heavy quark pair production for 750GeV diphoton resonance

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based on the work with
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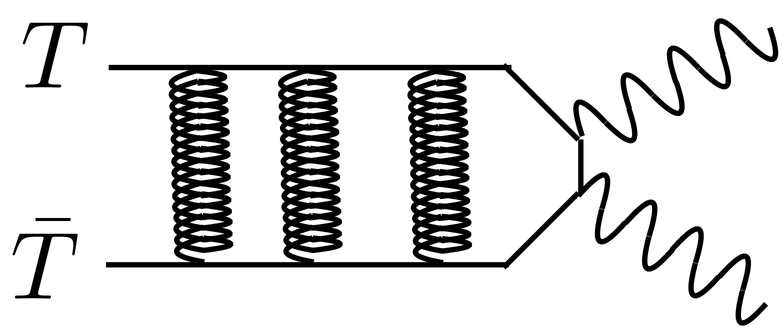
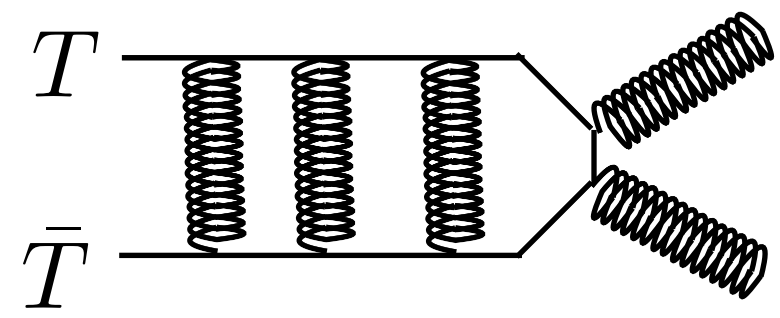
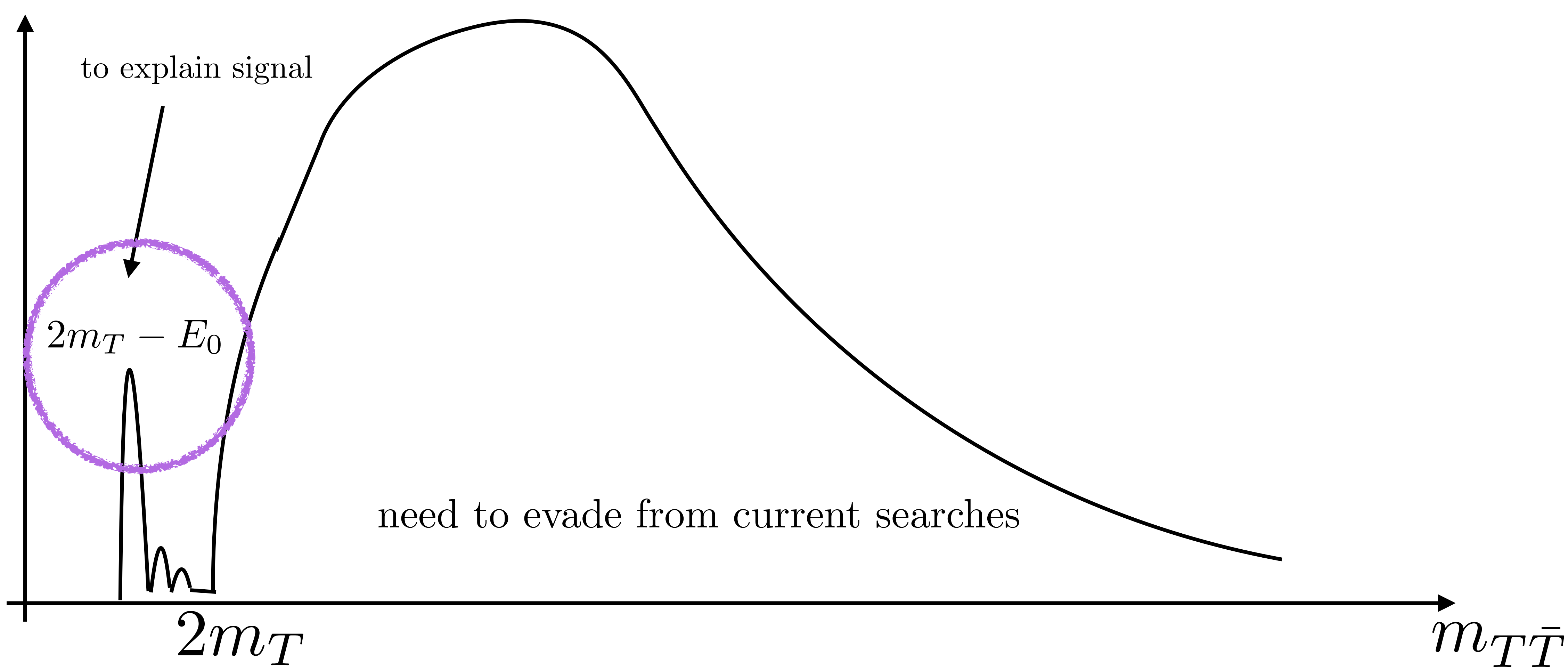
Shigeki Matumoto Michihisa Takeuchi
(1602.08100. Published in JHEP)

