Extracting limits on Dark Matter annihilation from dwarf Spheroidal galaxies

Work done with Paolo Salucci,
PRD 86, 023528 (arXiv:1203:2954)

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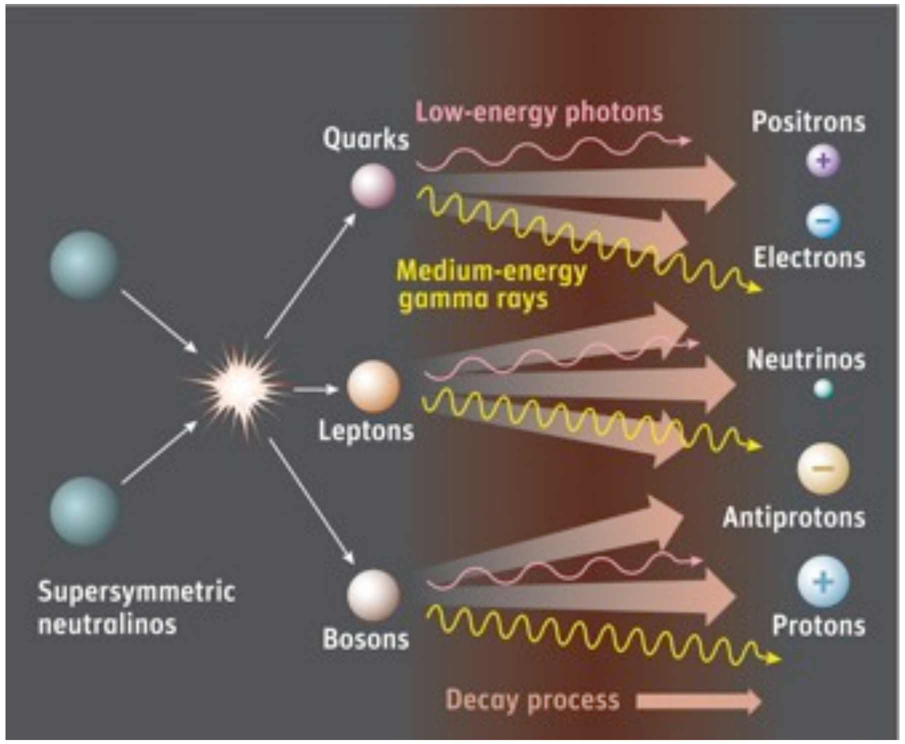
Identification of Dark Matter 2012, 26th July

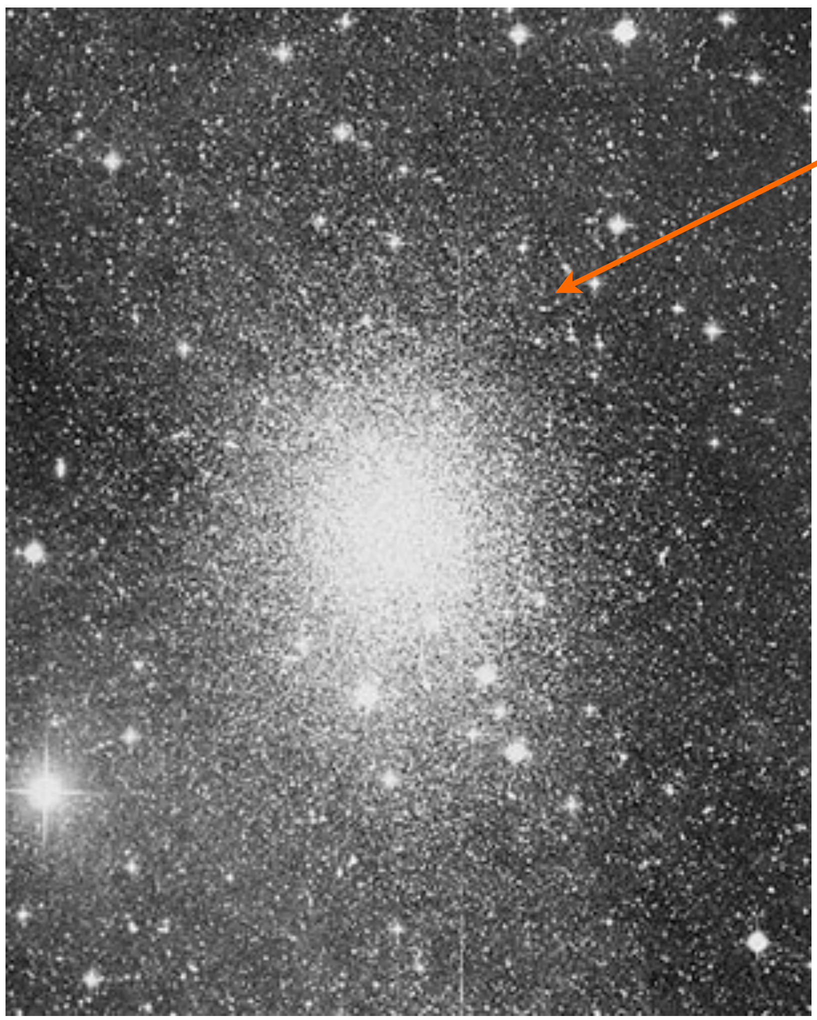
Outline



- Motivate for search of signals by DM annihilation from dwarf spheroidal galaxies (dSphs)
- Background gamma-rays for dSphs
- Dark Matter distribution in dwarf spheroidal galaxies
- Extracting Residual gamma-ray Spectra and Limits on DM annihilation
- Best constraints from Dwarf Spheroidal galaxies
- Conclusions

Significance of dwarf spheroidal galaxies for Dark Matter annihilation signals

Sculptor



dwarf Spheroidal galaxies are low luminosity galaxies (spheroidal in shape) containing ~10-100 million stars with the observed ones being companions to our Galaxy or to Andromeda. Their typical mass is ~ 100 times smaller than our galaxy.

Why we care:

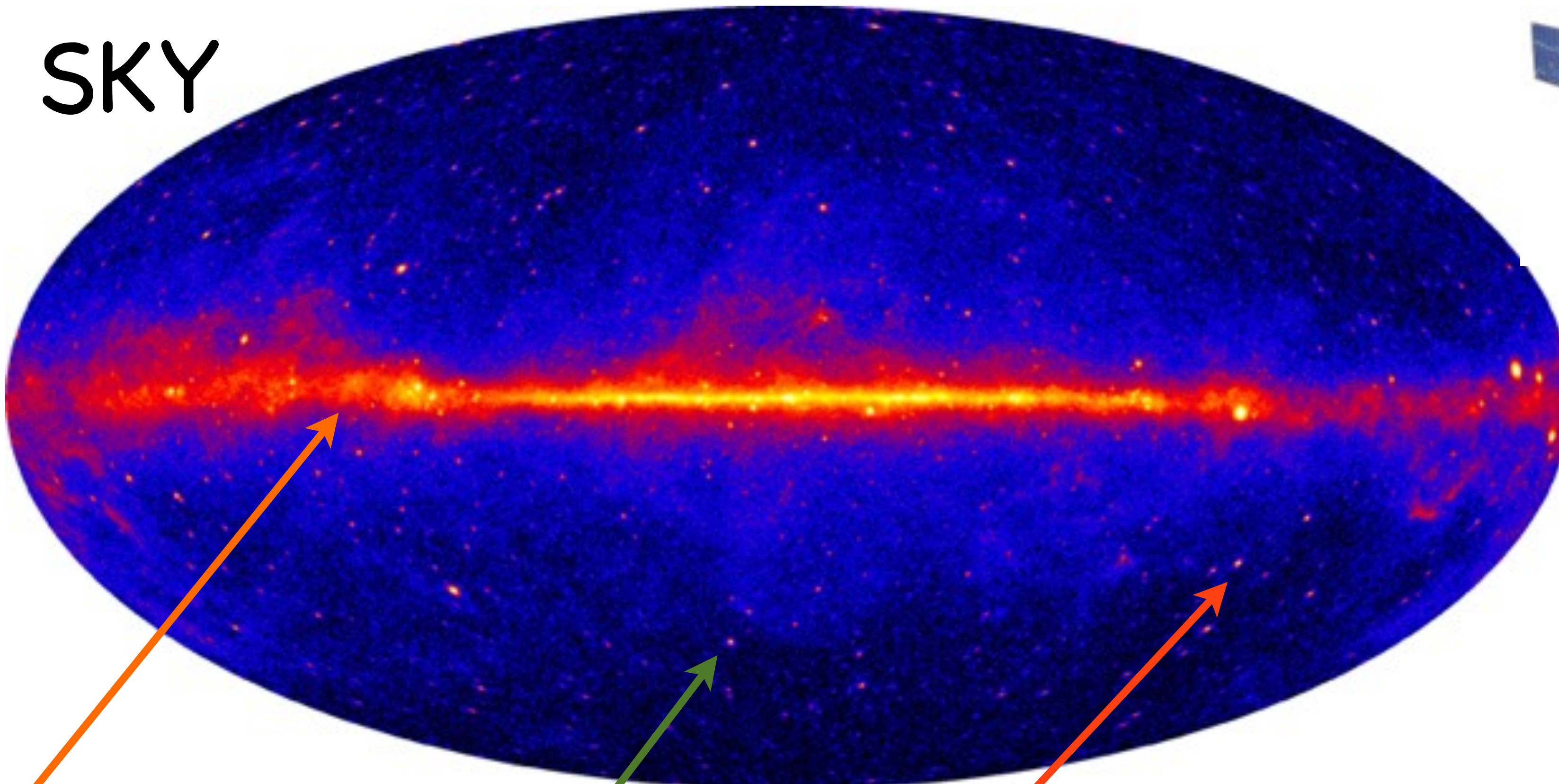
among the most dark matter-dominated galaxies with very low baryonic gas densities, and suppressed star formation rates ->

flux of gamma-rays from individual sources and CRs interacting with local medium is low (small backgrounds in gammas),

thus a "good" target to look for a DM signal in gamma-rays, especially for detectors as the Fermi-LAT, Air-Cherenkov telescopes (Evans,Ferrer&Sarkar 04, Colafrancesco,Profumo,Ullio 07, Strigari, Koushiappas, Bullok, Koplinghat 07, ...)

Gamma-ray Backgrounds

Fermi SKY



Known sources for the observed gamma-rays are:

i)Galactic Diffuse: decay of pi0s (and other mesons) from pp (NN) collisions (CR nuclei inelastic collisions with ISM gas), bremsstrahlung radiation off CR e, Inverse Compton scattering (ICS): up-scattering of CMB and IR, optical photons from CR e

ii)from point sources (galactic or extra galactic) (1873 detected in the first 2 years)

iii)Exragalactic Isotropic

iv)"extended sources"

iv)misidentified CRs (isotropic dew to diffusion of CRs in the Galaxy)

Caveats in dSph analysis

- assumed DM distribution profile? cuspy vs cored.
- Signal for DM annihilation is very small compared to background, and can be easily hidden from it
- One needs to model the background for each dSph in a method that does not allow for many degrees of freedom that could result in hiding a small excess("over-fit")
- Dependence of the method on whether other undetected point sources exist in the region of analysis (Region Of Interest) as has been the case with galaxy clusters
- Avoid low energy gamma-rays (with much higher statistics) dominate the results
- The Fermi LAT instrument has a Point Spread Function that depends strongly on energy (especially at low E)
- CR contamination

J-factors in dSphs

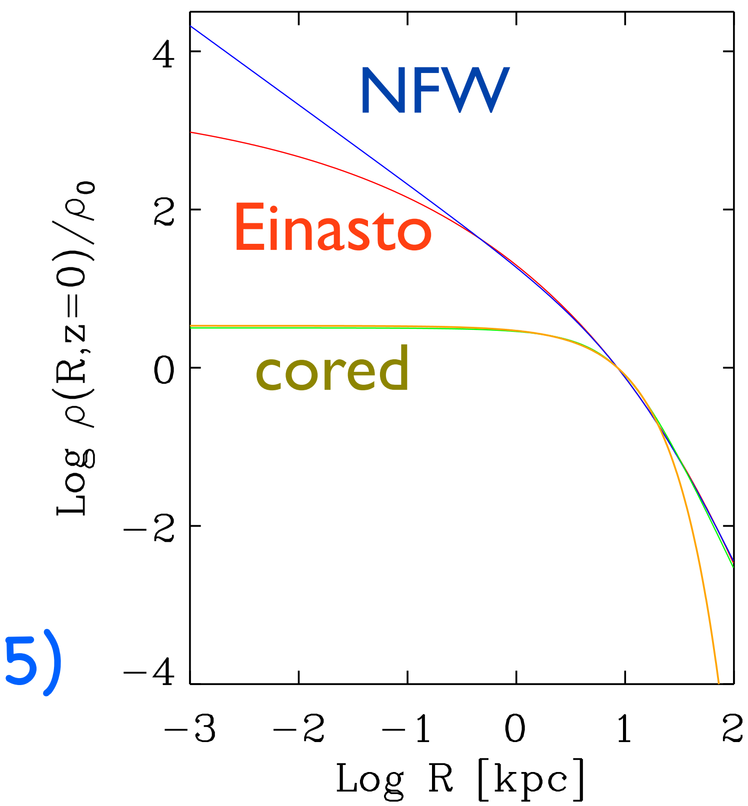
We hope to observe: $$\frac{d\Phi_\gamma}{dE} = \int\int \frac{\langle\sigma v\rangle}{4\pi}\frac{dN_\gamma}{dE}_{DM}\frac{\rho^2_{DM}(l,\Omega)}{2\,m_\chi^2}dl d\Omega$$

