Probing Jet Structure More Exclusively, Effectively

C. Lee, MIT 9/27/2011, INT Frontiers of QCD

in collaboration with

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Inclusive ⟶ Exclusive

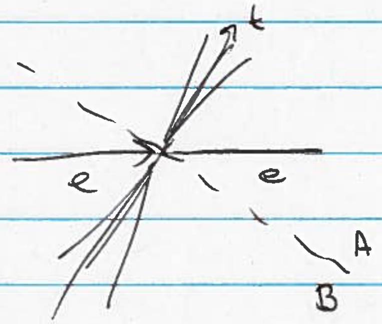
I. Event Shapes	II. Angularities	III. Jet Shapes	IV. Conclusion
&	&	&	&
"Ordinary" SCET	"$SCET_a$"	Non-Global Logs	more SCETs!
		$SCET_{a,\Lambda,R}$ ---	

Focus here on e^+e^- collisions ⟶ 2 jets.
Technology applicable to pp collisions ⟶ jets.

Goals of talk:

1) flavor of how to use EFT to sum logs in jet observables
2) give intuition for origin of NGLs.

Theory I Ordinary SCET : event shapes like thrust, total/heavy jet mass



thrust $T = \frac{1}{Q} \max_{\hat{t}} \sum_{i \in X} |\hat{t} \cdot \vec{p}_i|$

or $\tau = 1 - T \rightarrow 0$ in 2 jet limit

(similarly $\rho = \frac{m_A^2 + m_B^2}{Q^2}$ or $\rho_H = \max(\rho_A, \rho_B)$)

QCD: $\Sigma(\tau) = \int_0^\tau \frac{d\sigma}{d\tau'} d\tau' = 1 - \frac{\alpha_s C_F}{\pi} \left(\ln^2 \tau + \frac{3}{2} \ln \tau \right) + \cdots$

large logs as $\tau \to 0$
come from soft & collinear divergences of QCD

Form EFT of soft & collinear d.o.f. : SCET

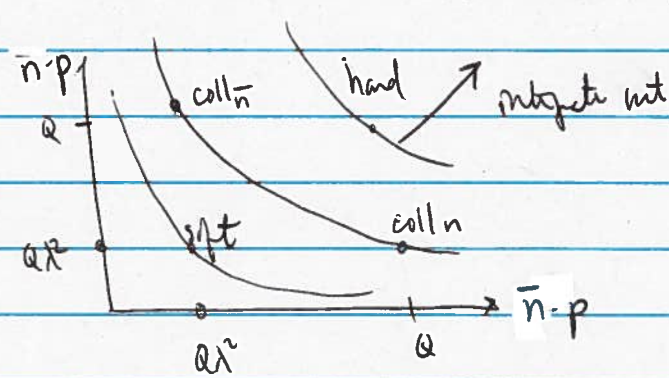
{ Bauer, Fleming, Luke, Pirjol, Stewart

modes $p = (\bar{n} \cdot p, n \cdot p, p_\perp)$

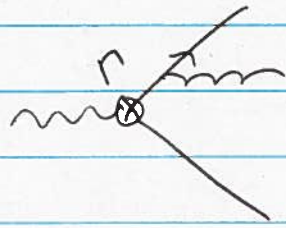
collinear $p_n \sim Q(1, \lambda^2, \lambda)$ for thrust

$p_{\bar{n}} \sim Q(\lambda^2, 1, \lambda)$ $\lambda \sim \sqrt{\tau}$

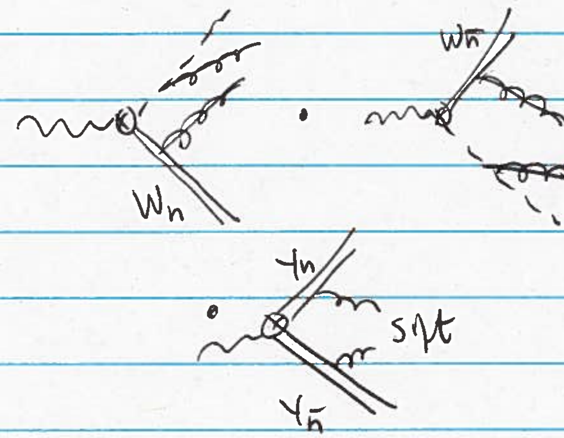
soft $p_s \sim Q(\lambda^2, \lambda^2, \lambda^2)$ $p_n^2 \sim Q^2 \tau$, $p_s^2 \sim Q^2 \tau^2$



