Quark-phobic Dark Matter

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Exploring the Dark Sector/KIAS/Seoul/
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Outline

- Glory of WIMP dark matter
- Predicament of WIMP dark matter
- Quark-phobic dark matter
- Conclusion

Glory of WIMP DM

- Well-known for the WIMP miracle

  DM annihilates involving weak scale particles (~100 GeV) and weak scale strength (~0.2) naturally with rate~1pb.

- Predicted by supersymmetry!!!

- More generically, connected to TeV new physics,

  Such as hierarchy problem, neutrino and flavor physics, etc., servicing as a model source.

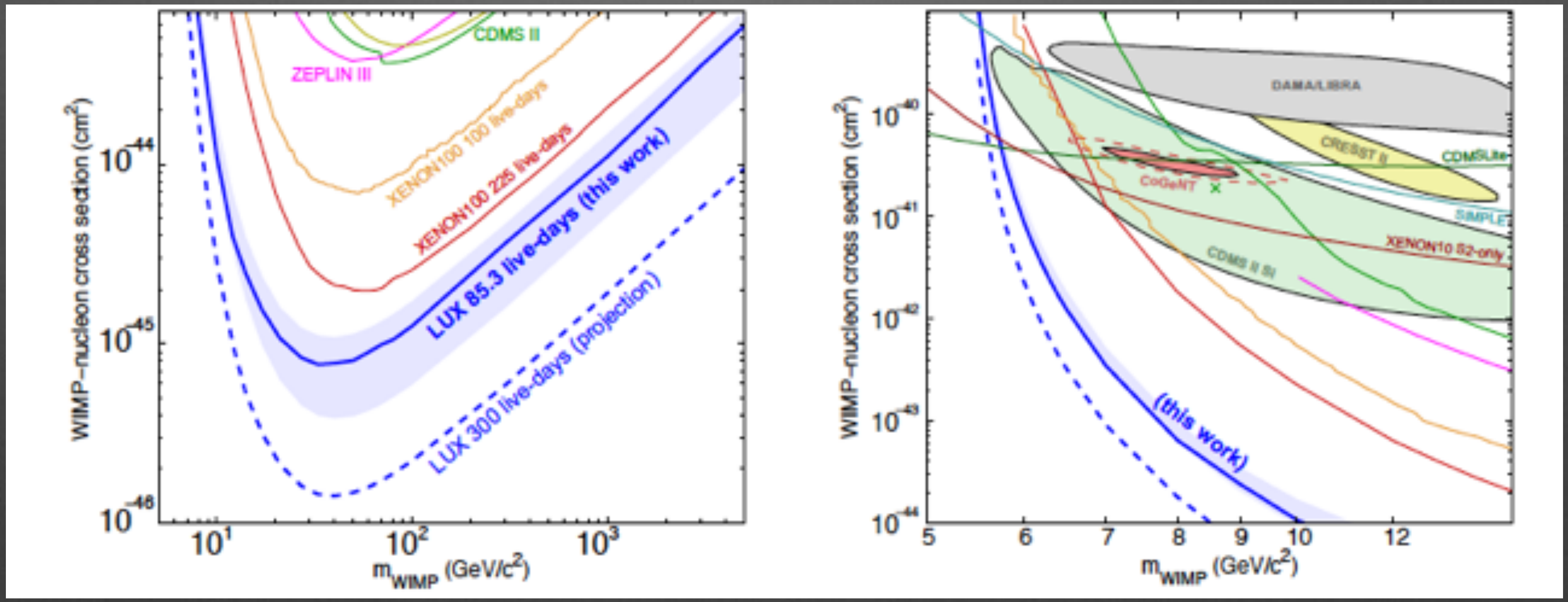
- Promoting a long research chain, along which—

  Particle, astronomical, cosmological and nuclear

Predicament of WIMP DM

- Direct detection attacks

Limits from LUX (heavy>mb) & CDMSlite (light<mb)



