Hunting Gravitino Dark Matter with the Fermi LAT

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Workshop on Indirect Dark Matter Searches, DESY Hamburg

Based on **JCAP 1105 (2011) 027**
and ongoing work with
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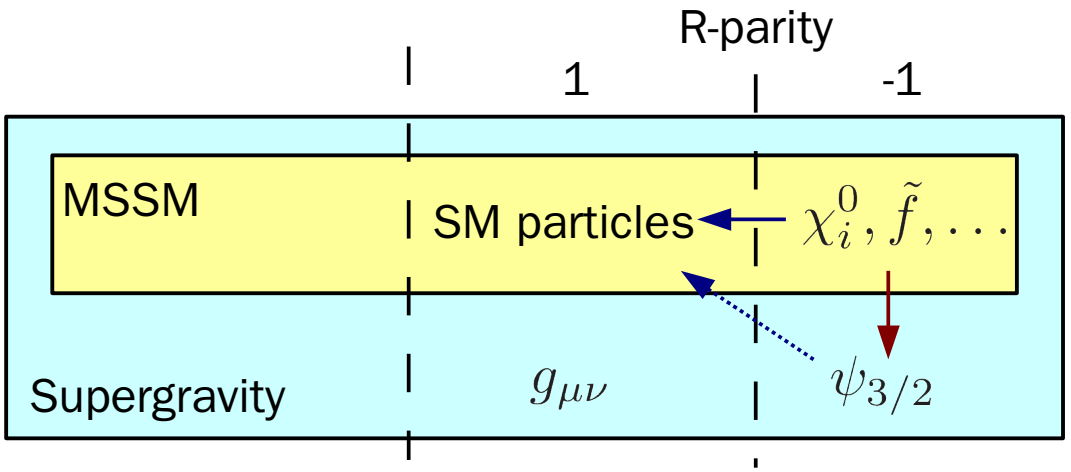
17 Jun 2011

Gravitino DM with R-parity violation



DM scenario

- consistent with thermal leptogenesis as source for the baryon asymmetry
- consistent with primordial nucleosynthesis

- can be probed at colliders and in the sky

NLSP decay (→ LHC)

$e.g.\ \tilde{\tau}_1 \to \tau\nu$

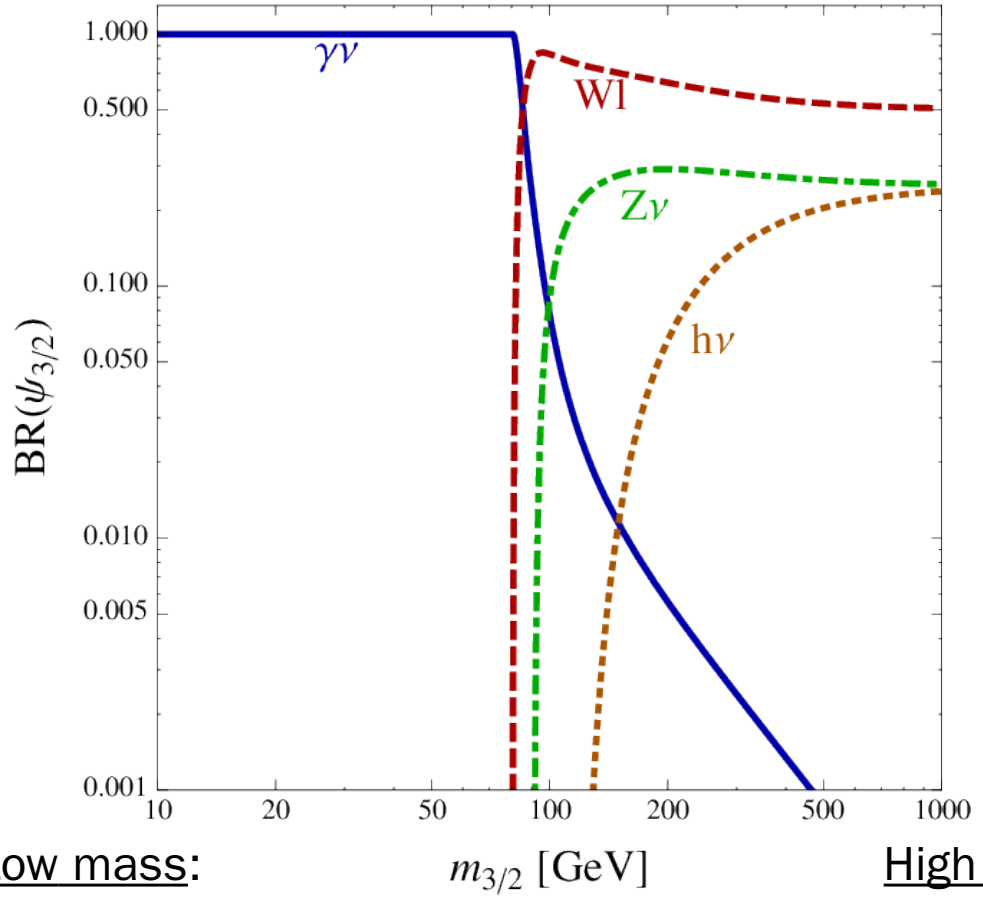
ζ

Gravitino decay (→ Cosmic Rays)

$\psi_{3/2} \to \gamma\nu, W^{\pm}\ell^{\mp}, \ldots$

e.g. Takayama et al. (2000), Bertone et al. (2007), Ibarra, Tran (2008)

Branching Ratios



Low mass:
Intense gamma-ray lines

$$\psi_{3/2} \to \gamma\nu$$

→ „Full-sky“ searches
(max. statistics for spectral analysis)

High mass:
Broad continuous spectrum

$$\psi_{3/2} \to W^{\mp}\ell^{\pm}, \ldots$$

→ Nearby Galaxy Clusters
(large signal, low background)
extragalactic gamma-rays, antiprotons...

