# Cross-section for low mass resonance production

Amit Adhikary

## 1 SM + Axion Model

The Effective Lagrangian for the light scalar, a, in this model is,

$$\mathcal{L}_{axion} = \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2}m_a^2 a^2 + i\sum_f g_{aff} m_f \, a \bar{f}\gamma_5 f \, . \tag{1}$$

where, $g_{aff} = \frac{C_f}{f_a}$.

| Mass ($m_a$) (GeV) | Coupling ($g_{aff}$) | Decay width ($\Gamma_a$) (GeV) |
|---|---|---|
| 20 | 0.1 | 0.340122 |
| | $10^{-3}$ | $0.340122\times10^{-4}$ |
| | $10^{-5}$ | $0.340122\times10^{-8}$ |
| 40 | 0.1 | 0.780416 |
| | $10^{-3}$ | $0.780416\times10^{-4}$ |
| | $10^{-5}$ | $0.780416\times10^{-8}$ |
| 60 | 0.1 | 1.39909 |
| | $10^{-3}$ | $1.39909\times10^{-4}$ |
| | $10^{-5}$ | $1.39909\times10^{-8}$ |

Table 1: *Total decay width of light scalar for different mass and coupling.*

### Production channels:

### 1.1 The $pp \to a\gamma$ process

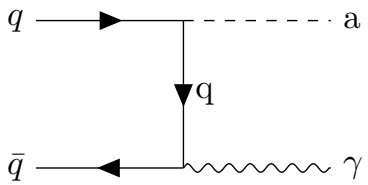


Figure 1: Feynman diagram for $pp \to a\gamma$ process.

Backgrounds:

1. $pp \to b\bar{b}\gamma$

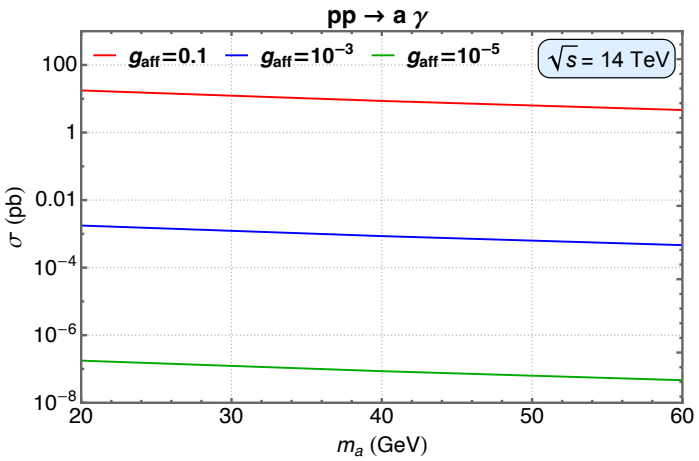


Figure 2: Production cross-section of $pp \to a\gamma$ process vs scalar mass. Here, $p_{T,\gamma} \geq 10$ GeV.

## 1.2 The $pp \to aj$ process

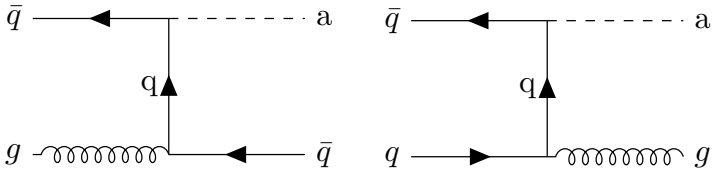


Figure 3: Feynman diagram for $pp \to aj$ process.

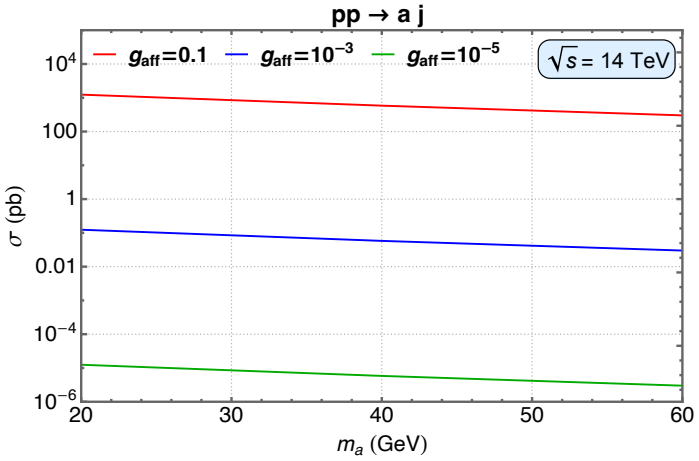


Figure 4: Production cross-section of $pp \to a\gamma$ process vs scalar mass. Here, $p_{T,j} \geq 20$ GeV.