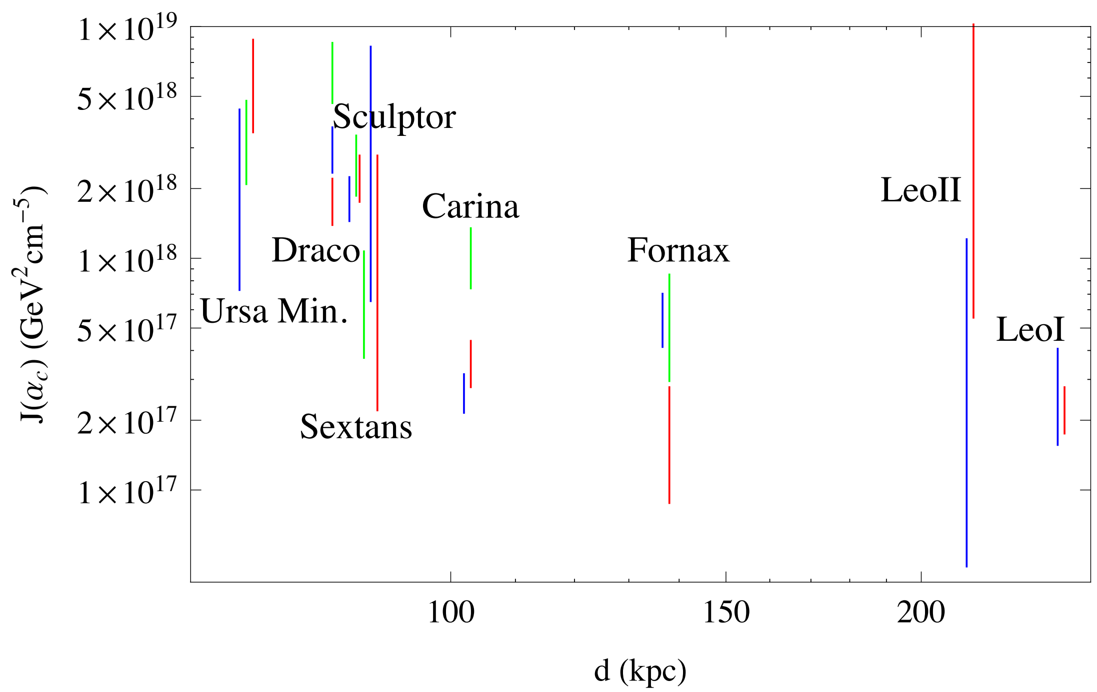
J-factor, gives part in the annihilation rate due the DM distribution

$$J = \int\int \rho^2_{DM}(l,\Omega) dl d\Omega$$

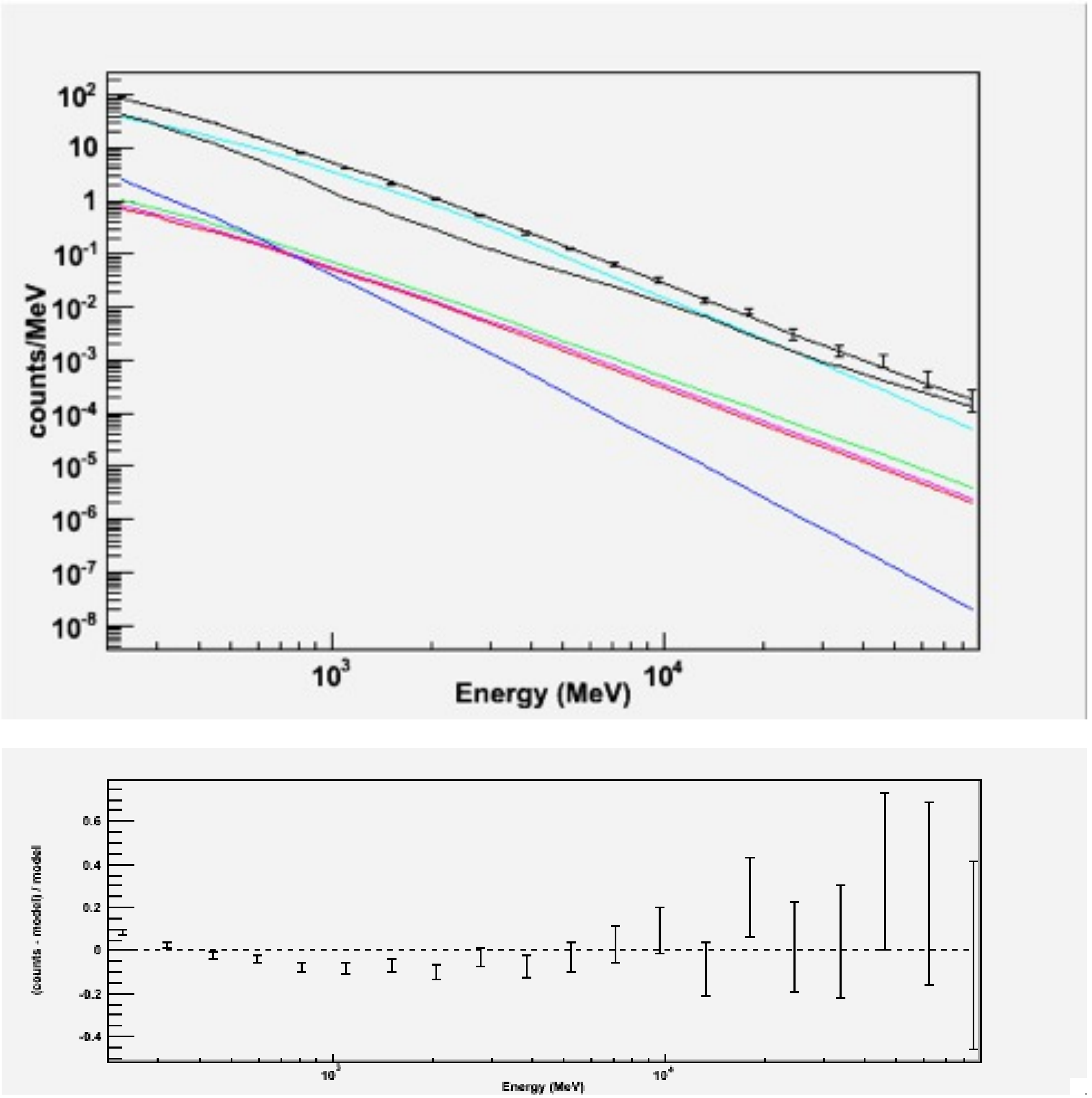
Charbonnier et al. MNRAS 418, 1526(2011)

Fermi Coll. Salucci et al. MNRAS 2012 (arXiv:1111.1165)

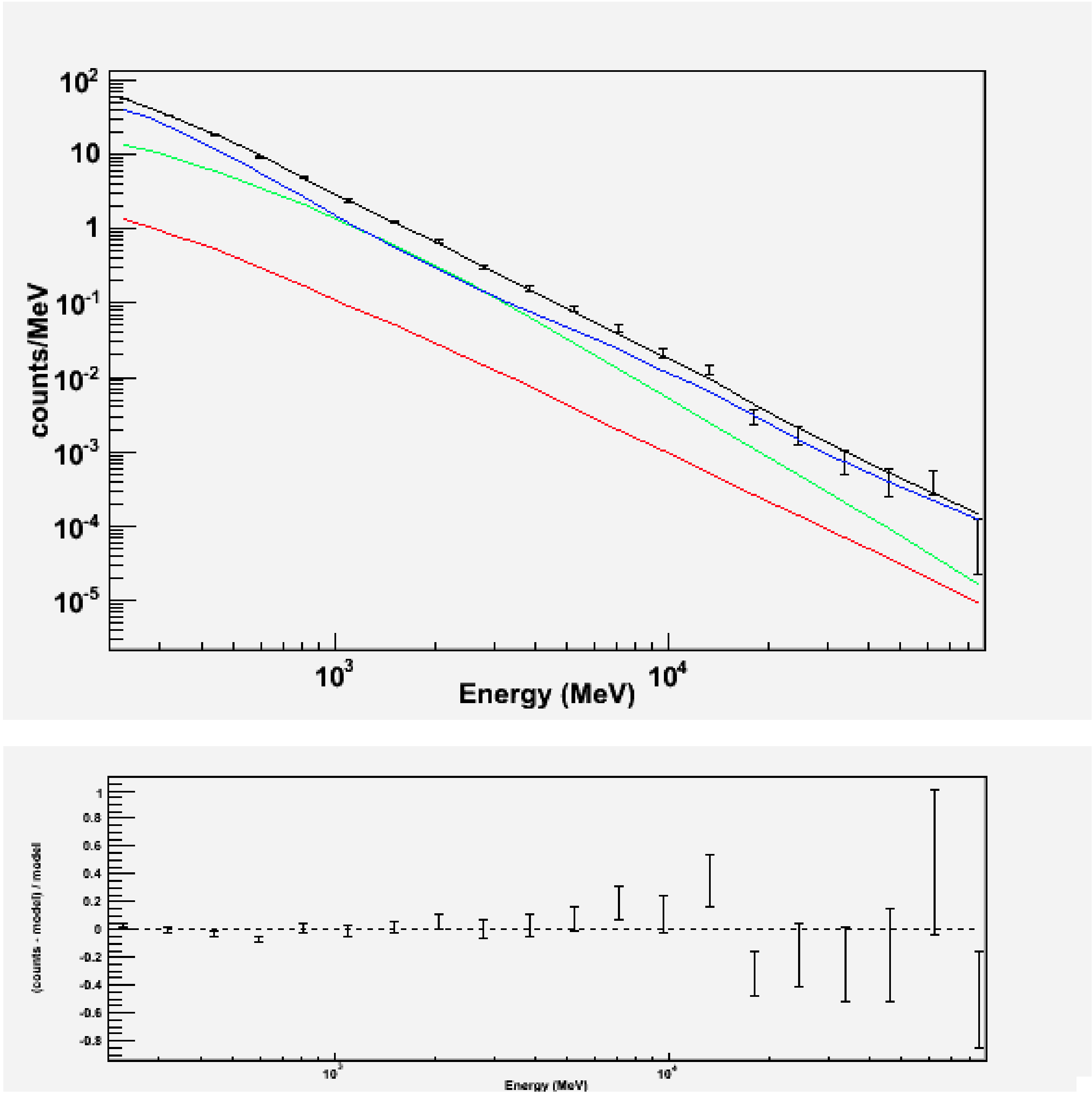




Calculating Residual Spectra (with templates)



