2011 Fermi Symposium
9-12 May 2011
Rome, Italy

Constraining dark matter signal from a combined analysis of Milky Way satellites with the Fermi-LAT

Maja Llena Garde

Jan Conrad, Johann Cohen-Tanugi

On behalf of the Fermi-LAT collaboration

Oskar Klein centre
Stockholm University
LABORATOIRE UNIVERS & PARTICULES MONTPELLIER

Outline

- Overview
  - dSphs
- Analysis
  - Combined Likelihood
  - Tests
  - Treating astrophysical uncertainties
- Results
- Conclusion

DM signal in high energy γ-rays

The γ-ray flux from self-annihilating dark matter can be expressed as:

$$\Phi_{WIMP}(E,\Psi) = J(\Psi) \times \Phi^{PP}(E)$$

Astrophysical factor

Particle physics factor

$$J(\Psi) = \int_{l.o.s} dl(\Psi)\, \rho^2(l)$$

$$\Phi^{PP}(E) = \frac{1}{2} \frac{\langle \sigma_{ann} v \rangle}{m^2_{WIMP}} \sum_f \frac{dN_f}{dE} B_f$$

> **"J-factor"**
> From now on defined as integrated over a cone of solid angle 2.4 10^−4 sr centered on the dwarf. (~size of PSF of LAT in our region)

Why dwarf Spheroidals?

✔ dSphs are DM dominated systems (they have very high M/L ratios).

✔ Many dSphs are closer than 100 kpc to the Galactic Centre.

✔ Low background

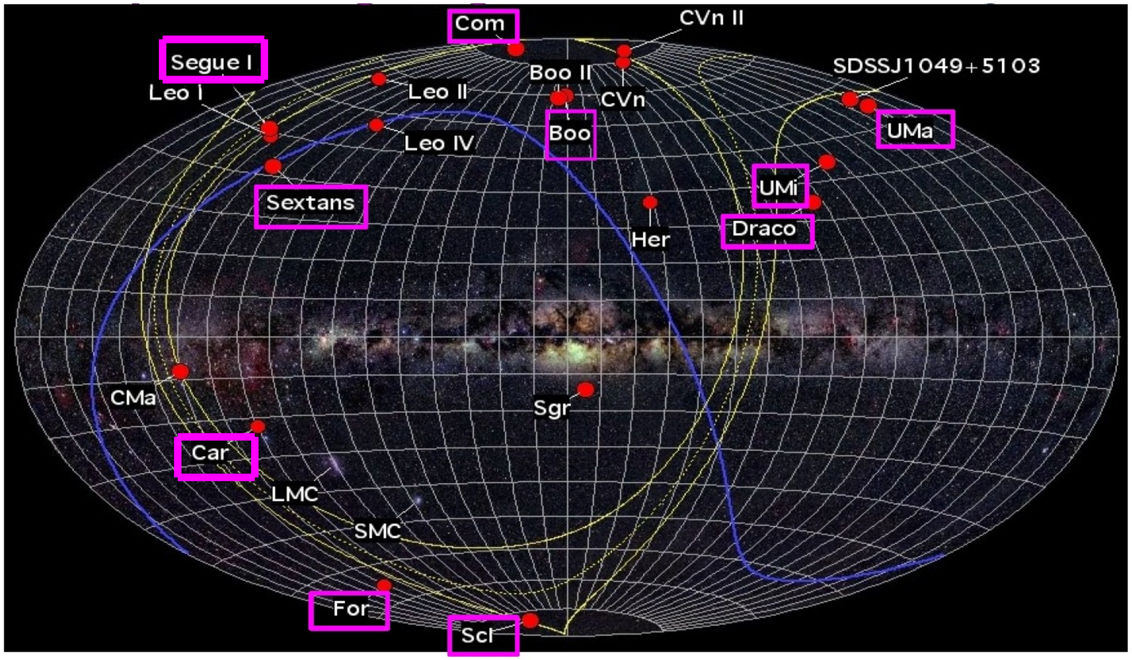
- Most dSphs are expected to be free from other astrophysical γ-ray sources.
- Small content of gas and dust.

✗ Predicted flux from DM is very low.

✗ Dependence on DM distribution.

But:

fortunately estimates from stellar data



Stockholm University

Oskar Klein centre

LUPM LABORATOIRE UNIVERS & PARTICULES MONTPELLIER

Combined Likelihood

• For a given particle physics model (WIMP mass and branching ratio), the γ-ray yield per annihilation is the same for all the dwarfs. The J-factors of course are different.

• Combined likelihood (not data stacking) - we add the likelihood function of each dwarf ROI, and keep σv as one and the same parameter across all the likelihood functions:

$$L(\langle\sigma_{ann}v\rangle, m_{WIMP}; \vec{\Theta}) = \prod_{i=1}^{N} L_i(\langle\sigma_{ann}v\rangle, m_{WIMP}, C, b_i; \vec{\Theta}_i)$$

Constants (e.g. branching fraction in our case)

DM properties Same for all dSphs

Individual parameters (e.g. galactic diffuse normalisation..)

• We report profile likelihood intervals as implemented in MINUIT/MINOS

• The analysis can be individually optimised, and is more robust under background fluctuations and J-factor uncertainties.

