Exploring the Advantages of an Undoped, Cryogenic CsI Detector for CEvNS Experiments at the SNS with COHERENT

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INTRODUCTION

Inorganic crystal scintillators, especially doped alkali-halide scintillators such as NaI[Tl], CsI[Tl] and CsI[Na], play an important role in neutrino experiments. The pioneering achievement by the COHERENT experiment, utilizing CsI[Na] for the initial detection of Coherent Elastic Neutrino-Nucleus Scattering (CEvNS), demonstrated a nuclear recoil detection threshold of approximately **8 keV$_{nr}$** with a light yield of **13.35 PE per keV$_{ee}$**. However, to advance the capabilities of next-generation neutrino detectors, it is crucial to significantly reduce this detection threshold and increase statistics.

When cooled to cryogenic temperatures, undoped CsI crystals exhibit unparalleled light yield properties: increasing both PE per keV output and the quenching factor of the observed recoil energies, while simultaneously decreasing the energy threshold and the afterglow effects.

LIGHT YIELD MEASUREMENT

The light yield of an undoped CsI crystal at 77 K was measured using dual directly-coupled top and bottom silicon photomultipliers (SiPMs) using X and Ɣ-ray peaks from an ^{241}Am source.

Together, the light yield was measured to be **43.0 ± 1.1 PE per keV$_{ee}$**, indicating a significant enhancement (**over 3x**) over room-temperature sodium-doped CsI.

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[3] Ding et al., Eur. Phys. J. C **82** 344, 2022

