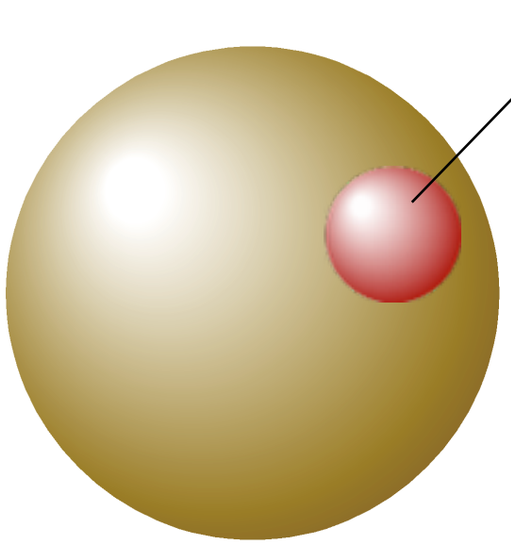
Pionic Atom 分光実験@理研

理化学研究所仁科加速器研究センター
板橋健太

Spectroscopy of bound meson to nucleus



pionic atoms
π⁻ bound to nucleus

pionic atom = negative pion bound to nucleus
η′-mesic nuclei = η′ meson bound to nucleus

- meson-nucleus interaction
  π-nucleus potential
- meson properties in nuclei
  Mass reduction of η′-meson
- …

Low energy QCD
Origin of hadron mass

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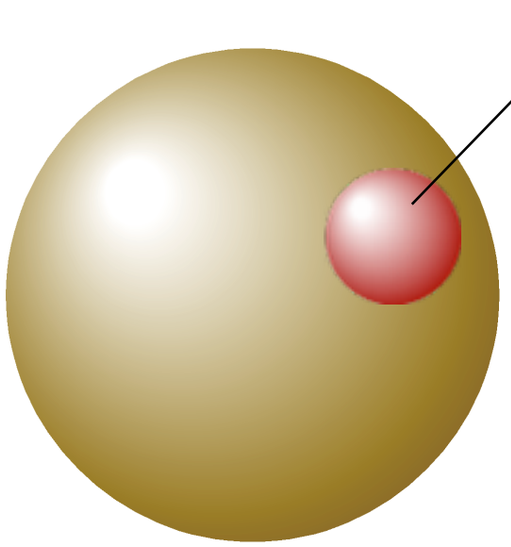
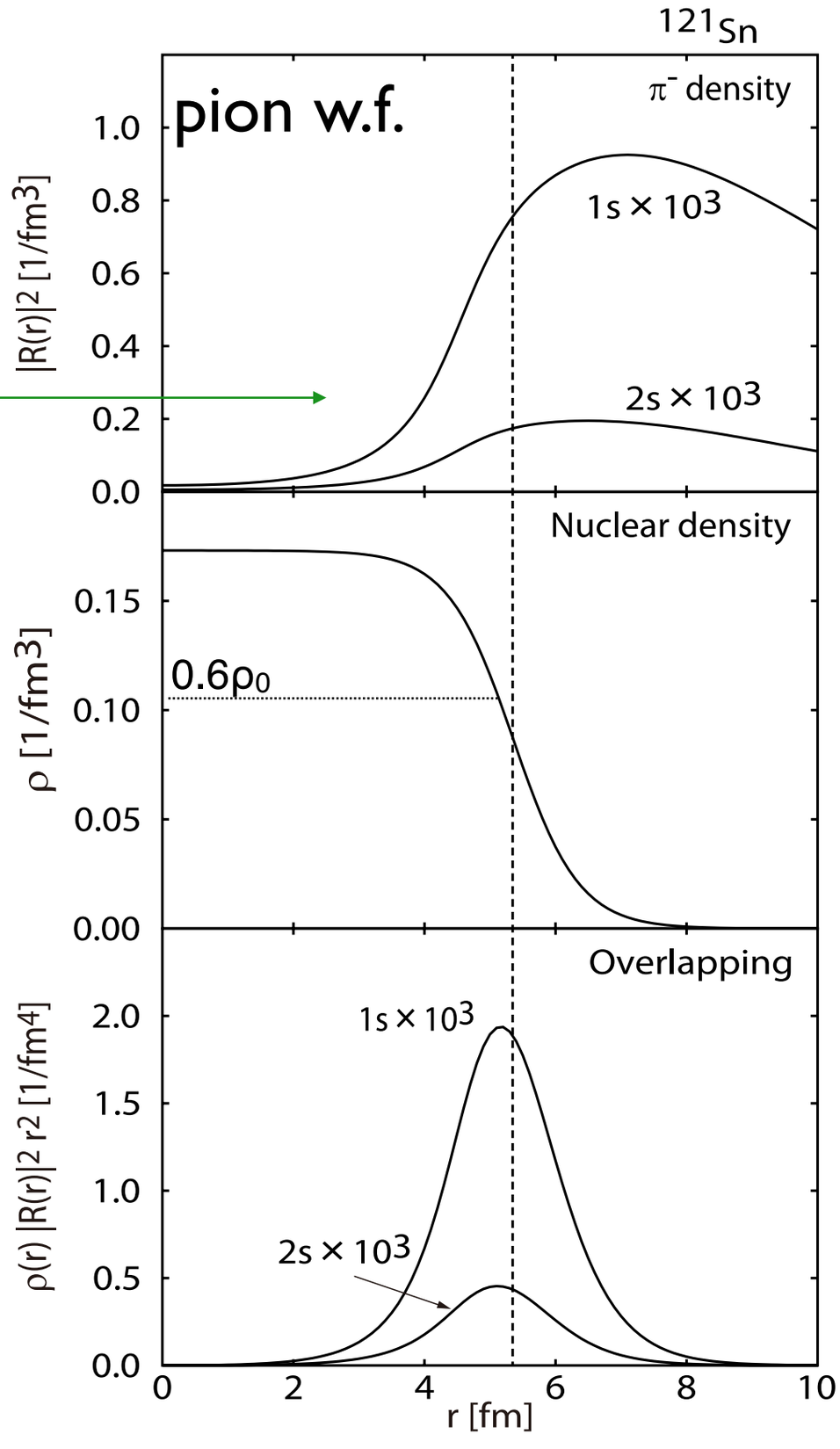
Pionic Atoms and piA interaction



pionic atoms
π⁻ bound to nucleus

pion wave function locates
at vicinity of nucleus



Sensitivity to
π-nucleus s-wave potential

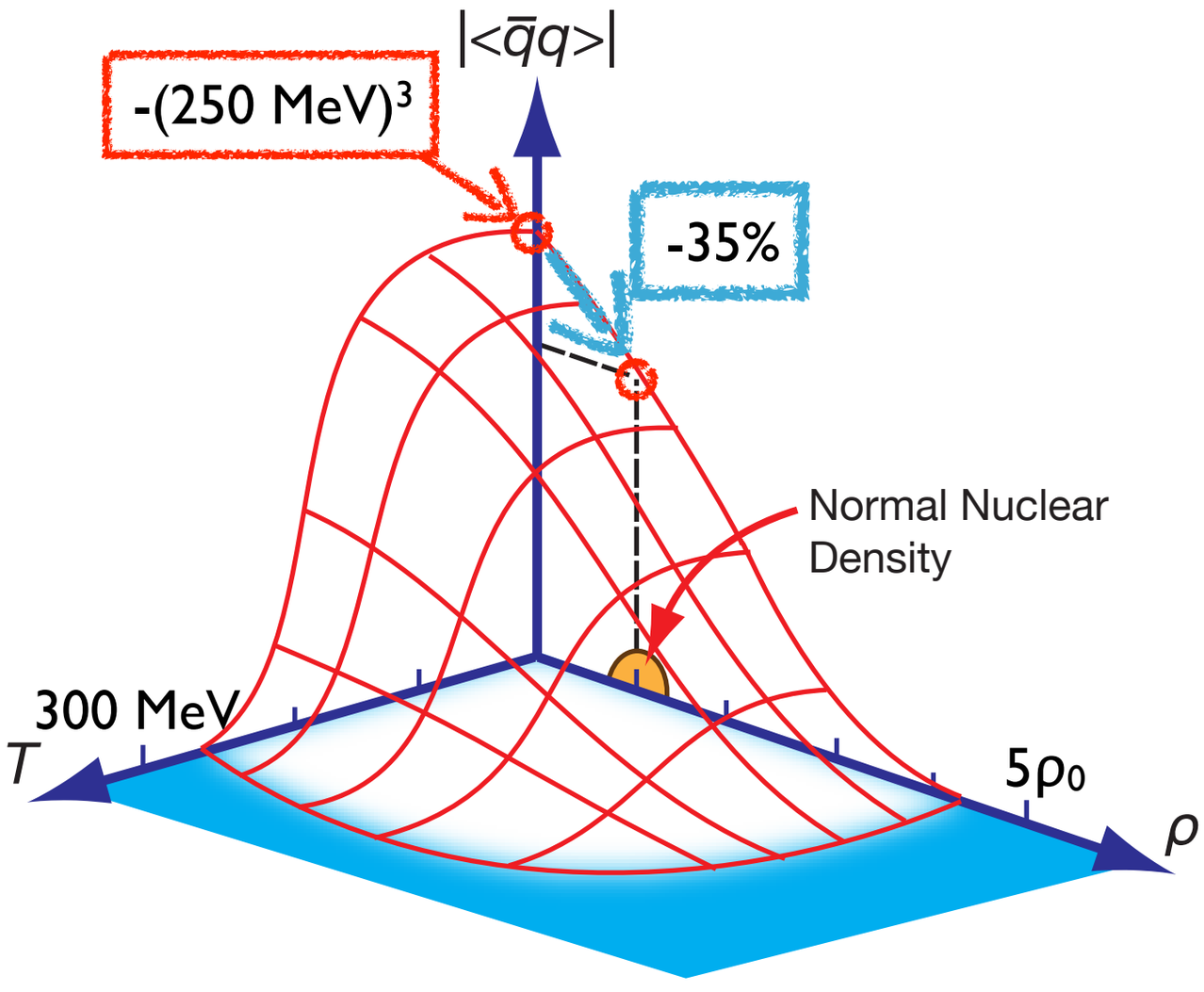
$$V_{s\text{-wave}} = b_0\,\rho + b_1\,(\rho_n - \rho_p) + B_0\,\rho^2$$

for $\rho_e = 0.6\,\rho_0$

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

Chiral symmetry at finite density

Jido, Hatsuda, Kunihiro, Phys.Lett.B670:109-113,2008.
Kolomeitsev, Kaiser, Weise, Phys. Rev. Lett. 90(2003)092501



M. Gell-Mann *et al.*, PR175(1968)2195.

Gell-Mann-Oakes-Renner relation

$$f_\pi^2 m_\pi^2 = -2m_q \langle \bar{q}q \rangle$$

f_π : pion decay constant

Y. Tomozawa, NuovoCimA46(1966)707.
S. Weinberg, PRL17(1966)616.

Tomozawa-Weinberg relation

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

b_1: isovector πN scattering length

$$\frac{\langle \bar{q}q \rangle_\rho}{\langle \bar{q}q \rangle_0} \approx \frac{b_1^{\mathrm{free}}}{b_1(\rho)}$$

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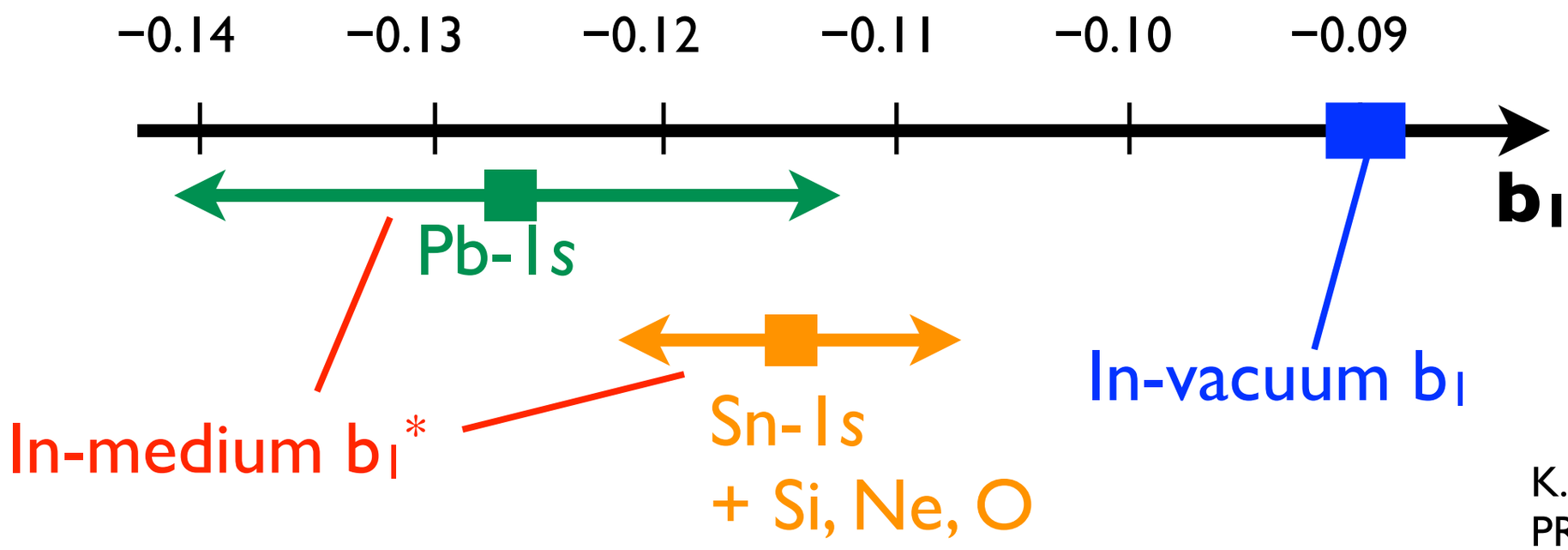
Present b_1 precision



