Calibration of Silicon Drift Detectors for High Precision Spectroscopy in SIDDHARTA-2 Experiment

Aleksander Khreptak

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

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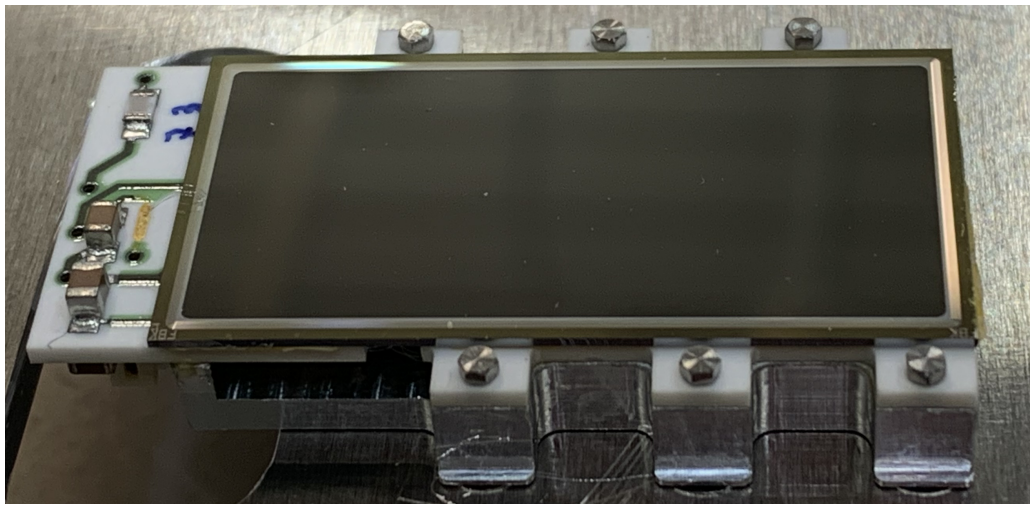
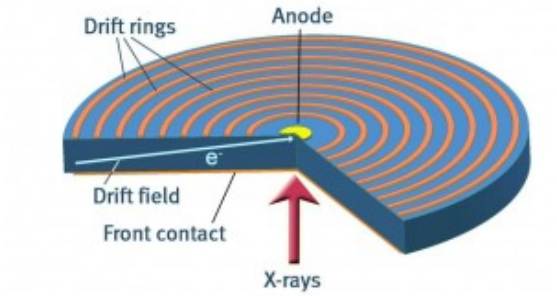
Outline

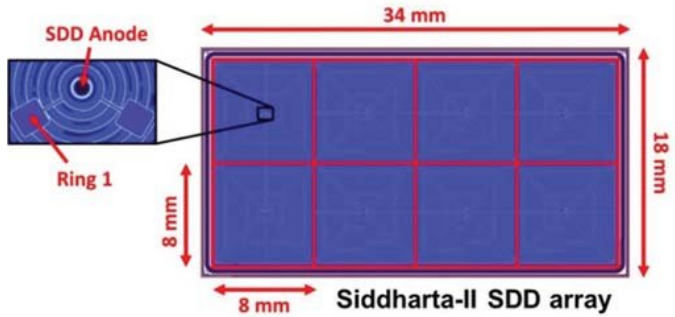
Silicon Drift Detector

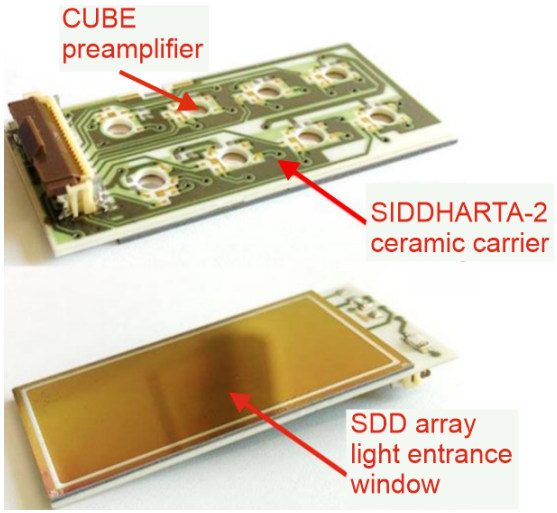
Monolitic 450 μm thick SDD array consists of a 2×4 matrix of square cells (0.64 cm^2) with a total active area of 5.12 cm^2



