UiO : Fysisk institutt

Det matematisk-naturvitenskapelige fakultet

Antideuterons as signature for dark matter

Based on Master's Thesis at NTNU supervised by Michael Kachelrieß

Lars Andreas Dal

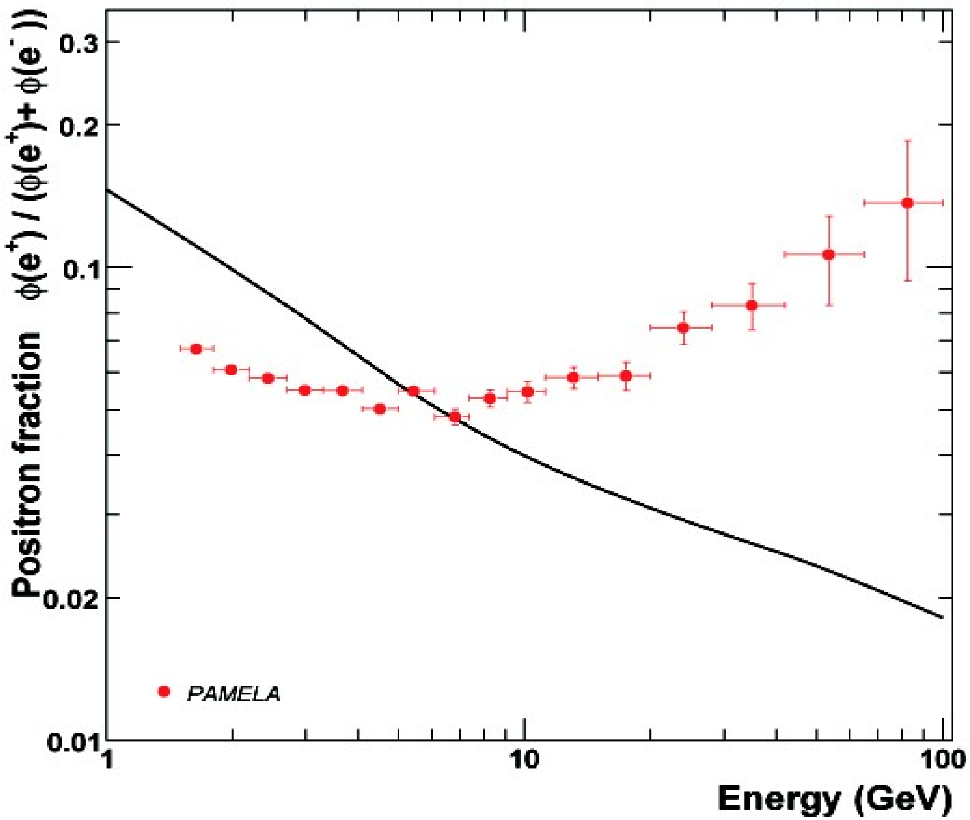
Detection of Dark Matter

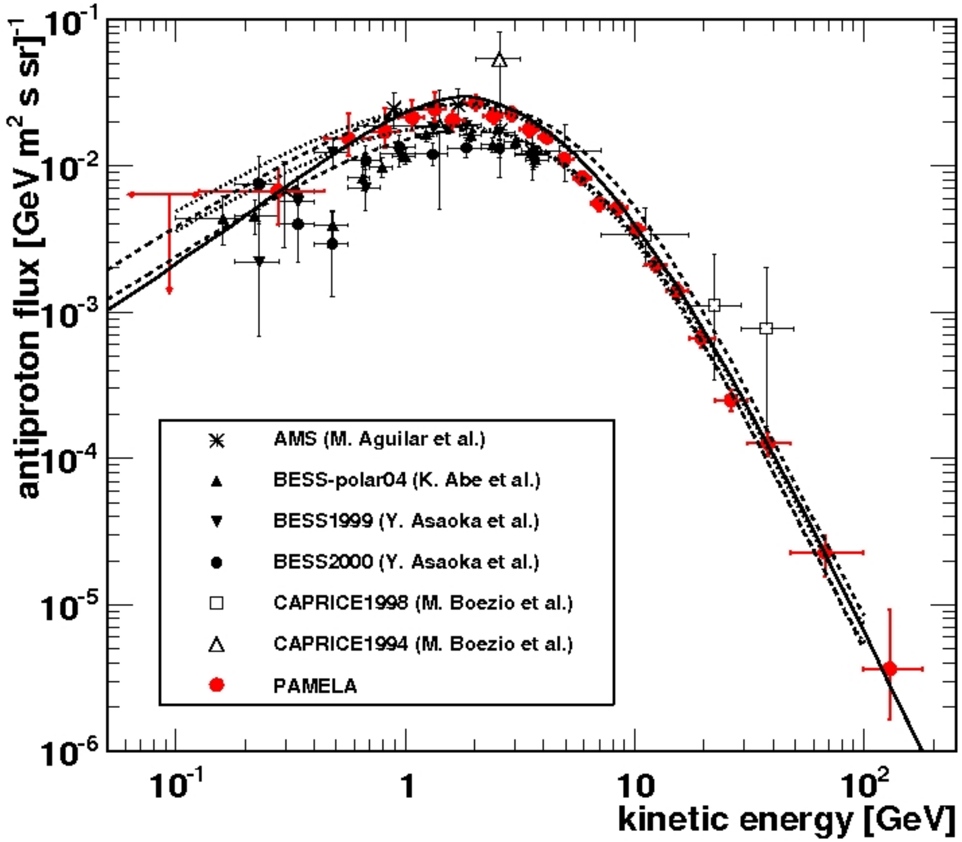
- Assume DM in the form of unknown particles
- Most DM candidates have interactions which allow them to scatter, decay and/or annihilate
- 3 Ways to explore:
  - Direct searches: Particle Colliders
  - Direct detection: Direct Scattering
  - Indirect detection
- Indirect detection: Detection of DM annihilation/decay products (cosmic rays)

Suitable particle channels?

- What channels (particle species) are possible?
- DM is still around:
  - Long lifetime, low annihilation/decay rate
  - Weak signal
- Need channels where a signal is not “drowned”
- Charged VS. neutral particles: γ and ν
- Antimatter: Little around, seldom produced
- Positrons, antiprotons, antideuterons

The PAMELA data





