Silicon Drift Detectors for high precision kaonic atoms X-ray spectroscopy

FRANCESCO CLOZZA - On Behalf of the SIDDHARTA-2 Collaboration

ECT* - ROCKSTAR: Towards a ROadmap of the Crucial measurements of Key observables in Strangeness reactions for neutron sTARs equation of state

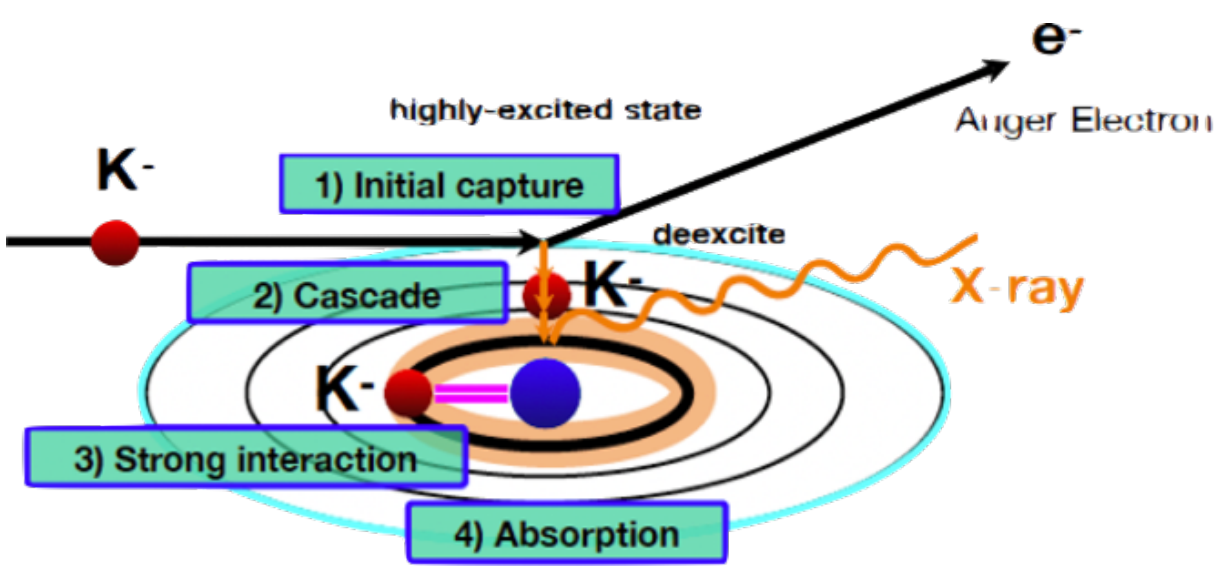
SAPIENZA
UNIVERSITÀ DI ROMA

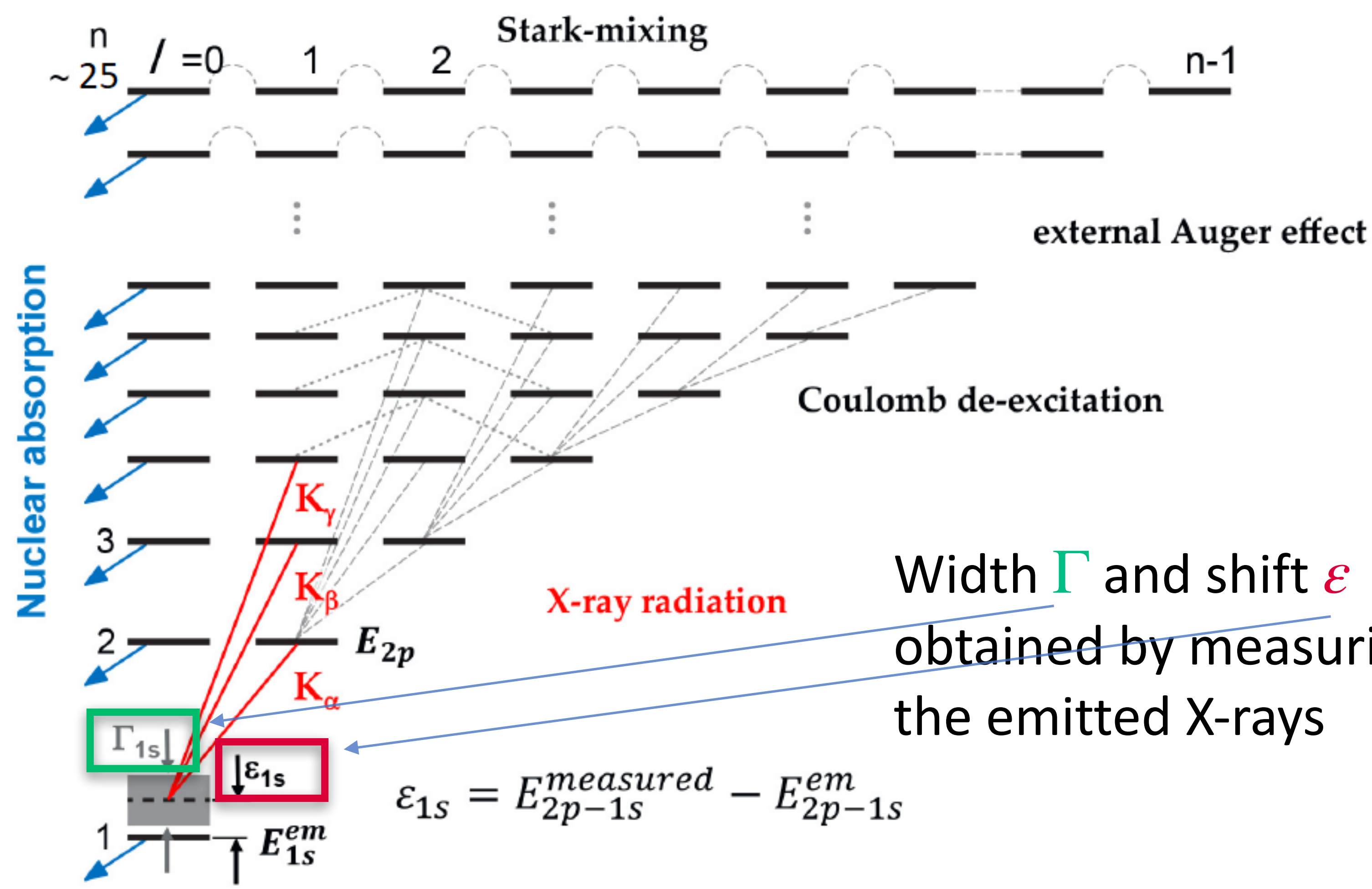
INFN
LNF
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

STRONG-2020

Scientific Goal: the SIDDHARTA-2 experiment

- **Physics Goal**: performing the first measurement of Kaonic Deuterium X-ray transition to the fundamental level
- Antikaon-Neutron interaction happens at threshold (non perturbative QCD with **strangeness**)