Draco

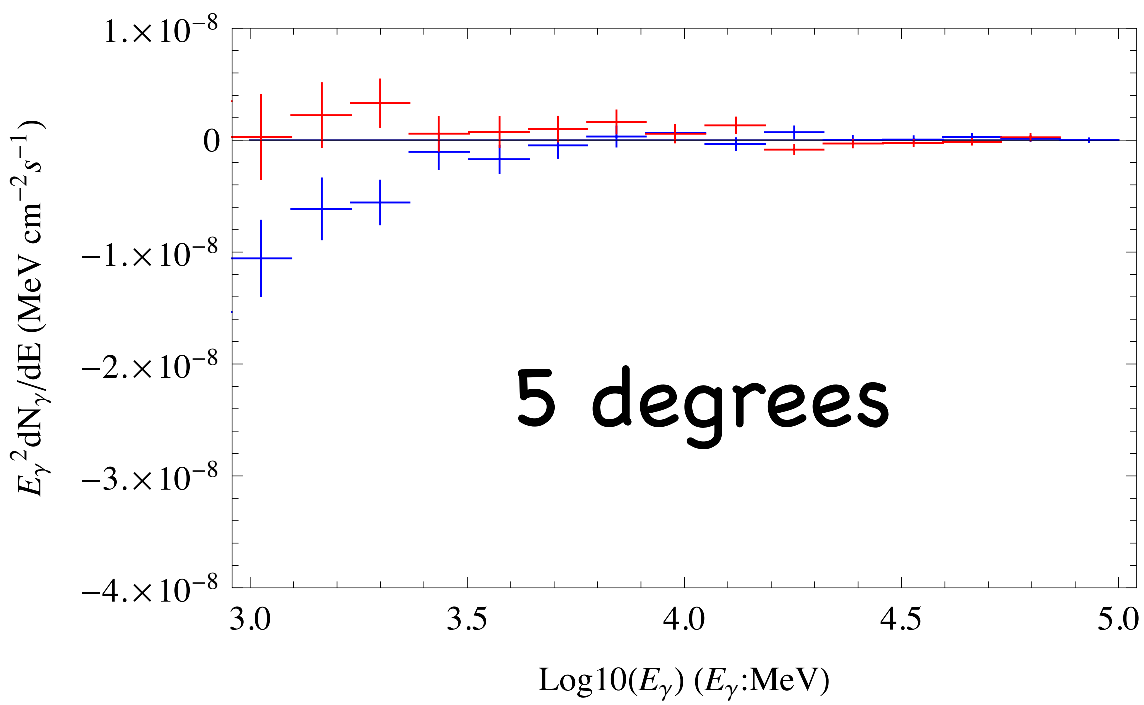


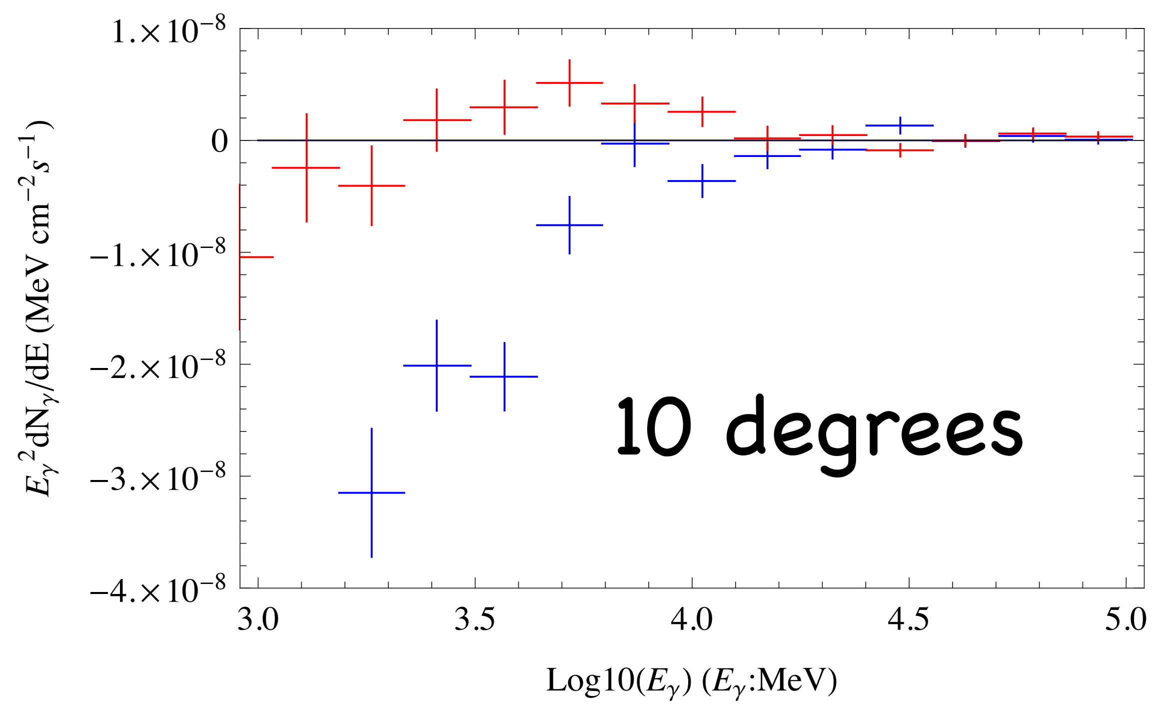
Sculptor

Background model assumptions: Point Sources+galactic diffuse gamma-rays+isotropic diffuse gammas, with free normalizations...

Changing the exact assumptions on the energy range and the size of the "Region of Interest" (window of the sky) that we use to perform the fit, we get sensitively different results for the residual spectra and for parameters describing the background flux.

ROI	E_{min} (MeV)	# of P.S.	N_{GDM}	F_{GDM} ($\times 10^{-4}$)	N_{iso}	F_{iso} ($\times 10^{-4}$)	N_{J1725}	α_{J1725}
5°	200	1 p.s.	1.458 ± 0.041	4.160 ± 0.118	0.830 ± 0.032	0.697 ± 0.028	-	-
5°	200	4 p.s.	1.403 ± 0.042	4.001 ± 0.121	0.803 ± 0.036	0.674 ± 0.030	4.00 ± 0.58	-2.526 ± 0.14
10°	200	1 p.s.	1.574 ± 0.021	4.489 ± 0.060	0.795 ± 0.016	0.669 ± 0.014	-	-
10°	200	10 p.s.	1.426 ± 0.021	4.068 ± 0.060	0.781 ± 0.017	0.655 ± 0.014	4.12 ± 0.59	-2.31 ± 0.14
10°	200	15 p.s.	1.406 ± 0.007	4.012 ± 0.020	0.775 ± 0.005	0.650 ± 0.005	4.00 ± 0.43	-2.25 ± 0.10
10°	100	1 p.s.	1.582 ± 0.017	7.617 ± 0.084	0.903 ± 0.011	1.871 ± 0.022	-	-
10°	100	10 p.s.	1.462 ± 0.018	7.058 ± 0.086	0.871 ± 0.012	1.804 ± 0.024	3.49 ± 0.53	-2.40 ± 0.16
10°	100	15 p.s.	1.474 ± 0.018	7.120 ± 0.087	0.842 ± 0.014	1.744 ± 0.029	3.29 ± 0.58	-2.19 ± 0.17
5°	200	4 p.s.	1.192 ± 0.018	3.401 ± 0.052	1.000 ± 0.000	0.839 ± 0.000	3.69 ± 0.58	-2.12 ± 0.13
10°	200	15 p.s.	1.157 ± 0.003	3.301 ± 0.008	1.000 ± 0.000	0.839 ± 0.000	3.70 ± 0.21	-2.10 ± 0.04
10°	100	15 p.s.	1.274 ± 0.009	6.150 ± 0.043	1.000 ± 0.000	2.071 ± 0.000	3.03 ± 0.57	-2.02 ± 0.14

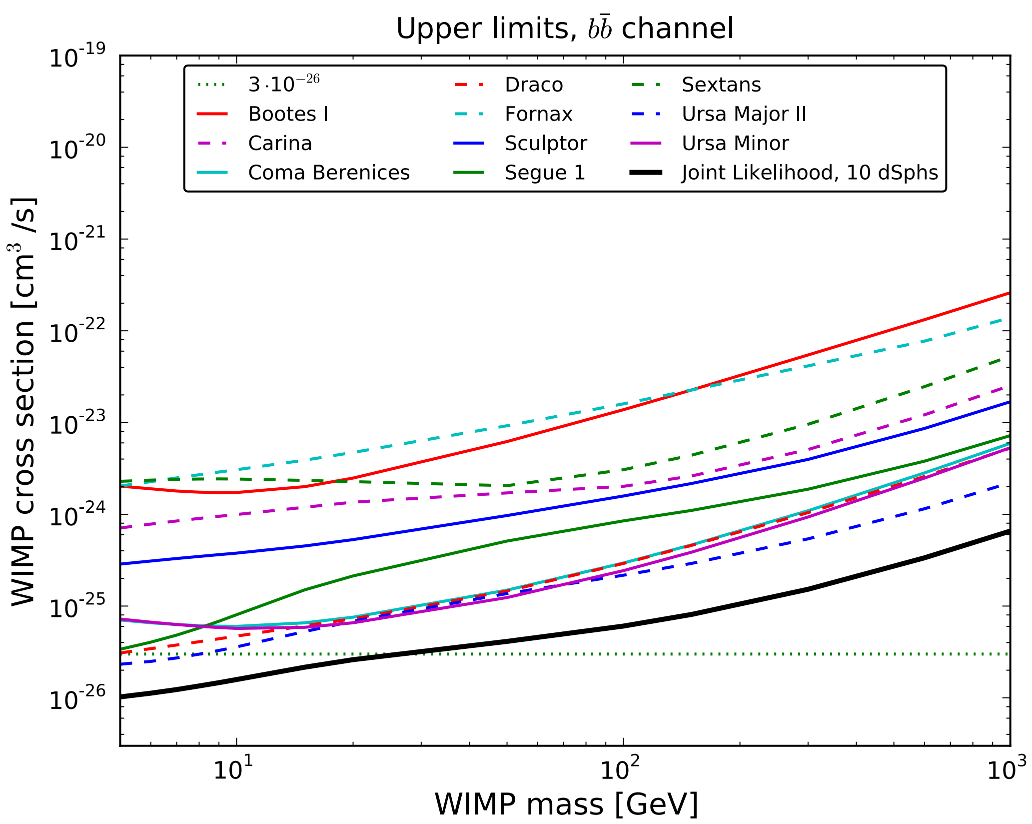


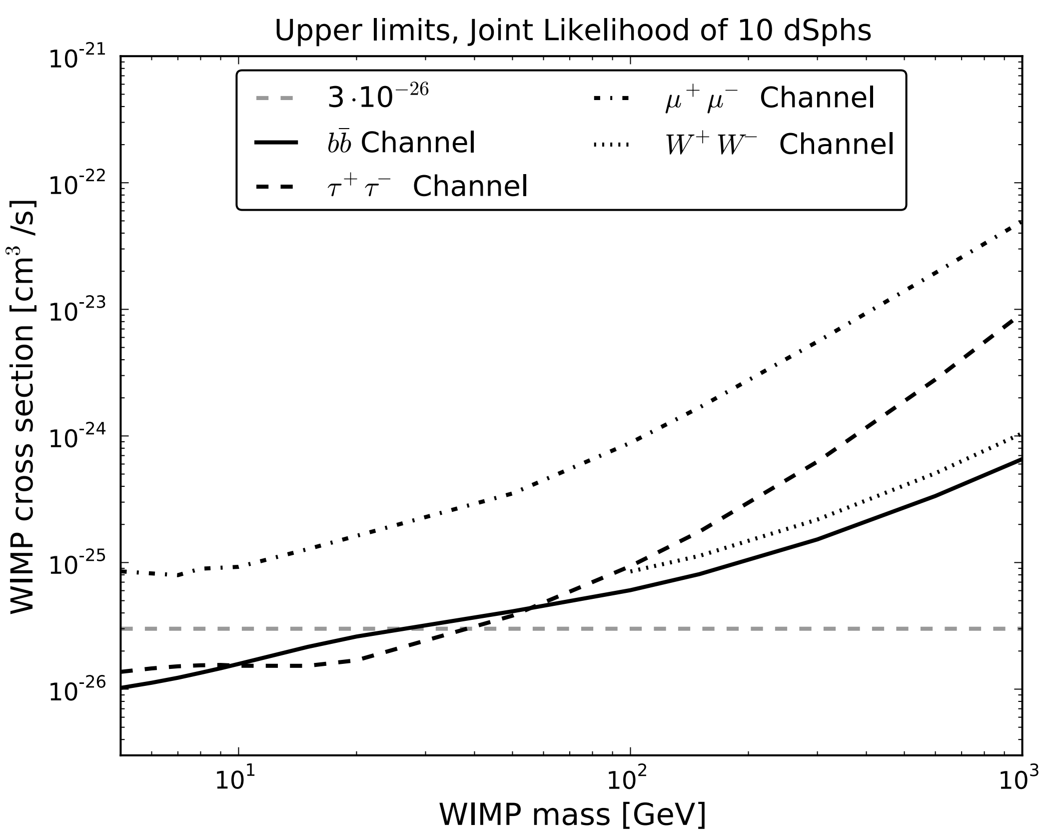


Different residual spectra result also in different limits on DM annihilation.