Another possibility: bound state of heavy fermion

$1S(J^{PC} = 0^{-+})$ $at\ 750GeV$ $\quad m_T :\ 375 \sim 380GeV$







heavy scalar/fermion bound state as the origin of diphoton excess

- If the life time of **a heavy colored particle X** is longer than time scale forming XX bound state, there are a channel

- pp →X Xbar → S → gg, $\gamma\,\gamma$, ZZ

we take X SU(2) singlet

PDF

$$\sigma(pp \to S_0 \to \gamma\gamma) = \frac{K}{s\,m_{S_0}} \frac{\Gamma_{\gamma\gamma}\Gamma_{gg}}{\Gamma_{\rm tot}} \left[\frac{\pi}{8}\int dx_1 dx_2\, \delta(x_1x_2 - m_{S_0}^2/s) f_g(x_1) f_g(x_2)\right]$$

$$\Gamma_{\rm tot} = \Gamma_{\gamma\gamma}/c_W^4 + \Gamma_{gg} + 2\Gamma_X,$$

X width must be small

$$\Gamma_{\gamma\gamma} = 48\pi Y_X^4 \alpha^2 |\psi_0(0)|^2/m_{S_0}^2,$$

$$\Gamma_{gg} = 32\pi\alpha_s^2 |\psi_0(0)|^2/(3m_{S_0}^2),$$

wave function of XX system at origin

4th power of hypercharge (…fit anything)

bound state of X

QED part+ linear part

- wave function at origin

$$\left[-\frac{\nabla_{\boldsymbol{r}}^2}{m_X}+V(\boldsymbol{r})-E_0\right]\psi_0(\boldsymbol{r})=0,$$

$$V(\boldsymbol{r})=-Y_X^2\frac{\alpha}{|\boldsymbol{r}|}+V_{\rm QCD}(|\boldsymbol{r}|).$$

- numerically solve and fit

(consistent with Hagiwara Kato Martine, Ng 1990 for Y=0)

$$|\psi_0(0)|=\sum_{n=0}^{4}a_n\left[\ln(m_{S_0}/750\,\mathrm{GeV})\right]^n,\qquad E_0=\sum_{n=0}^{4}b_n\left[\ln(m_{S_0}/750\,\mathrm{GeV})\right]^n,$$

Y_X	a_0	a_1	a_2	a_3	a_4	b_0	b_1	b_2	b_3	b_4
0	87.78	114.4	76.85	37.76	10.71	4.119	2.458	0.9314	0.2429	0.04078
1/3	88.44	115.3	77.54	38.14	10.82	4.145	2.481	0.9416	0.2461	0.04143
2/3	90.44	118.1	79.64	39.30	11.17	4.226	2.552	0.9726	0.2557	0.04341
1	93.82	122.9	83.20	41.25	11.76	4.363	2.672	1.026	0.2721	0.04682
4/3	98.64	129.8	88.28	44.05	12.61	4.559	2.845	1.102	0.2960	0.05180
5/3	105.0	138.8	95.01	47.76	13.73	4.822	3.077	1.206	0.3285	0.05858
2	112.6	150.7	104.5	51.83	14.40	5.162	3.366	1.322	0.3812	0.07999

