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Towards new intermediate-mass kaonic atoms measurements with novel CdZnTe X-ray detectors at DAFNE

Francesco Artibani

“Rockstar workshop”, ECT*, Trento 9-13/10/2023

STRONG-2020

Fast recap

From previous workshop “Fundamental Physics at the strangeness frontier ad DAFNE”: concluding slides by prof. J. Obertova (left) and prof. E. Friedman (right)

Conclusions: kaonic atoms calculations

- The microscopic K^-NN model was applied in the calculations of kaonic atoms
- Preliminary results:
  - data are best described by $K^-N + K^-NN$ potentials based on Pauli blocked BCN amplitudes
  - $K^-N + K^-NN$ potentials supplemented by a phenomenological term describing 3 and 4 nucleon processes
  - fit to the data suggests that $\mathrm{Re}(K^-N + K^-NN)$ should be more attractive and $\mathrm{Im}(K^-N + K^-NN)$ should be less absorptive
- EXPERIMENT:
  - It would be desirable to revise some kaonic atom data
  - More data on 3N and 4N absorption fractions are needed

Summary

- Significant progress in understanding kaonic atoms, converging on multinucleon interaction with the nucleus.
- 35-40 years old data have yielded beyond expectations.
- High quality measurements for L=1 kaonic states in ^{3,4}He, ^{6,7}Li, ^{9}Be, ^{10,11}B and ^{12}C could allow for few-body approaches, connecting to the density dependence in heavier kaonic atoms.
- It is high time for new experiments.

I wish to thank Avraham Gal and Nir Barnea for meetings and discussions.

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JRA8 Strong 2020: ASTRA

Advanced ultra-fast solid STate detectors for high precision RAdiation spectroscopy

Aim: to produce a novel CdZnTe/CdTe radiation detector from keV to MeV

Organization legal name	Short name	Activity leader
Austrian Academy of Sciences, Stefan Meyer Institute, Austria	OEAW	J. Zmeskal
Istituto Materiali per Elettronica e Magnetismo, CNR, Parma, Italy	CNR	A. Zappettini
Jagiellonian University, Krakow, Poland	UJ	P. Moskal
Laboratori Nazionali di Frascati (LNF) – INFN, Italy	INFN	A. Scordo
Politecnico Milano, Dipartimento di Elettronica, Italy	POLIMI	C. Fiorini
University of Zagreb, Croatia	UNIZG	D. Bosnar

LNF, UniPa and IMEM-CNR Collaboration

Aim: to build a detector for kaonic atoms spectroscopy in DAFNE with CdZnTe detector.

- The group of Palermo (UniPa) is responsible for CdZnTe readout and digitalisation
- The group of Parma (IMEM-CNR) is responsible for the realisation and optimisation of the CdZnTe detectors
- The group of Frascati is responsible for the MC simulations, installations, trigger system and kaonic atoms data analysis

Previously on ECT*...

From “EXOTICO” 2022:

CZT: proposal for new measurements at DAΦNE

E. Friedman et al. / Nuclear Physics A579 (1994) 518–538

Table 1
Compilation of K^- atomic data

Nucleus	Transition	ϵ (keV)	Γ (keV)	Y	Γ_u (eV)
He	3 → 2	−0.04 ±0.03	–	–	–
		−0.035 ± 0.012	0.03 ±0.03	–	–
Li	3 → 2	0.002 ± 0.026	0.055 ± 0.029	0.95 ± 0.30	–
Be	3 → 2	−0.079 ± 0.021	0.172 ± 0.58	0.25 ± 0.09	0.04 ± 0.02
^{10}B	3 → 2	−0.208 ± 0.035	0.810 ± 0.100	–	–
^{11}B	3 → 2	−0.167 ± 0.035	0.700 ± 0.080	–	–
C	3 → 2	−0.590 ± 0.080	1.730 ± 0.150	0.07 ± 0.013	0.99 ± 0.20
O	4 → 3	−0.025 ± 0.018	0.017 ± 0.014	–	–
Mg	4 → 3	−0.027 ± 0.015	0.214 ± 0.015	0.78 ± 0.06	0.08 ± 0.03
Al	4 → 3	−0.130 ± 0.050	0.490 ± 0.160	–	–
		−0.076 ± 0.014	0.442 ± 0.022	0.55 ± 0.03	0.30 ± 0.04
Si	4 → 3	−0.240 ± 0.050	0.810 ± 0.120	–	–
		−0.130 ± 0.015	0.800 ± 0.033	0.49 ± 0.03	0.53 ± 0.06
P	4 → 3	−0.330 ± 0.08	1.440 ± 0.120	0.26 ± 0.03	1.89 ± 0.30
S	4 → 3	−0.550 ± 0.06	2.330 ± 0.200	0.22 ± 0.02	3.10 ± 0.36
		−0.43 ±0.12	2.310 ± 0.170	–	–
		−0.462 ± 0.054	1.96 ±0.17	0.23 ± 0.03	2.9 ±0.5

Element	Transition	E (keV)
$K^{12}C$	3-->2	63
$K^{12}C$	4-->2	85
$K^{12}C$	5-->2	95
$K^{12}C$	6-->2	101
$K^{12}C$	7-->2	104
$K^{12}C$	4-->3	22
$K^{12}C$	5-->3	32
$K^{12}C$	6-->3	38
$K^{12}C$	7-->3	41

Element	Transition	E (keV)
$K^{27}Al$	3-->2	302
$K^{27}Al$	4-->3	106
$K^{27}Al$	5-->3	155
$K^{27}Al$	6-->3	181
$K^{27}Al$	7-->3	197
$K^{27}Al$	8-->3	208
$K^{27}Al$	5-->4	49
$K^{27}Al$	6-->4	76
$K^{27}Al$	7-->4	91
$K^{27}Al$	8-->4	102
$K^{27}Al$	9-->4	109
$K^{27}Al$	10-->4	114

Element	Transition	E (keV)
$K^{32}S$	4-->3	161
$K^{32}S$	5-->4	74
$K^{32}S$	6-->4	115
$K^{32}S$	7-->4	139
$K^{32}S$	8-->4	155
$K^{32}S$	9-->4	166
$K^{32}S$	10-->4	174

KC(3 → 2), KAl(3 → 2), KS(4 → 3):

Precisions < 20 eV (ε) and <40 eV (Γ) are reachable in few months

Measurements of several parallel transitions ⇨ new inputs for cascade casculations

