Examining W, g-2, and DM anomalies with the NMSSM

Yue-Lin Sming Tsai
(Purple Mountain Observatory)

in collabration with M. Abdughani, Y.-Z. Fan, L. Feng, T.-P. Tang, L. Wu, Q. Yuan

2104.03274 (Science Bulletin)
2204.04356

Outline

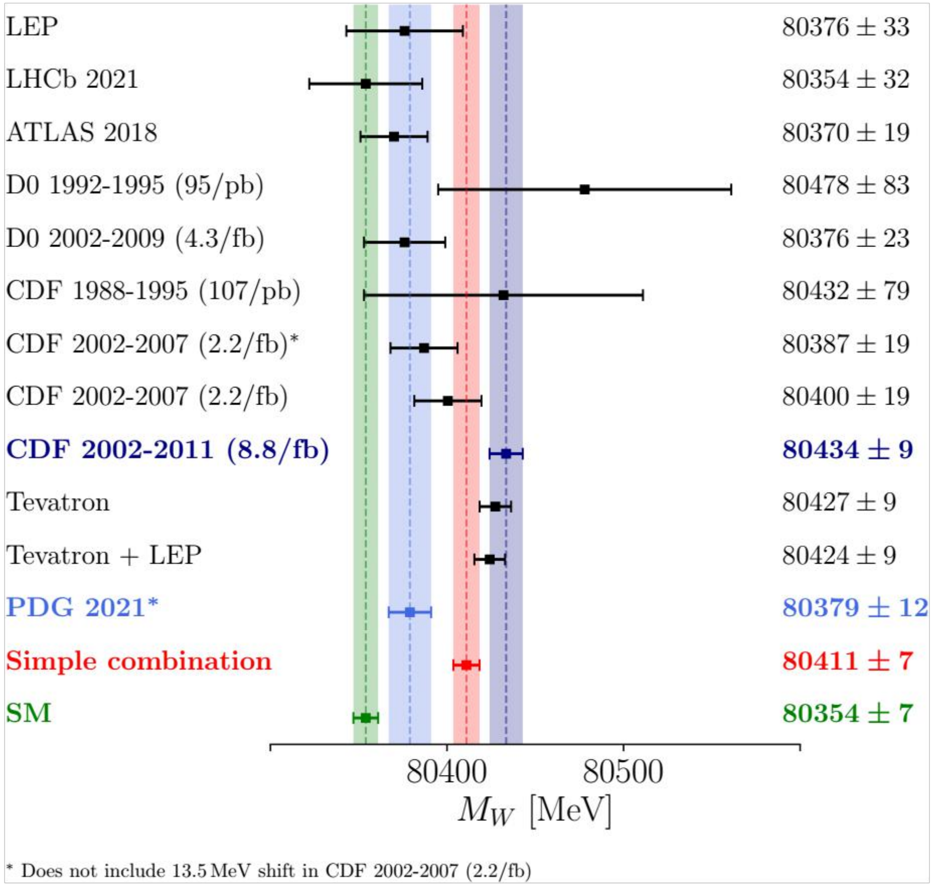
① W mass, muon g-2, and DM anomalies.

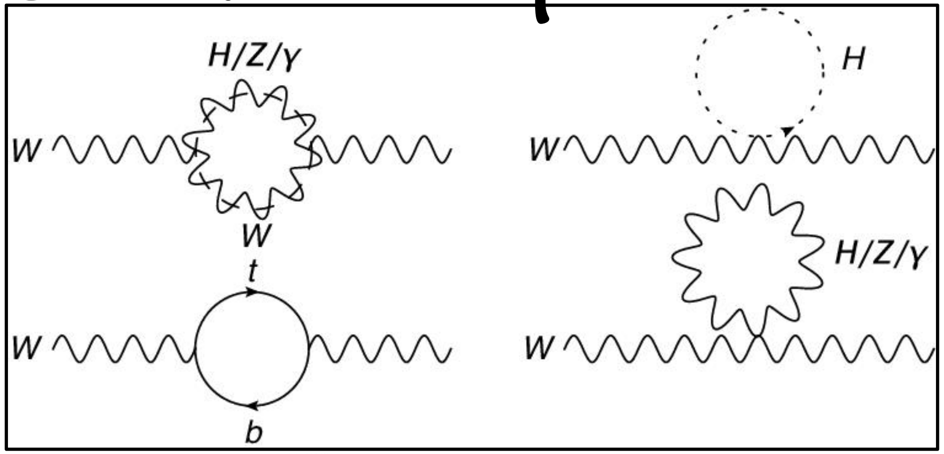
② Next-Minimum SUSY.

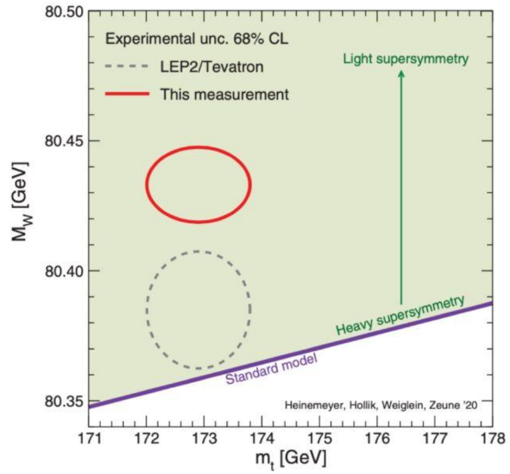
③ Allowed region.

④ Summary.