K. Suzuki et al.,
PRL92(04)072302.

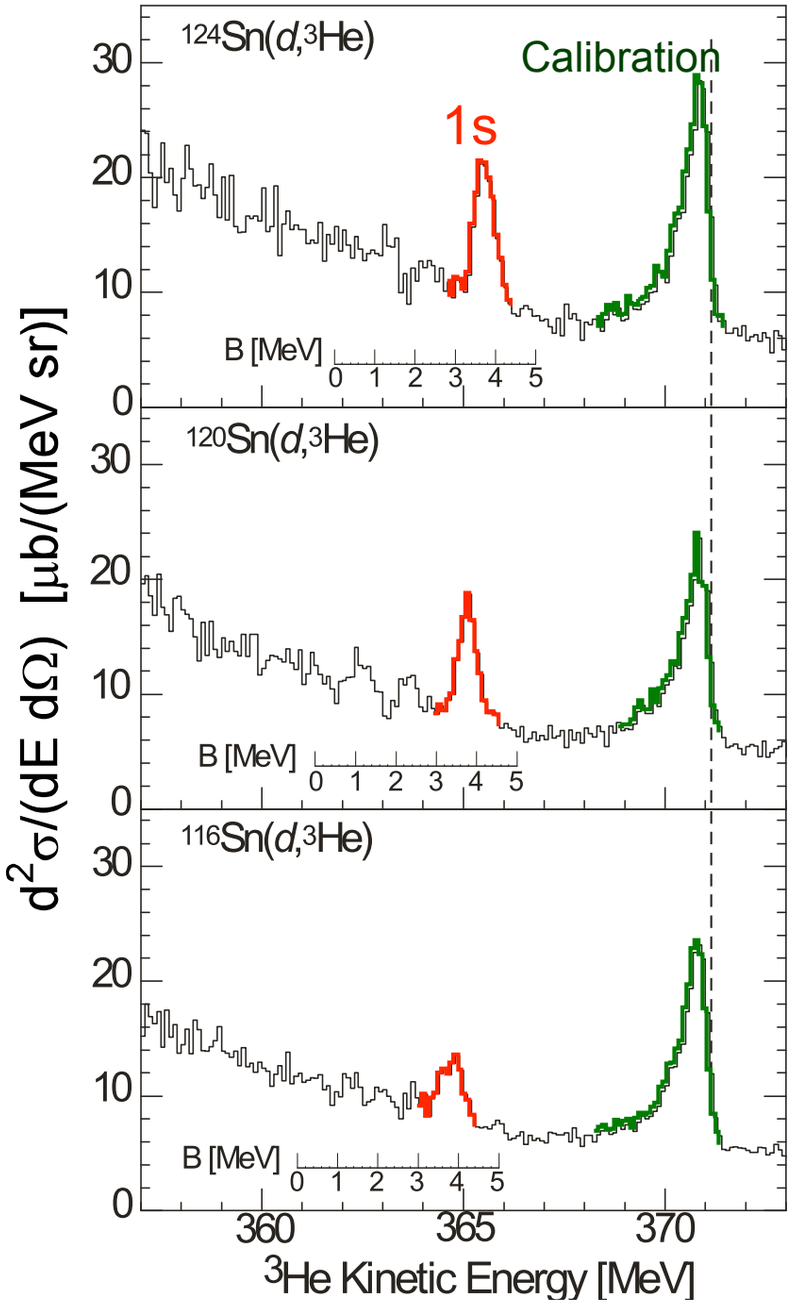
b_1^* still has a large error

$V_{s\text{-wave}} = b_0 \rho + b_1 (\rho_n - \rho_p) + B_0 \rho^2$

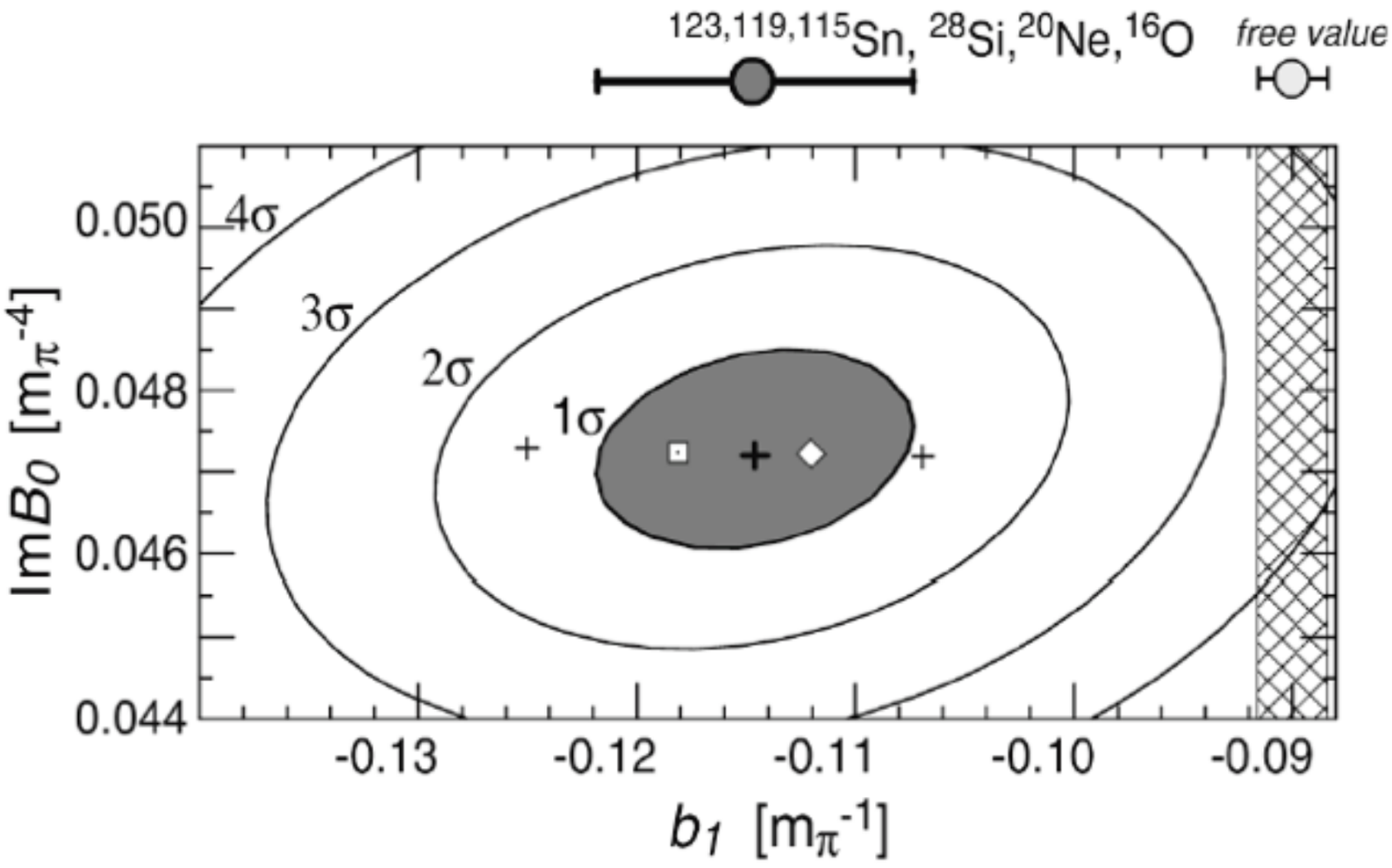
← spectroscopy of pionic atoms

In-medium b_1 is calculated based on deeply bound pionic states data combined with light spherical pionic atom data.

Present b_1 precision



K. Suzuki et al.,
PRL92(04)072302.



$$V_{s\text{-wave}} = b_0\,\rho + b_1\,(\rho_n - \rho_p) + B_0\,\rho^2$$

$$\rho_e = 0.6\,\rho_0$$

In-medium b_1 is calculated based on deeply bound pionic states data combined with light spherical pionic atom data.

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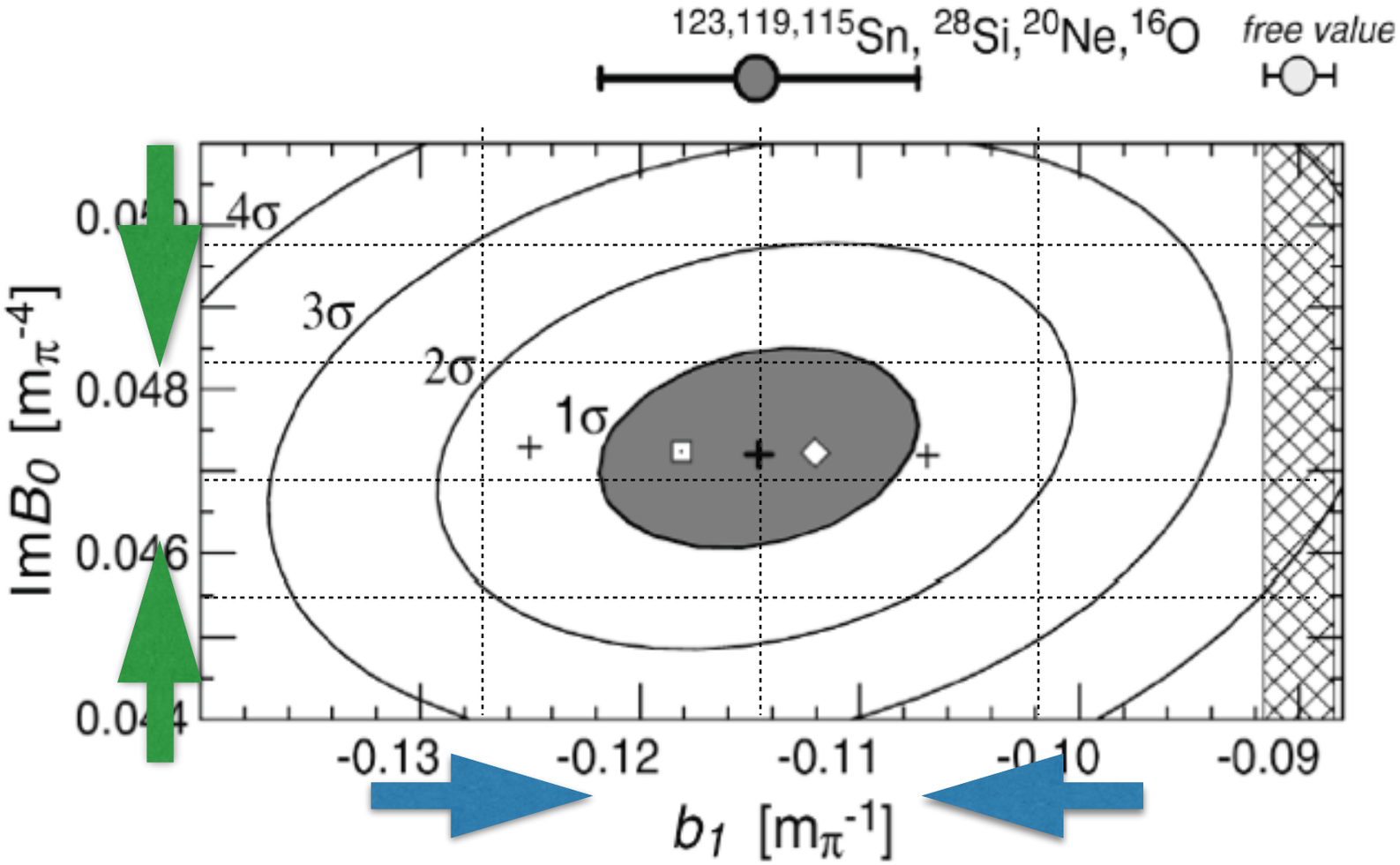
Present b_1 precision

Γ_{1s} [MeV]
^{115}Sn 0.441 ± 0.087
^{119}Sn 0.326 ± 0.080
^{123}Sn 0.341 ± 0.072

B_{1s} [MeV]
^{115}Sn 3.906 ± 0.024
^{119}Sn 3.820 ± 0.018
^{123}Sn 3.744 ± 0.018



$$V_{s\text{-wave}} = b_0\,\rho + b_1\,(\rho_n - \rho_p) + B_0\,\rho^2$$

$$\rho_e = 0.6\,\rho_0$$

K. Suzuki et al., PRL92(04)072302.

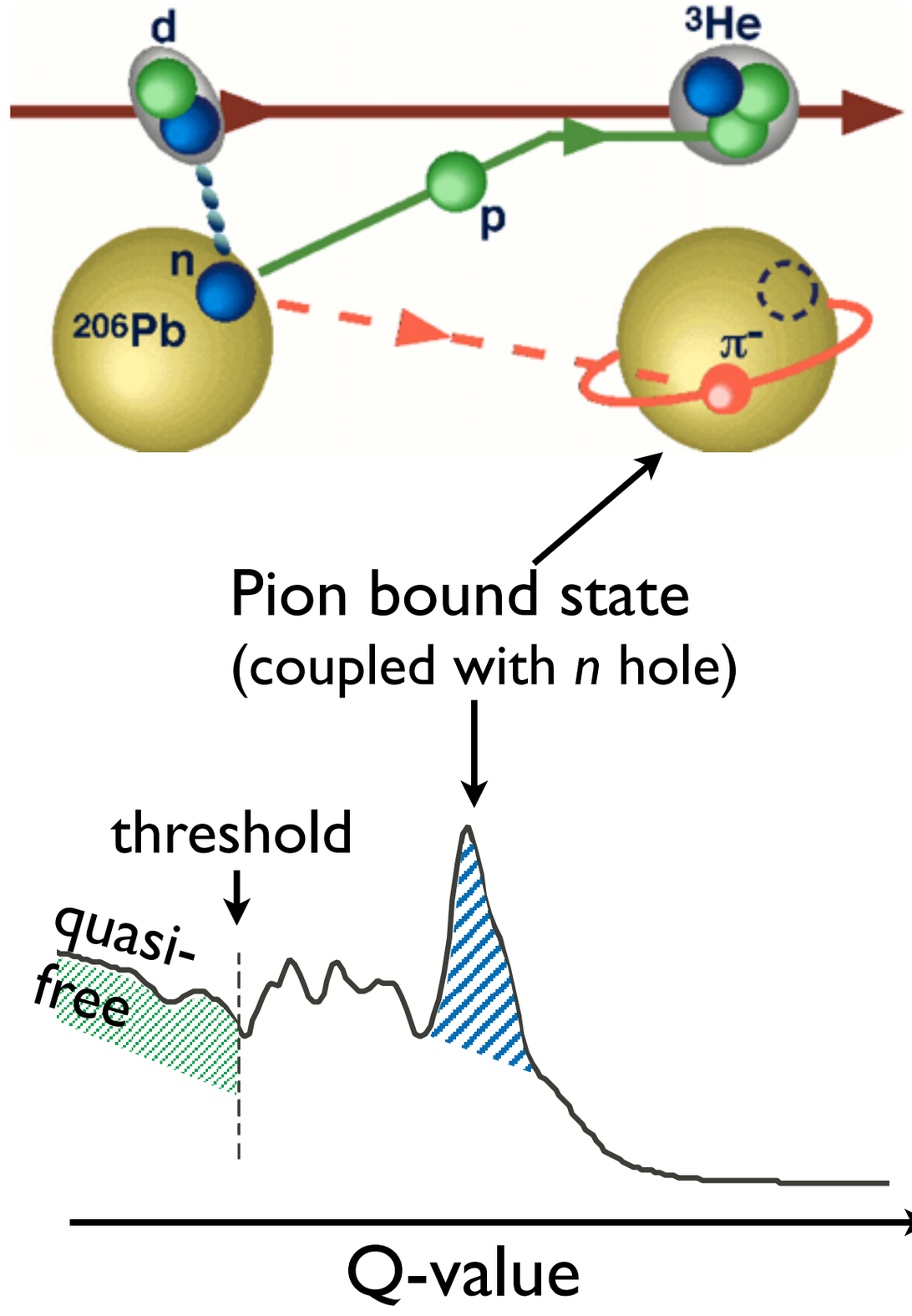
In-medium b_1 is calculated based on deeply bound pionic states data combined with light spherical pionic atom data.

