USING JETS FOR TMD SEARCH

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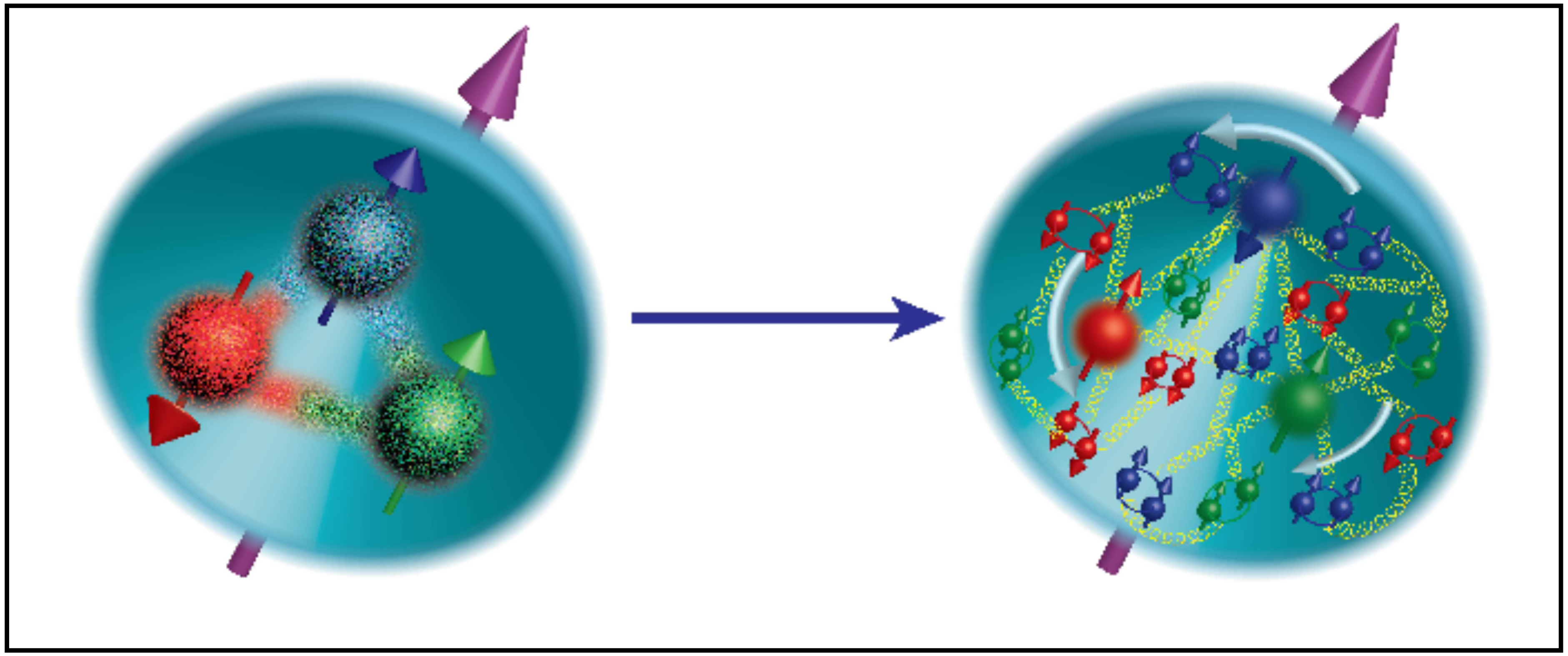
Based on :

D. Gutierrez-Reyes, I.S., W. Waalewijn, L. Zoppi PRL **121,** 162001(2018)

D. Gutierrez-Reyes, I.S., W. Waalewijn, L. Zoppi JHEP 1910 (2019) 031

D. Gutierrez-Reyes, Y. Makris, I.S., V. Vaidya, L. Zoppi JHEP **1908** (2019) 161

The study of the hadron structure is (again) a hot topic

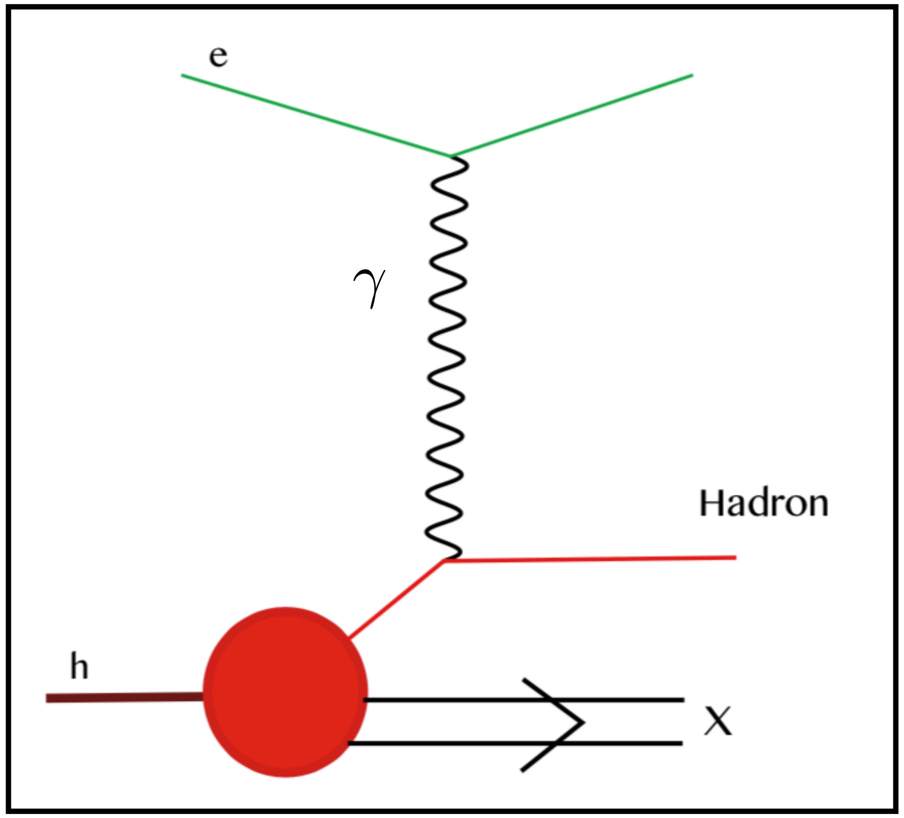


The 3D mapping of hadrons is still challenging…

↓

Let us use jets to investigate hadron structure!

TMDS WITHOUT JETS

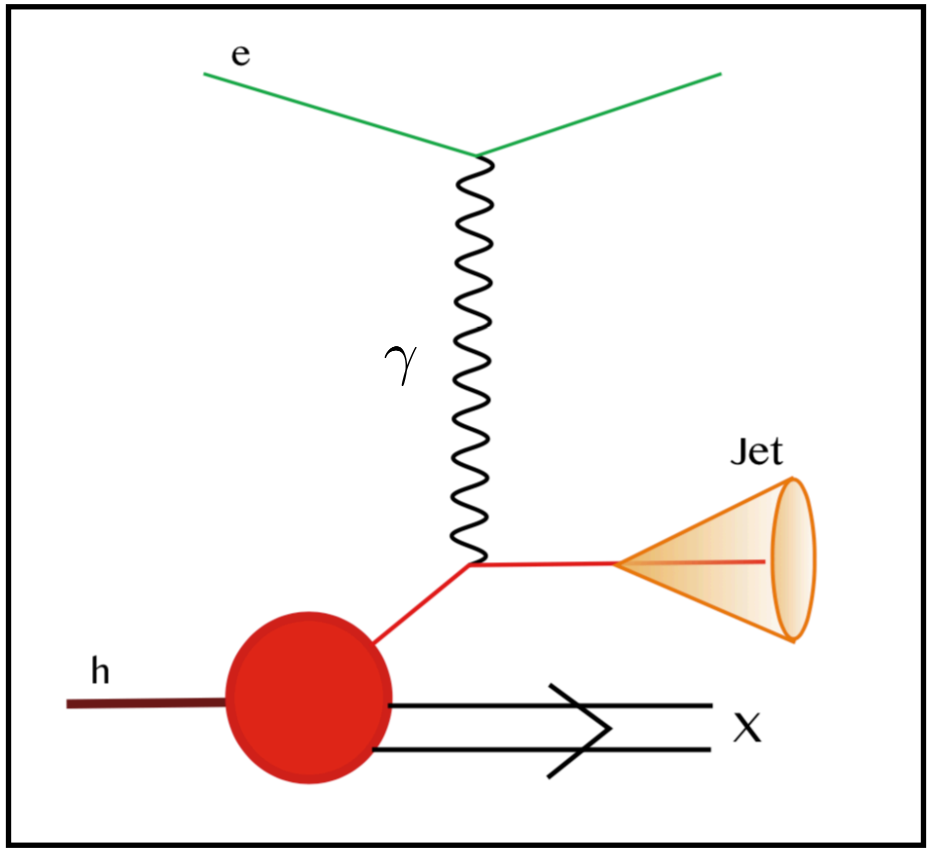


Factorization theorem for SIDIS

$$\frac{d\sigma_{eN\to eN'X}}{dQ^2dxdzd\boldsymbol{q}} = \sum_a \mathcal{H}_a(Q^2,\mu)\int \frac{d\boldsymbol{b}}{(2\pi)^2} e^{-i\boldsymbol{b}\boldsymbol{q}} f_{a/N}(x,\boldsymbol{b},\mu,\zeta) d_{a/N'}(z,\boldsymbol{b},\mu,\zeta)$$

TMDPDF TMDFF

TMDS WITH JETS

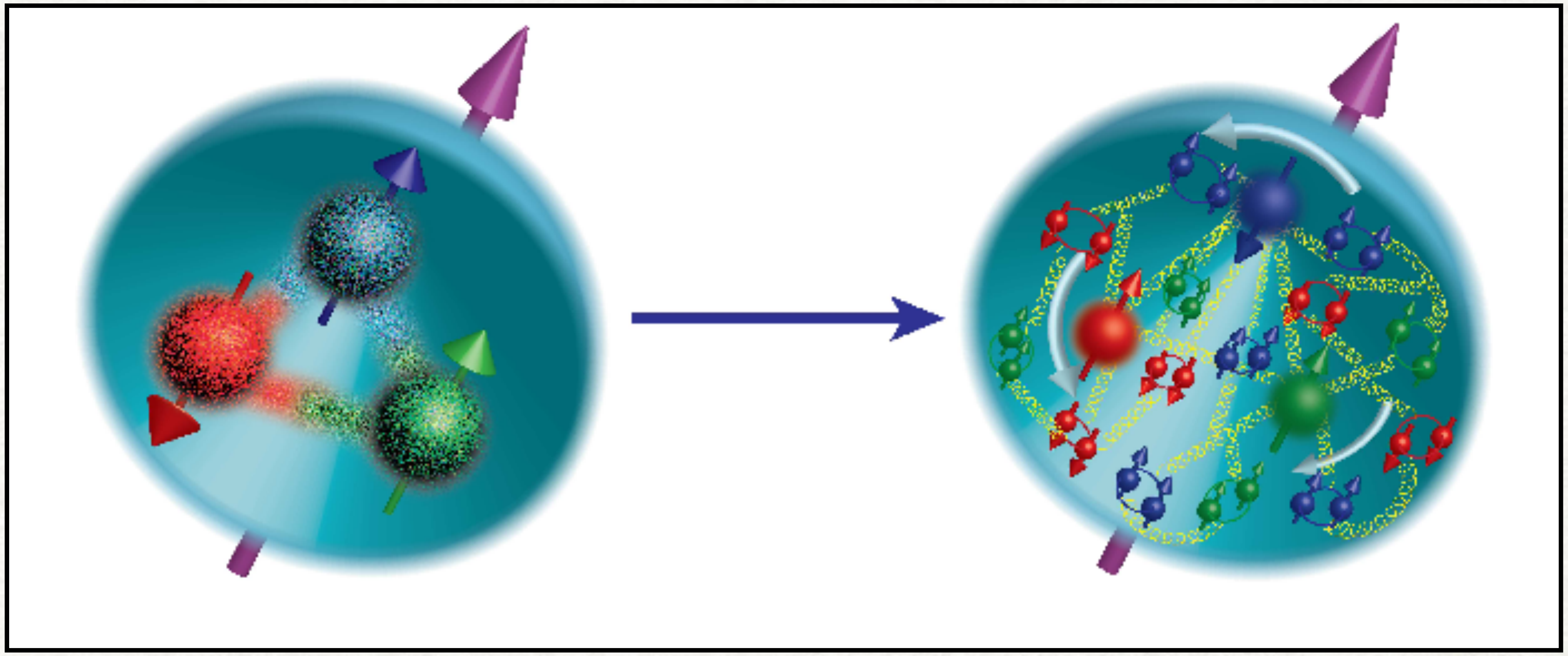


Factorization theorem for SIDIS

$$\frac{d\sigma_{eN\to eJX}}{dQ^2dxdzd\boldsymbol{q}} = \sum_a \mathcal{H}_a(Q^2,\mu)\int\frac{d\boldsymbol{b}}{(2\pi)^2}e^{-i\boldsymbol{b}\boldsymbol{q}}f_{a/N}(x,\boldsymbol{b},\mu,\zeta)J_q^{\text{axis}}(z,\boldsymbol{b},QR,\mu,\zeta)$$

TMDPDF

TMD jet function



We want to study the non-perturbative part of the evolution kernel:
We consider the possibility to reduce non-perturbative effects in final states using jets.