1.65

Abnormal candidate remains

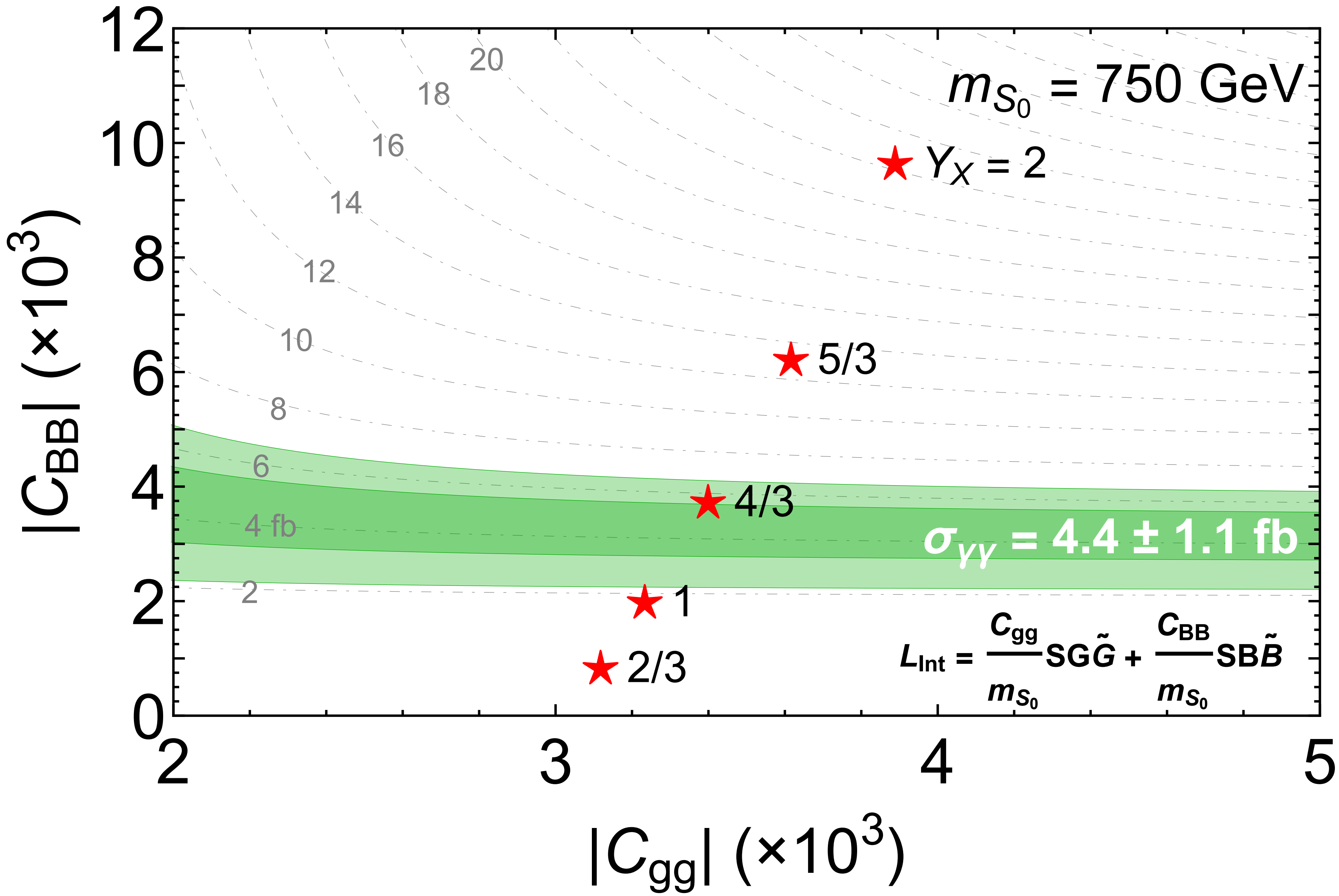


Figure 1: *Red stars are predictions of our model on the $(|C_{gg}|, |C_{BB}|)$-plane with Y_X being 2/3, 1, 4/3, 5/3 and 2, respectively. Contours of the diphoton cross section as a function of $|C_{gg}|$ and $|C_{BB}|$ are also shown by gray-dashed lines. Darker (lighter) green-shaded region corresponds to the cross section experimentally favored by the diphoton excess at 1σ (2σ) level [3].*

Numerically tough calculation, completely relay on Ishikawa-san

Thoughts about X decay

- There are no dim 4 operator involving X and SM particles →The X decay must be suppressed by some cutoff scale Λ →**Consistent with small width assumption to get signal**

- **If X is Z_2 odd in some conserved parity, decaying into lightest Z2 odd particle (dark matter)**

  - X: strongly interacting particle with (3,0,-4/3)

  - χ: weakly interacting particle. X and χ interact through some higher dim operators such as

$$\mathcal{O}_F \sim (X u^c)(\bar{\chi} u^c)/\Lambda^4 \qquad \mathcal{O}_S \sim (\bar{X} d^c)(\bar{u^c} d^c)^\dagger \chi/\Lambda^3$$

dark matter density

effective pair annihilation cross section

$$\langle \sigma v \rangle = \sum_{ij} \langle \sigma_{ij} v \rangle \frac{g_i g_j}{g_{\mathrm{eff}}^2} (1+\Delta_i)^{3/2} (1+\Delta_j)^{3/2} \exp[-x(\Delta_i + \Delta_j)],$$

$$x = m_\chi / T$$

Griest and Seckel Phys. Rev. D43, 3191(1991)

"Three exceptions in the calculation of relic abundance"

