Inclusive Jets and their substructure within SCET

Felix Ringer

Los Alamos National Laboratory

Washington, 02/02/17

Outline

- Inclusive jets *Kang, FR, Vitev `16*
- The jet fragmentation function *Kang, FR, Vitev `16*
- Conclusions

Chien, Kang, FR, Vitev, Xing `15

Kang, Qiu, FR, Xing, Zhang
- in preparation

Los Alamos NATIONAL LABORATORY EST. 1943

Outline

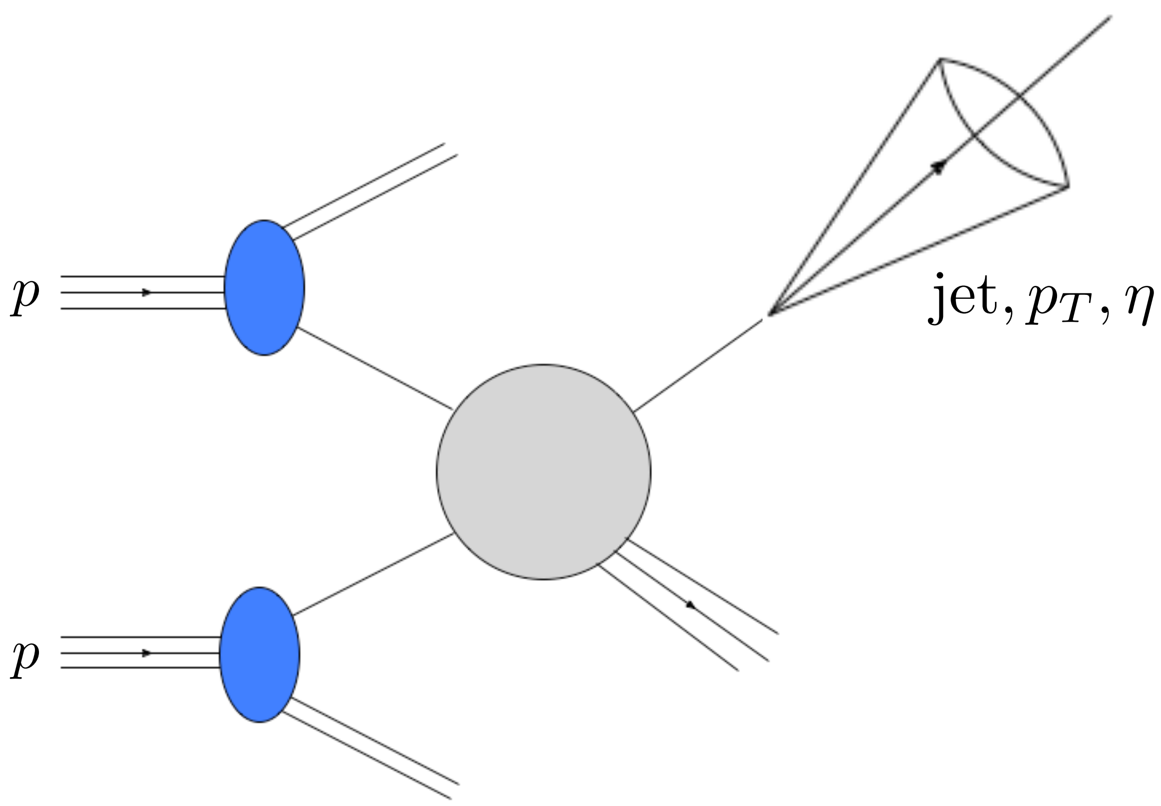
- Inclusive jets — *Kang, FR, Vitev `16*
- The jet fragmentation function — *Kang, FR, Vitev `16*
- Conclusions

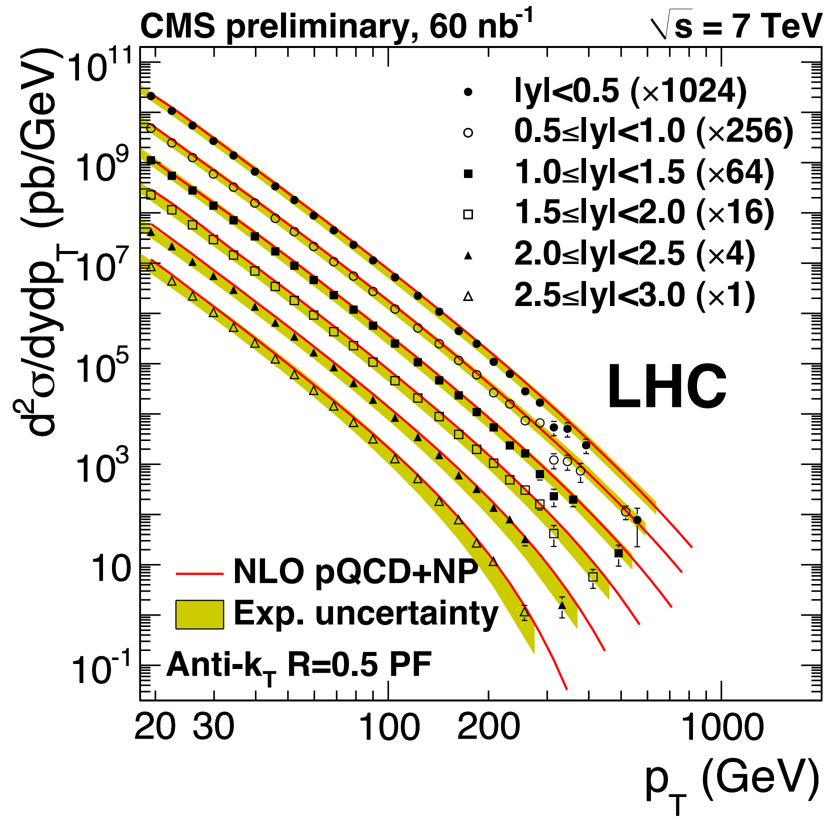
Chien, Kang, FR, Vitev, Xing `15

Kang, Qiu, FR, Xing, Zhang - in preparation

Inclusive Jet Production $pp \to \text{jet}X$

- Large theoretical uncertainties especially at high p_T
- PDFs are constrained by collider jet data, especially $g(x), \Delta g(x)$
- Determination of α_s
- High p_T jets are a promising observable for the search of BSM physics at the LHC
- Jet quenching studies in heavy-ion collisions
- …





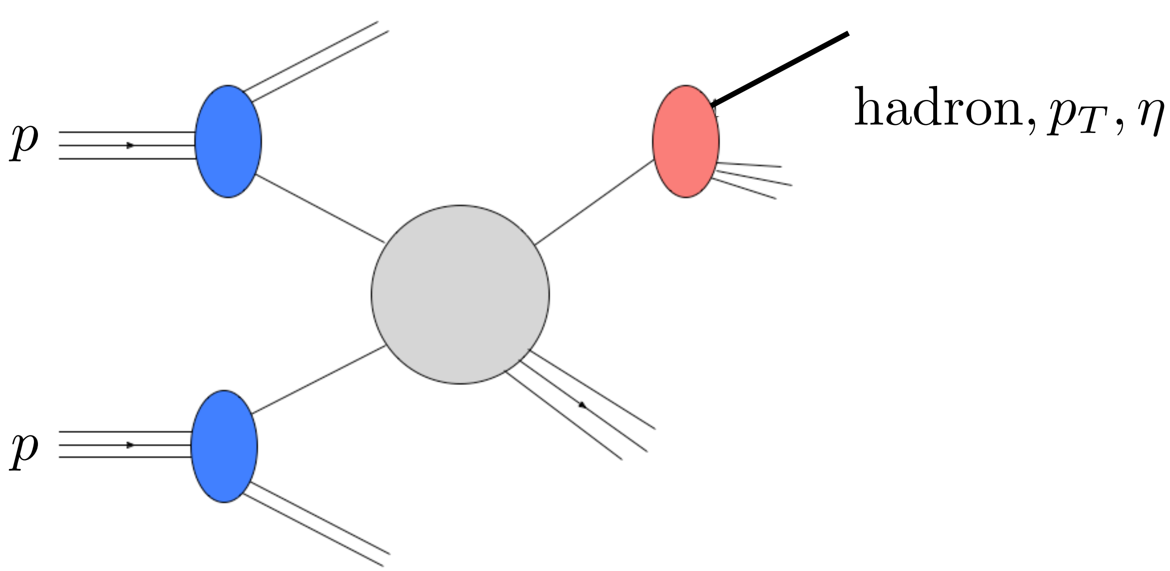
Recall Inclusive Hadron Production $pp \to hX$

Factorization

$$\frac{d\sigma^{pp\to hX}}{dp_T d\eta} = \frac{2p_T}{s} \sum_{a,b,c} \int_{x_a^{\min}}^1 \frac{dx_a}{x_a} f_a(x_a,\mu) \int_{x_b^{\min}}^1 \frac{dx_b}{x_b} f_b(x_b,\mu) \int_{z_c^{\min}}^1 \frac{dz_c}{z_c^2} \frac{d\hat{\sigma}_{ab}^c(\hat{s},\hat{p}_T,\hat{\eta},\mu)}{dv dz} D_c^h(z_c,\mu)$$

timelike DGLAP for FFs

$$\mu \frac{d}{d\mu} D_i^h(z,\mu) = \frac{\alpha_s(\mu)}{\pi} \sum_j \int_z^1 \frac{dz'}{z'} P_{ji}\left(\frac{z}{z'},\mu\right) D_j^h(z',\mu)$$



