New Frontiers in Theoretical Physics
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The 750 GeV resonance and Dark Matter as heavy pions

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Antipin, Redi, Strumia, Vigiani (arXiv:1503.08749)

Redi, Strumia, Tesi, Vigiani (arXiv:1602.07297)

Outline

- Vectorlike Confinement
- Phenomenology of techni-pions as dark matter and digamma candidates
- Conclusions

Vectorlike Confinement

Kilic, Okui, Sundrum (arXiv:0906.0577)

$$\mathcal{Q} = \sum_i (N_{\rm TC}, r_i) \oplus (\bar{N}_{\rm TC}, \bar{r}_i)$$

new fermions in a vectorial rep of the SM charged under
a new strong interaction that confines without breaking the SM :

$\langle \mathcal{Q}\bar{\mathcal{Q}} \rangle \sim$ SM singlet

let's call it "techni-color" ($\neq$ old Technicolor theories !!!)

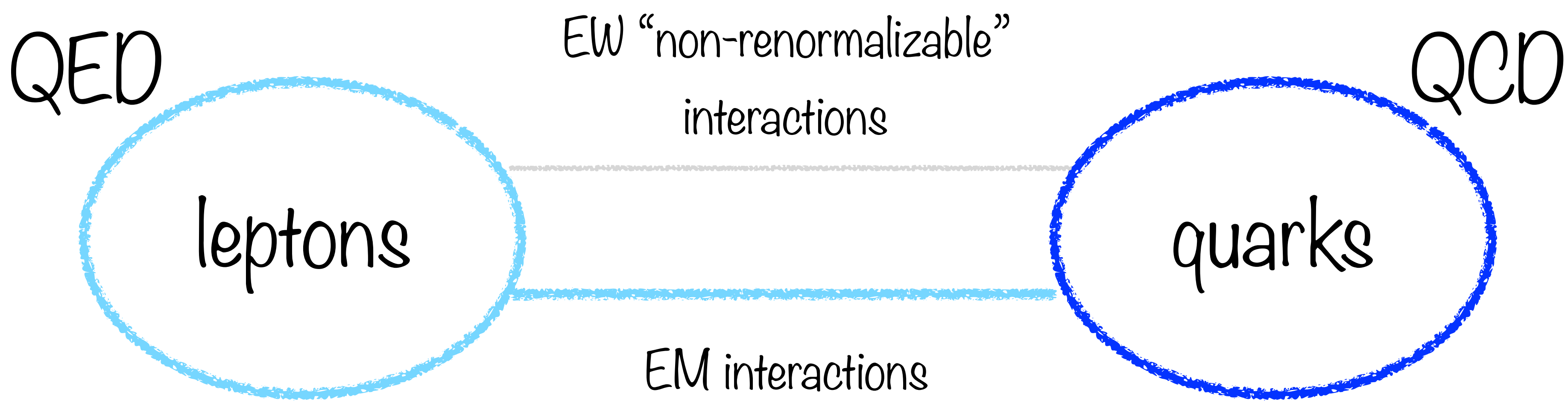
EWPT ✓

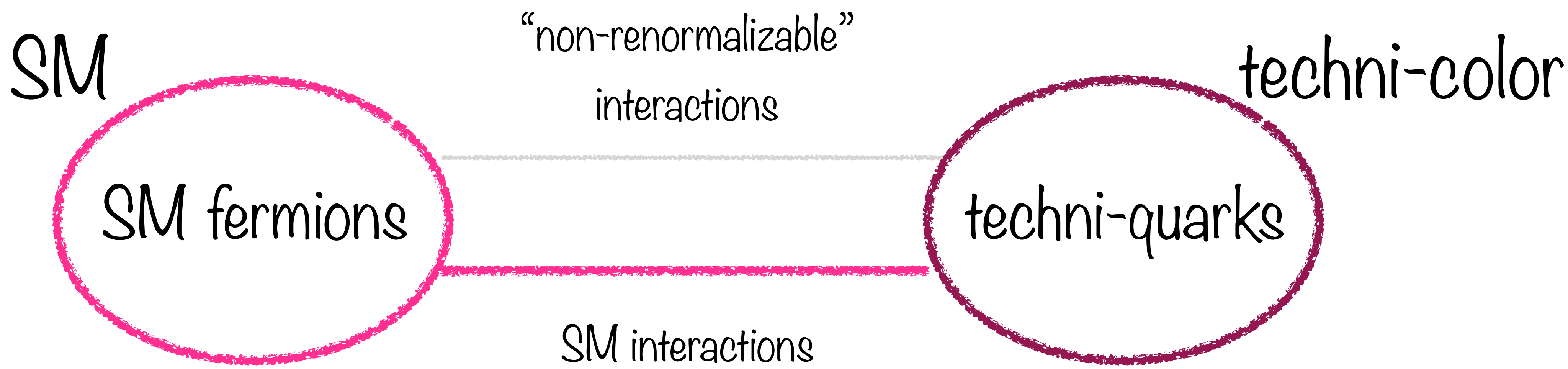
MFV ✓

LHC ✓

DM candidates :
stable thanks to accidental symmetries

VC is like seeing QCD from the point of view of QED :





$\mathrm{SU}(N_{\mathrm{TC}})$

with N_{TF} techni-flavors

SSB of the chiral symmetry

$$\mathrm{SU}(N_{\mathrm{TF}})_L \otimes \mathrm{SU}(N_{\mathrm{TF}})_R \to \mathrm{SU}(N_{\mathrm{TF}})$$

$N_{\mathrm{TF}}^2 - 1$ **techni-pions** $(\mathcal{Q}\bar{\mathcal{Q}})$

pseudo Goldstone Bosons

$$m^2_{\mathrm{TC}\pi} \sim m_{\mathcal{Q}} \Lambda_{\mathrm{TC}} + \underbrace{\Delta_{\mathrm{gauge}}}_{\sim 1/100 \Lambda^2_{\mathrm{TC}}}$$

techni-baryons

techni-color singlets made of N_{TC} techni-quarks

fermions if N_{TC} odd

bosons if N_{TC} even

mass of techni-pions

$\sim 1/10$ of the mass of techni-baryons

Accidental Symmetries

techni-baryons as DM

Antipin, Redi, Strumia, Vigiani (arXiv:1503.08749)

- techni-baryon number : $\mathcal{Q} \to e^{i\alpha}\mathcal{Q}$

  the lightest techni-baryon is stable

see A. Mitridate's talk tomorrow

techni-pions as DM

Redi, Strumia, Tesi, Vigiani (arXiv:1602.07297)

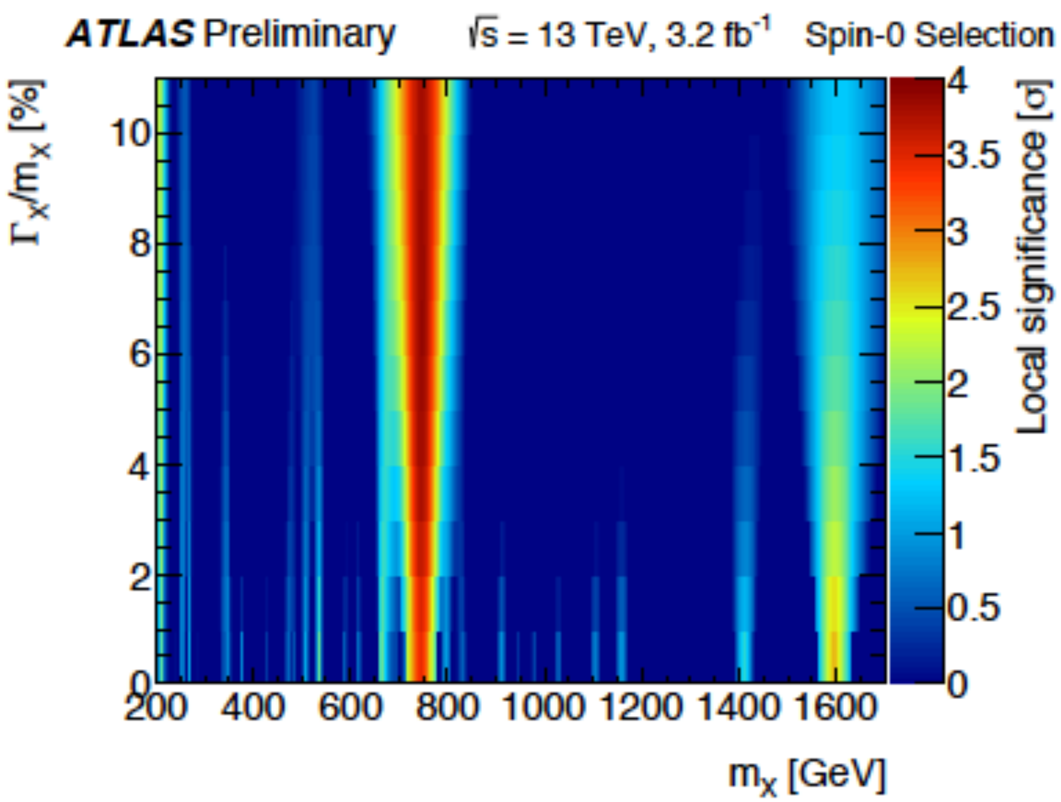
- species number : the lightest $\bar{\mathcal{Q}}_i \mathcal{Q}_j$, $i \neq j$ is stable

  in analogy with $\pi^+(u\bar{d})$

- G-parity : $\mathcal{Q} \to e^{i\pi T_2}\mathcal{Q}^c$

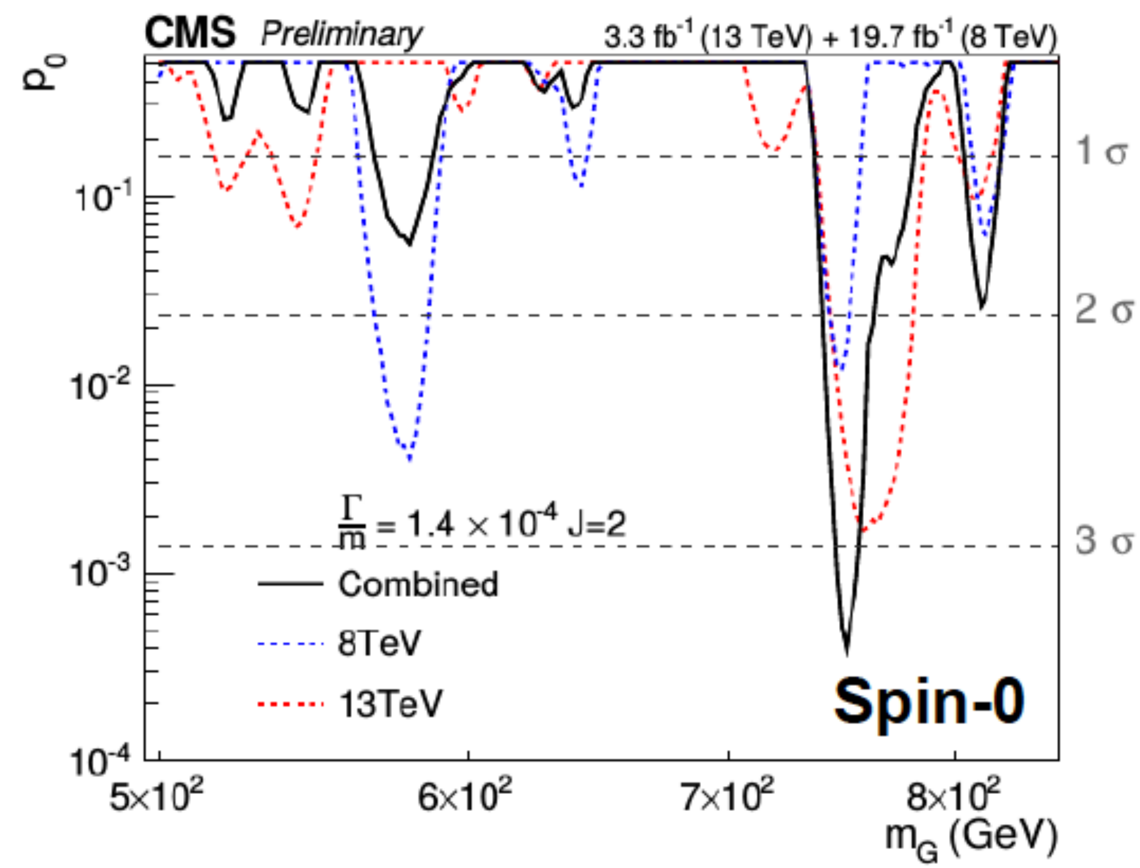
  techni-pions with even (odd) isospin are G-even (odd)