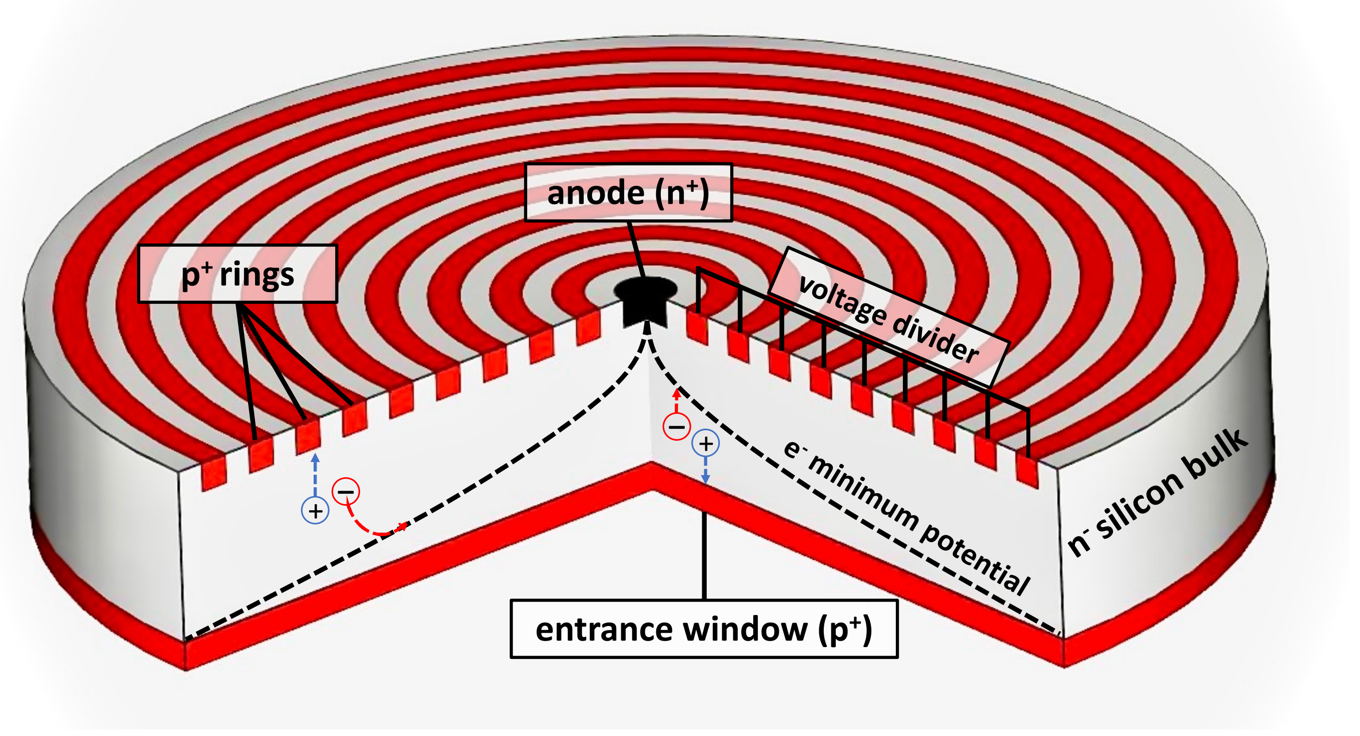




Width Γ and shift ε obtained by measuring the emitted X-rays

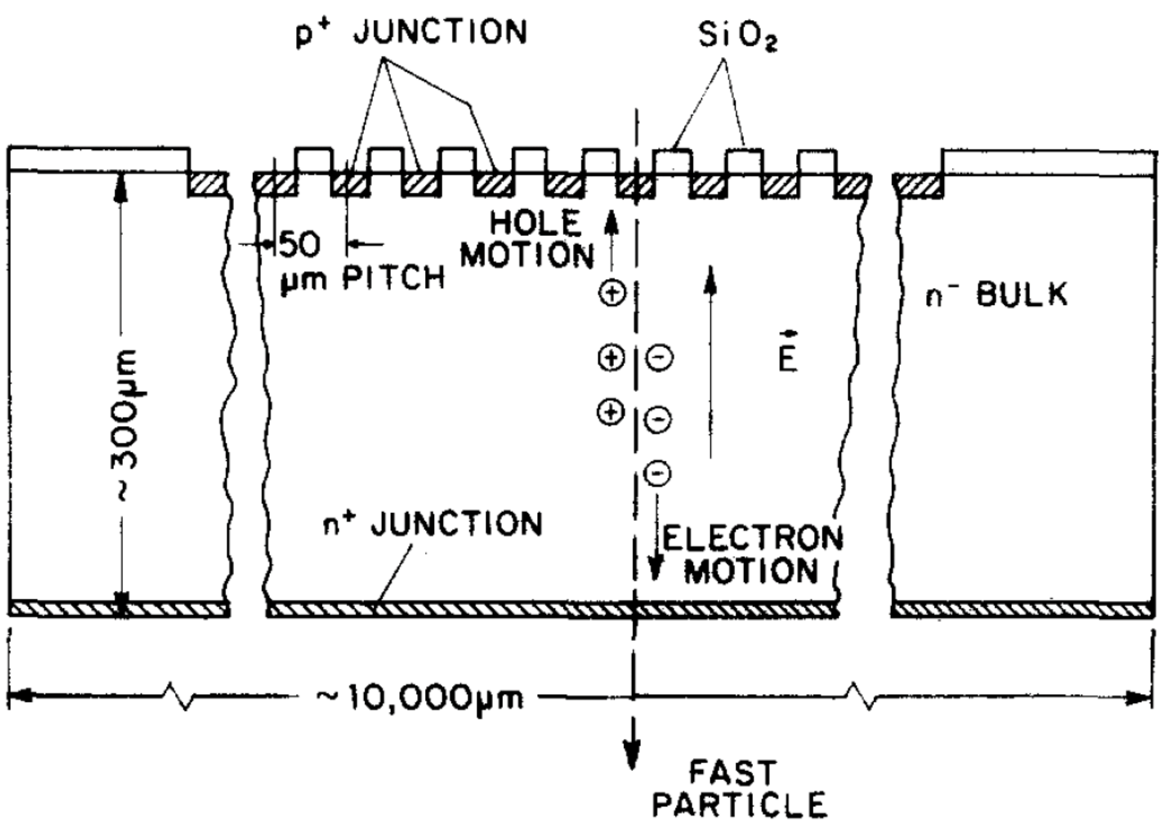
Silicon Drift Detectors: description

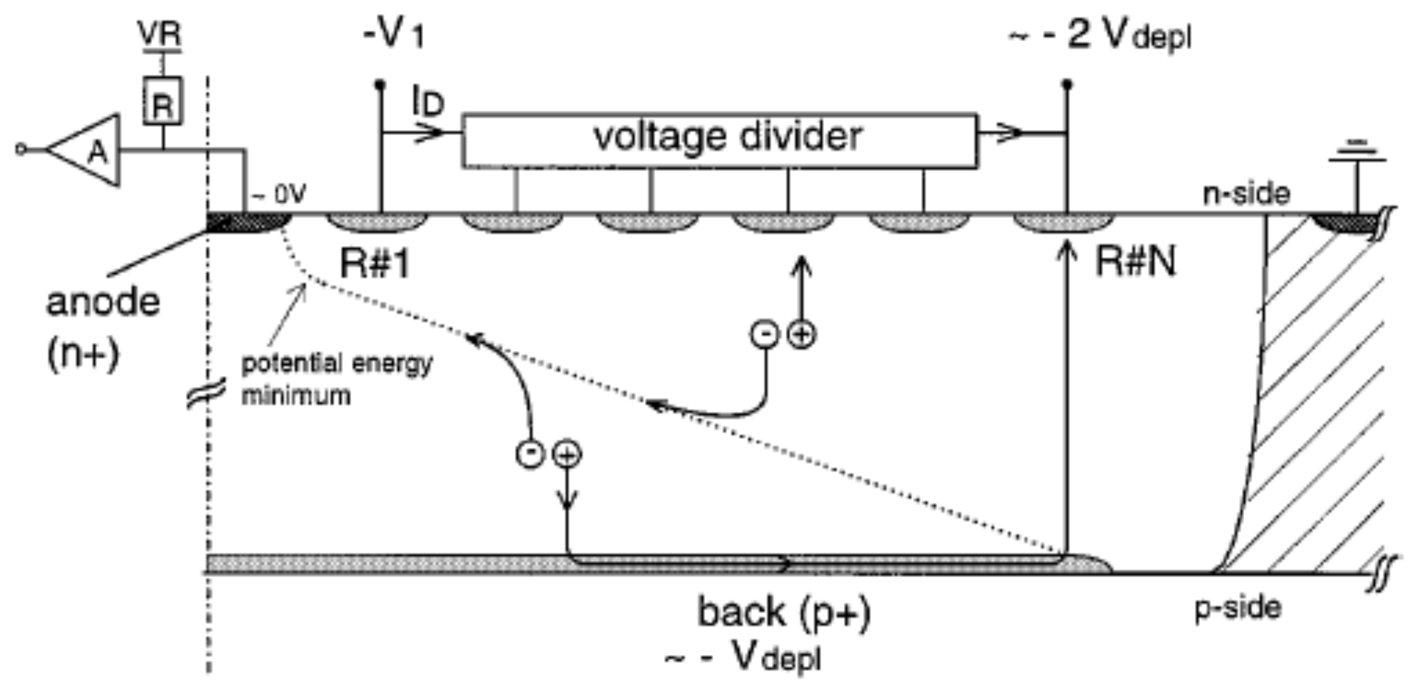
- Cylindrical shaped SDDs: n^- silicon bulk with string shaped p^+ strips on one side and a p^+ non structured layer on the other
- The latter works as the entrance window for the incident particles
- Homogeneous sensitivity
- n^+ collecting anode in the center of the ring shaped strips
- p^+ entrance and strips at negative voltage wrt n^- anode (3.3V)
- Negative voltage increasing from the center (~ -15V) to the borders (~ -60V)



