KEK-PS E570 Experiment

Precision spectroscopy of Kaonic Helium 3d → 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 → 2p X-rays

J-PARC E17 Experiment

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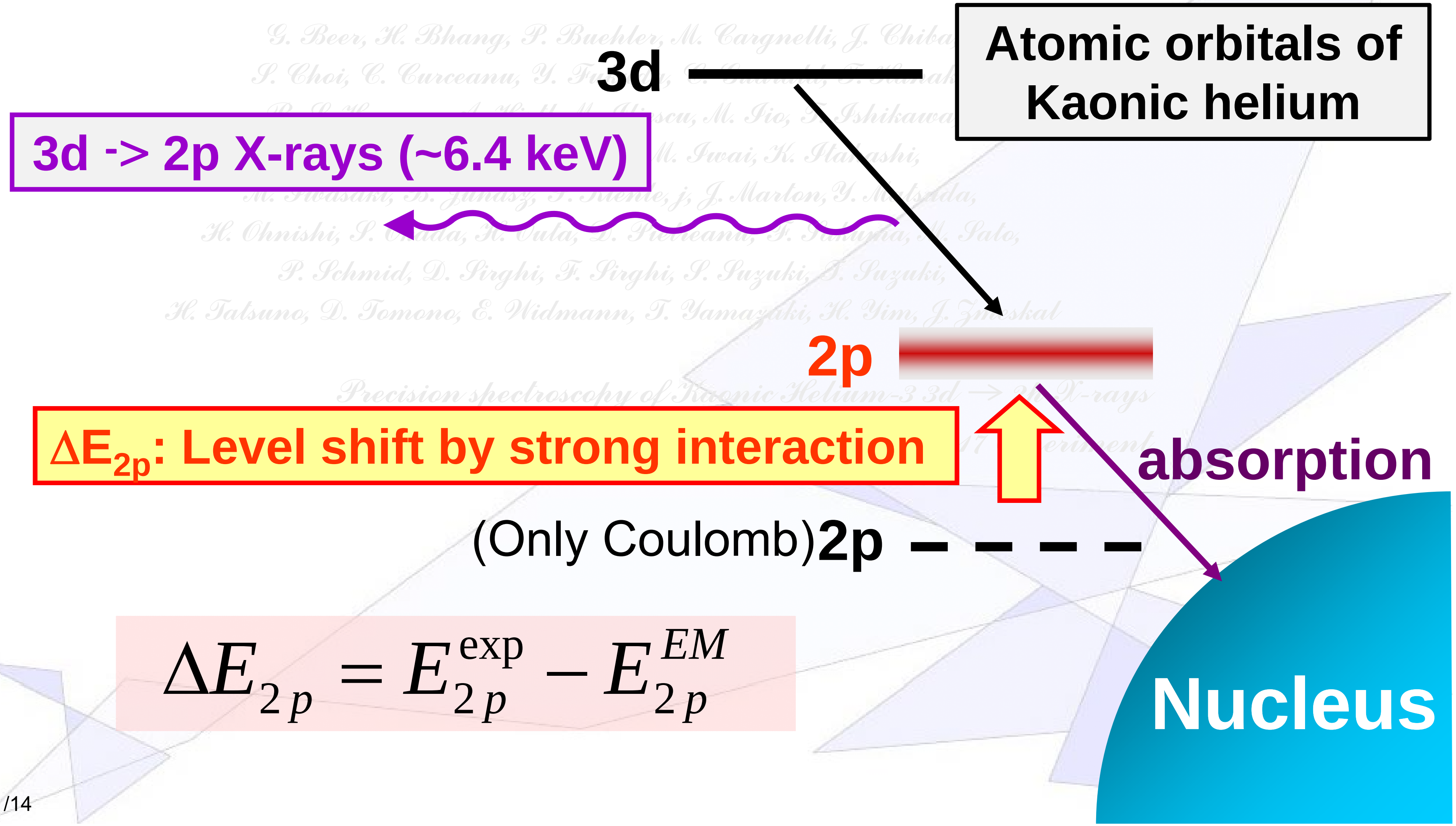
6. Summary

