Transverse Energy-Energy Correlators in DIS

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Based on the work arXiv:2006.02437
In collaboration with Ivan Vitev and YuJiao Zhu

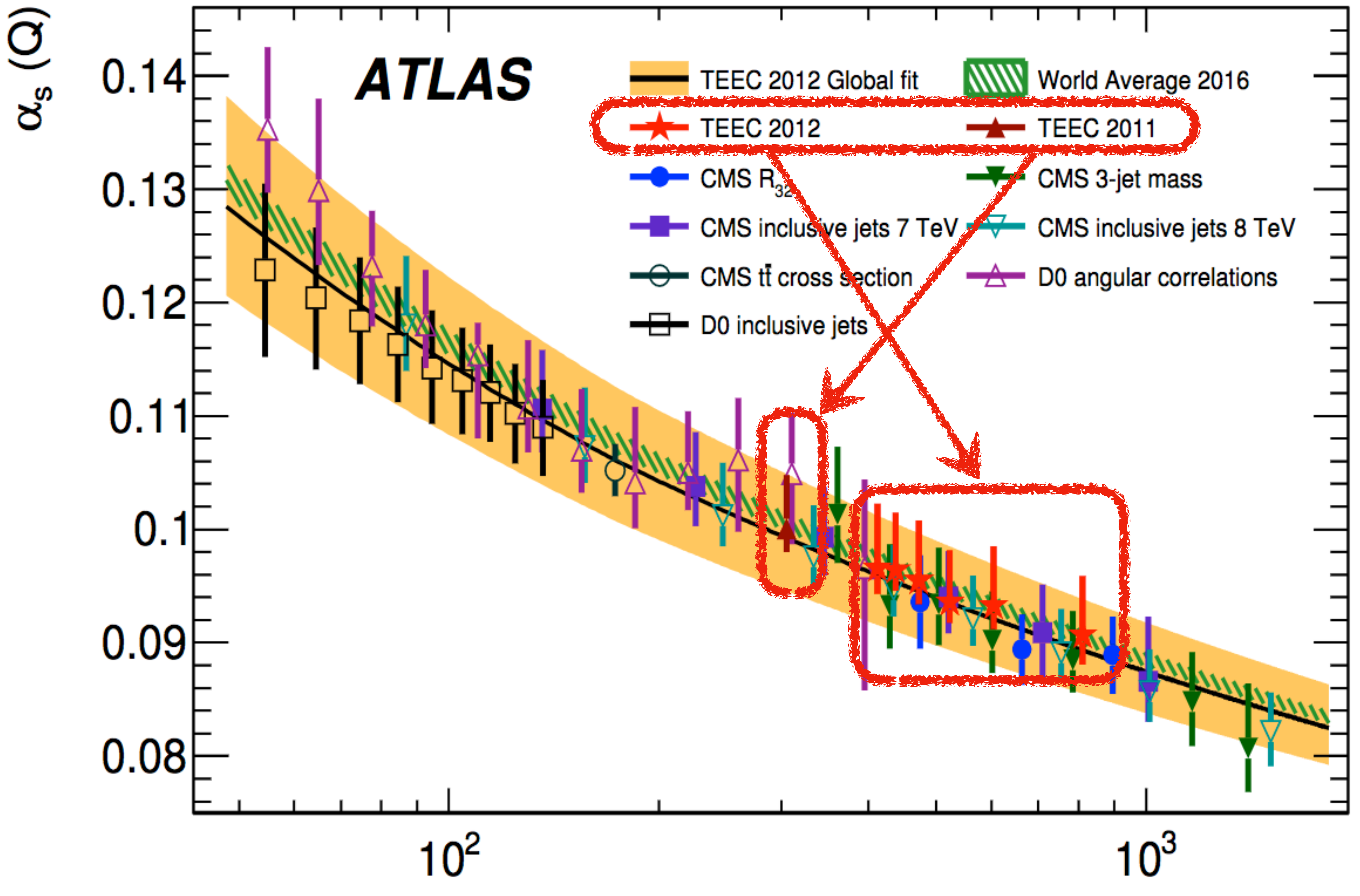
EIC Yellow Report: Jets and Heavy Flavor Physics WG meeting

06-22-2020

Motivations

As other event shape observables

- TEEC measures the flow of radiation in a scattering event.
- TEEC can be studied theoretically with high precision
- TEEC can be measured with high precision
- TEEC can be used to determinate strong coupling
- TEEC can be used to study TMD physics in various colliders



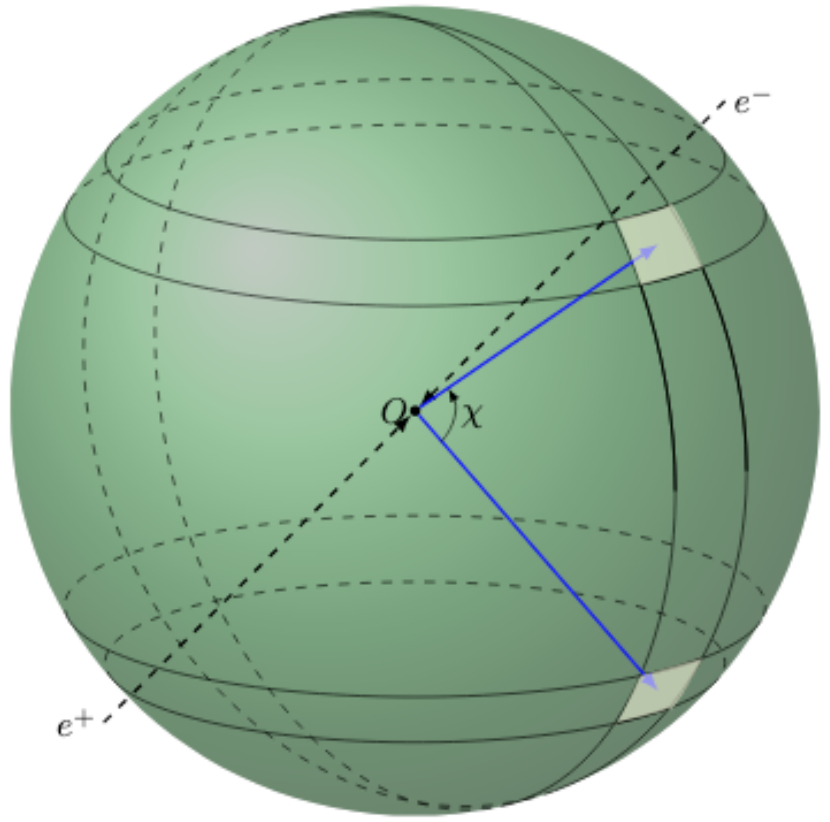
$$\alpha_s(m_Z) = 0.1162 \pm 0.0011\ (\text{exp.})\ ^{+0.0076}_{-0.0061}\ (\text{scale}) \pm 0.0018\ (\text{PDF}) \pm 0.0003\ (\text{NP}),$$

TEEC serve as aprecision test of QCD and new probes to reveal the proton or nuclear structure

Introduction to TEEC

electron-positron collider: Basham et al 1978

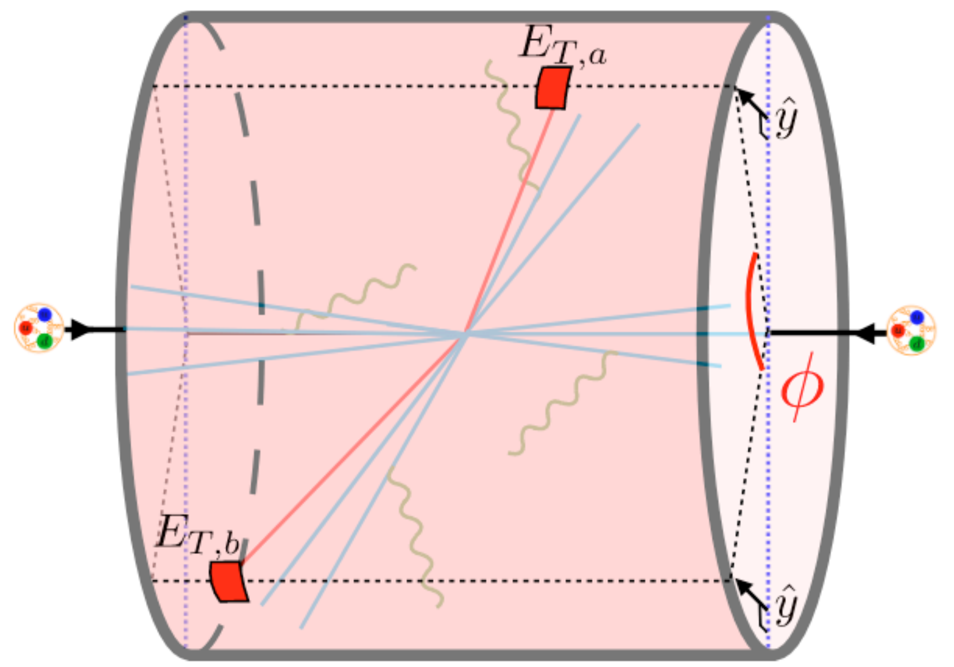
e^+e^- Collisions



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

hadronic collider: Ali et al 1984

Hadronic initial state



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

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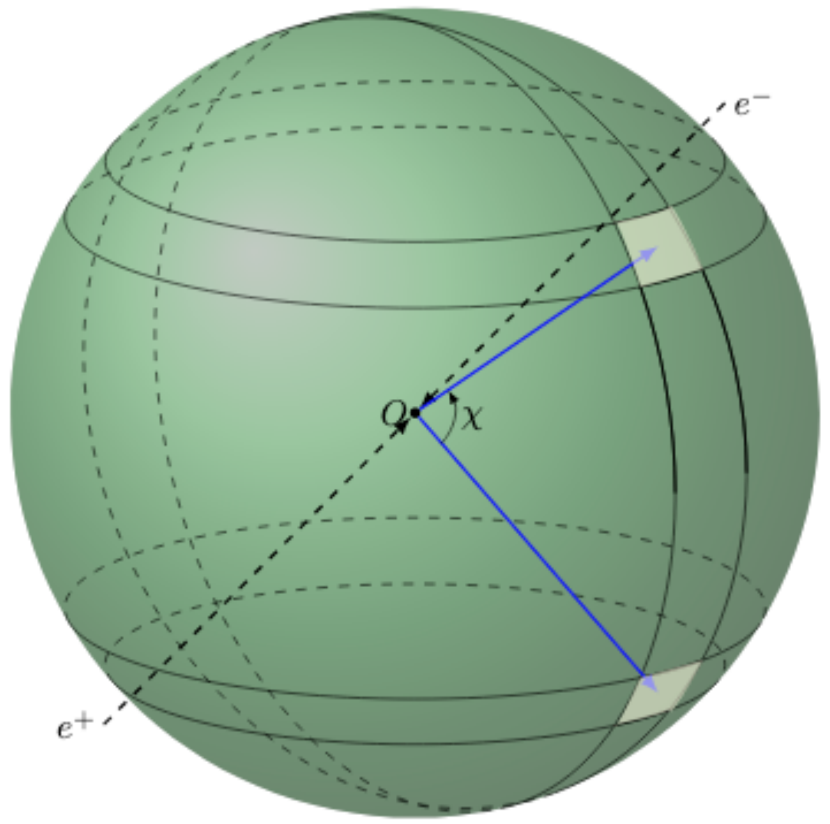

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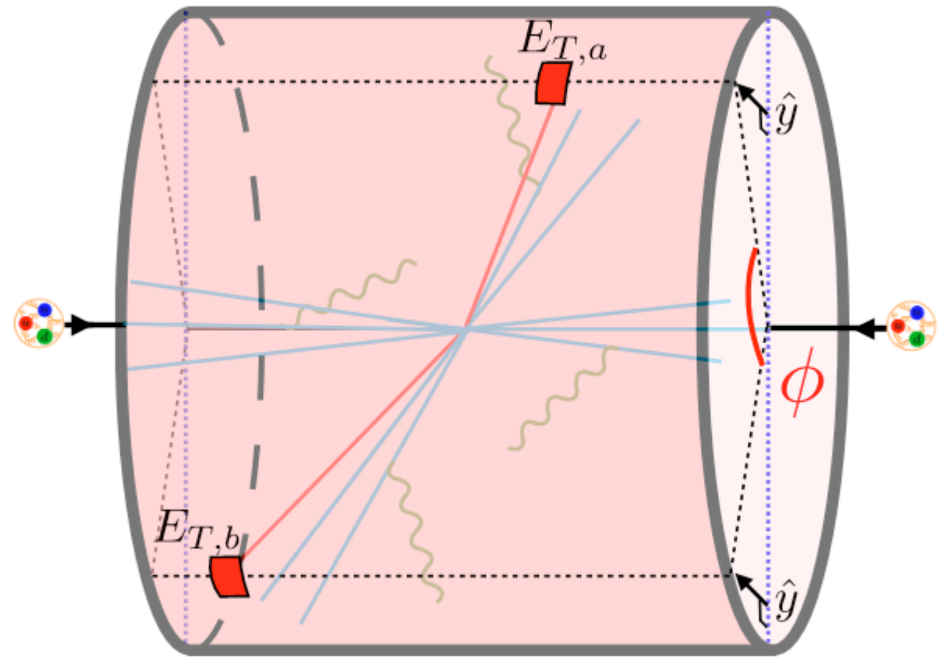

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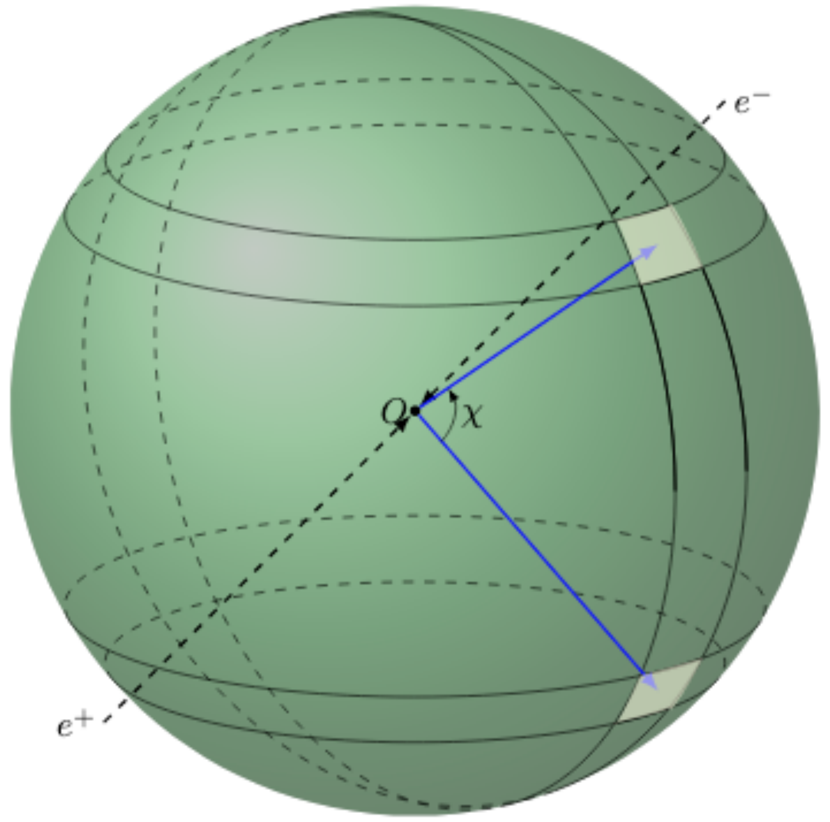