W-boson mass anomaly

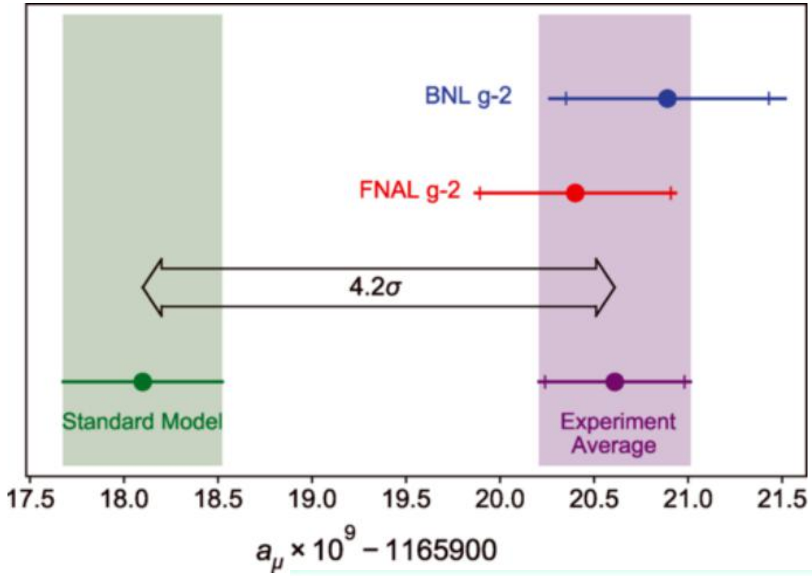


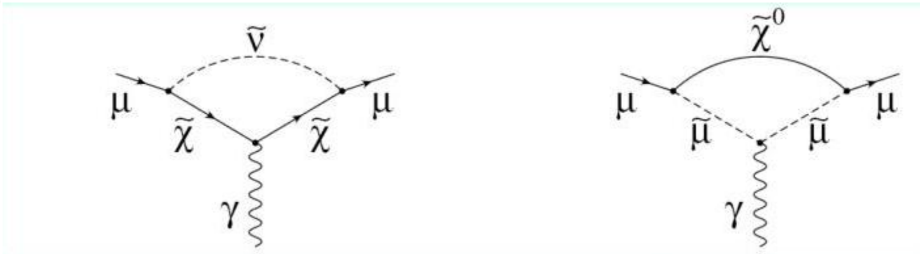


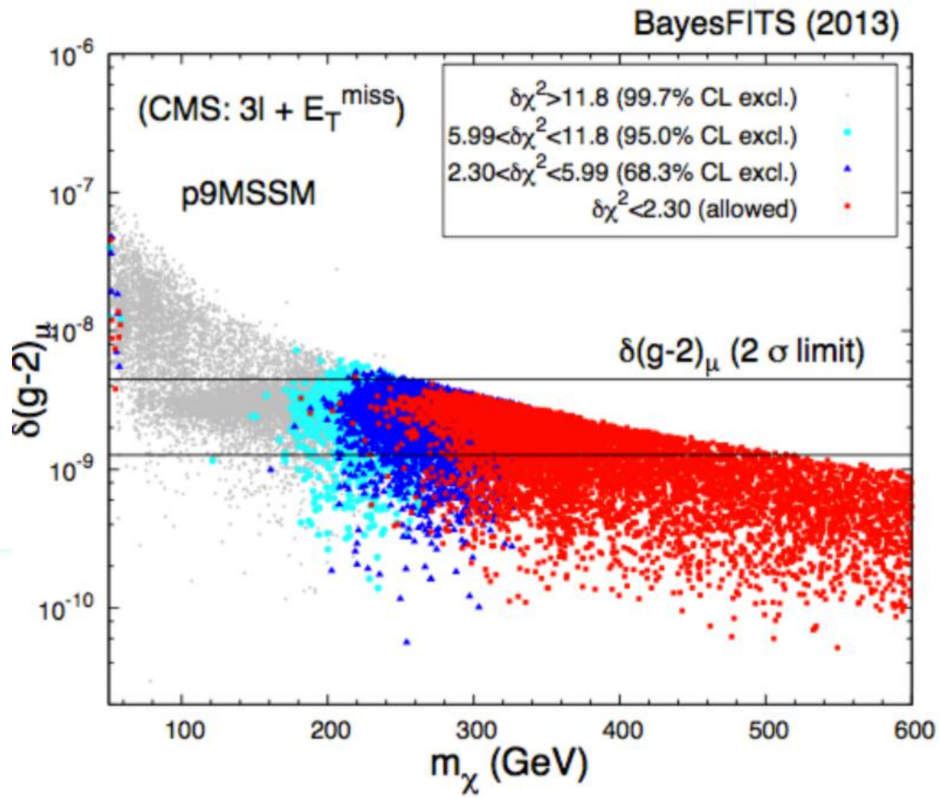


CDF II reported an anomaly with the SM by 7 sigma!
If confirmed, it is physics beyond the SM.

muon g-2 anomaly



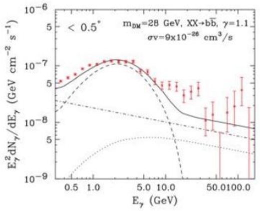




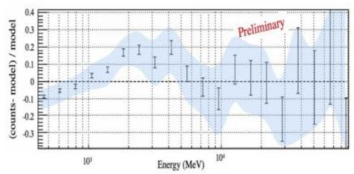
By combining the new E989 data with the previous measurement from Brookhaven National Lab (BNL), they found a deviation 4.2 sigma.
Physics beyond the SM must be at the low mass region.

