Resummation of Flattened Jet Angularity

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Outline

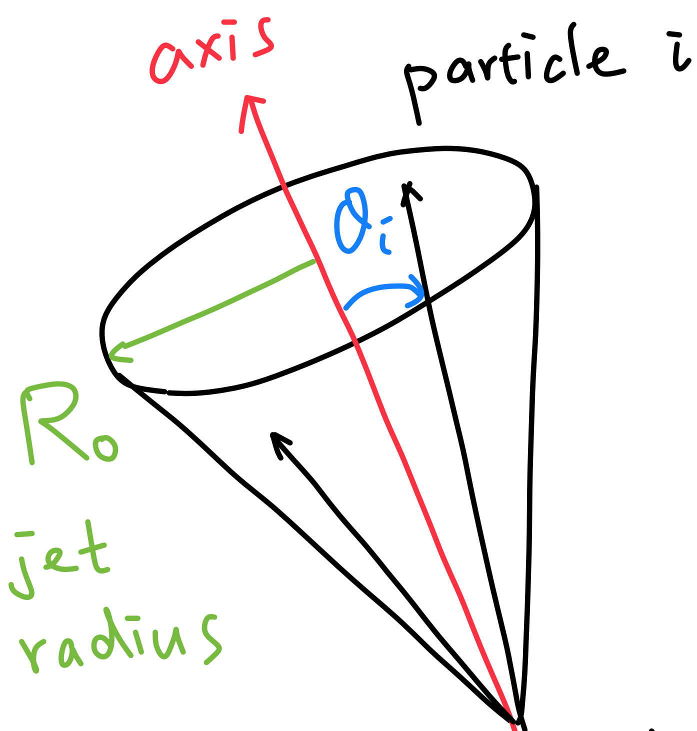
- Introduction
  - Collinear-drop and flattened jet angularity
- Factorization and resummation
- Monte Carlo comparison
- Conclusion

Chien, Stewart, JHEP06(2020)064
Chien, Fedkevych, work in progress

Jet angularity

Berger, Kucs, Sterman, PRD 68 (2003) 014012 ← Introduced 23 years ago

Larkoski, Thaler, Waalewijn, JHEP 11 (2014) 129 ← Generalized angularity



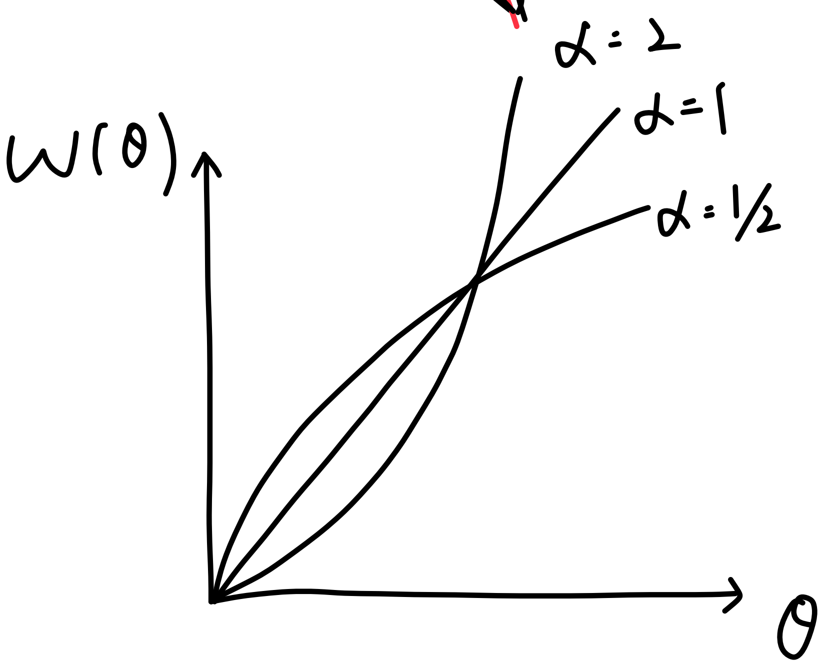
$$\lambda_\alpha^\kappa = \sum_{i \in \text{jet}} z_i^\kappa \boxed{\left(\frac{\theta_i}{R_0}\right)^\alpha} \quad w(\theta)$$

$\kappa = 1$ for IRC safety

$\alpha > 0$

momentum fraction $\quad z_i = \frac{p_t^{\,i}}{p_t^{\,\text{jet}}}$

SUM over per particle contribution weighed by angles ⇒ angularity



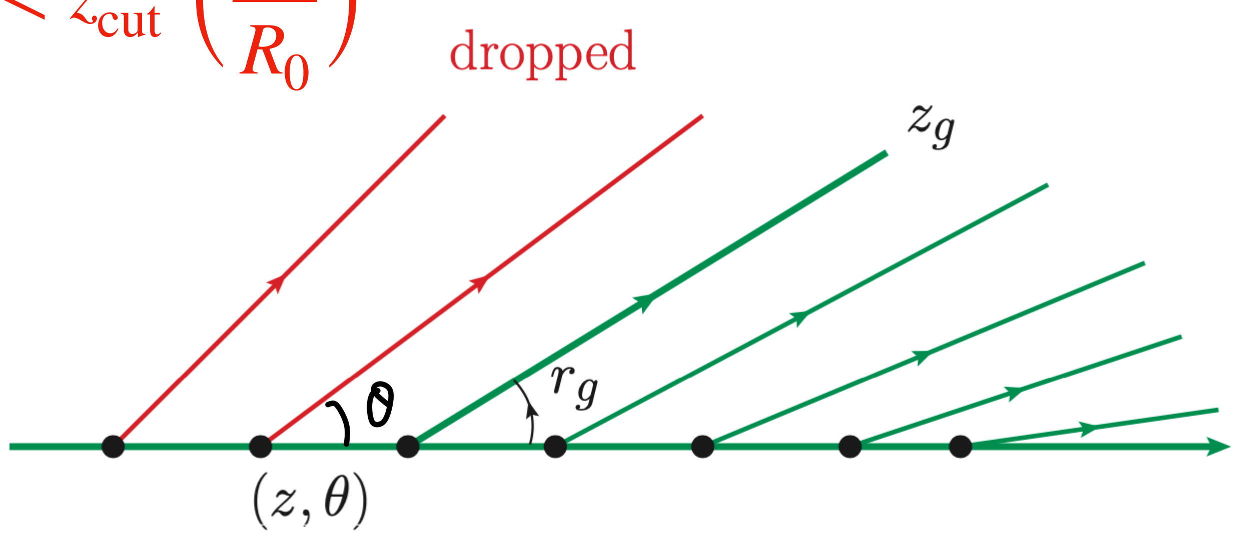
For $\alpha > 0$, $w(\theta)$ is monotonic therefore weighs wide angle particles the most. Suffers from contaminations such as underlying events, pileup, or even event-wide radiation

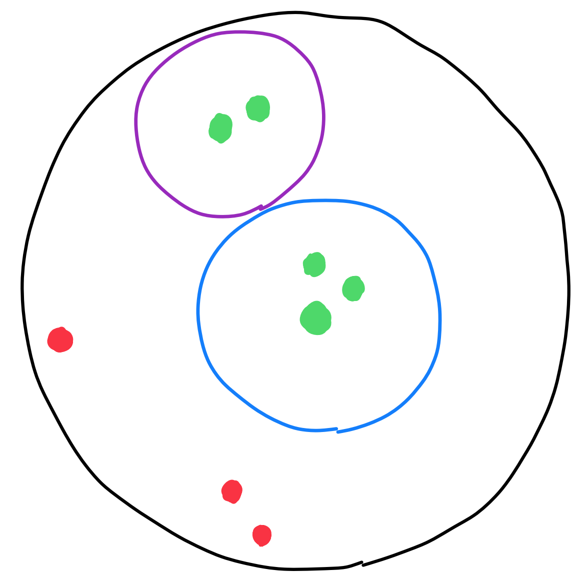
theoretical control challenging!

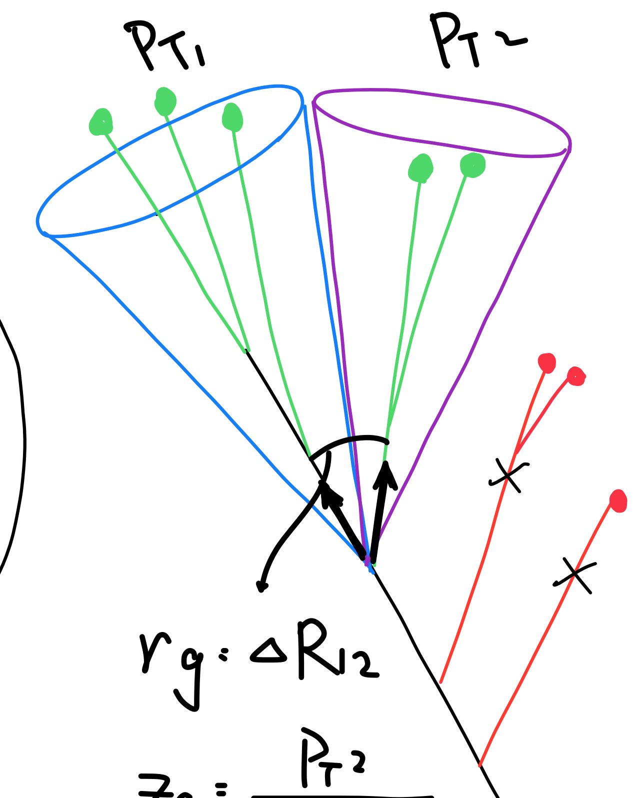
Soft-drop grooming

Larkoski, Marzani, Soyez, Thaler, JHEP05(2014)146

$$z < z_{\rm cut}\left(\frac{\theta}{R_0}\right)^{\beta}$$







$r_g : \Delta R_{12}$

$z_g = \frac{p_{T2}}{p_{T1} + p_{T2}}$

Procedure :