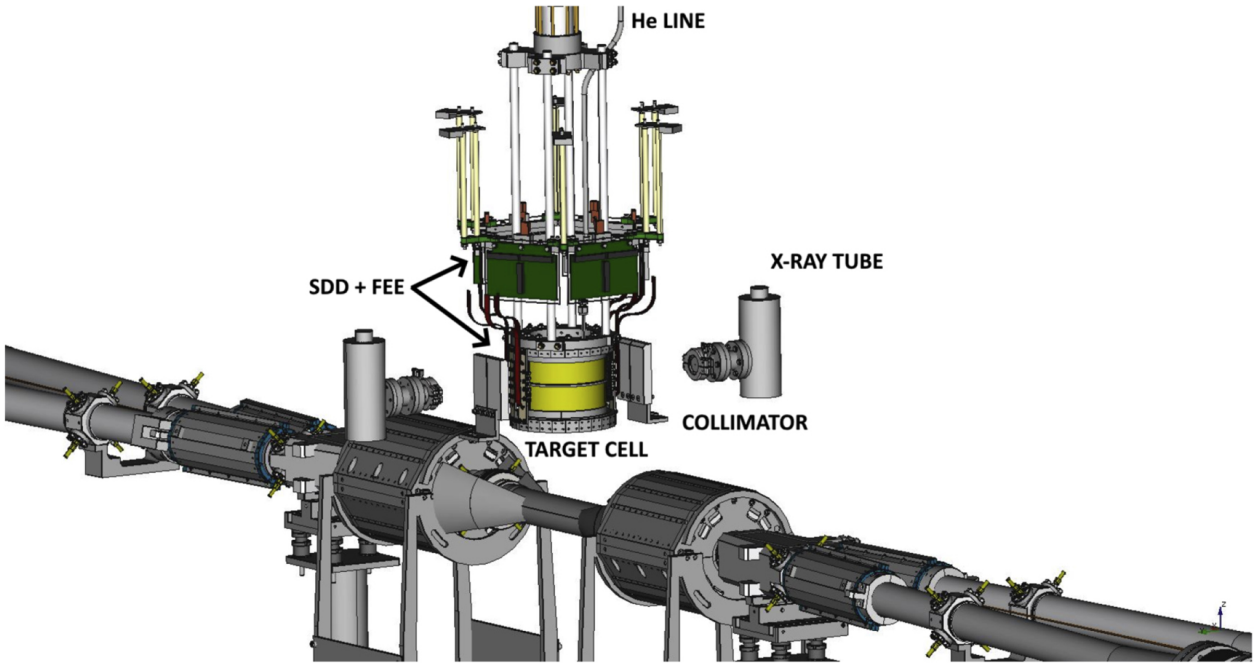
SIDDHARTA-2 experimental apparatus consists of 48 SDD arrays, resulting in a total of 384 readout channels