1. Introduction

Strong interaction shift of kaonic helium atoms

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



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

Kaoinc helium puzzle

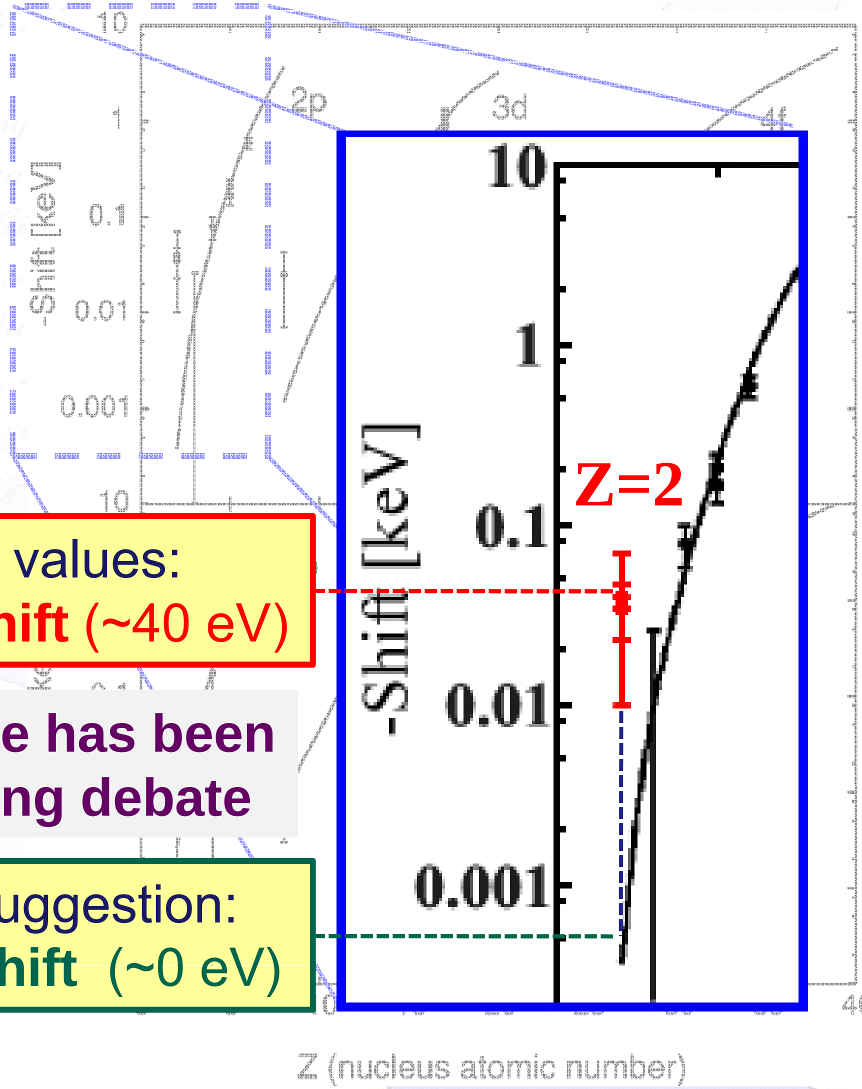
Past Measurements

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

We measured the kaonic-^{4}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)

S.Hirenzaki, Y.Okumura, H.Toki, E.Oset,and A.Ramos Phys. Rev. C 61 055205

2. E570 experiment

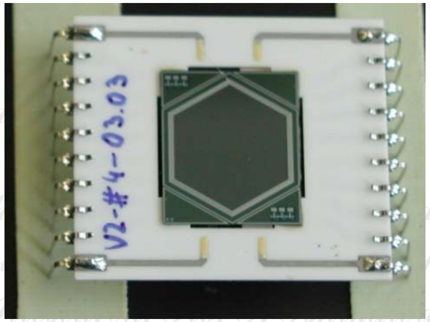
Experimental setup

- **Silicon Drift Detector (SDD) :**
  for high-resolution X-ray energy measurement

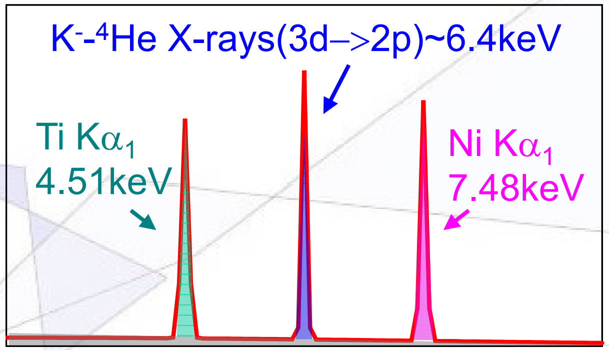
- **Fiducial volume cut :**
  for kaons stopping point measurement with drift chambers for
  - Incident Kaons
  - Secondary charged particles

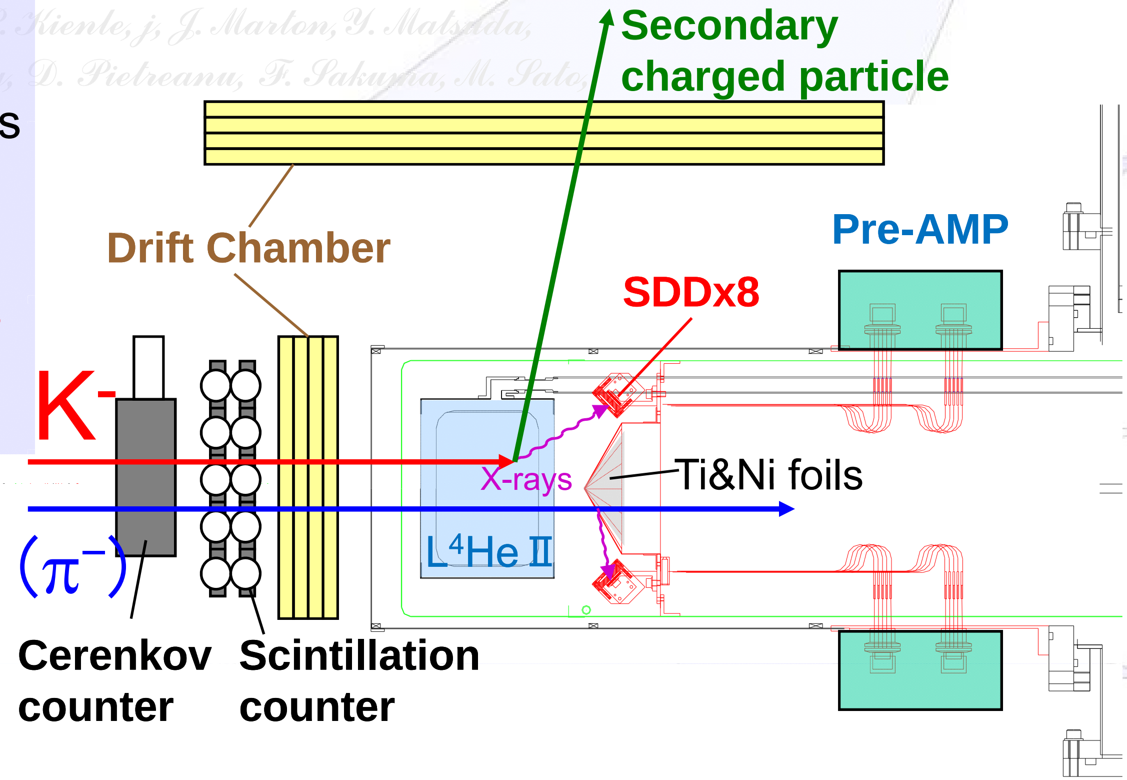
- **In-situ energy calibration :**
  using characteristic X-rays from titanium and nickel foils

