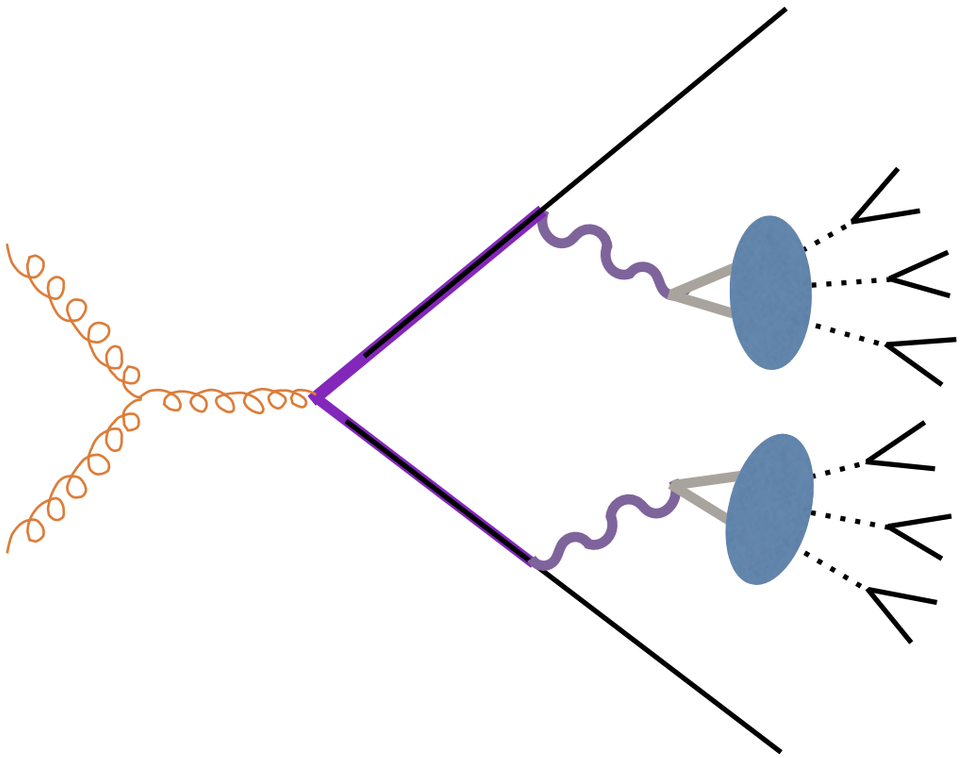
Topologies for X+Displaced Signals

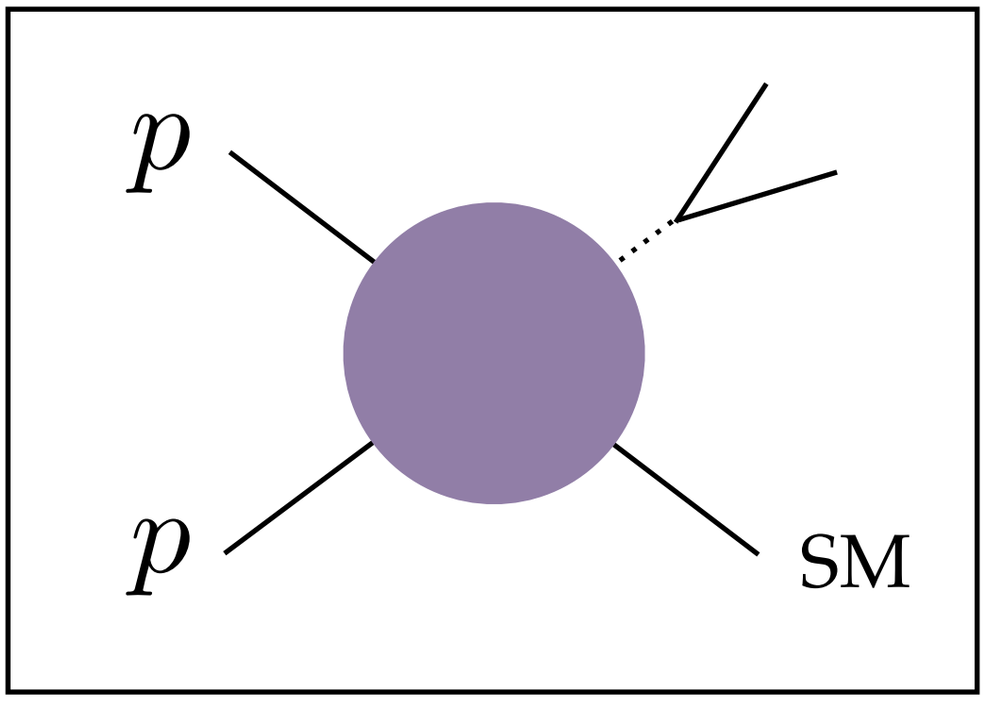


Yuhsin Tsai

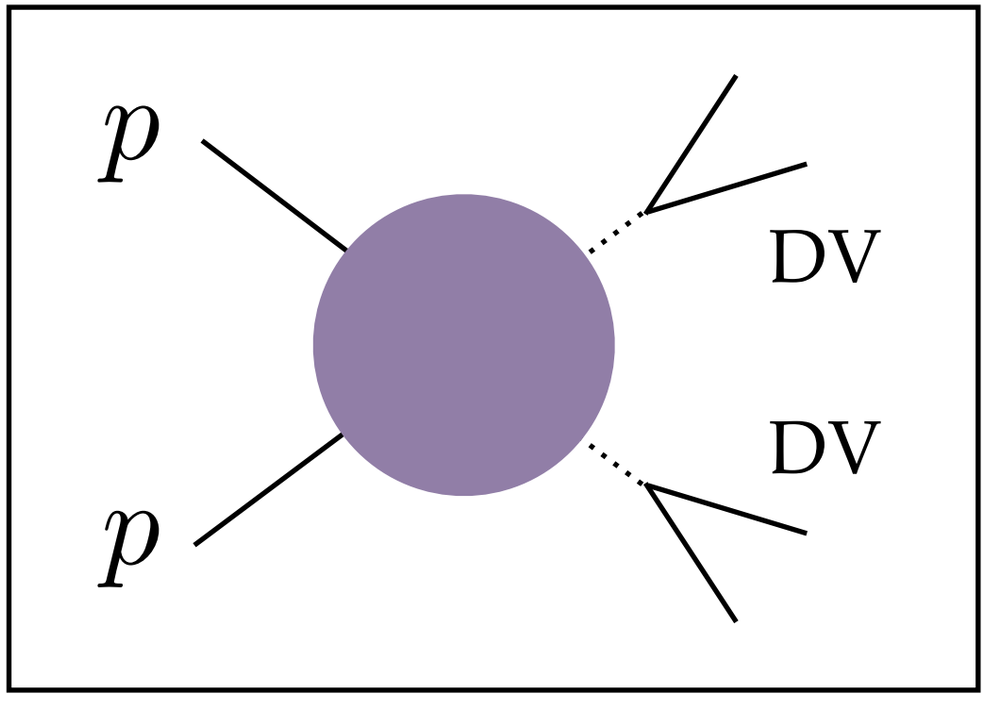
University of Maryland

Triggering on New Physics @ LH-LHC, PCTS, Jan 16, 2018

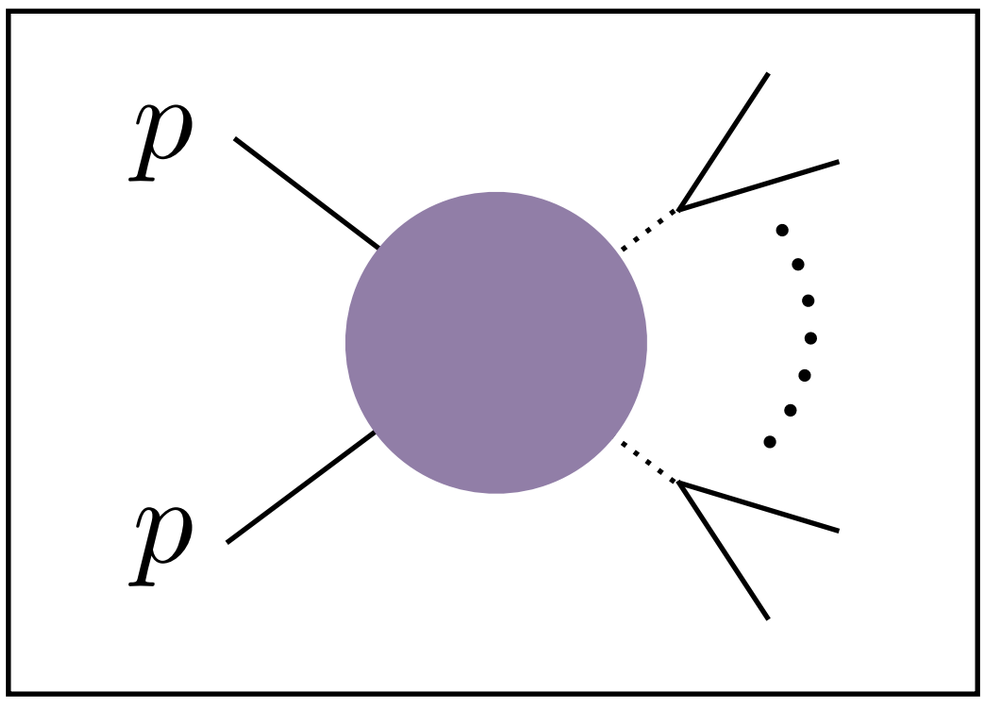
DV + SM



DV + DV



DV + DV + ...



Theoretical motivation for DV searches (an incomplete list)

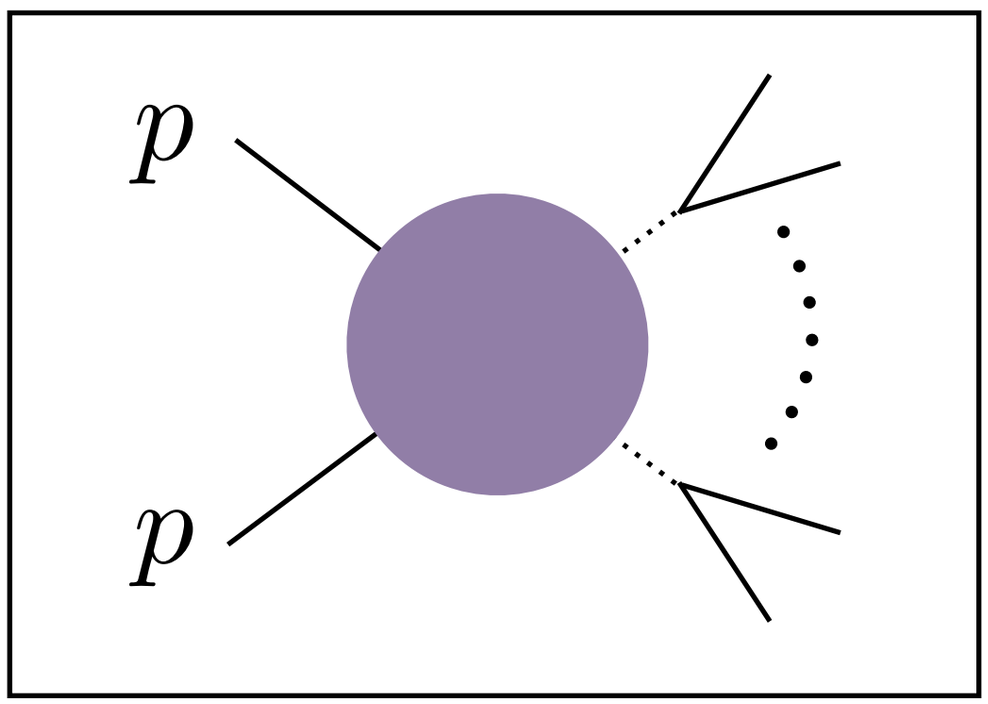
Higgs hierarchy problem

Small scale structure puzzles of the universe

Connection to indirect detection signal?

