Toward precision jet event shape for future Electron-Ion Collider

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- ☐ Jet Event Shapes and Angularity
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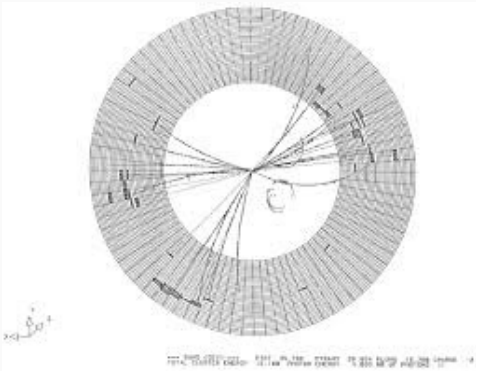
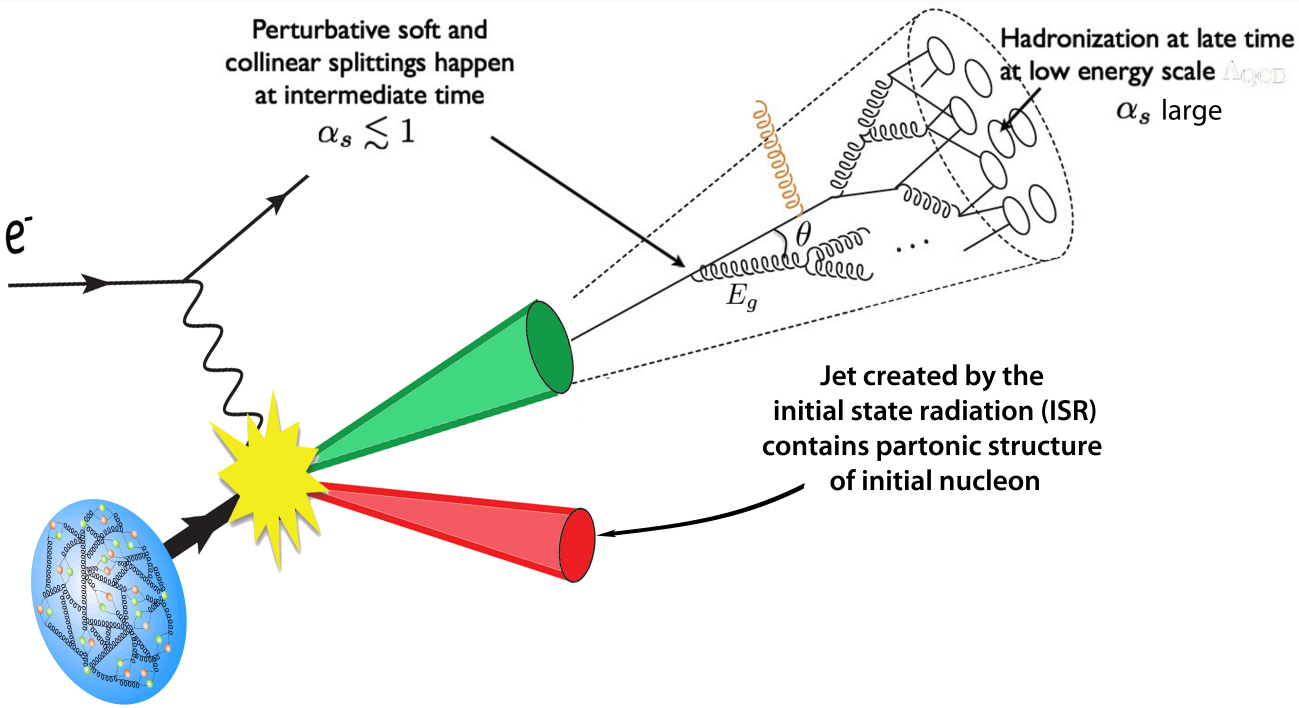
- ☐ Numerical Results and prediction to future EIC

Introduction & Motivation

- Jet?

