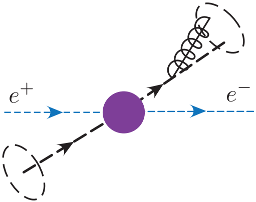
Simplifications with Helicity at Leading and Next-to-Leading Power

Ian Moult

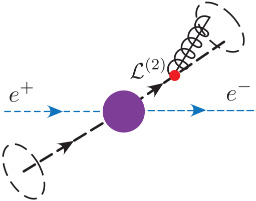
Berkeley Center For Theoretical Physics/ Lawrence Berkeley Laboratory

Outline

- Leading Power:
  - Organizing SCET Calculations with Helicity



- Next-to-Leading Power:
  - SCET at Subleading Power
  - Symmetry Constraints from Helicity Conservation
  - Subleading Power Calculations



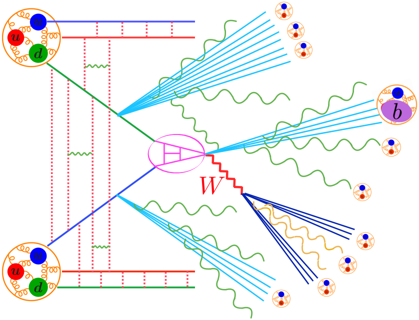
[Moult, Stewart, Tackmann, Waalewijn] 1508.02397

Leading Power

SCET

[Bauer, Fleming, Pirjol, Stewart]

- SCET describes soft and collinear radiation in the presence of a hard scattering.

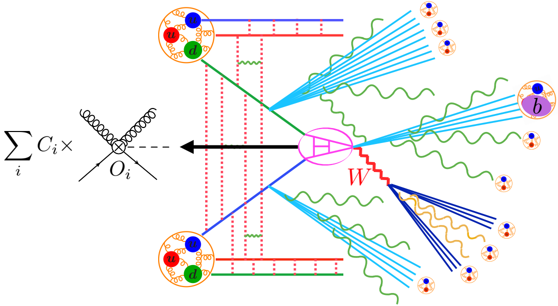


- Allows for a factorized description: Hard, Jet, Beam, Soft functions

$$\frac{d\sigma}{d\mathcal{M}_1\cdots} = \sum_{\{\kappa\}} \mathrm{tr} H_\kappa \mathcal{I}\mathcal{I} J_{\kappa_i} \otimes \cdots \otimes J_{\kappa_j} S_{\kappa_s} \otimes f_{p/i} f_{p/j} \otimes f_{k\to H} \otimes \cdots \otimes f_{l\to H} \otimes F$$

SCET

- Hard scattering is described by operators in EFT



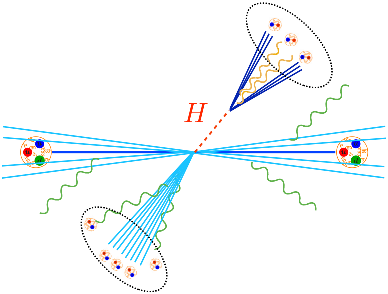
- At leading power, operator contains one quark or gluon jet field for each well separated jet direction.

$$\chi_{n,\omega}(x) = \left[\delta(\omega - \overline{\mathcal{P}}_n)\, W_n^\dagger(x)\, \xi_n(x)\right]$$

$$\mathcal{B}^{\mu}_{n,\omega\perp}(x) = \frac{1}{g}\left[\delta(\omega + \overline{\mathcal{P}}_n)\, W_n^\dagger(x)\, \mathrm{i}D^{\mu}_{n\perp}\, W_n(x)\right]$$

SCET

- Many applications involve higher multiplicity:



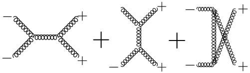
- Becomes tedious to make bases in terms of standard Lorentz/ Dirac structures:

$$\mathcal{O}^{abc\bar{\alpha}\beta} = \mathcal{B}^{\mu a}_{n_1\perp}\mathcal{B}^{\nu b}_{n_2\perp}\mathcal{B}^{\sigma c}_{n_3\perp}\bar{\chi}^{\bar{\alpha}}_{n_4}\Gamma_{\mu\nu\sigma}\chi^{\beta}_{n_5}$$

Helicity Amplitudes

- Well known simplicity in on-shell helicity amplitudes
  - Compact expressions.
  - Manifest symmetry properties.
  - ...
- e.g. $4g$ scattering:

$$\mathcal{A}(1^-2^-3^+4^+) = g^2 \sum_{\sigma \in S_n/\mathbb{Z}_n} \mathrm{Tr}(T^{a_{\sigma(1)}} \ldots T^{a_{\sigma(4)}}) A(\sigma(1^-), \ldots, \sigma(4^+)) =$$



$$A(1^-, 2^-, 3^+, 4^+) = \frac{\langle 12 \rangle^4}{\langle 12 \rangle \langle 23 \rangle \langle 34 \rangle \langle 41 \rangle}$$

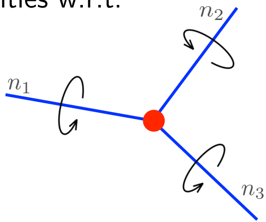
- Can we use similar tricks at the operator level?

