THE 750 GEV EXCESS

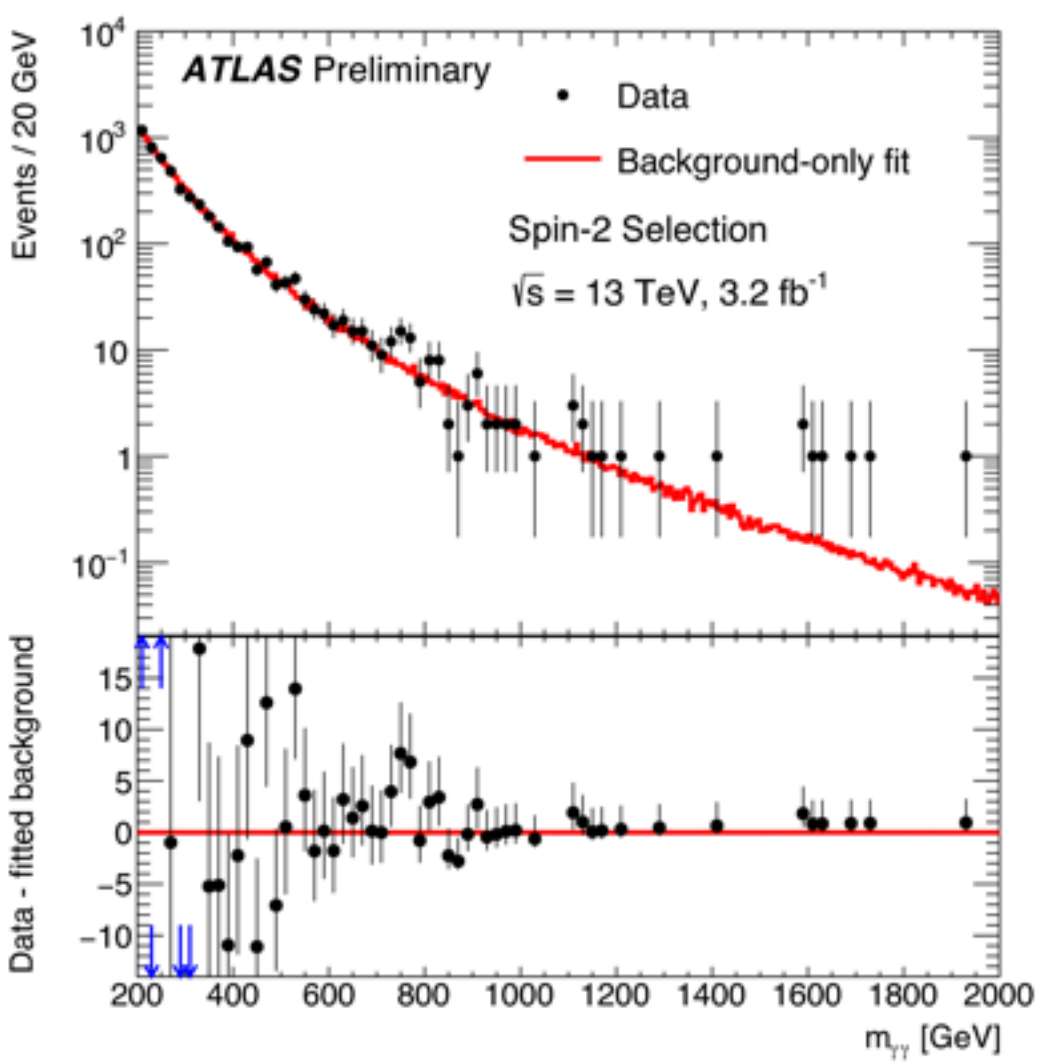
K. ZUREK

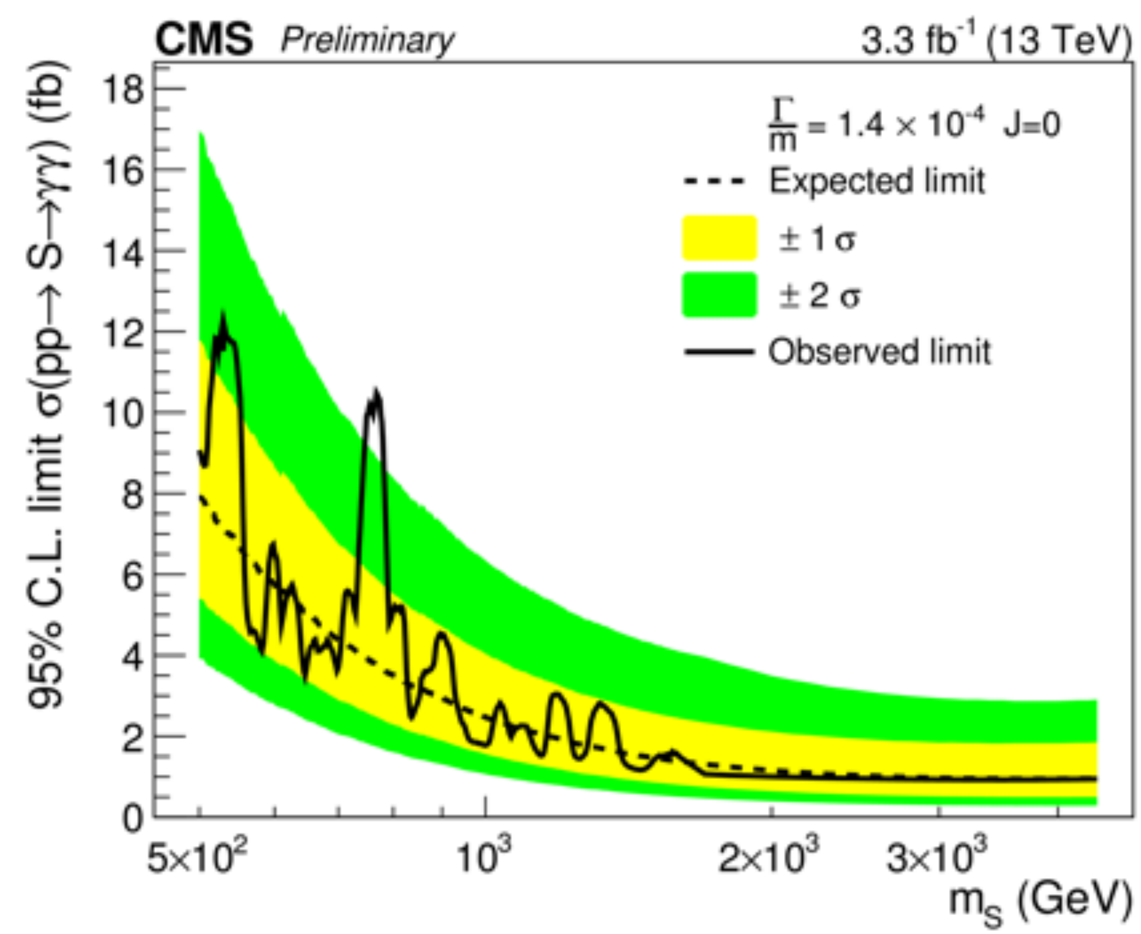
NEW PHYSICS OR FLUCTUATION?

