Dark side of the Universe: enlightenment through positrons, gamma-rays and neutrinos

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in collaboration with
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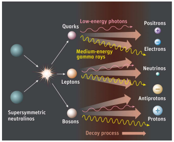
MITP | Mainz | July 2, 2013

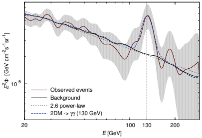
Outlines

1. **DM interpetation of AMS-02 positron fraction**



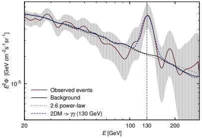
The paper will appear in $\sim$ this week

2. **γ-rays from galaxy clusters**



Our papers: 1207.4466, next one appearing soon

3. **Secondary neutrinos from DM annihilation in the Sun**



Paper under preparation

(1)

A DM interpetation of AMS-02 positron fraction

Prologue

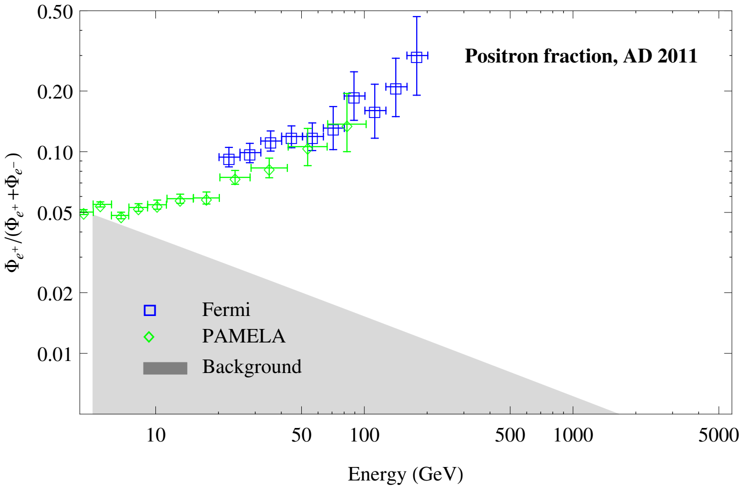
e^+ excess from the annihilation signal of the Galactic halo

- Boost factor $\mathcal{O}(1000)$
- Leptonic channels favoured (other killed by $\bar{p}$ & γ constraints)
- SUSY DM is dead, long live SUSY DM!

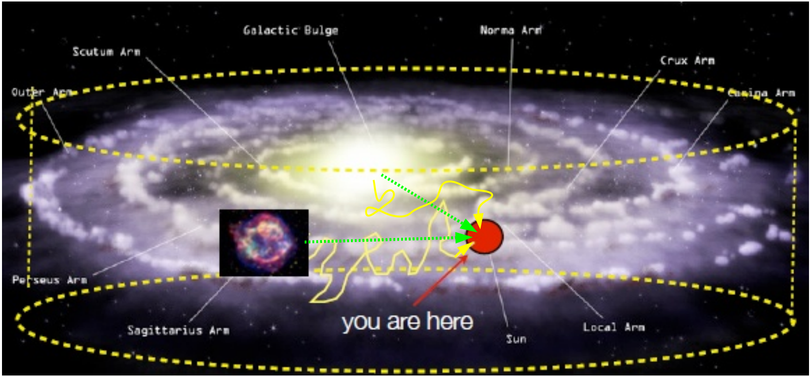
e^+ excess from the annihilation signal of local overdensity

- No need for the large boost factor
- $\bar{p}$ constraint reduced, γ constraints depend on details
- A close subhalo?
  No – constrained by γ-rays + very low probability
- Living in an overdensity fluctuation?
  Yes – wait for next slides!
- WW, ZZ, bb, tt and HH favoured – SUSY DM is back!

Positron fraction, AD 2011

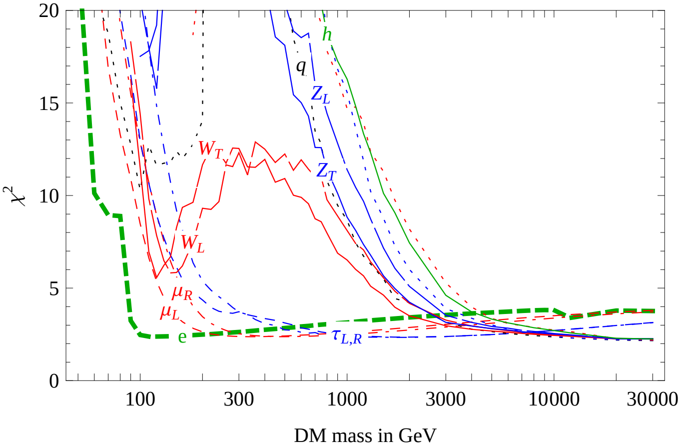


Annihilation signal from the main halo



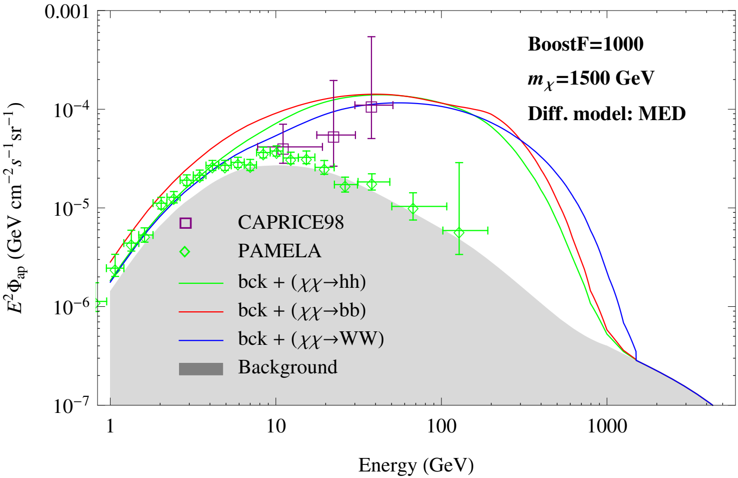
Annihilation signal from the main halo

Fitting of PAMELA e^+ data, no antiproton fitting



From [Cirelli et al, 0809.2409]

