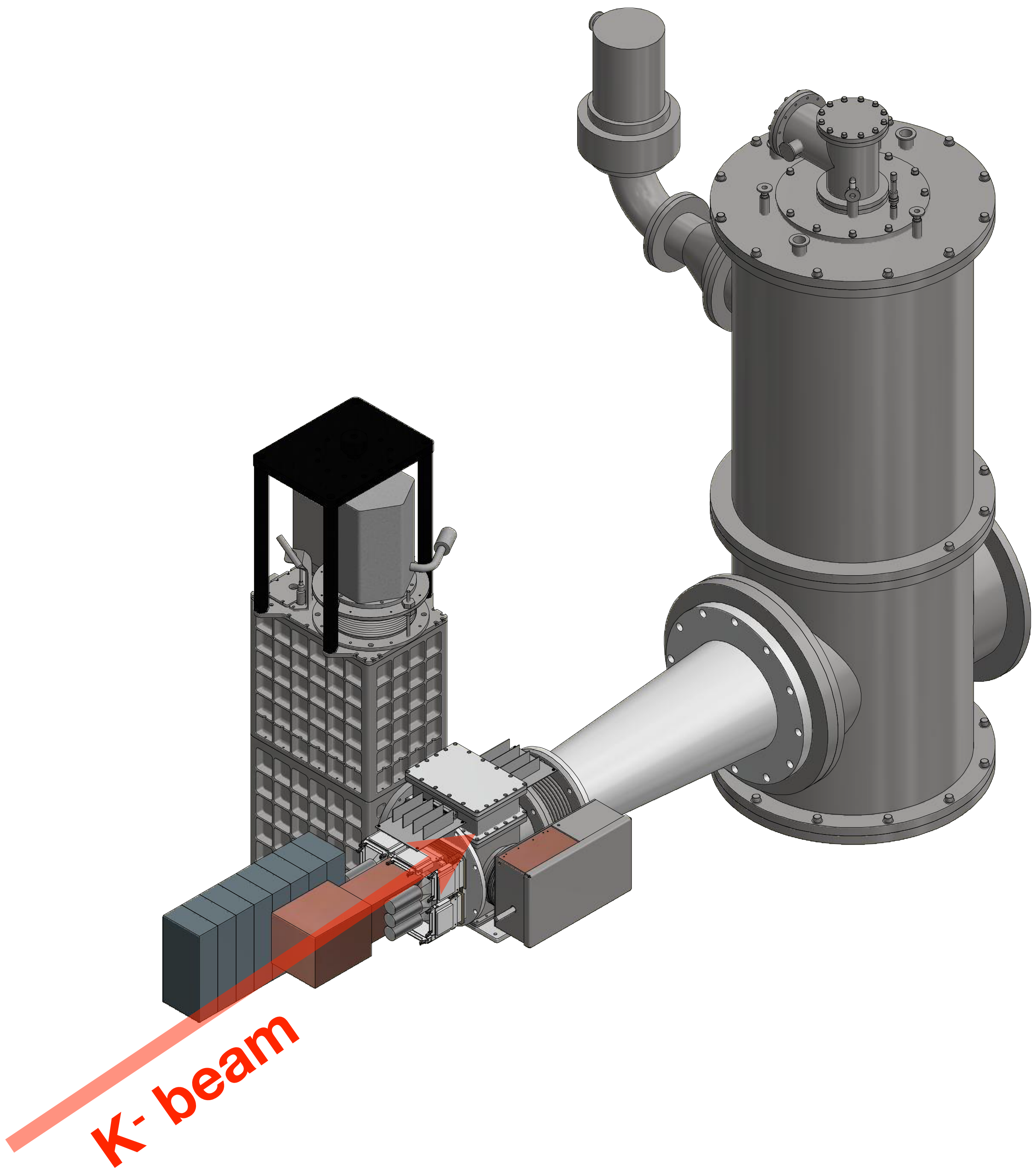
Status of kaonic atom experiments at J-PARC

Tadashi Hashimoto

K-atom experiments @ J-PARC K1.8BR

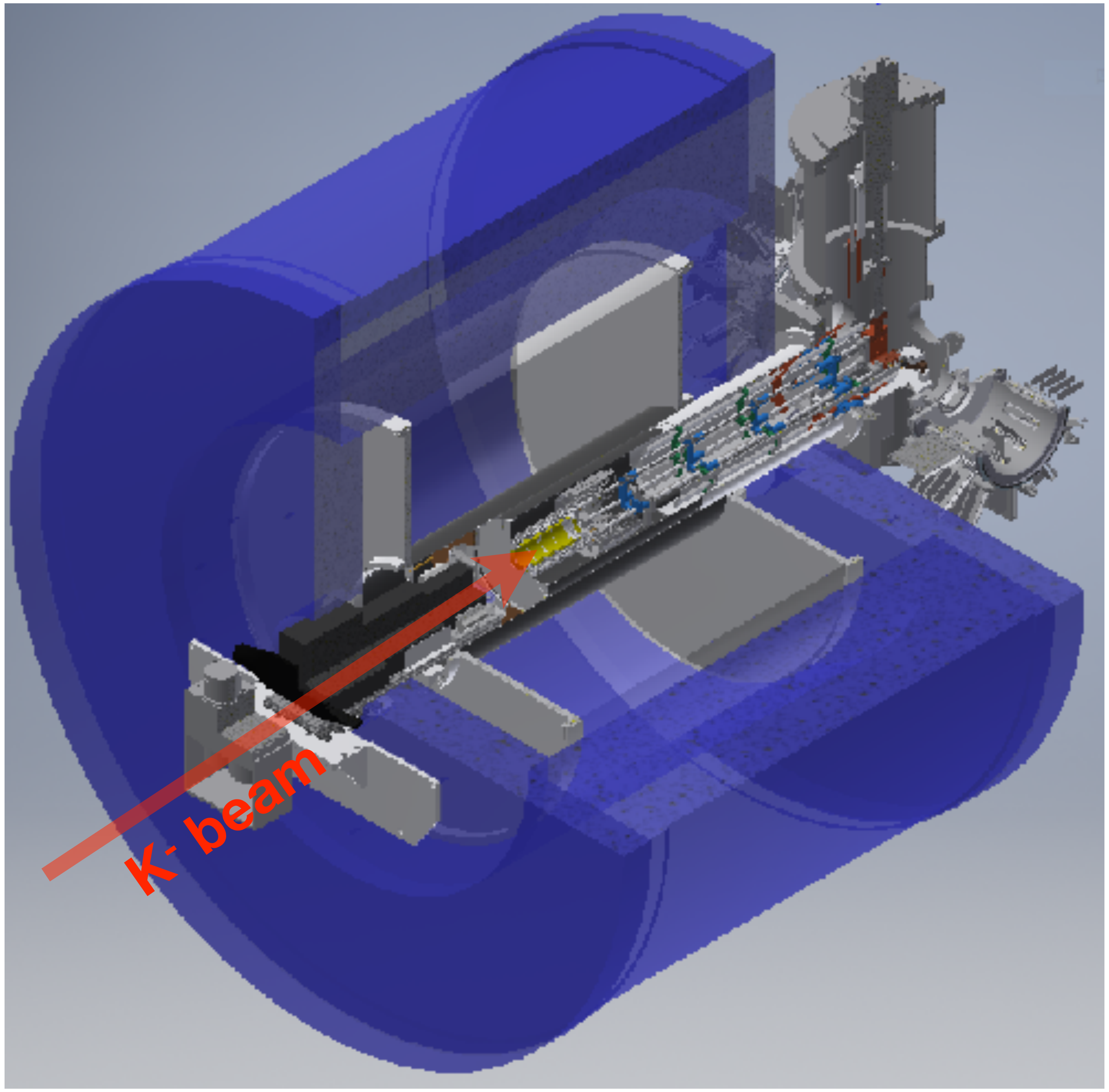
E62: K^{-}He 3d-2p

sub-eV precision (ΔE_{2p})
to distinguish "deep" or "shallow" potential



E57: K^{-}d 2p-1s

first measurement
to resolve isospin-dependent $K^{bar}N$ scat. length



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Present status

Year	E62	E57
2006	E17 proposal (1st PAC)	
. . .		
2014	TES demonstration @ PSI	E57 proposal (18th PAC)
2015	E62 proposal (20th PAC) →**stage-2** approval	updated proposal (20th PAC) →**stage-1** approval
2016	Commissioning at K1.8BR (**K-Li X-rays**)	
2017		
2018	**K-He Physics run** (June)	SDD commissioning
2019		**K-H (+K-He) full commissioning** (Feb.—Apr.)
2020		to submit updated proposal

K^-He with TES

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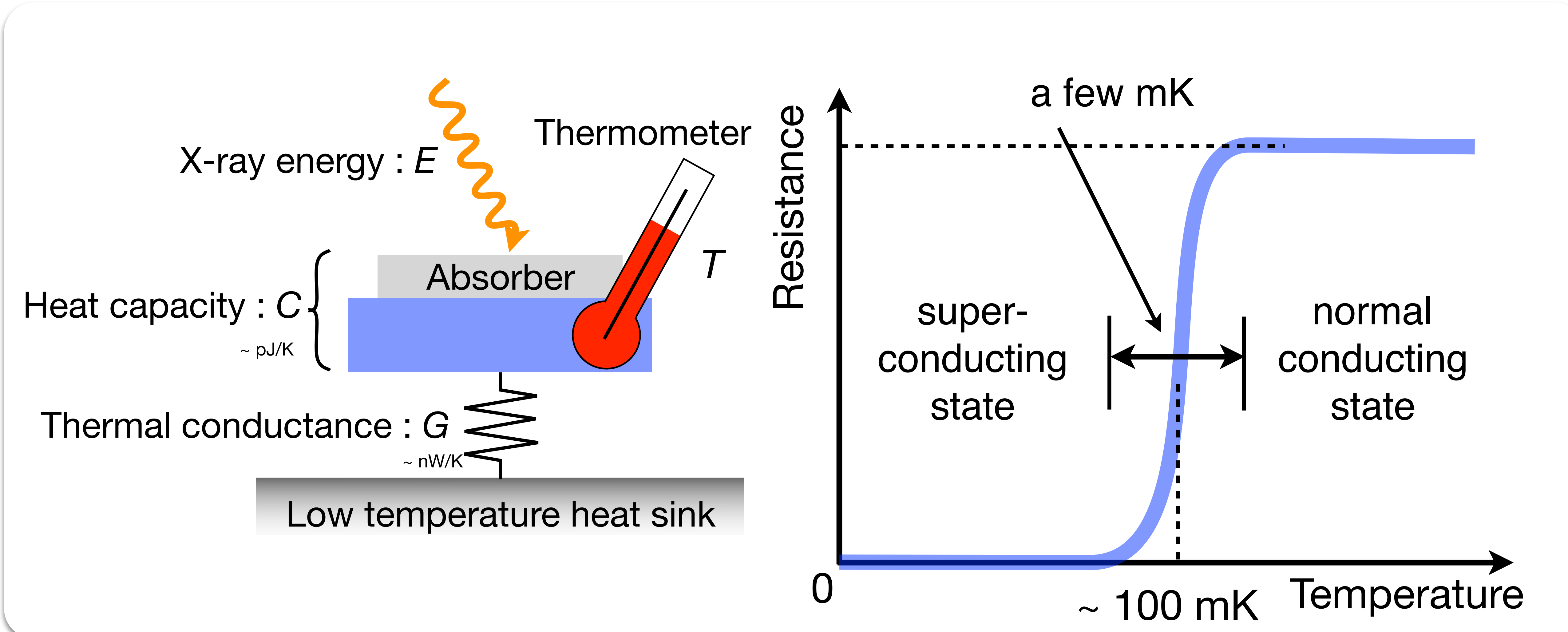
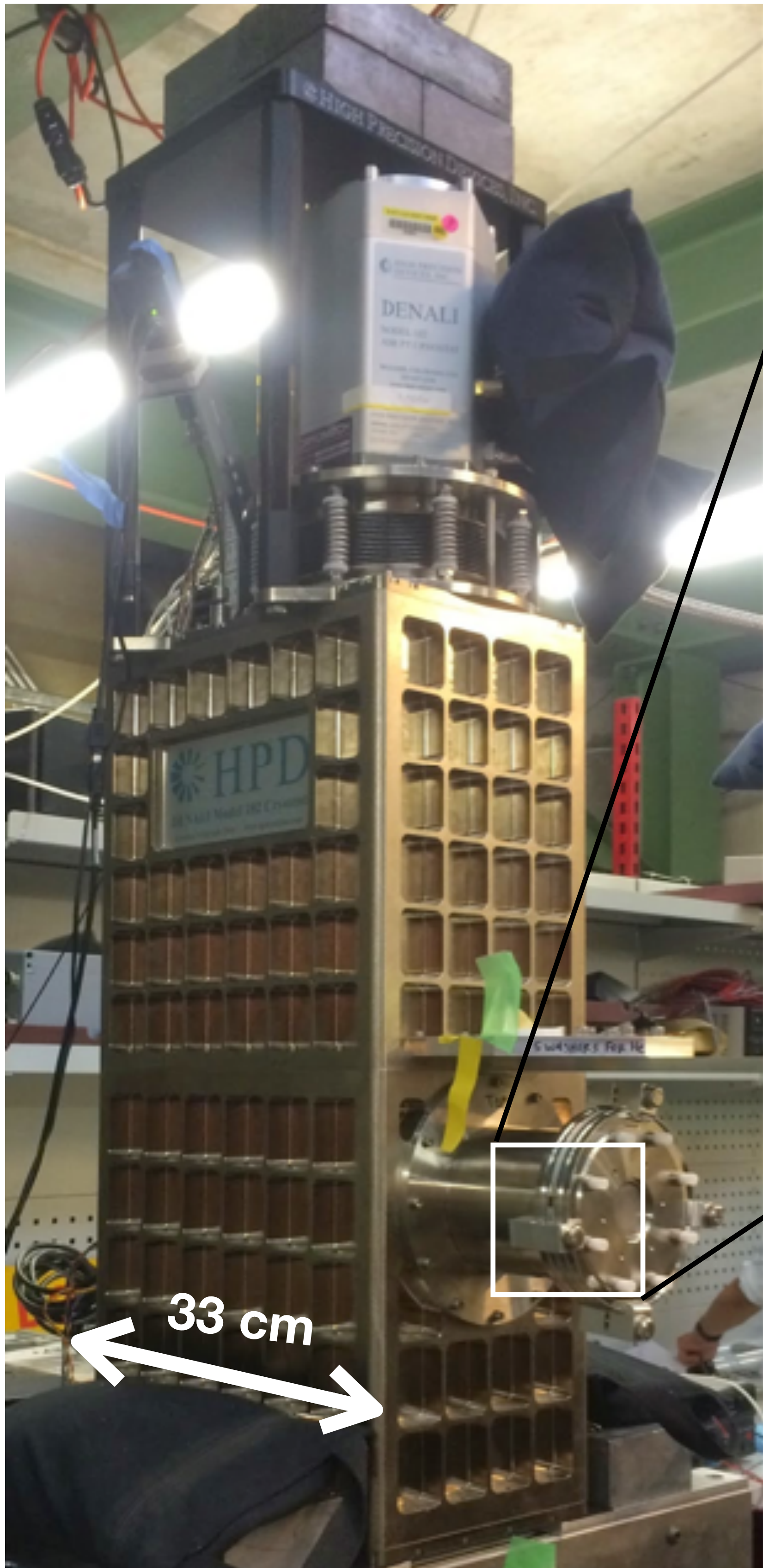
Transition-Edge-Sensor microcalorimeters