Overview

Gamma-ray line searches

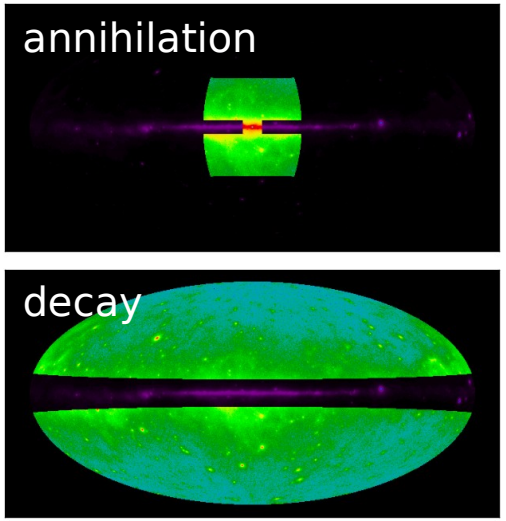
Galaxy Clusters

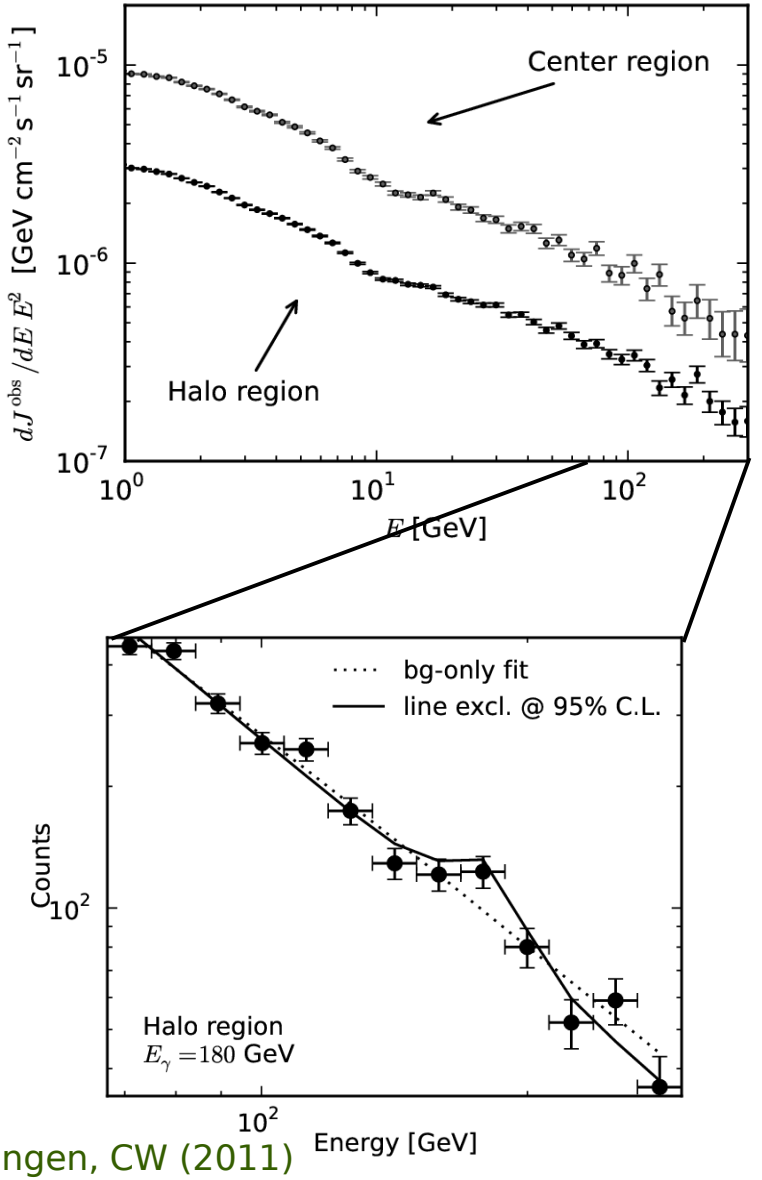
→ NLSP decay length

Conclusions

Gamma-ray Line searches with Fermi LAT

1) Select target regions with best S/N (for Ein., NFW, isoth. profiles)





2) Consider small energy window around gamma-ray line energy

3) Use profile likelihood method to fit
Line signal (given by energy dispersion)
+ Power-law background

cp. Bringmann, Calore, Vertongen, CW (2011)

Gamma-ray Line searches with Fermi LAT

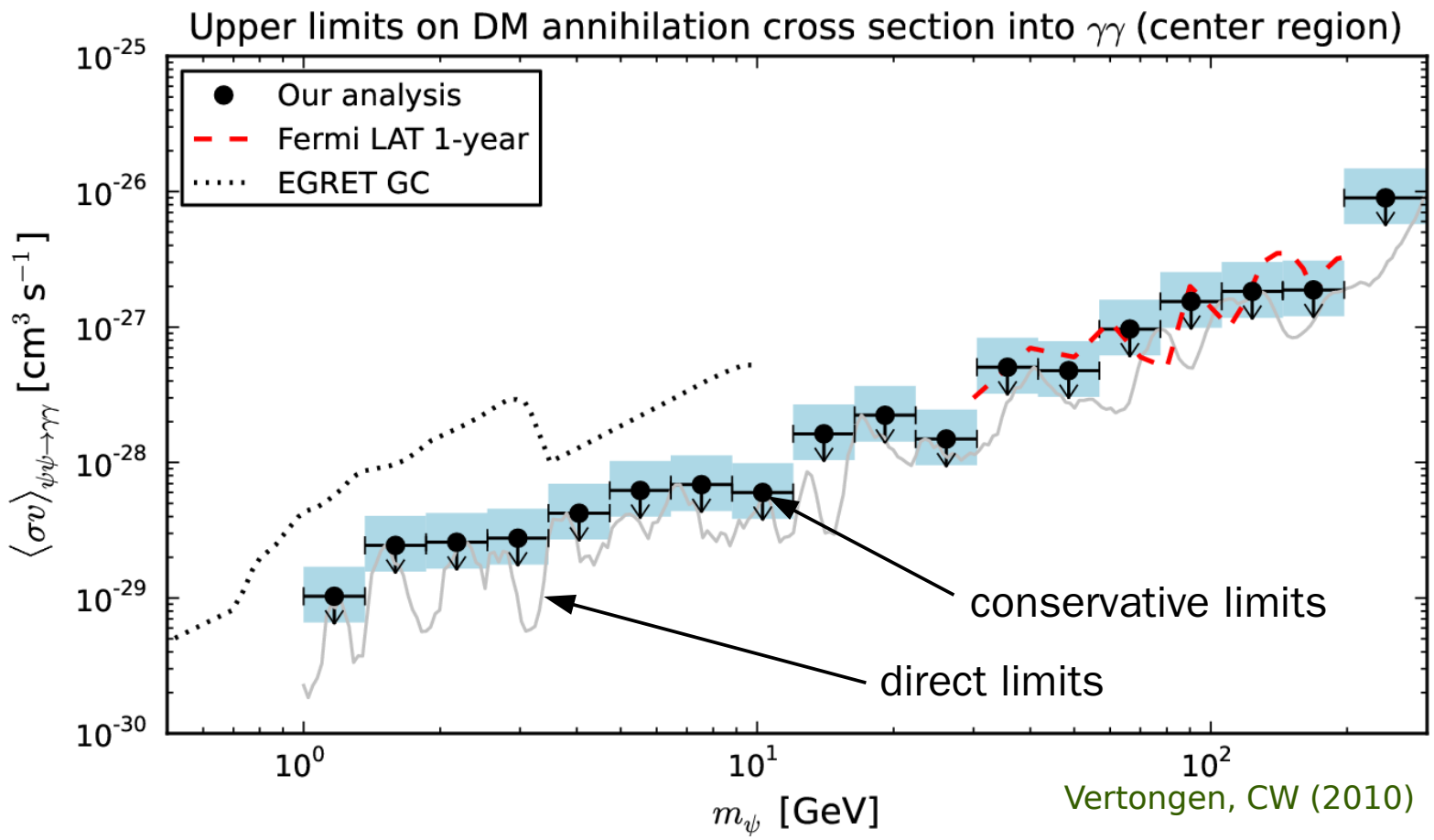
EGRET: limits on gamma-ray lines up to 10 GeV (annihilation only) Pullen et al. 2006
Fermi LAT: limits on gamma-ray lines with 30-200 GeV (by Fermi Collaboration)
Abdo et al. 2010

