Novel approaches in low energy threshold detectors for Dark Matter searches

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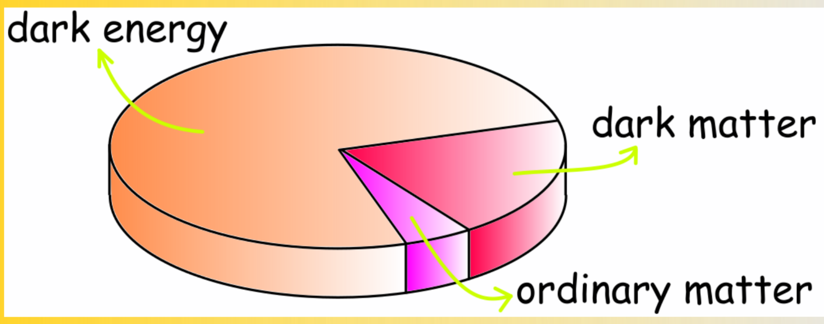
Axioma MATRIX

DM — Dark Matter

- ≈27% of the Universe energy
- ρ=0.45GeV/cm3

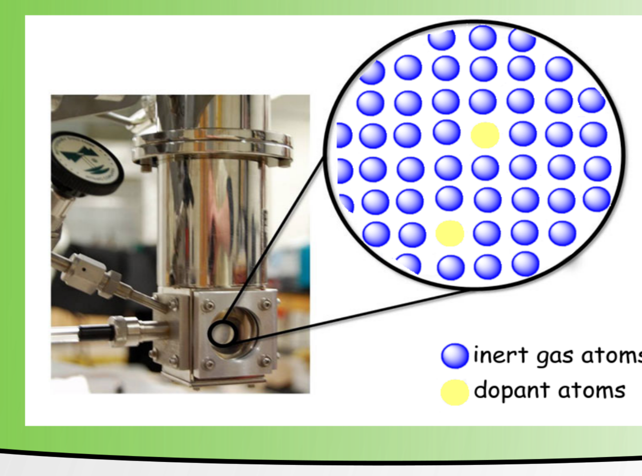


- Axion: strong CP problem solution
- $m_a \cong 0.6[\text{eV}]\,\frac{10^7[\text{GeV}]}{f_a}$

The Axioma experiment is an R&D project for the development of a novel class of particle detectors based on solid crystals of inert gases such as Neon, Xenon, para-Hydrogen and others. We exploit ultra-pure and doped crystals combined with laser spectroscopic technique to improve the actual standard of the detectors' energy threshold. The final goal is thus to reach an innovative technology for Dark Matter searches as well as for the investigation of feeble interacting phenomena characterized by low energy deposition events.

MIT — Matrix isolation technique

- Solidified inert gases at cryogenic temperature
- Condensed phase crystals
- Unreactive matrices (hosts)
- Guest samples embedded-in