- Antideuterons? Ongoing experiment: AMS-02

The Coalescence Model

- Need a model for nucleus formation
- Simple model: Coalescence
  - Nucleons with $\Delta p < p_0$ form a nucleon
  - p_0 calibrated against known processes
  - Developed in the 70's for heavy ion collisions
- Two approaches:
  - Direct approach: Applied per-event
  - Traditional approach: Applied to average energy spectra from multiple events

- Lab frame:

$$\underbrace{\left(\frac{dN_{\bar{d}}}{d^3k}\right)_{\vec{k}_{\bar{d}}}}_{\substack{\bar{d}\text{-density in}\\ \text{momentum space}}} = \frac{1}{8}\gamma \underbrace{\frac{4\pi p_0^3}{3}\left(\frac{dN_{\bar{p}}}{d^3k}\right)_{\vec{k}_{\bar{p}}=\vec{k}_{\bar{d}}/2}}_{\substack{\text{probability of finding } \bar{p}\\ \text{within sphere of radius } p_0\\ \text{around } \vec{k}_{\bar{n}} \text{ in momentum space}}} \cdot \underbrace{\left(\frac{dN_{\bar{n}}}{d^3k}\right)_{\vec{k}_{\bar{n}}=\vec{k}_{\bar{d}}/2}}_{\substack{\bar{n}\text{-density in}\\ \text{momentum space}}}$$