### 1.3 $pp \to b\bar{b}a$ process

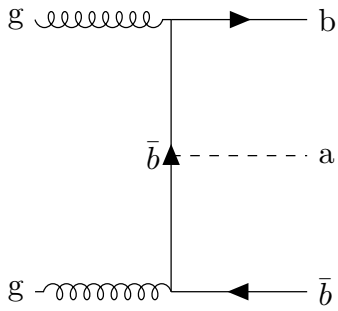


Figure 5: Feynman diagram for $pp \to b\bar{b}a$ process.

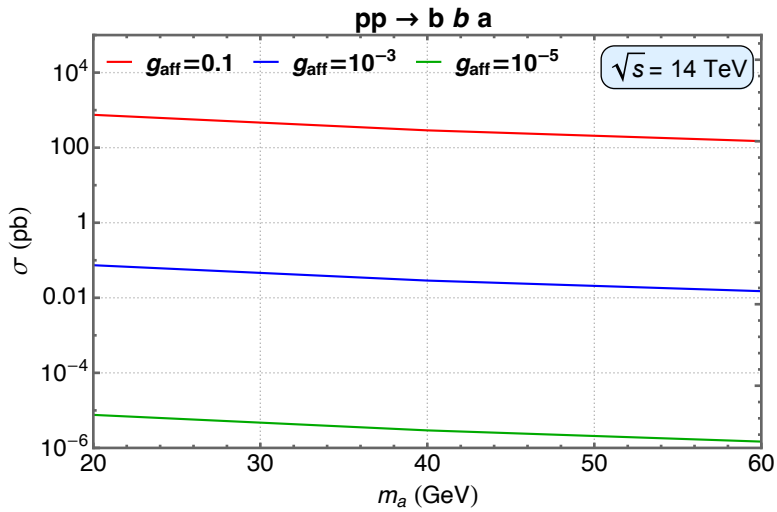


Figure 6: Production cross-section of $pp \to b\bar{b}a$ process vs scalar mass. Here, $p_{T,b} \geq 20$ GeV.

### 1.4 $pp \to t\bar{t}a$ process

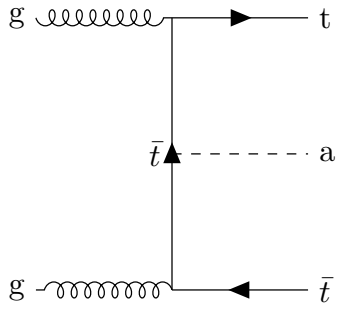


Figure 7: Feynman diagram for $pp \to t\bar{t}a$ process.

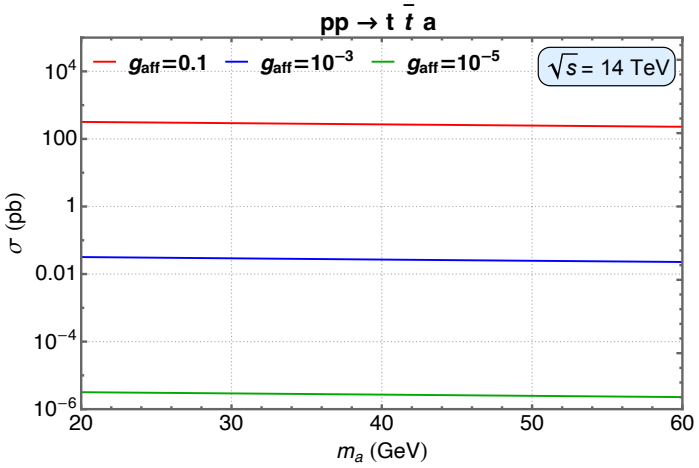


Figure 8: Production cross-section of $pp \to t\bar{t}a$ process as a function of scalar mass.

## 1.5 $pp \to aV$, $V = W/Z$ process

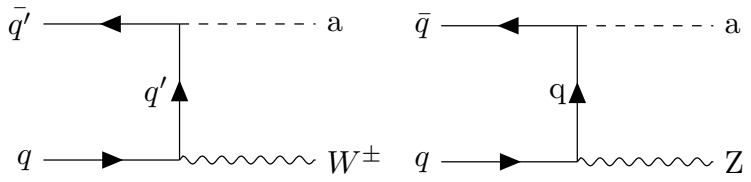


Figure 9: Feynman diagram for $pp \to aV$, $V = W/Z$ process.

