The KAMEO proposal

(Kaonic Atoms Measuring nuclear resonance Effects Observables)

Investigating strong kaon-nucleus with Nuclear E2 Resonance Effect in kaonic atoms

Luca De Paolis

ROCKSTAR workshop: Towards a ROadmap of the Crucial measurements of Key observables in Strangeness reactions for neutron sTARs equation of state; **ECT*** Trento, Italy

INFN

Istituto Nazionale di Fisica Nucleare
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10/10/2023

ROCKSTAR

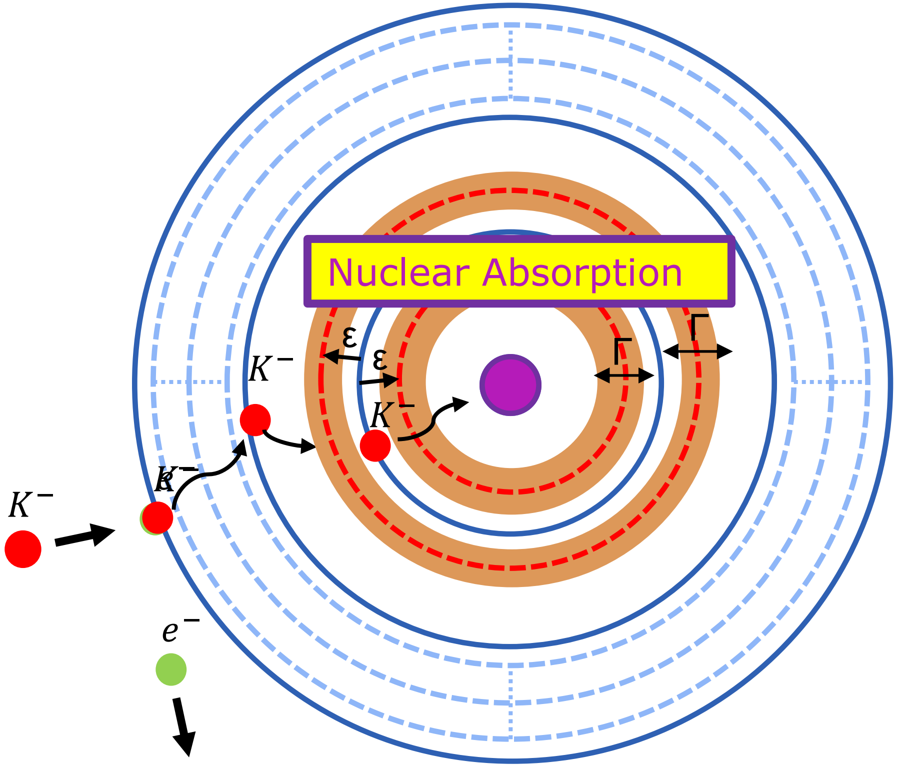
Ligth Kaonic atoms

Light kaonic atoms, like kaonic Hydrogen and Deuterium, provides fundamental informations on strong kaon-nucleon interaction by measure of x-ray transition yields, and energy shift (ε) and width (Γ) of the innermost atomic levels.

The kaon is captured in a higly excited state of the atom and starts a de-excitation cascade process.

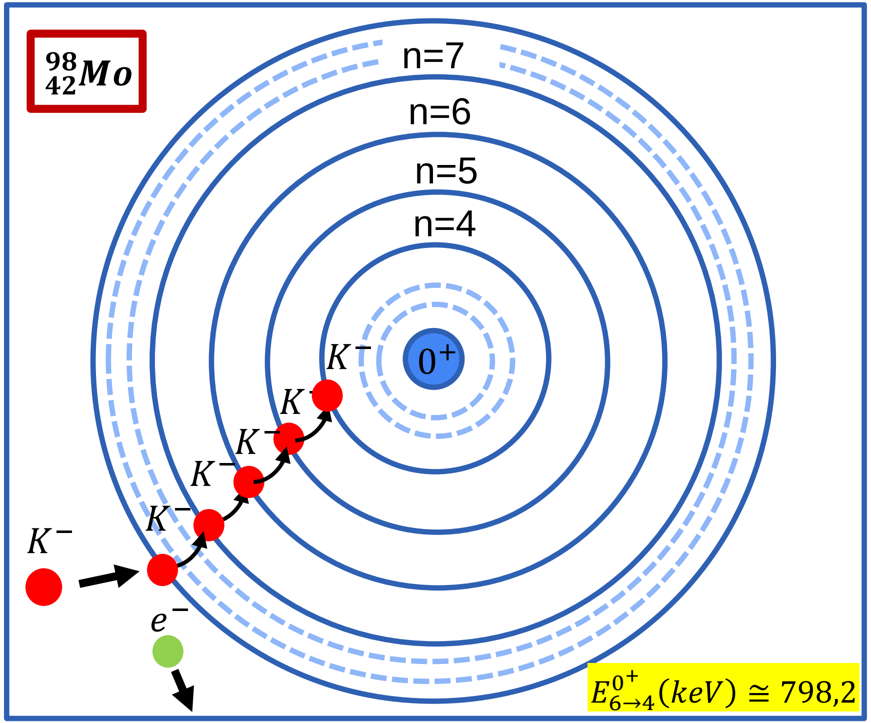
In ligth kaonic atoms experiments, it is essential to favor the cascade process down to the innermost atomic levels, in which shift (ε) and width (Γ) due to strong kaon-nucleon interaction become measurable.

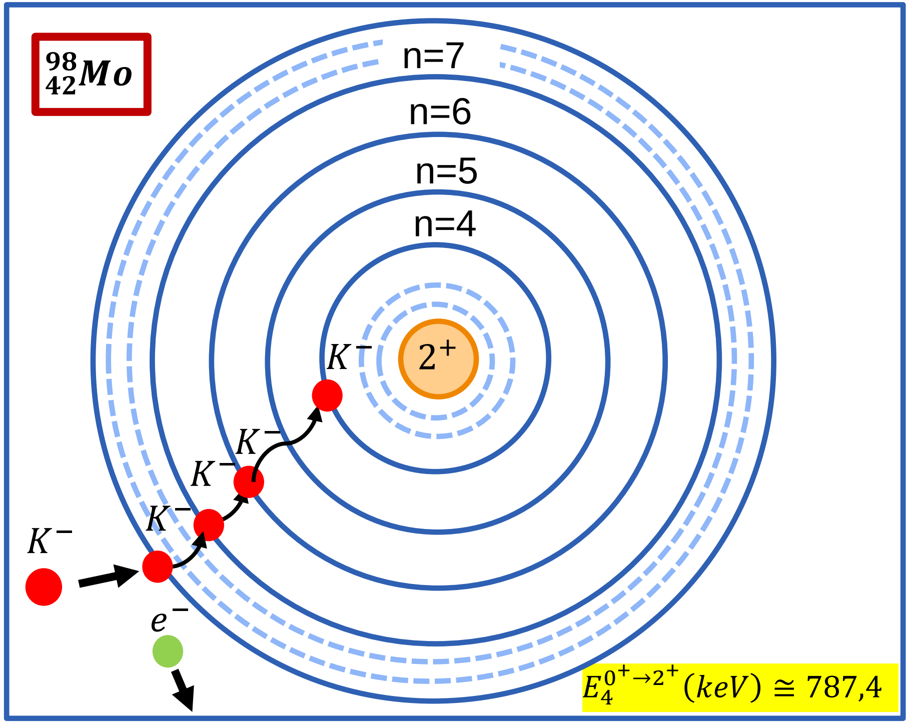
Finally, the kaon is absorbed by the nucleus



The E2 Nuclear Resonance Effect

In “thicklish 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 $\alpha = \pm \frac{\langle n, l-2, 2^+ | H_q | n', l, 0^+ \rangle}{E_{(n,l,2^+)} - E_{(n,l,0^+)}}$ (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

The matrix element $\langle H_Q \rangle$ ***for a spin-zero hadron*** is given by:

$$\langle H_Q \rangle = \pm\frac{1}{2}e^2\underline{Q_0\langle r^{-3}\rangle}\underline{[(2l+1)(2l'+1)(2l+1)(2l'+1)]^{\frac{1}{2}} \times \begin{pmatrix} 2 & I & I' \\ 0 & -K & K \end{pmatrix}\begin{pmatrix} 2 & l & l' \\ 0 & 0 & 0 \end{pmatrix}\begin{Bmatrix} 2 & I & I' \\ F & l' & l \end{Bmatrix}}$$

Q_0 is the nuclear quadrupole strength

$\langle r^{-3}\rangle$ is the quadrupole orbital radius

I, I', K, K', l, l', F are angular momentum factors

H.L. Acker, Nucl. Phys. **87**, *153*, 1966

- Q_0 comes directly from the measured Coulomb excitation cross-sections ($B(E2\uparrow)$ values).
- $\langle r^{-3}\rangle$ can be evaluated using point Coulomb wave functions
- I, I', K, K', l, l', F can be with angular-momentum rules (i.e. for spin one-half $l \rightarrow j, \mathrm{etc}$ ...)

CALCULATIONS ARE INDEPENDENT OF ANY PARTICULAR NUCLEAR MODEL

The E2 Nuclear Resonance Effect

HADRONIC ATOMS ARE VERY SENSITIVE TO QUITE AMOUNTS OF CONFIGURATION MIXING

The nuclear absorption rate increases very drasically (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: $\Gamma_{n,l}^{Ind} = |a^2|\Gamma_{n',l-2}^{0}$

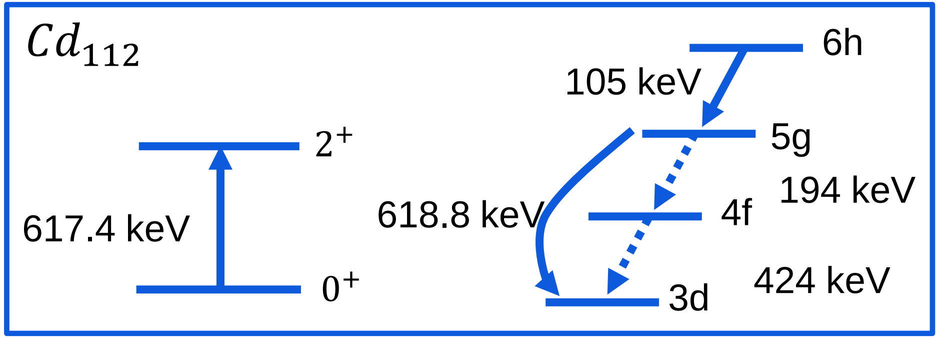
A significant weakening/attenuation of corresponding hadronic x-ray line and any lower lines can be observed.

