Dipolarity

Top-Tagging with Color Flow

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with Anson Hook and Jay Wacker

arXiv:hep-ph/1102.1012

SUSY 2011

Outline

- Color flow
- Dipolarity
- HEPTopTagger in color

Jet substructure at the LHC

- the excellent resolution of the ATLAS & CMS detectors means that we can "peer inside" jets

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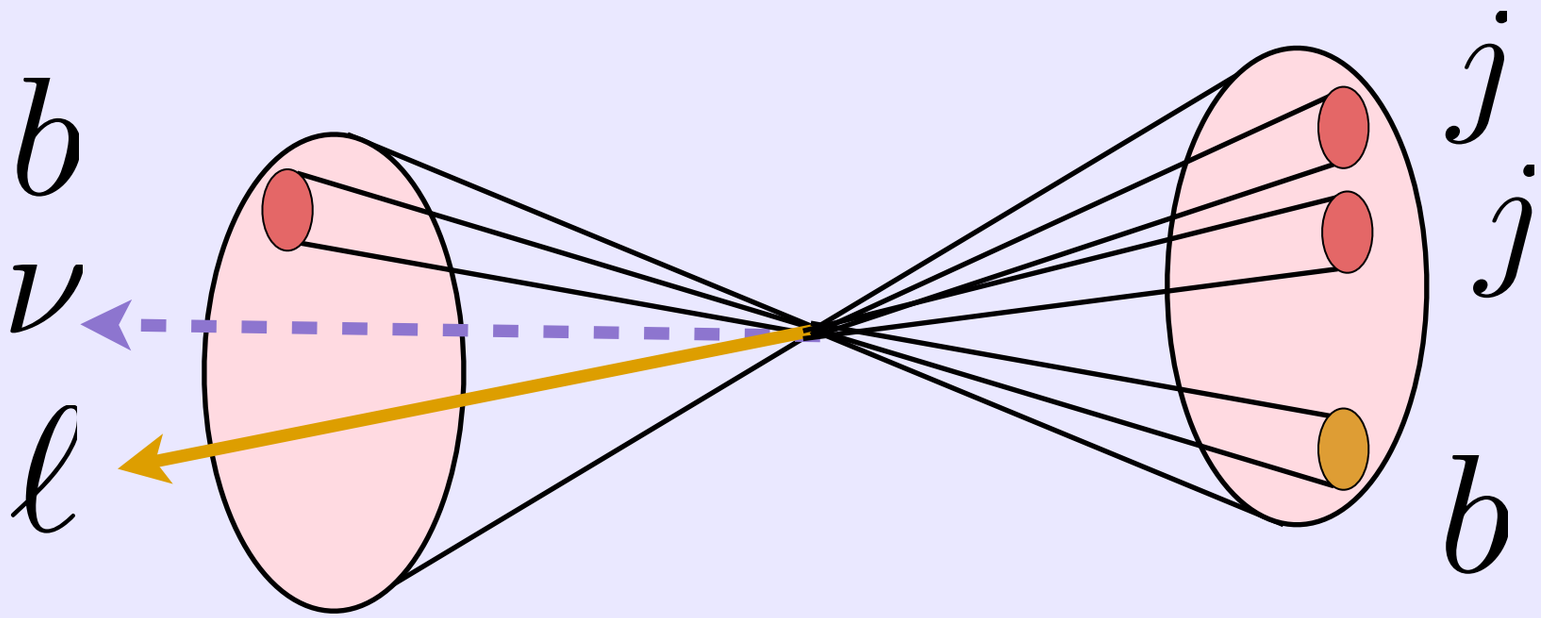
Jet substructure at the LHC

for concreteness focus on a particular application:

tagging boosted hadronic top jets



Color flow

- a top jet has more structure than is encoded by kinematic constraints:

$$(p_1 + p_2 + p_3)^2 = m_t^2$$
$$(p_1 + p_2)^2 = m_W^2$$

- the W boson is a color singlet and the color indices of q and $\bar{q}$ are contracted

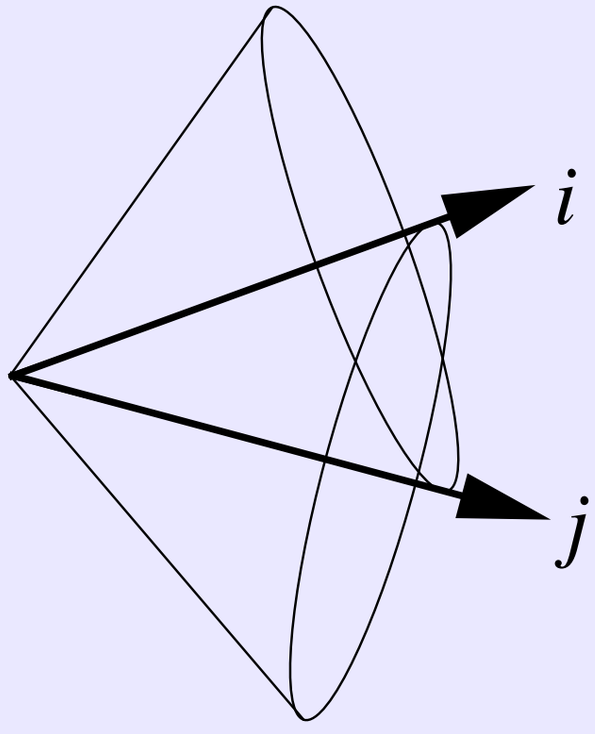
Question: can we use color information to improve top tagging algorithms?

Color flow

- QCD radiation is controlled by:
  i) Kinematics of hard partons
  ii) Color Flow: color structure of hard partons

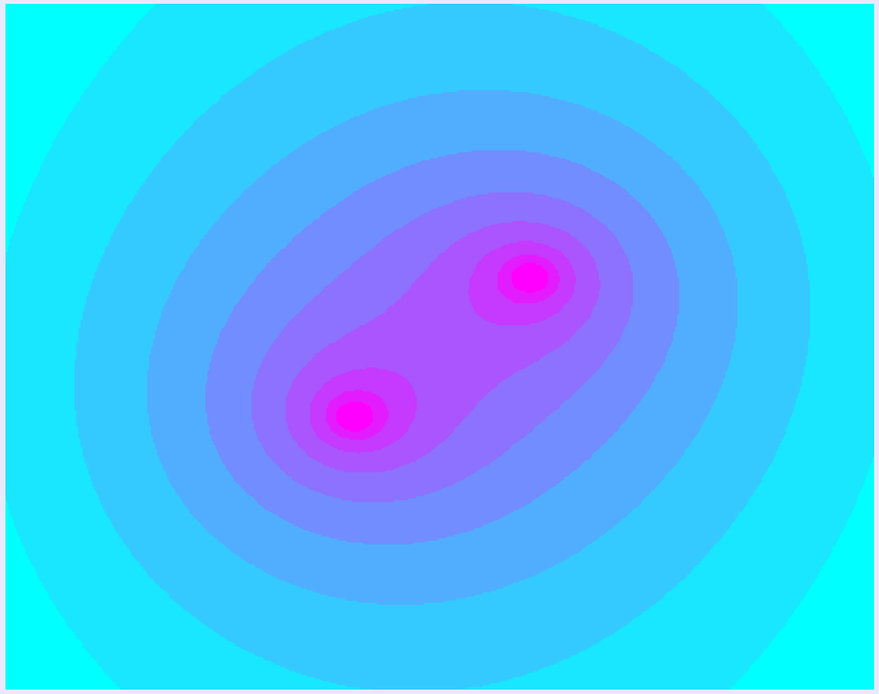
- soft emissions that are not angular-ordered are suppressed by destructive interference

- how does a color singlet radiate?