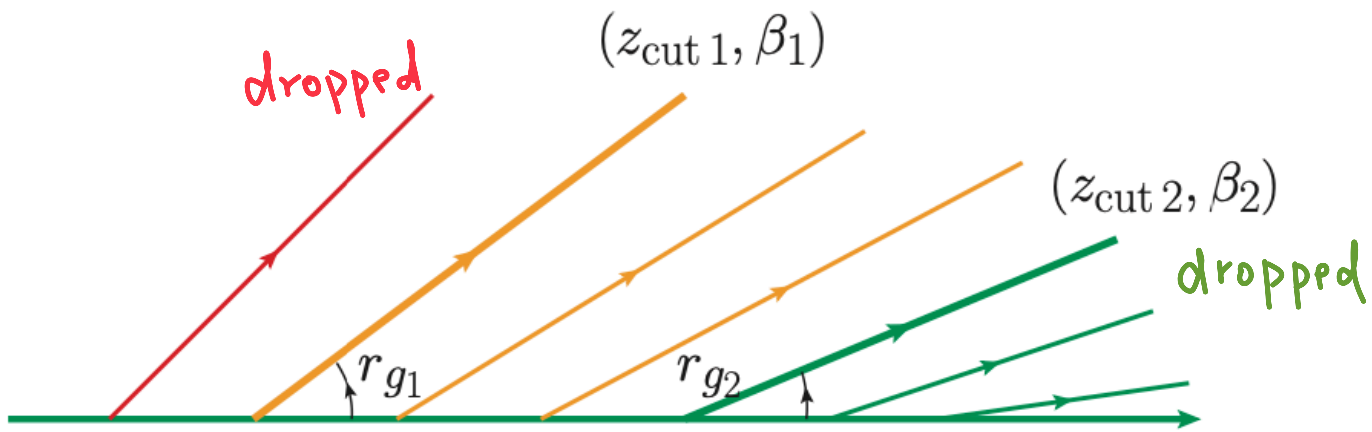
* Recluster jet using Cambridge - Aachen algorithm → angular ordering
* Starting from the "root" and check the i, j merging satisfy soft-drop condition $z < z_{cut}\left(\frac{\theta}{R_0}\right)^{\beta}$

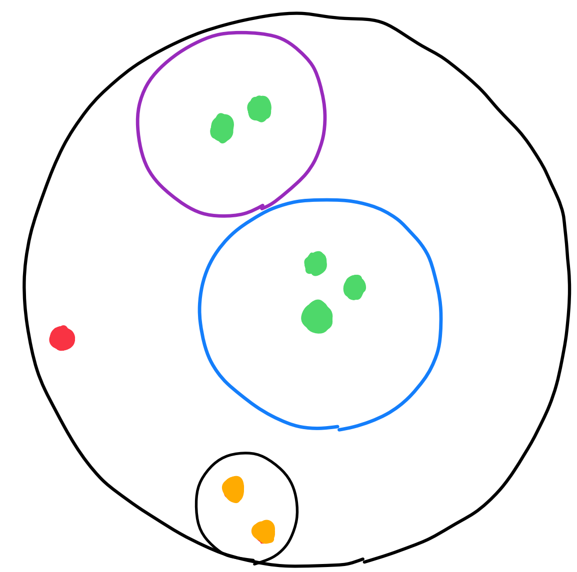
Yes → drop the soft branch and move on to the hard branch

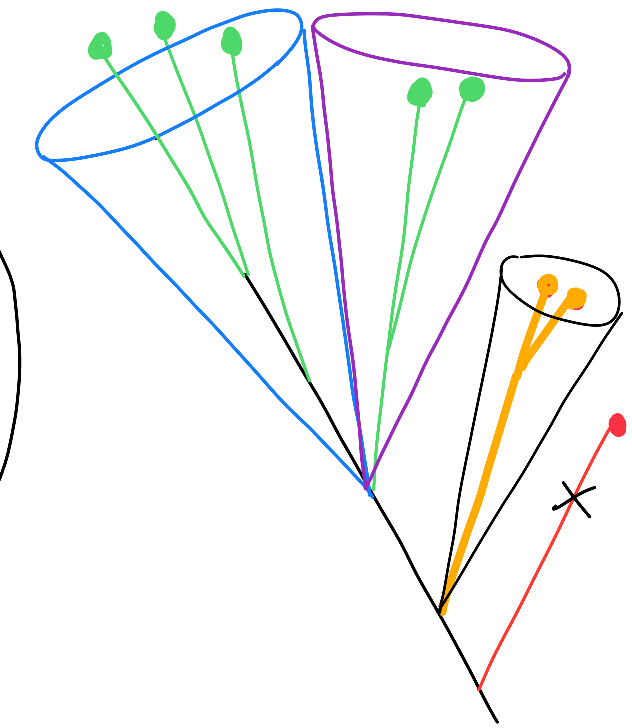
No → stop

Collinear-drop

Chien, Stewart, JHEP06(2020)064

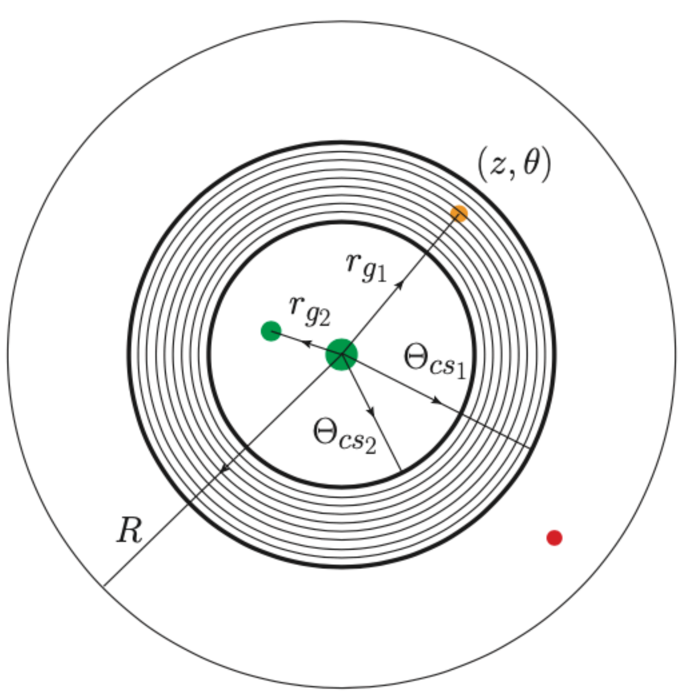






$$z_{cut_1}\left(\frac{\theta}{R_0}\right)^{\beta_1} < z < z_{cut_2}\left(\frac{\theta}{R_0}\right)^{\beta_2}$$

Collinear drop condition



- Conventionally only particles surviving soft drop are studied. However, one could study the dropped particles as well
- One could even pick out an intermediate branch with two soft drop conditions

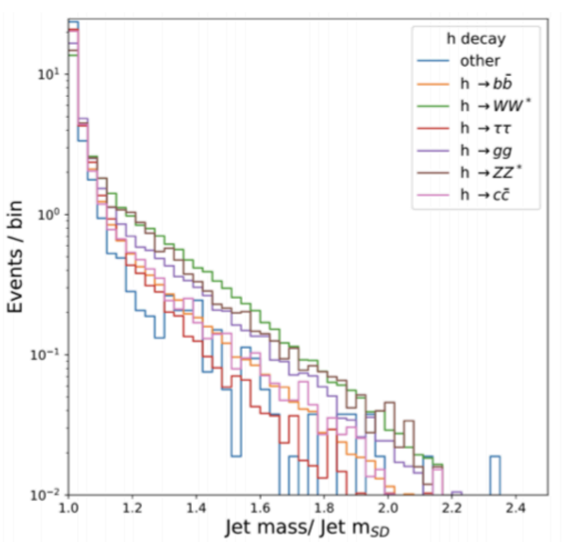
An extension of soft drop mass is the collinear drop mass

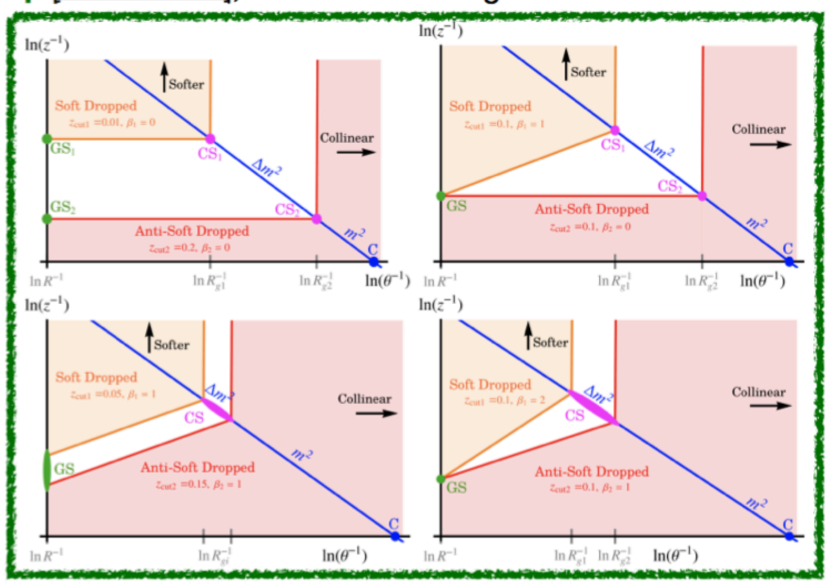
$$\boxed{\Delta m^2 = m_{SD_1}^2 - m_{SD_2}^2}$$