Effective area: 100mm^2



KETEK SDD

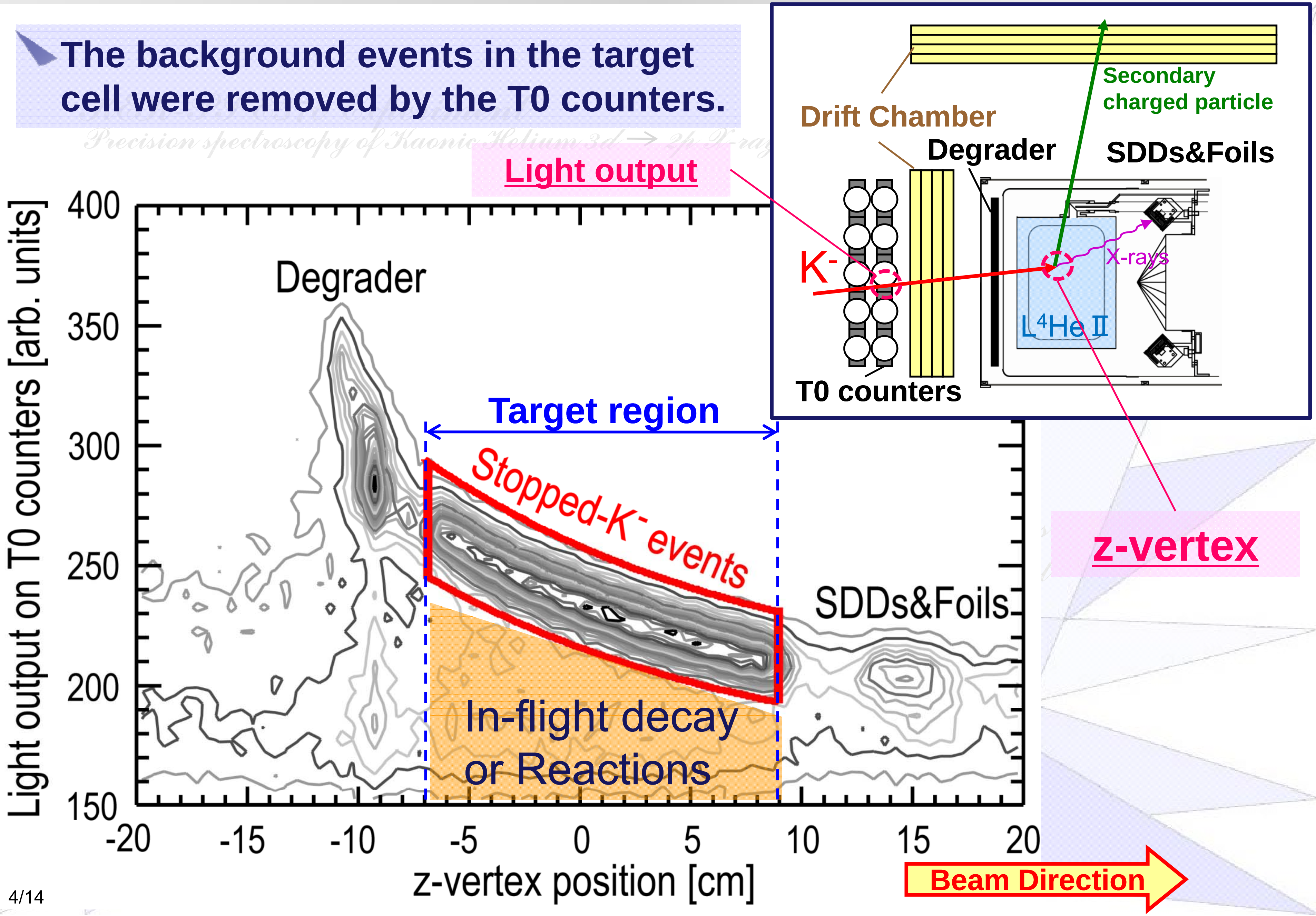




3. Result

Stopped-K$^-$ selection

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



