Multi-differential resummation with SCET+

Wouter Waalewijn

University of Amsterdam

Delta Institute for Theoretical Physics

Motivation

- Resummation has mostly been restricted to single variables
- Classic example of joint resummation: threshold and transverse momentum [Li; Laenen, Sterman, Vogelsang; …]
- In this talk, joint resummation of:
  - beam thrust $\mathcal{T}_0 = \sum_i p_{iT}\, e^{-|y_i|} = \sum_i \min\{p_i^+, p_i^-\}$
  - transverse momentum $\vec{p}_T = \sum_i \vec{p}_{iT}$
  - threshold $1 - z = 1 - \frac{Q^2}{\hat{s}}$ Drell-Yan invariant mass / partonic c.o.m. energy
- Achieved by adding modes to SCET = SCET+
- Consider pp → color-singlet + X for definiteness

Outline

1. Resummation in SCET
2. p_T and beam thrust resummation
3. p_T and threshold resummation
4. Conclusions

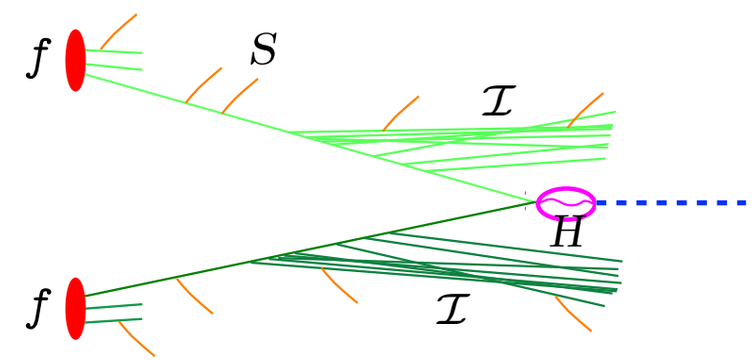
1. Resummation in SCET

Factorization in SCET

- Effective theory of QCD for collinear and soft radiation

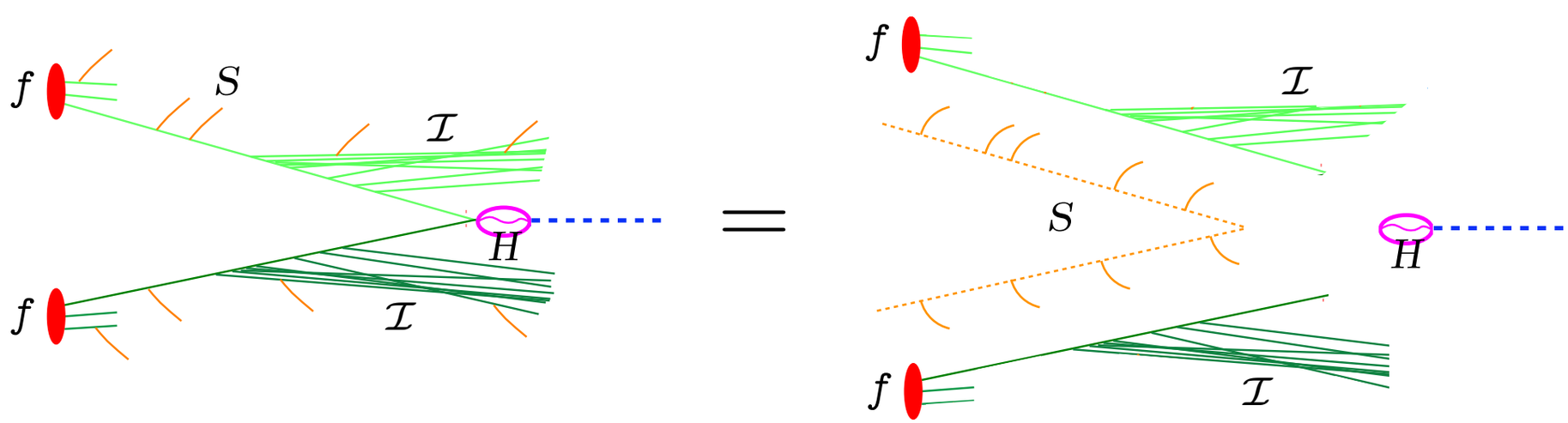
  [Bauer, Fleming, Luke, Pirjol, Rothstein, Stewart, ….]

$$\mathcal{L}_{\rm SCET} = \mathcal{L}_{\rm coll} + \mathcal{L}_{\rm coll} + \mathcal{L}_{\rm soft} + \sum_i C_i O_i$$



- Hard virtual corrections are integrated out

- Factorize collinear and soft modes in Lagrangian



$$\mathcal{T}_0 = \mathcal{T}_0^{\rm coll} + \mathcal{T}_0^{\rm coll} + \mathcal{T}_0^{\rm soft}$$

Beam thrust factorization

$$\frac{d\sigma}{d\mathcal{T}_0} = H(Q,\mu)\int d\mathcal{T}_0^{\rm coll}\, B_a(Q\mathcal{T}_0^{\rm coll}, x_a, \mu)\int d\mathcal{T}_0^{\rm coll}\, B_b(Q\mathcal{T}_0^{\rm coll}, x_b, \mu)$$
$$\times \int d\mathcal{T}_0^{\rm soft}\, S(\mathcal{T}_0^{\rm soft}, \mu)\, \delta(\mathcal{T}_0 - \mathcal{T}_0^{\rm coll} - \mathcal{T}_0^{\rm coll} - \mathcal{T}_0^{\rm soft})$$

- Hard function contains hard virtual corrections at the scale Q
- Beam functions describe the contribution from collinear radiation at scale $\sqrt{Q\mathcal{T}_0}$ and parton distribution functions

$$B_i(t = Q\mathcal{T}_0^{\rm coll},\, x, \mu) = \sum_{i'} \int \frac{dx'}{x'}\, \mathcal{I}_{ii'}\left(t, \frac{x}{x'}, \mu\right) f_{i'}(x', \mu)$$

[Stewart, Tackmann, WW]

