Kaonic atoms beyond SIDDHARTA-2: future measurements and perspectives at the DAΦNE collider

" Nuclear E2 resonance effects in kaonic molybdenum isotopes"
Symposium

A. Scordo, Frascati (online), 08/04/2022

Why (again and still) kaonic atoms?

402 C.J. Batty et al. / Physics Reports 287 (1997) 385–445

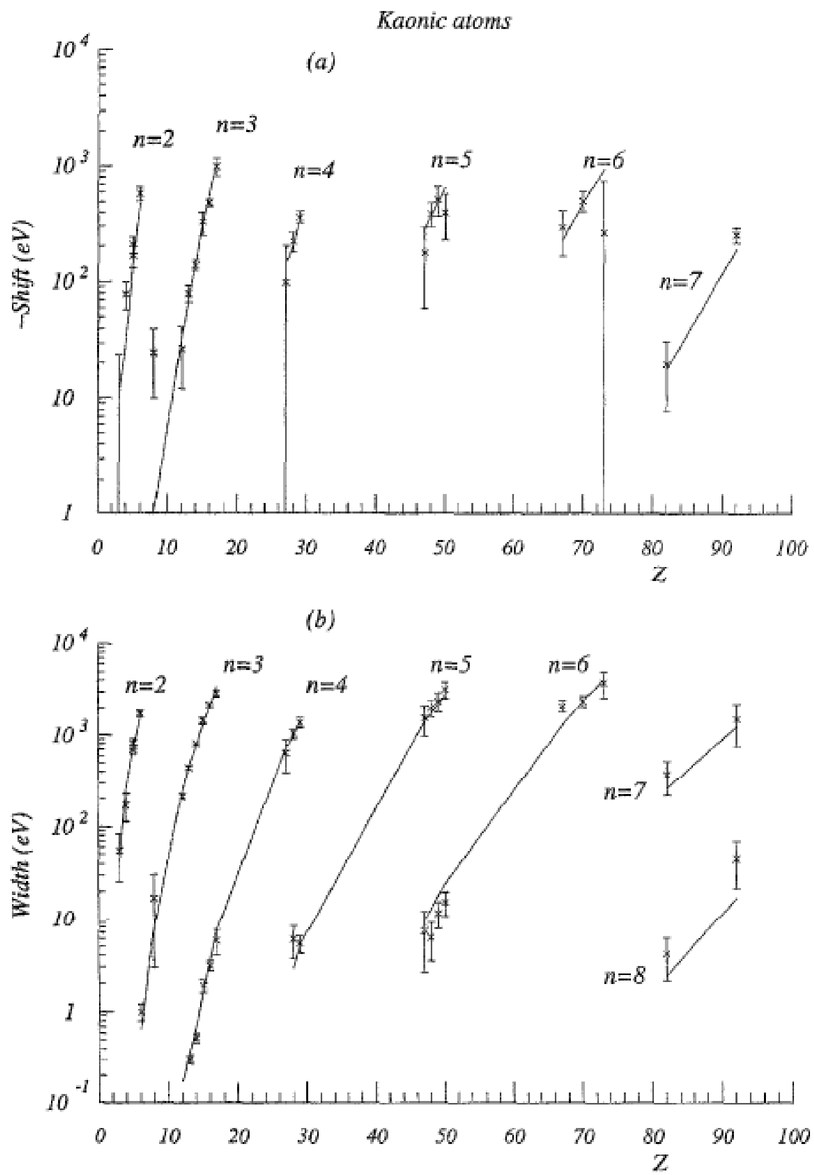

Fig. 7. Shift and width values for kaonic atoms. The continuous lines join points calculated with the best-fit optical potential discussed in Section 4.2.

Except for the most recent measurements at DAΦNE and JPARC on KHe and KH, the whole knowledge on kaonic atoms dates back to 1970s

These data, are the experimental basis for all the development theoretical models

These theoretical models are used to derive, for example:

- KN interaction at threshold
- KNN interaction at threshold
- Nuclear density distributions
- Possible existence of kaon condensates
- Kaon mass
- Kaonic atoms cascade models

Why (again and still) kaonic atoms?

E. Friedman et al. / Nuclear Physics A579 (1994) 518–538 521

Table 1
Compilation of K^- atomic data

Nucleus	Transition	ϵ (keV)	Γ (keV)	Y	Γ_u (eV)	Ref.
He	3 → 2	−0.04 ± 0.03	–	–	–	[15]
		−0.035 ± 0.012	0.03 ± 0.03	–	–	[16]
Li	3 → 2	0.002 ± 0.026	0.055 ± 0.029	0.95 ± 0.30	–	[17]
Be	3 → 2	−0.079 ± 0.021	0.172 ± 0.58	0.25 ± 0.09	0.04 ± 0.02	[17]
^{10}B	3 → 2	−0.208 ± 0.035	0.810 ± 0.100	–	–	[18]
^{11}B	3 → 2	−0.167 ± 0.035	0.700 ± 0.080	–	–	[18]
C	3 → 2	−0.590 ± 0.080	1.730 ± 0.150	0.07 ± 0.013	0.99 ± 0.20	[18]
O	4 → 3	−0.025 ± 0.018	0.017 ± 0.014	–	–	[19]
Mg	4 → 3	−0.027 ± 0.015	0.214 ± 0.015	0.78 ± 0.06	0.08 ± 0.03	[19]
Al	4 → 3	−0.130 ± 0.050	0.490 ± 0.160	–	–	[20]
		−0.076 ± 0.014	0.442 ± 0.022	0.55 ± 0.03	0.30 ± 0.04	[19]
Si	4 → 3	−0.240 ± 0.050	0.810 ± 0.120	–	–	[20]
		−0.130 ± 0.015	0.800 ± 0.033	0.49 ± 0.03	0.53 ± 0.06	[19]
P	4 → 3	−0.330 ± 0.08	1.440 ± 0.120	0.26 ± 0.03	1.89 ± 0.30	[18]
S	4 → 3	−0.550 ± 0.06	2.330 ± 0.200	0.22 ± 0.02	3.10 ± 0.36	[18]
		−0.43 ± 0.12	2.310 ± 0.170	–	–	[21]
		−0.462 ± 0.054	1.96 ± 0.17	0.23 ± 0.03	2.9 ± 0.5	[19]
Cl	4 → 3	−0.770 ± 0.40	3.80 ± 1.0	0.16 ± 0.04	5.8 ± 1.7	[18]
		−0.94 ± 0.40	3.92 ± 0.99	–	–	[22]
		−1.08 ± 0.22	2.79 ± 0.25	–	–	[21]
Co	5 → 4	−0.099 ± 0.106	0.64 ± 0.25	–	–	[19]
Ni	5 → 4	−0.180 ± 0.070	0.59 ± 0.21	0.30 ± 0.08	5.9 ± 2.3	[20]
		−0.246 ± 0.052	1.23 ± 0.14	–	–	[19]
Cu	5 → 4	−0.240 ± 0.220	1.650 ± 0.72	0.29 ± 0.11	7.0 ± 3.8	[20]
		−0.377 ± 0.048	1.35 ± 0.17	0.36 ± 0.05	5.1 ± 1.1	[19]
Ag	6 → 5	−0.18 ± 0.12	1.54 ± 0.58	0.51 ± 0.16	7.3 ± 4.7	[19]
Cd	6 → 5	−0.40 ± 0.10	2.01 ± 0.44	0.57 ± 0.11	6.2 ± 2.8	[19]
In	6 → 5	−0.53 ± 0.15	2.38 ± 0.57	0.44 ± 0.08	11.4 ± 3.7	[19]
Sn	6 → 5	−0.41 ± 0.18	3.18 ± 0.64	0.39 ± 0.07	15.1 ± 4.4	[19]
Ho	7 → 6	−0.30 ± 0.13	2.14 ± 0.31	–	–	[23]
Yb	7 → 6	−0.12 ± 0.10	2.39 ± 0.30	–	–	[23]
Ta	7 → 6	−0.27 ± 0.50	3.76 ± 1.15	–	–	[23]
Pb	8 → 7	–	0.37 ± 0.15	0.79 ± 0.08	4.1 ± 2.0	[24]
		−0.020 ± 0.012	–	–	–	[25]
U	8 → 7	−0.26 ± 0.4	1.50 ± 0.75	0.35 ± 0.12	45 ± 24	[24]

The available data on “lower levels” have big uncertainties

Many of them are actually UNmeasured

Many of them are hardly compatible among each other

Relative yields with upper levels are not always measured

Absolute yields are basically unknown (except for few transitions)

The REmeasured ones have been proved WRONG

This situation would already be a proper justification for new measurements

What more can we learn from new measurements?

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AN ADVANTAGE OF "UPPER LEVELS"*

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Hadronic atoms allow, in principle, to understand hadron–nucleon interactions just below thresholds. So far, the X-ray atomic transitions have offered atomic level shifts in the "lowest" of accessible atomic states. Level broadenings have been measured directly in these states and indirectly also in higher "upper" levels. Recent experimental progress allows to find level shifts also in some upper states. Such measurements are much easier to analyse as the levels are determined essentially by a single hadron–nucleon collision at a fairly well-determined subthreshold energy. Light anti-protonic and K-mesic atoms are discussed.

Hyperfine Interact (2012) 209:133–138
DOI 10.1007/s10751-011-0539-6

Kaonic atoms and $\Lambda(1405)$

Slawomir Wycech

Published online: 9 February 2012

Abstract Studies of $\Lambda(1405)$ in $\Sigma\pi$ decay channels are briefly presented and the related uncertainties indicated. The advantages of measurements in the $\bar{K}N$ channel are stressed. Two methods: studies of upper levels in K-mesic atoms and radiative decays from the hydrogen atom to $\Lambda(1405)$ are discussed.

In analogy to anti-protons, the scenario under the $\bar{K}N$ threshold is determined by a resonant state $\Lambda(1405)$ with a pole close to $E_{\mathrm{cm}} = 1410$ MeV that is in the ^{3}He region. On the other side, one has $\Sigma(1385)$ state which exerts maximum repulsive effect in the ^{4}He region. Apparently, these two main agents yield attractive shift in ^{3}He and repulsive in ^{4}He. Now, in order to go above the errors, one has to magnify the shifts and enhance the atomic–nuclear overlaps. The proper targets would be ^{9}Be and ^{6,7}Li. These offer similar values of E_{cm} as ^{4}He and ^{3}He. A simple re-scaling of overlaps generates the level shifts of about 100 eV. One should perhaps consider also studies of $3D$ levels in these atoms. One interesting outcome might be the estimate at what energy the isospin 0 Re $T(\bar{K}N \to \bar{K}N)$ amplitude crosses zero. That will help to settle the controversy as to where is the $\Lambda(1405)$ pole in the complex plane located.