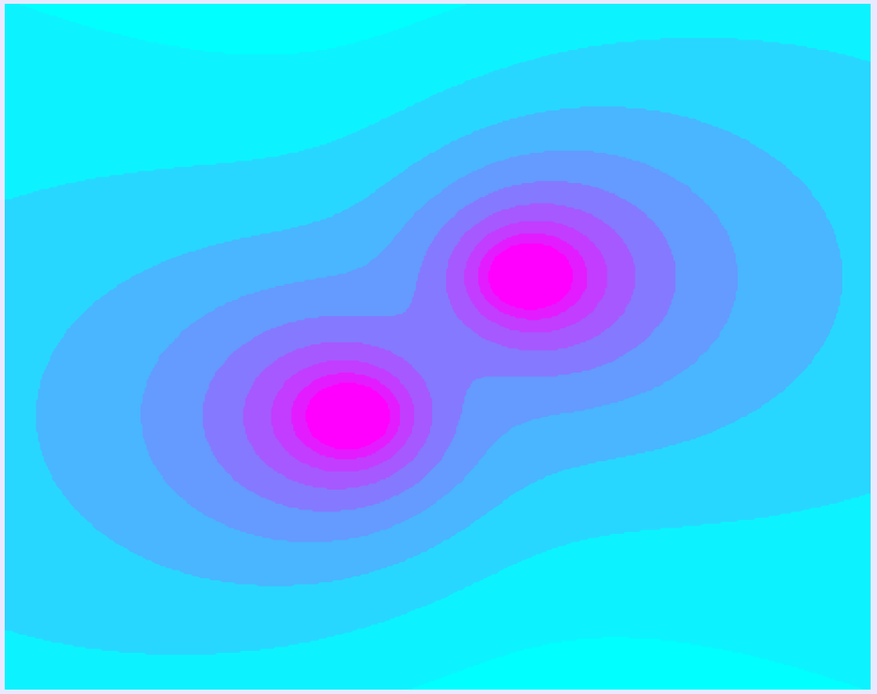


Color flow

radiation patterns in the eikonal limit



color singlet



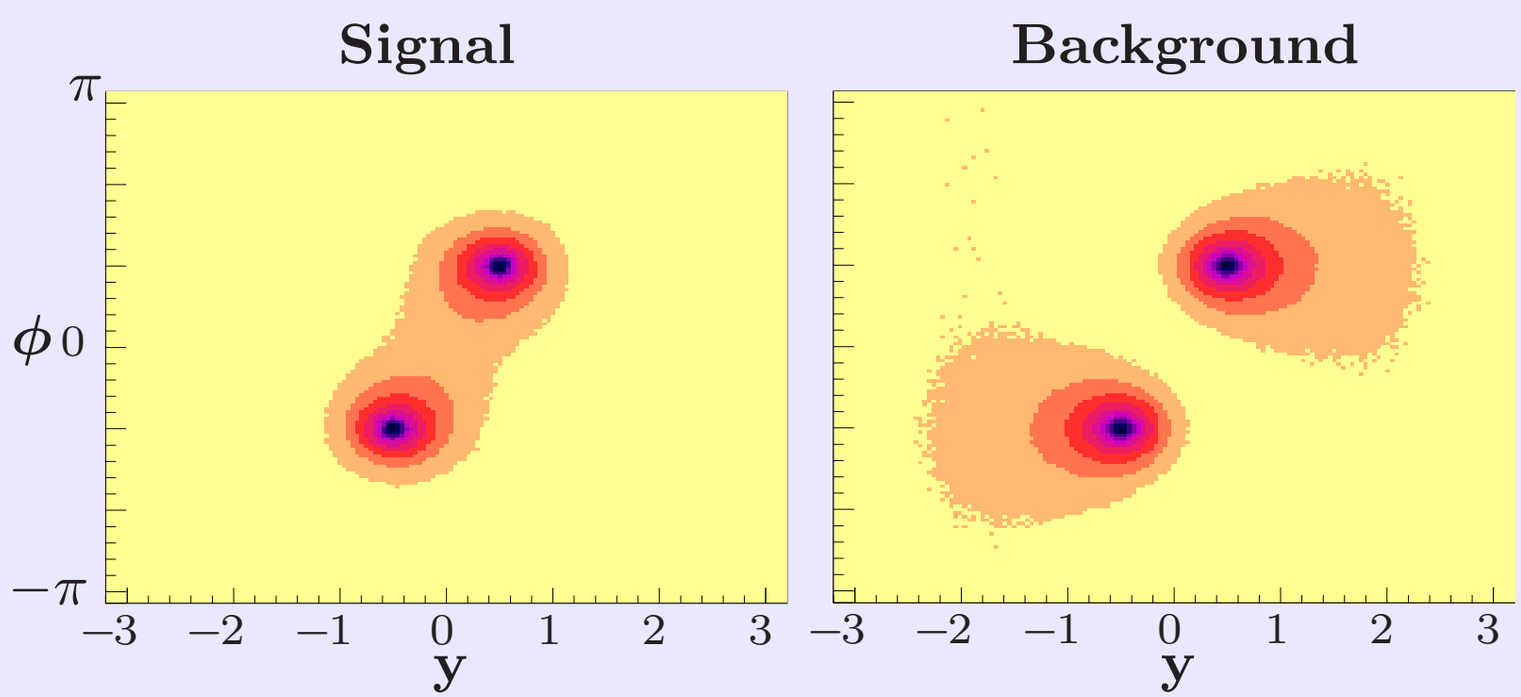
non-singlet

Color flow

- the jet observable "pull"

$$\vec{t} = \sum_{i \in \text{jet}} \frac{p_T^i \, |r_i|}{p_T^{\text{jet}}} \, \vec{r}_i$$