The \digamma particle



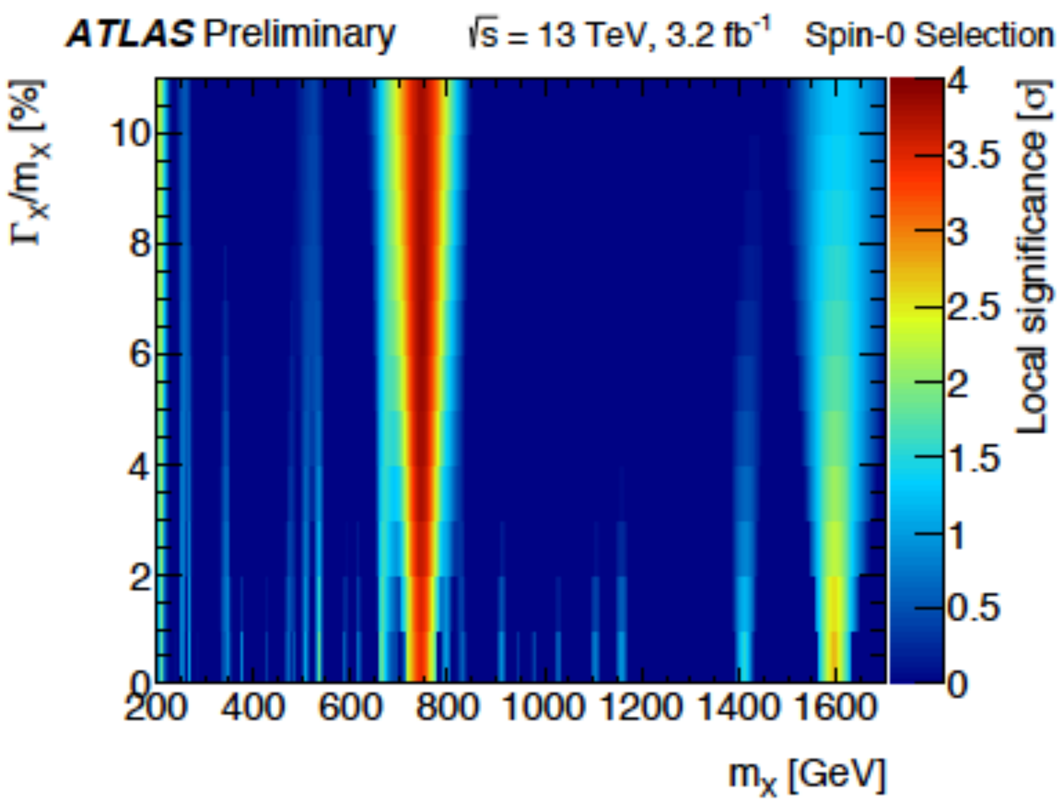
- Largest deviation from B-only hypothesis
  - ✓ m_X ~ 750 GeV, Γ_X ~ 45 GeV (6%)
  - ✓ Local Z = **3.9 σ**
  - ✓ Global Z = **2.0 σ**

from Moriond 2016 Conference



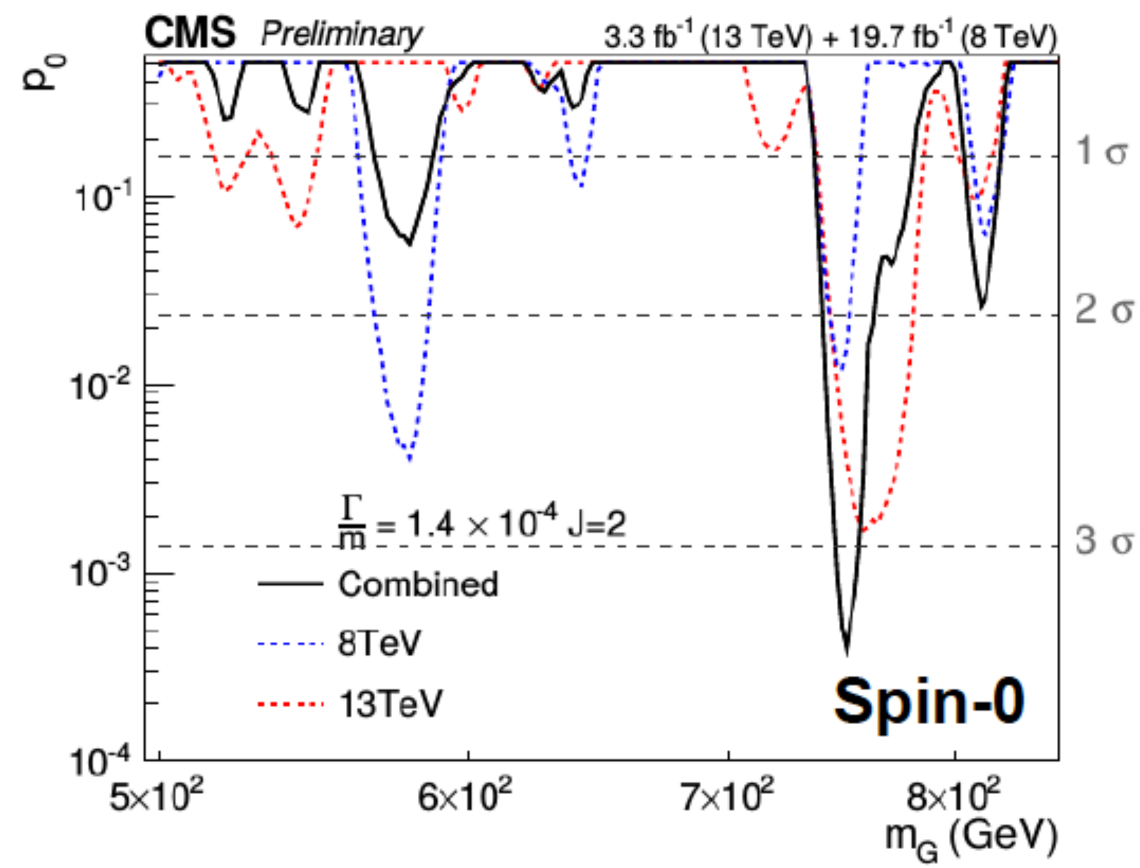
- Largest excess observed at **m_x = 750GeV** and for **narrow** width.
  - **Local** significance: **3.4σ**
  - Taking into account mass range 500-3500GeV (and all signal hypotheses), "**global**" significance becomes **1.6σ**

The F particle



- Largest deviation from B-only hypothesis
  - ✓ $m_X \sim 750$ GeV, $\Gamma_X \sim 45$ GeV (6%)
  - ✓ Local Z = **3.9 σ**
  - ✓ Global Z = **2.0 σ**

from Moriond 2016 Conference



- Largest excess observed at $\mathbf{m_x}$ **= 750GeV** and for **narrow** width.
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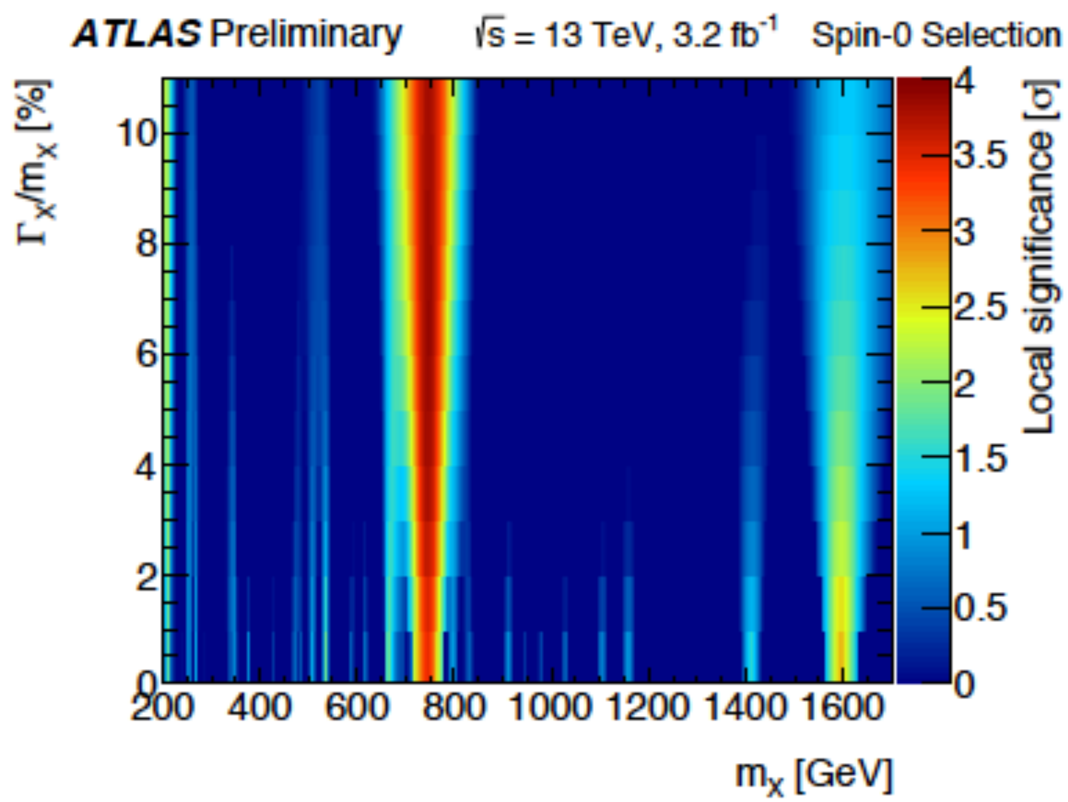
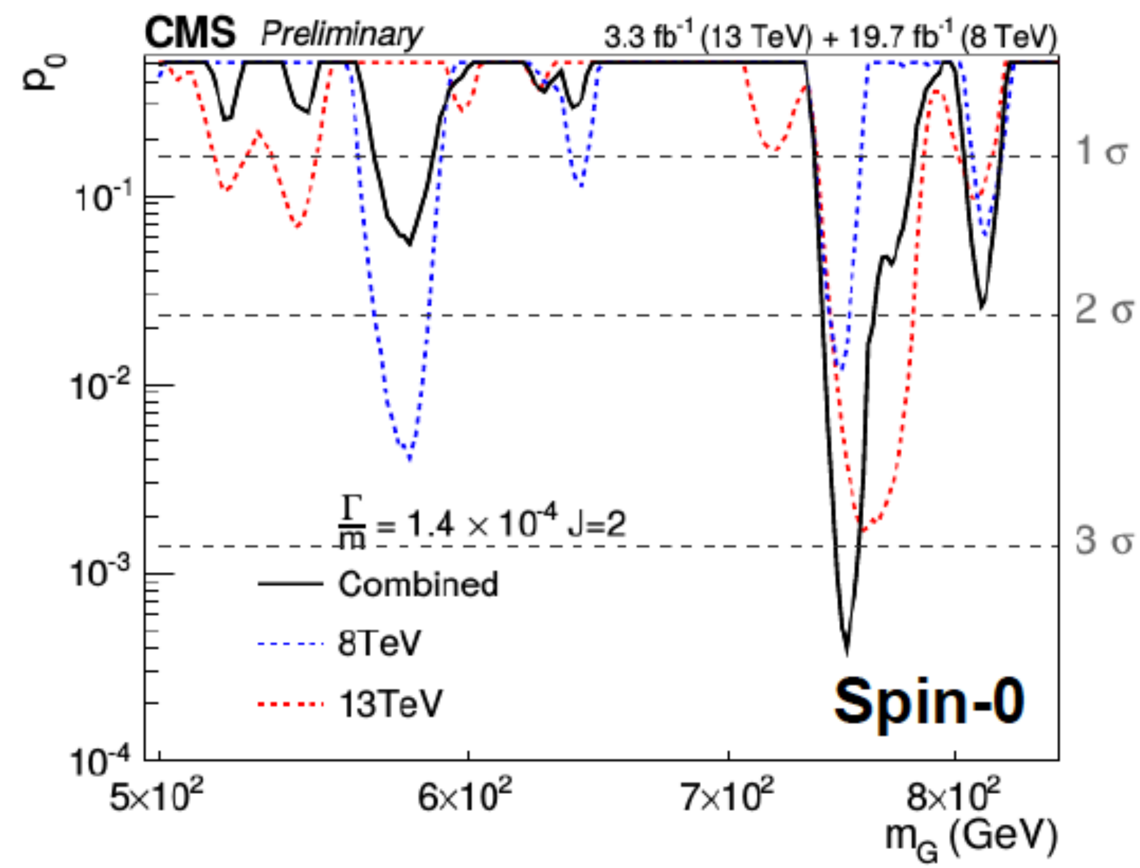
The F particle



- Largest deviation from B-only hypothesis
  - ✓ m_X ~ 750 GeV, Γ_X ~ 45 GeV (6%)
  - ✓ Local Z = **3.9 σ**
  - ✓ Global Z = **2.0 σ**

not enough to claim a discovery,
but enough to be excited!

from Moriond 2016 Conference



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Some properties...

- **spin 0** or spin 2? different analysis by CMS and ATLAS

- production mechanism

  the background grows by 2.3 at $750\,\mathrm{GeV}$, the signal by

$r_{b\bar{b}}$	$r_{c\bar{c}}$	$r_{s\bar{s}}$	$r_{d\bar{d}}$	$r_{u\bar{u}}$	r_{gg}	$r_{\gamma\gamma}$
5.4	5.1	4.3	2.7	2.5	4.7	1.9

  $gg, b\bar{b}, c\bar{c}, s\bar{s}$ favored by the compatibility with Run-I

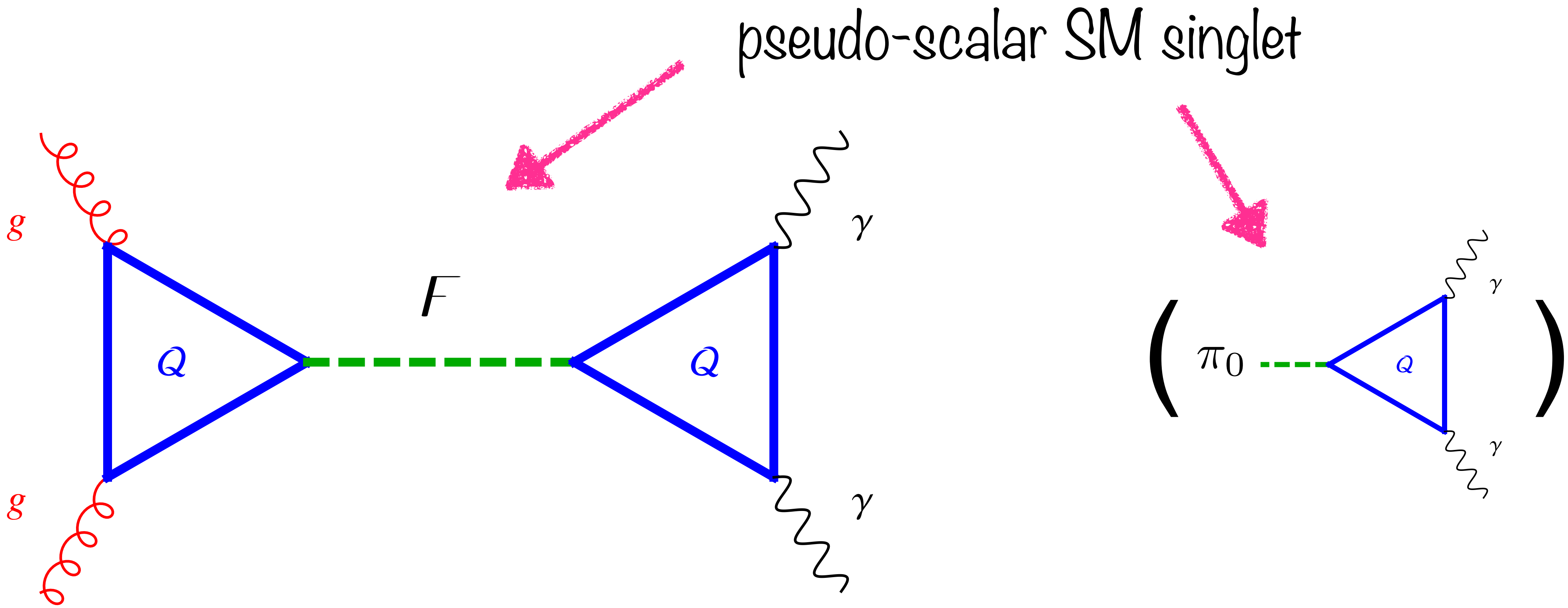
- **CP odd**, CP even (or CP is violated)? Franceschini et al. (arXiv:1604.06446)