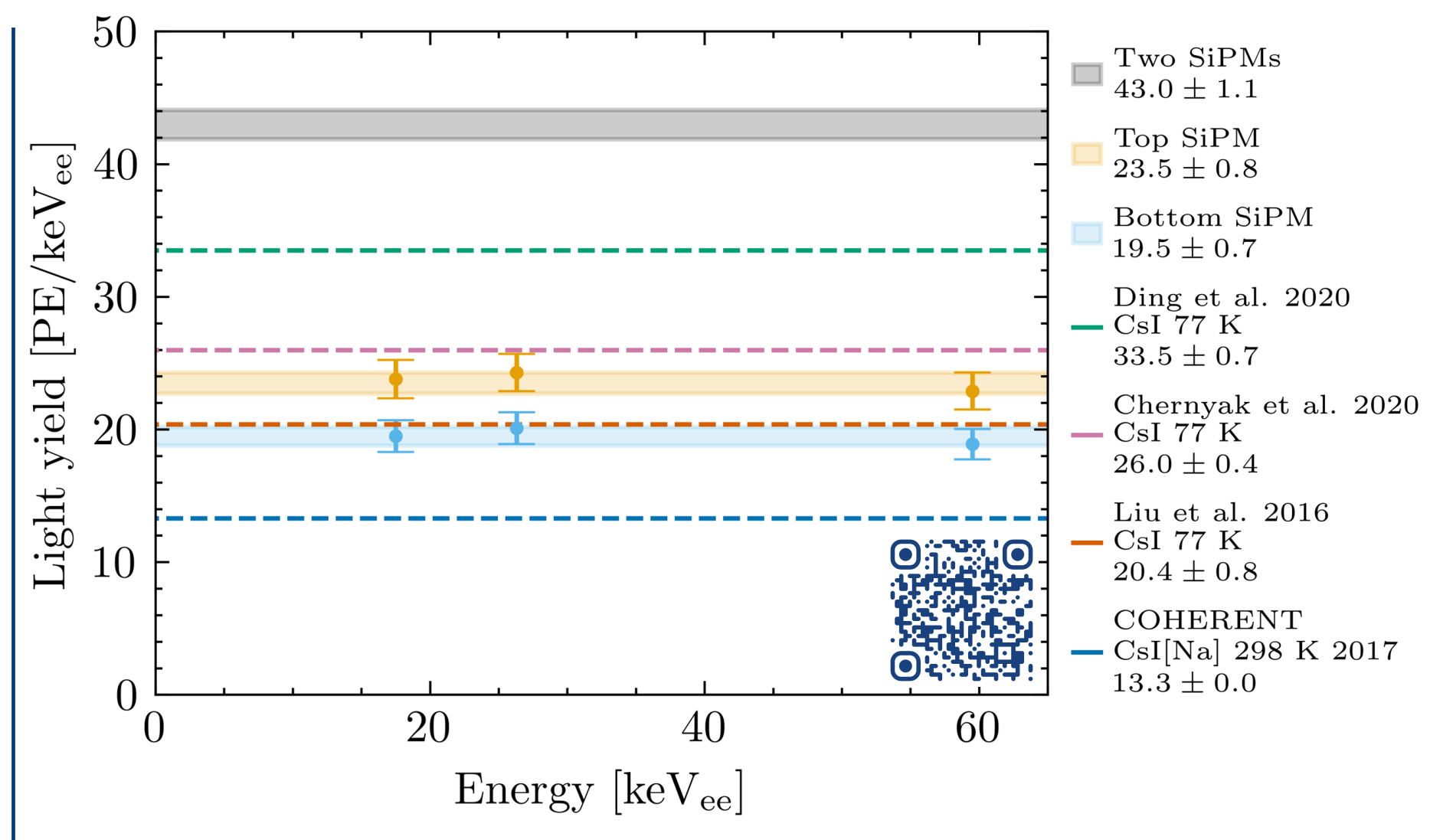

Fig. 4: CsI and CsI[Na] light yields measured by various experiments compared to results from [3]. Dashed lines are used to indicate mean values, with errors reported in the legend. Scan the QR code for full references.

