Precision spectroscopy of Kaonic Helium-3 X rays at J-PARC

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on behalf of J-PARC E17 collaboration

THE UNIVERSITY OF TOKYO

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J-PARC E17 collaboration

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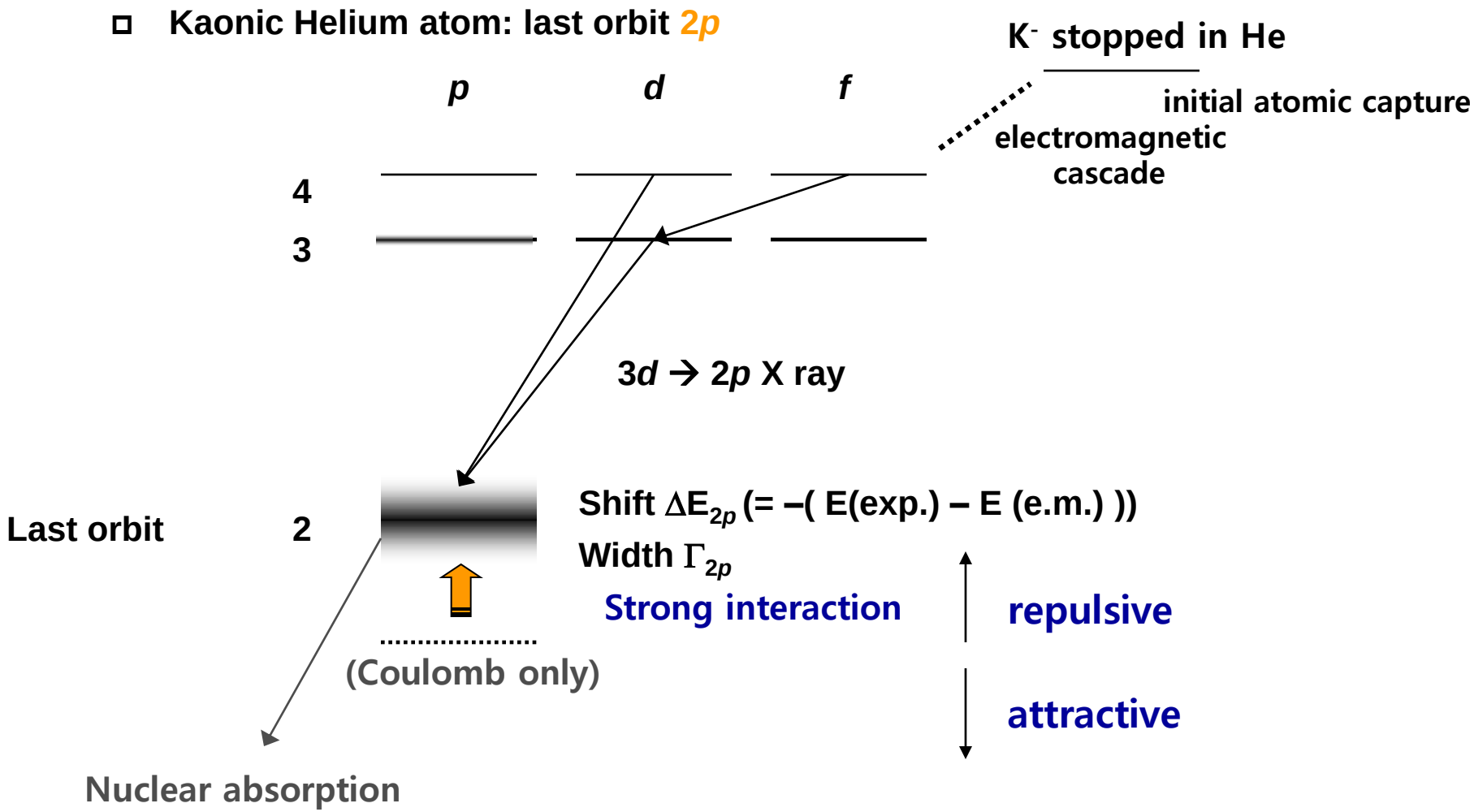
Contents

Kaonic Helium atoms

- **Formation of Kaonic He atoms**
  - **Kaonic Helium atom: last orbit 2*p***



Latest experiment on Kaonic Helium-4

- **KEK-PS E570 motivated by**

  "*Kaonic Helium puzzle*"

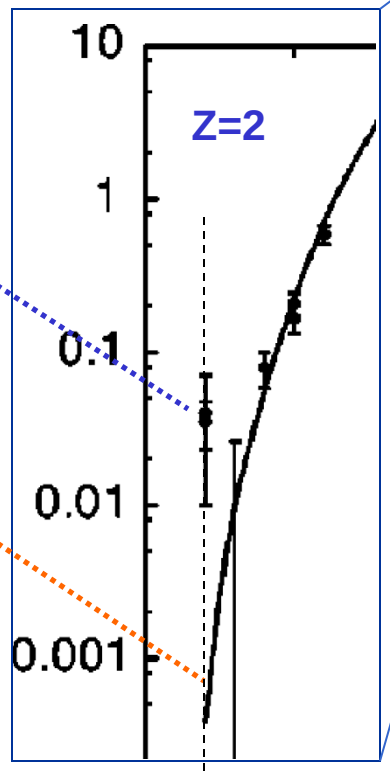
Exp. before E570 ('71, '79, '83)

Avr . of ΔE_{2p} = − 43 ± 8 eV

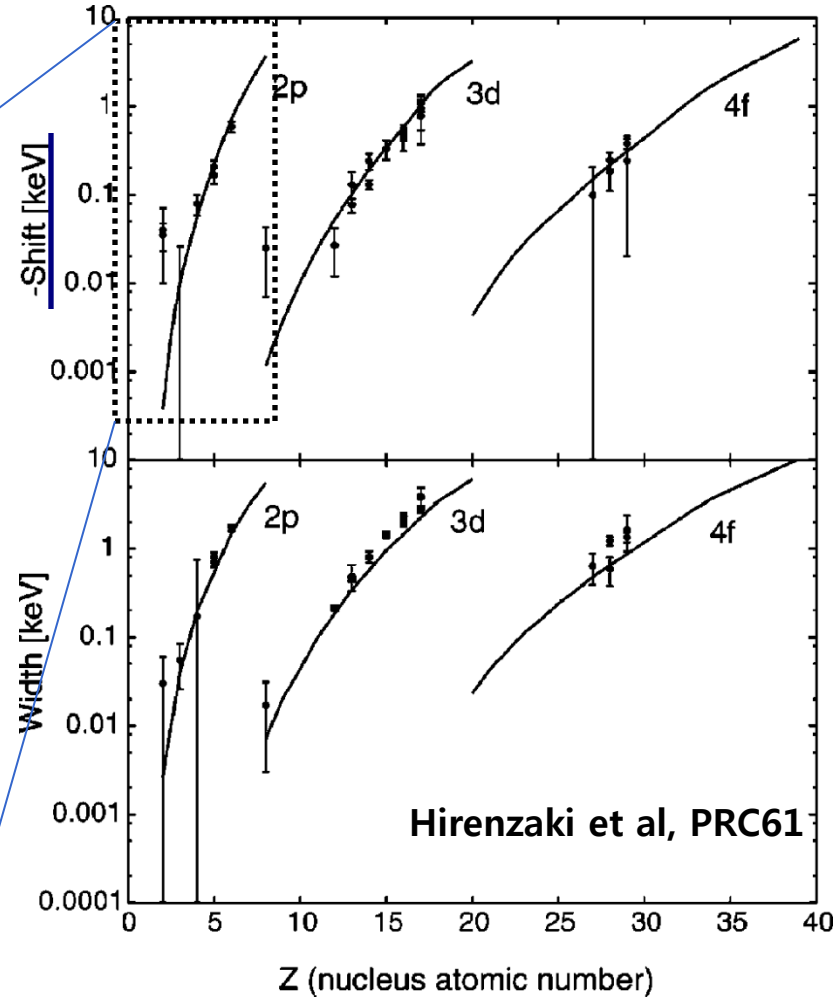
Theoretical calculations
< 1 eV

Batty et al, PRC61

Hirenzaki et al, PRC61
etc.



Chiral unitary + Optical potential



- **Goal of E570**

  precision measurement of Kaonic 4He 3d → 2p X ray

Recent relevant work

- **Theoretical study by Akaishi, EXA05 proceedings**

Possible large shift (|ΔE2p| > 5 eV)

Coupled-channel w/ deep potential

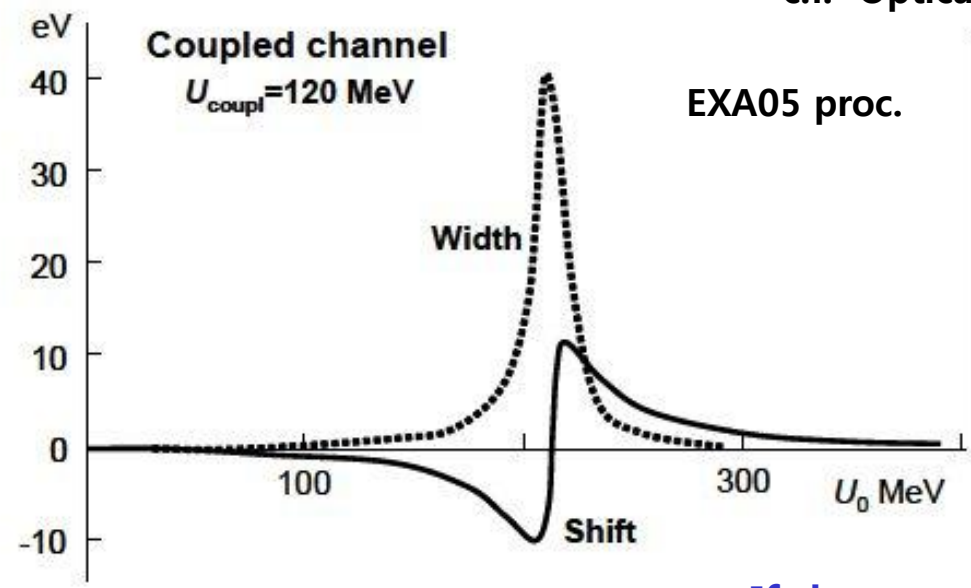
$$U_{\mathrm{D}}(r) = -U_0 F(r), \quad U_{\mathrm{C}}(r) = U_{\mathrm{coupl}} F(r)$$

Diagonal **Coupling**

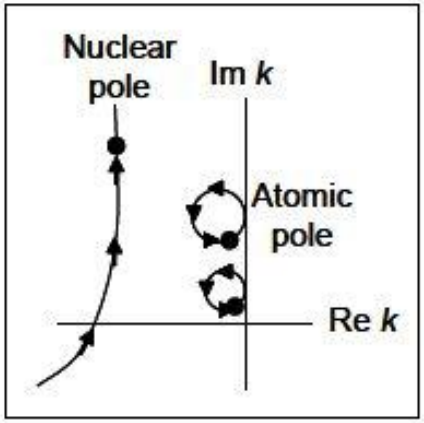
F(r): helium density dist.