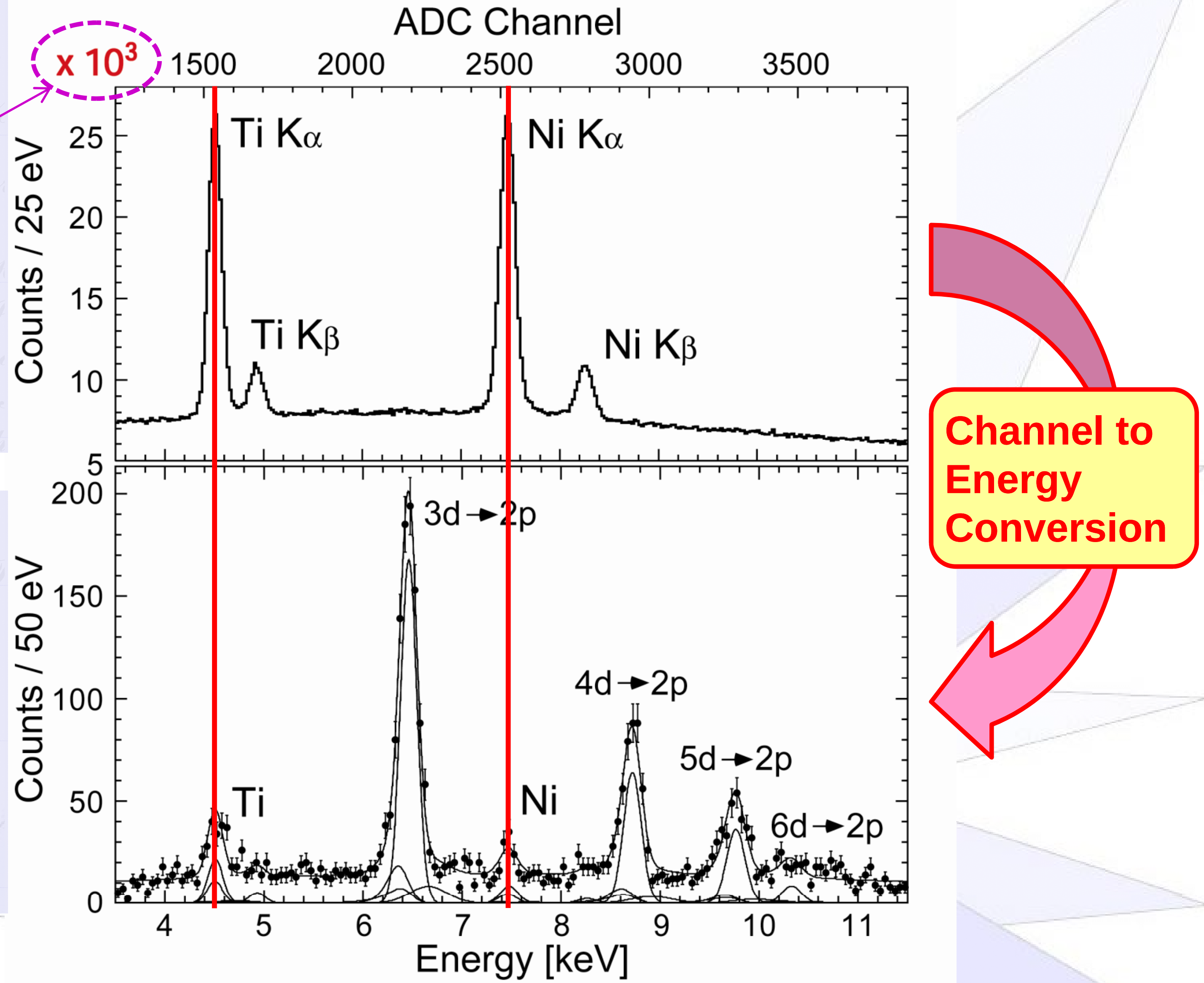
Energy calibration

SDD self-triggered events

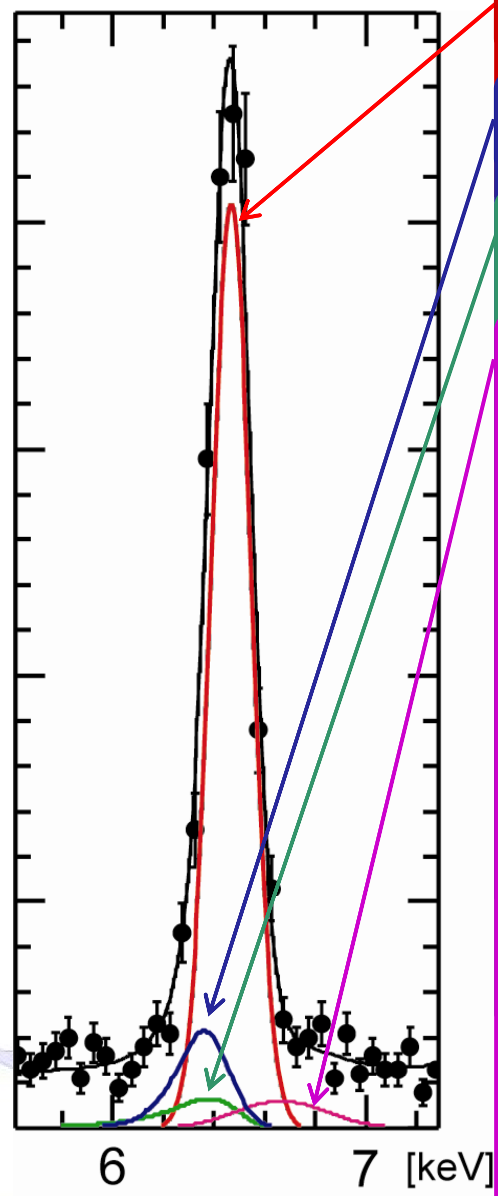
High statistical characteristic X-ray peaks of Ti & Ni

