



XII INTERNATIONAL CONFERENCE ON HADRON SPECTROSCOPY

KEK-PS E570 Experiment

Precision spectroscopy of Kaonic Helium $3d \rightarrow 2p$ X-rays

G. Beer, H. Bhang, P. Buehler, M. Cargnelli, J. Chiba,



Precise measurement of kaonic helium atoms X-rays

H. Tatsuno, D. Tomono, E. Widmann, T. Yamazaki, H. Yim, J. Zmeskal

Precision spectroscopy of Kaonic Helium-3 $3d \rightarrow 2p$ X-rays



RIKEN Nishina Center
Masami Ito



**for KEK-PS E570 Collaboration
& J-PARC E17 Collaboration**

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E. Widmann, T. Yamazaki, H. Yim, J. Zmeskal**



Contents

Measurement of Kaonic helium-4 (KEK-PS E570)

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*Buehler, M. Cargnelli, J. Chiba,
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H. Ohnishi, S. Okada, H. Ota, D. Pietreanu, F. Sakuma, M. Sato,

Measurement of Kaonic helium-3 (J-PARC E17)

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6. Summary



*KKEK-PS E570 Experiment
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1. Introduction

Precision spectroscopy of Kaonic Helium-3 $3d \rightarrow 2p$ X-rays

J-PARC E17 Experiment

Last orbit level shift of Kaonic atom is sensitive to K-nucleus strong interaction.

G. Beer, H. Bhang, P. Buehler, M. Cargnelli, J. Chiba,
J. Choi, C. Curceanu, Y. Fujita, O. Goto, T. Ishikawa,
D. P. Jackson, A. Kanda, M. Ito, S. Ishikawa,
M. Iwai, K. Itaya, M. Iwasaki, S. Junisz, S. Niemeier,
J. Marton, Y. Matsuda, H. Ohnishi, S. Ohzawa, H. Tada,
L. P. Peticanu, T. Sakayra, M. Sato, P. Schmid, D. Sirghi,
T. Sirghi, P. Suzuki, S. Suzuki, H. Tatsuno, D. Tomono,
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Atomic orbitals of
Kaonic helium

3d -> 2p X-rays (~6.4 keV)

2p

ΔE_{2p} : Level shift by strong interaction

(Only Coulomb) 2p - - - -



absorption

$$\Delta E_{2p} = E_{2p}^{\text{exp}} - E_{2p}^{EM}$$

Nucleus

Kaonic helium puzzle

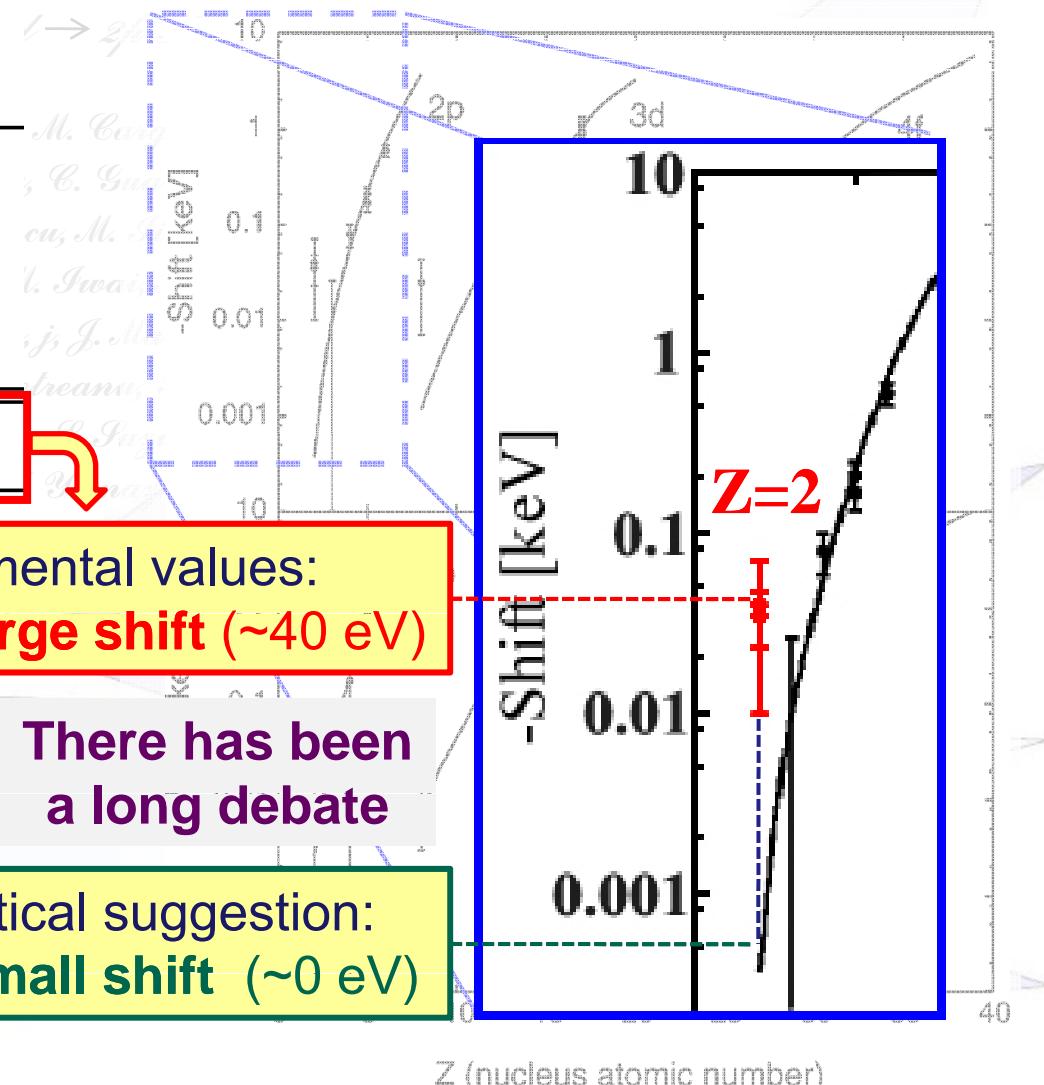


Past Measurements

ΔE_{2p} (eV)	Γ_{2p} (eV)
- Shift -	- Width -
-41 ± 33	—
-35 ± 12	30 ± 30
-50 ± 12	100 ± 40
-43 ± 8	55 ± 34

We measured the kaonic- ${}^4\text{He}$ Balmer-series X-rays with a precision of ~ 2 eV
(KEK-PS E570)

Last orbit energy level shift and width of kaonic atoms



Experimental values:
Very large shift (~ 40 eV)

There has been
a long debate

Theoretical suggestion:
Very small shift (~ 0 eV)



