Gluonic Quartic Gauge Couplings @ Hadron Colliders

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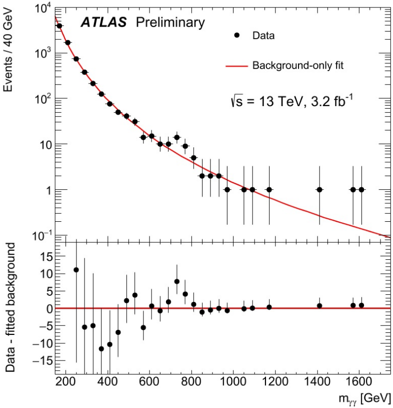
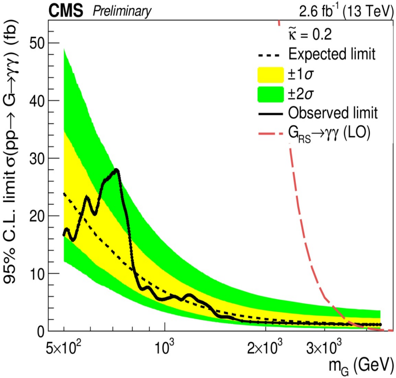
John Ellis & SFG, Phys.Rev.Lett. 121 (2018) no.4, 041801 [arXiv:1802.02416]

750GeV Diphoton





ATLAS-CONF-2015-081 (**535 citations**)

CMS PAS EXO-15-004 (**514 citations**)

At the beginning

虽千万人吾往矣！！！_哔哩哔哩(° -…

SFG, Hong-Jian He, Jing Ren, Zhong-Zhi Xiangyu, Phys.Lett. B757 (2016) 480-492 [arXiv:1602.01801]

After a while

Anyway, we can learn a lot about model buildings

Half an Year Later

I want to die.

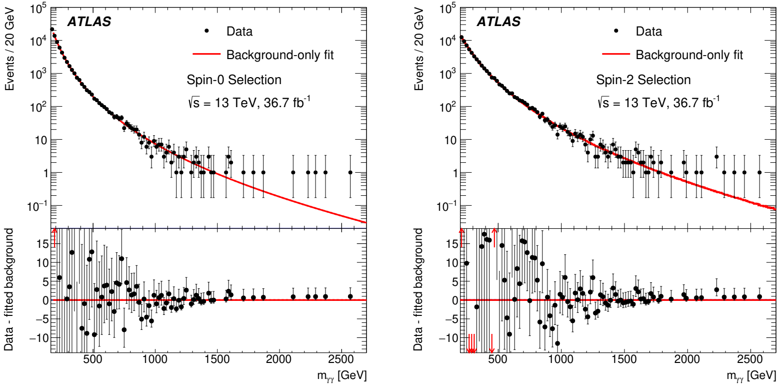
Now Alive Again

Grab Something before Standing Up

ATLAS Keeps Measuring the Diphoton Signal

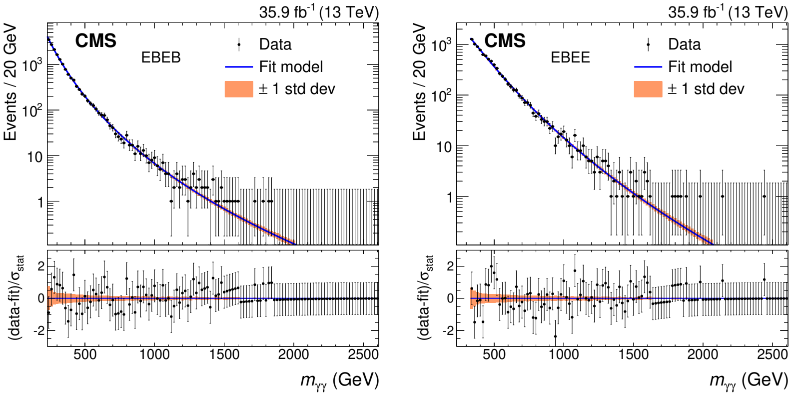
Search for new phenomena in high-mass diphoton final states using 37 fb^{-1} of proton–proton collisions collected at $\sqrt{s}$ = 13 TeV with the ATLAS detector

