$\gamma\gamma$ excess at the LHC:

the proof of concept towards the strongly coupled theory

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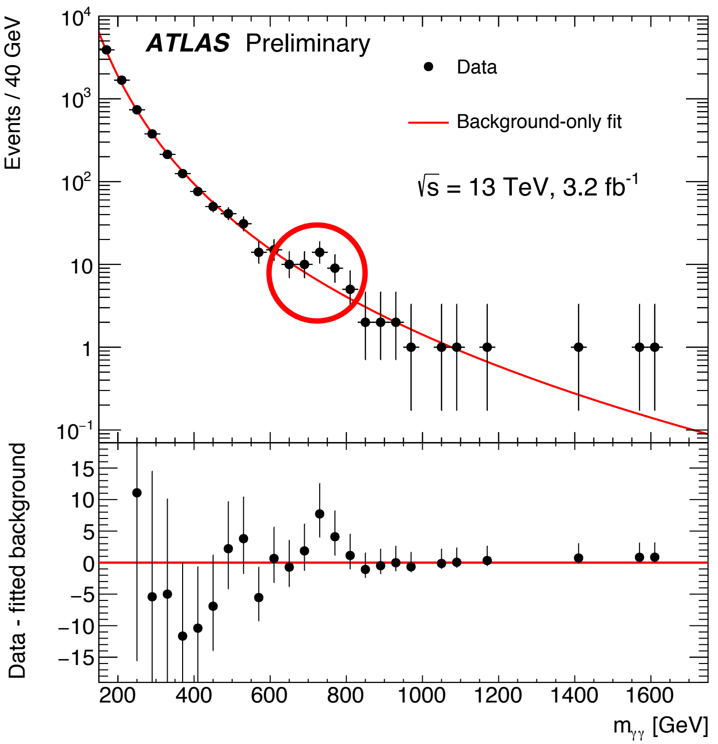
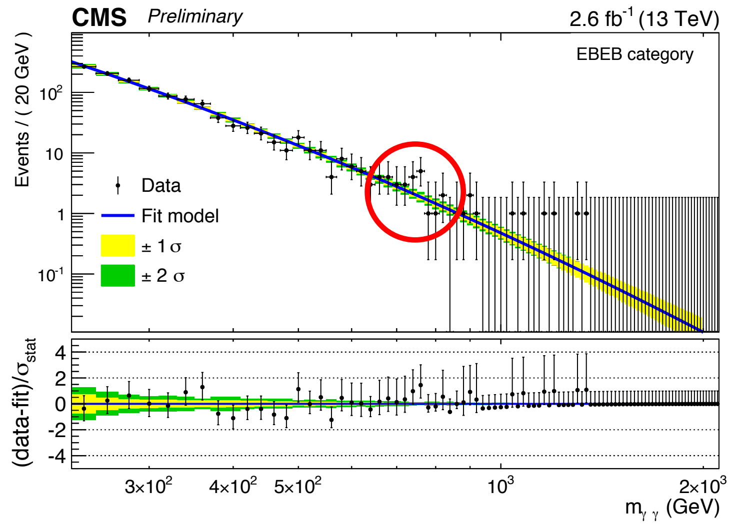
Based on arXiv:1512.08307, 1602.04801

With A. Katz (CERN), F. Geortz (CERN), A. Urbano (CERN)

Recent $\gamma\gamma$ excess at both ATLAS and CMS



ATLAS-CONF-2015-081



CMS-PAS-EXO-15-004

No significant MET, leptons, or jets

ATLAS: 3.9σ (local), 2.3σ (global)

CMS: 2.6σ (local), 1.2σ (global)

Update from Moriond

Recent $\gamma\gamma$ excess at both ATLAS and CMS

ATLAS

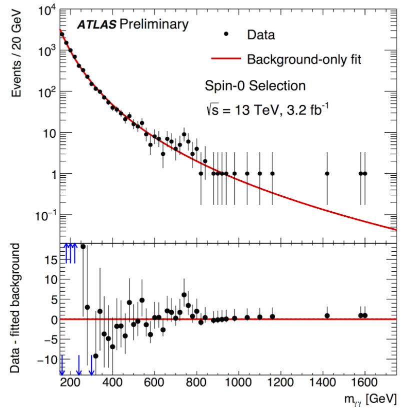
$\sqrt{s}$ =13 TeV

Run-2

Update

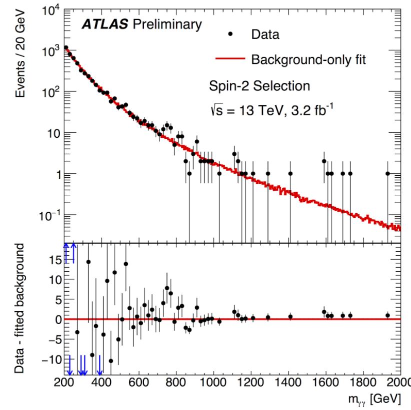
SPIN-0 ANALYSIS

background-only fit



SPIN-2 ANALYSIS

background-only fit



Γ ~45 GeV (6%)

$\boxed{3.9\sigma \text{ (local)}/2.0\sigma \text{ (global): spin-0}}$

3.6σ (local)/1.8σ (global): spin-2

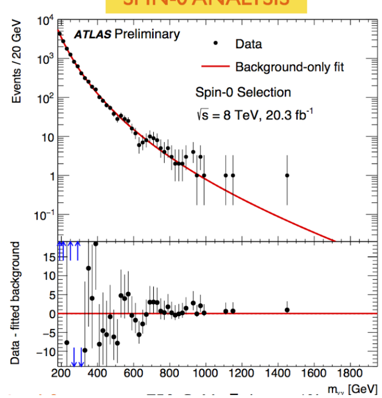
Comapatibility ~ 1.2σ (gg PDF)

$\sqrt{s}$ = 8 TeV

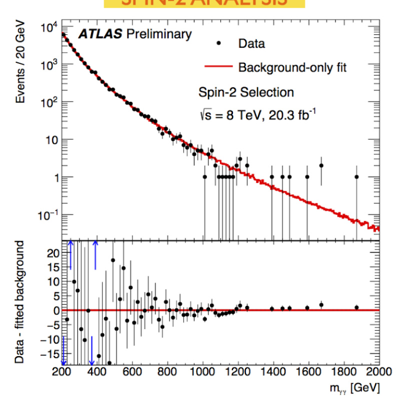
Run-1

Update

SPIN-0 ANALYSIS



SPIN-2 ANALYSIS



$\boxed{1.9\sigma \text{ (local): spin-0}}$

No excess: spin-2

https://indico.in2p3.fr/event/12279/session/12/contribution/163/material/slides/1.pdf

Update from Moriond

Recent $\gamma\gamma$ excess at both ATLAS and CMS

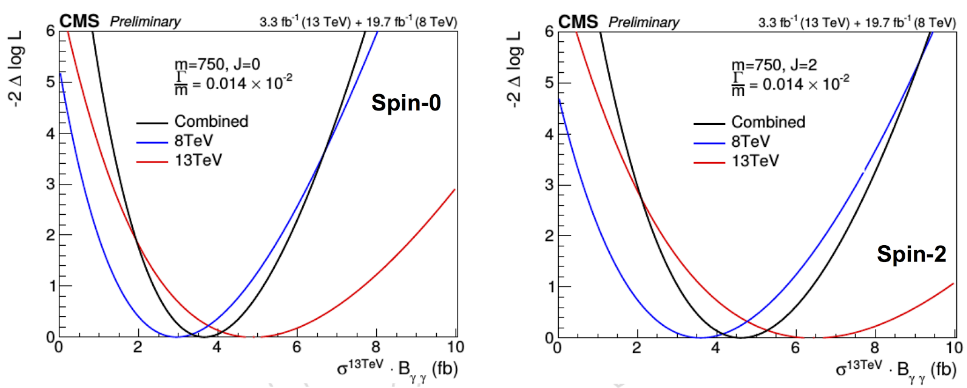
CMS

Update

$$\Gamma/m = 1.4\times10^{-4}, 1.4\times10^{-2}, 5.6\times10^{-2}$$

Local: 3.4σ(combined)/2.9σ(13TeV), Global: 1.6σ($< 1\sigma$)

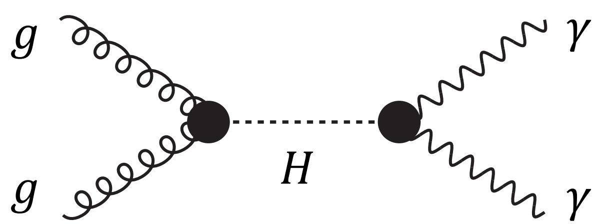
Consistency between 8TeV and 13TeV



https://indico.in2p3.fr/event/12279/session/12/contribution/218/material/slides/0.pdf

$\gamma\gamma$ excess as a scalar resonance S

What if it is a 750 GeV heavy SM Higgs?



$$\sigma(pp \to H \to \gamma\gamma) = 0.74\ \text{pb} \times \text{BR}_{\gamma\gamma} = 1.3\times10^{-4}\ \text{fb}$$

$$\Gamma_{\text{Total}} \sim \Gamma_{VV} \sim 200\ \text{GeV}$$

$$\text{BR}_{\gamma\gamma} \sim 1.79\times10^{-7} \qquad \text{BR}_{gg} \sim 2.5\times10^{-4}$$

$$\to \Gamma_{\gamma\gamma} \sim 3.6\times10^{-5}\ \text{GeV}$$

$\sigma(pp \to H{:}\, m_H = 125\ \text{GeV}) \sim 44\ \text{pb}$

$\text{BR}_{\gamma\gamma}(125\text{GeV}) \sim 2.28\times10^{-3}$

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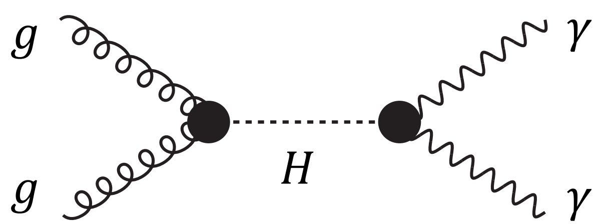

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The actual signal rate and total decay width

$$\sigma(pp \to S \to \gamma\gamma) = 6 - 10 \text{ fb}$$

These are quite large numbers!

$$\Gamma_{\text{total}}^{\text{ATLAS}} \sim 45 \text{ GeV}$$

With no significant MET, leptons, or jets

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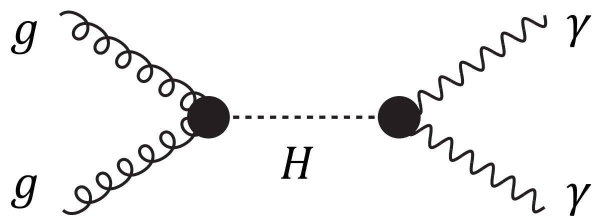

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With no significant MET, leptons, or jets

It smells like some large number or big couplings are secretly involved

indicate strongly-interacting theory ??