• We have used *Composite2* in Fermi ScienceTools

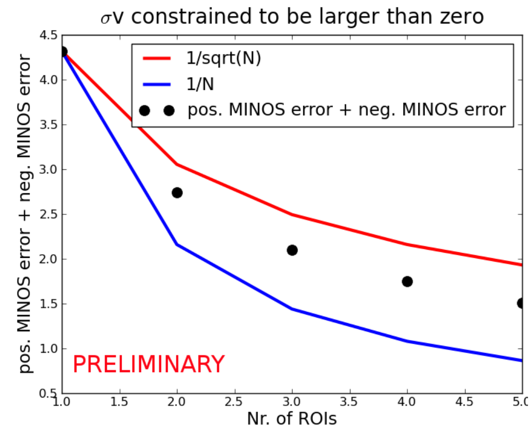
For other analyses using Combined Likelihood: see S. Zimmer's talk on Combined Analysis on Clusters of Galaxies, and the poster by B. Berenji and E. Bloom on Search for Large Extra Dimensions.

Maja Llena Garde
on behalf of the Fermi-LAT collaboration

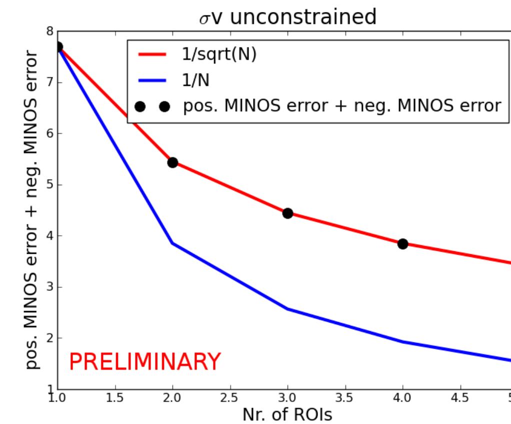
Behaviour of the combined limits

- For a **Gaussian likelihood**, the confidence interval is expected to scale as $1/\sqrt{N}$ where N is the number of samples, but what is the behaviour in our case?
- Test on identical background simulations using Fermi ScienceTools:
  - σv > 0: better than $1/\sqrt{N}$
  - σv unconstrained: $1/\sqrt{N}$
- Test on different spectra using bootstrapped data:
  - Harder spectra: $1/N$
  - Softer spectra: $1/\sqrt{N}$
- Is the coverage still ok when constraining σv to be larger zero?

