Constraints on Dark Matter from the BESS-Polar II Antiproton Search

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Thermal WIMPs

- Dark Matter relic density: $\Omega_\chi h^2 \simeq 0.1$ (WMAP)
- Thermal WIMPs

$$\Omega_\chi h^2 \simeq \frac{3 \times 10^{-27}\,\text{cm}^3\,\text{s}^{-1}}{\langle \sigma v \rangle}$$

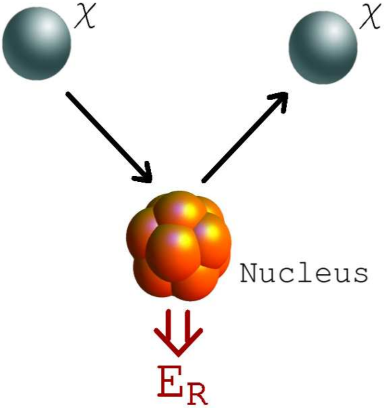
- Velocity expansion: $\sigma v = \underbrace{a}_{\text{s-wave}} + \underbrace{bv^2}_{\text{p-wave}}$
- Freeze-Out: $\langle v^2 \rangle \sim 1/10$

Direct Detection of WIMPs

- WIMP χ passes detector
  $\rightarrow$ liquid noble gas (Xenon...)
  $\rightarrow$ crystal (CRESST...)
- scatters off target nucleus
- $E_R \rightsquigarrow$ Light, Heat

$\downarrow$

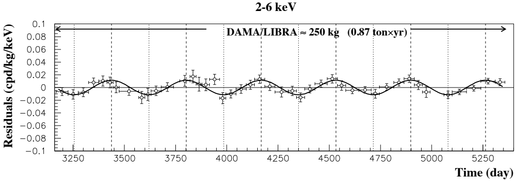
detector signal

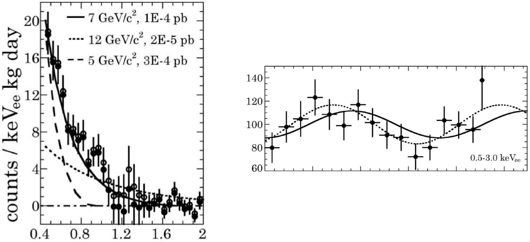


Possible Signals

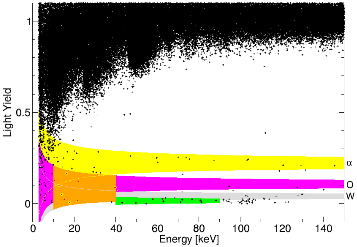
- modulation signal at **DAMA**

  Bernabei et al., Eur. Phys. J. **C67** (2010)





Aalseth et al., **arXiv:1106.0650** [astro-ph] (2011)

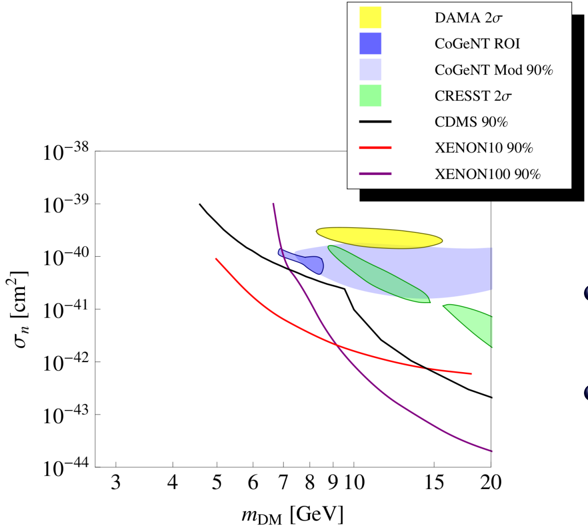


Angloher et al., **arXiv:1109.0702** [astro-ph] (2011)

