α_s dependence of DIS EEC in Breit frame

Haitao Li

山东大学物理学院
SCHOOL OF PHYSICS, SHANDONG UNIVERSITY

Based on the work with

Zhi-Hong He, D.Y. Shao in preparation

X. Chen, Zhi-Hong He in preparation

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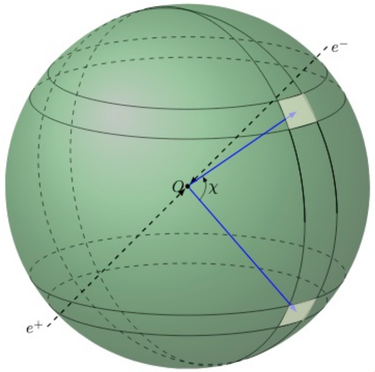
Outline

- Introduction
- EEC with jets
- EEC and α_s measurements
- Summary

Introduction

e^+e^- Collisions



Hadronic initial state

observable

$$\mathrm{EEC} = \sum_{a,b} \int d\sigma_{V\to a+b+X} \frac{2E_aE_b}{Q^2\sigma_{\mathrm{tot}}} \delta(\cos(\theta_{ab}) - \cos(\chi))$$

$$\mathrm{TEEC} = \sum_{a,b} \int d\sigma_{pp\to a+b+X} \frac{2E_{T,a}E_{T,b}}{|\sum_i E_{T,i}|^2} \delta(\cos\phi_{ab} - \cos\phi)$$

- sum over all the jets for each event
- sum over all the particles for each event

Basham et al 1978
Moult, Zhu, 2018

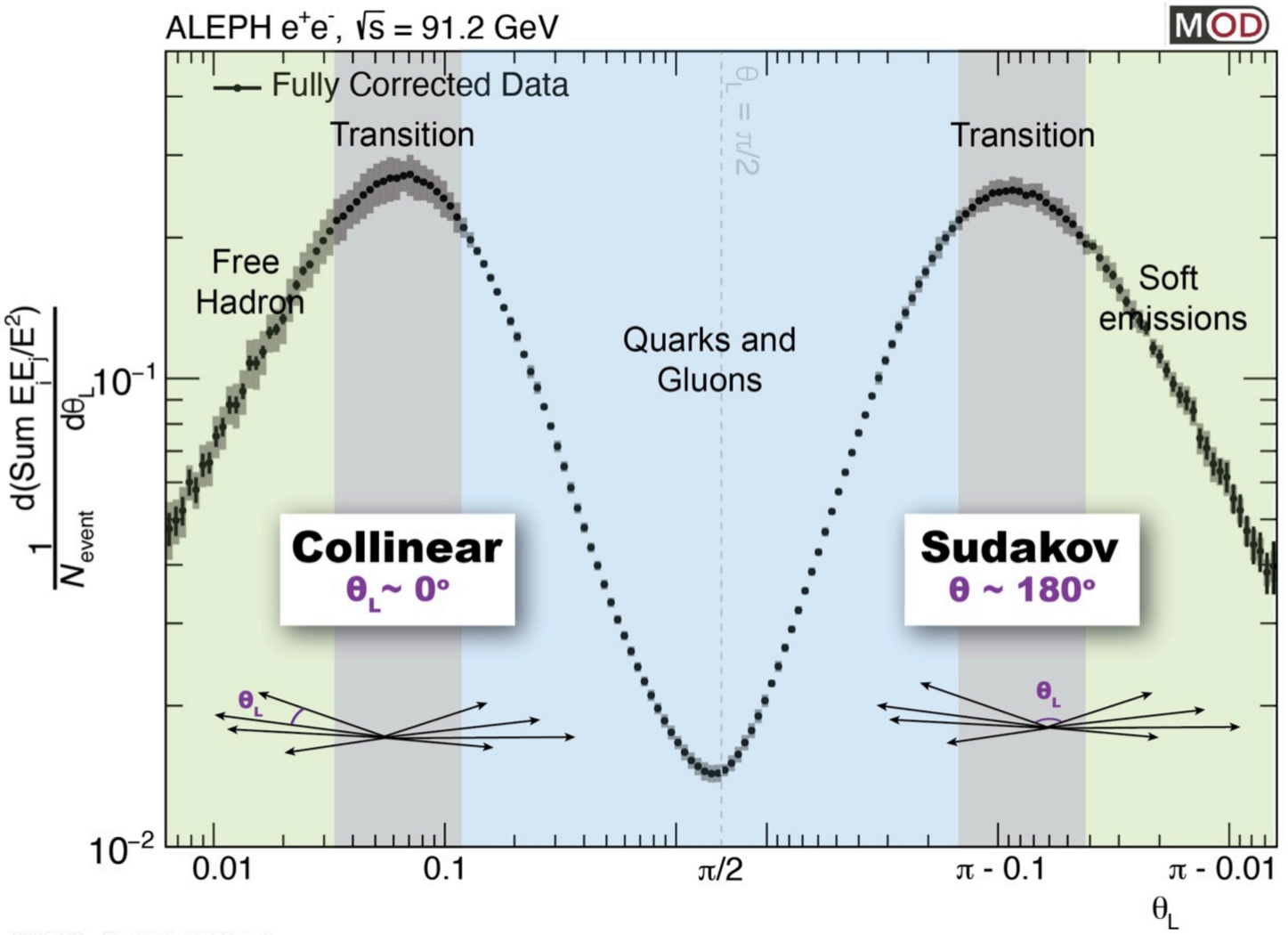
- weighted cross section
- the soft radiation does not contribute directly to the observable at leading power
- soft gluon contributes only via recoil

Ali et al 1984
Gao, HTL, Moult, Zhu, PRL, 2019 & JHEP

Introduction

many works recently

in the collinear region

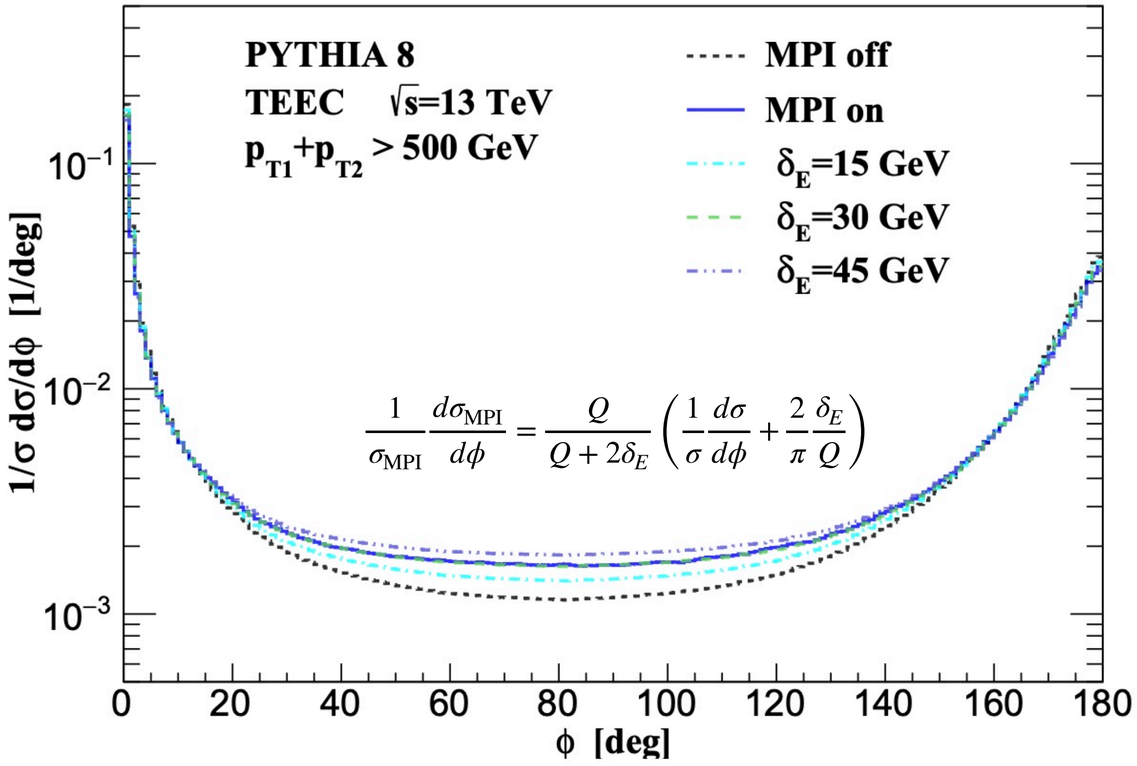


TMD region

arXiv:2505.11828

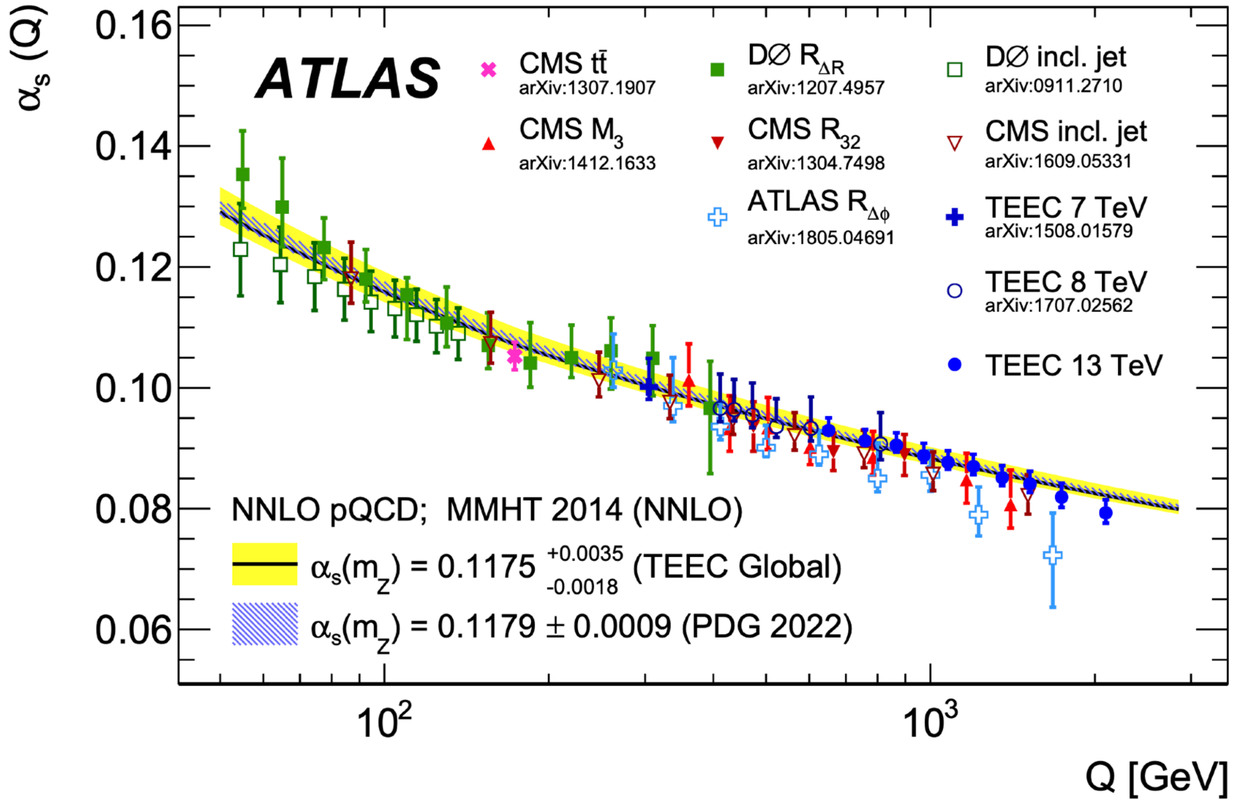
Introduction

TEEC in pp



$$\frac{1}{\sigma_{\mathrm{MPI}}}\frac{d\sigma_{\mathrm{MPI}}}{d\phi} = \frac{Q}{Q+2\delta_E}\left(\frac{1}{\sigma}\frac{d\sigma}{d\phi} + \frac{2}{\pi}\frac{\delta_E}{Q}\right)$$