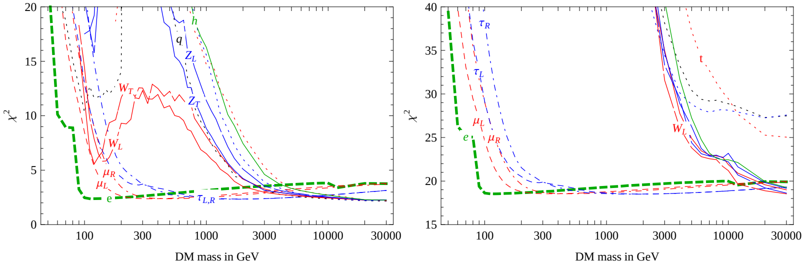
Antiproton flux, AD 2013



Calculated using tools from [Cirelli et al, 1012.4515]

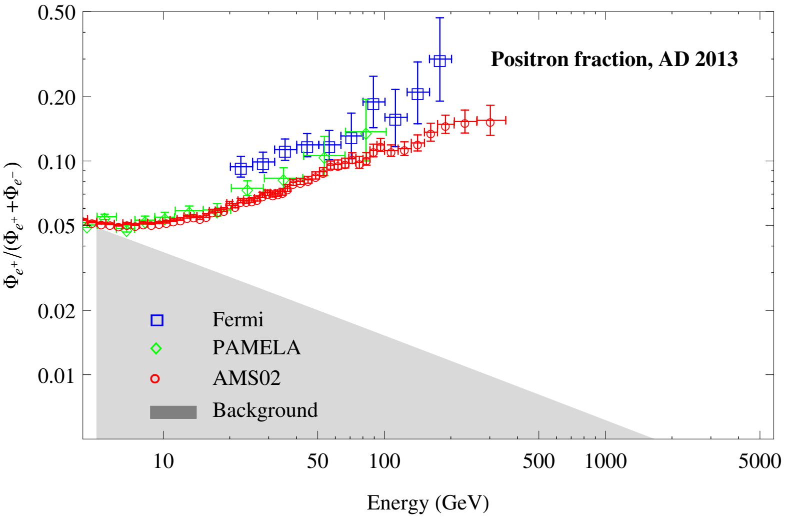
Annihilation signal from the main halo

Effect of the $\bar{p}$ fitting



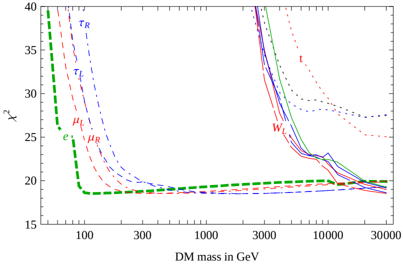
From [Cirelli et al, 0809.2409]

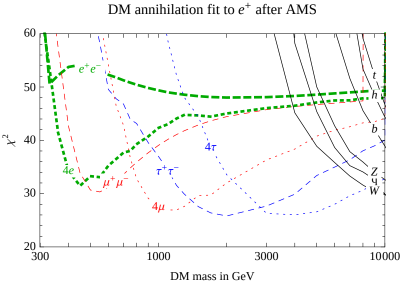
Positron fraction, AD 2013



Annihilation signal from the main halo

From PAMELA to AMS02





From [Cirelli et al, 0809.2409]

If the e^+ excess arises locally...

If the e^+ excess arises locally...

Why locally?

- Annoying constraints from GC, dwarfs, extragalactics, CMB, etc get weaker (no boost there!)
- If no energy loss ($R \lesssim 1$ kpc) $\Phi_{e^+}(E)/\Phi_{\bar{p}}(E)$ gets better

Need to be checked...

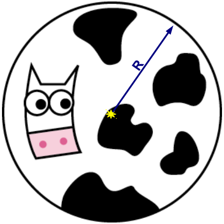
- Shape of the e^+ spectrum?
- $\Phi_{e^+}/\Phi_\gamma(E)$?
- Direct detection?

Spherical Cow Model (SCM)

- A spherical region of overdensity

$$Q_x(r,E) = \begin{cases} Q_x(E), & \text{if } r \leq R \\ 0, & \text{if } r > R \end{cases} \qquad (1)$$

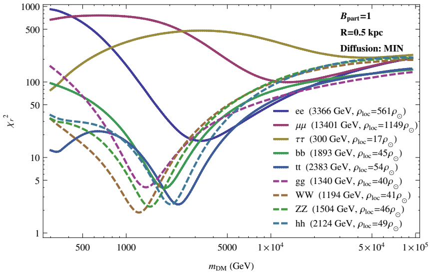
$$Q_x(E) = \left(\frac{\rho}{m_{\rm DM}}\right)^2 \frac{\langle\sigma v\rangle_x}{2} f_x(E) \qquad (2)$$

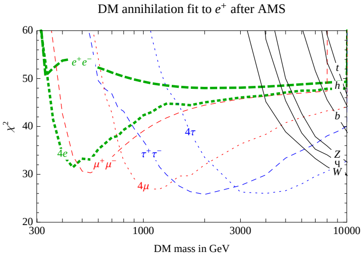


- $R \lesssim 0.5$ kpc (no energy loss – enhances $\Phi_{e^+}(E)/\Phi_{\bar{p}}(E)$)
- $\Phi_{e,p}(E) = \frac{v_{e,p}(E)}{K_{e,p}(E)} \int dr\ r\ Q_{e,p}(r,E) \propto \frac{v^{e,p}(E)}{K_{e,p}(E)} \frac{R^2}{2}$
- $\Phi_\gamma(E) = \int dr\ Q_\gamma(r,E) \propto R$

