BSM Physics at ICAL@INO

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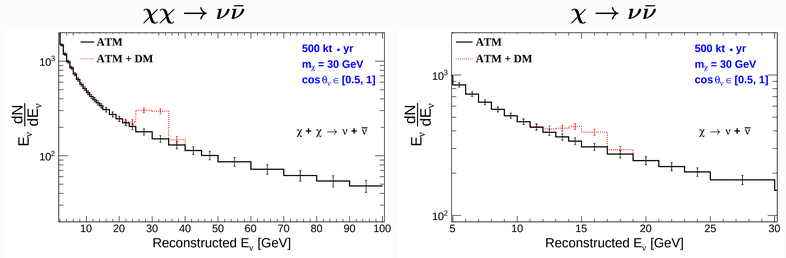
Important Features of Proposed ICAL Detector at INO

- **Optimized for multi-GeV energy and wide ranges of baselines**
- **Good energy and direction resolutions for muons:** in multi-GeV energy range, energy resolution for muons $\sim 10\%$ to 15%, direction resolution is $< 1^\circ$
- **Excellent charge identification capability:** distinguish μ^- from μ^+, thus ν_μ from $\bar{\nu}_\mu$ CC interactions with $\sim 99\%$ efficiency arXiv:1405.7243
- **Reconstruction of hadron energy (E'_{had}):** energy carried by hadrons at final state of neutrino and antineutrino interactions can be reconstructed at ICAL with a resolution of around 40% arXiv:1304.5115

Indirect Detection of Diffuse Galactic Dark matter

arXiv:1703.10221

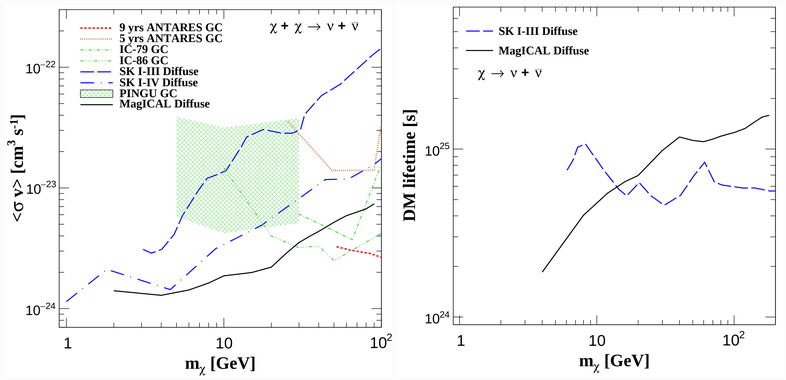
We study the self-annihilation and decay of dark matter (χ) to neutrino and antineutrino pair



Neutrino events at ICAL for annihilation (left) and decay (right) of dark matter.

ATM: Atmospheric neutrino events, **ATM+DM:** Atmospheric neutrino events in presence of dark matter annihilation/decay.

✓Similar event distributions for antineutrino can be obtained separately at ICAL



Limits at 90% C.L. on self-annihilation cross-section ($< \sigma v >$) and decay lifetime (τ) of dark matter.

Expected 90% C.L. limits from ICAL: $\langle\sigma v\rangle \leq 1.87 \times 10^{-24}$ cm^3 s^{-1} and $\tau \geq 4.8 \times 10^{24}$ s for dark matter of 10 GeV mass.

Long-Range Forces due to $L_e - L_{\mu/\tau}$ Symmetries

arXiv:1801.00949

The LRF induced potential for the solar electrons is

$$V_{e\mu/e\tau} = \alpha_{e\mu/e\tau} \frac{N_e^\odot}{R_{SE}} \sim 1.3 \times 10^{-11} \left(\frac{\alpha_{e\mu/e\tau}}{10^{-50}}\right) \text{eV}\,.$$

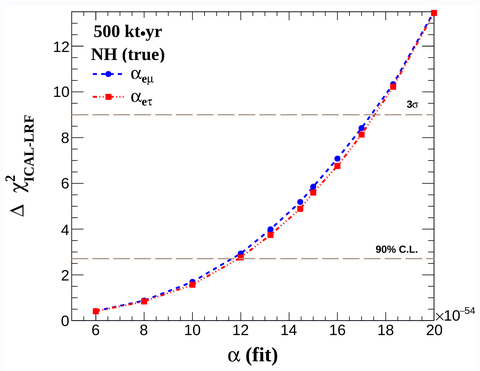
For antineutrino, $V_{e\mu/e\tau}$ appears with -ve sign.

