AUSTRIAN ACADEMY OF SCIENCES

SMI – STEFAN MEYER INSTITUTE FOR SUBATOMIC PHYSICS

Characterization of Silicon drift detectors (SDDs) for SIDDHARTHA and J-PARC

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Outline

- Motivation
- Theory
- Experimental Setups
- Results
- Outlook
- Summary

Motivation

- 48 SDDs are used to measure the kaonic deuterium X-ray spectrum
- Characterization of SDDs important:
  ->To guarantee that SDDs work stable and have good energy resolution => energy calibration -> to sum up all channels at the end of the experiment -> precise data analysis
- Proposed:

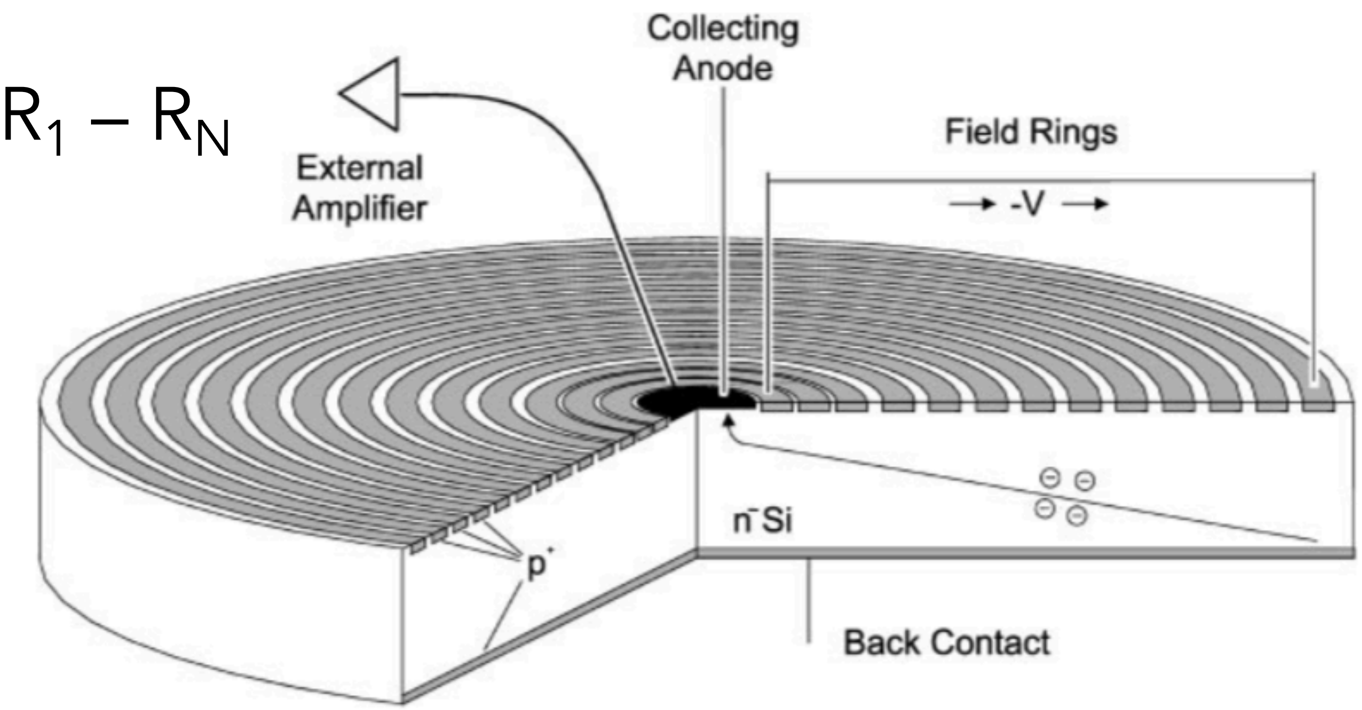
Energy resolution:	< 180eV at 6keV
Time resolution:	300ns at 120K
Stability:	stability of peak position < 6eV at 6keV

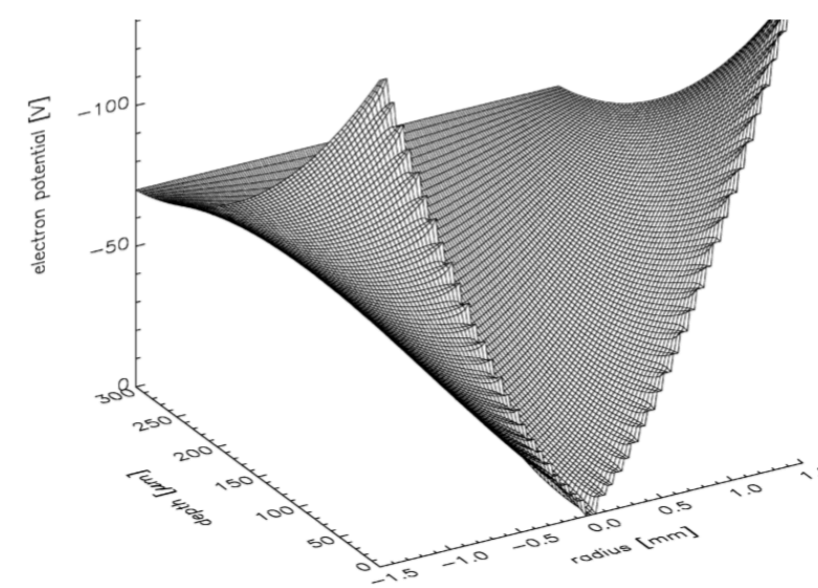
Silicon drift detector (SDD)

- Ring shaped p^+ junctions $R_1 – R_N$
- n^+ anode: lowest point of potential energy

- Typical values:
  R_1 = -15V
  R_N = -80V
  R_B = -60V

- SDD converts X-ray into electron hole pairs

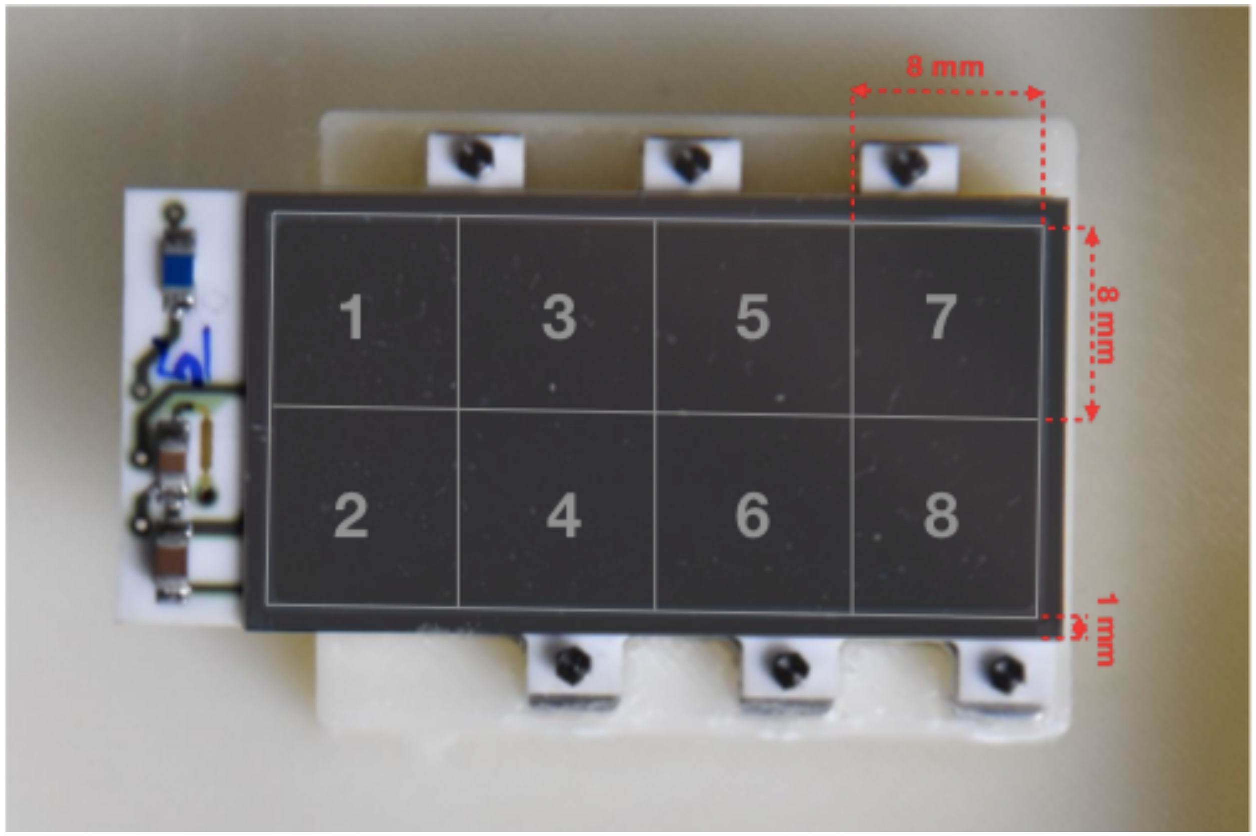




[1]