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

The pionic cadmium 112 experiment

An experiment measuring E2 resonance effect cadmium 112 was performed in 1975 by J. N. Bradbury, H.Daniel, J. Reidy and M. Leon at the biomedical pion beam of Los Alamos Meson Physics Facility (LAMPF).

In pionic cadmium (112), the energy difference between 5g and 3d levels, 618.8 keV, is very nearly equal to the nuclear excitation energy of 617.4 keV.

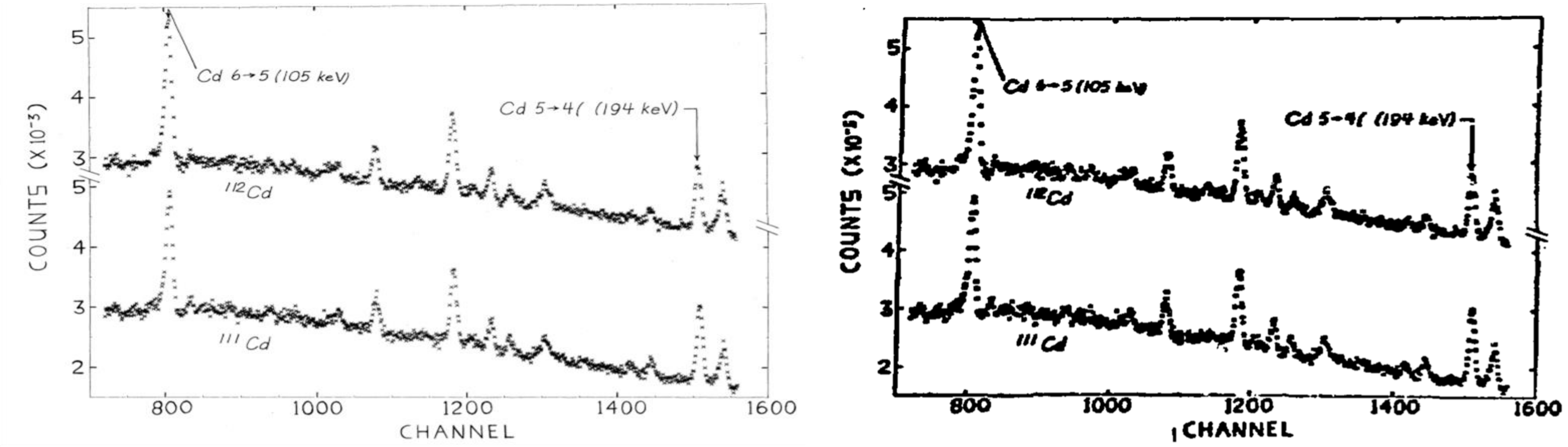


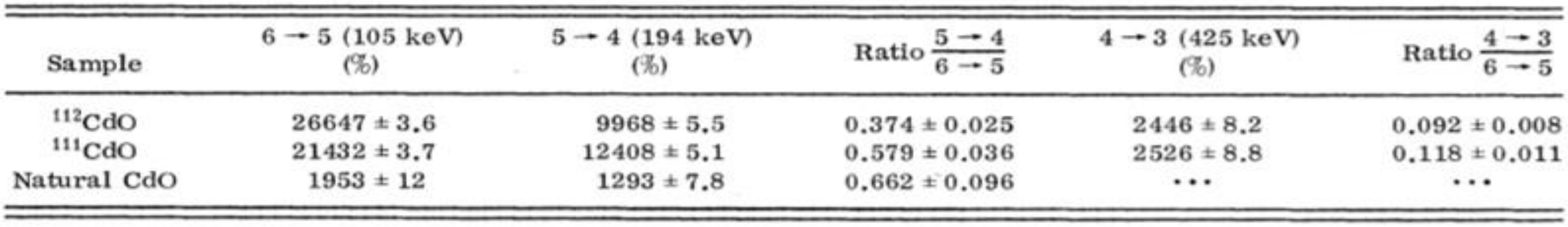
Experimental apparatus and measurement features:

- The experiment consisted of placing enriched isotope targets of Cd(111) e Cd(112) in turn into the negative pion beam for **2 hours**.
- The spectra were collected using a **germanium detector** feeding a pulse height analyzer.
- Natural Cadmio was exposed for a shorter time to provide consistency check.

Pionic cadmium 112 measurement

These results demonstrate the existence of the Nuclear Resonance Effect: the ratios are very significantly different from one.





Sample	6 → 5 (105 keV) (%)	5 → 4 (194 keV) (%)	Ratio $\frac{5 \to 4}{6 \to 5}$	4 → 3 (425 keV) (%)	Ratio $\frac{4 \to 3}{6 \to 5}$
^{112}CdO	26647 ± 3.6	9968 ± 5.5	0.374 ± 0.025	2446 ± 8.2	0.092 ± 0.008
^{111}CdO	21432 ± 3.7	12408 ± 5.1	0.579 ± 0.036	2526 ± 8.8	0.118 ± 0.011
Natural CdO	1953 ± 12	1293 ± 7.8	0.662 ± 0.096	···	···

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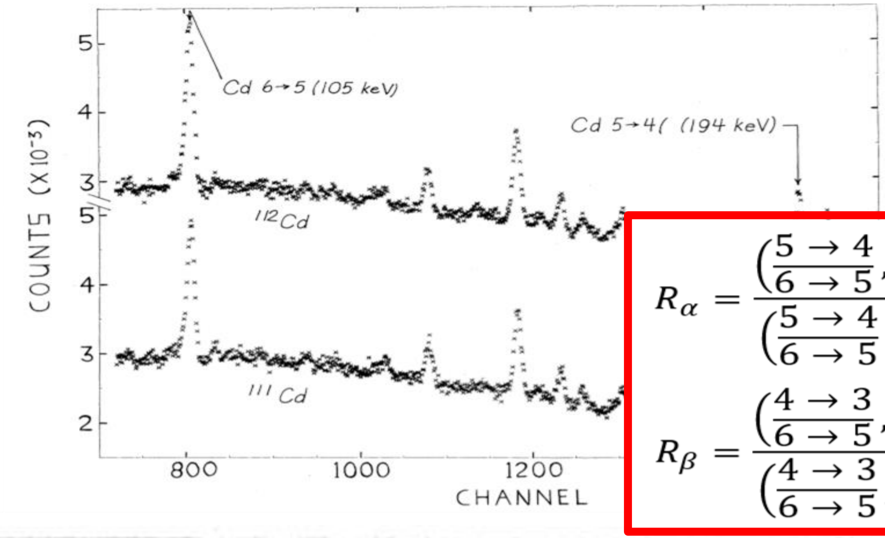
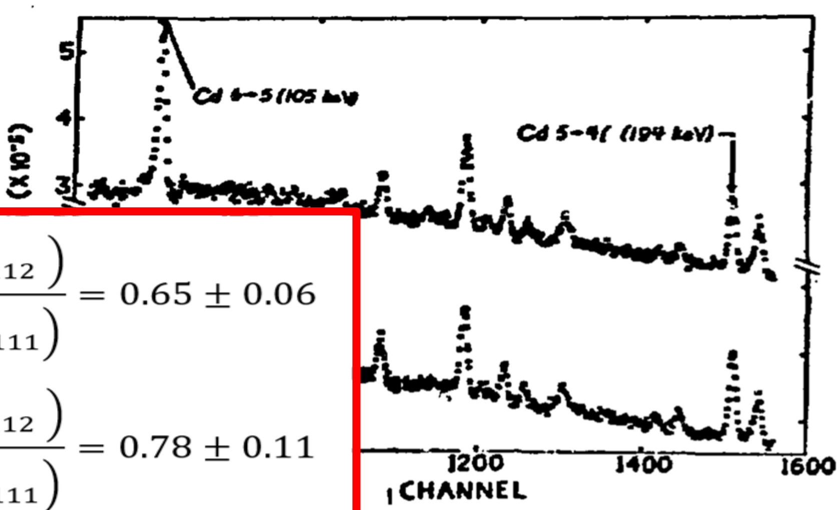
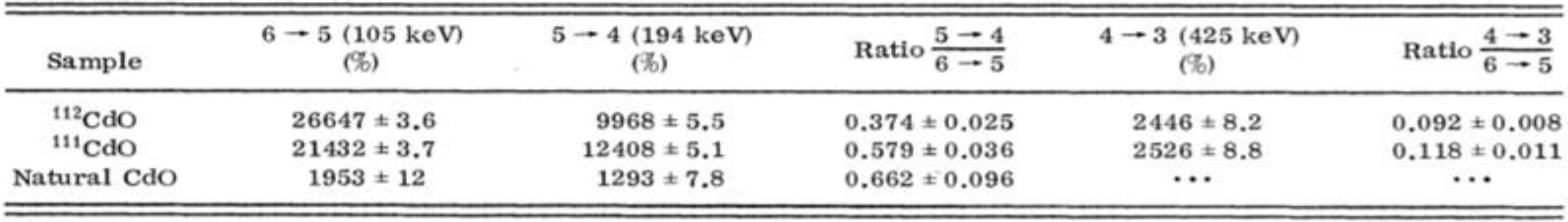




$$R_\alpha = \frac{\left(\frac{5\to 4}{6\to 5}, Cd_{112}\right)}{\left(\frac{5\to 4}{6\to 5}, Cd_{111}\right)} = 0.65 \pm 0.06$$

$$R_\beta = \frac{\left(\frac{4\to 3}{6\to 5}, Cd_{112}\right)}{\left(\frac{4\to 3}{6\to 5}, Cd_{111}\right)} = 0.78 \pm 0.11$$



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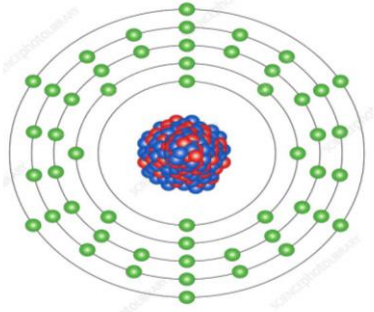
E2 effect in antiprotonic Te atoms

The nuclear E2 resonance effect was recently studied in even-A Te atoms for several reasons:

- The E2 effect allows to obtain informations on the properties of deeply bound antiprotonic atoms, not accessible by the antiprotonic cascade, in ticklish nuclei.

