E57 Kaonic Deuterium at J-PARC

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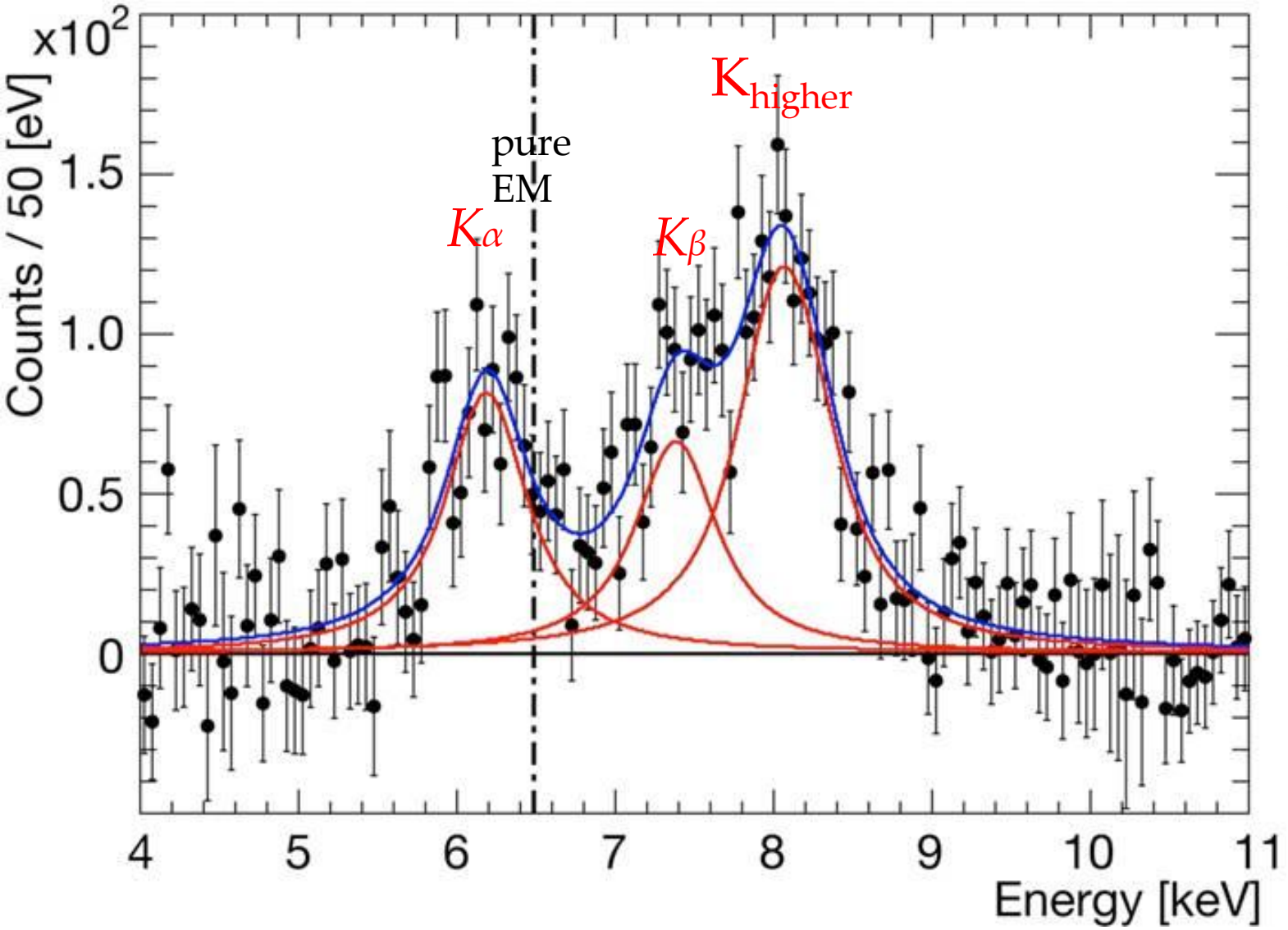
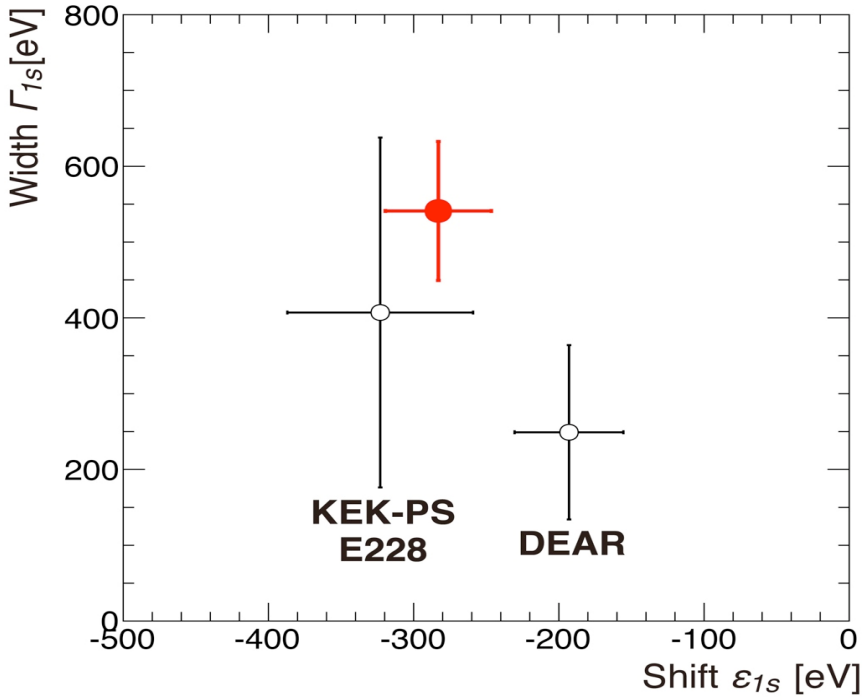
Motivation to study hadronic atoms

- exotic hadronic atoms are bound by Coulomb force - QED
- e.g. $\pi^+\pi^-$, π^-p, π^-d, K^-p, K^-d, …
- Bohr radii > as the typical scale of strong interaction, but due to the larger kaon mass
  - observable effects of QCD
    - energy shift from pure Coulomb value
    - decay width
  - **access to scattering at zero energy**
- these scattering lengths are sensitive to chiral and isospin symmetry breaking in QCD
- can be analysed systematically in the framework of low-energy Effective Field Theory

