Flavor Tagging TeV Jets for BSM and QCD

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BSM jet signatures at the TeV scale

A typical signature of particles beyond the standard model (BSM) involves TeV-scale **jets**. Given the enormous QCD background, **flavor tagging** the jets can reduce the dominant light jet background, *if* the flavor tag can reject TeV light jets.

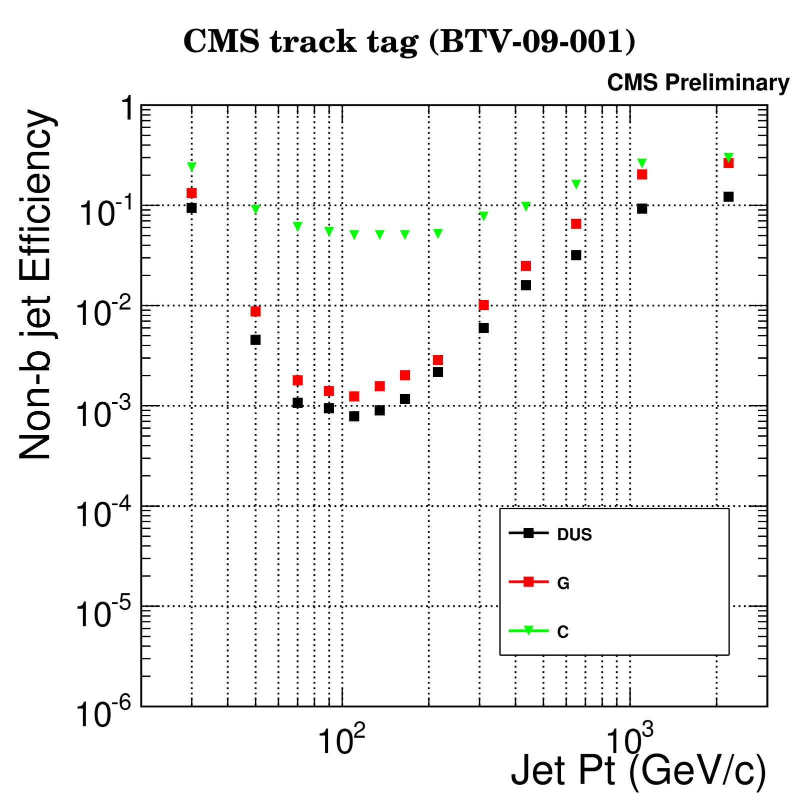
Jet/hadron flavor, defined by the originating parton

heavy = (b or c) **light =** (d, u, s, or g)

Distinguishing features of heavy flavor jets:

- Heavy hadrons decay with displaced **secondary vertices** (SV).
- Heavy hadrons have a significant rate of **semi-leptonic** decay.
  - $BF(Y_{b/c} \to l\,\nu_l\,X) \approx 0.1$ for each $l \in \{e, \mu\}$.
  - b hadrons decay to c hadrons, so 20% of b jets have muons.
- Heavy hadrons carry a **large fraction** of their jet's $\vec{p}$.