Silicon Drift Detectors: working principle

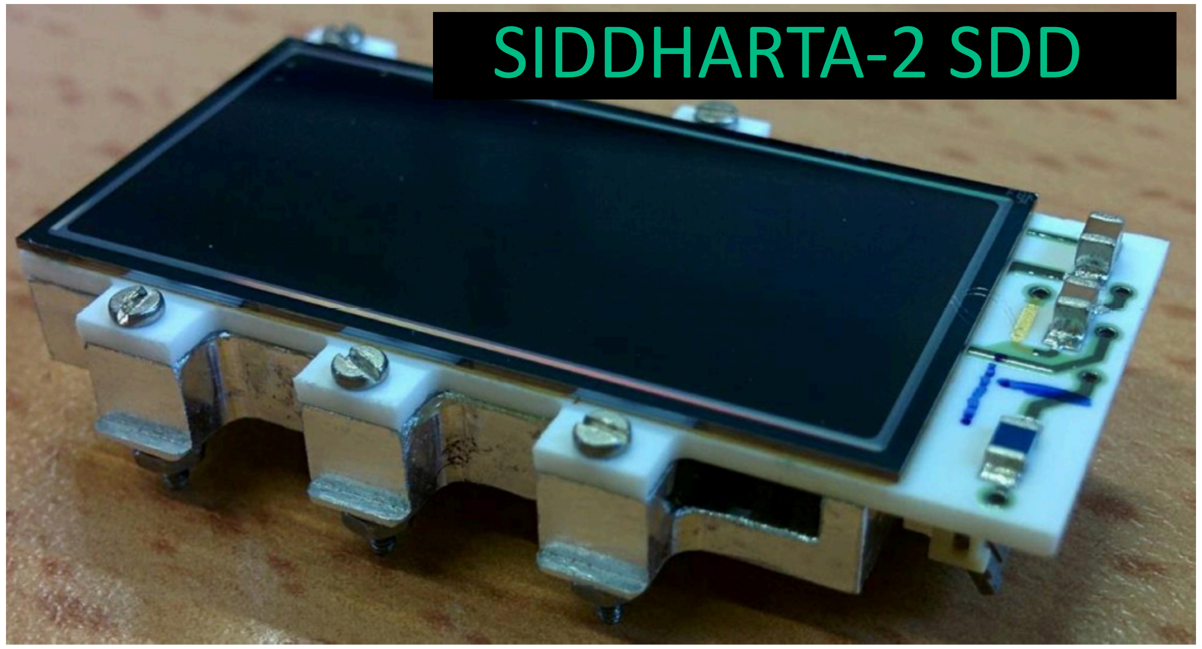
- p-n diode with depleted region in the silicon bulk
- e-h pairs separated through a reverse polarization field ("vertical drift")
- Second electric field superposed to transport the charges towards a collection anode ("horizontal drift")
- **"Gutter-like"** field configuration is achieved for the charge collection

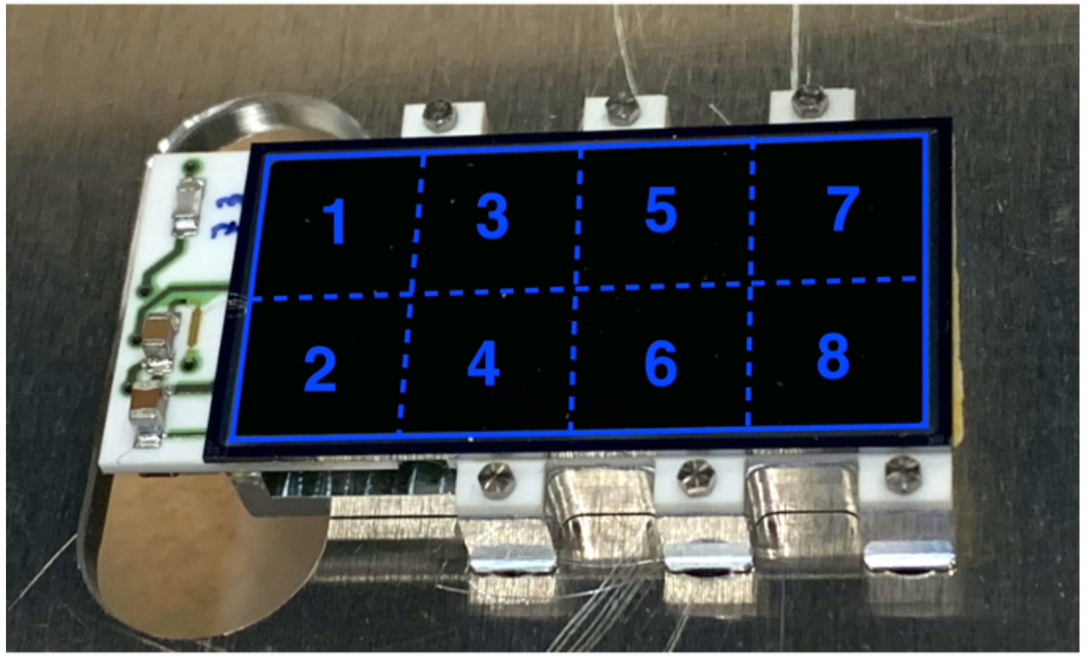




Silicon Drift Detectors for X-ray spectroscopy

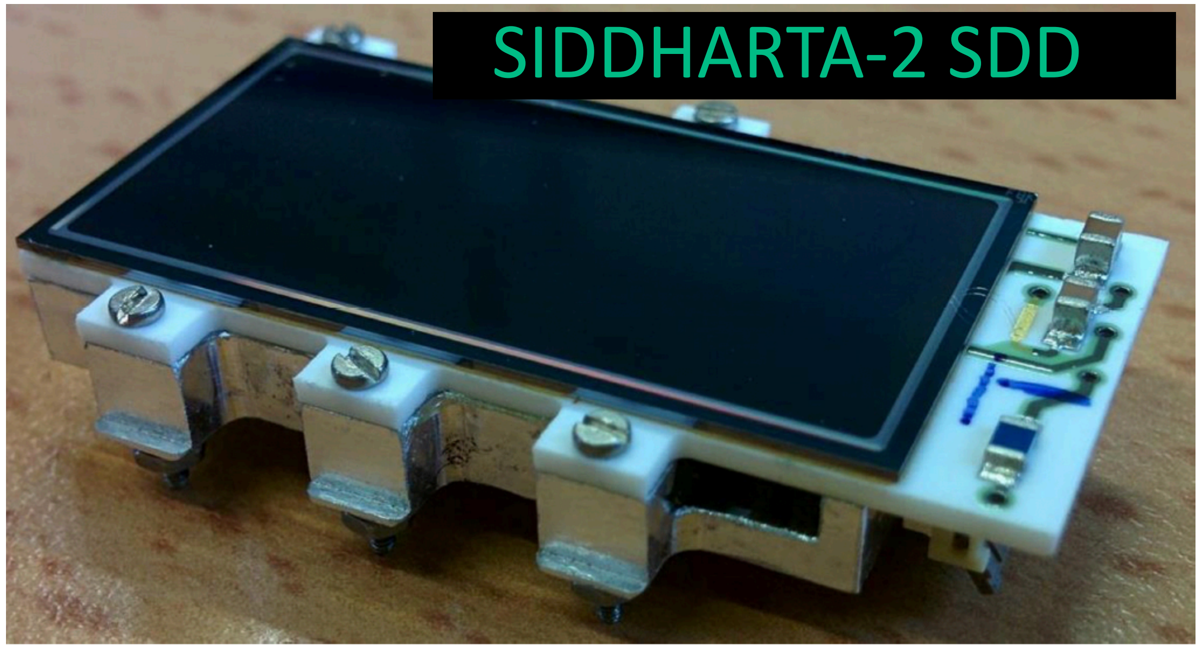
- Eight square SDD cells: 8x8mm^2 active area
- 450µm thick silicon bulk: it allows a ~100% detection efficiency for 5-12keV X-rays (region of interest for kaonic deuterium)
- SDD cells packed in 2x4 array (total active area of 5.12cm^2)
- Silicon wafer glued on alumina ceramic carrier

