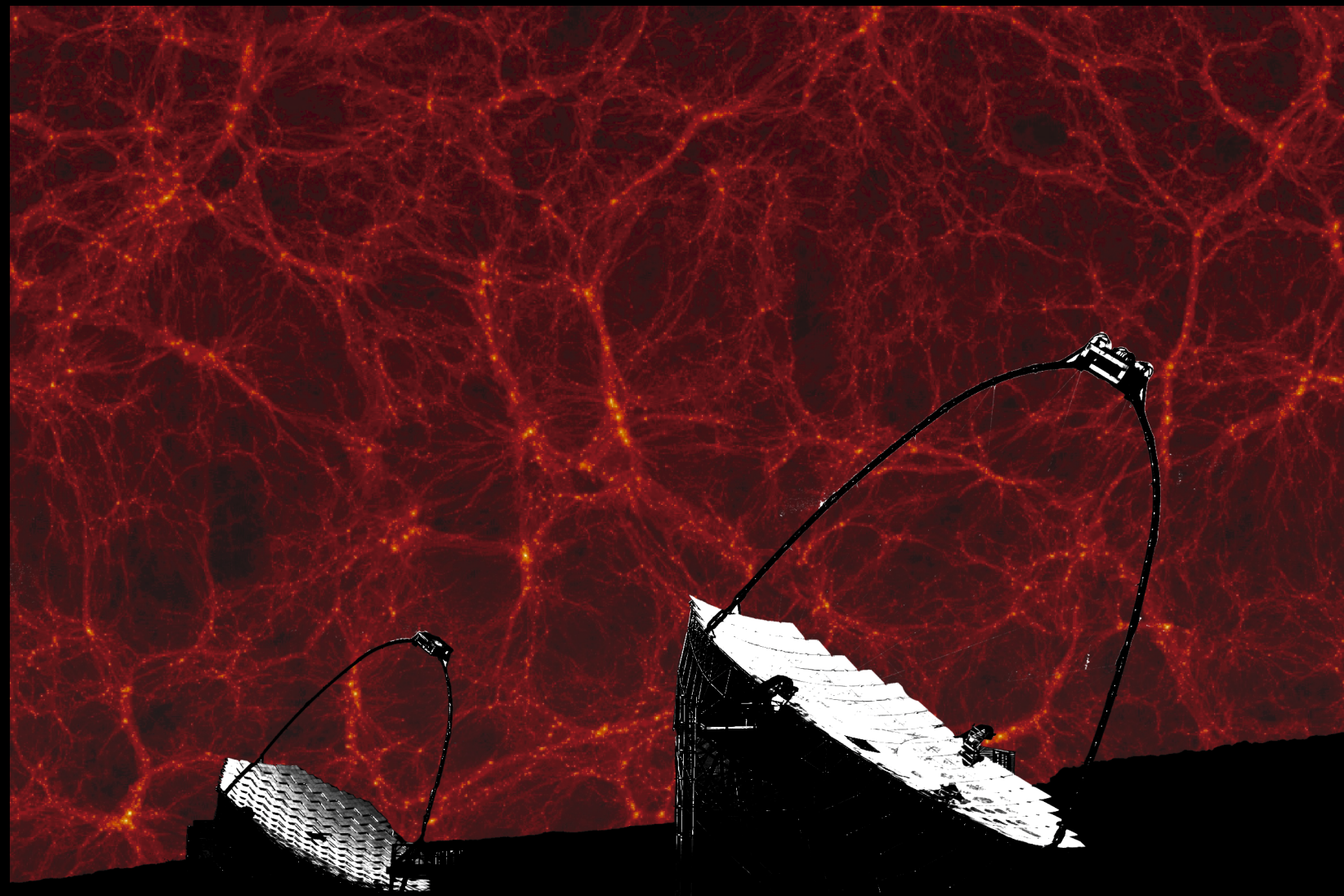

Stockholm,
July 18th 2013

Jelena Aleksić
on behalf of the MAGIC Collaboration

Deep Survey of Segue 1 with MAGIC

Outline

- ★ Dark Matter Searches with MAGIC
- ★ Observations
- ★ Dedicated analysis
- ★ Results
- ★ Conclusions

Dark Matter Searches with MAGIC

★ Active efforts in indirect dark matter searches

- Galactic Center

  (17 h) ApJ Lett. 638 (2006) L101
- Galaxy Cluster

  (25 h) ApJ 710 (2010) 634
- Dwarf Spheroidals

  Segue 1 (30 h): JCAP 06 (2011) 035

  Willman 1 (16 h): ApJ 697 (2009) 1299

  Draco (8 h): Apj 679 (2008) 428
- Subhalos

Dark Matter Searches with MAGIC

- ★ All existing publications on dark matter searches with mono data
- ★ Goal: Improve our best (published) limits by a factor 10

- ☆ Stereo system since 2009
  - ✦ Major upgrade finished in 2012
- ☆ Long-term observational campaign on best dark matter candidate
- ☆ Dedicated analysis approach

Segue 1

ApJ 692 (2009) 1464; Apj 733 (2011) 46

Segue 1	
Coordinates	$10^h\ 07^m\ 04^s$, $+16^\circ\ 04'\ 55''$
Distance	23 ± 2 kpc
Number of resolved stars	71
Magnitude	$-1.5^{+0.6}_{-0.8}$
Apparent magnitude	13.8 ± 0.5
Luminosity	$340\ L_\odot$
Mass	$5.8^{+8.2}_{-3.1} \times 10^5\ M_\odot$
M/L	$\sim 3400\ M_\odot/L_\odot$
Half-light radius	29^{+8}_{-5} pc
System velocity	208.5 ± 0.9 km/s
Velocity dispersion	$3.7^{+1.4}_{-1.1}$ km/s
Mean [Fe/H]	-2.5

SEGUE = Sloan Extension for Galaxy Understanding and Exploration

- ★ The most dark matter dominated object known so far
- ★ The least luminous galaxy
- ★ Close, no background, Northern hemisphere

Observations

- ★ January 2011 – February 2013
- ★ Low zenith angle (13 – 35 deg)
- ★ Wobble mode

- ★ Different telescope configurations(!):
  - ✦ Jan 2011 – May 2011: 47.0 h
  - ✦ Jan 2012 – Feb 2012: 12.3 h
  - ✦ Mar 2012 – May 2012: 51.3 h
  - ✦ Nov 2012 – Feb 2013: 47.5 h

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Total effective observation time: 157.9 h

The deepest survey of any dSph by any IACT!

Full Likelihood Method

$$\mathcal{L}(N_{\mathrm{EST}}, M(\theta) \mid N_{\mathrm{OBS}}, E_1, .., E_{N_{\mathrm{OBS}}}) = \frac{N_{\mathrm{EST}}{}^{N_{\mathrm{OBS}}}}{N_{\mathrm{OBS}}!} e^{-N_{\mathrm{EST}}} \times \prod_{i=1}^{N_{\mathrm{OBS}}} \mathcal{P}(E_i; M(\theta))$$

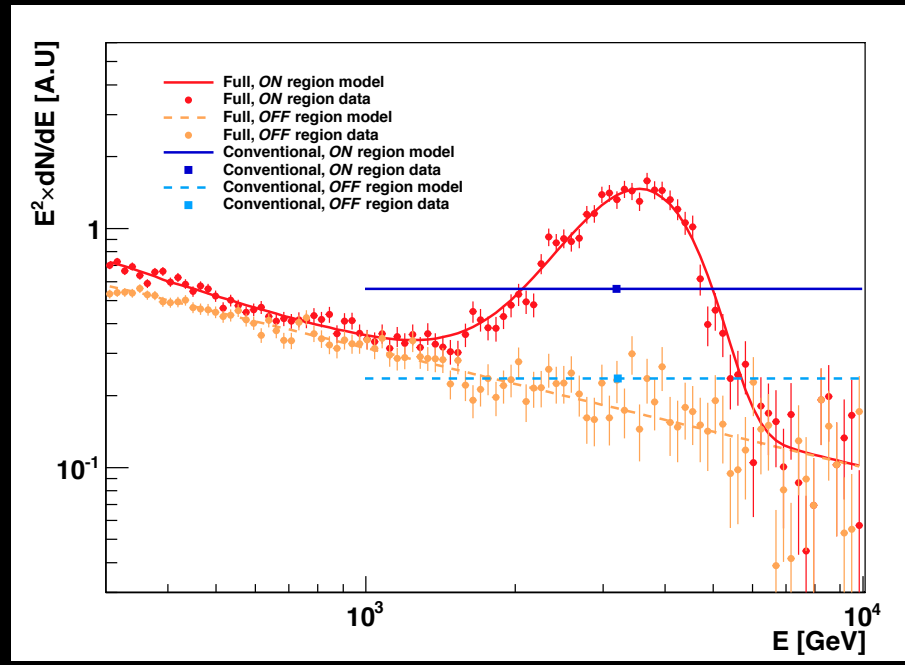
N_{OBS}, N_{EST} – total measured and estimated number of events

E, E' – measured and true energy

$M(\theta)$ – model with parameters θ

Measured and estimated
spectral distributions

JCAP 10 (2012) 032



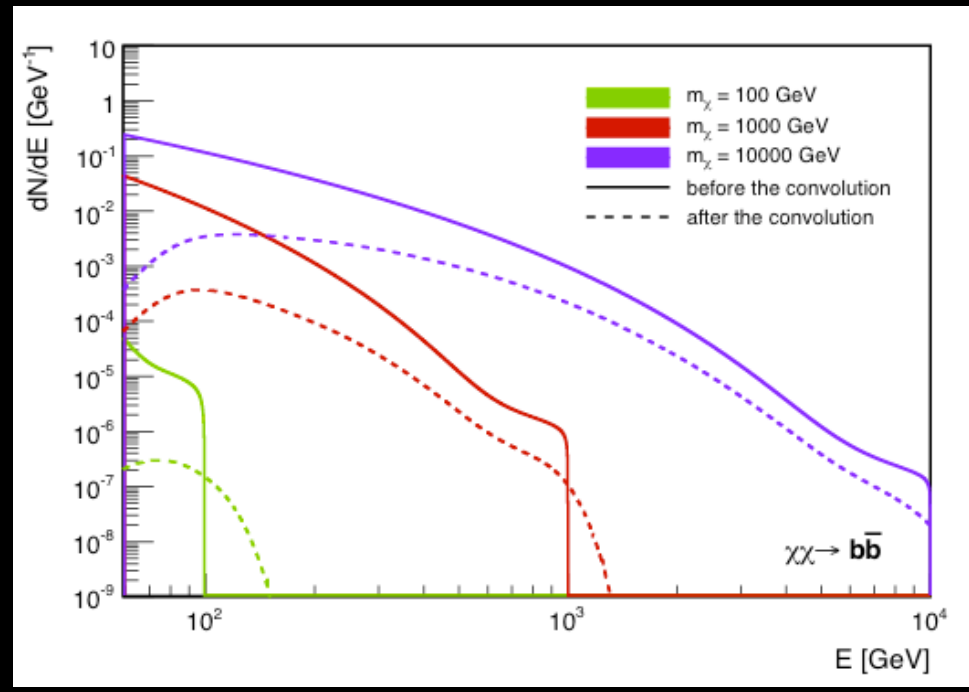
Full Likelihood Method

- ★ *A priori* assumption on the expected spectral shape → maximum advantage of potential features
- ★ Unbiased, stable, robust
- ★ Significant improvement with respect to the conventional analysis
- ★ Straightforward combination of results from different instruments / sources

$$\mathcal{L}_T(M(\boldsymbol{\theta})) = \prod_{i=1}^{N_{\text{inst}}} \mathcal{L}_i(M(\boldsymbol{\theta}))$$