Spectroscopy of pionic atoms

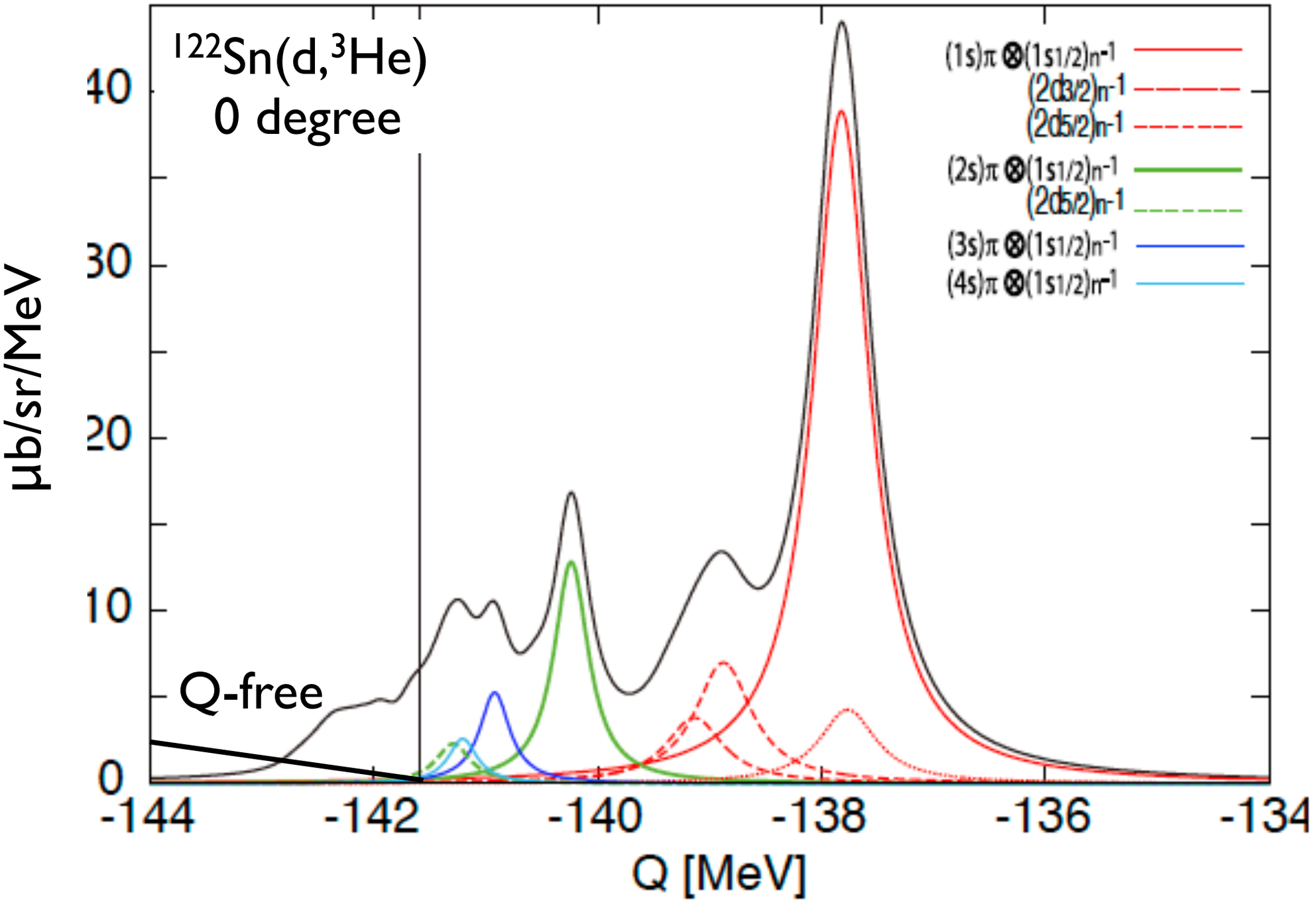
Direct production
in (d,^{3}He) nuclear reaction

Missing mass spectroscopy
to measure excitation spectrum
in Q-value measurement

We are aiming at
300 keV (FWHM) resolution.
(prev. 400 keV)



Theoretical Spectrum for ^{122}Sn(d,^{3}He)



N. Ikeno, Eur.Phys.J. A47 (2011) 161

Precision measurement of deeply bound pionic Sn atoms in RIBF

Kenta Itahashi

Advanced Meson Science Laboratory, RIKEN
for piAF collaboration

DeukSoon Ahn, Georg P. A. Berg, Masanori Dozono, Hiroyuki Fujioka, Naoki Fukuda, Nobuhisa Fukunishi, Hans Geissel, Emma Haettner, Ryugo S. Hayano, Satoru Hirenzaki, Hiroshi Horii, Natsumi Ikeno, Naoto Inabe, Kenta Itahashi*, Masahiko Iwasaki, Daisuke Kameda, Nobuyuki Kobayashi, Toshiyuki Kubo, Hiroaki Matsubara, Shin'ichiro Michimasa, Kenjiro Miki, Go Mishima, Daichi Murai, Hiroyuki Miya, Hideko Nagahiro, Megumi Niikura, Takahiro Nishi**, Shumpei Noji, Shinsuke Ota, Haruhiko Outa, Naruhiko Sakamoto, Hiroshi Suzuki, Ken Suzuki, Motonobu Takaki, Hiroyuki Takeda, Yoshiki K. Tanaka, Tomohiro Uesaka, Yuni N. Watanabe, Helmut Weick, Hiroki Yamakami, Koichi Yoshida.

* spokesperson, ** co-spokesperson

RIKEN Nishina Center, RIKEN
Department of Physics, University of Notre Dame
Department of Physics, Kyoto University
GSI Helmholtzzentrum fuer Schwerionenforschung GmbH
Department of Physics, The University of Tokyo
Department of Physics, Nara Women's University
National Institute of Radiological Sciences
Center of Nuclear Study, The University of Tokyo
Research Center for Nuclear Physics, Osaka University
National Superconducting Cyclotron Laboratory, Michigan State University
Stefan-Meyer-Institut für subatomare Physik, Österreichische Akademie der Wissenschaften

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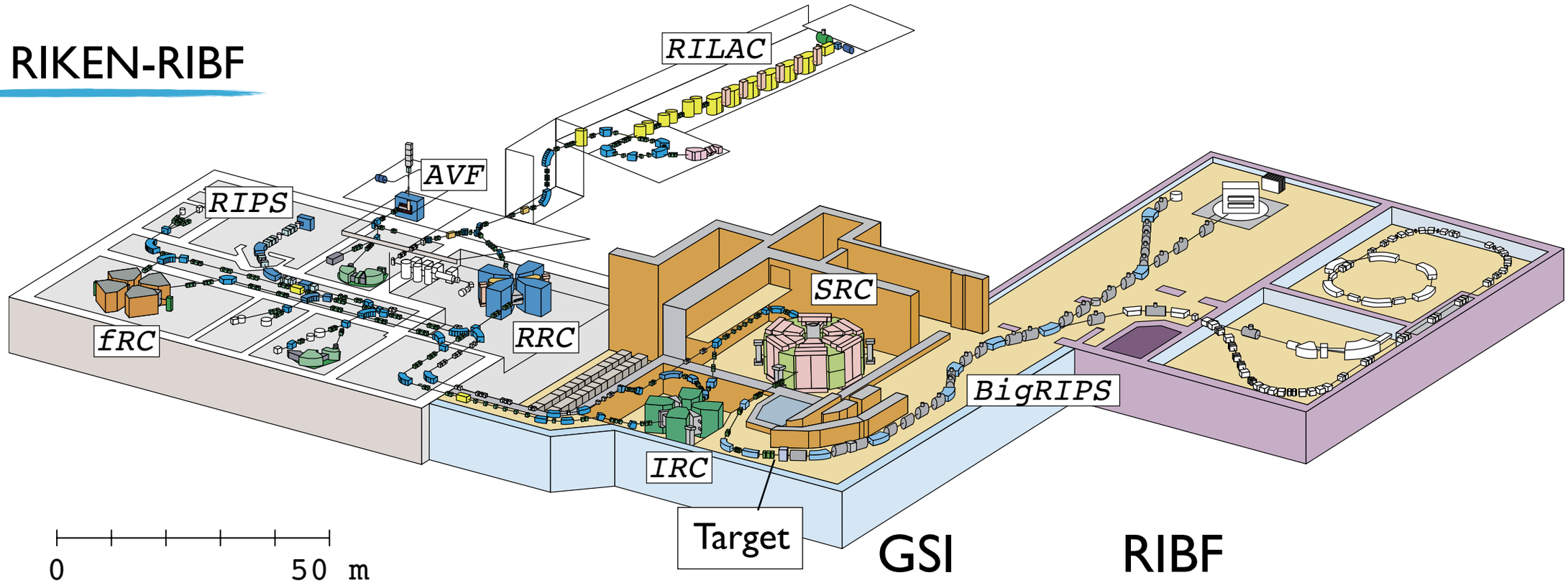
Precision spectroscopy at RI Beam Factory

RIKEN-RIBF



	GSI	RIBF
d beam Intensity	10	10
Target	20 mg/cm	10 mg/cm
Δ	0.03%	0.06%
Resolution (FWHM)	400 keV	< 300 keV
Acceptance (mrad)	15H, 10V	40H, 60V

Resol. Matching

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RIBF-54 Objectives

- 2010 Pilot run (~3 days)

  Establish experimental methods

  (calibration, optics, detectors etc.)

  Take a short production run w. Sn target for overall test

- 2014 Main run (~10 days)

  Achieve world highest resolution < 400 keV

  First observation of 1*s* + 2*s* pionic Sn states

  → better precision + better sys. error for B and Γ

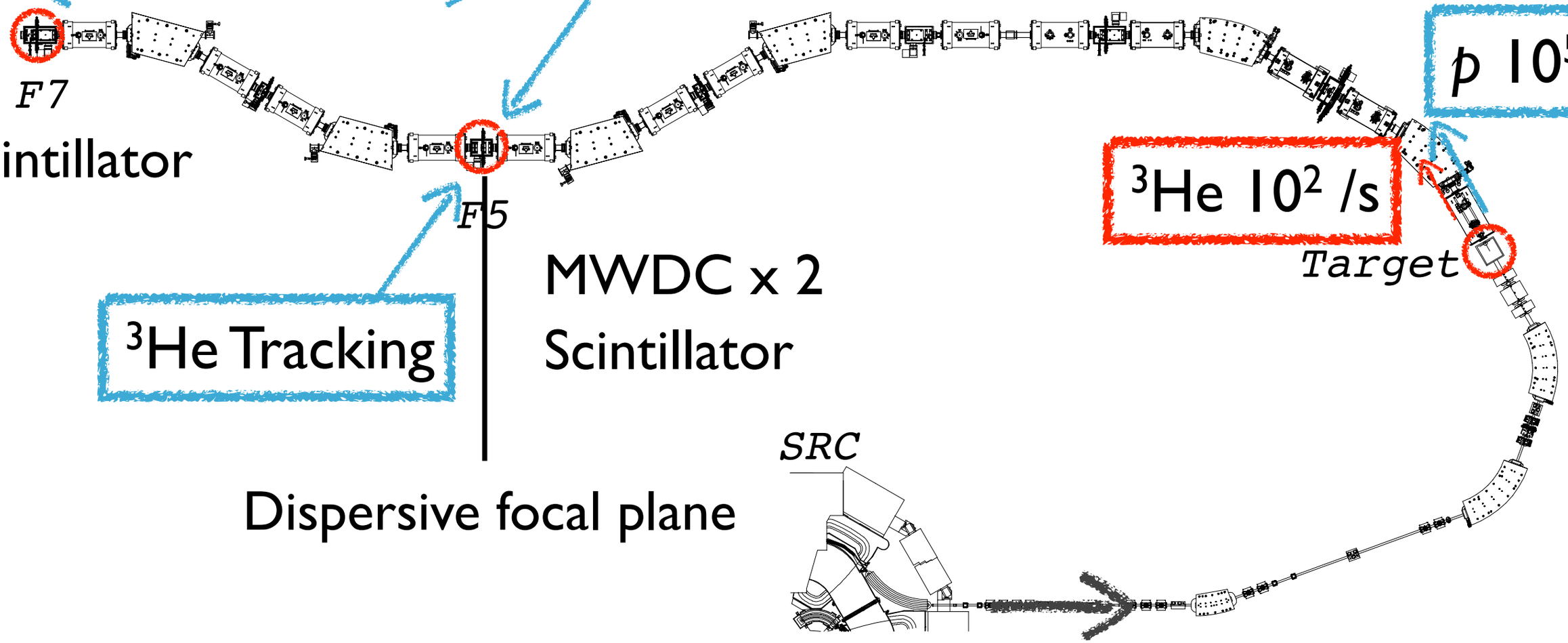
  First data for pionic even *N* Sn atom

