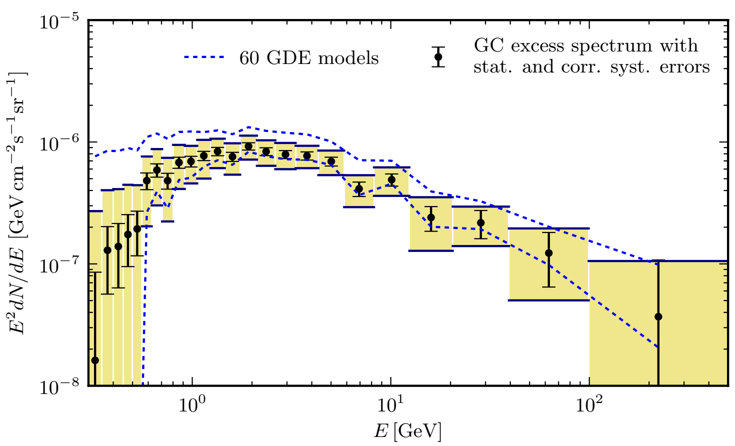
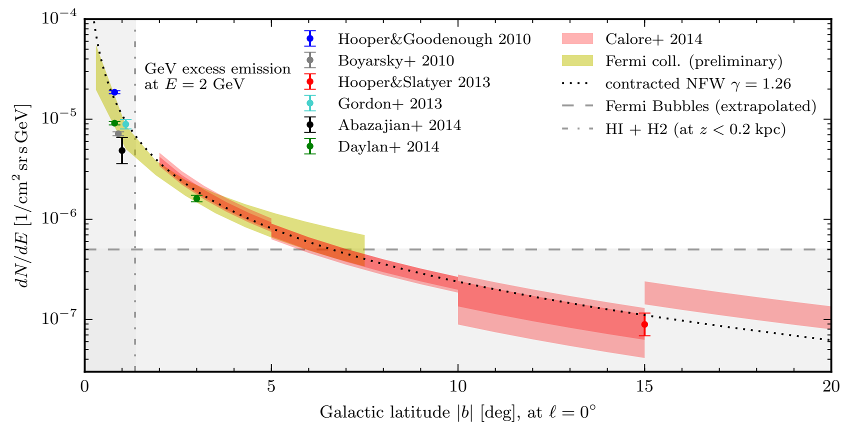
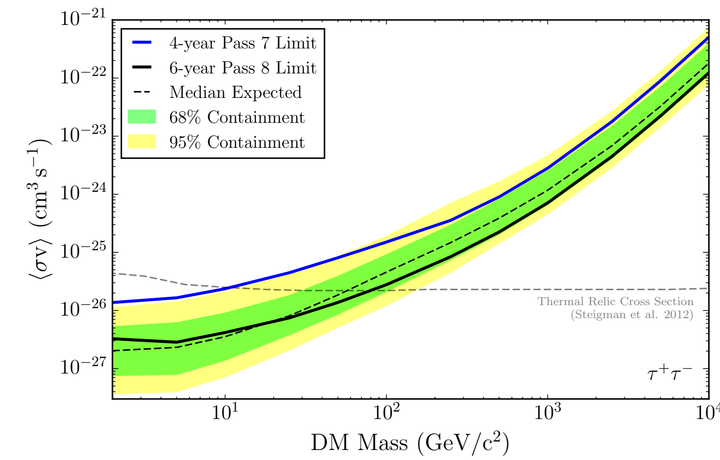
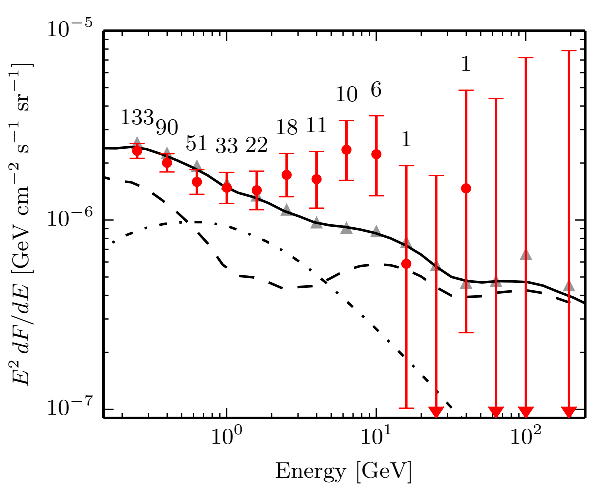
Gamma Rays from DM annihilation, and speculations on MSSM

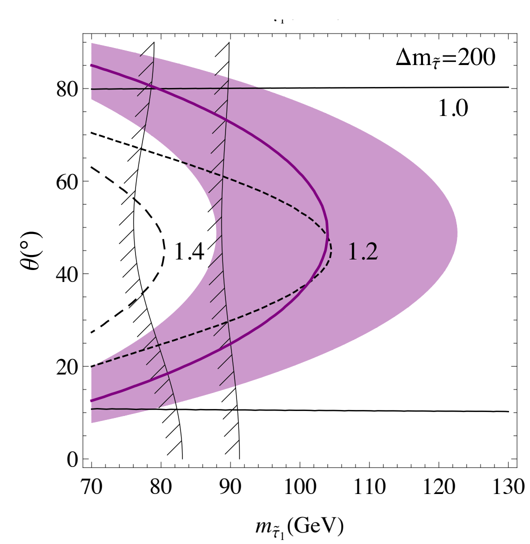
Satyanarayan Mukhopadhyay, Kavli IPMU, University of Tokyo

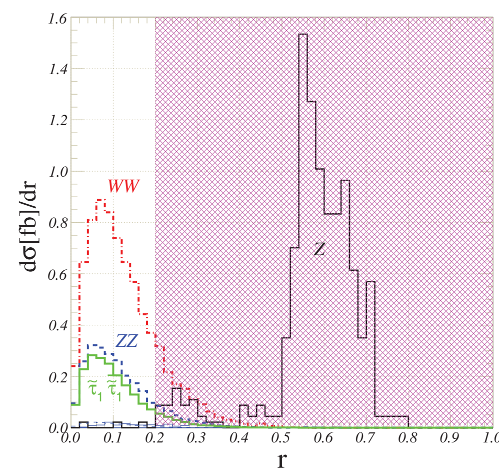


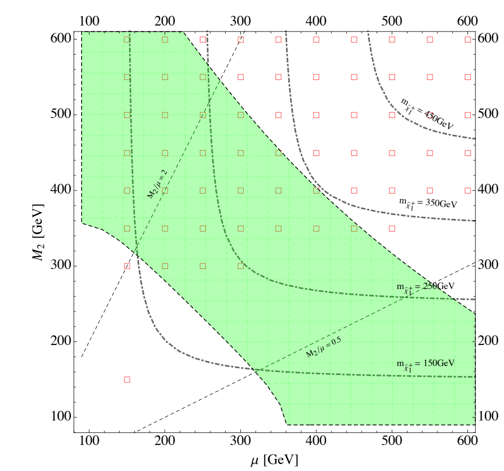












KAERU

March 25, 2015

WIMP's and gamma-ray signal

Requirement: chemical equilibrium with the SM sector in the early universe

Consequence: pair annihilation in the present epoch in DM-dense regions

annihilation rate ~ weak-coupling cross-section

Caveat: not true if we are "unlucky" (co-annihilations, s-channel pole etc. in the early universe). Need σv to be large enough for $v \to 0$

Why continuum gamma-rays is a promising signal to look for:

1. Travels in straight lines : can focus on interesting targets (GC, dSphs)

2. Almost all possible SM final states lead to hard photons (Brems., ICS, decays of neutral pions). Only neutrinos don't (unless they radiate W/Z).

Where to look?

1. Inner few degrees around the Galactic Centre: high signal rate expected, difficult to model background sources. Large profile uncertainty.

2. Nearby dwarf galaxies: DM dominated, more robust, J-factor ~100 times smaller than GC. Profile better measured : best for setting bounds.

Gamma-ray sky as observed by Fermi-LAT

Fermi Sky − Galactic Diffuse − Isotropic − Point Sources

= Residual (e.g., dark matter)

Sources of Galactic Diffuse Emission (GDE)

1. Inverse Compton: CR electrons up-scattering low-energy photons
2. Neutral pion decays: CR protons inelastic collision with nuclei (gas)
3. Bremsstrahlung : CR electrons interacting with interstellar gas