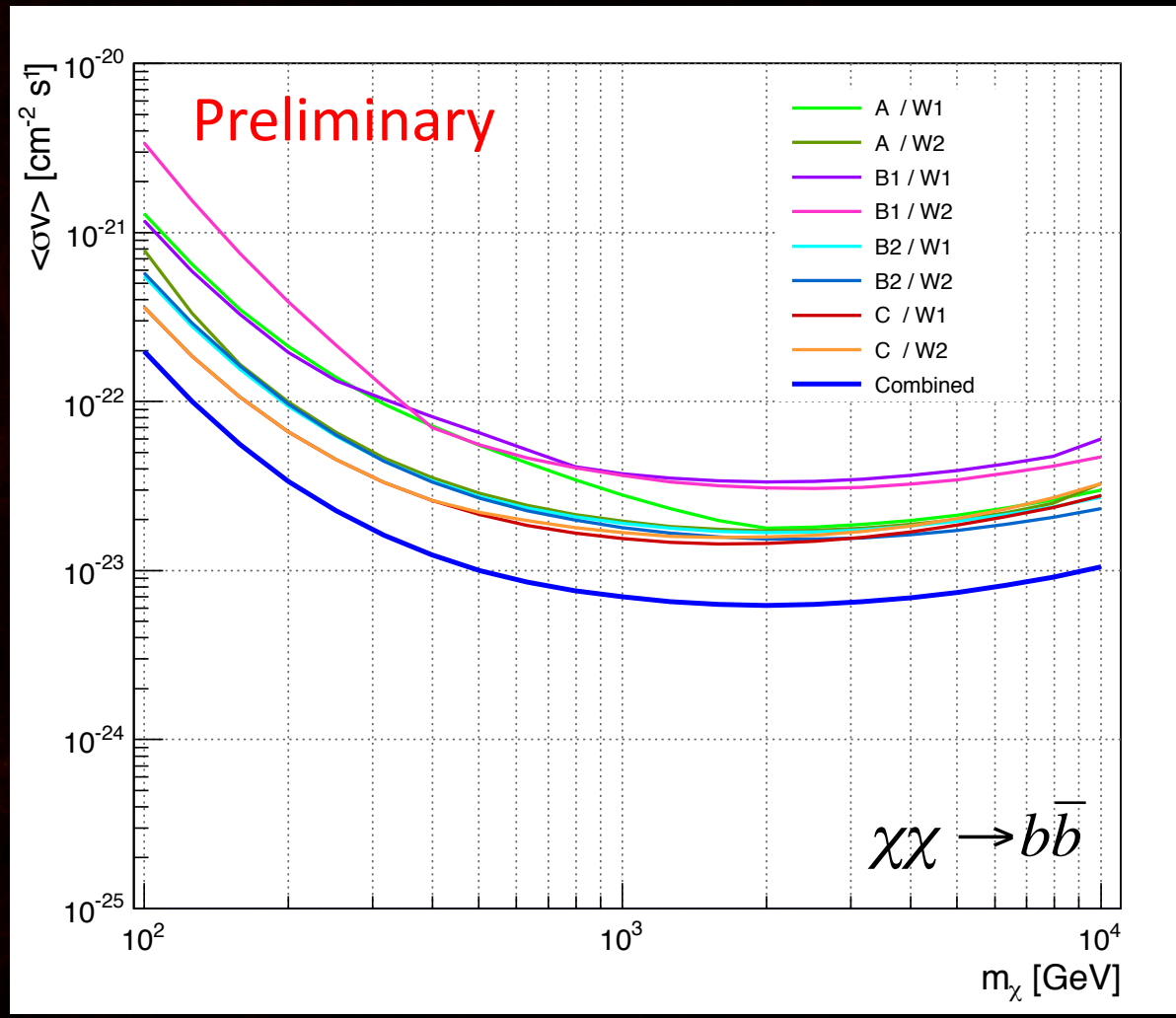
Full Likelihood Analysis

- ★ Response function: calculated for each observation period separately
- ★ Background spectral shape: modeled from the Segue 1 observations
- ★ Signal spectral shape: few models of dark matter annihilation and decay:
  - ✦ Secondary photons
  - ✦ Monochromatic line
  - ✦ Virtual Internal Bremsstrahlung
  - ✦ Gamma-ray boxes



- ★ m_χ in the 100 GeV – 10 TeV (200 GeV – 20 TeV) range
- ★ Br = 100%
- ★ Einasto density profile

Secondary Photons



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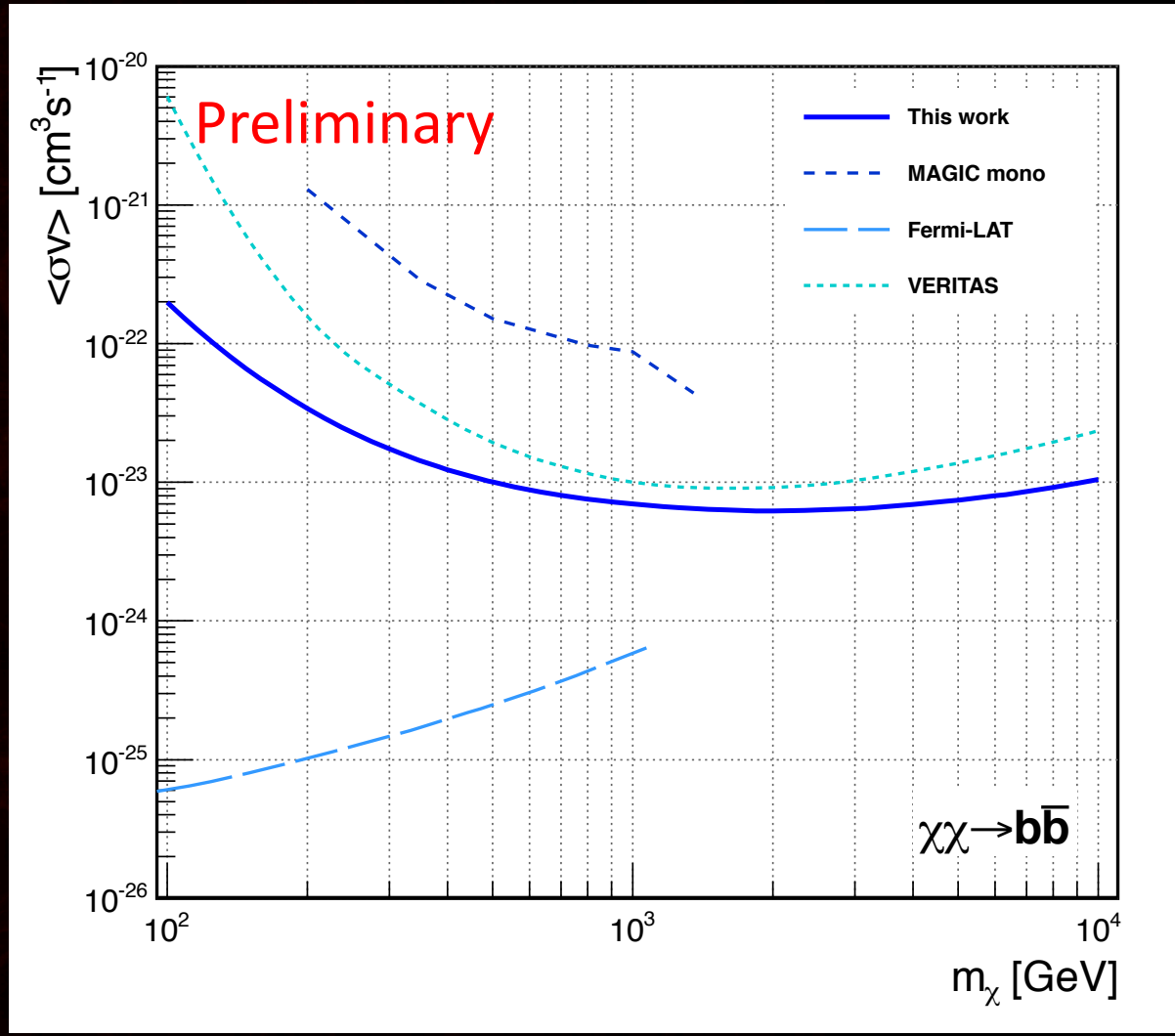

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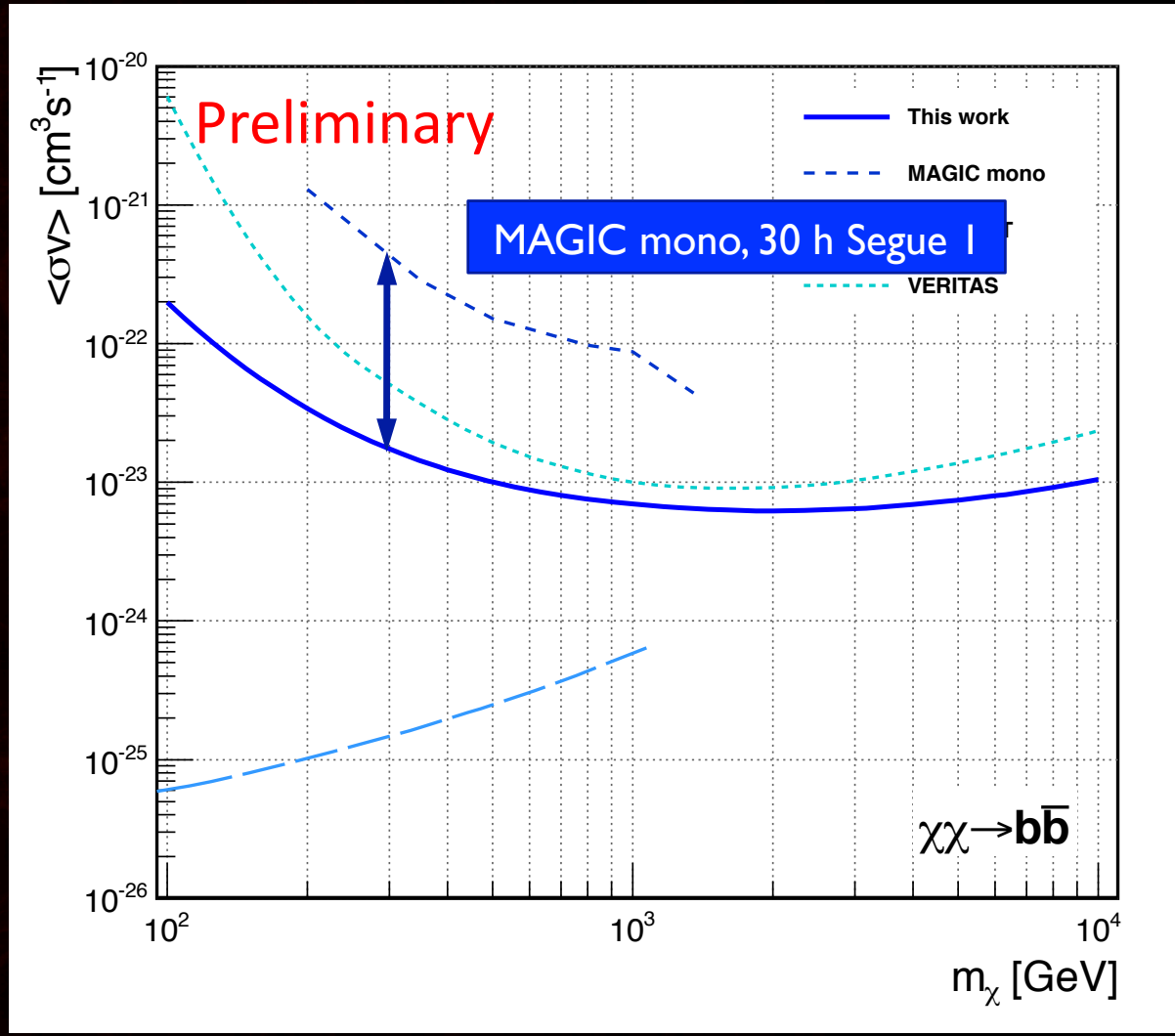

