Automation of Beam and Jet functions at NNLO

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Outline

- Motivation
- Jet functions
  - General set-up
  - Results
- Beam functions
  - General set-up
  - Results
- Outlook

Higher order QCD corrections

- Explosion of higher order QCD corrections in the last two decades.

- NNLO predictions are available for many processes in the SM and even beyond. (See talks from Monday)
  - Public codes are available like **MCFM, MATRIX** etc.

- Complete N^3LO corrections are also available for a few processes (inclusive Higgs, DY) and for a few observables (eg. Rapidity, P_T).
  [Mistlberger, Dulat, Duhr '20
  Cieri, Chen, Gehrmann, Glover, Huss '18,'21]

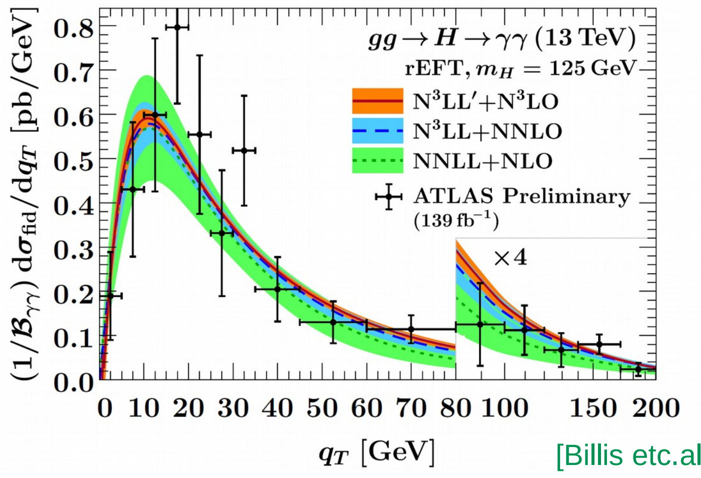
- Efforts towards N^4LO level are also ongoing. [Das, Moch, Vogt '20, Agarwal,Manteuffel, Panzer, Schabinger '21]

Resummation

- Fixed order caculations are often plagued by large logarithms

  Resummation is needed for these large logarithms to all orders in perturbation theory!

- Resummation has been proved useful in correctly describing observables in lepton and hadron colliders.



[Billis etc.all '21]

- **SCET** has emerged as an important tool in studying the IR sector of QCD and resum these large logarithms in a systematic framework.
- The backbone relies on the underlying factorization theorems.

Factorization

- Factorization in **SCET** for different observables

$$d\sigma \simeq H(\mu_f) \prod_i B_i(\mu_f) \otimes \prod_j J_j(\mu_f) \otimes S(\mu_f)$$

Hard interaction

ISR

FSR

Soft radiation

- Each functions can be calculated perturbatively
- Resummation is performed by calculating them at their characteristic scales and evolving them to a common scale.

RG Evolution

- An example- RGE of the Hard function:

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

[Becher & Neubert ‘10]

- Hard anomalous dimension has the structure

$$\gamma_H(Q,\mu) = \Gamma_{cusp}(\alpha_S)\ln\frac{Q}{\mu} + \gamma_{(nc),H}(\alpha_S)$$

$$H(Q,\mu) = H(Q,\mu_H)U(\mu_H,\mu)$$

Boundary term

Evolution kernel

$$U(\mu_H,\mu) = \exp\left[\int_{\mu_H}^{\mu} d\ln\mu' \gamma_H(Q,\mu')\right]$$

- Boundary term is free from logarithms $\mu_H \simeq Q$
- Evolution kernel resums logarithms $\ln^n(Q/\mu)$ to all orders

Ingredients for Resummation

- We need to have all the anomalous dimensions & matching coefficients

$$\underbrace{\Gamma_{cusp},\quad \gamma_{(nc),H},\quad c_H,}_{\text{Observable-independent}}\quad \underbrace{\gamma_{(nc),B},\quad c_B,\quad \gamma_{(nc),J},\quad c_J,\quad \gamma_{(nc),S},\quad c_S}_{\text{Observable-dependent}}$$

- Hard anomalous dimensions are known to three-loops [Becher & Neubert '09, Almelid, Duhr, Gardi '15]
- Beam, Jet and Soft quantities are computed on a case-by-case basis
- Need two-loop matching coefficients to achieve NNLL' accuracy

	Γ_{cusp}, β	$\gamma_{(nc)H,B,J,S}$	Boundary term $(c_{H,B,J,S})$
NLL	2-loop	1-loop	1
NLL$'$	2-loop	1-loop	α_S
NNLL	3-loop	2-loop	α_S
NNLL$'$	3-loop	2-loop	α_S^2

Soft Function

- An automated framework exists to calculate Soft functions up to two loop

- SoftSERVE Version-1.0.1 [Bell, Rahn, Talbert '18, '20]
  - NNLO di-jet soft functions
  - A large class of SCET-I and SCET-II observables has been calculated

    Thrust, C-parameter, Angularities, Hemisphere masses ...

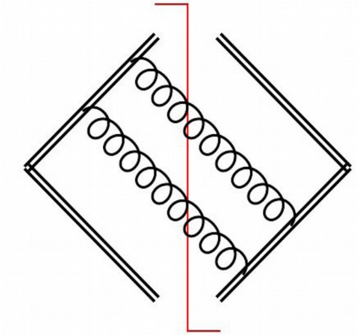
    Threshold resummation, P_T resummation, Jet-veto resummation ...
  - Available at https://softserve.hepforge.org

- In progress [Bell, Dehnadi, Mohrmann, Rahn]
  - Arbitrary light-like directions (for SCET-I observables)

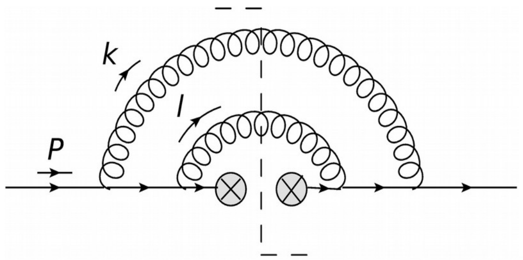
    N-jettiness, N-angularities, invariant mass of boosted tops ...

Automation: Beam and Jet functions

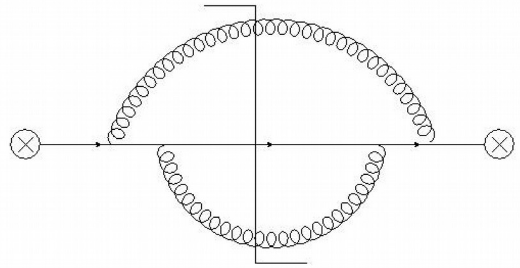
- Set up a general framework to automatically calculate Beam and Jet functions for a general class of observables.