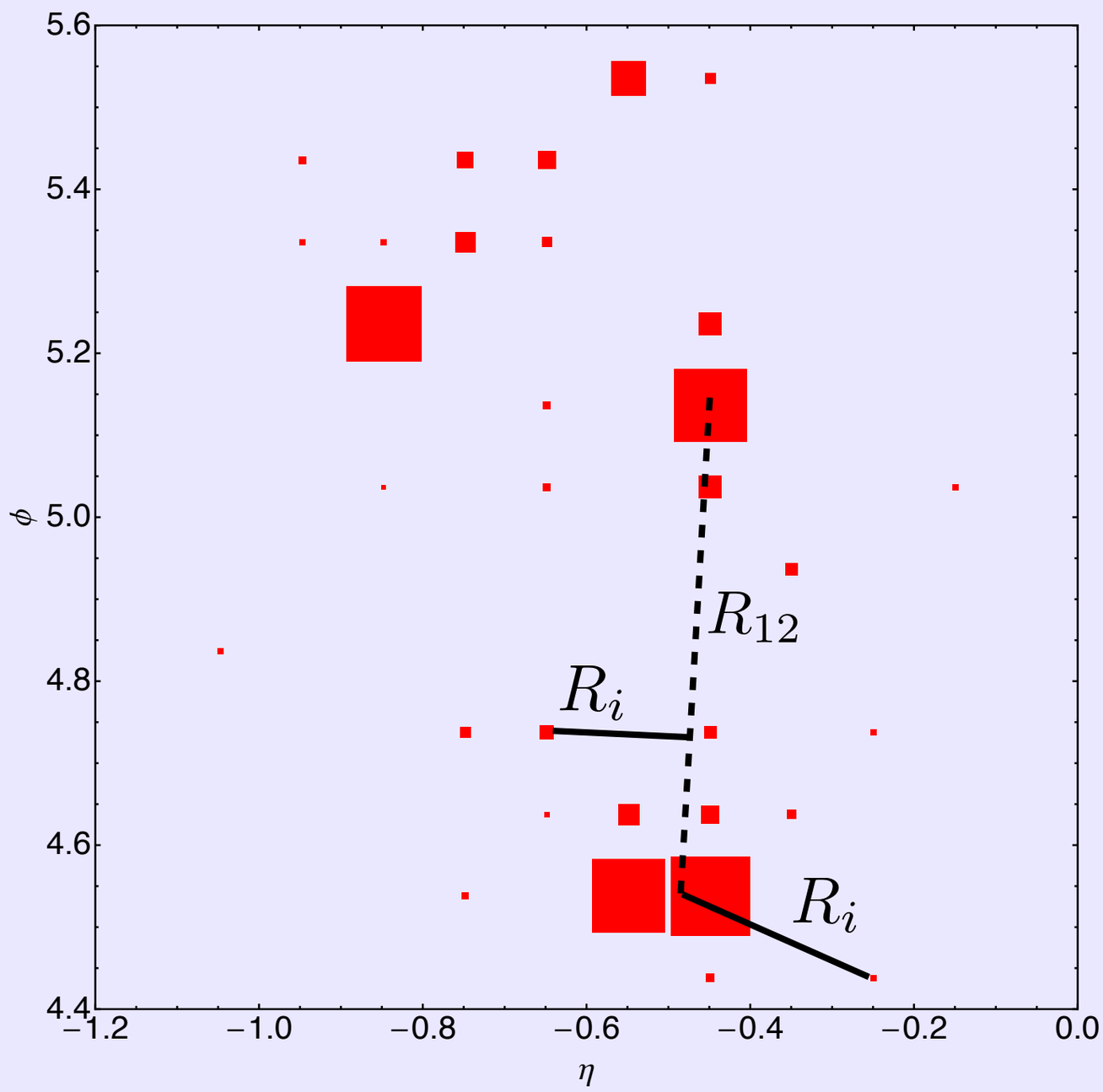
- pull is not well suited to top-tagging



Jason Gallicchio and Matthew Schwartz hep-ph/1001.5027

Dipolarity

consider the entire radiation pattern of the W at once



$$\mathcal{D} \equiv \frac{1}{R_{12}^2} \sum_{i \in J} \frac{p_{Ti}}{p_{T_J}} R_i^2$$

R_{12} is the separation between the two W subjets

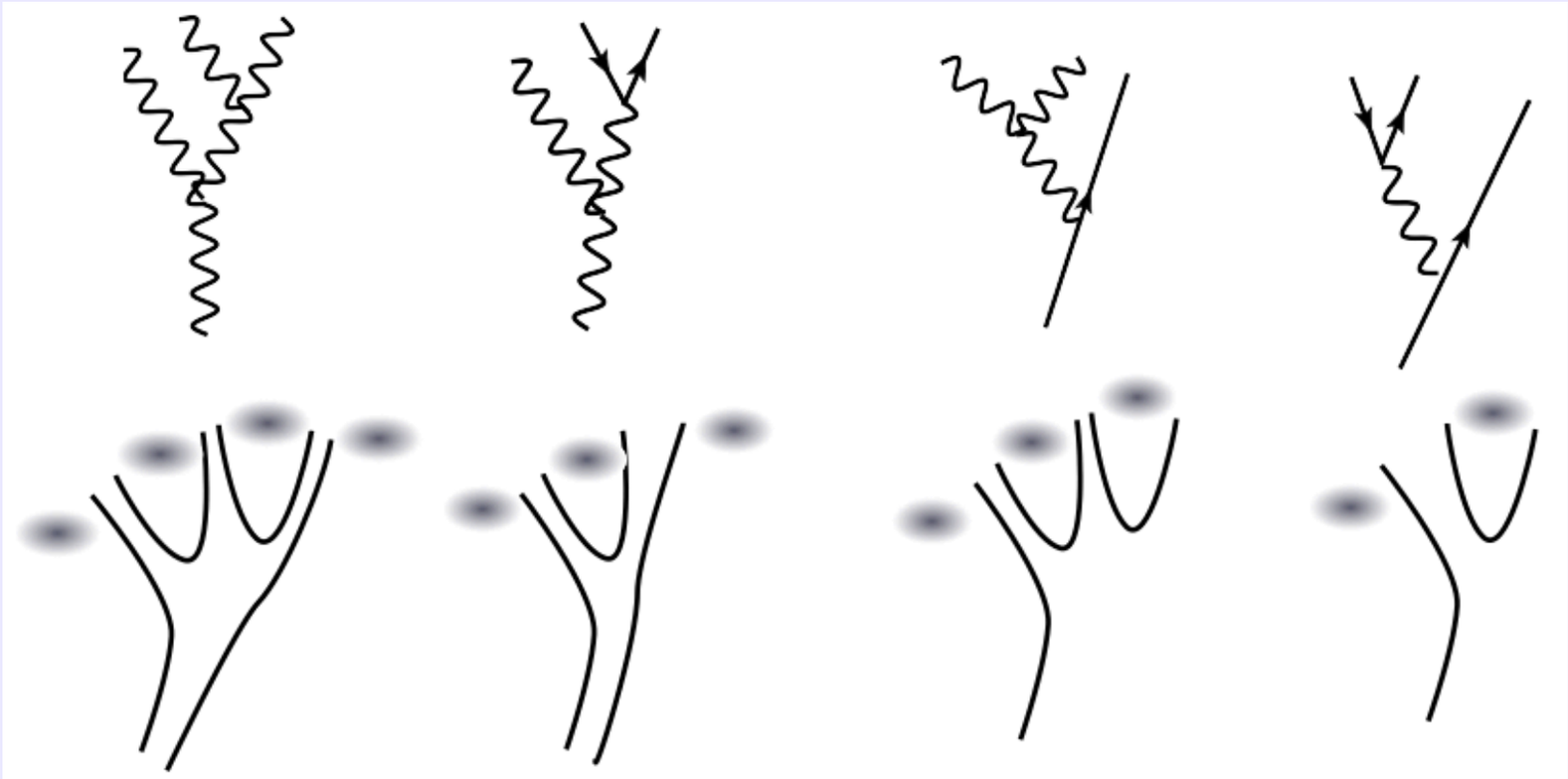
p_{Ti} is the transverse momentum of cell i