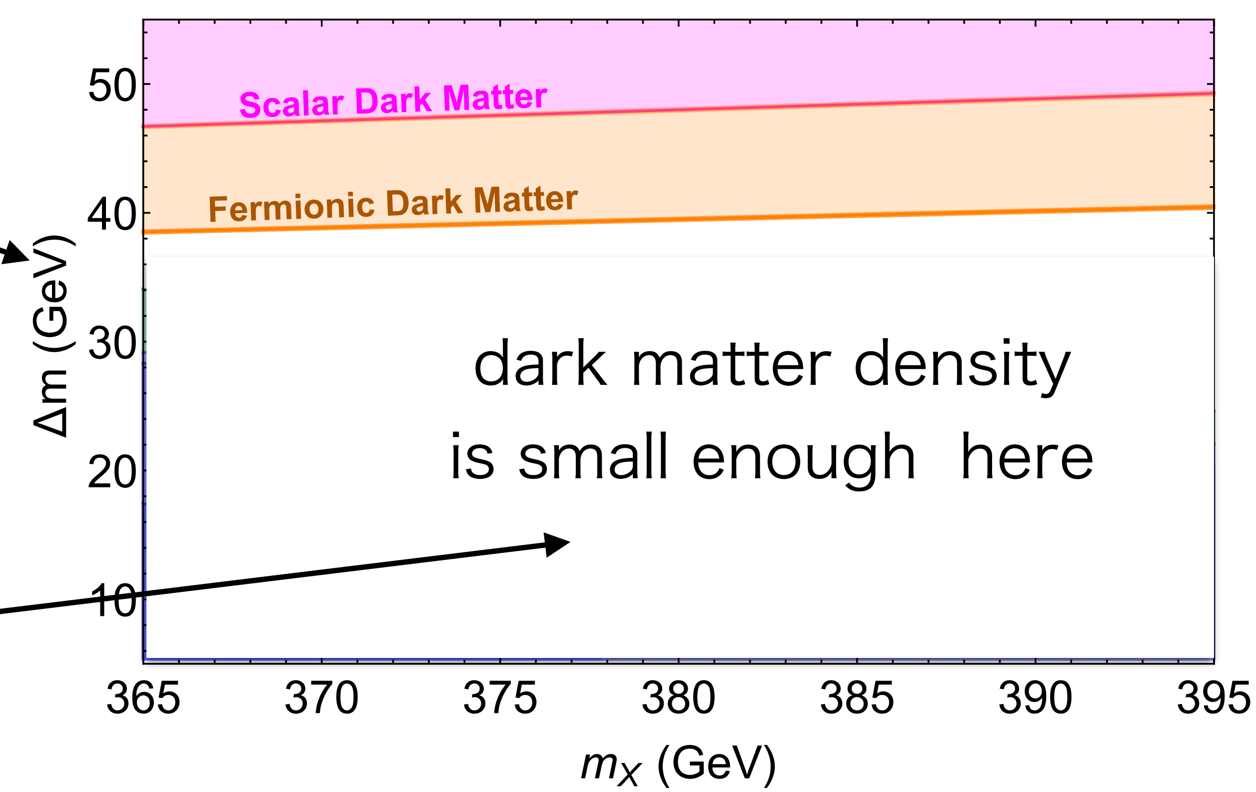
$$\Delta_i = (m_i - m_\chi)/m_\chi$$ mass difference

for our case

$$\langle \sigma v \rangle \simeq 2 \frac{43 \pi \alpha_s^2}{27 m_X^2} \frac{36(1+\Delta_X)^3 \exp(-2x\Delta_X)}{\left[g_\chi + 12(1+\Delta_X)^{3/2} \exp(-x\Delta_X)\right]^2}.$$