Assuming the narrow Width

$$\sigma(pp \to S \to \gamma\gamma) = \frac{1}{M\Gamma s}\left[C_{gg}\Gamma(S \to gg) + \sum_q C_{q\bar{q}}\Gamma(S \to q\bar{q})\right]\Gamma(S \to \gamma\gamma)$$

$$\text{PDF Lumi. Ratio: } {}^{13\text{TeV}}/_{8\text{TeV}} = 5.4\ (\text{bb}), 5.0\ (\text{cc}), 4.4(\text{ss}), 2.7(\text{dd}), \text{uu}(2.5), \boxed{4.7\ (\text{gg})}$$

@ 750 GeV

To be compatible with 8 TeV data

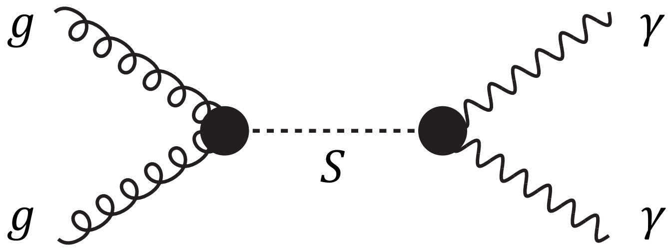
Assuming the production via gg PDF

$$\sigma(pp \to S \to \gamma\gamma) \approx \frac{1}{M\Gamma s}\mathrm{C}_{gg}\Gamma(S \to gg)\Gamma(S \to \gamma\gamma)$$

$$\mathrm{C}_{gg} = \frac{\pi^2}{8}\int_{M^2/s}^{1}\frac{dx}{x}g(x)g(M^2/sx) = 2137\ (174)\ \text{ at } \sqrt{s} = 13\ (8)\ \text{TeV}$$

EFT approach

EFT: dim-5 operators

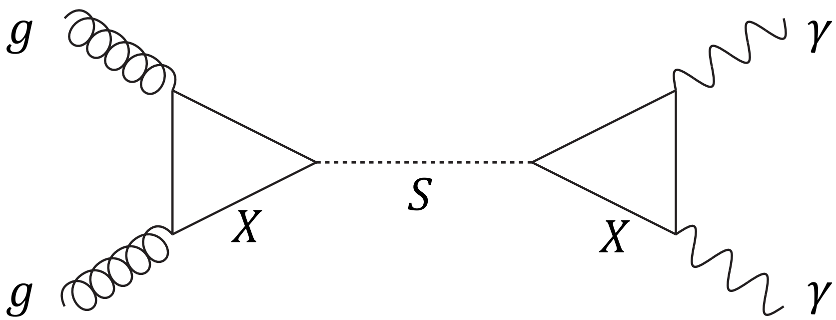


$$L_{eff} = \frac{e^2}{16\,\pi^2}\frac{c_{s\gamma\gamma}}{M} S F_{\mu\nu} F^{\mu\nu} + \frac{g_s^2}{16\,\pi^2}\frac{c_{sgg}}{M} S G^a_{\mu\nu} G^{a\;\mu\nu}$$

How to UV-complete S

This is all we care!

A simple weakly-coupled realization is to introduce Vector-like fermions/scalars



SM-loop excluded due to too large tree-level decay, e.g. $t\bar{t}$, $\Gamma_{tt}/\Gamma_{\gamma\gamma} \sim 10^5$

$$L_X = \bar{X}\left(i\gamma^\mu D_\mu - m_X\right)X - y_X S\bar{X}X$$

X: Vector-like Quark for simplicity

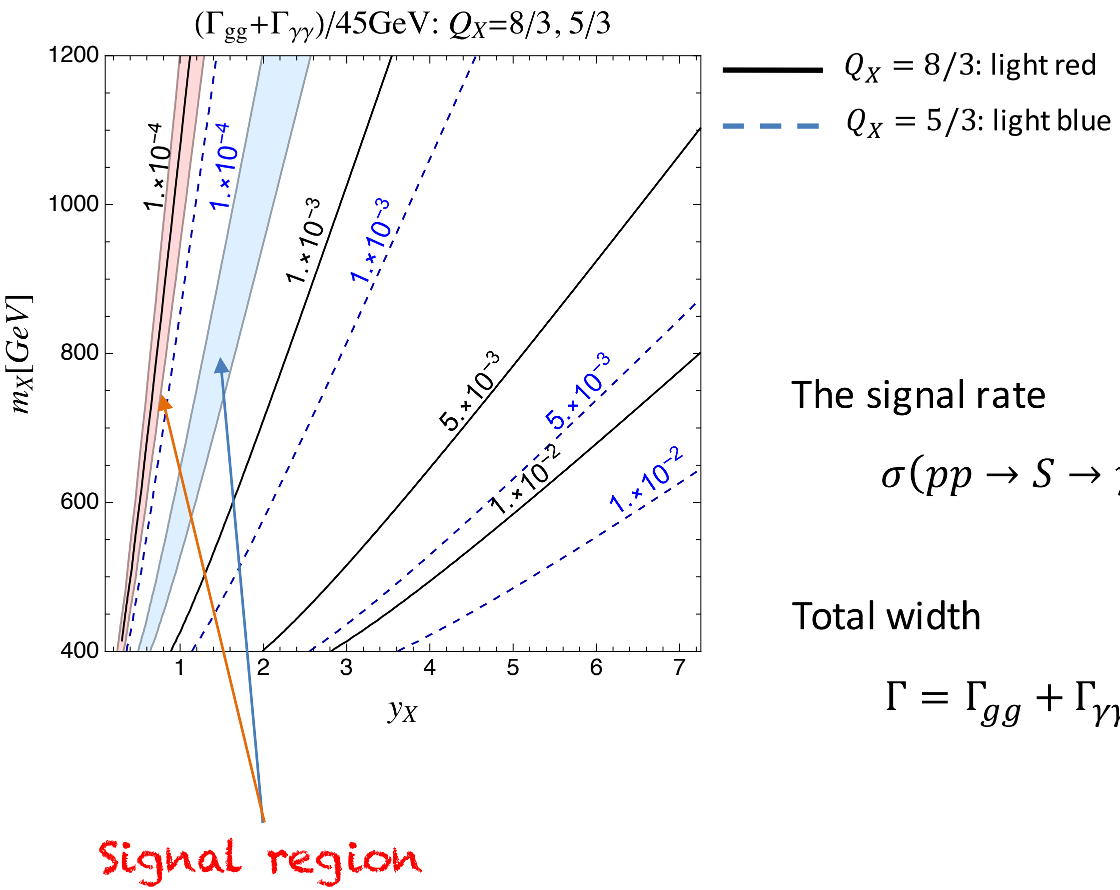
$$\Gamma_{\gamma\gamma} = \frac{\alpha^2}{16\,(4\pi)^3} c_{s\gamma\gamma}^2 M$$

$$\Gamma_{gg} = \frac{\alpha_s^2}{2\,(4\pi)^3} c_{sgg}^2 M$$

$$c_{s\gamma\gamma} = 6\ Q_X^2\left[y_X 2\sqrt{\tau}A_{\frac{1}{2}}(\tau)\right] = 6\ Q_X^2 c_{Sgg} \text{ and } \tau = M^2/(4m_X^2)$$

Typical decay width in Vector-like Quark model

Assume $\Gamma = \Gamma_{gg} + \Gamma_{\gamma\gamma}$



The signal rate

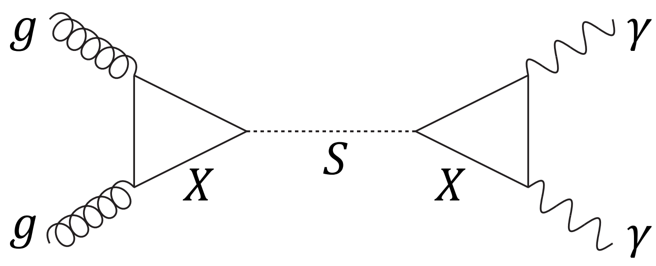
$$\sigma(pp \to S \to \gamma\gamma) \approx \frac{1}{Ms} C_{gg} \frac{\Gamma_{gg}\Gamma_{\gamma\gamma}}{\Gamma} \sim 6 - 10 \text{ fb}$$

Total width

$$\Gamma = \Gamma_{gg} + \Gamma_{\gamma\gamma} \sim \text{a few} \times 10^{-3}\,\text{GeV} \ll 1 \text{ or } 45\,\text{GeV}$$

Can we explain both

1. the large total width as big as $\Gamma \sim O(1\ \mathrm{GeV})$
2. the observed $\gamma\gamma$ excess rate $\sigma(pp \to S \to \gamma\gamma) = 6 - 10$ fb ?