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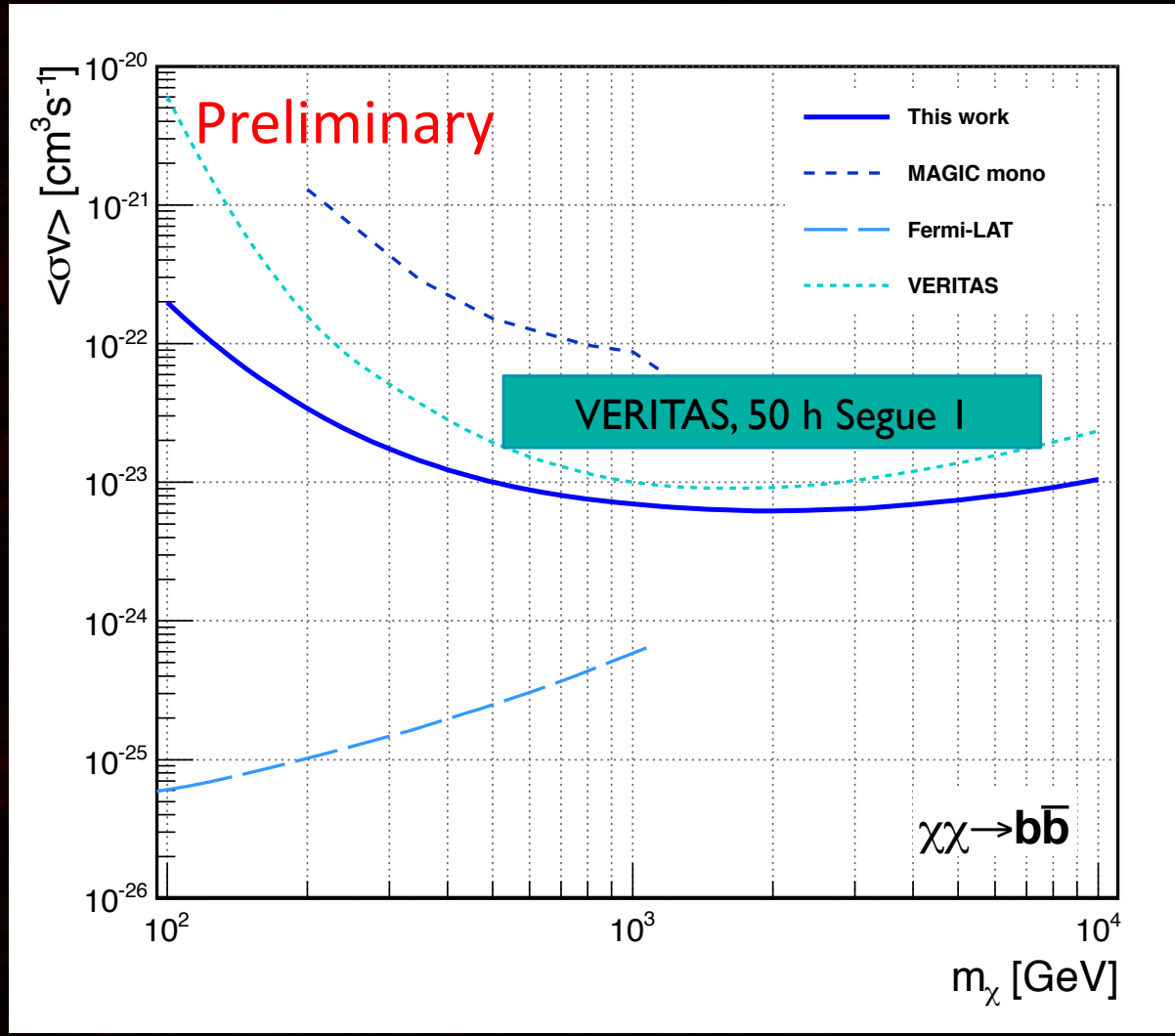

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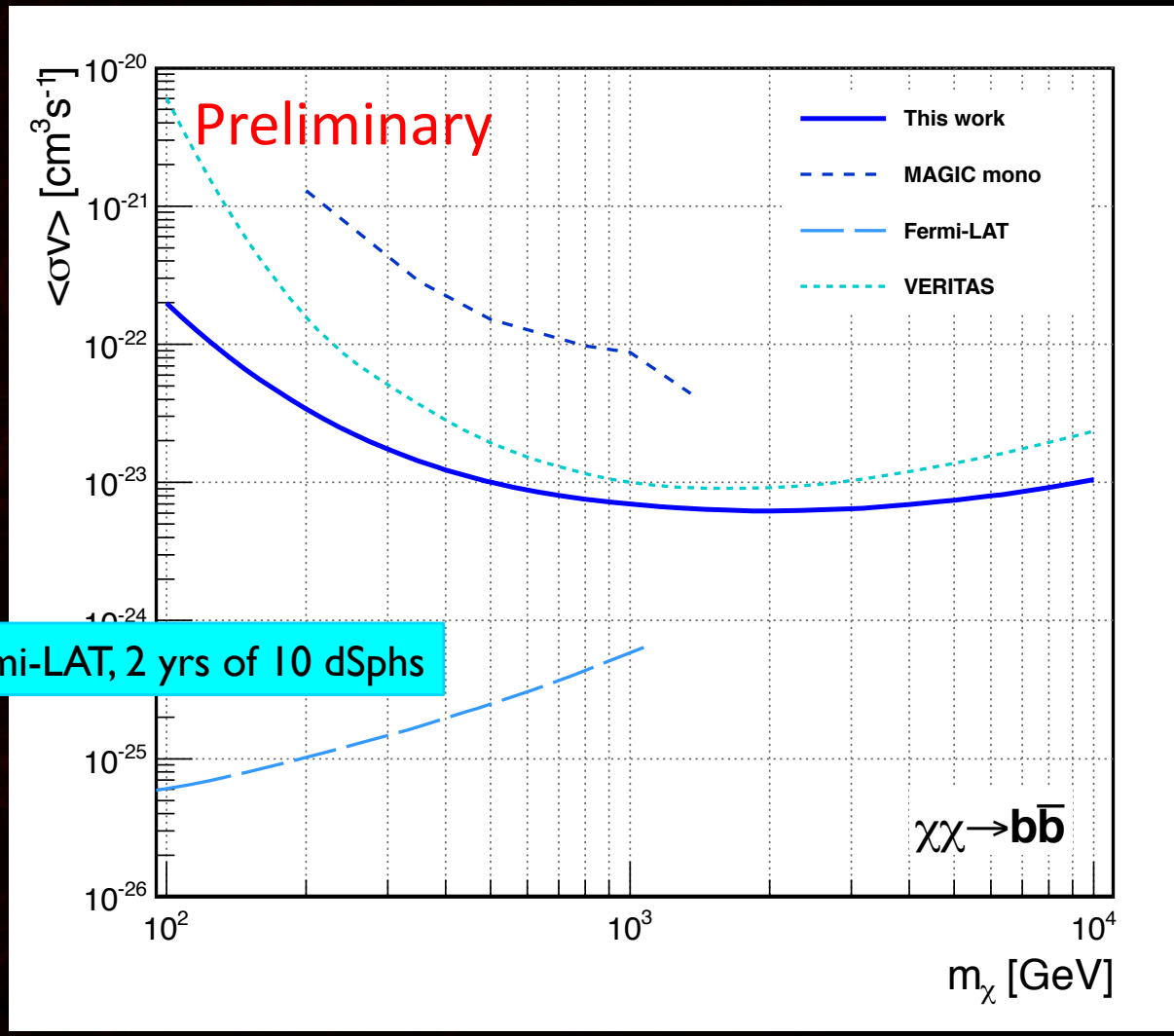
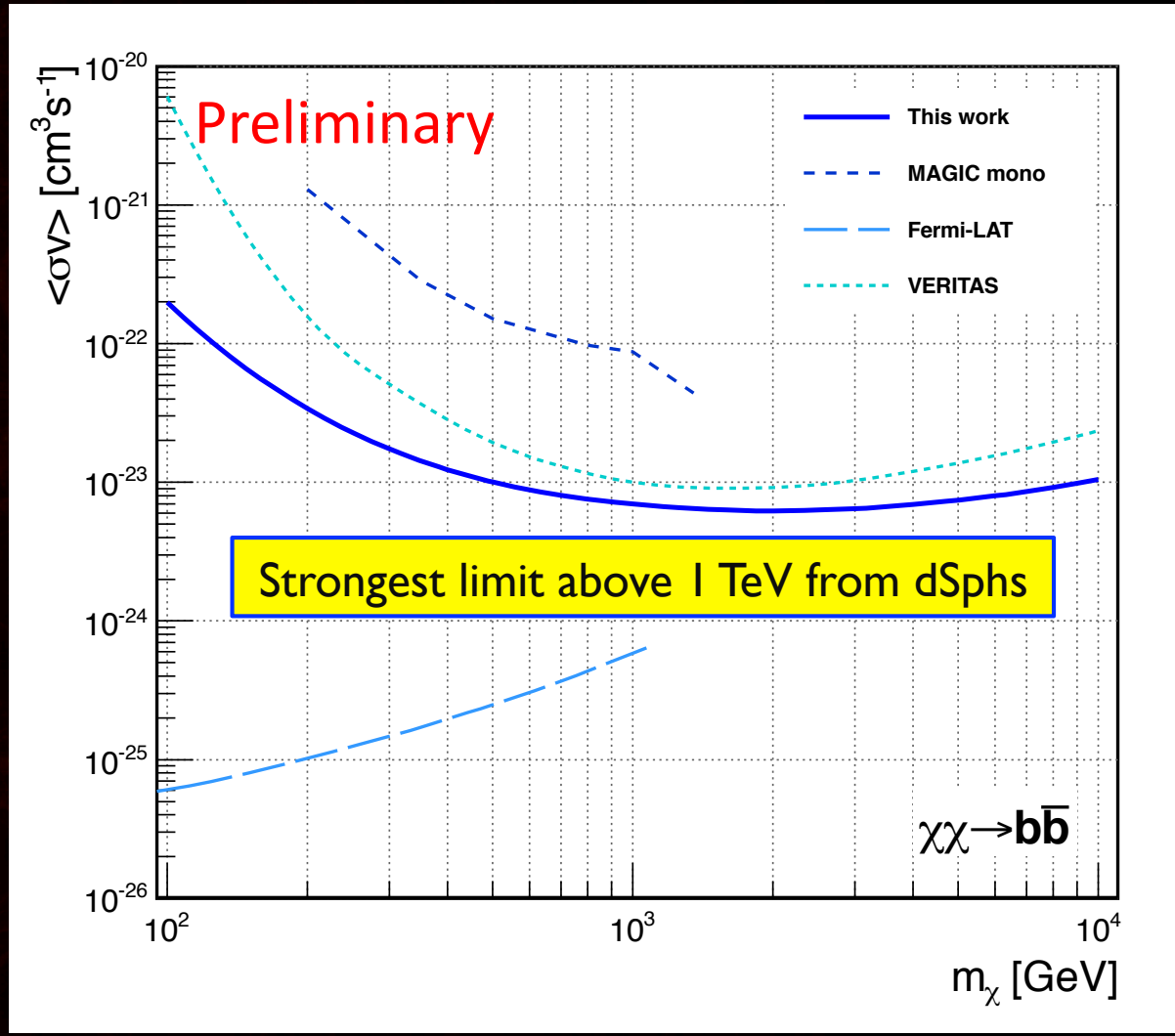