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2. E570 experiment

Precision spectroscopy of Kaonic Helium-3 $3d \rightarrow 2p$ X-rays

J-PARC E17 Experiment

Experimental setup

Silicon Drift Detector (SDD) :

for high-resolution X-ray energy measurement

Effective area: 100mm²

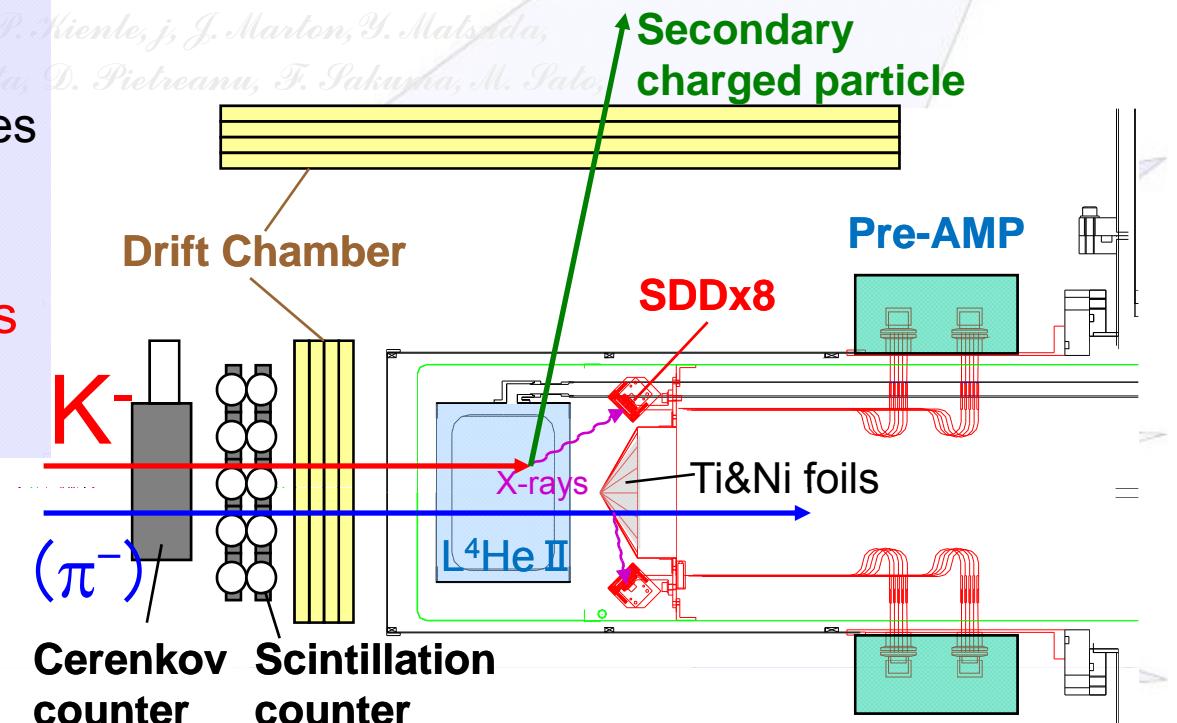
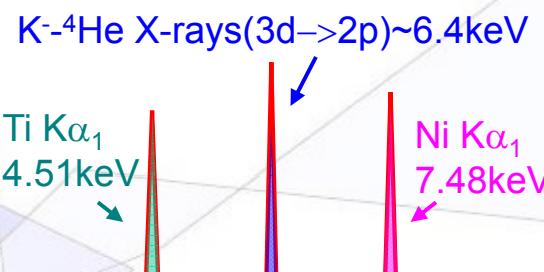


Fiducial volume cut :

for kaons stopping point measurement with drift chambers for
 - Incident Kaons
 - Secondary charged particles

In-situ energy calibration :

using characteristic X-rays from titanium and nickel foils





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H. Ohnishi, S. Okada, H. Oita, D. Pietrana, T. Sakurada, M. Sato,
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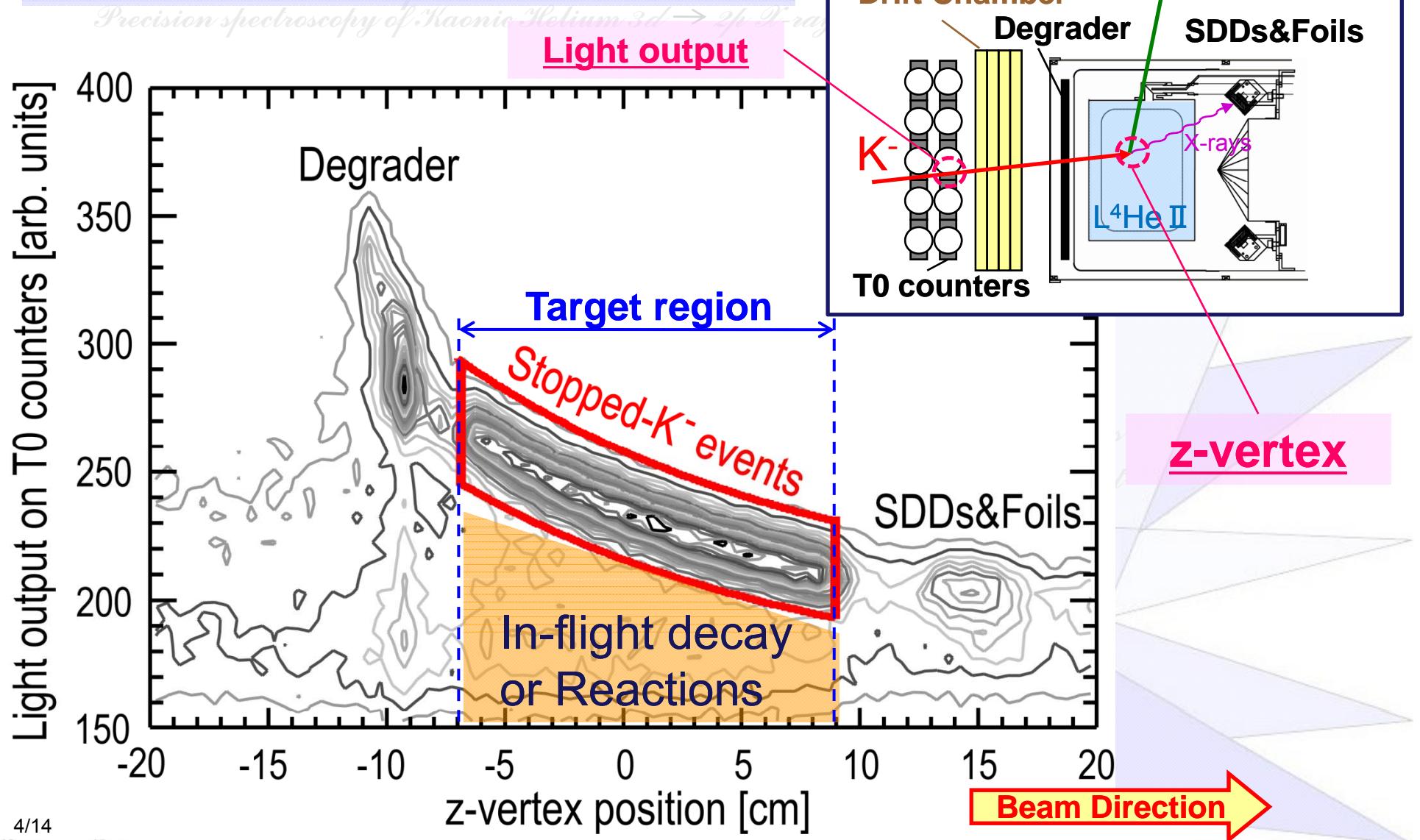
3. Result

*Precision spectroscopy of Kaonic Helium-3 $3d \rightarrow 2p$ X-rays
J-PARC E17 Experiment*

Stopped-K⁻ selection



► The background events in the target cell were removed by the T0 counters.