  $F \to \gamma^*\gamma^* \to 4l$ → the rate is only 10^{-3} of the digamma rate

  $F \to \gamma\gamma \to e^+e^-e^+e^-$ → in matter, small e^+e^- angle

  $pp \to Fjj$ → from the di-jet angular distribution

Simple and predictive



$$\mathcal{L}_{\rm anomalies} \supset -\frac{1}{16\pi^2}\frac{F}{f}\left[g_1^2 c_B B_{\mu\nu}\tilde{B}^{\mu\nu} + g_2^2 c_W W^a_{\mu\nu}\tilde{W}_a^{\mu\nu} + g_3^2 c_G G^a_{\mu\nu}\tilde{G}_a^{\mu\nu}\right]$$

$$c_B = 2N_{\rm TC}{\rm Tr}(T_F Y^2) \quad c_W\delta^{ab} = 2N_{\rm TC}{\rm Tr}(T_F T^a T^b) \quad c_G\delta^{AB} = 2N_{\rm TC}{\rm Tr}(T_F T^A T^B)$$

$$\frac{\Gamma(F\to VV)}{M_F} = c_V^2\,\frac{\kappa_V\,\alpha_V^2}{64\pi^3}\,\frac{M_F^2}{f^2}$$

Digamma candidates in VC models

Redi, Strumia, Tesi, Vigiani (arXiv:1602.07297)

Q	$N_{\rm TF}$	$\frac{c_B^\eta}{N_{\rm TC}}$	$\frac{c_W^\eta}{N_{\rm TC}}$	$\frac{c_G^\eta}{N_{\rm TC}}$	$\frac{\Gamma^\eta_{\gamma Z}}{\Gamma^\eta_{\gamma\gamma}}$	$\frac{\Gamma^\eta_{ZZ}}{\Gamma^\eta_{\gamma\gamma}}$	$\frac{\Gamma^\eta_{GG}}{\Gamma^\eta_{\gamma\gamma}}$	$\frac{f({\rm GeV})}{N_{\rm TC}}$	$\frac{c_B^{\eta'}}{N_{\rm TC}}$	$\frac{c_W^{\eta'}}{N_{\rm TC}}$	$\frac{c_G^{\eta'}}{N_{\rm TC}}$	$\frac{\Gamma^{\eta'}_{\gamma Z}}{\Gamma^{\eta'}_{\gamma\gamma}}$	$\frac{\Gamma^{\eta'}_{ZZ}}{\Gamma^{\eta'}_{\gamma\gamma}}$	$\frac{\Gamma^{\eta'}_{GG}}{\Gamma^{\eta'}_{\gamma\gamma}}$	$\frac{f({\rm GeV})}{N_{\rm TC}}$
$D\oplus L$	5	$\frac{1}{6}\sqrt{\frac{5}{3}}$	$\frac{1}{2}\sqrt{\frac{3}{5}}$	$-\frac{1}{\sqrt{15}}$	1.8	4.7	240	96	$\frac{1}{3}\sqrt{\frac{5}{2}}$	$\frac{1}{\sqrt{10}}$	$\frac{1}{\sqrt{10}}$	0.23	1.9	180	–
$D\oplus U$	6	$\frac{1}{\sqrt{3}}$	0	0	0.57	0.082	0	–	$\frac{5}{3\sqrt{3}}$	0	$\frac{1}{\sqrt{3}}$	0.57	0.082	470	150
$D\oplus E$	4	$\frac{4}{3}\sqrt{\frac{2}{3}}$	0	$-\frac{1}{2\sqrt{6}}$	0.57	0.082	46	170	$\frac{2\sqrt{2}}{3}$	0	$\frac{1}{2\sqrt{2}}$	0.57	0.082	180	–
$D\oplus Q$	9	$-\frac{1}{6}$	$\frac{1}{2}$	0	17	22	0	–	$\frac{1}{3\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	2.9	6.1	740	150
$D\oplus T$	6	$\frac{8}{3\sqrt{3}}$	$\frac{2}{\sqrt{3}}$	$-\frac{1}{2\sqrt{3}}$	0.43	2.4	15	430	$\frac{10}{3\sqrt{3}}$	$\frac{2}{\sqrt{3}}$	$\frac{1}{2\sqrt{3}}$	0.23	1.9	12	–
$L\oplus U$	5	$\frac{7}{6\sqrt{15}}$	$-\frac{1}{2}\sqrt{\frac{3}{5}}$	$\frac{1}{\sqrt{15}}$	200	180	12000	–	$\frac{11}{3\sqrt{10}}$	$\frac{1}{\sqrt{10}}$	$\frac{1}{\sqrt{10}}$	0.0027	0.83	60	230
$L\oplus Q$	8	$-\frac{2}{3\sqrt{3}}$	0	$\frac{1}{2\sqrt{3}}$	0.57	0.082	740	61	$\frac{1}{3}$	1	$\frac{1}{2}$	2.9	6.1	180	210
$L\oplus S$	8	$\frac{7}{12\sqrt{3}}$	$-\frac{\sqrt{3}}{4}$	$\frac{5}{4\sqrt{3}}$	200	180	74000	–	$\frac{19}{12}$	$\frac{1}{4}$	$\frac{5}{4}$	0.095	0.47	610	290
$U\oplus E$	4	$\frac{5}{3\sqrt{6}}$	0	$-\frac{1}{2\sqrt{6}}$	0.57	0.082	120	110	$\frac{7}{3\sqrt{2}}$	0	$\frac{1}{2\sqrt{2}}$	0.57	0.082	60	260
$U\oplus Q$	9	$-\frac{5}{6}$	$\frac{1}{2}$	0	32	17	0	–	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	0.79	3.0	330	220
$U\oplus V$	6	$-\frac{4}{3\sqrt{3}}$	$\frac{2}{\sqrt{3}}$	$-\frac{1}{2\sqrt{3}}$	83	82	740	–	$\frac{4}{3\sqrt{3}}$	$\frac{2}{\sqrt{3}}$	$\frac{1}{2\sqrt{3}}$	1.5	4.1	29	310
$U\oplus N$	4	$-\frac{2}{3}\sqrt{\frac{2}{3}}$	0	$-\frac{1}{2\sqrt{6}}$	0.57	0.082	180	87	$\frac{2\sqrt{2}}{3}$	0	$\frac{1}{2\sqrt{2}}$	0.57	0.082	180	–
$E\oplus Q$	7	$-\frac{5}{6}\sqrt{\frac{7}{3}}$	$\frac{1}{2}\sqrt{\frac{3}{7}}$	$\frac{1}{\sqrt{21}}$	3.6	0.52	70	150	$\frac{1}{3}\sqrt{\frac{7}{2}}$	$\frac{3}{\sqrt{14}}$	$\sqrt{\frac{2}{7}}$	1.2	3.7	180	–
$E\oplus S$	7	$-\frac{10}{3\sqrt{21}}$	0	$\frac{5}{2\sqrt{21}}$	0.57	0.082	740	120	$\frac{11}{3}\sqrt{\frac{2}{7}}$	0	$5\sqrt{14}$	0.57	0.082	610	310
$S\oplus V$	9	$-\frac{8}{9}$	$\frac{4}{3}$	$-\frac{5}{6}$	83	82	4600	–	$\frac{8\sqrt{2}}{9}$	$\frac{2\sqrt{2}}{3}$	$\frac{5}{3\sqrt{2}}$	0.43	2.4	380	350
$S\oplus N$	7	$-\frac{8}{3\sqrt{21}}$	0	$-\frac{5}{2\sqrt{21}}$	0.57	0.082	1200	93	$\frac{8}{3}\sqrt{\frac{2}{7}}$	0	$\frac{5}{\sqrt{14}}$	0.57	0.082	1200	230
$N\oplus Q$	7	$\frac{1}{6\sqrt{21}}$	$\frac{1}{2}\sqrt{\frac{3}{7}}$	$\frac{1}{\sqrt{21}}$	4.9	8.5	470	58	$\frac{1}{3\sqrt{14}}$	$\frac{3}{\sqrt{14}}$	$\sqrt{\frac{2}{7}}$	4.9	8.5	470	140

Digamma candidates in VC models

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$D \oplus E$	4	$\frac{4}{3}\sqrt{\frac{2}{3}}$	0	$-\frac{1}{2\sqrt{6}}$	0.57	0.082	46	170
$D \oplus T$	6	$\frac{8}{3\sqrt{3}}$	$\frac{2}{\sqrt{3}}$	$-\frac{1}{2\sqrt{3}}$	0.43	2.4	15	430
$U \oplus N$	4	$-\frac{2}{3}\sqrt{\frac{2}{3}}$	0	$-\frac{1}{2\sqrt{6}}$	0.57	0.082	180	87
$E \oplus Q$	7	$-\frac{5}{6}\sqrt{\frac{7}{3}}$	$\frac{1}{2}\sqrt{\frac{3}{7}}$	$\frac{1}{\sqrt{21}}$	3.6	0.52	70	150

the digamma candidate is η,
expected an heavier singlet $\sim$ TeV

- ✗ bounds on extra singlets from digamma searches
- ✗ bounds on colored objects from di-jet searches ($\lesssim$ TeV)

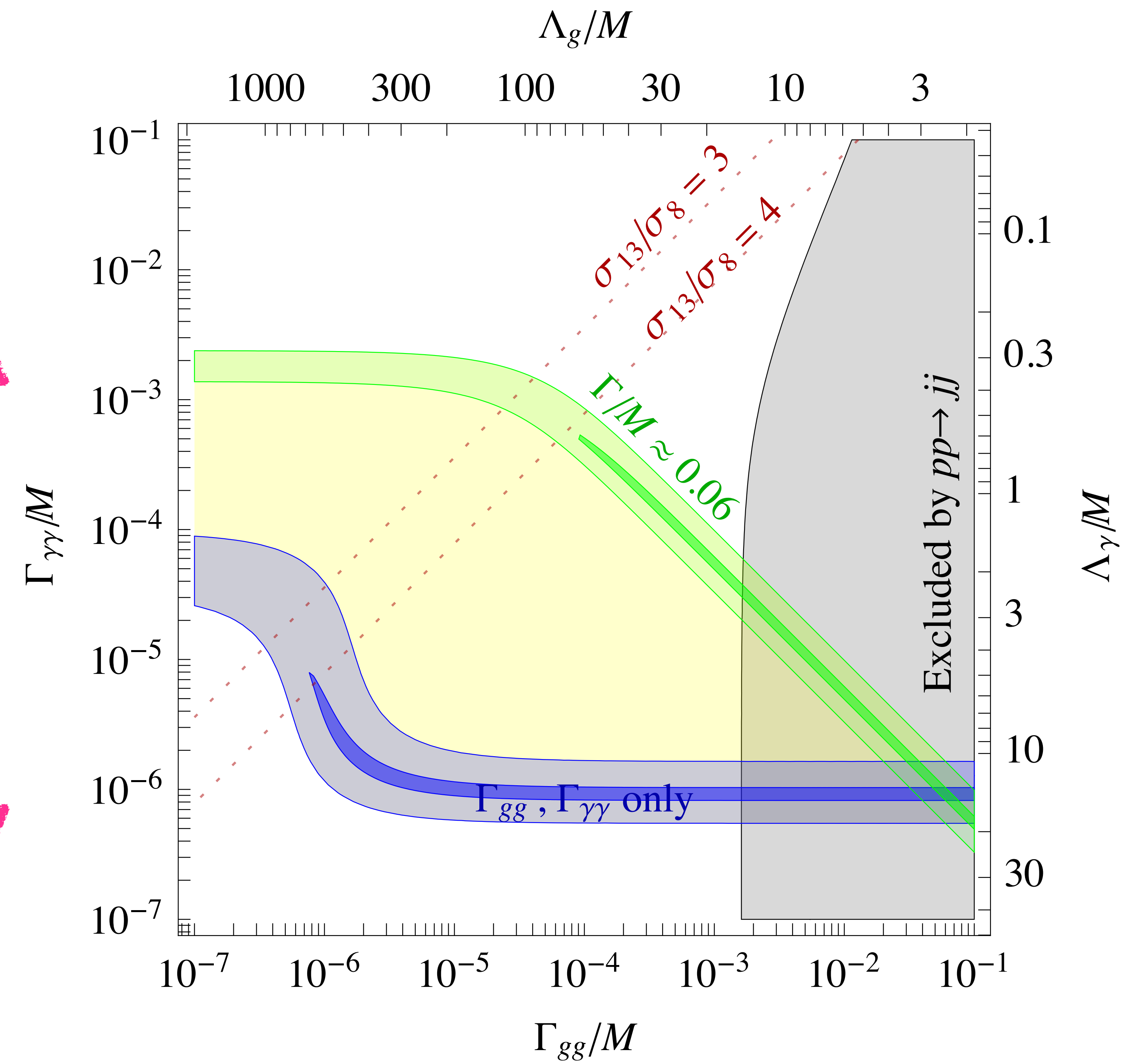
\+ other models where the digamma candidate is η' and a lighter singlet η is expected

− more difficult to threat

Reproducing the signal

another decay channel
maybe DM ?