- Soft functions → 2-particle final state



- Beam functions → 2-particle final state
  - Non-trivial matching onto pdfs



- Jet functions → 3-particle final state
  - Complicated divergence structures

Jet Function

- Definition

$$J_q(\tau) \sim \sum_{i\in X} \delta\Big(Q - \sum_i \bar{n}\cdot k_i\Big)\delta^{(d-2)}\Big(\sum_i k_\perp^i\Big) \langle 0|\chi|X\rangle \langle X|\bar{\chi}|0\rangle \mathcal{M}(\tau, \{k_i\})$$

- Collinear field operators

$$\chi = W^\dagger \frac{\not{\bar{n}}\not{n}}{4}\psi$$

- Automation exists at NLO

[K. Brune's master thesis '18,
Basdew-Sharma, Herzog, Velzen, Waalewijn '20]

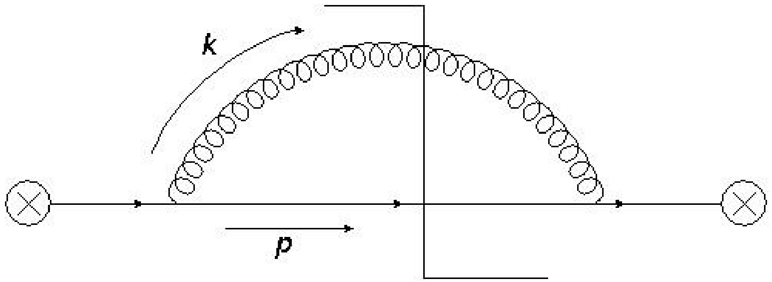
Jet Function : NLO

- Matrix element: LO splitting kernel

$$P_{qg}^{(0)}(z) = C_F \, \frac{1}{z} \left[(1-\epsilon) z^2 + 2\bar{z} \right]$$

[Altarelli & Parisi '77]

- Phase space:



$$z = \frac{k_-}{Q}, \quad k_T = \sqrt{k_+ k_-}, \quad t_k = \frac{1-\cos(\theta_k)}{2}$$

$$\left\{ k_-, k_T, \theta_k \right\} \to \left\{ z, k_T, t_k \right\}$$

Jet Function : NLO

- Generic Measurement function for one emission (in Laplace space)

$$\mathcal{M}_1(\tau, k) = \exp\left[-\tau k_T \left(\frac{k_T}{zQ}\right)^n f(z, t_k)\right]$$

Non-zero in the singular limit of ME

- Examples:
  - Thrust: $n = 1,\ f(z, t_k) = \frac{1}{1-z}$
  - Angularity: $n = 1 - A,\ f(z, t_k) = 1 + \left(\frac{z}{1-z}\right)^{1-A}$

- Master Formula

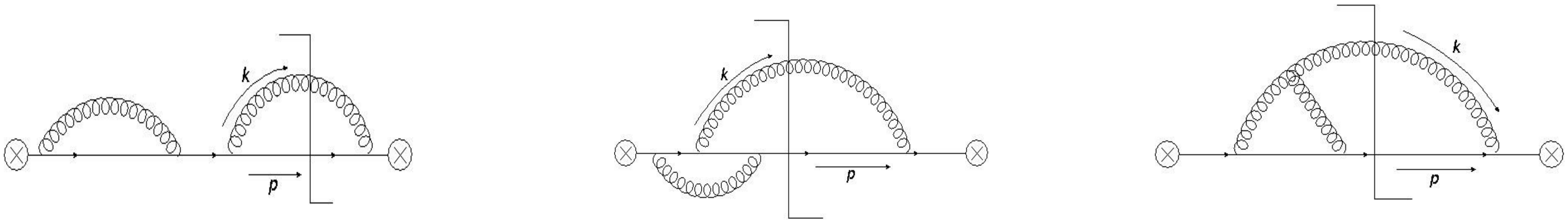
$$J_q^{(1)}(\tau) \sim \Gamma\left(\frac{-2\epsilon}{1+n}\right) \int_0^1 dz\, z^{-1-\frac{2n\epsilon}{1+n}} \left[z P_{qg}^{(0)}\right] \int_0^1 dt_k (4 t_k \bar{t}_k)^{-\frac{1}{2}-\epsilon} f(z, t_k)^{\frac{2\epsilon}{1+n}}$$

All singularities are factorised !

Jet Function : NNLO(Real-Virtual)

- Matrix Element:

  related to NLO collinear splitting kernel - $P_{qg}^{(1)}(z)$ [Furmanski, Petronzio '80]



- Phase Space

  2-particle phase space

$$\left\{k_-, k_T, \theta_k\right\} \to \left\{z, k_T, t_k\right\}$$

- Measurement

$$\mathcal{M}_1(\tau, k) = \exp\left[-\tau k_T \left(\frac{k_T}{zQ}\right)^n f(z, t_k)\right]$$

Similar to NLO !

Jet Function : NNLO(Real-Virtual)

- Master Formula

$$J_q^{(2),RV}(\tau) \sim V(\epsilon)\,\Gamma\left(\frac{-4\epsilon}{1+n}\right) \int_0^1 dz \int_0^1 dt_k \; z^{-1-\frac{4n\epsilon}{1+n}} \mathcal{W}(z,t_k)\; f(z,t_k)^{\frac{4\epsilon}{1+n}}$$

ME w/o divergent term
PSP, Jacobian

- Divergences:
  - Virtual corrections - $V(\epsilon) \sim \frac{1}{\epsilon^2} + \mathcal{O}(\epsilon^{-1})$
  - Phase space singularities - $\Gamma\left(\frac{-4\epsilon}{1+n}\right) \quad z^{-1-\frac{4n\epsilon}{1+n}}$

All phase space singularities are factorised !

Jet Function : NNLO (Real-Real)

- Matrix element: LO triple collinear splitting kernel

[Catani, Grazzini '98]

$$P^{(0),C_F T_F}_{q'\,\bar{q}'\,q}\,, \;\; P^{(0),id}_{q\bar{q}q}\,, \;\; P^{(0),C_F^2}_{ggq}\,, \;\; P^{(0),C_A C_F}_{ggq}$$

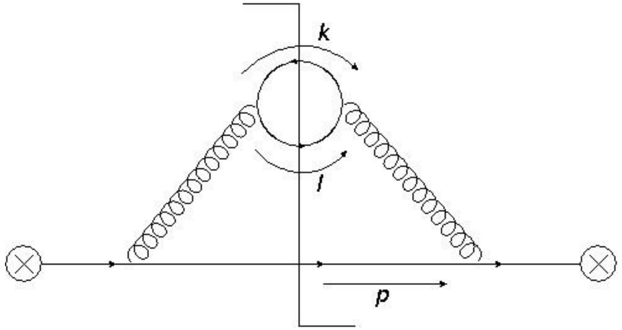
- Complicated divergence structures

$$\frac{1}{s_{12}^2 s_{123}^2 (z_1+z_2)^2}, \;\; \frac{1}{s_{13}s_{23}z_1 z_2}, \;\; \frac{1}{s_{13}s_{123}z_1 z_2}, \;\; \frac{1}{s_{13}s_{123}z_2\bar{z}_3}, \cdots$$

Jet Function: NNLO (R-R): $C_F\ T_F\ n_f$

- Divergence structure

$$\frac{1}{s_{12}^2 s_{123}^2 (z_1 + z_2)^2}$$



- Phase Space:

3-particle phase space

$$a = \frac{k_- l_T}{l_- k_T}, \quad b = \frac{k_T}{l_T},$$

$$z_{12} = \frac{k_- + l_-}{Q}, \quad q_T = \sqrt{(k_- + l_-)(k_+ + l_+)}$$

$$\Big\{k_-, k_T, l_-, l_T, \theta_k, \theta_l, \theta_{kl}\Big\} \to \Big\{a, b, z_{12}, q_T, t_k, t_l, t_{kl}\Big\}$$