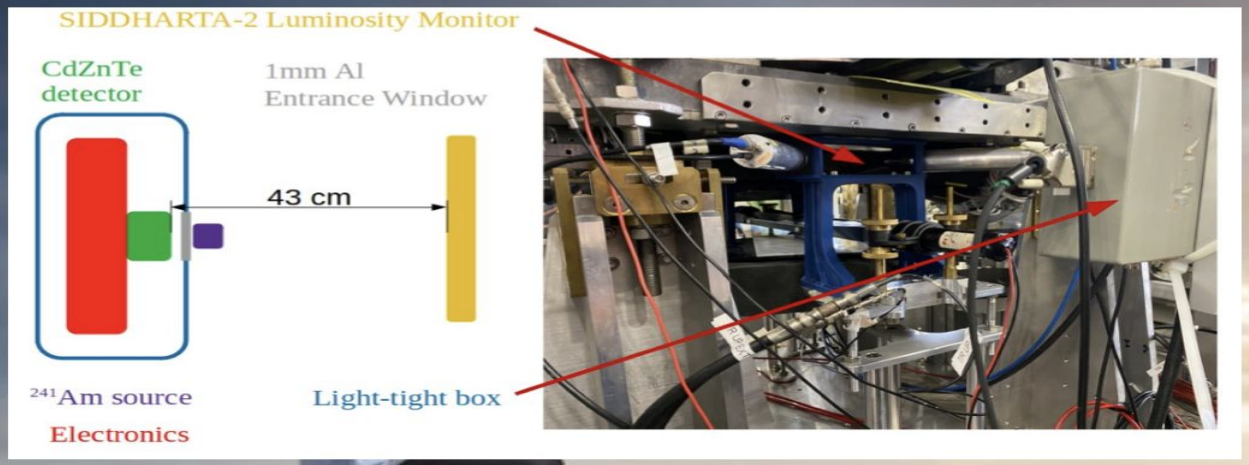
“EXOTICO workshop“ - *A. Scordo*, Trento (ECT*), 18/10/2022

Previously on ECT*...

From “EXOTICO” 2022:

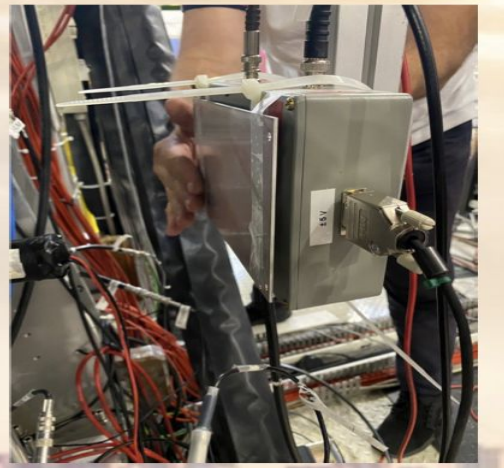
CZT: first tests @ DAΦNE

Goal: background and resolution assessment in machine environment (first time)



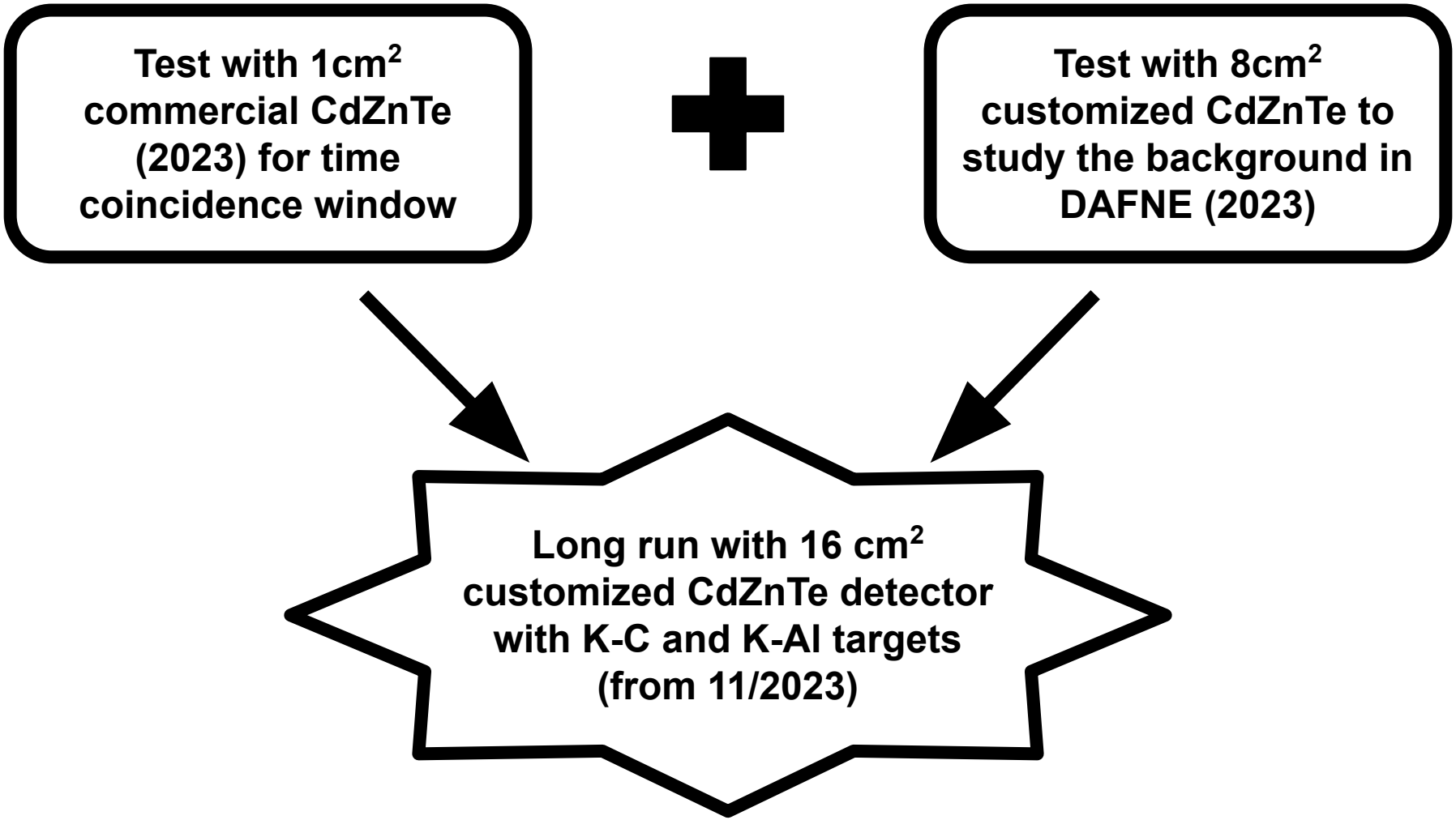
22/06/2022:

First prototype installed in DAΦNE to check “on beam” response and possible issues



“EXOTICO workshop“ - *A. Scordo*, Trento (ECT*), 18/10/2022

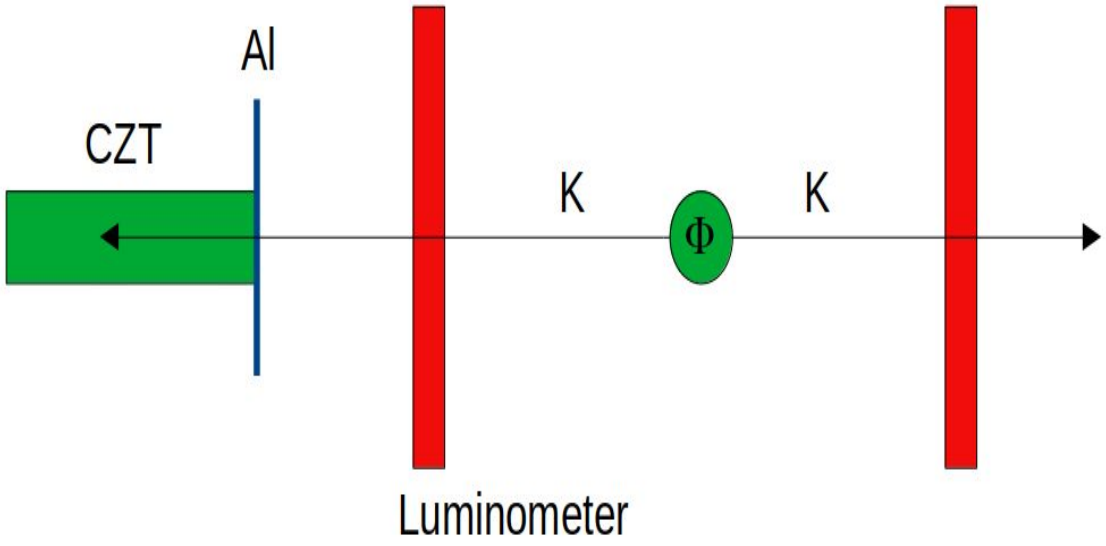
The Roadmap to new K-C and K-Al measurements with CdZnTe Detector



