Antideuteron Searches for Dark Matter

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Dark Matter Detection

- Direct detection critical
- Recently recognized potential significance of indirect detection
- Photons
  - HESS, VERITAS
  - Fermi
- Positrons
  - PAMELA
- Antiprotons
  - PAMELA

Model-Dependent

- Which signal dominates is model-dependent
- Many models favor annihilation into
  - Quark/antiquark pairs
  - W boson pairs
- In either case, antiprotons would be a good signal
- Problem is most models give signal below the current background predicted rate
  - Cosmic ray protons hitting interstellar hydrogen and helium

Antiproton Flux

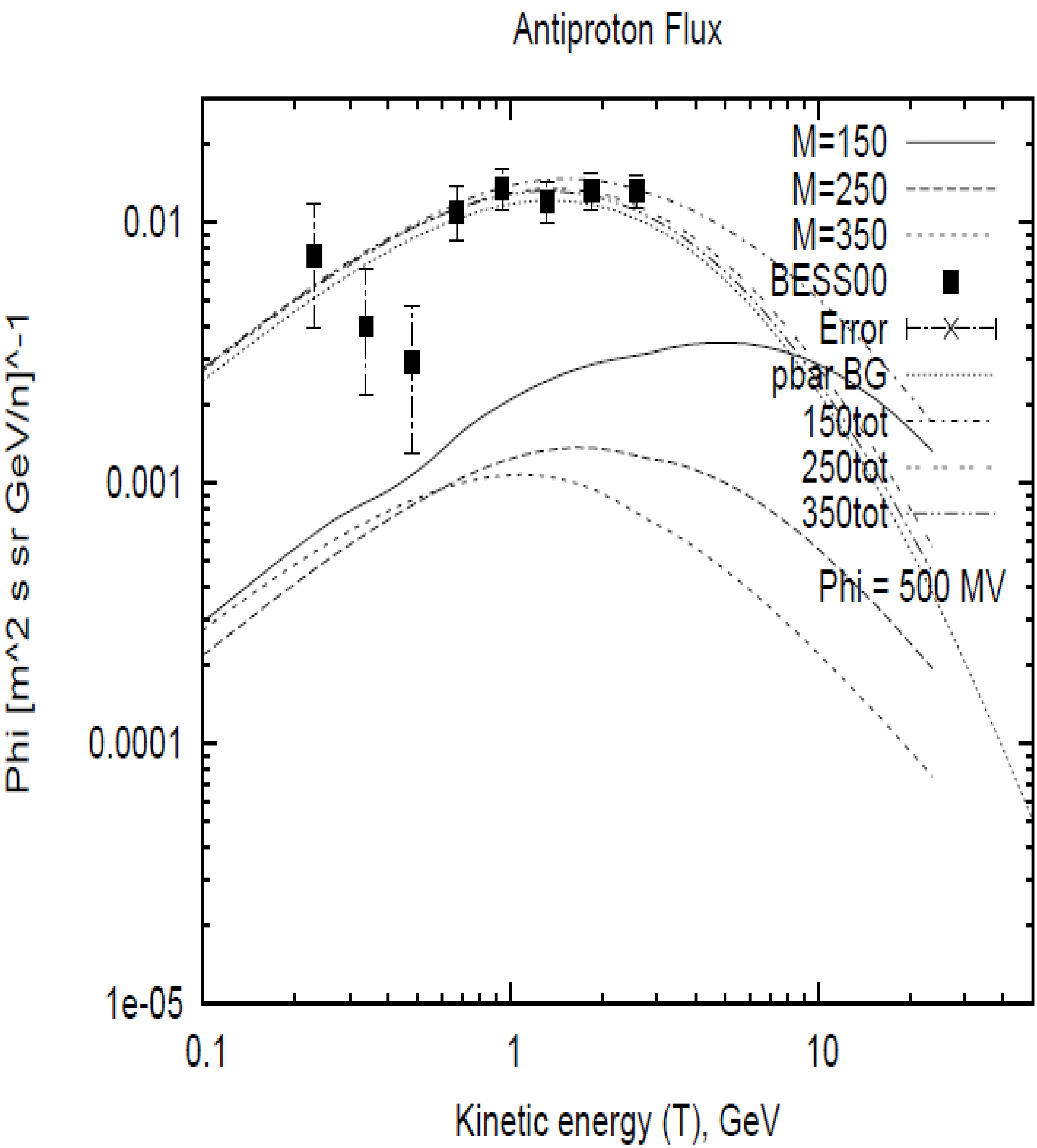


FIG. 13: The antideuteron flux for MED models. $m_{DM} = 150, 250, 350$ GeV

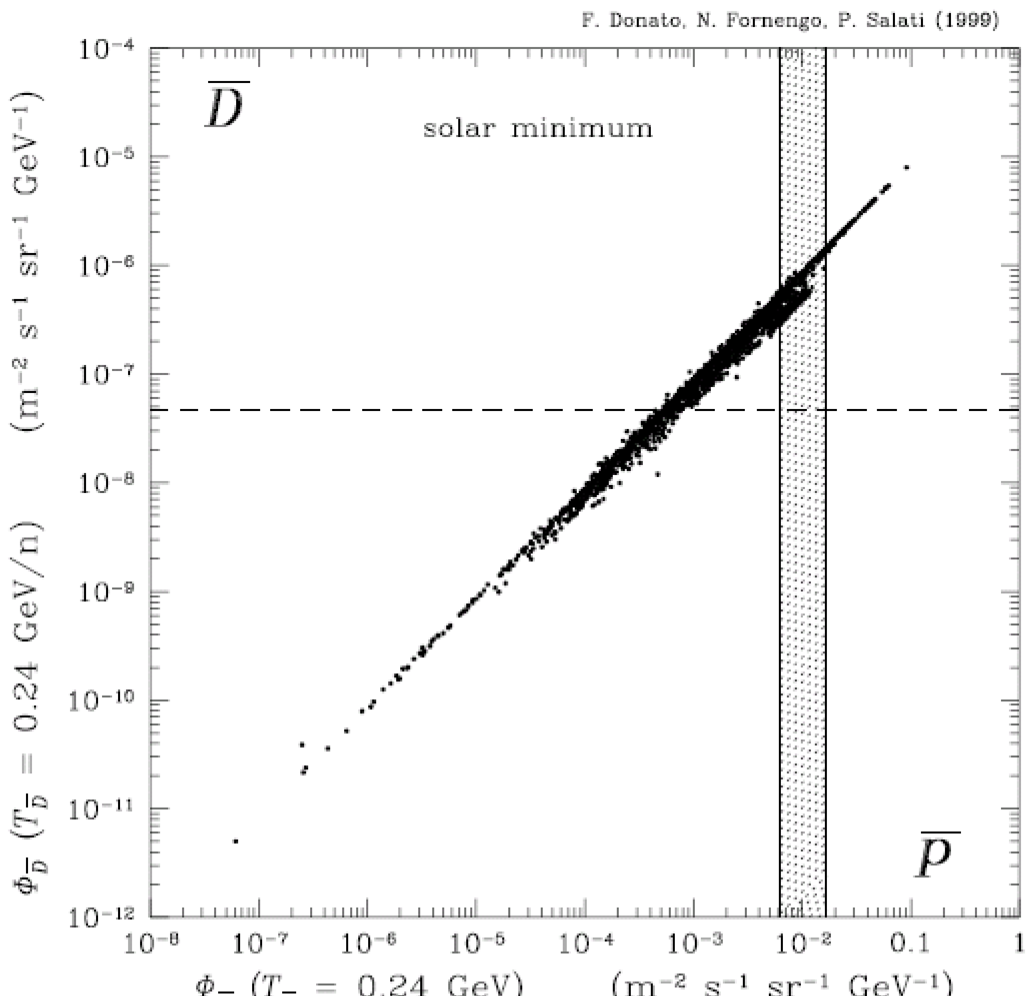
DM dominates antiproton signal

- DM dominates over background only for kinetic energy >50 GeV
- Large mass: 5-10 TeV
- Annihilation rate too low assuming thermal freezeout
- (Exception is if nonthermal or large boost factor)
- **Alternative ways to look for q qbar final state?**