The Galactic Center Gamma-Ray Excess

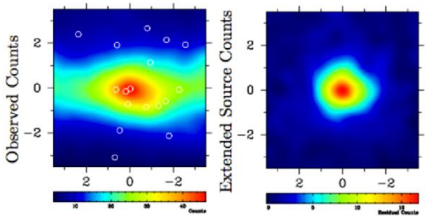
GeV Excess: a well known issue since 2009



Goodenough & Hooper 2009



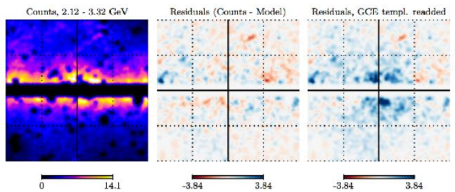
Vitale & Morselli 2009



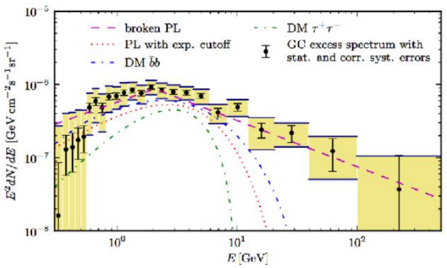
Galactic Center
Boyarsky+ 2011
Gordon & Macias 2013
Macias & Gordon 2014
Carlson+ 2015
...

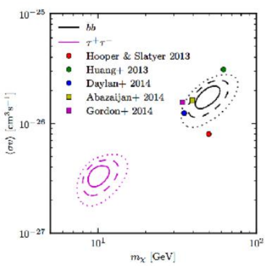
Abazajian & Kaplinghat 2012

Calore+ 2014



Inner Galaxy
Hooper & Slatyer 2013
Huang+ 2013
Zhou+ 2014
Daylan+ 2014
...

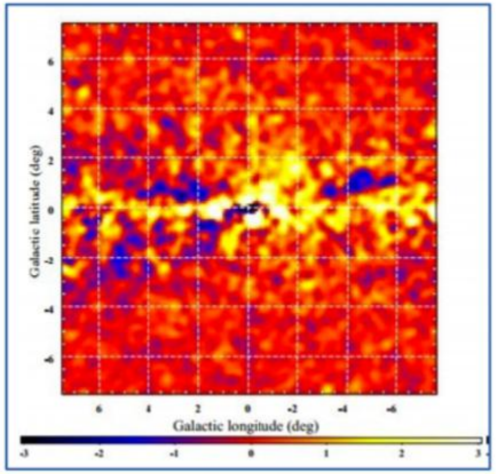


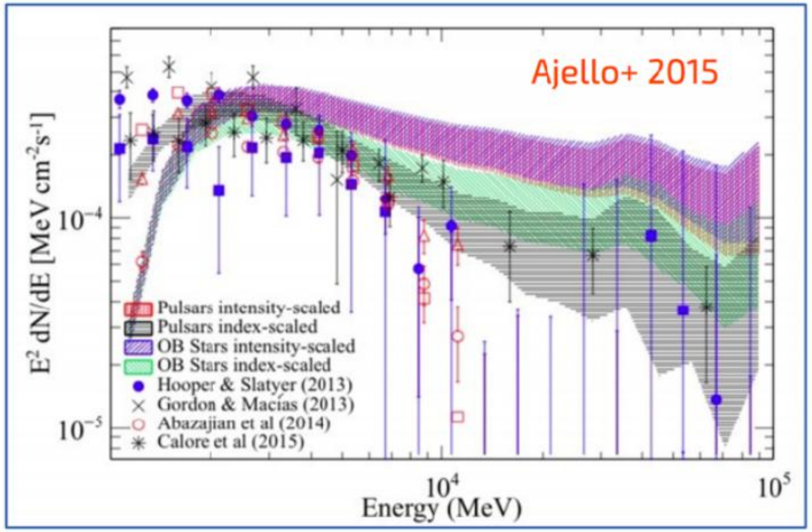


GeV Excess: confirmed by Fermi Collaboration

Fermi–LAT OBSERVATIONS OF HIGH-ENERGY γ-RAY EMISSION TOWARD THE GALACTIC CENTRE

of the interstellar emission and energy ranges used by the respective analyses. Three 1FIG sources are found to spatially overlap with supernova remnants (SNRs) listed in Green's SNR catalog; these SNRs have not previously been associated with high-energy γ-ray sources. Most 3FGL sources with known multi-wavelength counterparts are also found. However, the majority of 1FIG point sources are unassociated. After subtracting the interstellar emission and point-source contributions from the data a residual is found that is a sub-dominant fraction of the total flux. But, it is brighter than the γ-ray emission associated with interstellar gas in the inner $\sim$ 1 kpc derived for the IEMs used in this paper, and comparable to the integrated brightness of the point sources in the region for energies > 3 GeV. If spatial templates that peak toward the GC are used to model the





Taken from Xiaoyuan Huang

AMS02 antiproton Excess

APS physics | Physics

SYNOPSIS

Antiprotons May Hold Dark Matter Signal

May 9, 2017 • *Physics* 10, s50

Recently released data on cosmic-ray antiprotons may contain hints of dark matter, as revealed by two new analyses.