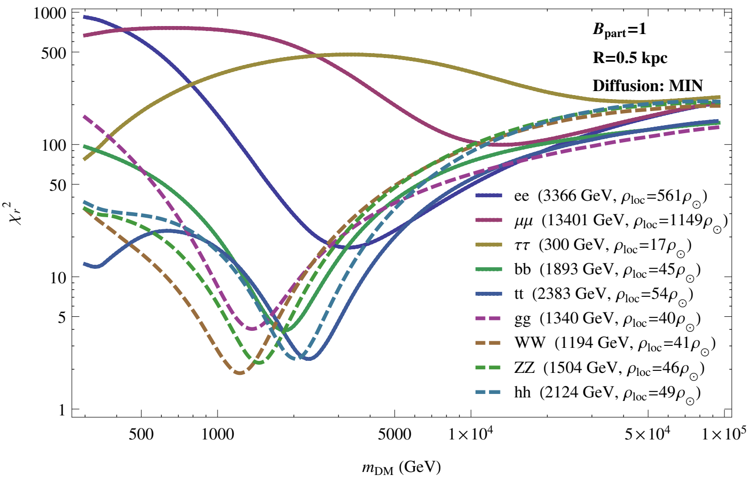
SCM + Galactic *versus* pure Galactic

Fitting of $\Phi_{e^+}^{\mathrm{total}}(E) = \Phi_{e^+}^{\mathrm{SCM}}(E) + \Phi_{e^+}^{\mathrm{Gal}}(E)$

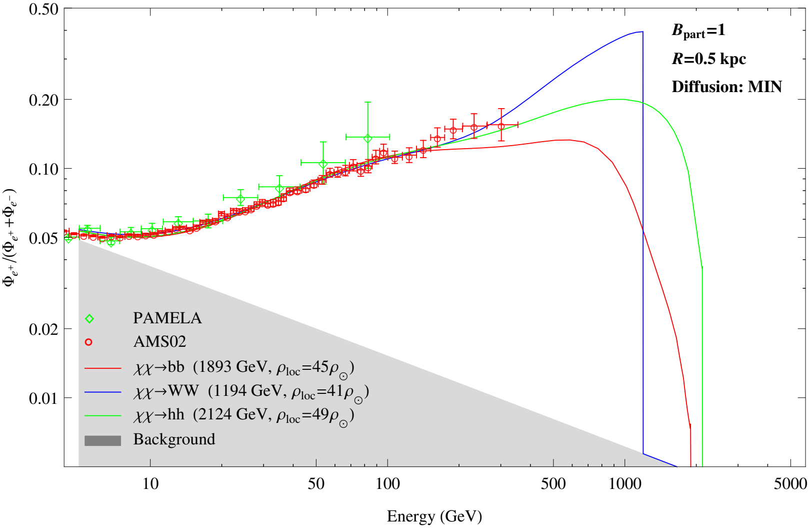




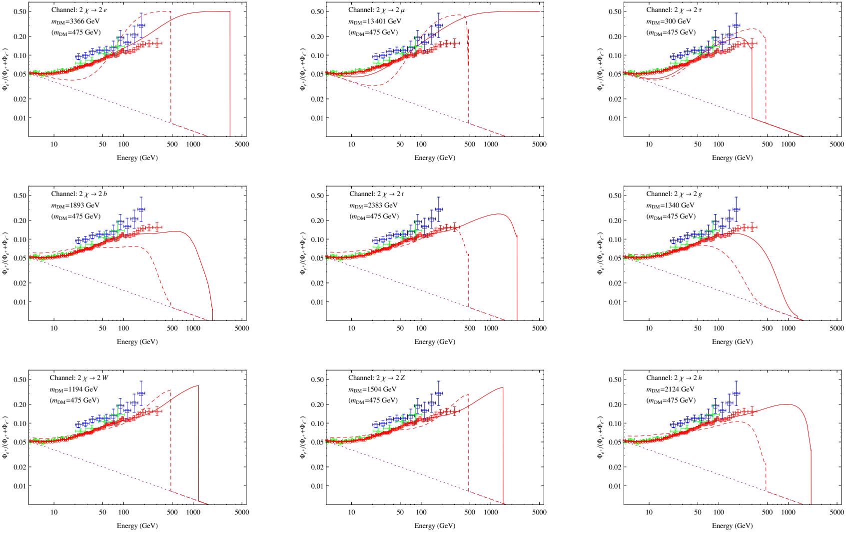
Fitting SCM


B_{part}=1
R=0.5 kpc
Diffusion: MIN
ee (3366 GeV, ρ_{loc}=561$\rho_{\odot}$)
$\mu\mu$ (13401 GeV, ρ_{loc}=1149$\rho_{\odot}$)
$\tau\tau$ (300 GeV, ρ_{loc}=17$\rho_{\odot}$)
bb (1893 GeV, ρ_{loc}=45$\rho_{\odot}$)
tt (2383 GeV, ρ_{loc}=54$\rho_{\odot}$)
gg (1340 GeV, ρ_{loc}=40$\rho_{\odot}$)
WW (1194 GeV, ρ_{loc}=41$\rho_{\odot}$)
ZZ (1504 GeV, ρ_{loc}=46$\rho_{\odot}$)
hh (2124 GeV, ρ_{loc}=49$\rho_{\odot}$)
χ_r^2
1000
500
100
50
10
5
1
500
1000
5000
1×10^4
5×10^4
1×10^5
m_{DM} (GeV)