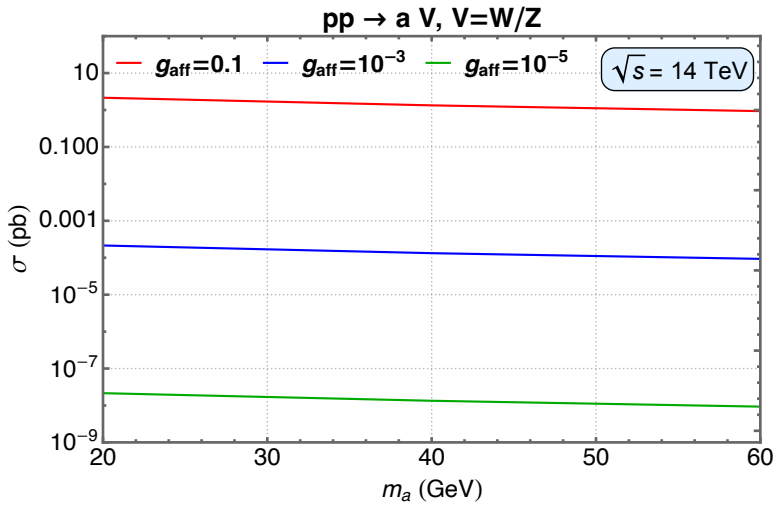


Figure 10: Production cross-section of $pp \to aV$, $V = W/Z$ process as a function of scalar mass.

**After trigger cuts:**

## 1.6 The $pp \to a\gamma$ process

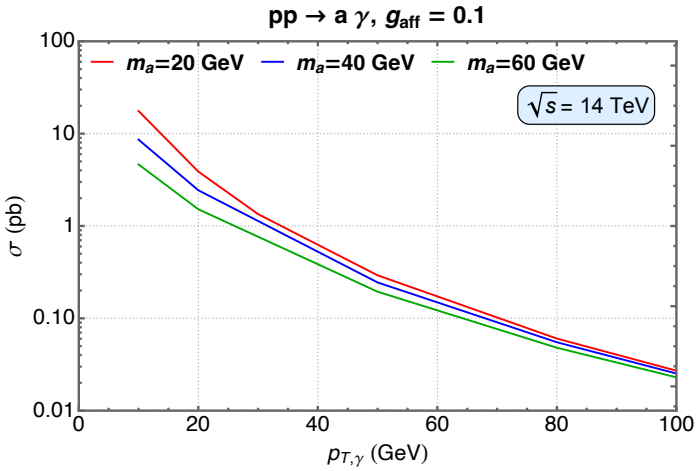


Figure 11: Production cross-section of $pp \to a\gamma$ process vs $p_{T,\gamma}$.

## 1.7 The $pp \to aj$ process

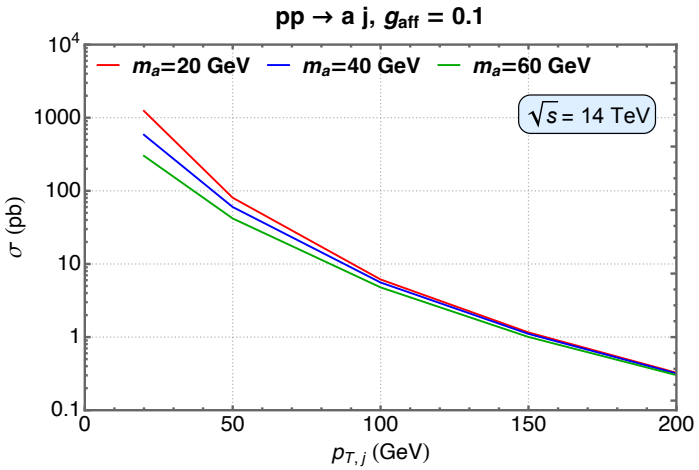


Figure 12: Production cross-section of $pp \to aj$ process vs $p_{T,j}$.

## 1.8 The $pp \to b\bar{b}a$ process

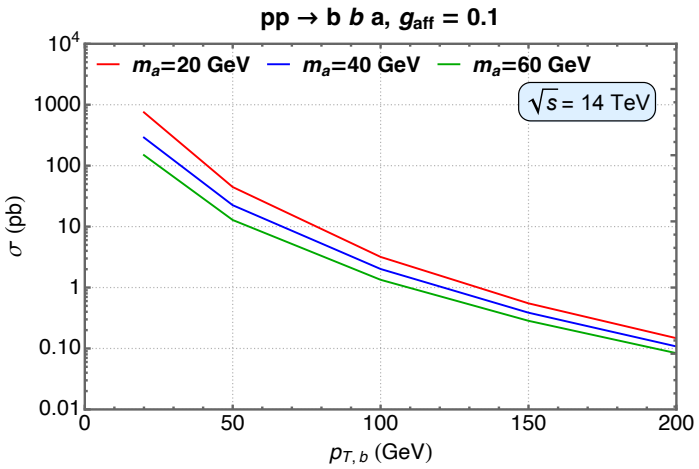


Figure 13: Production cross-section of $pp \to b\bar{b}a$ process vs $p_{T,b}$.