Antideuterons

- Donato, Fornengo, Salati antideuterons can dominate over background in low energy region
- E_th=7m_p for antiprotons, 17m_p for antideuterons
  - Pppbar, pppbarnnbar final states
  - Rest frame of p
- Binding energy is 2.2MeV
  - Can’t slow it down without dissociating
- Very little background T<1GeV
- Dark matter can populate low energy region
- Better way in principle to search for many good dark matter candidates
  - Assuming PAMELA not detecting dark matter!
  - q qbar final states best

DPS: Correlated antiproton and antideuteron fluxes



DPS: Essentially Background Free

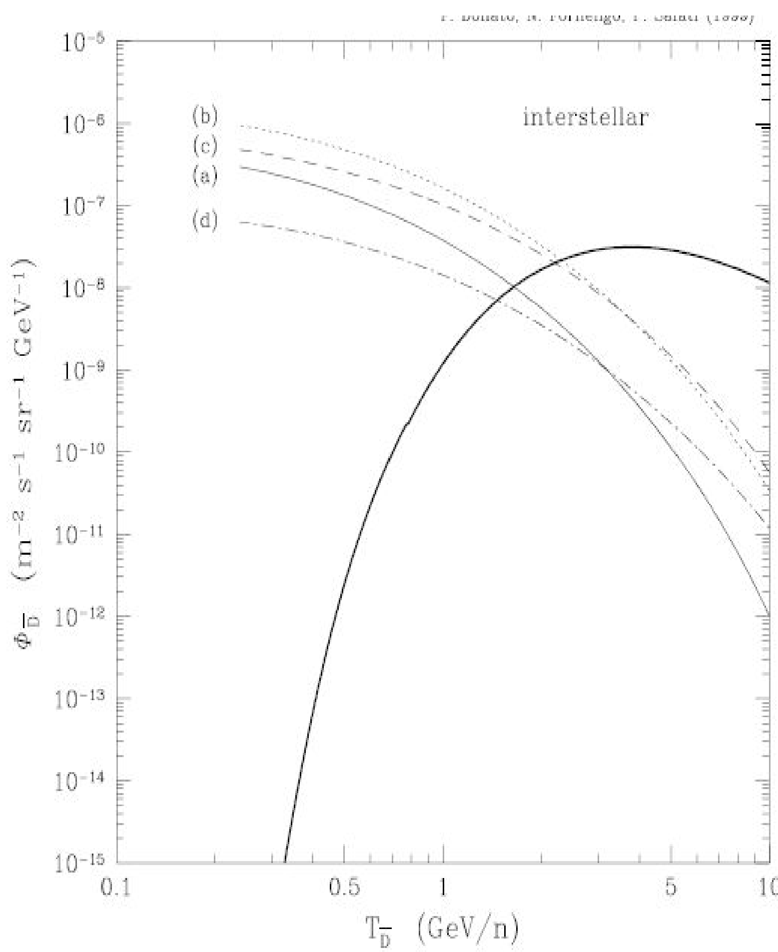


FIG. 3. The IS flux of secondary antideuterons (heavier solid curve) decreases at low energy whereas the energy spectrum of the antideuterons from supersymmetric origin tends to flatten. The four cases of table I are respectively featured by the solid (a), dotted (b), dashed (c) and dot-dashed (d) curves.