Match QCD onto SCET



$\bar{q}\Gamma q$



Freedman
Stewart

$$C_2 \cdot \underbrace{(\bar{\psi}_n P_{\bar{n}} \Gamma W_n)}_{P_{\bar{n}} = \frac{\not{n}\not{\bar{n}}}{4}} \underbrace{(Y_n Y_{\bar{n}})}_{\text{soft}} (W_{\bar{n}} P_{\bar{n}} \psi_{\bar{n}})$$

soft (only sees color, direction of jets)

boosted QCD

leading order $\not{n}\,\psi_n = 0$

$\not{\bar{n}}\,\psi_{\bar{n}} = 0$

$$\Rightarrow \quad \Sigma(\tau) = H(Q,\mu) \int J_n(\tau_n,\mu)\, J_{\bar{n}}(\tau_{\bar{n}},\mu)\, S(\tau_s,\mu)\, \Theta(\tau - \tau_n - \tau_{\bar{n}} - \tau_s)$$

to $\mathcal{O}(\alpha_s)$,
$$H = 1 + \frac{\alpha_s(\mu)}{4\pi}\left(-8C_F \ln^2\frac{\mu}{Q} - 12C_F \ln\frac{\mu}{Q}\right)$$

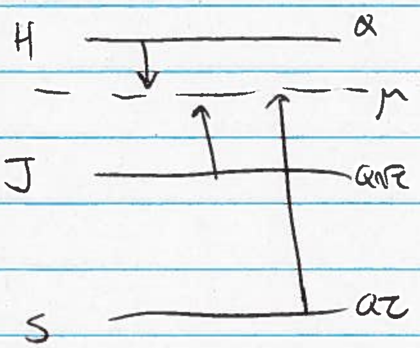
$$J = 1 + \frac{\alpha_s(\mu)}{4\pi}\left(8C_F \ln^2\frac{\mu}{Q\sqrt{\tau}} + 6C_F \ln\frac{\mu}{Q\sqrt{\tau}}\right)$$

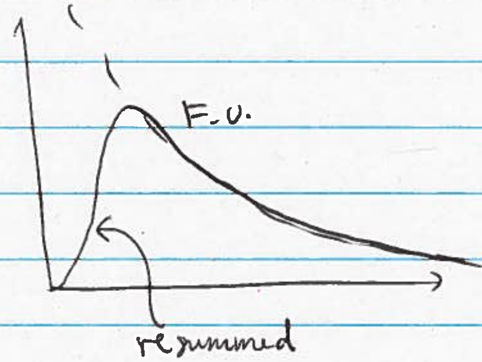
$$S = 1 + \frac{\alpha_s(\mu)}{4\pi}\left(-8C_F \ln^2\frac{\mu}{Q\tau}\right)$$

Γ is μ-independent. RGE evolves H, J, S $\quad \mu\frac{d}{d\mu}F = \gamma_F F$

$\downarrow$

Solve to resum logs between any scales





allows minimization of logs in H, J, S separately,

RG running to other scales resums logs.

known to NNNLL accuracy {Becher, Schwartz}

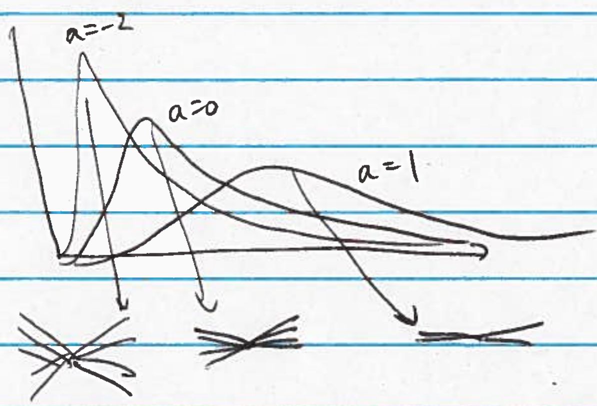
used for most precise extraction of α_s {Abbate, Fickinger, Hoang, Mateu, Stewart}