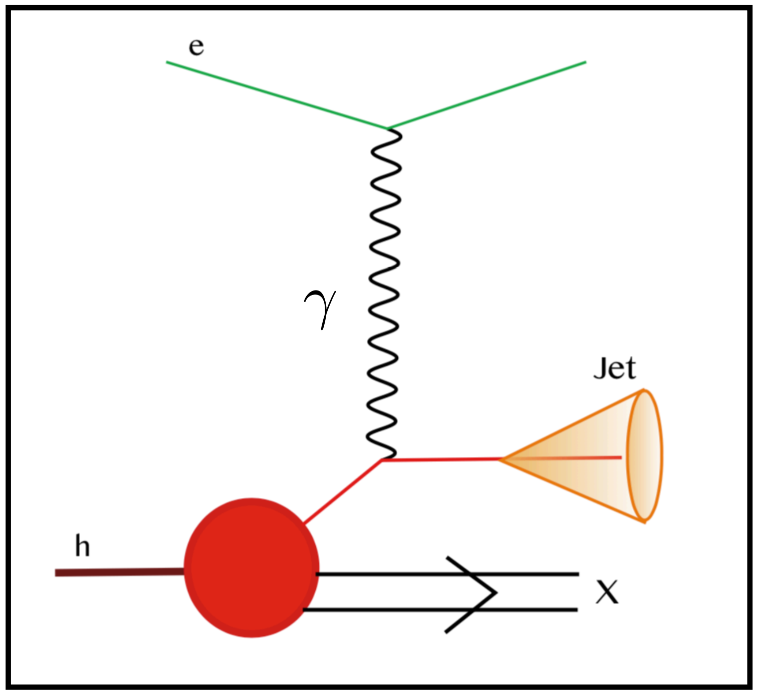
In SIDIS With a jet:

$$\frac{d\sigma}{dQ^2 dx dz dq_T^2} = \sigma_0 \sum_{f_1,f_2} \int \frac{d^2\mathbf{b}}{4\pi} e^{i\mathbf{b}\mathbf{q_T}} \{R[\mathbf{b};(Q,Q^2)]\}^2 F_{f_1\leftarrow h}(x,\mathbf{b}) J_{f_2\to J}(z,\mathbf{b})$$

In DY:

$$\frac{d\sigma}{dQ^2 dy dq_T^2} = \sigma_0 \sum_{f_1,f_2} \int \frac{d^2\boldsymbol{b}}{4\pi} e^{i(\boldsymbol{b}\cdot\boldsymbol{q}_T)} H_{f_1 f_2}(Q,Q) \{R[\boldsymbol{b};(Q,Q^2)]\}^2 F_{f_1\leftarrow h_1}(x_1,\boldsymbol{b}) F_{f_2\leftarrow h_2}(x_2,\boldsymbol{b}).$$

TMDS WITH JETS



Questions:
Can we write TMD factorization theorems for processes with jets?

Can we write factorization theorems for jets regardless of the size of the jet?

Non-perturbative effects for jets are in principle more suppressed than for nuclear TMDs!

This would be a clean channel to measure non-perturbative effects in the initial nucleon

Hadronization effects should be considered (ungroomed/groomed jets)

OUTLINE

- Building a jet
  - Radius and jet algorithms
  - Jet axis
- TMD factorization
- Factorization: ungroomed/groomed jets. Phenomenology
  - Ungroomed jets: Factorization for dijet decorrelation and SIDIS processes
  - Groomed jets: Factorization for dijet decorrelation and SIDIS processes
- Conclusions

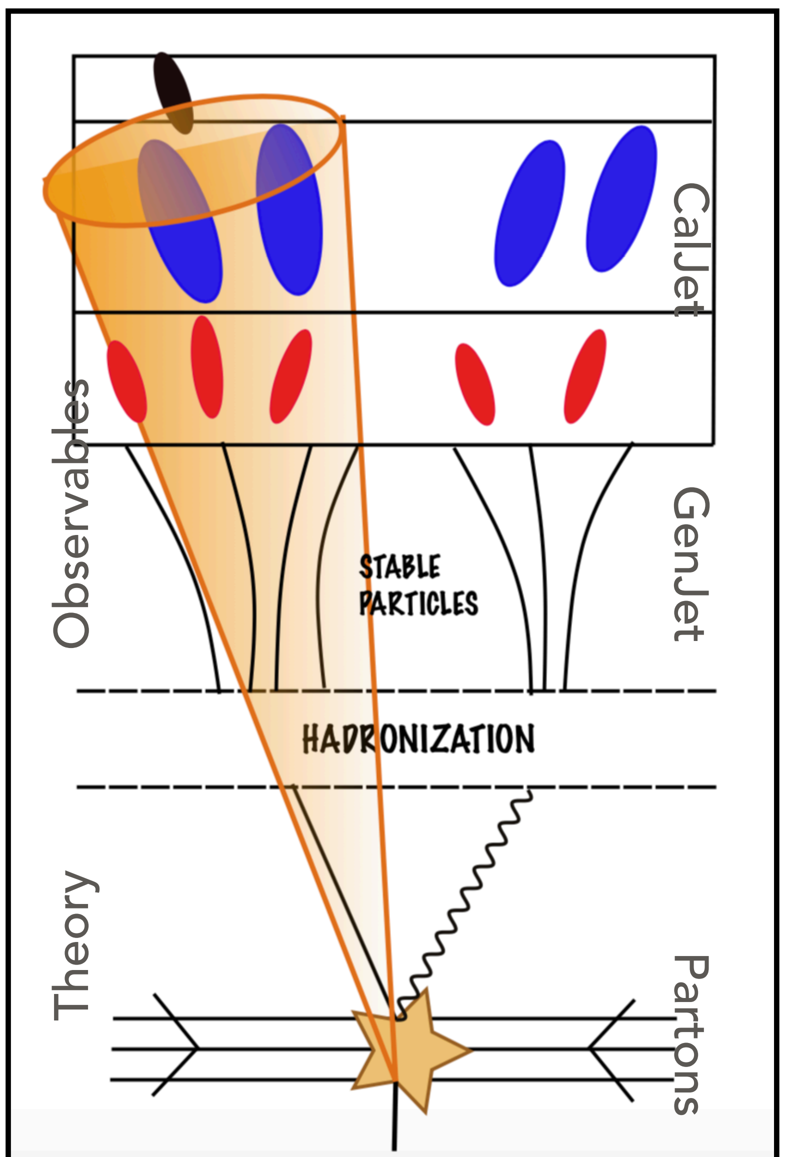
JETS

RADIUS AND JET ALGORITHMS

Standard kt-type algorithms

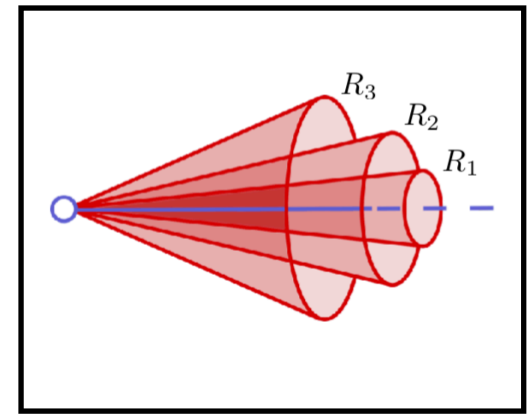
$$d_{ij} = \min\left(k_{T,1}^{2w}, k_{T,2}^{2w}\right)\frac{\Delta R_{ij}}{R}$$

$$w \in \{-1, 0, 1\}$$

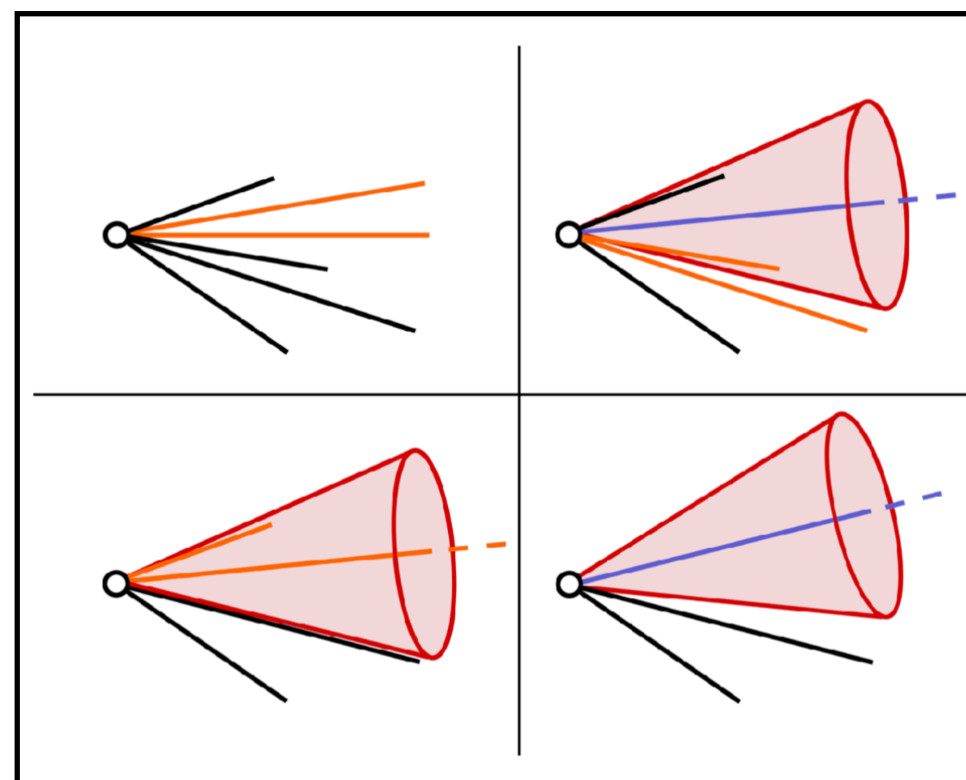


Building a jet…

Step 1:
Set a size
(Radius)



Step 2:
Run a jet
algorithm



JET AXIS

Larkoski, Neill, Thaler `14
arXiv: 1401.2158

Standard jet axis (SJA)