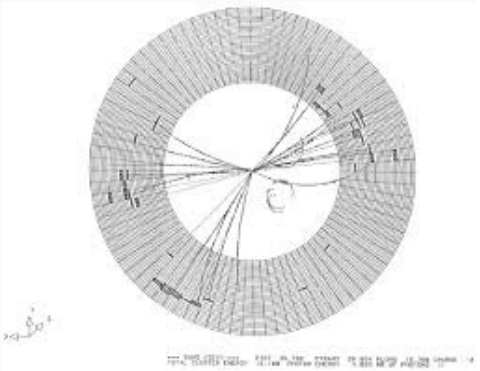


PETRA at DESY in 1979



Introduction & Motivation

- Jet?



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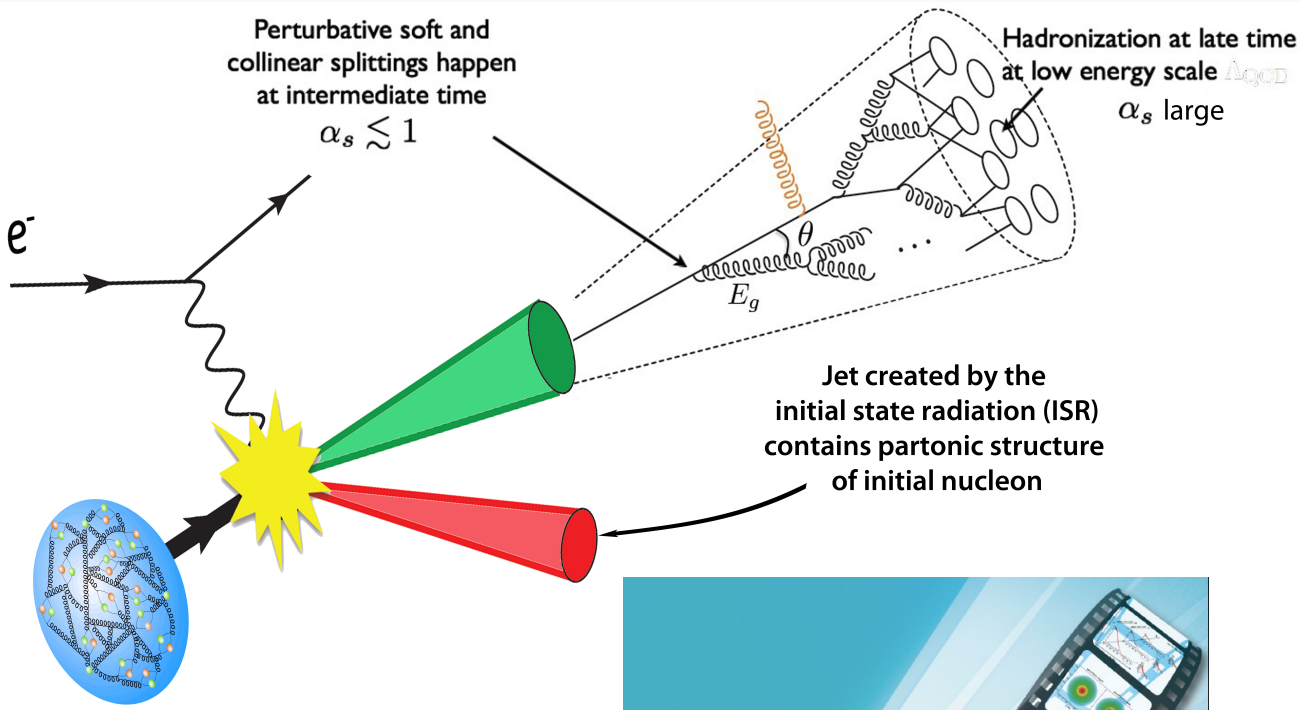


- The jet observables are called Event Shape

- Precision jet physics:
  a new tool to probe strong dynamics
  a new level of precision for jets at the
  future Electron-Ion-Collider (EIC)

- **One of early milestones!**

Talk by 邢宏喜 (Xing Hongxi), 22nd June at 17:15

Event Shapes: Jet observables

Several event shapes: Thrust (τ), Angularity (τ_a), Jet Broadening...