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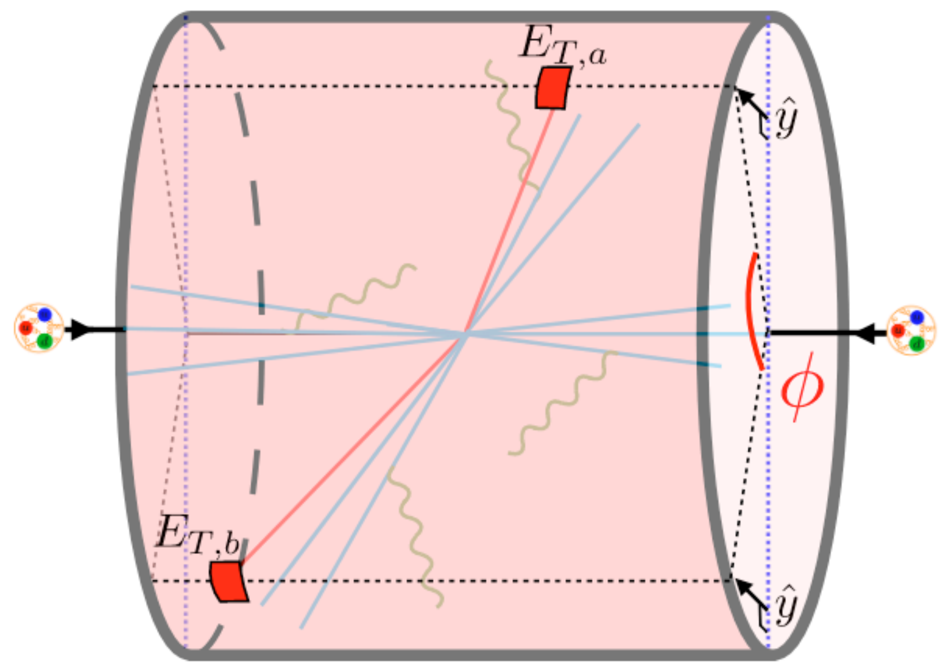

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- the soft radiation does not contribute directly to the observable at leading power
- soft gluon contributes only via recoil

Introduction to TEEC

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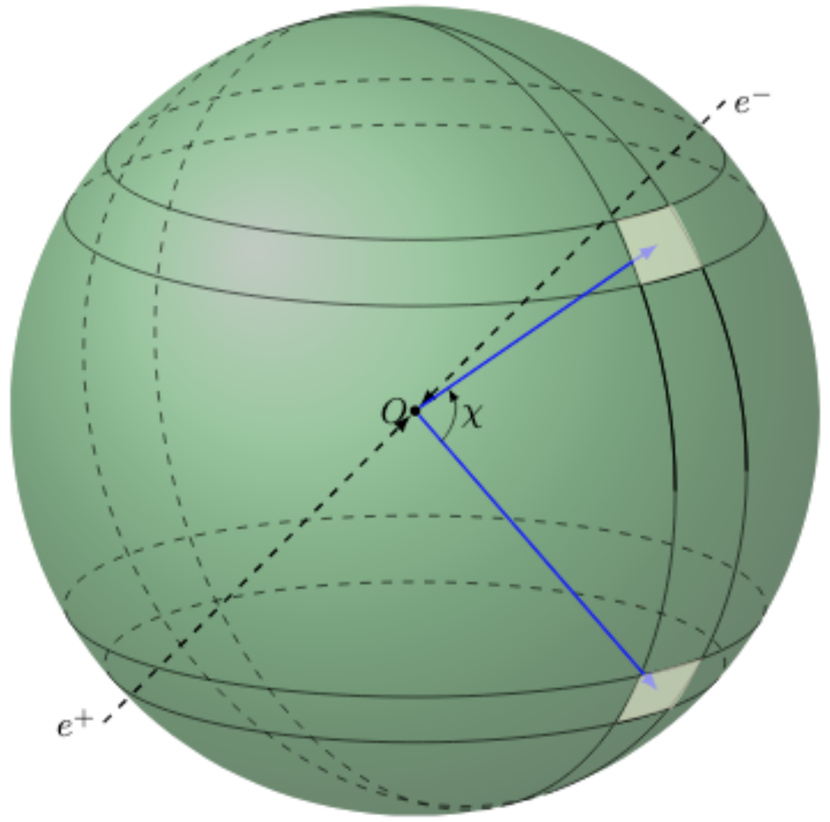

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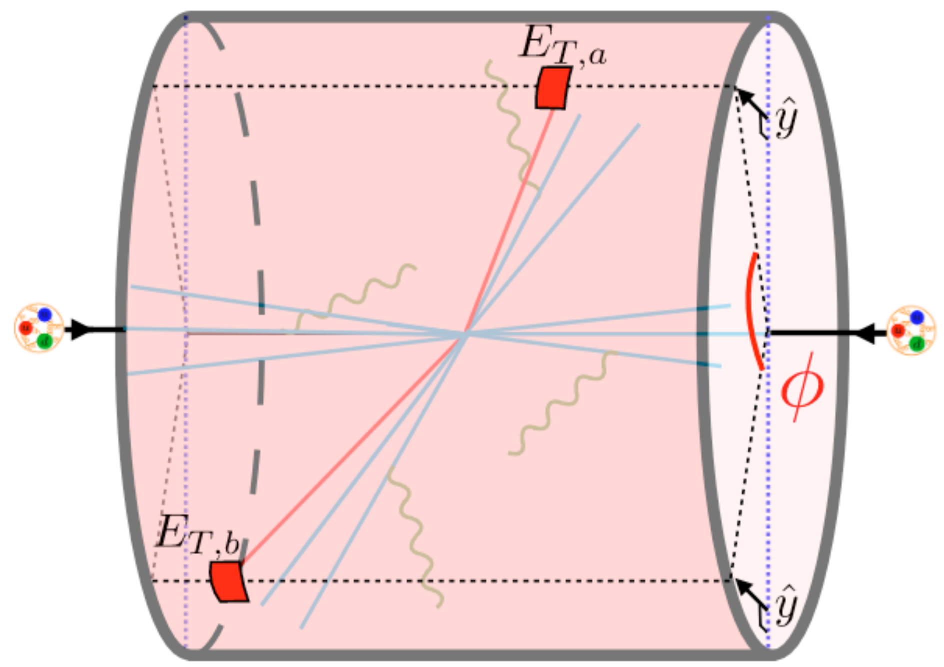

observable

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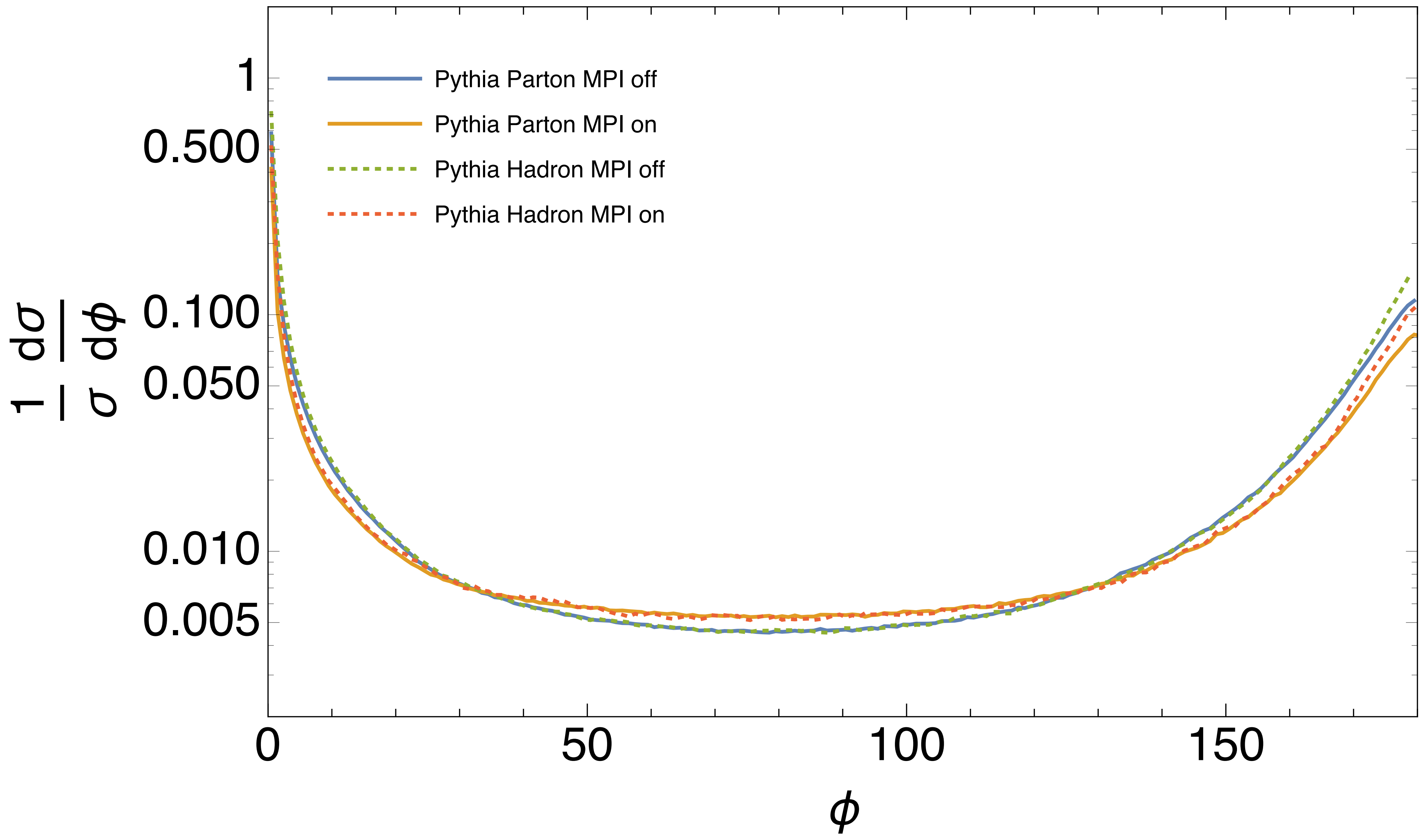
Introduction to TEEC

For both of leptonic and hadronic collisions



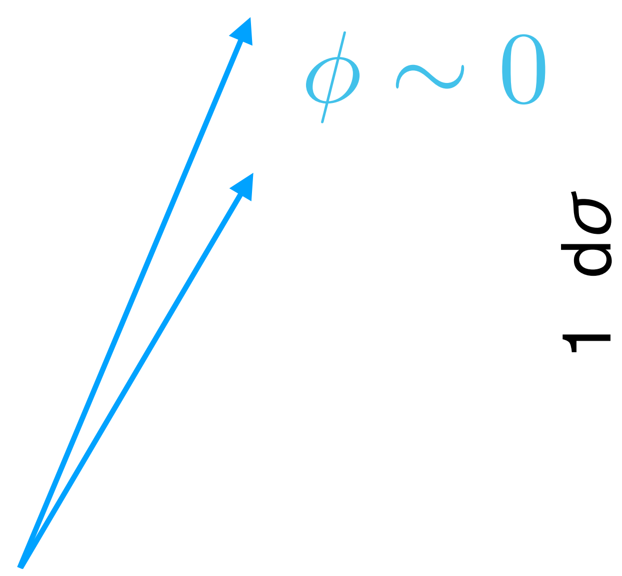
Introduction to TEEC

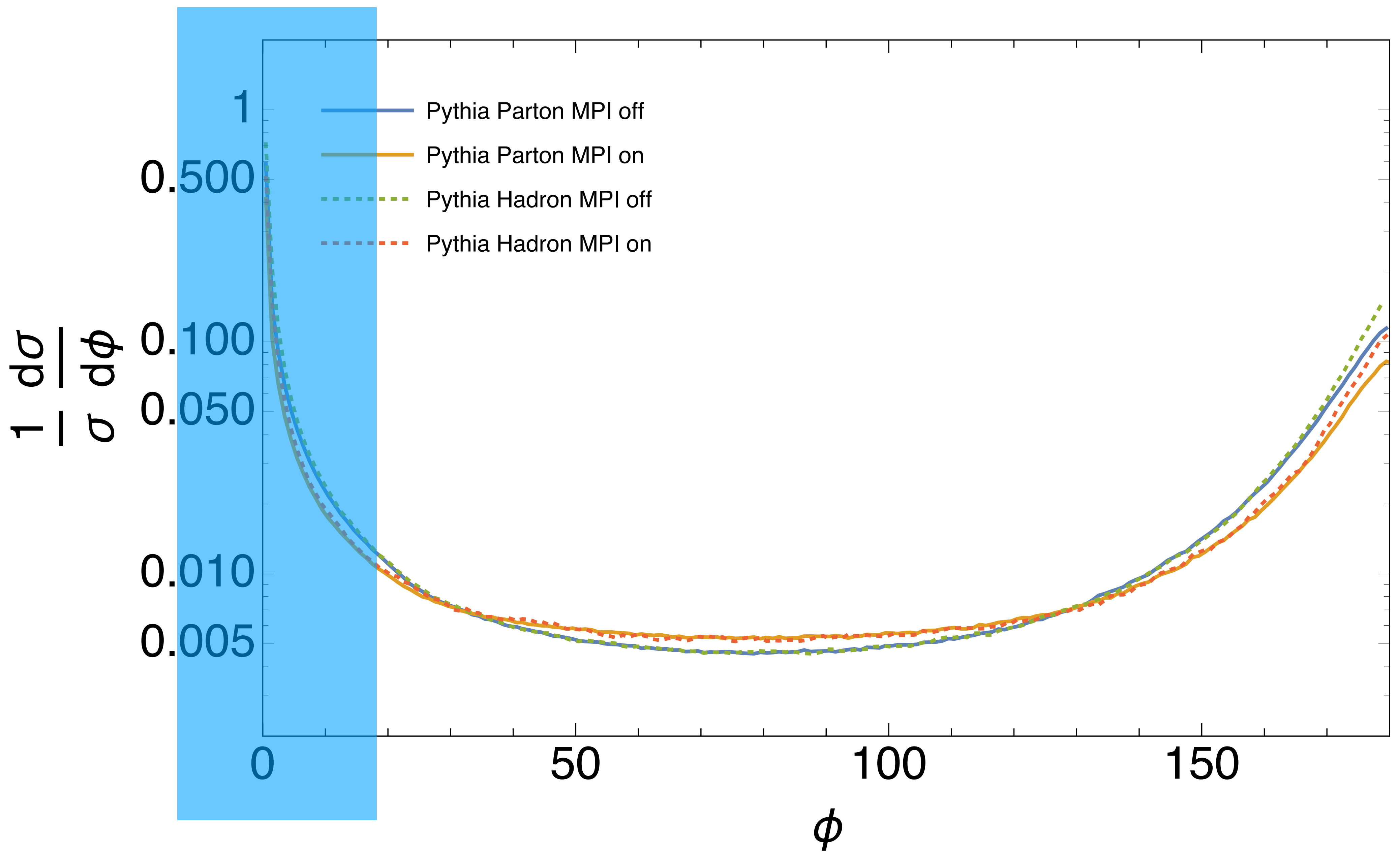
For both of leptonic and hadronic collisions

Collinear singularity

$\cos\phi_{ab} \to 0$

$J \otimes H$





Dixon, Moult, Zhu, 2019
Kologlu, Kravchuk, et al2019
Korchemsky 2019

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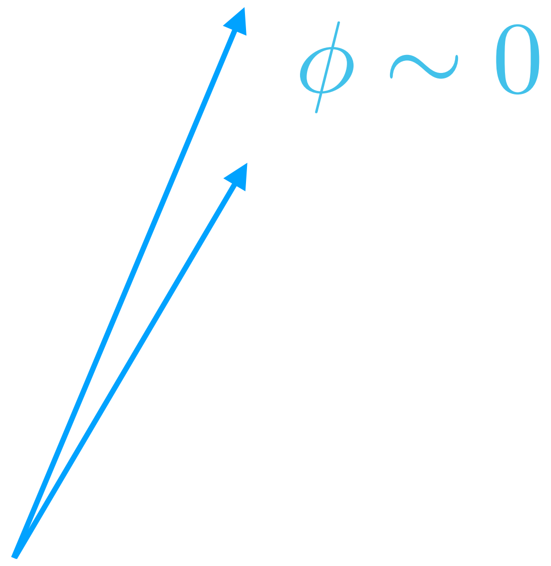

