Cosmological Constraints on Twin Higgs Models

Yuhsin Tsai

1512.02647 Hsin-Chia Cheng, Sunghoon Jung, Ennio Salvioni, YT
1601.07556 Marat Freytsis, Simon Knapen, Dean Robinson, YT

Hidden Naturalness Workshop, April 30 2016

Twin Higgs gives a well-motivated mirror-sector DM model

$\tilde{\ell}^{\pm}$ $\tilde{W}/\tilde{Z}$

Twin Hadrons $\tilde{\gamma}$ $\tilde{\nu}$

Mirror symmetry fixes various couplings & masses

Twin Higgs gives a well-motivated mirror-sector DM model

WIMP-DM

$\tilde{\ell}^{\pm}$ $\tilde{W}/\tilde{Z}$

Asymmetric-DM

Twin Hadrons

$\tilde{\gamma}$ $\tilde{\nu}$

Mirror symmetry fixes various couplings & masses

But the mirror-sector can be well-constrained by cosmology

Relic density, Direct & Indirect Detections

$\tilde{\ell}^{\pm}$ $\tilde{W}/\tilde{Z}$

BBN

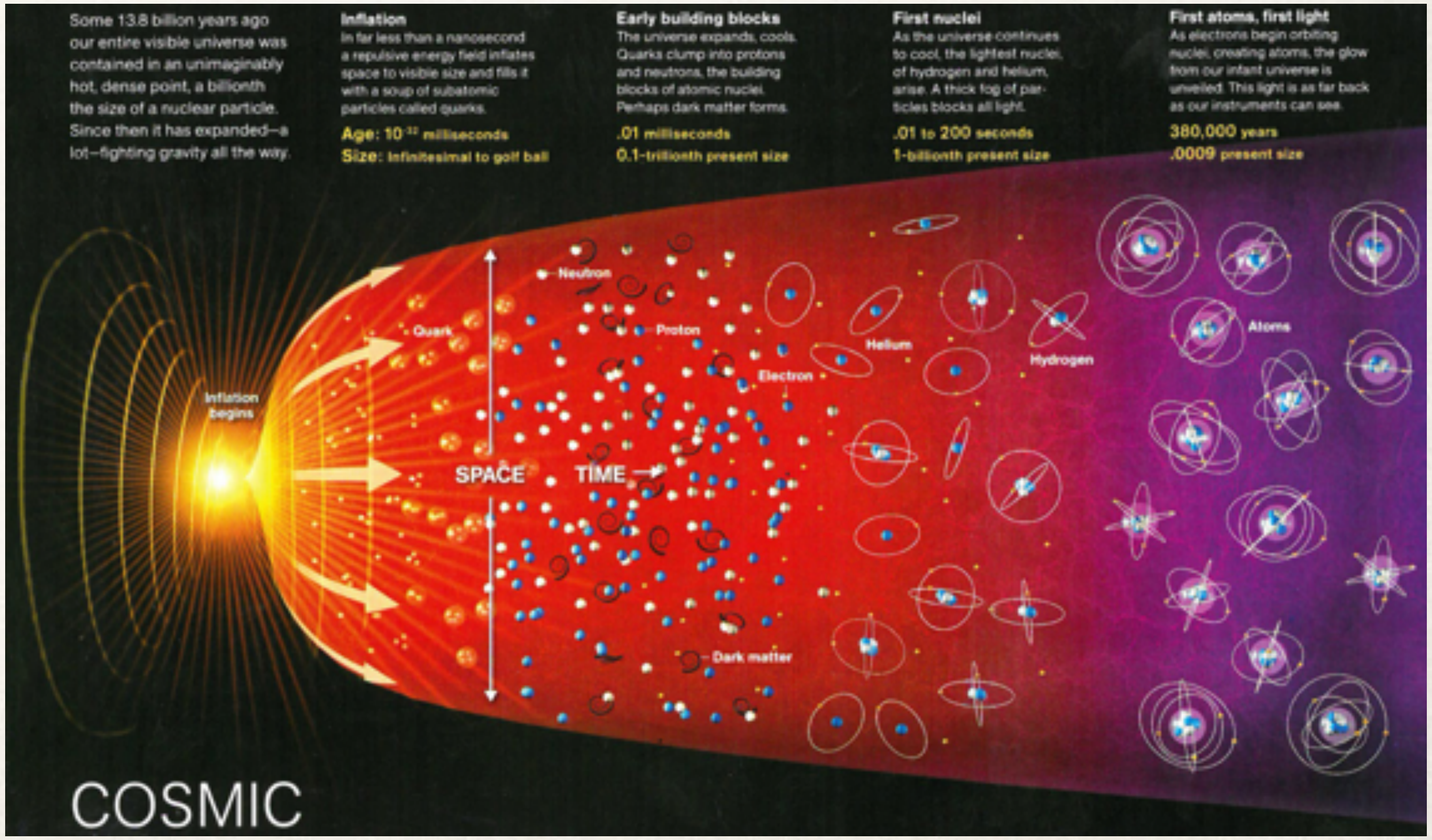
Twin Hadrons

ΔN_{eff}

$\tilde{\gamma}$ $\tilde{\nu}$

How Z2 symmetric can the TH model be?

BBN constraint



If not annihilating into dark radiation, massive twin hadrons need to decay/annihilate into SM sector (bound from relic density)

BBN bound requires the twin-hadron decay into SM to happen before ~ 1 sec

There are few examples that the BBN bound can be complimentary to the LHC or intensity frontier experiments

$\tilde{\Upsilon}_b$ Fraternal TH model

$\tilde{\pi}^0$ Hadrosymmetric TH model

Example: BBN constraint on the $\hat{\Upsilon}$ decay

In the b-onium case without light twin photon/leptons

For the lightest twin bottomina $\hat{\eta}_b(0^{-+}),\ \hat{\Upsilon}(1^{--})$

$\hat{\Upsilon}$ decays through kinetic mixing, but the lifetime depends on the twin photon mass and mixing

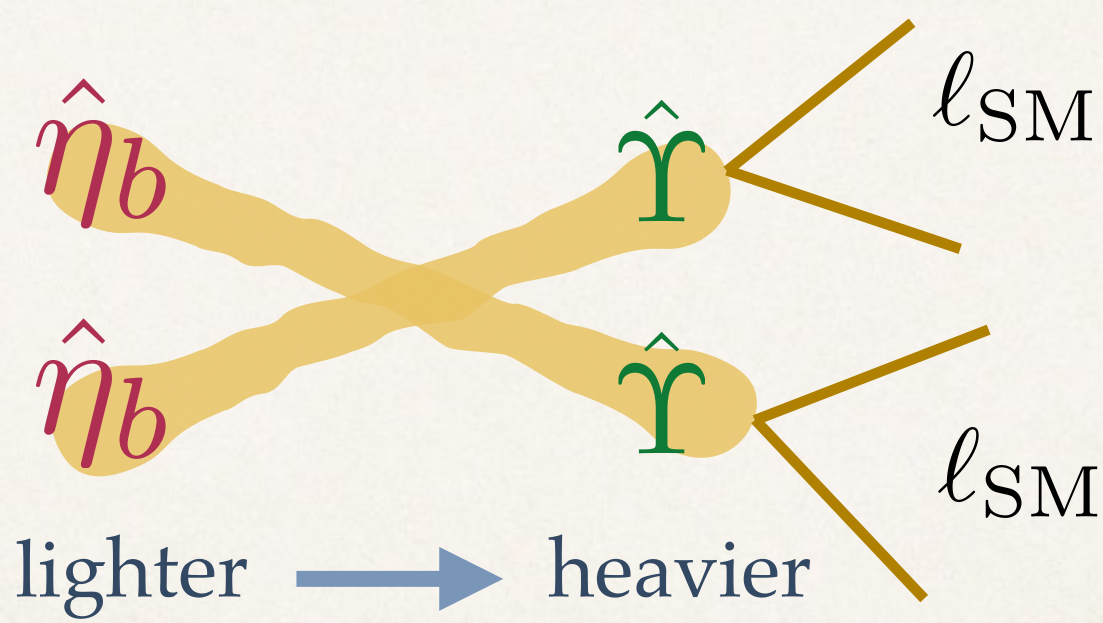
$\hat{\eta}_b$ only decays through highly off-shell processes, which are always slow (>> BBN time scale)

Need to deplete the pseudo-scalar density before BBN!

Example: BBN constraint on the $\hat{\Upsilon}$ decay

When the temperature $T > m_{\hat{\Upsilon}} - m_{\hat{\eta}_b} \simeq \hat{\Lambda}_{\rm QCD}$

$\hat{\eta}_b$ can annihilate into heavier $\hat{\Upsilon}$'s, which then decay into SM

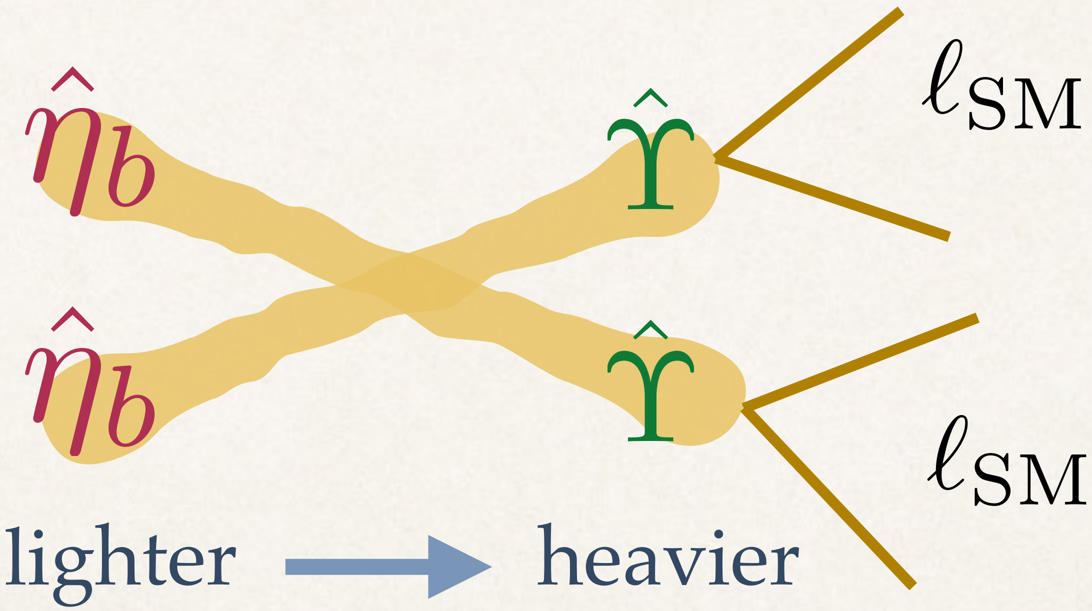


Example: BBN constraint on the $\hat{\Upsilon}$ decay

To reduce the $\hat{\eta}_b$ density before this temperature, we need

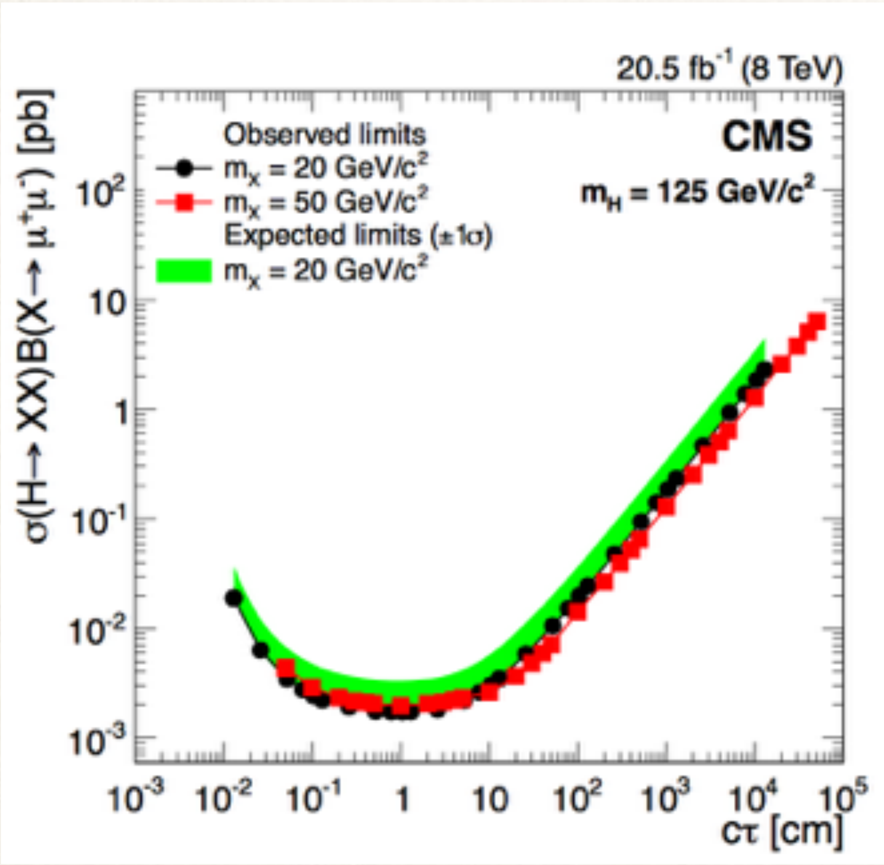
$$\tau_{\hat{\Upsilon}} < H^{-1}(T \simeq \Lambda) \sim 10^{-9}\,\mathrm{sec}$$