NASA

ScienceNews

NEWS IN BRIEF | PARTICLE PHYSICS

Antiproton count hints at dark matter annihilation

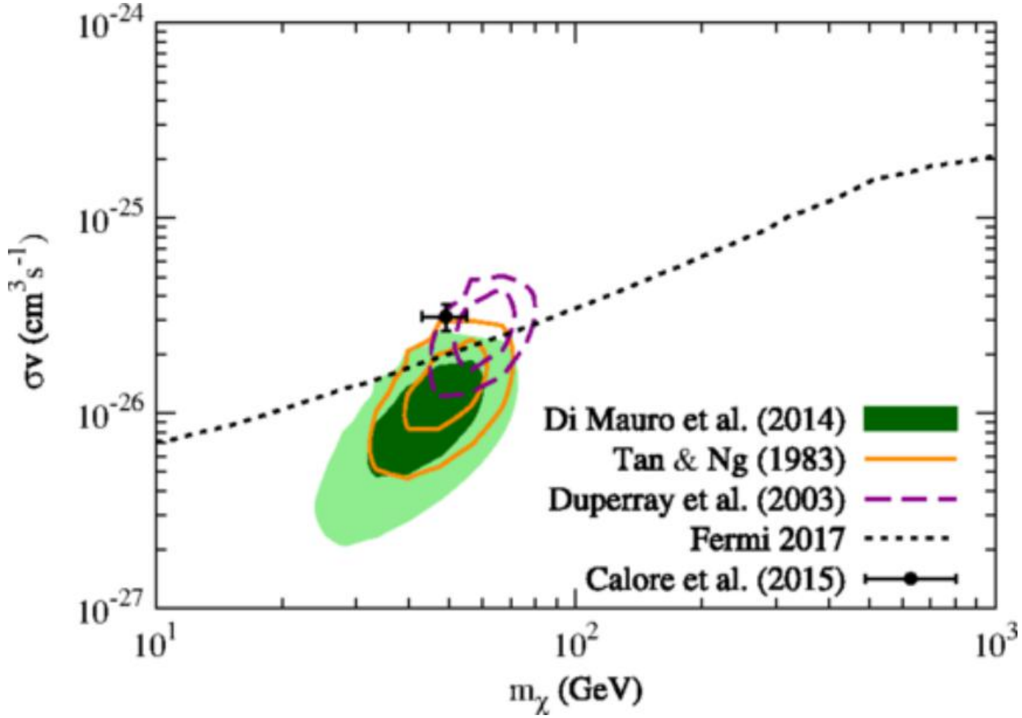
New analyses of data from Space Station's AMS experiment show signs of elusive cosmic mass

ANTIPROTON ODDITY Two teams of researchers report possible signs of dark matter in data from the AMS experiment on the International Space Station (shown). Some of the antiprotons detected by AMS could have come from dark matter particles annihilating one another in space.

NASA

By Emily Conover

MAY 11, 2017 AT 5:27 PM

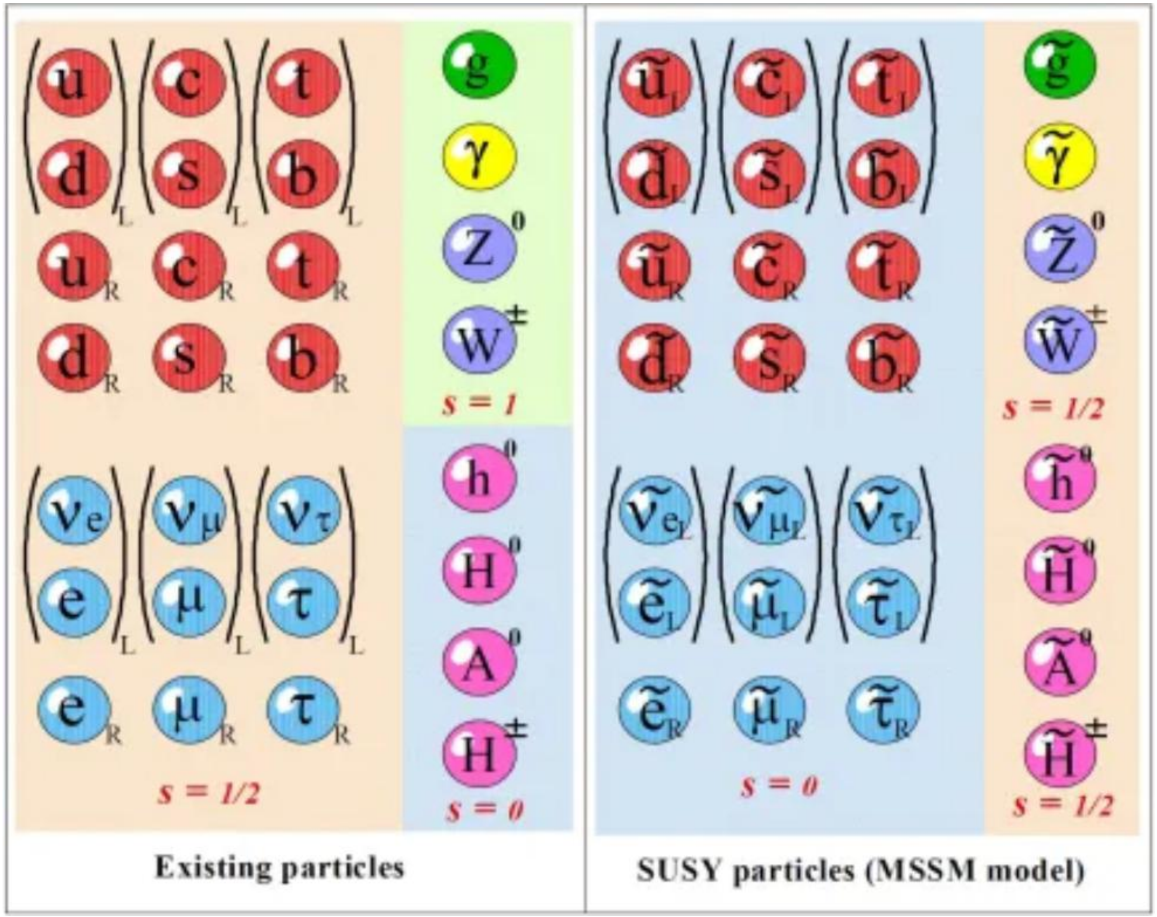


They found that a model with a DM particle of mass between 40 and 60 GeV gave the best fit to the antiproton data.