- Soft function captures the soft radiation effects at scale $\mathcal{T}_0$

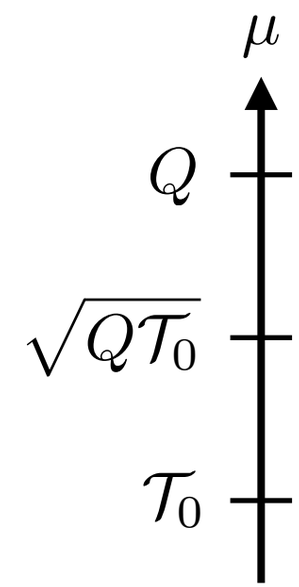
Resummation in SCET

- Achieve resummation by evaluating each ingredient at its natural scale and RG evolving to a common scale

$$\mu \frac{d}{d\mu} H(Q,\mu) = \gamma_H(Q,\mu)\, H(Q,\mu)$$

$$\mu \frac{d}{d\mu} B_i(t,x,\mu) = \int dt'\, \gamma_B^i(t-t',\mu)\, B_i(t',x,\mu)$$

$$\ldots$$



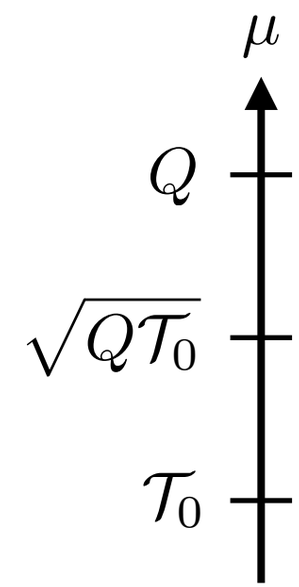
Resummation in SCET

- Achieve resummation by evaluating each ingredient at its natural scale and RG evolving to a common scale

$$\mu \frac{d}{d\mu} H(Q,\mu) = \gamma_H(Q,\mu)\, H(Q,\mu)$$

$$\mu \frac{d}{d\mu} B_i(t,x,\mu) = \int dt'\, \gamma_B^i(t-t',\mu)\, B_i(t',x,\mu)$$

$$\ldots$$



- Features of SCET:
  - Manifest gauge invariance
  - Matrix element definitions of ingredients. E.g.

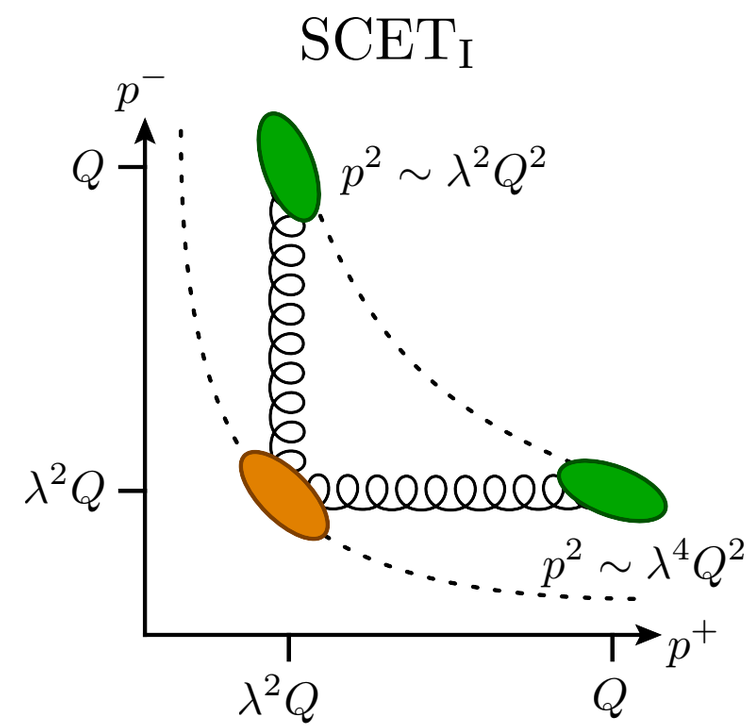
Wilson lines

$$S(\mathcal{T}_0^{\rm soft},\mu) = \frac{1}{N_c}\, {\rm tr}\, \langle 0|\bar{T}\left[Y_n^\dagger Y_{\bar{n}}\right] \delta(\mathcal{T}_0^{\rm soft} - \hat{\mathcal{T}}_0) T\left[Y_{\bar{n}}^\dagger Y_n\right]|0\rangle$$

measurement

Modes and power counting

	$\mathrm{SCET_I}$
n-collinear	$Q(\lambda^2, 1, \lambda)$
$\bar{n}$-collinear	$Q(1, \lambda^2, \lambda)$
soft	$Q(\lambda^2, \lambda^2, \lambda^2)$



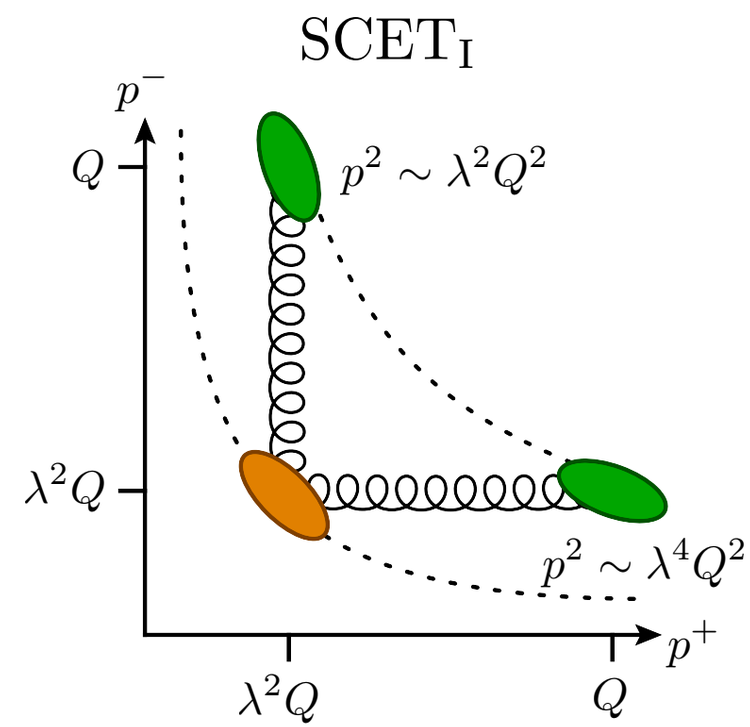
- Light cone coordinates

$$p^\mu = (p^+, p^-, p_\perp^\mu) = (n\cdot p, \bar{n}\cdot p, p_\perp^\mu)$$

- Measurement determines modes:
  - Beam thrust is described by SCET$_\mathrm{I}$ with $\lambda^2 = \mathcal{T}_0/Q$

