Discovering WIMPless Dark Matter through 4th generation quarks

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arXiv:1001.xxxx (soon!)

4th generation workshop, NTU, Taiwan, 15 January 2010

Introduction: The WIMP miracle

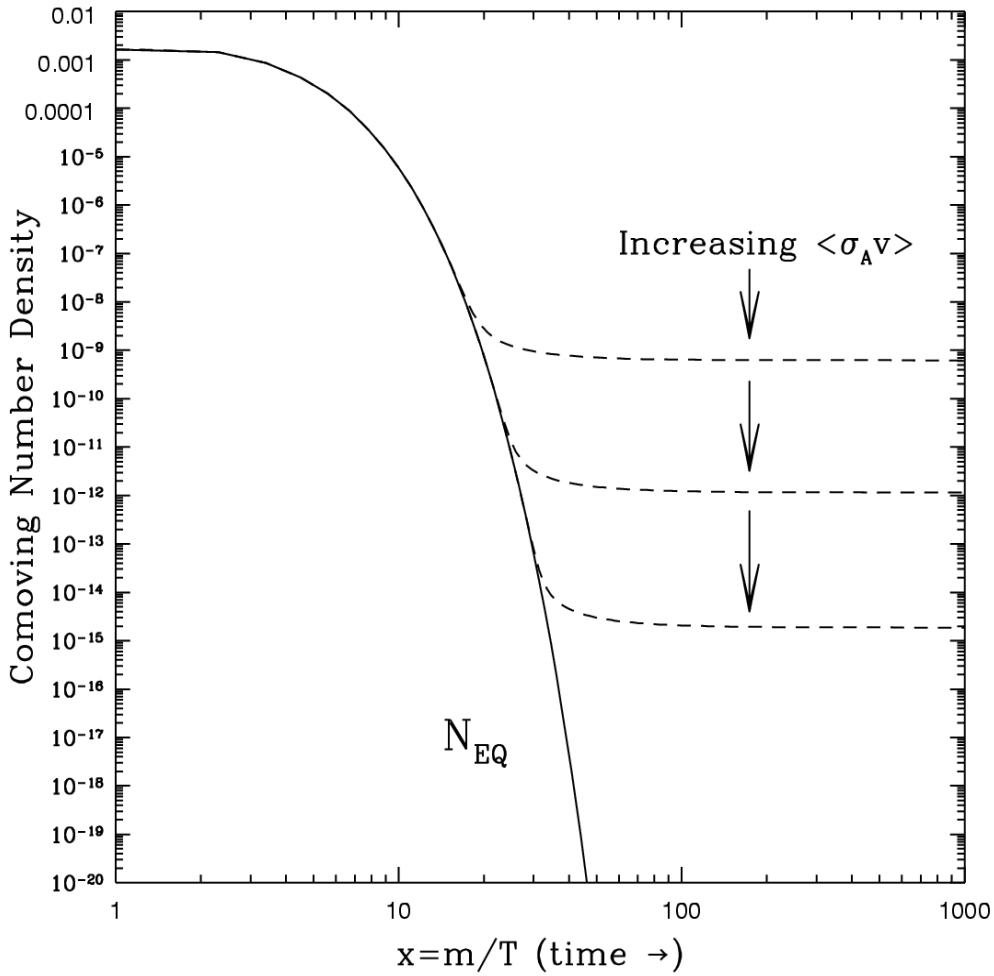
Relic density of particles in the universe:

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

$$m_X \simeq m_W \sim 100\mathrm{GeV}$$

$$g_X \simeq g_{\mathrm{Weak}} \sim 0.6$$

$$\Rightarrow \Omega_X \sim 0.1$$



The "WIMP miracle"!

Gauge mediated SUSY breaking

Can this “miraculous” ratio be natural?

- Gauge mediated supersymmetry breaking gives soft masses to SUSY partners according to

$$m_S^2 = -\frac{g^4 N_{mess}}{4\pi^4}\left(\frac{F}{M_{mess}}\right)^2$$

- So, naturally

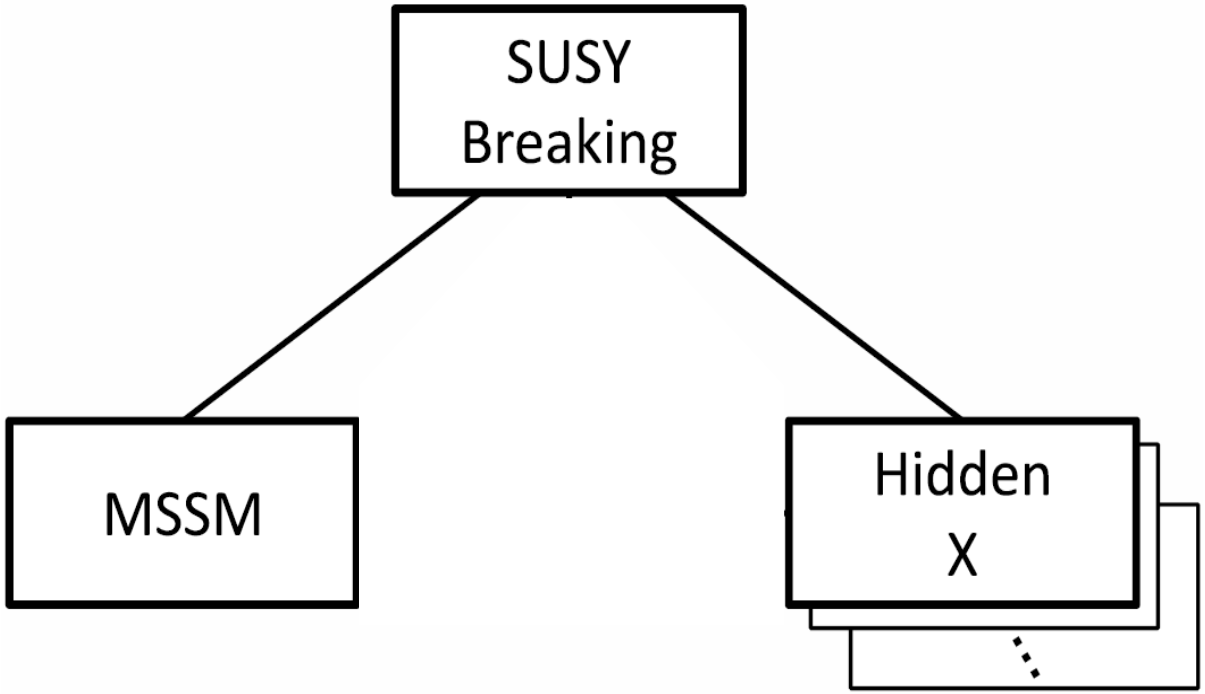
$$\frac{m_S}{g^2} \sim \frac{F}{M_{mess}} = \text{const}$$