SDD layout

- Organized in 8 units
- Unit: 8x8 mm^2
- 450 µm thick
- Active area: 512 mm^2
- Dead area: edge 1mm



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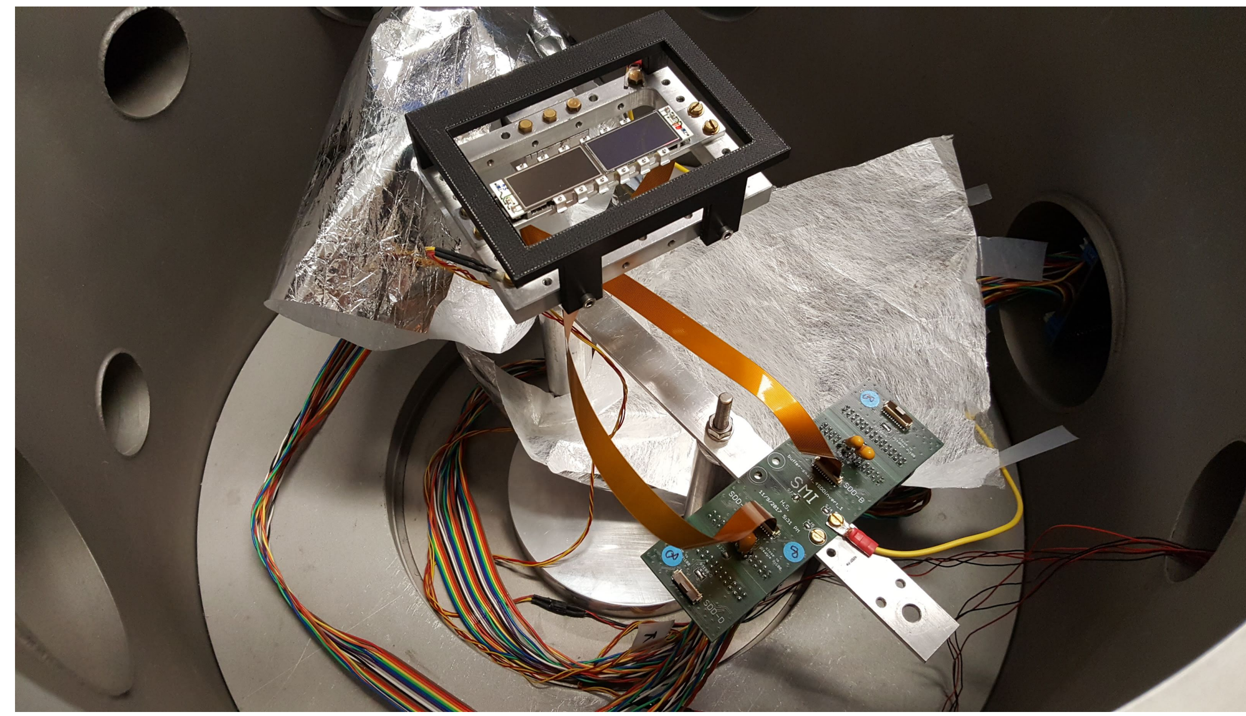
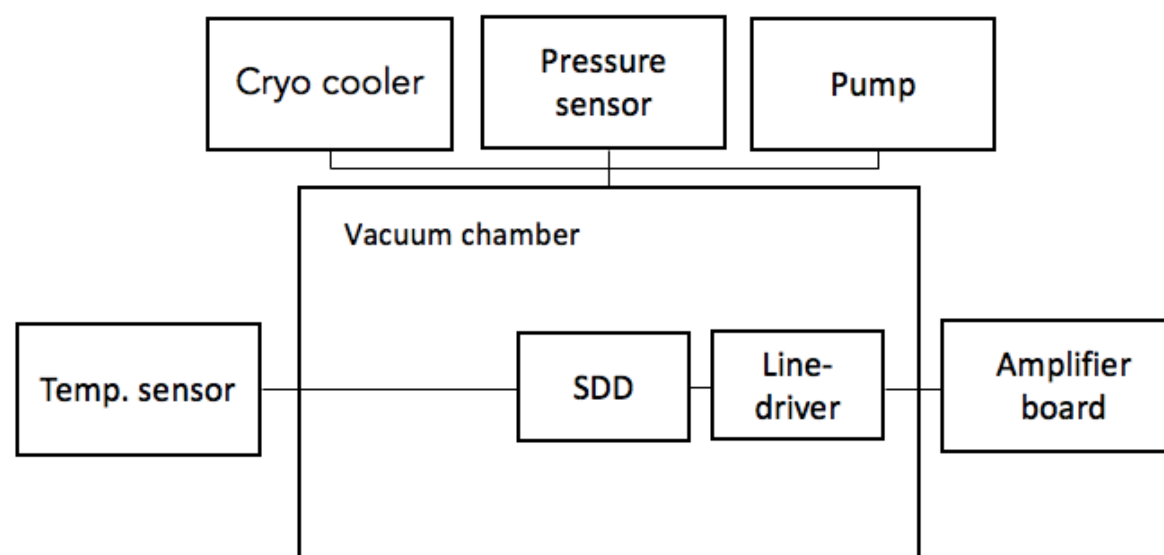
I. Experimental Setup at SMI



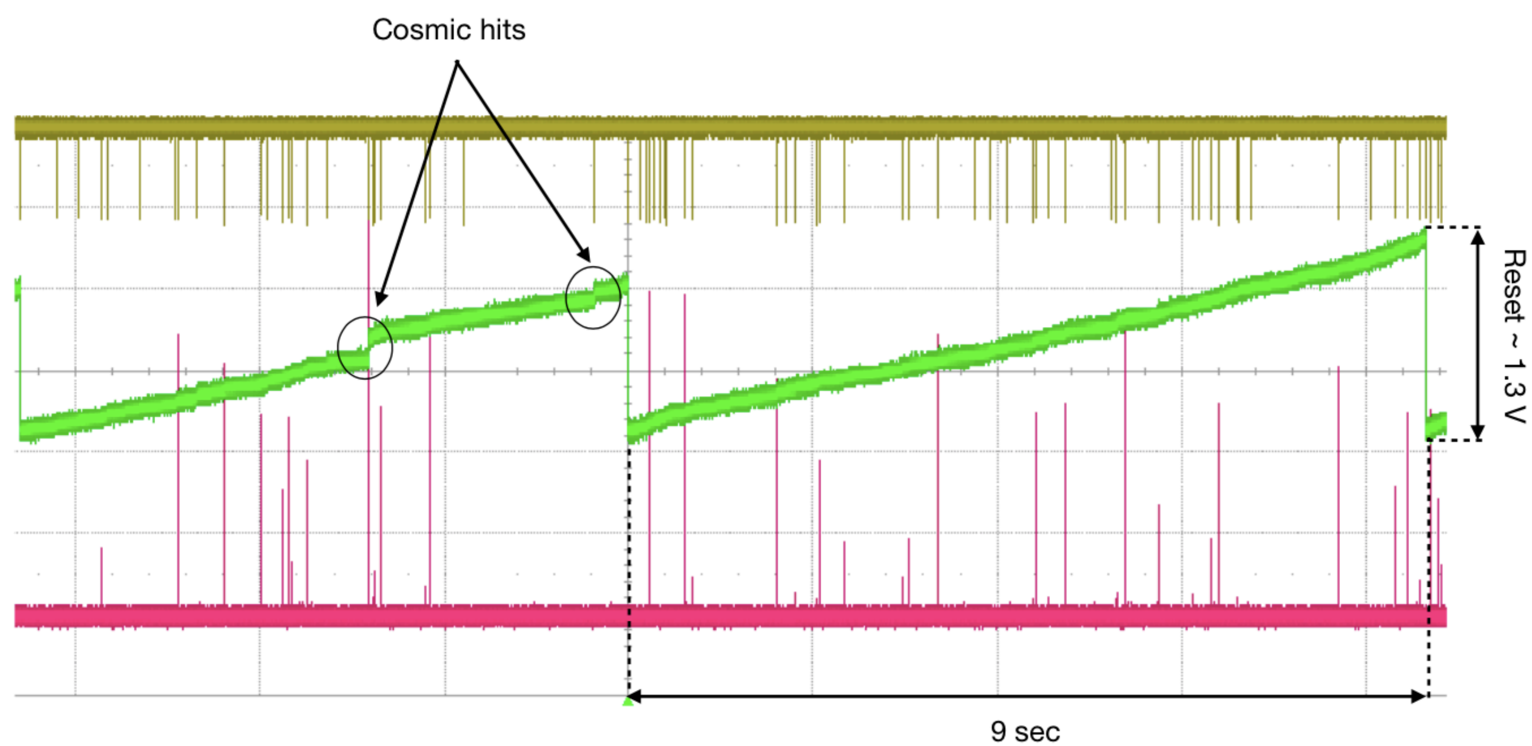
Measurements of:

