DARK MATTER AND NEW PHYSICS
IN 30’

Neal Weiner
ICHEP Melbourne 2012
CCPP - NYU
July 11, 2012
Dark matter, baby. @OHFScratch what's left after nailing down Higgs? graviton?
• Higgs took 45 years!

DM: 80 years?  Or at least 40 years?
WHERE TO LOOK?

• Unlike the Higgs, for DM at best we have guesses
NEW IDEAS

Dynamical Dark Matter
K. Dienes; B. Thomas

Pangenesis
B. von Harling; K. Petraki

Mirror Matter
R. Foot

Our ideas of what dark matter is gives us ideas on how to find it
• Unlike the Higgs DM has been discovered many times
INDIRECT DETECTION

DIRECT DETECTION

JETS + MET
INDIRECT DETECTION

DIRECT DETECTION

JETS + MET
INDIRECT DETECTION

DIRECT DETECTION

JETS + MET

NB: I won’t discuss the axion for time, but it is a great DM candidate
INDIRECT DETECTION

DM annihilation => positrons [antimatter]

Fig. 2.—

a. The HEAT positron fraction compared with best-fit model predictions. The dashed curve is the baseline solar-modulated leaky-box secondary-production prediction, renormalized by a factor of 0.85. The solid curve shows an increased positron content due to annihilating 380 GeV/c\(^2\) neutralinos in the model of Kamionkowski and Turner. The dotted and dot-dash curves show an increased positron content due to annihilating 336 or 130 GeV/c\(^2\) neutralinos, respectively, in the model of Baltz and Edsjö.

b. The HEAT positron fraction compared with best-fit model predictions from astrophysical sources of positrons that are in addition to secondary production mechanisms. The dashed curve is the positron enhancement resulting from high-energy gamma rays converting to \(e^+e^-\) pairs near the magnetic poles of pulsars. The dotted curve represents an additional positron enhancement due to high-energy gamma rays interacting with low-energy optical or UV photon fields. The solid curve shows the enhancement from cosmic-ray interactions within giant molecular clouds.

Coutu et al, ’99

1999 - HEAT results
NOW THAT'S A SIGNAL!

It's too great to be dark matter!

PAMELA results, March 2012

It’s too great to be dark matter!
FERMI POSITRONS

The Fermi-LAT has measured the cosmic-ray positron and electron spectra separately, between 20 and 130 GeV, using the Earth's magnetic field as a charge discriminator.

- Two independent methods of background subtraction produce consistent results.
- The observed positron fraction is consistent with the one measured by PAMELA.
- Differences between different experiments below few GeV, probably due to charge-sign-dependent modulation, but still under study.

*Fermi Coll., PRL, 108 (2012) 011103*  
*arXiv:1109.0521*

Signal is confirmed
IS THERE AN ‘‘ANOMALY’’?
SO WHAT IS IT?
No associated anti-proton signal
Positron fraction

- more data
- new classification algorithms

factor 2+3 more statistics

Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and PAMELA results.


What if we randomly vary the pulsar parameters relevant for $e^+e^-$ production? (injection spectrum, $e^+e^-$ production efficiency, PWN "trapping" time)

Pulsars? [Blasi, Hooper, Serpico; Profumo; Cholis, Gelfand, Malyshev...]

Under reasonable assumptions, electron/positron emission from pulsars offers a viable interpretation of Fermi CRE data which is also consistent with the HESS and Pamela results. What if we randomly vary the pulsar parameters relevant for $e^+e^-$ production? (injection spectrum, $e^+e^-$ production efficiency, PWN “trapping” time)

Are we turning everything to 11?
the levels of anisotropy expected for Geminga-like and Monogem-like sources (i.e. sources with similar distances and ages) seem to be higher than the scale of anisotropies excluded by the results. However, it is worth to point out that the model results are affected by large uncertainties related to the choice of the free parameters.
PULSARS & POSITRONS

- Pulsars remain the best explanation of the PAMELA/ Fermi excess (i.e., we know there are pulsars and they make $e^+e^-$)

- They have not taken it upon themselves to demonstrate that they are, in fact, the origin (spectral breaks, anisotropies)
GIVE UP?