dark matter density is the function of mX-m χ

It is enough to exclude this region



Collider Constraints

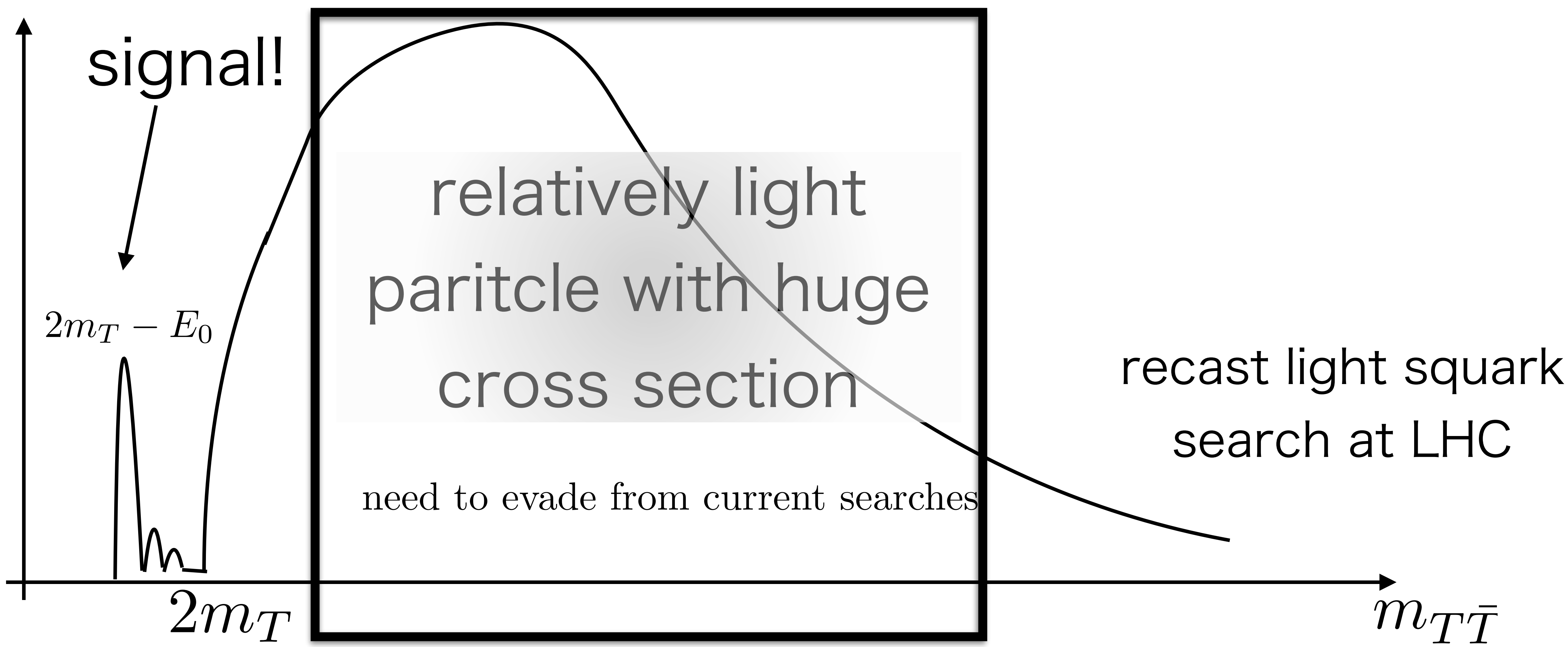
X decay pattern

X→ χ (jj, jjj) χ =DM

Other possibility

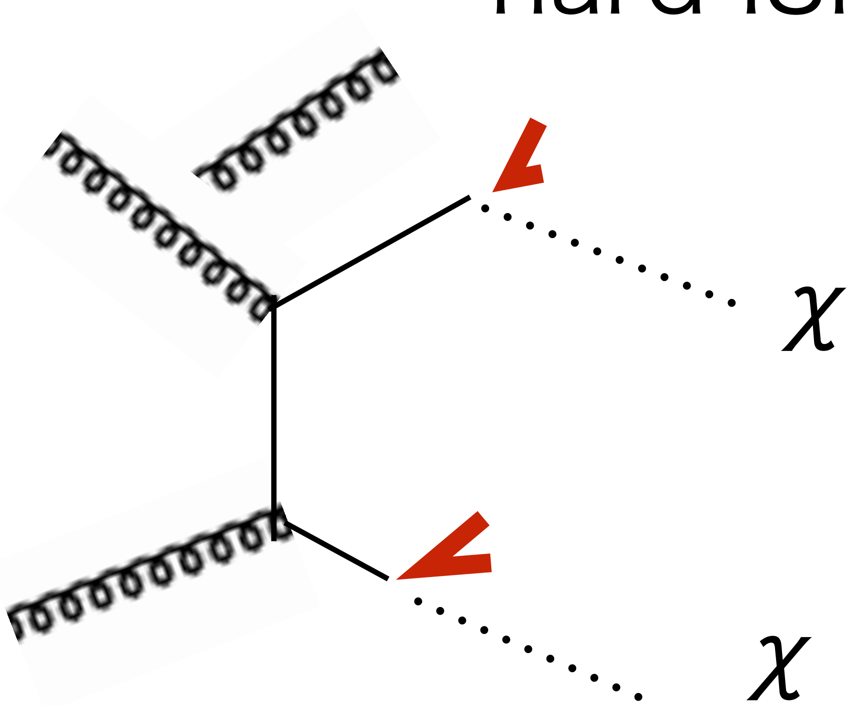
1. X-> W j, Zj Hj etc   is not allowed because of Q=4/3
2. X-> 2j, 3j (Kats and Strassler 1602.08819) weaker collider bound: large QCD background fat jet search at 13TeV?

