Azimuthal Angular Correlation as a Boosted Top Jet Substructure

Zhite Yu

Michigan State University

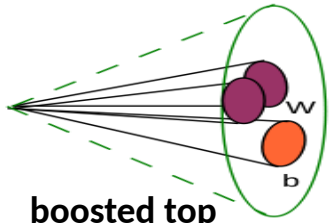
PIKIMO 11
12/4/2021

Zhite Yu and C.-P. Yuan, arXiv:2110.11539

Boosted top quark

❑ Why boosted top quark? [1012.5412]

- Important portal to new physics $pp \to X_{\text{heavy}} \to t \to bW(\to f\bar{f}')$
- Easier to separate signal from the background

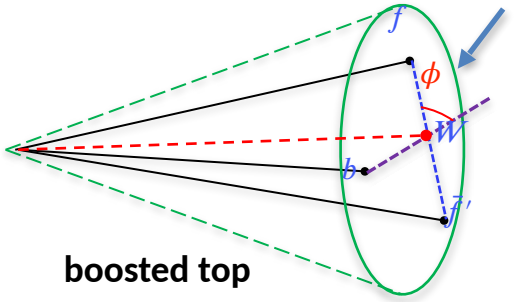


❑ Tagging of boosted top quark jet

- W and t masses
- 3-subjet structure
- Azimuthal angular correlation

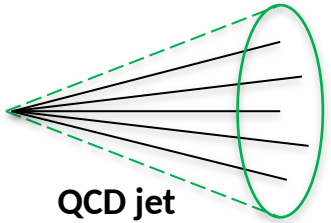
CMS-PAS-JME-13-007, 1006.2833, 1808.07858

$\cos 2\phi$



❑ Measurement of top polarization in *boosted* regime

- Production mechanism [arXiv:1103.3274]
- Polarization of top ⟸ azimuthal angular correlation