p_{T_J} is the transverse momentum of the W

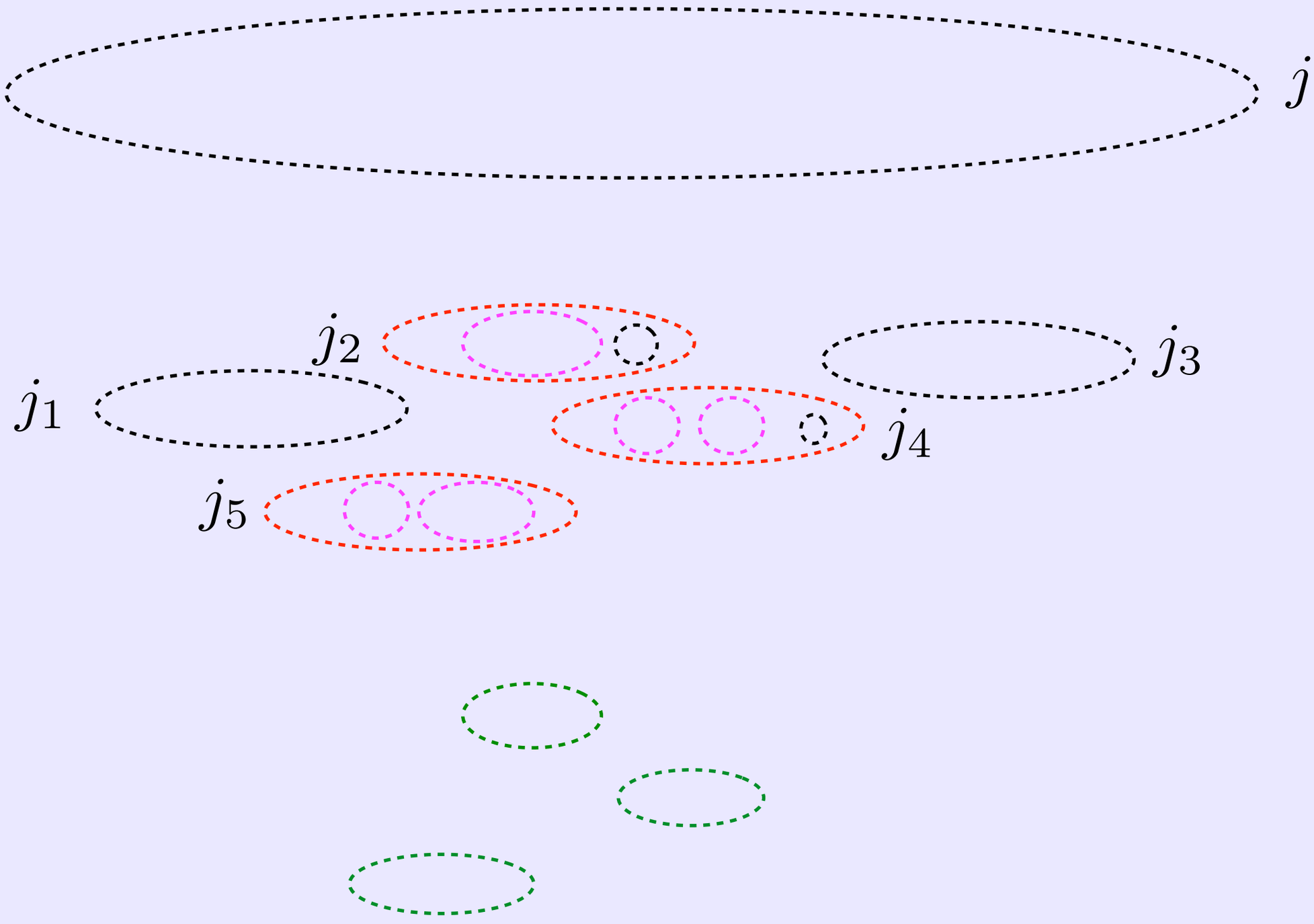
R_i is the distance between cell i and the line segment that spans the W subjets

Dipolarity

- dipolarity is a two-subjet observable
- dipolarity is IRC safe if the two subjets are IRC safe
- expectation: top jets will yield smaller values of $\mathcal{D}$ than QCD jets