Useful applications

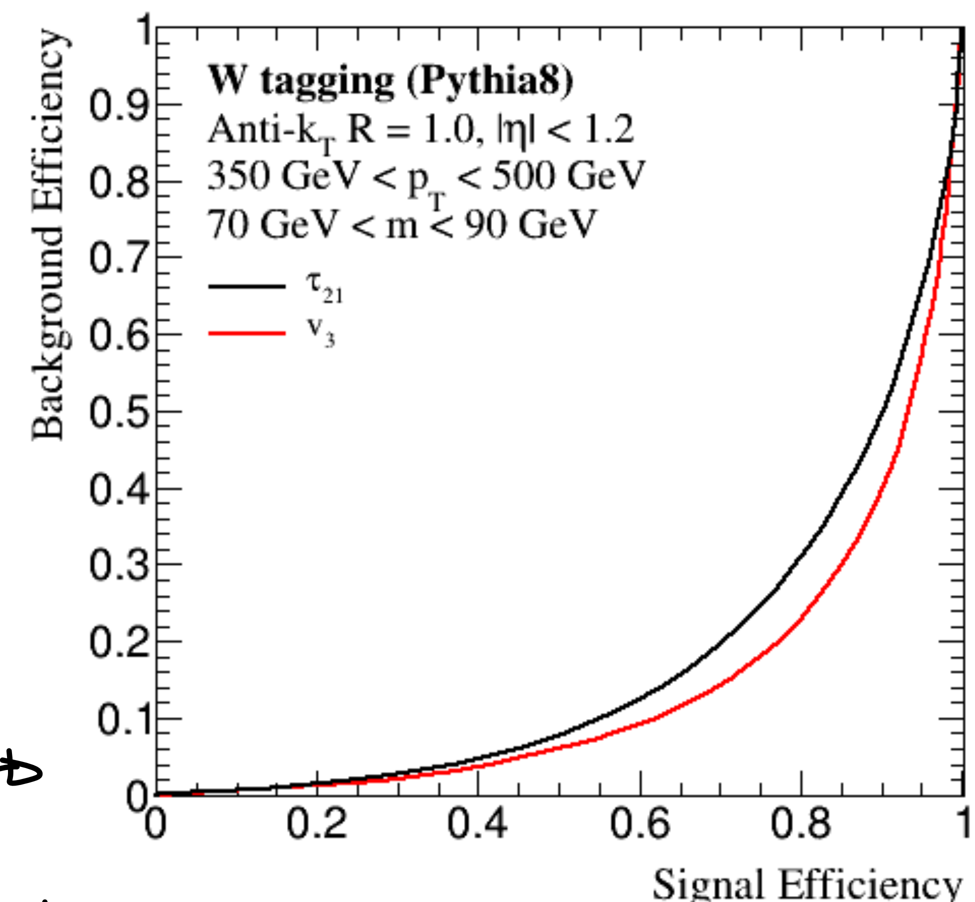
Higgs Tagging - gg

- Particle content of h→gg jet similar to QCD jet
  - Dedicated GRU struggles to differentiate
- MLP with expert features - *jet mass ratios*
  - Similar concept to **collinear drop** [1907.11107], isolates color singlet





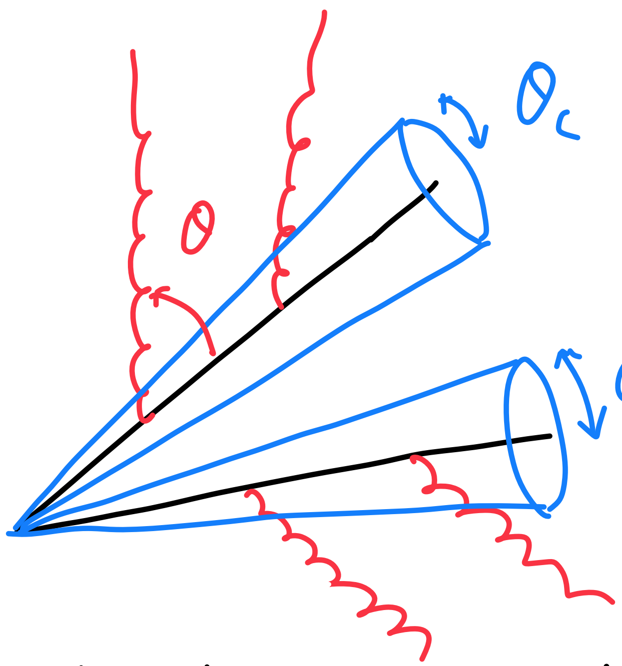
Color-singlet jet isolation
Chien et al, PRD 101 (2020) 11, 114006
(arXiv 1711.11041, Telescoping jet substructure)



"Jet color ring"
Larkoski et al
arxiv: 2006.10480
SciPost Phys. 9.2.026

Back then, color-singlet jet isolation was utilised using a class of jet observables called variability. Once such feature is identified, it really is collinear drop.

Useful applications

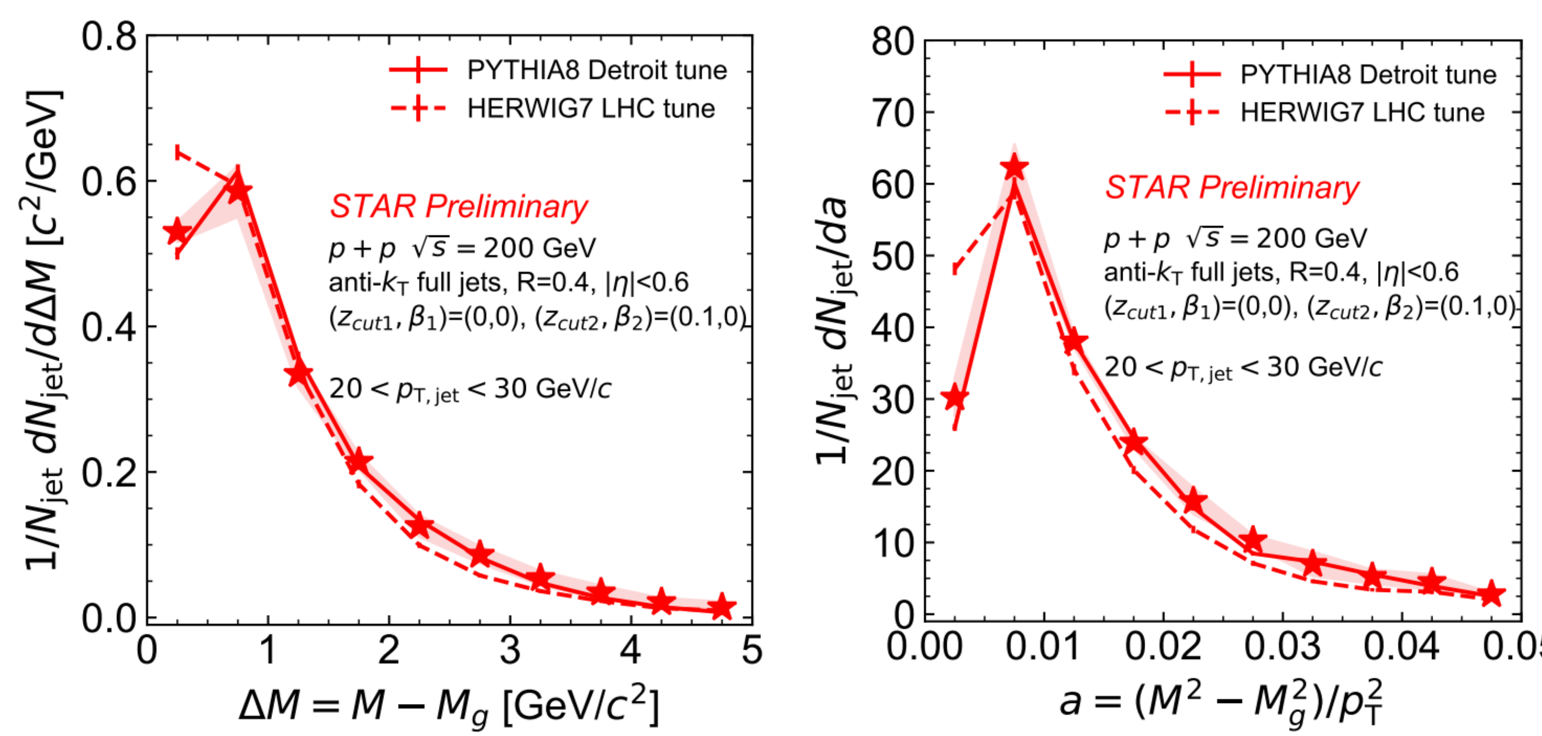


θ_c : medium resolution angle

* Collinear drop first realized in STAR experiment at RHIC

* Omni-fold was used to simultaneously unfold multiple jet observable, making collinear drop jet mass measurement straight forward.

Medium-induced, color decoherent radiation is not angular-ordered and may just be soft-dropped.

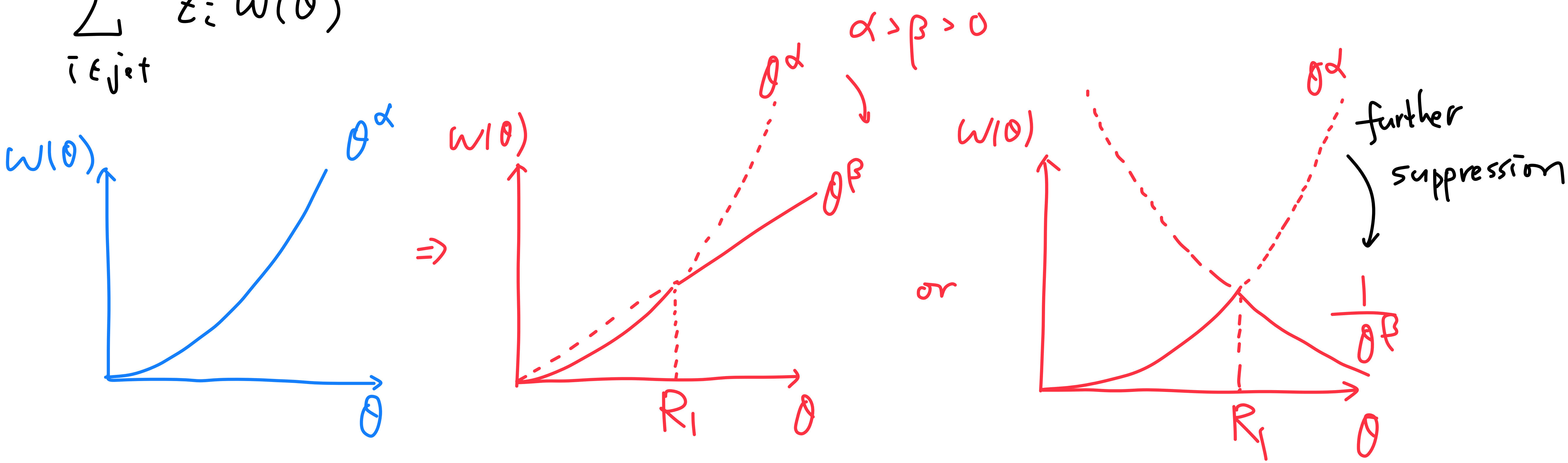


Flattened jet angularity

While groomed observables are mostly constructed using clustering algorithms, which often complicate theoretical calculations, in this talk we introduce a jet-shape based technique to suppress wide-angle radiation