Main differences to previous Fermi analysis:

- Limits down to 1 GeV
- Two optimized target regions
- Scanning through all gamma-ray line energies from 1 to 300 GeV
- Independent software
- Public data (DataClean event class) and ISR P6v3 from Aug 2008 – Nov 2010

→ No line is found at 5σ at energies 1 and 300 GeV

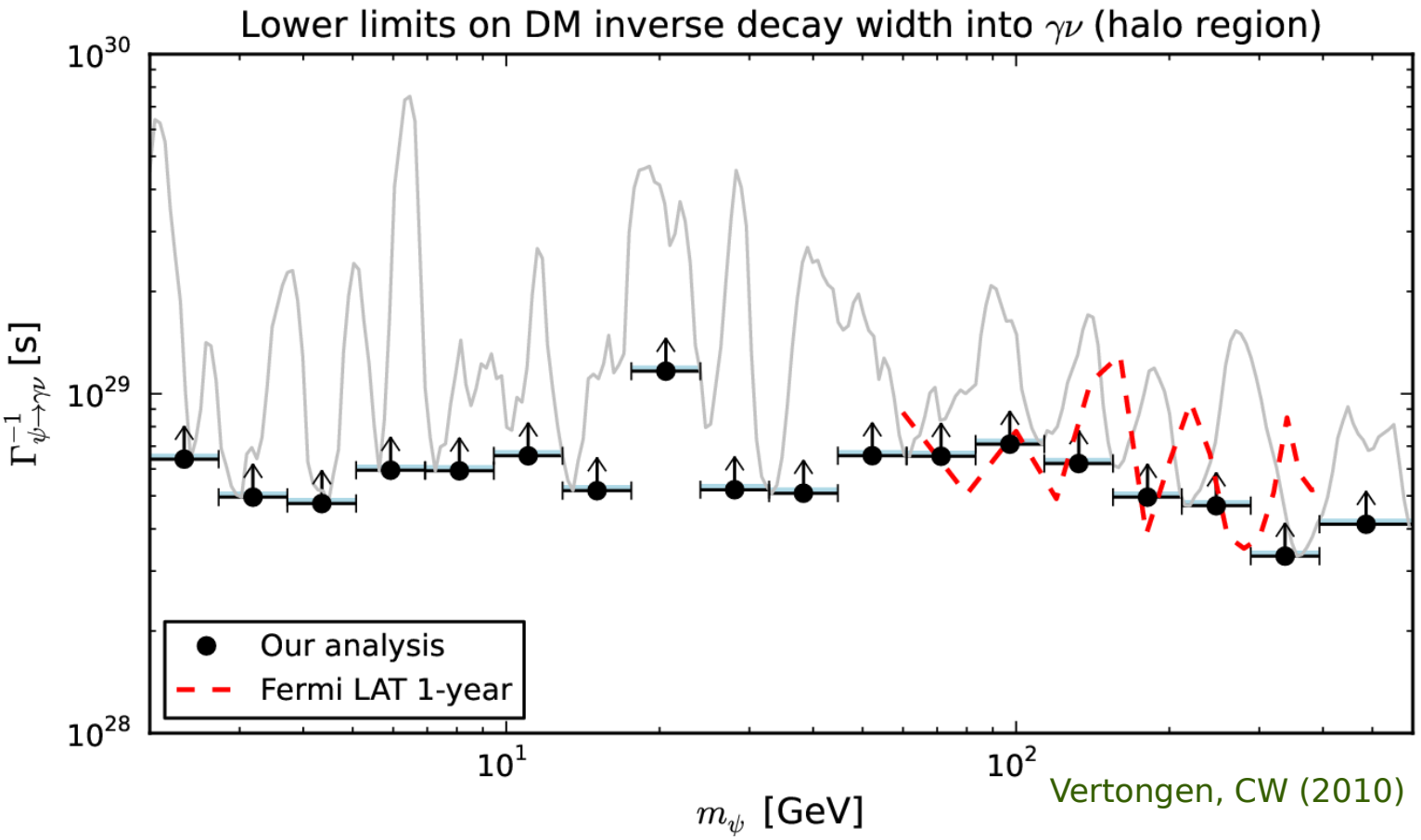
Limits on WIMP annihilation $\chi_1^0\chi_1^0 \to \gamma\gamma$



Limits on dark matter masses from 1 to 300 GeV

- Compatible with previous Fermi LAT results
- EGRET limits significantly improved