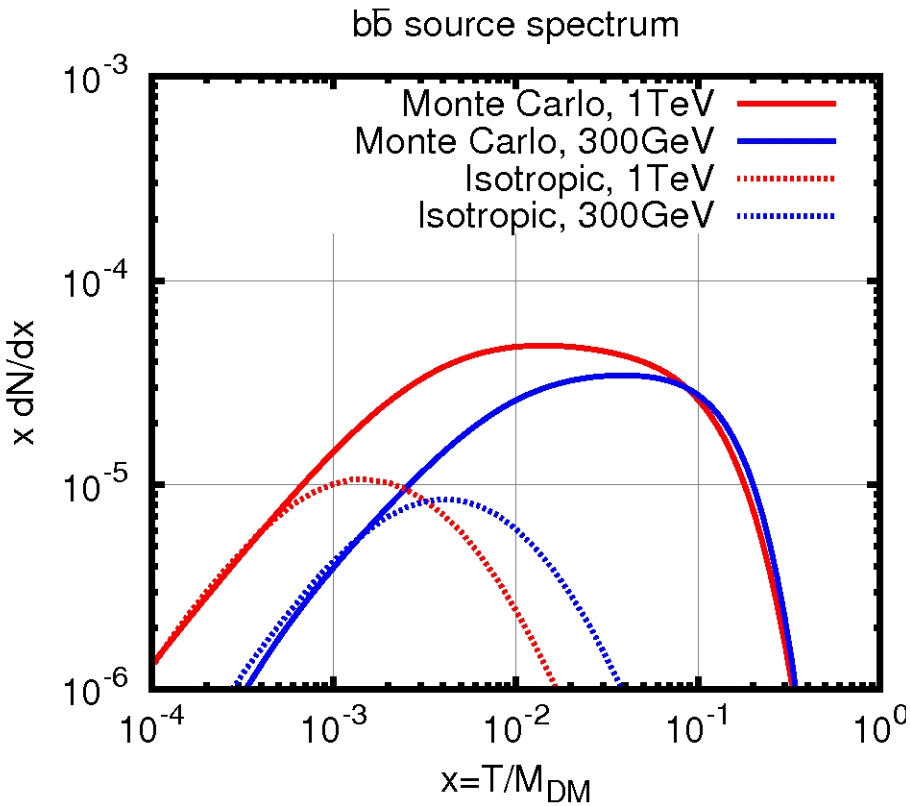
$$\left(\frac{dN_{\bar{d}}}{dx_{\bar{d}}}\right) = \frac{p_0^3}{6}\frac{m_{\bar{d}}}{M_{DM}^2 m_{\bar{n}} m_{\bar{p}}}\frac{1}{\sqrt{x_{\bar{d}}^2 + 2m_{\bar{d}}x_{\bar{d}}/M_{DM}}}\left(\frac{dN_{\bar{n}}}{dx_{\bar{n}}}\right)\left(\frac{dN_{\bar{p}}}{dx_{\bar{p}}}\right)$$

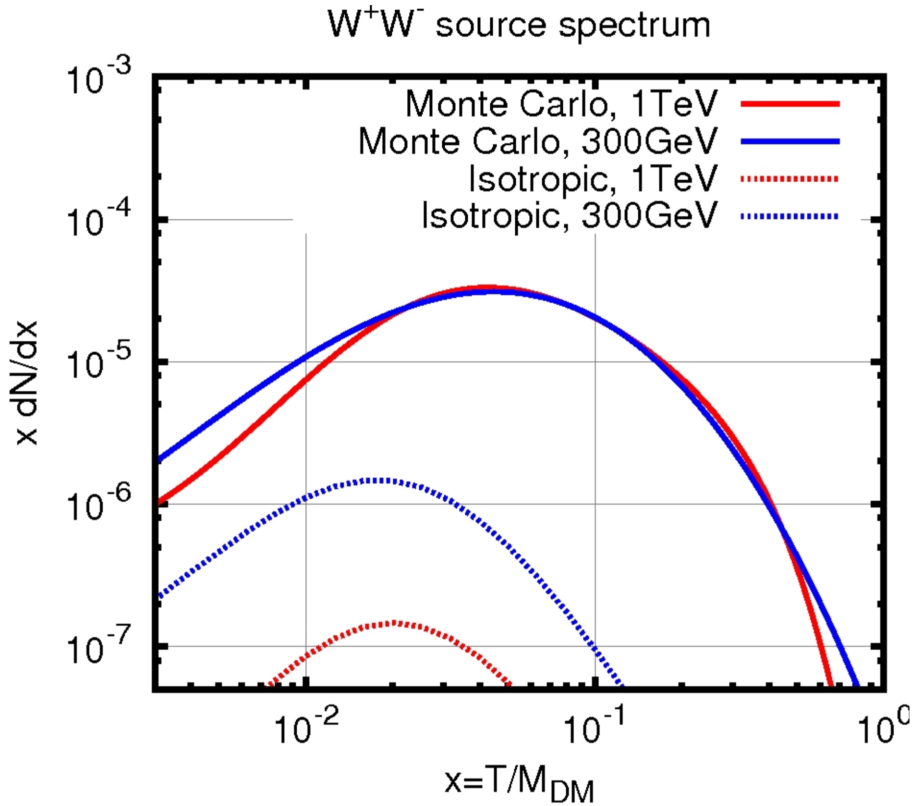
  - $x_i = T_i / M_{DM}$, $x_{\bar{p}} = x_{\bar{n}} = x_{\bar{d}}/2$
  - Assumptions: Uncorrelated, isotropic distributions
- Why use the traditional approach?
  - $\bar{d}$ production rate: $\sim 10^{-4}$
  - $\bar{n}$, $\bar{p}$ production rate: $\sim 10^{0}$