- A. Cuoco, M. Kramer, and M. Korsmeier [Phys. Rev. Lett. 118 (2017), no. 19 191102]
- **M.-Y. Cui, Q. Yuan, Y.-L. S. Tsai, and Y.-Z. Fan [Phys. Rev. Lett. 118 (2017), no. 19 191101]**
- A. Reinert and M. W. Winkler [JCAP 1801 (2018), no. 01 055]
- I. Cholis, T. Linden, and D. Hooper [Phys. Rev. D99 (2019), no. 10 103026]

Next-to-Minimal Supersymmetric Standard Model (NMSSM)

The simplest SUSY:
The Minimal Supersymmetric extension of the Standard Model

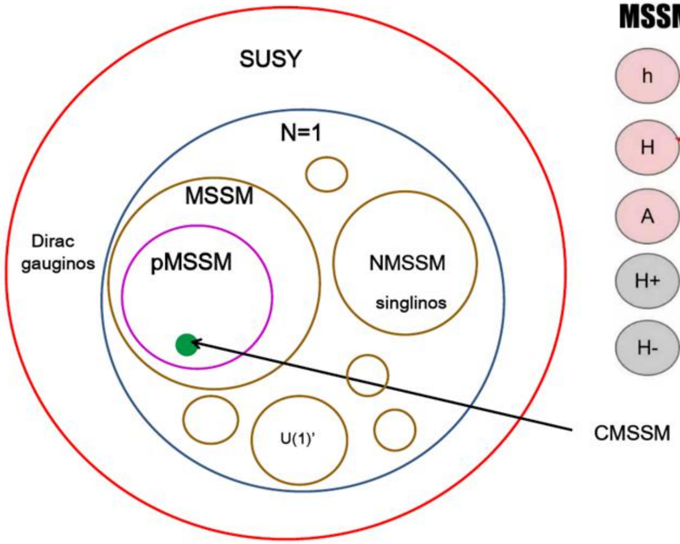


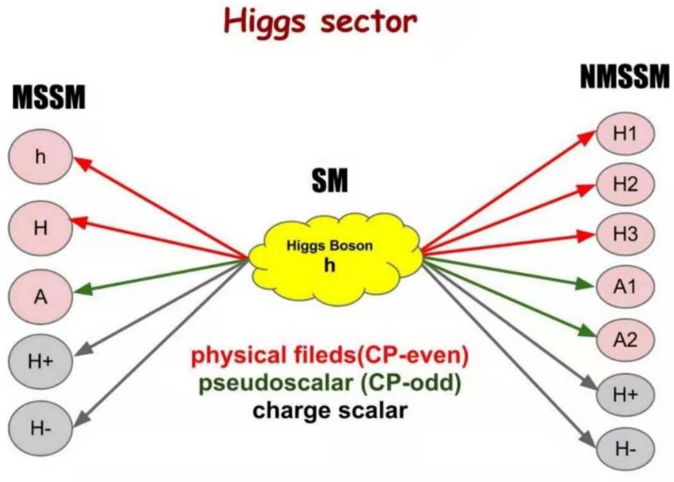
※ SM -> supersymmetrizing -> MSSM

※ Hierarchy problem, GUT unification, DM.

※ Cannot explain GCE + Relic density and saytisfy DM direct detection and colliders constraints.

The first step of going to beyond simplest SUSY





In the scale invariant NMSSM [27], a Z_3 symmetric gauge singlet chiral superfield $\hat{S}$ is introduced. In addition to MSSM, the superpotential is

$$W = W_{\rm MSSM} + \lambda S H_u H_d + \frac{\kappa}{3} S^3, \tag{1}$$

where the new singlet Higgs develops a vev $\langle S \rangle = s$. The superpartner of S (singlino) can mix with gaugino and Higgsino as the neutralino mass matrix

$$M_{\chi^0} = \begin{pmatrix} M_1 & 0 & -m_Z c_\beta s_W & m_Z s_\beta s_W & 0 \\ & M_2 & m_Z c_\beta c_W & -m_Z s_\beta c_W & 0 \\ & & 0 & -\mu & -\lambda v_u \\ & & & 0 & -\lambda v_d \\ & & & & \frac{2\kappa}{\lambda}\mu \end{pmatrix}. \tag{2}$$

A next-minimum setup:
SM+ Higgs doublet (minimum)+
one SM singlet complex scalar mediator.

One of the virtues of the NMSSM is that it can provide a solution to the μ problem

More resonances may help to find a solution of "GCE+ oh2 + DD".

Allowed regions

Constraints BEFORE CDF II W mass measurement

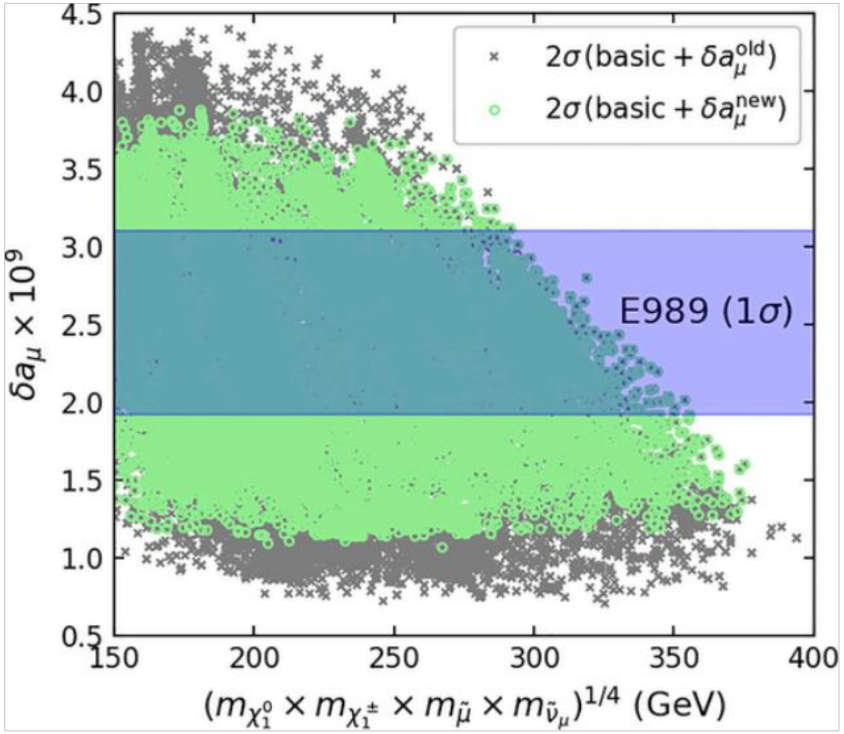
TABLE I. The experimental constraints used in this study.