Matter/anti-matter asymmetry

DV + DV + …

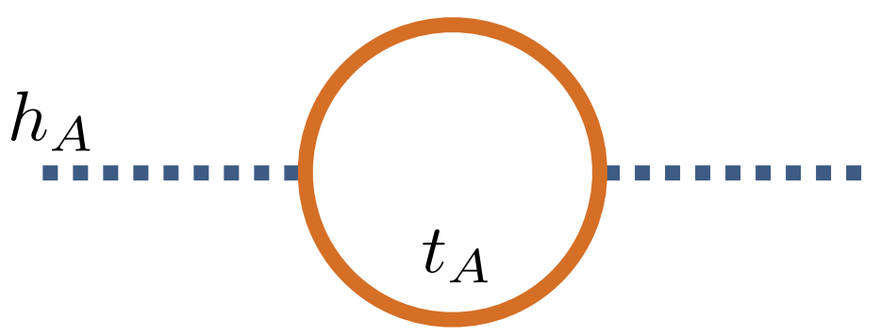


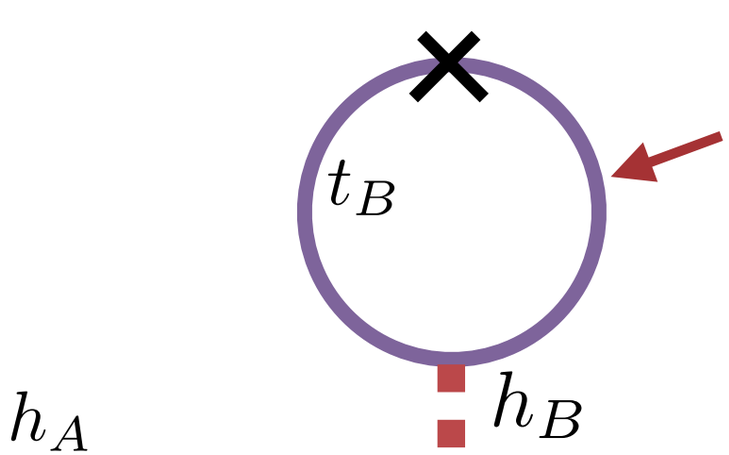
from Neutral Naturalness models

Example: Twin Higgs model

Chacko, Goh, Harnik 05' (see Daniel's talk)

A solution to the little hierarchy problem
without colored partners





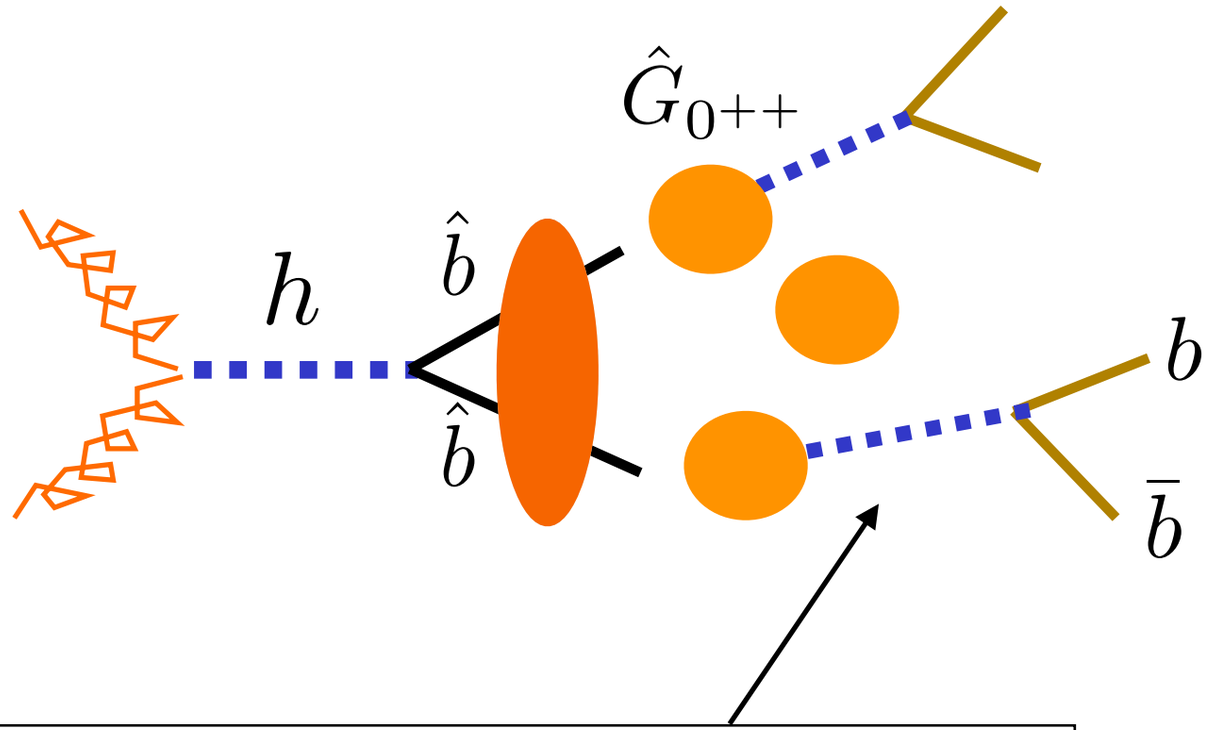
Twin-top
$SU(3)_B \times SU(2)_B$

$$\delta m_h^2 \approx \frac{3\Lambda^2}{4\pi^2}(y_t^2 - \hat{y}_t^2)$$

SM		Twin
y_t	$=$	$y_{\hat{t}}$
SU(3) x SU(2) gauge couplings	$=$	SU(3) x SU(2) gauge couplings
EWSB scale v	$\simeq$	EWSB scale f
Other Yukawa couplings	$\sim$	Other Yukawa couplings
$U(1)_Y$ coupling	$\sim$	$U(1)_Y$ coupling

Displaced jet signal in Fraternal TH

Scalar glueballs can be the lightest twin hadron



displaced decay via Higgs portal

Craig, Katz, Strassler, Sundrum (15')
Curtin, Verhaaren (15')
Chacko, Curtin, Verhaaren (15')

Displaced decay into jets

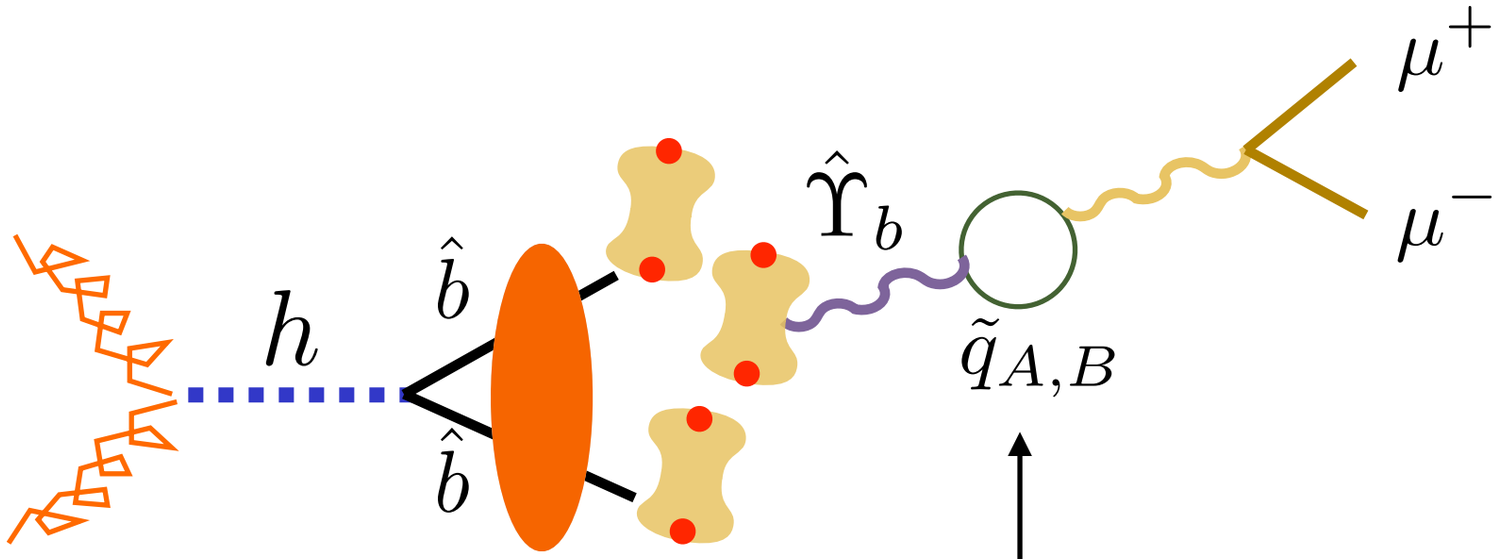
Lifetime ~ mm to km

~ 2-4 hadrons from Higgs
~ 15 - 30 GeV b's

Can also come from associate Higgs productions
=> additional W/Z, forward jets

Displaced lepton signal in Fraternal TH

Light vector twin-b mesons (twin Upsilon)