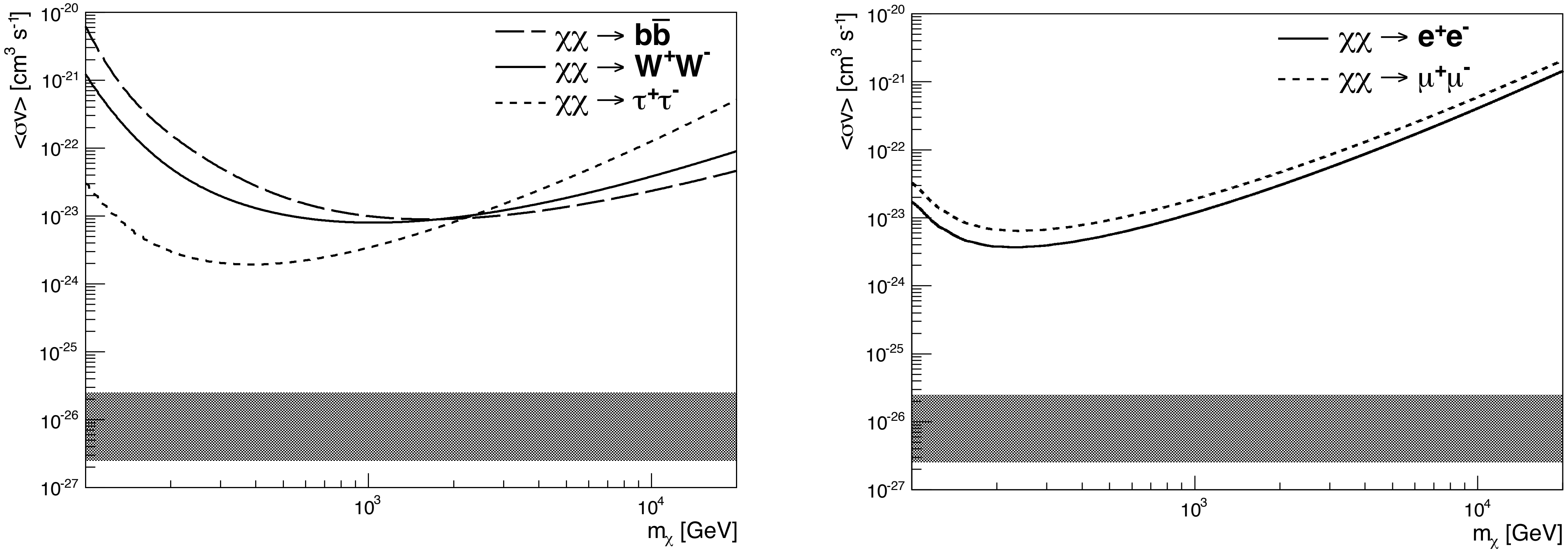
Limits from Dwarf Spheroidal galaxies

Fermi Collaboration:Phys.Rev. Lett.107,241302 (arXiv:1108.3546): For specific choice of spectrum of data, and ROI but for free normalizations on templates

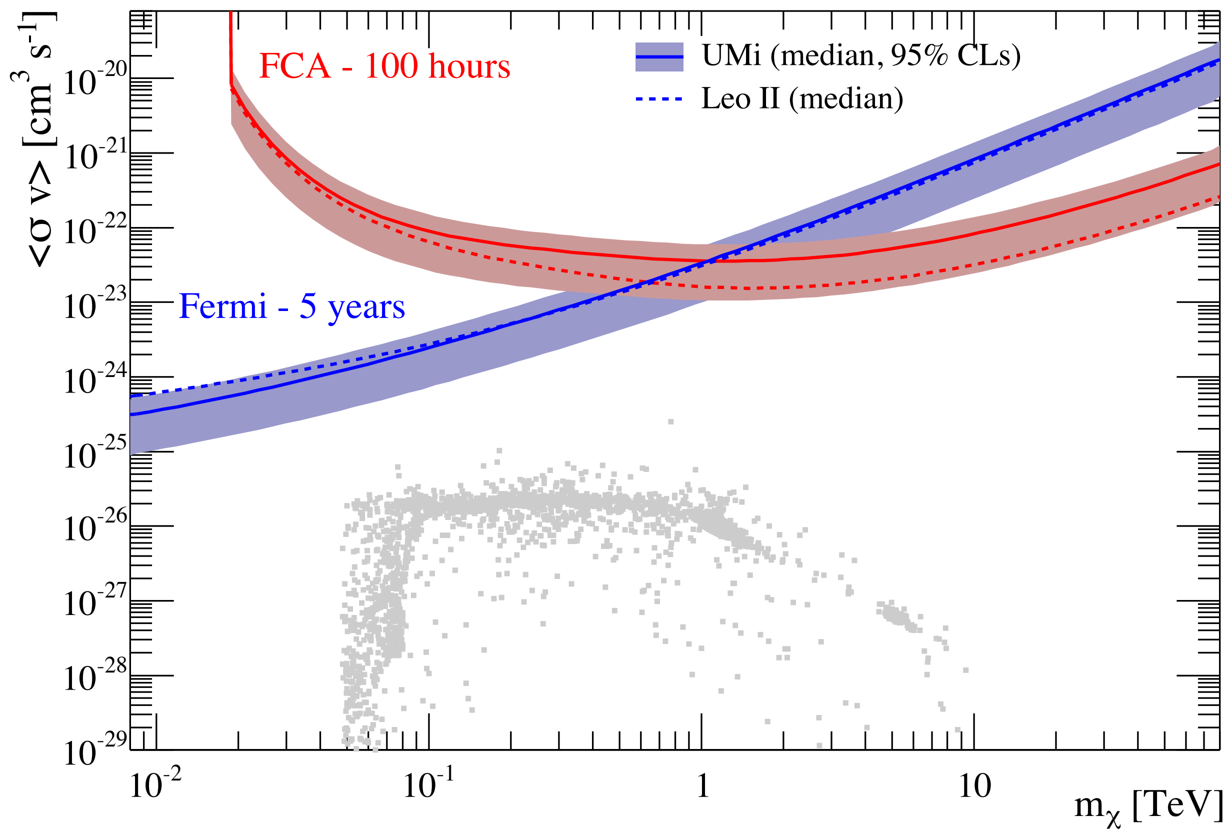




Using known dSphs calculated strong limits on DM annihilation, from various targets and for various annihilation channels



VERITAS, PhysRevD 85 06001 (2012)



Charbonnier et al. MNRAS 418, 1526(2011)

Alternative Methods, to calculate the residual spectra

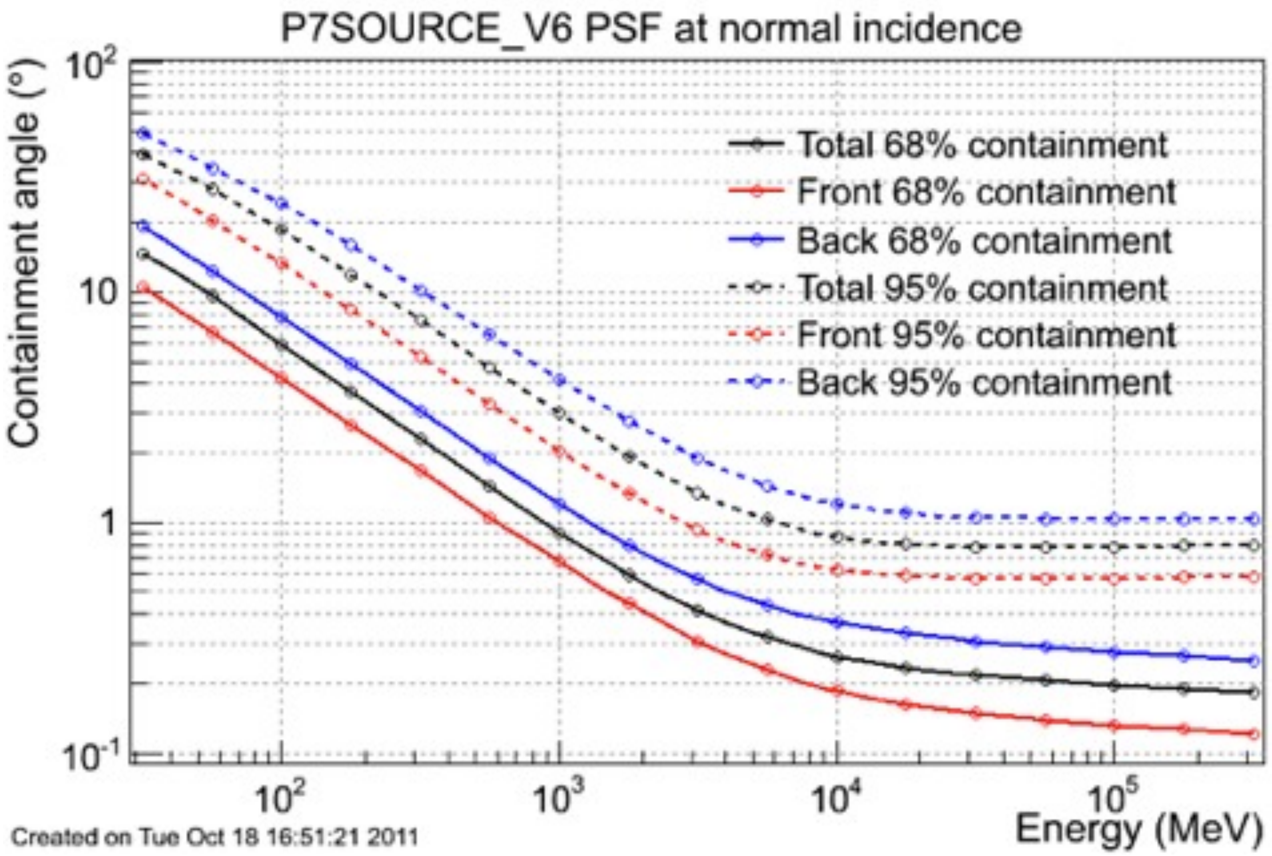
Fermi LAT PSF strong dependence on energy(especially at lower E):

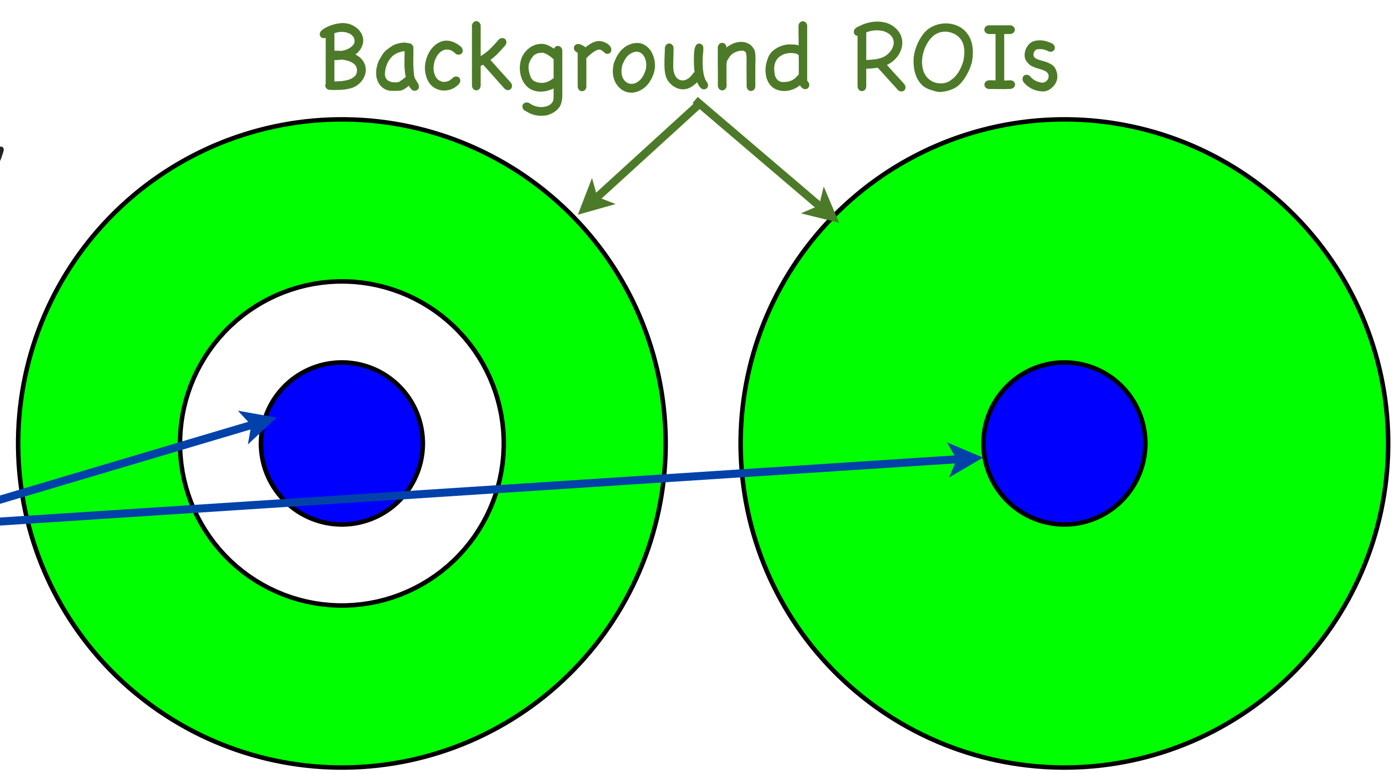
We need to take the PSF(E) into account.

Need to avoid too many dof for the background.

Avoid low Energies (where background gamma-ray sources dominate) to affect too much our results on DM.