QUENCHING FACTORS

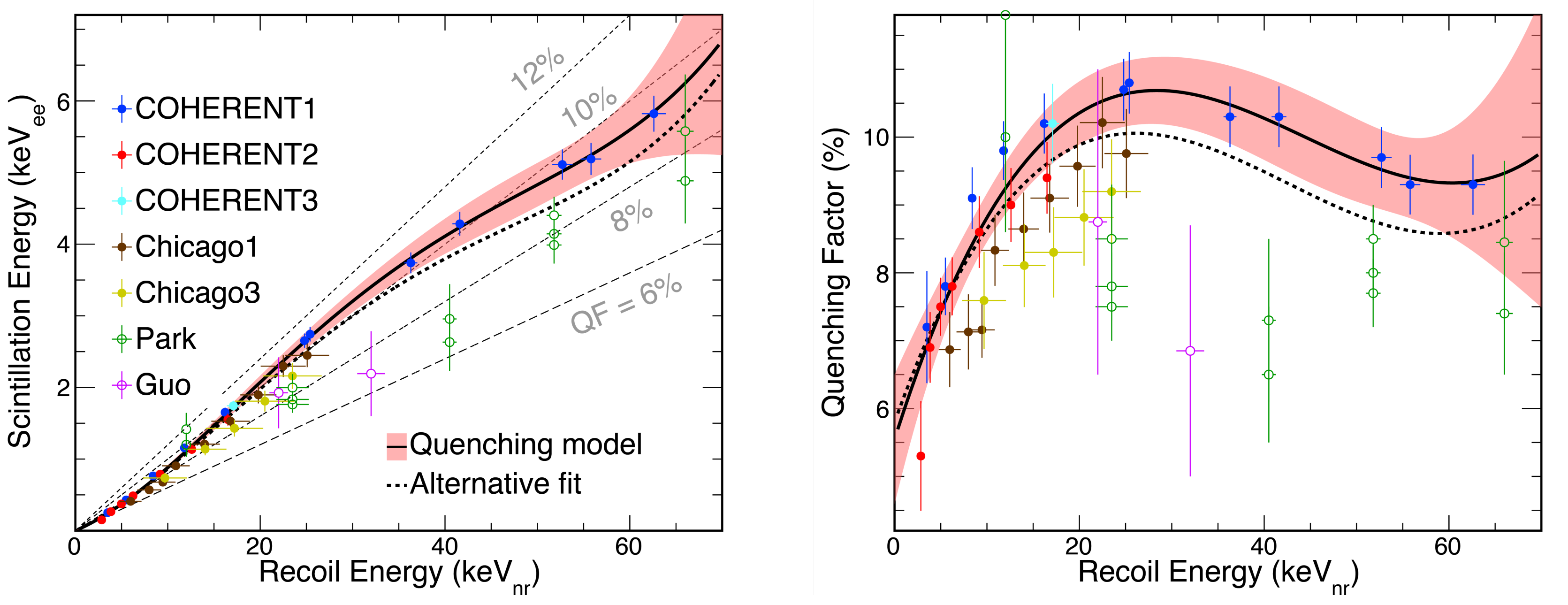

Fig. 1: Quenching factor for CsI[Na] at room temperature.[1]

Quenching factors are an energy-dependent measure of the detector response in electron-equivalent scintillation energy to a particular nuclear recoil energy. They are defined as the ratio of the scintillation energy over the recoil energy. A higher quenching factor means that less of the energy in the detector is lost to radiative processes.

Quenching factors were previously measured on CsI[Na] by the COHERENT Collaboration (Fig. 1). At recoil energies above 20 keV$_{nr}$ the quenching factor was found to be approximately **10%**.

Lewis & Collar performed a measurement (Fig. 2) on 108 K undoped CsI and found a quenching factor at comparable energies of approximately **9%**, thus showing no significant improvement over room-temperature CsI[Na].

In 2022, we conducted a measurement (Fig. 3-4) at the quenching factor facility at the Triangle Universities Nuclear Laboratory in Durham NC, USA on undoped CsI at 77 K and found an improved quenching factor of **14-18%** above 20 keV$_{nr}$.

This is one of the promising results that demonstrates the advantages of undoped, cryogenic CsI over room-temperature CsI[Na].