HEPTopTagger in color



fat jet

↓

mass drop

↓

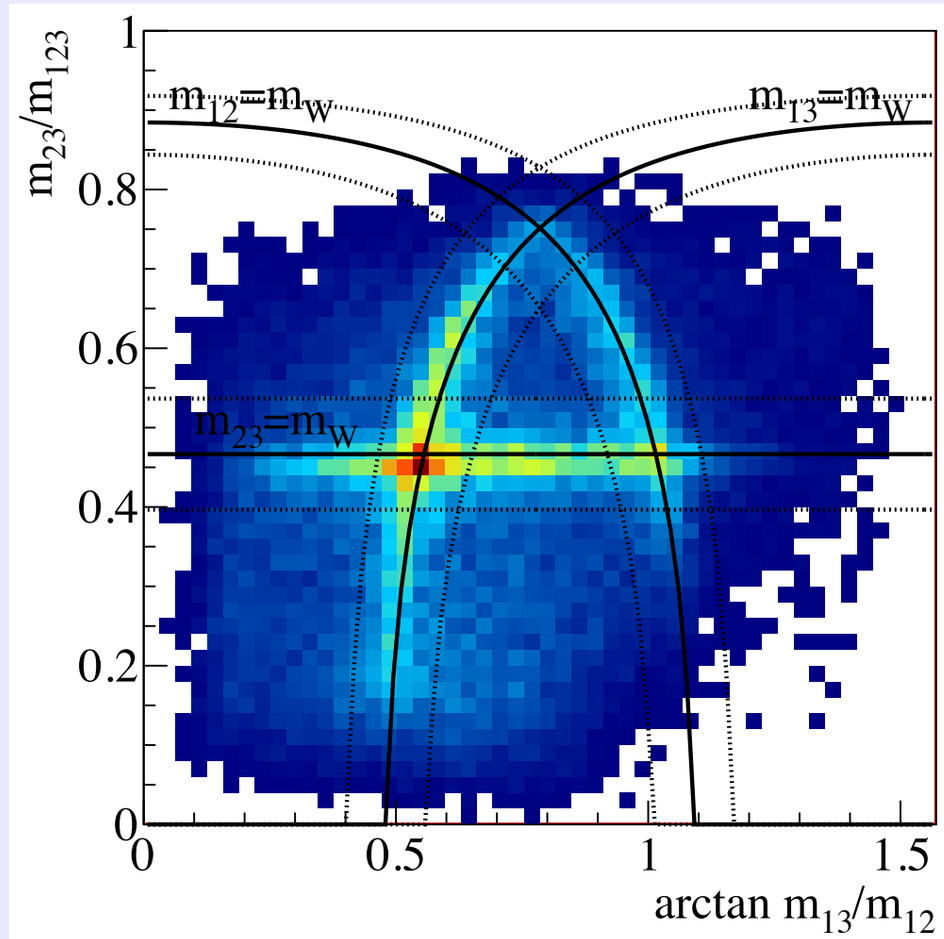
filter

↓

recluster

HEPTopTagger: T. Plehn, G.P. Salam, M. Spannowsky, M. Takeuchi and D. Zerwas
hep-ph/0910.5472 hep-ph/1006.2833

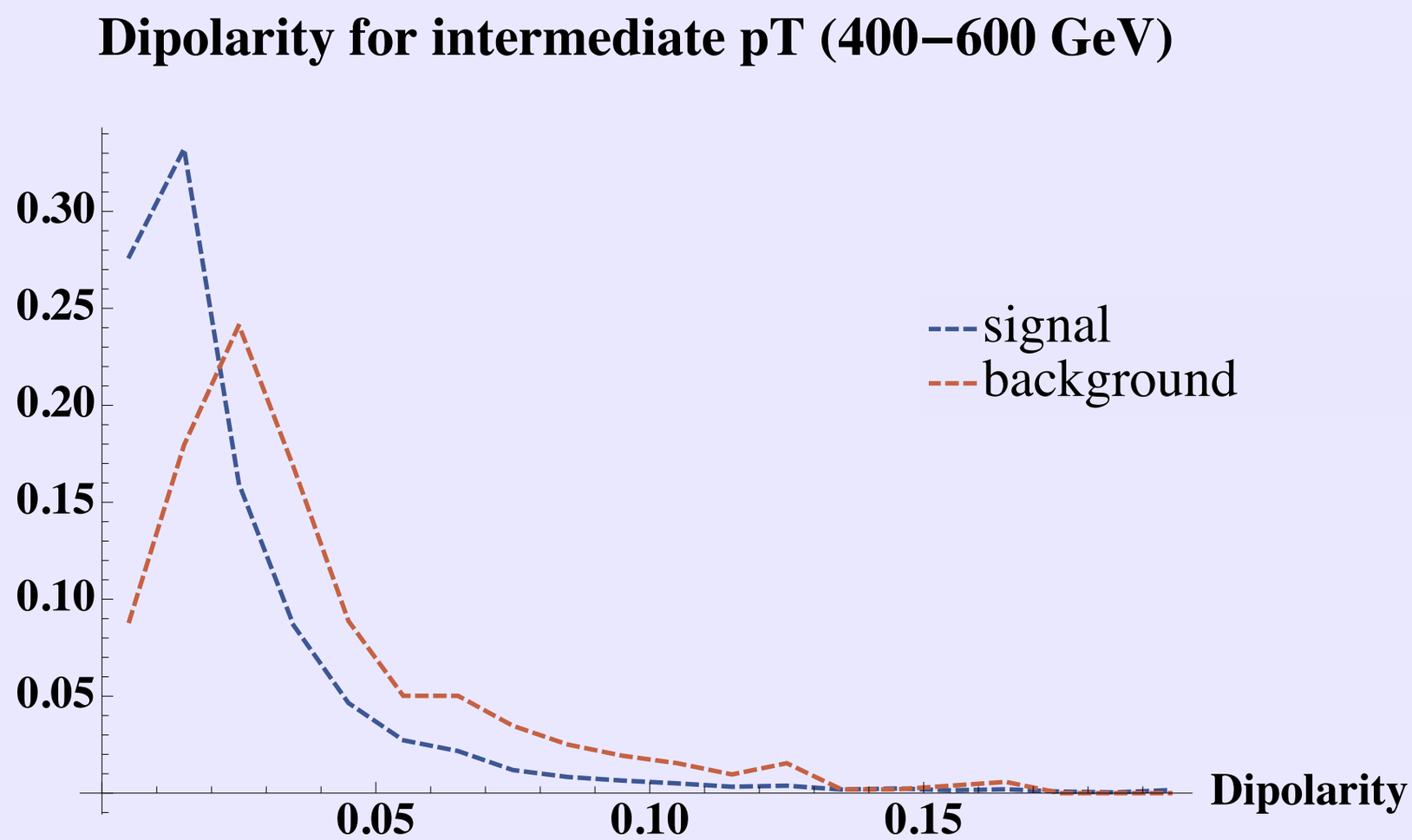
HEPTopTagger in color



hep-ph/1006.2833

- calculate the dipolarity of the pair of subjets identified as the W
- make a dipolarity cut $\mathcal{D} < \mathcal{D}_{\max}$