Stopped-K$^-$ triggered events

- Fiducial volume cut
- Stopped-K$^-$ selection
- SDD timing cut

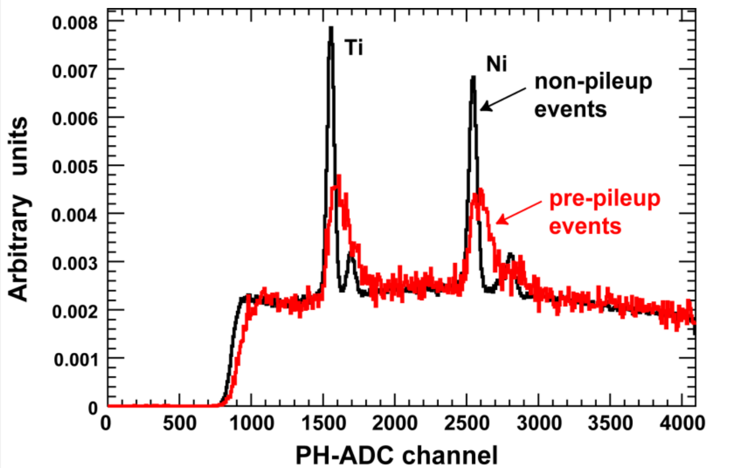


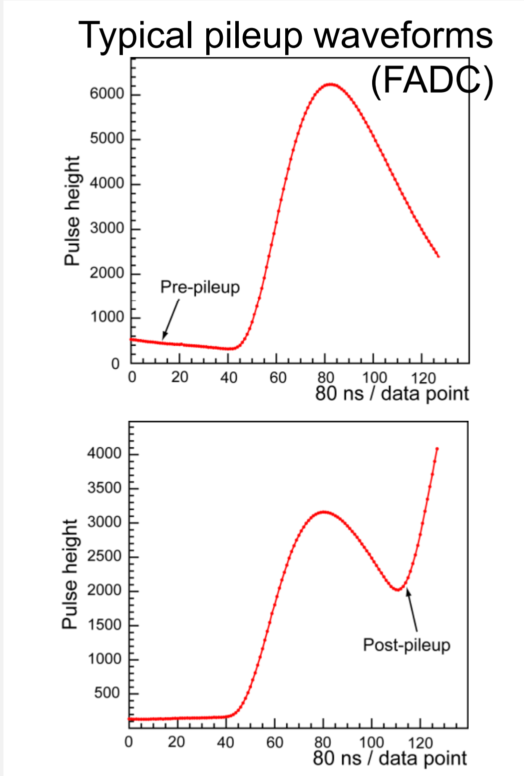
Spectrum analysis



Main peak	Voigt function
Response of SDD	Shelf + Tail function
Compton scattering	Tail function
Pileup effect	Gaussian

The parameters were estimated by FADC data





Systematic error

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

→ ~ ±1 eV

Compton scattering

LECS(Low Energy Compton Scattering) package

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

±5 % (Intensity fluctuation) = ~ ±0.4 eV

Pileup effect

- **The error of intensity ratio was plus or minus 10 percent from the error of pileup evens identification by the FADC analysis**

±10 % (Intensity fluctuation) = ~ ±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

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

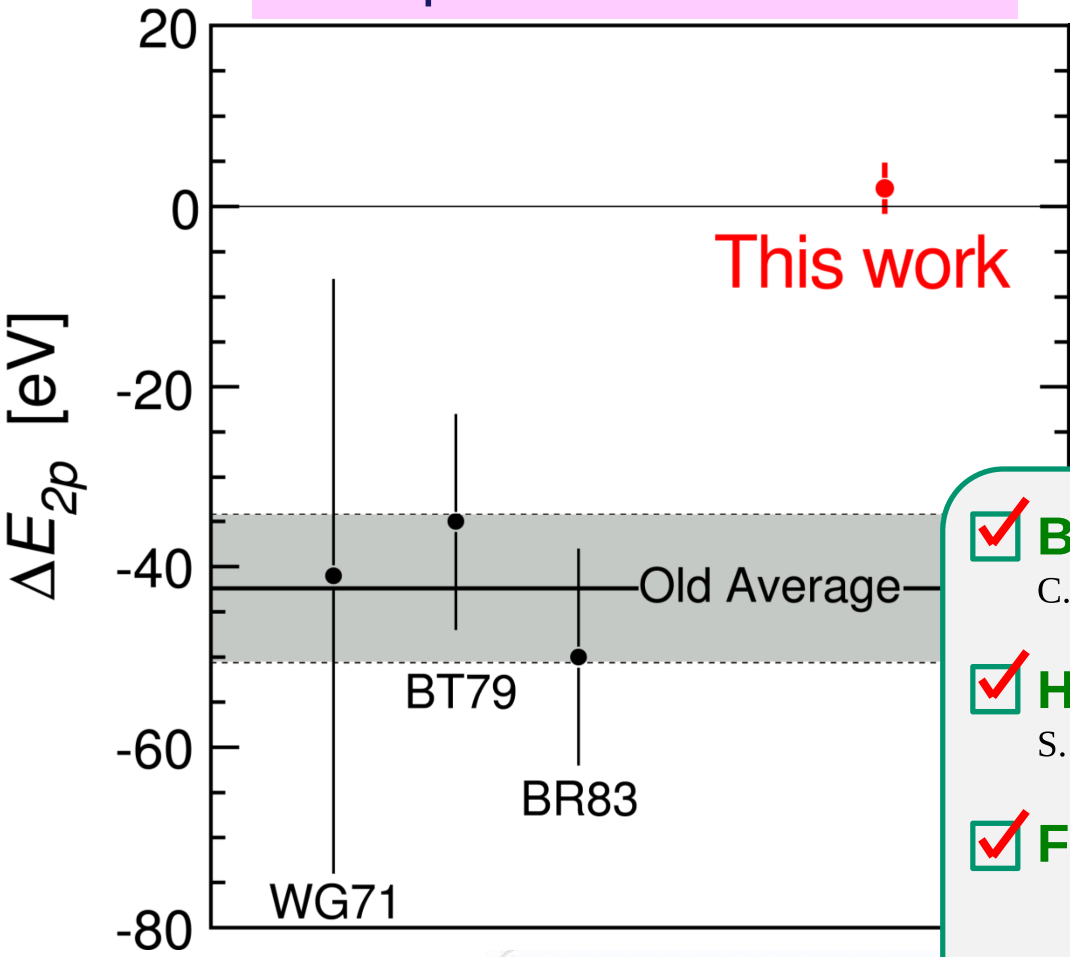
EM calculation **(T. Koike)**

- 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

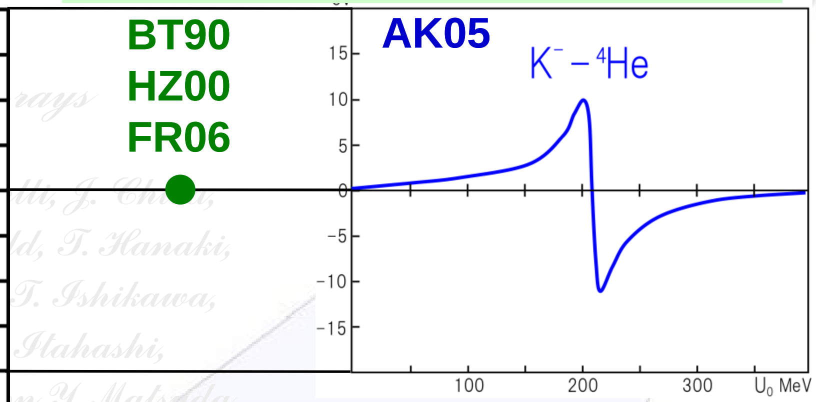
Experimental values



WG71: C. E. Wiegand, R. Pehl, PRL27, 1410 (1971)
BT79: C. J. Batty, et al., NPA326, 455 (1979)
BR83: S. Baird, et al., NPA392, 297 (1983)

Solving the long-standing puzzle!

