One-Ponit Energy correlator inside jet

An New Jet observable

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Base on arxiv:2507.21613 with Zihao Mi

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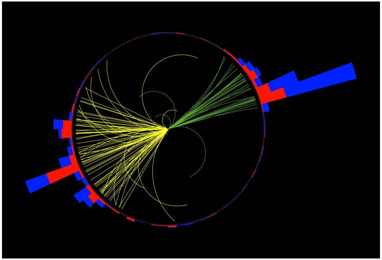
Outline

- Motivation
- One-Point Energy Correlator
- Factorization and Resummation
- Summary and Outlook

Jet Substructure



Hadrons within the jet are detected at infinity

Study QCD dynamics and probe New Physics

from field theory first principles

Energy flow operator

$$\mathcal{E}(n) = \lim_{r\to\infty} \int d\vec{n} \int_0^\infty dt T_{0\vec{n}}(t, \vec{n}r) r^2$$

ideal detector

Motivation

Energy-Energy Correlators

$$\text{EEC}(\chi) = \frac{1}{\sigma}\sum_{a,b}\int \frac{E_a E_b}{Q^2} d\sigma_{e^-e^+\to h_a h_b X}\,\delta(\chi-\theta_{ab})$$

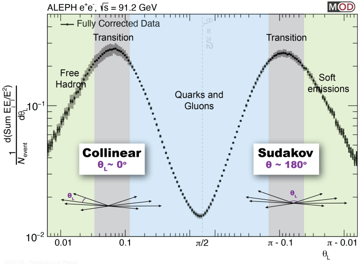
- Separation of energy scales: different slopes in different regimes, and probe different physics.

  Strong coupling constant

  W. Chen, J. Gao, Y. B. Li, Z. Xu, X. Y. Zhang, H. X. Zhu, **2307.07510**

  Nucleon structure

  X. H. Liu, H. X. Zhu, **2209.02080**

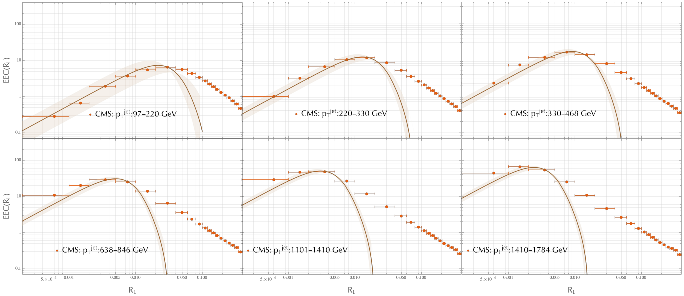


H. Bossi, et al., **2505.11828**

TMD Model Description

Near-Side Energy-Energy Correlator

X.H Liu, W. Vogelsang, F. Yuan, H.X. Zhu, **2410.16371**



$$\frac{1}{\sigma_h}\frac{d^3\sigma}{dz d^2 p_T} = d_h(z)\int \frac{db}{2\pi} b J_0(p_T b) e^{-S_{\text{Pert}}(b,\mu)-S_{\text{NP}}(b,\mu)}$$

Perturbative Sudakov factor

$S_{\text{Pert}}(b,\mu)$ calculated by theory

Non-perturbative Collin-Soper kernel

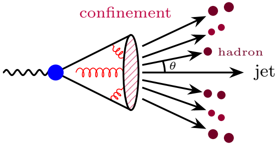
$S_{\text{NP}}(b,\mu)$ constrained by experiment

One-Ponit Energy Correlator

Energy weighted jet cross-section

$$\mathsf{EC}(\chi) = \frac{1}{\sigma_J} \sum_h \int d\sigma \frac{\omega_h}{\omega_J} \delta(\chi - \theta_h)$$

θ_h : angular respect to standard jet axis.

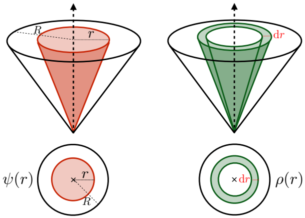


Jet Shape

P. Cal, F. Ringer, W.J. Waalewijn, **1901.06389**

$$\psi(r) = \frac{\sum_{r_i < r} p_{Ti}}{\sum_{r_i < R} p_{Ti}}, \qquad \rho(r) = \frac{d\psi(r)}{dr}$$

- fraction of the jet transverse momentum
- Differential mathematically equvalent to EC

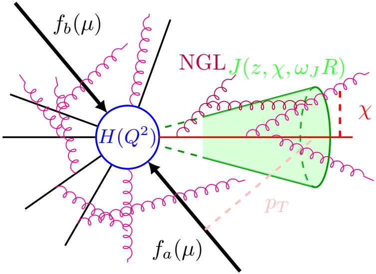


One-Ponit Energy Correlator

Inclusive jet cross section

Z.B. Kang, F. Ringer, I. Vitev, **1606.06732**

$$\frac{d\sigma^{pp\to(\text{jet}h)X}}{dp_T d\eta d\chi} = \sum_{a,b,c}\int_{x_a^{\min}}^{1}\frac{dx_a}{x_a}f_a(x_a,\mu)\int_{x_b^{\min}}^{1}\frac{dx_b}{x_b}f_b(x_b,\mu) \times \int_{z^{\min}}^{1}\frac{dz}{z^2}H_{ab}^{c}(\hat{s},\hat{p}_T,\hat{\eta},\mu)J_c(z,\chi,\omega_J R,\mu)$$