σ (pp-> XX)



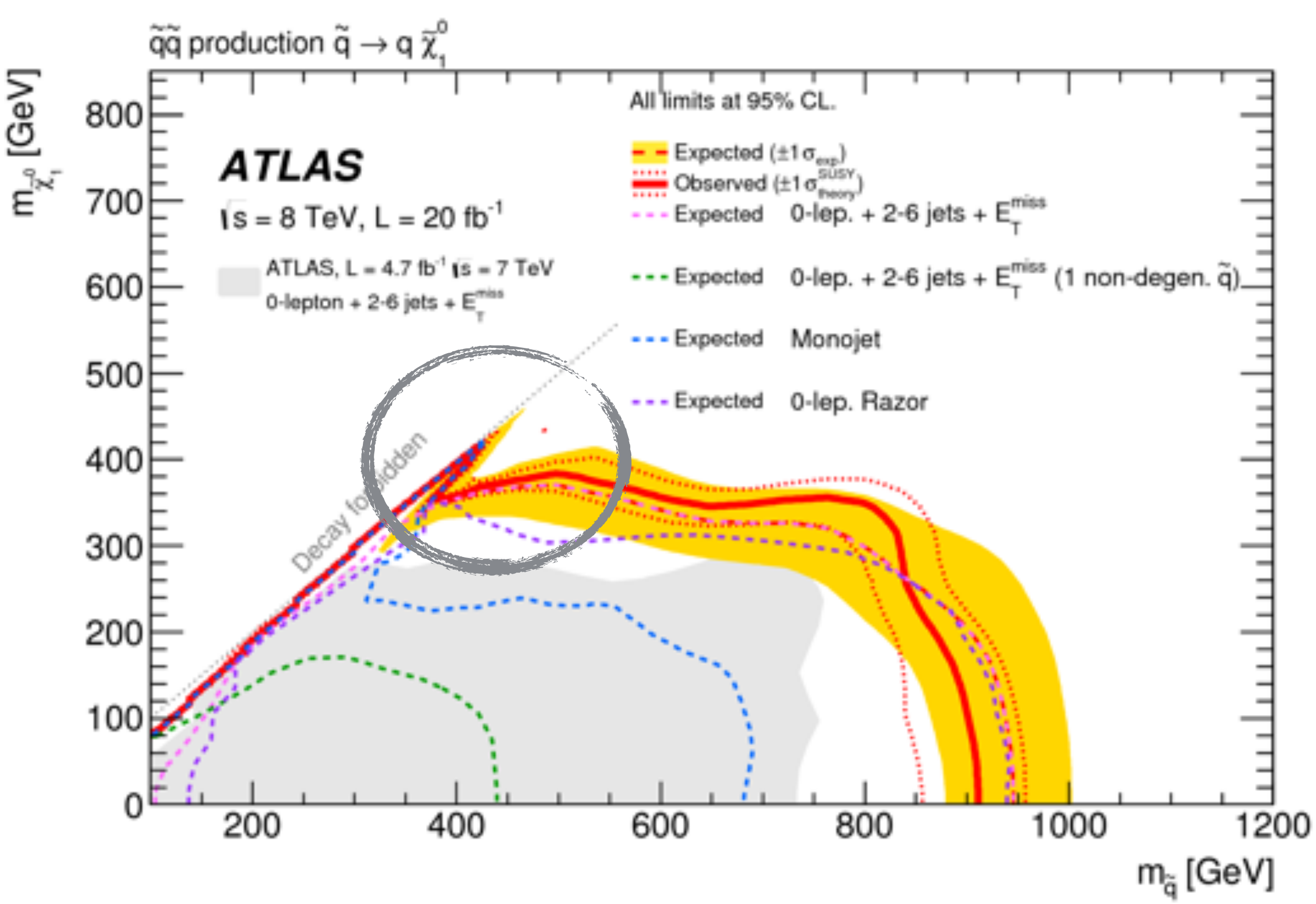
degenerate BSM search

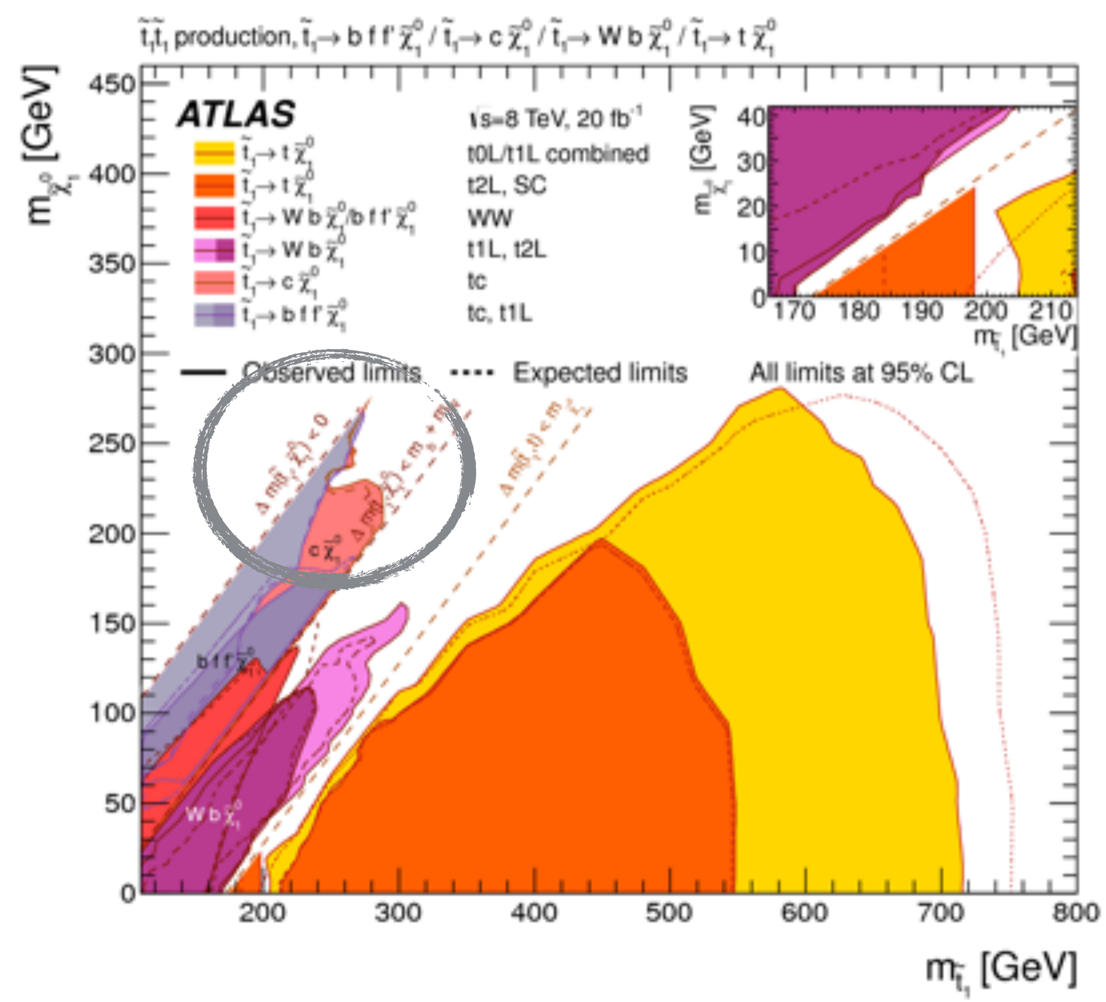
hard ISR (better prediction)



SM particle rather
difficult to be seen

monojet searches
at 8 and 13TeV are relevant





degenerate heavy fermion search at LHC

- generate p p → X X upto 2jet matched sample.
- force X to decay into X-> χ jj or χ jjj to obtain efficiency.
- signature is therefore jet (ISR , hard) + missing + soft activities
- compare with ATLAS and CMS SUSY searches results using checkmate

8TeV stop -LSP degenerate

more general missing pT search

	$\not{E}_T$ [GeV]	$p_{T\,j_1}$ [GeV]	$\Delta\phi\,(j, \not{p}_T)$	n_j	$\not{E}_T/\sqrt{H_T}$	$m_{\rm eff}$ (incl.)	$\sigma^{95\%}_{\rm obs}$	Ref.
M2	340	340	0.4	≤ 3	-	-	28.4 fb	[44]
SR5	350	$0.5\not{E}_T$	1.0	-	-	-	21 fb	[45]
SR6	400	$0.5\not{E}_T$	1.0	-	-	-	12 fb	[45]
SR2jm	200	300	0.4	≥ 2	15 GeV$^{1/2}$	1.2 TeV	21 fb	[46]

Table 3: *Signal regions and upper bounds on the signal cross sections at 95% C.L. Here, p_{T,j_1}, H and $m_{\rm eff}$ (incl.) are the leading jet p_T, the scalar p_T sum of all jets and $H_T + \not{E}_T$, respectively.*

13TeV data

all the other limits included in Checkmate are investigated.

background modeling at 13TeV

Background Estimation at LHC:NNLO cross section and +NLO multijet for some process

