Kaonic atom x-ray spectroscopy with superconducting microcalorimeters

1. Motivation
2. **T**ransition-**E**dge-**S**ensor microcalrimeters
3. Feasibility test at PSI
4. J-PARC experiment
5. Summary

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for the HEATES (J-PARC E62) collaboration

HEATES collaboration (J-PARC E62)

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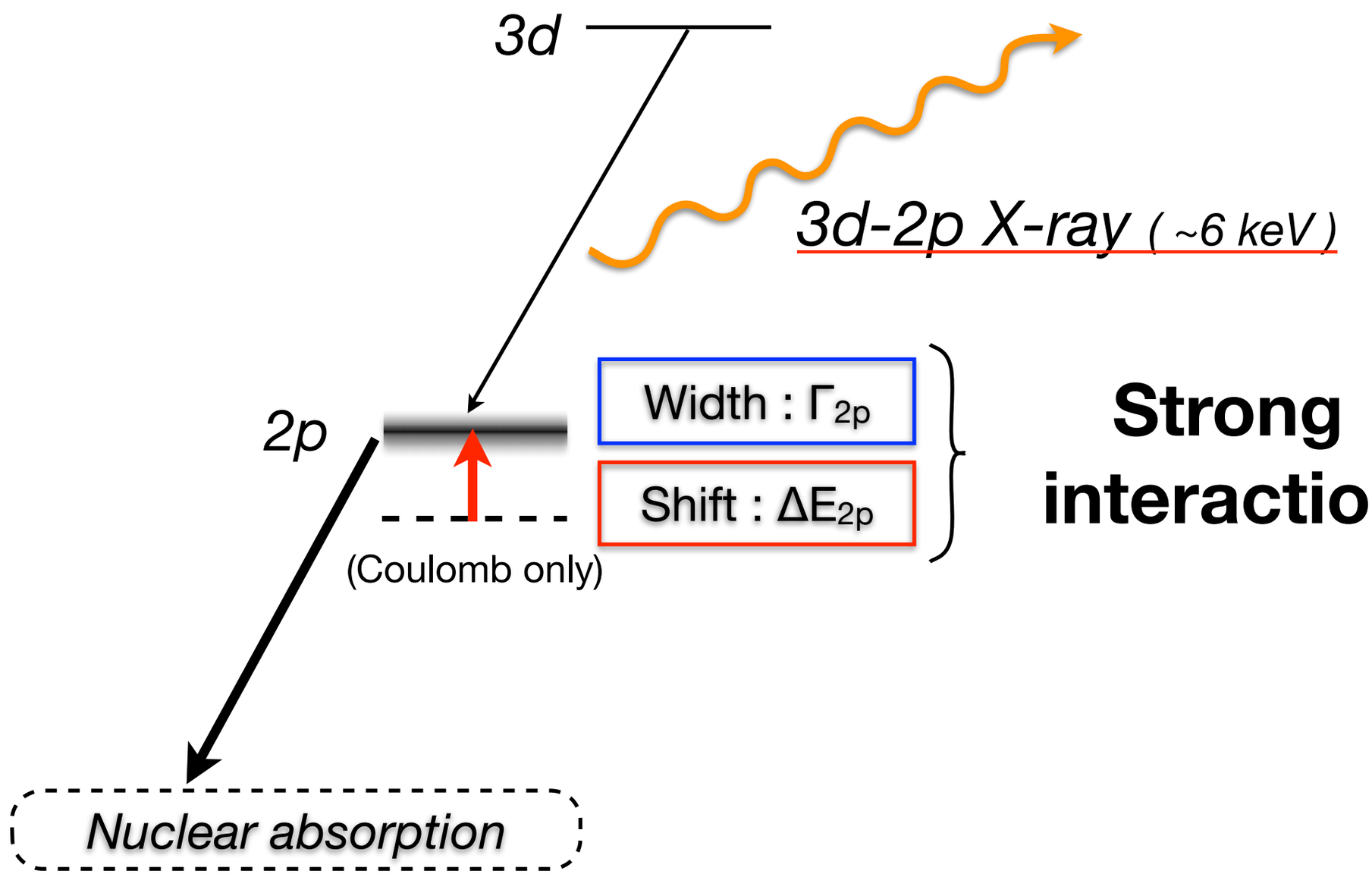
Kaonic atom X-rays

