Boost 2014, UCL (London)

Q-Jets in SCET:

from Q-thrust to Q-(sub)jettiness

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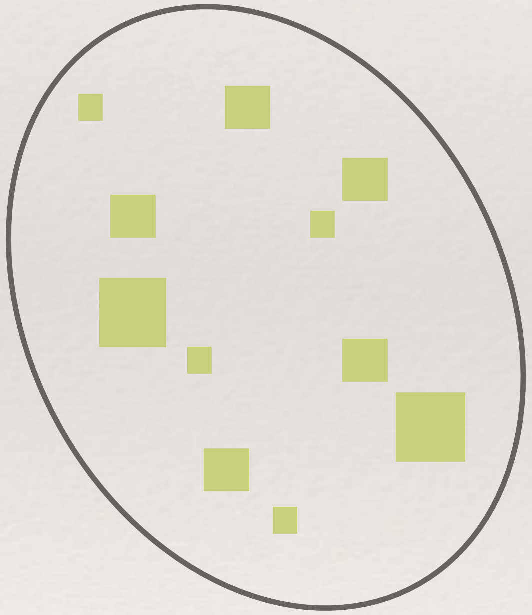
LANL
Aug 18, 2014

all arXiv citations are hyperlinks

What is a "Q-Jet"?

- classical (deterministic) substructure analyses

#1: find jet



Ellis, AH, Krohn, Roy, Schwartz 1201.1914

What is a "Q-Jet"?

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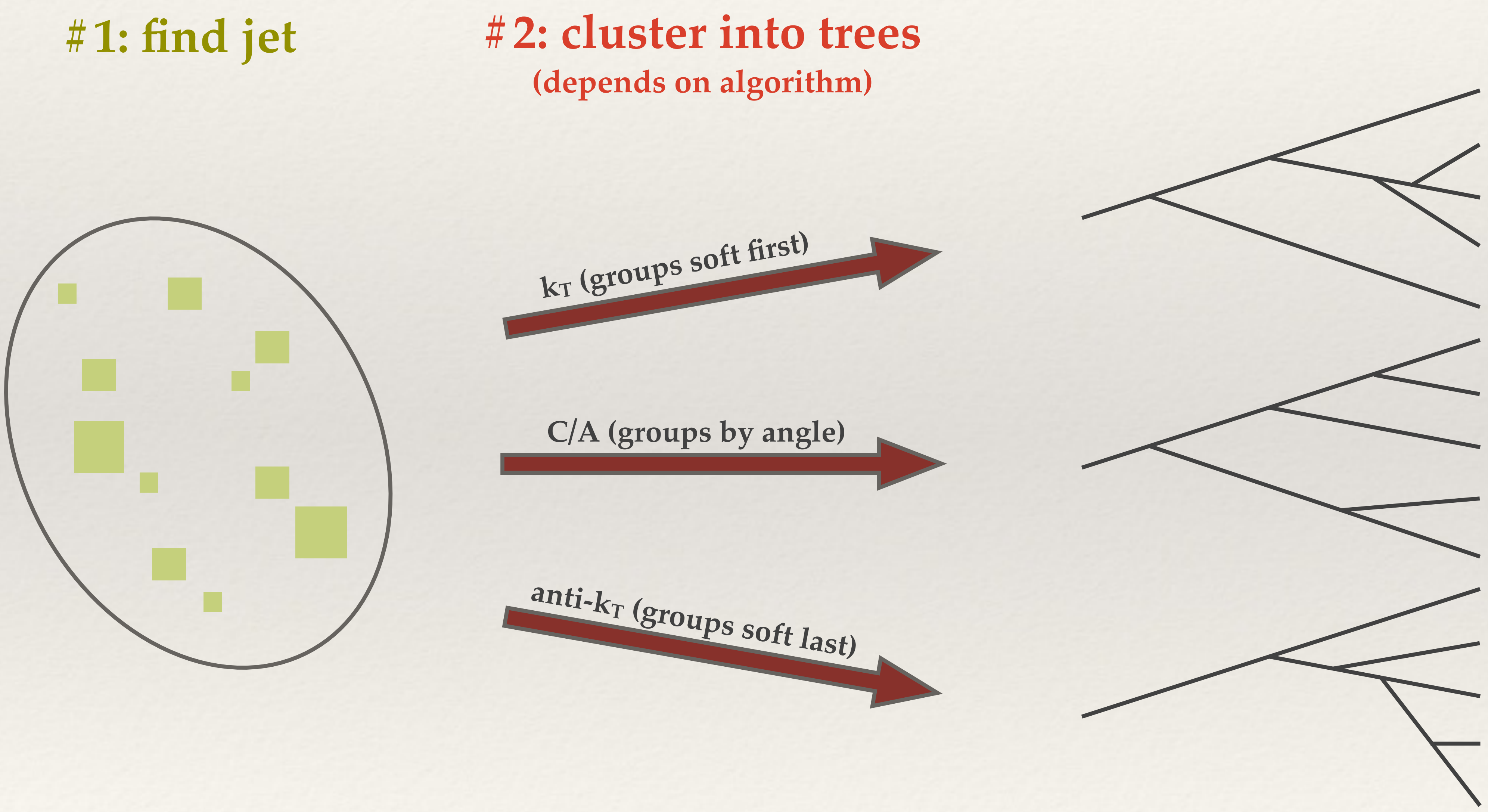


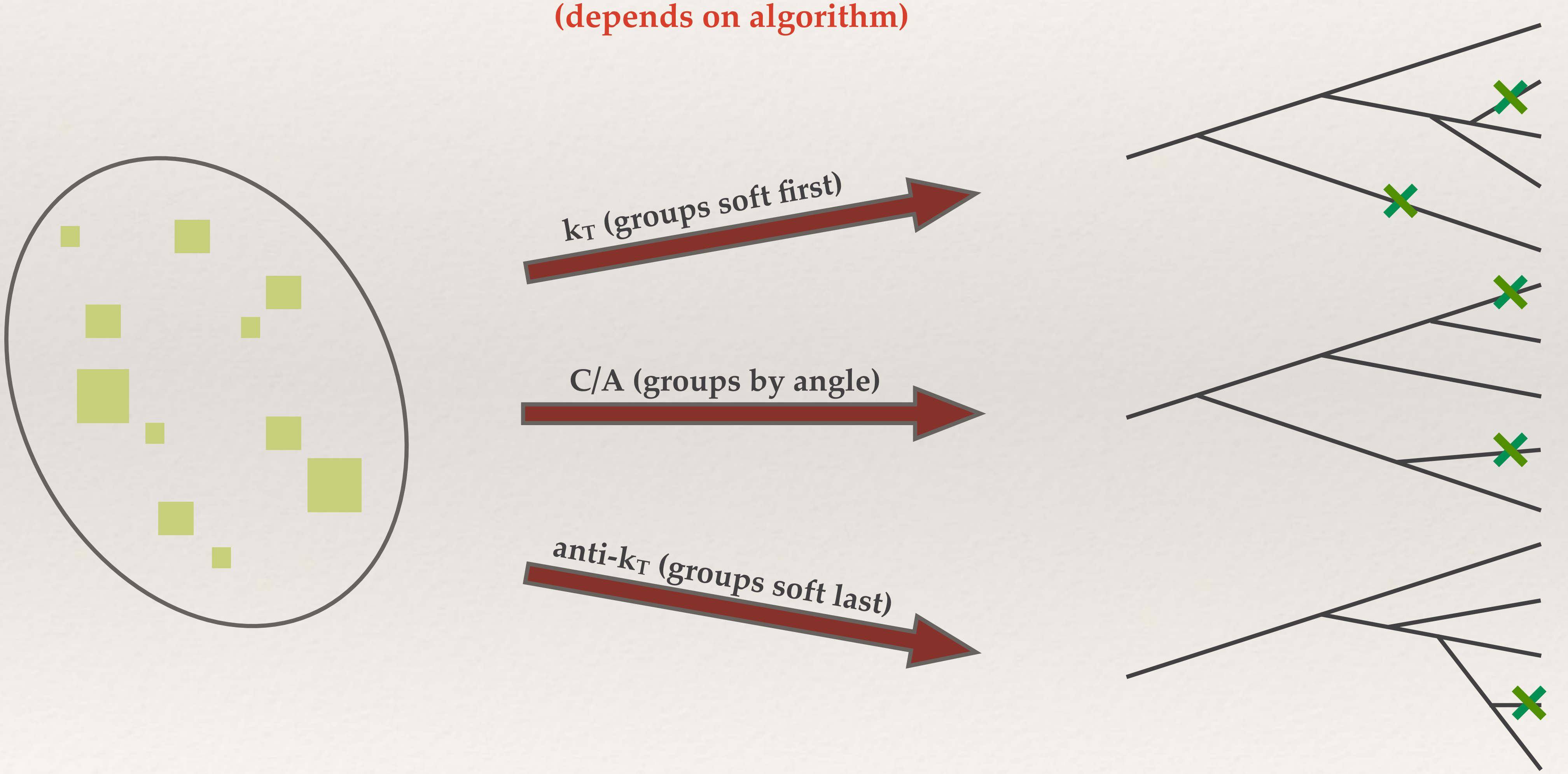
What is a "Q-Jet"?

- classical (deterministic) substructure analyses

#1: find jet

#2: cluster into trees
(depends on algorithm)

#3: get "groomed" m_J



"Mass Drop+Filter"
Butterworth, Davison, Rubin, Salam
(0802.2470)

"Pruning"
Ellis, Walsh, Vermilion
(0912.0033)

"Trimming"
Krohn, Thaler, Wang
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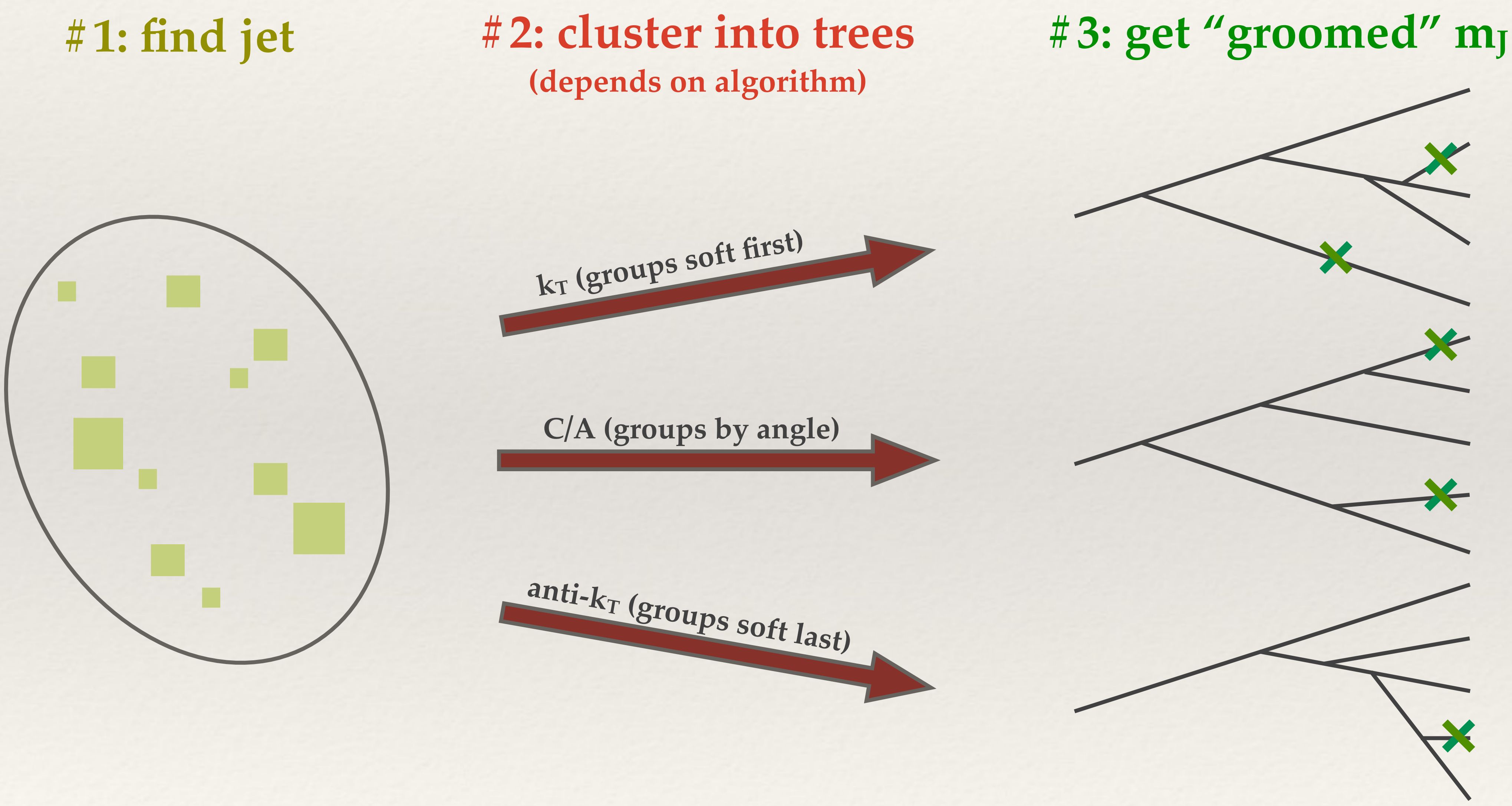