Measurements of widths of upper levels in kaonic atoms may provide information on $\Lambda(1405)$

What more can we learn from new measurements?

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Kaonic atoms and in-medium K^-N amplitudes II: Interplay between theory and phenomenology

E. Friedman, A. Gal *

4. Summary

We have presented fits to kaonic atom data across the whole periodic table based on the IHW free-space NLO chiral K^-N amplitudes below threshold [11]. The WRW MS procedure [12] was used to form in-medium K^-N amplitudes in terms of which a $1N$ potential $V^{(1)}_{K^-}$ is constructed. The strong energy dependence of the free-space subthreshold K^-N amplitudes induces substantial density dependence in $V^{(1)}_{K^-}$ within the SC calculation of the energy parameter $\sqrt{s}$. This dependence is enhanced further by the implicit coupling to a phenomenological $V^{(2)}_{K^-}$ term and good fits to the data were reached in this way. It was found, in full agreement with part I of this work [5] which was based on in-medium NLO30 amplitudes due to CS [7], that a sizable empirical mN potential was required, both for the imaginary part as well as for the real part. By considering in some detail the contribution of Im $V^{(2)}_{K^-}$ to the width of 'upper' and 'lower' states in Ni, we have demonstrated how its relative importance develops as one enters the denser regions of the nuclear surface and further inward. With a theoretically-based $1N$ term coupled to a phenomenological mN term within a self-consistent subthreshold approach, the latter could guide more theoretical work to derive the origin of such a strong multi-nucleon $V^{(2)}_{K^-}$ component. Finally, new precision measurements of strong-interaction observables for more than a single level on a given target could greatly enhance our understanding of the various nuclear absorption processes of stopped K^- mesons.

9th August 2020

Features of K^-NN interaction in light kaonic atoms

E. Friedman, A Gal

Generally speaking, studies of 'beyond single nucleon interactions' in kaonic atoms are at present necessary and feasible theoretically, and are feasible experimentally. Several chiral models of K^- nucleon interactions near threshold have been successful in reproducing K^- nucleon data. These models form a solid basis for global optical potentials that reproduce very well strong interaction observables in kaonic atoms throughout the Periodic Table, when supplemented by a phenomenological term representing interaction of K^- with two or several nucleons. Current projects (e.g. in Prague and in Barcelona) are tackling this topic in medium weight and heavy nuclei.

We have been engaged recently in a more phenomenological approach to interaction of K^- with two nucleons in kaonic atoms. We get a clear picture showing that features of K^-NN interaction are evident already in very light nuclei. In particular, from 12C upwards features of K^-2N interaction in the nuclear medium are already fully developed. Similar analyses of pionic atoms where the experimental results are more extensive and are of much higher quality show great similarity with kaonic atoms. Moreover, gradual build-up of in-medium features is clearly observed over the sequence of 3He, 6Li, 7Li, 9Be, 10B and 11B. We believe these species are amenable to few-body approaches using present-day methods.

Returning to kaonic atoms, only for 9Be, 10B and 11B the experimental results are of sufficient quality and indeed gradual build-up of in-medium features in parallel with pionic atoms is evident. We believe that good quality data, particularly values of strong interaction widths of the 2p level in kaonic atoms of 3He, 6Li, 7Li and 9Be will be a significant contribution to few-body studies of the onset of K^-NN interaction in the nuclear medium.

Therefore we propose that these four species of kaonic atoms will be part of the near future experimental program.

Parallel measurements of different transitions in a single target may provide information on the nuclear absorption processes for K-

What more can we learn from new measurements?

K^-NN absorption and kaonic atoms

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25 - 26 February, 2021

New fits to kaonic atoms data are ongoing to investigate KNN absorption

Removing ^{32}S from the fits dramatically improve the χ^2

What if other experimental points are wrong (not so unlikely…)?

Kaonic atoms calculations

Table 4: Values of χ^2 for shifts, widths and yields in selected K^- atoms, calculated with K^-N, $K^-N + K^-NN$ and K^-N+phen. multiN potentials based on BCN Pauli or WRW modified amplitudes. Experimental data are shown for comparison.

BCN		WRW		Pauli		phen.	EXP
		KN	+KNN	KN	+KNN	KN + phen. multiN	
C^{12}	$\Delta(\epsilon)$	74.81	20.85	8.46	4.63	0.53	-0.59 (0.08)
	Γ	22.68	21.38	9.46	5.27	1.77	1.73 (0.15)
	Γ^*	1.29	1.17	0.06	0.57	2.45	0.99 (0.20)
P^{31}	$\Delta(\epsilon)$	23.23	6.14	1.84	1.82	0.07	-0.33 (0.08)
	Γ	10.49	12.96	6.02	4.63	0.78	1.44 (0.12)
	Γ^*	7.40	5.96	0.70	0.42	0.42	1.89 (0.30)
S^{32}	$\Delta(\epsilon)$	324.03	134.55	74.54	77.37	15.81	-0.494 (0.038)
	Γ	20.73	40.37	5.35	3.50	0.57	2.19 (0.10)
	Γ^*	37.82	31.30	20.62	14.05	6.47	3.03 (0.44)
Cl^{35}	$\Delta(\epsilon)$	18.81	7.4	0.80	1.15	0.00	-0.99 (0.17)
	Γ	0.26	6.08	3.60	2.70	0.27	2.91 (0.24)
	Γ^*	8.78	5.32	0.60	0.24	0.17	5.8 (1.70)
Cu^{63}	$\Delta(\epsilon)$	9.31	0.43	0.20	0.56	1.23	-0.370 (0.047)
	Γ	0.05	0.46	1.33	1.40	2.23	1.37 (0.17)
	Γ^*	1.39	0.16	0.25	0.47	1.44	5.2 (1.1)
Sn^{118}	$\Delta(\epsilon)$	2.52	2.57	4.71	5.12	3.23	-0.41 (0.18)
	Γ	0.06	0.06	0.06	0.25	0.45	3.18 (0.64)
	Γ^*	22.83	14.44	6.31	5.72	4.09	15.1 (4.4)
Pb^{208}	$\Delta(\epsilon)$	0.12	0.50	0.13	0.41	1.14	-0.02 (0.012)
	Γ	0.09	0.06	0.21	0.29	0.41	0.37 (0.15)
	Γ^*	0.11	0.26	0.39	0.44	0.50	4.1 (2)
χ^2	total	586.82	312.43	145.62	131.01	44.00	
	S^{32} out	204.24	106.20	45.10	36.09	21.16	

I stop here, but don't forget impacts on the Kaon Mass and cascades models

Transitions: energies and widths…which detector?

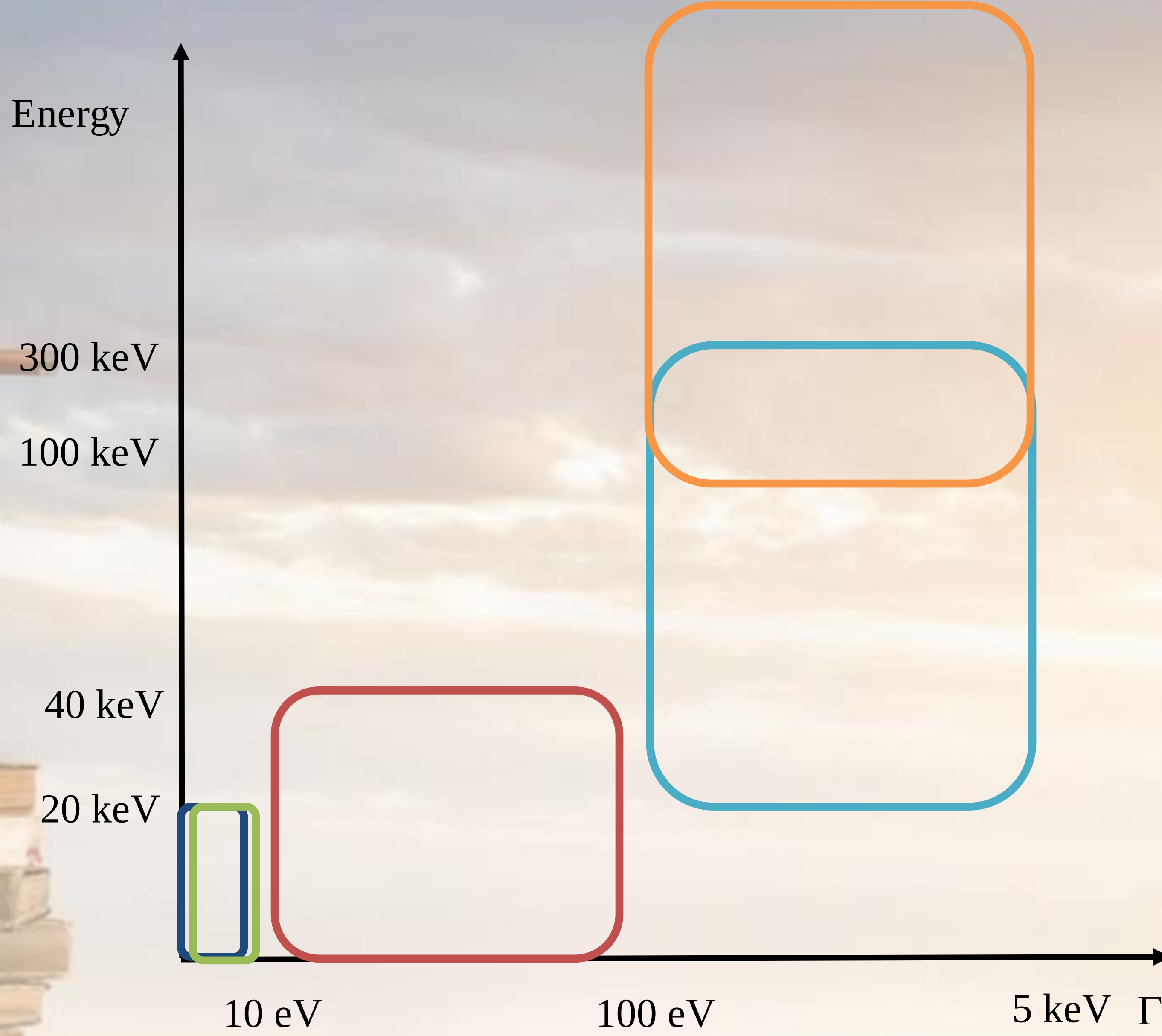
Crystal spectrometers:
- High resolution
- Low efficiency
- 0-20 keV range