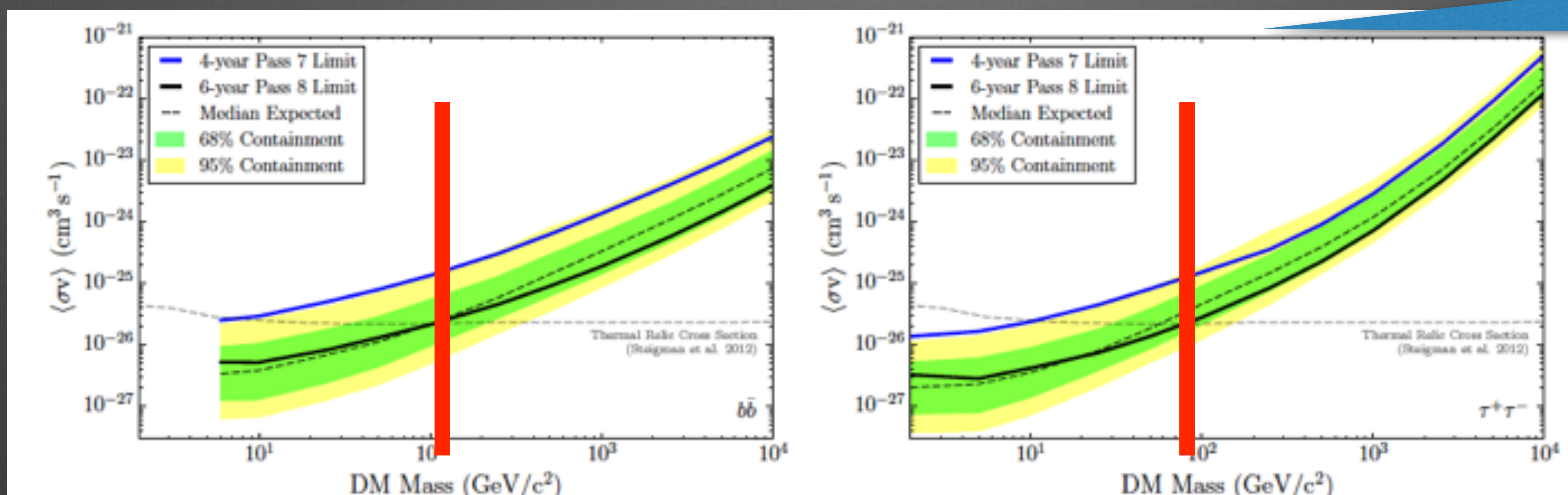
Anomalies from GoGeNT, etc., ~10 GeV DM? ? Isospin-violating DM to reconcile them with LUX, etc.??? An inspiring coincidence:

$$\frac{\langle \sigma_{an} v \rangle}{\sigma_p} \sim \frac{M_{\rm DM}^2}{\mu_p^2}, \quad \mu_p \simeq 1\,{\rm GeV}.$$

Predicament of WIMP DM

- Indirect detection attacks

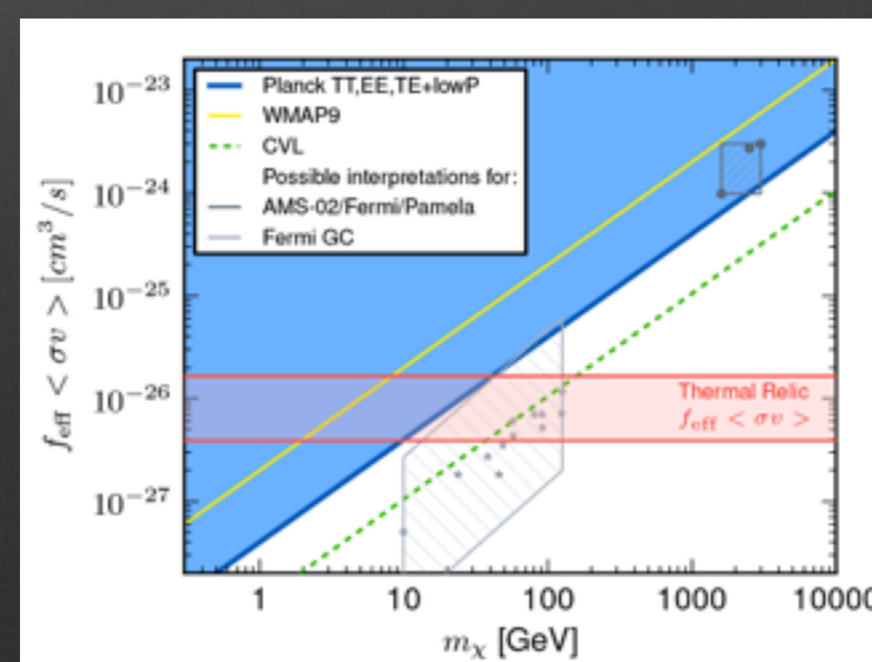
AMS-02 (positron killer) & Fermi-LAT (Gamma killer)