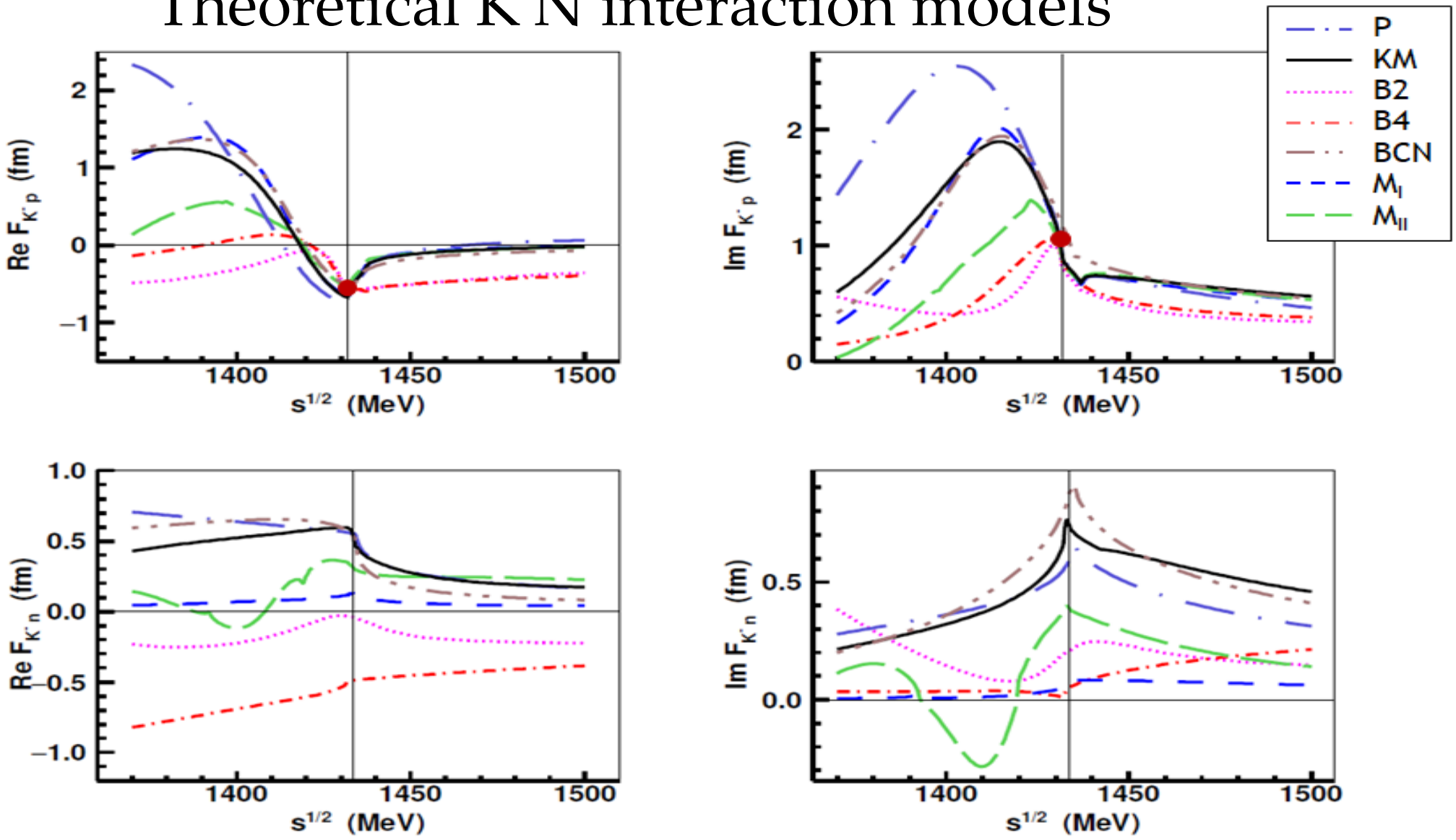
Kaonic Hydrogen results



ε_{1s} = -283 ± 36(stat) ± 6(syst) eV
Γ_{1s} = 541 ± 89(stat) ± 22(syst) eV



Theoretical K⁻N interaction models



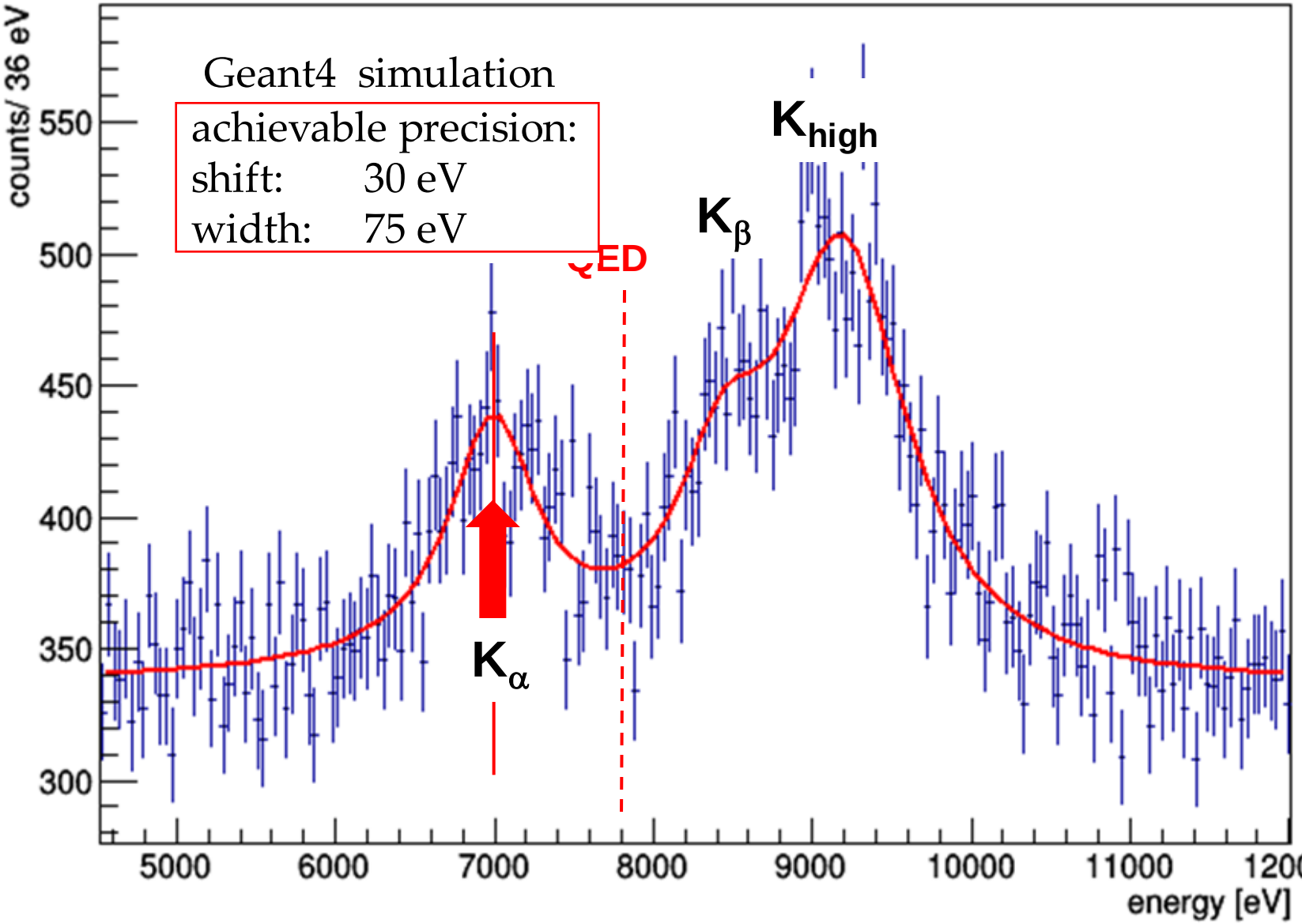
A Cieplý *et al.* 2016 *Nucl. Phys. A* **954** 17-40.

Experimental challenges towards K^-d

- X-ray yield: K^-p ~ 1 %
  K^-d ~ 0.1 %
- 1s state width: K^-p ~ 540 eV
  K^-d ~ 800 – 1000 eV

BG sources: asynchronous BG → timing
synchronous BG → spatial correlation

Goal of E57 - Kaonic Deuterium



INPUT

signal: shift - 800 eV
width 800 eV

density: 2% (LHD)
detector area: 246 cm^2

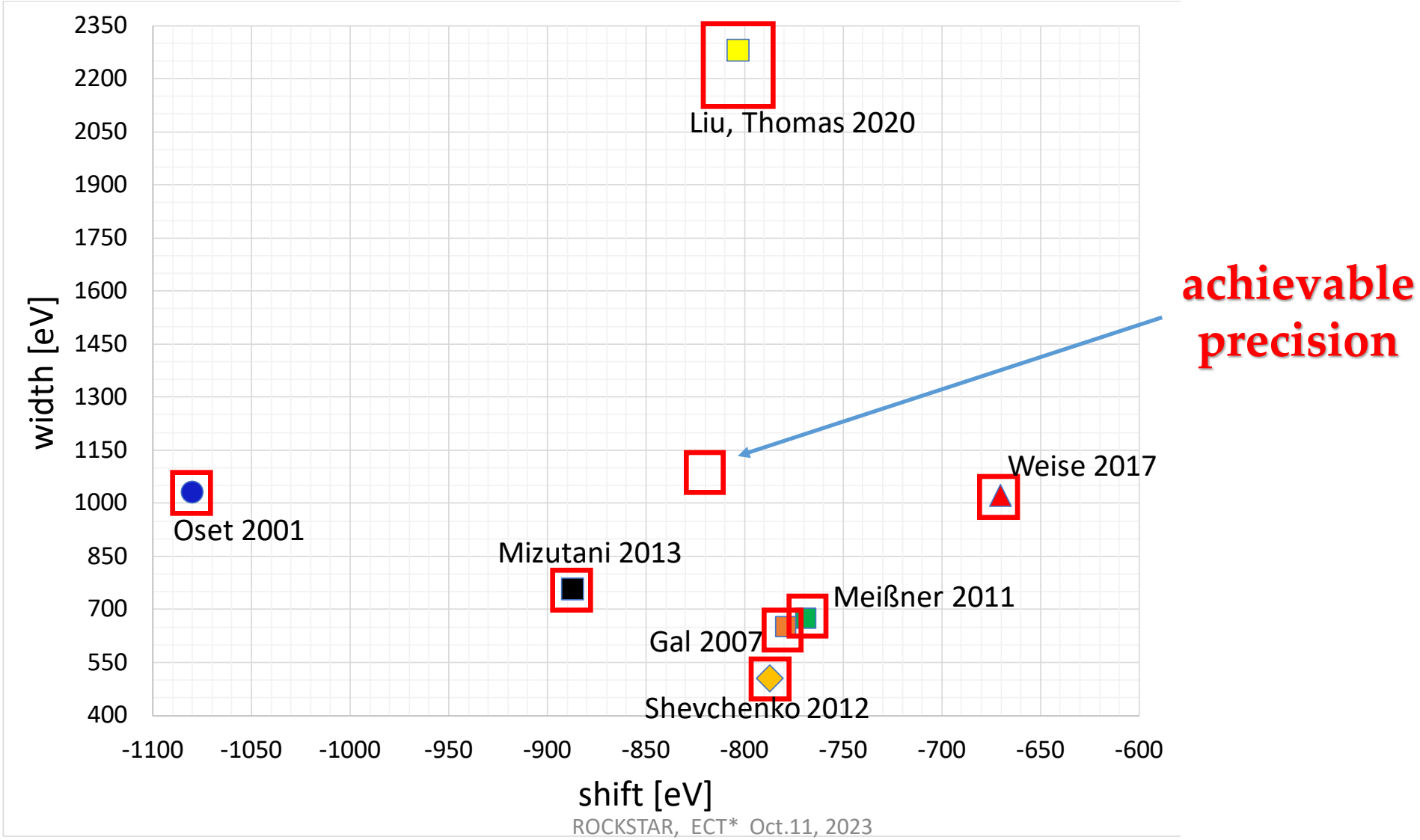
Kα yield: 0.1 %
yield ratio as in K^-p

S/B ~ 1 : 4

$$a_{K^-p} = \frac{1}{2}[a_0 + a_1]$$

$$a_{K^-n} = a_1$$

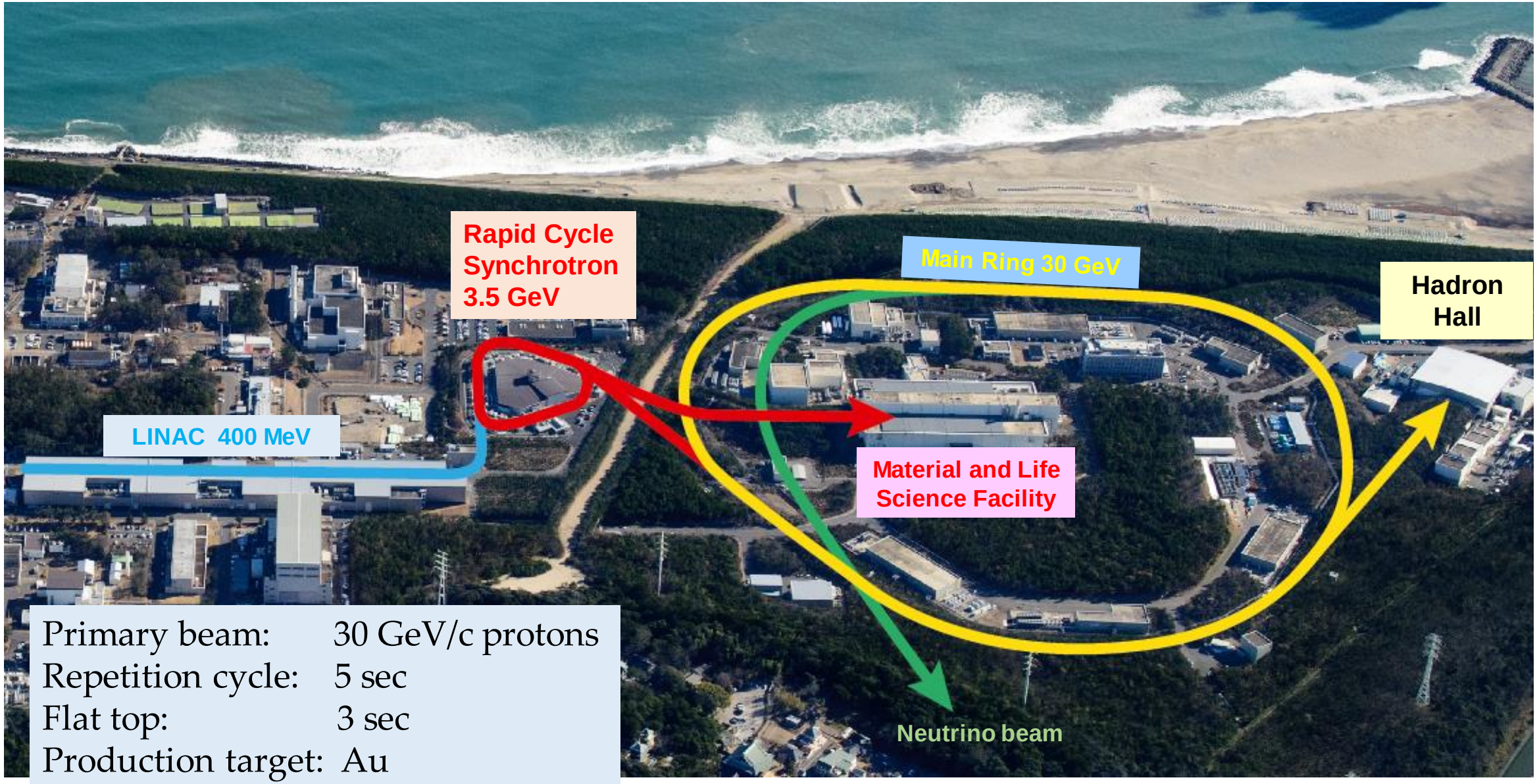
Kaonic deuterium measurement



Why an additional measurement at J-PARC?