- **CoGeNT**: exponential rise
  modulation

- **CRESST:** event excess

Direct Detection of WIMPs

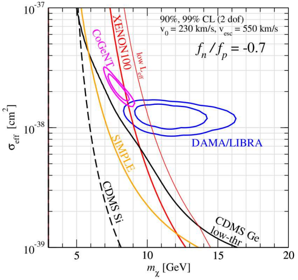


- DAMA, CoGeNT, CRESST close
- Tension with XENON, CDMS

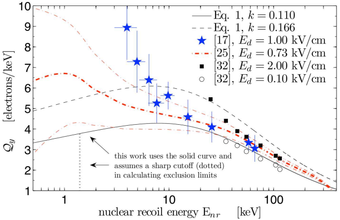
XENON 10/100, CDMS, CoGeNT rate, CRESST from official papers, CoGeNT modulation from Fox et al. arXiv:1107.0717

Attempts

- Non-standard astrophysics
  Frandsen et al., **arXiv:1111.0292** [hep-ph] (2011)
- Non-standard WIMPs, e.g. Isospin violation
  Feng et al., Phys. Lett. B703 (2011)



- Backgrounds, e.g. neutrons
  Ralston, **arXiv:1006.5255** [hep-ph] (2010)
- Experim. Uncertainties, e.g. Q_y in XENON



What can we learn from indirect detection?

Antiprotons in Cosmic Rays

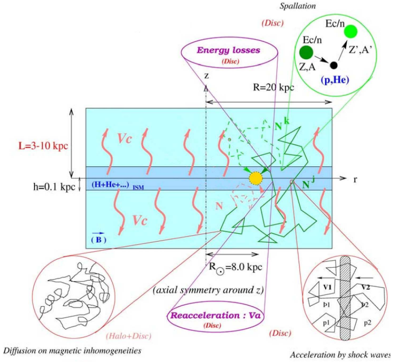
- Secondary background

$$p,\ He + H_{\mathrm{ISM}},\ He_{\mathrm{ISM}} \rightarrow \bar{p} + X$$

- Source term

$$q^{\mathrm{sec}}(T) \sim \int dT' \left(\frac{d\sigma}{dT}\right)_{\bar{p}} n_{\mathrm{H_{ISM}}} \Phi_p$$

DTUNUC model or
Fit to experimental data



from D. Maurin

Diffusion equation:

$$\nabla(-K\,\nabla N_{\bar{p}} + \mathbf{V}_c\, N_{\bar{p}}) + \partial_E(b_{\mathrm{loss}}\, N_{\bar{p}} - K_{EE}\,\partial_E N_{\bar{p}}) + \Gamma_{\mathrm{ann}}\, N_{\bar{p}} = q_{\bar{p}} + q_{\bar{p}}^{\mathrm{ter}}$$

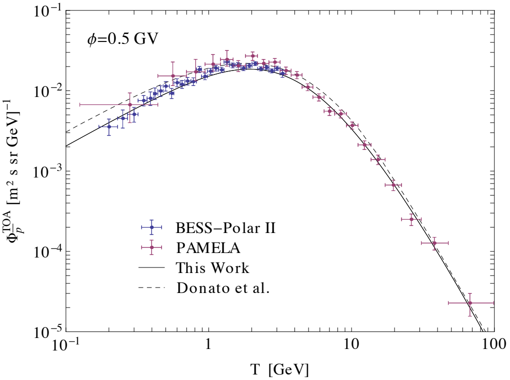
Antiproton Propagation

- 2 Zone diffusion model
  Maurin et al. Astrophys. J. **555** (2001)
- Five propagation parameters: K_0, δ, L, V_c, V_A.
- (Partly) fixed by B/C analysis
  Putze et al., A & A **516** (2010)
- Solar Modulation:
  $\rightarrow$ Complicated
  $\rightarrow$ Force-field approximation (solar minimum):

$$\Phi_{\bar{p}}^{\mathrm{TOA}}(T) = \frac{p^2}{p_{\mathrm{IS}}^2}\,\Phi_{\bar{p}}^{\mathrm{IS}}(T_{\mathrm{IS}}) \quad \text{with} \quad T_{\mathrm{IS}} = T + \phi\ .$$