Helicity Operators in SCET

- SCET formulated as expansion about lightlike directions n_i:

$$\mathcal{B}_{n_i\perp},\ \chi_{n_i,\omega}$$

- Define natural directions to define helicities w.r.t.



- Can define jet fields of definite helicity:

Gluons: $\mathcal{B}^a_{i\pm} = -\varepsilon_{\mp\mu}(n_i, \bar{n}_i)\,\mathcal{B}^{a\mu}_{n_i,\omega_i\perp_i}$

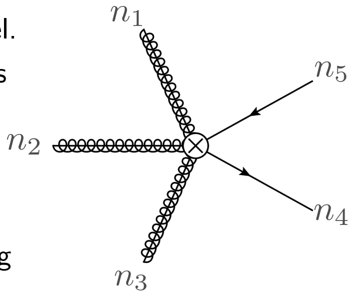
Quark Bilinear :

$$J^{\bar{\alpha}\beta}_{ij+} = \frac{\sqrt{2}\,\varepsilon^{\mu}_{-}(n_i, n_j)}{\sqrt{\omega_i\,\omega_j}}\,\frac{\bar{\chi}^{\bar{\alpha}}_{i+}\,\gamma_\mu \chi^{\beta}_{j+}}{\langle n_i n_j\rangle}\,,$$

$$J^{\bar{\alpha}\beta}_{ij-} = -\,\frac{\sqrt{2}\,\varepsilon^{\mu}_{+}(n_i, n_j)}{\sqrt{\omega_i\,\omega_j}}\,\frac{\bar{\chi}^{\bar{\alpha}}_{i-}\,\gamma_\mu \chi^{\beta}_{j-}}{[n_i n_j]}$$

An Example

- Example: $pp- > 3$ jets, $q\bar{q}ggg$ channel.
- With standard operators, minimal basis hard to find, hard to match to:



$$\mathcal{O}^{abc\bar{\alpha}\beta} = \mathcal{B}^{\mu a}_{n_1\perp}\mathcal{B}^{\nu b}_{n_2\perp}\mathcal{B}^{\sigma c}_{n_3\perp}\bar{\chi}^{\bar{\alpha}}_{n_4}\Gamma_{\mu\nu\sigma}\chi^{\beta}_{n_5}$$

- Helicity operators trivialize constructing a basis:

$$\mathcal{O}^{abc\bar{\alpha}\beta}_{+++(\pm)} = \frac{1}{3!}\mathcal{B}^a_{1+}\mathcal{B}^a_{2+}\mathcal{B}^a_{3+}J^{\bar{\alpha}\beta}_{45\pm}\ ,\ \mathcal{O}^{abc\bar{\alpha}\beta}_{++-(\pm)} = \frac{1}{2}\mathcal{B}^a_{1+}\mathcal{B}^a_{2+}\mathcal{B}^a_{3-}J^{\bar{\alpha}\beta}_{45\pm}$$

$$\mathcal{O}^{abc\bar{\alpha}\beta}_{--+(\pm)} = \frac{1}{2}\mathcal{B}^a_{1-}\mathcal{B}^a_{2-}\mathcal{B}^a_{3+}J^{\bar{\alpha}\beta}_{45\pm}\ ,\ \mathcal{O}^{abc\bar{\alpha}\beta}_{---(\pm)} = \frac{1}{3!}\mathcal{B}^a_{1-}\mathcal{B}^a_{2-}\mathcal{B}^a_{3-}J^{\bar{\alpha}\beta}_{45\pm}$$

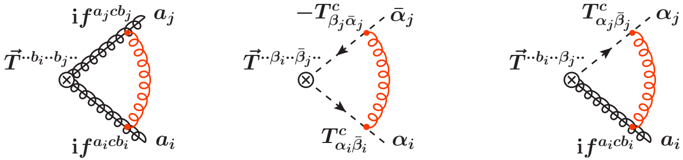
- Wilson coefficients, $C^{a_1\cdots\bar{\alpha}\beta}_{+\cdots\cdots-}$ found by matching.

Matching, RG and Symmetries

- Basis has many nice features:
  - Wilson coefficients in EFT are given by finite part of color stripped helicity amplitudes
    $\implies$ Trivial to interface with on-shell helicity amplitudes.

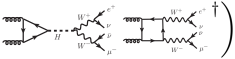
$$C^{a_1\cdots\bar{\alpha}\beta}_{+\cdots\cdot-} = -\mathrm{i}\mathcal{A}_{\mathrm{fin}+\cdots\cdot-}$$

  - Leading power SCET interactions preserve helicity of each sector
    $\implies$ RG evolution diagonal in helicity space (and no evanescent operators)

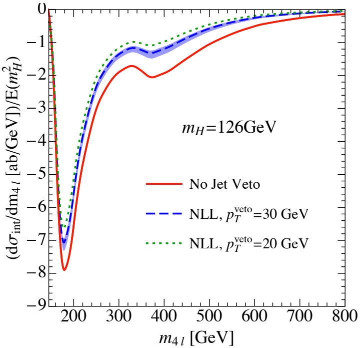


  - Many symmetries manifest: C/P, angular momentum conservation, crossing symmetry.