Simulations

- Tree level annihilation processes
  - $X\bar{X} \rightarrow W^{+}W^{-}$
  - $X\bar{X} \rightarrow b\bar{b}$
  - Spectra only depend on M_{DM} , not on the model
  - Total spectrum from branching ratios
  - Lightest MSSM neutralino
- Programs (Monte Carlo Generators)
  - MadGraph: Tree level process events
  - Herwig++: Showering, hadronization, (coalescence)

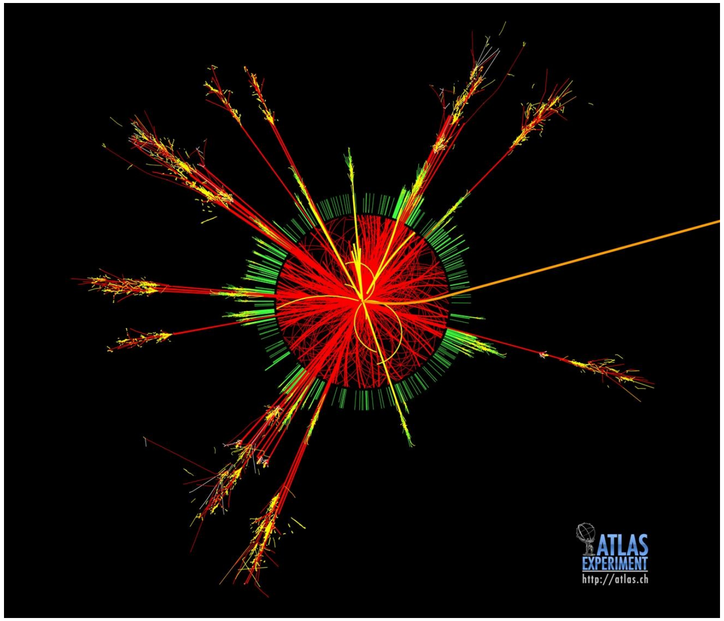