Gao, HTL, Moult, Zhu, PRL, 19 & JHEP 24



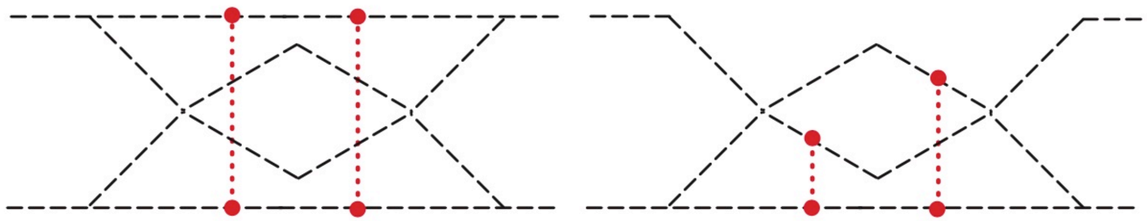
ATLAS, 2023

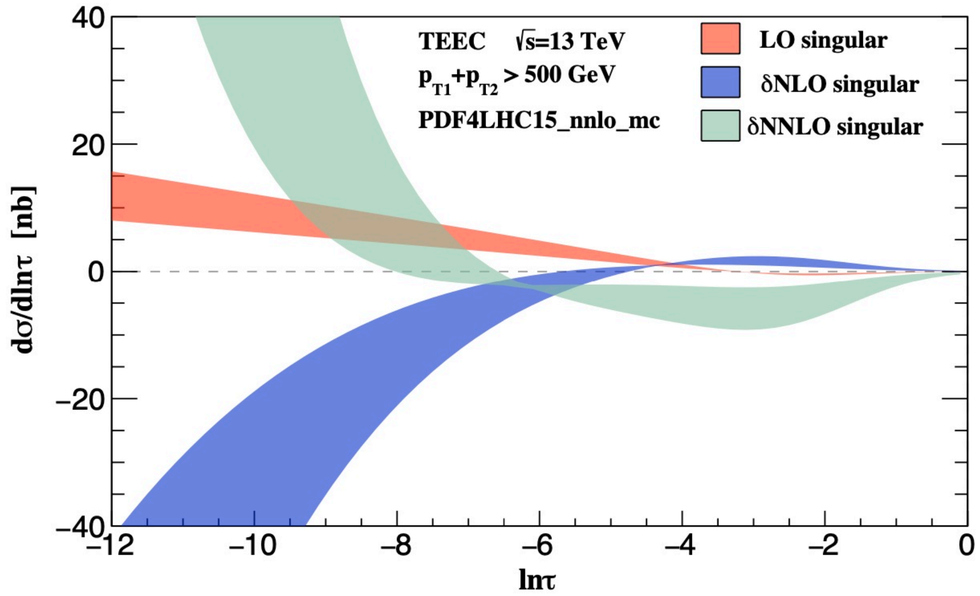
Introduction

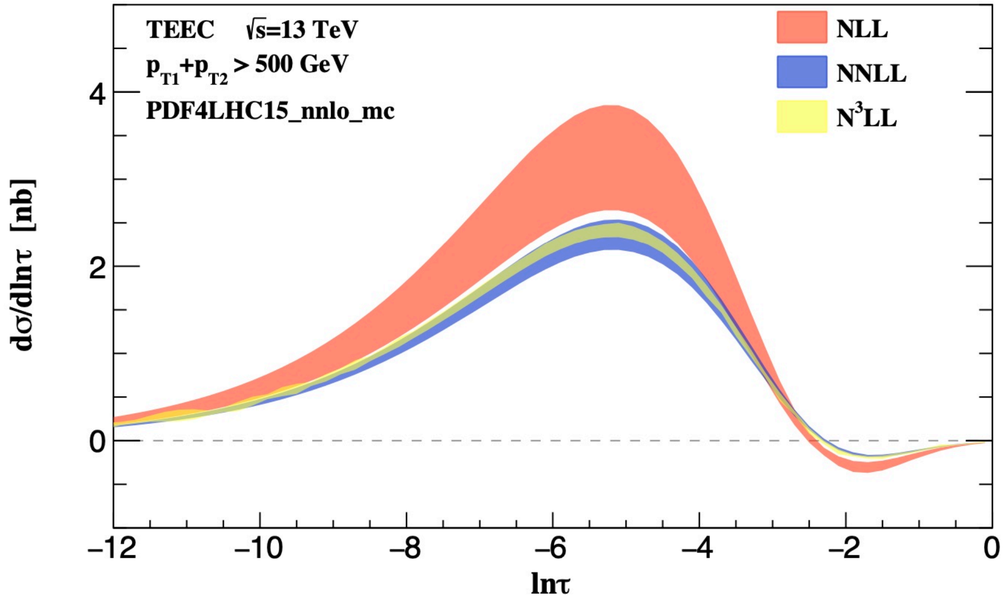
in pp collisions

- Such as violation in collinear factorization
- Whether rapidity factorization is still valid
- RG invariance of the cross section

$$\mathscr{L}^{(0)} = \mathscr{L}^{(0)}_{B_1} + \mathscr{L}^{(0)}_{B_2} + \mathscr{L}^{(0)}_{J_1} + \mathscr{L}^{(0)}_{J_2} + \boxed{\mathscr{L}^{(0)}_{G}}$$





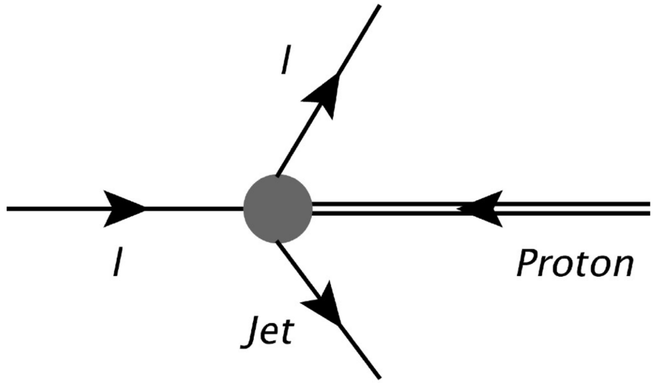


NNNLL accuracy for a hadron collider diet event shape for the first time.

Gao, HTL, Moult, Zhu, PRL, 19 & JHEP 24

Introduction

TEEC in DIS



Definition

$$\mathrm{TEEC} = \sum_a \int d\sigma_{lp\to l+a+X} \frac{E_{T,l}E_{T,a}}{E_{T,l}\sum_i E_{T,i}} \delta(\cos\phi_{la} - \cos\phi)$$

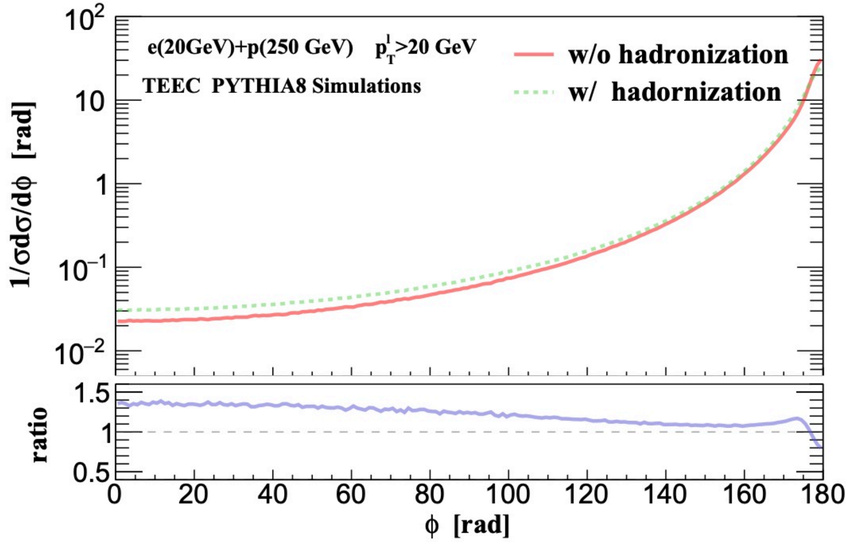
sum over all hadrons

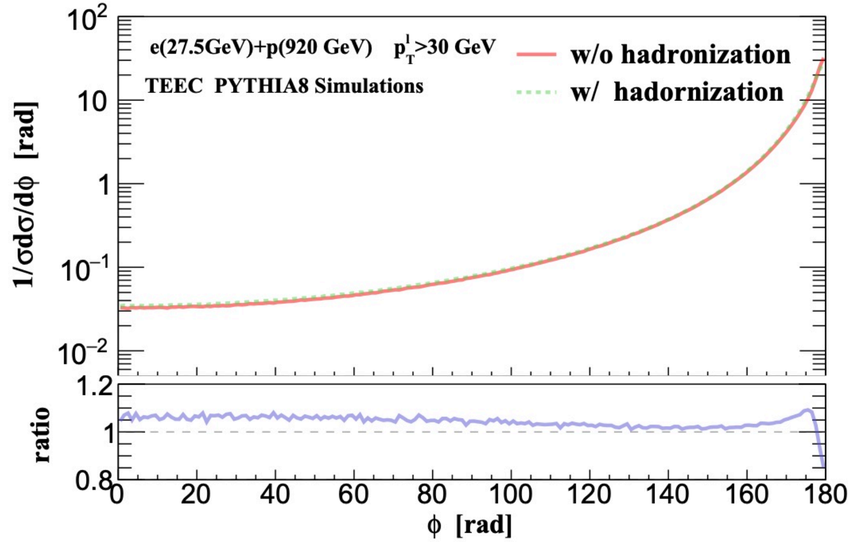
energy weighted

measure azimuthal angle correlations

Simulation by Pythia

HTL, Vitev, Zhu, JHEP, 20



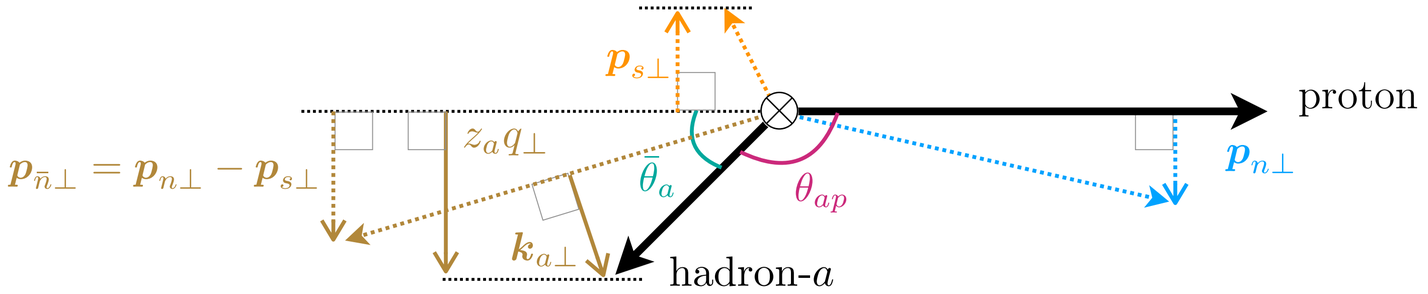


Introduction

EEC in DIS

In Breit Frame.

proton $+ \gamma^* \rightarrow$ jet/hadron $+ X$



We proposed a new definition of EEC in DIS:
correlation between initial proton and final state hadron

In the back to back limit

$$\mathrm{EEC} = \sum_a \int d\sigma_{lp\to l+a+X} \left(\frac{p\cdot p_a}{\sum_i p\cdot p_i}\right) \delta(\cos\chi - \cos\theta_{ap})$$

$$\frac{d\sigma_h}{d^2p_\perp} = \sum_f \int \frac{d\xi dQ^2}{\xi Q^2} Q_f^2 H(Q,\mu) \int \frac{db}{2\pi} e^{ib_\perp\cdot p_\perp} f_{f/N}(b,\xi,\mu,\nu)\, S\left(b,\frac{n_2\cdot n_4}{2},\mu,\nu\right) \int dz F_{h/f}(z,b/z,E_4,\mu,\nu)$$

HTL, Makris, Vitev, PRD, 2021

Introduction

EEC in DIS

In Breit Frame.

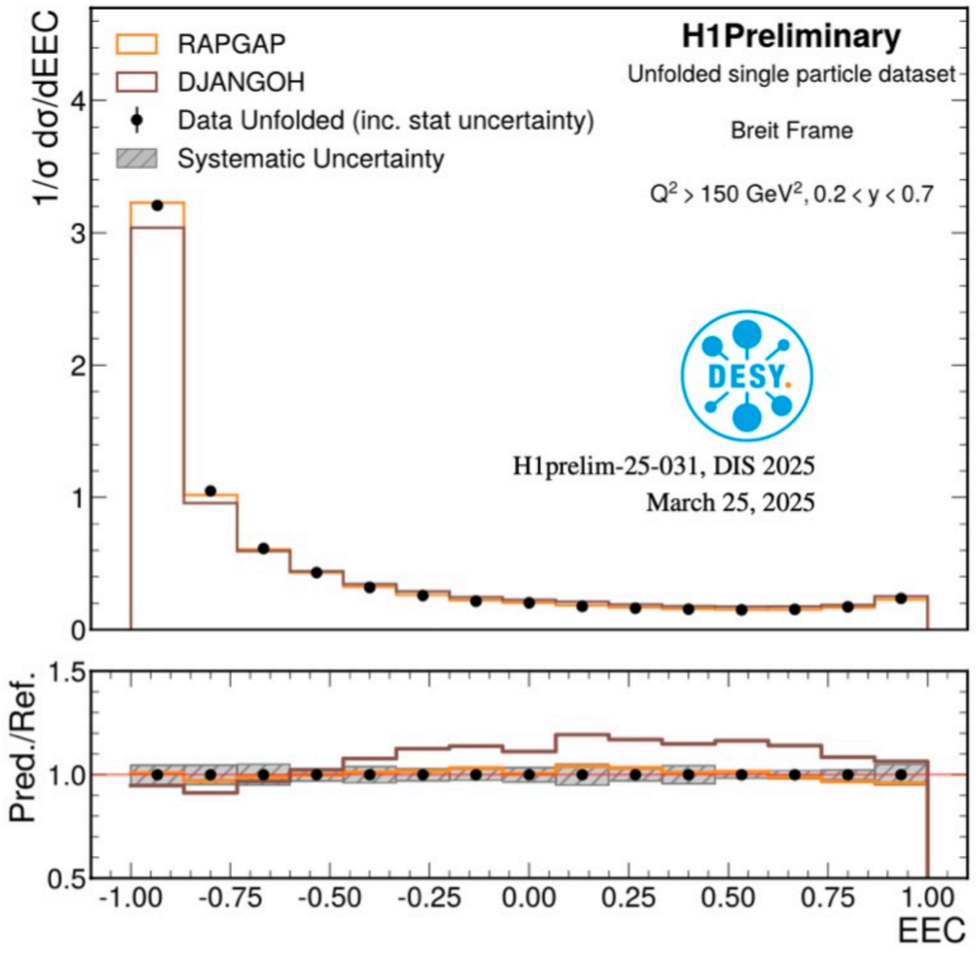
proton $+ \gamma^* \rightarrow$ jet/hadron $+ X$