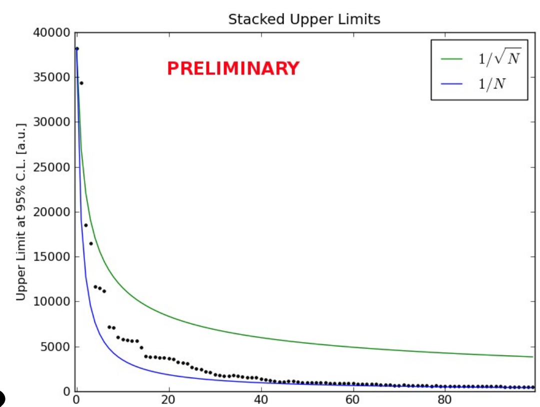
σv > 0



σv unconstrained

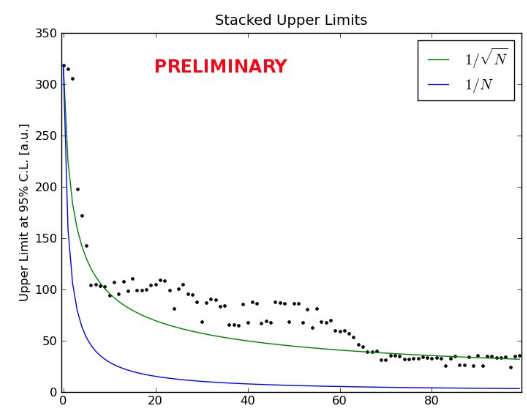


Hard DM spectra, M=1000GeV



Plot by Alex Drlica-Wagner

Soft DM spectra, M=20GeV



Plot by Alex Drlica-Wagner

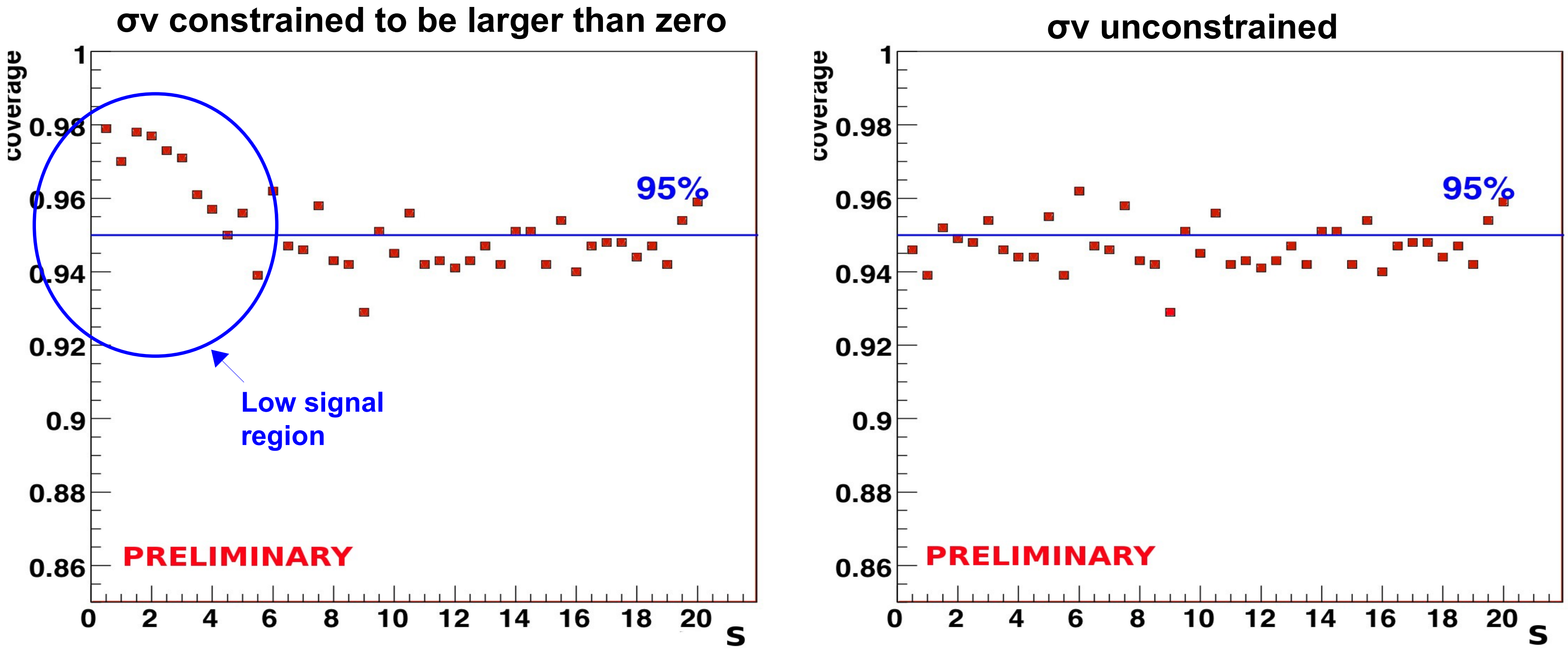
Coverage tests

Coverage: **the fraction of times the true value is contained in the confidence interval in a large number of repeated identical experiment**

Here we have tested the coverage on a toy model: Poisson with known background

Coverage looks ok.

5 ROIs, Background=3



J-factor uncertainties

- Example: Bootes I has value J = $0.16 \pm^{0.35}_{0.13}$ (e19 GeV^2 cm^{-5})
- We include the uncertainties from the J-factors by including their distribution in the likelihood fit.

$$L(<\sigma_{ann}v>, m_{WIMP}; \vec{\Theta}) =$$

$$\prod_i^N L_i(<\sigma_{ann}v>, m_{WIMP}, J_i^m, C, b_i; \vec{\Theta}_i) \frac{1}{J_i^m \sigma_{J,i}\sqrt{2\pi}} e^{\frac{-(\ln(J_i^m) - J_i^{true})^2}{2\sigma_{J,i}^2}}$$

PRELIMINARY

Dwarf	J [10^19 GeV^2 cm^-5]	Error +	Error -	σ_J logNormal
Bootes I	0.16	0.35	0.13	0.73
Carina	0.06	0.02	0.01	0.10
Coma Berenices	0.16	0.22	0.08	0.30
Draco	1.20	0.31	0.25	0.10
Fornax	0.06	0.03	0.03	0.30
Sculptor	0.24	0.06	0.06	0.12
Seguel	2.00	5.95	1.49	0.59
Sextans	0.06	0.03	0.02	0.18
Ursa Major II	0.58	0.91	0.35	0.40
Ursa Minor	0.64	0.25	0.18	0.14

This has never been done before!
(to our knowledge)