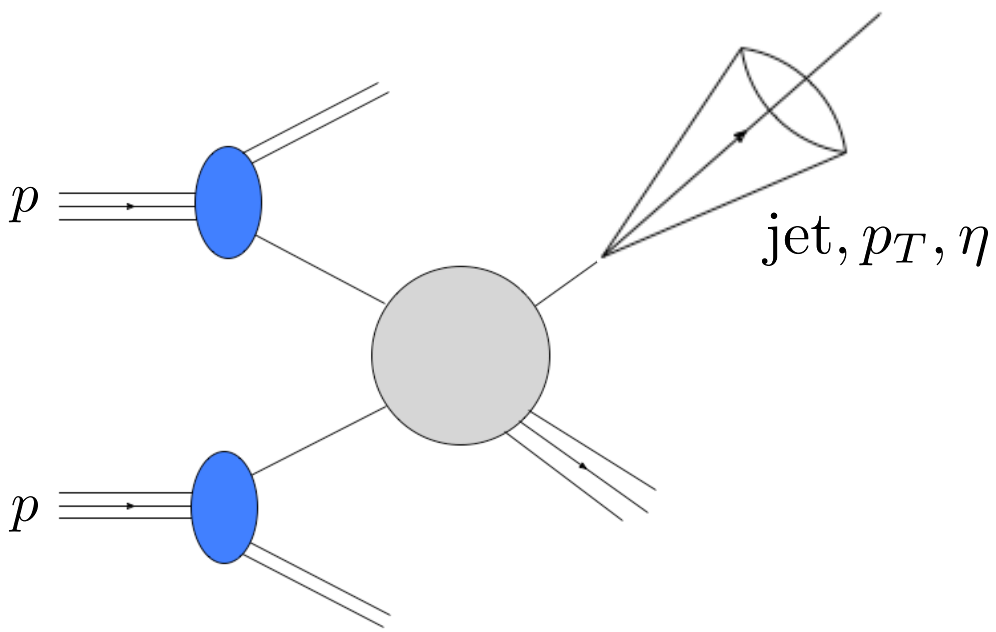
Aversa, Chiappetta, Greco, Guillet `89, Jäger, Schäfer, Stratmann, Vogelsang `04

Inclusive Jet Production $pp \to \mathrm{jet}X$

Factorization

Kang, FR, Vitev `16

$$\frac{d\sigma^{pp\to \mathrm{jet}X}}{dp_T d\eta} = \frac{2p_T}{s}\sum_{a,b,c}\int_{x_a^{\min}}^1 \frac{dx_a}{x_a} f_a(x_a,\mu)\int_{x_b^{\min}}^1 \frac{dx_b}{x_b} f_b(x_b,\mu)\int_{z_c^{\min}}^1 \frac{dz_c}{z_c^2}\frac{d\hat{\sigma}_{ab}^c(\hat{s},\hat{p}_T,\hat{\eta},\mu)}{dvdz} J_c(z_c,\omega_J,\mu)$$



Los Alamos NATIONAL LABORATORY EST. 1943

Inclusive Jet Production $pp \to \mathrm{jet}X$

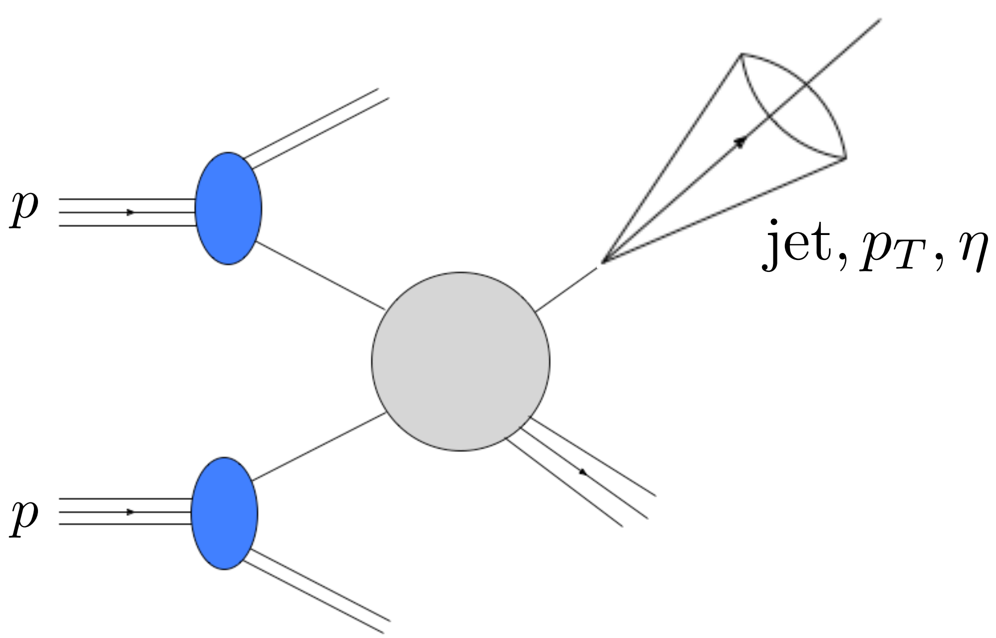
Factorization

Kang, FR, Vitev `16

$$\frac{d\sigma^{pp\to\mathrm{jet}X}}{dp_T d\eta} = \frac{2p_T}{s}\sum_{a,b,c}\int_{x_a^{\min}}^1 \frac{dx_a}{x_a} f_a(x_a,\mu)\int_{x_b^{\min}}^1 \frac{dx_b}{x_b} f_b(x_b,\mu)\int_{z_c^{\min}}^1 \frac{dz_c}{z_c^2}\frac{d\hat\sigma_{ab}^c(\hat s,\hat p_T,\hat\eta,\mu)}{dv dz} \boxed{J_c(z_c,\omega_J,\mu)}$$

timelike DGLAP for <u>semi-inclusive jet function</u>

$$\boxed{\mu\frac{d}{d\mu}J_i(z,\omega_J,\mu) = \frac{\alpha_s(\mu)}{\pi}\sum_j\int_z^1 \frac{dz'}{z'}P_{ji}\left(\frac{z}{z'},\mu\right)J_j(z',\omega_J,\mu)}$$

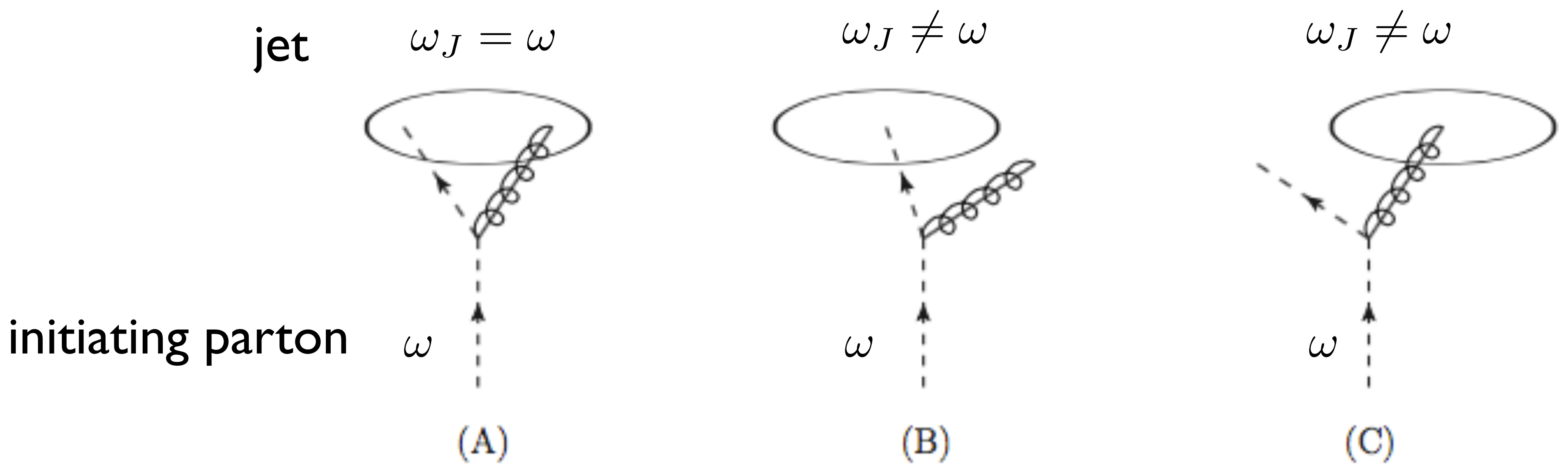


$\longrightarrow$ resummation of $\sim (\alpha_s \ln R)^n$

$\mathrm{NLO} \sim \mathcal{A} + \mathcal{B}\ln R + \mathcal{O}(R^2)$

Semi-inclusive jet function in SCET at NLO

- The siJF describes how a parton (q or g) is transformed into a jet with radius R and energy fraction z



where $z = \omega_J/\omega$

momentum sum rule: $\int_0^1 dz\, z J_i(z, \omega R, \mu) = 1$

Los Alamos NATIONAL LABORATORY EST. 1943

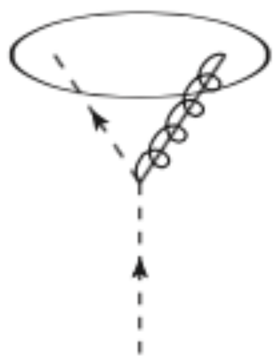
Semi-inclusive jet function in SCET at NLO

Leading order $$J_q^{(0)}(z, \omega_J) = \delta(1-z)$$

Semi-inclusive jet function in SCET at NLO

Leading order $$J_q^{(0)}(z,\omega_J) = \delta(1-z)$$

Next-to-leading order



(A)

$$J_q(z,\omega_J) = \delta(1-z)\frac{\alpha_s}{\pi}\left(\frac{\mu^2 e^{\gamma_E}}{4\pi}\right)^{\epsilon}\int_0^1 dx \hat{P}_{qq}(x,\epsilon)\int \frac{dq_\perp}{q_\perp^{1+2\epsilon}}\Theta_{\text{alg}}$$

where: anti-k$_{\mathrm{T}}$: $$\Theta_{\text{anti-k}_\mathrm{T}} = \theta\left(x(1-x)\omega_J \tan\frac{R}{2} - q_\perp\right)$$