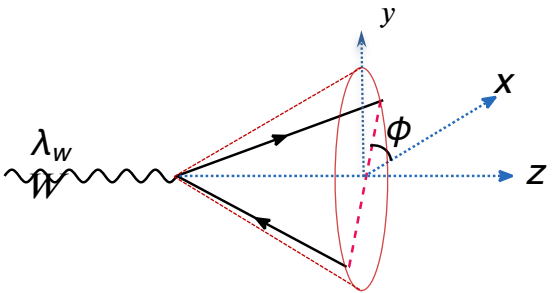


Azimuthal angular correlation in $t \to bW(\to f\bar{f}')$ decay

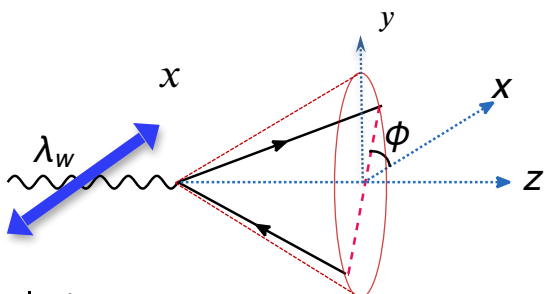
- **Azimuthal correlation angle**

  $\sigma^{-1}\mathrm{d}\sigma/\mathrm{d}\phi$ is the ***angular correlation.***

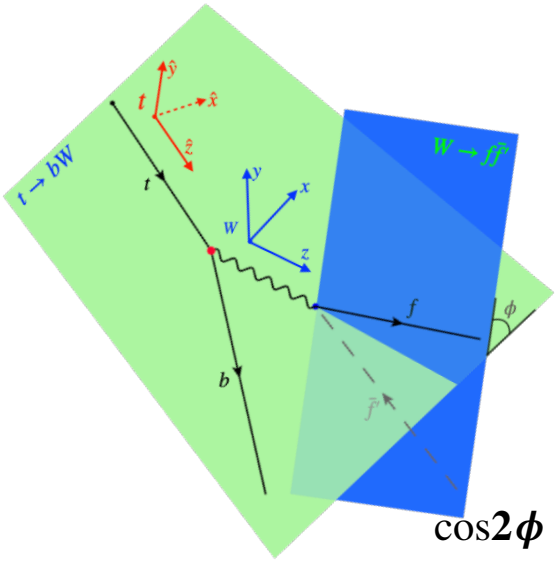
- **Depends on W polarization**

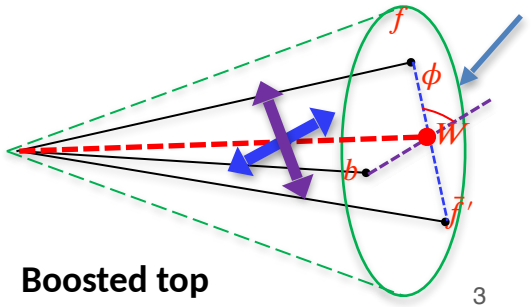


$|\lambda_w\rangle : \mathrm{d}\sigma/\mathrm{d}\phi \propto 1$



$|x\rangle : \mathrm{d}\sigma/\mathrm{d}\phi \propto A - B\cos 2\phi$





- W decay plane tends to be $\perp$ W linear polarization.
- Direction: $\parallel$ / $\perp$ tbW plane

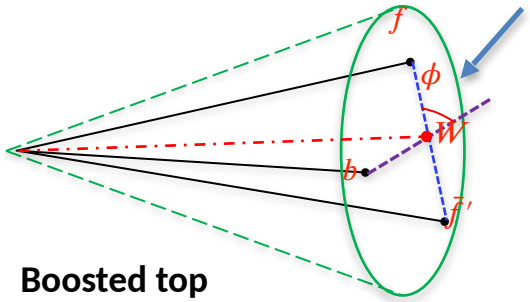
Azimuthal angular correlation: result

$\cos 2\phi$

❑ Azimuthal correlation

$$\frac{1}{\sigma}\frac{d\sigma}{d\phi} = \frac{1}{2\pi}\left[1 + \lambda_T \cos 2\phi - \frac{3\pi}{8} J_1 \cos\phi\right]$$