Unique theoretical result for large shift (|ΔE2p| > 5 eV)

c.f. Optical model w/ deep potential → small shift



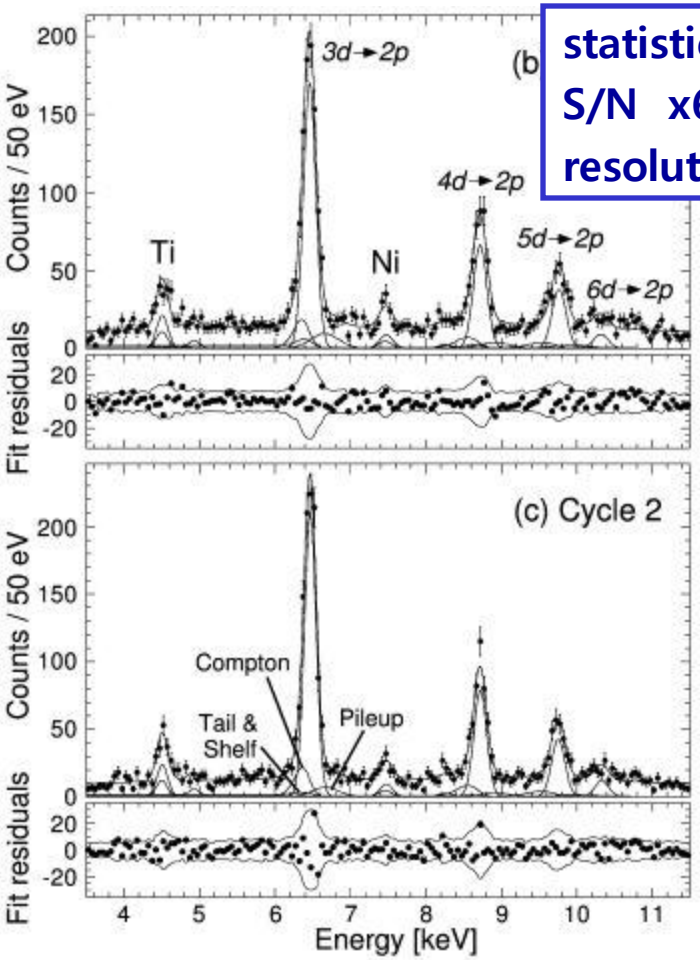
EXA05 proc.



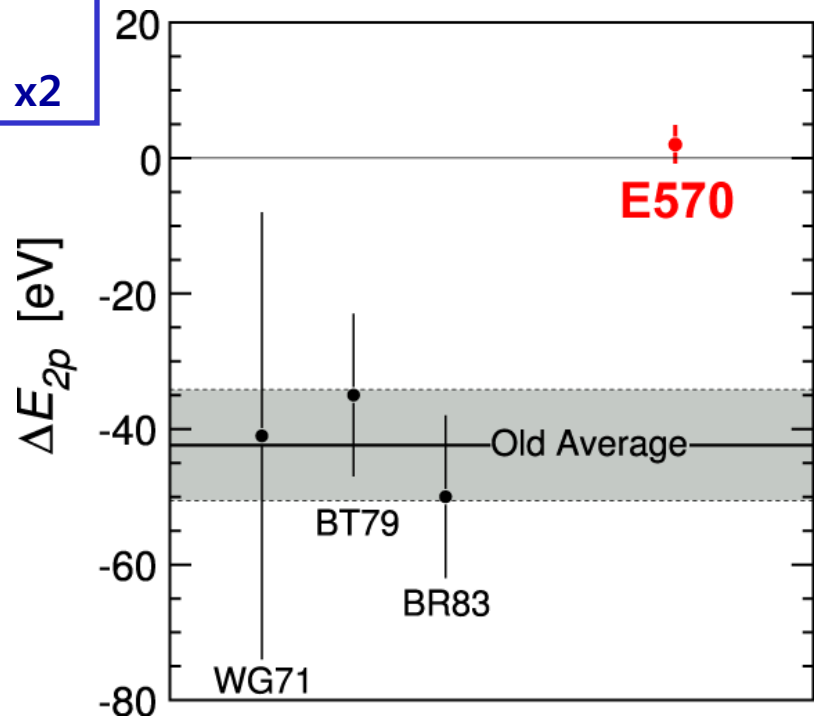
If deep potential, large shift can be possible

E570 result

- **result of KEK-PS E570**
  S. Okada et al, PLB653, 2007



statistics x3
S/N x6
resolution x2

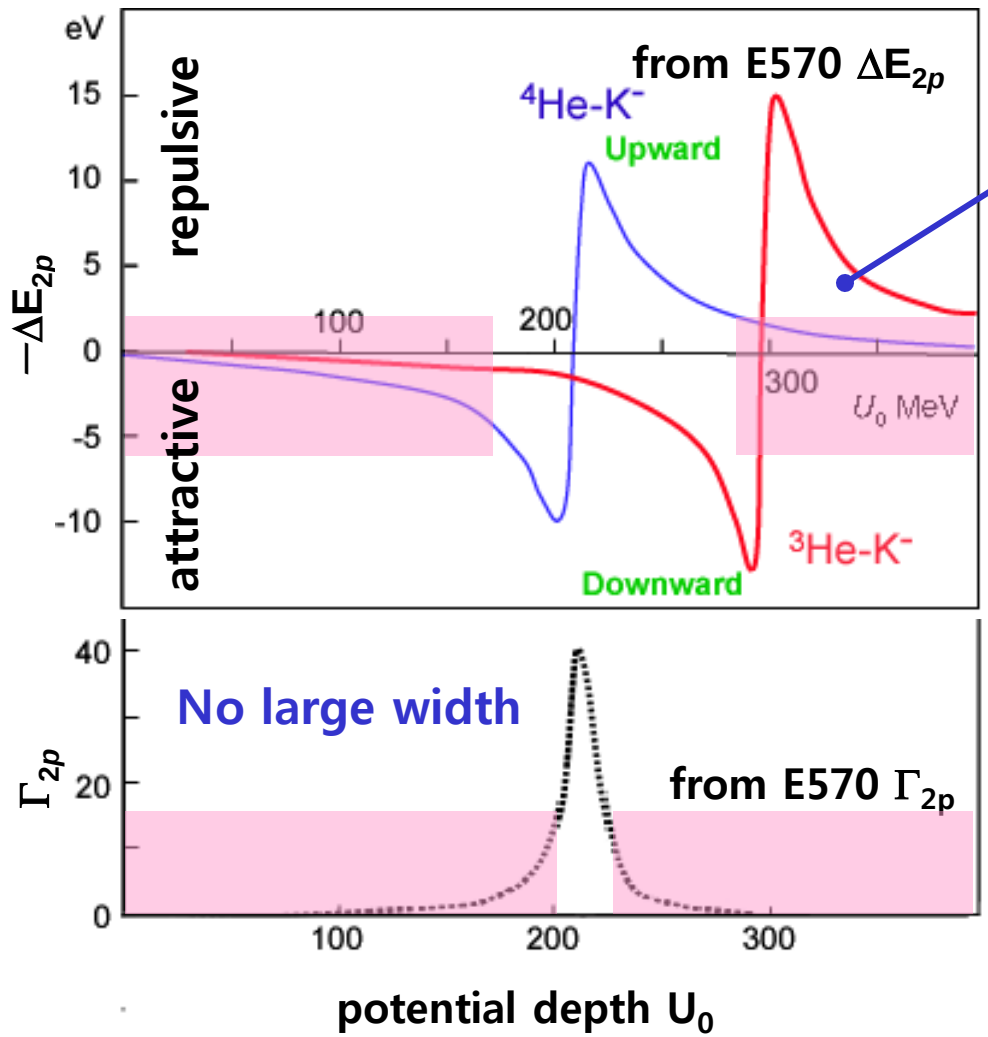


ΔE_{2p} = **2 ± 2 (stat)± 2 (syst) eV**

Definitive answer for kaonic helium puzzle

Motivation of J-PARC E17

- **Akaishi-Yamazaki framework (Coupled-channel + deep pot.)**



Possible large shift for 3He

Goal of J-PARC E17

Measurement of Kaonic 3He X-rays with "high precision"

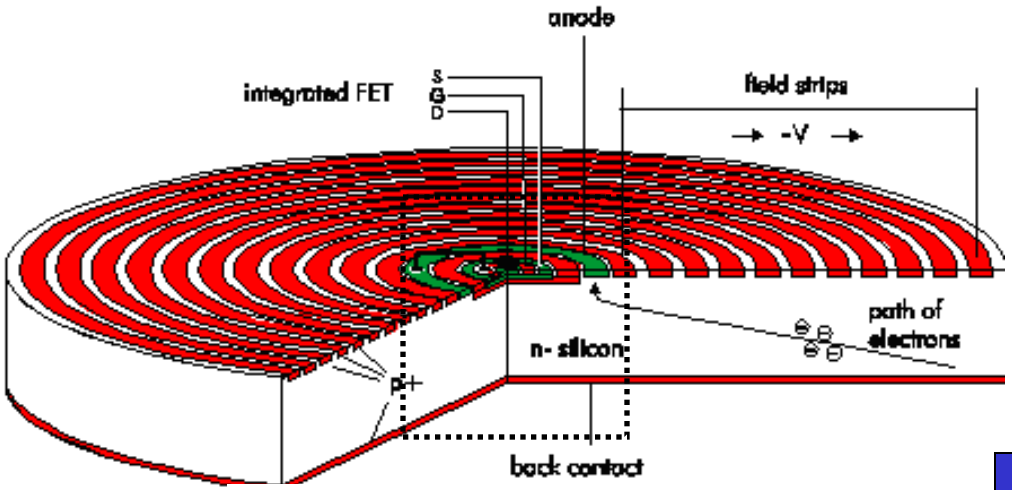
- constraint to the potential depth of AY framework
- If non-zero ($|\Delta E_{2p}|$> 5 ev) shift, deep potential
  - ✓ need additional framework for theory
  - ✓ repulsive (upward) shift : existence of p-wave nuclear state

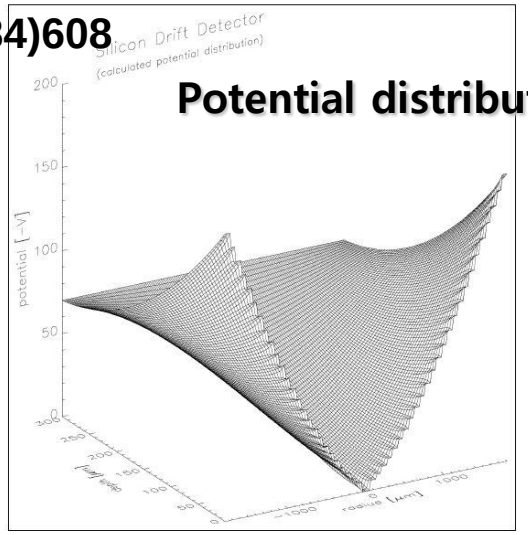
E17 Experimental strategy

- **Following successful E570 techniques**
  - Silicon Drift Detector
  - In-beam energy calibration
  - fiducial volume cut