$\Gamma_F \approx \Gamma_{gg} < 1\text{GeV}$



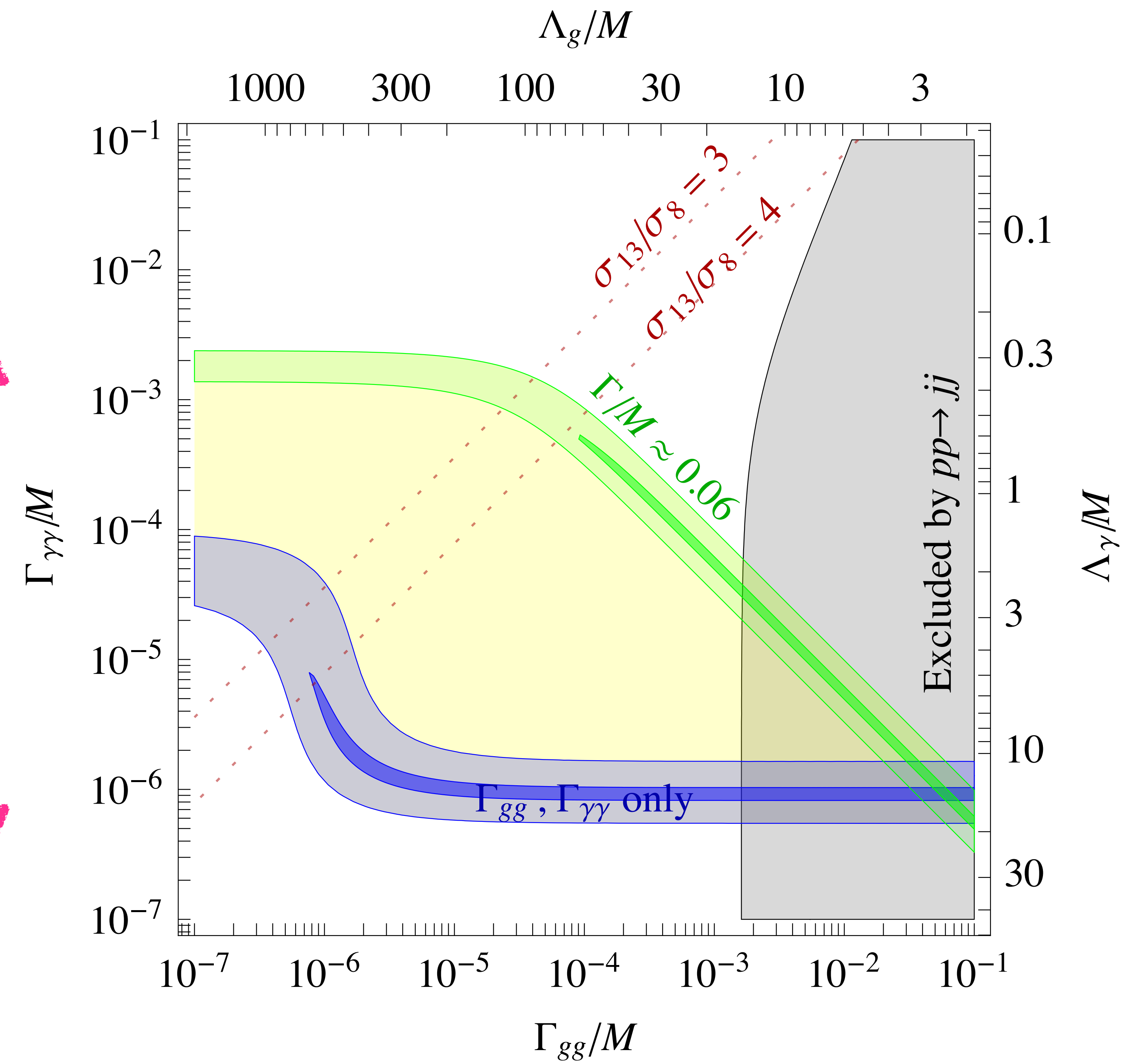
Franceschini et al. (arXiv:1512.04933)

Reproducing the signal

another decay channel
maybe DM ?

both F and DM are techni-pions
C/P decays of digamma into DM induced
by the $\theta_{\rm TC}$ angle of the new strong sector

$$\Gamma_F \approx \Gamma_{gg} < 1\text{GeV}$$



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An explicit model :

DM from species number

$$\mathcal{Q} = N_1 \oplus N_2 \oplus U = (1,1)_0 \oplus (1,1)_0 \oplus (\bar{3},1)_{-2/3}$$

pseudo-scalars with given anomalous couplings to SM gauge bosons, up to mixing effects

$$\eta_1 \sim U\bar{U} - 3/2(N_1\bar{N}_1 + N_2\bar{N}_2)$$

$$\eta_2 \sim N_1\bar{N}_1 - N_2\bar{N}_2$$

$$\eta' \sim U\bar{U} + N_1\bar{N}_1 + N_2\bar{N}_2$$

also heavier colored objects $(m_U > m_{N_1,\,N_2})$

$$m_{\eta'} \sim \Lambda_{\rm TC}$$

digamma resonance →

$$m^2_{\eta_1} \approx 4/5\, B_0 m_U \;\; (B_0 \sim \Lambda_{\rm TC})$$

$$m^2_{\eta_2} \lesssim m^2_{\Pi} = B_0(m_{N_1} + m_{N_2})$$

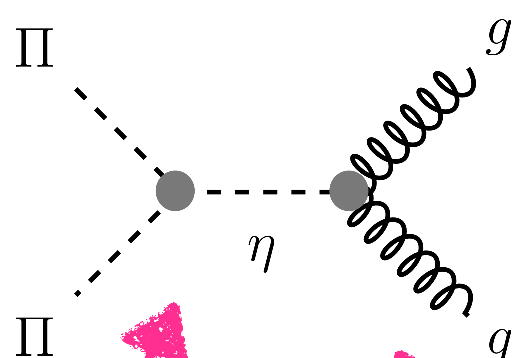
← DM

$$\Gamma_{\eta_1 \to \Pi\Pi^*} \sim \theta^2_{\rm TC}{\rm GeV} \; < \; 45{\rm GeV}$$

DM interactions

$$\mathcal{L}_{\rm DM} = C_{\eta\Pi\Pi}\frac{\eta\,\Pi^2}{2} + \frac{g_3^2}{16\pi^2}C_{\Pi\Pi gg}\frac{\Pi^2}{f^2}G^a_{\mu\nu}G^{a,\mu\nu}$$

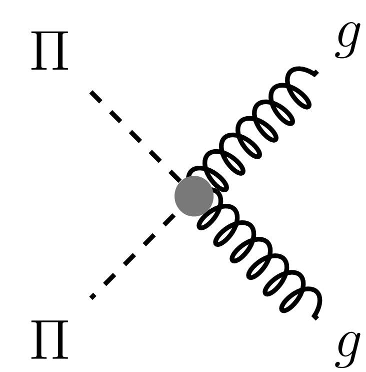
resonant scattering



anomaly coefficient

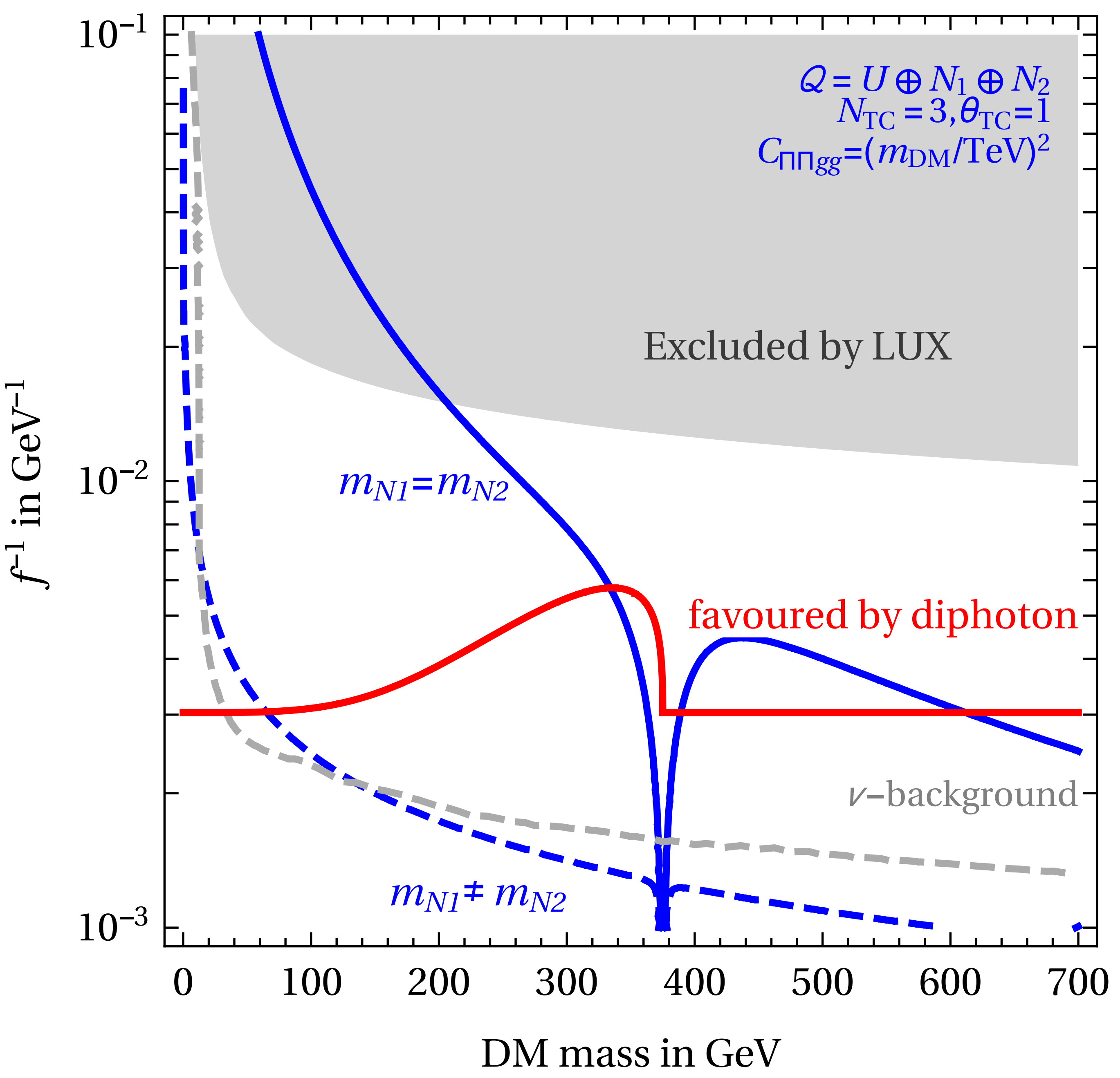
$$C_{\eta\Pi\Pi} \sim \frac{m_\Pi^2}{f}\theta_{\rm TC}$$

Rayleigh interactions

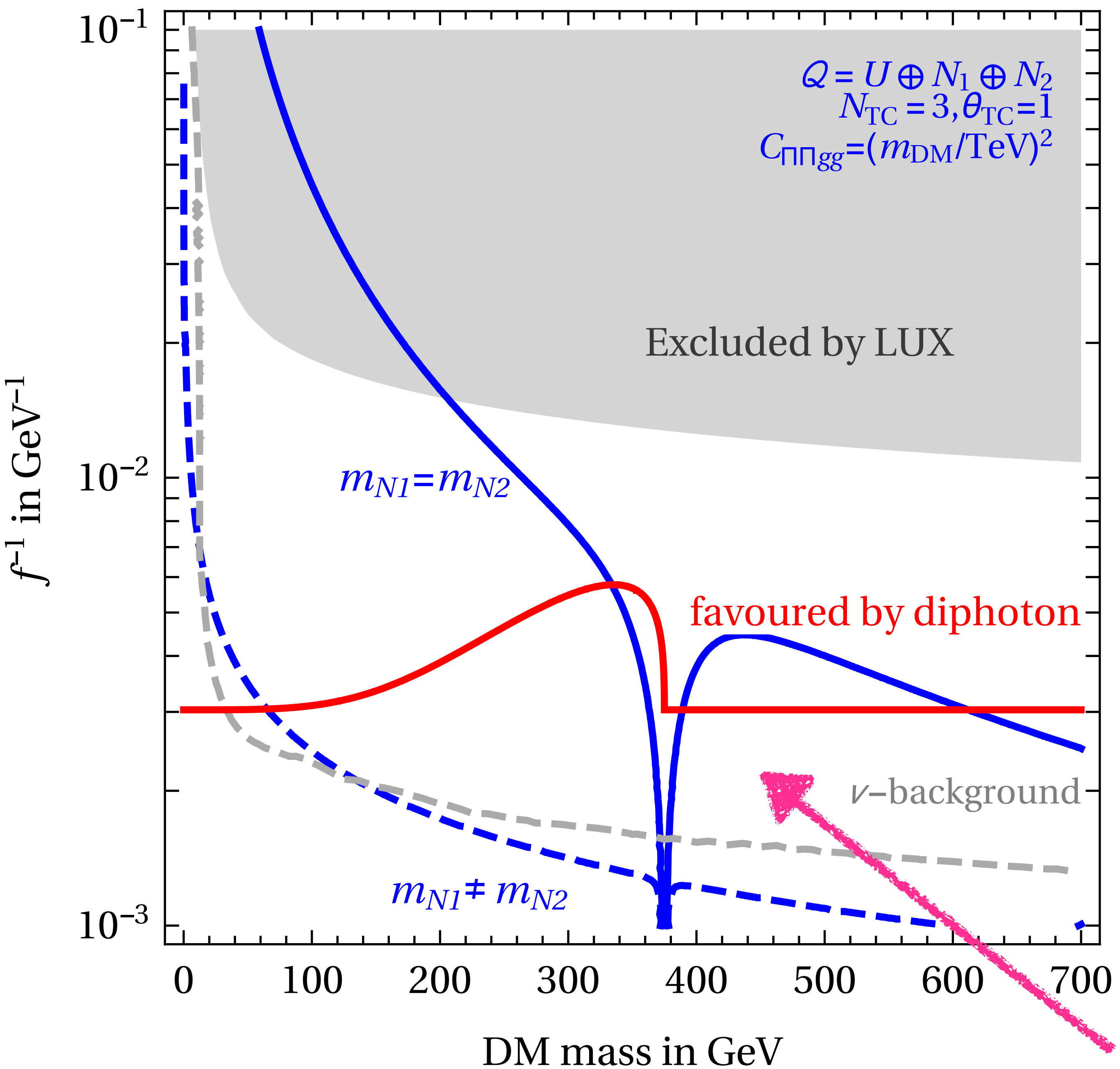


$$C_{\Pi\Pi gg} \sim N_{\rm TC}\frac{m_\Pi^2}{\Lambda_{\rm TC}^2}$$

if allowed, also techni-pion/techni-pion scattering can be important



$Q = U \oplus N_1 \oplus N_2$
$N_{TC} = 3, \theta_{TC} = 1$
$C_{\Pi\Pi gg} = (m_{DM}/\text{TeV})^2$
Excluded by LUX
$m_{N1} = m_{N2}$
favoured by diphoton
ν–background
$m_{N1} \neq m_{N2}$
f^{-1} in GeV^{-1}
DM mass in GeV
10^{-1}
10^{-2}
10^{-3}
0
100
200
300
400
500
600
700