Remap **{a,b}** to unit hypercube → 4 sectors

NNLO : Measurement

- Generic Measurement function for two emissions (in Laplace space):

$$\mathcal{M}_2(\tau, \{k, l\}) = \exp\left[-\tau q_T \left(\frac{q_T}{z_{12} Q}\right)^n \mathcal{F}(z_{12}, a, b, t_{kl}, t_k, t_l) \right]$$

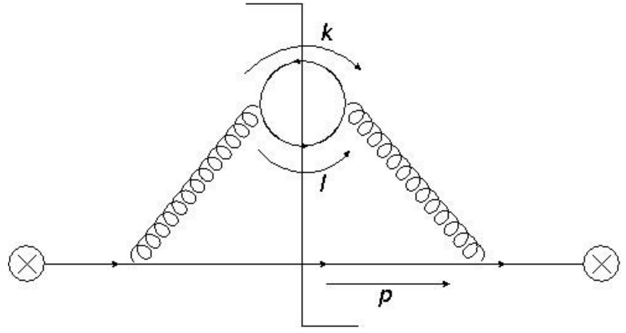
- Due to complicated structures of the matrix element, the exact form could be different → depends on parametrisation & ME divergences

$$\mathcal{F}(z_{12}, a, b, t_{kl}, t_k, t_l)$$ → ensure it does NOT vanish in the singular limits of ME !

Jet Function: NNLO(R-R): $C_F\ T_F\ n_f$

- Additional non-linear transformation

$$\{a, t_{kl}\} \to \{u, v\}$$



Removes overlapping in collinear divergence

between k and l $\quad (\bar{a}^2 + 4at_{kl})^{-1} \to u^{-1}$

- Master formula

$$J_q^{(2),C_F T_F} \sim \Gamma\left(\frac{-4\epsilon}{1+n}\right) \int_0^1 dz_{12} \int_0^1 du\ z_{12}^{-1-\frac{4n\epsilon}{1+n}}\ u^{-1-2\epsilon} \int_0^1 dv \int_0^1 db \int_0^1 dt_l \int_0^1 dt_5\ \mathcal{W}(z_{12}, u, v, b, t_l, t_5) \times \mathcal{F}(z_{12}, u, v, b, t_l, t_5)^{\frac{4\epsilon}{1+n}}$$

Triple collinear

$\bar{n}$ collinear

Double collinear

Finite function

All singularities factorise

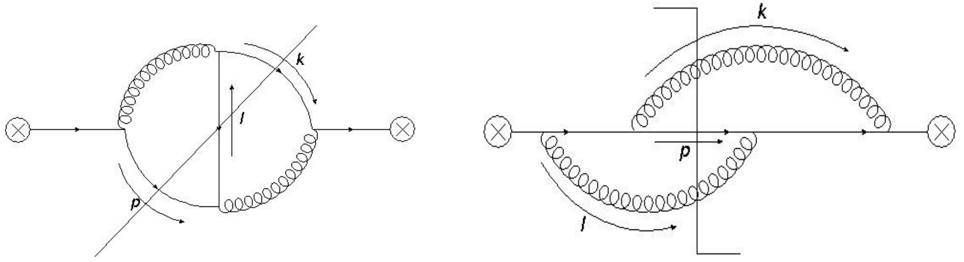
Exploit k-l symmetry

4 sectors → 2 sectors

Jet Function : NNLO (R-R): C_F^2

- Divergence structures

$$\frac{1}{s_{12}s_{13}\bar{z}_2\bar{z}_3},\quad \frac{1}{s_{12}s_{123}\bar{z}_2\bar{z}_3},\cdots\quad \frac{z_3}{s_{13}s_{23}z_1z_2},\quad \frac{1}{s_{13}s_{123}z_1z_2},\cdots$$

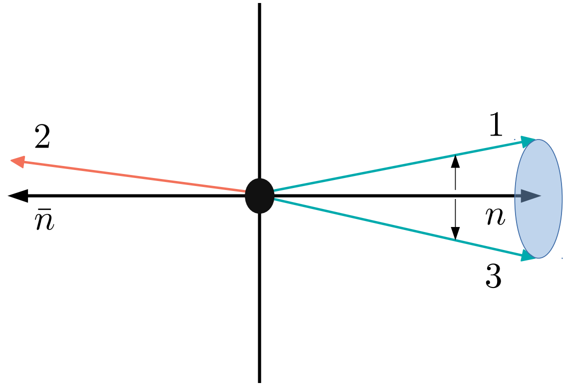


- Complications due to many overlapping divergences in ME

- Additional complications from measurement

$$\mathcal{F} \sim (a+b)(1+ab)\bar{z} + az\left(\bar{b}^2 + 4b\bar{t}_{kp}\right)$$

Must stay non-zero in the physical limits
$$\left\{\begin{array}{l} a\to 0, b\to 0 \\ a\to 0, \bar{z}\to 0 \\ \bar{b}\to 0, \bar{z}\to 0, \bar{t}_{kp}\to 0 \end{array}\right\}$$



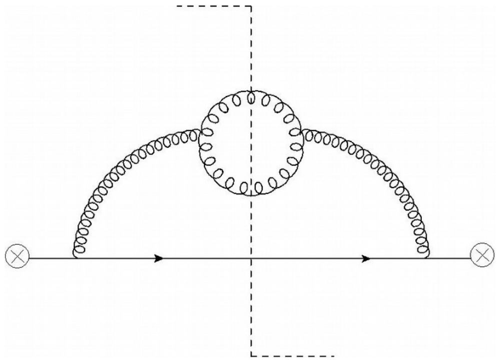
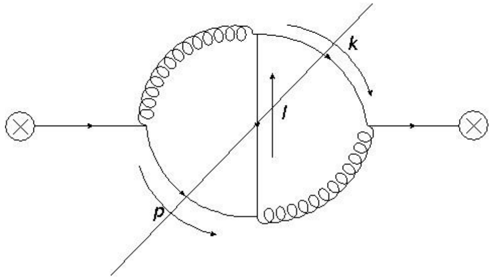
- Strategy:
  - Smart **selector functions**
  - Use of complicated **non-linear transformations**
  - **Sector decomposition**

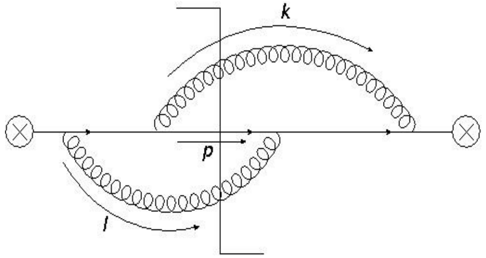
~40 sectors

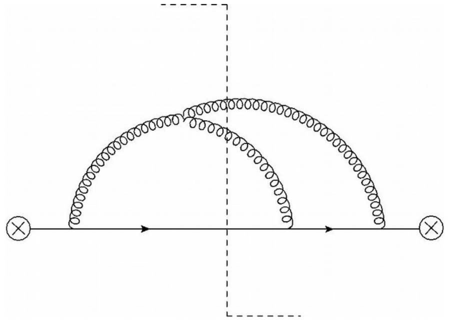
Jet Function : NNLO (R-R): C_A C_F

- Divergence structures:

$$\frac{1}{s_{12}s_{13}z_2\bar{z}_3}, \quad \frac{1}{s_{12}s_{123}z_2\bar{z}_3}, \quad \frac{1}{s_{13}s_{123}z_2\bar{z}_3}$$