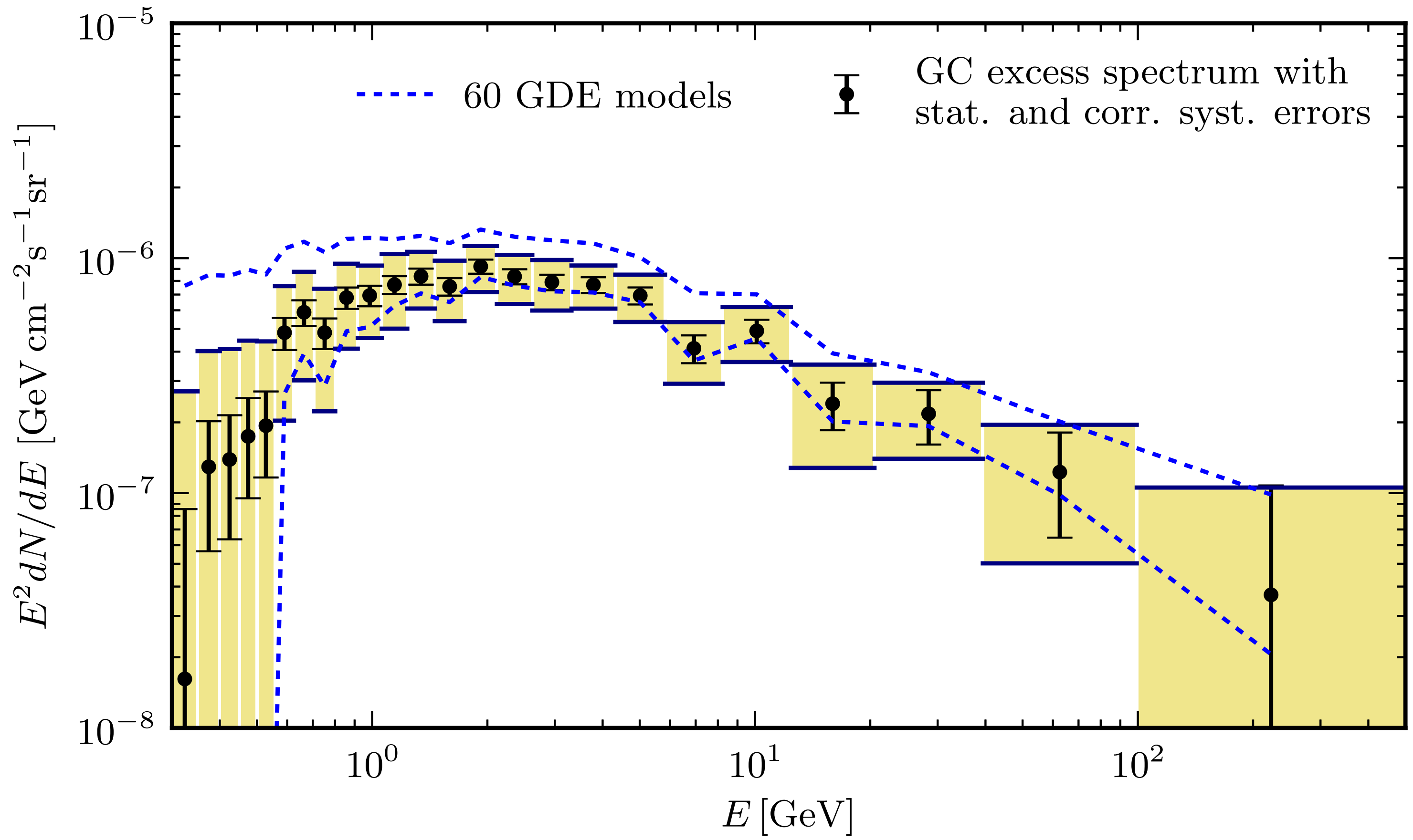
Modelling of cosmic-ray properties near the GC leads to largest systematic uncertainty in GDE

A gamma-ray excess from the GC?

- CCW: Take a 20 deg x 20 deg region around the GC (mask the inner 2 deg). Fermi collaboration uses a 15 deg x 15 deg region
- Try many many GDE models. Can they fit the gamma ray data (300 MeV to 500 GeV)?
- No. Add a new template for a second emission mechanism.
- The data-model agreement improves “significantly”.
- Variation of GDE gives the systematic uncertainty
- The residual spectrum: GCE

Fermi-LAT (preliminary)
S. Murgia, Talk given at Fifth Fermi Symposium, Nagoya, October 2014

Calore, Cholis, Weniger, 1409.0042

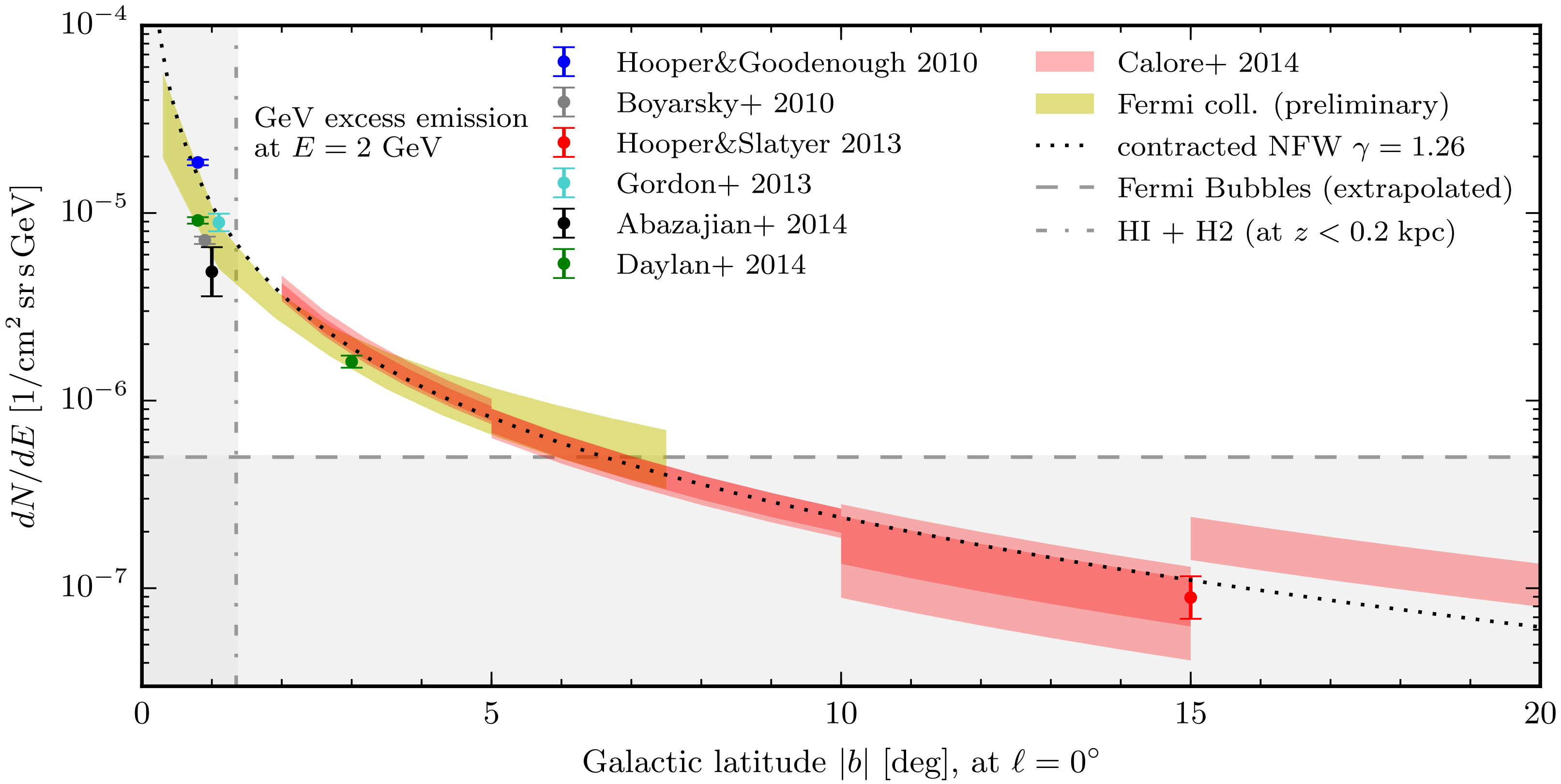


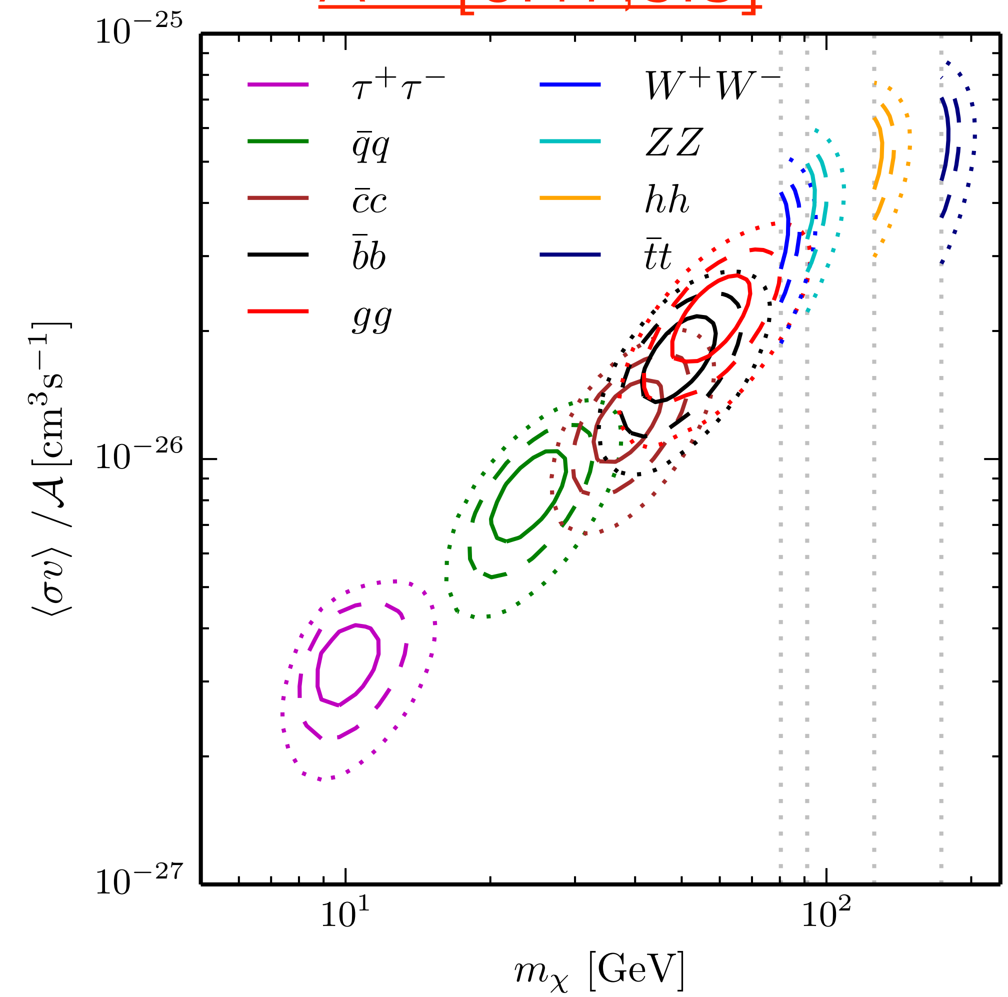
Is it DM annihilation? Spatial extension of the Excess

Check-1: extension at higher latitudes should follow the DM distribution

1411.4647, Calore, Cholis, McCabe, Weniger

Due to uncertainties in DM halo in the Milky Way: A = [0.17,5.3]





Extension upto 10 deg. latitude following a gNFW^2 profile is intriguing from the DM annihilation point of view. The residual is spherically symmetric, and of uniform energy.