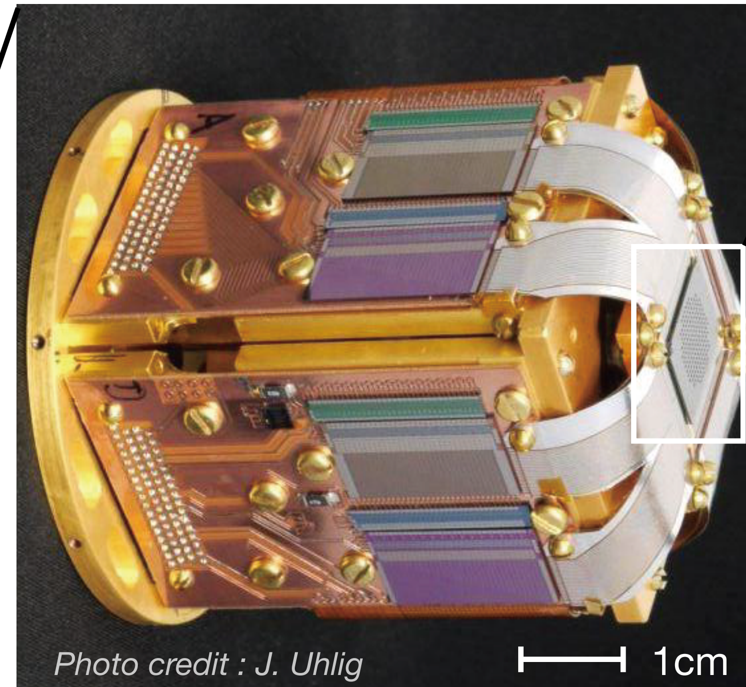
- ✓ Excellent energy resolution ~2 eV FWHM@ 6 keV
- ✓ Wide dynamic range possible

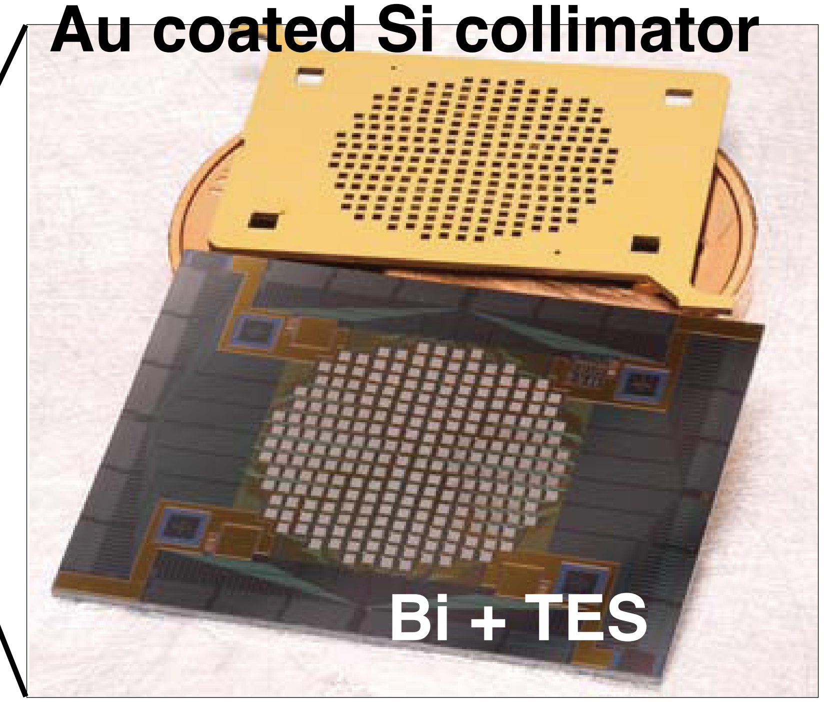
$$\alpha \equiv \frac{d\ \ln R}{d\ \ln T} \qquad \Delta E = \sqrt{\frac{k_B T^2 C}{\alpha}} \qquad E_{max} \sim C T_C / \alpha$$

NIST TES system

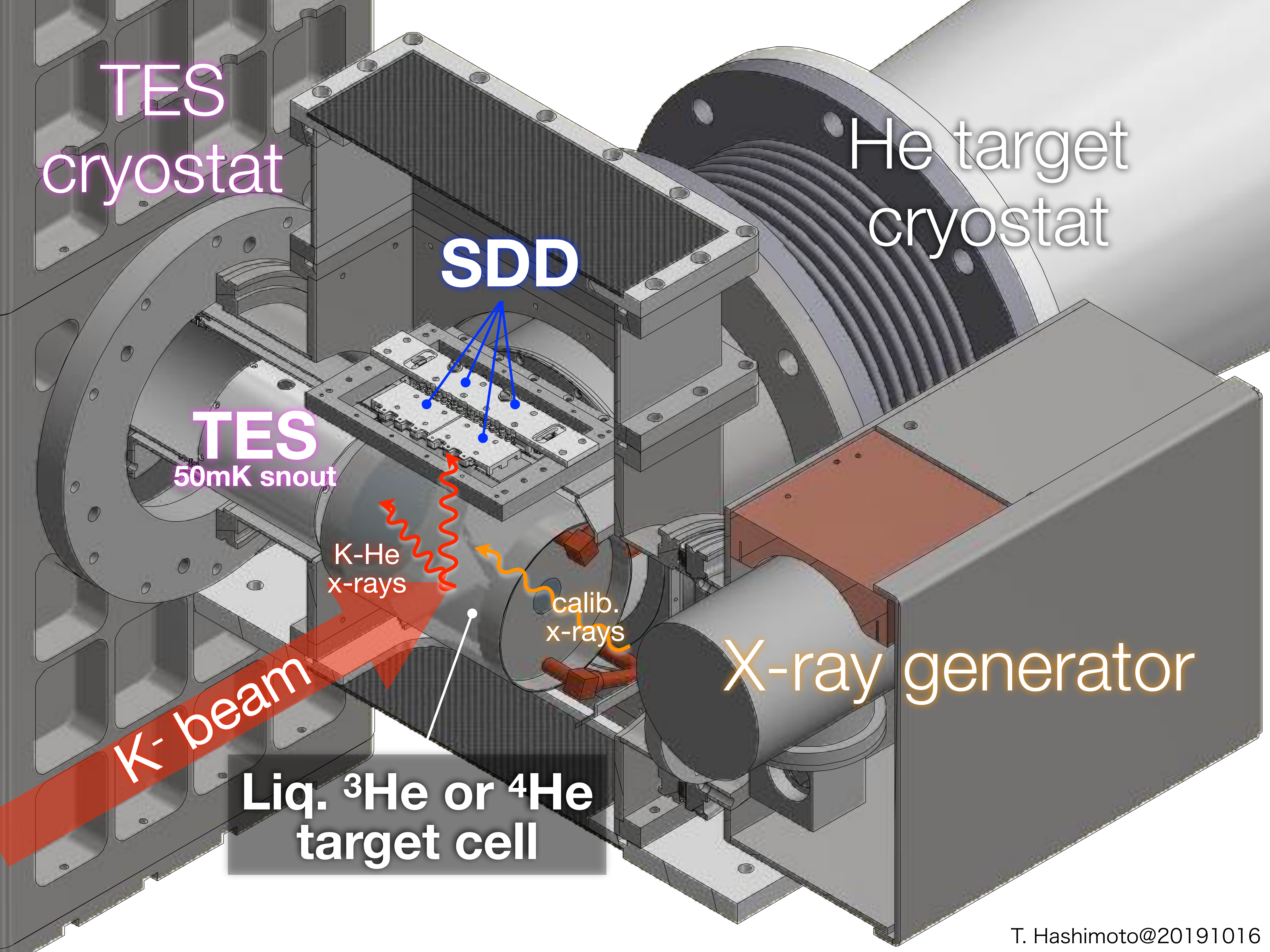


J.N. Ullom et al., Synchrotron Radiation News, Vol. 27, 24 (2014)





- **50mK cryostat**
  - Pulse tube (60K, 3K) + ADR (1K, 50mK)
  - ADR hold time: > 1 day
- **Detector snout**
  - 240 pixel Mo-Cu bilayer TES
    30 ch TDM(time division multiplexing) readout
  - 1 pixel : 300 x 320 um^2 → total ~ 23 mm^2
  - 4 um Bi absorber → efficiency ~0.85@6 keV


TES
cryostat
He target
cryostat
SDD
TES
50mK snout
K-He
x-rays
calib.
x-rays
X-ray generator
K- beam
Liq. ³He or ⁴He
target cell
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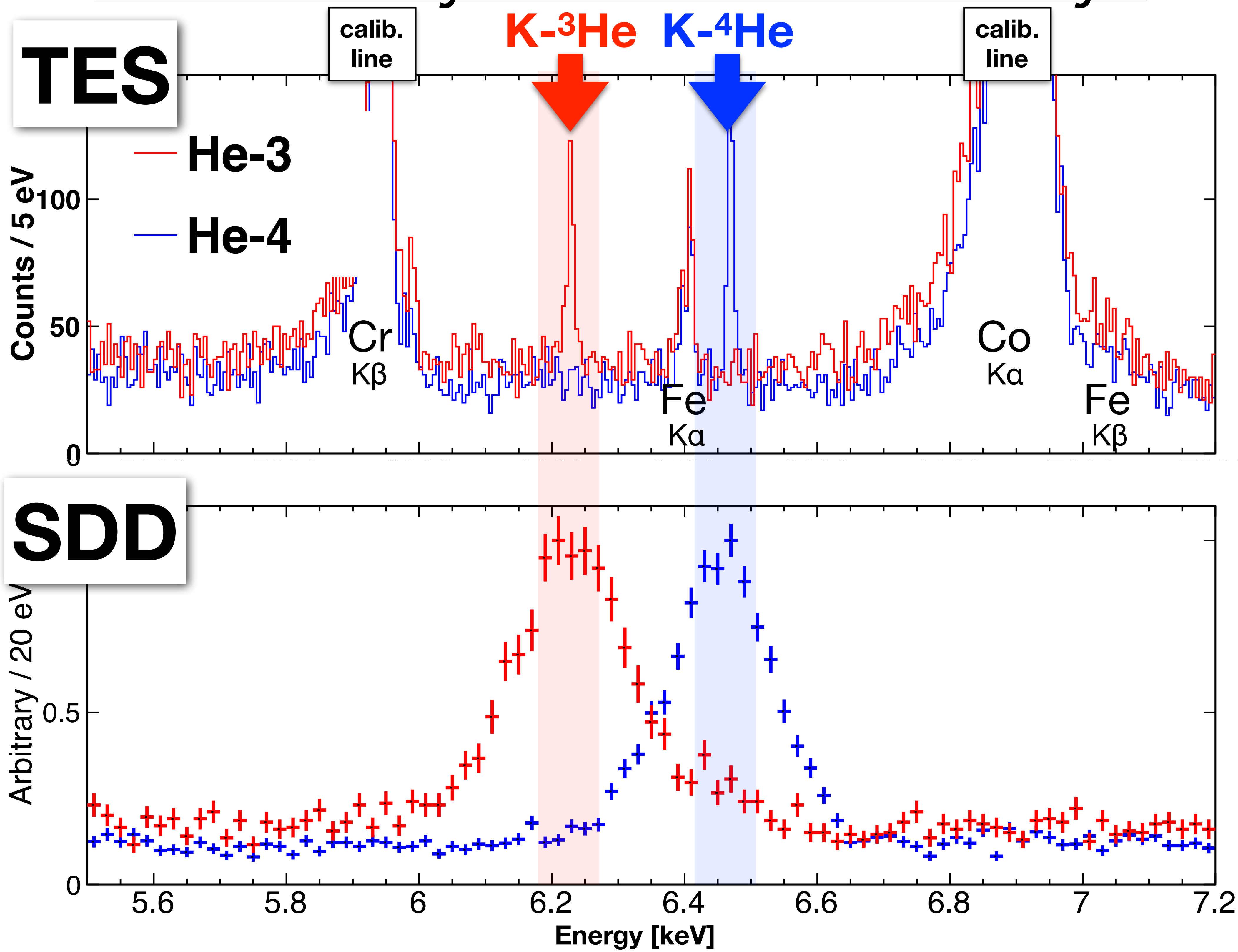
Preliminary result : K-He x-rays



- X-rays from Kaon atoms are clearly observed !