Based in significant part on Knapen, Melia, Papucci, KZ

THE MOST CONVINCING EXCESS YET

- Local Significance 3.6-3.9σ in ATLAS, 2.9σ in CMS



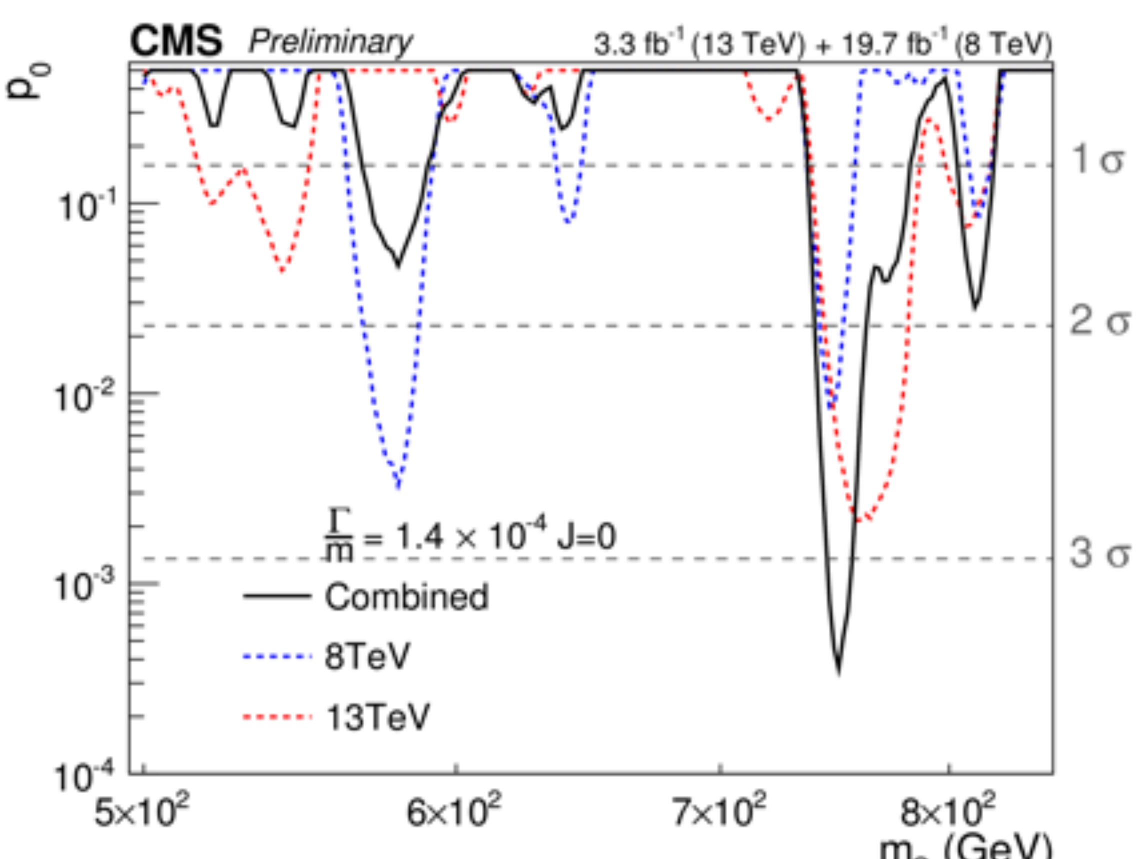


ATLAS-CONF-2016-018

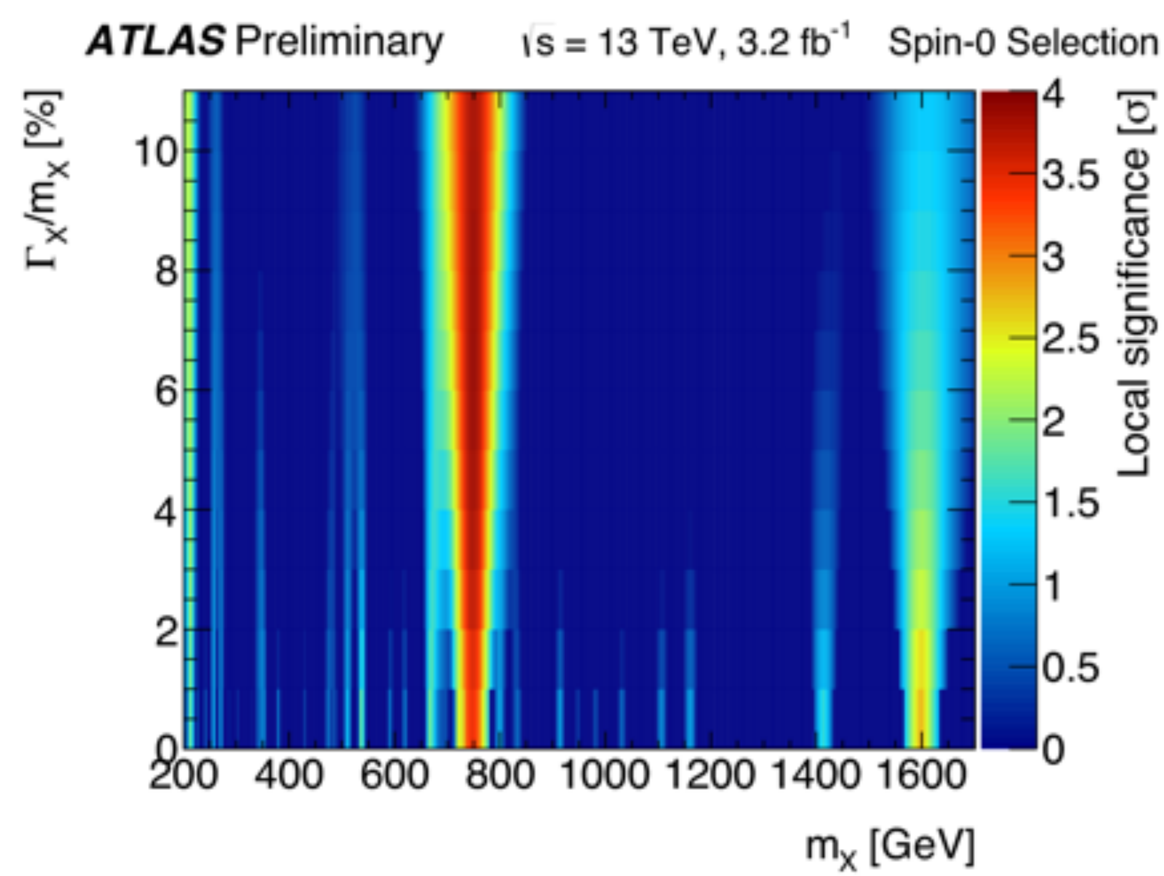
CMS-EXO-16-018

THE MOST CONVINCING EXCESS YET

- **Compatible with 8 TeV data** if gg, bb fusion assumed
- Rate: σ(pp→Φ)*BR(Φ→γγ) ~ 5-10 fb
- Not enough data to constrain width



CMS-EXO-16-018



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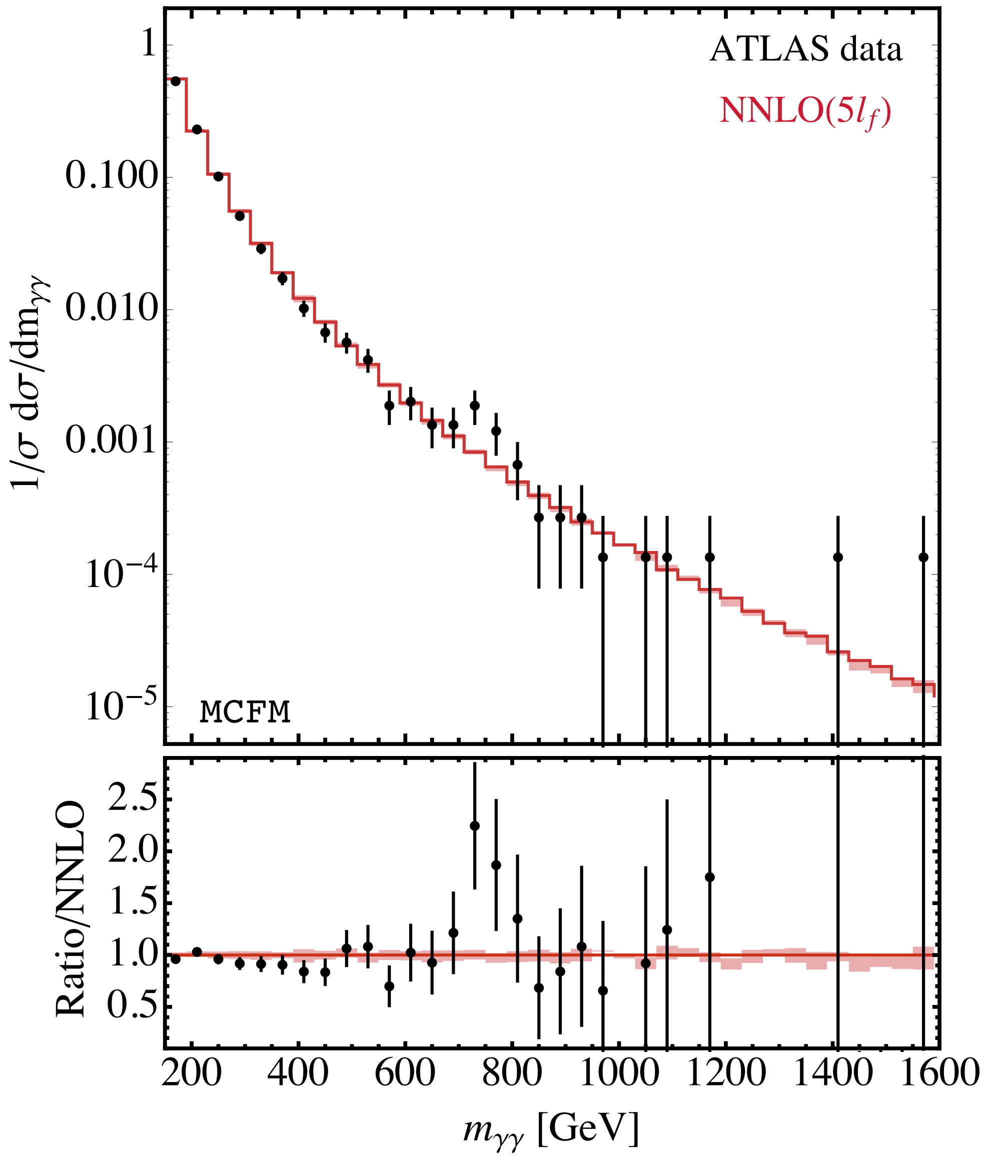
THE MOST CONVINCING EXCESS YET

- It's not the Standard Model
- Recent calculations of inclusive pp→γγ cannot explain the excess



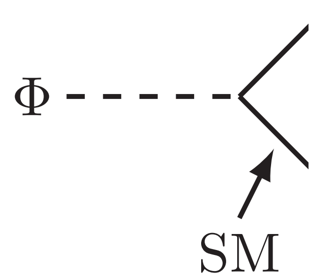
Campbell et al. 1603.02663

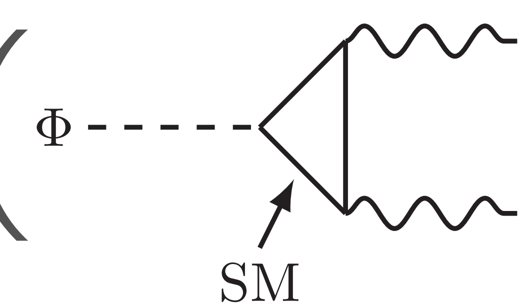
NEW PHYSICS!

- Basic feature of all models:
  - Need 750 GeV resonance + other state(s)
  - Reason: large tree level decay to SM particle in loop mediating decay to gaga

Knapen et al 1512.04298

Final state	95% C.L. U.L. on $\sigma \times$ BR [fb]	Upper lim. on $\mathrm{Br}(\Phi \to XX)/\mathrm{Br}(\Phi \to \gamma\gamma)$
WW (gluon fusion)	174	17.4–34.8
WW (VBF)	70	7–14
ZZ (gg prod.)	89	9–18
ZZ (VBF prod.)	40	4–8
$Z\gamma$	42	4.2–8.4
Zh	572	57–114
hh	209	21–42
bb	10^4	$1–2 \times 10^3$
tt	4.04×10^3	404–807
$\tau\tau$ (gg prod.)	56	6–11
$\tau\tau$ (assoc. b production)	54	5.4–10.8
qq	10^4	$1–2 \times 10^3$
$\ell\ell$	3.5	0.35–0.7

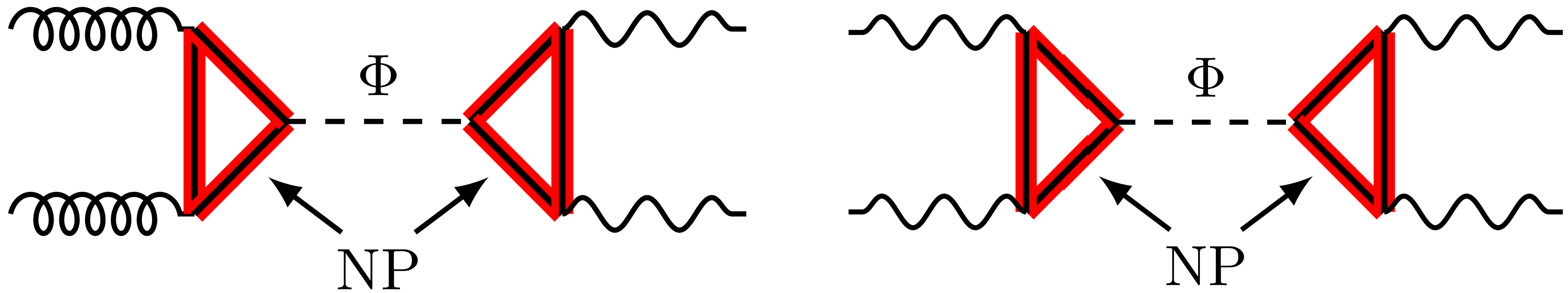
BR(

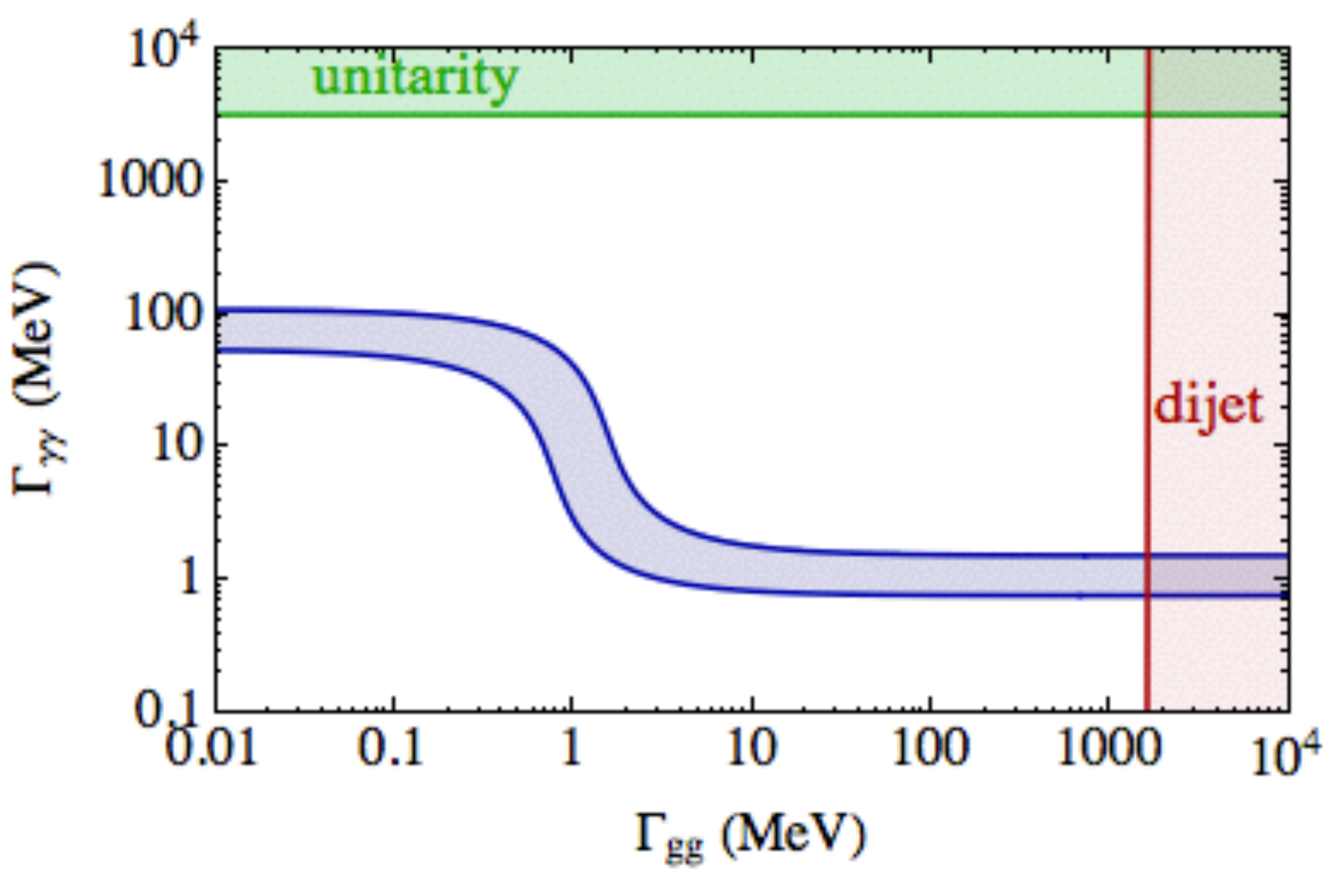
) $\gtrsim 10^5 \times$ BR(

)