Off-shell Higgs Production with a Jet Veto

$\sigma_I \sim 2\mathrm{Re}\Big($  $\Big)^\dagger$

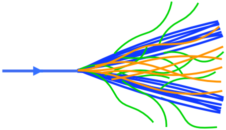
Signal-Background Interference

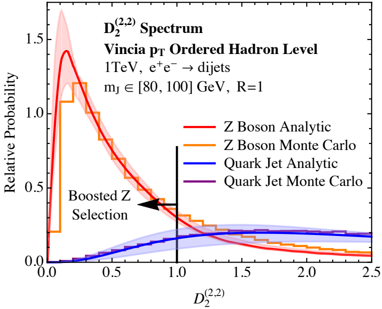


[Moult,Stewart]

Matching For Jet Substructure

$$\bar{\chi}^{\bar{\alpha}}_{t+} = \sum_{\lambda_g} \int d\omega_1\, d\omega_2\, C^{a\,\beta\bar{\gamma}}_{+\lambda_g} \left(X_{n_1} \mathcal{B}_{1\lambda_g} X^\dagger_{n_1}\right)^a \left(\bar{\chi}_{2+} X^\dagger_{n_2}\right)^{\bar{\beta}} V^{\gamma\bar{\alpha}}_{n_t}$$





[Pietrulewicz, Tackmann, Waalewijn], [Larkoski, Moult, Neill]

[Kolodrubetz, Moult, Stewart] 1601.02607
[Feige, Kolodrubetz, Moult, Stewart] Forthcoming
[Moult, Rothen, Stewart, Tackmann, Zhu] Forthcoming

Next-to-Leading Power

Introduction

- A large class of observables τ (p_T, threshold, event shapes, etc.) exhibit singularities in perturbation theory:

$$\frac{d\sigma}{d\tau} = \sum_{n=0}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^n \sum_{m=0}^{2n-1} c_{nm}^{(0)} \left(\frac{\log^m \tau}{\tau}\right)_+ + \sum_{n=1}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^n \sum_{m=0}^{2n-1} c_{nm}^{(2)} \log^m \tau + \sum_{n=1}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^n \sum_{m=0}^{2n-1} c_{nm}^{(4)} \tau \log^m \tau + \cdots$$

- Expansion about singular (soft/collinear) limits
  - Simplifies structure/ calculation
  - Often gives phenomenologically large contributions
  - Reveals universal structures in gauge theories

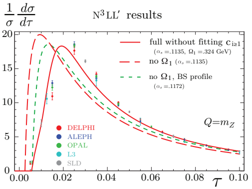
Leading Power

- Observables can be organized in an expansion in τ.

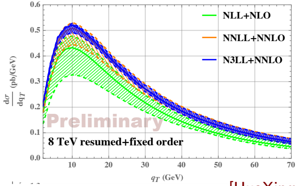
$$\frac{d\sigma}{d\tau} = \frac{d\sigma^{(0)}}{d\tau} + \frac{d\sigma^{(2)}}{d\tau} + \frac{d\sigma^{(4)}}{d\tau} + \cdots$$

- Leading power well understood for a wide variety of observables.

$$\frac{d\sigma^{(0)}}{d\tau} = \sum_{n=0}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^n \sum_{m=0}^{2n-1} c_{nm}^{(0)} \left(\frac{\log^m \tau}{\tau}\right)_+$$
$$= H^{(0)} J_\tau^{(0)} \otimes J_\tau^{(0)} \otimes S_\tau^{(0)} + \mathcal{O}\left(\frac{\Lambda_{\rm QCD}}{Q\tau}\right)$$



[Stewart, et al.]



[HuaXing Zhu's Talk]

Subleading Power

- Subleading powers much less well understood.
- Are there factorization theorems at each power?

$$\frac{\mathrm{d}\sigma^{(n)}}{\mathrm{d}\tau} = \sum_j H_j^{(n_{Hj})} \otimes J_j^{(n_{Jj})} \otimes S_j^{(n_{Sj})}$$

- What is the degree of universality?
- Start by looking at Next-to-Leading Power (NLP):

$$\frac{\mathrm{d}\sigma^{(2)}}{\mathrm{d}\tau} = \sum_{n=1}^{\infty} \left(\frac{\alpha_s}{\pi}\right)^n \sum_{m=0}^{2n-1} c_{nm}^{(2)} \log^m \tau$$

Soft Collinear Effective Theory

[Bauer, Fleming, Pirjol, Stewart]

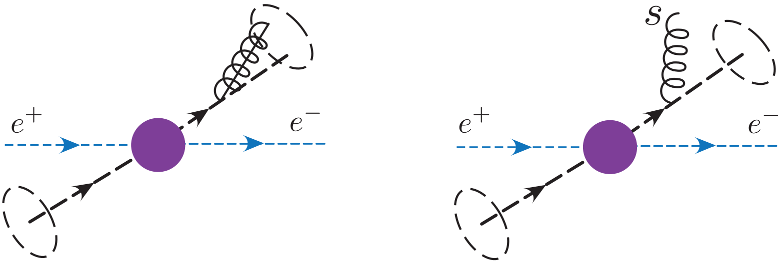
- SCET has proven to be a powerful framework for studying factorization.
- Allows a systematic expansion about soft $p_s \sim (\lambda^2, \lambda^2, \lambda^2)$ and collinear $p_c \sim (1, \lambda, \lambda^2)$ limits in a power counting parameter $\lambda \sim \sqrt{\tau}$.
- In Collider context has been applied primarily at leading power.
- Fields/Lagrangians have a definite power counting in λ.