- Voltage ramp
- Energy resolution
- Time resolution
- Stability



Measurement: Voltage ramp

- CUBE pre-amplifier first amplification stage
- Periodical charging and restoring of the CUBE to avoid saturation on the feedback capacitance
- 2 sources of charge:
  => Leakage current
  => Charge generated from X-rays
- After reset 20 μs dead time



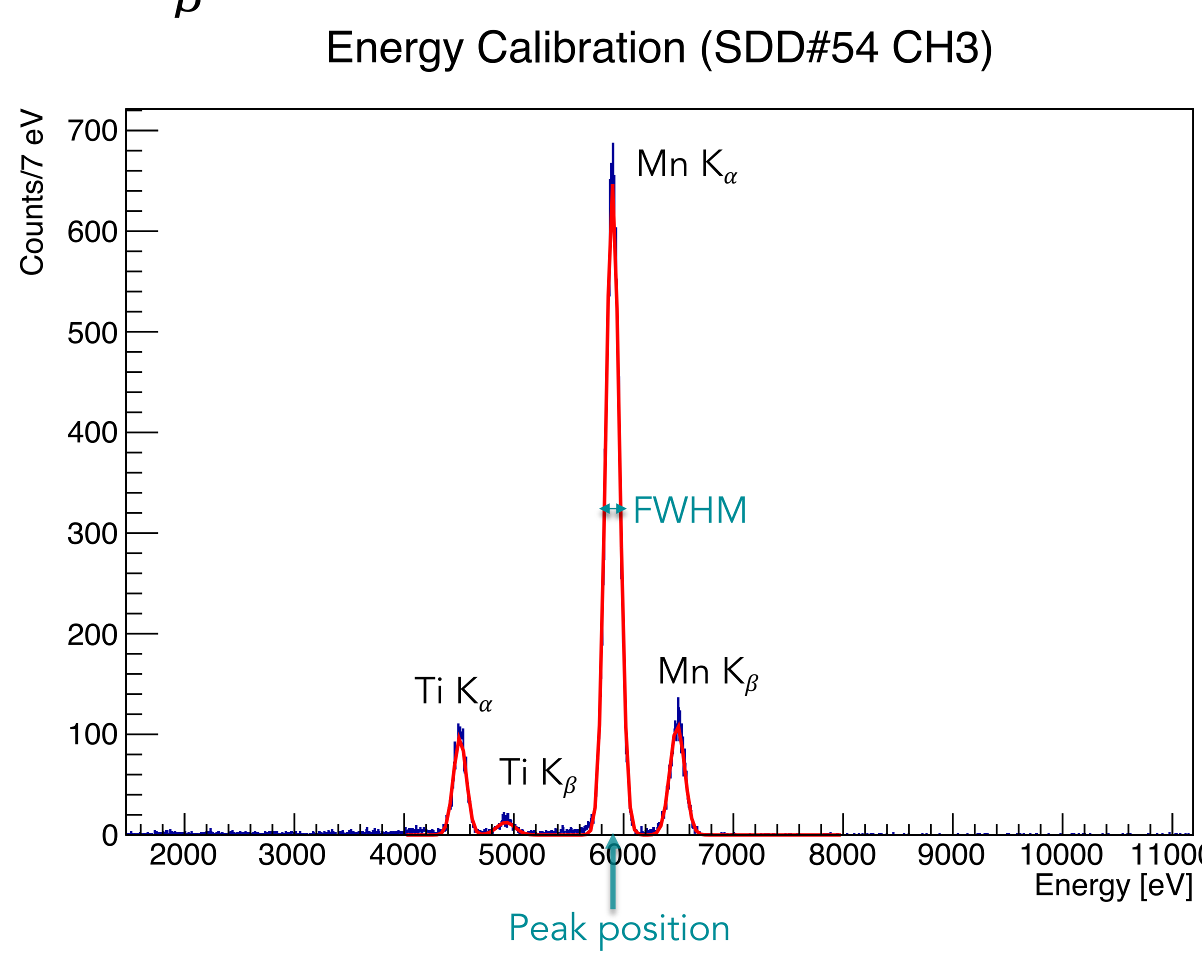
Measurement: Voltage ramp

- Voltage ramp depends on temperature
- Longer ramps -> lower leakage current -> less dead time (fewer events get lost)
- Measurements at room temperature and around 140K

SDD#	Bias voltage [V]	Date	Temp. [K]	CH 1 [ms/1V]	CH 2 [ms/1V]	CH 3 [ms/1V]	CH 4 [ms/1V]	CH 5 [ms/1V]	CH 6 [ms/1V]	CH 7 [ms/1V]	CH 8 [ms/1V]
60	R_1= -14.54 R_N= -85.20 R_B= -60.60	26.11.18	298.45	0.2	0.1	0.2	0.2	0.2	0.2	0.15	0.15
60	R_1= -14.54 R_N= -85.20 R_B= -60.60	27.11.18	144.53	12000	5000	9000	9000	9000	7000	10000	x

