TeV Probes of WIMPless Dark Matter

Jason Kumar
University of Hawaii

Collaborators

- Johan Alwall
- Vernon Barger
- Jonathan Feng
- John Learned
- Danny Marfatia
- Enrico Sessolo
- Stefanie Smith
- Louis Strigari
- Shufang Su
  - 0803.4196, 0806.3746, 0808.4151, 0908.1768, 1002.3366, 1004.4573

The WIMP miracle

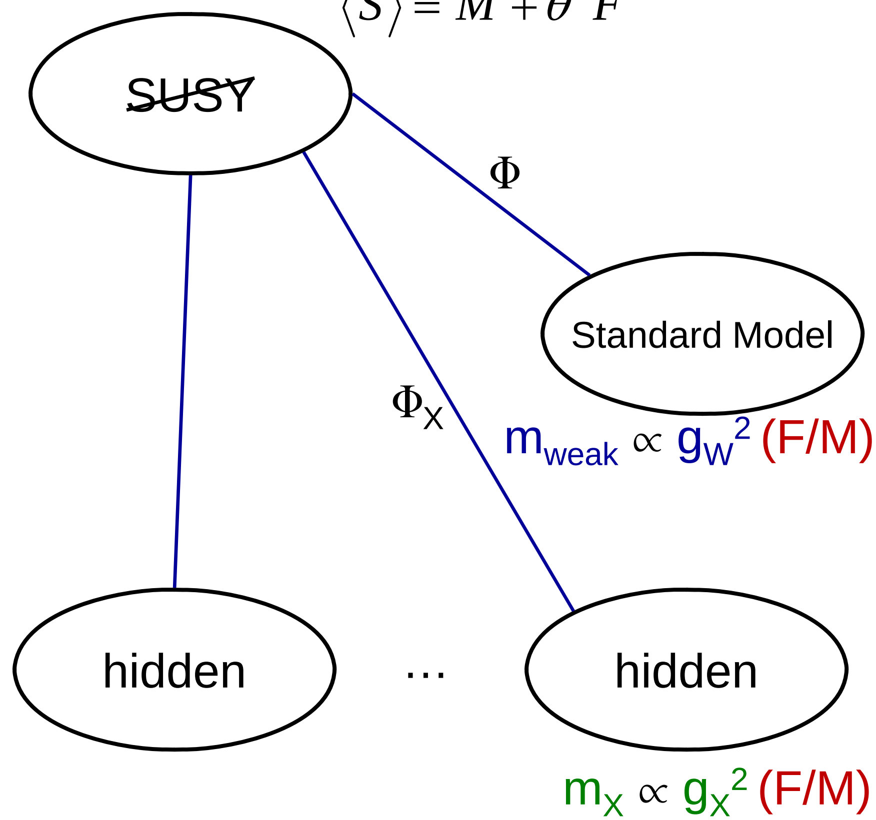
- non-relativistic thermal dark matter → solve Boltzman eq.
  - $\rho \propto \langle \sigma_A v \rangle^{-1}$ (Zeldovich; Lee, Weinberg; Scherrer, Turner; Kolb, Turner)
  - $\langle \sigma_A v \rangle$ basically determines ρ
- to get observed DM density need $\langle \sigma_A v \rangle \sim$ 1 pb
- stable matter with coupling and mass of the electroweak theory would have about right relic density for dark matter
  - WIMP miracle
- one of the best theoretical ideas for dark matter
- guide for most experimental searches
- but is this miracle really a WIMP miracle?

WIMPless dark matter setup

- extension of standard "low-energy SUSY" setup (GMSB)
- one SUSY-breaking sector mediated to multiple sectors
  - $m_{soft} \propto g^2$ (F/M)
  - but $\langle \sigma v \rangle \propto g^4/m^2$
  - so for stable particle at SUSY-breaking scale, $\rho \propto (F/M)^2$
  - depends only on SUSY-breaking spurion
- DM candidate in hidden sector
  - assume symmetry stabilizes a particle at soft scale
  - soft scale can be anything, but relic density is universal
  - WIMP Miracle → it's also right!
  - WIMPless Miracle