Operator	$\mathcal{B}^{\mu}_{n_i\perp}$	χ_{n_i}	$\mathcal{P}^{\mu}_{\perp}$	q_{us}	D^{μ}_{us}
Power Counting	λ	λ	λ	λ^3	λ^2

$$\mathcal{L}_{\text{SCET}} = \mathcal{L}_{\text{hard}} + \mathcal{L}_{\text{dyn}} = \sum_{i\geq 0} \mathcal{L}^{(i)}_{\text{hard}} + \sum_{i\geq 0} \mathcal{L}^{(i)}$$

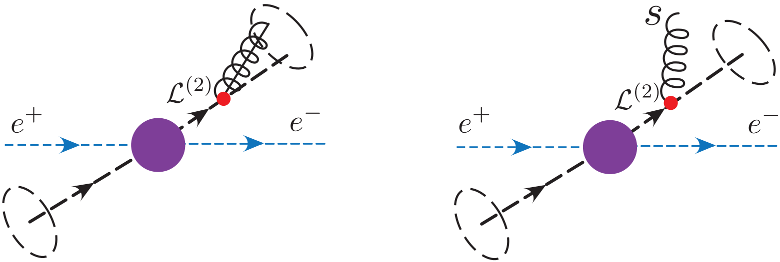
Leading Power SCET

- Leading Power SCET:
  - Leading Power Hard Scattering Operators: $\bar{\chi}_n \Gamma \chi_{\bar{n}}$
  - Leading power Feynman rules (eikonal/ collinear)
  - Measurement function/ kinematics expanded to leading power



Subleading Power SCET

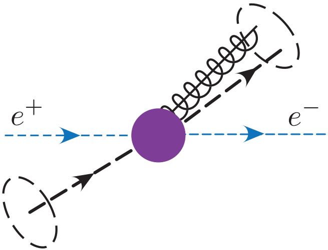
- Subleading Power in SCET:
  - Subleading Lagrangian Insertions

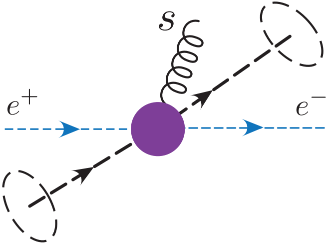


- Corrects dynamics of propagating soft/collinear particles.

Subleading Power SCET

- Subleading Power in SCET:
  - Subleading Lagrangian Insertions
  - Subleading Hard Scattering Operators

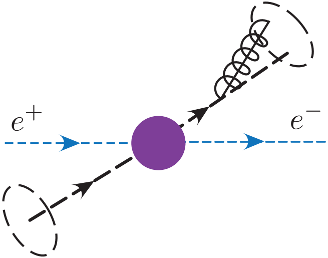


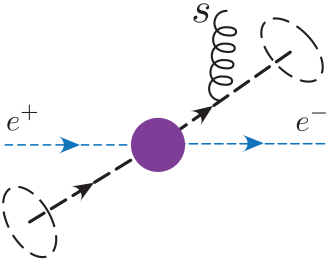


- Local Corrections to scattering vertex. Multiple fields per collinear sector.

Subleading Power SCET

- Subleading Power in SCET:
  - Subleading Lagrangian Insertions
  - Subleading Hard Scattering Operators
  - Subleading Measurement function



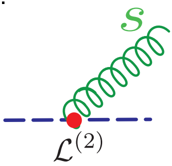


- Corrects definition of measurement: $\tau = \tau^{(0)} + \tau^{(1)} + \tau^{(2)}$

Subleading Lagrangian

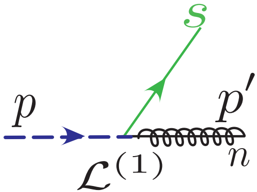
- Subleading Lagrangians are universal, and known.
- Correct the dynamics of soft and collinear particles. e.g.
  - Correction to eikonal emission:

$$\mathcal{L}^{(2)}_{\chi_n} = \bar{\chi}_n \left(i\not{D}_{us\perp} \frac{1}{\overline{\mathcal{P}}} i\not{D}_{us\perp} - i\not{\mathcal{D}}_{n\perp} \frac{i\bar{n}\cdot D_{us}}{(\overline{\mathcal{P}})^2} i\not{\mathcal{D}}_{n\perp} \right) \frac{\not{\bar{n}}}{2}\chi_n$$



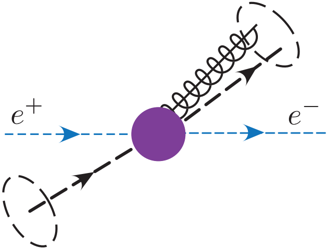
  - Emission of soft quarks:

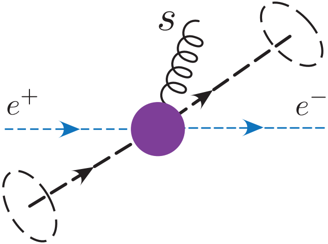
$$\mathcal{L}^{(1)}_{\chi_n q_{us}} = \bar{\chi}_n \frac{1}{\overline{\mathcal{P}}} g\not{\mathcal{B}}_{n\perp} q_{us} + \text{h.c.}$$