DV into muons

Lifetime: depending on the photon mixing

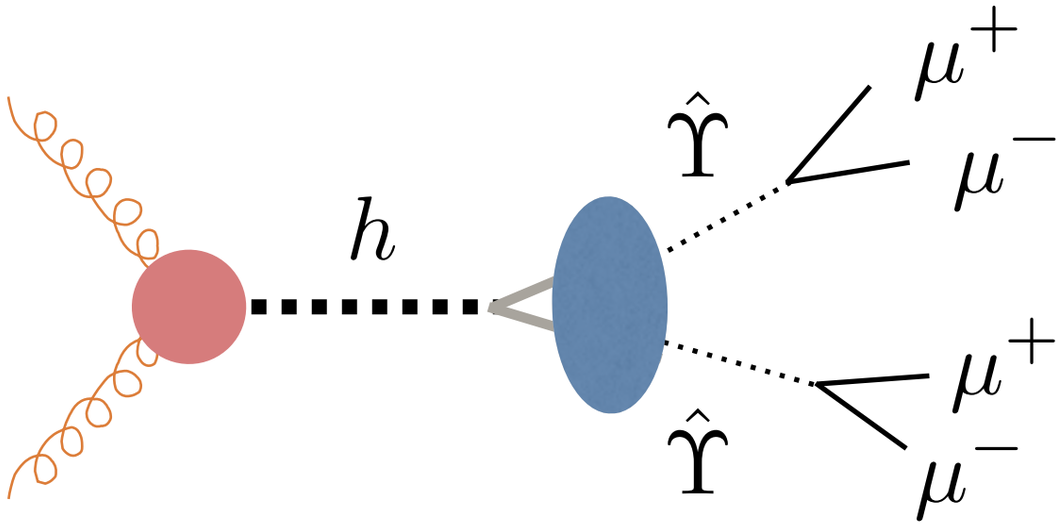
~ 2-4 hadrons from Higgs

~ 15 - 30 GeV muons

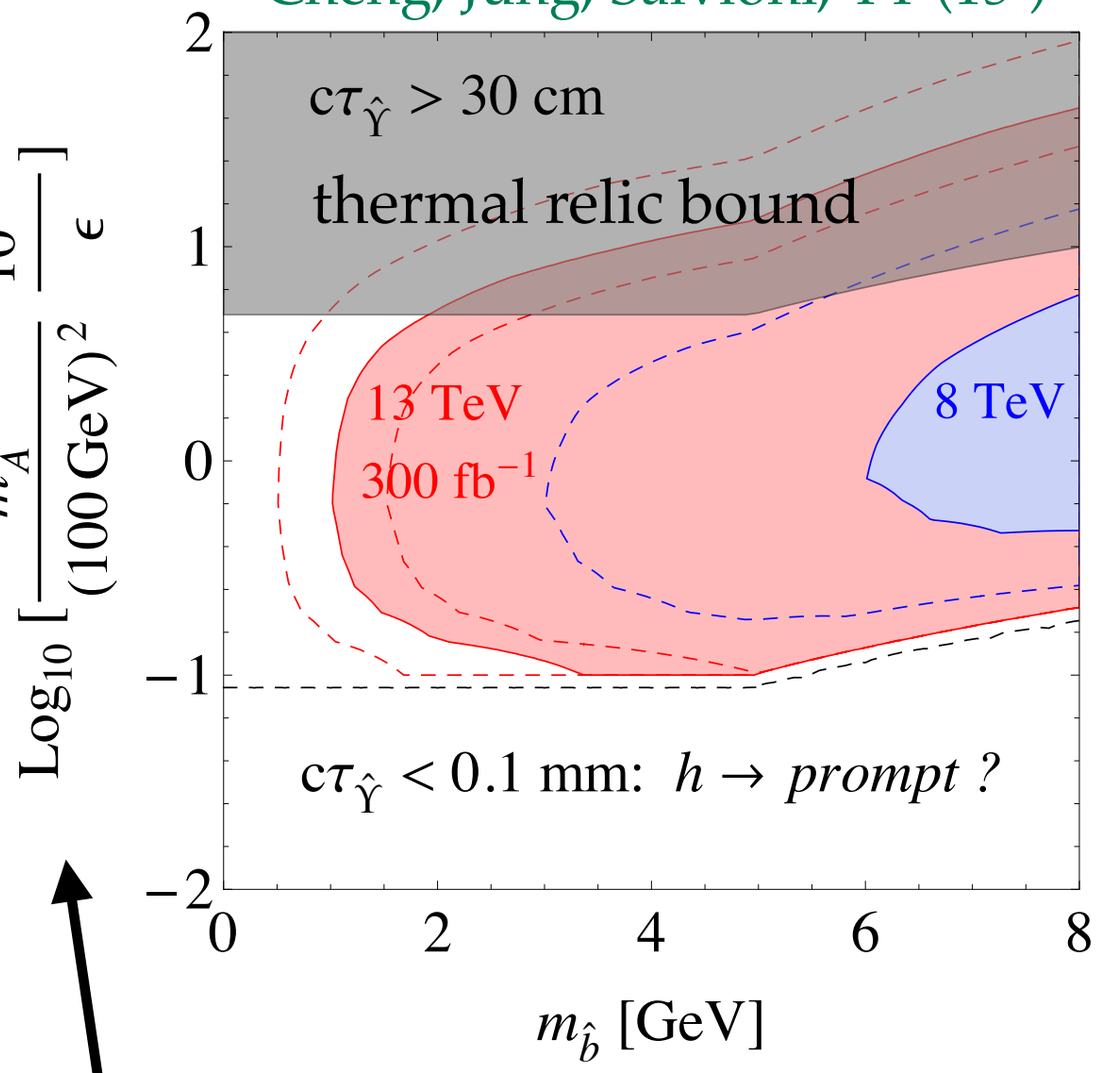
Vector meson decays via Twin/SM photon mixing

Cheng, Jung, Salvioni, YT (15')

Exotic Higgs decay in Fraternal Twin Higgs



Cheng, Jung, Salvioni, YT (15')



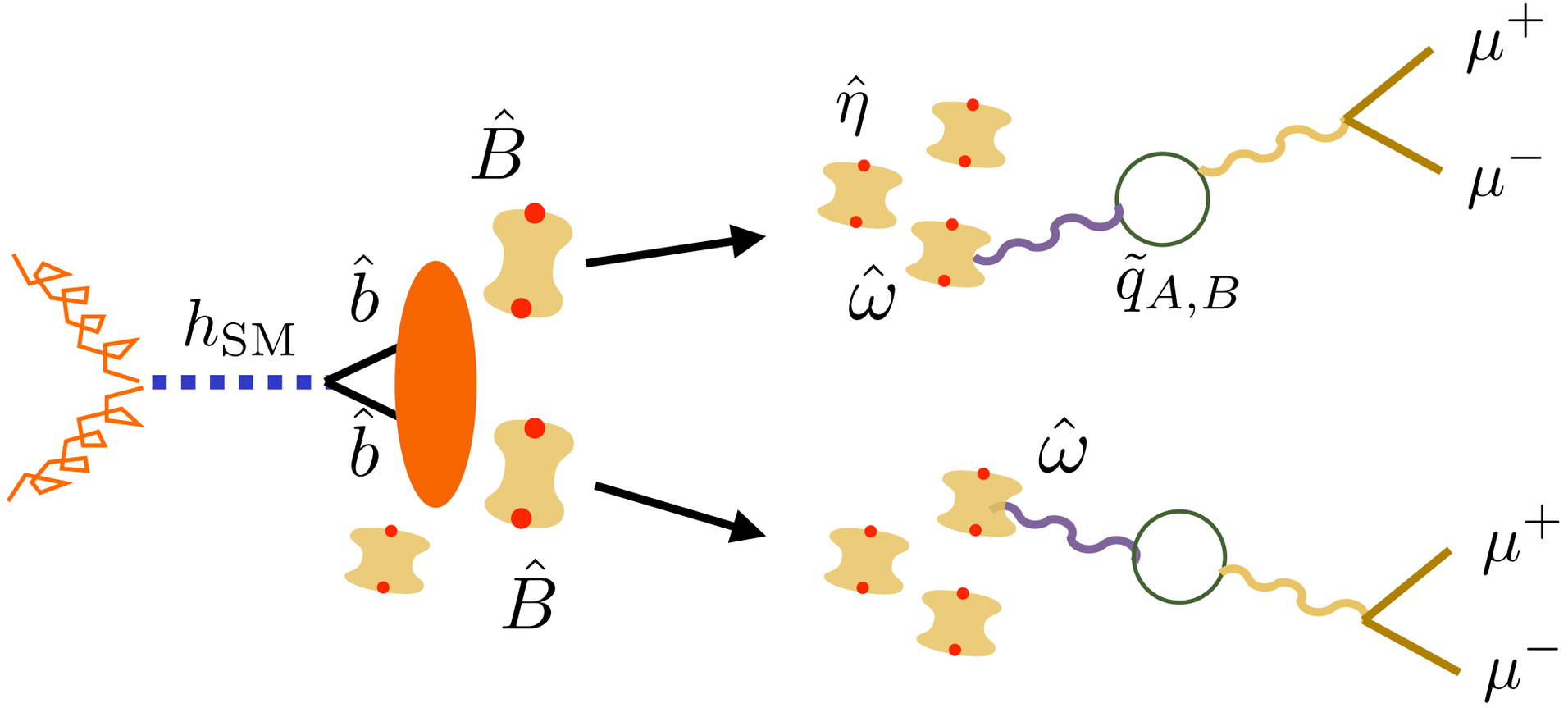
e.g. CMS displaced di-muon search (1411.6977)