$$W = \lambda S \bar{\Phi} \Phi + \lambda_X S \bar{\Phi}_X \Phi_X$$

$$\langle S \rangle = M + \theta^2 F$$

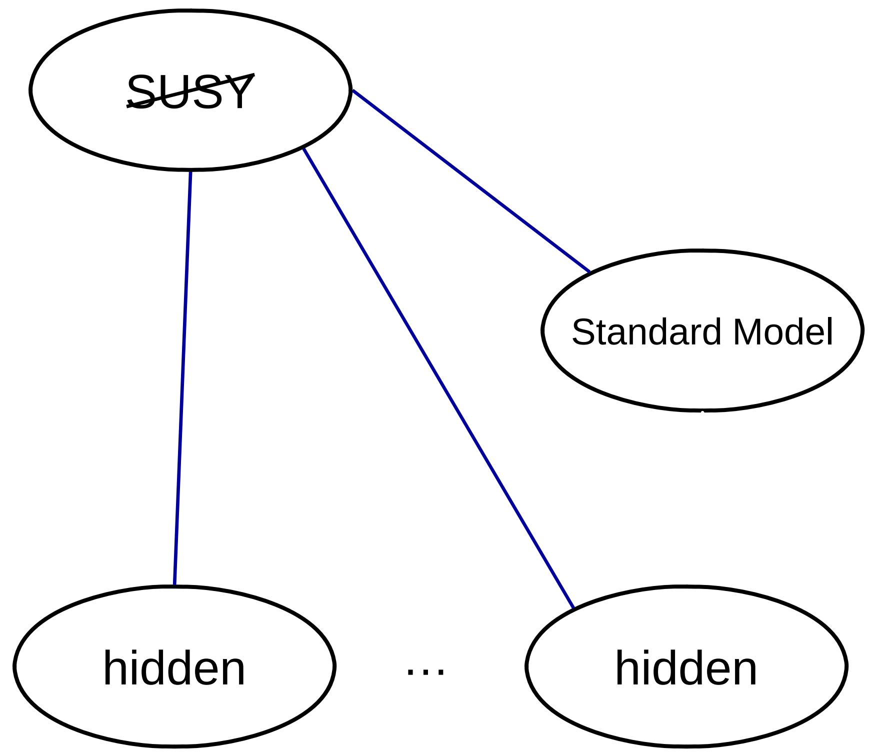


WIMPless Miracle

- a new, well-motivated scenario for dark matter (scalar or fermion)
- natural dark matter candidates with approximately correct mass density
- unlike "WIMP miracle" scenario, here dark matter candidate can have a range of masses and couplings
- opens up the window for observational tests, beyond standard WIMP range
- implications for collider, direct and indirect detection strategies

Yukawa coupling to SM

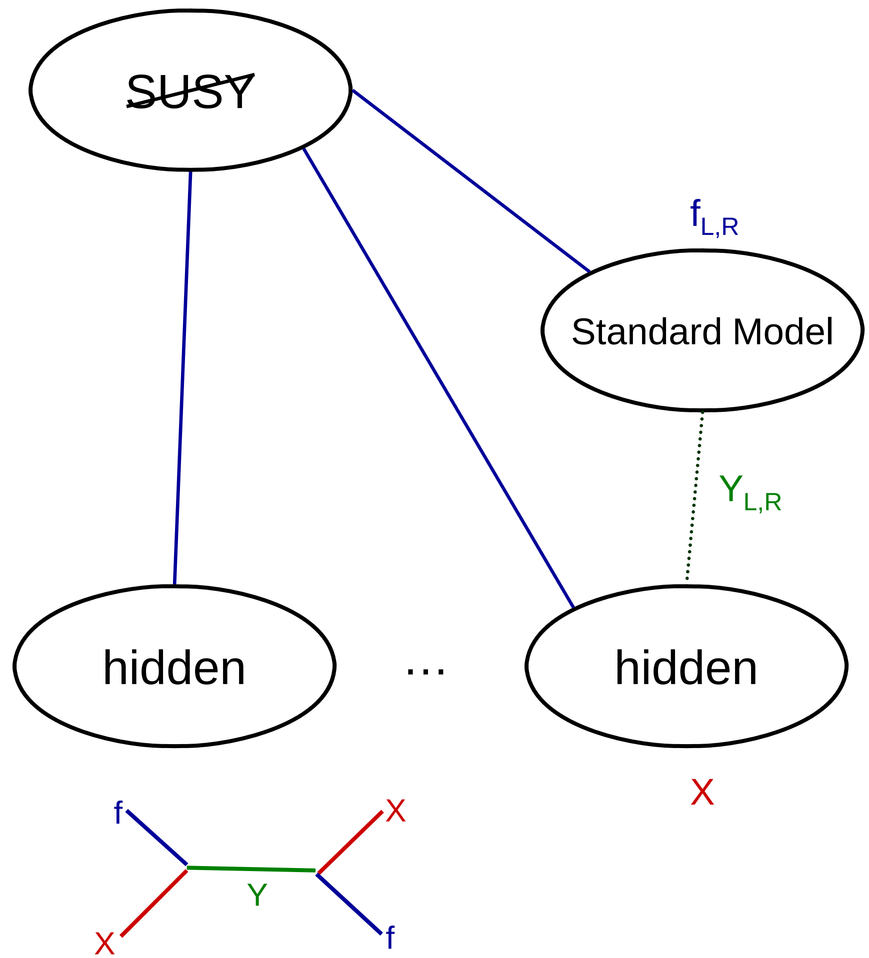
- if no connection between SM and hidden sector…
  - only gravitational effects



