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Resonant production of vectorlike quarks at the HL-LHC

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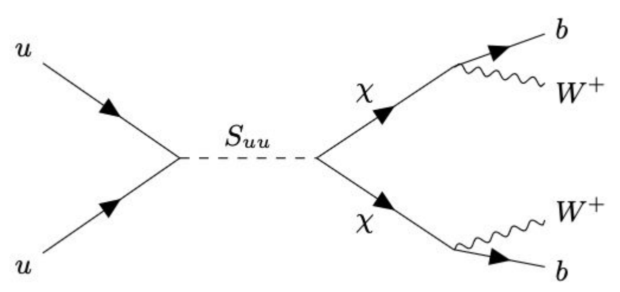
ABSTRACT

- We investigate the potentially observable consequences at the LHC and HL-LHC of resonant production of a **vectorlike quark** (VLQ) pair through an **ultraheavy diquark scalar**.
- To evaluate the signal selection efficiency, we employed several Machine Learning models trained to discriminate against a multitude of relevant background sources.
- We have found out that even a diquark as heavy as 8.5 TeV may be discovered or ruled out by the end of the HL-LHC runs.

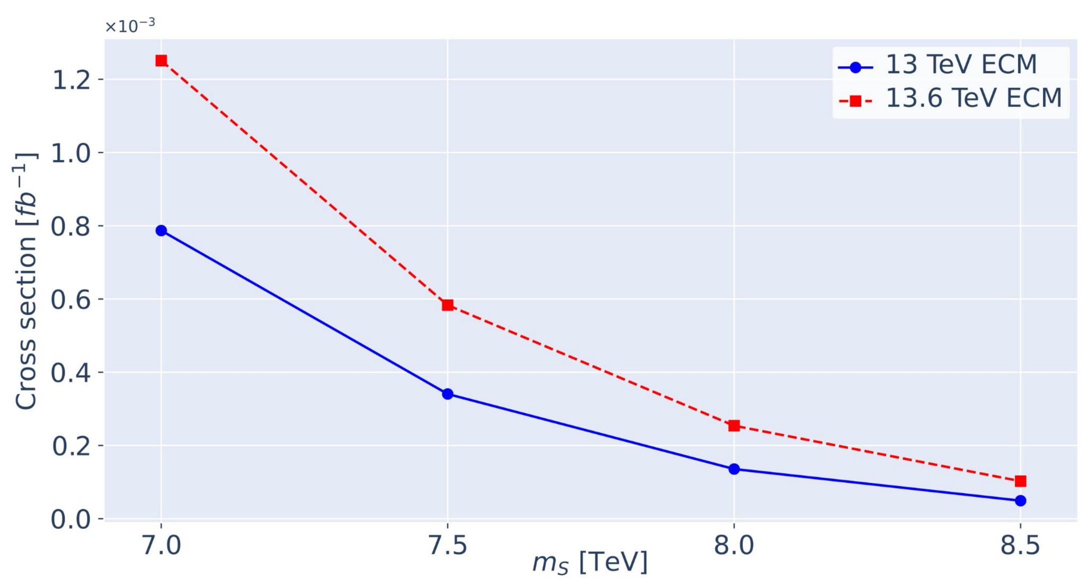
THEORETICAL MODEL

- We consider the diquark scalar as model independent, with the following characteristics: colour sextet, weak-singlet particle, +4/3 electric charge, decaying mainly into: +⅔ charged scalars, up quarks, top quarks, VLQs.
- VLQs are Beyond Standard Model (BSM) fermions, arising in many Standard Model (SM) extensions.
- VLQs are easy to trigger and isolate, with an **experimental upper limit of 1.5 TeV**. A few characteristics of these fermions are: colour triplets, weak-singlet particles, +⅔ electric charge, main decay assumption: B.R.(W^+b):B.R.(Z^0t):B.R.(Ht) = 50%:25%:25%.



MONTE CARLO SAMPLES

- We assume that each vectorlike quark decays into a W^+ boson and a b quark. Given the very large invariant mass of the events, we focus on the **6-jet final state**.
- For this study, we performed comprehensive Monte Carlo (MC) signal simulations for diquark masses ranging from 7 to 8.5 TeV.
- The kinematics of both signal and background are constrained by setting a **minimum invariant mass** of 5.5-7 TeV, according to each sample.
- Data samples of numerous background processes were produced: 2 → 2 QCD, W+jets, Higgs processes, dibosons, ttbar.
- All samples have been generated at centre-of-mass energies of 13 and 13.6 TeV at the LHC and HL-LHC, using both **ATLAS** and **CMS** detector configurations respectively.