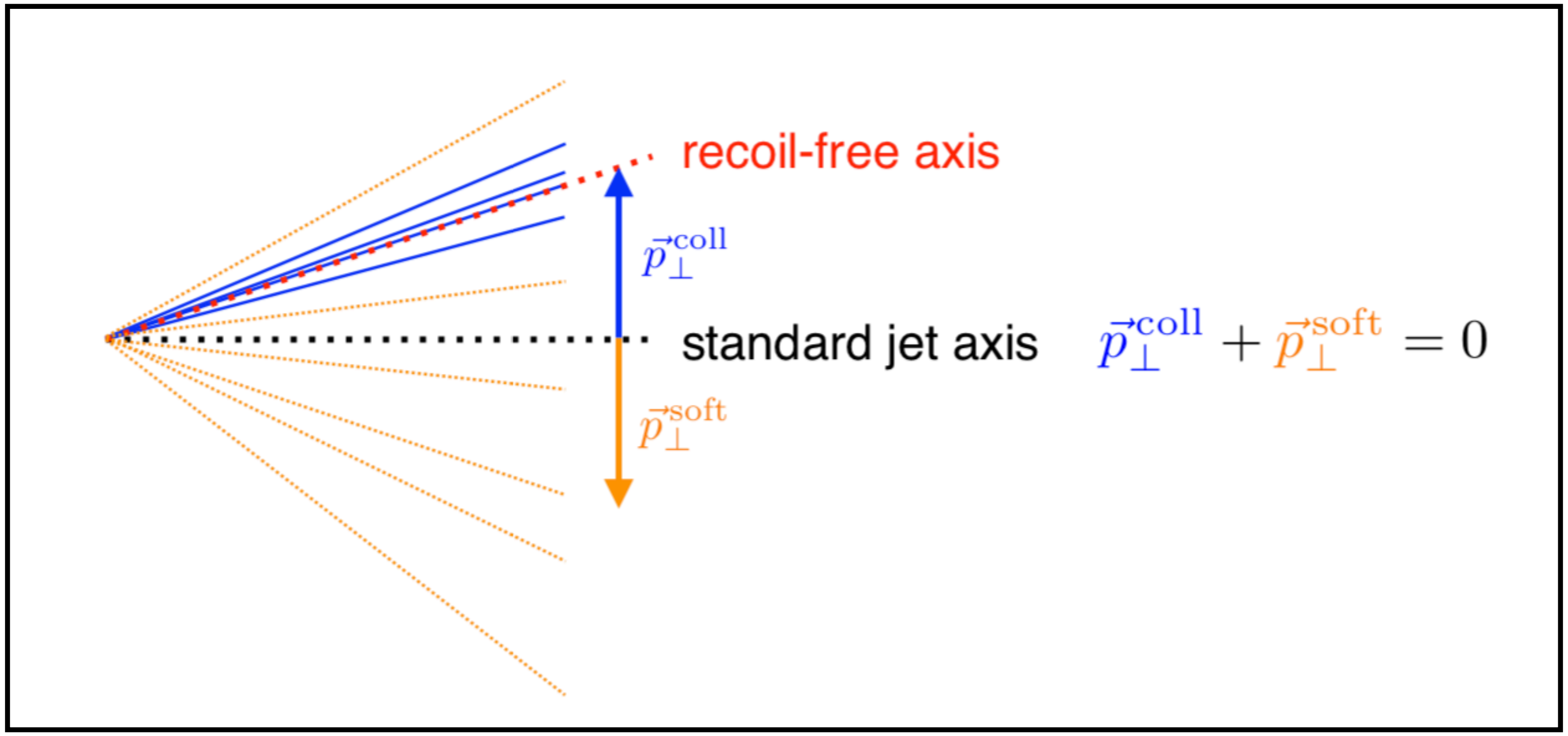
The sum of the momentum of collinear and soft particles is zero

Introduces soft-sensitivity to the axis definition. Important with unintegrated transverse momentum

Winner-take-all (WTA)

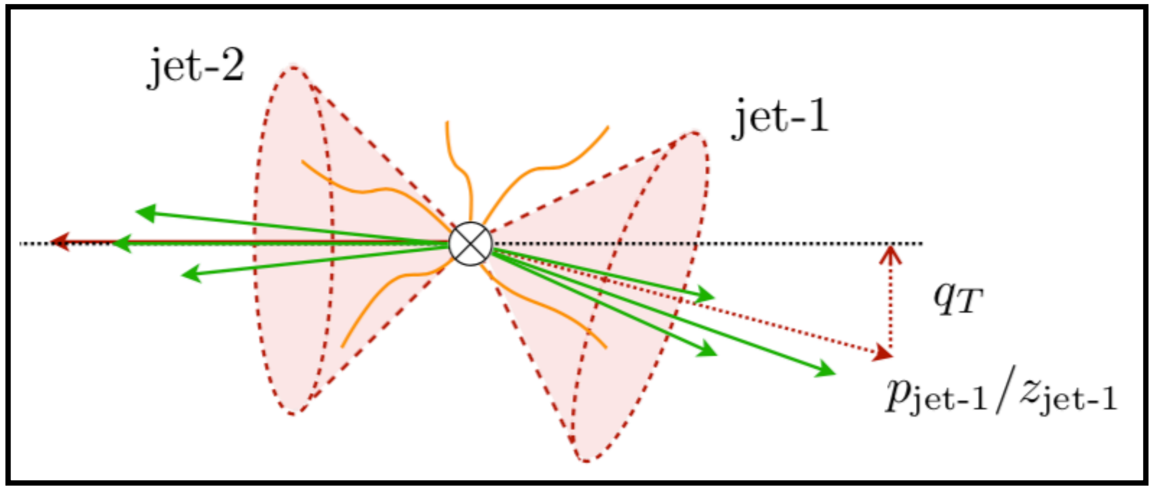
It always follows the direction of the most energetic particle

Recoil invariant. It is not sensitive to soft radiation

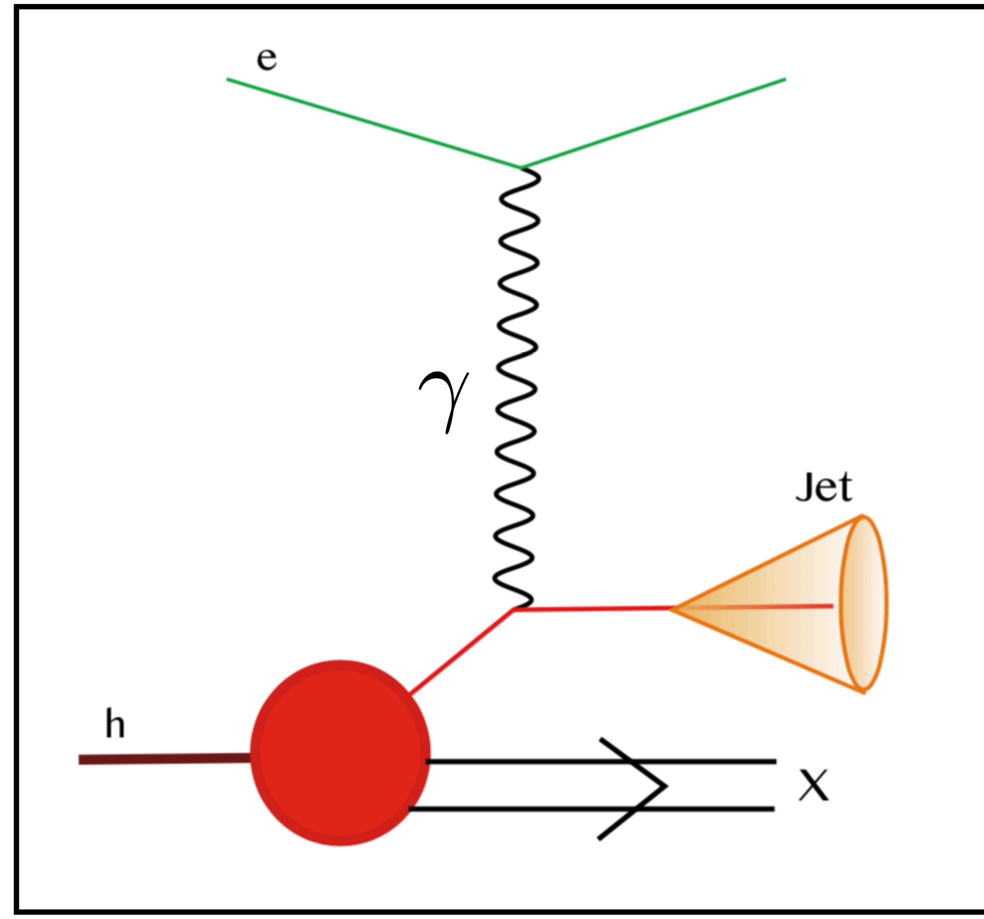


INTERESTING PROCESSES TO FACTORIZE

$e^+e^- \to \text{dijet} + X$



SIDIS with jet



UNGROOMED JETS

The factorization depends on jet axis definitions

↓

Dependence on the radius

Small jet-radii: *Standard/WTA*

Large jet-radii: *WTA*

Even if NP effect are reduced from hadronic TMDs

↓

Final state NP hadronization effects

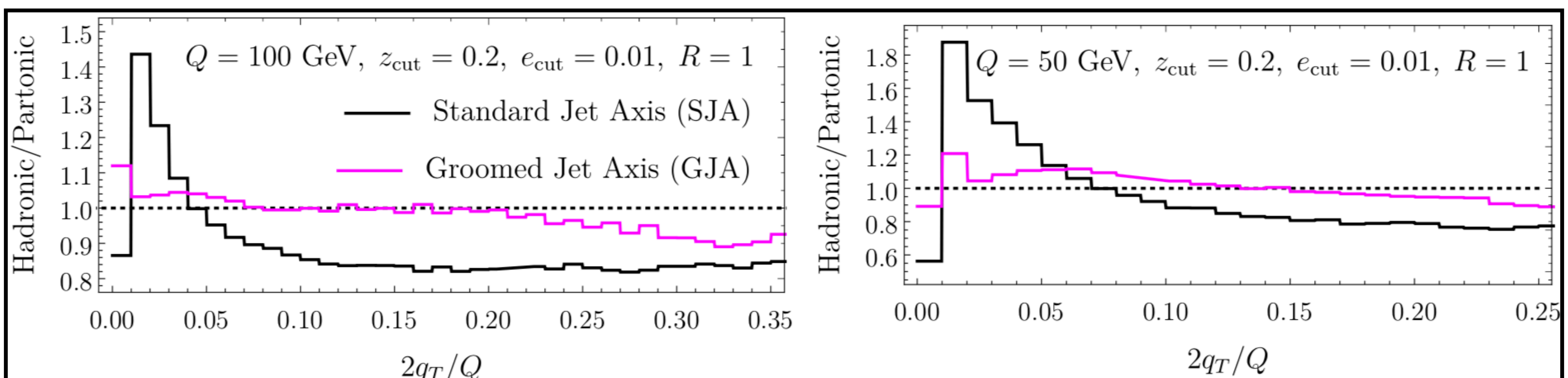
GROOMED JETS

SOFT-DROP : Removes large angle (soft) radiation

1. Construction an angular tree of the jet
2. Removal of branches that fail an energy requirement

Only narrow energetic core remains from the original jet

NP hadronization effects are highly reduced!



FACTORIZATION: UNGROOMED JETS

FACTORIZATION: UNGROOMED JETS

Dijet decorrelation

$e^+e^- \to \text{dijet} + X$

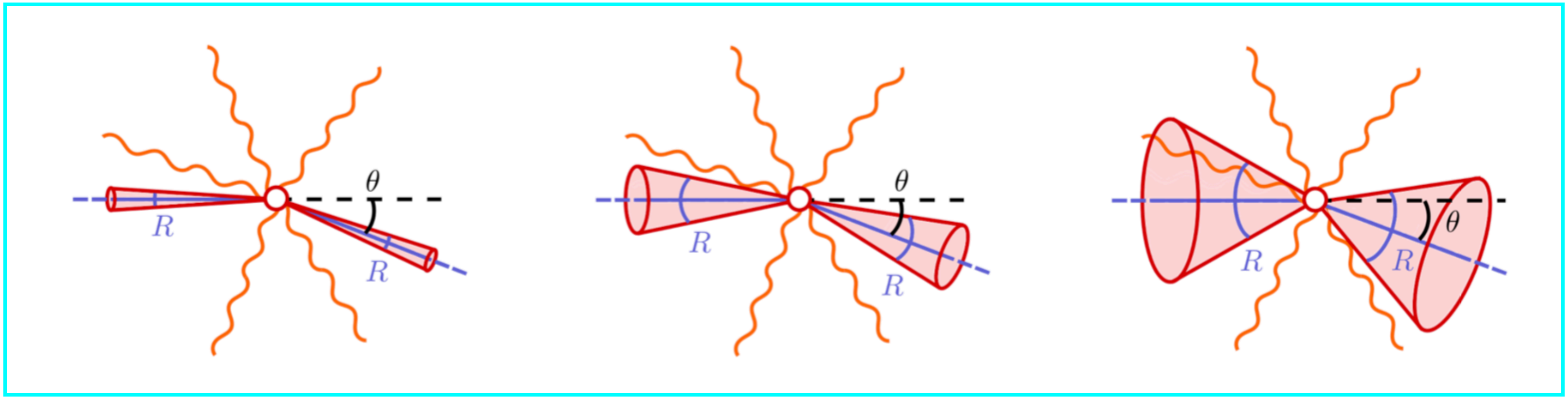
$$\boldsymbol{q} = \frac{\boldsymbol{p}_1}{z_1} + \frac{\boldsymbol{p}_2}{z_2}$$