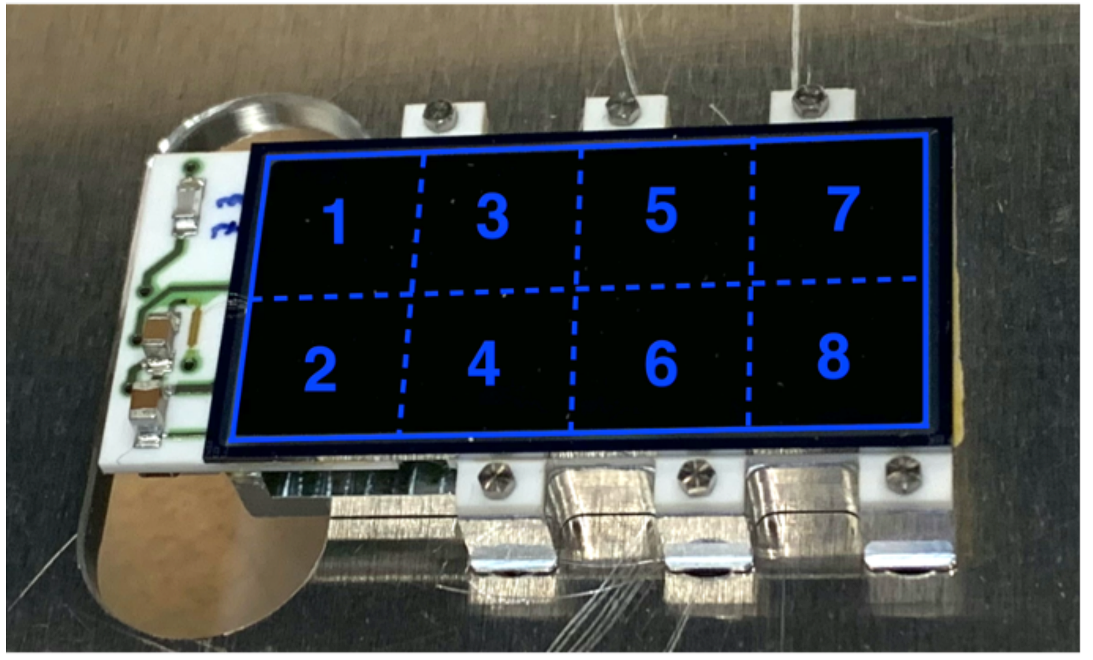




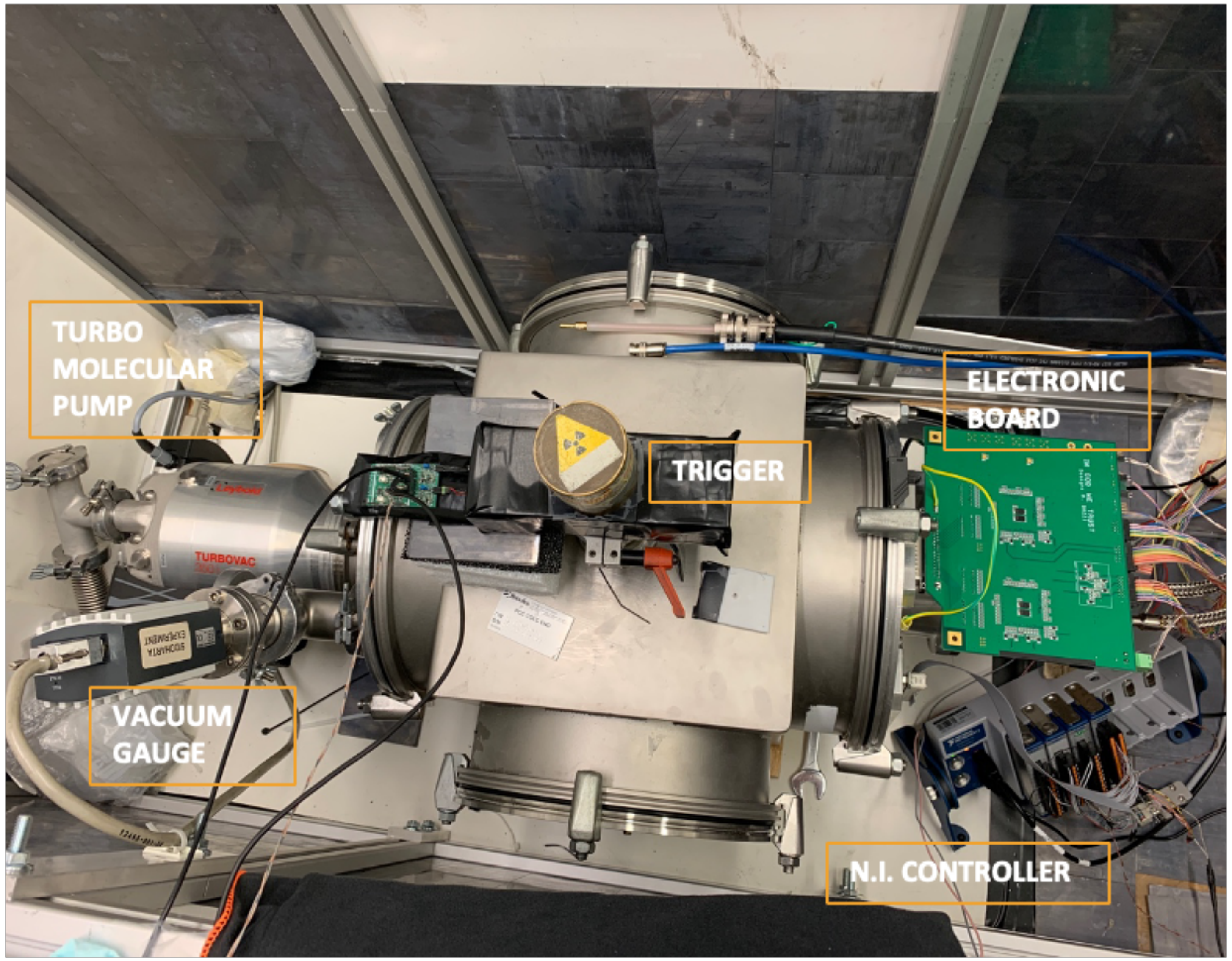
Silicon Drift Detectors for X-ray spectroscopy

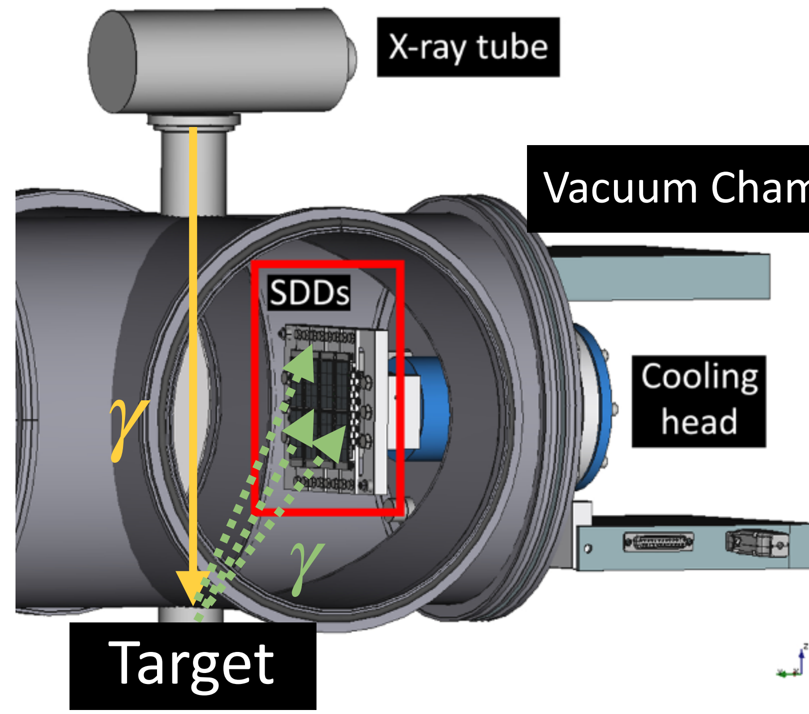
- High thermal conductive block: can be cooled down to (100÷150)K
- Preamplifier system in collaboration with Politecnico di Milano (PoliMi)
- CUBE: Metal-oxide semiconductor integrated charge sensing amplifier
- Small capacitance: lower rise time and independent from the detector's active area
- Large area detectors with a 400ns drift time at 140K