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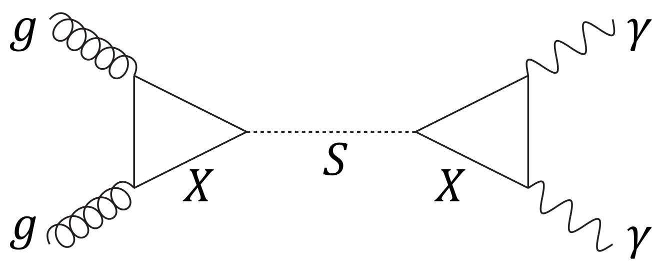

The signal rate

$$\sigma(pp \to S \to \gamma\gamma) \approx \frac{1}{Ms} C_{gg} \frac{\Gamma_{gg}\Gamma_{\gamma\gamma}}{\Gamma}$$

- ✓ Small Γ helps to achieve a large signal rate but it fails explaining a large total decay width
- ✓ Large Γ reduces the signal rate and thus partial decay widths need to be large to get a large signal rate

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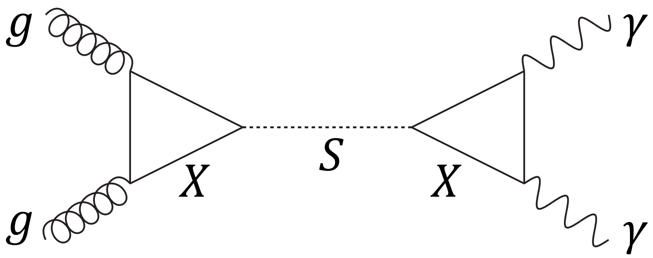


The signal rate

$$\sigma(pp \to S \to \gamma\gamma) \approx \frac{1}{M_S} C_{gg} \frac{\Gamma_{gg}\Gamma_{\gamma\gamma}}{\Gamma}$$

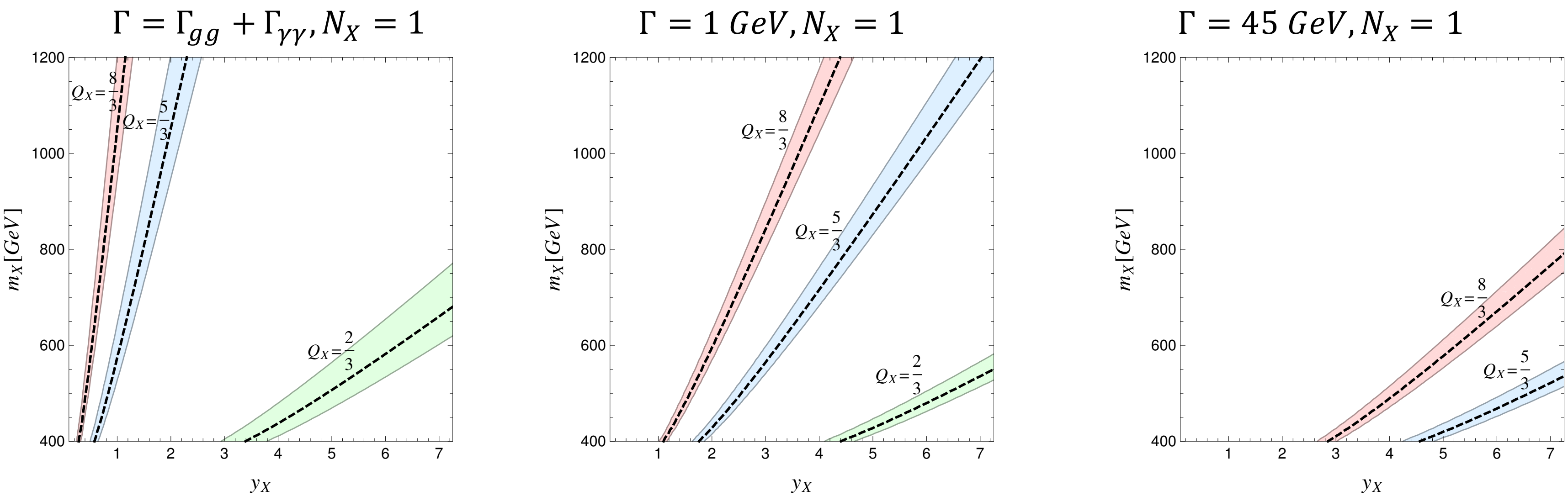
- ✓ Small Γ helps to achieve a large signal rate but it fails explaining a large total decay width
- ✓ Large Γ reduces the signal rate and thus partial decay widths need to be large to get a large signal rate

- Asking both necessarily calls for a large number or big coupling

Alarming from a weakly-coupled theory viewpoint

The compatible parameter space with the signal rate

$$\sigma(pp \to S \to \gamma\gamma) = 6 - 10 \text{ fb}$$

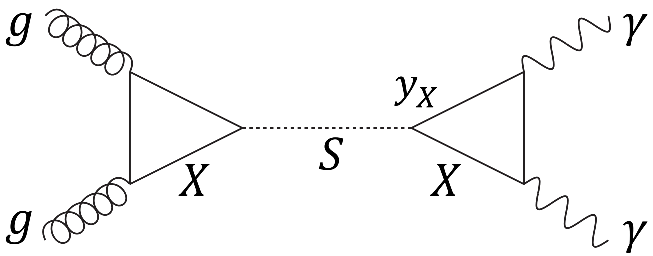


A weak coupling is allowed for a large EM charge

A strong coupling is favored

Parametric behavior

The parametric behavior will tell us what to do to bring a strong coupling to a weak coupling



The signal rate

$$\sigma(pp \to S \to \gamma\gamma) \approx \frac{1}{Ms} C_{gg} \frac{\Gamma_{gg}\Gamma_{\gamma\gamma}}{\Gamma}$$

$$= \frac{9}{8} \frac{C_{gg}}{s} \frac{M}{\Gamma_0} \frac{c_0^4(\tau)}{(4\pi)^{10}} g_s^4 e^4 y_X^4 Q_X^4 N_X^4$$

As long as $y_X Q_X N_X \sim$ const. signal rate remains the same

When $\Gamma = \Gamma_0 \sim$ 1- 45 GeV

$$= \frac{9}{4} \frac{C_{gg}}{s} \frac{c_0^2(\tau)}{(4\pi)^5} g_s^4 e^4 \frac{y_X^2 Q_X^4 N_X^2}{g_s^4 + 9/2\, e^4 Q_X^4}$$

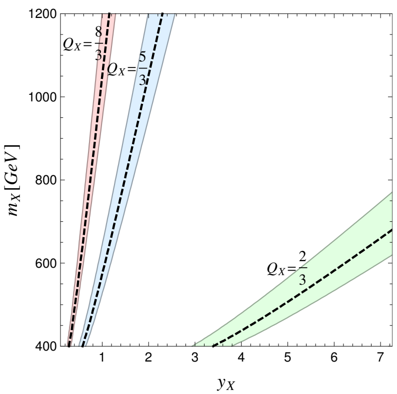
Similarly for this case

When $\Gamma = \Gamma_{gg} + \Gamma_{\gamma\gamma}$

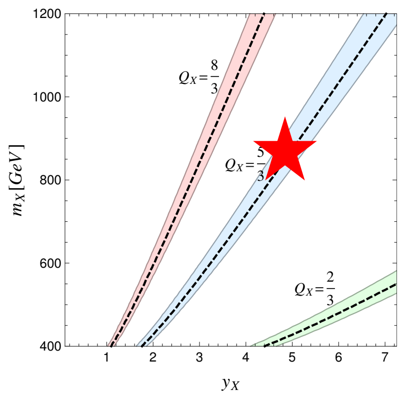
The compatible parameter space with the signal rate

$$\sigma(pp \to S \to \gamma\gamma) = 6 - 10 \text{ fb}$$

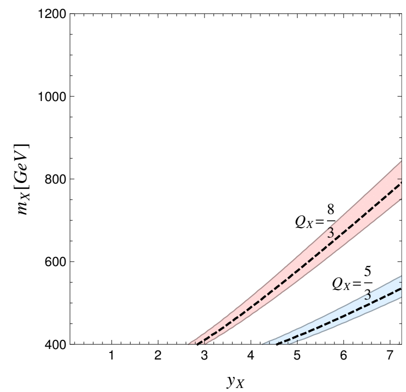
$\Gamma = \Gamma_{gg} + \Gamma_{\gamma\gamma}, N_X = 1$



$\Gamma = 1\ GeV, N_X = 1$



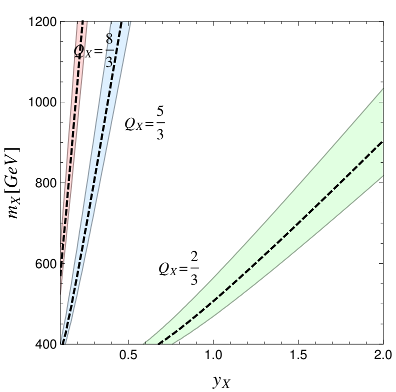
$\Gamma = 45\ GeV, N_X = 1$



Varying N_X to bring y_X to a weak value

As long as $y_X Q_X N_X \sim$ const. for large width

$\Gamma = \Gamma_{gg} + \Gamma_{\gamma\gamma}, N_X = 5$



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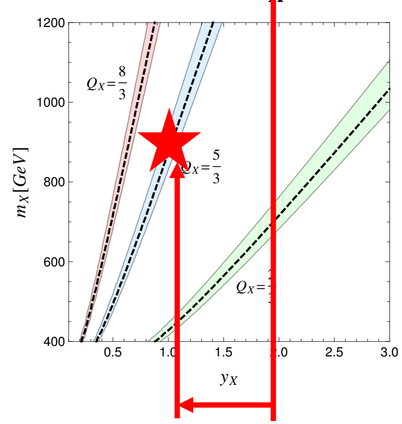
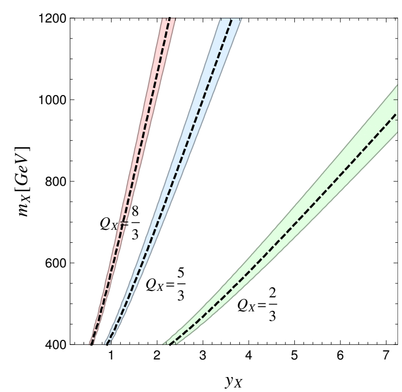
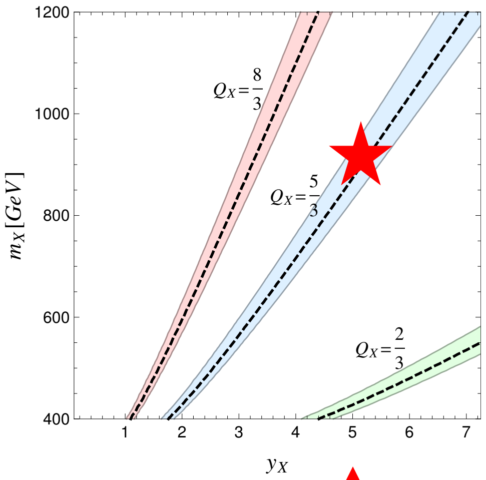


$\Gamma = 45\ GeV, N_X = 5$



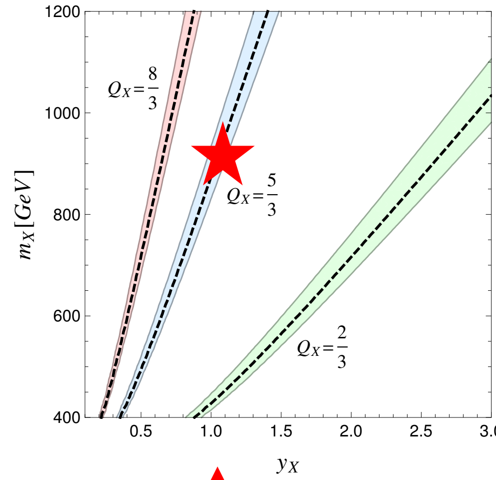
$\Gamma = 1\ GeV, N_X = 1$



$y_X = 5$

As long as $y_X Q_X N_X \sim$ const.