Fermi-LAT, 2 yrs of 10 dSphs

Secondary Photons



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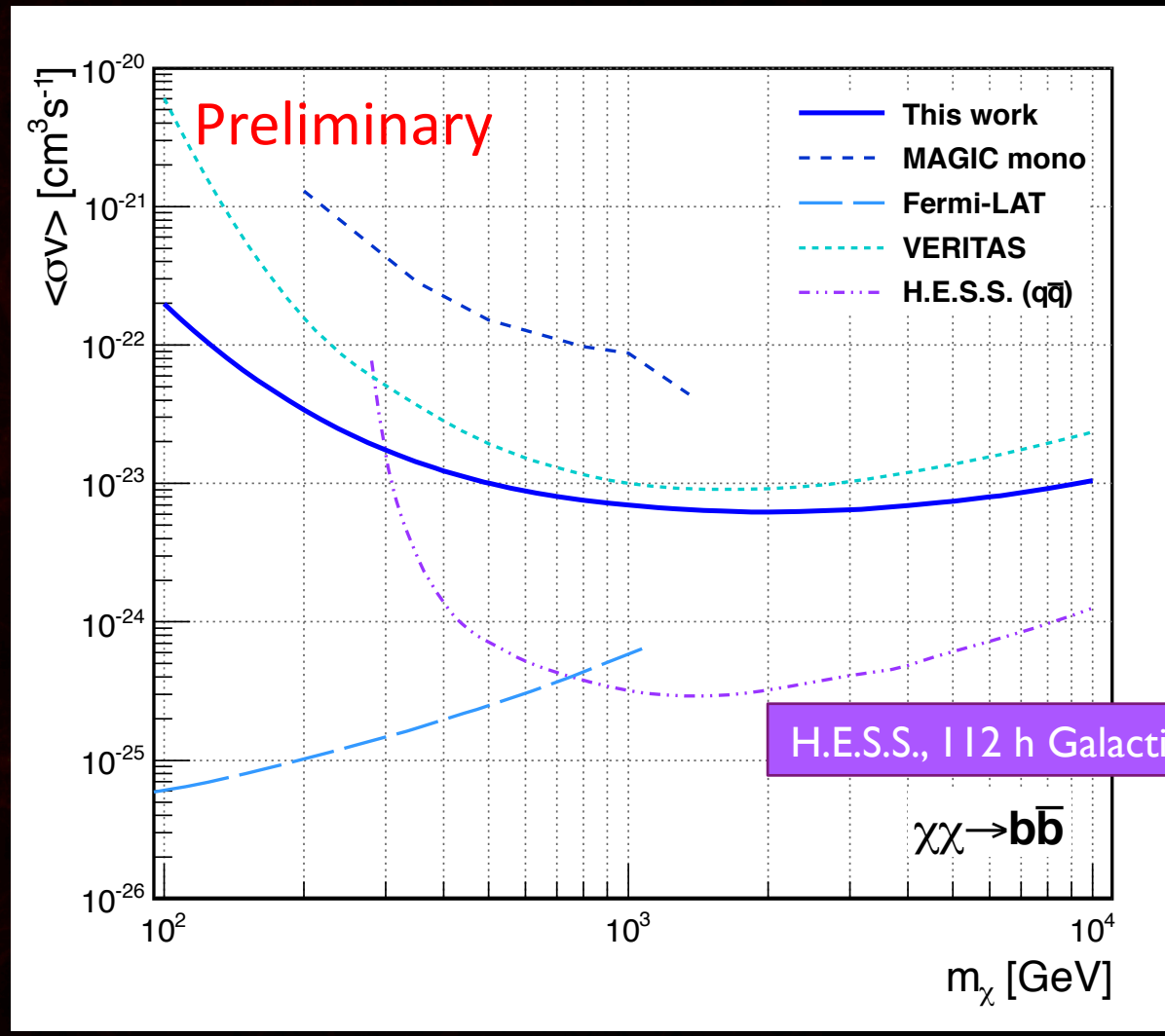

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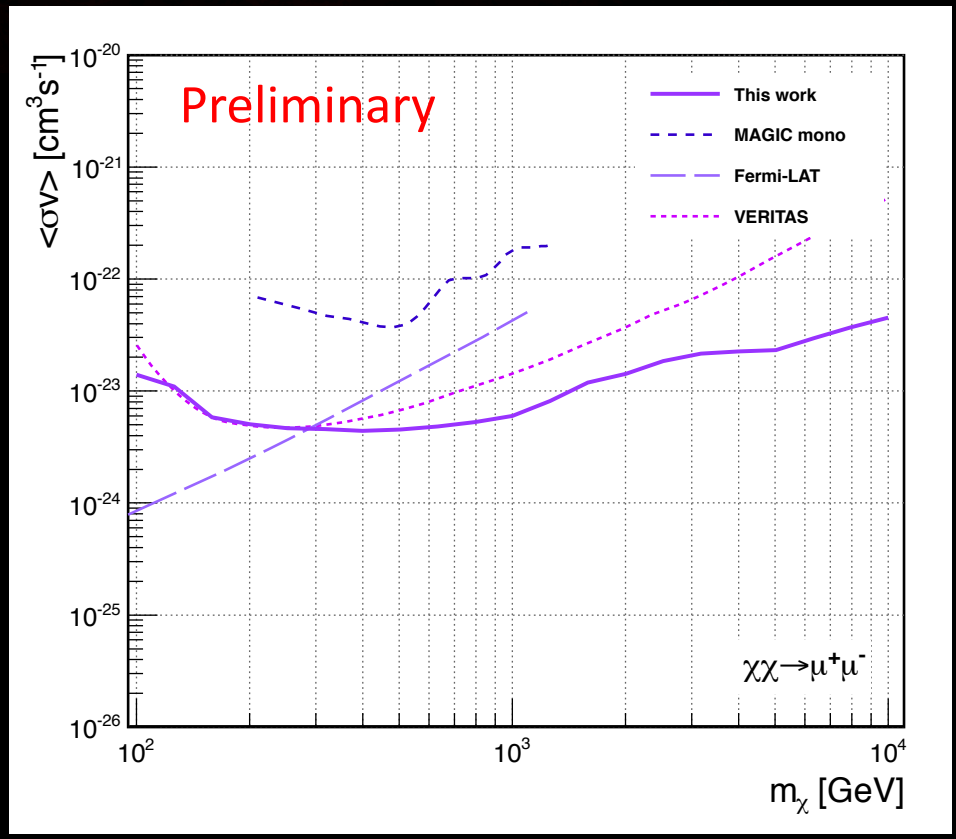