The attenuation of the $n = 8 \rightarrow n = 6$ x-ray transition affected by the E2 resonance measured in several even-A Te isotopes can lead to a precise determination of shift and width of the $n = 6$ level.

Tellurium atom



- The search for isotope effects in the level shift (ε) and width (Γ) would reveal sign of changes in the nuclear periphery when pair of neutrons are added to the lighest isotope ($^{122}_{52}Te$).

SAME TOPICS COULD BE INVESTIGATED WITH KAONIC MOLYBDENUM ATOMS (4 even-A ISOTOPES)

The antiprotonic Te experiment

The $|n = 8, l = 7, 0^+\rangle$ states in Tellurium are mixed with the $|n = 6, l = 5, 2^+\rangle$ states. The small ratio of mixing strenght and level spacing (respectively $\cong 1\ keV$ and $\cong 15\ keV$) allows a perturbative treatment and the E2-induced, complex energy shift due to this mixing is approximately given by:

$$\varepsilon(E2;8,7) - i\frac{\Gamma(E2;8,7)}{2} \cong \frac{\langle 8,7;0^+|H_q|6,5;2^+\rangle^2}{E_{(8,7,0^+)} - E_{(6,5,2^+)}}$$

where:

- $E_{(8,7,0^+)}$ is the energy of the $|n = 8, l = 7, 0^+\rangle$ state
- $E_{(6,5,2^+)} = \mathrm{E}(2^+) + E_{em}(6,5) + \varepsilon(6,5) - i\Gamma(6,5)/2$ is the energy of the state $|n = 6, l = 5, 2^+\rangle$

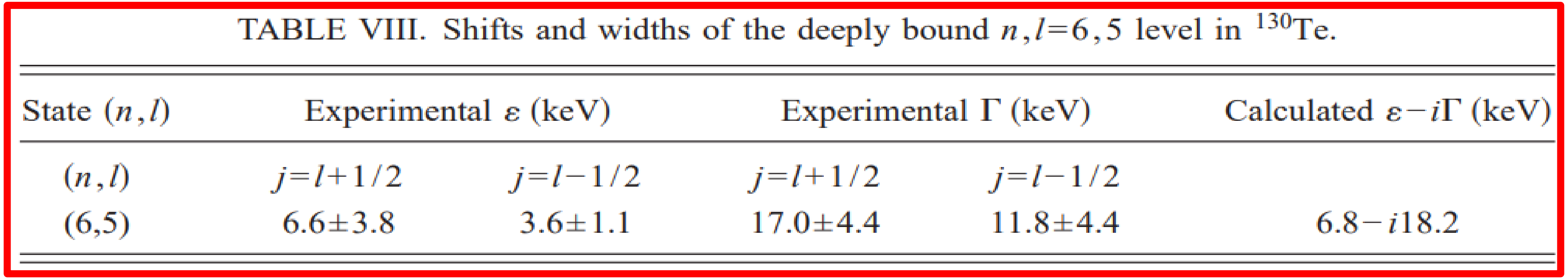


TABLE VIII. Shifts and widths of the deeply bound n,l=6,5 level in ^{130}Te.

State (n,l)	Experimental ε (keV)		Experimental Γ (keV)		Calculated $\varepsilon-i\Gamma$ (keV)
(n,l)	$j=l+1/2$	$j=l-1/2$	$j=l+1/2$	$j=l-1/2$	
(6,5)	6.6±3.8	3.6±1.1	17.0±4.4	11.8±4.4	$6.8-i18.2$

B. Klos, S. Wycech *et al.*, PHYS. REV. C **69**, 044311 (2004)

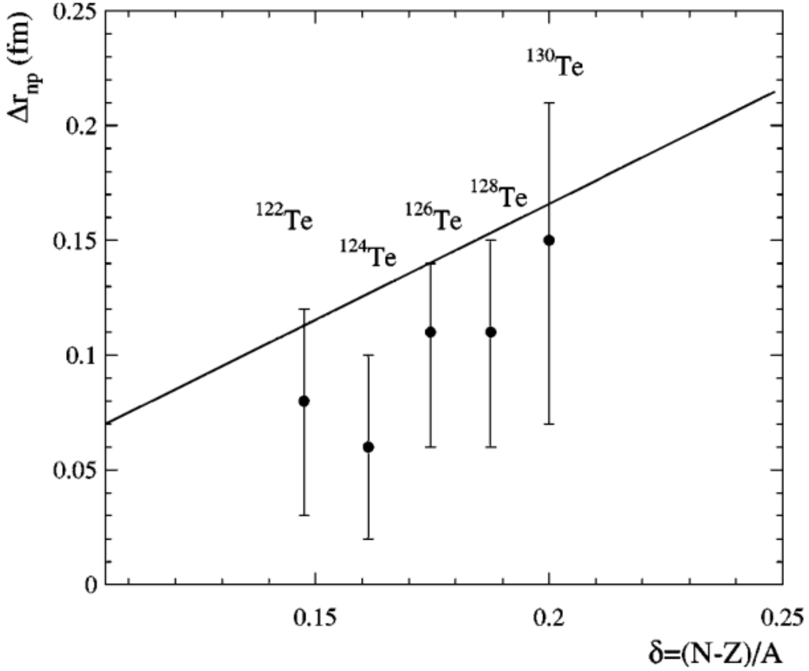
The antiprotonic Te experiment

The measured level shifts (ε) and widths (Γ) of the energy levels n=8,6 in even-A antiprotonic tellurium isotopes allowed the investigation toward the **neutron density in nuclear periphery**.

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

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

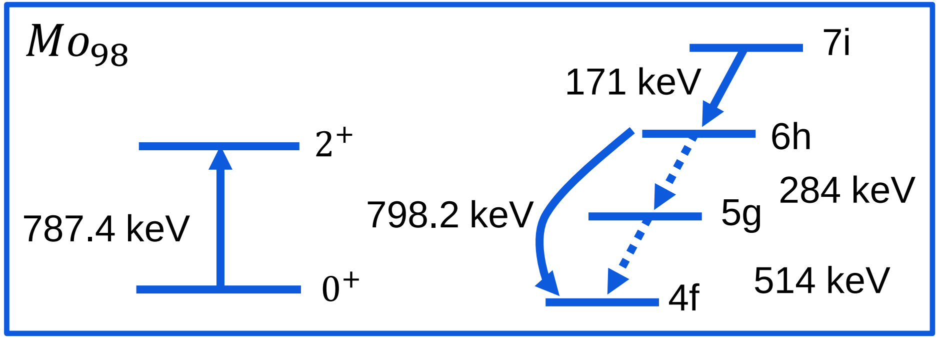
THE DIFFERENCE BETWEEN NEUTRON AND PROTON RMS RADII Δr_{np} WAS DETERMINE.



The Molybdenum 98 experiment

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.

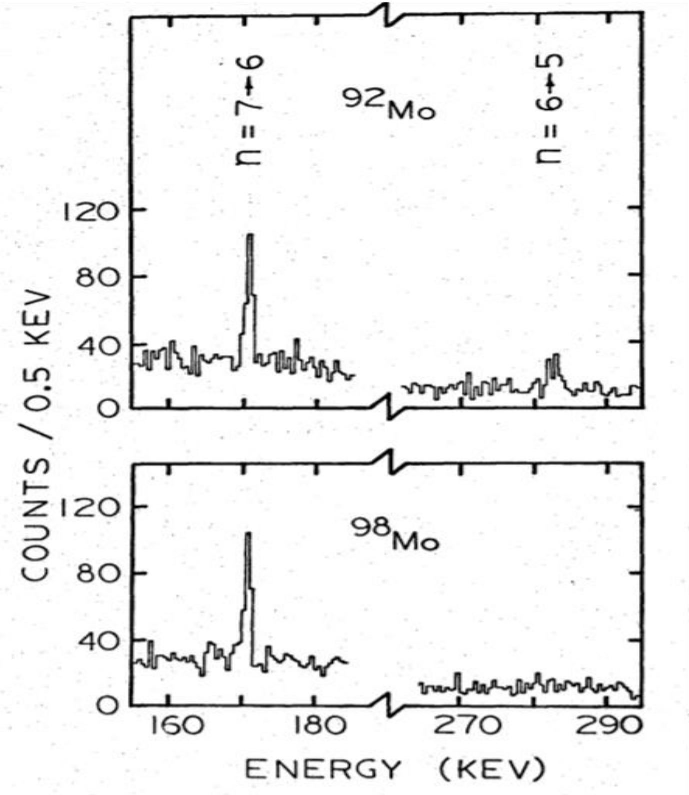


Experimental apparatus and measurement features:

- 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.

The Molybdenum 98 experiment

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



Target	$E^{K-Mo}_{(6,5)\to(4,3)}(keV)$	$E^{Nucl}_{0^+\to 2^+}(keV)$	$\lvert a \rvert$	R_α
${}^{98}_{42}Mo$	798.2	787.4	0.033	0.16 ± 0.16
${}^{92}_{42}Mo$	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

Double-β decay in Mo-98 isotope

Double beta (ββ) 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: ${}^{98}_{42}Mo \rightarrow {}^{98}_{44}Ru + e^- + e^- + 2\bar{\nu}_e$ ➡ Lepton number conserved

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

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

The ββ-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:

$\boxed{r_{12} \leq 2R_{nucl}}$ with $\boxed{R_{nucl} \approx 1.2A^{1/3}}$

The *rms* neutron radius could provide further constrains to define relative distance among neutrons in ${}^{98}_{42}Mo$

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.