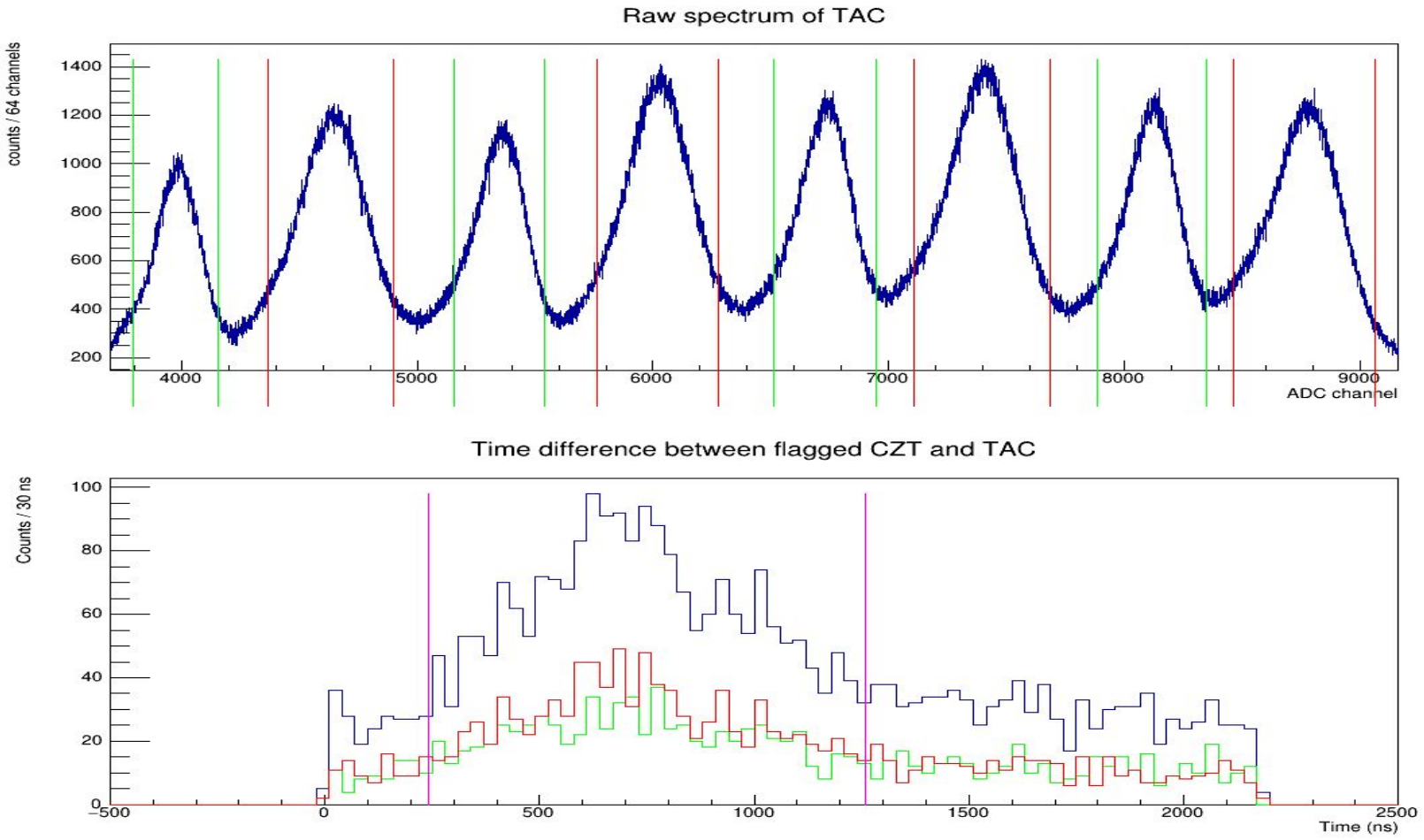
Test with 1cm^2 commercial CdZnTe (2023) for time coincidence window

Test with 1cm^2 commercial CdZnTe (2023)

- **Goal:** Time window for **TAC-CZT coincidence** and behavior when closer to the IP.
- **Detector:** is a **1 cm^2 surface**, 5 mm thick CZT/500 from RITEC CZT, installed on the AntiBoost side, **just after the Luminometer(~8cm)**.
- **Target: >1 mm Al** foil is placed between the LM and the CZT surface