Flattened jet angularity generalize the functional form of $w(\theta)$

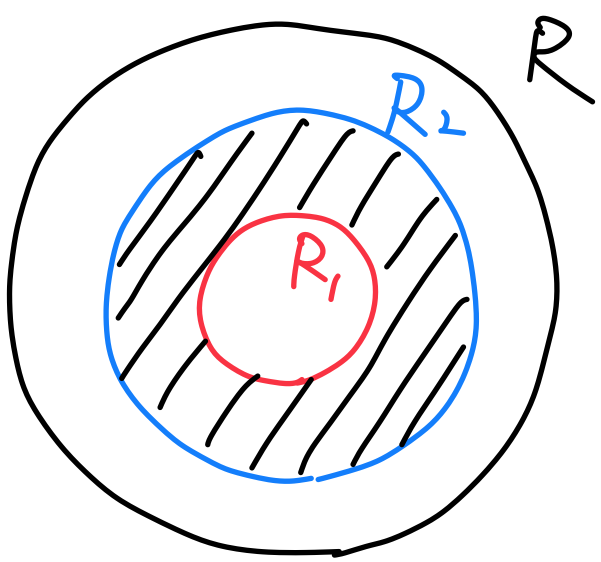
$$\sum_{i \in \text{jet}} z_i \, w(\theta)$$

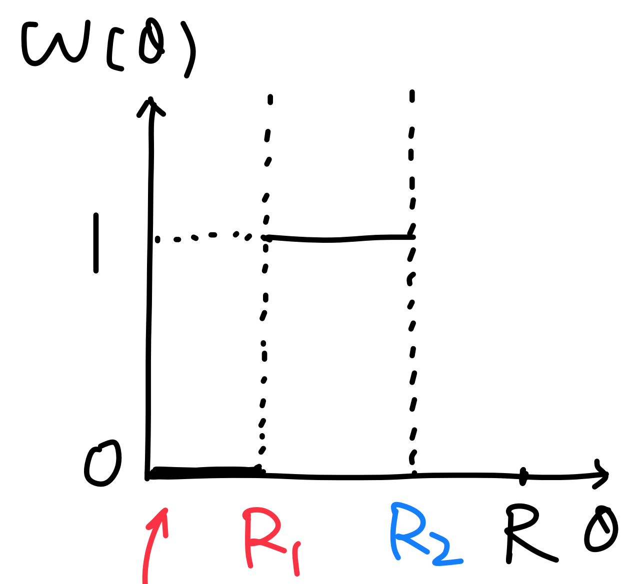


piecewise polynomial

Flattened jet angularity: an example

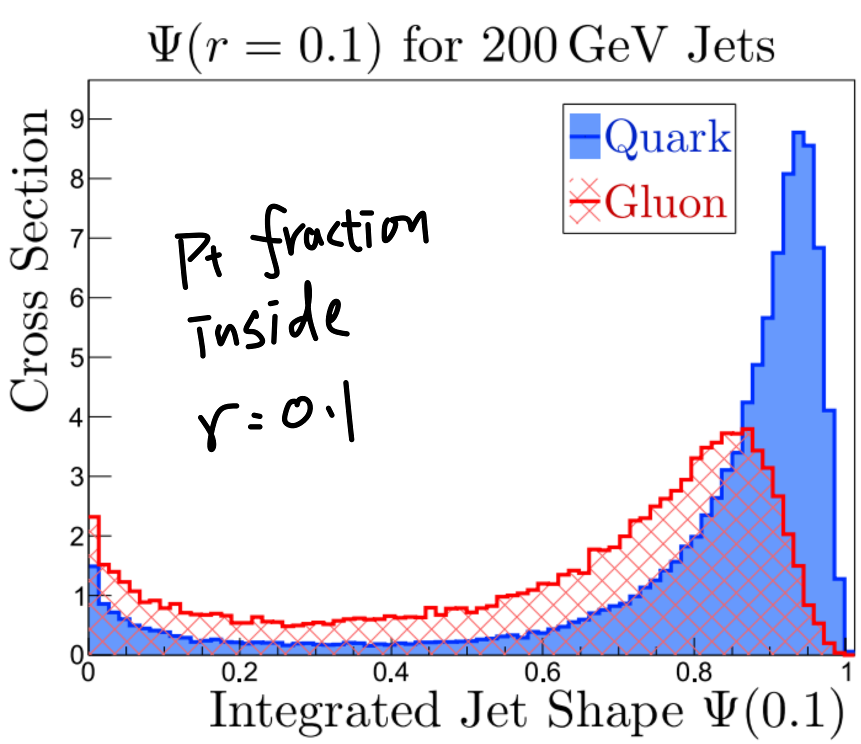
Annulus p_t fraction χ





another implementation of collinear drop

A jet substructure version of the classic nonglobal observable: away-from jet energy flow

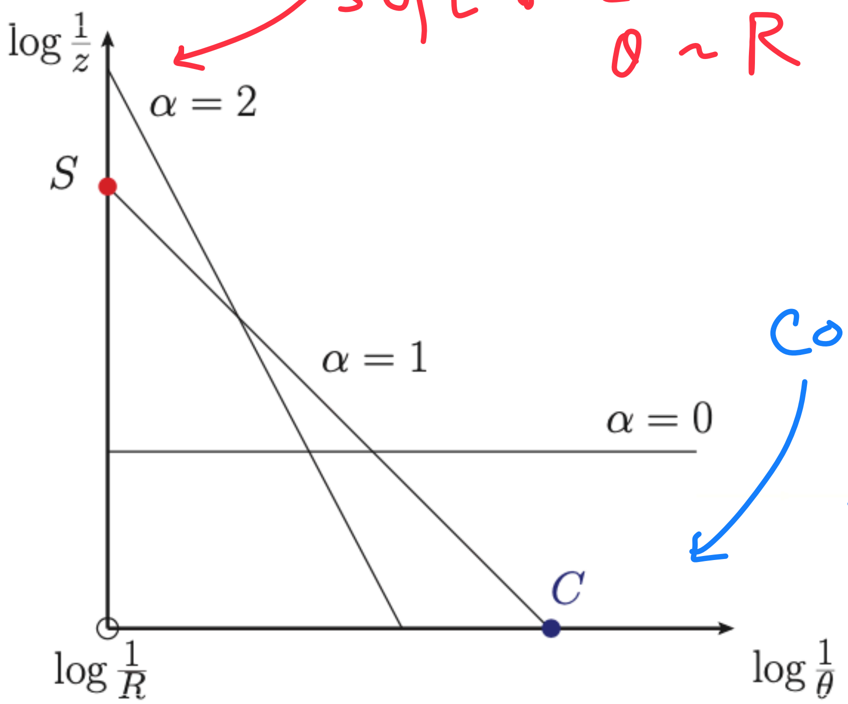


Gallicchio, Schwartz PRL 107 (2011) 172001

Instead of the average quantity, which is the conventional jet shape, this jet-by-jet distribution is shown to be sensitive to quark/gluon differences

Lund plane and SCET modes

Soft : z small, $\theta \sim R$



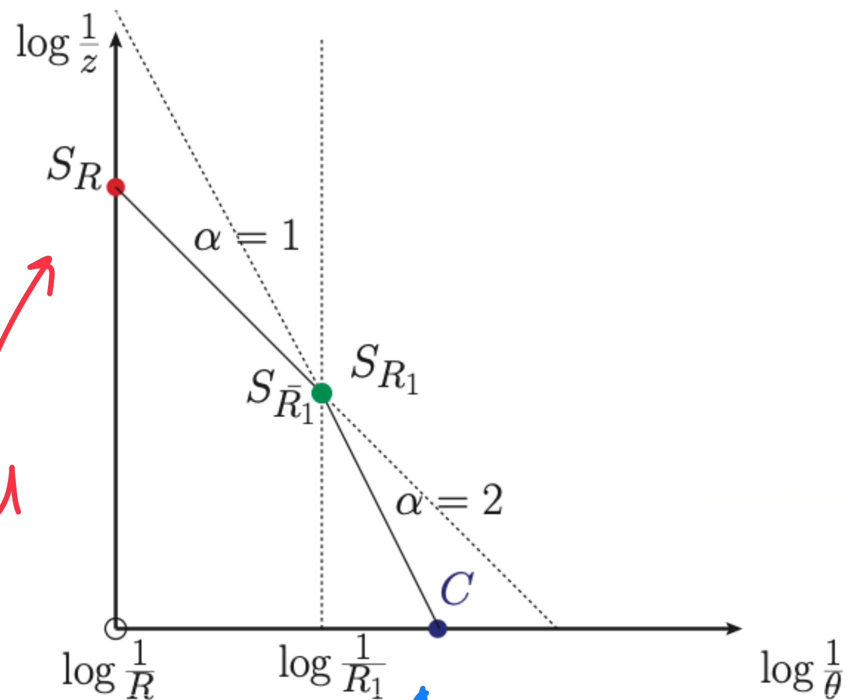
collinear: θ small, $z \sim 1$

$$\lambda_w : \sum_{i \in jet} z_i \theta_i^{\alpha}$$

$$\log\frac{1}{\lambda_w} \sim \log\frac{1}{z} + \alpha \log\frac{1}{\theta}$$

Jet angularity measurement represents as a straight line on the Lund plane $\left(\log\frac{1}{\theta}, \log\frac{1}{z}\right)$ with slope $-\alpha$

Factorization of flattened jet angularity



standard soft mode for $\alpha = 1$

standard collinear mode for $\alpha = 2$

Piecewise polynomial angular weight $W(\theta)$ becomes piecewise straight lines (polygons)