1707.04147v2

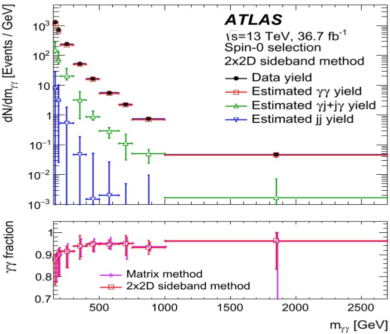


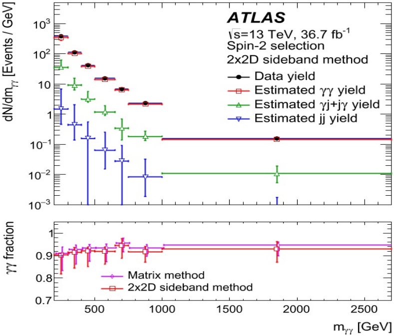
CMS Keeps Measuring the Diphoton Signal

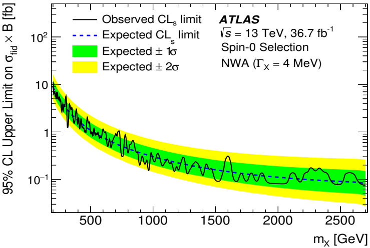
Search for physics beyond the standard model in high-mass diphoton events from proton-proton collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ 1809.00327v2

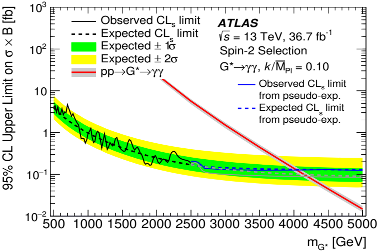


Diphoton Signal @ ATLAS

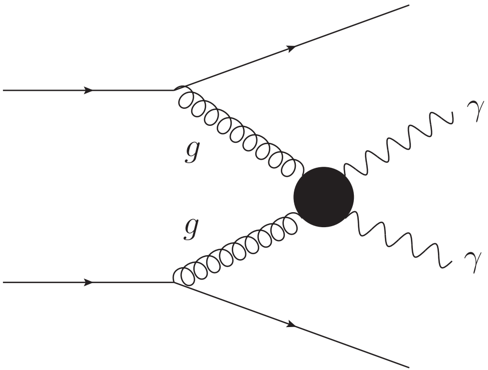








Gain Something from EFT?



Most promising channel

- Clean signal
- Largest cross section
- No interference

Gluonic Quartic Gauge Couplings (gQGC)

Born-Infeld Extensions

$$\beta^2\left[1-\sqrt{1+\sum_{\lambda=1}^{12}\frac{F^\lambda_{\mu\nu}F^{\lambda,\mu\nu}}{2\beta^2}-\left(\sum_{\lambda=1}^{12}\frac{F^\lambda_{\mu\nu}\widetilde{F}^{\lambda,\mu\nu}}{4\beta^2}\right)^2}\,\right]$$

$$\approx -\frac{1}{4}\sum_{\lambda=1}^{12}F^\lambda_{\mu\nu}F^{\lambda,\mu\nu}+\frac{1}{32\beta^2}\left[\left(\sum_{\lambda=1}^{12}F^\lambda_{\mu\nu}F^{\lambda,\mu\nu}\right)^2+\left(\sum_{\lambda=1}^{12}F^\lambda_{\mu\nu}\widetilde{F}^{\lambda,\mu\nu}\right)^2\right]\equiv\mathcal{L}_{\rm SM}+\mathcal{L}_{\mathbf{gT}}$$