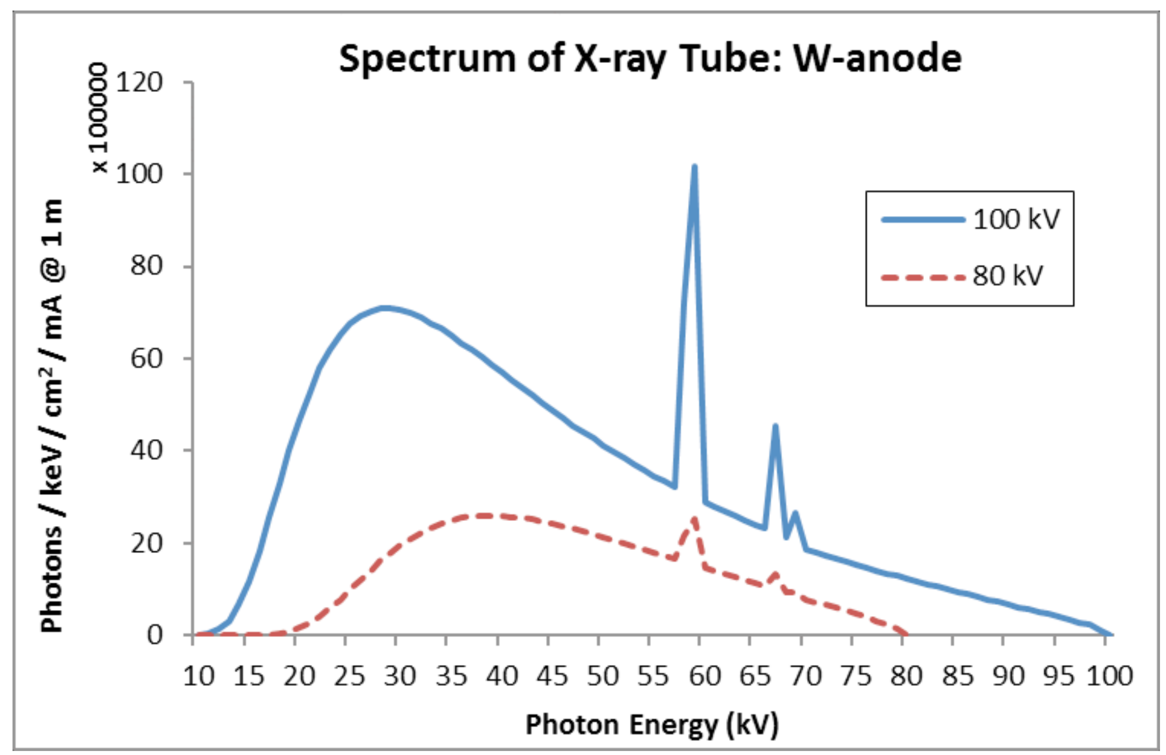




SDD Characterization: experimental apparatus



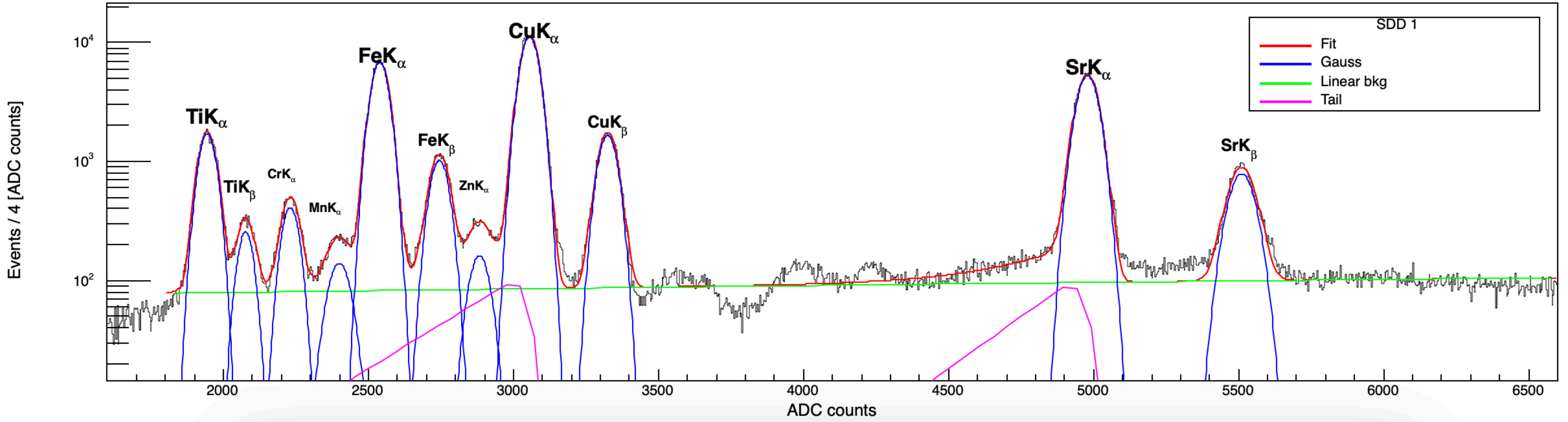




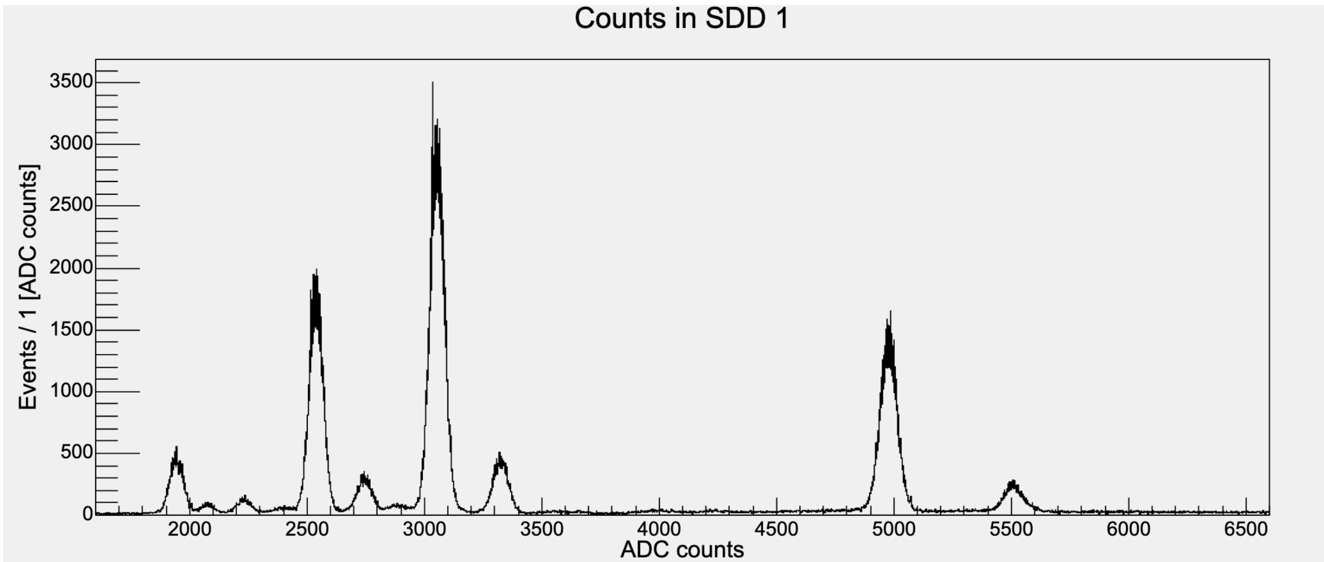
SDD Characterization: data analysis

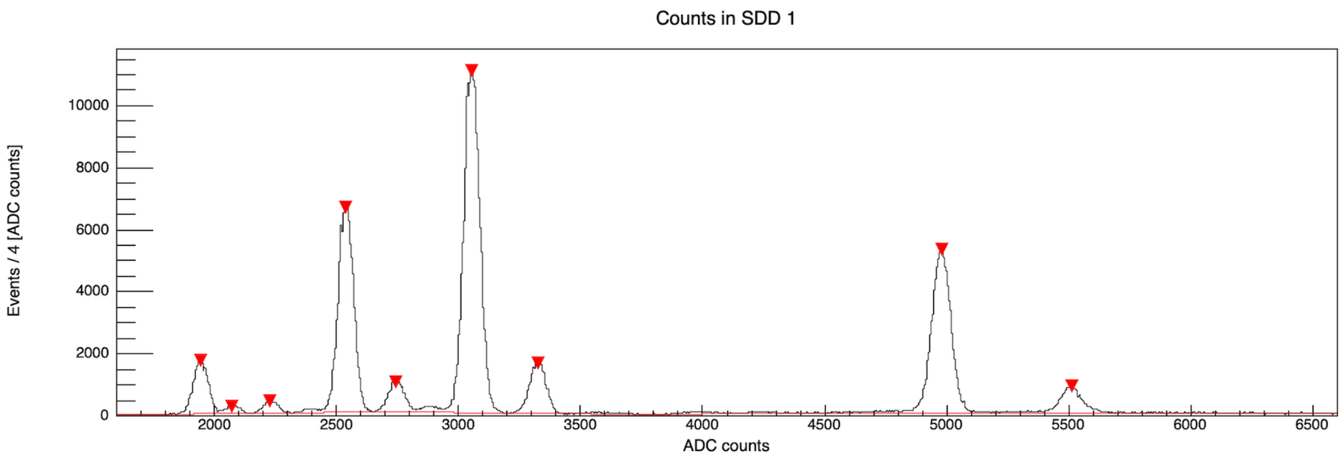
- The energy response function of the SDD exhibits two main contributions:
  1. A Gaussian curve for every peak
  2. A Tail function accounting for the low energy component due to incomplete charge collection and e-h recombination
- In addition, a linear bkg has been taken into account
- A Peakfinder has been implemented using ROOT C++

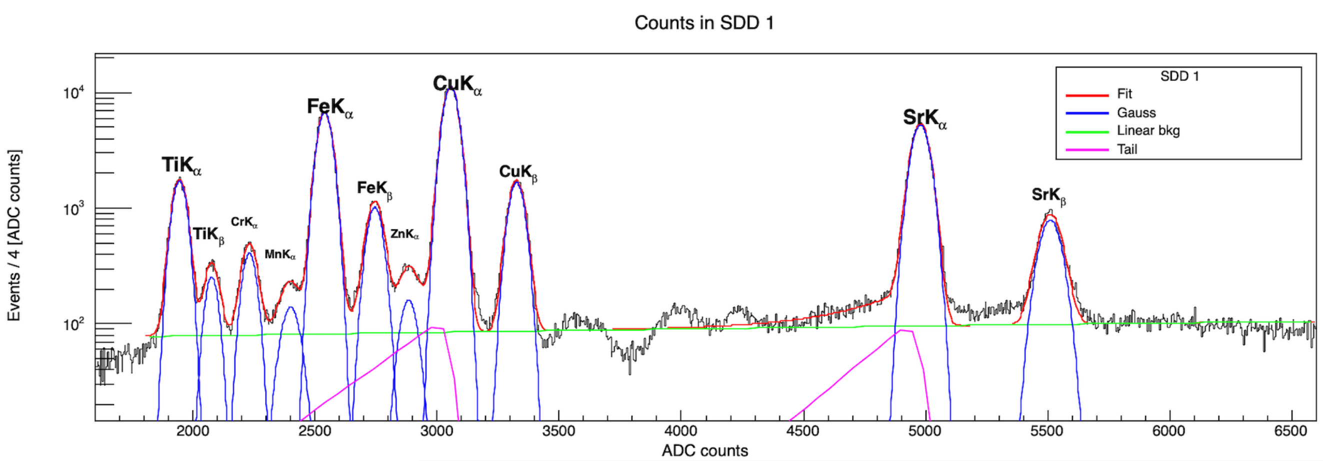
$$T(x) = A_T \cdot e^{\frac{x-x_0}{\beta\sigma}+\frac{1}{2\beta^2}} \cdot erfc\left(\frac{x-x_0}{\sqrt{2}\sigma}+\frac{1}{\sqrt{2}\beta}\right)$$