Theory II "SCET$_a$" : Angularities

note $\tau = \frac{1}{Q}\sum_i |\vec{p}_i^{\,T}|\, e^{-|\eta_i|}$ {Berger, Kucs, Sterman}

$\xrightarrow{\text{generalize}}$ angularity $\tau_a = \frac{1}{Q}\sum_i |\vec{p}_i^{\,T}|\, e^{-|\eta_i|(1-a)}$

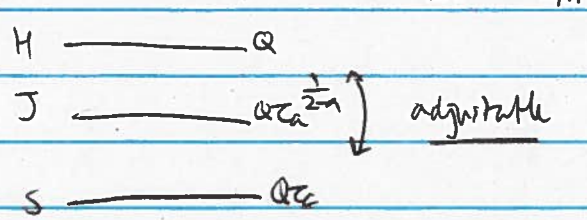
$-\infty < a < 2$ for IR safety



probe jets of different sizes
map out jet profile

$$\Sigma(\tau_a) = H\left(\ln\frac{\mu}{Q}\right) J^a_{n,\bar n}\left(\ln\frac{\mu}{Q\tau_a^{\frac{1}{2-a}}}\right) S^a\left(\ln\frac{\mu}{Q\tau_a}\right) \quad \text{for } a<1$$

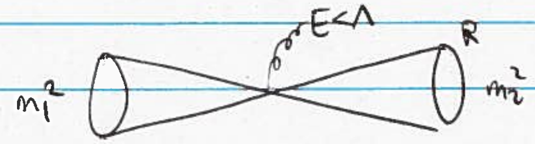
(see Chiu, Jain for a=1)



resummed to NLL accuracy for all a<1 (AH, CL, GO)

Theory III   SCET$_{a,\Lambda,R\ldots}$!   Jet Shapes

(SDE, AH, CL, JW, CV)
for $N \geq 2$, $-\infty < c < 1$
cone, a-kt, kt, C/A



$$\sigma(m_1^2, m_2^2, \Lambda) = H(Q;\mu)\, J_n(m_1;\mu)\, J_{\bar{n}}(m_2;\mu)\, S\left(\frac{m_1^2}{Q}, \frac{m_2^2}{Q}, \Lambda;\mu\right)$$

H —— Q

J_1 —— m_1 ——] → decoupled in SCET

—— m_2 —— J_2] →

S [m_1^2/Q , m_2^2/Q , Λ] → single soft sector in SCET

Can sum logs between one soft scale and H or J scale using RG
but not (yet) ratios of soft scales to one another.

$\left(\frac{m_1}{m_2}, \frac{\Lambda}{m_1}, \frac{\Lambda}{m_2}\right)$ → "non-global logs"

Def. NGLs are logs of ratios of soft scales due to soft radiation in sharply-divided regions of phase space measured with different scales.

($\ln \frac{\mu_S}{Q}$, $\ln \frac{\mu_{1,2}}{Q}$ are global, i.e. RG-resummable.)

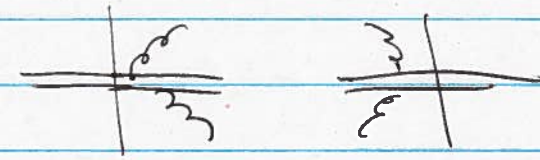
In 1105.4628, we introduced "Phase Space Factorization" for NGL

$$S(Q\rho_1, Q\rho_2; \mu) = S_{gl}(Q\rho_1,\mu)\, S_{gl}(Q\rho_2,\mu)\, S_{ng}\left(\frac{\rho_1}{\rho_2}\right)$$

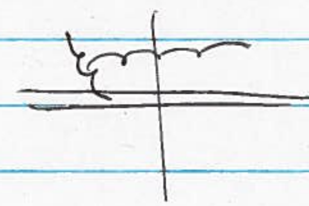
↓ ↓

obey "global" RGE,

calculate from



S_{ng} from



i.e. not in product $S^1_{gl} S^2_{gl}$

$$S_{ng} = 1 - \frac{\alpha_s^2 C_F C_A}{(2\pi)^2} \frac{\pi^2}{3} \ln^2 \frac{\rho_1}{\rho_2}$$

← first derived by Dasgupta, Salam

↓

proposed large-N_c resummation of NGLs

$$S_{ng} = e^{-C_F C_A \frac{\pi^2}{3}\left(\frac{1+(at)^2}{1+(bt)^c}\right)t^2}$$

where $t = \frac{1}{4\pi\beta_0} \ln \frac{1}{1-2\beta_0 \alpha_s L}$

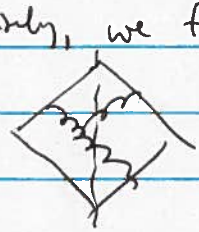
$a = 0.85\, C_A$

$b = 0.86\, C_A$

$c = 1.33$

↘ how to get in QCD?!?!

