Bottom Fermion Fusion initial states

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The usefulness of special initial states

- Specific initial states are utilized in various ways to search for new physics:
  1. Direct dark matter production +1 jet → Monojet searches
  2. New physics + Vector Boson Fusion quark jets → VBF searches

- These kinds of analyses utilize known physics for the initial state to suppress Standard Model backgrounds

- As a bonus, different initial states make these analyses complementary by design

- So let’s add a state to the list
Bottom Fermion Fusion

- Utilizes the only reliably identifiable jet state (bottom quarks)
- Is a handle on physics coupling to 3rd generation quarks
  - $+0$ jet states suppressed in direct production by bottom PDFs
  - $+1$ jet radiative diagrams suppressed by e.g. $\frac{1}{M_{Z'}^2}$
Suppression of $+0$ jet initial states

- Bottom states directly from the parton distribution functions are very rare
- Having a bottom + anti-bottom initial state carrying appreciable momenta is exceedingly unlikely
Suppression of $+1$ jet initial states

- Taking a gluon from one proton solves most of the necessary momentum supply for heavy resonance production.
- But radiating e.g. a $Z'$ is suppressed by a factor of $\frac{1}{M_{Z'}^2}$ in addition to the bottom pdf.
- Having a gluon split to $b\bar{b}$ solves the radiative suppression, but adds a $g \rightarrow b\bar{b}$ branching ratio factor in addition to the bottom pdf.
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Kinematics of BFF compared to likely backgrounds

If the BFF-generated heavy resonance decays hadronically, a final state with 4 bottom jets is likely:

- The dominant background in this scenario is QCD (gg → b\overline{b}b\overline{b}, as well as misidentified jets).
- Subdominant backgrounds include DY in Z+2 bottom jets and di-boson production.

If the BFF-generated heavy resonance decays leptonically, we'd expect two bottoms and two leptons in the final states:

- The dominant background in this scenario is ttbar.
- Subdominant backgrounds include DY +2 jets and di-boson production.
If a heavy resonance is produced, the BFF jets are most likely to be the least energetic jets in the event.

So taking the 3rd and 4th leading jet (generator jet level, $p_T(4) > 30$ GeV) denotes the BFF system.

The first two leading jets are hypothesized to originate from a $Z'$ here.
Depending on the resonance mass, a large gap between the BFF jet transverse momenta and the $Z'$ jet transverse momenta will occur.

For QCD, a large gap is the least likely case.

Therefore, in heavy resonance cases the background is more easily suppressed.
Sign products of BFF vs Z’ hypotheses

**Z’ 500 GeV**

- The BFF production is, unlike for VBF, very central
- There are slight differences in the forward-backward configurations of the jet systems with respect to QCD
Current main background is DY, subdominant background is ttbar

Assuming a BFF production scenario, would hypothetically allow to suppress DY heavily

Limits might be extended to lower masses
The nominal background of DY can be suppressed almost entirely.

TTbar remains as a background, but can likely be suppressed with more sophisticated cuts on e.g. transverse mass, top mass or simply an upper limit on missing transverse momentum.
Conclusions

- Additional jets in initial states have their place in complementary ways to access new physics (Monojet or VBF)
- Bottom Fermion Fusion initial states might be yet another way to access new physics coupling to third generation quarks
- Preliminary look into discriminating variables are somewhat promising with respect to QCD and ttbar