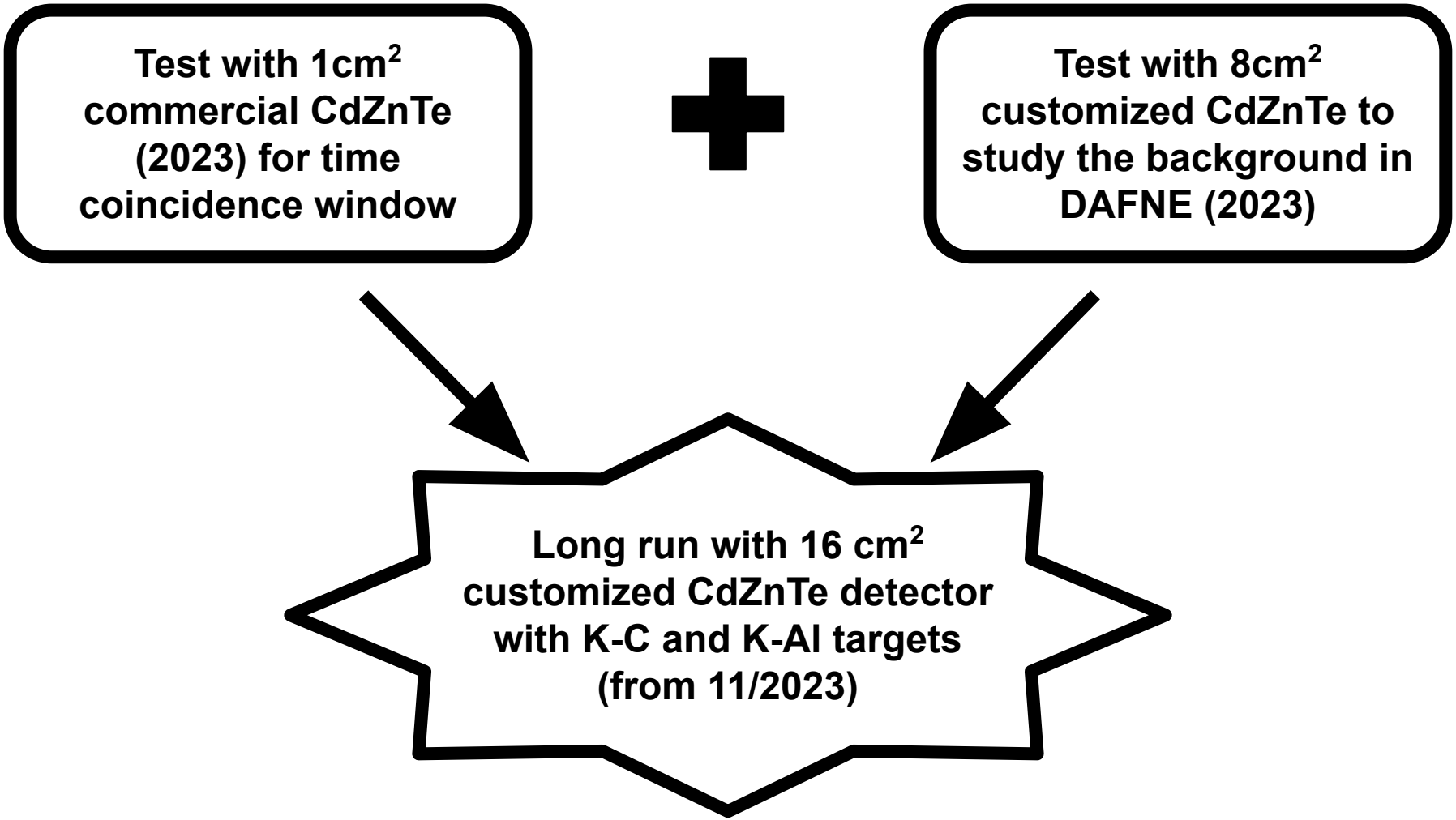


Test with 1cm^2 commercial CdZnTe (2023)



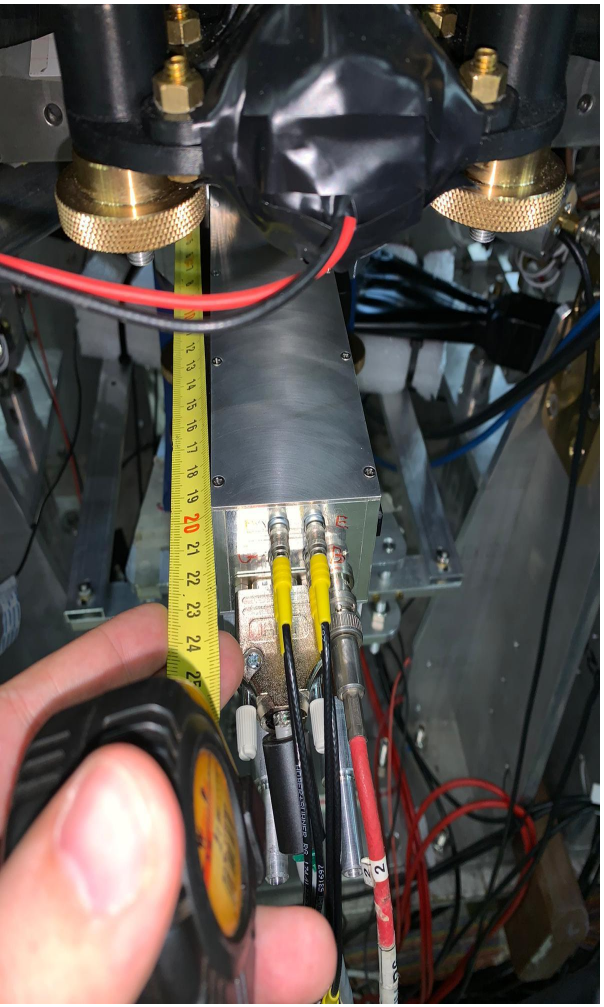
A time coincidence window between TAC and CdZnTe was found.

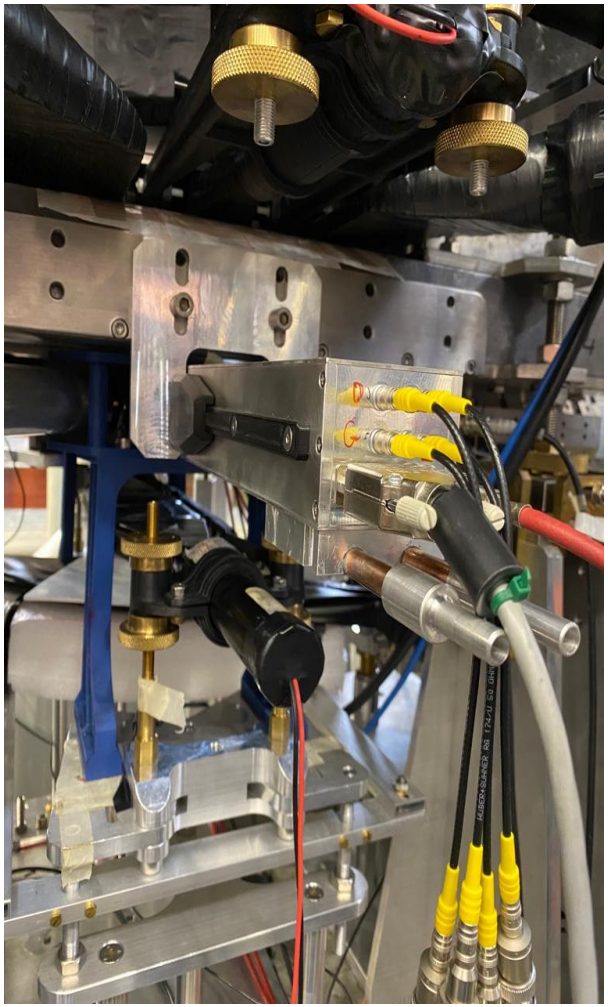
The Roadmap to new K-C and K-Al measurements with CdZnTe Detector

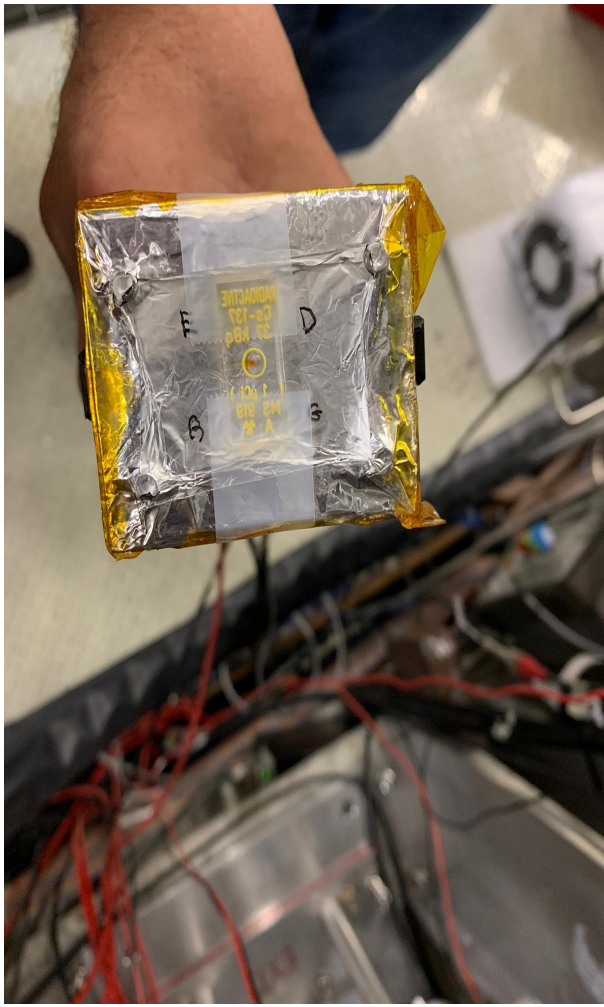


Test with 8cm^2 customized CdZnTe to study the background in DAFNE (2023)

