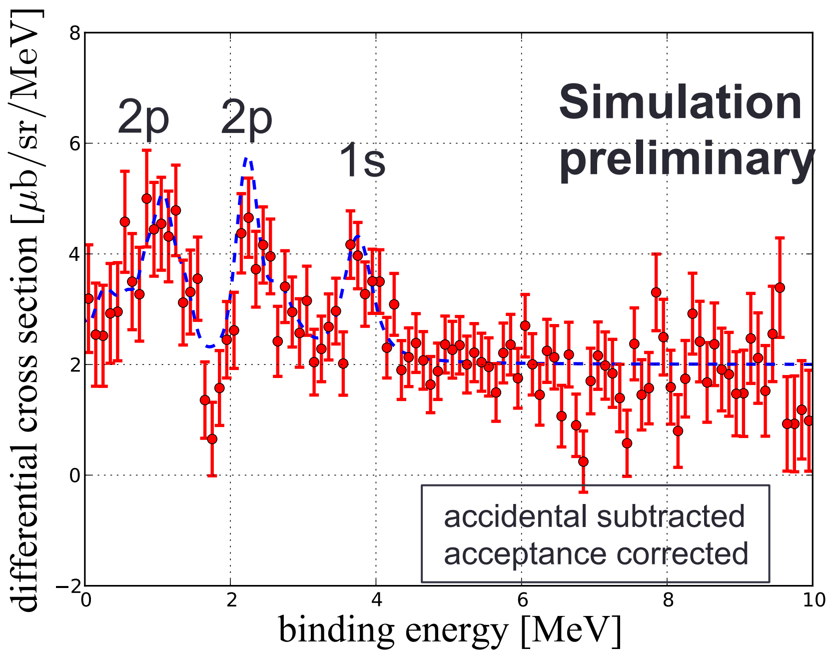
The analysis is ongoing…

Plan of the first experiment

Plan of the first experiment: expected spectrum

Yamagata-Sekihara et al., private communication





- 4.5 degrees, 350 MeV proton beam, 200 keV resolution
- 10 days of measurement
- proposal for B-PAC in August 2016 was submitted

Summary

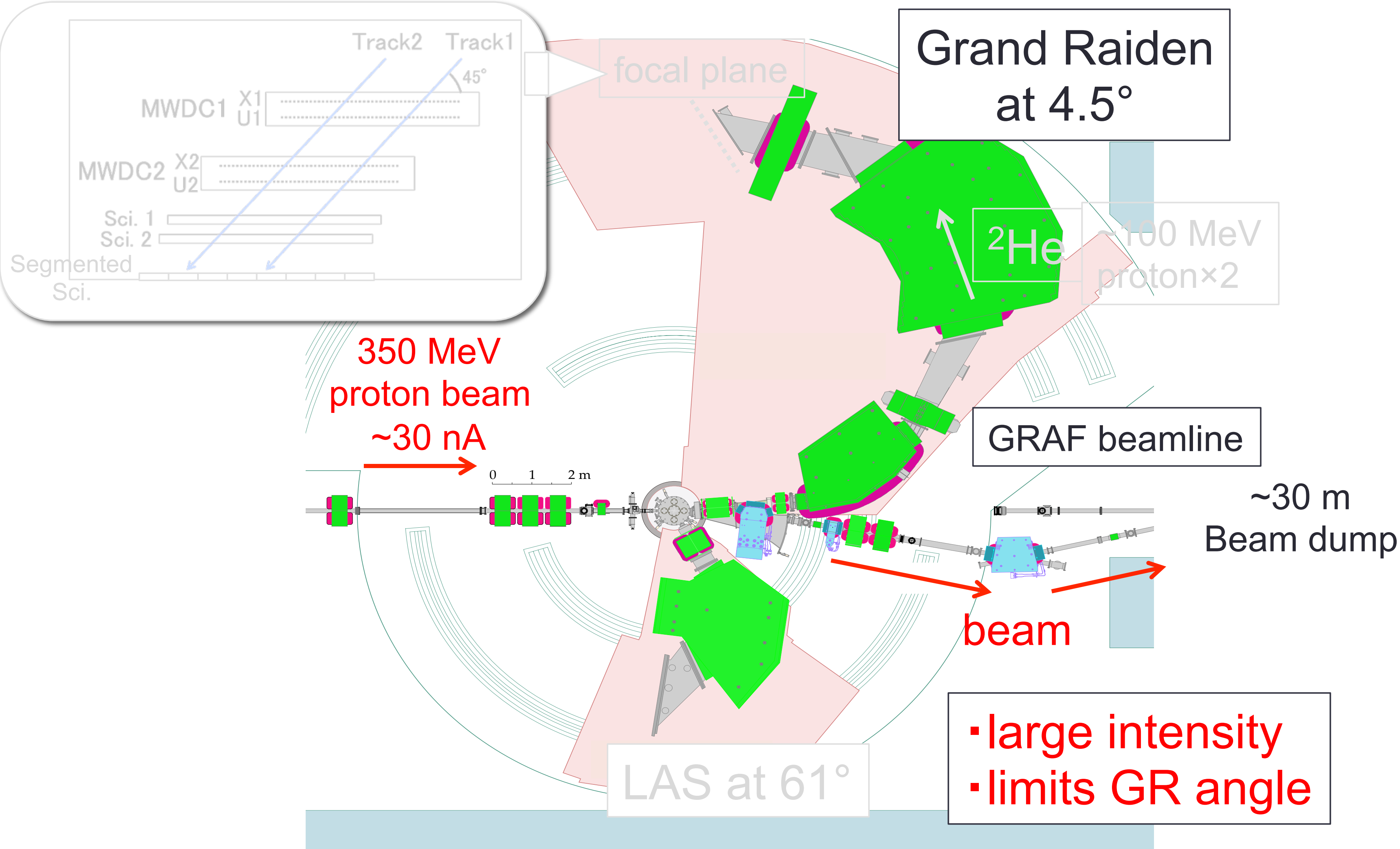
- We are planning to perform a spectroscopy of pionic atoms via (p, ^{2}He) reaction.
- In future, Xe gas target and dispersion matching will be adopted.

- ^{2}He is analyzed by Grand Raiden to achieve high resolution

- Test experiments: background evaluation, ^{12}C(p, ^{2}He)^{11}B, calibration method

- First experiment: ^{124}Sn target, aiming to observe 3 peaks to establish the method

Experimental Setup: GRAF beamline



- large intensity
- limits GR angle