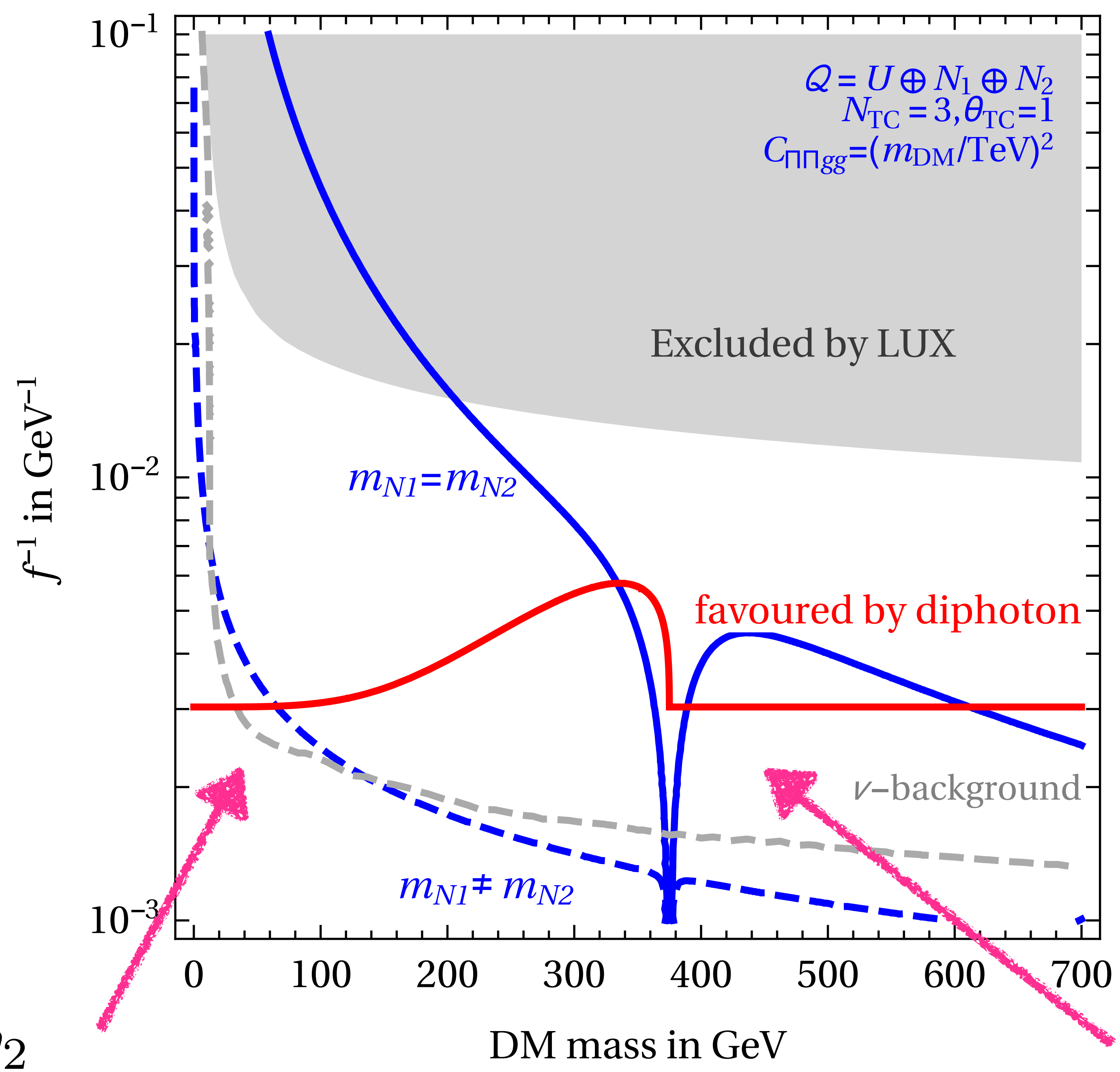


$m_{\eta_2} = m_\Pi$ and

$\eta_2,\ \Pi,\ \Pi^*$ becomes a triplet of DM candidates

$\Pi\Pi^* \to \eta_1 \to gg$

dominates, relic abundance reproduced for $m_\Pi \approx 750\,\mathrm{GeV}/2$



$m_{\eta_2} = m_\Pi$ and

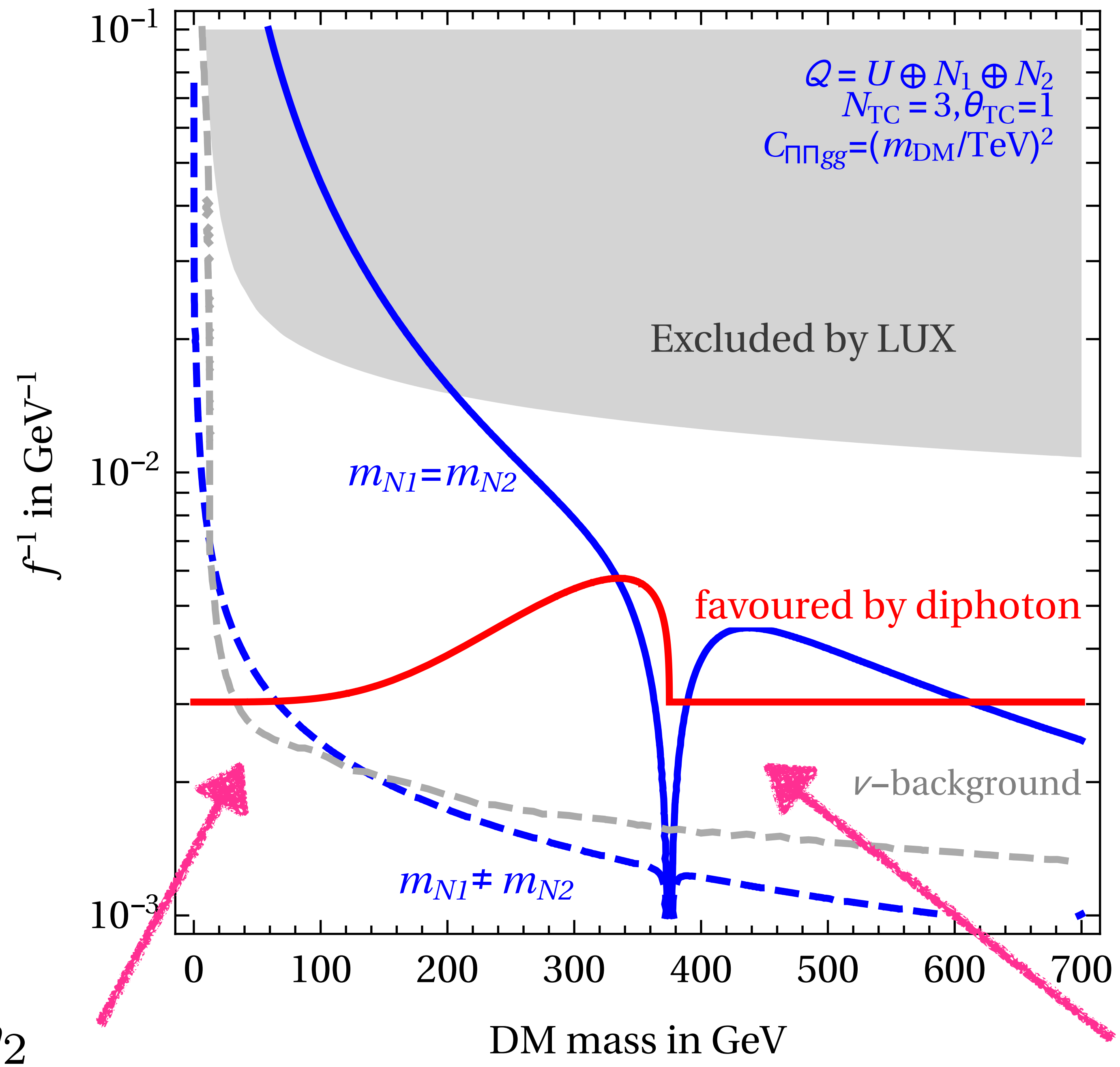
η_2, Π, Π^* becomes a triplet of DM candidates

$\Pi\Pi^* \to \eta_2\eta_2$

dominates, relic abundance reproduced for $m_\Pi < 100\,\text{GeV}$

$\Pi\Pi^* \to \eta_1 \to gg$

dominates, relic abundance reproduced for $m_\Pi \approx 750\,\text{GeV}/2$



look for extra resonances!

$m_{\eta_2} = m_\Pi$ and $\eta_2,\ \Pi,\ \Pi^*$ becomes a triplet of DM candidates

$\Pi\Pi^* \to \eta_2\eta_2$ dominates, relic abundance reproduced for $m_\Pi < 100\,\mathrm{GeV}$

$\Pi\Pi^* \to \eta_1 \to gg$ dominates, relic abundance reproduced for $m_\Pi \approx 750\,\mathrm{GeV}/2$

Conclusions

- Vectorlike Confinement as interesting scenario for BSM physics
- Dark Matter can be a composite techni-baryon
- Techni-pions as Dark Matter and digamma candidates :
  both digamma signal and relic abundance are reproduced, small width

If the digamma excess will survive, it would be the first BSM discovery at LHC!

VC would be one of the simplest and most predictive scenarios,
with more data we would be able to get the right model !

Conclusions

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If the digamma excess will survive, it would be the first BSM discovery at LHC!

VC would be one of the simplest and most predictive sc
with more data we would be able to get the right model

be patient!

Backup

Techni-baryons as DM candidates

SU(5)	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	name	$\Delta b_3/N_{TC}$	$\Delta b_2/N_{TC}$	$\Delta b_Y/N_{TC}$
1	1	1	0	N	0	0	0
$\bar{5}$	$\bar{3}$	1	1/3	D	1/3	0	2/9
	1	2	−1/2	L	0	1/3	1/3
10	$\bar{3}$	1	−2/3	U	1/3	0	8/9
	1	1	1	E	0	0	2/3
	3	2	1/6	Q	2/3	1	1/9
15	3	2	1/6	Q	2/3	1	1/9
	1	3	1	T	0	4/3	2
	6	1	−2/3	S	5/3	0	8/9
24	1	3	0	V	0	4/3	0
	8	1	0	G	2	0	0
	$\bar{3}$	2	5/6	X	2/3	1	25/9
	1	1	0	N	0	0	0

Backup

Techni-baryons as DM candidates

SU(5)	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	name	$\Delta b_3/N_{\rm TC}$	$\Delta b_2/N_{\rm TC}$	$\Delta b_Y/N_{\rm TC}$
1	1	1	0	N	0	0	0
$\bar{5}$	$\bar{3}$	1	1/3	D	1/3	0	2/9
	1	2	−1/2	L	0	1/3	1/3
10	$\bar{3}$	1	−2/3	U	1/3	0	8/9
	1	1	1	E	0	0	2/3
	3						
15	3						
	1						
	6						
24	1						
	8						
	$\bar{3}$						
	1						

$\mathrm{SU}(N_{\rm TC})$ techni-color Techni-quarks	Yukawa couplings	Allowed $N_{\rm TC}$	Techni-pions	Techni-baryons	under
$N_{\rm TF}=3$			8	$8, \bar{6}, \ldots$ for $N_{\rm TC}=3,4,\ldots$	$\mathrm{SU}(3)_{\rm TF}$
$\mathcal{Q}=V$	0	3	3	$VVV=3$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=N\oplus L$	1	$3-14$	unstable	$(N^{N_{\rm TC}})^*=1$	=
$N_{\rm TF}=4$			15	$\overline{20}, 20', \ldots$	$\mathrm{SU}(4)_{\rm TF}$
$\mathcal{Q}=V\oplus N$	0	3	3×3	$VVV, VNN=3,\ VVN=1$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=N\oplus L\oplus\tilde{E}$	2	3, 4, 5	unstable	$(N^{N_{\rm TC}})^*=1$	=
$N_{\rm TF}=5$			24	$\overline{40}, \overline{50}$	$\mathrm{SU}(5)_{\rm TF}$
$\mathcal{Q}=V\oplus L$	1	3	unstable	$VVV=3$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=N\oplus L\oplus\tilde{L}$	2	3	unstable	$NL\tilde{L}=1$	=
=	2	4	unstable	$NNL\tilde{L}, L\tilde{L}L\tilde{L}=1$	=
$N_{\rm TF}=6$			35	$70, \overline{105'}$	$\mathrm{SU}(6)_{\rm TF}$
$\mathcal{Q}=V\oplus L\oplus N$	2	3	unstable	$VVV, VNN=3, VVN=1$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=V\oplus L\oplus\tilde{E}$	2	3	unstable	$VVV=3$	=
$\mathcal{Q}=N\oplus L\oplus\tilde{L}\oplus\tilde{E}$	3	3	unstable	$NL\tilde{L}, \tilde{L}\tilde{L}\tilde{E}=1$	=
=	3	4	unstable	$NNL\tilde{L}, L\tilde{L}L\tilde{L}, N\tilde{E}\tilde{L}\tilde{L}=1$	=
$N_{\rm TF}=7$			48	112	$\mathrm{SU}(7)_{\rm TF}$
$\mathcal{Q}=L\oplus\tilde{L}\oplus E\oplus\tilde{E}\oplus N$	4	3	unstable	$LLE, \tilde{L}\tilde{L}\tilde{E}, L\tilde{L}N, E\tilde{E}N=1$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=N\oplus L\oplus\tilde{E}\oplus V$	3	3	unstable	$VVV, VNN=3,\ VVN=1$	=
$N_{\rm TF}=9$			80	240	$\mathrm{SU}(9)_{\rm TF}$
$\mathcal{Q}=Q\oplus\tilde{D}$	1	3	unstable	$QQ\tilde{D}=1$	$\mathrm{SU}(2)_L$
$N_{\rm TF}=12$			143	572	$\mathrm{SU}(12)_{\rm TF}$
$\mathcal{Q}=Q\oplus\tilde{D}\oplus\tilde{U}$	2	3	unstable	$QQ\tilde{D}, \tilde{D}\tilde{D}\tilde{U}=1$	$\mathrm{SU}(2)_L$

Backup

Techni-baryons as DM candidates

SU(5)	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	name	$\Delta b_3/N_{\rm TC}$	$\Delta b_2/N_{\rm TC}$	$\Delta b_Y/N_{\rm TC}$
1	1	1	0	N	0	0	0
$\bar{5}$	$\bar{3}$	1	1/3	D	1/3	0	2/9
	1	2	$-1/2$	L	0	1/3	1/3
10	$\bar{3}$	1	$-2/3$	U	1/3	0	8/9
	1	1	1	E	0	0	2/3
	3						
15	3						
	1						
	6						
24	1						
	8						
	$\bar{3}$						
	1						