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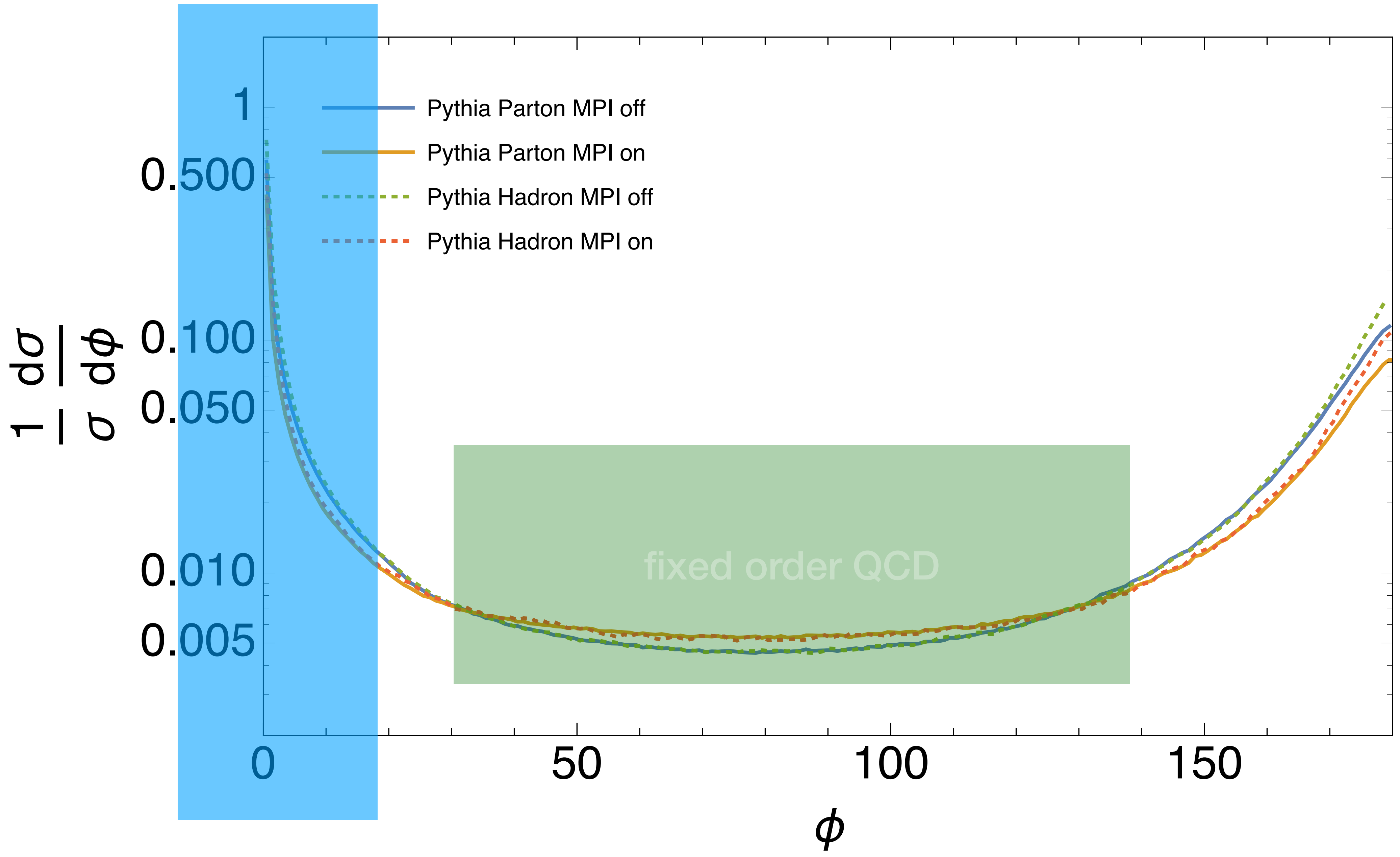

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Collinear and soft singularity

$\cos\phi_{ab} \to -1$

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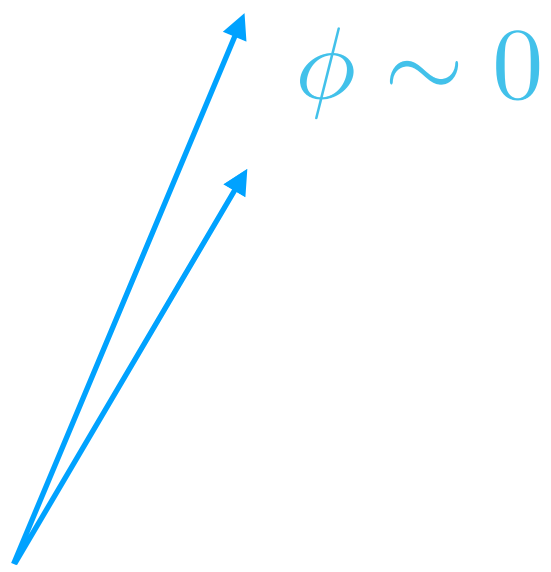
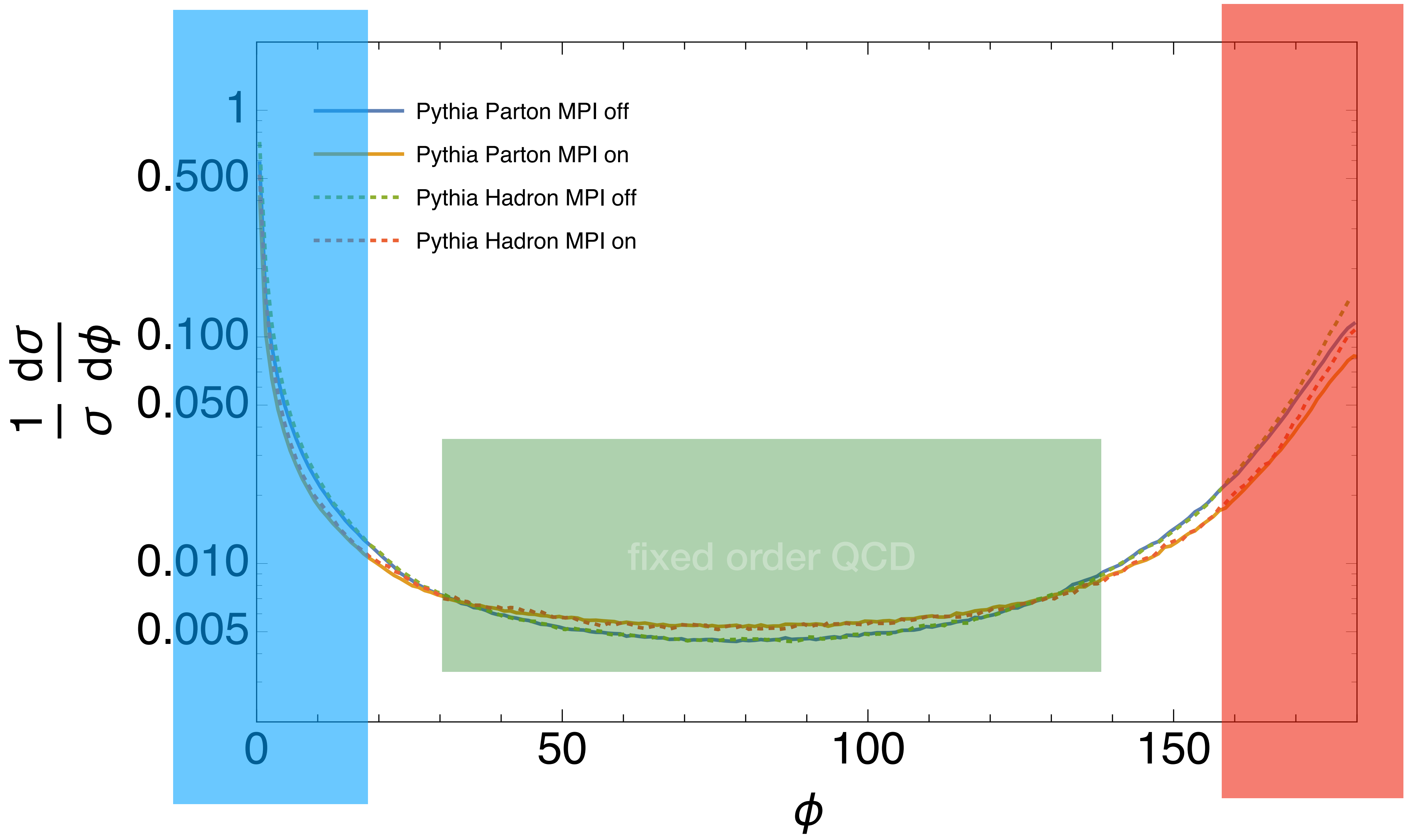
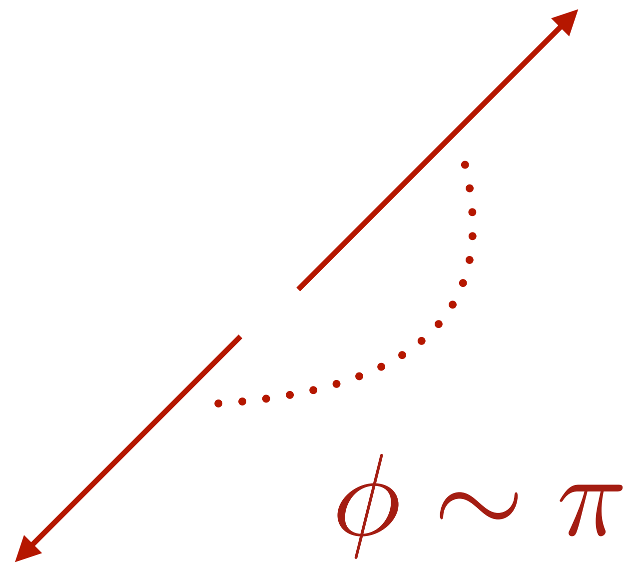




$B \otimes H \otimes J \otimes S$



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Moult, Zhu, 2018
Gao, HTL, Moult, Zhu, 2019&2020

TEEC in DIS

Defined as the correlations between the lepton and hadrons in the final state

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

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- **Easier to be measured in DIS**
- **NO Collinear singularity when** $\phi \to 0$
- **Hadronization effects are suppressed**

It is a fantastic new observable which was first studied by HTL, Vitev and Zhu

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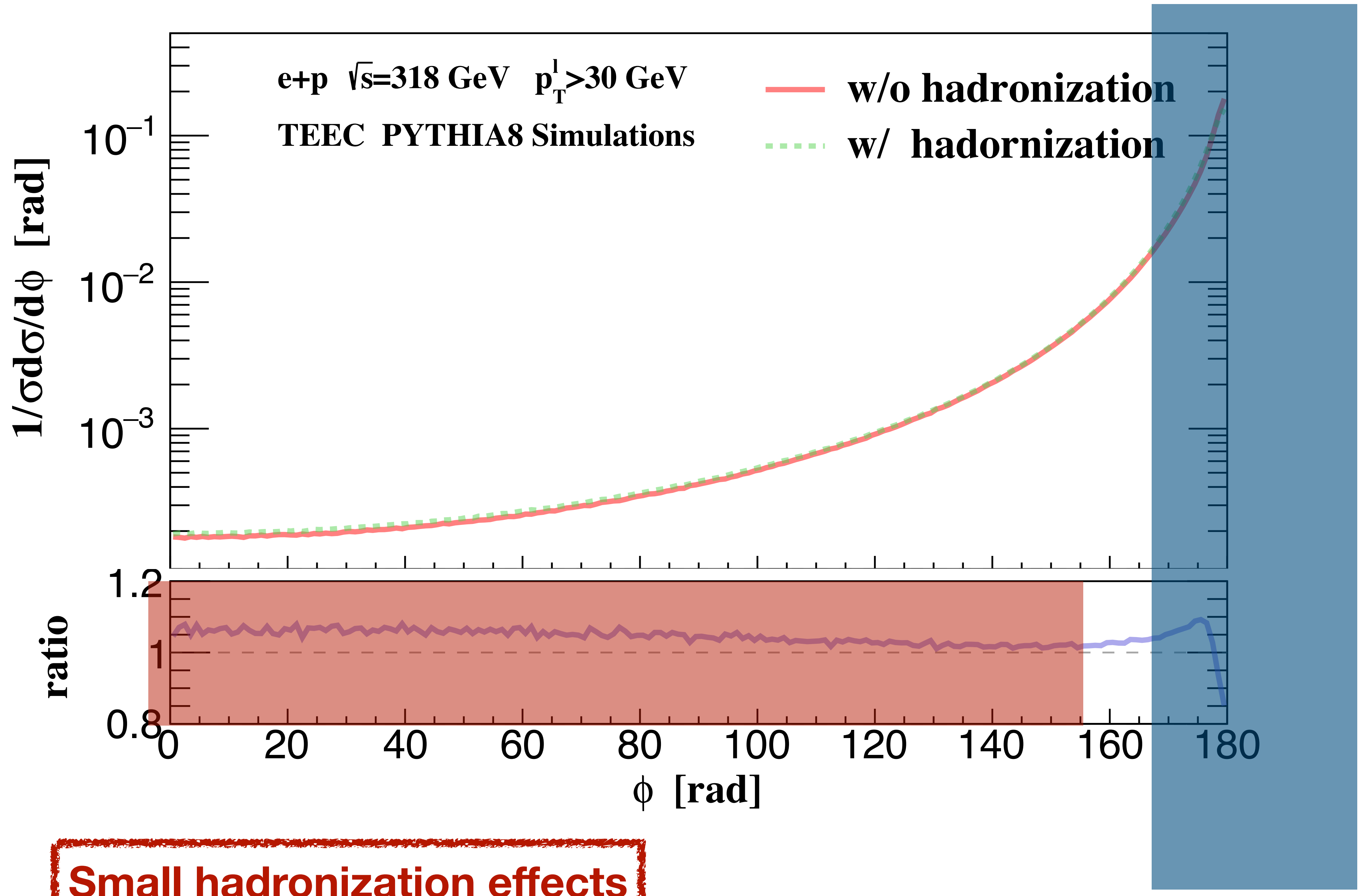