And the story of 15 dwarfs

jp.arXiv.org > astro-ph > arXiv:1503.02641

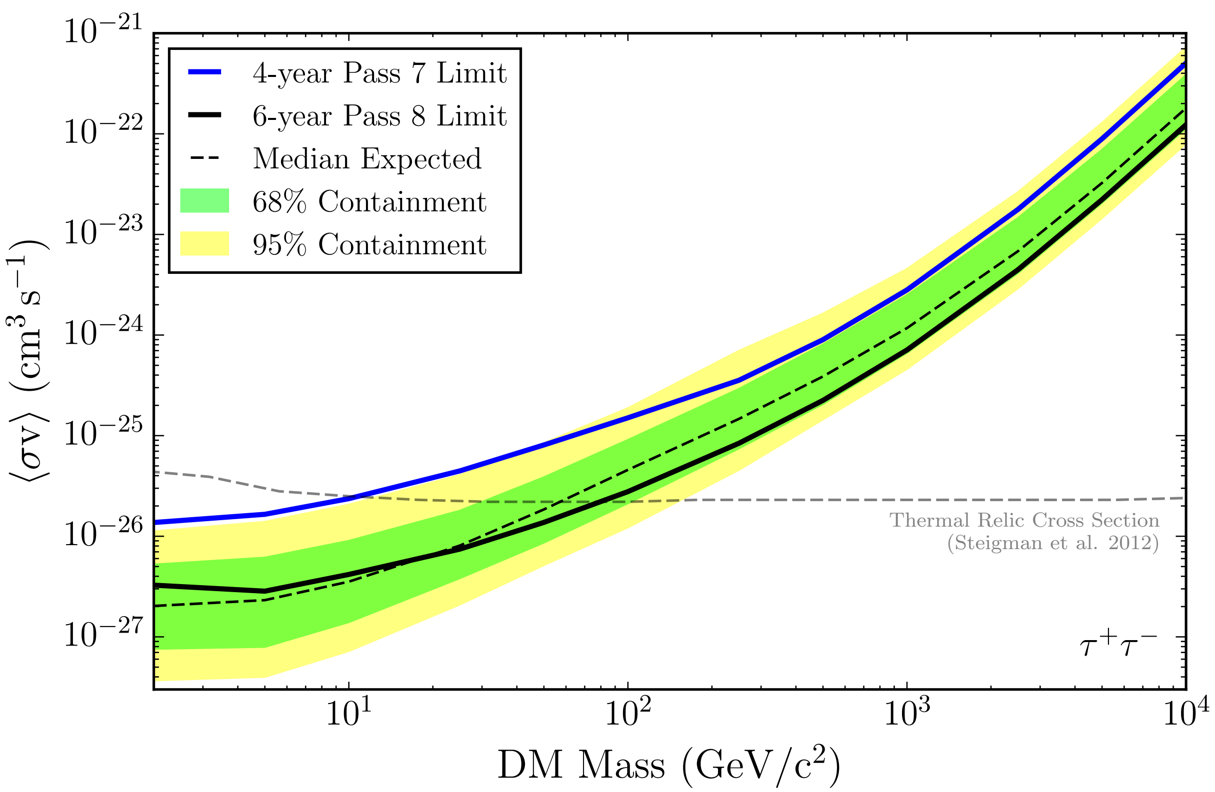
Astrophysics > High Energy Astrophysical Phenomena

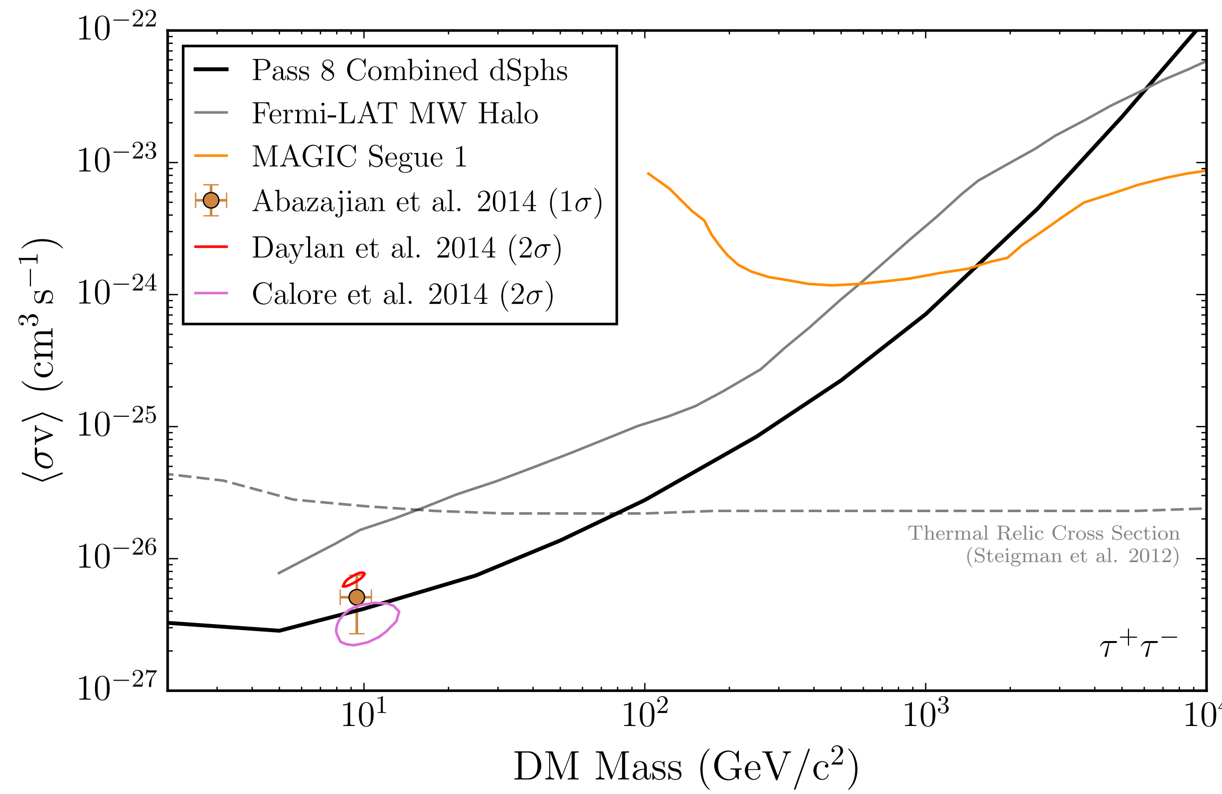
Searching for Dark Matter Annihilation from Milky Way Dwarf Spheroidal Galaxies with Six Years of Fermi-LAT Data

Fermi-LAT Collaboration

(Submitted on 9 Mar 2015)

Pass8 data

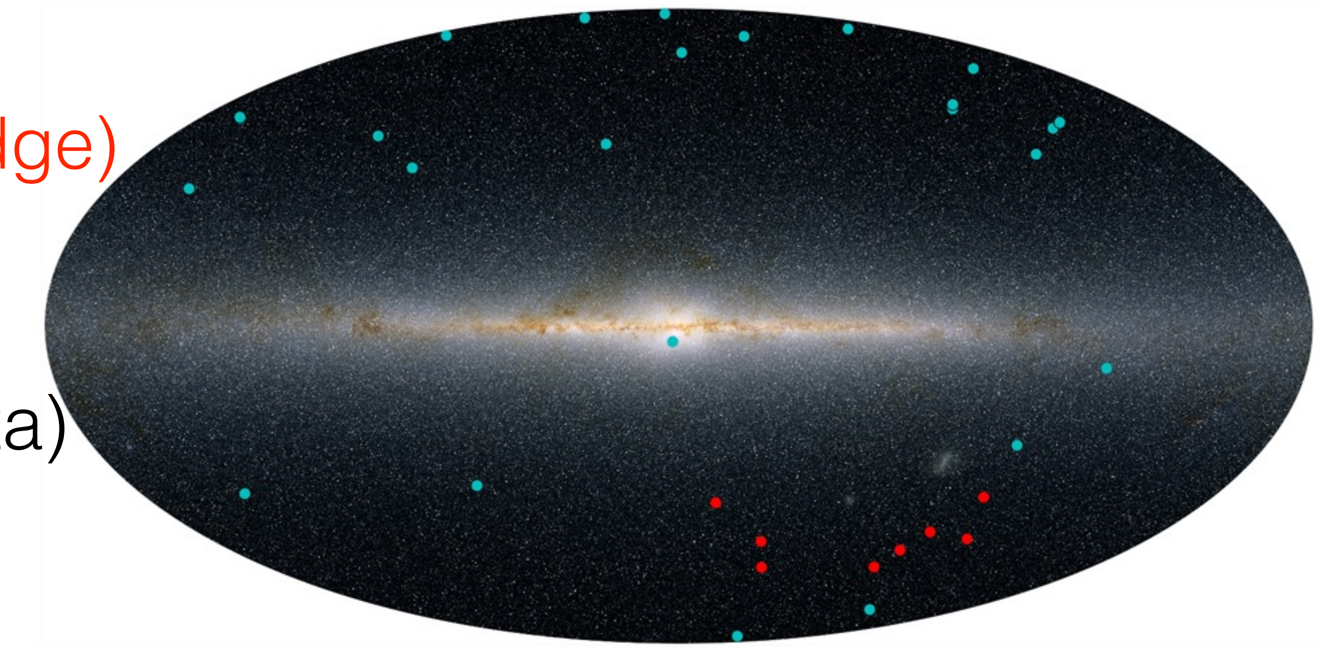




Additional systematic uncertainty (mostly from halo model): around 30%

And more dwarfs coming (with a signal?)?