Theoretical suggestion



- ☑ **BT90**: Global fitting
  C. J. Batty, NPA508, 89c (1990)
- ☑ **HZ00**: SU(3) Chiral unitary model
  S. Hirenzaki et al,. PRC61. 055205 (2000)
- ☑ **FR06**: Consideration for nonlinearly density dependence (~0.4 eV as the lowest)
  E. Friedman, private communication (2006)
- ☑ **AK05**: Coupled-Channel model
  Y. Akaishi, EXA05 proceedings (2005)

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Precision measurement of the 3d → 2p x-ray energy in kaonic ^{4}He

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4. Motivation for J-PARC E17

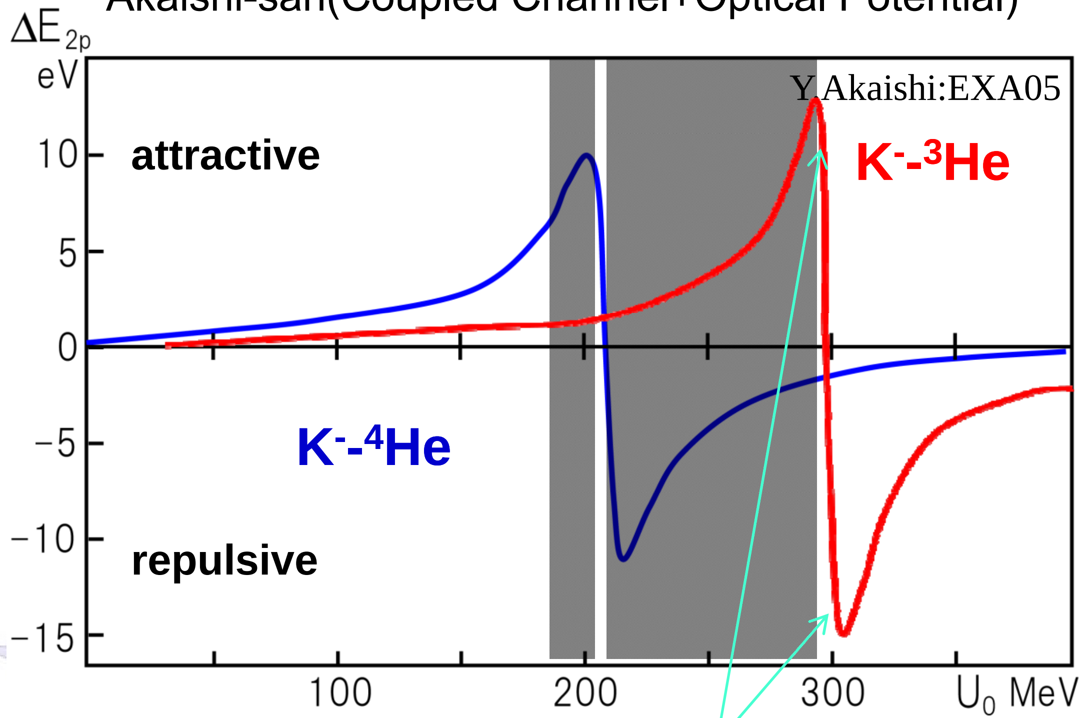
Motivation for x-rays measurement of kaonic-^{3}He

Deeply-bound kaonic nuclei predicted by Akaishi-Yamazaki

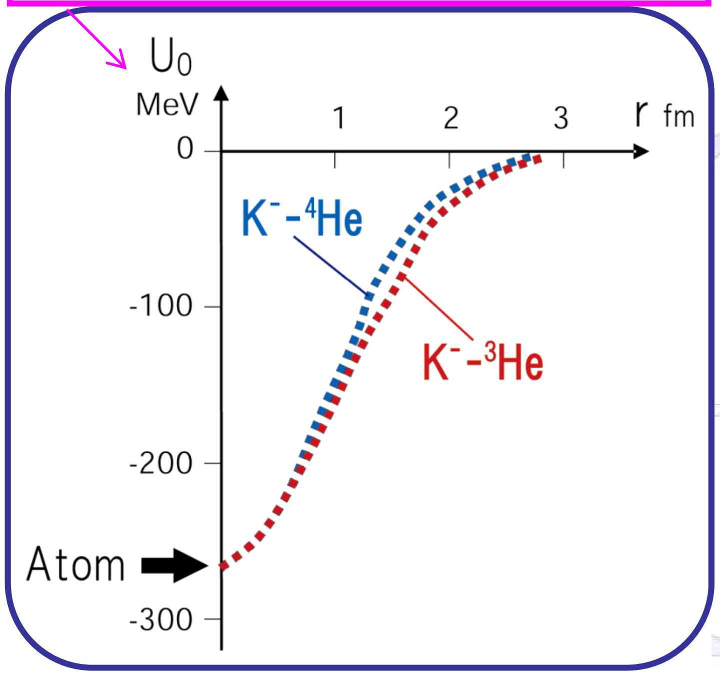
Direct search for the kaonic nucleus ($K^{-}pp$) ⟶ J-PARC E15 Exp.