Experimental setup

BigRIPS

TOF measurement

ΔE measurement



Scintillator

p 10^5 /s

^{3}He 10^2 /s

^{3}He Tracking

MWDC x 2

Scintillator

Dispersive focal plane

d beam >10^{12} /s, 250 MeV/u

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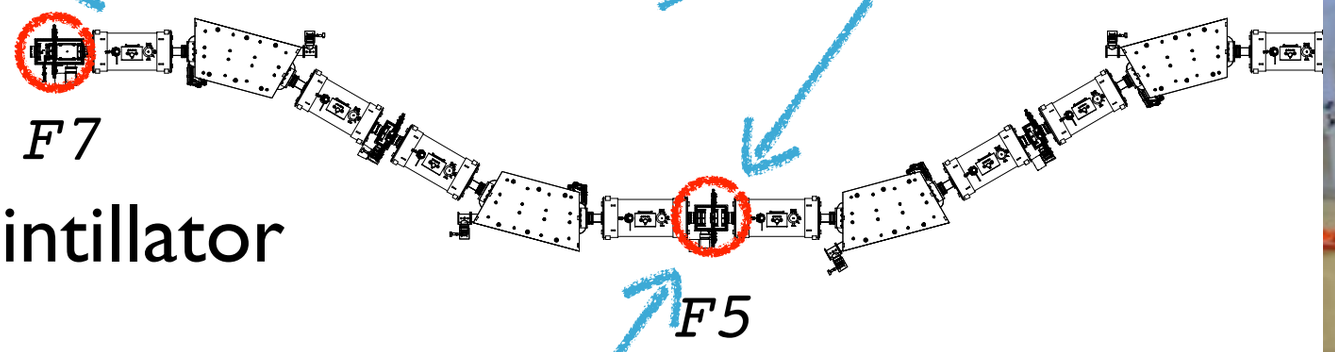
Experimental setup

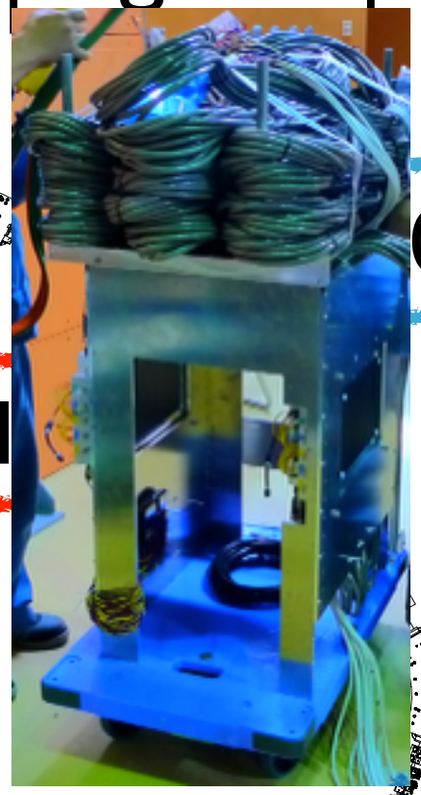
TOF measurement

ΔE measureme

BigRIPS



Scintillator

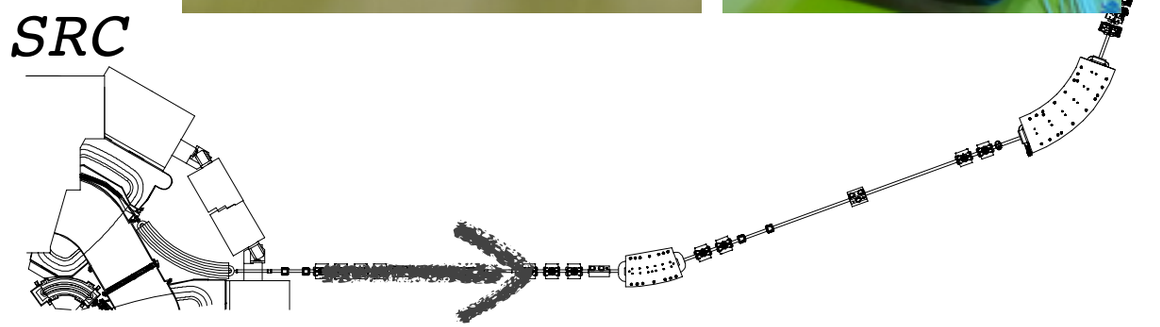


0^5 /s

MWDC x 2

Scintillator

^{3}He Tracking



d beam >10^{12} /s, 250 MeV/u

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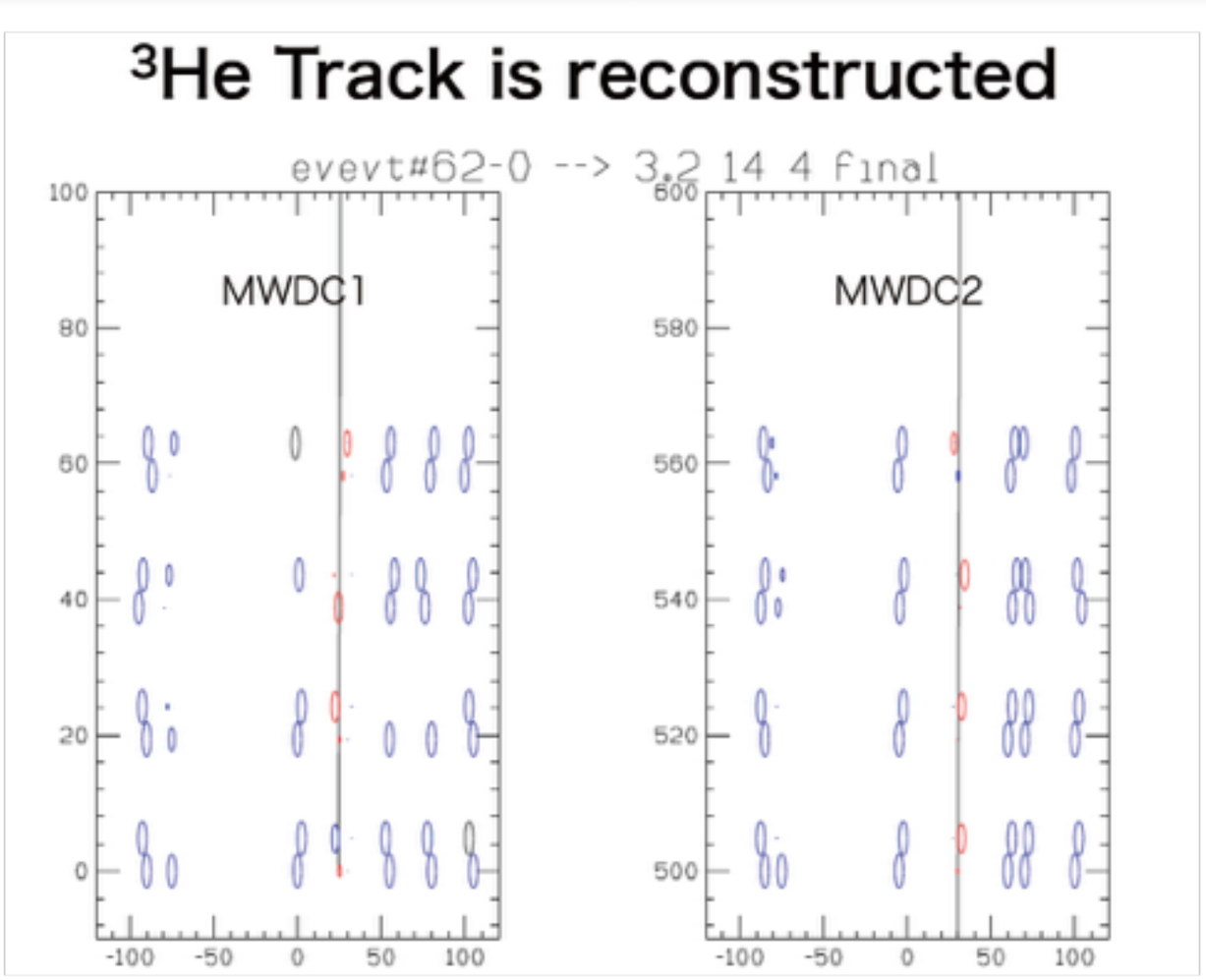
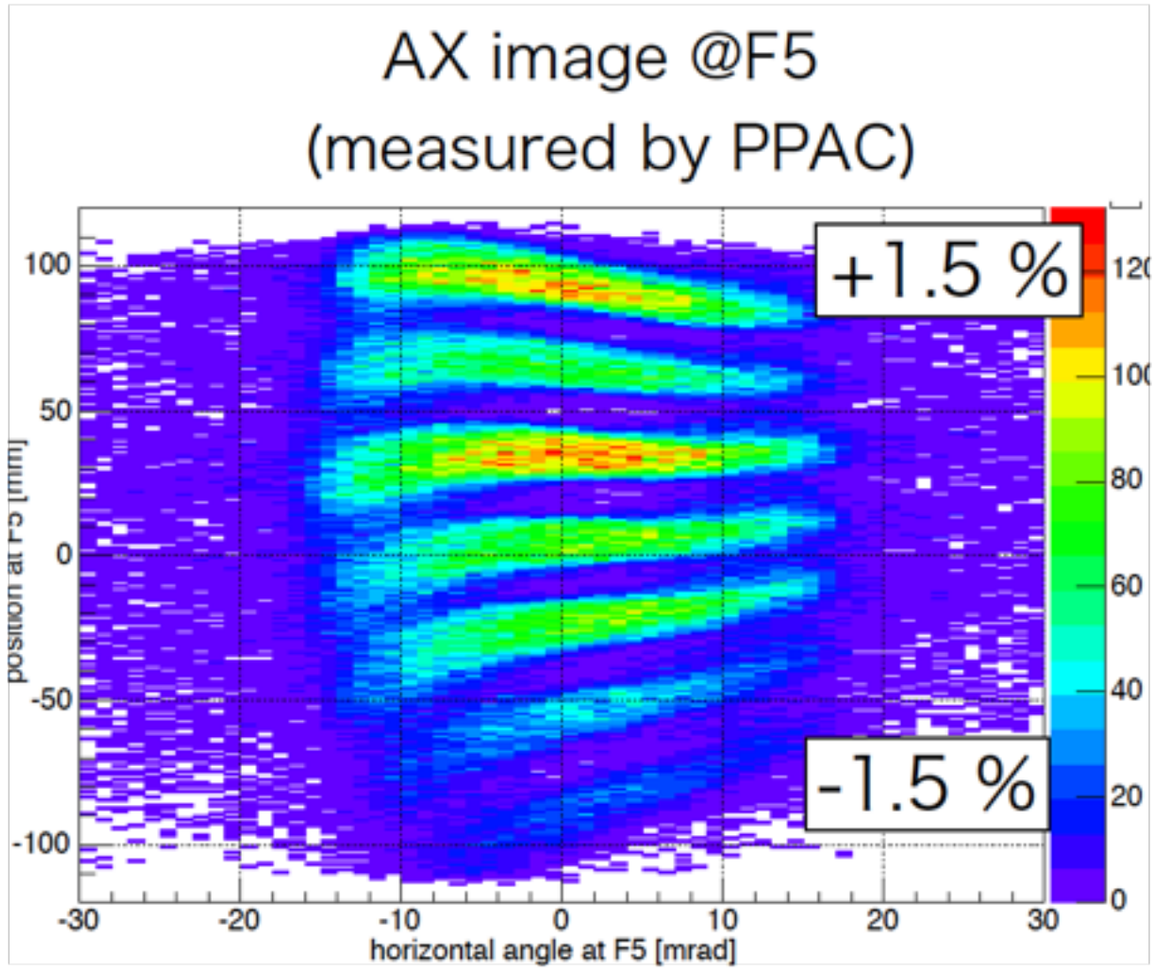
Instruments and analysis