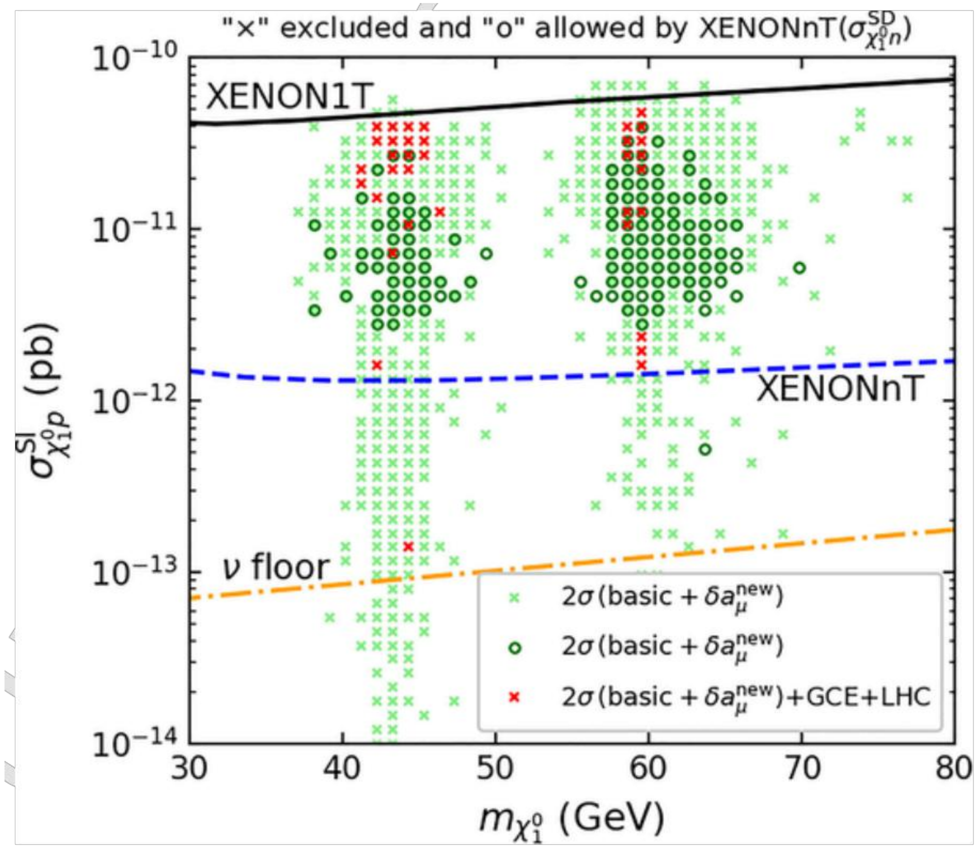
Category	Experimental observables
DM relic density	$\Omega_\chi h^2 = \Omega h^2 = 0.1186 \pm 0.002 \pm 0.1\mu_t$ [29]
B physics	$\mathrm{BR}(B \to X_s\gamma) = (3.27 \pm 0.14 \pm 0.1\mu_t) \times 10^{-4}$ [30]
	$\mathrm{BR}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6 \pm 0.3) \times 10^{-9}$ [31]
	$\mathrm{BR}(B_u \to \tau\nu) = (1.09 \pm 0.24 \pm 0.1\mu_t) \times 10^{-4}$ [32]
Higgs physics	$R_{\mathrm{inv}} < 9\%$ at 95% CL [33]
	$m_{h_{\mathrm{SM}}} = (125.36 \pm 0.41 \pm 2.0)$ GeV [34]
DM DD	XENON1T [35, 36], PICO-60 [37].
muon (g-2)	$\delta a_\mu^{\mathrm{old}} = (2.61 \pm 0.48 \pm 0.63) \times 10^{-9}$ [32]
	$\delta a_\mu^{\mathrm{new}} = (2.51 \pm 0.59) \times 10^{-9}$ [2]
GCE	As implemented in Ref. [38].
LHC	$pp \to \chi_1^+\chi_1^-$, $pp \to \chi_1^\pm\chi_2^0$ and $pp \to \tilde{\ell}_{L,R}^+\tilde{\ell}_{L,R}^-$.

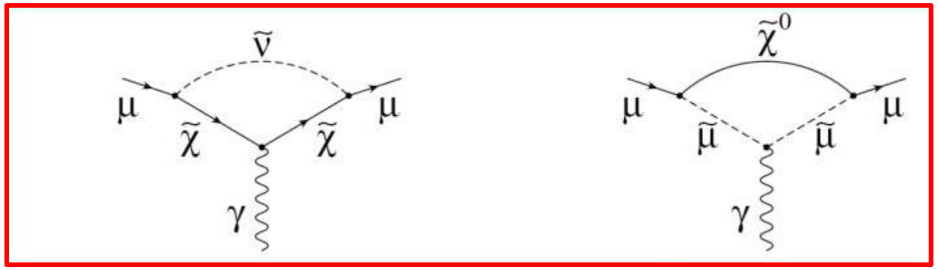
We set those irrelavant parameters to be heavier than SUSY scale~ 3TeV.