T… calorimeters
- …
- accep…
- …
- …ult calibration

SDDs
- 100 eV max resolution
- 4-40 keV range
- High efficiency

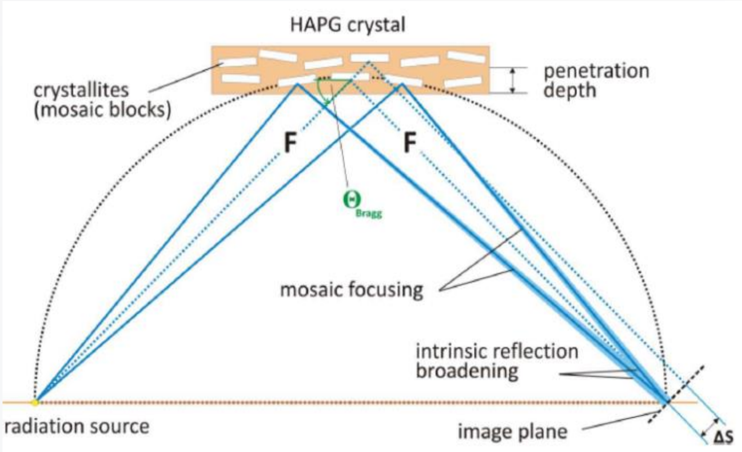
Cd(Zn)Te
- 20-300 keV range
- FWHM / E ~ %
- High efficiency
- Room Temperature

…
- …
- FW…
- …
- …ing needed



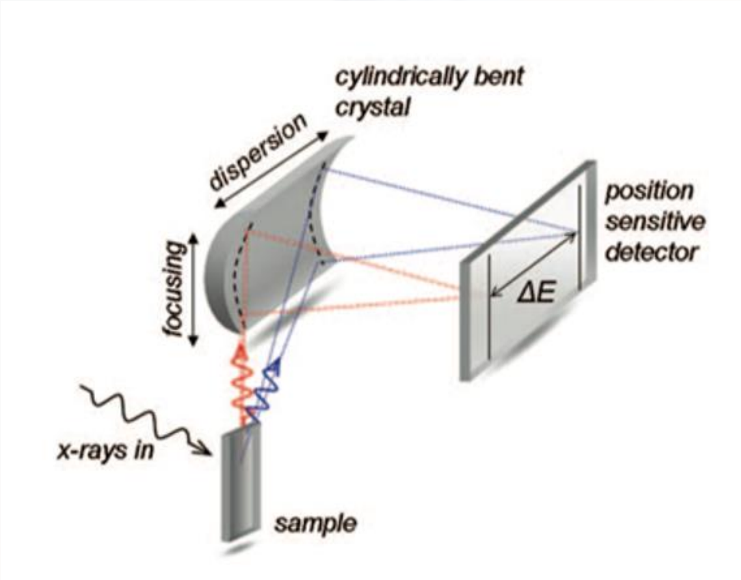
Crystal spectrometers: VOXES

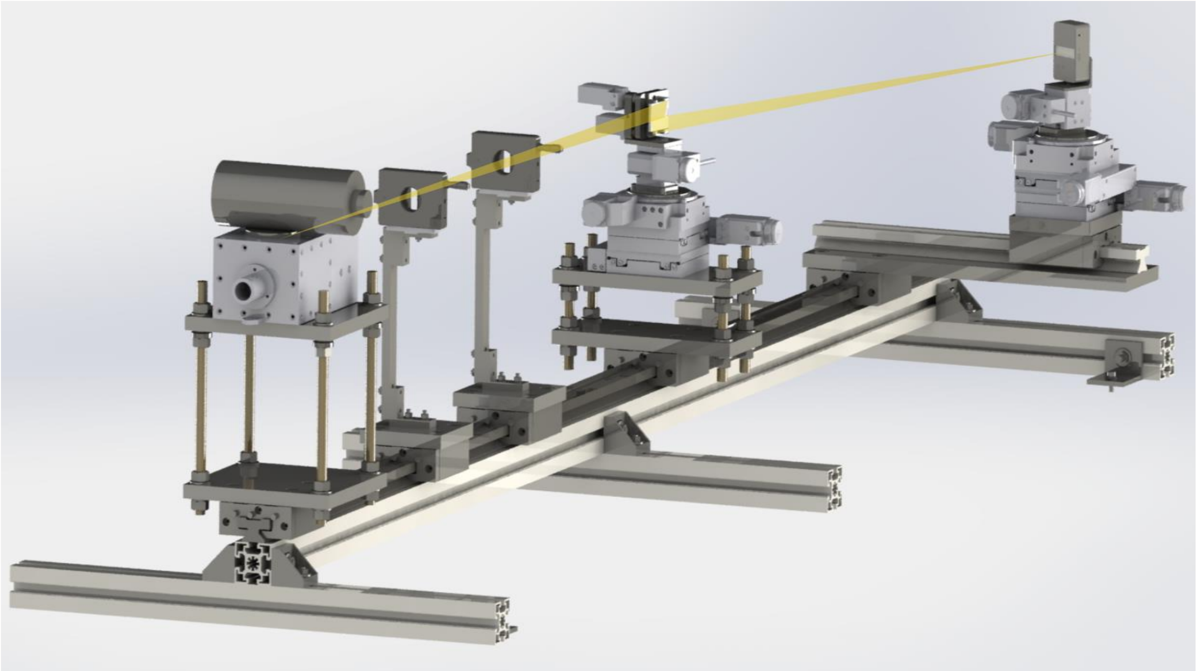
Spectrometer developed under CSN5 Young Researcher Grant (2016-2018)



HAPG mosaic crystals in Von Hamos configuration:

- Higher intrinsic reflectivity wrt standard crystals
- VH configuration to exploit sagittal focusing
- Optical optimisation to work with millimetric/centimetric sources



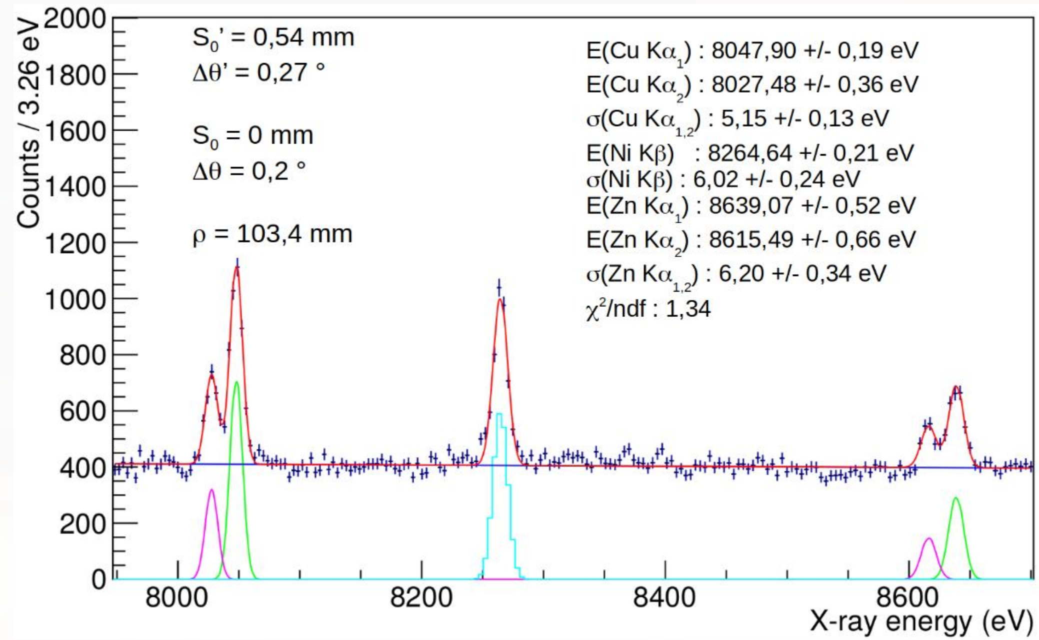


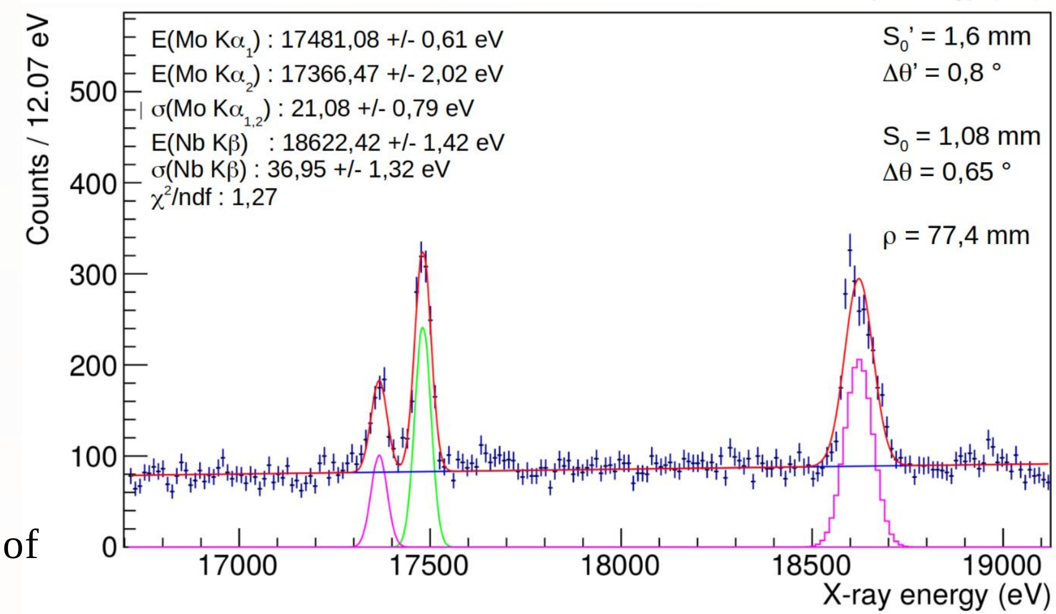
Crystal spectrometers: VOXES

Table 3 Best achieved resolutions and precisions summary.