- Unfortunately, GMSB has light gravitino, so no stable WIMP...

The WIMPless miracle

[Feng, Kumar (2008)]

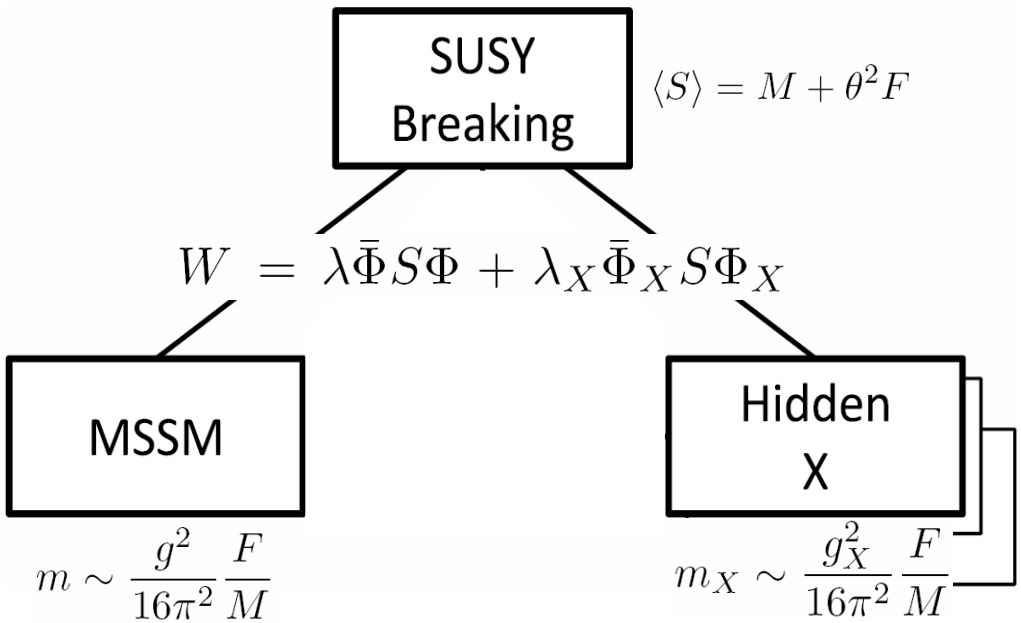
What if there are other, hidden, sectors?



Each sector has its own particle content,
gauge groups, couplings, ...

The WIMPless miracle

- Particle Physics



Superpartner masses depend on gauge couplings

- Cosmology

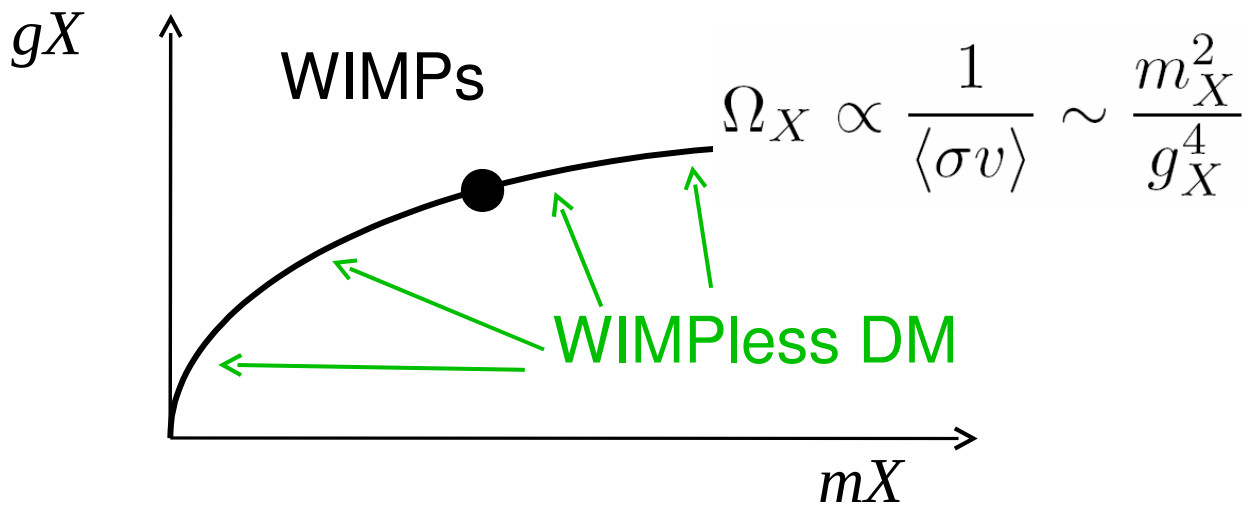
$$\frac{m_X}{g_X^2} \sim \frac{m}{g^2} \sim \frac{F}{16\pi^2 M}$$