SIMPLIFIED MODELS

- Most common simplified model to appear in the literature





Knapen et al 1512.04298

BIG CHARGES NEEDED

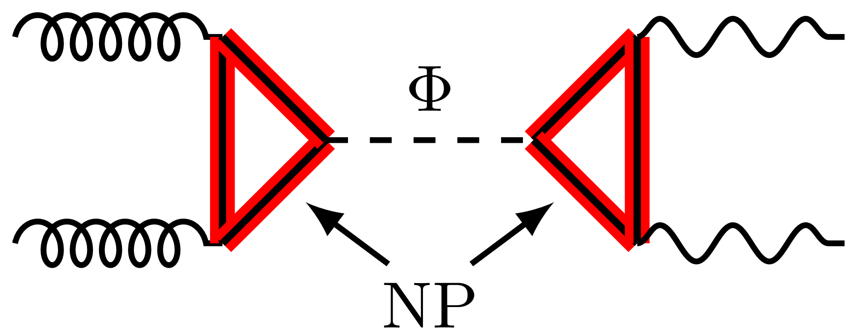
Natural Width:

$$\Gamma_{\gamma\gamma} \sim \frac{\alpha_{\mathrm{e.m.}}^2}{128\pi^3} m_\Phi \left(gNQ^2\right)^2 \sim \mathcal{O}\left(10\,\mathrm{keV}\right) \times \left(gNQ^2\right)^2$$

"in" = any production mode; "other" = any contribution to decay not in "in" or gaga

$$\sigma\left(\mathrm{pp} \to \Phi\right) \cdot BR(\Phi \to \gamma\gamma) \sim \frac{\Gamma_{\mathrm{in}}}{m_\Phi} \frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma} + \Gamma_{\mathrm{in}} + \Gamma_{\mathrm{other}}} \frac{d\mathcal{L}}{dm_\Phi^2}$$

LOOKING INSIDE LOOPS

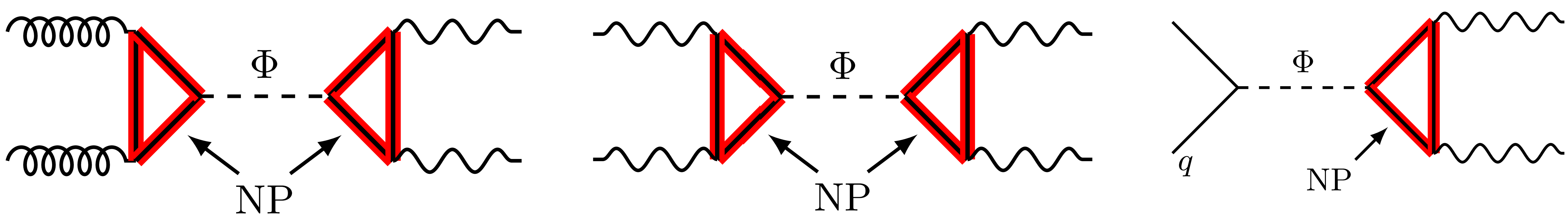


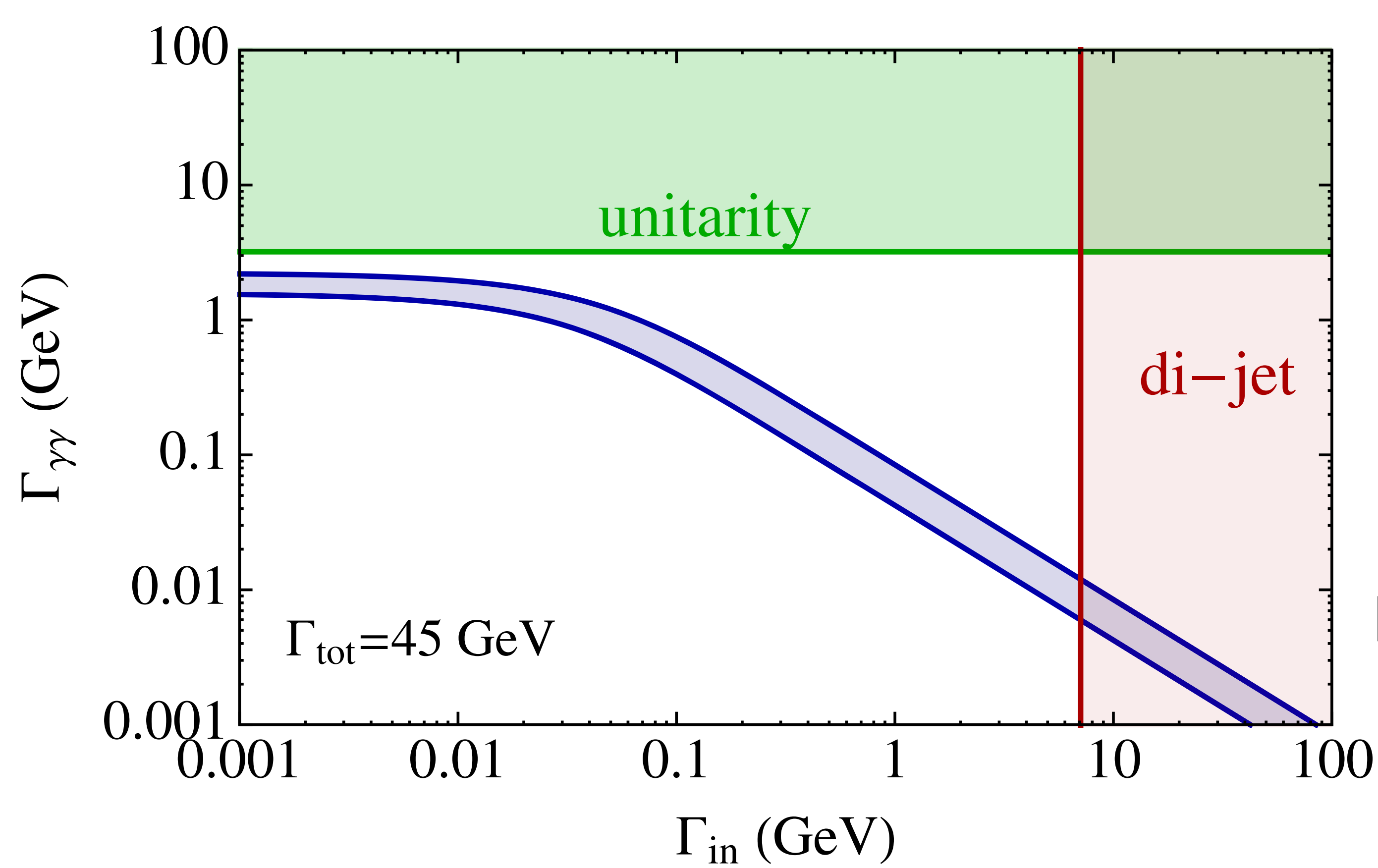
$m = g_s = 1\,\text{TeV},\ g_f = 1$

Model	Representation	$\gamma Z/\gamma\gamma$	$WW/\gamma\gamma$	$ZZ/\gamma\gamma$	$gg/\gamma\gamma$	$R^0_{\Phi\to\gamma\gamma}$ [fb]	Γ_{tot} [MeV]	$\Gamma_{\Phi\to\gamma\gamma}$ [MeV]	Decay mode
					Scalars				
S1	$(3,1,-\frac{4}{3})$	0.6	0	0.09	9.54	0.02	0.03	$3.\times10^{-3}$	d^c+e^c
S2	$(\bar{3},1,\frac{4}{3})$	0.6	0	0.09	9.54	0.02	0.03	$3.\times10^{-3}$	$2u^c$
S3	$(3,2,\frac{7}{6})$	0.06	0.91	0.6	11.62	0.06	0.14	9.9×10^{-3}	u^c+1
S4	$(\bar{3},2,-\frac{7}{6})$	0.06	0.91	0.6	11.62	0.06	0.14	9.9×10^{-3}	$e^c+\mathrm{q}$
S5	$(\bar{3},3,\frac{1}{3})$	4.44	27.78	8.48	49.84	0.02	0.47	5.2×10^{-3}	$\mathrm{q}+1$
S6	$(3,3,-\frac{1}{3})$	4.44	27.78	8.48	49.84	0.02	0.47	5.2×10^{-3}	$2\ \mathrm{q}$
S7	$(\bar{3},1,-\frac{2}{3})$	0.6	0	0.09	1.5×10^{2}	1.4×10^{-3}	0.03	1.9×10^{-4}	$2d^c$
S8	$(3,2,\frac{1}{6})$	5.07	30.62	9.26	3.9×10^{2}	$2.\times10^{-3}$	0.13	2.9×10^{-4}	d^c+1
S9	$(3,1,-\frac{1}{3})$	0.6	0	0.09	2.4×10^{3}	8.7×10^{-5}	0.03	1.2×10^{-5}	e^c+u^c
S10	$(\bar{3},1,\frac{1}{3})$	0.6	0	0.09	2.4×10^{3}	8.7×10^{-5}	0.03	1.2×10^{-5}	d^c+u^c
					Fermions				
F1	$(3,2,\frac{7}{6})$	0.06	0.91	0.6	11.62	3.52	8.19	0.58	$u^c+\mathrm{V/h}$
F2	$(\bar{3},3,-\frac{2}{3})$	1.55	13.61	4.53	24.42	2.49	27.86	0.62	$\mathrm{q}+\mathrm{V/h}$
F3	$(3,2,-\frac{5}{6})$	0.01	2.65	1.22	33.8	1.29	7.67	0.2	$d^c+\mathrm{V/h}$
F4	$(\bar{3},3,\frac{1}{3})$	4.44	27.78	8.48	49.84	1.23	27.7	0.3	$\mathrm{q}+\mathrm{V/h}$
F5	$(\bar{3},1,-\frac{2}{3})$	0.6	0	0.09	1.5×10^{2}	0.08	1.69	0.01	$\mathrm{q}+\mathrm{V/h}$
F6	$(3,2,\frac{1}{6})$	5.07	30.62	9.26	3.9×10^{2}	0.11	7.49	0.02	$u^c+\mathrm{V/h}$
F7	$(\bar{3},1,\frac{1}{3})$	0.6	0	0.09	2.4×10^{3}	5.1×10^{-3}	1.68	6.9×10^{-4}	$\mathrm{q}+\mathrm{V/h}$