SDD Characterization: data analysis

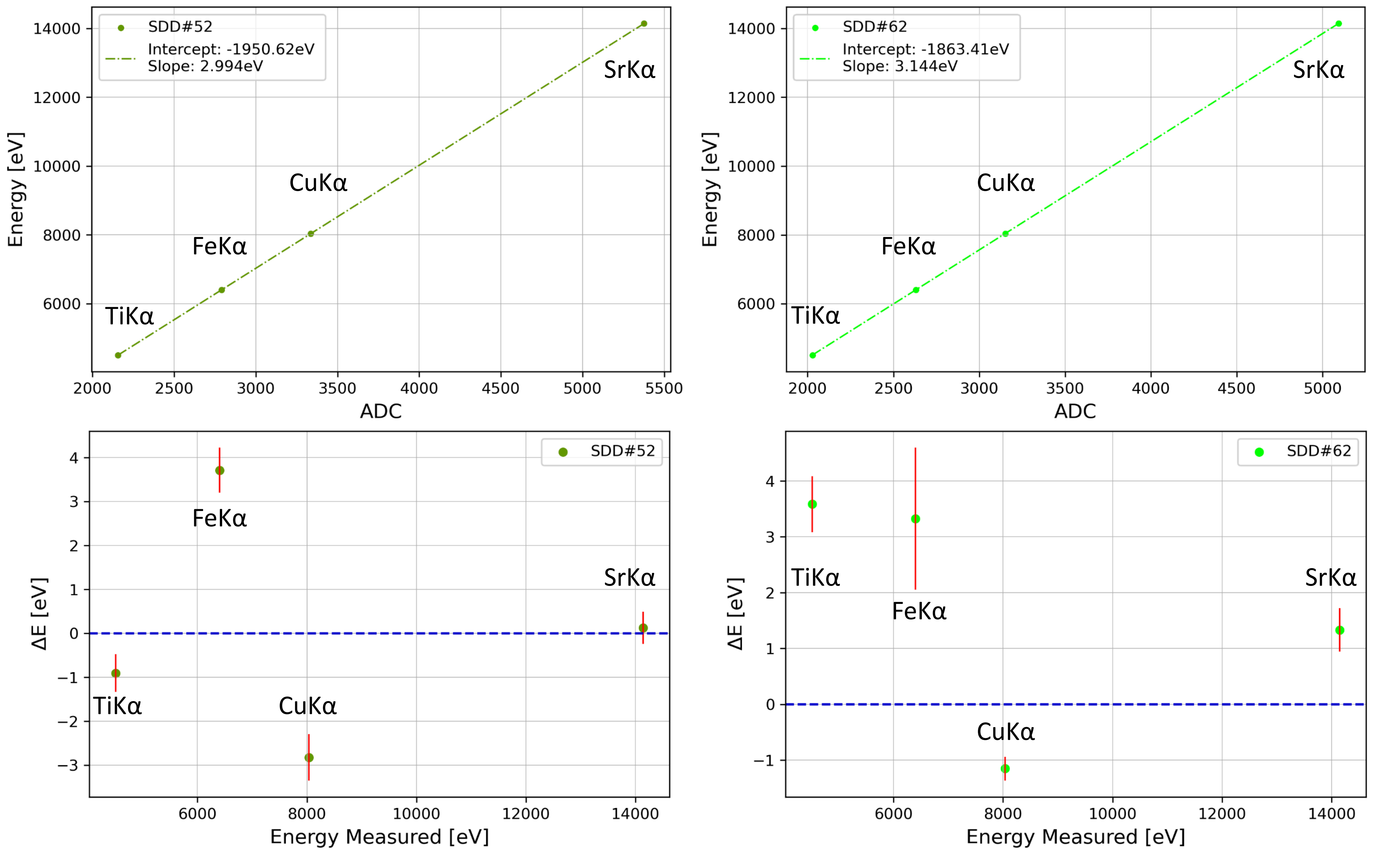




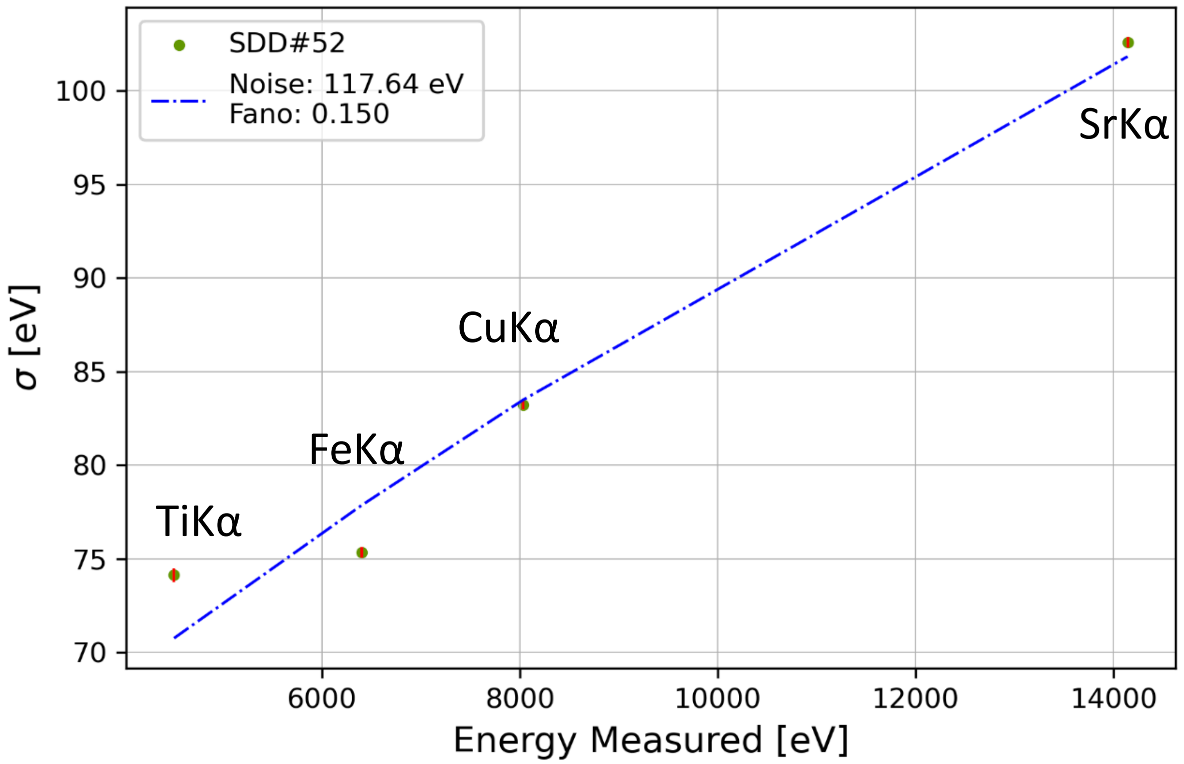


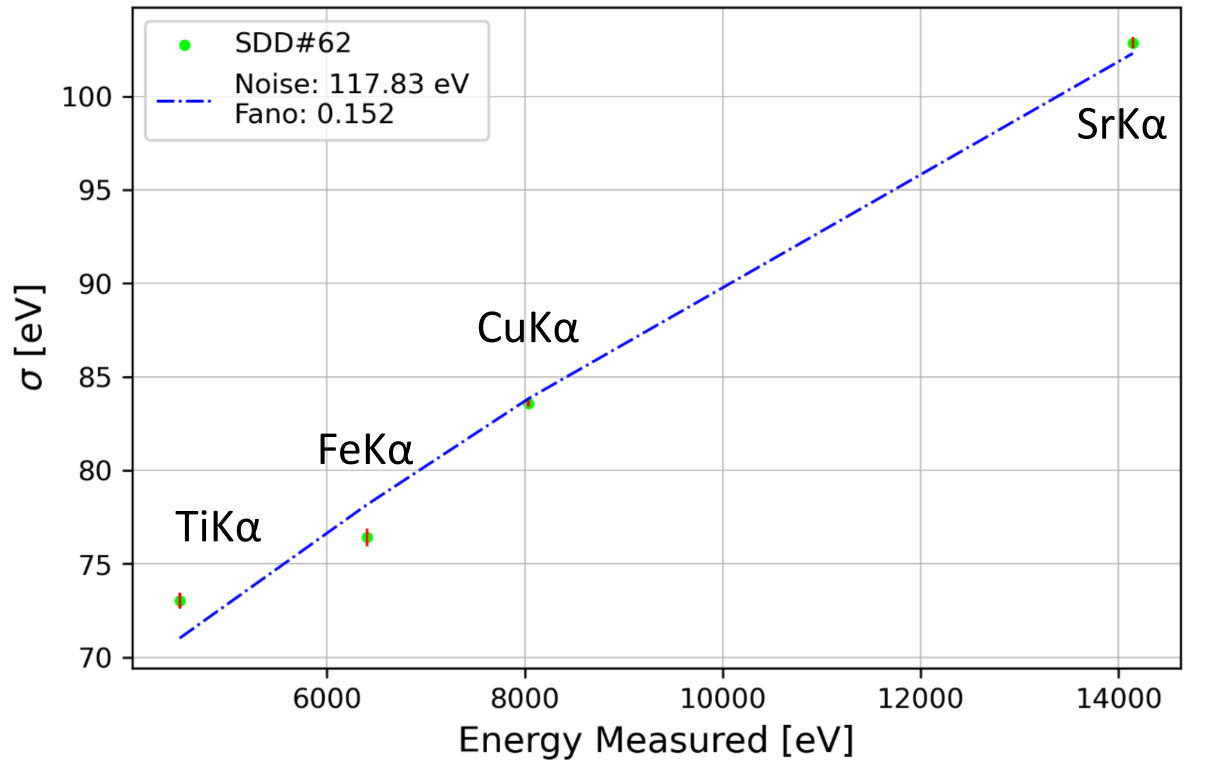

```
FCN=4862.92 FROM MIGRAD    STATUS=CONVERGED    24534 CALLS       24535 TOTAL
                    EDM=3.02287e-07    STRATEGY= 1  ERROR MATRIX UNCERTAINTY   1.4 per cent
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME       VALUE           ERROR          SIZE      DERIVATIVE
  1  q            6.75965e+01   1.72483e+00   1.24042e-03   3.75982e-04
  2  m            5.72731e-03   3.32117e-04  -2.12507e-07   3.97143e-01
  3  Amplitude    1.12198e+04   2.95300e+01   8.85257e-03   1.03284e-05
  4  MEAN         3.05550e+03   7.94218e-02  -1.59594e-05   3.88234e-04
  5  SIGMA        3.07372e+01   6.09141e-02   2.10151e-06   3.02245e-03
  6  eps          5.45049e-03   6.42777e-04  -3.37396e-06   3.05604e-02
  7  beta         9.42635e+00   8.02156e-01   2.55756e-04  -5.67863e-04
  8  Amplitude    6.77853e+03   2.34075e+01   9.68613e-05  -3.70258e-06
  9  MEAN         2.53922e+03   9.08827e-02  -1.53684e-06   6.97226e-04
 10  SIGMA        2.94326e+01   7.30698e-02  -1.24173e-05  -3.77174e-03
 11  eps          3.48374e-11   1.65289e-03   4.85180e-05** at limit **
 12  beta         3.06484e+00   1.17444e-01  -1.22732e-04  -2.37275e-07
 13  Amplitude    5.23556e+03   1.91130e+01  -3.98430e-03   2.05436e-06
 14  MEAN         4.97908e+03   1.20846e-01   1.90287e-06  -1.62877e-03
 15  SIGMA        3.65413e+01   9.51677e-02  -6.92159e-06   1.53986e-04
 16  eps          1.17035e-02   6.09584e-04   3.86010e-06   1.91012e-02
 17  beta         6.83993e+00   3.34017e-01  -2.76084e-04   2.79310e-03
 18  Amplitude    1.71022e+03   1.10841e+01   8.97067e-04   2.54379e-05
 19  MEAN         1.94449e+03   1.88333e-01  -1.78114e-06  -2.00230e-05
 20  SIGMA        2.86702e+01   1.36822e-01  -2.29813e-05   3.63319e-04