The Effective Hamiltonian in presence matter and of LRF is

$$H_f = U \begin{bmatrix} 0 & 0 & 0 \\ 0 & \Delta_{21} & 0 \\ 0 & 0 & \Delta_{31} \end{bmatrix} U^\dagger + \begin{bmatrix} V_{CC} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} \zeta & 0 & 0 \\ 0 & \xi & 0 \\ 0 & 0 & \eta \end{bmatrix}\,.$$

U : PMNS matrix, $\Delta_{ij} = \Delta m^2_{ij}/2E$, V_{CC} : Matter induced potential
ζ = -ξ = $V_{e\mu}$, η = 0 for $L_e - L_\mu$ case. ζ = -η = $V_{e\tau}$, ξ = 0 for $L_e - L_\tau$ case.

Event distributions of μ^- and μ^+ at ICAL.



Sensitivity of ICAL to set limits on $\alpha_{e\mu}$ and $\alpha_{e\tau}$.

Existing bounds:

1. $\alpha_{e\mu} < 5.5 \times 10^{-52}$ and $\alpha_{e\tau} < 6.4 \times 10^{-52}$ at 90% C.L from SK. arXiv:hep-ph/0310210
2. $\alpha_{e\tau} < 2.5 \times 10^{-53}$ at 3σ C.L. from Solar and KamLAND data. arXiv:hep-ph/0610263

Expected from ICAL: $\alpha_{e\mu/e\tau} < 1.2 \times 10^{-53}$ (1.75×10^{-53}) at 90% (3σ) C.L.

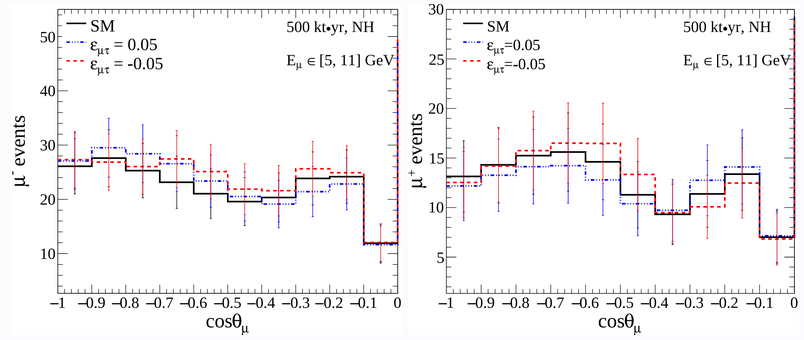
Neutral-current Nonstandard Neutrino Interactions

arXiv 1907.02027

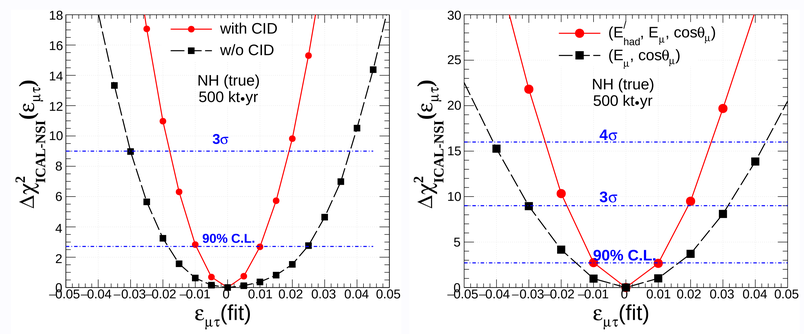
$$\mathcal{L}_{\text{NC-NSI}} = -2\sqrt{2}\, G_F\, \varepsilon^{Cf}_{\alpha\beta}\, (\bar{\nu}_\alpha \gamma^\rho P_L \nu_\beta)\, (\bar{f}\gamma_\rho P_C f),$$

$$\varepsilon_{\alpha\beta} = \sum_{f=e,u,d} \frac{V_f}{V_{CC}} (\varepsilon^{Lf}_{\alpha\beta} + \varepsilon^{Rf}_{\alpha\beta})\,,$$

where $V_f = \sqrt{2}\, G_F\, N_f$, $f = e, u, d$. The quantity N_f denotes the number density of matter fermion f in the medium. For antineutrino, $V_f \to -V_f$ and $V_{CC} \to -V_{CC}$.
Neutral current NSI may affect neutrino propagation with the additional matter induced potentials.



Event distributions of μ^- and μ^+ at ICAL.



Left plot: Sensitivity for $\varepsilon_{\mu\tau}$ gets more than two-fold enhancement due to charge identification capability. Right plot: Sensitivity for $\varepsilon_{\mu\tau}$ is enhanced due to inclusion of E'_{had} in the analysis.

Expected 90% C.L. limits from ICAL: $|\varepsilon_{\mu\tau}| < 0.01$ with E_μ, $\cos\theta_\mu$, E'_{had}

Concluding Remarks

The unique features of the ICAL detector will provide an unparalleled window to probe the beyond the Standard Model Physics in neutrino and antineutrino channels separately in multi-GeV energy range.