Element	ρ_c (mm)	Parameter	value (eV)	$S_0'/\Delta\theta'$ (mm,°)
		$\sigma(K\alpha_{1,2})$	$4,17 \pm 0,16$	0,3/0,24
	77,5	$\delta(K\alpha_1)$	0,11	0,6/0,44
		$\delta(K\alpha_2)$	0,18	0,6/0,44
		$\sigma(K\alpha_{1,2})$	$4,05 \pm 0,13$	0,3/0,18
Fe	103,4	$\delta(K\alpha_1)$	0,09	0,7/0,34
		$\delta(K\alpha_2)$	0,13	0,7/0,34
		$\sigma(K\alpha_{1,2})$	$4,02 \pm 0,08$	1,1/0,60
	206,7	$\delta(K\alpha_1)$	0,1	1,2/0,70
		$\delta(K\alpha_2)$	0,15	1,2/0,70
		$\sigma(K\alpha_{1,2})$	$6,8 \pm 0,07$	0,3/0,16
	77,5	$\delta(K\alpha_1)$	0,07	0,6/0,32
		$\delta(K\alpha_2)$	0,1	0,6/0,32
		$\sigma(K\alpha_{1,2})$	$4,77 \pm 0,05$	0,3/0,16
Cu	103,4	$\delta(K\alpha_1)$	0,04	0,7/0,32
		$\delta(K\alpha_2)$	0,07	0,7/0,32
		$\sigma(K\alpha_{1,2})$	$3,60 \pm 0,05$	0,8/0,60
	206,7	$\delta(K\alpha_1)$	0,04	1,1/0,70
		$\delta(K\alpha_2)$	0,07	1,1/0,70
		$\sigma(K\alpha_{1,2})$	$5,15 \pm 0,13$	0,5/0,27
Cu	103,4	$\delta(K\alpha_1)$	0,10	0,6/0,22
		$\delta(K\alpha_2)$	0,21	0,6/0,22
		$\sigma(K\beta)$	$6,02 \pm 0,24$	0,5/0,27
Ni	103,4	$\delta(K\beta)$	0,13	0,6/0,22
		$\sigma(K\alpha_{1,2})$	$6,20 \pm 0,34$	0,5/0,27
Zn	103,4	$\delta(K\alpha_1)$	0,26	0,6/0,22
		$\delta(K\alpha_2)$	0,42	0,6/0,22
		$\sigma(K\alpha_{1,2})$	$21,1 \pm 0,8$	1,6/0,80
Mo	77,5	$\delta(K\alpha_1)$	0,6	1,6/0,80
		$\delta(K\alpha_2)$	2,0	1,6/0,80
		$\sigma(K\beta)$	$36,9 \pm 1,3$	1,6/0,80
Nb	77,5	$\delta(K\beta)$	1,3	1,6/0,80

High precision measurements with VOXES in LNF Lab



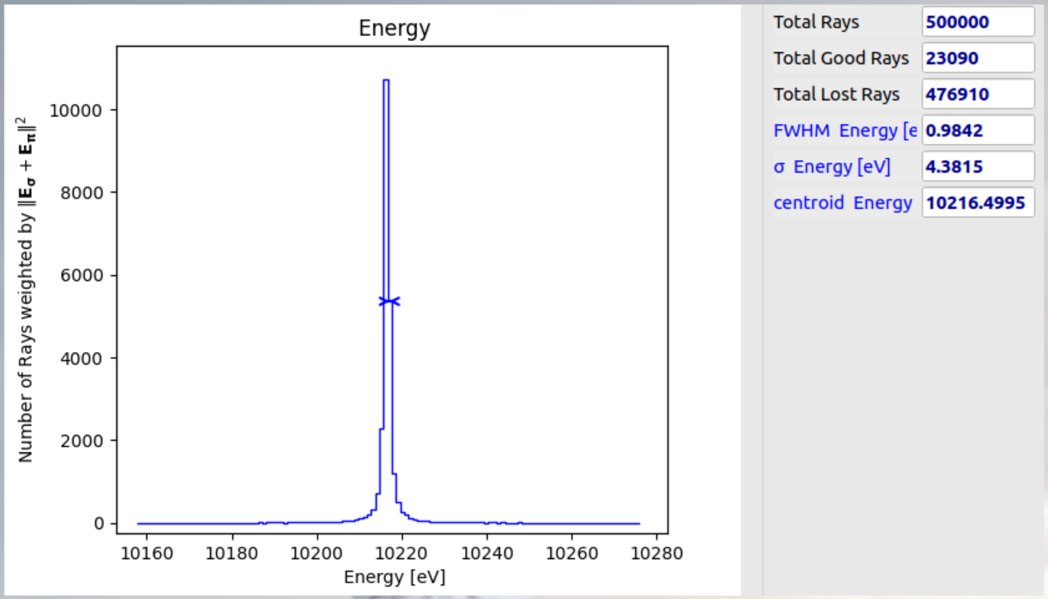


Possible feasibility test to be done in parallel with SIDDHARTA-2

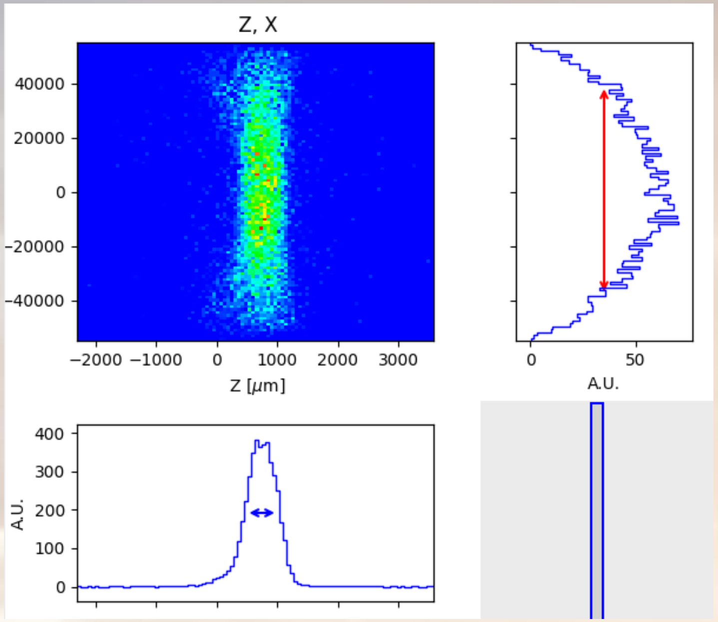
Main goal: assess background and on beam behaviour of crystals and strip detector

Example: KC (5→4) @ 10261.5 keV

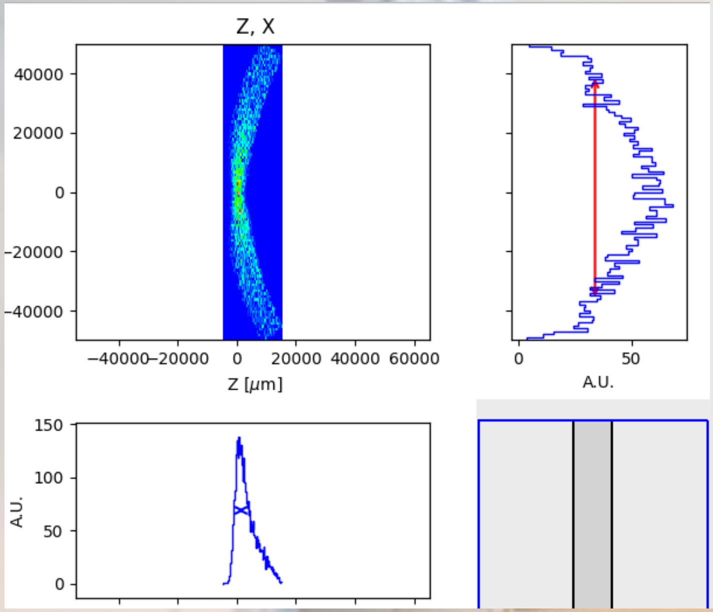
Input energy: 10216,5 eV, Γ = 1 eV



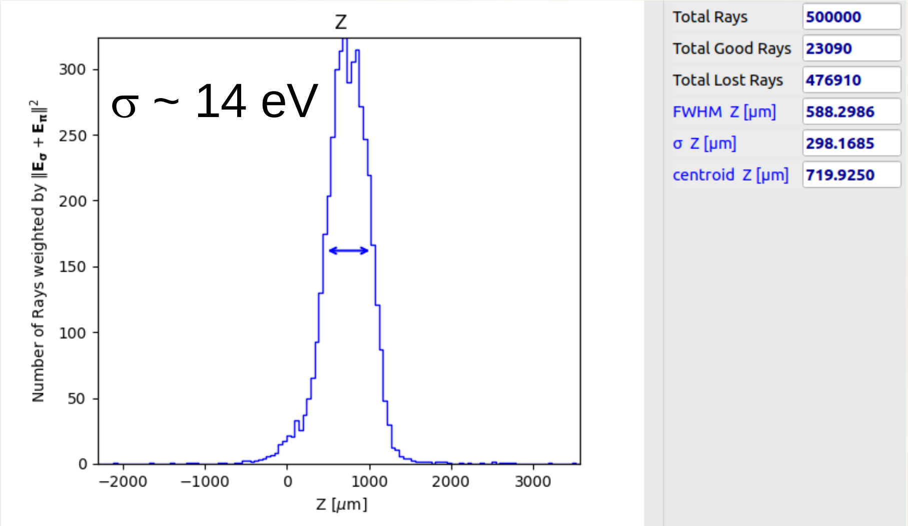
Hits on detector (2D)



Hits on detector (1D projection)



Theoretical inputs are very important for RT simulations and feasibility studies



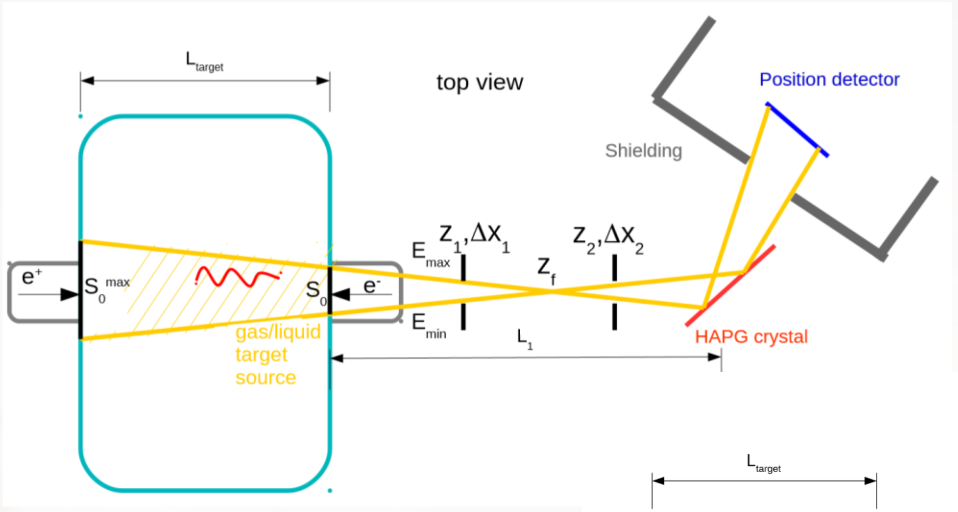
Hits on HAPG (2D)

