LHC prospects for low mass ALP searches via bb signature

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Based on

2410.09033, with Aoife Bharucha, Lorenzo Feligioni and Michele Frigerio

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Why to look for light resonances?

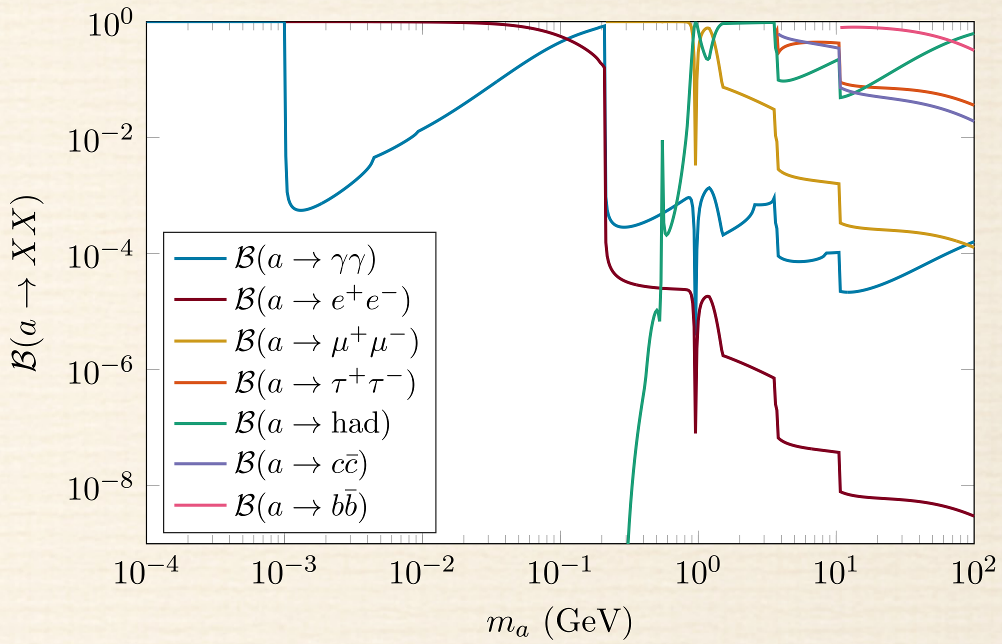
Well-motivated beyond the SM (BSM) models : LHC is searching for new states and pushing the scale to ≫ TeV. But new light states could be present. $m_a = \mathcal{O}(10 - 100)$ GeV

ATLAS and CMS searches: 1801.08769, 1909.04114, 1905.10331

Axion-like particle (ALP): appear in portal models and interesting for explaining non-thermal dark matter production mechanisms [2209.03932].

The preferred fermionic decay of a light scalar is to $b\bar{b}$ below top-quark mass. So we focus on the final state $a \to b\bar{b}$ which is not yet explored.

2209.03932, A. Bharucha, F. Brümmer, N. Desai, S. Mutzel



Difficulties:

- Object reconstruction ⇨ Jet substructure
- Background contamination ⇨ Prong discriminant
- Trigger requirements ⇨ $pp \to a + \gamma$, and lowering trigger threshold

Signal and Backgrounds

$$\mathscr{L}_{\mathrm{ALP}} \supset \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2} m_a^2 a^2 + i \sum_f g_{aff} m_f a \bar{f}\gamma_5 f \, , \quad (m_a, \ g_{aff})$$

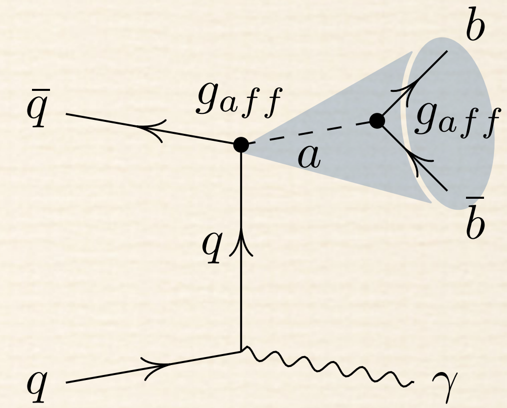
ALP-fermion coupling : $g_{aff} = \frac{C_f}{f_a}$, C_f is dimensionless and f_a is an energy scale. We assume C_f to be universal for all SM fermions.

