TASI-2012
Lectures on Dark Matter

Figures for Lecture 3

Rouven Essig
Some operators for “model-independent” collider constraints

<table>
<thead>
<tr>
<th>Name</th>
<th>Operator</th>
<th>Coefficient</th>
</tr>
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<tbody>
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<td>D1</td>
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<td>$m_q/M_\chi^2$</td>
</tr>
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<td>D9</td>
<td>$\bar{\sigma}^{\mu \nu} x \bar{q} \sigma^{\mu \nu} q$</td>
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<tr>
<td>D11</td>
<td>$\bar{\chi} x G_{\mu \nu} G^{\mu \nu}$</td>
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</tr>
<tr>
<td>D15</td>
<td>$\bar{\sigma}^{\mu \nu} x F_{\mu \nu}$</td>
<td>$M$</td>
</tr>
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Effective Field Theory

consider DM coupling to quarks and gluons

from arXiv:1008.1783
Some constraints from LHC mono-jet searches

1109.4398
Some constraints from LHC mono-jet searches translated to limits on direct detection cross section
Direct Detection Signals and (some) Experiments

**Ionization**
- XENON10/100 (Xe)
- LUX (Xe)
- ZEPLIN (Xe)
- PANDAX (Xe)
- WARP (Ar)
- ArDM (Ar)

**Scintillation**
- DAMA/Nal (NaI)
- DAMA/LIBRA (NaI)
- XMASS (Xe)

**Phonons**
- CRESST (CaWO₄)
- KIMS (CsI)

+ Heavy-liquid bubble chamber:
- COUPP (CF3Br)
- PICASSO
- SIMPLE

**Other Experiments**
- CoGeNT (Ge)
- MAJORANA (Ge)
- CDMS (Ge, Si)
- super-CDMS (Ge, Si)
- EDELWEISS (Ge)
The XENON10/100 experiment

detector schematic

two-phase xenon time projection chamber
How to detect WIMPs

$\text{Xe} \rightarrow \text{Xe}^*, \text{Xe}^+$

produces photons and electrons

Two types of signal:

S1: prompt scintillation

S2: proportional scintillation (from ionization)
Two types of signal:

S1: prompt scintillation
S2: proportional scintillation
(from ionization)

background photons/electrons produce more electrons (ionization)
Usual WIMP searches

\[ \left( \frac{S_2}{S_1} \right)_{\text{WIMP}} \ll \left( \frac{S_2}{S_1} \right)_{\gamma} \]
Distinguishing nuclear from electron recoils

(test data)

XENON100
Snapshot of current direct detection situation
Snapshot of current direct detection situation

DM-Nucleon scattering cross section
Snapshot of current direct detection situation

DM-mass
(Weak scale!)
Constraints from various experiments

best constraint for large DM masses from XENON100
(constraint weaker than expected since they saw 3 events)
Beginning to probe supersymmetric Dark Matter models
Snapshot of current direct detection situation

Constraints weaken at high DM masses, since number density decreases.
Snapshot of current direct detection situation

Constraints weaken at low DM masses, since events fall below threshold.

(current limit for nuclear recoils is a few GeV, BUT we can go MUCH lower: see next lecture!)
A detector sensitive to the direction of an incoming dark matter particle could see a daily modulation, as position of detector with respect to DM wind changes over a day.

e.g. DM-TPC, DRIFT etc.
The DAMA/LIBRA annual modulation signals

dark matter?
Here is where it gets messy…

Snapshot of current direct detection situation
Snapshot of current direct detection situation

approximate region to explain DAMA/LIBRA data

spin-independent elastic scattering

seems highly constrained…
Another “anomaly”: CRESST-2

- Collects phonons and scintillation light
- Target: CaWO$_4$
  - 730 kg-days
  - Found 67 events
  - 4.2$\sigma$-4.7$\sigma$
And yet another “anomaly”: CoGeNT

442 live days on a 0.33kg Ge detector
(low-threshold, 0.5 keV)
Annual modulation in CoGeNT?

Agrees with DM within 2σ.

Excludes no-modulation by 3σ.

DM expectation

Farina et.al., 1107.0715
Additional background in CoGeNT?

**PRELIMINARY (Collar, work in progress)**

- Dashed line: 12 GeV/c^2, 1.5E-5 pb WIMP (CRESST-like)
- Solid line: best WIMP fit from 2-D energy-time modulation analysis
- Circles: best fit to bulk events after correction (flat spectral component subtracted)

Component of low energy surface events estimated to be leaking into spectrum after best fit to surface events.

Difference between total events after cuts, after subtracting estimates of known backgrounds.
Summary of “signals”

CoGeNT, DAMA, CRESST

\[ \sigma \sim 10^{-40} \text{ cm}^2 \]

\[ m_{\text{DM}} \sim 10 \text{ GeV} \]