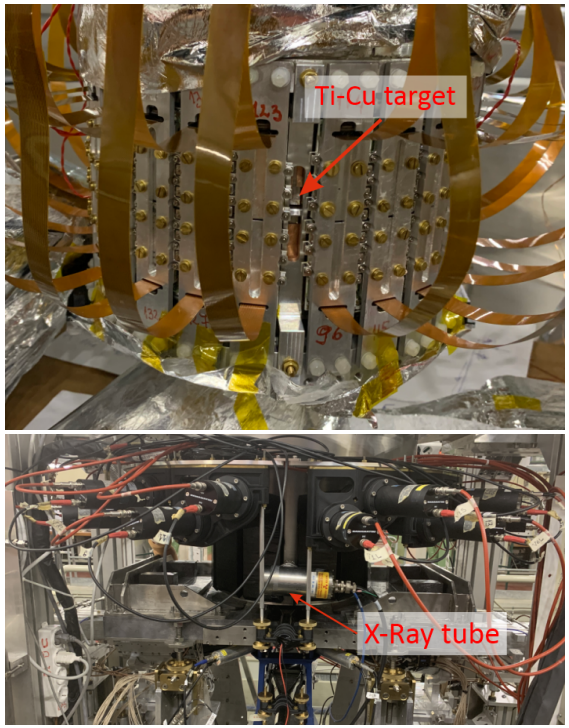






Experimental setup

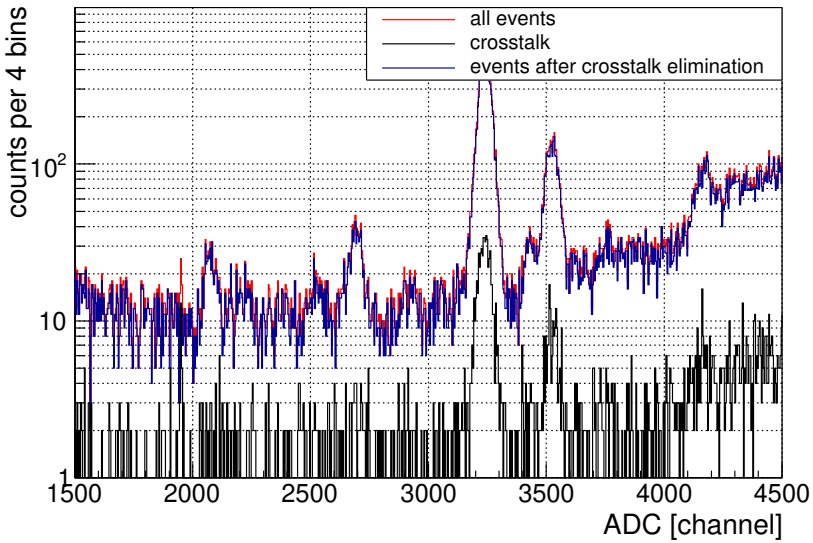


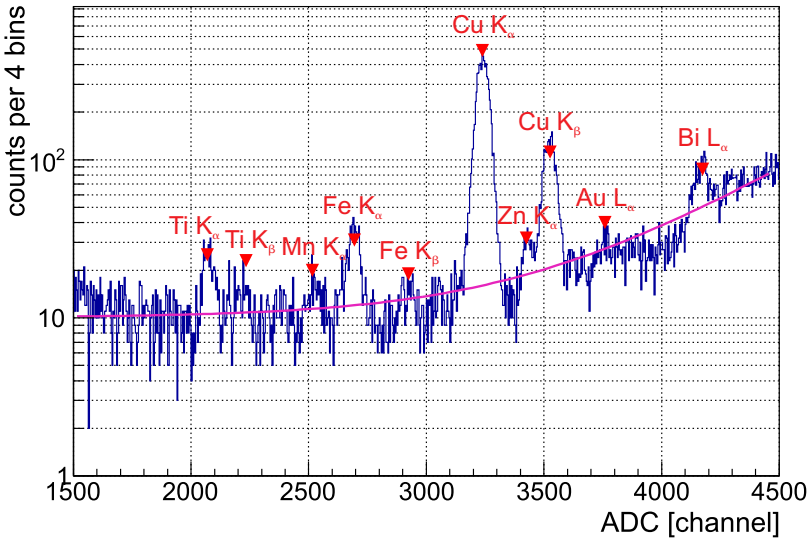


The calibration were performed with X-ray tubes exciting a target made of high-purity titanium and copper strips

SDDs spectroscopic response

1. Crosstalk rejection
2. Automatic peak position search
3. Peak identification
4. Background evaluation ($p_0 + e^{p_1 + p_2 x}$)





X-ray lines

Element	Line	Energy [eV]	Intensity ratio
Ti	K_{α_1}	4510.90	100 (base)
	K_{α_2}	4504.92	50
	K_{β_1}	4931.83	15
Mn	K_{α_1}	5898.80	100 (base)
	K_{α_2}	5887.60	50
Fe	K_{α_1}	6404.01	100 (base)
	K_{α_2}	6391.03	50
	K_{β_1}	7058.0	17
Cu	K_{α_1}	8047.82	100 (base)
	K_{α_2}	8027.84	51
	K_{β_1}	8905.41	17
Zn	K_{α_1}	8638.86	100 (base)
	K_{α_2}	8615.78	51
Au	L_{α_1}	9713.3	100 (base)
	L_{α_2}	9628.0	11
Bi	L_{α_1}	10838.8	100 (base)
	L_{α_2}	10730.91	11