Signal :

$pp \to a\gamma \to b\bar{b}\gamma$ (a ≡ ALP)

ALP Mass Range : m_a = [12 , 100] GeV

Madgraph, Pythia8, Delphes



AK1.0 (Boosted)

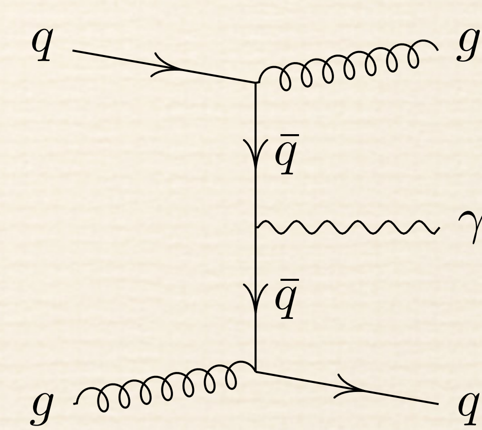
m_{SD} = mass of soft-drop AK1 jet

high $p_{T,\gamma}$

Backgrounds :

Multijet ∈ Multijet+γ, $W + \gamma$, $Z + \gamma$

Pythia8, Pythia8, Delphes



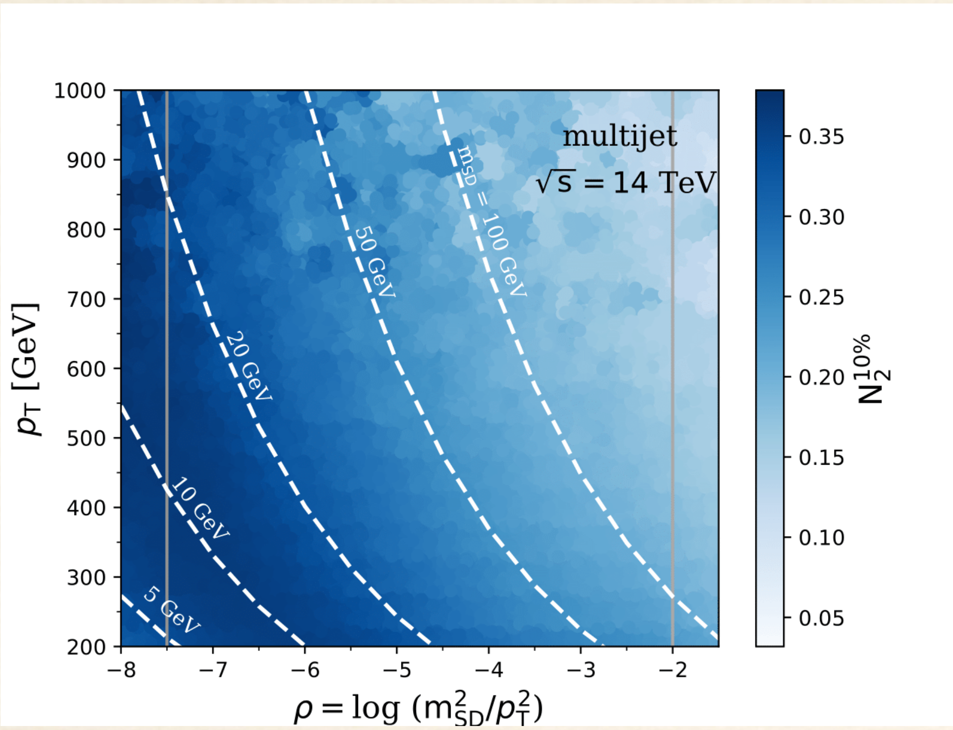
AK1.0

Flavor discussion later

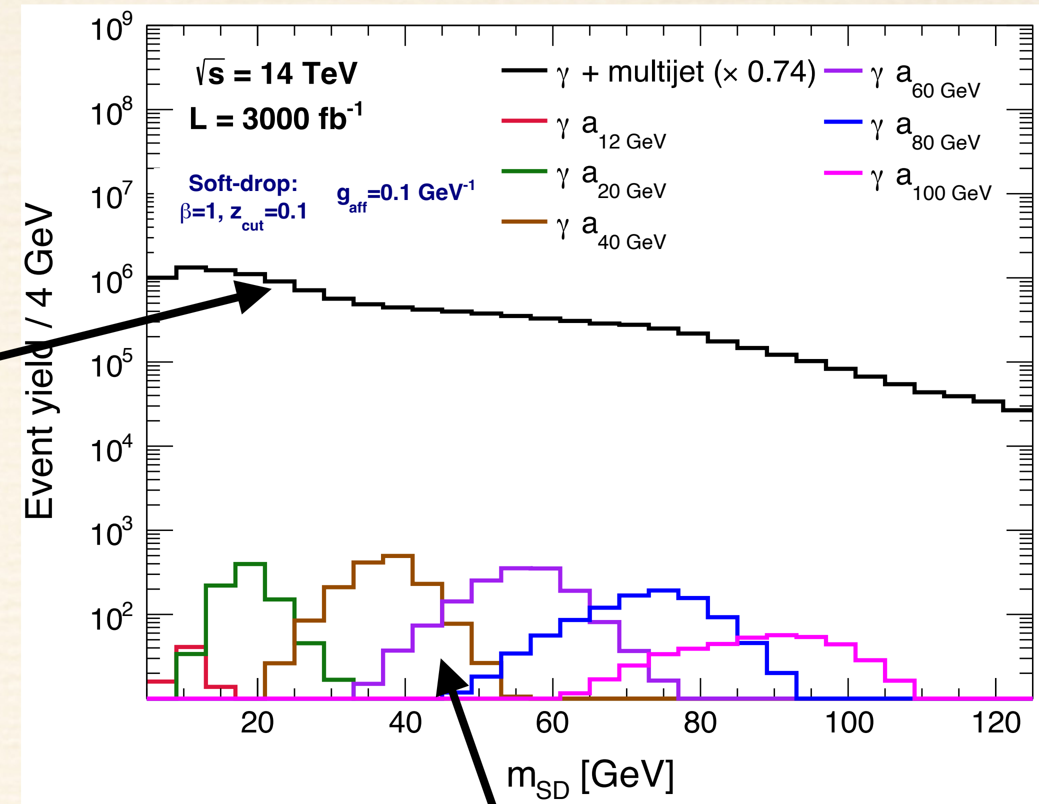
Grooming AK1.0 jet : Soft-drop ($z_{\mathrm{cut}} = 0.1$, $\beta = 1$)

ATL-PHYS-PUB-2021-028

2-prong discriminant observable



m_{SD} = mass of the soft-dropped Fatjet



Background

Signal

$N_2^{DDT}(\rho, p_T) \equiv N_2 - N_2^{10\%}(\rho, p_T)$

1603.00027, James Dolen, Philip Harris, Simone Marzani, Salvatore Rappoccio, Nhan Tran

N_2 = 2-prong discriminating observable = $\frac{{}_2e_3}{({}_1e_2)^2}$

$N_2^{10\%}$ = cut on N_2 to reject 90 % of multijet background events

$\rho = \log(m_{SD}^2/p_T^2)$, a dimensionless scaling variable

$${}_1e_2 = \sum_{1\le i<j\le N} z_i z_j \Delta R_{ij}\,,$$

$${}_2e_3 = \sum_{1\le i<j<k\le N} z_i z_j z_k \min\left\{\Delta R_{ij}\Delta R_{ik}\,, \Delta R_{ij}\Delta R_{jk}\,, \Delta R_{ik}\Delta R_{jk}\right\}, \quad z_i \equiv \frac{p_{T,i}}{p_{T,jet}}$$