VOXES: possible scenarios on DAΦNE (1)

Example of possible kaonic transitions to be measured with HAPG crystal spectrometer:

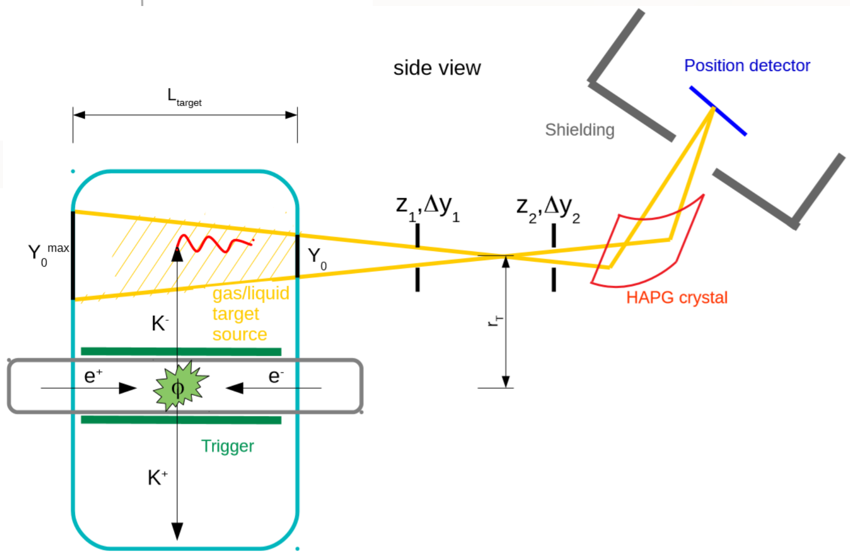
KN(6→5) : 7.6 keV
KN(7→5) : 12.1 keV
KN(8→5) : 15.1 keV
KN(7→6) : 4.6 keV
KN(8→6) : 7.5 keV
KN(9→6) : 9.6 keV
KN(10→6) : 11 keV
KN(11→6) : 12.1 keV
KN(10→7) : 6.5 keV
KN(11→7) : 7.5 keV
KN(12→7) : 8.3 keV

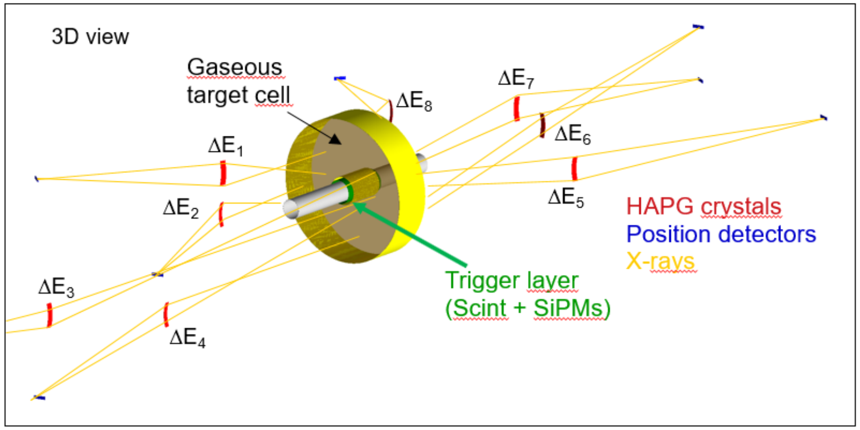
KO(5→4) : 18.3 keV
KO(7→5) : 15.9 keV
KO(6→5) : 9.9 keV
KO(8→6) : 9.9 keV
KO(7→6) : 6 keV
KO(9→7) : 6.6 keV



Pro : L_{target} ~ 100 mm

Con: K^- stopping is more difficult





VOXES: possible scenarios on DAΦNE (2)

Example of possible kaonic transitions to be measured with HAPG crystal spectrometer:

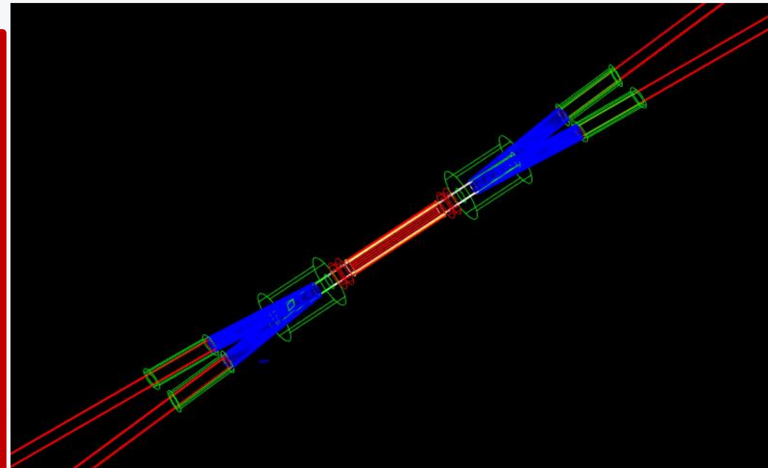
$K^6Li(3\rightarrow2)$: 15.1 keV
$K^6Li(5\rightarrow3)$: 7.7 keV
$K^6Li(4\rightarrow3)$: 5.3 keV

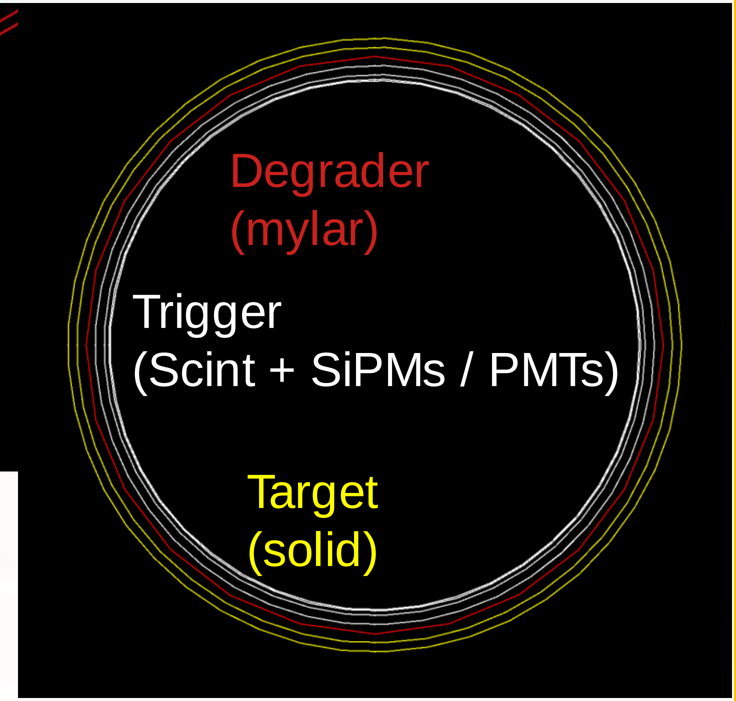
$K^7Li(3\rightarrow2)$: 15.3 keV
$K^7Li(5\rightarrow3)$: 7.8 keV
$K^7Li(4\rightarrow3)$: 5.3 keV

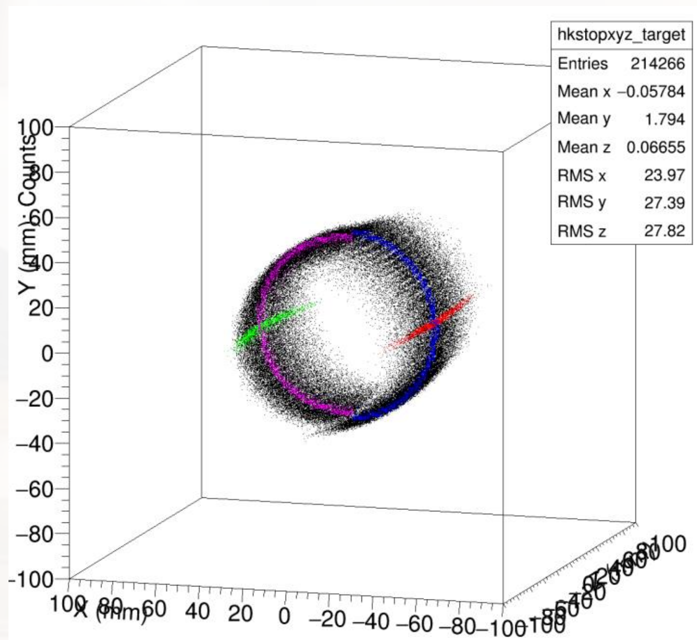
$K^8Be(5\rightarrow3)$: 14 keV
$K^8Be(4\rightarrow3)$: 9.6 keV
$K^8Be(6\rightarrow4)$: 6.8 keV
$K^8Be(5\rightarrow4)$: 4.4 keV

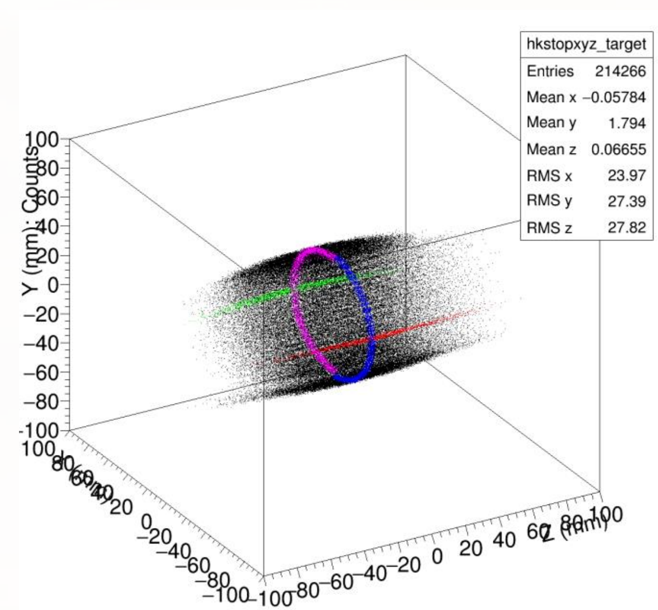
$K^9Be(5\rightarrow3)$: 14.1 keV
$K^9Be(4\rightarrow3)$: 9.6 keV
$K^9Be(6\rightarrow4)$: 6.9 keV
$K^9Be(5\rightarrow4)$: 4.4 keV