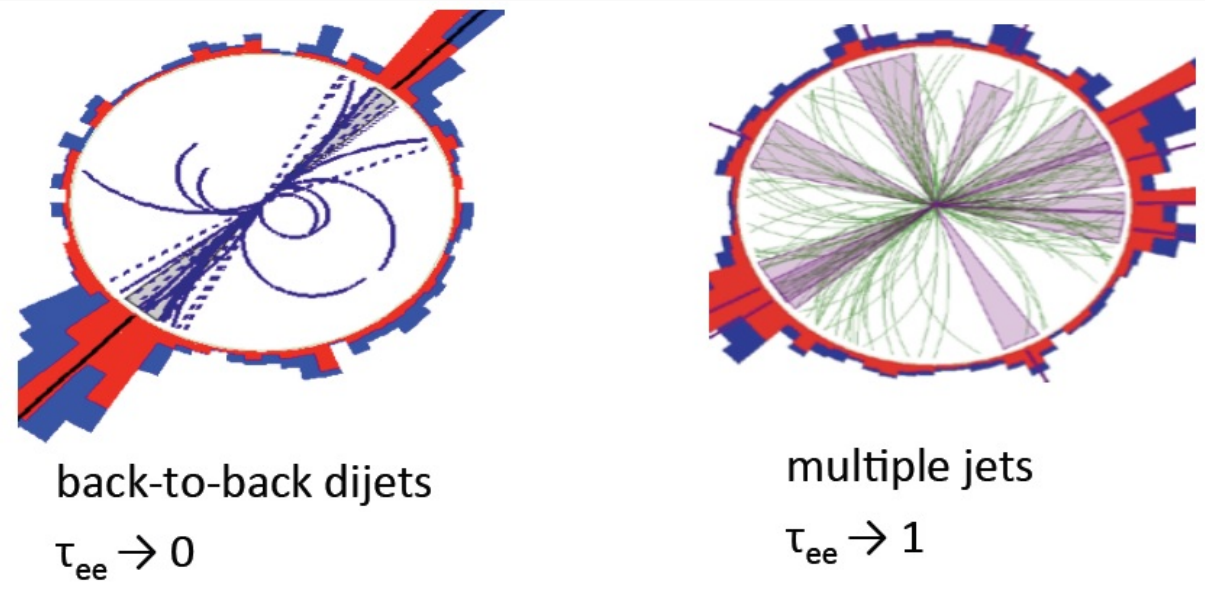
Event Shapes: Jet observables

Several event shapes: Thrust (τ), Angularity (τ_a), Jet Broadening...

◂ Thrust (τ) ▸

One of the most precisely measured observables!

$$\tau = \frac{2}{Q} \sum_{i \in \mathcal{X}} |\mathbf{p}_\perp^i| \, e^{-|\eta_i|}$$



Thrust event shape characterised the geometry of the collision!

- Expt.: LEP, CMS and ATLAS, HERA by the ZEUS and H1

Event Shapes: Angularity

Several event shapes: Thrust (τ), Angularity (τ_a), Jet Broadening...

◂ Angularity (τ) ▸

A more general event shapes!

$$\tau_a = \frac{2}{Q} \sum_{i \in \mathcal{X}} |\mathbf{p}_\perp^i| \; e^{-|\eta_i|(1-a)}$$

Angularity depends on the continuous parameter a.

$$a \to 0: \quad \text{Thrust}$$
$$a \to 1: \quad \text{Jet Broadening}$$

- Expt.: Electron-Ion-Collider (EIC) can provide a new level of precision for DIS jets.

Event Shapes: Angularity

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Theoretical Prediction: Accuracy in the theoretical prediction to the event shapes!