$\Gamma = 1\ GeV, N_X = 5$



$y_X = 1$

Varying N_X seems bring y_X to a weak value

But are we really in a weakly coupled regime?

Or is it just an illusion?

✓ OUR WORRY: Any large numbers, e.g. y_X, N_X, Q_X can widely change RG running of the couplings → some running couplings might rapidly blow up

To answer our question, we need to carefully examine RGEs

$$\beta_g = \mu\frac{dg}{d\mu} = \frac{1}{(4\pi)^2}\beta_g^{(1)} + \frac{1}{(4\pi)^4}\beta_g^{(2)} + \cdots$$

One-loop β-function of gauge couplings

$$\beta_{g_1}^{(1)} = \left(\frac{41}{10} + N_X Q_X^2 \frac{12}{5}\right) g_1^3$$

$$\beta_{g_2}^{(1)} = -\frac{19}{6} g_2^3$$

$$\beta_{g_3}^{(1)} = \left(-7 + N_X \frac{2}{3}\right) g_3^3$$

One-loop β-function of Yukawa couplings

$$\beta_{y_t}^{(1)} = y_t\left(-\frac{9}{2}y_t^2 - \frac{17}{20}g_1^2 - \frac{9}{4}g_2^2 - 8g_3^2\right)$$

$$\beta_{y_X}^{(1)} = y_X\left(3(2N_X+1)y_X^2 - \frac{18}{5}Q_X^2 g_1^2 - 8g_3^2\right)$$

One-loop β-function of scalar couplings

$$\beta_{\lambda_H}^{(1)} = \left[\lambda_H\left(12y_t^2 - \frac{9}{5}g_1^2 - 9g_2^2 + 24\lambda_H\right) - 6y_t^4 + \frac{9}{20}g_1^2 g_2^2 + \frac{27}{200}g_1^4 + \frac{9}{8}g_2^4 + \frac{1}{2}\lambda_{HS}\right] \qquad \lambda_H h^4$$

$$\beta_{\lambda_{HS}}^{(1)} = \lambda_{HS}\left(6y_t^2 - \frac{9}{10}g_1^2 - \frac{9}{2}g_2^2 + 12\lambda_H + 6\lambda_S + 12N_X y_X^2 + 4\lambda_{HS}\right) \qquad \lambda_{HS} h^2 S^2$$

$$\beta_{\lambda_S}^{(1)} = 2\lambda_{HS}^2 + 24N_X\lambda_S y_X^2 + 18\lambda_S^2 - 24N_X y_X^4 \qquad \lambda_S S^4$$

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One-loop β-function of gauge couplings

g_1

$$\boxed{\beta_{g_1}^{(1)} = \left(\frac{41}{10} + N_X Q_X^2 \frac{12}{5}\right) g_1^3} \rightarrow \text{Landau Pole}$$

$$\beta_{g_2}^{(1)} = -\frac{19}{6} g_2^3$$

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One-loop β-function of Yukawa couplings

$y_X S \bar{X} X$

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One-loop β-function of scalar couplings

$$\beta_{\lambda_H}^{(1)} = \left[\lambda_H \left(12 y_t^2 - \frac{9}{5} g_1^2 - 9 g_2^2 + 24\lambda_H\right) - 6 y_t^4 + \frac{9}{20} g_1^2 g_2^2 + \frac{27}{200} g_1^4 + \frac{9}{8} g_2^4 + \frac{1}{2}\lambda_{HS}\right]$$

$$\beta_{\lambda_{HS}}^{(1)} = \lambda_{HS} \left(6 y_t^2 - \frac{9}{10} g_1^2 - \frac{9}{2} g_2^2 + 12\lambda_H + 6\lambda_S + 12 N_X y_X^2 + 4\lambda_{HS}\right)$$

$\lambda_S S^4$

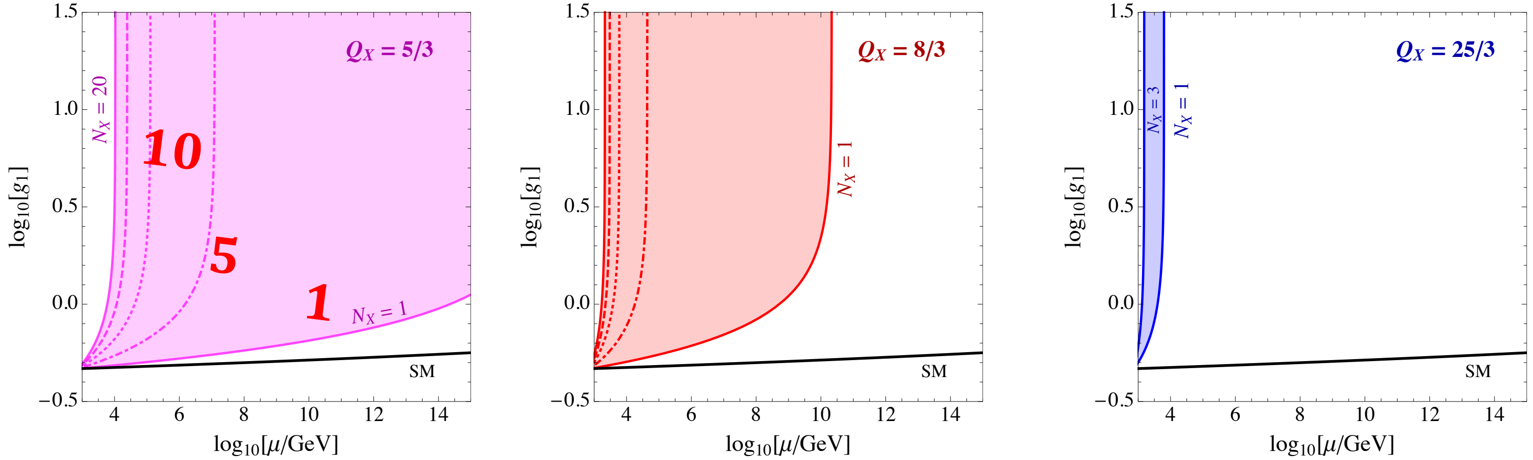
$$\boxed{\beta_{\lambda_S}^{(1)} = 2\lambda_{HS}^2 + 24 N_X \lambda_S y_X^2 + 18\lambda_S^2 - 24 N_X y_X^4} \rightarrow \text{Vacuum Instability}$$

Running Hypercharge coupling

$$\beta_{g_1}^{(1)} = \left(\frac{41}{10} + N_X Q_X^2 \frac{12}{5}\right) g_1^3$$

$$\rightarrow \; g_1(\mu) = \frac{4\sqrt{2}\,\pi g_1(\mu_0)}{\sqrt{80\pi^2 - g_1^2(\mu_0)(24 N_X Q_X^2 + 41)\ln(\mu/\mu_0)}}$$

: It could lead to Laudau pole



$N_X = 20, 15, 10, 5, 1$

$$\beta_{y_X}^{(1)} = y_X\left(3(2N_X + 1)y_X^2 - \frac{18}{5}Q_X^2 g_1^2 - 8g_3^2\right)$$

$$\beta_{\lambda_S}^{(1)} = 2\lambda_{HS}^2 + 24N_X\lambda_S y_X^2 + 18\lambda_S^2 - 24N_X y_X^4$$

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$$\beta_{\lambda_S}^{(1)} = 2\lambda_{HS}^2 + 24N_X\lambda_S y_X^2 + 18\lambda_S^2 - 24N_X y_X^4$$

- Illustrative example for qualitative discussion

$\lambda_{HS} = 0.01, s_\theta = 0.01, m_X = 1.5\ \mathrm{TeV}, y_X = 0.75, \mathrm{Q_X} = 2/3, N_X = 1$: $\lambda_S = 0.06$

$$\beta_{y_X}^{(1)} = y_X\left(3(2N_X+1)y_X^2 - \frac{18}{5}Q_X^2 g_1^2 - 8g_3^2\right)$$

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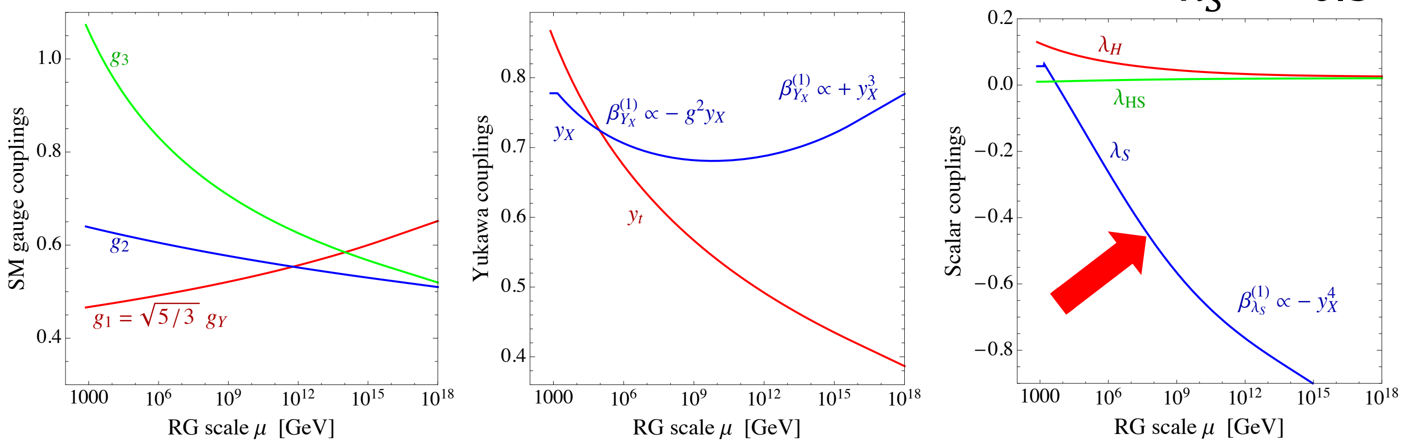
$$\lambda_{HS} = 0.01, s_\theta = 0.01, m_X = 1.5\ \text{TeV}, y_X = 0.75, \mathrm{Q_X} = 2/3, N_X = 1: \quad \lambda_S = 0.06$$