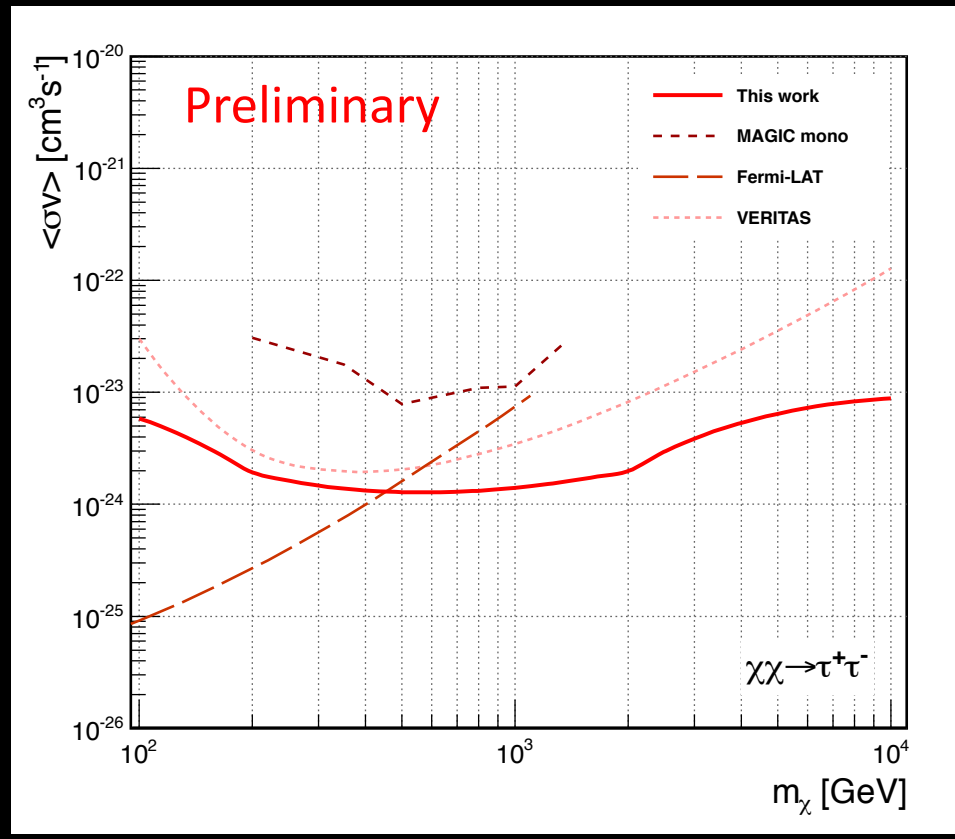

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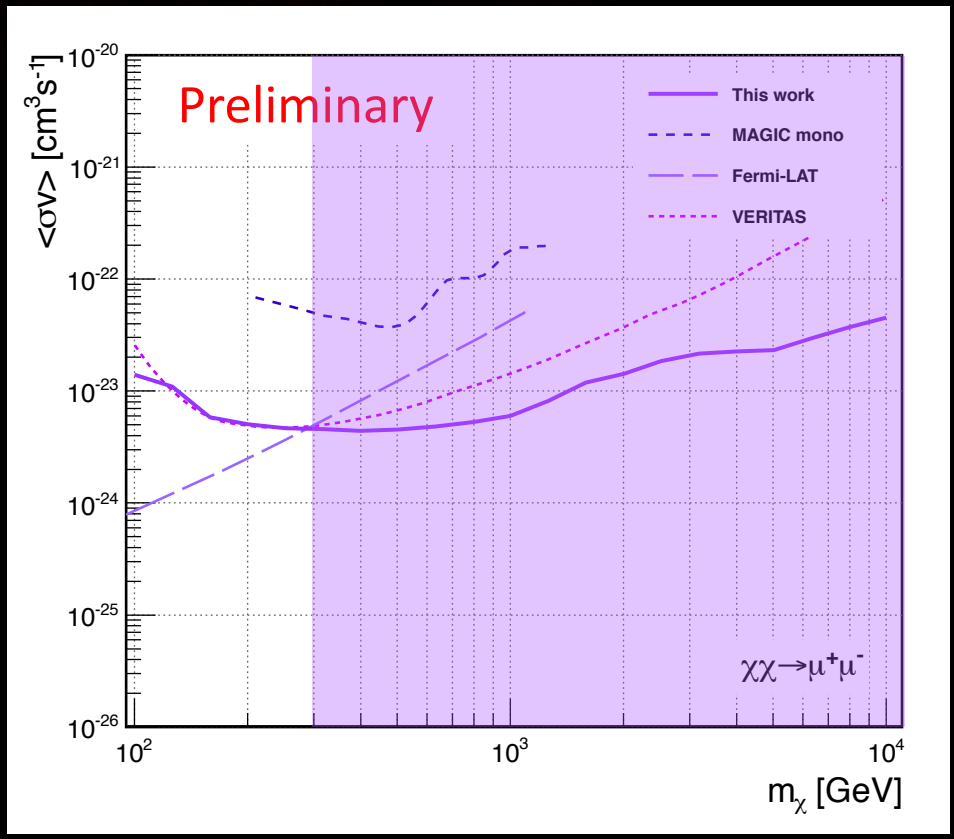
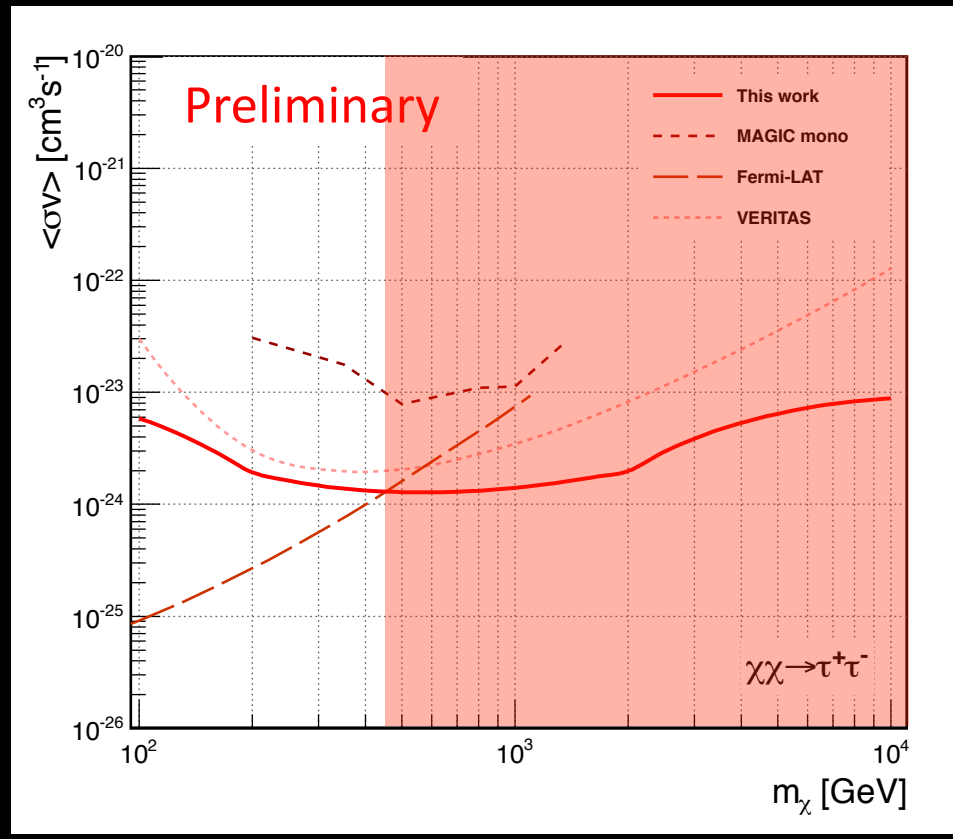
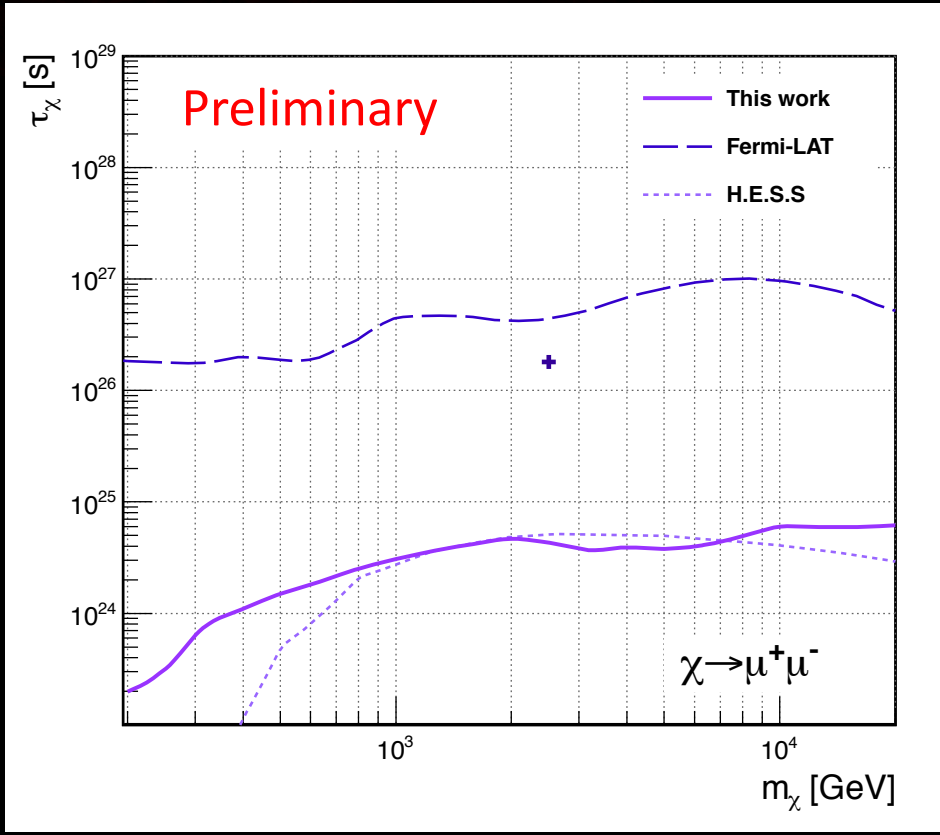


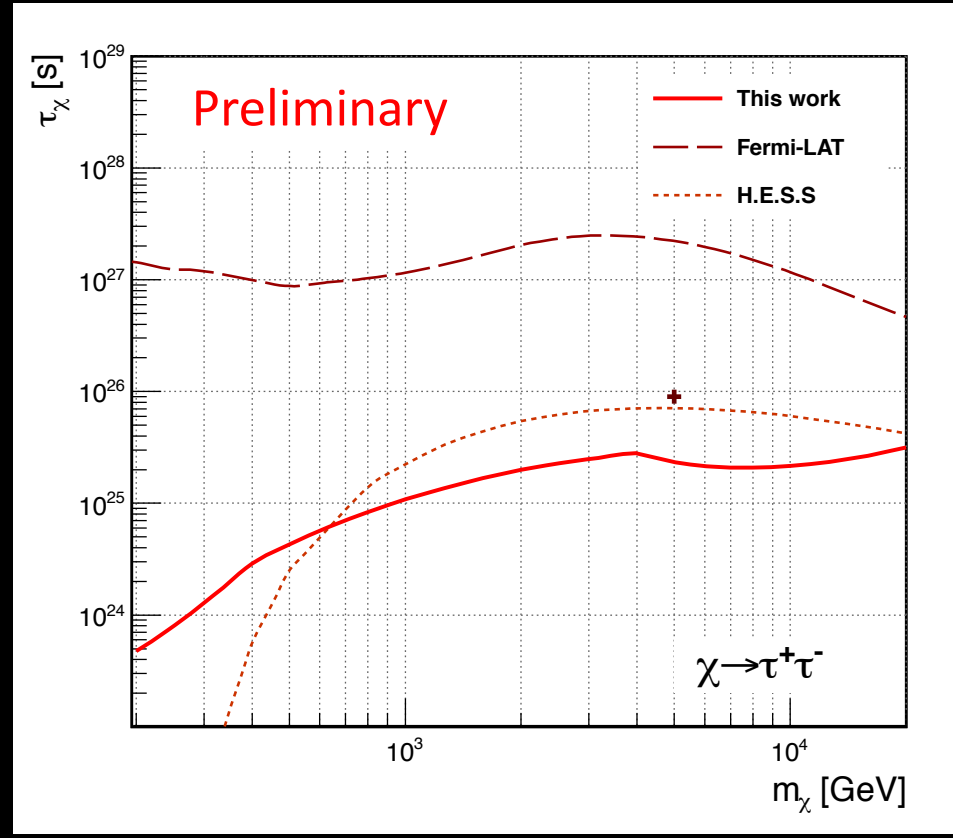
Strongest limit above 300 GeV from dSphs