Subleading Hard Scattering Operators

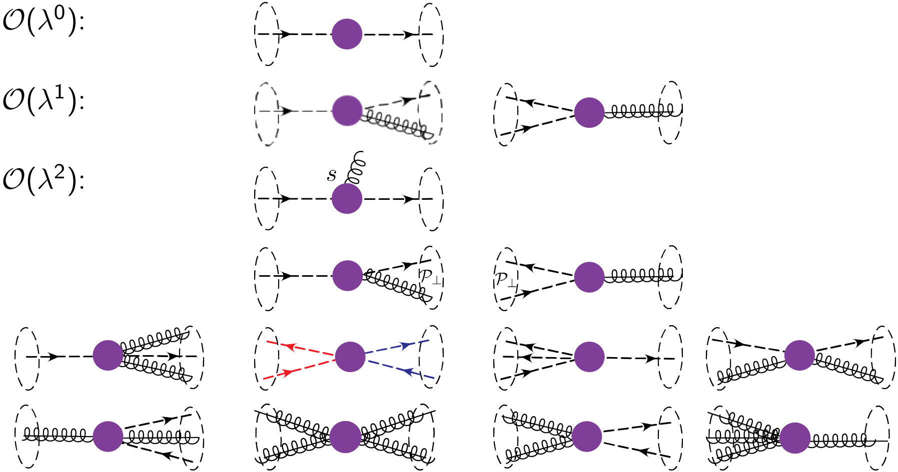
- Hard Scattering Operators describe process dependence.
- Obtained by matching calculation.
- Need a complete basis of operators consistent with symmetries.
- Consider $e^+e^- \to$ dijets:





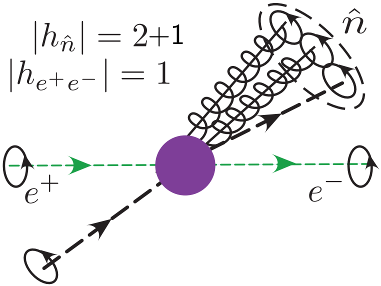
Subleading Hard Scattering Operators

- Want basis to all orders in α_s. Finite by power counting.
- Multiple collinear fields per sector.



Organize Using Helicities

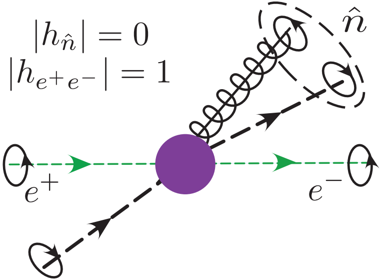
- Operators, and interferences easily organized in terms of helicities.
- In SCET, all fields expanded about a common axis.
- Interesting constraints at subleading powers.
- Multiple collinear fields per sector:



- Wilson coefficient vanishes by basic QM.

Organize Using Helicities

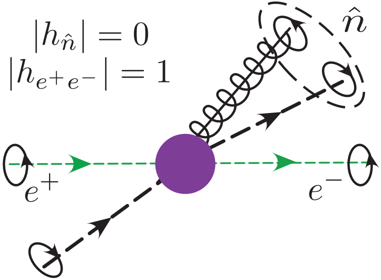
- Operators, and interferences easily organized in terms of helicities.
- In SCET, all fields expanded about a common axis.
- Interesting constraints at subleading powers.
- Multiple collinear fields per sector:



- Spinor helicity encodes spin projections (Wigner-D functions).

Organize Using Helicities

- Operators, and interferences easily organized in terms of helicities.
- In SCET, all fields expanded about a common axis.
- Interesting constraints at subleading powers.
- Multiple collinear fields per sector:

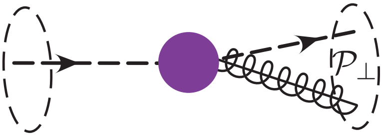


- Spinor helicity encodes spin projections (Wigner-D functions).
- Also strong constraints for $gg \to H$

Relevant Hard Scattering Operators

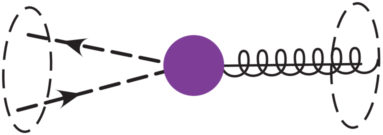
- For leading log (singularity), $\alpha_s^n \log^{2n-1}(\tau)$, two relevant hard scattering operators:

qg In Same Sector



$J_{n\bar{n}\lambda_1}\mathcal{P}_\perp^{\lambda_2}\mathcal{B}_{n\lambda_3}$

$q\bar{q}$ In Same Sector

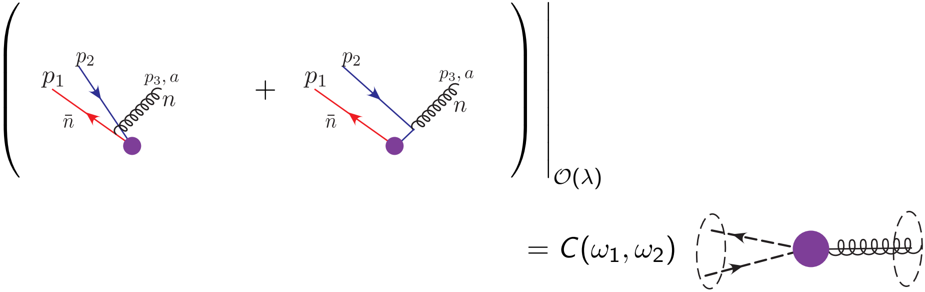


$J_{\bar{n}\lambda_1}\mathcal{B}_{n\lambda_2}$

- $q\bar{q}$ in same sector has no LP analog.