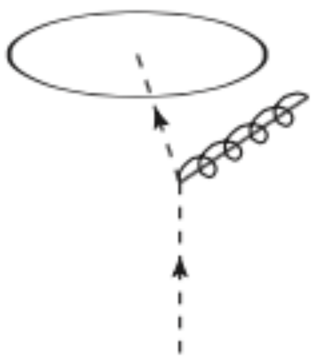
$$\hat{P}_{qq}(x,\epsilon) = C_F\left[\frac{1+x^2}{1-x} - \epsilon(1-x)\right]$$

$$x = \frac{\ell^- - q^-}{\ell^-}$$

Semi-inclusive jet function in SCET at NLO

Leading order $$J_q^{(0)}(z,\omega_J) = \delta(1-z)$$

Next-to-leading order

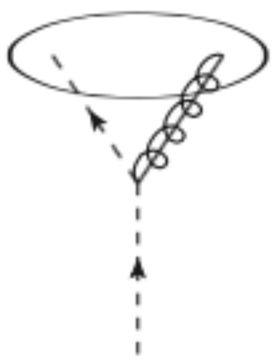


$$J_{q\to q(g)}(z,\omega_J) = \frac{\alpha_s}{\pi}\left(\frac{\mu^2 e^{\gamma_E}}{4\pi}\right)^{\epsilon} \hat{P}_{qq}(z,\epsilon)\int \frac{dq_\perp}{q_\perp^{1+2\epsilon}}\Theta_{\rm alg}$$

where: $$\Theta_{\text{anti-k}_T} = \theta\left(q_\perp - (1-z)\omega_J \tan\frac{R}{2}\right)$$

Semi-inclusive jet function

$\overline{\mathrm{MS}}$ scheme, anti-$\mathrm{k_T}$

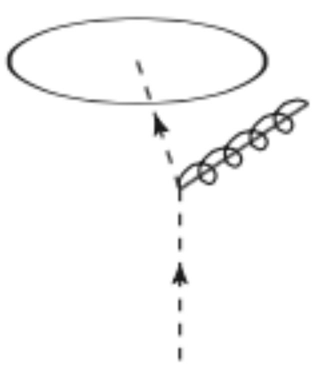


(A)

$$J_q(z,\omega_J) = \delta(1-z)\frac{\alpha_s}{2\pi}C_F\left[\frac{1}{\epsilon^2}+\frac{3}{2\epsilon}+\frac{1}{\epsilon}L+\frac{1}{2}L^2+\frac{3}{2}L+\frac{13}{2}-\frac{3\pi^2}{4}\right]$$

Ellis, Vermilion, Walsh, Hornig, Lee `10

where $L = \ln\left(\frac{\mu^2}{\omega_J^2\tan^2(R/2)}\right)$



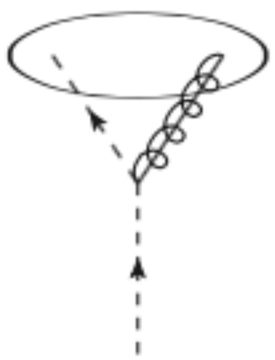
(B)

$$J_q(z,\omega_J) = \frac{\alpha_s}{2\pi}\delta(1-z)\left[-\frac{1}{\epsilon^2}-\frac{1}{\epsilon}L-\frac{1}{2}L^2+\frac{\pi^2}{12}\right] + \frac{\alpha_s}{2\pi}\left[\left(\frac{1}{\epsilon}+L\right)\frac{1+z^2}{(1-z)_+}-2(1+z^2)\left(\frac{\ln(1-z)}{1-z}\right)_+-(1-z)\right]$$

(C) ...

Semi-inclusive jet function

$\overline{\mathrm{MS}}$ scheme, anti-k_T



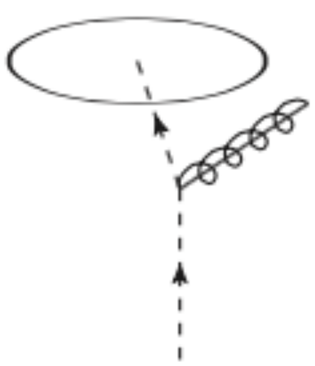
(A)

$$J_q(z,\omega_J) = \delta(1-z)\frac{\alpha_s}{2\pi}C_F\left[\frac{1}{\epsilon^2}+\frac{3}{2\epsilon}+\frac{1}{\epsilon}L+\frac{1}{2}L^2+\frac{3}{2}L+\frac{13}{2}-\frac{3\pi^2}{4}\right]$$

Essentially the same result as in the exclusive case

Ellis, Vermilion, Walsh, Hornig, Lee `10

where $L = \ln\left(\frac{\mu^2}{\omega_J^2 \tan^2(R/2)}\right)$



(B)

$$J_q(z,\omega_J) = \frac{\alpha_s}{2\pi}\delta(1-z)\left[-\frac{1}{\epsilon^2}-\frac{1}{\epsilon}L-\frac{1}{2}L^2+\frac{\pi^2}{12}\right] + \frac{\alpha_s}{2\pi}\left[\left(\frac{1}{\epsilon}+L\right)\frac{1+z^2}{(1-z)_+}-2(1+z^2)\left(\frac{\ln(1-z)}{1-z}\right)_+-(1-z)\right]$$

(C) … ⟶ only a single logarithmic $\ln R$ remains

Renormalization and RG evolution

Bare - renormalized semi-inclusive jet function

$$J_{i,\mathrm{bare}}(z,\omega_J) = \sum_j \int_z^1 \frac{dz'}{z'} Z_{ij}\left(\frac{z}{z'},\mu\right) J_j(z',\omega_J,\mu)$$

RG equation

$$\mu\frac{d}{d\mu}J_i(z,\omega_J,\mu) = \sum_j \int_z^1 \frac{dz'}{z'} \gamma_{ij}^J\left(\frac{z}{z'},\mu\right) J_j(z',\omega_J,\mu)$$

Anomalous dimension

$$\gamma_{ij}^J(z,\mu) = -\sum_k \int_z^1 \frac{dz'}{z'} (Z)_{ik}^{-1}\left(\frac{z}{z'},\mu\right) \mu\frac{d}{d\mu} Z_{kj}(z',\mu)$$

Los Alamos NATIONAL LABORATORY EST. 1943

Renormalization and RG evolution

We find

$$\gamma_{ij}^J(z,\mu) = \frac{\alpha_s(\mu)}{\pi} P_{ji}(z)$$

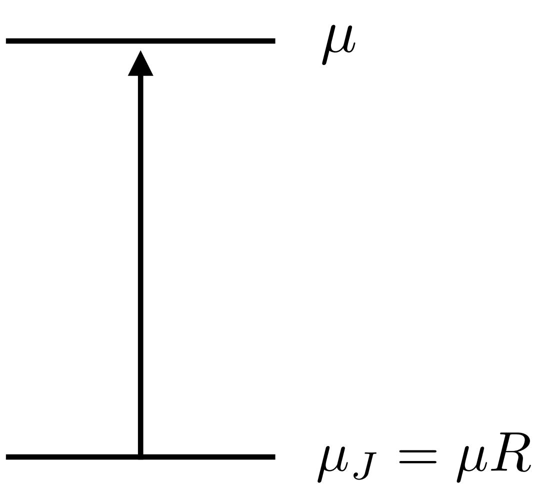
$$\longrightarrow \quad \mu \frac{d}{d\mu} J_i(z,\omega_J,\mu) = \frac{\alpha_s(\mu)}{\pi} \sum_j \int_z^1 \frac{dz'}{z'} P_{ji}\left(\frac{z}{z'},\mu\right) J_j(z',\omega_J,\mu)$$

DGLAP evolution equation like for FFs. Resums single $\ln R$: LL_R, NLL_R

see also
Dasgupta, Dreyer, Salam, Soyez `15, `16

Jet function evolution

$$\frac{d}{d\log\mu^2}\begin{pmatrix} J_S(z,\omega_J,\mu) \\ J_g(z,\omega_J,\mu) \end{pmatrix} = \frac{\alpha_s(\mu)}{2\pi}\begin{pmatrix} P_{qq}(z) & 2N_f P_{gq}(z) \\ P_{qg}(z) & P_{gg}(z) \end{pmatrix} \otimes \begin{pmatrix} J_S(z,\omega_J,\mu) \\ J_g(z,\omega_J,\mu) \end{pmatrix}$$



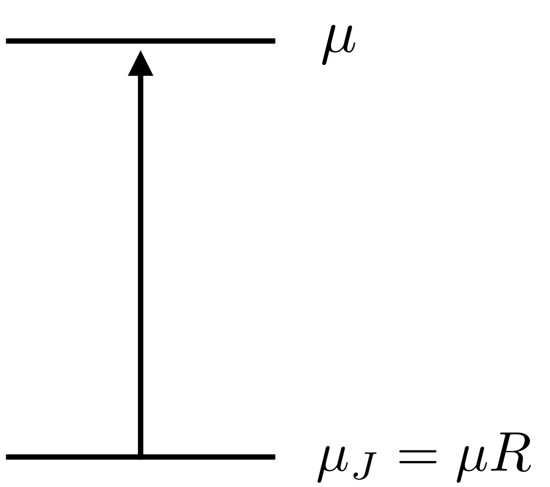
initial condition contains distributions in $1-z$

where $J_S(z,\omega_J,\mu) = \sum_{q,\bar{q}} J_q(z,\omega_J,\mu) = 2N_f J_q(z,\omega_J,\mu)$ (singlet jet function)

Los Alamos NATIONAL LABORATORY EST. 1943

Jet function evolution

$$\frac{d}{d\log\mu^2}\begin{pmatrix} J_S(z,\omega_J,\mu) \\ J_g(z,\omega_J,\mu)\end{pmatrix} = \frac{\alpha_s(\mu)}{2\pi}\begin{pmatrix} P_{qq}(z) & 2N_f P_{gq}(z) \\ P_{qg}(z) & P_{gg}(z)\end{pmatrix} \otimes \begin{pmatrix} J_S(z,\omega_J,\mu) \\ J_g(z,\omega_J,\mu)\end{pmatrix}$$



initial condition contains distributions in $1-z$

where $J_S(z,\omega_J,\mu) = \sum_{q,\bar{q}} J_q(z,\omega_J,\mu) = 2N_f J_q(z,\omega_J,\mu)$ (singlet jet function)

solve in Mellin space: $$f(N) = \int_0^1 dz\, z^{N-1} f(z)$$

$$(f\otimes g)(N) = f(N)\, g(N)$$

Jet function evolution

solve in Mellin space to LL_R

$$\begin{pmatrix} J_S(N,\omega_J,\mu) \\ J_g(N,\omega_J,\mu) \end{pmatrix} = \left[e_+(N) \left(\frac{\alpha_s(\mu)}{\alpha_s(\mu_J)} \right)^{-r_-(N)} + e_-(N) \left(\frac{\alpha_s(\mu)}{\alpha_s(\mu_J)} \right)^{-r_+(N)} \right] \begin{pmatrix} J_S(N,\omega_J,\mu_J) \\ J_g(N,\omega_J,\mu_J) \end{pmatrix}$$

where $$e_\pm(N) = \frac{1}{r_\pm(N) - r_\mp(N)} \begin{pmatrix} P_{qq}(N) - r_\mp(N) & 2N_f P_{gq}(N) \\ P_{qg}(N) & P_{gg}(N) - r_\mp(N) \end{pmatrix}$$

see
Vogt `04 (Pegasus),
Anderle, FR, Stratmann `15

$$r_\pm(N) = \frac{1}{2\beta_0} \left[P_{qq}(N) + P_{gg}(N) \pm \sqrt{(P_{qq}(N) - P_{gg}(N))^2 + 4P_{qg}(N)P_{gq}(N)} \right]$$