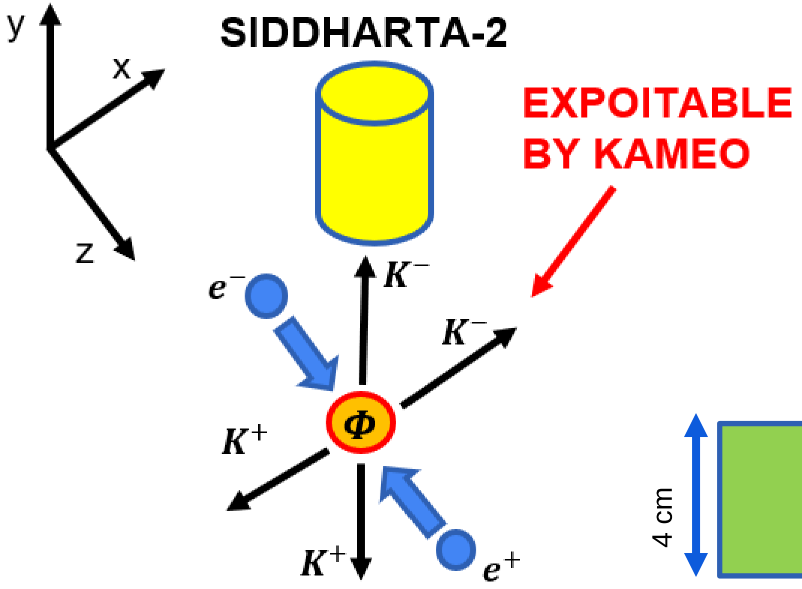
Nucleus	$E_{2^+} - E_{0^+}[keV]$	Levels mixed	$E_{n,l} - E_{n,l-2}[keV]$	$\Gamma_{n,l-2}[keV]$	Atten lines	Energy [keV]	Ref lines	Energy [keV]
$^{94}_{42}Mo$	871	(6,5)+(4,3)	798.8	24.8	6 → 5	284.3	7 →6	171.1
$^{96}_{42}Mo$	778	(6,5)+(4,3)	798.5	25.2	6 → 5	284.3	7 →6	171.1
$^{98}_{42}Mo$	787.4	(6,5)+(4,3)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

MOLYBDENUM OFFERS A UNIQUE OPPORTUNITY TO INVESTIGATE WITH NUCLEAR RESONANCES THE STRONG $K^- - N$ INTERACTION

EXPERIMENTAL PROPOSAL: KAMEO

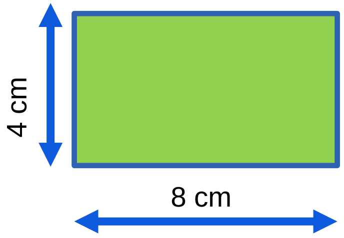
Kaonic Atoms Measuring nuclear resonance Effects Observables

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 High-Purity Germanium (HPGe) detector.



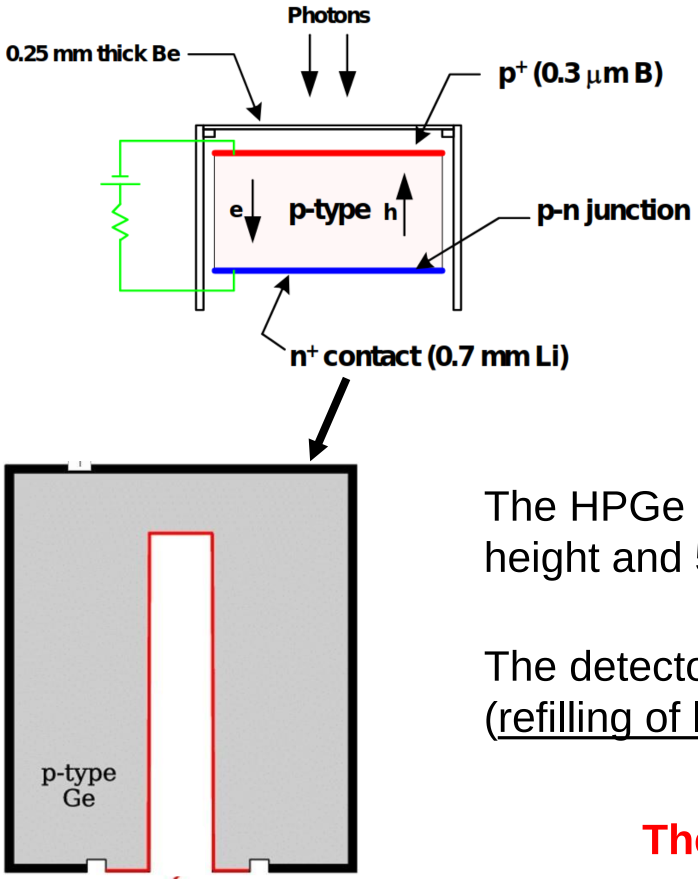
EXPOITABLE BY KAMEO

Mo isotope	Abundance	Half-Time
${}^{94}_{42}Mo$	9%	*stable*
${}^{96}_{42}Mo$	16%	*stable*
${}^{98}_{42}Mo$	24%	*stable*
${}^{100}_{42}Mo$	10%	$7.7 \times 10^{18}\ y$



Enriched (>99%) solid strip target of Mo isotopes 94, 96, 98, 100 and 92 (non-resonant suitable as refernce) will be exposed to the HPGe detector.

HPGe detector



A High Purity p-type Germanium Detector (HPGe), designed by Baltic Scientific 253 Instruments, could be used covering a wide energy range from hundred keV to a few MeV.

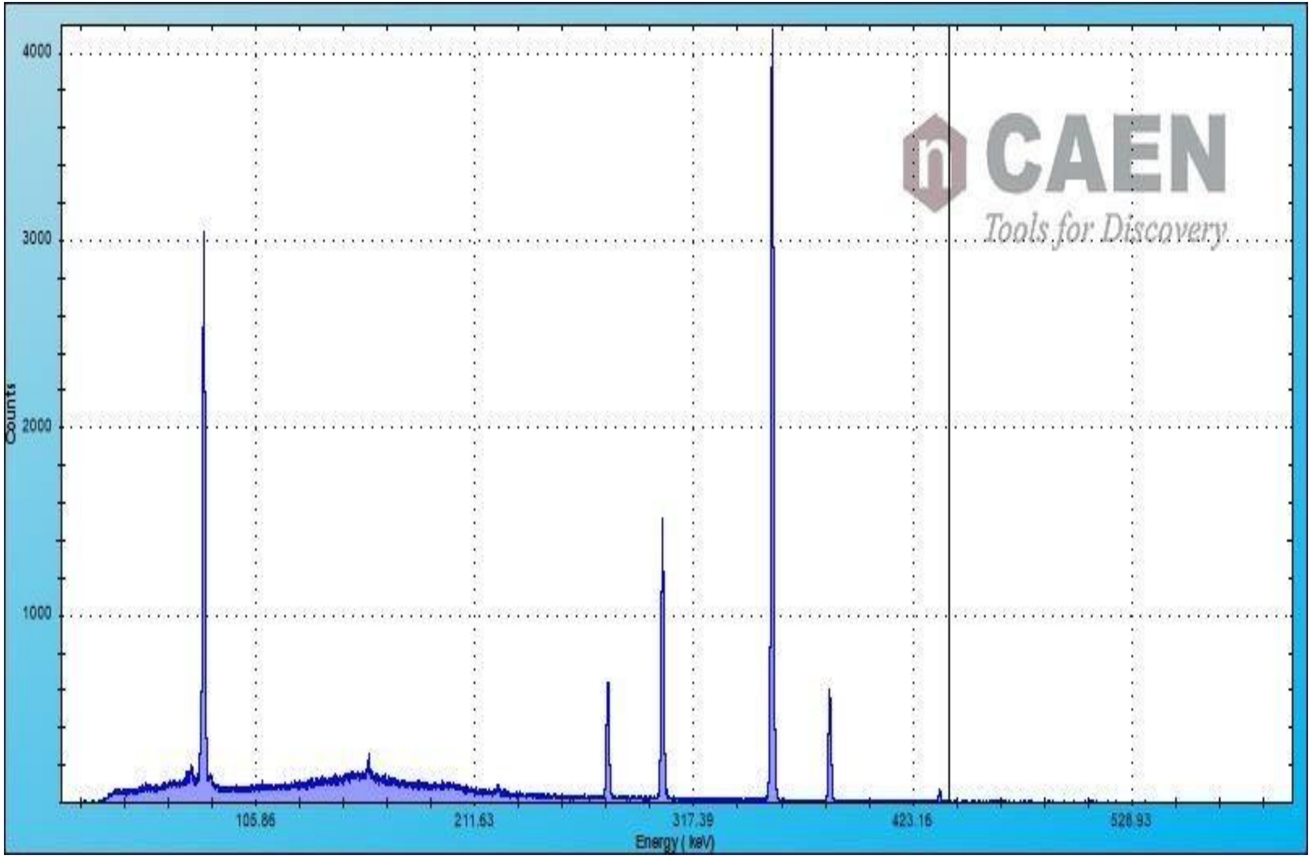
Such detector is able to work under high-rate conditions (to 150 kHz) and is 254 ideal to perform the measurements in the DAΦNE facility.

The HPGe detector has a cylindrical active volume with 59.3 mm of height and 59.8 mm of base diameter.

The detector need a cryogenic cooling for high-quality performances (refilling of liquid helium every week).