Small hadronization effects

Soft and Collinear radiations dominate

Hadronization effects is less than 20%

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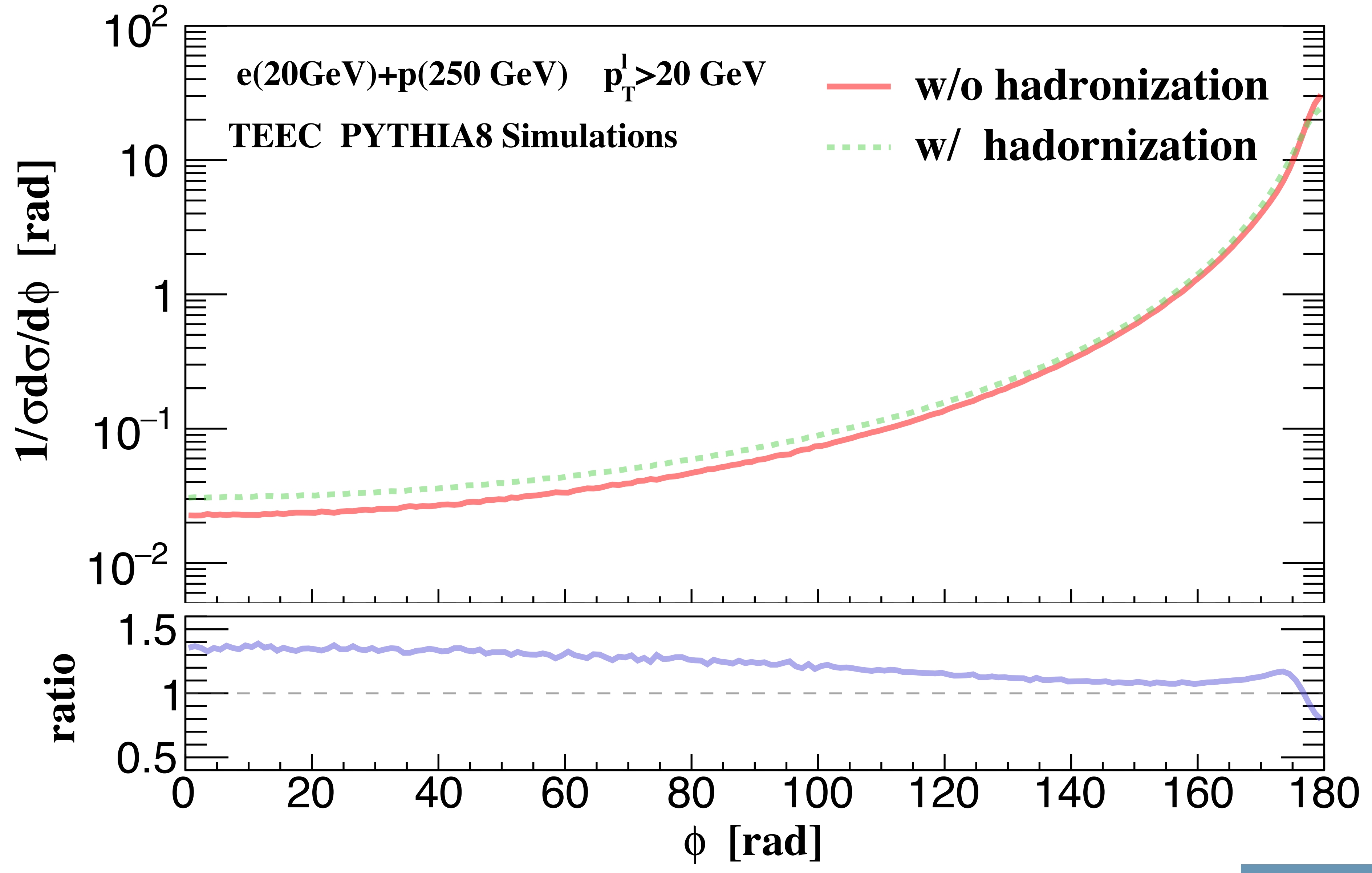

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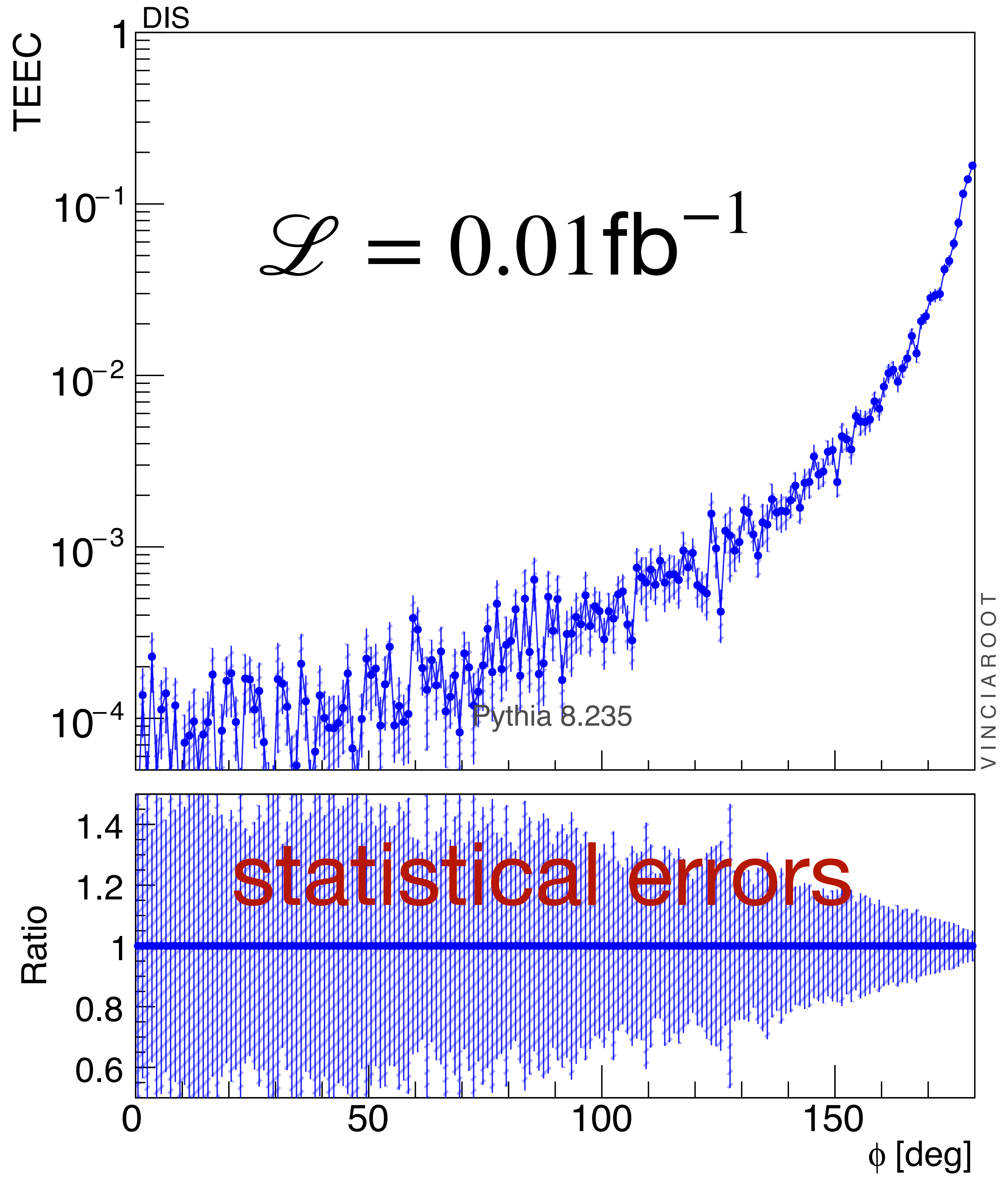
Simulations of TEEC in DIS

$e(18\text{GeV}) + p(275\text{GeV})$ Select events with $p_{T,l} > 20\text{GeV}, \quad -1 < \eta_h < 3$



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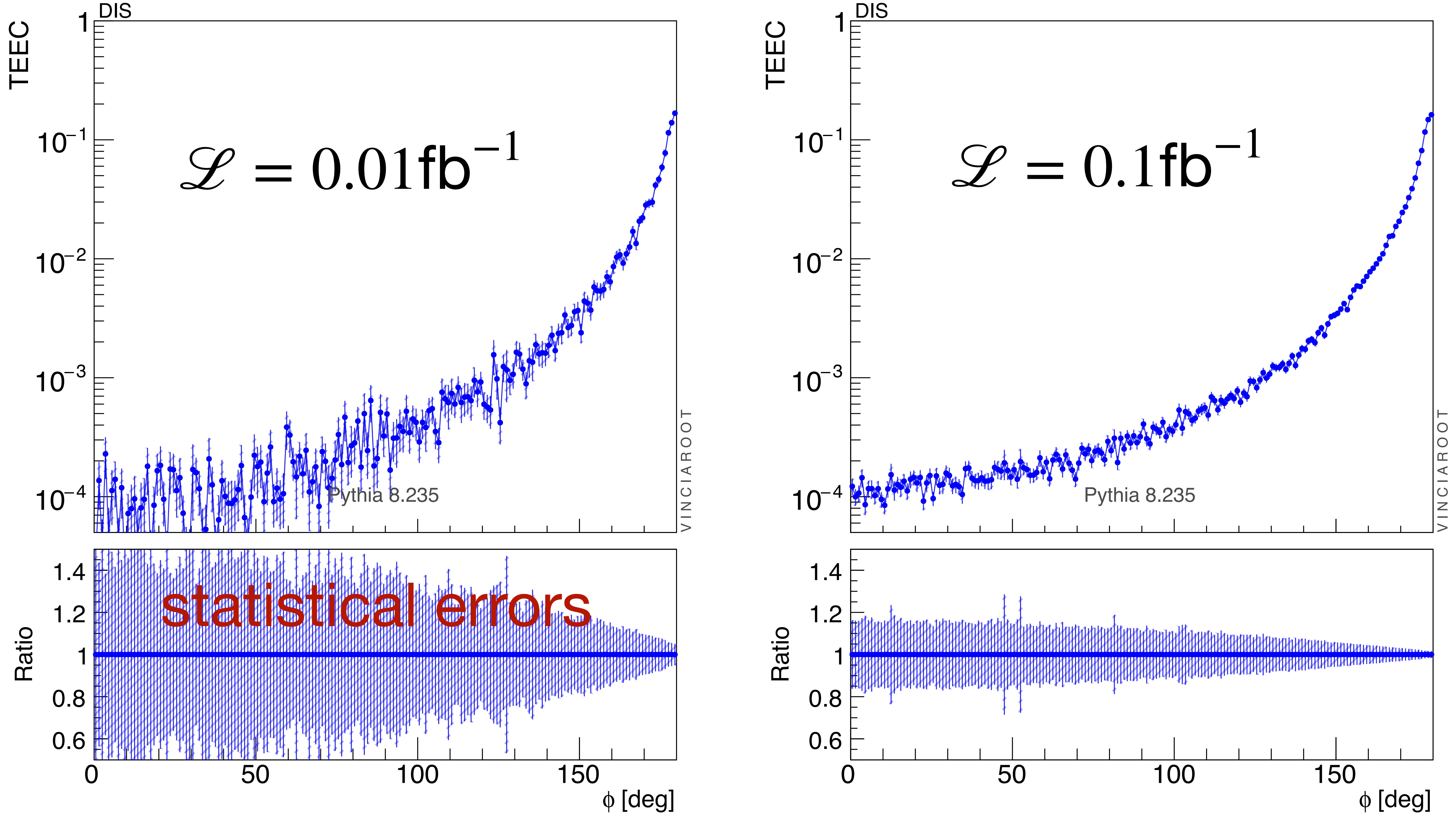

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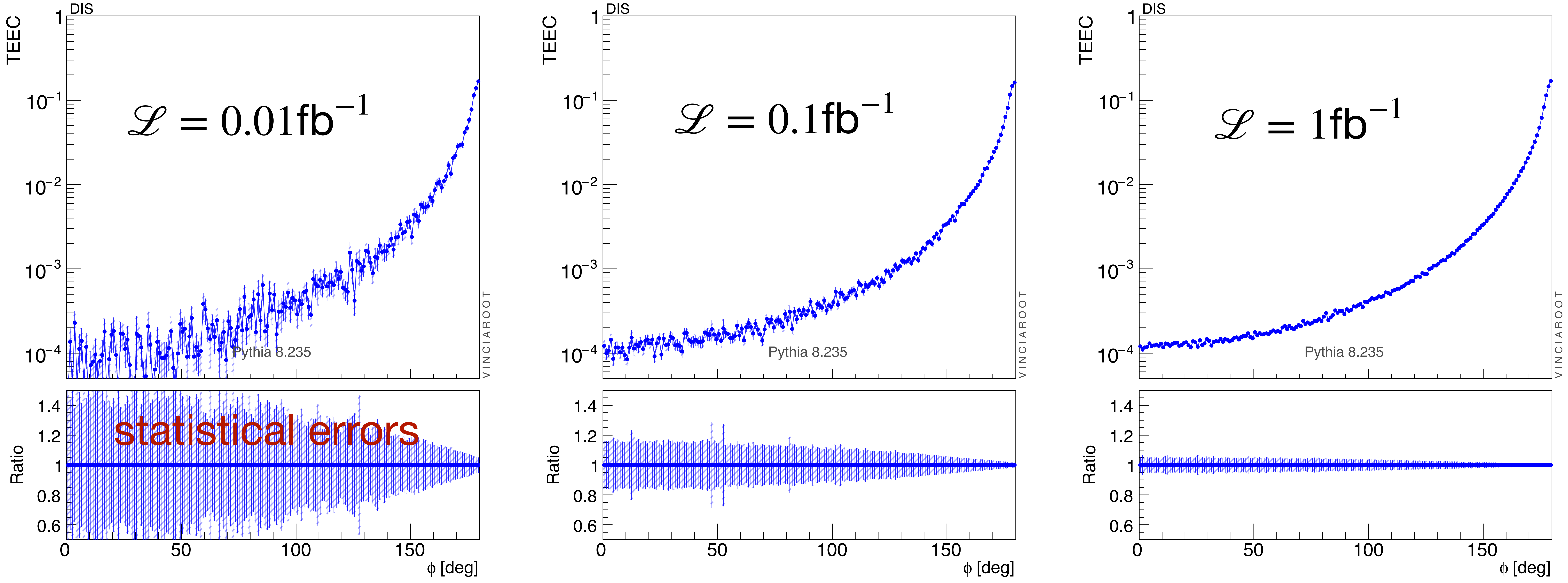

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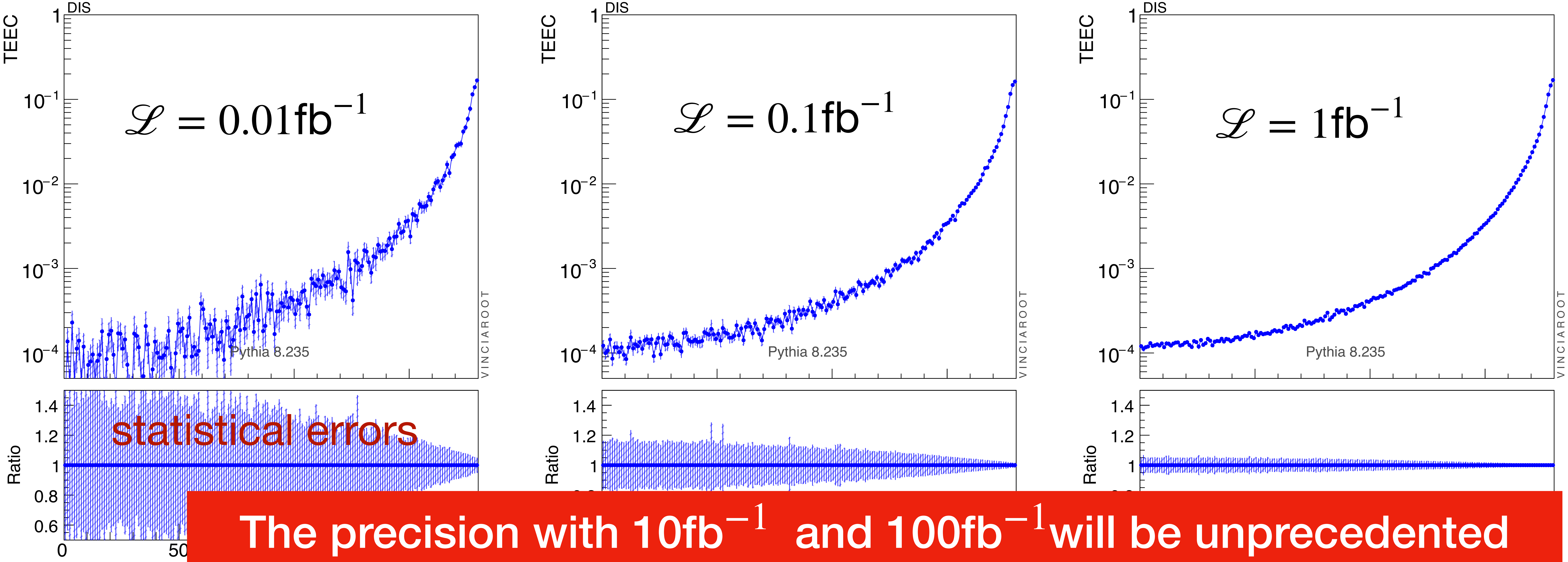
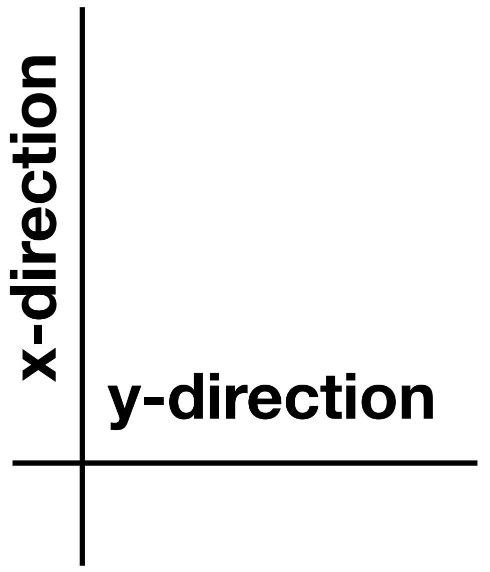