Fitting SCM

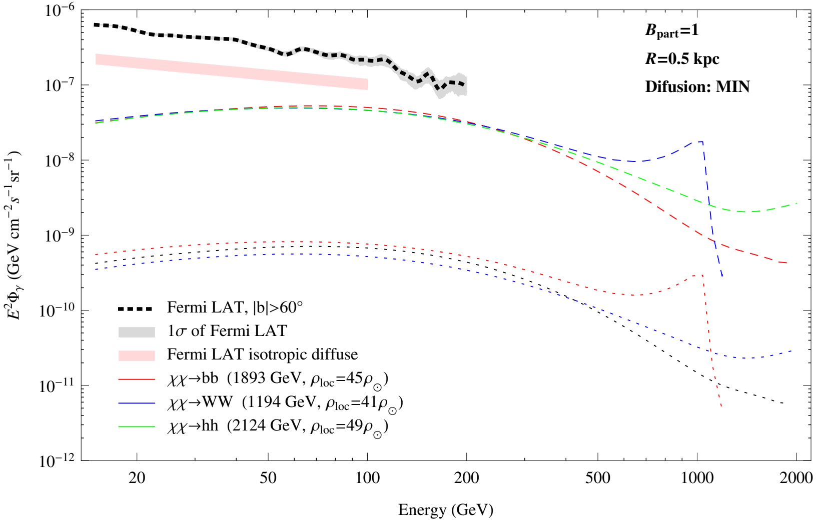


0.50
0.20
0.10
0.05
0.02
0.01
$\Phi_{e^+}/(\Phi_{e^+}+\Phi_{e^-})$
10
50
100
500
1000
5000
Energy (GeV)
B_{part}=1
R=0.5 kpc
Diffusion: MIN
PAMELA
AMS02
$\chi\chi\to$bb (1893 GeV, $\rho_{loc}=45\rho_\odot$)
$\chi\chi\to$WW (1194 GeV, $\rho_{loc}=41\rho_\odot$)
$\chi\chi\to$hh (2124 GeV, $\rho_{loc}=49\rho_\odot$)
Background

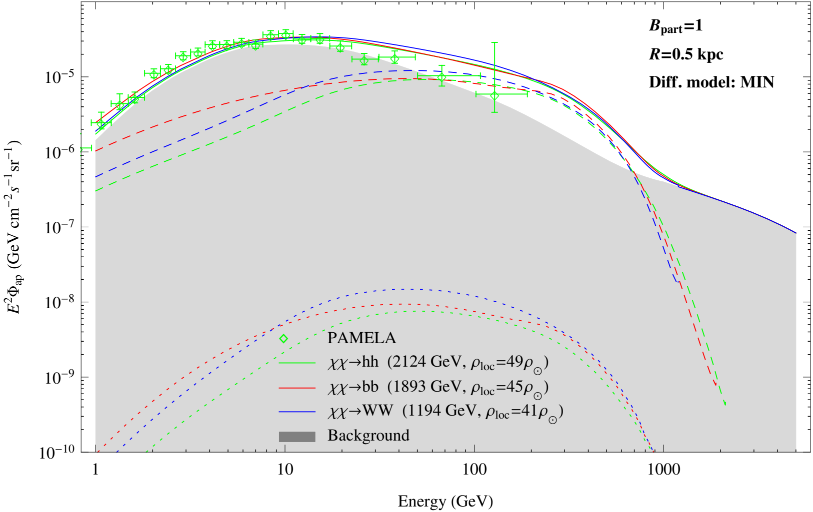


Channel: 2 χ → 2 e
m_DM=3366 GeV
(m_DM=475 GeV)
Channel: 2 χ → 2 μ
m_DM=13 401 GeV
(m_DM=475 GeV)
Channel: 2 χ → 2 τ
m_DM=300 GeV
(m_DM=475 GeV)
Channel: 2 χ → 2 b
m_DM=1893 GeV
(m_DM=475 GeV)
Channel: 2 χ → 2 t
m_DM=2383 GeV
(m_DM=475 GeV)
Channel: 2 χ → 2 g
m_DM=1340 GeV
(m_DM=475 GeV)
Channel: 2 χ → 2 W
m_DM=1194 GeV
(m_DM=475 GeV)
Channel: 2 χ → 2 Z
m_DM=1504 GeV
(m_DM=475 GeV)
Channel: 2 χ → 2 h
m_DM=2124 GeV
(m_DM=475 GeV)
Φe+/(Φe+ +Φe−)
Energy (GeV)

γ-ray constraints from the polar regions $|b| > 60°$

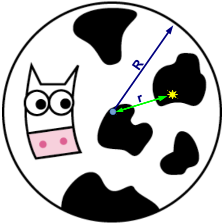


Antiproton constraints



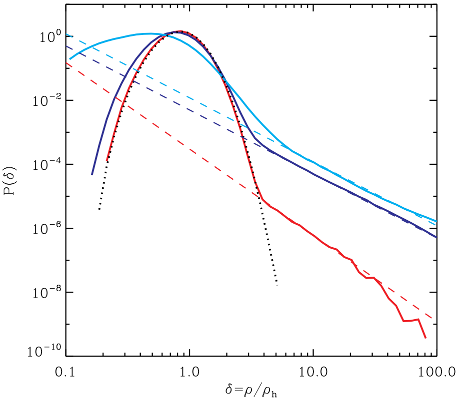
Semi-conclusions

- Favoured channels: WW, ZZ, hh, bb, tt, gg
- SUSY is back
- Beyond SCM
  - Diffusive flux $\propto (R^3 - r^3)/R$
  - Direct flux (max) $\propto R + r$



