

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

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# Why (again and still) kaonic atoms?

Except for the most recent measurements at DAΦNE and JPARC on KHe and KH, the whole knowledge on kaonic atoms dates back to 1970s and 1980s

These data are the experimental basis for all the developed 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

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

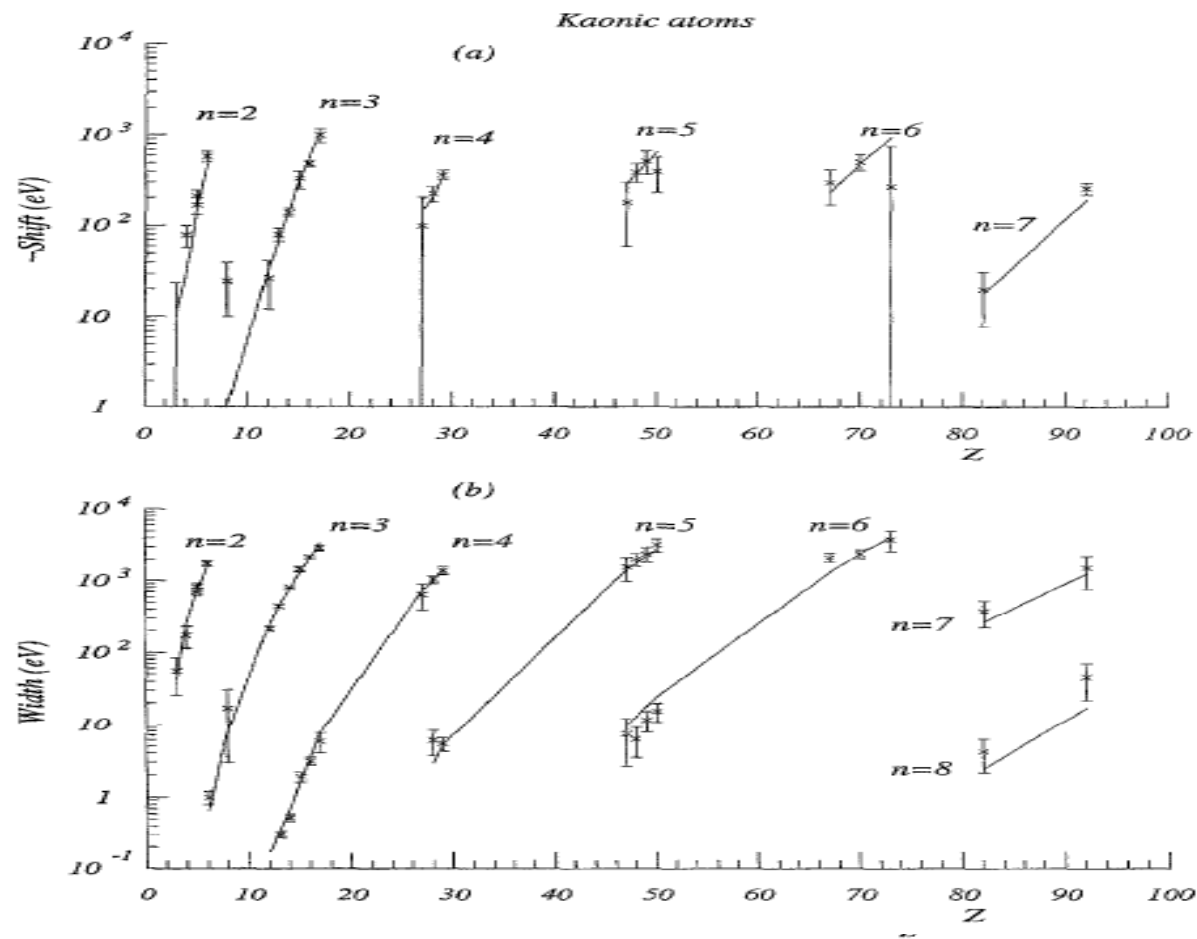


Fig. 7. Shift and width values for kaonic atoms. The continuous lines join points calculated with the best-fit optical potential discussed in Section 4.2.

# Why (again and still) kaonic atoms?

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

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1. The available data on “lower levels” have big uncertainties
2. Many of them are actually UNmeasured
3. Many of them are hardly compatible among each other
4. Relative yields with upper levels are not always measured
5. Absolute yields are basically unknown (except for few transitions)
6. The REmeasured ones have been proved WRONG

This situation would already be a  
**proper justification for new  
measurements**

Table 1  
Compilation of  $K^-$  atomic data

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



# Transitions: energies and widths...which detector?

Crystal spectrometers:

- High resolution
- Low efficiency
- 0-20 keV range

SDDs

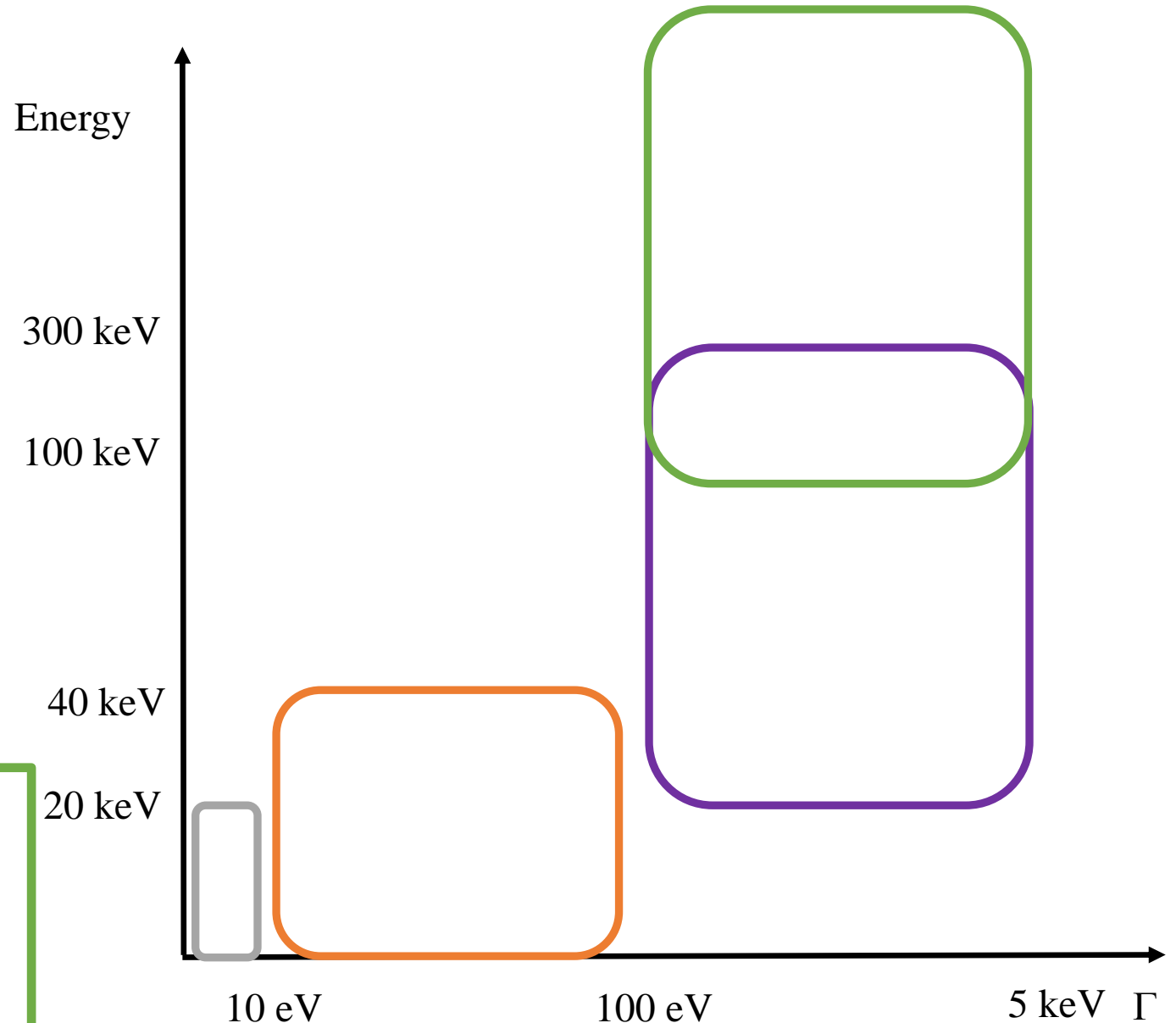
- 100 eV max resolution
- 4-40 keV range
- High efficiency

Cd(Zn)Te

- 20-300 keV range
- $\text{FWHM} / E \sim \%$
- High efficiency
- Room Temperature

HPGe

- 100-1000 keV range
- $\text{FWHM} / E \sim \%$
- High efficiency
- Cooling needed

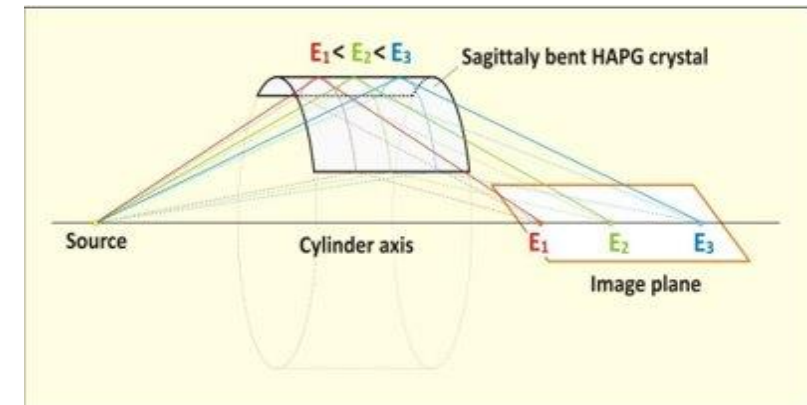
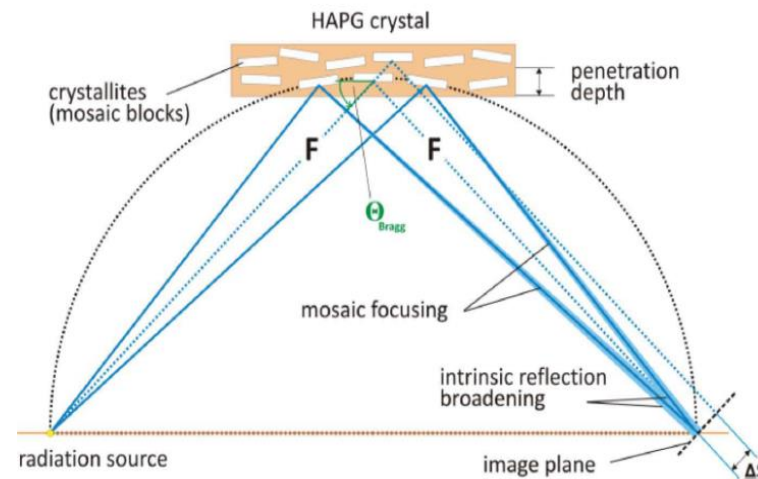
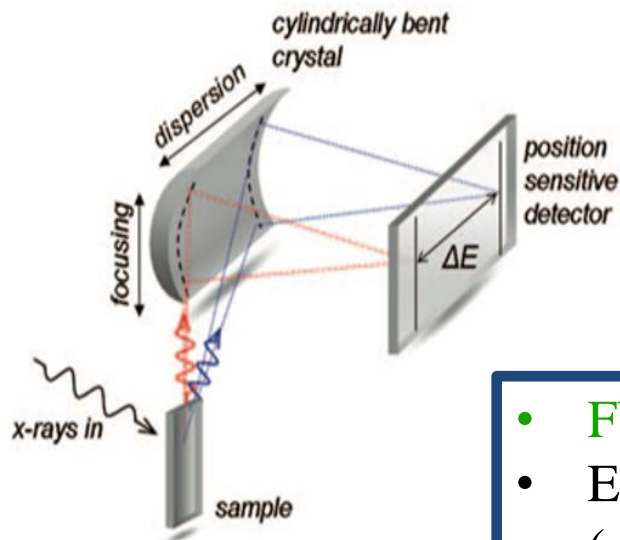
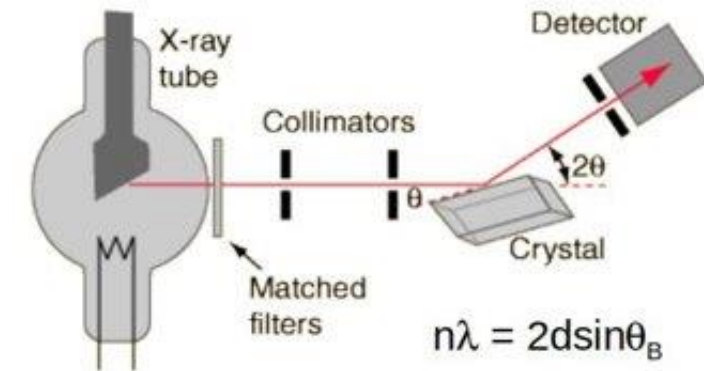