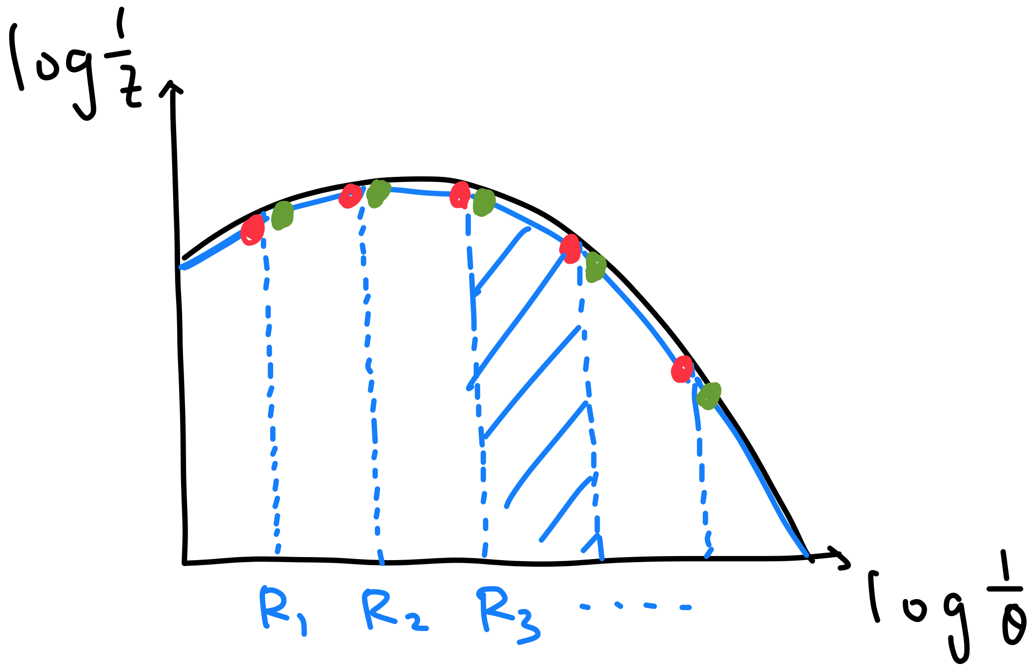
Each vertex requires two modes with exactly the same momentum scaling

S_{R_1} and $S_{\bar{R}_1}$

the soft mode correspond to the measurement of $\alpha = 2$ for θ up to R_1

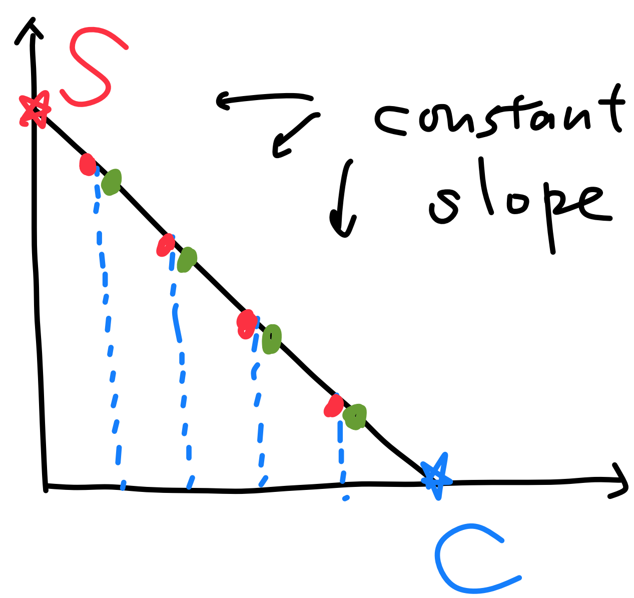
the dropped soft mode correspond to the measurement of $\alpha = 1$ for θ not below R_1

Factorization of flattened jet angularity



One can approximate any arbitrary measurement contour with piecewise straight lines. Therefore an annulus represents a differential building block of an EFT of a general jet substructure observable

special case



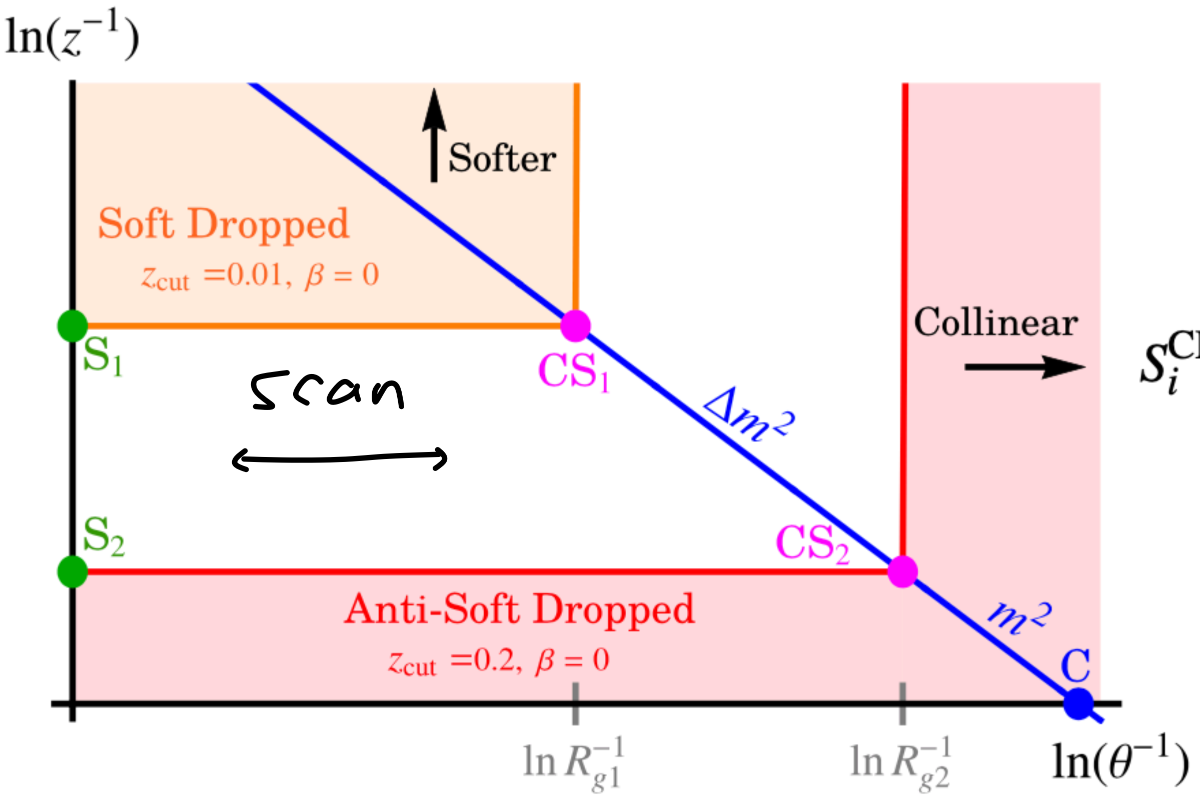
One can think of the classical jet angularity as factorized into an infinite number of modes, whose effects cancel except at the end points: Soft & collinear modes.

An infinite number of SCET modes.

Compare factorization of collinear drop

Two soft-drops:

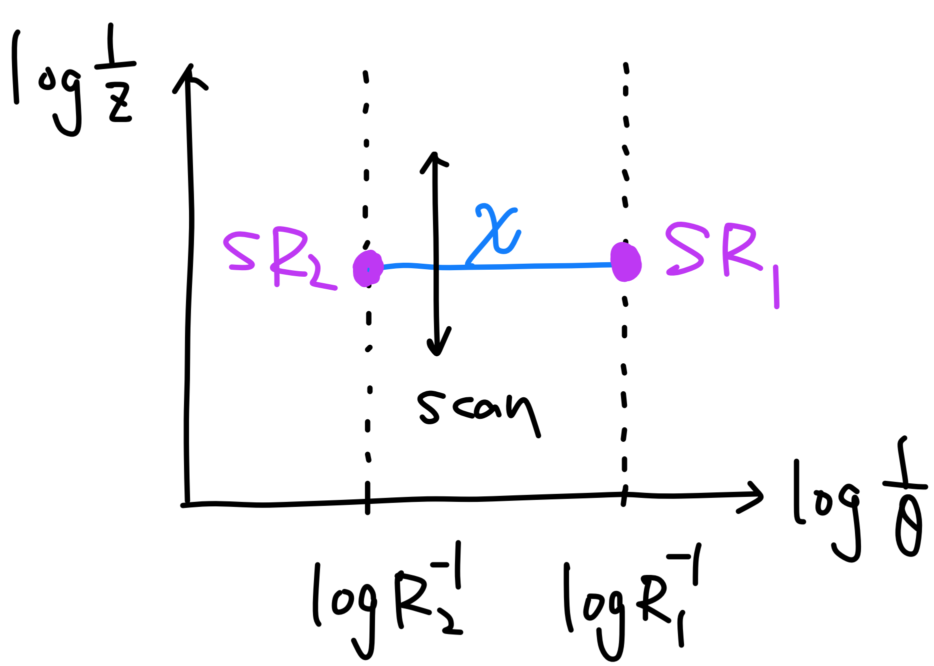
Chien, Stewart, JHEP06(2020)064



$$\frac{d\sigma}{d\Delta m^2} = \sum_{i=q,g} N_i(\mu) J^{\rm SD}_{{\rm un},i}(z_{{\rm cut}\,2},\beta_2,\mu) S_i^{\rm CD}(\Delta m^2, z_{{\rm cut}\,i},\beta_i,\mu)$$

$$S_i^{\rm CD}(\Delta m^2,\mu) = \int dk_i \overline{S_{C_2,i}}(k_2,\mu) S_{C_1,i}(k_1,\mu)\delta(\Delta m^2 - 2E_J(k_1+k_2))$$

Annulus energy fraction:



$$P_i^{\rm FA}(x,R_1,R_2) = \int dx_1 dx_2\ S_{\overline{R}_1 i}(x_1,\mu)\ S_{R_2 i}(x_2,\mu)\delta(x-x_1-x_2)$$

$P_{S_R} \sim E_J \times (R^2, 1, R)$: momentum scaling of such soft modes.