Energy calibration

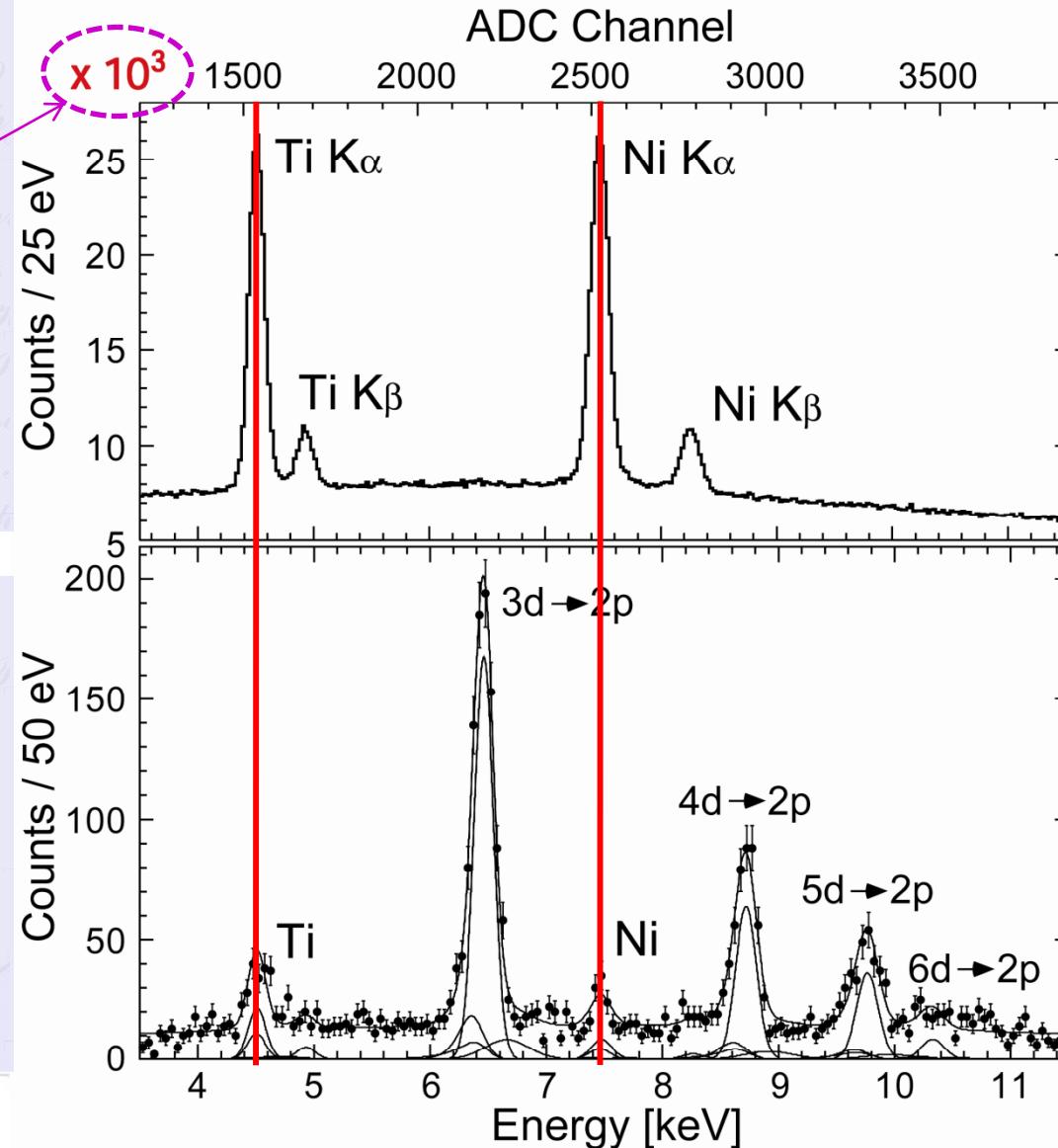


SDD self-triggered events

High statistical characteristic X-ray peaks of Ti & Ni

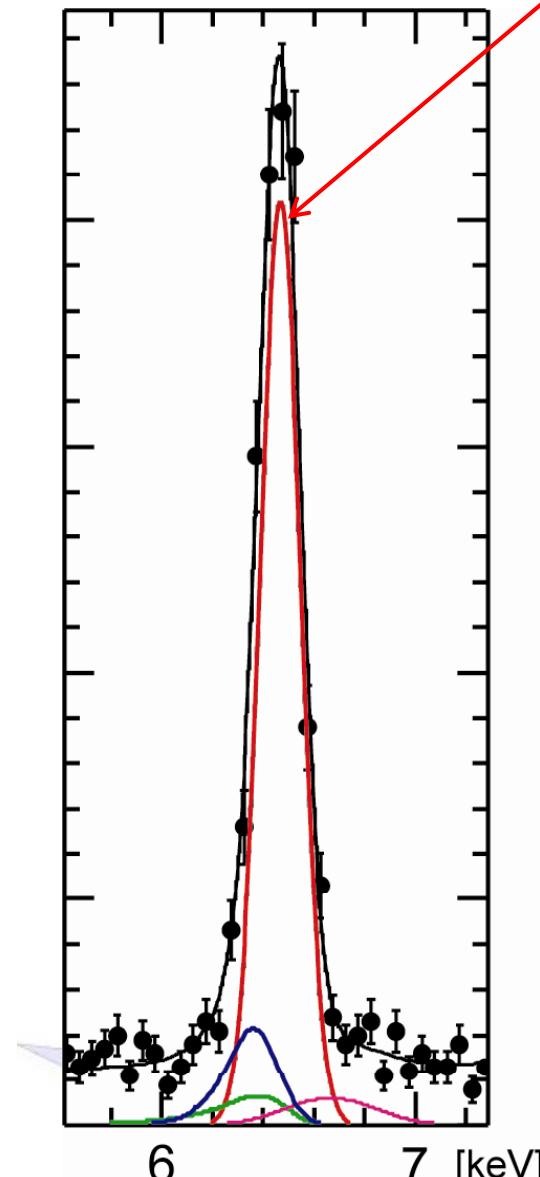
Stopped-K⁻ triggered events

- Fiducial volume cut
- Stopped-K⁻ selection
- SDD timing cut



Channel to Energy Conversion

Spectrum analysis



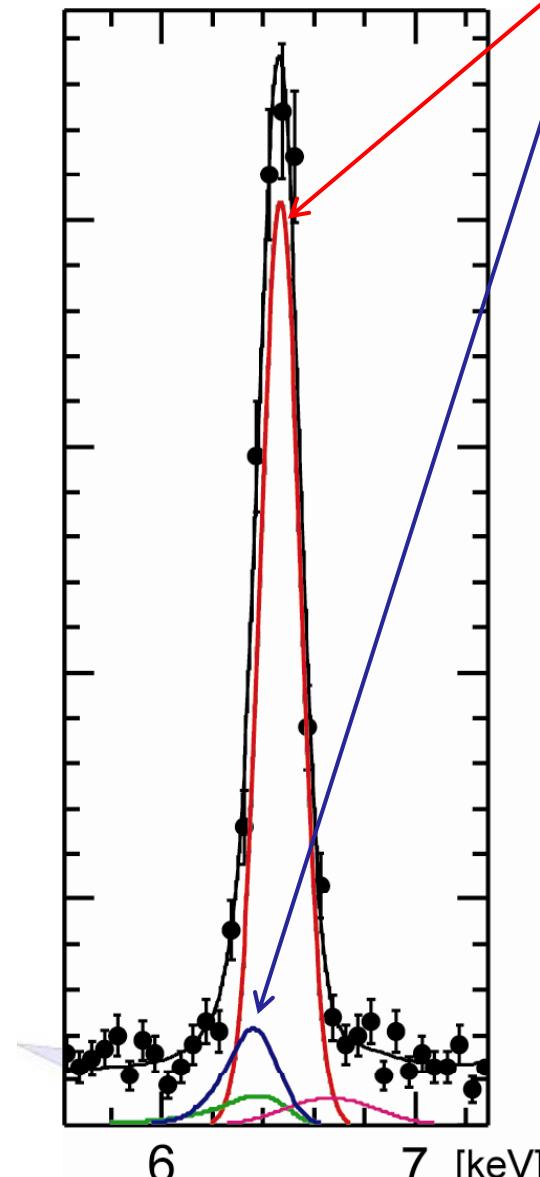
Main peak

Voigt function

Convolution of the Gaussian and Lorentzian

H. Bhang, P. Buehler, M. Cargnelli, J. Chiba,
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Precision spectroscopy of kaonic Helium-3 $3d \rightarrow 2p$ X-rays
J-PARC E17 Experiment