## 1.9 The $pp \to aV,\ V \to$ leptons process

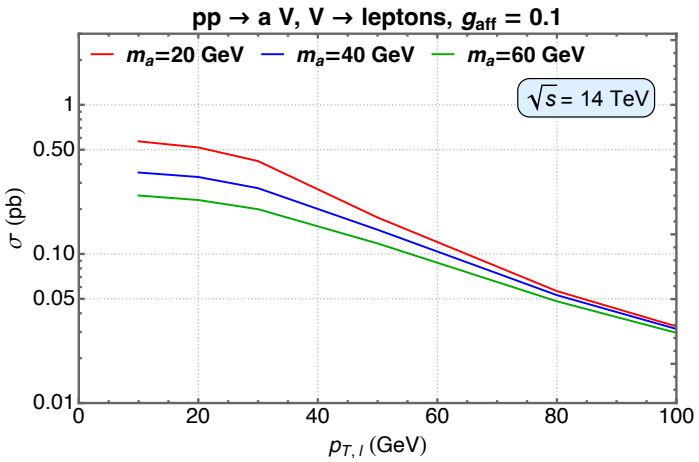


Figure 14: Production cross-section of $pp \to aV,\ V \to$ leptons process vs $p_{T,l}$.

## 1.10 The $pp \to aV,\ V \to$ jets process

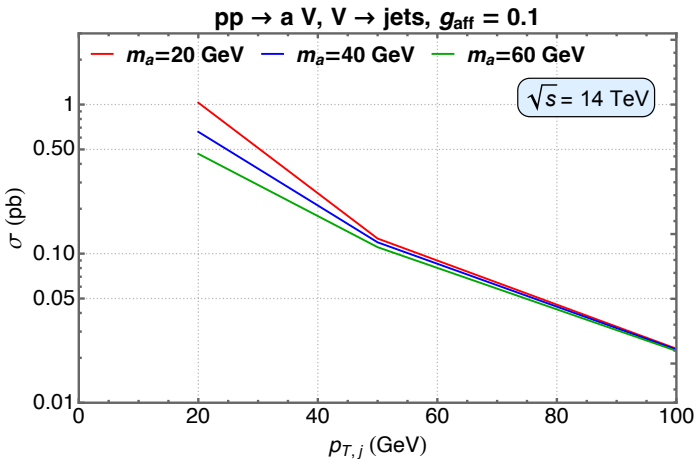


Figure 15: Production cross-section of $pp \to aV,\ V \to$ jets process vs $p_{T,j}$.

| Channel | Mass of a, $m_a$ (GeV) | Backgrounds (V=W/Z) |
|---|---|---|
| $a$ + jet, $a \to b\bar{b}$ [1] | $[70, 230]$ | QCD multijet, V+jets, $t\bar{t}$, single top |
| $a + \gamma$, $a \to$ jets [2] | $[225, 1100]$ | QCD multijet+$\gamma$ |
| $t\bar{t}a,\ a \to b\bar{b}$ [3] | $[20, 100]$ | $t\bar{t} + X$, $X = b$/light-jet/$h/V$ |
| $a,\ a \to$ jets [4] | $[450, 1800]$ | QCD multijet |
| $Zh,\ h \to aa \to 4b,\ Z \to ll$ [5] | $[20, 60]$ | $t\bar{t}$, $Z$+jets, $t\bar{t}b\bar{b}$, $VV$+jets, $t\bar{t}V$, $Wt$, $t\bar{t}t\bar{t}$, $t\bar{t}WW$ |

Table 2: *Existing collider searches for scalar production, decaying to b-jets/ light jets.*

# References


[1] ATLAS collaboration, *Search for boosted resonances decaying to two b-quarks and produced in association with a jet at $\sqrt{s} = 13$ TeV with the ATLAS detector*, tech. rep., CERN, Geneva, 2018.

[2] ATLAS collaboration, M. Aaboud et al., *Search for low-mass resonances decaying into two jets and produced in association with a photon using pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, *Phys. Lett. B* **795** (2019) 56–75, [1901.10917].

[3] M. Casolino, T. Farooque, A. Juste, T. Liu and M. Spannowsky, *Probing a light CP-odd scalar in di-top-associated production at the LHC*, *Eur. Phys. J. C* **75** (2015) 498, [1507.07004].

[4] ATLAS collaboration, M. Aaboud et al., *Search for low-mass dijet resonances using trigger-level jets with the ATLAS detector in pp collisions at $\sqrt{s} = 13$ TeV*, *Phys. Rev. Lett.* **121** (2018) 081801, [1804.03496].

[5] ATLAS collaboration, G. Aad et al., *Search for Higgs boson decays into two new low-mass spin-0 particles in the 4b channel with the ATLAS detector using pp collisions at $\sqrt{s} = 13$ TeV*, *Phys. Rev. D* **102** (2020) 112006, [2005.12236].