Ω depends only on the SUSY Breaking sector:

$$\Omega_X \sim \Omega_{\rm WIMP} \sim \Omega_{\rm DM}$$

Hidden sector generically has the right relic density

The WIMPless miracle

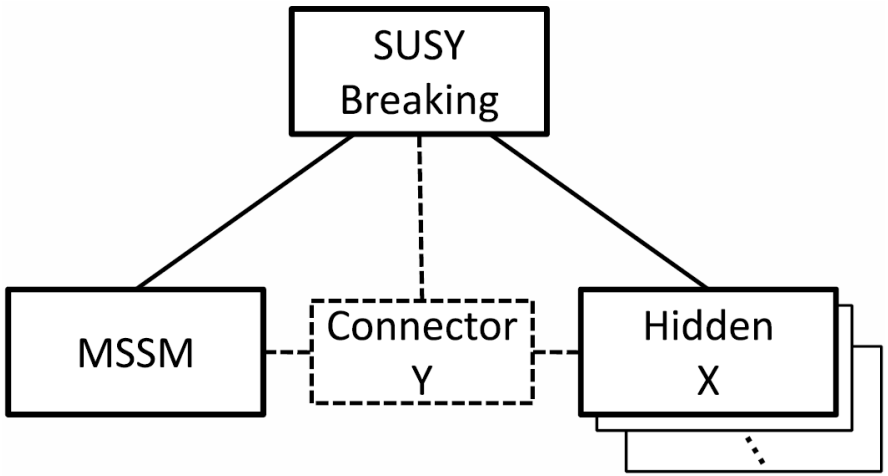


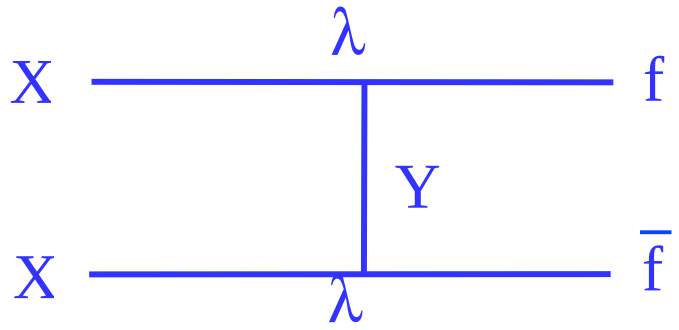
- No longer necessarily WIMPs, but allow for a range of masses and couplings
- The WIMPless miracle!

Detecting WIMPless DM

[Feng, Kumar, Strigari (2008)
Feng, Kumar, Learned, Strigari (2008)]

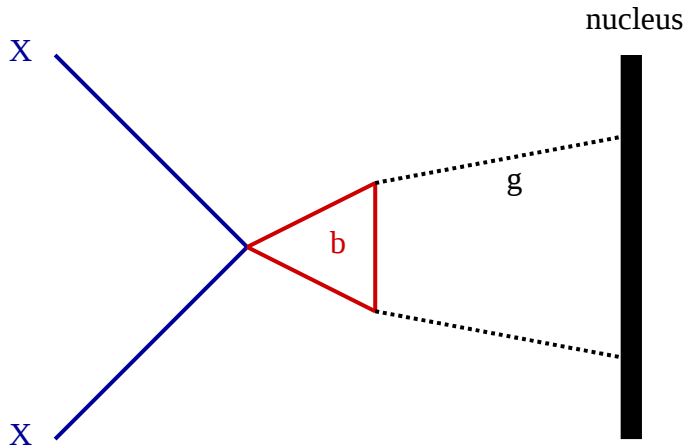
- DM sector has no SM gauge charges, but might interact through Yukawa couplings
- For example, introduce connector Y with both SM and hidden charge
- Y particles will mediate both annihilation to, and scattering by, SM particles





Detecting WIMPless DM

- Connector should not introduce FCNC
- Must couple (rather) strongly to protons
- Natural solution: 4th generation-like quarks with hidden charge, coupling only to 3rd generation quarks, and scalar DM
- DM then couples to gluons in proton through loops of b-quarks



Dark matter production

[J.A., Feng, Kumar, Su, in progress]

- 4^{th} generation quarks charged under QCD and hidden charge
  - Pair produced at the Tevatron and the LHC
  - Decay to 3^{rd} generation quarks and dark matter
- Have to obey constraints from SM precision and partial wavefunction unitarity
  - Masses between ~ 300 - $\lesssim$ 600 GeV
- Low mass, large cross section: Should be possible to find at Tevatron and early LHC