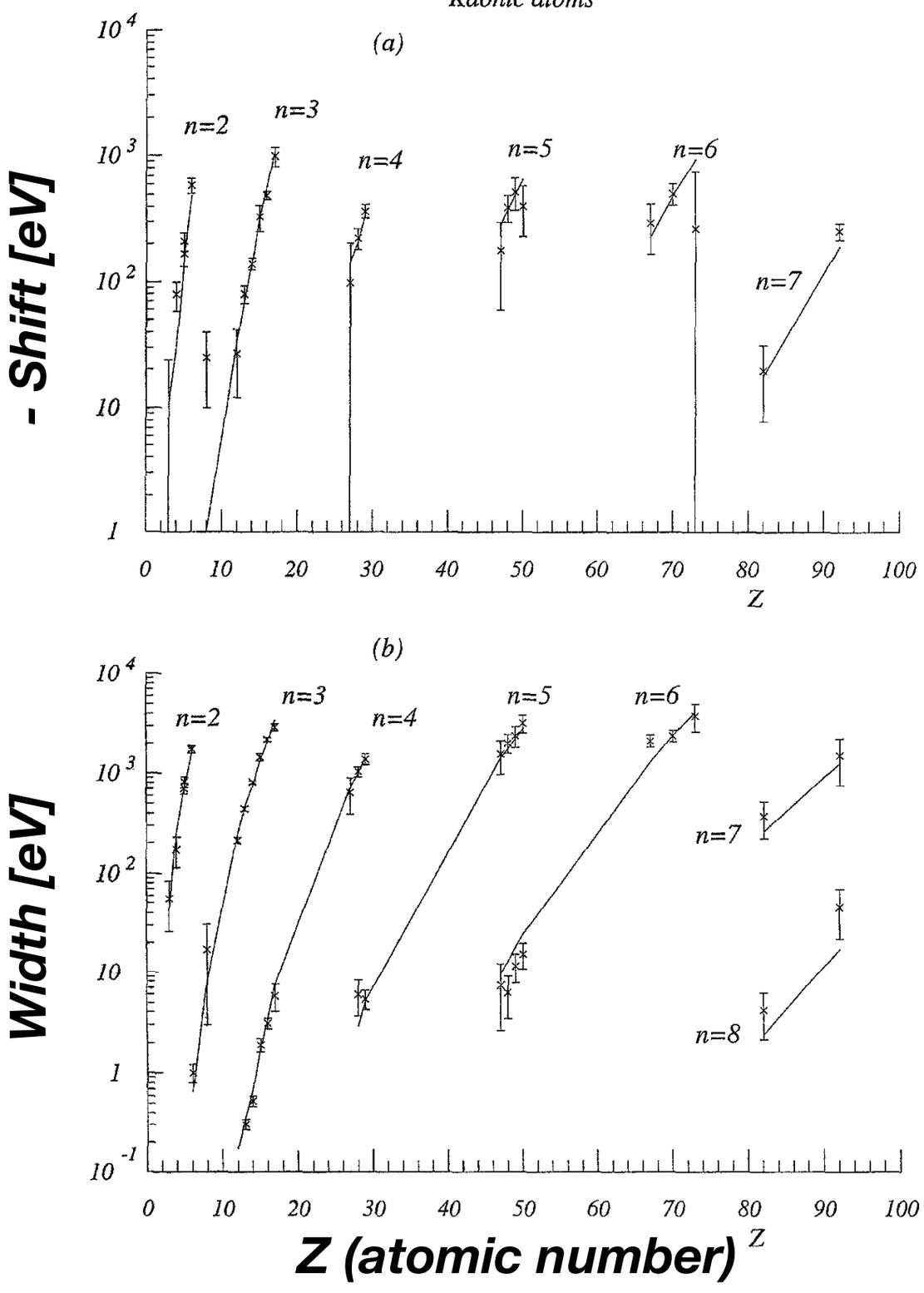
kaonic helium case



Unique probe of the K^{bar}-nucleus strong interaction at the threshold energy

K^{bar}-nucleus interaction from Kaonic atom data

C. J. Batty, E. Friedman, and A. Gal, Phys. Rep., 287 (1997) 385.



- **Data points exist across the periodic table**
  - K-p, K-d: $K^{bar}N$ scattering length
    talk by J. Zmeskal on Thursday
  - Z = 2(He) ~ 92(U)
    - measurements in 1970's & 80's
    - not so good quality…

- **Global analysis prefer a deep potential?**
  - Re V ~ 150~200 MeV
  - Phenomenological density dependence optical potential
    Phys. Rep., 287 (1997) 385.
  - Chiral potential (~50 MeV) *Ramos, Oset, NPA671(00)481* + phen. multi nucleon terms.
    E. Friedman and A. Gal, NPA 899(2013) 60.

K^{bar}-nucleus interaction from Kaonic atom data

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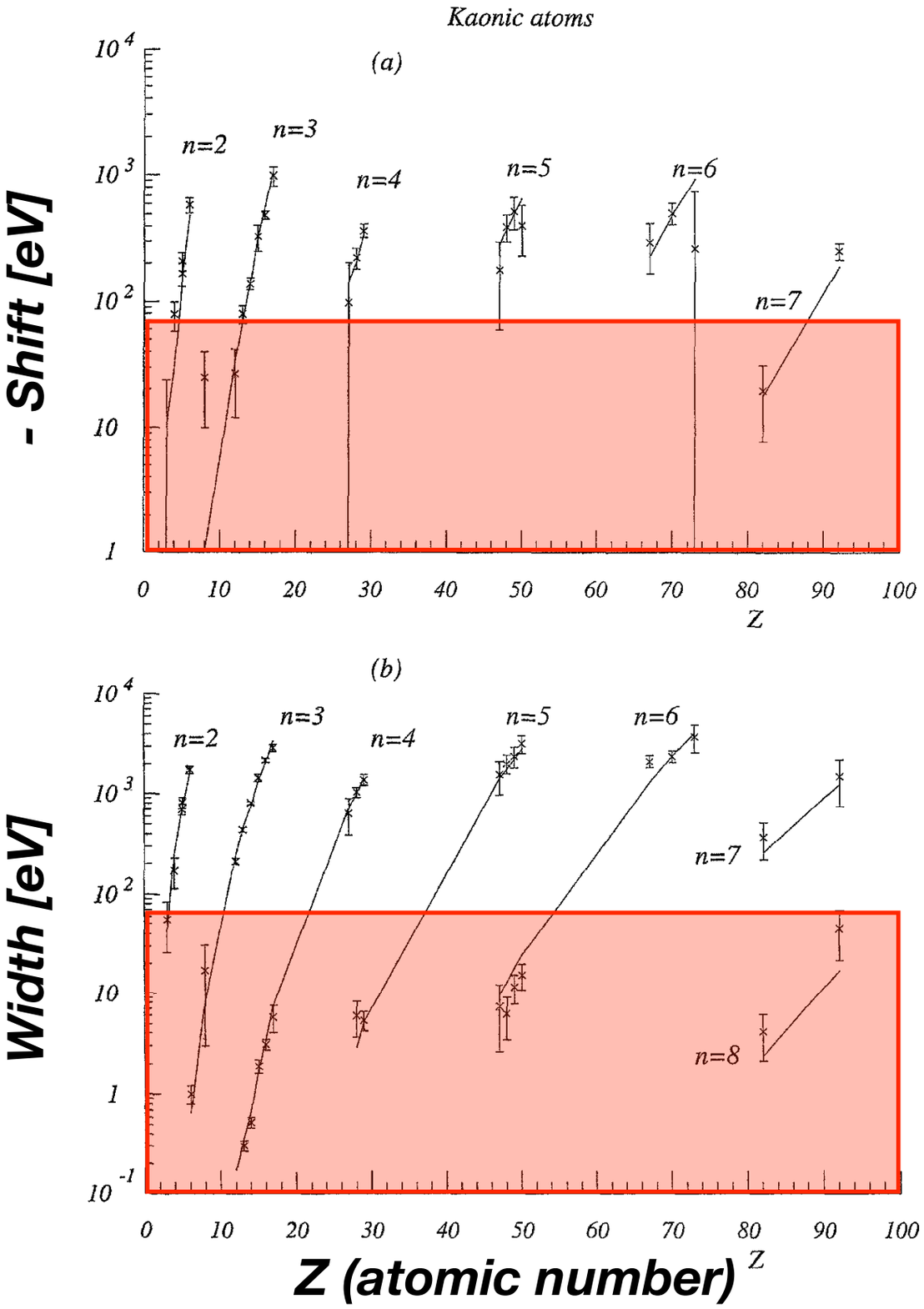