Trigger: 2 muons, decay inside tracker, each muon pT > 26 GeV

Mediation scale of photon mixing

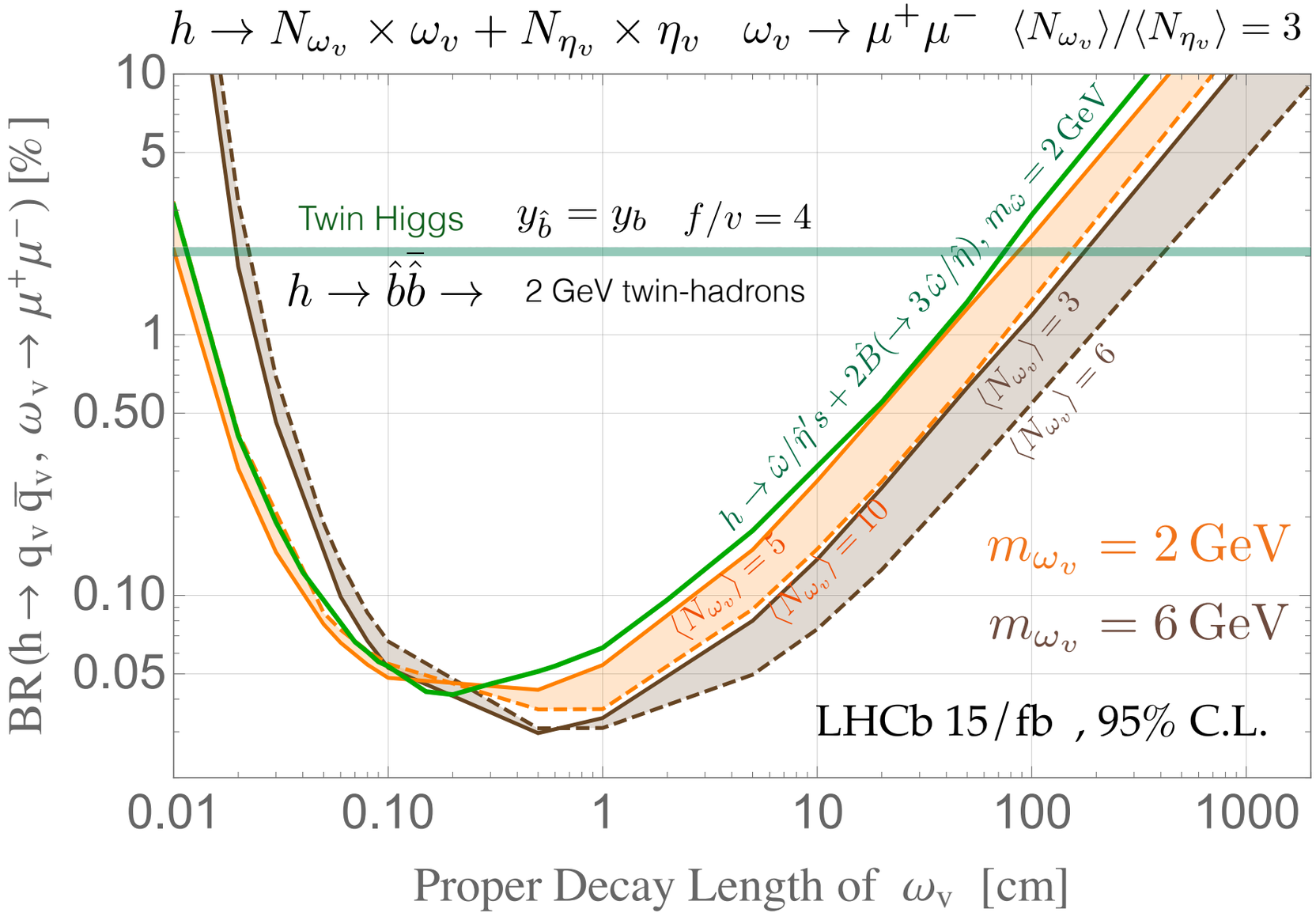
With lighter generation twin-qurks

Twin (b, c, s), twin hadrons ~ O(1) GeV, multiplicity ~ 6 - 8



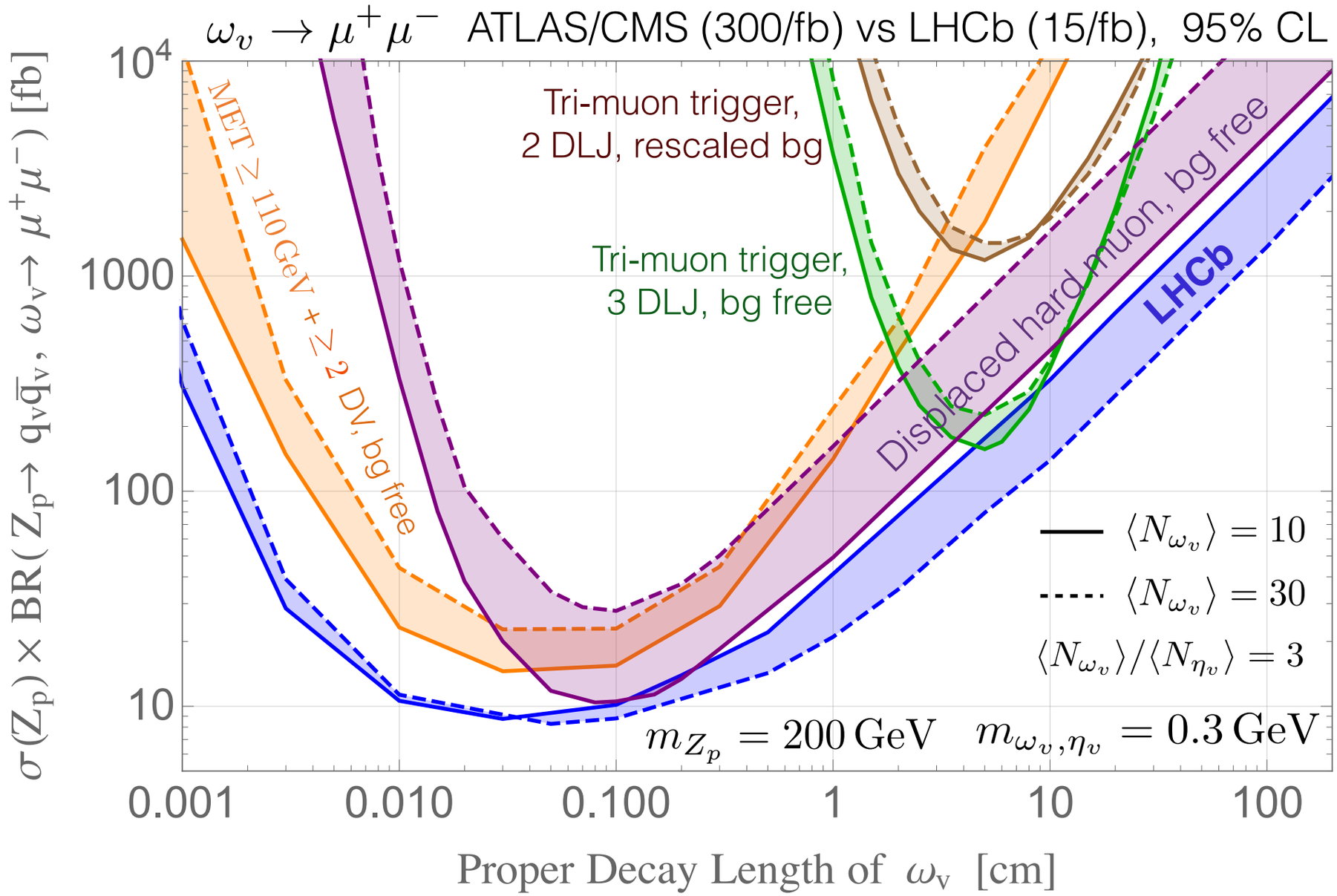
Several DVs with muons < 10 GeV

LHCb search, Higgs decays into dark showers



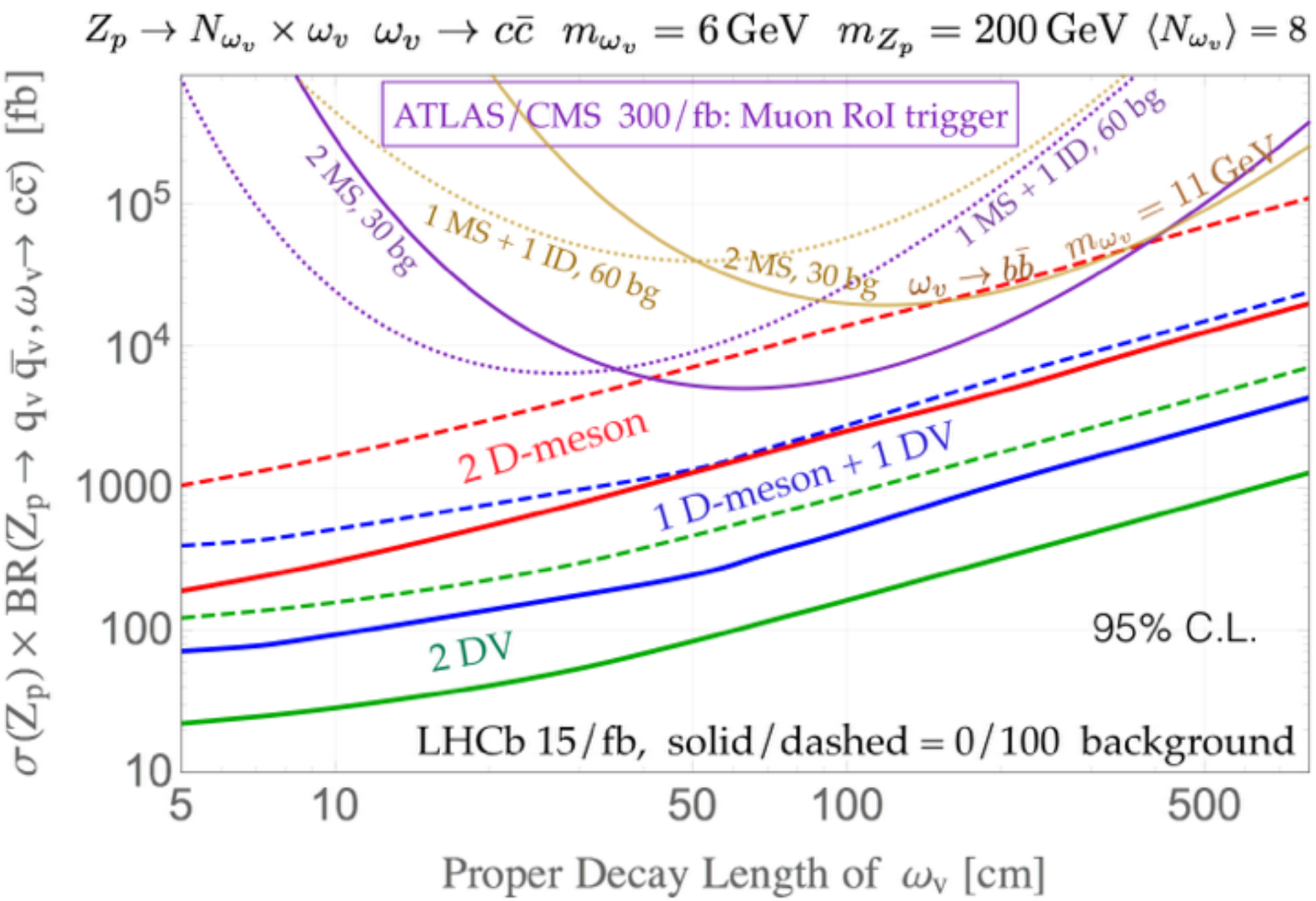
Pierce, Shakya, YT, Zhao (17')

Search of light/soft DVs (Zp model, muons)



Pierce, Shakya, YT, Zhao (17')

Search of light/soft DVs (Zp model, bb or cc)



Pierce, Shakya, YT, Zhao (17')

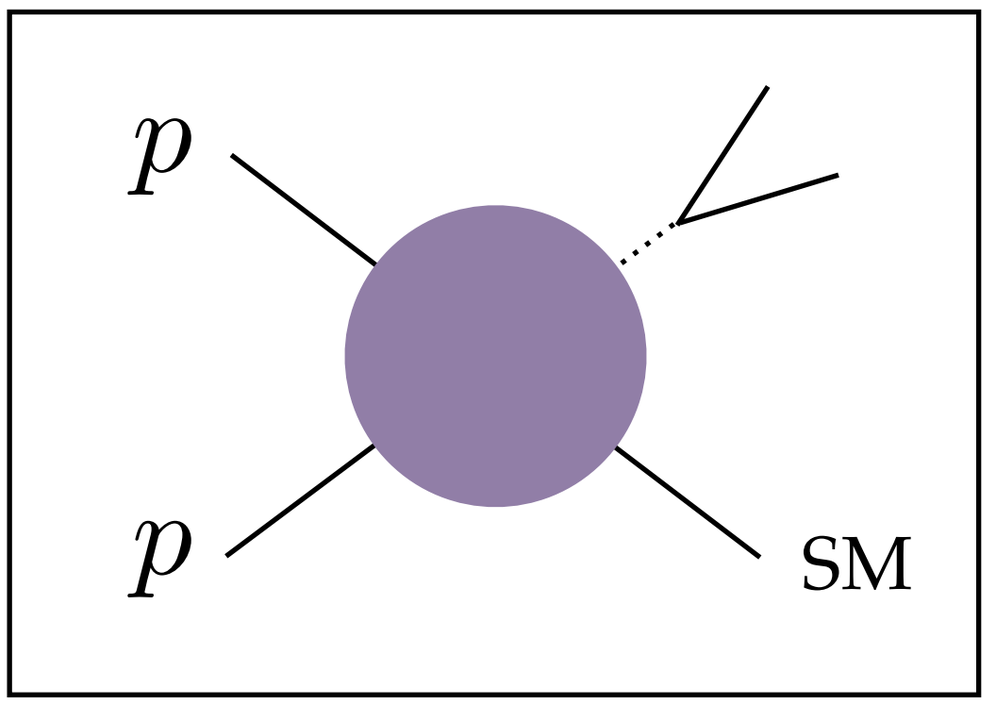
DV signals from Neutral Naturalness models