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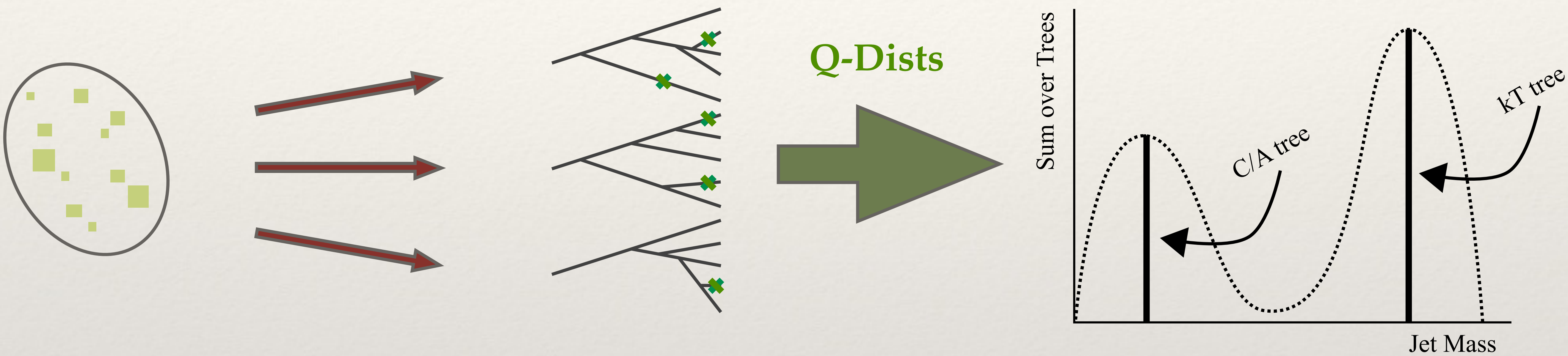
- Q-Jets: use "all" clusterings ⇒ mass distribution *for each jet*

What is a "Q-Jet"?

- different for different algorithms :

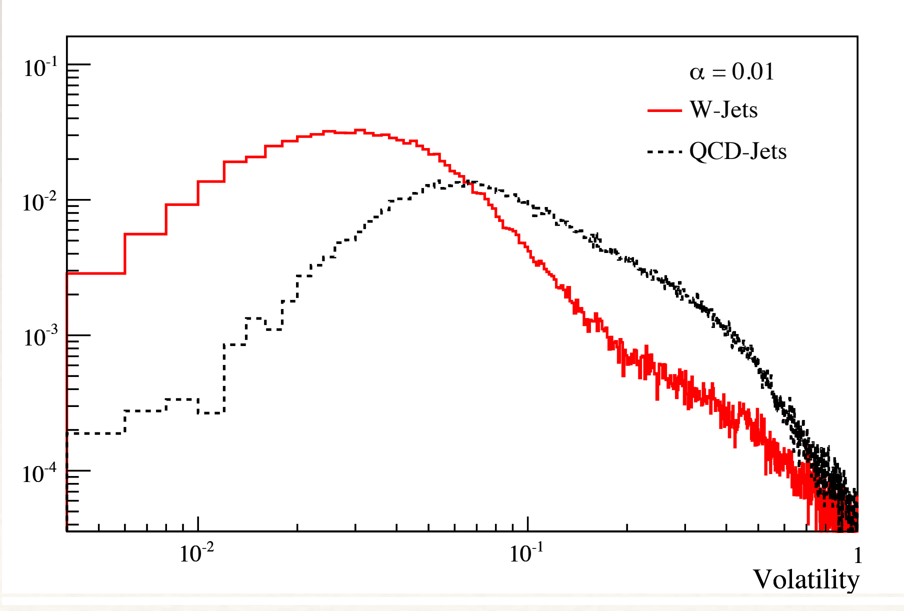


- Variation larger for QCD jets (no real m_J scale)

$\Rightarrow$ "Volatility":

$$\mathcal{V} = \Gamma / \langle m \rangle$$

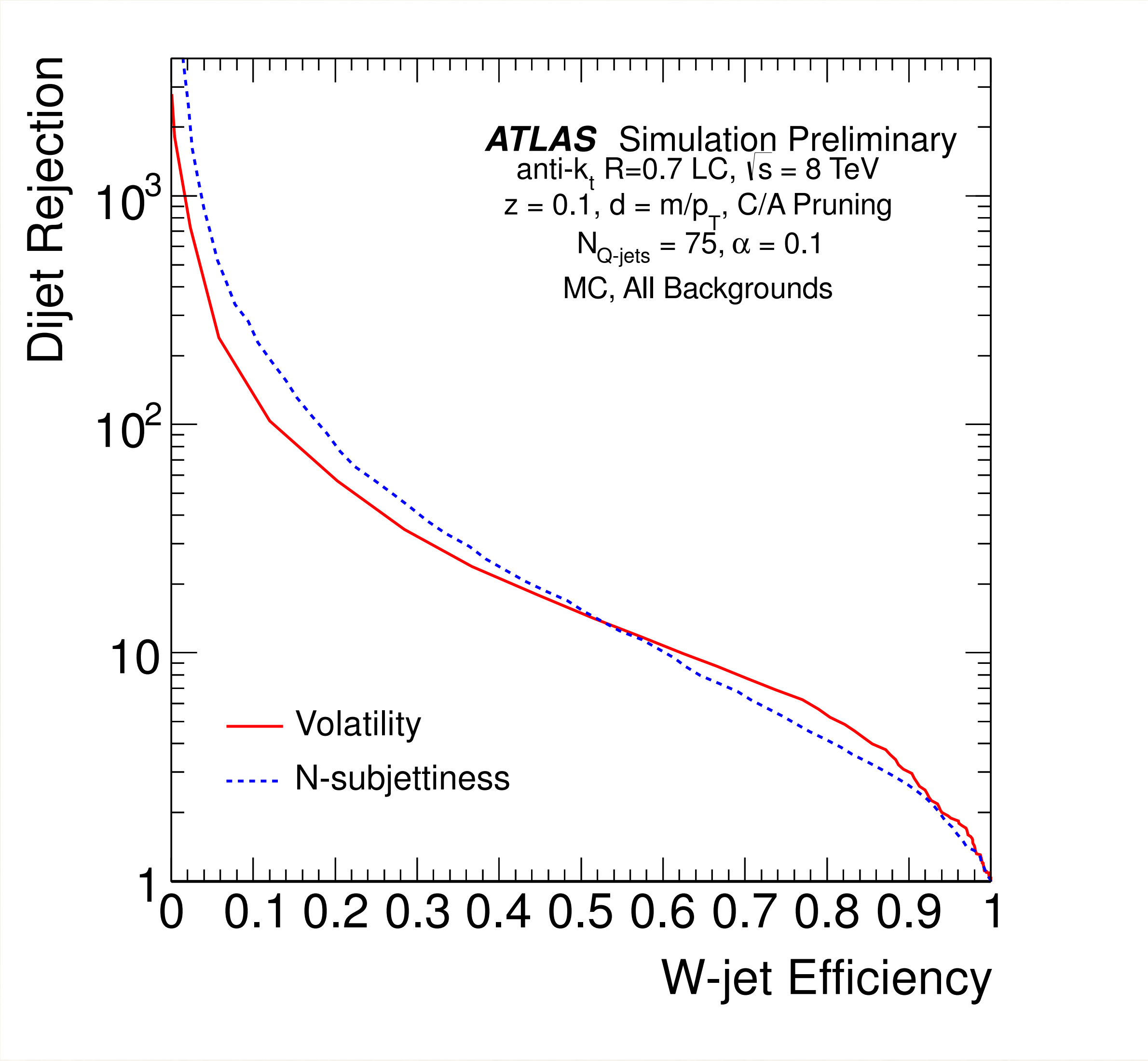
$$\Gamma \equiv \sqrt{\langle m^2 \rangle - \langle m \rangle^2}$$