Dark matter production

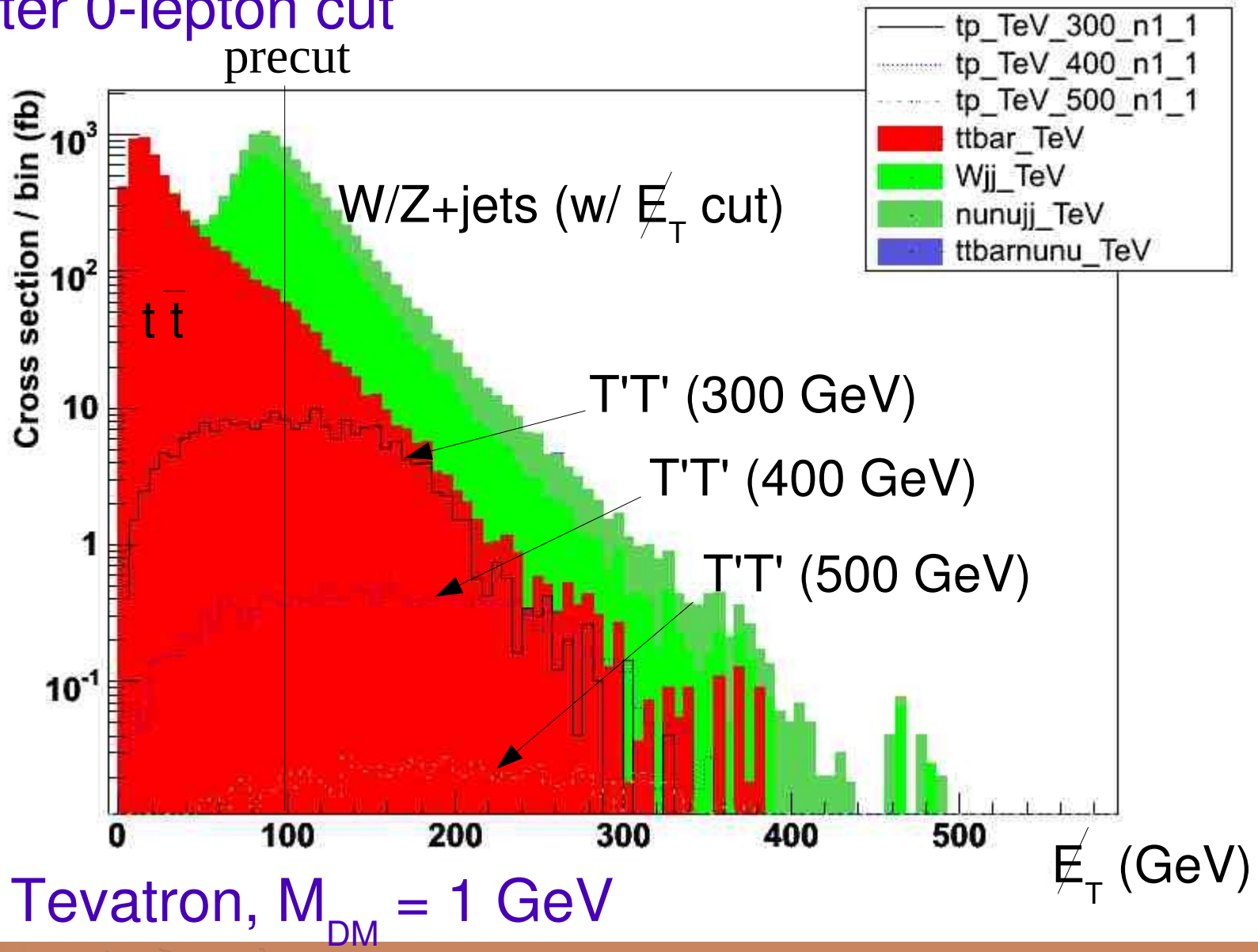
- Easiest signal: T' $\rightarrow$ t X (pair) production giving pair of top quarks + missing energy
- Main background: SM top pair production
- Best channel: Fully hadronic channel
  - Signal: many jets + missing energy
  - With lepton veto, main background mistagged tau + neutrino from W and top
  - Anti-tau tagging could strongly reduce background!
- B-tagging no help – same for signal and top background

How to choose cuts?

- We (obviously) want cuts which remove more background than signal (at least ^2))
- Precuts in common for all mass parameter points
- Stronger cuts, chosen point by point for best exclusion/discovery significance
- Additional requirements:
  > 2 signal events, S/B > 0.1

How to choose cuts?