$$\theta \approx \tan\theta = 2|\boldsymbol{q}|/Q$$

competes with R

In all cases

$\theta \ll 1$



$\theta \gg R$ $\theta \sim R$ $\theta \ll R$

FACTORIZATION: UNGROOMED JETS

Dijet decorrelation

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$$\boldsymbol{q} = \frac{\boldsymbol{p}_1}{z_1} + \frac{\boldsymbol{p}_2}{z_2}$$
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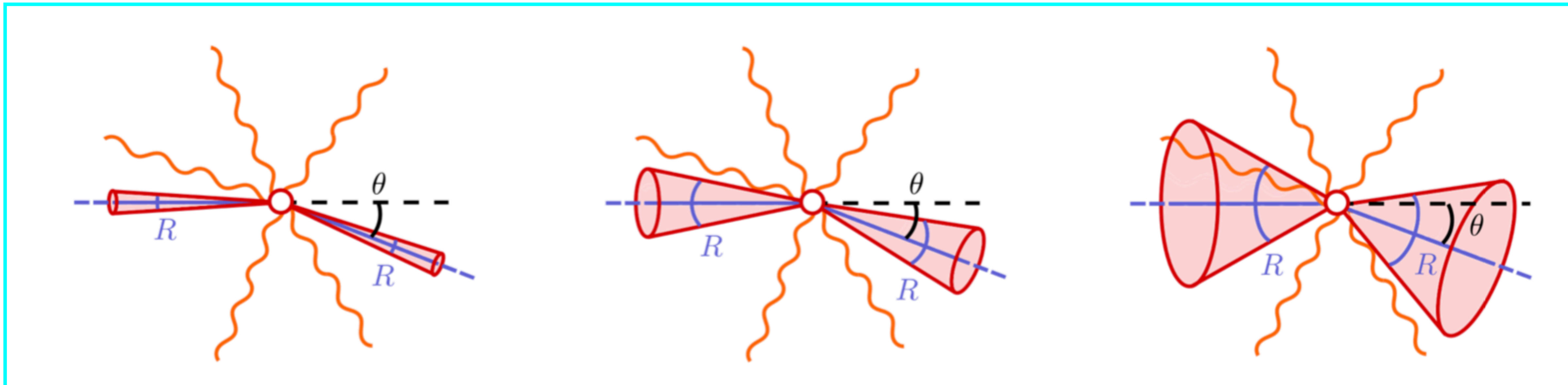
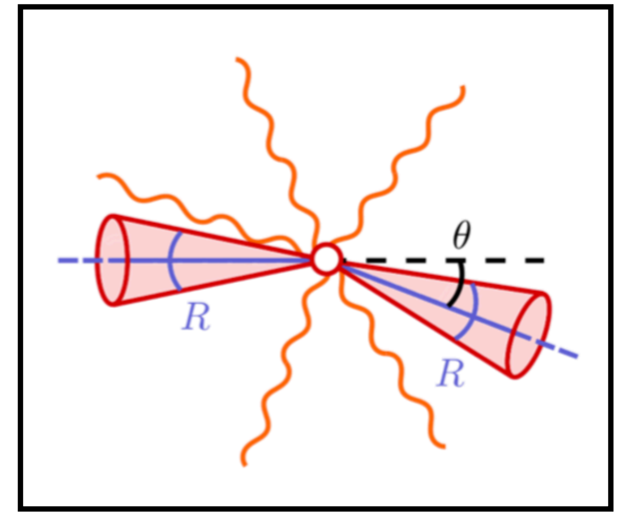


$\theta \gg R$ $\qquad$ $\theta \sim R$ $\qquad$ $\theta \ll R$

Most interesting case for current and future experiments!

FACTORIZATION: UNGROOMED JETS

$$\theta \sim R \ll 1$$



$$\frac{d\sigma_{ee\to JJX}}{dz_1 dz_2 d\boldsymbol{q}} = H(s,\mu)\int \frac{d\boldsymbol{b}}{(2\pi)^2} e^{-i\boldsymbol{b}\boldsymbol{q}} J_q^{\rm axis}\left(z_1, \boldsymbol{b}, \frac{\sqrt{s}}{2}R, \mu, \zeta_1\right) J_q^{\rm axis}\left(z_2, \boldsymbol{b}, \frac{\sqrt{s}}{2}R, \mu, \zeta_2\right)\left[1+\mathcal{O}\left(\frac{\boldsymbol{q}^2}{s}\right)\right]$$

$$J_q^{\rm axis} = \frac{z}{2N_c}\sum_X {\rm Tr}\left\{\frac{\bar{\not n}}{2}\langle 0|\delta\left(\bar n\cdot p_J/z - \bar n\cdot P\right) e^{-i\boldsymbol{b}\boldsymbol{P}_\perp}\chi_n(0)|J^{\rm axis}_{{\rm alg},R}X\rangle\langle J^{\rm axis}_{{\rm alg},R}X|\bar\chi_n(0)|0\rangle\right\}$$

TMD semi-inclusive Jet function

Refactorized!

$$R \ll \theta \ll 1$$

$$J_i^{\rm axis} = \sum_j \int \frac{dz'}{z'}\left[(z')^2 \mathbb{C}(z', \boldsymbol{b}, \mu, \zeta)\right] \mathcal{J}_i\left(\frac{z}{z'}, \frac{\sqrt{s}}{2}R, \mu\right)\left[1+\mathcal{O}\left(b^2 s^2 R^2/4\right)\right]$$

NNLO TMDFFs Coefficients $\otimes$ Coll. jet Function

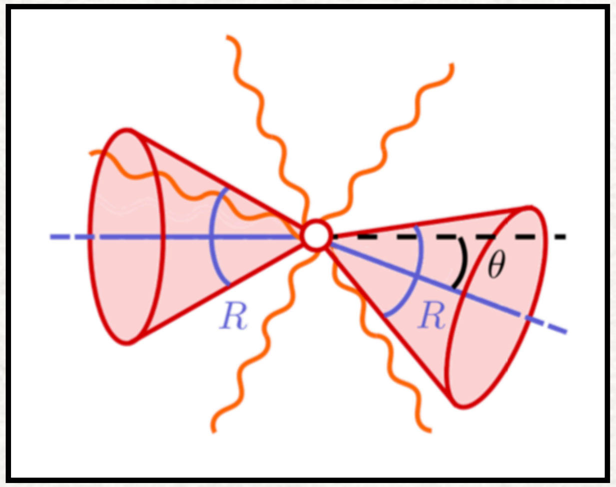
Echevarría, Scimemi, Vladimirov `16

Kang, Ringer, Vitev `16
arXiv:1606.06732

The wide angle soft radiation does not resolve individual collinear emissions in the jet → The soft function is the same Than that for TMD fragmentation

FACTORIZATION: UNGROOMED JETS

$\theta \ll 1 \quad \theta \ll R$



WTA axis

The soft radiation does resolve the jet boundary, but this fact does not affect to the position of the axis

↓

No distinction between soft radiation inside and outside the jet!

↓

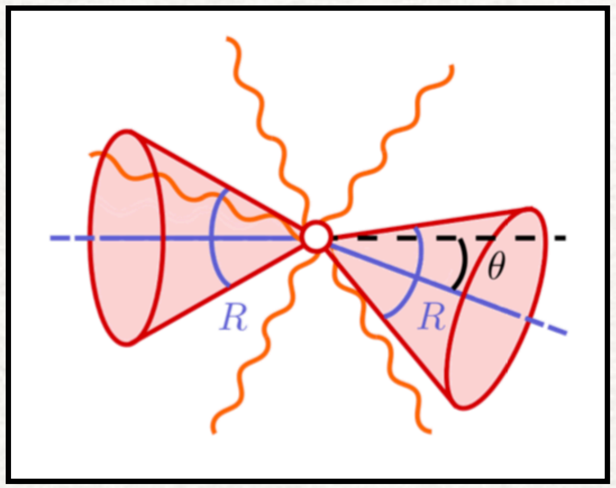
TMD Soft function is conserved!
And factorization holds!

$$\frac{d\sigma^{\text{WTA}}_{(ee\to JJX)}}{dz_1 dz_2 d\boldsymbol{q}} = H \int \frac{d\boldsymbol{b}}{(2\pi)^2} J_q^{WTA}(z_1, \boldsymbol{b}) J_q^{WTA}(z_2, \boldsymbol{b})$$

The factorization with WTA Works for every R!

FACTORIZATION: UNGROOMED JETS

$\theta \ll 1 \quad \theta \ll R$



Standard Jet Axis

The SJA is aligned with the total momentum of the jet

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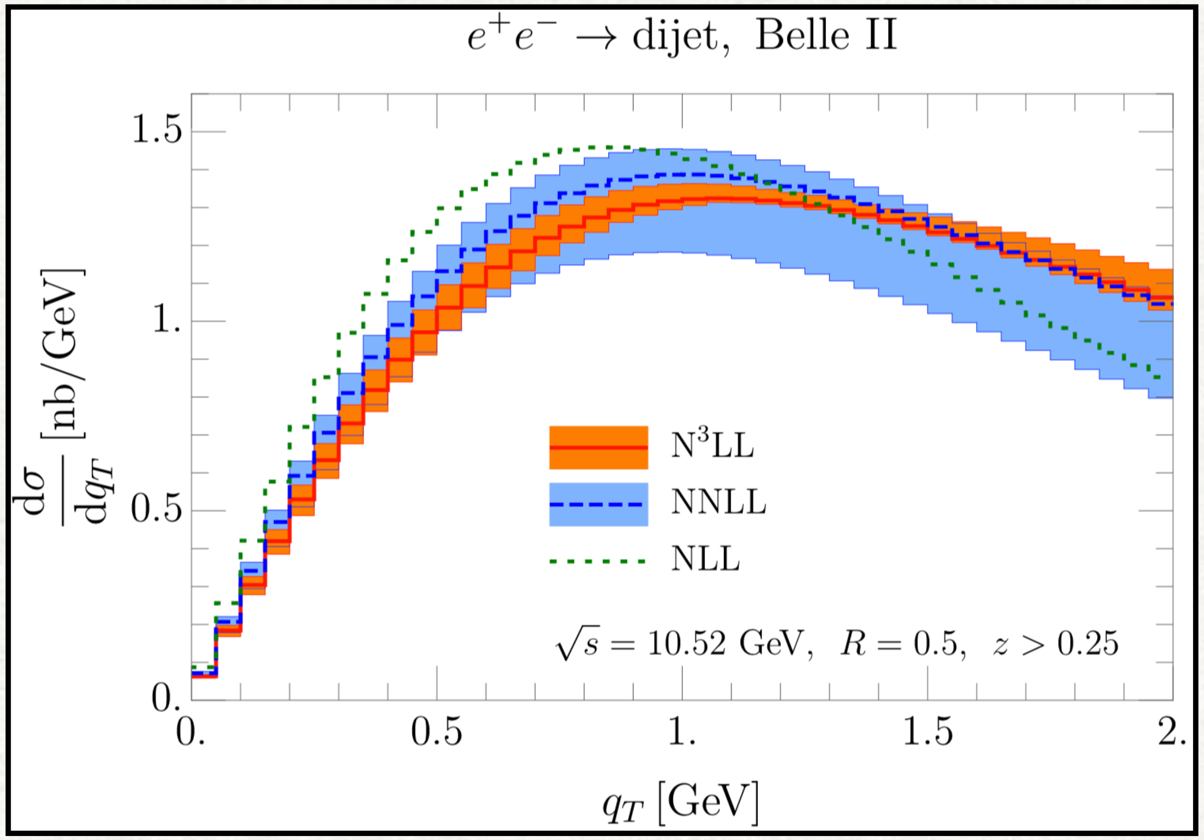
Hard splittings with typical angle R are allowed inside the jet, generating additional soft radiation