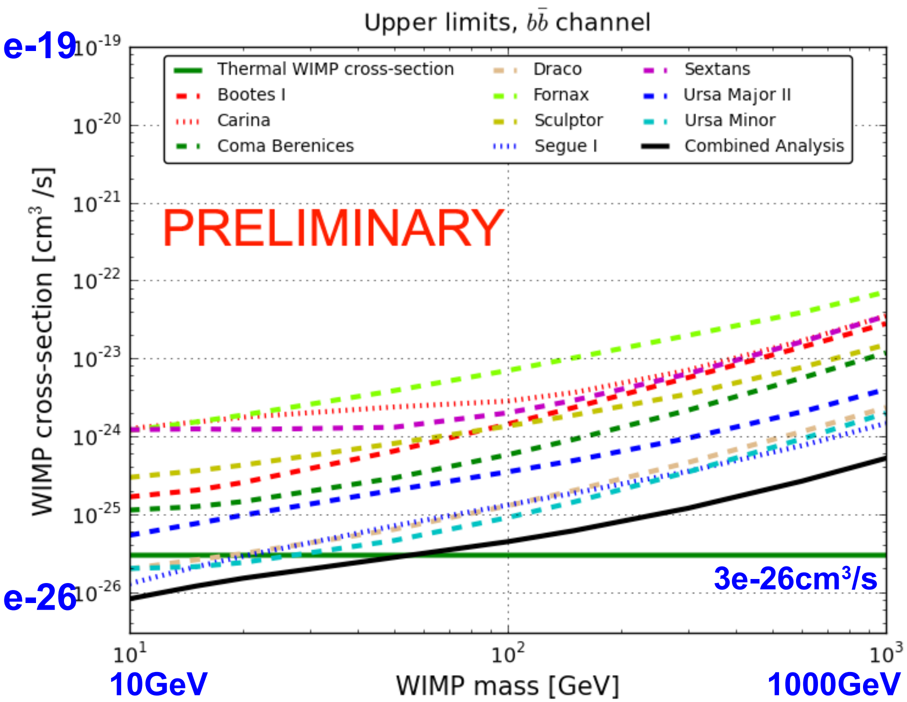
Analysis details

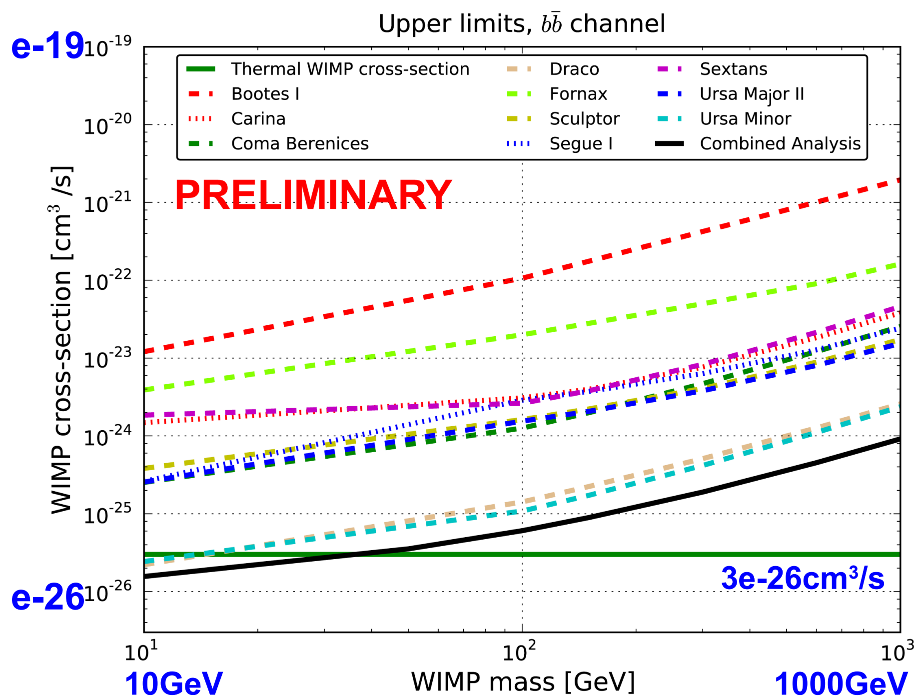
- 10 dSphs
- 24 month data
- Diffuse event class (only events with the highest γ-like confidence)
- Region of interest: 10° radius centred on dSph location
- Energy range from 200MeV to 100GeV
- Standard cuts removing Earth albedo (zenith angle < 100°)
- Instrument response function: P6_V3_DIFFUSE
- Models:
  - dSphs modelled as DM point sources (DMFIT)
  - Galactic and Isotropic diffuse models recommended by the Fermi-LAT collaboration
  - Point-like sources from the 1FGL point source catalogue *(A. A. Abdo et al 2010 ApJS 188 405)* with some additions
- Binned Likelihood (using energy and spatial information)
- *Parameter of interest*: DM cross-section
  Nuisance parameters: J-factors, normalisations of the Diffuse Backgrounds, and the normalisation of nearby sources (<5°)

