New Signatures of WIMPless Dark Matter

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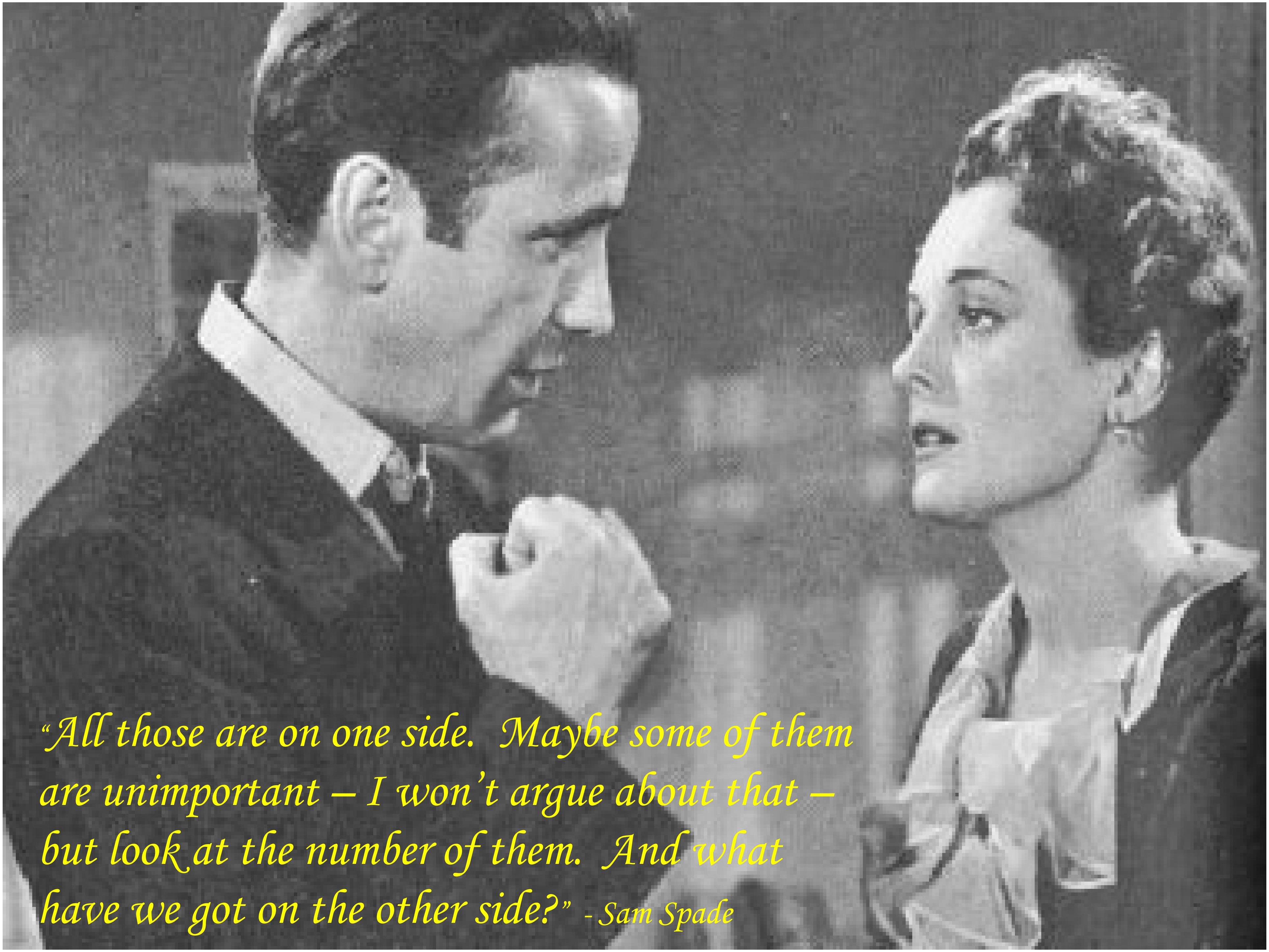
  - 0803.4196, 0806.3746, 0808.4151, 0908.1768, 1002.3366, 1004.4573