Signal_Neutral Naturalness Models: Twin Higgs (TH), Fraternal TH (FTH), Folded-SUSY (FSUSY), Quirky Little Higgs (QLH) **Exotic Higgs Decay, Heavy Resonance Decay, Pair Production & Decay**	**Paper**	**LLP Mass**	**LLP Multiplicity**	**ctau** Higgs portal Kinetic mixing	**SM contents** Higgs portal Kinetic mixing	**Trigger**
h > ***glueball*** (FTH, FSUSY), signal: DV bb	**1501.05310, 1506.06141**	10-60 GeV	2-4	micro m - km	DV bb, tautau	monojet, VBF, single lepton, tau(?),MuRol
h > ***twin bottomonia*** (FTH), signal: DV bb or mumu	**1501.05310,1512.02647**	10-60 GeV	2-4	~< m (twin upsilon, assume heavy twin photon & cosmo bound), 0.01mm - 1m (twin chi, SM/5 < twin yb < SM)	DV bb, tautau, mumu	monojet, VBF, single lepton, tau(?),MuRol
h > ***lighter twin hadrons*** (~MTH), signal: DV mumu, cc, tautau	**1708.05389**	1-10 GeV	2-8	~< m (twin omega, assume heavy twin photon & cosmo bound), Higgs portal too slow	DV cc, tautau, mumu	multi-muon, MuRol, mono-jet, tau(?)
Exotic fermion bound state > SM W + ***twin glueball*** (FTH), DV to bb	**1612.03176, 1710.06437**	10-60 GeV	1-2 (T=0.3-0.5 TeV)	micro m - km	DV bb, tautau + prompt lepton	prompt lepton (pT > 100 GeV)
Quirky bound state > ***glueball*** (FSUSY), signal: DV bb	**1512.05782**	10-60 GeV	2-8 (T=0.5-1 TeV)	micro m - km	DV bb, tautau	monojet, VBF, single lepton, tau(?),MuRol
Quirky bound state > ***glueball*** (QLH), signal: DV bb	**1512.05782**	10-60 GeV	2-8 (T=0.5-1 TeV)		DV bb, tautau	monojet, VBF, single lepton, tau(?),MuRol
Heavy Higgs > ***glueball*** (FTH), signal: DV bb	**1711.03107**	10-60 GeV	20-30 (H=1-2.5 TeV)	micro m - km	DV bb, tautau	monojet, VBF, single lepton, tau(?),MuRol
2 Exotic fermion, each decay into SM t + twin Z, and twin Z decay into ***twin glueballs***, signal: prompt lepton + DV bb (FTH)	**1512.02647**	10-60 GeV	2-8 from a twin Z = 270-450 GeV, 4-16 from both twin Z's	micro m - km	DV bb, tautau, mumu + prompt lepton	prompt lepton (pT > 100 GeV)
2 Exotic fermion, each decay into SM t + twin Z, and twin Z decay into ***twin bottomonia***, signal: prompt lepton + DV bb or mumu (FTH)	**1512.02647**	10-60 GeV	2-8 from one twin Z = 270-450 GeV, 4-16 from both twin Z's	~< m (twin upsilon, assume heavy twin photon & cosmo bound), 0.01mm - 1m (twin chi, SM/5 < twin yb < SM)	DV bb, tautau, mumu + prompt lepton	prompt lepton (pT > 100 GeV)

Lots of assumptions in the mass / multiplicity / lifetime estimation

See the reference for details

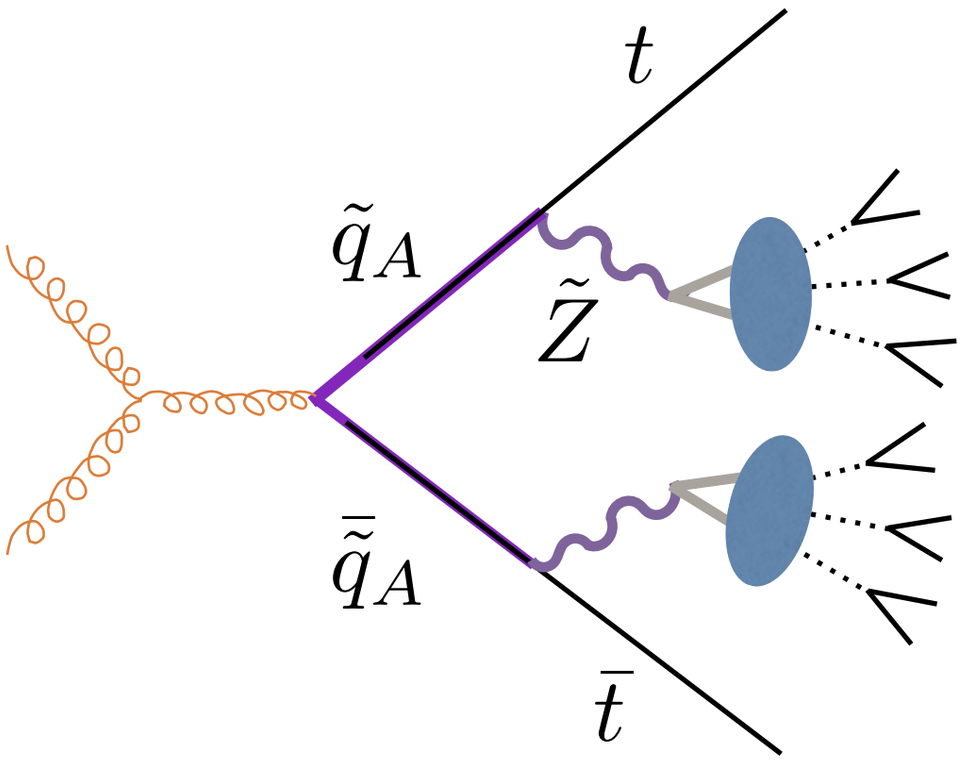
DV + prompt SM object

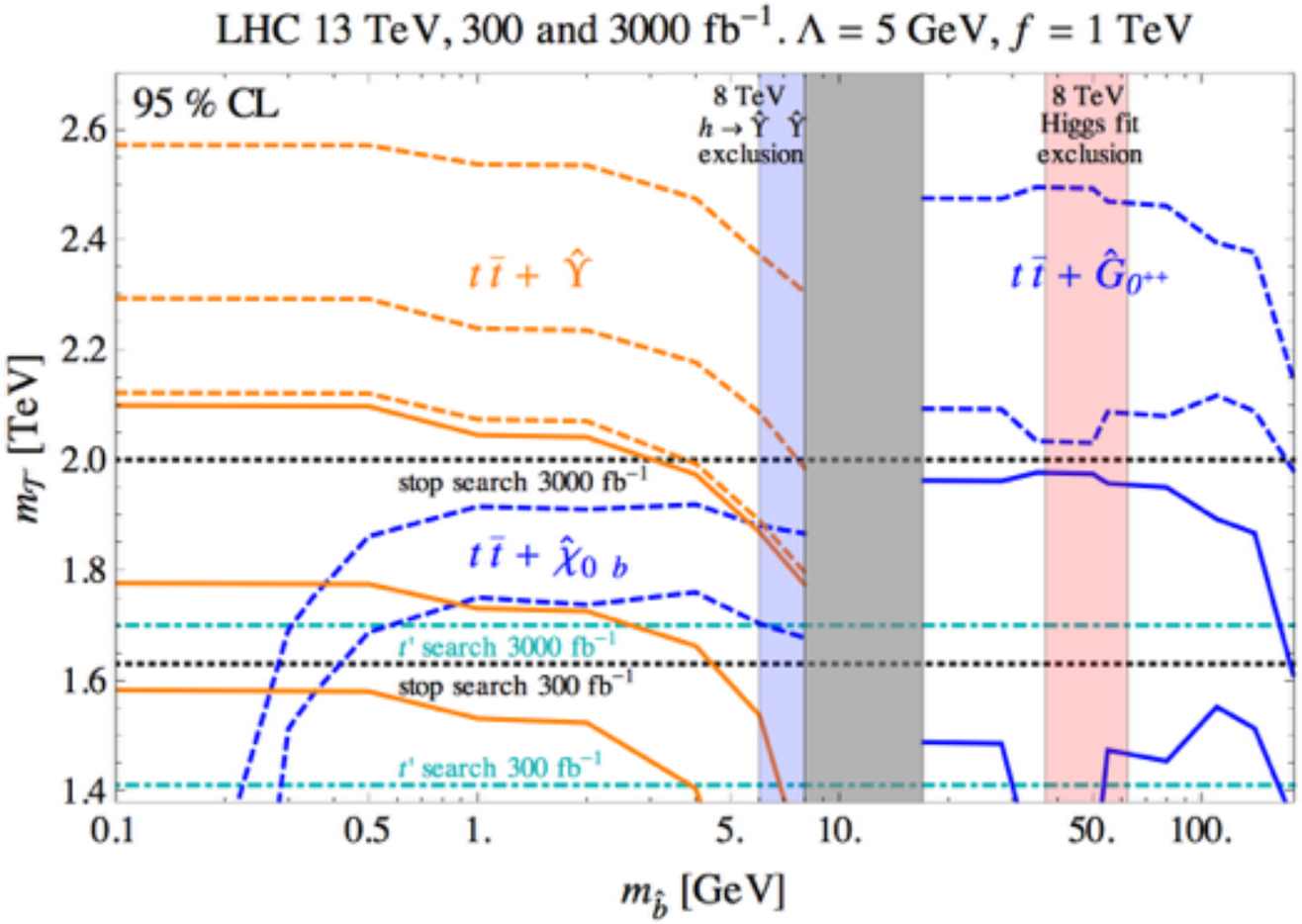


From Neutral Naturalness models

Probing the UV structure: exotic-quarks @ LHC

DV into bb or muons + lepton (pT > 100)



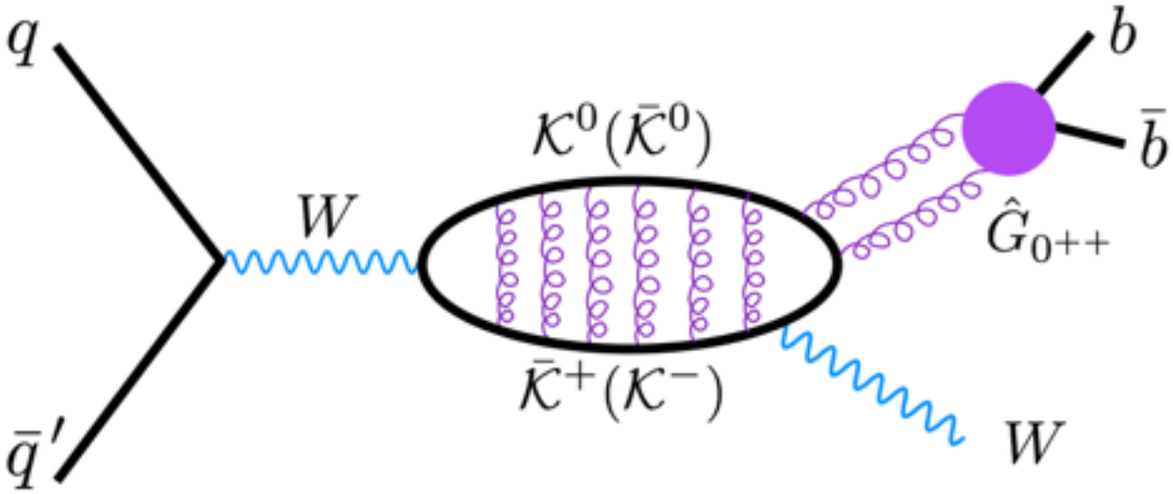


Cheng, Jung, Salvioni, YT (15')

Different curves in the same style:
different assumptions of g-ball multiplicities