Los Alamos
NATIONAL LABORATORY
EST. 1943

Jet function evolution

solve in Mellin space to LL_R

$$\begin{pmatrix} J_S(N,\omega_J,\mu) \\ J_g(N,\omega_J,\mu) \end{pmatrix} = \left[e_+(N) \left(\frac{\alpha_s(\mu)}{\alpha_s(\mu_J)}\right)^{-r_-(N)} + e_-(N) \left(\frac{\alpha_s(\mu)}{\alpha_s(\mu_J)}\right)^{-r_+(N)} \right] \begin{pmatrix} J_S(N,\omega_J,\mu_J) \\ J_g(N,\omega_J,\mu_J) \end{pmatrix}$$

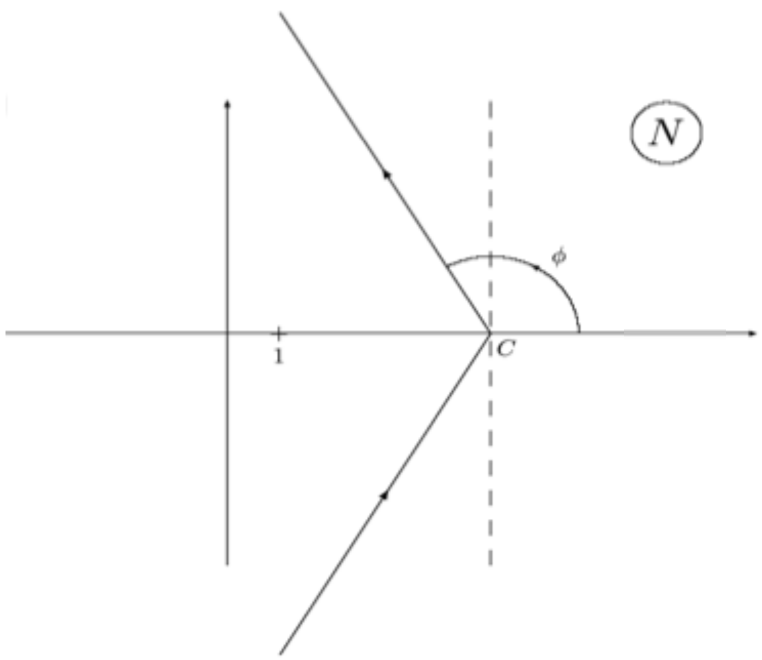
where $$e_\pm(N) = \frac{1}{r_\pm(N) - r_\mp(N)} \begin{pmatrix} P_{qq}(N) - r_\mp(N) & 2N_f P_{gq}(N) \\ P_{qg}(N) & P_{gg}(N) - r_\mp(N) \end{pmatrix}$$

see
Vogt `04 (Pegasus),
Anderle, FR, Stratmann `15

$$r_\pm(N) = \frac{1}{2\beta_0} \left[P_{qq}(N) + P_{gg}(N) \pm \sqrt{(P_{qq}(N) - P_{gg}(N))^2 + 4P_{qg}(N)P_{gq}(N)} \right]$$

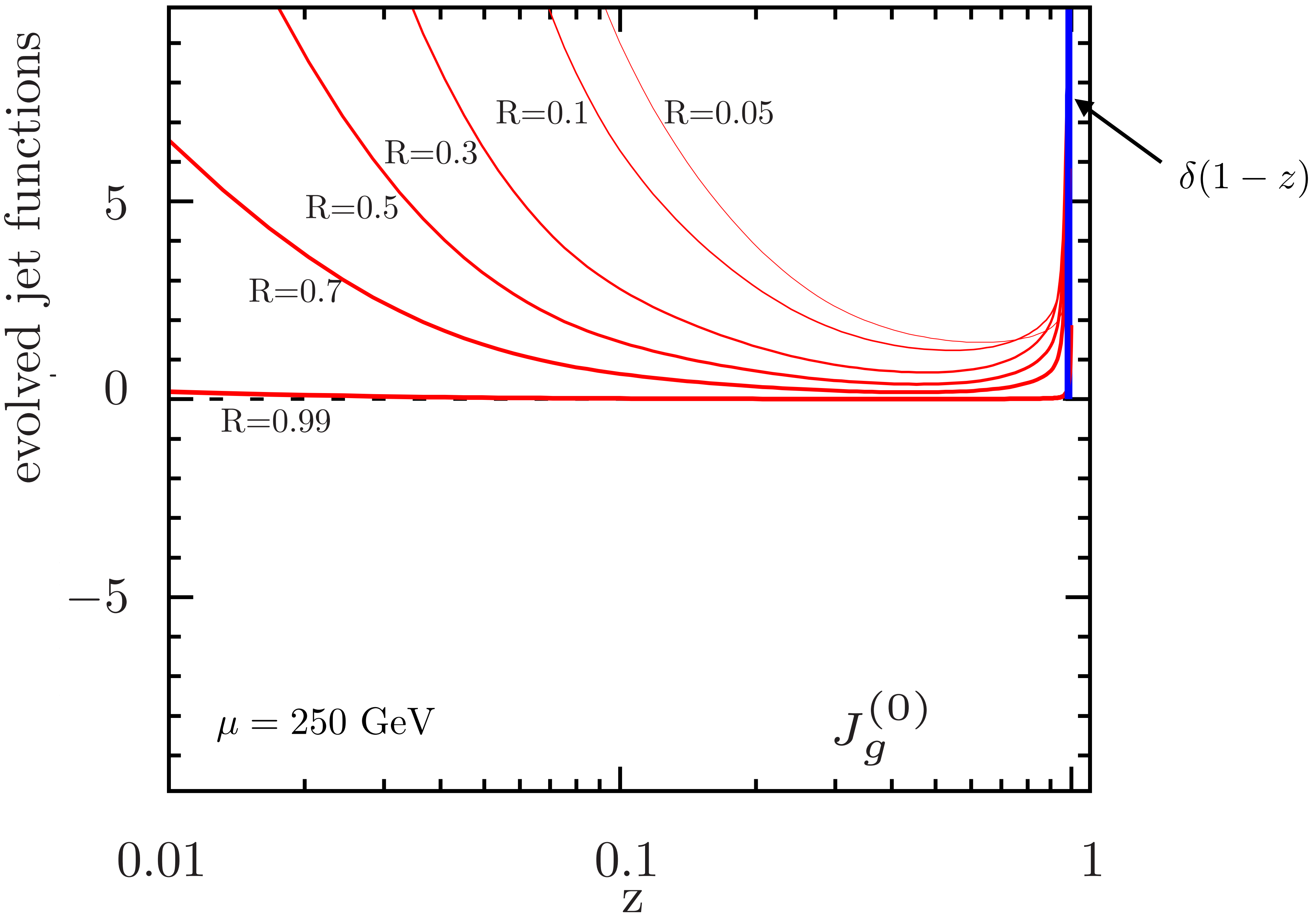
Mellin inverse

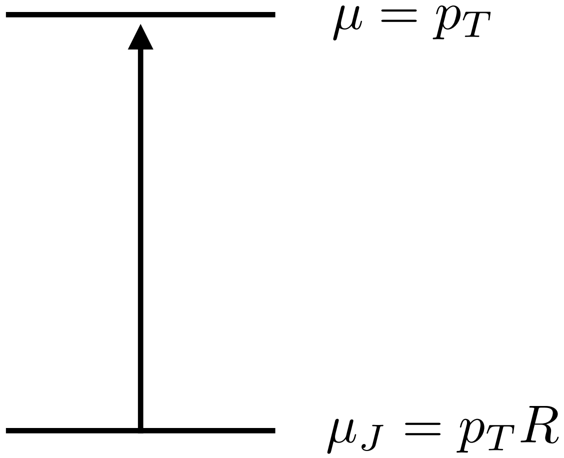
$$J_{S,g}(z,\omega_J,\mu) = \frac{1}{2\pi i} \int_{\mathcal{C}_N} dN\, z^{-N} J_{S,g}(N,\omega_J,\mu)$$



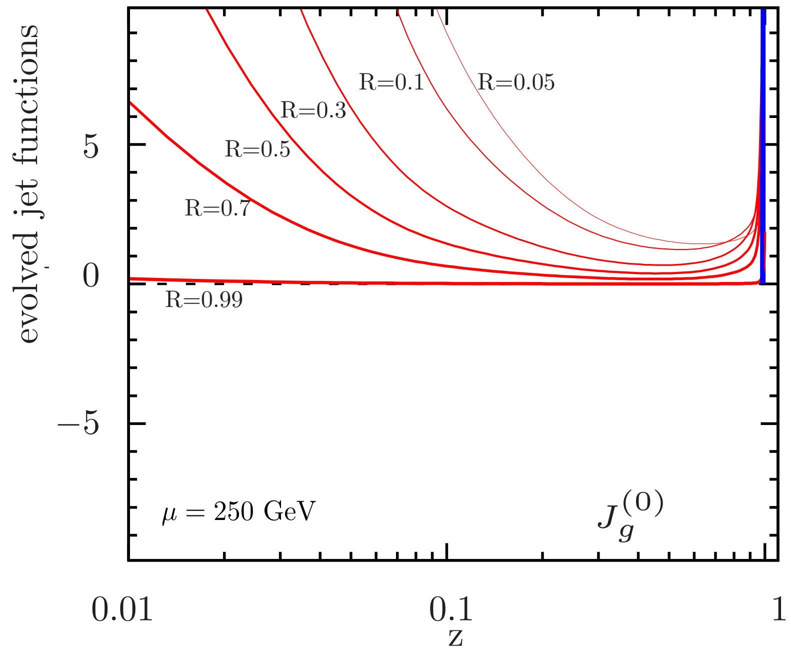
Los Alamos
NATIONAL LABORATORY
EST. 1943