 21  eps          5.00000e-01   7.46941e-01  -0.00000e+00   0.00000e+00
 22  beta        -1.00000e+00   1.41421e+00  -0.00000e+00   0.00000e+00
 23  Amplitude    1.66410e+03   1.16473e+01   1.28672e-03   4.54137e-06
 24  MEAN         3.32479e+03   2.02999e-01   1.65788e-05  -3.94820e-04
 25  SIGMA        3.14956e+01   1.55374e-01  -2.32856e-05   1.77117e-03
 26  eps          5.00000e-01   7.46941e-01  -0.00000e+00   0.00000e+00
 27  beta        -1.00000e+00   1.41421e+00  -0.00000e+00   0.00000e+00
 28  Amplitude    1.01759e+03   1.00362e+01  -6.98231e-04  -9.04239e-06
 29  MEAN         2.74471e+03   2.96507e-01   2.63239e-05   2.47061e-04
 30  SIGMA        3.11792e+01   3.01004e-01  -1.24882e-05  -3.60814e-04
 31  eps          5.00000e-01   7.46941e-01  -0.00000e+00   0.00000e+00
 32  beta        -1.00000e+00   1.41421e+00  -0.00000e+00   0.00000e+00
 33  Amplitude    7.87638e+02   7.33085e+00   3.57917e-04  -1.82428e-05
 34  MEAN         5.51062e+03   3.75215e-01   9.96483e-05   7.40365e-04
 35  SIGMA        4.43486e+01   3.41263e-01  -5.55271e-05  -6.02087e-05
 36  eps          5.00000e-01   7.46941e-01  -0.00000e+00   0.00000e+00
 37  beta        -1.00000e+00   1.41421e+00  -0.00000e+00   0.00000e+00
 38  Amplitude    4.09628e+02   7.02457e+00   3.86263e-04   1.75345e-05
 39  MEAN         2.23088e+03   4.50526e-01  -3.64534e-05  -1.48641e-04
 40  SIGMA        2.82614e+01   4.22621e-01  -1.30003e-04  -3.35491e-04
 41  eps          5.00000e-01   7.46941e-01  -0.00000e+00   0.00000e+00
 42  beta        -1.00000e+00   1.41421e+00  -0.00000e+00   0.00000e+00
 43  Amplitude    2.54517e+02   5.71283e+00  -2.12708e-03  -1.77239e-05
 44  MEAN         2.07633e+03   5.76343e-01  -1.64593e-04  -1.92203e-04
 45  SIGMA        2.66213e+01   5.52758e-01  -7.84558e-07  -3.98344e-04
 46  eps          5.00000e-01   7.46941e-01  -0.00000e+00   0.00000e+00
 47  beta        -1.00000e+00   1.41421e+00  -0.00000e+00   0.00000e+00
```