Modes and power counting

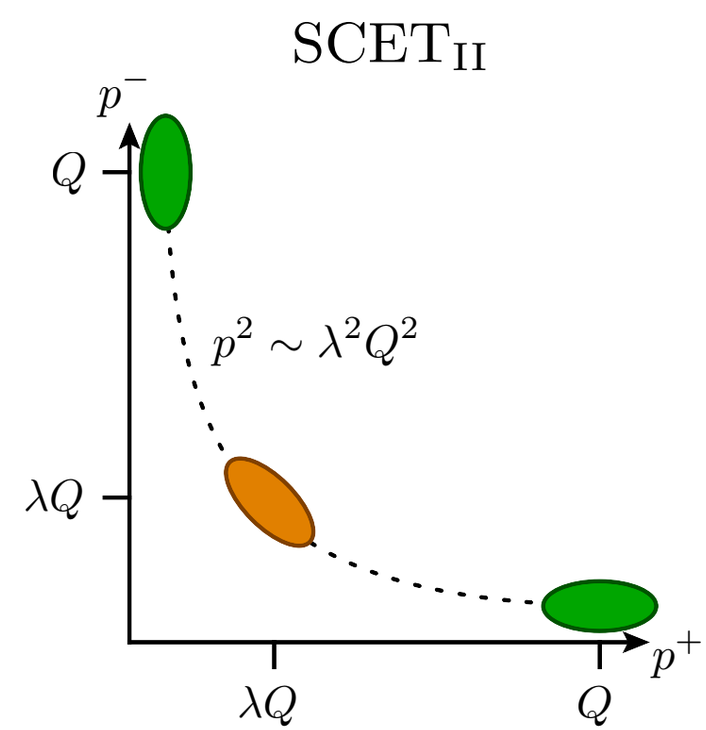
	$\mathrm{SCET_I}$	$\mathrm{SCET_{II}}$
n-collinear	$Q(\lambda^2, 1, \lambda)$	$Q(\lambda^2, 1, \lambda)$
$\bar{n}$-collinear	$Q(1, \lambda^2, \lambda)$	$Q(1, \lambda^2, \lambda)$
soft	$Q(\lambda^2, \lambda^2, \lambda^2)$	$Q(\lambda, \lambda, \lambda)$



- Light cone coordinates

$$p^\mu = (p^+, p^-, p_\perp^\mu) = (n\cdot p, \bar{n}\cdot p, p_\perp^\mu)$$

- Measurement determines modes:
  - Beam thrust is described by $\mathrm{SCET_I}$ with $\lambda^2 = \mathcal{T}_0/Q$
  - p_T is a $\mathrm{SCET_{II}}$ observables, $\lambda^2 = p_T^2/Q^2$



Transverse momentum resummation

- SCET_{II} involves rapidity divergences

$$S^{(1)}(p_T) \propto \alpha_s \frac{\mu^{2\epsilon}}{p_T^{1+2\epsilon}} \int dy$$

Transverse momentum resummation

- SCET_{II} involves rapidity divergences

$$S^{(1)}(p_T) \propto \alpha_s \frac{\mu^{2\epsilon}\,\nu^{\eta}}{p_T^{1+2\epsilon+\eta}} \int dy\, |2\sinh y|^{-\eta}$$

[Chiu, Jain, Neill, Rothstein]

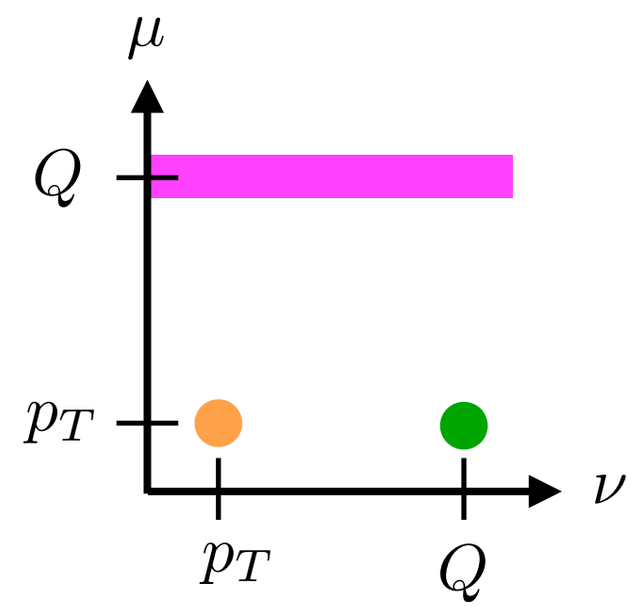
- Many other choices for rapidity regulator
  [Collins; Chiu, Fuhrer, Hoang, Kelley, Manohar; Becher, Bell; …]

Transverse momentum resummation

- SCET_{II} involves rapidity divergences

$$S^{(1)}(p_T) \propto \alpha_s \frac{\mu^{2\epsilon}\,\nu^{\eta}}{p_T^{1+2\epsilon+\eta}} \int dy\, |2\sinh y|^{-\eta}$$

[Chiu, Jain, Neill, Rothstein]



- Many other choices for rapidity regulator
  [Collins; Chiu, Fuhrer, Hoang, Kelley, Manohar; Becher, Bell; …]

- Rapidity resummation encoded in rapidity RG evolution

$$\frac{d\sigma}{d\vec{p}_T} = H(Q,\mu) \int d\vec{p}_T^{\,\text{coll}}\, B_a(\vec{p}_T^{\,\text{coll}}, x_a, \mu, \nu) \int d\vec{p}_T^{\,\text{coll}}\, B_b(\vec{p}_T^{\,\text{coll}}, x_b, \mu, \nu)$$
$$\times \int d\vec{p}_T^{\,\text{soft}}\, S(\vec{p}_T^{\,\text{soft}}, \mu, \nu)\, \delta(\vec{p}_T - \vec{p}_T^{\,\text{coll}} - \vec{p}_T^{\,\text{coll}} - \vec{p}_T^{\,\text{soft}})$$

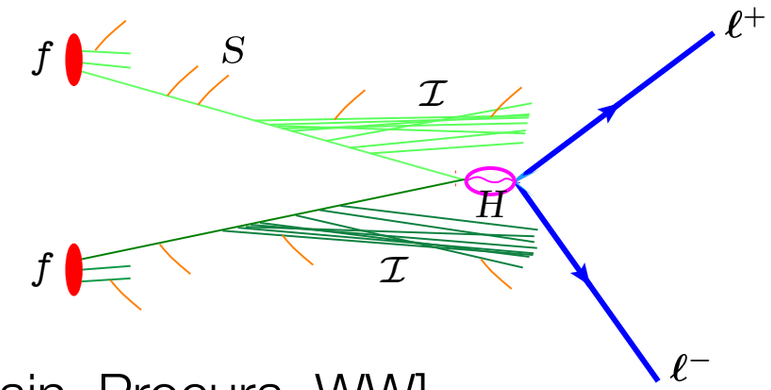
- E.g. $\nu \frac{d}{d\nu} B_i(\vec{p}_T, x, \mu, \nu) = \int d\vec{p}_T^{\,\prime}\, \gamma_B^{\nu}(\vec{p}_T - \vec{p}_T^{\,\prime}, \mu)\, B_i(\vec{p}_T^{\,\prime}, x, \mu, \nu)$

2. p_T and beam thrust resummation

Based on arXiv:1410.6483 (Procura, WW, Zeune)