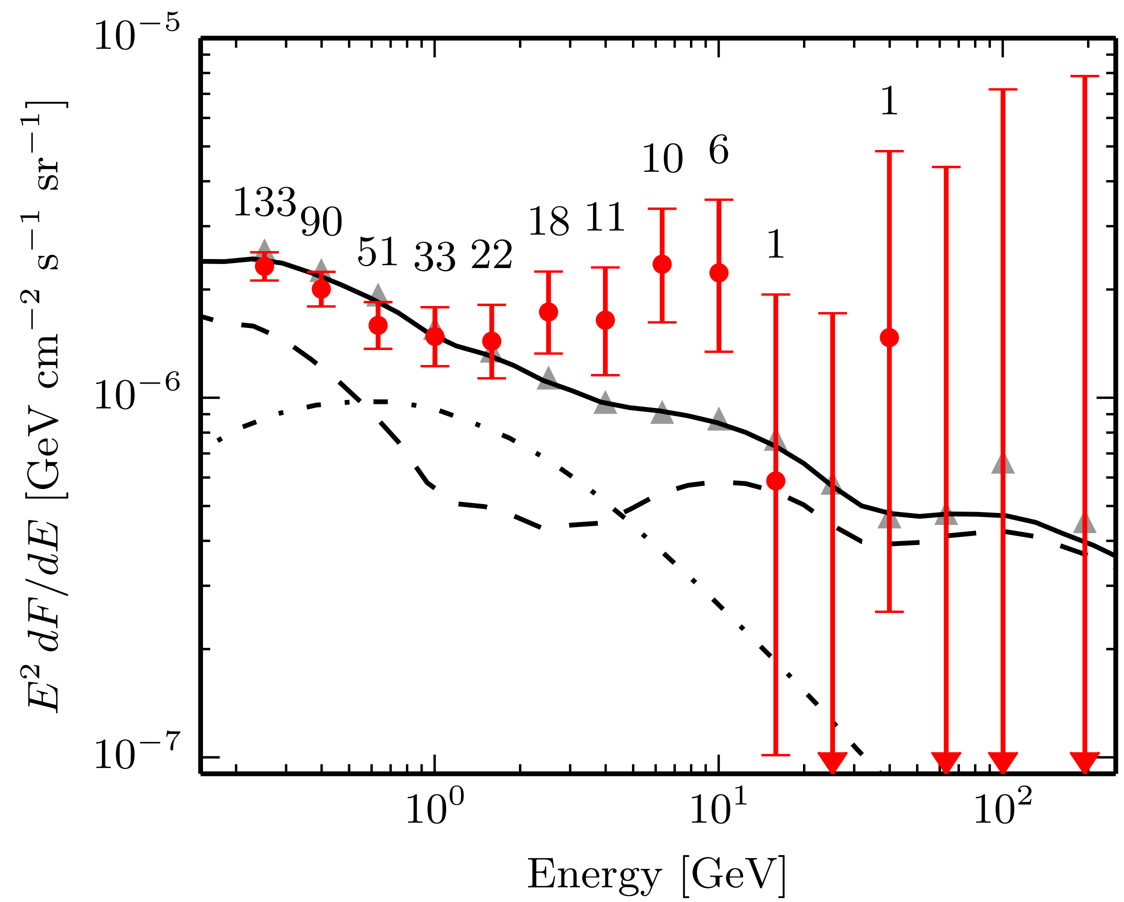
8 (9?) new dSph candidates found in Dark Energy Survey data by two groups DES collab., and Koposov et al (Cambridge)

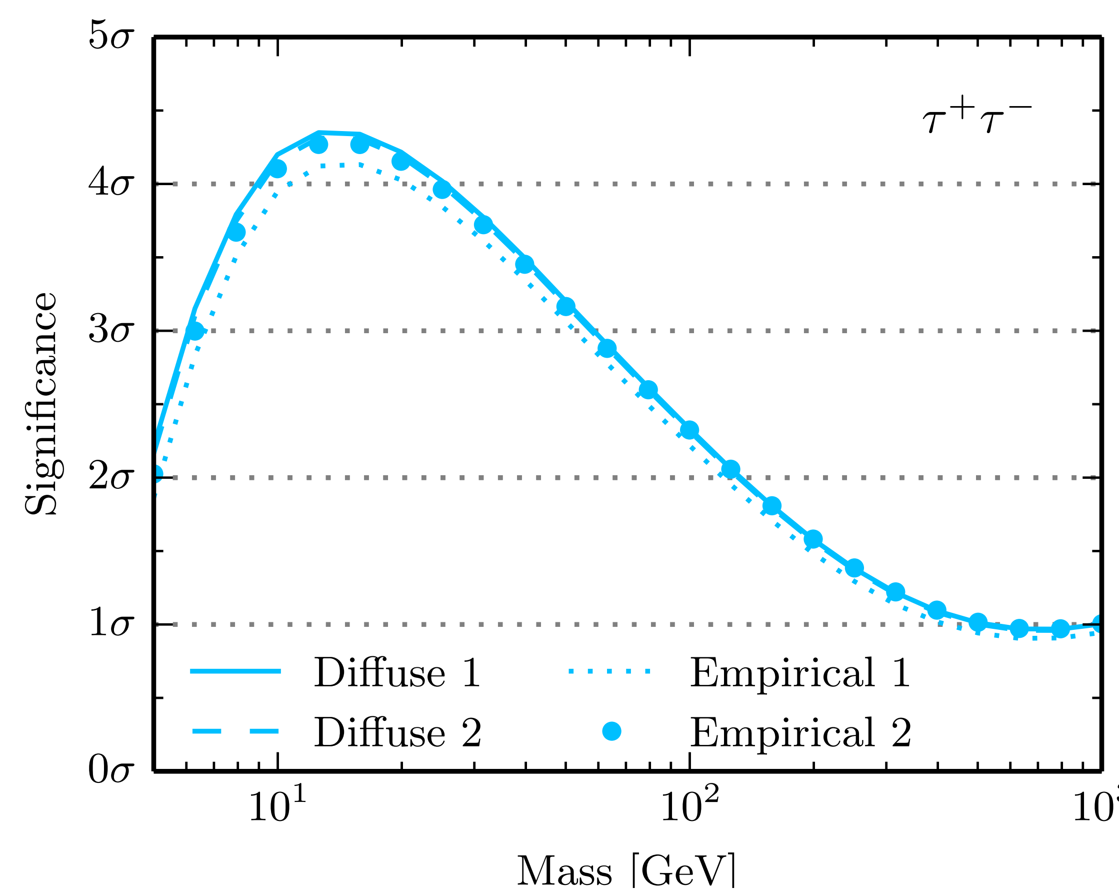


Fermi-LAT does not find an excess in the 8 DES dSph candidates (PASS8 data)

1503.02632, Fermi-LAT+DES

1503.02320, Geringer-Sameth, Walker, Koushiappas+Koposov et al





Our Speculation: an MSSM scenario with light Stau and Bino DM

Hagiwara, SM, Nakamura, 1308.6738

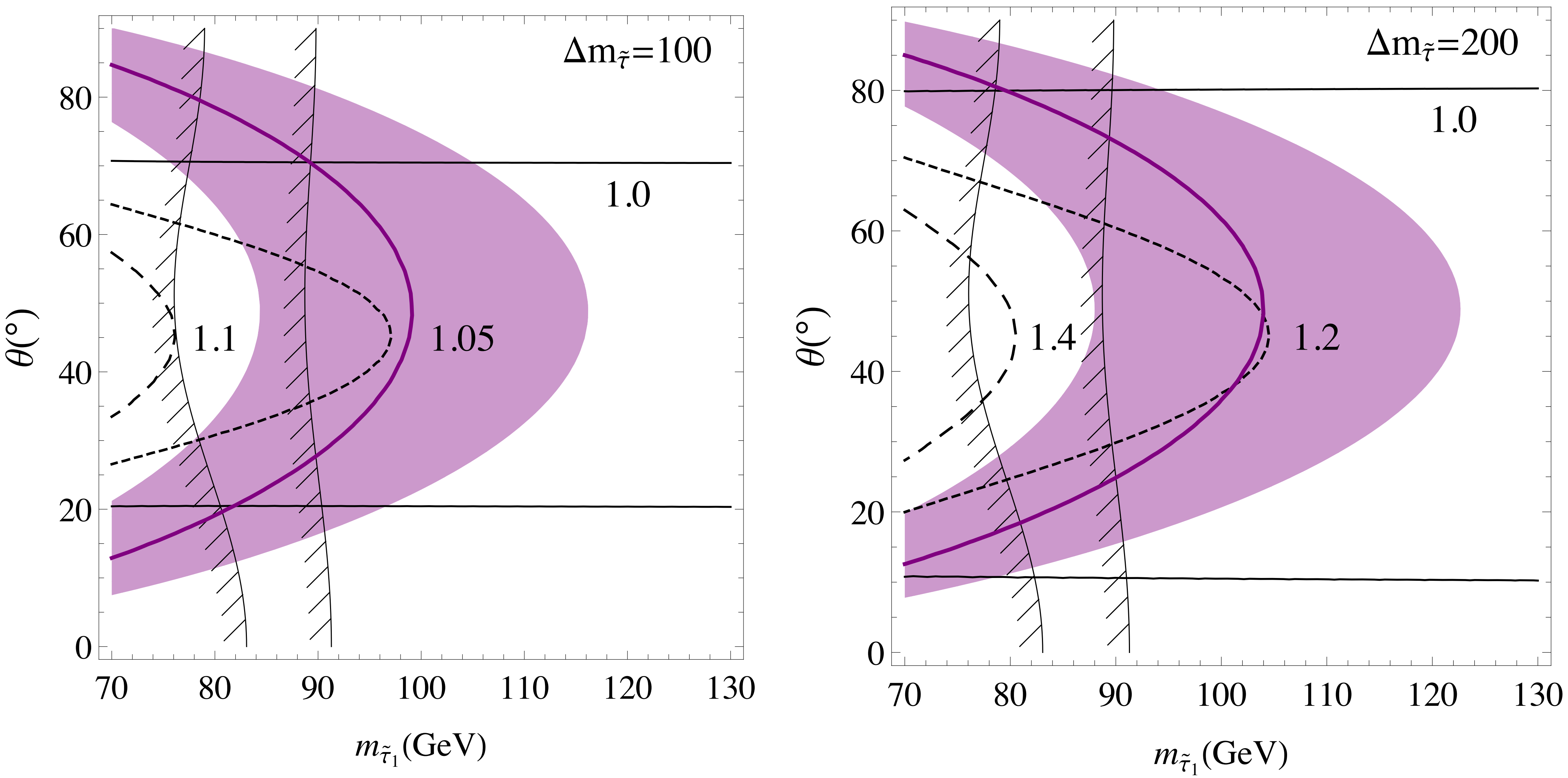
$$\tilde{B}\tilde{B} \to \tau^+\tau^-$$

- ~10 GeV neutralino has to be almost a pure Bino
- The Higgsino fraction should be very small: Invisible Z-boson and Higgs decay constraints
- S-wave annihilation of a Majorana fermion pair is suppressed by m_τ^2 : not enough to match the GCE normalization.
- This suppression can be lifted if the t-channel exchanged stau has large L-R mixing, also need somewhat large splitting of the stau's
- Such a stau mixing also impacts $h \to \gamma\gamma$
- Required L-R mixing, and large mass splitting OK with electroweak precision (and vacuum metastability etc).

