Directional Dark Matter Detection with DMTPC

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(on behalf of the DMTPC collaboration)

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WIMPs have a preferred direction in galactic coordinates

Dark matter "wind"
Sidereal modulation in direction ~10x annual modulation

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Sidereal modulation in direction ~10x annual modulation

A correlated signal would be unambiguous proof

Dark matter "wind"
Gas-based detectors / TPCs

Directional community

http://arxiv.org/abs/0911.0323

Not pictured: NITEC, columnar recombination...
DMTPC

DARK MATTER TIME PROJECTION CHAMBER

Canary

- 30 torr pressure
- Triple-mesh amplification region

10-L

- Deployed underground
- Dark matter limit

4-shooter

- Multi-camera readout
- Low-background materials;
- Event discrimination with charge readout
DMTPC

DARK MATTER TIME PROJECTION CHAMBER

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- 30 torr pressure
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J. Battat et al., Nucl. Instrum. Meth. A 755 (2014) 6-19:
- Multi-camera readout
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m³
DMTPC

+HV

DARK MATTER TIME PROJECTION CHAMBER

E

F

F

F

F

0V

-HV
DMTPC

DARK MATTER TIME PROJECTION CHAMBER

\[ F \quad C \quad F \]

\[ E \]
DMTPC

DARK MATTER TIME PROJECTION CHAMBER
DMTPC

DARK MATTER TIME PROJECTION CHAMBER
DMTPC

DARK MATTER TIME PROJECTION CHAMBER
CCD camera

+HV

DARK MATTER TIME PROJECTION CHAMBER

X

E

F

0V

-HV

Amplifiers
Measure:
- energy
- range
- axial angle
- dE/dx profile
- head-tail sense
- transverse width ($\sigma$)
Diffusion vs. directional sensitivity

To improve directional sensitivity at low E, need to constrain drift height: \( z < 25 \text{ cm} \)

Key parameter for directional sensitivity

Go to lower pressure: \( P \sim 30 \text{ torr} \)
What is the ability of a $m^3$ DMTPC detector to distinguish a WIMP source from an isotropic background?

Assuming:

- 30 torr pressure
- 100K gas gain
- Drift height < 25 cm
Projected $m^3$ directional sensitivity

Take simulated response and run many fake experiments with $n$ signal events.

Compute head-tail and axial spread in each energy bin.

Calculate $p$ of obtaining value in each bin from isotropic distribution and combine to build an overall $\chi^2$ statistic.

![Graph showing acceptance probabilities with a quality cut](image)

Probability of rejecting isotropy to the given significance level with $n$ signal events.

Assuming target mass at 30 torr and 100 (1000) GeV WIMP, with $\sigma = 1$ fb, it would take **500 (300) $m^3$-years** to acquire 450 events necessary to reject isotropy half of the time at 0.1% significance.

This is equivalent to only **4.3 (2.6) Excalibur-years**.
1-shooter side:
- 2 x TPC
- 1 x CCD
- 4 x PMT

4-shooter side:
- 2 x TPC
- 4 x CCD
- 1 x PMT

Charge readout for E measurement, background subtraction and trigger
4 x FLI ProLine 9000

Front-illuminated Kodak sensor
3056 x 3056 pixels
12 μm pixel size
0.2 c/channel

up to 8 MHz readout speed
Read noise: 9 e- RMS @ 1 MHz
< 0.01 e-/pixel/sec @ -40 C

1 x Spectral 1100S

Back-illuminated Fairchild sensor
4096 x 4096 pixels
15 μm pixel size
0.5 c/channel

up to 8 MHz readout speed
Read noise: 7 e- RMS @ 1 MHz
< 1 e-/pixel/sec

5 x Hamamatsu R1408

2 x CAEN N6730 WFD
Amplification region

Field cage

Cathode

* Maximize ratio of fiducial volume to surface area
Assembly and Integration
A first look at the data!

Summed bias image

First α track - Am241

~30 cm

Charge-sensitive preamplifier (Anode)
Gain calibration

Measured gas gain (multiplication) using Fe-55 source and amplitude of anode signal

$$G \sim \frac{(V_{\text{out}} / \text{Amplifier gain})}{(5.9 \text{ keV} / \text{W})}$$

$W$ for $\text{CF}_4 = 33.8 \pm 0.4 \text{ eV}$

For anode at 690 V:

Gas gain = $82,000 \pm 6000$
Summary

Full detector model, validated with data, now available for DMTPC

Developed directional sensitivity metric incorporating head-tail and axial measurements

300 (500) m³-years necessary for 3σ detection of 1 fb 1000 (100) GeV WIMPs

1 (out of 4) TPC's installed into m³ chamber

Demonstrated proof-of-principle at m³ scale using modular, scalable design

Next steps:

Complete fabrication and continue commissioning studies

Study directionality performance of detector at the surface

Deploy at SNOLAB in 2016

Directional detectors are on the verge of learning how to solve scale-up problem!