Tool: Soft-collinear effective theory (SCET)

a systematic way to achieve high precision in high-energy scattering

▸ SCET Predictions so far...

- Thrust at N^3LL: e^+e^- [Becher,Schwartz'08; Stewart,Tackmann,Waalewijn'10]
  pp-collision[Stewart,Tackmann,PRL'10,'11;PRD'13],
  DIS [D. Kang,C. Lee,I. Stewart'13]...
- Angularity at N^3LL: e^+e^- [Hornig,Lee,Ovanesyan'09; Bell,Lee'19]
  DIS [!!] Could be important for future EIC!

Event Shapes: Angularity

Several event shapes: Thrust (τ), Angularity (τ_a), Jet Broadening...

◄ Angularity (τ) ►

A more general event shapes!

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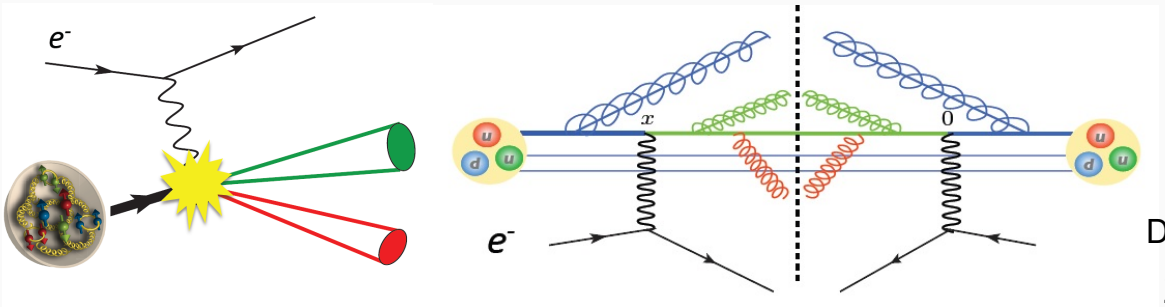
- Expt.: Electron-Ion-Collider (EIC) can provide a new level of precision for DIS jets.

► Investigation of angularity event shape in DIS in the frame-work of soft-collinear effective theory (SCET) tools and to push the frontier of the precision jet physics in the future Electron-Ion Collider (EIC)

DIS factorization and Beam function at NNLL

DIS process: $e\ P \to 2\text{Jets}$



D.Kang,Lee,Stewart'2013

Z.Kang,Mantry,Qiu'2012

$$\text{SCET facto.} \quad \sigma_{eP} = Hard \times Jet \otimes Beam \otimes Soft$$

• Beam is produced due to the initial state radiation (ISR) and can be used to study internal structure of proton!

$$\begin{aligned} \text{Beam func.} \quad B(\tau_a, x, \mu) &= f \otimes \mathcal{I} \\ &= \text{pdf} \otimes \left[\delta_{qj}\delta(1-z) + \mathcal{I}^{(1)}_{qj} + \mathcal{O}(\alpha_s^2) + ...\right] \\ &\quad NP \qquad LO \qquad NLO \qquad NNLO \end{aligned}$$

• Angularity Jet and soft function is presented at NNLL accuracy [Bell,Horning,Lee'2018]

Angularity beam function is presented for the first time!