How to achieve $\langle\sigma v\rangle_0 \sim 2\times 10^{-27}\mathrm{cm}^3/\mathrm{s}$?

$$\langle\sigma v\rangle \xrightarrow{v\to 0} \frac{g'^4\beta_\tau}{128\pi}\left[\frac{4\left(m_\tau Y_R^2 s^2 + 2m_{\tilde{B}}Y_L Y_R sc + m_\tau Y_L^2 c^2\right)}{\Delta_1} + \frac{4\left(m_\tau Y_R^2 c^2 - 2m_{\tilde{B}}Y_L Y_R sc + m_\tau Y_L^2 s^2\right)}{\Delta_2}\right]^2$$

$$\Delta_i = m_{\tilde{\tau}_i}^2 + m_{\tilde{B}}^2 - m_\tau^2.$$



How to test such a scenario?

- Find a O(100 GeV) scalar-tau at the LHC! No constraint from LHC8. May be new cuts to improve the reach at LHC13 (or sufficient luminosity?) arXiv:15**.*****(hep-ph): Hagiwara, Ma, Nakamura, and Zheng

- Direct detection rates too low, as the Higgsino fraction is constrained (checked upto 1-loop level, can be above neutrino-nucleon floor). But not correlated as such.

- Indirect probe: Charginos or (Neutralino2) can decay via a light-stau to give 2-3 tau (hadronic)+MET final state. But how to motivate light C1 or N2? : the muon (g-2) anomaly? Talks by Thomas Teubner and Naohito Saito

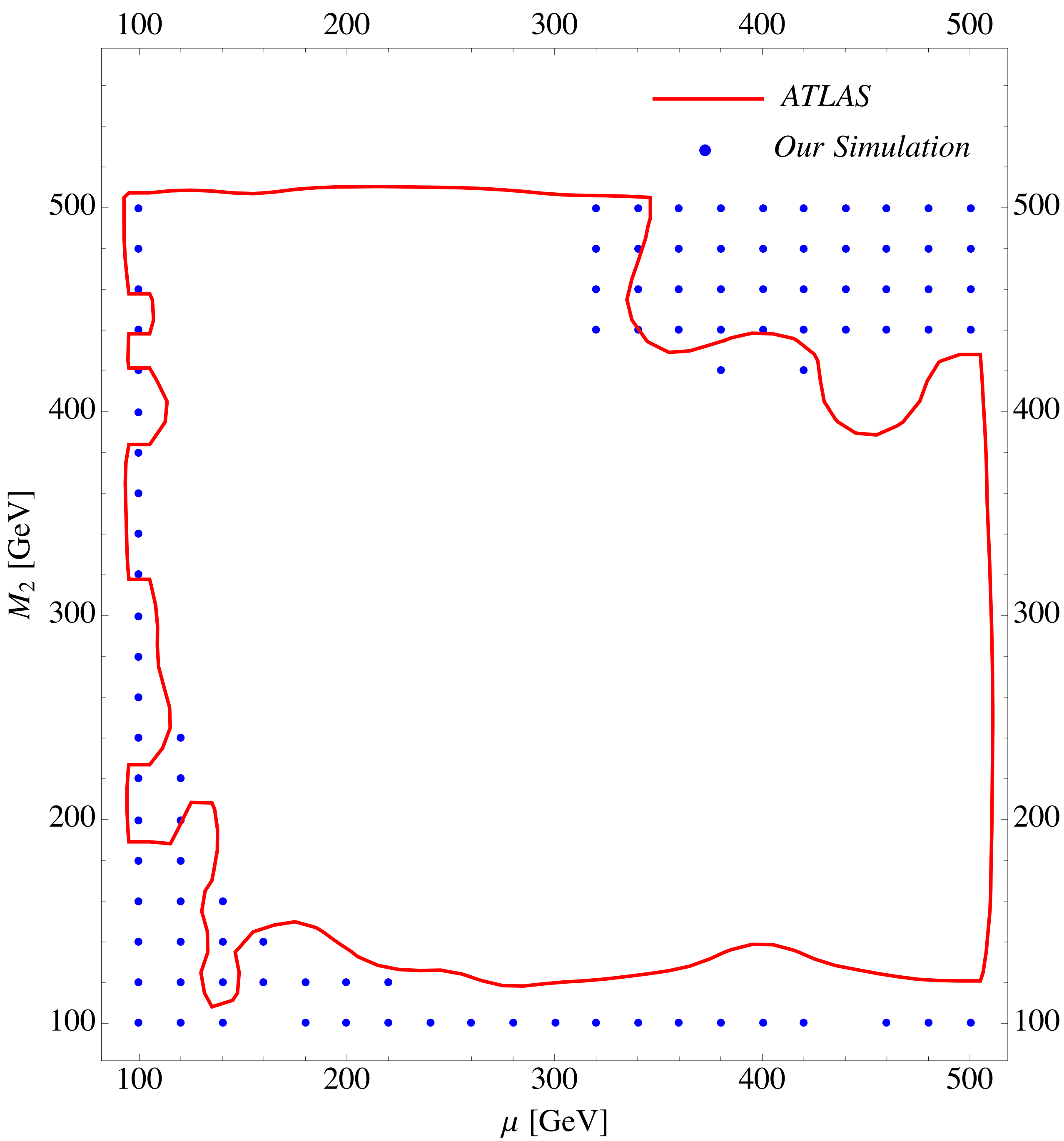
- If Bino is only 10 GeV, and has almost no mixing with Higgsino, the dominant contribution to the muon (g-2) in MSSM comes from chargino-muon sneutrino loop.

- Even without the GCE, thermal neutralino DM can be light and O(30 GeV) with the help of a light stau (new dSphs bounds?). Then from the muon (g-2) point-of-view the search for C1C1+C1N2 production in multi-tau+MET final state is important (given the current LHC bounds on selectrons/smuons/C1/N2).

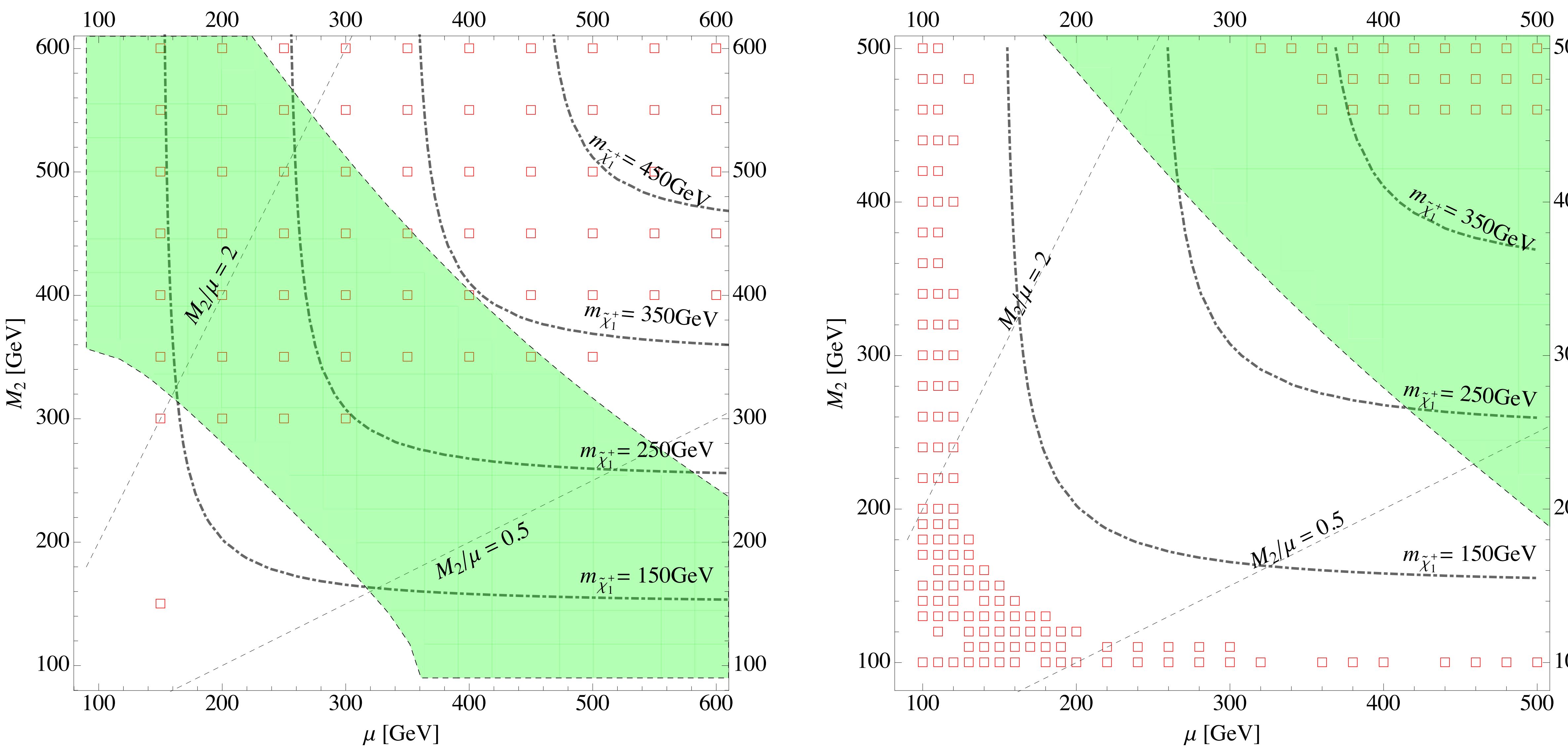
Revisiting the LHC search for weak-inos in multi-tau channel

