

Two-Dimensional Transverse-Momentum Subtraction and Semi-Inclusive Deep-Inelastic Scattering at N3LO in QCD

[董亮 方申 高俊 李海涛 邵鼎煜 朱华星 朱雨蛟 arXiv: 2603.29673]

董亮

上海交通大学



第十二届高能物理全国会议

2026年7月15日至19日，广州

Content



- 1. Introduction**
- 2. Two-dimensional transverse momentum subtraction**
- 3. Numerical results**
- 4. Summary and Outlook**

Introduction

[Anastasiou et al. PRL 2015]

[Anastasiou et al. JHEP 2016]

[Dreyer et al. PRL 2016]

[Mistlberger, JHEP 2018]

[Duhr et al. PRL 2020]

[Duhr et al. PRL 2020]

[Duhr et al. JHEP 2020]

[Duhr et al. JHEP 2020]

[Duhr et al. JHEP 2022]

[Baglio et al. JHEP 2022]

[Chen et al. PRL 2022]

● N3LO QCD

Higgs/Higgs pair production, Drell-Yan, top quark decay, ...

[Chen et al. JHEP 2020]

[Chen et al. PLB 2020]

[Chen et al. 2309.01937]

[Chen et al. PRD 2024]

● Identified hadron production

□ significance

- Confinement
- Non-perturbative fragmentation functions
- Proton's spin structure
- Flavor-dependent new physics

Introduction

▣ Rich experimental data

Abundant data available from e^+e^- , ep , pp collisions

▣ Future programs

➤ Electron-Ion Collider (EIC)

➤ e^+e^- factories

promise measurements of unprecedented precision

▣ Theoretical calculation

➤ To exploit datasets and match experimental precision, N3LO QCD corrections are required.

➤ Challenges: Complexity of handling final-state infrared singularities

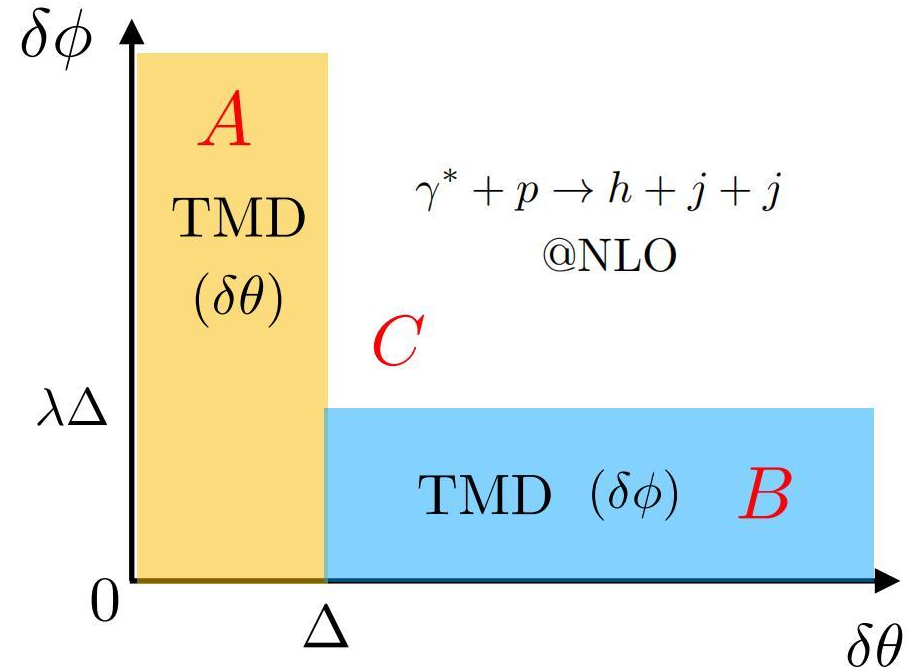
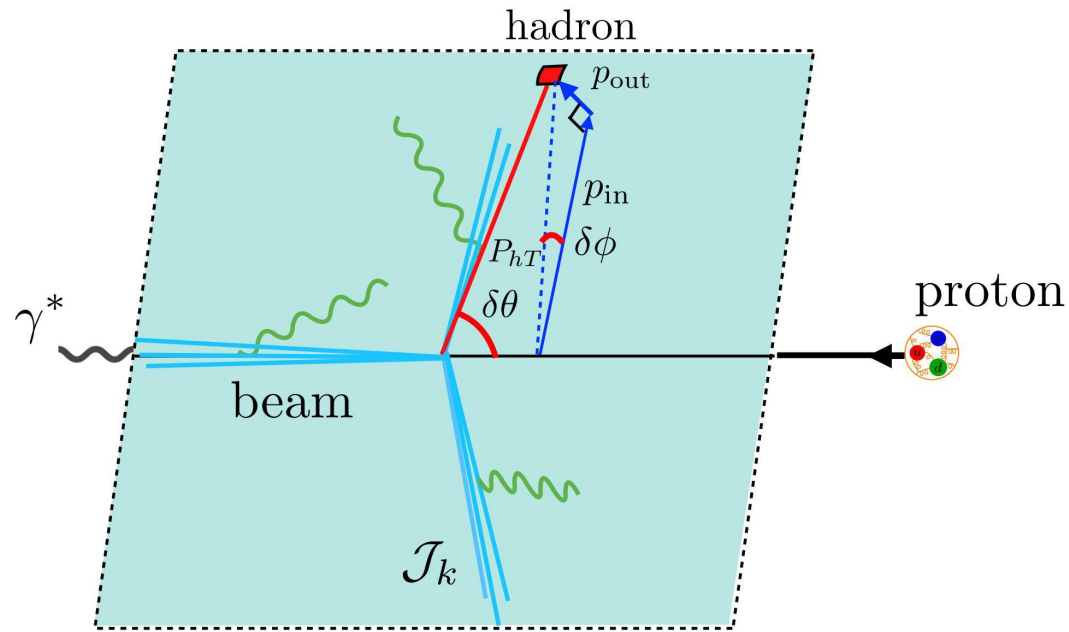
2D q_T subtraction