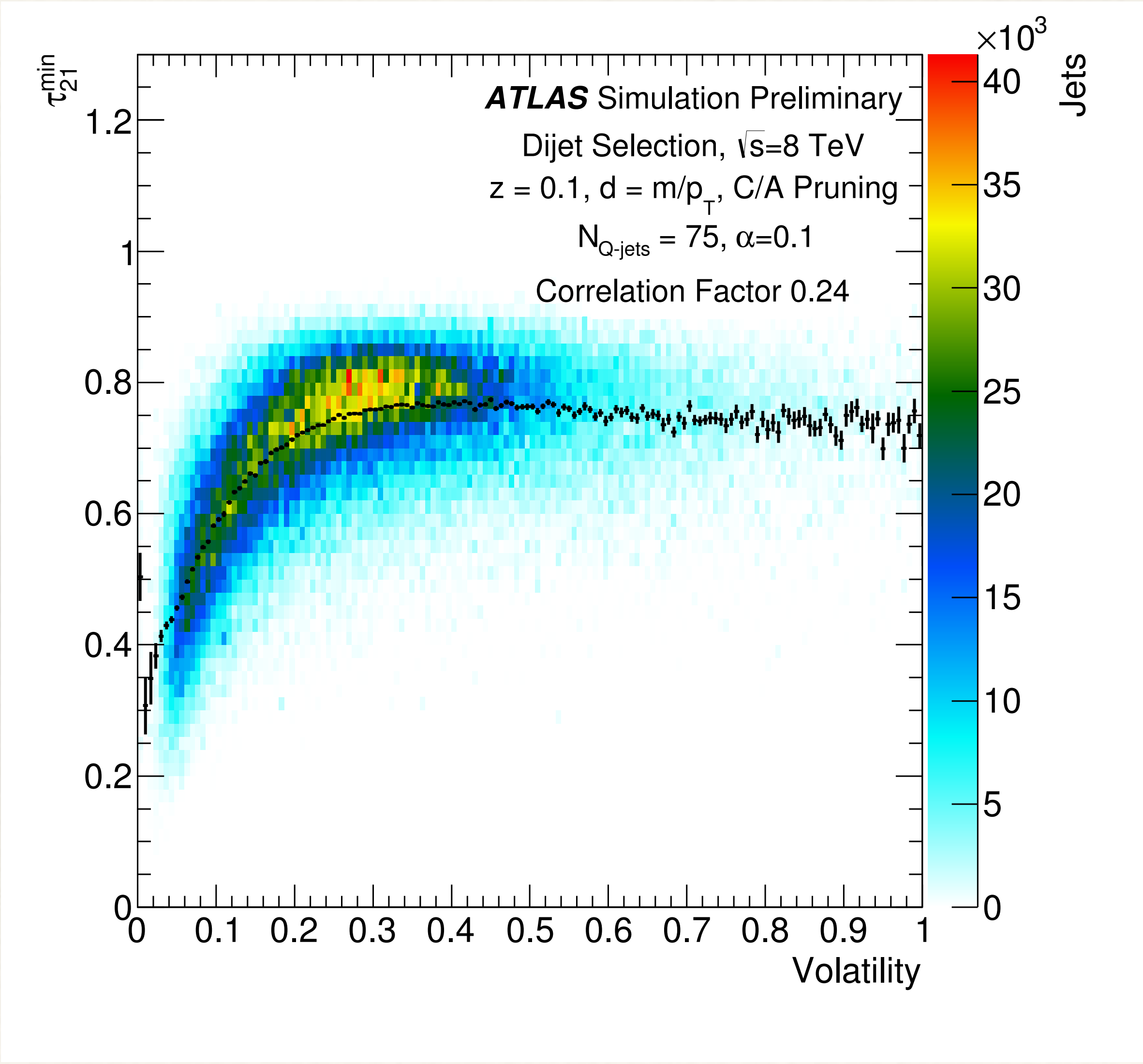


Results from Last Year

- compare to standard candle (N-subjettiness):

Thaler, Tilburg 1011.2268



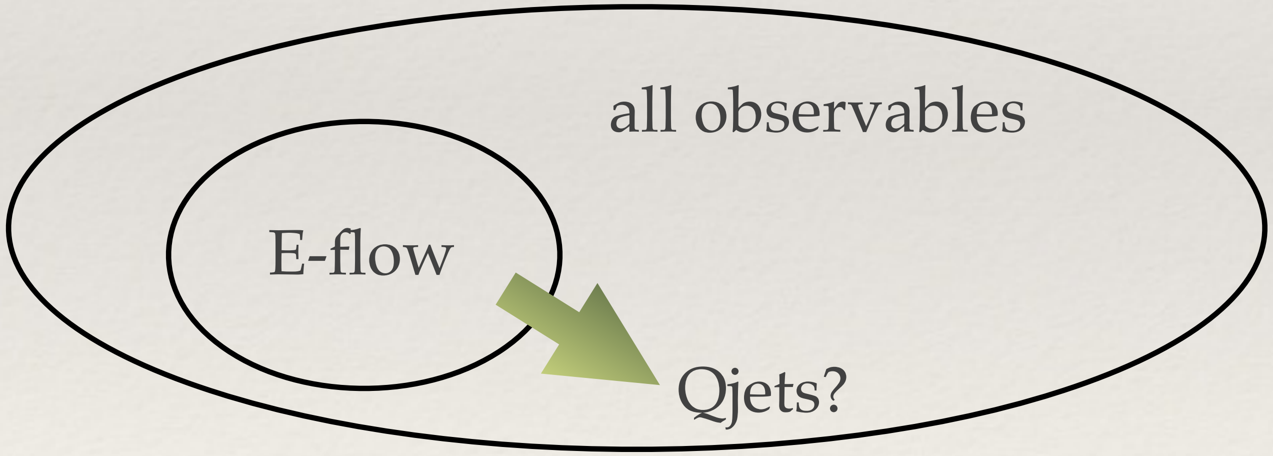


- BOOST2013 working groups: understand correlations

Why are Q-Jets different?

- 2 reasons:
  1. NOT deterministic: probabilistic assignments
  2. NOT energy-flow variable (event/jet shape): fundamentally iterative

     (depends on clustering, not just particle 4-momenta)

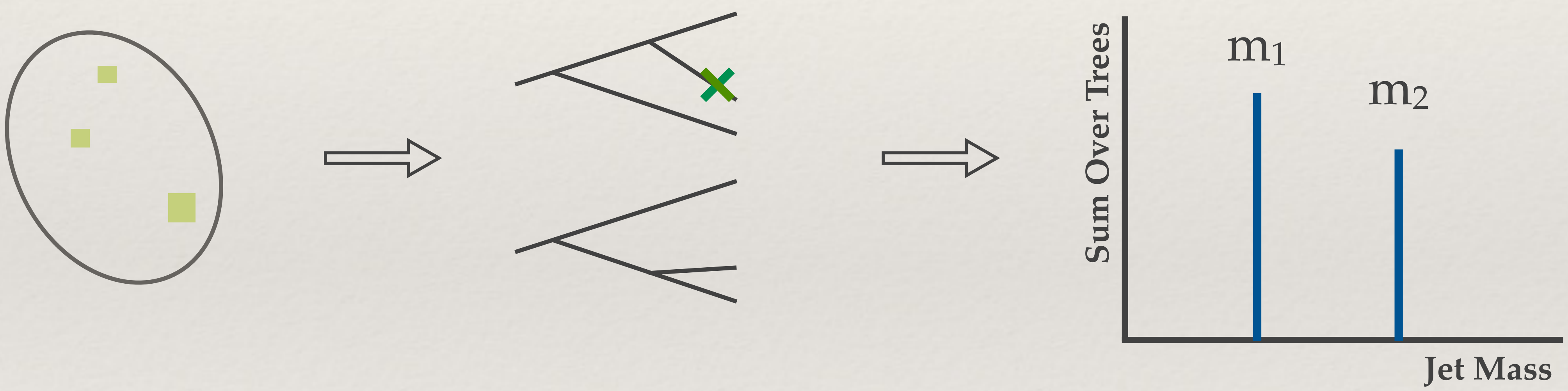


- Can we understand differences analytically?

Q-Jet Volatility Calculation (?)

- non-trivial mass Q-dists require at least O(10) particles

  $\Rightarrow$ need $O(\alpha^{10})$ calculation….



- also not well-suited for resummation in SCET
- *both related to fact that Q-jets is recursive/iterative….*

What *can* we Calculate?

- energy-flow (non-iterative) easier

- are probabilistic observables possible / sensible?

- if calculable, what is effect on Non-Global Logs? (important in general, but esp. substructure)

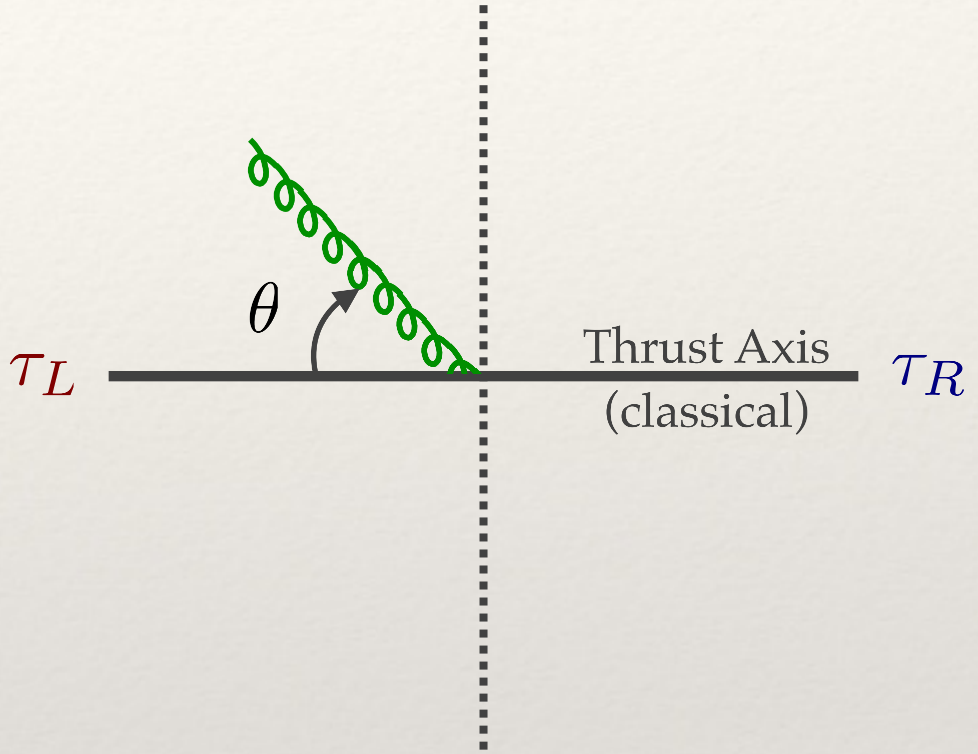
➡ define Q-thrust (then on to Q-(sub)jettiness)

Q-Thrust

- cluster L, R with some probability:

$$\delta(\tau_L - k^+/Q)\underbrace{\Theta\left(\theta < \frac{\pi}{2}\right)}_{\to P_L(\theta)}$$

$$+\delta(\tau_R - k^-/Q)\underbrace{\Theta\left(\theta > \frac{\pi}{2}\right)}_{\to P_R(\theta)}$$



- disentangle Q-Jets / N-subjettiness (un)correlation???

1. non-deterministic (like traditional Q-Jets)
2. *but* now energy-flow / shape var

Q-Thrust

- probability conservation:

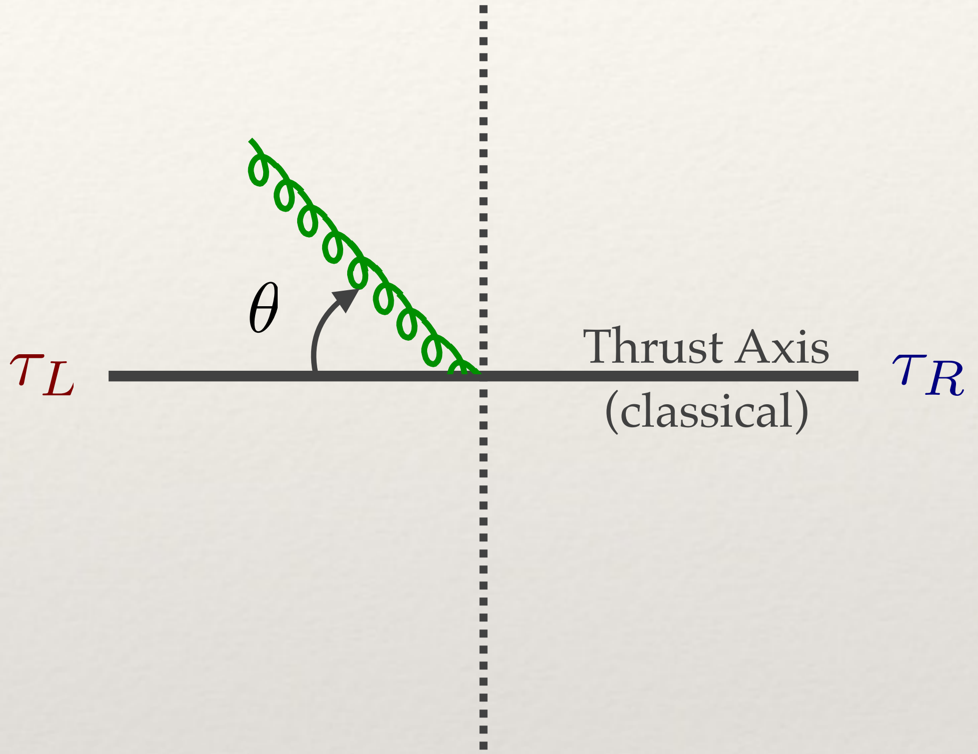
$$P_L(\theta) + P_R(\theta) = 1$$

- IR safety:

$$P_L(0) = P_R(\pi) = 1$$

- symmetry (not needed):

