FIFRELIN, a fission code for neutrinos and dark matter experiments

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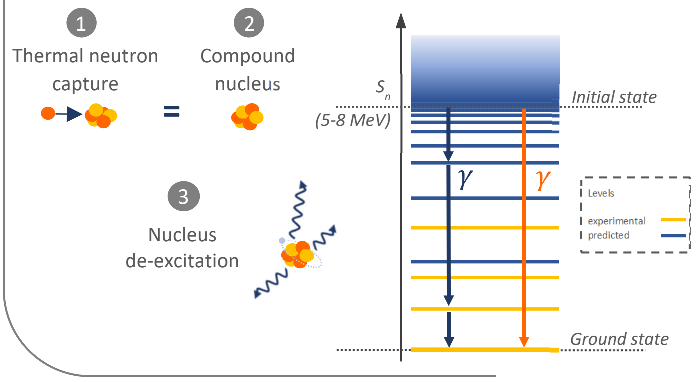
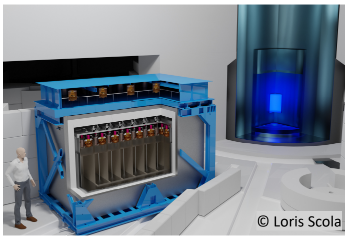
FIFRELIN

- State-of-the-art Monte Carlo simulation code for the de-excitation of fission fragments [1,2]
- With accurate predictions of neutrons/γ/e⁻ emissions, FIFRELIN bridges the gap between the nuclear, neutrino and solid-state physics communities
- Radiative thermal neutron ($\approx 25\ meV$) capture:

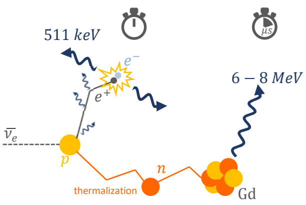


Light sterile neutrino search

- **STEREO** = Search for Sterile Reactor Neutrino Oscillations
- 10 m away from the ILL research reactor core (58 MW), in Grenoble, France
- High precision measurement of the $\overline{\nu}_e$ energy spectrum as a function of the distance to the reactor core

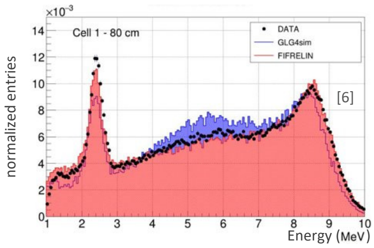


6 cells filled with ^{155,157}Gd-loaded liquid scintillator, surrounded by various shieldings and a muon veto [3]



Neutrino detection process:
Inverse Beta Decay
$\overline{\nu}_e + p \rightarrow e^+ + n$

- Detector response depends on the de-excitation of ^{156,158}Gd (neutron signal)



Neutron calibration, with an AmBe source placed at the *top of the cell*

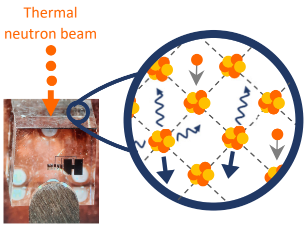
→ detector more sensitive to the Gd γ-cascade details

→ FIFRELIN significantly improves the data/simulation agreement [4, 5]

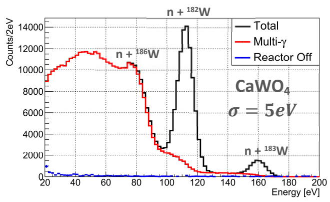
With FIFRELIN Gd cascades, unprecedented agreement between STEREO data and simulation

Calibration for CEνNS and Dark Matter

- **CRAB**: Direct calibration method for sub-keV nuclear recoils (light dark matter, reactor antineutrinos CEνNS) [7]



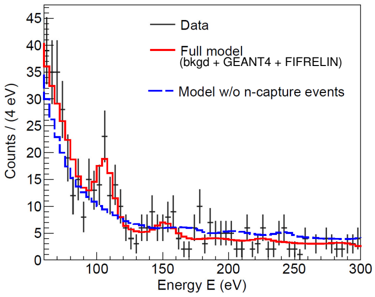
NUCLEUS $CaWO_4$ low-threshold (50 eV) cryogenic detector with 6 eV energy resolution



Recoil energy spectrum for NUCLEUS $CaWO_4$ [3] cryogenic detector, based on GEANT4 [1] and FIFRELIN [2] simulations

- Nuclear recoils induced by γ-emission after thermal neutron capture:
  - → **Single-γ** emission: recoil of known energy = **Clear calibration peak**
  - → **Multi-γ cascade**: continuum of nuclear recoil energies, depending on the γ energies and relative directions. **Key contribution of FIFRELIN**

Portable thermal neutron source (^{252}Cf source in moderator) near a cryostat at TUM for the first CRAB experimental measurement

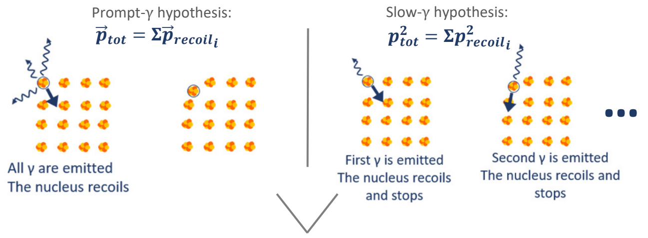


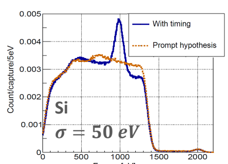
Comparison between experimental data and models based on simulations (GEANT4+FIFRELIN) [8]

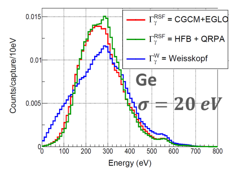
- 3σ significance for 112eV peak from the single-γ de-excitation of $n + ^{182}W$
- 6σ significance for the contribution of radiative neutron captures
- Peak observed also by the CRESST-III experiment (low mass dark matter) [9]

FIFRELIN played a key role in demonstrating the feasibility of an in-situ non-intrusive calibration method for sub-keV nuclear recoils

γ-timing vs recoil timing







- Accurate predictions of the CRAB nuclear recoil spectra [10] with the interplay between
  - **γ-cascade timing:** FIFRELIN (half-lives from databases, RSF, Weisskopf)
  - **atomic collisions timing:** IRADINA [11] (Binary Collision Approximation code)
- New calibration peaks
- Impact on the shape of the continuous recoil distribution

CRAB has the potential to set constraints on the nuclear models used by FIFRELIN

References

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