Breakthrough in the

x-ray detector resolution

is must to improve data quality for

small shift & narrow width levels

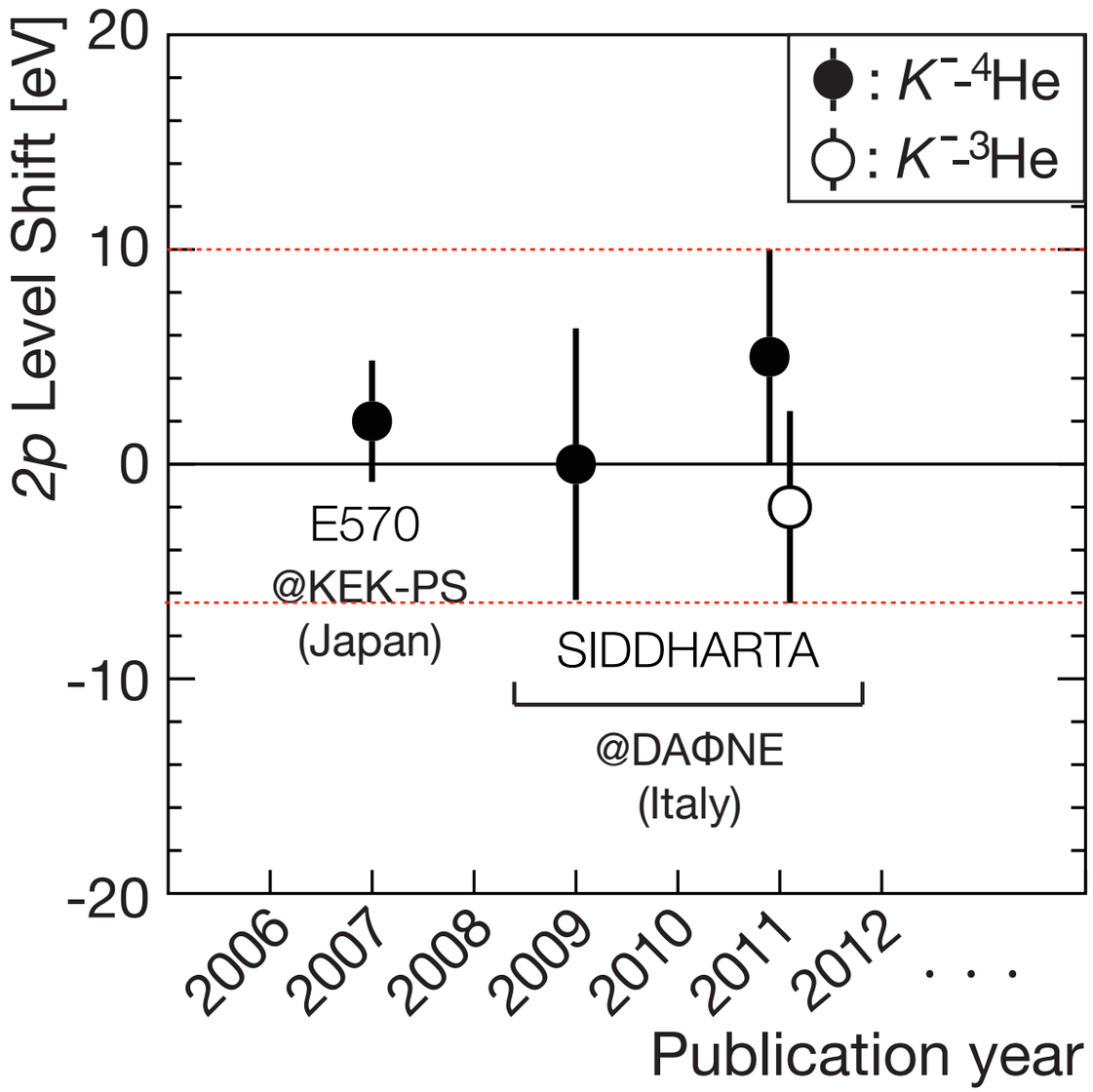
(ΔE, Γ << 100 eV)

↓

More precise discussion about the K-nucl. potential

Kaonic helium x-rays

3d → 2p transition ~ 6 keV x-rays

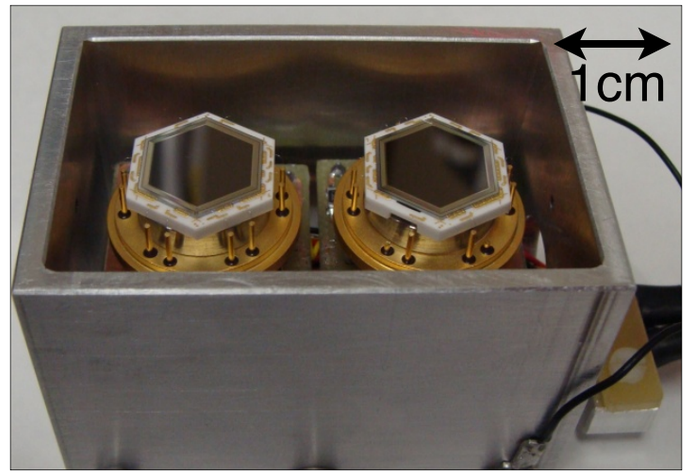


Theoretical calculations predict
$| \Delta E_{2p} | < 1$ eV, $\Gamma \sim 2$ eV

updated !

J-PARC E17 with SDD

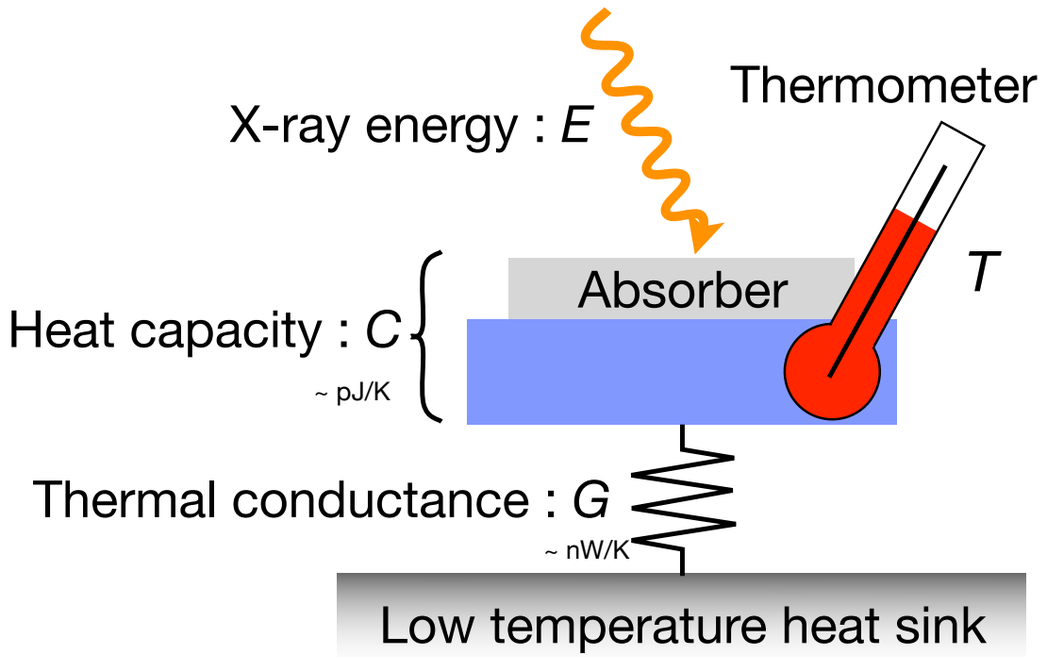
Resolution [FWHM@6 keV]: ~ **150 eV**
Precision goal for ΔE: ~ **2 eV**