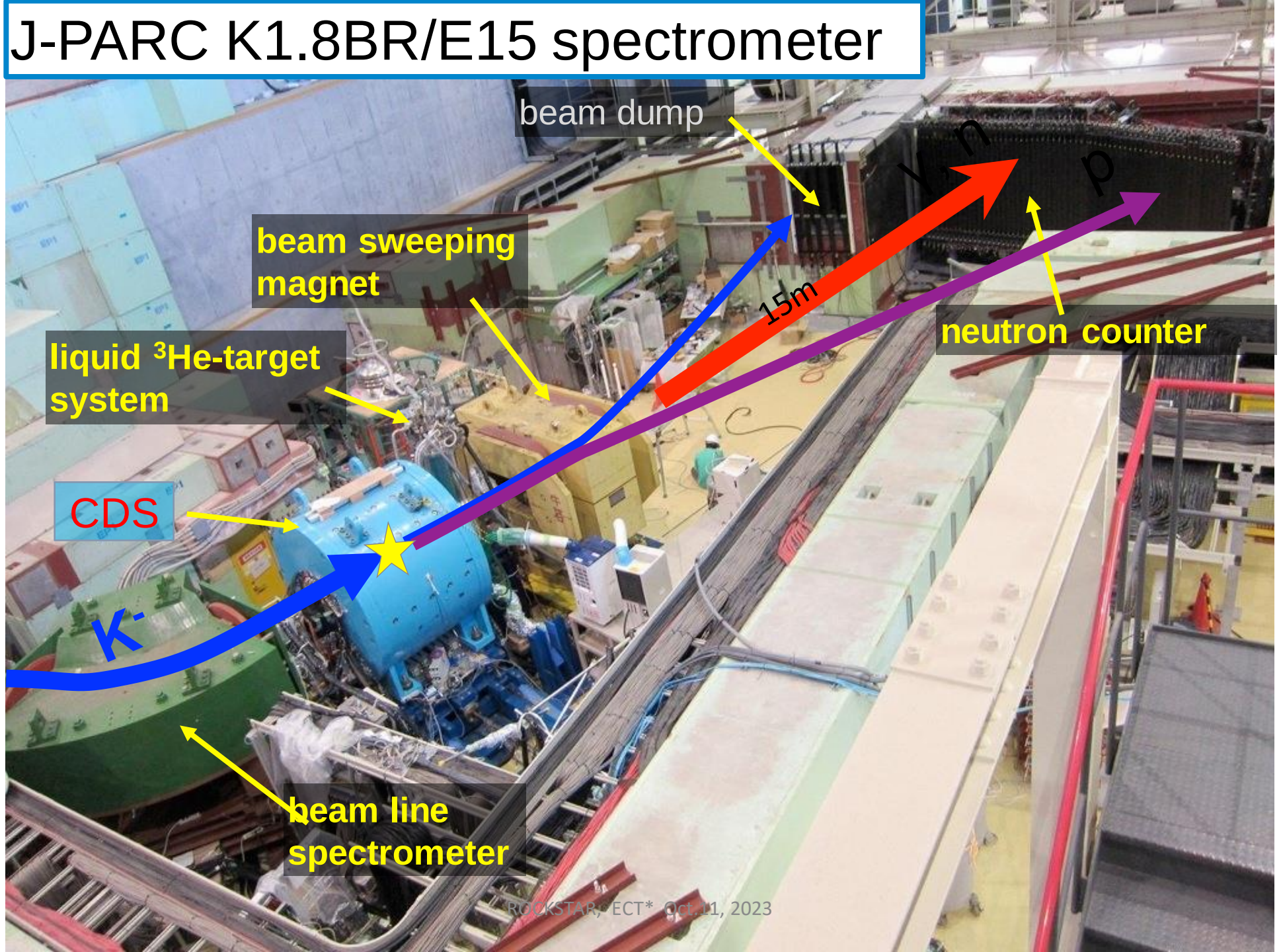
- to validate the SIDDHARTA-2 result
- different systematic corrections
- advanced background suppression
  - fiducial cut method
  - strongly reduced kaonic X-ray lines (carbon, nitrogen, oxygen, ..)
  - possible coincidence with kaonic deuterium L-lines

Japan Proton Accelerator Research Complex - J-PARC



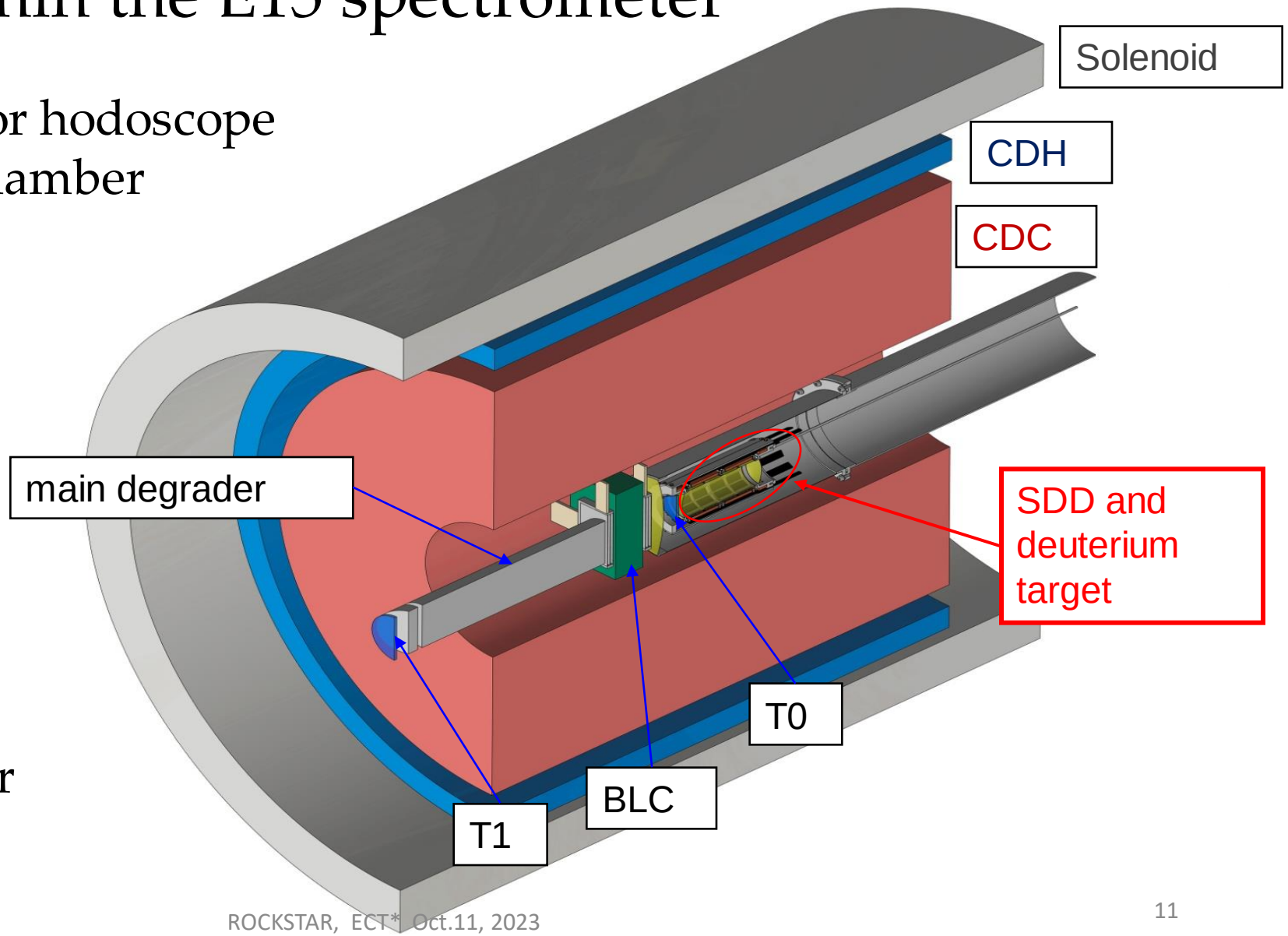
Primary beam: 30 GeV/c protons
Repetition cycle: 5 sec
Flat top: 3 sec
Production target: Au
Kaon momentum: 1.2 GeV/c (max.)

J-PARC K1.8BR/E15 spectrometer



K^-d within the E15 spectrometer

CDH...cylindrical detector hodoscope
CDC...cylindrical drift chamber



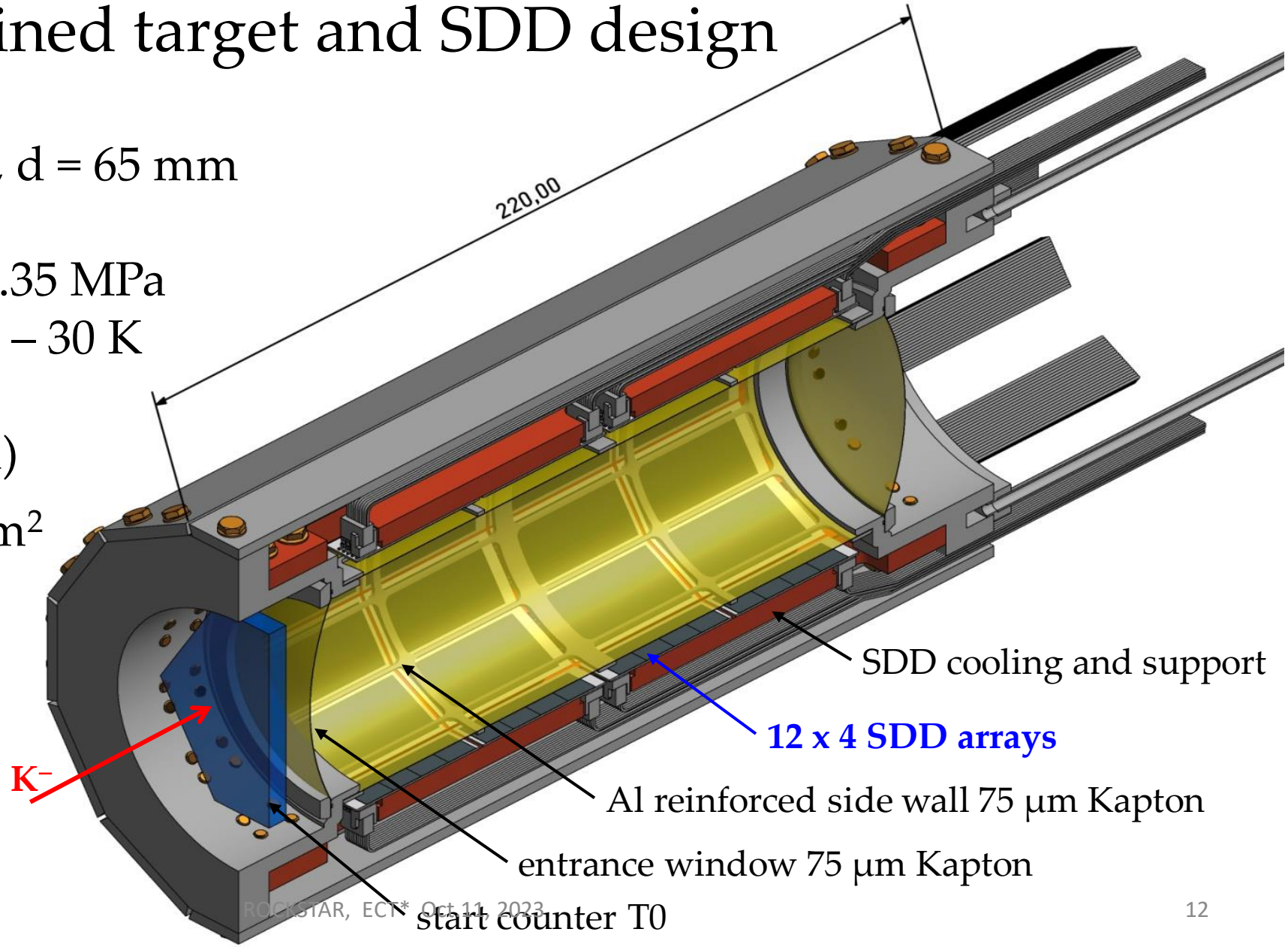
T0.....beam line counter
T1.....beam line counter
BLC....beam line chamber