Local overdensity

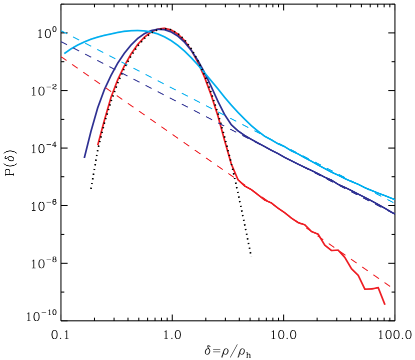
Best fit needs large overdensity: $\rho_{SCM} \simeq 40\rho_\odot$



Kamionkowski, Koushiappas & Kuhlen, 1001.3144

Arithmetics of boost factors

- $\Phi_{e^+}^{\text{total}}(E) = B_{\text{part}}\ \Phi_{e^+}^{\text{SCM}}(E) + B_{\text{part}}\ \rho_{\text{SCM}}^2\ (B_{\text{vel}})\ \Phi_{e^+}^{\text{Gal}}(E)$
- γ and $\bar{p}$ constraints allow $B_{\text{part}} \sim 100 \Rightarrow \rho_{\text{SCM}} \sim 4\ldots5$



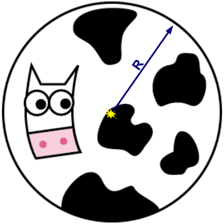
Kamionkowski, Koushiappas & Kuhlen, 1001.3144

Other constraints

- Local DM density from gravitational effects?
  – No problem, $V_{\rm SCM}/V_{\rm loc} \lesssim 0.01$
- Direct detection constraints?
  – e.g. Wino (W-loop, $\sigma_{\rm SI} \sim 0.6 \times 10^{-46}$ cm^2)

Conclusions

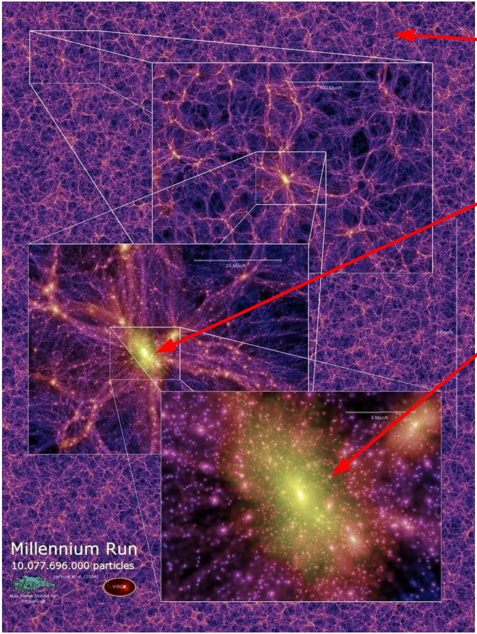
- Local annihilation boost due to a density (or velocity distribution) fluctuation is a plausible explanation of the AMS02 results
- Favoured channels: WW, ZZ, hh, bb, tt, gg
- Predictions:
  – mild excess in $\Phi_{\bar{p}}$ at $E \gtrsim 50$ GeV
  – anisotropy of $\Phi_{\bar{p}}$ and Φ_{e^+}



(2)

γ-rays from galaxy clusters

Where are clusters. . .



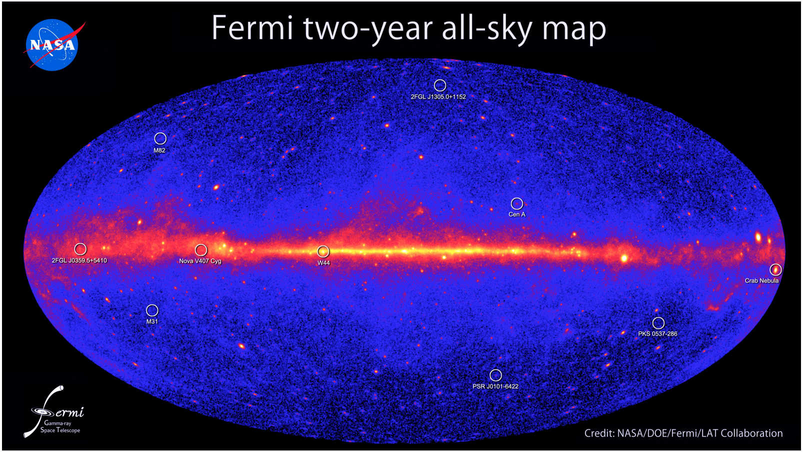
Large scale:
CMB, 21-cm,
isotropic diffuse γ-rays

Galaxy clusters:
γ-rays, SZ-effect

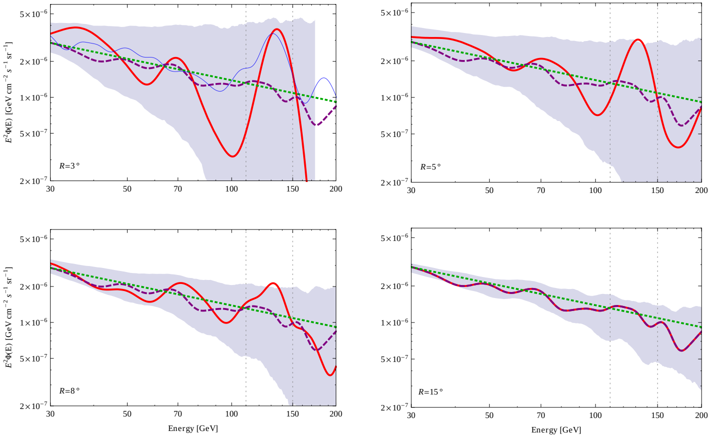
Galactic scale:
γ-rays, charged particles,
synchrotron, CMB haze