$\mathrm{SU}(N_{\rm TC})$ techni-color Techni-quarks	Yukawa couplings	Allowed $N_{\rm TC}$	Techni-pions	Techni-baryons	under
$N_{\rm TF}=3$			8	$8, \bar{6}, \dots$ for $N_{\rm TC}=3,4,\dots$	$\mathrm{SU}(3)_{\rm TF}$
$\mathcal{Q}=V$	0	3	3	$VVV=3$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=N\oplus L$	1	$3-14$	unstable	$(N^{N_{\rm TC}})^*=1$	=
$N_{\rm TF}=4$			15	$\overline{20}, 20', \dots$	$\mathrm{SU}(4)_{\rm TF}$
$\mathcal{Q}=V\oplus N$	0	3	3×3	$VVV, VNN=3,\ VVN=1$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=N\oplus L\oplus \tilde{E}$	2	3, 4, 5	unstable	$(N^{N_{\rm TC}})^*=1$	=
$N_{\rm TF}=5$			24	$\overline{40}, \overline{50}$	$\mathrm{SU}(5)_{\rm TF}$
$\mathcal{Q}=V\oplus L$	1	3	unstable	$VVV=3$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=N\oplus L\oplus \tilde{L}$	2	3	unstable	$NL\tilde{L}=1$	=
=	2	4	unstable	$NNL\tilde{L}, L\tilde{L}L\tilde{L}=1$	=
$N_{\rm TF}=6$			35	$70, \overline{105'}$	$\mathrm{SU}(6)_{\rm TF}$
$\mathcal{Q}=V\oplus L\oplus N$	2	3	unstable	$VVV, VNN=3, VVN=1$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=V\oplus L\oplus \tilde{E}$	2	3	unstable	$VVV=3$	=
$\mathcal{Q}=N\oplus L\oplus \tilde{L}\oplus \tilde{E}$	3	3	unstable	$NL\tilde{L}, \tilde{L}\tilde{L}\tilde{E}=1$	=
=	3	4	unstable	$NNL\tilde{L}, L\tilde{L}L\tilde{L}, N\tilde{E}\tilde{L}\tilde{L}=1$	=
$N_{\rm TF}=7$			48	112	$\mathrm{SU}(7)_{\rm TF}$
$\mathcal{Q}=L\oplus \tilde{L}\oplus E\oplus \tilde{E}\oplus N$	4	3	unstable	$LLE, \tilde{L}\tilde{L}\tilde{E}, L\tilde{L}N, E\tilde{E}N=1$	$\mathrm{SU}(2)_L$
$\mathcal{Q}=N\oplus L\oplus \tilde{E}\oplus V$	3	3	unstable	$VVV, VNN=3,\ VVN=1$	=
$N_{\rm TF}=9$			80	240	$\mathrm{SU}(9)_{\rm TF}$
$\mathcal{Q}=Q\oplus \tilde{D}$	1	3	unstable	$QQ\tilde{D}=1$	$\mathrm{SU}(2)_L$
$N_{\rm TF}=12$			143	572	$\mathrm{SU}(12)_{\rm TF}$
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$$M_{\rm DM}\sim 100\ \mathrm{TeV}$$

if DM as a thermal relic

Backup

DM phenomenology

DM as a thermal relic : non relativistic annihilation of techni-baryons to techni-pions via techni-strong interactions

$$\sigma_{p\bar{p}}^{\rm ann}\, v \sim 100/m_p^2 \quad \rightarrow \quad M_{\rm DM} \sim 100\,{\rm TeV}$$

too high for minimal direct detection interactions!

but fermionic DM, even if a SM singlet, can have typical interactions with photons

↓

Magnetic and Electric Dipole Moments $\frac{1}{2}\bar{\Psi}\gamma_{\mu\nu}(\mu_M + i d_E \gamma_5)\Psi F^{\mu\nu}$

Backup

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Magnetic and Electric Dipole Moments $\quad \frac{1}{2}\bar{\Psi}\gamma_{\mu\nu}(\mu_M + i d_E \gamma_5)\Psi F^{\mu\nu}$

$\not{C}\not{P}$

$$\mathcal{L} = \mathcal{L}_{\text{SM}} - \frac{1}{4g_{\text{TC}}^2}\mathcal{G}^A_{\mu\nu}\mathcal{G}^{\mu\nu}_A + \frac{\theta_{\text{TC}}}{32\pi^2}\mathcal{G}^A_{\mu\nu}\tilde{\mathcal{G}}^{\mu\nu}_A + \bar{\mathcal{Q}}_i(i\not{D} - m_i)\mathcal{Q}_i + \left[H\bar{\mathcal{Q}}_i(y^L_{ij}P_L + y^R_{ij}P_R)\mathcal{Q}_j + \text{h.c.}\right]$$

Backup

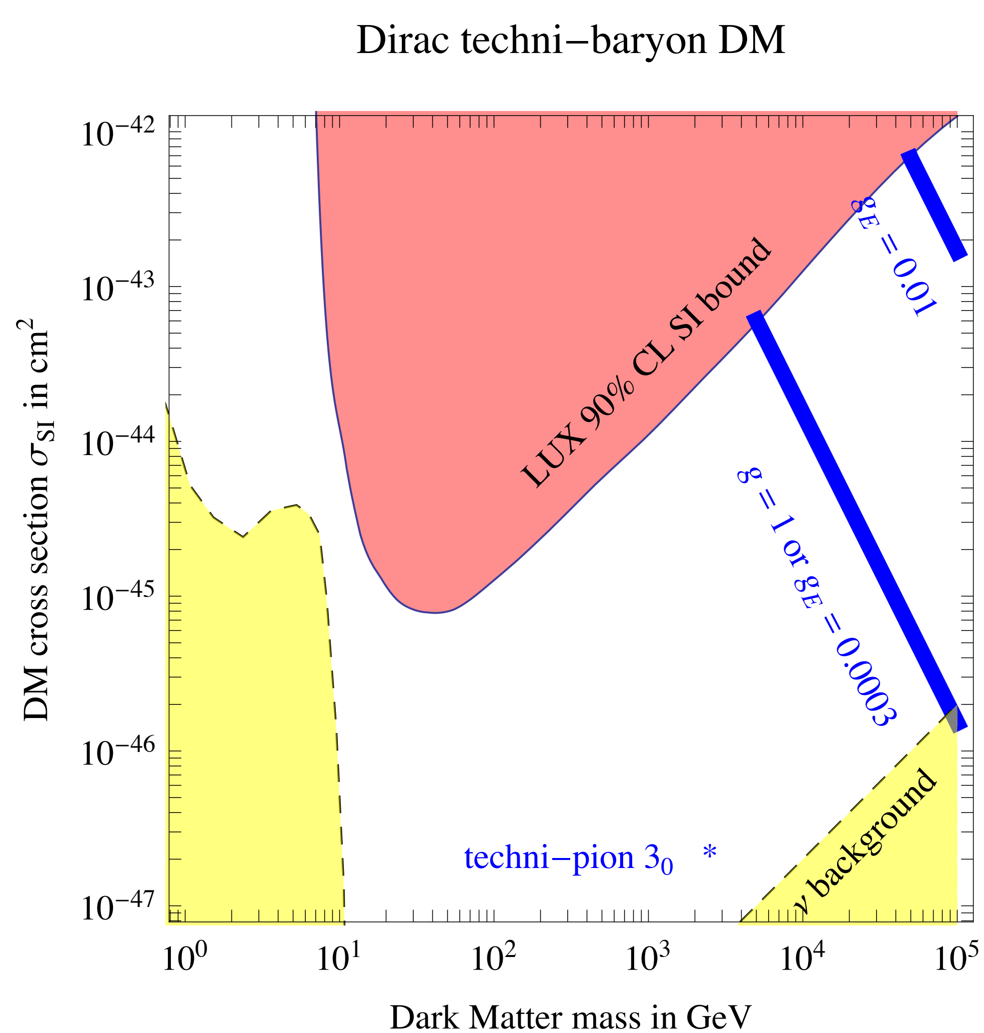
DM phenomenology

$$\frac{1}{2}\bar{\Psi}\gamma_{\mu\nu}(\mu_M + i d_E \gamma_5)\Psi F^{\mu\nu}$$

$$\sim \frac{e}{2M_{\rm DM}} \qquad \sim \theta_{\rm TC}\,\frac{e}{2M_{\rm DM}}\,\frac{\min[m_{\mathcal{Q}}]}{M_{\rm DM}}$$

direct detection :

$$\frac{d\sigma}{dE_R} \approx \frac{e^2 Z^2}{4\pi E_R v^2}\left(\mu_M^2 v^2 + d_E^2\right)$$

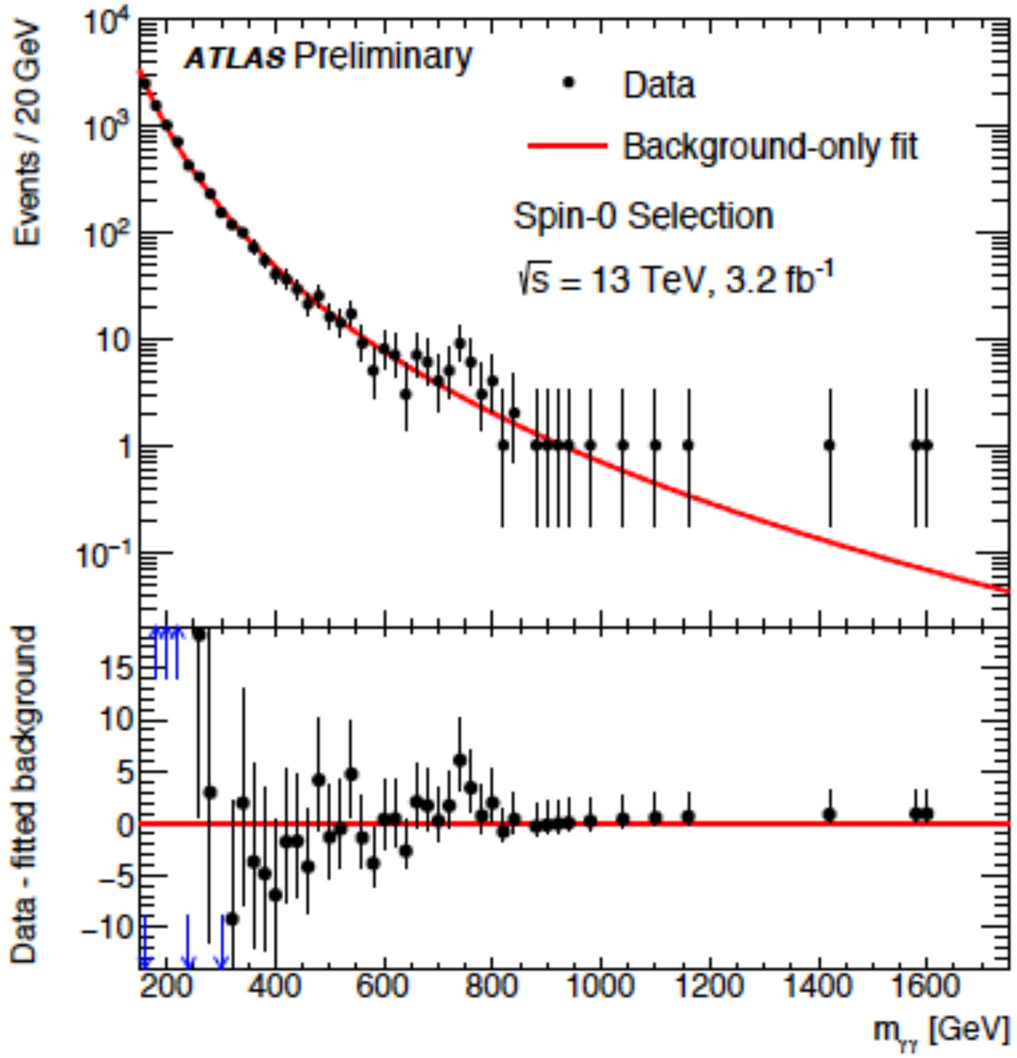


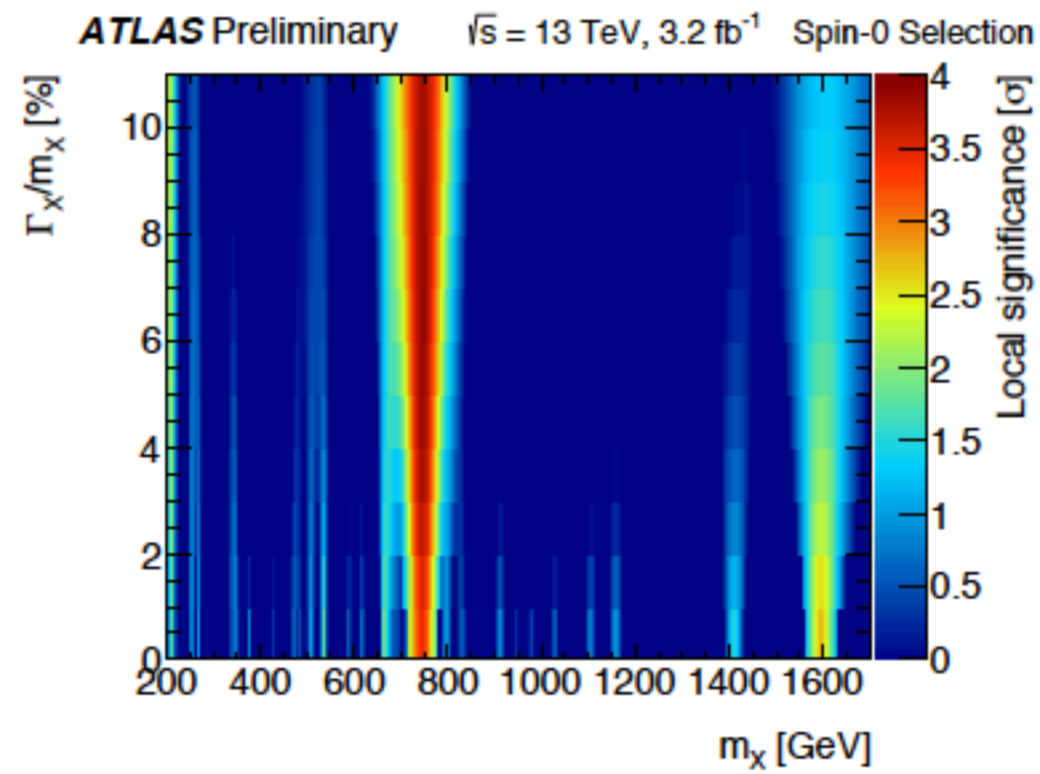
Backup

Di-photon excess

SPIN-0 ANALYSIS

background-only fit





- Largest deviation from B-only hypothesis
  - ✓ m_X ~ 750 GeV, Γ_X ~ 45 GeV (6%)
  - ✓ Local Z = **3.9 σ**
  - ✓ Global Z = **2.0 σ**