SIMPLIFIED MODELS

- Most common simplified model to appear in the literature





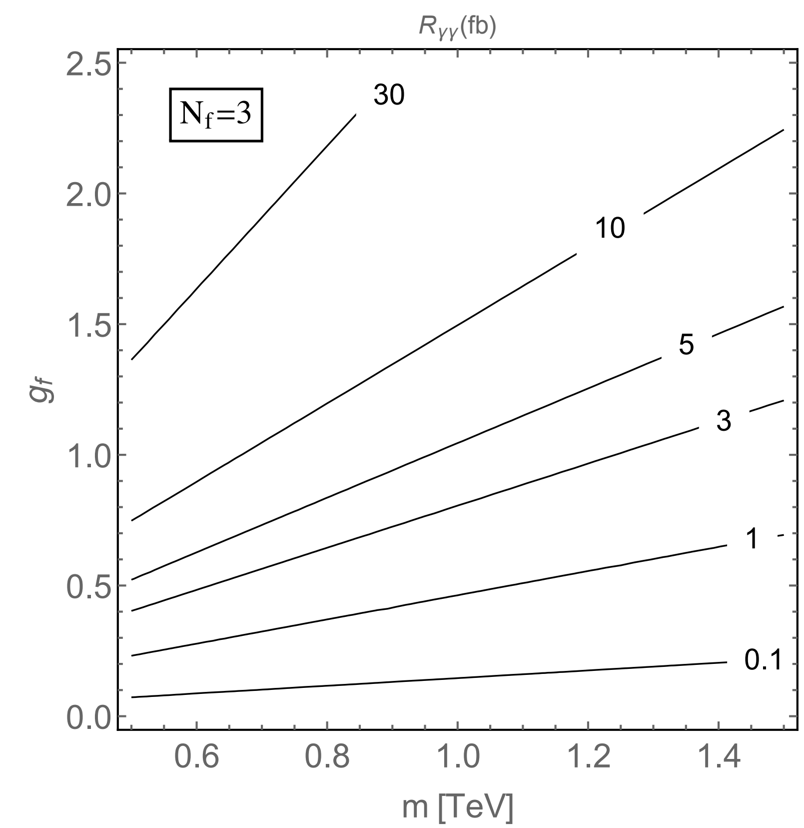
Knapen et al 1512.04298

LOOKING INSIDE LOOPS

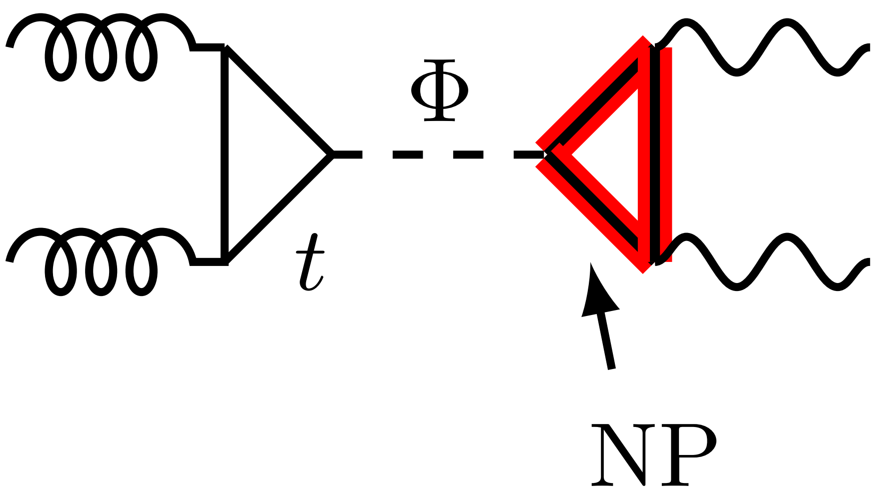
Model	Representation	$\gamma Z/\gamma\gamma$	$WW/\gamma\gamma$	$R^0_{\gamma\gamma}$ [fb]	$\Gamma_{\gamma\gamma}$ [MeV]	Decay mode
Scalars						
$S11$	$(1,1,-2)$	0.6	0	7.7×10^{-3}	1.4×10^{-3}	$2e^c$
$S12$	$(1,3,1)$	0.33	6.05	1.1×10^{-2}	2.3×10^{-3}	2ℓ
$S13$	$(1,2,-\frac{1}{2})$	0.82	9.45	4.7×10^{-4}	9.0×10^{-5}	d^c+q
$S14$	$(1,2,\frac{1}{2})$	0.82	9.45	4.7×10^{-4}	9.0×10^{-5}	u^c+q
Fermions						
$F8$	$(1,1,1)$	0.6	0	0.031	5.8×10^{-3}	$\ell+V/h$
$F9$	$(1,2,-\frac{3}{2})$	0.19	0.38	0.76	1.4×10^{-1}	e^c+V/h
$F10$	$(1,3,1)$	0.33	6.05	0.76	1.4×10^{-1}	$\ell+V/h$
$F11$	$(1,2,-\frac{1}{2})$	0.82	9.45	0.031	5.6×10^{-3}	e^c+V/h
$F12$	$(1,3,0)$	6.7	37.81	0.12	2.3×10^{-2}	$\ell+V/h$

Knapen et al 1512.04298

Model F9, y = 0.02

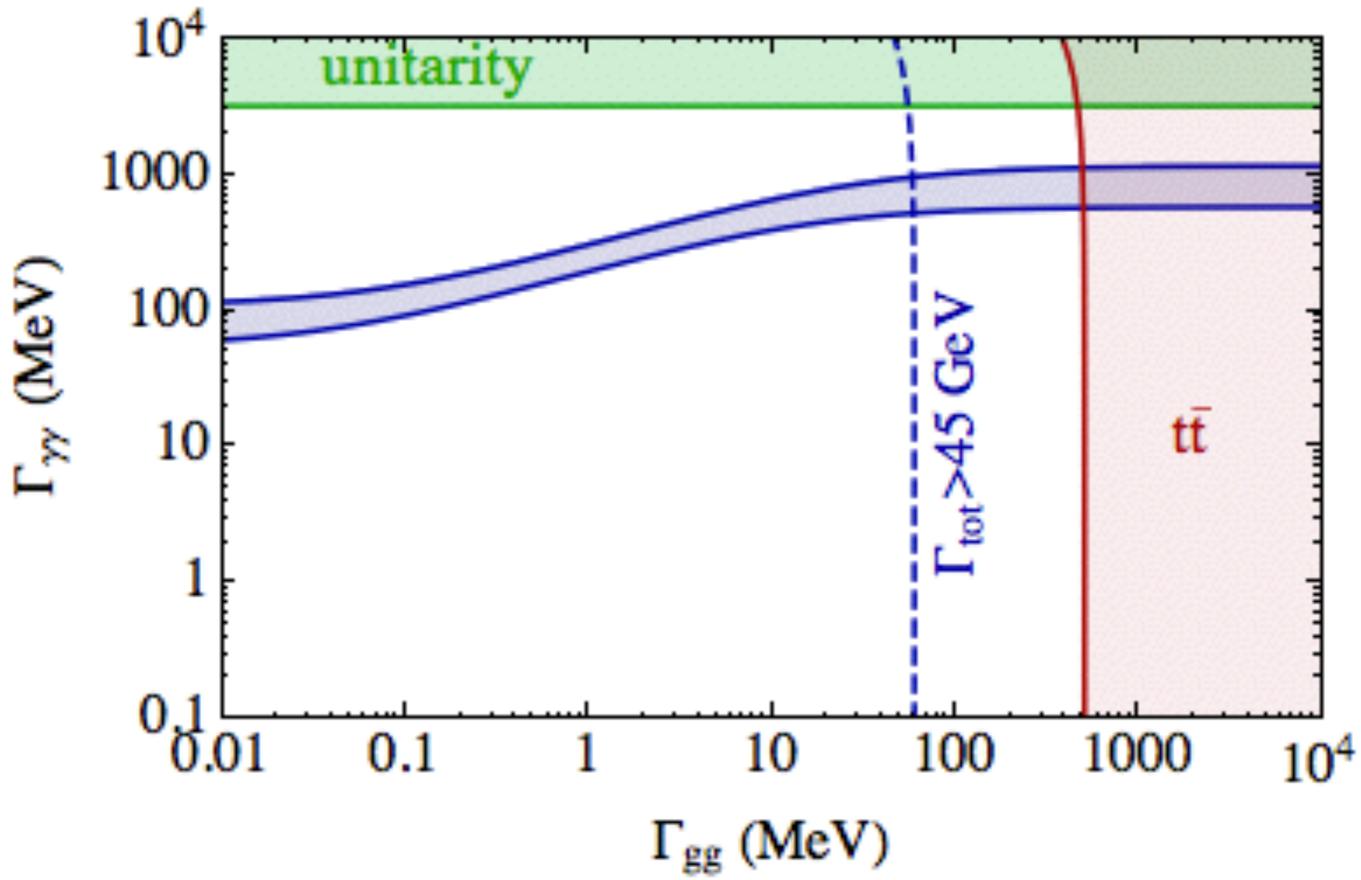


ELECTROWEAK STATES ONLY



No new colored particles needed

Knapen et al 1512.04298



MIXING WITH HIGGS

- Resonance part of EW Doublet only complicates constraints

$$\mathcal{L} \supset y\, \Phi \psi \chi + m\, \psi \bar{\psi} + m\, \chi \bar{\chi}$$

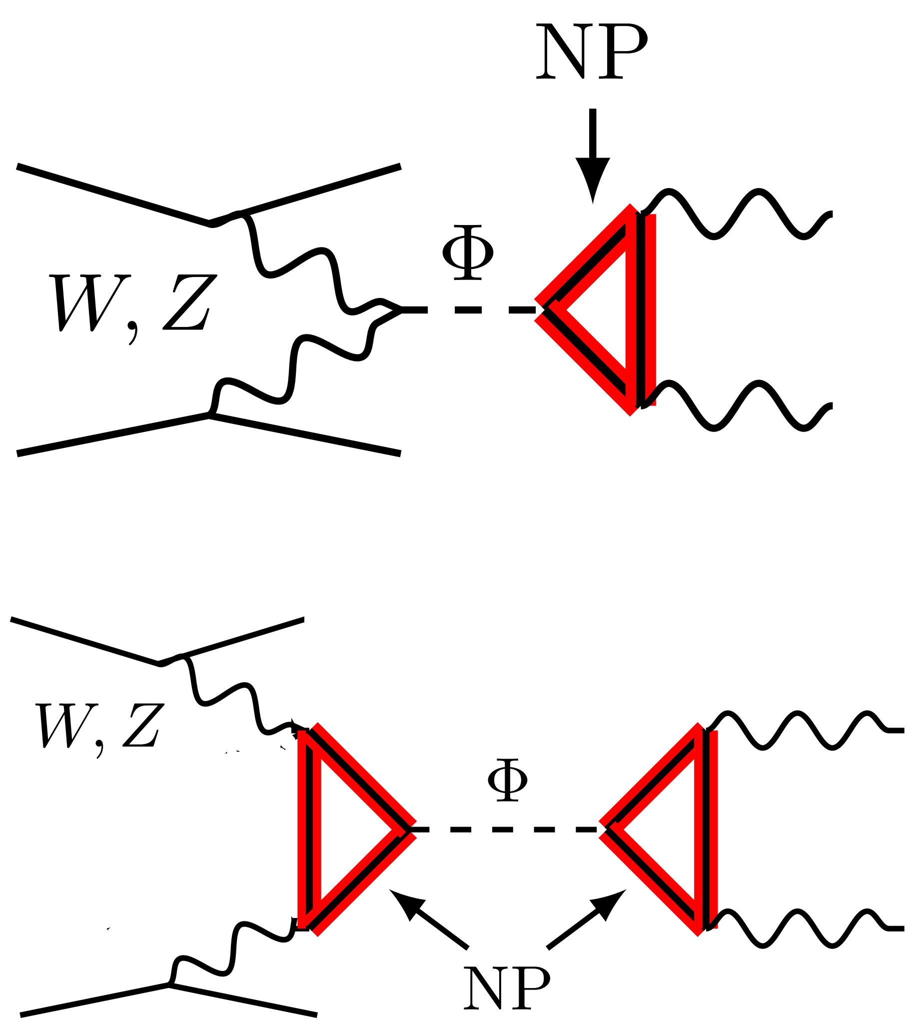
$$\longrightarrow \quad \frac{y^2}{m^2} \Phi \Phi^\dagger B^{\mu\nu} B_{\mu\nu} \quad \text{etc}$$