Test with 8cm^2 customized CdZnTe (2023)







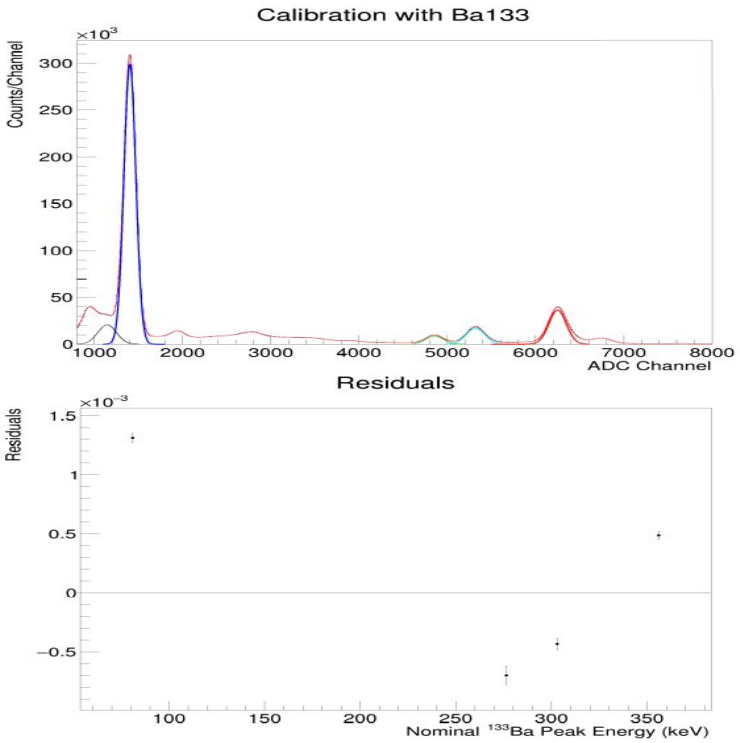
Test with 8cm^2 customized CdZnTe (2023)

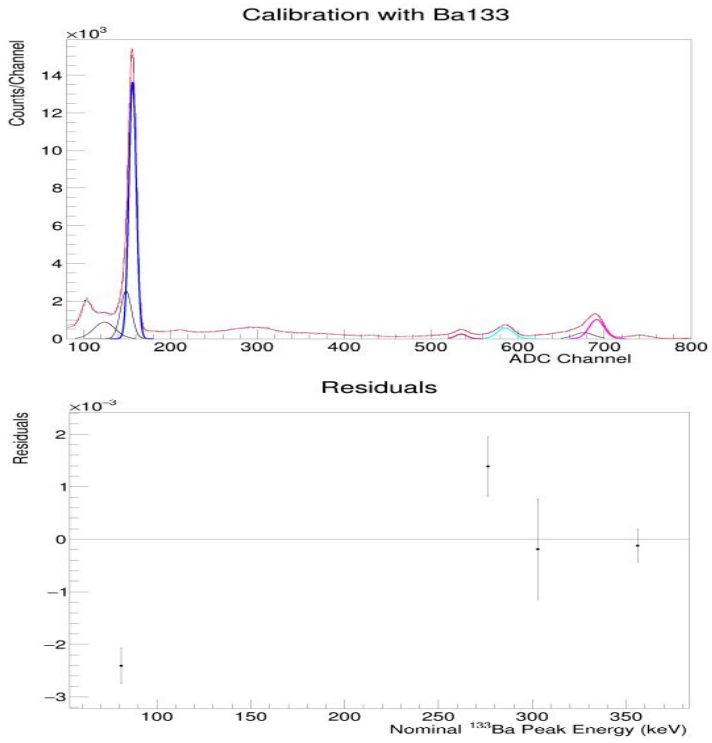
- **Goal:** test of Multi-channel DAQ, test of new customized CdZnTe and background estimations for a bigger device close to the beam-pipe.

- **Detector:** CdZnTe detection system is an **array of 4 13x15x10 mm^3** detectors from REDLEN, installed in DAFNE, on the AntiBoost side, **216 mm from the IP.**

- **Target: 1 mm Al + 1 mm C** is placed on the Luminometer and on the box.

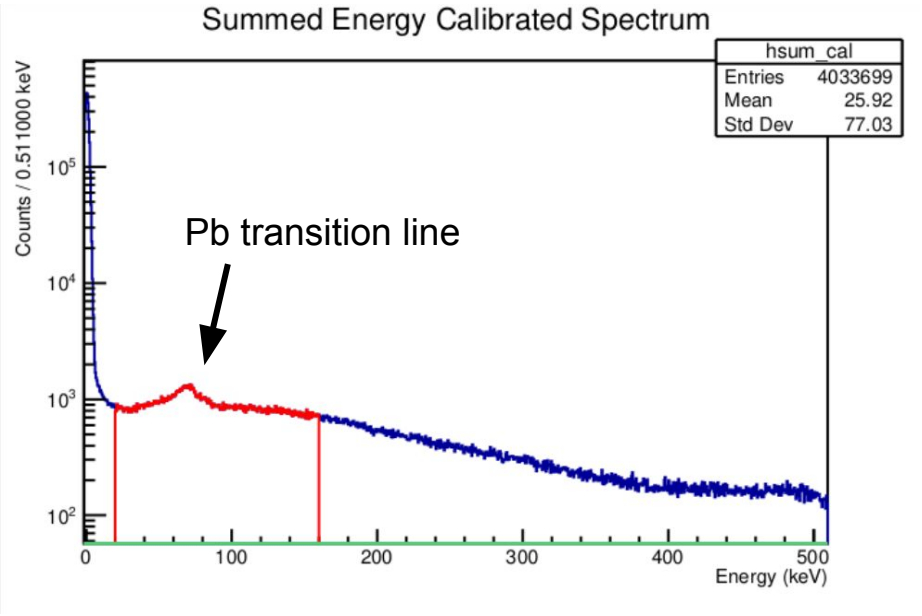
Test with 8cm^2 customized CdZnTe (2023)

