Luca De Paolis on behalf of the SIDDHARTA-2 Collaboration
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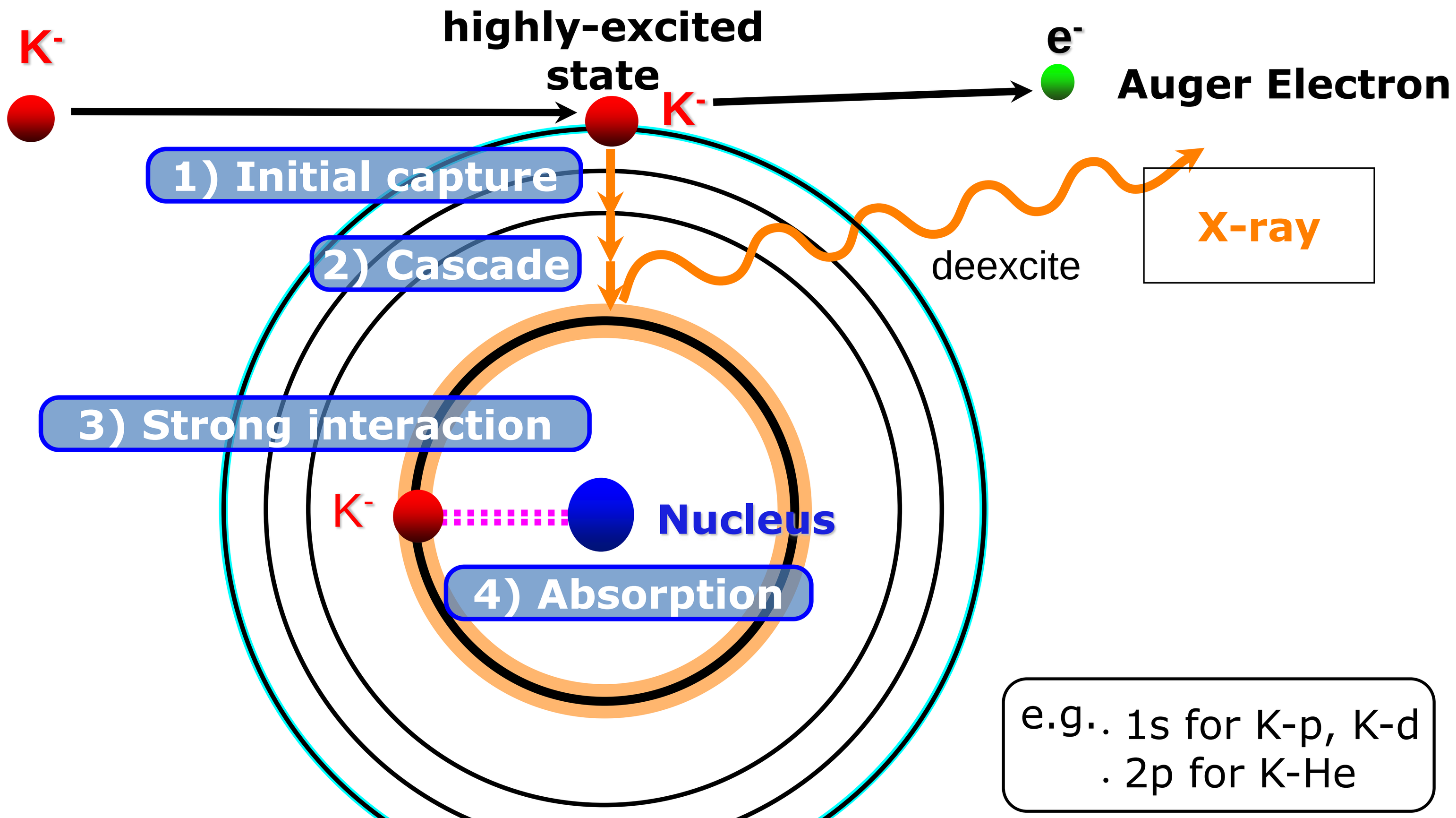
Nuclear Resonance effect in kaonic atoms

