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Nuclear Physics B (Proc. Suppl.) 70 (1999) 111–113

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

The CASPAR Recoil Discrimination Detector for WIMP Searches with Calcium and Fluorine

D.R. Tovey *, C.D. Peak, J.W. Roberts and N.J.C. Spooner

Department of Physics, University of Sheffield, Hounsfield Rd., Sheffield, S3 7RH, UK.

We present the results of development work on the CASPAR ('Cocktail with Alkali-halide Scintillating PARticles') WIMP Dark Matter detector. The results of Monte Carlo simulations and neutron-scattering tests indicate that even a modest sized detector should provide improved spin-dependent WIMP sensitivity.

1. INTRODUCTION

Scintillator detectors for WIMP Dark Matter may use pulse-shape analysis to discriminate signal (nuclear recoils) from background (electron recoils). Current NaI detectors of the UK collaboration [1,2] make use of an intrinsic difference in exponential pulse-shape time-constant (τ_c) between the two classes of event. The CASPAR detector gives improved discrimination by using differences in recoil range [3]. The target consists of sub-micron grains of scintillating CaF_2(Eu) suspended in an organic liquid scintillator matched to the same refractive-index (r.i.). For a given recoil energy electrons originating anywhere within the detector will pass through both materials giving a combined scintillation pulse containing two characteristic decay components ($\tau_c \sim 900$ ns and ~ 4 ns respectively). WIMP-induced nuclear recoils of the same energy will originate and remain purely within the grains owing to cross-section enhancements and their shorter recoil range (~ 10 times less than electrons). The scintillation pulse will then have only a single slow component characteristic of the CaF_2(Eu), enabling discrimination [4].

2. SCINTILLATION EFFICIENCIES

To give sensitivity to low-mass WIMP events CASPAR should have the lowest possible energy threshold and hence use the most efficient scintillators. The liquid is a mixture of dioxane and naphthalene, while CaF_2 was chosen as the inorganic scintillator owing to its low r.i. and high efficiency. Preliminary experiments [4] used grains of raw undoped CaF_2. This however has a high level of radioactive impurities and a grain-size too large to be of use in a low-threshold experiment. An alternative technique has been developed in which the CaF_2 is synthesized chemically as a precipitate upon the addition of HF to $CaCl_2$. The high solubility of $CaCl_2$ in water permits purification with DIPHONIX beforehand [5], removing actinides and hence improving the radiopurity of the CaF_2 powder. The technique gives in addition smaller grain sizes. Eu doping of the powder is also performed.

3. MONTE CARLO RESULTS

In parallel with efforts to improve the scintillation efficiency of CASPAR, work has been performed quantifying the sensitivity to WIMPs. A flat compton background of 2 events/kg/day was assumed in a detector containing 10% by volume CaF_2(Eu) grains of average diameter 300 nm. The total mass of CaF_2(Eu) was 120g, with a running-time of 365 days. A scintillation efficiency of 1 photo-electron per keV was assumed in both grains and liquid giving an energy threshold of 4 keV electron equivalent. Individual recoils were tracked through the detector using range-energy data derived from the Lindhard model [6], while nuclear form-factors were taken from [7]. The results show that the sensitivity of even a modest detector will be comparable to that of a 6

*d.r.tovey@sheffield.ac.uk

PII S0920-5632(98)00398-3

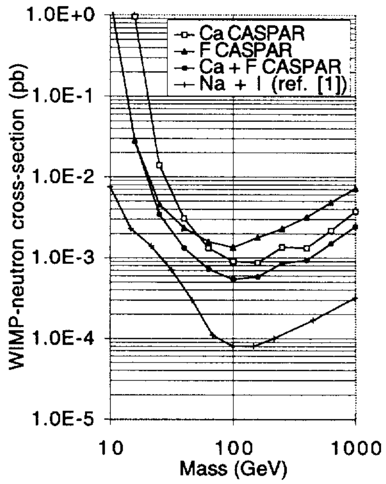

Figure 1. Predicted CASPAR spin-independent cross-section sensitivity compared with existing limits from [1].

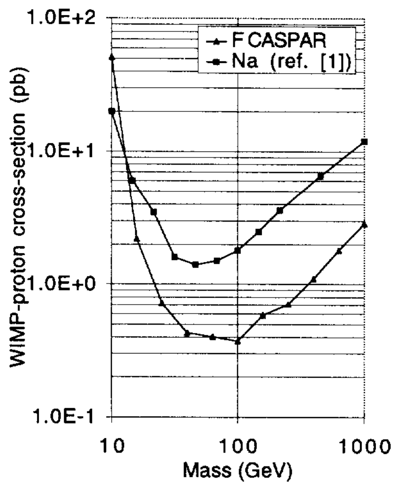

Figure 2. Predicted CASPAR spin-dependent cross-section sensitivity compared with existing limits from [1].

kg NaI crystal [1] due to improved discrimination (e.g. ~ 98 % for 60 % efficiency at 7 keV electron equivalent). The spin-independent cross-section sensitivity (Figure 1) will be less than from 6 kg NaI owing to the low mass of the Ca and F nuclei and hence their poor coherence factors. The spin-dependent cross-section sensitivity (Figure 2) on the other hand will be considerably better due to the large spin-factor enhancement given by F nuclei [8].

4. NUCLEAR RECOIL EFFICIENCIES

These simulation results assume energy-independent recoil efficiencies for Ca and F of 8% and 12% respectively, as found in [9]. There is evidence that at lower recoil energies these values increase [10] and if this is the case then the achievable limits will be considerably lower than those quoted here. We are currently investigating this effect with neutron-scattering tests using the 2.85 MeV mono-energetic neutron beam of the Sheffield group. Nuclear recoils are selected by looking for coincidences between events in the CaF_2(Eu) (0.5% M) target crystal and neutron signals observed in NE213 counters. Specific recoil energies are chosen by varying the angle between these counters and the beam axis. Further details of the technique may be found in [9,11]. Preliminary results suggest that the recoil efficiency for F is in excess of 20% at 10 keV recoil energy, with a slightly lower value for Ca (Figure 3). This would lead to a significantly lower recoil-energy threshold in CASPAR and hence improved sensitivity to low-mass WIMPs.

5. CONCLUSIONS

A number of possible improvements to the CASPAR technique were highlighted by the original work [4]. We have had significant success in realising these and have quantified the potential performance of a CASPAR detector incorporating them. We look forward to testing these predictions with an operational detector in the near future.

ACKNOWLEDGEMENTS

The authors wish to thank Hilger Analytical Ltd., the University of Sheffield, Electron Tubes Ltd. and PPARC for support.

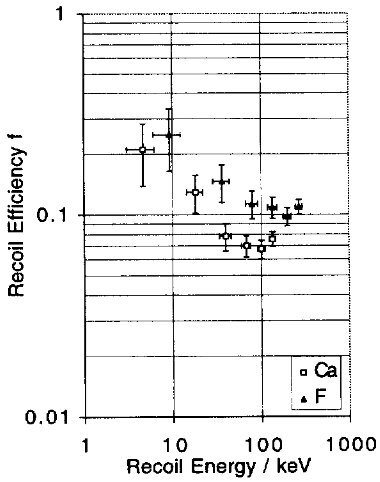

Figure 3. Nuclear recoil efficiencies for Calcium and Fluorine in CaF_2(Eu).

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