TES

- **We can reduce the background by factor 3~4 using beam info.**

- **Publication should come soon on the shifts and widths.**

- **More experiences with TES**
  - at Muon beam line in J-PARC. (Apr. 2019)
  - at Synchrotron Radiation Facility (SPring-8, July, 2019)

- **TES in DAFNE?? Machine background??**

K^-Li/He/H_2 with SDD

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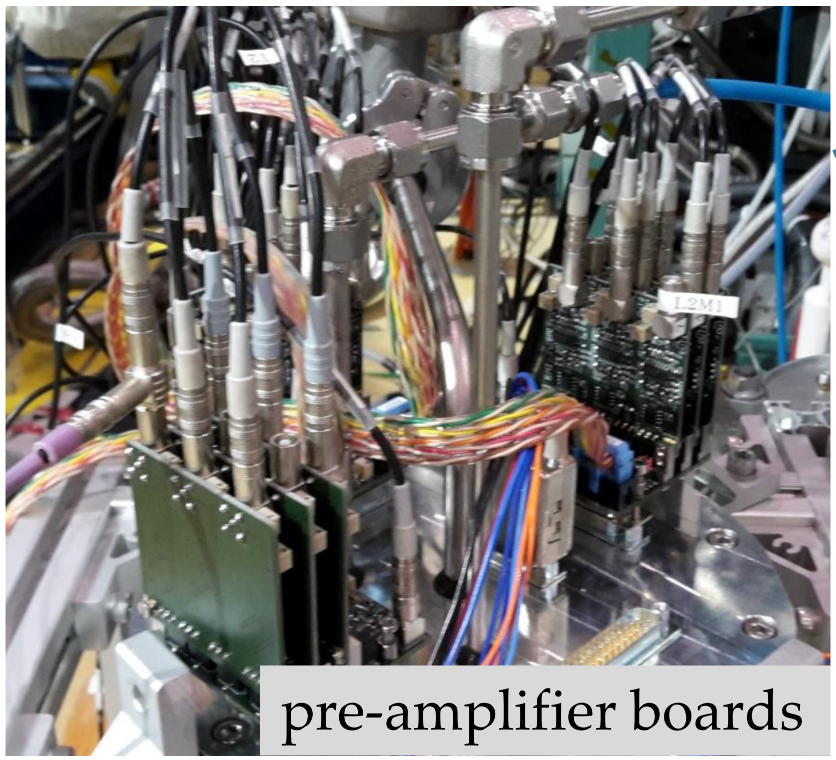
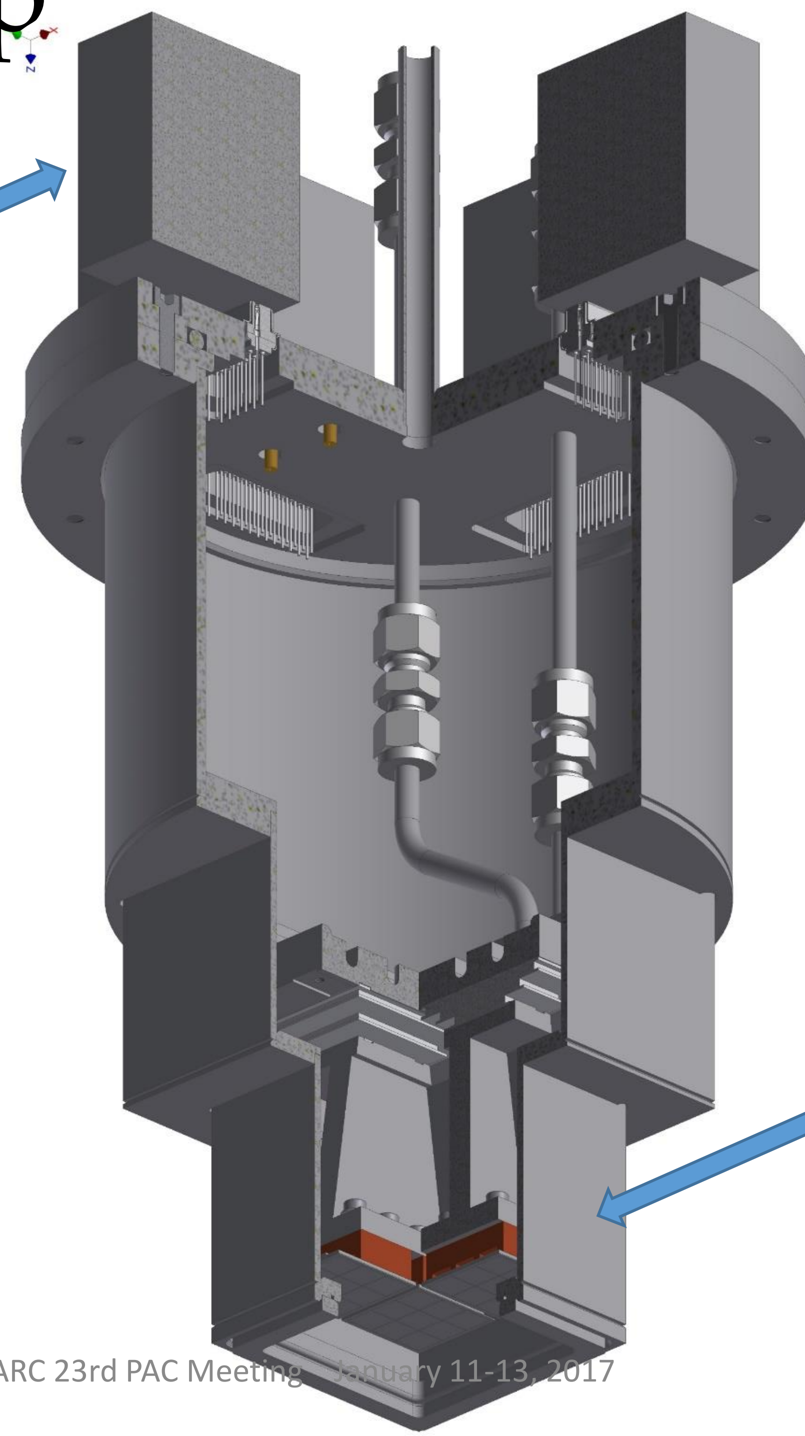
SDDs in commissioning run in 2016

3-day beam time

E57 - SDD test setup



pre-amplifier boards



4 arrays installed
24/36 channels worked

3x3 SDD array

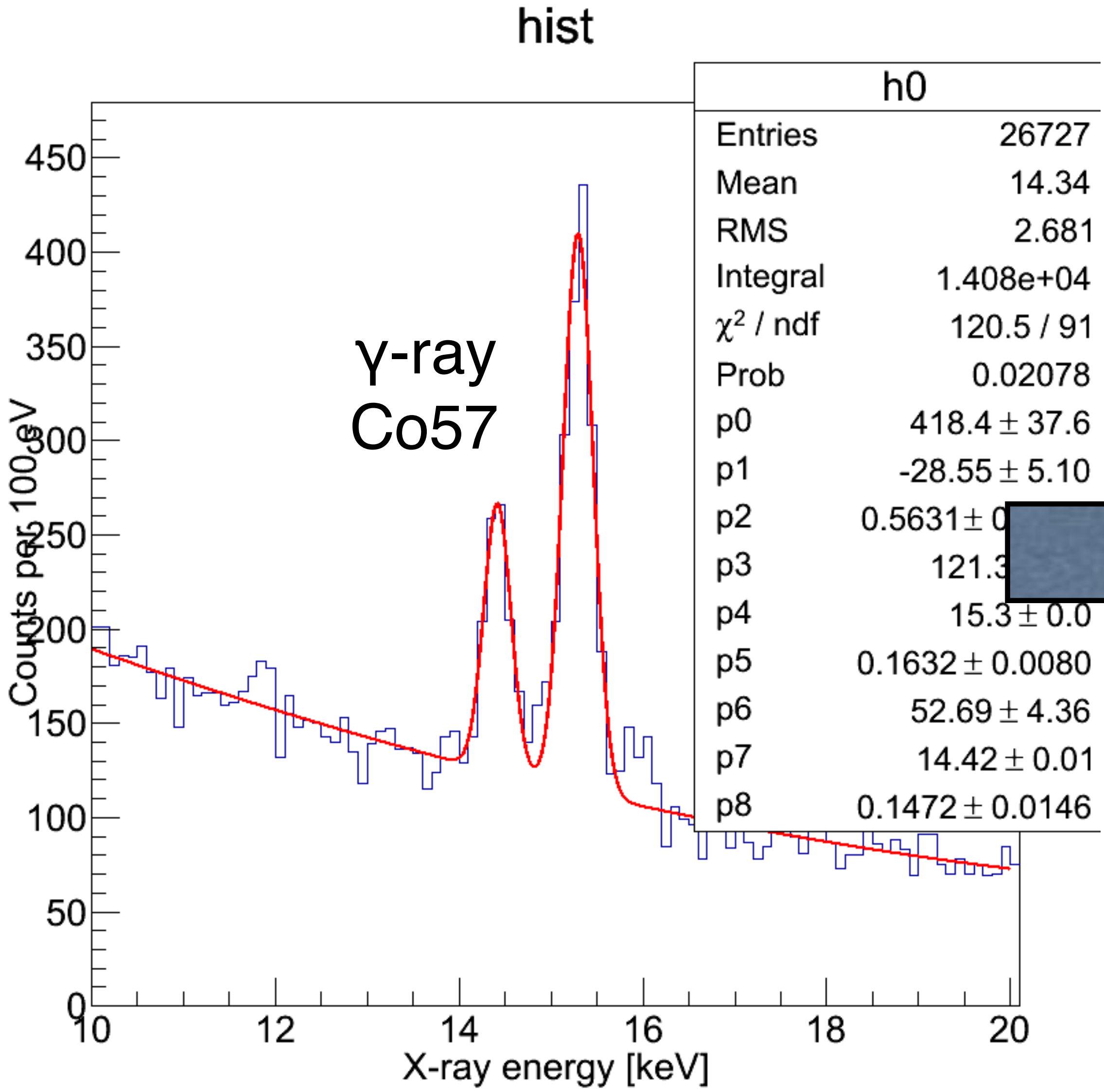
3-stage Peltier-cooler

SDDs @ -40℃

-> N568 CAEN Shaping Amp.
-> V785 CAEN PADC

Kaonic Lithium with SDDs

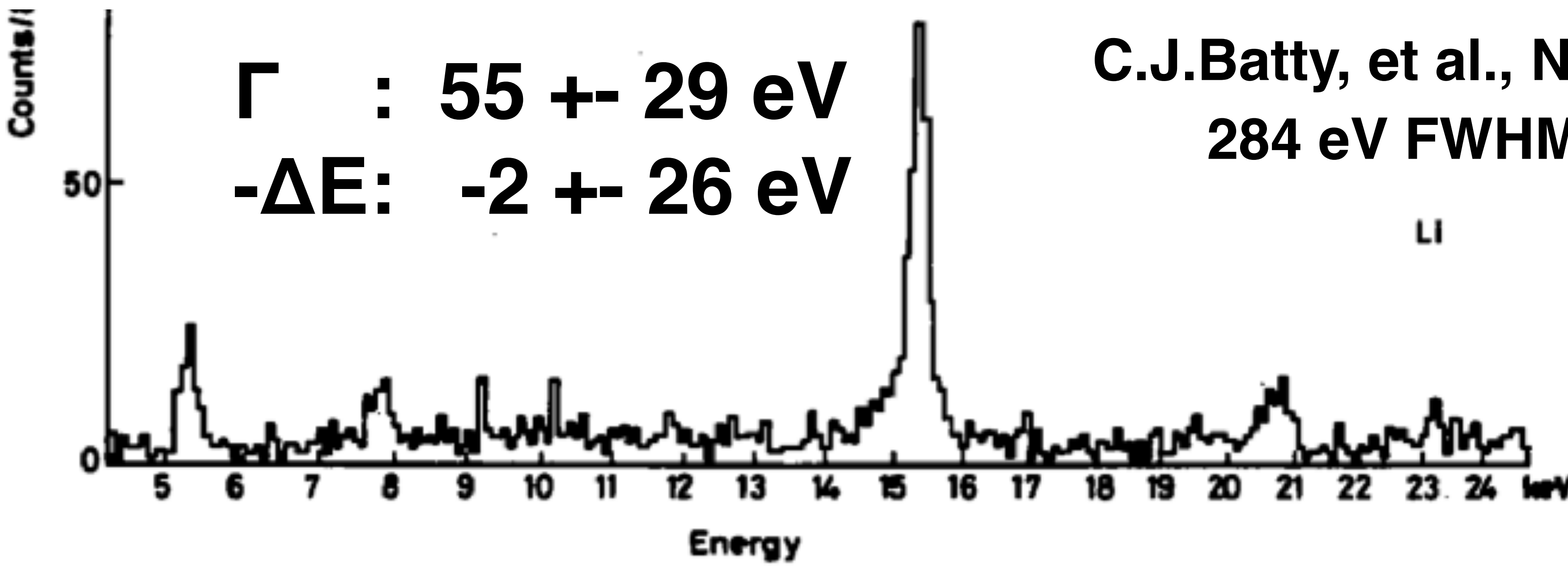
Shown in PAC July, 2016



Now (very preliminary)

- Now more X-ray counts and better S/N with updated event selection.
- Need to check everything once again…

Kaonic Lithium



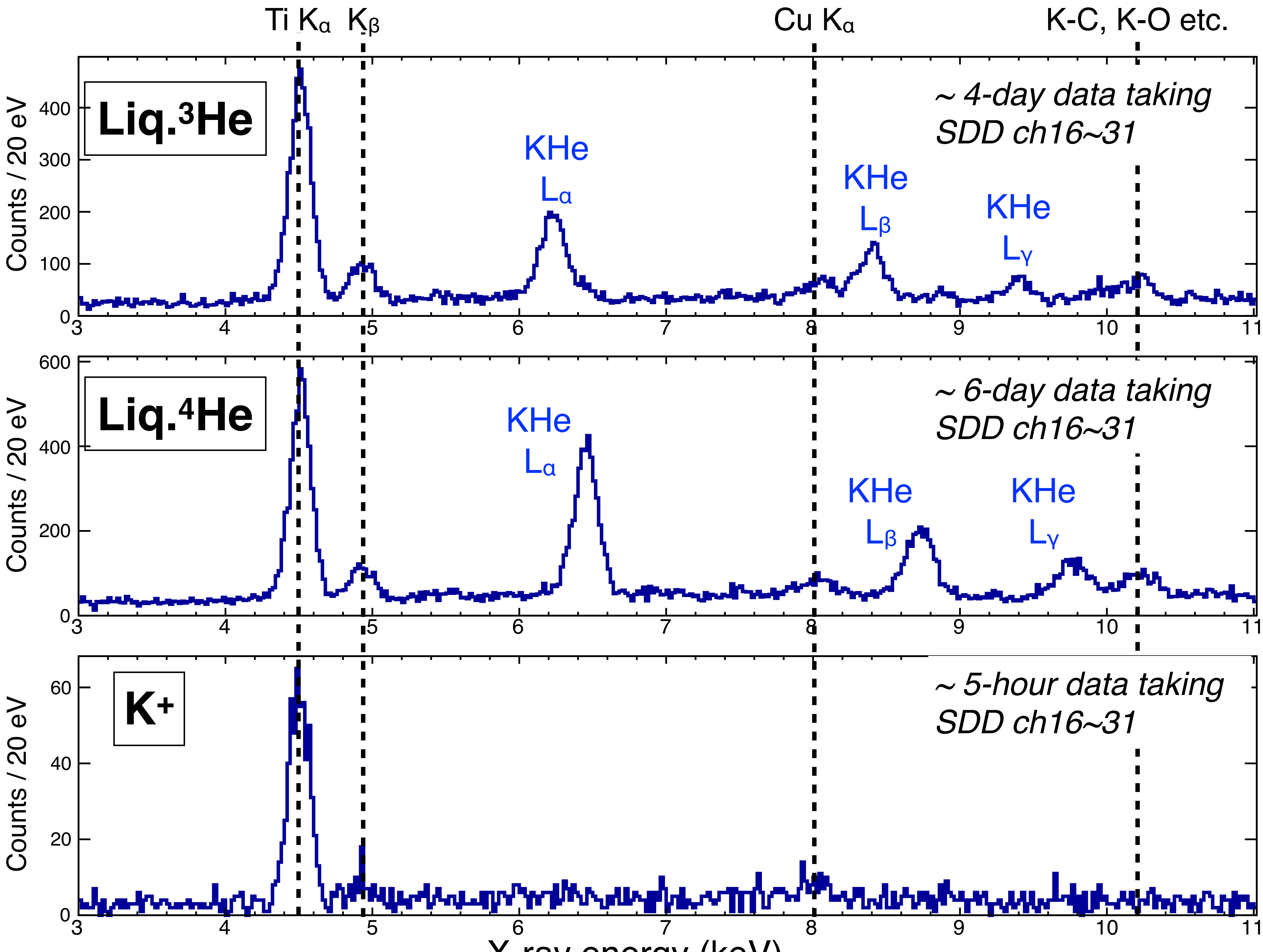
C.J.Batty, et al., NPA282(1977)487-492
284 eV FWHM@14.4 keV

Fig. 1. Measured spectra obtained with Li (metal) and LiH target. The Li spectra was obtained with 2.7×10^7 kaons stopping in the target whilst for LiH the number of stopping kaons was 1.9×10^7.