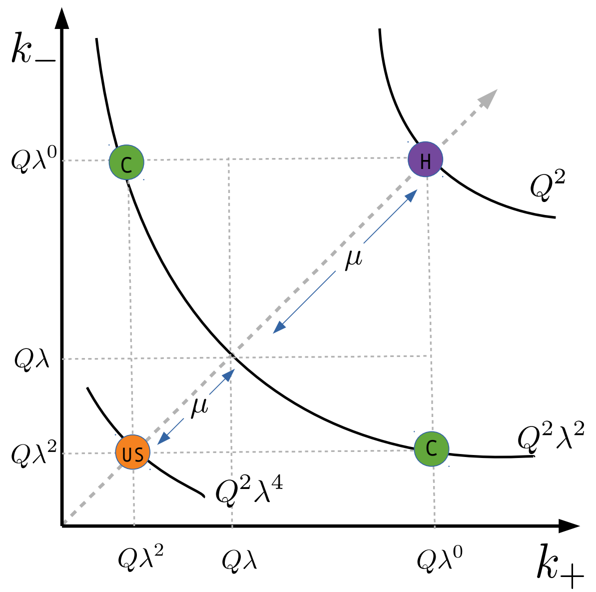
- Calculation follows similar to C_F^2 structures.

~ new 35 sectors

Jet Function : Renormalization

- RGE for **SCET-I** type observables:

$$\frac{d\ln J(\tau,\mu)}{d\ln\mu} = \frac{2(1+n)}{n}\Gamma_{cusp}L + 2\gamma_{(nc),J}$$



- Solution:

$$J(\tau,\mu) = 1 + \left(\frac{\alpha_S}{4\pi}\right)\left[\sum_{i=1}^{2} a_i(n)L^i + C_1\right] + \left(\frac{\alpha_S}{4\pi}\right)^2\left[\sum_{i=1}^{4} b_i(n)L^i + C_2\right]$$

$$L = \ln(\bar{\tau}\mu)$$

- Extract anomalous dimensions and matching coefficients

$$\{\Gamma_0, \Gamma_1, \gamma_0, \gamma_1, C_1, C_2\}$$

Results: Thrust

Implementation → **pySecDec** [G. Heinrich et.al.]

- Thrust

Intermediate checks with **MB.m** [M. Czakon '05]

$$\omega_0 = \sum_i k_{i+}$$

[1. Becher & Neubert '06]

γ_1	Analytical[1]	This work
$C_F T_F n_f$	-13.35	$-13.35(1)$
C_F^2	10.61	$10.48(18)$
$C_A C_F$	-3.26	$-3.22(11)$

C_2	Analytical[1]	This work
$C_F T_F n_f$	-10.79	$-10.79(3)$
C_F^2	4.66	$4.53(33)$
$C_A C_F$	-2.16	$-2.03(32)$

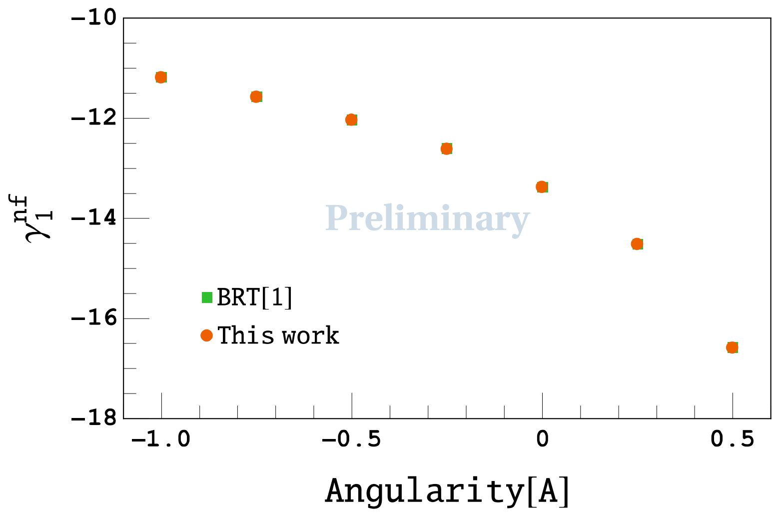
Results: Angularity

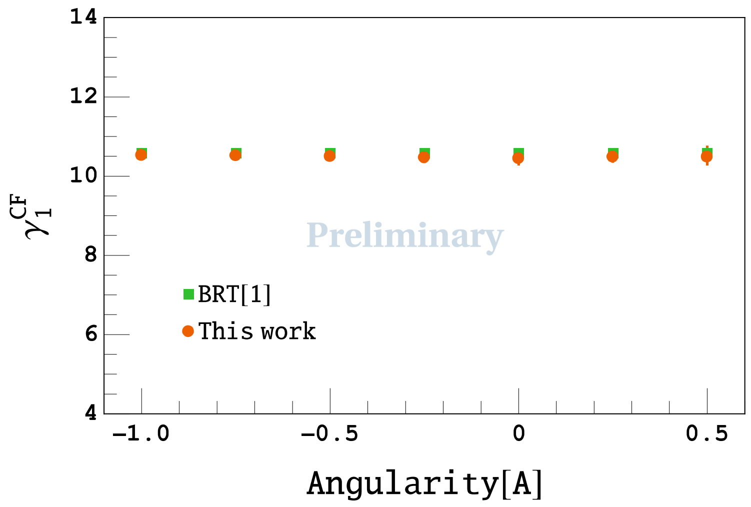
- Angularity

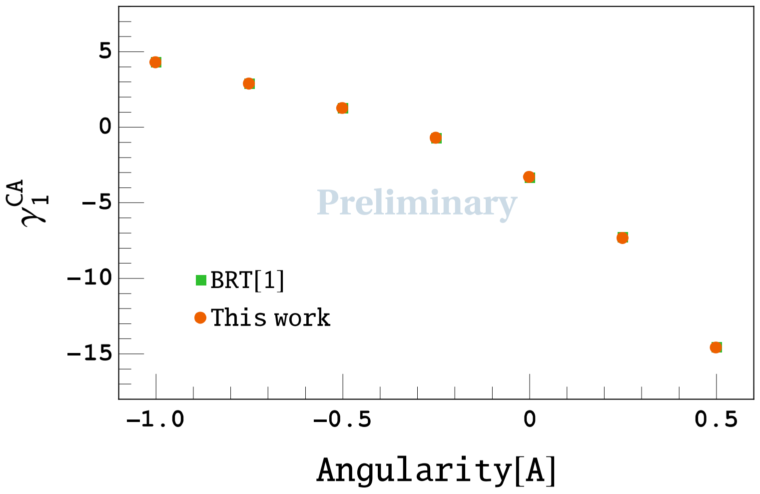
$$\omega_A = \sum_i k_{i+}^{1-A/2} k_{i-}^{A/2}$$

- Additional complications depending on Angularity values
- Check: Anomalous dimensions @ 2 loops (against **SoftSERVE**)

[1. Bell, Rahn, Talbert '19]