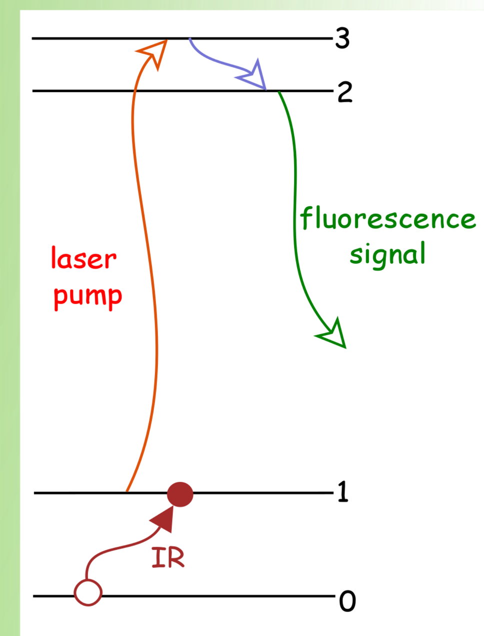


Rare gas matrices represent an interesting environment because of their chemically inert property and weak perturbations. In addition other advantages are the suppression of guest-guest interactions (at sufficient dilution) and the excellent optical properties, including isotropy and transparency from the far IR to the vacuum UV.
The initial gas is purified under the ppb level through a composite filter set-up made of active charcoal filters and Oxysorb cartridges. The high-purity gas thus obtained is injected for hours into the growing chamber at a pressure lower than 0.0001mbar. The doping can be done at this point, by evaporating in the chamber the guest material at a pressure n times lower with respect to the gas (1/n represents the concentration of the dopant). The crystals obtained after a further annealing process can be used for our tests as particle detectors.
In some of these crystals, the self-energy of electrons V_0 is also positive and the free electrons are more prone to be emitted through the solid-vacuum interface. Then, the in-vacuum electrons can be measured through high efficiency sensors with low dark count rate such as microchannel plate (MCP) or channeltron detectors.

In order to reach a suitable low energy threshold scheme, we are investigating three different possibilities:

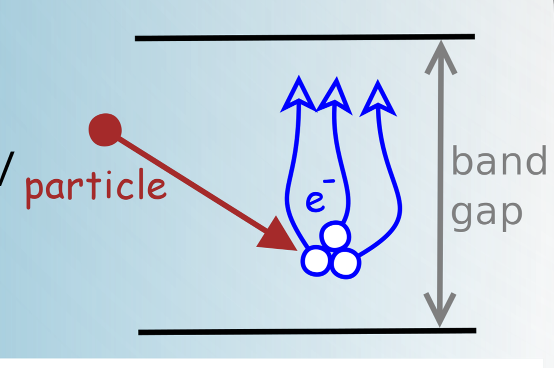
IRQC — InfraRed quantum counter

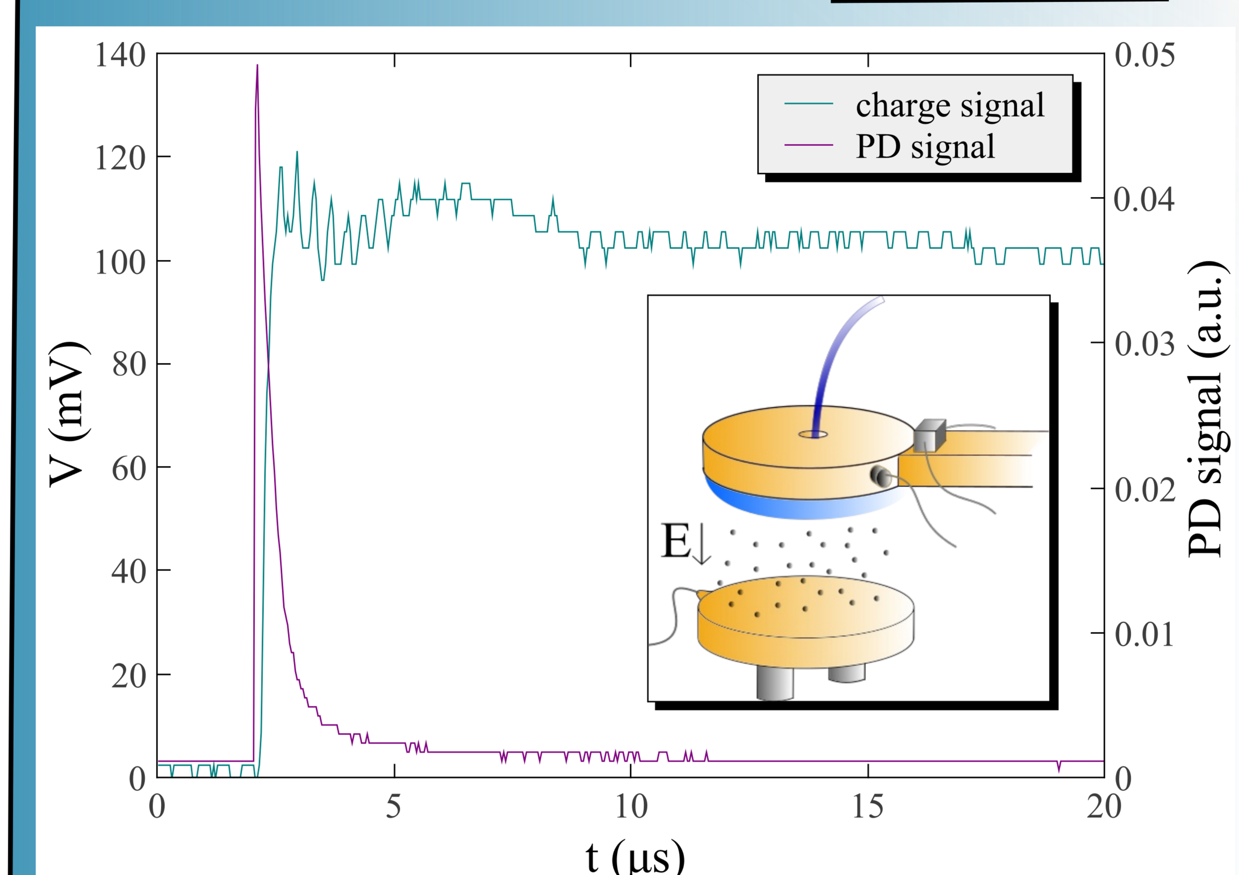
- Rare-earth doped solid crystals
- Laser up-conversion: IR to VIS photon
- Efficiency: $\eta \cong N\sigma_{13}\tau_2$
- IR transition 0→1
- Laser pump 1→3
- Non-radiative decay 3→2
- Fluorescence signal 2→0