We proposed a new definition of EEC
correlation

In the back to back limit $\mathrm{EEC} = \sum_a$

$$\frac{d\sigma_h}{d^2p_\perp} = \sum_f \int \frac{d\xi dQ^2}{\xi Q^2} Q_f^2 H(Q,\mu) \int \frac{db}{2\pi} e^{ib_\perp \cdot p_\perp}$$

HTL, Makris, Vitev, PRD, 2021



proton

$p_{n\perp}$

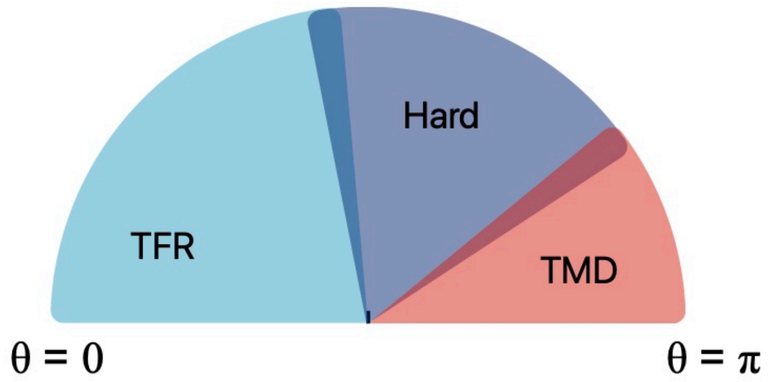
Introduction

NEEC in DIS

Nucleon Energy Correlators

$$\Sigma_N(Q^2,\theta^2)=\sum_i\int d\sigma(x_B,Q^2,p_i)\,x_B^{N-1}\frac{\bar{n}\cdot p_i}{P}\,\delta(\theta^2-\theta_i^2)$$

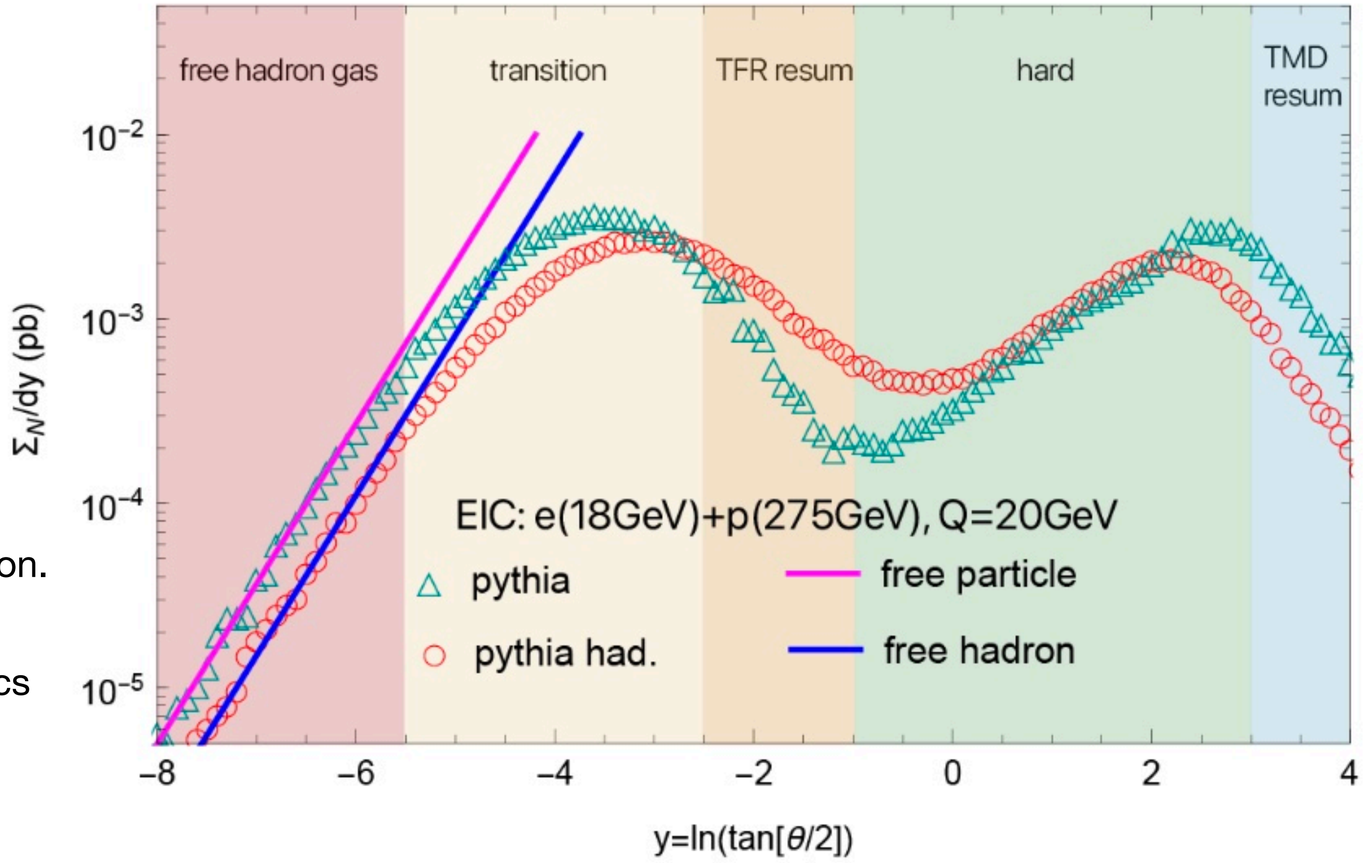
Liu, Zhu, arXiv:2209.02080
Cao, Liu, Zhu, arXiv:2303.01530



TFR: the correlation of the energy flows from the initial nucleon.

Hard: measures the perturbative behavior of QCD

TMD: measures perturbative and nonperturbative TMD physics



Cao, HTL, Mi, PRD, 24

Introduction

NEEC in DIS

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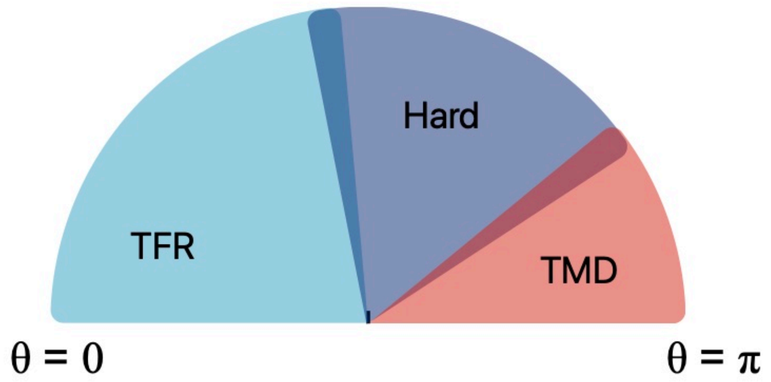

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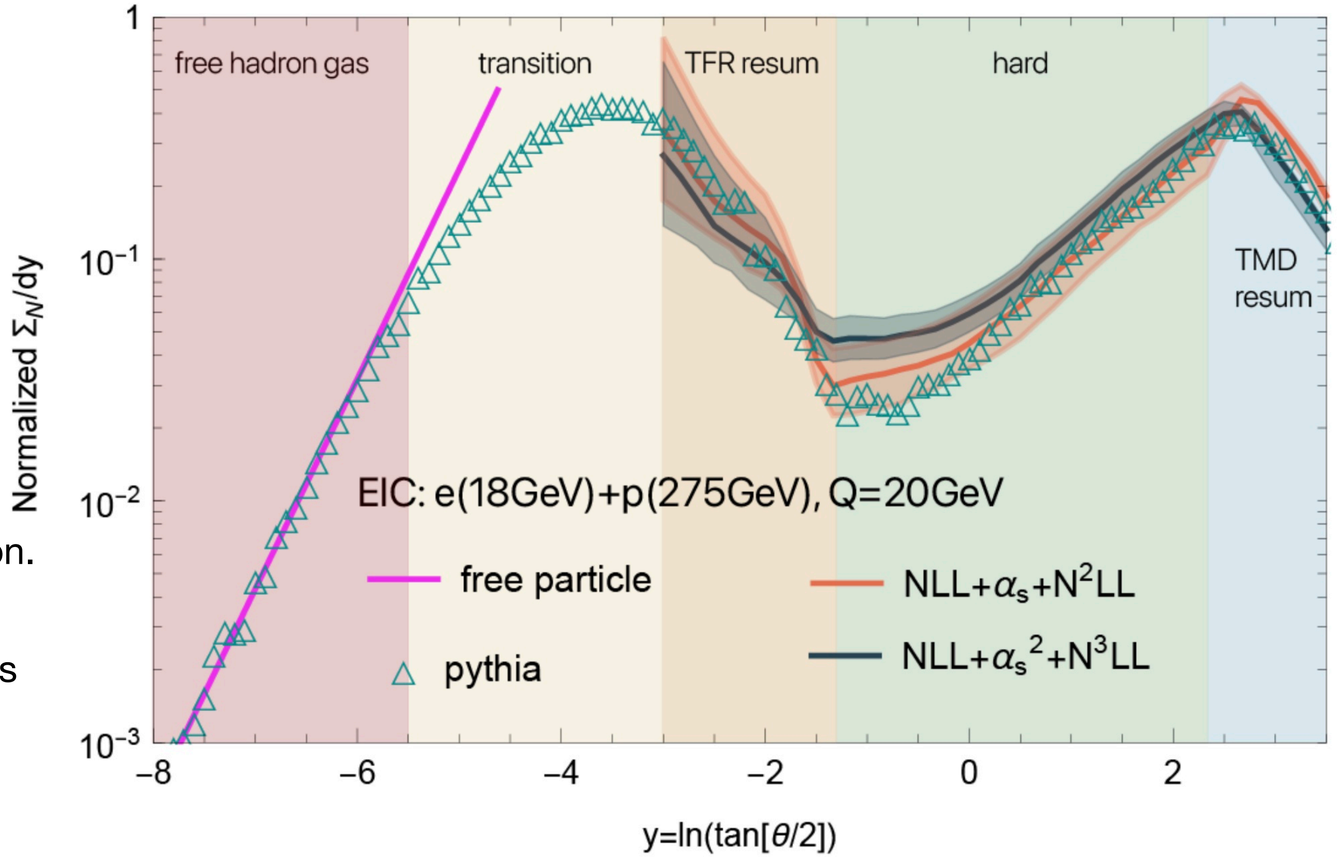

Cao, HTL, Mi, PRD, 24

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Introduction

$$\mathrm{TEEC} = \sum_{a,b} \int d\sigma_{pp\to a+b+X} \frac{2E_{T,a}E_{T,b}}{|\sum_i E_{T,i}|^2} \delta(\cos\phi_{ab} - \cos\phi)$$

Jets as input

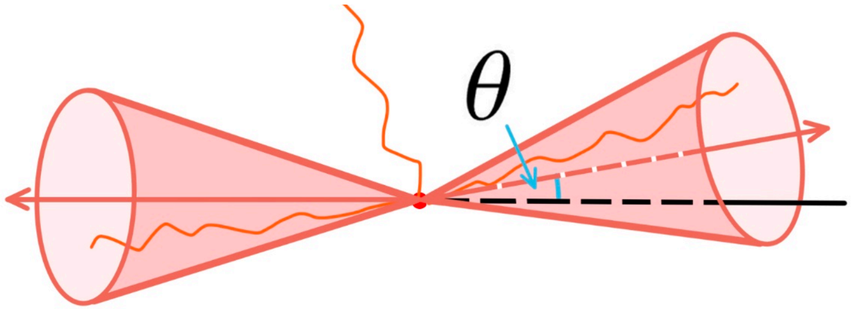
- The jets are usually defined through an angular resolution parameter R and a transverse momentum cutoff
- Less contamination from underlying events
- Introduce new cutoff scale
- Problem of globalness, i.e. non-global logs
- Measurable at LHC and EIC

Particles as input

- Simpler defined observable
- relative larger effects from underlying events
- NO new cutoff scale introduced
- Global event shapes
- Measurable at LHC and EIC