Isotropic gammas (+CR cont.) are dominant at high latitudes where many dSphs lay



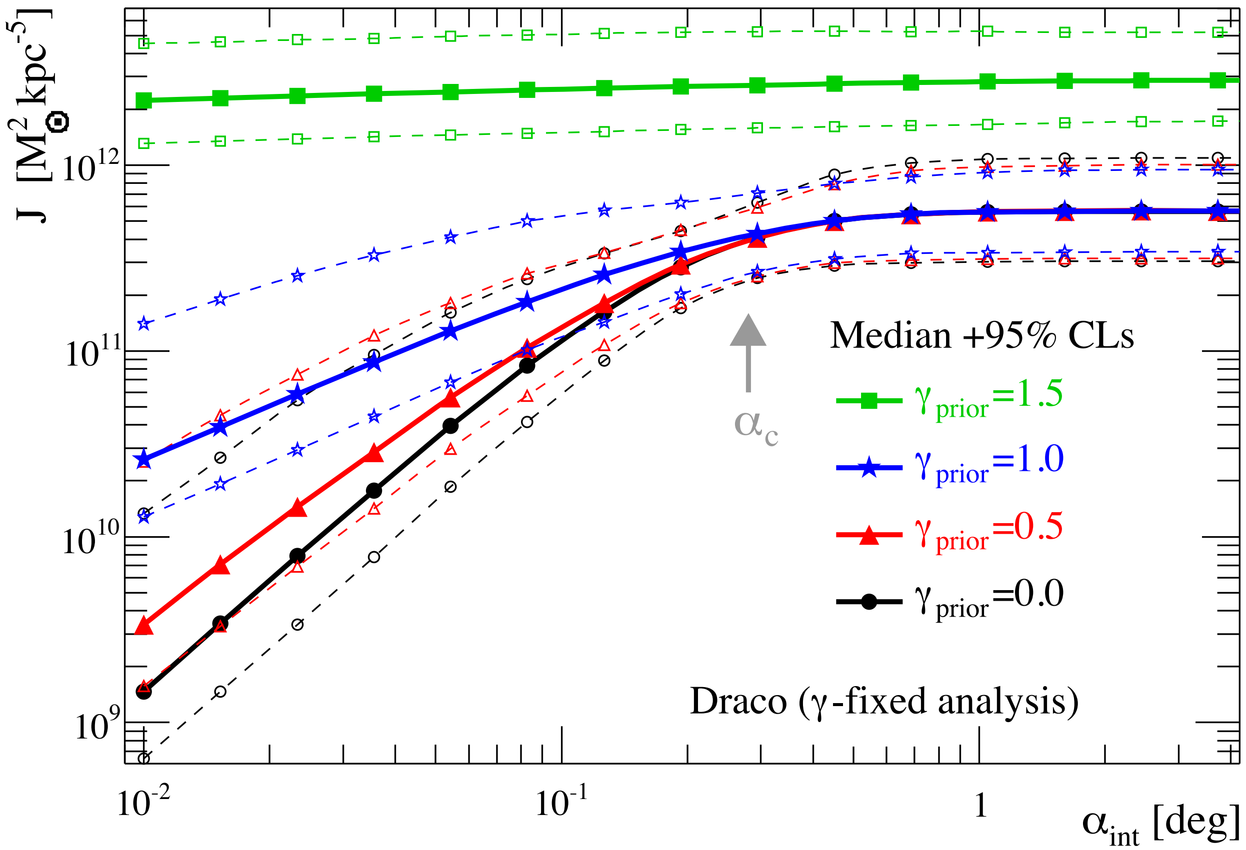


Size criteria for Regions of Interest

Use for the Signal ROI (inner disk) either "optimal integration angle" or the PSF angle depending on which one is larger.

$$\alpha_c = \frac{2\overline{r_{half}}}{D}$$

See consistency of results for variations of signal/background ROI sizes.



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dSph	D (kpc)	δD (kpc)	l	b	$\overline{J} \times 10^{17}$ $(GeV^2 cm^{-5})$	$\delta J_{high} \times 10^{17}$ $(GeV^2 cm^{-5})$	$\delta J_{low} \times 10^{17}$ $(GeV^2 cm^{-5})$	α_c
Carina	103	4	260.1	-22.2	2.69	0.47	0.54	0.27°
Draco	84	8	86.4	34.7	29.2	7.52	5.84	0.27°
Fornax	138	9	237.1	-65.7	5.66	1.38	1.51	0.56°
LeoI	247	19	226.0	49.1	3.07	1.00	1.51	0.11°
LeoII	216	9	220.2	67.2	3.98	8.11	3.52	0.08°
Sculptor	87	5	287.5	-83.2	18.3	4.08	3.85	0.42°
Sextans	88	4	243.5	42.3	23.6	58.3	17.2	0.89°
Ursa Minor	74	12	105.0	44.8	25.0	18.9	17.7	0.49°

Since the ROIs depend on energy so should the J-factors, be varying with the observing ENERGY

$$\left.\frac{d\Phi_\gamma}{dE}^{i}\right._{DMdSph} = \frac{\langle\sigma v\rangle}{4\pi}\left.\frac{dN_\gamma}{dE}\right._{DM}\frac{J^i}{2\,m_\chi^2}$$

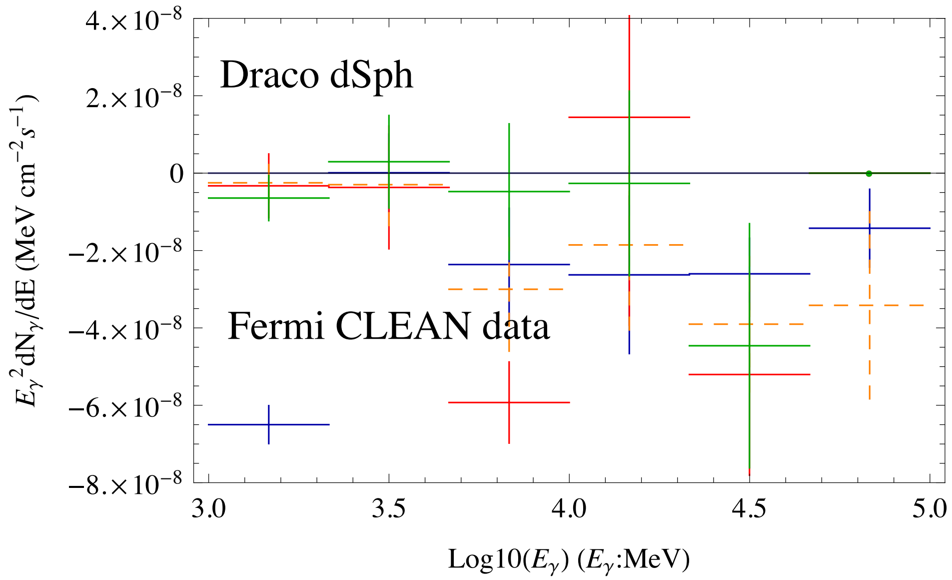
$$J^i = \int\int dl d\Omega^i \rho^2_{DM}(l,\Omega)$$

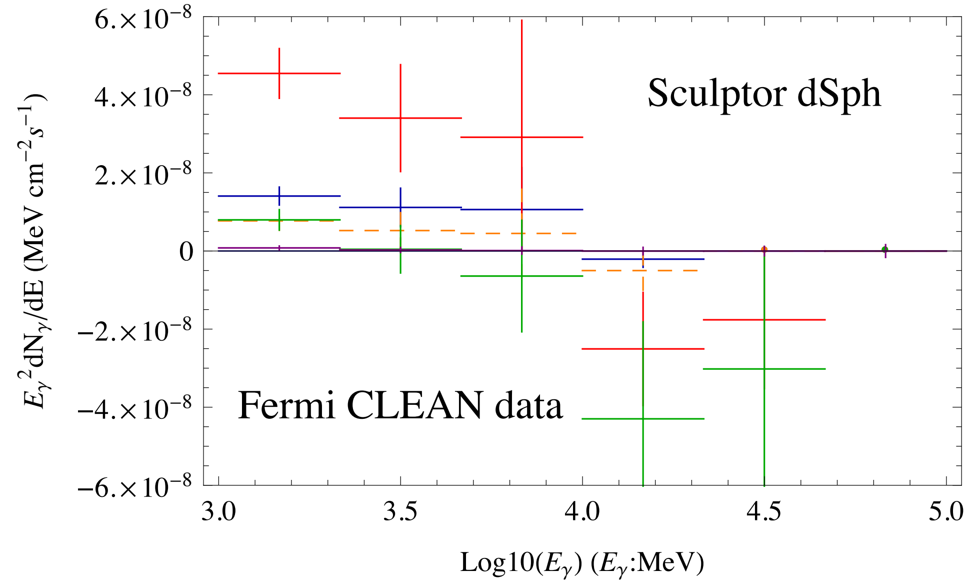
Draco case:

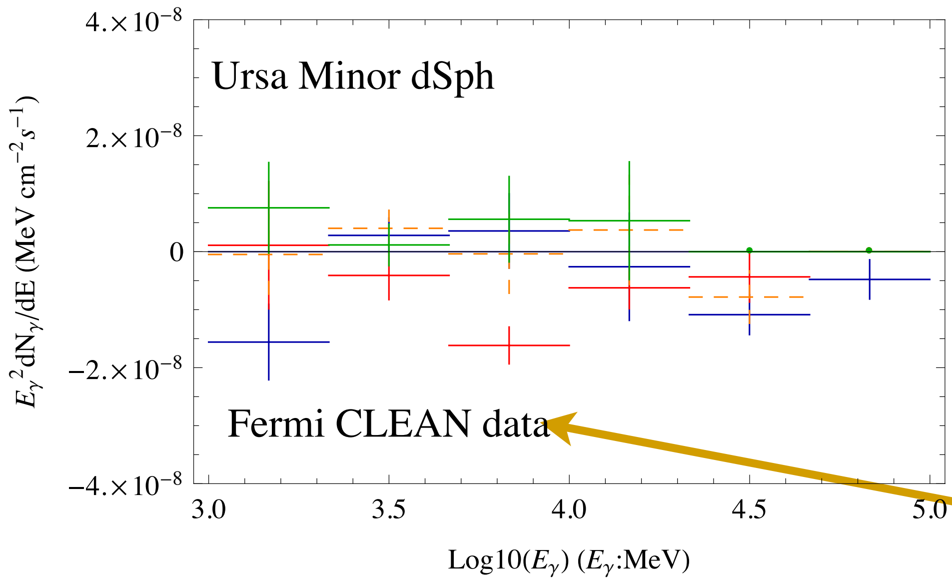
$\overline{J} \times 10^{17}$ (GeV^2cm^{-5})	$\delta J_{upp} \times 10^{17}$ (GeV^2cm^{-5})	$\delta J_{low} \times 10^{17}$ (GeV^2cm^{-5})	α
74.4	45.8	33.8	2.50°
72.7	39.6	32.3	1.50°
69.0	29.5	29.3	1.00°
65.3	22.3	26.3	0.80°
51.7	9.70	16.4	0.48°
29.2	7.52	5.84	0.27°

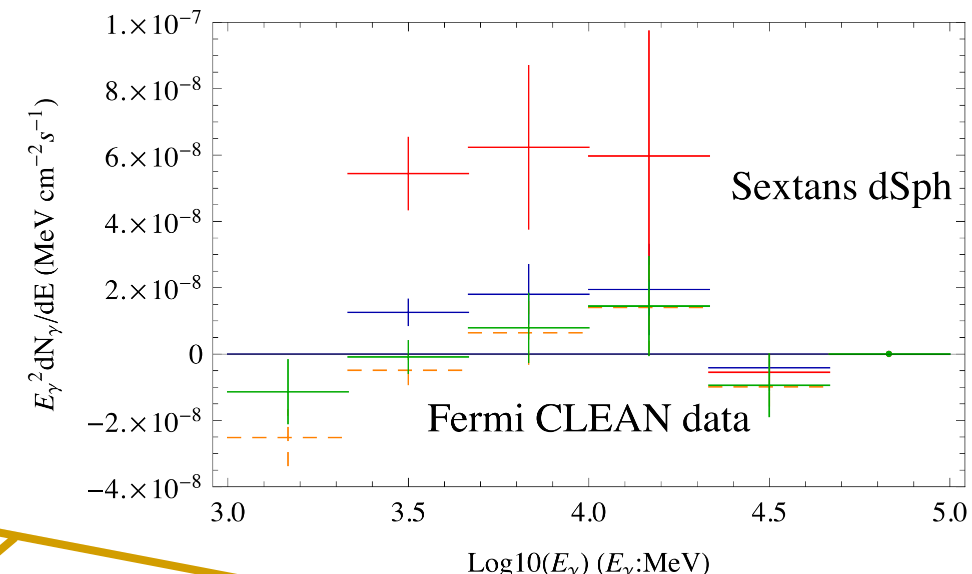
The difference in the J-factors mean values is of the order of 50% between different energy bins

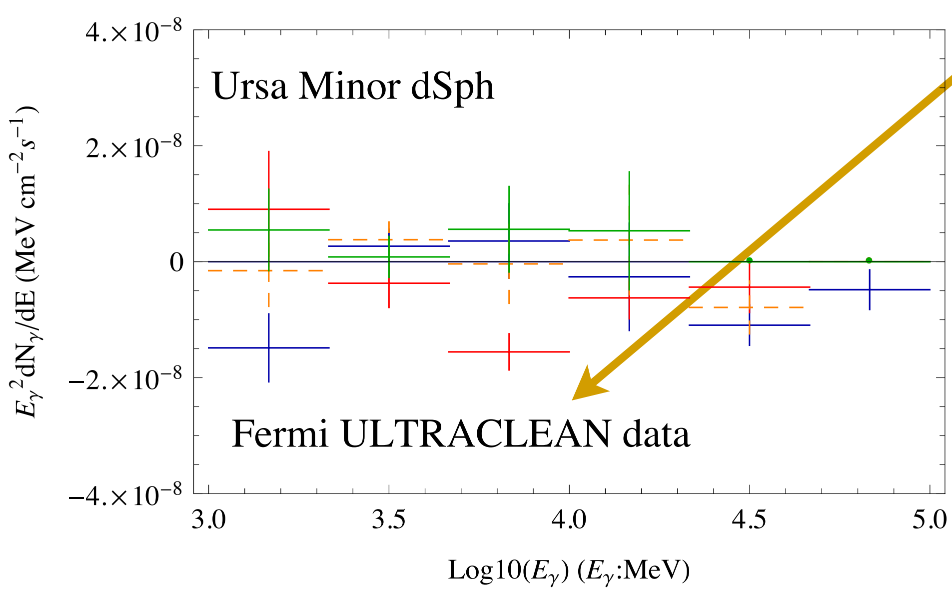
Evaluate Residual Spectra from various methods (different choices for ROI(E))