• Pulsars leading candidate - tough to prove

• Could still be DM - too important not to check

• Has also not taken advantage of opportunities to present itself (galactic center, diffuse background...)

• how do we test?
talk by T. Slatyer

Padmanabhan + Finkbeiner, '05; Galli, Bertone, Iocco, Melchiori, '09; Slatyer, Padmanabhan, Finkbeiner, '09

should have some result in 2013...
MODELS FOR PAMELA

- Dark Matter Explanations for PAMELA are tough
  - Large rates
  - Large rates into $e^+e^-$
  - Low rates into antiprotons
generates hard leptons by annihilations into a light mediator, no anti-protons

Realization: We are amazingly ignorant of weakly coupled GeV scale physics!
OTHER MOTIVATIONS FOR LIGHT DARK FORCES

Goodenough, Hooper; Hooper + Linden;...
We can look for Higgsstrahlung. Has the advantage of being suppressed only by $\varepsilon^2$. Search for $e^+e^-$ combinations.

What are we looking for?

Accessible final states depend on mass of $A'$

Talk by Bevan
BaBar searches
New light, weakly-coupled particles

$10^{-8}$ $10^{-7}$ $10^{-6}$ $10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^{0}$ $10^{1}$ $10^{2}$ $10^{3}$ $10^{4}$ $10^{5}$ $10^{6}$ $10^{7}$ $10^{8}$

$m_{A'}$ (GeV)

Figure 6-2. Parameter space for hidden-photons ($A_0$) with mass $m_{A_0} > 1$ MeV (see Fig. 6-3 for $m_{A_0}$). Shown are existing 90% confidence level limits from the SLAC and Fermilab beam dump experiments E137, E141, and E774 [86, 87, 88, 36] the muon anomalous magnetic moment $a_\mu$ [59], KLOE [54], the test run results reported by APEX [40] and MAMI [42], an estimate using a BaBar result [36, 47, 148], and a constraint from supernova cooling [36] (see also [37]). In the green band, the $A_0$ can explain the observed discrepancy between the calculated and measured muon anomalous magnetic moment [59] at 90% confidence level. Projected sensitivities are shown for the full APEX run [39], HPS [41], DarkLight [38], and VEPP-3 [43]. MAMI has plans (not shown) to probe similar parameter regions as these experiments. Existing and future $e^+e^-$ colliders such as BABAR, BELLE, KLOE, SuperB, BELLE-2, and KLOE-2 can also probe large parts of the parameter space for $A_0$, and include BABARAR, Belle, KLOE, SuperB, Belle-2, and KLOE-2 (the figure only shows existing constraints, and no future sensitivity). Proton colliders such as the LHC and Tevatron can also see remarkable signatures for light hidden-sectors [46]. This rich experimental program is discussed in more detail in §6.3.

For $m_{A_0} < 1$ MeV, the $A_0$ decay to $e^+e^-$ is kinematically forbidden, and only a much slower decay to three photons is allowed. Fig. 6-3 shows the constraints, theoretically and phenomenologically motivated regions, and some soon-to-be-probed parameter space. At very low masses, the most prominent implication of kinetic mixing is that, similar to neutrino mixing, the propagation and the interaction eigenstates are misaligned, giving rise to the phenomenon of photon $A_0$ oscillations [60]. In the early universe, these oscillations convert thermal photons into $A_0$ bosons, generating a "hidden Cosmic Microwave Background" (hCMB) [61]. For $\sim$ meV masses and $\epsilon \sim 10^{-6}$, they occur resonantly after big bang nucleosynthesis and before the decoupling of the CMB, and the corresponding hCMB could lead to an apparent increase.
BF(\(\Upsilon(1S)\rightarrow\gamma A^0\))BF(A^0\rightarrow\mu\mu) < (0.3–10)\times10^{-6}$ for $0.2 \leq m_{A^0} < 9.2 \text{ GeV}$
• the PAMELA excess is challenging to achieve with dark matter, but viable scenarios exist

• hasn’t shown up elsewhere yet

• CMB test (hopefully) in 2013

• Dark forces easy to come by, esp in SUSY theories => should keep looking regardless
POSITRONS ARE TOO MESSY

“The only really convincing signal of DM would be a monoenergetic line. Nothing can fake that.”