$0.001 < \lambda < 1,\ 0.001 < |\kappa| < 2,\ |A_\lambda| < 3000,\ |A_\kappa| < 20,$
$30\ \mathrm{GeV} < M_1 < 80\ \mathrm{GeV},\ 100\ \mathrm{GeV} < M_2 < 1000\ \mathrm{GeV},$
$100\ \mathrm{GeV} < |\mu| < 1000\ \mathrm{GeV},\ 100\ \mathrm{GeV} < M_{\tilde{\ell}_{1,2}} < 1000\ \mathrm{GeV},$
$1 < \tan\beta < 60,$

The geometric mean of the masses of the electroweakinos and sleptons







Future DD can probe entirely parameter space!!!

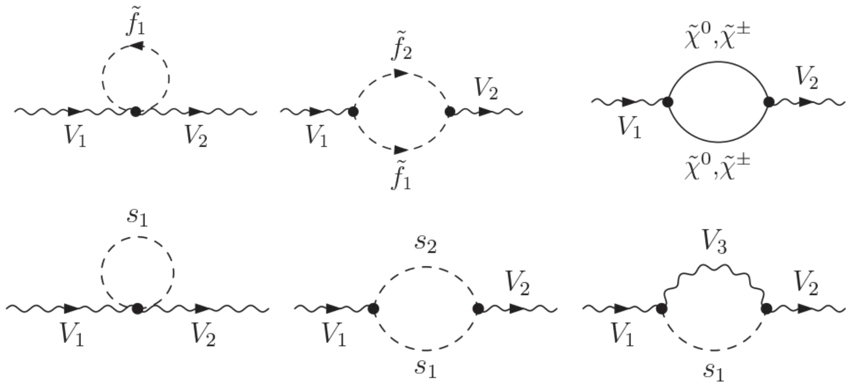
Constraints After CDF II W mass measurement

1. XENON1T -> PandaX-4T.
2. LHC compressed spectra searches.
3. CDF II mW measurement.
4. GCE and antiproton DM signals removed.

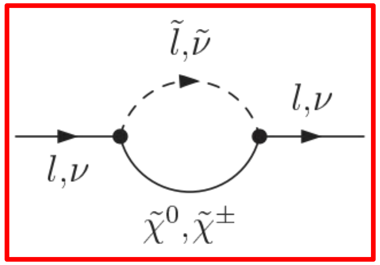
$$m_{W,\mathrm{CDF}} = 80.4335 \pm 0.009\ \mathrm{GeV}$$

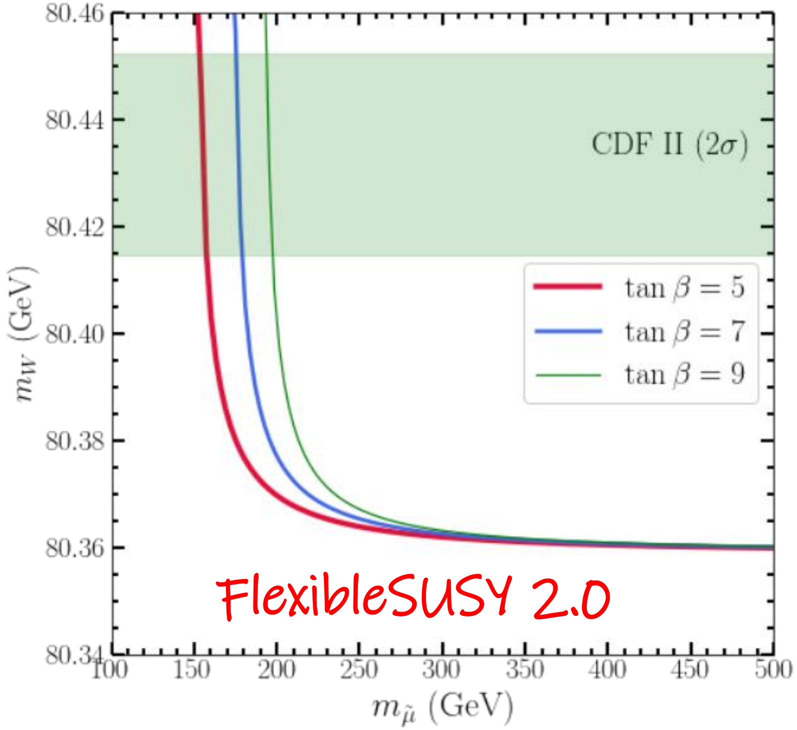
In total, we have nine free parameters at electroweak scale and their ranges are: $10^{-4} < \lambda < 1$, $10^{-4} < |\kappa| < 2$, $|A_\lambda| < 3000\,\mathrm{GeV}$, $|A\kappa| < 100\,\mathrm{GeV}$, $30\ \mathrm{GeV} < M_1 < 700\ \mathrm{GeV}$, $1.5M_1 < M_2 < 10M_1$, $1.5M_1 < |\mu| < 10M_1$, $100\ \mathrm{GeV} < M_{\tilde{\ell}_{1,2}} < 700\ \mathrm{GeV}$, and $2 < \tan\beta < 65$.