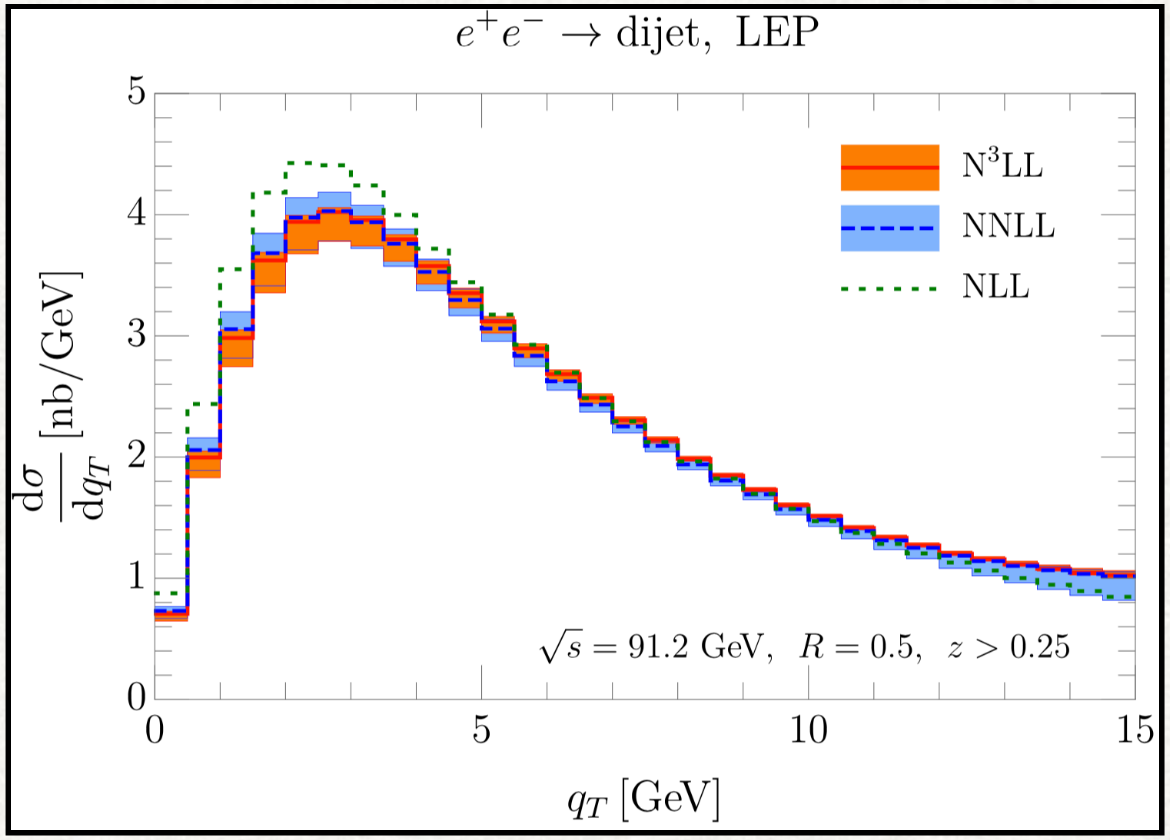
↓

Factorization broken!

$$\frac{d\sigma^{\mathrm{SJA}}_{(ee\to JJX)}}{d\boldsymbol{q}} = \sum_{m=2}^{\infty} \mathrm{Tr}_c \left[\mathcal{H}_m(\{n_i\}) \otimes \mathcal{S}_m(\boldsymbol{q}, \{n_i\})\right]$$

PERTURBATIVE CONVERGENCE: LARGE RADIUS





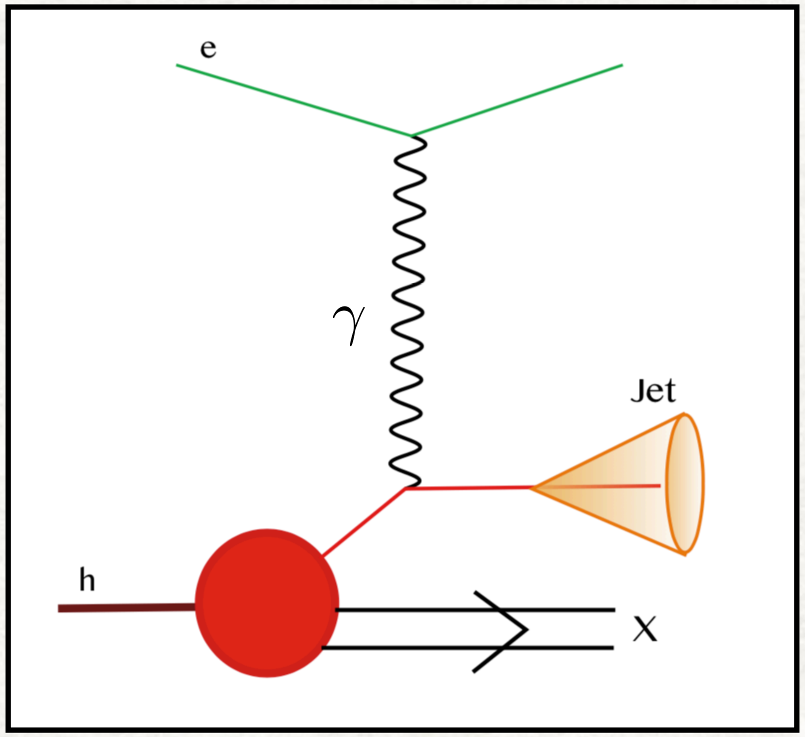
As the large-R jet function does not depend on radius or z, we can predict the two loop jet function by RG + Numerical constant (Event2)

We use an improved NLO + NNLO large-R jet functions
Resummation up to N3LL!

Theoretical errors are reduced when the perturbative order is increased!

FACTORIZATION: UNGROOMED JETS SIDIS

Factorization in SIDIS with a jet is analogous to the one already studied!

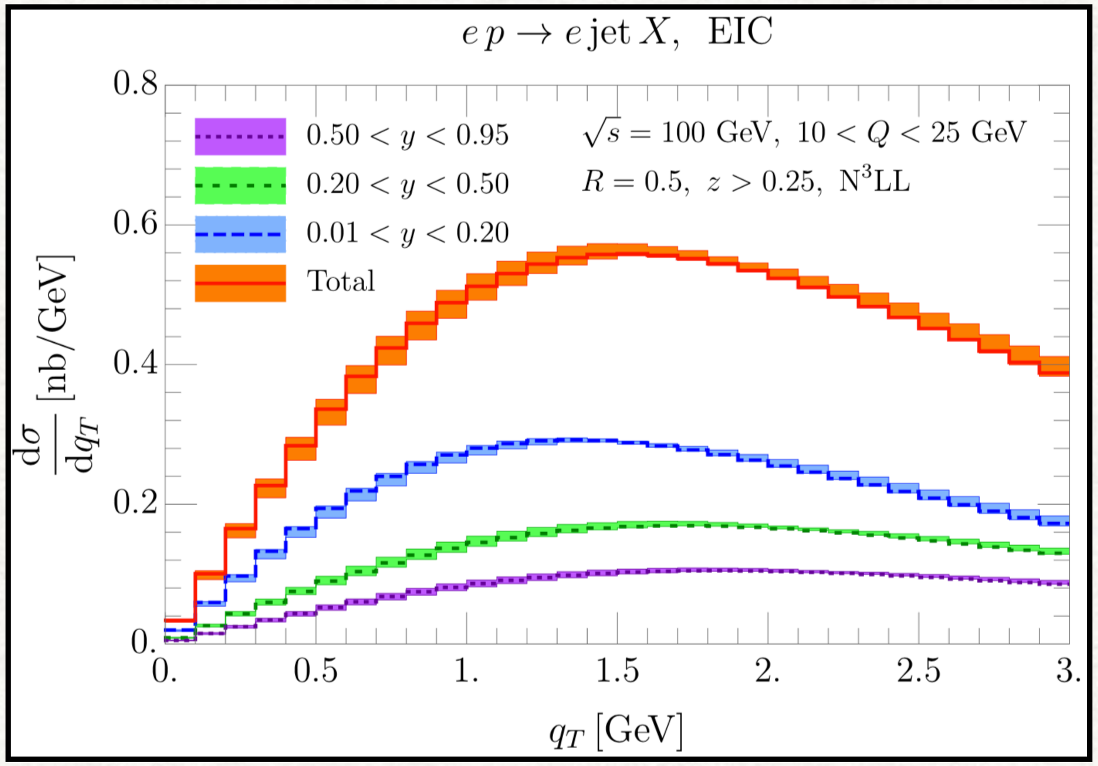


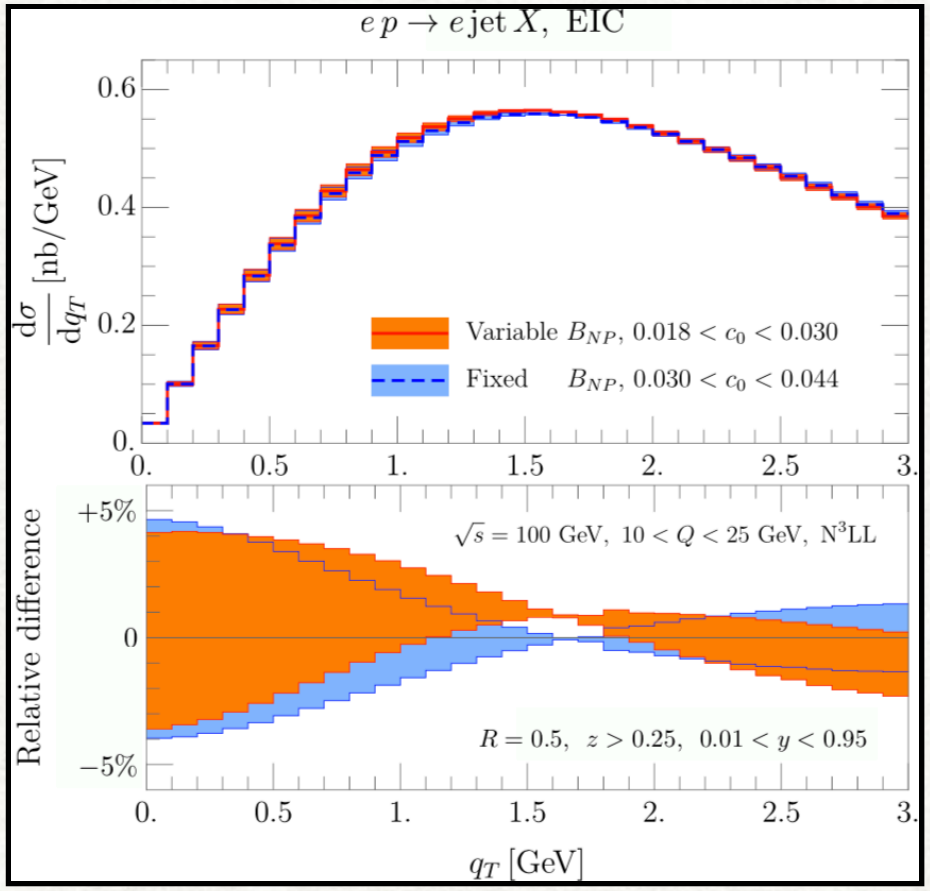
Factorization for SIDIS with jet in hadron/jet Breit frame

$$\frac{d\sigma_{eN\to eJX}}{dQ^2dxdzd\boldsymbol{q}} = \sum_a \mathcal{H}_a(Q^2,\mu)\int\frac{d\boldsymbol{b}}{(2\pi)^2}e^{-i\boldsymbol{b}\boldsymbol{q}}\underbrace{f_{a/N}(x,\boldsymbol{b},\mu,\zeta)}_{\text{TMDPDF}}\underbrace{J_q^{\text{axis}}(z,\boldsymbol{b},QR/2,\mu,\zeta)}_{\text{TMD jet function}}$$

It has dependence on the jet radius. For all R we use WTA axis

PHENO RESULTS FOR SIDIS WITH UNGROOMED JET





We include an effect of the two-loop jet function

Most of the cross section comes from low elasticity region

Theoretical errors from the Hard scale and the OPE scale are shown and are small

Non perturbative model for the TMDPDF taken from Bertone, Scimemi, Vladimirov `19 arXiv:1902.08474

$$f_{NP}(x, \boldsymbol{b}) = \exp\left(- \frac{(\lambda_1(1-x) + \lambda_2 x + \lambda_3 x(1-x))\boldsymbol{b}^2}{\sqrt{1 + \lambda_4 x^{\lambda_5} \boldsymbol{b}^2}} \right)$$

But the cross section is dominated by non-perturbative parameters of evolution (BNP, c0)

FACTORIZATION: GROOMED JETS

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Two extra scales for groomed jets