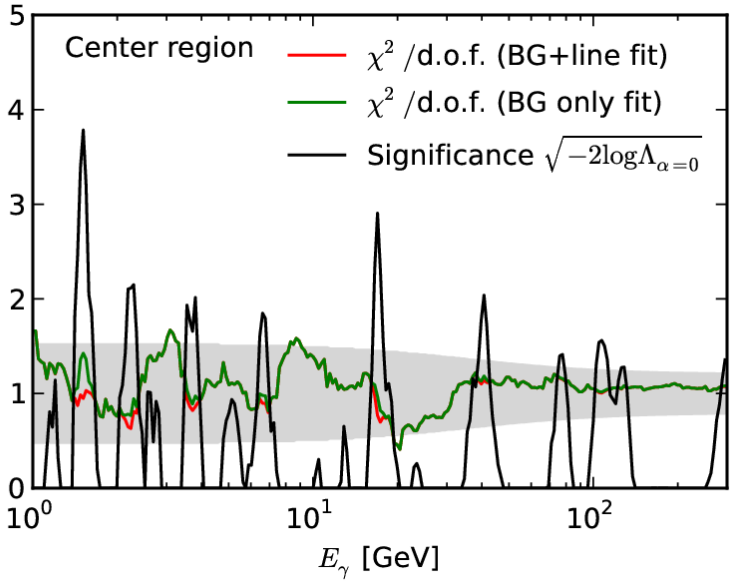
Limits on dark matter decay $\psi_{\rm dm} \to \gamma\nu$

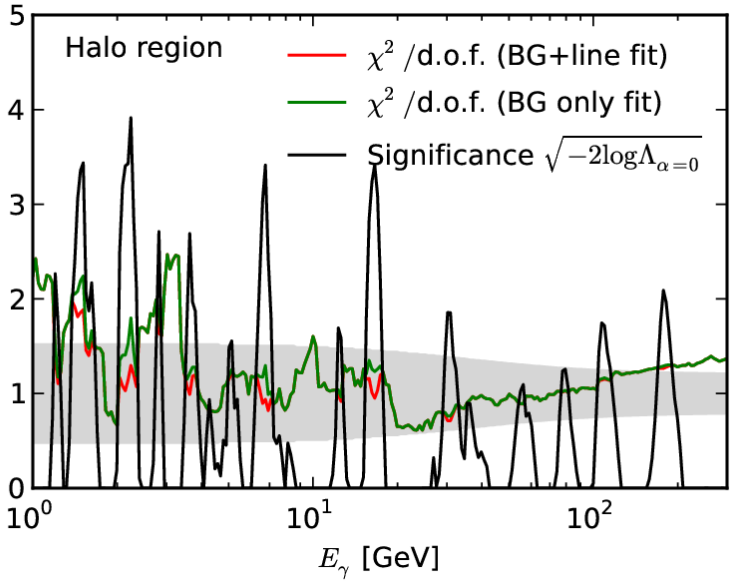


Limits on dark matter masses from 2-600 GeV

- Compatible with previous results
- New limits cover the whole mass range relevant for gravitino DM

All that glisters is not gold





Vertongen, CW (2010)

- χ^2/d.o.f. in center region OK (due to lower statistics), in halo region problematic at low energies
- Several 3-4σ line-like signatures present in halo signal below ~20 GeV
  → most probably due to instrumental artifacts in energy reconstruction

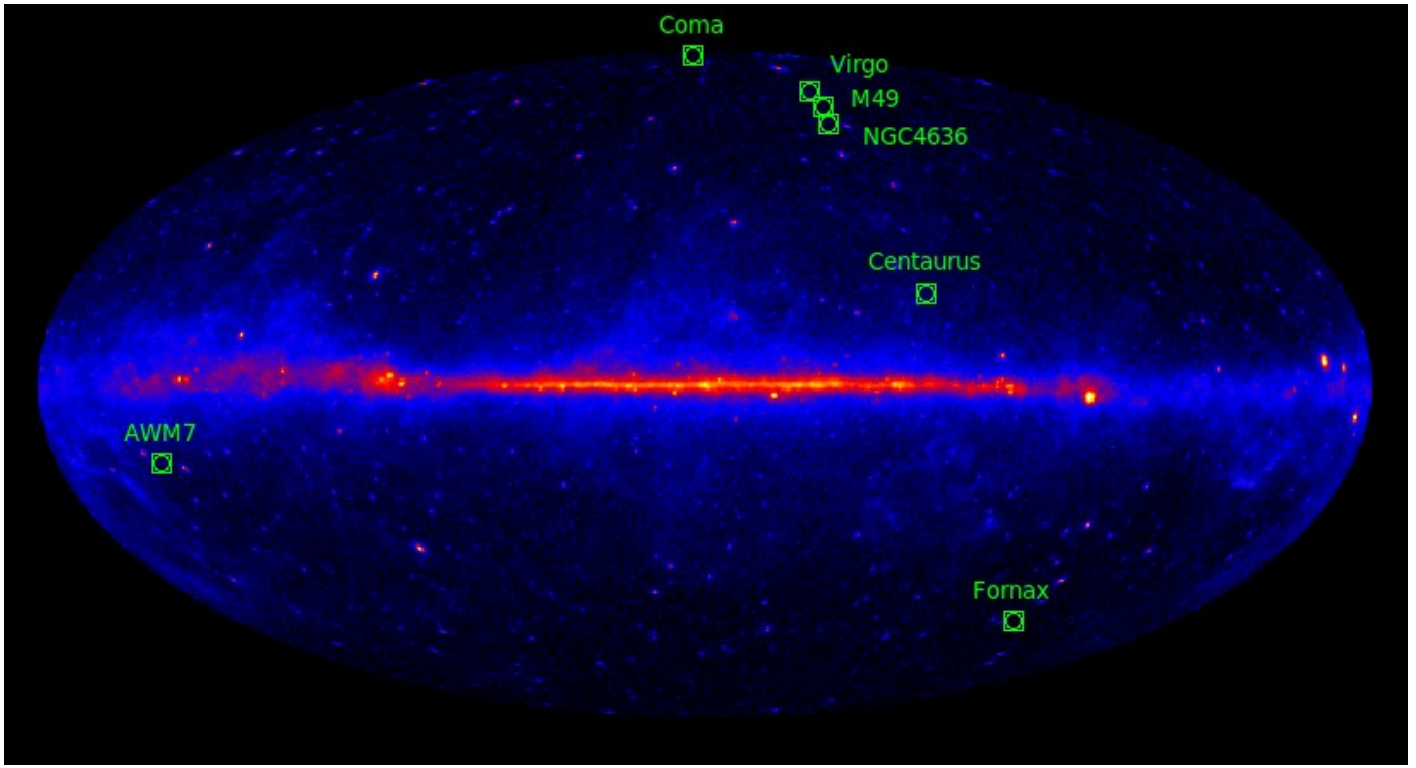
Galaxy Cluster Limits

Galaxy Clusters are the largest collapsed structures in the Universe, often they don't shine in gamma-rays