case	m_χ	$P_g(\%)$	$\Omega_\chi h^2$	$\Phi_{\bar{p}}^{min}$ (0.24 GeV)	$\Phi_{\bar{D}}^{min}$ (0.24 GeV/n)	$\Phi_{\bar{D}}^{max}$ (0.24 GeV/n)	$N_{\bar{D}}^{max}$
a	36.5	96.9	0.20	1.2×10^{-3}	1.0×10^{-7}	2.9×10^{-8}	0.6
b	61.2	95.3	0.13	3.9×10^{-3}	3.5×10^{-7}	1.1×10^{-7}	2.9
c	90.4	53.7	0.03	1.1×10^{-3}	1.8×10^{-7}	6.1×10^{-8}	2.0
d	120	98.9	0.53	2.9×10^{-4}	2.5×10^{-8}	8.6×10^{-9}	0.3

Greatly Improved Sensitivity Planned

- New Experiments
- AMS : Anti-Matter Spectrometer
  - T/n<1 GeV
- GAPS: General/Gaseous Antiparticle Spectrometer
  - T/n<0.2 GeV

$$\Phi_{\bar{D}} < 1.9 \times 10^{-4} [m^2\ s\ sr\ \mathrm{GeV/n}]^{-1}\ \ \text{BESS current bound},$$

$$\Phi_{\bar{D}} < 4.5 \times 10^{-7} [m^2\ s\ sr\ \mathrm{GeV/n}]^{-1}\ \ \text{AMS}-02,$$

$$\Phi_{\bar{D}} < 3 \times 10^{-8} [m^2\ s\ sr\ \mathrm{GeV/n}]^{-1}\ \ \text{GAPS(ULDB)}.$$

GAPS

- Long duration balloon experiment
- Antideuterons captured and result in exotic atom in final state
- Decays into X-rays at well-defined energies
  - Plus a correlated pion signature
- Time of flight detection to tag events and particle velocities
  - Distinguish from eg antiprotons
- Si/Li detctors for X-ray resoltuion and particle tracking
- Schedule
  - 2011 prototype
  - 2014 full experiment from Antarctica

Model Perspective:Vs. Direct Detection

- Not having seen direct detection signal favors models where
  - Interaction with gauge bosons dominates
  - Spin-dependent interactions
  - Heavy fermions in final annihilation state (Higgs-like mediator)

- Such models have suppressed direct detection rate
- But conceivably sufficiently large indirect detection
- We do general search in terms of any final state, not assuming particular models
- Assume mass, thermal cross sections

Antideuteron Production

- Poorly understood but estimated
  - Coalescence model
    - Background: pp->pppbar, ppnbar
  - Monte Carlo
    - Annihilation to quarks, gauge bosons
    - Subseqeuent hadronization and fragmentation
- P, n nearly at rest but ke<B, probably no antideuteron
- K_n- k_p<$(2m_pB)^{1/2}$~70MeV,~p_{coal} most likely form antideuteron