Fit function

$$G(x_{ij}) = \frac{Gain}{\sqrt{2\pi}\sigma} e^{-\frac{(x-x_{ij})^2}{2\sigma_{ij}^2}}, \tag{1}$$

$$T(x_{ij}) = \frac{Gain}{2\beta\sigma_{ij}} e^{\frac{(x-x_{ij})^2}{\beta\sigma_{ij}} + \frac{1}{\beta^2}} \cdot erfc\left(\frac{x - x_{ij}}{\sqrt{2}\sigma_{ij}} + \frac{1}{\sqrt{2}\beta}\right), \tag{2}$$

where:

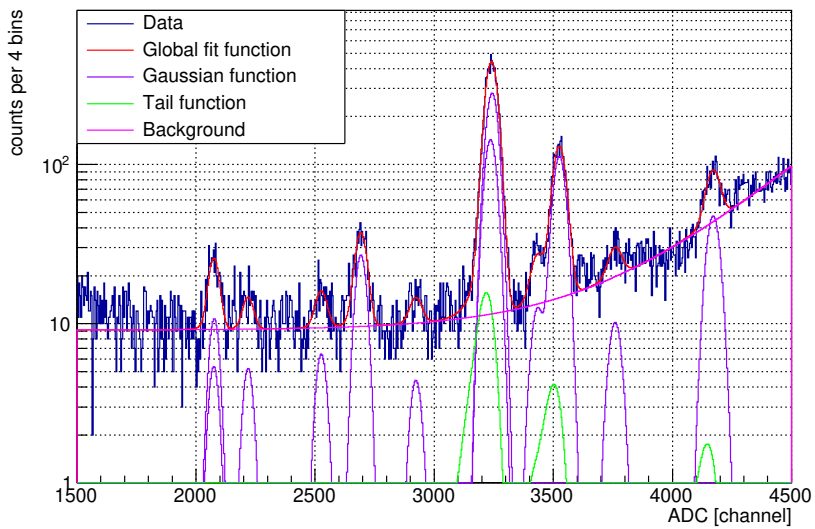
$$\sigma_{ij} = \sqrt{\left(\frac{Noise}{2\sqrt{2 \cdot ln2}}\right)^2 + \varepsilon \cdot Fano \cdot E_{ij}}. \tag{3}$$

The model describing spectrum with N groups of peaks can be written as:

$$fit = \sum_{i=1}^{N} A_i \sum_{j=1}^{n(i)} R_{ij} \left[G(x_{ij}) + f_T T(x_{ij})\right] + p_0 + e^{p_1 + p_2 x} \tag{4}$$

Fitting of fluorescence spectrum

Fit function obtained by convolution of a Gaussian with an exponential low energy tail for each peak together with a constant plus an exponential function to reproduce the background shape. Main fitting procedure is done with MINUIT, and is performed calling MIGRAD function



Fitting parameters

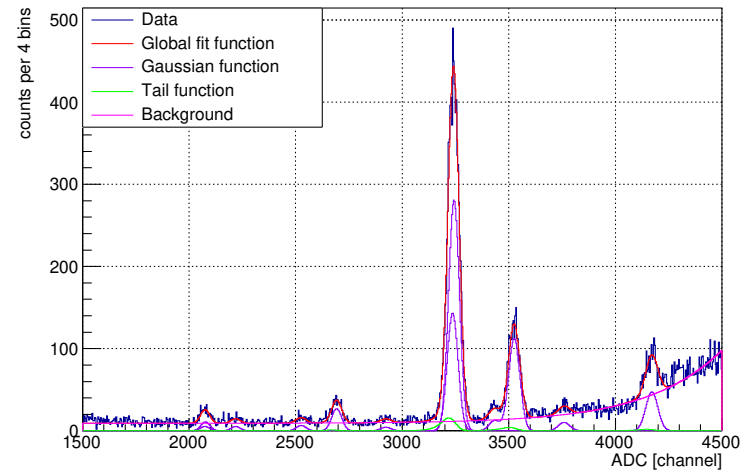
FCN=984.182 FROM MIGRAD STATUS=CONVERGED 3534 CALLS 3535 TOTAL
EDM=1.55922e-14 STRATEGY= 1 ERROR MATRIX UNCERTAINTY 0.5