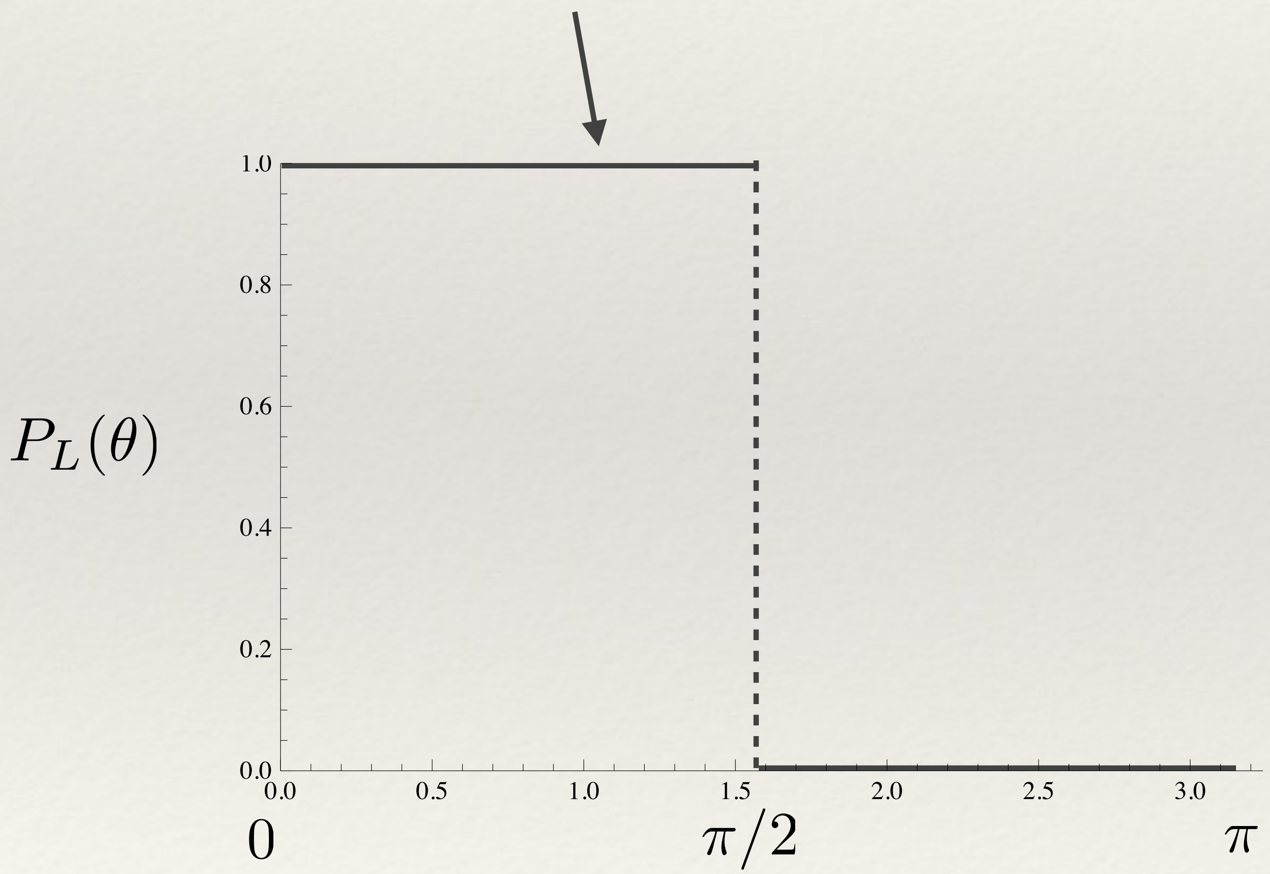
$$P_{L,R}(\theta) = 1 - P_{L,R}(\pi - \theta)$$

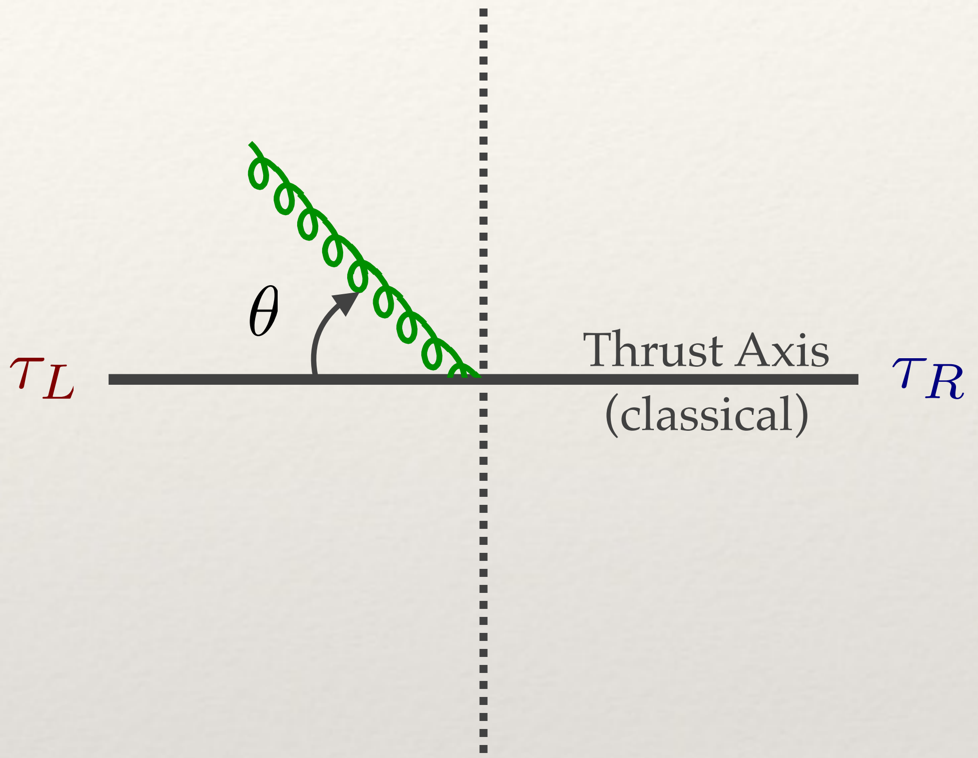


Q-Thrust

- Examples:

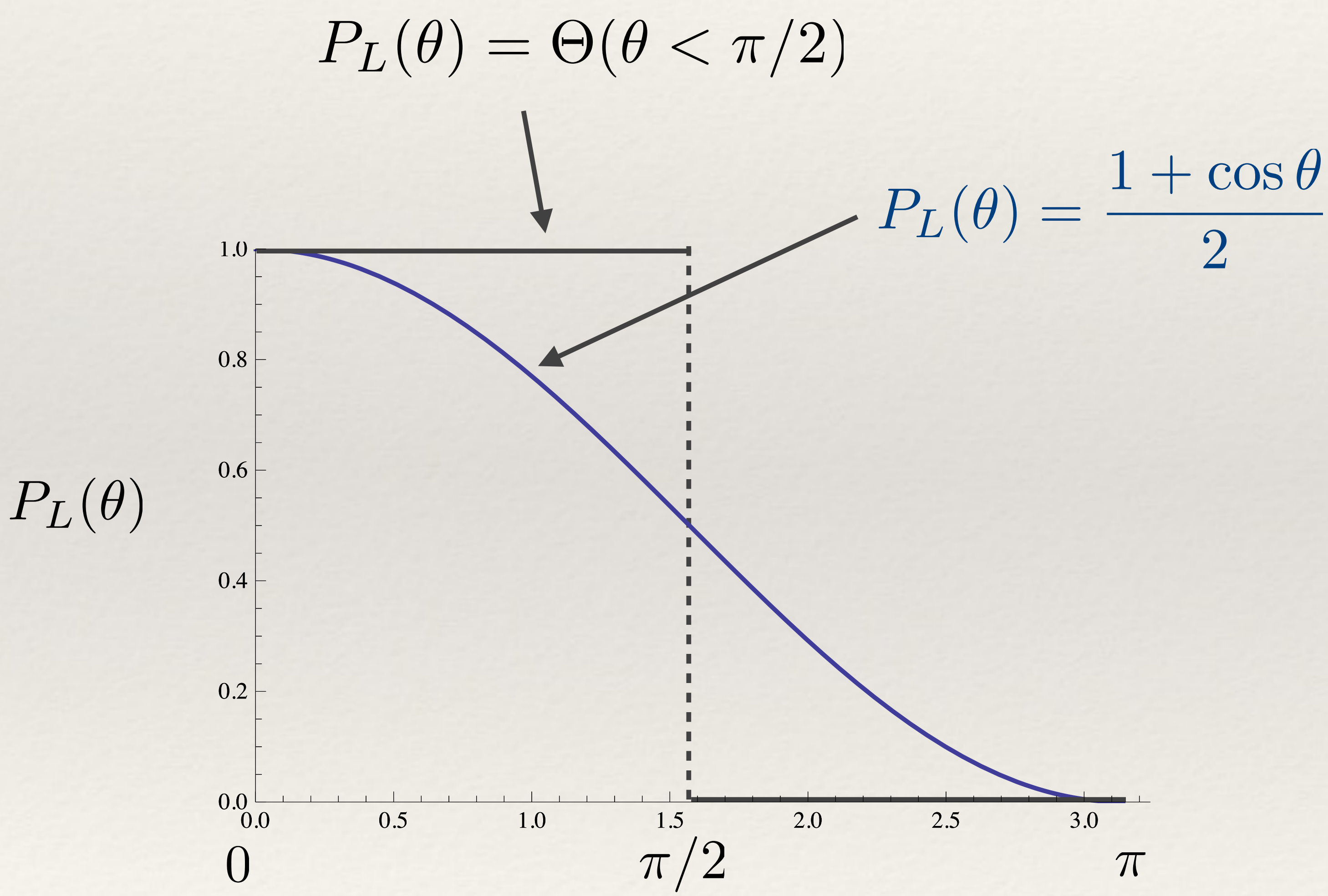
$$P_L(\theta) = \Theta(\theta < \pi/2)$$