Antideuteron source spectra

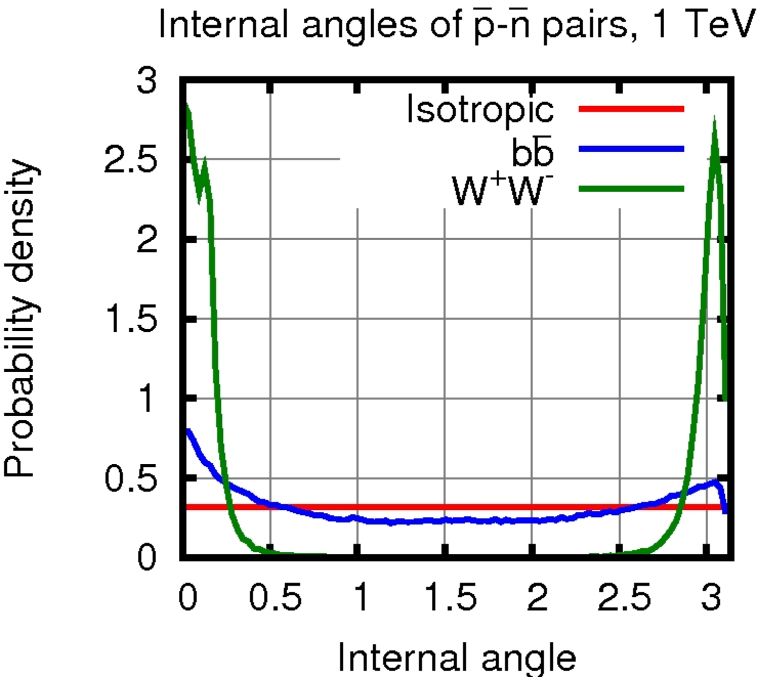




- Differences in the spectra at high energies
- DM mass dependence in the W^+W^- case

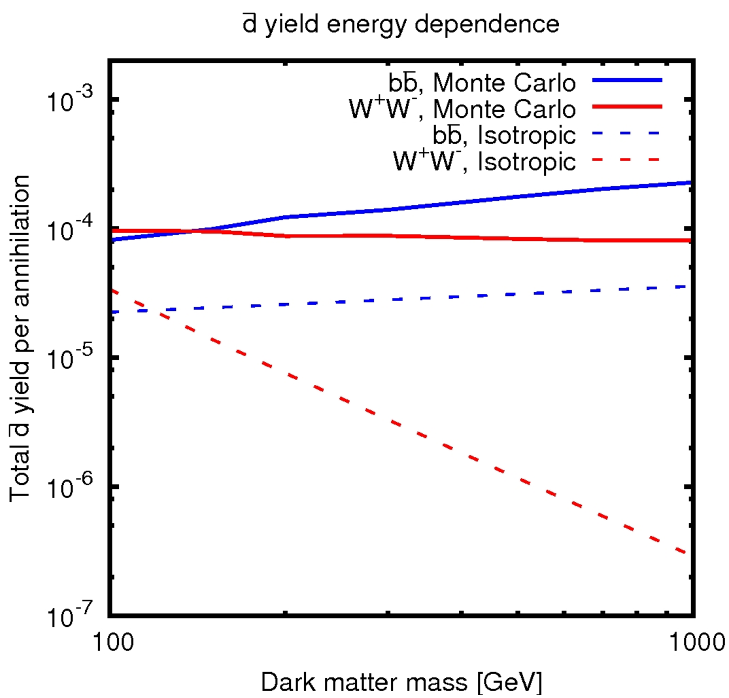
Bad assumptions

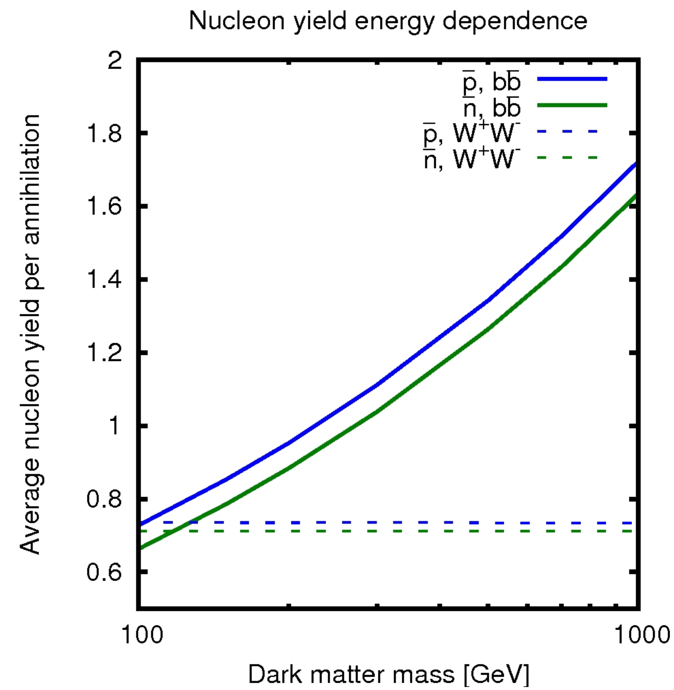




- Assumed uncorrelated, isotropic distributions
- QCD effects lead to confined jets
- Heavy ion collisions VS. DM annihilations