  Use data from Z decay

  p_{coal}~160MeV

Spectra of final states

- qqbar: Dominated by low kinetic energy antideuterons

- WW: peaked at higher energy

WW*->WW u dbar peaked at low energy

Injection Spectrum

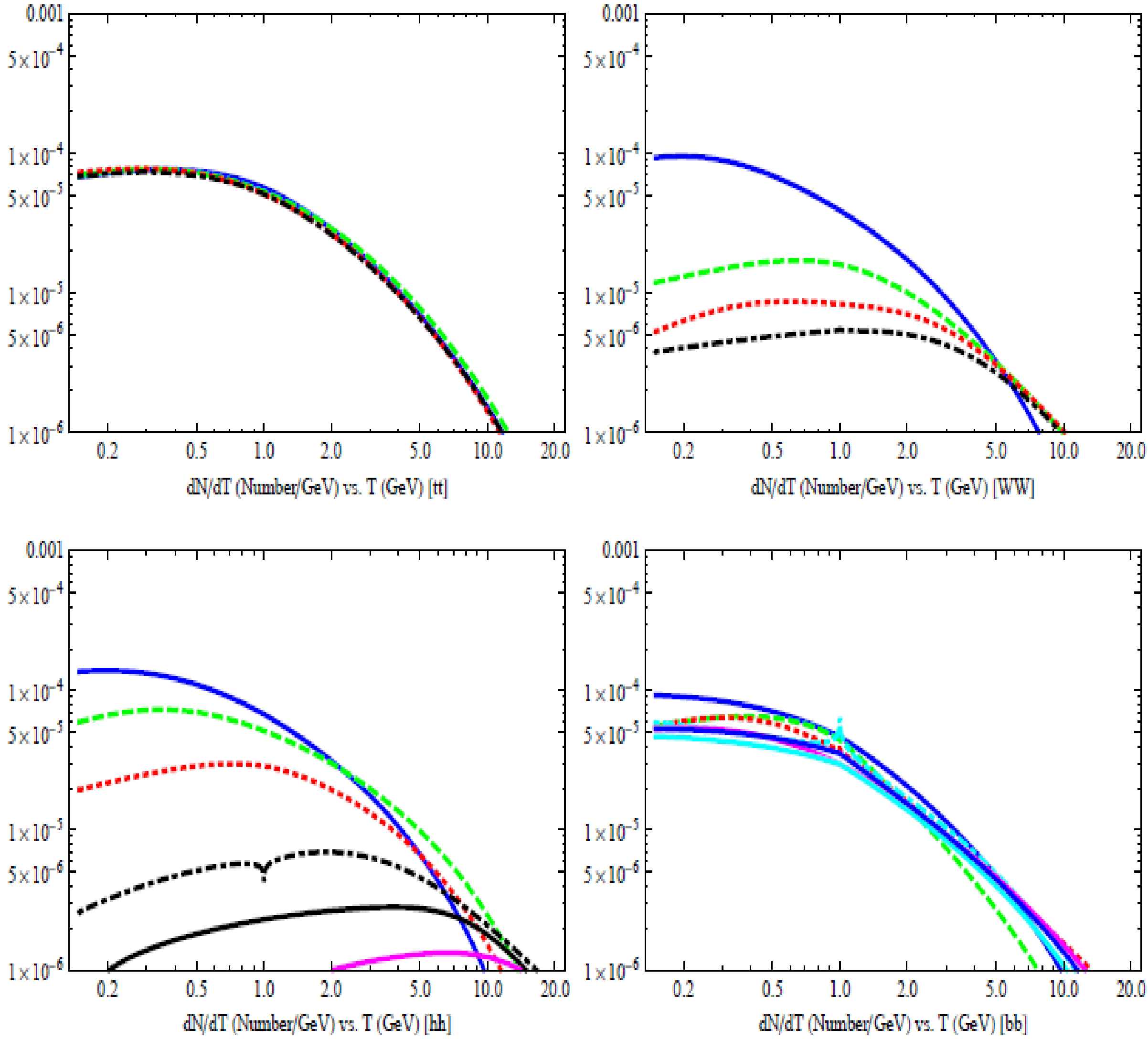


FIG. 1: The antideuteron injection spectrum as a function of Kinetic Energy, T, for DM annihilation to $\bar{t}t$ (m_{DM} = 200 GeV, 250 GeV, 300 GeV, 350 GeV), W^+W^- (m_{DM} = 82.5 GeV, 150 GeV, 200 GeV, 250 GeV), h^0h^0 (m_{DM} = 125 GeV, 150 GeV, 200 GeV, 500 GeV, 600 GeV, 900 GeV) (m_{higgs} = 115 GeV), and $b\bar{b}$ (m_{DM} = 100 GeV, 200 GeV, 300 GeV, 400 GeV, 500 GeV, 700 GeV) as computed using PYTHIA 6.400 and a coalescence momentum p_0 = 160 MeV.

