Background Rejection with the DMTPC Dark Matter Search Using Charge Signals

Jeremy Lopez, MIT
For the DMTPC Collaboration
DPF Meeting, 12 Aug. 2011
Outline

1. Directional Detection of Dark Matter
2. The DMTPC Experiment
3. Charge Readout and Background Rejection
4. Conclusions and Outlook
The Directional Signal of WIMP-Induced Recoils

Sidereal modulation of recoil directions

Sky map of nuclear recoils & backgrounds

Motion around galactic center

Jeremy Lopez, MIT
DPF2011
The DMTPC Collaboration

Dark Matter Time Projection Chamber

• Boston University
  – S. Ahlen, M. Chernikoff, A. Inglis, H. Tomita
• Brandeis University
  – A. Dushkin, L. Kirsch, H. Ouyang, G. Sciolla, H. Wellenstein
• Bryn Mawr College
  – J.B.R. Battat
• MIT
• RHUL
  – R. Eggleston, J. Monroe

Underground Lab, Aug. 2010

WIPP, Carlsbad, NM 1600 mwe

• Low-pressure gas TPC
• CCD readout of light from electron avalanches for sub-mm spatial resolution on readout plane
DMTPC Detectors

10L, field cage

10L, WIPP

CCD

Lens

R&D Vessel

4shooter

+several others

Used in this talk

Jeremy Lopez, MIT
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Schematic

CF$_4$: $\chi$F elastic scattering
-SD cross section

Channels:

Charge readout:
• 1 s exposure/event
• 4 ns samples
• Save triggered pulses
• Mesh: Current signal
• Anode/Veto: Integrated charge

CCD:
• 1 s + readout (0.3 s))
  exposure / event
• No shutter used
• Tracks during readout appear shifted in position: must reject

Mesh (GND)

Veto Ring (+HV) Central Anode (+HV)
Example Event

Nuclear recoil candidate in R&D vessel during a surface run at MIT.

Note: In this talk, keV\textit{i} = electron-equivalent ionization yield.

Region of amplification plane
Near field cage rings.
Small signal \(\rightarrow\) No ionization near edge of field cage.

Pulses smoothed with Gaussian convolution
Potential Backgrounds

• Electronic Recoils
  – Invisible to CCD: Low pressure $\rightarrow$ Low $\Delta E / Volume$, pixel noise $> signal$.
  – Measured in charge signals.
  – Use charge pulse shape discrimination.

• CCD Artifacts
  – Use redundant measurements, track shape parameters.

• Radon Progeny Recoils
• Cosmogenic Nuclear Recoils
Rejection of Electronic Recoils

1. How blind is the CCD to these?
2. How well can we discriminate between charge signals from nuclei and electrons?

Place $^{137}$Cs source inside detector:
- Generate $\sim 25$ e$^-$ recoils ($E>30$ keVi) per 1 s exposure.
- Get light pileup in CCD, no pileup in charge.

In this run:
Monte Carlo studies: CCD efficiency 90% or better for $E>40$ keVi (for nuclear recoils).
From trigger level for charge: expect near 100% charge readout efficiency for $E>30$ keVi.
CCD Rejection of Electronic Recoils

Cuts Used

- No tracks on edge of image.
- Peak pixel value must be small compared to total light, large enough to be like a nuclear recoil.
- Range is short.
- Multiple tracks don’t appear in same position throughout a run.
- Much more restrictive cuts are used in WIMP searches.

Calculation of CCD Rejection of e- Tracks

- Can measure # of e- events with charge signals.
- Compare to total # of excess (compared to source-free run) tracks found.
- e- rejection of $3 \times 10^{-5}$ (40-250 keV)
Nuclear vs Electronic Recoils

$\Delta z$ small
Nuclear rec.

$1 \mu s$ drift time

$\Delta z$ large
e$^{-}$ rec.

@ 81x525 Nuclear rec.