Dwarf scale:
γ-rays

Sub-halo scale (solved/unresolved):
γ-rays, charged particles

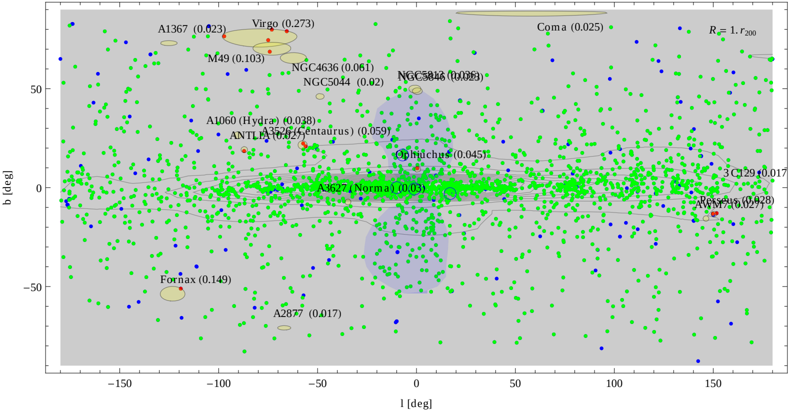

Fermi two-year all-sky map
NASA
2FGL J1305.0+1152
M82
Cen A
2FGL J0359.5+5410
Nova V407 Cyg
W44
Crab Nebula
M31
PKS 0537-286
PSR J0101-6422
fermi
Gamma-ray
Space Telescope
Credit: NASA/DOE/Fermi/LAT Collaboration

Galaxy clusters: first study

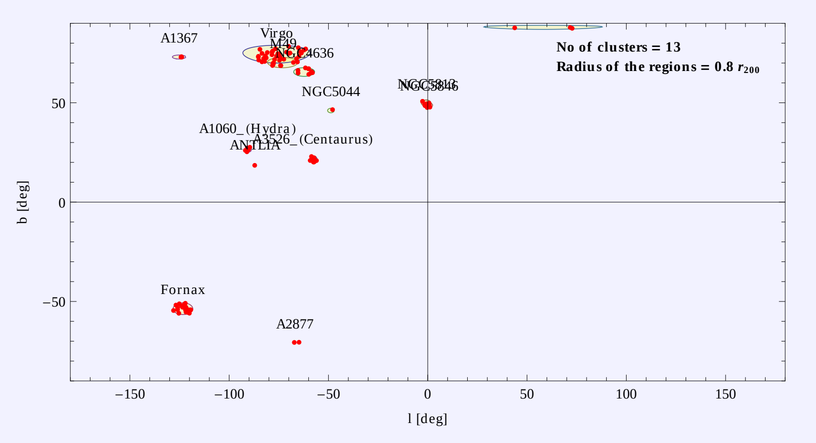


Hektor, Tempel & Raidal [1207.4466]

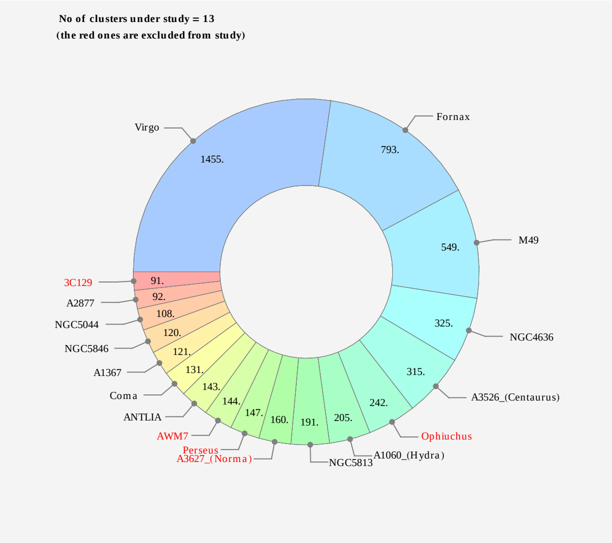
Galaxy clusters (refreshed study): analysed clusters



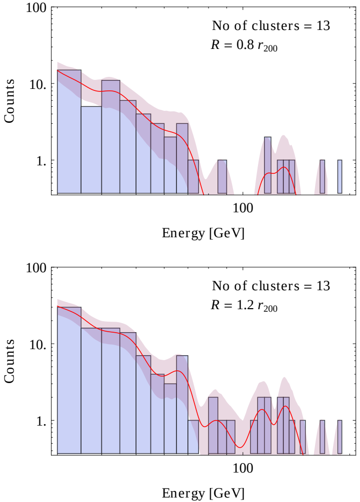
Galaxy clusters (refreshed study): analysed “cleaner” clusters



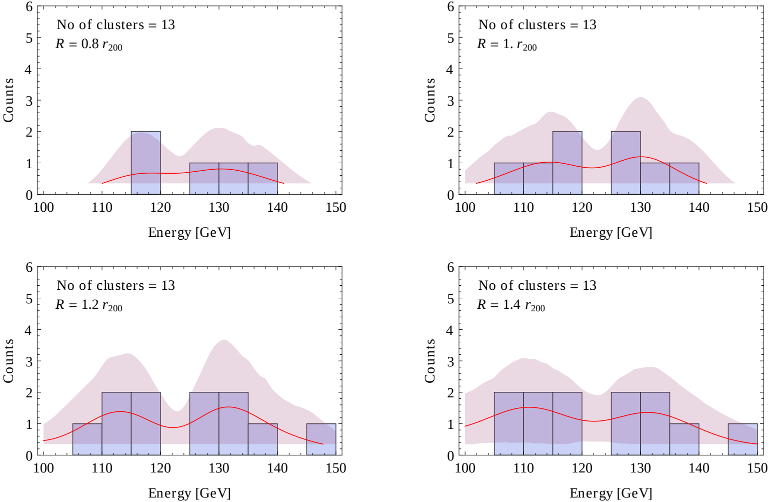
Galaxy clusters (refreshed study): J-factors



