Simplifying Multidimensional Constraints on Narrow Resonances

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Based on work presented in
[arXiv:2103.06283]

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Introduction

- In this talk we focus on model-independent constraints from narrow resonance searches.
- To maximize the information gained from the LHC, we should also consider combinations of channels.
- How can we best maintain model-independence when combining statistics from multiple channels?
- Here we will focus on the case of combining two channels with an assumed common production mode.

Simplified Limits

- For single channel searches for narrow width resonances, simplified limits were introduced by Chivukula et al. [1607.05525]

- Use the NWA to constrain model-independent products of BRs,

$$\sigma(ab \to R \to xy) \propto \mathrm{BR}_{ab}\,\mathrm{BR}_{xy}\,\Gamma_R/M_R.$$

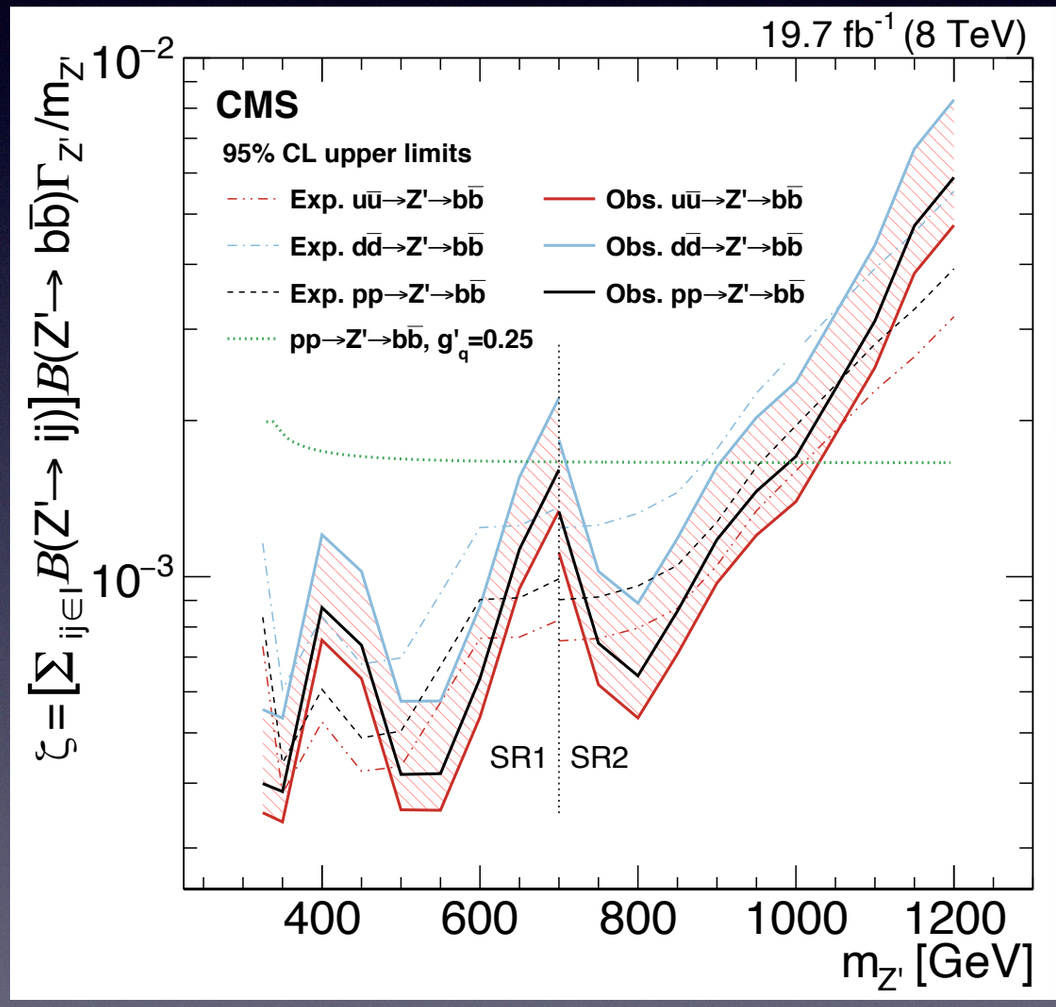
- The simplified limits variable is defined as

$$\zeta \equiv \mathrm{BR}_{ab}\,\mathrm{BR}_{xy}\,\Gamma_R/M_R = \frac{\sigma(pp \to R \to xy)}{16\pi^2\mathcal{N}}\left[\frac{1+\delta_{ab}}{s}\frac{dL_{ab}}{d\tau}\right]^{-1}_{\tau=M_R^2/s}.$$

- By deconvolving the proton PDFs from the constraints, one can parameterize directly in terms of the resonance properties: BR's, Γ_R, and M_R.

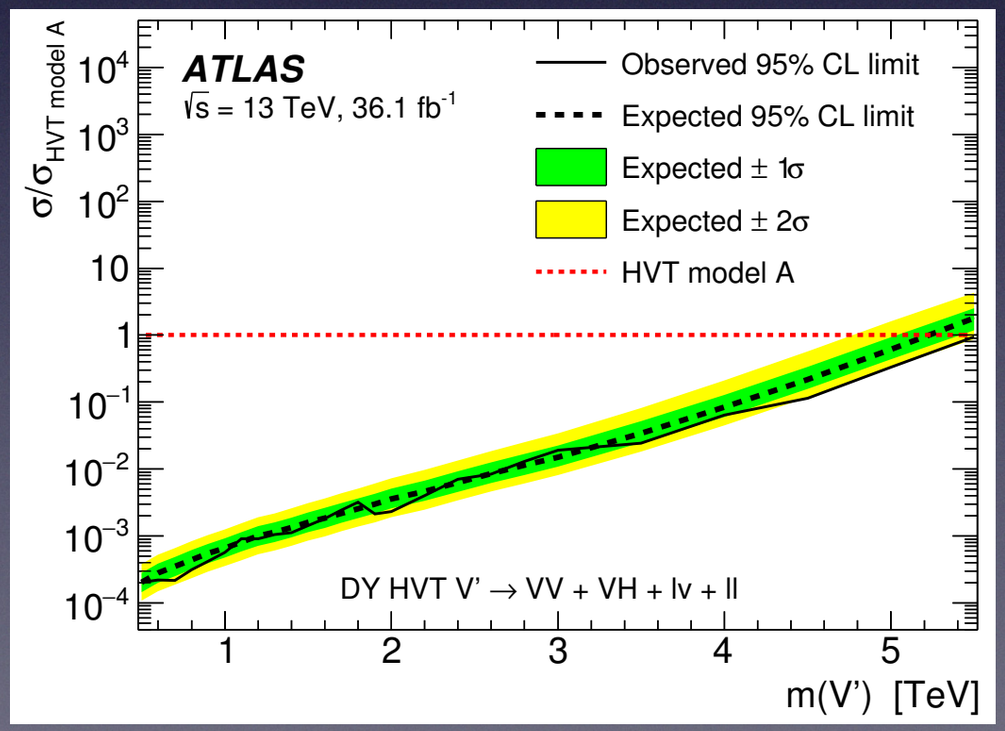
Simplified Limits

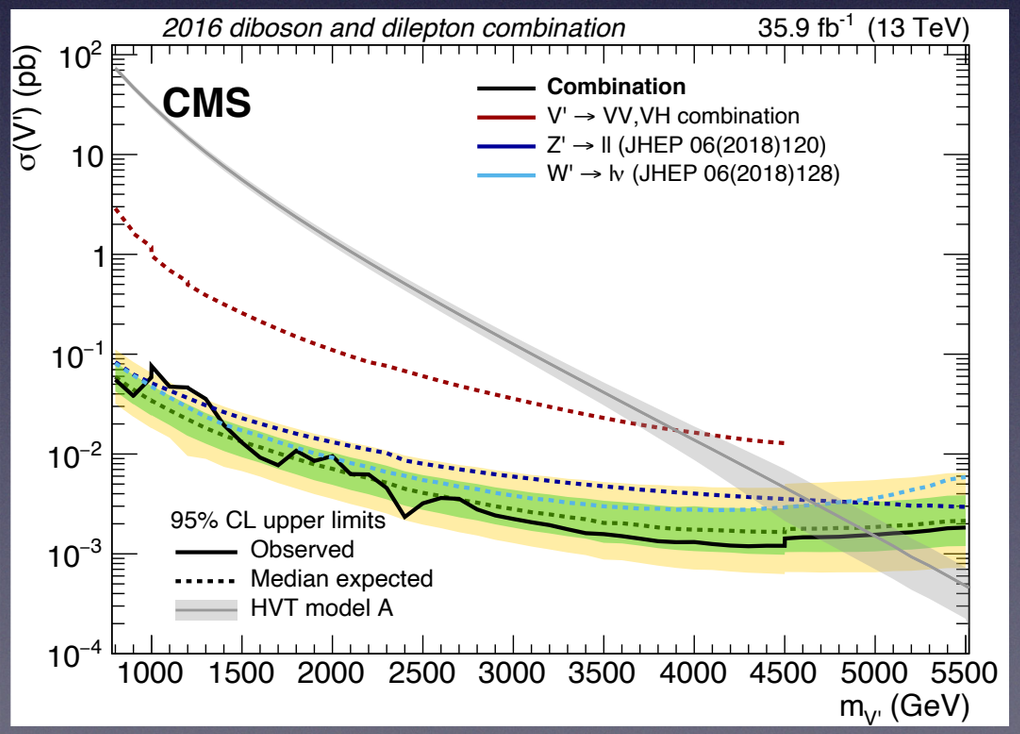
- Employed previously by CMS to constrain $pp \to Z' \to bb$ [1802.06149]



Combined Constraints

- Recently, there has been an interest in combining constraints from multiple channels by both ATLAS [1808.02380] and CMS [1906.00057]





Combined Constraints

- A natural choice is to combine two observations using a common quantity, σ_{prod}. This requires one to know the relationship between BRs.

- Mono-channel experimental acceptance is relatively insensitive to specific model assumptions, depending predominantly on the spin and helicity of the resonance.

- This allows us to translate constraints smoothly between models. How can we incorporate this property for multi-channel searches?

Combined Constraints

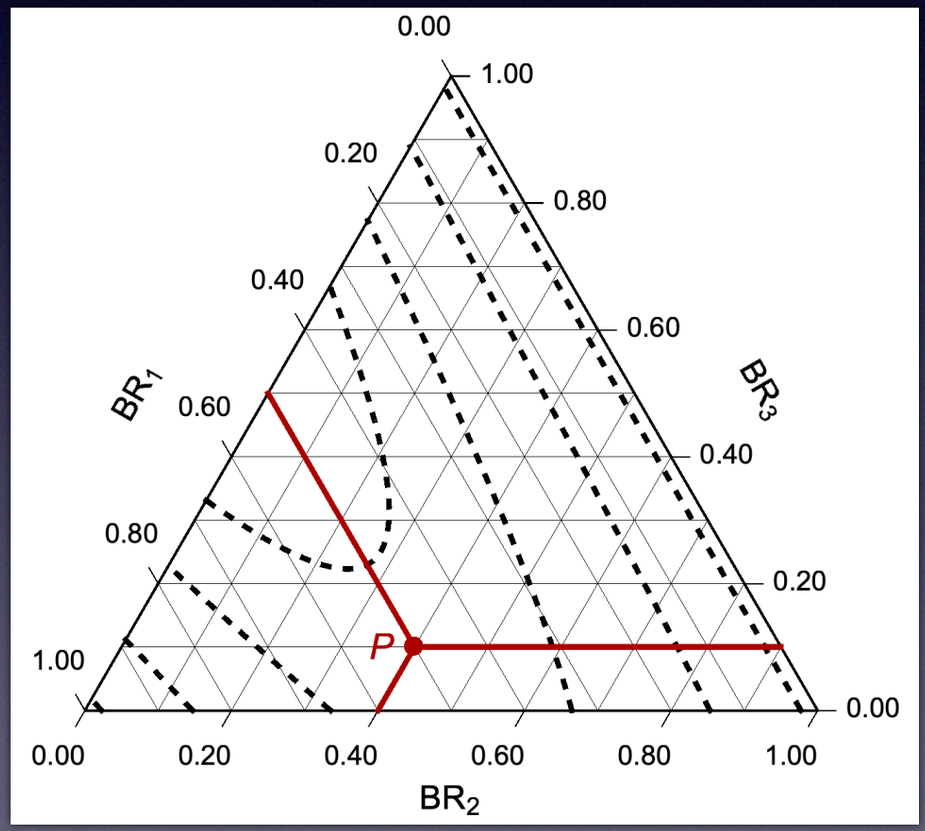
- Returning to the NWA, recall $\sigma(ab \to R \to xy) \propto \mathrm{BR}_{ab}\,\mathrm{BR}_{xy}\,\Gamma_R/M_R$.

- For three dominant BRs, we can project limits onto a 2D plane using the simple unitarity property

$$\sum_{i=1}^{3} \mathrm{BR}_i = 1.$$

- Of the two remaining degrees of freedom, Γ_R and M_R, can fix one and constrain the other.

Ternary Diagram



Combined Constraints

- Of course, in many cases it is not reasonable to assume that there are only two dominant decay modes.

- The scenario presented here can be trivially extended to models with more decay channels via the rescaling

$$\widetilde{\mathrm{BR}}_i \equiv \mathrm{BR}_i / \left(1 - \mathrm{BR}_{\mathrm{other}}\right), \quad \widetilde{\Gamma}_R \equiv \Gamma_R \left(1 - \mathrm{BR}_{\mathrm{other}}\right)^2, \quad \sum_{i=1}^{3} \widetilde{BR}_i = 1,$$

  which leaves σ^{NWA} and the simplified limits variable ζ invariant.

- The focus on a ternary diagram serves to address the question of presentation in a paper. For a given model's parameter space, it is often found that only a few modes provide similar experimental sensitivity.

Combined Constraints

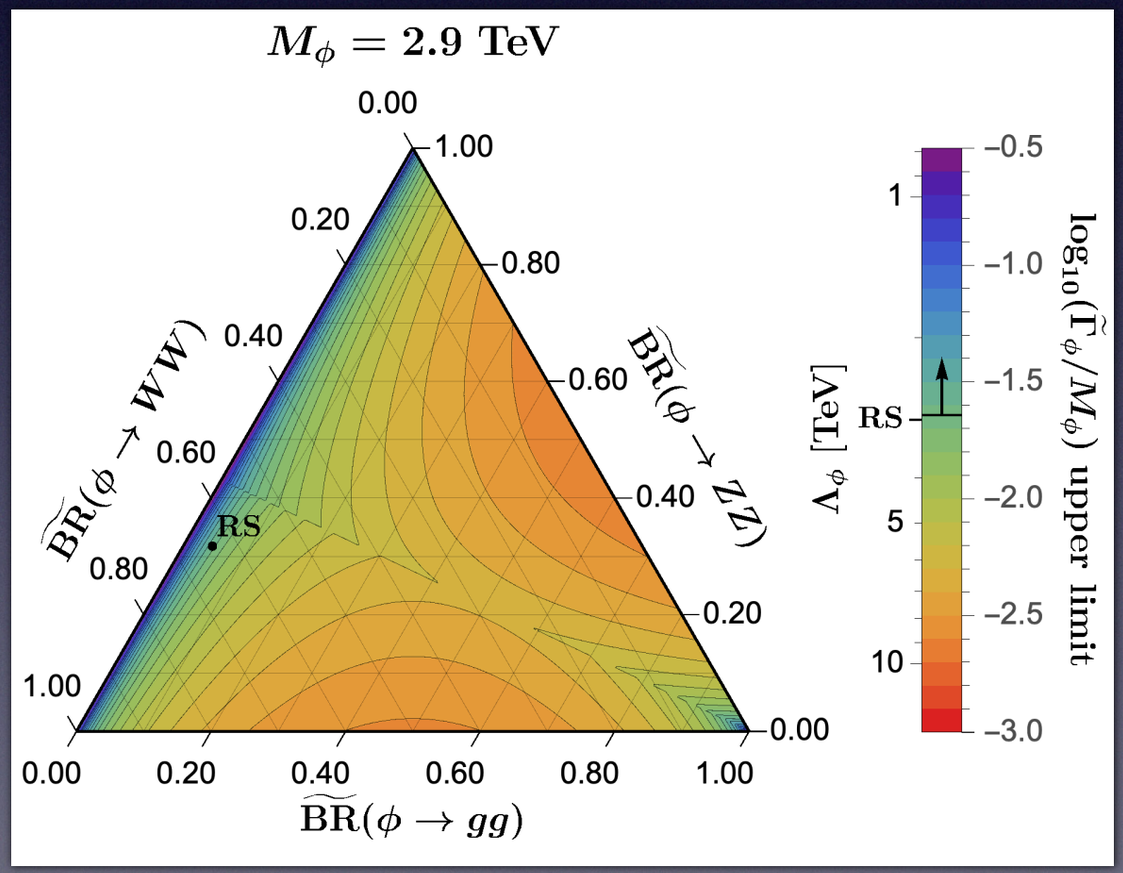
$$pp \to \phi \to VV$$

- Making the simplifying assumption

$$\sigma^{95}_{\text{prod}} = \begin{cases} \sigma_1^{\text{obs}}/\text{BR}_1 & \sigma_1^{\text{exp}}/\text{BR}_1 < \sigma_2^{\text{exp}}/\text{BR}_2\,, \\ \sigma_2^{\text{obs}}/\text{BR}_2 & \text{otherwise}\,, \end{cases}$$

- We display constraints on a benchmark RS radion, $\Lambda_\phi = 3$ TeV & $kL = 35$.

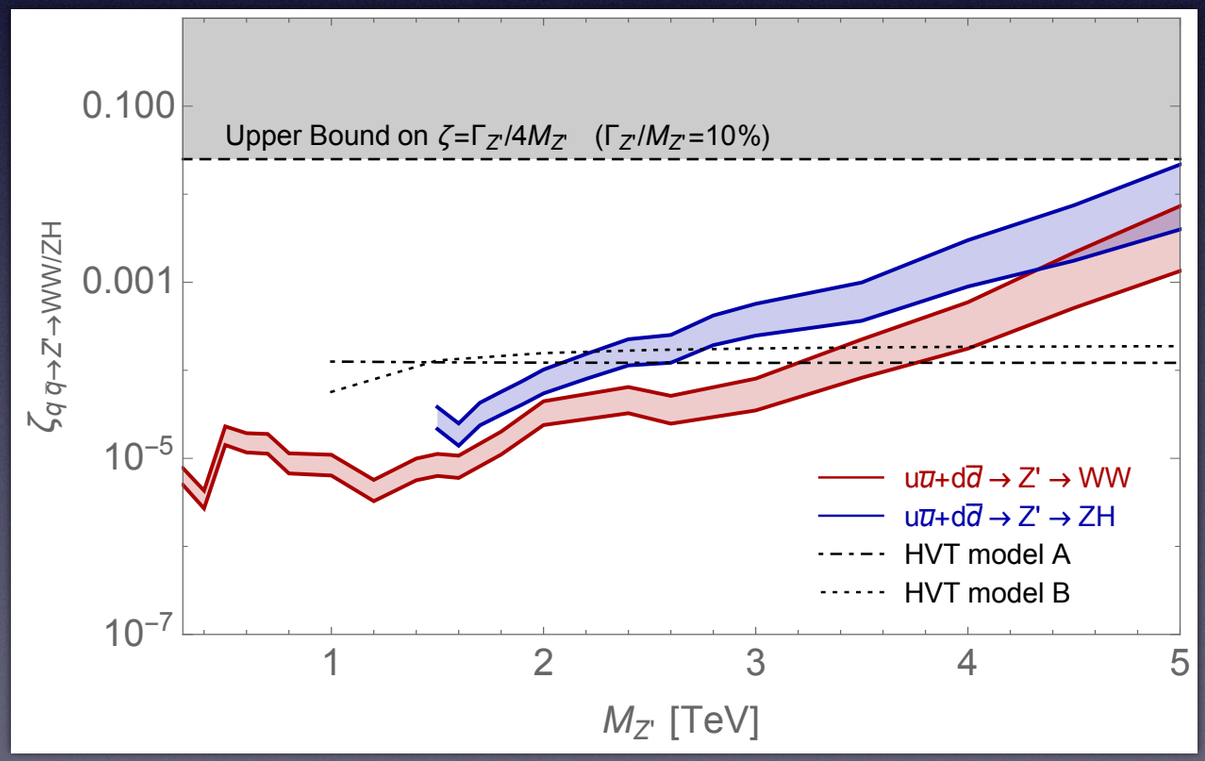
- For this example we fix $M_\phi = 2.9$ TeV while displaying limits on Γ_ϕ / M_ϕ. Constraints from ATLAS. [2004.14636]



Production Modes

$$pp \to Z' \to VV$$

- When considering mixed production modes, an ambiguity can arise in the simplified parameter,
  $\zeta = \sum_{ab} \mathrm{BR}_{ab}\, \mathrm{BR}_{ij}\, \Gamma_R / M_R$.
- Consider Z' production via Drell-Yan. Produced primarily from $u\bar{u} + d\bar{d}$.
- Without imposing model-specific assumptions about $\mathrm{BR}_{u\bar{u}}/\mathrm{BR}_{d\bar{d}}$, the strict limit from $\sigma_{\mathrm{prod}} \times \mathrm{BR}$ becomes a band. Constraints from ATLAS. [2004.14636] [2007.05293]

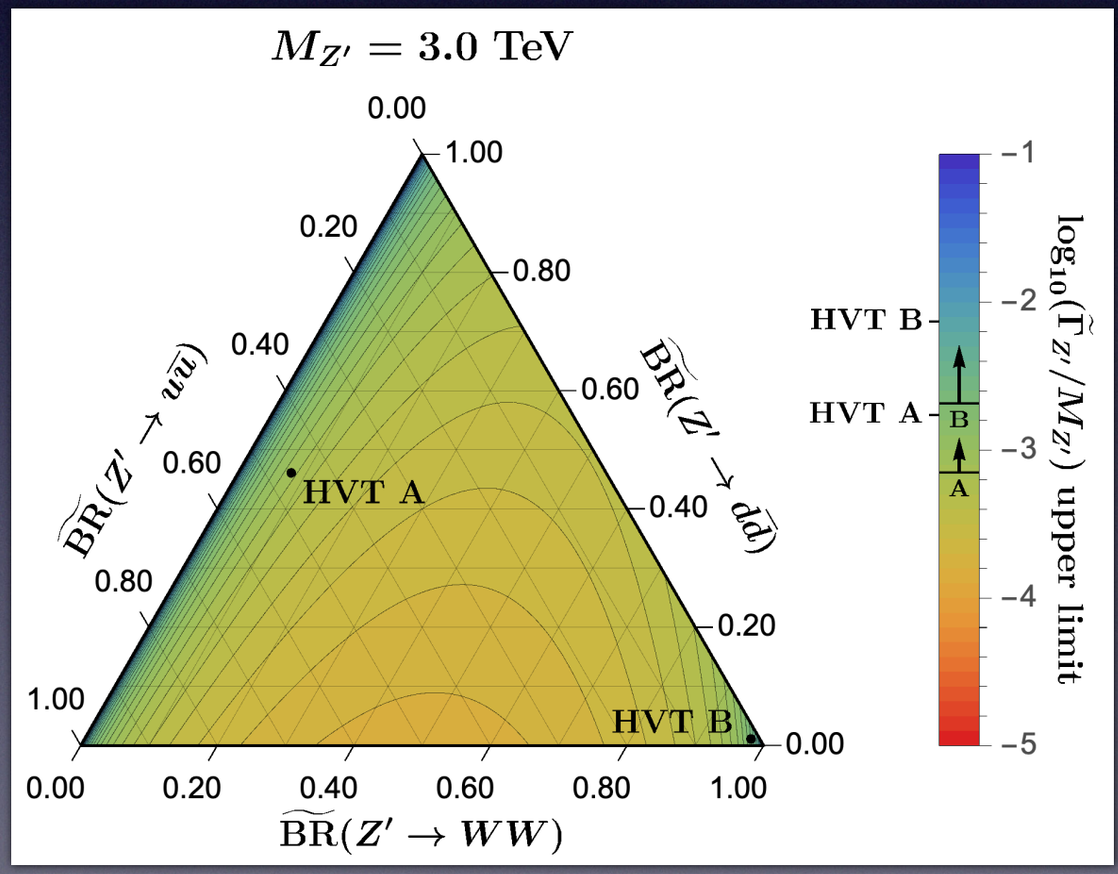


Production Modes

$$pp \to Z' \to W^+W^-$$

- We display constraints on HVT benchmarks Z',
  A. $g_V = 1$ (weakly coupled)
  B. $g_V = 3$ (strongly coupled)

- For this example we fix $M_{Z'} = 3$ TeV while displaying limits on Γ_ϕ / M_ϕ. Constraints from ATLAS. [2004.14636]



Outlook

- For searches encompassing more than a few independent channels, the principles presented here can be easily extended to larger simplexes.
- Although one can not easily plot a larger simplex, a statistical analysis of the constraints in this parameter space can nevertheless help to understand the shape of the allowed region for a given model.

Conclusion

- We have presented a model-independent method to explore combining narrow resonance searches.
- Ternary diagrams provide a simple method of displaying combined constraints from two channels, and are complimentary to traditional $\sigma \times$ BR limits.
- Larger digital data sets can be stored and distributed for analysis using this simplified limits parametrization and, for example, the HEPdata repository.