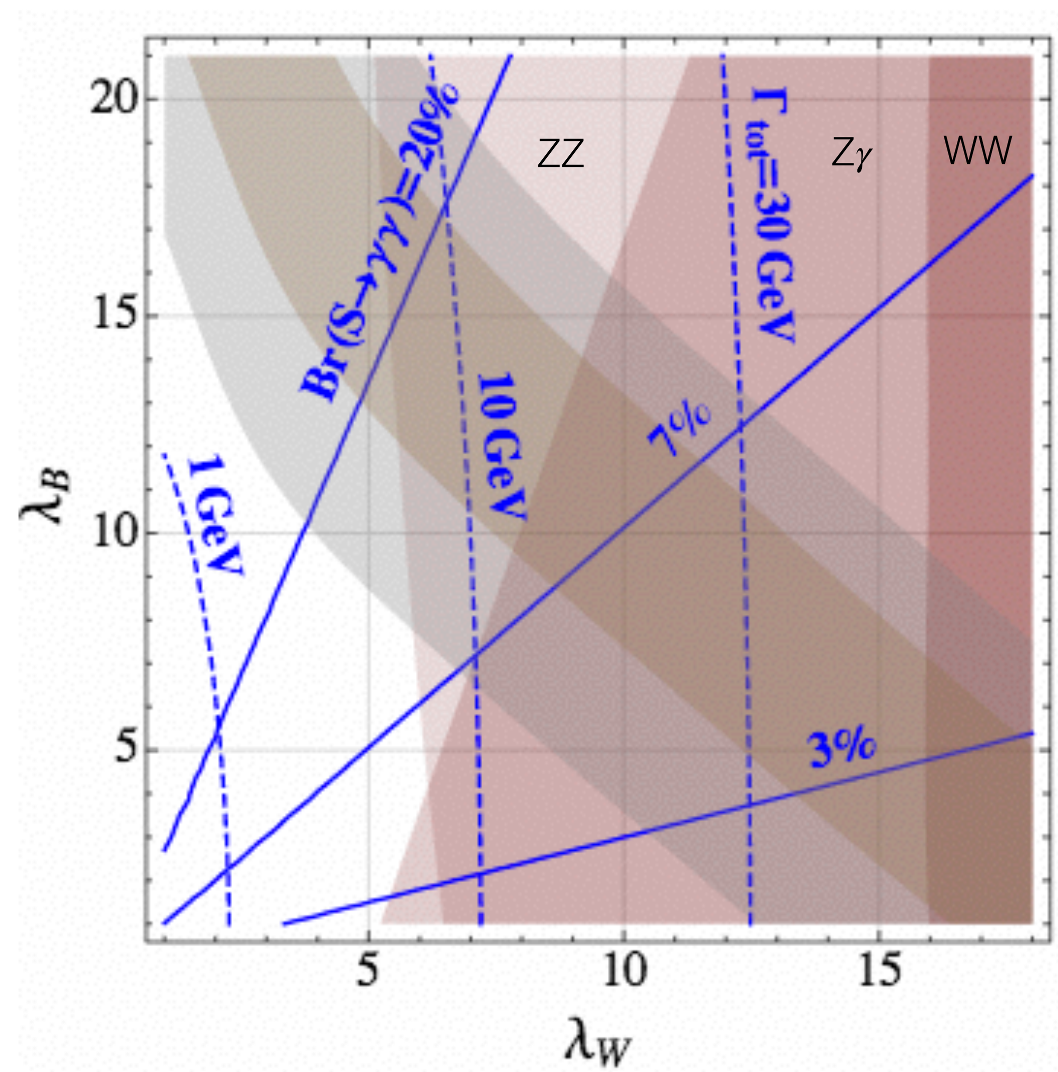
- Small Phi vev means Big Yukawas
- Or $$\mathcal{L} \supset y'\, H \psi \chi \quad \text{with} \quad y' < y$$

$$\longrightarrow \quad \frac{y y'}{m^2} \Phi H^\dagger B^{\mu\nu} B_{\mu\nu} \quad \text{etc}$$

(Very) stretched but not ruled out? .....

$$\mathcal{L} \supset \lambda_B \frac{\alpha}{\pi c_W^2 v} \Phi B_{\mu\nu} B^{\mu\nu} + \lambda_W \frac{\alpha}{\pi s_W^2 v} \Phi W_{\mu\nu} W^{\mu\nu}$$