Hagiwara, SM, Ma, in preparation

- ATLAS LHC8 analysis (JHEP 10, 2014, 096). Plot: pMSSM model with M1=50 GeV, mStauR=95 GeV, tan(beta)=50. Rest of the sparticles decoupled.
- Rather complex search with hadronic tau's+MET in 4 signal regions: all our work went into making this figure!
- *For sufficient chargino-muon sneutrino contribution to the (g-2) (with left smuon>350 GeV), we need large tan(beta) (>20), (M2/mu) not too small/large, and (M2 x mu) > 0.*
- Then depending upon tan(beta), this search implies an upper limit on left smuon mass.



Recasting the ATLAS results and the muon (g-2)



tan(beta)=20 tan(beta)=30

M1=10 GeV, scalar-muon masses fixed to 350 GeV

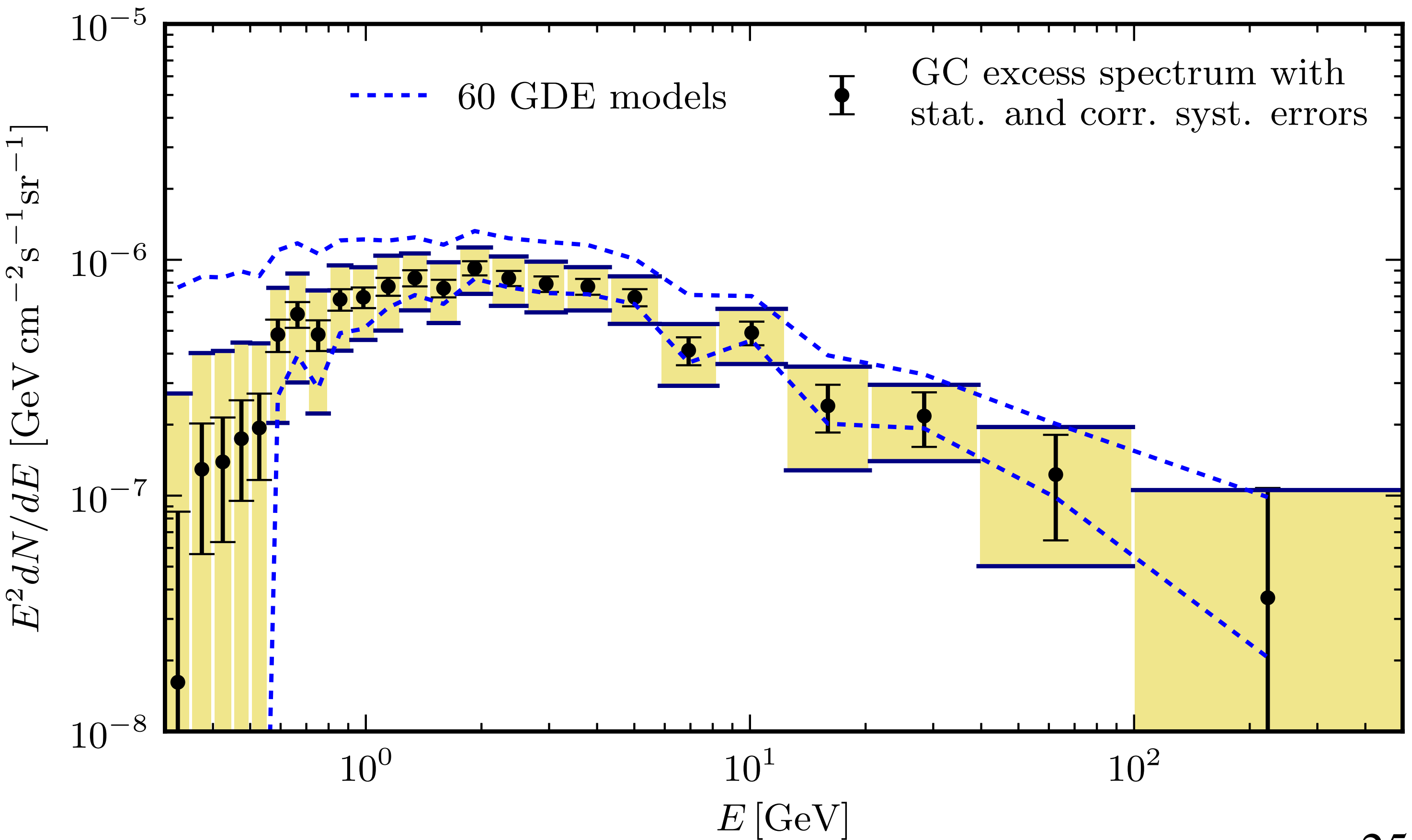
Left scalar-muon with mass upto 600-700 GeV is OK, to accommodate the (g-2) anomaly within 1-sigma. Can probe the whole region at LHC13?

Loose ends: still thinking!

- The annihilation rate at freeze-out epoch is not enough. Left like this, the Bino will over-close the universe.
- Strong bounds on 1st/2nd generation sleptons : not enough p-wave contribution.
- Recent dSphs bounds force us to look for large p-wave amplitudes only (or s-wave to neutrinos).
- Possible way out-1: non-standard thermal history—entropy production at late times, after freeze-out epoch.
- Need a reheating temperature of ~ 0.3 GeV, dilution by (T_RH/ T_FO)^3
- Safe from BBN, but how about n_effective measurement of PLANCK?