Main peak

Voigt function

Response of SDD

Shelf + Tail function

Shelf function :

Convolution of the Gaussian and Step function

Tail function :

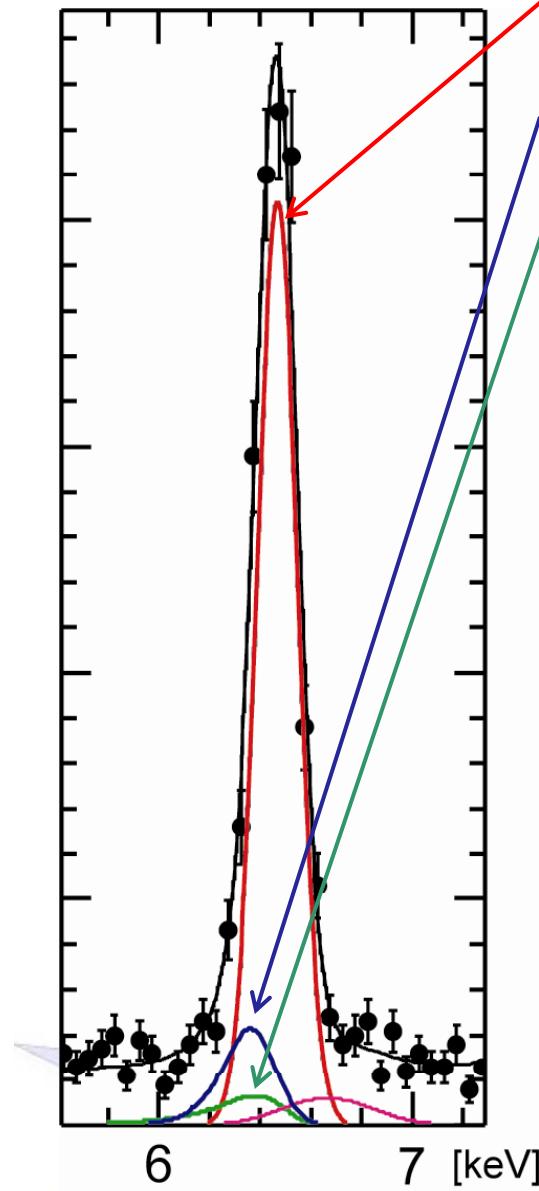
Convolution of the Gaussian and Exponential



The parameters were estimated

High statistical spectral fitting
(Self-triggered events)