Strongest limit above 450 GeV from dSphs

Secondary Photons





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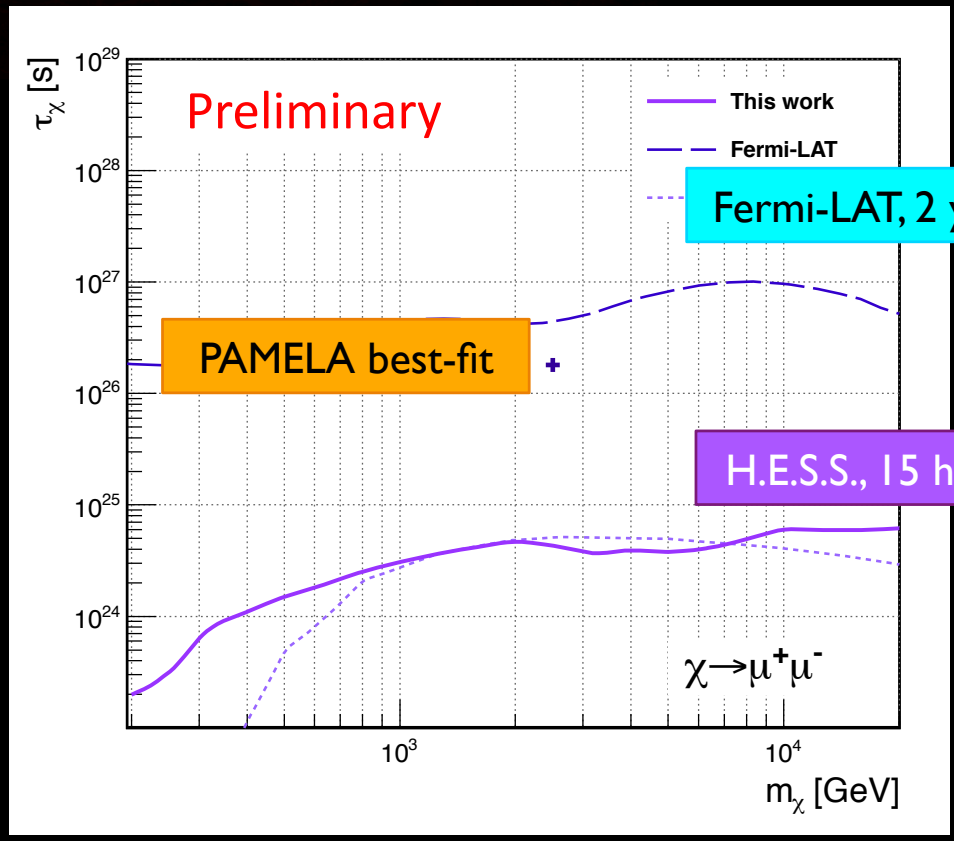
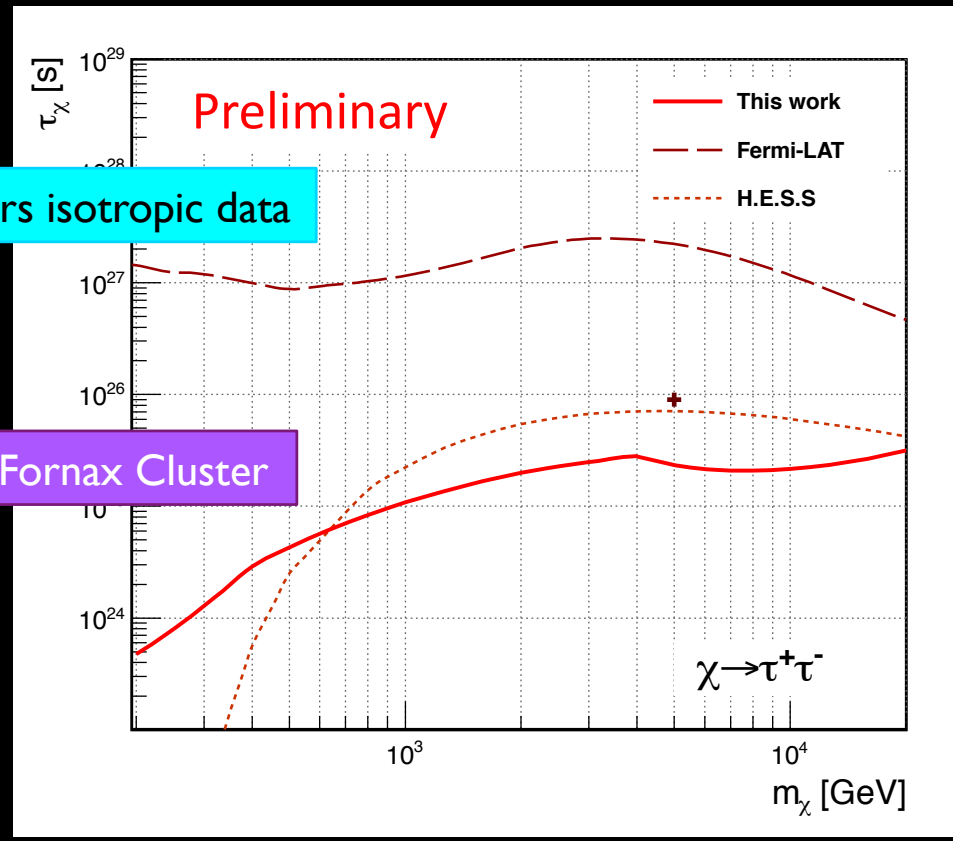
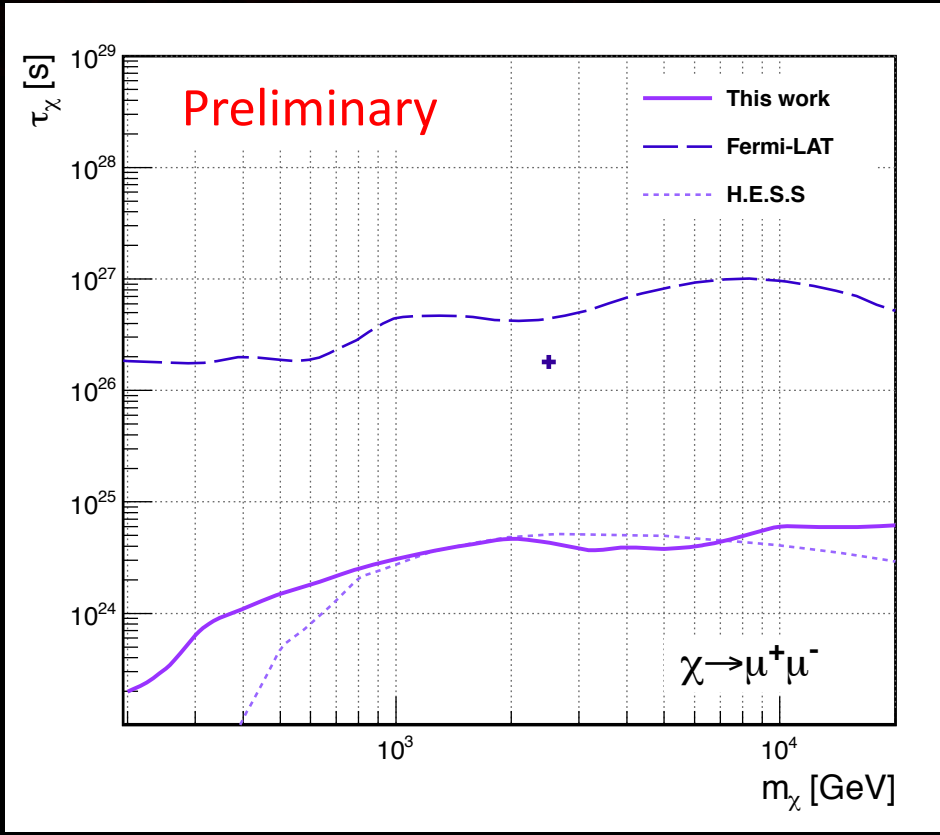