LL_R DGLAP evolution





see
Vogt `04 (Pegasus), Anderle, FR, Stratmann `15



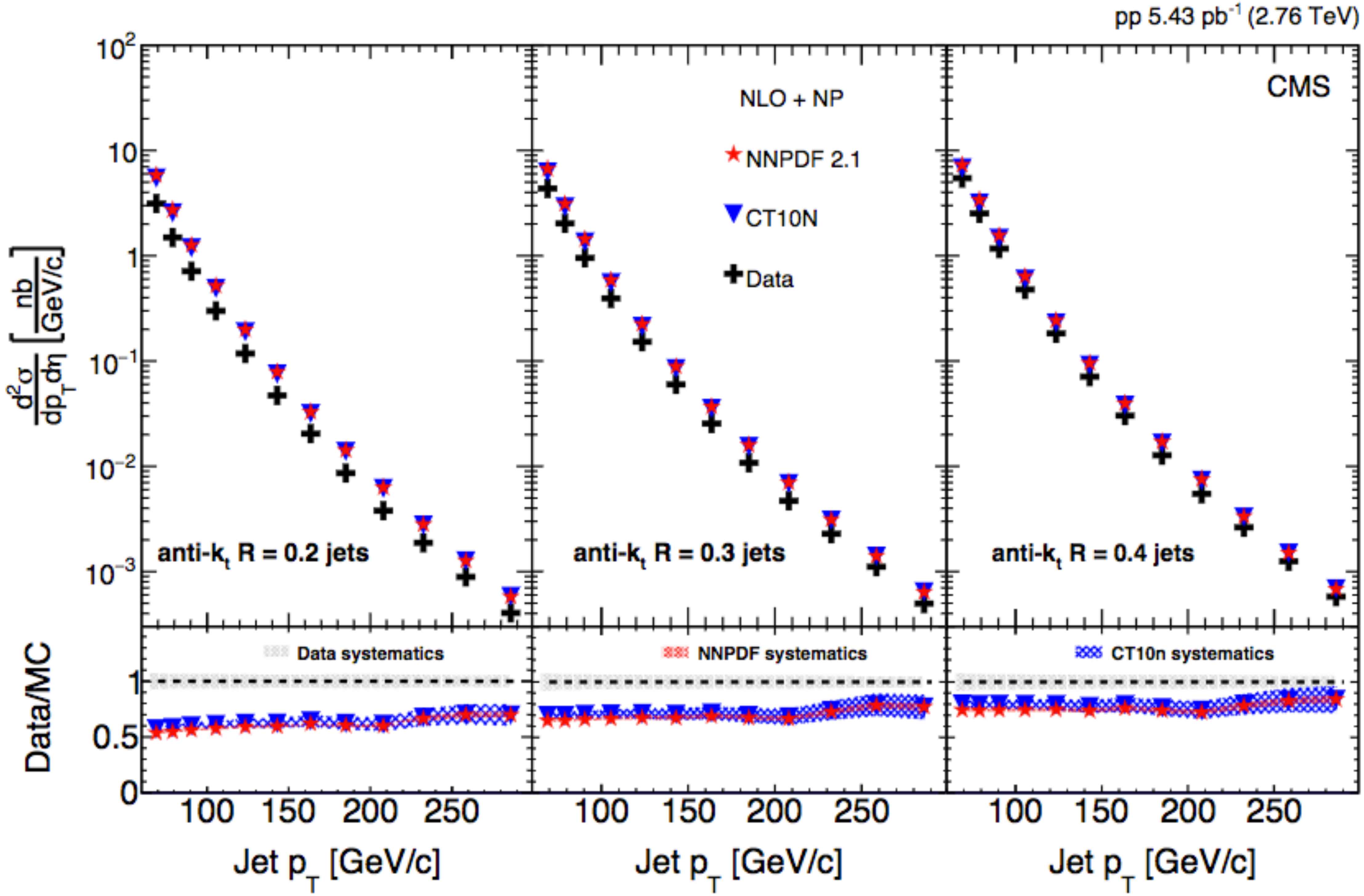
$$\frac{d\sigma^{pp\to \mathrm{jet}X}}{dp_T d\eta} = \sum_{a,b,c} f_a \otimes f_b \otimes H_{ab}^c \otimes J_c$$

- Resummation of $\alpha_s^n \ln^n R$
- Adopt a prescription used for quarkonium fragmentation functions

  Bodwin, Chao, Chung, Kim, Lee, Ma `16

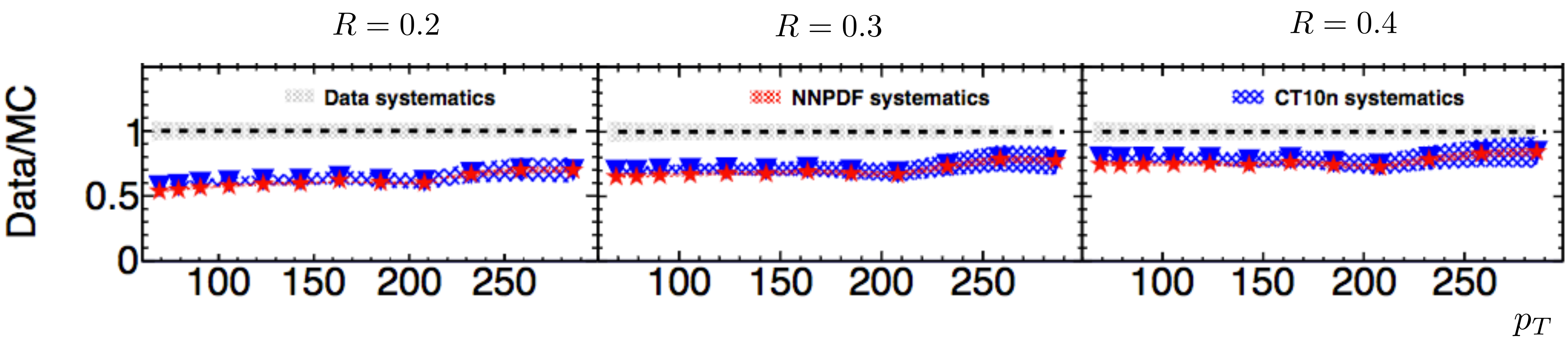
Los Alamos NATIONAL LABORATORY EST. 1943

Inclusive Jet Production in SCET $pp \to \mathrm{jet} X$



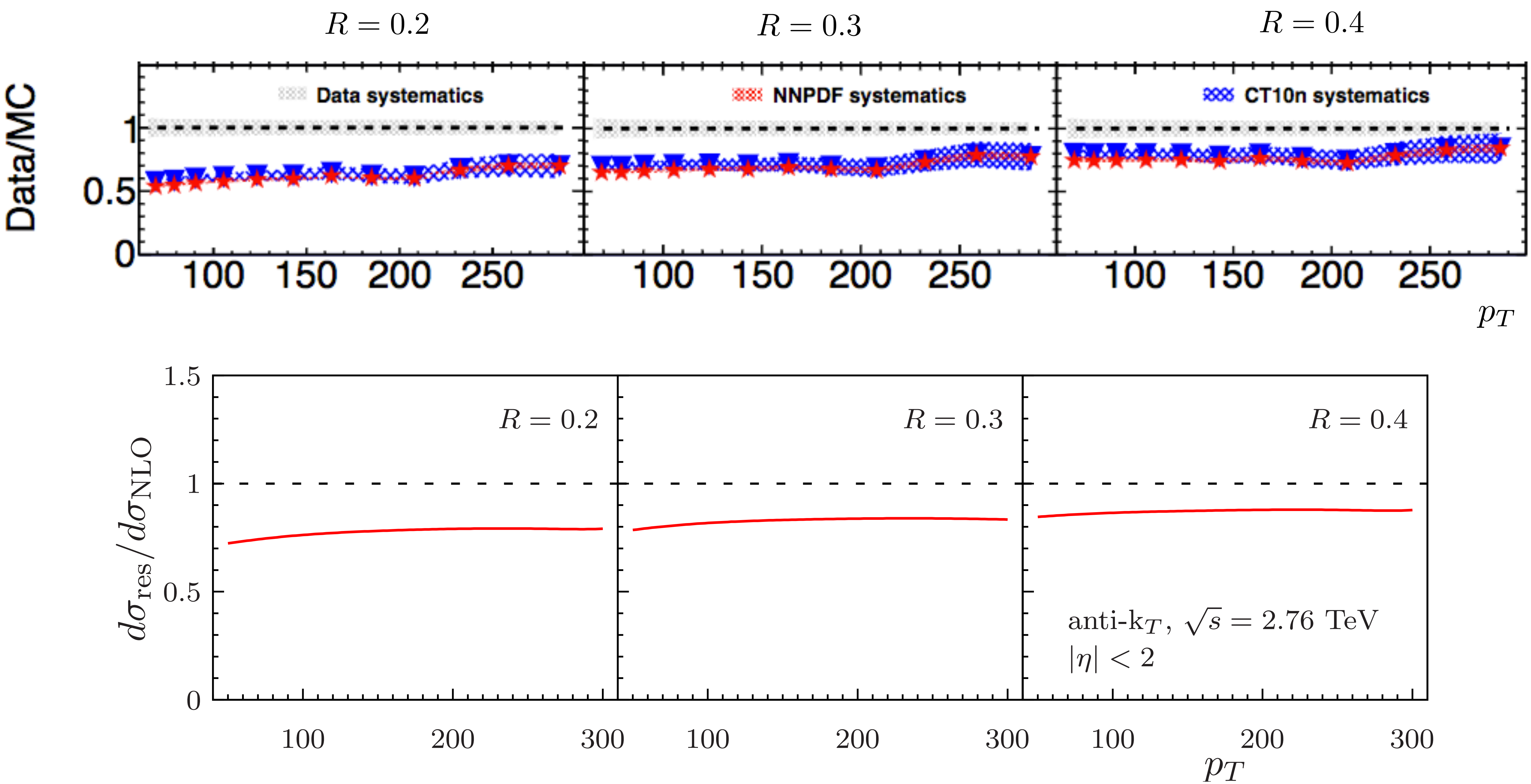
CMS data arXiv:1609.05383

Inclusive Jet Production in SCET $pp \to \text{jet} X$



CMS data arXiv:1609.05383

Inclusive Jet Production in SCET $pp \to \text{jet} X$



CMS data arXiv:1609.05383

Outline

- Inclusive jets — *Kang, FR, Vitev `16*
- The jet fragmentation function — *Kang, FR, Vitev `16*
- Conclusions