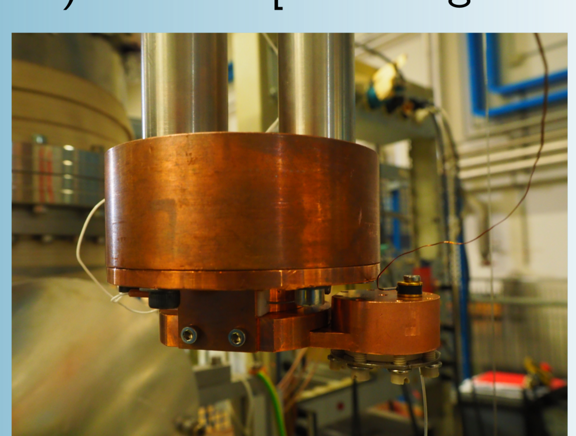
A — Undoped matrices

- Incident particles ionize the undoped matrix
- Band gap energy is tens of eV
- Electron extraction
- Charge signal

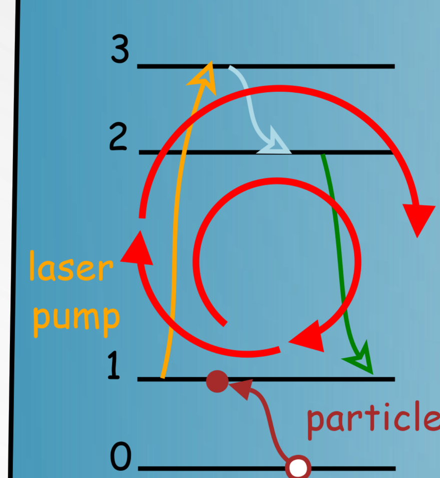




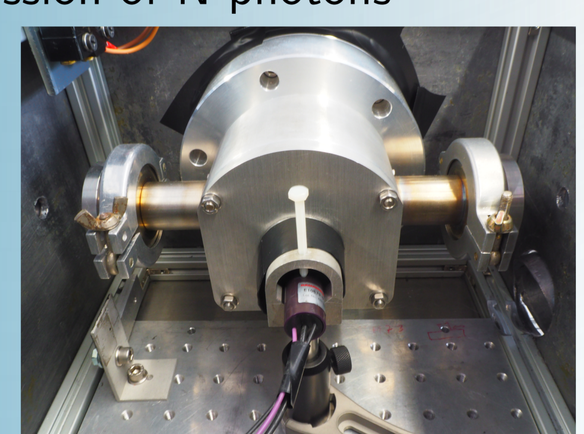
We measured electrons extraction from a solid crystal of Neon (≈1cm^3) at 5.5K [in the figure the charge signal]. For our tests, photoelectrons are injected into the crystal when UV laser pulses impinge on a gold substrate.