More precisely, we found



+

$(C_F C_A)$

Master formula for leading NGL

$$= 4 g^4 C_F C_A \mu^{4\epsilon} \int d^D k_1\, d^D k_2 \frac{k_1^+ k_2^-}{k_1 \cdot k_2} \frac{1}{k_1^+ k_1^- k_2^+ k_2^-} \Theta(k_1 \in R)\, \Theta(k_2 \in L) \times \delta\left(\rho_1 - \frac{k_1^+}{Q}\right) \delta\left(\rho_2 - \frac{k_2^-}{Q}\right)$$

$$= \frac{\alpha_s^2 C_F C_A}{(2\pi)^2} \frac{\pi^2}{3} \ln^2 \frac{\mu^2}{Q^2 \rho_1 \rho_2}$$ (replace $\rho_{1,2}$ for other observables, R, L for other regions)

μ-dependent!

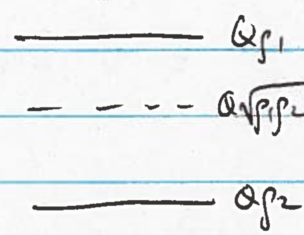
but no such term in anom dim γ_S of full soft func, which is known.

So "same-hemi" pieces  must contain "extra" terms canceling μ-dependence above.

$$- \frac{\alpha_s^2 C_F C_A}{(2\pi)^2} \frac{\pi^2}{3} \left(2 \ln^2 \frac{\mu}{Q\rho_1} + 2 \ln^2 \frac{\mu}{Q\rho_2} - \ln^2 \frac{\mu^2}{Q^2 \rho_1 \rho_2} \right)$$

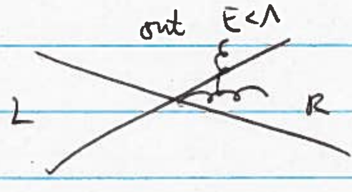
$$\text{Sum} = - \frac{\alpha_s^2 C_F C_A}{(2\pi)^2} \frac{\pi^2}{3} \ln^2 \frac{\rho_1}{\rho_2}$$

Suggests possible factorization into μ-dep pieces:



Can RGE sum NGLs?? future direction

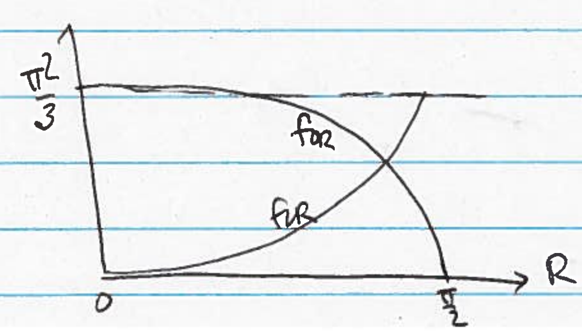
New Work: 1110.



Veto Λ on jets outside L, R regions

$$S_{NG} = 1 - \frac{\alpha_s^2 C_F C_A}{(2\pi)^2} \left[f_{OL}(R) \ln^2 \frac{Q\rho_L}{\Lambda} + f_{OR}(R) \ln^2 \frac{Q\rho_R}{\Lambda} + f_{LR}(R) \ln^2 \frac{\rho_L}{\rho_R} \right]$$