Excellent targets to search for decaying dark matter Dugger et al. (2010)

Seven clusters: Coma, M49, NGC4636, Centaurus, AWM7, Fornax, Virgo
Ackermann et al. (2010)
Pinzke et al. (2011)

(mainly HIFLUGCS X-ray catalog) Reiprich et al. (2002)



Methods

Cluster DM profiles from

- X-ray observations Reiprich et al. (2002)
- Concentration-mass relation Buote et al. (2007)
- NFW profile

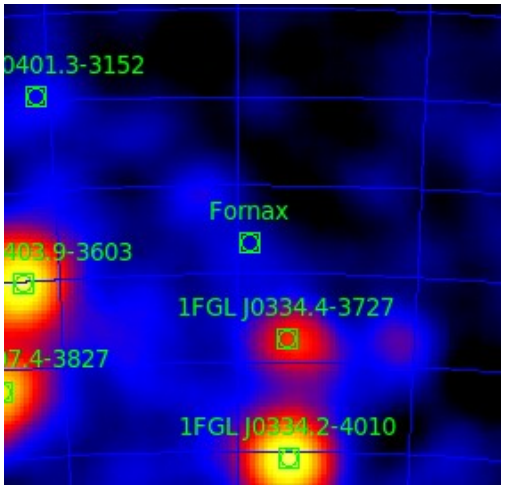
Technicalities

Binned profile-likelihood method (using ScienceTools v9r23p1)

Signal modeled as extended source

Adopted Backgrounds:

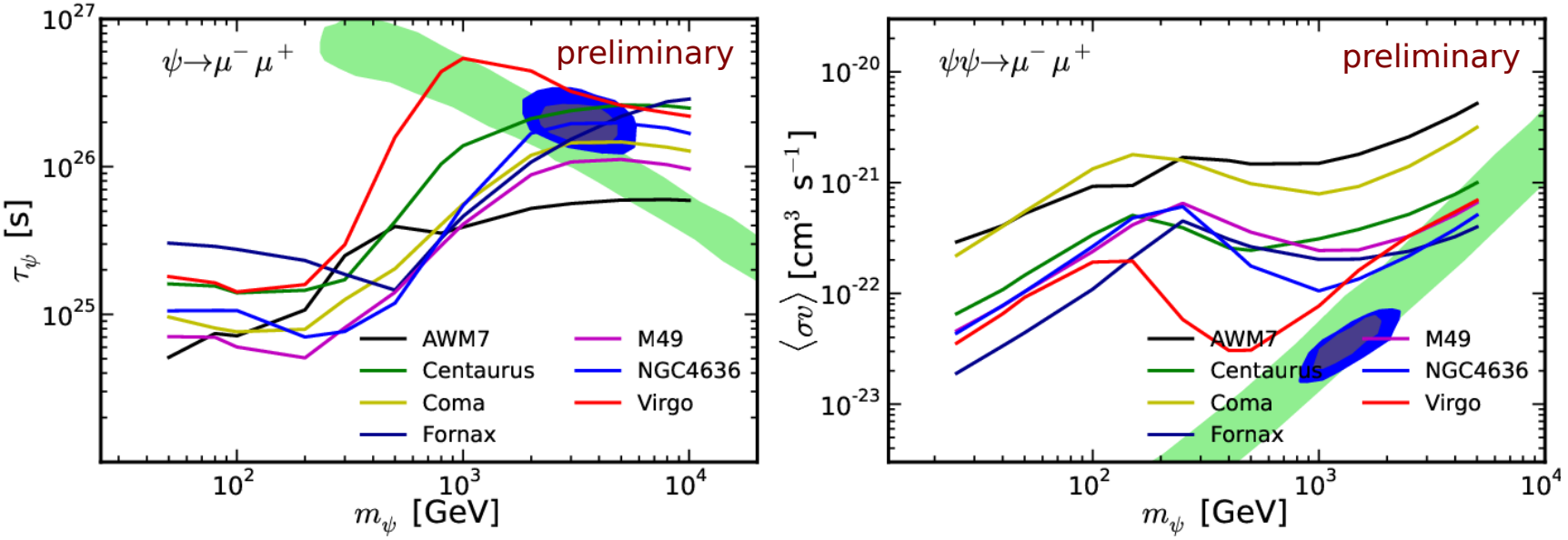
- Galactic emission (gal_v02, free norm.)
- Extragalactic emission (eg_v02, free norm.)
- 1FGL Point Source Catalog (mostly fixed) Abdo et al. (2010)



We only use 1 year data (and P6v11) to be consistent with background models and 1FGL