DV from a decay of EW-charged bound state

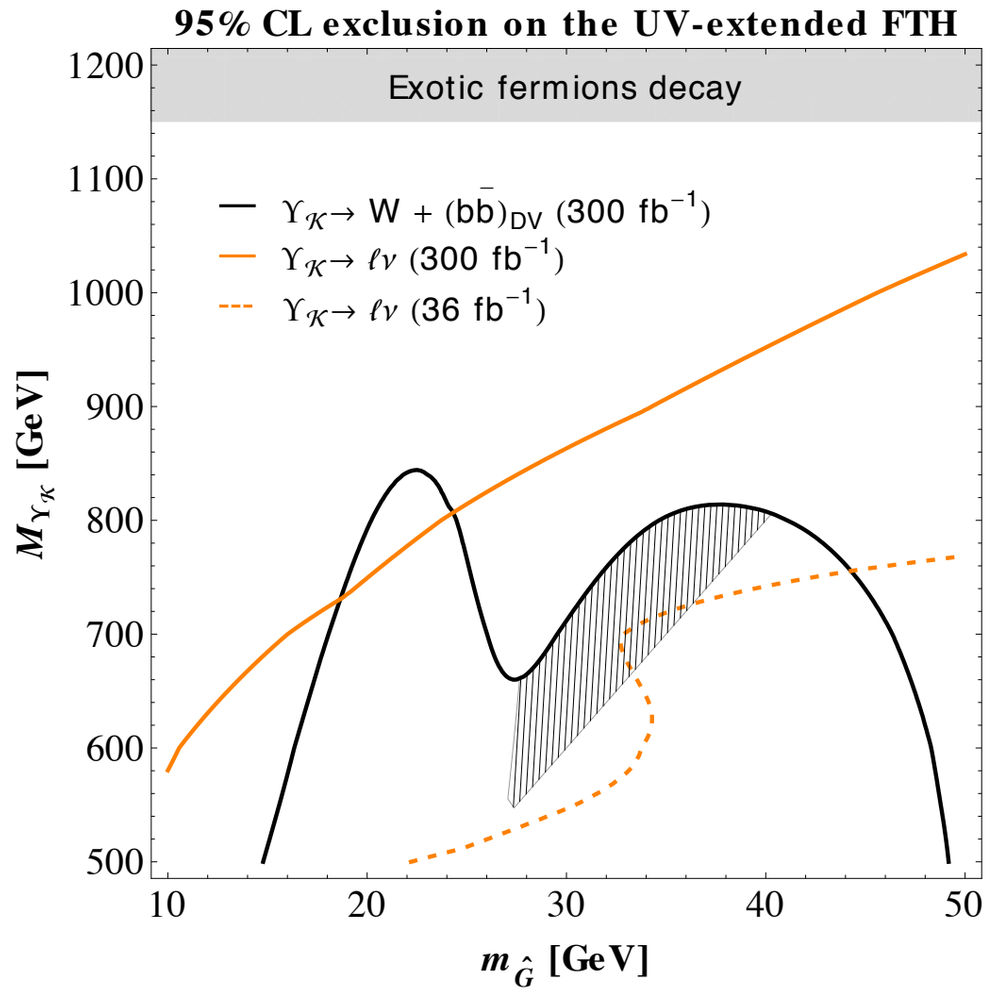
Resonance decays into SM + DV



EW-charged bound state from twin QCD binding force

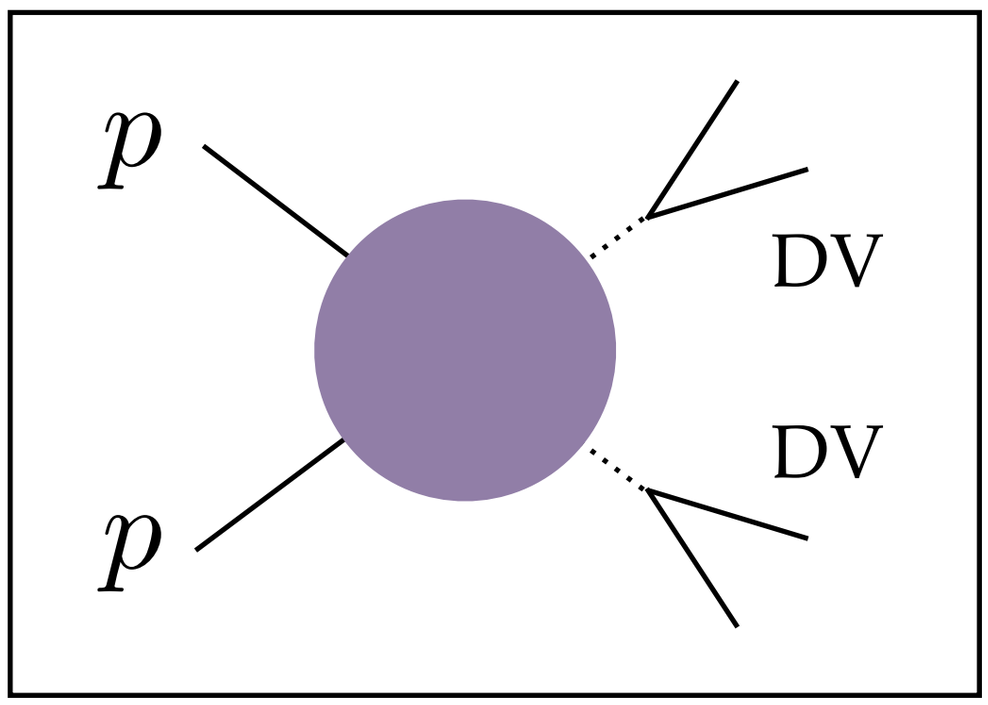
(can produce more than one G_0's)

Trigger using the hard lepton



Li, Salvioni, YT, Zheng (17')

DV + DV



From Self Interacting Dark Matter

Self-Interacting DM (SIDM) provides solutions to small scale structure puzzles

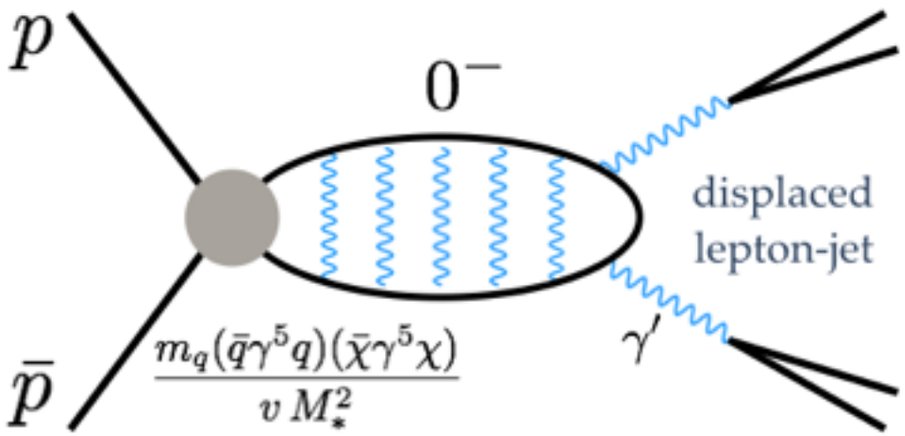
e.g., Core/Cusp problem, Diversity Problem

Strong self-interaction helps to thermalize DM in the inner part of the halo, thus explains the star motion we see

If self-interaction comes from a dark photon,
need O(10) GeV DM, sub-GeV photon mass with O(1) coupling

Tulin, Yu, Zurek (15')
Kaplinghat, Tulin, Yu (13')
For a review: Tulin, Yu (17')

SIDM bound state at collider



DM annihilation at the LHC

Two displaced lepton-jets

Dark photon can be quite boosted

One of the final decays can be prompt, displaced, MET

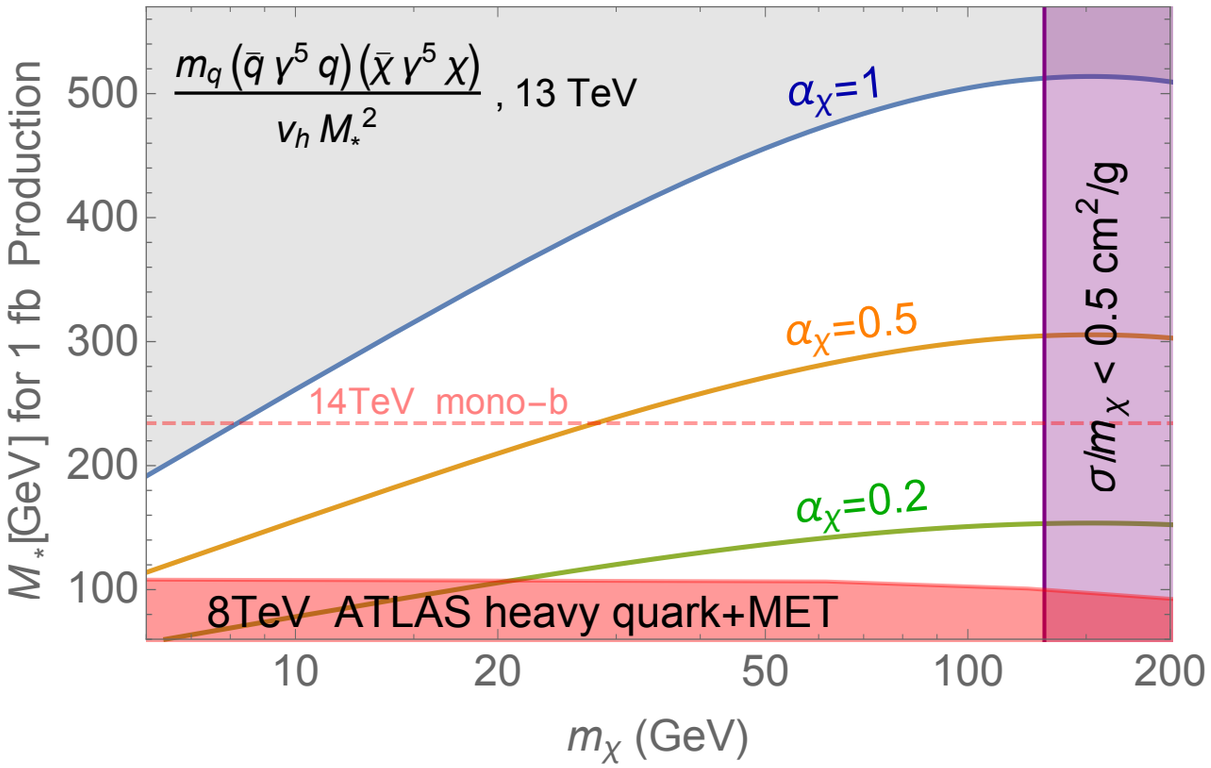
YT, Wang, Zhao (15')