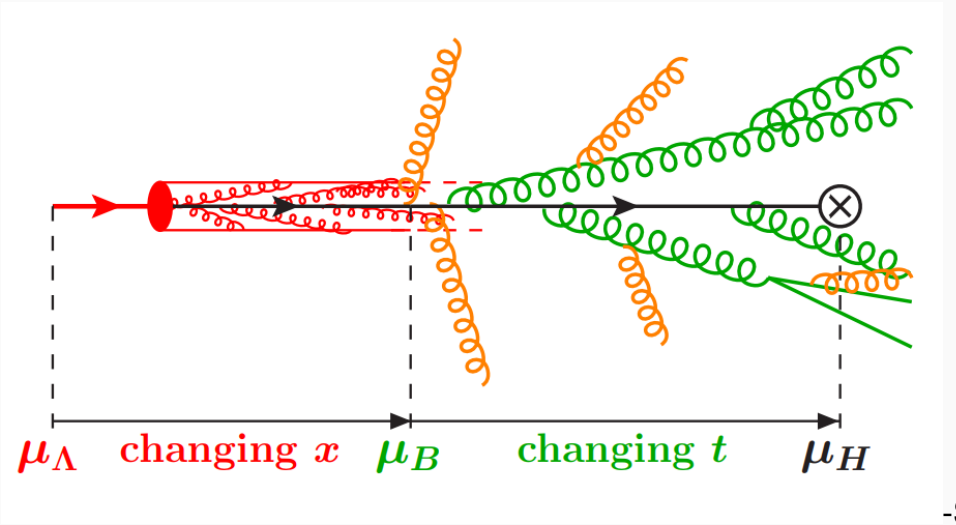
Resummation from evolution

Evolution Equation for beam function

$$\mu\frac{d}{d\mu}B(\nu,\mu) \;=\; \gamma_G(\mu)\,B(\nu,\mu)\;\;; \qquad \text{similar to} J,S,H$$

$$\text{Solution}: \;\; B(\nu,\mu) \;=\; B(\nu,\mu_B)\,e^{K_B(\mu_B,\mu)+j_B\eta_B(\mu_B,\mu)L_B}\;,$$

- Jet and beam functions are defined by same collinear operator: $\gamma_J(\mu)=\gamma_B(\mu)$



-Stewart et. al. PRD81(2010)

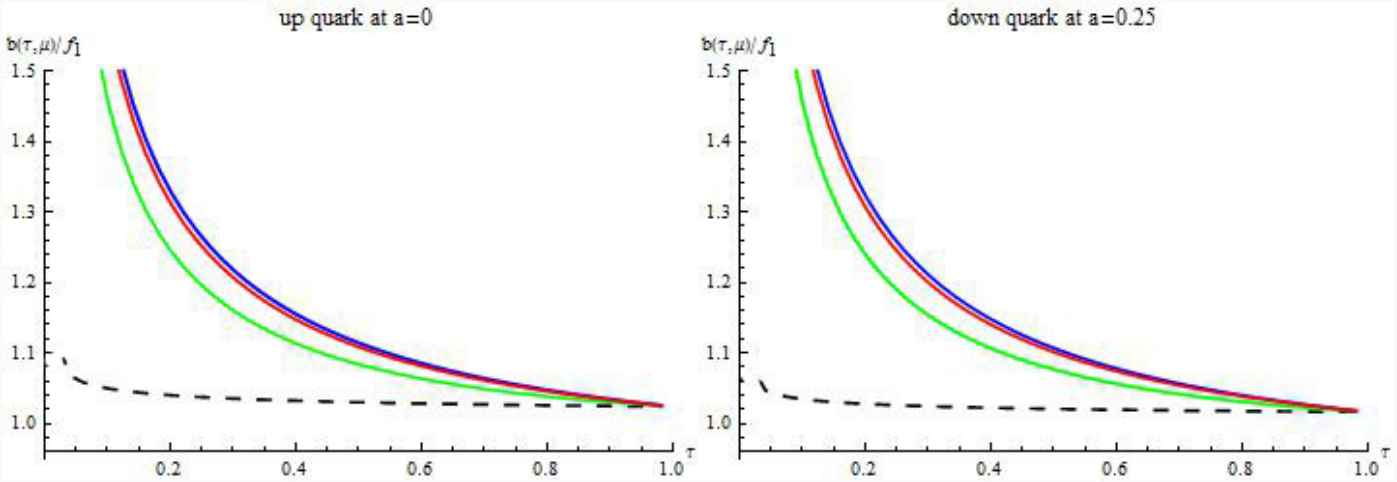
$$K_B(\mu_B,\mu) \;=\; L_B\sum_{k=1}^{\infty}(\alpha_s L_B)^k + \sum_{k=1}^{\infty}(\alpha_s L_B)^k + \ldots$$

LL $\qquad$ NLL

- Resum large logs: No large logs in the function at its natural scale μ_B, evolve from μ_B to a common scale μ.