Hints of low-mass dark matter

- DAMA/LIBRA (see Belli's talk)
  - 8.9σ annual modulation of event rate
  - potentially explainable by low mass, large σ_{SI} DM (no channeling?)
- CDMS (see Saab's talk)
  - two candidate events (~1 bg. expected → ~77% CL)
  - both have relatively low recoil energy, but issues with timing cuts....
- CoGeNT
  - event rate unexplained by **known** backgrounds, fits low mass DM
  - 90% CL region excludes null hypothesis (no DM contribution)
- CRESST ...? (see Seidel's talk)
  - excess events in oxygen band which may fit low mass DM...?
- fit to DAMA/CoGeNT/CRESST (Collar, Hall, Hooper, McKinsey)
  - fit point→ $m_X \sim 7$GeV ,$\sigma_{SI} \sim 2\times10^{-4}$pb (v. dist., form factors, **quenching**)


"All those are on one side. Maybe some of them are unimportant – I won't argue about that – but look at the number of them. And what have we got on the other side?" - Sam Spade

the key to low mass is low recoil energy...

- XENON100
  - claims to rule out CoGeNT/DAMA
  - major questions about $L_{eff.}$
- XENON10
  - reanalysis by SGGF suggests they can put tighter bounds than XENON100
  - would rule out most of DAMA/CoGeNT region
  - questions about assumptions of efficiency at low recoil energy (Collar)
  - but the plot thickens... analysis using S2 signal could rule out the entire CoGeNT/DAMA region (wish I had seen P. Sorensen's talk)
- CDMS
  - analyzing data using lower threshold
  - issues with energy scale calibration of silicon detectors?

What’s a simple theorist to do?

“My interest ... is purely a sporting one.” – *Rick Blaine*

The WIMPless miracle

- non-relativistic thermal dark matter
  - Boltzmann equation → $\rho \propto \langle \sigma_A v \rangle^{-1}$
- to get observed DM density need $\langle \sigma_A v \rangle$ ~ 1 pb

- stable matter with coupling and mass of the electroweak theory would have about right relic density for dark matter
  - WIMP miracle

- $\sigma_A v \propto g^4 / m^2$
- the real miracle is in what controls this ratio

- in GMSB, $m_{soft} \propto g^2 (F/M_{mess.})$

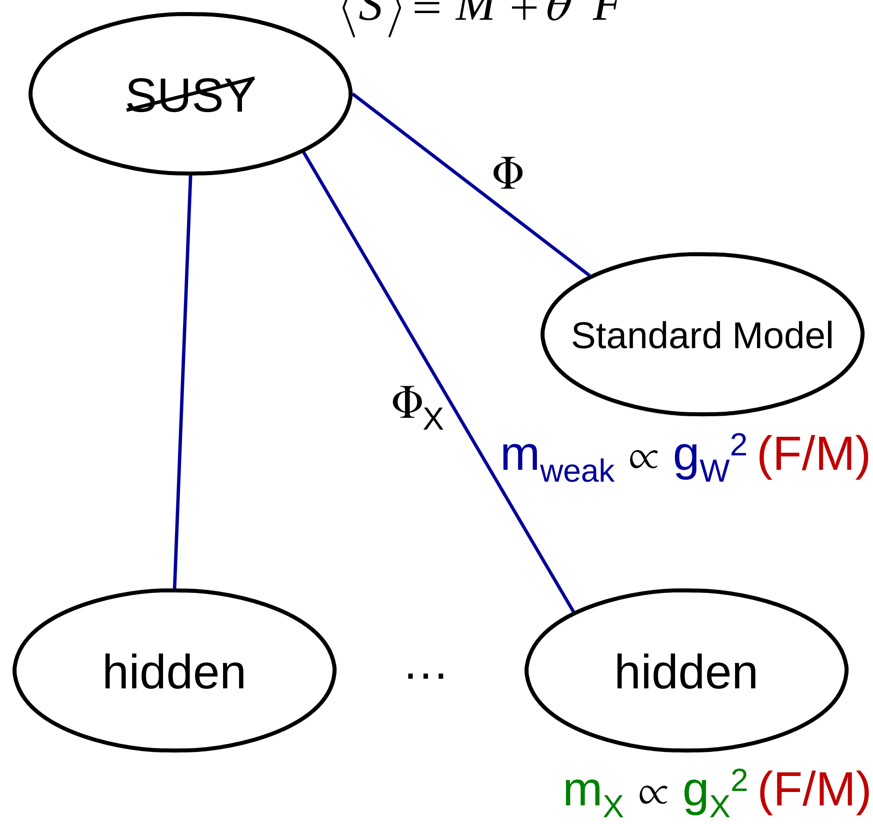
- if particle at m_{soft} is stable, $\rho \propto (F/M)^2$, regardless of what m_{soft} is
- WIMPless miracle