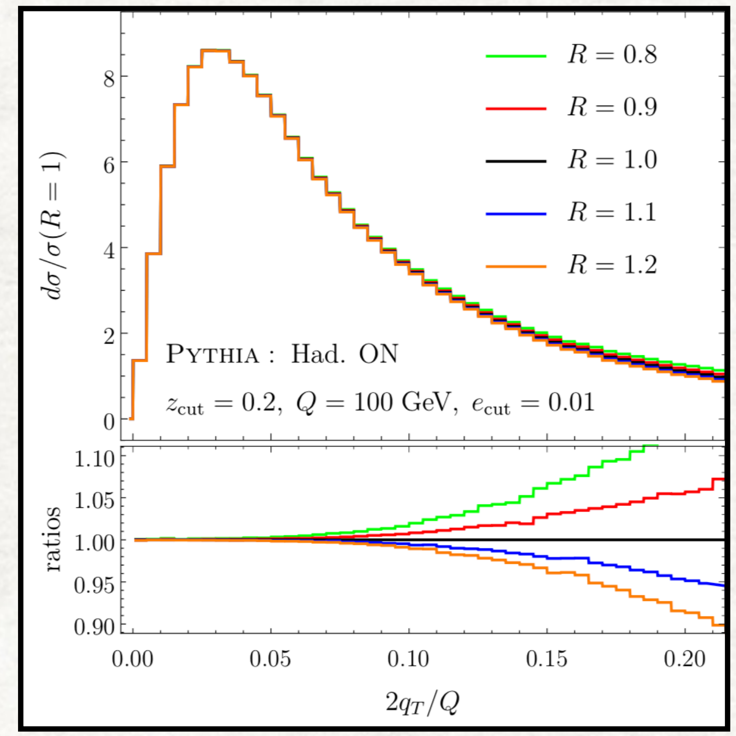
Grooming parameter → $\frac{\min\{\mathrm{E_i}, \mathrm{E_j}\}}{E_i + E_j} > z_{\rm cut} \left(\frac{\theta_{ij}}{R}\right)^{\beta}$

Jet mass → $e \equiv \left(\frac{m_J}{2E_J}\right)^2$

Hierarchy

$$Q \gg Q z_{\rm cut} \gg q_T \geq Q\sqrt{e} \gg Q\sqrt{e z_{\rm cut}}$$

Remove contaminating Soft radiation → Independence on the radius → Pythia check



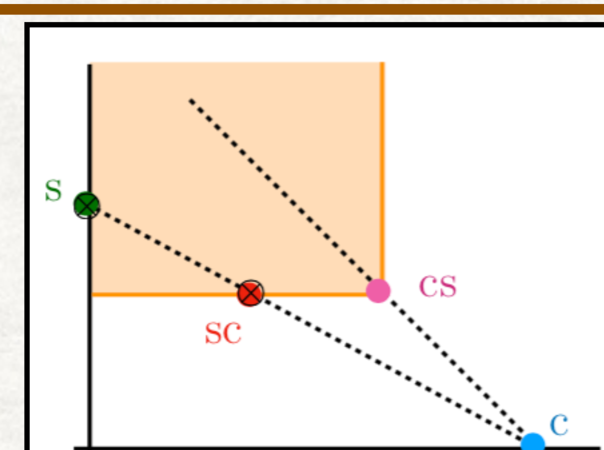
New modes in factorization!

Soft: $p_s^\mu \sim q_T(1,1,1)$

Collinear: $p_c^\mu \sim Q(\lambda_c^2, 1, \lambda_c),\ \lambda_c = \sqrt{e}$

Soft-collinear: $p_{sc}^\mu \sim Q z_{\rm cut}(\lambda_{sc}^2, 1, \lambda_{sc}),\ \lambda_{sc} = q_T/(Q z_{cut})$

Collinear-soft: $p_{cs}^\mu \sim Q z_{\rm cut}(\lambda_{cs}^2, 1, \lambda_{cs}),\ \lambda_{cs} = \sqrt{e/z_{cut}}$



FACTORIZATION: GROOMED JETS

The cross-section is factorized as

$$\frac{d\sigma}{de_1 de_2 d^2\boldsymbol{q}_T} = H^{ij}(Q;\mu) \times \mathcal{J}_i^{\perp}(e_1, Q, z_{\rm cut}, \boldsymbol{q}_T; \mu, \zeta_A) \otimes \mathcal{J}_j^{\perp}(e_2, Q, z_{\rm cut}, \boldsymbol{q}_T; \mu, \zeta_B)$$

Groomed jet function

$$\mathcal{J}_i^{\perp}(e, Q, z_{\rm cut}, \boldsymbol{b}; \mu, \zeta) = \sqrt{S(\boldsymbol{b})}\, \mathcal{J}_i^{\perp}(e, Q, z_{\rm cut}, \boldsymbol{b})$$

Soft radiation absorbed
same as TMDs

$$\zeta_A \zeta_B = Q^4 z_{\rm cut}^4$$

Energy needed is higher!

FACTORIZATION: GROOMED JETS

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$$\frac{d\sigma}{de_1 de_2 d^2\boldsymbol{q}_T} = H^{ij}(Q;\mu) \times \mathcal{J}_i^{\perp}(e_1, Q, z_{\text{cut}}, \boldsymbol{q}_T; \mu, \zeta_A) \otimes \mathcal{J}_j^{\perp}(e_2, Q, z_{\text{cut}}, \boldsymbol{q}_T; \mu, \zeta_B)$$

Groomed jet function

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$$\zeta_A \zeta_B = Q^4 z_{\text{cut}}^4$$

Energy needed is higher!

Soft radiation absorbed
same as TMDs

New modes → Refactorization!

$$\mathcal{J}_i^{\perp}(e, Q, z_{\text{cut}}, \boldsymbol{b}) = S_{sc,i}^{\perp}(Q z_{\text{cut}}, \boldsymbol{b}) \times \int de' S_{cs,i}(e - e', Q z_{\text{cut}}) J_i(e', Q)$$

All at NLO!

Soft-collinear

Collinear-soft

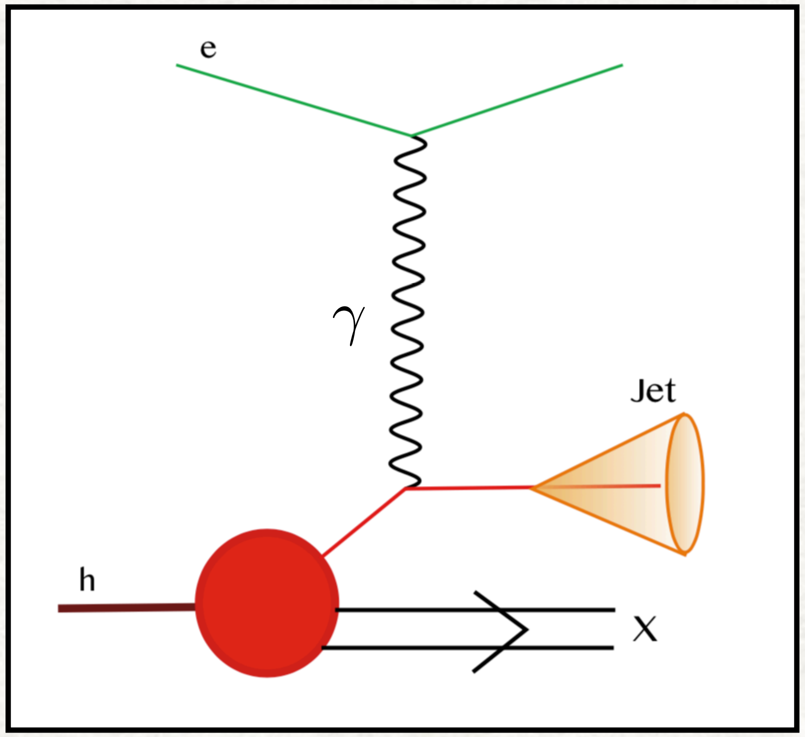
Jet

Integrate parameters
as in experiments

$$\frac{d\sigma}{d^2\boldsymbol{q}_T}(e_{\text{cut}}) = H^{ij}(Q;\mu) \int \frac{d^2\boldsymbol{b}}{4\pi} e^{i(\boldsymbol{b}\boldsymbol{q})_T} \mathcal{J}_i^{\perp}(e_{\text{cut}}, Q, z_{\text{cut}}, \boldsymbol{b}; \mu, \zeta) \mathcal{J}_j^{\perp}(e_{\text{cut}}, Q, z_{\text{cut}}, \boldsymbol{b}; \mu, \zeta)$$

FACTORIZATION: GROOMED JETS SIDIS

Factorization in SIDIS with a groomed jet introduces now the groomed jet function



Factorization for SIDIS with jet in Breit frame

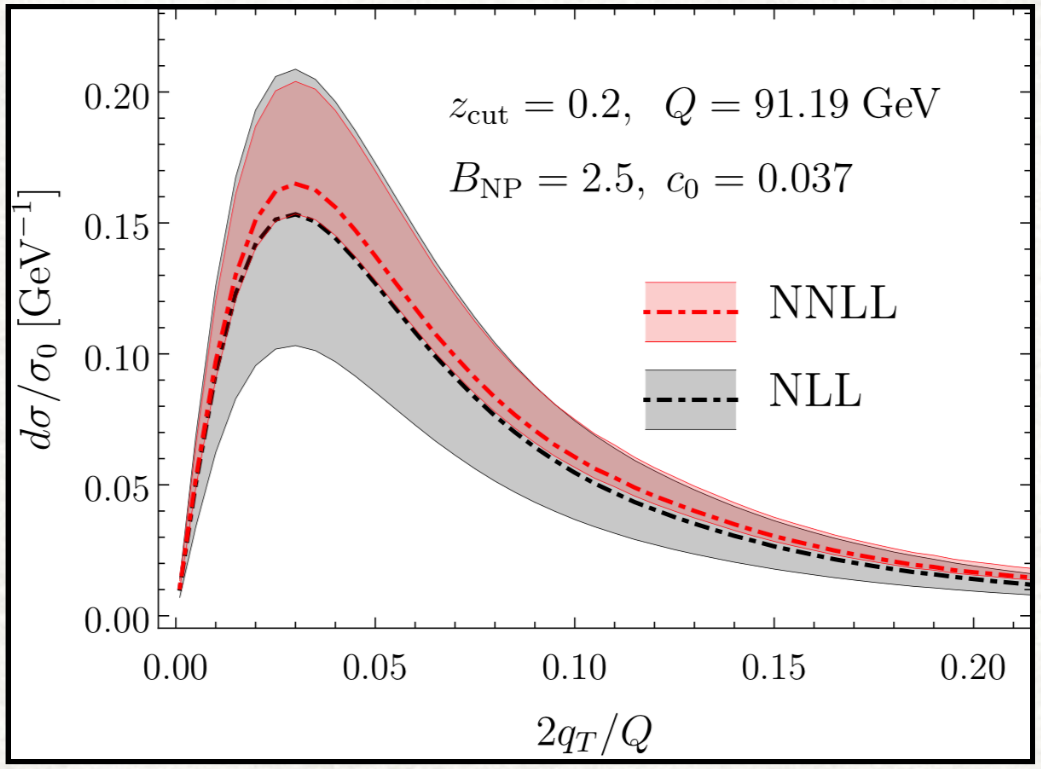
$$\frac{d\sigma_{eN\to eJX}}{dQ^2 dx dy d\boldsymbol{q}} = \sum_a \mathcal{H}_a(Q^2,\mu)\int \frac{d\boldsymbol{b}}{(2\pi)^2} e^{-i\boldsymbol{b}\boldsymbol{q}} f_{a/N}(x,\boldsymbol{b},\mu,\zeta)\mathcal{J}^{\perp}(e_{\rm cut},Q,z_{\rm cut},\boldsymbol{b};\mu,\zeta)$$