# Crystal spectrometers: VOXES

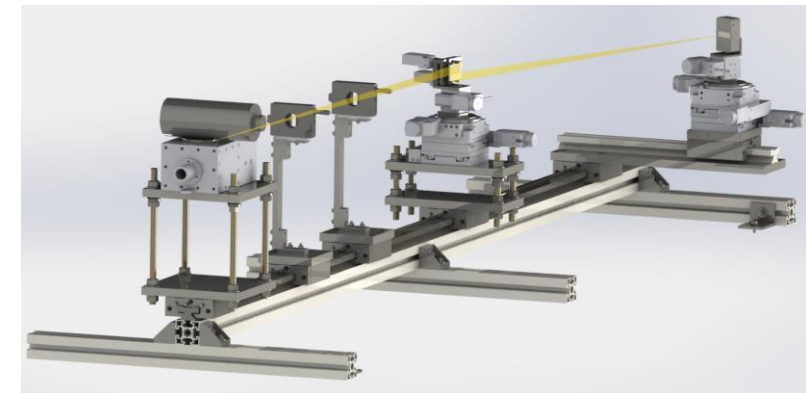
Photons of different energies are reflected in different positions

With a crystal and a position detector, energy spectra with ultra-high resolution can be obtained

For monochromatic sources, also directionality could be tested

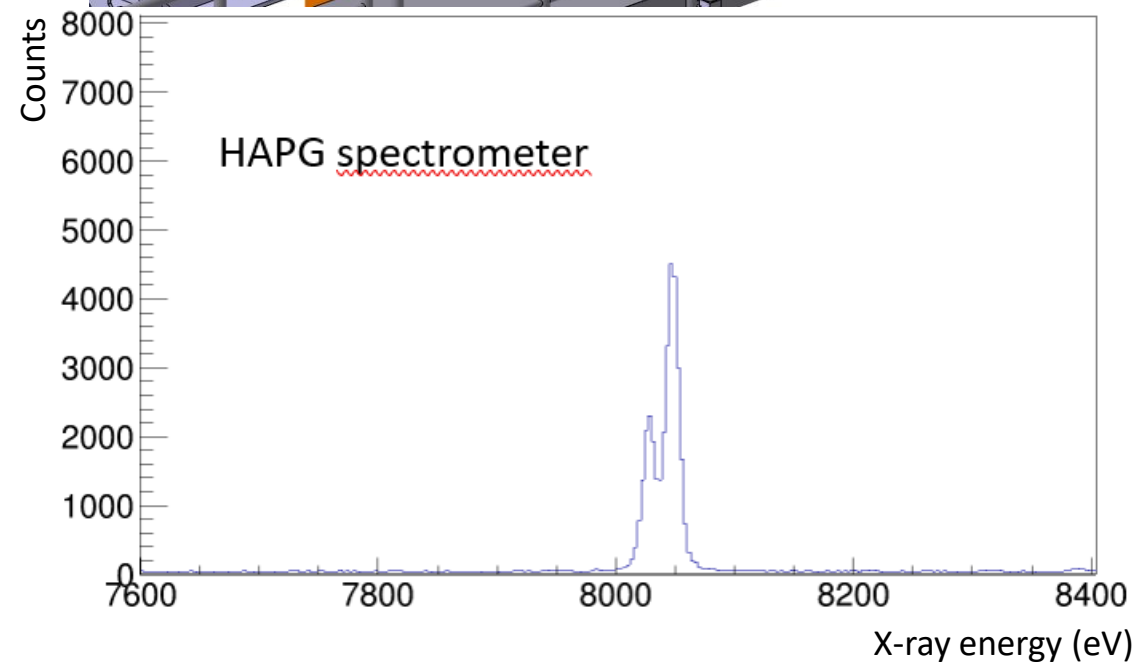
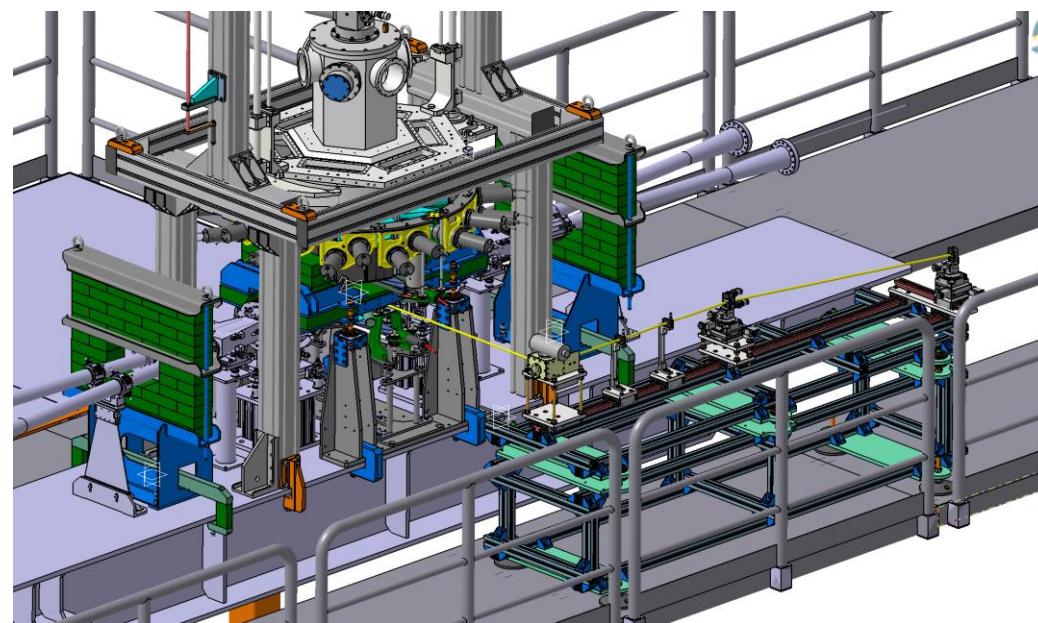
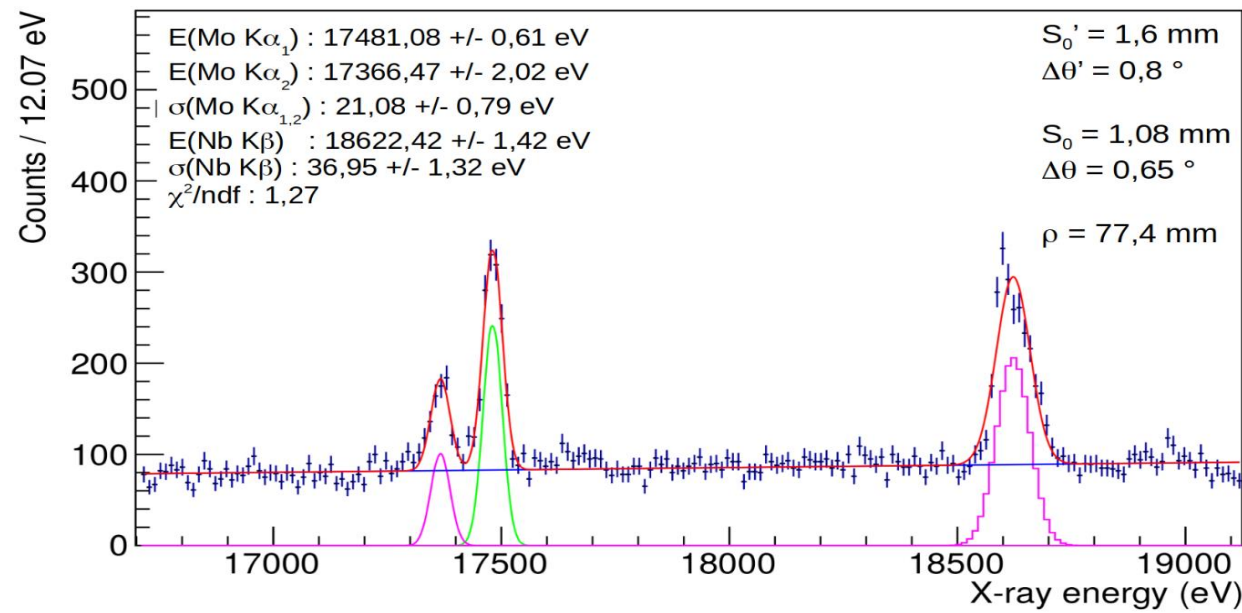
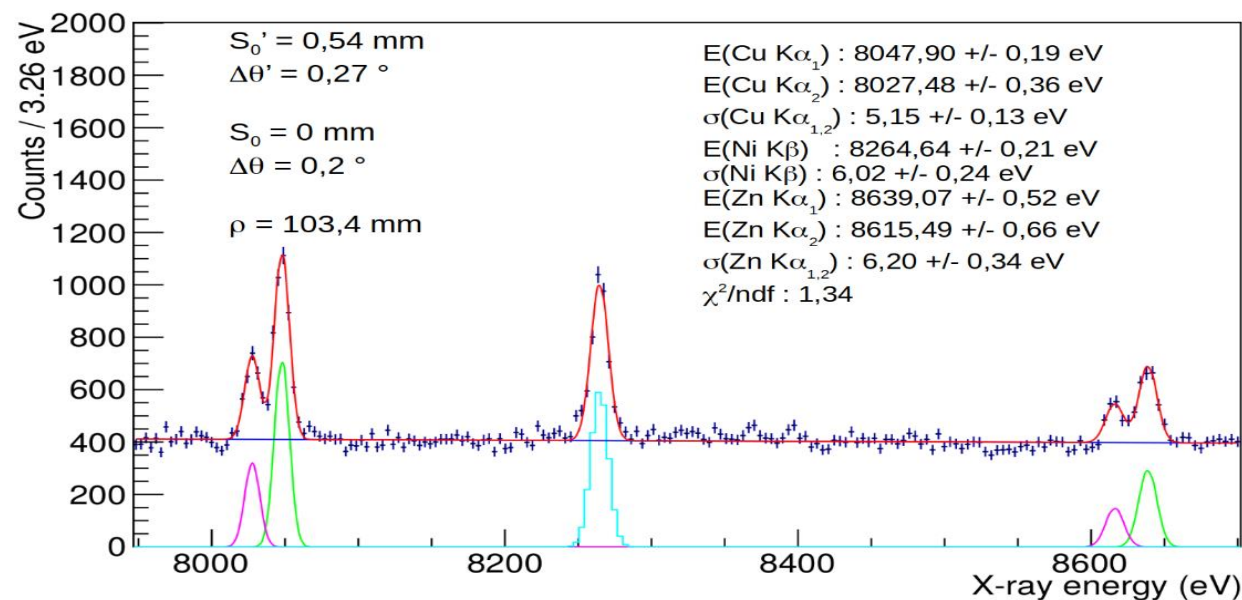


- FWHM of few eV with NO COOLING
- Energy range between 1-20 keV (n=1, depending on the crystal)
- Extremely low efficiencies (solid angle)



# Crystal spectrometers: VOXES

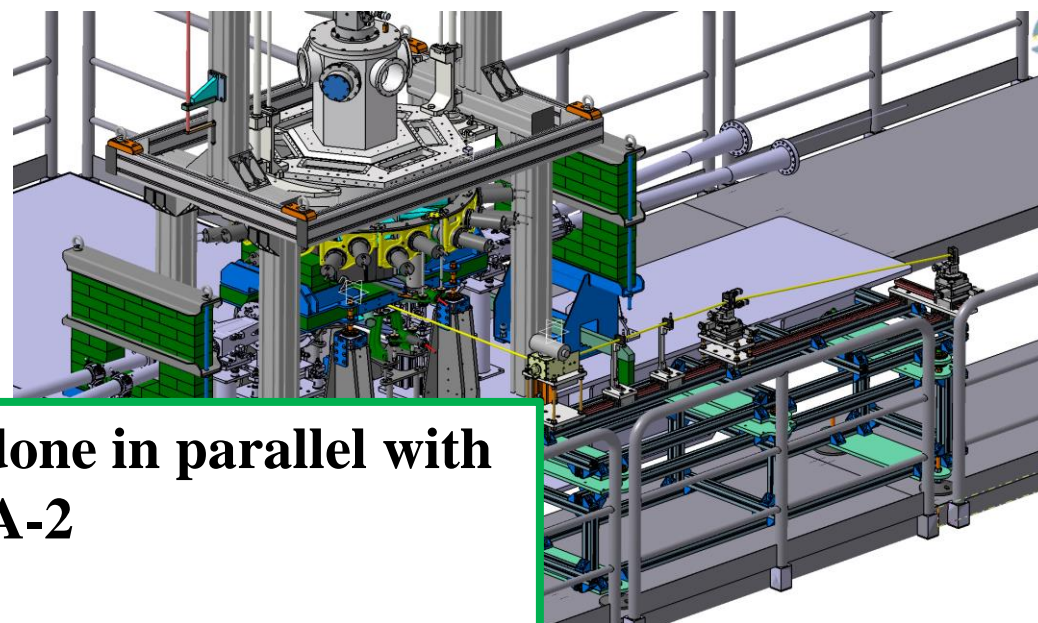
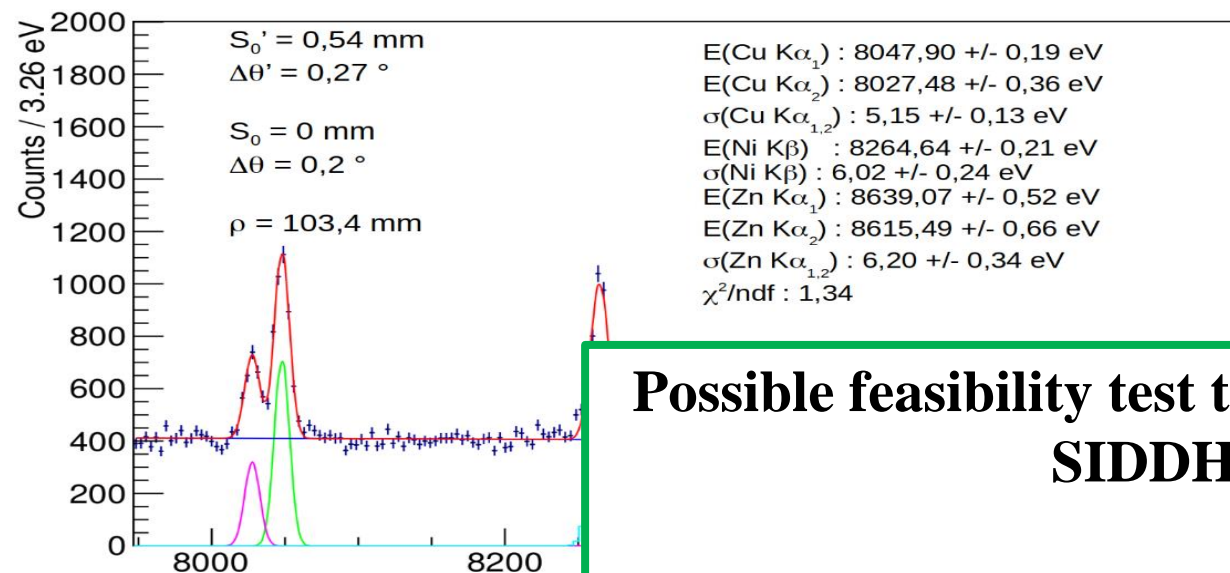
High precision measurements with VOXES in LNF Lab