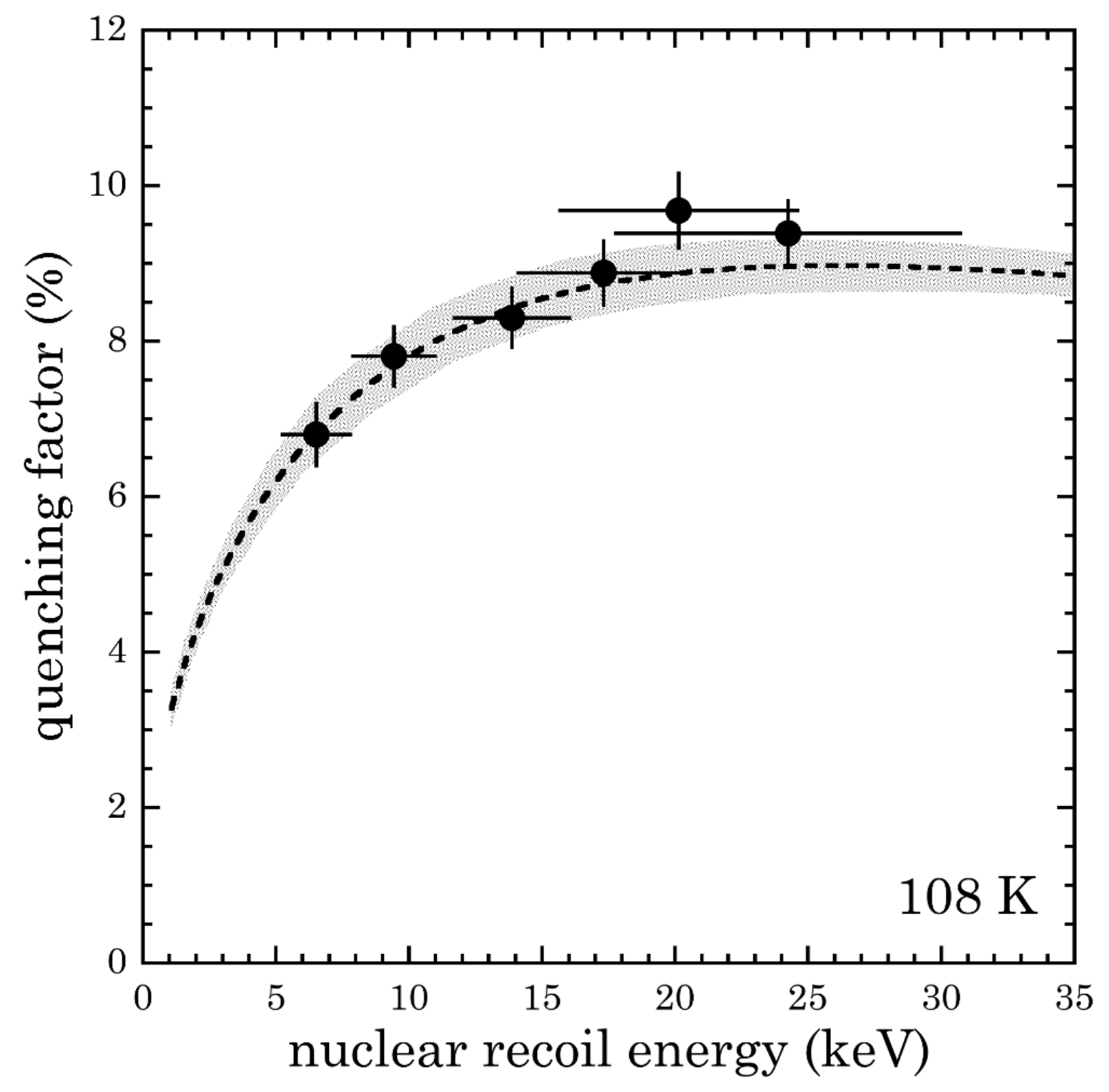

Fig. 2: Quenching factor for undoped CsI at 108 K.[2]