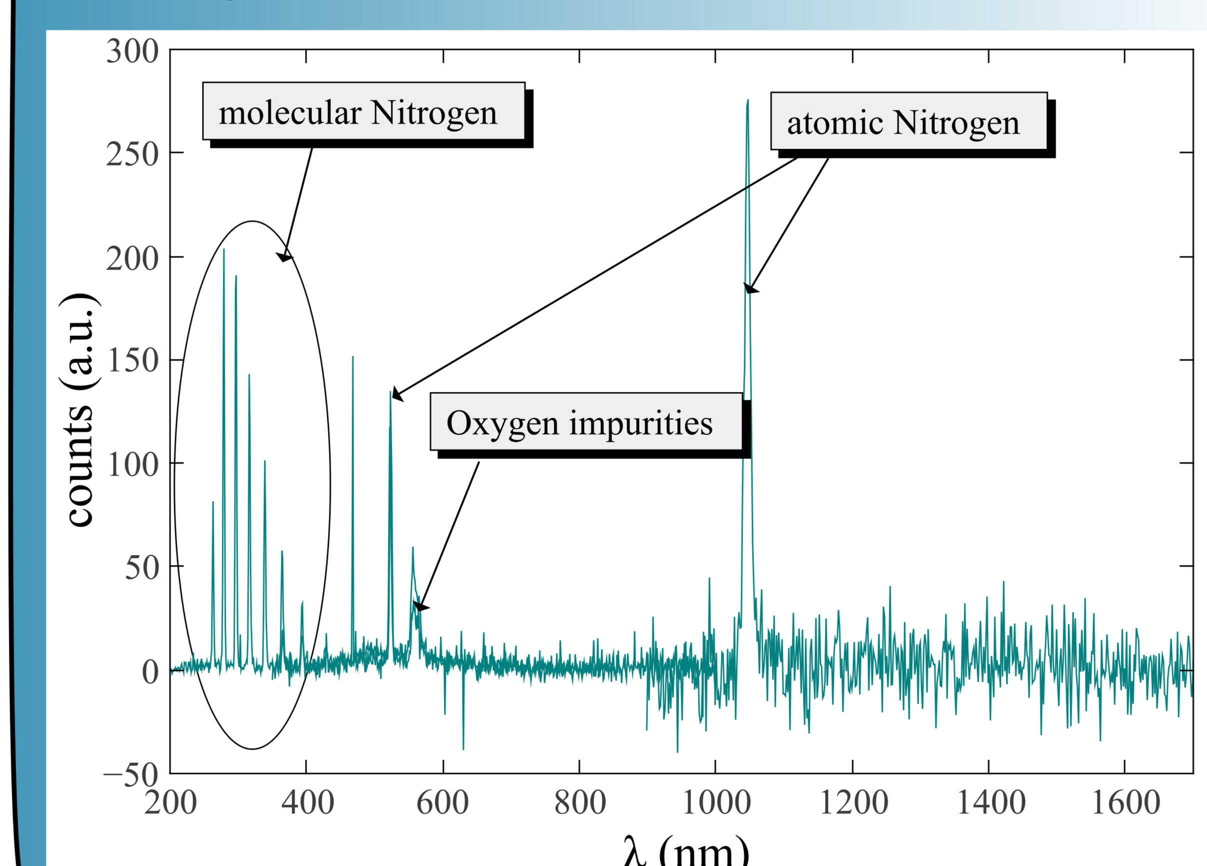
B — Recycling scheme



- Laser-assisted transition 1→3
- Fluorescence signal 2→1
- Recycling mechanism 1→3→2→1
- One single transition 0→1 triggers the emission of N photons