# Crystal spectrometers: VOXES

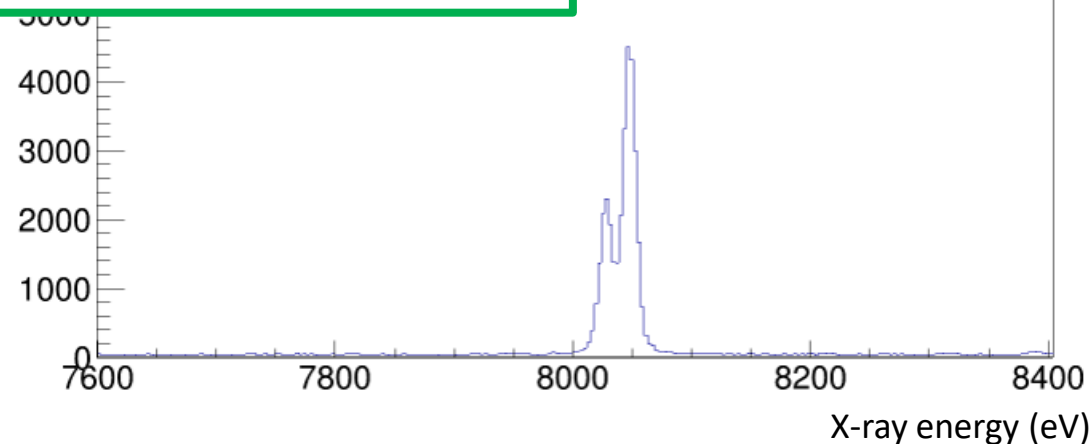
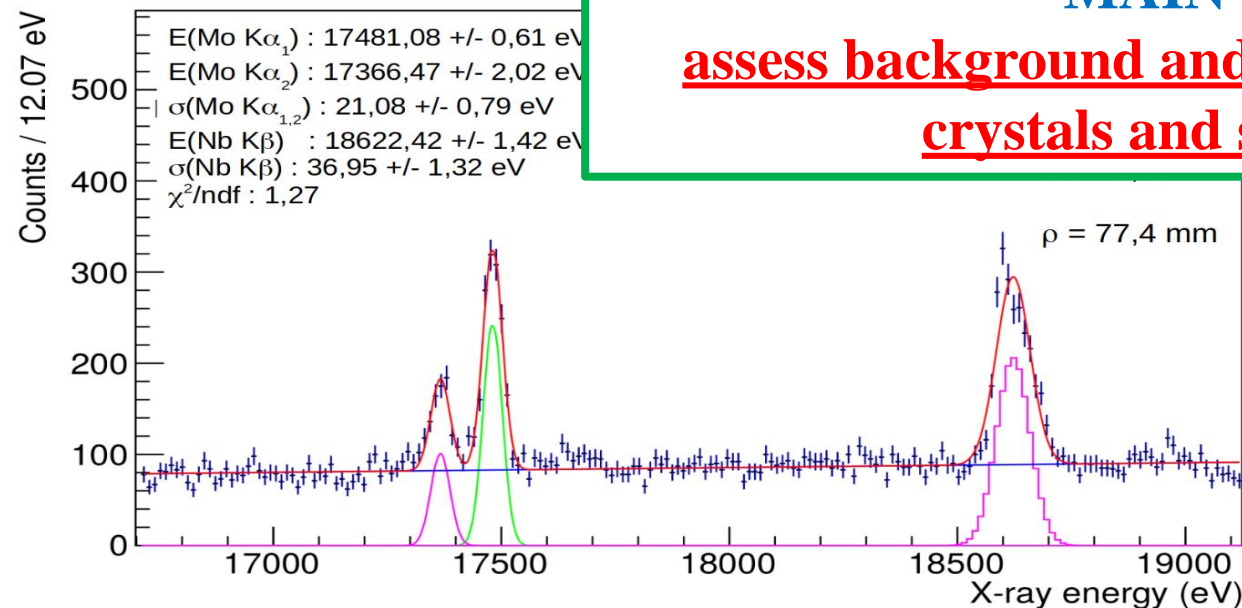
High precision measurements with VOXES in LNF Lab



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

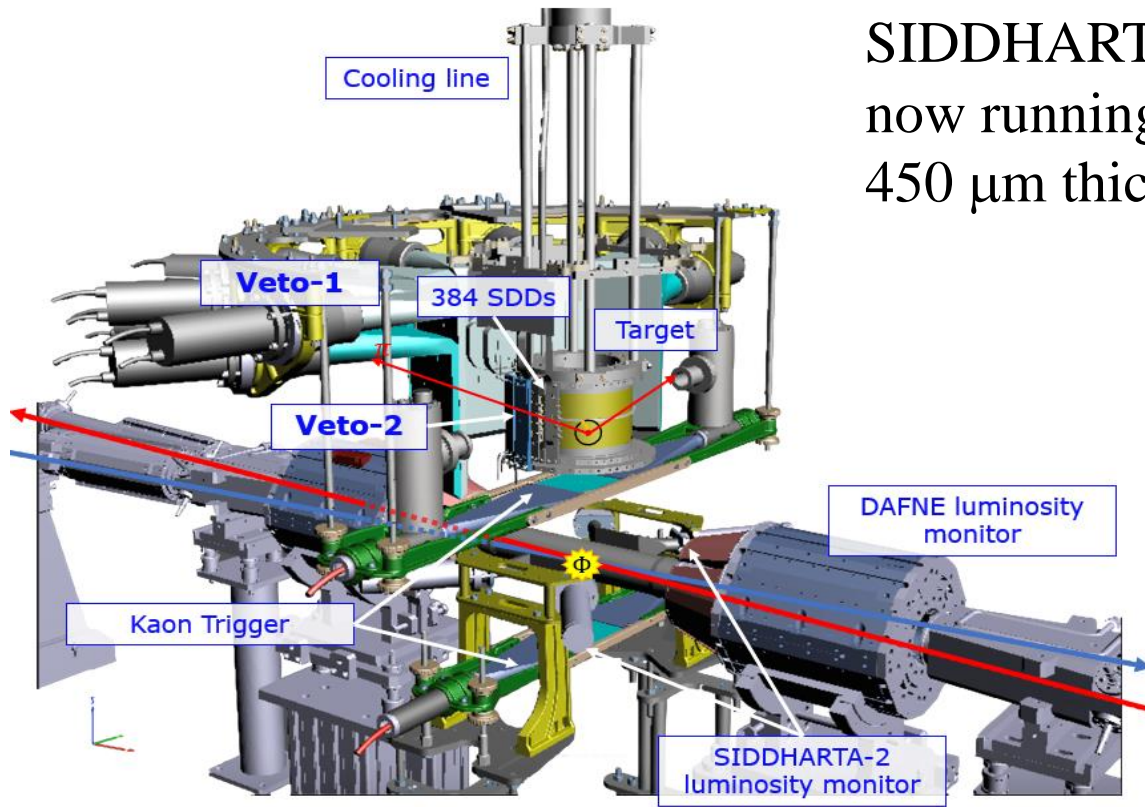
**MAIN GOAL:**

assess background and on beam behaviour of  
crystals and strip detector



# SDDs: present and future at DAFNE

## SIDHARTA-2 SETUP



SIDDHARTA-2 is  
now running with  
450  $\mu\text{m}$  thick SDDs



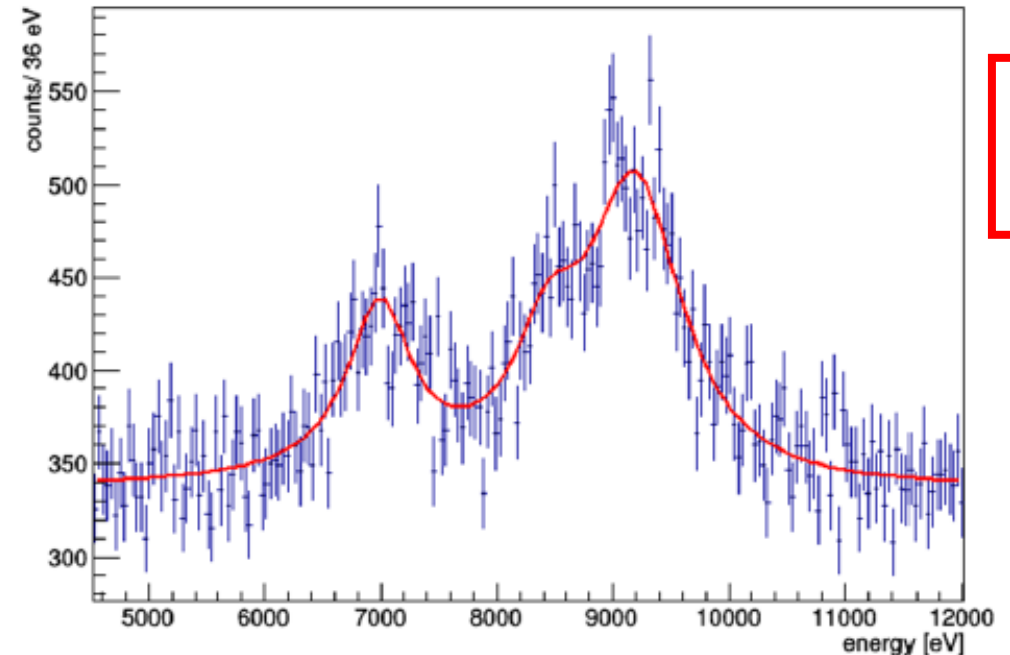
### Assumptions

**signal:** shift - 800 eV  
width 750 eV

**density:** 5% (LHD)  
**detector area:** 246  $\text{cm}^2$

**$K\alpha$  yield:** 0.1 %  
**yield ratio as in  $K^-p$**

Previous talk F. Sgaramella



Expected:  
 $\Delta\epsilon(1s) = 30 \text{ eV}$   
 $\Delta\Gamma(1s) = 70 \text{ eV}$

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

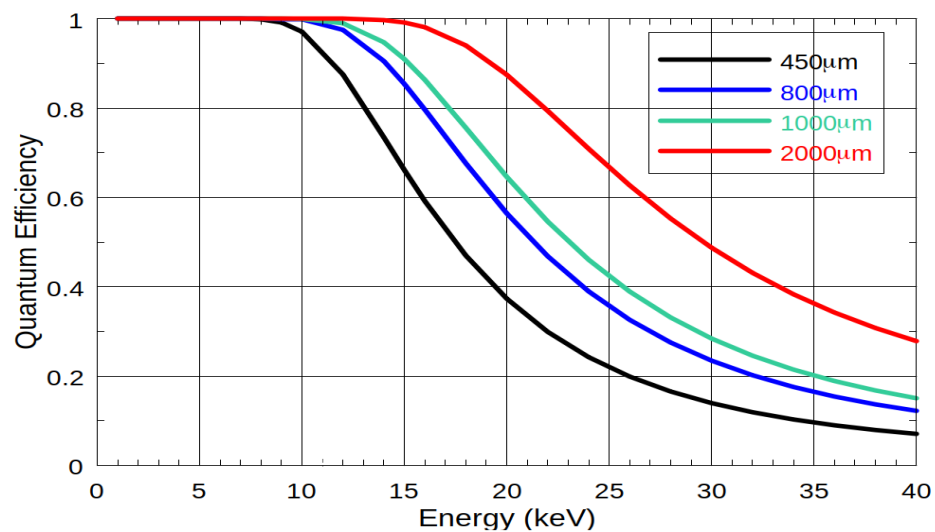


# SDD: present and future at DAΦNE

Kaonic Helium transitions on 1s level would be accessible (very difficult):