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

The calculation result of the 2p level shift by Akaishi-san(Coupled Channel+Optical Potential)



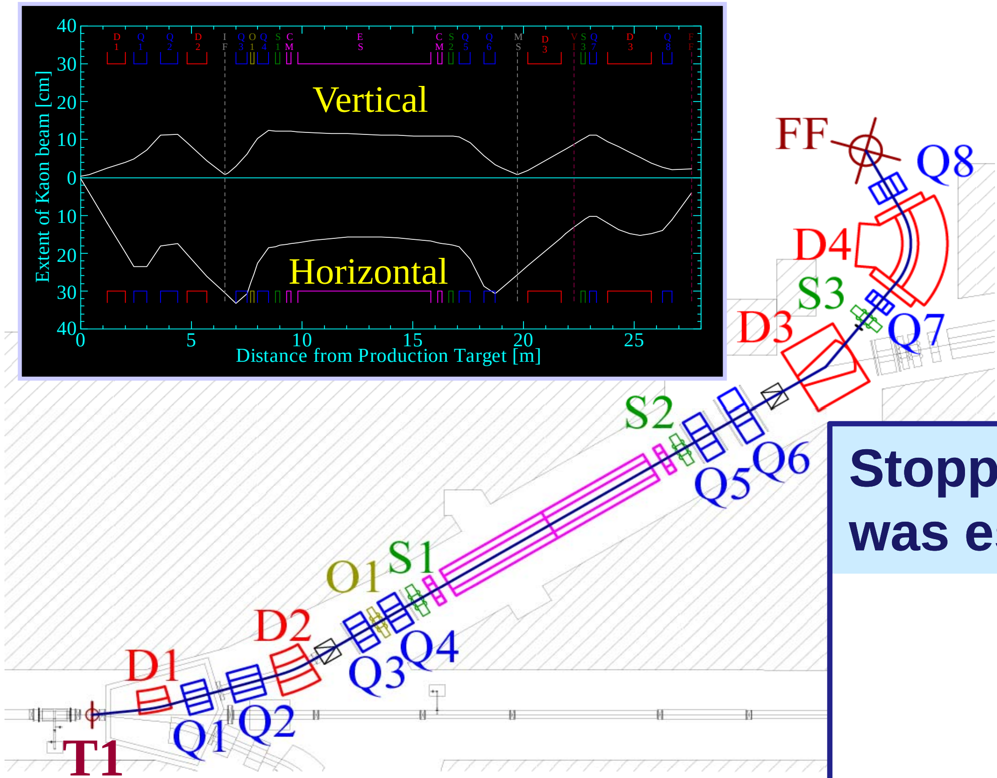
U_0: Real part of the K^{-}-He strong interaction potential



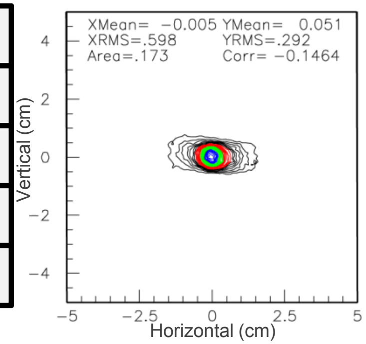
Deep potential : Large shift (~±10 eV) will be observed?

5. Plan of the experiment

J-PARC K1.8BR beam line

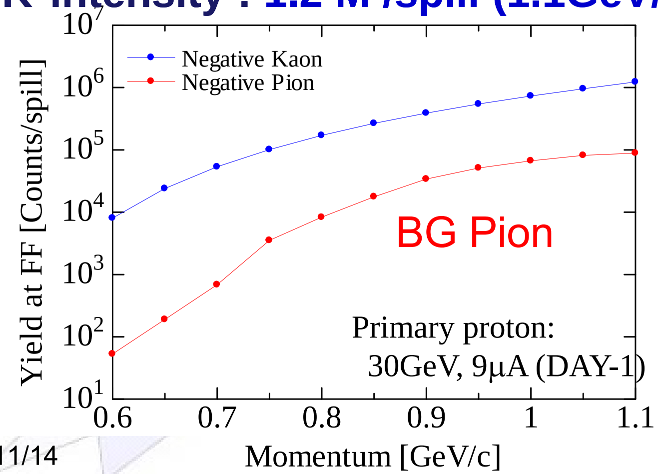


Beam profile@FF

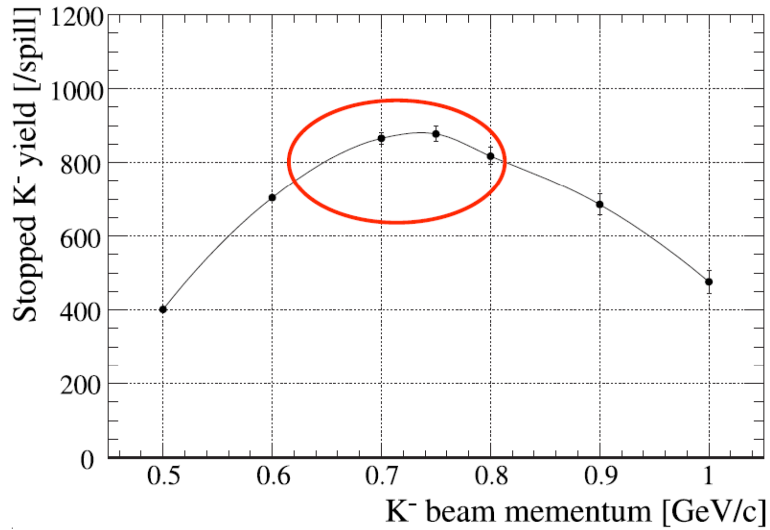


Max Momentum	1.1 GeV/c
Beam line length	27.573 m
Acceptance	2.6 msr·%
Horizontal extent @FF (rms)	6.0 mm
Vertical extent @FF (rms)	2.9 mm