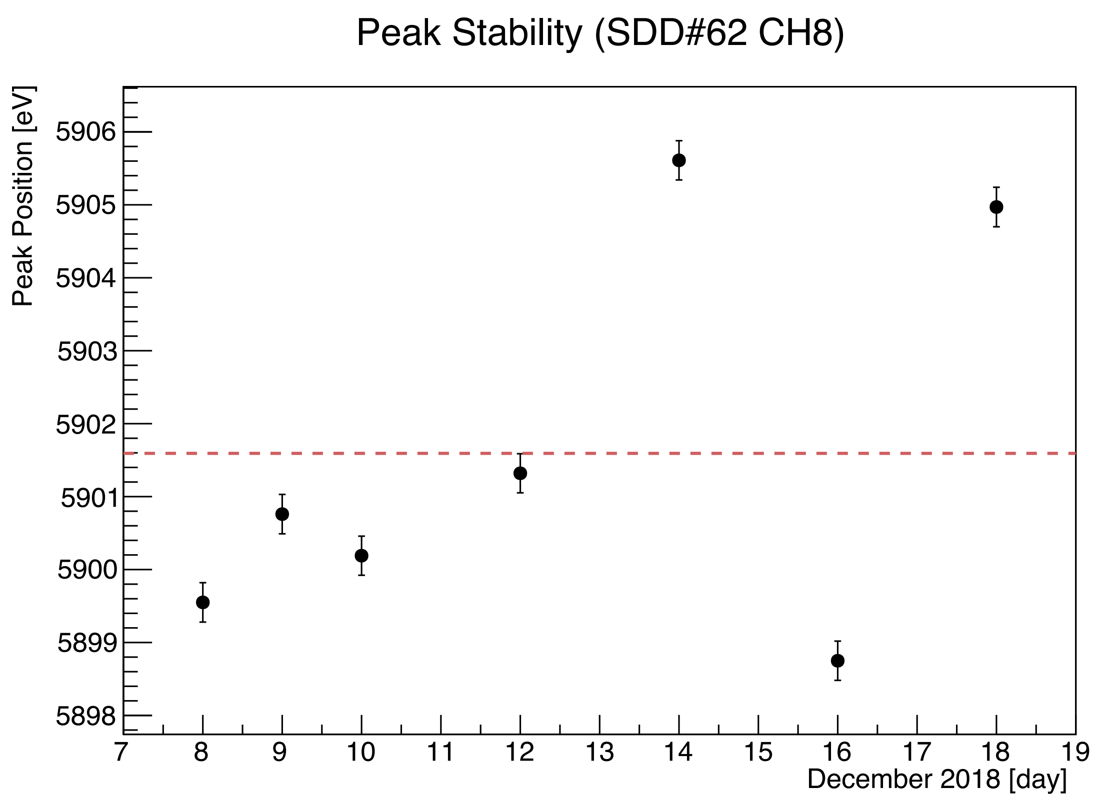
Energy resolution

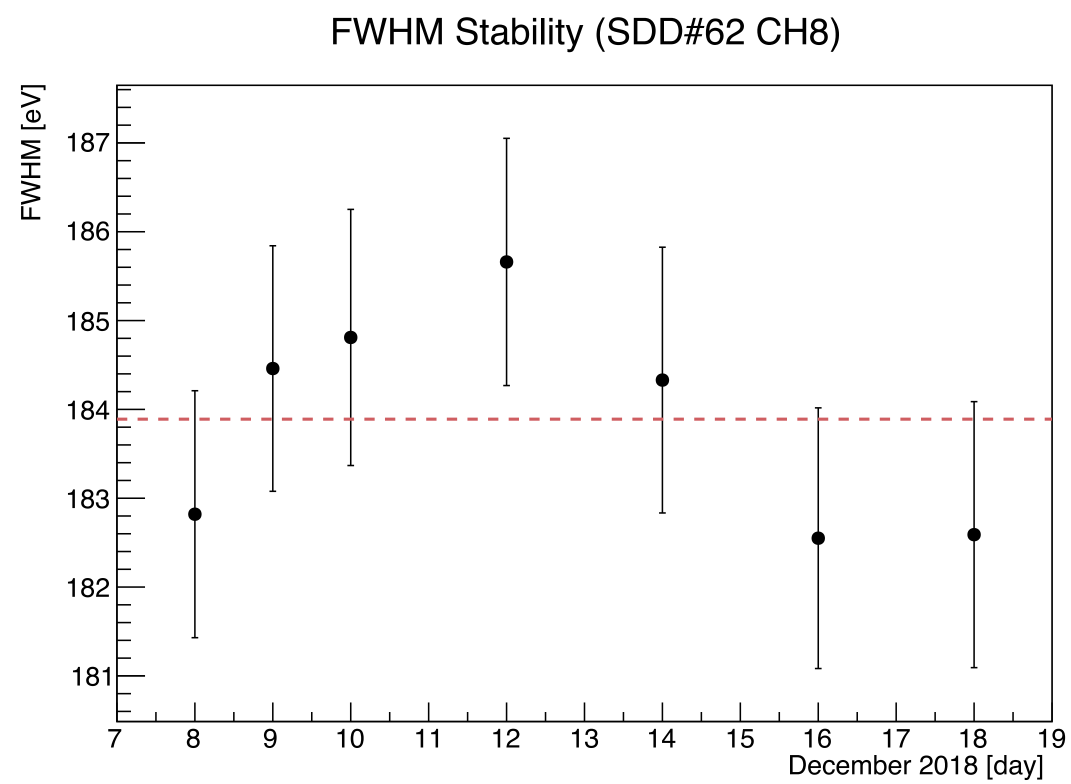
- Fe-55 source + 5μm Ti-foil
- Fit of Ti K_α, Ti K_β , Mn K_α and Mn K_β
- Peak position and FWHM of Mn K_α



Long-term stability measurements I

- Mn K_α Peak – Measurement 10 days





- Average peak position: ~5901.5 eV
- Average FWHM: ~184 eV

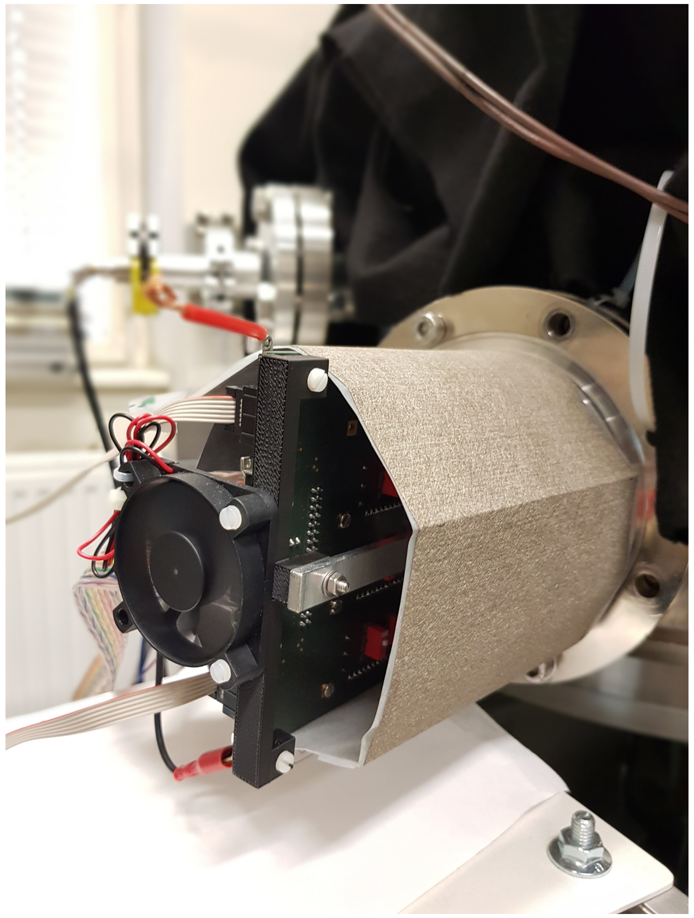
Improvements on the setup

To get rid of the sinus oscillation shortly before signals
June 2019:

- Line-driver got an additional filter
  (10 μF + 10 μF) for the CUBE bias voltage

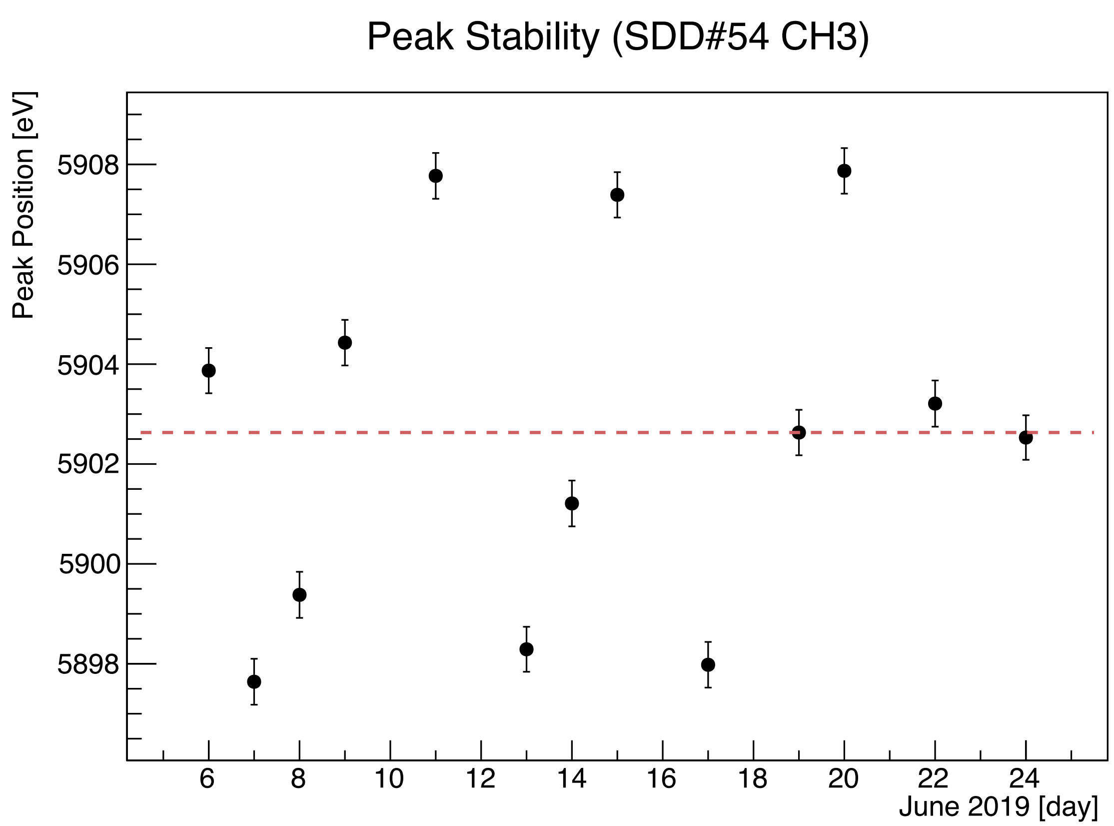
- A improved amplifier board with a shaping time of
  2 μs.
  NIM output: low threshold, high threshold, reset