Need to propagate

- Include effects of
  - Magnetic fields
  - Antideuteron annihilation
  - Energy losses
- Introduces model dependence
  - Vary parameters to give range of predictions

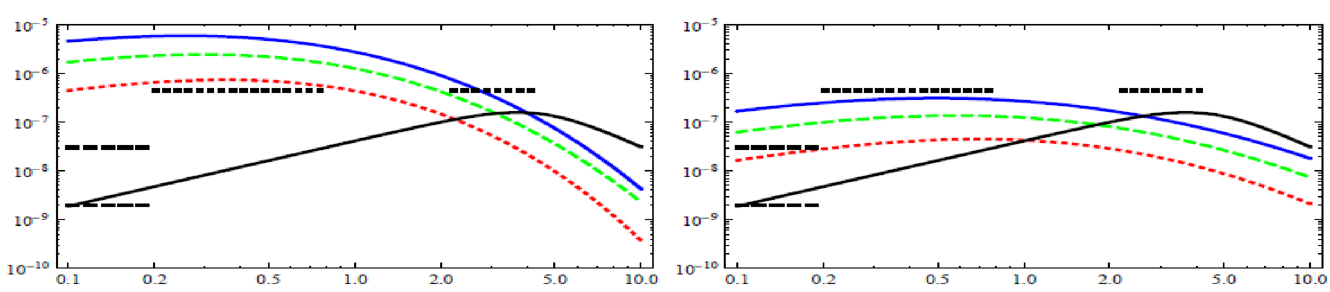


FIG. 3: Here the blue (solid), green (dashed), and red (dotted) lines correspond to MAX, MED, and MIN propagation parameters, respectively. The left plot shows the antideuteron flux from annihilation into a $b\bar{b}$ final state (m_{DM} = 100 GeV). The right plot shows the antideuteron flux from annihilation into WW final states (m_{DM} = 200GeV).