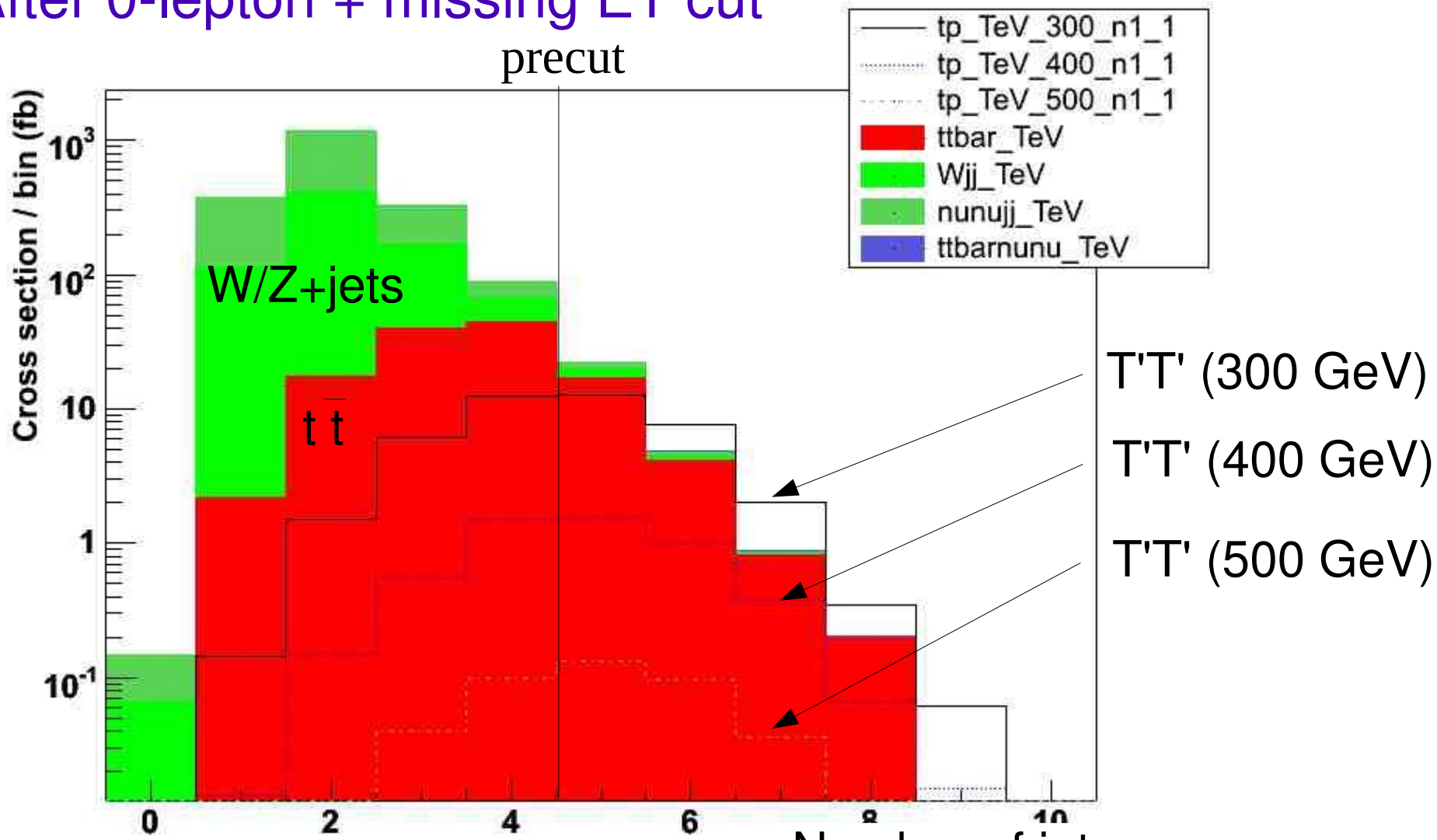
After 0-lepton cut



Tevatron, M_{DM} = 1 GeV

How to choose cuts?