Although these look fine, it develop a dangerous pathology

$\lambda_S^{th} \approx 0.3$



→ positive terms $\beta_{\lambda_S}^{(1)}$ dominate over negative term to avoid negative λ_S if

$$\lambda_S > \lambda_S^{th} = \frac{1}{3}\left(\sqrt{-\lambda_{HS}^2 + 4N_X^2 y_X^4 + 12N_X y_X^4} - 2N_X y_X^2\right)$$

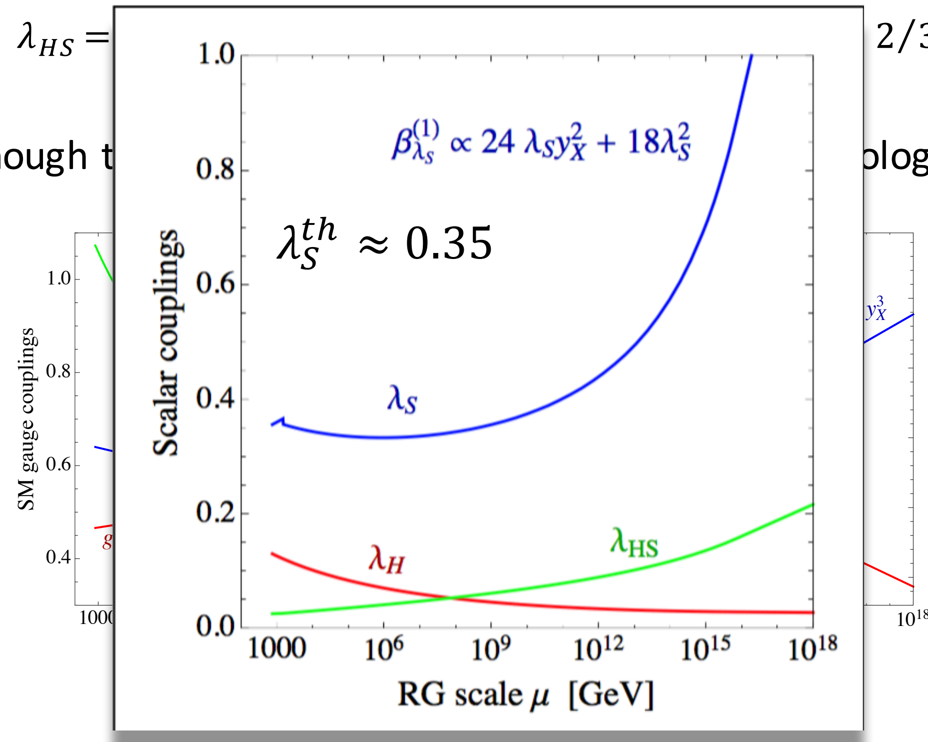
$$\beta_{y_X}^{(1)} = y_X\left(3(2N_X+1)y_X^2 - \frac{18}{5}Q_X^2 g_1^2 - 8g_3^2\right)$$

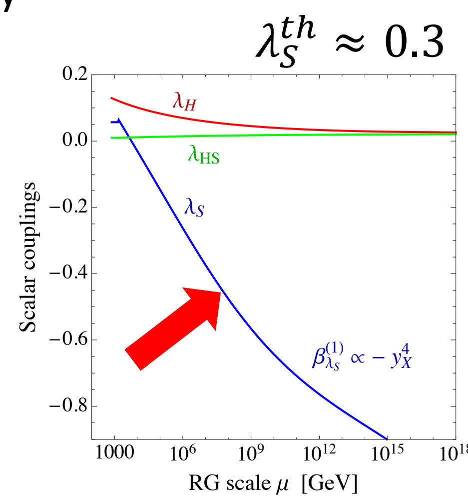
$$\beta_{\lambda_S}^{(1)} = 2\lambda_{HS}^2 + 24N_X\lambda_S y_X^2 + 18\lambda_S^2 - 24N_X y_X^4$$

- Illustrative example for qualitative discussion

$\lambda_{HS} =$ … $2/3, N_X = 1$: $\lambda_S = 0.06$

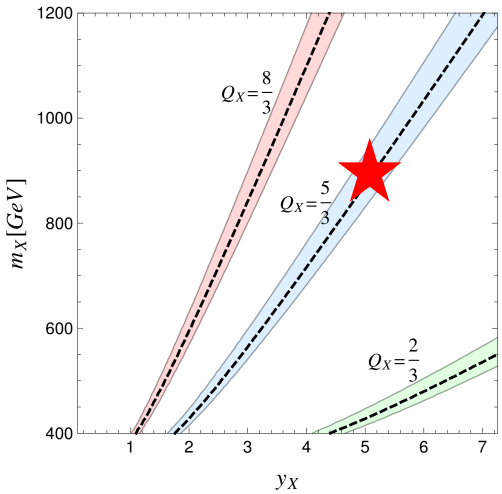
Although t… …ology





As you see, the problem is already evident even if we decided to work, for illustrative purposes, with a moderately small Yukawa coupling, $y_X = 0.75$

Illustration of realistic example

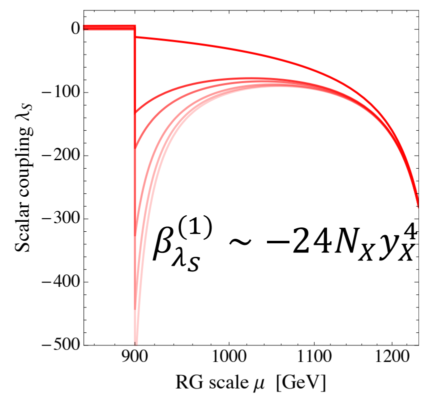


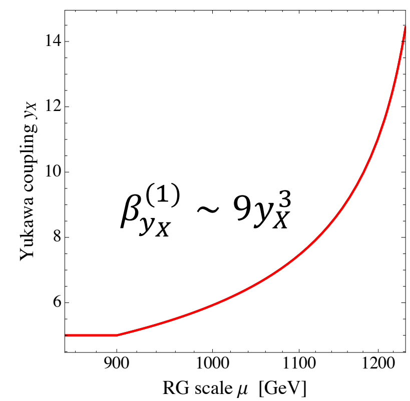
$\Gamma = 1$ GeV : represents a large total width

Pick one benchmark point

$$m_X = 900\ GeV,$$
$$N_X = 1, Q_X = 5/3, y_X = 5$$

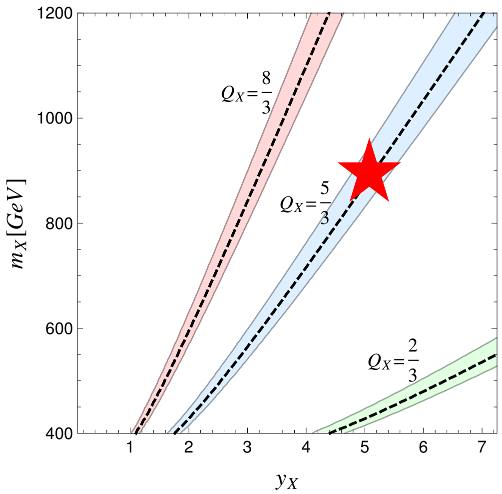
Obviously strongly coupled





✓ Can we play with varying N_X, Q_X (while keeping $y_X N_X Q_X \sim 25/3$) to alleviate the strong coupling problem?

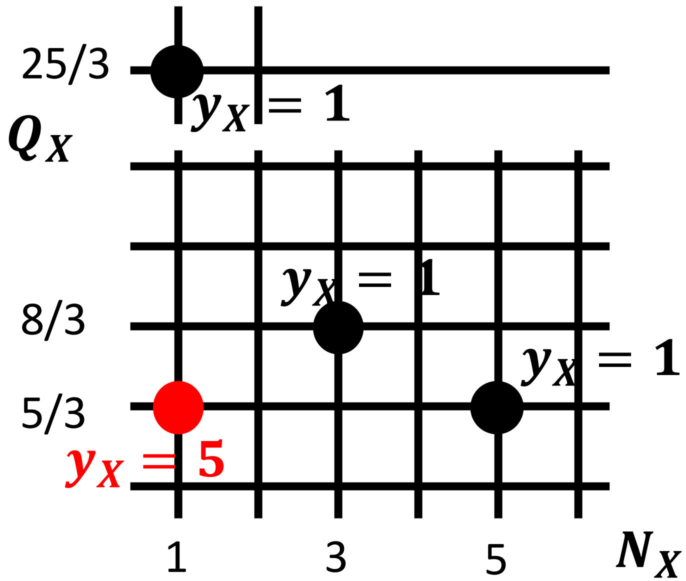
Illustration of realistic example



$\Gamma = 1$ GeV : represents a large total width

Pick one benchmark point

$m_X = 900\ GeV$,
$N_X = 1, Q_X = 5/3, y_X = 5$



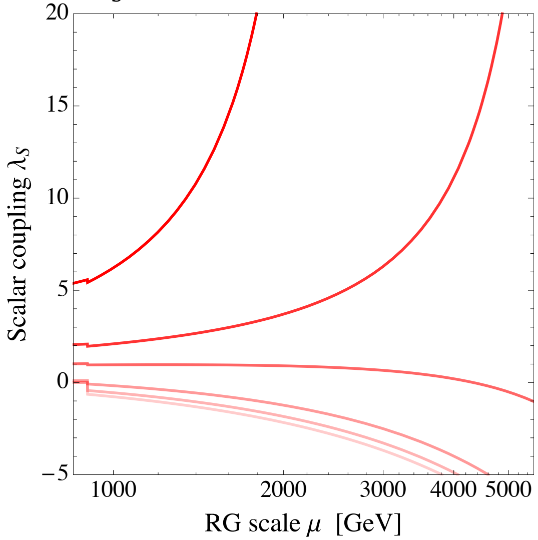
$y_X N_X Q_X \sim 25/3$

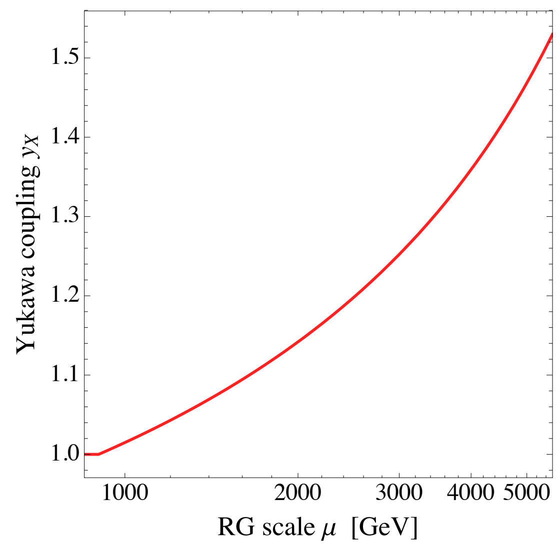
✓ Can we play with varying N_X, Q_X (while keeping $y_X N_X Q_X \sim 25/3$) to alleviate the strong coupling problem?