Selection requirements	
$p_{T,\gamma}$	> 160 GeV
$\lvert\eta_\gamma\rvert$	< 2.1
$p_{T,AK1.0}$	> 200 GeV
$\Delta R(\gamma,\ AK1.0)$	> 2.2
ρ	[−7.5, −2.0]
N_2^{DDT}	< 0

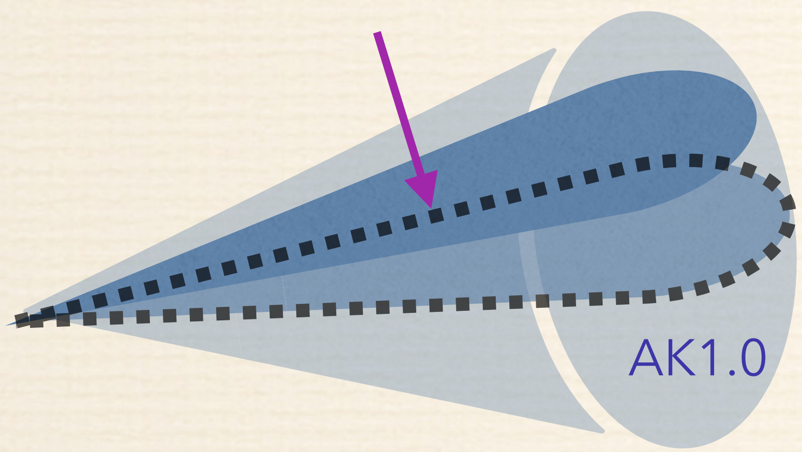
b-tagging of AK1.0 jet

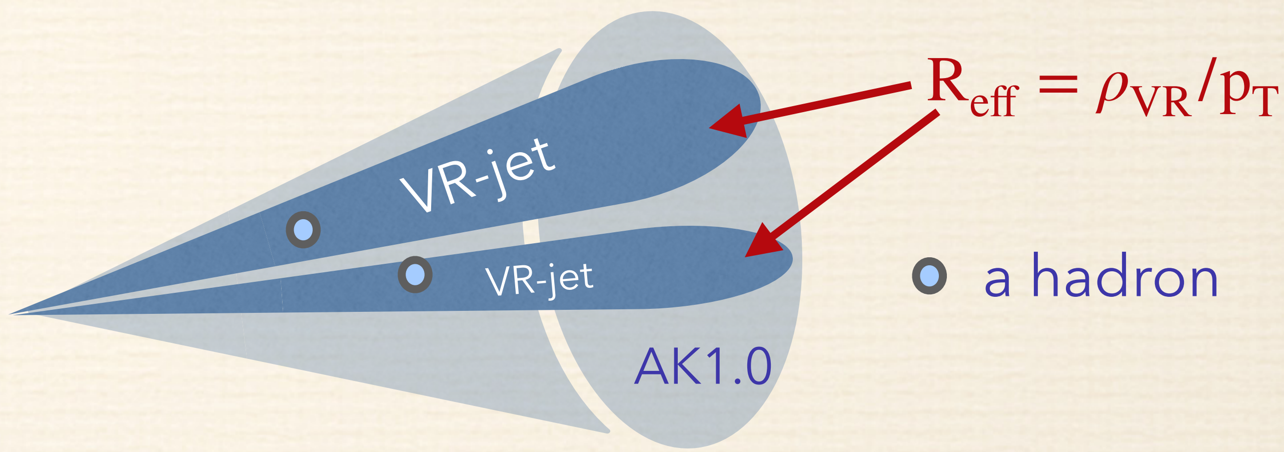
Flavor labelling [ATL-PHYS-PUB-2023-021] **: Find two small radius subjets,** variable radius (VR), inside the AK1.0 jet and **match each of them to a hadron** in event.