The light DM (<100 GeV) with s-wave annihilation is in danger

Ice cube (neutrino killer) &

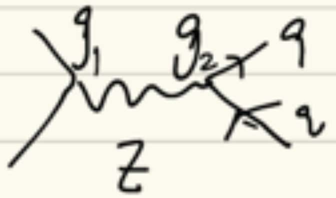
Planck CMB (sensitive to *p*-wave annihilating DM!!!)



Predicament of WIMP DM

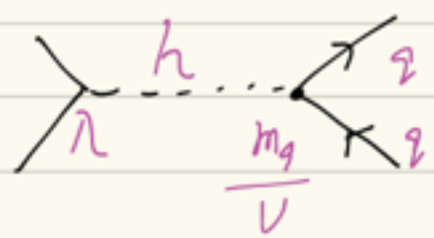
- Implications to DM with SM mediators

DM with Z-portal:



$$\Rightarrow \sigma_{SI} \sim \frac{1}{4\pi} \cdot \frac{g_1^2 g_2^2}{m_Z^4} m_n^2 \lesssim 10^{-9}\,pb \Rightarrow \sqrt{g_1 g_2} \lesssim 10^{-2} \ll 1$$

DM with Higgs portal



$$\Rightarrow \sigma_{SI} \sim \frac{f_T^2}{4\pi} \cdot \frac{\lambda^2}{v^2} \cdot \left(\frac{m_n}{m_h}\right)^4 \lesssim 10^{-9}\,pb \Rightarrow \lambda \lesssim 10^{-2} \ll 1$$

$f_T \sim \mathcal{O}(0.1)$ $\quad$ $m_h = 125\,\mathrm{GeV}$

for the scalar DM, $\lambda \sim \lambda v/2m_{DM} < 10^{-2}$, so the heavier scalar DM is less constrained; the simplest DM survives

Thus, they can not account for correct relic density for DM. The WIMP miracle requires new mediators. Or, we give up the miracle. Anyway, we can not jump to the conclusion that WIMP DM encounters a real crisis——

Quark-phobic Dark Matter

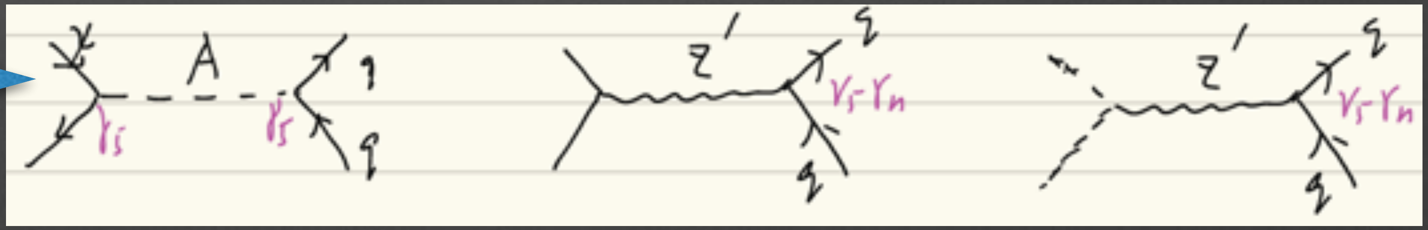
- Actually, there are a lot of ways to break siege

Tuning scenarios: Annihilating with a resonance (near Higgs pole) or coannihilating with a partner (degenerate LSP & stop in SUSY)

Point: allow very weakly coupling between DM and the mediators

Axial mediators: A fermionic DM with CP-odd Higgs or axial-vector coupling, etc.,

Only gives spin-dependent DM-nucleon scattering



DM annihilates into the dark states, which feebly couple to SM

…….
one dead, thousands born!!