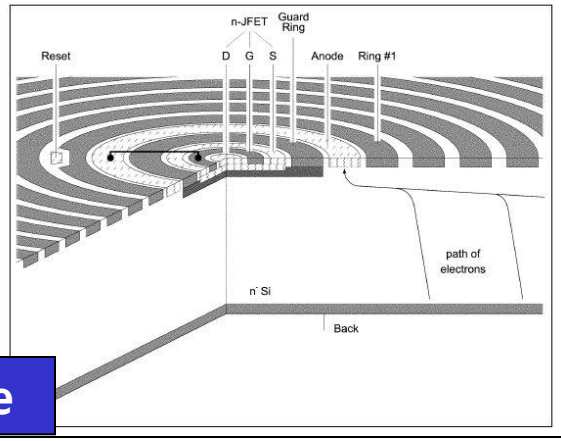
Silicon Drift Detector

- A novel X ray detector by KETEK GmbH NIMA 225(1984)608





Potential distribution



E17 case

- Low temperature operation of SDD
- Preamp inside vacuum

features

- Small anode side

$$Q = CV = (\varepsilon_0 S / d)\, V$$

small capacitance

- Large effective area

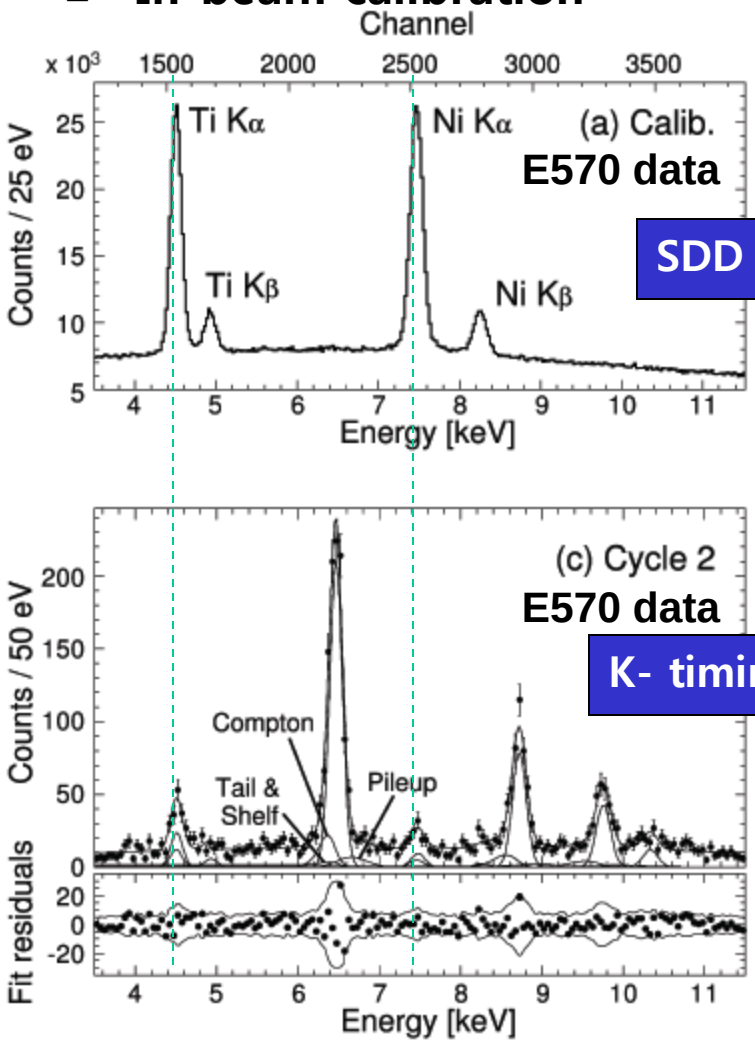
~100 mm²

- Thin active layer

reduce Compton background

Absolute energy calibration

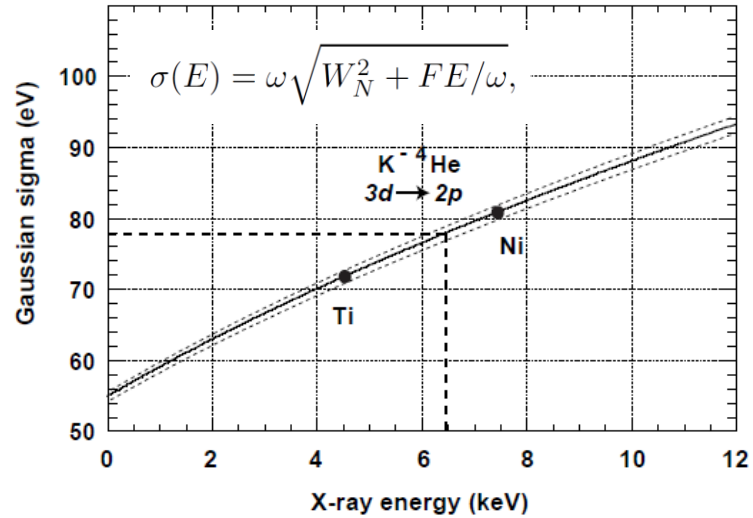
- **In-beam calibration**



SDD self trigger

K- timing trigger

Ti Ka	K-He	Ni Ka
4510.84		7478.15



Precise determination for the energy scale

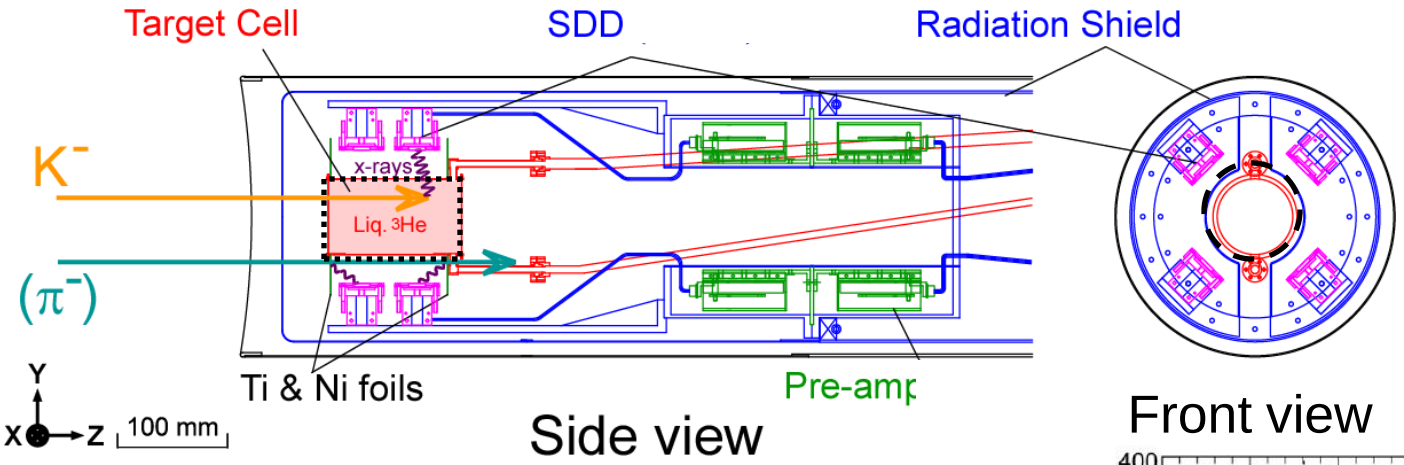
E17 case

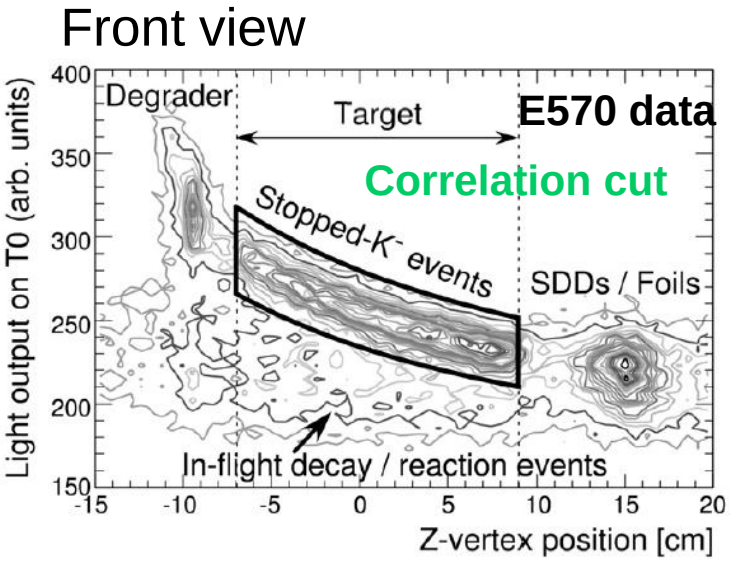
- **Self trigger → 2nd level trigger**
  offline timing selection/ tracking to improve S/N

fiducial volume cut

- **Event selection by secondary charged particle**
  - **Liquid helium-3 target (density = 0.08 g/cm3(1 g/cm2), D=6.8 cm)**

Reaction vertex determination by secondary charged particle





In-flight decay/reaction events contamination still remains

Tracking of secondary charged particle improves S/N

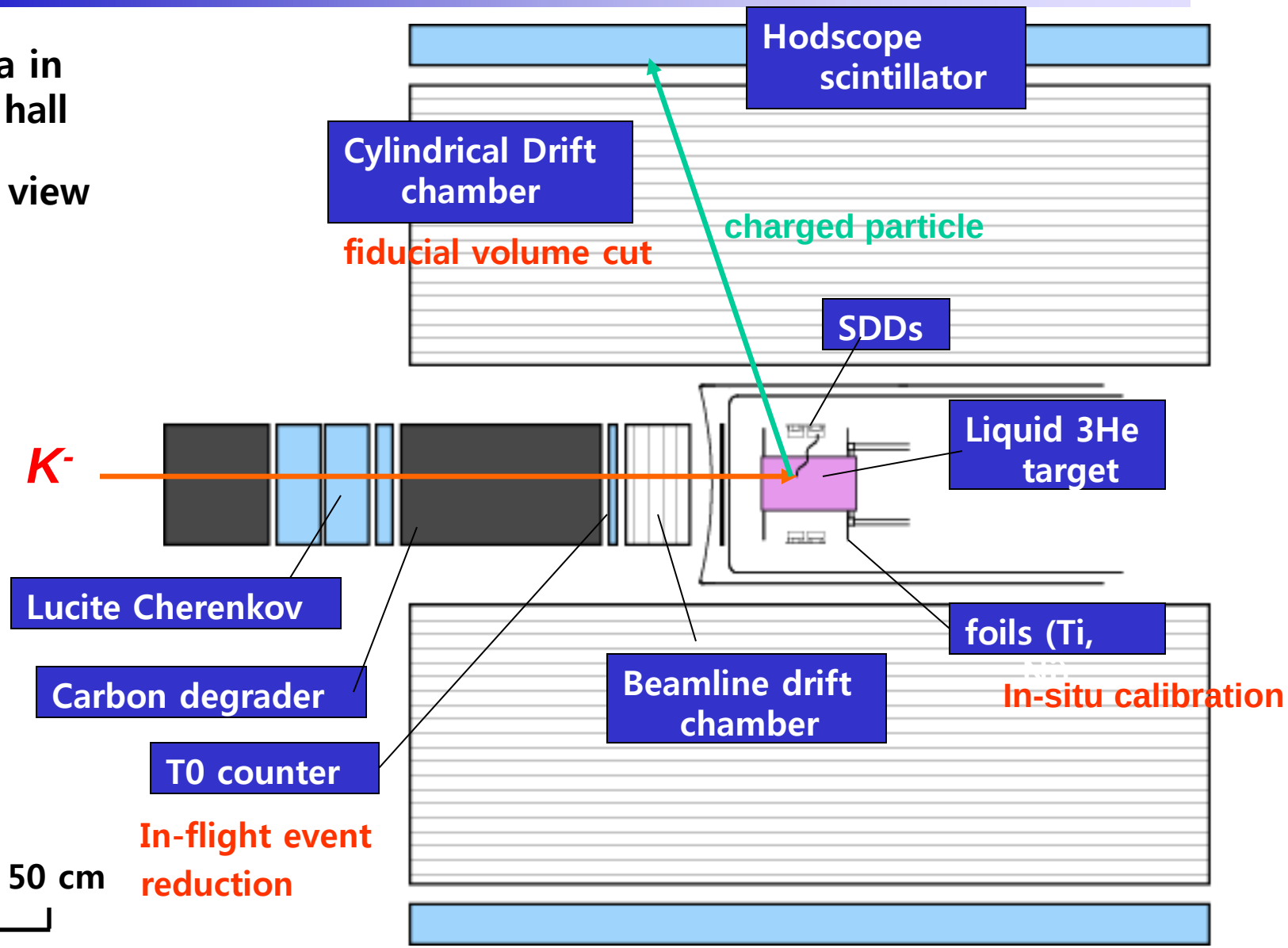
Setup and Preparation status

- Beamline spectrometer
- Cylindrical detector system
- Liquid 3He target
- Silicon drift detector