Results

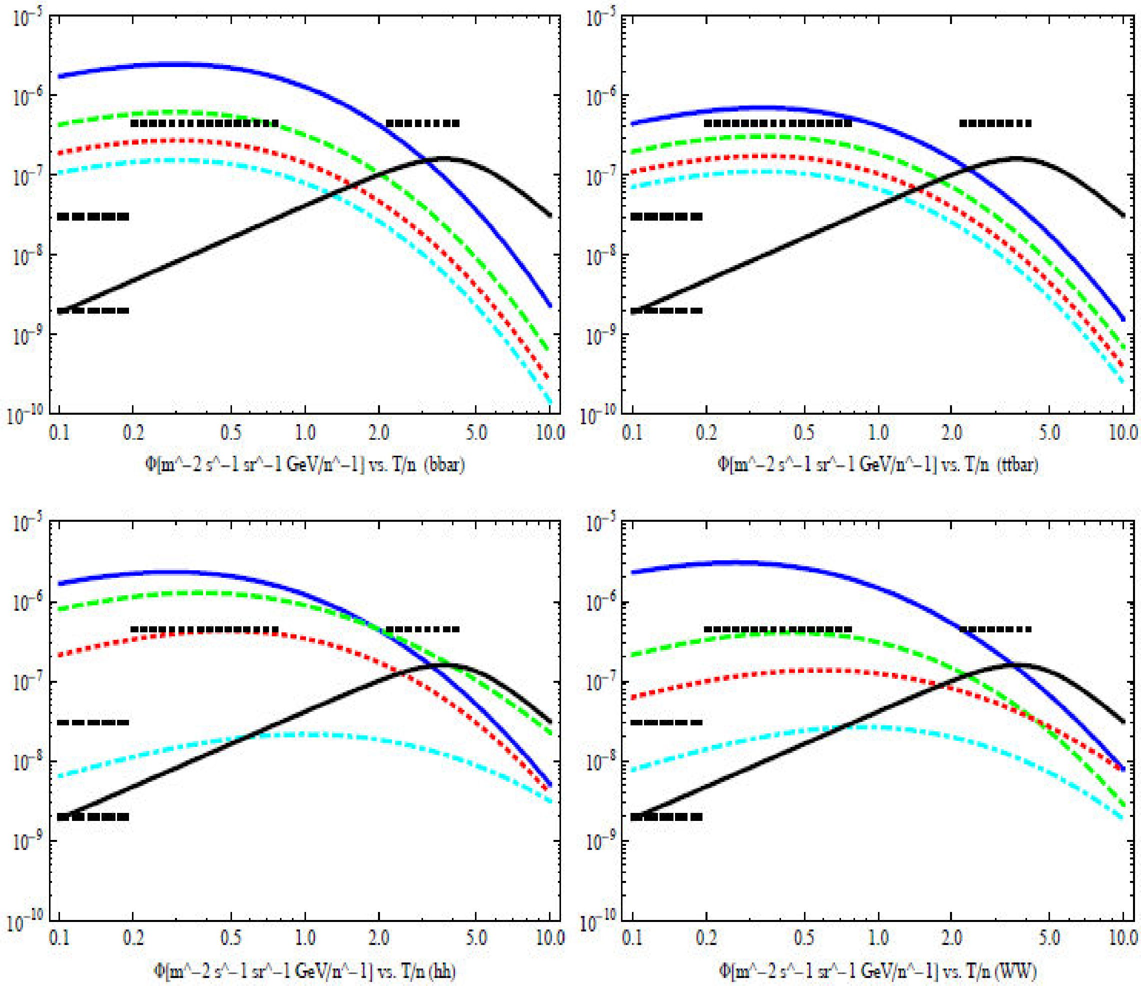
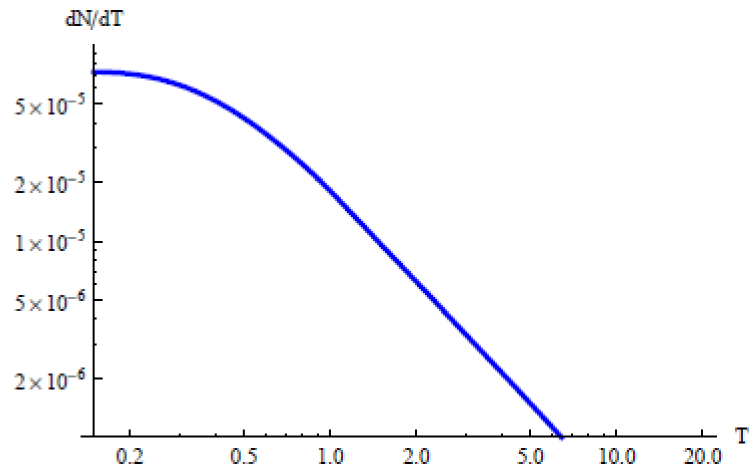


FIG. 2: The antideuteron reach of the AMS-02 (dotted) and GAPS ULDB (upper-Dashed) and satellite (lower-dashed) experiment for Dark Matter annihilation to $b\bar{b}$, $t\bar{t}$, h^0h^0 ($m_{h^0} = 115$ GeV), and W^+W^- final states. In each case the Dark Matter present day annihilation is set to $< \sigma|v| >= 3x10^{-26}\frac{cm^3}{s}$. For $b\bar{b}$: $m_{DM} = 100$ GeV, $m_{DM} = 200$ GeV, $m_{DM} = 300$ GeV, $m_{DM} = 400$ GeV, for $t\bar{t}$: $m_{DM} = 200$ GeV, $m_{DM} = 300$ GeV, $m_{DM} = 400$ GeV, $m_{DM} = 500$ GeV, for h^0h^0: $m_{DM} = 125$ GeV, $m_{DM} = 150$ GeV, $m_{DM} = 200$ GeV, $m_{DM} = 500$ GeV, for W^+W^-: $m_{DM} = 82.5$ GeV, $m_{DM} = 150$ GeV, $m_{DM} = 200$ GeV, $m_{DM} = 250$ GeV. The Flux decreases as the mass increases. Also note that the background is given by the solid line.