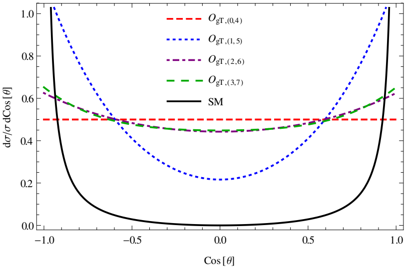
with a single parameter $\beta\equiv\mathbf{M^2}$ & $\boxed{\mathcal{L}_{\mathbf{gT}}=\sum_{i=0}^{7}\frac{1}{16\beta_i^2}\mathcal{O}_{\mathbf{gT},\mathbf{i}}}$

$$\begin{aligned}
\mathcal{O}_{gT,0} &= \sum_a G^a_{\mu\nu}G^{a,\mu\nu}\times\sum_i W^i_{\alpha\beta}W^{i,\alpha\beta}, &\quad \mathcal{O}_{gT,4} &= \sum_a G^a_{\mu\nu}G^{a,\mu\nu}\times B_{\alpha\beta}B^{\alpha\beta},\\
\mathcal{O}_{gT,1} &= \sum_a G^a_{\alpha\nu}G^{a,\mu\beta}\times\sum_i W^i_{\mu\beta}W^{i,\alpha\nu}, &\quad \mathcal{O}_{gT,5} &= \sum_a G^a_{\alpha\nu}G^{a,\mu\beta}\times B_{\mu\beta}B^{\alpha\nu},\\
\mathcal{O}_{gT,2} &= \sum_a G^a_{\alpha\mu}G^{a,\mu\beta}\times\sum_i W^i_{\nu\beta}W^{i,\alpha\nu}, &\quad \mathcal{O}_{gT,6} &= \sum_a G^a_{\alpha\mu}G^{a,\mu\beta}\times B_{\nu\beta}B^{\alpha\nu},\\
\mathcal{O}_{gT,3} &= \sum_a G^a_{\alpha\mu}G^a_{\beta\nu}\times\sum_i W^{i,\mu\beta}W^{i,\nu\alpha}, &\quad \mathcal{O}_{gT,7} &= \sum_a G^a_{\alpha\mu}G^a_{\beta\nu}\times B^{\mu\beta}B^{\nu\alpha},
\end{aligned}$$

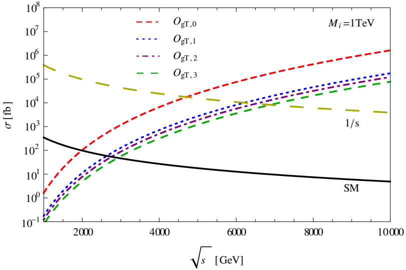
Already many discussions on EW QGC, but not gluonic ones.

Testing Dimension-8 gQGC @ Colliders

Born-Infeld ext $-\frac{1}{4}\sum_{\lambda=1}^{12} F^{\lambda}_{\mu\nu}F^{\lambda,\mu\nu} + \frac{1}{32\beta^2}\left[\left(\sum_{\lambda=1}^{12} F^{\lambda}_{\mu\nu}F^{\lambda,\mu\nu}\right)^2 + \left(\sum_{\lambda=1}^{12} F^{\lambda}_{\mu\nu}\tilde{F}^{\lambda,\mu\nu}\right)^2\right]$



Simulated with CalcHEP



$$\frac{d\sigma_{gT,i}}{dt} = \frac{(s_W^4, c_W^4)}{\beta_i^4}\begin{cases} \frac{s^2}{4096\pi} & i=0,4\,, \\ \frac{s^4-2s^2(t^2+u^2)+3(t^4+u^4)}{32768\pi s^2} & i=1,5\,, \\ \frac{2s^4+t^4+u^4}{131072\pi s^2} & i=2,6\,, \\ \frac{s^4+t^4+u^4+4t^2u^2}{131072\pi s^2} & i=3,7\,, \end{cases}$$