Combined target and SDD design

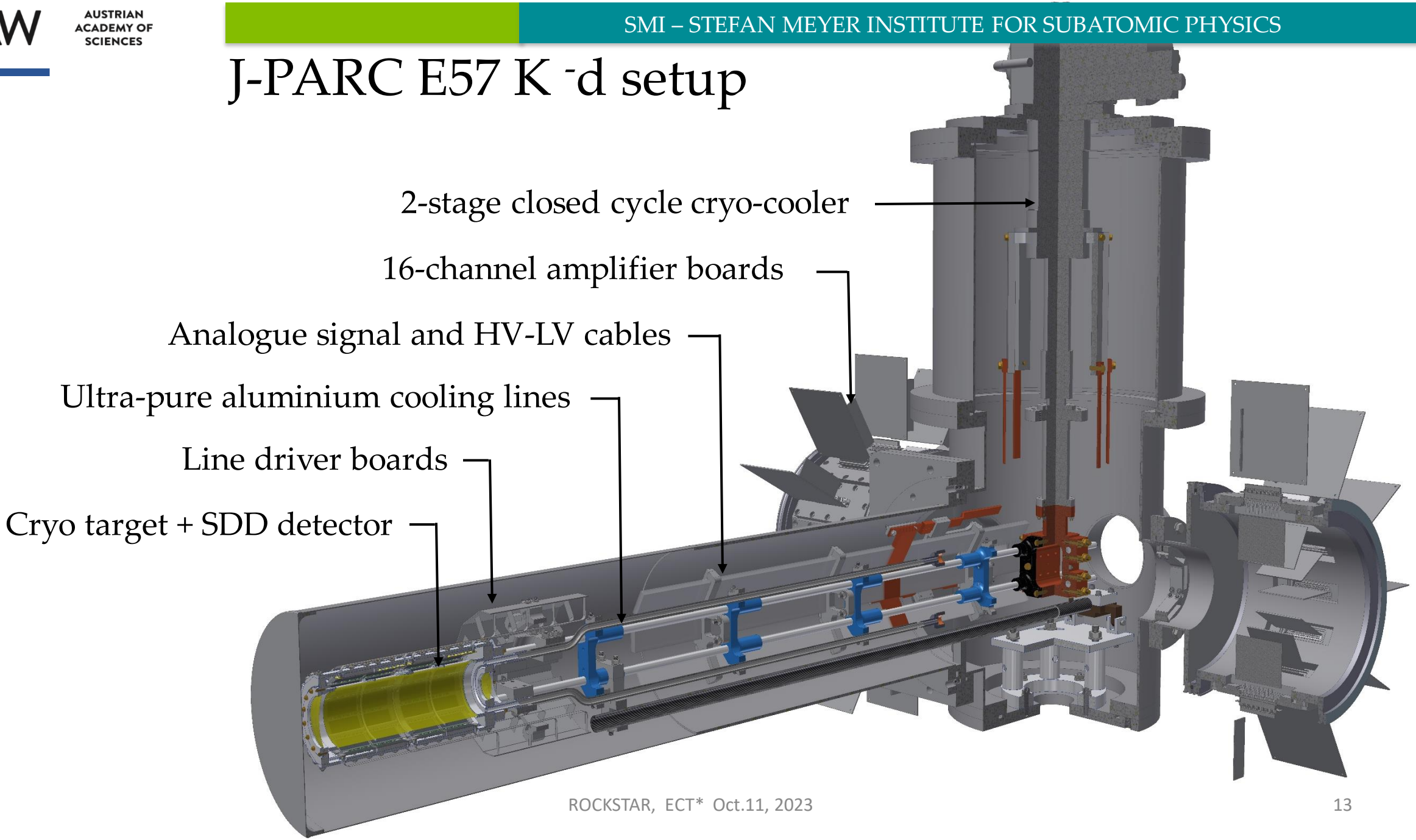
target cell: l = 160 mm, d = 65 mm

target pressure max.: 0.35 MPa
target temperature: 23 – 30 K
density: 5% LHD
(29K/0.35 MPa)