$K^3\text{He}(2 \rightarrow 1)$  : 33 keV

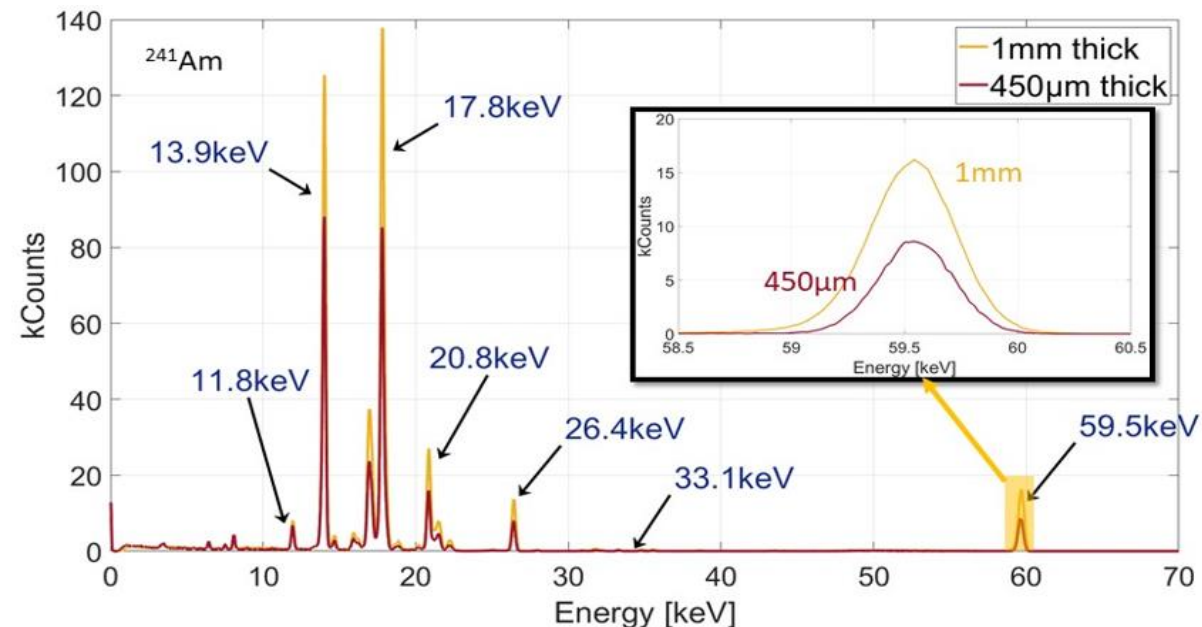
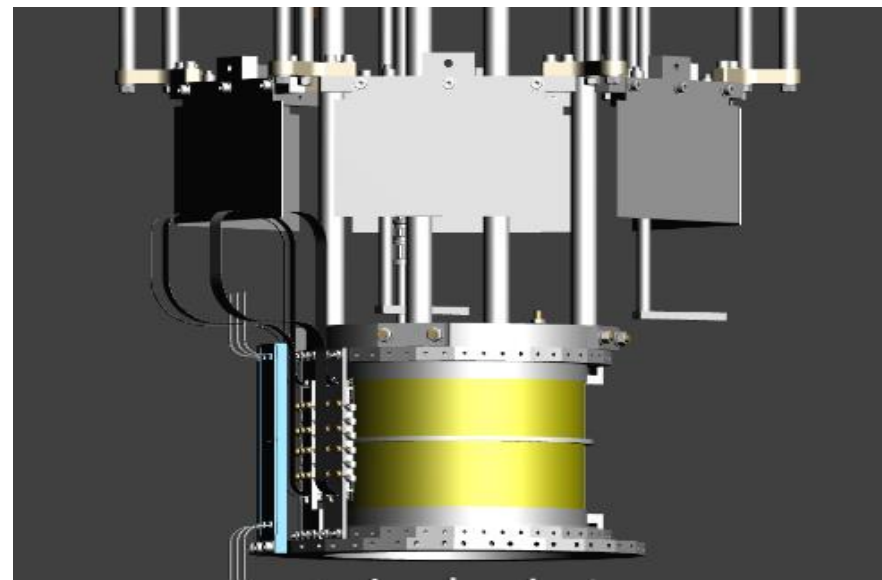
$K^4\text{He}(2 \rightarrow 1)$  : 35 keV



## Feasibility:

- 1-2 mm SDDs already financed by INFN CSN3
- Electronics is similar to SIDDHARTA-2 SDDs
- 800 μm and 1mm SDDs prototypes already produced by FBK for ARDESIA (INFN)

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

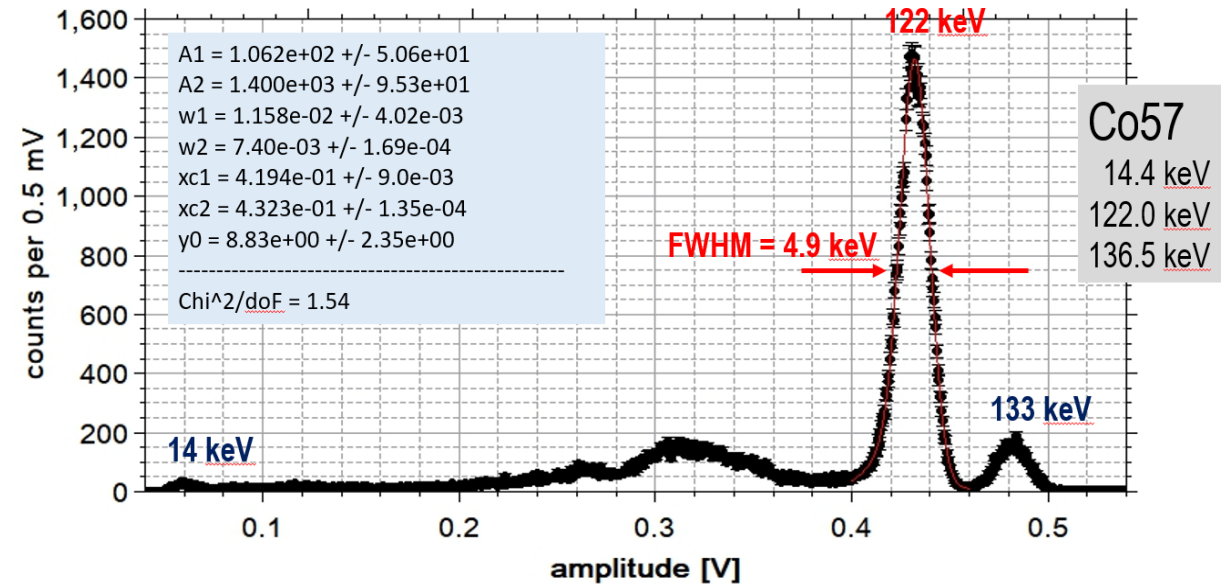


# CZT: proposal for new measurements at DAΦNE

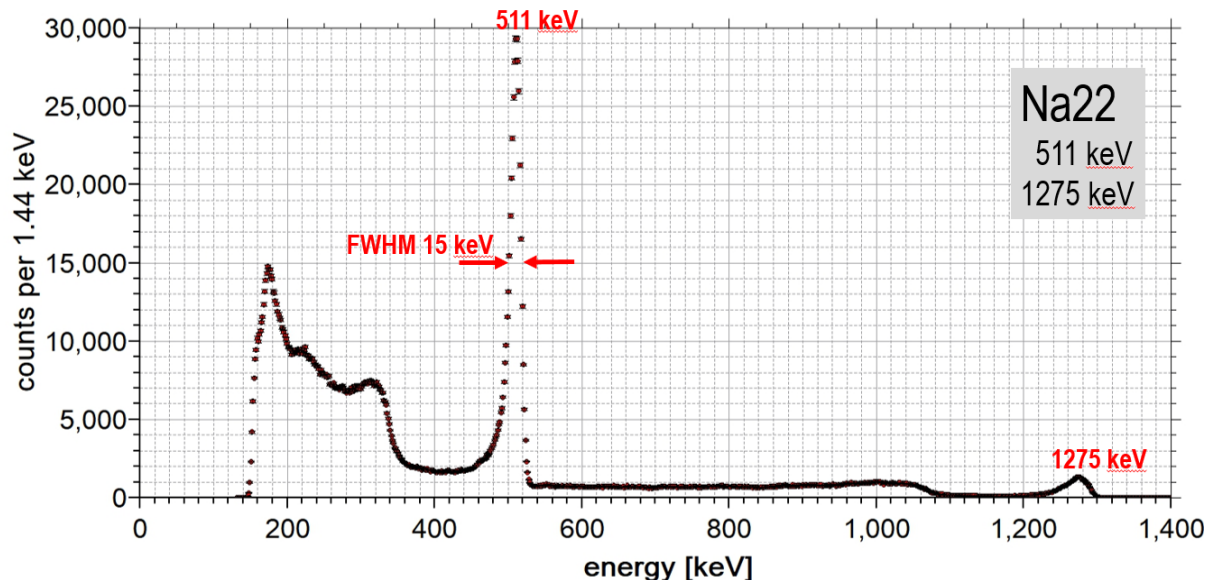
## Detector Key Points:

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

Sample A – Co57 bias: 1000 V



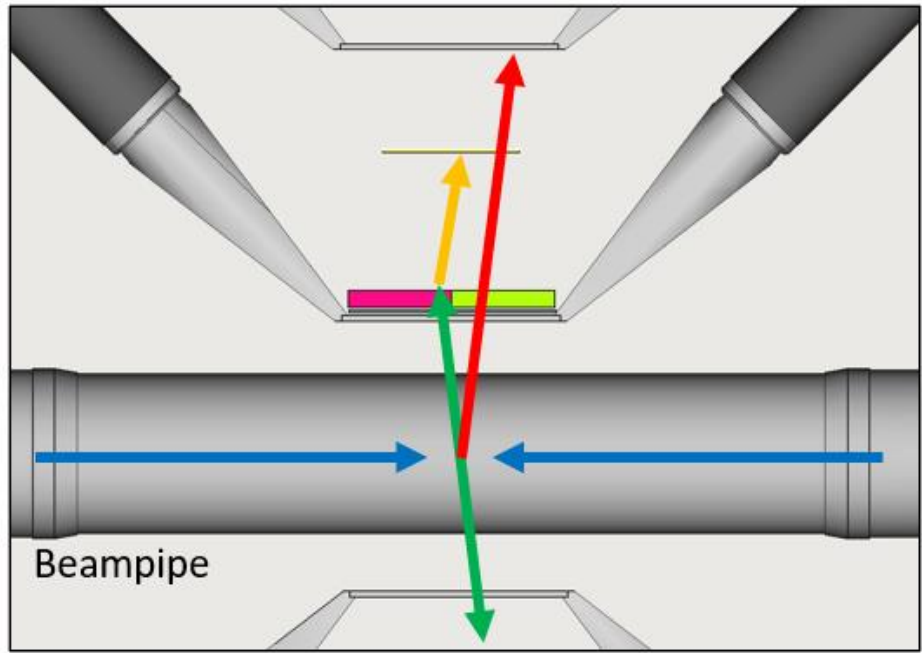
CZT-500 – Na22 bias: 600 V



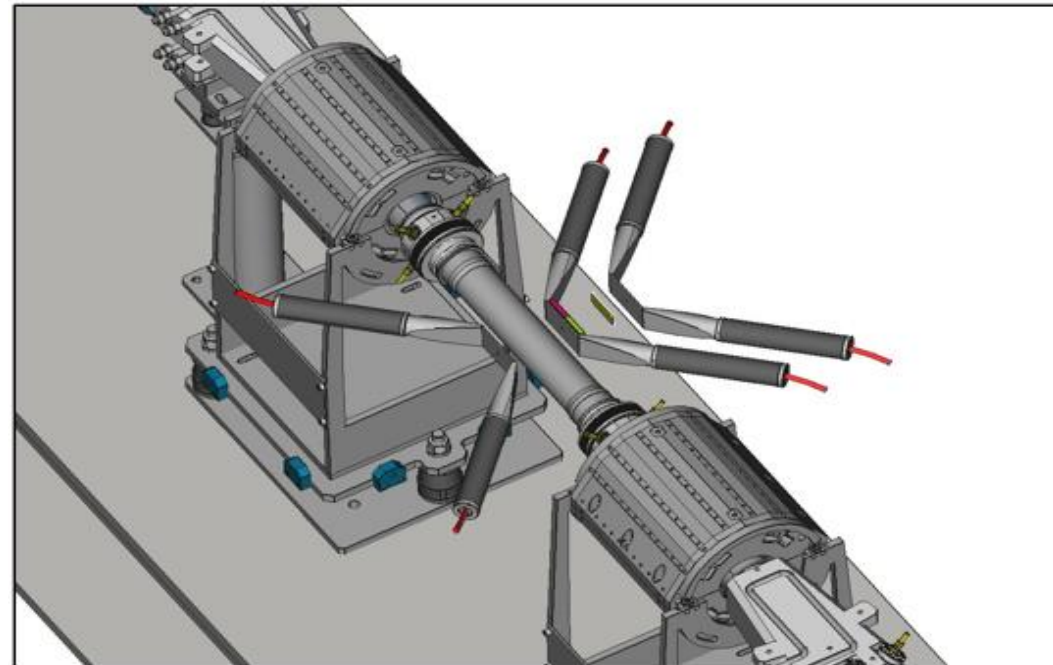
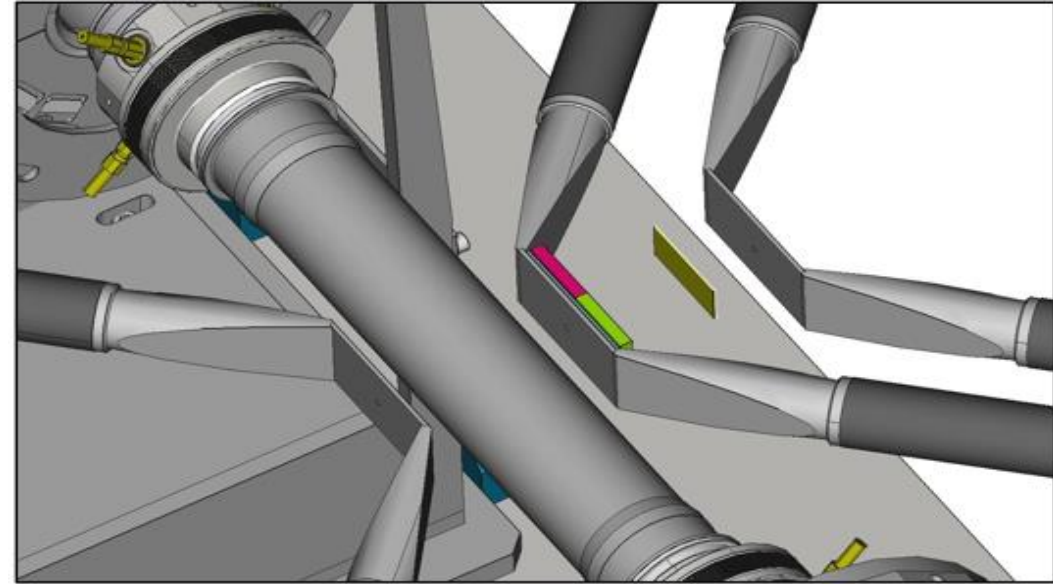
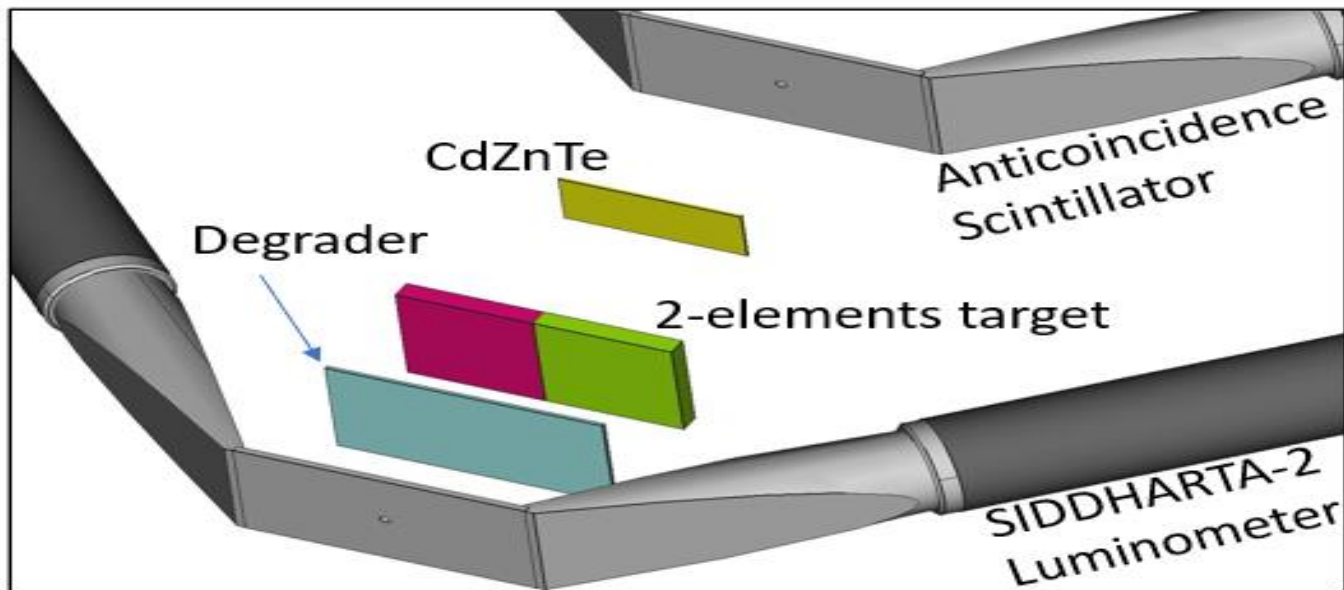
Precisions < 10 eV ( $\epsilon$ ) and < 20 eV ( $\Gamma$ ) are reachable in few months

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

# CZT: proposal for new measurements at DAΦNE



- Kaonic atoms
- X-rays
- $e^+e^-$
- $K^+K^-$
- MIP





# New Kaon Mass measurement with HPGe

The main disagreement is between the two most recent and precise measurements (x-ray energies from kaonic atoms):

$$m_K = 493.696 \pm 0.007 \text{ MeV}$$

A.S. Denisov et al. JEPT Lett. 54 (1991)558

$K^-^{12}\text{C}$ , crystal diffraction spectrometer

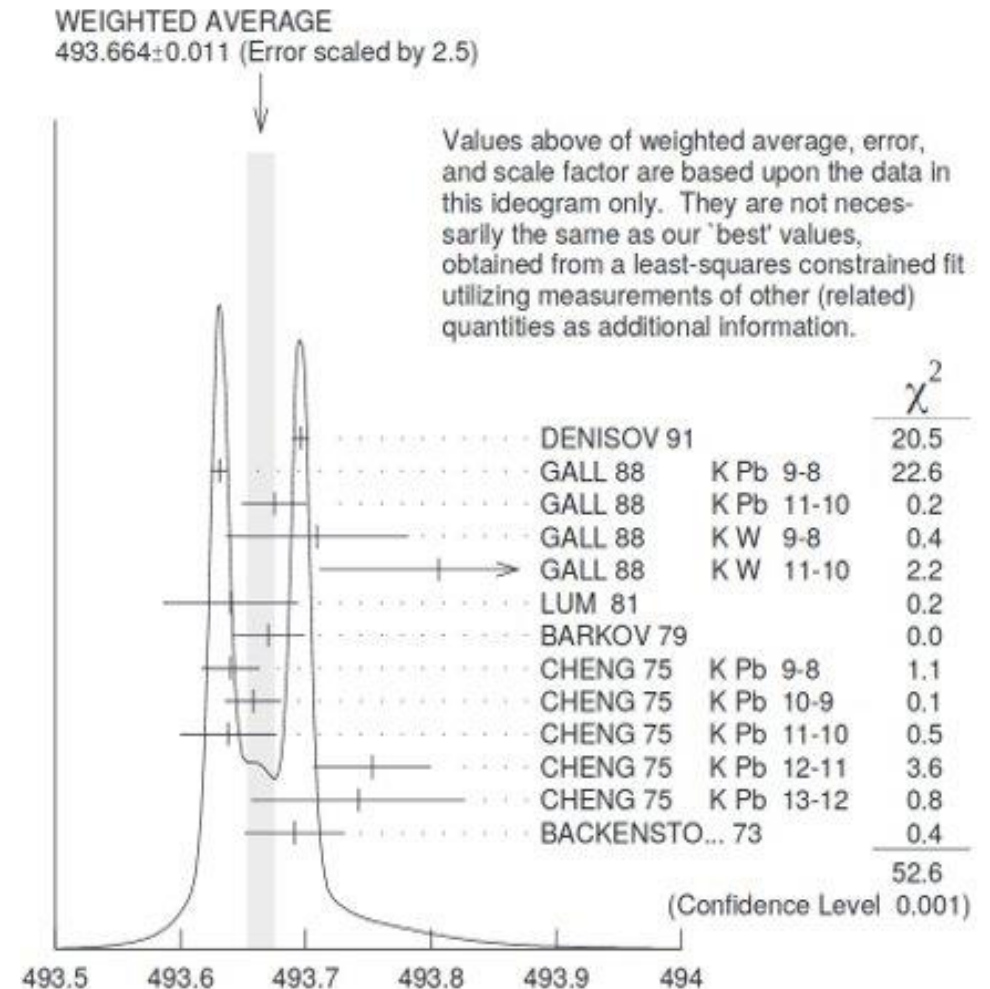
$$m_K = 493.636 \pm 0.011 \text{ MeV}$$

K.P. Gall et al.

Phys. Rev. Lett. 60 (1988)186

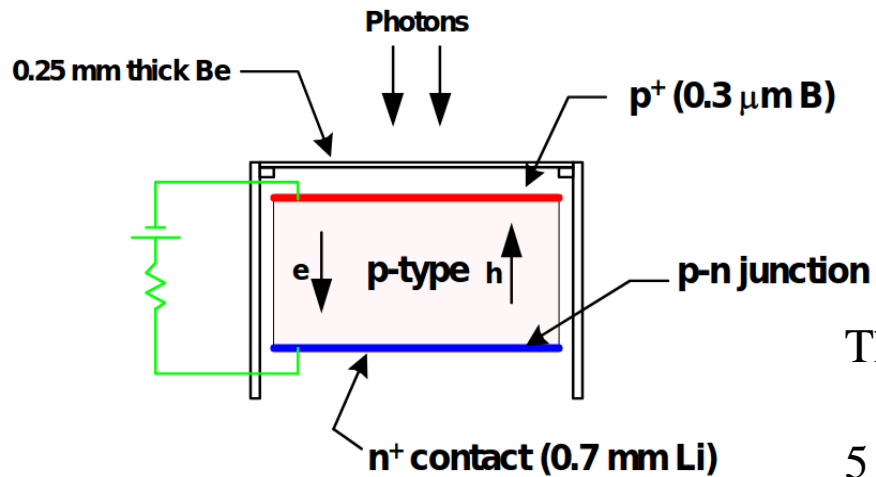
This puzzle could be addressed, together with the renewal of the kaonic atoms database, again with the recent advancements in radiation detectors.

TES, Bragg Spectrometers, HPGe, SDD, and CdZnTe



[M. Tanabashi et al.\(Particle Data Group\), Phys. Rev. D 98, 030001 \(2018\).](#)

# New Kaon Mass measurement with HPGe



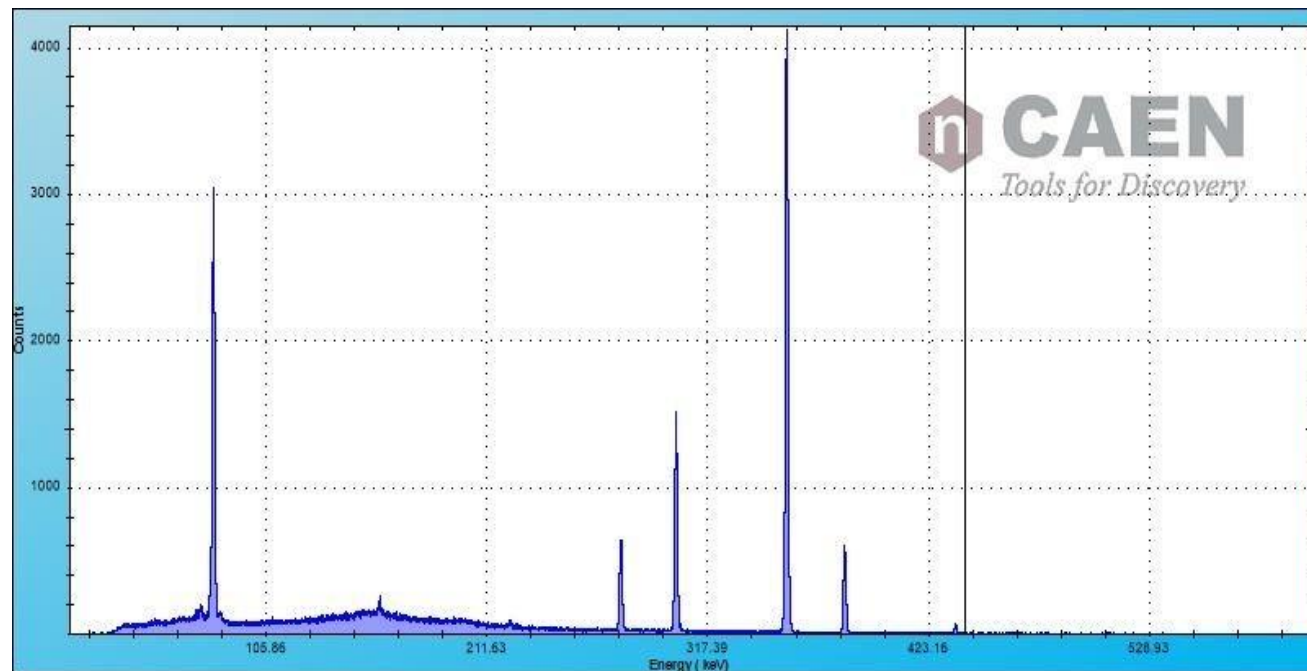
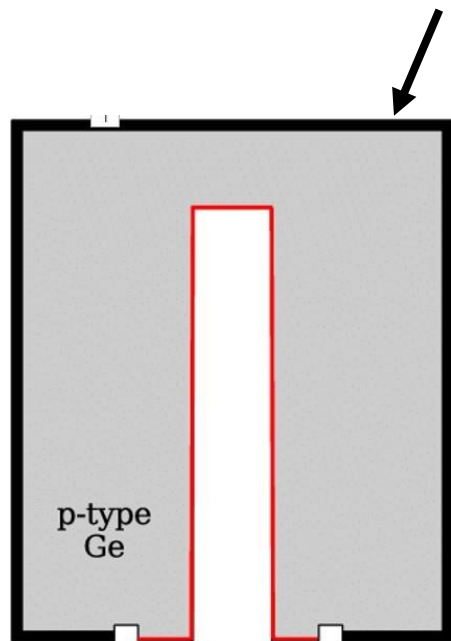
High resolutions in a very wide energy range

Cryogenic cooling is needed

Subject to radiation damage

The maximum depletion depth for the planar detectors is limited to 1-2 cm.