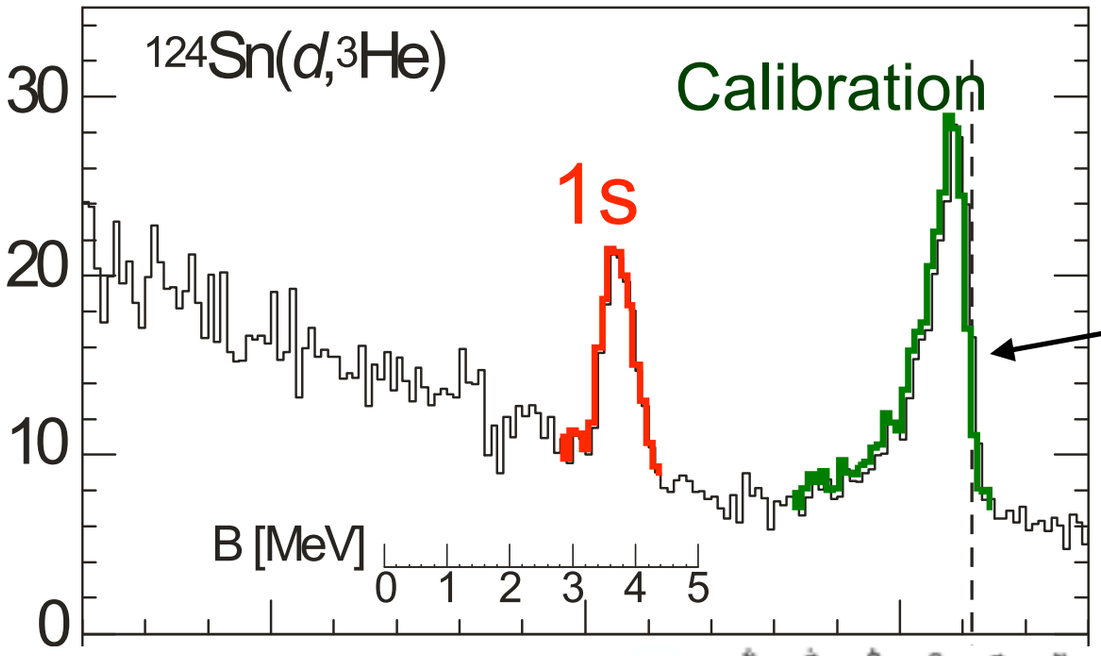
MWDC as PID device



higher order aberration (x,aaaδδδ) correction



Experimental resolution / systematic errors



K. Suzuki et al.,
PRL92(04)072302.

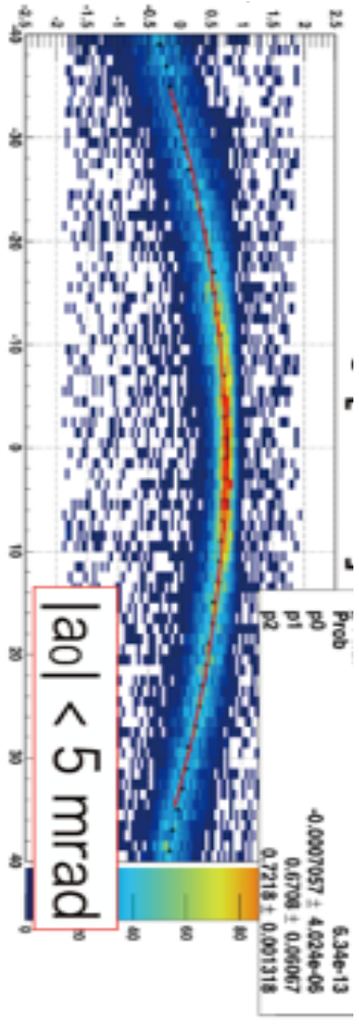


Figure based on
data taken at RIBF

in-situ Calibration
$p(d,^3\mathrm{He})\pi^0$

using CH2 pasted Sn target

Resolution ~ 400 keV
(beam p spread, target thickness)

Systematic errors
in absolute energy scale
(calibration, incident energy, dx/dp…)

We want to improve precision.

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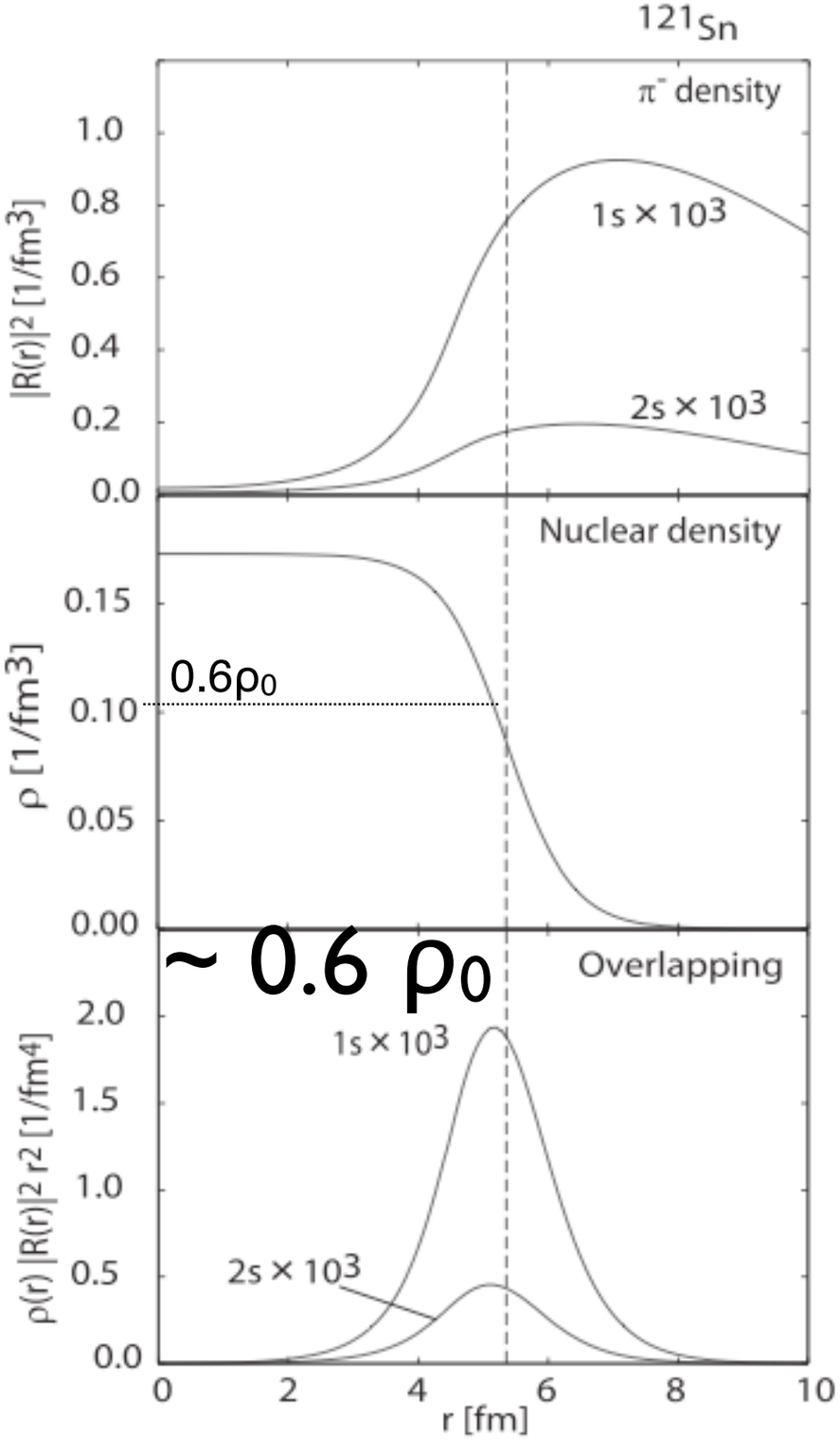
Feasibility study has started for

Deeply-Bound Pionic Atoms with Unstable Nuclei

Y.N. Watanabe

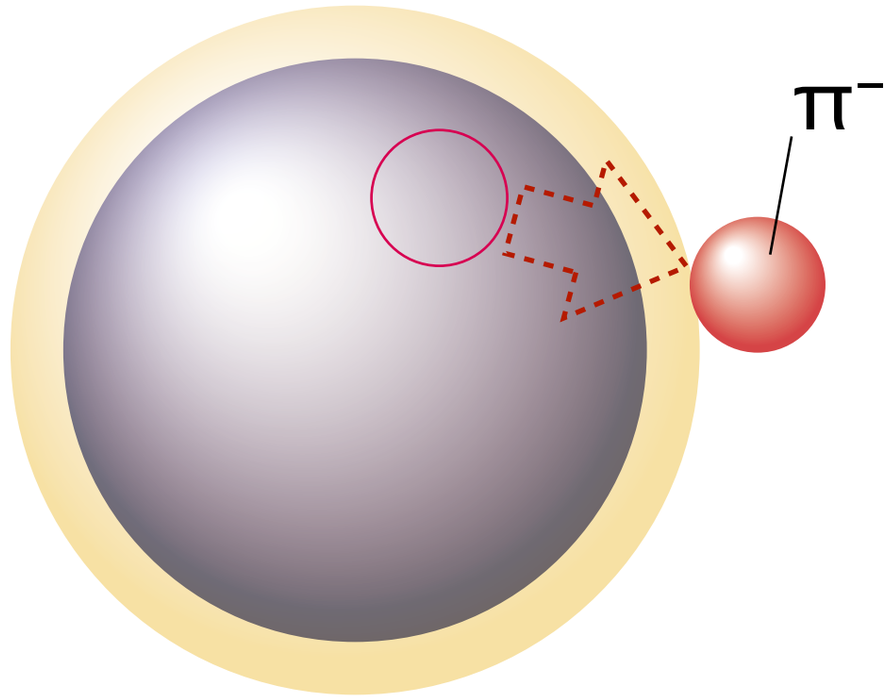
Kenta Itahashi, RIKEN

Deeply-Bound Pionic Atoms with Unstable Nuclei



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

neutron rich nucleus



neutron skin

Pion bound at $\rho < 0.6\ \rho_0$

ρ_0 : normal nuclear density

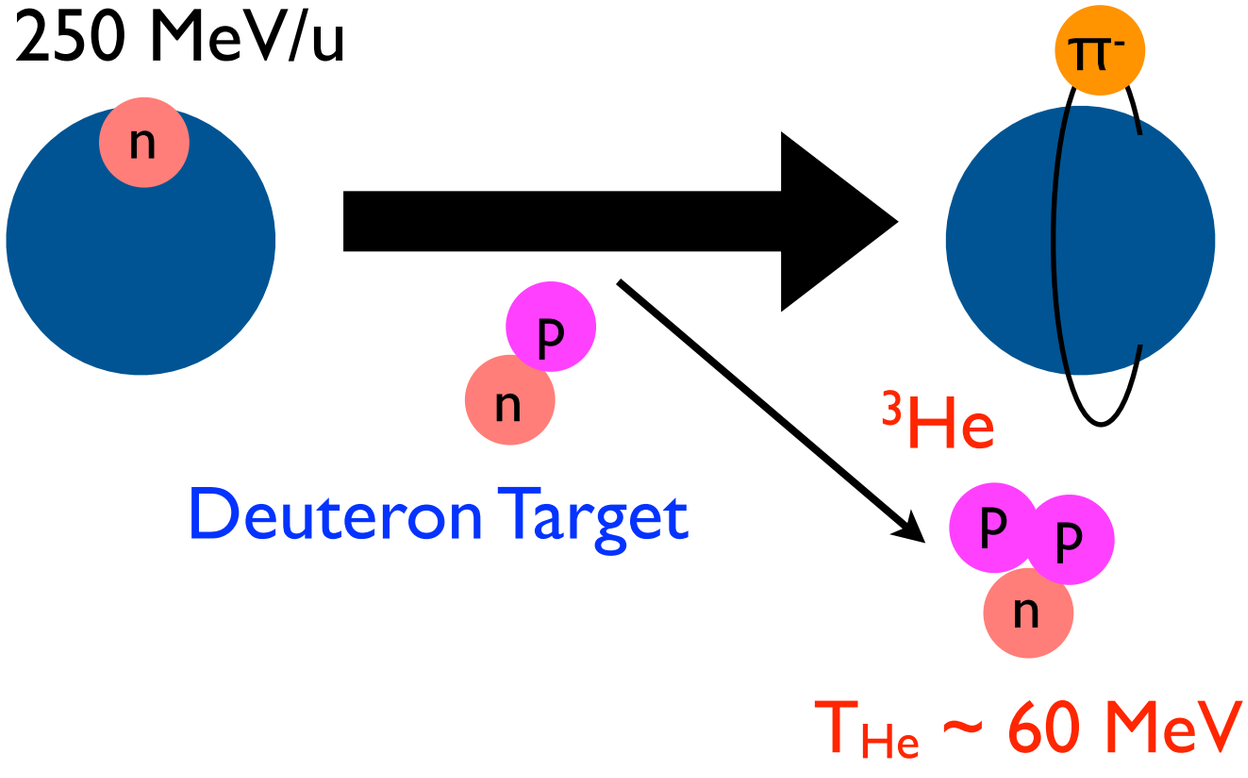
Density dependence of $\langle\bar{q}q\rangle$

Missing mass spectroscopy in d(HI, ^{3}He) reaction

Keeping the same kinematical condition as normal kinematics !!