WIMPless setup

- the standard “low-energy SUSY” setup (GMSB)
  - one sector breaks supersymmetry
  - MSSM receives SUSY-breaking, as well as other hidden sectors
  - soft scales controlled by one spurion field
- we add to this extra gauge sectors, which behave in a qualitatively similar way
  - assume symmetry stabilizes particle at SUSY-breaking scale, which could be anything
  - but $\rho \propto (F/M)^2$ is always approximately right

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

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

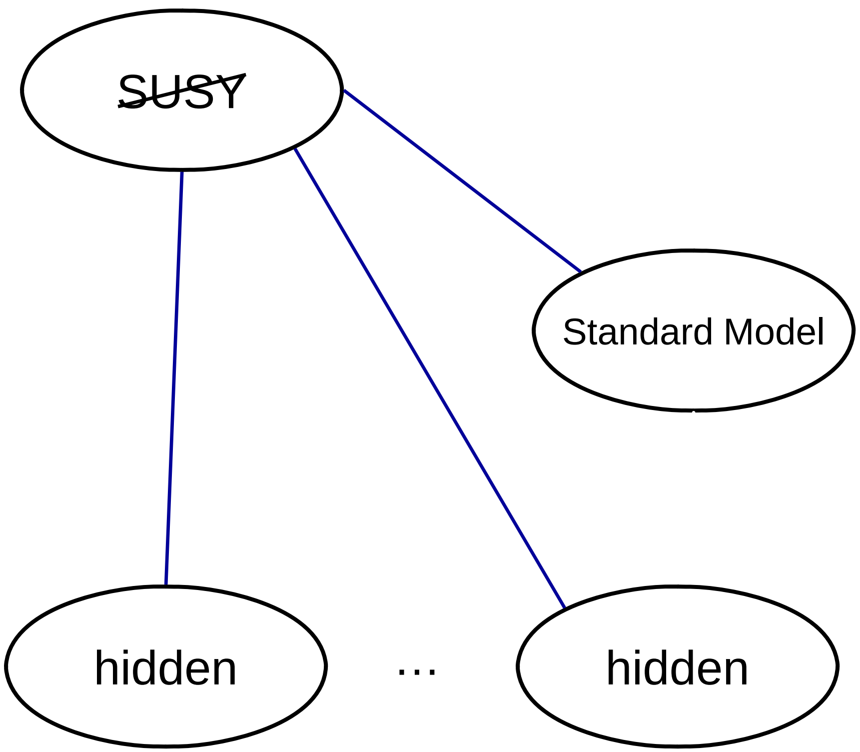


WIMPless Miracle

- 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 (with a focus on low mass, but more general)