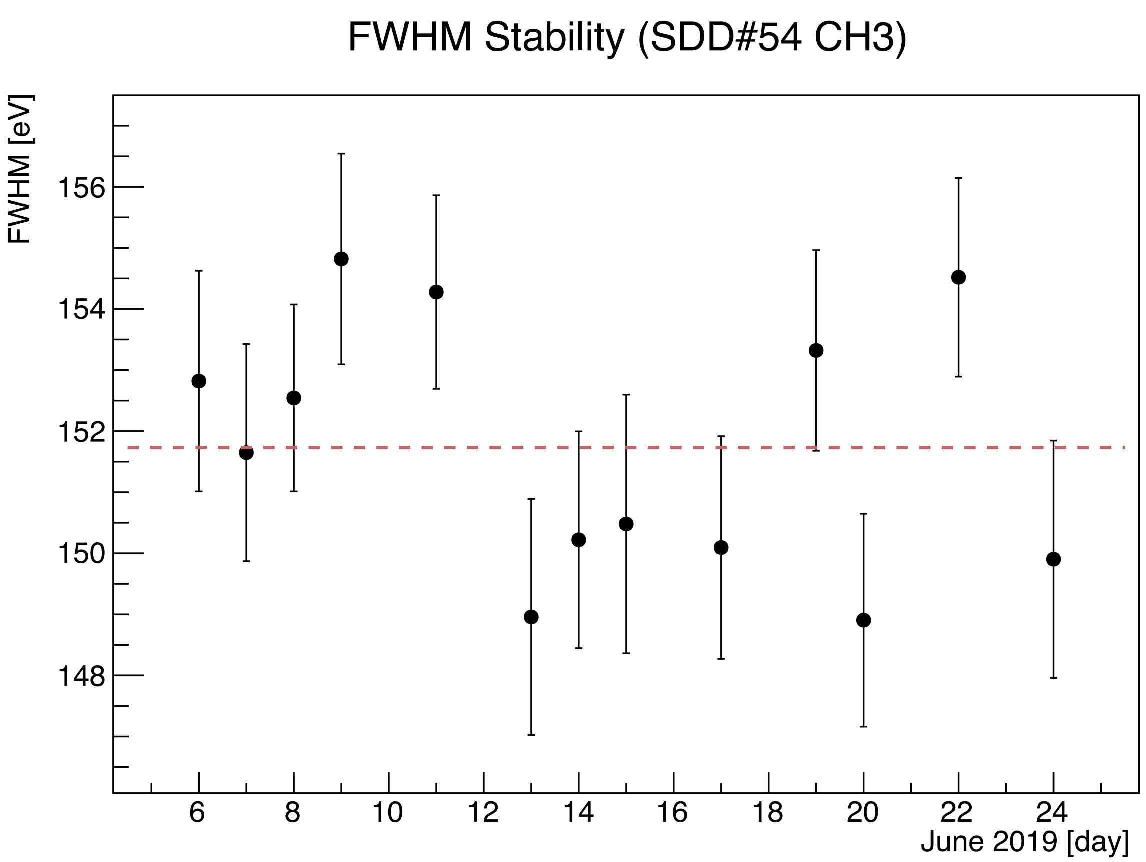
- Aaronia X-Dream RF shielding fleece was mounted
  amplifier board