J-PARC E17 experimental setup

K1.8BR area in Hadron hall

- Side view

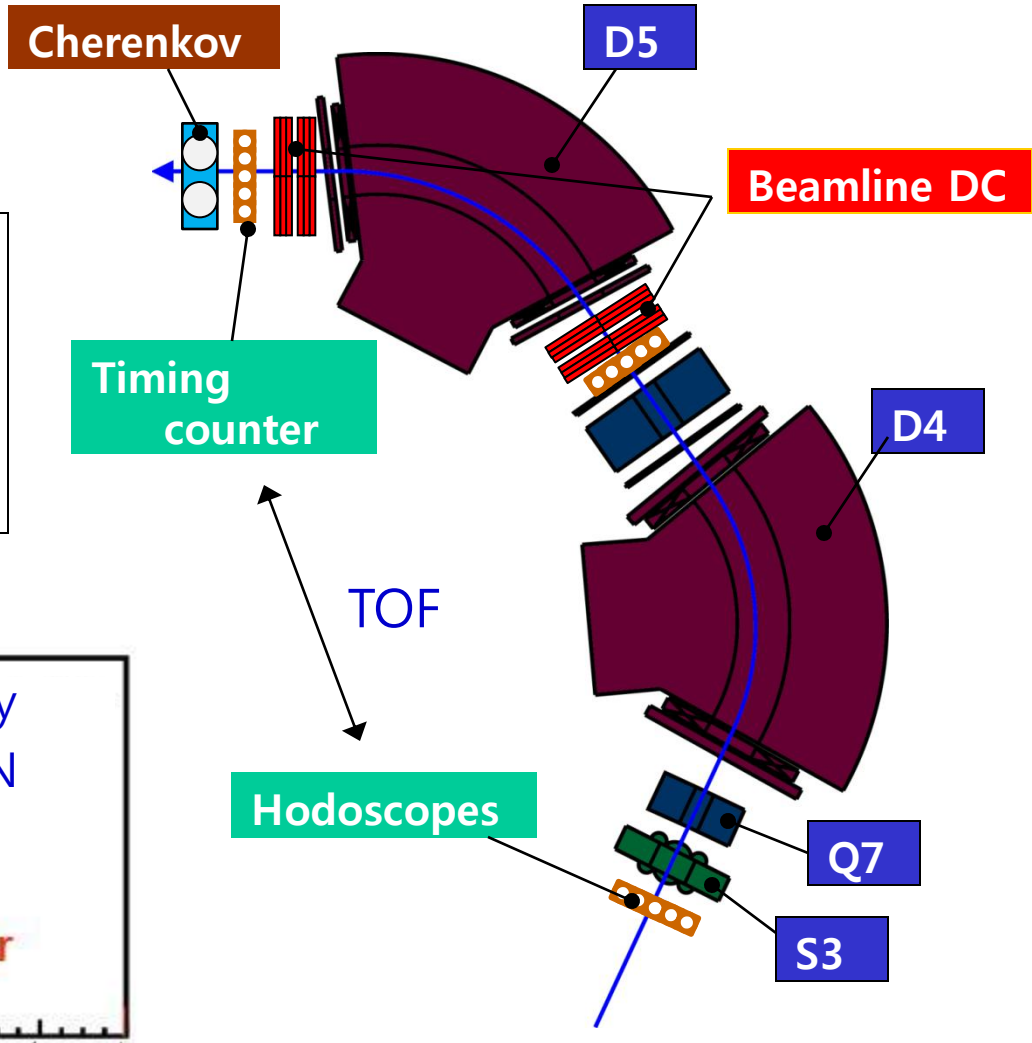


Beamline spectrometer

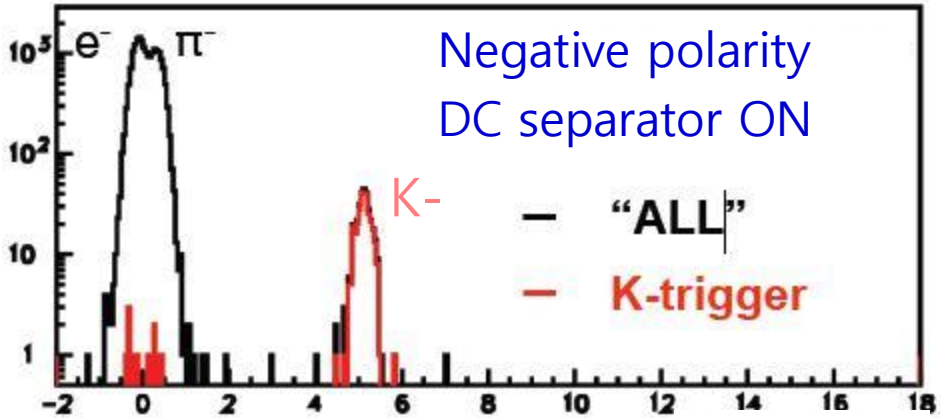
- stopped K- exp.@K1.8BR

Stopped K- exp. @ K1.8BR

- 0.7 GeV/c K-(+) beam tunig
- Absolute momentum measurement
- Range measurement
- K/π($\bar{p}$,μ,e) separation by Lucite cherenkov counter



PID : TOF with hardware trigger



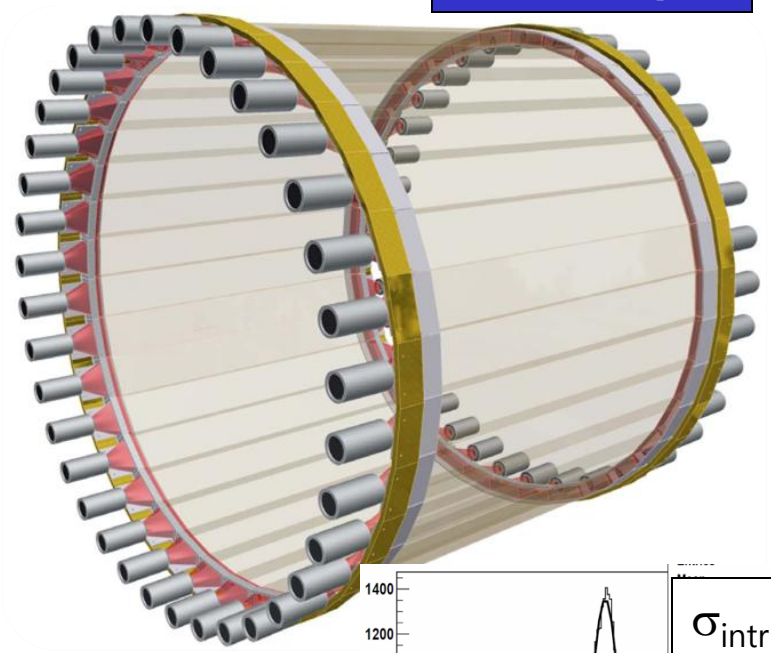
Beam tuning is well under way

Cylindrical Detector System (CDS)

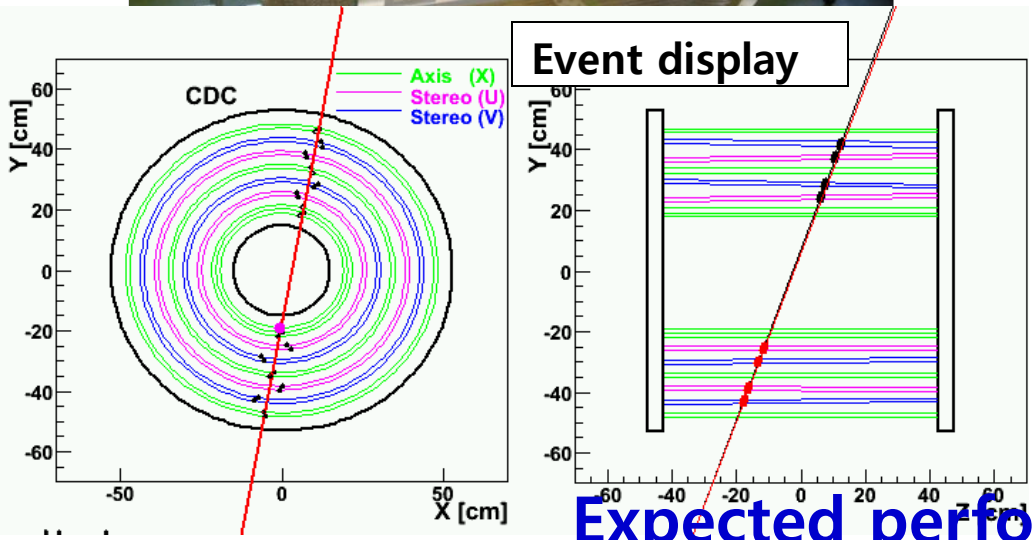
- **Track secondary charged particles → apply target volume cut**