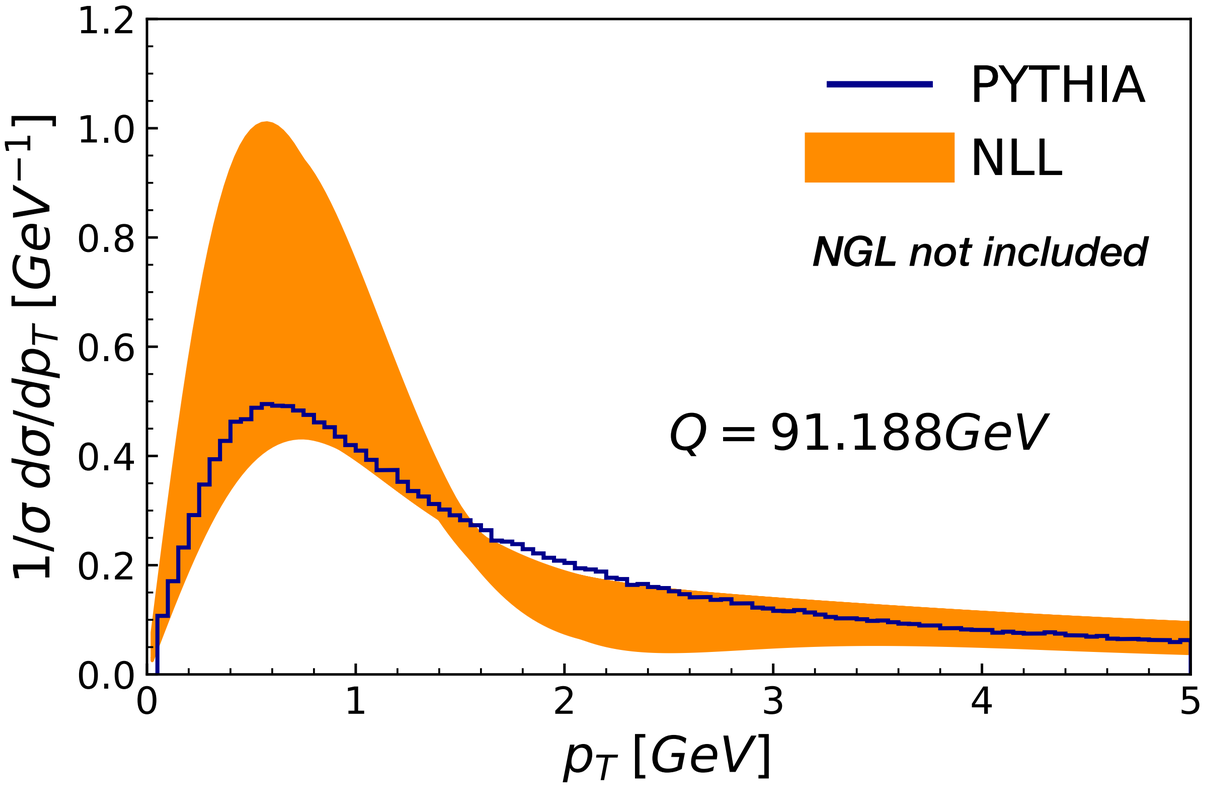
EEC with jets

$$\mathrm{EEC} = \sum_{a,b} \int d\sigma_{V\to a+b+X} \frac{2E_a E_b}{Q^2 \sigma_{\mathrm{tot}}} \delta(\cos(\theta_{ab}) - \cos(\chi))$$



In jet, soft and/or collinear radiations do not change the opening angle of the jets

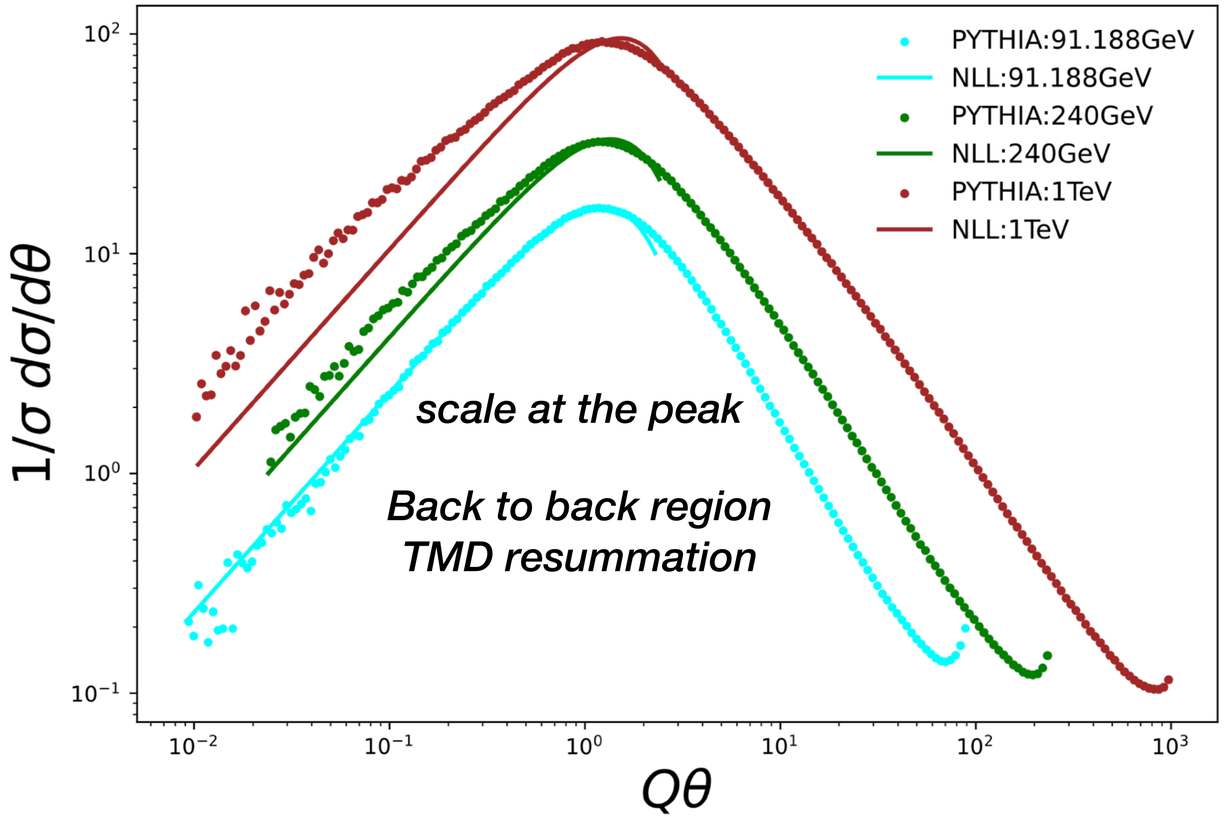
Outside of jet, soft radiation would shift the angle away from back to back region



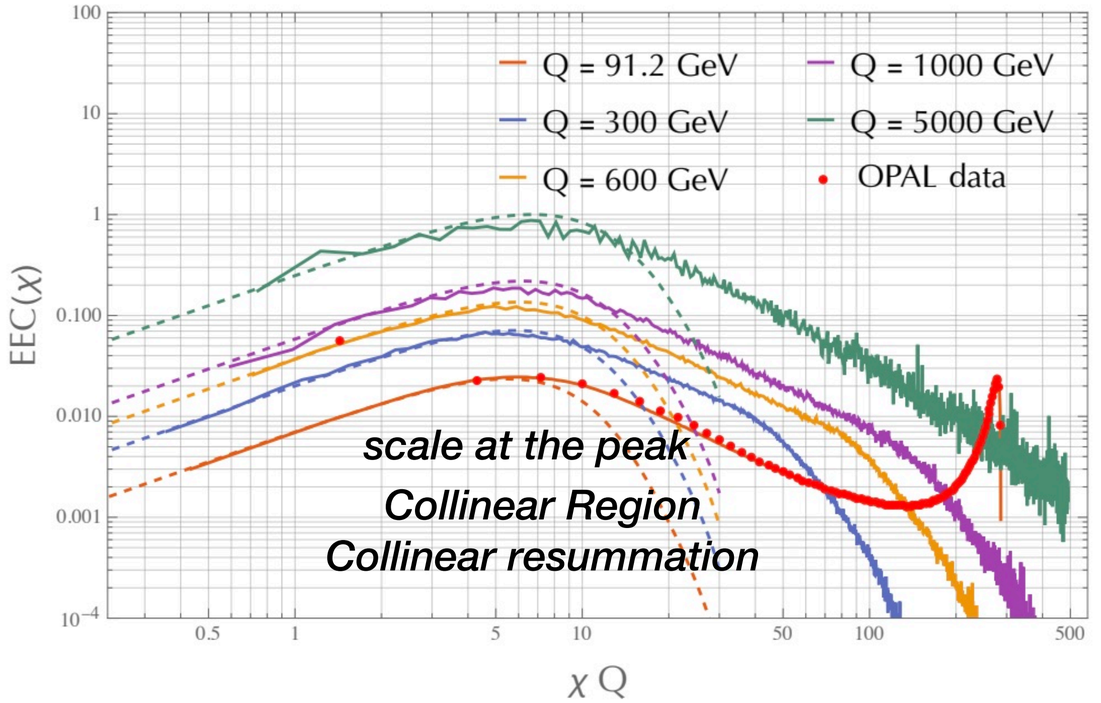
$$\frac{1}{\sigma_0}\frac{d\sigma}{d^2\mathbf{p}_\perp} = H\left(Q^2,\mu\right) J_c\left(Q^2,\delta,\mu\right) J_{\bar{c}}\left(Q^2,\delta,\mu\right)$$

$$\times \int \frac{d\vec{b}}{(2\pi)^2} e^{i\vec{b}\cdot\vec{p}_\perp} S\left(Q^2,\vec{b},\mu,\nu\right) S_{sc}\left(\delta Q^2,\vec{b},\mu,\nu\right) S_{s\bar{c}}\left(\delta Q^2,\vec{b},\mu,\nu\right)$$

EEC with jets



He, HTL, Shao, in preparation



$$c^3 N E_J^2 \chi \int dbbJ_0\left(cE_J\chi b\right) e^{-\frac{g_1}{c^2}b^2} \times e^{-\frac{g_2}{2}\ln\left(\frac{b}{b_*}\right)\ln\frac{cE_J}{\mu_0}}$$

Liu, Vogelsang, Yuan, Zhu, PRL 2025

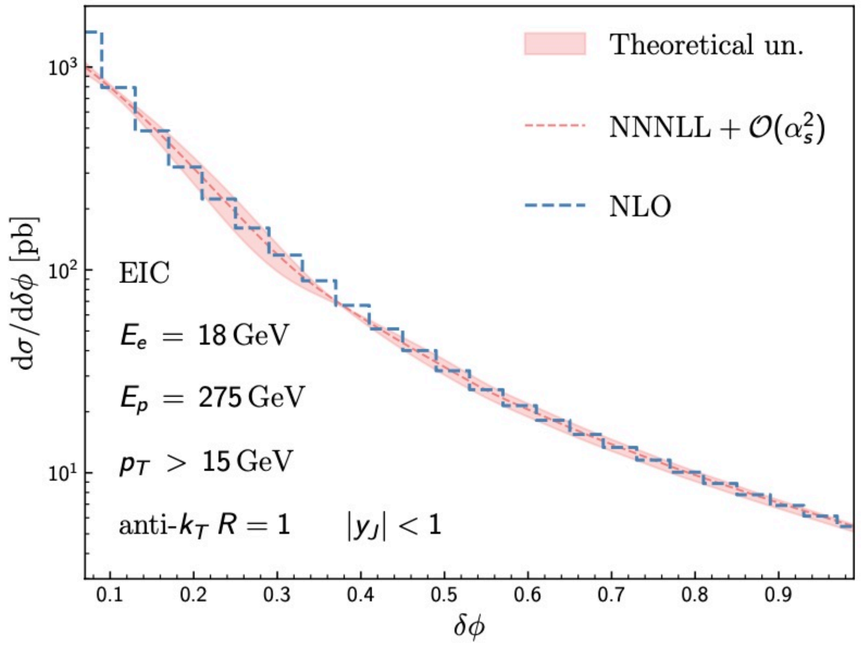
EEC with jets

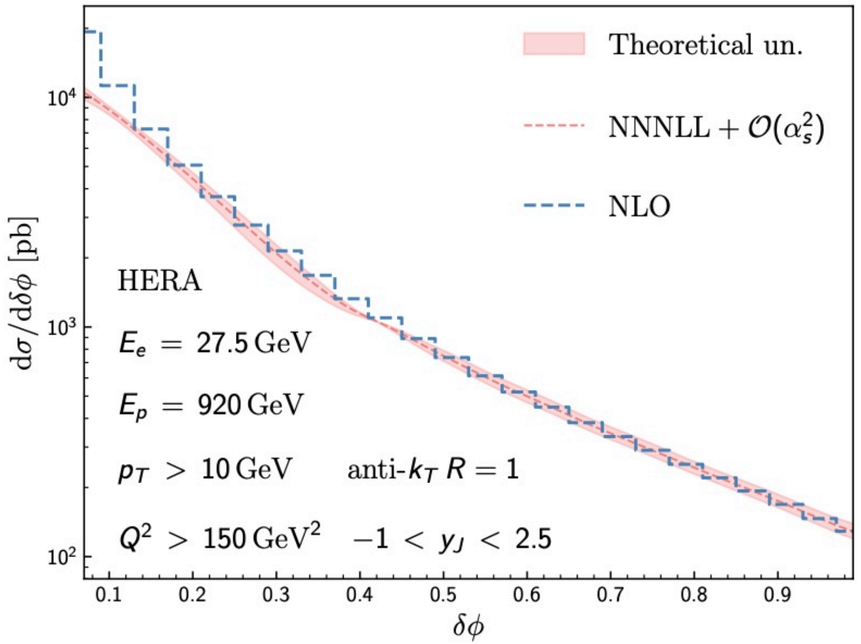
WTA jet axis in ee and DIS

Jets are defined by the anti-kTclustering algorithm and the winner-take-all recombination scheme.

$$\frac{\mathrm{d}\sigma}{\mathrm{d}^2 p_T \,\mathrm{d}y_J \,\mathrm{d}\lambda_x} = \sigma_0 \, H(Q,\mu) \int_{-\infty}^{+\infty} \frac{\mathrm{d}b_x}{2\pi} e^{ib_x\lambda_x} \sum_q e_q^2 \; \mathcal{B}_{q/p}\left(x_{\mathtt{bj}}, b_x, \mu, \zeta_B/\nu^2\right)$$