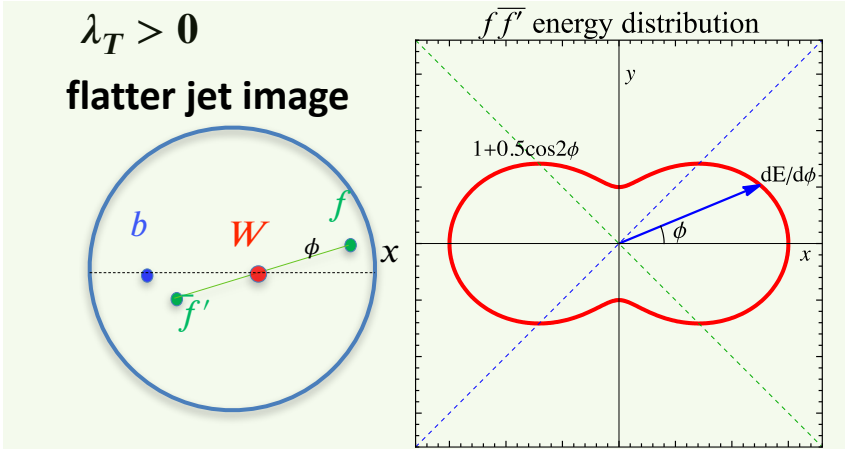
$\phi \in [0, 2\pi]$

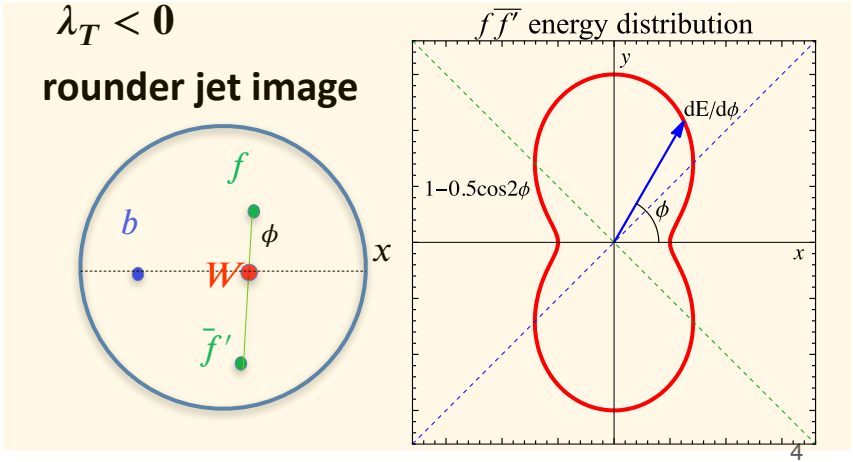


Boosted top

$\cos 2\phi$ only exists in the boosted top frame

❑ $\cos 2\phi$: "roundness" of the energy distribution

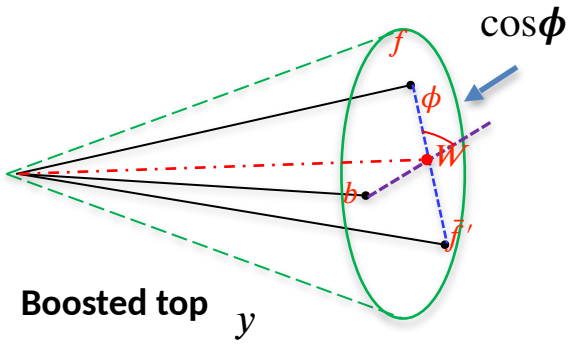




Azimuthal angular correlation: result

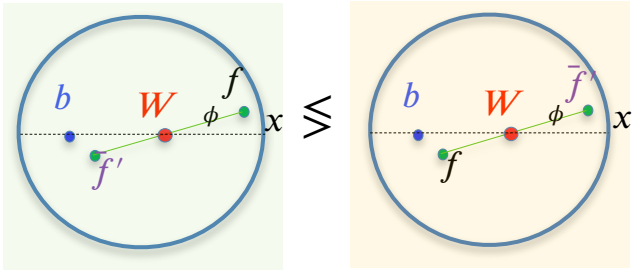
❑ Azimuthal correlation

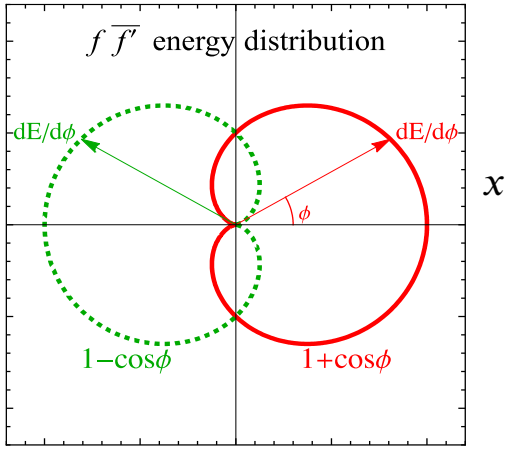
$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\phi} = \frac{1}{2\pi}\left[1 + \lambda_T \cos 2\phi - \frac{3\pi}{8} J_1 \cos\phi\right] \qquad \phi \in [0,2\pi]$$



❑ cosϕ: "forward-backward" asymmetry along x

$J_1 \gtrless 0 \implies$





- **Requires distinguishing f from $\bar{f}'$: semileptonic t decay.**
- **For hadronic t decay, we cannot tell ϕ from $\phi + \pi$**

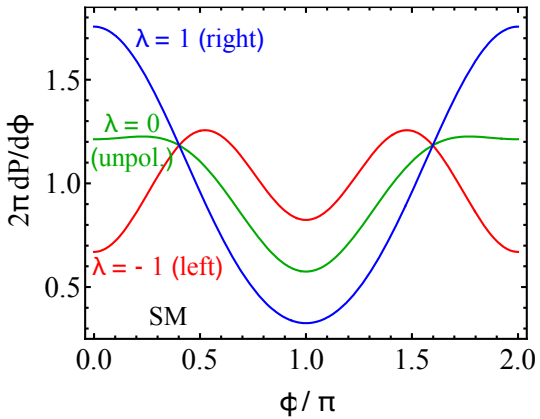
$$\frac{1}{\sigma^{(h)}}\frac{\mathrm{d}\sigma^{(h)}}{\mathrm{d}\phi} = \frac{1}{\pi}\left[1 + \lambda_T \cos 2\phi\right], \quad \phi \in [0,\pi]$$

Dependence on top polarization

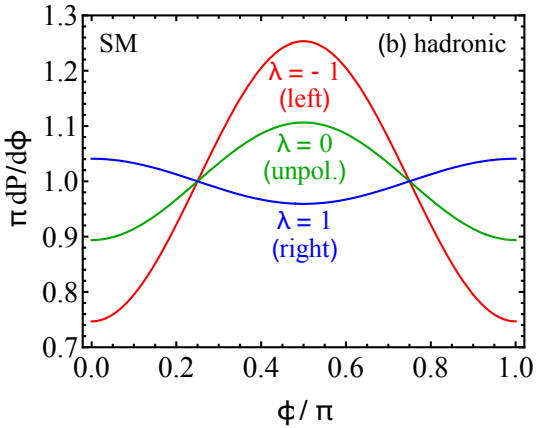
semileptonic $\frac{1}{\sigma^{(l)}}\frac{\mathrm{d}\sigma^{(l)}}{\mathrm{d}\phi} = \frac{1}{2\pi}\left[1 + \lambda_T \cos 2\phi - \frac{3\pi}{8} J_1 \cos\phi\right], \quad \phi \in [0, 2\pi]$