The precision with 10fb^{-1} and 100fb^{-1} will be unprecedented
It does not depend on uncertainties related to the jet radius and jet finding algorithm

It is possible to study this observable in percent level

Factorization in back-to-back limit



Define scattering plane: x-z

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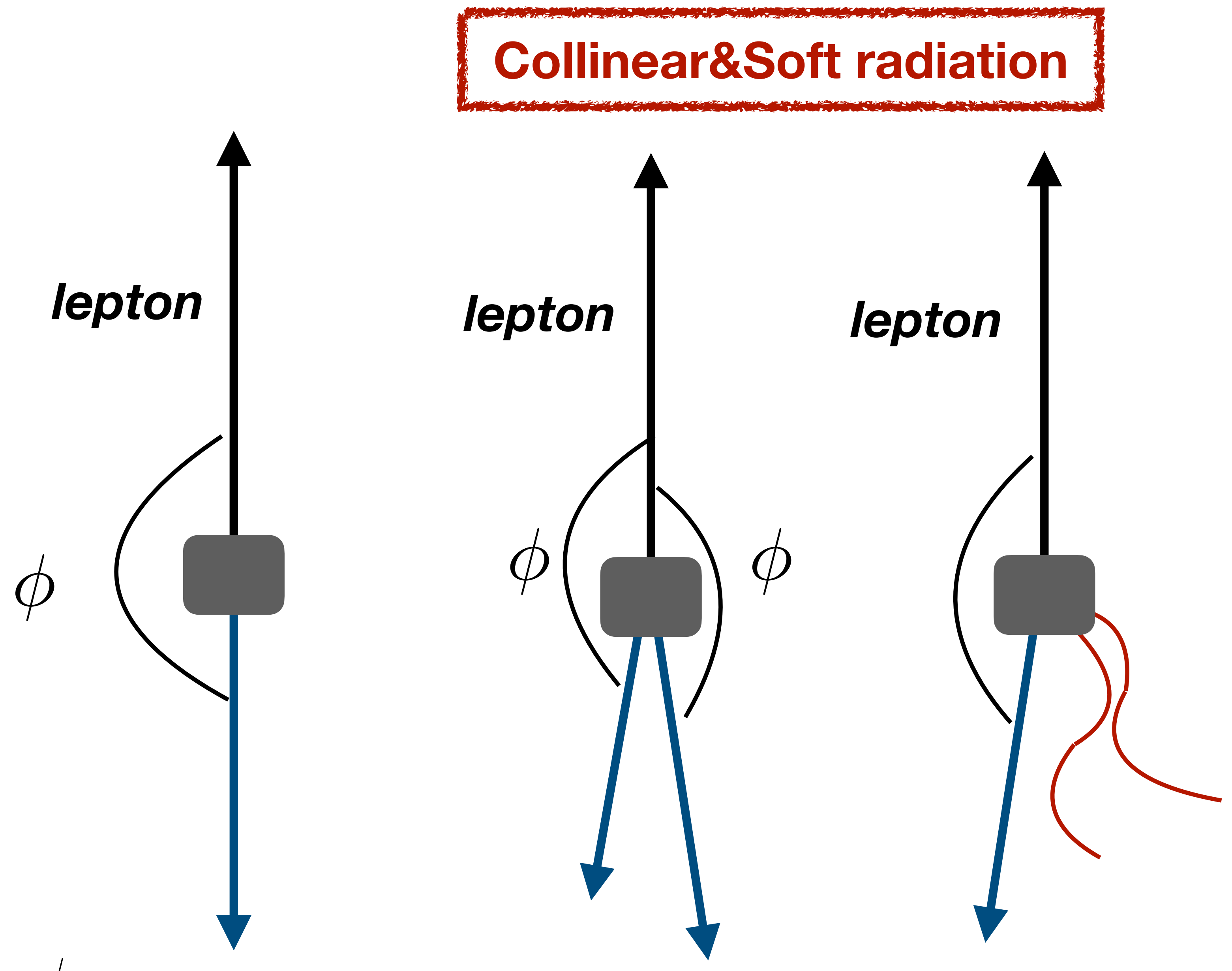
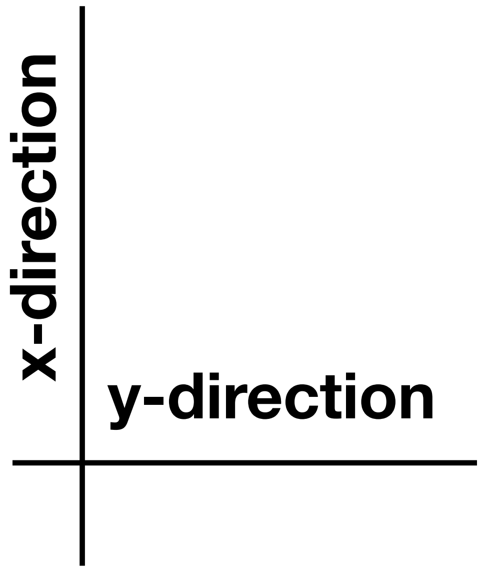


$\tau = \frac{1+\cos\phi}{2}$ $\quad \delta(\tau)$ $\quad A\delta(\tau) + B\frac{1}{\tau} + C\frac{\ln\tau}{\tau}\cdots$

Factorization in back-to-back limit



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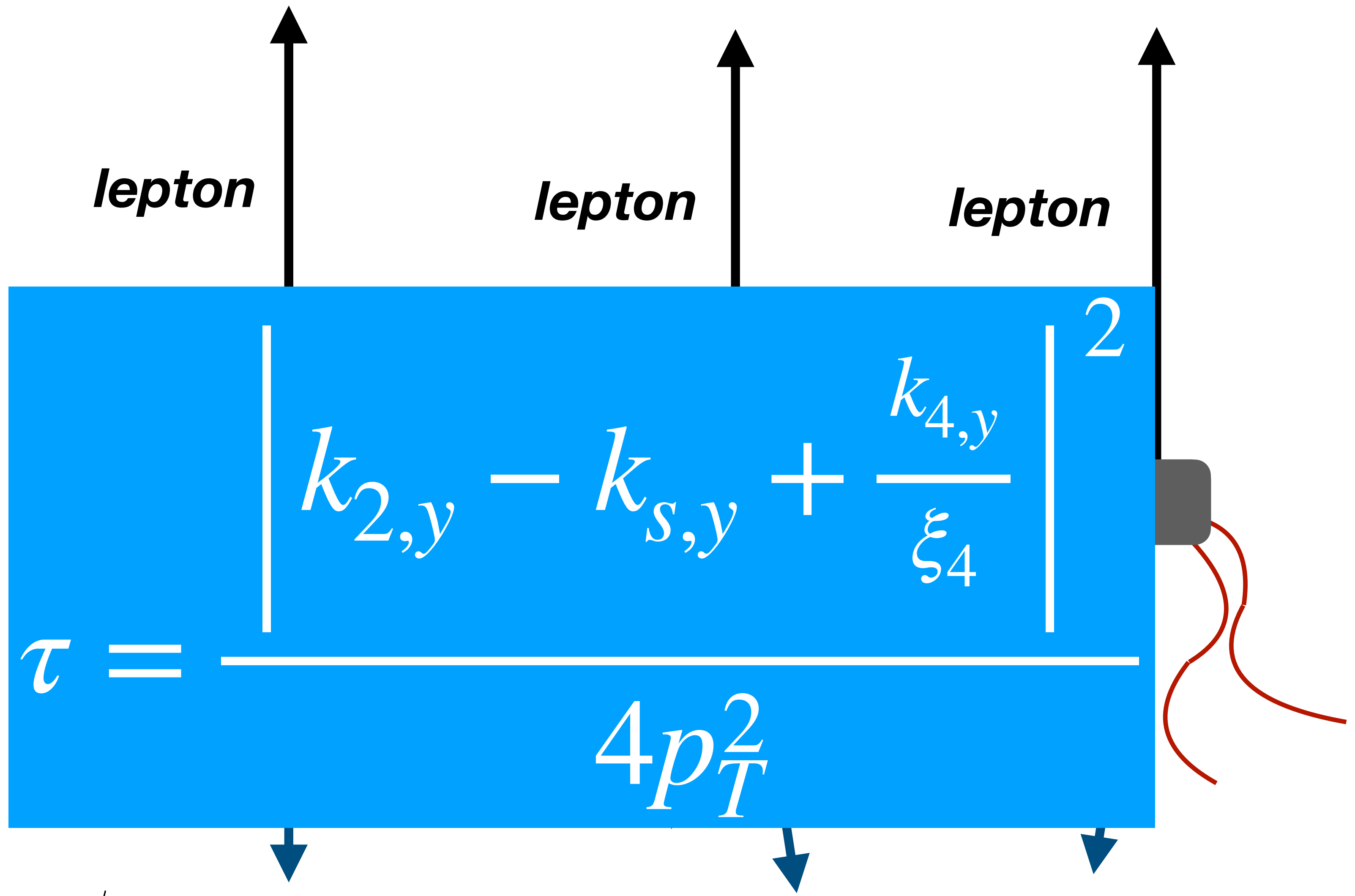
Collinear&Soft radiation



$$\tau = \frac{\left| k_{2,y} - k_{s,y} + \frac{k_{4,y}}{\xi_4} \right|^2}{4p_T^2}$$

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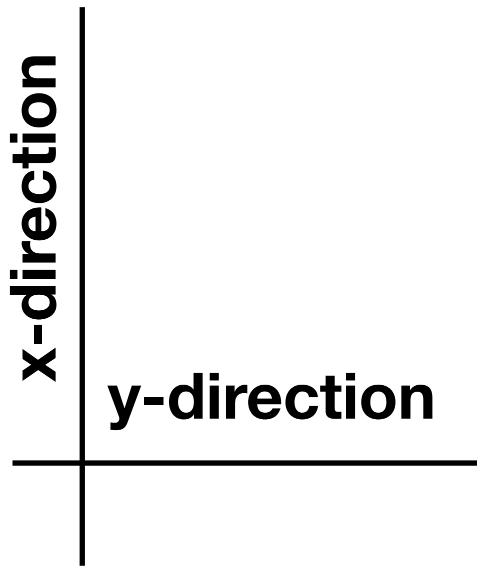
TMD Physics

Factorization in back-to-back limit



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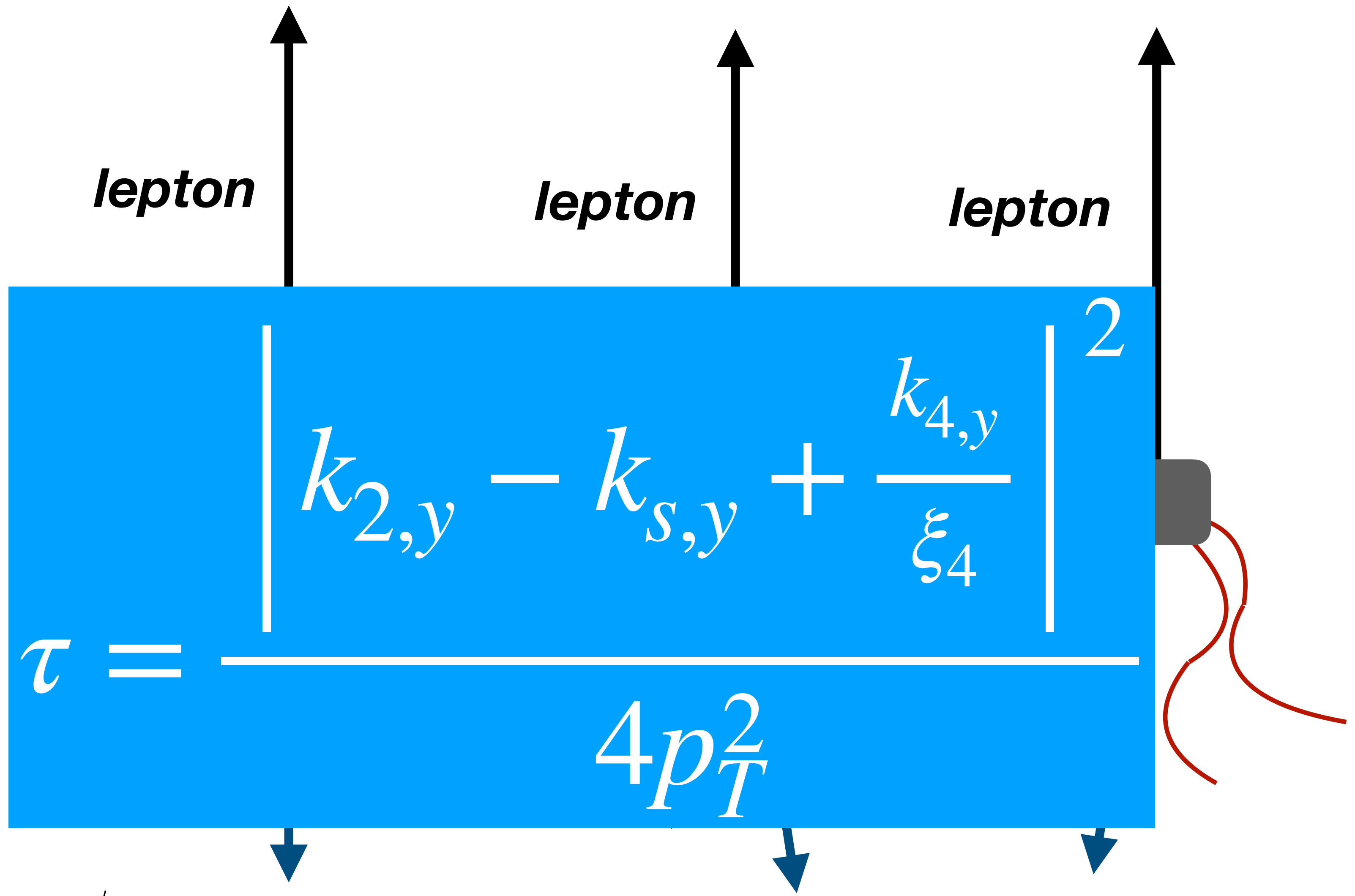

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Factorization in back-to-back limit

x-direction

y-direction

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lepton *lepton* *lepton*

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Hard function know up to 3 loops

Beam Function

Soft function

TMD PDFs

Jet Function

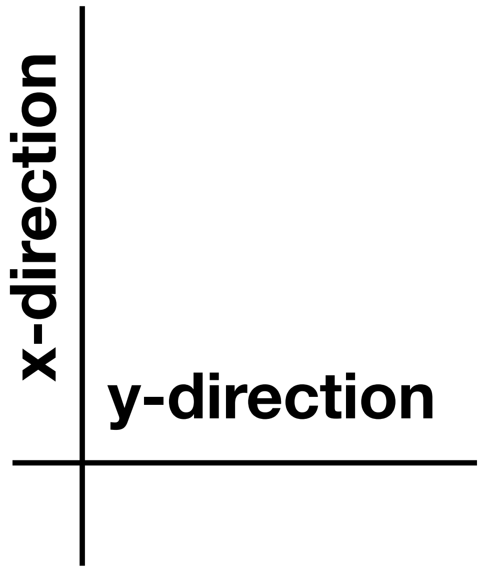
TMD FFs

The jet function is the second Mellin-moment of the matching coefficients

$$J^q\left(b_\perp, \mu, \nu\right) = \sum_i \int_0^1 dx x \mathscr{C}_{iq}\left(x, b_\perp/x, \mu, \nu\right)$$