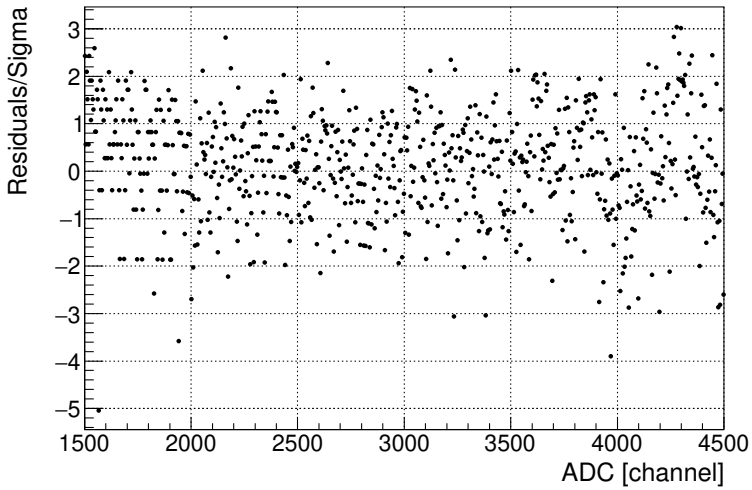
EXT NO.	PARAMETER NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	Noise	2.32101e+01	1.59868e+01	-2.05486e-07	-1.80365e-07
2	FanoFactor	1.35339e-01	3.41375e-02	1.92848e-07	3.84624e-07
3	Tail	4.61282e-02	5.67524e-02	-1.02272e-06	2.04791e-07
4	SlopeTail	1.47387e+00	5.61985e-01	1.59281e-07	1.18985e-07
5	Amp_1	1.07751e+01	1.14494e+00	1.46729e-08	-2.80421e-07
6	Mean_1	2.07645e+03	2.41384e+00	2.78532e-08	2.68145e-07
7	Amp_2	2.80837e+02	6.98710e+00	2.12234e-08	2.60456e-06
8	Mean_2	3.24311e+03	5.47360e-01	-1.64765e-08	8.28596e-07
9	Amp_3	5.24828e+00	1.19831e+00	1.00790e-07	3.32859e-07
10	Mean_3	2.21882e+03	6.27557e+00	-2.47976e-07	-3.26834e-07
11	Amp_4	1.12263e+02	3.72473e+00	1.22580e-08	-1.03961e-06
12	Mean_4	3.52563e+03	8.58976e-01	-4.36223e-08	-1.47596e-06
13	Amp_5	4.73881e+01	2.85912e+00	2.94531e-08	1.06365e-06
14	Mean_5	4.17109e+03	2.01779e+00	3.83750e-08	3.16566e-07
15	Amp_6	2.70082e+01	1.85526e+00	2.49697e-08	-5.00699e-08
16	Mean_6	2.69244e+03	1.82580e+00	-4.44565e-08	-4.71190e-07
17	Amp_7	1.24081e+01	1.63101e+00	-6.84574e-09	-1.24100e-07
18	Mean_7	3.43362e+03	3.25070e+00	-4.32644e-09	-1.43923e-07
19	Amp_8	6.45341e+00	1.25414e+00	2.74482e-08	3.01245e-08
20	Mean_8	2.52582e+03	5.34379e+00	5.77523e-07	-5.74034e-07
21	Amp_9	1.02050e+01	1.62189e+00	1.41457e-08	-3.67866e-08
22	Mean_9	3.75951e+03	5.64572e+00	8.69511e-08	1.33390e-07
23	Amp_10	4.40854e+00	1.12555e+00	2.78775e-08	9.74509e-08
24	Mean_10	2.92323e+03	7.35847e+00	5.67084e-08	1.89271e-07
25	Bkg1	9.11297e+00	1.98141e-01	-2.79237e-09	8.47877e-07
26	Bkg2	2.93594e+03	3.47532e+01	1.89356e-09	-4.91605e-05
27	Bkg3	2.86910e-03	7.15735e-05	5.75788e-09	2.74498e-05