Beam thrust and transverse momentum resummation

- Make $\mathcal{T}_0$ or p_T factorization formulas more differential



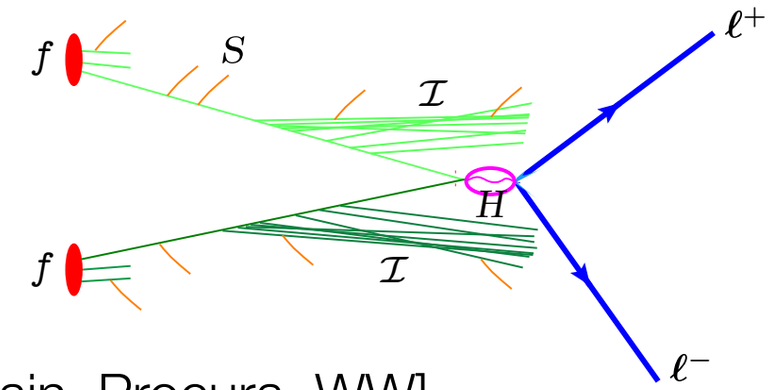
$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(Q\mathcal{T}_0, \vec{p}_T) \otimes B(Q\mathcal{T}_0, \vec{p}_T) \otimes S(\mathcal{T}_0)$$ [Jain, Procura, WW]

- Structure dictated by power counting

$$\mathrm{SCET_I}: \ \vec{p}_T = \vec{p}_T^{\,\mathrm{coll}} + \vec{p}_T^{\,\mathrm{coll}} + \mathcal{O}(\lambda^2) \qquad \rightarrow \qquad Q\mathcal{T}_0 \sim \vec{p}_T^{\,2}$$

Beam thrust and transverse momentum resummation

- Make $\mathcal{T}_0$ or p_T factorization formulas more differential



$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(Q\mathcal{T}_0, \vec{p}_T) \otimes B(Q\mathcal{T}_0, \vec{p}_T) \otimes S(\mathcal{T}_0)$$ [Jain, Procura, WW]

$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(\vec{p}_T) \otimes B(\vec{p}_T) \otimes S(\mathcal{T}_0, \vec{p}_T)$$ [Larkoski, Moult, Neill]

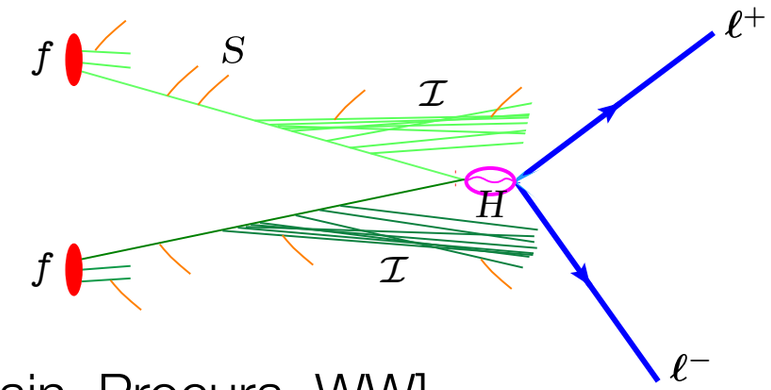
- Structure dictated by power counting

$$\mathrm{SCET_I}: \ \vec{p}_T = \vec{p}_T^{\,\mathrm{coll}} + \vec{p}_T^{\,\mathrm{coll}} + \mathcal{O}(\lambda^2) \qquad \rightarrow \qquad Q\mathcal{T}_0 \sim \vec{p}_T^{\,2}$$

$$\mathrm{SCET_{II}}: \ \mathcal{T}_0 = \mathcal{T}_0^{\mathrm{soft}} + \mathcal{O}(\lambda^2) \qquad \rightarrow \qquad \mathcal{T}_0^2 \sim \vec{p}_T^{\,2}$$

0-jettiness and transverse momentum resummation

- Make $\mathcal{T}_0$ or p_T factorization formulas more differential



$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(Q\mathcal{T}_0, \vec{p}_T) \otimes B(Q\mathcal{T}_0, \vec{p}_T) \otimes S(\mathcal{T}_0)$$ [Jain, Procura, WW]

$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(\vec{p}_T) \otimes B(\vec{p}_T) \otimes S(\mathcal{T}_0)$$????

$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(\vec{p}_T) \otimes B(\vec{p}_T) \otimes S(\mathcal{T}_0, \vec{p}_T)$$ [Larkoski, Moult, Neill]

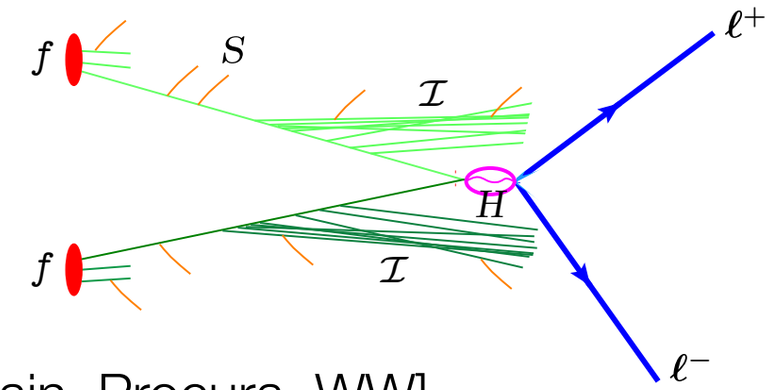
- Structure dictated by power counting

$$\mathrm{SCET_I}: \ \vec{p}_T = \vec{p}_T^{\,\mathrm{coll}} + \vec{p}_T^{\,\mathrm{coll}} + \mathcal{O}(\lambda^2) \qquad \rightarrow \qquad Q\mathcal{T}_0 \sim \vec{p}_T^{\,2}$$

$$\mathrm{SCET_{II}}: \ \mathcal{T}_0 = \mathcal{T}_0^{\mathrm{soft}} + \mathcal{O}(\lambda^2) \qquad \rightarrow \qquad \mathcal{T}_0^2 \sim \vec{p}_T^{\,2}$$

Beam thrust and transverse momentum resummation

- Make $\mathcal{T}_0$ or p_T factorization formulas more differential



$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(Q\mathcal{T}_0, \vec{p}_T) \otimes B(Q\mathcal{T}_0, \vec{p}_T) \otimes S(\mathcal{T}_0)$$ [Jain, Procura, WW]

$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(\vec{p}_T) \otimes B(\vec{p}_T) \otimes S_+(\mathcal{T}_0, \vec{p}_T) \otimes S_+(\mathcal{T}_0, \vec{p}_T) \otimes S(\mathcal{T}_0)$$

[Procura, WW, Zeune]

$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(\vec{p}_T) \otimes B(\vec{p}_T) \otimes S(\mathcal{T}_0, \vec{p}_T)$$ [Larkoski, Moult, Neill]