- Almost everyone
A line at \( \sim 130 \text{ GeV} \) ?

Bringmann et al ’12; Weniger ’12; Tempel, Hektor, Raidal ’12; Linden + Profumo ’12; Boyarsky, Malyshev, Ruchayski ’12; Finkbeiner + Su ’12
range from about 20 MeV to several hundreds of GeV.

is designed to survey the gamma-ray sky in the energy
containment at 1 GeV and decreases with energy as
incoming photons convert to

that we build our maps.

are available on the Internet, and it is from these files
arrival recorded. Event files for every week of the mission
energy of each event are reconstructed, and the time of
tracked through the detector. The arrival direction and
we now use 3.7 years of Pass 7 (2010; Su et al. 2010; Su & Finkbeiner 2012), except that
LAT event files as in our previous work (Dobler et al.
findings in Section
year with no trials factor, and we summarize our main
Ac u s p t r u c u t e r t o w a r d t h eG a l a c t i c c e n t e ri sr e v e a l e da st
are smoothed with a Gaussian kernel of FWHM = 10
The point spread function (PSF) is about 0.8
LAT is a pair-conversion telescope, in which

For this project, we constructed full-sky maps from the
CLEAN
3.7 year maps in 5 energy bins, and a residual map (Fermi
the only significant structure in the residual gamma-ray map.

All of the maps

The only significant structure in the residual gamma-ray map.

SOURCE
CLEAN
ULTRACLEAN

Finkbeiner + Su '12
Gaussian distribution with FWHM = 10

thermore, this energy range coincides with the recently
with Poisson noise. This excess at

case, and the rest of the gamma-ray sky is consistent

GeV maps from the 120

Fig. 8.—

We show in Figure

Spatial templates used in the Poisson likelihood analysis.

\begin{align*}
E^2 dN/dE \ [\text{GeV/cm}^2 \text{s/\text{s}r}] & \\
\text{Photon Energy [GeV]} & \\
90 & 100 & 110 & 120 & 130 & 140 & 150 & 160 & 170 & 180 & 190 & 200
\end{align*}

Two lines?
\[ \mathcal{L} = \frac{1}{4\Lambda^3} \left\{ \bar{\chi} \chi \left( \cos \theta_x B_{\mu\nu} B^{\mu\nu} + \sin \theta_x \text{Tr} W_{\mu\nu} W^{\mu\nu} \right) + i \bar{\chi} \gamma_5 \chi \left( \cos \theta_x B_{\mu\nu} \tilde{B}^{\mu\nu} + \sin \theta_x \text{Tr} W_{\mu\nu} \tilde{W}^{\mu\nu} \right) \right\} \]

effective theory of DM-> photons

contain both Z and photon;

expect \( \gamma\gamma \) and \( \gamma Z \)
\[ \mathcal{L} = \frac{1}{4\Lambda^3_R} \left\{ \bar{\chi} \chi \left( \cos \theta_\chi B_{\mu\nu} B^{\mu\nu} + \sin \theta_\chi \text{Tr} W_{\mu\nu} W^{\mu\nu} \right) \right. \\
+ \left. i \bar{\chi} \gamma_5 \chi \left( \cos \theta_\chi B_{\mu\nu} \tilde{B}^{\mu\nu} + \sin \theta_\chi \text{Tr} W_{\mu\nu} \tilde{W}^{\mu\nu} \right) \right\} \]

effective theory of DM-> photons
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effective theory of DM -> photons
effective theory of DM→ photons

New physics scale of 400-500 GeV => should be weakly coupled ~ 100 GeV/
Strongly coupled ~ 500 GeV

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\[ + i \bar{\chi}\gamma_5\chi \left( \cos \theta_x B_{\mu\nu} \tilde{B}^{\mu\nu} + \sin \theta_x \text{Tr} W_{\mu\nu} \tilde{W}^{\mu\nu} \right) \left\} \]