Drift chamber

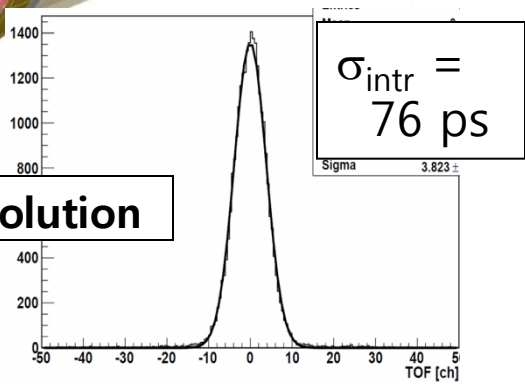
Hodoscope



Event display



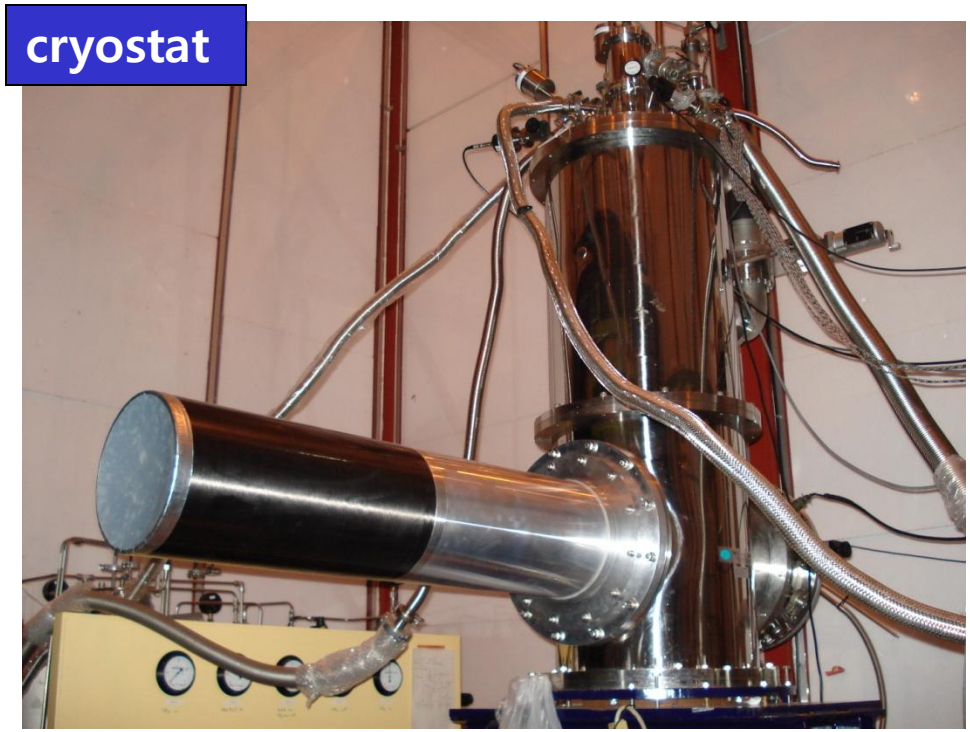
Time resolution

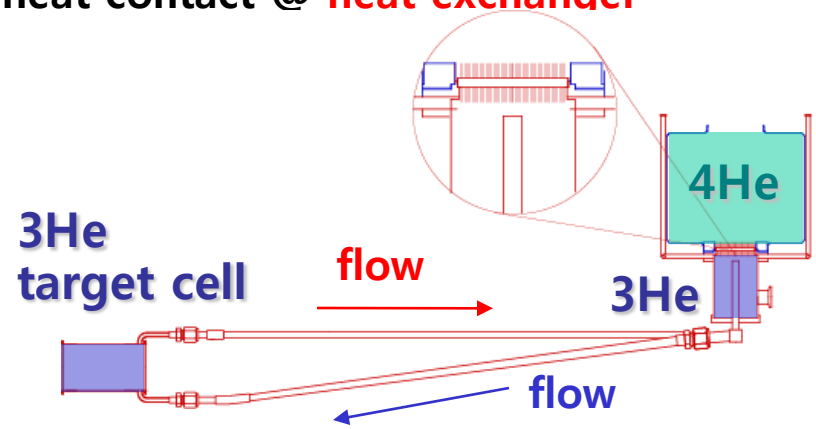


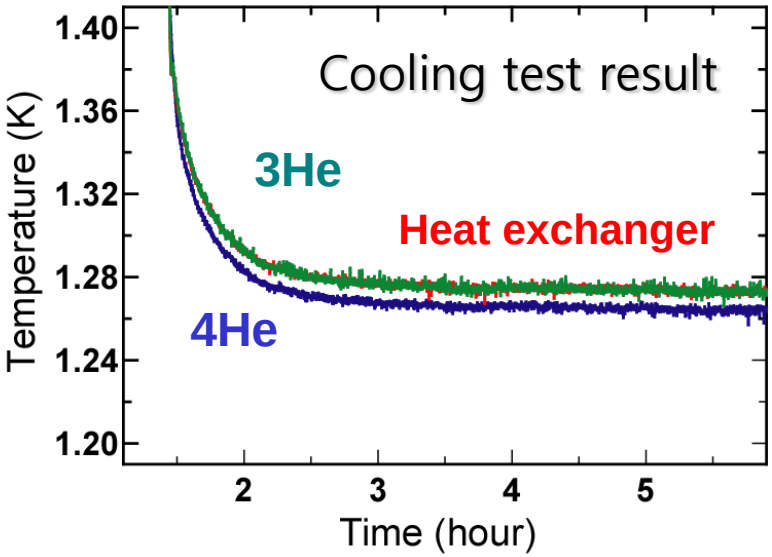
Expected performances are achieved

Liquid Helium-3 target

- Condense gaseous 3He by liquid 4He (He-II): heat contact @ heat exchanger
- 3He convection flow







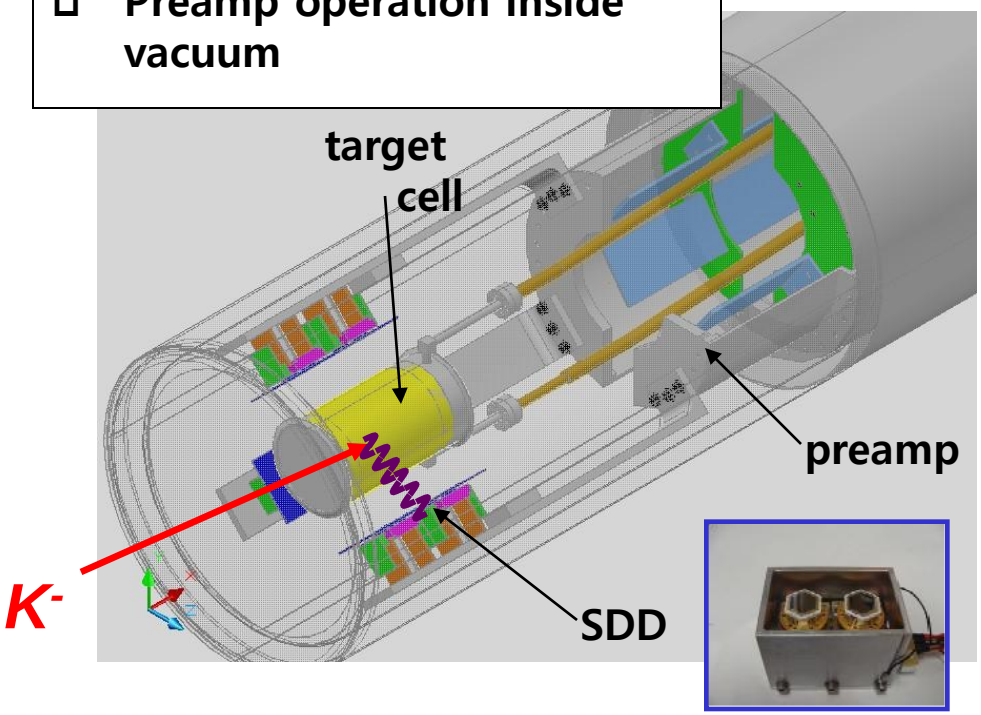
Coolant L-4He consumption ~ 45 □/day

Succeed in 3He condensation

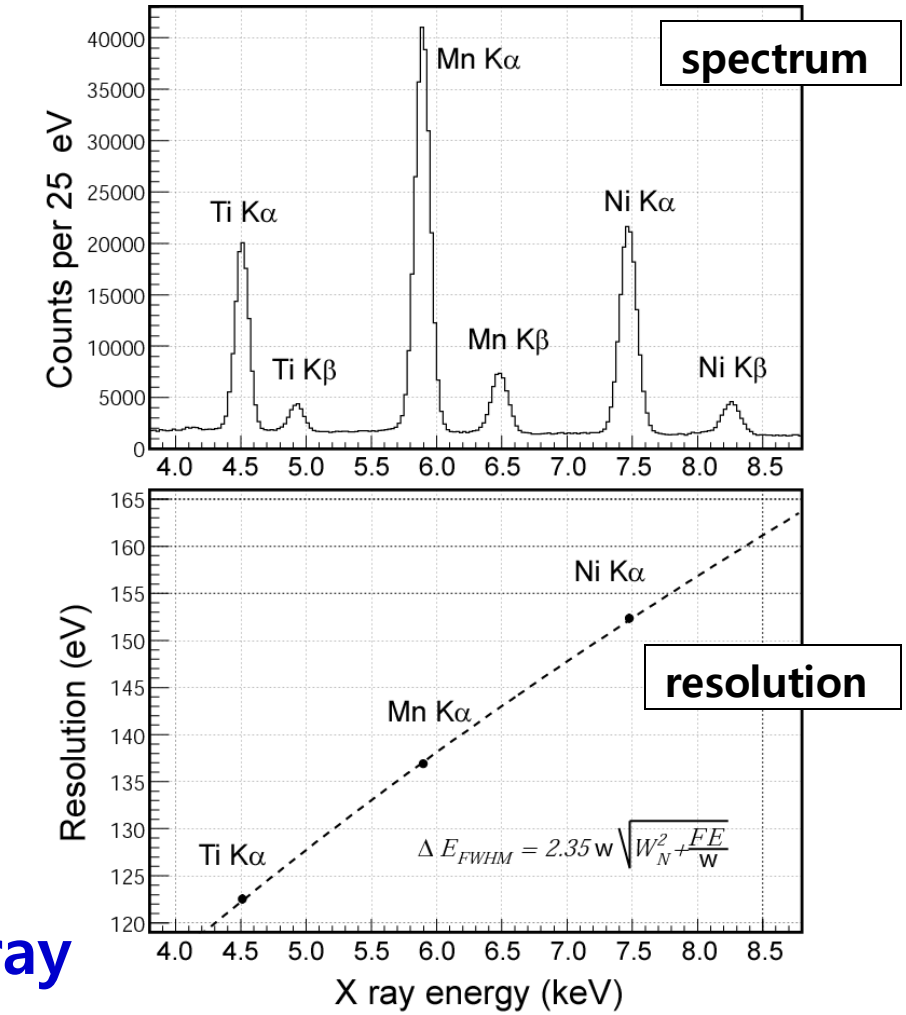
Silicon Drift Detector

- **SDD installed into the cryostat**

  - **SDD (120K) close to the target**
  - **Preamp operation inside vacuum**



Operation check with fluorescence X rays



Successfully operated

ΔE_{FWHM} ~ 140 eV at K-3He X ray

Summary & Outlook

- Precision spectroscopy of Kaonic ^{3}He at J-PARC with precision below 2 eV.

- All detectors show good performances and constructions are almost finalized.

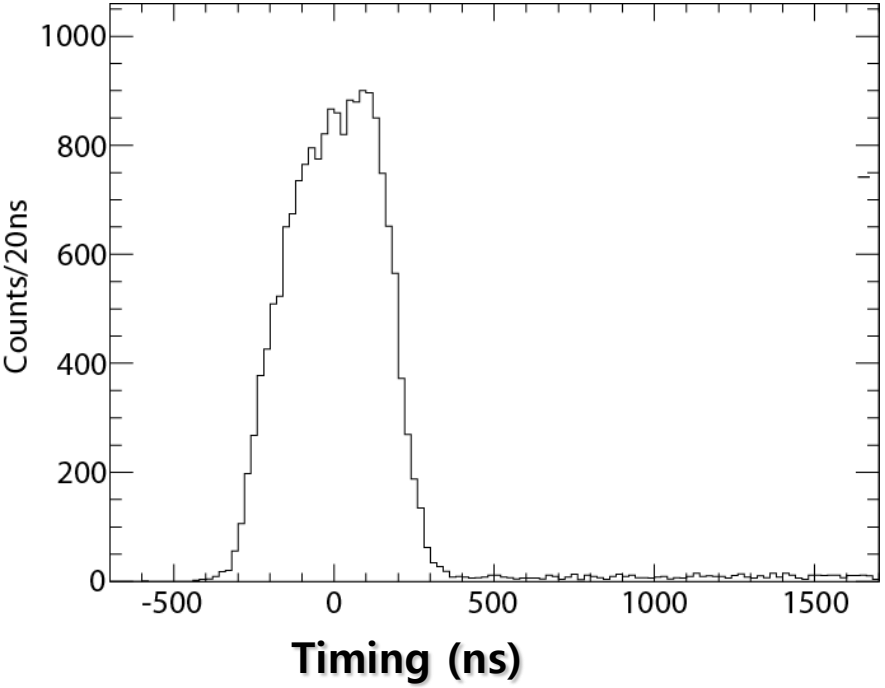
- E17 experiment will be performed in Day-1 at J-PARC hadron facility