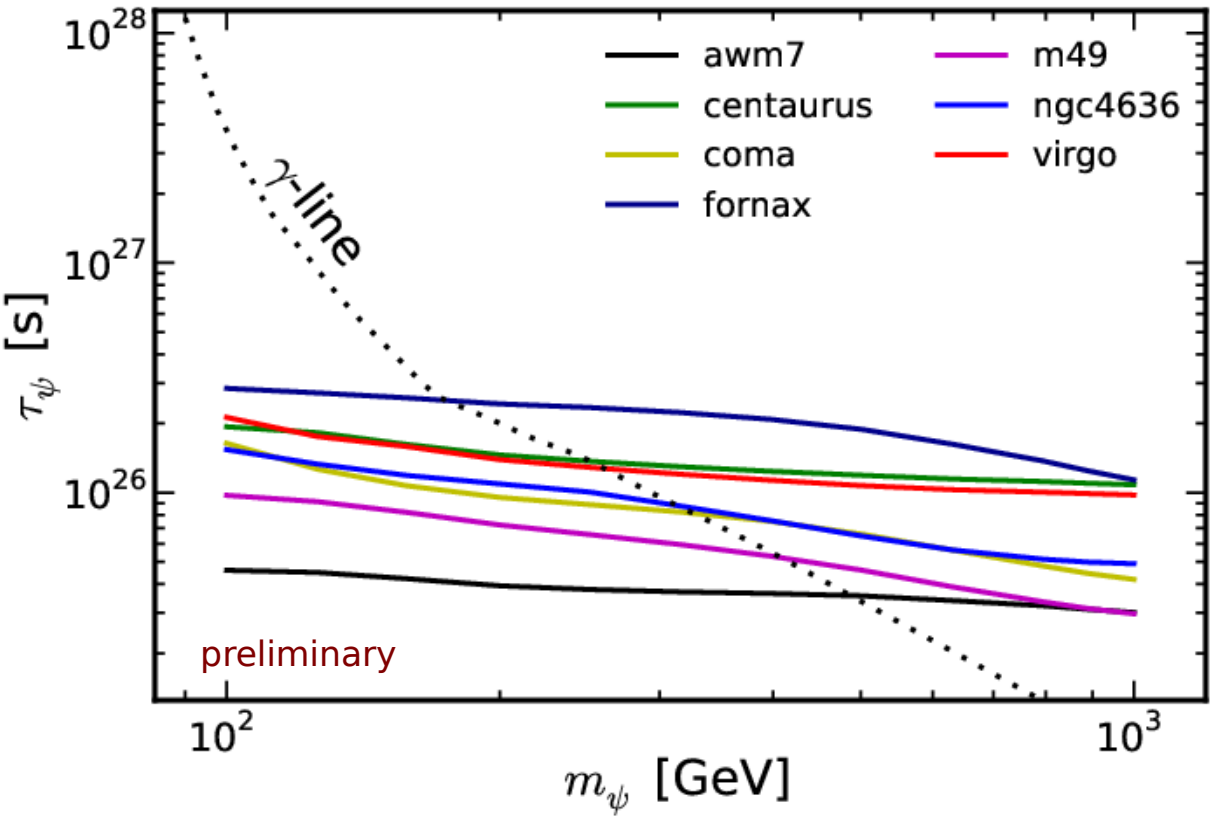
Inverse Compton Scattering of Electrons/Positrons from DM on CMB is taken into account. $e^- \gamma_{\rm CMB} \rightarrow e^- \gamma$

PAMELA excess



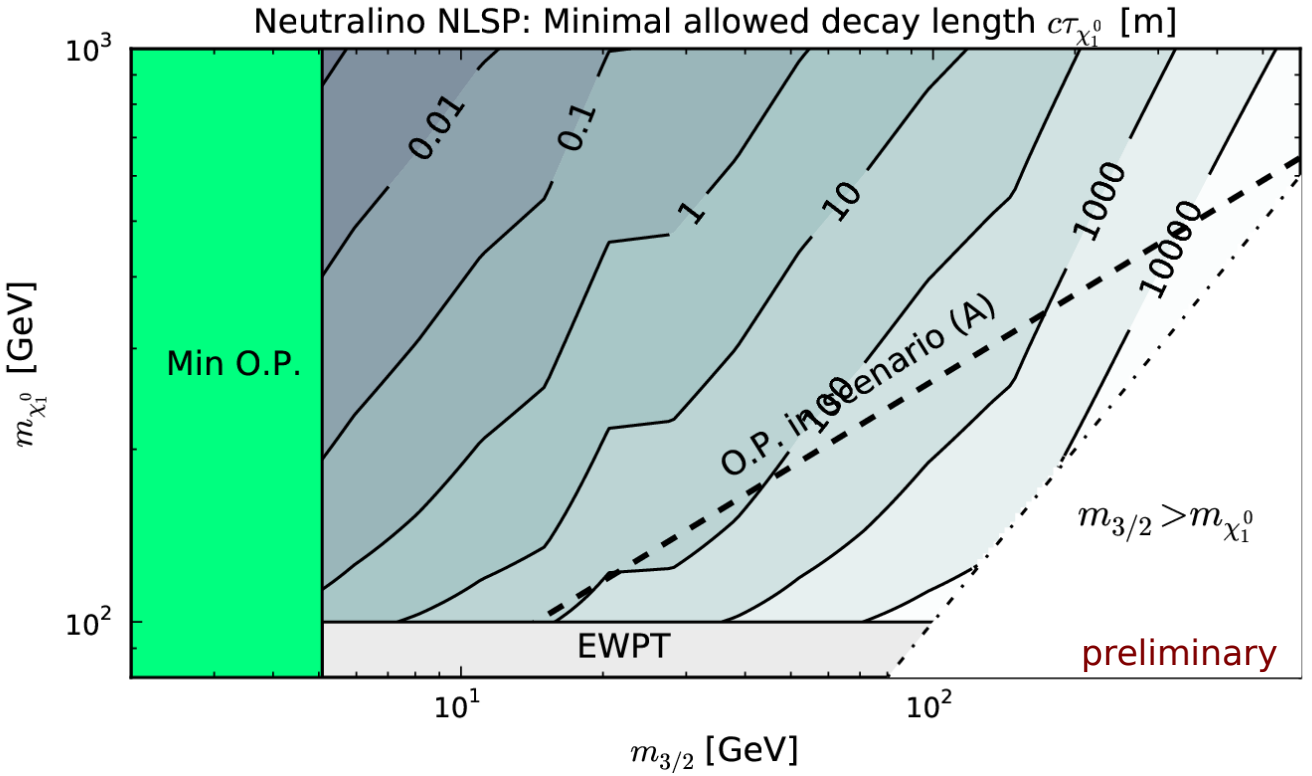
- Decaying DM interpretation of PAMELA/Fermi anomaly marginally consistent
- Annihilation (w/o substructures) remains unconstrained
- Due to proper modeling as extended sources, limits on dark matter decay are factor ~O(2) weaker than what was found in Dugger et al. (2010) from one-year data