Variable Radius (VR)

JHEP 06 (2009) 059, D. Krohn, J. Thaler and L.-T. Wang

Merged Fixed Radius subjets! ✘





Categories in multijet background : **bb, bc, bl, ll,cl,cc**

b : b-jet **c** : c-jet **l** : light-jet

Flavor labelling : **80% bb-tag**ging signal efficiency is used

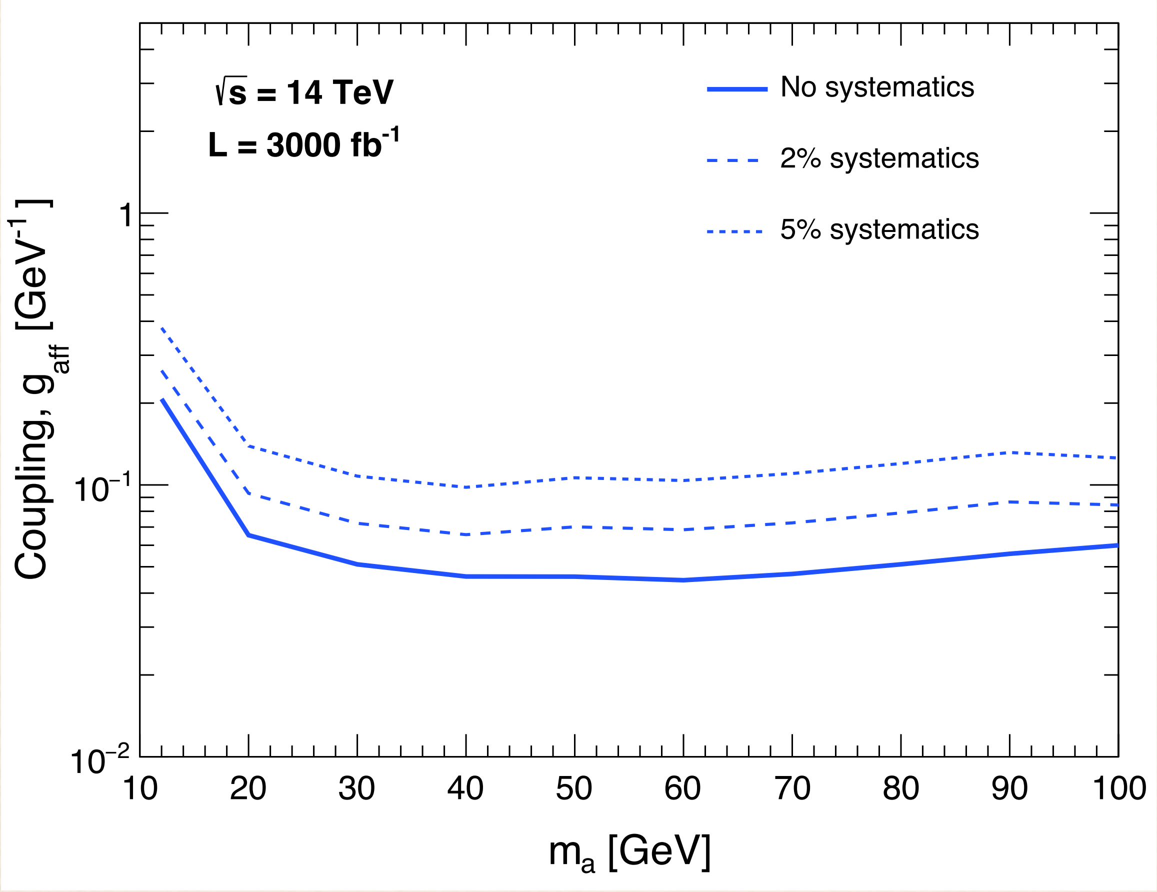
Projected sensitivities

Crystal ball fits to the Jet mass, m_{SD} variable, Chosen mass range = $[\mu + \sigma, \mu - \sigma]$.

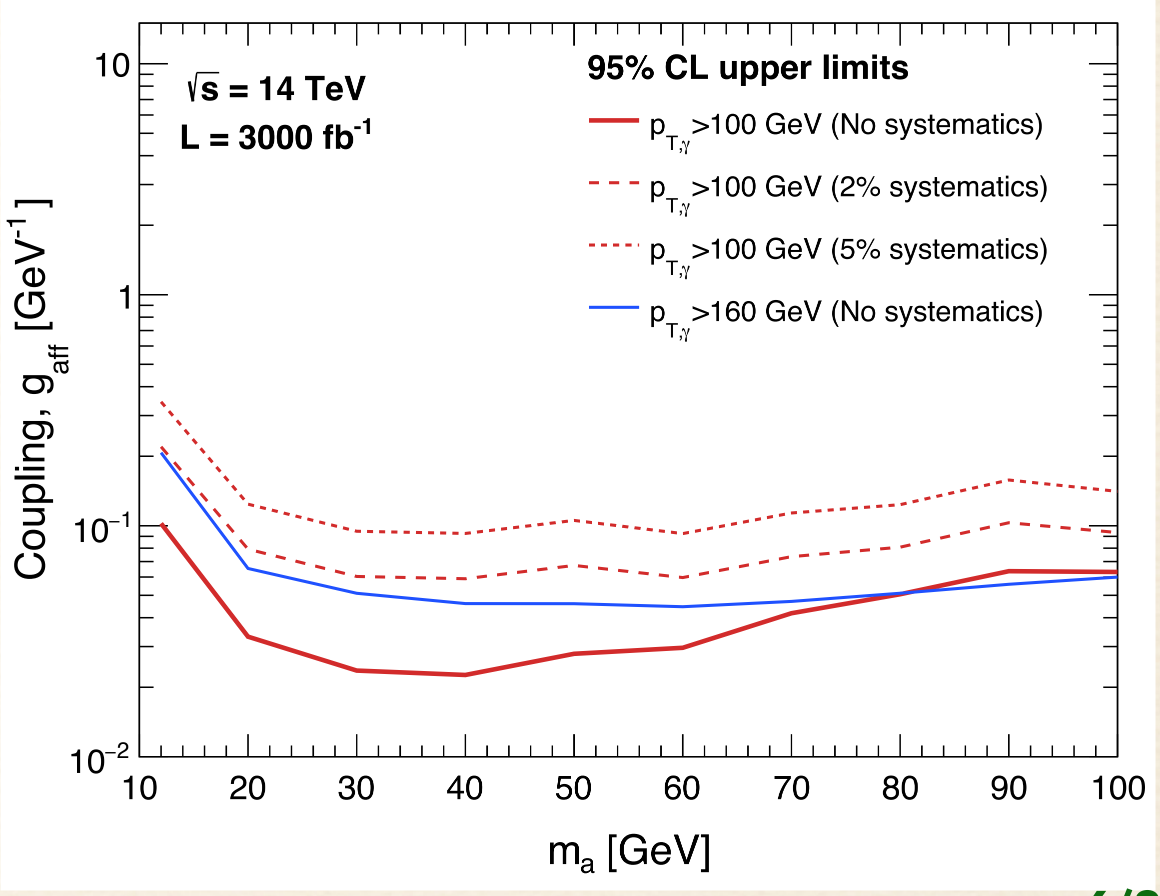
95 % CL exclusions on g_{aff} :

Lowering trigger threshold

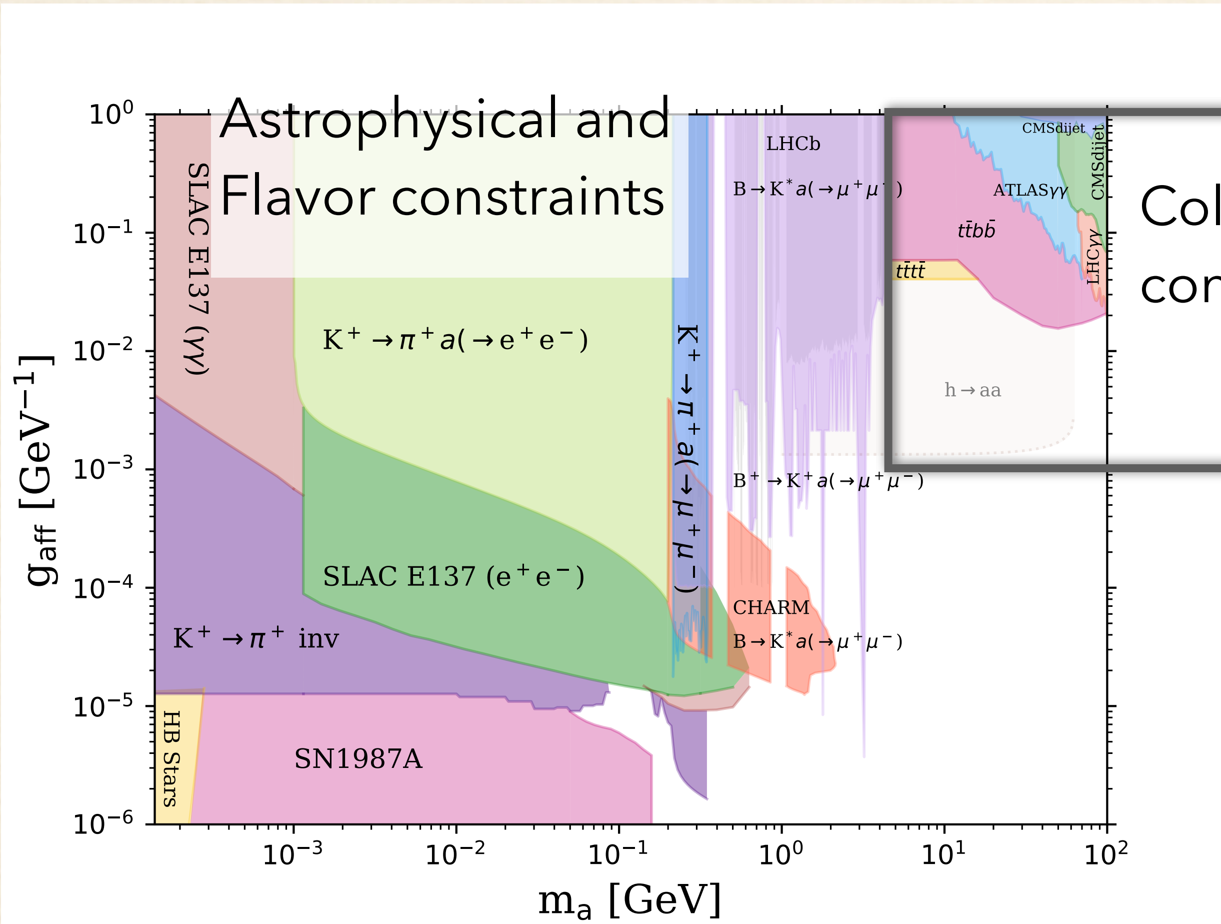
$p_{T,\gamma}$ > 160 GeV



$p_{T,\gamma}$ > 100 GeV



Status of the parameter space



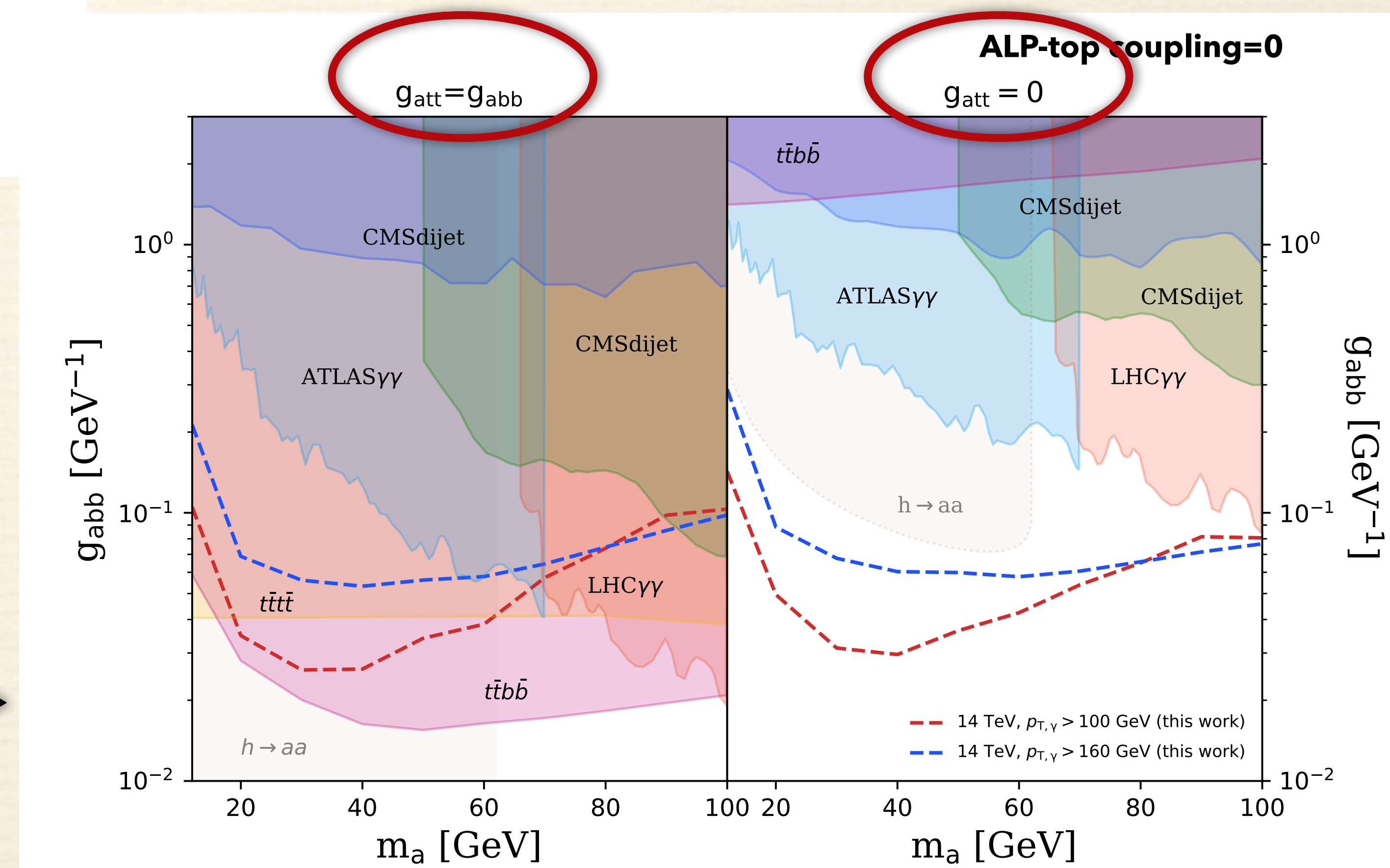
Current parameter space of m_a - g_{aff}

$t\bar{t}b\bar{b}, t\bar{t}t\bar{t}$: ALP contribution to SM production cross-section

di-jet, di-photon : ATLAS/CMS measurements are interpreted in ALP the model

$h \to aa$: Decay via fermion loops and applied the measured Br($h \to$ BSM)

Comparison with derived limits



Summary and outlook

- Light resonance searches are important along with TeV scale physics as a solution to many BSM physics.
- ALPs are an interesting avenue to look for light scalars.
- They can be looked for in different kind of final states at LHC. We explored associated production here.
- Jet substructure techniques can improve analysis in most of the low mass regions.
- b-tagging is important to reject backgrounds in these kinds of signature.
- Possibly new trigger requirements may improve these searchers further.
- The techniques used can be applied to any low mass resonance decaying to $b\bar{b}$.

Thank you

Changing the β parameter

$$\text{Soft-drop condition}: \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} > z_{cut} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$$