The gauge boson case

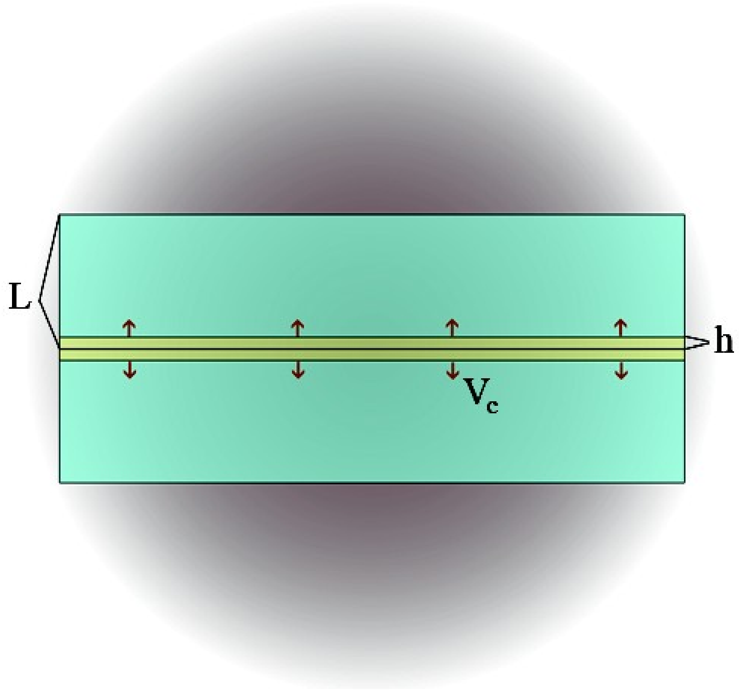




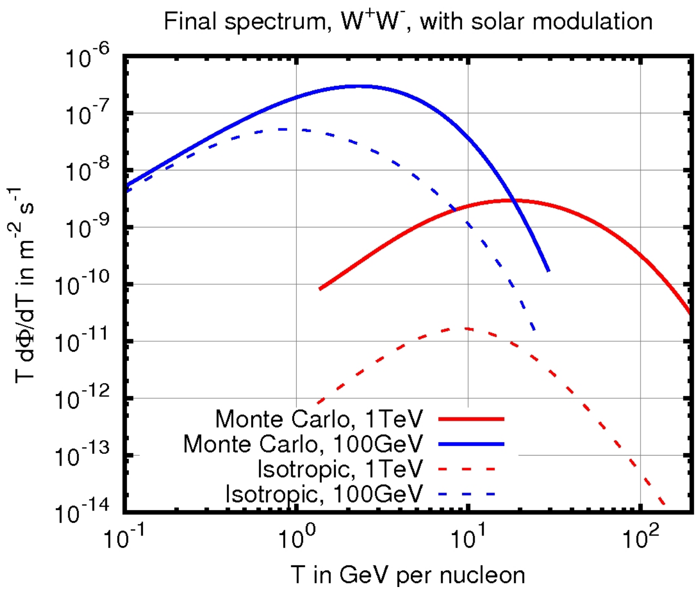
- MadGraph/Herwig++ connection:
  - Quarks always virtual
  - Gauge bosons taken to be real (on-shell)
  - Recurring mistake