Backup slides

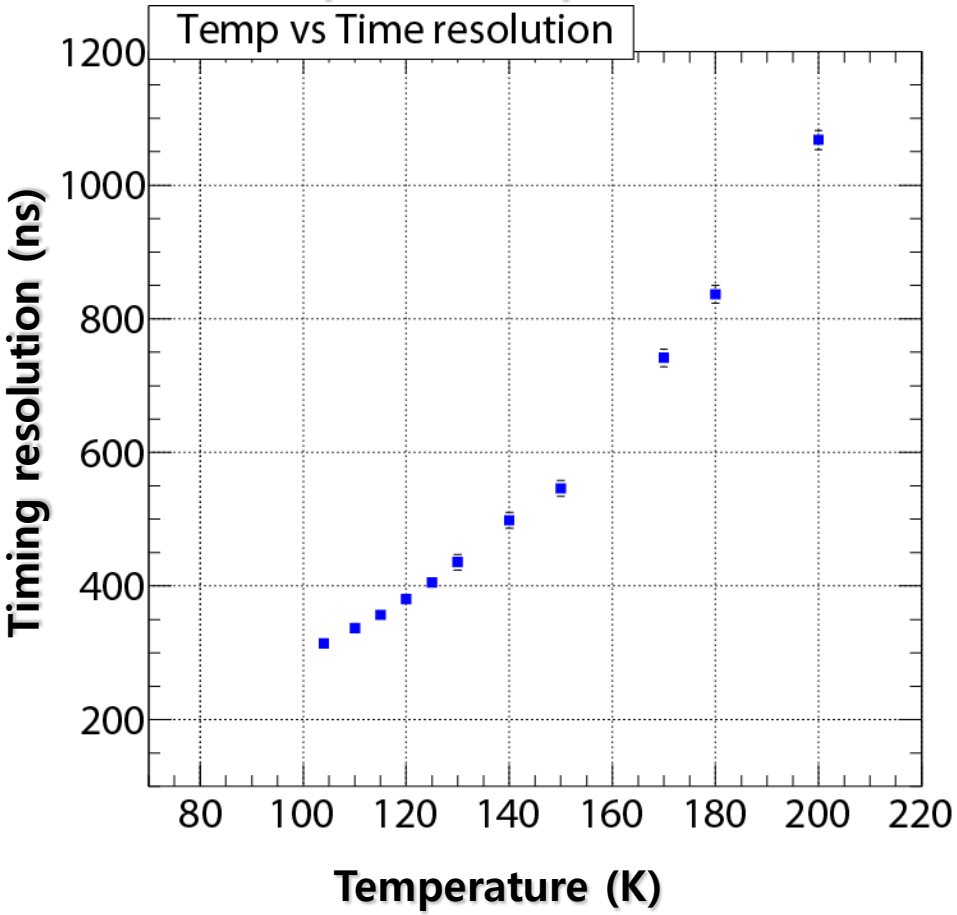
Timing resolution of SDD

- **Sr90 source with thin semiconductor detector (PIPS)**

Typical TDC spectrum

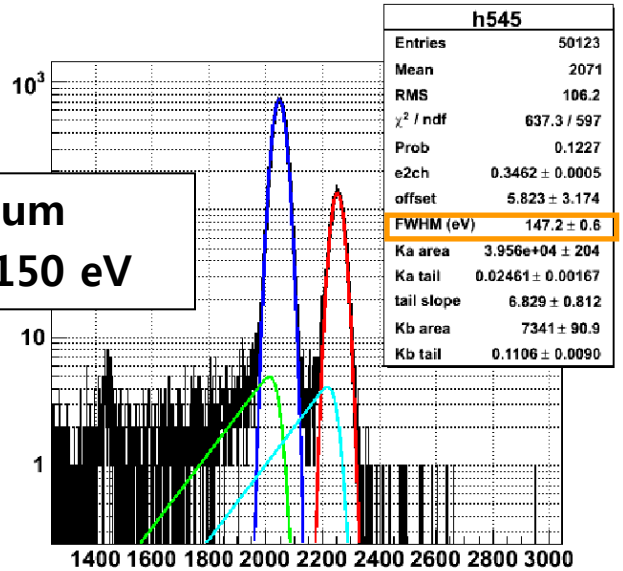


Temperature dependence

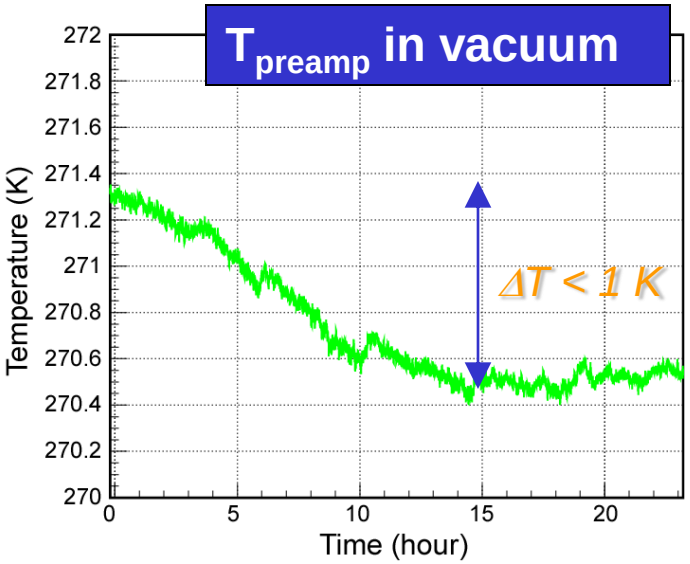


Preamp operation in vacuum

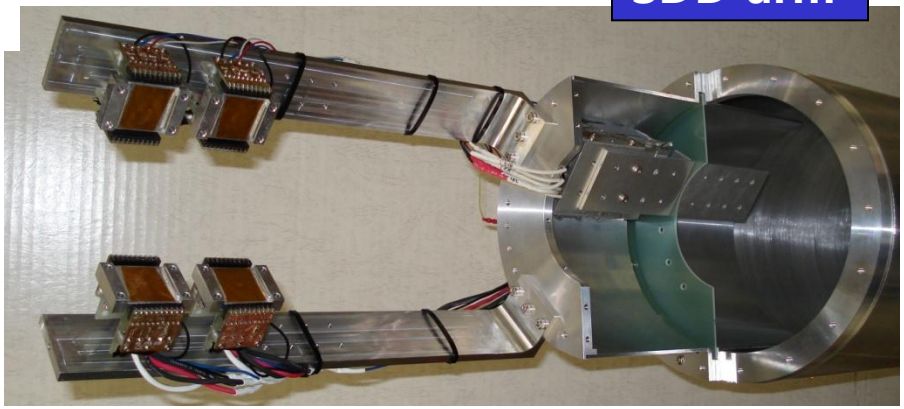
- **Installation preamp into the cryostat**



Preamp in vacuum
Resolution ~ 150 eV



SDD arm



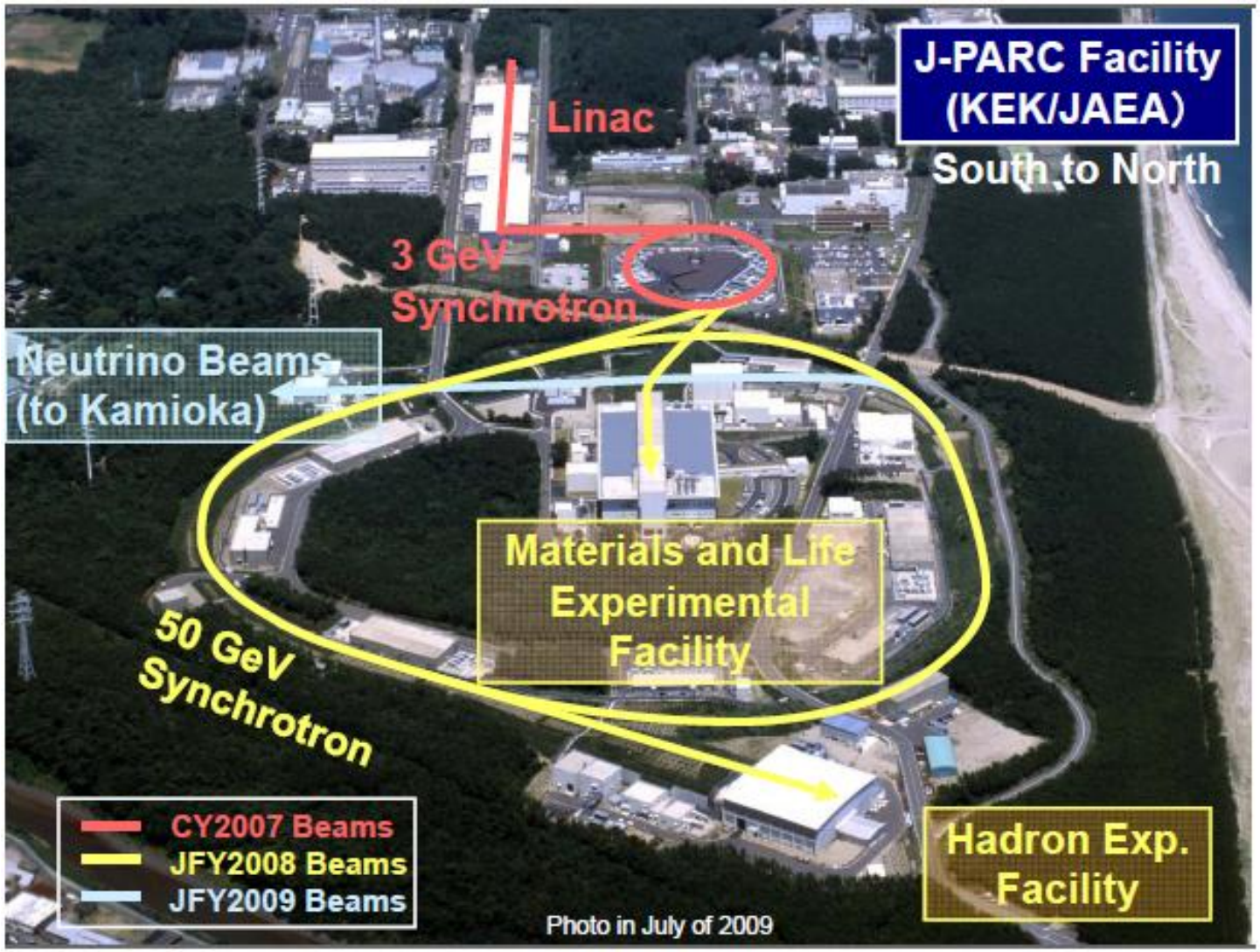
succeed in preamp operation in vacuum

Comparison with past experiments

	E570 (present)	Past exp.
Resolution (FHWM)	~185eV @6.5keV	~300eV @6.5keV
Effective area	100mm^2 * 8 SDDs	300 mm^2
Detector thickness	0.26 mm → Good S/N	~4 mm
Energy calibration	In-beam calib. (Ti,Ni)	Not in-beam calib.
Fiducial volume cut	Yes	No

J-PARC

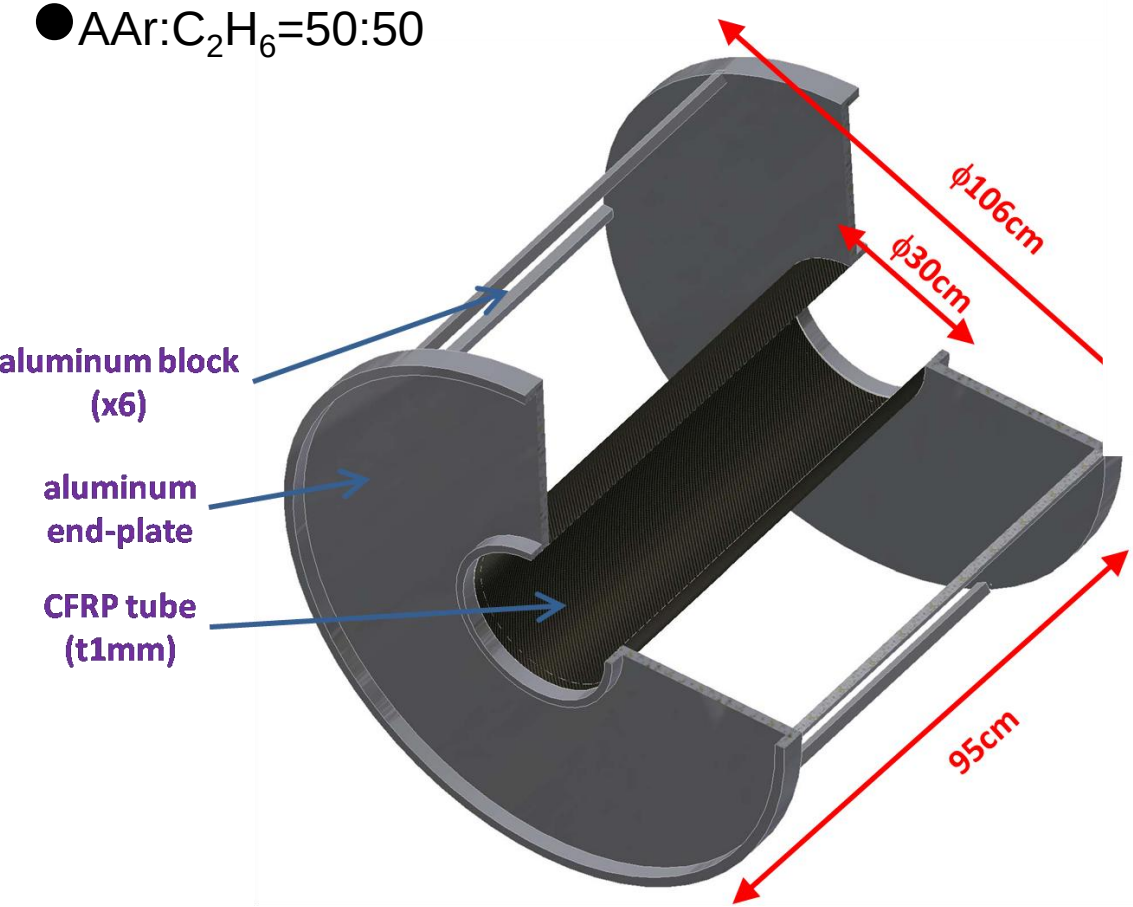
J-PARC = (Japan Proton Accelerator Research Complex)