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



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

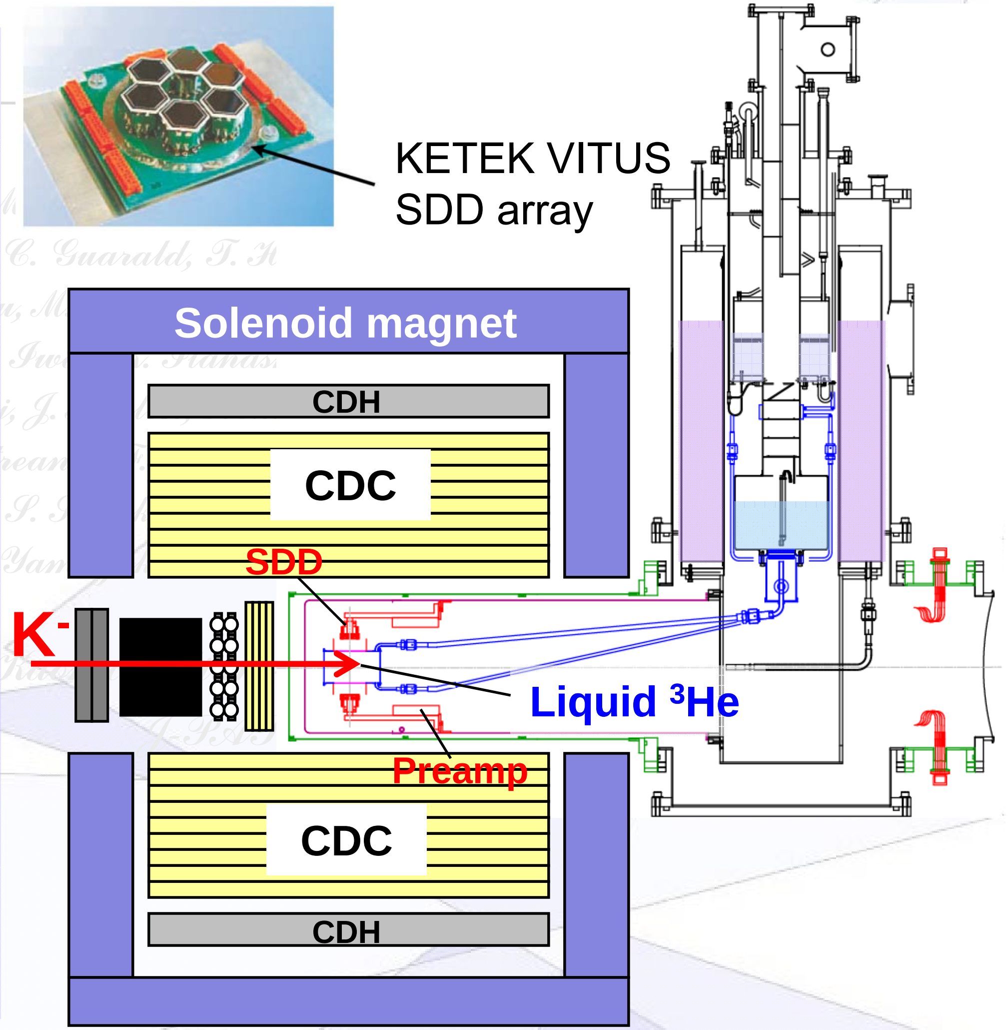
- **Silicon Drift Detector (SDD) :**
  New SDD packages will be used for accumulation rate increase

- **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



^{3}He 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**

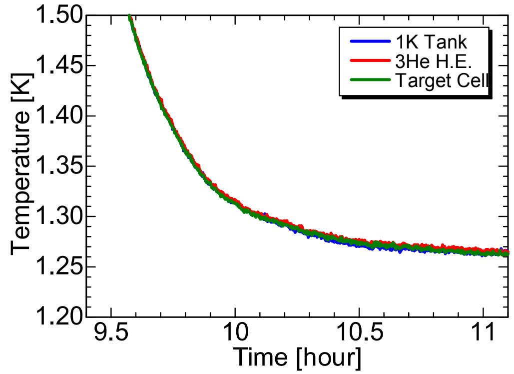
↓

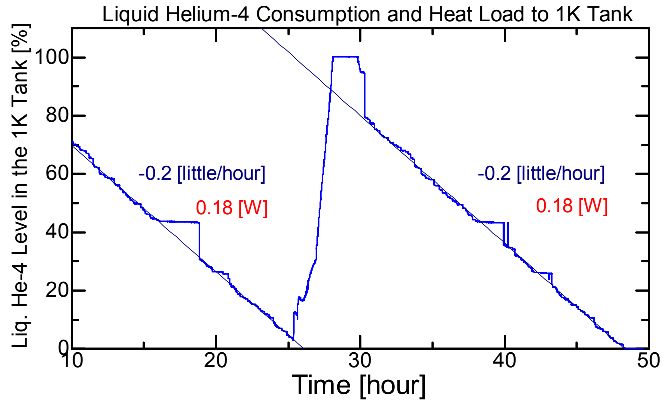
The x-ray detection device will be installed in the target **next year**

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

6. Summary

Summary

- Kaonic-^{4}He Balmer-series x-rays were measured with a precision of ~2 eV (statistical) at KEK-PS K5 beam line.
- The kaonic-^{4}He atoms x-ray energy of the 3d → 2p transition was determined to be 6467 ±3(stat)± 2(syst) eV.
- 2p level strong interaction shift was deduced as ΔE_{2p} = 2 ± 2 (stat) ± 2 (sys) eV.

- Precise measurement of kaonic-^{3}He 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

Thank you