Long-term stability measurements II

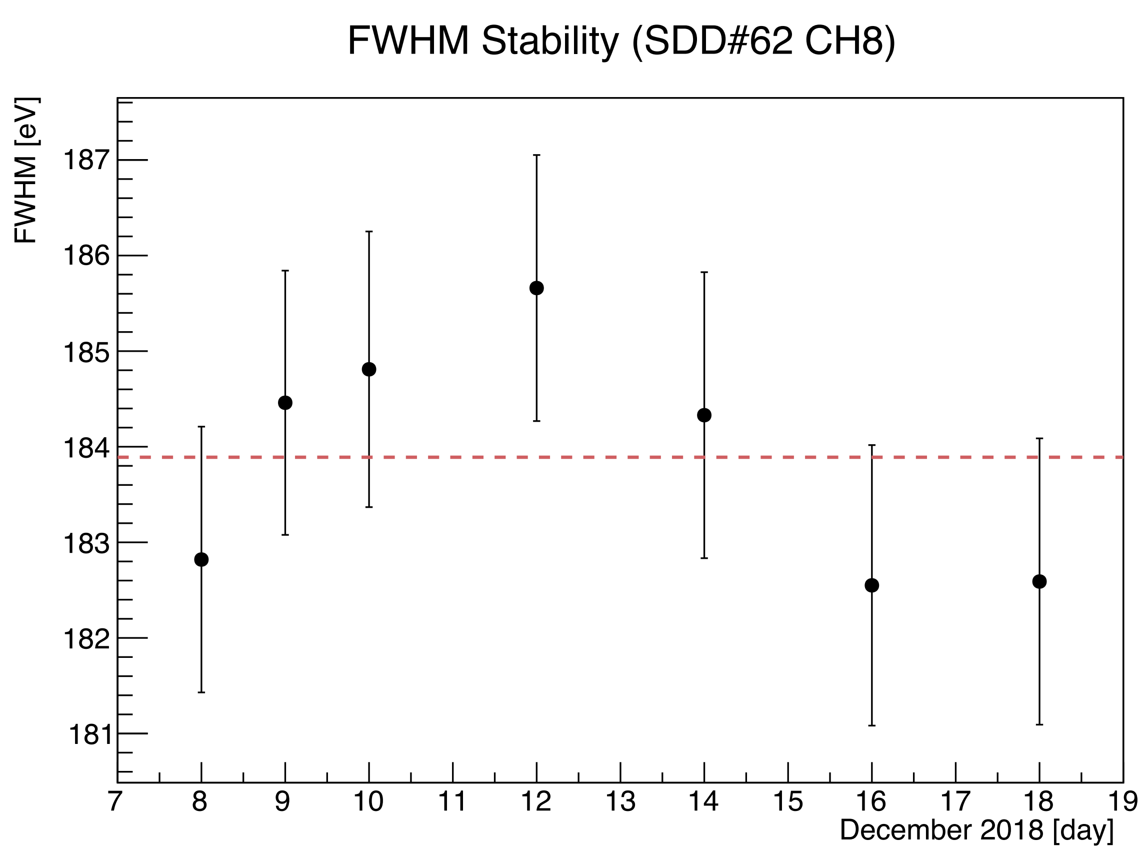
- Mn K_α Peak – Measurement 18 days

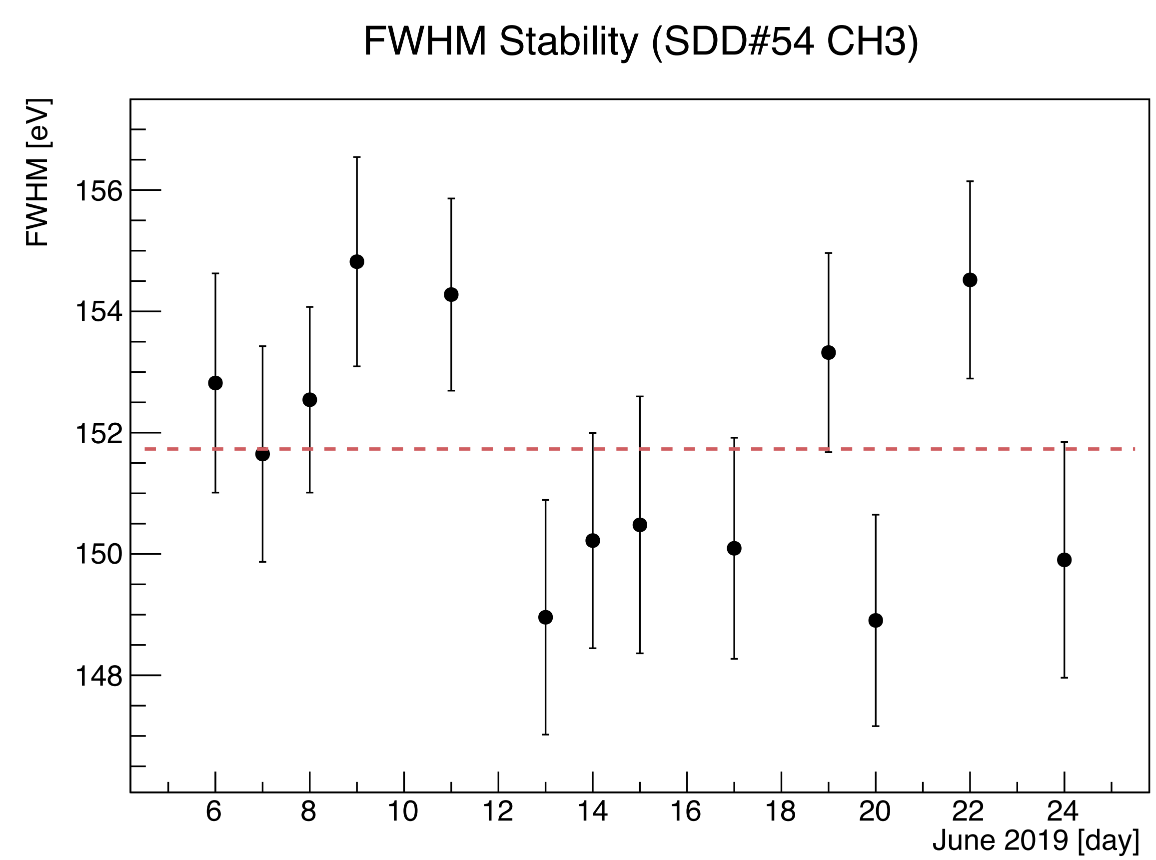




- Average peak position: ~5902.5 eV
- Average FWHM: ~152 eV

Comparison of FWHM before and after the improvements

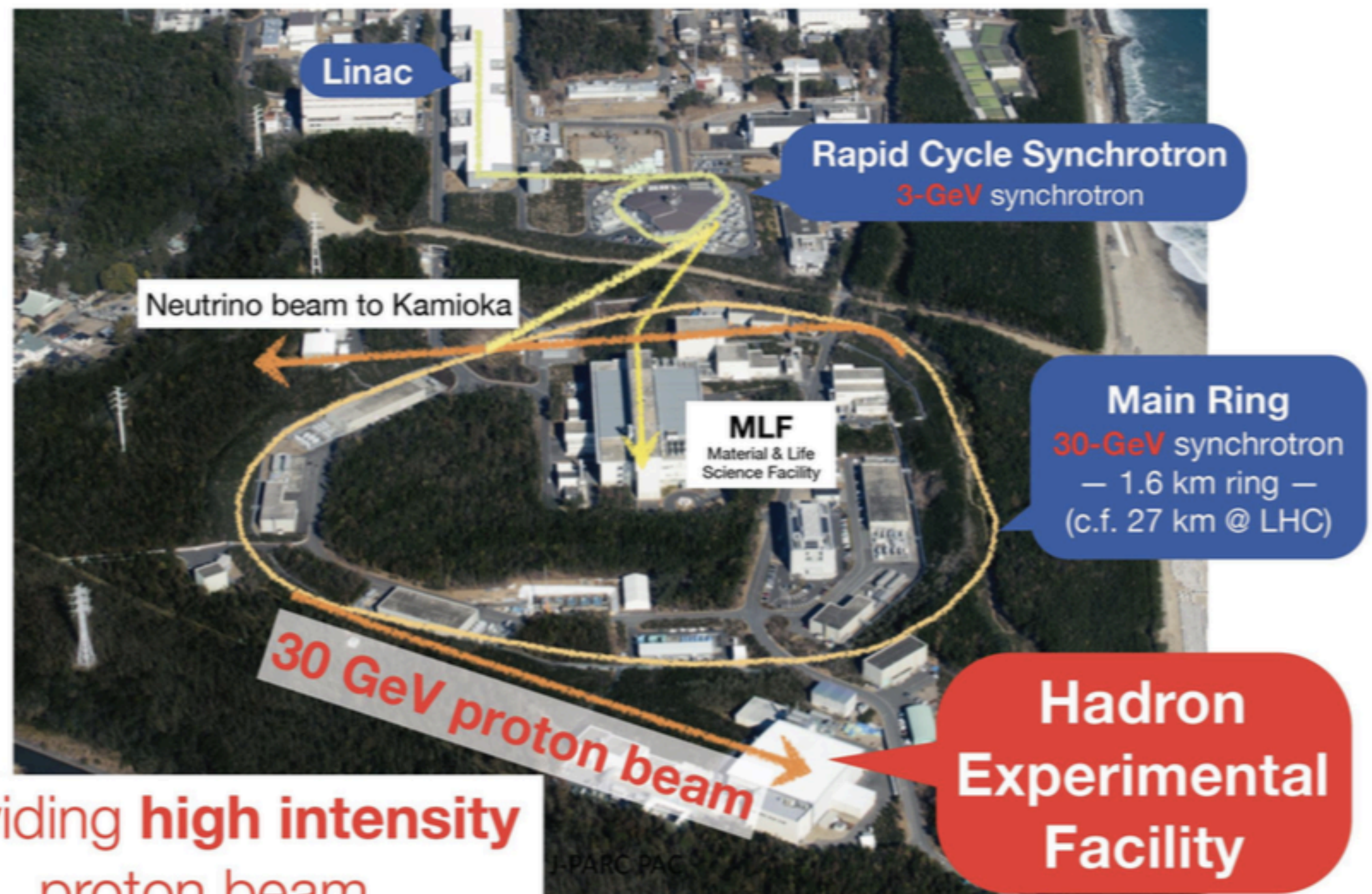




- Before: ~180 eV
- After: ~150 eV

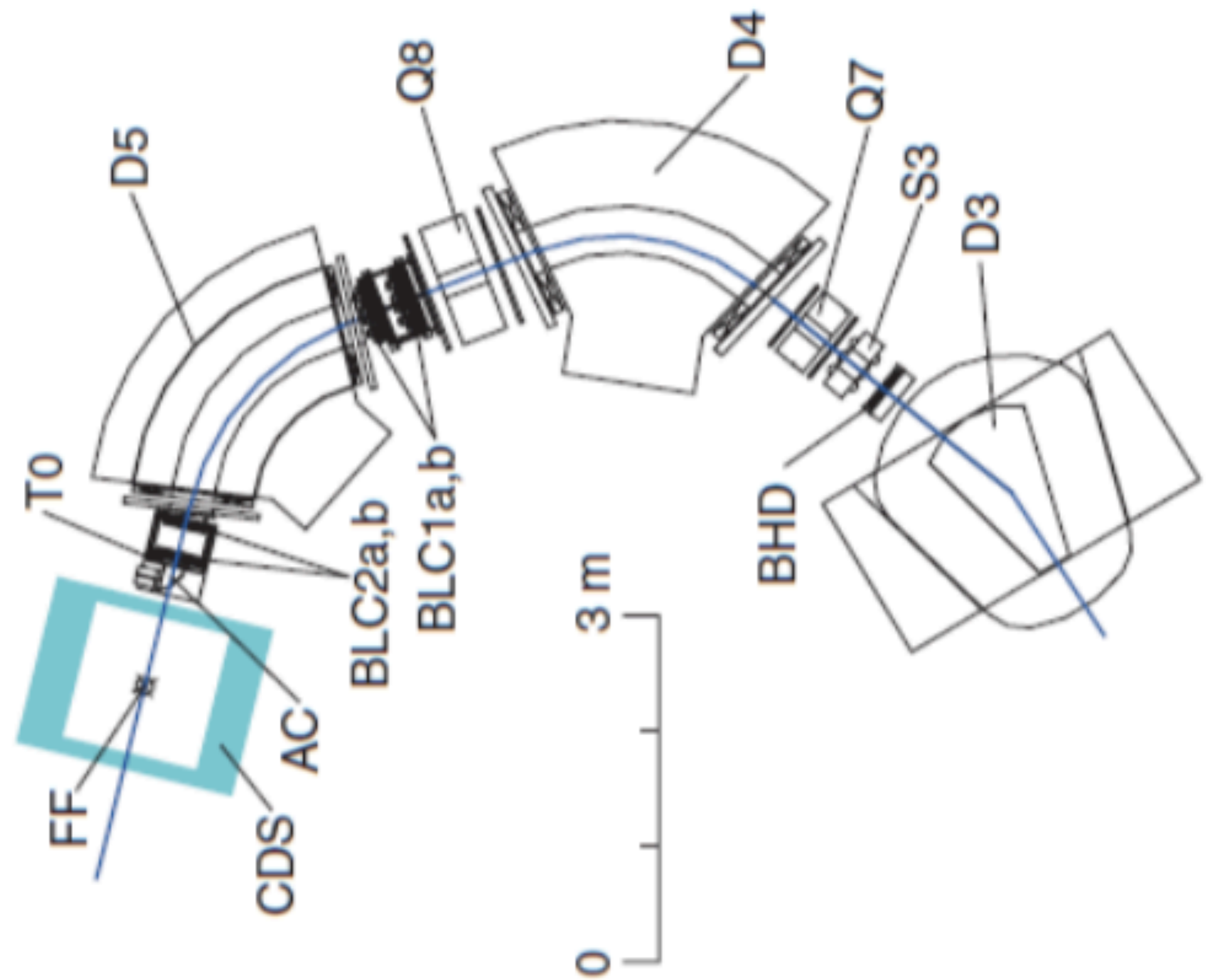
E57 at J-PARC

Japan Proton Accelerator Research Complex



