Title: DM-TPC: a novel approach to directional Dark Matter detection Denis Dujmic (MIT) on behalf of the DM-TPC collaboration

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Abstract: Directional detection of dark matter can provide unambiguous observation of dark matter (DM) interactions even in the presence of insidious backgrounds. The DM-TPC collaboration is developing a detector with the goal of measuring the direction and sense ('head-tail') of nuclear recoils produced in spin-dependent DM interactions. The detector consists of a low pressure TPC with optical readout filled with CF4 gas at low pressure. A collision between a WIMP with a gas molecule results in a nucleus recoil of 1-2 mm. The measurement of the energy loss along the recoil allows us to determine the sense and the direction of the recoil. Results from a prototype detector operated in a low-energy neutron beam clearly demonstrate the suitability of this approach to measure directionality. In particular, the first observation of the 'head-tail' effect for low-energy neutrons had been recently published by our Collaboration. A full-scale (1m^3) module is now being designed. This detector, which will be operated underground in 2009, will allow us to set limits on spin-dependent Dark Matter interactions using a directional detector. The sensitivity of this experiment will be discussed in this talk.
WIMP Dark Matter

Direct search disagreement:
- Observation of annual oscillations by DAMA/LIBRA
- Limits on counting rates by others

Possible explanations:
Non-WIMP DM?
Local WIMP halo assumptions?
Interaction assumptions?
Experimental?

... Unambiguous proof of DM signal?

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Dark Matter Wind

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Direction-sensitive DM search

If DAMA annual oscillations (1-2%) due to DM wind... … search for much larger (30-100%) diurnal oscillations in WIMP *direction*

Spergel, PRD37

*Directional detector needed!*
DMTPC@Boston

Directional DM Detectors

DRIFT@Boulby

CF4 gas, micromesh+CCD readout, direction tag; D. Dujmic, et al., NIM A 584:337 (2008)

MIMAC@ILL

wire readout, CS2 gas, negative ion drift, 16 kg-day exposure S. Burgos et al., Astropart. Phys. 28, 409 (2007)


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DMTPC Collaboration

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DMTPC

- WIMP-induced elastic recoil
  - $F_{recoil} \sim 1\text{-}2\text{mm}$
  - $CF_4$ 50-100 Torr
  - $F(86\%): \lambda^2 J(J+1) \sim 0.65$
  - Low diffusion
  - Non flammable, non toxic

- Mesh amplification plane
  - scintillation photons produced in avalanche
  - $n(\gamma)/n(e^-) \sim 1/3$

- Optical readout
  - CCD: 2D plane
  - PMT: $\Delta z$, trigger

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DM-TPC Prototype (~5 l)

Surface operation at BU:

- 256 um pitch
- 30 um wire diameter
- 79% transparency
- Gain > 10,000
- Inexpensive

23 cm
Next Stage: 1m³ Module

PMT

CCD camera

Amplification stage

~1m mesh frames

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2D (CCD) + 1D (PMT)

Alpha tracks (Am-241)

Nuclear recoils (Cf-252 exposure):

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arXiv:0804.4827
arXiv:0803.2195
NIMA584,327 (arXiv:0706.2370)
Background Rejection: Energy-Range

- 30keV F ions in 50mbar CF4. Typical ion range is about 1mm. These produce same ionization as 15 keV electrons.
- 15keV electrons in 50mbar CF4. Typical electron range is about 30mm.

- e⁻ rejection (>10⁶ from previous study with Cs137)

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Direction + Sense (head-tail)

2D angle + head-tail from light asymmetry

Signed cosine of 2D recoil angle:

Cf-252, 75Torr CF$_4$$^\cos(\theta_{Recoil})$

~100keV head-tail threshold

arXiv:0804.4827

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Physics Reach

Spin-dependent:

- 1m³ module (1/4kg; improves current limits)
- 400 x 1m³ modules (100kg; tests MSSM)

 Assumes bg of 0.01/(kg y keV)

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DUSEL

- Unique facility: large + deep caverns

Mid-level (4850ft): site of Ray Davis’ experiment and birthplace “solar neutrino problem”; expanded with large caverns

Deep campus (7400ft): world-best shielding from cosmics + large caverns

- 2008- Lab development/physics experiments thanks to $100M private grant by Sanford ➔ Stanford Laboratory (SUSEL, 4850ft)
- 2012- US federal funding to complete deep lab (~$600M/NSF)
Summary

- Goal is to develop 100kg (1t) direction-sensitive detector for operation at DUSEL
- Unambiguous proof for dark matter by correlating signal with astrophysical phenomena
- Stepping stone into dark matter astronomy

\[ \sim O(10) \text{ events to detect WIMP wind} \]
A. M. Green, B. Morgan, astro-ph/0609115

\[ \sim O(10^5) \text{ events to measure velocity anisotropy} \]
Physics Reach

Spin-dependent:

$\sigma_p$ (pb)

1$m^3$ module (1/4kg; improves current limits)

400$x$ 1$m^3$ modules (100kg; tests MSSM)

Assumes bg of 0.01/(kg y keV)

preliminary WIMP mass (GeV)

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