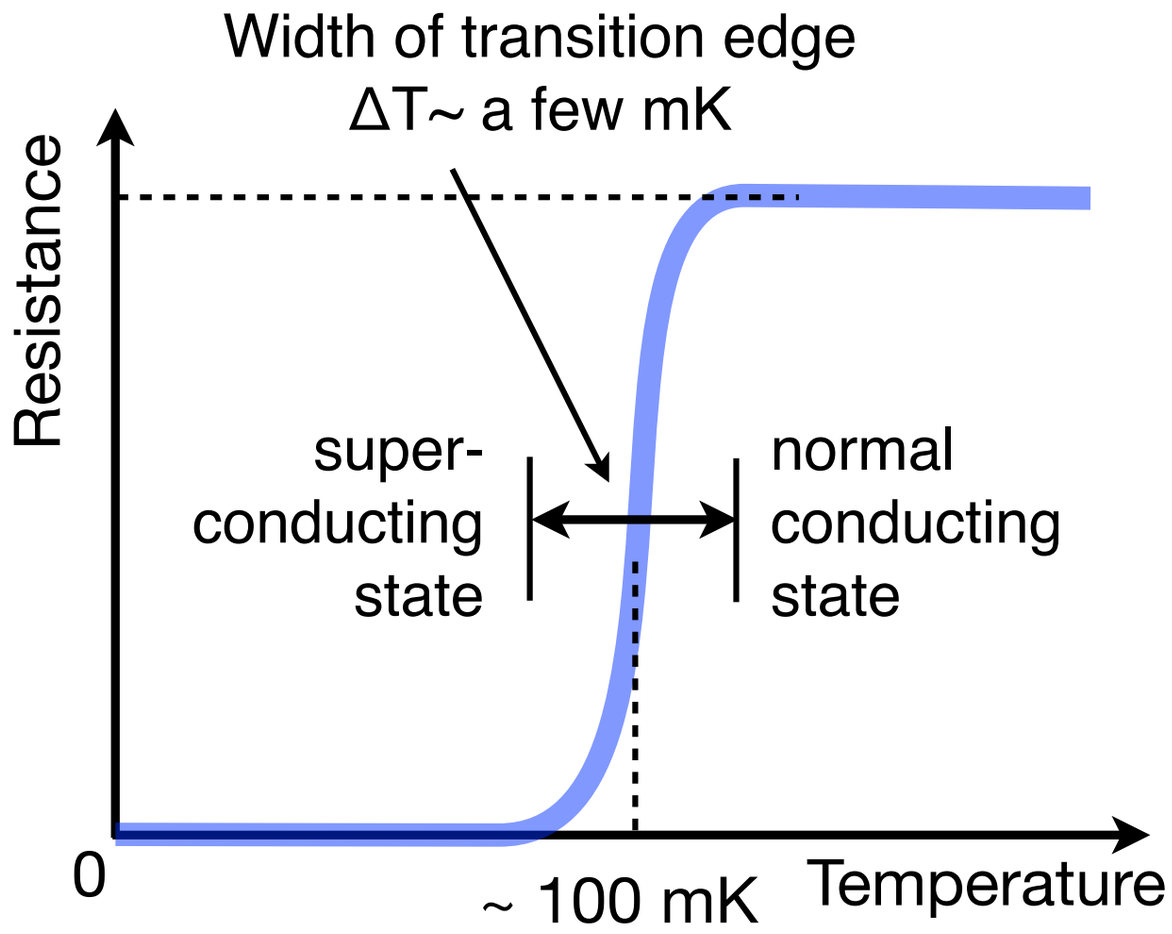


J-PARC E62 with TES

Resolution [FWHM@6 keV]: ~ **6 eV**
Precision goal for ΔE: ~ **0.2 eV**

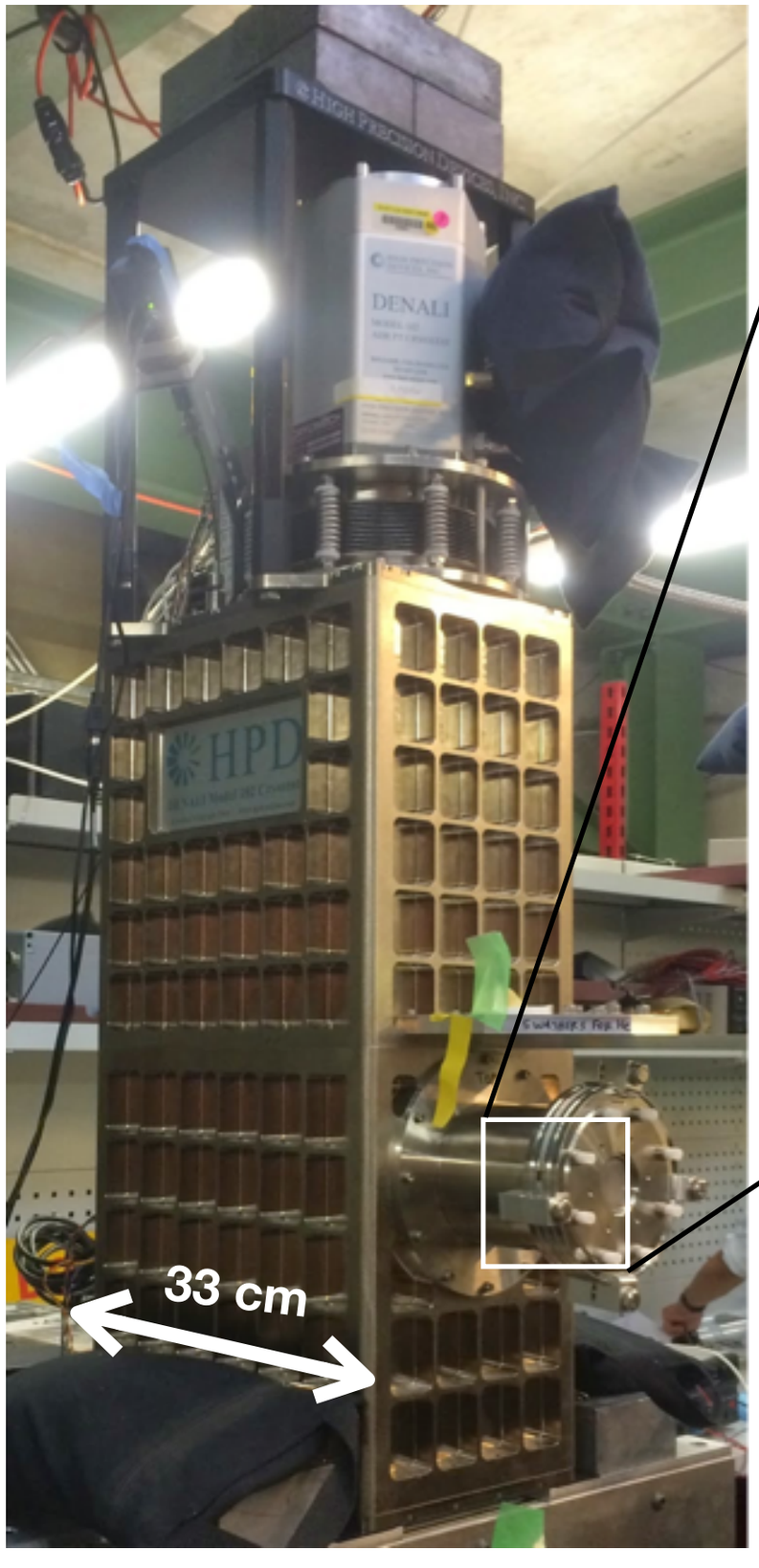
Transition-Edge-Sensor microcalorimeters