TMD Region $\Lambda_{\text{QCD}} \lesssim j_\perp \ll p_T R$

$$J_c = \sum_X \sum_{h\in J}\delta(\theta_h-\chi)\langle 0|\bar{\chi}_n\delta_{\omega-\bar{n}\cdot\text{P}}|(Jh)X\rangle\frac{\omega_h}{\omega_J}\langle (Jh)X|\chi_n|0\rangle$$
$$= \sum_h \frac{\pi\omega_J^2\chi}{2}\mathcal{H}(z,\omega_J R,\mu)\int dz_h\int dk_\perp^2\int d\lambda_\perp^2 \times \delta^{(2)}(z_h\lambda_\perp + k_\perp - \frac{z_h\omega_J\chi}{2})\underbrace{z_h D_{h/i}(z_h,k_\perp,\mu,\nu)}_{\text{second order mellin moment}} S_i(\lambda_\perp,\mu,\nu R)$$

Sum Rule

$$\sum_h\int_0^1 dz\; z\; d_{h/i}(z;\mu) = 1$$

Z.B Kang, X.H Liu, F. Ringer, H.X Xing, **1705.08443**

Resummation Global Logs

RG evolution equation $\Longrightarrow \mu_J$

$$\frac{d}{d\ln\mu}\mathcal{H}_{i\to j}(z,\omega_J R,\mu) = \sum_k \int_z^1 \frac{dz'}{z'}\gamma_{ik}\left(\frac{z}{z'},\frac{\omega_J \tan(R/2)}{\mu};\alpha_s(\mu)\right)\mathcal{H}_{k\to j}(z',\omega_J R,\mu)$$

$$\frac{d}{d\ln\mu}\ln D_{h/i}(z_h,b,\mu,\nu) = \gamma_D\left(\frac{\nu}{\omega_J};\alpha_s(\mu)\right)$$

$$\frac{d}{d\ln\mu}\ln S(b,\mu,\nu) = \gamma_S\left(\frac{\nu\tan(R/2)}{\mu};\alpha_s(\mu)\right)$$

$$\frac{d}{d\ln\nu}\ln D_{h/i}(z_h,b,\mu,\nu) = -\gamma_R\left(\frac{\mu}{\mu_b};\alpha_s(\mu)\right)$$

$$\frac{d}{d\ln\nu}\ln S(b,\mu,\nu) = \gamma_R\left(\frac{\mu}{\mu_b};\alpha_s(\mu)\right)$$

Central scale choice

$$\mu_b = \frac{2e^{-\gamma_E}}{b}$$

$$\mu_D \sim \mu_b,$$

$$\mu_S \sim \mu_b,$$

$$\mu_J \sim p_T R,$$

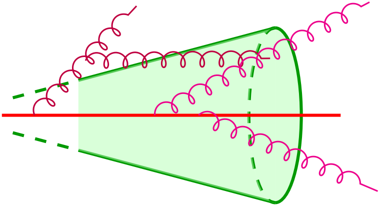
$$\mu_H \sim p_T,$$

Small-R resummation: TimeLike DGLAP $\Longrightarrow \mu_H$

$$\mu\frac{d}{d\mu}J_i(z,\chi,\omega_J R,\mu) = \frac{\alpha_s}{2\pi}\sum_j \int_z^1 \frac{dz'}{z'}P_{ji}\left(\frac{z}{z'}\right)J_j(z,\chi,\omega_J R,\mu)\,.$$

Resummation Non-Global Logs

Non-global observable



$$U_{\mathsf{NG}}(\mu_b, \mu_J) = \exp\left[-C_A C_a \frac{\pi^2}{3} u^2 \frac{1+(au)^2}{1+(bu)^c}\right]$$

$$u = \int_{\mu_b}^{\mu_J} \frac{d\mu}{\mu} \frac{\alpha_s(\mu)}{2\pi} = \frac{1}{\beta_0} \ln\left[\frac{\alpha_s(\mu_b)}{\alpha_s(\mu_J)}\right]$$