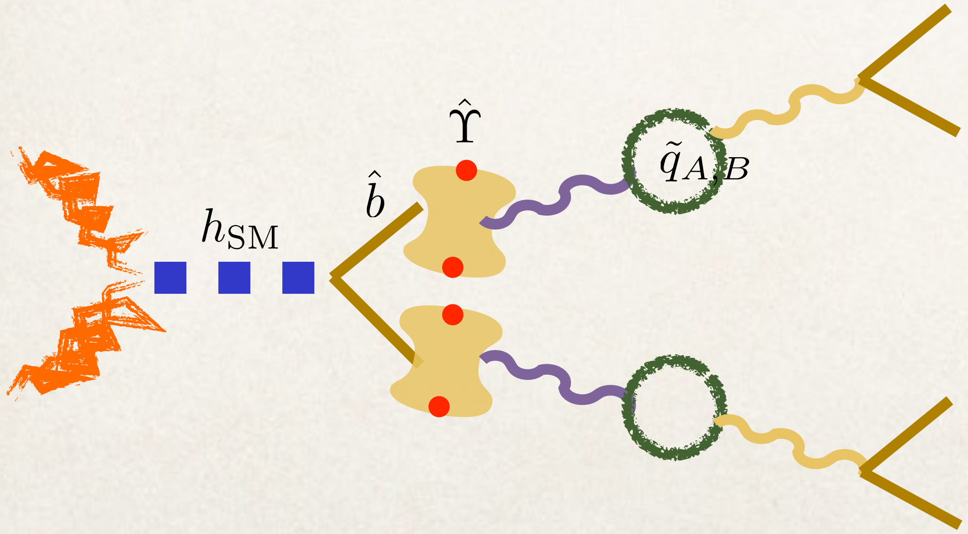
This means $\hat{\Upsilon}$ should decay inside the collider

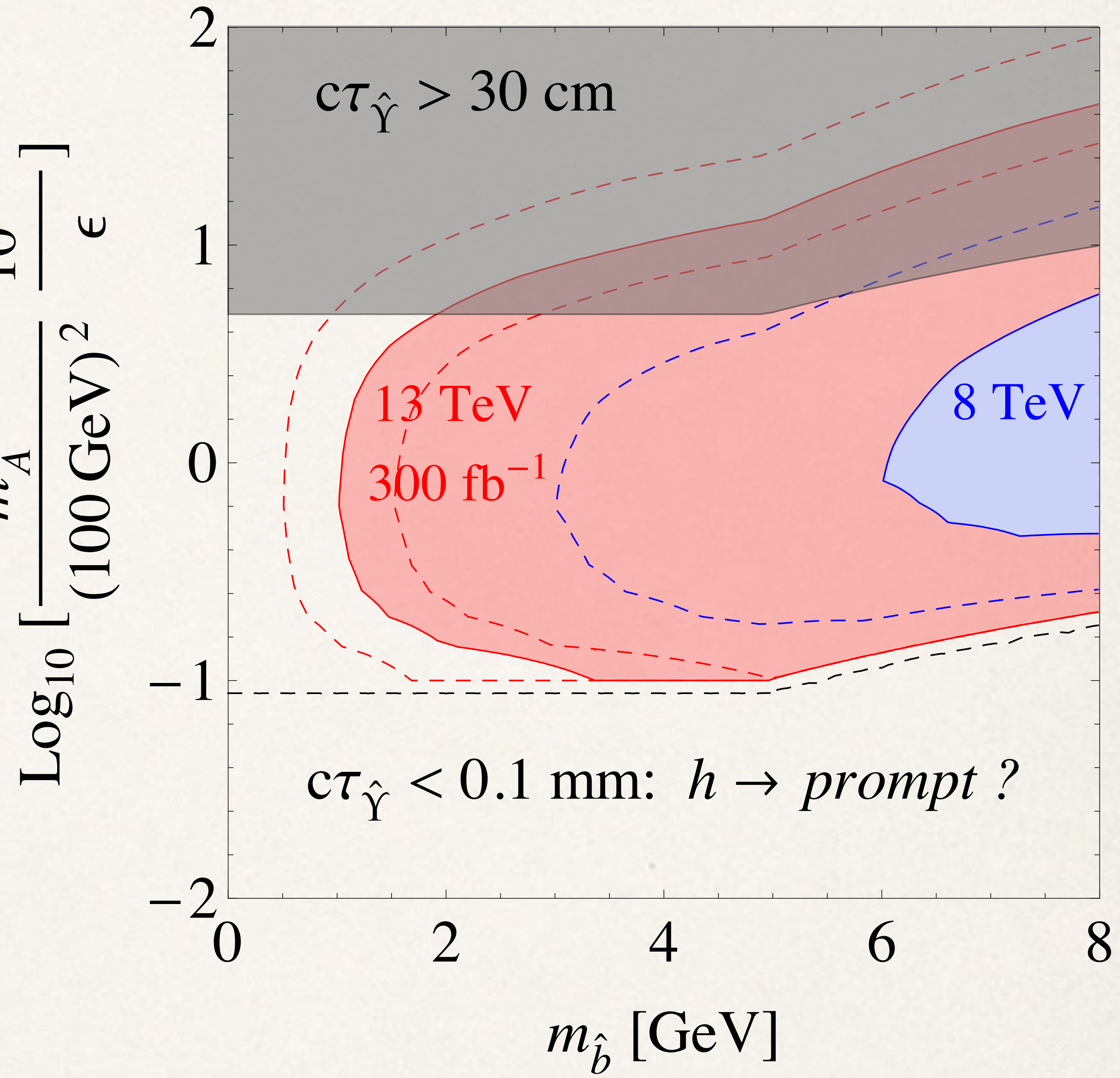


Bound on the vector meson decay

Search of two displaced muon pairs







Dashed contours : different number of light meson states

More Z2 symmetric: Hadrosymmetric TH

Freytsis, Knapen, Robinson, YT (16')

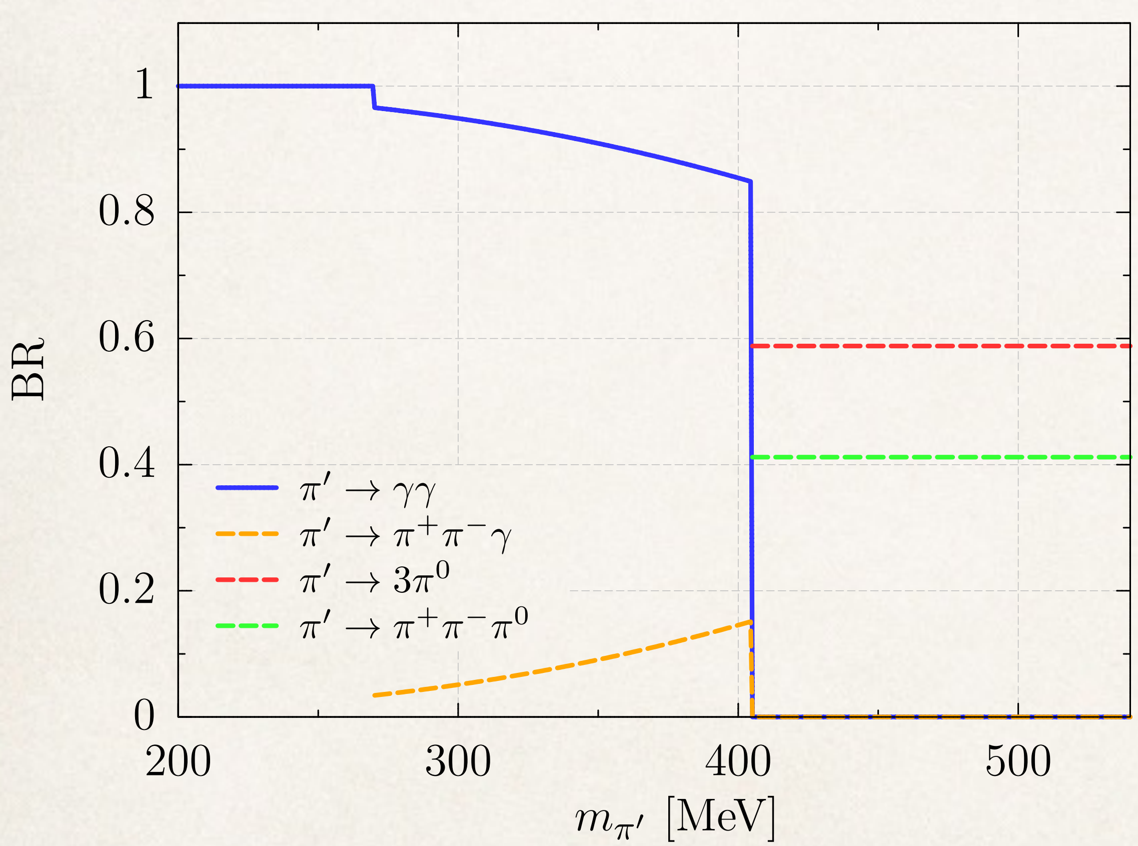
TH model with a Z2 symmetric quark sector (flavor, gauge and yukawa couplings) but no light lepton/photon

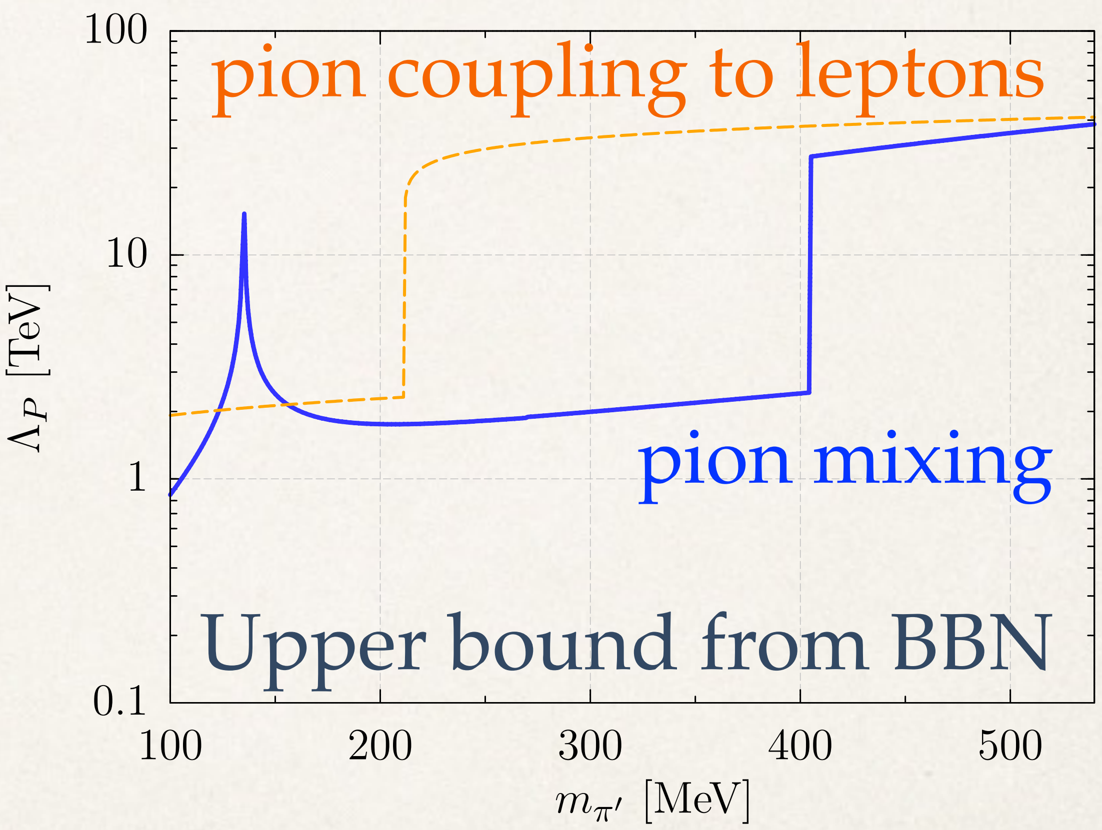
Lightest twin hadrons: twin pion, need to decay them!