Chien, Kang, FR, Vitev, Xing `15

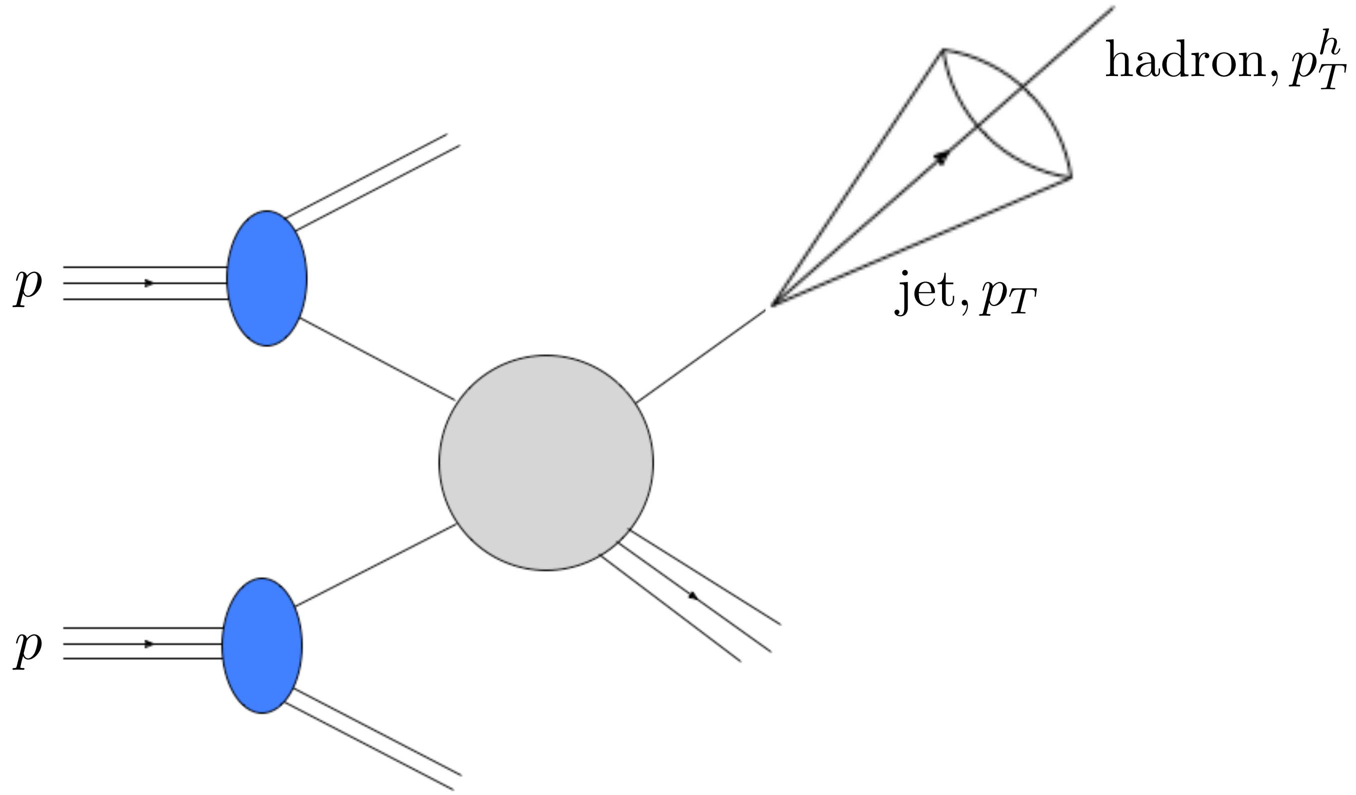
Kang, Qiu, FR, Xing, Zhang
- in preparation

Los Alamos
NATIONAL LABORATORY
EST. 1943

Jet fragmentation function $pp \to (\text{jet}h)X$

- Jet substructure observable studying the distribution of hadrons inside a jet

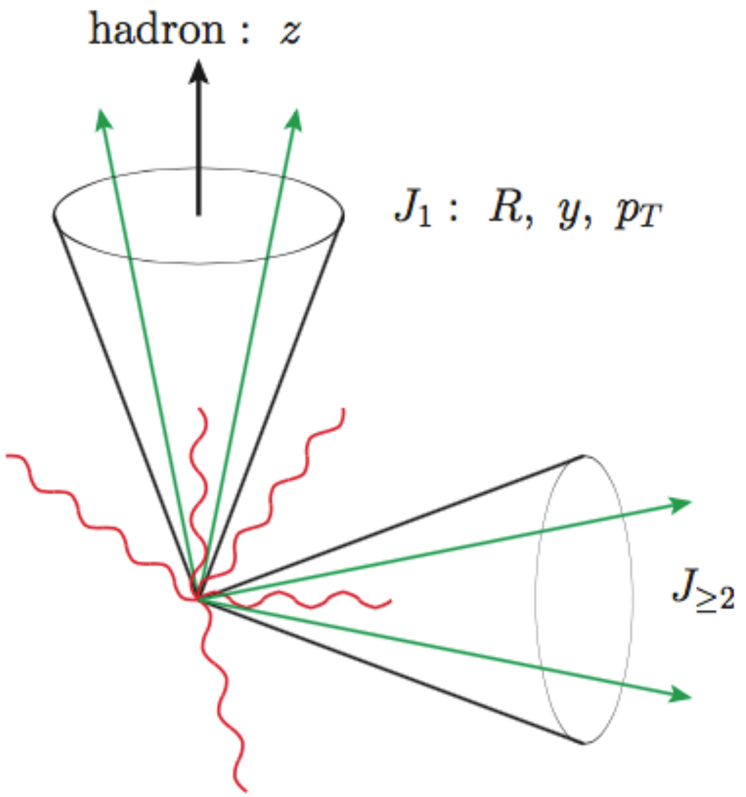
- Provides further constraints for fits of fragmentation functions
- Possible studies include spin correlations and TMDs
- Differential probe for the modification of jets in AA and eA



Jet fragmentation function

Definition: $$F(z_h, p_T) = \frac{d\sigma^{pp\to(\text{jet}h)X}}{dp_T d\eta dz_h} \bigg/ \frac{d\sigma^{pp\to\text{jet}X}}{dp_T d\eta}$$

where $$z_h = p_T^h / p_T$$



The JFF describes the longitudinal momentum distribution of hadrons inside a reconstructed jet

Procura, Stewart `10; Liu `11; Jain, Procura, Waalewijn `11 and '12; Procura, Waalewijn `12; Bauer, Mereghetti `14;
Baumgart, Leibovich, Mehen, Rothstein `14,
Chien, Kang, FR, Vitev, Xing `15,
Bain, Dai, Hornig, Leibovich, Makris, Mehen `16,
Bain, Makris, Mehen `16,
Arleo, Fontannaz, Guillet, Nguyen `14,
Kaufmann, Mukherjee, Vogelsang `15 …

Los Alamos NATIONAL LABORATORY EST. 1943

Semi-inclusive fragmenting jet function

Factorized cross section:

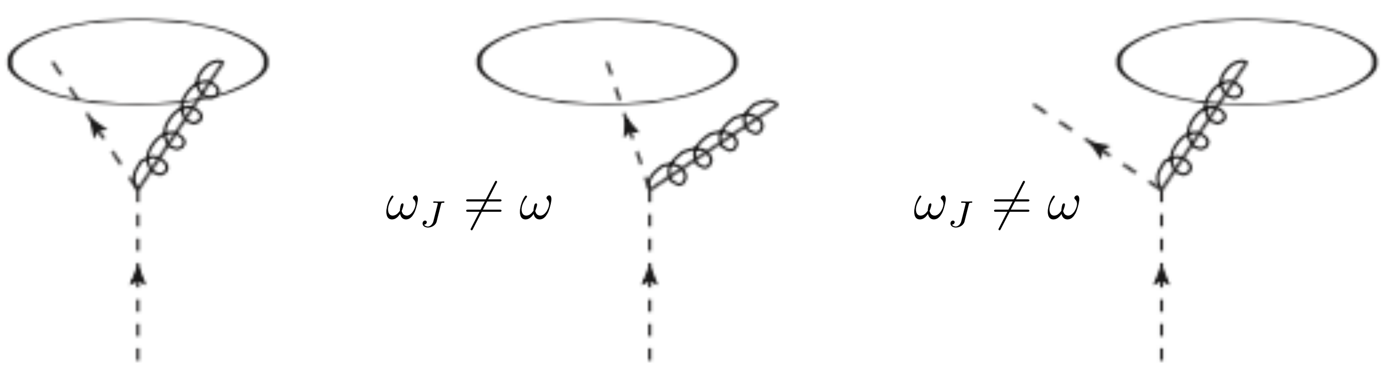
$$\frac{d\sigma^{pp\to(\mathrm{jet}h)X}}{dp_T d\eta dz_h} = \sum_{a,b,c} f_a \otimes f_b \otimes H_{ab}^c \otimes \mathcal{G}_c^h$$

where

$$\mathcal{G}_i^h(z, z_h, \omega_J, \mu) = \sum_j \int_{z_h}^1 \frac{dz_h'}{z_h'} \mathcal{J}_{ij}(z, z_h', \omega_J, \mu) D_j^h\left(\frac{z_h}{z_h'}, \mu\right)$$