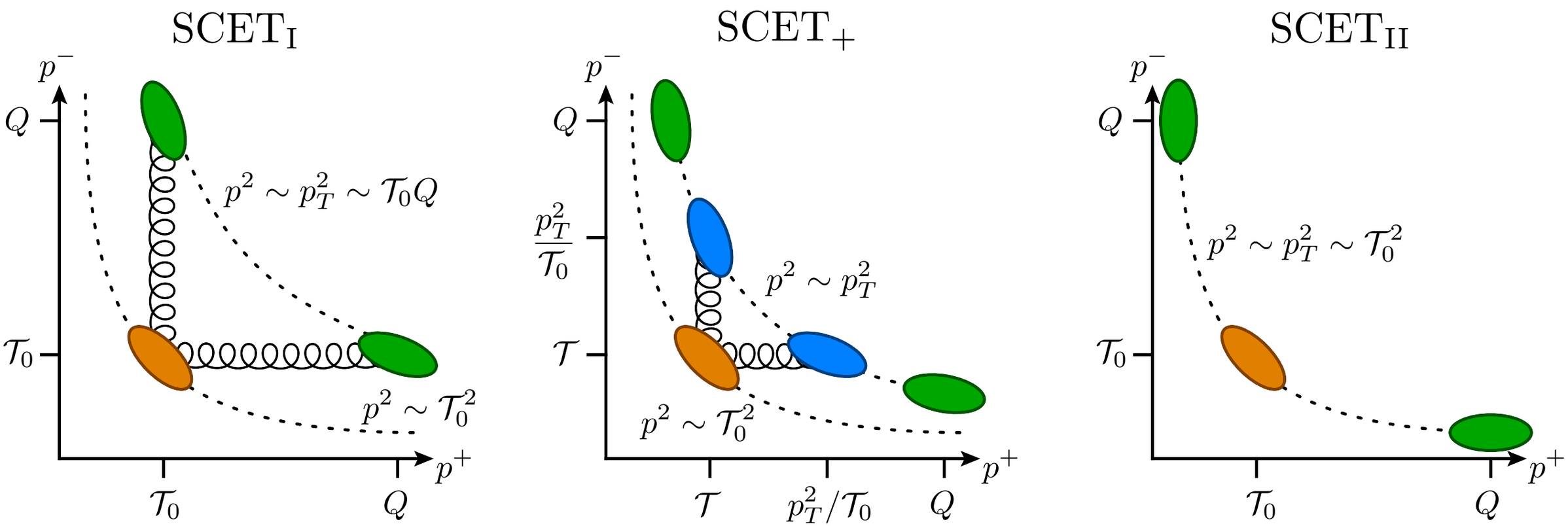
- Structure dictated by power counting

$$\mathrm{SCET_I}: \ \vec{p}_T = \vec{p}_T^{\,\mathrm{coll}} + \vec{p}_T^{\,\mathrm{coll}} + \mathcal{O}(\lambda^2) \qquad \rightarrow \qquad Q\mathcal{T}_0 \sim \vec{p}_T^{\,2}$$

$$\mathrm{SCET_{II}}: \ \mathcal{T}_0 = \mathcal{T}_0^{\mathrm{soft}} + \mathcal{O}(\lambda^2) \qquad \rightarrow \qquad \mathcal{T}_0^2 \sim \vec{p}_T^{\,2}$$

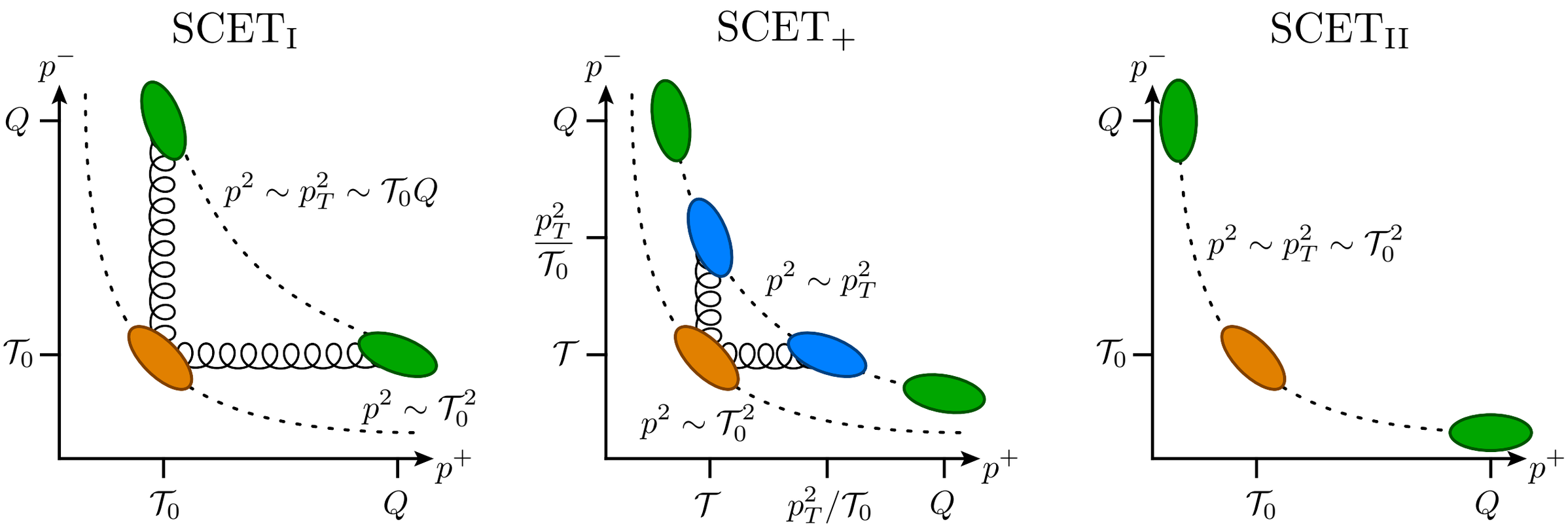
- Intermediate regime requires additional collinear-soft functions

Modes in SCET+



- Collinear-soft mode uniquely fixed by $p_T, \mathcal{T}_0$ measurement

Modes in SCET+



- Collinear-soft mode uniquely fixed by $p_T, \mathcal{T}_0$ measurement
- *n*-collinear-soft modes behaves for factorization like a
  - soft mode with respect to the *n*-collinear mode
  - collinear mode with respect to the rest

[Bauer, Tackmann, Walsh, Zuberi]

Ingredients of factorization formulas

$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(Q\mathcal{T}_0, \vec{p}_T) \otimes B(Q\mathcal{T}_0, \vec{p}_T) \otimes S(\mathcal{T}_0) \qquad Q\mathcal{T}_0 \sim \vec{p}_T^{\,2}$$