DM annihilation: into dark shower, which can generate the possible galactic center gamma ray signal (from FERMI)

Need an extra mediation for pion decay

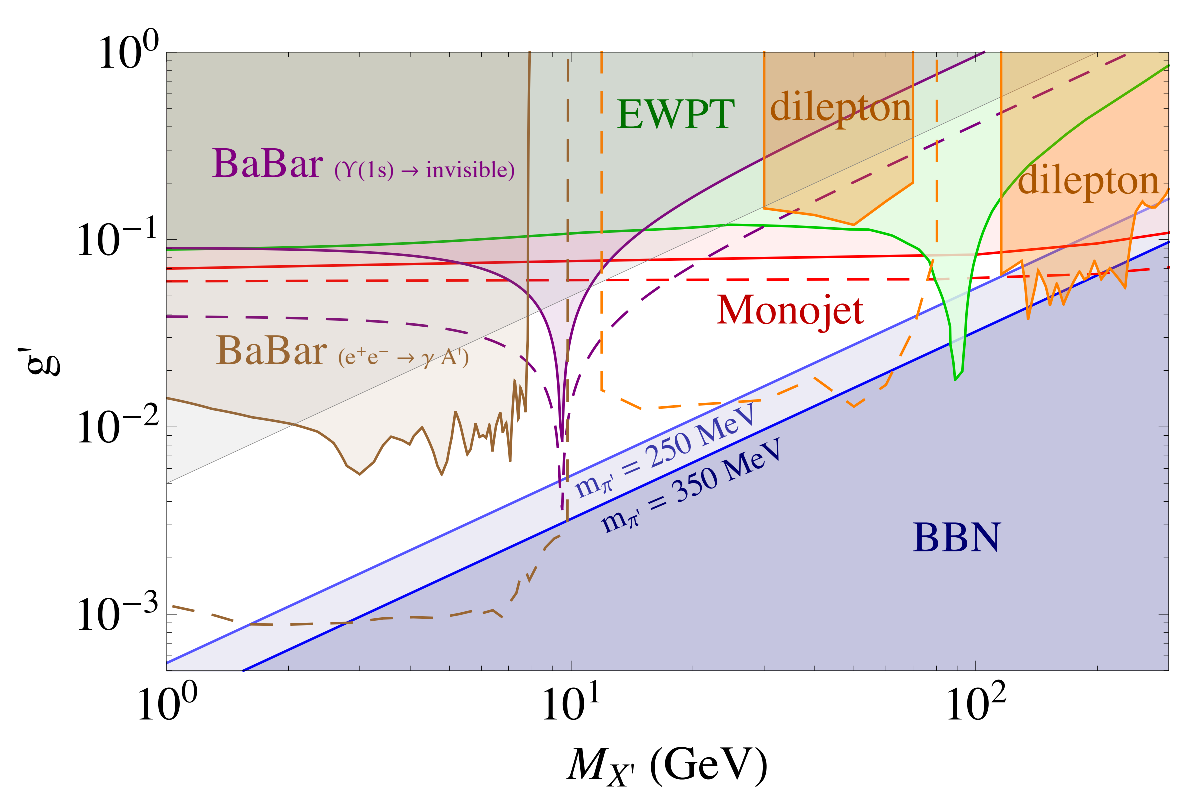
Twin-SM pion mixing: $$\frac{1}{\Lambda_P^2}(J^{u'}_{V+A} - J^{d'}_{V+A}) \cdot (J^{u}_{V+A} - J^{d}_{V+A})$$

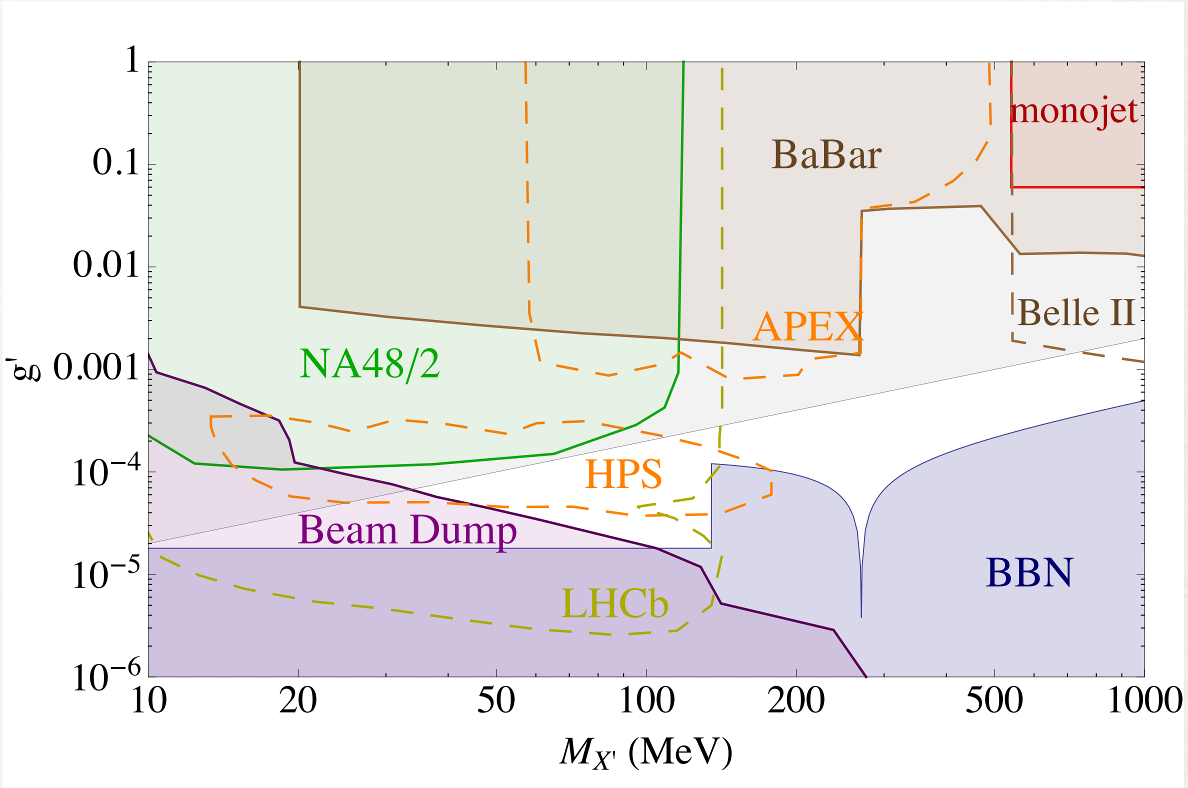




BBN sets an upper bound on the twin-hadron mediation scale

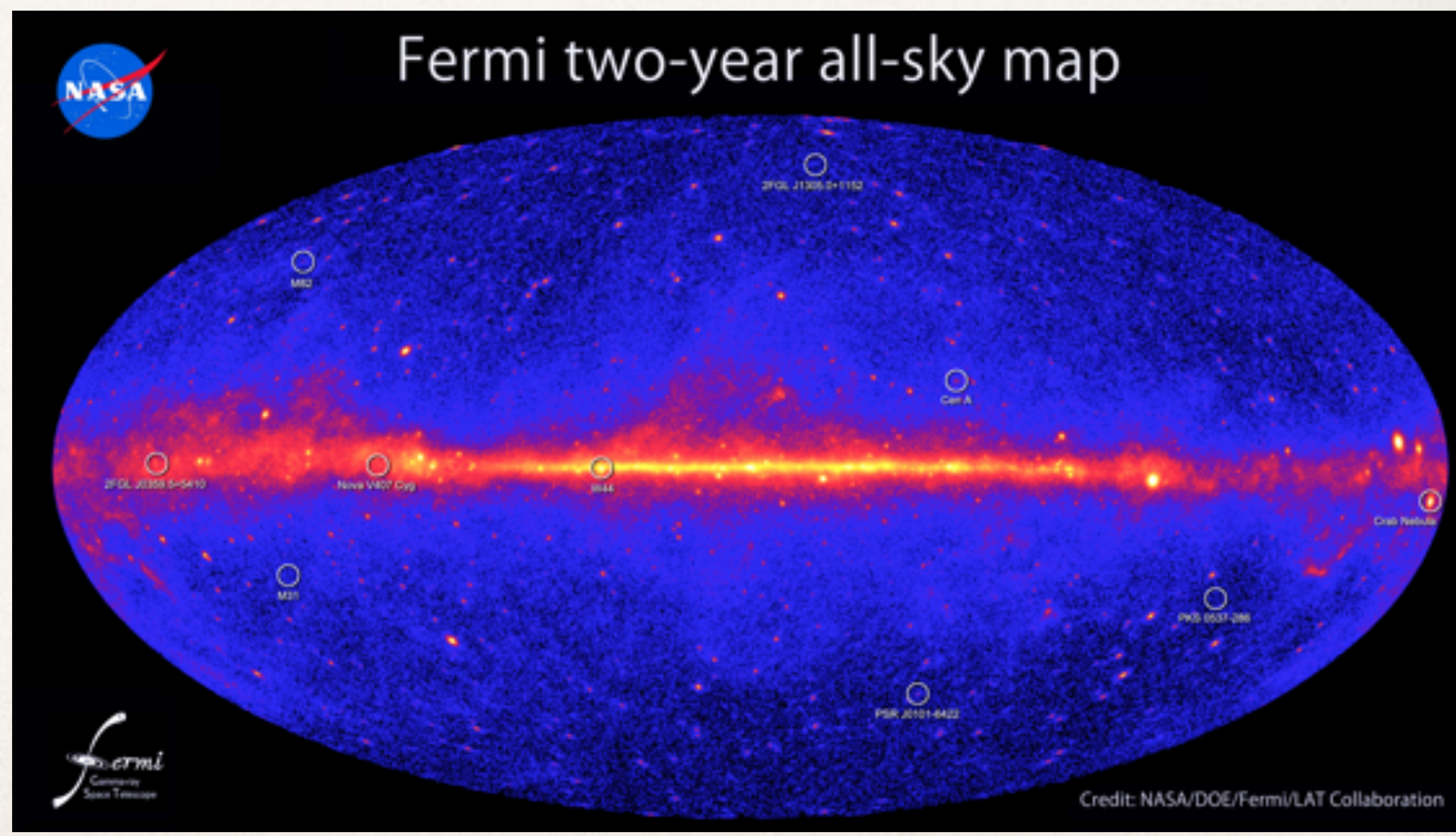
$$\mathcal{L} = g_X X'_\mu \left(u^\dagger \sigma^\mu u + u'^\dagger \sigma^\mu u'\right) - g_X X'_\mu \left(d^\dagger \sigma^\mu d + d'^\dagger \sigma^\mu d'\right)$$





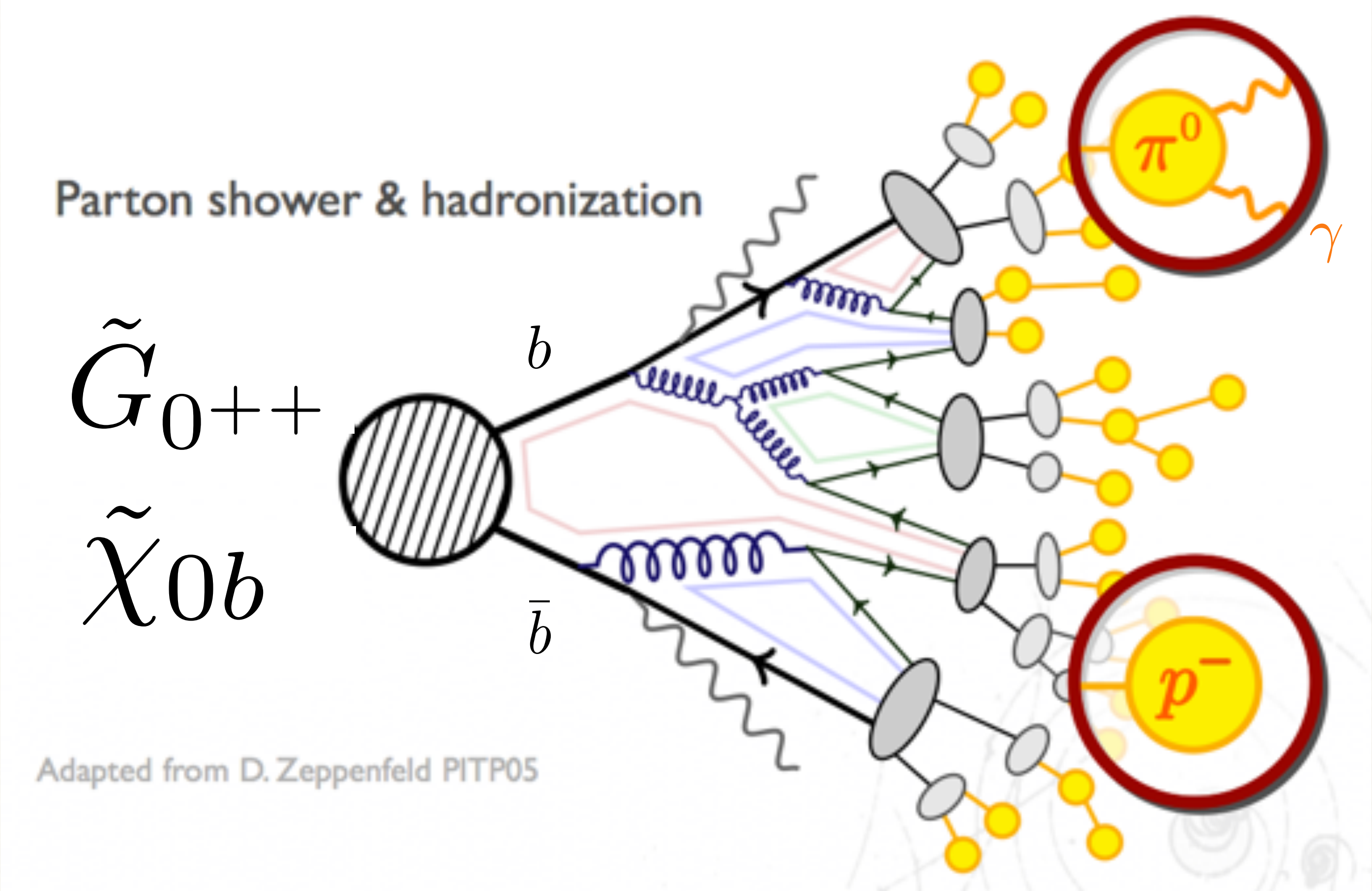
The allowed parameter space is well-covered by the BBN, LHC, and intensity frontier experiments