The detector is subject to RADIATION DAMAGE

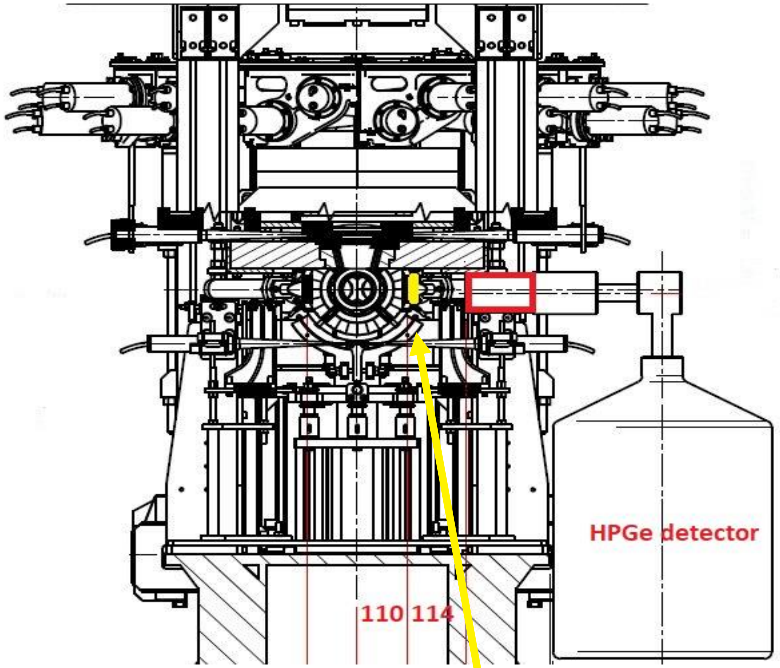
HPGe detector



Resolutions (FWHM) obtained with ^{60}Co, ^{133}Ba

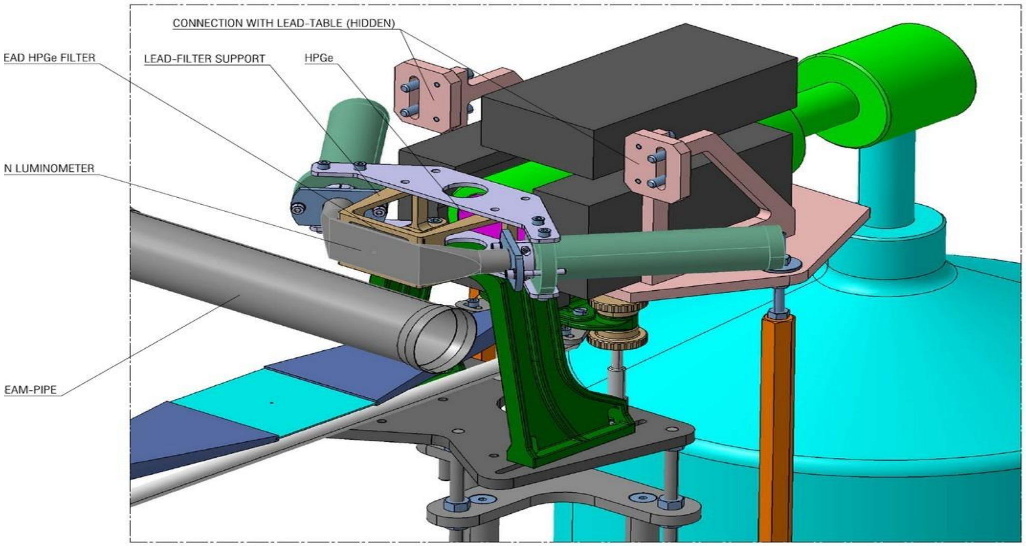
0.870 keV @ 81 keV
1.106 keV @ 302.9 keV
1.143 keV @ 356 keV
1.167 keV @ 1330 keV

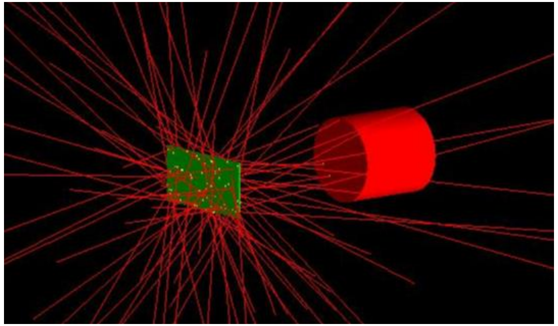
KAMEO setup with HPGe detector



Molibdenum solid target

Able to run in parallel with SIDDHARTA-2





Monte Carlo simulation to estimate target dimensions, timing and signal/background ratio.

SCIENTICIC IMPORTANCE OF KAMEO

- To obtain informations on the properties of deeply bound kaonic atoms, not accessible by the kaonic cascade, in ticklish nuclei → shift and width of the $n = 4$ level!

- In $K^{-} - {}^{98}_{42}Mo$ the attenuation coefficient (α) due to the nuclear resonance effect can be measured with higher precision.

- The α coefficient can be measured in ${}^{94}_{42}Mo$, ${}^{96}_{42}Mo$ and ${}^{100}_{42}Mo$ for the first time, providing new reference value for theorical models.

- The comparison of measurements in ${}^{94}_{42}Mo$, ${}^{96}_{42}Mo$, ${}^{98}_{42}Mo$ and ${}^{100}_{42}Mo$ could reveal new properties of strong kaon-nucleon interaction (also ${}^{96}_{44}Ru$).

- The search for isotope effects in the level shift (ε) and width (Γ) would reveal sign of changes in the nuclear periphery when pair of neutrons are added to the lighest isotope (${}^{94}_{42}Mo$)

- To study nuclear distribution in ${}^{98}_{42}Mo$, providing important details to investigate neutrinoless double beta ($0\nu\beta\beta$) and two-neutrino double beta decay ($2\nu\beta\beta$)

WHAT ARE WE DOING?

1. Developing the Monte Carlo simulation for estimate best target dimensions

2. Estimating shifts and width of 4f level in K-Mo isotopes in nuclear excited 2+ state due to the strong kaon-nucleus interaction, to evaluate needed precision for an experimental measurement

3. Collecting environmental data in the DAFNE collider, with HPGe detector, to estimate the background.

4. Looking for further information and parameters that can be extracted about strong interaction in strangeness sector and nuclear structure, investigating the E2 nuclear resonance in kaonic atoms.

ANY SUGGESTION???

THANK YOU FOR YOUR ATTENTION!!!

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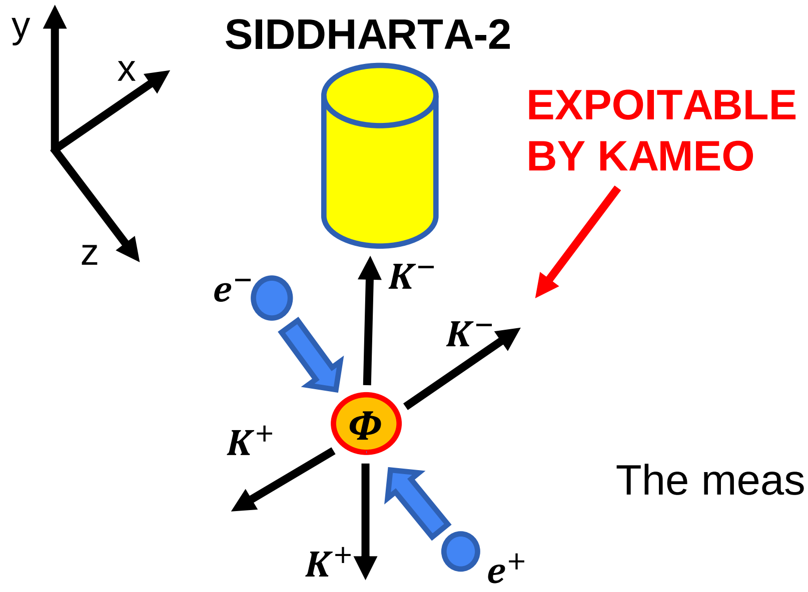

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The measure could be performed with two different detectors:

- Cadmium-Zinc-Telluride (CdZnTe)
- High Purity Germanium Detector (HPGe)

REFERENCES

- Gary L. Godfrey, Gary K. Lum, Clyde E. Wiegand, «OBSERVATION OF DYNAMIC E2 MIXING VIA KAONIC X-RAY INTENSITIES », Phys. Lett B, https://escholarship.org/uc/item/6v72406j, 1975
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The nucleus is excited to the 2^+ rotational state by the *electric quadrupole interaction*:

$$V_q = -\frac{e^2}{2r^3} Q_{2\mu} Y_{2\mu}$$

where μ is the $K^- - N$ reduced mass, $Q_{2\mu}$ is the nuclear quadrupole operator and $Y_{2\mu}$ are the spherical harmonics.

$$|\Phi\rangle = \sqrt{1 - |\alpha|^2}\, |n, l, j, 0^+, F\rangle + \alpha |n', l-2, j', 2^+, F\rangle$$

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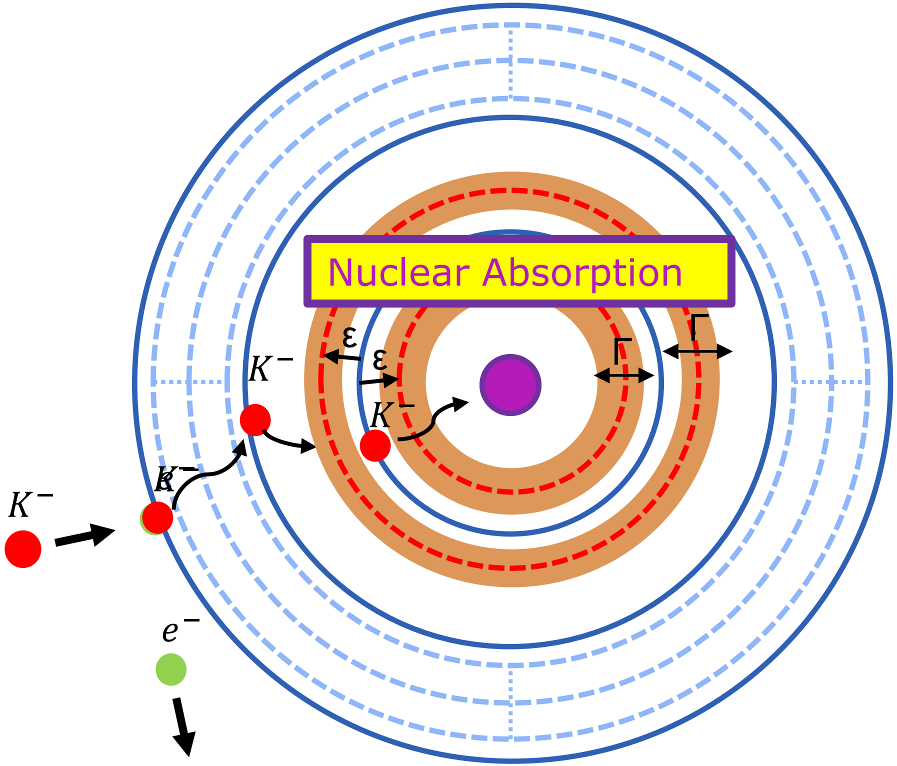
In ligth kaonic atoms experiments, it is essential to favor the cascade process down to the innermost atomic levels, in which shift (ε) and width (Γ) due to strong kaon-nucleon interaction become measurable.

Finally, the kaon is absorbed by the nucleus



The E2 Nuclear Resonance Effect

The **classical analogy** would be to have *the period of a hadron in its elliptical orbital match the natural vibration frequency of the nucleus*, so that every pass through perigee the hadron strokes the nucleus at just the right time, *and* hence *builds up a large nuclear oscillation*.