Yavin+NW

New physics scale of 400-500 GeV =>
should be weakly coupled ~ 100 GeV/
Strongly coupled ~ 500 GeV

effective theory of DM→ photons
CONSTRAINTS
$R^{th} \equiv \frac{\sigma_{\text{ann}}}{2 \sigma_{\gamma\gamma} + \sigma_{\gamma Z}}$, 

Cohen, Lisanti, Slatyer & Wacker; Buchmuller + Garney; Cholis, Tavakoli, Ulio; 

want a signal here

not here

No astrophysical uncertainties!
Models with sizable tree-level annihilation cannot yield this signal
Models with sizable tree-level annihilation cannot yield this signal.
MONOPHOTON/JET SEARCHES

(a) MiDM
(b) RayDM
(c) $\phi$FF

Yavin+NW

detection is model dependent
YOU DON’T HAVE TO BELIEVE IN ANOMALIES TO BE EXCITED ABOUT INDIRECT SEARCHES
Prospects with 2007-2010 data:

- **Muon flux limit**

<table>
<thead>
<tr>
<th>Mass (GeV)</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>WIMP &lt; m_w</td>
</tr>
<tr>
<td>2.0</td>
<td>WIMP &gt; m_w</td>
</tr>
</tbody>
</table>

Factors 3-4 wrt present

**Strong constraints on models with smaller SI couplings**

Ice Cube
• 10 years of data instead of $2(5x)$
• 30 dSphs ($3x$) (supposing that the new optical surveys will find new dSph)
• $-10\%$ from spatial extension (source extension increases the signal region at high energy $E > 10$ GeV, $M > 200$ GeV)

There are many assumptions in this prediction

Dwarf searches already probing interesting models
DIRECT DETECTION
ANOMALIES AND CONSTRAINTS
Summary elastic SI scattering

$\sigma_p^{SI} [cm^2]$

10^{-41} - 10^{-39}

$m_\chi [GeV]$ 10

DAMA + CoGeNT
CoGeNT
DAMA
CRESST
CDMS Si (2005)
CDMS Ge
XENON100 (mean $L_{eff}$)
XENON10 S2 analysis
P. Sorensen, talk @ IDM2010

solid: $q_{Na} = 0.3 \pm 0.03$
dashed: $q_{Na} = 0.3 \pm 0.1$

T. Schwetz, IDM, 29 July 2010 – p. 31
THE CONTROVERSY
WANT MODEL INDEPENDENT CONSTRAINTS

Figure 2: Velocity distribution functions: the left panels are in the host halo’s restframe and the right panels in the restframe of the Earth on June and the peak of the Earth’s velocity relative to Galactic DM halos. The solid red line is the distribution for all particles in a v kpc wide shell centered at 8sz kpc, the light and dark green shaded regions denote the –8σ scatter around the median and the minimum and maximum values over the vuu sample spheres, and the dotted line represents the best-fitting Maxwell-Boltzmann distributions are independent of location and persistent in time and hence reflect the detailed assembly history of the host halo rather than individual streams or subhalos. The extrema of the subsample distributions, however, exhibit numerous distinctive narrow spikes at certain velocities, and these are due to just such discrete structures. Note that although only a small fraction of sample spheres exhibits such spikes, they are clearly present in some spheres in all three simulations. The Galilean transform into the Earth’s rest frame washes out most of the broad bumps, but the spikes remain visible, especially in the high velocity tails, where they can profoundly affect the scattering rates for inelastic and light DM models (see Section...)