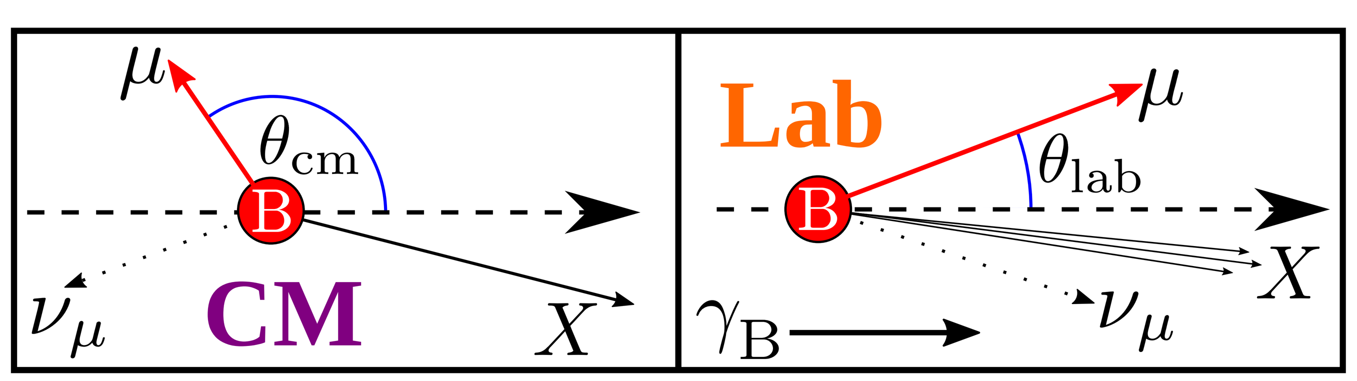
Existing flavor tags at LHC (**SV** and muon $p_T^{\rm rel}$) work well for jets with p_T<300 GeV but can't adequately reject light-jets as $p_T \to 1$ TeV. This makes it difficult to study BSM jet signatures at the TeV scale.



Boosted semi-muonic B decay

Consider a jet containing a B hadron. In the center-of-momentum (CM) frame, a muon is emitted with some speed $\beta_{\mu,\rm cm}$ and at some angle $\theta_{\rm cm}$ w.r.t. the boost axis. In the lab frame, the boost γ_B compresses the B decay products into a subjet. Defining $\kappa \equiv \beta_B/\beta_{\mu,\rm cm}$, we can define a lab frame observable

$$x \equiv \gamma_B \tan(\theta_{\rm lab}) = \frac{\sin(\theta_{\rm cm})}{\kappa + \cos(\theta_{\rm cm})}$$



