European Spallation Source: the future of Coherent $\nu$ Scattering

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Based on arXiv:1911.00762 [see also arXiv:1911.09109]
Coherent Elastic $\nu$eutrino Nucleus Scattering

- $\text{CE}\nu\text{NS}$ has the largest $\nu$ cross section at low energies, as $\nu$ interacts with the whole nucleus.

- Very small nuclear recoils made it challenging to detect, until recently!
Introduction

A very rich physics programme

New (light) forces

\[ \frac{1}{q^2 + M^2_\chi} \]

Dark Matter

\[ \chi \]

Nuclear properties

Detector miniaturization

Barranco, Miranda, Rashba, hep-ph/0508299

deNiverville, Pospelov, Ritz, arXiv:1505.07805

Cadeddu, Giunti, Li, Zhang, arXiv:1710.02730

COHERENT Collaboration, arXiv:1708.01294
Still statistics-limited

\[ e^+ \rightarrow ve \rightarrow \pi^+ \nu_\mu \]

\[ -15 \leq \text{Res. counts} / 2 \text{ PE} \leq 30 \]

Number of photoelectrons (PE)

\[ \sim \text{Nuclear recoil energy [keV]} / 1.2 \]

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Low threshold, state-of-the-art detectors

![Graph showing detector performance vs. threshold]

Large neutrino flux: **ESS**

Online ~ 2023

\(~ 1 \) order of magnitude more $$\nu_s$$!
\[ \mathcal{L}_{\text{NSI, NC}} = 2\sqrt{2} G_F \sum_{\alpha\beta} \varepsilon_{\alpha\beta}^u (\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta)(\bar{u} \gamma^\mu u) + \text{h.c.} \]

\[ \varepsilon \sim 10^9 \text{MeV}^2 \frac{g^2}{M_X^2} \]

**Diagram:**

- **COHERENT official**
- **C\textsubscript{3}F\textsubscript{8} bubble chamber**
- **Ar(l) scintillating bubble chamber**
- **Cryogenic CsI scintillator**
- **Si CCD**
- **Ge P-type Point Contact detector**
- **Xe(g) TPC**

**Legend:**

- **90% normalisation**
- **Systematic uncertainty**
Conclusions

- CE$\nu$NS is a leading channel in the $\nu$ intensity frontier.
- In addition to detector miniaturization, it is sensitive to a plethora of light new physics scenarios.
- Currently, COHERENT is statistics-limited.
- The statistics frontier can be overcome with a combination of a large neutrino flux + low threshold detectors.
- ESS can achieve both in $\sim$ 2023. Initial inquiries to the ESS team indicate available, properly shielded space.
- For more information (e.g., flavour discrimination) + caveats in current COHERENT analysis, come to my poster!
- Stay tuned!
Thanks!
Backup

Cross section: some formulae

\[
\frac{d\sigma}{d T_{\text{nucl}}} = \left[ \frac{G_F^2}{2\pi} \frac{Q_W^2(Z,N)}{4} \right] M_{\text{nucl}} F^2(Q^2) \left(2 - \frac{Q^2}{2E_{\nu}^2}\right)
\]

\[Q^2 = 2M_{\text{nucl}} T_{\text{nucl}}\]

\[T_{\text{max}} = \frac{2E_{\nu}^2}{M_{\text{nucl}}}\]
- ESS long pulse spoils flavour discrimination through timing
- Very large statistics might permit *kinematic* discrimination
COHERENT $t+E$

- COHERENT official
- COHERENT $t+E$

- $C_3F_8$ bubble chamber
- Ar(l) scintillating bubble chamber
- Cryogenic CsI scintillator
- Si CCD
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$\varepsilon_{\mu\mu}^u$ vs $\varepsilon_{ee}^u$ with 90% C.L.
Background time-modelling

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COHERENT binned analysis: caveats
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Energy modelling

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