$KC(6\rightarrow4)$: 15.7 keV
$KC(5\rightarrow4)$: 10.2 keV
$KC(7\rightarrow5)$: 8.9 keV
$KC(6\rightarrow5)$: 5.5 keV
$KC(8\rightarrow6)$: 5.5 keV

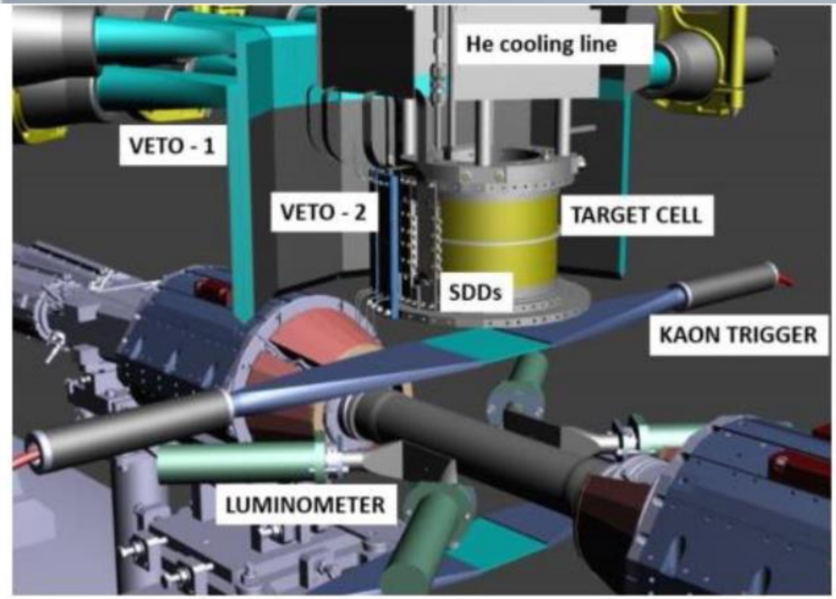








SDDs: present and future at DAΦNE



SIDDHARTA-2 is now running with 450 μm thick SDDs

Assumptions
signal: shift - 800 eV
width 750 eV
density: 5% (LHD)
detector area: 246 cm^2

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

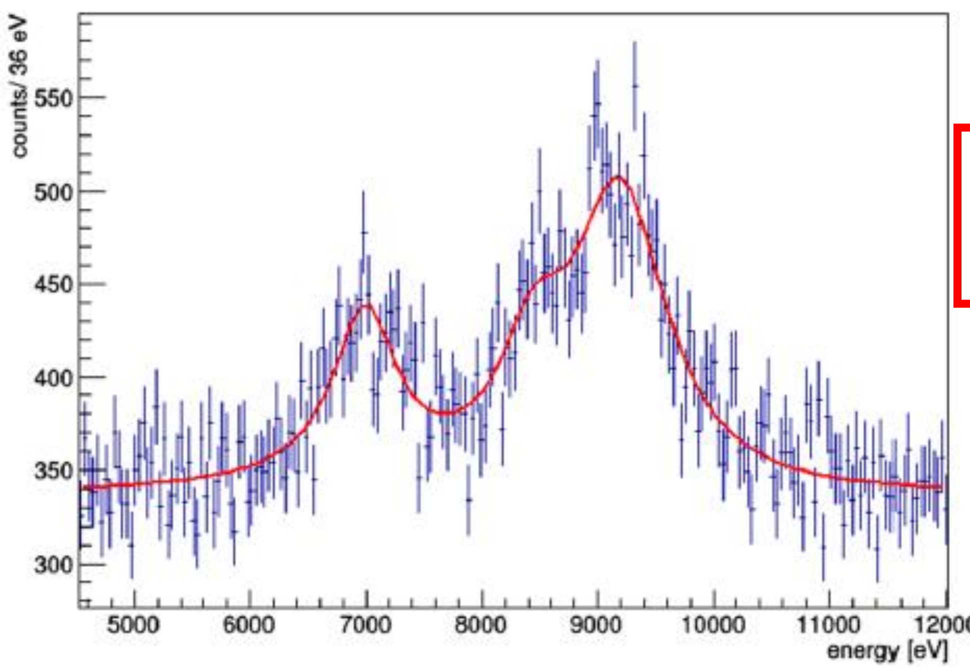


Figure 21: The simulated spectrum of K$^-$d for SIDDHARTA-2 for 800 pb^{-1} (the K$_\alpha$ line is at 7 keV, while from 8 to 10 keV there is the K-complex)

Expected:
$\Delta\varepsilon(1s)$ = 30 eV
$\Delta\Gamma(1s)$ = 70 eV

SDD: present and future at DAΦNE

Possible kaonic transitions to be measured with 1-2 mm SDDs:

$K^3He(2\to1)$: 33 keV
$K^4He(2\to1)$: 35 keV

$K^{6,7}Li(3\to2)$: 15 keV
$K^{6,7}Li(4\to2)$: 20 keV

$K^{8,9}Be(3\to2)$: 27 keV
$K^{8,9}Be(4\to2)$: 37 keV
$K^{8,9}Be(5\to3)$: 14 keV

$K^{9,10,11}B(4\to3)$: 15 keV
$K^{9,10,11}B(5\to3)$: 22 keV
$K^{9,10,11}B(6\to4)$: 11 keV

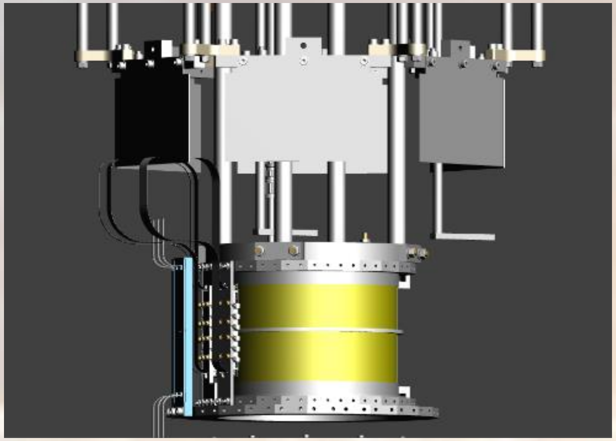
Feasibility:

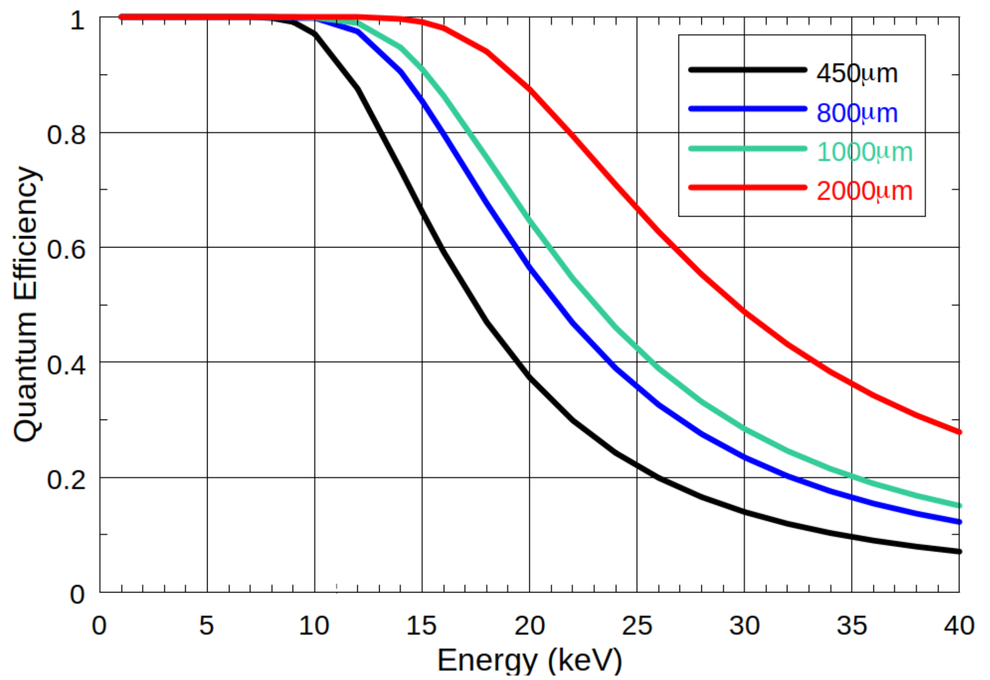
1-2 mm SDDs already financed by INFN CSN3

Electronics is similar to SIDDHARTA-2 SDDs

800µm and 1mm SDDs prototypes already produced by FBK for ARDESIA (INFN)

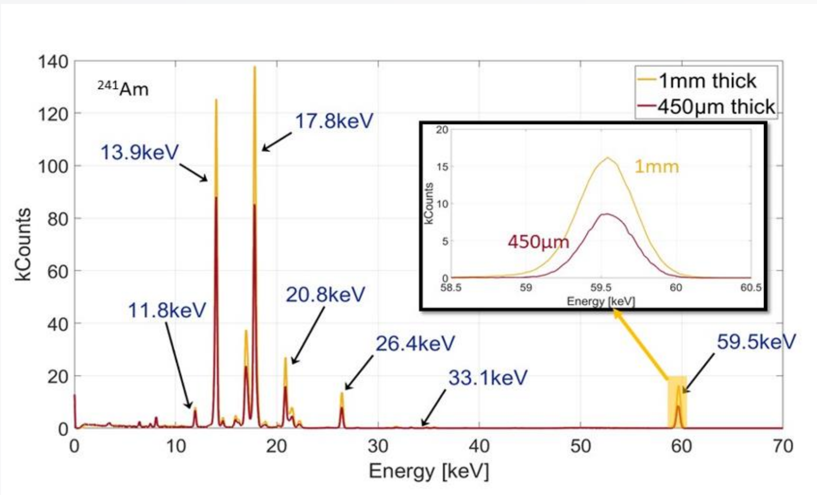
SIDDHARTA-2 – like setup with 1-2 mm thick SDDs