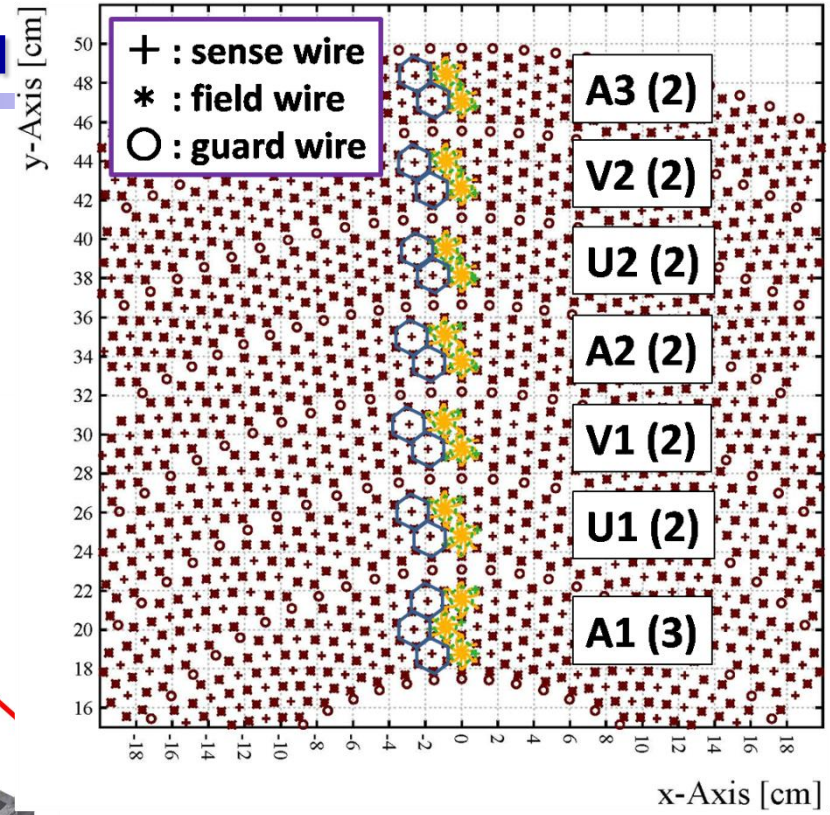


J-PARC hadron facility

CDS : Configu

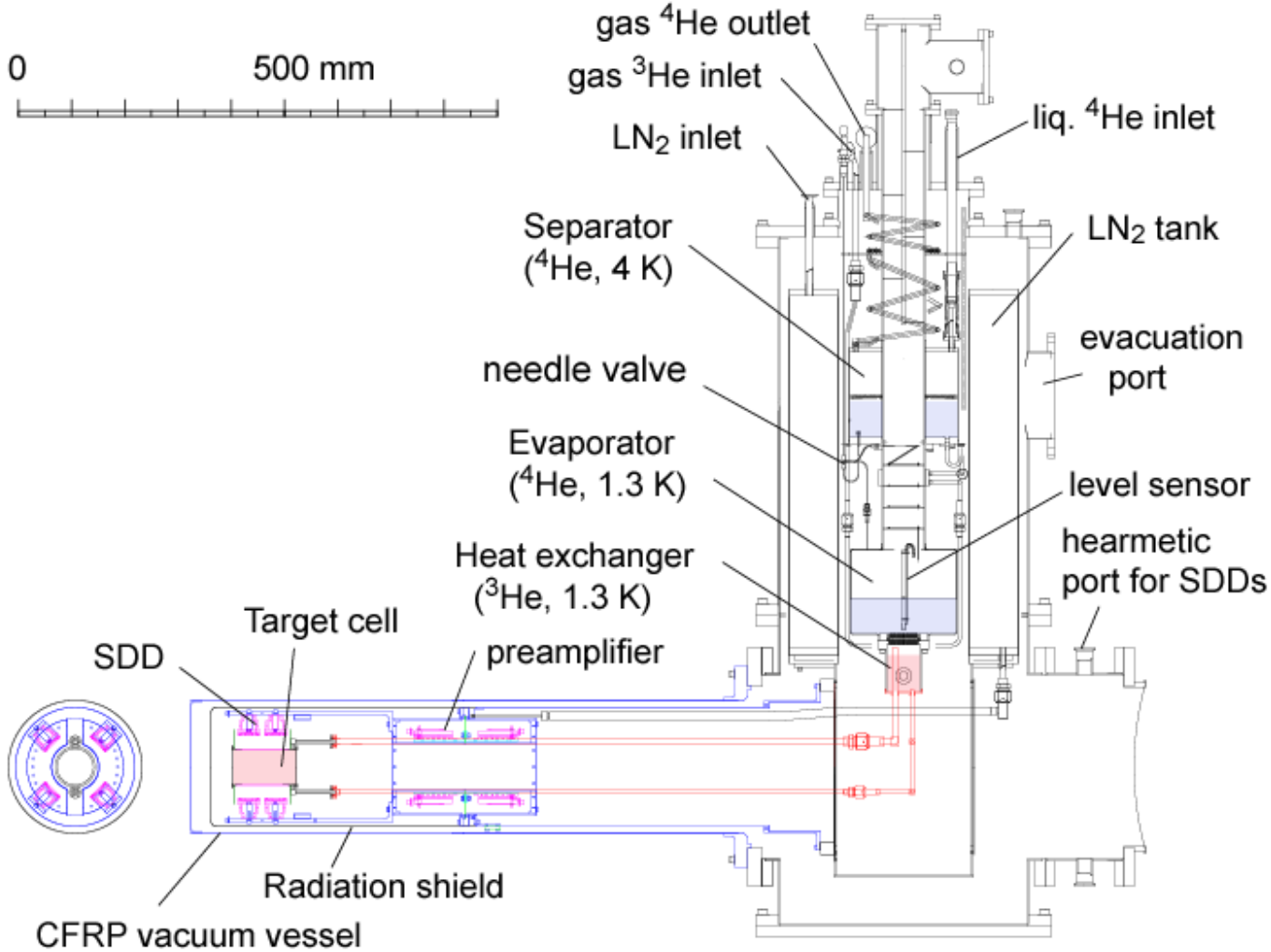
- made of Aluminum and CFRP
- # of wires : 8136
  (read-out : 1816ch)
- ssolid angle = 2.6 π
- AAr:C_2H_6=50:50





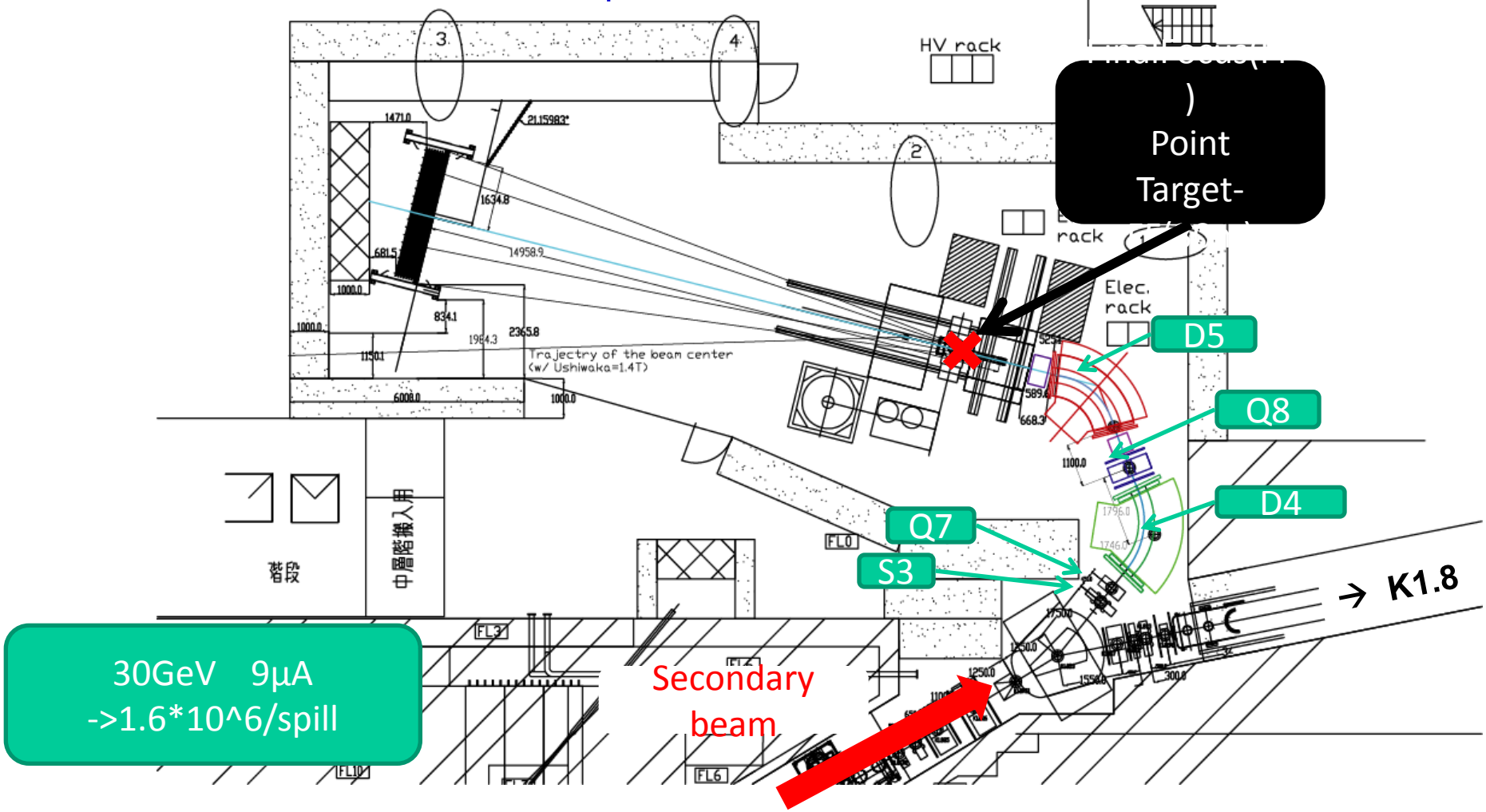
- hexagonal cell
  (drift length ~9mm)
- 15 layers
  (r = 19.05~48.45cm)
- 7 super layers
  (AUVAUVA)