MACHINE LEARNING ANALYSIS

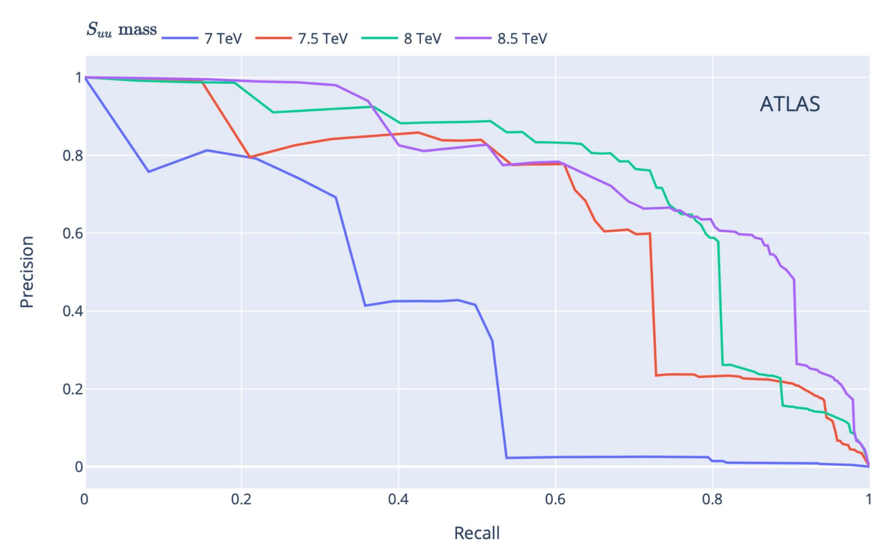
- We tested 3 classification models: **Boosted Decision Tree** (BDT), **Random Forest** (RF) and **Neural Networks** (NN).
- **Input variables**: jet kinematics ($p_T^{(i)}$, $\eta^{(i)}$, $\phi^{(i)}$), jet pair $\Delta R^{(i,j)}$, 2-jet&3-jet invariant mass, event level multiplicity, N_{jj} whose combined mass is m_W±20 GeV, minimum m_{jj} etc.
- All our ML models perform similarly.

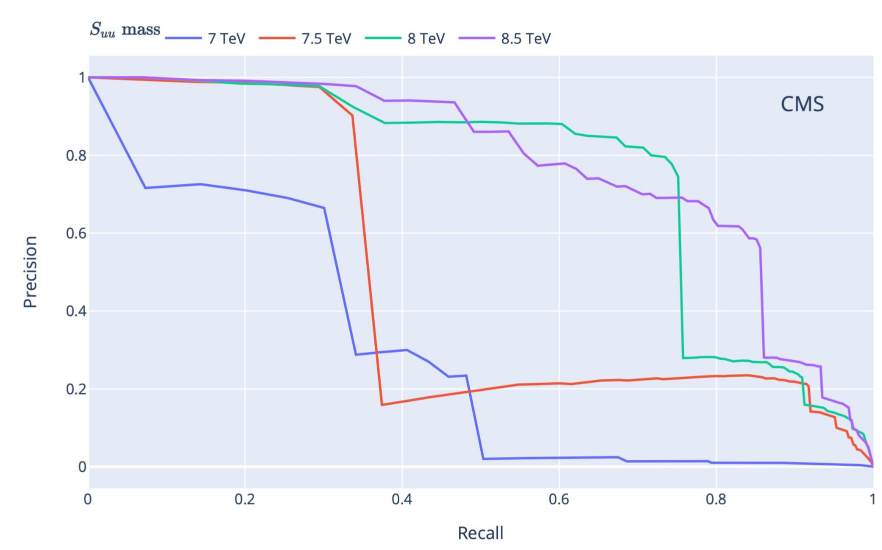
MAIN REFERENCES

[1] https://arxiv.org/abs/2206.09997
[2] http://www.arxiv.org/abs/1810.09429
[3] https://arxiv.org/abs/1912.13155