Kuhlen, et al
WANT MODEL INDEPENDENT CONSTRAINTS

Usual: make assumptions on this set limits on this

\[
\frac{dR}{dE_R} = \frac{N_T M_T \rho}{2m_\chi \mu^2} \sigma(E_R) \int_{v_{\text{min}}(E_R)}^{\infty} \frac{f(v)}{v} d^3v
\]

Alternative: set limits on this

Fox, Liu, NW
For the energy resolution, we use the light emission from Ref. [7] into S1 values, and use the Poisson fluctuation values of the Na quenching factor: 0.3 and 0.45 (the latter local Galactic escape velocity). We show results for two modulation amplitudes we use the 95% upper bound of the bounds (6) and (7) apply to a DM mass of 10 GeV. The energy resolution is [0.25, 0.3] keV, and does not depend on the nucleus. Therefore, it is based on the so-called S2 ionization signal which already includes energy contributions from other recoiling nuclei. However, the bound from SIMPLE is in strong disagreement with the CoGeNT and DAMA search result of Xe and Ge experiments are then irrelevant. For this case of spin-independent DM particle coupling to the spin of the proton, the null modulation signal from CDMS LT even for the general halo. If one were to assume both the modulation amplitudes and maximum gap upper limits coincide.

Let us briefly describe the data we use to derive the upper limit on the total event rate. From CDMS we use results from a dedicated low-background Na-only run. From CoGeNT, we combine the 36 bins from Fig. 1 of [9] into 9 bins of 2 keV where the energy resolution is 0.2 keV. The exposure is 48 kg days and no observed candidate event. We estimate the Ca contribution to the presence of fluorine in their target. (A comparison with a fluorine target. We consider the results from SIMPLE for Xe and Ge experiments are then irrelevant. For this case of spin-independent DM particle coupling to the spin of the proton, the null modulation signal from CDMS LT even for the general halo. If one were to assume both the modulation amplitudes and maximum gap upper limits coincide.

For compound detectors like SIMPLE, Eq. (13) is equivalent but more transparent than the method in Appendix A. We use this equation in the maximum gap method [14] to obtain less or equal events than observed. For XE100, we use only the T1Z5 detector [9], which gives the most ground contribution.

For a conservative acceptance of 0.94. A stringent limit at low WIMP masses. The energy resolution is [0.25, 0.3] keV, and does not depend on the nucleus. Therefore, it is based on the so-called S2 ionization signal which already includes energy contributions from other recoiling nuclei. However, the bound from SIMPLE is in strong disagreement with the CoGeNT and DAMA search result of Xe and Ge experiments are then irrelevant. For this case of spin-independent DM particle coupling to the spin of the proton, the null modulation signal from CDMS LT even for the general halo. If one were to assume both the modulation amplitudes and maximum gap upper limits coincide.

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IF IT'S NOT A LIGHT WIMP?

- DAMA: NaI(Tl) => What about iodine scattering?
- Some models (Magnetic Inelastic DM) can have dominant signals on Iodine
- Other models we haven’t thought of

Want direct comparisons to iodine targets -
COUPP (CF$_3$I) and KIMS (CsI)
Exposure

@16 keV $0.026 \pm 0.015$ (90% est) cpd/kg
(no bubble efficiency corr)

• 17.4, 21.9, 97.3 live-days at 8, 11, 16 keV thresholds

• 4.048 kg target, 79% cut-efficiency for nuclear recoils

For 100% DAMA modulation expect .
$0.037 \pm .007$ (90% )
Limits on nuclear recoil rates

Bayesian method was used to estimate the NR rates.

Example: 6 keV bin, DET09

Total weighted limits for 1keV bin.

RED: 1 sigma limit
BLACK: 90% CL limit

3.6 - 5.8 keV (2 - 4 keV in DAMA)

90% CL limit is 0.0098 cpd/kg/keV < 0.0183 cpd/kg/keV signal of DAMA

Analysis with PSD

Our PSD parameter

Claim: exclude Iodine interpretation at O(1)

Strong limit, but...
energy scale uncertainties? energy resolution comparison?
does the model describe the data?
DIRECT ANOMALIES

• Light WIMPs seem really constrained
  • Someone has to be quite wrong

• Iodine scattering must be very highly modulated
  • Models exist - but at the edge

• XENON100 could see rates at high (30-60 keV) energy
  • Nuclear recoil+nuclear excitation of Xe (40 keV photon) would be striking signature
XENON100?