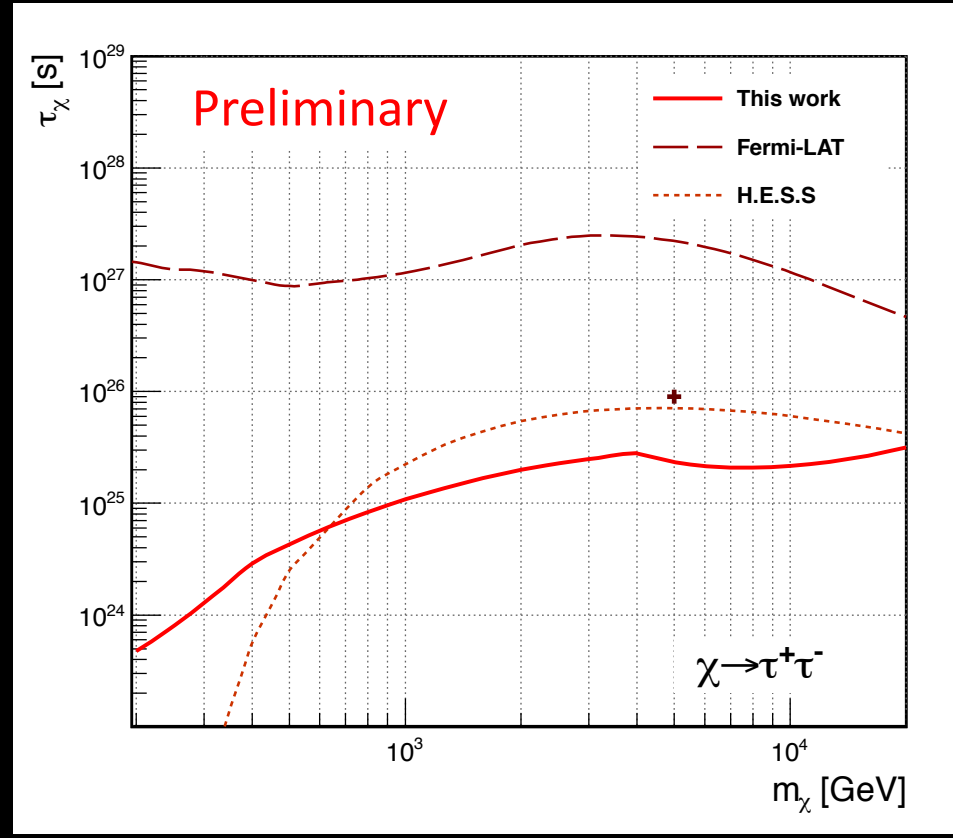
Fermi-LAT, 2 yrs isotropic data

H.E.S.S., 15 h Fornax Cluster



Secondary Photons

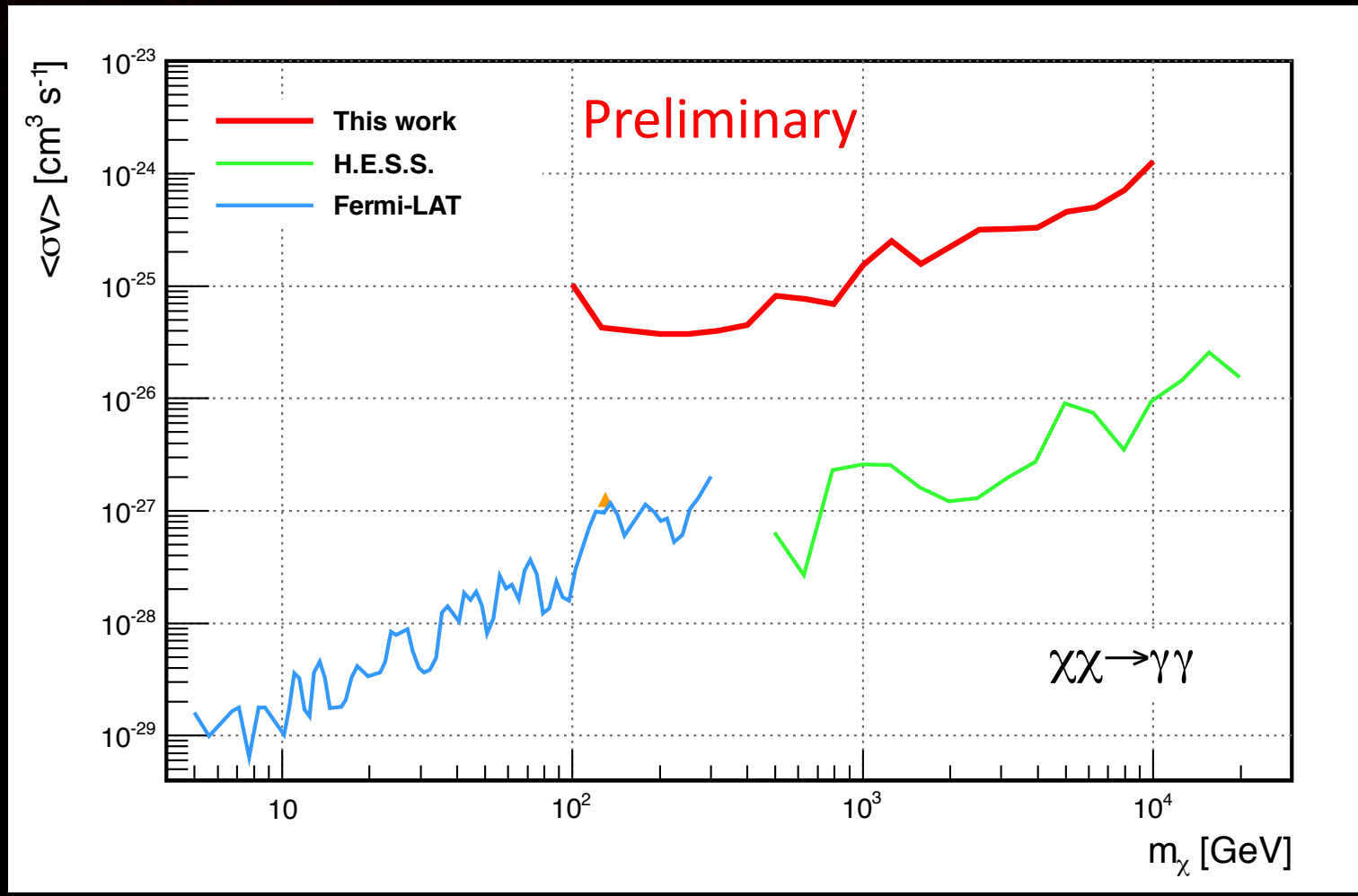




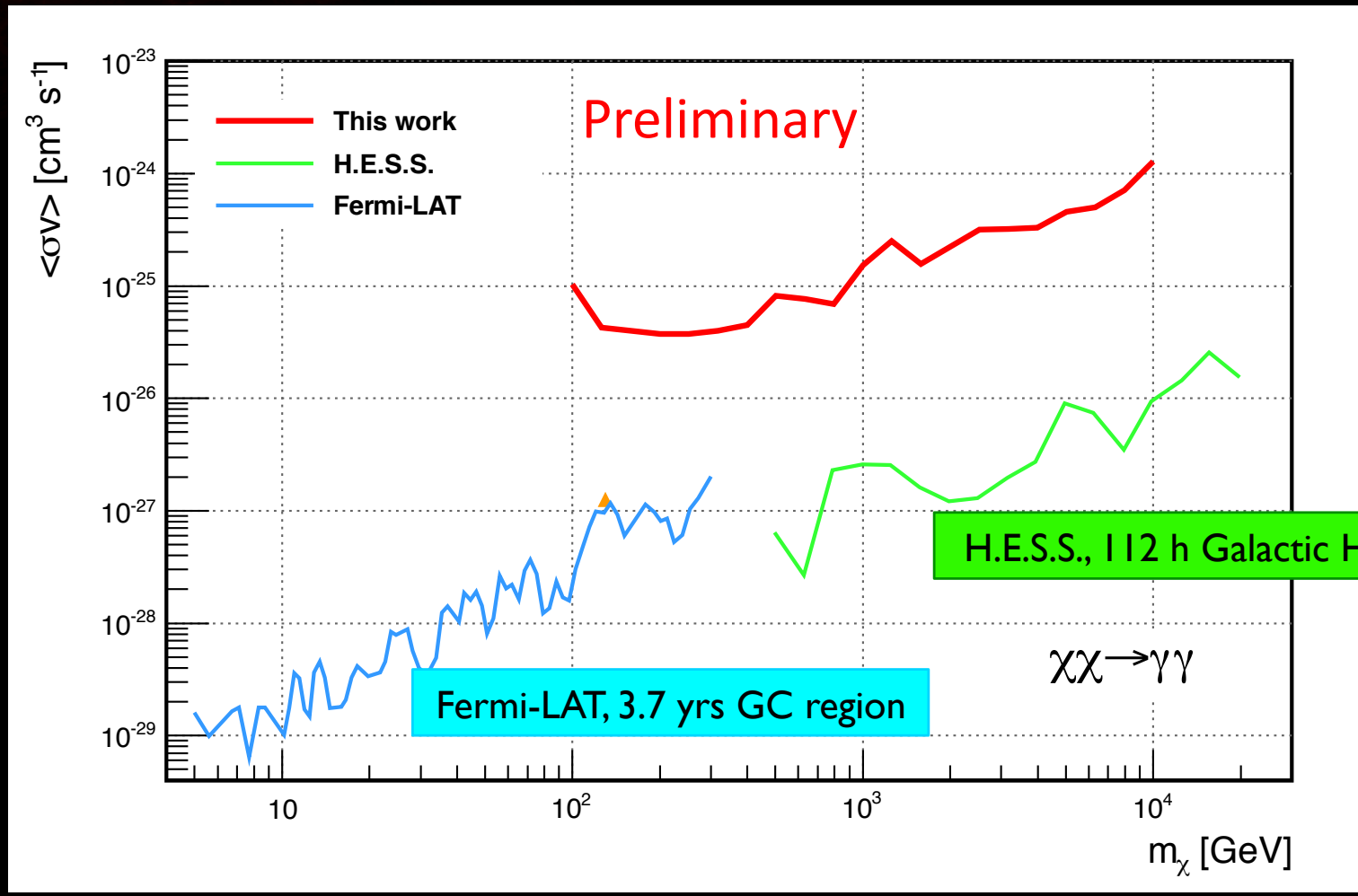
Strongest limit from IACTs

Close to the best-fit value

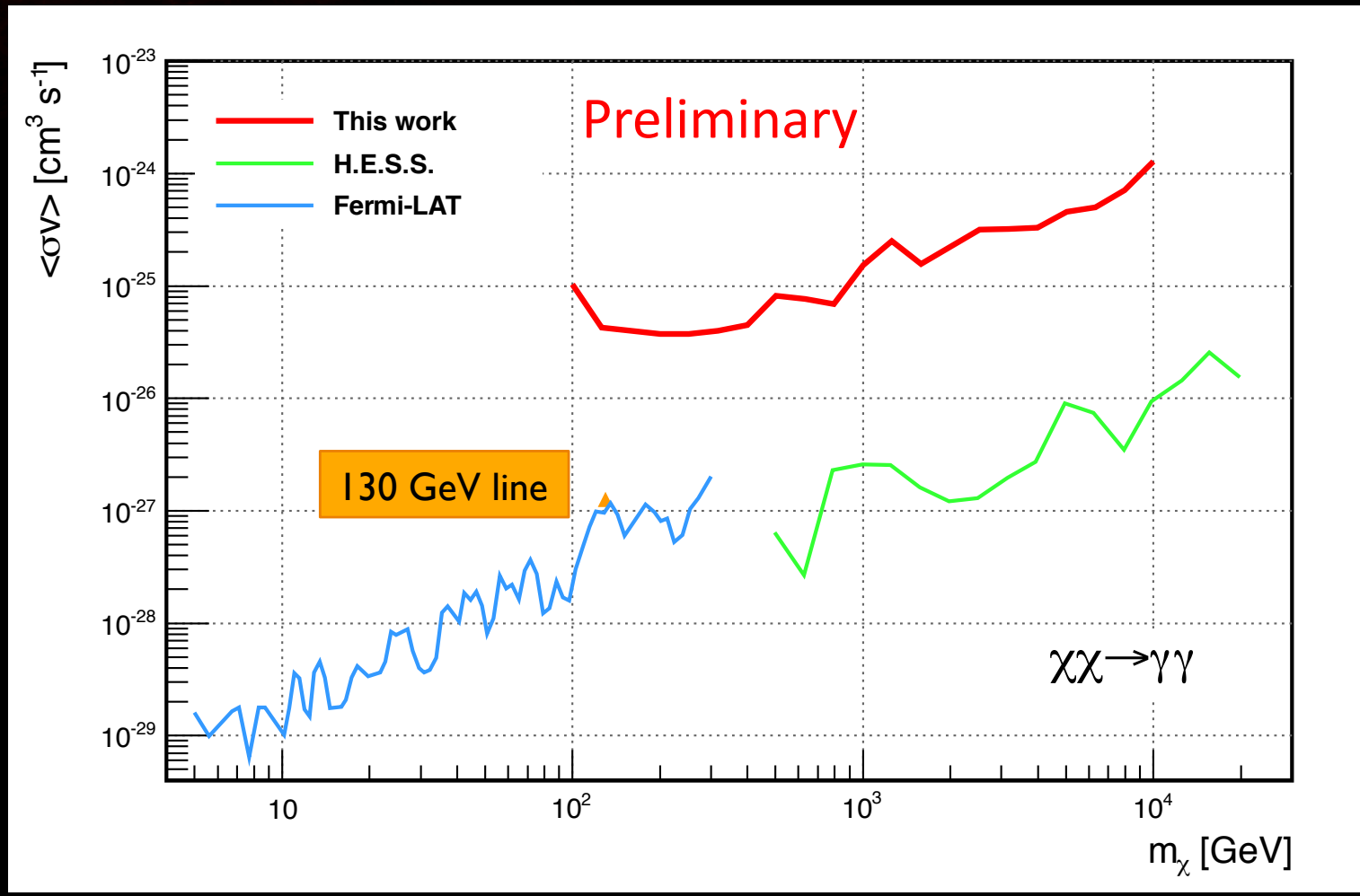
Monochromatic Line



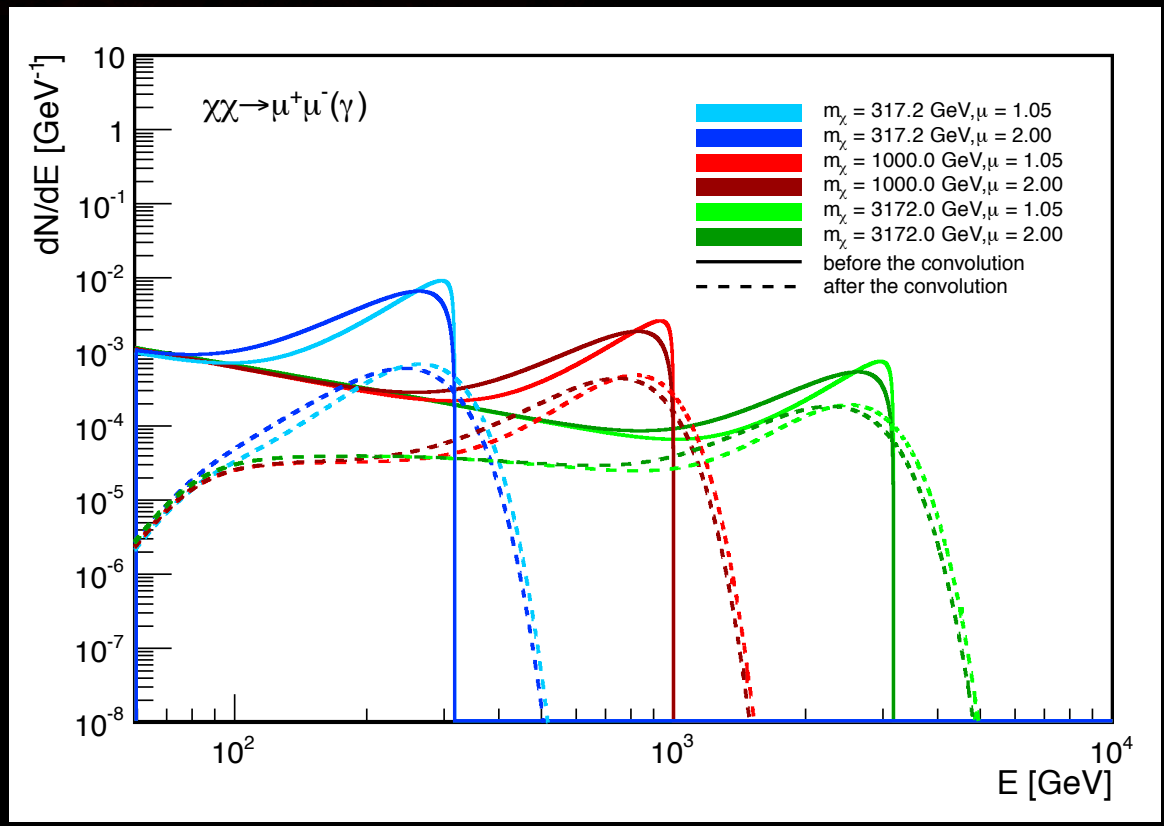
Monochromatic Line

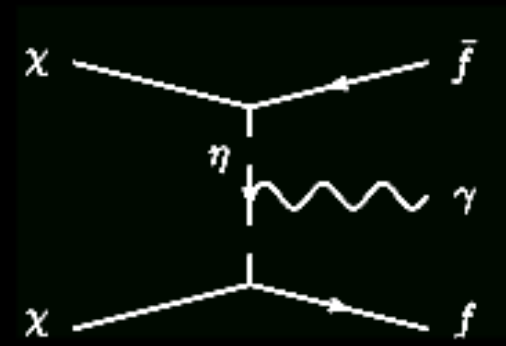


Monochromatic Line



Virtual Internal Bremsstrahlung





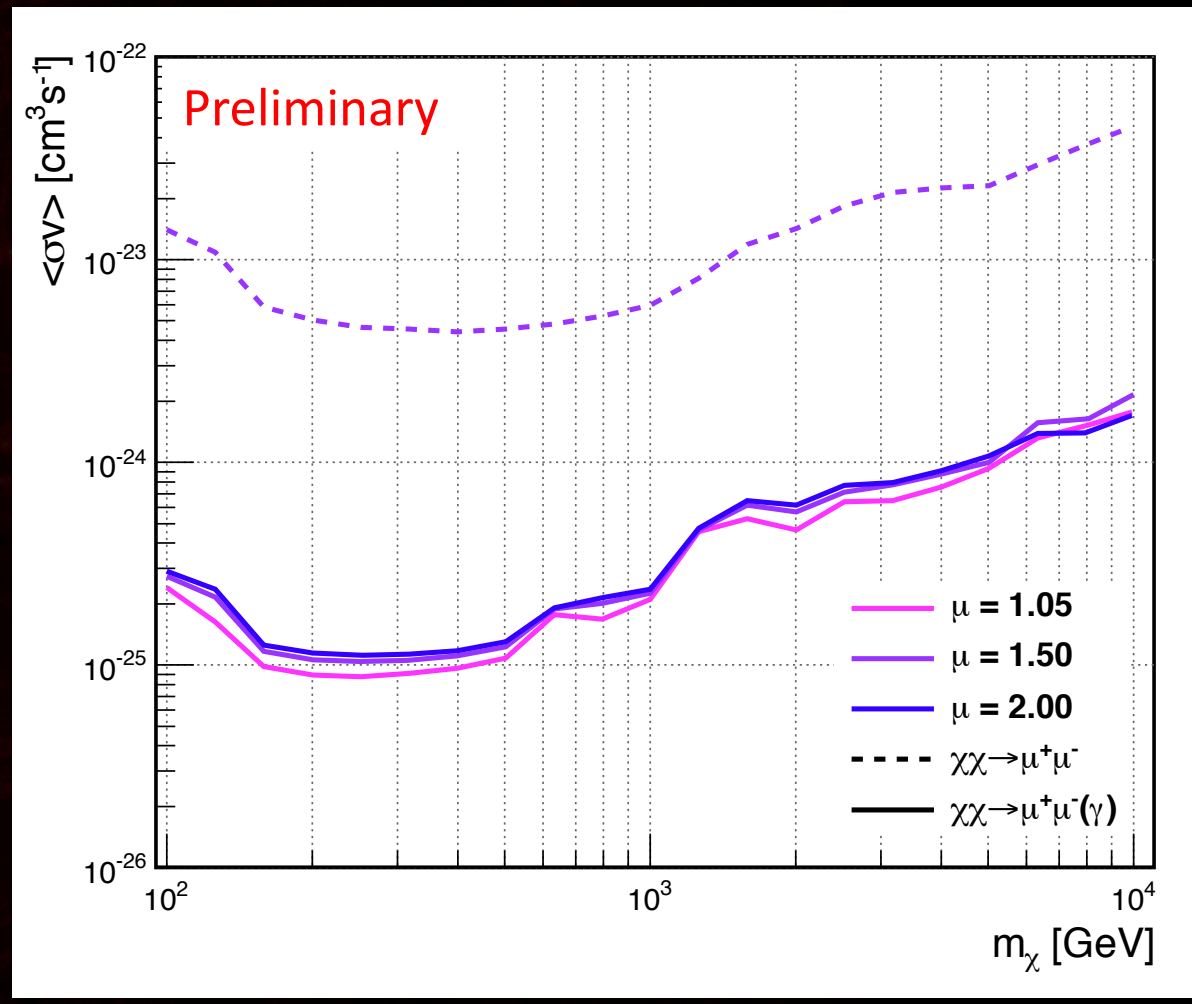
★ Mass splitting parameter μ :

$$\mu = (m_\eta / m_\chi)^2$$

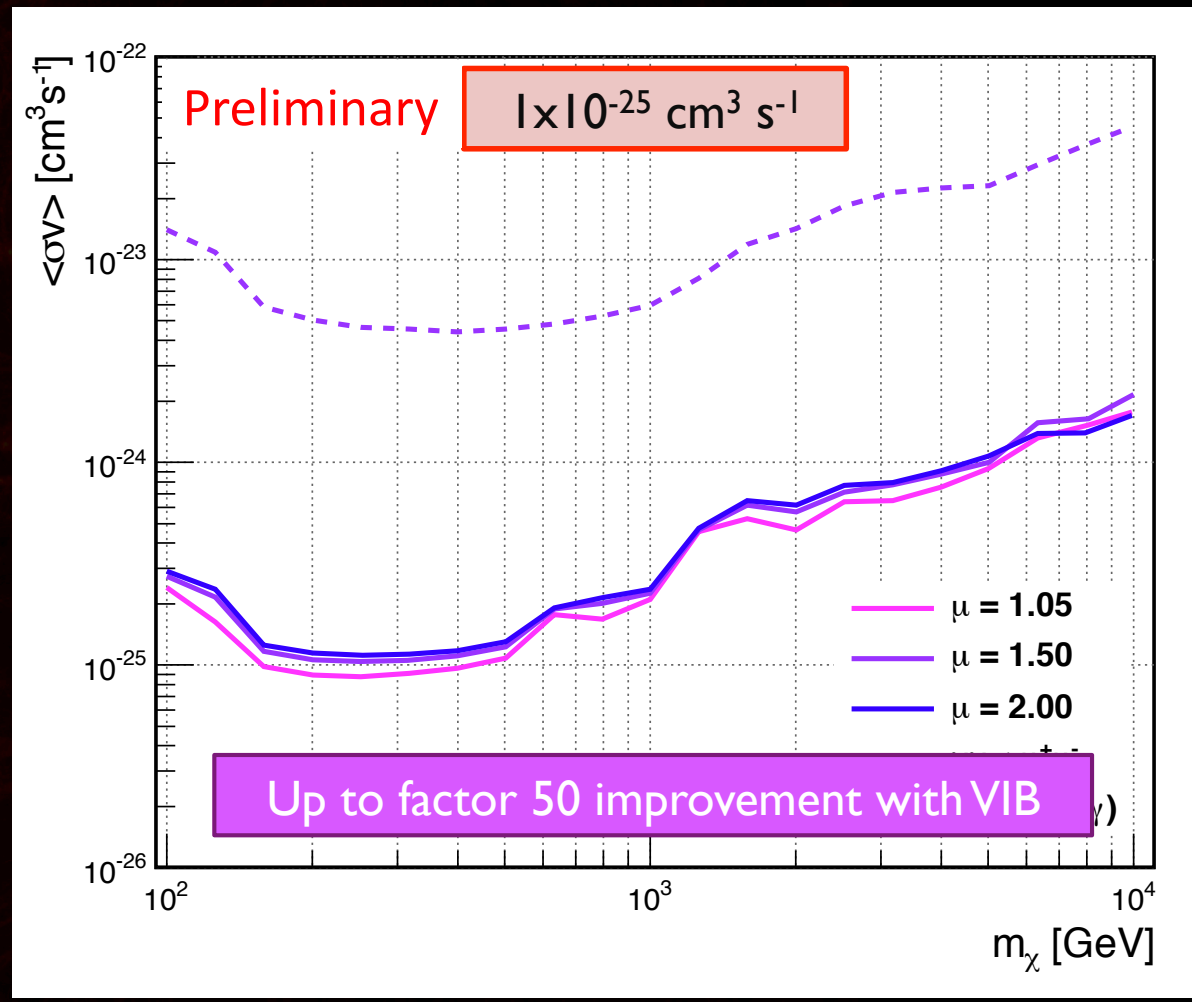
★ Degenerate μ values