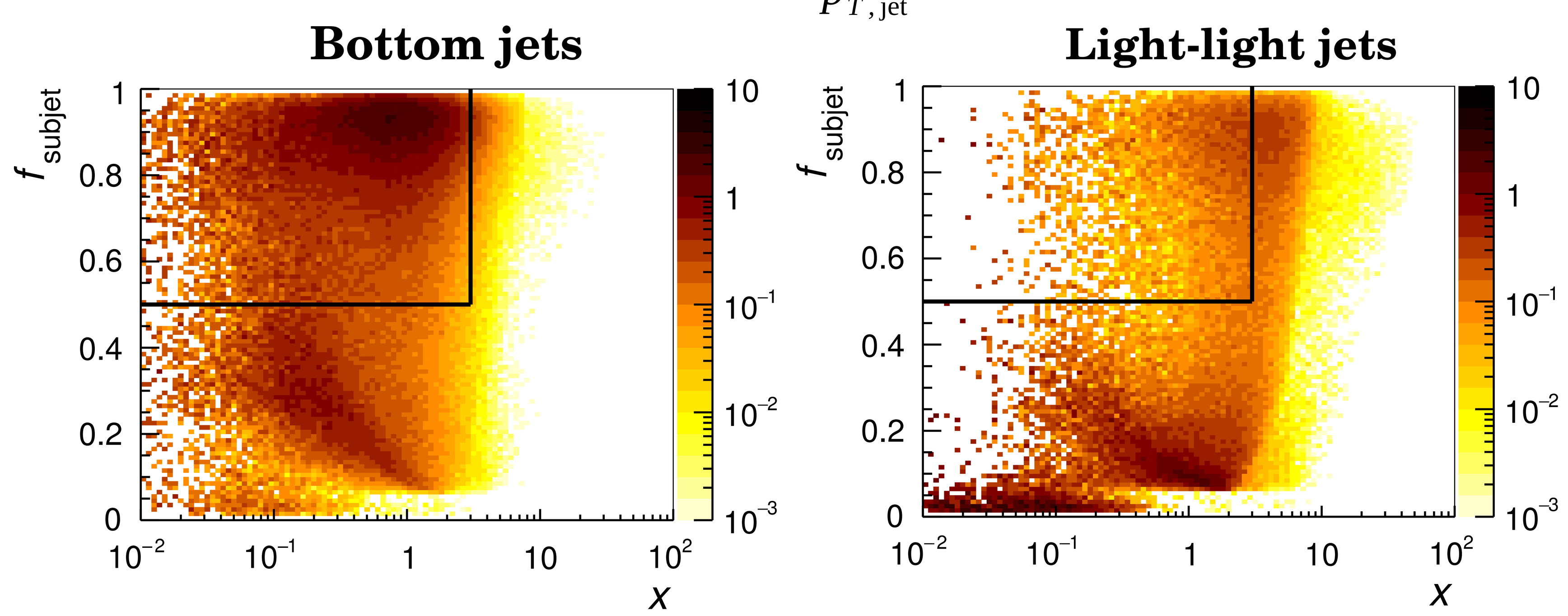
The μ_x flavor tag

For TeV jets $\gamma_B \gg \gamma_{\mu,\rm cm} \gg 1$, and thus the lab frame distribution of muon count N vs. x is effectively independent of κ

$$\frac{dN}{dx} \approx \frac{2x}{(x^2+1)^2}$$

At least 90% of muons arrive in a cone defined by $x \le 3$. In addition, the boosted subjet's momentum