Factorization in back-to-back limit

Define scattering plane: x-z



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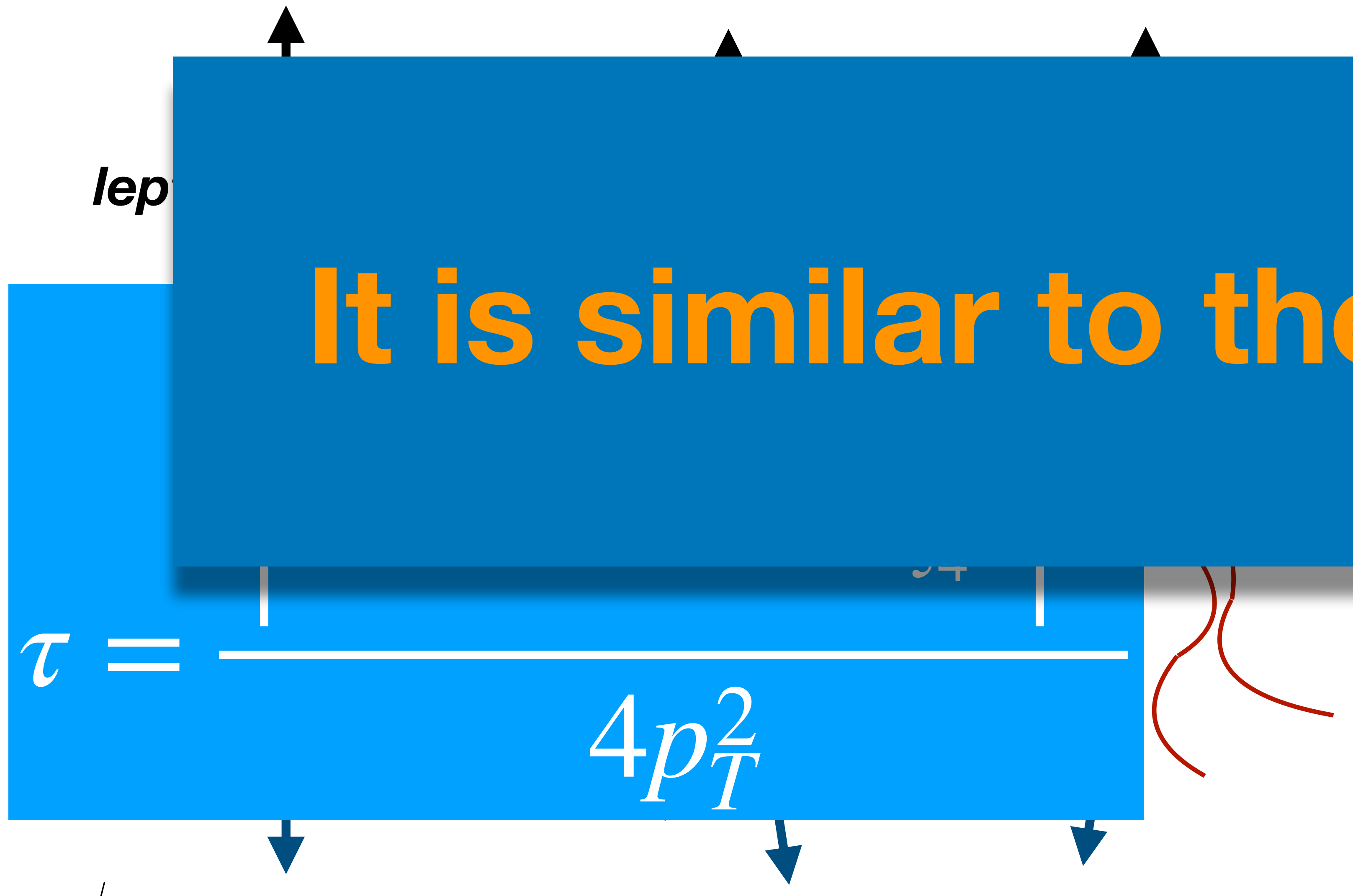

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Hard function know up to 3 loops

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...ction

It is similar to the 1-dimensional TMD factorization

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Factorization in back-to-back limit

lepton+lepton

$$\frac{d\sigma}{d\tau} = \frac{1}{2}\int d^2\vec{k}_\perp \int \frac{d^2\vec{b}_\perp}{(2\pi)^2} e^{-i\vec{b}_\perp\cdot\vec{k}_\perp} H(Q,\mu) J^q_{\rm EEC}\left(\vec{b}_\perp,\mu,\nu\right) J^{\bar{q}}_{\rm EEC}\left(\vec{b}_\perp,\mu,\nu\right) S_{\rm EEC}\left(\vec{b}_\perp,\mu,\nu\right)\delta\left(1-\tau-\frac{\vec{k}^2_\perp}{Q^2}\right)$$

proton+lepton

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proton+proton

$$\frac{d\sigma^{(0)}}{d\tau} = \frac{1}{16\pi s^2\left(1+\delta_{f_5 f_4}\right)\sqrt{\tau}} \sum_{\rm channels} \frac{1}{N_{\rm init}} \int \frac{dy_3 dy_4 p_T dp_T^2}{\xi_1\xi_2} \int_{-\infty}^{\infty} \frac{db}{2\pi} e^{-2ib\sqrt{\tau}p_T}$$
$$\times\, {\rm tr}\left(\mathbf{H}^{f_1 f_2\to f_3 f_4}\left(p_T,y^*,\mu\right)\mathbf{S}\left(b,y^*,\mu,\nu\right)\right] B_{f_1/N_1}\left(b,\xi_1,\mu,\nu\right) B_{f_2/N_2}\left(b,\xi_2,\mu,\nu\right) J_{f_3}(b,\mu,\nu) J_{f_4}(b,\mu,\nu)$$

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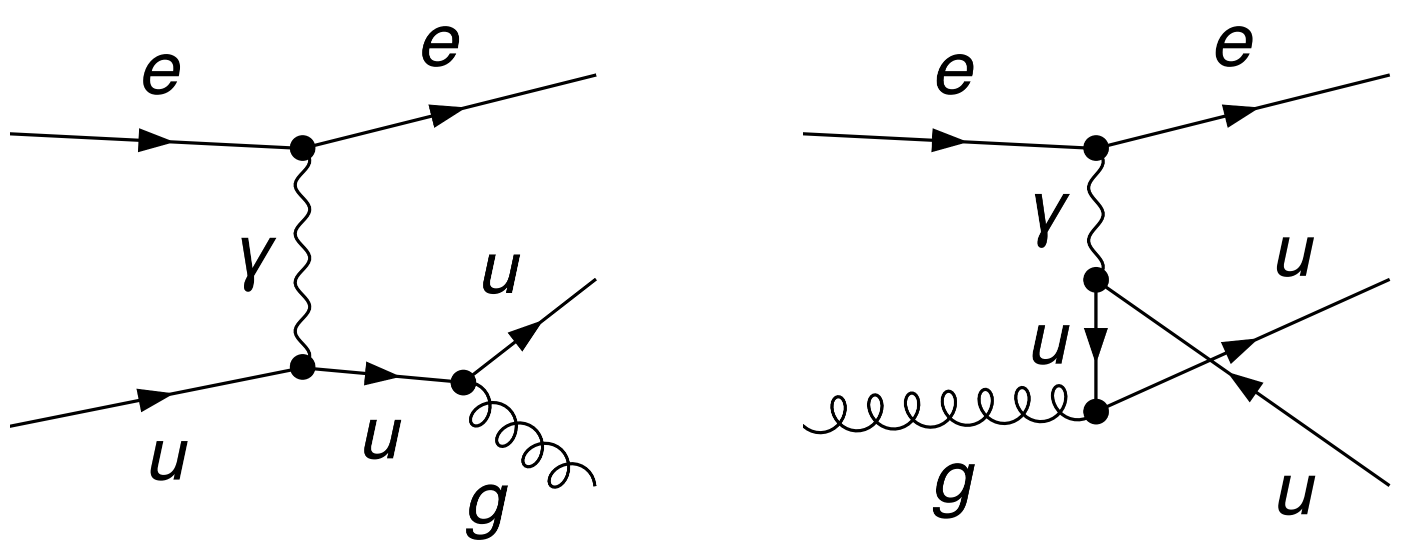
proton+proton

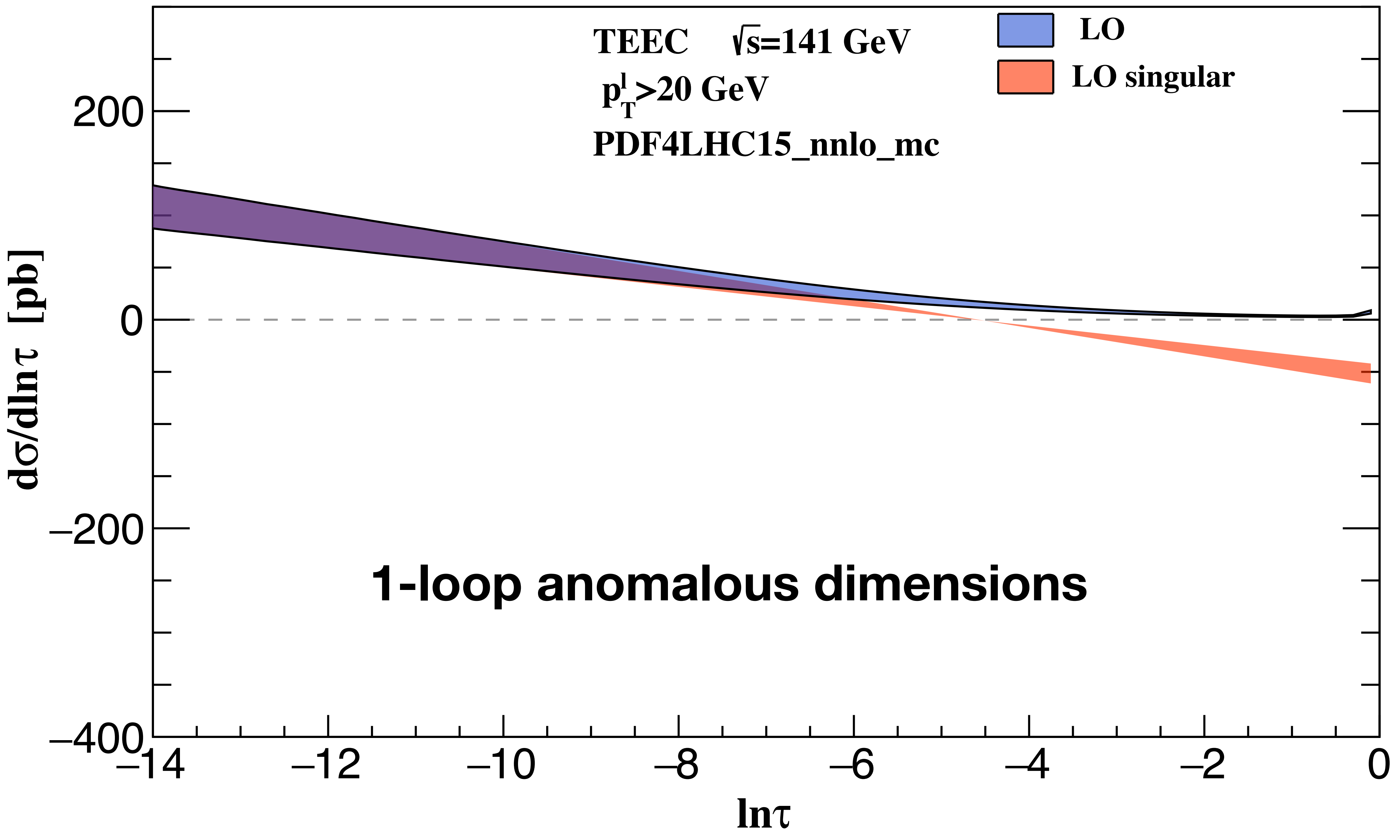
$$\frac{d\sigma^{(0)}}{d\tau}=\frac{1}{16\pi s^2\left(1+\delta_{f_5f_4}\right)\sqrt{\tau}}\sum_{\mathrm{channels}}\frac{1}{N_{\mathrm{init}}}\int\frac{dy_3dy_4p_Tdp_T^2}{\xi_1\xi_2}\int_{-\infty}^{\infty}\frac{db}{2\pi}e^{-2ib\sqrt{\tau}p_T}$$
$$\times\,\mathrm{tr}\left(\mathbf{H}^{f_1f_2\to f_3f_4}\left(p_T,y^*,\mu\right)\mathbf{S}\left(b,y^*,\mu,\nu\right)\right]B_{f_1/N_1}\left(b,\xi_1,\mu,\nu\right)B_{f_2/N_2}\left(b,\xi_2,\mu,\nu\right)J_{f_3}(b,\mu,\nu)J_{f_4}(b,\mu,\nu)$$