from Moriond 2016 Conference

Backup

Di-photon excess

SPIN-0 ANALYSIS

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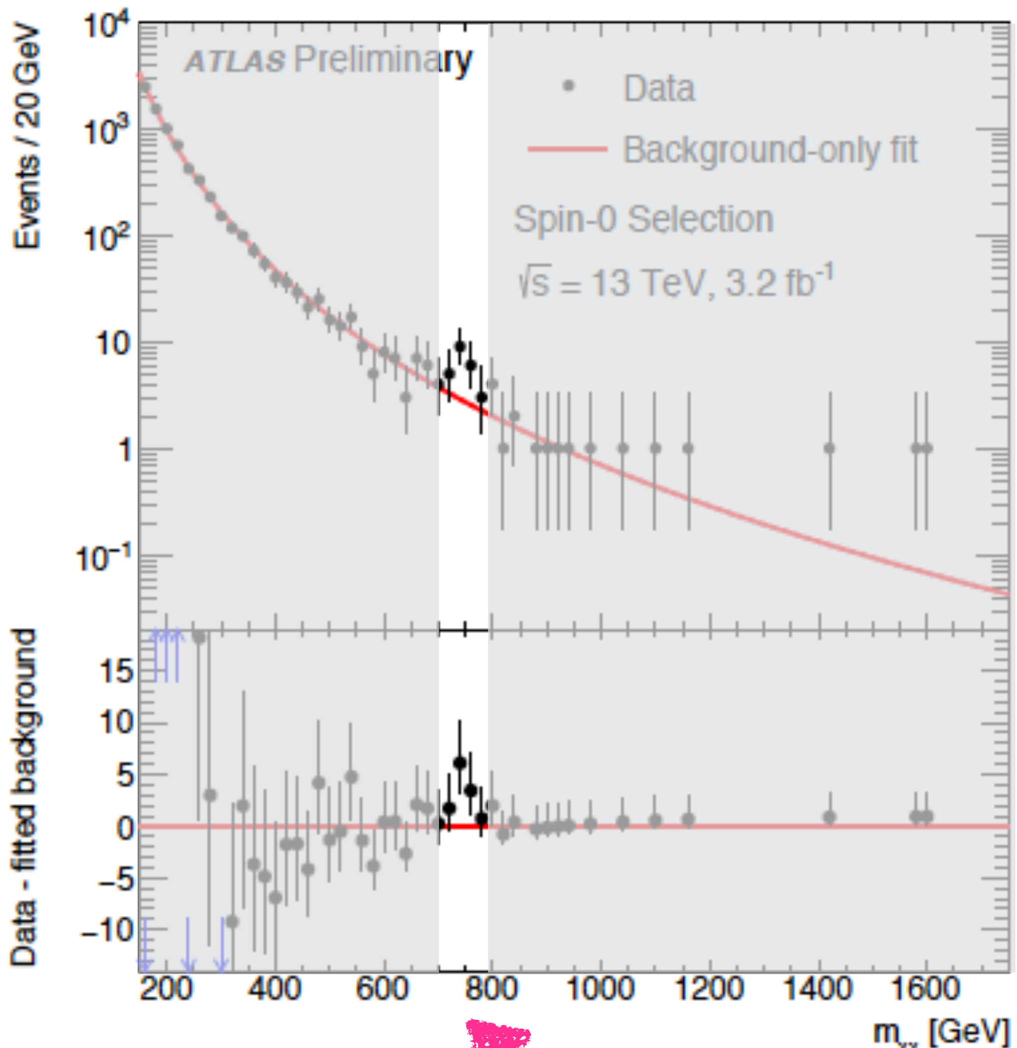
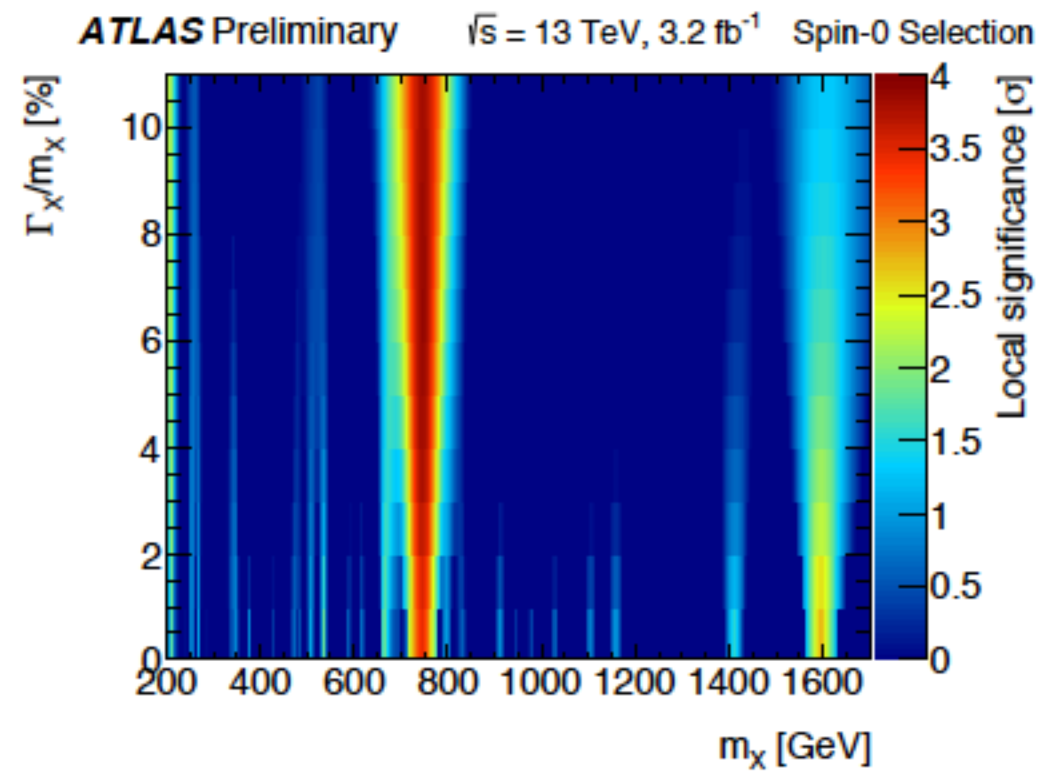


750 GeV



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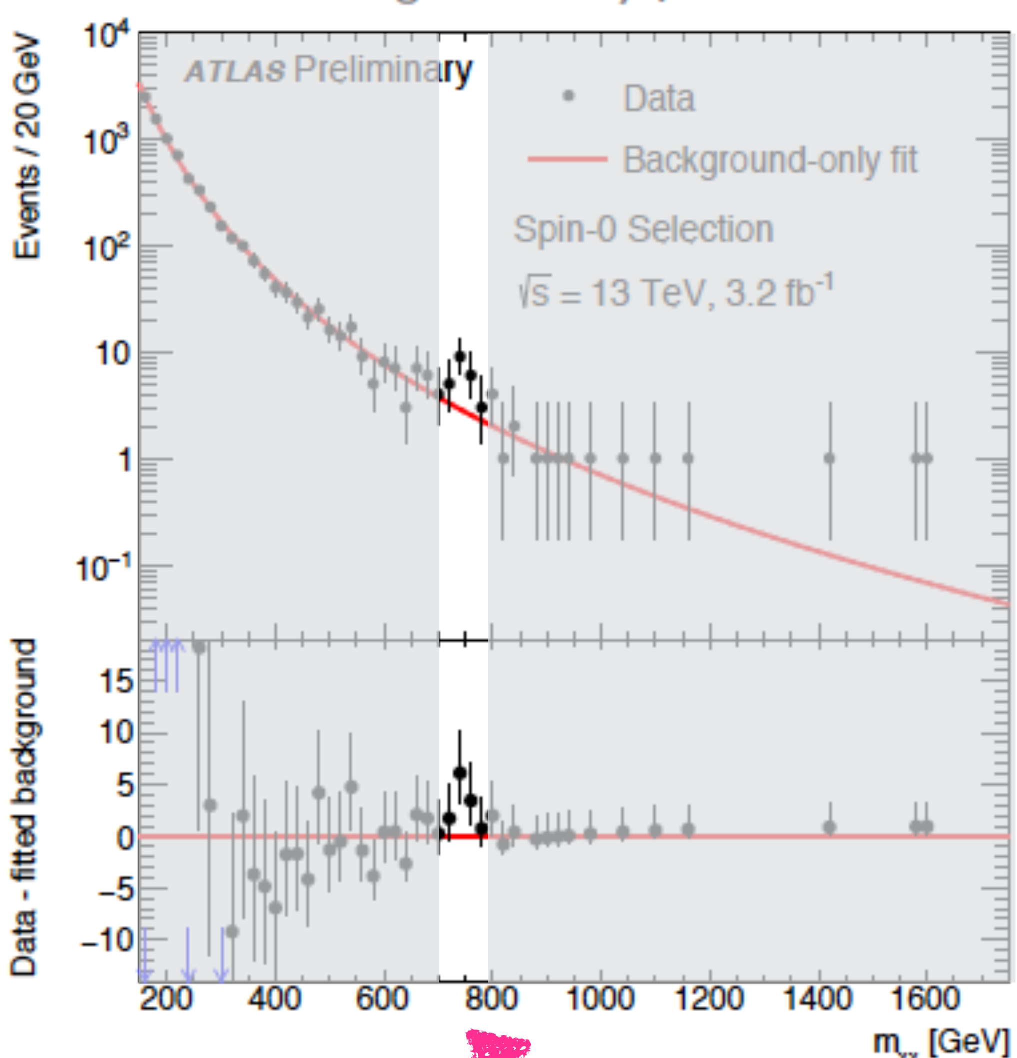
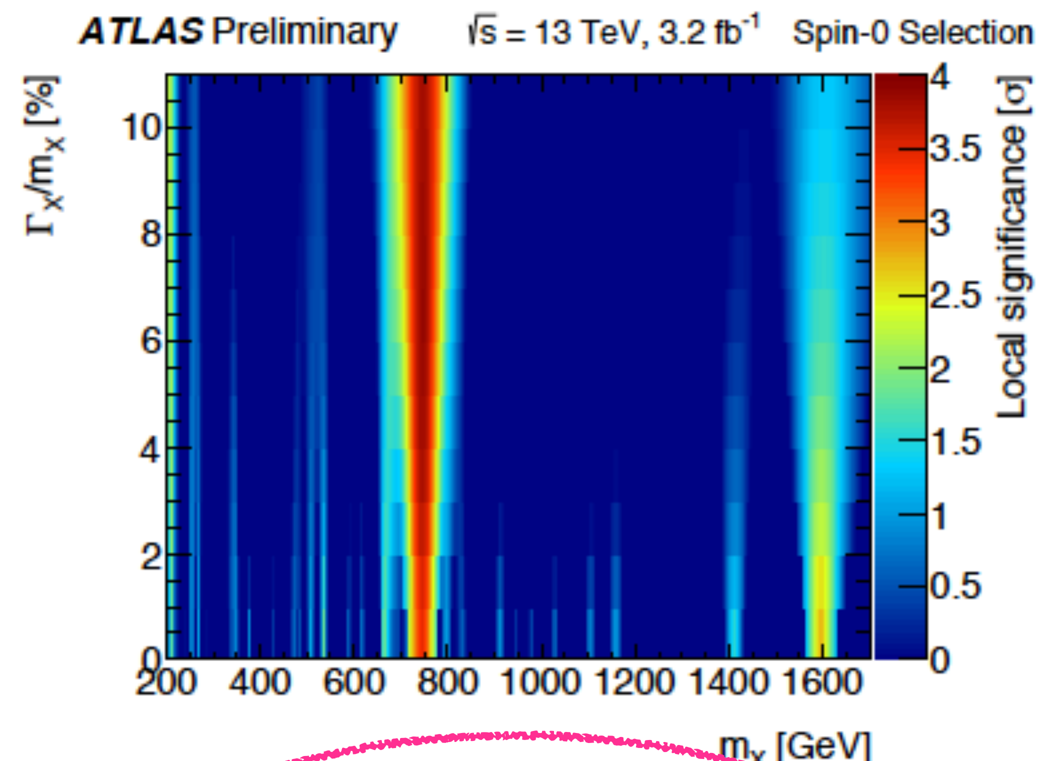


750 GeV



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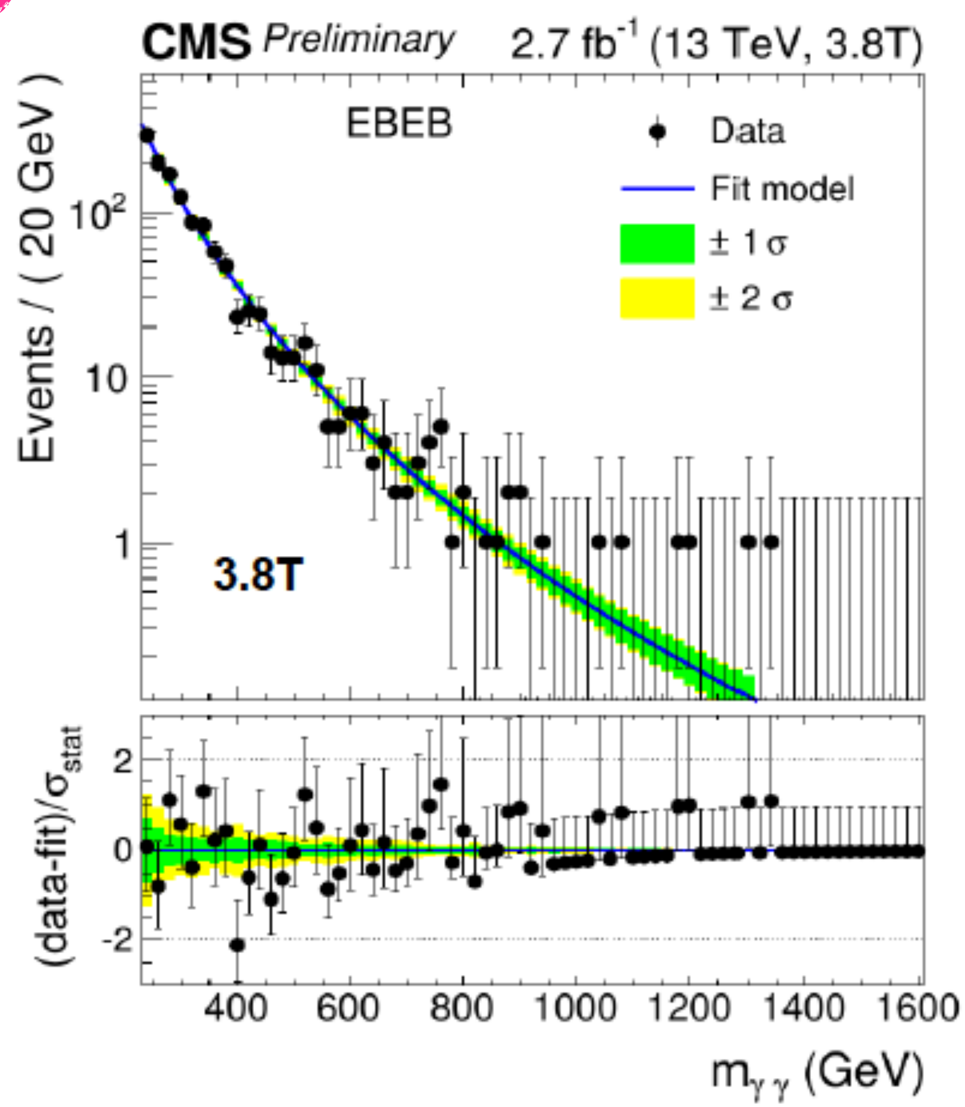
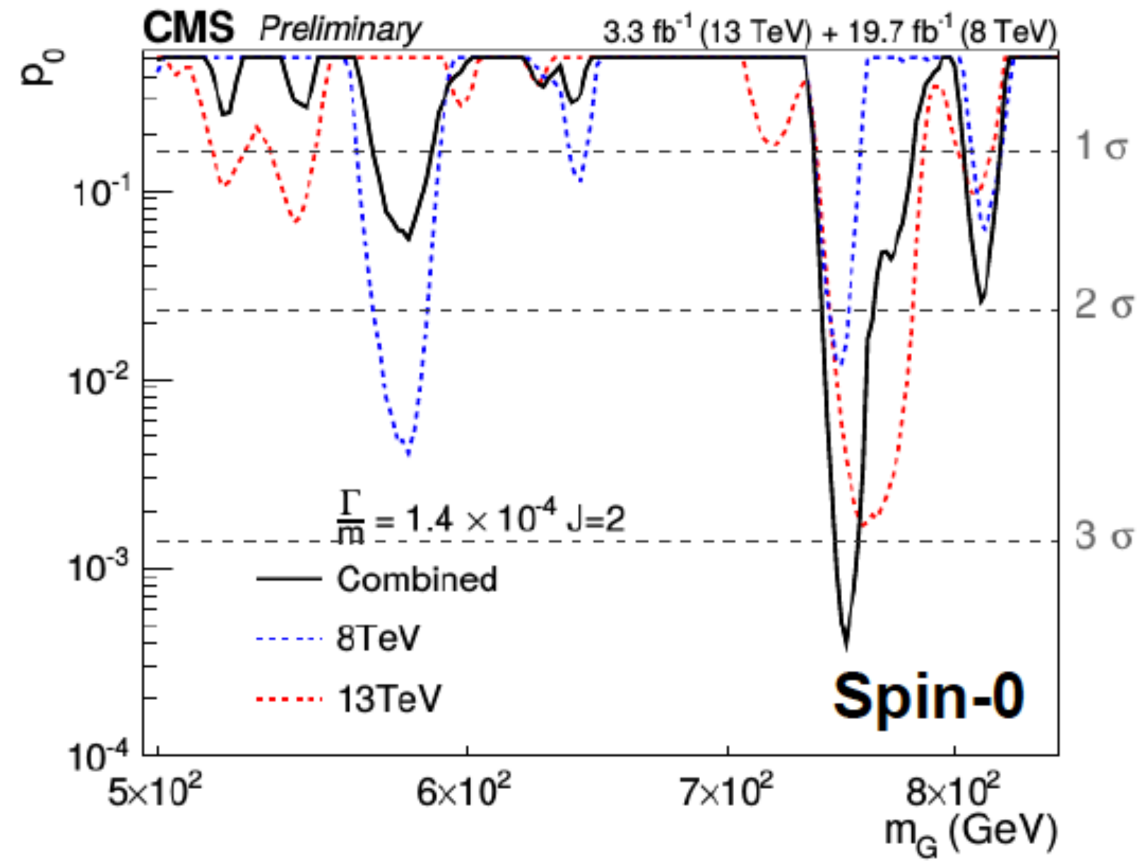
from Moriond 2016 Conference