Spectrum analysis



Main peak

Response of SDD

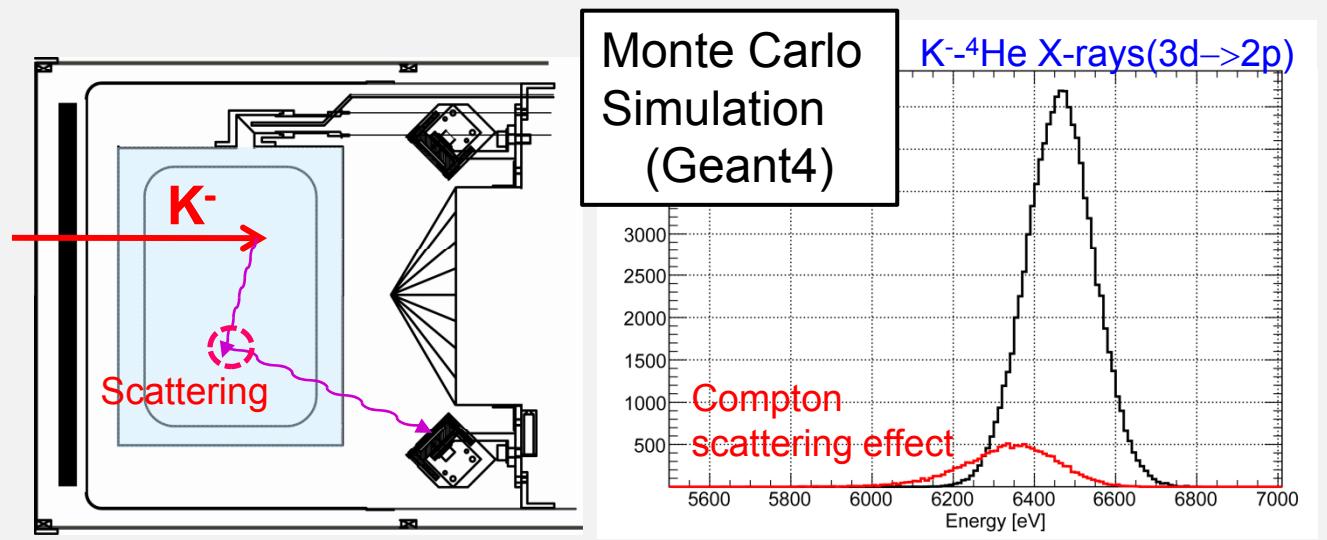
Compton scattering

Voigt function

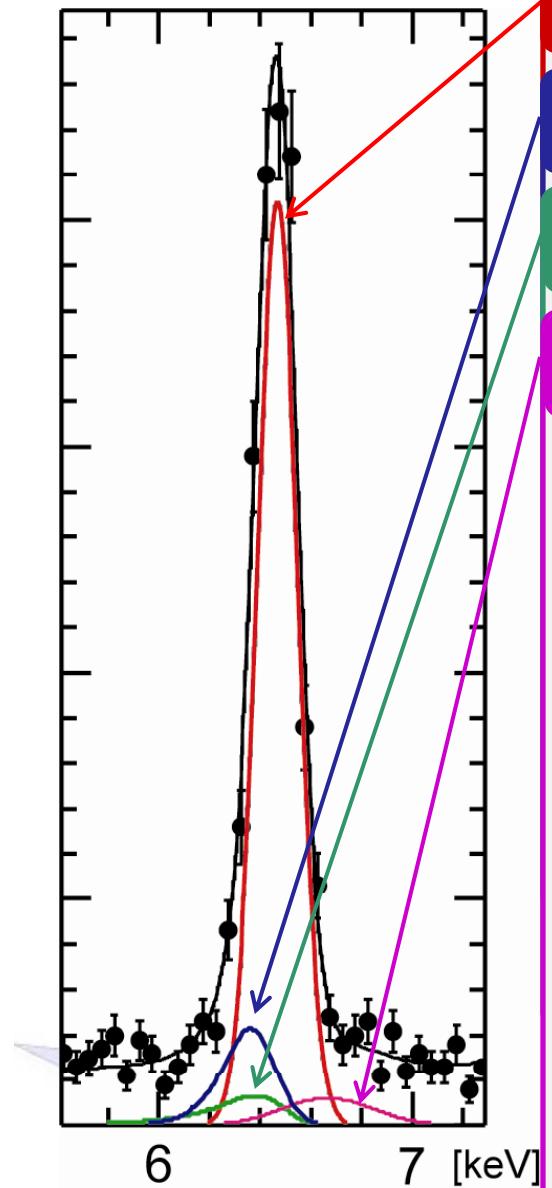
Shelf + Tail function

Tail function

The parameters were estimated by
fitting the simulated spectrum



Spectrum analysis



Main peak

Response of SDD

Compton scattering

Pileup effect

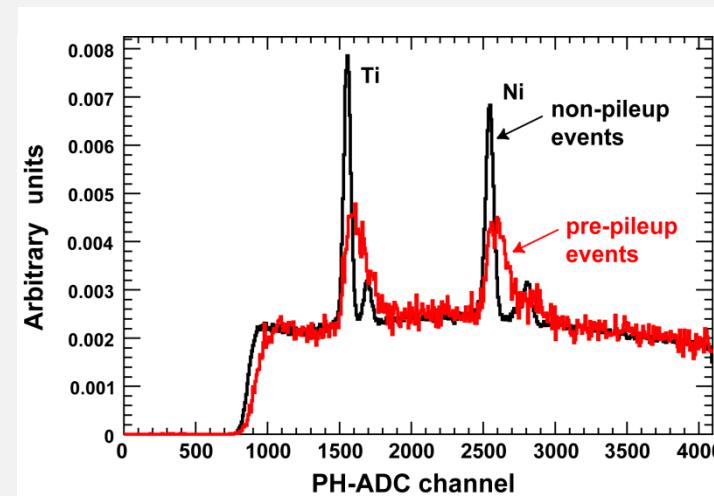
Voigt function

Shelf + Tail function

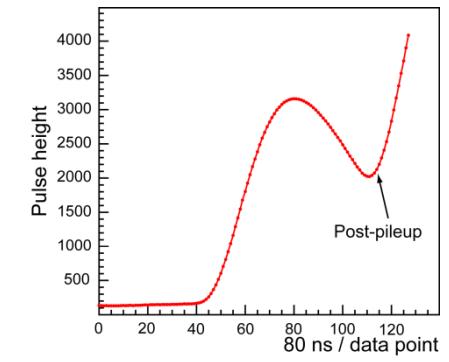
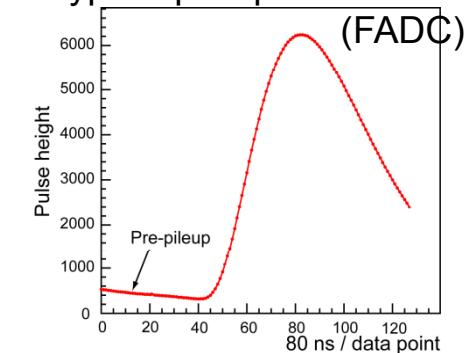
Tail function

Gaussian

The parameters were estimated by FADC data



Typical pileup waveforms



Response function

Intensity ratios of the shelf and tail components to main-peak :

► Fitting by the high-statistic spectra for self-triggered events

► Consideration of the energy dependence of the detector resolution

$$\Delta E(FWHM) = 2.35\omega\sqrt{W_N^2 + FE/\omega}$$

ω : average energy for electron-hole creation (3.81 eV)

W_N : Contribution noise to resolution

F: Fano factor (~0.12 for Si), E: X-ray energy



$\sim \pm 1$ eV

Compton scattering

LECS(Low Energy Compton Scattering) package

► The error of the total compton scattering cross section was few percent

$\pm 5\%$ (Intensity fluctuation) =

$\sim \pm 0.4$ eV

Pileup effect

► The error of intensity ratio was plus or minus 10 percent from the error of pileup events identification by the FADC analysis

$\pm 10\%$ (Intensity fluctuation) =

$\sim \pm 0.4$ eV

Derivation of the 2p level strong interaction shift



3d → 2p transition energy : **6467±3 (stat)±2 (sys) eV**

Transition	E570 measurements	EM calculation
3d → 2p	6467.0±2.5 (stat)	6463.5
4d → 2p	8723.5±4.5 (stat)	8721.7
5d → 2p	9761.4±7.6 (stat)	9766.8

The strong interaction shift of 3d, 4d and 5d levels were negligibly small



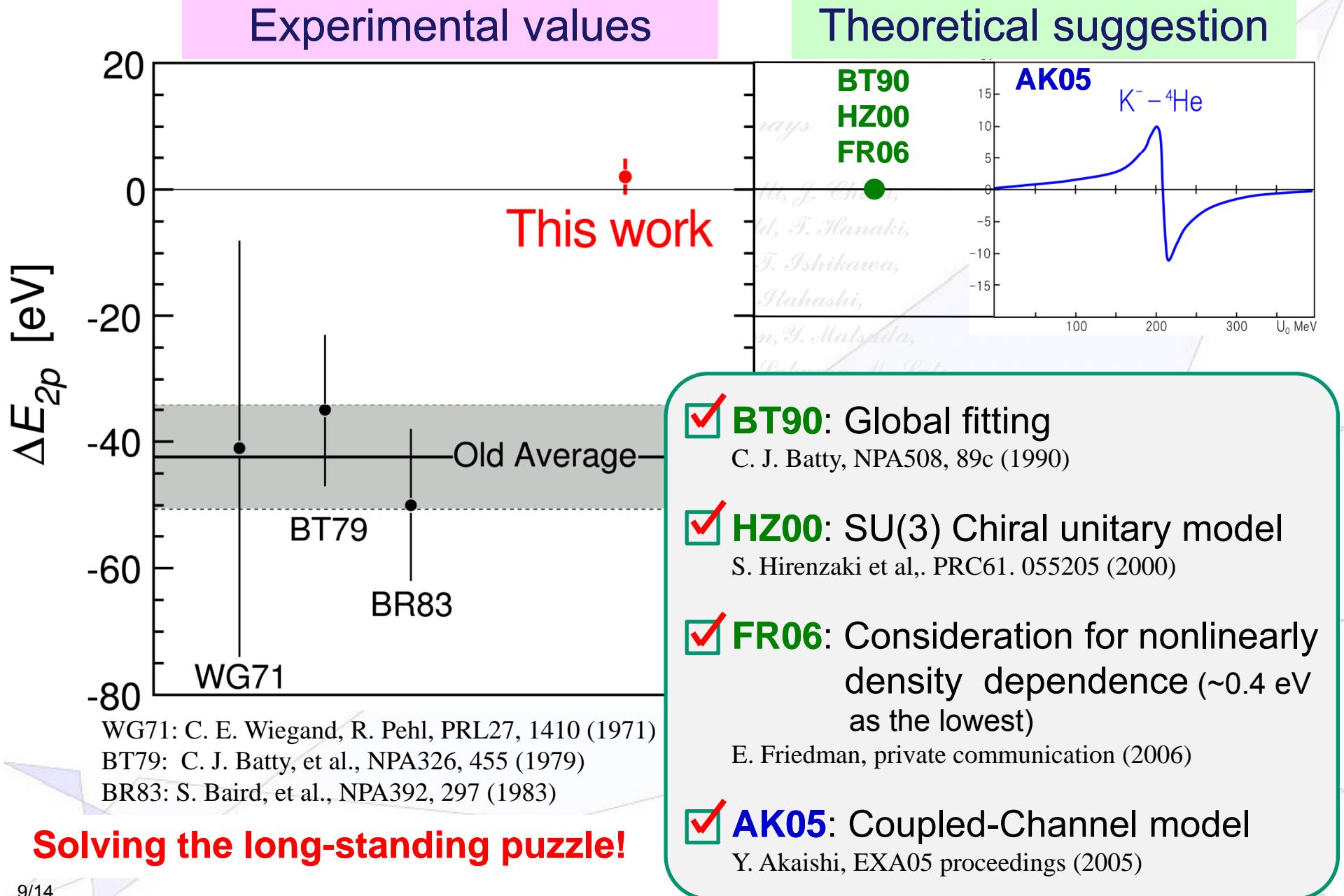
$$\Delta E_{2p} = (E_{(n,d)} - E_{(2,d)}) - (E_{(n,d)}^{EM} - E_{(2,d)}^{EM})$$