Off-Shell W: (IDM?) M_{DM}=70GeV



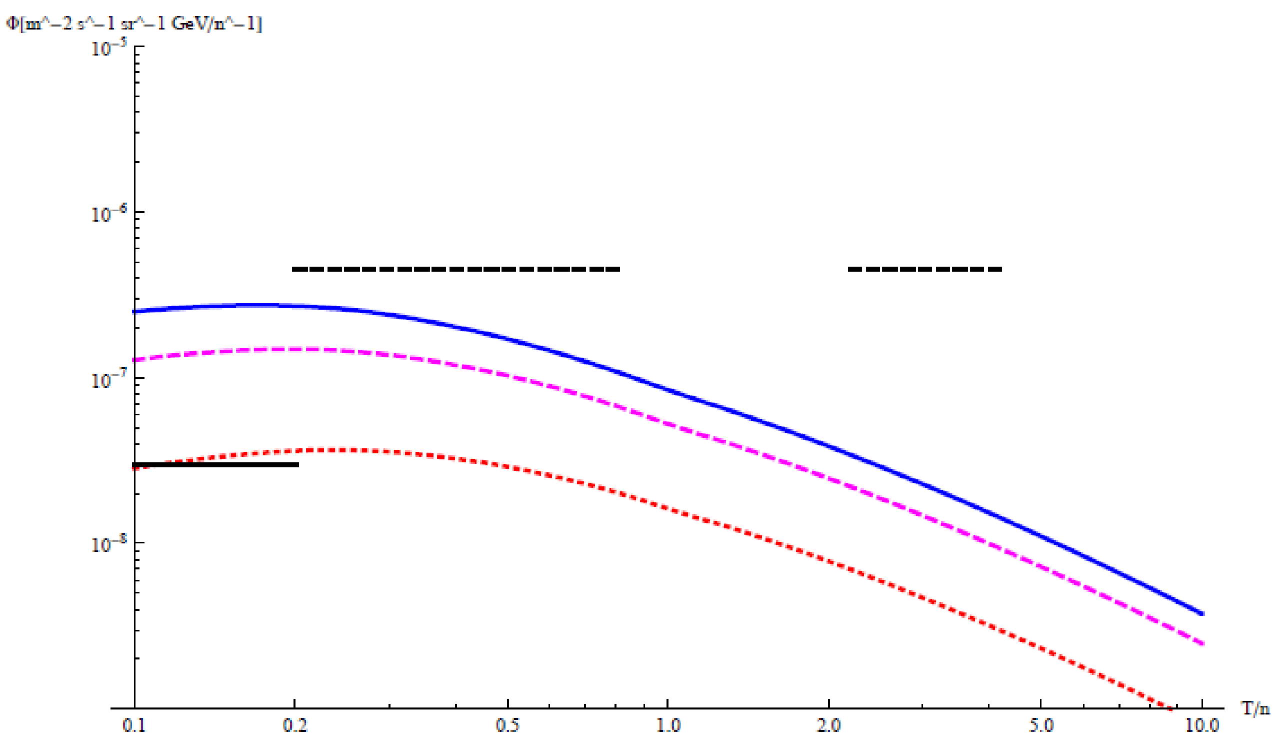


FIG. 5: The antideuteron flux for MIN, MED, and MAX models.

Conclude

- Antideuteron search excellent way to look for DM candidates with qqbar final states
  - 500Gev-TeV reach for GAPs balloon
    - 700 GeV qqbar final state
    - 400 GeV for hh
    - 225 GeV for WW
  - Higher for satellite GAPS
- In some cases, can be best way to find DM
  - Will give complementary information about DM interactions
- Implications for models in progress