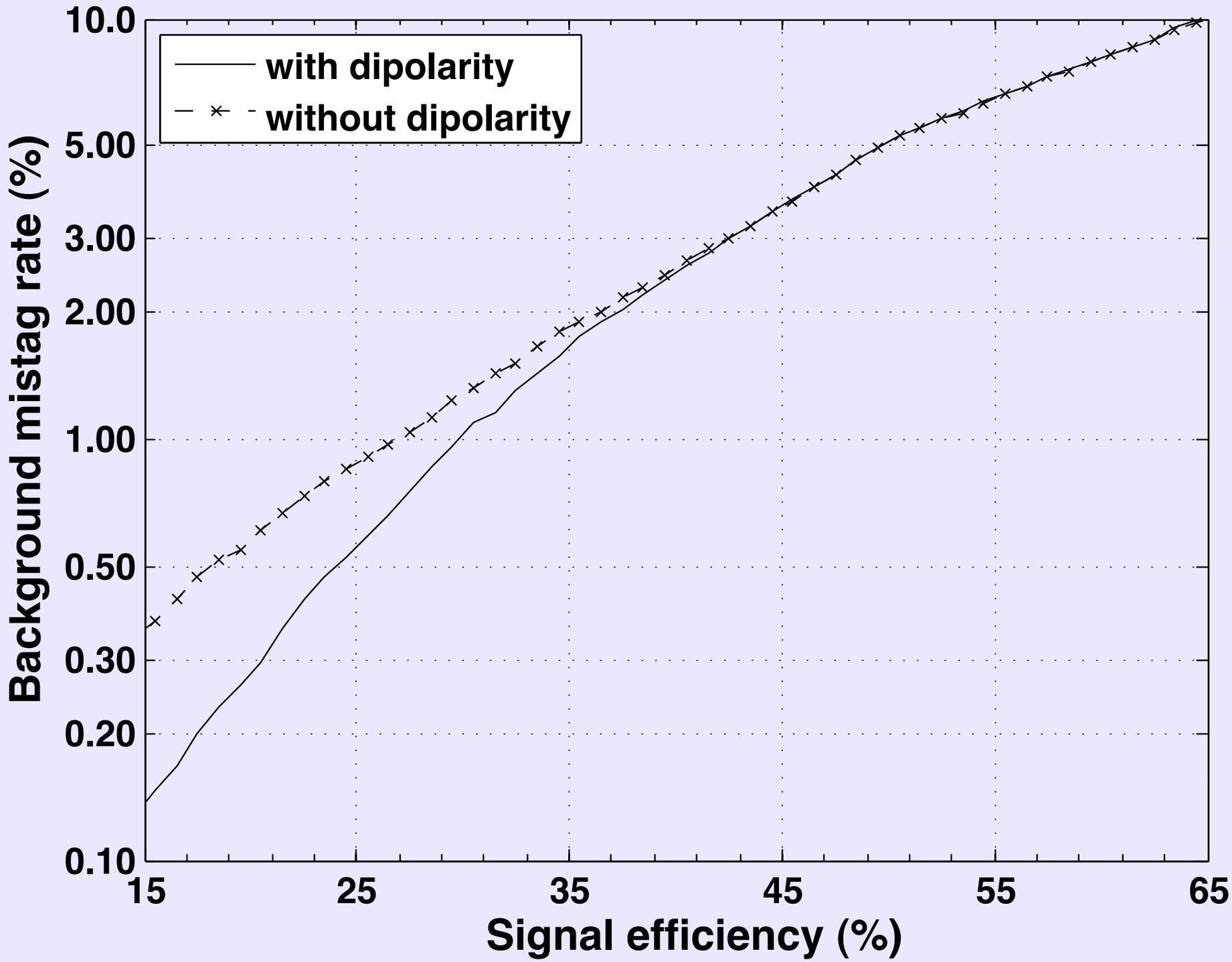
HEPTopTagger in color



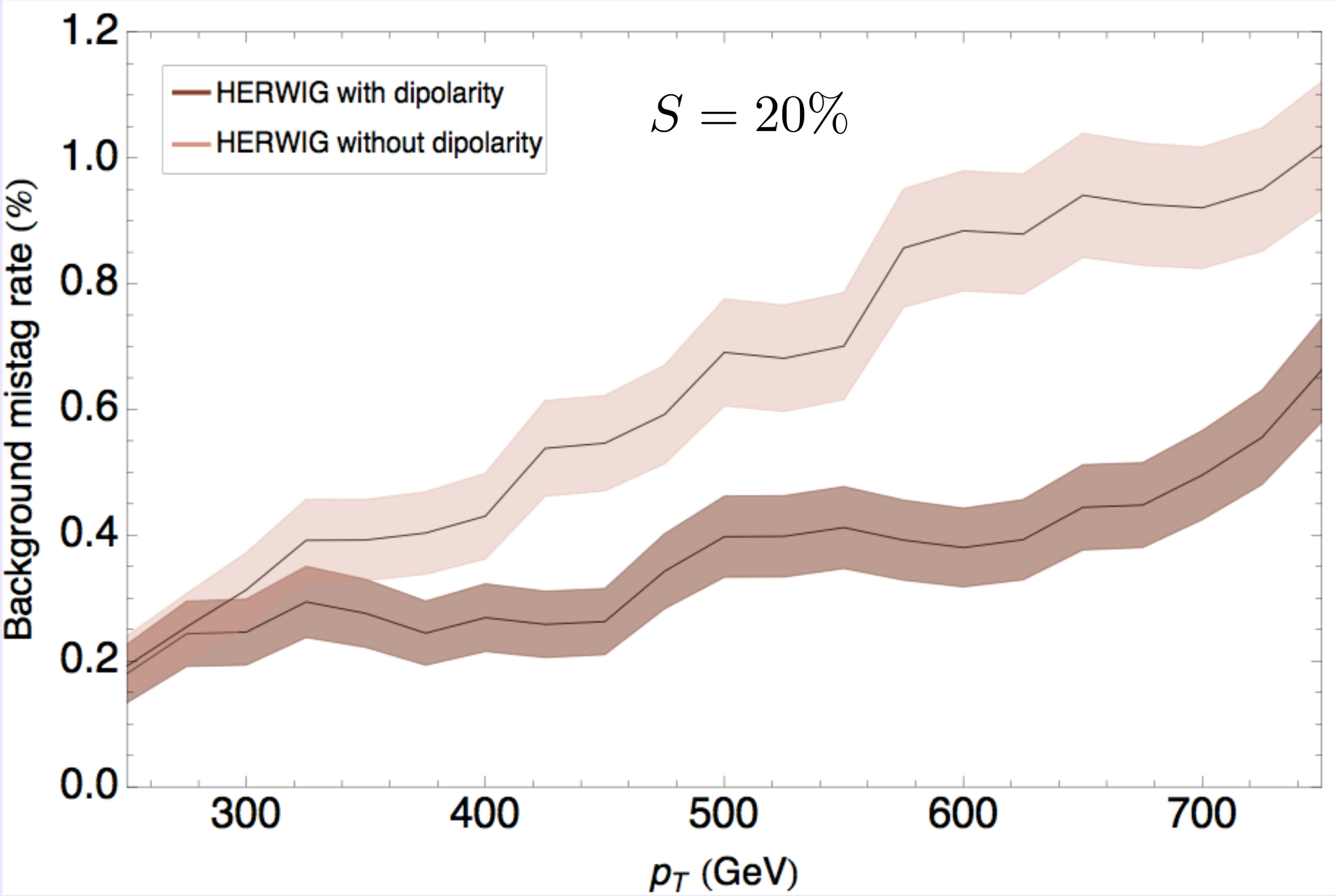
- Are dipolarity cuts orthogonal to the kinematic cuts imposed by the HEPTopTagger?
- Choose cuts at each signal efficiency to minimize background mistag rate