Indirect Detection



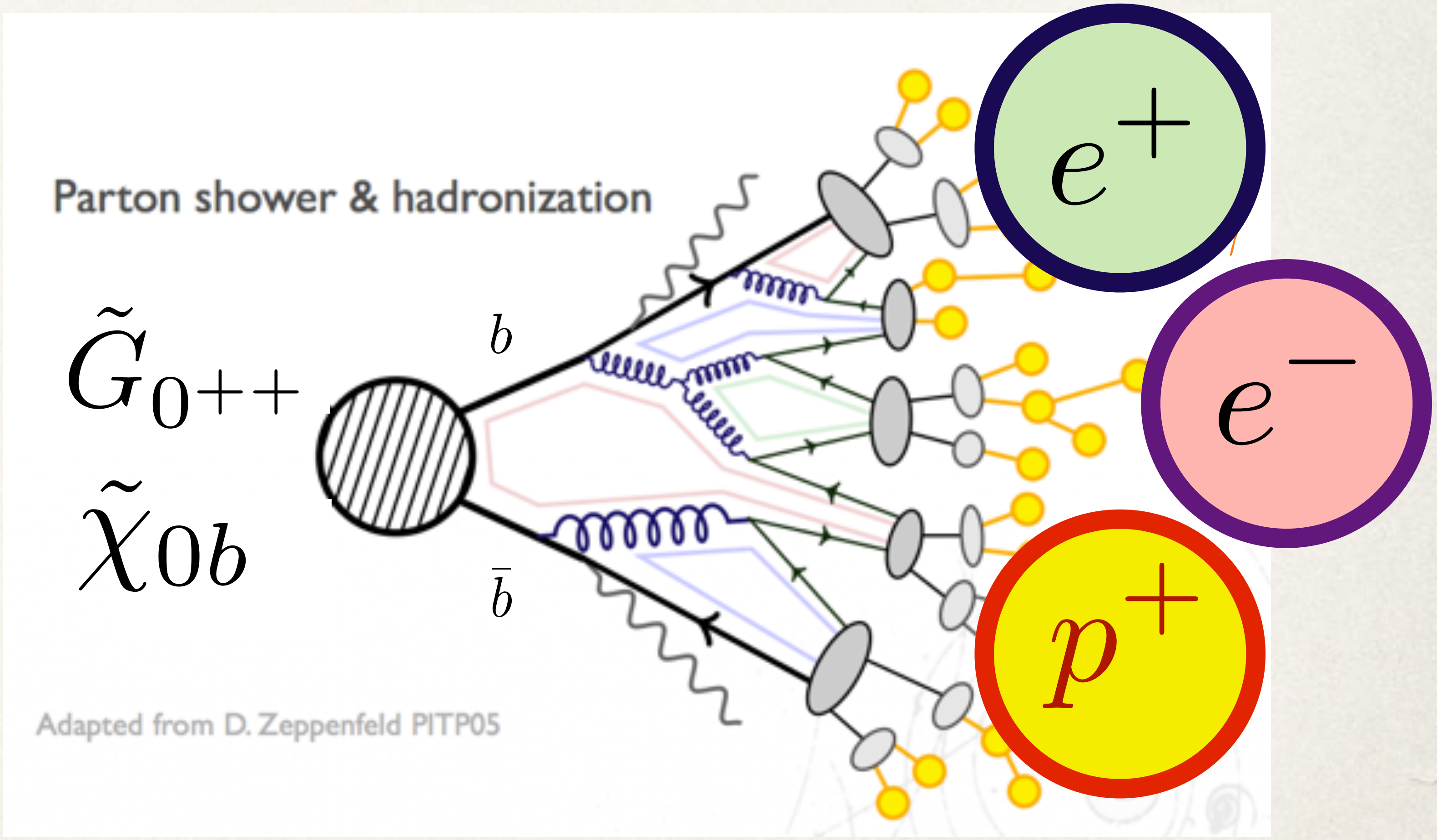
DM annihilation in Fraternal TH

(cosmo) the safest scenario: Scalar glueballs as the lightest hadron, decays quickly into SM bb



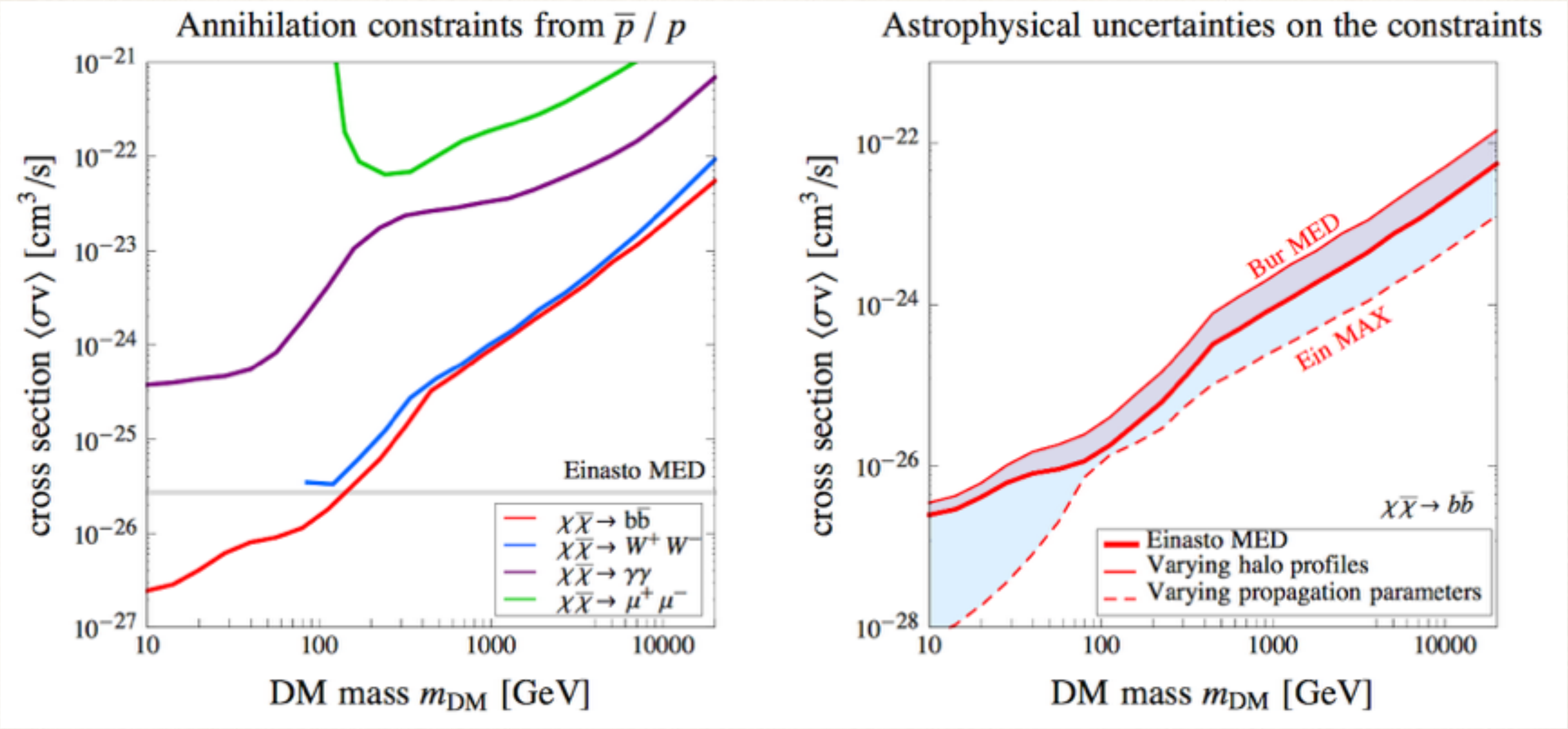
DM annihilation in Fraternal TH

Even so…
The glueball decay into bb can still be constrained by searches of secondary emissions



Bounds from the anti-proton search

Constraint from AMS-02



The recent AMS-02 result has set a stronger constraint

Naive estimation

Assuming $\hat{\tau}\bar{\hat{\tau}} \to n\,\tilde{G}_{0^{++}}$

Naive estimation

Assuming $\hat{\tau}\bar{\hat{\tau}} \to n\,\tilde{G}_{0^{++}}$

Each glueball carries energy $\dfrac{2m_{\hat{\tau}}}{n}$, and their decay into bb is the same as the annihilation of DM with mass $\dfrac{m_{\hat{\tau}}}{n}$

Naive estimation

Assuming $\hat{\tau}\bar{\hat{\tau}} \to n\,\tilde{G}_{0^{++}}$

Each glueball carries energy $\frac{2m_{\hat{\tau}}}{n}$, and their decay into bb is the same as the annihilation of DM with mass $\frac{m_{\hat{\tau}}}{n}$

The number density of twin-tau is n^{-1} times smaller then DM particle with this mass

Naive estimation

Assuming $\hat{\tau}\bar{\hat{\tau}} \to n\,\tilde{G}_{0++}$

Each glueball carries energy $\frac{2m_{\hat{\tau}}}{n}$, and their decay into bb is the same as the annihilation of DM with mass $\frac{m_{\hat{\tau}}}{n}$

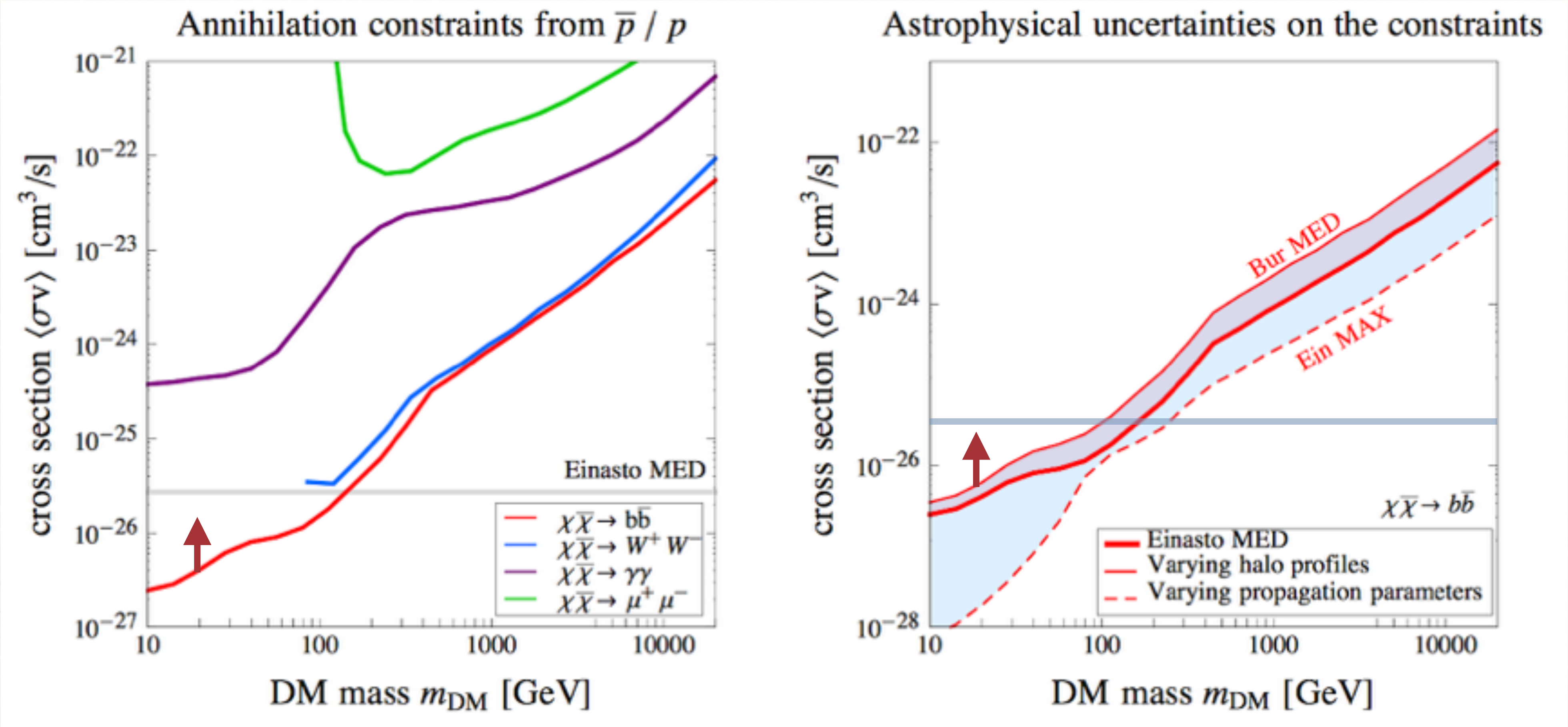
The number density of twin-tau is n^{-1} times smaller then DM particle with this mass

The signal rate is proportional to $n^{-2} \times n \times \langle \sigma v \rangle$ which corresponds to the $\langle \sigma v \rangle$ bound n times weaker