Back-ups

A Tale of Tails : the difference from earlier studies

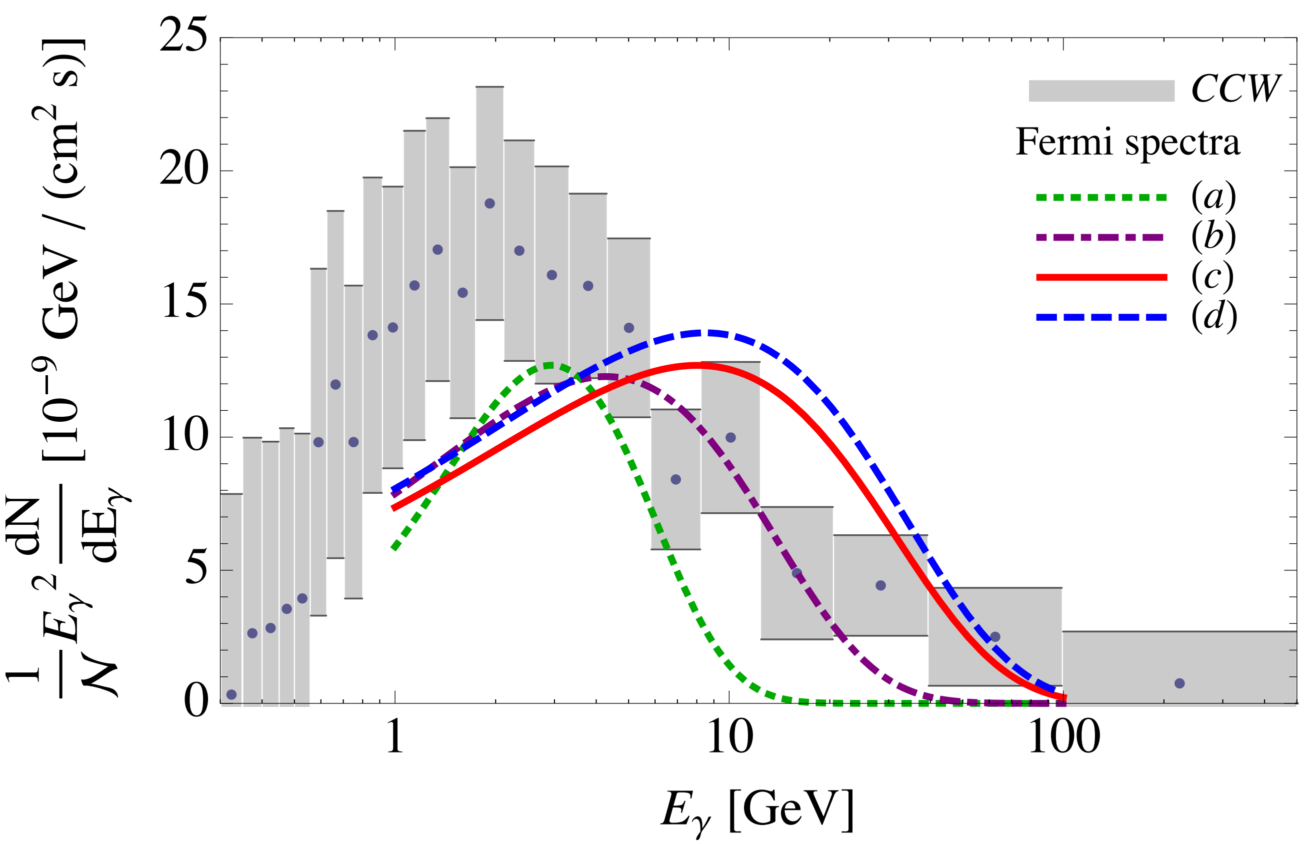


CCW,2014

The peak remains the same

The tail extends further

From 1411.2592



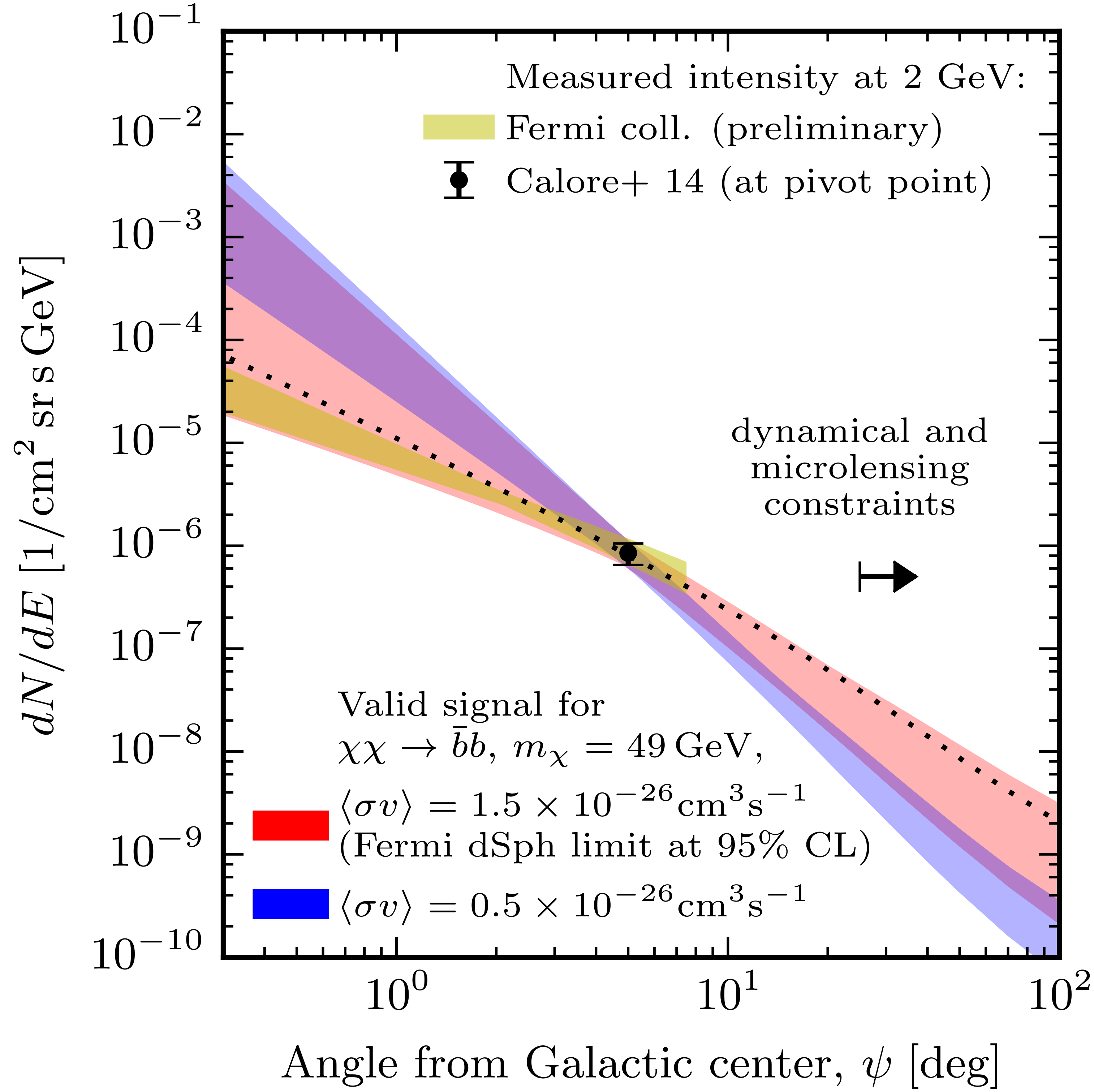
The uncertainties can be even larger

CCW vs Fermi-LAT models:

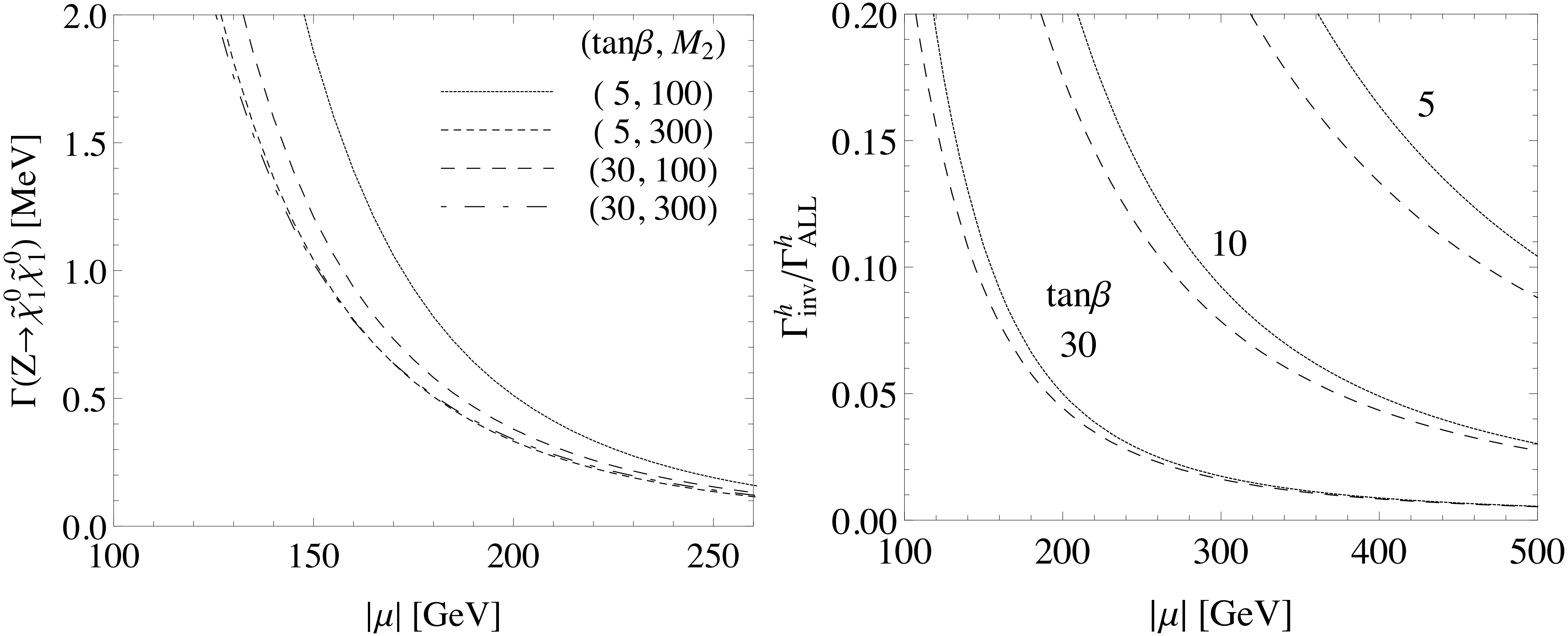
Fermi-LAT considers 1-100 GeV gamma rays for this analysis

How can we compare?