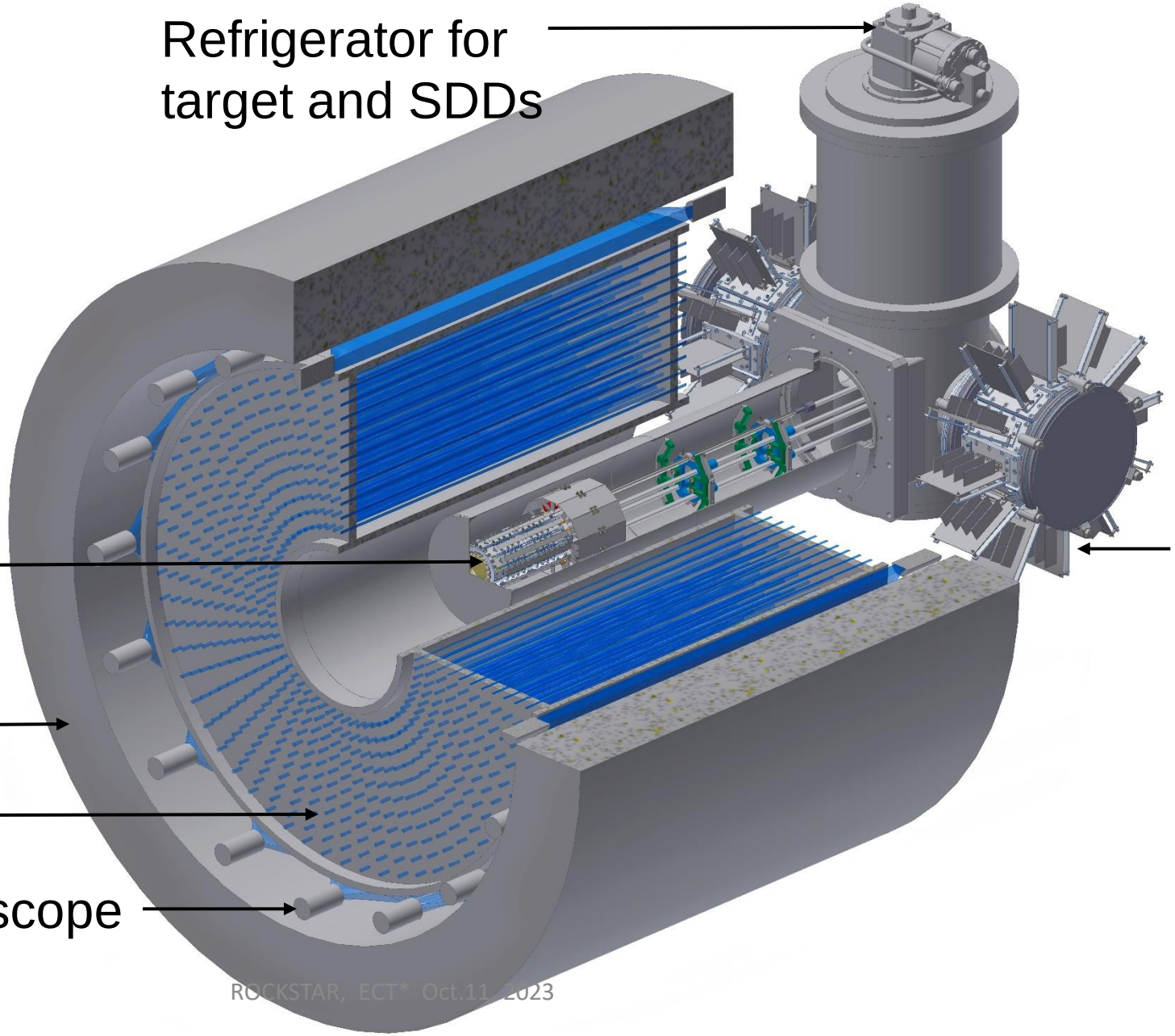
SDD active area: 246 cm²



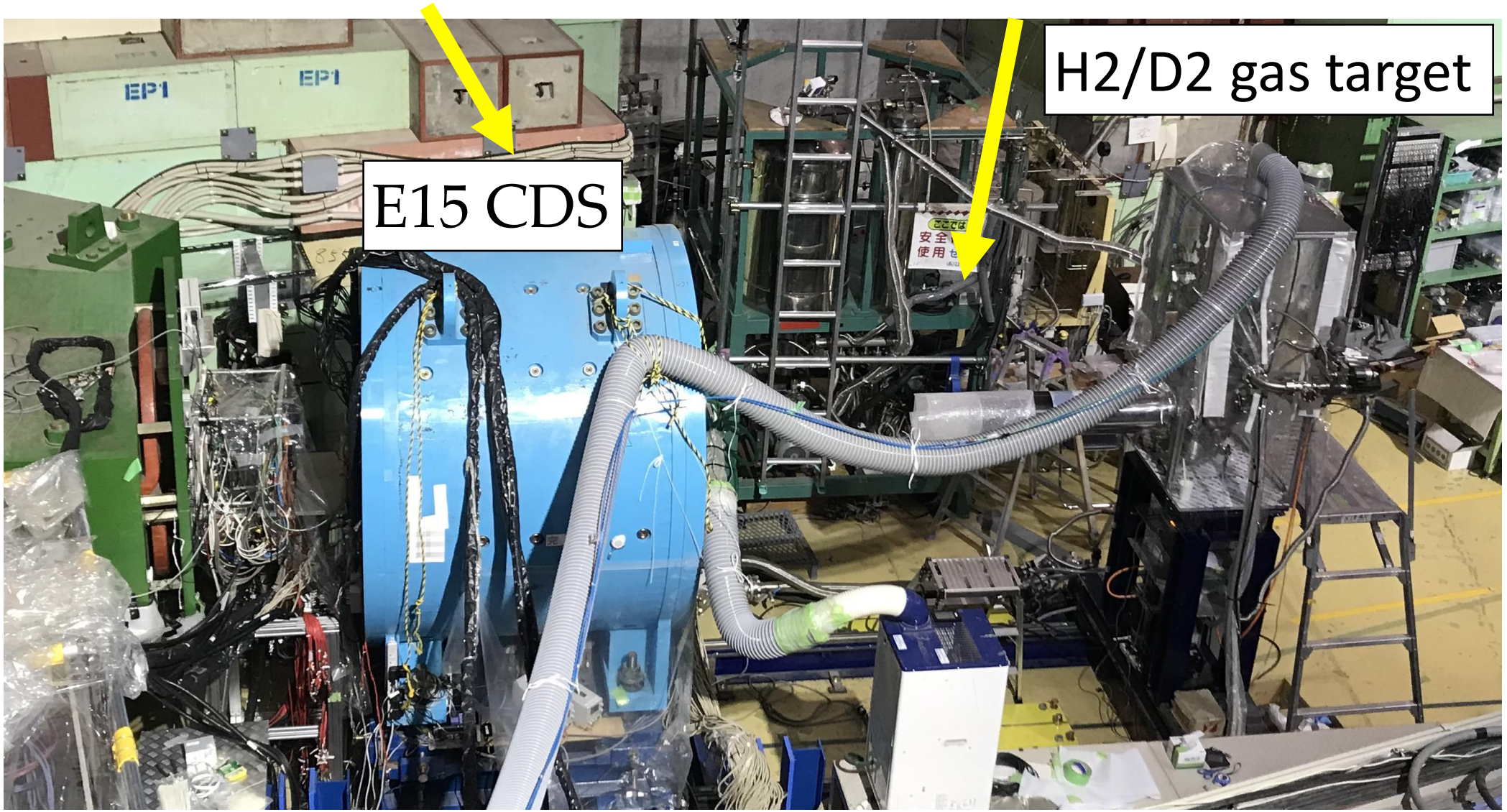
J-PARC E57 K⁻d setup



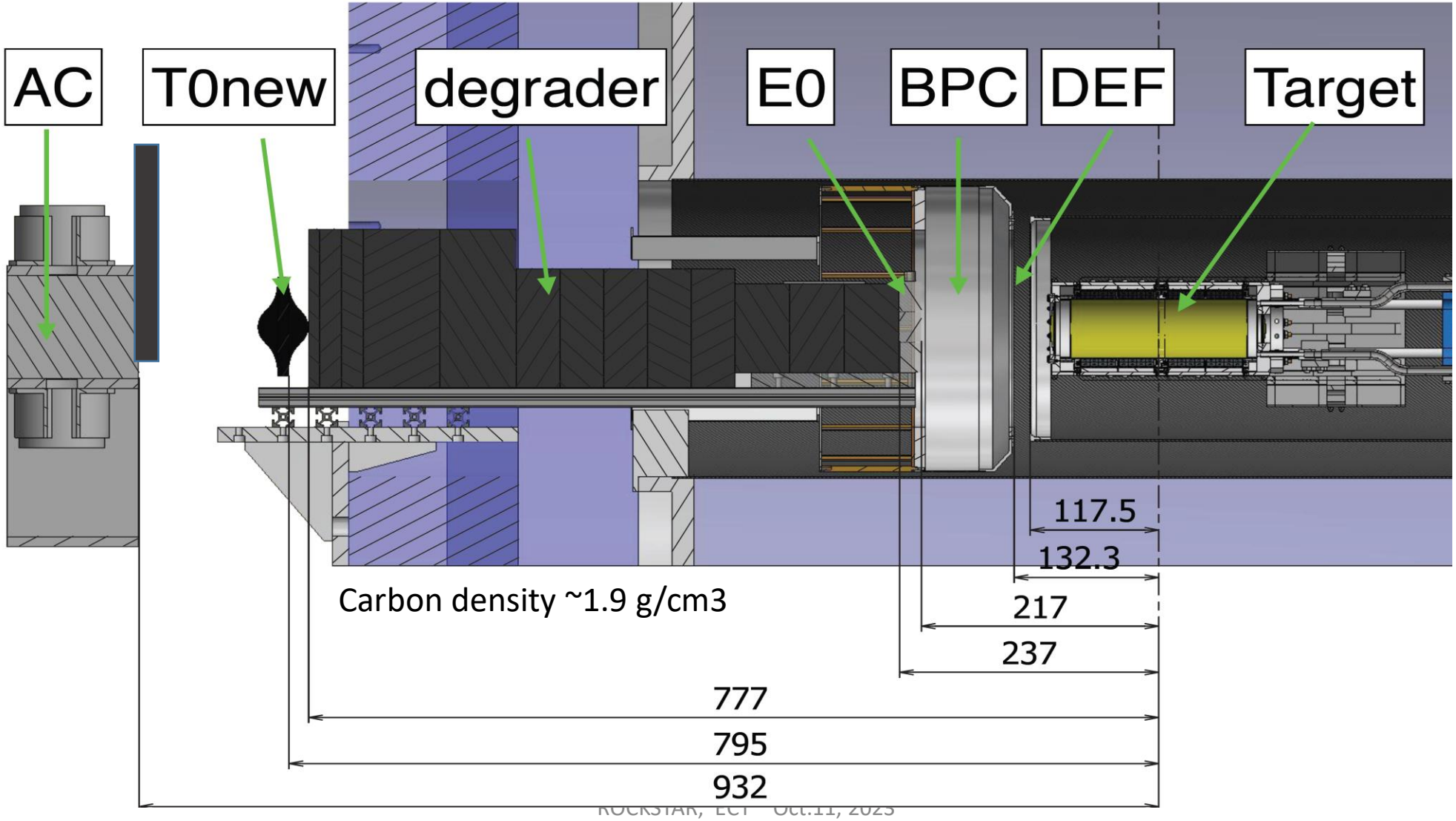
E57 within E15



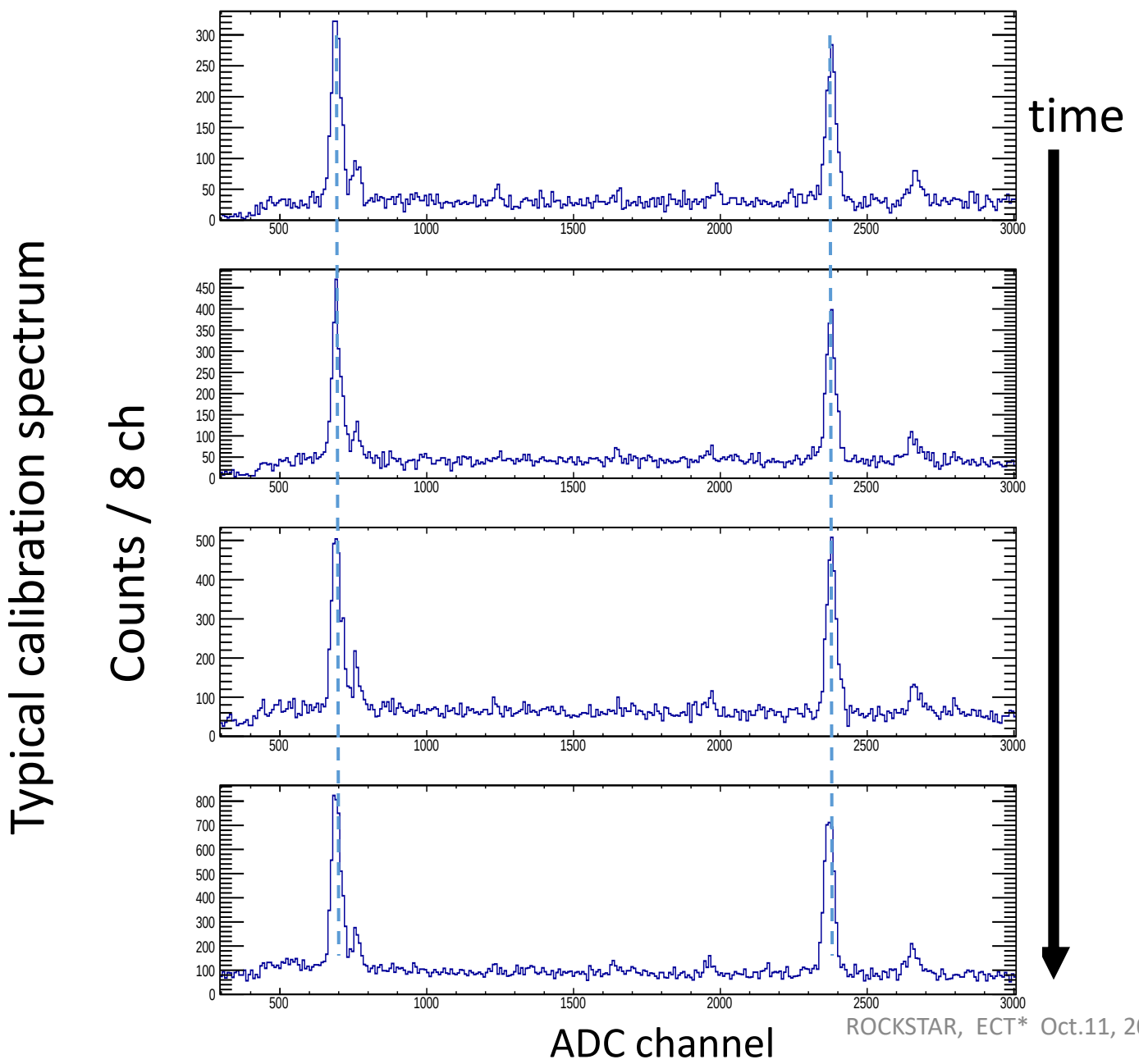
K1.8BR area as of Jan. 16, 2019



E57 pilot run geometry



SDD performance & calibration



- We installed 26 units
- **145** / 208 channels worked well
  - ~70% yield

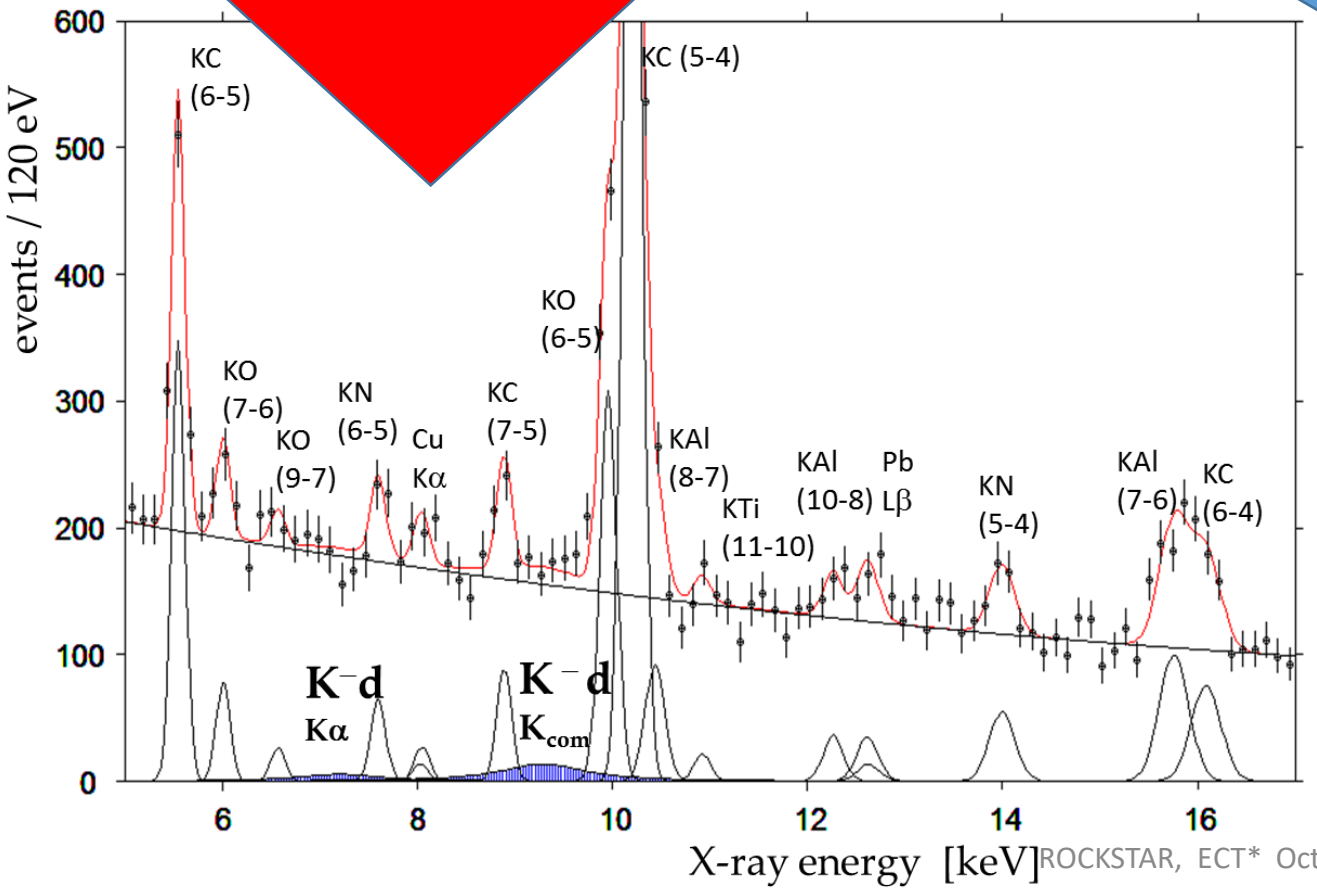
- Energy calibration
  - In-beam condition
  - TiKa (4.5 keV) & ZrKa (15.7 keV)
  - Day by day
  - Peak position was stable during the experiment, even after re-cooling for the Apr. run.

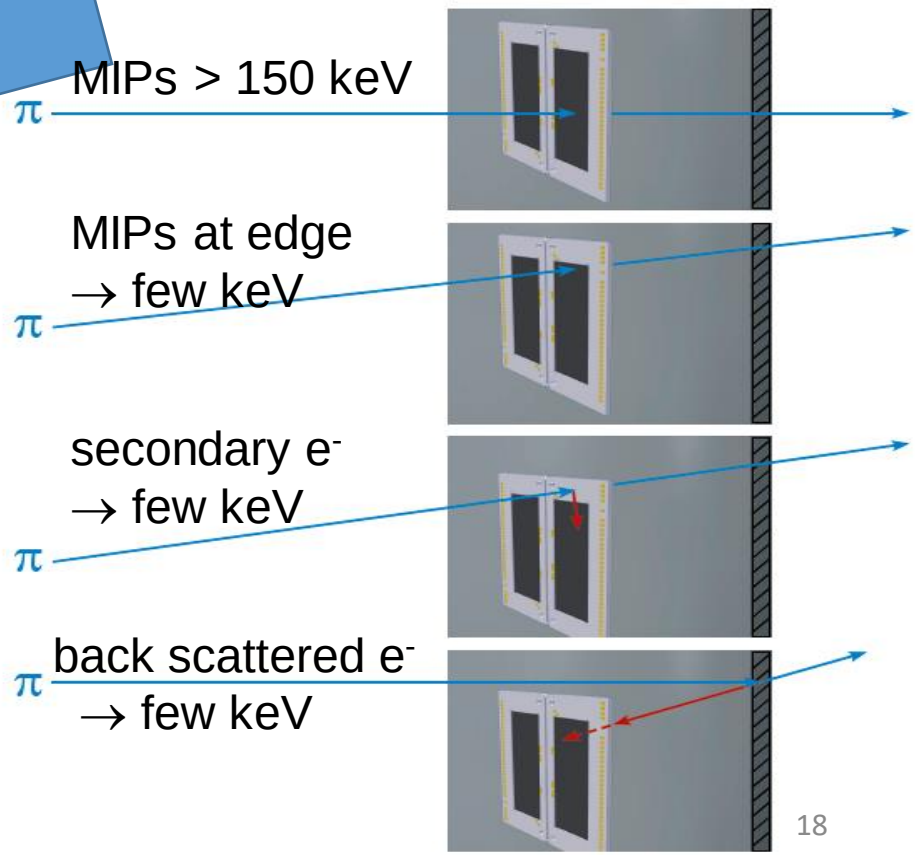
- Energy resolution
  - < 200 eV FWHM @ 6 keV