Yukawa coupling to SM

- if no connection between SM and hidden sector…
  - only gravitational effects
- but could have connectors between those sectors
  - exotics (Y) charged under both SM and hidden sector
  - exotic 4th generation multiplet
- Yukawa couplings between dark matter, SM matter and exotic connectors
  - get nuclear scattering through light or heavy (loop) quarks
  - annihilation to SM matter

$W = \lambda X Y_L f_L + \lambda X Y_R f_R + m Y_L Y_R$



New WIMPless features....

- scalar WIMPless DM
  - can have larger σ_{SI} than you would expect from neutralinos
  - for σ_{SI}, need to couple to $f^{\dagger}_{L}\, f_{R}$
    - need light quark mass or squark mixing insertion
    - chirality suppression
  - with scalar DM, chirality flip from m_Y
    - not suppressed

- Majorana fermion WIMPless DM
  - for Majorana fermion DM, σ_{SI}=0, but σ_{SD} is non-zero
  - most models will be seen first through σ_{SI}, σ_{SD} can confirm
  - Majorana fermion WIMPless DM is only found through σ_{SD}

Novel detection prospects....

- direct detection
  - DAMA can (?) be matched with low-mass particle with $\sigma_{SI} \sim 10^{-2\text{-}5}$ pb
  - CoGeNT has a signal which can fit similar region (CRESST?)
    - we'll leave aside the controversy (XENON, CDMS, etc.)
  - hard to fit with neutralino models (σ_{SI} suppressed, mass larger)
  - WIMPless DM scalar can fit (λ_b ~0.8, m_X ~ 6-7GeV, m_Y ~ 400GeV)
    - see Feng, Tu, Yu also
- indirect detection (neutrino)
  - excel at low mass (Super-K) and σ_{SD} (IceCube)
  - Super-K can make model-independent check of DAMA/CoGeNT (soon!)
  - may get signals at IceCube/DeepCore from σ_{SD} of Majorana ferm. DM

- Tevatron/LHC
  - can produce YY pairs through QCD processes
  - missing E_T signal
  - results with short-term data (including most of DAMA/CoGeNT)

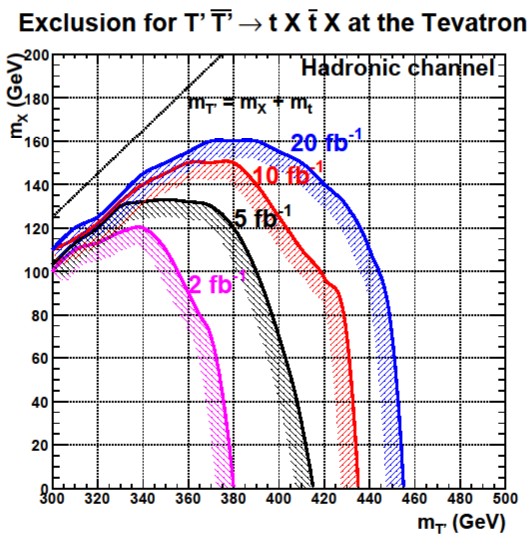
Collider searches for Y=T'

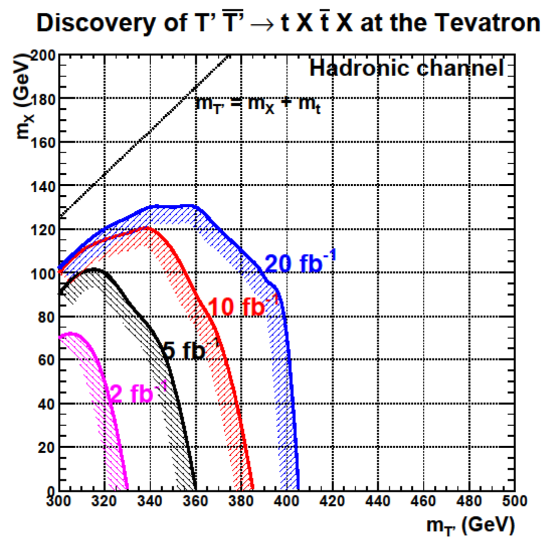
- pp → T'T' controlled by QCD
  - 300 GeV < $m_{T'}$ < 600 GeV (perturbativity, precision EW, direct search)
  - our example →assume hierarchical coupling to 3rd generation
    - simple FCNC solution