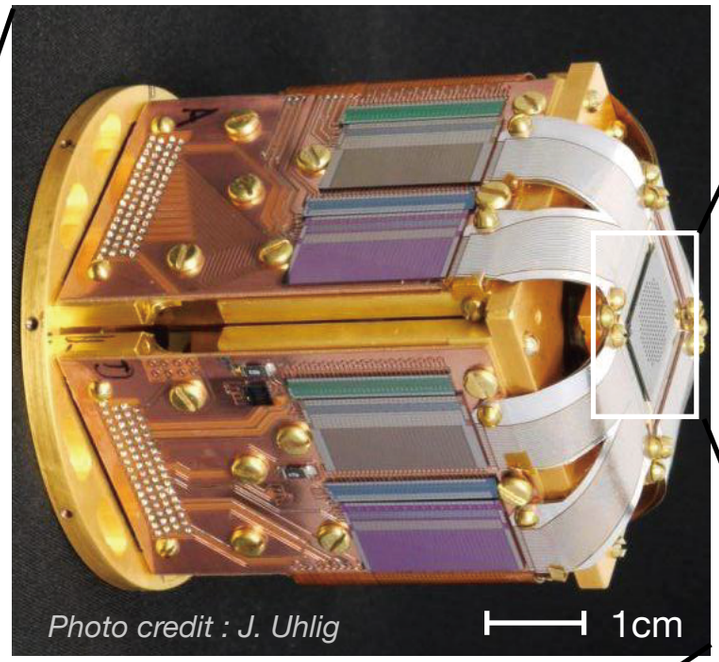


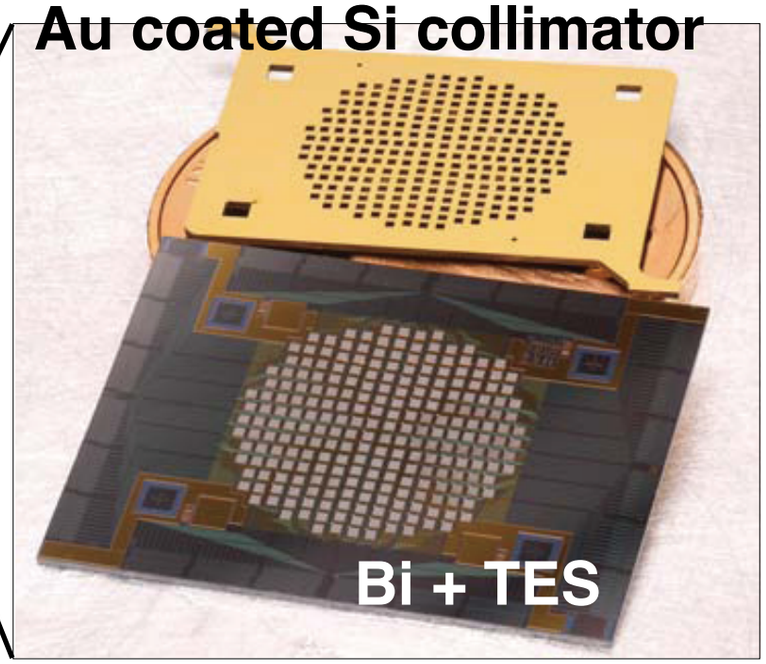
- ✓ Excellent energy resolution ~2 eV FWHM@ 6 keV
- ✓ Wide dynamic range
- ✓ Large effective area with multiplexing technique
- ✓ Portable & compact system

NIST TES system



J.N. Ullom et al., Synchrotron Radiation News, Vol. 27, 24 (2014)