Varying N_X

$m_X = 900\ GeV,$
$N_X = 5, Q_X = 5/3\,, y_X = 1$

$\beta^{(1)}_{\lambda_S} = 120\ \lambda_S y_X^2 + 18\lambda_S^2 - 120\ y_X^4$



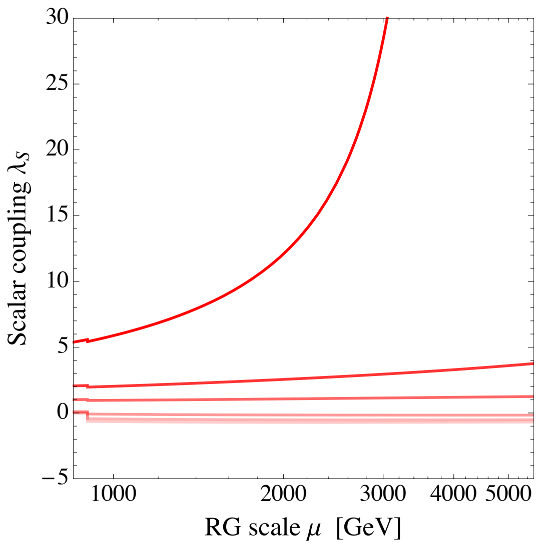


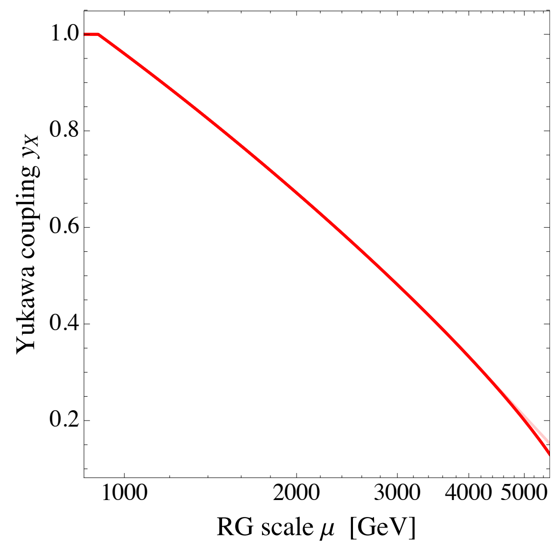
$\lambda_S(\mu_0) = 10^{-3}, 10^{-2}, 10^{-1}, 1, 2, 5$ (from lighter to darker)

- ✓ Theory reveals an instability at a scale not far away $O(\mathrm{TeV})$ for generic values of the couplings
- ✓ There exists a very fine-tuned initial value, $1 \leq \lambda_S(\mu_0) \leq 2$ which are almost unaffected by RG effects, this particular point does not correspond to a special property of the theory.

Varying Q_X

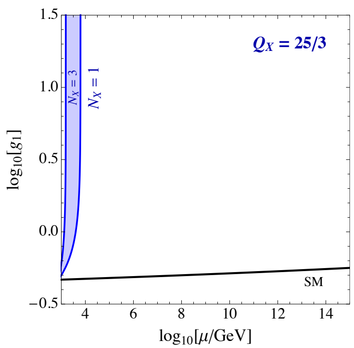
$m_X = 900\ GeV,$
$N_X = 1, Q_X = 25/3, y_X = 1$





$\lambda_S(\mu_0) = 10^{-3}, 10^{-2}, 10^{-1}, 1, 2, 5$ (from lighter to darker)

$$\beta^{(1)}_{y_X} = y_X\left(9y_X^2 - \frac{18}{5}Q_X^2 g_1^2 - 8g_3^2\right)$$

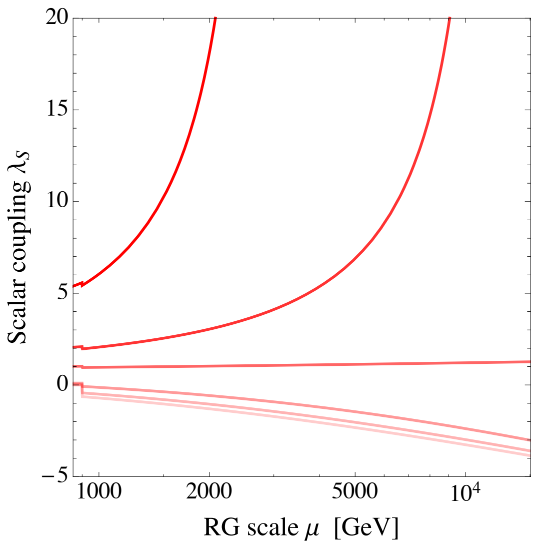


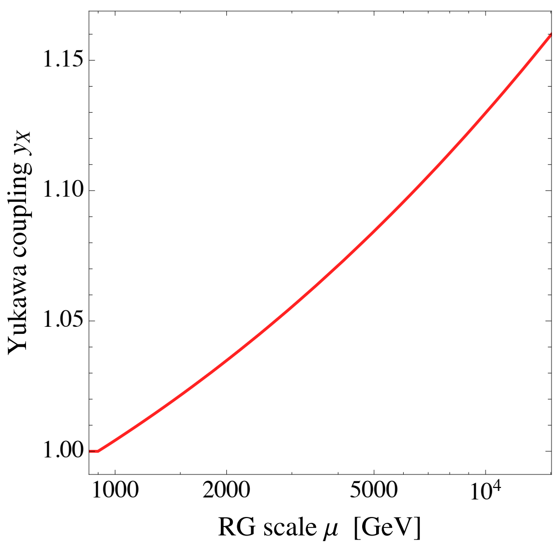
✓ Large EM charge was already unrealistic from the point of hypercharge coupling running

$$\beta^{(1)}_{g_1} = \left(\frac{41}{10} + N_X Q_X^2 \frac{12}{5}\right) g_1^3$$

Varying N_X, Q_X

$m_X = 900\ GeV,$
$N_X = 3, Q_X = 8/3\,, y_X = 1$





$\lambda_S(\mu_0) = 10^{-3}, 10^{-2}, 10^{-1}, 1, 2, 5$ (from lighter to darker)

- ✓ If $\lambda_S(\mu_0) \sim 1$, a stable solution exists, almost unaffected by RG flow. Again, this solution looks like the result of a fine-tuning rather than a special property of the theory.

- ✓ However, it is undeniable that in this scenario a weakly coupled theory valid to a high energy scale can be constructed. The upper limit of the validity of the theory is set by the hypercharge coupling running, $\Lambda \sim 300$ TeV

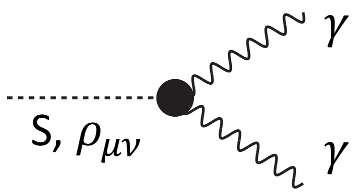
No matter what we do, the large total width as big as $\Gamma \sim O(1 \text{ GeV})$ indicates a strongly coupled theory not far away from TeV scale

When increasing $\Gamma \sim 1 \text{ GeV}$ to $\Gamma \sim 45 \text{ GeV}$,
the $y_X N_X Q_X$ gets worse by the factor of $y_X N_X Q_X \sim (45 \text{ GeV})^{1/4}$

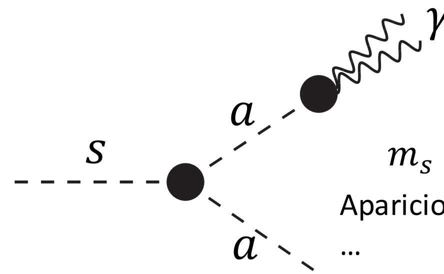
$$\sigma(pp \to S \to \gamma\gamma) \propto \frac{y_X^4 Q_X^4 N_X^4}{\Gamma}$$

Other resonance-interpretation

Spin-0, 2



Too many papers

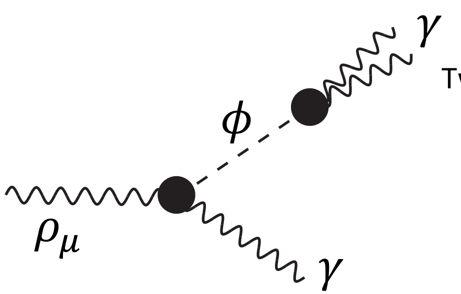


$m_s \gg m_a \rightarrow$ Boosted a

Aparicio, Azatov,Hardy,Romanino 16’

…

Spin-1



Two photons are not experimentally resolved

$m_{\rho_\mu} \gg m_\phi \rightarrow$ Boosted ϕ

Chala et al. PLB755, 16’

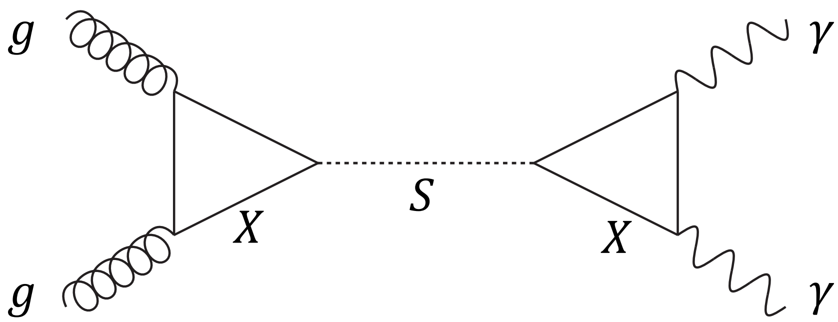
Our arguments apply to all these variants.
Have equally hard time to be weakly-realized

Precison Drell-Yan process

If $\gamma\gamma$ excess is confirmed to be true, Drell-Yan process becomes one of the important window to the New Physics

New particles in the loop

If the diphoton excess is true, catching new particles X in the loop becomes an important business