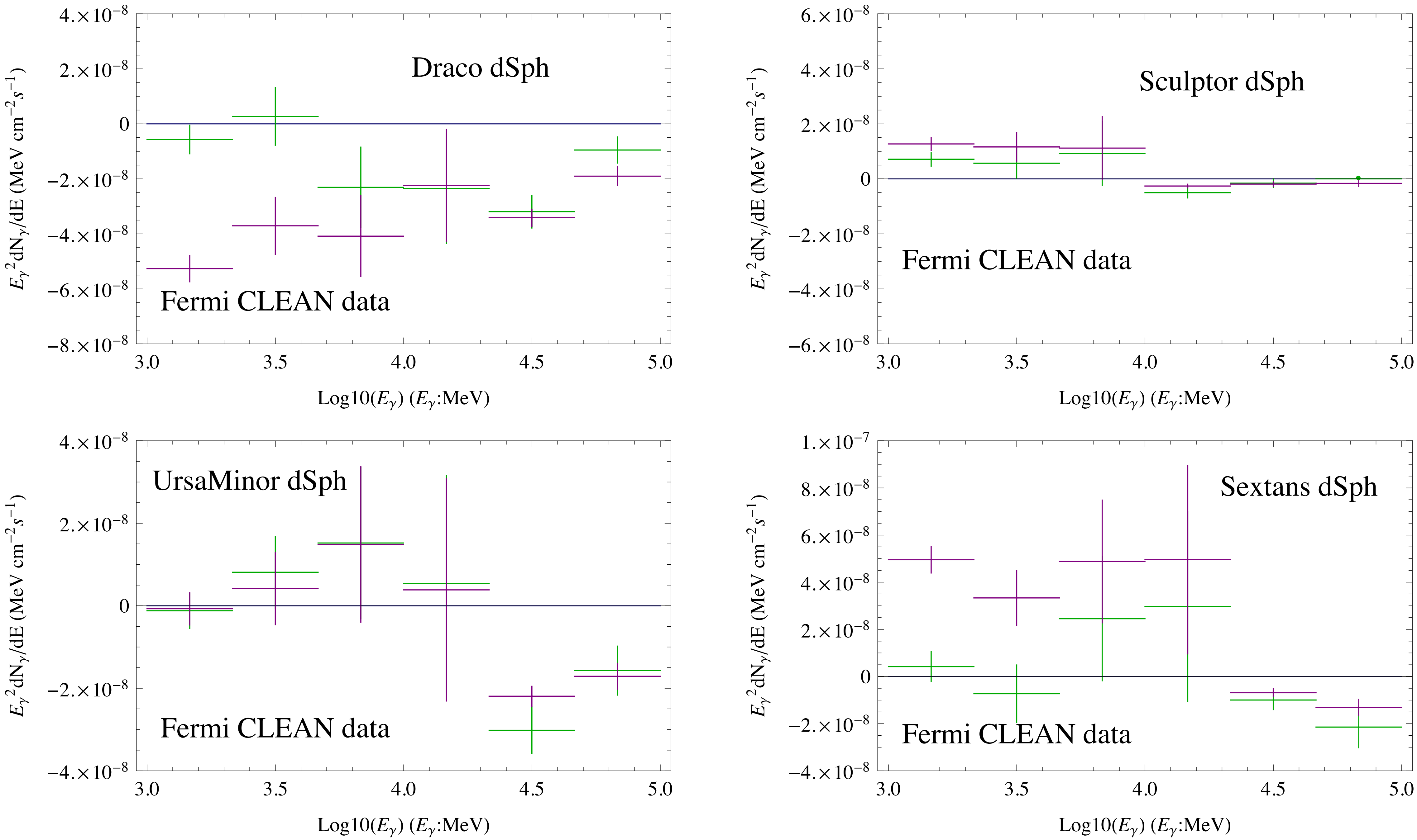




Check among different event classes of Fermi data

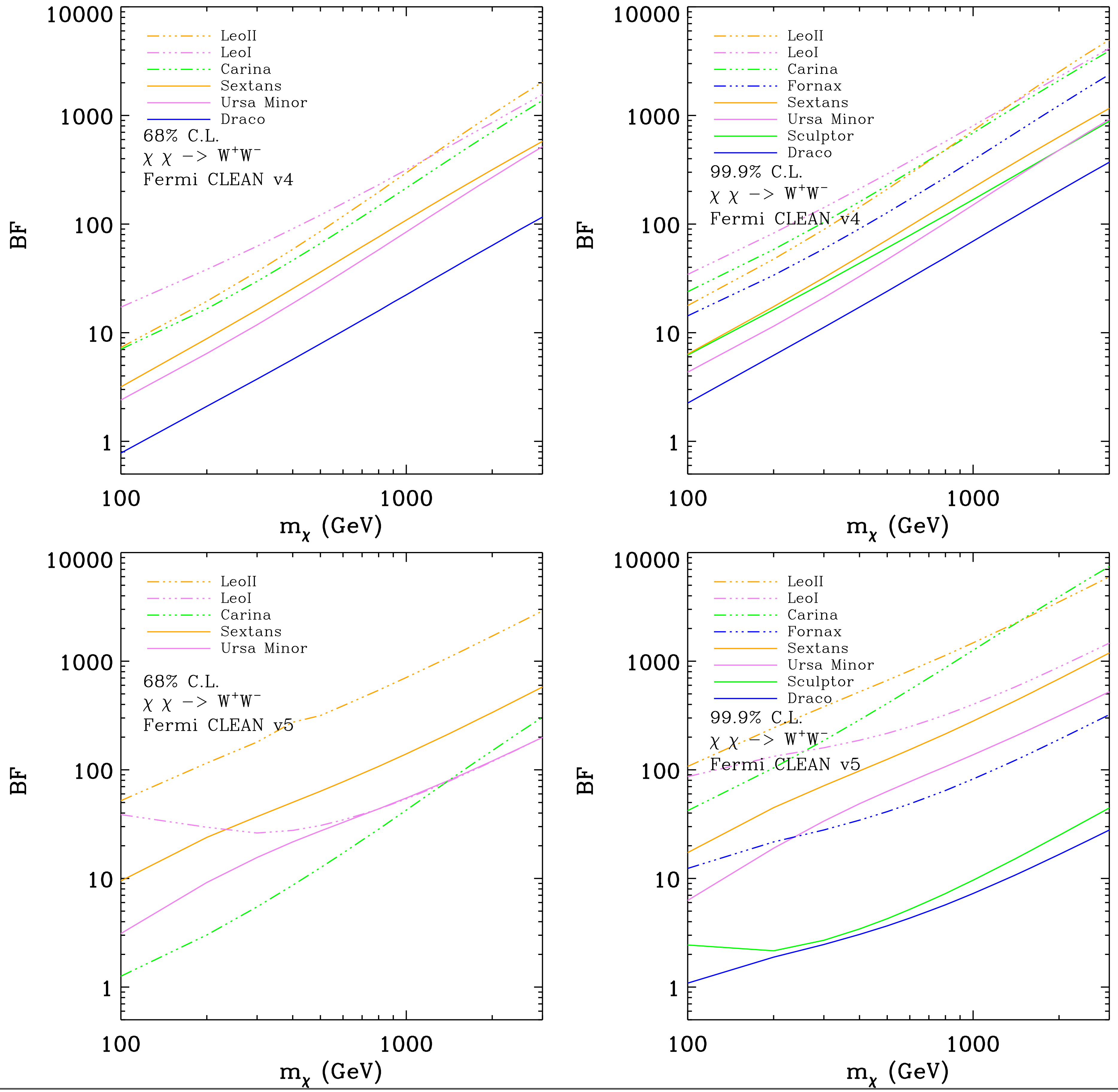
For Some dSphs there is simply too much scatter of the residual spectra (e.g. Draco), while for other dSphs (e.g. Sextans Ursa Minor) there is better agreement between the various methods

Further alternative methods:



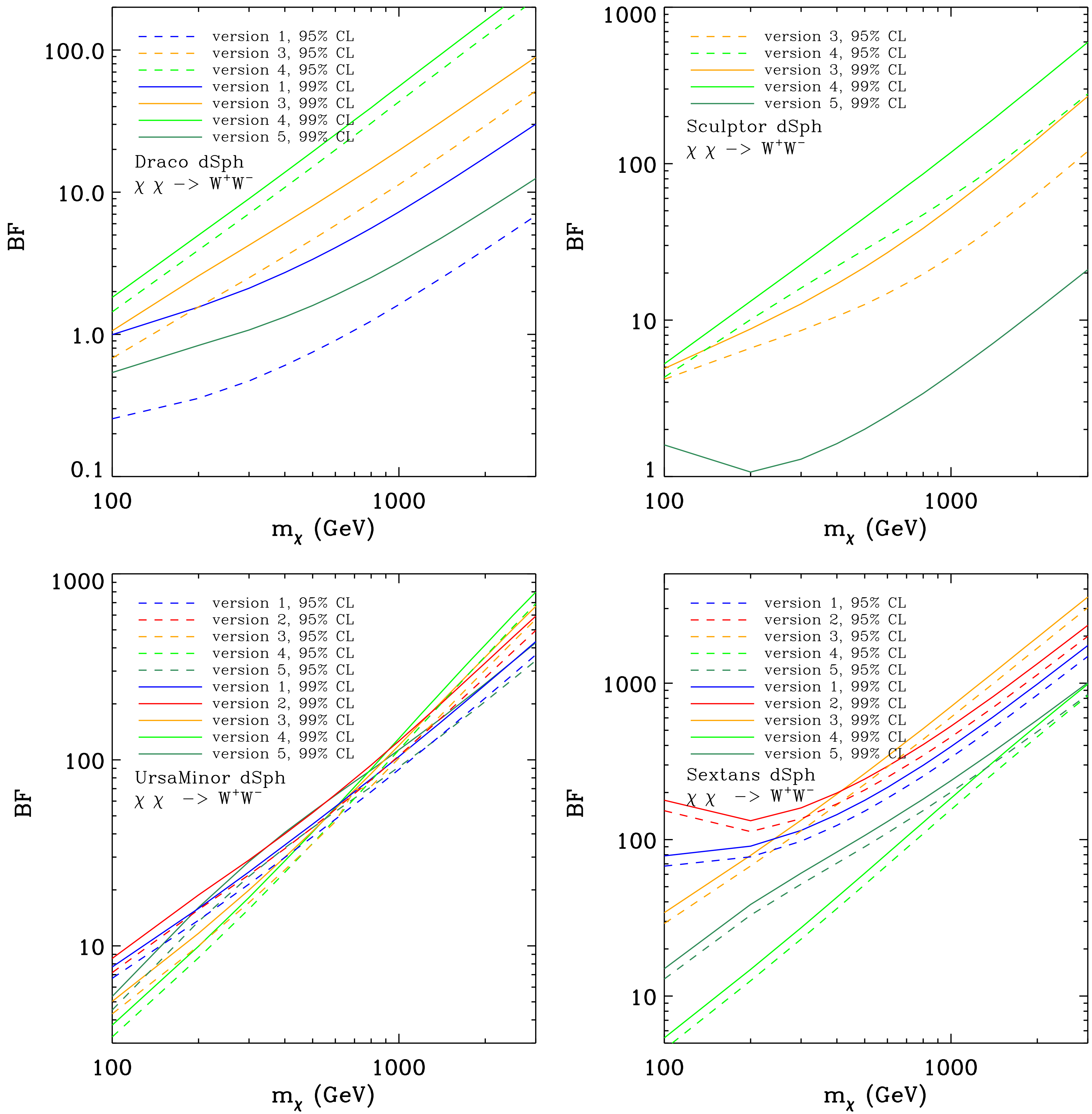
Based on arguments of proximity of background ROI to the signal ROIs, avoiding too low statistics, having too many point sources in the ROIs (that dominate at low E), we choose preferable ROIs versions (i.e. residual spectra)

DM annihilation limits from different dSphs



$$BF = \frac{\langle \sigma \mid v \mid \rangle_{fit}}{3 \times 10^{-26} cm^3 s^{-1}}$$