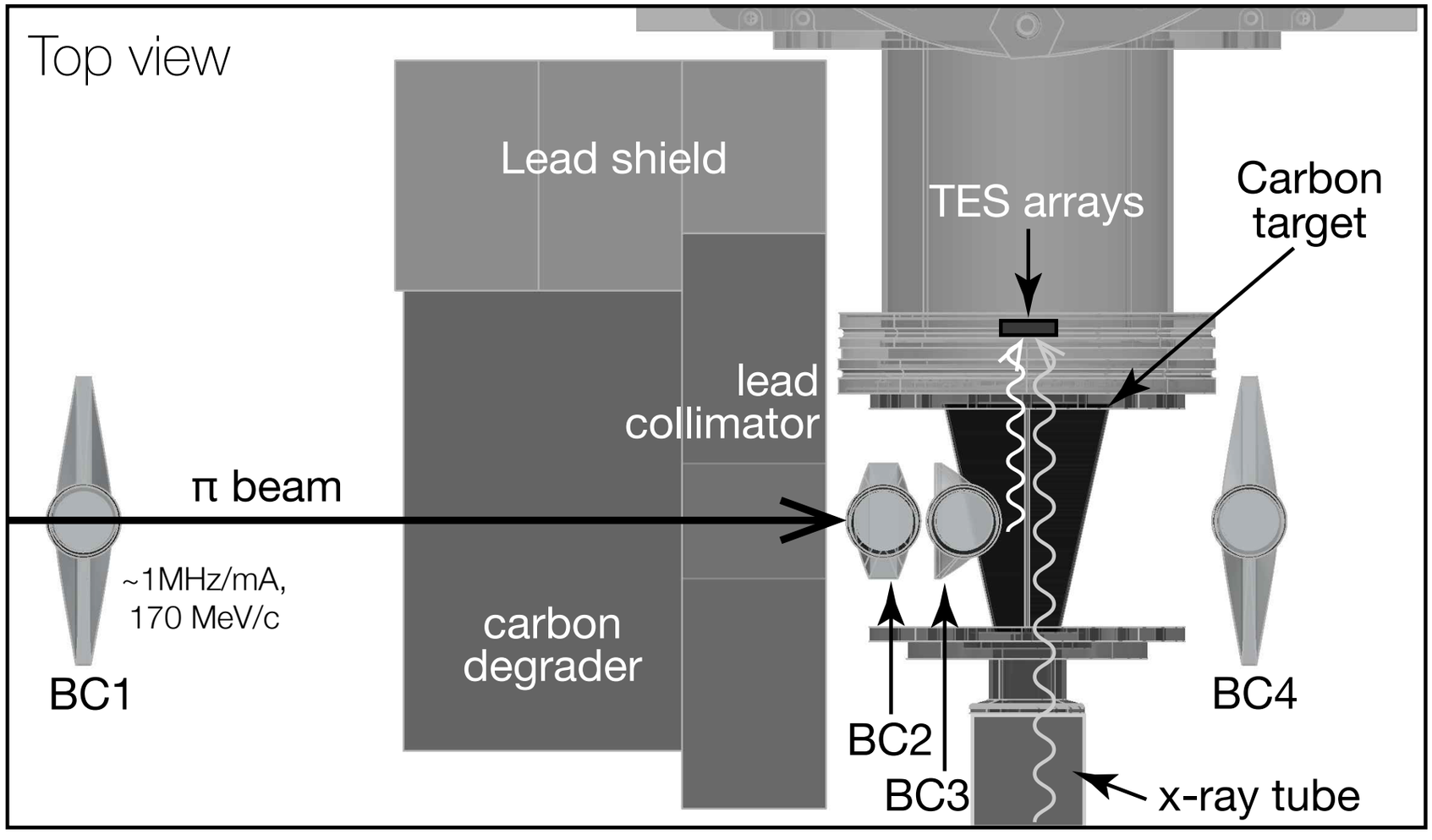
- **NIST designed cryostat**
  - Pulse tube (60K,3K) + ADR (1K, 50mK)
  - ADR hold time: > 1 day
  - Manufactured by High Precision Devices, Inc.
    http://www.hpd-online.com/102_cryostat.php

- **Detector snout**
  - 240 pixel Mo-Cu bilayer TES
    30 ch TDM(time division multiplexing) readout
  - 1 pixel : 300 x 320 um
  - 4 um Bi absorber → efficiency ~0.85@6 keV, ~0.4@10 keV

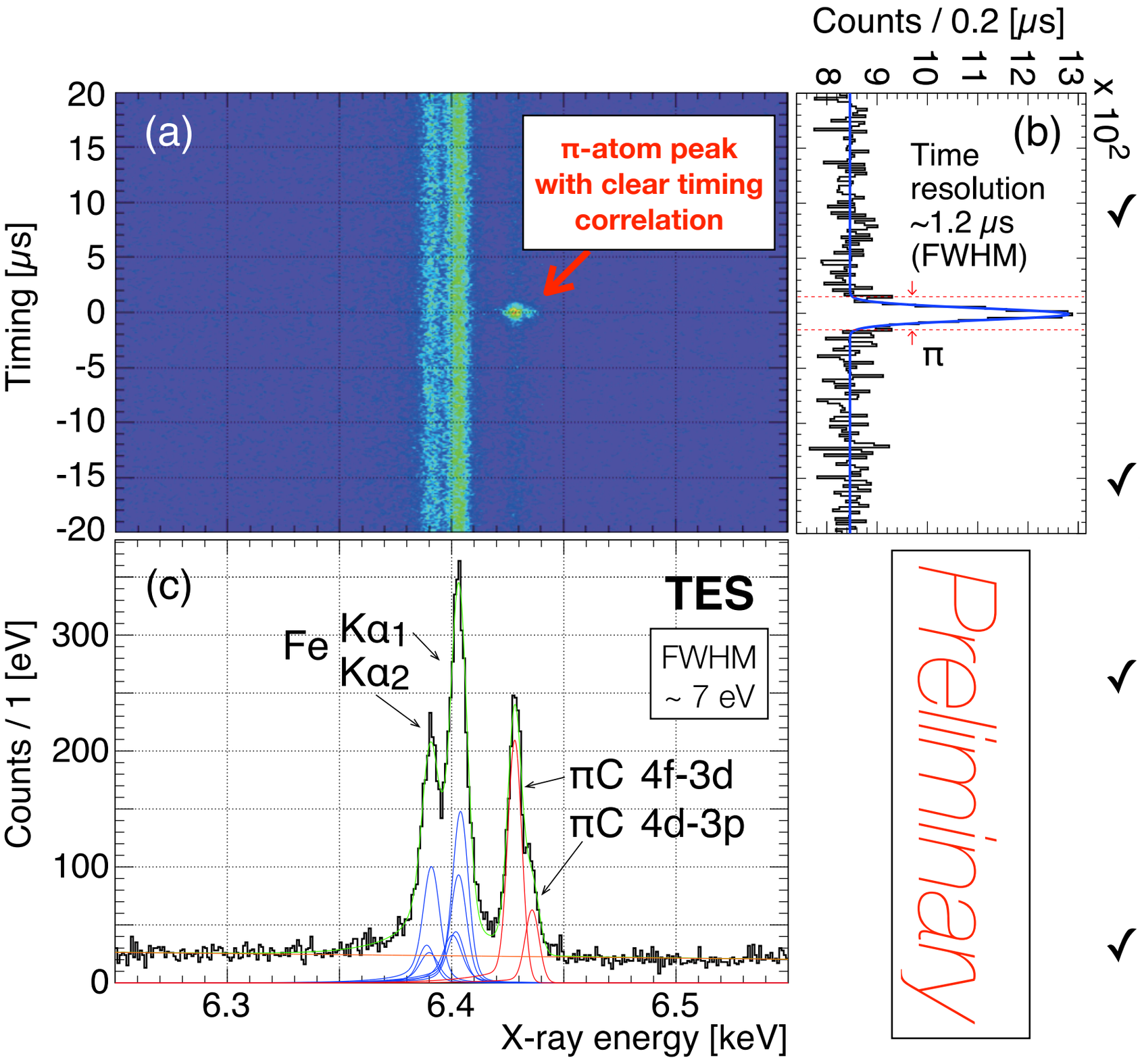
Feasibility test : πC x-ray measurement

- Aim : studying in-beam performance of TES
- Site : Paul Scherrer Institute (PSI) at PiM1 beamline
- Measured x-rays: πC 4f→3d transition ~ 6.4 keV