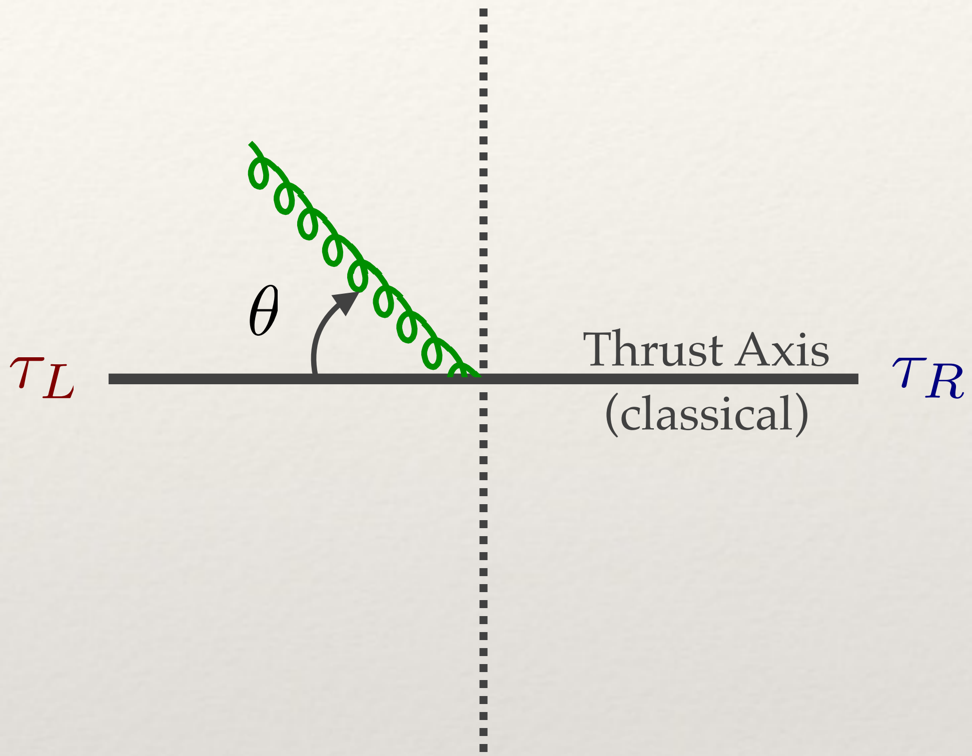




Q-Thrust

- Examples:



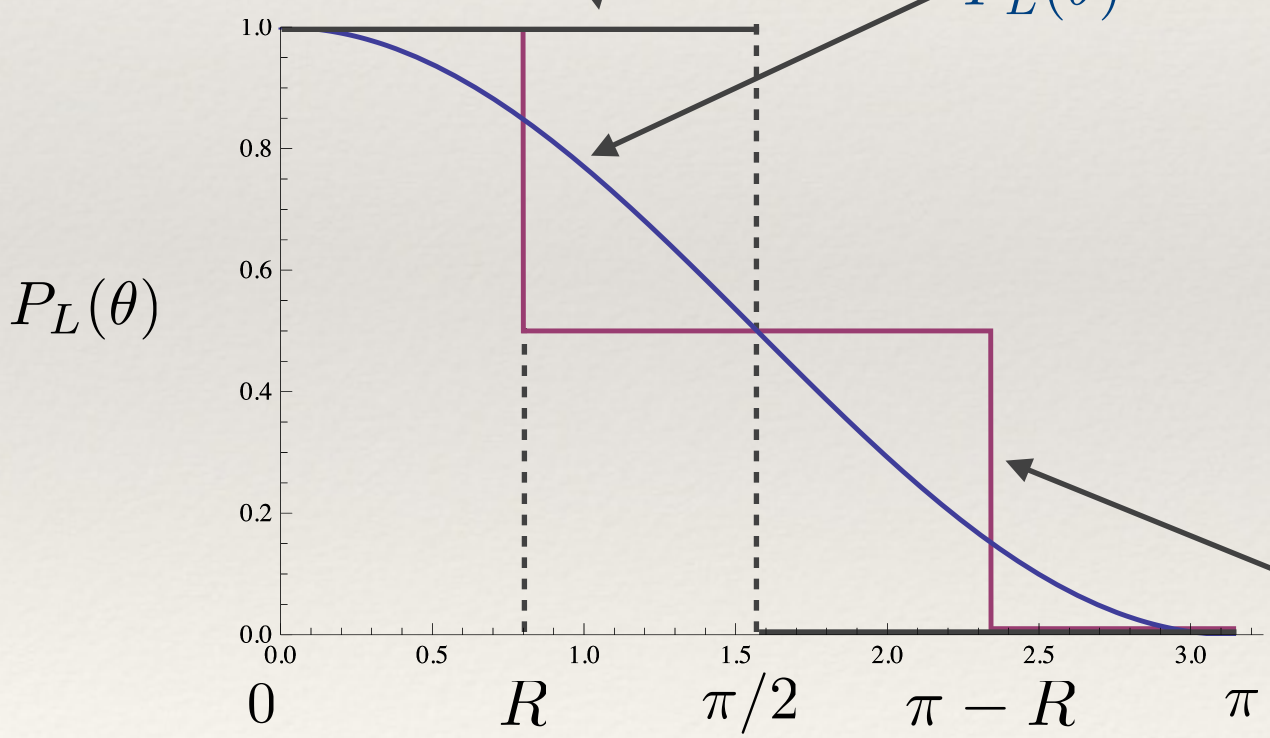


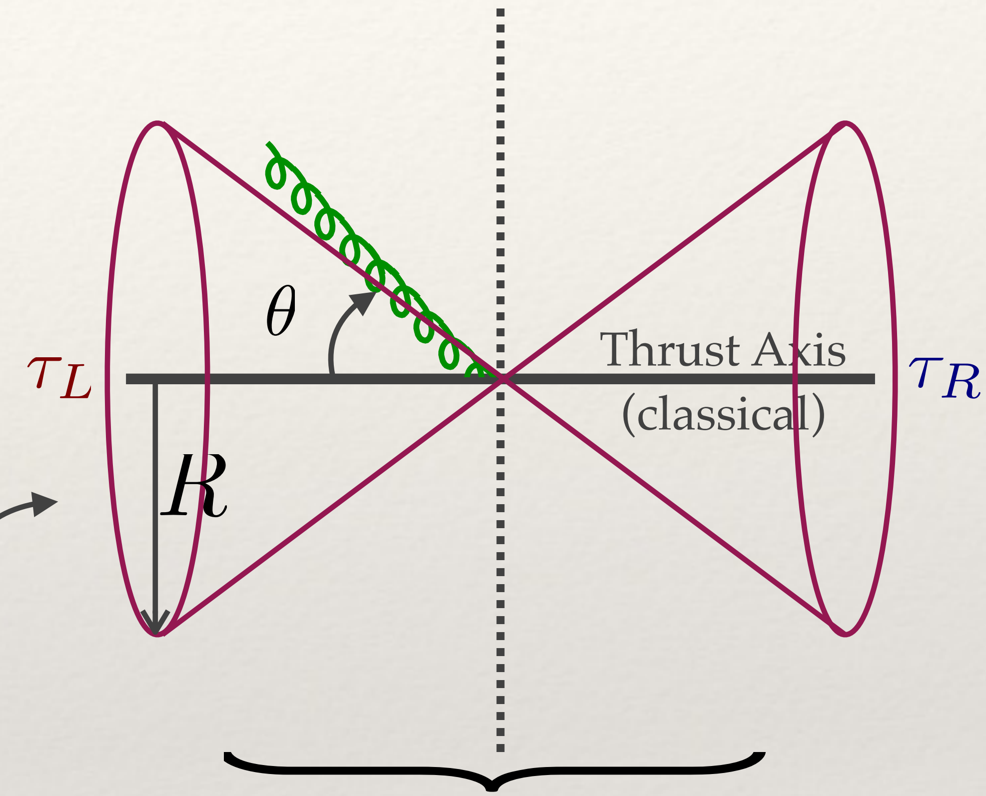
Q-Thrust

- Examples:

$$P_L(\theta) = \Theta(\theta < \pi/2)$$

$$P_L(\theta) = \frac{1 + \cos\theta}{2}$$



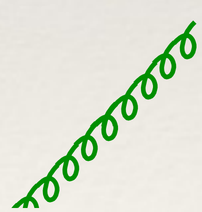
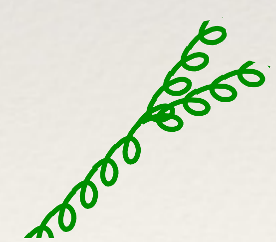


$$P_L(\theta) = \Theta(\theta < R) + \frac{1}{2}\Theta(R < \theta < \pi - R)$$

"double step function"

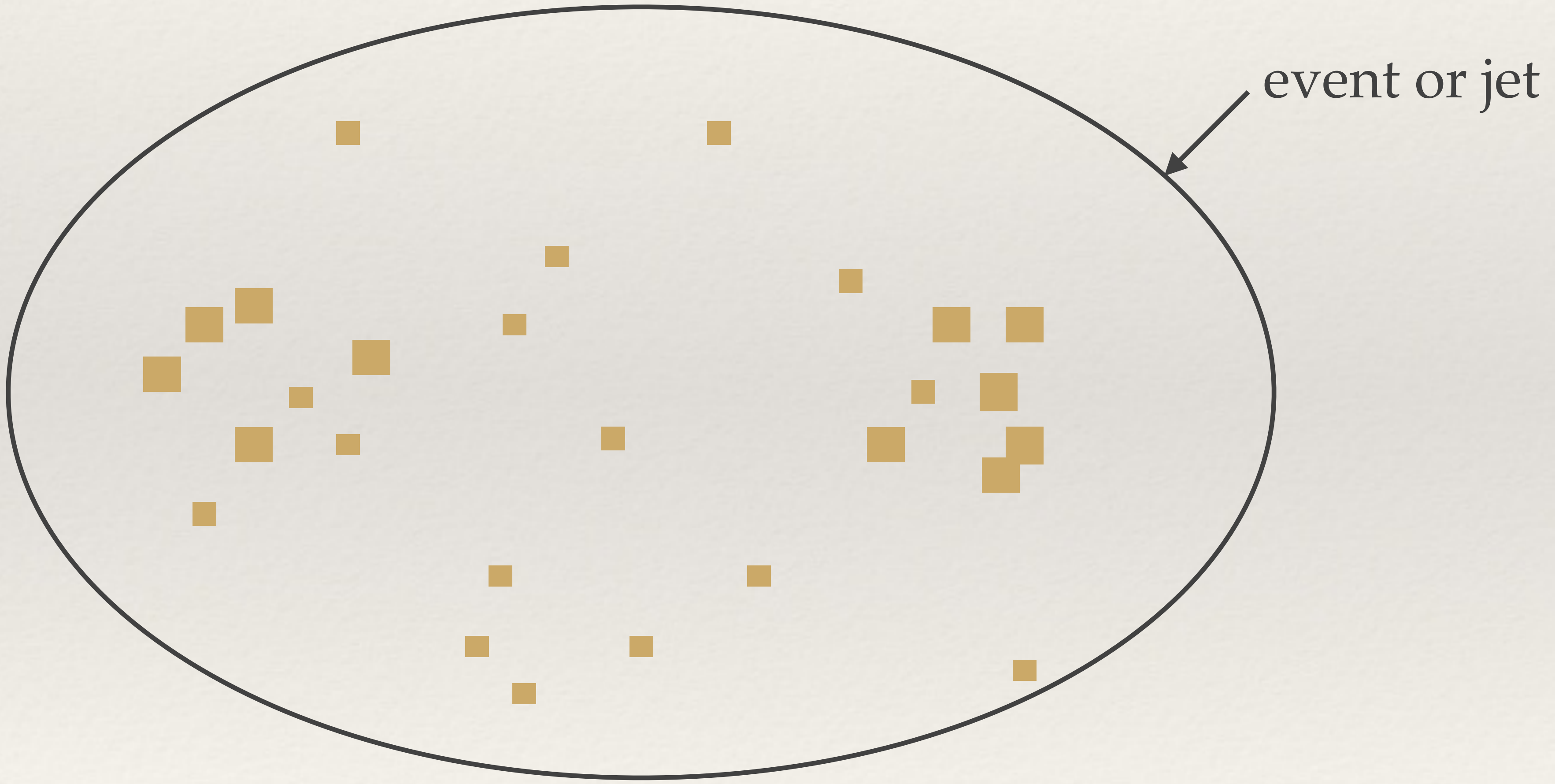
Q-Thrust

- definition for higher orders - IR safety:
  - must use clustering!
  - IR safety requires (in collinear limit):
    - before splitting:
    - after splitting:

$P_L($  $)$ $\xrightarrow[\text{limit}]{\text{collinear}}$ $P_L($  $)$

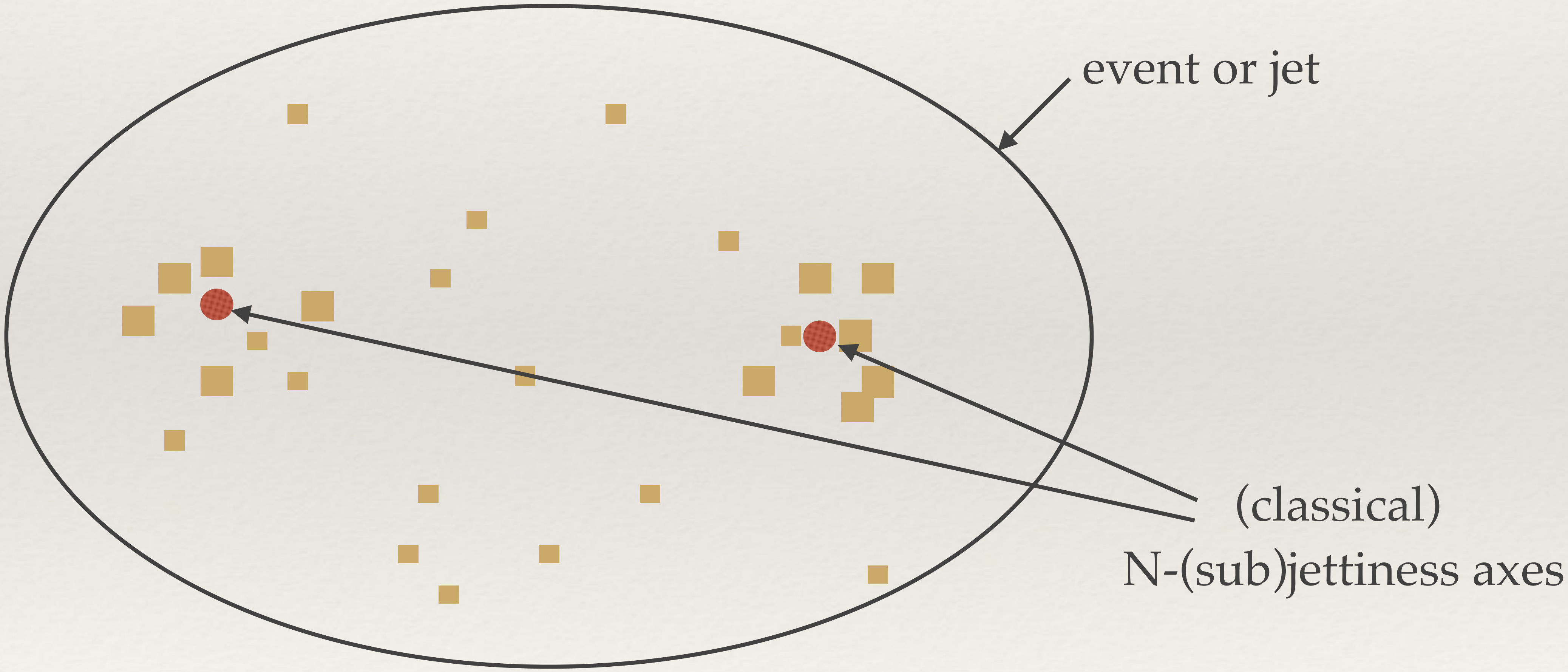
Q-Thrust to Q-(sub)jettiness

- definition for higher orders



Q-Thrust to Q-(sub)jettiness

- definition for higher orders



Q-Thrust to Q-(sub)jettiness

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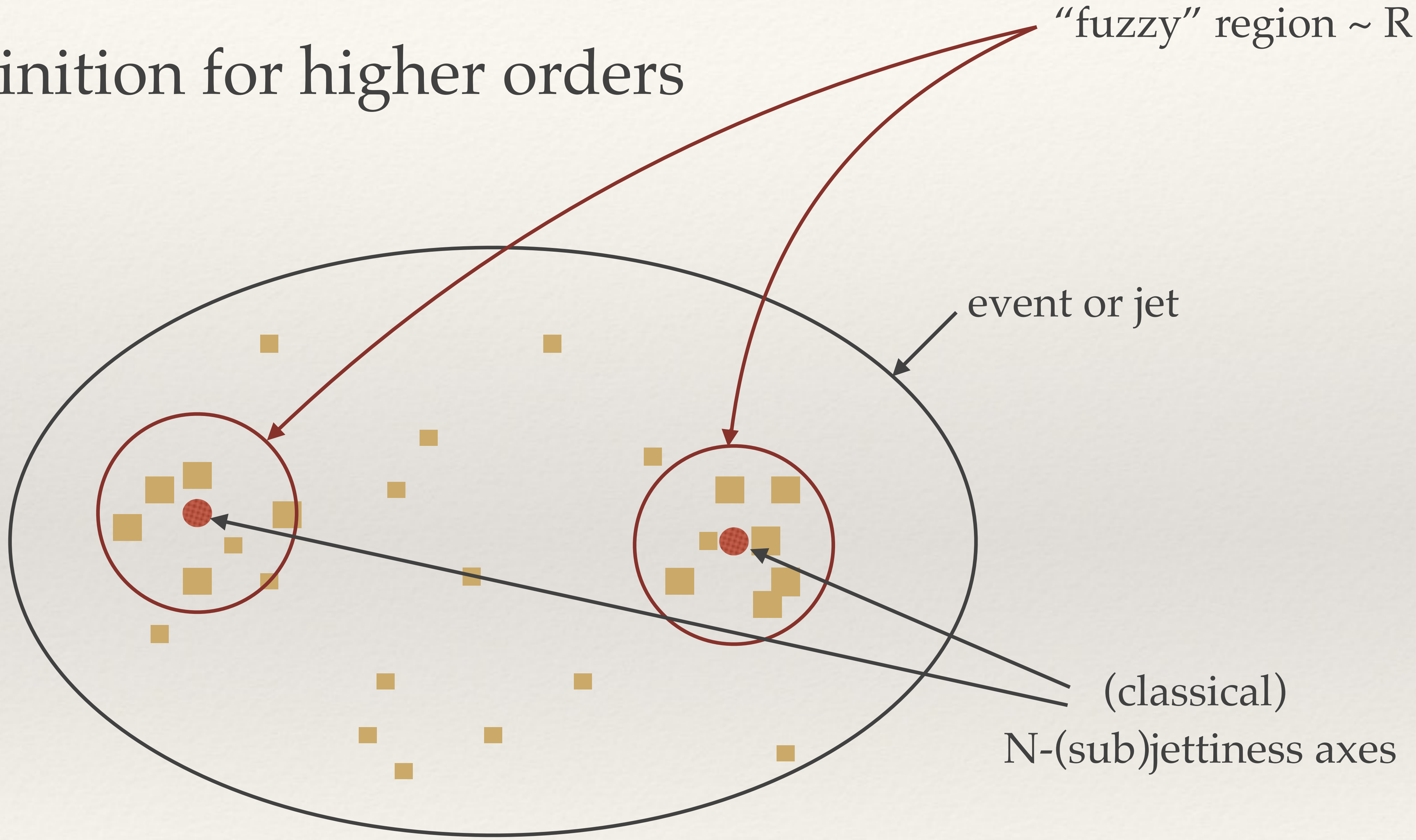
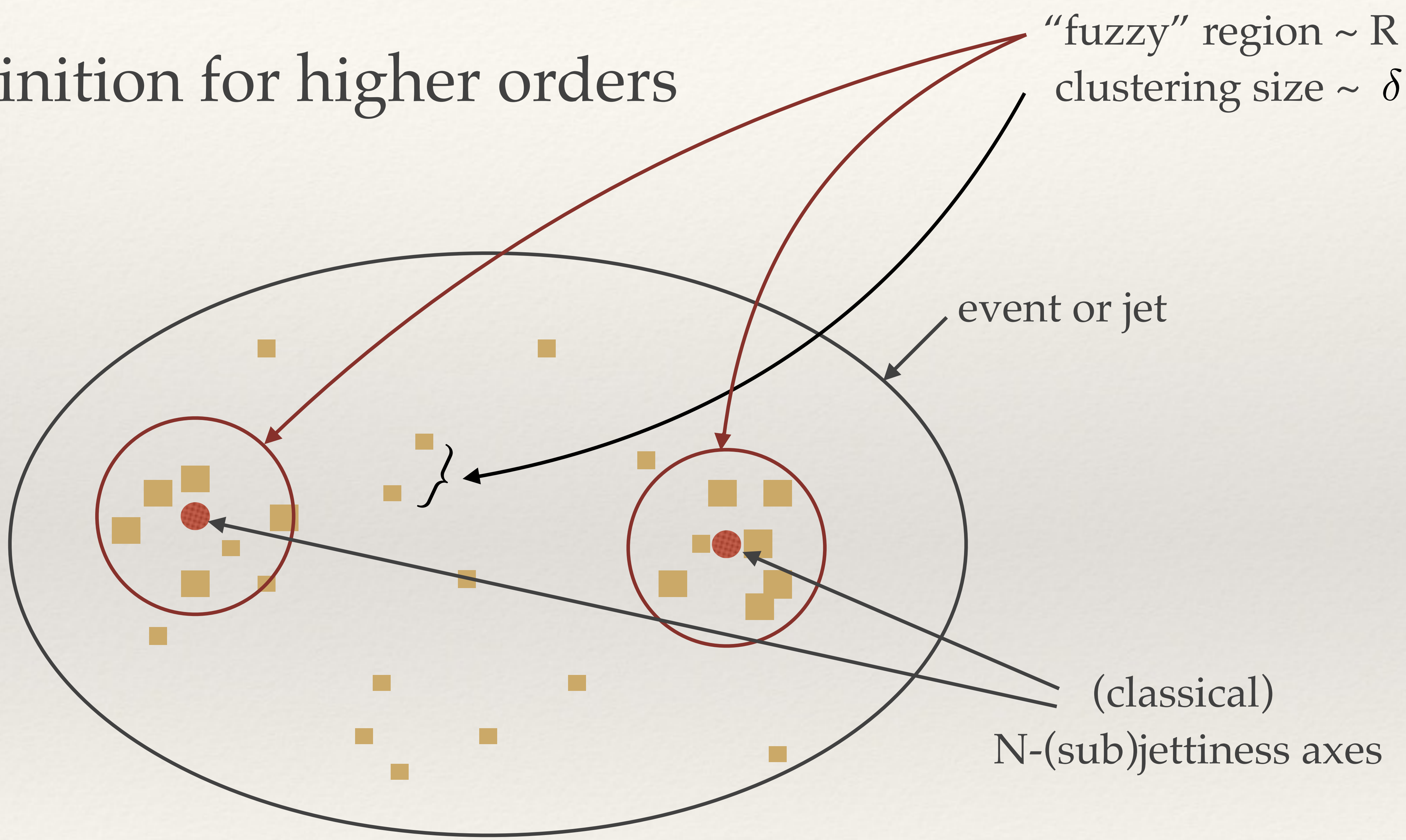