Quanto-mechanically, the noncentral coupling between the hadron and the nucleus produces configuration mixing (E2), so that the *energy eigenfunction contains a small admixture of excited nucleus-deexcited atom wavefunction*:

$$\psi = \sqrt{1-a}\,\phi(6h,0^+) + a\,\phi(4f,2^+)$$

where the admixture coefficient $a = \pm \dfrac{\langle 4f,2^+ | H_q | 6h,0^+ \rangle}{E_{(4f,2^+)} - E_{(6h,0^+)}}$ (very small), and H_Q

expresses the *electric quadrupole interaction* between hadron and nucleus.

The E2 Nuclear Resonance Effect

The matrix element $\langle H_Q \rangle$ ***for a spin-zero hadron*** is given by:

$$\langle H_Q \rangle = \pm\frac{1}{2}e^2\underline{Q_0\langle r^{-3}\rangle}\underline{[(2l+1)(2l'+1)(2l+1)(2l'+1)]^{\frac{1}{2}}\times\begin{pmatrix}2 & I & I' \\ 0 & -K & K\end{pmatrix}\begin{pmatrix}2 & l & l' \\ 0 & 0 & 0\end{pmatrix}\begin{Bmatrix}2 & I & I' \\ F & l' & l\end{Bmatrix}}$$

Q_0 is the nuclear quadrupole strength

$\langle r^{-3}\rangle$ is the quadrupole orbital radius

I, I', K, K', l, l', F are angular momentum factors

H.L. Acker, Nucl. Phys. **87**, *153*, 1966

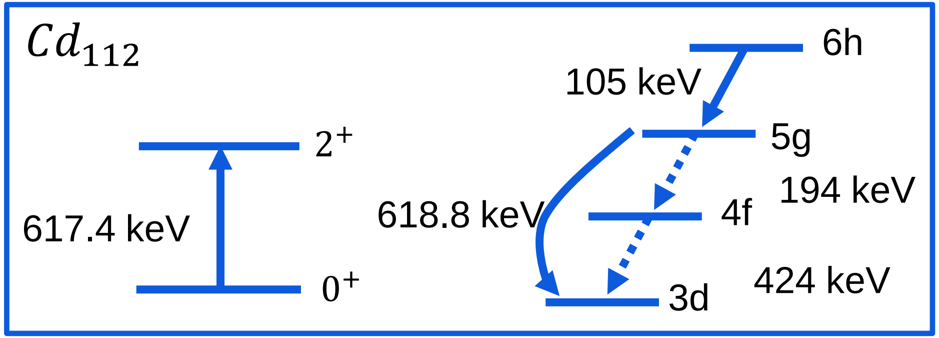
- Q_0 comes directly from the measured Coulomb excitation cross-sections ($B(E2\uparrow)$ values).
- $\langle r^{-3}\rangle$ can be evaluated using point Coulomb wave functions
- I, I', K, K', l, l', F can be with angular-momentum rules (i.e. for spin one-half $l \rightarrow j, \mathrm{etc}$ ...)

CALCULATIONS ARE INDEPENDENT OF ANY PARTICULAR NUCLEAR MODEL

The pionic cadmium 112 experiment

An experiment measuring E2 resonance effect cadmium 112 was performed in 1975 by J. N. Bradbury, H.Daniel, J. Reidy and M. Leon at the biomedical pion beam of Los Alamos Meson Physics Facility (LAMPF).

In pionic cadmium (112), the energy difference between 5g and 3d levels, 618.8 keV, is very nearly equal to the nuclear excitation energy of 617.4 keV.

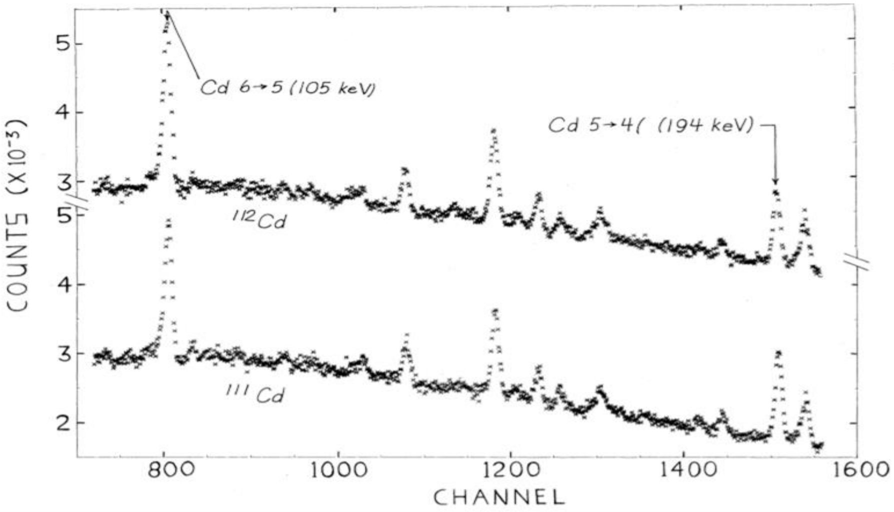


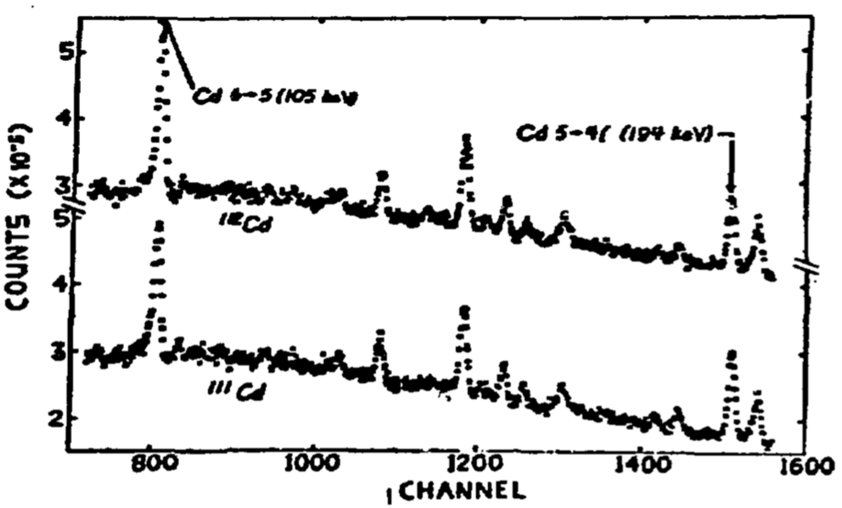
Experimental apparatus and measurement features:

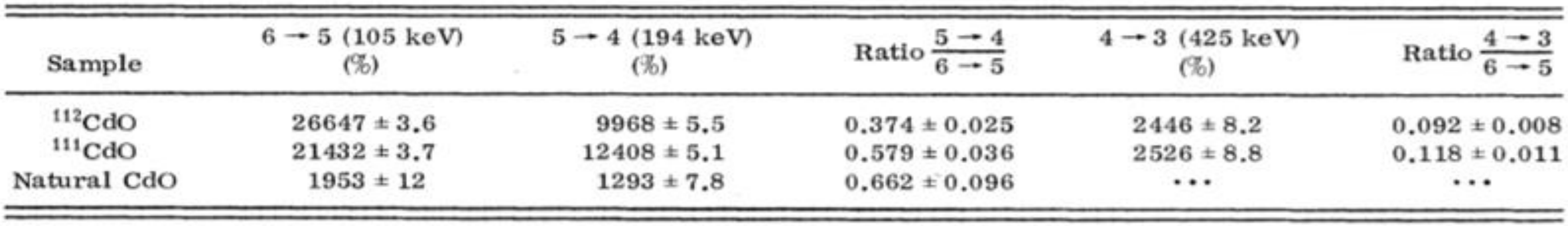
- The experiment consisted of placing enriched isotope targets of Cd(111) e Cd(112) in turn into the negative pion beam for **2 hours**.
- The spectra were collected using a **germanium detector** feeding a pulse height analyzer.
- Natural Cadmio was exposed for a shorter time to provide consistency check.

Pionic cadmium 112 measurement

These results demonstrate the existence of the Nuclear Resonance Effect: the ratios are very significantly different from one.







Sample	6 → 5 (105 keV) (%)	5 → 4 (194 keV) (%)	Ratio $\frac{5 \to 4}{6 \to 5}$	4 → 3 (425 keV) (%)	Ratio $\frac{4 \to 3}{6 \to 5}$
^{112}CdO	26647 ± 3.6	9968 ± 5.5	0.374 ± 0.025	2446 ± 8.2	0.092 ± 0.008
^{111}CdO	21432 ± 3.7	12408 ± 5.1	0.579 ± 0.036	2526 ± 8.8	0.118 ± 0.011
Natural CdO	1953 ± 12	1293 ± 7.8	0.662 ± 0.096	···	···