EM calculation (T. Koike)

- Vacuum polarization
- Nuclear finite size effect
- Relativistic recoil effect
- Electron screening effect
- Totally corrected energy levels

2p level strong interaction shift : **2±2 (stat)±2 (sys) eV**

Comparison with the past experiments and theoretical suggestion





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Precision measurement of the $3d \rightarrow 2p$ x-ray energy in kaonic ^4He

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Precise measurement of kaonic helium atoms X-rays



4. Motivation for J-PARC E17

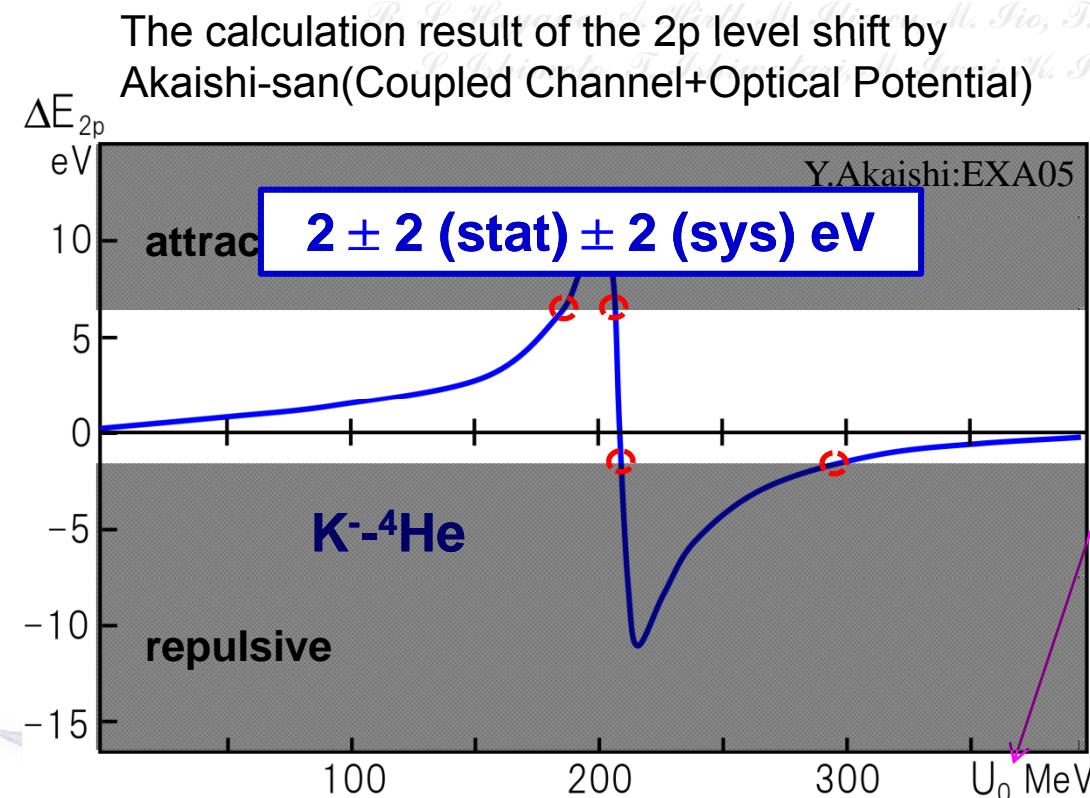


Motivation for x-rays measurement of kaonic-³He

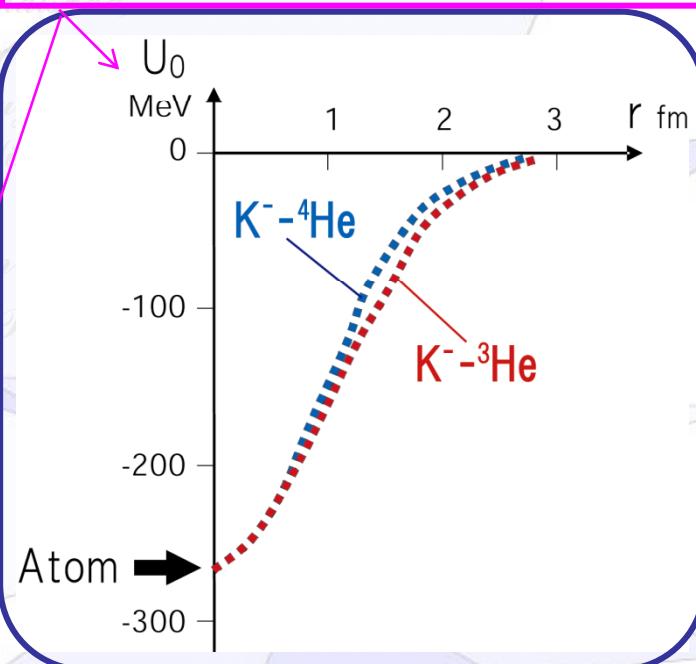
Deeply-bound kaonic nuclei predicted by Akaishi-Yamazaki

↗ Direct search for the kaonic nucleus (K^-pp) → J-PARC E15 Exp.

Measurement of the strong interaction shift of kaonic-³He atoms will provide the important information about the existence