will be a large fraction of the total jet momentum

$$f_{\rm subjet} = \frac{p_{T,\rm subjet}}{p_{T,\rm jet}} \ge 0.5$$



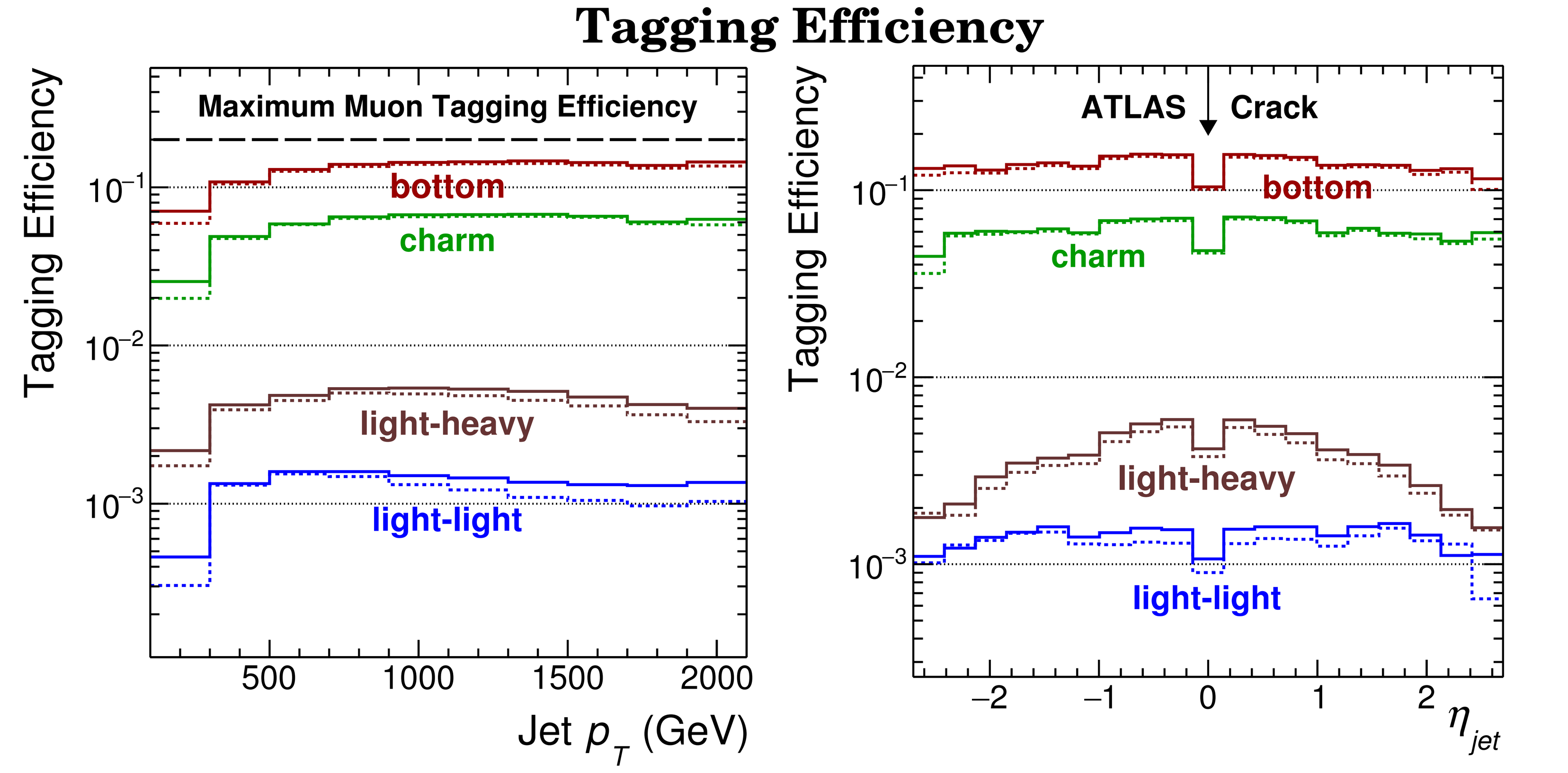
Jets originating from a light parton are classified as **light-heavy** if the taggable muon came from a heavy hadron inside the jet (i.e. gluon splitting), and **light-light** otherwise.