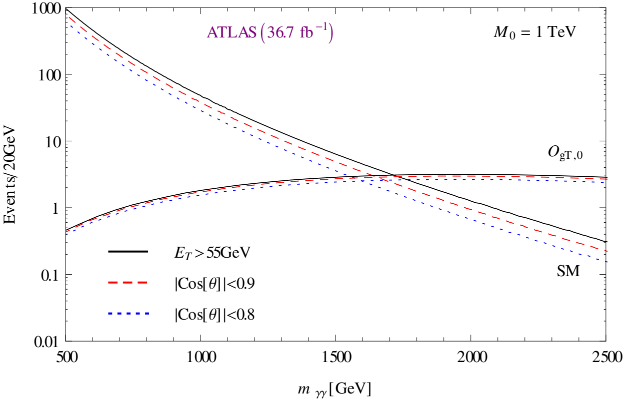
$$\sigma_{gT,i} = \frac{(s_W^4, c_W^4)}{4096\pi\beta_i^4} \times \left(1, \frac{13}{120}, \frac{3}{40}, \frac{23}{480}\right) \times s^3$$

$$\sigma_{gT,4} \approx 10\sigma_{gT,(0,5,6,7)} \approx 100\sigma_{gT,(1,2,3)}$$

$$\sigma_{\mathrm{SM}} \approx -\sum_q \frac{Q_q^4}{24\pi \mathbf{s}}[\log(1-\cos\theta_{\mathbf{cut}}) + 2]$$

Background

- **SM background** $q\bar{q} \to \gamma\gamma$: $\sigma_{\rm SM} \approx -\sum_q \frac{Q_q^4}{24\pi \mathbf{s}}[\log(1-\cos\theta_{\rm cut})+2]$



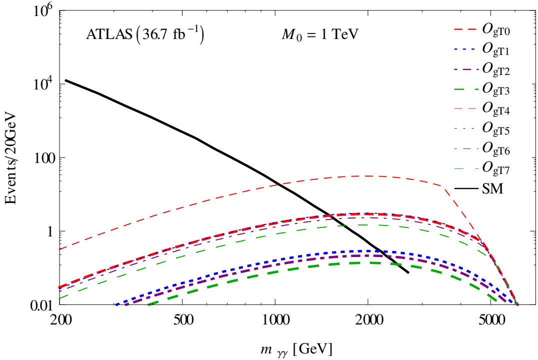
- **Dim-6 dipoles**: $\boxed{\bar{Q}\gamma^\mu W_{\mu\nu} D^\nu Q + h.c.}$ & $\boxed{\bar{Q}\gamma^\mu B_{\mu\nu} D^\nu Q + h.c.}$

Unitarity Saturation

- **If $\sqrt{s} > M_i$, EFT is no longer valid!**

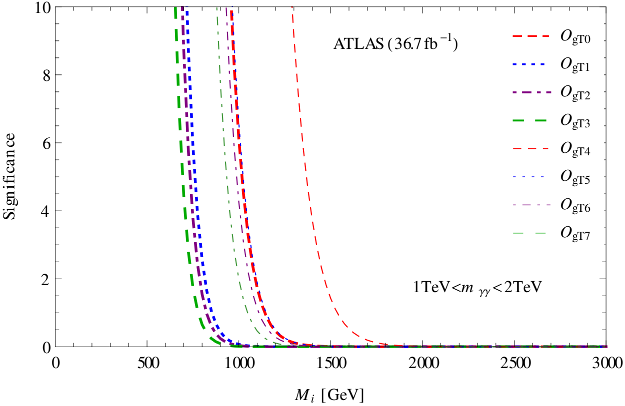
$$\sqrt{s_i} = M_i \left[\frac{(s_W^4, c_W^4)}{4096\pi} \left(1, \frac{13}{120}, \frac{3}{40}, \frac{23}{480}\right) \right]^{-\frac{1}{8}},$$

- $\boxed{\sigma \sim 1/s}$ for $\sqrt{s_i}/M_i >$ **4.71, 6.21, 6.51, 6.88, 3.49, 4.60,4.82, 5.10** $[i = 0, \cdots, 7]$



Sensitivity @ LHC

- Current ATLAS data can produce stringent bound: $\boxed{M_0 \gtrsim 1\,\text{TeV}}$

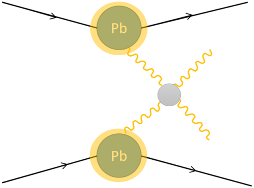


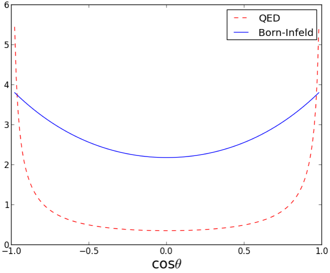
- Roughly one order of magnitude improvement from the previous analysis.