HEPTopTagger in color

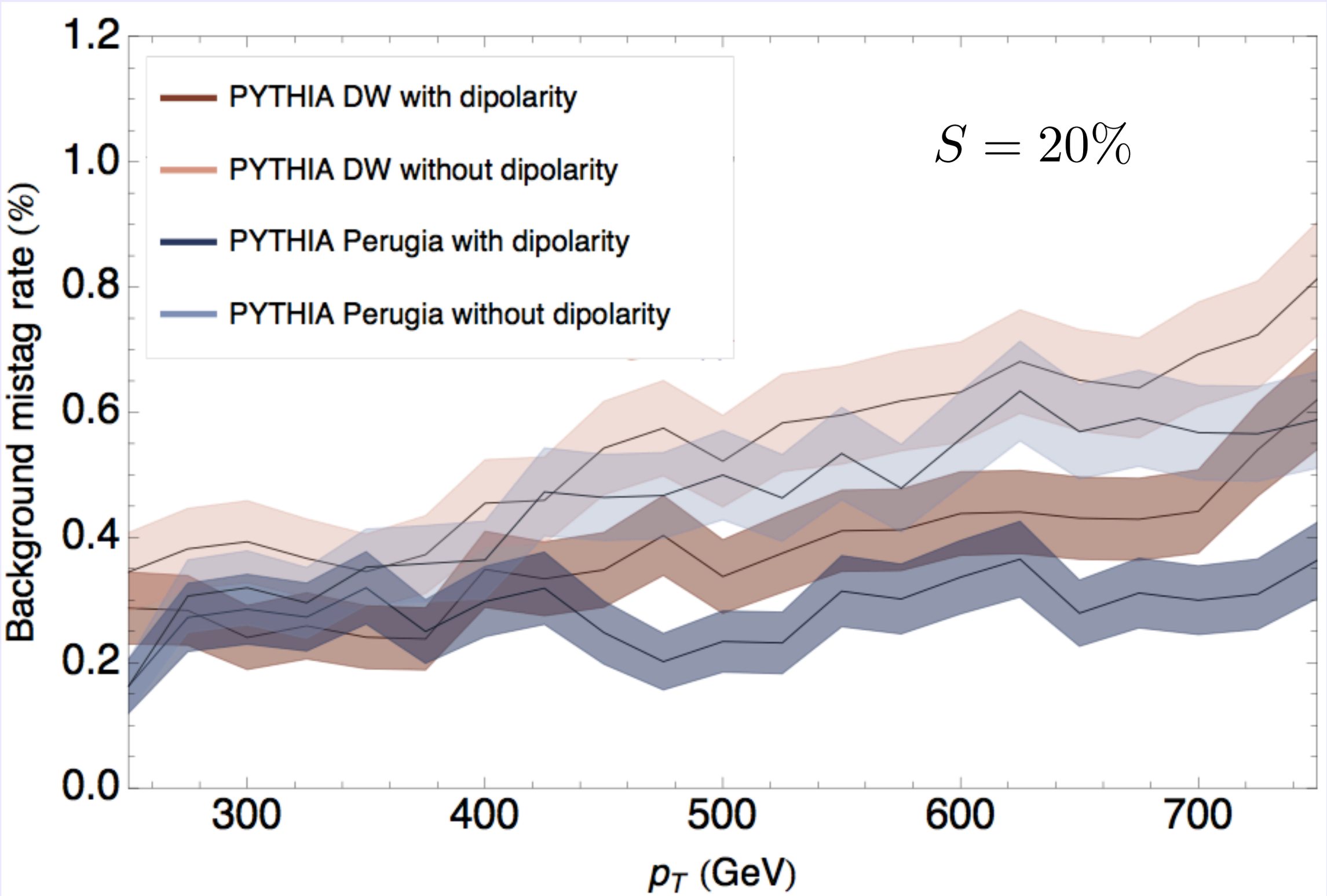
- improves background rejection at lower S



HEPTopTagger in color



HEPTopTagger in color



HEPTopTagger in color

- for intermediate to high p_T $(400\ \mathrm{GeV} < p_T < 800\ \mathrm{GeV})$ and for lower signal efficiencies dipolarity cuts can improve background rejection

- there is sizable disagreement between the different Monte Carlo event samples

- disagreement has its origin in the details of the parton showers (not e.g. the underlying event models)

- not surprising - theoretical understanding of color coherence (and its inclusion in MC) is limited

Summary & Outlook

- introduced a jet observable "dipolarity" to distinguish between different color configurations in jets with significant mass drops

- incorporating dipolarity in the HEPTopTagger improves background rejection

- due to theoretical uncertainties, the ultimate utility of dipolarity awaits data

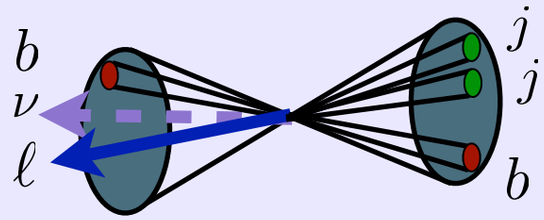
Summary & Outlook

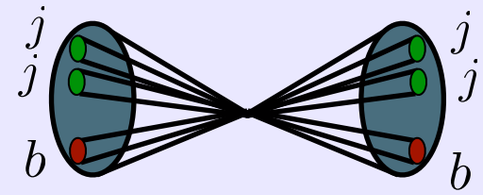
- not just for purifying samples of jets - can use to characterize the color structure of a pure sample

- people at ATLAS are looking at dipolarity in the data now!

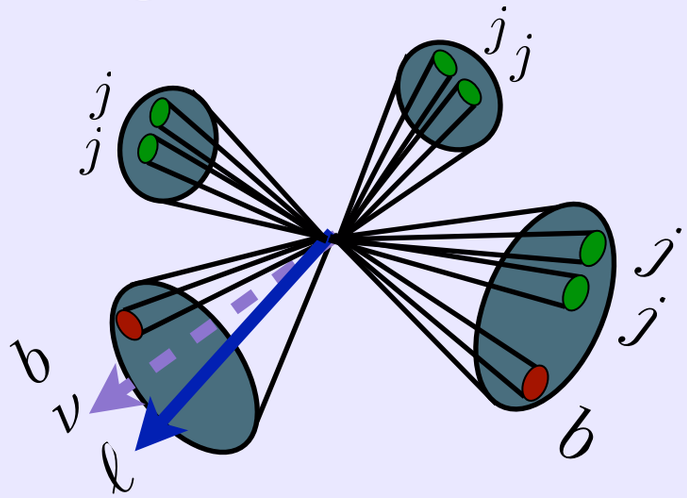
- dipolarity should have other applications outside of top-tagging (e.g. W/Z physics, heavy Higgs)