Q-Thrust to Q-(sub)jettiness

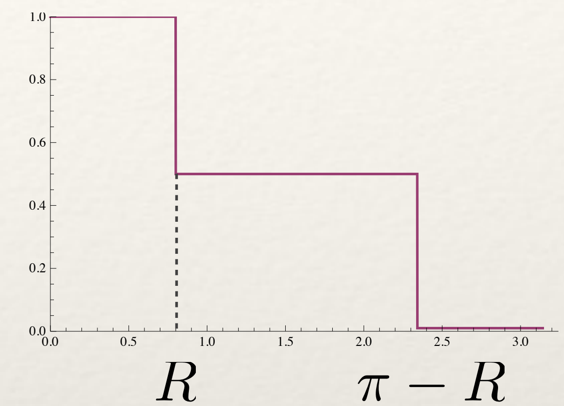
- definition for higher orders



Q-Thrust

- factorization (for R ~ 1):

$$\frac{d\sigma}{d\tau_Q} = \int d\tau_L \, d\tau_R \, \delta(\tau_Q - \tau_L - \tau_R) \, \frac{d\sigma}{d\tau_L \, d\tau_R}$$

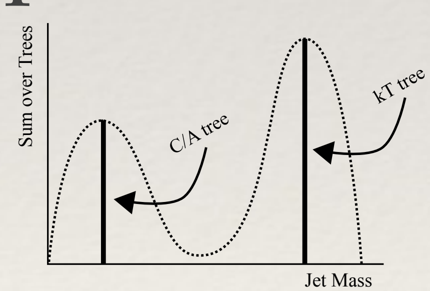


$$\frac{d\sigma}{d\tau_L \, d\tau_R} = H(E_{cm}) \, J(\tau_L) \otimes J(\tau_R) \otimes S_Q(\tau_L, \tau_R)$$

incl. jet fnc.

$$S_Q(\tau_L, \tau_R) = \frac{1}{N_C} \mathrm{Tr} \, \langle 0 | \, \overline{Y}_{\bar{n}}^{\dagger}(0) Y_n^{\dagger}(0) \, \mathcal{O}(\tau_L, \tau_R) \, Y_n(0) \overline{Y}_{\bar{n}}(0) \, | 0 \rangle$$

- Inspiration for observable from Q-Jets:



$$= \sum_i \omega(\mathrm{tree}_i) \delta(\mathcal{O} - \hat{\mathcal{O}}(\mathrm{tree}_i))$$

$$\Rightarrow \quad \mathcal{O}(\tau_L, \tau_R) = \sum_i \left[P_L(k_i) \delta(\tau_L - k_i^+/Q) \delta(\tau_R) + P_R(k_i) \delta(\tau_L) \delta(\tau_R - k_i^-/Q) \right]$$

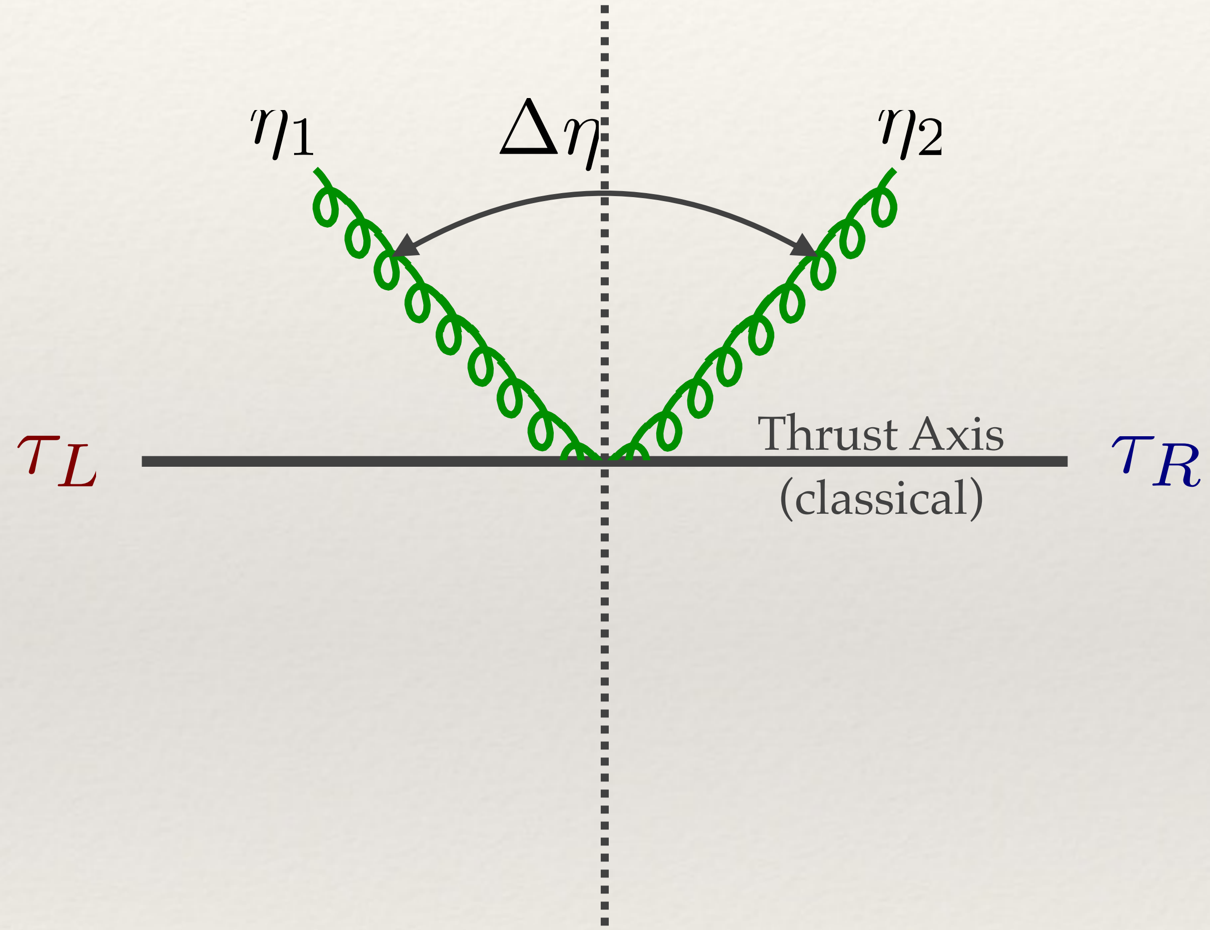
- NGLs in soft function?

Non-Global Logs (classical)

Dasgupta, Salam hep-ph/0104277

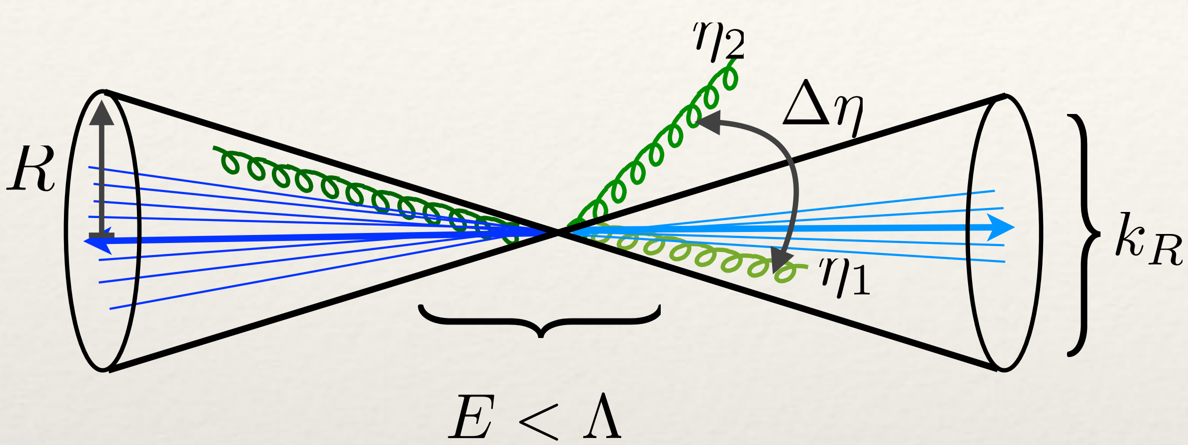
Kelley, Schwartz, Schabinger, Zhu 1105.3676

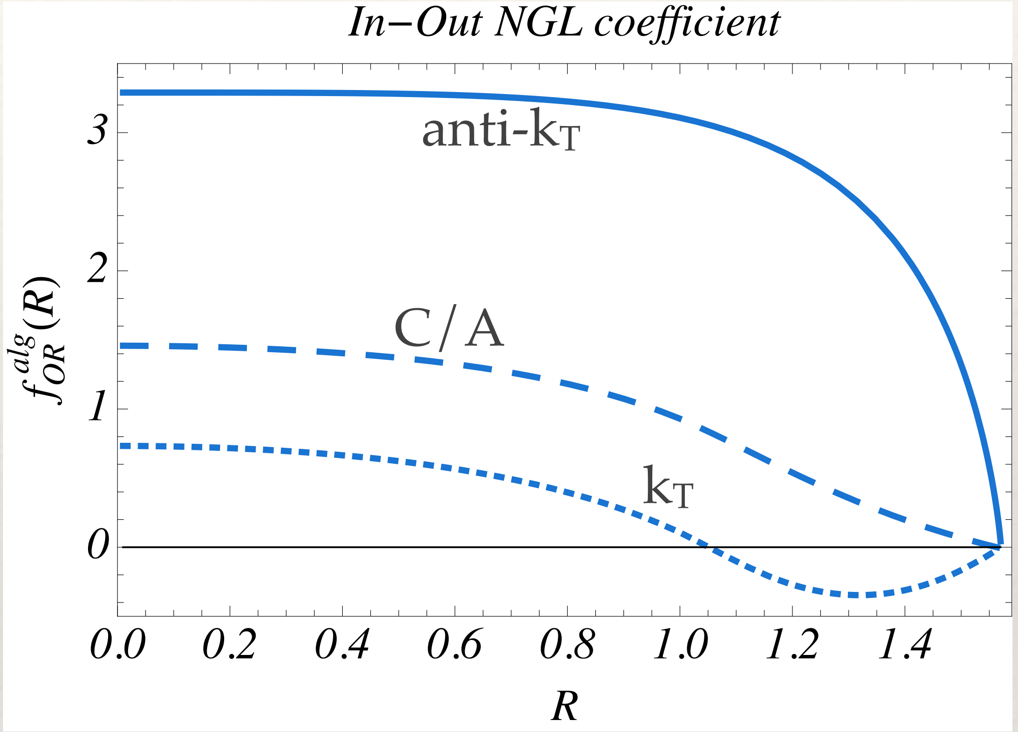
AH, Lee, Stewart, Walsh, Zuberi 1105.4628



$$\alpha_s^2 C_F C_A \frac{\pi^2}{3} \ln^2 \frac{\tau_L}{\tau_R}$$

Non-Local Globs (classical)





$$-f_{\mathrm{OR}}(R_R, R_L)\ln^2\frac{\mu^2\tan(R_R/2)}{2\Lambda k_R}$$

$$f_{\mathrm{OR}}^{\mathrm{cone}}(R_R, R_L) = \underbrace{\int_{\eta_R}^{\infty} d\eta_1 \int_{-\eta_L}^{\eta_R} d\eta_2}_{\text{1 in R, 2 outside}} \underbrace{\frac{8}{e^{2(\eta_1-\eta_2)}-1}}_{\text{largest when 1,2 both approach boundary}}$$