Matching

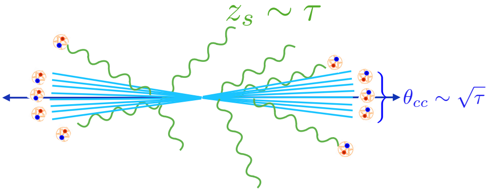
- Wilson coefficients, $C(\omega_1, \omega_2)$ can be obtained by matching.
- $C(\omega_1, \omega_2)$ depends on large momentum fraction, i.e. $z, 1-z$.



Fixed Order Thrust at NLP

- Begin by studying structure in fixed order pert theory.
- Most interested in the leading log: $\alpha_s \log(\tau)$, $\alpha_s^2 \log^3(\tau)$, $\cdots$
- Simple playground is Thrust in e^+e^-

$$\tau = 1 - \max_{\hat{t}} \frac{\sum_i |\hat{t} \cdot \vec{p}_i|}{\sum_i |\vec{p}_i|}$$

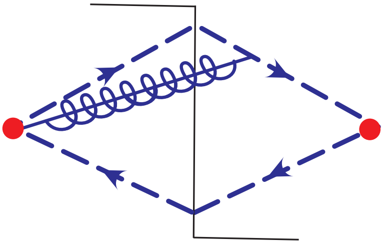


- Exact NLO result known.

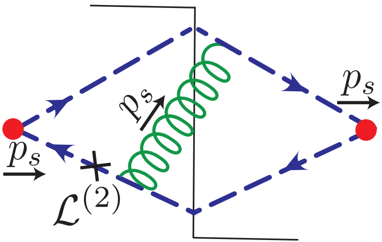
NLO Thrust at NLP

- Calculate one-loop graphs with NLP operators/ Lagrangians.

Collinear Gluon



Soft Gluon



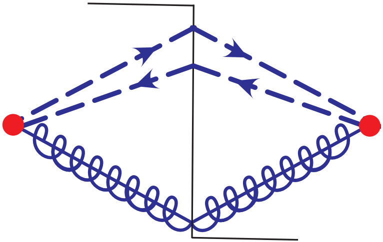
$$\frac{1}{\sigma_0}\frac{d\sigma_1^{(2)}}{d\tau} = 8C_F\left[\frac{1}{\epsilon} + \log\left(\frac{\mu^2}{Q^2\tau}\right)\right] - 8C_F\left[\frac{1}{\epsilon} + \log\left(\frac{\mu^2}{Q^2\tau^2}\right)\right]$$

$$= 8C_F\log(\tau)$$

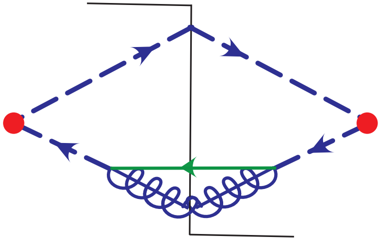
NLO Thrust at NLP

- Calculate one-loop graphs with NLP operators/ Lagrangians.

Collinear Quarks



Soft Quark

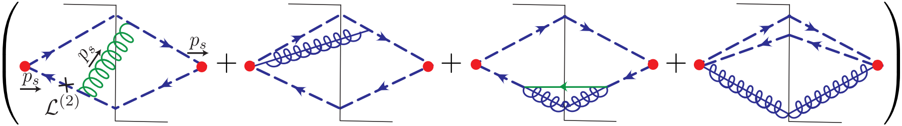


$$\frac{1}{\sigma_0}\frac{d\sigma_1^{(2)}}{d\tau} = -4C_F\left[\frac{1}{\epsilon}+\log\left(\frac{\mu^2}{Q^2\tau}\right)\right]+4C_F\left[\frac{1}{\epsilon}+\log\left(\frac{\mu^2}{Q^2\tau^2}\right)\right]$$

$$= -4C_F\log(\tau)$$

NLO Thrust at NLP

- Sum four graphs, reproduces the NLP piece of well known NLO thrust result:



Total

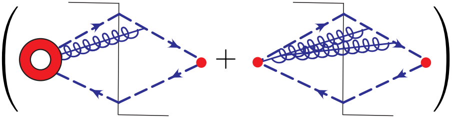
$$\frac{1}{\sigma_0}\frac{d\sigma_1^{(2)}}{d\tau} = 4C_F \log(\tau)$$

- Result gives directly (no expansions) the NLP contribution.

NNLO Thrust at NLP

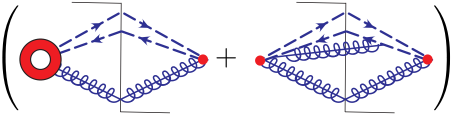
- Proceed to NNLO.
- Dress NLP emission with leading power emission (collinear, soft, hard).