Comparison with Experiment

- New precision measurement by BESS-Polar II
  Abe et al., **arXiv:1107.6000**



- Reduced flux compared to Donato et al.
  Donato et al., Astrophys. J. **563** (2001)
- BESS-Polar II consistent with pure secondary background

Antiprotons from Dark Matter

- Model-independent approach

$$\chi\chi \rightarrow u\bar{u},\ d\bar{d},\ s\bar{s},\ c\bar{c},\ b\bar{b}, WW, ZZ$$

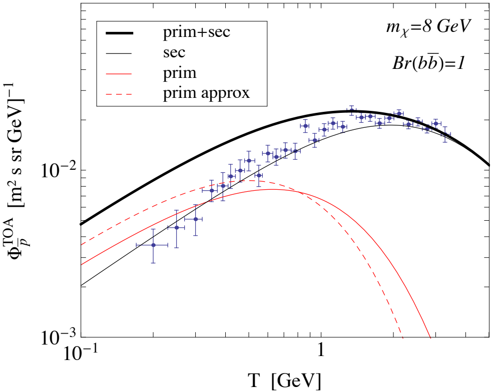
- Primary source term

$$q_{\bar{p}}^{\text{prim}}(\mathbf{r}, T) = \frac{\rho_\chi^2}{m_\chi^2} \frac{\langle \sigma_{\text{ann}} v \rangle}{2} \frac{dN_{\bar{f}f}}{dT}$$

- neglecting low energy effects (energy losses, reaccelleration, tertiaries)

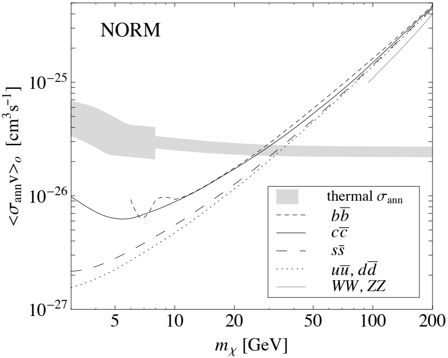
$$\Phi_{\bar{p}} \sim q^{\text{prim}} \cdot R_\odot$$

Primary Flux



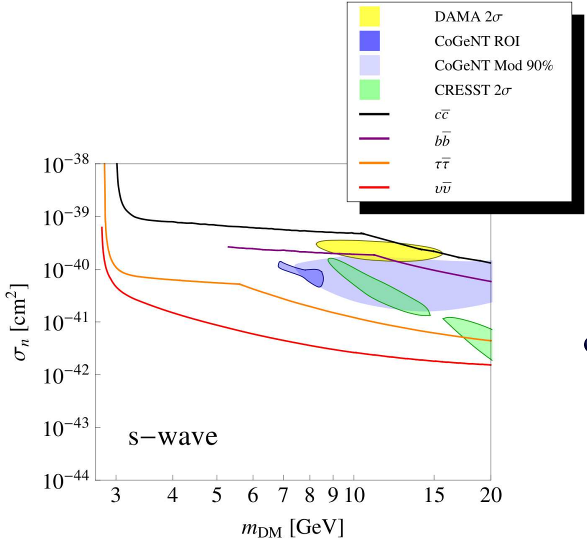
- Primary flux for 8 GeV WIMP
- Low energy effects non-negligible

Constraints from BESS-Polar II



- Stronger limits for annihilation into light quarks
- Thermal WIMPs with $m_\chi = 3 \ldots 20$ GeV disfavored unless annihilation is non-hadronic or p-wave suppressed

Limits from Super-Kamiokande



- WIMP capture in Sun $\rightarrow \nu-$ signal

Kappl et al., Nucl. Phys. **B850** (2011)

Conclusion

- Signals at several DM direct detection experiments might hint at light WIMPs (but tension)
- Such WIMPs can be strongly constrained by indirect detection
- BESS-Polar disfavors annihilation into quarks
- Super-Kamiokande disfavors annihilation into neutrinos and taus
- Exception: p-wave annihilation