- Overview

- Apply q_T subtraction to identified hadron production
- Use two slicing variables: P_{hT} and P_{out}
- Divide full phase space into three regions

2D q_T subtraction

● Kinematics



$$\frac{d\sigma}{d\mathcal{O}} = \int_0^\Delta d\delta\theta \frac{d\sigma^A}{d\delta\theta d\mathcal{O}} + \int_\Delta^{\delta\theta^{\max}} d\delta\theta \times \left(\int_0^{\lambda\Delta} d\delta\phi \frac{d\sigma^B}{d\delta\theta d\delta\phi d\mathcal{O}} + \int_{\lambda\Delta}^{\delta\phi^{\max}} d\delta\phi \frac{d\sigma^C}{d\delta\theta d\delta\phi d\mathcal{O}} \right)$$

2D q_T subtraction

● Calculation

➤ Region A [\[Gao, Li, Zhu, Zhu 2602.06364\]](#)

$$\frac{d\sigma^A}{dx\,dy\,dz\,d^2\vec{P}_{hT}} \propto \int \frac{d^2\vec{b}_\perp}{4\pi^2} e^{-i\vec{P}_{hT}\cdot\vec{b}_\perp/z} \sum_i H_{ei\rightarrow ei}(Q) \times \mathcal{B}_{i/p}(x, \vec{b}_\perp) \mathcal{D}_{h/i}(z, \vec{b}_\perp) S_{qq}(\vec{b}_\perp) [1 + \mathcal{O}(\Delta)]$$

➤ Region B [\[LD, Fang, Gao, Li, Shao, Zhu 2602.22972\]](#) **See Shen Fang(方申)'s poster !**

$$\frac{d\sigma^B}{dx\,dy\,dz\,d^2\vec{P}_{hT}\,dp_{\text{out}}} \propto \int \frac{db}{2\pi} e^{ip_{\text{out}}b/\zeta} \times \sum_{ijk} \int d\xi H_{ei\rightarrow ejk}(Q, \xi, \zeta) \times \mathcal{B}_{i/p}(\xi, b) \mathcal{D}_{h/j}(\zeta, b) \mathcal{J}_k(b) S_{ijk}(b) [1 + \mathcal{O}(\lambda)]$$