Consistency/Robustness of limits

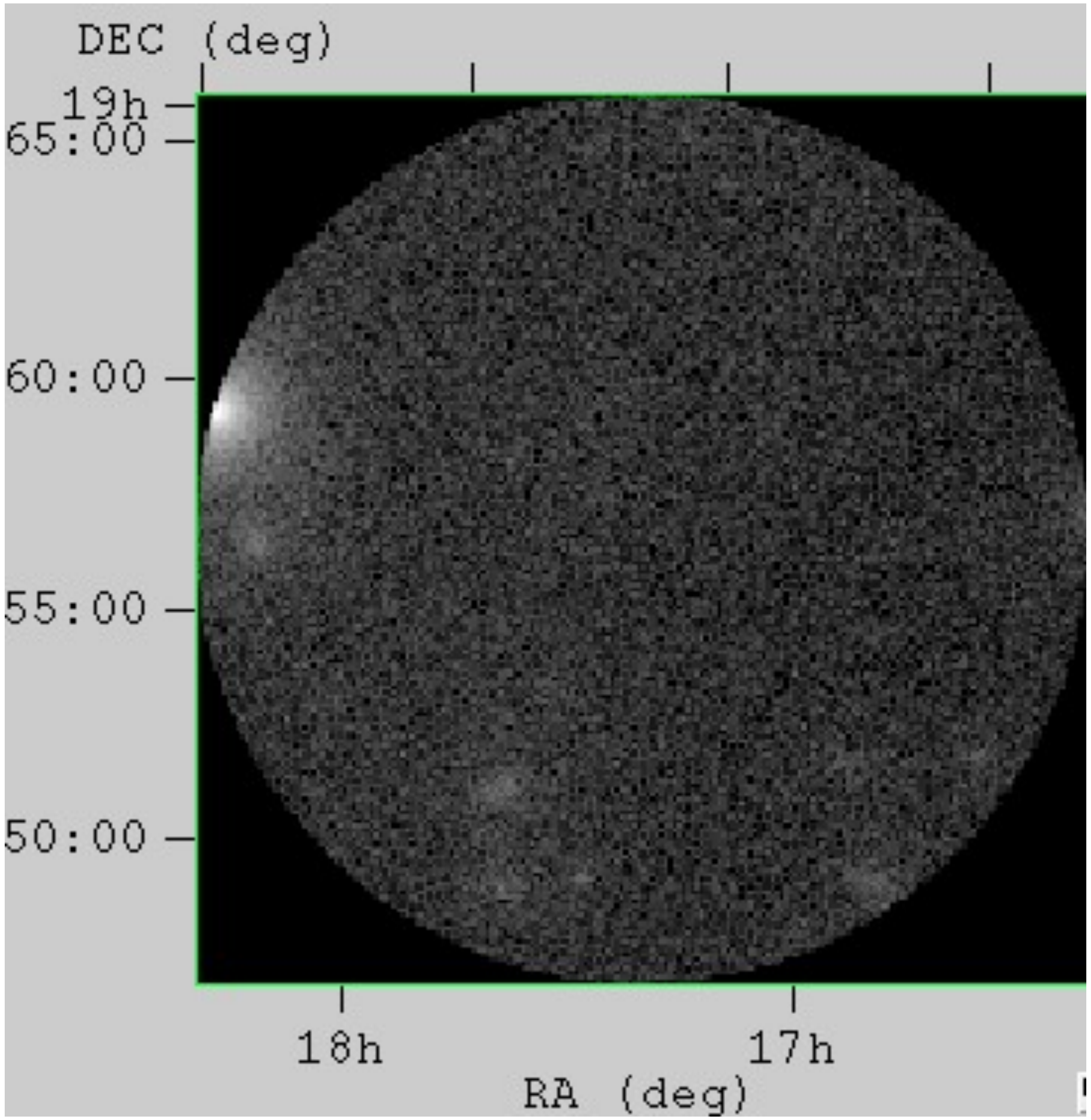


Not all targets can give equally robust limits. How well do we understand the background?

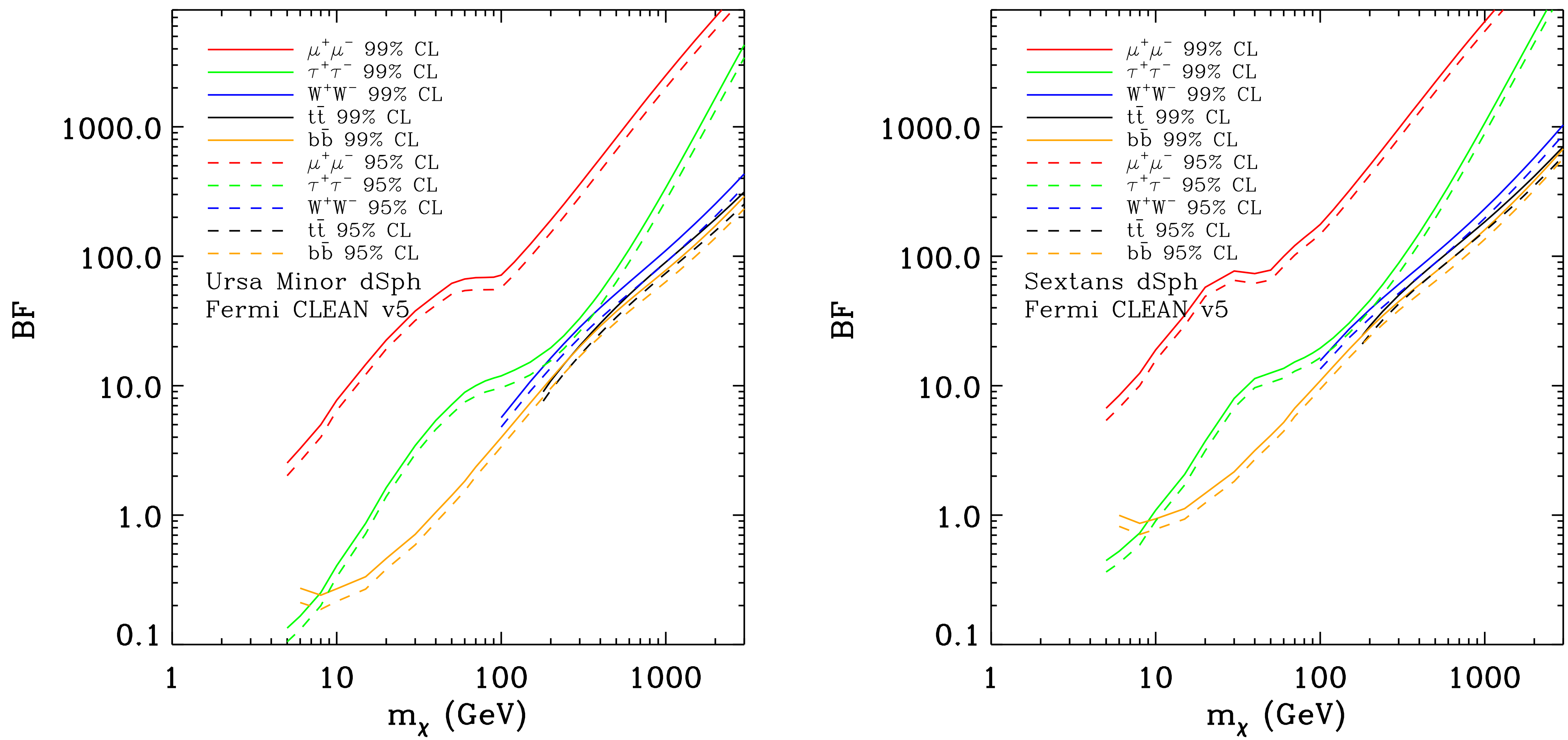
Some point source(s) and/or some gas structure in the galactic diffuse component that is inside the window of observation can have strong influence on the residual spectra calculation -> DM limits.

Ursa Minor is the best case to set robust and tight limits on DM annihilation.

Draco



Our Limits



Our limits for Ursa Minor are tighter than Fermi Coll. by a factor of 2-4 (which is though within our uncertainty in setting these limits), but about the same to a factor of 4 less strong than the combined analysis limits (which considers all dSphs and their backgrounds equally well understood/modeled).

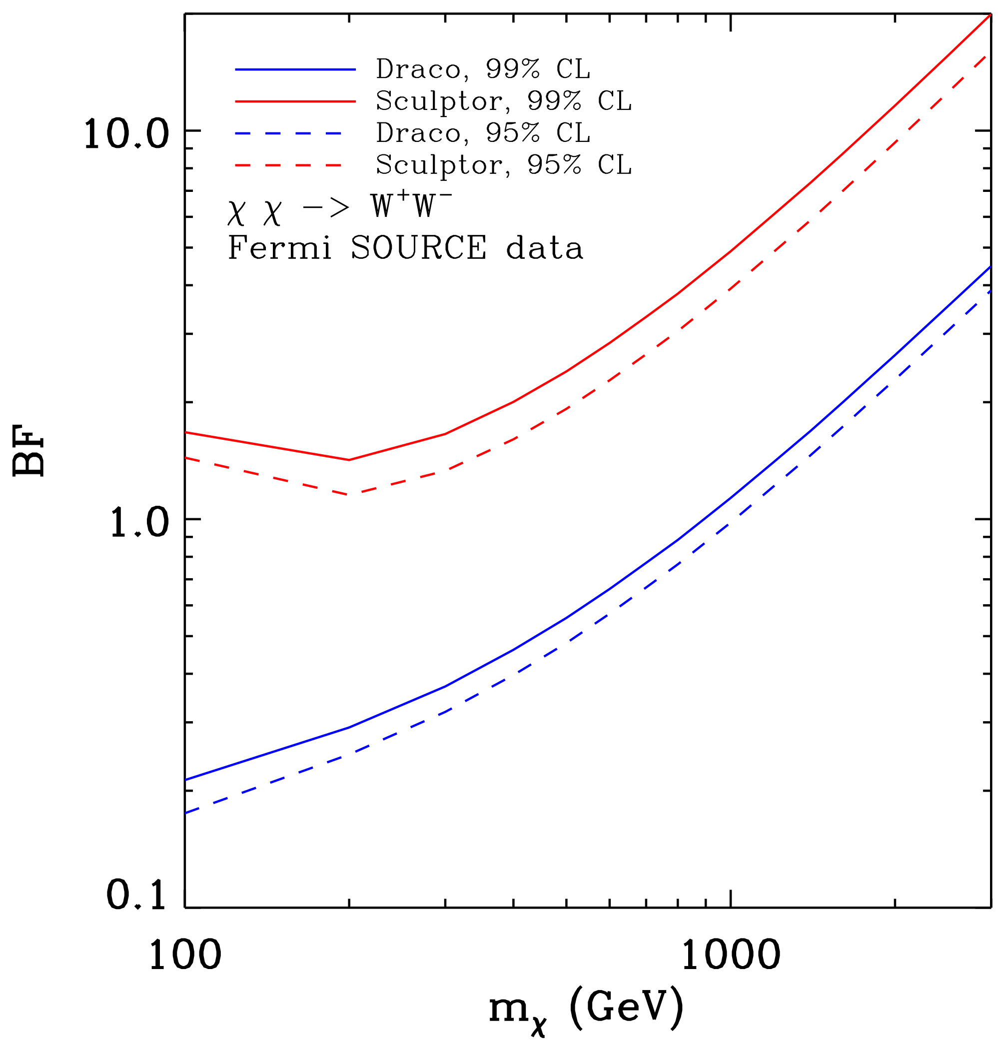
Conclusions

- There is a garden variety of possible signals from DM annihilation or decay even just in the gamma-rays(not including other indirect detection probes or direct or colliders)
- Dwarf Spheroidal galaxies have been suggested to give the strongest constraints among the gamma-ray search regions (GC, GR, high latitudes, intermediate latitudes, dSphs, clusters)
- For dSph galaxies Caveats originating either from background assumptions or form the assumptions on the DM distribution (main halo profiles) or the DM model(s) considered (DM mass/ annihilation channel, annihilation cross-section)
- Need to study dSphs case by case. Few dSphs are indeed "clean" to get robust limits (Ursa Minor)
- Expect more results from including more dSphs into the analysis (Ursa Major I, Segue I). Also as data accumulate form the Fermi LAT instrument and also Air Cherenkov Telescope Arrays (HESS, VERITAS, MAGIC)