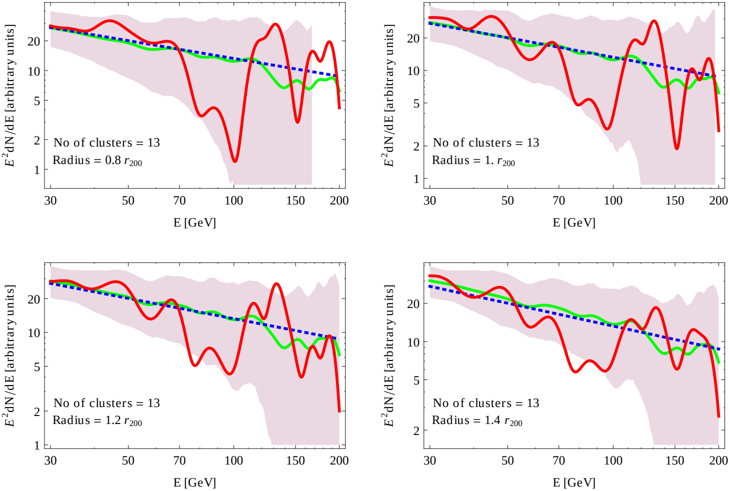
Galaxy clusters (refreshed study): histograms with better energy resolution



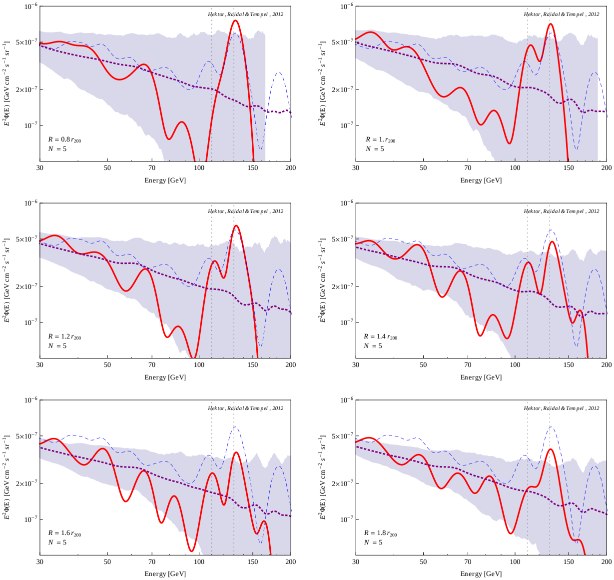
Galaxy clusters (refreshed study): histograms with better energy resolution



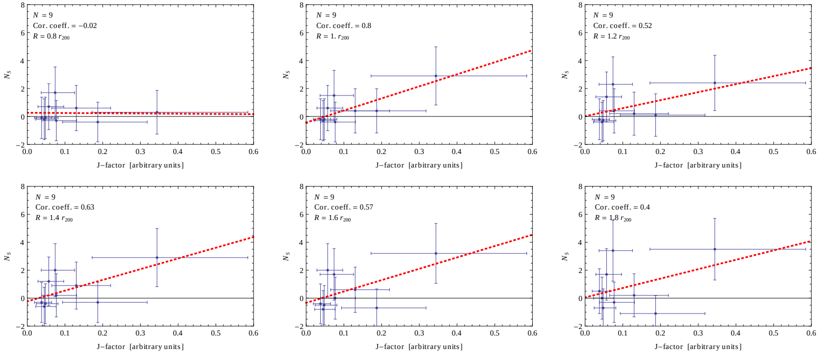
Galaxy clusters (refreshed study): kernel-smoothed spectra (13 “cleanest”)



Galaxy clusters (refreshed study): kernel-smoothed spectra (5 strongest)



Galaxy clusters: correlation between the signal and J-factor



Conclusions

What next?

- Reprocessed data from Fermi LAT
- HESS-II
- Using a newer cluster catalog – more accurate masses and r_{200}
- Analysis of the lower energy data, $E < 20$ GeV – a lot of non-DM physics there also!

(3)

Secondary neutrinos from DM annihilation in the Sun

Refreshing memory

- Sun captures DM ($m_{\rm DM} \gtrsim 5$ GeV)
- Annihilation rate $\propto$ capture rate
- DM annihilation happens in the solar core ($\rho_{\rm core} \sim 160$ g cm^{-3}, $T \sim 1$ keV)
- Only neutrinos can escape from the core
- Stable and semi-stable annihilation products interact with the solar core environment initiating EM and hadronic cascades
- Long-living π^+, n etc get stopped and decay at rest
- Process $\pi^+ \to \mu^+ + \nu_\mu$ produces a "neutrino line"

What is done and what is not?

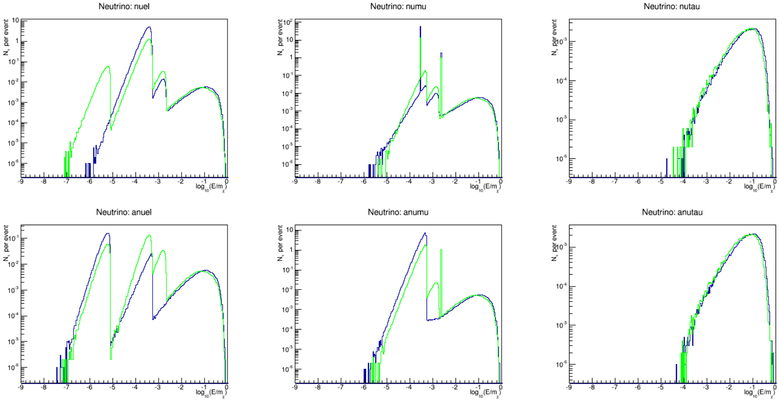
What is done?