Including J-factor uncertainties

Nominal J-factor used, no uncertainties included

J-factor uncertainties included

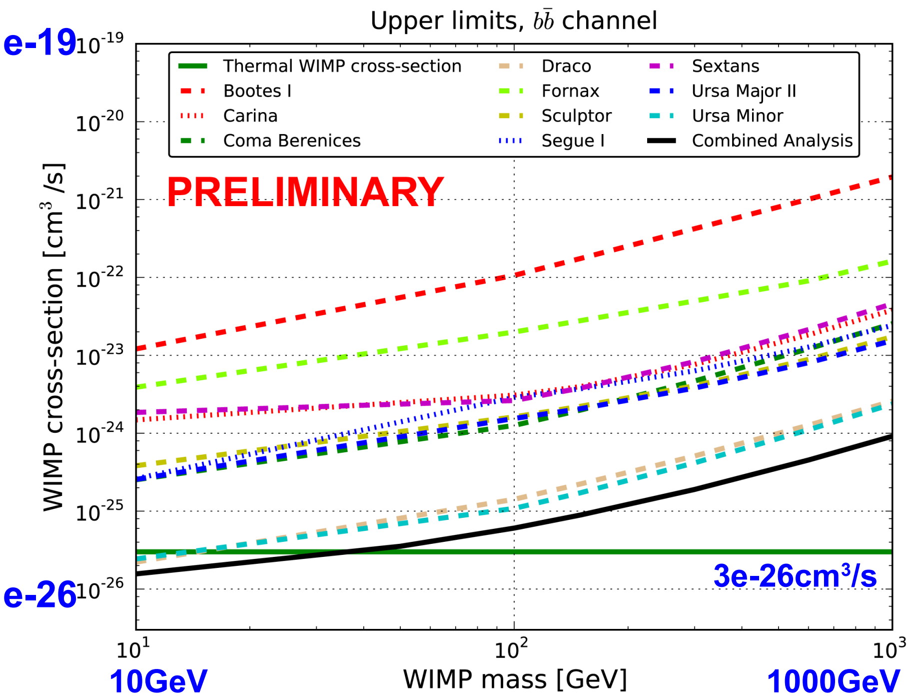


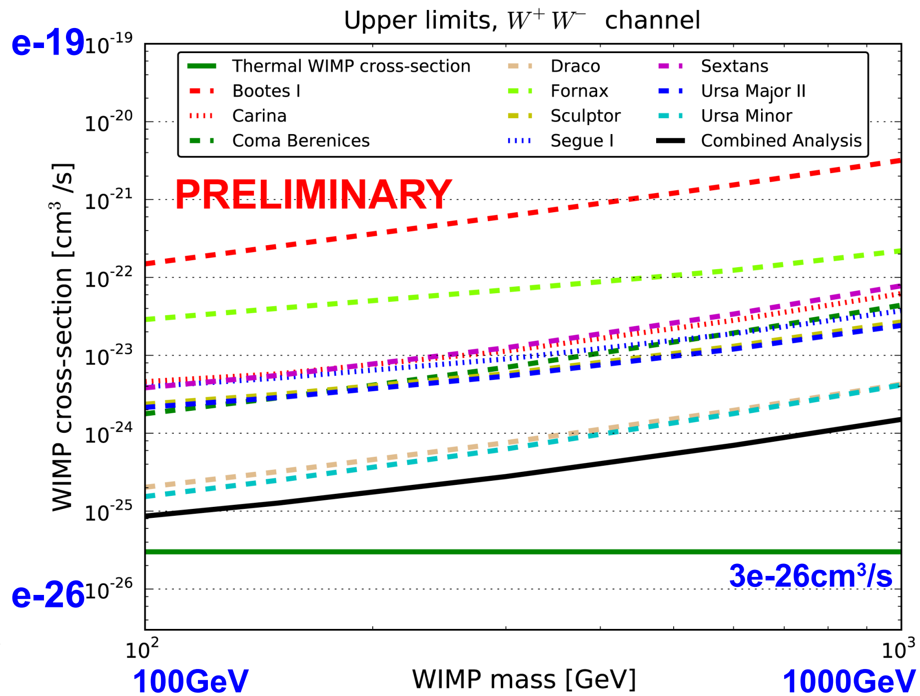


Example:
For M=150GeV, the combined limit using nominal J is 6.1e-26 cm³/s, and the combined limit with J-factor uncertainties included is 8.9e-26 cm³/s

In the following slides, all limits include the uncertainty on the J-factor

Results $b\bar{b}$ and W+W- Channels



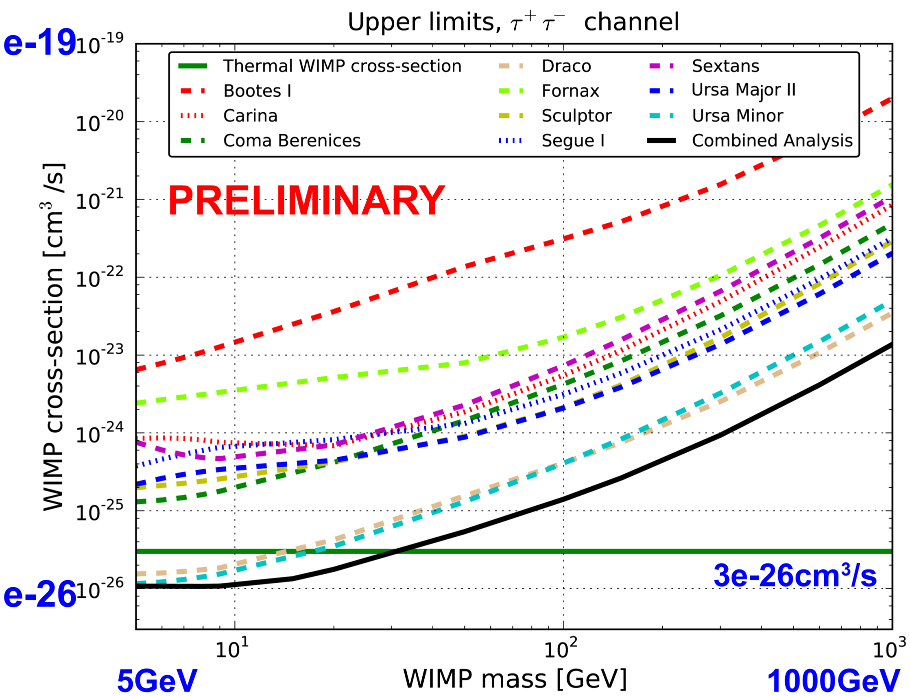


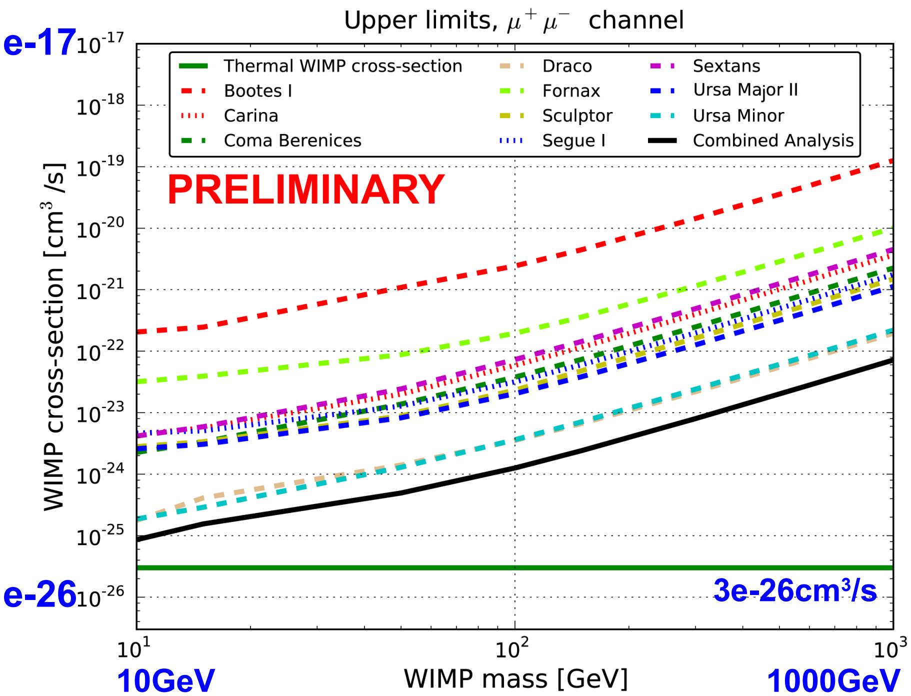
Evaluated at M= 10, 15, 50, 100, 150, 300, 600 and 1000 GeV