Bounds from the anti-proton search

For example

$\hat{\tau} = 80\,\mathrm{GeV}$ $\hat{G}_{0++} = 35\,\mathrm{GeV}$ $n \simeq 4$ $\sim m_{\mathrm{DM}} = 20\,\mathrm{GeV}$

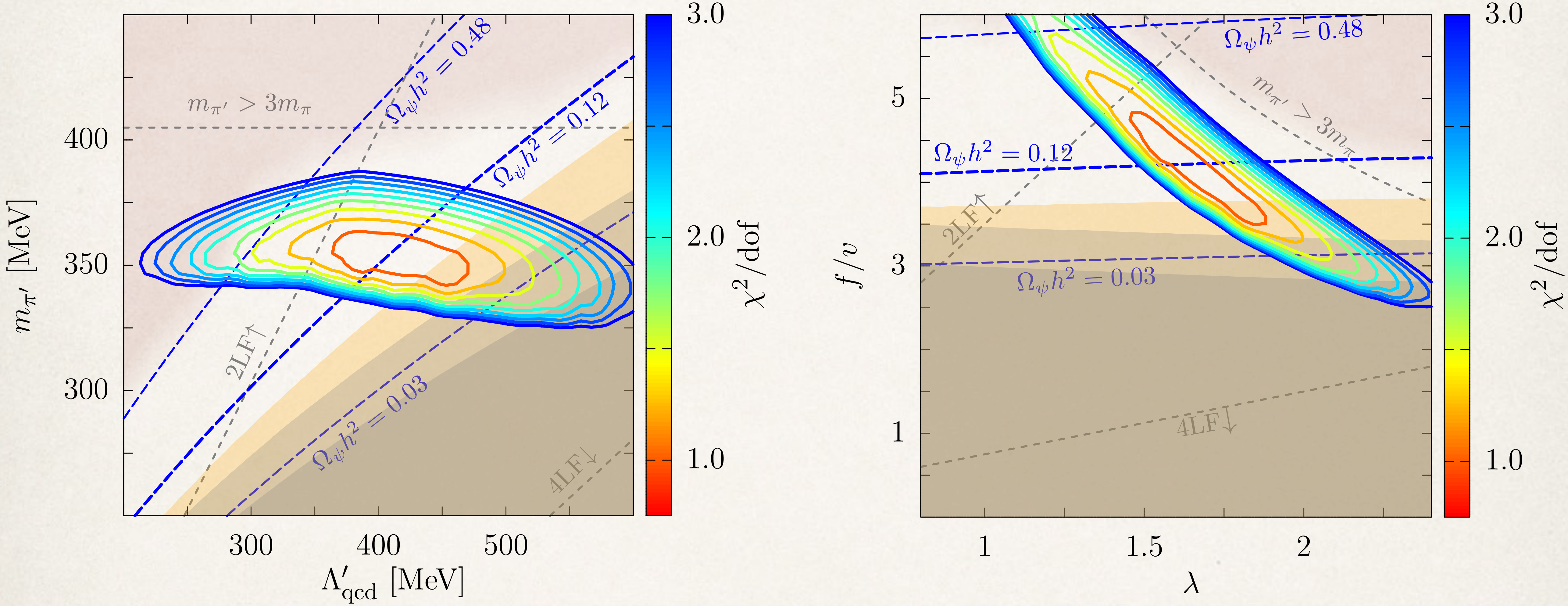


The estimation here has not taken into account the smearing of proton energy, which can weaken the bound

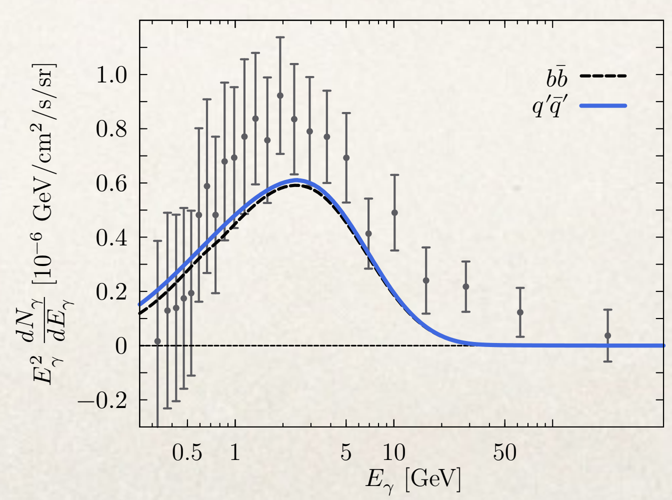
In the hadrosymmetric case

Much fewer anti-protons, mainly photon signals

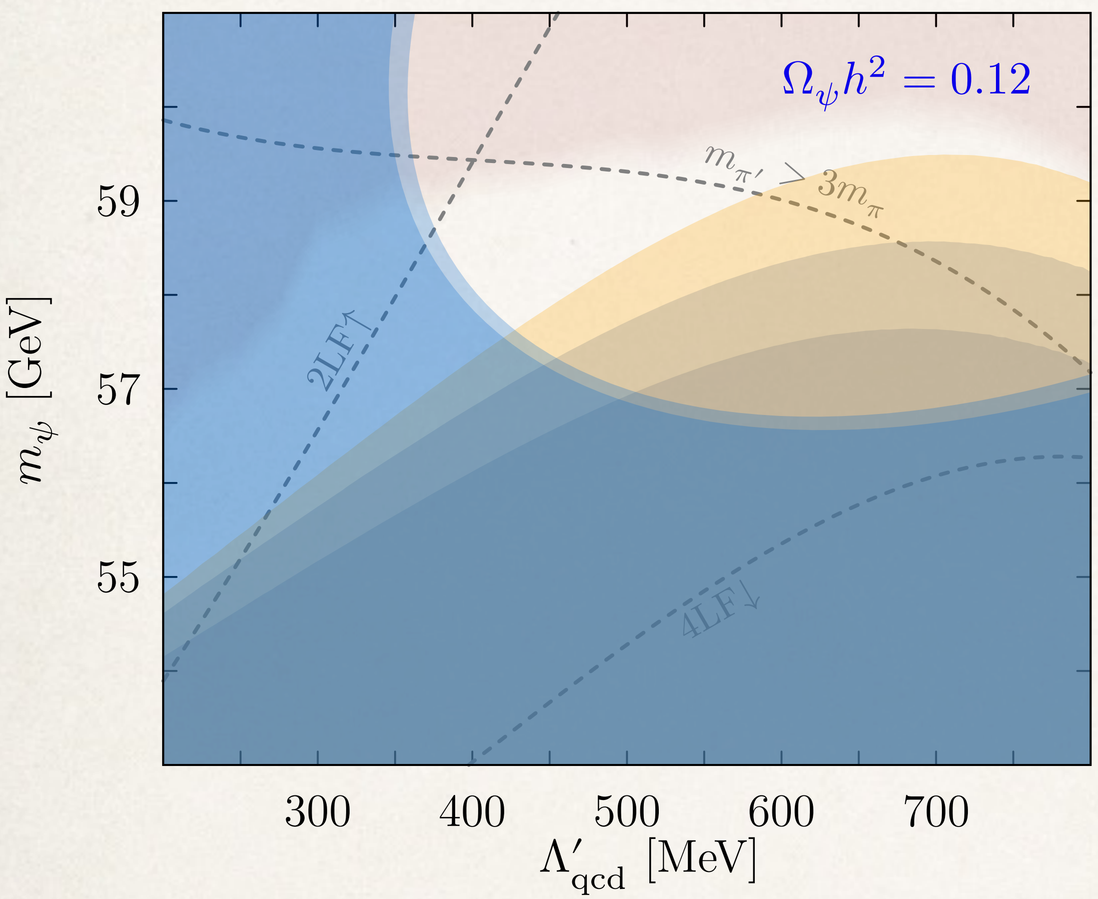
Galactic center gamma-ray emission

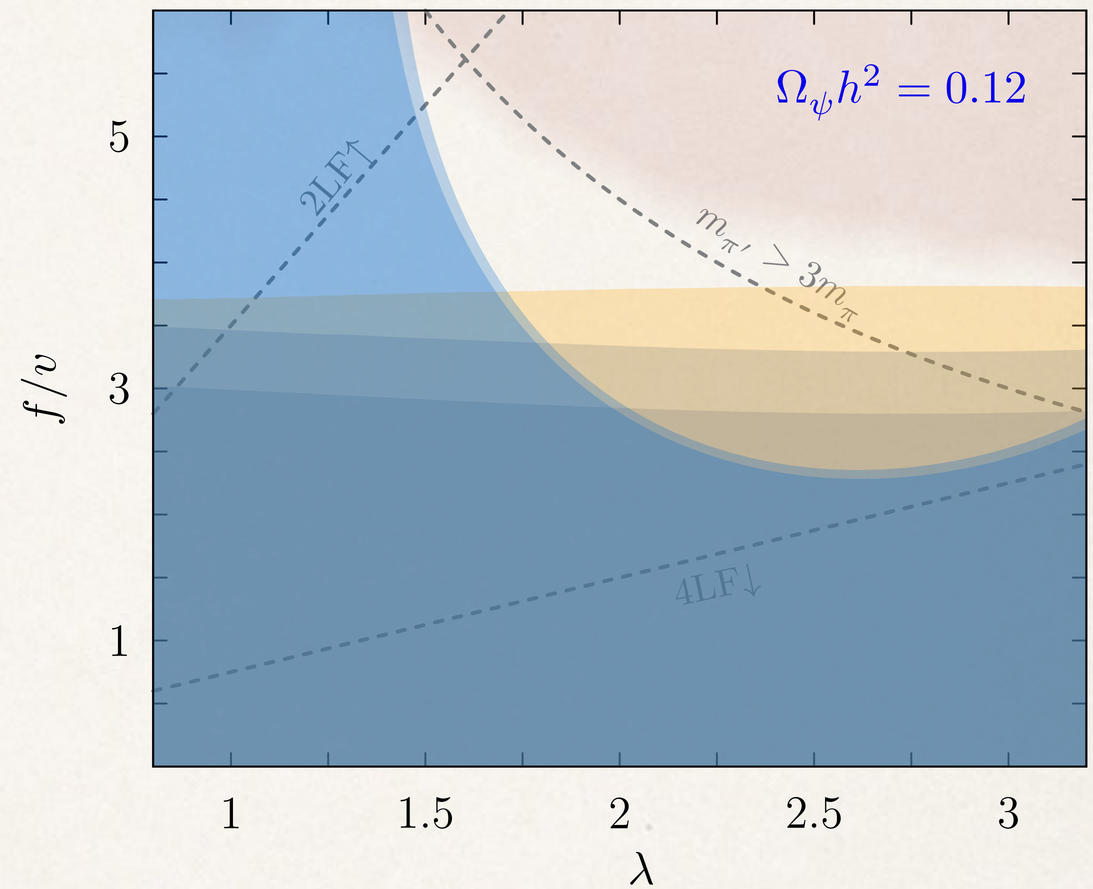


Can provide the observed photon signals, while satisfying all the direct/indirect detection constraints



If the gamma-rays are not from DM





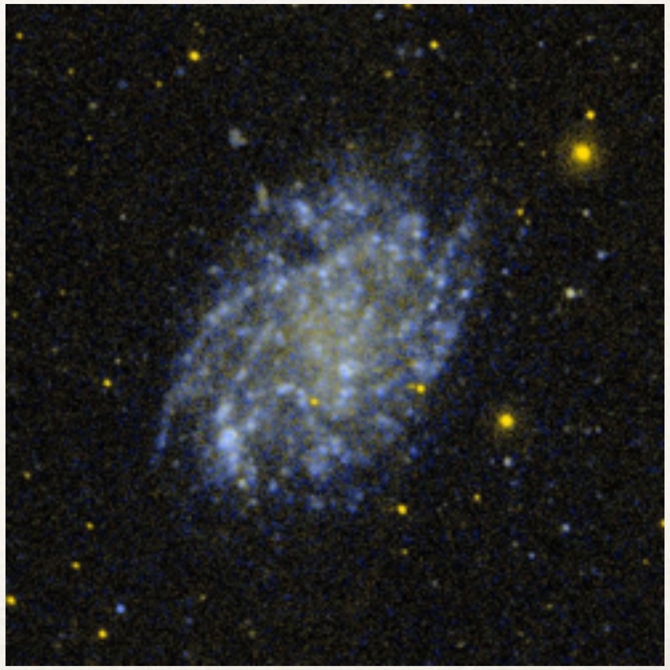
Using the data to set a bound on photon flux

(68% and 90% CL)