Gravitino Lifetime Limits from Clusters



- Limits from galaxy clusters go up to 2-3 x 10^{26} s
- They dominate over the line limits only above ~180 GeV
- But: still weaker than the “extragalactic” bounds
- Limits will improve with
  1) growing statistics (we are awaiting two-years point source catalog)
  2) using stacked analysis

→ Neutralino NLSP Decay Length



→ Collider signatures

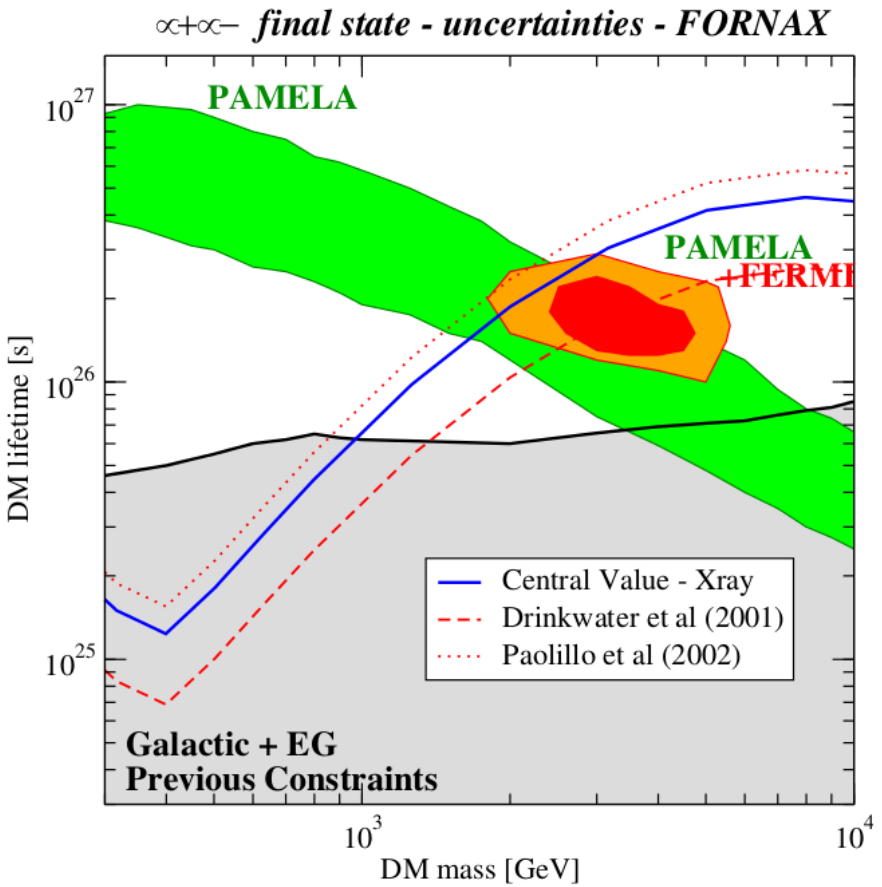
- e.g. $\chi_1^0 \to Z^0\nu$ with $Z^0 \to \mu^-\mu^+$
  Missing energy + displaced vertex allows efficient background rejection
- If NLSP lifetime close to limit, large part of parameter space can be probed by LHC, starting with 1fb^{-1}

[Buchmüller et al. (in preparation)]

Conclusions

- Decaying gravitino DM features rich phenomenology, from Cosmic Rays to LHC observations
- Gamma-rays from gravitinos could be seen by Fermi LAT as monochromatic lines or fluxes from galaxy clusters
- We searched for such features in the public Fermi LAT data and derived limits on the gravitino lifetime
- The remaining parameter space will be very efficiently probed by LHC and future Fermi LAT observations

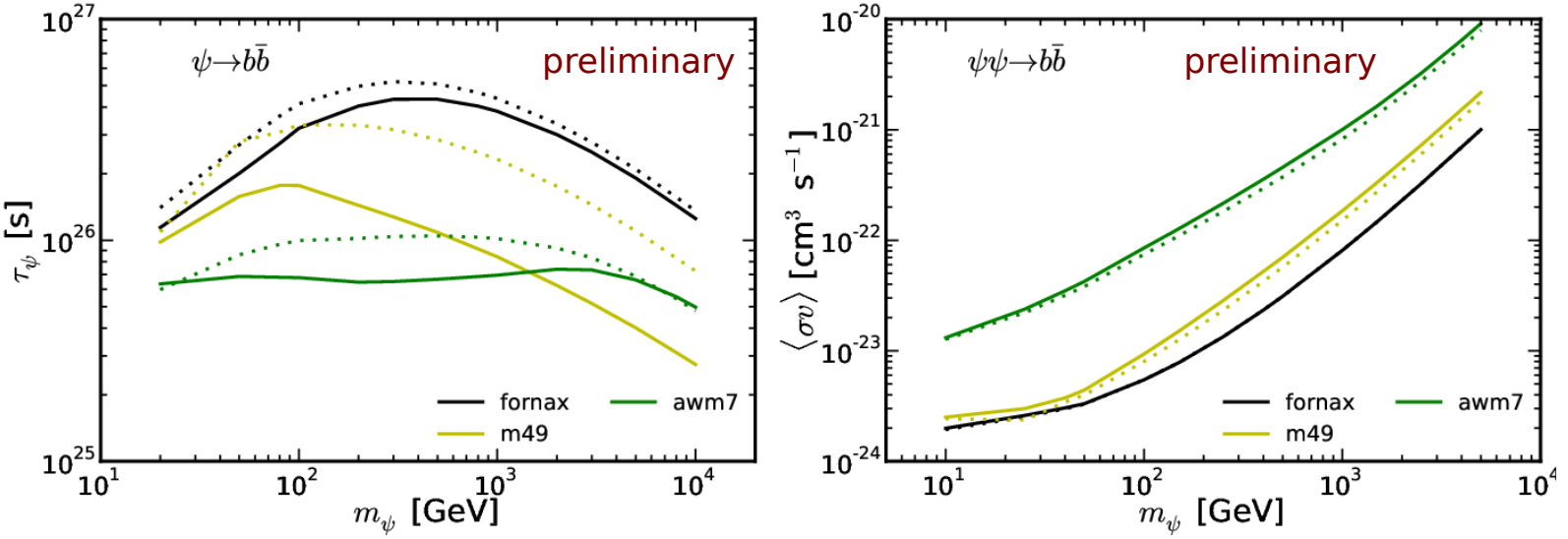
Halo Profile Uncertainty



Dugger et al. (2010)

DM signal is extended

- LAT angular resolution above 5 GeV is < 0.4 deg
- Scaling radius of considered clusters corresponds to 0.23 – 0.76 deg



Dotted lines: point-source approx.
Solid lines: treatment as extended sources

Point source approximation could wrongly increase the limits by factor ~O(2).