TMDPDF

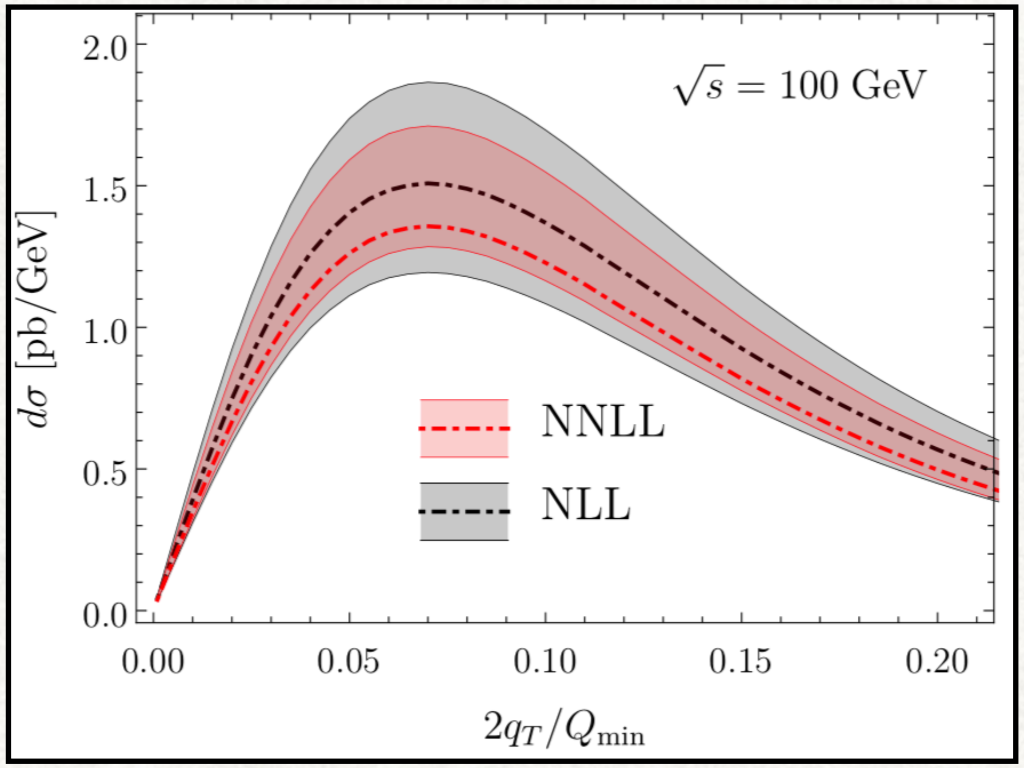
Groomed
TMD jet function

PHENO: GROOMED JETS. PERTURBATIVE CONVERGENCE

$e^+e^- \to \text{dijet} + X$



SIDIS with jet

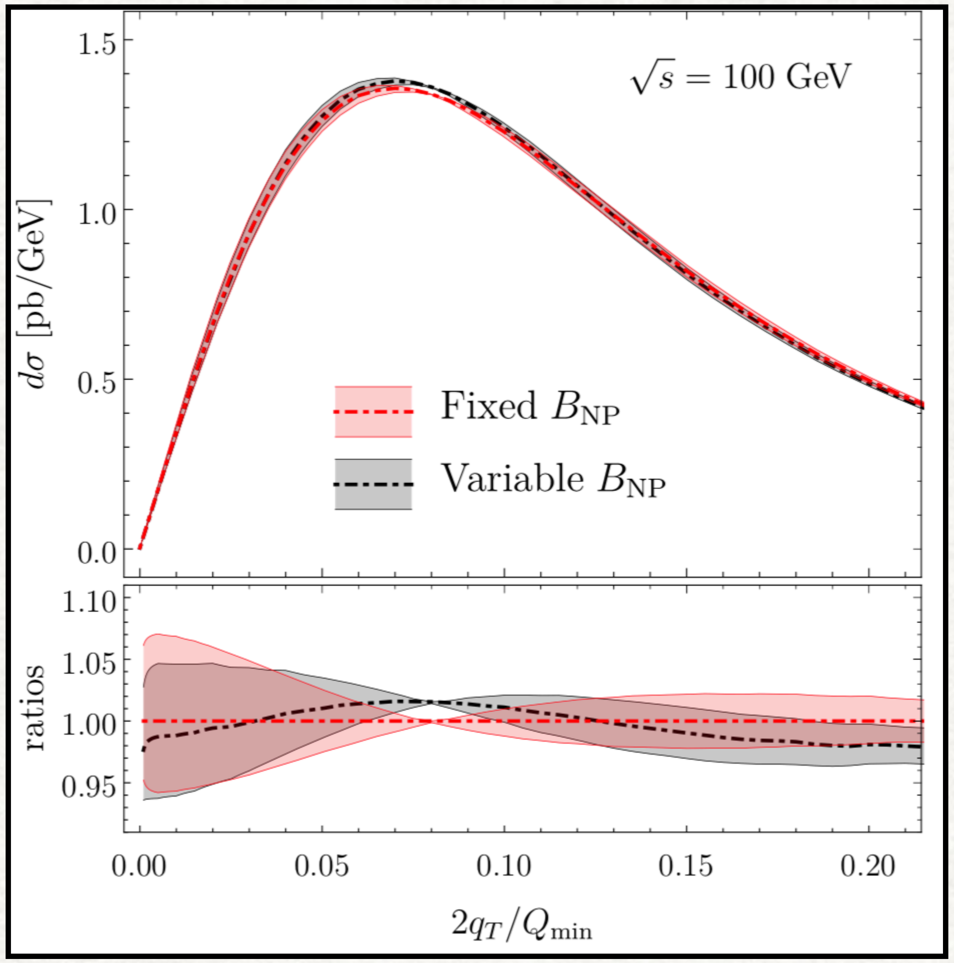


Scale variations are reduced when we go to NNLL calculation

But they are somewhat larger for a NNLL calculation → $\mu_{cs} \sim Q\sqrt{e_{\text{cut}} z_{\text{cut}}}$ approaches to NP-regime → Profiles

Increase Pert. order

PHENO: GROOMED JETS. SIZE OF NP EFFECTS



Non perturbative model for the TMDPDF taken from Bertone, Scimemi, Vladimirov `19 arXiv:1902.08474

$$f_{NP}(x,\boldsymbol{b}) = \exp\left(-\frac{(\lambda_1(1-x)+\lambda_2 x+\lambda_3 x(1-x))\boldsymbol{b}^2}{\sqrt{1+\lambda_4 x^{\lambda_5}\boldsymbol{b}^2}}\right)$$

But the cross section is dominated by nonperturbative parameter of evolution

$$\mathcal{D}(\mu,\boldsymbol{b}) = \int_{\mu_0}^{\mu}\frac{d\mu'}{\mu'}\Gamma + \mathcal{D}_{\rm pert}(\mu_0,\boldsymbol{b}) + c_0\boldsymbol{b}\boldsymbol{b}^*$$

NP effects are smaller for groomed-jets than for ungroomed-jets!

CONCLUSIONS

CONCLUSIONS

Our aim is to extract information about NP contributions to hadronic TMDs

↓

We use jets, in order to reduce NP effects in final state with hadrons (TMDFFs)

TWO APPROACHES

UNGROOMED JETS (N3LL)

Factorization depends on the radius of the jet

WTA axis election the Soft function is the same that for hadronic TMD

↓

We find a way to study big radius jets

GROOMED JETS (NNLL)

Factorization does not depend on the radius of the jet

New modes

Contaminating soft radiation is out!

Due to grooming parameter energy needed is higher

Hadronic TMDs and TMD jet functions share the same double-scale RG evolution

arTeMiDe → Pheno

https://teorica.fis.ucm.es/artemide/

↓

Needs future comparison with data!

BACKUP SLIDES

DOUBLE-SCALE RENORMALIZATION GROUP EVOLUTION

Same RG evolution for hadronic TMDs and for TMD jet functions!

TMDs

$$\mu^2 \frac{d}{d\mu^2} D_i(z, \boldsymbol{b}, \mu, \zeta) = \frac{1}{2} \gamma_F^i(\mu, \zeta) D_i(z, \boldsymbol{b}, \mu, \zeta)$$

$$\zeta \frac{d}{d\zeta} D_i(z, \boldsymbol{b}, \mu, \zeta) = -\mathcal{D}^i(\mu, \boldsymbol{b}) D_i(z, \boldsymbol{b}, \mu, \zeta)$$

Jets

$$\mu^2 \frac{d}{d\mu^2} J_i^{\text{axis}}(z, \boldsymbol{b}, QR, \mu, \zeta) = \frac{1}{2} \gamma_F^i(\mu, \zeta) J_i^{\text{axis}}(z, \boldsymbol{b}, QR, \mu, \zeta)$$

$$\zeta \frac{d}{d\zeta} J_i^{\text{axis}}(z, \boldsymbol{b}, QR, \mu, \zeta) = -\mathcal{D}^i(\mu, \boldsymbol{b}) J_i^{\text{axis}}(z, \boldsymbol{b}, QR, \mu, \zeta)$$

DOUBLE-SCALE RENORMALIZATION GROUP EVOLUTION

They have a common evolution factor

TMDs

$$D_i(z,\boldsymbol{b},\mu_f,\zeta_f) = \exp\left[\int_{(\mu_i,\zeta_i)}^{(\mu_f,\zeta_f)}\left(\gamma_F^i(\mu,\zeta)\frac{d\mu}{\mu} - \mathcal{D}^i(\mu,\boldsymbol{b})\frac{d\zeta}{\zeta}\right)\right] D_i(z,\boldsymbol{b},\mu_i,\zeta_i)$$

Jets

$$J_i^{\text{axis}}(z,\boldsymbol{b},QR,\mu_f,\zeta_f) = \exp\left[\int_{(\mu_i,\zeta_i)}^{(\mu_f,\zeta_f)}\left(\gamma_F^i(\mu,\zeta)\frac{d\mu}{\mu} - \mathcal{D}^i(\mu,\boldsymbol{b})\frac{d\zeta}{\zeta}\right)\right] J_i^{\text{axis}}(z,\boldsymbol{b},QR,\mu_i,\zeta_i)$$

This fact makes phenomenological analysis simpler!

arTeMiDe

Scimemi, Vladimirov `17

https://teorica.fis.ucm.es/artemide/

TMD SEMI-INCLUSIVE JET FUNCTION AT NLO

$$\theta \ll 1$$
$$\theta \ll R$$

Collinear radiation of typical angle **θ** sees the jet boundary infinitely far away

↓

Independence of the radius of the jet!

The collinear radiation is mostly inside the jet

↓

The dependence on z is power suppressed!

$$J_i^{\text{WTA}}(z, \boldsymbol{b}, ER, \mu, \zeta) = \delta(1-z)\, \mathscr{J}_i^{\text{WTA}}(\boldsymbol{b}, \mu, \zeta) \left[1 + \mathcal{O}\left(\frac{1}{\boldsymbol{b}^2 E^2 R^2}\right)\right]$$

where

$$\mathscr{J}_i^{\text{WTA}}(\boldsymbol{b}, \mu, \zeta) = \frac{1}{2N_c(\bar{n} \cdot p_J)} \text{Tr}\left\{ \frac{\bar{\not{n}}}{2} \langle 0 | e^{-i\boldsymbol{b}\boldsymbol{P}_\perp} \chi_n(0) | J_{\text{alg}}^{\text{WTA}} \rangle \langle J_{\text{alg}}^{\text{WTA}} | \bar{\chi}_n(0) | 0 \rangle \right\}$$

$$\mathscr{J}_i^{[0]\text{WTA}}(\boldsymbol{b}, \mu, \zeta) = 1$$

$$\mathscr{J}_i^{[1]\text{WTA}}(\boldsymbol{b}, \mu, \zeta) = 2\left\{ N_i + L_\mu \left[\mathcal{C}_i' + \mathcal{C}_i \left(\mathbf{l}_\zeta - \frac{1}{2} L_\mu \right) \right] \right\}$$

$$N_q = C_F \left(\frac{7}{2} - \frac{5\pi^2}{12} - 3 \ln 2 \right)$$

$$N_g = C_A \left(\frac{131}{36} - \frac{5\pi^2}{12} \right) - \frac{17}{18} n_f T_R - \beta_0 \ln 2$$

TMD SEMI-INCLUSIVE JET FUNCTION AT NNLO

We know the evolution of the TMD jet function and in this limit it does not depend on radius or z

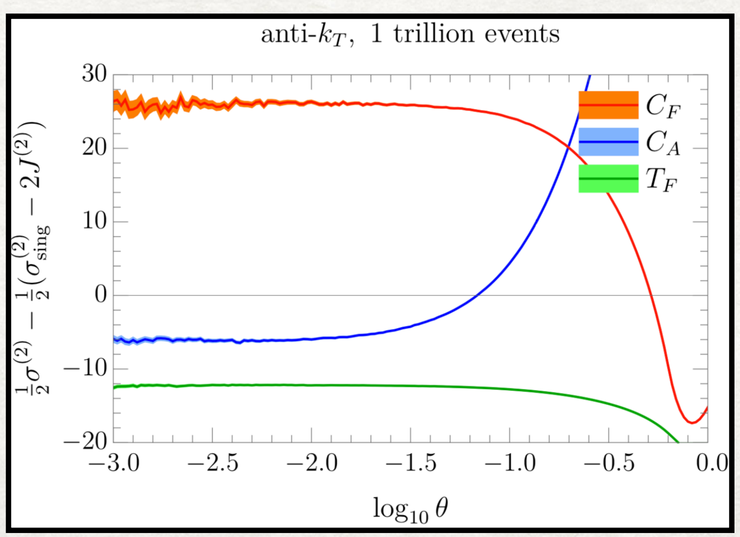
↓

We can predict the log behavior of the two-loop jet function solving renormalization group equations and the constant can be numerically calculated (EVENT2)

$$\theta \ll 1$$
$$\theta \ll R$$

Predicted by RG equations ↑ Predicted by EVENT2 ↑

$$\mathscr{J}^{[2]\mathrm{WTA}}(\boldsymbol{b}, \mu, \zeta) = \sum_{k=1}^{4} \sum_{l=0}^{k} C_{kl} L_\mu^k \mathbf{l}_\zeta^l + C_0$$



$$C_0 = j_{C_F} + j_{C_A} + n_f j_{T_F}$$

TMD SEMI-INCLUSIVE JET FUNCTION AT NLO

The Soft function is the same that for TMDs in some cases for SJA and in ALL cases for WTA

The Semi-inclusive jet function is renormalized as a TMD

$$J_q^{\text{axis}}(z, \boldsymbol{b}, QR, \mu, \zeta) = Z_{UV}(\mu, \epsilon) R_q(\delta, \zeta, \epsilon) J_q^{\text{axis}, B}(z, \boldsymbol{b}, QR, \mu, \delta)$$

$$\theta \ll 1$$
$$\theta \ll R$$

We have a new definition of the operator only valid for WTA axis!