SDD Characterization: linearity

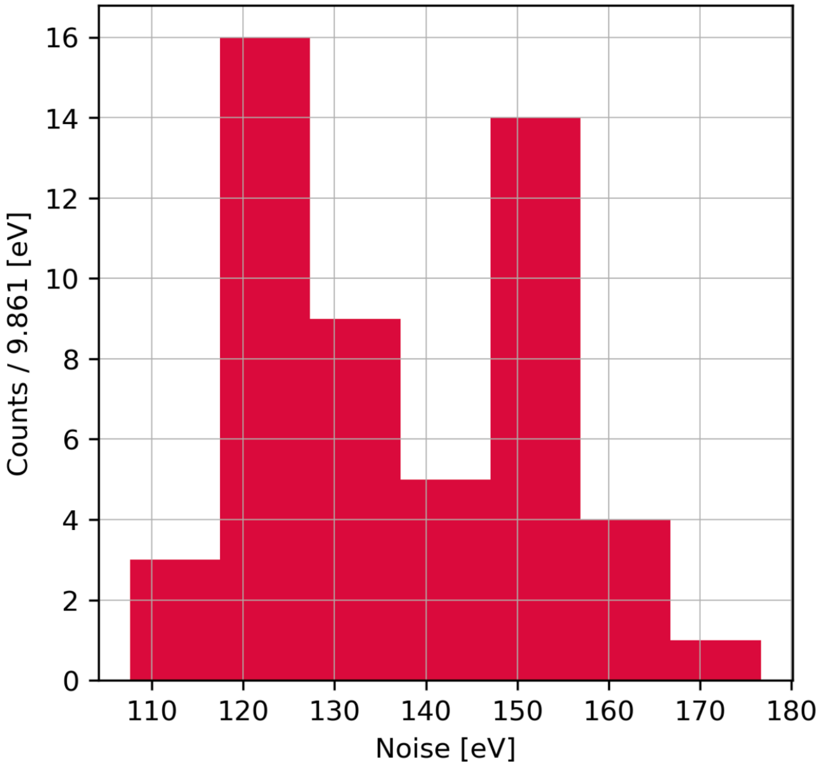


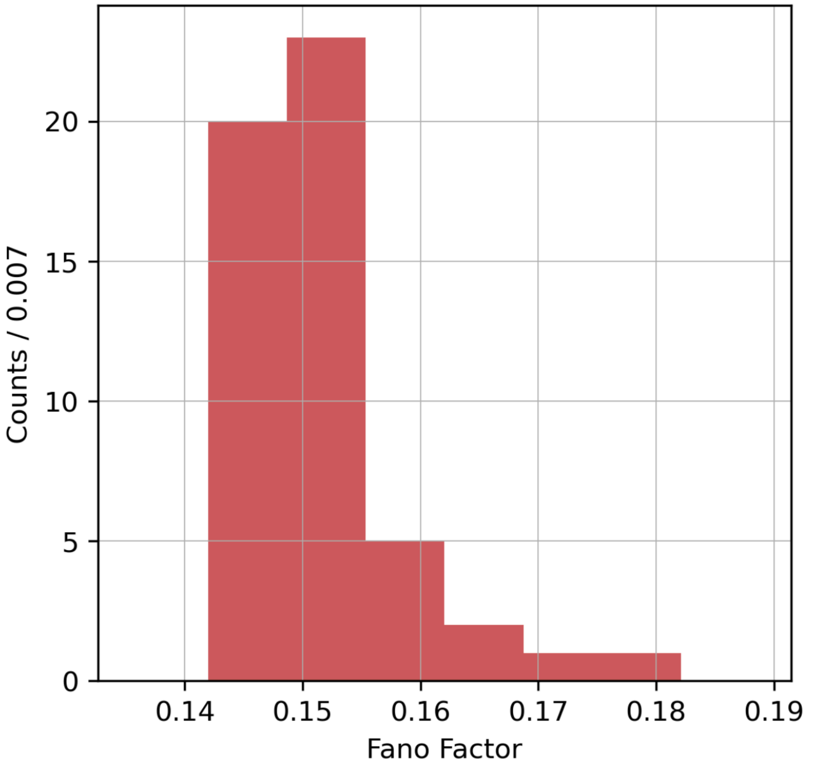
SDD Characterization: resolution





$$\sigma = \sqrt{FF \cdot \varepsilon \cdot E + \left(\frac{Noise}{2.35}\right)^2}$$





Conclusions

- The SIDDHARTA-2 experiment aims at performing the first measurements of the kaonic deuterium shift and width
- In order to investigate the non perturbative QCD regime with strangeness with X-ray spectroscopy, the SDDs are the best candidate to do the job (kaonic deuterium)
- A calibration of the SDDs in a controlled environment is needed so as to perform the measure
- The study of the SDDs energy response has ended up yielding:
  1. Energy resolution of σ~75eV @6.4keV (140K working temperature)
  2. Good linearity with $\Delta E/E \sim 10^{-3}$
  3. Residuals $\lesssim$ 5eV in the 4÷14keV range, giving a small calibration uncertainty wrt to the **expected** statistical error (O(30eV) for kaonic deuterium)

THANK YOU FOR YOUR ATTENTION!

FRANCESCO CLOZZA

SAPIENZA
UNIVERSITÀ DI ROMA

INFN
LNF
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

STRONG-2020

BIBLIOGRAPHY

I. Sgaramella, F., et al. "The SIDDHARTA-2 calibration method for high precision kaonic atoms x-ray spectroscopy measurements." *Physica Scripta* 97.11 (2022): 114002.

II. Miliucci, M., Iliescu, M., Sgaramella, F., Bazzi, M., Bosnar, D., Bragadireanu, M., ... & Zmeskal, J. (2022). Large area silicon drift detectors system for high precision timed x-ray spectroscopy. *Measurement Science and Technology*, *33*(9), 095502.

III. Gatti, Emilio, and Pavel Rehak. "Semiconductor drift chamber—An application of a novel charge transport scheme." *Nuclear Instruments and Methods in Physics Research* 225.3 (1984): 608-614.