Heavy Ion Beam

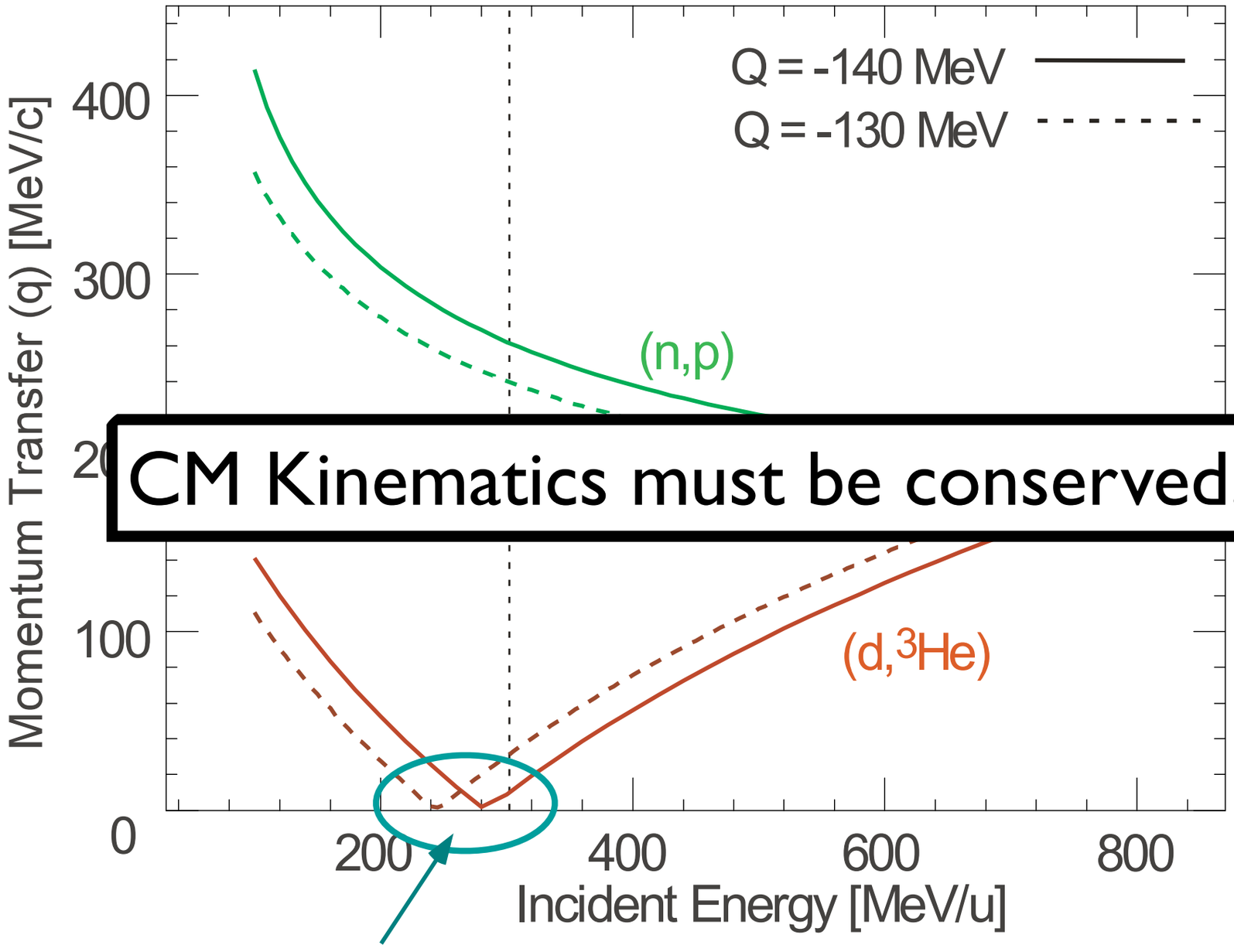
~ 250 MeV/u



Pionic Atom

T_{He} ~ 60 MeV

Momentum Transfer



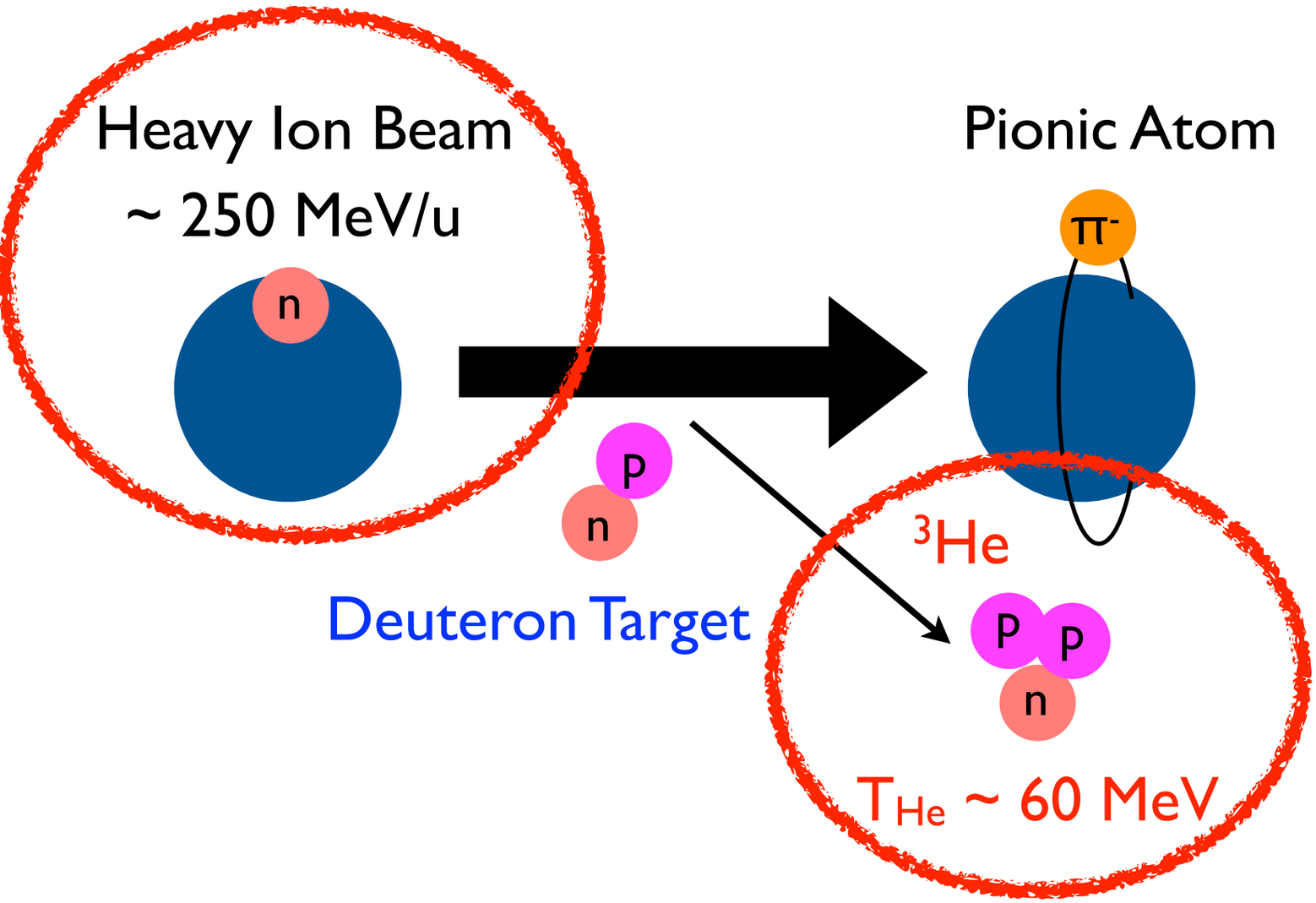
CM Kinematics must be conserved.

Quasi-substitutional (ΔL~0) reaction
Small momentum transfer(q)

(d,^{3}He) reaction

Missing mass spectroscopy in d(HI, ^{3}He) reaction

Keeping the same kinematical condition as normal kinematics !!

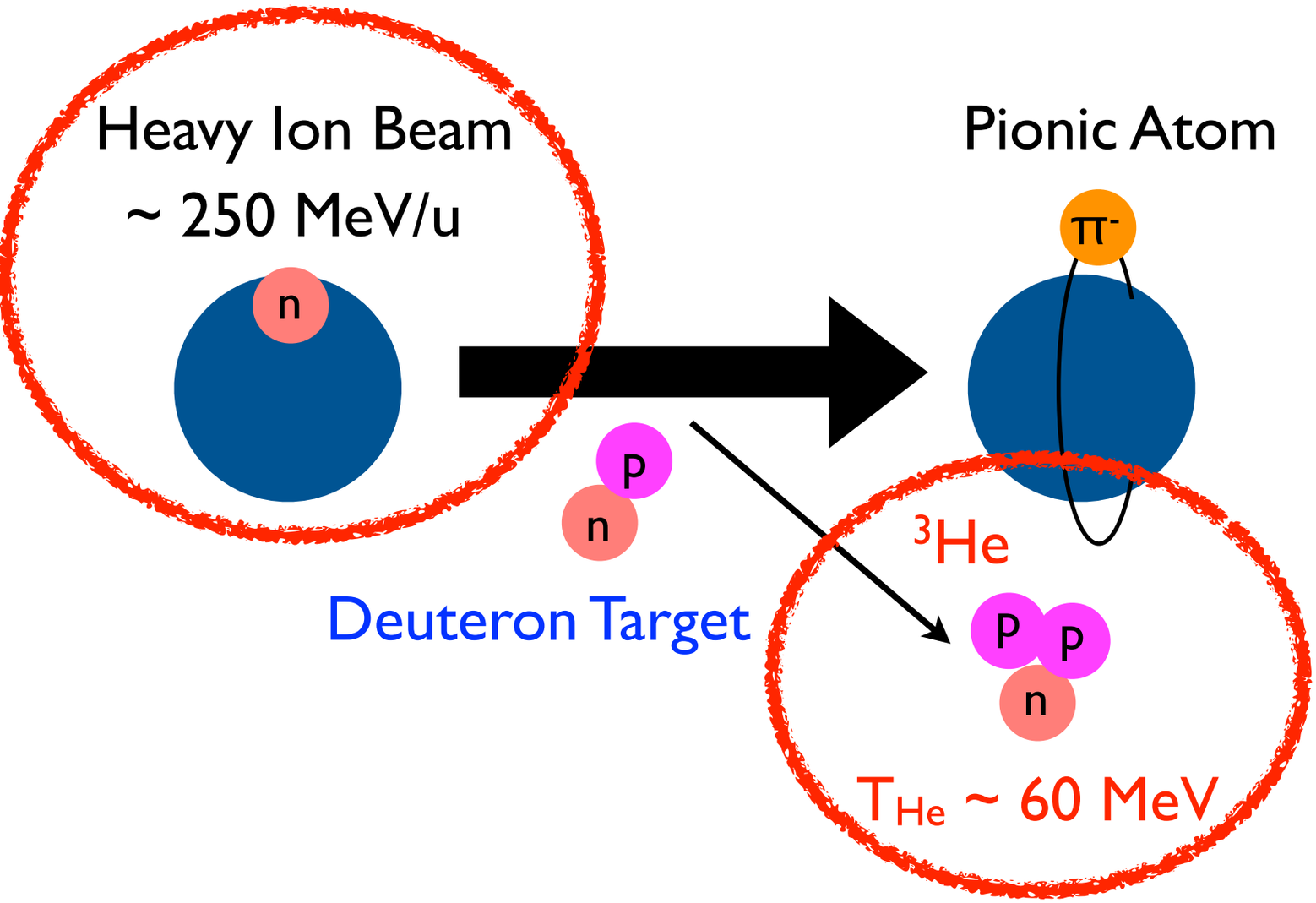


- ^{3}He recoil angle
- ^{3}He kinetic energy

Q value

Missing mass spectroscopy in d(HI, ^{3}He) reaction

Keeping the same kinematical condition as normal kinematics !!



- ^{3}He recoil angle
- ^{3}He kinetic energy

Q value

60 MeV ^{3}He range is 1.8 mm in Silicon

Conceptual design at RIBF as a first step

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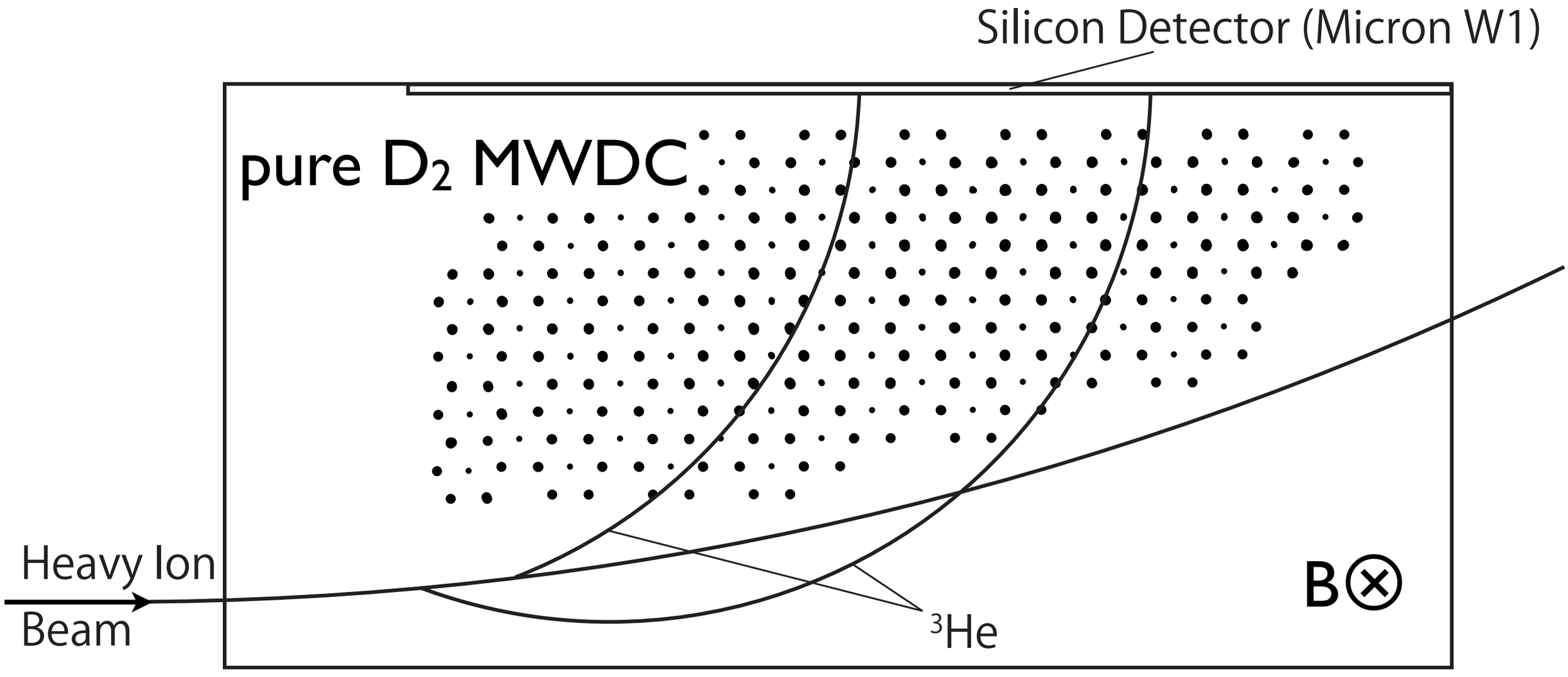
Experimental Setup