- S/N is worse in our spectrum, but we have a lot more X-ray count
- Shift : ~ 2 eV stat. error
- Width : ~ 5 eV stat. error?
- Yield :
  - might better to use partial dataset with relatively stable beam condition
  - Compare with K+ decay and K- vertex analysis to confirm the # of stopped kaons in the Li block

SDD spectra in E62

4 SDDs @ 115K
< 200 eV FWHM @ 6 keV



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X-ray yields from Kaonic Helium

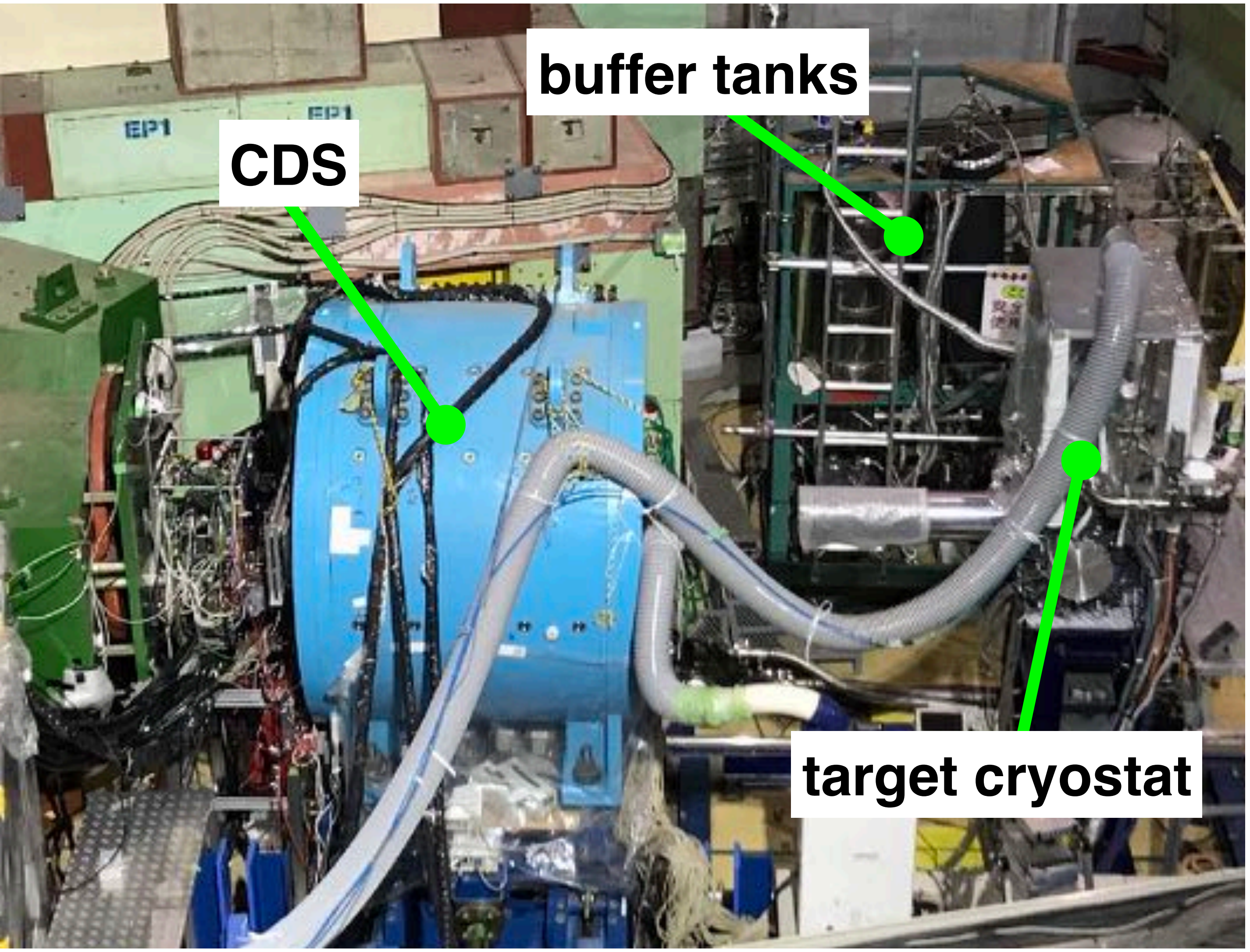
Eur. Phys. J. A (2014) **50**: 91

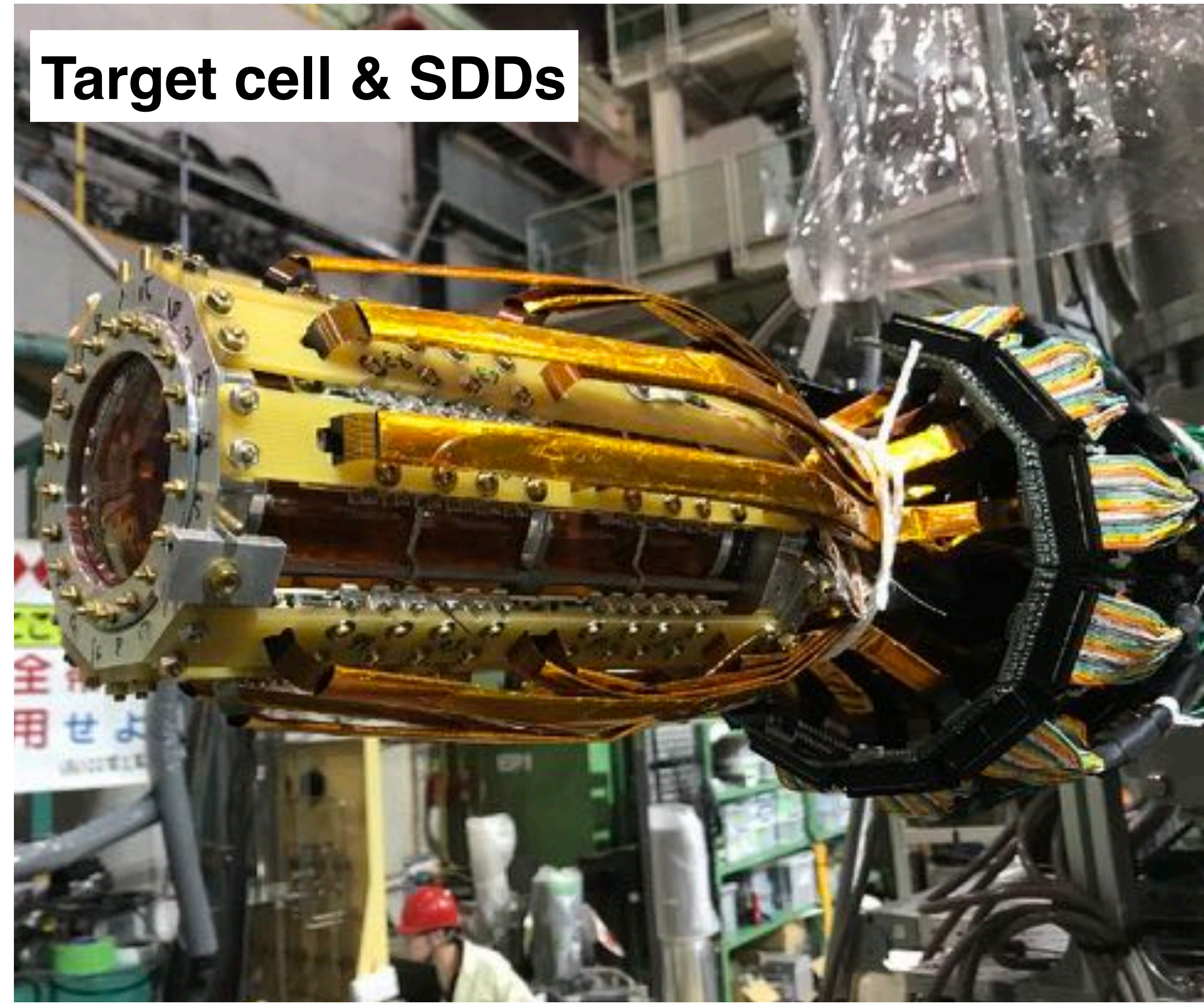
Table 2. Absolute X-ray yields of K^{-3}He and K^{-4}He measured in gas targets. The yields are shown in percentages per stopped K^-. The experimental results for liquid ^{4}He, refs. [1,3], are also shown in the last columns. The value of L_{high} in the liquid density data [3] includes the contribution of $L\delta$ only.

Transition	^{3}He (0.96 g/l)	^{4}He (1.65 g/l)	^{4}He (2.15 g/l)	^{4}He (Liquid) [1]	^{4}He (Liquid) [3]
$L\alpha$	$25.0^{+6.7}_{-5.8}$	$23.1^{+6.0}_{-4.2}$	$17.2^{+2.6}_{-9.5}$	9.2 ± 2.4	8.9 ± 4.5
$L\beta$	$3.6^{+1.3}_{-0.7}$	4.2 ± 1.1	$3.1^{+0.6}_{-1.6}$	5.2 ± 1.3	2.3 ± 1.2
$L\gamma$	$1.3^{+0.5}_{-0.4}$	1.3 ± 0.6	$0.7^{+0.3}_{-0.5}$	2.4 ± 0.7	1.6 ± 0.8
L_{high}	5.2 ± 2.1	$6.9^{+2.0}_{-1.9}$	$4.1^{+1.1}_{-2.1}$	–	$0.4 \pm 0.3^*$

- X-ray yields
  - Liquid Helium-3: new data
  - Liquid Helium-4: data only in 1970's
- Not so good secondary particle detectors in E62
- No theoretical calculation to compare (?)
- Gaseous Helium-4 with E57 setup is possible as well
  - limited statistics, but (potentially) well controlled systematics.

E57 setup as of Feb. 2019

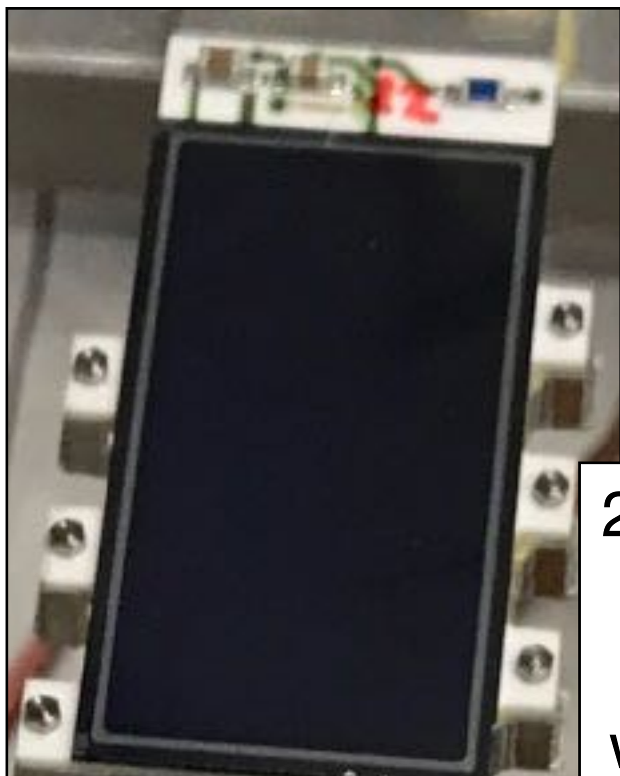




- ✓ 30 SDD units installed.
- ✓ ~145 ch in 26 units worked. (145/208 ~ 70%)
- ✓ Target gas at 30K, 3.5bar, SDDs at 190K