$g' \to t\bar{t}$

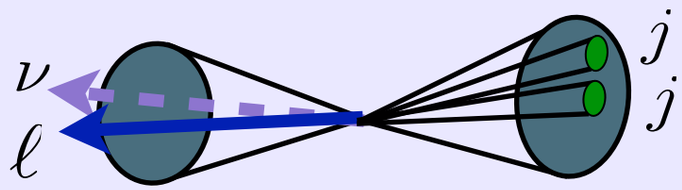




$b' \to tW^-$

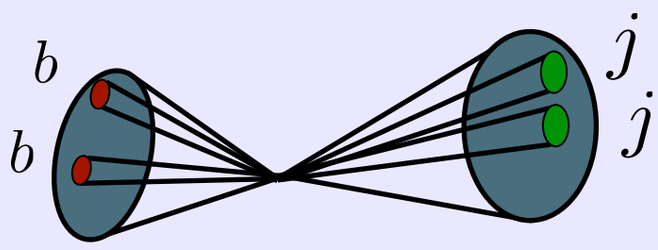


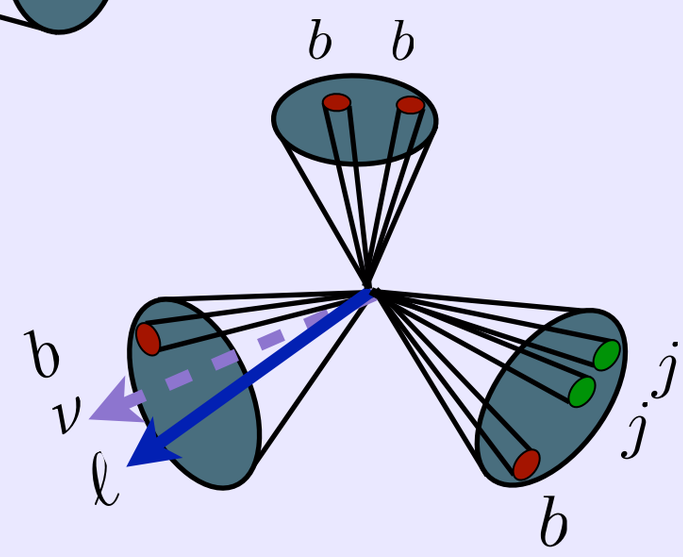
$h^0 \to W^+W^-$



$Z^0 h^0$

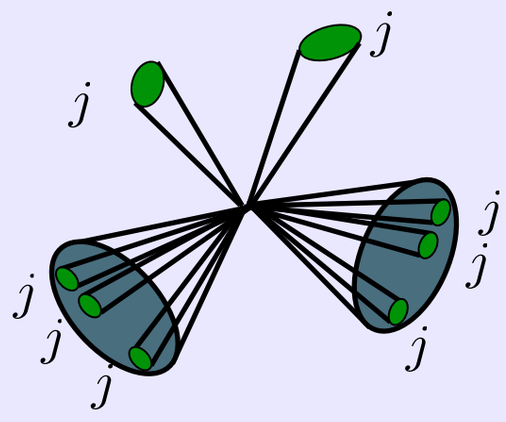
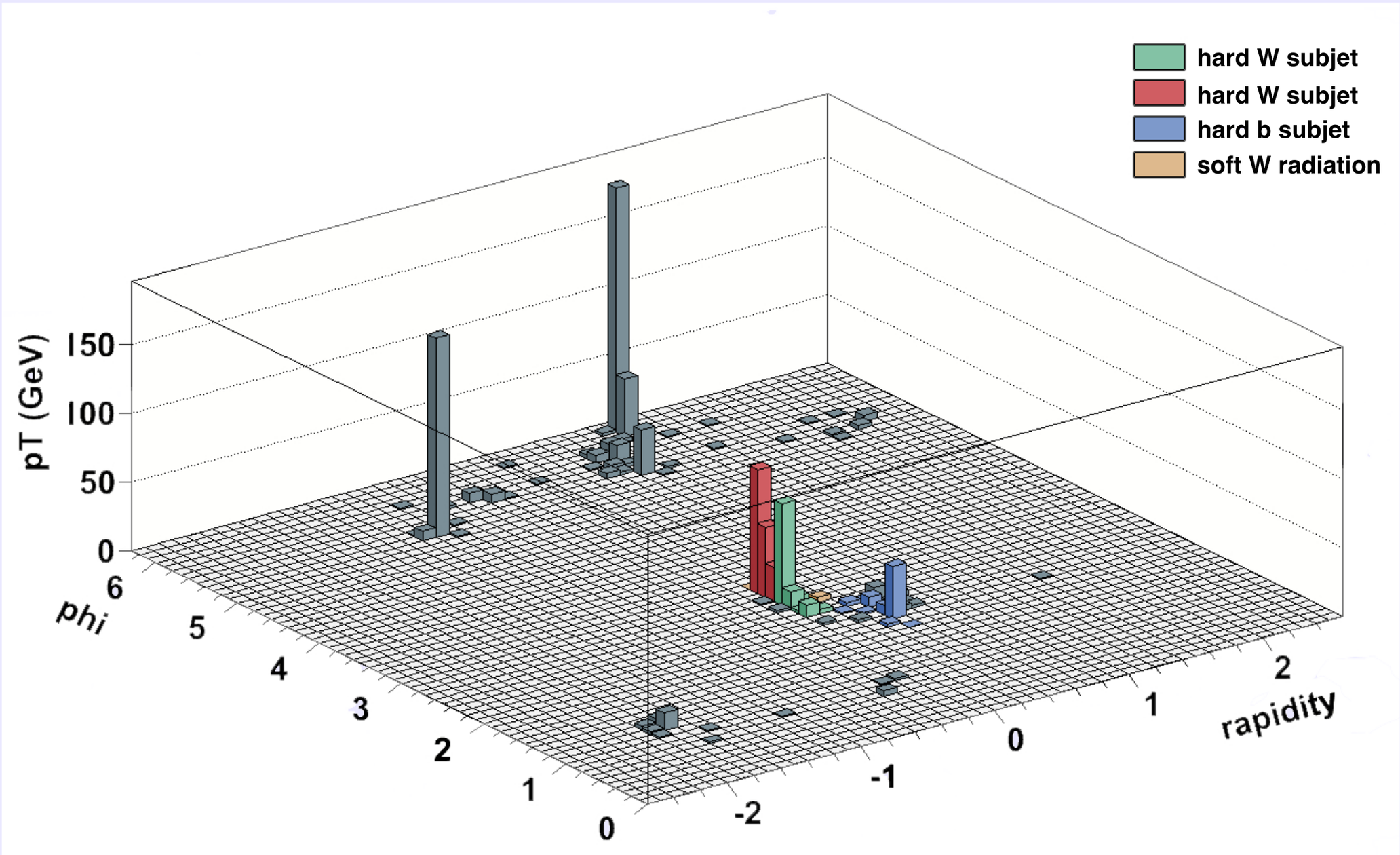
$t\bar{t}h^0$





$\tilde{q} \to \tilde{\chi}^0 q$

$\tilde{\chi}^0 \to 3q$



Legoplot for a top jet with hard substructure as identified by the HEPTopTagger