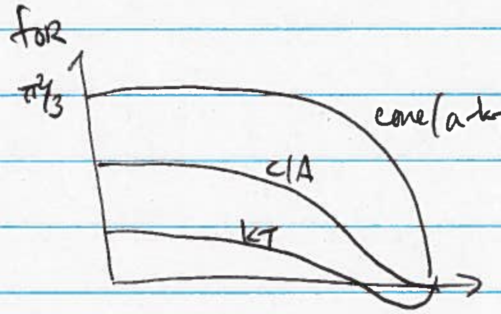
for cone/anti-k_T



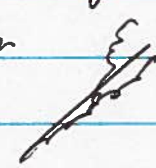
$f_{LR} = 2\,\mathrm{Li}_2(\tan^4 R/2)$

$f_{OR} = \frac{\pi^2}{3} - f_{LR}.$

In general $f_{AB} = \int d\eta_1 \int d\eta_2 \int \frac{d\varphi}{\pi} \frac{4\cos\varphi}{\cosh(\eta_1-\eta_2)-\cos\varphi}\, \Theta(1\in A)\,\Theta(2\in B)$



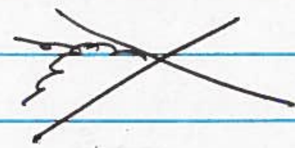
C/A, kT algo. recombine soft gluons near jet boundaries, blunting coll. enhancement at $\Delta\eta=0$.

Lessons: – NGL comes largely but not entirely from boundary region
(sometimes thought that NGLs only come from )

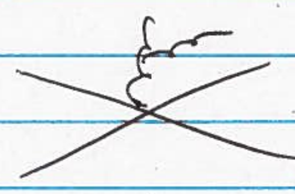
– NGL comes from <u>any ratio</u> of soft scales
not only strongly-ordered region $Q\rho \ll \Lambda$.
(as sometimes thought).

<u>Phase Space Factorization & Relations among coeffs</u>:

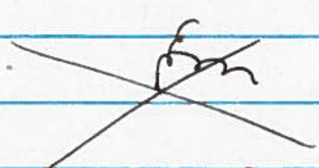
$-f_{RR}\ln^2\frac{\mu}{Q\rho_R}$



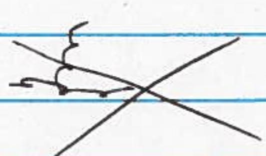
$-f_{LL}\ln^2\frac{\mu}{Q\rho_L}$



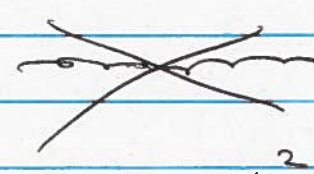
$-f_{00}\ln^2\frac{\mu}{\Lambda}$



$f_{0R}\ln^2\frac{\mu^2}{Q\rho_R\Lambda}$



$f_{0L}\ln^2\frac{\mu^2}{Q\rho_L\Lambda}$

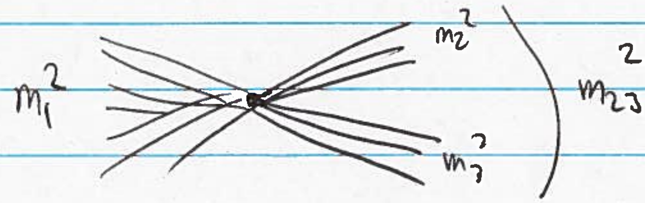


$f_{LR}\ln^2\frac{\mu^2}{Q^2\rho_L\rho_R}$

$$\Rightarrow \boxed{\begin{aligned} f_{00} &= 2(f_{0L}+f_{0R}) \\ f_{LL} &= 2(f_{0L}+f_{LR}) \\ f_{RR} &= 2(f_{0R}+f_{LR}) \end{aligned}}$$

IV. Other SCETs:

— $SCET_+$

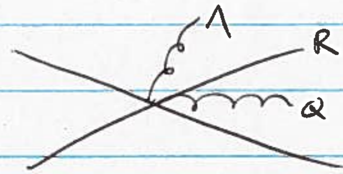


{ C. Bauer
JW
SZ
Tackmann

new "collinear-soft" mode resums logs of $\frac{m_{23}^2}{Q^2}$

in addition to $\frac{m_i^2}{Q^2}$

— $SCET_R$

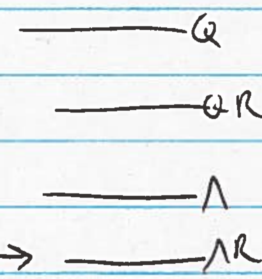


2-jet rate:

$\sigma_{2\text{-jet}}(\Lambda, R)$

sum logs of R

w/ new "soft-collinear" mode →



— etc...

Conclusion: More Exclusive Jet Observables

↓

More Effective Field Theories!