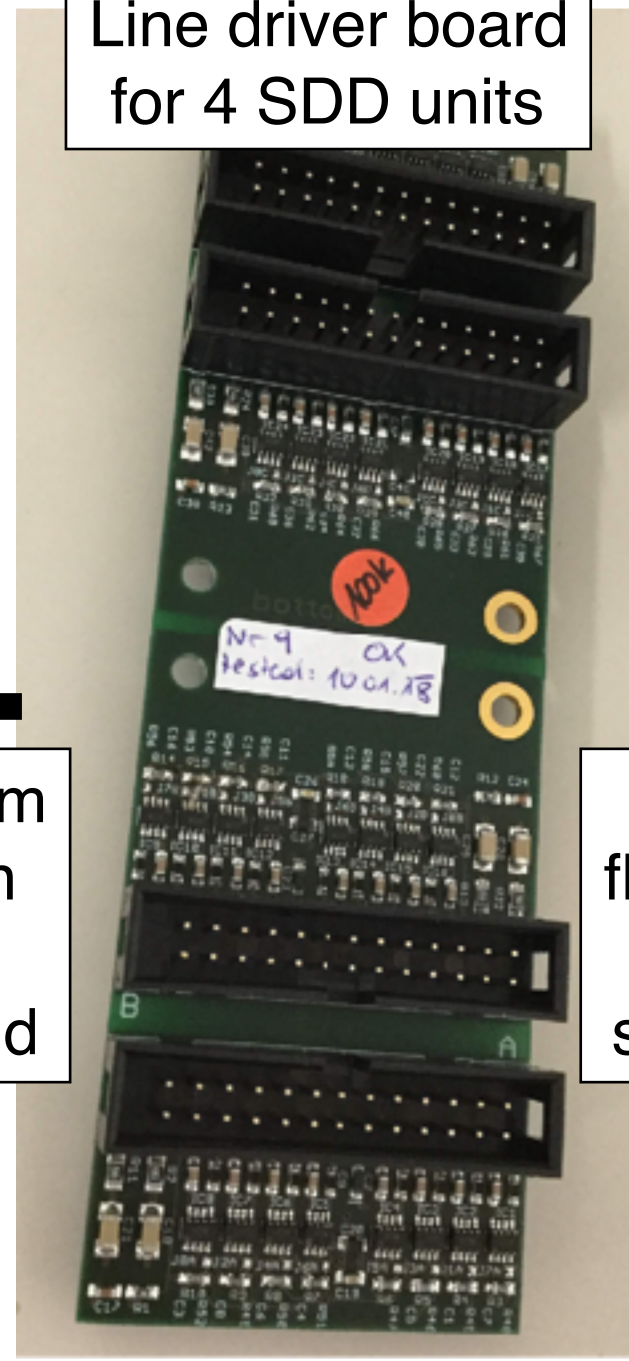
SDD Readout for J-PARC E57/E62

SDD with CUBE exactly the same as SIDDHARTA2



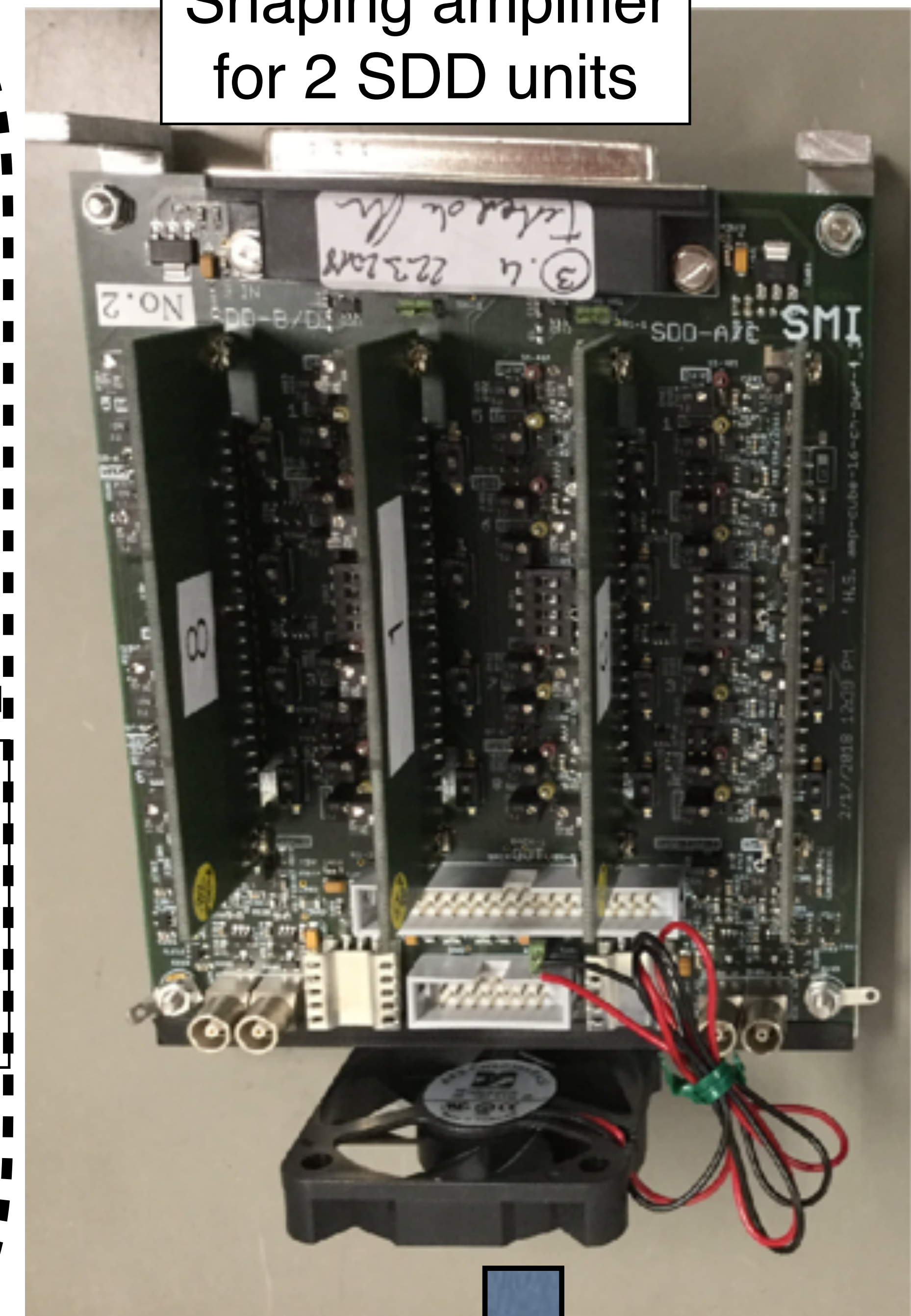
25~30cm Kapton cable w/ shield

Line driver board for 4 SDD units



~1m flat cable twisted shielded

Shaping amplifier for 2 SDD units

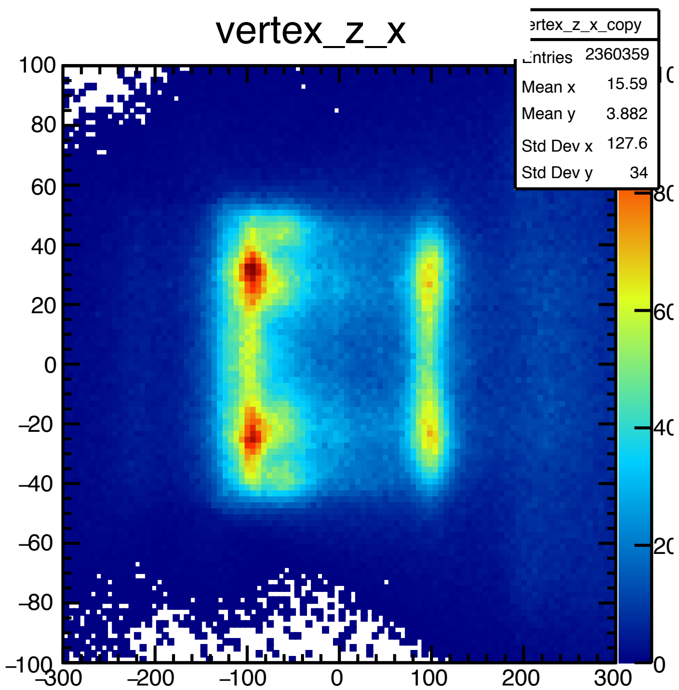


Vacuum

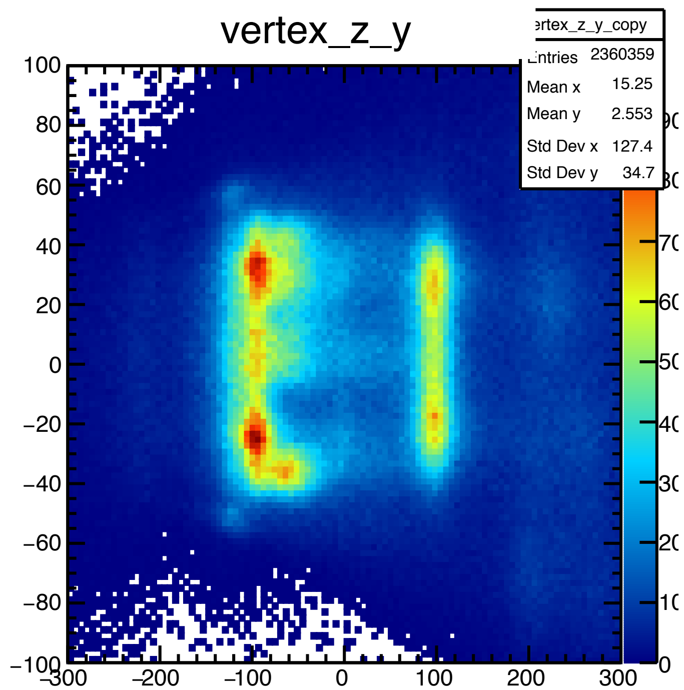
50m flat cable to CAEN V785 PADC

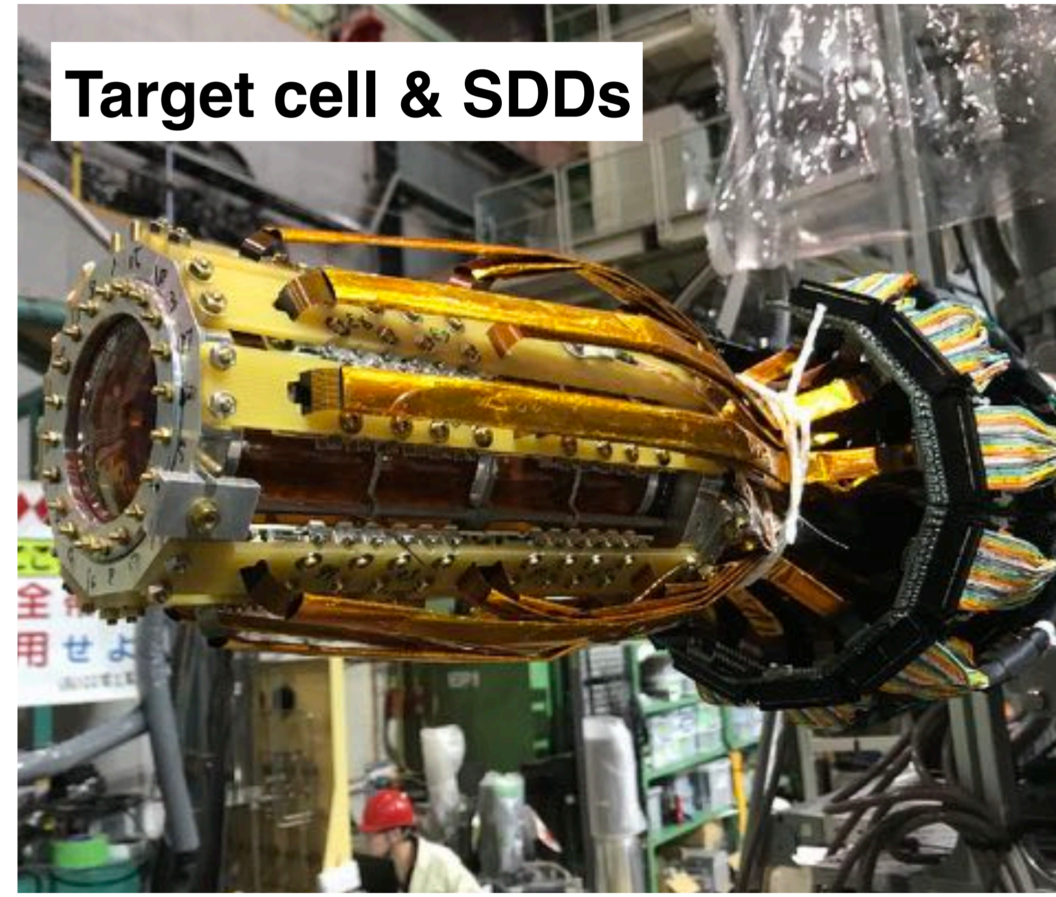
Vertex reconstruction (BPC&CDC)