$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(\vec{p}_T) \otimes B(\vec{p}_T) \otimes S_+(\mathcal{T}_0, \vec{p}_T) \otimes S_+(\mathcal{T}_0, \vec{p}_T) \otimes S(\mathcal{T}_0)$$

$$\frac{d\sigma}{d\vec{p}_T\, d\mathcal{T}_0} = H(Q)B(\vec{p}_T) \otimes B(\vec{p}_T) \otimes S(\mathcal{T}_0, \vec{p}_T) \qquad \mathcal{T}_0^2 \sim \vec{p}_T^{\,2}$$

- $B(\vec{p}_T, x, \mu, \nu)$ transverse momentum beam function
- $S(\mathcal{T}_0, \mu)$ beam thrust soft function
- $B(Q\mathcal{T}_0, \vec{p}_T, x, \mu)$ double differential beam function
- $S(\mathcal{T}_0, \vec{p}_T, \mu, \nu)$ double differential soft function
- $S_+(\mathcal{T}_0, \vec{p}_T, \mu, \nu)$ collinear-soft function

Note: p_T beam function without p_T soft function

Collinear-soft function

- Matrix-element of eikonal collinear-soft Wilson lines

$$S_+(\mathcal{T}_0^{\rm csoft}, \vec{p}_T^{\,\rm csoft}) = \frac{1}{N_c}\,{\rm tr}\,\langle 0|\bar{T}\big[X_n^\dagger V_{\bar{n}}\big]\,\delta(\mathcal{T}_0^{\rm soft} - \hat{p}^+)\,\delta(\vec{p}_T^{\,\rm csoft} - \hat{\vec{p}}_T)T\big[V_n^\dagger X_n\big]|0\rangle$$

- Differs from soft function $S(\mathcal{T}_0^{\rm soft}, \vec{p}_T^{\,\rm soft})$ because the collinear-soft radiation goes into one hemisphere, $\hat{\mathcal{T}}_0 \to \hat{p}^+$

Collinear-soft function

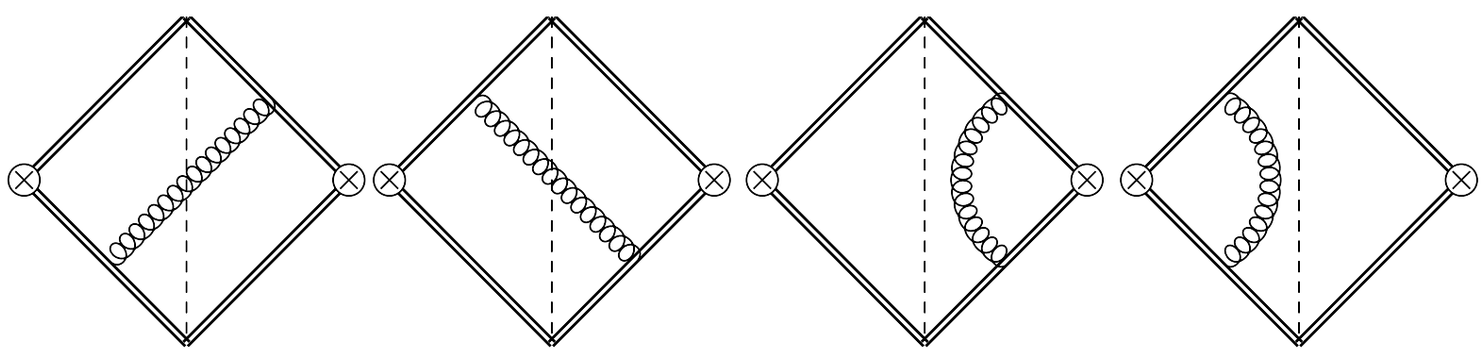
- Matrix-element of eikonal collinear-soft Wilson lines

$$S_+(\mathcal{T}_0^{\rm csoft}, \vec{p}_T^{\,\rm csoft}) = \frac{1}{N_c}\,{\rm tr}\,\langle 0|\bar{T}\big[X_n^\dagger V_{\bar{n}}\big]\,\delta(\mathcal{T}_0^{\rm soft} - \hat{p}^+)\,\delta(\vec{p}_T^{\,\rm csoft} - \hat{\vec{p}}_T)T\big[V_n^\dagger X_n\big]|0\rangle$$

- Differs from soft function $S(\mathcal{T}_0^{\rm soft}, \vec{p}_T^{\,\rm soft})$ because the collinear-soft radiation goes into one hemisphere, $\hat{\mathcal{T}}_0 \to \hat{p}^+$

- At one loop

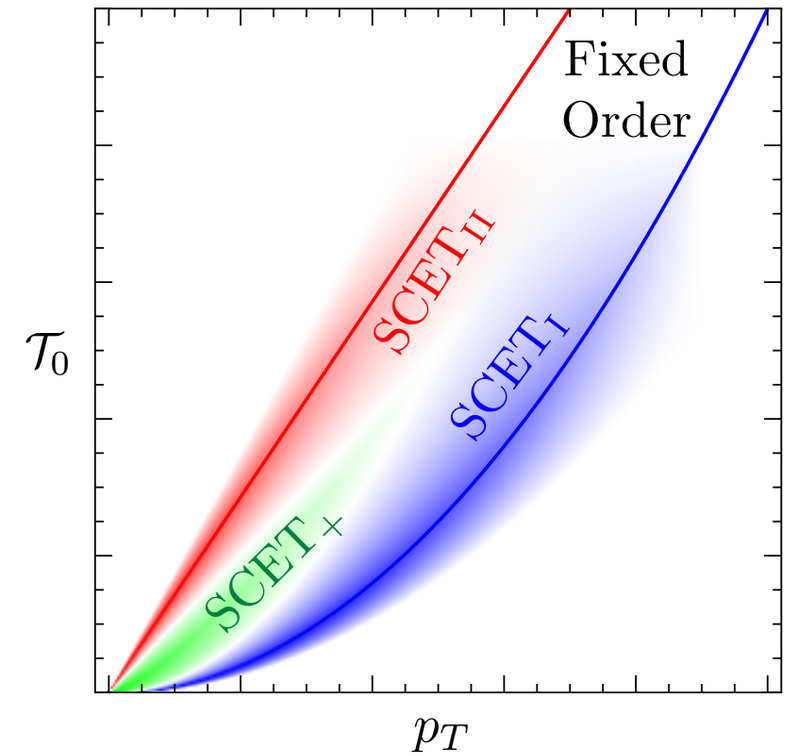
$$S_+^{(1)}(k^+, \vec{k}_T, \mu, \nu) = \frac{\alpha_s C_F}{\pi^2}\Bigg\{\frac{1}{\mu^3}\frac{1}{(k^+/\mu)_+}\frac{1}{(k_T^2/\mu^2)_+} + \delta(k^+)\Bigg[-\frac{1}{\mu^2}\Big[\frac{\ln(k_T^2/\mu^2)}{k_T^2/\mu^2}\Big]_+ + \frac{1}{\mu^2}\frac{1}{(k_T^2/\mu^2)_+}\ln\frac{\nu}{\mu} - \frac{\pi^2}{12}\delta(k_T^2)\Bigg]\Bigg\}$$