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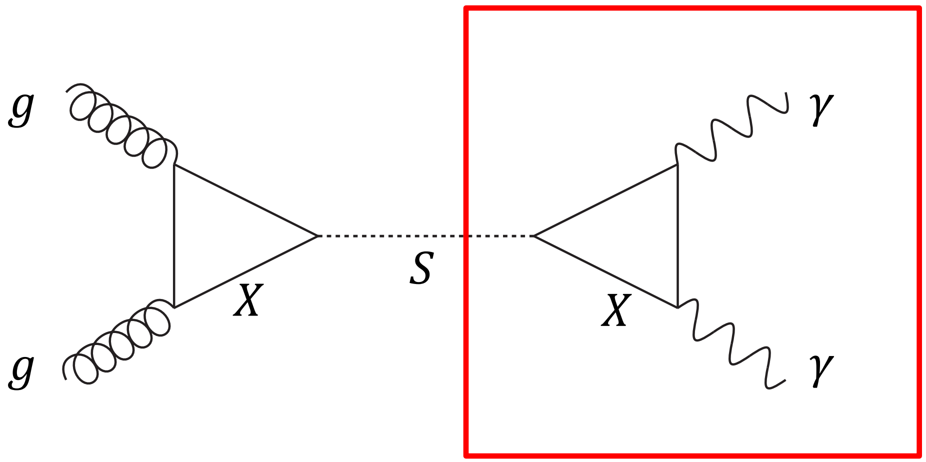

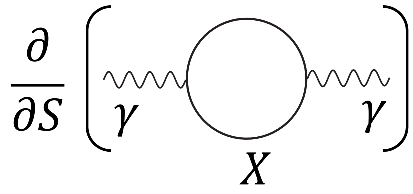

Basically two-point function carries all the information

Where can we see the non-standard behavior of two-point function?

- We will assume X is SU(2) singlet. SU(2) doublet is more vulnerable to EWPT

List all quantities that are related to the two-point function

LEP bound (assuming $q^2 \ll m_X^2$)

$$\Pi_{BB}(q^2) \sim \Pi_{BB}(0) + q^2 \Pi_{BB}^{(1)} + \boxed{q^4 \Pi_{BB}^{(2)}} + \cdots$$

$$Y = d_X N_X Q_X^2 \alpha_Y^2 \frac{m_W^2}{15\pi\, m_X^2}$$

d_X: accounts for the colour

List all quantities that are related to the two-point function

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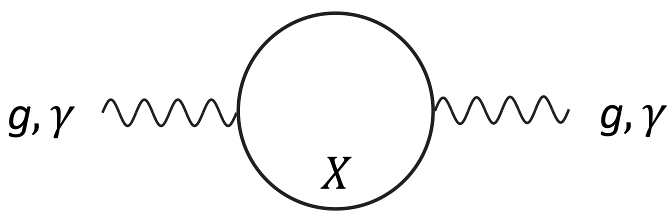
d_X: accounts for the colour

Running hyper-charge/strong-QCD couplings



Virtually accessible to X
Its effect appears indirectly

Modifying REGs

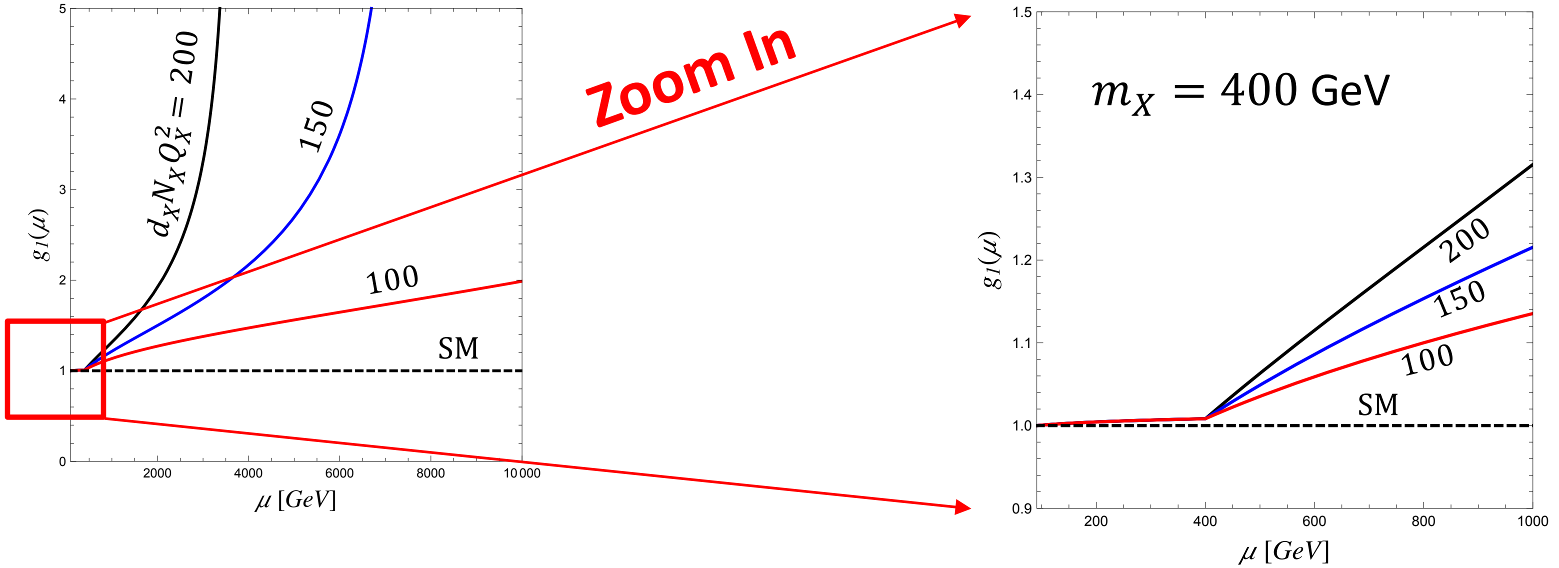
$$\boxed{\mu\frac{dg_1}{d\mu} = \beta_{g_1} = \left(\frac{41}{10} + d_X N_X Q_X^2 \frac{1}{5}\right) g_1^3}$$

We will focus on hypercharge running

$$\mu\frac{dg_3}{d\mu} = \beta_{g_3} = \left(-7 + N_X\frac{2}{3}\right) g_3^3$$

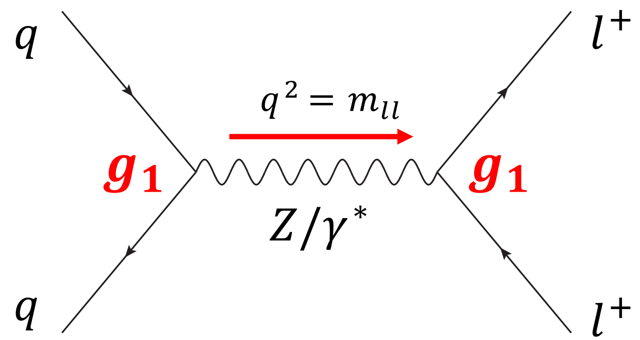
Running hyper-charge coupling

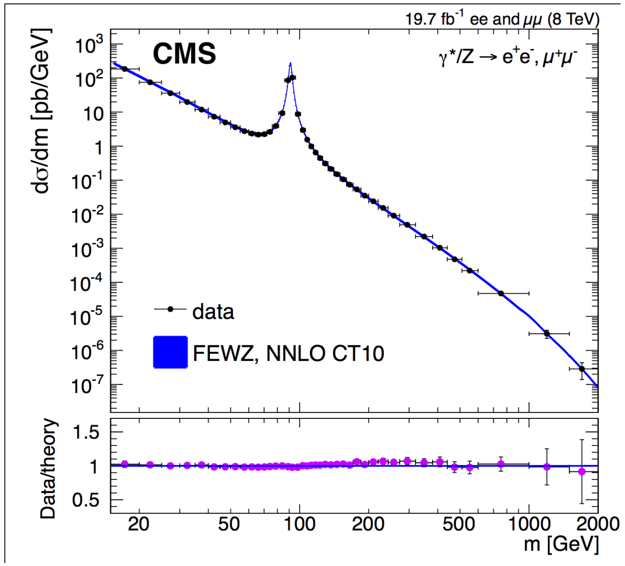
$$\mu \frac{dg_1}{d\mu} = \beta_{g_1} = \left(\frac{41}{10} + d_X N_X Q_X^2 \frac{1}{5}\right) g_1^3$$



Precison Drell-Yan process at the LHC

CMS arXIv:1412.1115

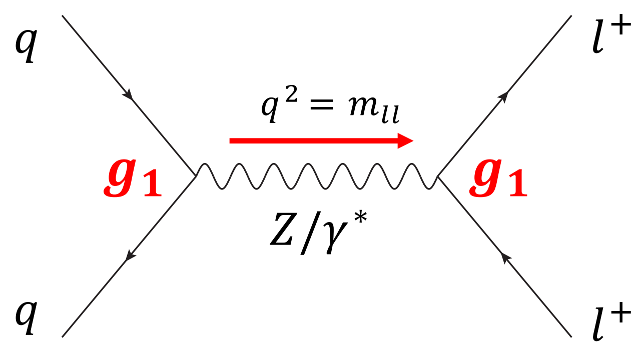


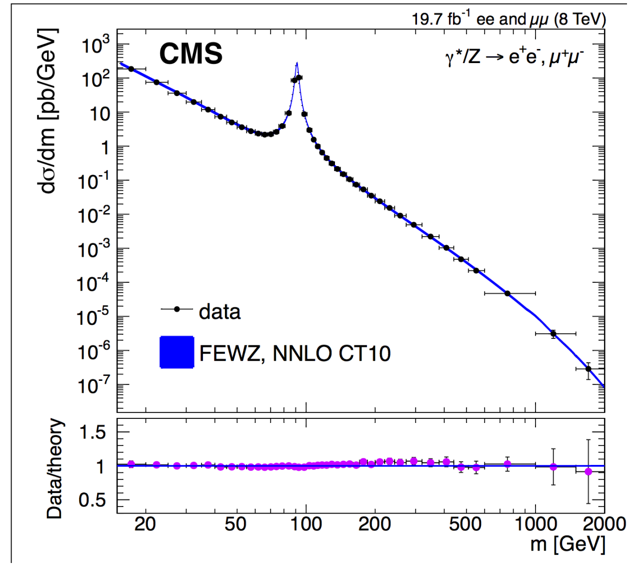


- Running hypercharge coupling changes the differential cross section above the scale $\sim m_X$