Yukawa coupling to SM

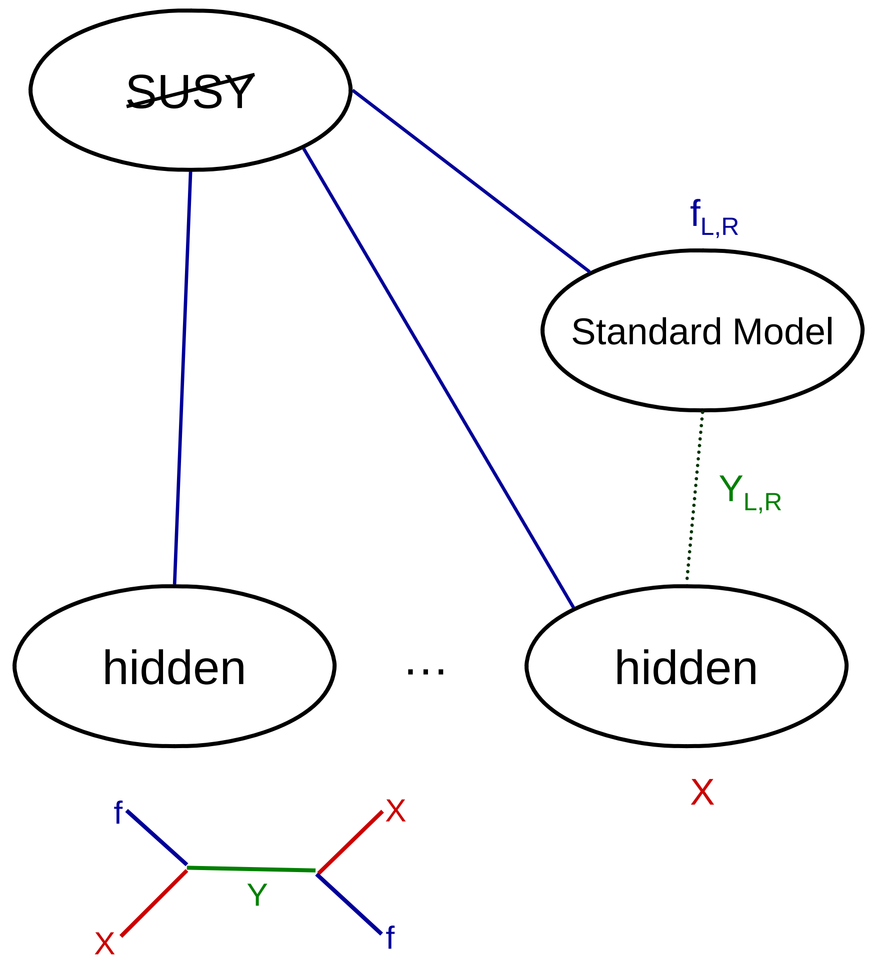
- if no connection between SM and hidden sector…
  - only gravitational effects



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

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



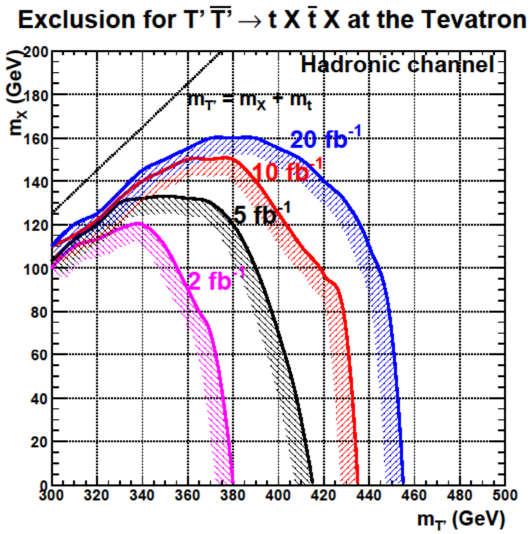
New WIMPless features for low mass....

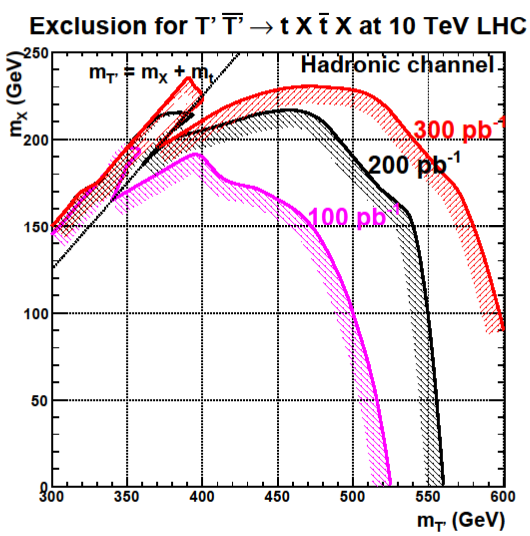
- scalar WIMPless DM
  - can have larger σ_{SI} than expected for neutralinos
  - for σ_{SI}, need to couple to $f^{\dagger}_L f_R$
    - need light quark mass or squark mixing insertion
    - chirality suppression
  - with scalar DM, chirality flip from m_Y
  - can fit near CHHM region (λ_b ~ 0.8, m_X ~ 6-7 GeV, m_Y ~ 400 GeV)
    - assuming hierarchical Yukawa coupling to 3rd generation only (simple FCNC solution)
    - can be tested with near term data
    - collider QCD production of 4th generation quark connectors (Y)
      - Y → X + jets → always missing E_T (hidden sector charge)
      - distinctive signature can be seen with Tevatron and near-term LHC data
    - DM annihilation to SM → ν can be see at Super-K