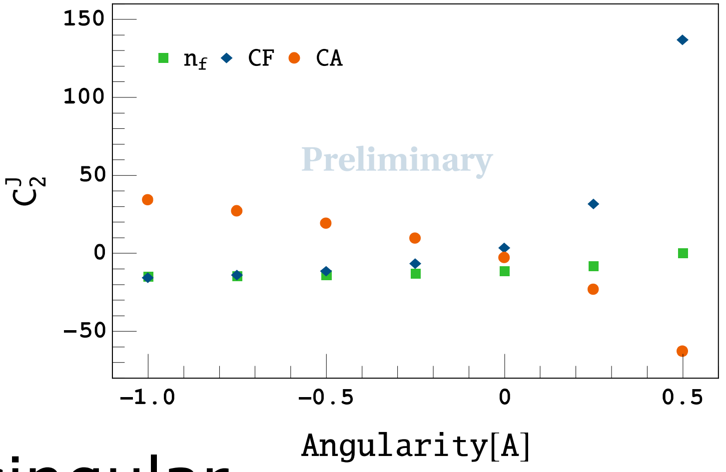






Results: Angularity

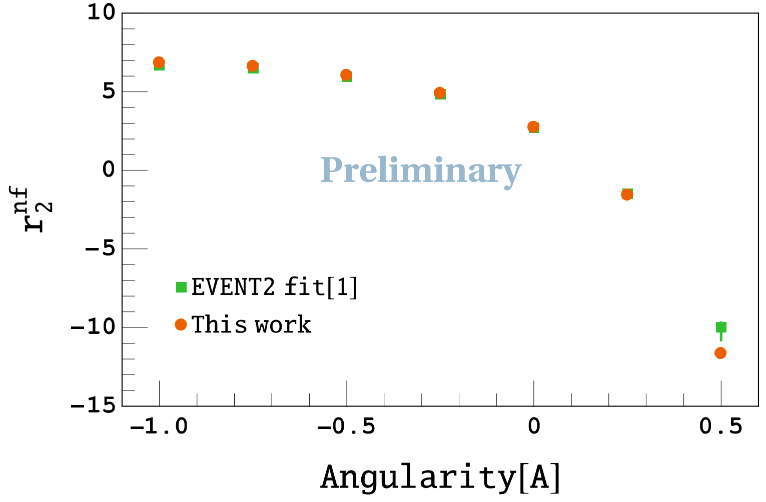
- Matching coefficients at two loops

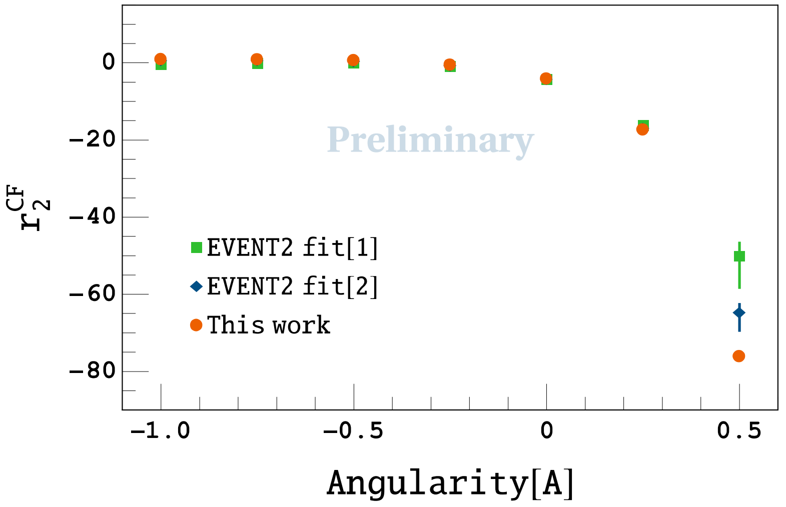


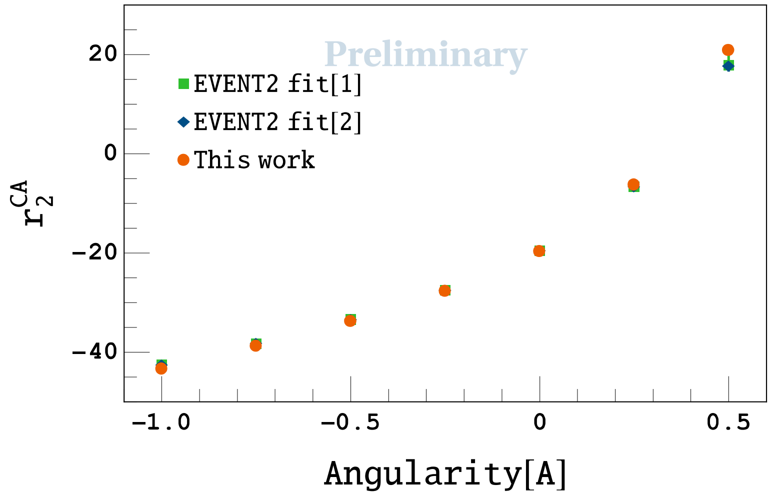
- Comparison with non-singular remainder coefficients r_2 from **EVENT2** fit

[Catani & Seymour '96,97]

[1. Bell, Hornig, Lee, Talbert '18
2. Bell, Hornig, Lee, Talbert (unpublished)]







Beam Function

Proton matrix element of renormalized operator composed of partonic fields (with additional dependence on measurement)

$$\mathcal{B}_{qq}(\tau, x, \mu) = \sum_{i \in X_c} \delta\Big((\bar{n}\cdot P)(1-x) - \bar{n}\cdot k_{X_c}\Big) \langle P|\bar{\chi}|X_c\rangle \frac{\bar{\not{n}}}{2} \langle X_c|\chi|P\rangle \, \mathcal{M}(\tau, \{k_i\})$$

Contains non-perturbative contributions

- In the limit $\tau >> \Lambda_{QCD}$

$$\mathcal{B}_{qq}(\tau, x, \mu) = \sum_i \mathcal{I}_{qi}(\tau, x, \mu) \otimes f_{iq}(x, \mu)$$

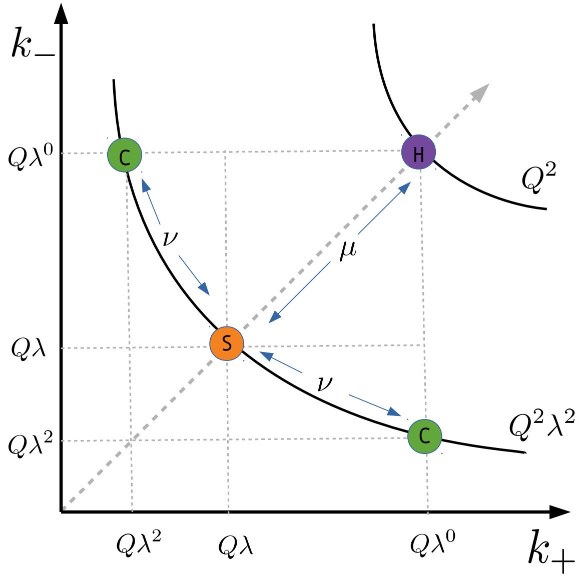
IR-divergent

IR-finite
Matching coefficients

IR-divergent.
Partonic PDF

Rapidity Divergences

- **SCET-II observables** :
  - Suffers from additional rapidity divergences
  - Rapidity logs can be resummed to all orders
  - Follow the collinear-anomaly approach. [Becher & Neubert, '10]
  - Introduce analytic regulators at the phase space level



[Becher & Bell, '11]