Quark-phobic DM?

Quark-phobic Dark Matter

- Easy ways to quark-phobic DM

  The presence of a new sector, to which DM tightly couples to. The new sector does not lead to DM coupling to quarks

- Easily defeats LUX & superCDMS

- Consistent with leptonic DM for XXX-anomaly?

  Old famous anomaly: excess in e^+ but not p^+,

  Very new anomaly: Galaxy center GeV-γ excess

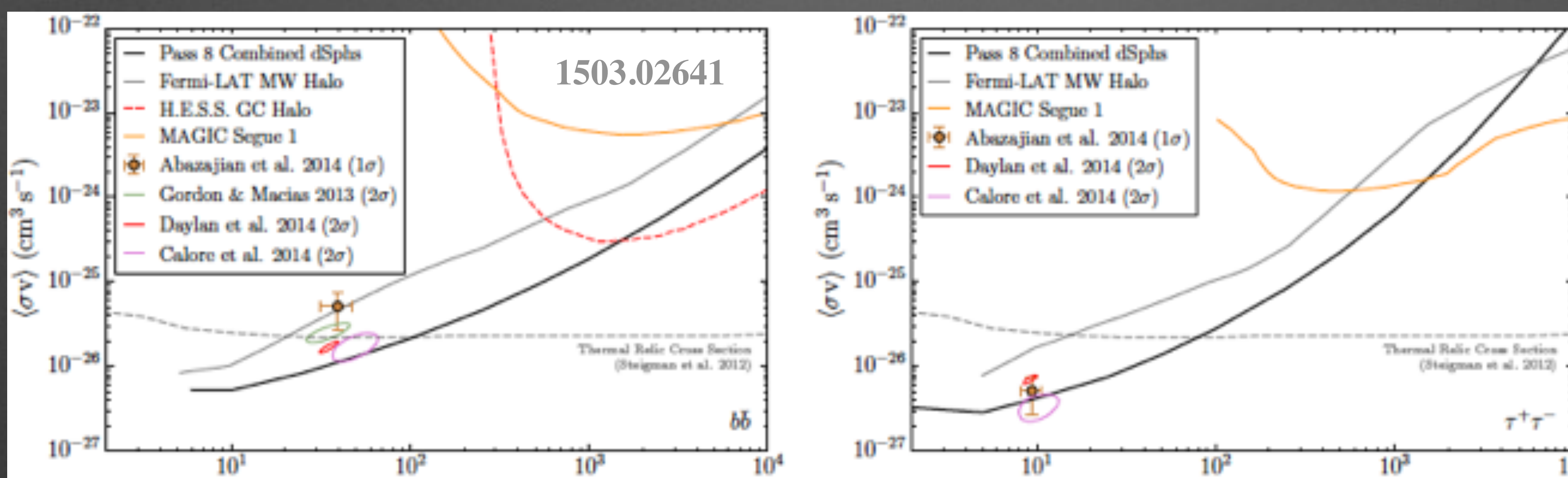
  Very old anomaly: muon g-2!