Small Scale Structure

Dwarf Galaxy

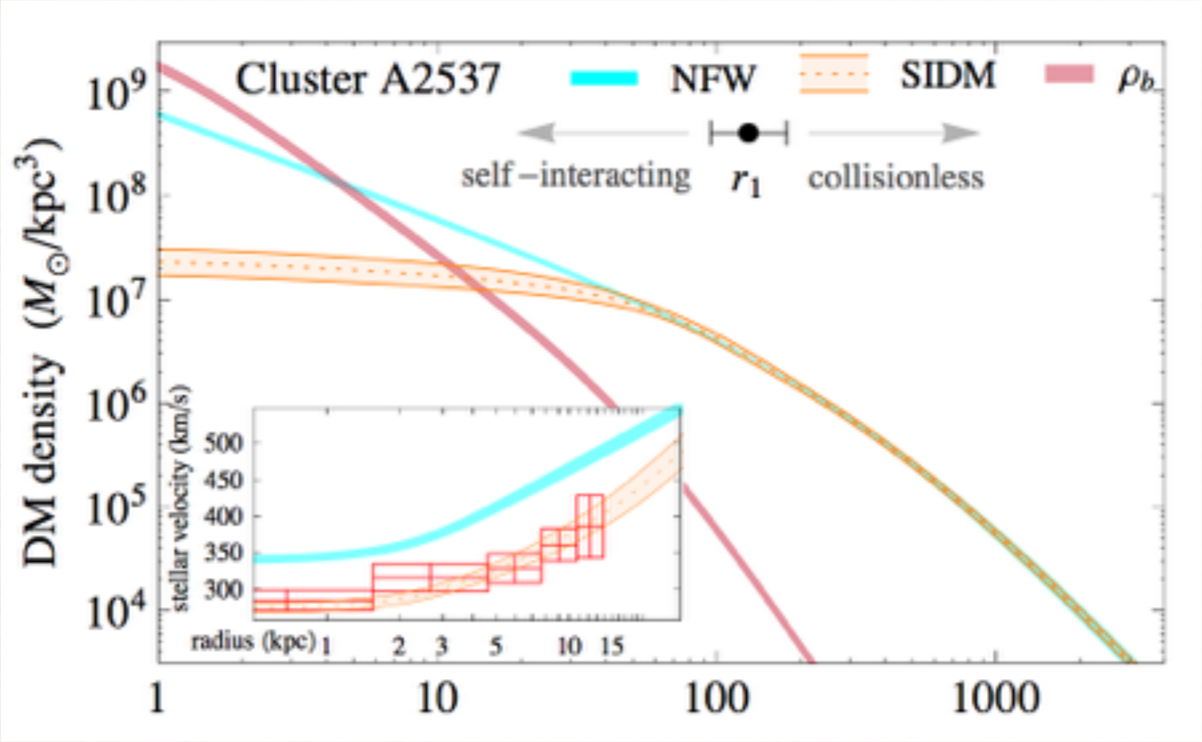
LSBs

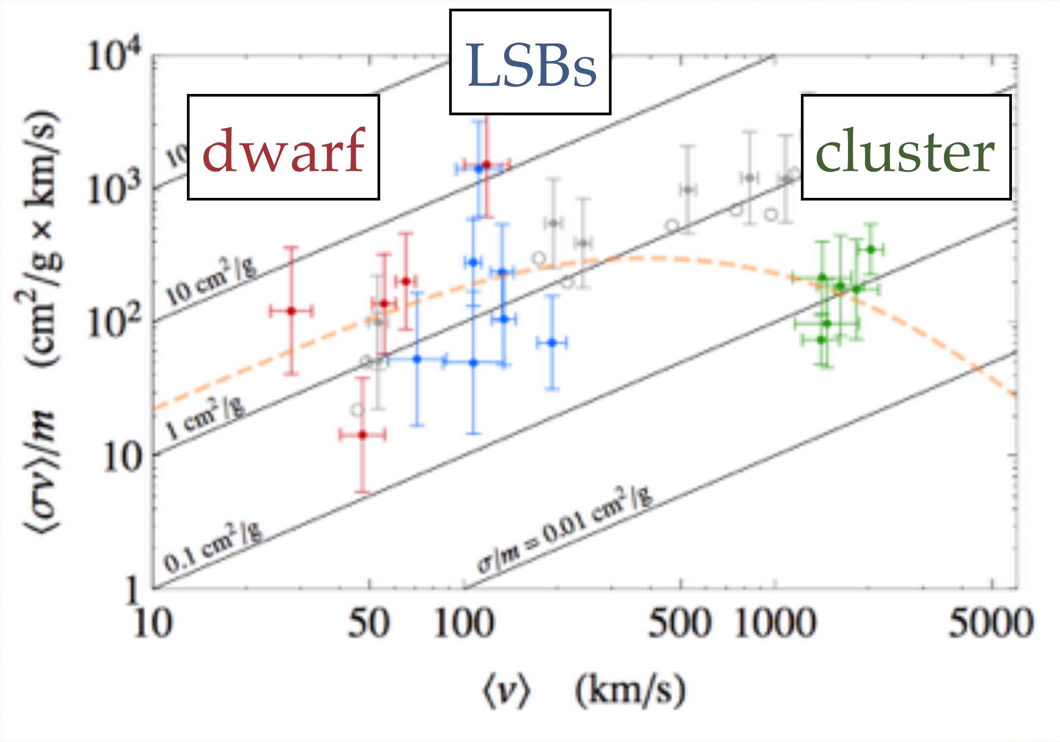


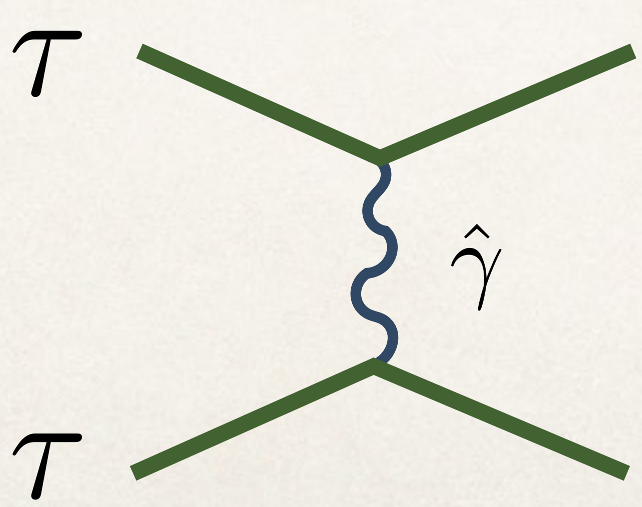
Galaxy Clusters

Puzzles of the small scale structure

Kaplinghat, Tulin, Yu (15′)





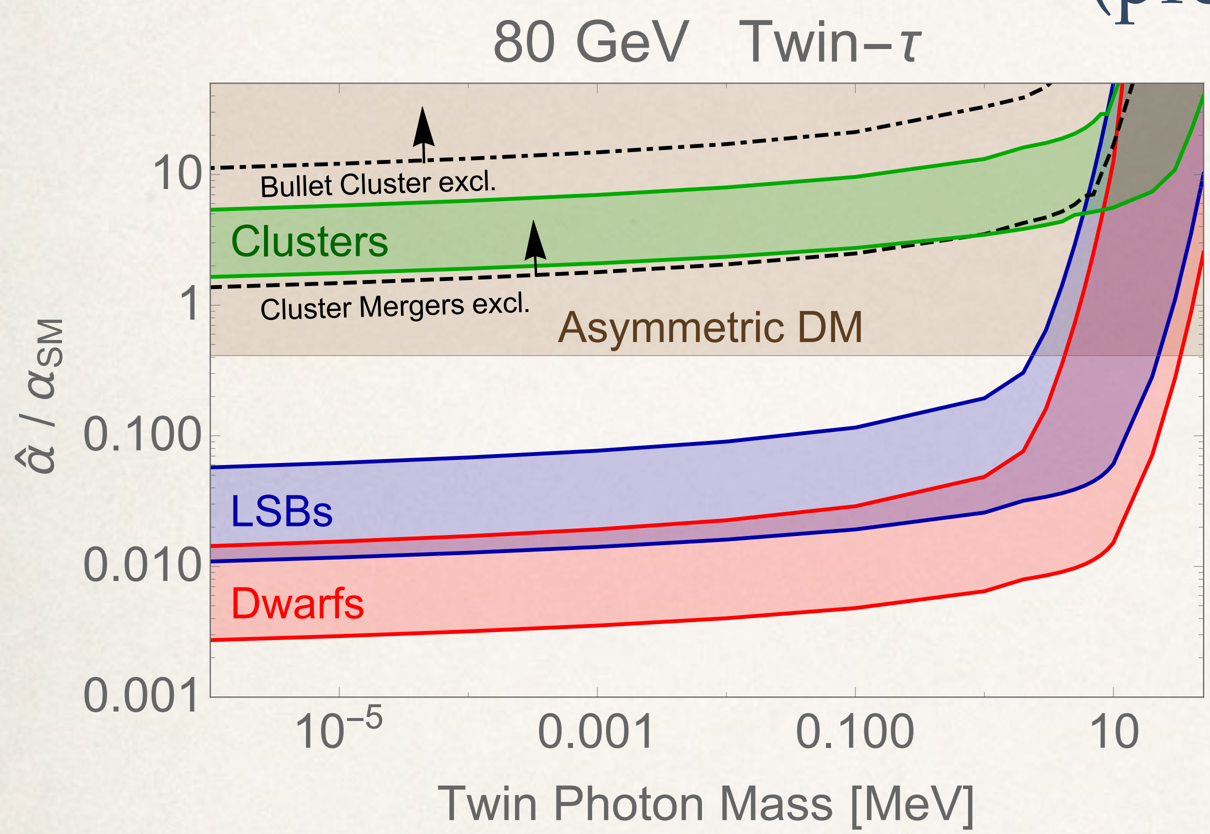


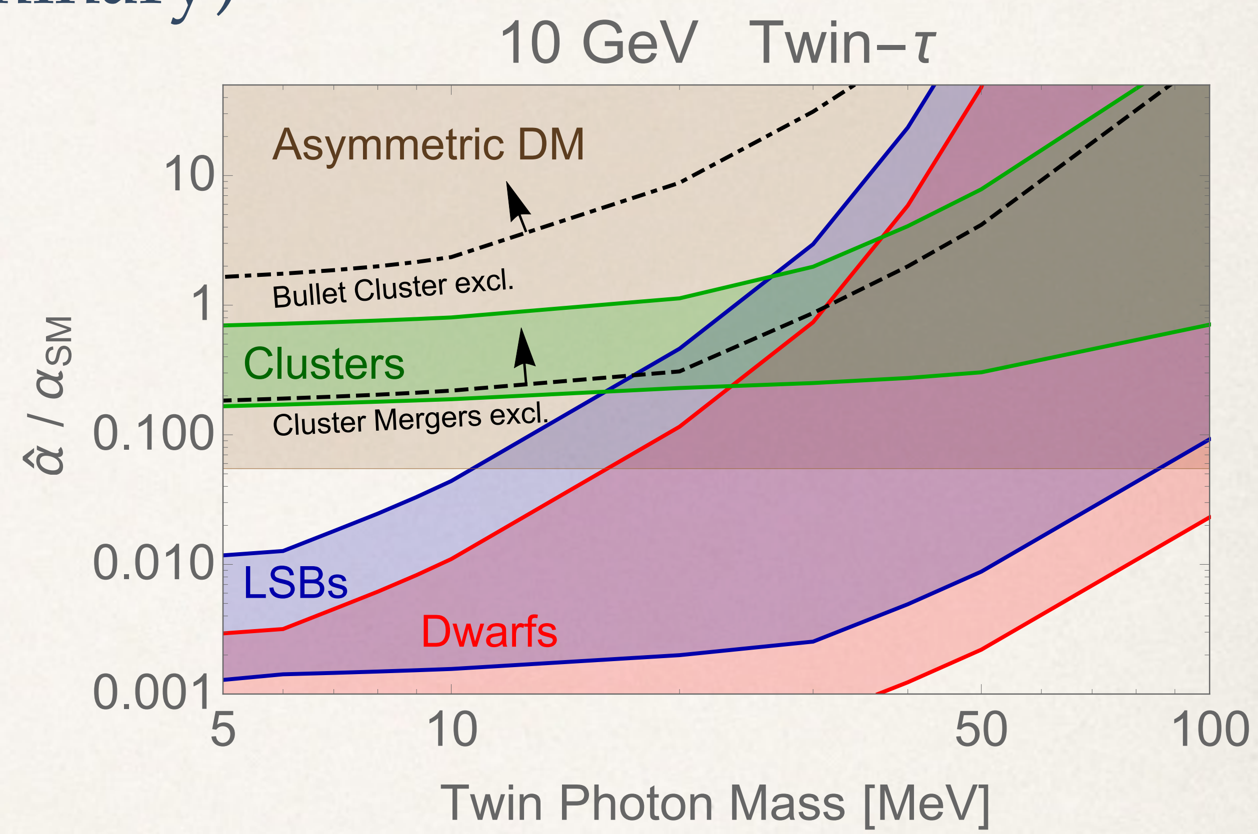
Twin-lepton as a self-interacting DM

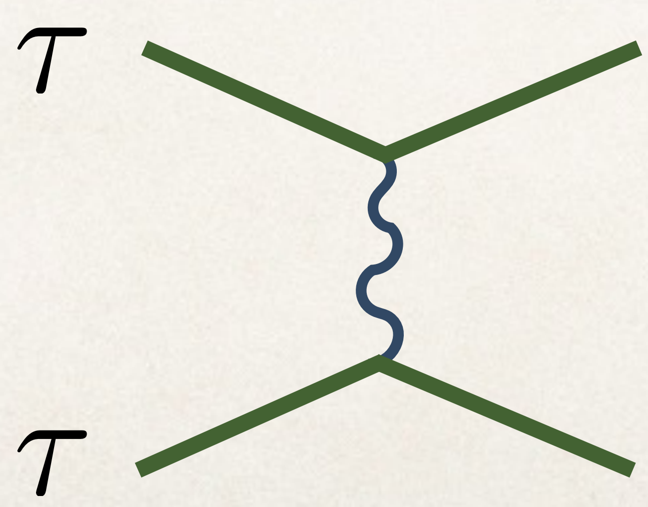
Twin SIDM (or the twin-photon bound)