NLO: $z = \omega_J/\omega$ $\qquad$ $z_h = \omega_h/\omega_J$

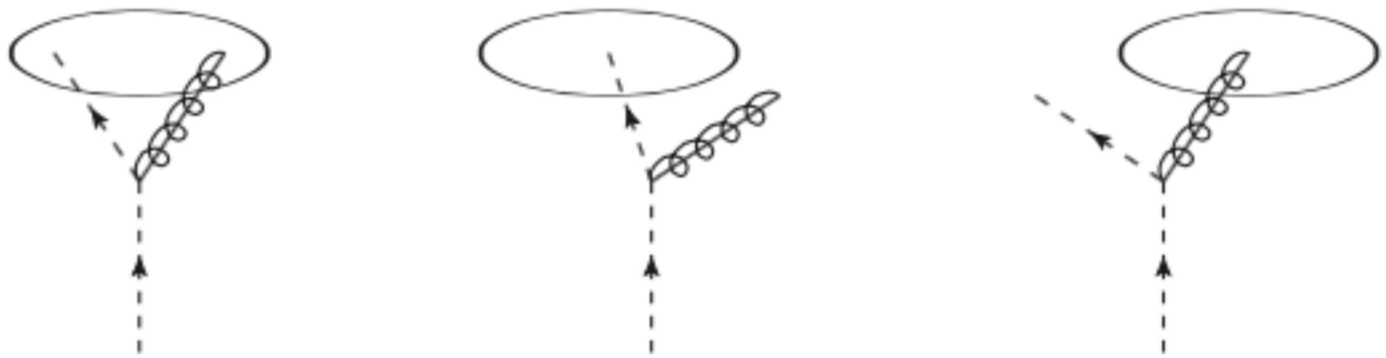
- fragmenting parton: $\omega_h \neq \omega_J$ $\qquad$ $\omega_h = \omega_J$ $\qquad$ $\omega_h = \omega_J$



- jet: $\omega_J = \omega$ $\qquad$ $\omega_J \neq \omega$ $\qquad$ $\omega_J \neq \omega$
- initiating parton: ω $\qquad$ ω $\qquad$ ω

Los Alamos NATIONAL LABORATORY EST. 1943

Semi-inclusive jet function

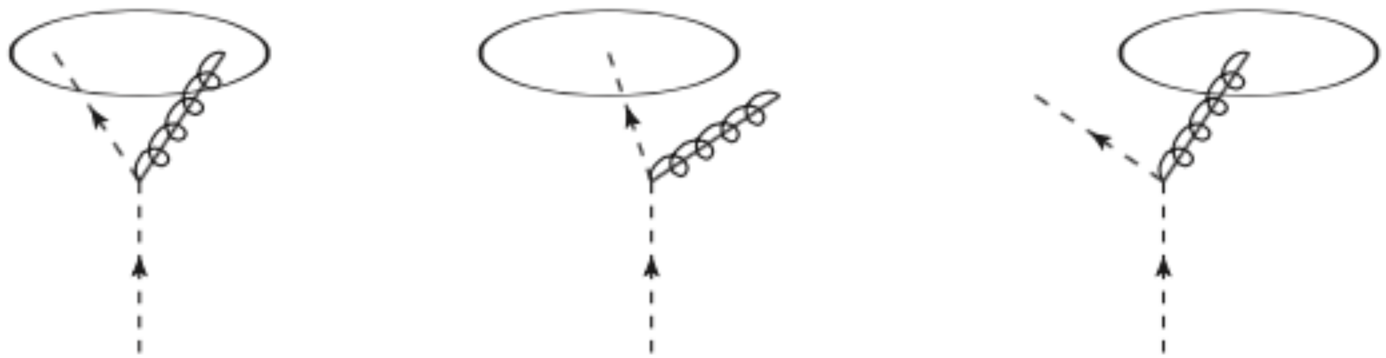


$\overline{\mathrm{MS}}$ scheme, $\mathrm{anti}-k_T$

Quark-quark:

$$\begin{aligned}\mathcal{G}_{q,\mathrm{bare}}^{q}(z,z_h,\omega_J,\mu) =& \,\delta(1-z)\delta(1-z_h) + \frac{\alpha_s}{2\pi}\left(-\frac{1}{\epsilon}-L\right)P_{qq}(z_h)\delta(1-z)\\ &+\frac{\alpha_s}{2\pi}\left(\frac{1}{\epsilon}+L\right)P_{qq}(z)\delta(1-z_h)\\ &+\delta(1-z)\frac{\alpha_s}{2\pi}\left[2C_F(1+z_h^2)\left(\frac{\ln(1-z_h)}{1-z_h}\right)_+ + C_F(1-z_h)+2P_{qq}(z_h)\ln z_h\right]\\ &-\delta(1-z_h)\frac{\alpha_s}{2\pi}\left[2C_F(1+z^2)\left(\frac{\ln(1-z)}{1-z}\right)_+ + C_F(1-z)\right]\end{aligned}$$

Semi-inclusive jet function



$\overline{\text{MS}}$ scheme, $\text{anti}-k_T$

Quark-quark:

IR

UV

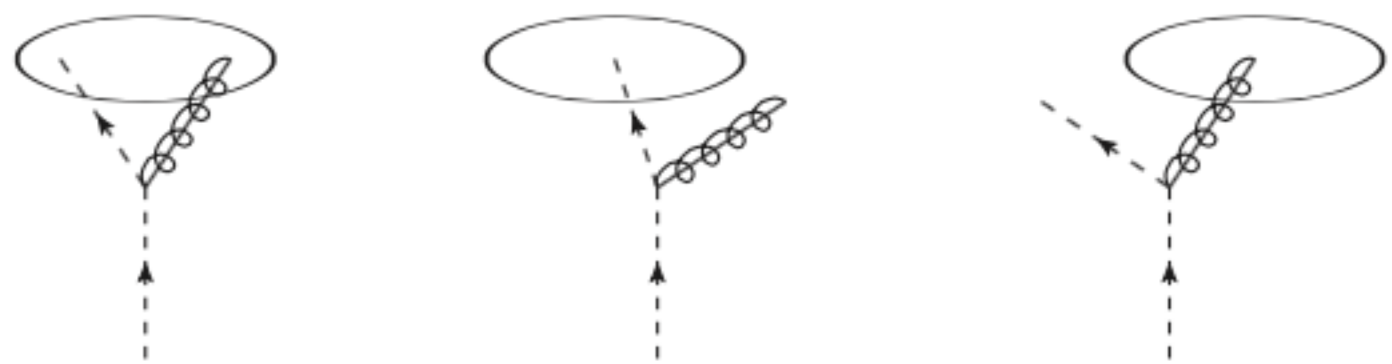
$$\mathcal{G}_{q,\text{bare}}^q(z, z_h, \omega_J, \mu) = \delta(1-z)\delta(1-z_h) + \frac{\alpha_s}{2\pi}\left(-\frac{1}{\epsilon} - L\right) P_{qq}(z_h)\delta(1-z)$$
$$+ \frac{\alpha_s}{2\pi}\left(\frac{1}{\epsilon} + L\right) P_{qq}(z)\delta(1-z_h)$$
$$+ \delta(1-z)\frac{\alpha_s}{2\pi}\left[2C_F(1+z_h^2)\left(\frac{\ln(1-z_h)}{1-z_h}\right)_+ + C_F(1-z_h) + 2P_{qq}(z_h)\ln z_h\right]$$
$$- \delta(1-z_h)\frac{\alpha_s}{2\pi}\left[2C_F(1+z^2)\left(\frac{\ln(1-z)}{1-z}\right)_+ + C_F(1-z)\right]$$

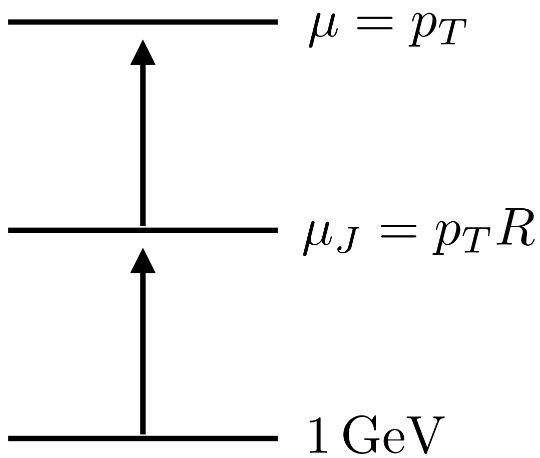
Matching:

$$\mathcal{G}_i^h(z, z_h, \omega_J, \mu) = \sum_j \int_{z_h}^1 \frac{dz_h'}{z_h'} \mathcal{J}_{ij}\left(z, z_h', \omega_J, \mu\right) D_j^h\left(\frac{z_h}{z_h'}, \mu\right)$$

Los Alamos NATIONAL LABORATORY EST. 1943

Semi-inclusive jet function





Quark-quark:

IR

$$\mathcal{G}_{q,\mathrm{bare}}^{q}(z, z_h, \omega_J, \mu) = \delta(1-z)\delta(1-z_h) + \frac{\alpha_s}{2\pi}\left(-\frac{1}{\epsilon} - L\right) P_{qq}(z_h)\delta(1-z)$$

UV

$$+ \frac{\alpha_s}{2\pi}\left(\frac{1}{\epsilon} + L\right) P_{qq}(z)\delta(1-z_h)$$

$$+ \delta(1-z)\frac{\alpha_s}{2\pi}\left[2C_F(1+z_h^2)\left(\frac{\ln(1-z_h)}{1-z_h}\right)_+ + C_F(1-z_h) + 2P_{qq}(z_h)\ln z_h\right]$$

$$- \delta(1-z_h)\frac{\alpha_s}{2\pi}\left[2C_F(1+z^2)\left(\frac{\ln(1-z)}{1-z}\right)_+ + C_F(1-z)\right]$$

… 2 DGLAPs now

Matching:

$$\mathcal{G}_i^h(z, z_h, \omega_J, \mu) = \sum_j \int_{z_h}^1 \frac{dz_h'}{z_h'} \mathcal{J}_{ij}\left(z, z_h', \omega_J, \mu\right) D_j^h\left(\frac{z_h}{z_h'}, \mu\right)$$

In-jet fragmentation

- Light charged hadrons

  Arleo, Fontannaz, Guillet, Nguyen `14,
  Kaufmann, Mukherjee, Vogelsang `15
  Kang, FR, Vitev `15