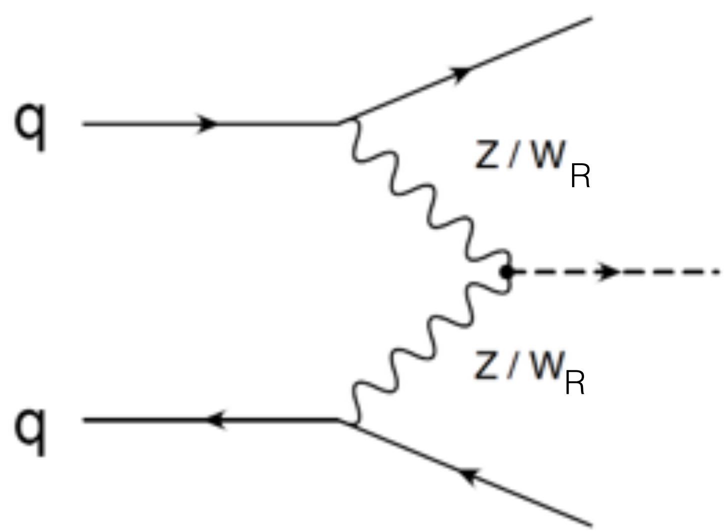


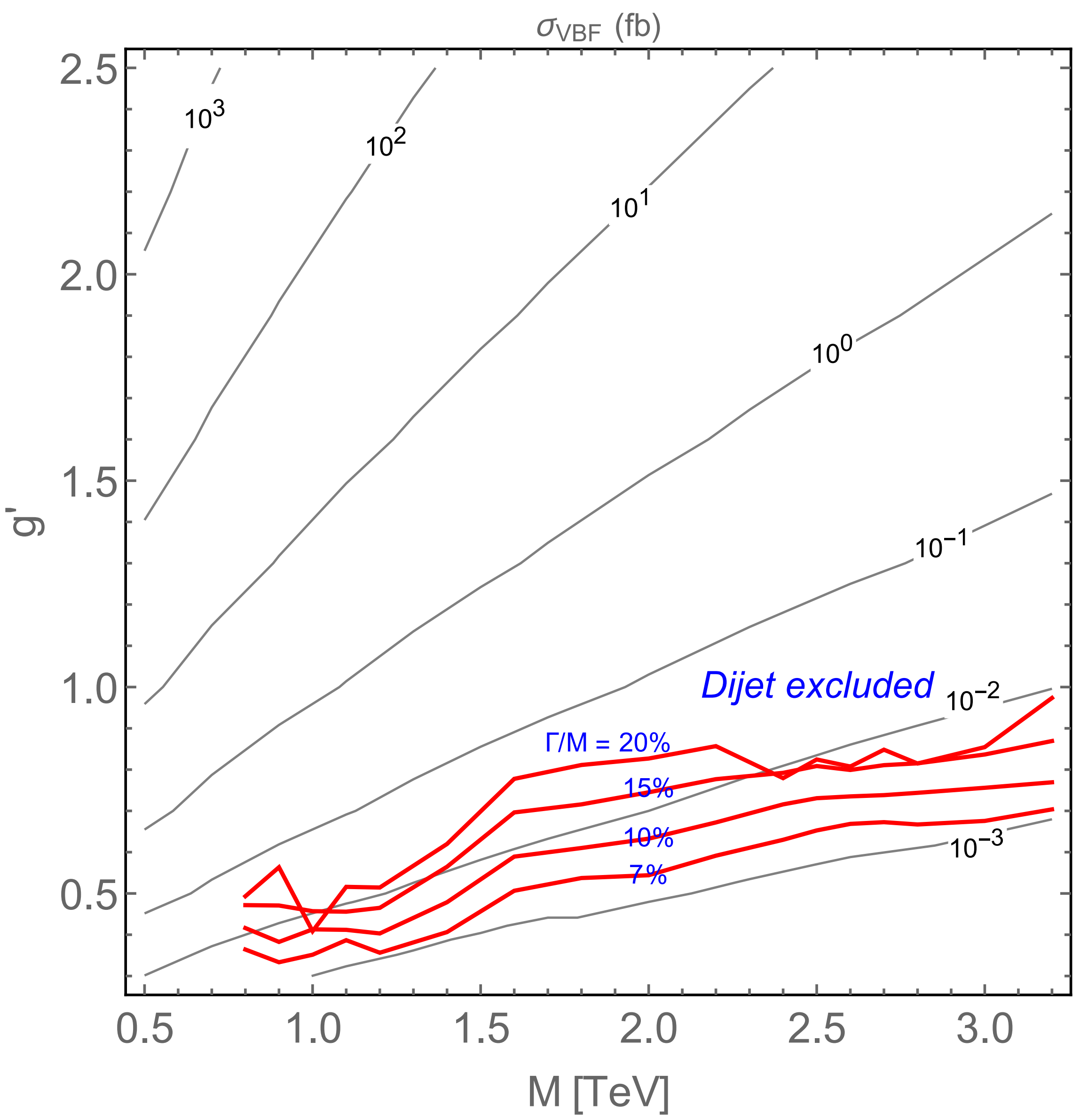
Altmannshofer et al.:1512.07616

SU(2)_R

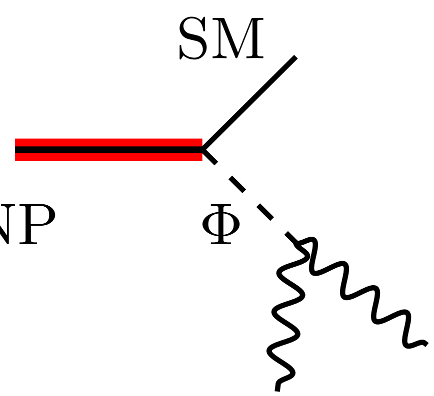
- Ruled out by dijets

Knapen et al 1512.04298



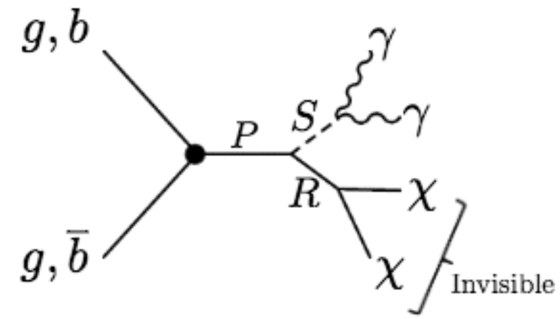


750 GEV RESONANCE + ADDITIONAL ACTIVITY

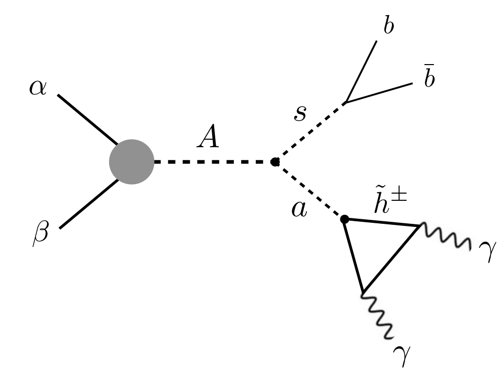


$$W' \to W\Phi$$

Knapen et al 1512.04298



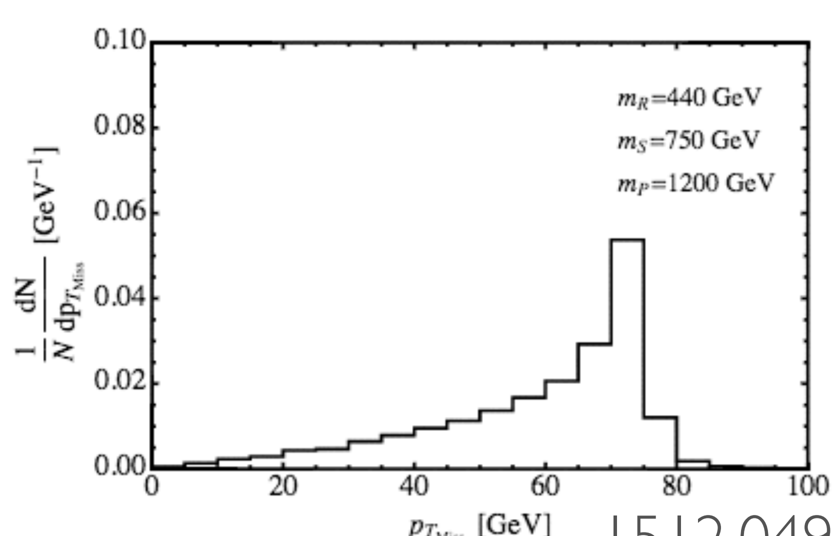
Franceschini et al, 1512.04933



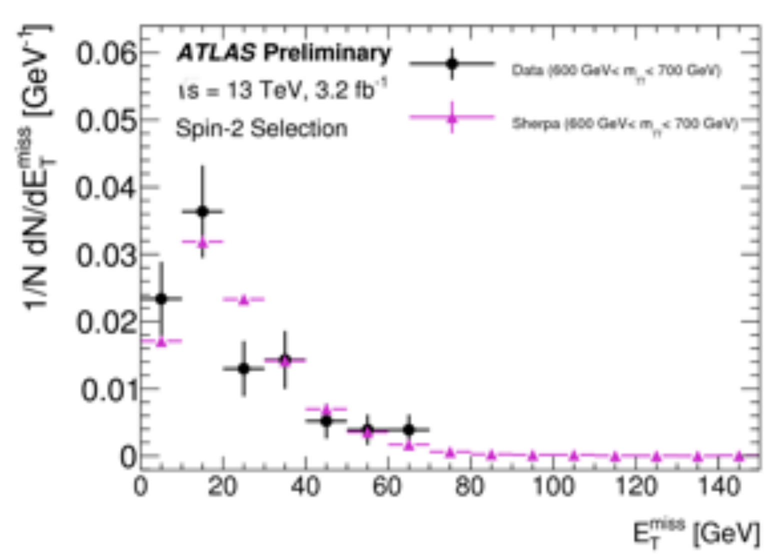
Badziak et al., 1603.02203

- Why has nothing else been reported in the events?

e.g.



1512.04933



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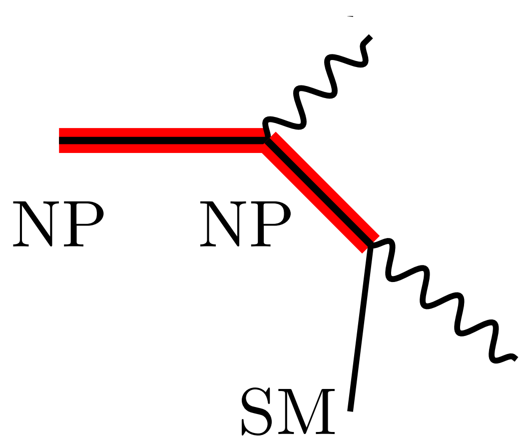
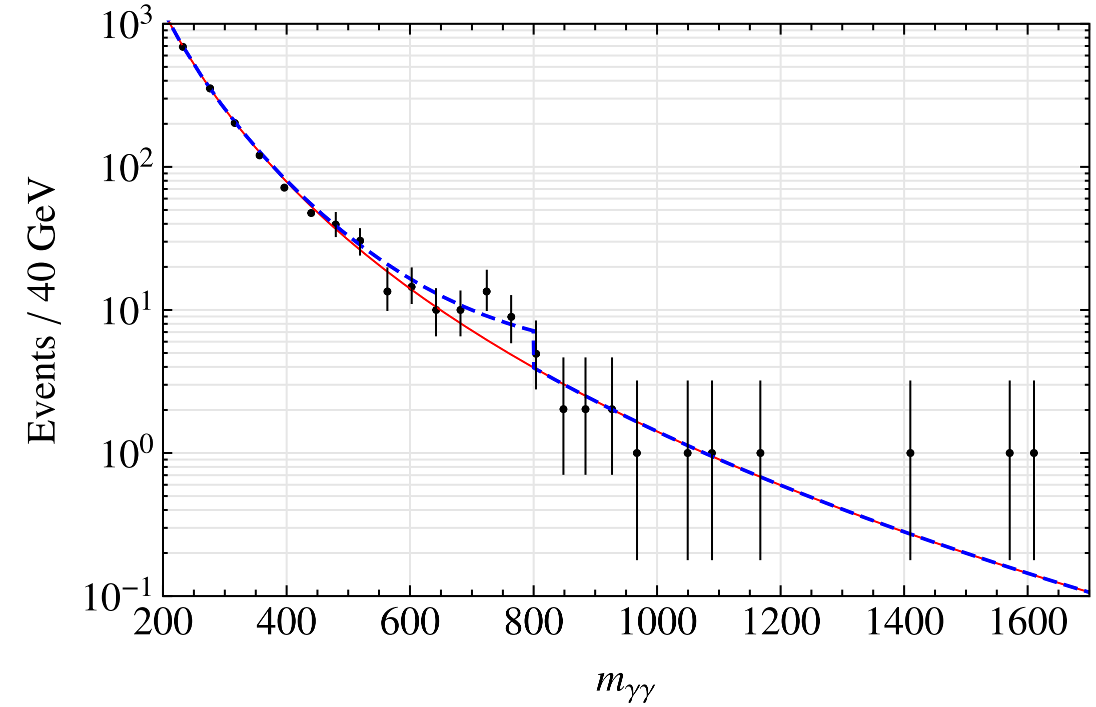
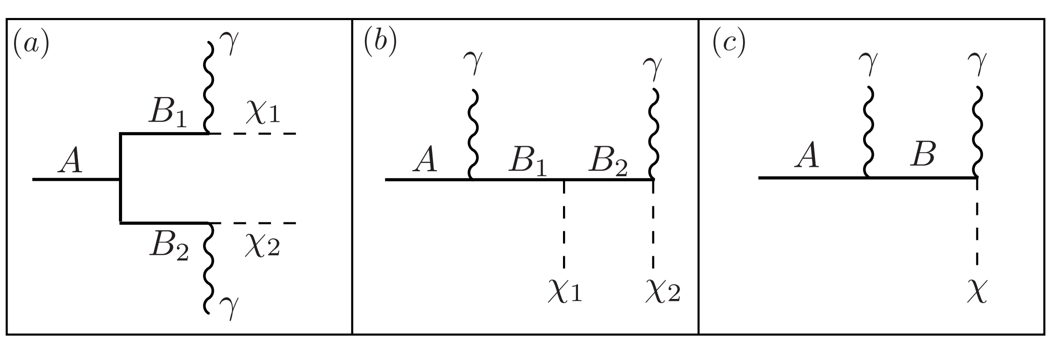
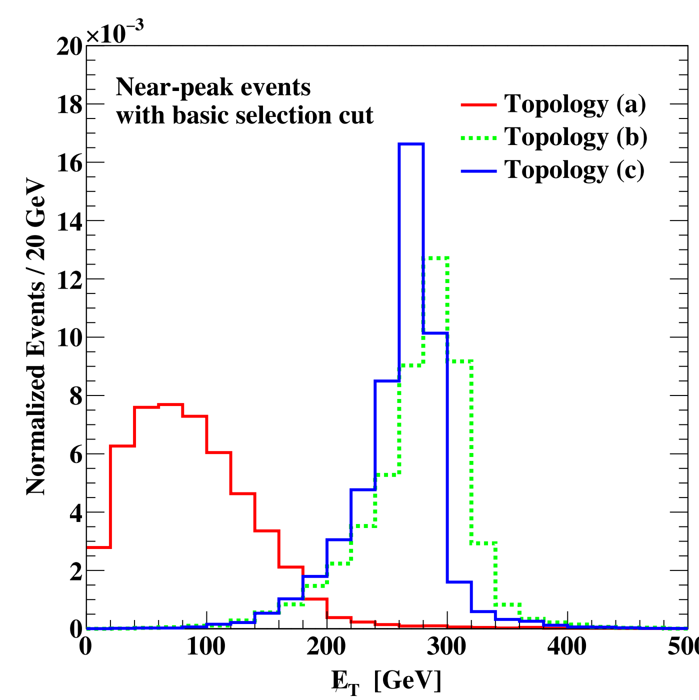
FAKE A RESONANCE WITH AN EDGE





- Again, why has nothing else been observed?