5 cm is required for efficient detection of MeV photons.

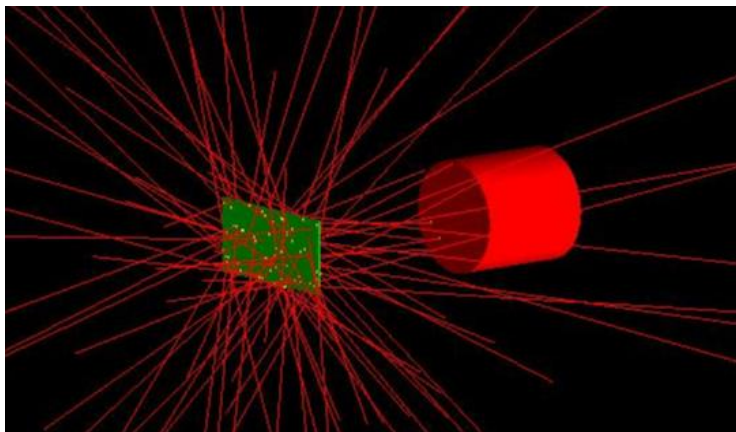
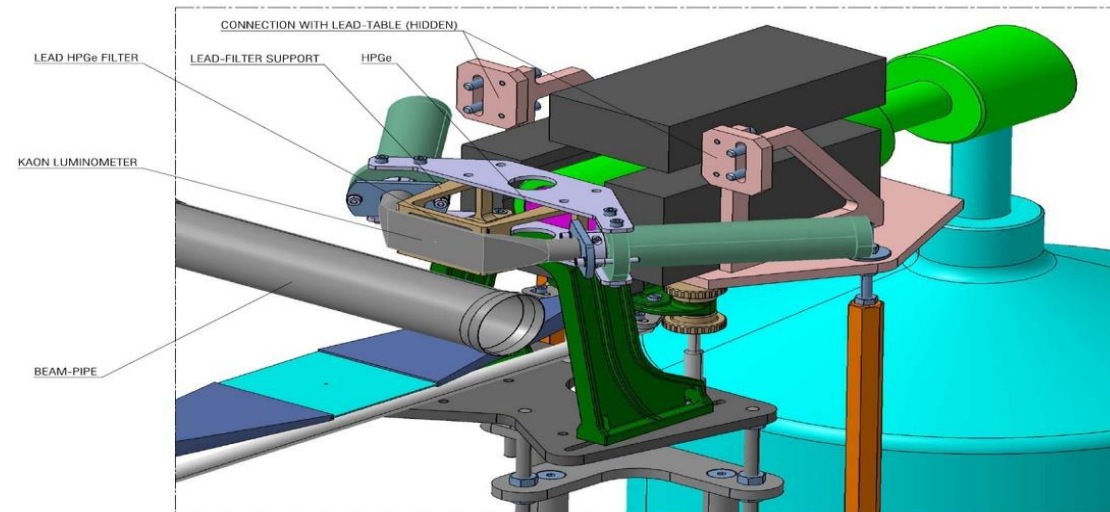
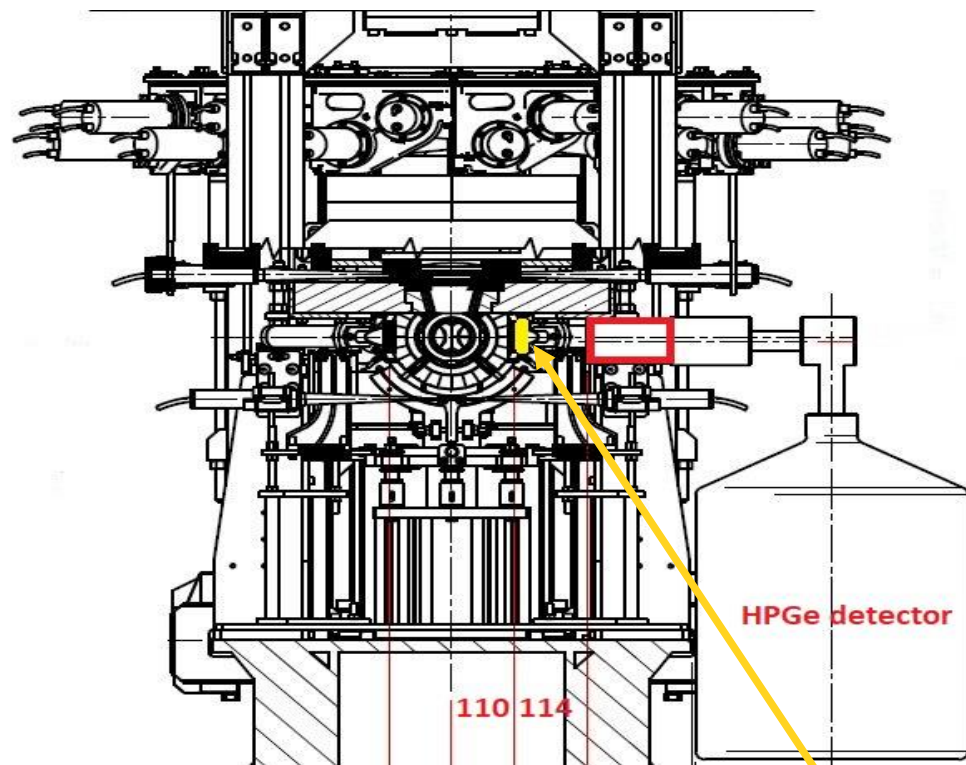


Resolutions (FWHM)  
obtained with <sup>60</sup>Co, <sup>133</sup>Ba

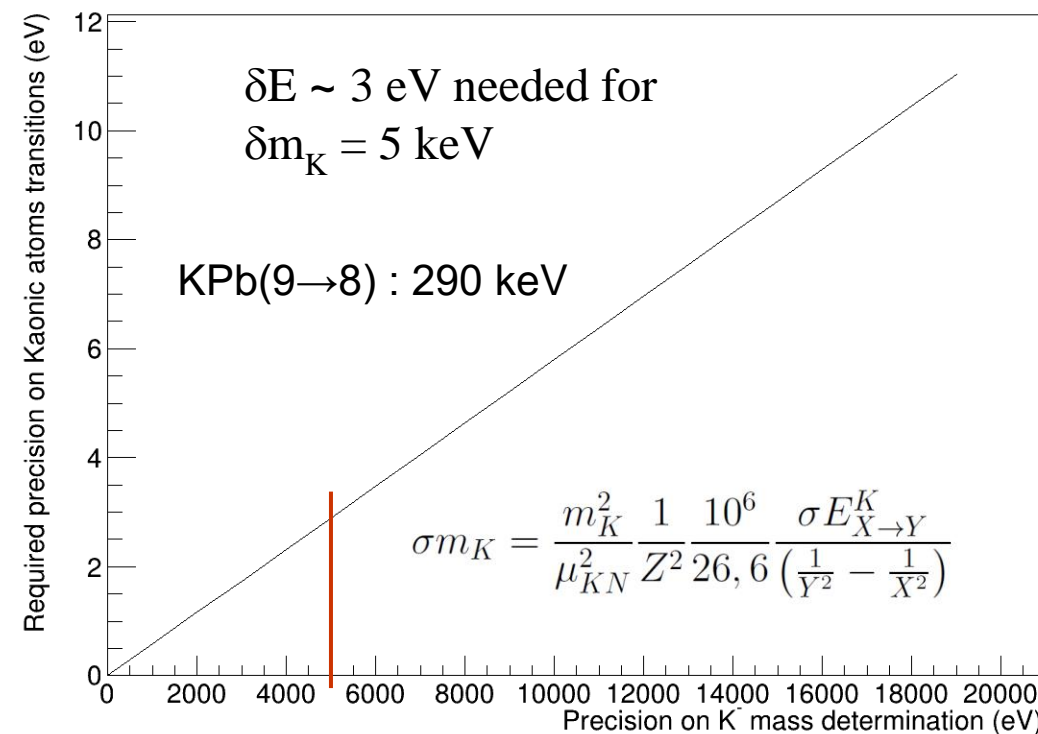
0.870 keV	@	81 keV
1.106 keV	@	302.9 keV
1.143 keV	@	356 keV
1.167 keV	@	1330 keV

# New Kaon Mass measurement with HPGe

Parallel run with SIDDHARTA-2 (already installed):



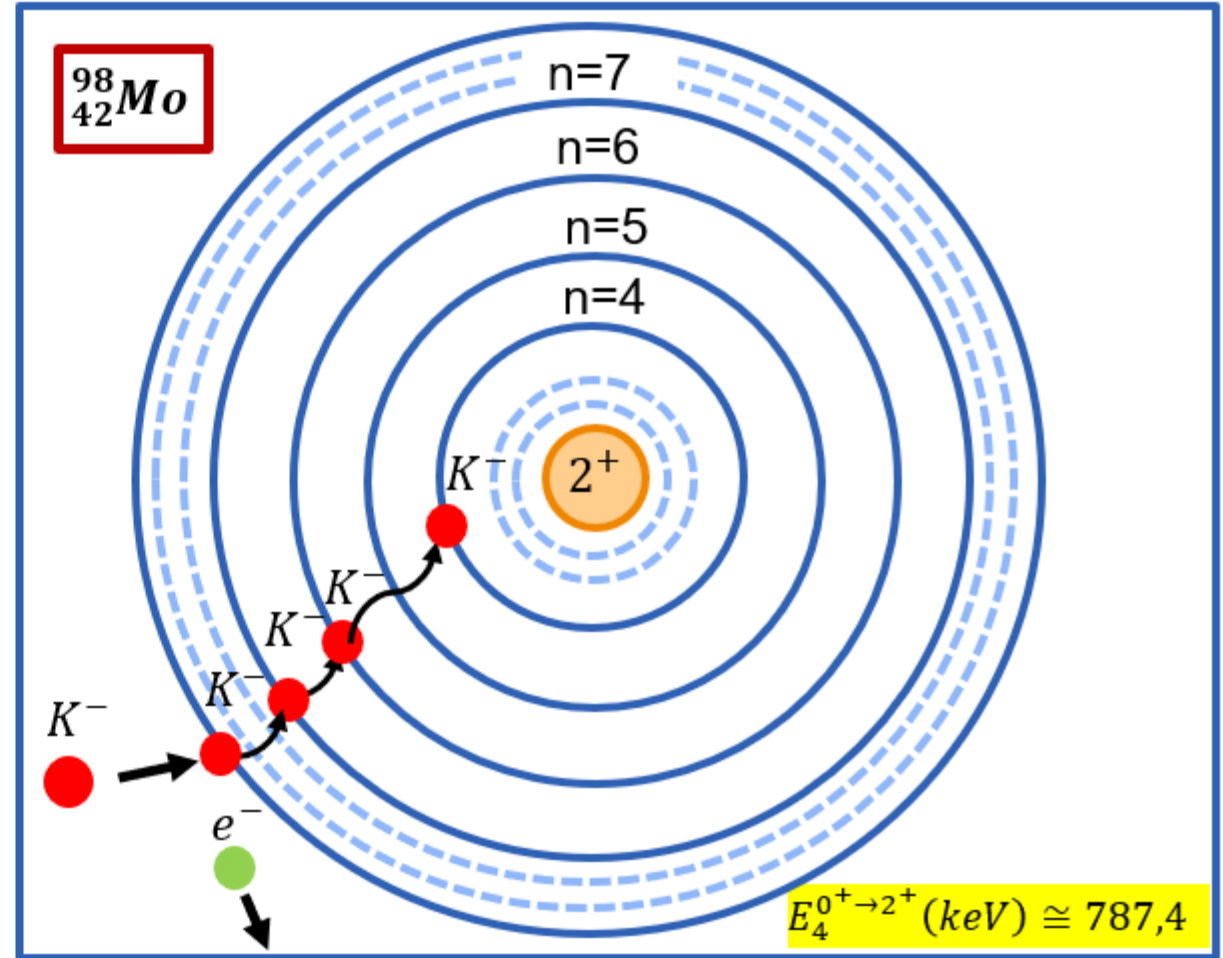
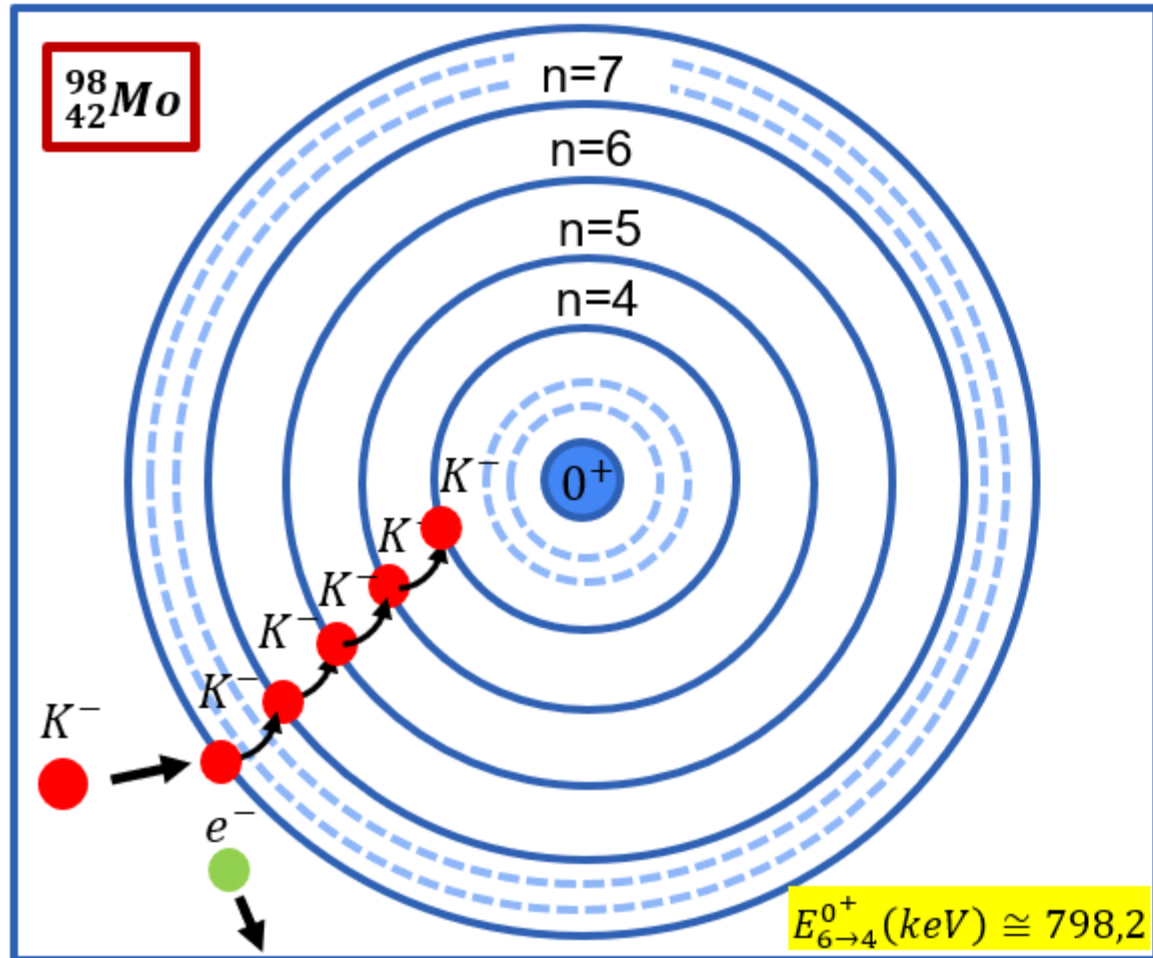
Pb target just behind the SIDDHARTA-2 luminometer, which is used as trigger