hadronic $\frac{1}{\sigma^{(h)}}\frac{\mathrm{d}\sigma^{(h)}}{\mathrm{d}\phi} = \frac{1}{\pi}\left[1 + \lambda_T \cos 2\phi\right], \quad \phi \in [0, \pi]$

$\lambda_T = -0.106 + 0.147\lambda, \quad J_1 = -0.271 - 0.336\lambda$ **(with SM *Wtb* coupling)**

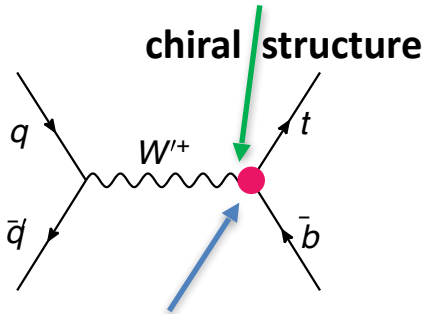


semileptonic



hadronic

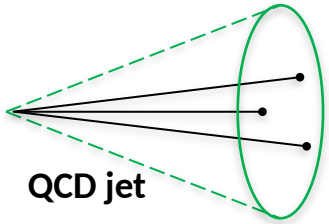
Angular correlation helps measure *top polarization λ*

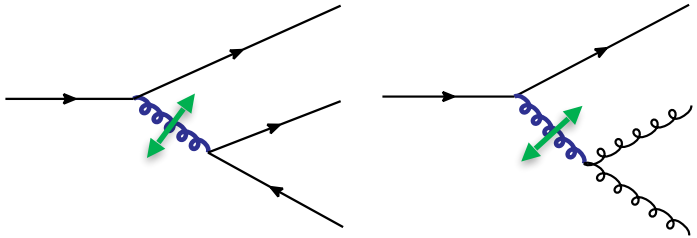


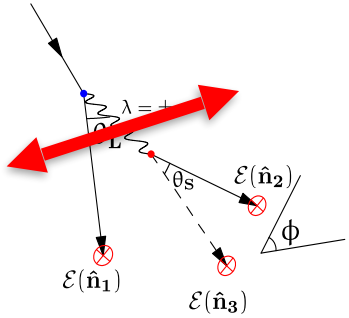
$\bar{t}\gamma^\mu \left(f_L P_L + f_R P_R\right) b\, W'_\mu + \mathrm{h.c.}$

Azimuthal correlation as a boosted top tagger

❑ 3-point energy correlator of QCD jet [2011.02492]







Parity conserving ⇒ $1 + \lambda_j \cos 2\phi$ $\quad \phi \in [0, \pi]$

$\lambda_j \simeq 1\%$ is small

❑ Comparison to QCD jet

Top jet (hadronic mode): $1 + \lambda_T \cos 2\phi$

Polarization			
Top			

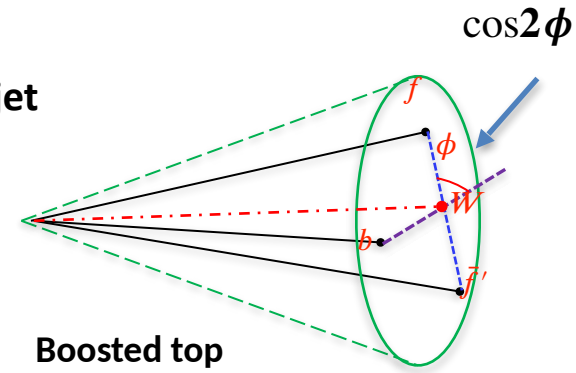
$\lambda_T \gg \lambda_j$

⇒ $\cos 2\phi$ correlation can be a boosted top quark tagger

Summary

❑ Proposed a new observable

- $\cos 2\phi$ angular correlation $\Longrightarrow$ "roundness" of the top jet
- Due to W linear polarization
- Only exists in boosted top frame



❑ Phenomenological significance

- Measuring longitudinal polarization of boosted top
- Distinguish from QCD jet
- Suppress top background

Thank you!