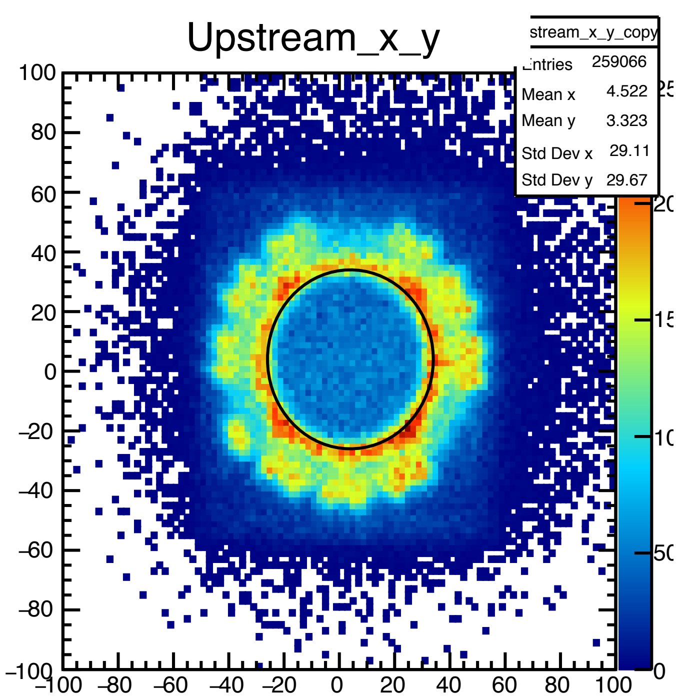
ZX



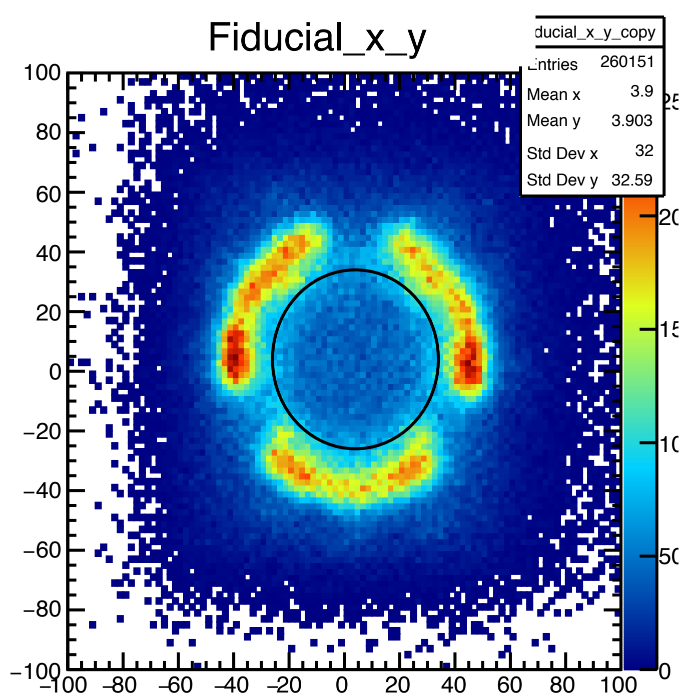
ZY



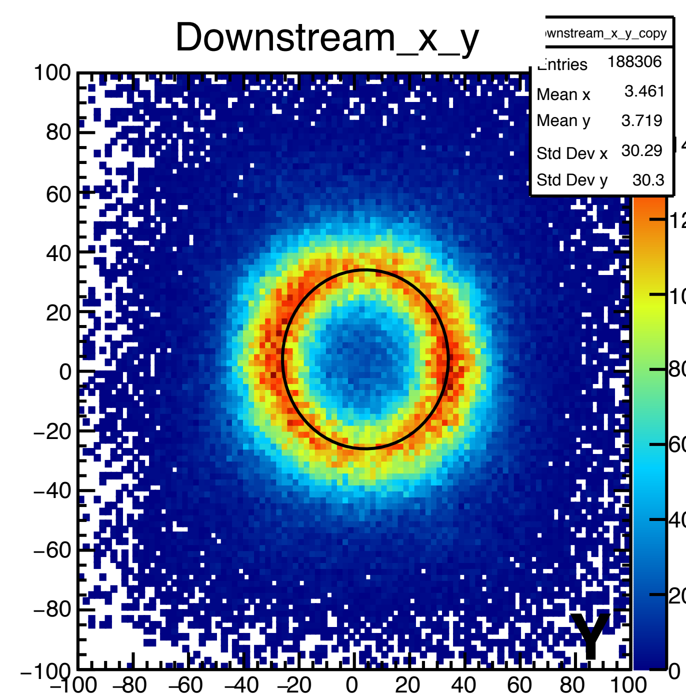




-130<Z<-70



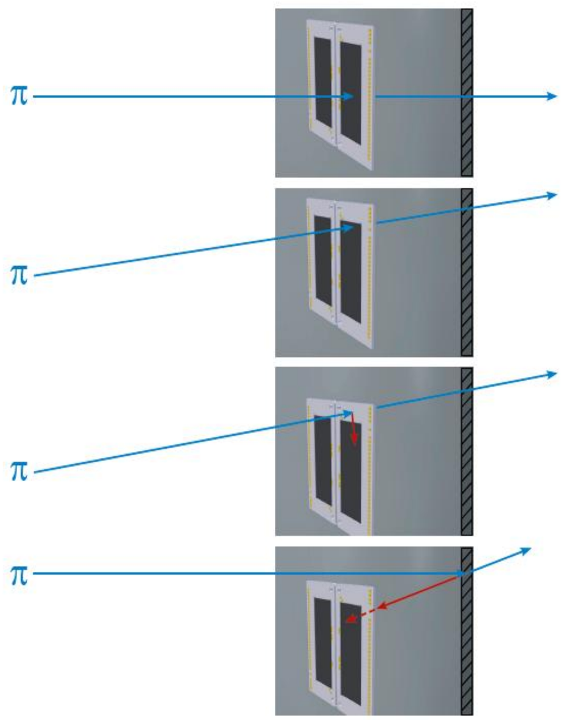
-60<Z<60



70<Z<130

XY

Charged particle VETO on SDDs using CDC

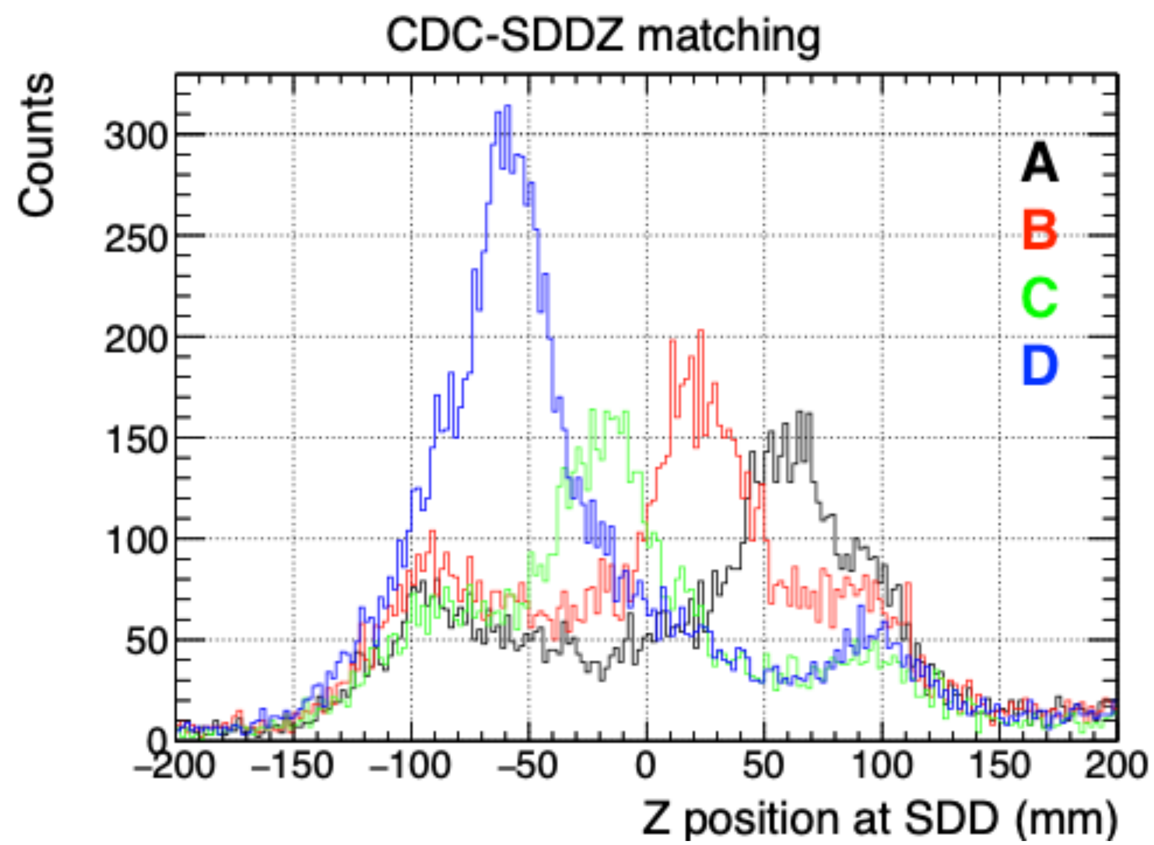


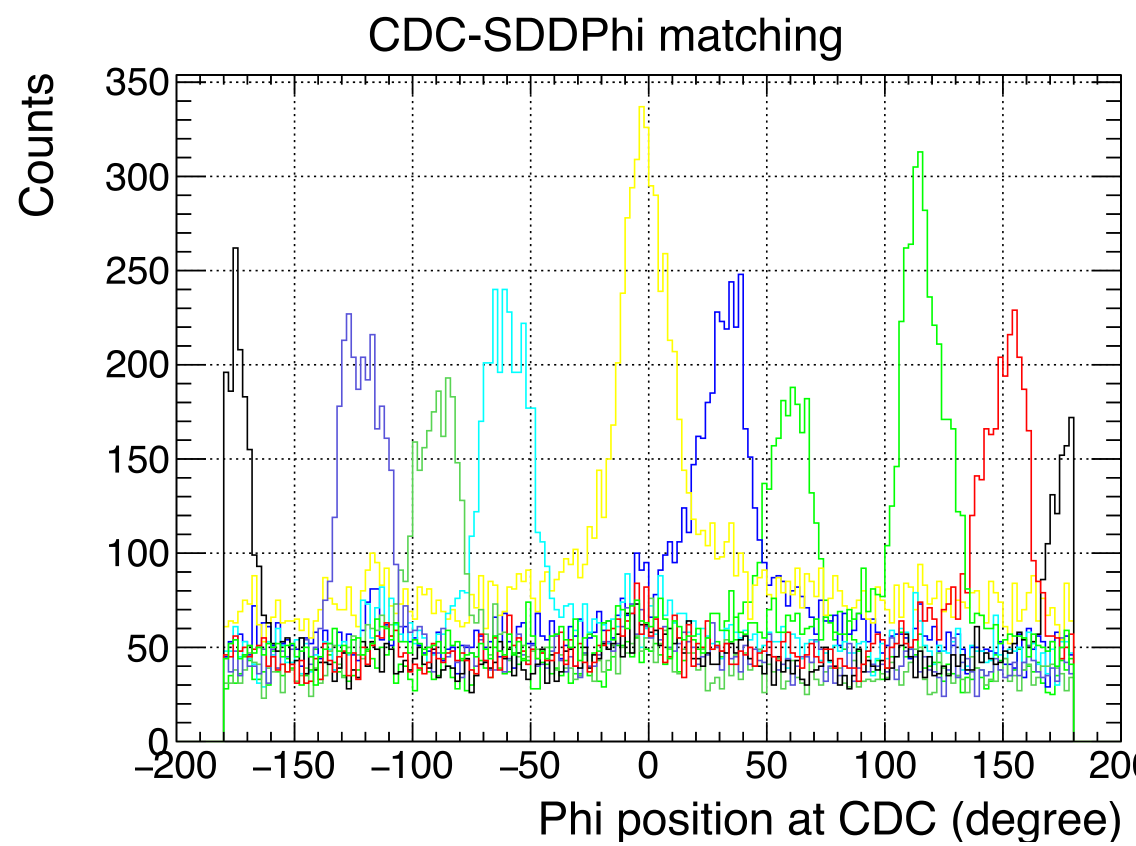
MIP traversing SDD at some distance from the edge → large signal > 150 keV

MIP traversing SDD at the edge of the active area → small signal

electron from secondary produced near the SDD

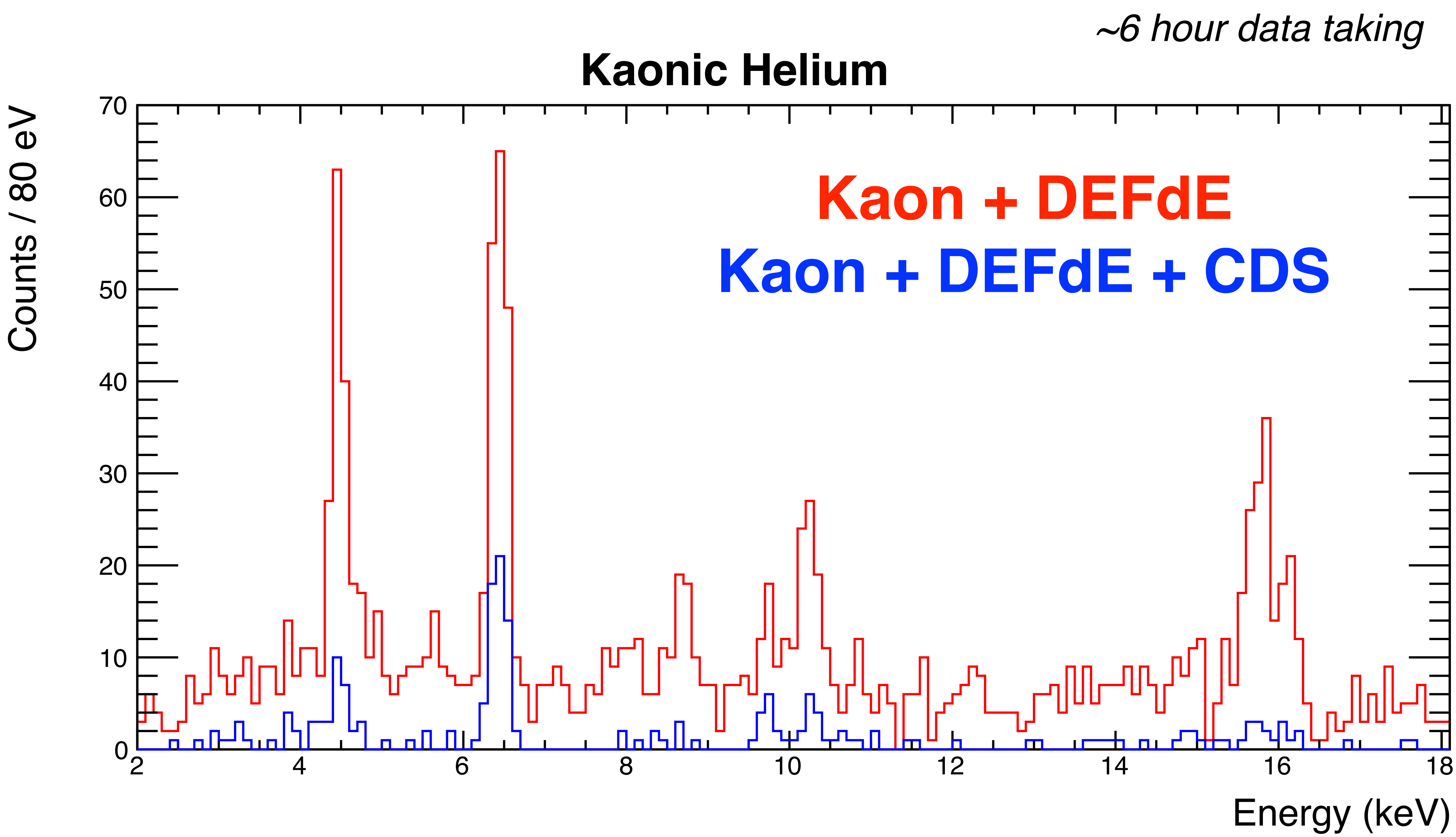
X-ray or electron from secondary produced in the setup





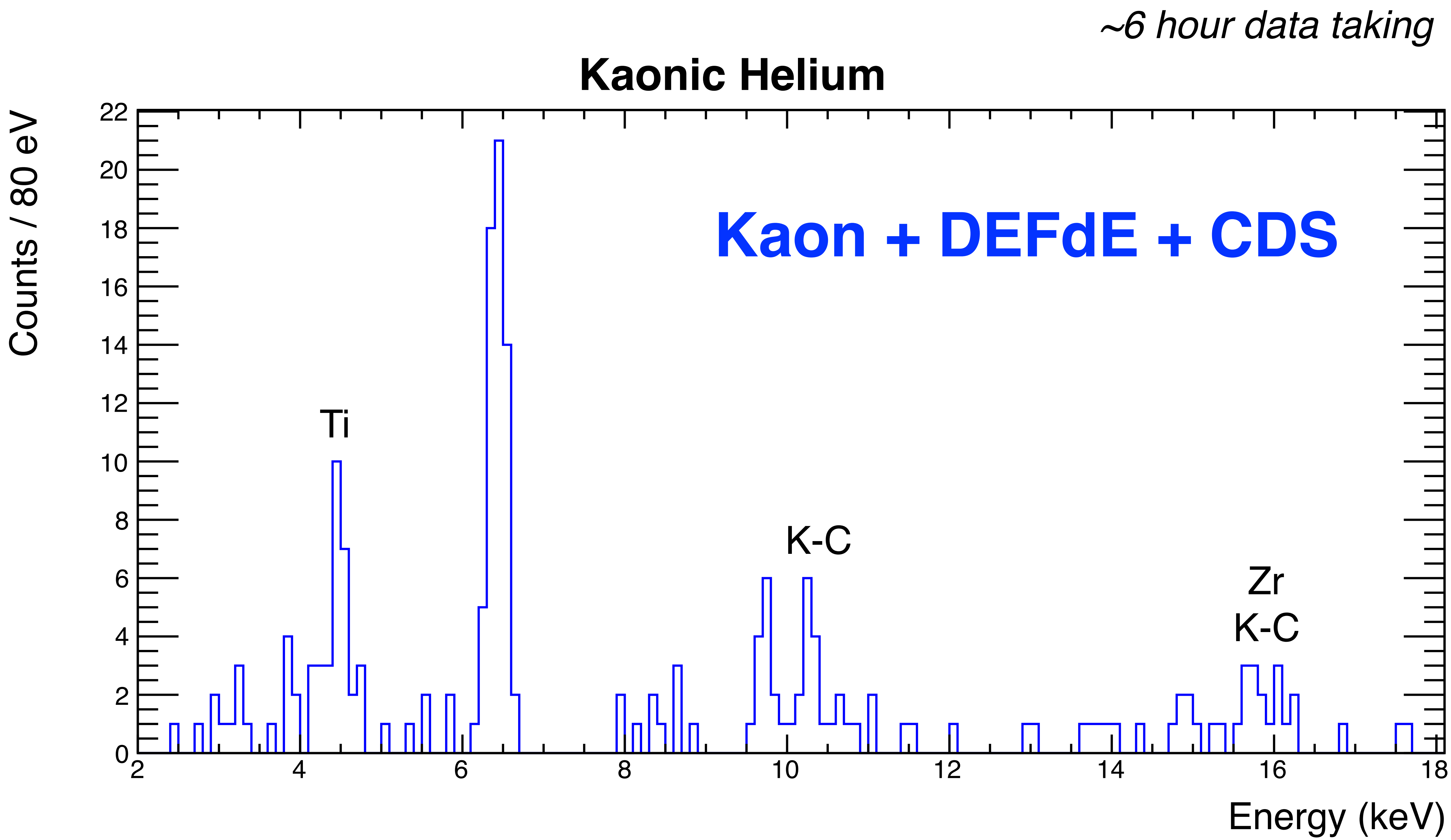
Correlation between the CDC charged track and the SDD position was clearly observed
→ We can remove charged particle events on SDDs