2D q_T subtraction

● Calculation

➤ Region C

[Liu, Shen, Zhou, Gao JHEP 09 (2023) 108]

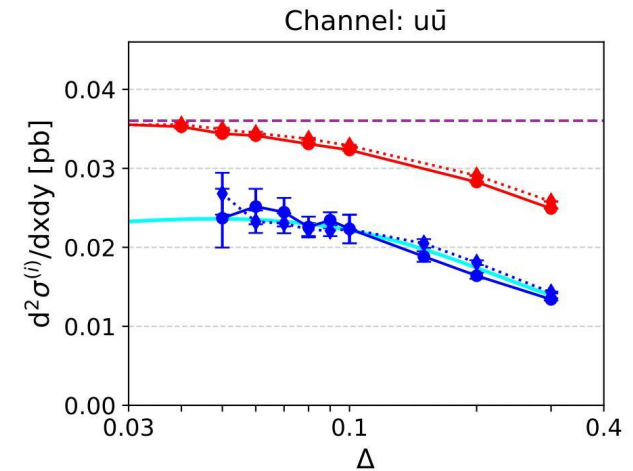
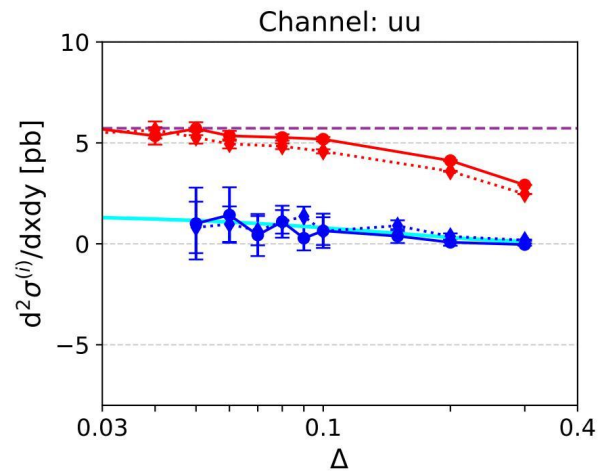
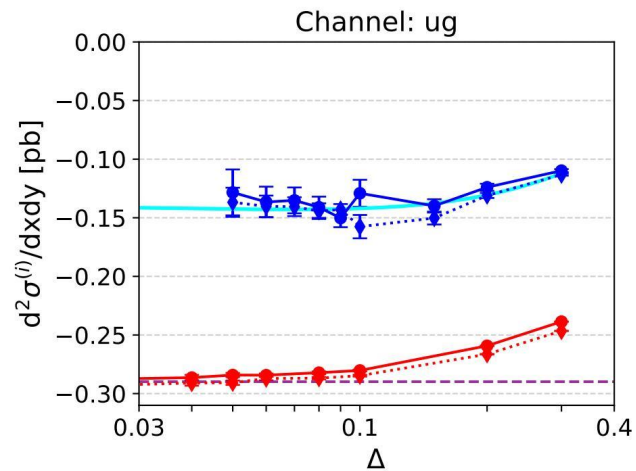
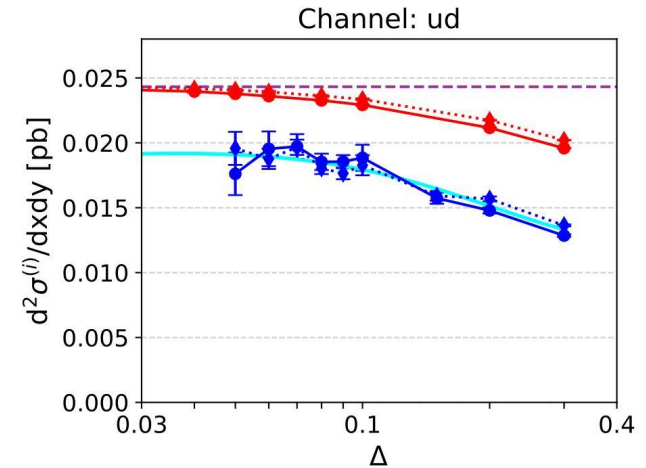
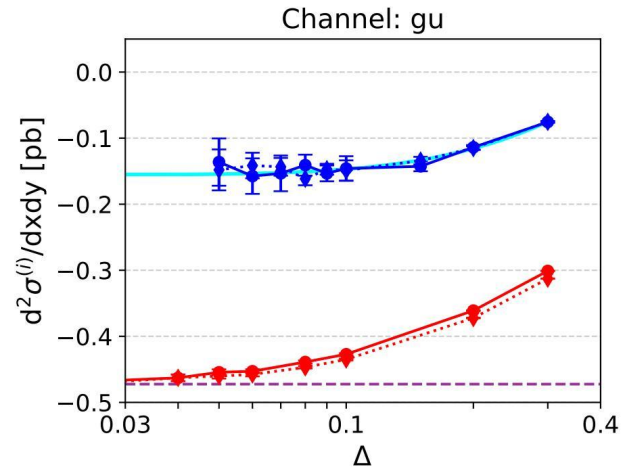
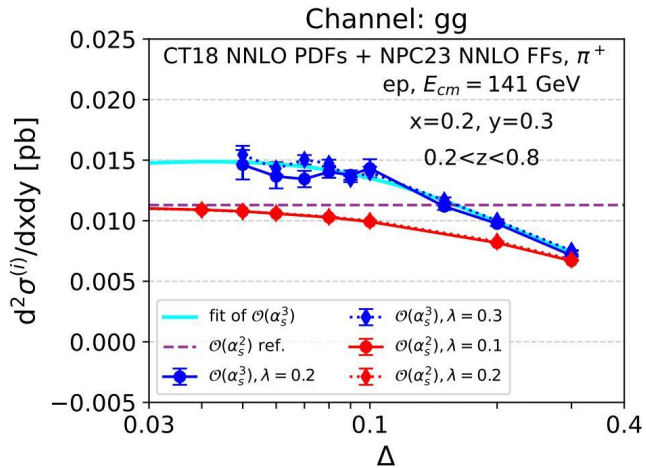
FMNLO