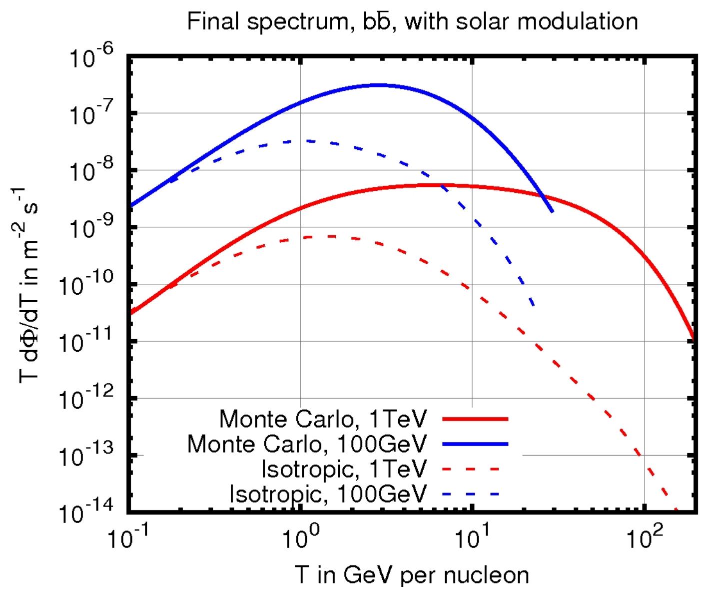
Propagation through the Galaxy

- Two-zone diffusion model
  - Cylindrical symmetry
  - Large cylinder
    - Diffusion of charged particles in magnetic field
  - Small cylinder (disk)
    - Annihilations on interstellar matter
  - Convective wind
  - Diffusion equation solved (mostly) numerically

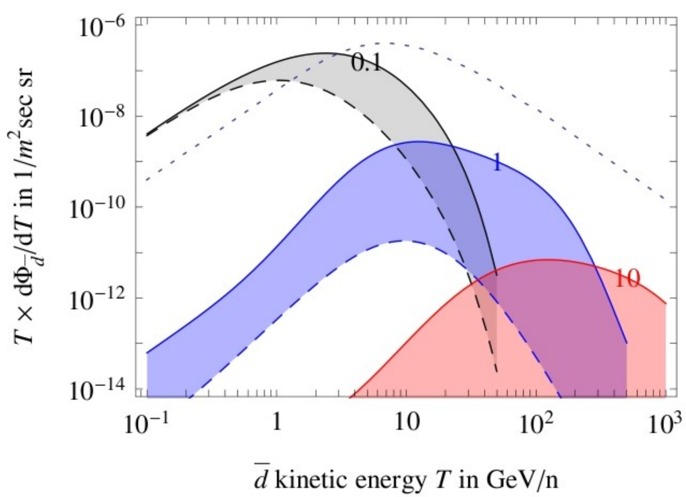


Final spectra

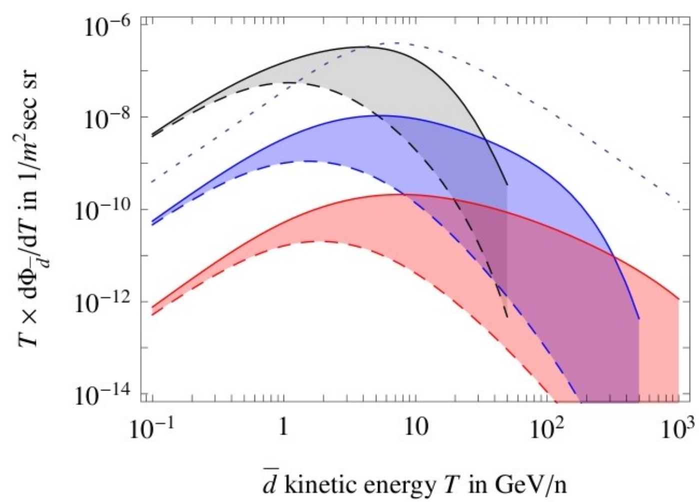




DM DM $\rightarrow W^+W^-$



DM DM $\rightarrow q\bar{q}$



Summary & current project

- Summary
  - The isotropic approximation in coalescence is not valid for DM annihilation processes
  - Recurring error when simulating spectra from annihilations into gauge bosons
  - The antideuteron channel is being measured by the ongoing AMS-02 experiment
- Current project
  - Use antideuteron spectrum from gravitino decays in R-parity violating SUSY models to set limits on R-parity violating couplings