Results from the Antonella experiment

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Low threshold Silicon detectors: DAMIC, SuperCDMS Si

DAMIC ACCEPTANCE

EXISTING MEASUREMENTS

No Nuclear recoil calibration data for ROI
Ionization efficiency vs Nuclear Recoil energy

This Work
Systematic uncertainty
Gerbier et al. (1990)
Sattler (1965)
Lindhard calculation (1963)
Textbook scattering experiment

Monochromatic neutrons

\[ E_{NR} = E_n \frac{2}{(A + 1)^2} \left[ A + \sin^2 \theta - \cos \theta \sqrt{A^2 - \sin^2 \theta} \right] \]

- \( \theta \): Scattering angle
- \( A \): Atomic mass
- \( E_n \): Neutron energy
- \( E_{NR} \): Energy of Nuclear recoil

Measured in a silicon detector calibrated with electron recoils

Calculated from kinematics

\[ I_{on_{eff}} = \frac{E_{ionization}}{E_{NR}} \]
ToF scattering experiment

Broad neutron spectrum
\( E_n \) in [50, 600] keV

\[ E_n = \frac{m}{2(\Delta t)^2} \left[ l + r \frac{(A + 1)}{\cos \theta + \sqrt{A^2 - \sin^2 \theta}} \right]^2 \]  

(1) \( \Delta t \) = neutron total Time-of-flight

\[ E_{NR} = E_n \frac{2}{(A + 1)^2} \left[ A + \sin^2 \theta - \cos \theta \sqrt{A^2 - \sin^2 \theta} \right] \]  

(2)

Program:

1. Measure neutron energy by time-of-flight (1)
2. Detect a scattered neutrons in a neutron detector
3. Measure charge produced by ionization
4. Calculate the nuclear recoil energy with kinematics (2)
Our setup

Collimator  
Silicon Detector  
Plastic Scintillator counters

neutron beam
Our setup at ND University beam

- **collimator**
- **scintillator bar array**
- **silicon detector**

The image shows a particle treatment facility with a collimator, scintillator bar array, and a silicon detector. The particles *p* and *n* are directed through the setup.
Neutron beam at ND University

University of Notre Dame, Indiana, USA
Tandem Van de Graaff, 10 MV

- $^7\text{Li}(p,n)^7\text{Be}$ reaction on thick $\text{LiF}$ target
- 2.3 MeV proton energy
- Bunched beam. 1 $\mu$s bunch separation
- 20 nA nominal proton current at this bunch separation
- 1-2 ns bunching resolution
Neutron beam at ND University

Broad neutron spectrum
\[ E_n \in [50, 600] \text{ keV} \]

\[ (a) \]

LiF: Lithium Fluoride
actual target material

\[ E_{acc} = 2.3 \text{ MeV} \]

Background: \((p, \gamma)\) reactions

\( (dE/dx)_{LiF} = 26 \text{ keV}/\mu\text{m} \)

Target thickness = 18 \( \mu\text{m} \)  
Maximize the neutron yield
Our setup - SiDet

Collimator        Silicon Detector        Plastic Scintillator counters

neutron beam

$\theta$
Detector: Silicon Drift Diode, commercial XRay detector

Built-in Peltier cooler, $T = 220$ K

- Detector used in the Neutron Star Interior Composition Explorer (NICER), at ISS (NASA, USA)

Detector mass is only 29 mg
Calibration using an $^{55}$Fe source

Main source of systematic uncertainty
Neutron detectors: plastic scintillator bars + PMTs

- Bar dimensions: 3 x 3 x 25 cm$^3$
- Plastic scintillator: EJ-200
- Base polymer: polyvinyl toluene ($C_{27}H_{30}$)

1. The neutron transfers kinetic energy to $^1$H
2. The recoiling $^1$H produces the scintillation light (same for $^{12}$C, but less efficiently)

- PMTs from CDF central hadronic calorimeter
- EMI 9854KB

- Triggered at 0.2 p.e.
- One PMT at each end → Request coincidence
- Reduce the neutron detection threshold to less than 50 keV
Neutron detectors: plastic scintillator bars + PMTs

2 ns resolution translates to $\frac{\sigma_{ENR}}{E_{NR}} \sim 1 - 5\%$
DAQ system
DAQ system

Trigger on the siDet $\rightarrow$ read the whole detector state
Points: a hit in the silicon detector and a hit in a scintillator bar
Raw data

E\text{ionization} vs time-of-flight for Bar 6

gamma prompt hitting a bar
high energy deposited in SiDet + environmental bkg on a bar

following beam bunch

neutrons arrival interval
Science Run

- Took data for 10 days
- \( \sim 10^6 \) gamma+neutron hits in silicon detector
- Trigger rate \( \sim 170 \) Hz (of which \( \sim 4 \) Hz real particles hitting the silicon detector)
- \( 1.5 \times 10^8 \) triggers, mostly noise from the silicon detector
- \( 1.8 \times 10^5 \) events, after requesting hit in a Bar (PMT in coincidence)
- \( 5.1 \times 10^3 \) events, after timing and no-saturation cuts (reject gamma prompt)
$E_{\text{recoil}}$ vs. $E_{\text{ionization}}$ for All Bars
$E_{\text{recoil}}$ vs. $E_{\text{ionization}}$ for All Bars
Profile histogram: $E_{\text{recoil}}$ distribution, for $E_{\text{ionization}}$ in [0.94, 1.29) keV

Mean = 4.61 keV

Error in fit = 0.04 keV

Sigma = 0.61 keV
$E_{\text{recoil}}$ vs. $E_{\text{ionization}}$ for All Bars
Ionization efficiency vs Nuclear Recoil energy

- **This Work**
- Systematic uncertainty
- Gerbier et al. (1990)
- Sattler (1965)
- Sattler (1965)
- Lindhard calculation (1963)
Ionization efficiency in silicon

- UChicago $^{124}$Sb$^9$Be
- Antonella (systematic)
- Antonella
- Gerbier et al (1990)
- Lindhard, $k=0.15$
- Lindhard, $k=0.05$

Next talk by Alvaro.
\[ E_n = \frac{m}{2(\Delta t)^2} \left[ t + r \frac{(A + 1)}{\cos \theta + \sqrt{A^2 - \sin^2 \theta}} \right]^2 \]

\[ E_{NR} = E_n \frac{2}{(A + 1)^2} \left[ A + \sin^2 \theta - \cos \theta \sqrt{A^2 - \sin^2 \theta} \right] \]

\( \Delta t \) = neutron total Time-of-flight

Overall MC correction below 15%