Beam function result

- Beam function with angularity τ_a at $a = 0.25$



NNLL
NLL
LL
NLO

Beam function result

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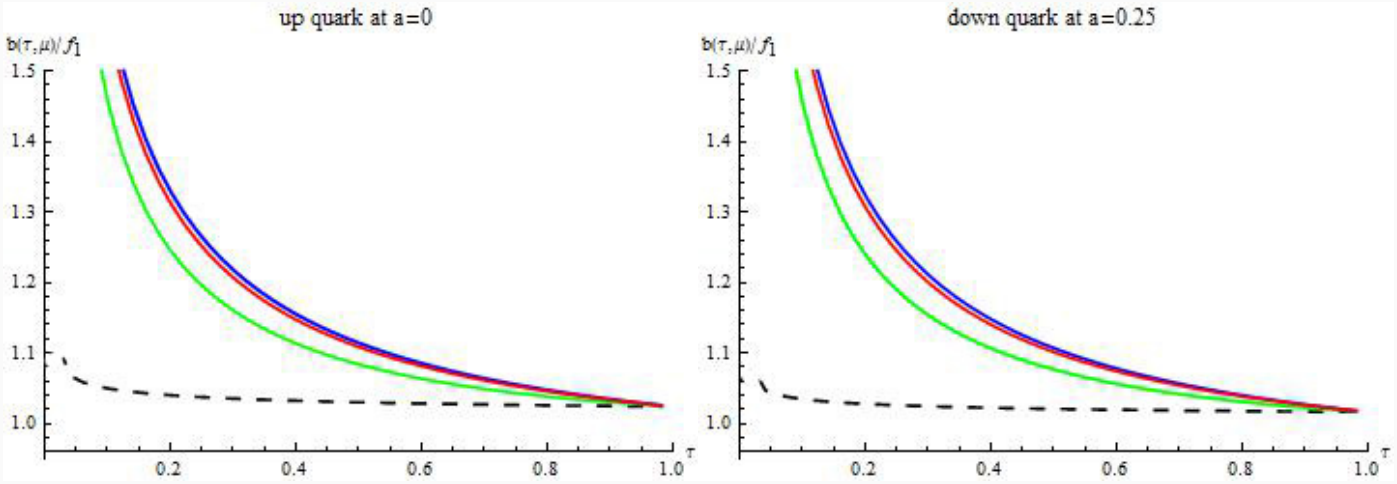
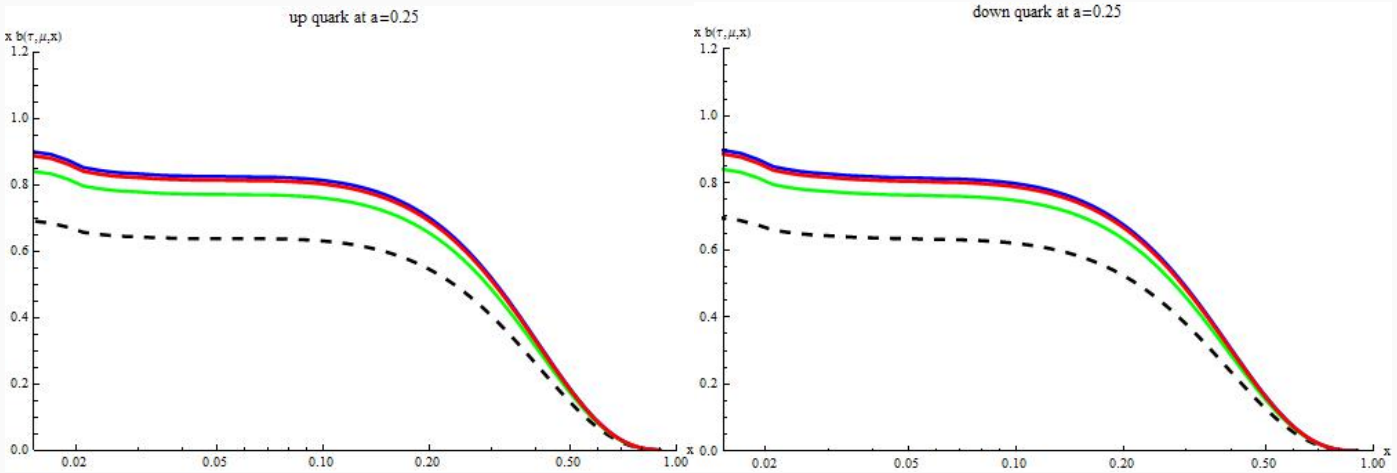