Biggest uncertainty comes from the process calculated only up to one loop

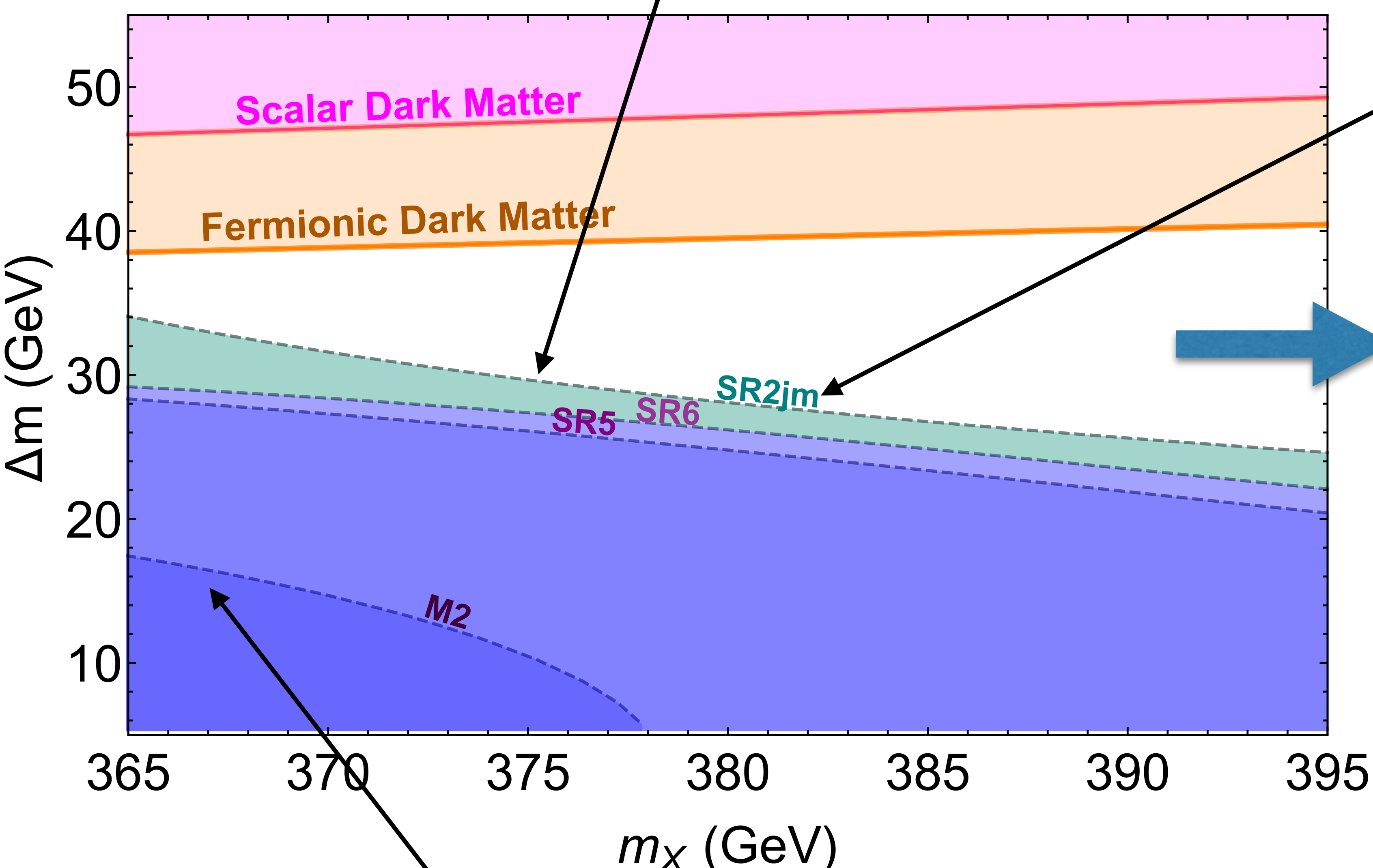
Signal cross section is NNLO level but not ready for NLO multi jet

Channel	**2jl**	**2jm**
Total bkg	237	163
Total bkg unc.	±22 [9%]	±20 [12%]
MC statistics	–	±1.8 [1%]
$\Delta\mu_{Z+\text{jets}}$	±6 [3%]	±5 [3%]
$\Delta\mu_{W+\text{jets}}$	±4 [2%]	±4 [2%]
$\Delta\mu_{\text{Top}}$	±1.2 [1%]	±1.6 [1%]
$\Delta\mu_{\text{Multi-jet}}$	±0.05 [0%]	±0.09 [0%]
CRγ corr. factor	±8 [3%]	±6 [4%]
Theory W	±1.4 [1%]	±2.3 [1%]
Theory Z	±6 [3%]	±3.2 [2%]
Theory Top	±2.7 [1%]	±2.1 [1%]
Theory Diboson	±16 [7%]	±16 [10%]
Jet/$E_{\text{T}}^{\text{miss}}$	±1.5 [1%]	±2.1 [1%]

results

The limit depends on signal error assumptions (we take 16%)

13TeV data gives best limit, and the limit is weaker than expected



limit is weaker here because mono-jet condition (pT1 vs ETmiss) two body decay case (X-> jχ) is excluded by multi-jets+ missing search

Tight mono-jet requirement leads worse sensitivity for heavy quark: (more ISR). Stop search is optimize for M2

summary

- **Heavy quark and dark matter for 750GeV resonance:** We proposed a effective theory with rather few number of particles. It turns out this is a new class of effective DM theory with **almost Model independent prediction of DM density.**

- **Our case** still barely survives from mono-jet search constraints. More stringent constraint this year, if scale dependence of the signal can be controlled.

- **LHC will exclude narrow width heavy fermion though $\gamma\gamma$ channel.**