$$\begin{aligned} \frac{d\sigma}{dp_{T,h}} = & \int dx \int dPS_m \left[|M|_{B,m}^2 + |M|_{V,m}^2 + |\tilde{\mathcal{J}}|_m^2 \right] \sum_{i=1}^m \delta(p_{T,h} - xp_{T,i}) D_{h/i}^0(x) \\ & + \int dx \int dPS_{m+1} (\Theta(\lambda - C) + \Theta(C - \lambda)) \left[|M|_{R,m+1}^2 \sum_{i=1}^{m+1} \delta(p_{T,h} - xp_{T,i}) D_{h/i}^0(x) \right. \\ & \left. - |\mathcal{J}|_{m+1}^2 \sum_{\tilde{i}=1}^m \delta(p_{T,h} - x\tilde{p}_{T,\tilde{i}}) D_{h/\tilde{i}}^0(x) \right] \end{aligned}$$

Numerical results

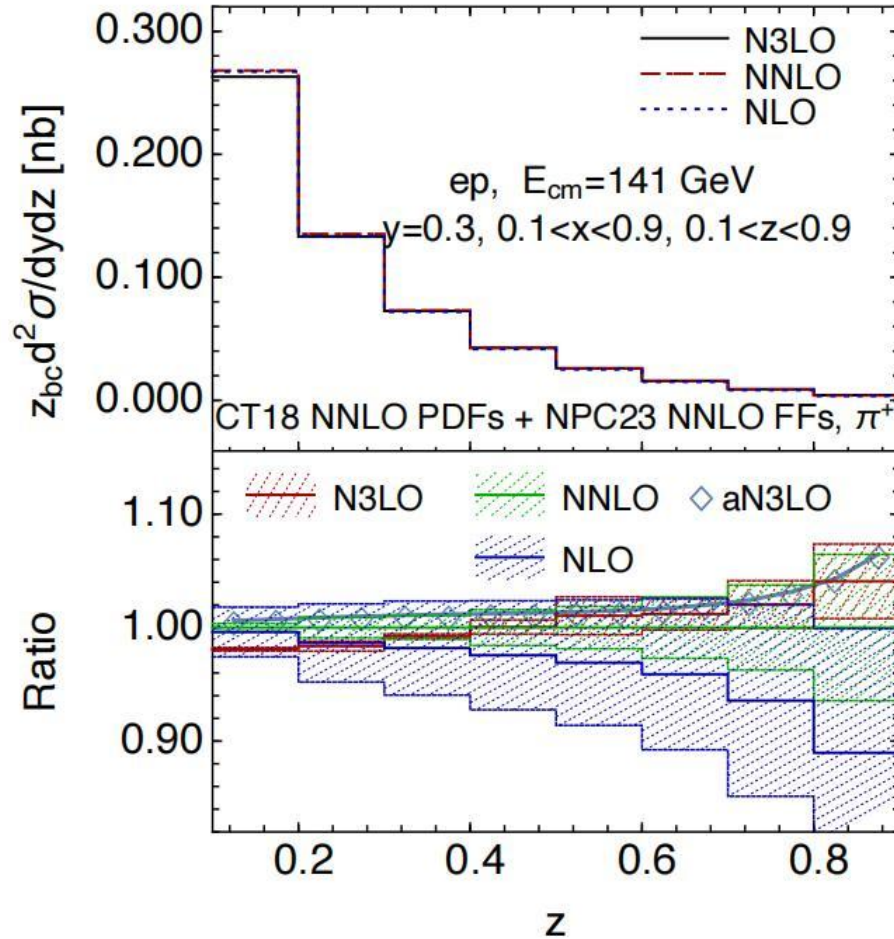
● Slicing parameter Δ

$$Q^2 = -q^2, \quad x = \frac{Q^2}{2P \cdot q}, \quad y = \frac{P \cdot q}{P \cdot l}, \quad z = \frac{P \cdot P_h}{P \cdot q},$$