Upshot

Y=T'
$m_{T'}$~300-600GeV

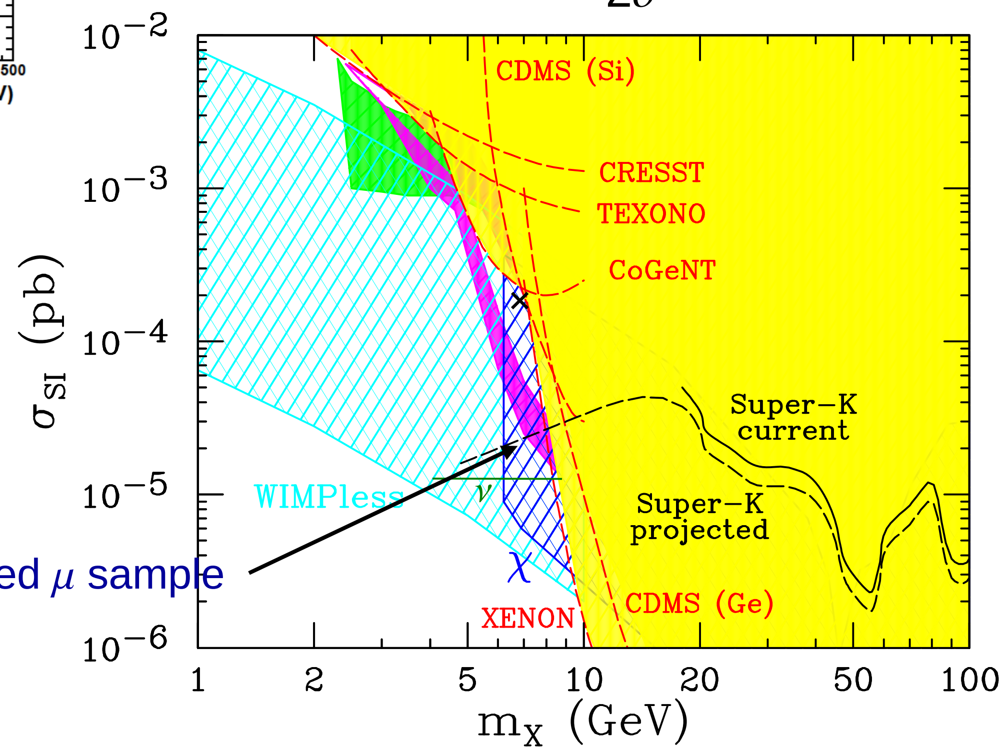
95%





projected Super-K bounds using fully-contained events and 3000 live days, plus WIMPless ($0.3<\lambda_b<1.0$) and neutralino (Bottino, et al) predictions

2σ



fully-contained μ sample

New WIMPless features for Majorana fermion DM....

- Majorana fermion WIMPless DM
  - for Majorana fermion DM, σ_{SI}=0, but σ_{SD} is non-zero
    - so not targeting low mass DAMA/CoGeNT/CRESST now....
  - most models will be seen first through σ_{SI}, σ_{SD} can confirm
  - Majorana fermion WIMPless DM is only found through σ_{SD}

- IceCube/DeepCore will soon have among the best bounds on σ_{SD}
  - like SK, uses DM annihilation to SM in the sun, followed by ν shower
  - here, consider coupling only to 1st gen. quarks (nuclear spin)
  - best annihilation channels are for superpartners, or τ
  - upshot → 3σ evidence possible in 5 yr. ($\lambda_{u,d}$ ~ 0.5)

Conclusion

- new WIMPless 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