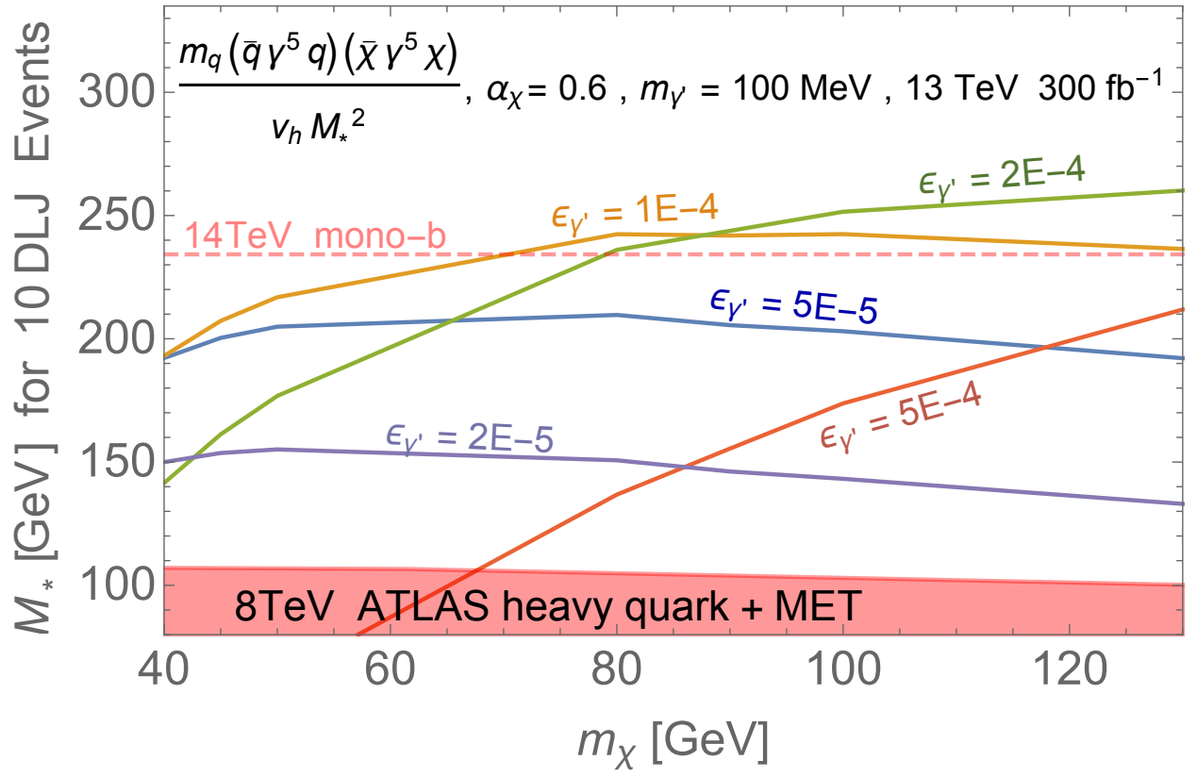
e.g. ATLAS displaced lepton-jets (ATLAS-CONF-2016-042)

Narrow-Scan trigger for muon signals / Tri-muon MS only trigger

Estimate the bound on SIDM production

Decay in HCAL, pT(LJ) > 30 GeV, assume 25% reconstruction efficiency

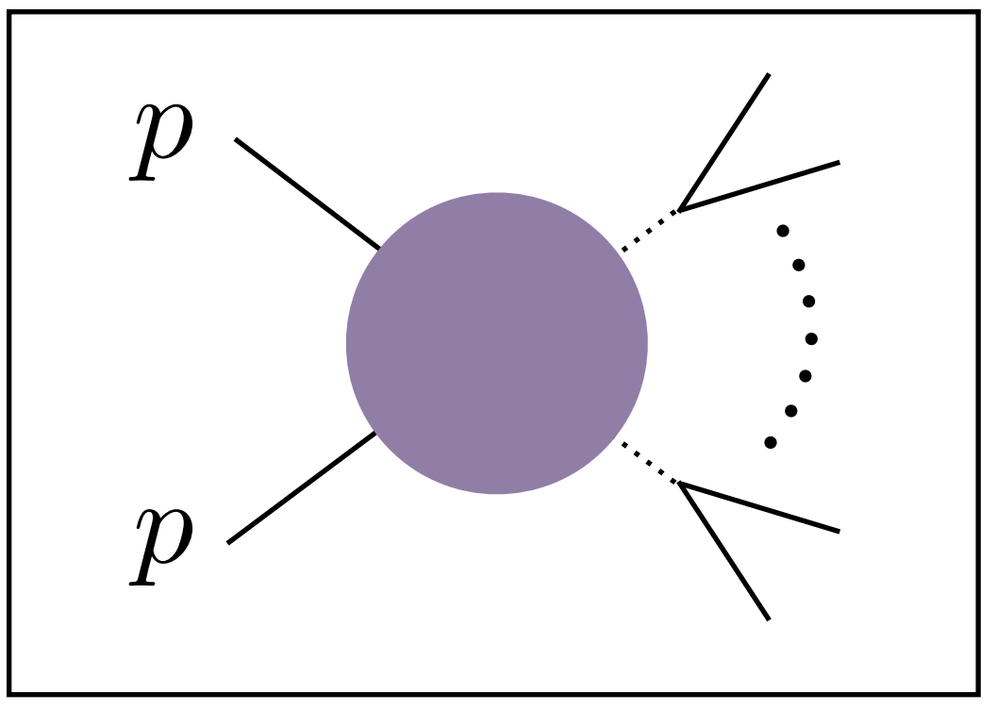




Due to the low center of mass energy (=2x DM mass), the EFT description works fine in the study.

Dark photon with boost >~ 1000 can be hard to see

DV + DV + …

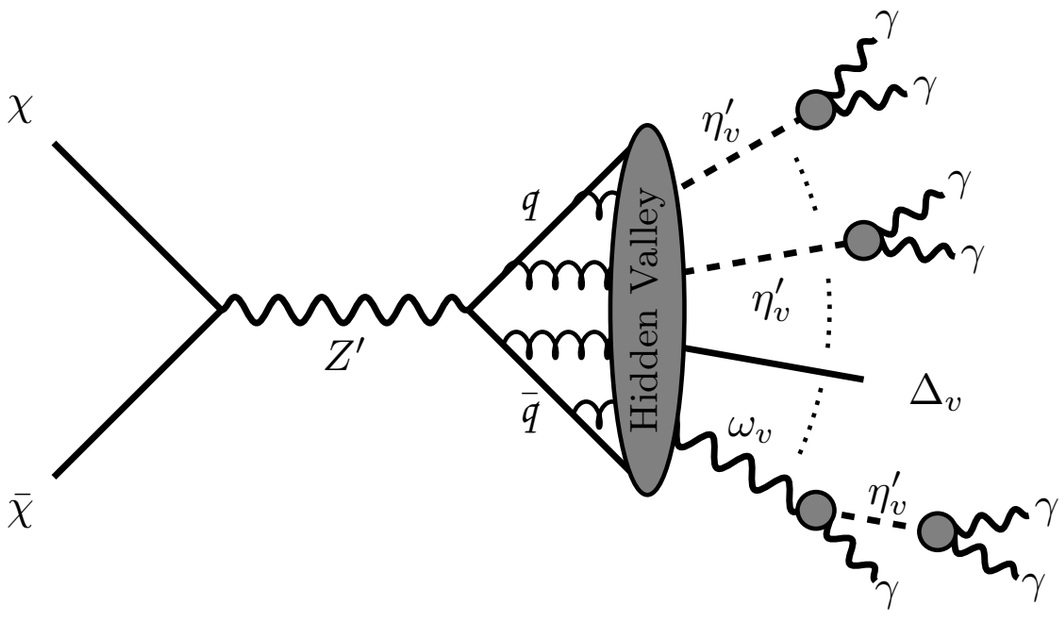


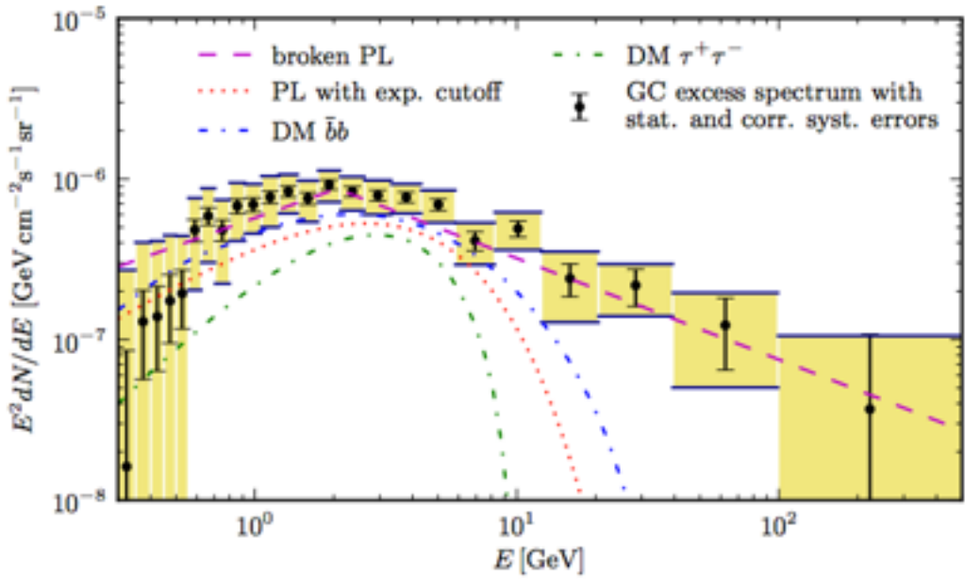
Relation to Indirect Detection Signals

Example: galactic center gamma ray (?)

Freytesis, Robinson, YT (14') and Freytesis, Knapen, Robinson, YT (16')

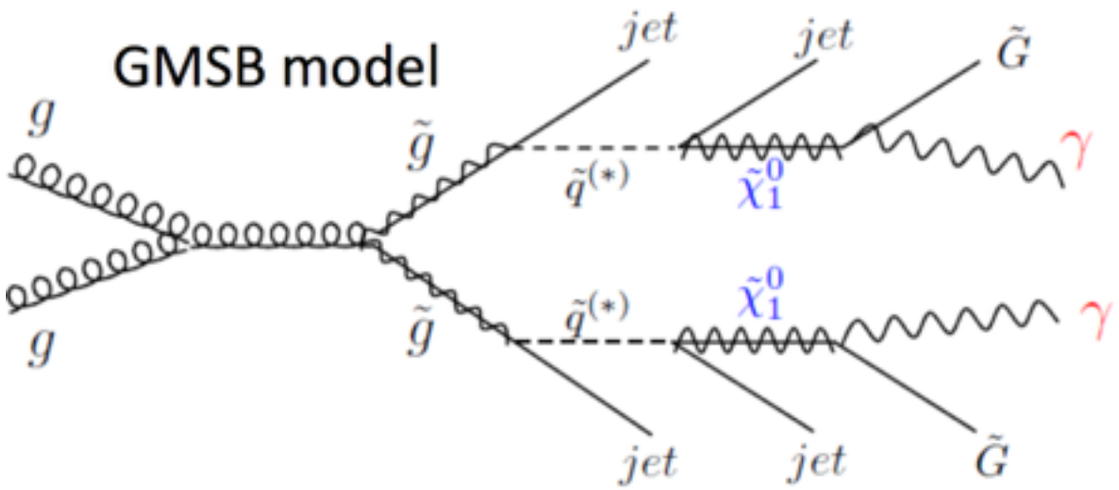
Dark showers can provide a reasonable spectrum for the galactic center gamma-ray excess, while avoiding constraints from other cosmic-ray searches (positron, anti-proton)