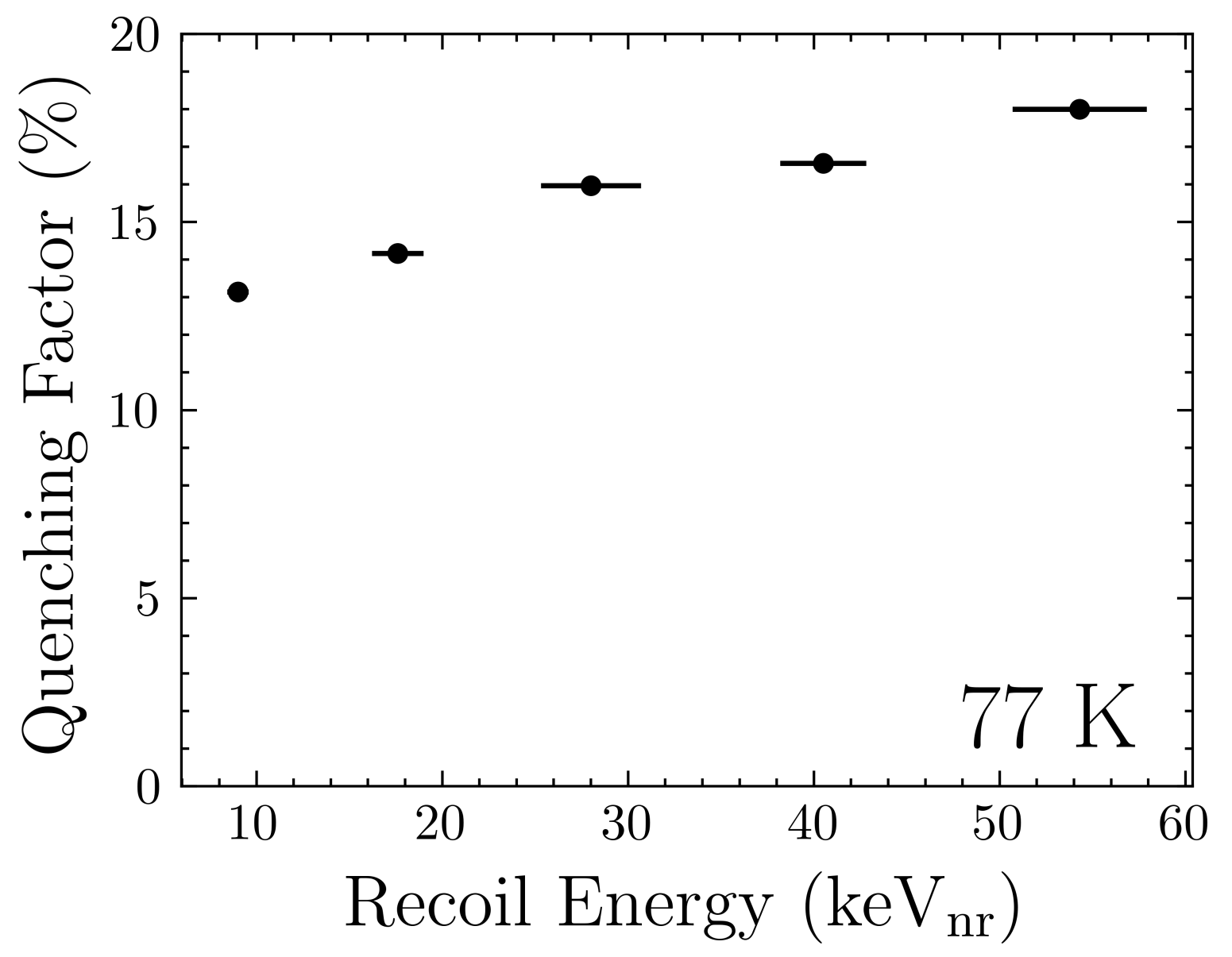

Fig. 3: Quenching factor for undoped CsI at 77 K.

Fig. 4: Setup for 77 K QF measurement at TUNL.

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[1] COHERENT, JINST **17** P10034, 2022

[2] C. M. Lewis and J. I. Collar, Phys. Rev. C **104**, 014612, 2021

CEvNS IMPLICATIONS

COHERENT is an experimental program at the Oak Ridge National Laboratory in Oak Ridge, TN, USA. COHERENT made the first observation of CEvNS on CsI[Na] in 2017 using the Spallation Neutron Source, which produces neutrinos through pion decay-at-rest.

COHERENT is currently exploring the possibility of adding a 10 kg-scale undoped cryogenic (40 K) CsI detector to its suite of detectors in "Neutrino Alley", which would expand our physics reach in several ways.

Highlighted here (Fig. 5) is the improved CEvNS rate spectrum expected from a lowered threshold resulting from an increased light yield. By increasing the sensitivity of our experiment, we are better able to probe the Standard Model.

This is highlighted in Fig. 6, which shows the sensitivity to ν_e disappearance in the sterile-neutrino hypothesis. A 2016 global fit of sterile-neutrino data is also shown, demonstrating that COHERENT can probe the best-fit parameter space. Not shown here is the Δm^2_{41}-$\sin^2 2\theta_{24}$ parameter space, which is also well-probed by COHERENT.

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[4] COHERENT, arXiv:2311.13032, 2023