Fiducial cut method and charged particle VETO with CDC

charged particle tracking

charged particle veto

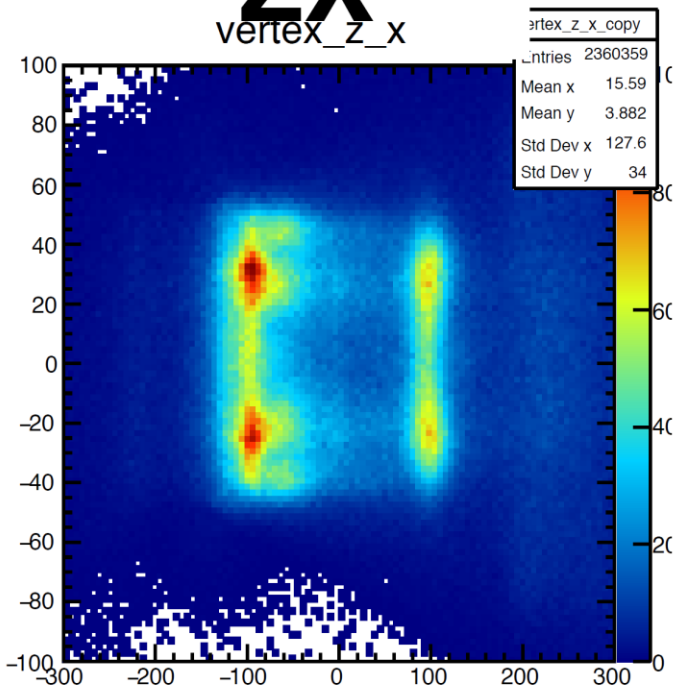




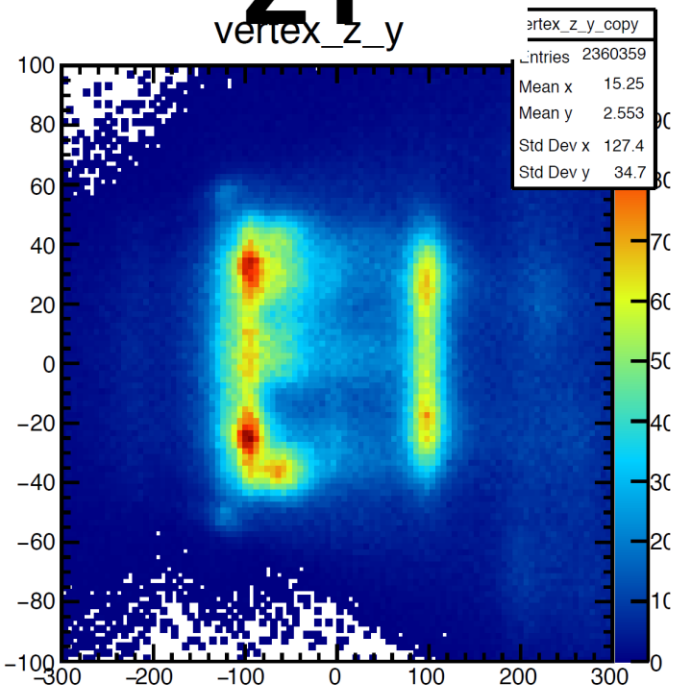
Vertex image (BPC&CDC)

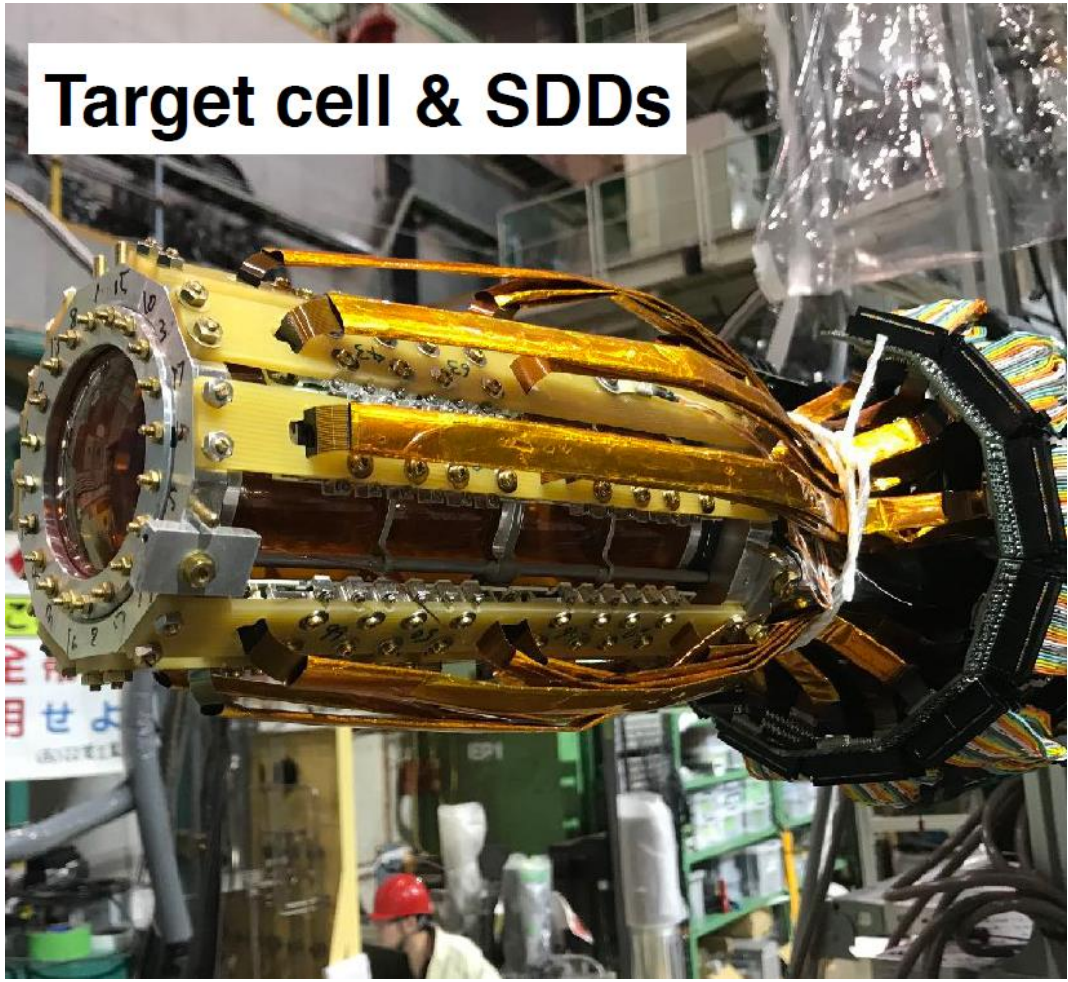
Vertex defined by using a min.-DCA (distance of closest approach)
CDC to BPC tracks
XY on BPC track, Z on CDC track