NNLL
NLL
LL
NLO

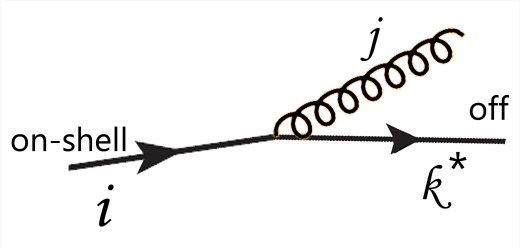
- Beam function with x at $a = 0.25$



NNLL
NLL
LL
NLO

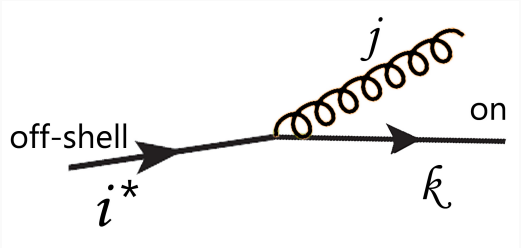
Beam Func. and Fragmentation Func.

Beam at NLO: $i \to k^* j$



Crossing Symmetry!

Fragmentation at NLO: $i^* \to kj$

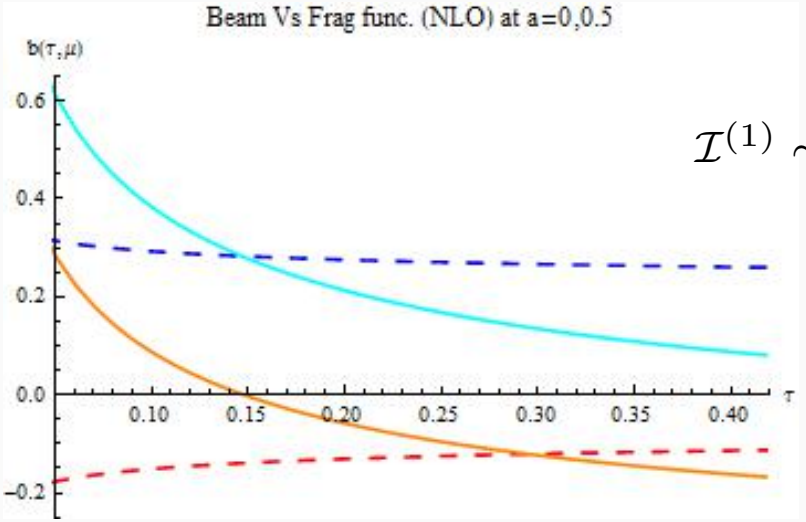


Splitting Function:

[M.Ritzmann,W.J.Waalewijn,PRD90(2014)]

$$P_{i\to k^* j}(2pi.pj, x) \equiv (-1)^{\Delta_f} P_{k*\to ij}(-2pi.pj, 1/x)$$

• Change comes only from the two-particle phase-space and effectively change in sign of the $\log(x)$ term in the matching co-efficient $\mathcal{I}^{(1)}$.