★ Extended spectrum; softened peak

Virtual Internal Bremsstrahlung



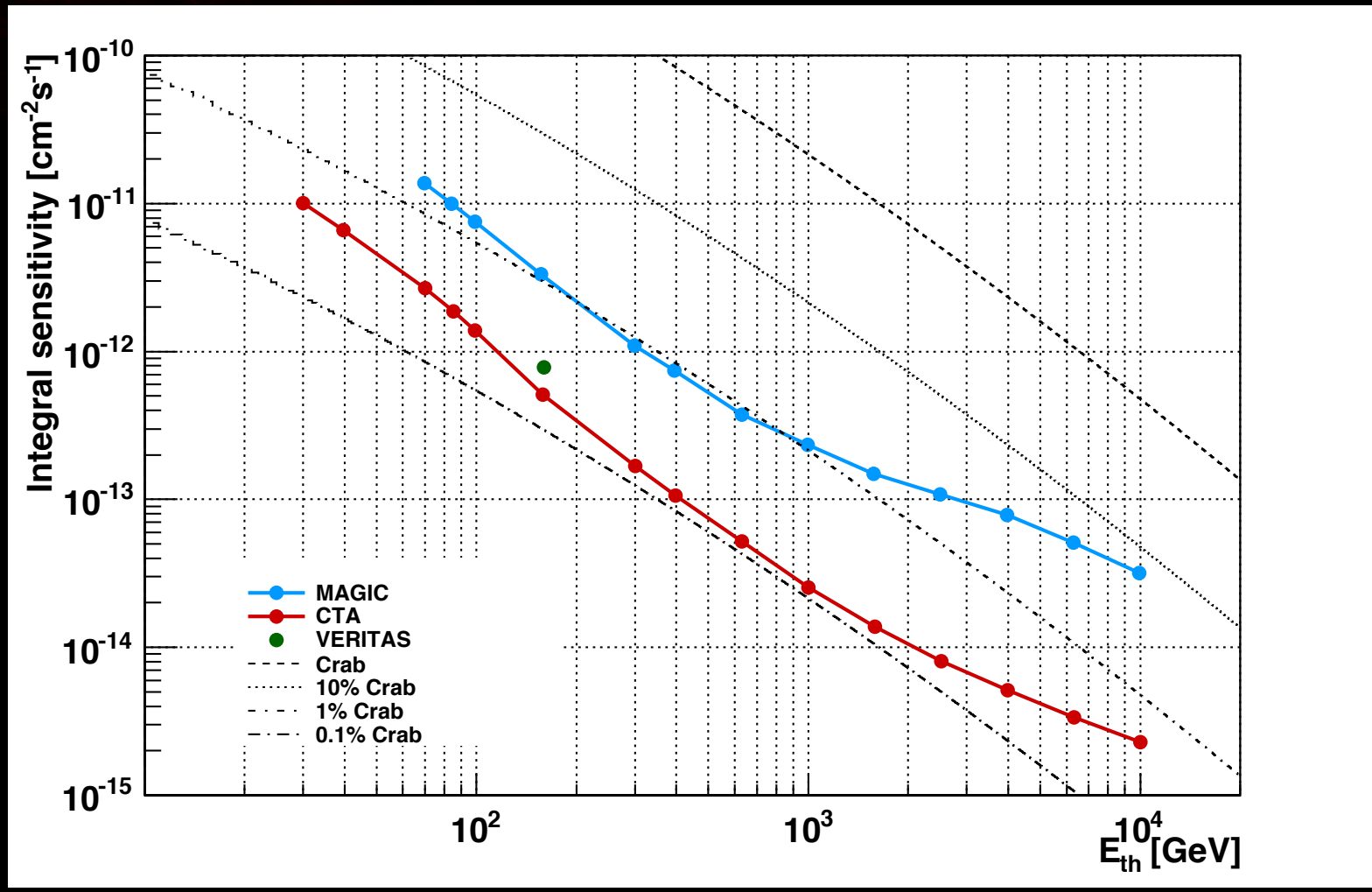
Virtual Internal Bremsstrahlung



Conclusions

- ★ 157.9 h of Segue 1 observations with MAGIC: deepest ever survey of any dSph with any IACT
- ★ Complex combined analysis (different configurations)
- ★ Dedicated analysis, optimized for spectra with features
- ★ Strongest limits on various models of dark matter annihilation/decay from dSph with IACT
- ★ Above certain m_χ, strongest limits from dSphs

VERITAS


Integral sensitivity [cm^{-2}s^{-1}]
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{2}
10^{3}
10^{4}
E_{th} [GeV]
MAGIC
CTA
VERITAS
Crab
10% Crab
1% Crab
0.1% Crab