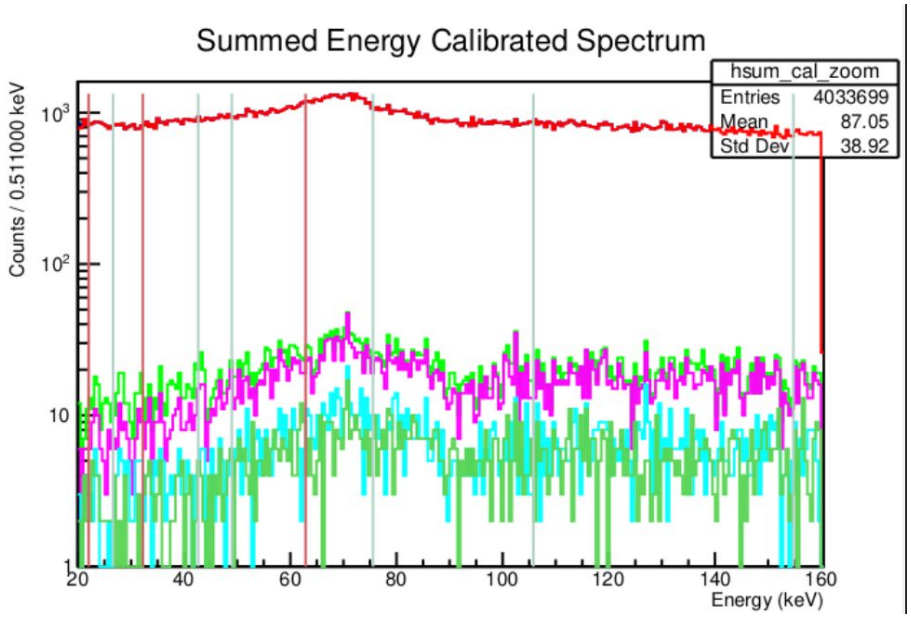




	RITEC CZT/500		IMEM-CNR CdZnTe	
^{133}Ba Peak (keV)	Residuals (10^{-3})	FWHM/E	Residuals (10^{-3})	FWHM/E
80.1	1.3	0.110	-2.4	0.064
276.4	-0.7	0.048	1.4	0.028
302.9	-0.4	0.046	-0.2	0.036
356.0	0.5	0.037	-0.1	0.030