# The E2 Nuclear Resonance in Kaonic atoms

In “thickish nuclei” kaonic atoms, when an atomic de-excitation energy is closely matched by a nuclear excitation energy, a resonance condition occurs, which produces an attenuation of some of the atomic x-ray lines from a resonant versus a normal isotope target – as Mo(98).



# The E2 Nuclear Resonance Effect

**The E2 Nuclear Resonance effect is a mixing of the atomic states due to the electrical quadrupole excitations of nuclear rotational states.**

Quanto-mechanically, *the effect mixes  $(n, l, 0^+)$  levels with  $(n', l - 2, 2^+)$  levels* producing a wave function which contains a small admixture of excited nucleus-deexcited atom wavefunctions:

$$\psi = \sqrt{1 - |\alpha|^2} \phi(n, l, 0^+) + \alpha \phi(n', l - 2, 2^+)$$

where the admixture coefficient  $\alpha = \pm \frac{\langle n', l - 2, 2^+ | H_q | n, l, 0^+ \rangle}{E_{(n', l - 2, 2^+)} - E_{(n, l, 0^+)}}$  (very small), and  $H_q$  expresses the *electric quadrupole interaction* between hadron and nucleus.

As example, for the nuclear E2 resonance effect in  $K^- - Mo$  isotopes:

$$\psi = \sqrt{1 - |\alpha|^2} \phi(6h, 0^+) + \alpha \phi(4f, 2^+) \quad \text{with} \quad \alpha = \pm \frac{\langle 4f, 2^+ | H_q | 6h, 0^+ \rangle}{E_{(4f, 2^+)} - E_{(6h, 0^+)}}$$

# The E2 Nuclear Resonance Effect

**HADRONIC ATOMS ARE VERY SENSITIVE TO QUITE AMOUNTS OF CONFIGURATION MIXING**

The nuclear absorption rate increases very drastically (by a factor of several hundred) for each unit decrease of orbital angular momentum; thus for a decrease of  $\Delta l = 2$ , the factor may be around  $10^5$ .



A very small admixture coefficient  $a$  (typically 1%) can mean a significant induced width!

**INDUCED WIDTH:**  $\Gamma_{n,l}^{Ind} = |a^2| \Gamma_{n',l-2}^0$

**A significant weakening/attenuation of corresponding hadronic x-ray line and any lower lines can be observed.**

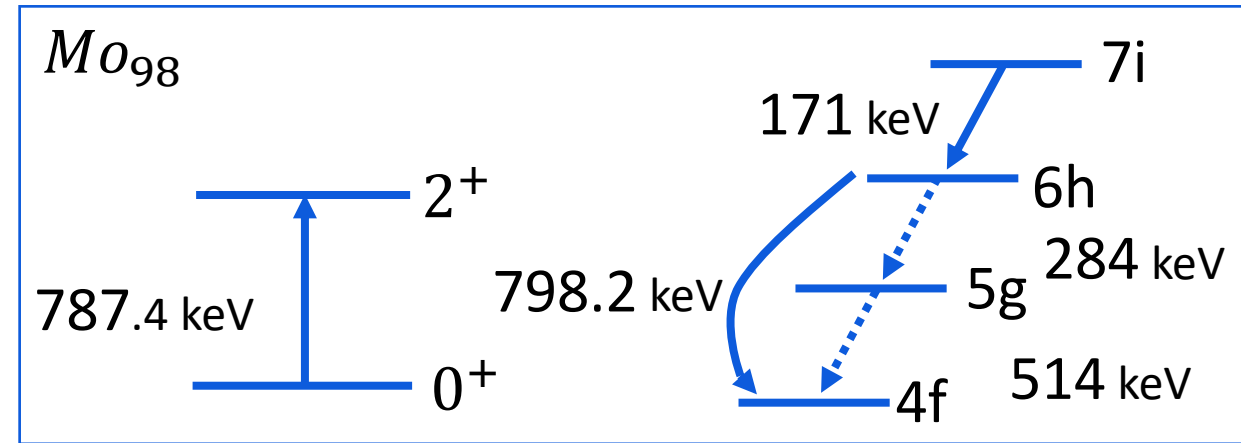
Moreover, comparing the ratio of intensities (attenuated line/reference) from the resonant isotope (thickish) to a non resonant one, we have the **direct measure of the fraction of hadrons absorbed by the excited nucleus.**



# First experiment on Mo98 isotope (1975)

An experiment measuring E2 Nuclear Resonance Effects in Molybdenum 98 was performed in 1975 by G. L. Goldfrey, G- K. Lum and C. E. Wiegand at Lawrence Berkeley Laboratory (LBL) in California.

In kaonic molybdenum (98), the energy difference between 6h and 4f levels, 798.2 keV, is very nearly equal to the nuclear excitation energy of 787.4 keV.

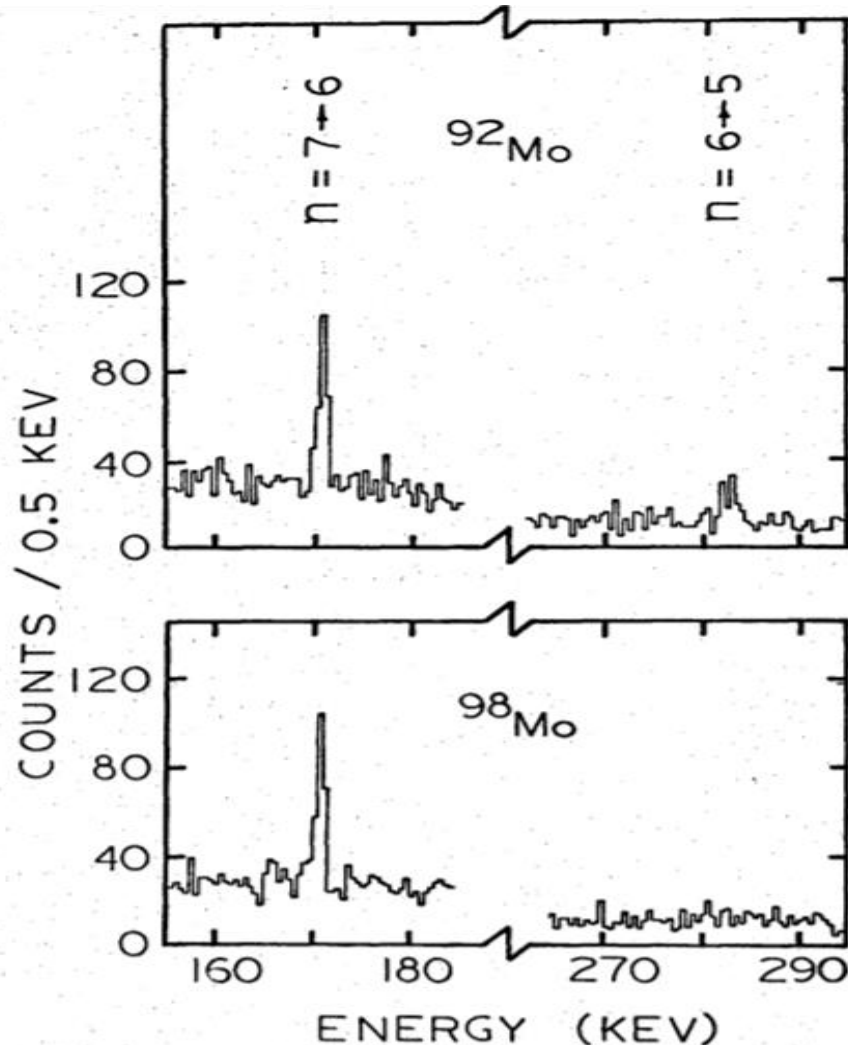


## Experimental apparatus and measurement features:

- The experiment was performed with a negative kaon beam, turning **the targets of Mo(98), and Mo(92) as reference.**
- The spectra were collected using **germanium detectors** feeding a pulse height analyzer.

# First experiment on Mo98 isotope (1975)

The E2 Nuclear Resonance effect was observed  $K^- - {}^{98}_{42}\text{Mo}$ , expressed as the attenuation of x-ray line .



Target	$E_{(6,5) \rightarrow (4,3)}^{K-\text{Mo}}(\text{keV})$	$E_{0^+ \rightarrow 2^+}^{\text{Nucl}}(\text{keV})$	$ a $	$R_\alpha$
${}^{98}_{42}\text{Mo}$	798.2	787.4	0.033	$0.16 \pm 0.16$
${}^{92}_{42}\text{Mo}$	799.1	1540.0	0.001	1.00 (ref)

Only 25 hours of data taking with K-beam was  
not enough for a conclusive result!!



IMPROVABLE WITH MODERN DETECTORS AND  
MORE DATA TAKING TIME

# The E2 Nuclear Resonance in Kaonic atoms

Nuclear Resonances are expected also for kaonic atoms. Such predictions have been obtained by integrating the Klein-Gordon equation with a phenomenological kaon-nucleon potential.

Nucleus	$E_{2+} - E_{0+} [keV]$	Levels mixed	$E_{n,l} - E_{n,l-2} [keV]$	$\Gamma_{n,l-2} [keV]$	Atten lines	Energy [keV]	Ref lines	Energy [keV]
$^{94}_{42}Mo$	871	(6,5)+(4,3)	798.8	24.8	$6 \rightarrow 5$	284.3	$7 \rightarrow 6$	171.1
$^{96}_{42}Mo$	778	(6,5)+(4,3)	798.5	25.2	$6 \rightarrow 5$	284.3	$7 \rightarrow 6$	171.1
$^{98}_{42}Mo$	787.4	(6,5)+(4,3)	798.2	25.5	$6 \rightarrow 5$	284.3	$7 \rightarrow 6$	171.1
$^{100}_{42}Mo$	535.5	(6,5)+(4,3)	797.9	25.8	$6 \rightarrow 5$	284.3	$7 \rightarrow 6$	171.2
$^{96}_{44}Ru$	832.3	(6,5)+(4,3)	874.9	29.8	$6 \rightarrow 5$	312.1	$7 \rightarrow 6$	187.9
$^{122}_{50}Sn$	1140.2	(6,5)+(4,3)	1105.8	70.4	$6 \rightarrow 5$	403.5	$7 \rightarrow 6$	243.1
$^{138}_{56}Ba$	1426.0	(6,5)+(4,3)	1346.3	126.1	$6 \rightarrow 5$	505.7	$7 \rightarrow 6$	305.4
$^{198}_{80}Hg$	411.8	(8,7)+(7,5)	406.1	7.8	$8 \rightarrow 7$	403.2	$9 \rightarrow 8$	276.1

**MOLYBDENUM ISOTOPES OFFER A UNIQUE OPPORTUNITY TO INVESTIGATE THE STRONG  $K^- - N$  INTERACTION THROUGH THE E2 NUCLEAR RESONANCE EFFECTS.**



# The E2 Nuclear Resonance in kaonic Mo

The  $|n = 6, l = 5, 0^+\rangle$  states in  $K^- - {}^{96}_{42}\text{Mo}$  and  $K^- - {}^{98}_{42}\text{Mo}$  are mixed with the  $|n = 4, l = 3, 2^+\rangle$  states. The small ratio of mixing strength and level spacing (respectively  $\cong 10 \text{ keV}$  and  $\cong 20 \text{ keV}$ ) allows a perturbative treatment and the E2-induced, complex energy shift due to this mixing is approximately given by:

$$\varepsilon(E2; 6,5) - i \frac{\Gamma(E2; 6,5)}{2} \cong \frac{\langle 6,5; 0^+ | H_q | 4,3; 2^+ \rangle}{E_{(6,5,0^+)} - E_{(4,3,2^+)}}$$

where:

- $E_{(6,5,0^+)}$  is the energy of the  $|n = 6, l = 5, 0^+\rangle$  state
- $E_{(4,3,2^+)} = E(2^+) + E_{em}(4,3) + \varepsilon(4,3) - i\Gamma(4,3)/2$  is the energy of the state  $|n = 4, l = 3, 2^+\rangle$

The E2 Nuclear resonance allows  $K^-$  to access the 4f atomic level, not easily accessible during normal cascade because of the nuclear absorption. It allows to study strong interaction in strangeness sector, at low distances with an excited nucleus.