Consistency relations

- Consistency between SCET_{I} and SCET+

$$B(Q\mathcal{T}_0, \vec{p}_T) = B(\vec{p}_T) \otimes S_+(\mathcal{T}_0, \vec{p}_T) \times \left[1 + \mathcal{O}\left(\frac{p_T^2}{Q\mathcal{T}_0}\right)\right]$$



- Consistency between SCET_{II} and SCET+

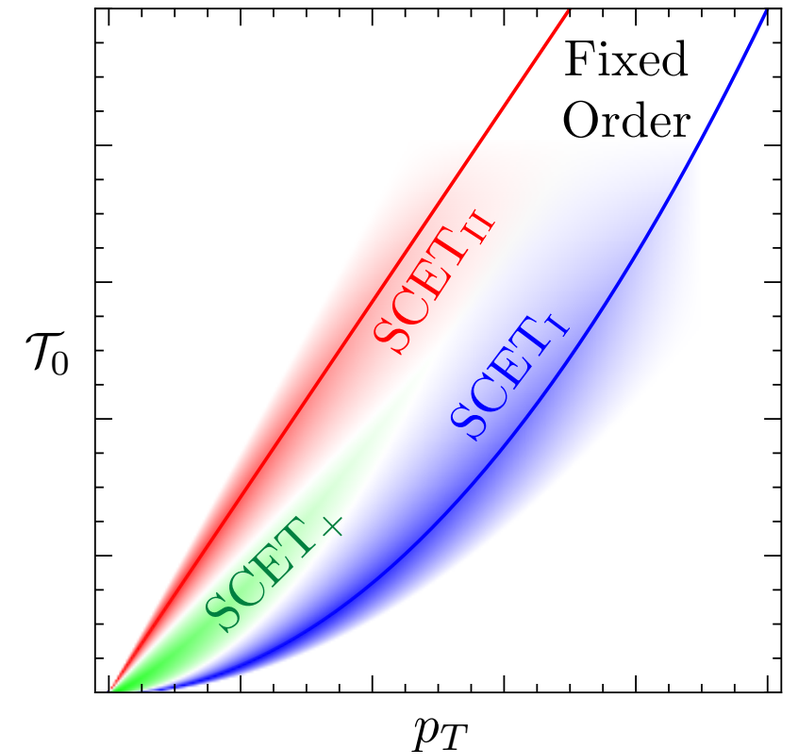
$$S(\mathcal{T}_0, \vec{p}_T) = S_+(\mathcal{T}_0, \vec{p}_T) \otimes S_+(\mathcal{T}_0, \vec{p}_T) \otimes S(\mathcal{T}_0) \left[1 + \mathcal{O}\left(\frac{\mathcal{T}_0^2}{p_T^2}\right)\right]$$

- Verified for anomalous dimensions and NLO ingredients

Scales choices and matching

- Natural scales of the ingredients are

$$\mu_H = Q\,,$$
$$\mu_B = p_T\,, \quad \nu_B = Q\,,$$
$$\mu_{S_+} = p_T\,, \quad \nu_{S_+} = p_T^2/\mathcal{T}_0\,,$$
$$\mu_S = \mathcal{T}_0$$



- Scales / resummation smoothly connect all regimes
- SCET+ sums all logarithms but has more power corrections
- Starting at NNLL/NLO there are corrections from the SCET$_I$, SCET$_{II}$ and fixed-order boundaries that must be included

3. p_T and threshold resummation

Based on arXiv:1605.02740 (Lustermans, WW, Zeune)

Transverse momentum and threshold resummation

- Start from p_T or threshold factorization

1. $$\frac{d\sigma}{d\vec{p}_T} = H(Q)B(\vec{p}_T, z) \otimes B(\vec{p}_T, z) \otimes S(\vec{p}_T) \qquad 1 - z \sim 1$$

3. $$\frac{d\sigma}{d\vec{p}_T} = H(Q)f(z) \otimes f(z) \otimes S(\vec{p}_T, z) \qquad p_T \sim (1-z)Q$$

where the threshold parameter is $1 - z = 1 - \frac{Q^2}{\hat{s}}$

Transverse momentum and threshold resummation

- Start from p_T or threshold factorization

1. $$\frac{d\sigma}{d\vec{p}_T} = H(Q)B(\vec{p}_T, z) \otimes B(\vec{p}_T, z) \otimes S(\vec{p}_T) \qquad 1 - z \sim 1$$

2. $$\frac{d\sigma}{d\vec{p}_T} = H(Q)f(z) \otimes f(z) \otimes S_+(\vec{p}_T, z) \otimes S_+(\vec{p}_T, z) \otimes S(\vec{p}_T)$$

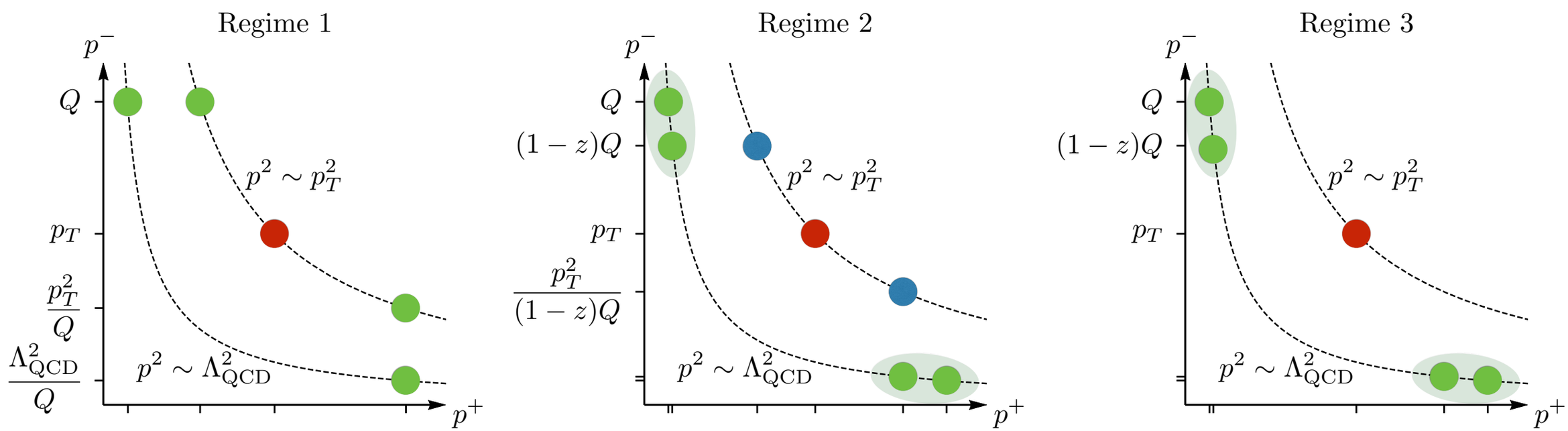
3. $$\frac{d\sigma}{d\vec{p}_T} = H(Q)f(z) \otimes f(z) \otimes S(\vec{p}_T, z) \qquad p_T \sim (1-z)Q$$