- Upcoming XENON100 results - already strong
- Lower threshold
- Higher exposure in “iodine” range (30-60 keV)
- Could see strange signals (e.g., nuclear recoil + $^{129}$Xe 40 keV excitation)
YOU DON’T HAVE TO BE EXCITED ABOUT ANOMALIES TO BE EXCITED ABOUT DIRECT DETECTION
Is there any reason to think this range is special?
THE TWO CROSS SECTIONS TO THINK ABOUT

\[ \sigma_0 \approx \frac{G^2 f \mu^2}{2\pi} \sim 10^{-39} \text{cm}^2 \]
Ruled out (just a little bit)
THE TWO CROSS SECTIONS TO THINK ABOUT

\[ \sigma_0 \approx \frac{G_f^2 \mu^2}{2\pi} \sim 10^{-39} \text{cm}^2 \]

\[ g \sim 1 \Rightarrow y_p \sim \frac{1}{\text{few}} \frac{m_p}{v} \]

\[ \sigma_0 \sim 10^{-39} \text{cm}^2 \times 10^{-6} \sim 10^{-45} \text{cm}^2 \]
Various physics can move it up or down - but this is a natural starting point
Figure 3: Predictions of the scalar singlet model for a few values of the Higgs boson mass: 115 GeV (green), 140 GeV (yellow), 200 GeV (red), 300 GeV (magenta). The dots are the predictions of the constrained model of [6, 30].

In absence of a theoretical motivation for having $m_h$ comparable to the Higgs mass, [6, 30] considered the case $m_h = 0$, such that the model has no parameters and is unable to predicting a point in the plane $(M_{DM}, \sigma_{SI})$. Such prediction is also shown in Fig. 3, for the same values of the Higgs boson mass.

We remark two uncertainties not explicit from the plot. First, the Xenon 100 exclusion bound is plotted assuming $\sigma = 0.3$ GeV/cm$^3$ for the local DM density. This is the canonical value routinely adopted in the literature, with a typical associated error bar of $\pm 0.1$ GeV/cm$^3$.

Recent computations found a higher central value closer to 0.4 GeV/cm$^3$ [32] that two imply stronger bounds on the cross section $\sigma_{SI}$.

Second, the prediction for the conventional spin-independent DM/nucleon cross section is:

$$\sigma_{SI} = \frac{2}{9} \frac{m_4}{N_f^2} \frac{\pi}{M_{DM}^2 m^4_h},$$

(12)

where $f$ parameterizes the nucleon matrix element:

$$h_N |\bar{q}q| N_{ji} f_q m_N \frac{\bar{N} N_f}{f_q},$$

(13)

The main uncertainty comes from $f_s$. The recent analyses use $f = 0.56 \pm 0.01$, or $f = 0.30 \pm 0.01$, in agreement with the lattice results [35] and phenomenological determination [36].

Here and in the following we assume the default value in the Micromegas code: $f = 0.467$ [37].

5 Supersymmetry

In this section we study the impact of new Xenon 100 data on constraining SUSY models. We first consider the CMSSM, the most popular SUSY model with an unified scalar mass $m_0$, an unified gaugino mass $M_1/2$ and an unified trilinear scalar $A$-term at the GUT scale. Given that Xenon 100 adds to many other experimental constraints, we perform a global fit to all relevant data as described in the next subsection. Most importantly, we include the recent CMS and...
IF XENON SEES NOTHING, THEN WHAT?
• Are WIMPs dead? No!

• Consider an SU(2) triplet (aka a “pure Wino”)

• no Z-boson coupling; no (tree level) Higgs boson coupling

talk by R. Hill
Figure qx Cross section for low k velocity scattering on a nucleon for a heavy real scalar in the isospin \( J^3 \) representation of \( SU(3) \). The dark shaded region represents the uncertainty from perturbative QCD estimated by varying factorization scales. The light shaded region represents the uncertainty from hadronic input. Variation is insignificant compared to other uncertainties. We perform the RG running and heavy quark matching from \( \mu_t \) to \( \mu_c \) at NLO. Hadronic input uncertainties from each source in Table o and Table p are added in quadrature. We have ignored power corrections appearing at relative order \( s \epsilon m c f \) QCD/\( m_c^2 \). Typical numerical prefactors appearing in the coefficients of the corresponding power-suppressed operators suggest that these effects are small.