chi2/n.d.f. = 1.3105

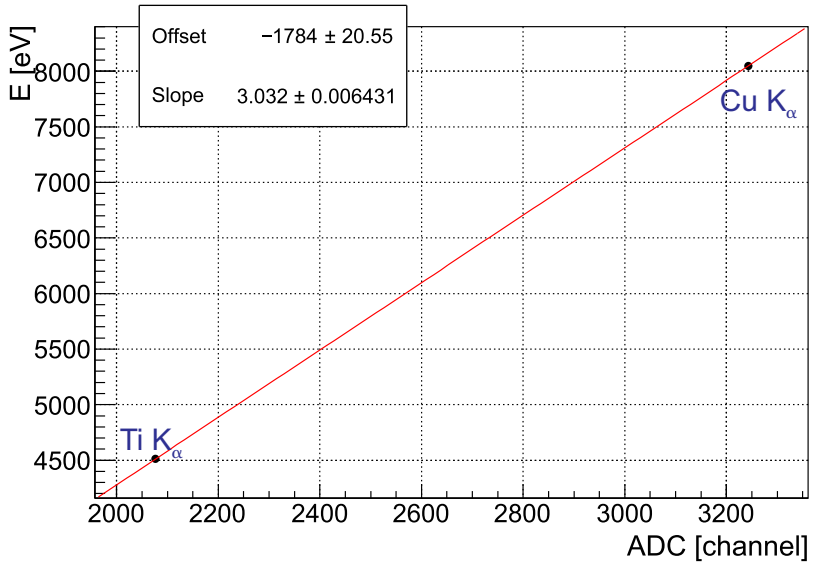
Linearity

Fluorescence spectrum



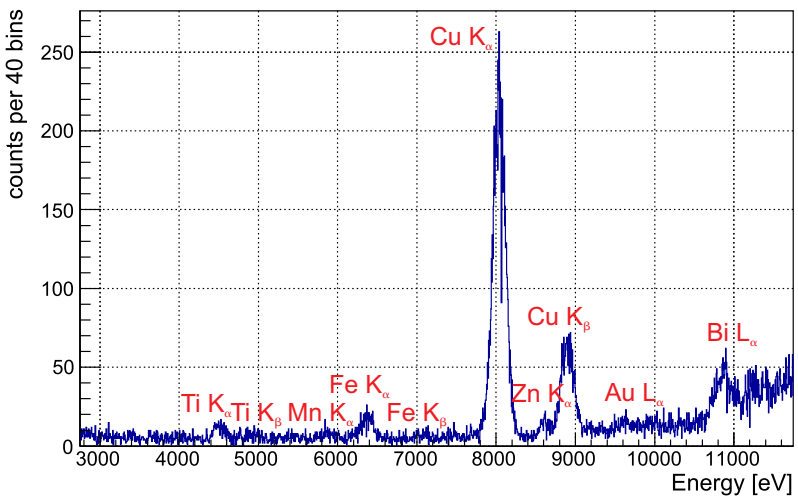


Linear interpolation

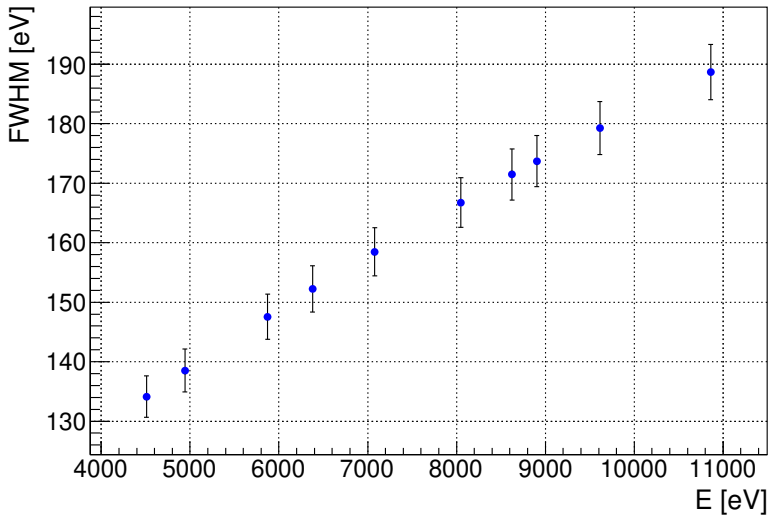


SDD energy response

Energy spectrum



Energy Resolution



Summary

- SIDDHARTA-2 experiment studies kaonic atoms using Silicon Drift Detectors System (SDD). Calibration of each SDD detector is crucial for accurate data analysis
- The energy response function of the SDD includes a Gaussian curve and a low-energy component
- The calibration system for SIDDHARTA-2 was specifically designed to achieve high accuracy, with the goal of calibrating the SDD detectors to within a few eV

Thank you for your attention!