where the threshold parameter is $1 - z = 1 - \frac{Q^2}{\hat{s}}$

- Intermediate regime 2 described by SCET+ with

$$p_T/Q \ll 1 - z \ll 1$$

Modes



Regime:	1: $1 \sim 1-z \gg p_T/Q$	2: $1 \gg 1-z \gg p_T/Q$	3: $1 \gg 1-z \sim p_T/Q$
n-collinear	$(\Lambda_{\rm QCD}^2/Q, Q, \Lambda_{\rm QCD})$	$(\Lambda_{\rm QCD}^2/Q, Q, \Lambda_{\rm QCD})$	$(\Lambda_{\rm QCD}^2/Q, Q, \Lambda_{\rm QCD})$
	$(p_T^2/Q, Q, p_T)$	$\big(\Lambda_{\rm QCD}^2/[(1-z)Q], (1-z)Q, \Lambda_{\rm QCD}\big)$	$\big(\Lambda_{\rm QCD}^2/[(1-z)Q], (1-z)Q, \Lambda_{\rm QCD}\big)$
$\bar{n}$-collinear	$(Q, \Lambda_{\rm QCD}^2/Q, \Lambda_{\rm QCD})$	$(Q, \Lambda_{\rm QCD}^2/Q, \Lambda_{\rm QCD})$	$(Q, \Lambda_{\rm QCD}^2/Q, \Lambda_{\rm QCD})$
	$(Q, p_T^2/Q, p_T)$	$\big((1-z)Q, \Lambda_{\rm QCD}^2/[(1-z)Q], \Lambda_{\rm QCD}\big)$	$\big((1-z)Q, \Lambda_{\rm QCD}^2/[(1-z)Q], \Lambda_{\rm QCD}\big)$
n-csoft		$\big(p_T^2/[(1-z)Q], (1-z)Q, p_T\big)$	
$\bar{n}$-csoft		$\big((1-z)Q, p_T^2/[(1-z)Q], p_T\big)$	
soft	(p_T, p_T, p_T)	(p_T, p_T, p_T)	(p_T, p_T, p_T)

Collinear-soft function

- Measures other light-cone component than before, $p^+ \to p^-$

$$S_+(p^-, \vec{p}_T) = \frac{1}{N_c} \operatorname{tr} \langle 0 | \bar{T}\left[X_n^\dagger V_{\bar{n}}\right] \delta(p^- - \hat{p}^-)\, \delta(\vec{p}_T - \hat{\vec{p}}_T) T\left[V_n^\dagger X_n\right] | 0 \rangle$$

- The $p^+ \leftrightarrow p^-$ symmetry broken by rapidity regulator *or* due to double counting with soft radiation

$$S_+(p^+, \vec{p}_T) = [S_+(p^-, \vec{p}_T) \text{ with } p^- \to p^+] \otimes S(\vec{p}_T)$$

Collinear-soft function and consistency relations

- Measures other light-cone component than before, $p^+ \to p^-$

$$S_+(p^-, \vec{p}_T) = \frac{1}{N_c}\,\mathrm{tr}\,\langle 0|\bar{T}\big[X_n^\dagger V_{\bar{n}}\big]\,\delta(p^- - \hat{p}^-)\,\delta(\vec{p}_T - \hat{\vec{p}}_T)T\big[V_n^\dagger X_n\big]|0\rangle$$

- The $p^+ \leftrightarrow p^-$ symmetry broken by rapidity regulator *or* due to double counting with soft radiation

$$S_+(p^+, \vec{p}_T) = [S_+(p^-, \vec{p}_T)\ \text{with}\ p^- \to p^+] \otimes S(\vec{p}_T)$$

- Consistency relations

$$B(\vec{p}_T, z) = S_+(\vec{p}_T, z) \otimes f(z)\big[1 + \mathcal{O}(1-z)\big]$$

$$S(\vec{p}_T, z) = S_+(\vec{p}_T, z) \otimes S_+(\vec{p}_T, z) \otimes S(\vec{p}_T)\Big[1 + \mathcal{O}\Big(\frac{p_T^2}{(1-z)^2 Q^2}\Big)\Big]$$

SCET_{II} and SCET+

$$B_i(\vec{p}_T, z) = \sum_j I_{ij}(\vec{p}_T, z) \otimes f_j(z)$$
$$= S_{i+}(\vec{p}_T, z) \otimes f_i(z)\big[1 + \mathcal{O}(1-z)\big]$$

Dictates structure of coefficients I_{ij} in the threshold limit:

- Logarithms of p_T and z predicted by RG evolution

$$\mu_{S_+} = p_T\,, \quad \nu_{S_+} = (1-z)Q\,,$$

Proves conjecture by Echevarria, Scimemi, Vladimirov
[arXiv:1604.07869]

SCET_{II} and SCET+

$$B_i(\vec{p}_T, z) = \sum_j I_{ij}(\vec{p}_T, z) \otimes f_j(z)$$
$$= S_{i+}(\vec{p}_T, z) \otimes f_i(z)\big[1 + \mathcal{O}(1-z)\big]$$

Dictates structure of coefficients I_{ij} in the threshold limit:

- Logarithms of p_T and z predicted by RG evolution

$$\mu_{S_+} = p_T\,, \quad \nu_{S_+} = (1-z)Q\,,$$

  Proves conjecture by Echevarria, Scimemi, Vladimirov [arXiv:1604.07869]

- Can obtain SCET+ from SCET_{II}: $\nu_B = Q \;\to\; (1-z)Q = \nu_{S_+}$
- Corrections from SCET_{I} and fixed-order start at NNLL

Conclusions

- Collisions involve many scales
  → additional collinear-soft modes = SCET+
- SCET+ enables the simultaneous resummation of
  - Jet resolution parameters (this talk)
  - Jet kinematic logarithms [Bauer, Tackmann, Walsh, Zuberi; Larkoski, Neill, Moult; Pietrulewicz, Tackmann, WW]
  - Jet radius logarithms [Chien, Hornig, Lee; Kolodrubetz, Pietrulewicz, Stewart, Tackmann, WW]
  - Non-global logarithms [Larkoski, Moult, Neill; Becher, Neubert, Rothen, Shao]

Stay tuned!