- T' → X t → X + jets required by hidden sector charge
  - X → missing E_T
  - more distinctive than standard 4th generation search
  - hadronic channel

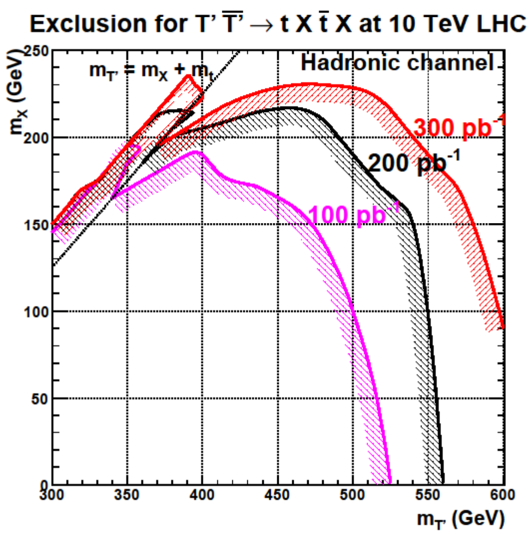
- upshot (via MadGraph, MadEvent, Pythia 6.4.20, PGS4)
  - good prospects with Tevatron
  - definitely will find with early LHC data

Collider search prospects

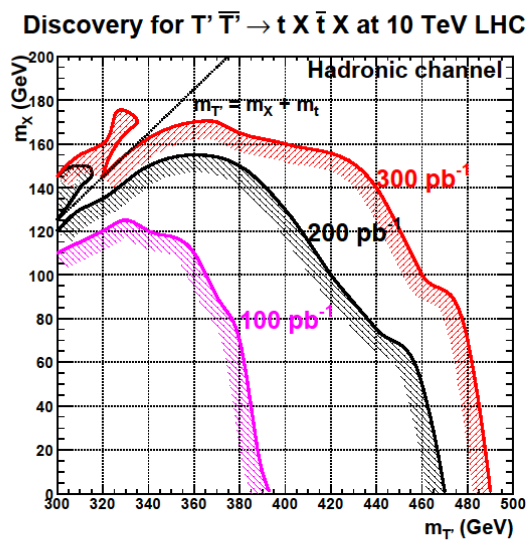




95%



low-mass region completely covered



3σ

Majorana fermion WIMPless DM

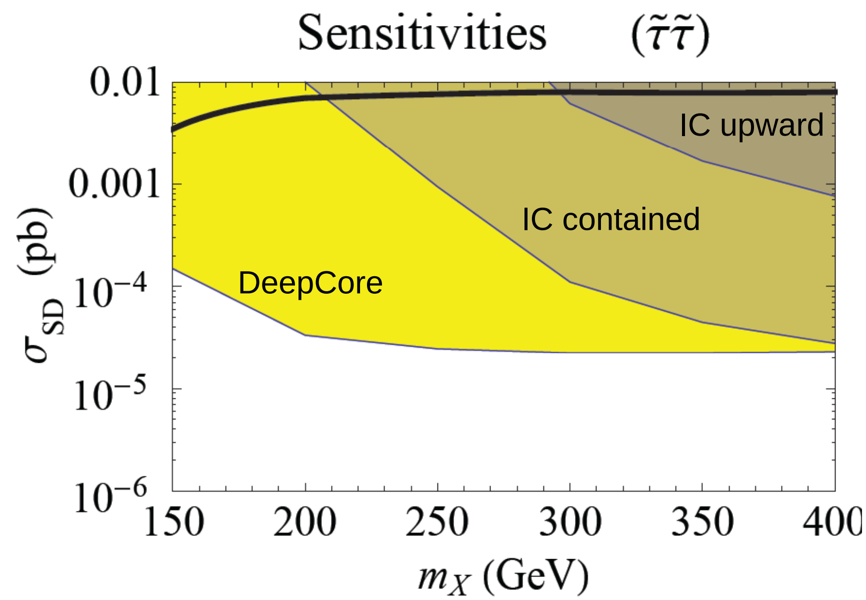
- nuclear scattering is spin-dependent
- Yukawa coupling to 1st generation quarks only
  - dominate nucleon spin content