Fast rise

Ion drift

-0.4 -0.2 0 0.2 0.4 0.6 0.8 1
Time [\mu s]

Fast rise

-0.4 -0.2 0 0.2 0.4 0.6 0.8 1
Time [\mu s]

Slow rise

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0 20 40 60 80
Voltage [mV]

0 20 40 60 80
Voltage [mV]
Measurement of Track $\Delta z$

- Compare measured E, 2D range to SRIM estimated 3D range to get $\Delta z$.
- Look at mesh pulse rise time.
- Low (120 V/cm) drift field $\rightarrow$ much diffusion.

![Graph showing diffusion/detector response](image)

- Mesh 25% to 75% Rise [ns]
- 10 cm drift
- $\Delta z \text{ [mm]}$
- Estimated $\Delta z \text{ [mm]}$

- $^{241}\text{Am }\alpha$ 0.1 ns $\pm 17.7$
- $R_0 = 17.7\pm0.1 \text{ ns}$
- Slope $= 3.35\pm0.13 \text{ ns/mm}$
Pulse Shape Analysis

<table>
<thead>
<tr>
<th>Cuts</th>
<th>Rejection</th>
<th>Total Rejection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veto (fiducialization)</td>
<td>0.054</td>
<td>0.054</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>0.0061</td>
<td>3x10⁻⁴</td>
</tr>
</tbody>
</table>
241Am source, positioned so only last O(100 keV) is measured. Compare all passing CCD tracks to all passing charge signals. Incorrect matches appear away from main band.
Final Results from e\(^{-}\) Discrimination Study

Results are conservative: CCD rejection will improve in source-free running (no pileup)

Lines: SRIM 3D range prediction
Points: Data 2D range measurement
Consistent with nuclear recoils

For 40-250 keV\(\text{e}\)

- Charge (pulse shape+veto): \(3 \times 10^{-4}\) rejection
- CCD: \(3 \times 10^{-5}\) rejection
- Combined: 90% C.L. < \(6 \times 10^{-6}\) rejection
- Combined result is statistics-limited
CCD Backgrounds

- Tracks in CCD Si ($\mu, \alpha, \beta$)
- Hot pixels, noise fluctuations
- Shifted tracks
- Residual bulk images

No corresponding charge signal!
CCD Artifact Rejection

<table>
<thead>
<tr>
<th>Background</th>
<th>Cuts on CCD Only</th>
<th>CCD Track Finding + Cuts Only on Charge</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBI</td>
<td>1320</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Hot pixel/CCD Si track/Noise</td>
<td>1287</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Section of Background Alpha</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Track</td>
<td>14</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

10 hr run at surface, no sources
Look for coincidence between charge signals and various classes of CCD tracks and artifacts
Can reduce CCD artifacts by $10^{-2}$ before applying CCD cuts!
Conclusions and Outlook

• Can reduce electronic backgrounds by at least $(40 \text{ keVi}<E<250 \text{ keVi})$:
  – $3 \times 10^{-5}$ with CCD analysis
  – $3 \times 10^{-4}$ with charge analysis
  – $6 \times 10^{-6}$ combined (90% C.L., statistics limited)

• Get additional $10^{-2}$ reduction of CCD artifacts with charge analysis.

• Can now eliminate shifted tracks occurring during CCD readout.

• Charge readout implemented on detectors for underground operation.
Thank You!
Charge Efficiency

Plateau at 80-85%:
Fraction of tracks during CCD readout

\[ \text{eff} = \frac{N_{\text{track}}}{N_{\text{pass}}} \]

$^{241}\text{Am data}$
Future Sensitivity

From J. Battat

- **NEWAGE@Kamioka**
- DMTPC 10L Surface
- **PICASSO (2009)**
- COUPP (2010)
- 10L at WIPP DRIFT
- 1 m³ at WIPP
- 50 keV recoil threshold
- 1 year live-time
WIPP

- Nuclear waste repository near Carlsbad, NM, USA.
- 650 m depth (1600 mwe)
- Built into salt (NaCl) deposits.
- \(<\leq 1\) cosmogenic n / year
- Low radon backgrounds.
- Summer 2010: set up lab underground
- Fall 2010: shipped 10L detector
- Winter 2010/11: 10L commissioning
- Spring/Summer 2011: AmBe and WIMP data taking
- Future: Move 4shooter to WIPP, plan for m$^3$ detector