- ^{3}He recoil angle
- ^{3}He kinetic energy
- vertex point

ΔE, Full Energy by Si +
Trajectory by MWDC
Incident beam < 10^6/s

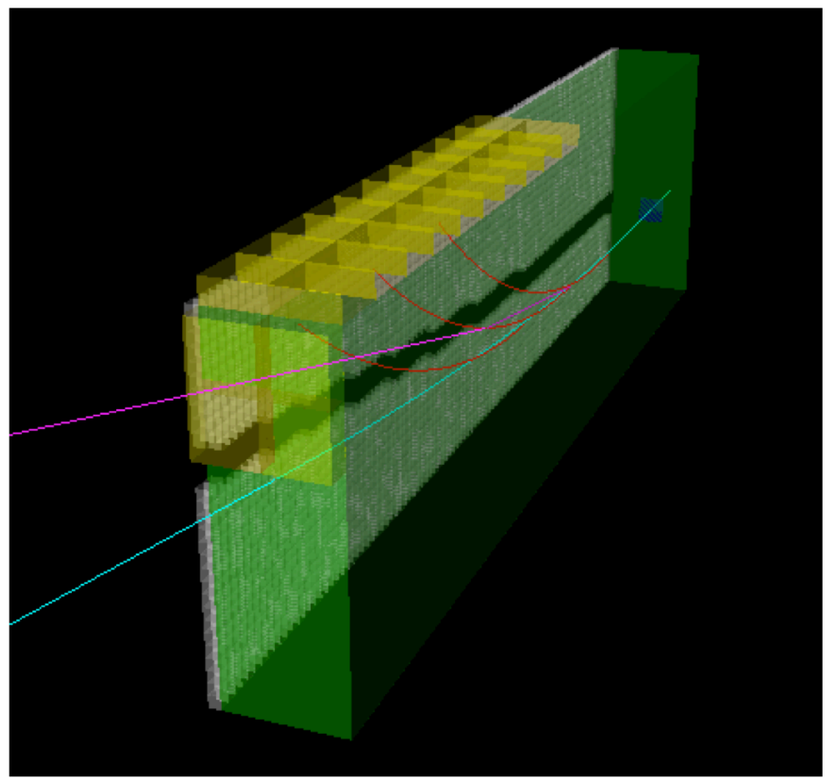
Yield and resolution estimation (simulation)

requirement

yield	10
resolution	$\Delta Q < 1$ MeV (FWHM)

input parameter

intensity	~ 10
TPC resolution	~ 500 μm
Si resolution	0.1%@60MeV



GEANT4 simulation

Q Value Resolution

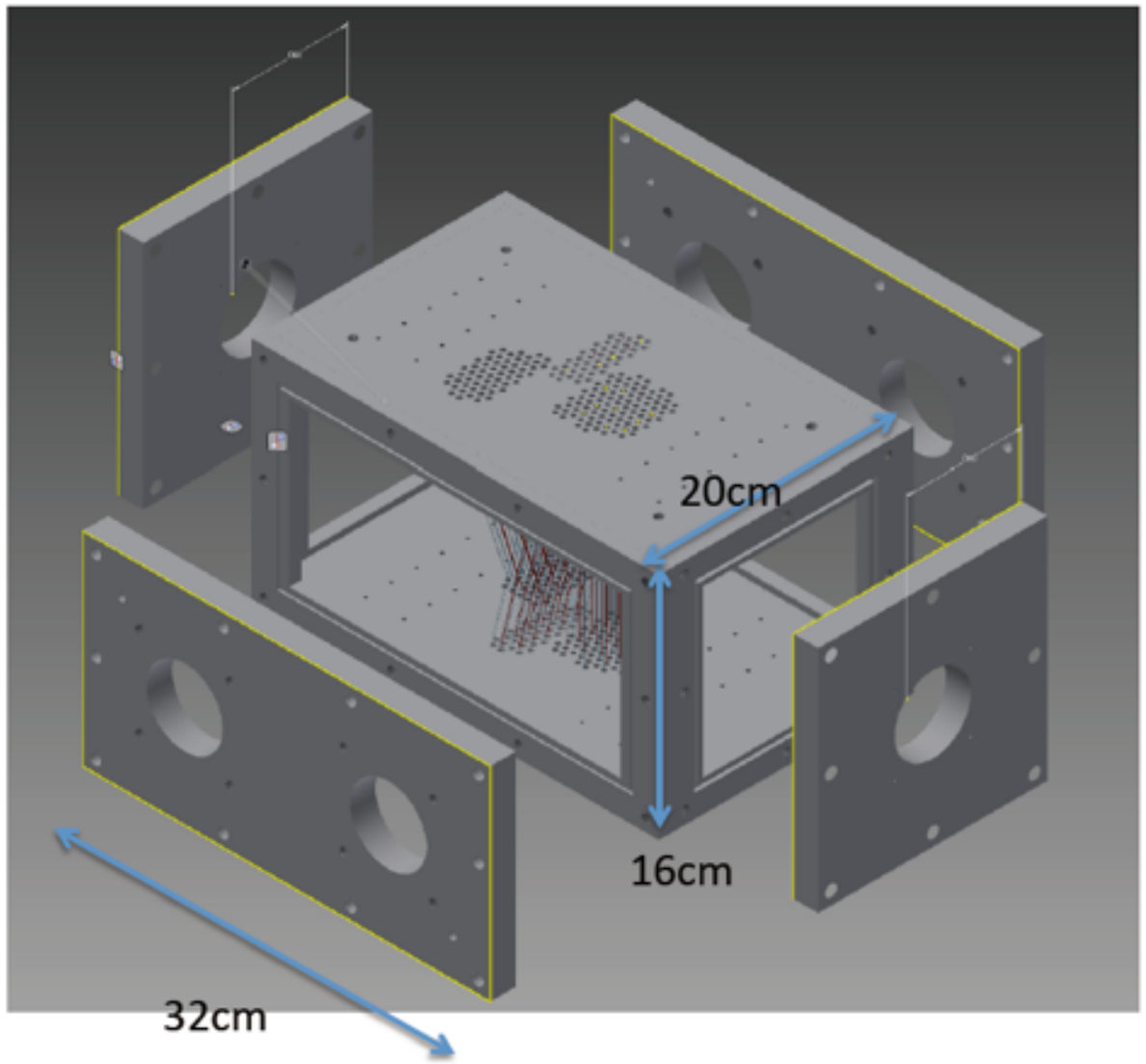
Cause	ΔQ (FWHM) [keV]
Energy Resolution of Si at T_{He} ~ 60 MeV σ_{Si} = 0.1 %	~ 350
Energy Straggling of ^{3}He in TPC	~ 350
Vertex Reconstruction With Incident Beam σ_{TPC} = 500 μm	~ 130
Total	**~ 500**

cf. 400 keV for normal kinematics

Detector Development

Silicon in deuterium test
+ pure deuterium GEM-TPC
(w. CNS) development.

prototype MWDC in construction



First test run with
stable nuclei in HIMAC

Y.N. Watanabe and S. Ogawa

Kenta Itahashi, RIKEN

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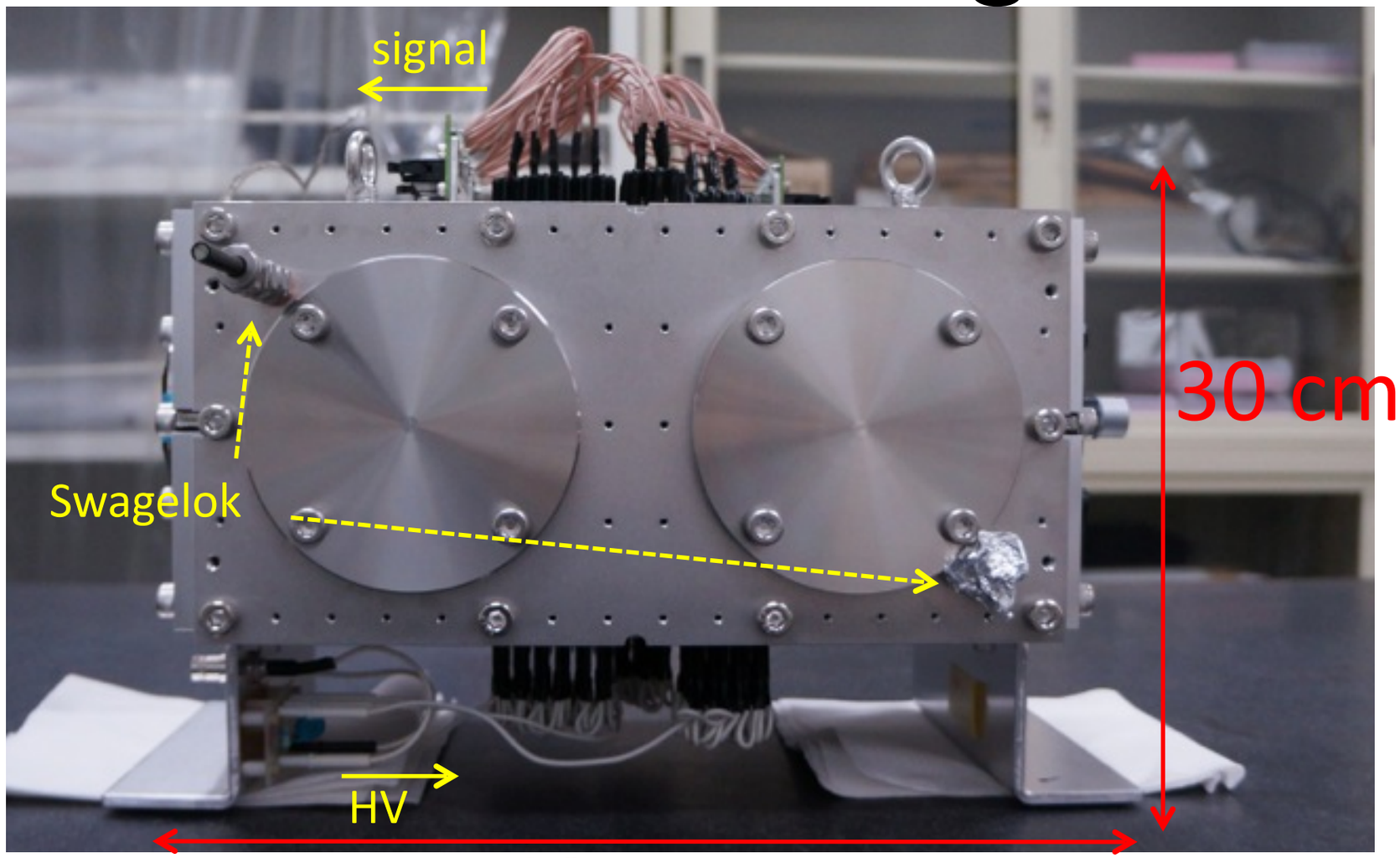
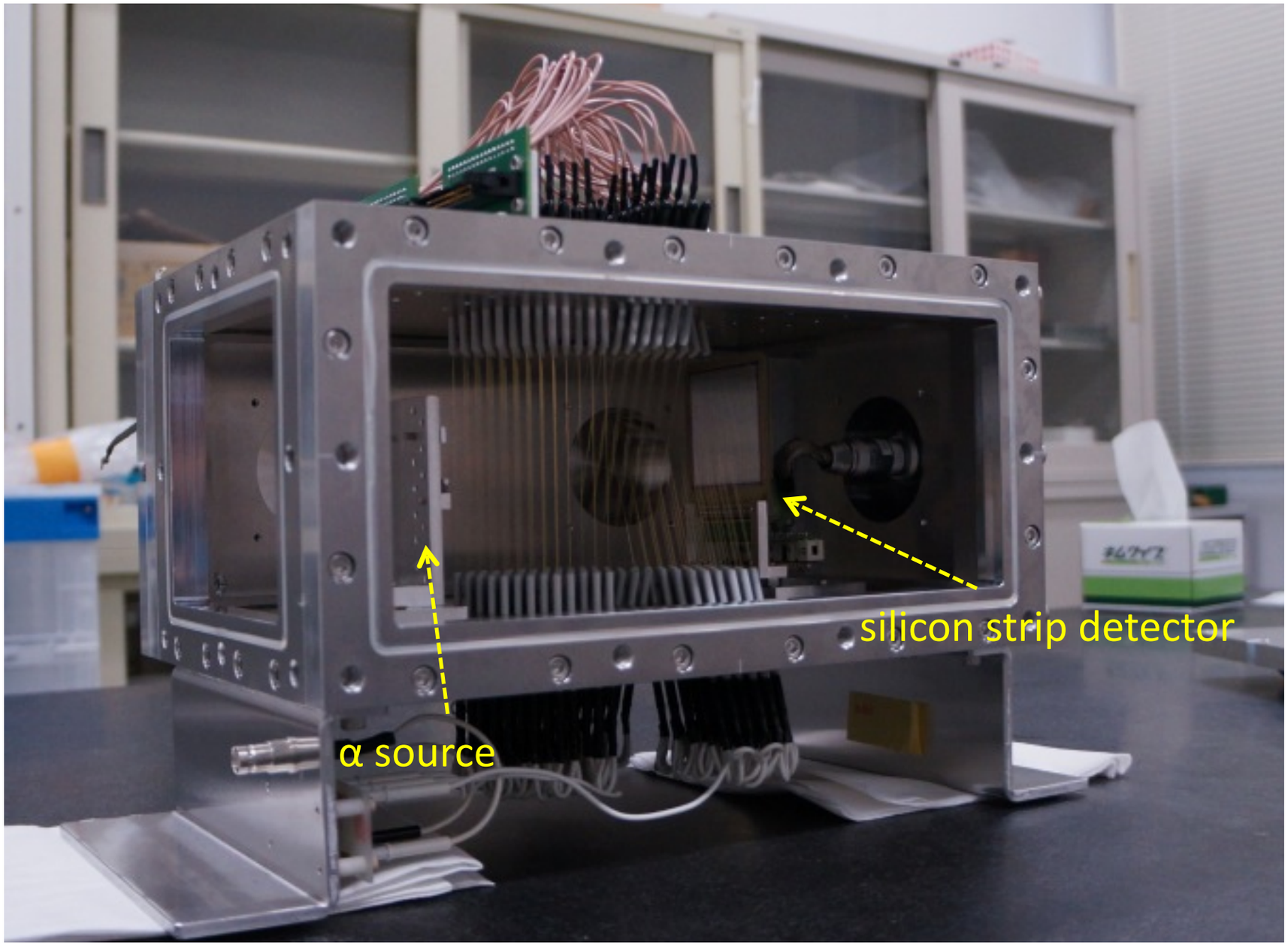
Detector Design