Measuring x requires reconstructing the heavy hadron subjet

$$\mathbf{p}_{\rm subjet} = \mathbf{p}_\mu + \mathbf{p}_{\nu_\mu} + \mathbf{p}_{\rm core}$$

where the large boost allows us to estimate $\mathbf{p}_{\nu_\mu} = \mathbf{p}_\mu$. The "core" contains the hadronic remnants. A list of candidate cores is built by reclustering an anti-kt jet (R=0.4) using a smaller radius parameter ($R_{\rm core}$=0.04). Since the mass of these candidate cores is poorly measured, we fix $m_{\rm core}$=2 GeV. The "correct" core is identified as the one which results in $m_{\rm subjet}$ closest to 5.3 GeV.

Tagging Efficiency



Leptophobic Z'

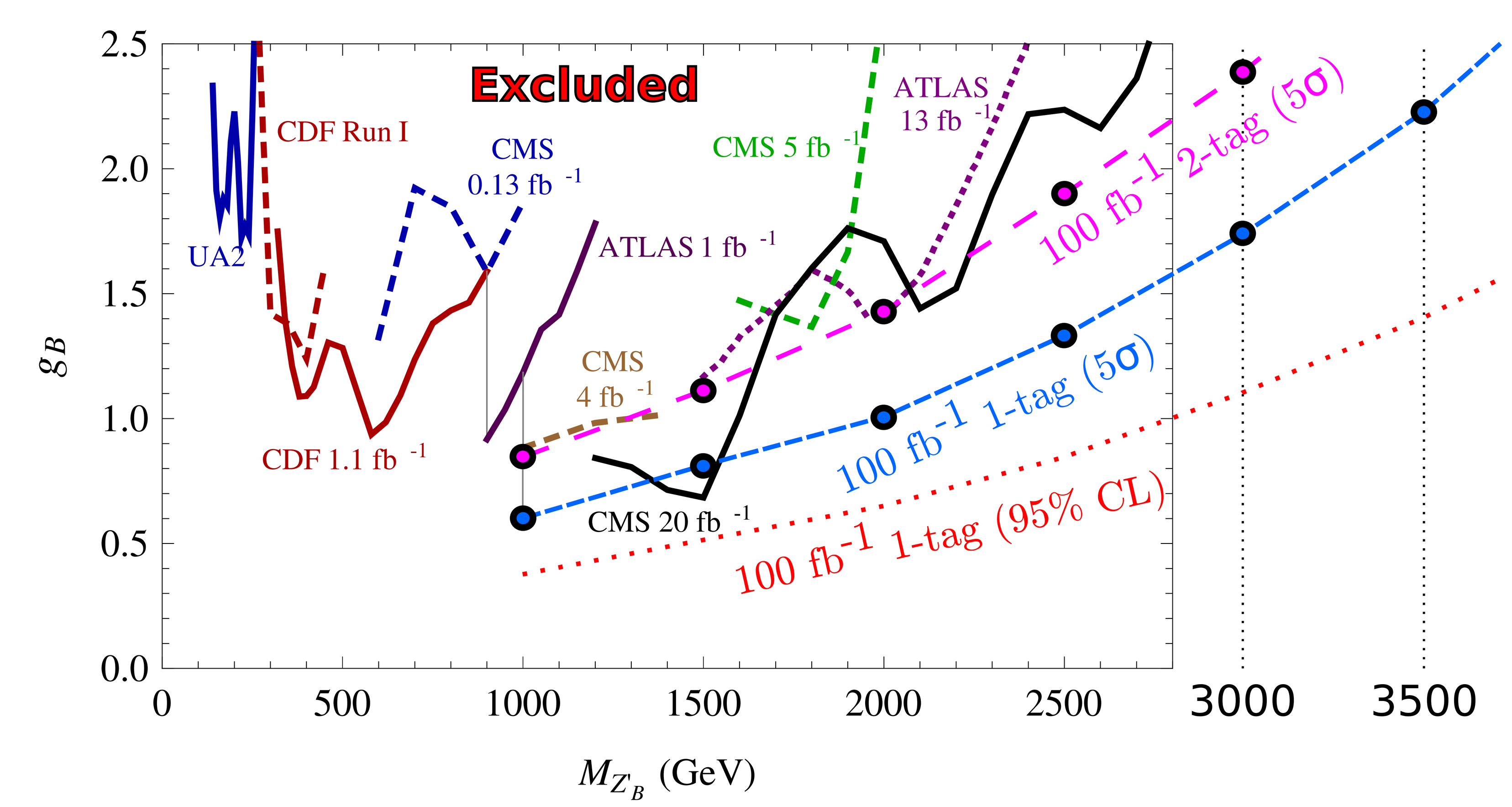
We examine the effectiveness of this new boosted heavy flavor tag by considering the discovery potential for a heavy leptophobic Z'_B that decays to dijets at the 13 TeV LHC. The Lagrangian for a simple $U(1)'_B$ coupling to quarks is[1]

$$\mathcal{L} = \frac{g_B}{6} Z'_{B\mu} \bar{q} \gamma^\mu q$$

We generate Z'_B heavy flavor dijet signals, and both heavy and light jet backgrounds, using MadGraph5, MLM matching, and Pythia 8 fragmentation. We simulate the ATLAS detector using Delphes 3 with custom modules to implement μ_x tagging. Events are sorted into 1-tag and 2-tag samples.

Discovery potential

We estimate the reach for **5 sigma** discovery or **95% CL** exclusion at Run II of the LHC and compare to existing exclusion limits for this model[1].



μ_x tagging is a significant improvement to the new class of boosted-bottom jet tags[2]. It increases the discovery potential for leptophobic Z'_B, and will be useful in multiple BSM searches at the LHC. μ_x and track tagging complement each other in the transition region where track tags are dominated by uncertainties in their tagging efficiency. A combination of both tags could create a heavy flavor tag with an overall higher efficiency and a tunable light jet rejection.

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[1]Dobrescu and Yu, Phys. Rev. D **88**, 035021 (13), arXiv:1306.2629.
[2]Duffty and Sullivan, Phys. Rev. D **90**, 015031 (14), arXiv:1307.1820.