INFN LNF Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

Kaonic atom formation

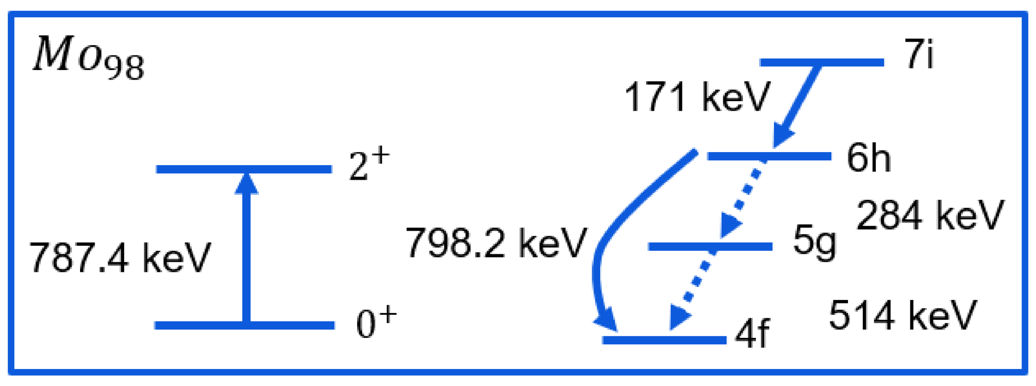
$n \approx \sqrt{\frac{\mu}{m_e}} \cdot n_e$, where μ is the reduced mass, m_e the electron mass and n_e is the principal quantum number of the outermost electron shell



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

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

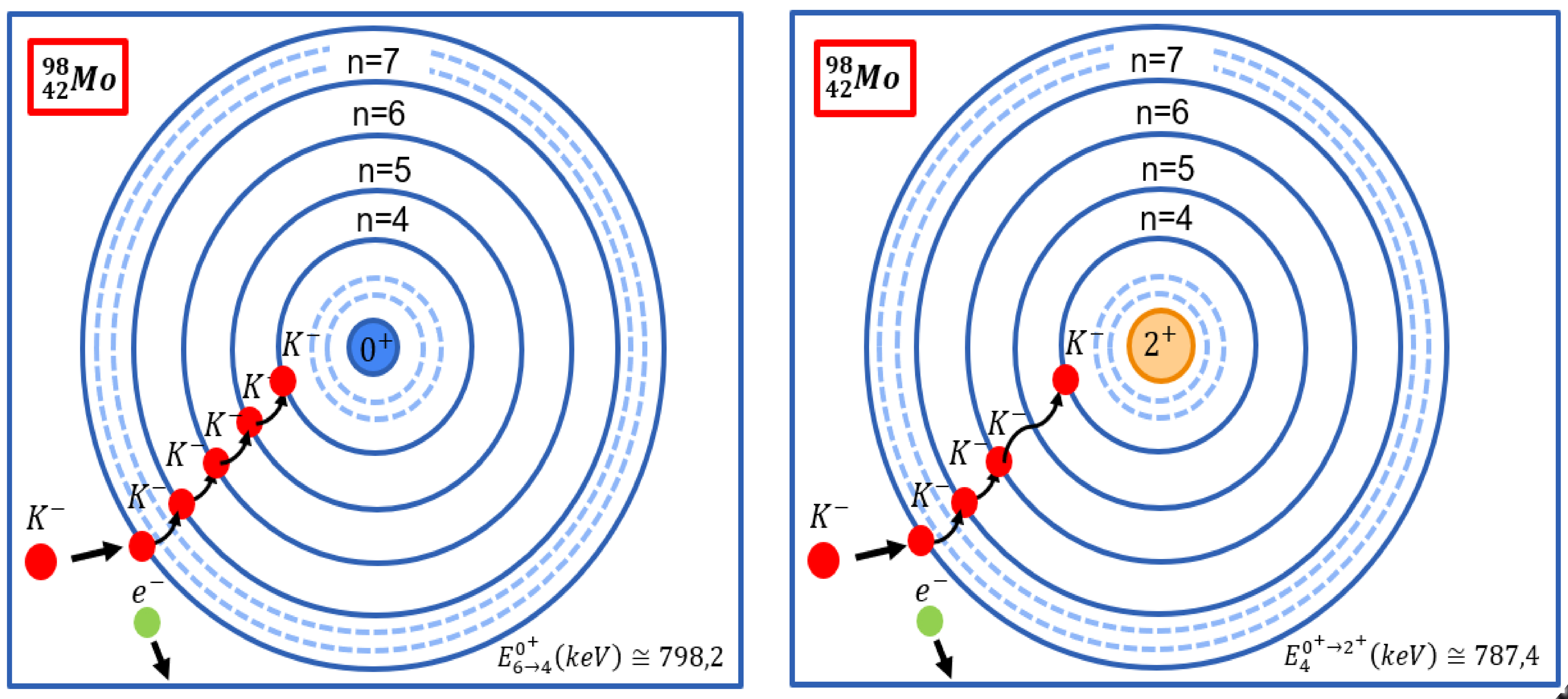
In kaonic $^{98}_{44}Mo$, the energy difference between 6h and 4f levels, 798.2 keV, is very nearly equal to the nuclear excitation energy of 787.4 keV.