Quark-phobic Dark Matter

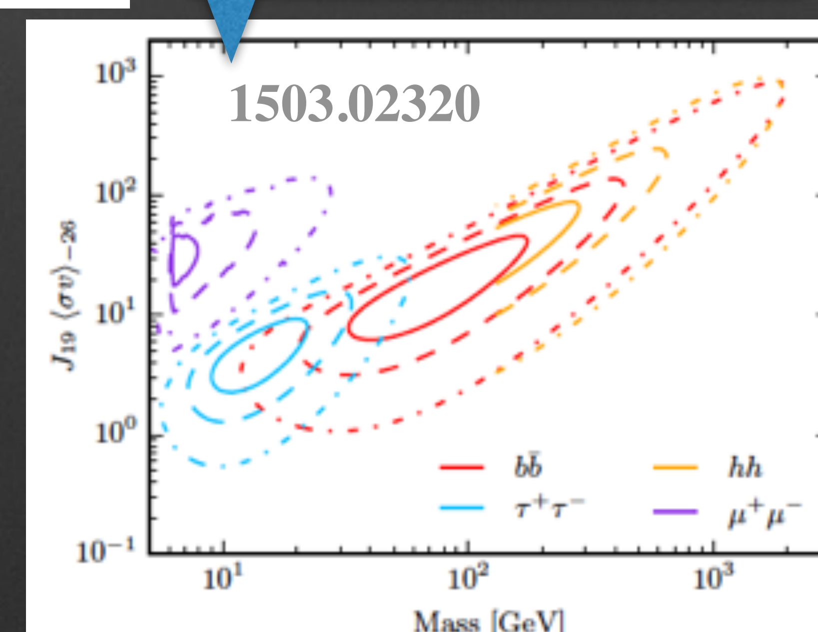
- More on GeV-anomaly

Well fit by thermal DM DM→bb/$\tau\tau$, tightly constrained by dSphs.

The *bb*-mode is in strong tension with dSphs while $\tau\tau$ is fine!!



The spectrum from Ret2 clearly rises above the expected background from 2 to 10 GeV, thus disfavoring millisecond pulsar but favoring DM:



A support from Reticulum 2? It is (the only) one of the 9 newly discovered dSphs that sees γ excess. In the DM explanation, the best fit is $\mu\mu$ and the next is $\tau\tau$.

Quark-phobic Dark Matter

- Several known ways (inspired by PAMELA etc.)

DM from a dark sector that has good DM dynamics but feebly couples to SM for thermalizing, via small kinematic/mass mixing

N.~Arkani-Hamed, D.~P.~Finkbeiner, T.~R.~Slatyer and N.~Weiner, Phys.Rev. D79 (2009) 015014

A new leptonic gauge group like $U(1)_L$ or $U(1)_{Li\text{-}Lj}$ under which DM is charged, as leads to leptonic DM.

P. J. Fox and E. Poppitz, Phys. Rev. D 79, 083528 (2009).

S. Baek and P. Ko, JCAP 0910, 011 (2009).

A t-channel leptonic mediator to the leptons, e.g., slepton in the supersymmetric standard models

- Focused example: via a leptonic Higgs doublet—

H. S. Goh, L. J. Hall and P. Kumar, JHEP 0905, 097 (2009)

M. S. Boucenna and S. Profumo, Phys. Rev. D 84, 055011 (2011)

Quark-phobic Dark Matter

- Ex: lepton-specific 2HDM (*S*+2HDML)

2HDML is characterized by a lepophilic Higgs doublet $\Phi_L = \Phi_1$,

$$-\mathcal{L}_Y = Y^u \overline{Q_L}\widetilde{\Phi}_2 u_R + Y^d \overline{Q_L}\Phi_2 d_R + Y^e \overline{l_L}\Phi_1 e_R + c.c.,$$

Embedded in $U(1)_{PQ}$ models? S is a complex scalar DM stabilized by a remnant of $U(1)_{PQ}$?

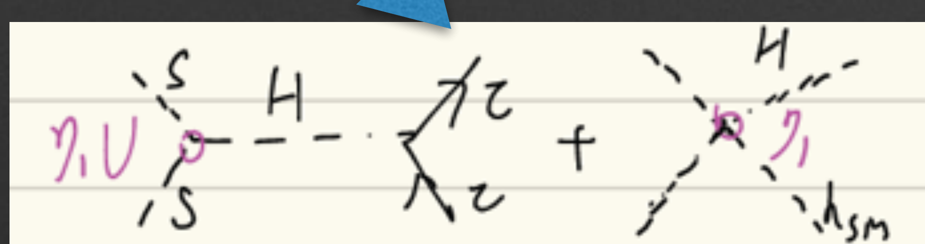
Φ_L provides a leptonic portal for the DM S, a real singlet scalar:

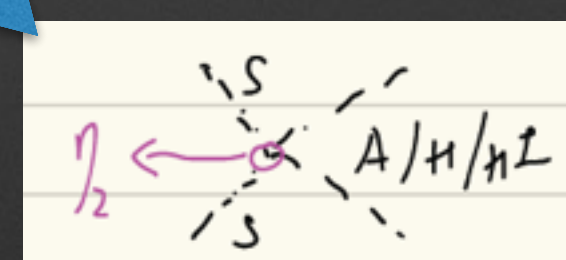
$$-\mathcal{L}_{\rm DM} = \frac{1}{2} m_S^2 S^2 + \left(\frac{\eta_1}{2} S^2 \Phi_2^\dagger \Phi_L + c.c.\right) + \frac{\eta_3}{2} S^2 |\Phi_L|^2 + \cancel{\frac{\eta_2}{2} S^2 |\Phi_2|^2} + \frac{\eta_4}{4} S^4$$

h_{SM}-S-S is suppressed by a large tanβ~100, leaving only Φ_L-portal to $\tau\tau$, or to $H\,h_{SM}$

For tanβ>>1, only the contact interactions between DM and the leptonic Higgs are sizable

In the supersymmetric version, this term, from the F-term, can be naturally suppressed

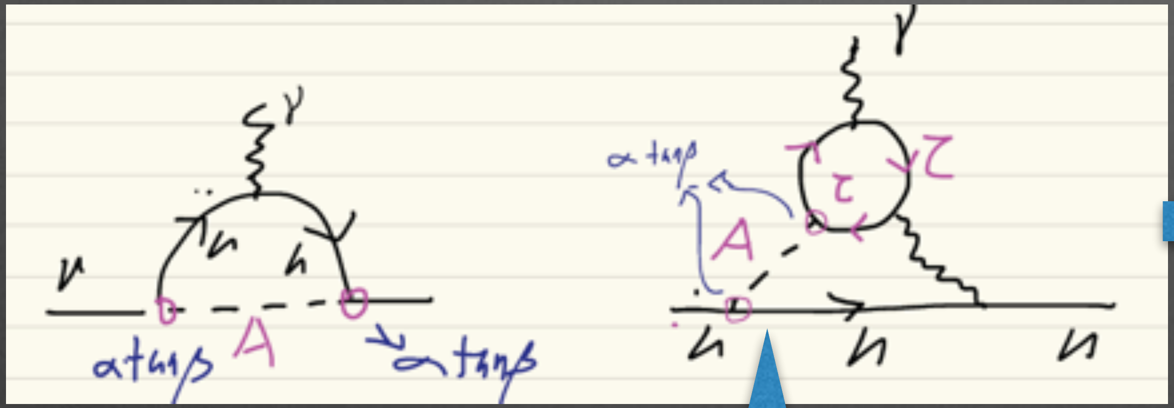




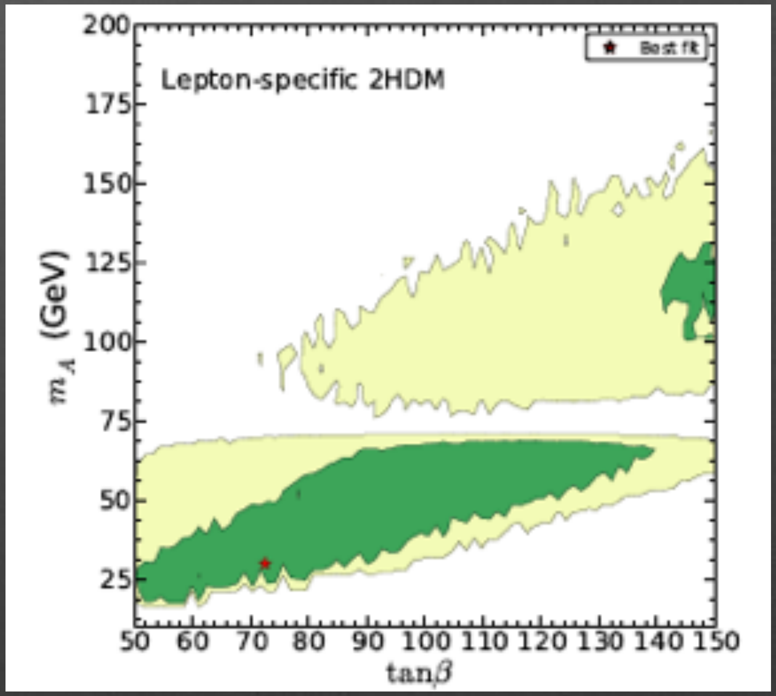
Quark-phobic Dark Matter

- Easy *g*-2 with a light *A* & large tanβ

In general, the CP-even Higgs bosons h_{SM} and *H* contribute negative to *g*-2 while *A* (>GeV) contribute positive——

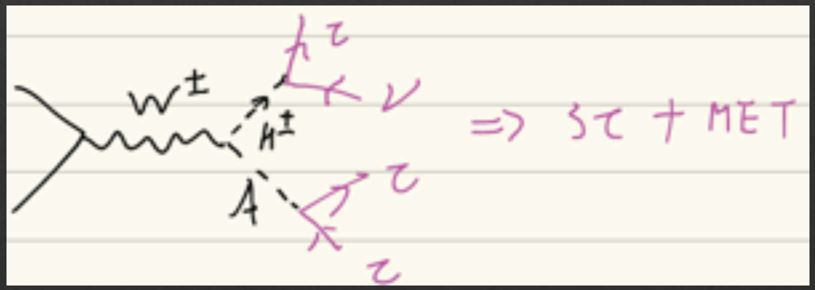


The two-loop Zee-Babu diagram tends to be dominant



In summary, we expect a lighter *A* but heavier $H \sim H^+$, to recover the custodial *SU*(2). They are testable at LHC

In other types of 2DHM like type-II, it is shown that the theoretical and B-physics constraints negate a light A for g-2, see 1409.3199, by A. Broggio etc



Quark-phobic Dark Matter

- Easy leptophilic dark matter

With the leptonic portal Φ_L, DM safely annihilates into $\tau\tau$ via *H* or directly into the portal, i.e., a pair of Higgs bosons AA/HH…