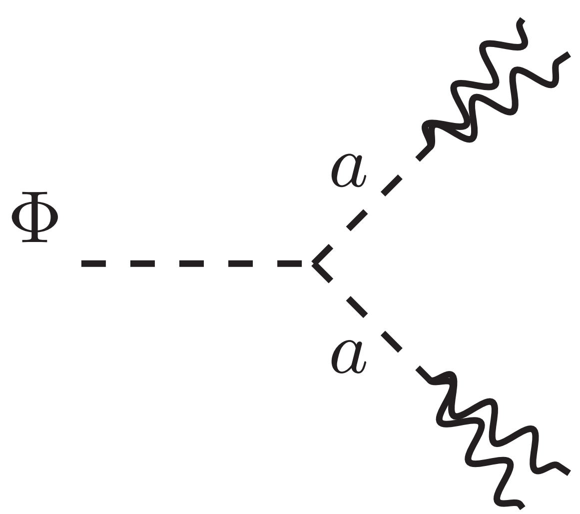


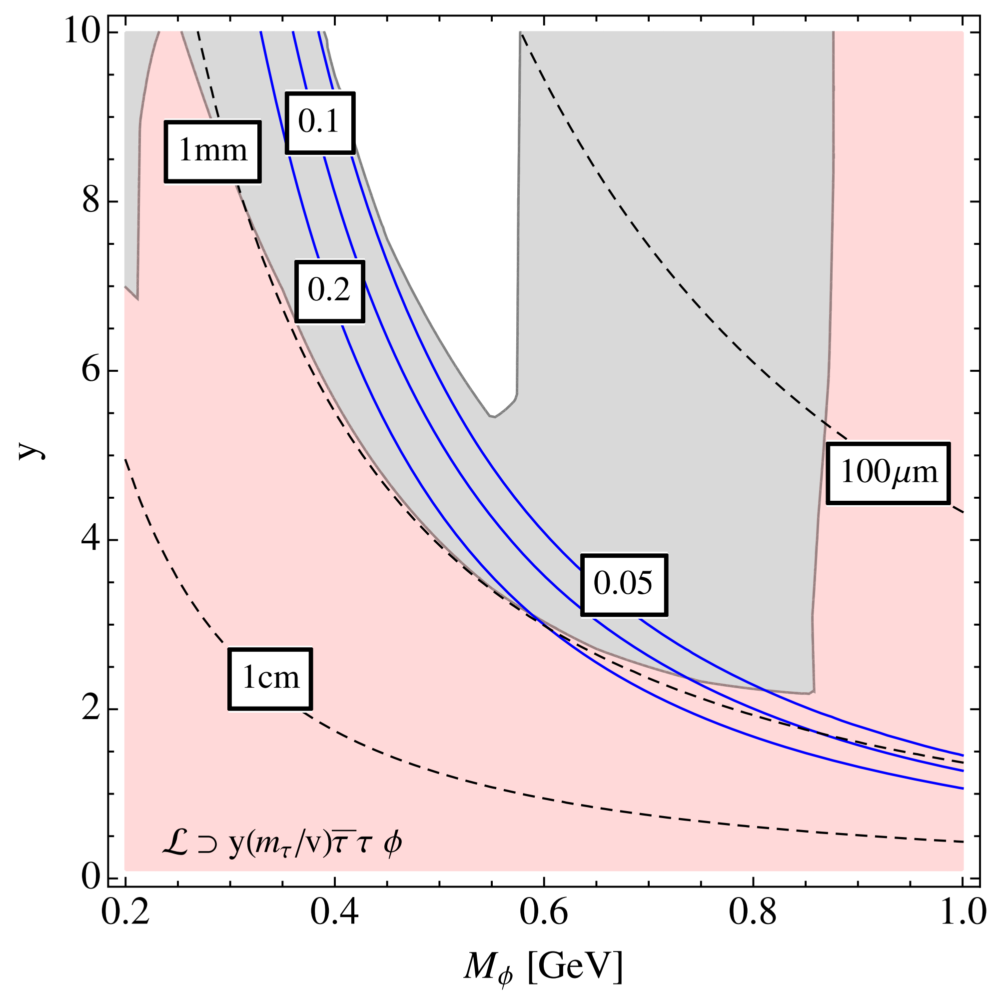


1512.06824v2

FAKE PHOTONS

- Sufficiently light secondary particles that decay products merge – Hidden-valley-like model

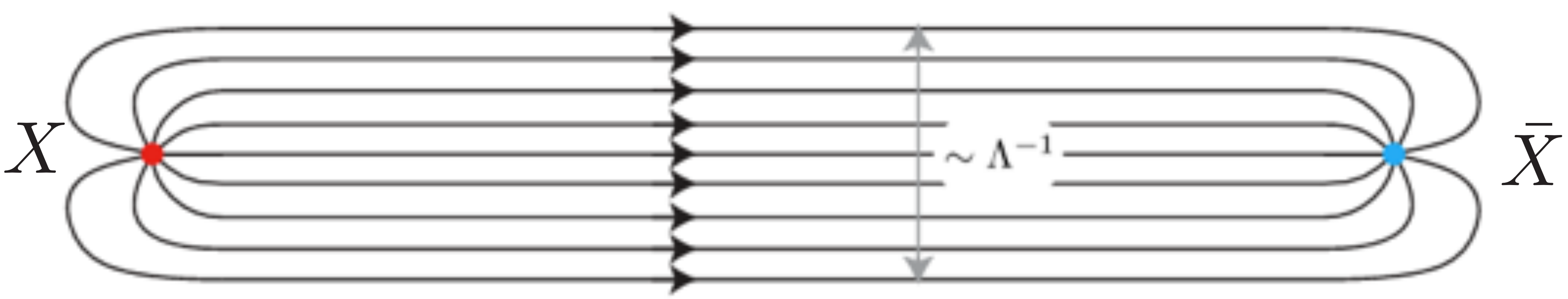




Knapen et al 1512.04298

QUIRKS

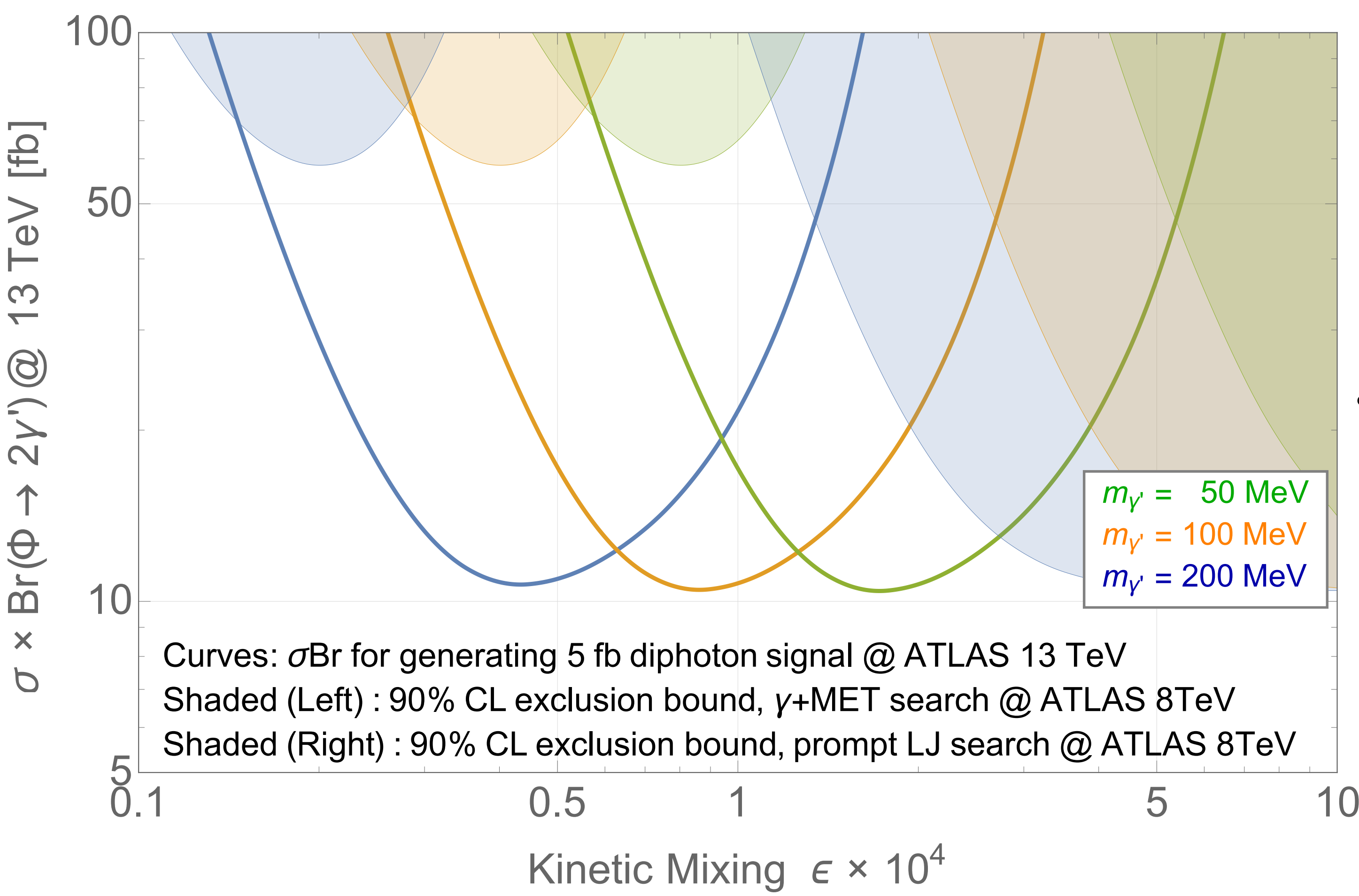
- If mX > Lambda, flux tube does not break
- Instead X-Xbar annihilates to hidden gauge bosons