providing **high intensity** proton beam

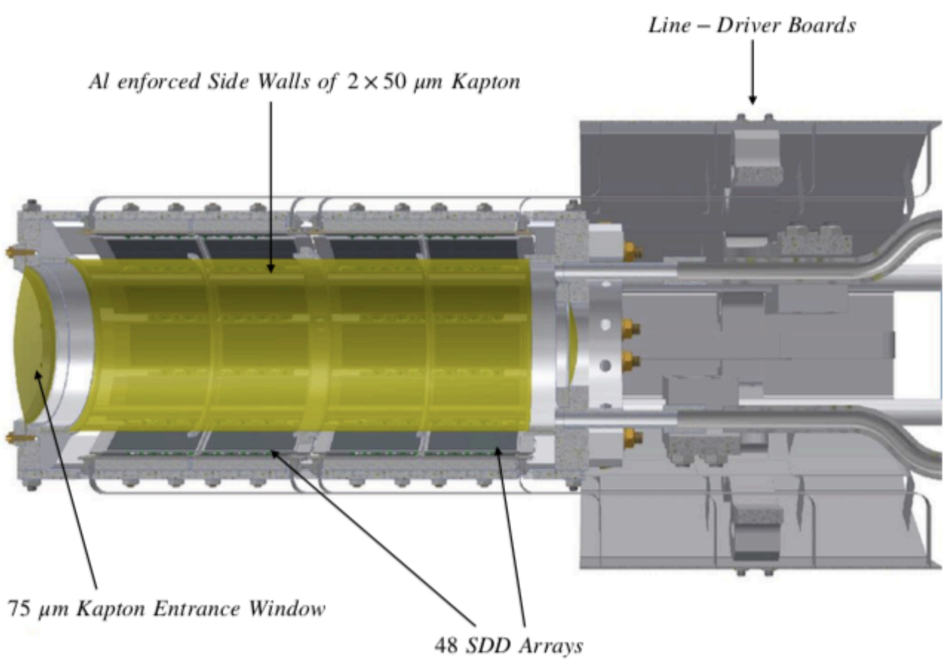
E57 at J-PARC

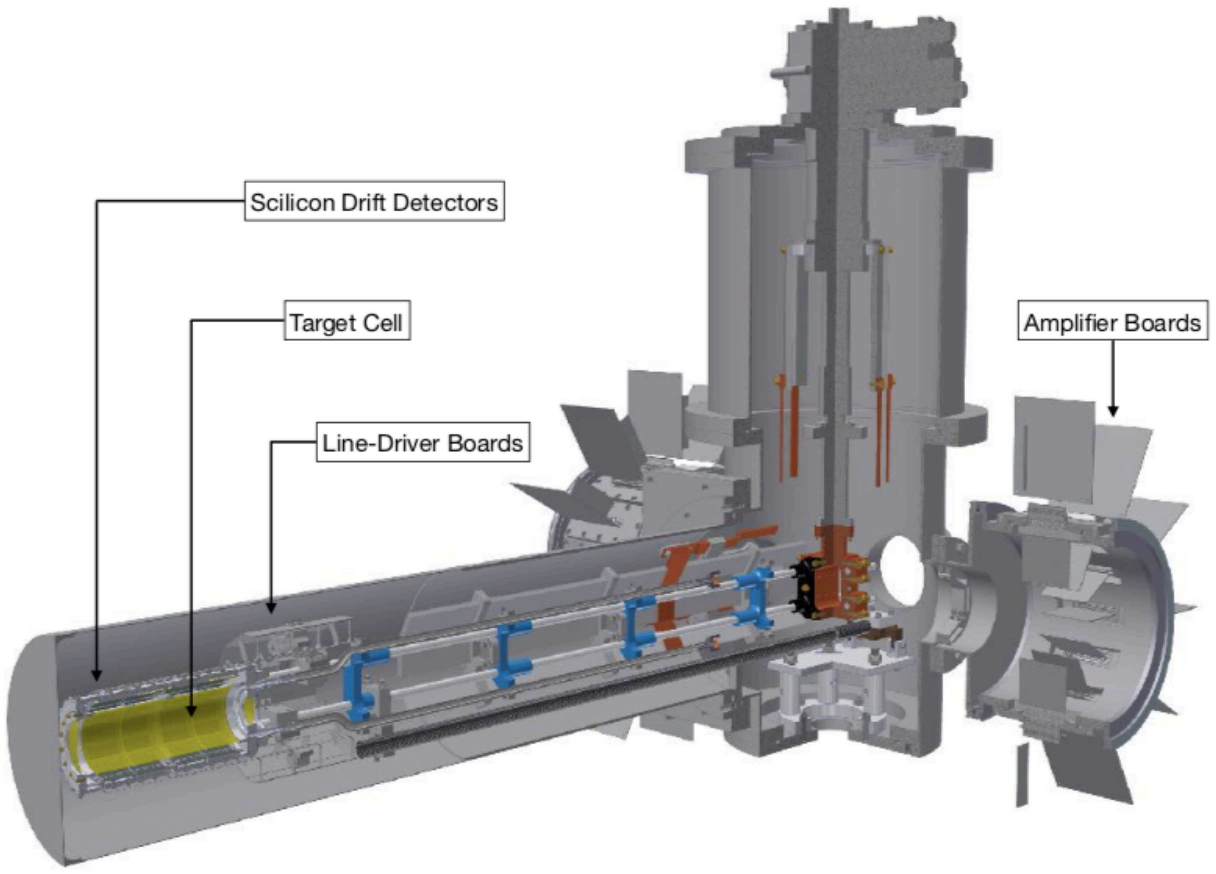


[3]

E57 at J-PARC

- Target cell surrounded by 48 SDDs





[4]

E57 at J-PARC

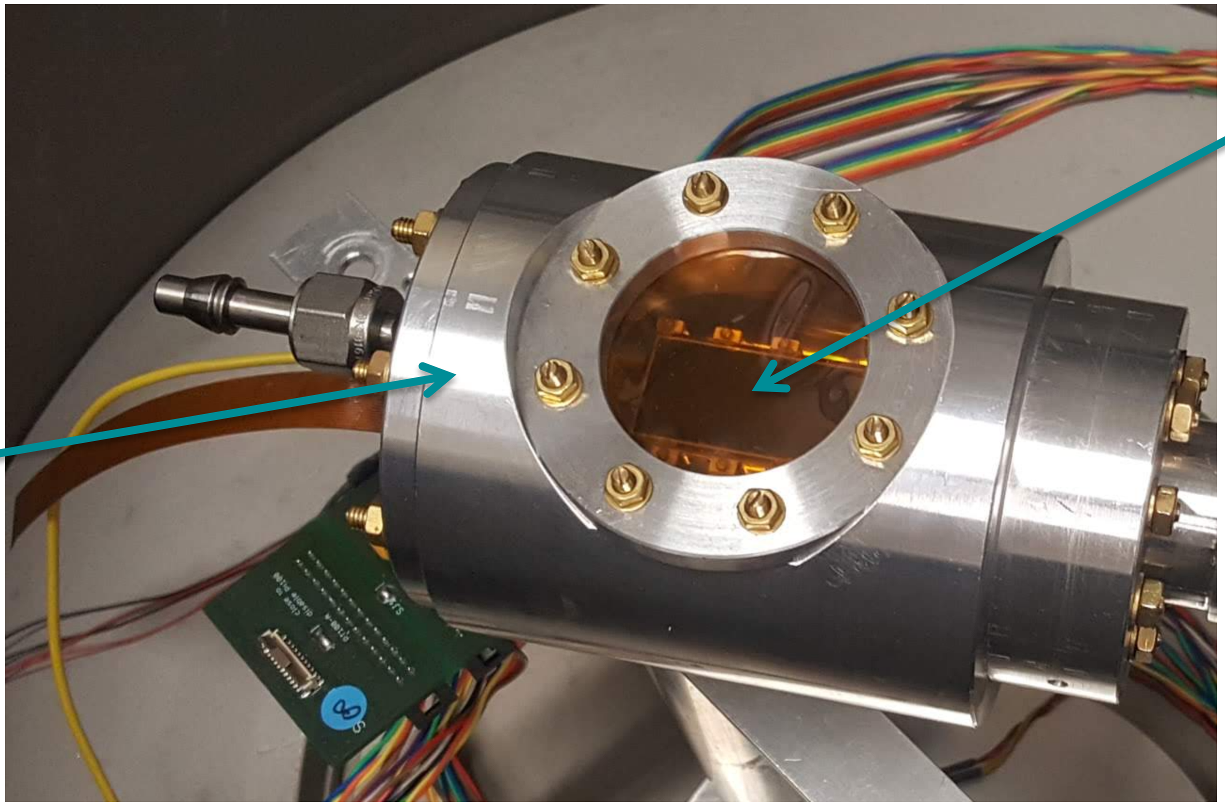
- Phase 1: study and optimization to stop the K-beam in the target (4 days-March/April 2019) with helium and proof of principle with kaonic hydrogen (background studies)