(strong-interaction effect is negligible)



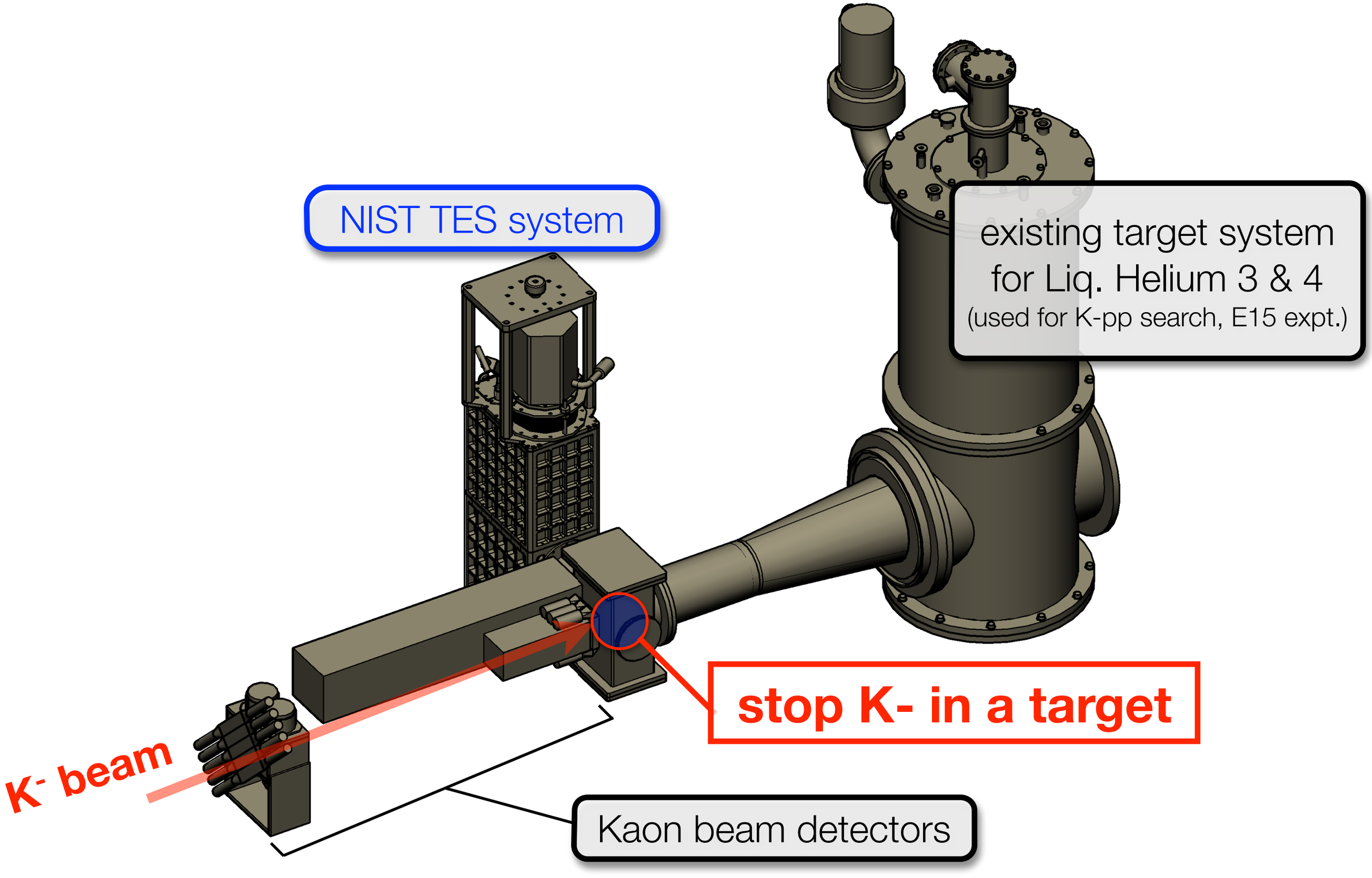
πC 4-3 X rays



Preliminary

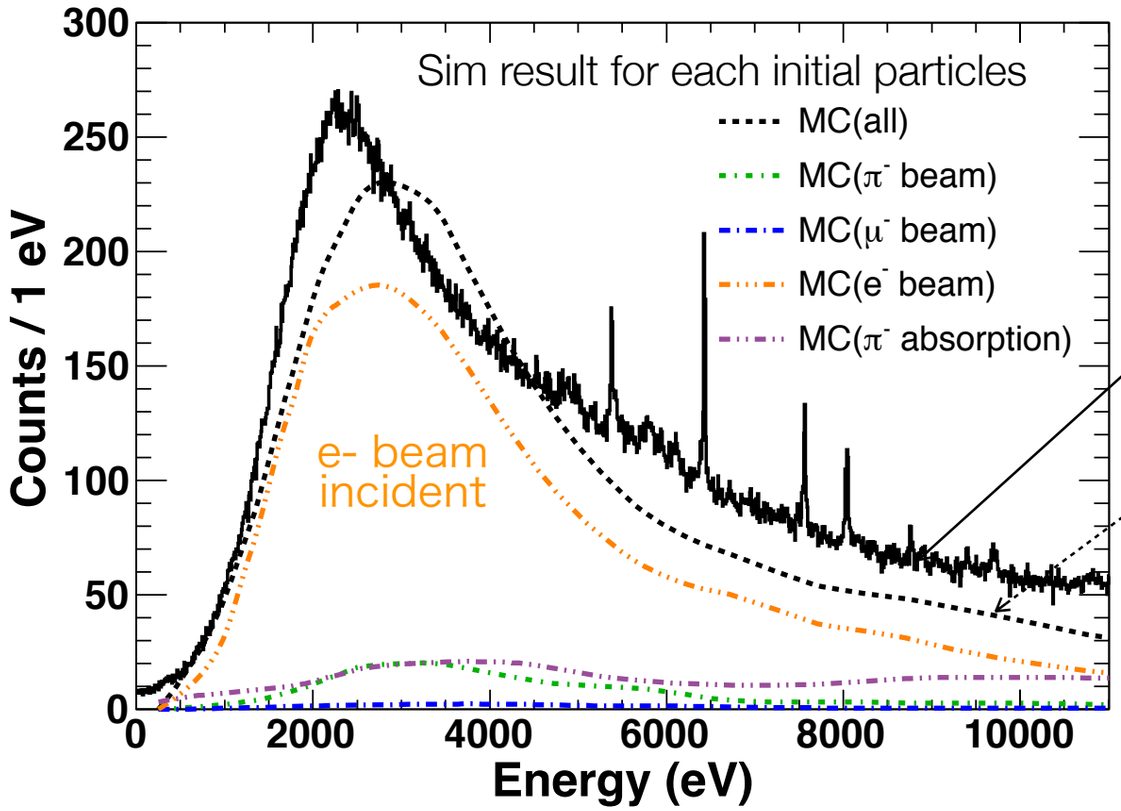
- ✓ Excellent energy resolution even in the hadron beam
  5 eV (beam off)→7 eV (beam on) [FWHM@ 6.4 keV]
- ✓ Good timing resolution comparable with SDDs
- ✓ Accurate energy calibration using Cr&Co lines
  < 0.1 eV accuracy @ FeKα
- ✓ piC x-ray energies agree with EM calc.