$$\mathcal{I}^{(1)} \sim \ldots - \frac{\alpha_s C_F}{2\pi} \frac{2(1-a)}{2-a} \frac{1+x^2}{1-x} \log x$$

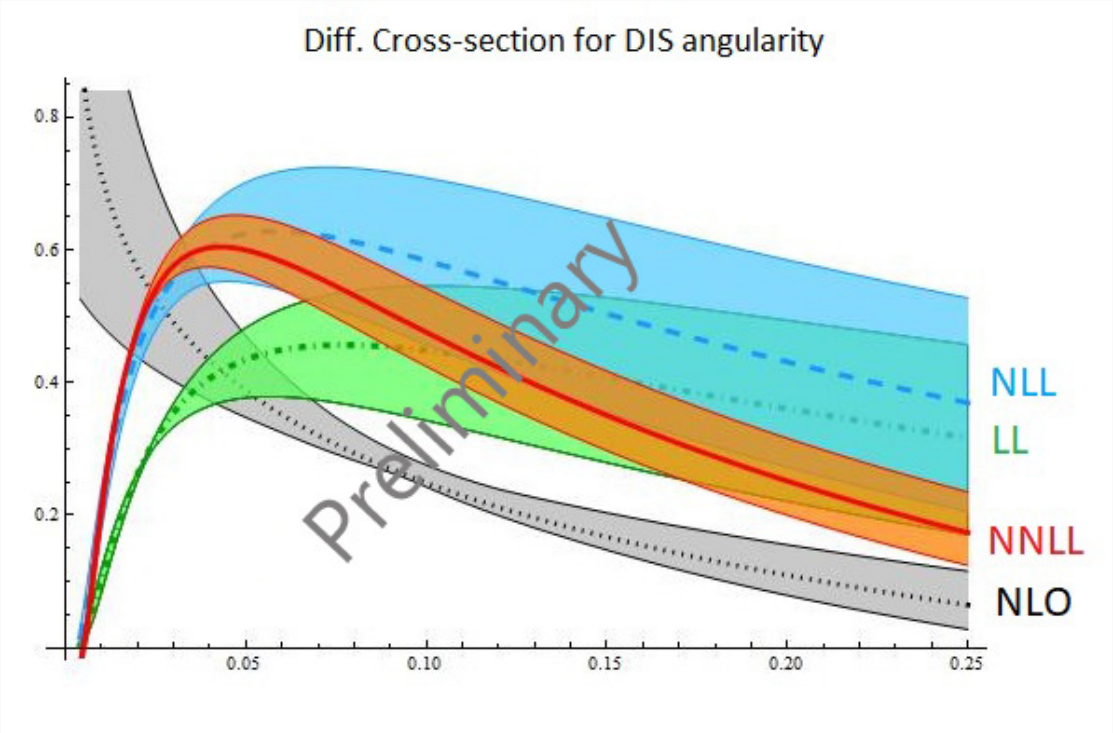
Beam match. Coeffi.: $a = 0$

Beam match. Coeffi.: $a = 0.5$

FF match. Coeffi.: $a = 0$

FF match. Coeffi.: $a = 0.5$

Resummation effect: Differential Cross-Section



$eP \to 2 - jets$

- Log singularity at NLO for low angularity region, Resummation gives convergence at NLL and NNLL.
- Choice of other scale profile functions than Canonical scale profile may improve tail region.
- Modelling of non-perturbative soft function need to have accuracy to experimental measurement.

Summary & Future direction

▶ We define DIS angularity event shape, τ_a^{DIS} , for the axis aligned to the jet axis and compute 1-jettiness cross-section to NNLL accuracy for the production of 2-jets (Beam and Jet).

▶ We present a preliminary result of differential cross-section for DIS angularity which could be a early prediction to future Electron-Ion-Collider.

[In collaboration with: Daekyoung Kang, IMP, Fudan University]

Future Direction...

▶ Multi-jets in DIS...

▶ Angularity in future CEPC...

Thanks!