U_0 : Real part of the K^-He strong interaction potential

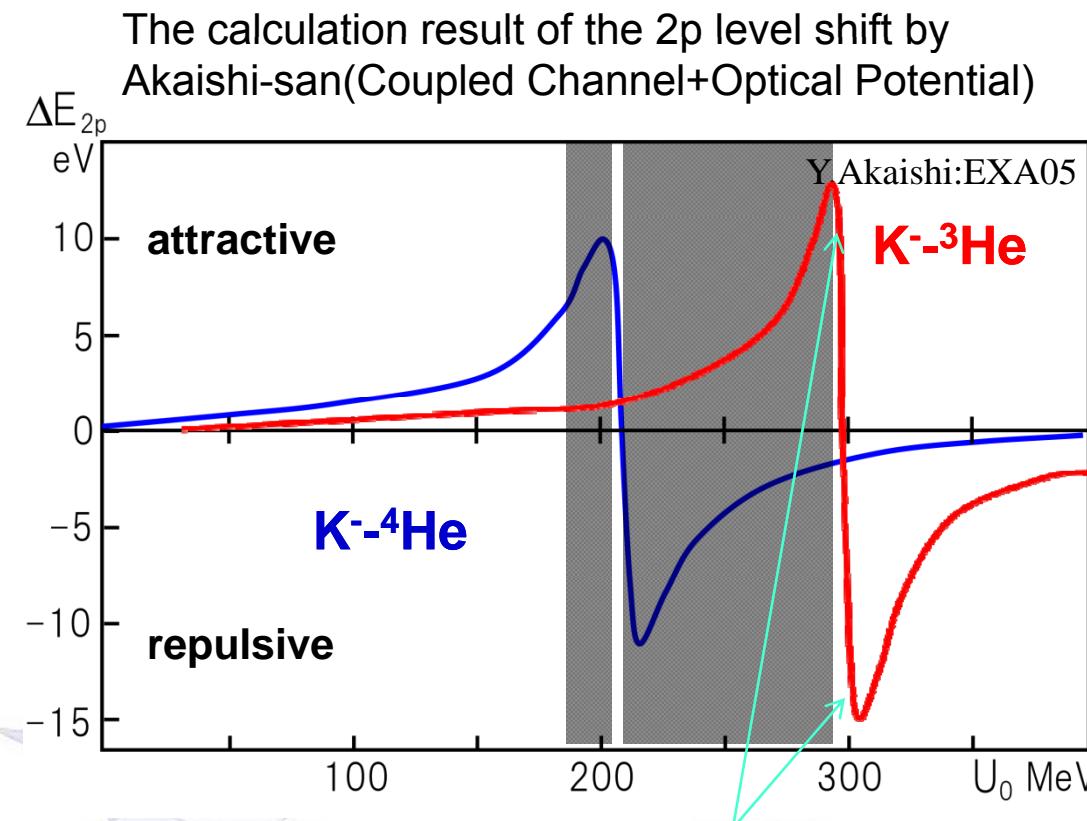


Motivation for x-rays measurement of kaonic- ^3He

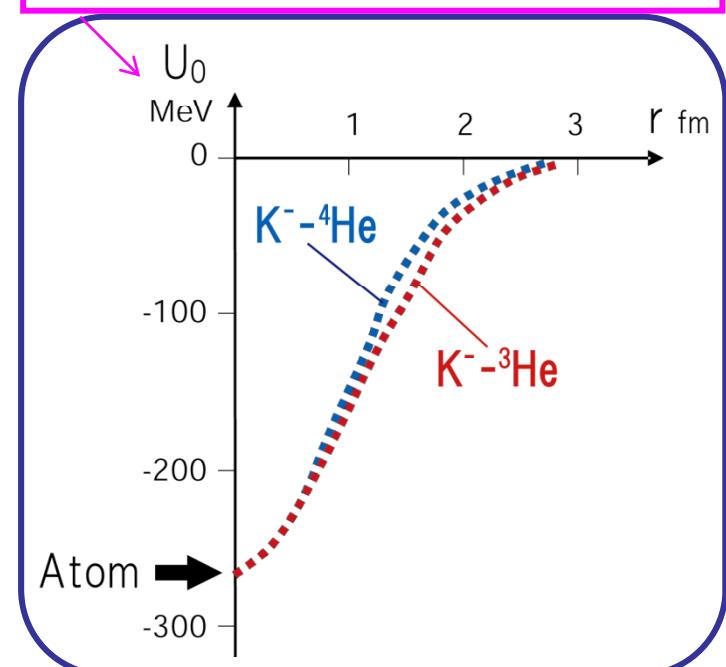
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Measurement of the strong interaction shift of kaonic- ^3He atoms will provide the important information about the existence



U_0 : Real part of the K^-He strong interaction potential



Deep potential : Large shift ($\sim \pm 10$ eV) will be observed?

Precise measurement of kaonic helium atoms X-rays

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5. Plan of the experiment

Precision spectroscopy of Kaonic Helium-3 $3d \rightarrow 2p$ X-rays

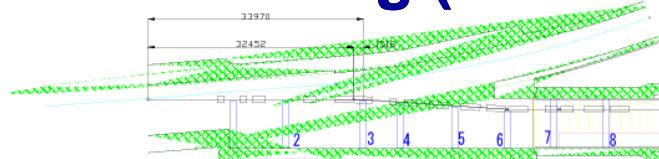
J-PARC E17 Experiment

J-PARC K1.8BR beam line

*K&K-PS E570 Experiment
Precision spectroscopy of Kaonic Helium $3d \rightarrow 2p$ X-rays*

J-PARC Hadron Facilities

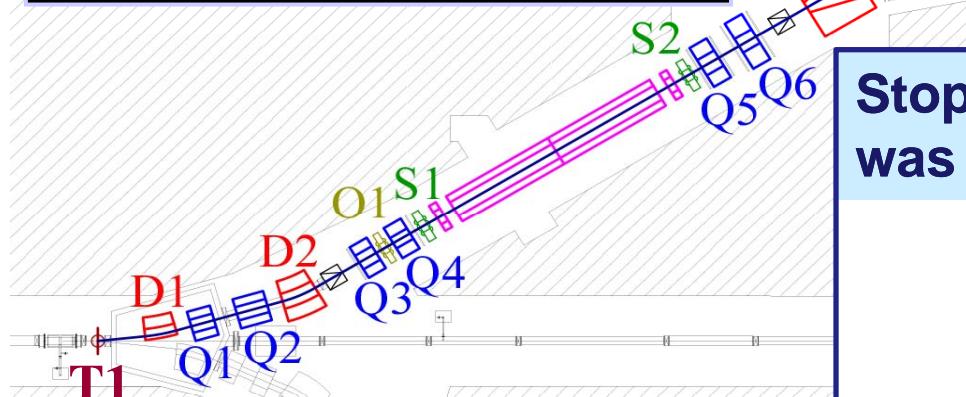
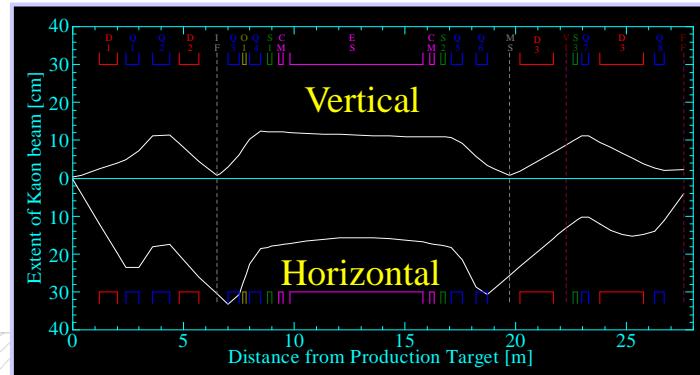
Main Ring (50 GeV)



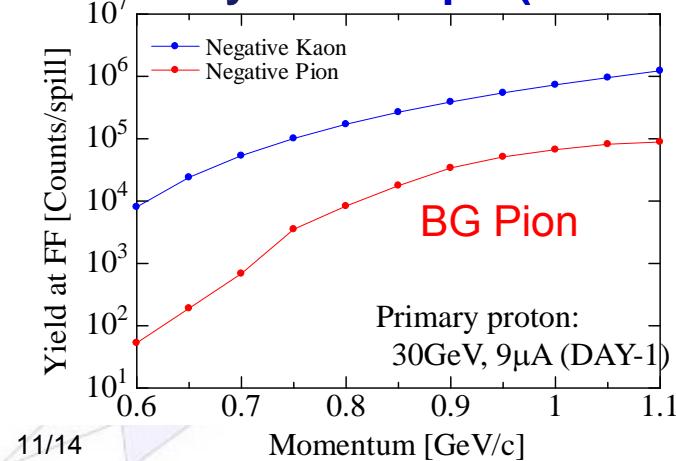
Switch Yard



J-PARC K1.8BR beam line



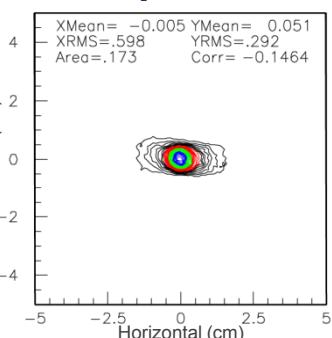
K⁻ intensity : 1.2 M /spill (1.1GeV/c)