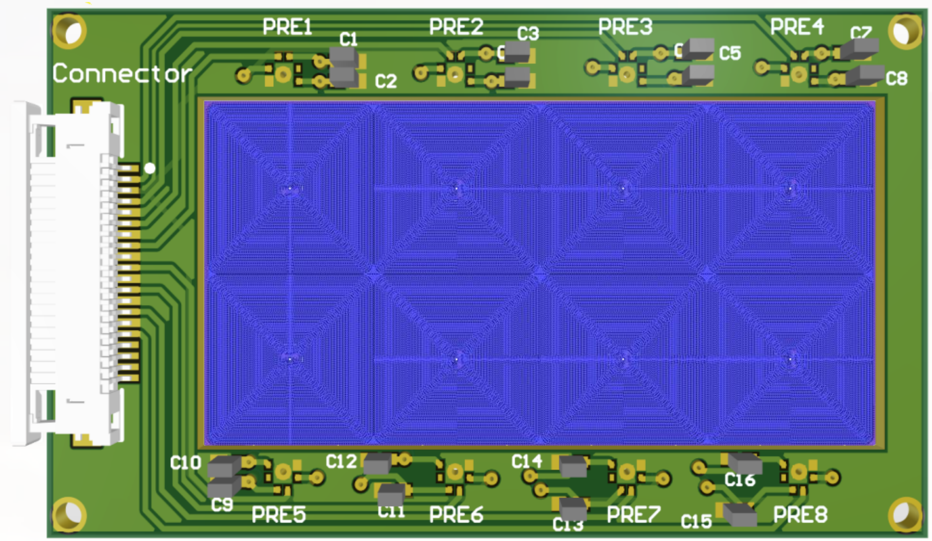
SDD: present and future at DAΦNE

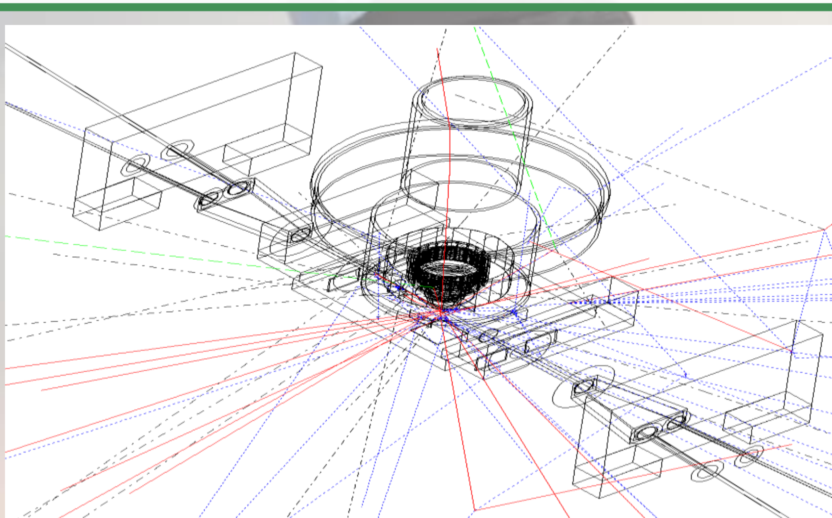
800μm and 1mm SDDs prototypes already produced by FBK for ARDESIA (INFN)



First XRF tests with known targets show very promising results

Prototypes of electronics boards are already available





Future implementations:

- Targets : ^{3,4}He, ^{6,7}Li, ^{8,9}Be, ^{9,10,11}B
- SIDDHARTA-2 like setup
- Optimised shielding according to feasibility test
- MC implementation (already started) with real DAΦNE conditions

CZT: proposal for new measurements at DAΦNE

Detector Key Points:

- High efficiency in the 20-100 keV region
- Reasonable efficiencies up to 300 keV
- Good resolution (FHWM/E ~ %)
- Fast response and time resolution (< 50 ns)

Precisions < 10 eV (ε) and <20 eV (Γ) are reachable in few months

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
$K^{32}S$	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

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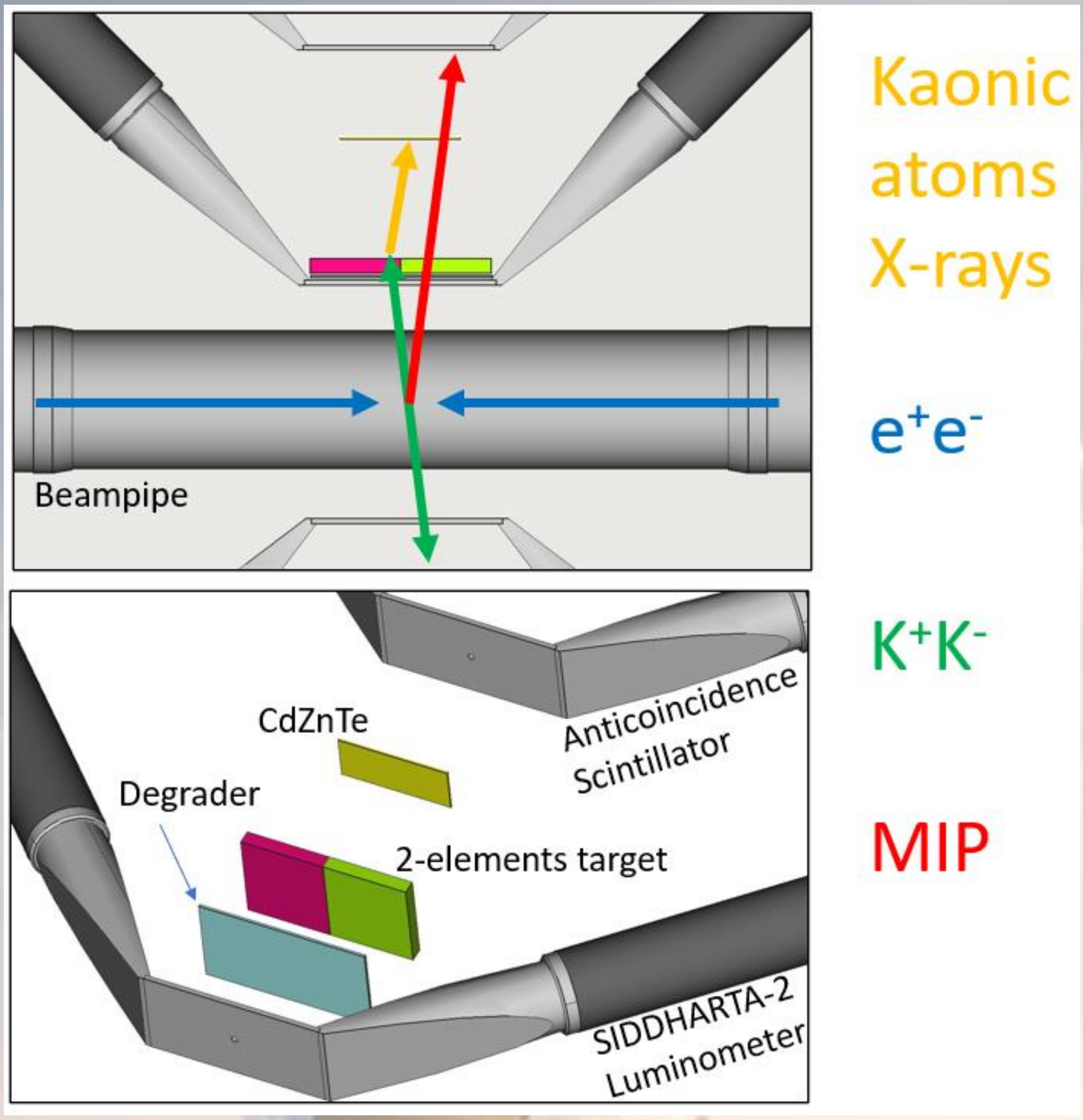
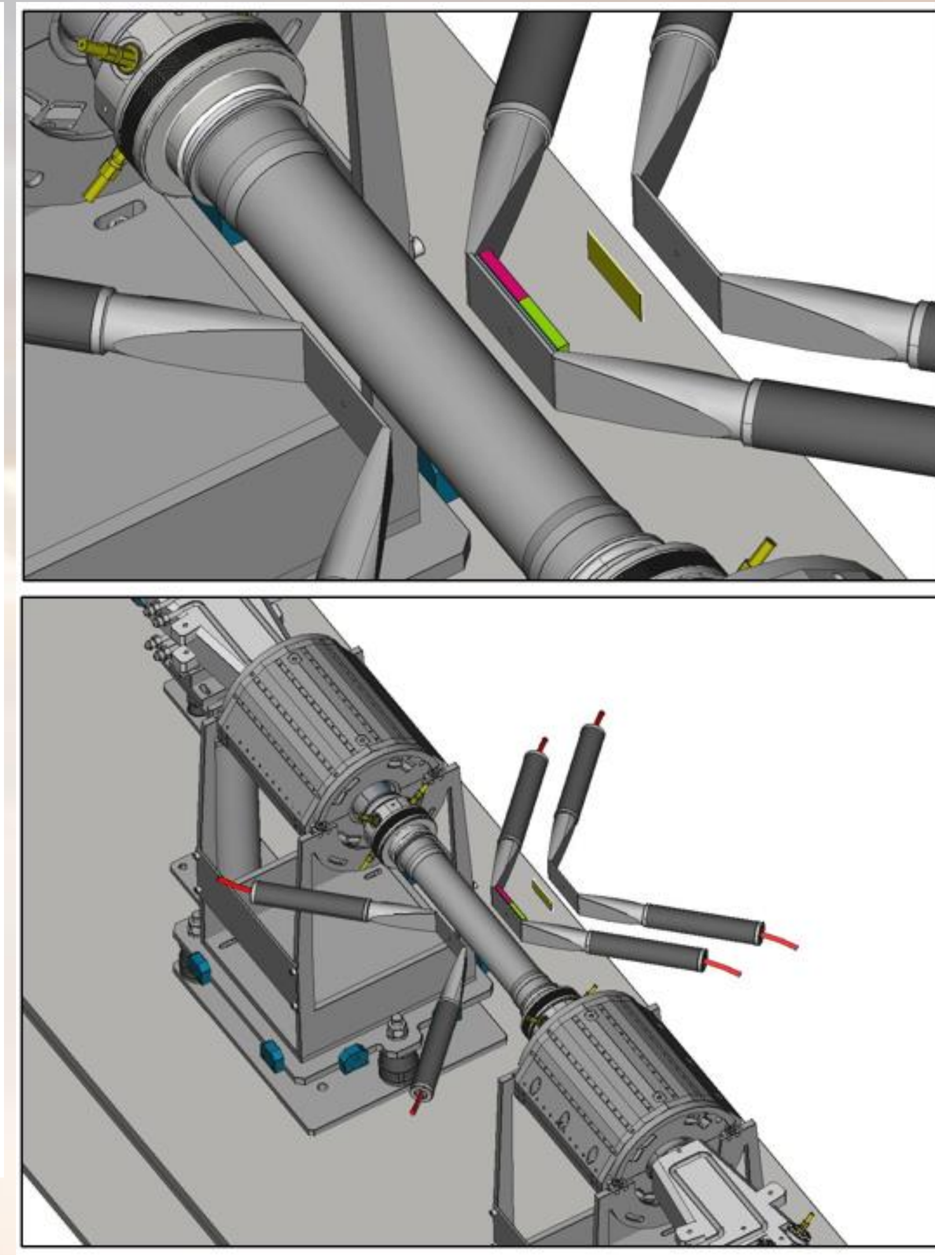
Table 1
Compilation of K^- atomic data