Check the universality of QCD in the infrared regime

Fixed order in back-to-back limit

The leading order process is

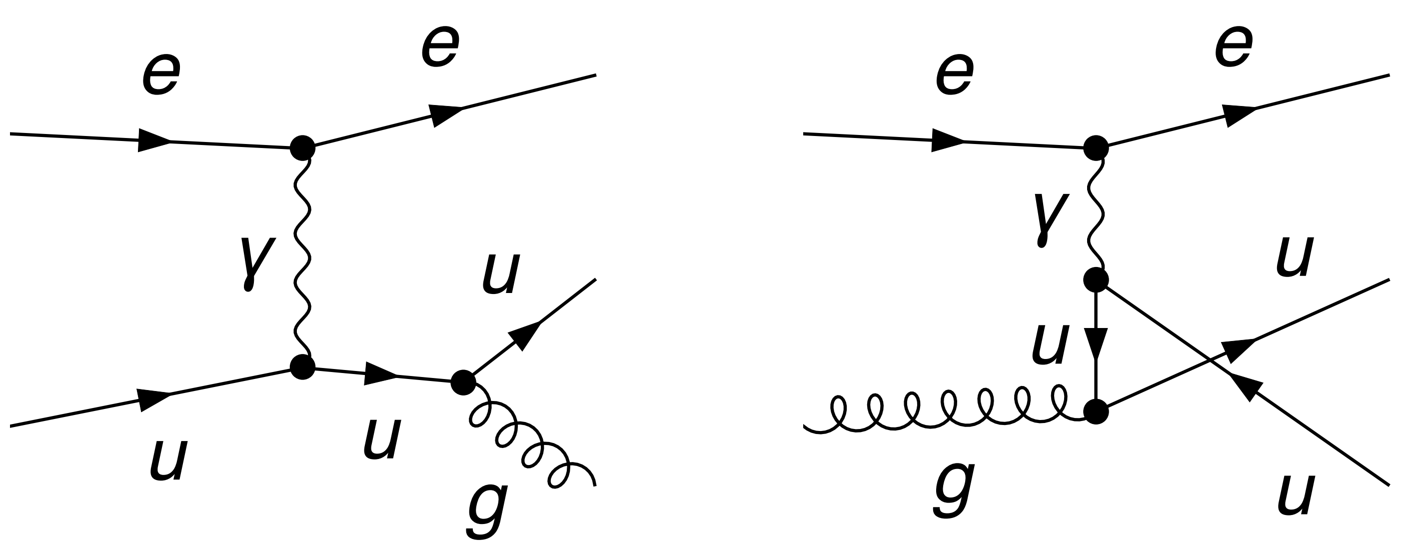


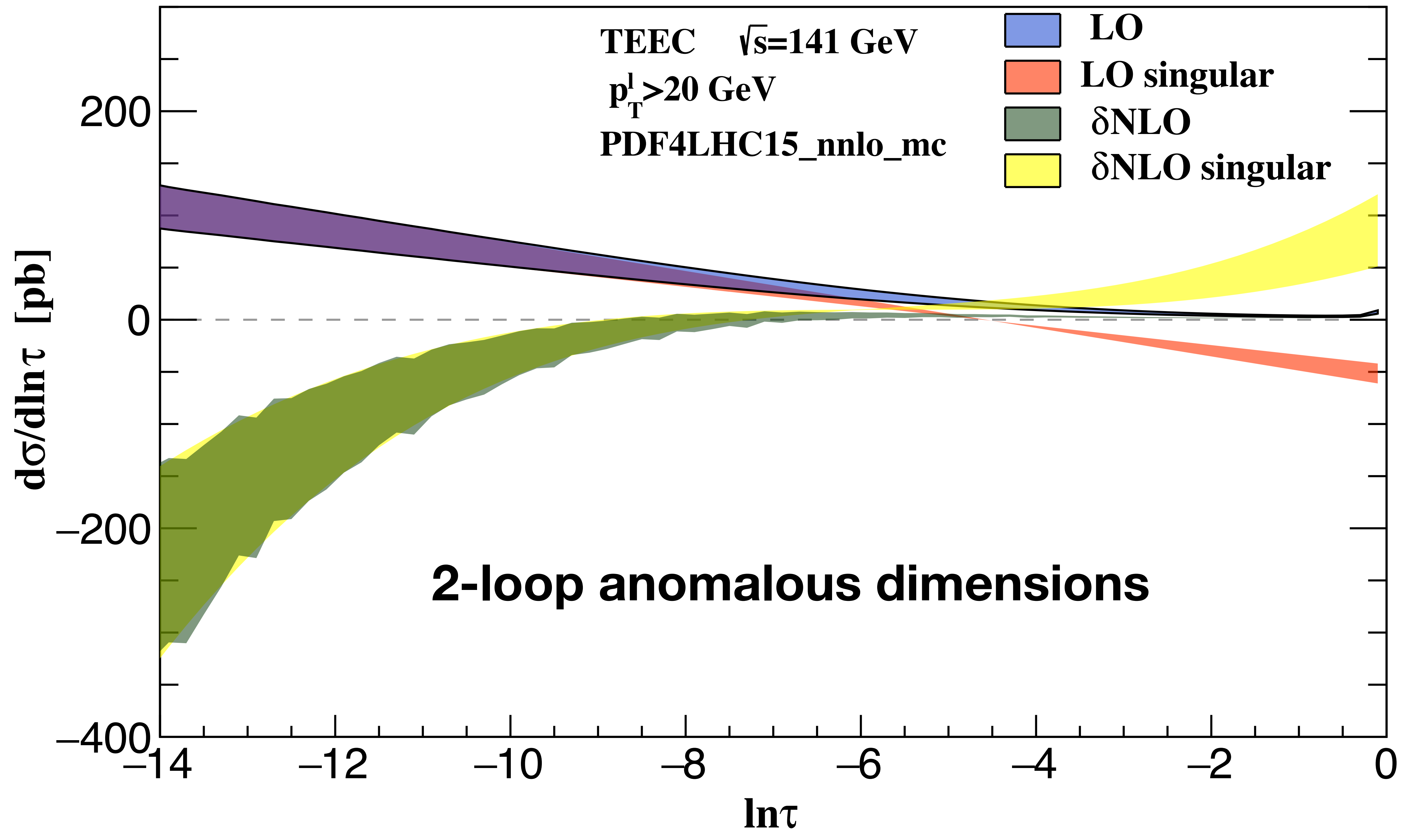


Full control of the distributions in the back-back limit.

Fixed order in back-to-back limit

The leading order process is





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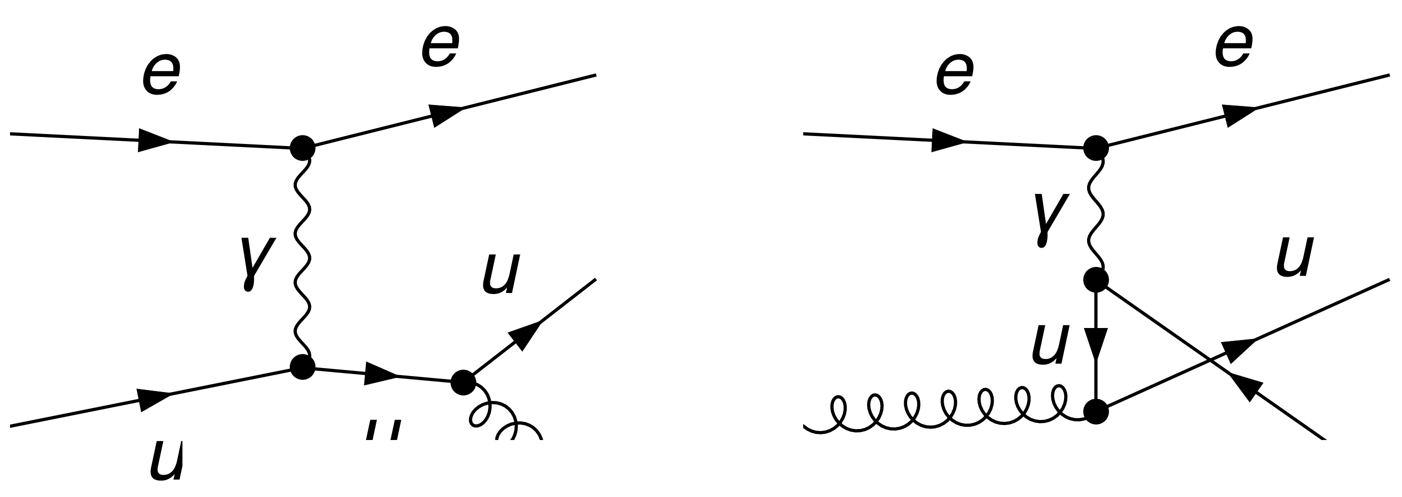
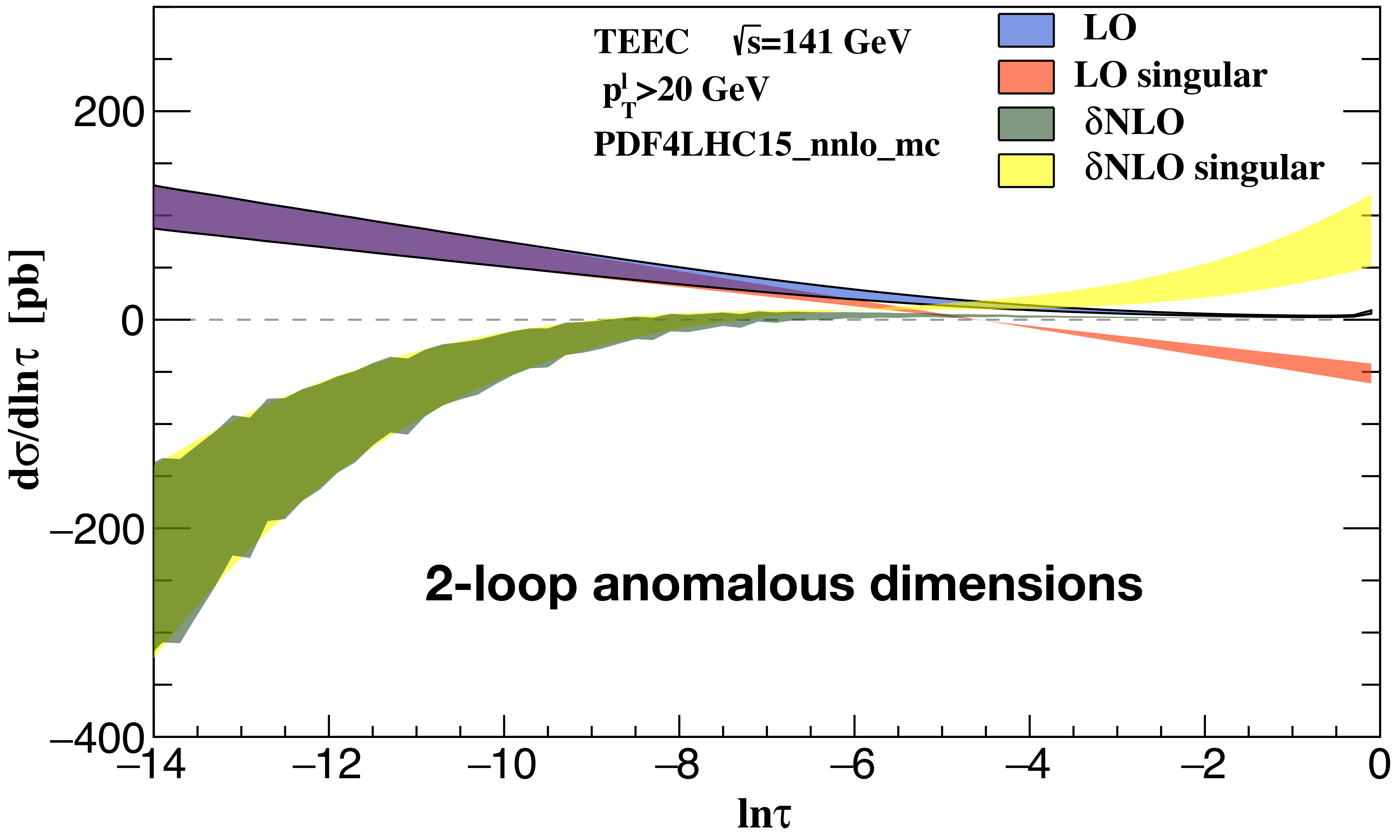
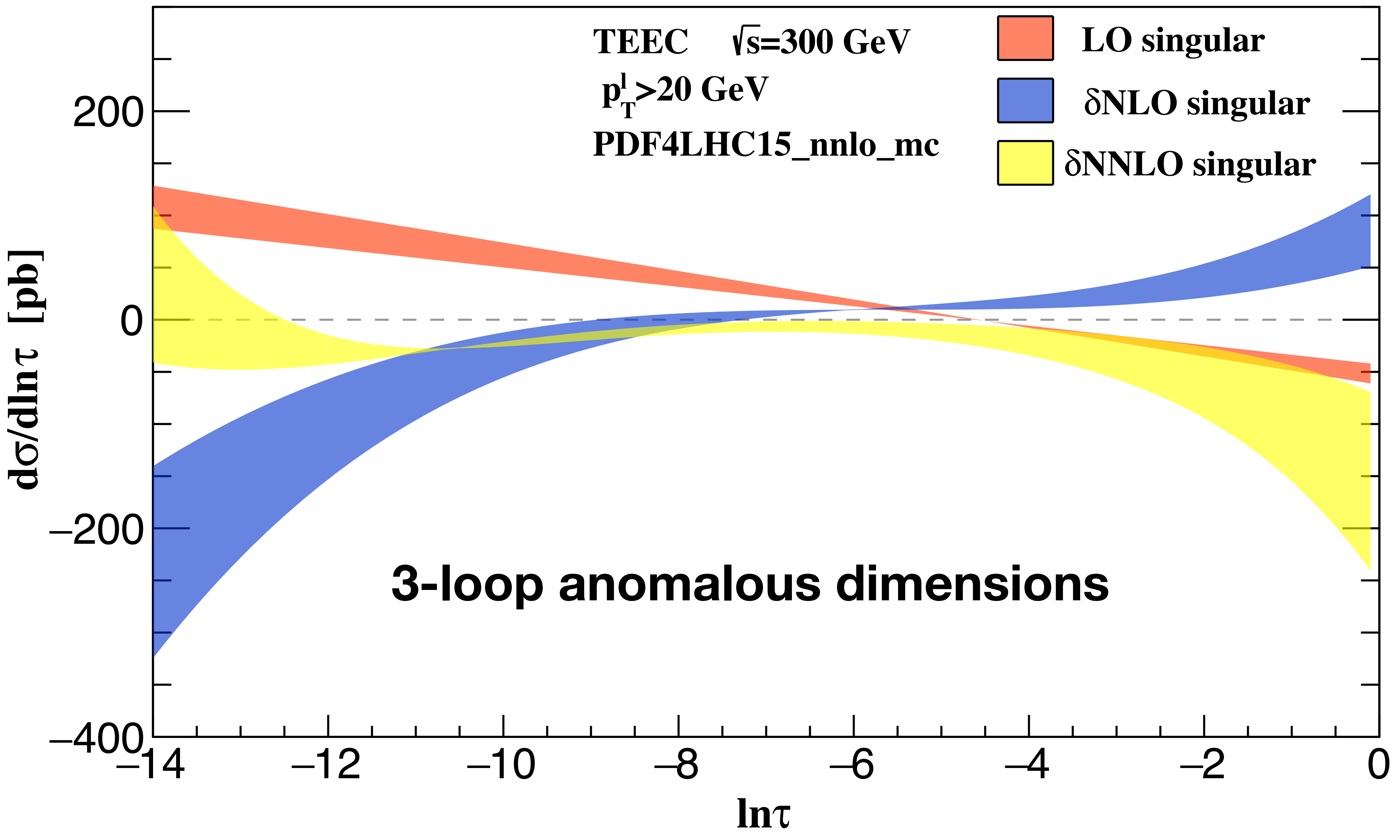
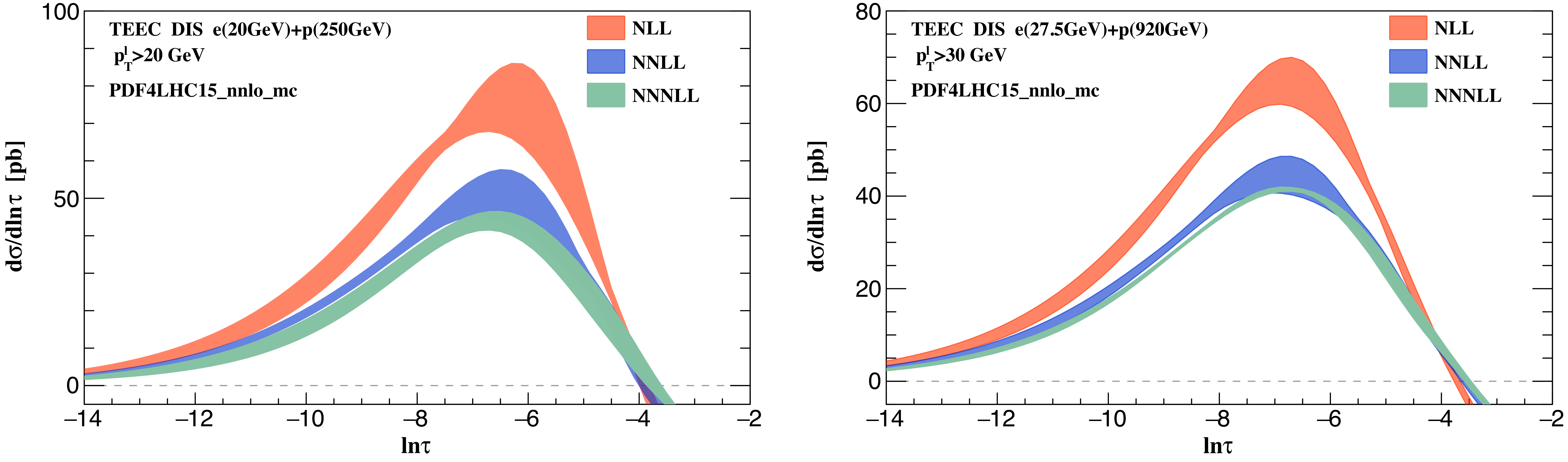






Full control of the distributions in the back-back limit.