YT, Prilepina (in progress)

(preliminary)



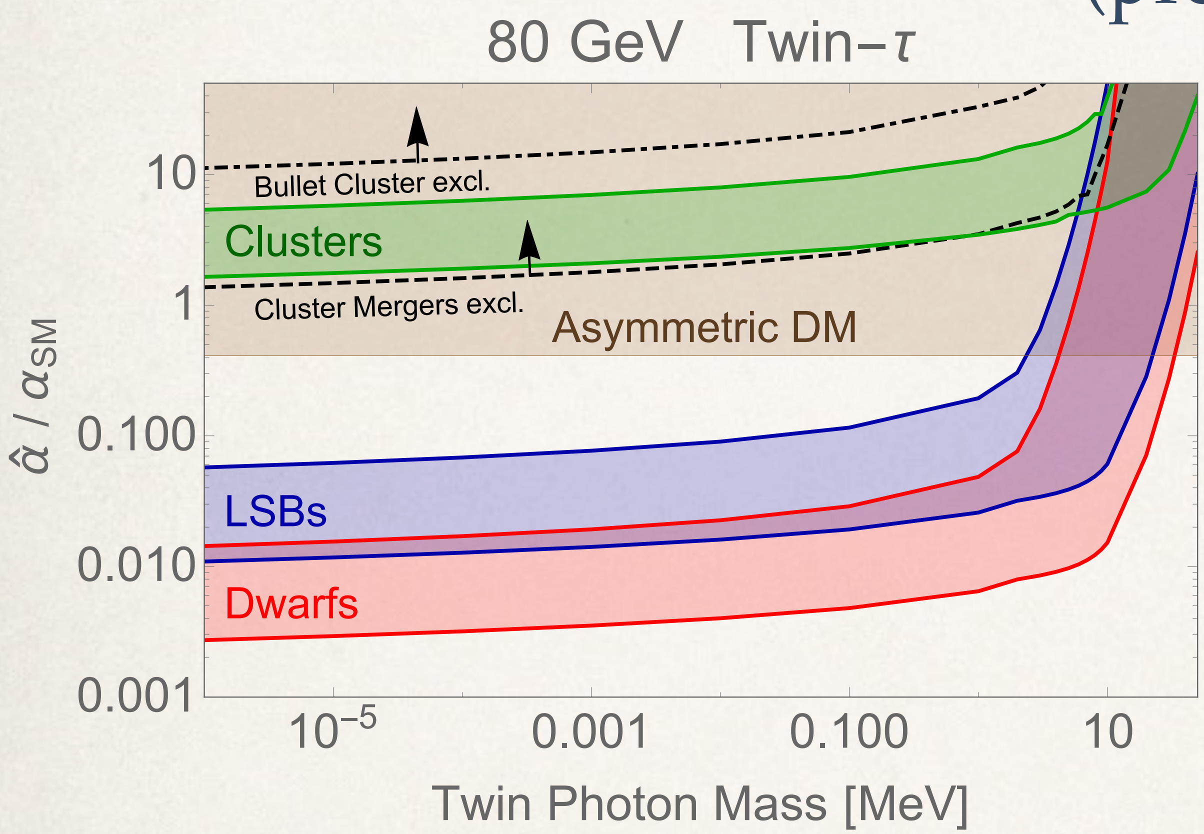


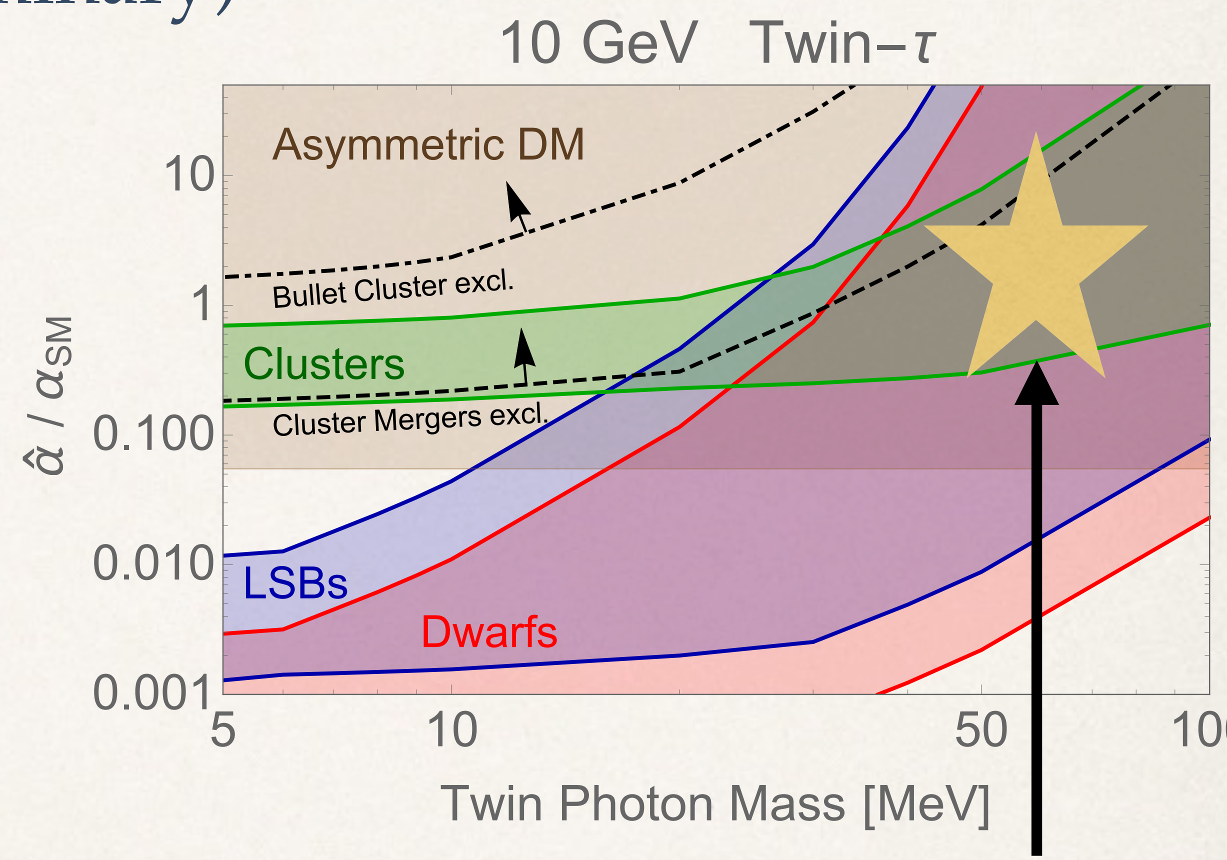


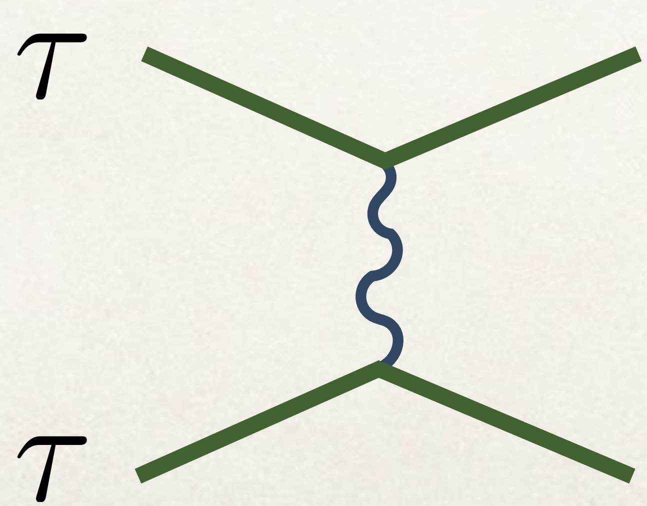
Twin SIDM (or the twin-photon bound)

YT, Prilepina (in progress)

(preliminary)





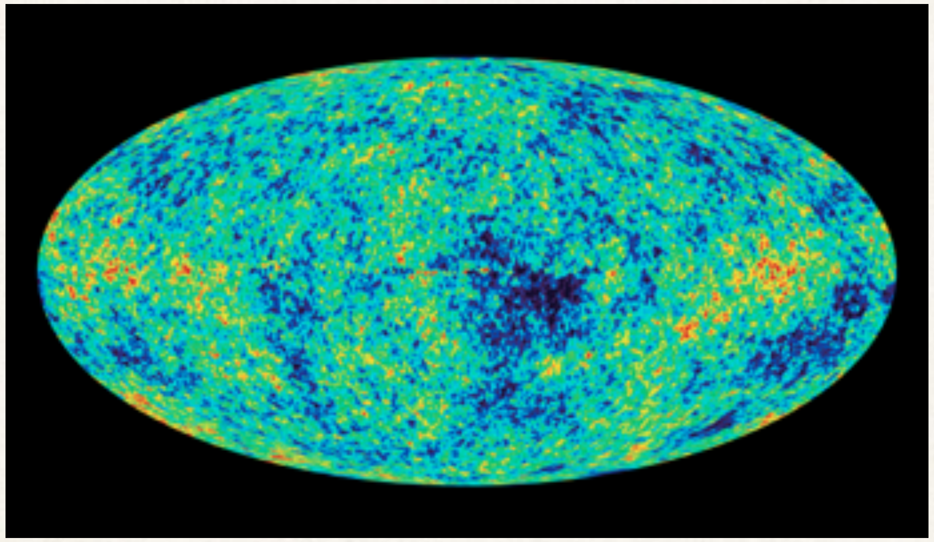


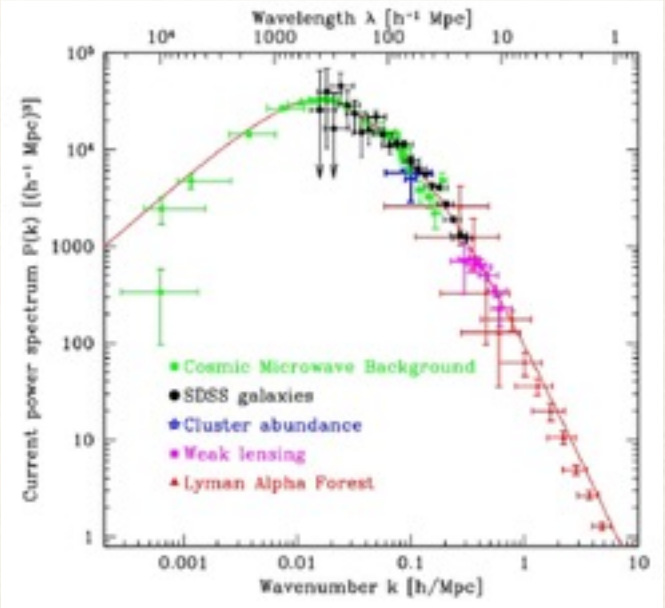
Asymmetric twin-tau (leptogenesis?)

$$m_{\hat{\tau}} \sim m_\tau \times \frac{f}{v}, \quad \hat{\alpha} = \alpha_{\rm SM}$$