Helium data in E57



- Reasonable event reduction rate ~ 1/3 with CDS (not confirmed the details of the CDS analysis yet)

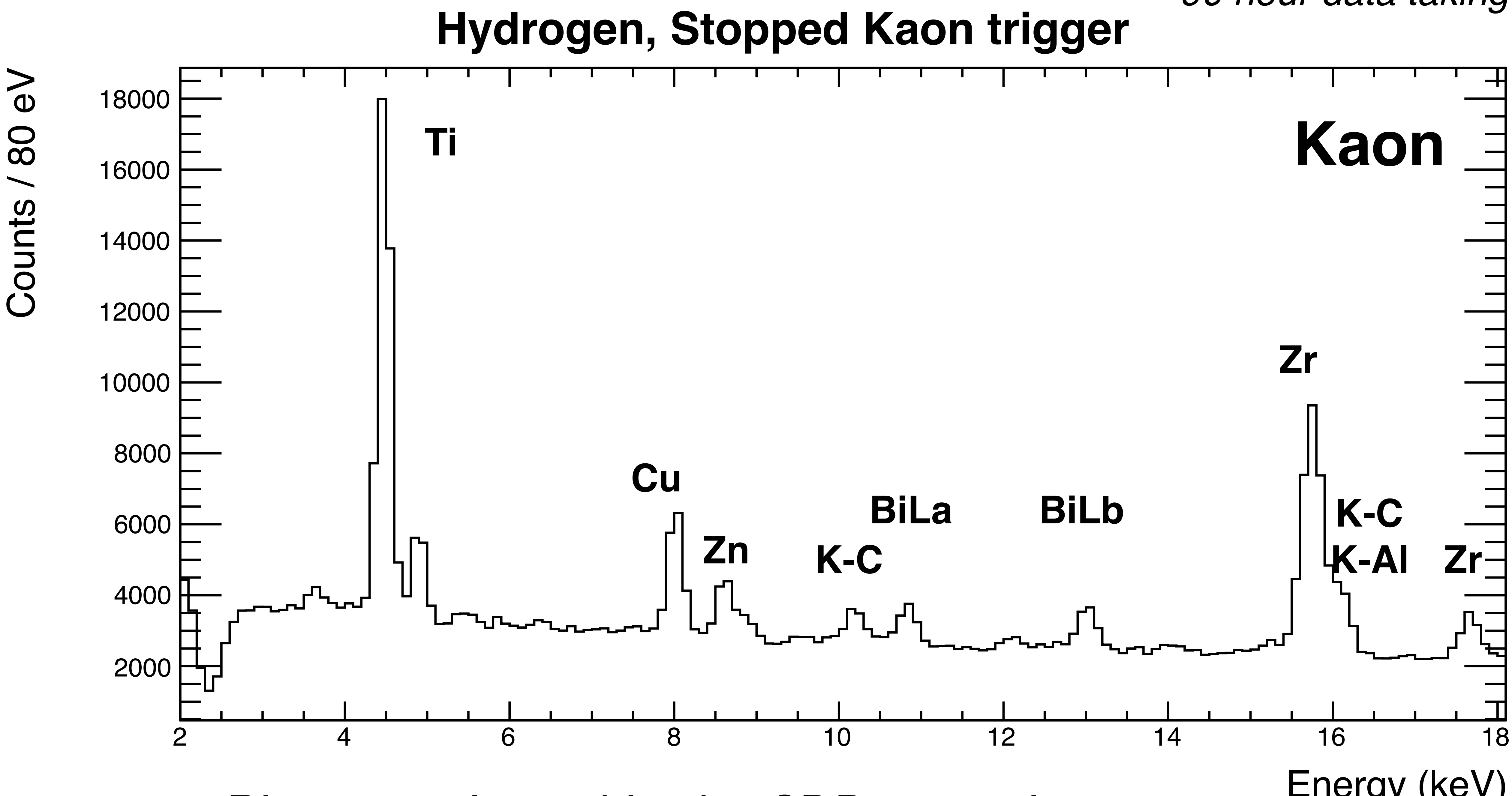
Helium data in E57



- 80 counts KHeLa
- almost background free as designed

Hydrogen data in E57

~90 hour data taking



- Bi: contaminated in the SDD ceramic
- Cu, Zn: where are they from? brass?
  - channel dependent intensity and ratio Cu/Zn

Hydrogen data

~90 hour data taking

Kaon + DEFdE

Kaon + DEFdE + CDS

Ti

Zr

K-C

K-C

K-Al

K-N

!?

Hydrogen data

~90 hour data taking

Ti

K-C

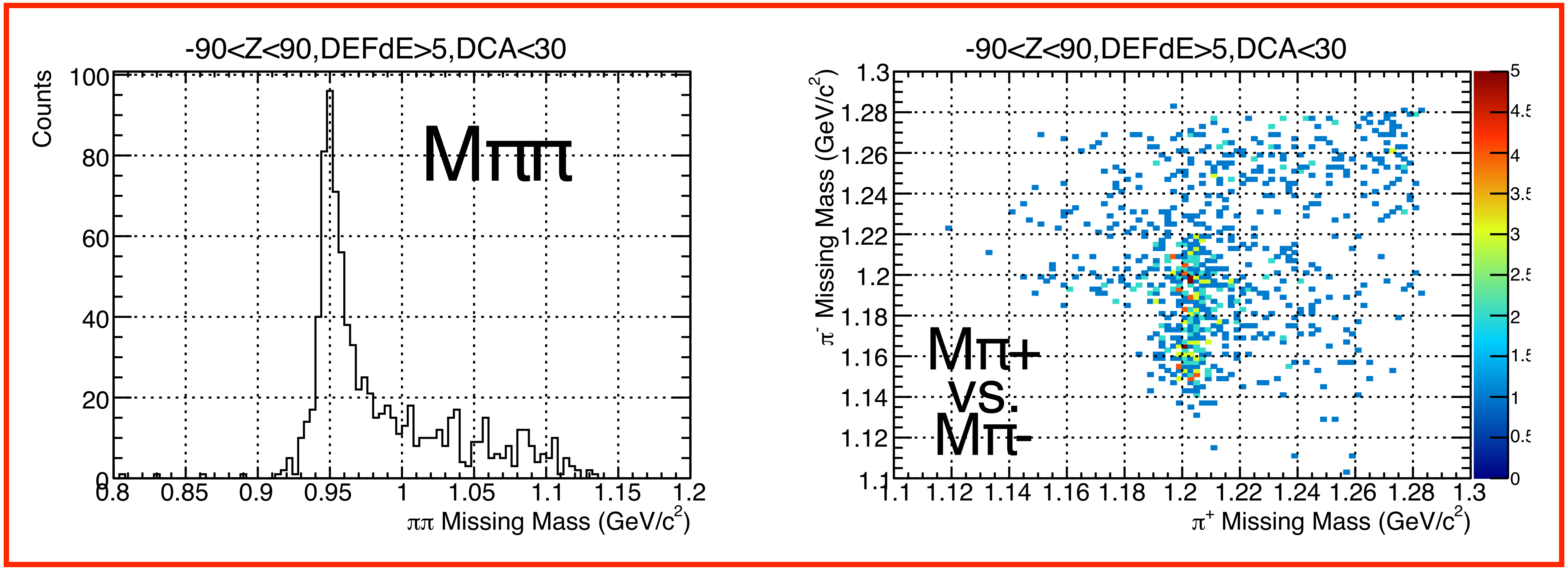
Kaon + DEFdE + CDS

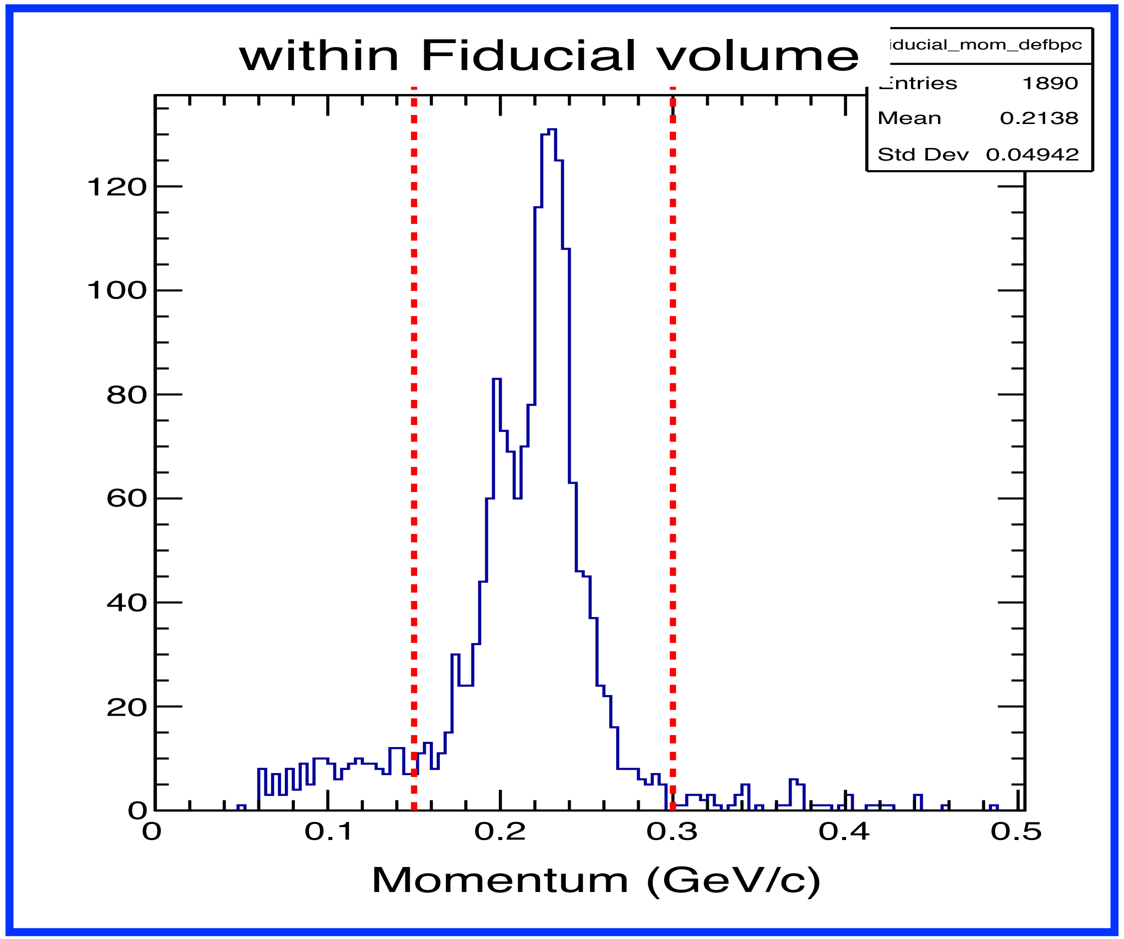
K-C

line shape from SIDDHARTA

- Higher transitions are observed
- at most 50 counts Ka X-rays
- Kaonic Kapton lines cannot be completely removed with the CDS.