1 in R, 2 outside

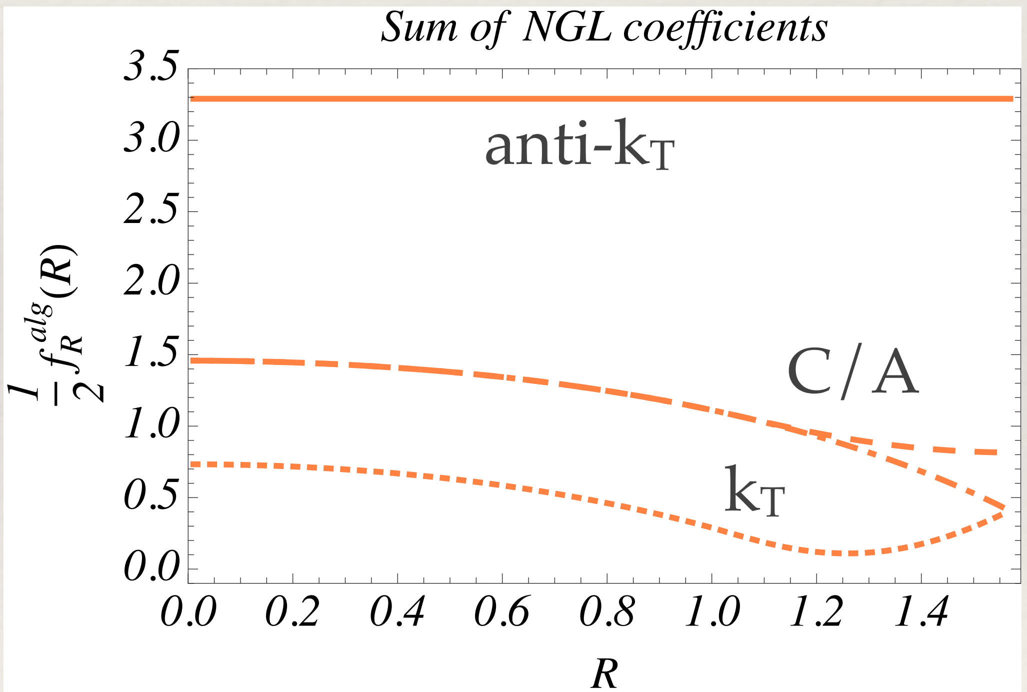
largest when 1,2 both approach boundary

(Soft) Clustering NGLs (classical)

- anti-k_T → only clusters soft when $\Delta\theta \sim E \sim \lambda^2$ 

  ⟹ cone and anti-k_T don't have clustering logs

total NGLs (including clustering)	C_F^2 (pure clustering) : Kelley, Walsh, Zuberi 1202.2361	$C_F C_A$: AH, Lee, Walsh, Zuberi 1110.0004
anti-k_T : (soft last)	0	
C/A : (democratic in angle)	non-zero	
k_T : (soft first)	non-zero *and bigger*	



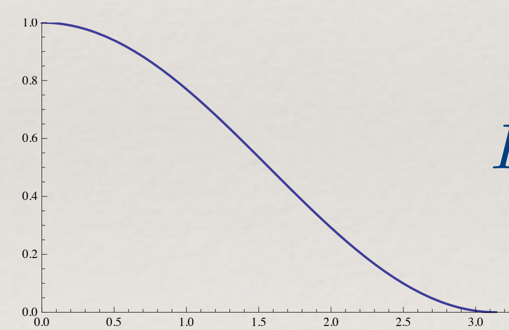
- *Note*: while C/A and k_T induce C_F^2 NGLs, clustering reduces $C_F C_A$ NGLs

1 Loop Results

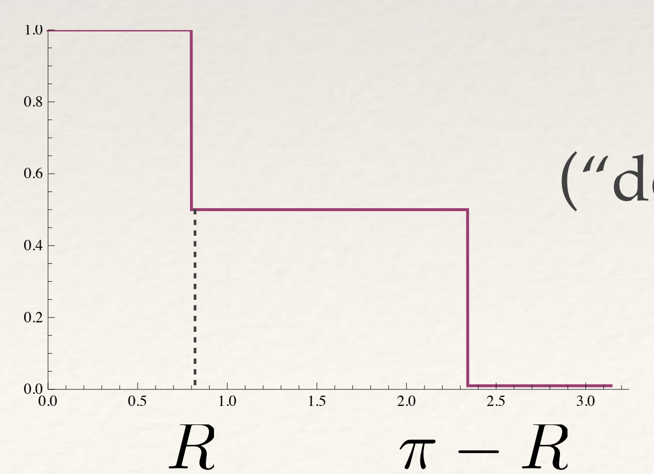
- jet function = inclusive (up to O(τ/R))
- same γ_s (soft anom dim) as thrust
- soft function has finite shift:

$$\Delta S^{(1)}(\tau) = -4\delta(\tau)\frac{\alpha_s C_F}{\pi}\int_0^1 \frac{d\cos\theta}{1-\cos^2\theta}\ln\tan\frac{\theta}{2}[P_L(\theta)-1] \qquad \text{(shift per hemi)}$$

$$= -\delta(\tau)\times\begin{cases} \dfrac{\pi^2}{12} \\ \ln^2\tan\dfrac{R}{2} \end{cases}$$



$$P_L(\theta) = \frac{1+\cos\theta}{2}$$



(“double step function”)

2 Loop Results

- after adding clustering, same as thrust $\gamma_s^{(2)}$

$$\mathcal{M} = \delta_L^{12}\delta^R f_1^L f_2^L + \delta_1^L \delta_2^R f_1^L f_2^R + (L \leftrightarrow R)$$

$$\rightarrow \delta_L^{12}\delta^R f_1^L f_2^L + \delta_1^L \delta_2^R f_1^L f_2^R (1 - f_{1,2}^{\rm clu}) + \delta_{12}^L \delta^R f_{1+2}^L f^R f_{1,2}^{\rm clu} + (L \leftrightarrow R)$$

- C_F^2 (can separate soft clustering)
  - $S^{(2)}(x, y) = 1/2(S^{(1)}(x,y))^2$ + clustering
- $C_F C_A$ (IR safety ⇒ don't separate clustering effect)
  - w/ clustering, all divergences cancel -> left with different (finite) NGLs

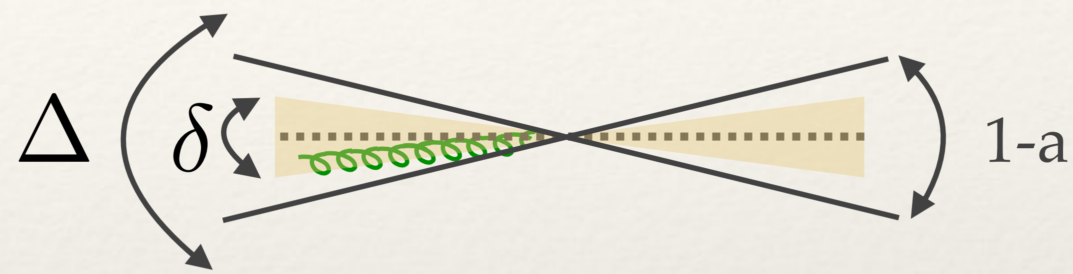
2 Loop Results

$$a \equiv \tan^2 \frac{R}{2}$$

"fuzzy" region ~ 1 - a

clustering size ~ δ < 1 - a

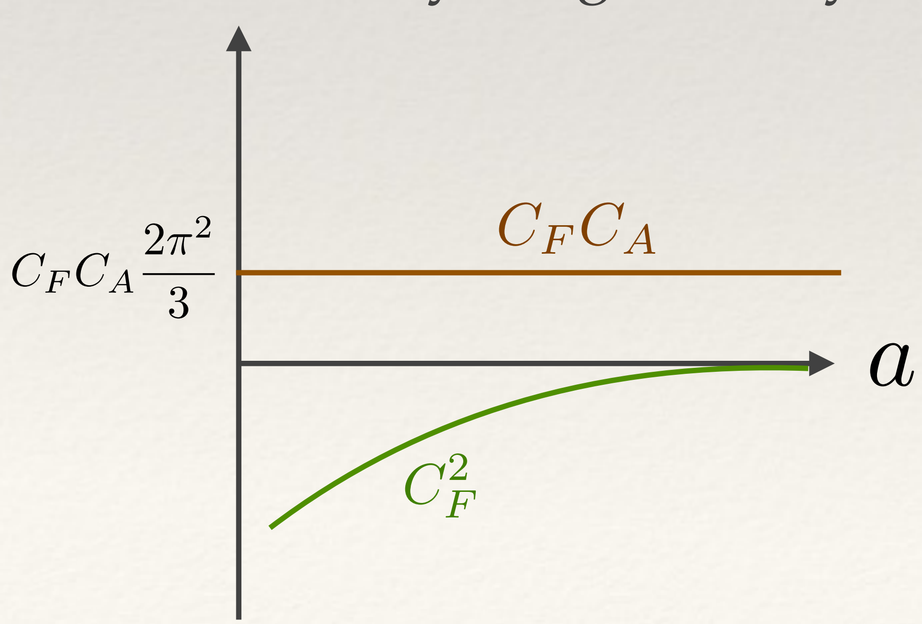
clustering region ~ Δ > 1 - a



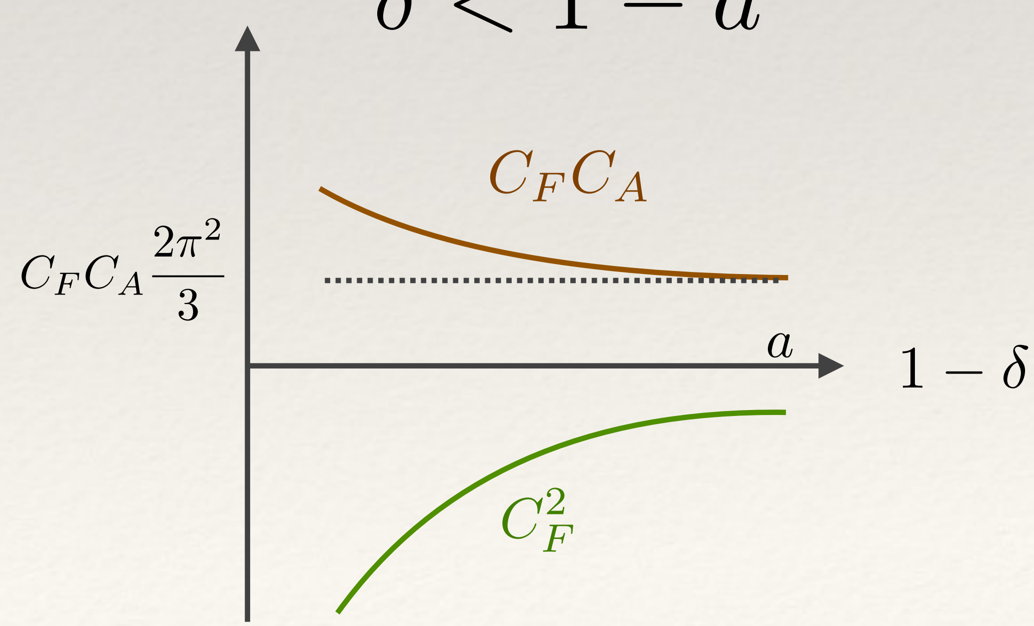
- Cancellation of NGLs:

$$\delta = 1 - a$$

(cluster everything in fuzzy region)



$$\delta < 1 - a$$



Conclusions and Outlook

- Q-thrust:
  - non-deterministic ***but*** energy-flow variable
  - calculable!
  - interesting (important?) effect on NGLs!
  - generalizes naturally to Q-(sub)jettiness
- Outlook:
  - performance & correlations
  - many related observables to study, should exhibit same generic properties (calculability and NGLs)