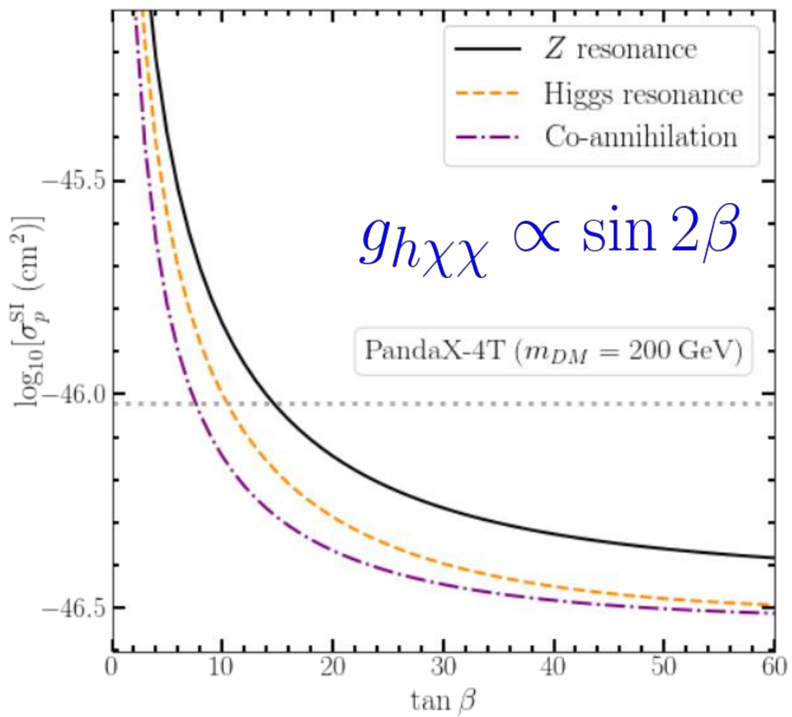
We modified the red parameters with a larger but focused on bino DM.



The new particles runing in the mW loops have a lot of similarilty to g-2 one.

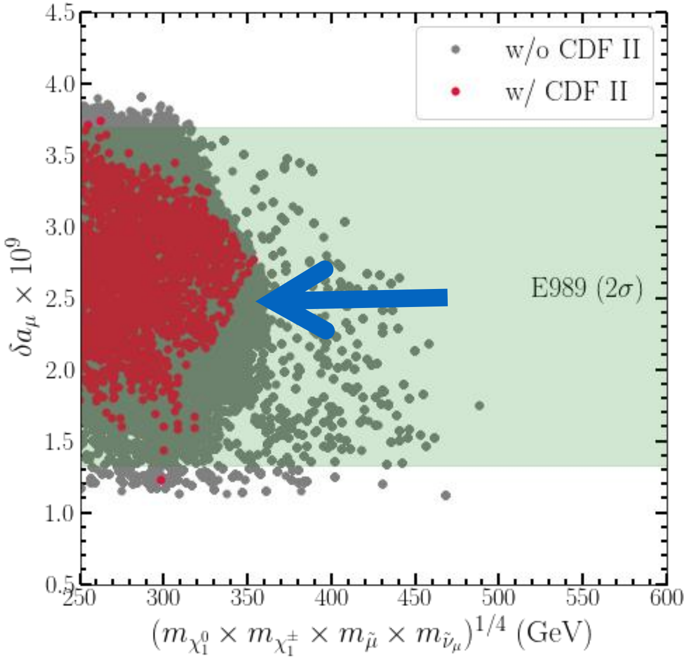




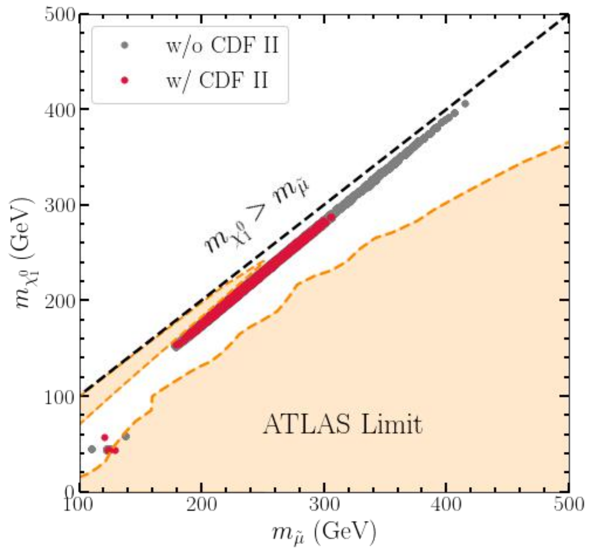


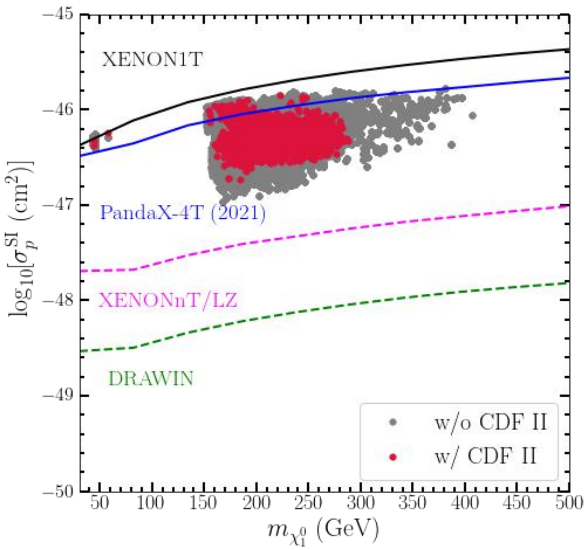
Low tanb can be probed by DD !

Summary



The geometric mean is also pushed to be small.





1. The lower mass NMSSM neutralino is favoured by the signal of W and g-2.
2. The parameter space is much squeezed after LHC missing energy searches.
3. Near future DM DD can probe the entirely parameter space.
4. DM GCE and antiproton anomaly cannot be explained after CDF II W mass data.

Thank you.