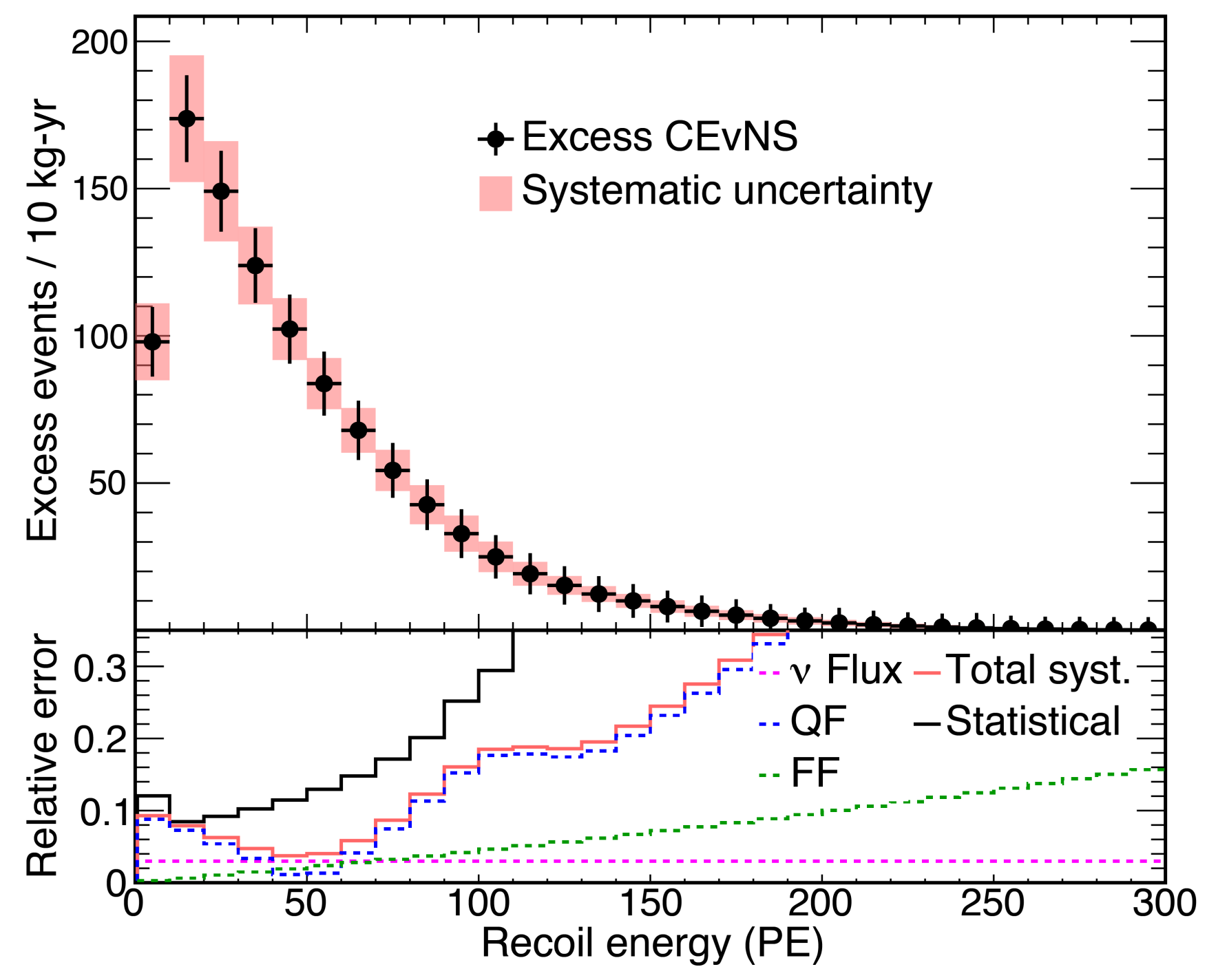

Fig. 5: Expected CEvNS rate in a future undoped CsI detector with statistical errors after background subtraction.[4]