ZX

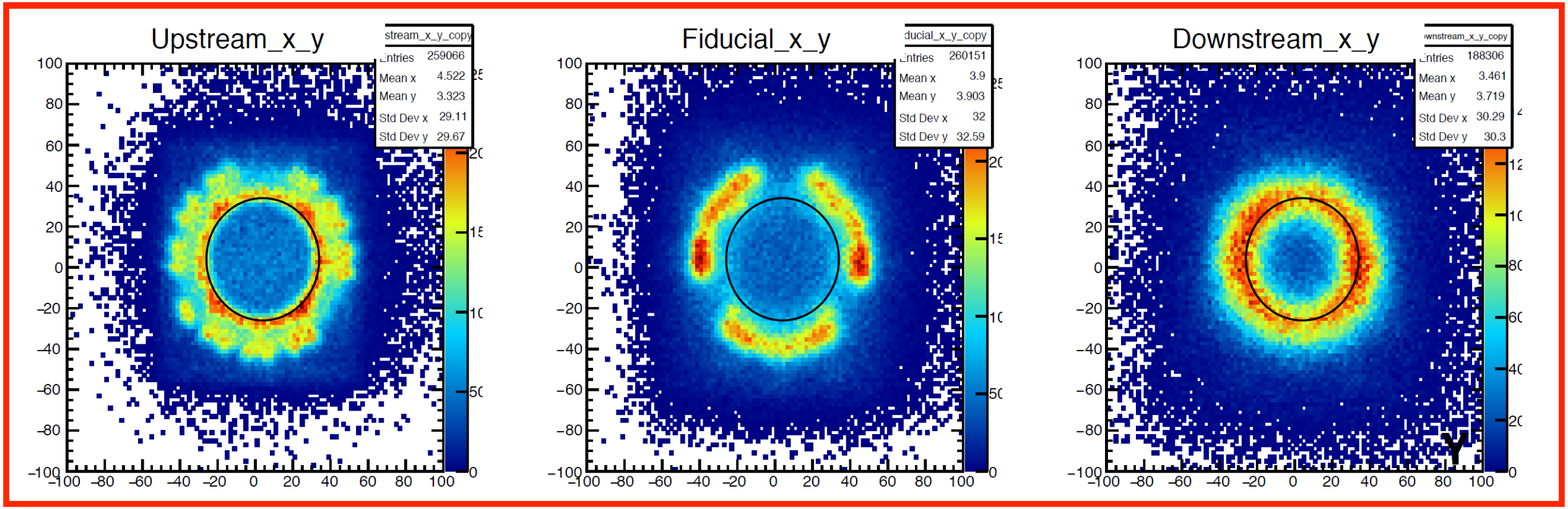


ZY

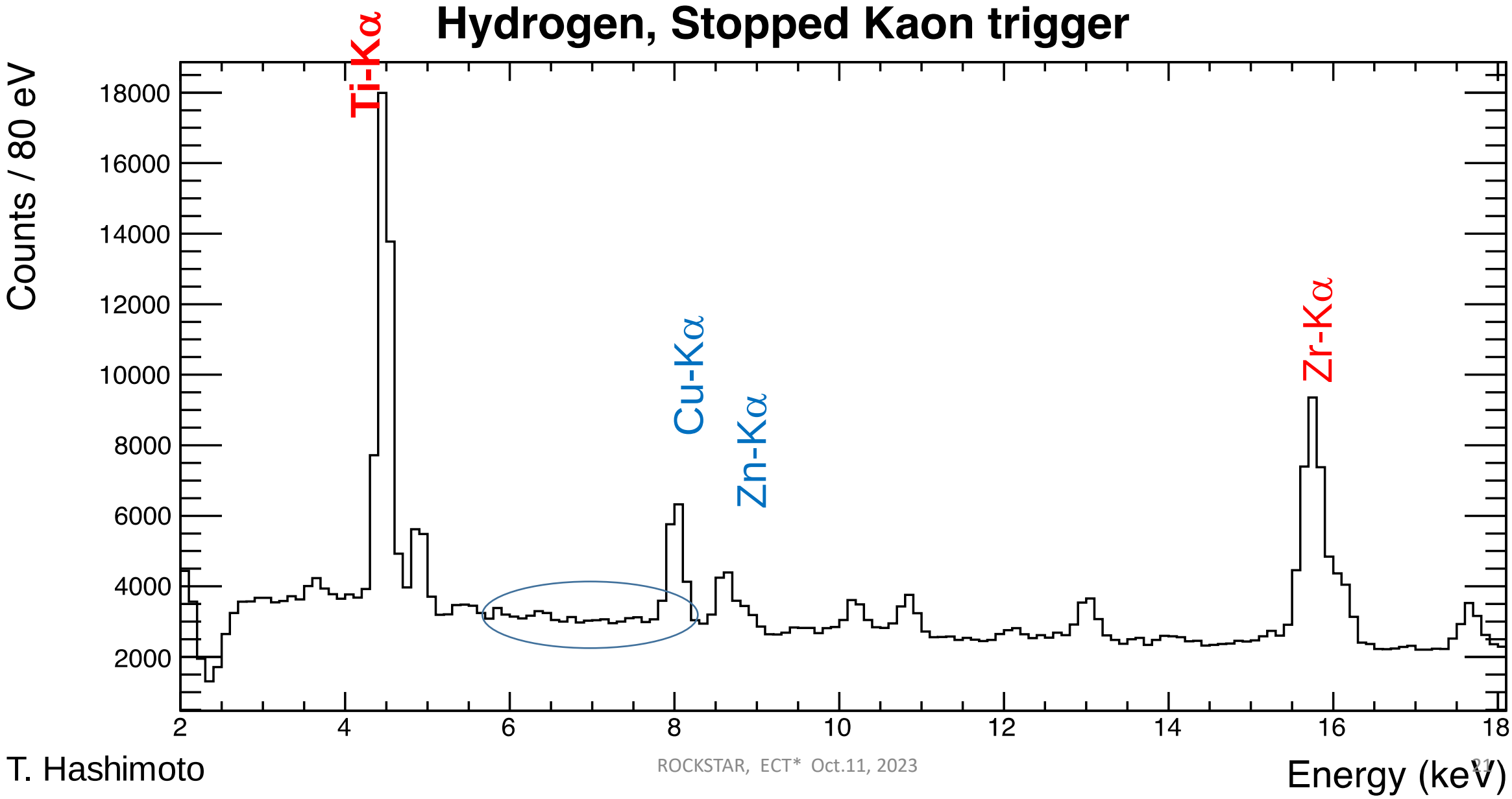




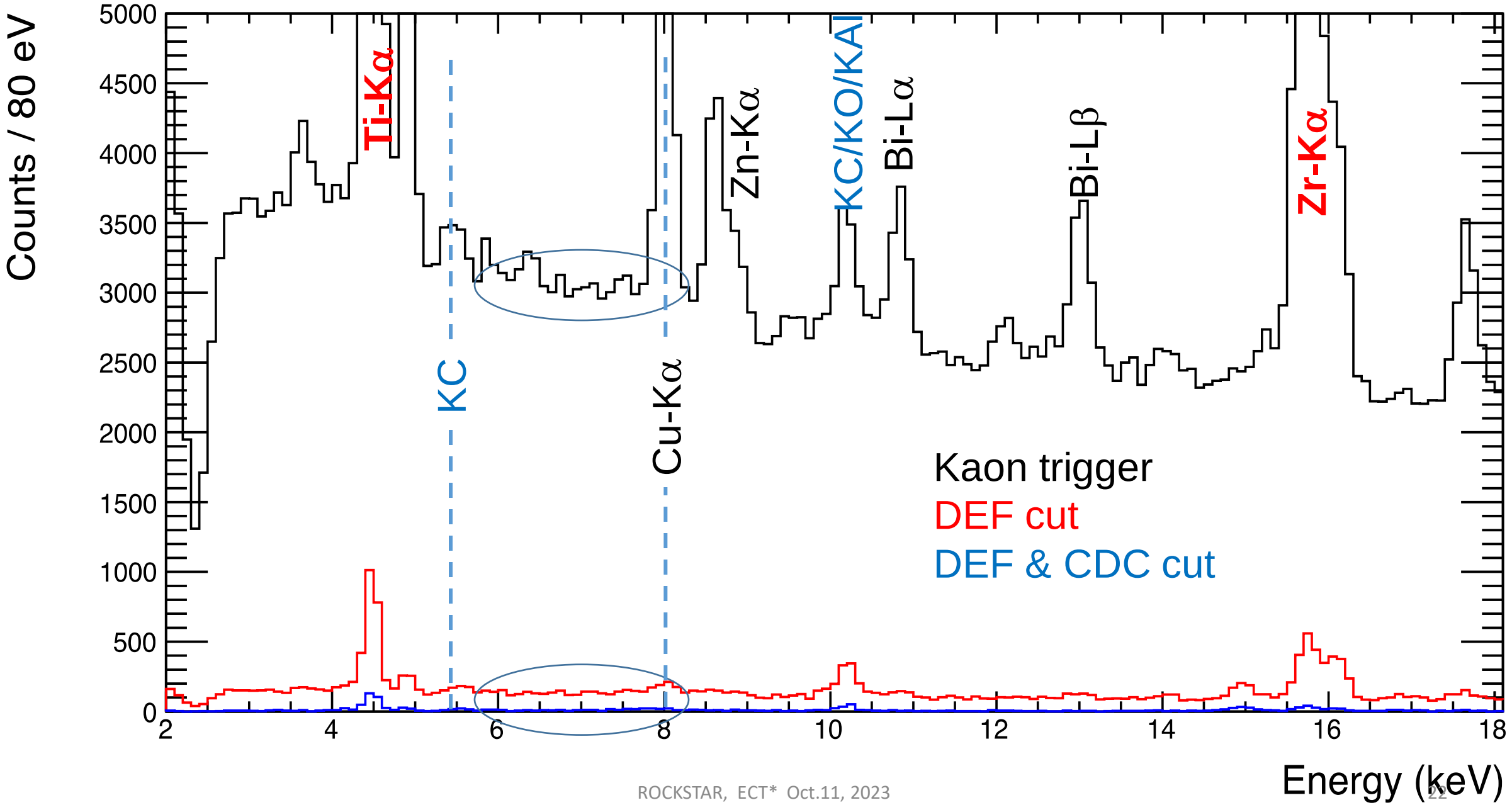
Vertex image (BPC&CDC)



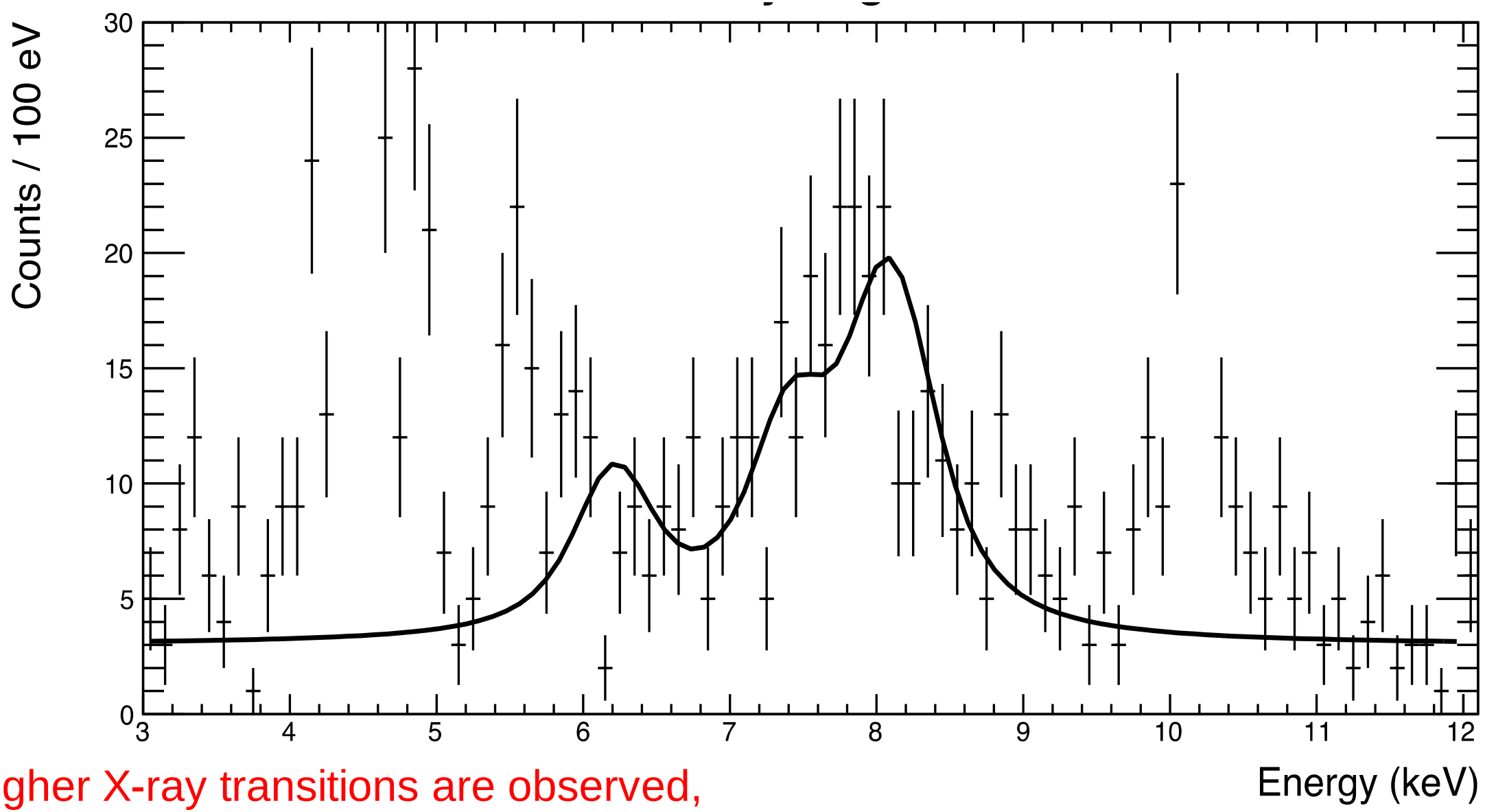
-130<Z<-70 **-60<Z<60** **70<Z<130**


Hydrogen, Stopped Kaon trigger
Ti-Kα
Cu-Kα
Zn-Kα
Zr-Kα
Counts / 80 eV
18000
16000
14000
12000
10000
8000
6000
4000
2000
2
4
6
8
10
12
14
16
18
Energy (keV)

Kaonic Hydrogen



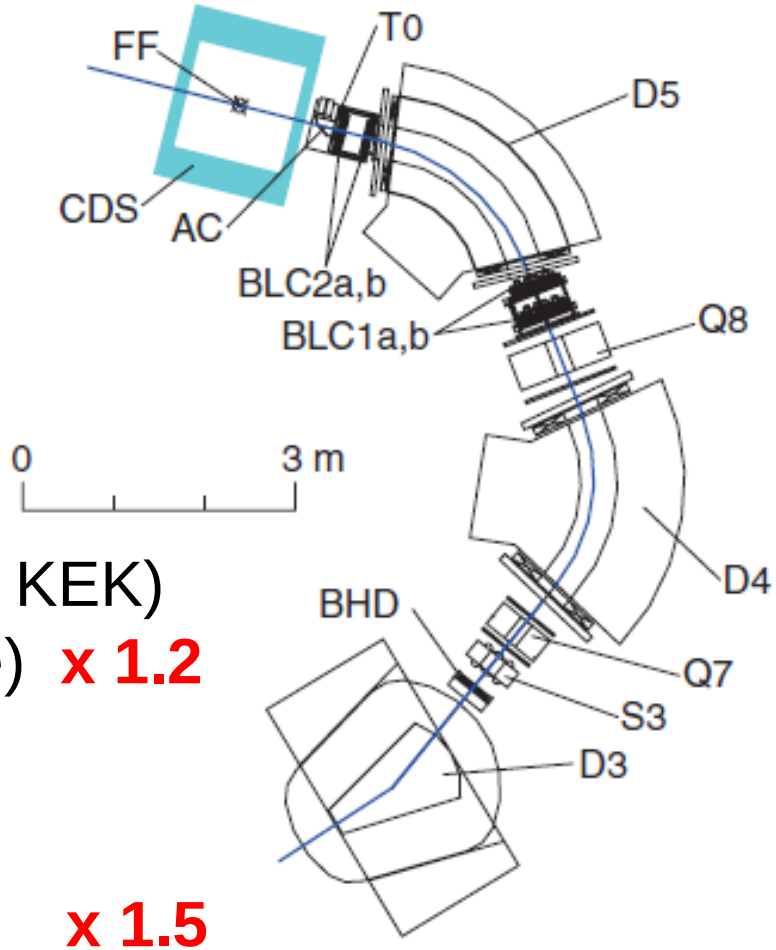
Kaonic Hydrogen spectrum with 90-hour data taking