- Isotope of $^{92}_{44}Mo$, in which the resonance doesn't occur, can be used as reference to measure the attenuations.
- X-rays measurable with **High Purity Ge detectors (HPGe)**

The E2 Nuclear Resonance Effect

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.



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

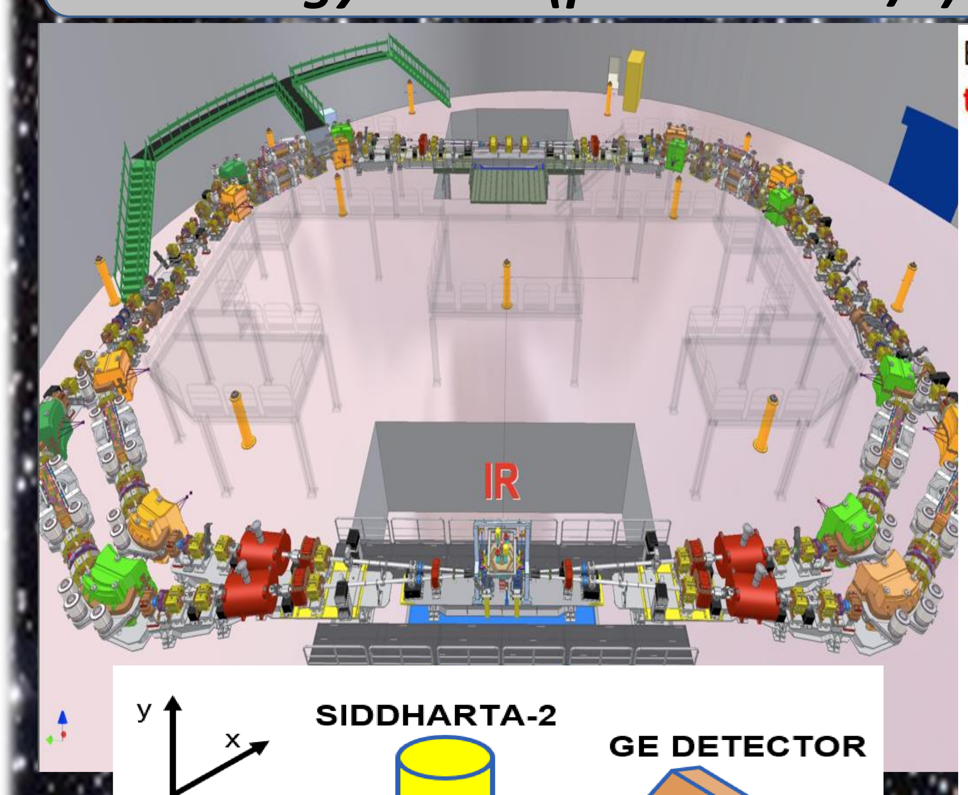
The nuclear absorption rate increases very drasically (by a factor of several hundred) for each unit decrease of orbital angular momentum; thus for a decrease of $\Delta l = 2$, the factor may be around 10^5.