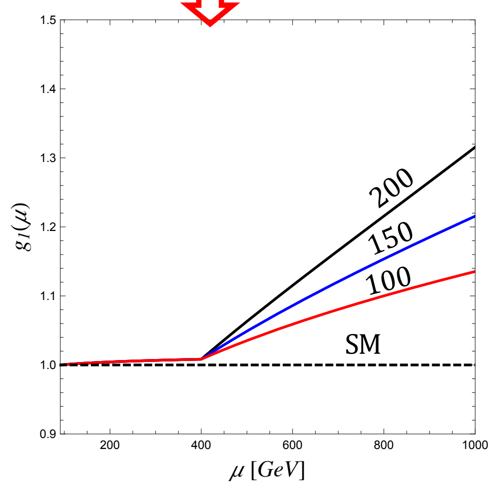
Precison Drell-Yan process at the LHC

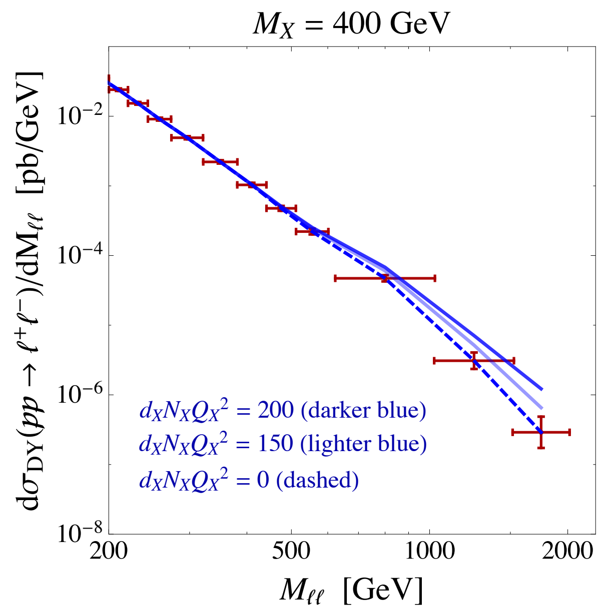
CMS arXIv:1412.1115





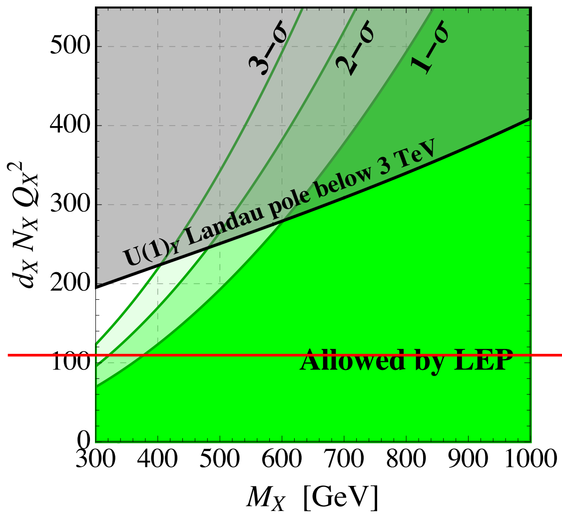
- Running hypercharge coupling changes the differential cross section above the scale $\sim m_X$

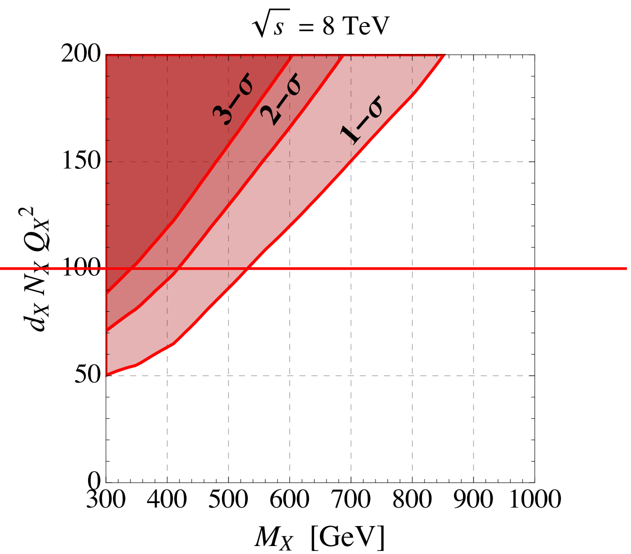




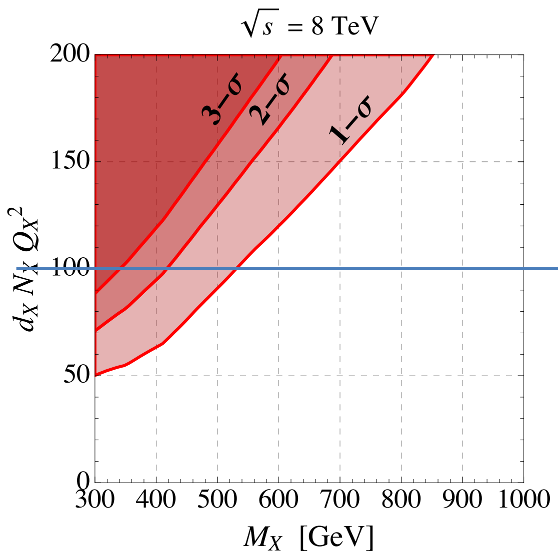
✓ If the differential cross section can be measured up to $\leq O(10\%)$, a meaningful bound on X can be extracted

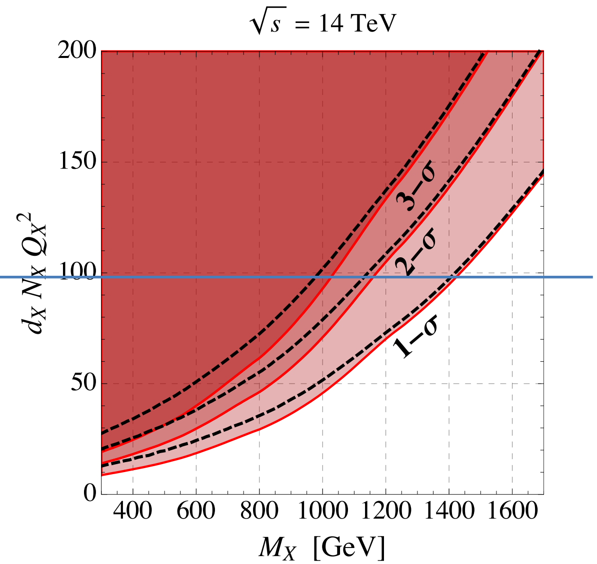
LEP vs Drell-Yan





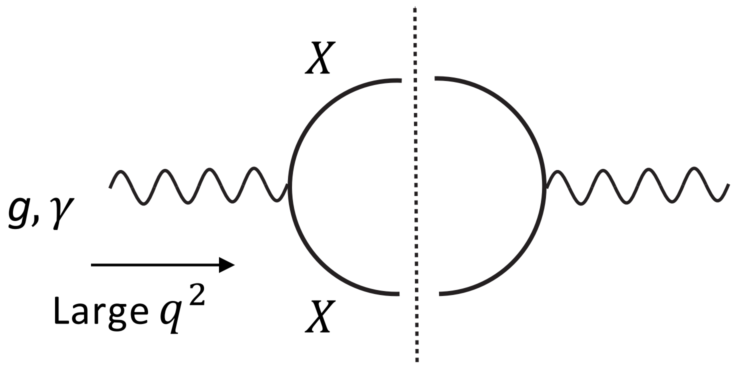
Drell-Yan process at the LHC at 8TeV and 14TeV



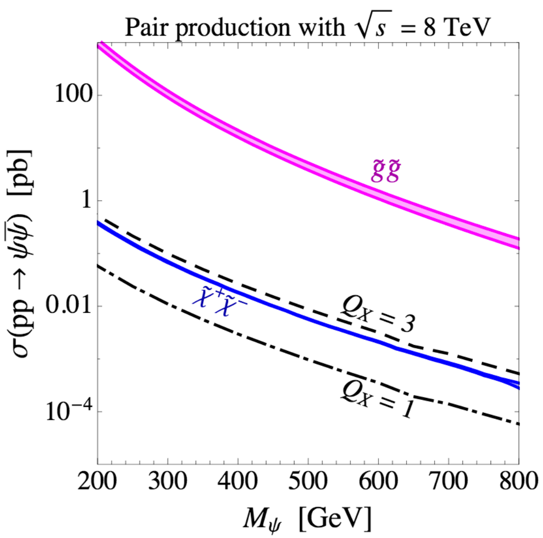


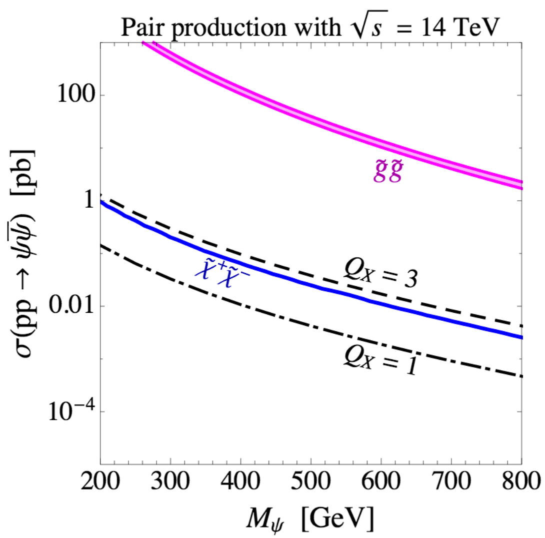
Projection at 14TeV

Drell-Yan vs. Direct detection at the LHC



When a large energy is available, X can be directly produced, e.g. Optical Theorem
Look for the smoking gun signals at the collider





Rescale by a factor of
$d_X N_X Q_X^2 \times$

❖ The direct search is not easy due to the very complicated decay modes whereas DY process depends on only quantum numbers (universal!)

Summary

$\gamma\gamma$ excess is getting better in both ATLAS and CMS

From RGE viewpoint

$\gamma\gamma$ excess and a large total width are not easy to be embedded in a weakly-coupled realization (except for the fine-tuned cases)

- ✓ It likely implies a strongly coupled dynamics not far away from O(TeV) scale

Precision Drell-Yan process

If $\gamma\gamma$ excess is confirmed, the Drell-Yan process at the LHC becomes a very important window to the New Physics

- ✓ It changes the differential cross section via the running of the gauge couplings
- ✓ It relies on only the quantum numbers, not specific to the decay channels