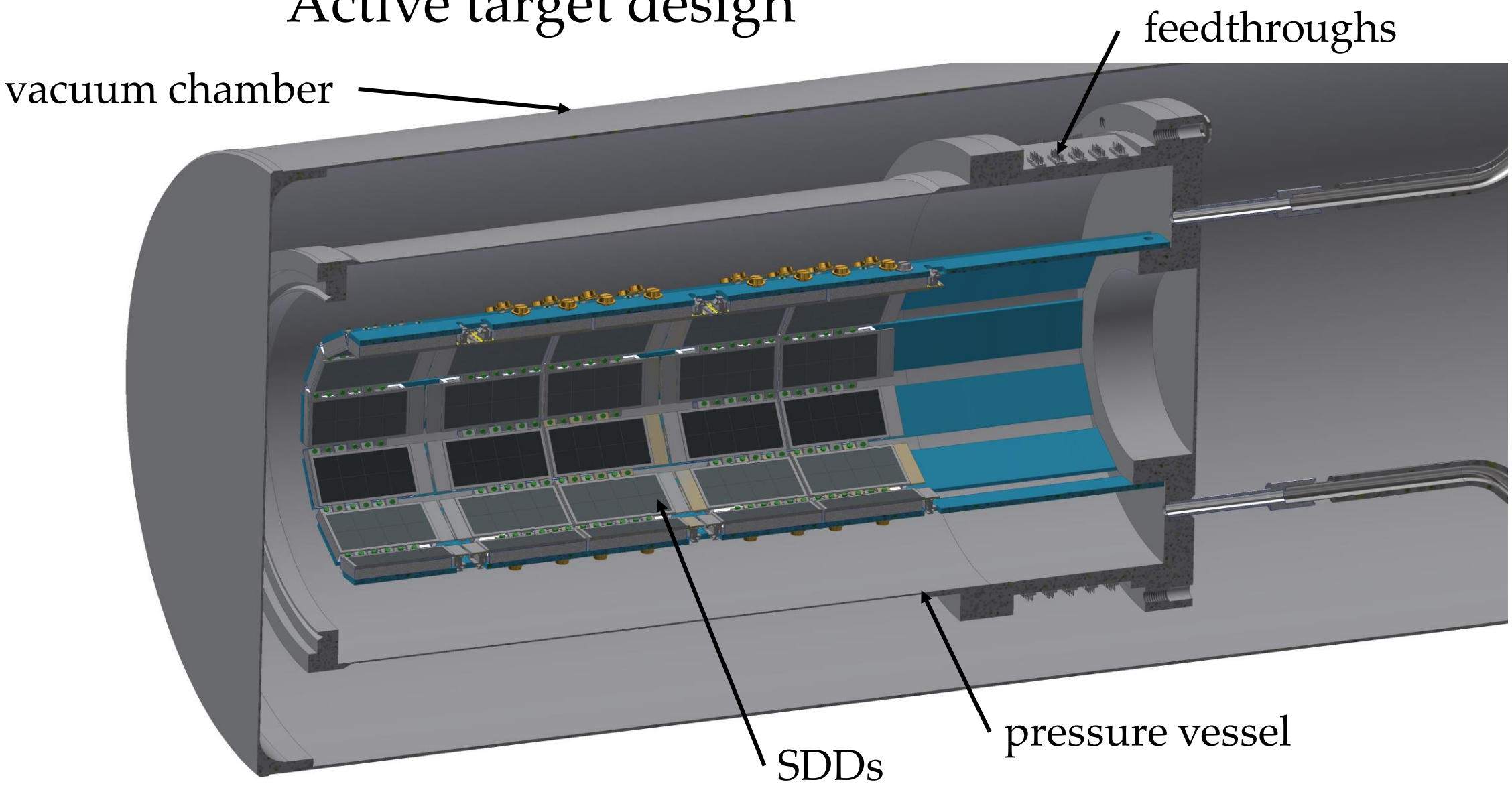
Higher X-ray transitions are observed,
Kα events less than expected

Possible options for upgrade

- Remove D5 to increase number of inflight kaons
  - shorter beam line (still long…) **x 1.5**
  - better beam focus **x 1.5**
- Larger target to increase stopping efficiency
  - add more SDDs **x 1.5**
- Shielding of SDDs **?**
- SDD inside the hydrogen gas target (similar to KpX at KEK)
  - no losses in the cell wall (now ~80% transmittance) **x 1.2**
  - to avoid kaonic kapton lines
  - possibility to measure 2p state
- Higher primary beam intensity 50kW → 80kW? **x 1.5**



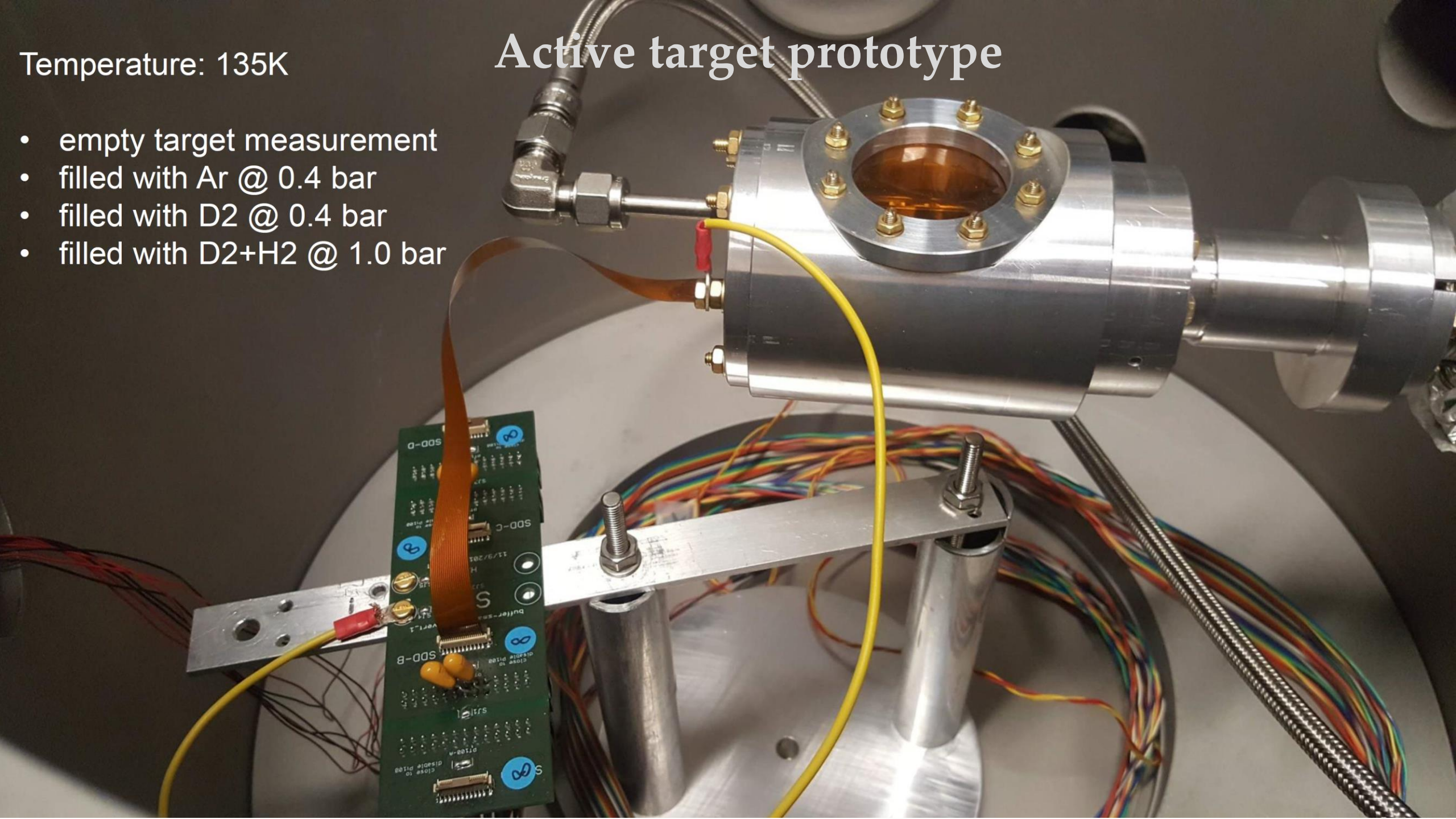
Active target design



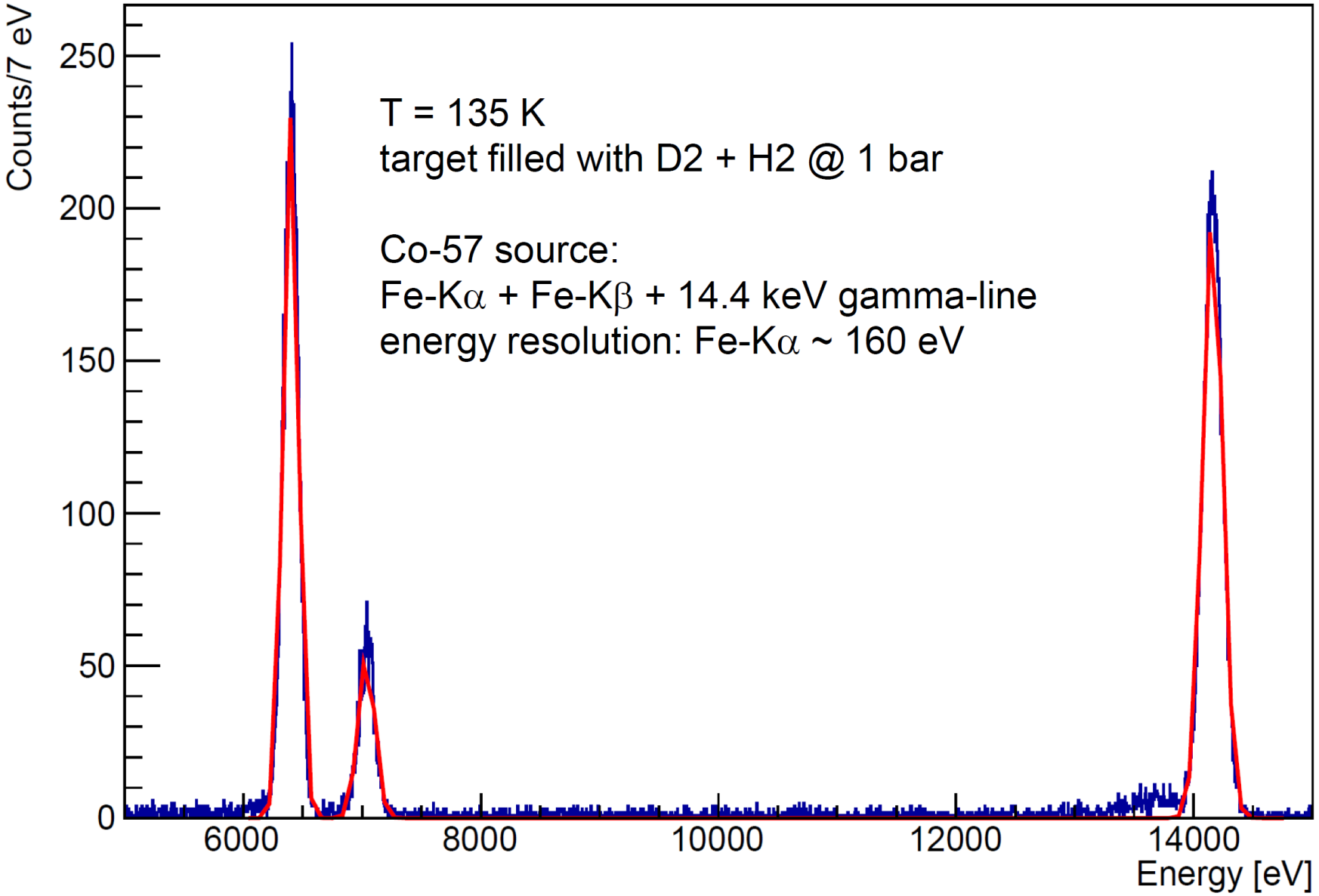
Active target prototype

Temperature: 135K

- empty target measurement
- filled with Ar @ 0.4 bar
- filled with D2 @ 0.4 bar
- filled with D2+H2 @ 1.0 bar



Active target prototype



Conclusion

First test beam time has shown that improvements are necessary:

- shorter beam line and better beam focus
- active target
- additional SDDs

➢ MC and design studies to shorten the beam line are finished
➢ Active target studies are ongoing

Possible time line for E57:
Test beam time end of FY 2024
Kaonic deuterium run FY2025

Thanks

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