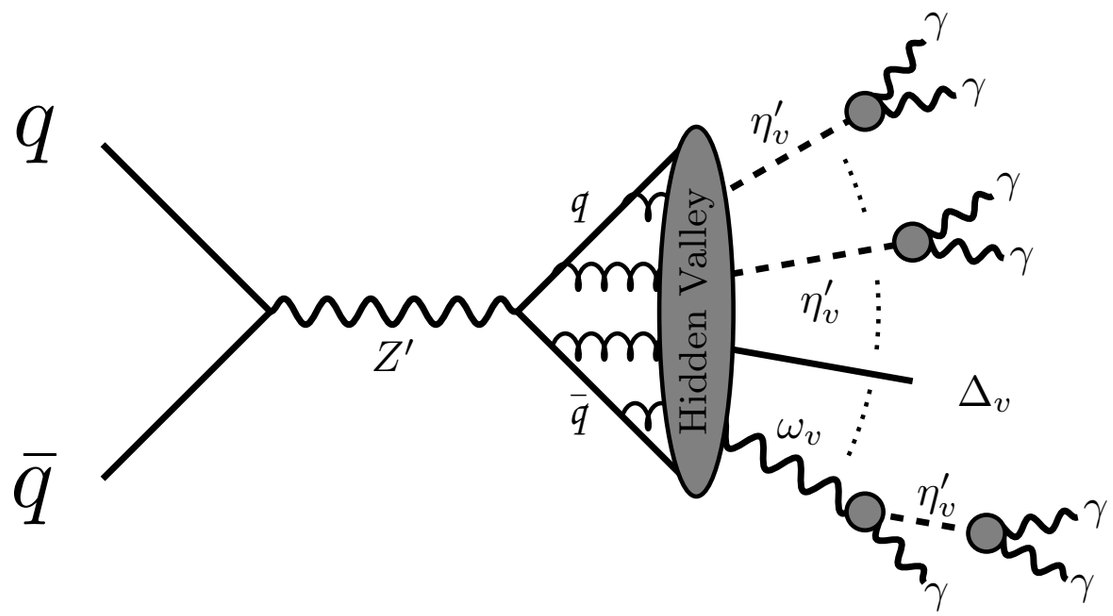




Calore, Cholis, Weniger (14')

Softer photons / higher multiplicity

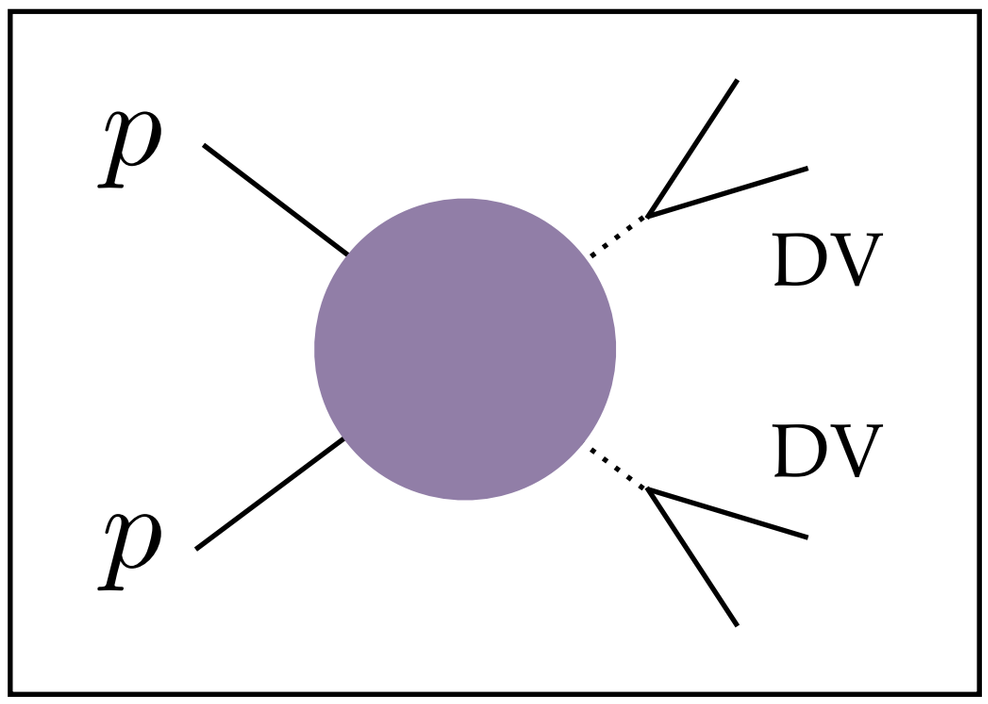




e.g., for Zp = 200 GeV, meson = 20 GeV, multiplicity ~ 4,
time to ECAL ~ 0.3 ns

Trigger? HT > 350 GeV (too high), di-photon trigger (22, 16 GeV),
single photon > 31 GeV, get from Cristina's slides

DV + DV



From WIMP Baryogenesis

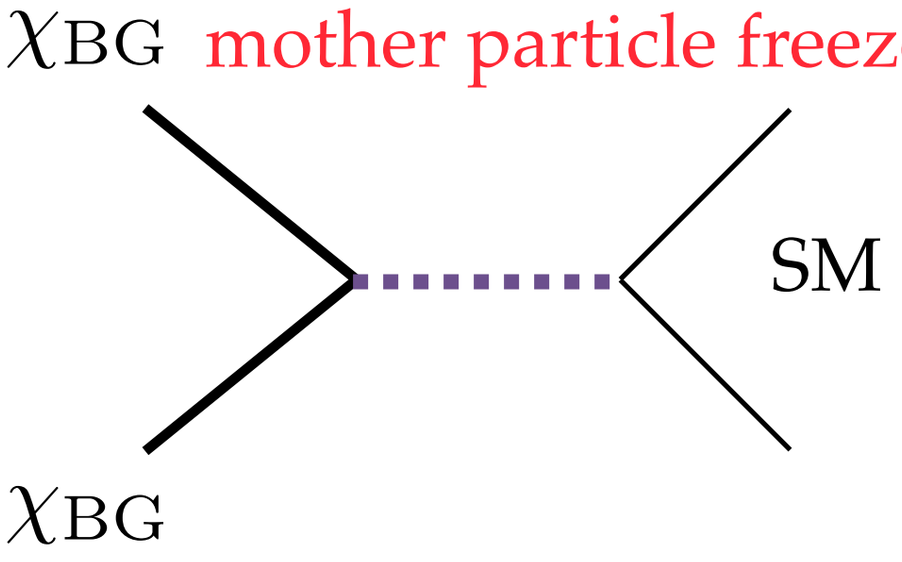
WIMP Baryogenesis

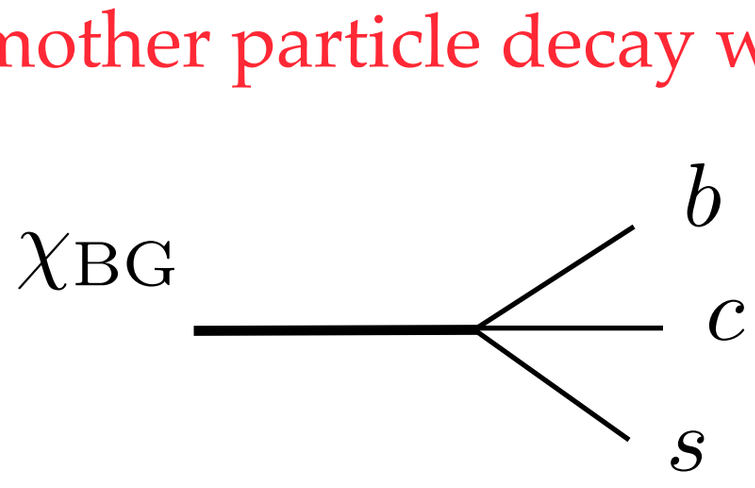
Cui, Sundrum (12')

Where does matter/anti-matter asymmetry come from?

Why does baryon has similar relic density to DM?

WIMP like mother particle decays into baryon (but not anti-baryon)

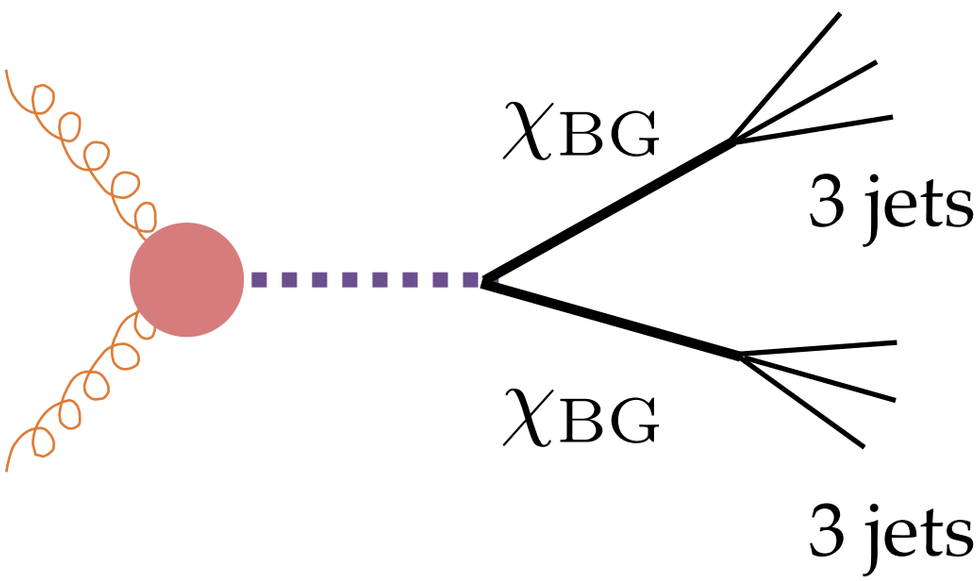




Decay needs to happen AFTER freeze out => lifetime > meter scale

DV from WIMP Baryogenesis

Cui, Shuve (15')



Two sets of displaced jets

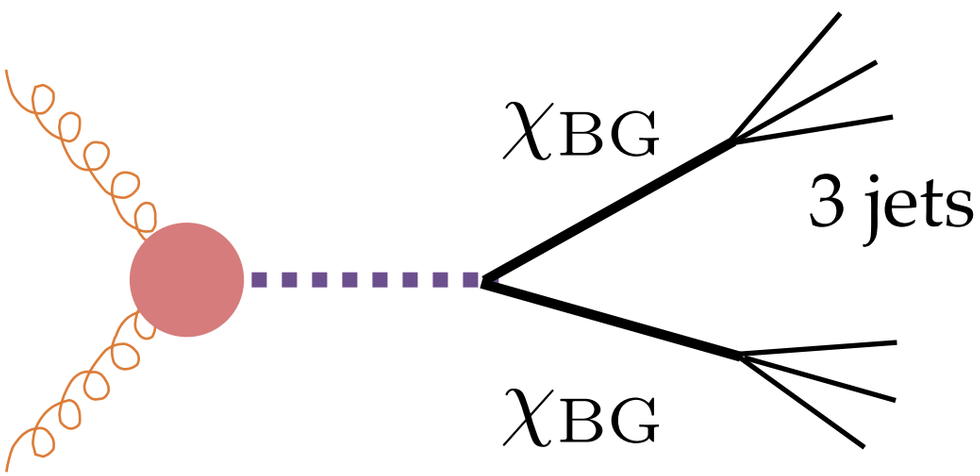
When the mother particle is heavier than the EW scale, they decay into jets/leptons with proper length ~ O(10) cm

e.g. ATLAS displaced di-jets (CMS-PAS-EXO-12-038)

Trigger: total jet HT > 300 GeV,
2 displaced jets, each pT > 60 GeV

DV from WIMP Baryogenesis

Cui, Shuve (15')



When the mother particle mass is below the EW scale, they decay into jets with proper length ~ O(10) cm

If both decays inside detector,
6 displaced jets, each has pT < 30 GeV

Two sets of displaced jets

Still not easy → e.g. ATLAS multi-track DV (1504.05162)

Trigger: (4, 5, 6) jets with pT > (80, 55, 45) GeV

Summary and outlook

- Displaced vertices can be accompanied by many different objects
- Connect to deep understanding of new physics
- DV + X = tops, leptons, jets, W/Z, MET, additional DV(’s)
- Need better trigger/search for soft displaced objects