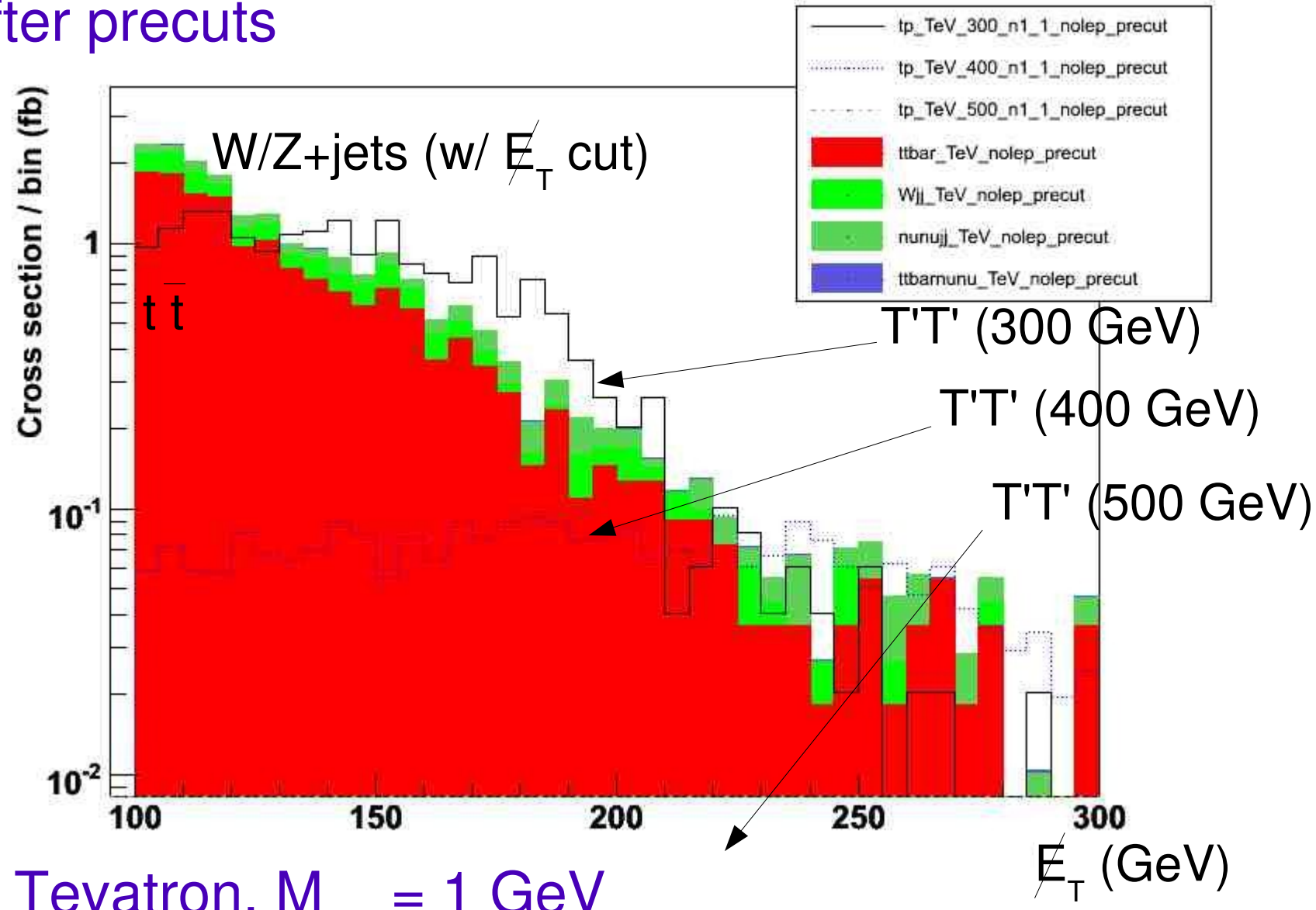
After 0-lepton + missing ET cut



Tevatron, M_{DM} = 1 GeV

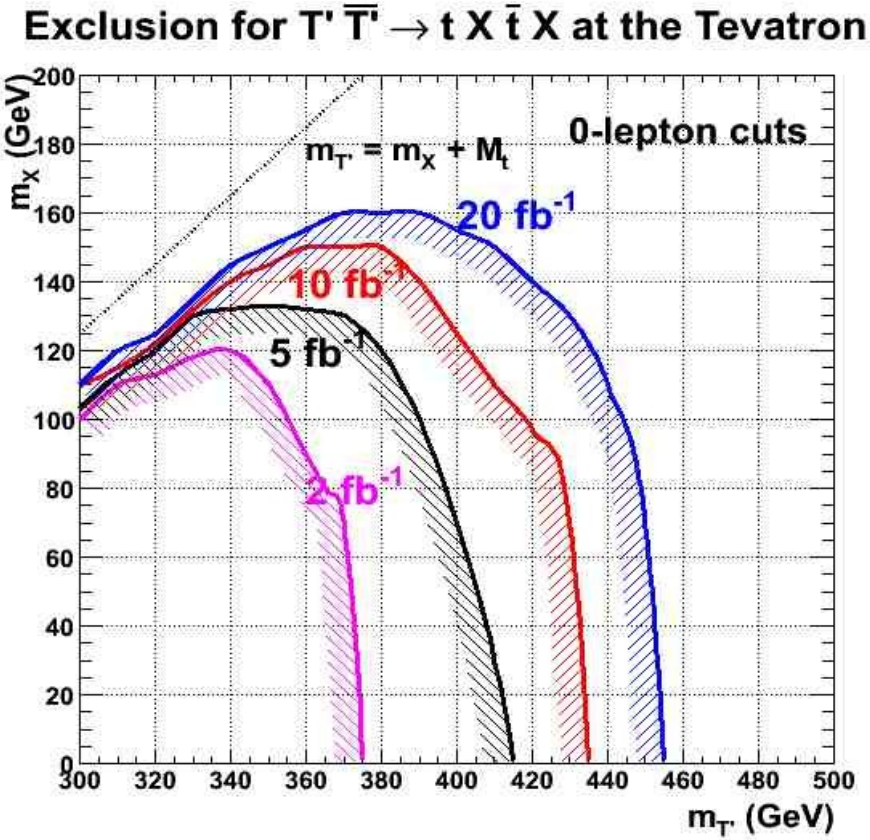
How to choose cuts?