Morphology: dependence on Halo profile



Invisible Z and Higgs decays

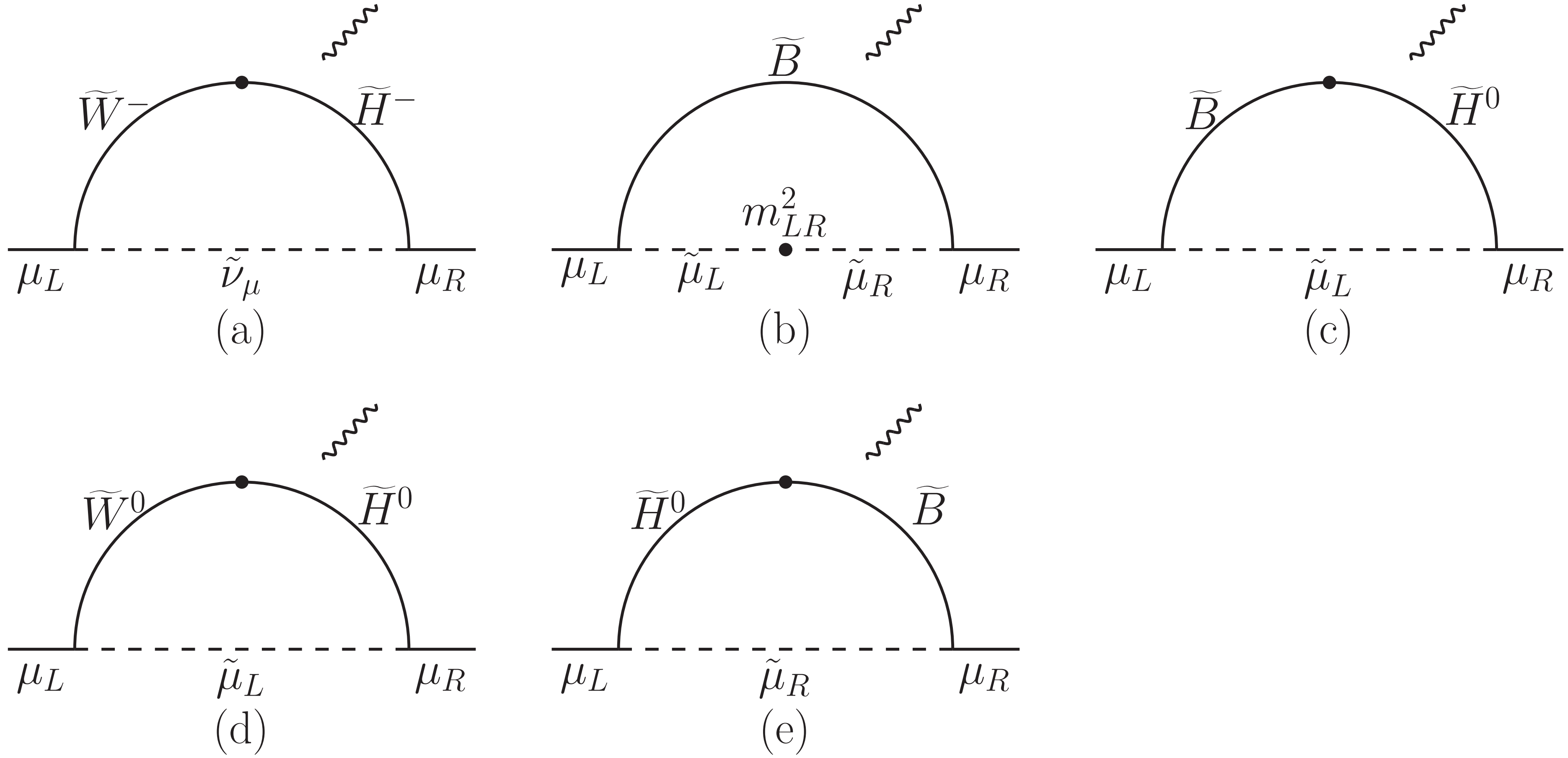


Stau mixing convention

$$\begin{pmatrix} \tilde{l}_L \\ \tilde{l}_R \end{pmatrix} = \begin{pmatrix} \cos\theta_l & \sin\theta_l \\ -\sin\theta_l & \cos\theta_l \end{pmatrix} \begin{pmatrix} \tilde{l}_1 \\ \tilde{l}_2 \end{pmatrix} .$$

$$\sin 2\theta_{\tilde{\tau}} = \frac{2m_\tau \big(A_\tau - \mu \tan\beta\big)}{m^2_{\tilde{\tau}_2} - m^2_{\tilde{\tau}_1}}.$$

Muon g-2 contributions



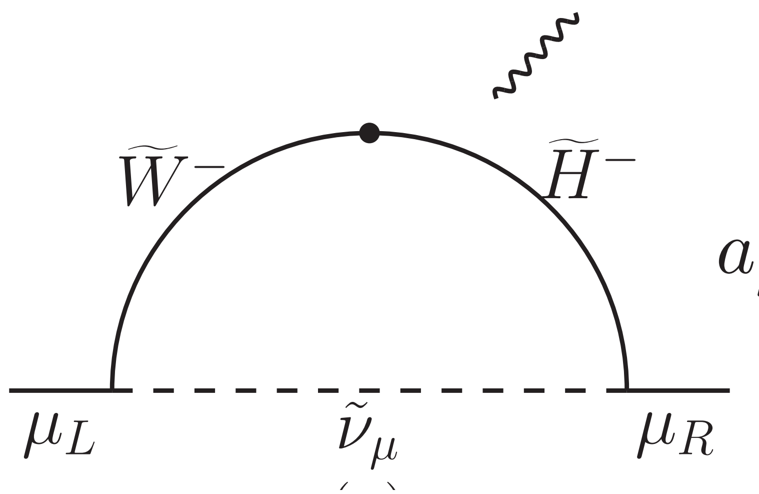
$$
\begin{aligned}
a_\mu(\tilde{W}\text{-}\tilde{H},\tilde{\nu}_\mu) &= \frac{g^2}{8\pi^2}\frac{m_\mu^2 M_2 \mu\tan\beta}{m_{\tilde{\nu}}^4}\ F_a\left(\frac{M_2^2}{m_{\tilde{\nu}}^2},\frac{\mu^2}{m_{\tilde{\nu}}^2}\right),\\
a_\mu(\tilde{B},\tilde{\mu}_L\text{-}\tilde{\mu}_R) &= \frac{g_Y^2}{8\pi^2}\frac{m_\mu^2 \mu\tan\beta}{M_1^3}\ F_b\left(\frac{m_{\tilde{\mu}_L}^2}{M_1^2},\frac{m_{\tilde{\mu}_R}^2}{M_1^2}\right),\\
a_\mu(\tilde{B}\text{-}\tilde{H},\tilde{\mu}_L) &= \frac{g_Y^2}{16\pi^2}\frac{m_\mu^2 M_1 \mu\tan\beta}{m_{\tilde{\mu}_L}^4}\ F_b\left(\frac{M_1^2}{m_{\tilde{\mu}_L}^2},\frac{\mu^2}{m_{\tilde{\mu}_L}^2}\right),\\
a_\mu(\tilde{W}\text{-}\tilde{H},\tilde{\mu}_L) &= -\frac{g^2}{16\pi^2}\frac{m_\mu^2 M_2 \mu\tan\beta}{m_{\tilde{\mu}_L}^4}\ F_b\left(\frac{M_2^2}{m_{\tilde{\mu}_L}^2},\frac{\mu^2}{m_{\tilde{\mu}_L}^2}\right),\\
a_\mu(\tilde{B}\text{-}\tilde{H},\tilde{\mu}_R) &= -\frac{g_Y^2}{8\pi^2}\frac{m_\mu^2 M_1 \mu\tan\beta}{m_{\tilde{\mu}_R}^4}\ F_b\left(\frac{M_1^2}{m_{\tilde{\mu}_R}^2},\frac{\mu^2}{m_{\tilde{\mu}_R}^2}\right),
\end{aligned}
$$

Muon (g-2) : dominant contribution

$$a_\mu^{EXP} - a_\mu^{SM} = (26.1 \pm 8.0) \times 10^{-10}$$ 3.3σ anomaly

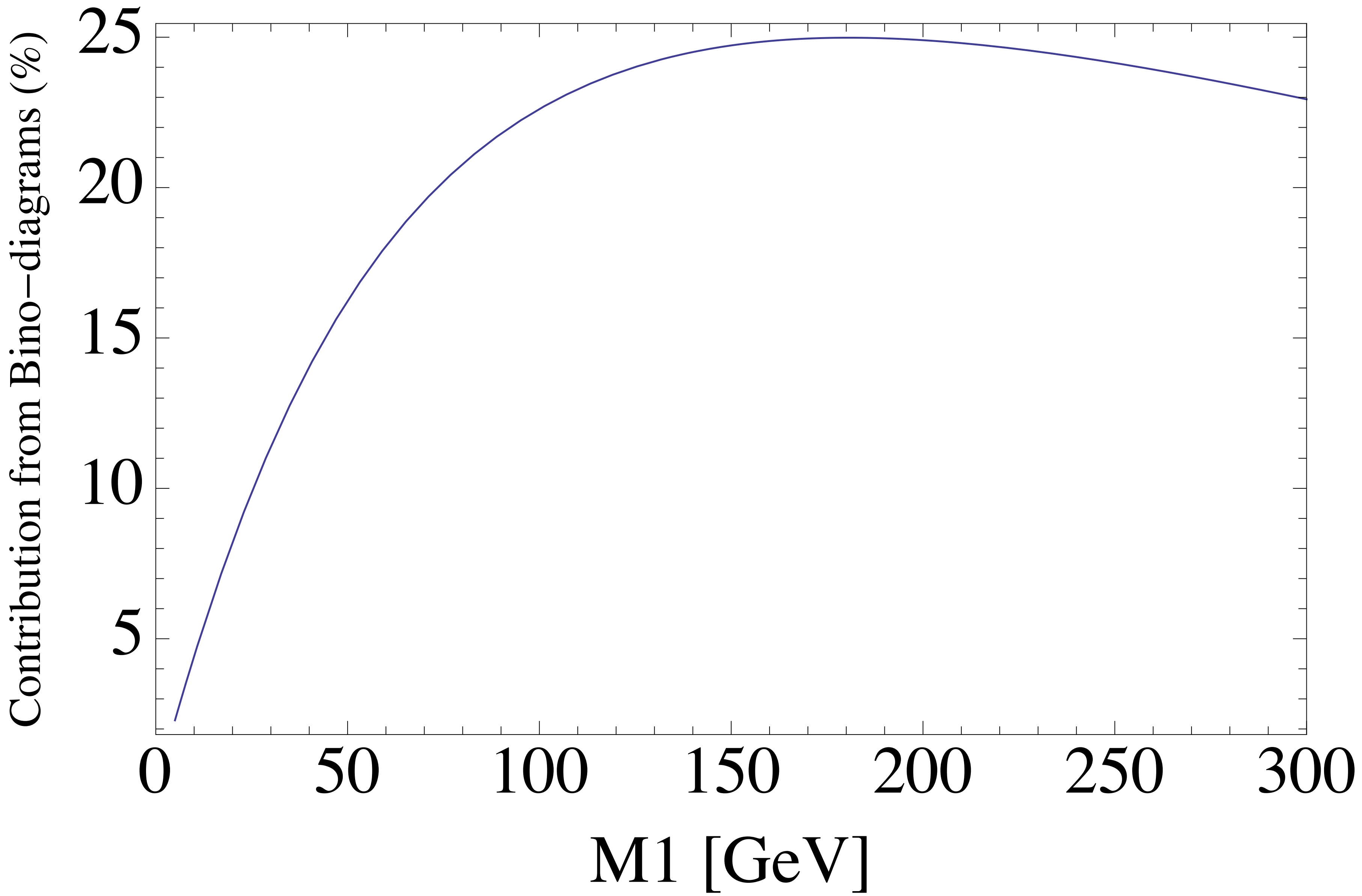
The contribution from the Neutralino-Smuon loops is small for $m_{\tilde{B}} \sim 10$ GeV

Rely on Wino-Higgsino mixed Chargino and Muon Sneutrino loop



$$a_\mu(\tilde{W}\text{-}\tilde{H}, \tilde{\nu}_\mu) = \frac{g^2}{8\pi^2} \frac{m_\mu^2 \boxed{M_2 \mu \tan\beta}}{\boxed{m_{\tilde{\nu}}^4}} F_a\left(\frac{M_2^2}{m_{\tilde{\nu}}^2}, \frac{\mu^2}{m_{\tilde{\nu}}^2}\right)$$

Muon (g-2): Contribution from diagrams with Bino



M2=300, mu=600, tb=30, smuL=smuR=350, all in GeV