Pionic cadmium 112 measurement

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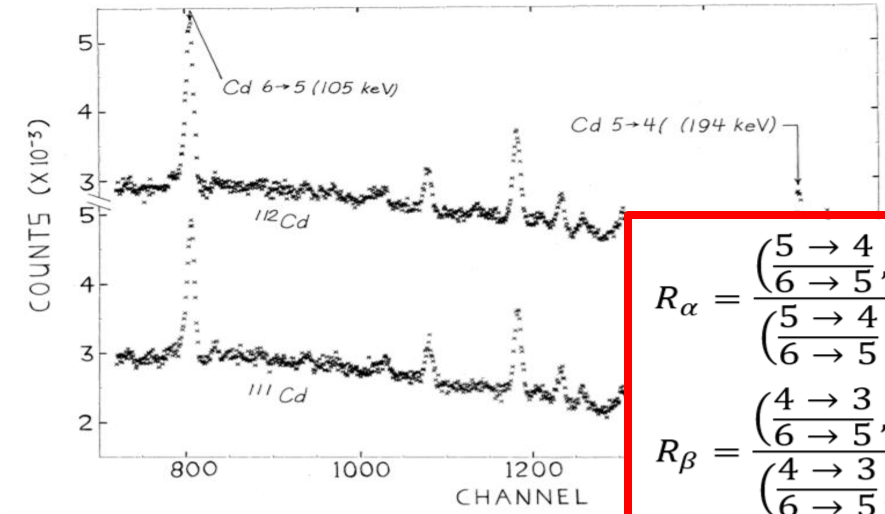
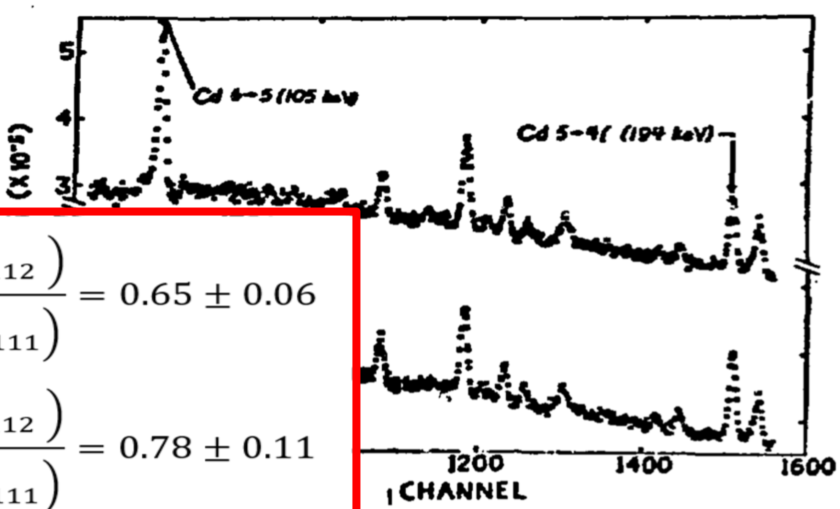
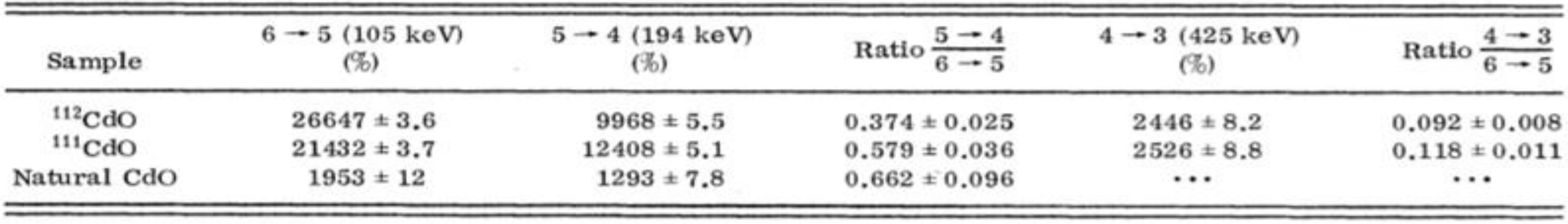




$$R_\alpha = \frac{\left(\frac{5\rightarrow 4}{6\rightarrow 5}, Cd_{112}\right)}{\left(\frac{5\rightarrow 4}{6\rightarrow 5}, Cd_{111}\right)} = 0.65 \pm 0.06$$

$$R_\beta = \frac{\left(\frac{4\rightarrow 3}{6\rightarrow 5}, Cd_{112}\right)}{\left(\frac{4\rightarrow 3}{6\rightarrow 5}, Cd_{111}\right)} = 0.78 \pm 0.11$$



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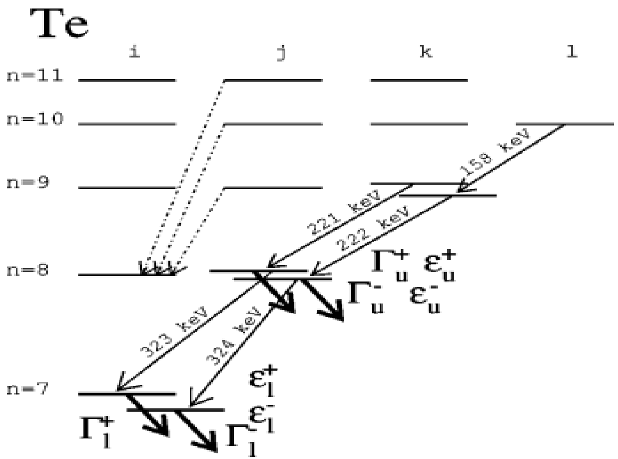
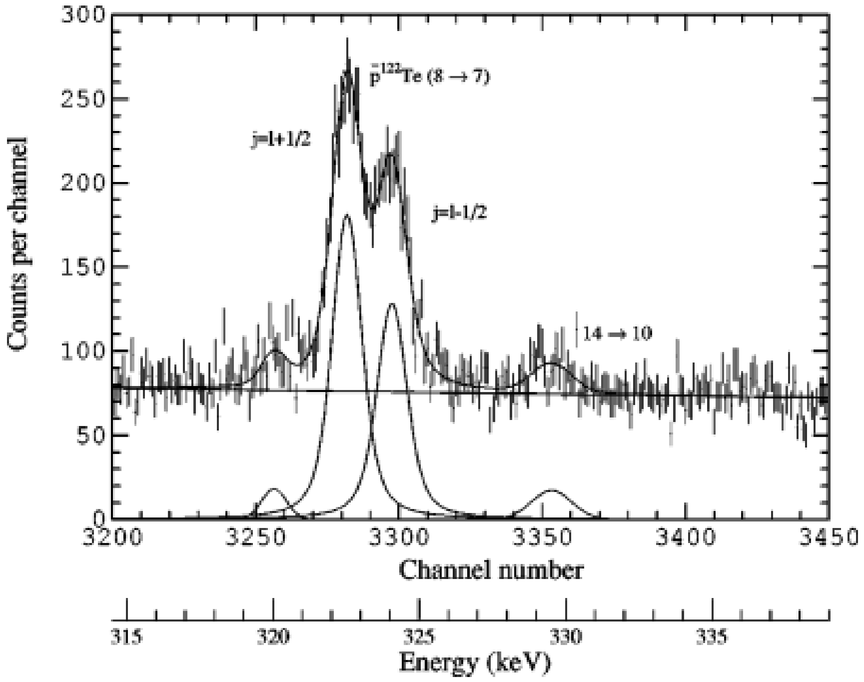
The antiprotonic Te experiment

Five even-A tellurium isotopes were investigate in two experiments conducted in 1995 and 1996 using antiprotons with momenta 300 MeV/c ($^{124}_{52}Te$, $^{128}_{52}Te$, $^{130}_{52}Te$) and 106 MeV/c ($^{122}_{52}Te$, $^{126}_{52}Te$).

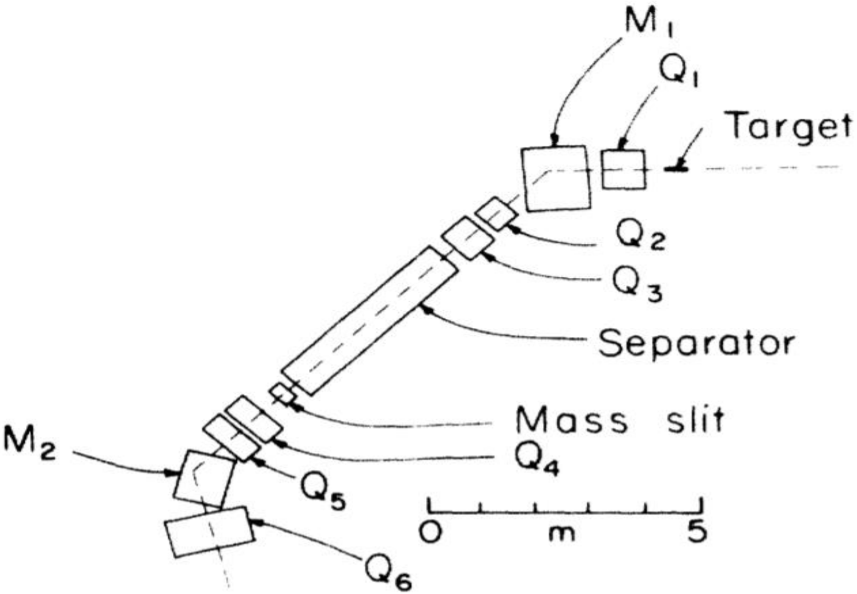
High Purity Germanium (HPGe) detectors were employed for the x-ray measurement. The energy resolution was about 1 keV at 200 keV (relative efficiency was about 19%)





The kaon beam at Bevatron

Negative kaons were produced in a tungsten target (5.08 cm in legth along the beam, 0.50 cm high and 0.76 cm wide) by a proton beam with 5.6 GeV energy and 5×10^{11} of proton intensity per machine burst. The duration of each burst was 1 second and it was repeated for 6 seconds.



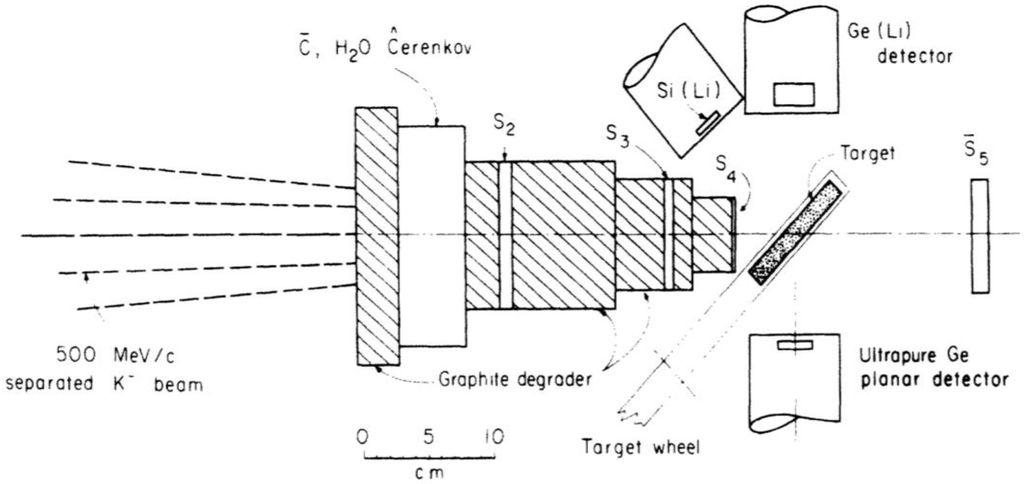
Kaons and other particles produced in the forward diections entered a mass spectrometer, consisting of 6 Quadrupoles (Q) two bending magnets (M), a separator and a «mass» slit.