Test with 8cm^2 customized CdZnTe (2023)






```
5347331 events rejected over 890169 in CZT 0 (0.857)
5270090 events rejected over 967410 in CZT 1 (0.845)
5228081 events rejected over 1009419 in CZT 2 (0.838)
5070799 events rejected over 1166701 in CZT 3 (0.813)
24349 events rejected over 6213151 in TAC (0.0039)
3986 events rejected over 6233514 in TRIGGER (0.000639)
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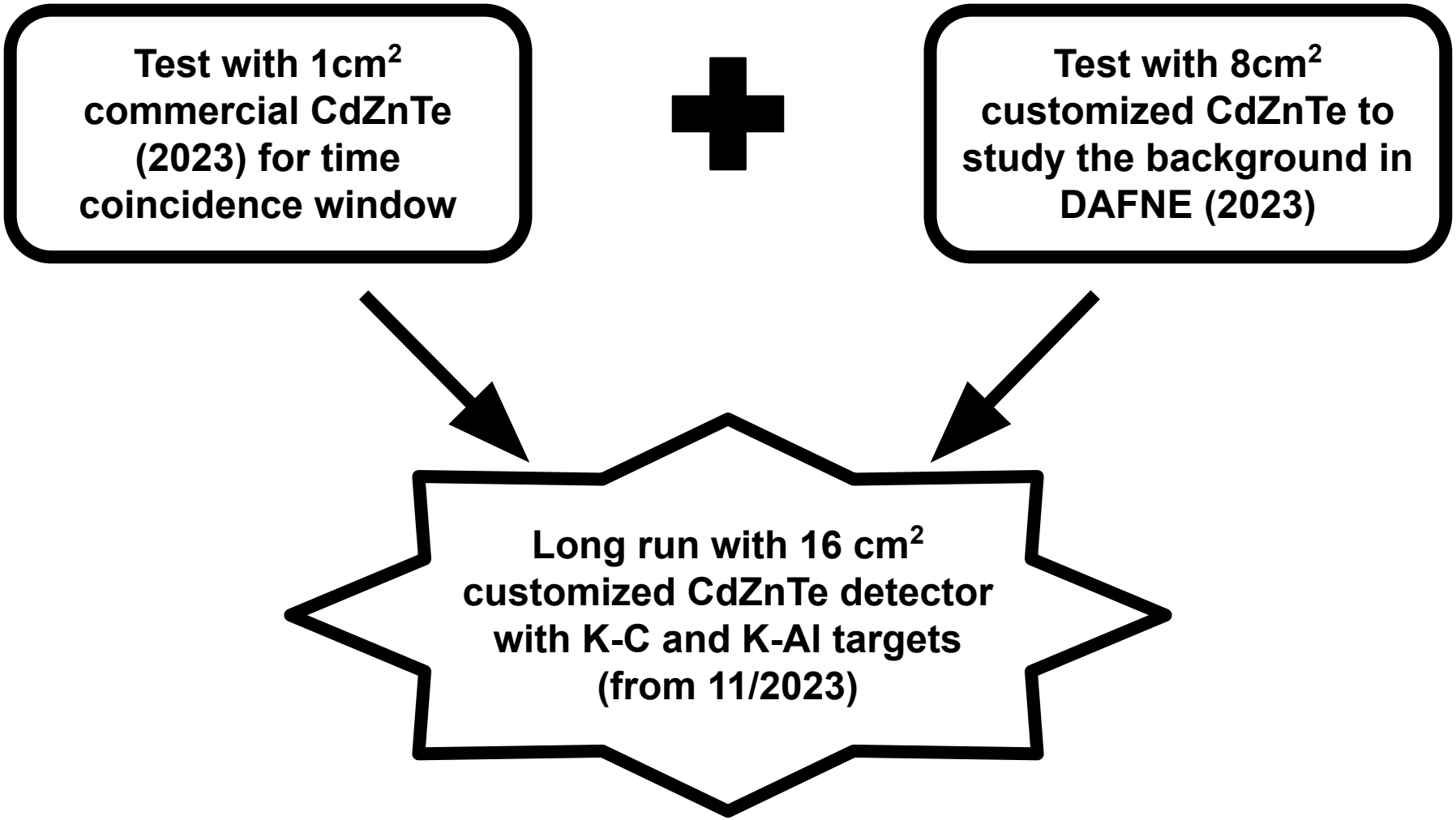
As expected the background in DAFNE near the IP is high

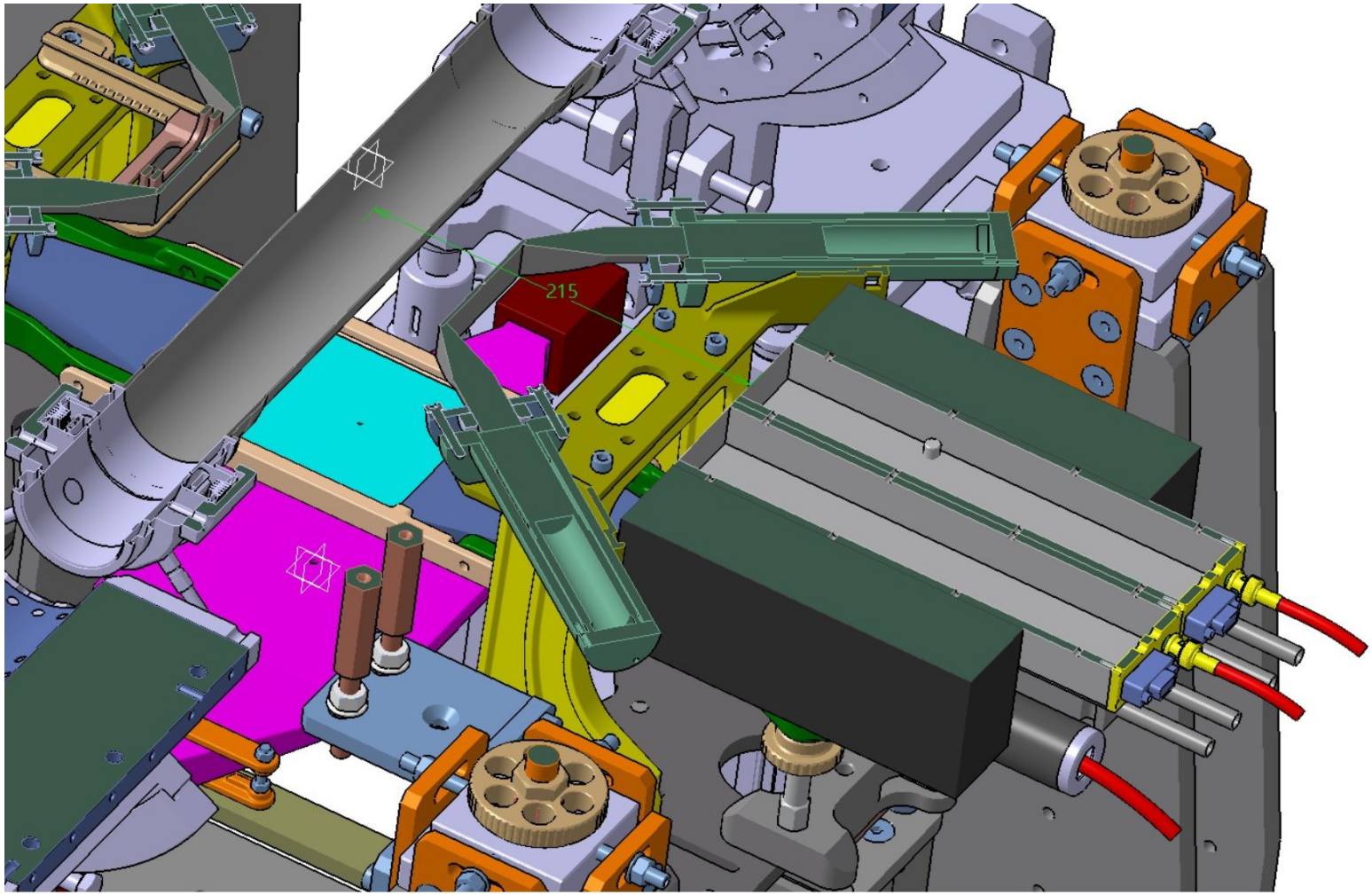
A Pb SHIELDING IS NEEDED!

The Roadmap to new K-C and K-Al measurements with CdZnTe Detector

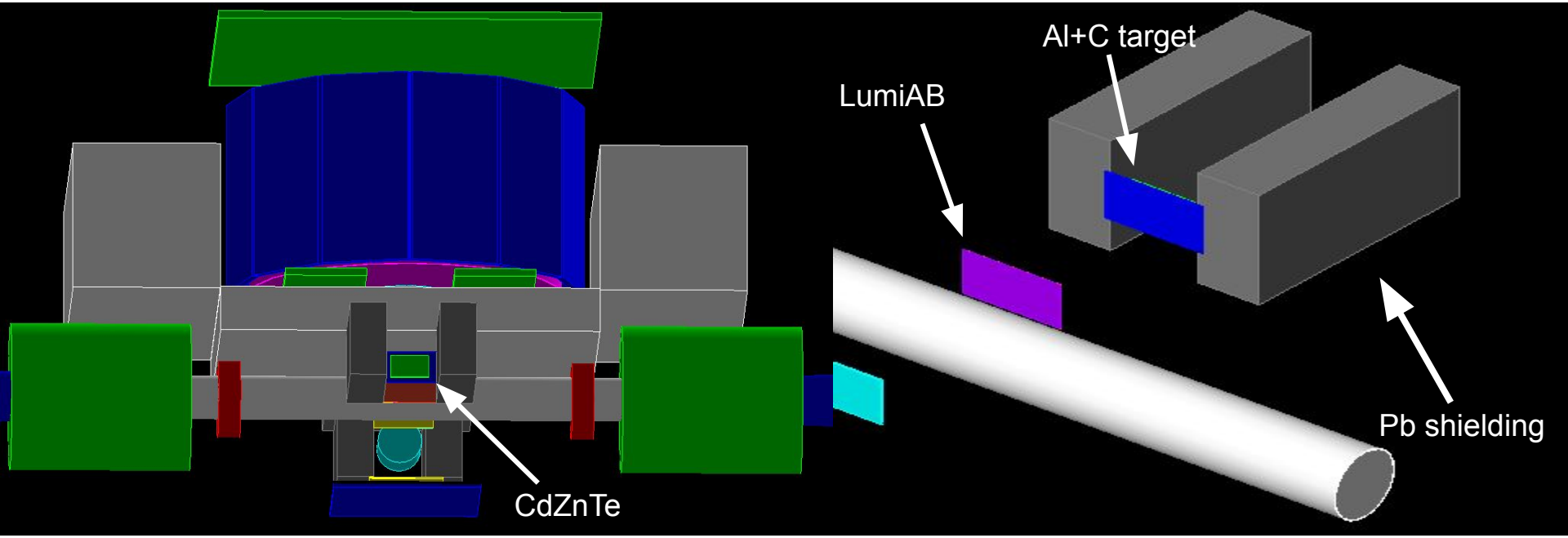


Long run with 16 cm^2 customized CdZnTe detector with K-C and K-Al targets (from 11/2023)

Long run with 16 cm^2 CdZnTe detector (from 11/2023): Simulations and expected results



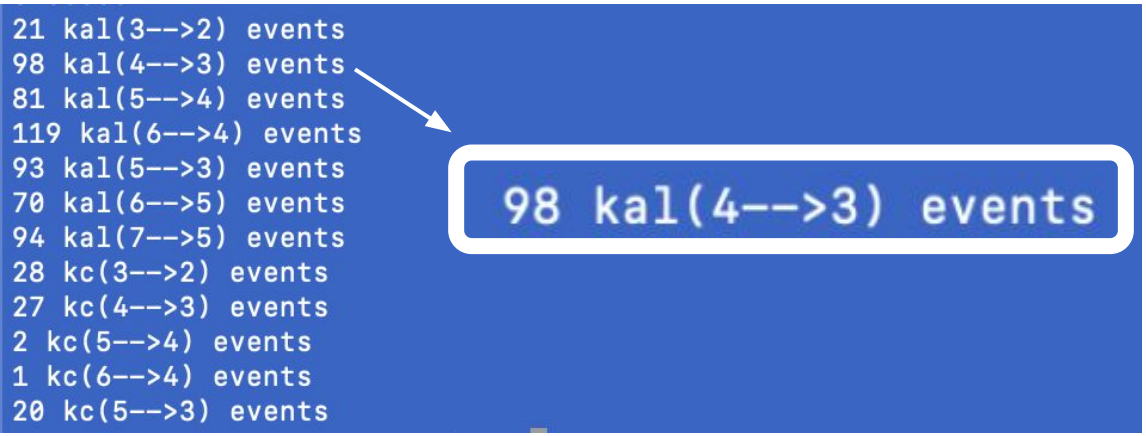
Long run with 16 cm^2 CdZnTe detector (from 11/2023): Simulations and expected results



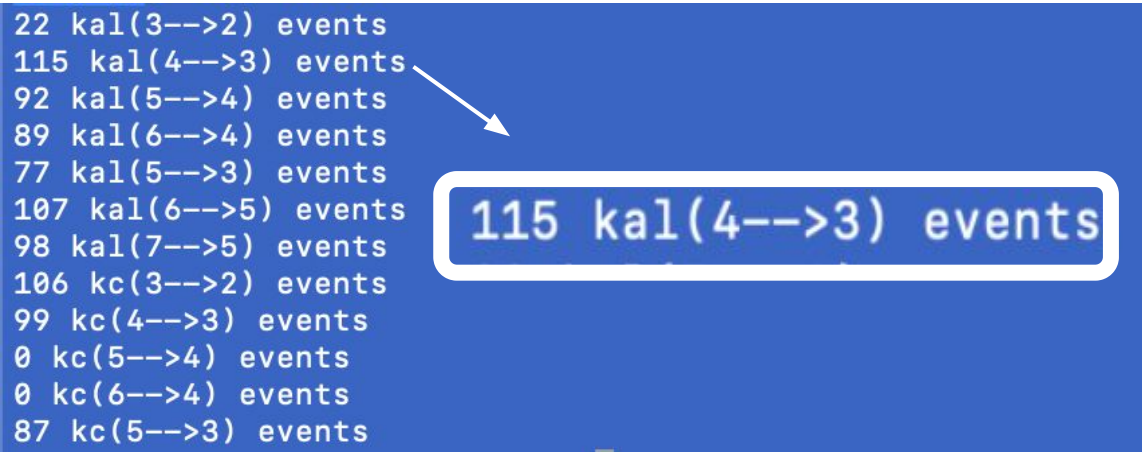
Main goals (for now):

- Optimize the set-up and targets' thickness.
- Estimate the results.

Long run with 16 cm^2 CdZnTe detector (2024): Simulations and expected results

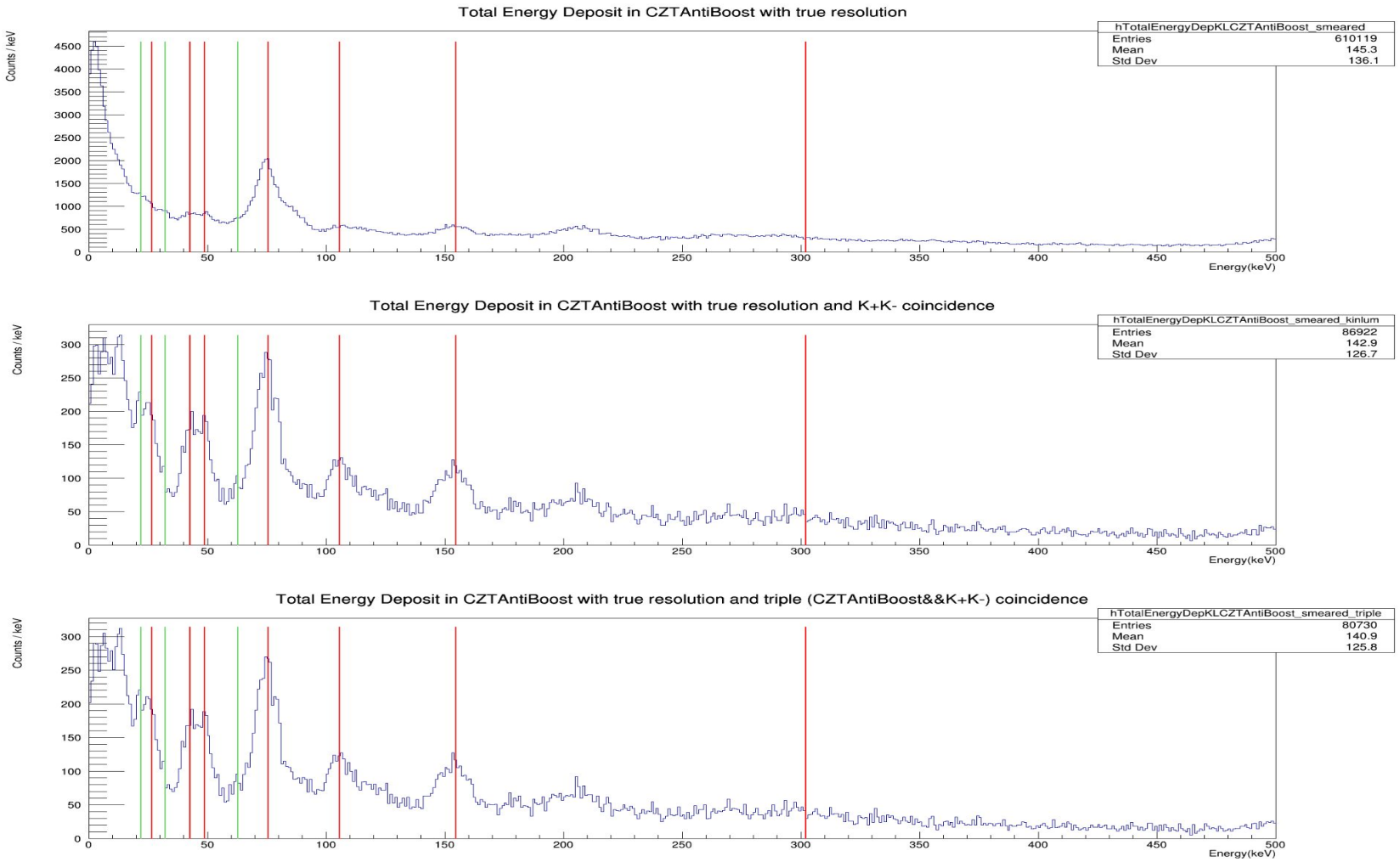


Target close to the detector



Target close to the LUMI

Long run with 16 cm^2 CdZnTe detector (2024): Simulations and expected results



40M Φ created in the simulation, that corresponds to ~10 pb^{-1} (~1.5 days of data taking).

~1200 events for $KAl_{4->3}$ (106 keV) ⇒ ~24000 events in 1 month

assuming a reasonable and conservative 10% yield
⇒ ~2400 events

Estimating $\partial E \sim \sigma/\sqrt{N}$ for a σ~2 keV

For a 2 month run a precision of <30 eV is expected.

Conclusions

- **CdZnTe proved to be the perfect technology for intermediate mass kaonic atoms**, with very good “in-beam” performances during the preliminary tests.

- **CdZnTe detectors** can be **easily used** in parallel with already existing experiments, requiring **very small space and not invasive electronics**.

- **Time coincidence window, trigger capabilities and background rejection** through a Pb shielding have been **assessed for a multi-channel setup**.

- What we learned until now will represent the **basis for the future Long Run with a 16 cm^2 setup**, exploting better shielding and MC-tuned targets and geometry.

- We plan to reach a **precision on ~20ev on shift** for K-Al, K-C and K-S transitions measurements in the next year.

THANK YOU FOR YOUR ATTENTION!