Evaluated at M= 100, 150, 300, 600 and 1000 GeV

Maja Llena Garde
on behalf of the Fermi-LAT collaboration

Results τ+ τ- and μ+μ- Channel



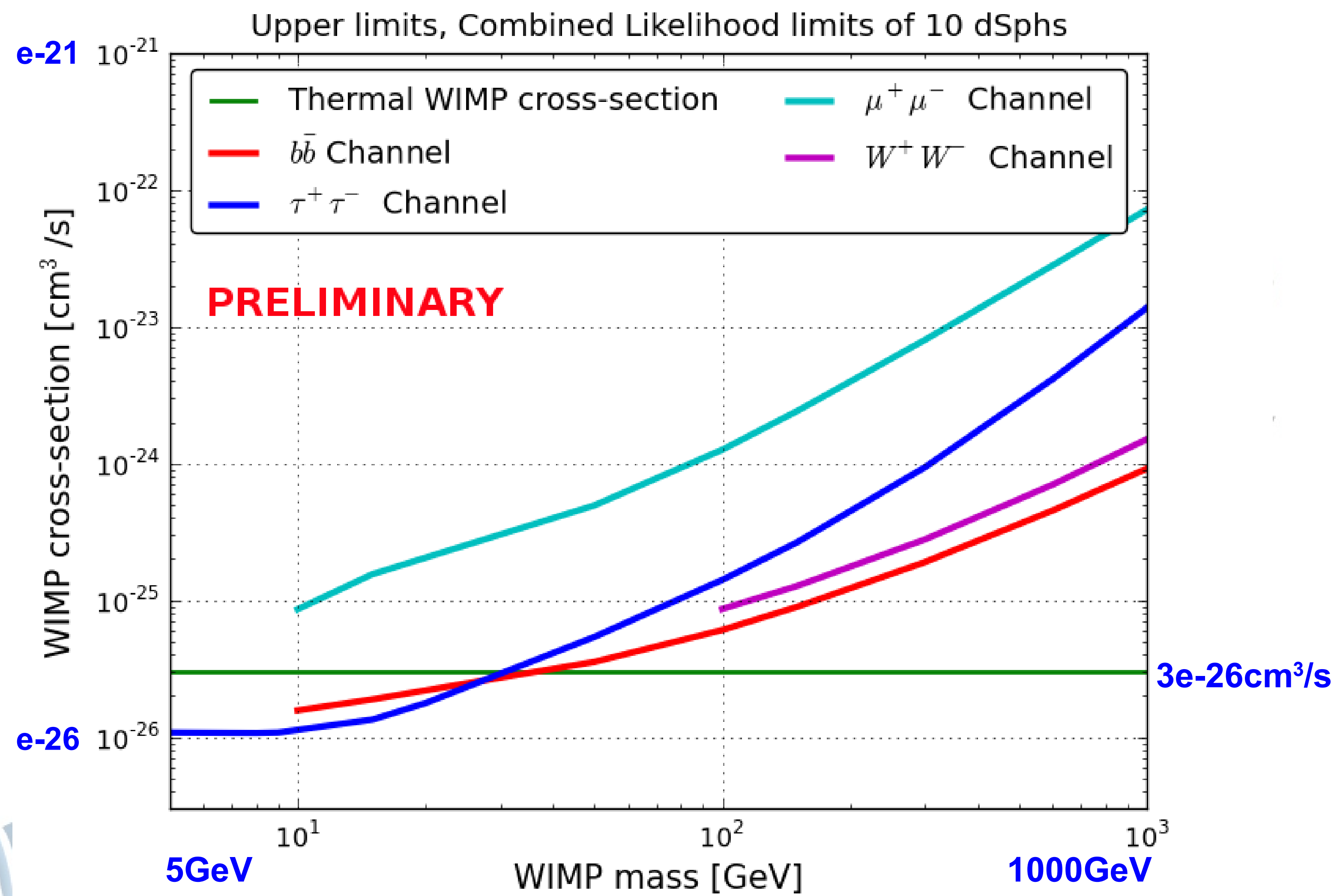


Evaluated at M= 5, 6, 7, 8, 9, 50, 100, 150, 300, 600 and 1000 GeV

Evaluated at M= 10, 15, 50, 100, 150, 300, 600 and 1000 GeV

Maja Llena Garde
on behalf of the Fermi-LAT collaboration

Results all channels



Maja Llena Garde
on behalf of the Fermi-LAT collaboration

Summary

- We have presented robust constraints including J-factor uncertainties on dark matter annihilation cross-sections from a combined likelihood analysis of 10 dSph galaxies for different annihilation channels.
- The limits start to cut into parameter space below the thermal WIMP cross-section for low masses!
- Various tests and cross-checks have been made to verify the method.
- A paper is in preparation within the collaboration.