Quark Channel



$$\frac{1}{\sigma_0}\frac{d\sigma_2^{(2)}}{d\tau} = c_1 C_F^2 \log^3(\tau)$$

Gluon Channel



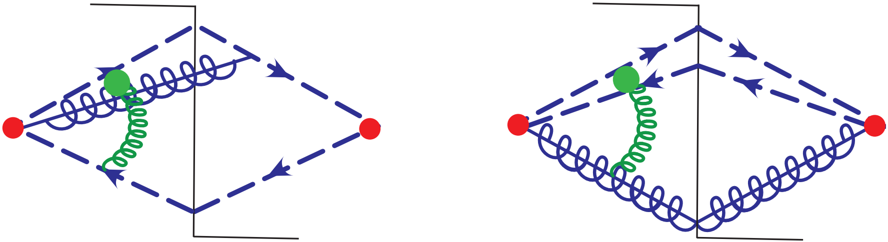
$$\frac{1}{\sigma_0}\frac{d\sigma_2^{(2)}}{d\tau} = c_2(c_3 C_F^2 + C_F C_A)\log^3(\tau)$$

Total

$$\boxed{\frac{1}{\sigma_0}\frac{d\sigma_2^{(2)}}{d\tau} = d_1(C_F C_A + d_2 C_F^2)\log^3(\tau)}$$

NNLO Thrust at NLP

- Interesting color structures for leading log (divergence).
- At LP, leading logarithmic divergence $\sim C_F^n$.
- More interesting structure at NLP.



Total

$$\frac{1}{\sigma_0}\frac{d\sigma_2^{(2)}}{d\tau} = d_1\left(C_F C_A + d_2 C_F^2\right)\log^3(\tau)$$

Applications

- Goal: Understand all orders structure of NLP logs. Derive RG, etc.
- Fixed order is first step in understanding this.
- Already at fixed order NLP logs have interesting applications.

Application to N-jettiness Subtractions

- NNLO calculations require cancellation of real/virtual poles.
- Use a physical resolution variable to slice phase space.
- Recently a general method allowing for jets in final state, based on N-jettiness (see also Xiaohui Liu's talk)

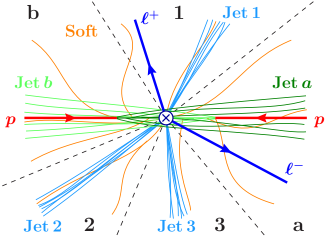
[Boughezal, Focke, Petriello, Liu]
[Gaunt, Stahlhofen,Tackmann, Walsh]

$$\sigma(X) = \int_0 d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N} = \int_0^{\mathcal{T}_N^{\text{cut}}} d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N} + \int_{\mathcal{T}_N^{\text{cut}}} d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N}$$

N-Jettiness

[Stewart, Tackmann, Waalewijn]

- N-jettiness: Inclusive event shape to identify $N-2$ jets.



$$\tau_N = \frac{2}{Q^2} \sum_k \min\left\{ q_a \cdot p_k, q_b \cdot p_k, q_1 \cdot p_k, \cdots, q_N \cdot p_k \right\}$$

- $\tau_N \ll 1 \implies N-2$ isolated jets.
- All orders factorization theorem:

$$\frac{d\sigma}{d\tau_N} = H B_a \otimes B_b \otimes S \otimes J_1 \otimes \cdots \otimes J_{N-1} + \mathcal{O}(\tau_N)$$

N-jettiness Subtractions

$$\sigma(X) = \int_0 d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N} = \int_0^{\mathcal{T}_N^{\text{cut}}} d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N} + \int_{\mathcal{T}_N^{\text{cut}}} d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N}$$

$$\int_0^{\mathcal{T}_N^{\text{cut}}} d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N}$$

Compute using factorization in soft/collinear limits:

$$\frac{d\sigma}{d\tau_N} = H B_a \otimes B_b \otimes S \otimes J_1 \otimes \cdots \otimes J_{N-1}$$

$$\int_{\mathcal{T}_N^{\text{cut}}} d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N}$$

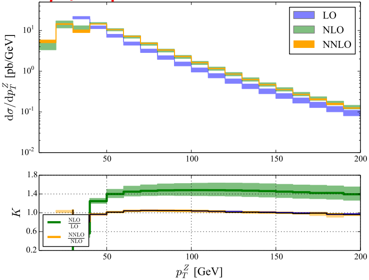
Additional jet resolved. Use NLO subtractions.

New NNLO Results with N-jettiness

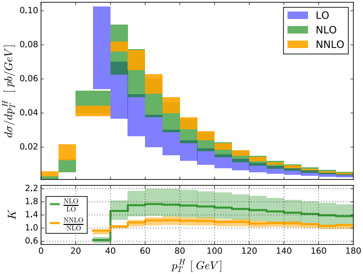
[Boughezal, Focke, Giele, Petriello, Liu]

- Impressive new results with jets in the final state: $W/Z/H$+jet at NNLO

p_T Spectrum in $Z+$ Jet



p_T Spectrum in $H+$ Jet



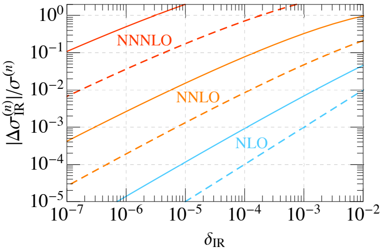
- Implemented in MCFM for color singlet production at NNLO.
- Conceptually simple, extendable to higher orders.