Resummation using RG evolution

$$\frac{P_i^{\rm FA}(x,\mu)\,J^{\rm un}_{R_1 i}(\mu)}{J^{\rm un}_{R_2 i}(\mu)} = \exp\Big[2C_i S(\mu_{R_1},\mu_{J_{R_1}}) - 2C_i S(\mu_{R_2},\mu_{J_{R_1}}) + 2C_i S(\mu_{J_{R_2}},\mu_{J_{R_1}})$$
$$+\,2A_{S_{\bar R_1 i}}(\mu_{R_1},\mu_{J_{R_1}}) + 2A_{S_{R_2 i}}(\mu_{R_2},\mu_{J_{R_2}}) + 2A_{J i}(\mu_{J_{R_1}},\mu_{J_{R_2}})\Big]\frac{J^{\rm un}_{R_1 i}(\mu_{J_{R_1}})}{J^{\rm un}_{R_2 i}(\mu_{J_{R_2}})}$$
$$\left[\frac{\mu_{R_2}}{\mu_{R_1}}\frac{\mu_{J_{R_1}}}{\mu_{J_{R_2}}}\right]^{\eta_{R_1}} \tilde S_{R_2 i}(\partial\eta,\mu_{R_2})\,\tilde S_{\bar R_1 i}\Big(\partial\eta + \ln\frac{\mu_{R_2}}{\mu_{R_1}}\frac{\mu_{J_{R_1}}}{\mu_{J_{R_2}}},\mu_{R_1}\Big)\frac{1}{x}\left(\frac{\mu_{J_{R_2}}x}{\mu_{R_2}}\right)^{\eta}\frac{e^{-\gamma_E\eta}}{\Gamma(\eta)}$$

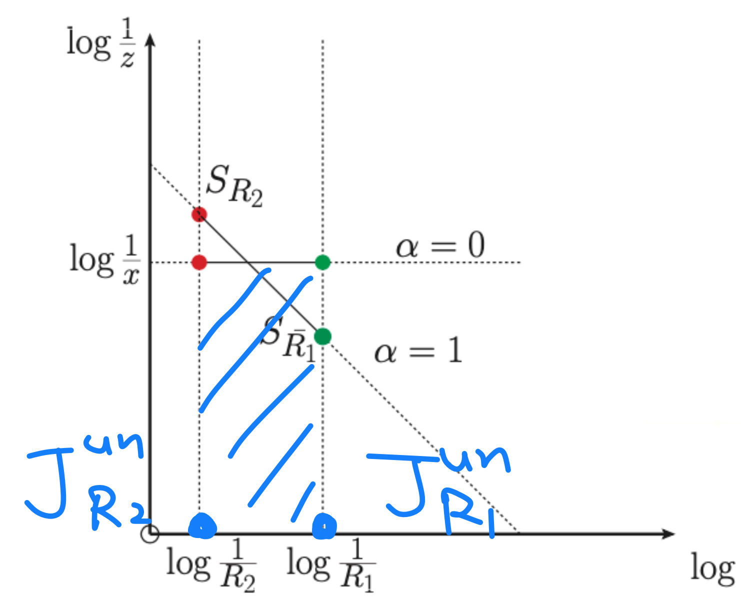
RG evolution kernels using anomalus dimension

One-loop expression for the soft and dropped soft function

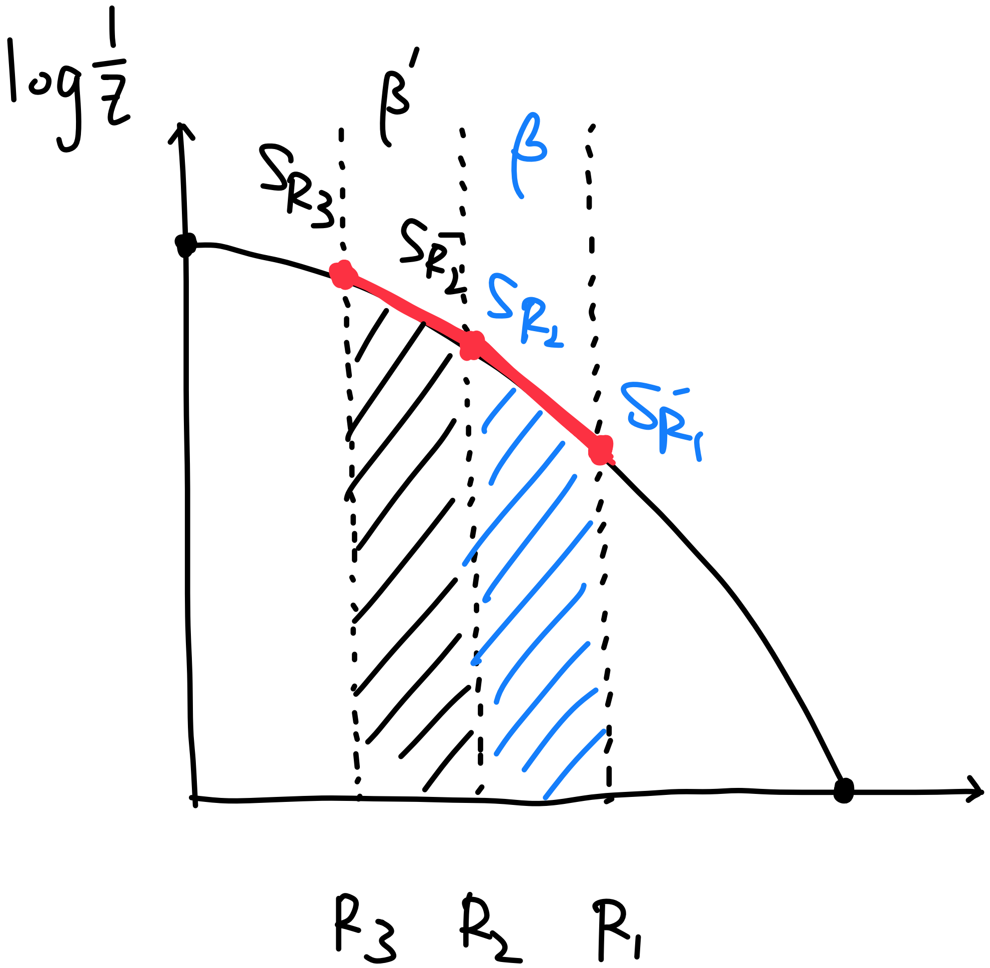
$$S_{\bar R_1 i}(x_1,\mu) = \frac{2E_J g^2 C_i \mu^{2\epsilon} e^{\epsilon\gamma_E}\Omega_{d-2}}{(2\pi)^{d-1}(4\pi)^{\epsilon}}\int\frac{dq^+dq^-}{(q^+q^-)^{1+\epsilon}}\,\delta(q^- - 2E_J x_1)\,\Theta\Big(\frac{q^+}{q^-} - \frac{R_1^2}{4}\Big)$$
$$S_{R_2 i}(x_2,\mu) = \frac{2E_J g^2 C_i \mu^{2\epsilon} e^{\epsilon\gamma_E}\Omega_{d-2}}{(2\pi)^{d-1}(4\pi)^{\epsilon}}\int\frac{dq^+dq^-}{(q^+q^-)^{1+\epsilon}}\,\delta(q^- - 2E_J x_2)\,\Theta\Big(\frac{R_2^2}{4} - \frac{q^+}{q^-}\Big)$$

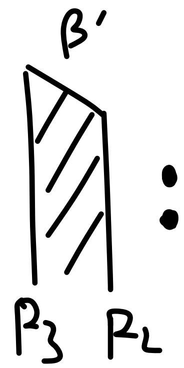
One-loop anomalus dimensions

$$\frac{d\log\tilde S_{\bar R_1 i}}{d\log\mu} = 2C_i\gamma_{\rm cusp}\ln\frac{\mu_{J_{R_1}}}{\nu\mu} - 2\gamma^{S_{\bar R_1 i}} \equiv \gamma_{S_{\bar R_1 i}}$$
$$\frac{d\log\tilde S_{R_2 i}}{d\log\mu} = -2C_i\gamma_{\rm cusp}\ln\frac{\mu_{J_{R_2}}}{\nu\mu} - 2\gamma^{S_{R_2,i}} \equiv \gamma_{S_{R_2 i}}$$
$$\gamma_{P_i^{\rm FA}} = \gamma_{S_{\bar R_1 i}} + \gamma_{S_{R_2 i}} = -2C_i\gamma_{\rm cusp}\log\frac{R_2}{R_1} = \gamma_{J_{R_2 i}} - \gamma_{J_{R_1 i}}$$



RG consistency at one-loop





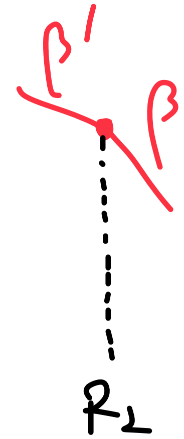
:

$$\frac{d(\tilde S_{R_3}\tilde S_{\bar R_2})}{d\ln\mu} = \gamma_{cusp}\, 2C_i \log\left(\frac{E_J}{\sqrt{\mu}}\right)^{\frac{1}{1+\beta'}} R_2 - \gamma_{cusp}\, 2C_i \log\left(\frac{E_J}{\sqrt{\mu}}\right)^{\frac{1}{1+\beta'}} R_3$$

$$= \gamma_{cusp}\, 2C_i \log\left(\frac{R_2}{R_3}\right)$$

indep. of β.

Summing over strips, the anomalous dimension $= \gamma_{cusp}\, 2C_i \log\left(\frac{R_{in}}{R_{out}}\right)$



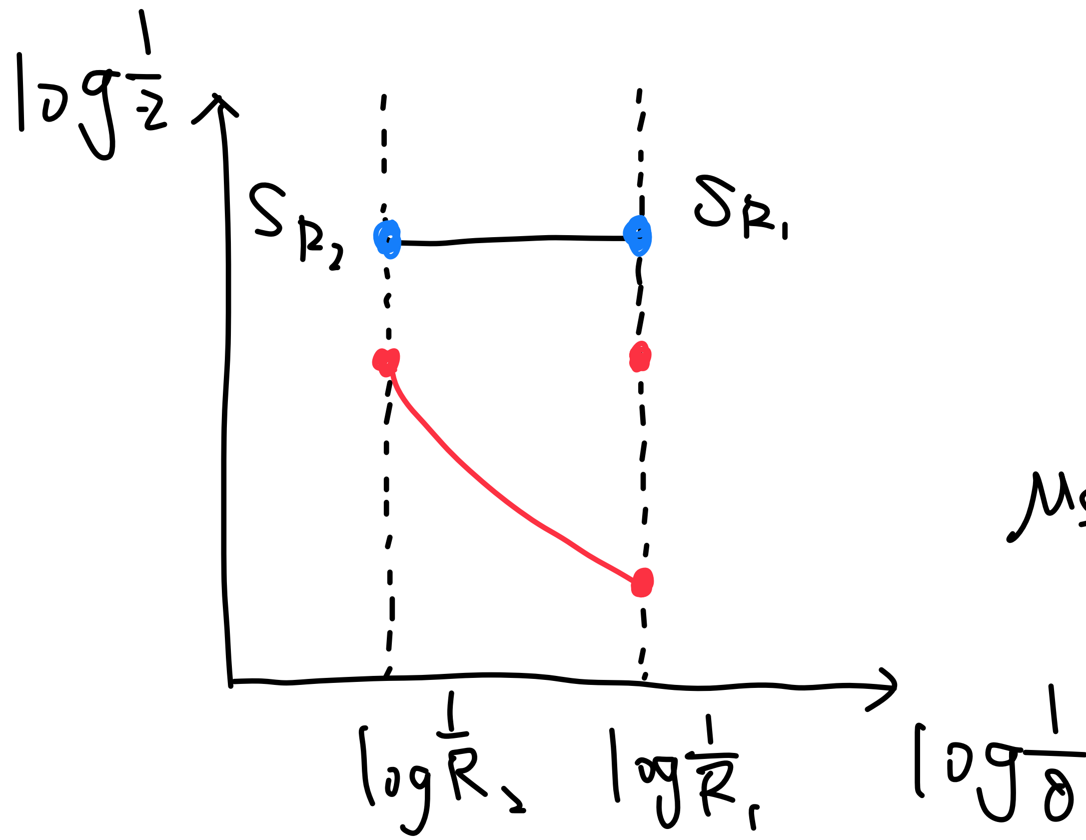
:

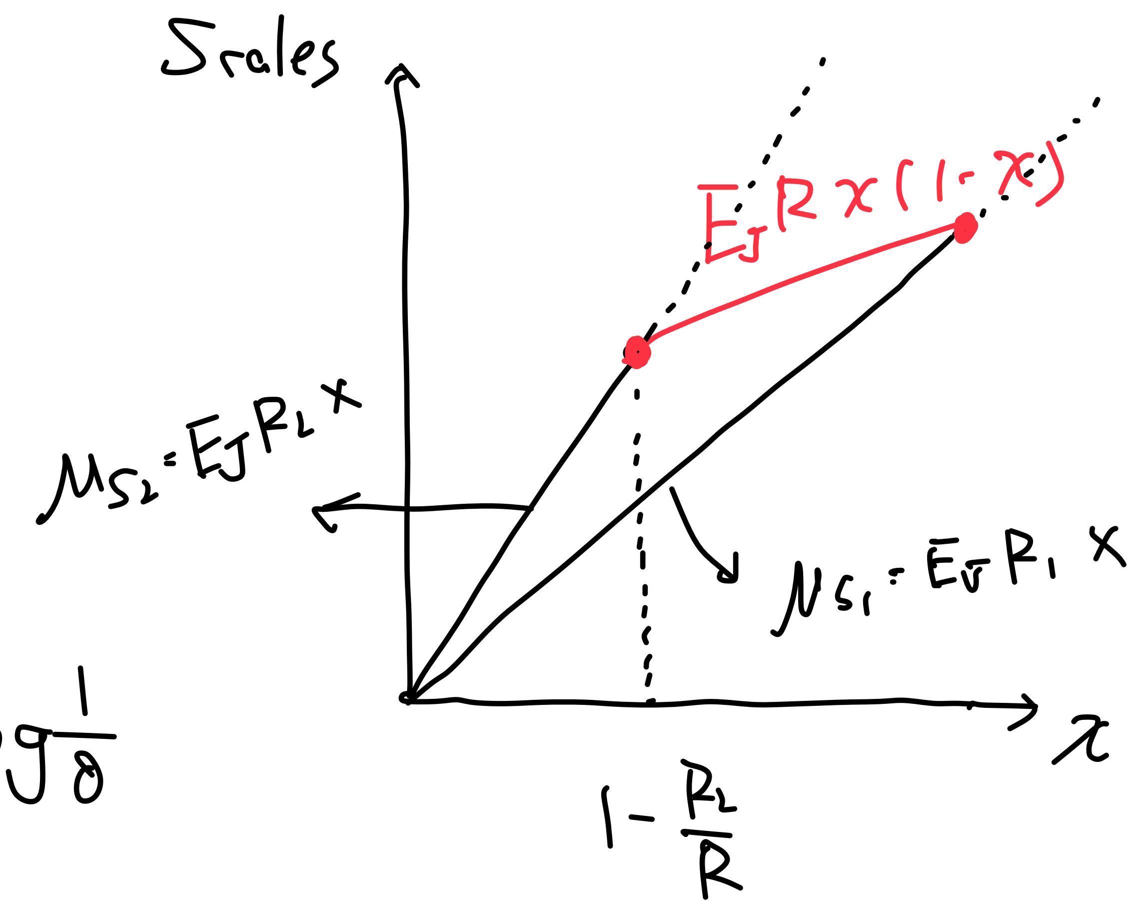
$$\frac{d(\tilde S_{R_2}\tilde S_{\bar R_2})}{d\ln\mu} = -\gamma_{cusp}\, 2C_i \log\left(\frac{E_J}{\sqrt{\mu}}\right)^{\frac{1}{1+\beta'}} R_2 + \gamma_{cusp}\, 2C_i \log\left(\frac{E_J}{\sqrt{\mu}}\right)^{\frac{1}{1+\beta}} R_2$$

$$= -\gamma_{cusp}\, 2C_i \log\left(\frac{E_J}{\sqrt{\mu}}\right) \Delta\left(\frac{1}{1+\beta}\right)$$

smoothly changing the slope.

Scale choices

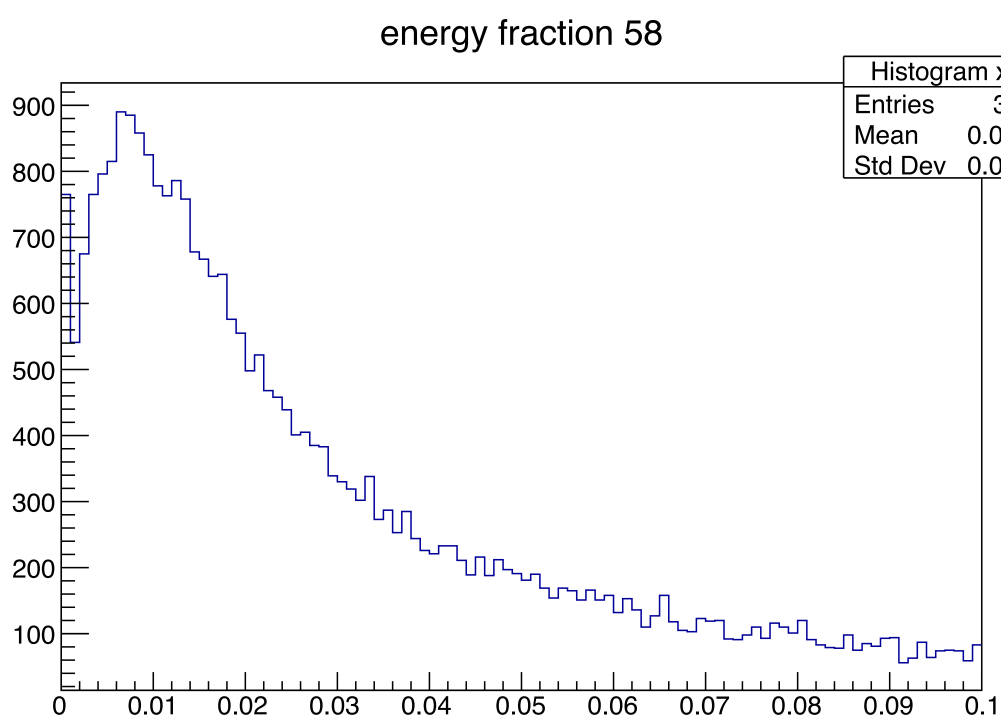


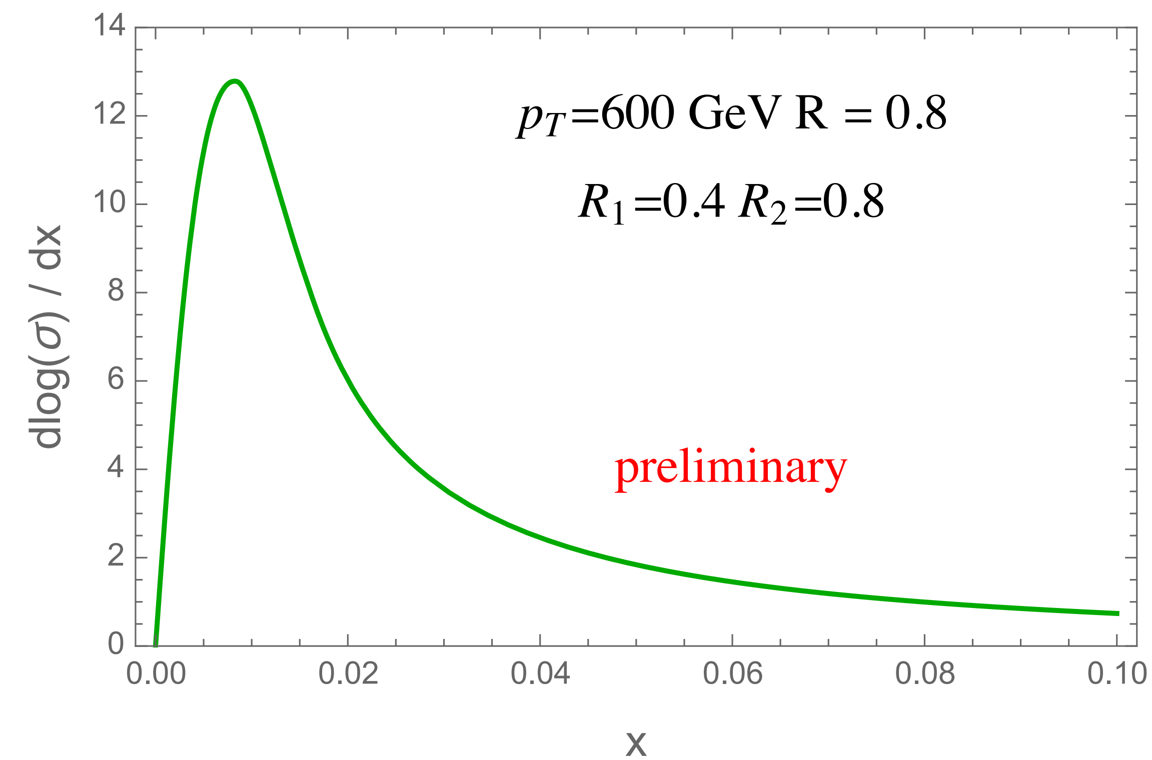


Characteristic scales for S_{R_1} and S_{R_2} in the $x \to 0$ limit

$\mu_{S_1} = E_J R_1 x$, $\mu_{S_2} = E_J R_2 x$ can not extend to all regions of x due to constraints from jet algorithm. Also, if R_1 is too small then the annulus may still enclose most of the jet energy.