Di-photon excess





- Largest excess observed at $\mathbf{m_x = 750GeV}$ and for **narrow** width.
  - **Local** significance: **3.4σ**
  - Taking into account mass range 500-3500GeV (and all signal hypotheses), "**global**" significance becomes **1.6σ**

from Moriond 2016 Conference

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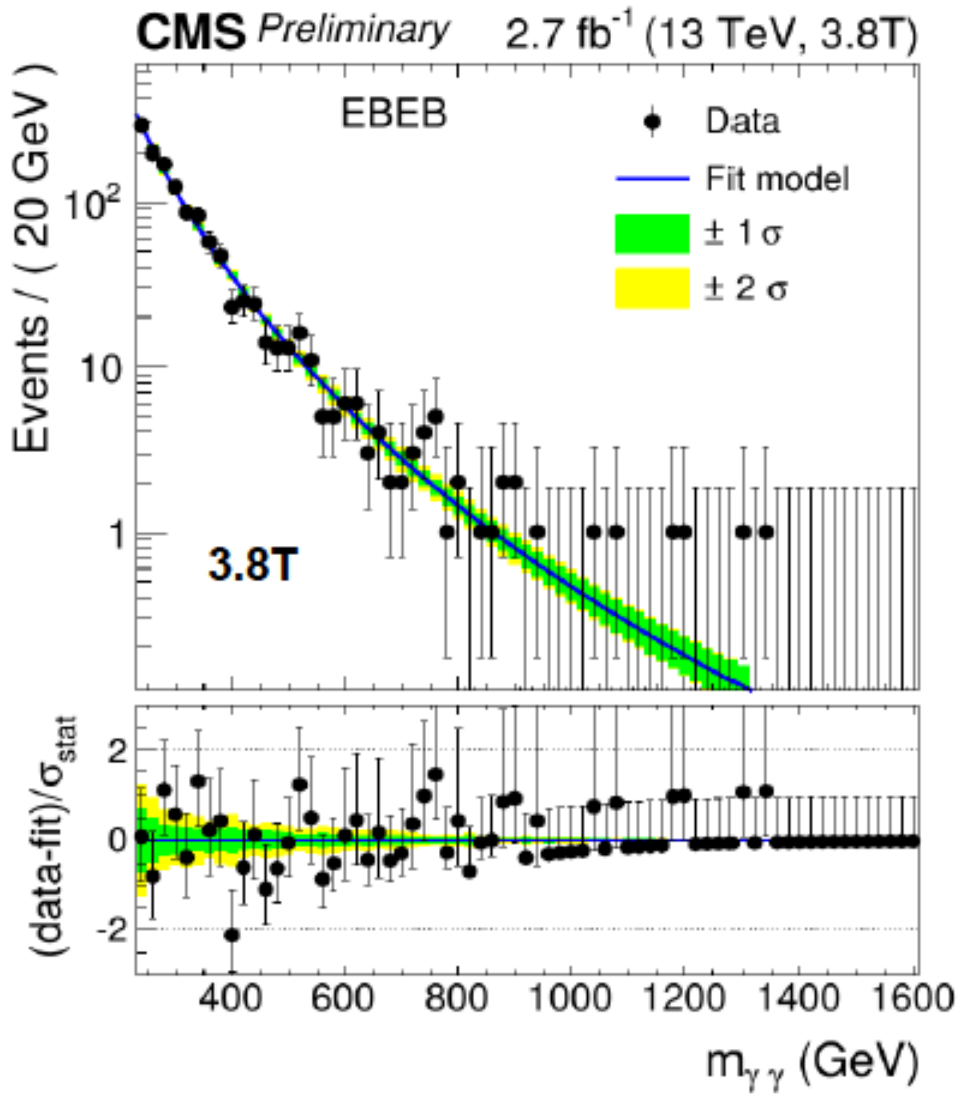
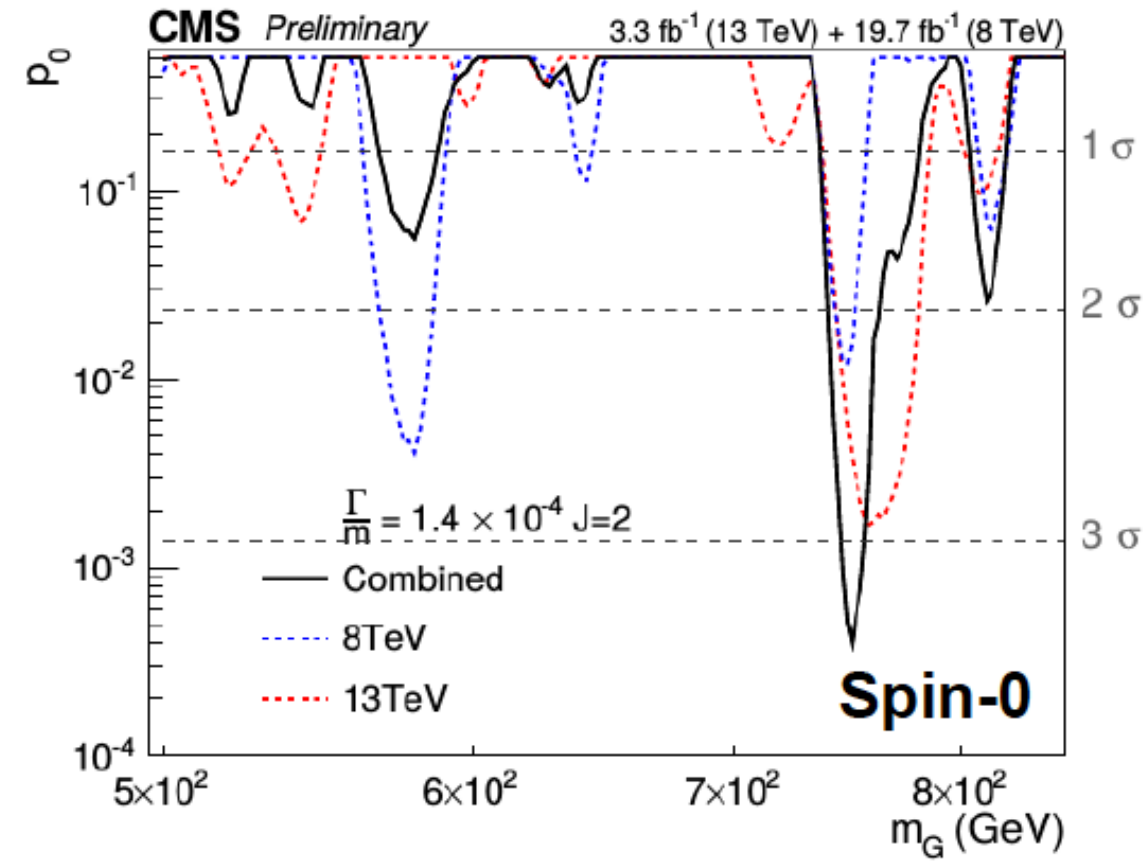
Di-photon excess





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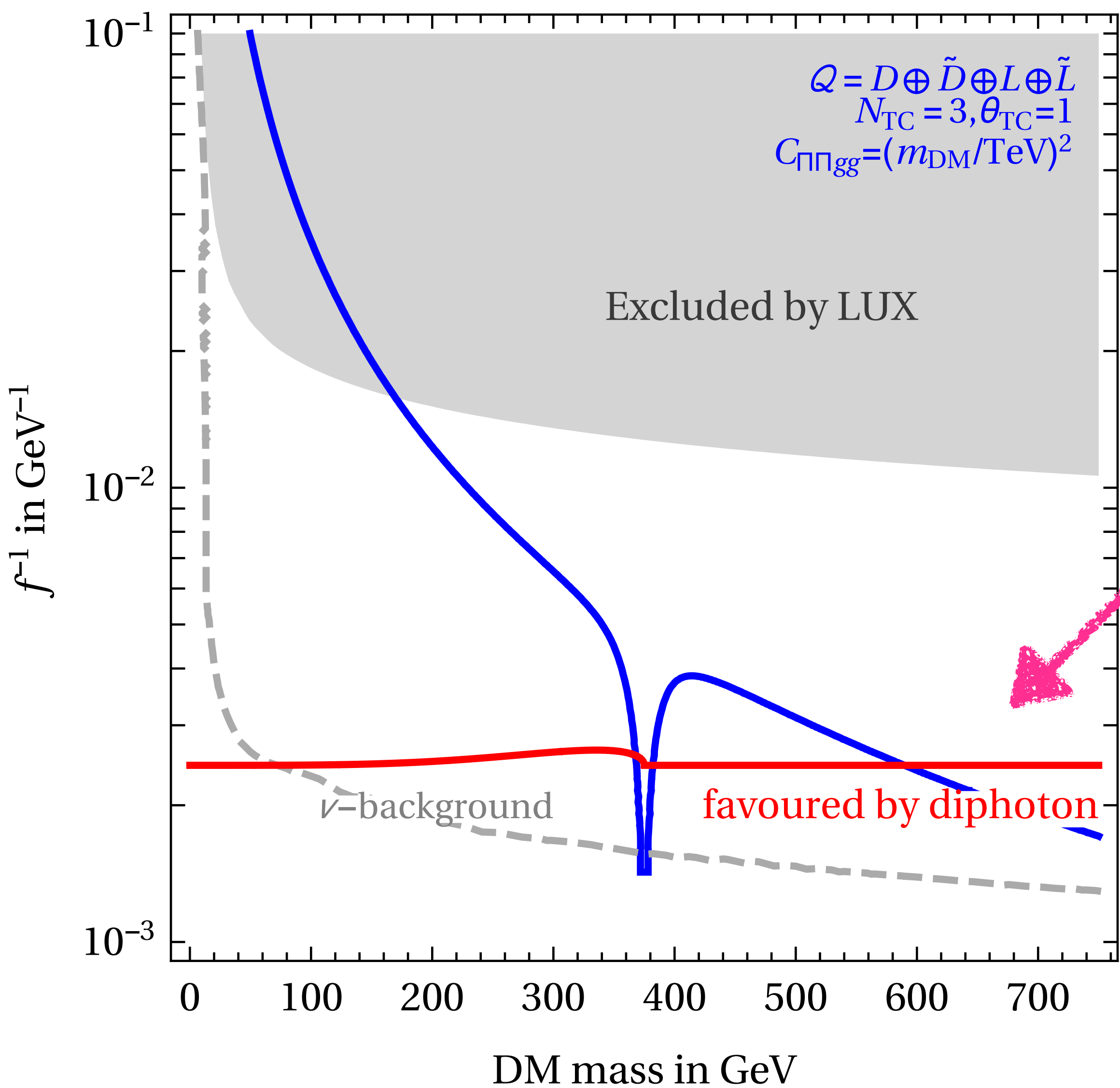
from Moriond 2016 Conference

Bai, Berger, Lu (arXiv:1512.05779)

$$\mathcal{Q} = D \oplus \tilde{D} \oplus L \oplus \tilde{L} = (\bar{3},1)_{1/3} \oplus (3,1)_{-1/3} \oplus (1,2)_{-1/2} \oplus (1,2)_{1/2}$$

$m_D = m_{\tilde{D}}\,,\ m_L = m_{\tilde{L}}$ → DM from a generalized G-parity

$$D \leftrightarrow \tilde{D} \quad L \leftrightarrow \tilde{L}$$



$1^-_A 1^-_A \to \eta \to gg$

dominates, relic abundance reproduced near the resonant region

narrow width,

look for extra resonances

Backup