Target : design



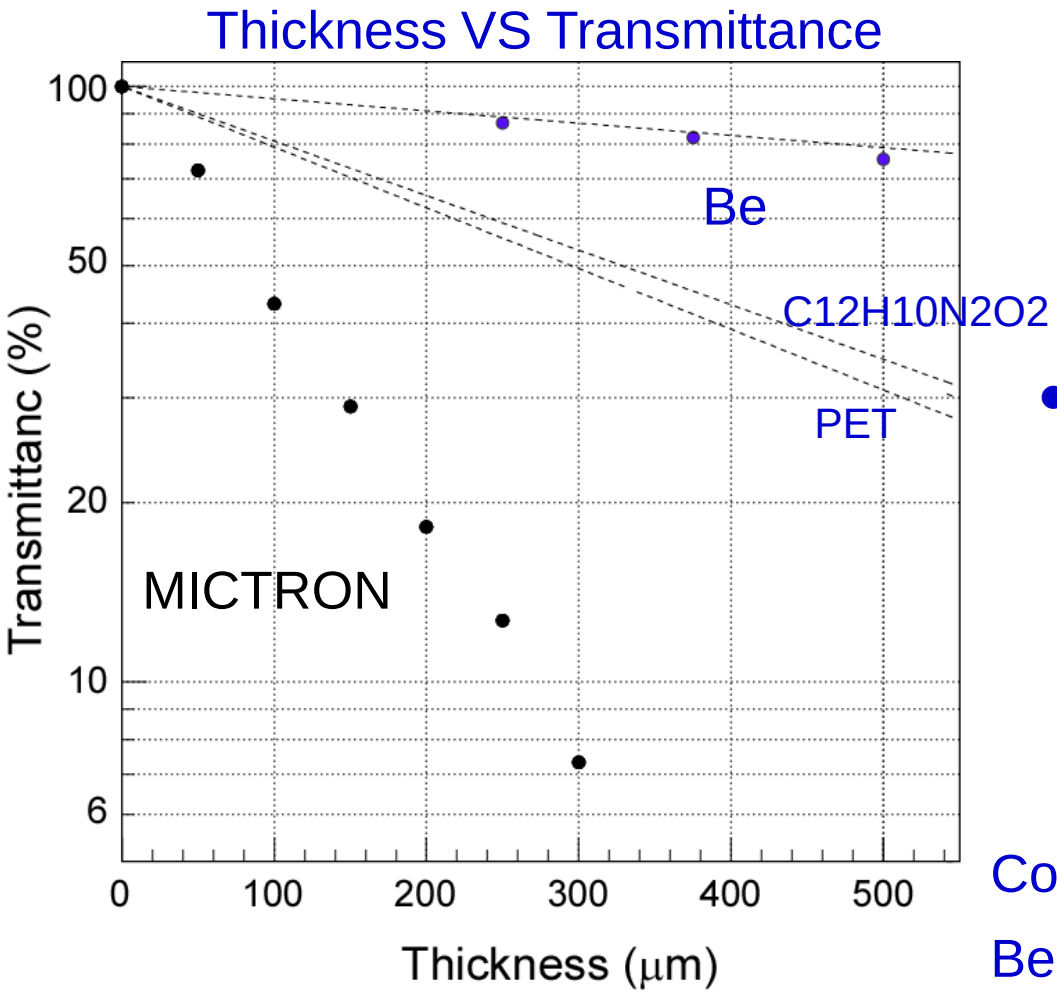
K1.8BR experimental area

- K1.8 & K1.8BR(branch)
  - E15 and E17 exp.@K1.8BR



30GeV 9μA
->1.6*10^6/spill

Target : Be transmittance : result



- Be (250、375、500μm)
  small contribution from impurity

  ~90 % @ 6.2 keV

- MICTRON : low transmittance
  λ : 110 μm
  T = 250 mm →～20%@6.2 keV
  (T = 100 mm →～50%@6.2 keV)

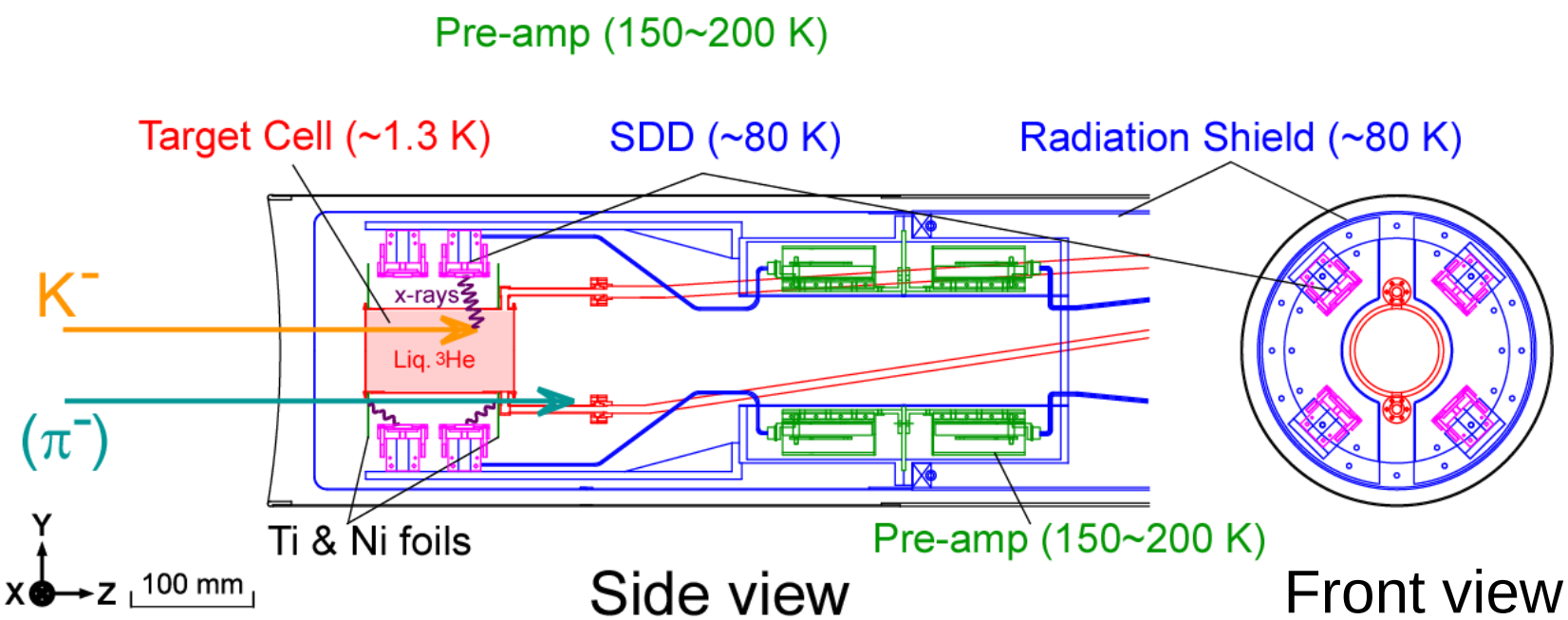
Unfavorable for X ray measurement

Conclusion :

Be cell is the best choice

E17 setup

Reaction	:	stopped $K^- + {}^3\mathrm{He} \rightarrow h\nu(\sim 6.4\mathrm{keV}) + X$
Primary beam	:	30 GeV, 9 μA proton
Secondary beam	:	0.75 GeV/c K^-
Beamline	:	K1.8BR or K1.1
Target	:	Liquid ^{3}He, diameter 6.4 cm, length 15 cm (482.5 cm^3)
Detectors	:	8×100 mm^2 silicon drift detectors (SDD),
		beamline counters and chambers,
		vertex trigger counters and tracking chambers.
Beam time	:	10 days for commissioning
		+3.5 days at K1.8BR (assuming full PS intensity)
		+35 days at K1.8BR (with 10% of the design intensity)[4]



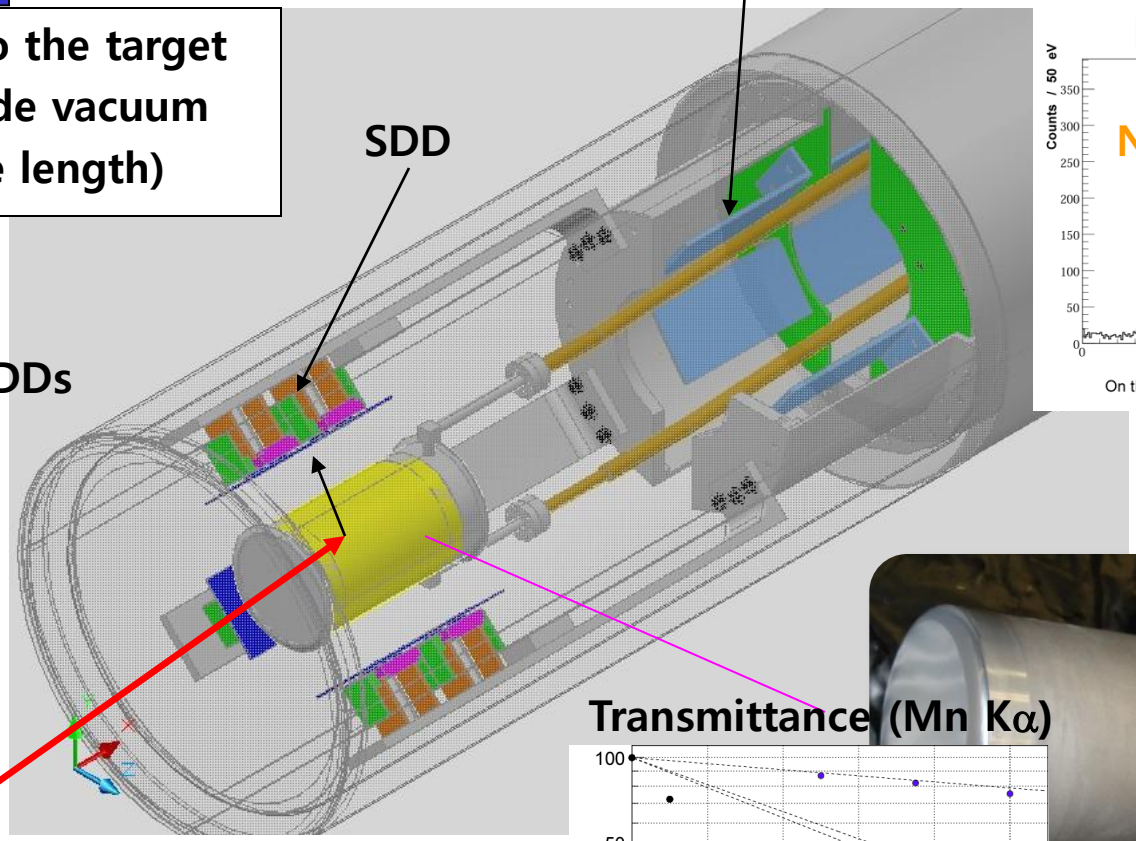
Application to X-ray detection system

- Install X ray detectors (SDDs) very close to the 3He target

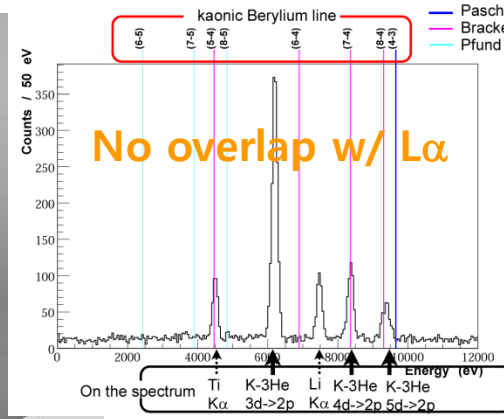
requirements

- SDD close to the target
- Preamp inside vacuum (minimum cable length)

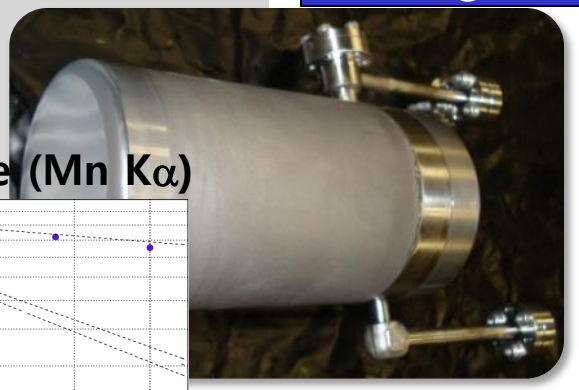
SDD acceptance
~1.0(1.3) % /8 SDDs
w/ (W/O) attenuation



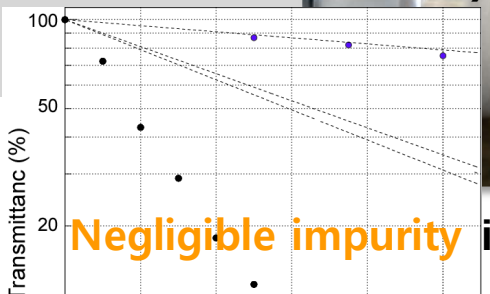
Kaonic Be lines



Beryllium target cell



Transmittance (Mn Kα)



ittance : 95 % at 6.2 keV

Realistic heat load test was done
→ No increase of 4He consumption

Target temperature map