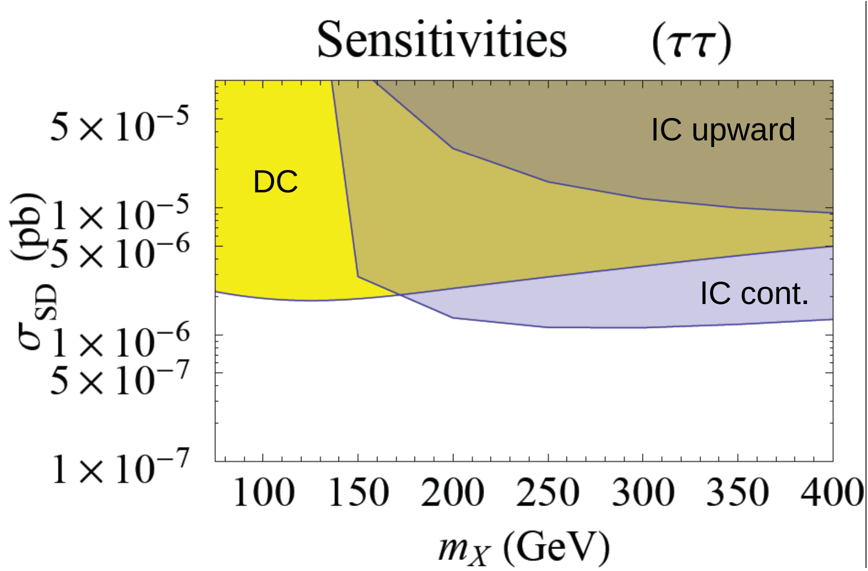
- neutrino detectors excel at measuring σ_{SD}
  - DM scatters of hydrogen in the sun and is captured
  - annihilates to MSSM → showers off ν_μ

- annihilation of Majorana fermions to light SM fermions is chirality/p-wave suppressed (also, ν spectrum much too soft)
- best neutrino spectrum (for detection) from τ, stau, sneutrino and up/down squarks
- focus on τ, stau and sneutrino channels
  - squarks more dependent on details of SUSY spectrum....

IceCube/DeepCore prospects

- IceCube/DeepCore will soon have the best bounds on σ_{SD}
- 3σ evidence obtainable at IceCube/DeepCore after 5y.
  - $\lambda_{u,d} \sim 0.5$
- DeepCore provides an edge for lower energy υ (~50 GeV)
  - advantage for lower mass DM or superpartner cascade decay)
- at higher energies, larger volume of IceCube is advantageous





Super-K bound

# of events at DeepCore per year
m_{stau} = 137 GeV , m_χ = 94.5 GeV
(Dimopoulos, Thomas, Wells)

Conclusion

- new theoretical scenario for dark matter
  - large range of masses and couplings
- possible explanation for results of DAMA/LIBRA, CoGeNT
- interesting searches at Tevatron and LHC
- signals possible at Super-Kamiokande and IceCube/DeepCore

Mahalo!

Back-up slides

Collider cuts

- Tevatron (hadronic)
- precuts
  - no isolated leptons
  - jets ≥ 5 (p_T > 20 GeV)
  - missing E_T > 100 GeV
  - isolation (jet from missing p_T)
    - $\Delta\phi$ > 90° for leading jet
    - $\Delta\phi$ > 50° for second jet
- additional cuts
  - missing E_T
    - 150, 200, 250 GeV
  - $H_T = \Sigma |p_T|$
    - 300, 350, 400 GeV
  - jets ≥ 6 (p_T > 20 GeV)

- LHC (hadronic)
- precuts
  - no isolated leptons
  - jets ≥ 5 (p_T > 40 GeV)
  - missing E_T > 100 GeV
  - isolation
    - $\Delta\phi$ > 11.5° for first 3 jets
- additional cuts
  - missing E_T
    - 150, 200, 250, 300 GeV
  - H_T
    - 400, 500 GeV
  - jets ≥ 6 (p_T > 40 GeV)

IceCube/DeepCore

- superpartner channel
  - spectrum from Dimopoulos, Thomas, Wells
  - m_{stau} = 137 GeV
  - $m_{sneutrino}$ = 111.5 GeV
  - m_χ = 94.5 GeV
- assume 1° angular acceptance
- IC E_μ-threshold = 100 GeV
- DC E_μ-threshold = 35 GeV
- account for matter effects in sun and vacuum oscillation
  - including τ-regeneration