Simplifying Multidimensional Constraints on Narrow Resonances

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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,
\[ \sigma(ab \rightarrow R \rightarrow xy) \propto \text{BR}_{ab} \text{BR}_{xy} \frac{\Gamma_R}{M_R}. \]

• The simplified limits variable is defined as
\[ \zeta \equiv \text{BR}_{ab} \text{BR}_{xy} \frac{\Gamma_R}{M_R} = \frac{\sigma(pp \rightarrow R \rightarrow xy)}{16\pi^2\mathcal{N}} \left[ \frac{1 + \delta_{ab}}{s} \frac{dL_{ab}}{d\tau} \right]^{-1}_{\tau=M_R^2/s}. \]

• By deconvolving the proton PDFs from the constraints, one can parameterize directly in terms of the resonance properties: \( \text{BRs}, \Gamma_R, \) and \( M_R. \)
Simplified Limits

• Employed previously by CMS to constrain $pp \rightarrow Z' \rightarrow bb$ [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, $\sigma_{\text{prod}}$. 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
  \[ \sigma(ab \to R \to xy) \propto BR_{ab} \cdot BR_{xy} \cdot \frac{\Gamma_R}{M_R}. \]

- For three dominant BRs, we can project limits onto a 2D plane using the simple unitarity property
  \[ \sum_{i=1}^{3} BR_i = 1. \]

- Of the two remaining degrees of freedom, \( \Gamma_R \) and \( M_R \), can fix one and constrain the other.
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

\[ \widetilde{\text{BR}}_i \equiv \text{BR}_i / (1 - \text{BR}_{\text{other}}), \quad \widetilde{\Gamma}_R \equiv \Gamma_R (1 - \text{BR}_{\text{other}})^2, \quad \sum_{i=1}^{3} \widetilde{\text{BR}}_i = 1, \]

which leaves \( \sigma^{\text{NWA}} \) and the simplified limits variable \( \zeta \) 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

\[ pp \rightarrow \phi \rightarrow VV \]

- Making the simplifying assumption
  \[ \sigma_{\text{prod}}^{95} = \begin{cases} 
    \sigma_{1}^{\text{obs/BR}_1} & \sigma_1^{\exp/BR_1} < \sigma_2^{\exp/BR_2}, \\
    \sigma_{2}^{\text{obs/BR}_2} & \text{otherwise,} 
  \end{cases} \]

- We display constraints on a benchmark RS radion, \( \Lambda_\phi = 3 \text{ TeV} \) & \( kL = 35 \).

- For this example we fix \( M_\phi = 2.9 \text{ TeV} \) while displaying limits on \( \Gamma_\phi/M_\phi \). Constraints from ATLAS. [2004.14636]
Production Modes

\[ pp \rightarrow Z' \rightarrow VV \]

- When considering mixed production modes, an ambiguity can arise in the simplified parameter,
  \[ \zeta = \sum_{ab} \text{BR}_{ab} \text{BR}_{ij} \frac{\Gamma_R}{M_R}. \]

- Consider \( Z' \) production via Drell-Yan. Produced primarily from \( u\bar{u} + d\bar{d} \).

- Without imposing model-specific assumptions about \( \text{BR}_{u\bar{u}}/\text{BR}_{d\bar{d}} \), the strict limit from \( \sigma_{\text{prod}} \times \text{BR} \) becomes a band. Constraints from ATLAS. [2004.14636] [2007.05293]

\[ \text{Upper Bound on } \zeta = \frac{\Gamma_{Z'}}{4 M_{Z'}} \quad (\frac{\Gamma_{Z'}}{M_{Z'}} = 10\%) \]

- Diagram showing the dependence of \( \zeta \) on \( M_{Z'} \).
Production Modes

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

- 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 $\Gamma_{\phi}/M_{\phi}$. 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.