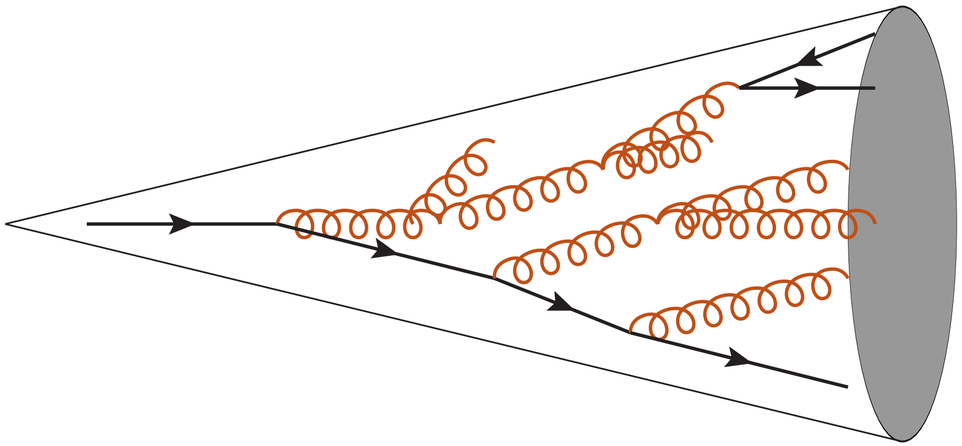
$$\times \, \mathcal{J}_q\left(b_x, \mu, \zeta_{\mathcal{J}}/\nu^2\right) \, \mathcal{S}\left(b_x, n\cdot n_J, \mu, \nu\right),$$

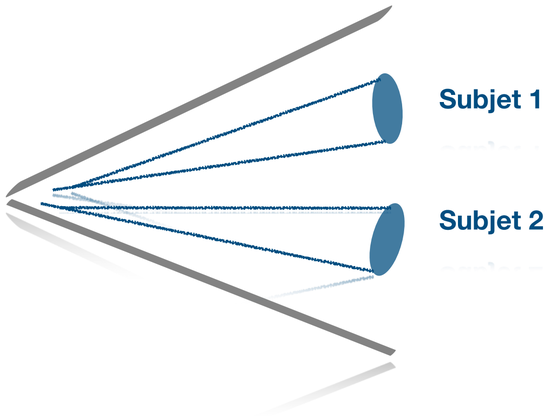




Feng, Gao, HTL, Shao, JHEP 25

EEC with jets





Original jet with radius

Undo last stage of C/A clustering

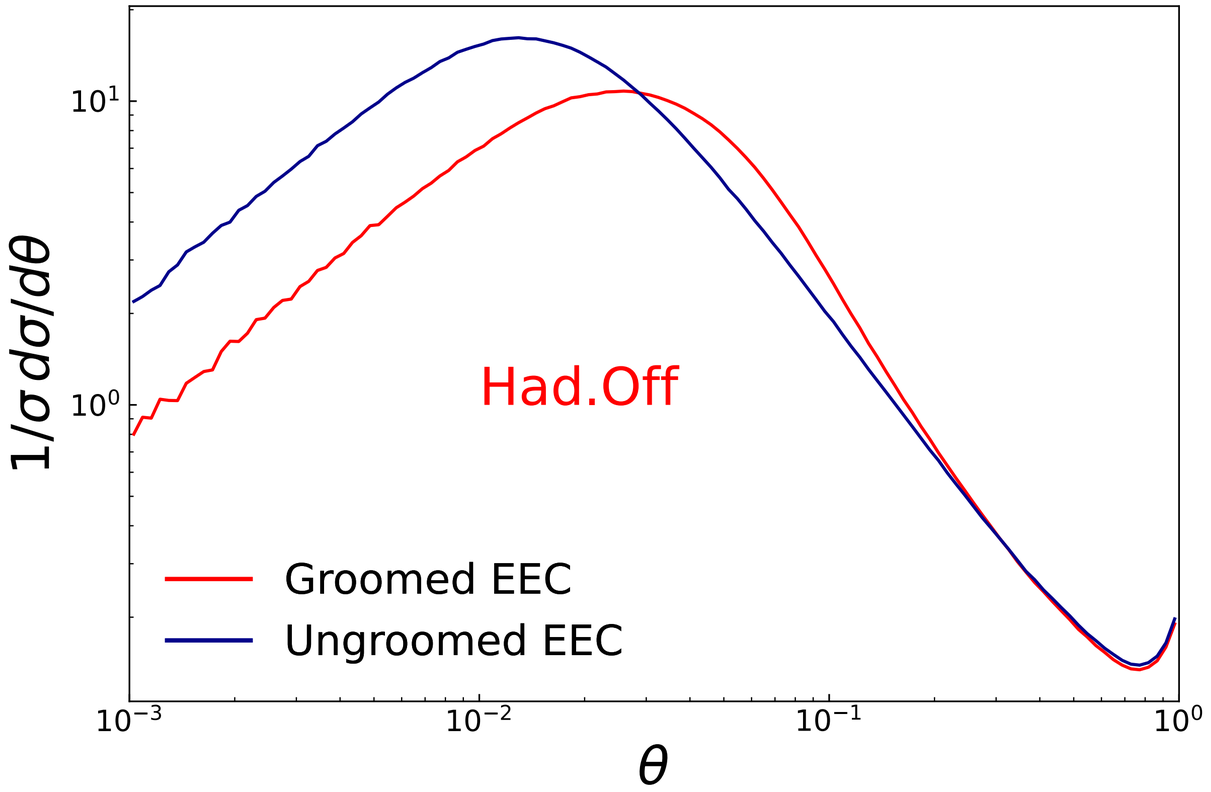
Define $$z_g = \frac{\min\left(p_{T1}, p_{T2}\right)}{p_{TG1} + p_{T2}}$$

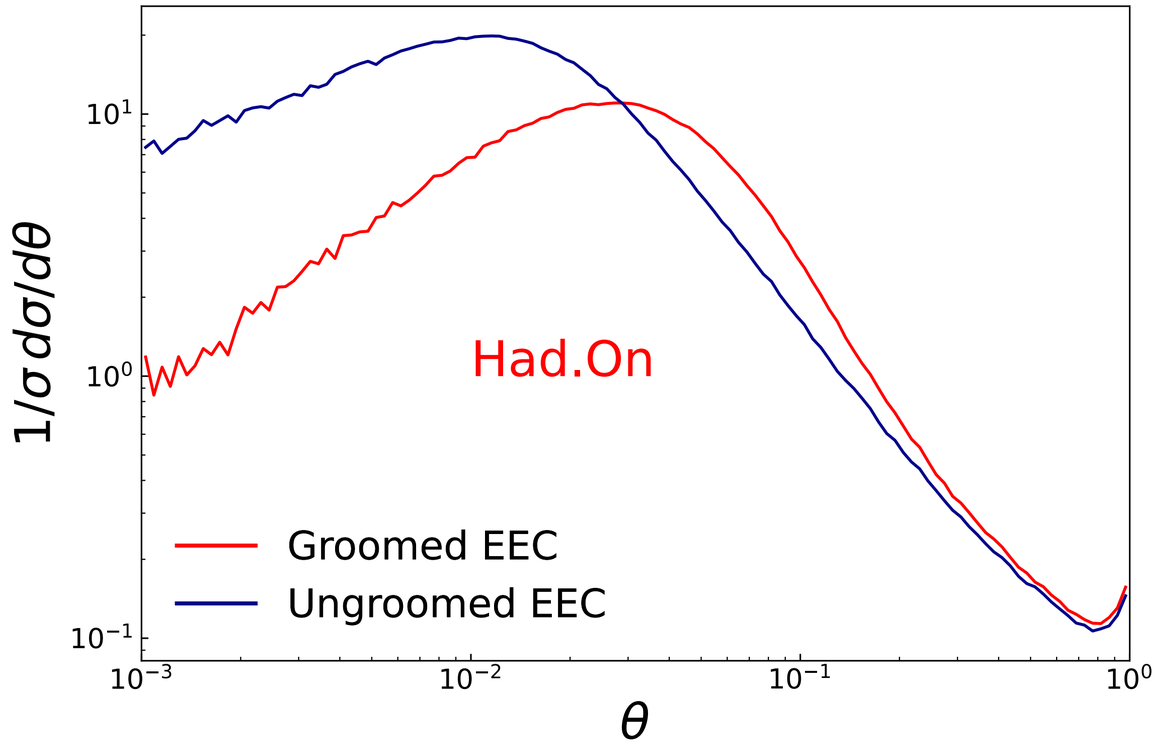
If $z_g < z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$ redefine j to be the harder one,