Due to a partial cancellation between spin k and spin p matrix elements, the total cross section and the fractional error depend sensitively on subleading perturbative corrections and on the Higgs mass parameter \( m_h \). We find \( \pm \) GeV, +0.90.3 on \( 47 \) cm\(^2\), where the first error is from hadronic inputs, assuming \( \tau \) and \( \tau \) from Table o, and the second error represents the effect of neglected higher order perturbative QCD corrections.

For the illustrative value \( m_h = \) GeV and as a function of the scalar strange quark matrix element \( \tau \) we display the separate contributions of each of the quark and gluon operators in Fig. rl.

Summary

We have presented the effective theory for heavy, weakly interacting dark matter candidates charged under electroweak \( SU(3) \). Having determined the general form of the effective lagrangian \( \Sigma \), we demonstrated matching conditions for subleading operators in op/\( M \)^3. Sample lattice inputs and baryon spectroscopy inputs are shown in the figure.

Talk by R. Hill
WIMP Mass \[\text{GeV}/c^2\]

Cross-section \[\text{cm}^2\] (normalised to nucleon)

DATA listed top to bottom on plot:

- DAMA/LIBRA, 2008, no ion channeling, 3sigma, SI
- CDMS II (Soudan), 2008, 121.3kg-days, Ge detector, SI
- XENON100, 2011, 100.9 live days of data, SI
- XENON1T, projection 2009, 3 ton, 2–30 keV, 45% eff
- LUX–ZEPLIN, projection 2008, 3 tonne (3 tonne-year), SI
- SuperCDMS, projection 2007, 25kg (7–ST@Snolab), SI
- LUX 300 kg Projected Sensitivity: 30000 kg-day, 5–30 keV, 45% eff

http://dmtools.brown.edu/ Gaitskell, Mandic, Filippini

may be hard to find
TWO CROSS SECTIONS

• If I had to pick two numbers for the cross section that a WIMP would scatter with, they’d be $10^{-39}$ cm$^2$ and $10^{-45}$ cm$^2$.

• It’s not the former.

• The latter is nigh

• But that’s no guarantee
A FINAL THOUGHT GIVEN THAT IT APPEARS THE HIGGS HAS BEEN DISCOVERED
THE HIGGS AND DM IN SUSY

In SUSY the Higgs is light for no good reason!

"X" may keep other things light, too.
THE HIGGS AND DM

• Maybe the Higgs couplings are non-standard=> new electroweak states?

• What if there is a sister partner to the Higgs, which has some symmetry group $G_s$ that keeps it from coupling to fermions?

• But what if this sister Higgs field gets a vev and participates in EWSB? (SUSY generalization of Type I 2HDM)

\[ H_u \quad H_d \quad \Sigma_u \quad \Sigma_d \]

\( G_s \Rightarrow \Sigma_n \) is combination of \( H, \Sigma \) More "well-tempered"

Arkani-Hamed, Delgado, Giudice
THE HIGGS AND DM

• Grand Unification implies GUT-related colored fields ("G-quarks" $D_g$)

\[
\begin{align*}
G_s & \Rightarrow \Sigma_u \\
\Sigma_d & \Rightarrow D_g \\
\end{align*}
\]
New opportunities for “stealth” or squeezed SUSY
Higgs

Hierarchy

SUSY

GUTs

DM

New colored states "G-quarks"
CONCLUSIONS

• After the Higgs, it’s time for new physics discoveries
• Dark matter is due: data from LHC, direct, indirect
• Rate of anomalies in > rate of anomalies out
• Slowly, we may be able to exclude the old ones
  • CMB tests for PAMELA
  • Iodine tests for DAMA
• More Fermi data from the GC
CONCLUSIONS

• But DM models also provide us great motivations for new searches
  
  • jets+MET
  
  • dark forces/rare GeV decays
  
  • monophoton/monojet
  
  • More complicated electroweak sectors => new colored states
  
  • “G-quarks” could play a role in SUSY signals
CONCLUSIONS

• Hopefully, it’s not another 40 years!