$$m_{\hat{\gamma}} \simeq 50 - 100\,\mathrm{MeV}$$

Large Scale Structure



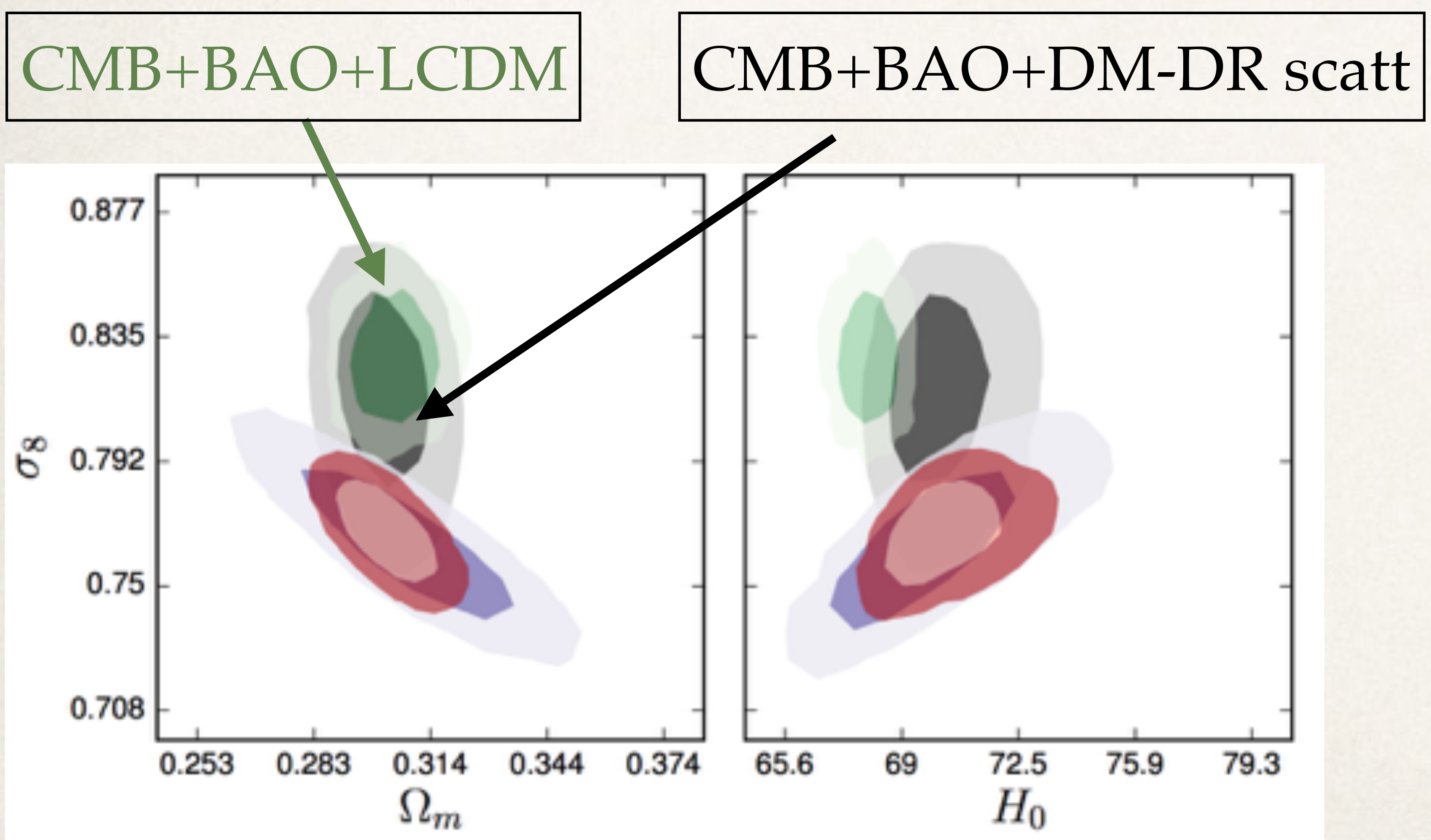


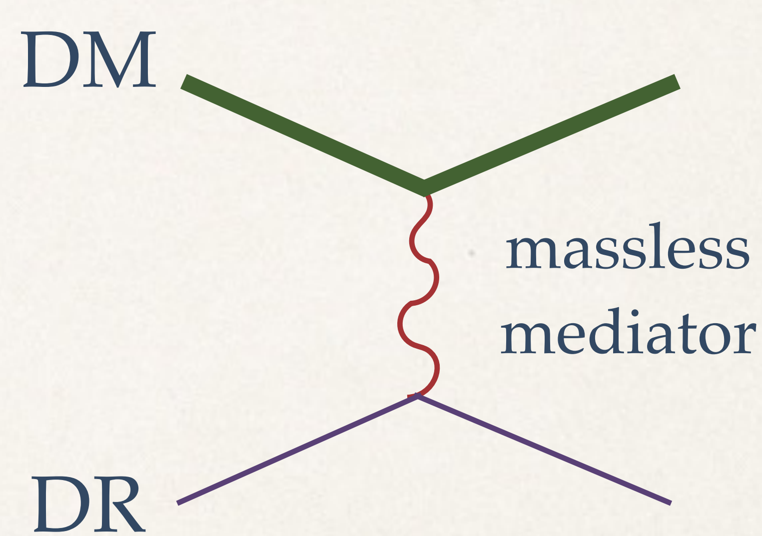
Puzzles of the large scale structure

The σ_8/H_0 fitting from the CMB+LCDM prediction is $3-4\sigma$ away from the weak lensing results

(σ_8 matter density perturbation on a sphere of $8h^{-1}\,\mathrm{Mpc}$)

Lesgourgues, Marques-Tavares, Schmaltz (15')

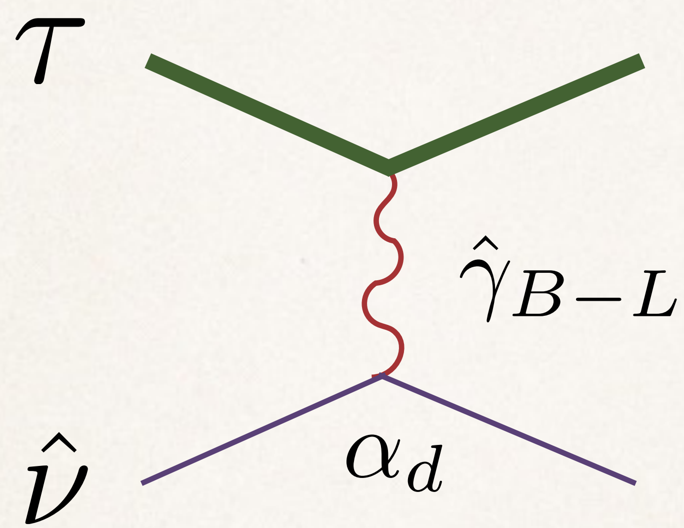


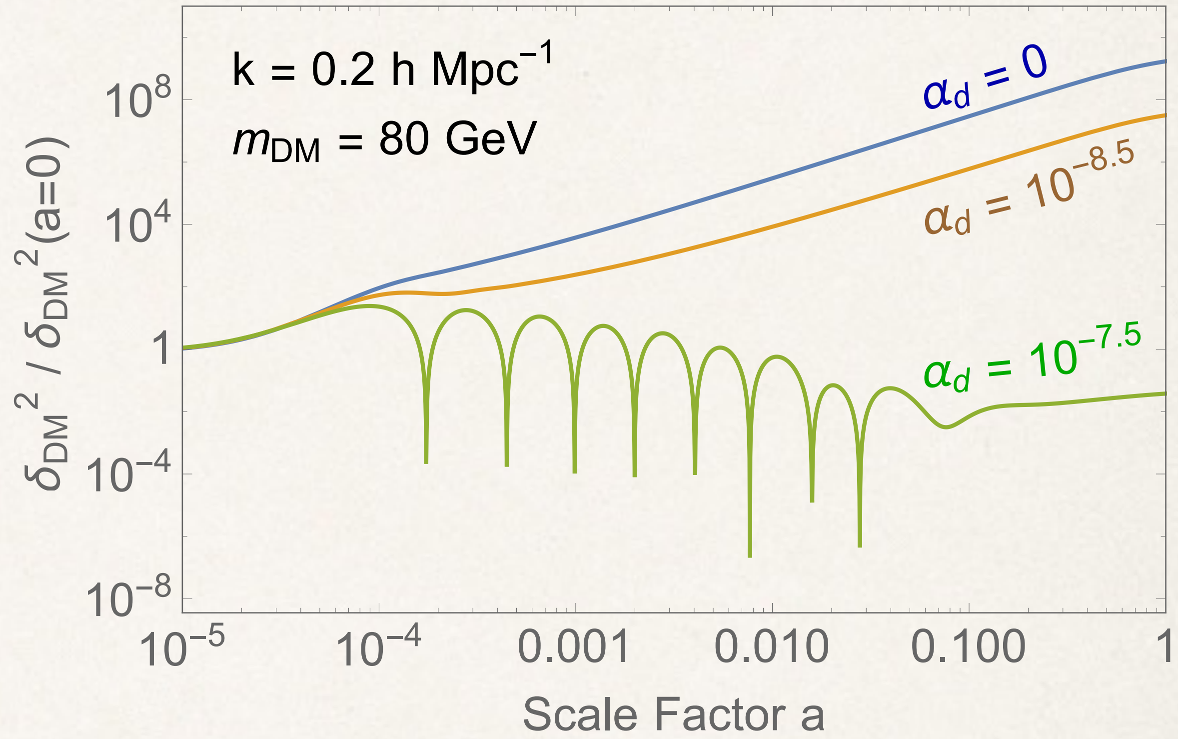


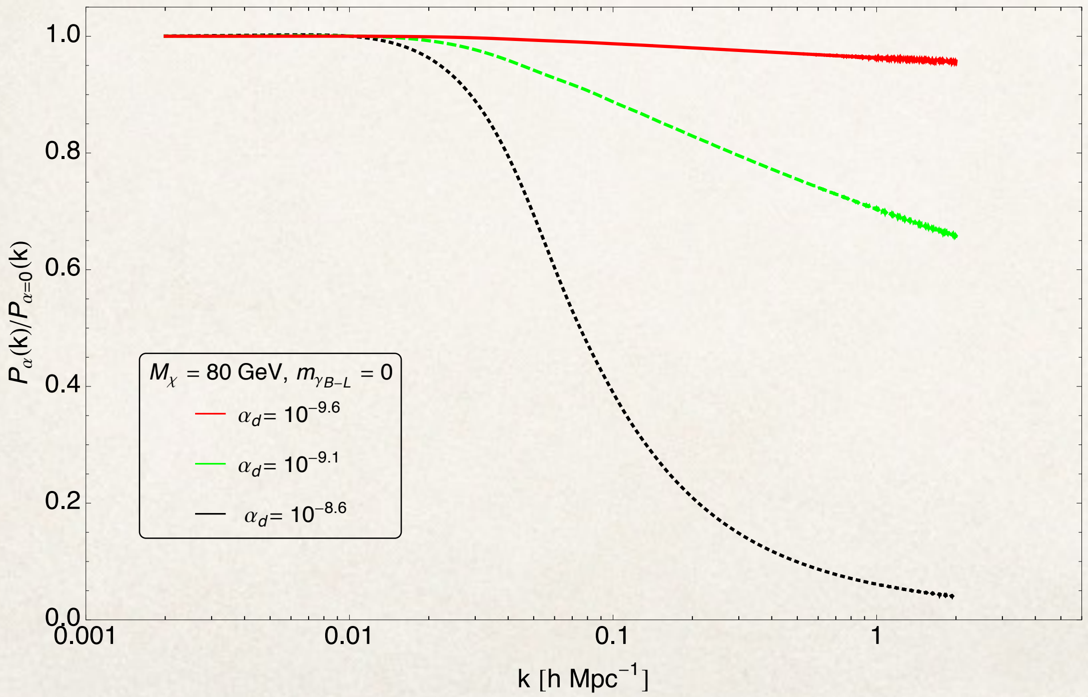
$$\frac{1}{a}\frac{\langle \delta \dot{p}_\chi^2\rangle}{\langle p_\chi^2\rangle} \propto \frac{T_d^2}{m_\chi} \propto H(T)$$

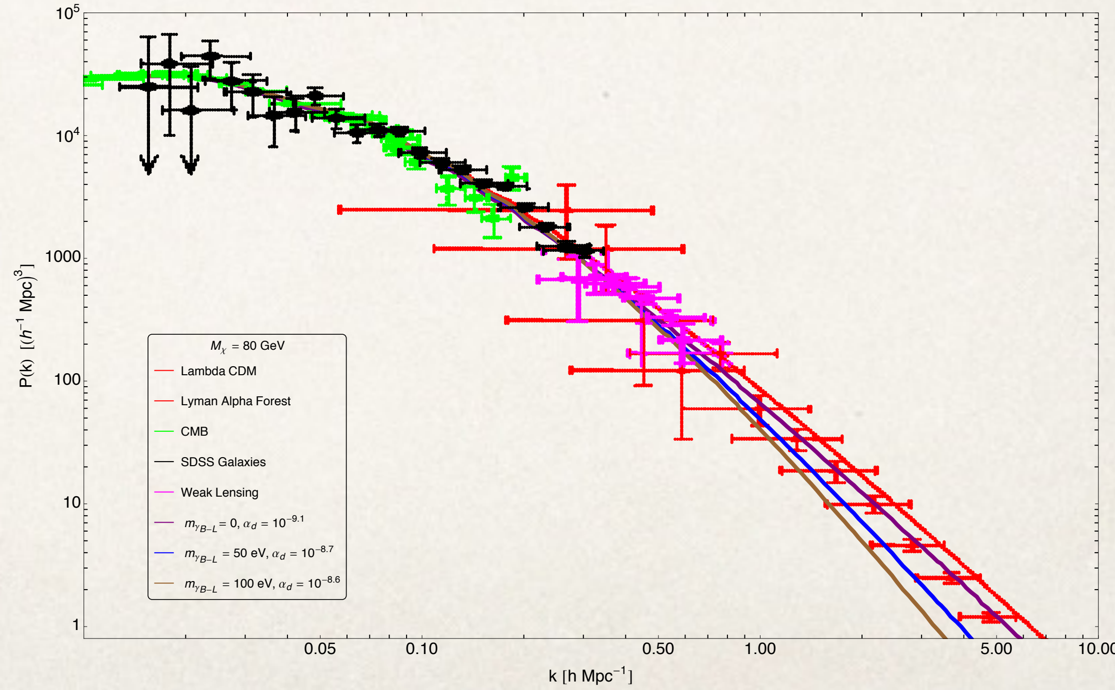
Puzzles of the large scale structure

YT, Prilepina (in progress)









Conclusion

Twin Higgs model gives a non-trivial cosmology

=> various cosmological constraints to consider

Many of them will be improved by a lot in O(10) years

CMBpol, CMB Stage-IV, $\Delta N_{eff} < 0.02$

better anti-proton constraint, bound on the halo structure

Can we make a conclusive statement of the TH
(or other hidden-naturalness) models using these constraints?

More about this in the afternoon discussion