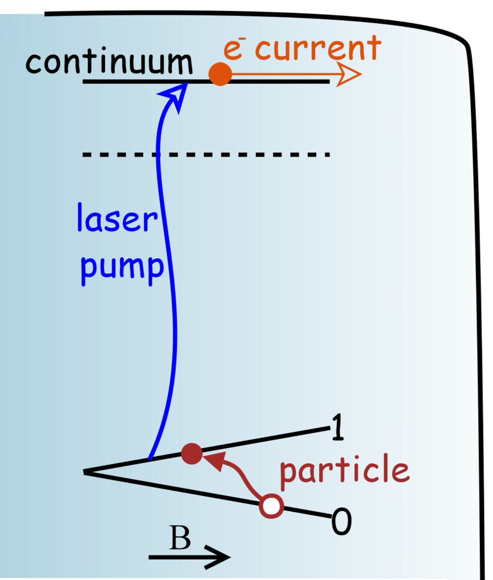


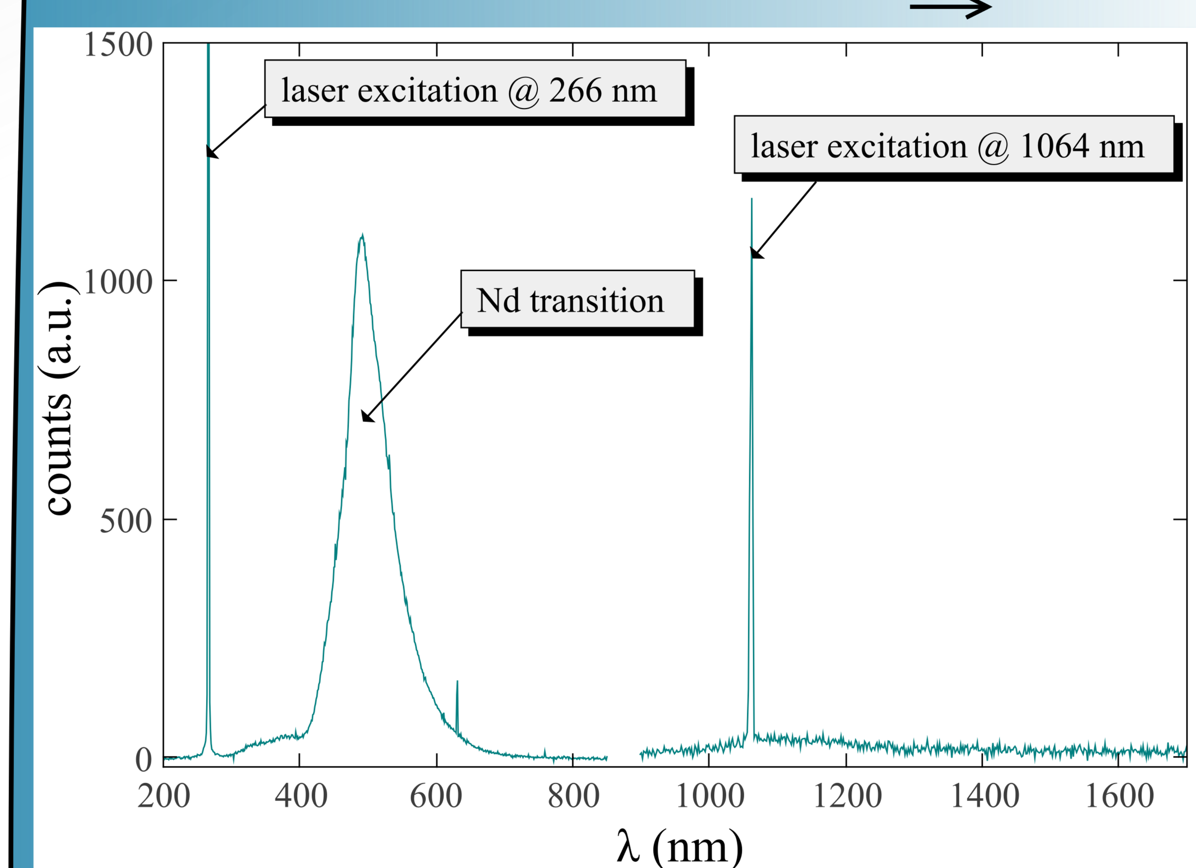
We are interested in schemes that involve both the vibrational bands of the undoped matrices [in the figure, the cathodoluminescence emission spectra of solid nitrogen @ 20K], and the energy levels of RE doped crystals.



C — Doped crystals

- Zeeman splitting of ground state level
- Very small energy transition (meV)
- Laser induced ionization (LII)
- Charge signal





We did initial tests with 1% Nd-doped solid Neon. Emission spectra was recorded when the crystal was excited with 266nm UV pulses. We found a long-lifetime emission band centered at ≈500nm.

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