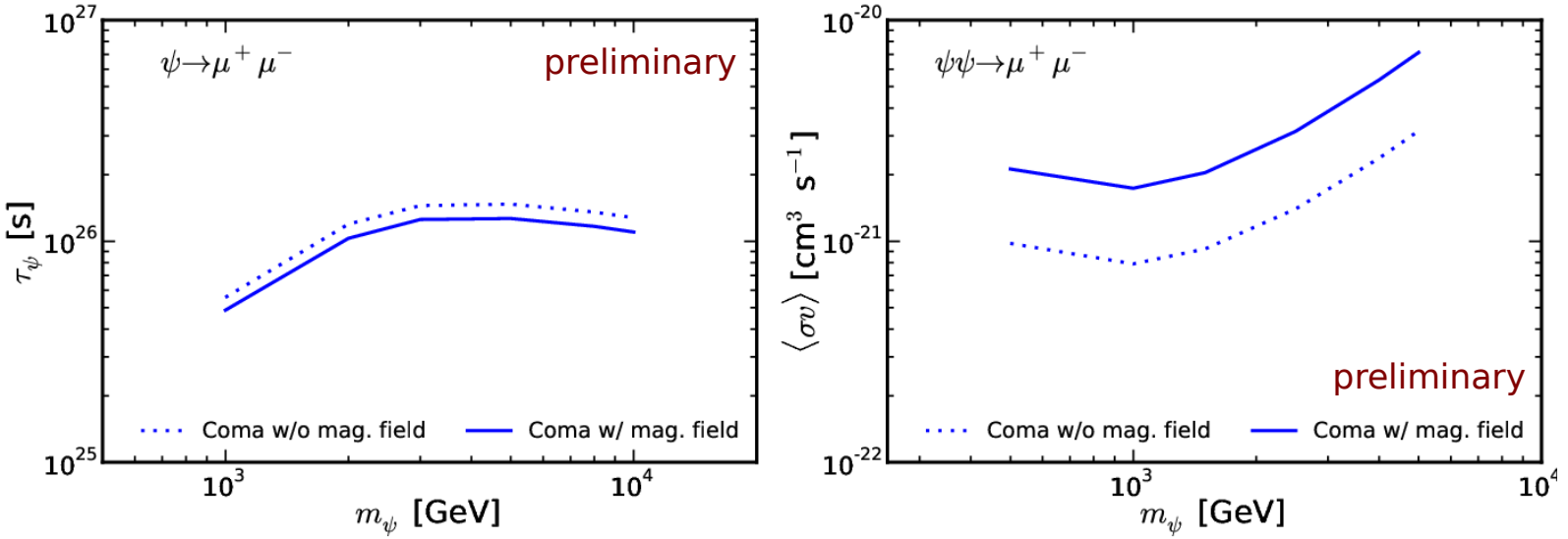
Inverse Compton Scattering & B-fields

Electrons from DM annihilation/decay suffer energy losses on intracluster radiation field:

- CMB → inverse Compton radiation
- B-field → synchrotron radiation (critical field: 3.2 muG)
- also: starlight, dust radiation (in innermost region, <0.1 r_vir) Pinzke et al. (2011)

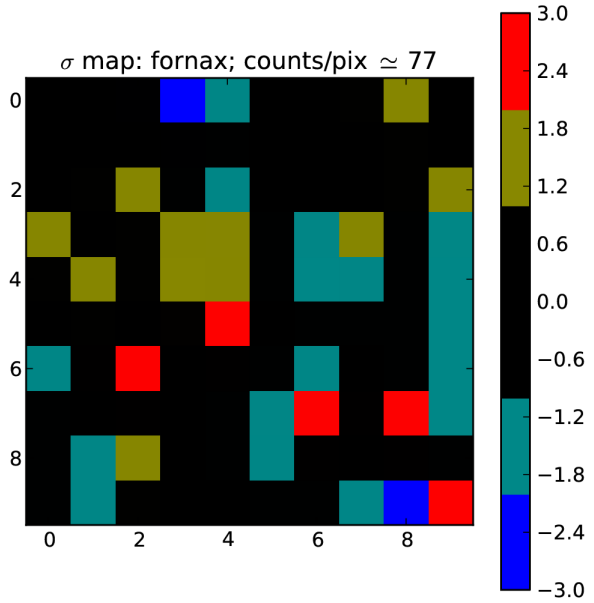
B-field in individual Clusters in general poorly known, ~O(1muG) expected.
For Coma cluster measurements exist (with ~4.7muG peak value)

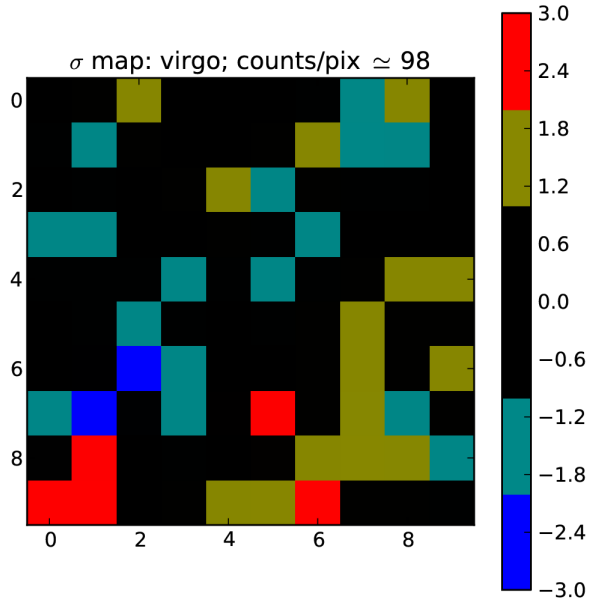
Bonafede et al. (2010)



→ negligible for DM decay

Background residuals





Stau NLSP Decay Length