Experimental setup at J-PARC K1.8BR



TES operation in the J-PARC kaon beam

Comparison of PSI data with the simulation



	TES trigger rate /pixel
Measured	**0.71 ± 0.11 /sec**
Simulation	**0.64 / sec**

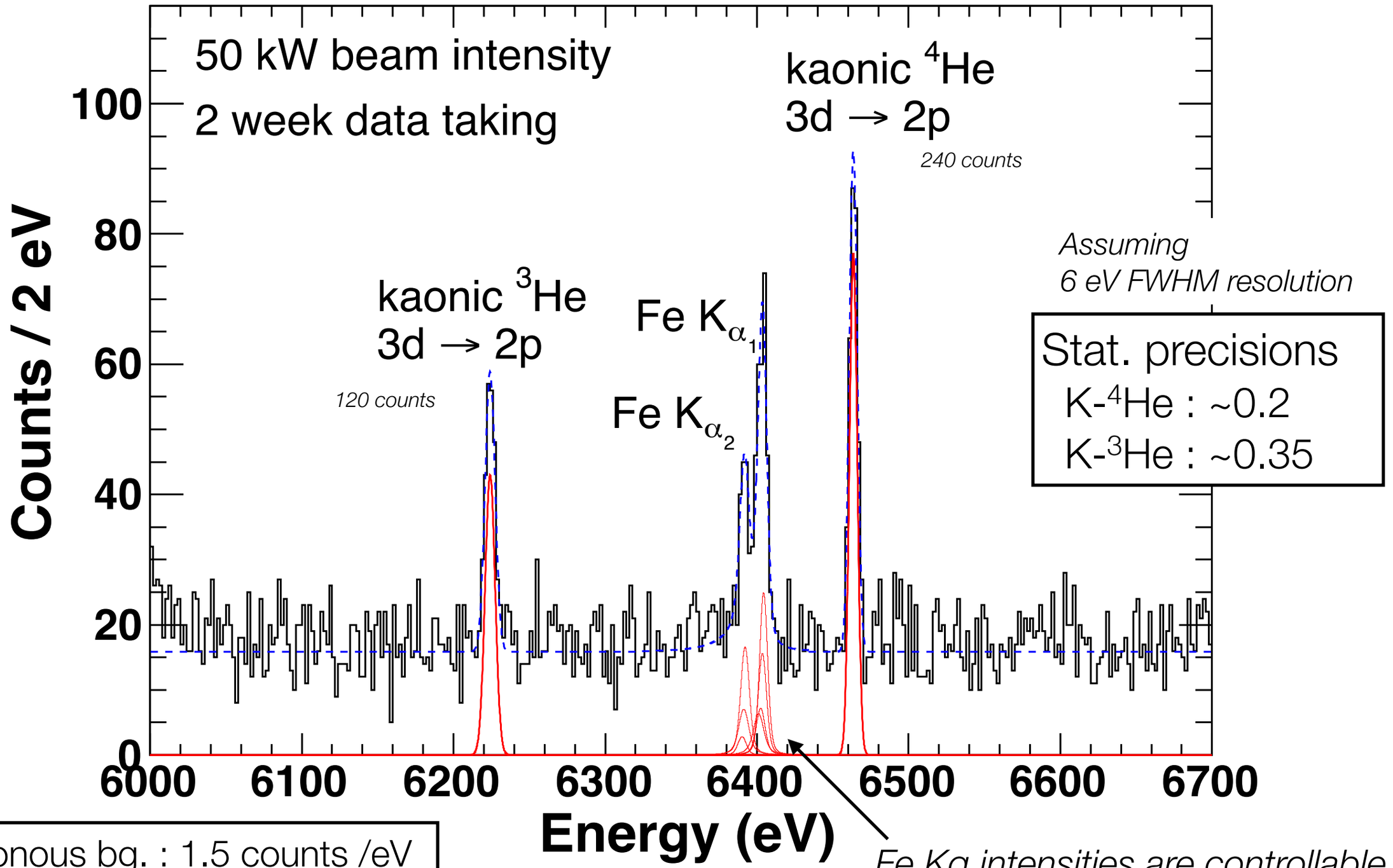
(normalized by # of incident beam)

Good reproducibility of hit rate & spectral shape

	πM1 at PSI	K1.8BR at J-PARC
Beam momentum	173 MeV/c	900 MeV/c
Total beam intensity	2.8×10^6 /sec	8.0×10^5 / spill (@ 50 kW)
$K^-/\pi^-/\mu^-/e^-$ ratio	—/ 40% / 5% / 55%	20% / 60% / 10% / 10%
TES trigger rate / pixel	0.64/sec	0.17 /spill
Energy deposit on Si	152 MeV/sec	46 MeV/spill

J-PARC will be less severe compared with PSI

Expected spectrum in J-PARC E62



Asynchronous bg. : 1.5 counts /eV
Synchronous bg. : 6 counts /eV

Fe Kα intensities are controllable with applied voltage of x-ray tube

Summary

- **Transition-edge-sensor microcalorimeters are now available for hadronic atom x-ray spectroscopy**
  - Drastic improvement in energy resolution
    ~150 eV (SDD) → ~6 eV (TES) [FWHM@6 keV]
  - Successfully demonstrated
    at a pion beamline at PSI

- **Kaonic helium x-rays will be measured in J-PARC E62**
  - Precision goal for ΔE_{2p} : ~ 0.2 eV
  - Contribute to the determination
    of the potential strength