else we have the two-prong subjets

EEC with jets

Pythia simulation in back to back region



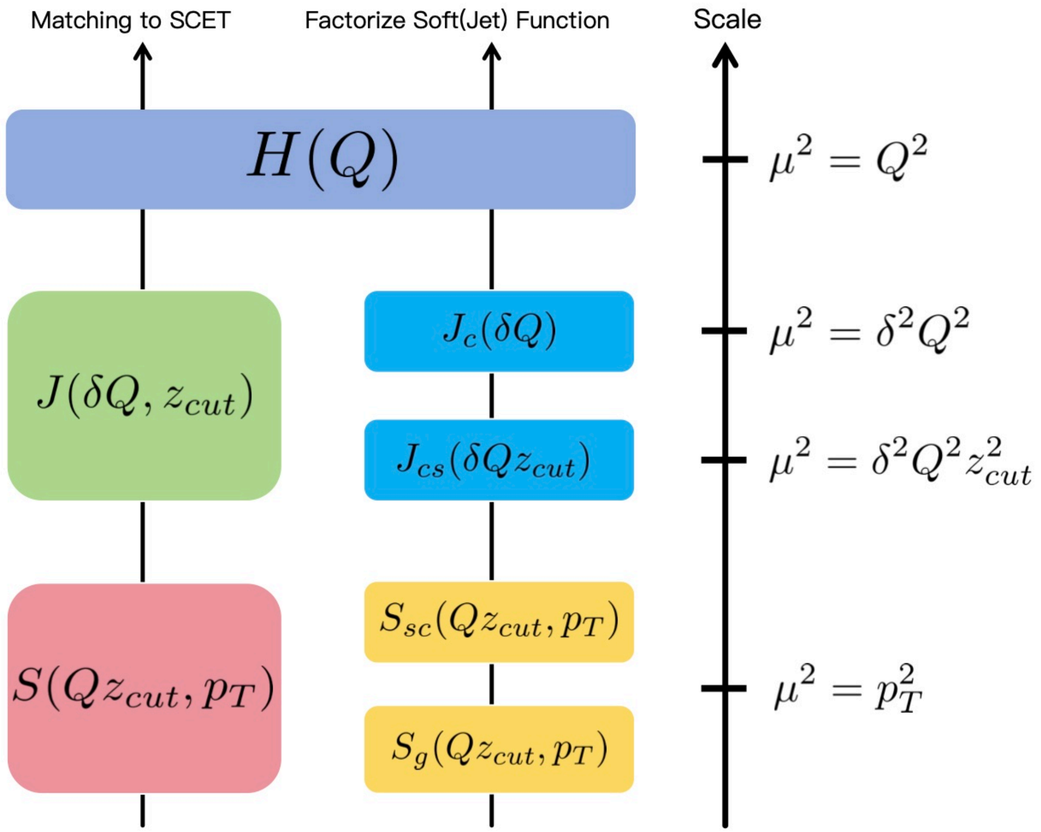


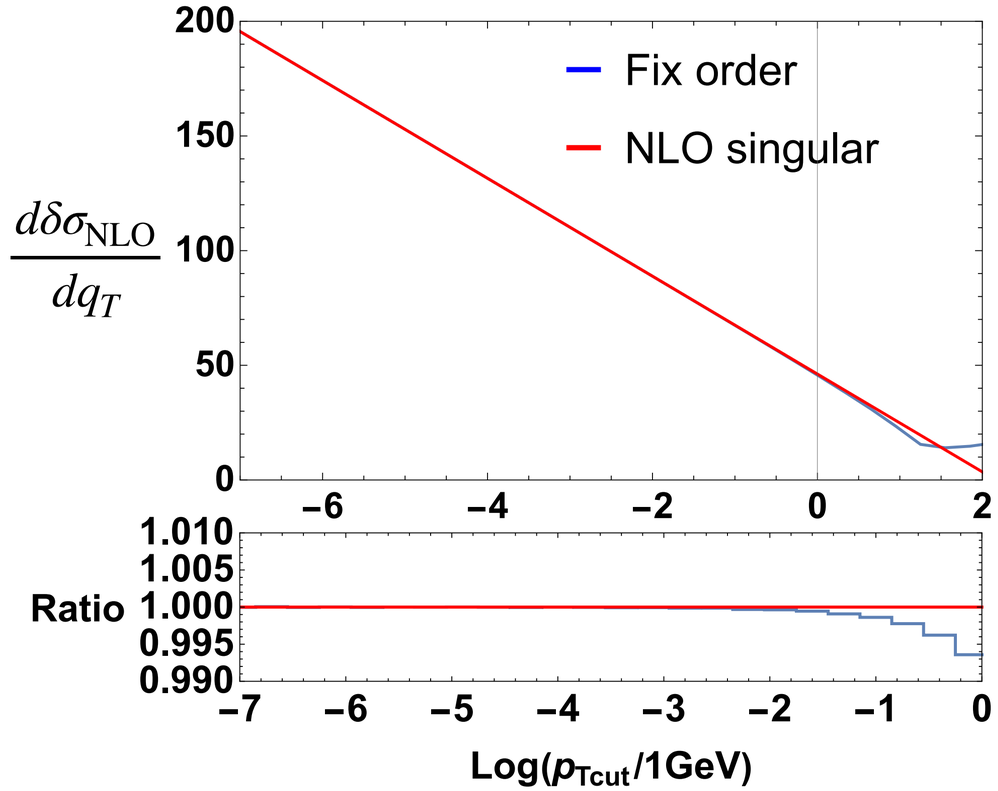
EEC with jets

Groomed jets in back to back limits

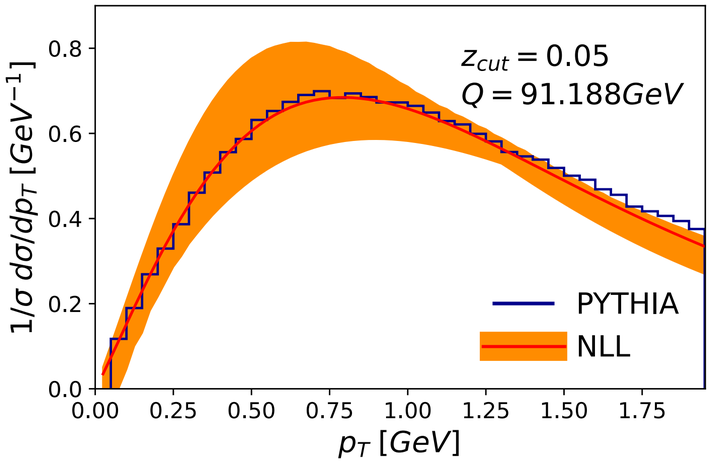
$$\frac{1}{\sigma_0}\frac{d\sigma}{d^2\mathbf{p}_\perp} = H\left(Q^2,\mu\right) J_c\left(Q^2,\delta,\mu\right) J_{\bar{c}}\left(Q^2,\delta,\mu\right) J_{cs}\left(Q^2,\delta,z_{\rm cut},\mu\right) J_{\bar{c}s}\left(Q^2,\delta,z_{\rm cut},\mu\right)$$

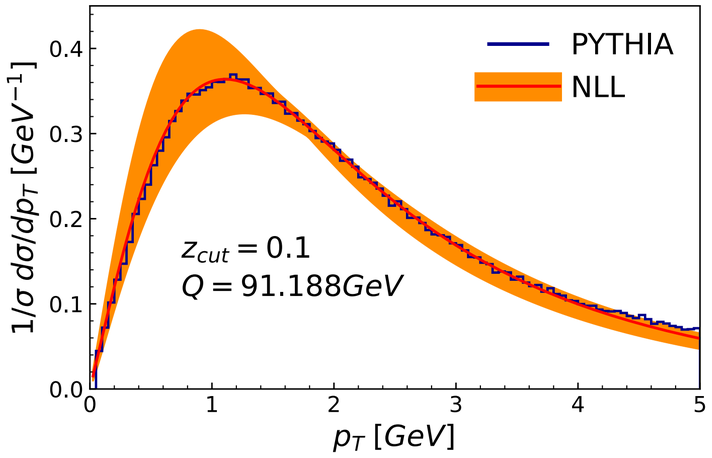
$$\times \int \frac{d\vec{b}}{(2\pi)^2} e^{i\vec{b}\cdot\vec{p}_\perp} S\left(Q^2,\vec{b},\mu,\nu\right) S_{sc}\left(Q^2,\vec{b},z_{\rm cut},\mu,\nu\right) S_{s\bar{c}}\left(Q^2,\vec{b},z_{\rm cut},\mu,\nu\right)$$