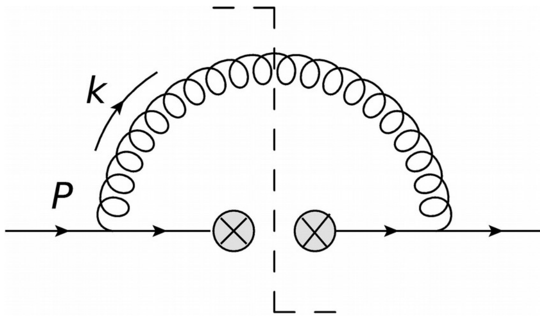
Single emission PSP

$$\left(\frac{\nu}{k_-}\right)^\alpha$$

Double emission PSP

$$\left(\frac{\nu}{k_-}\right)^\alpha \left(\frac{\nu}{l_-}\right)^\alpha$$

Beam Function : NLO



- Automated formalism is available at NLO [K. Brune's master thesis '18]
- Matrix Element: related to collinear splitting kernel $P_{qg}^{(0)}(x)$
- Phase Space: 1-particle phase space

$$\bar{x} = \frac{k_-}{P_-},\ k_T = \sqrt{k_+ k_-},\ t_k = \frac{1-\cos(\theta_k)}{2} \quad \Longrightarrow \quad \left\{k_-, k_T, \theta_k\right\} \to \left\{x, k_T, t_k\right\}$$

- Generic Measurement function for single emission

$$\mathcal{M}_1(\tau, k_i) = \exp\left[-\tau k_T \left(\frac{k_T}{(1-x)P_-}\right)^n f(t_k)\right]$$

Non-zero in the singular limit of ME

- P_T – resummation: $n = 0,\ f(t_k) = -2i\ (1-2t_k)$
- P_T - Veto: $n = 0,\ f(t_k) = 1$

- Master Formula

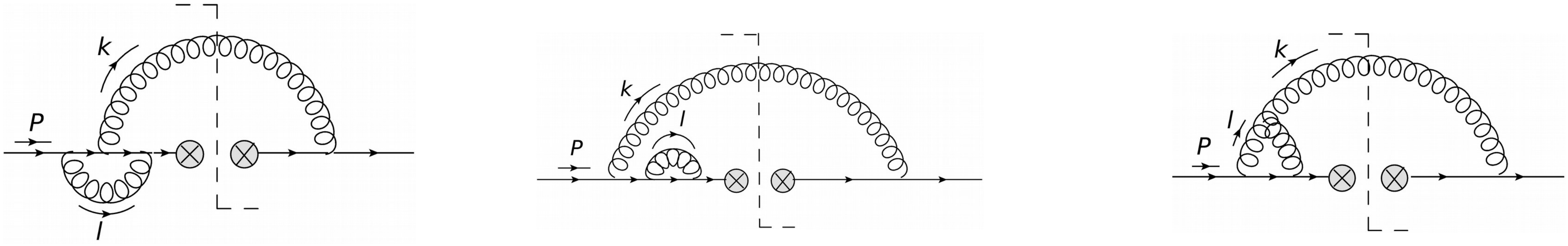
$$\mathcal{B}_{qq}^{(1)}(\tau, x) \sim \Gamma\left(\frac{-2\epsilon}{1+n}\right) \bar{x}^{-1-\frac{2n\epsilon}{1+n}-\alpha} \left[\bar{x} P_{qg}^{(0)}(x)\right] \int_0^1 dt_k (4t_k \bar{t}_k)^{-\frac{1}{2}-\epsilon} f(t_k)^{\frac{2\epsilon}{1+n}}$$

All singularities are factorised !

Beam Function : Real-Virtual

- Matrix Element:

  related to NLO collinear splitting kernel - $P_{qg}^{(1)}(x)$



- Phase Space & measurement function follow NLO type
- Master formula

$$\mathcal{B}_{qq}^{(2),RV}(\tau,x,\mu) \sim V(\epsilon)\,\Gamma\left(\frac{-4\epsilon}{1+n}\right)\bar{x}^{-1-\frac{4n\epsilon}{1+n}-\alpha}\mathcal{W}(x)\int_0^1 dt_k(4t_k\bar{t}_k)^{-\frac{1}{2}-\epsilon}\; f(t_k)^{\frac{4\epsilon}{1+n}}$$

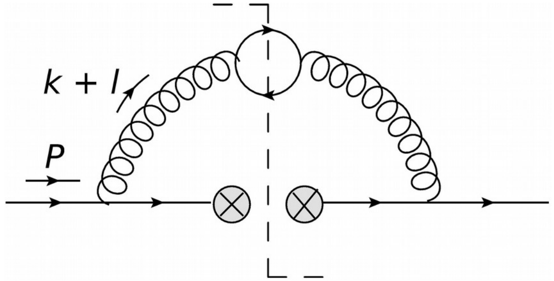
$\sim \epsilon^{-2} + \mathcal{O}(\epsilon^{-1})$

All Phase space singularities are factorised !

Beam Function: NNLO (R-R) $C_F\, T_F\, n_f$

- Matrix Element:

  related to the collinear splitting kernel - $P_{\bar{q}'q'q}(x)$



- Phase Space:

  2-particle phase space

$$a = \frac{k_- l_T}{l_- k_T}, \quad b = \frac{k_T}{l_T}, \qquad x_{12} = \frac{k_- + l_-}{P_-}, \quad q_T = \sqrt{(k_- + l_-)(k_+ + l_+)}$$

$$\left\{k_-, k_T, l_-, l_T, \theta_k, \theta_l, \theta_{kl}\right\} \to \left\{a, b, x_{12}, q_T, t_k, t_l, t_{kl}\right\}$$

Remap **{a,b}** to unit hypercube

- Avoid distribution valued functions → work in **Laplace-Mellin space**.

- Master formula

$$\mathcal{B}^{(2),nf}_{qq}(\tau, N_1) \sim \mathcal{C}(\epsilon)\left(\frac{\nu}{q_-}\right)^{2\alpha} \int_0^1 dx_{12}\; db\; du\; dv\; dt_l\; dt_5\;\; x_{12}^{-1-2\alpha}\;\; u^{-1-2\epsilon}\;\; \bar{x}_{12}^{N_1-1+2\alpha} \times$$
$$\mathcal{G}(x_{12}, b, u, v, t_l, t_5)\mathcal{F}(x_{12}, b, u, v, t_l, t_5)^{4\epsilon}$$

All singularities factorise !