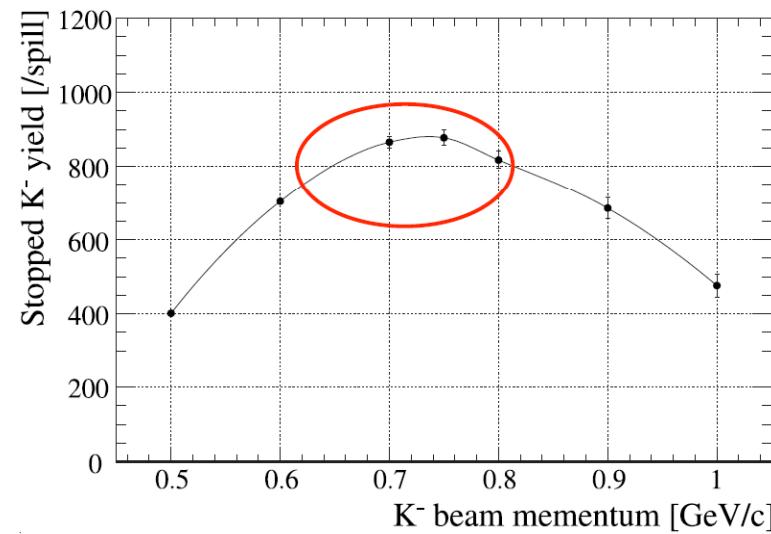
11/14

Max Momentum	1.1 GeV/c
Beam line length	27.573 m
Acceptance	2.6 msr·%
Horizontal extent @FF (rms)	6.0 mm
Vertical extent @FF (rms)	2.9 mm

Beam profile@FF



Stopped K⁻ yield in the liq.3He target was estimated by simulation



Momentum choice: 750 MeV/c

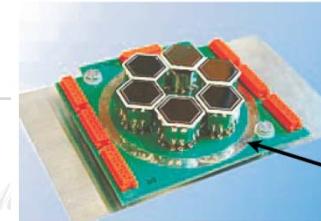
Beam time request: 3.5 days(DAY-1 full intensity)

Experimental apparatus

Method same as E570

Silicon Drift Detector (SDD) :

New SSD packages will be used for accumulation rate increase

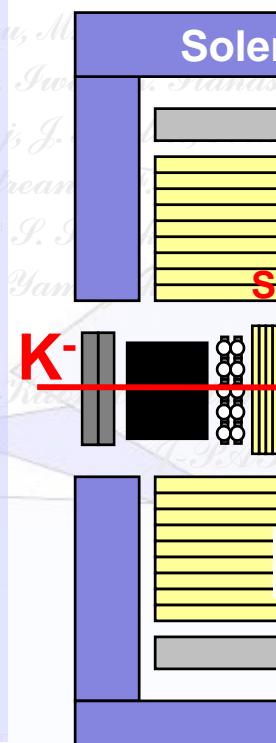


KETEK VITUS
SDD array

K⁻ stopping point measurement :

Beam line chamber is developed

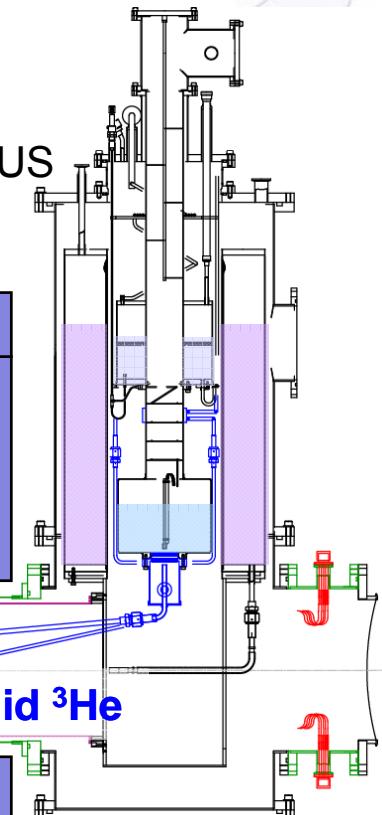
Cylindrical detector system is produced now for the J-PARC E15 experiment. We are going to use it (magnetic field is not applied)



In-situ energy calibration :

using characteristic X-rays from titanium and nickel foils

J-PARC E17 setup



^3He targets are developed for the E15 experiment
This is my work !

Liquid ^3He Target for E15



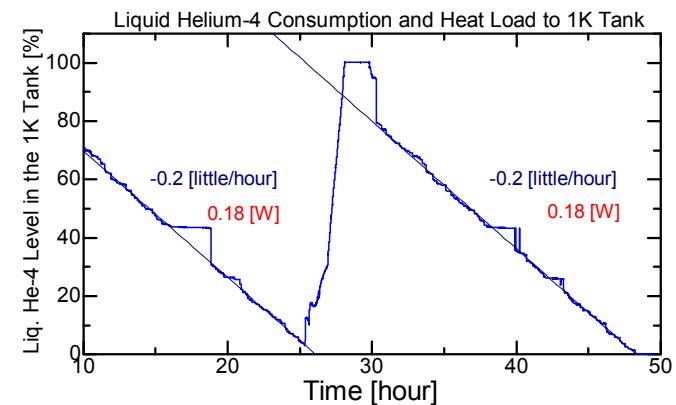
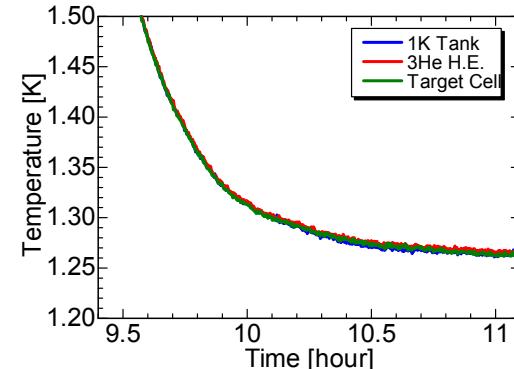
^3He liquefied system is completed by the end of **this year**



The x-ray detection device will be installed in the target **next year**

E17 will start in January, 2009
(First experiment? @J-PARC)

Cooling test with ^4He gas



Temperature of the Target Cell	1.25 K
Temperature of the 1K Tank	1.24 K
Pressure in the 1K Tank	1.2 Torr
Liq. ^4He Consumption	45 L/day
Heat Load of the 1K Tank	0.18 W

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6. Summary

Precision spectroscopy of Kaonic Helium-3 $3d \rightarrow 2p$ X-rays

J-PARC E17 Experiment

- Kaonic- ^4He Balmer-series x-rays were measured with a precision of ~ 2 eV (statistical) at KEK-PS K5 beam line.
- The kaonic- ^4He atoms x-ray energy of the $3d \rightarrow 2p$ transition was determined to be $6467 \pm 3(\text{stat}) \pm 2(\text{syst})$ eV.
- 2p level strong interaction shift was deduced as $\Delta E_{2p} = 2 \pm 2$ (stat) ± 2 (sys) eV.
- Precise measurement of kaonic- ^3He x-rays (J-PARC E17) is planned at J-PARC K1.8BR beam line.
- At present, some devices for the experiment is developed.
- E17 experiment will start in January, 2009 at the earliest.

Precise measurement of kaonic helium atoms X-rays

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Thank you



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