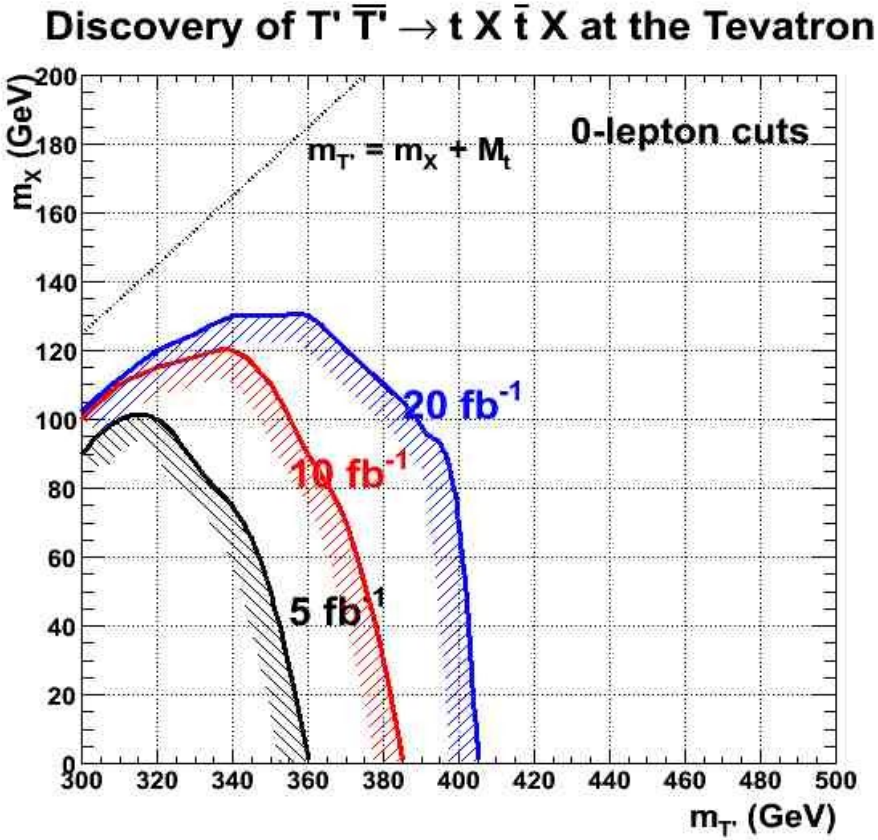
After precuts



Tevatron, M_{DM} = 1 GeV

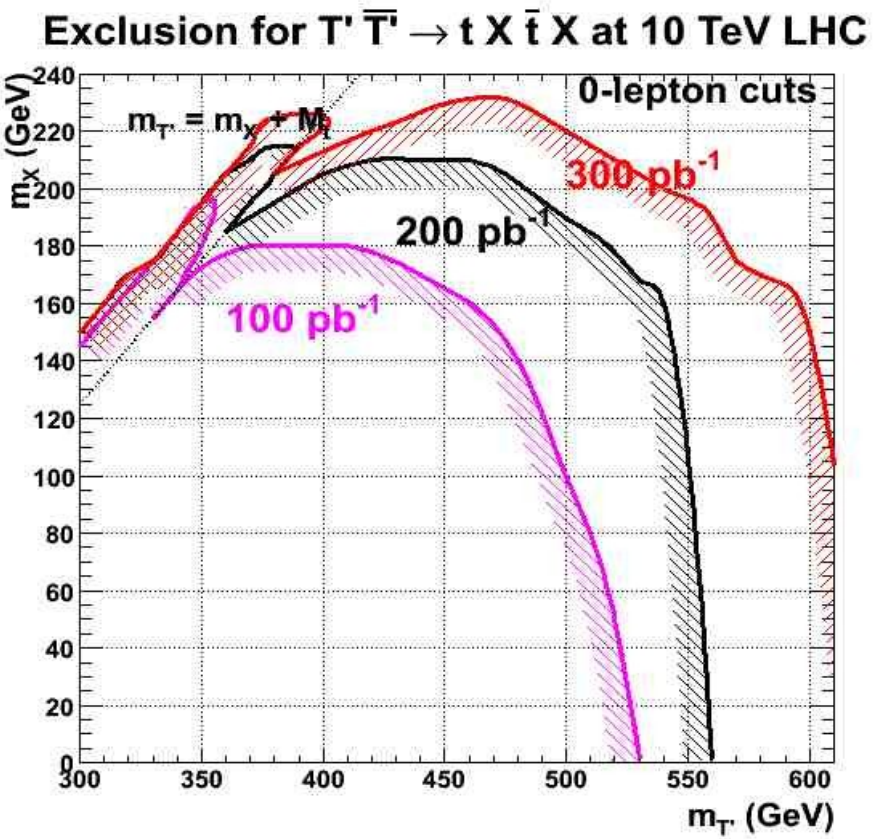
Production at the Tevatron

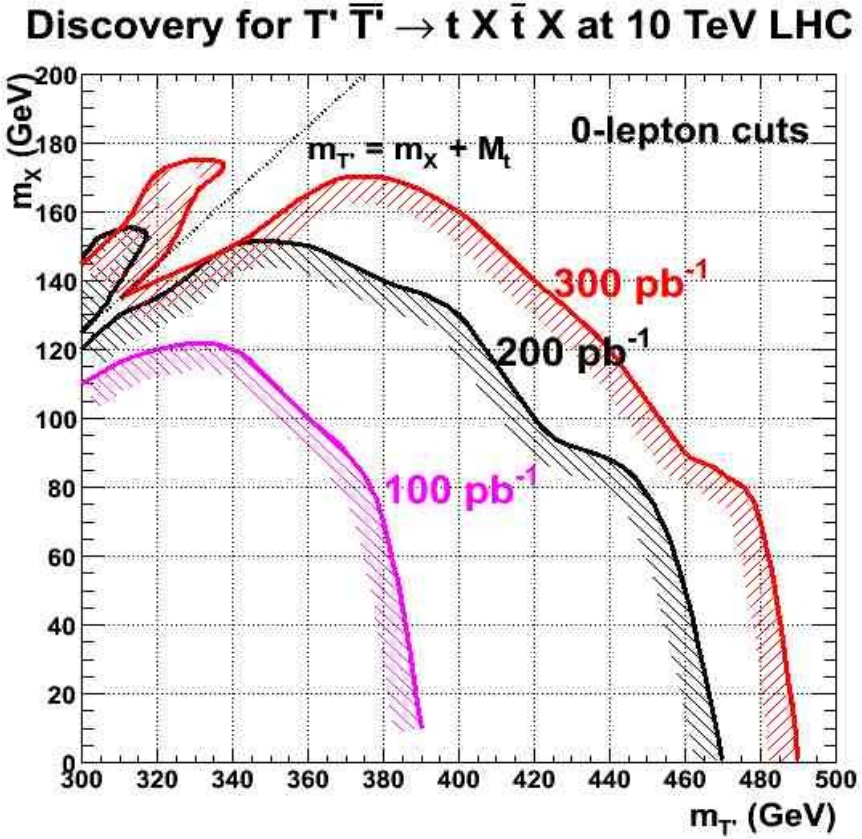




2 σ exclusion and 3 σ "evidence" reach for the Tevatron, with 2/5/10/20 fb^{-1} integrated luminocity

Production at early LHC





2 σ exclusion and 3 σ "evidence" reach for 10 TeV LHC, with 100/200/300 pb^{-1} integrated luminocity