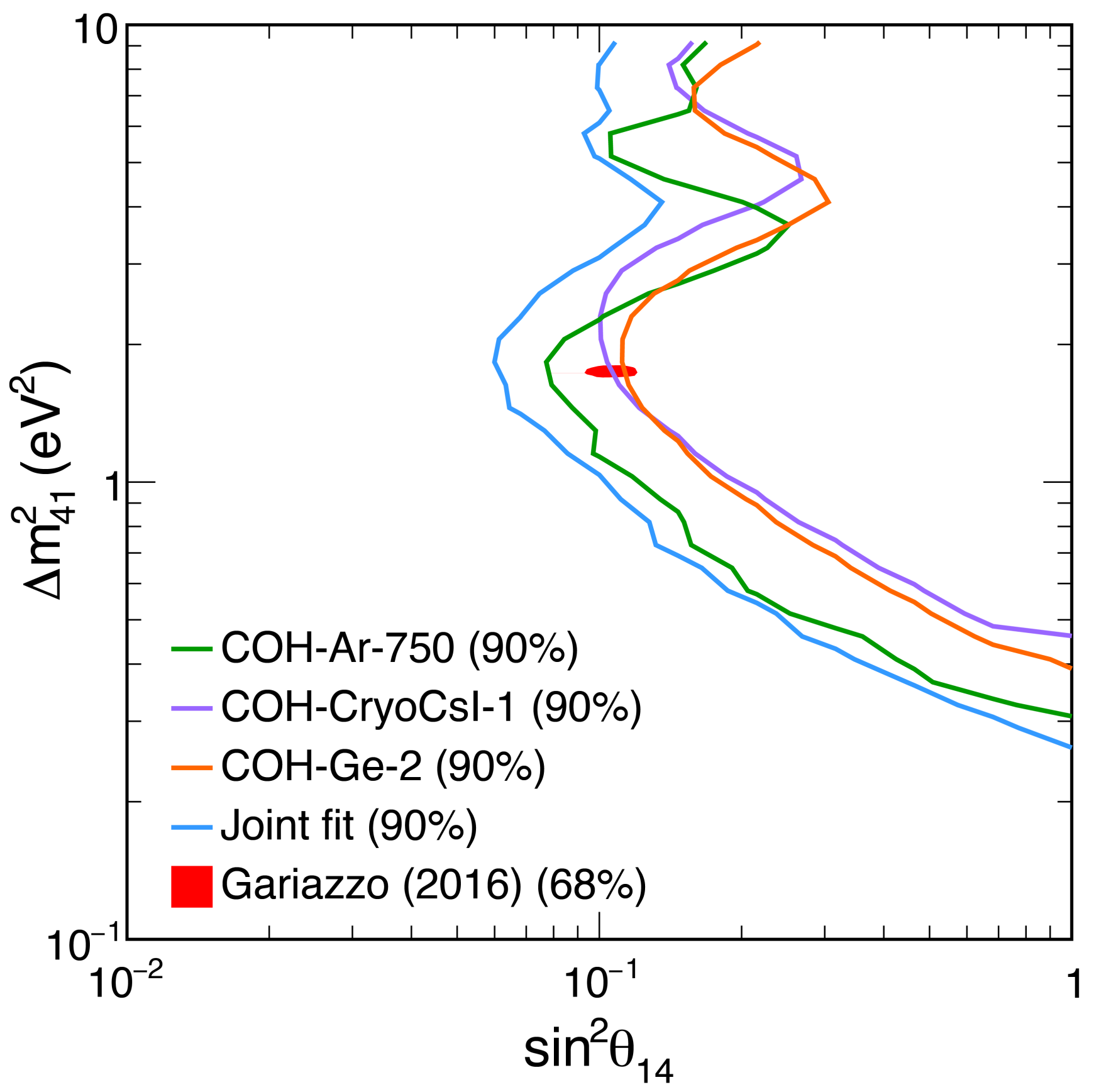

Fig. 6: Sensitivities for future COHERENT cryogenic CsI detectors to test the sterile-neutrino hypothesis in the ν_e disappearance case.[4]

FUTURE WORK

In July 2024, this team plans to measure the light yield and quenching factor on an undoped CsI crystal cooled to 40 K. This should theoretically result in an even higher light yield and quenching factor compared to measurements at 77 K. This will provide the measurement for the COHERENT deployment of a 10 kg-scale 40 K undoped CsI detector in the future.

Future physics searches could include searching for hidden-sector particles, low-mass mediators of new forces, and sterile neutrinos, and measuring the neutron charge distribution on ^{133}Cs and ^{127}I. A second-generation CryoCsI detector also has the potential to be sensitive to neutrinos from core-collapse supernovae.

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