A scintillator (S1) was placed behind the mass slit for kaon identification.

At the end of the mass spectrometer (Q6) a **500 MeV/c separated K^- beam is produced.**

The kaon beam at Bevatron

Downstream from Q6, a group of counters consisting of water Cerenkov counter, and 4 scintillators (S2, S3, S4, S5) were installed to discriminate kaons from pions, with the use of time of flight and anticoincidence with Cerenkov counter, and from background.



The target consists in a pill-box-shaped vessel made from stock methyl-methacrylate tubing 10.16 cm outside diameter (8.9 cm inside diameter).

Target thickness was 2 g/cm^2 (2.8 g/cm^2 along the beam)

The target was filled with 99% pure isotopes of Molybdenum 92 and 98, alternatively.

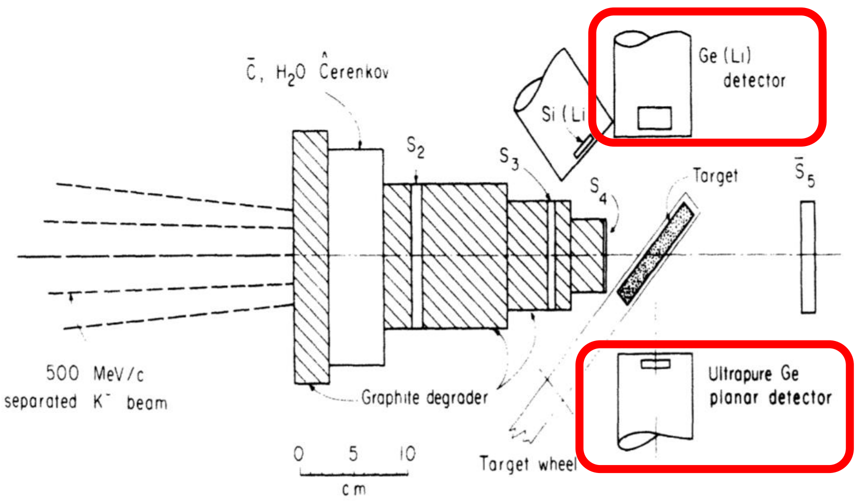
The flat sides of the container was of Mylar, less than 0.0127 cm thickness

The Germanium Detectors

The x-ray spectra coming from $K^- - {}^{98}_{42}Mo$ and $K^- - {}^{92}_{42}Mo$ were collected with ultrapure Germanium and Ge(Li) detectors, whose resolutions was estimated with the formula:

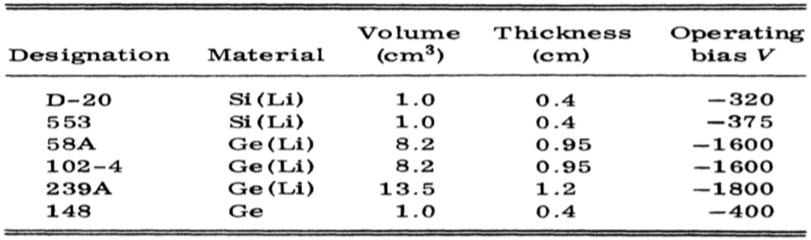
$$\Delta E(FWHM) = [P^2 + (2.36)^2 E\epsilon F]^{1/2}$$

where F=0.08 is the Fano Factor, $\epsilon = 2.94\ \mathrm{eV}$ is the average energy to make an electron-gole in Germanium, E is the energy deposited in the detector and P is the random noise



The ultrapure Ge detector is 0.4 cm thickness and has 1.8 cm of diameter, and provided a resolution of 580 eV FWHM at 85 keV

Ge(Li) detectors provided a resolution of 400 eV FWHM at 100 keV



Designation	Material	Volume (cm^3)	Thickness (cm)	Operating bias V
D–20	Si(Li)	1.0	0.4	−320
553	Si(Li)	1.0	0.4	−375
58A	Ge(Li)	8.2	0.95	−1600
102–4	Ge(Li)	8.2	0.95	−1600
239A	Ge(Li)	13.5	1.2	−1800
148	Ge	1.0	0.4	−400

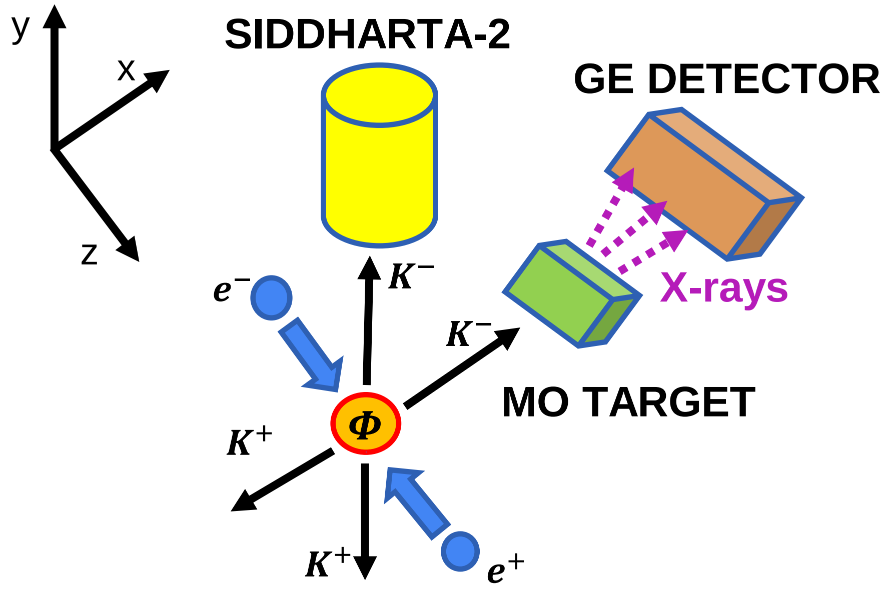
$K^{-}Mo$ Predicted Nuclear Resonance effects

Isotope	Abundance [%]	Energy [keV]	Attenuation [%]
${}^{92}_{42}Mo$	15.8	1540	NONE
${}^{94}_{42}Mo$	9.0	871	18
${}^{95}_{42}Mo$	15.7	786	7
${}^{96}_{42}Mo$	16.5	778	71
${}^{98}_{42}Mo$	23.8	787	81
${}^{100}_{42}Mo$	9.6	536	4.5

The molybdenum costs 45 $ per Kg. Some experiments carried out in Warsaw used ${}^{98}_{42}Mo$ and ${}^{100}_{42}Mo$ targets. Informations about enriched Mo isotopes target could be found.

M. Leon, Phys. Rev. **A260**, 461-473 (1976)

EXPERIMENTAL PROPOSAL



DAFNE luminosity: $L = 10^{32} cm^{-2} s^{-1}$

Number of ϕ particles produced per second:
$N_\phi = 10^{32} cm^{-2} s^{-1} \times (1968 \times 10^{-33} cm^2) = 197\ s^{-1}$

Probability of K^- production: $P_{\phi \to K^+ K^-} = 48{,}9\%$

Number of K^- particles produced per second:
$N_{K^-} = 197\ s^{-1} * 0{,}489 = 96\ s^{-1}$

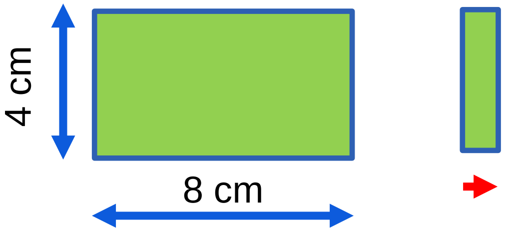
Minimum target distance: $d_{min} = 7.5\ cm$

Spherical K^- distribution: $S = 4\pi \cdot d_{min}^2 = 706.86\ cm^2$

Number of K^- on target: $N_{K^-}^T < \frac{N_{K^-}}{S} \cdot (32\ cm^2) \approx 4\ K^-\ s^{-1}$

Signal/background should been exstimated with MC to understand precision of measurement

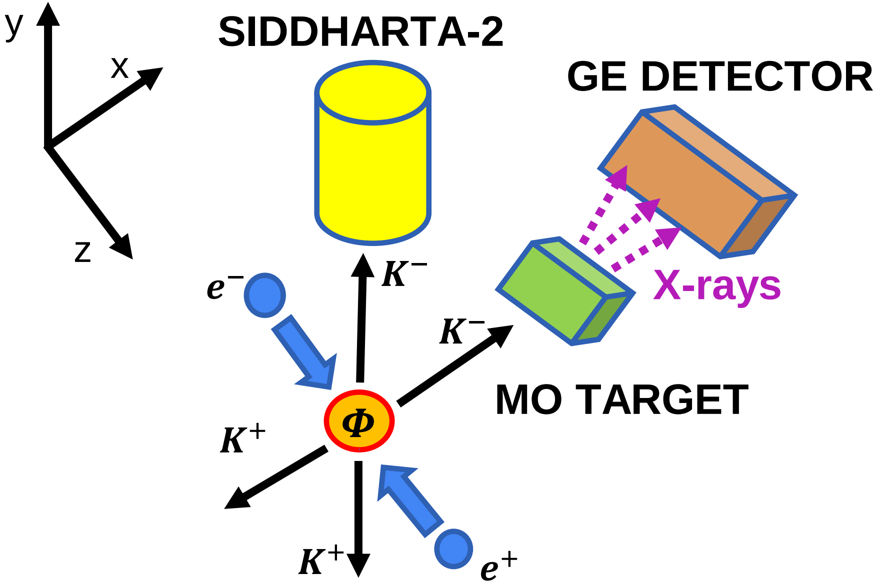
Minimum solid Mo target dimention:



Thickness to be determined with Monte-Carlo

EXPERIMENTAL PROPOSAL

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.



The measurement don't affect SIDDHARTA-2

Mo Transition	Energy (eV)	Intensity (%)
K_{α_1}	17479.34	100
K_{α_2}	17374.3	*52*
K_{β_1}	19608.3	*26*
L_{α_1}	2293.16	100
L_{α_2}	2289.85	11
L_{β_1}	2394.81	53
L_{β_2}	2518.3	5
L_{γ_1}	2623.5	3