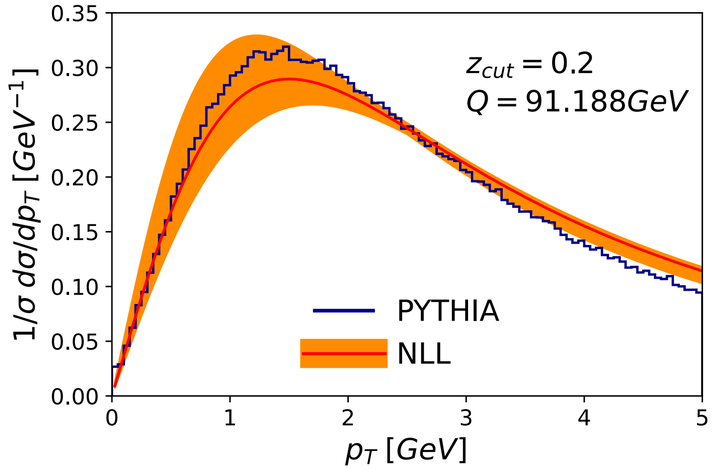


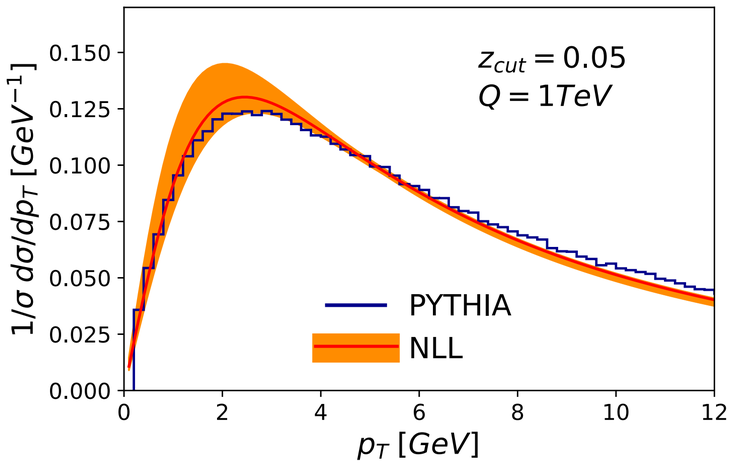


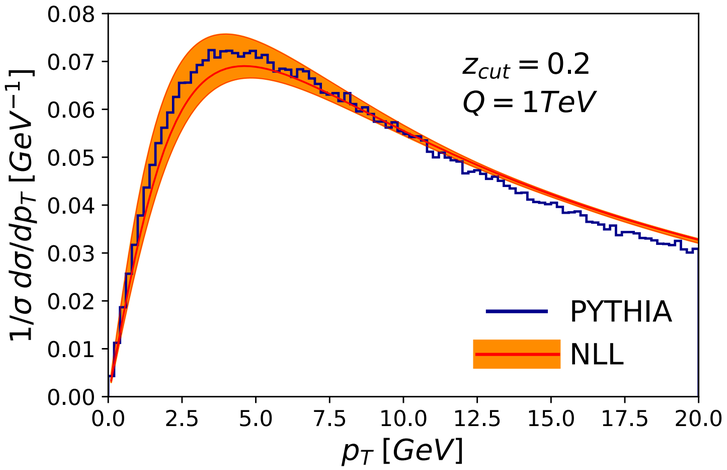
EEC with jets

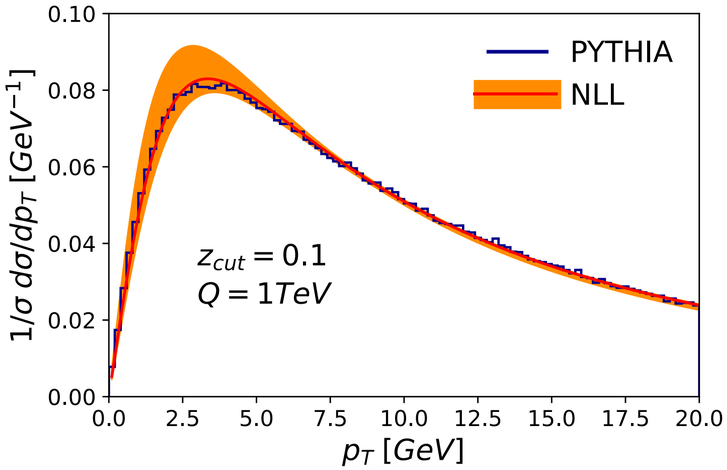








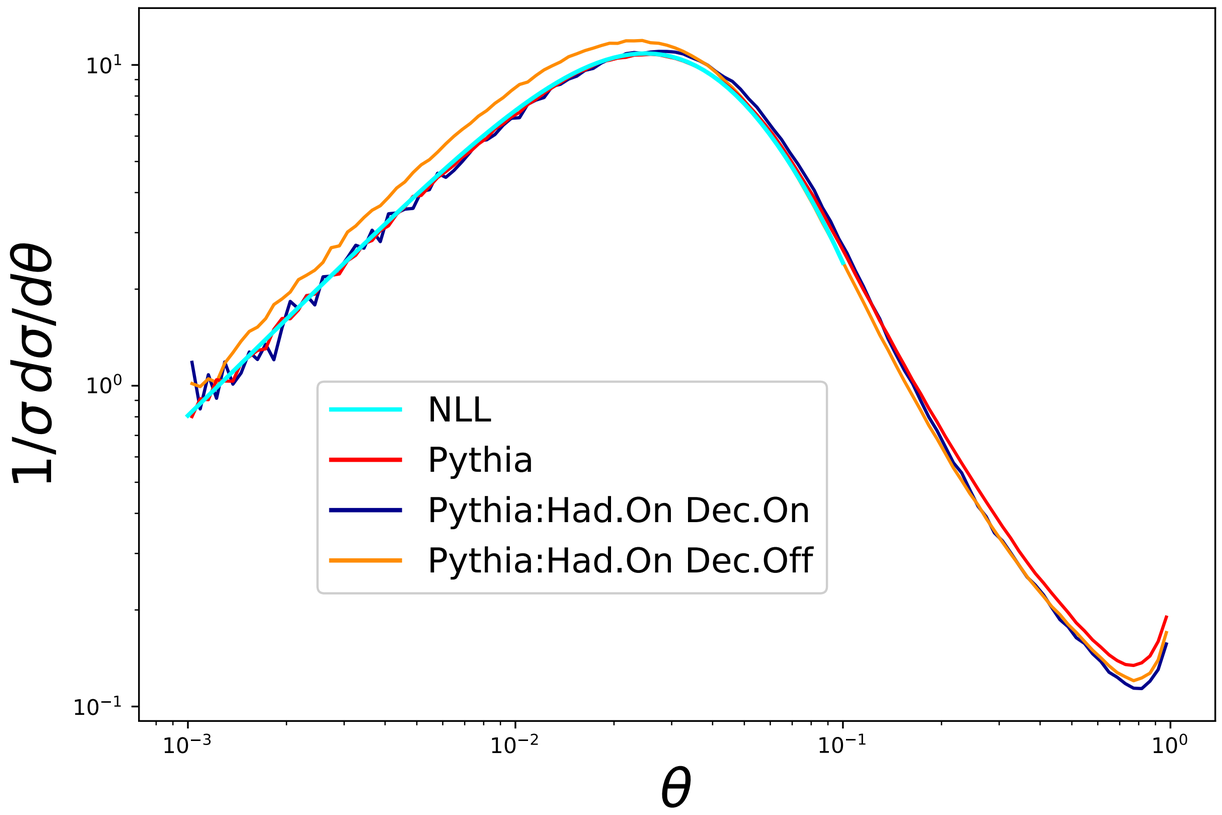


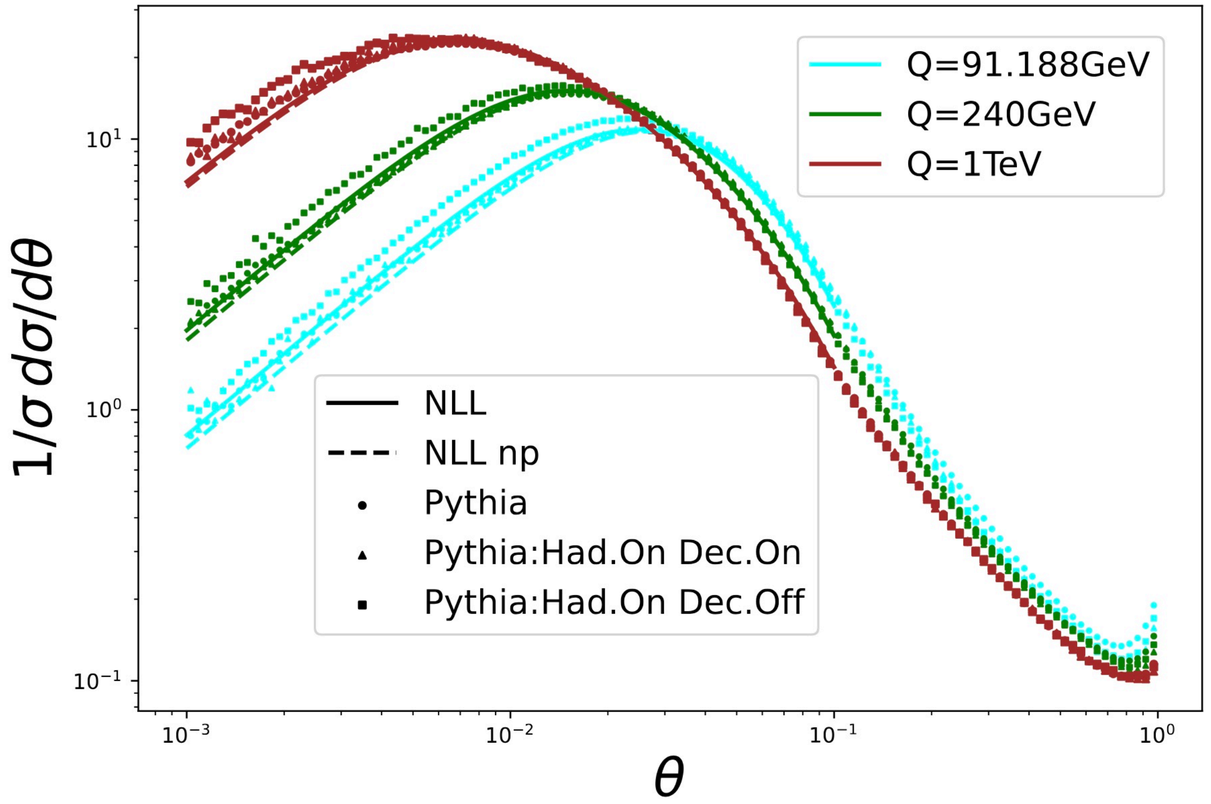


He, HTL, Shao, in preparation

EEC with jets

EEC with groomed jet





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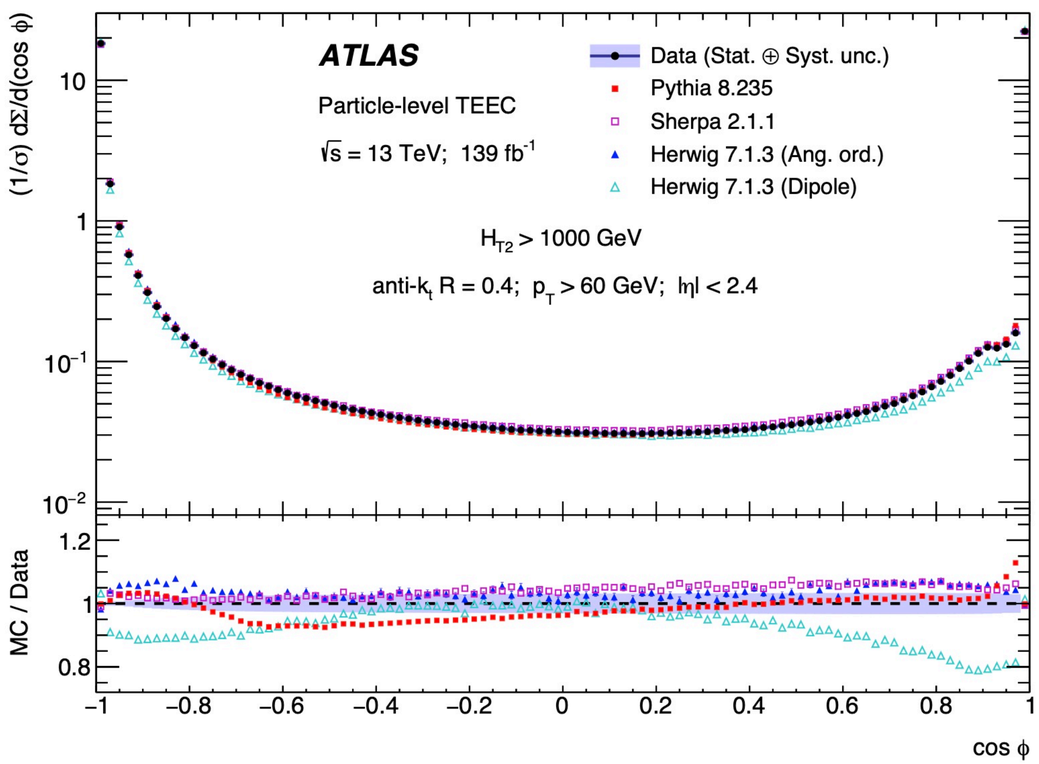
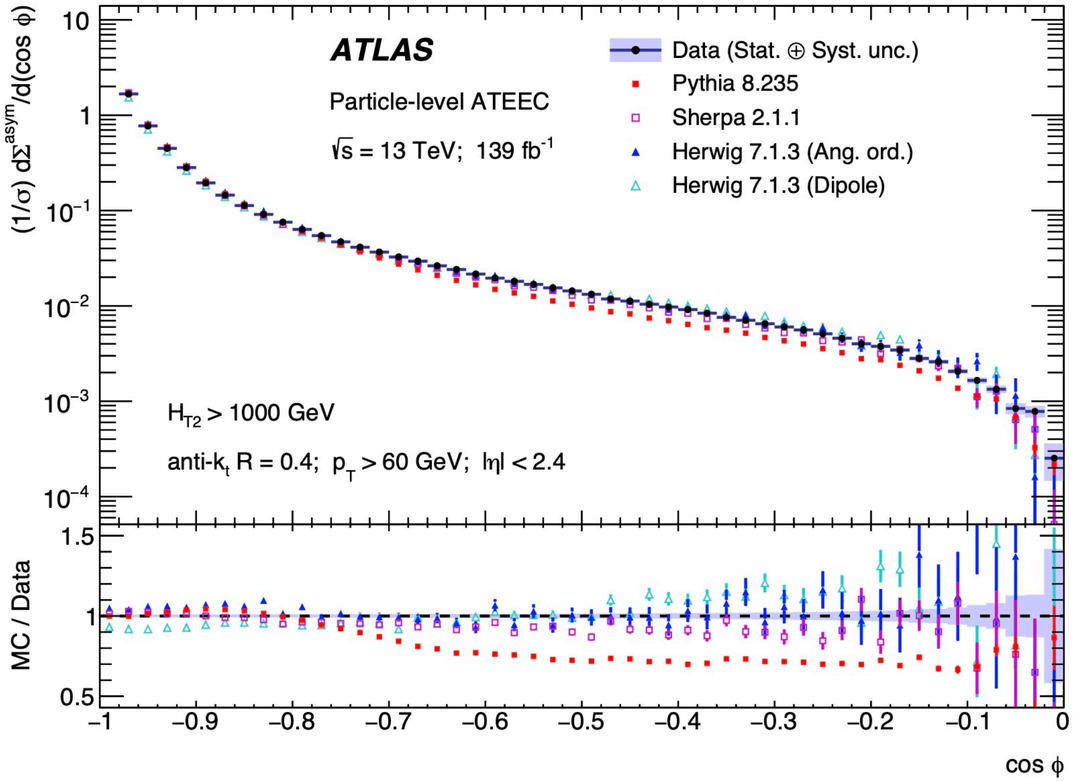
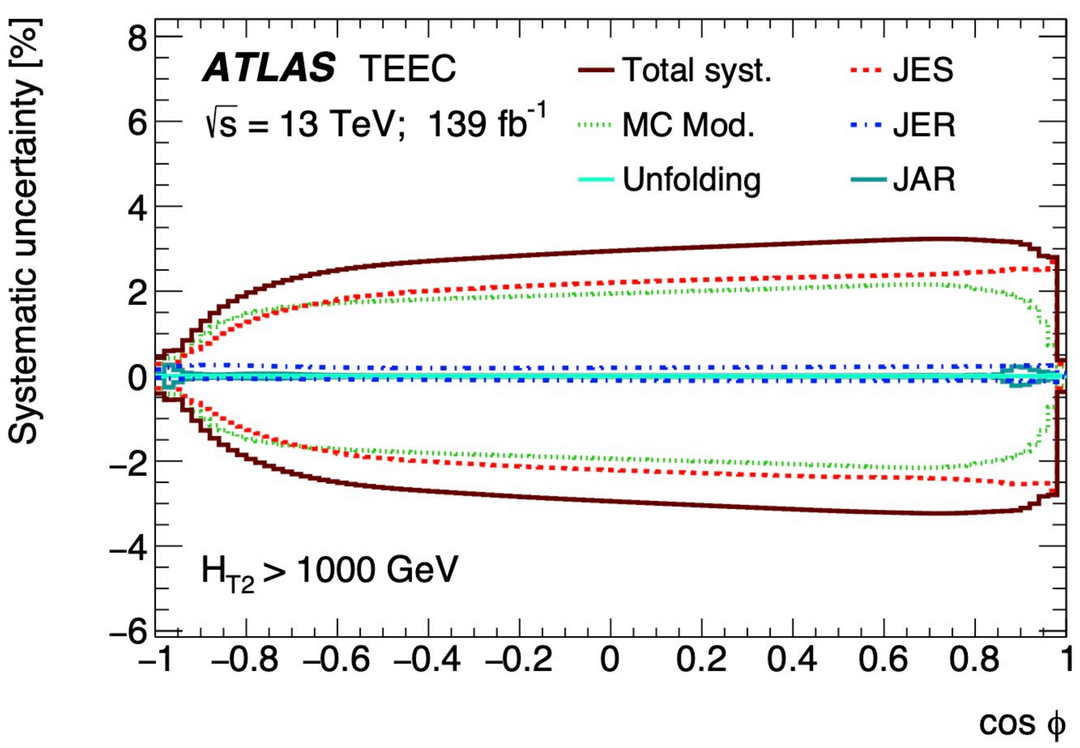
EEC and α_s measurement

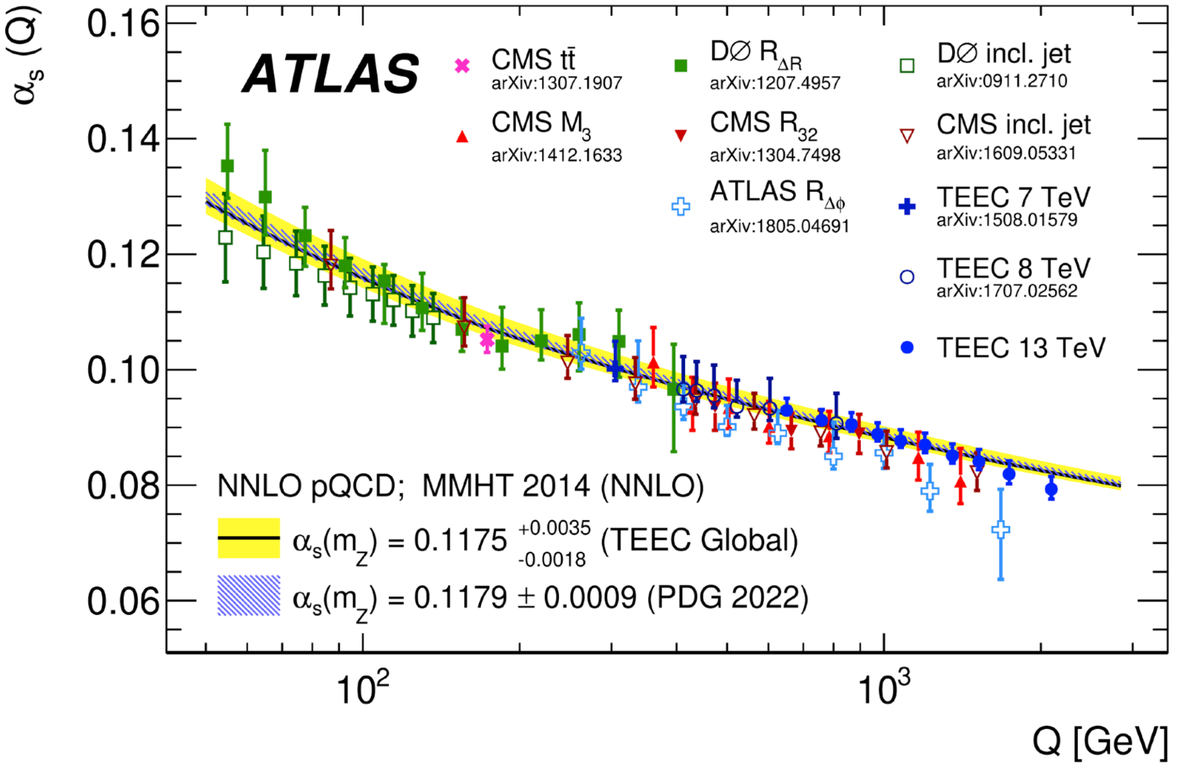




ATLAS, JHEP, 2023

EEC and α_s measurement





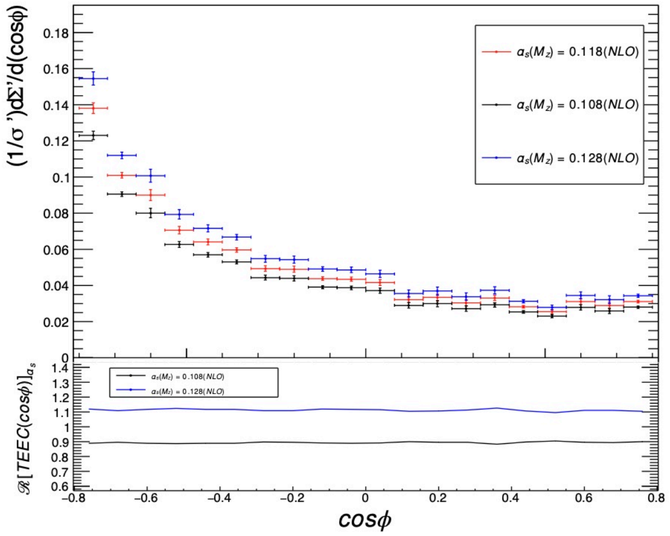
From TEEC $\alpha_s(m_Z) = 0.1185 \pm 0.0009\ (\text{exp.})^{+0.0025}_{-0.0012}\ (\text{theo.})$.