TeVPA 2011

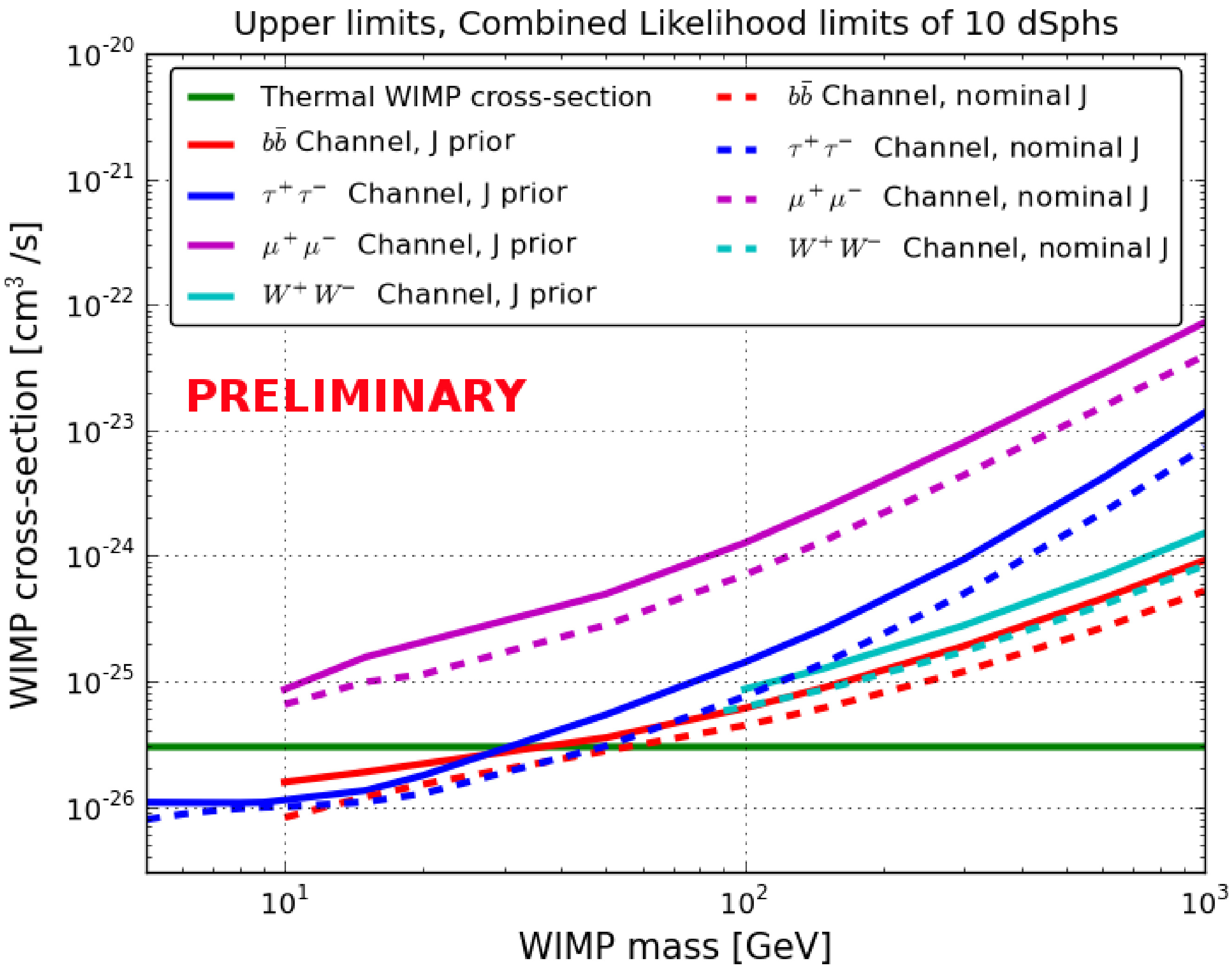
Stockholm Aug 1-5

Abstract submission deadline:
31 May

http://tevpa2011.albanova.se/

Back-up slides

Results all channels

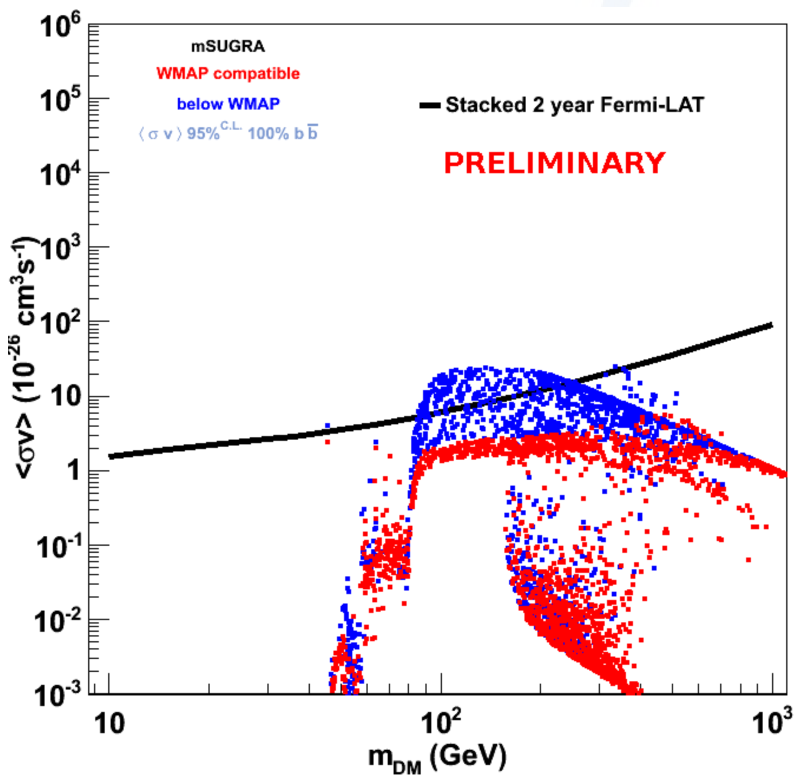


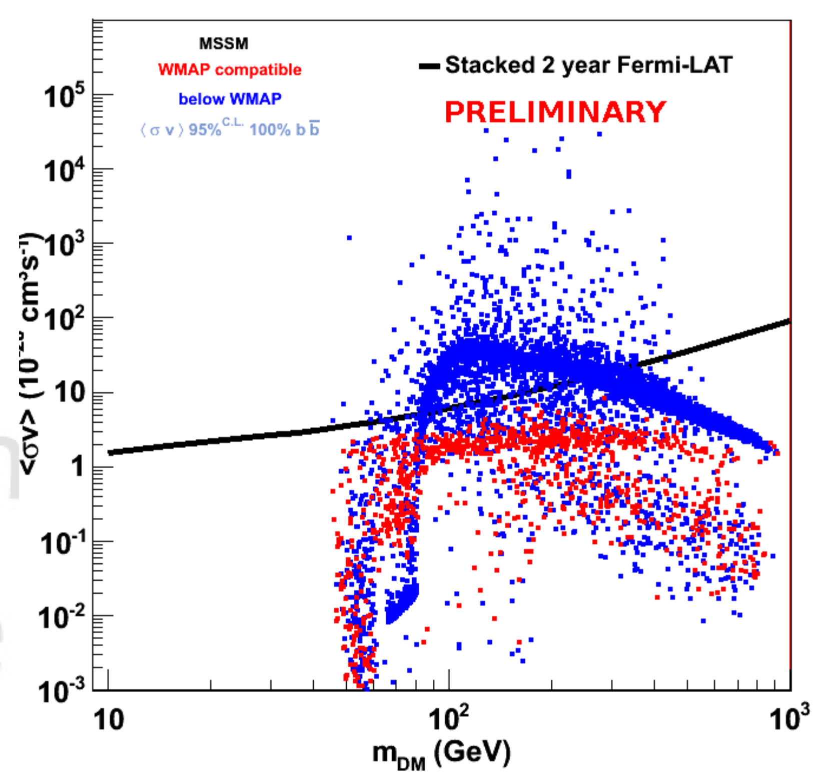
Maja Llena Garde
on behalf of the Fermi-LAT collaboration

Model scans

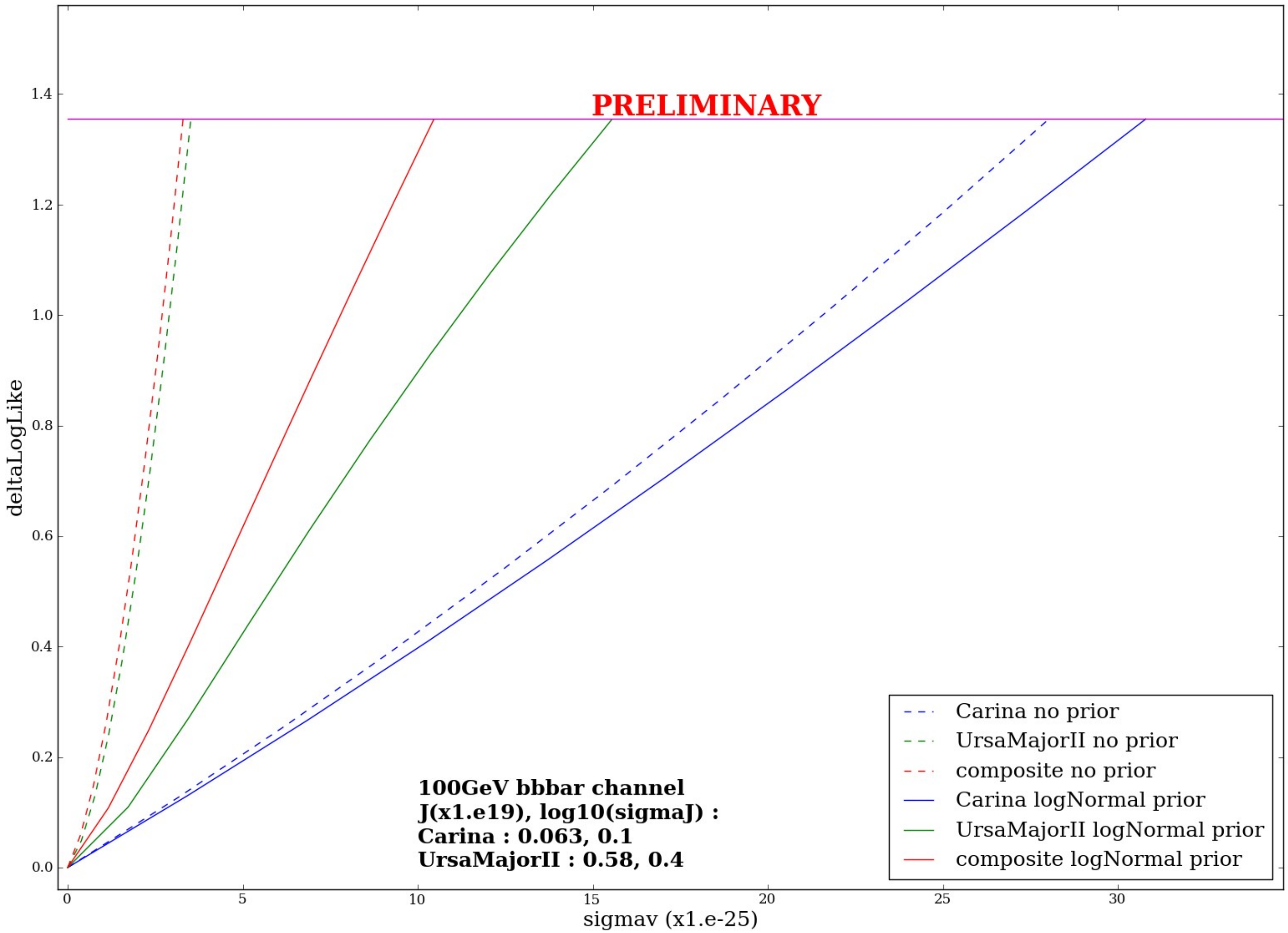
Combined Likelihood limits plotted with the same model scans as in the 11 month dSph paper

(11 month dSph paper: Abdo et al., ApJ 712, 147 (2010), arxiv:1001.4531)





Likelihood curves when including priors



The Fermi-LAT

- Launched on June 11, 2008
- 16 identical modules in a 4x4 array, where each module is made up by a tracker for direction determination and a calorimeter for energy measurements
- Field of view is ~2.4 sr
- Energy range 20MeV to >300GeV
- LAT observes the entire sky every ~3 h (2 orbits)

⇨ LAT is a great instrument for DM searches!