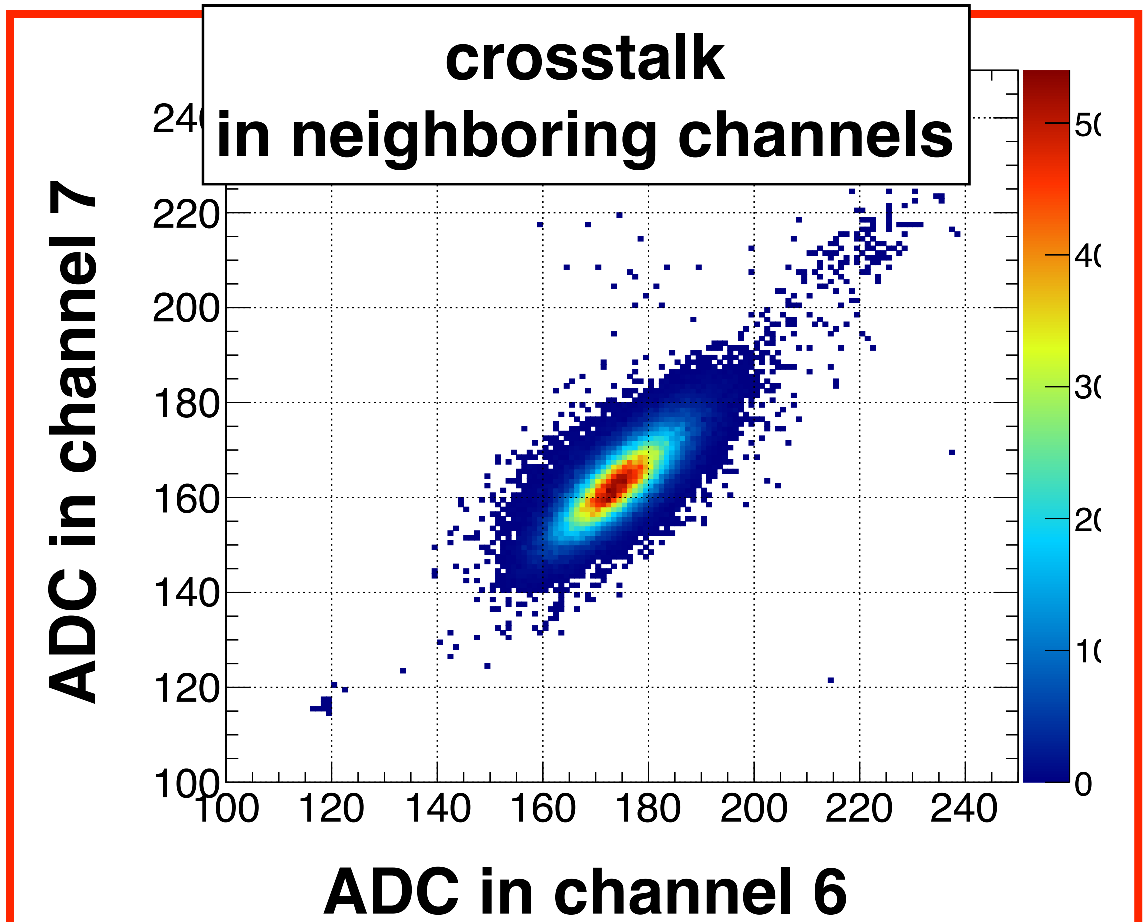
To confirm # of stopped kaons

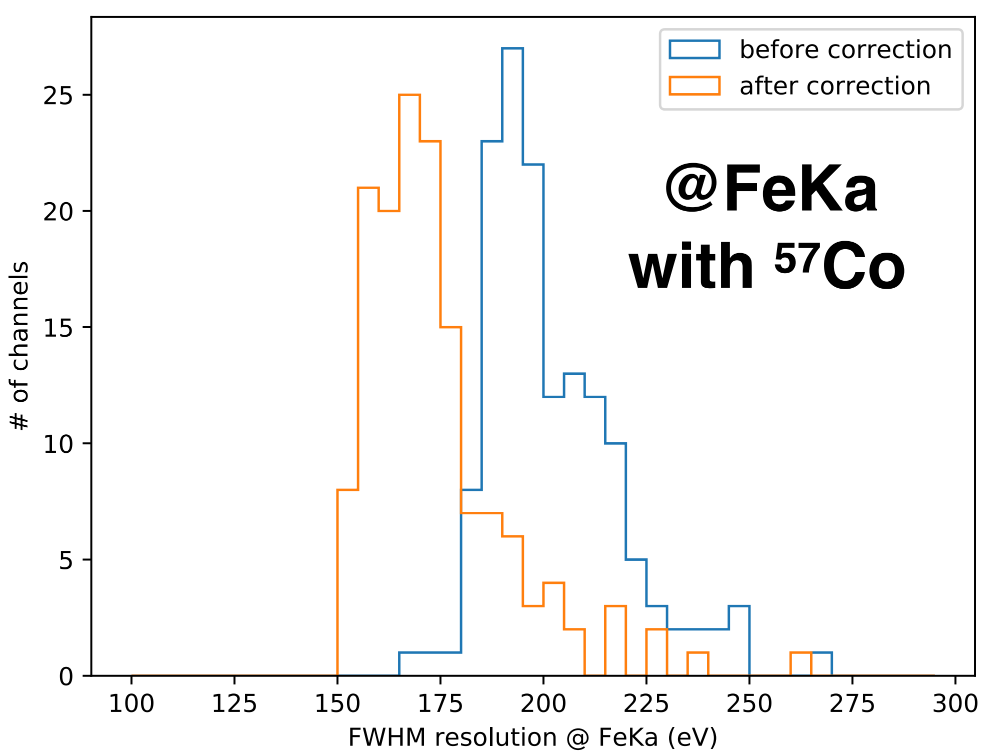


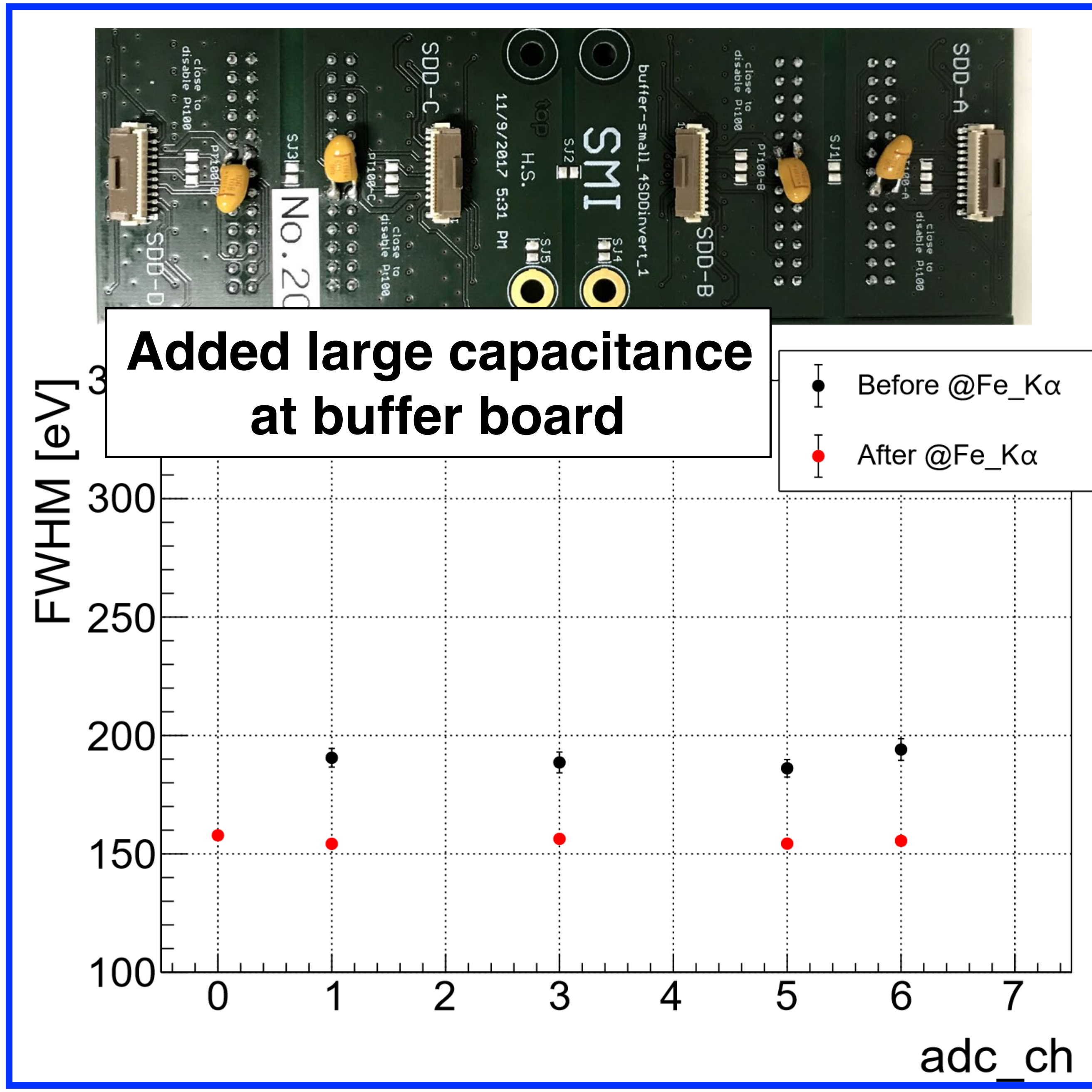


- We should estimate realistic # of stopped kaons from data
- $K^-p \to \pi\,\Sigma$
- $K^+ \to \mu^+\nu,\ \pi^0\pi^+$

Restore energy resolution

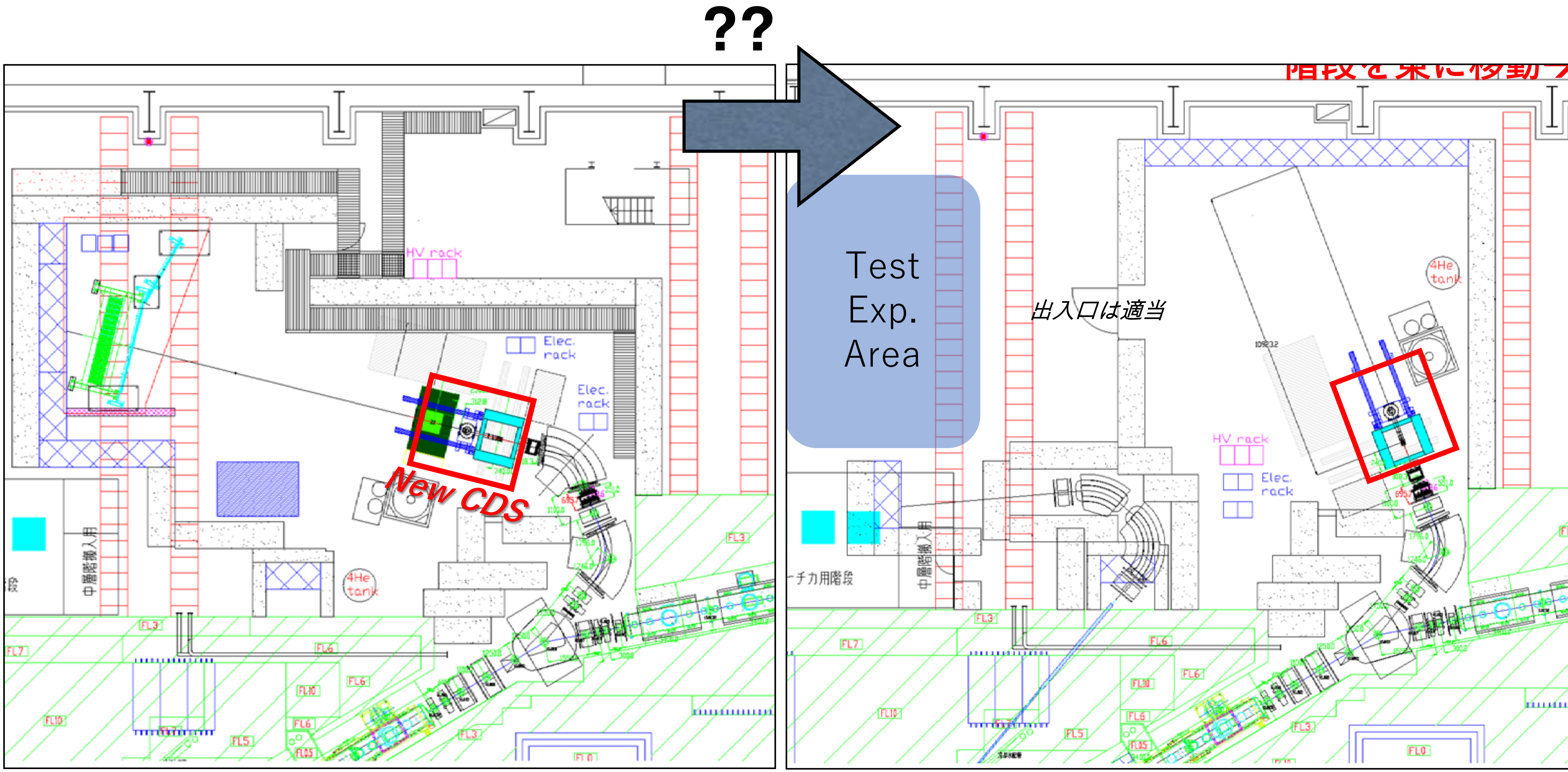






- Crosstalk due to unstable power line of CUBE
- Partial restoration by analysis
  (not yet applied to physics data)
- Now 150~160 eV FWHM @ FeKa

Possible change in the Beamline



- The last dipole magnet (D5) is just to change the direction to keep enough flight length for the forward TOF counters.
- Without D5, ~3m shorter beam line & better beam focusing.

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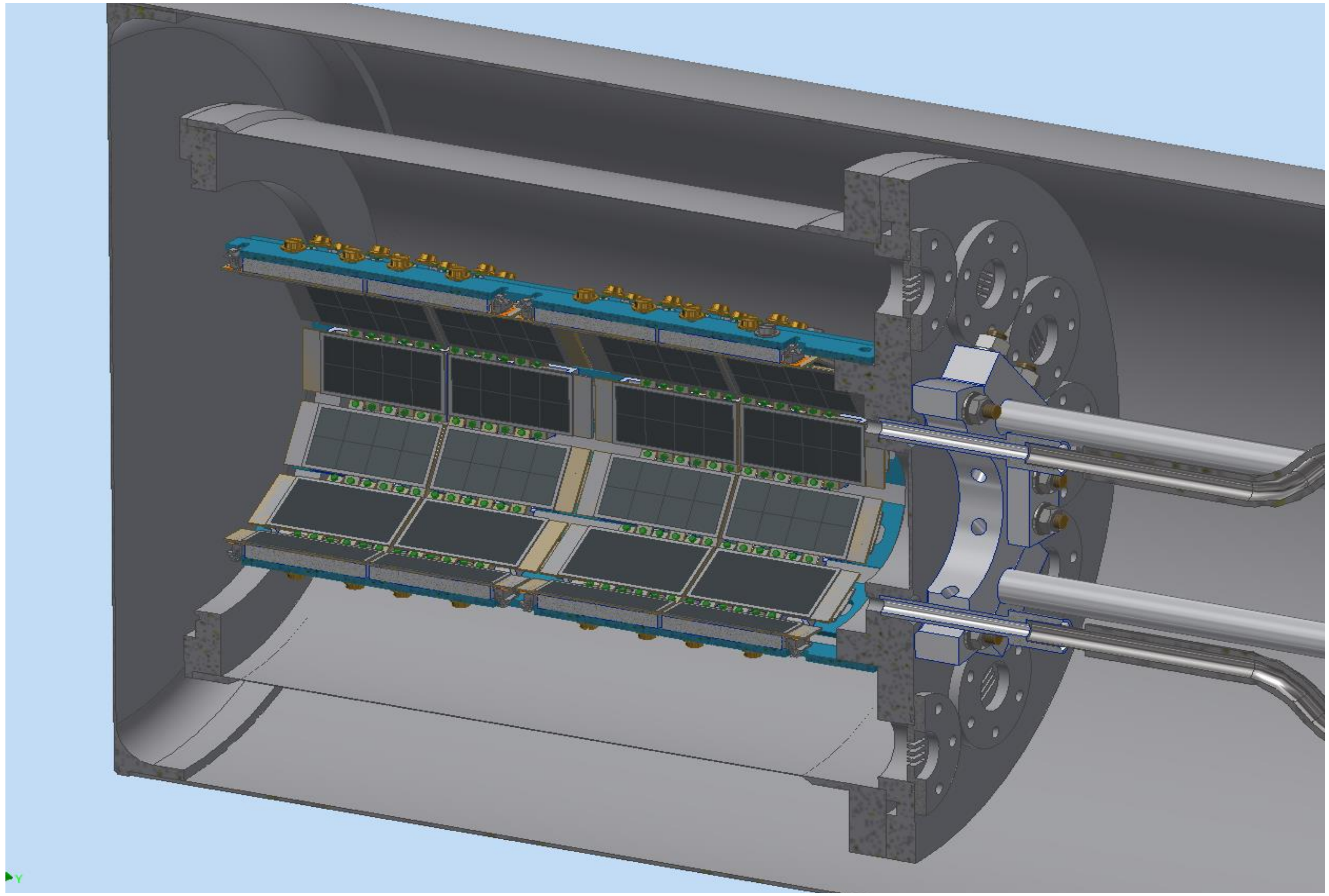
SDDs in a hydrogen atmosphere



- ✓ larger hydrogen volume
- ✓ no window
- ✓ no Kaonic Kapton lines
- ✓ Chance to detect lines to 2p state

We have already succeeded to operate SDDs in a hydrogen (<10bar, 135K) in Vienna!

Summary

Experiment	Year	Target	TES	SDD
Stoptune	2016	Lithium		Shift/Width? Yield?
E62	2018	Liq. Helium-3	Shift Width	Yield
E62	2018	Liq. Helium-4	Shift Width	Yield
E57	2019	Gas Helium-4		Yield?
E57	2019 2021??	Gas Hydrogen		Shift/Width? Yield?
E57	2022??	Gas Deuterium		???