$$\langle\sigma v\rangle_{\tau\tau} \approx \frac{\eta_1^2}{64\pi}\frac{1}{m_S^2}\left(\frac{m_\tau}{m_S}\right)^2\frac{\tan^2\beta}{(1-m_H^2/4m_S^2)^2}\left(1-\frac{m_\tau^2}{m_S^2}\right)^{3/2}$$

$$\langle\sigma v\rangle_{H_iH_i} \approx \frac{1}{64\pi}\frac{\eta_3^2}{m_S^2}C_i\left(1-\frac{m_{H_i}^2}{m_S^2}\right)^{1/2}$$

This DM still leaves full signatures in the cosmic ray, producing 2τ or 4τ which cascade decays into e±/p±/γ, with good prospects.

In particular, if DM is around 10 GeV, favored by the gamma-ray excesses, the only kinematically accessible mode is $\tau\tau$

$$\langle\sigma v\rangle_{\tau\tau} \approx \frac{\eta_1^2}{4\pi}\left(\frac{\tan\beta\times m_\tau}{m_H^2}\right)^2\left(1-\frac{m_\tau^2}{m_S^2}\right)^{3/2} = 1.2\times\left(\frac{\eta_1}{0.1}\right)^2\left(\frac{\tan\beta}{100}\right)^2\left(\frac{300}{m_H}\right)^4 \text{ pb.}$$

Conclusion

- Currently, the null direct detection results place stringent bound on the conventional WIMP
- Indirect detections are also stringent for the light (<100 GeV) DM. But recently, γ-ray excesses are reported, fit by DM DM->$\tau\tau$
- Quark-phobic dark matter easily avoid LUX etc., and is in accords with the anomaly, and g-2…
- We demonstrate a simple example: 2HDML+S

- Thanks for your attention