- Rott, Siegal-Gaskins & Beacom, 1208.0827
- Bernal, Martin-Albo & Sergio Palomares-Ruiz, 1208.0834
- No full scale MC simulations!

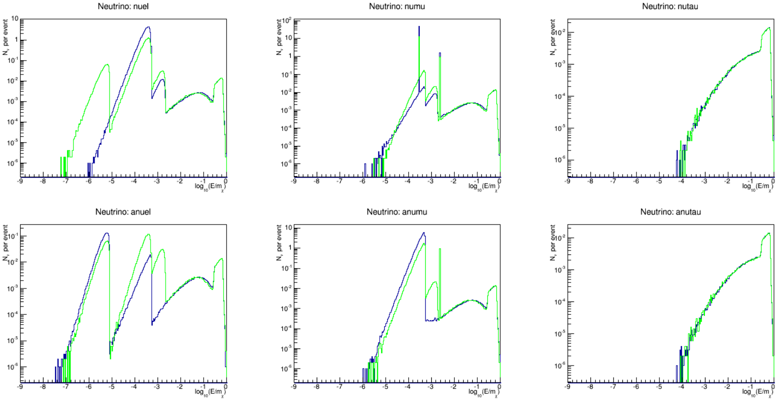
Our technical set up

- PYTHIA $\Rightarrow$ (semi)stable particles $\Rightarrow$ Geant4 $\Rightarrow$ oscillations $\Rightarrow$ detector response
- Computational intensive!

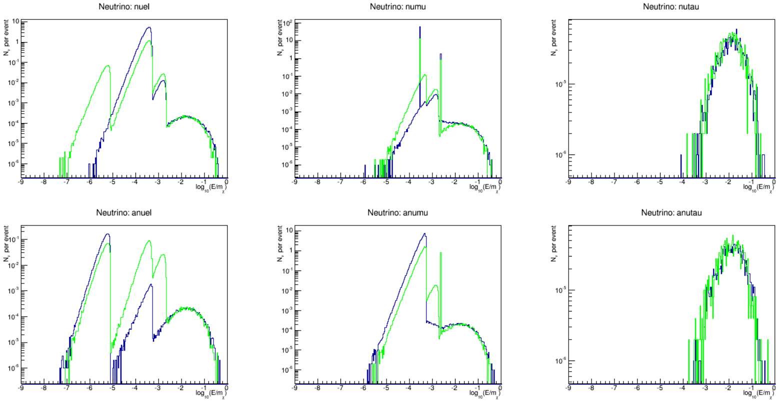
$\chi\chi \rightarrow bb$, $m_{\mathrm{DM}} = 100$ GeV



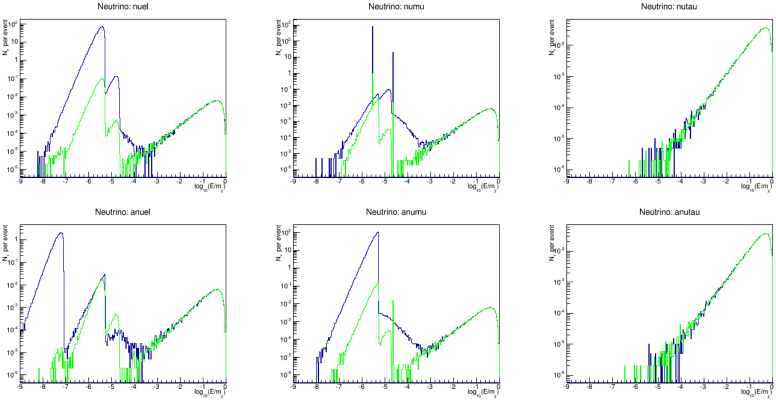
$\chi\chi \to ZZ$, $m_{\rm DM} = 100$ GeV



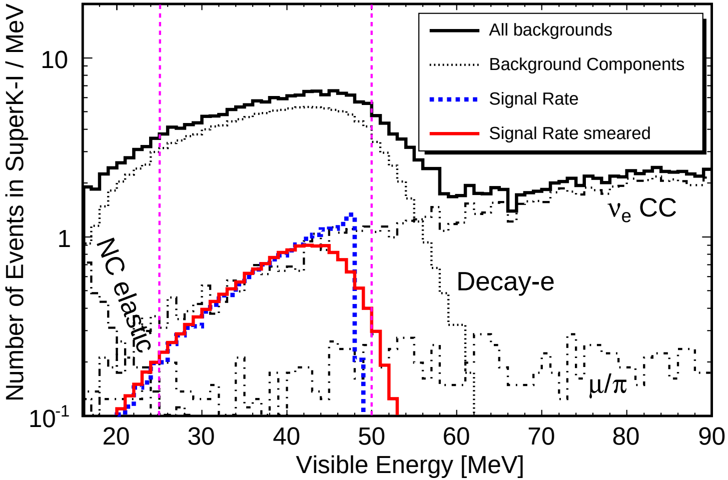
$\chi\chi \to qq$, $m_{\mathrm{DM}} = 100$ GeV



$\chi\chi \to \tau\tau$, $m_{\rm DM} = 10000$ **GeV**



π^+ decay signal *versus* background



From Rott, 1210.4161

Conclusions

- Signal of secondary solar neutrinos is an interesting new observable in DM physics
- However, it is computationally and statistically complex

Thank you!