Wide angle soft radiation

T Becher, B D. Pecjak, D.Y Shao, **1503.06090**

Small-R

same as the hemisphere mass

M. Dasgupta, G.P. Salam, **hep-ph/0104277**

M. Dasgupta, K. Khelifa-Kerfa, S. Marzani, M. Spannowsky, **1207.1640**

LL at large N_C limit

a = 0.85, b = 0.86, c = 1.33

Non-perturbative Collin-Soper kernel

Non-perturbative corrections

- Rapidity anomalous dimension
- TMD matrix elements

$$R(b,\mu,\nu) \Longrightarrow R(b,\mu,\nu) \times \exp\left(g_K(b)\ln\frac{\nu}{\nu_S}\right)$$

$$SJ_i(b,\mu_0,\nu_0) = S^{\text{pert}} J_i^{\text{OPE}}(b,\mu_0,\nu_0) j_i(b)$$

b_* prescription

$$b_{max} = 1.5$$

$$b_* = \frac{b}{\sqrt{1+b^2/b^2_{\text{max}}}}$$

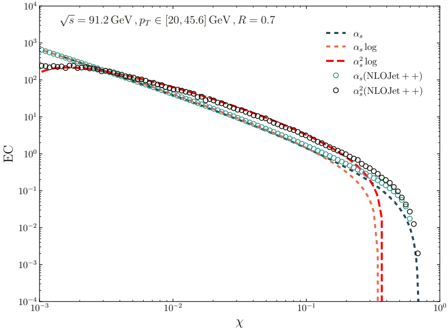
LO approximation model function

H.T. Li, Y. Makris, I. Vitev, **2102.05669**

$$j_i|_{\text{LO}}(b) = \sum_a \int_0^1 dy\; y \underbrace{di/a(y,1\text{GeV})}_{\text{DSS Fragmentation Dataset}} \underbrace{D^{\text{NP}}_{i/a}(y,b)}_{e^{-0.042b^2/y^2}} \Longrightarrow \begin{cases} j_q(b) = e^{-0.59b-0.03b^2} \\ j_g(b) = e^{-0.17b-0.09b^2} \end{cases}.$$

Stimulations Fixed Order

Comparion with NLOJET++ e^+e^- anihilation



theoretical

- α_s (W/O Factorization)
- α_sLog
- α_s^2Log
- anti-kt jet algorithm

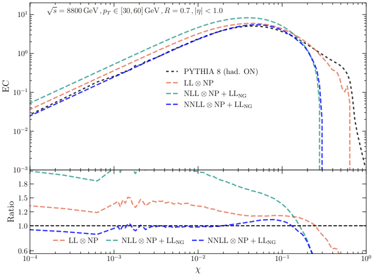
NLOJET++

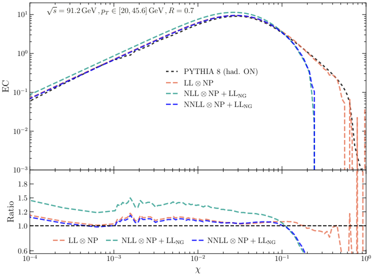
- α_s
- α_s^2

$$J_q(z,\chi,\omega_J,\mu) = \delta(1-z)\frac{\alpha_s}{2\pi^2}\frac{1}{\mu^2}\frac{\pi\omega_J^2(\tan\chi+\tan^3\chi)}{2} \times \left(\frac{\mu^2}{(\frac{\omega_J\tan\chi}{2})^2}\right)\left\{-\frac{3}{2}+\frac{3}{2}\frac{\tan\chi}{\tan\frac{R}{2}}-\frac{3}{8}\frac{\tan^2\chi}{\tan^2\frac{R}{2}}-\log\left(\frac{\tan^2\chi}{4\tan^2\frac{R}{2}}\right)\right\}$$

Stimulations Resumamtion

Comparion with Pythia





Theoretical

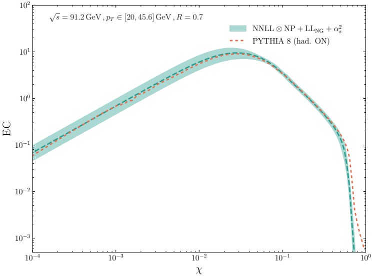
- NNLL for global logs
- LL for non-global logs
- NP corrections

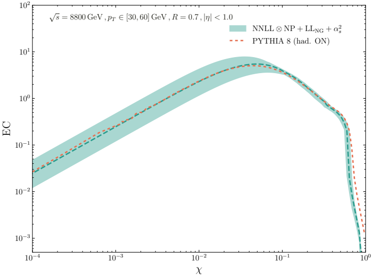
Pythia

- Hadronization
- Decay

Match

Combine fixed order and resumamtion





Match

- Resumamtion for $\lesssim 0.1$
- Fixed order for $\gtrsim 0.1$

Similar behavior as EEC

- Free hadron gas
- Confinement
- Perturbative

Summary And Outlook

Summary

- First Proposed and defined the one-point energy correlator inside jet in TMD region
- Developed a factorization framework and performed resummation of global and non-global logarithms
- NLO EC jet function without TMD Factorization

Outlook

- Similar QCD scaling behavior as EEC

  C. H Chang, H. Chen, X. H. Liu, D. Simmons-Duffin, F. Yuan, H. X. Zhu, **2507.15923**
- NLL non-global
- Track-Based EC for the measurement
- Nucleon structure using Spin-dependent EC

  M. S. Gao, Z. B. Kang, W. C. Li, D. Y. Shao, **2509.15809**

Thank you for listening!