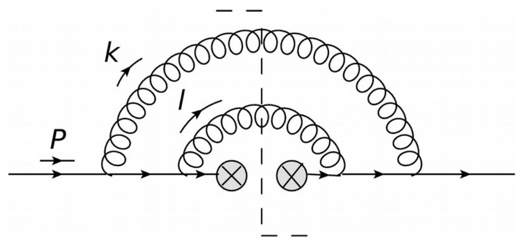
Finite function

Non-zero in the singular limit of ME

Beam Function: NNLO (R-R) C_F^2

- Matrix Element:

  related to the collinear splitting kernel - $P_{ggq}^{CF^2}(x)$



- Phase Space:
  - Two different parametrizations

$$(s_{12}s_{13}x_1x_2)^{-1} \quad : \quad x_1 = \frac{k_-}{P_-}, \quad x_2 = \frac{l_-}{P_-},$$

$$b = \frac{k_T}{l_T}, \quad q_T = k_T + l_T$$

- Master formula:

$$\mathcal{B}_{qq}^{(2),CF} \sim \mathcal{C}(\epsilon)\left(\frac{\nu}{q_-}\right)^{2\alpha} \int dx_1 dx_2 db dt_{kl} dt_l dt_5 \; x_1^{-1-\alpha} \; x_2^{-1-\alpha} \; b^{-1-2\epsilon} \; \bar{x}_1^{N_1-1+2\alpha} \bar{x}_2^{N_1-1+2\alpha} \times$$
$$\mathcal{G}(x_1, x_2, b, t_l, t_{kl}, t_5) \mathcal{F}(x_1, x_2, b, t_l, t_{kl}, t_5)^{4\epsilon}$$

- $(s_{123}s_{13}x_1x_2)^{-1}$: so far we did not resolve overlapping divergences

Renormalization

- **Collinear anomaly** approach

$$\Big[\mathcal{S}(\bar\tau,\mu,\nu)\mathcal{I}_{qq}(N_1,\bar\tau,\mu,\nu)\bar{\mathcal{I}}_{\bar q\bar q}(N_2,\bar\tau,\mu,\nu)\Big]_{q^2} \overset{\alpha=0}{=} \left(\bar\tau^2 q^2\right)^{2F_{q\bar q}(\bar\tau,\mu)} I_{qq}(N_1,\bar\tau,\mu)\bar I_{\bar q\bar q}(N_2,\bar\tau,\mu)$$

- RGE: Anomaly coefficients

[Becher & Neubert, '10]

$$\frac{d}{d\ln\mu}F_{q\bar q}(\bar\tau,\mu) = -\Gamma_{cusp}(\alpha_S)$$

$$F_{q\bar q}(\bar\tau,\mu) = -\left(\frac{\alpha_S}{4\pi}\right)\Big[\Gamma_0 L - d_1\Big] - \left(\frac{\alpha_S}{4\pi}\right)^2\Big[\beta_0\Gamma_0 L^2 + \Gamma_1 L + \beta_0 d_1 L - d_2\Big] + \mathcal{O}(\alpha_S^3)$$

- RGE: Matching coefficients

$$L = \ln(\bar\tau\mu)$$

$$\frac{d}{d\ln\mu}I_{qq}(N_1,\bar\tau,\mu) = \Big[2\Gamma_{cusp}(\alpha_S)L + 2\gamma_I(\alpha_S)\Big]I_{qq}(N_1,\bar\tau,\mu) - 2\sum_i I_{qi}(N_1,\bar\tau,\mu)P_{iq}(N_1,\mu)$$

- solution → renormalized matching kernel

Finite remainder coefficient $\tilde{\mathrm{I}}_{qq}(N_1)$ — Non-logarithmic piece

Result: P_T-Resummation

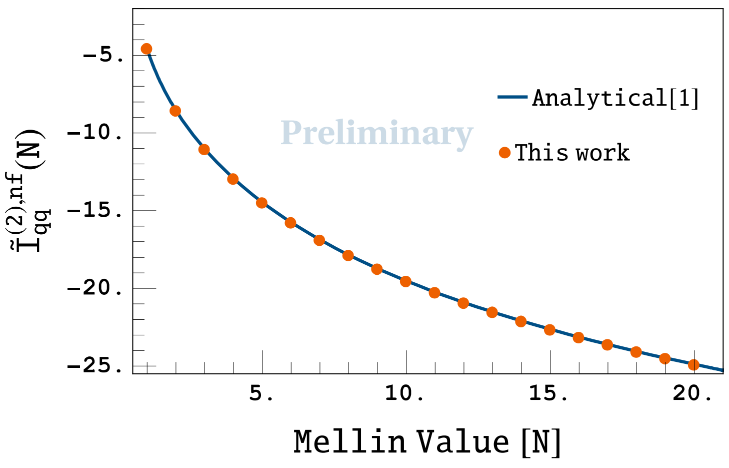
- P_T-resummation: $$\omega_{p_T} = -2i \sum_i |\vec{k}_{i,T}| \cos(\theta_i)$$
- Calculated the anomaly coefficients for two color structures.

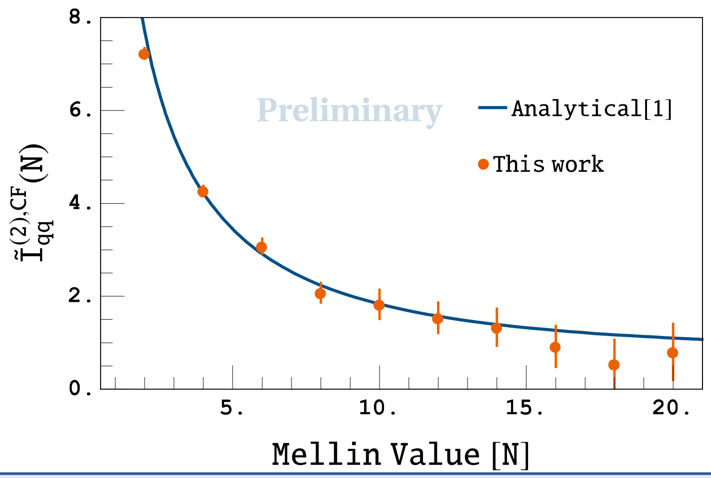
$$d_1 = 0$$

d_2	Analytical[1]	This Work
$d_2^{n_f}$	4.148	4.147(4)
$d_2^{C_F}$	0	0.02(6)

[1. Gehrmann, Lübbert, Yang '14]

- Renormalized matching kernels:





Result: P_T-Veto

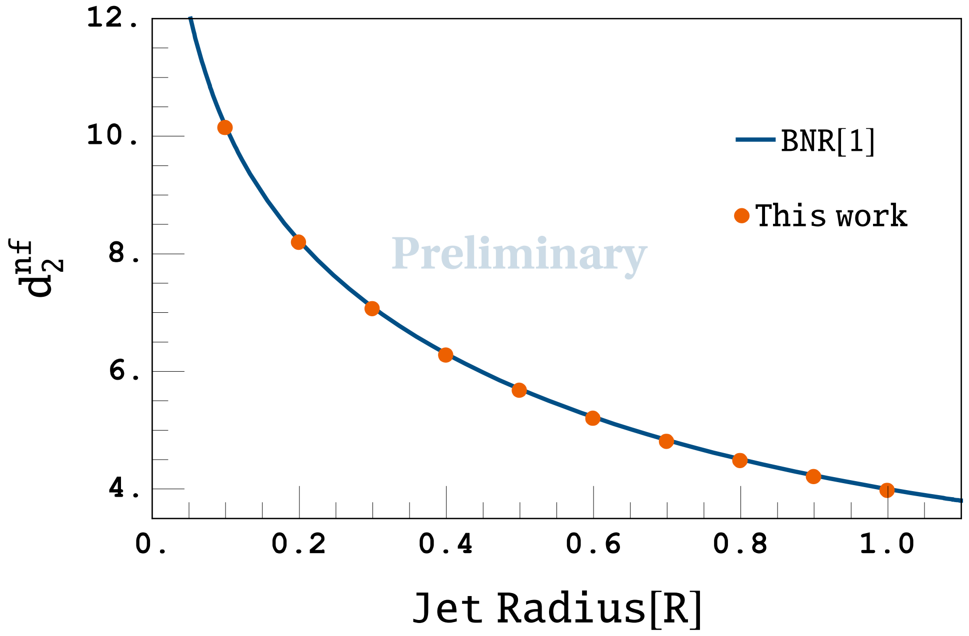
- P_T-veto:

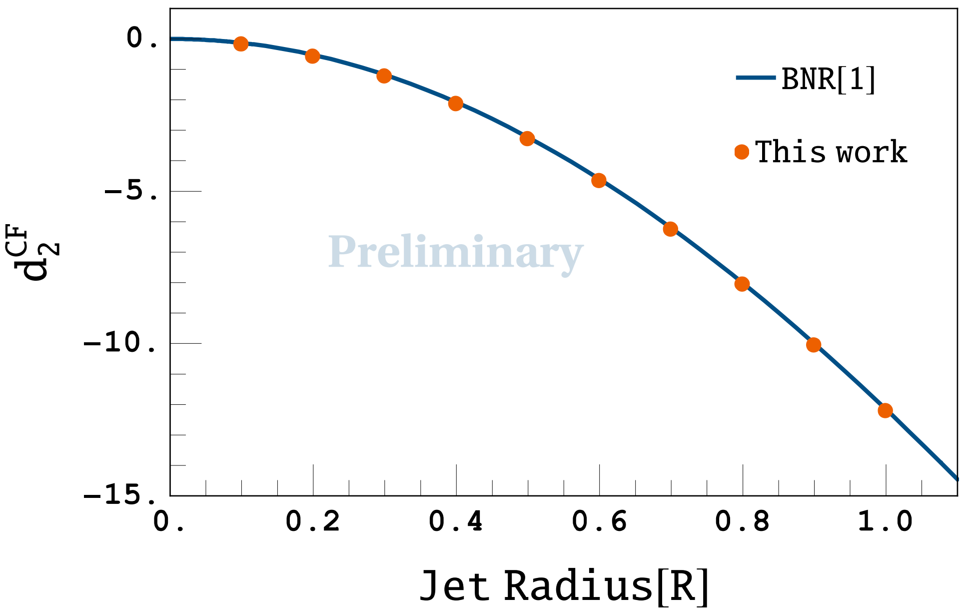
  Distance measure $$\Delta^2 = \frac{1}{4}\ln^2\left(\frac{l_+ k_-}{l_- k_+}\right) + \Theta_{lk}^2$$

$$\omega_{p_T-veto} = \Theta(\Delta - R)\max(\{k_{i,T}\}) + \Theta(R-\Delta)|\sum_i \vec{k}_{i,T}|$$

- Anomaly coefficients: depends on the jet radius at 2-loop

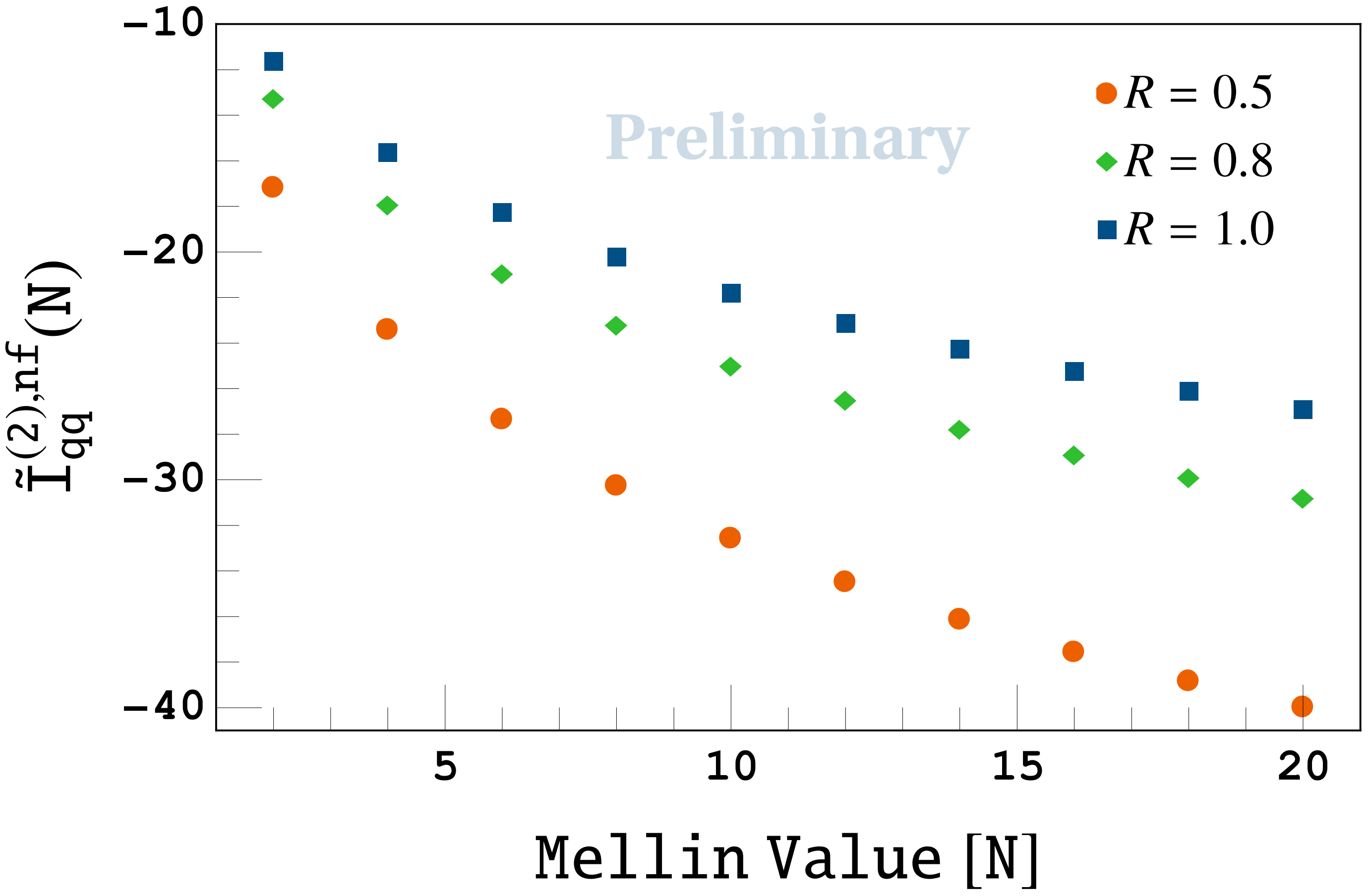
[1. Becher, Neubert, Rothen '13]





Result: P_T-Veto

- Matching coefficient at two loops



Outlook

- Developed an automated way to calculate **Jet** and **Beam** functions for a wide class of obervables at NNLO.

- Using a suitable phase-space parameterization(s) we are able to completely distangle IR divergences into monomial form.

- We have presented preliminary results for event shape observables and P_T-resummation and P_T-veto.

Outlook

- **Jet Functions:**

  - More observables are on the way (SCET-II observables, Jet algorithms, EEC ...)

  - Extend the method to calculate gluon Jet functions.

- **Beam Functions:**

  - Plans to extend to SCET-I observables (beam thrust, rapidity-dependent jet vetos ...).

  - Extend the method to remaining matching kernels.

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Thank you for your attention!

Backup: P_T-Veto Bare results

- The bare results for P_T-veto Beam function have been calculated for C_F^2 color structure.