Monte Carlo and analytic studies (preliminary)





- Peripheral rings ensure dropping collinear radiation and probes soft radiation
- Hadronization corrections shift to **smaller** values
- Native scale choices: $\mu_{\bar{R_1}} = E_J x R_1$, $\mu_{R_2} = E_J x R_2$ breaks down at large values of x and scale merging/fixed order matching needs to be done. Constraints from recoil need to be considered.
- Sudakov peak position predicted and sensitive to the running of strong coupling constant

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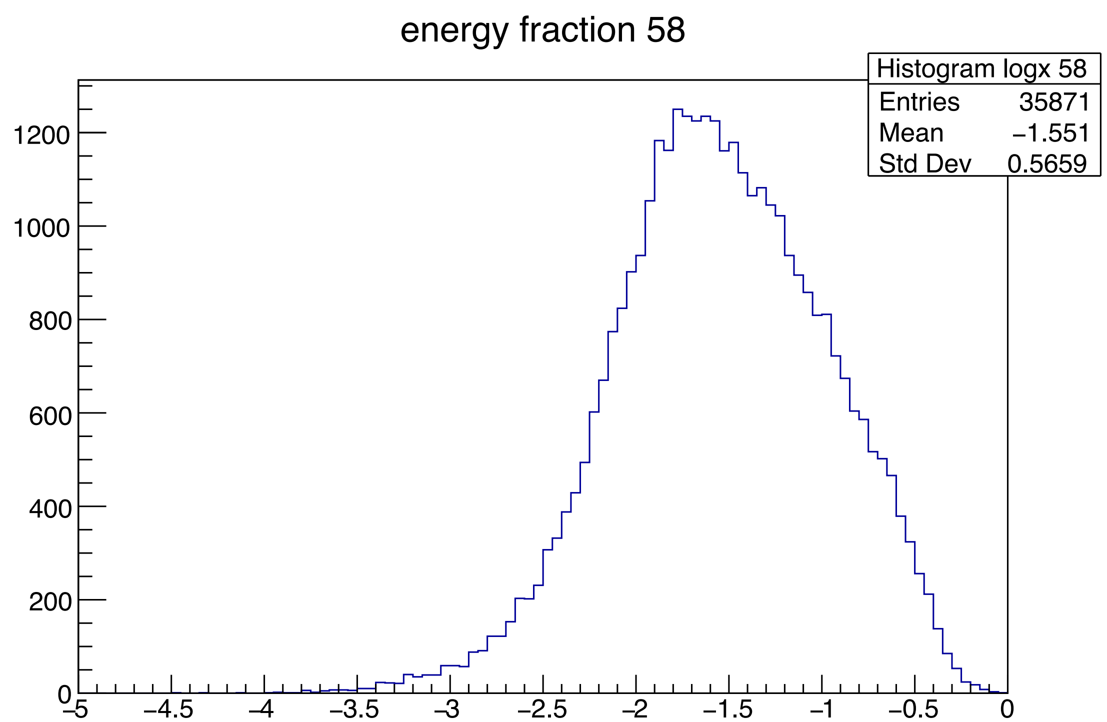

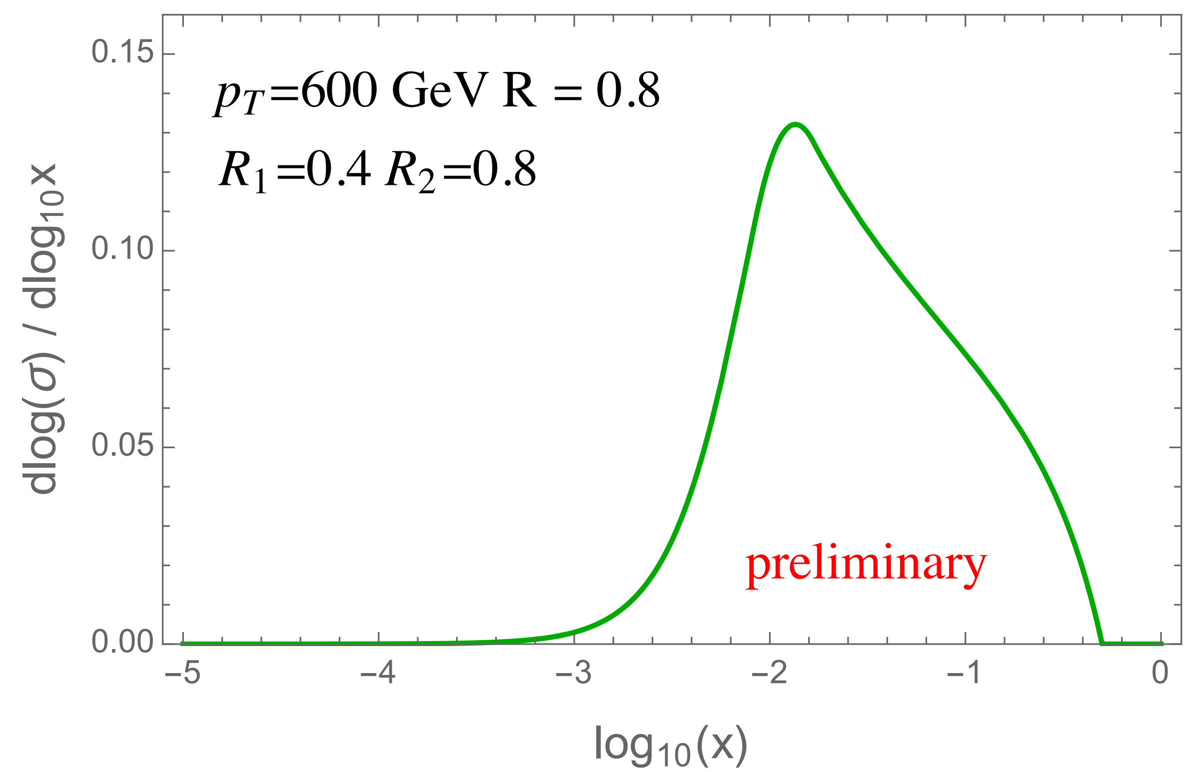

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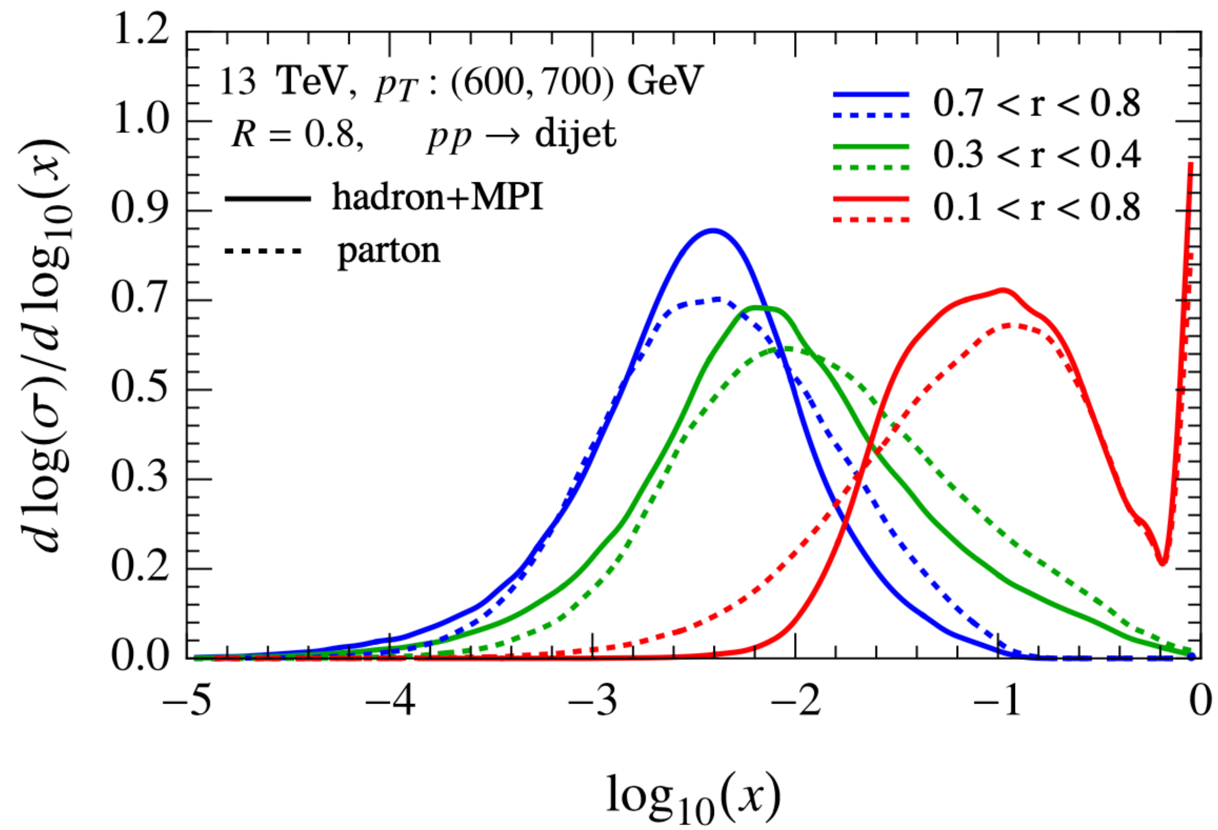
Chien, Stewart, JHEP06(2020)064



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Conclusions

- Explore a new jet substructure observable called flattened jet angularity
  - a jet-shape based generalization of the classic jet angularity
  - worked out the factorization expressions, still need to complete EFT scale merging and matching to fixed-order calculation, and NGL contributions
  - phenomenological applications is on the way
- Such observables do not rely on grooming nor clustering algorithms
- Their hadronization corrections can give interesting information about nonperturbative QCD effects within jets

Stay tuned!

Acknowledgement

I wouldn’t be here without the help from ~200 passengers and TSA for allowing me to go through security check 30 minutes before my flight departed at ATL that I could arrive at the gate 1 minute before it was closed. Thank you!