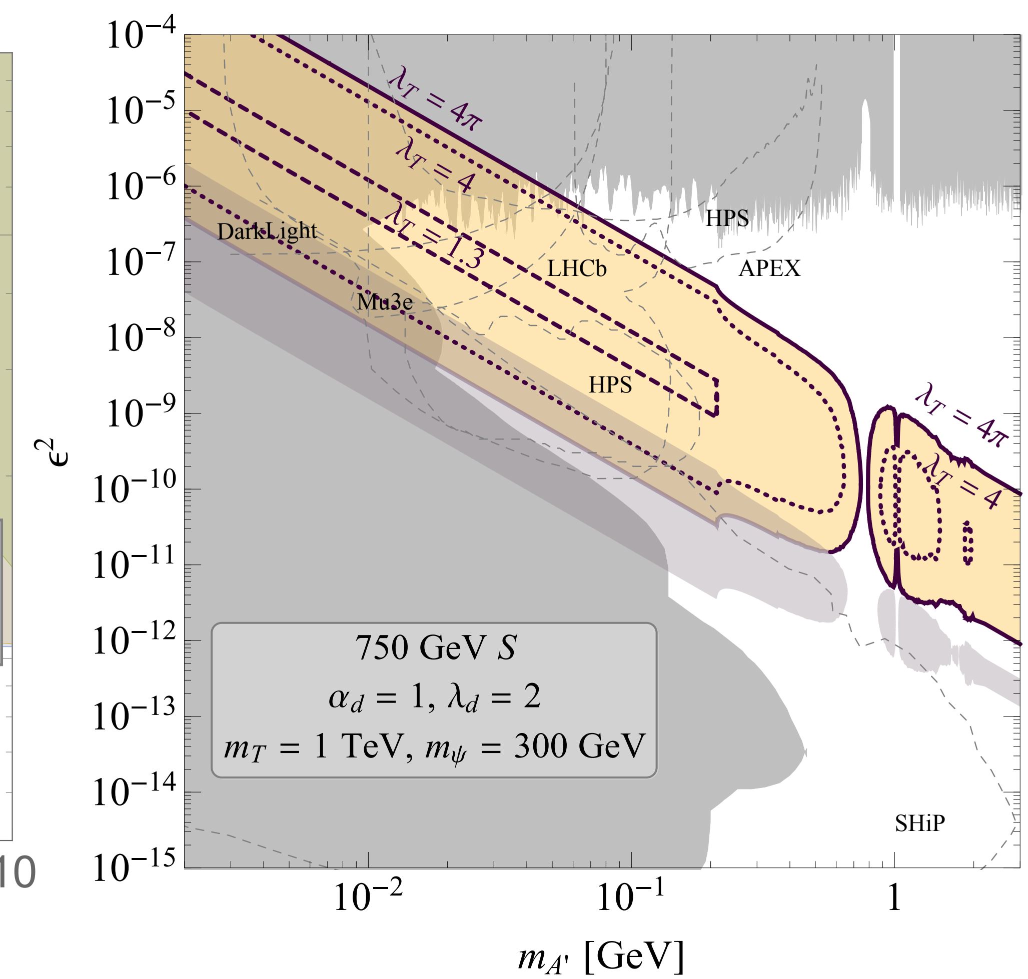
FAKE PHOTONS

- Long lived decays to pairs of electrons; evade tracker

$$\Phi \to A' A' \to 2e^+ 2e^-$$



Tsai et al. 1603.00024



Chen et al. 1603.01256

HIDDEN PIONS

- Confine at high scale

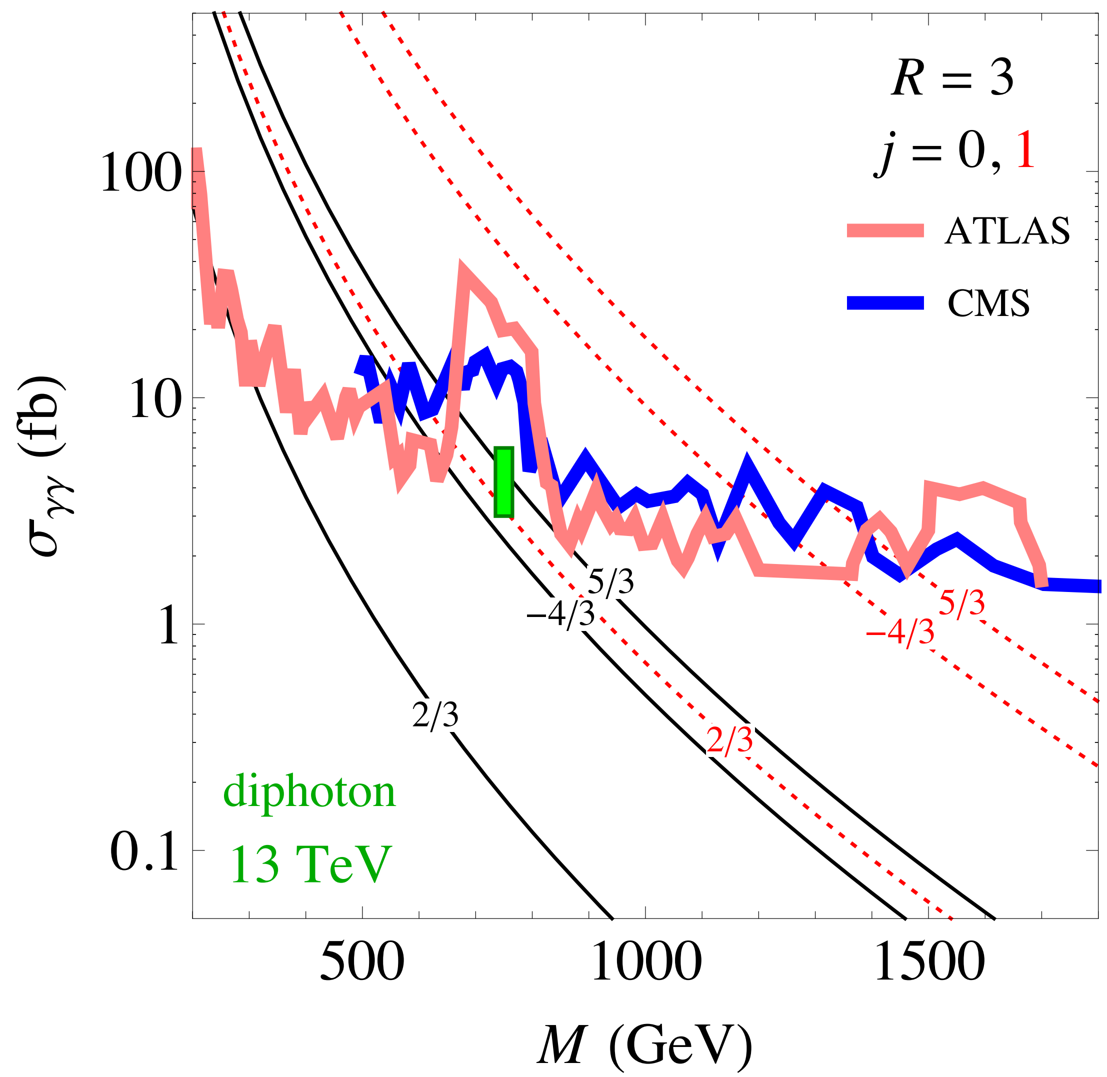
	G_H	$SU(3)_C$	$U(1)_Y$	$U(1)_A$
Q_1	$\Box$	$\bar{\Box}$	a	$1/3$
Q_2	$\Box$	$\mathbf{1}$	b	-1
$\bar{Q}_1$	$\bar{\Box}$	$\Box$	$-a$	$1/3$
$\bar{Q}_2$	$\bar{\Box}$	$\mathbf{1}$	$-b$	-1

$$\langle Q_1\bar{Q}_1\rangle \approx \langle Q_2\bar{Q}_2\rangle \equiv \langle Q\bar{Q}\rangle \approx \frac{1}{16\pi^2}\Lambda^3 \qquad \psi \sim Q_1\bar{Q}_1 \qquad (\mathbf{Adj}, 0),$$

Harigaya and Nomura 1603.05774

QCD OR NEW GROUP COMPOSITE

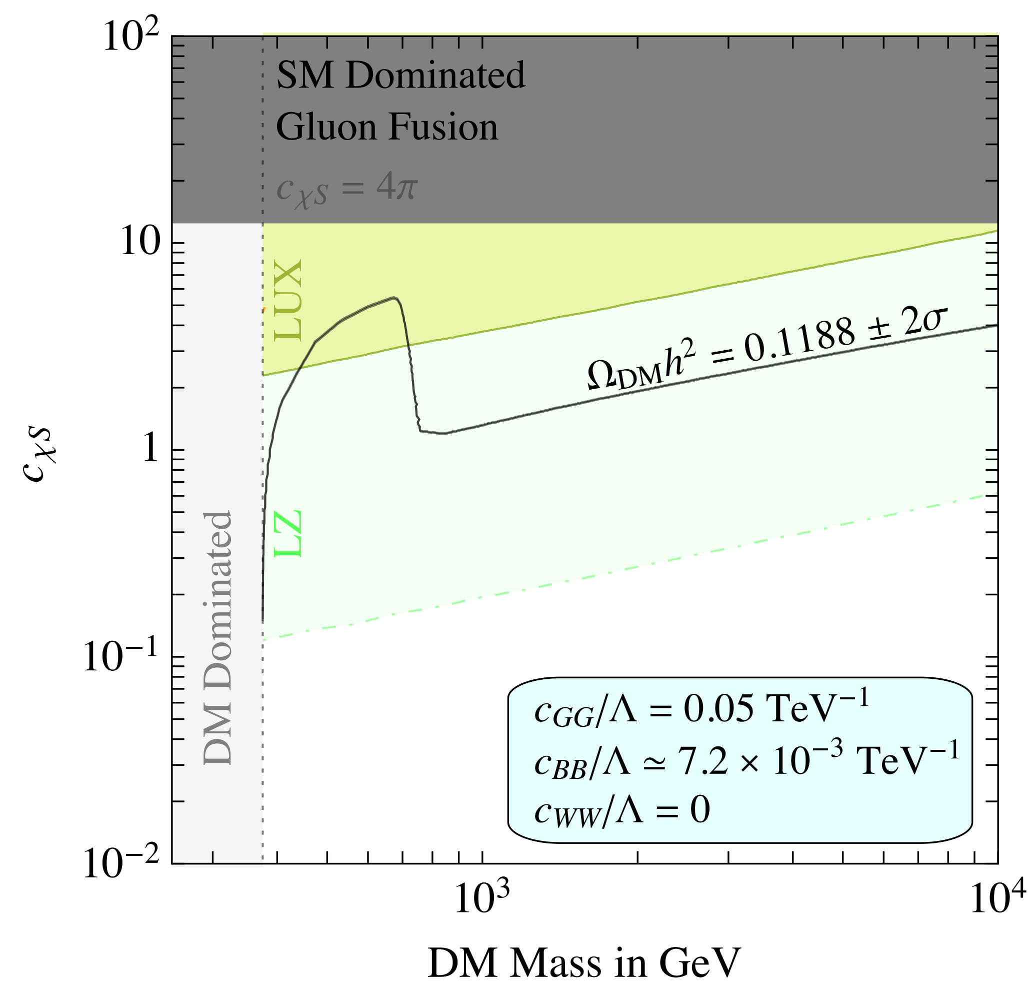
- Resonance as QCD composite if constituents decay slowly enough.
- Large charge needed to get large enough rate (Q = -4/3 charge preferred)



Kats et al. 1602.08819

SURE, WHY NOT?

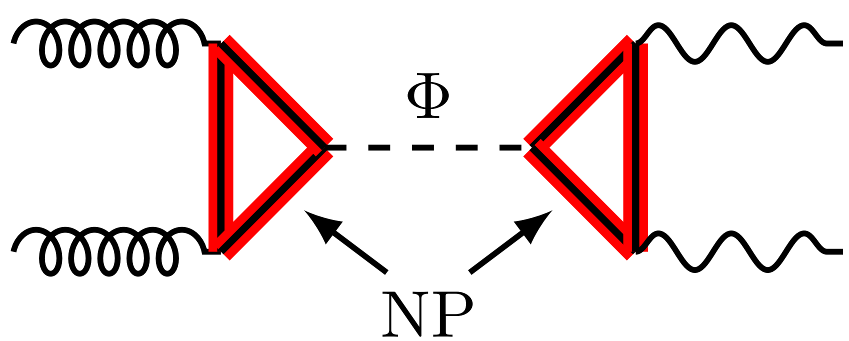
- Resonance can even provide an annihilation portal



d'Eramo et al: 1601.0157 (+ many others)

WHAT DO WE LEARN?

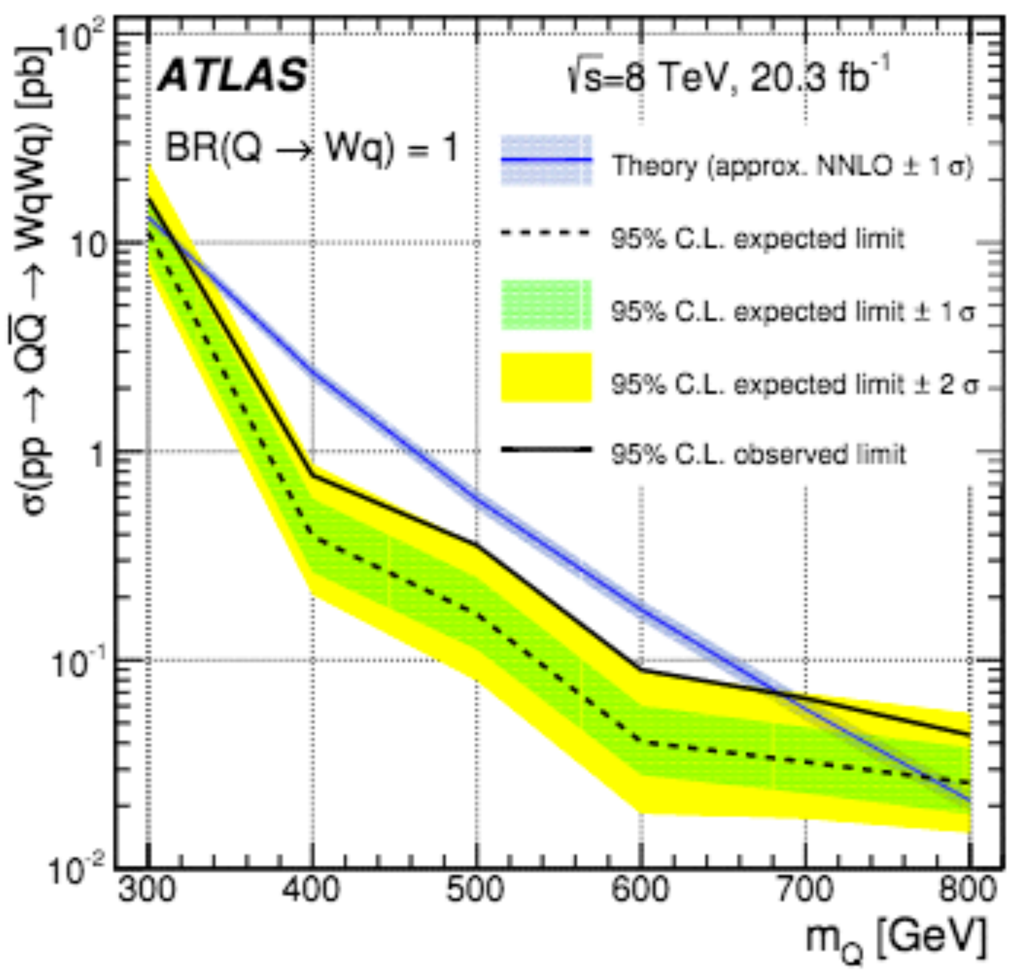
- Composite (pion) of new confining gauge group
- Or weakly coupled resonance + vector-like quarks



  - Both Work Well
  - Both predict extraordinary levels of activity in LHC Run II

WHAT DO WE LEARN?

- Many resonances ; discovering 2nd QCD.
- Or, messenger states $\psi \to q + W$



IT'S AN IMPORTANT YEAR FOR PHYSICS BSM AT LHC