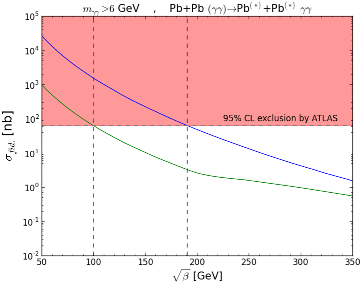
Born-Infeld QED @ Heavy Ion Collisions

$$\frac{d\sigma_{\rm BI}}{d\Omega} = \frac{1}{4096\pi^2}\frac{m_{\gamma\gamma}^6}{\beta^4}(3+\cos\theta)^2$$

$$\sigma_{\rm BI}(\gamma\gamma\to\gamma\gamma) = \frac{7}{1280\pi}\frac{m_{\gamma\gamma}^6}{\beta^4}$$



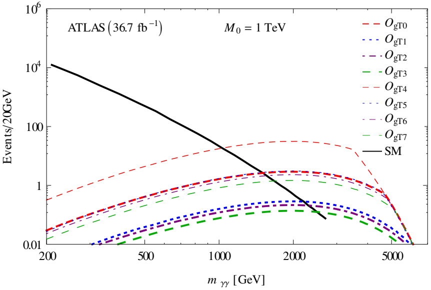


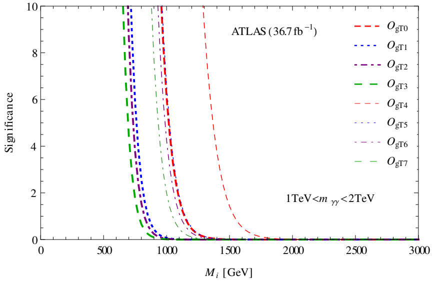


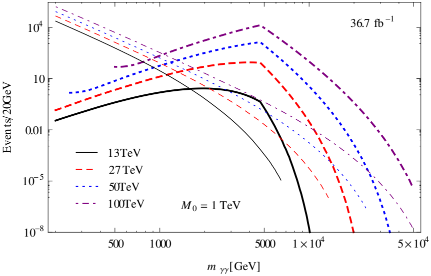
$M \gtrsim 100\,\text{GeV}$

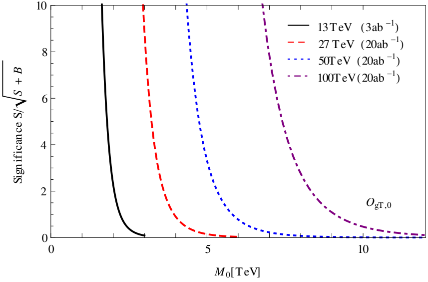
Ellis, Mavromatos, You, PRL 2017 [arXiv:1703.08450]

Significant Improvements @ Future Colliders









Summary

- **QGC is well studied, but not the gluonic counterpart**
- The **gluonic QGC** is a natural extension of QED Born-Infeld theory, supported by String Theory
- The $gg \to \gamma\gamma$ can probe the **NP related to both QCD & EW**
  - **Clean signal**
  - **SM background**
    - highly suppressed @ higher energy
    - different angular distribution
    - no interference with signal
  - **Dimension-6 dipole operators do not appear**
- The ATLAS data can significantly improve the sensitivity:
  - ATLAS $\mathrm{Pb} + \mathrm{Pb} \to \gamma\gamma$: $\mathbf{M} \gtrsim \mathbf{100}\,\mathrm{GeV}$
  - ATLAS $(37\,\mathrm{fb}^{-1})$ $gg \to \gamma\gamma$: $\mathbf{M_0} \gtrsim \mathbf{1}\,\mathrm{TeV}$
- **Another a factor of $\gtrsim 5$ improvement** @ **Future Hadron Colliders**

Thank You!