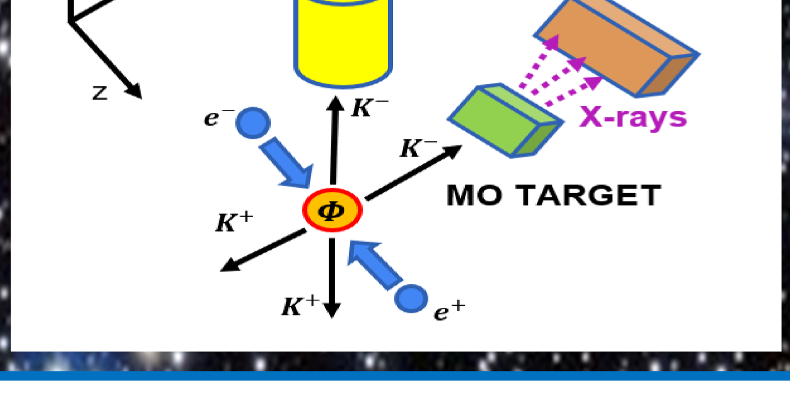
A very small admixture coefficient α (typically 1%) can mean a significant induced width!

INDUCED WIDTH: $\Gamma^{Ind}_{n,l} = |\alpha^2| \Gamma^0_{n',l-2}$

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

The DAΦNE collider provides low energy kaons (p ~ 127 MeV/c)





3.1. Detection unit GCD-30185 characteristics

#	Parameter	Value
1.	Relative efficiency (with respect to 3'' x 3'' NaI detector and Co-60 source mounted 25 cm above the detector) at 1.33 MeV γ-photon	> 30 %
2.	Energy resolution* at • 122 keV • 477.6 keV • 1.33 MeV *Measured with spectrometric device MS Hybrid at input count rate 1000 pulses/sec, shaping time constant = 6 μsec	875 eV 1400 eV 1850 ± 30 eV
3.	Peak shape: • FWTM/FWHM • FW.02M/FWHM	< 1.9 < 2.65
4.	Spectral Broadening of FWHM up to 100,000 counts/sec for 1.33 Mev	< 8 %
5.	Peak position shift	< +/- 0.018 %
6.	Peak to Compton ratio, not worse	58 : 1
7.	Energy range of detector operation	40 keV – 3 MeV
8.	Material of input window	Al
9.	Cooling time	< 8 hours
10.	Liquid nitrogen holding time in Dewar vessel	> 15 days
11.	Dewar volume	30 l
12.	Preamplifier (built – in detector capsule) with cooled FET and transistor reset preamplifier (TRP) • Preamplifier power supply is ±12 V with 9 pin connector compatible with NIM standards • TTL signal to shut down the HV: - detector warm -0V; - detector cold: +5V • HV INHIBIT – BNC	

WHY INVESTIGATE NUCLEAR RESONANCE EFFECTS IN KAONIC MOLYBDENUM?

1. To measure shift and width of the $n = 4$ level, not accessible by kaonic cascade, investigating deeply bound kaonic atoms.
2. The measurement of the attenuation α coefficients in $^{94}_{44}Mo$, $^{96}_{44}Mo$, $^{98}_{44}Mo$ and $^{100}_{44}Mo$ could provide fundamental information on kaon-nucleus strong interaction.
3. Isotope effects in the level shift and width would reveal sign of changes in the nuclear periphery when pair of neutrons are added to the lighest isotope ($^{94}_{44}Mo$)
4. To study nuclear distribution in $^{98}_{44}Mo$, providing important details to investigate neutrinoless double beta ($0\nu\beta\beta$) and two-neutrino double beta decay ($2\nu\beta\beta$)

MEASUREMENT WILL BE PERFORMED IN 2022/2023

References:
- M. Leon, «Hadronic Atoms and Ticklish Nuclei: The E2 Nuclear Resonance Effect», United States: N. p., (1975).
- S. Wycech, Nucl. Phys. A561, 607 (1993)
- Nesterenko, D.A., Jokiniemi, L., Kotila, J. *et al.*, Eur. Phys. J. A 58, 44 (2022)

Contact:
Email to: Luca.DePaolis@lnf.infn.it