Collinear radiation of typical angle **θ** sees the jet boundary infinitely far away

↓

Independence of the radius of the jet!

The collinear radiation is mostly inside the jet

↓

The dependence on z is power suppressed!

$$J_i^{\text{WTA}}(z, \boldsymbol{b}, QR, \mu, \zeta) = \delta(1-z)\, \mathscr{J}_i^{\text{WTA}}(\boldsymbol{b}, \mu, \zeta) \left[1 + \mathcal{O}\left(\frac{1}{\boldsymbol{b}^2 Q^2 R^2}\right)\right]$$

where

$$\mathscr{J}_i^{\text{WTA}}(\boldsymbol{b}, \mu, \zeta) = \frac{1}{2N_c(\bar{n} \cdot p_J)} \text{Tr}\left\{ \frac{\bar{\not{n}}}{2} \langle 0 | e^{-i\boldsymbol{b}\boldsymbol{P}_\perp} \chi_n(0) | J_{\text{alg}}^{\text{WTA}} \rangle \langle J_{\text{alg}}^{\text{WTA}} | \bar{\chi}_n(0) | 0 \rangle \right\}$$

TMD SEMI-INCLUSIVE JET FUNCTION AT NLO

The Soft function is the same that for TMDs in some cases for SJA and in ALL cases for WTA

The Semi-inclusive jet function is renormalized as a TMD

$$J_q^{\text{axis}}(z,\boldsymbol{b},QR,\mu,\zeta)=Z_{UV}(\mu,\epsilon)R_q(\delta,\zeta,\epsilon)J_q^{\text{axis},B}(z,\boldsymbol{b},QR,\mu,\delta)$$

$\theta \ll 1$

$\theta \sim R$

The definition of the operator is the usual one

$$J_i^{\text{axis}}=\sum_{n=0}^{\infty}a_s^n J_i^{[n]\text{axis}}$$

$$J_i^{[0]\text{axis}}(z,\boldsymbol{b},QR,\mu,\zeta)=\delta(1-z)$$

$$J_i^{[1]\text{axis}}(z,\boldsymbol{b},QR,\mu,\zeta)=2\left(\sum_j c_{ji}p_{ji}\right)\Big[L_R-L_\mu-2\ln(1-z)+\frac{1}{4}|\boldsymbol{b}|^2Q^2R^2(1-z)^2$$

$$\times{}_2F_3\left(\{1,1\},\{2,2,2\};-\frac{1}{4}|\boldsymbol{b}|^2Q^2R^2(1-z)^2\right)\Big]+\delta(1-z)\left[2\mathcal{C}_i'L_R-\mathcal{C}_iL_\mu^2+2\mathcal{C}_iL_\mu\mathbf{l}_\zeta+2\tilde{d}_i^{\text{axis}}(\boldsymbol{b}QR)\right]$$

The dependence on the axis is only here!

NUMERICAL RESULTS: LARGE RADIUS

The cross-section is simplified!

The jet functions do not depend on the radius size

The dependence in z is power suppressed (cross-section is less differential)

In the case of big radius factorization is only held for WTA axis!

$$\frac{d\sigma_{ee\to JJX}}{d\boldsymbol{q}} = H(Q^2,\mu)\int \frac{d\boldsymbol{b}}{(2\pi)^2} e^{-i\boldsymbol{b}\boldsymbol{q}} \mathscr{J}_q^{\mathrm{WTA}}(\boldsymbol{b},\mu,\zeta)\mathscr{J}_q^{\mathrm{WTA}}(\boldsymbol{b},\mu,\zeta)R^2[\boldsymbol{b};(\mu_i,\zeta_i)\to(\mu_f,\zeta_f)]$$

NUMERICAL RESULTS

Ingredients to build cross-section

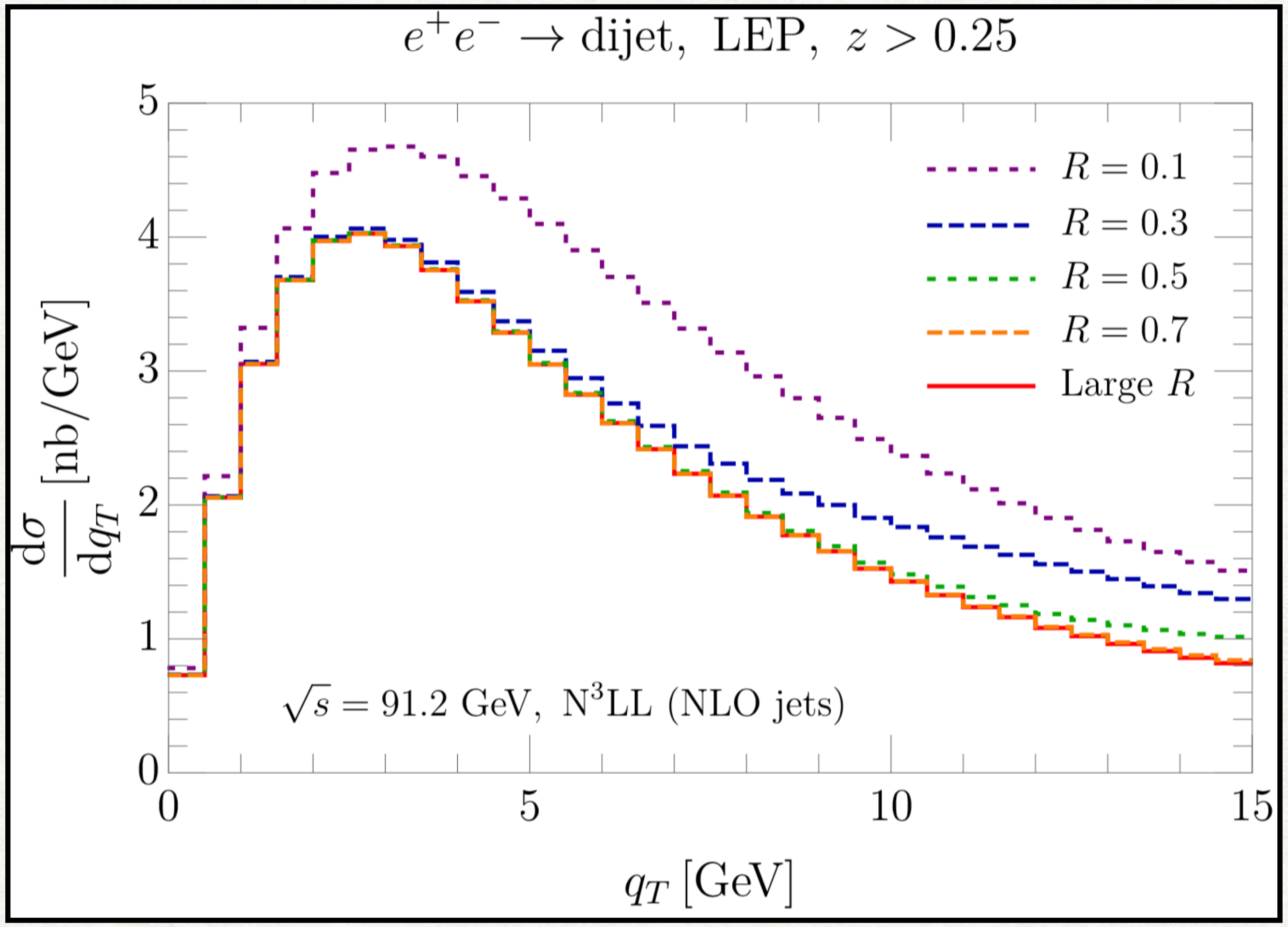
$$\frac{d\sigma_{ee\to JJX}}{dz_1 dz_2 d\boldsymbol{q}} = H(Q^2,\mu)\int \frac{d\boldsymbol{b}}{(2\pi)^2} e^{-i\boldsymbol{b}\boldsymbol{q}} J_q^{\text{axis}}(z_1,\boldsymbol{b},QR,\mu,\zeta) J_q^{\text{axis}}(z_2,\boldsymbol{b},QR,\mu,\zeta) R^2[\boldsymbol{b};(\mu_i,\zeta_i)\to(\mu_f,\zeta_f)]$$

Hard factor: Same that for DY. Known and introduced in arTeMiDe up to 2-loops.

Evolution kernel: Same that for TMDs. Known and introduced in arTeMiDe up to 3-loops.

TMD jet functions: Calculated at 1-loop. New arTeMiDe module built.

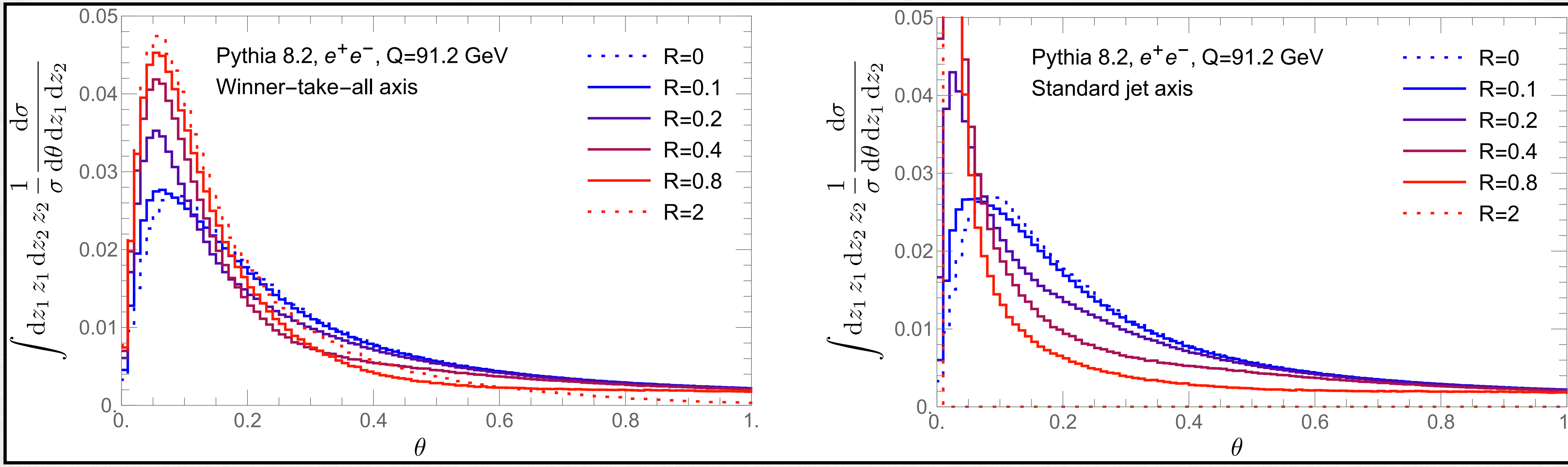
VARY RADIUS: LARGE-R VS FINITE R



The large radius approximation is a very accurate approximation for jet functions with finite radius (but not so small)

This fact allow us to skip some of the technical complications of the finite radius jet function

CHECKING WITH PYTHIA 8.2.



Cross-section of angular decorrelation for different values of the radii of the jets

For small values of R the cross-section for both axis elections agrees!

For big values of R the cross section in SJA is inconsistent!

Factorization is broken

WTA axis solves the problems!