Resummation in back-to-back limit

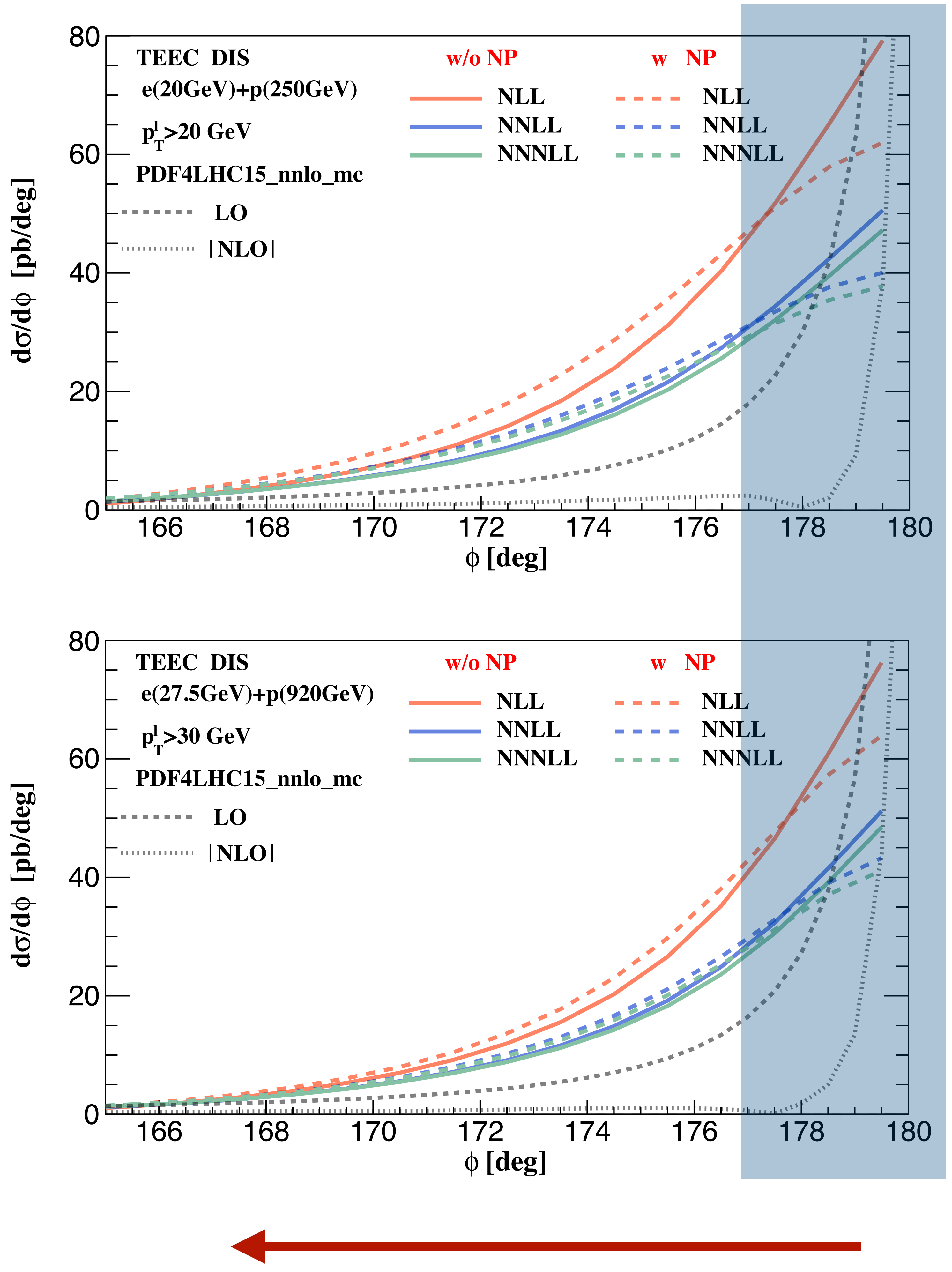


This is the highest resumed accuracy achieved in DIS

- **Convergence in back-to-back limit after resummation**
- **Resummation works better for higher energy collider due to larger scale hierarchy**
- **Huge difference from NLL to NNLL and good perturbative convergence from NNLL to NNNLL**
- **Reduction of scale uncertainties order by order from NLL to NNNLL**

Predictions with NP

$$S_{\rm NP} = \exp\left[-0.106\, b^2 - 0.84 \ln Q/Q_0 \ln b/b^*\right]$$



Finite after resummation

Large NP effects

Large nuclear matter effects are expected in this region

NP shifts the cross section

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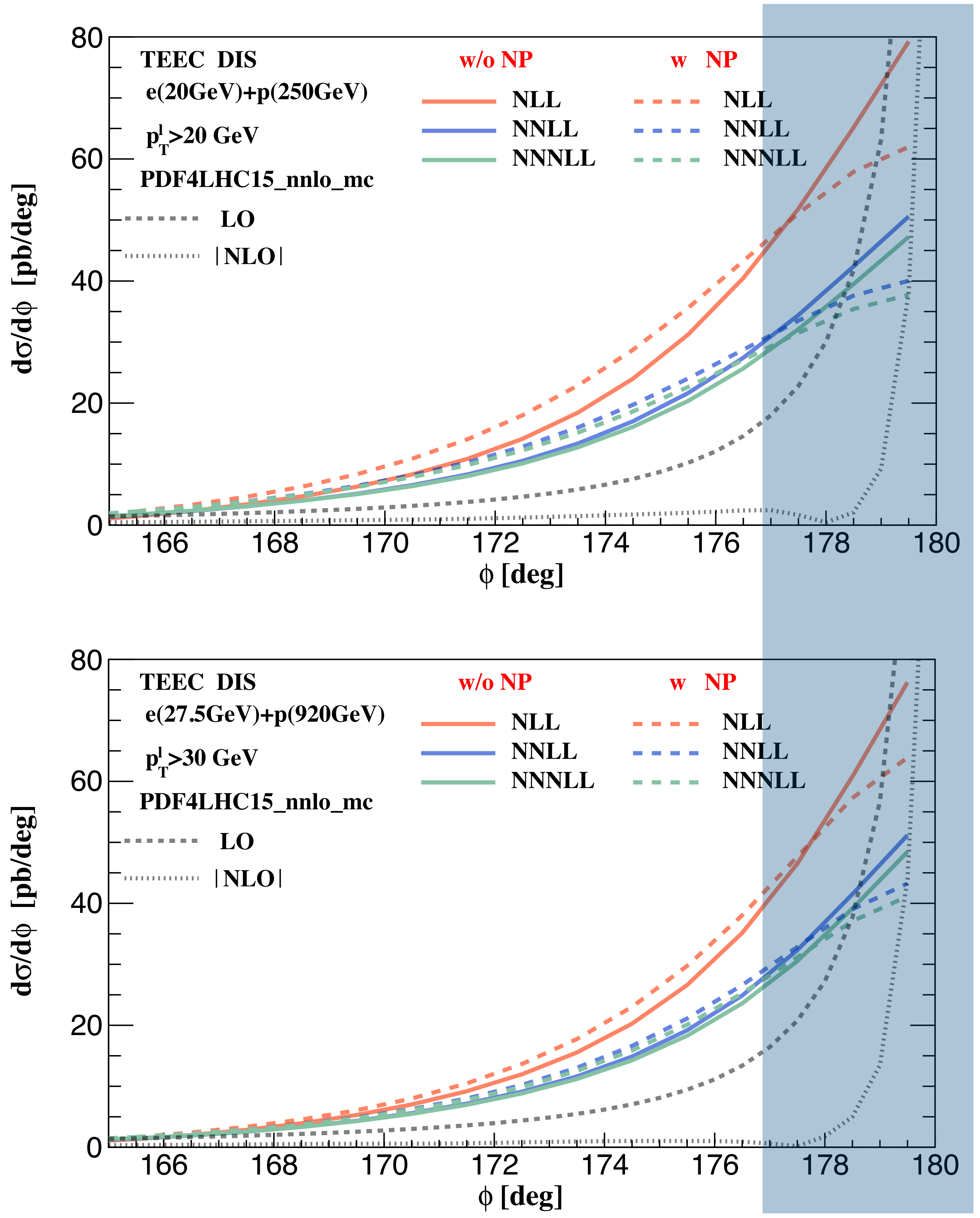

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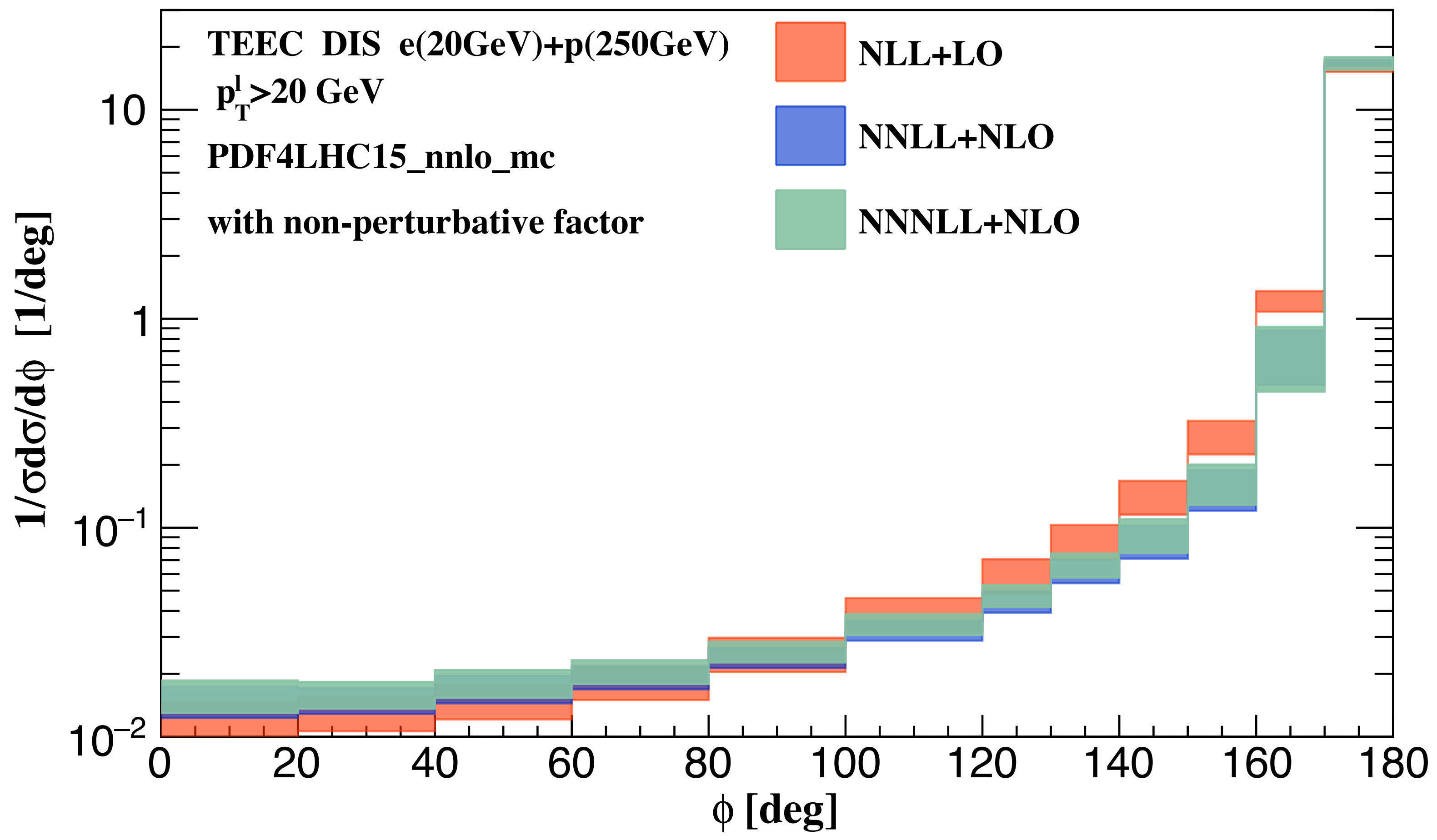

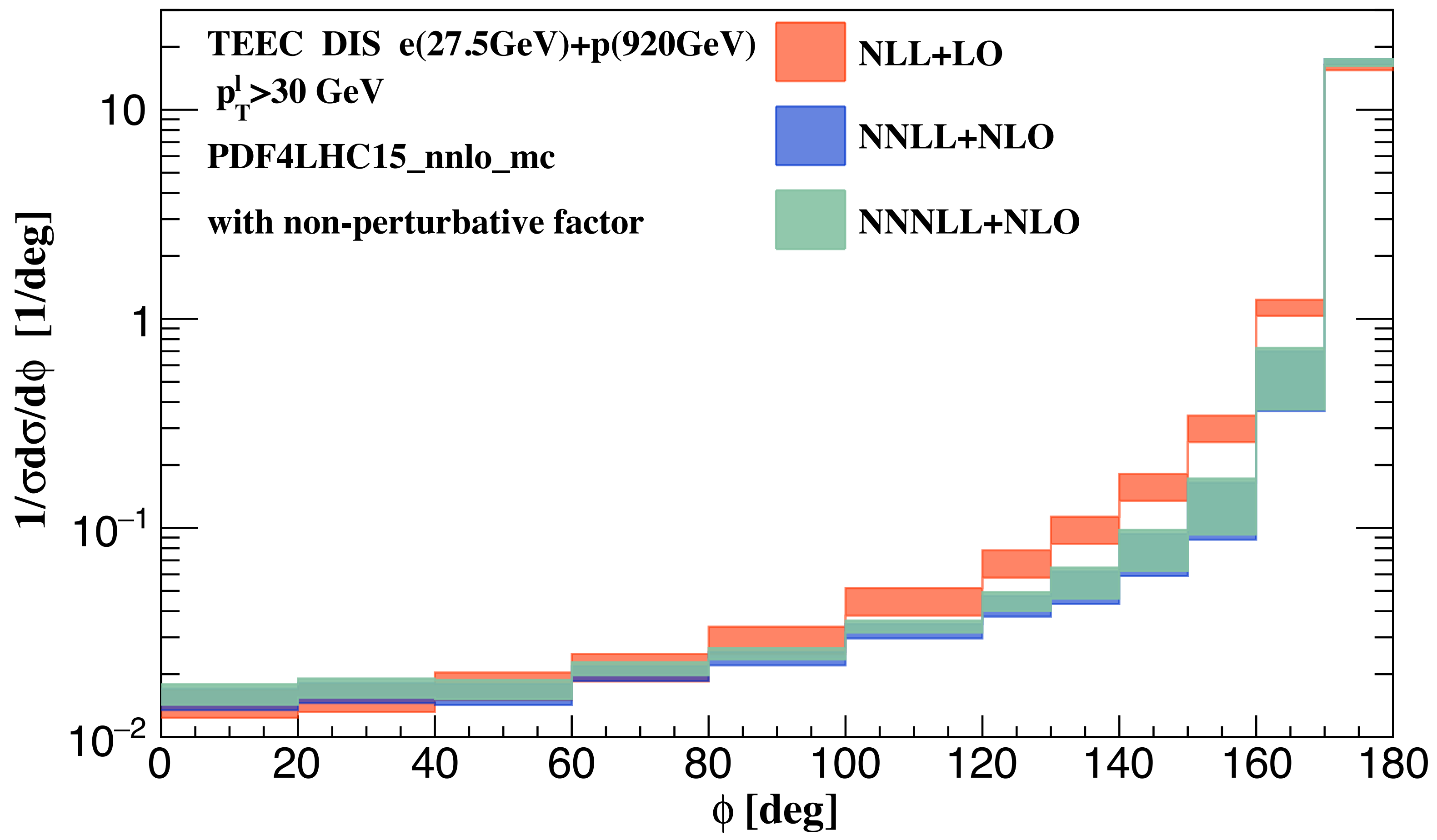

Prediction in full ϕ range

Uncertainties from fixed order are dominated

NNLO matching will improve the predictions

Conclusion

- TEEC in DIS can be measured extremely accurately at the EIC.
- We study the TEEC in the framework of SCET.
- We present fixed-order predictions and resummation up to NNNLL including non-perturbative effects which was achieved at highest perturbative accuracy.
- It is a great observable and fully utilizes EIC detector capabilities without any downside and uncertainty related to jet radius or jet reconstruction algorithm.
- **Open the avenue of precision event shape calculation and measurement at different types of colliders**

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Thank you!