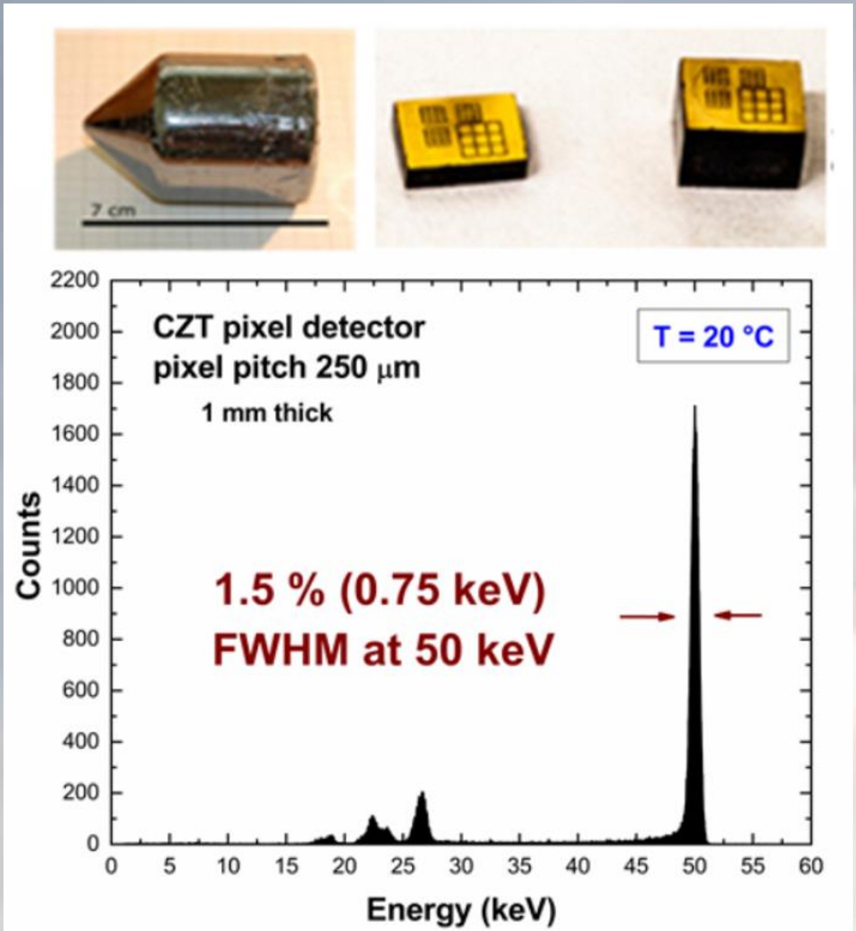
Nucleus	Transition	ϵ (keV)	Γ (keV)	Y	Γ_u (eV)
He	$3 \to 2$	-0.04 ± 0.03	–	–	–
		-0.035 ± 0.012	0.03 ± 0.03	–	–
Li	$3 \to 2$	0.002 ± 0.026	0.055 ± 0.029	0.95 ± 0.30	–
Be	$3 \to 2$	-0.079 ± 0.021	0.172 ± 0.58	0.25 ± 0.09	0.04 ± 0.02
^{10}B	$3 \to 2$	-0.208 ± 0.035	0.810 ± 0.100	–	–
^{11}B	$3 \to 2$	-0.167 ± 0.035	0.700 ± 0.080	–	–
C	$3 \to 2$	-0.590 ± 0.080	1.730 ± 0.150	0.07 ± 0.013	0.99 ± 0.20
O	$4 \to 3$	-0.025 ± 0.018	0.017 ± 0.014	–	–
Mg	$4 \to 3$	-0.027 ± 0.015	0.214 ± 0.015	0.78 ± 0.06	0.08 ± 0.03
Al	$4 \to 3$	-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	$4 \to 3$	-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	$4 \to 3$	-0.330 ± 0.08	1.440 ± 0.120	0.26 ± 0.03	1.89 ± 0.30
S	$4 \to 3$	-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

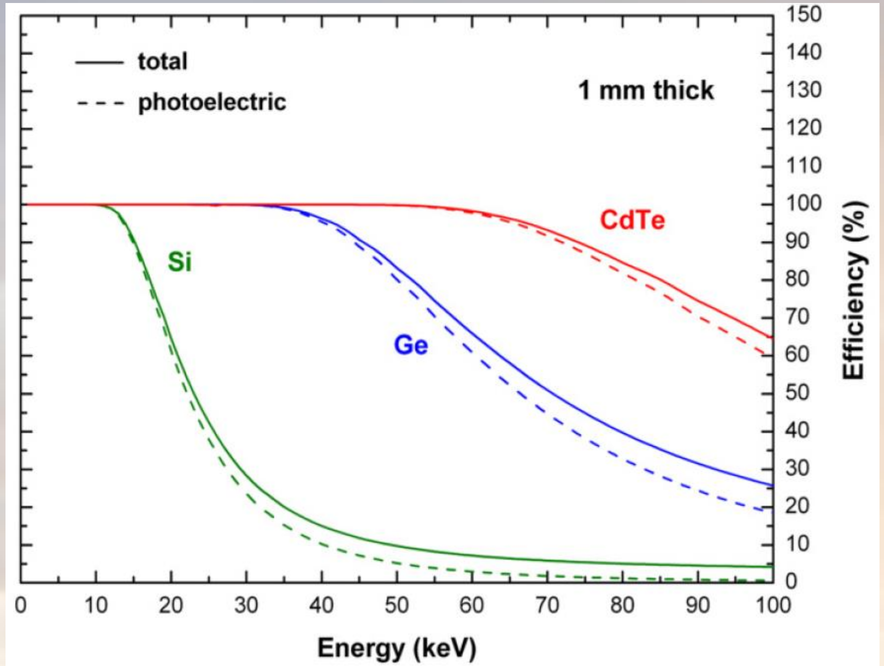
CZT: proposal for new measurements at DAΦNE

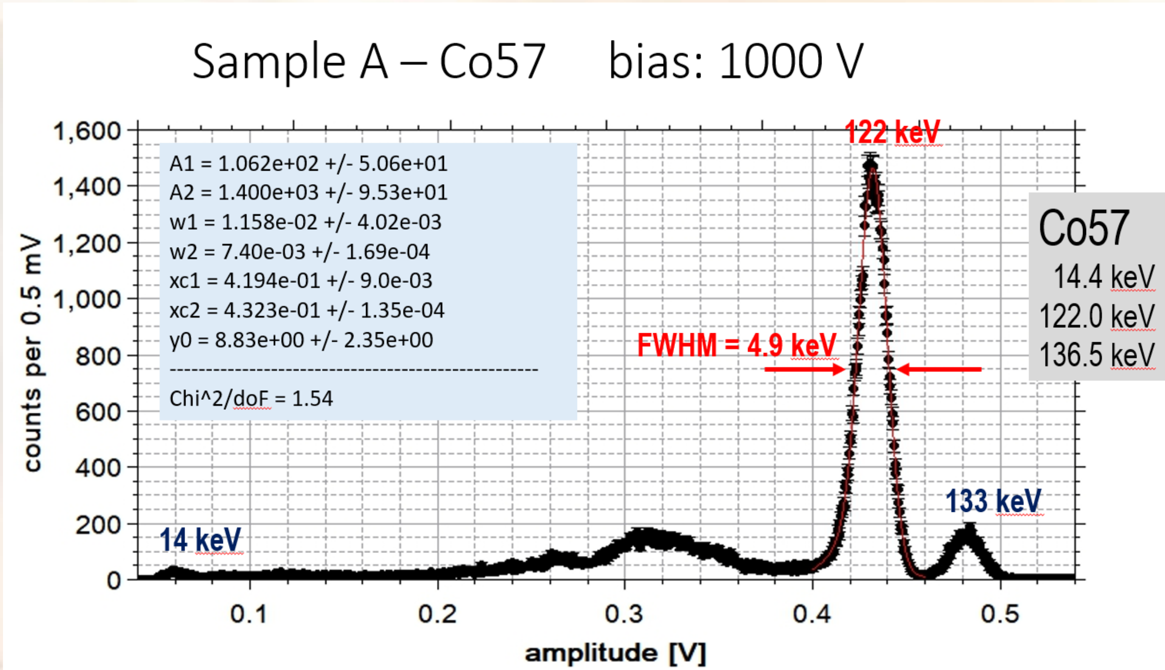




CZT: proposal for new measurements at DAΦNE







First prototypes of Cd(Zn)Te delivered by JRA8-ASTRA (STRONG-2020) and tested

Very good (and improvable) resolutions obtained

Advanced techniques for deconvolution of the detector's lineshape (IMEM-CNR, UniPa)

CONCLUSIONS

- Kaonic atoms measurements are still strongly demanded in the nuclear physics (and not only) community
- DAΦNE is a unique facility in the world to perform such kind of measurements
- There is a plethora of fundamental kaonic atoms transition lines to be measured, with different detectors and techniques
- Many measurements and tests can be carried on in parallel with SIDDHARTA-2
- New experiments with new setups can be proposed (some already have)
- Joint efforts between thereticians (ask, calculate, support, approve, endorse) and experimentalists (build strong teams and improve know-how) is crucial