Power Corrections

- Current subtractions use leading power result in singular region.
- Power corrections are dropped $\Longrightarrow$ small values of $\mathcal{T}_N^{\rm cut}$ necessary.

$$\frac{d\sigma}{d\tau} = \sum_{n=0}^{n=\infty}\left(\frac{\alpha_s}{\pi}\right)^n \sum_{n=0}^{2n-1} c_{nm}^{(0)} \left(\frac{\log^m \tau}{\tau}\right)_+ + \sum_{n=0}^{n=\infty}\left(\frac{\alpha_s}{\pi}\right)^n \sum_{n=0}^{2n-1} c_{nm}^{(2)} \log^m \tau + \sum_{n=0}^{n=\infty}\left(\frac{\alpha_s}{\pi}\right)^n \sum_{n=0}^{2n-1} c_{nm}^{(2)} \tau \log^m \tau + \cdots$$

Estimated Missing Correction
Solid=LP
Dashed=remove LL NLP

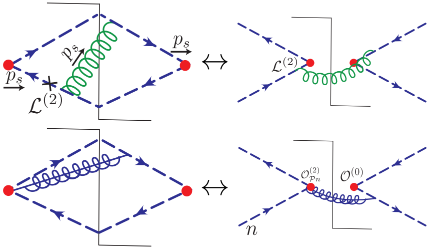


- Use of a physical resolution variable $\Longrightarrow$ power corrections analytically tractable. [Gaunt, Stahlhofen,Tackmann, Walsh], see also Xiaohui's Talk [Boughezal, Petriello, Liu, et al.]

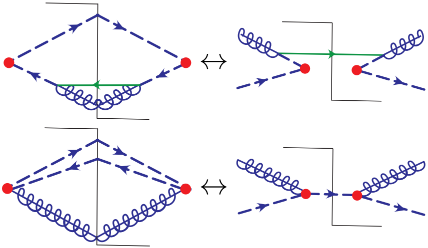
NLO Beam Thrust at NLP

- Start with simplest case: 0-jettiness (beam thrust)
- All hard work in setup done for thrust: operators, Lagrangian, identical.
- Simply cross results, and take into account pdfs, measurement...

$q\bar{q}$ channel

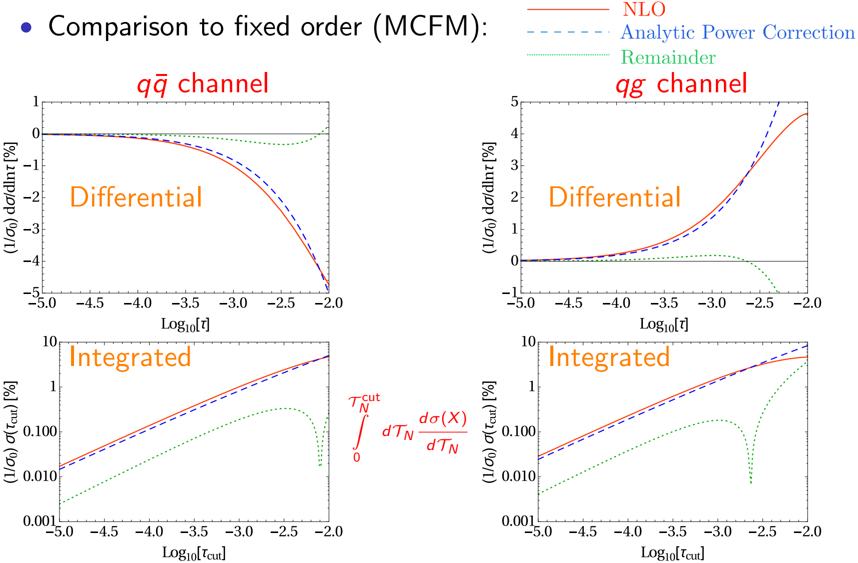


qg channel



NLO Beam Thrust at NLP

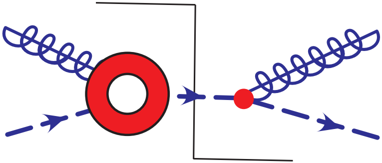
- Comparison to fixed order (MCFM):



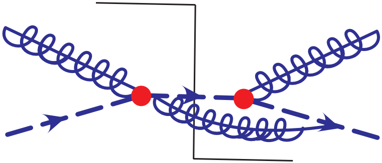
$$\int_0^{\mathcal{T}_N^{\rm cut}} d\mathcal{T}_N \frac{d\sigma(X)}{d\mathcal{T}_N}$$

NNLO 0-Jettiness at NLP

- NNLO result for both $q\bar{q}$ and qg also obtained by crossing, taking into account pdf, and measurement.
- Find good agreement with NNLO fixed order (MCFM):



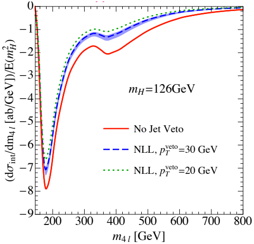
qg channel



Sequestered

Conclusions

- Helicity can be used to organize operators in SCET at both LP and NLP.



- LP: Facilitates matching to fixed order calculations.
  $\Longrightarrow$ Applications to processes with more legs.

- NLP: Simplifies organization of operator bases.
  $\Longrightarrow$ Fixed order power corrections for
  NNLO subtractions.

Thanks!