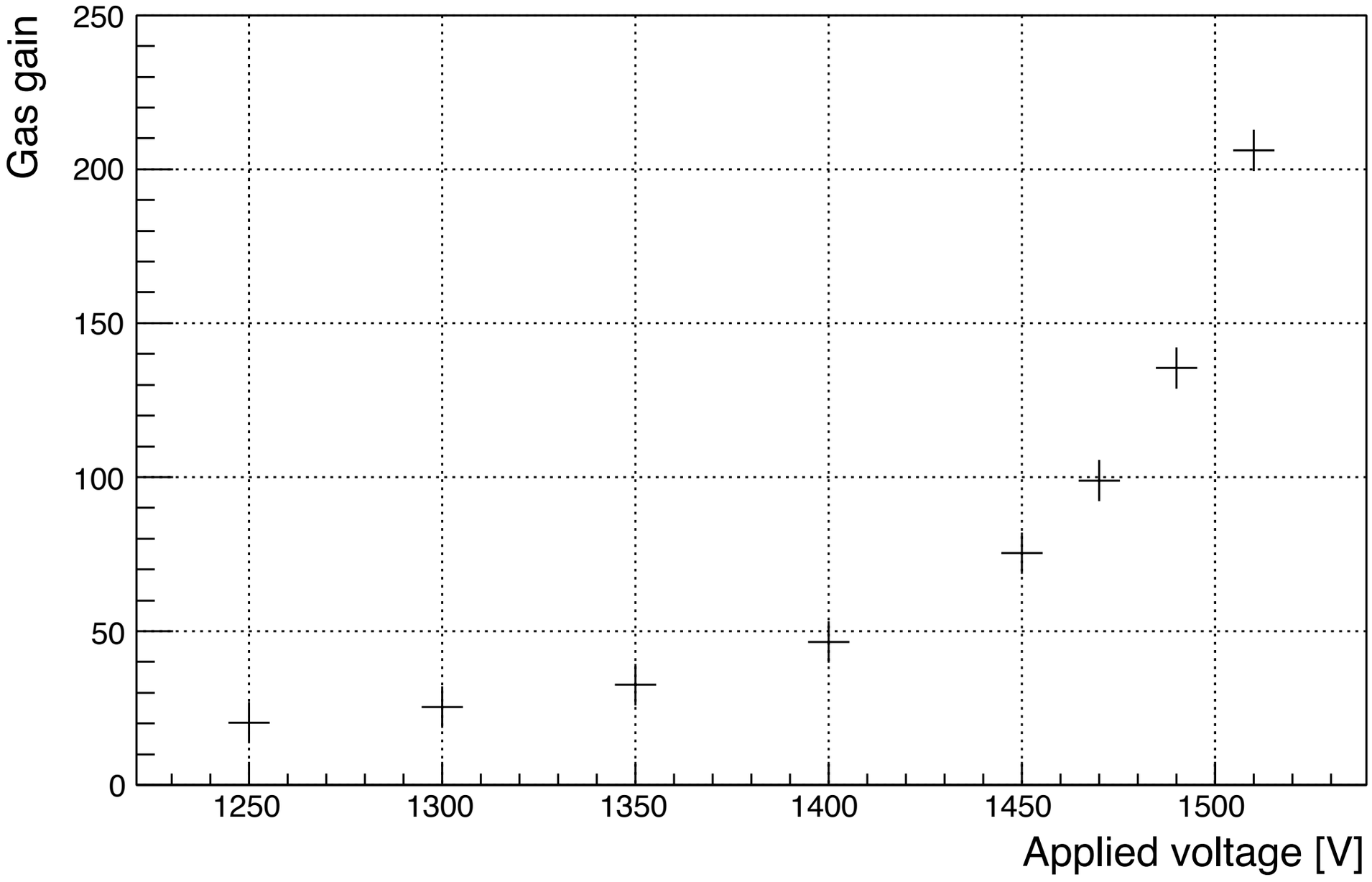
- Wire feedthrough, hexagonal wire geometry
- Raw material is Al
- Side walls are flange

Detector Design



- Inside the drift chamber, SSD and α source were installed

Gas Gain



Maximum gas gain was about 200

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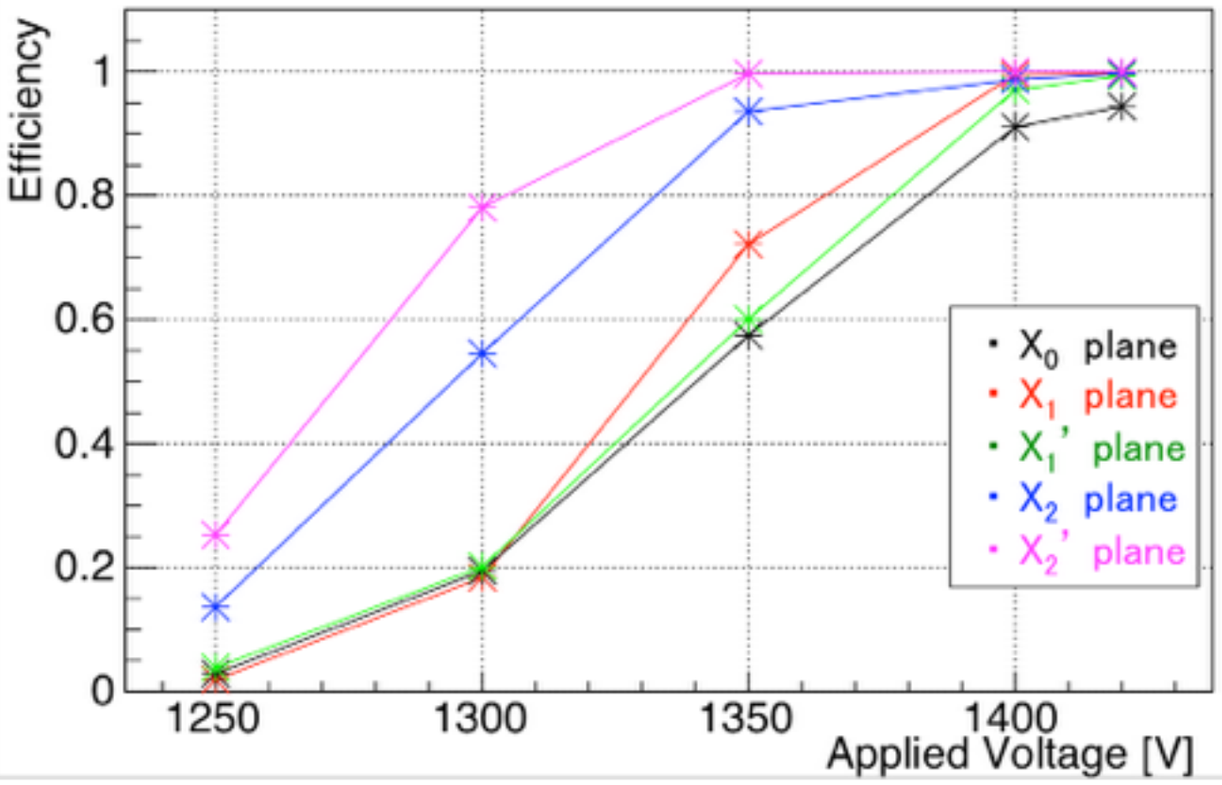
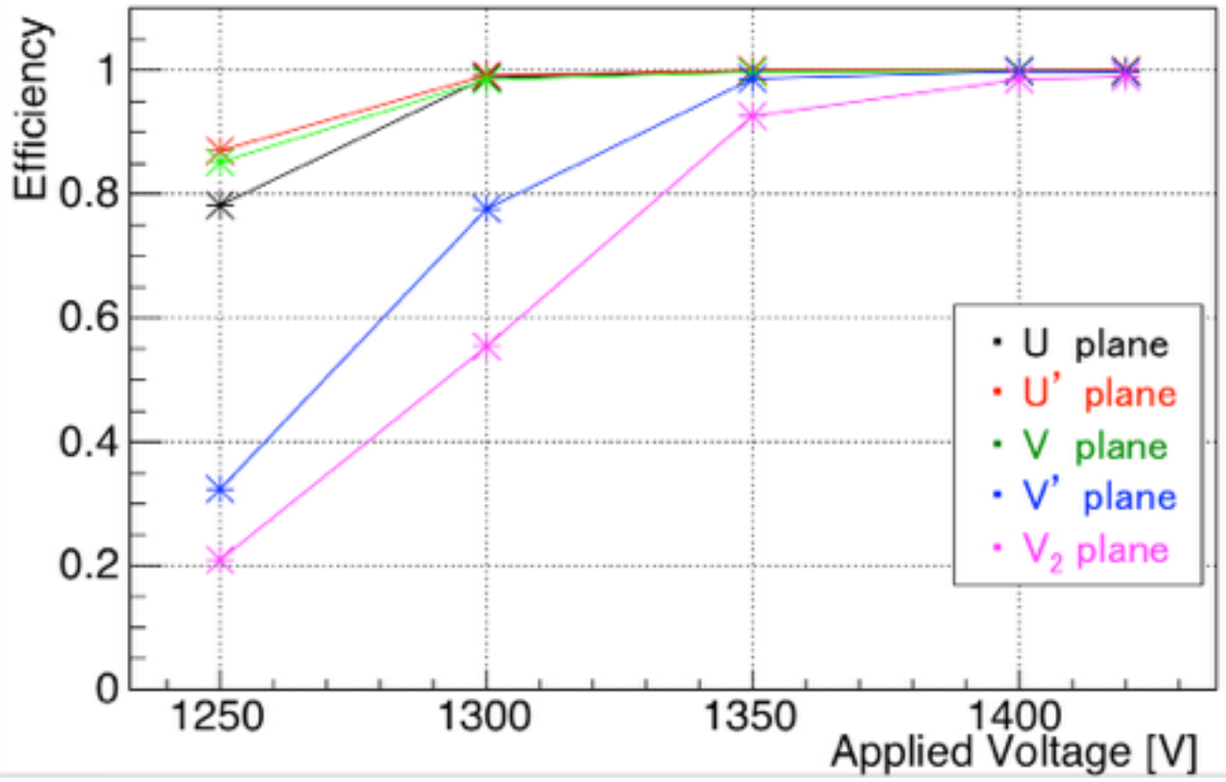
Efficiency for α rays

Efficiency for X palnes



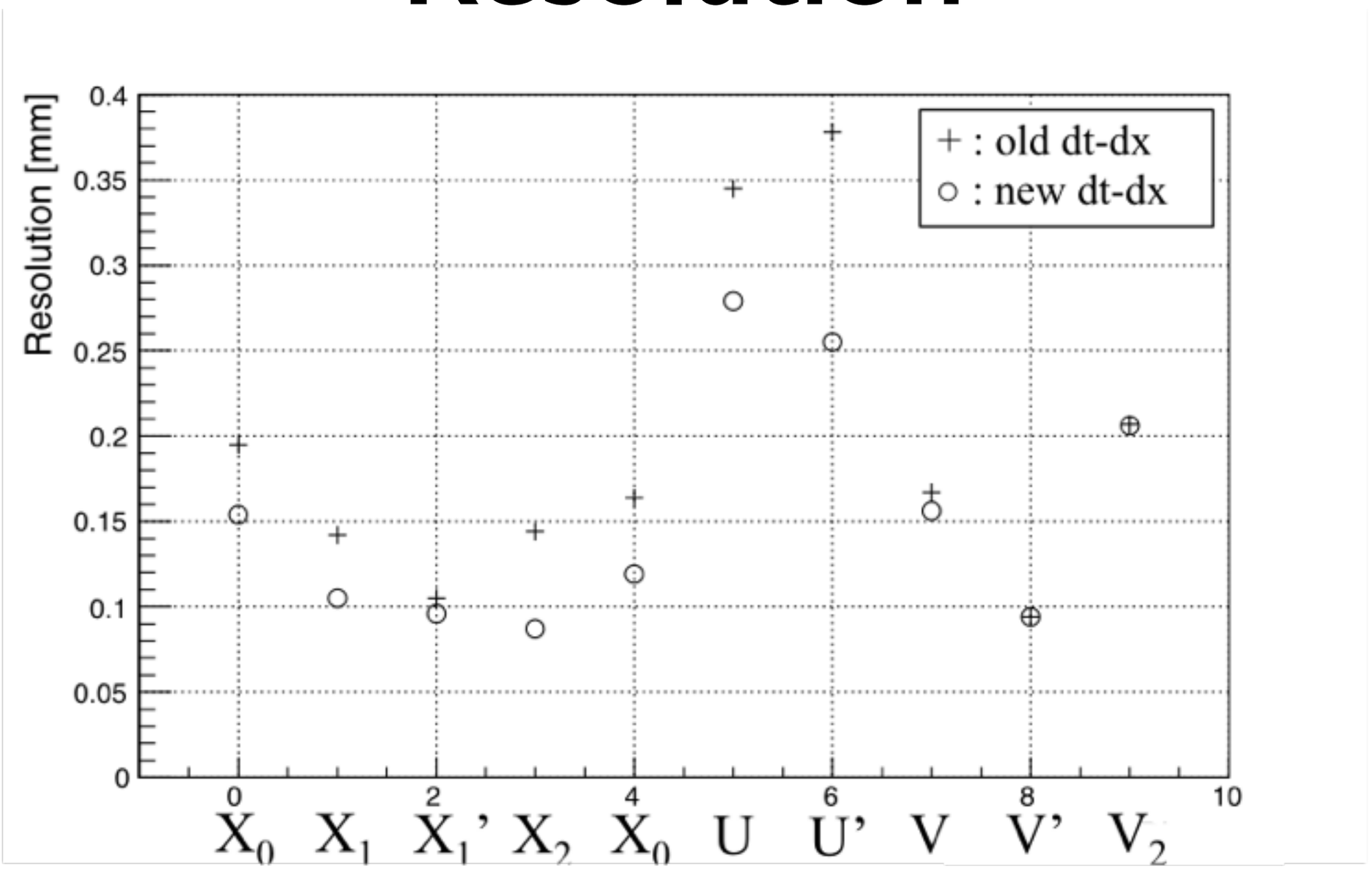
Efficiency for UV palnes



Efficiency =1 - (no hit event in each plane) / (number of trigger)

- Efficiency in X_2', U, U', V was higher
- Efficiency > 99% except for X_0 plane @ HV = -1420 V

Resolution



- Resolution is better than required resolution of 500 μm
- good enough for the experiment

Summary for piAF

- World highest resolution + potential to improve by 1/2-1/3
- Extremely good statistics for ^{121}Sn-pi
- First data for pionic even *N* pi-atom
- Analysis is ongoing now (by T. Nishi)

  → better χ condensate estimation
- First paper in short
- Proposing exp. to complete pionic tin isotopes
- We are also working on piA with unstable nuclei