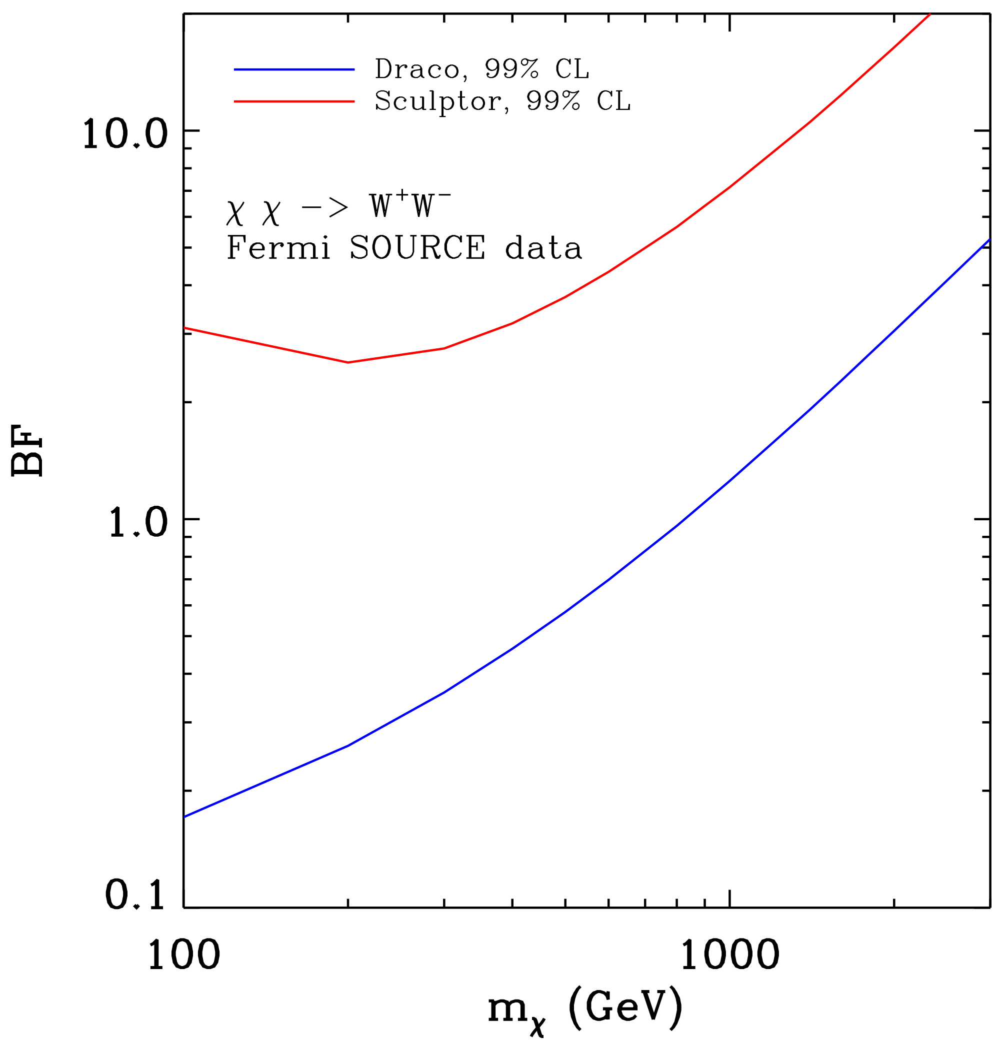
Thank you

Additional slides

Different residual spectra result also in different limits on DM annihilation:



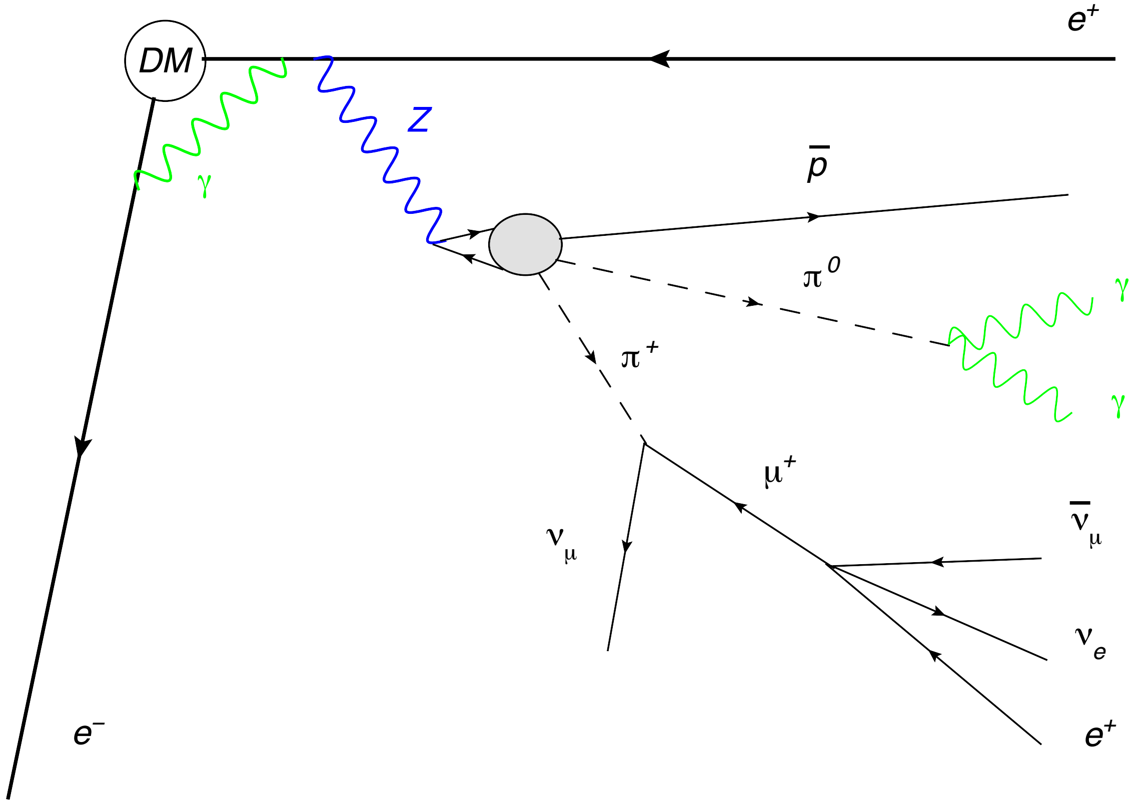
5 degrees

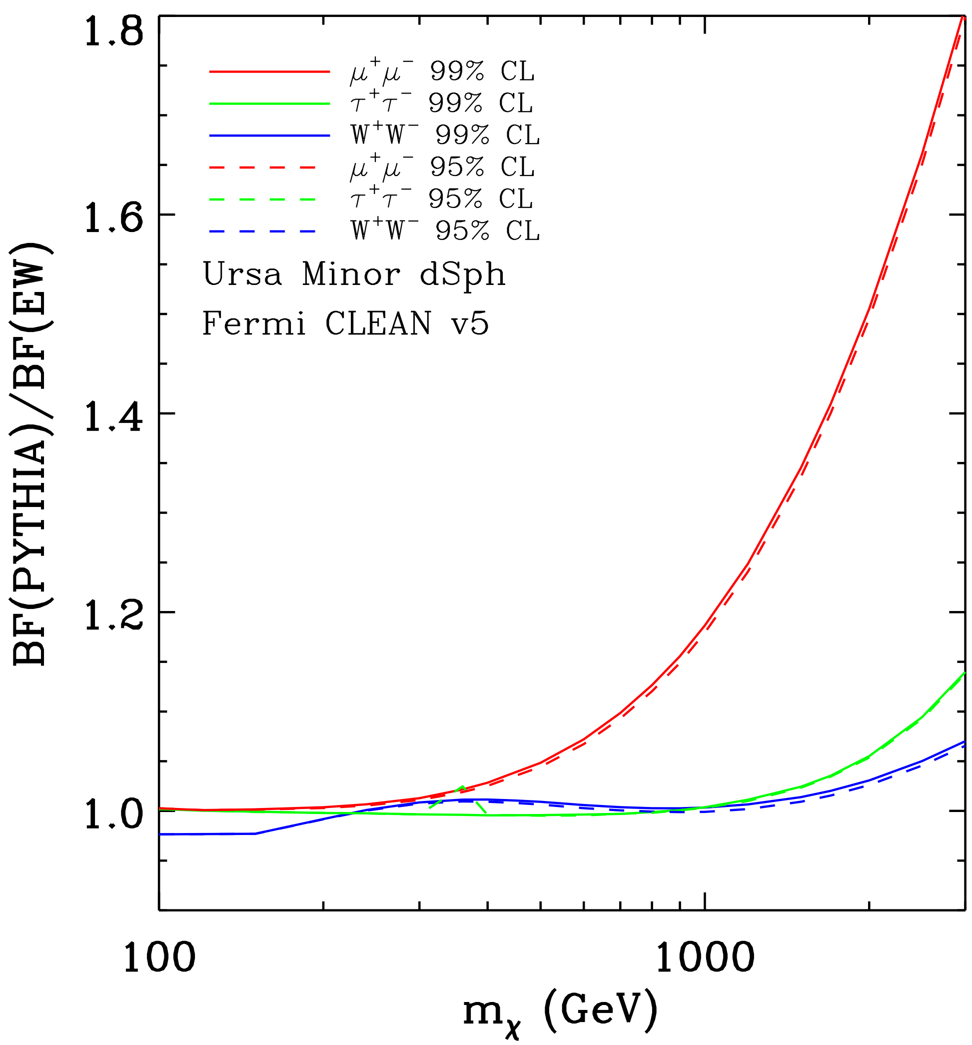


10 degrees

$$BF = \frac{\langle \sigma \mid v \mid \rangle_{fit}}{3 \times 10^{-26} cm^3 s^{-1}}$$

Adding/Ignoring EW corrections for the generic channels





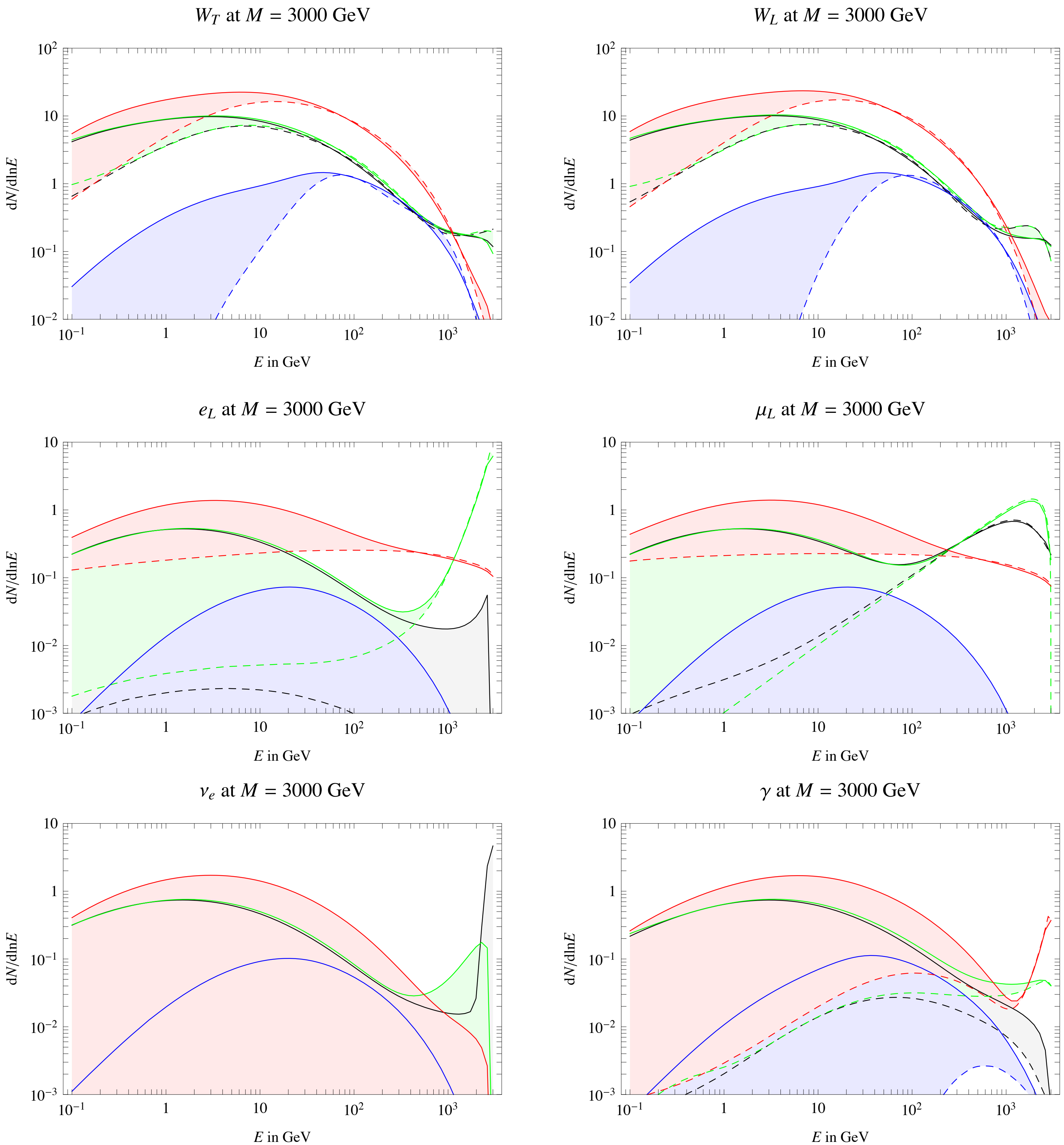


Figure 3: *Comparison between spectra with (continuous lines) and without EW corrections (dashed). We show the following final states: e^+ (green), $\bar{p}$ (blue), γ (red), $\nu = (\nu_e + \nu_\mu + \nu_\tau)/3$ (black).*

Salucci et al. MNRAS 2012: