Sensitivity to Dijet Resonances at Proton-Proton Colliders

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Introduction

A significant benchmark for discovery at a proton-proton collider is the sensitivity to a dijet resonance X, the intermediate state of the s-channel process pp $\rightarrow$ X $\rightarrow$ 2 jets. To probe the highest resonance masses, hadron collider experiments have used the classic technique of searching for bumps in the mass spectrum of two individually resolved jets [1]. We plan to perform a study of the sensitivity of proton-proton colliders to multiple benchmark models of dijet resonances, considering both the expected and proposed collision energies and integrated luminosities of the current and future proton-proton colliders.

Methodology and Scope

We will use the methodology of our own Snowmass 96 study [2], which provided a simple and straight forward estimate of the discovery reach from the lowest order parton level predictions of the background and signal of this process. The background was evaluated in a dijet mass window around the resonance peak estimated to contain roughly 90% of the excited quark signal events. This background cross section, along with the signal cross section for a narrow excited quark resonance, were used to estimate the 5σ discovery mass reach for the excited quark model. We plan to update this method to include several additional models, and new proton-proton collider operating points, cuts and resolutions that reflect the advancement over the last quarter century in our experiments and our expectations for future colliders.

The prior study [2] considered the collision energies 2 (Tevatron), 14 (LHC), 50, 100 and 200 TeV (VLHC) and integrated luminosities between 1 and 10^4 fb^{-1}. Here we plan to consider the collision energies 13 and 14 (LHC), 27 (HE-LHC), 75, 100 and 150 TeV (FCC-hh or SppC), and integrated luminosities between 10 and 10^5 fb^{-1} including the scenarios 140 fb^{-1} for 13 TeV (Run2), 0.2 ab^{-1} (Run3) and 3 ab^{-1} (HL-LHC) for 14 TeV, 10 ab^{-1} for 27 TeV (HE-LHC), and 2.5, 30 and 100 ab^{-1} for 75, 100, and 150 TeV (FCC-hh or SppC).

We will evaluate 95% CL exclusion and 5σ discovery masses for at least six benchmark models of resonances

1. Excited quarks: charge 1/3 and 2/3, spin ½, color triplet particles that couple to a quark-gluon (qg)
2. Axigluons/colorons: neutral, spin 1, color octet particles that couple to a quark-antiquark pair.
3. Scalar diquarks: charge 2/3 and 4/3, spin 0, color sextet particles that couple to a quark-quark pair.
4. Z' bosons: neutral, spin 1, color singlet SSM gauge boson that couple to a quark-antiquark pair.
5. W' bosons: charge 1, spin 1, color singlet SSM gauge bosons that couple to quarks (u dbar, etc.)
6. Randall-Sundrum gravitons: charge 0, spin 2, color singlet particles that couple to q qbar and gg.

Example

An example of the type of studies we plan to produce is shown in Fig. 1 taken from Ref. [2]. For a narrow resonance the relevant background cross section is essentially that underneath the peak, the cross section contained within a dijet mass window containing 90% of the signal cross section. The dashed curve in Fig. 1 left panel shows that background estimated from a lowest-order parton-level prediction for the 2$\rightarrow$ 2 process of QCD dijet production at a 200 TeV pp collider. The cross section times branching ratio and acceptance of a narrow resonance signal that would be required to obtain a 5σ discovery above this QCD background, is determined from the background cross section in the window, and is shown by the dotted curves in the middle panel of Fig. 1 for integrated luminosity values between 1 and 10^4 fb^{-1}. Those 5σ discovery cross section values are compared to the predicted excited quark cross section, shown as a solid curve in the middle panel of Fig. 1, and the excited quark mass value at which the two curves cross is the 5σ discovery mass reach for that integrated luminosity. The 5σ discovery mass reach values are plotted as a function of integrated luminosity in the right panel of Fig. 1 and connected with a solid line. This procedure was used to estimate the 5σ discovery mass reach as a function of integrated luminosity for a 50, 100, and 200 TeV pp collider as shown in the right panel of Fig. 1. For example, we found a 5σ discovery mass reach of 45 TeV for an excited quark decaying to dijets with 10 ab^{-1} of integrated luminosity at a 100 TeV pp collider. Extrapolation gives a discovery mass reach of 41, 48 and 52 TeV for 2.5, 30, and 100 ab^{-1} respectively, at a 100 TeV pp collider, which are 15-20% larger than the values 36, 40 and 43 TeV predicted by a recent study of these three FCC-hh scenarios [3].

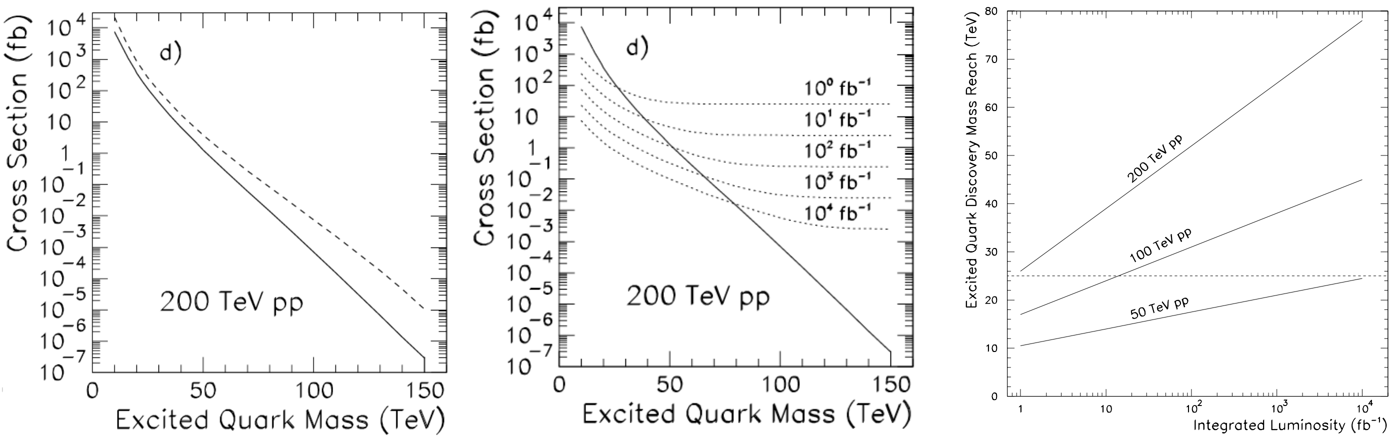

Fig. 1: Study for a 200 TeV pp collider from Ref. [2]. Left) The lowest order parton level cross section of excited quarks decaying to dijets (solid curve) is compared to the estimated QCD background (dashed curve) within a dijet mass window of the resonance peak estimated to contain 90% of the resonance cross section. Middle) The cross section of excited quarks decaying to dijets (solid curve) is compared to the estimated cross section required for a 5σ discovery for various integrated luminosities (dotted curves). Right) The resulting 5σ discovery mass reach for dijet decays of excited quarks is shown as a function of integrated luminosity for a pp collision energy of 50, 100 and 200 TeV (solid lines).

As discussed in the previous section, we will update the study in Fig. 1 to include the collision energies and integrated luminosities of future pp colliders, include 95% exclusion sensitivities, and include additional models. The study in Fig. 1 assumed a 10% dijet mass resolution when calculating the discovery cross section and mass, which was roughly correct for the Tevatron, but which needs to be updated to reflect the improved dijet mass resolution of the LHC and future pp colliders. The angular cut used in the analysis $|\cos\theta^*|<2/3$, on the parton-parton scattering angle θ^* in the center of momentum frame, should also be tightened. We expect that these updates will improve our estimated sensitivity to dijet resonances at proton-proton colliders.

References

[1] R. M. Harris and K. Kousouris, "Searches for dijet resonances at hadron colliders", *Int. J. Mod. Phys.* A26 (2011) 5005, https://arxiv.org/abs/1110.5302.

[2] Robert M. Harris, "Discovery mass reach for excited quarks at hadron colliders", Contribution to: 1996 DPF / DPB Summer Study on New Directions for High-Energy Physics (Snowmass 96), https://arxiv.org/abs/hep-ph/9609319.

[3] C. Helsens, D. Jamin, M. Mangano, T. Rizzo and M. Selvaggi, "Heavy resonances at energy-frontier hadron colliders", *Eur. Phys. J. C* 79 (2019) 569, https://arxiv.org/abs/1902.11217.