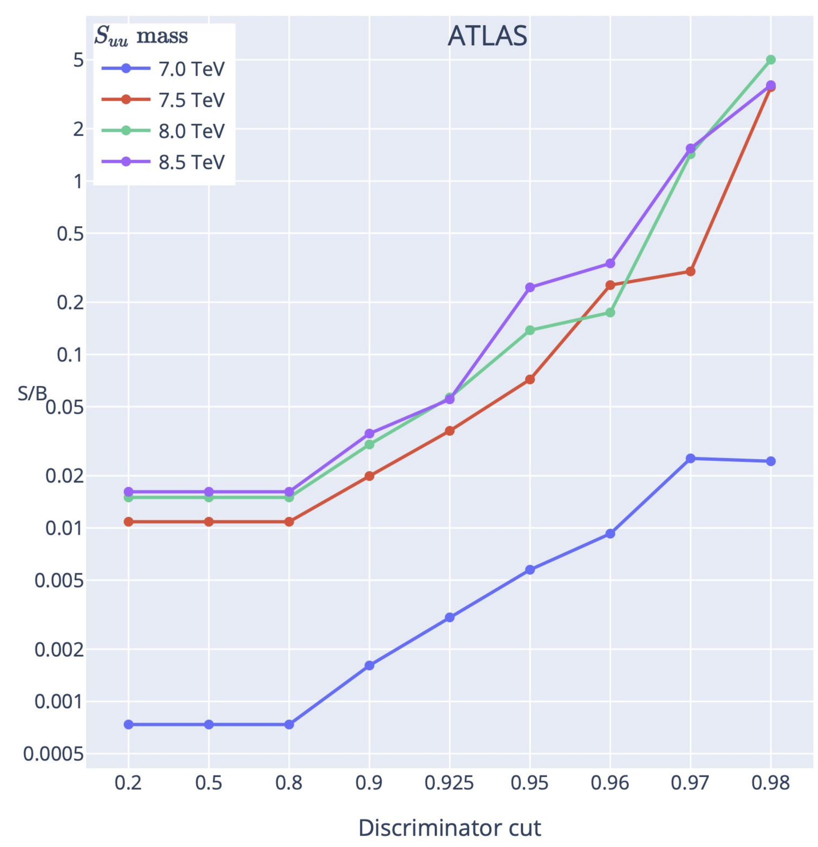
SIGNAL EFFICIENCY

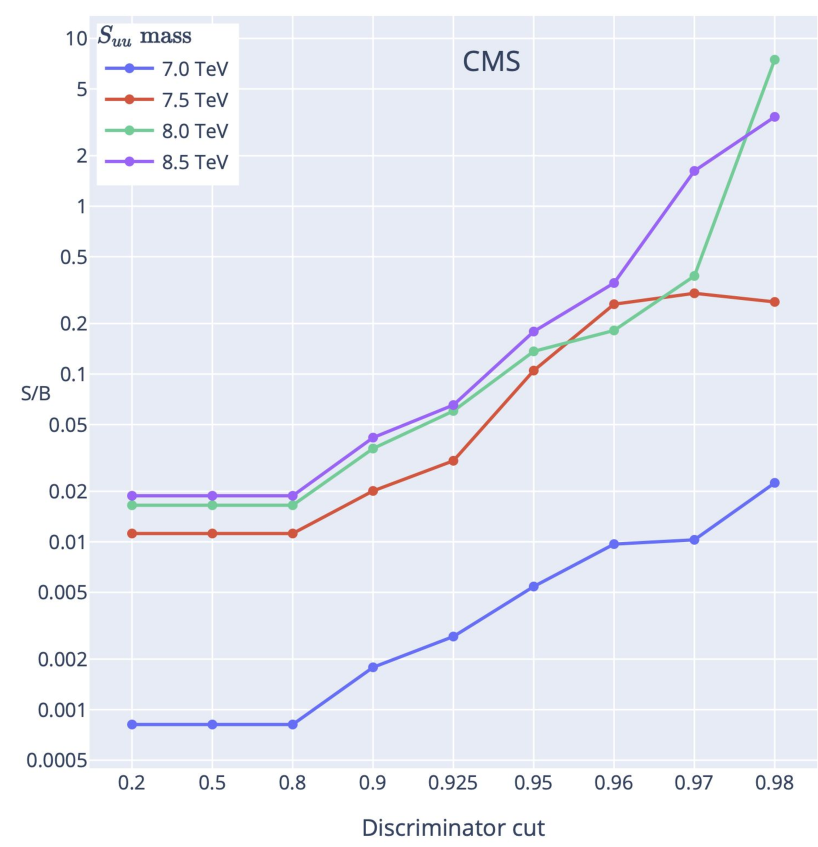
- Our Random Forest of 100 decision trees and the BDT perform almost identically, showing AUC figures of **0.770** and **0.780** on **ATLAS** simulations.
- Because we choose to increase the phase space as we lower the diquark scalar mass, the performance of our ML models is also decreasing.





- Depending on the random process of model parameter initialization, either the BDT or RF could end up slightly ahead on subsequent runs.
- We choose to work with the **RF model** because it is less prone to over-fitting.
- The RF model allows the selection of a clean sample of signal events which enables the identification of the scalar diquark resonance in the 6-jet invariant mass distribution.





- S/B has lower values for m_S=7 TeV, while for higher masses we see a increasing performance of our RF model as depicted in the first two plots.
- Regardless of the invariant mass, center-of-mass energy or detector, the S/B variable increases similarly with tighter working points. The **cross-section** brings the main difference.

OUTLOOK AND FUTURE PERSPECTIVES

- We studied the potential of observing the resonant production of VLQs through a diquark scalar at the LHC and HL-LHC.
- We produced MC signal samples of S_{uu} decaying into 2 VLQs, which subsequently decay hadronically resulting in a 6-jet final state.
- Three different ML models are used, showing **similar performance** for our case. We chose to work with the RF model.
- For **m_S≥7.5TeV** and discriminant value greater than 0.97, we obtain S/B values approaching 5, close to a discovery or a ruled out situation.
- We plan to continue our study by further investigating the semi-leptonic and the fully leptonic decay modes of the same channel.
- Considering the other decay possibilities of our VLQs, we foresee an in-depth analysis of all other final states.