Comments

- Exclusion unambiguous, but "discovery" just means discovery of jets+missing E_T
  - Much larger luminocity needed to unambiguously pin down signal (b-tagging, top reconstruction)
  - But: cross section much larger than SUSY
- 1-lepton exclusion/discovery limits considerably less stringent
  - But if both seen, can help pin down parameters

Conclusions

- The “WIMP miracle” looks like an exceptional coincidence of particle physics and cosmology
- If there are hidden sectors, GMSB would give right dark matter density for any DM mass (WIMPless dark matter)
- 4^{th} generation quarks natural connectors to hidden sector, with decay $T' \rightarrow t\ X$, $B' \rightarrow b\ X$
- $m_{T'} < 400$ GeV can be discovered at the Tevatron
- The **full parameter space** can be excluded by 10 TeV LHC

Backup slides

Cuts for Tevatron

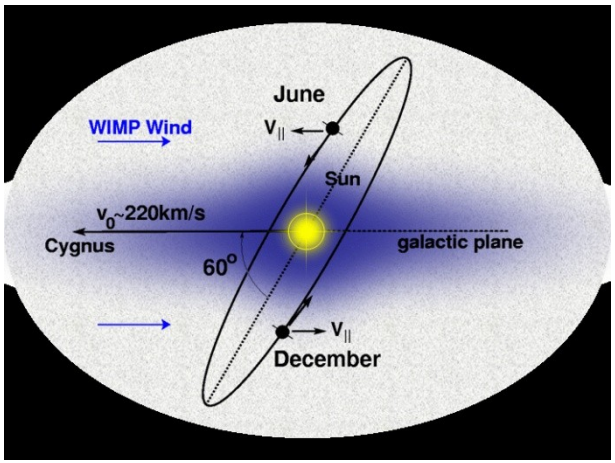
- Precuts (0-lepton channel):
  - No lepton or tau-tagged jet with pT > 2 GeV
  - MET > 100
  - At least 5 jets with pT > 20 GeV
  - Cuts on $\Delta\varphi$(jet, MET) for 2 hardest jets
- Final cuts:
  - MET > 150, 200, 250 GeV
  - HT > 250, 300, 350 GeV
  - N(jets) > 6, and combinations of these cuts

Cuts for LHC

- Precuts (0-lepton channel):
  - No lepton or tau-tagged jet with pT > 2 GeV
  - MET > 100
  - At least 5 jets with pT > 40 GeV
  - Cuts on $\Delta\varphi$(jet, MET) for 3 hardest jets
- Final cuts:
  - MET > 150, 200, 250, 300 GeV
  - HT > 400, 500 GeV
  - N(jets) > 6, and combinations of these cuts

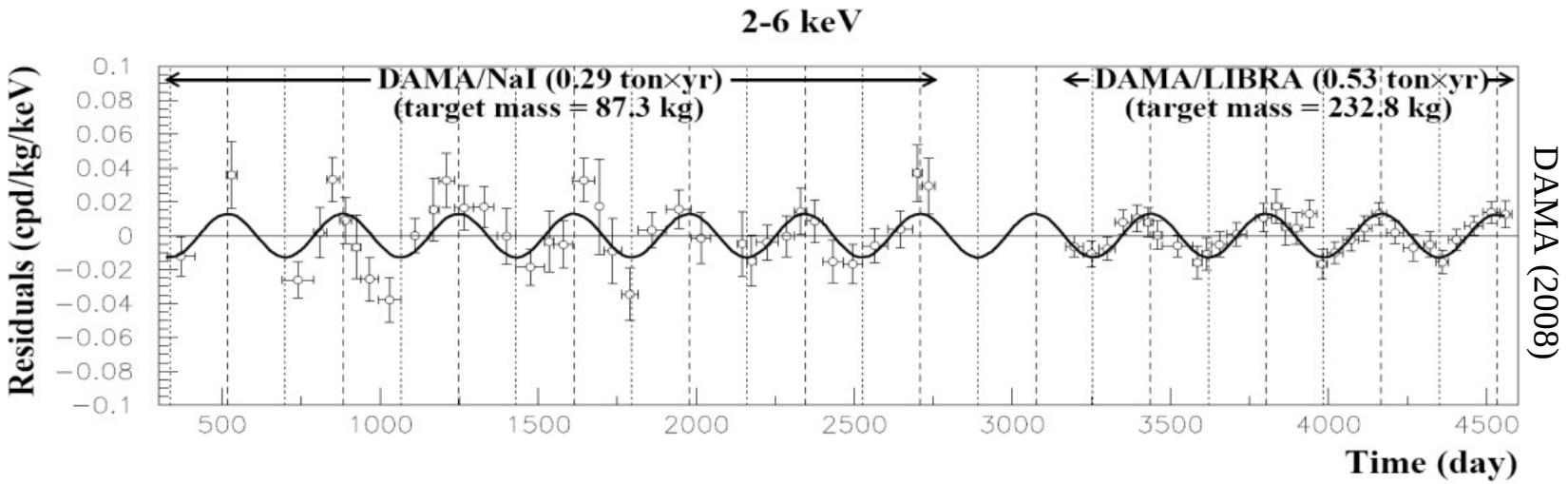
DAMA

Collision rate of dark matter with a detector should change as Earth's velocity adds constructively/ destructively with the Sun's



Drukier, Freese, Spergel (1986)

DAMA: 8σ signal with T ~ 1 year, max ~ June 2



DAMA

- Most of the allowed DAMA region has been ruled out by other direct detection experiments
- One corner still possible: Very small DM masses (~ 1 GeV) "invisible" for other experiments
- Awkward for WIMPS, but no problem for WIMPless!