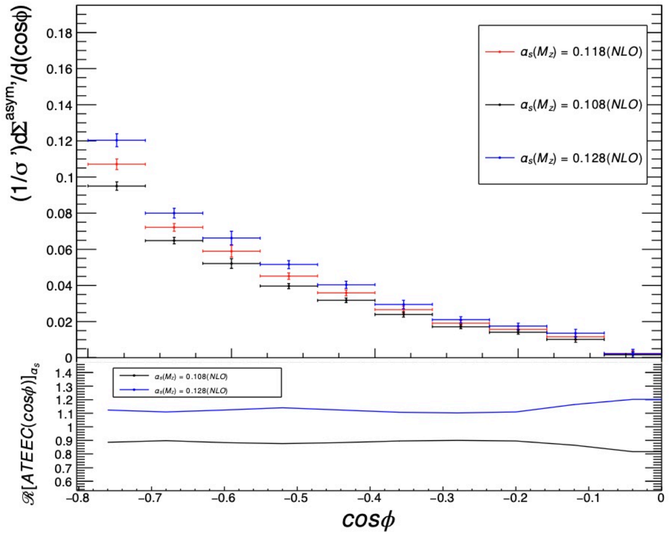
From ATEEC $\alpha_s(m_Z) = 0.1175 \pm 0.0006\ (\text{exp.})^{+0.0034}_{-0.0017}\ (\text{theo.})$

EEC and α_s measurement

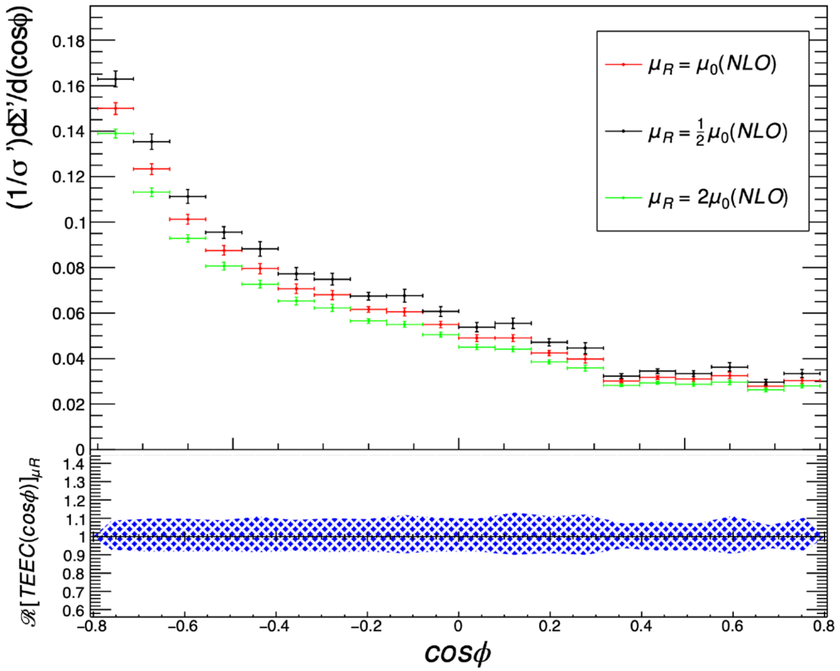
$$\frac{1}{\sigma'}\frac{d\Sigma'}{d\cos\phi} \equiv \frac{\sum_{a,b}\int dE_T d\cos\phi_{ab}\frac{d\sigma_{\gamma p\to a+b+X}}{dE_T d\cos\phi_{ab}}\frac{2E_{T,a}E_{T,b}}{|\sum_i E_{T,i}|^2}\delta(\cos\phi_{ab}-\cos\phi)}{\int dE_T d\sigma_{\gamma p\to a+b+X}/dE_T}$$

$$\frac{1}{\sigma'}\frac{d\Sigma'^{asym}}{d\cos\phi} \equiv \frac{1}{\sigma'}\frac{d\Sigma'}{d\cos\phi}|_{\phi} - \frac{1}{\sigma'}\frac{d\Sigma'}{d\cos\phi}|_{\pi-\phi}.$$





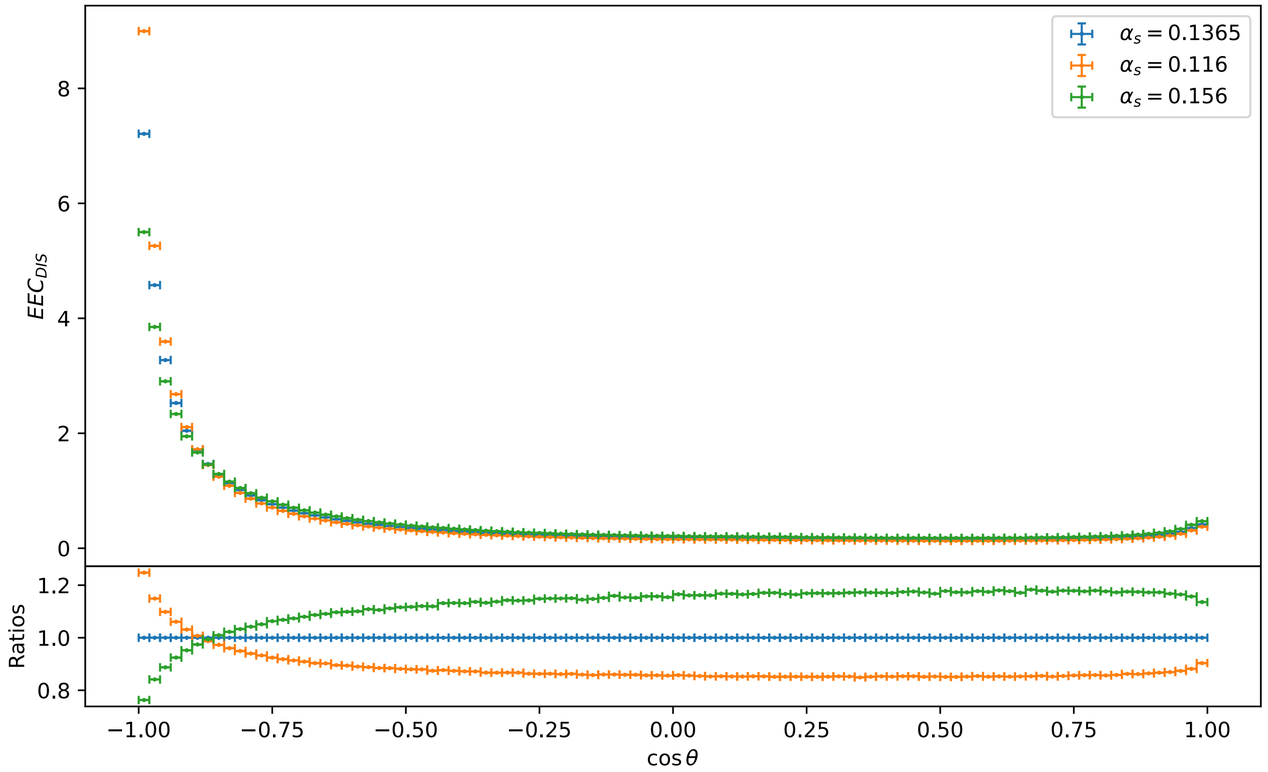
Ali, Li, Wang, Xing, 2020



scale uncertainties

EEC and α_s measurement

Back to Back Resummation region



Fixed order dominated region

From Pythia Simulation, vary the default α_s by $\pm 15\,\%$

Chen, He, HTL, in preparation

EEC and α_s measurement

Back to Back
Resummation regio

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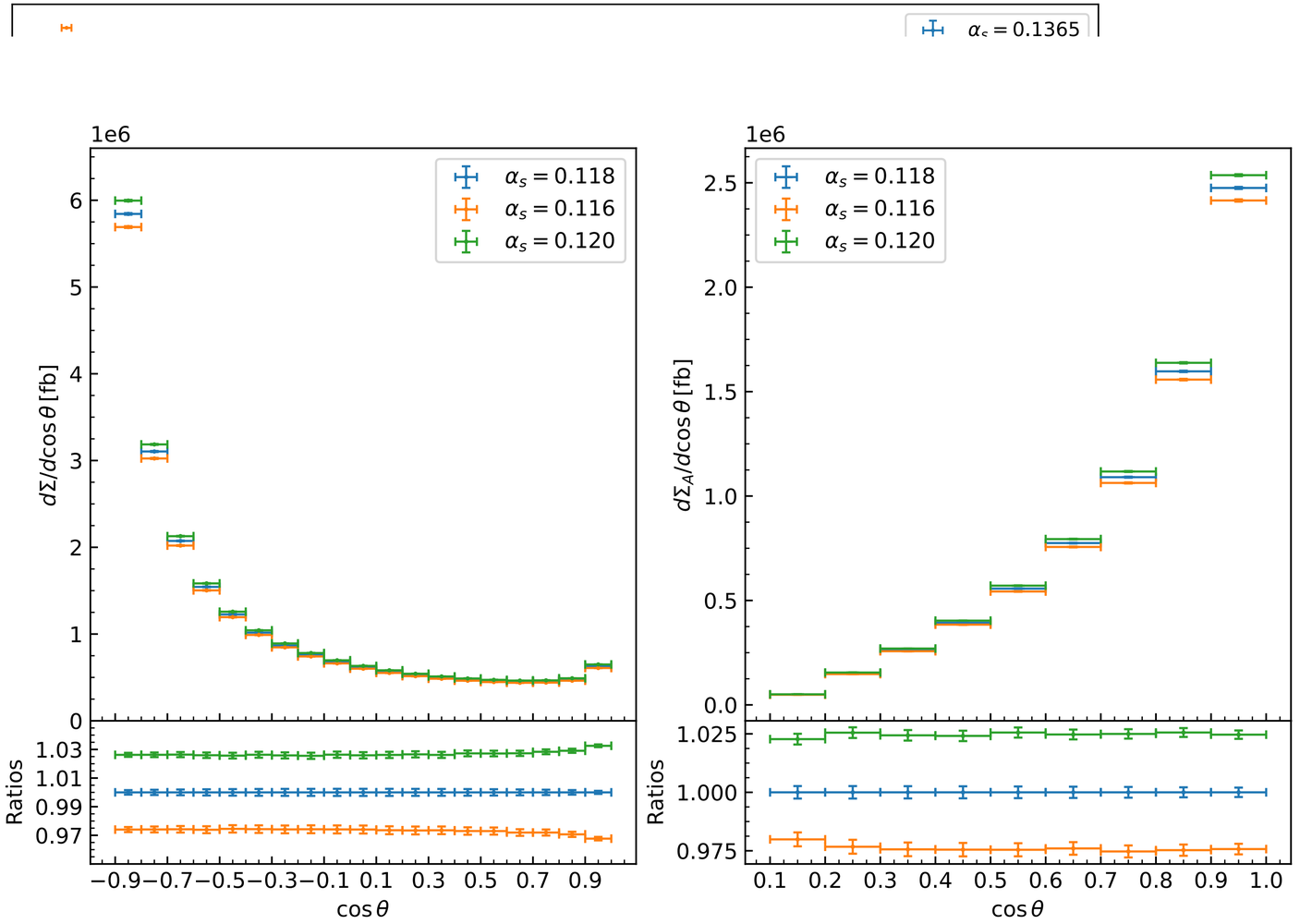
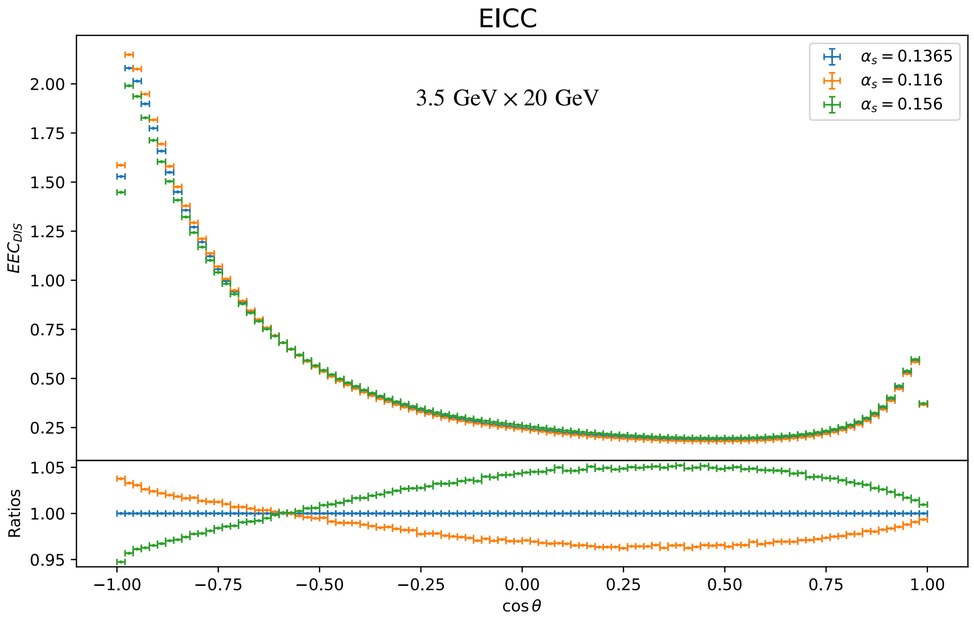


Chen, He, HTL, in preparati

Summary



- Showed EEC/TEEC in the pp and ep collisions as event shape
- Discussed EEC with jets and groomed jets which shows interesting perturbative and non perturbative properties
- Presented EEC distributions and α_s measurements

Thank You!