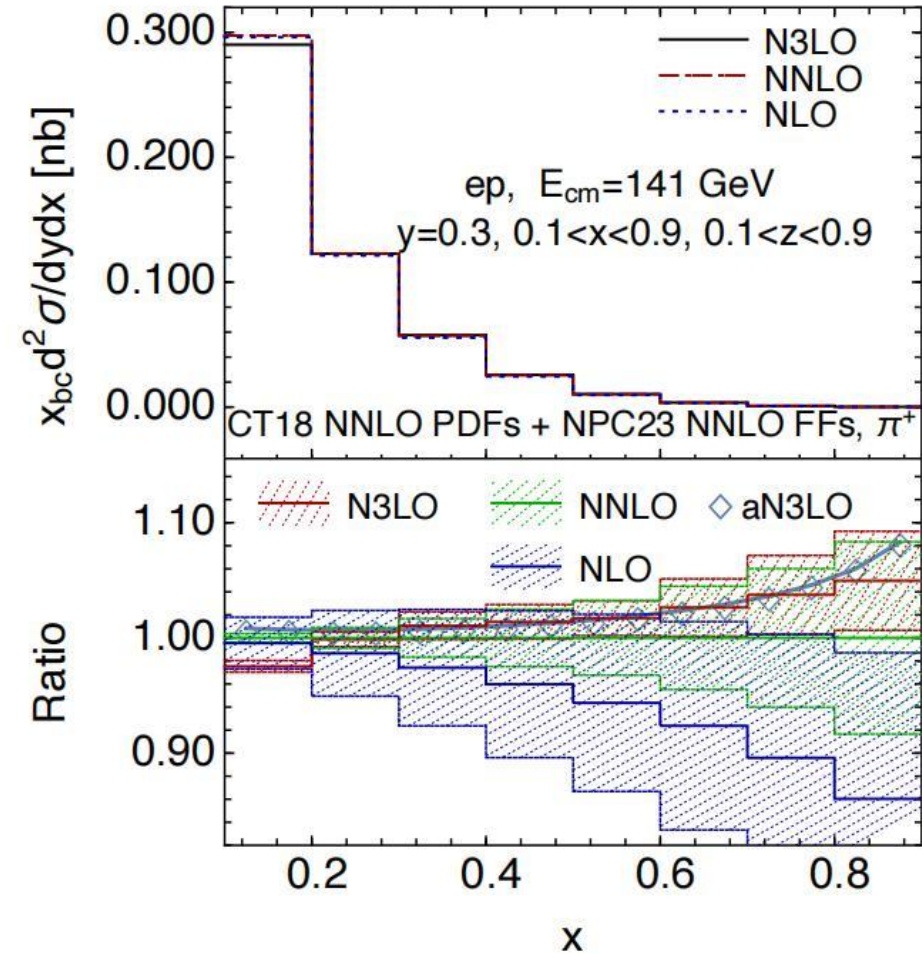


Numerical results

- hadron momentum fraction z

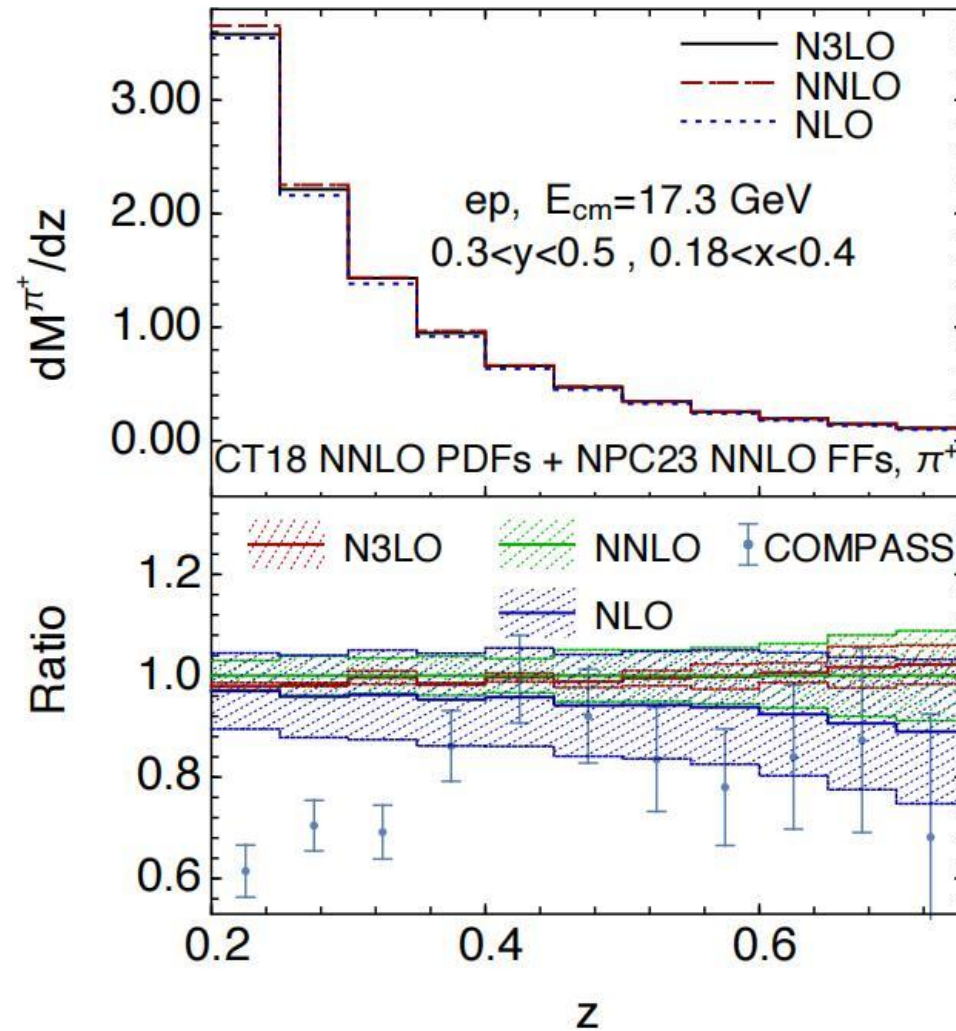


- Bjorken variable x



Numerical results

- Differential multiplicity



[COMPASS PRD 2025]

Summary and outlook

- Propose a novel method of two-dimensional transverse-momentum subtraction for calculations of identified hadron production.
- Present the *first* calculation of unpolarized SIDIS at N3LO in perturbative QCD. Fully differential descriptions allow arbitrary selection cuts and are especially applicable for efficient and precise study of hadron tomography at the upcoming Electron-Ion collider.
- Expandable to polarized SIDIS.

Thanks for your attention!