**IT OFFERS THE LARGEST NUCLEAR ATOMIC OVERLAP TESTED SO FAR WITH KAONIC ATOMS.**

**IN 4 COMPARABLE ISOTOPES!!!**

# The E2 Nuclear Resonance in Kaonic atoms

The measured level shifts ( $\varepsilon$ ) and widths ( $\Gamma$ ) of the energy levels  $n=6,4$  in even- $A$  kaonic molybdenum isotopes allowed the investigation toward the **neutron density in nuclear periphery**.

## AS PERFORMED IN ANTIPROTONIC TE ISOTOPES

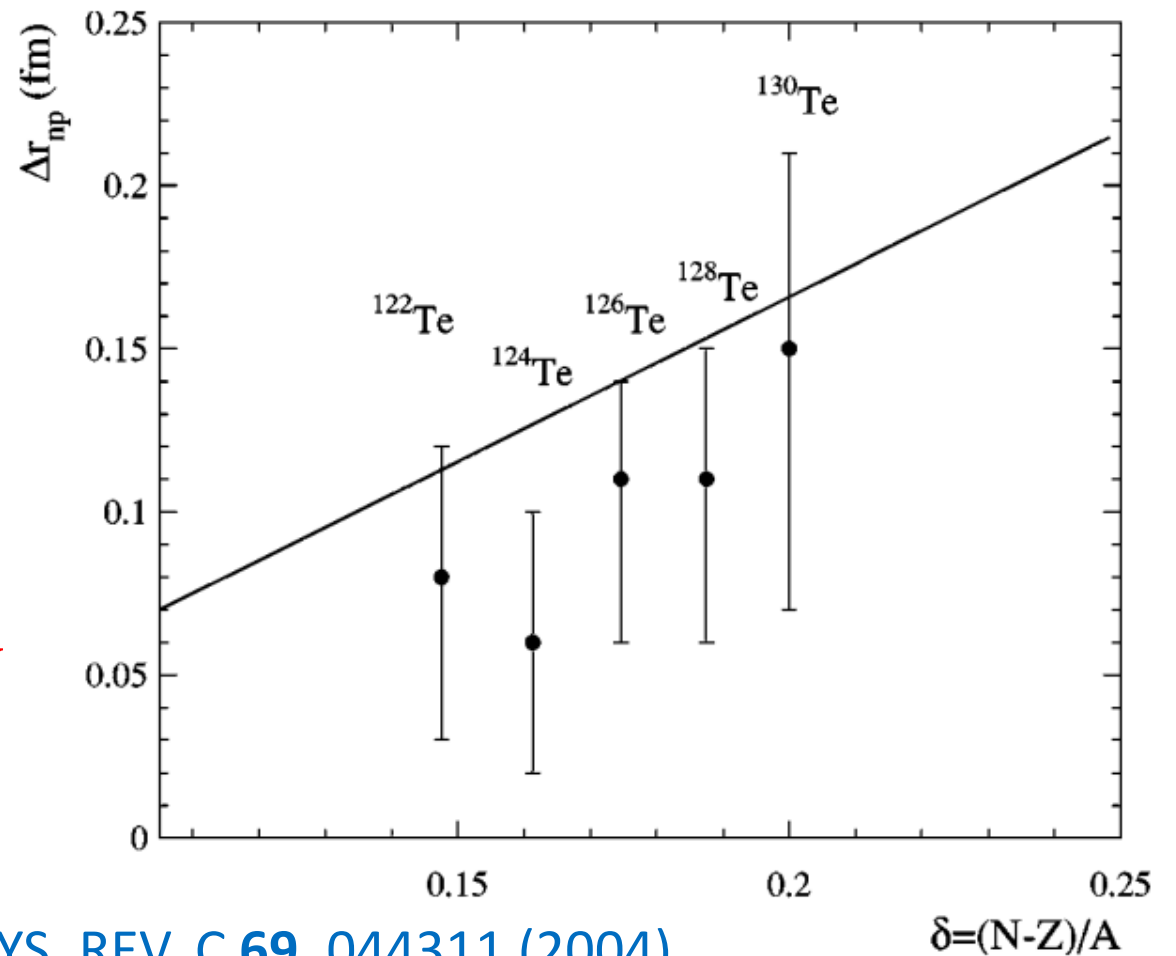
Neutron and proton distribution in the Te nuclei were described with two-parameter Fermi model.



The *rms* neutron radius was adjusted through experimental data.





**THE DIFFERENCE BETWEEN NEUTRON AND PROTON RMS RADII  $\Delta r_{np}$  WAS DETERMINED.**



# Double $\beta$ decay in Mo-98 and Mo-100 isotopes

Double beta ( $\beta\beta$ ) decay is a nuclear process in which two neutrons turn in two protons (or vice versa) and two electrons are emitted.

**STANDARD double-beta decay:**  ${}^{98}_{42}\text{Mo} \rightarrow {}^{98}_{44}\text{Ru} + e^{-} + e^{-} + 2\bar{\nu}_e$   
 ${}^{100}_{42}\text{Mo} \rightarrow {}^{100}_{44}\text{Ru} + e^{-} + e^{-} + 2\bar{\nu}_e$   Lepton number conserved

**Neutrinoless double-beta decay:**  ${}^{98}_{42}\text{Mo} \rightarrow {}^{98}_{44}\text{Ru} + e^{-} + e^{-}$   
 ${}^{100}_{42}\text{Mo} \rightarrow {}^{100}_{44}\text{Ru} + e^{-} + e^{-}$   **VIOLATION OF LEPTON  
NUMBER CONSERVATION LAW**

**Neutrinoless double-beta decay is only possible if neutrino is a Majorana particle**

The  $\beta\beta$ -decay nuclear matrix elements can be calculated using two different theory frameworks: proton-neutron quasiparticle random phase approximation (pnQRPA) and microscopic interacting boson model (IBM-2)

These model depends on the relative distance between the two neutron decays, which is estimated to be:

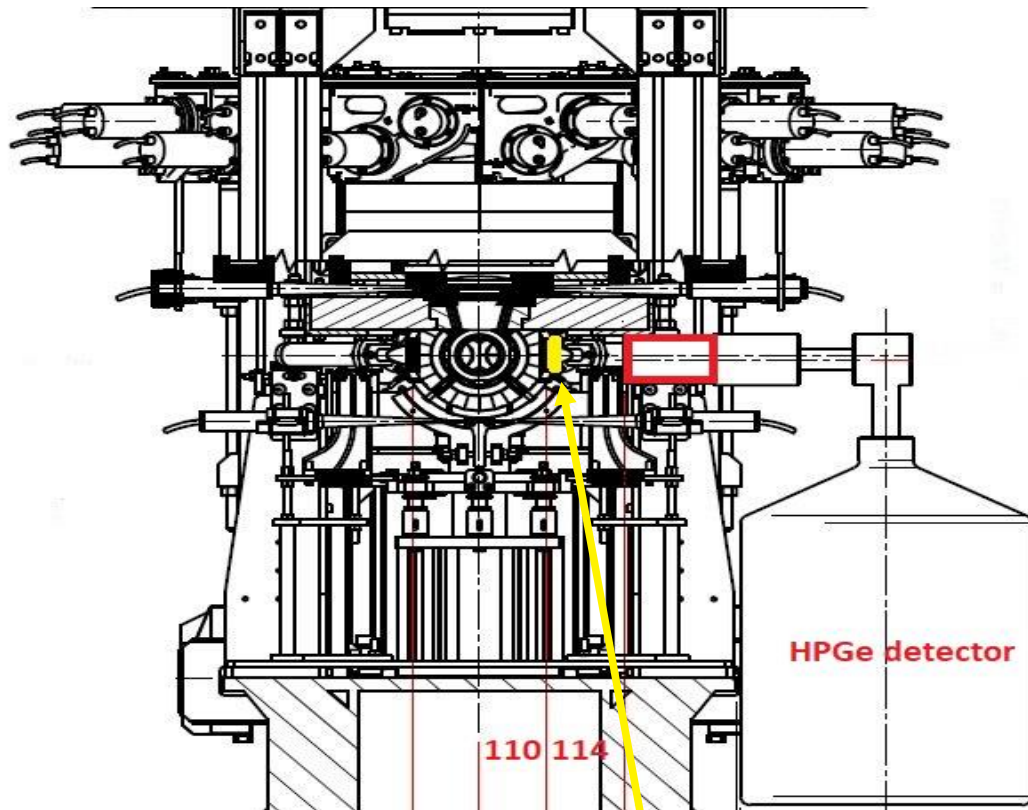
**The measurement of a more precise *rms* neutron radius in kaonic Mo isotopes could provide further constraints to define relative distance among neutrons in  ${}^{98}_{42}\text{Mo}$  and  ${}^{100}_{42}\text{Mo}$**



# EXPERIMENTAL PROPOSAL: KAMEO

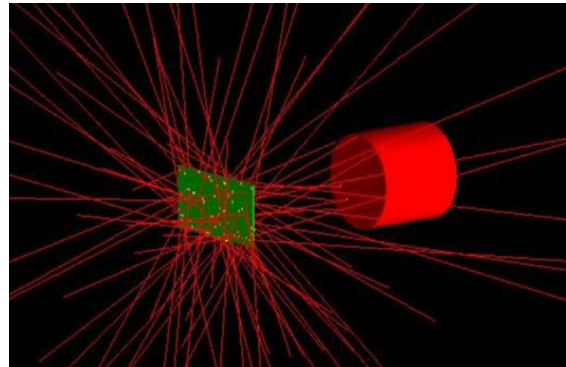
## Kaonic Atoms Measuring nuclear resonance Effects Observables

The measurement of Nuclear resonance E2 effects in Molybdenum kaonic isotopes could be performed **during the SIDDHARTA-2 data taking period**, exploiting the horizontal emitted kaons with dedicated targets and a Germanium detector.



Molibdenum solid target

Target parameters will be test with a Monte Carlo Simulation.



Mo isotope	Abundanc e	Half-Time
$^{94}_{42}\text{Mo}$	9%	<i>stable</i>
$^{96}_{42}\text{Mo}$	16%	<i>stable</i>
$^{98}_{42}\text{Mo}$	24%	<i>stable</i>
$^{100}_{42}\text{Mo}$	10%	$7.7 \times 10^{18} \text{ y}$

From a very **preliminary estimation**, with a target maximizing the geometrical efficiency, **the measurements could be performed in about 10-15 days for each isotope, including (for reference) the  $^{92}_{42}\text{Mo}$ .**

# Scientific Relevance of KAMEO

- To obtain informations on the properties of deeply bound kaonic atoms, not easily accessible by the kaonic cascade, in Mo nuclei  $\rightarrow$  shift and width of the  $n = 6,4$  levels (E2 effect and maybe strong interaction)!
- In  $K^- - {}^{98}_{42}\text{Mo}$  the attenuation coefficient ( $\alpha$ ) due to the nuclear resonance effect can be measured with higher precision.
- The  $\alpha$  coefficient can be measured in  ${}^{94}_{42}\text{Mo}$ ,  ${}^{96}_{42}\text{Mo}$  and  ${}^{100}_{42}\text{Mo}$  for the first time, providing new reference value for theoretical models.
- The comparison of measurements in  ${}^{94}_{42}\text{Mo}$ ,  ${}^{96}_{42}\text{Mo}$ ,  ${}^{98}_{42}\text{Mo}$  and  ${}^{100}_{42}\text{Mo}$  could reveal new properties of strong kaon-nucleon interaction (also  ${}^{96}_{44}\text{Ru}$ ).
- The search for isotope effects in the level shift ( $\varepsilon$ ) and width ( $\Gamma$ ) would reveal sign of changes in the nuclear periphery when pair of neutrons are added to the lightest isotope ( ${}^{94}_{42}\text{Mo}$ )
- To study nuclear distribution in  ${}^{98}_{42}\text{Mo}$  and  ${}^{100}_{42}\text{Mo}$ , providing important details to investigate neutrinoless double beta ( $0\nu\beta\beta$ ) and two-neutrino double beta decay ( $2\nu\beta\beta$ )

# THANK YOU FOR YOUR ATTENTION!!!





# What more can we learn from new measurements?