  => Not enough events
  => Setup improvements: SDDs inside the target cell

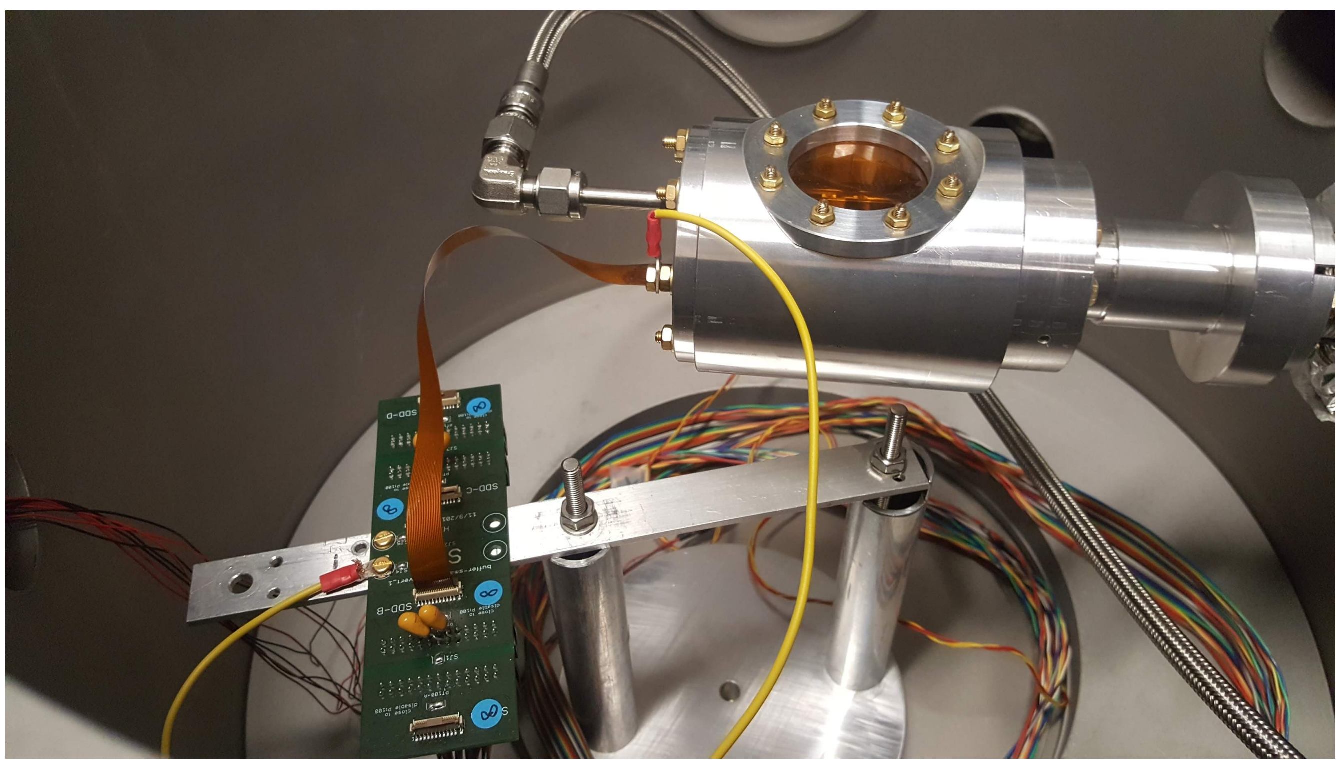
- Phase 2: reaching the required precision in the determination of shift and width (33 days) with deuterium

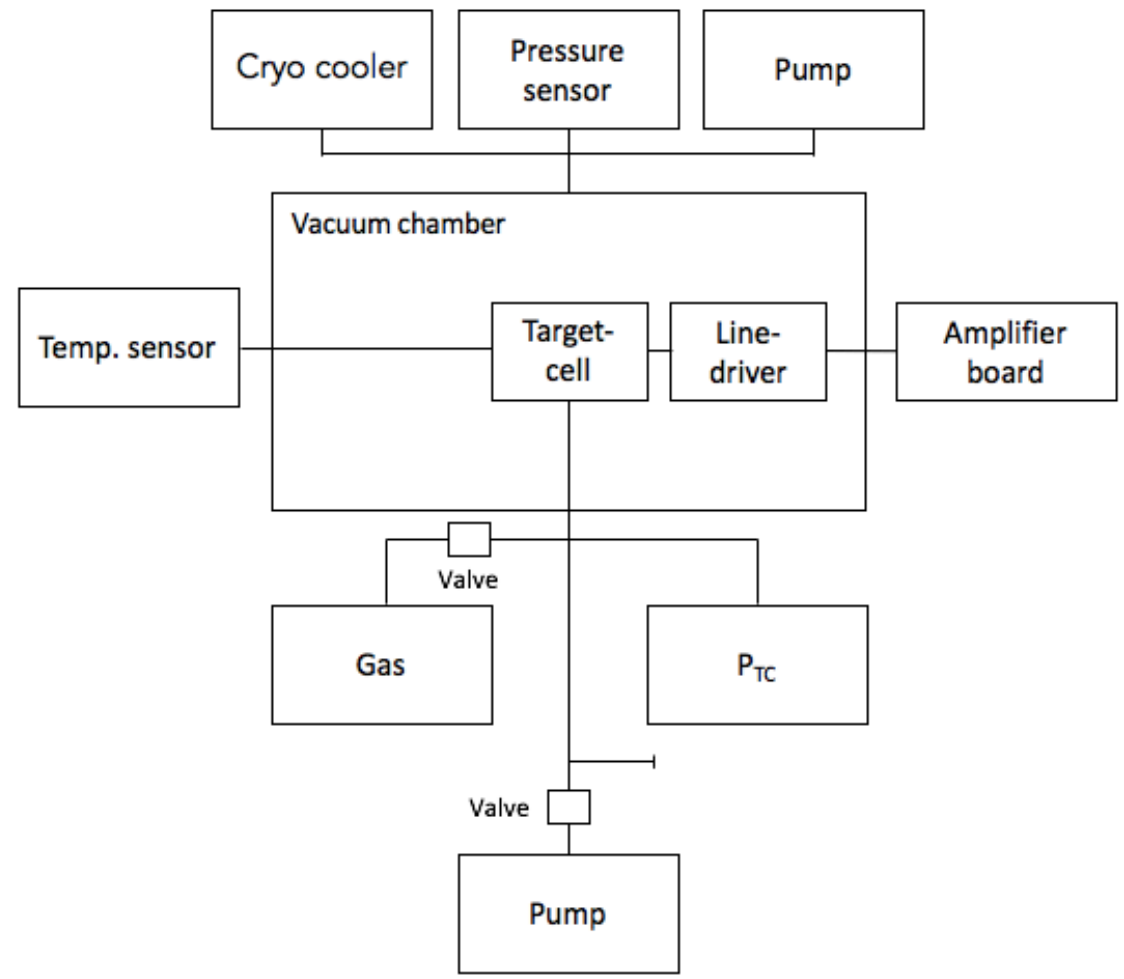
II. Experimental setup at SMI: Hydrogen target cell

- SDDs inside target cell
  - => Avoid losses through Kapton wall
  - => No Kapton lines in spectrum
  - => Possibility to measure the 2p state



II. Experimental setup at SMI: Target cell





Results: Target cell

- Same energy resolution with and without target cell

SDD#24 CH 1 - Mn K_α peak			
Kind of measurement	Date	Peak position [ADC channel]	FWHM [ADC channel]
without TC	29.08.19	0.586 ± 3.55E-05	0.0154 ± 3.73E-05
Vacuum	13.09.19	0.597 ± 1.33E-04	0.0165 ± 1.05E-04
Argon	14.09.19	0.595 ± 1.64E-04	0.0176 ± 1.32E-04
Argon	18.09.19	0.595 ± 1.11E-04	0.0155 ± 8.63E-05
Vacuum	20.09.19	0.591 ± 8.93E-05	0.0166 ± 6.94E-05
Vacuum	22.09.19	0.591 ± 8.56E-05	0.0171 ± 6.60E-05
Deuterium	23.09.19	0.601 ± 1.04E-04	0.0153 ± 8.05E-05
Deuterium	25.09.19	0.602 ± 1.08E-04	0.0154 ± 8.46E-05

Outlook

For second test phase a bigger cryogenic hydrogen target cell will be built -> slots for 4 SDDs

- More measurements with different SDDs in the target cell
- Measurements with the amplifier board to study the stability and long term test
- Crosstalk measurements

Summary

- New improvements on the experimental setup led to a better energy resolution
  -> FWHM from 180eV to 150eV

- Stability measurements showed SDDs work stable
  -> energy fluctuations ~few eV

- Measurements with SDDs inside a cryogenic hydrogen target cell are promising

Figures

[1] P. Lechner, C. Fiorini, A. Longoni, G. Lutz, A. Pahlke, H. Soltau, and L. Stru ̈der, "Silicon drift detectors for high resolution, high count rate x-ray spectroscopy at room temperature," International Centre for Diffraction Data, vol. Advances in X-ray Analysis, no. 47, pp. 53–58, 2004.

[2] C. Trippl et al., "A new silicon drift detector system for kaonic atom measure- ments," Journal of Physics: Conference Series (JPCS), accepted for publication.

[3] H. Takahashi, "Production target at j-parc hadron experimental facility," https:// conference-indico.kek.jp/ indico/ event/ 16/ session/ 29/ contribution/ 49/ material/ slides/ 0.pdf

[4] Picture courtesy of D. Pristauz-Telsnigg.