- Photons

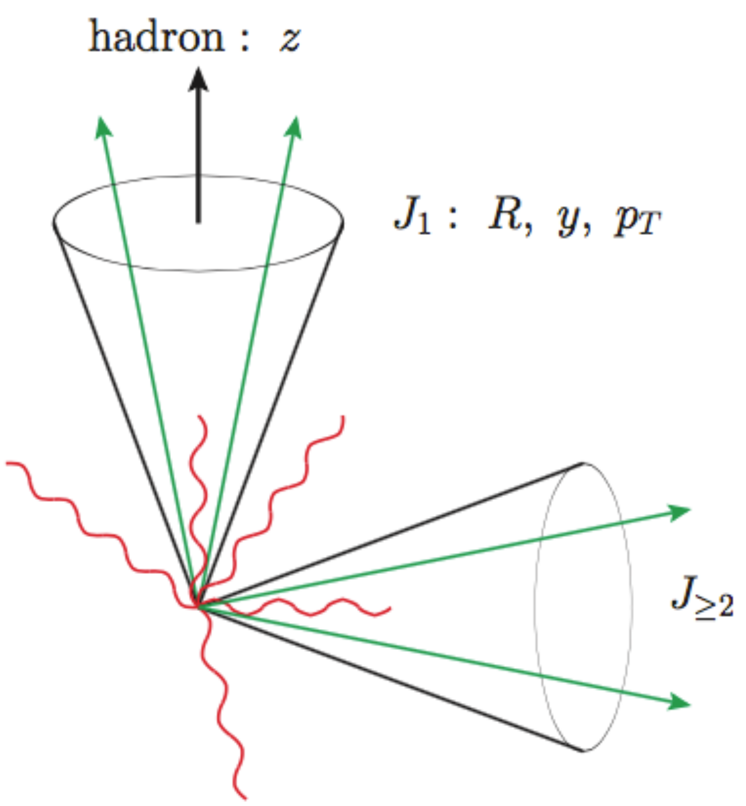
  Kaufmann, Mukherjee, Vogelsang `16

- Heavy flavor mesons

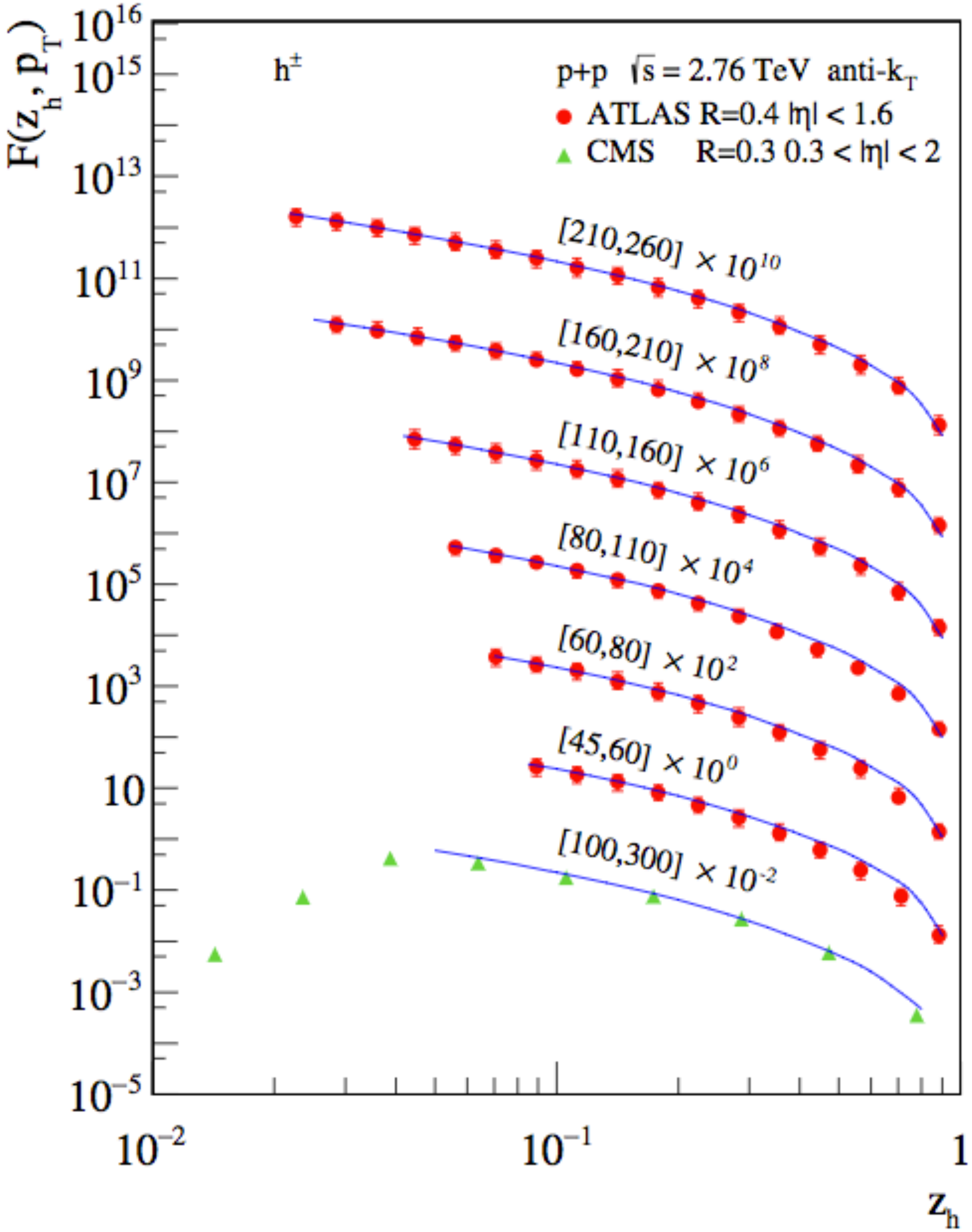
  Chien, Kang, FR, Vitev, Xing `15
  Bain, Dai, Hornig, Leibovich, Makris, Mehen `16

- Quarkonia

  Baumgart, Leibovich, Mehen, Rothstein `14
  Bain, Dai, Hornig, Leibovich, Makris, Mehen `16
  Kang, Qiu, FR, Xing, Zhang - in preparation



Los Alamos NATIONAL LABORATORY EST. 1943



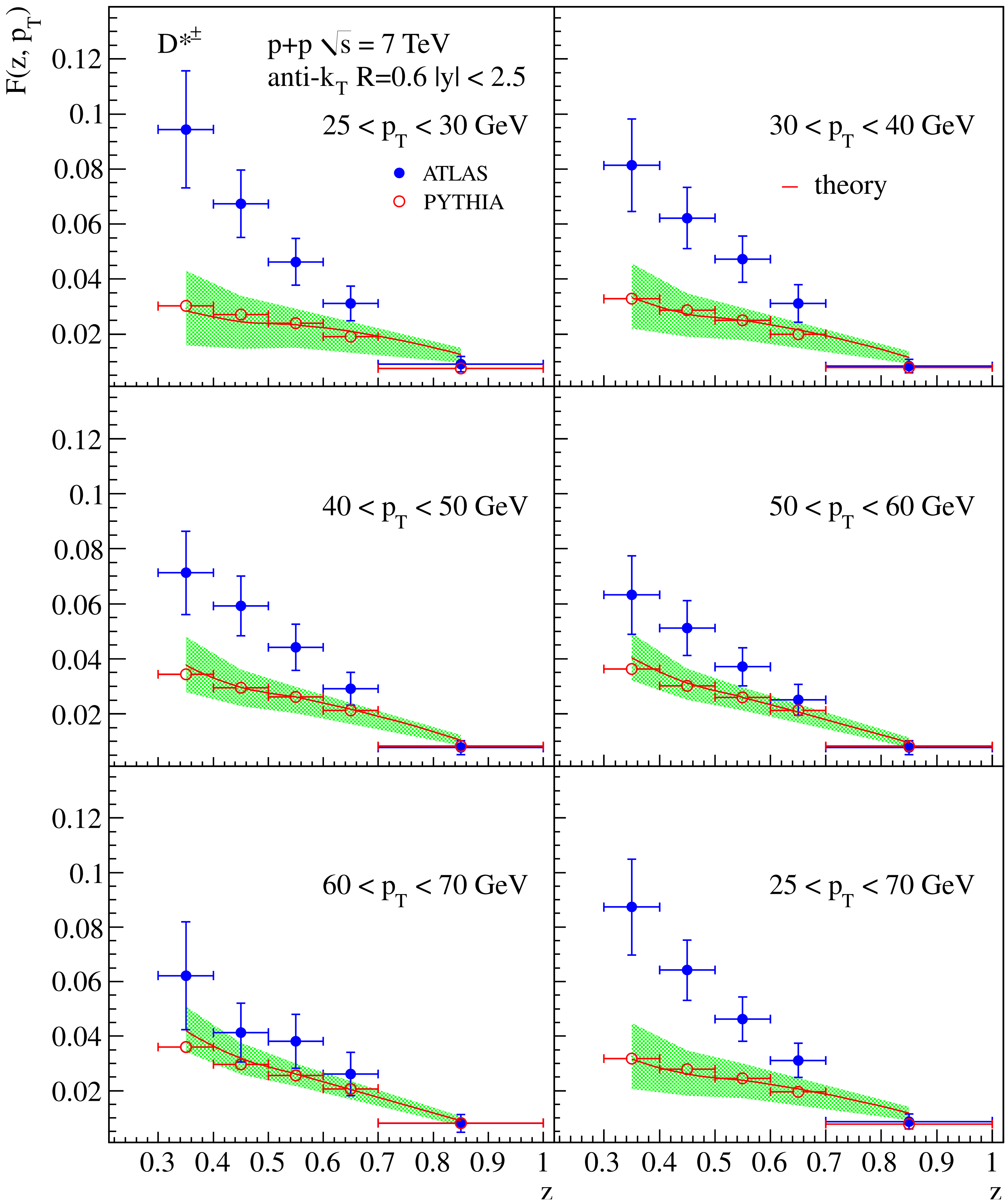
Comparison to ATLAS and CMS data at $\sqrt{s} = 2.76\,\mathrm{TeV}$

Light charged hadrons $h = \pi + K + p$

Using DSS FFs

de Florian, Sassot, Stratmann - '07

Los Alamos NATIONAL LABORATORY EST. 1943



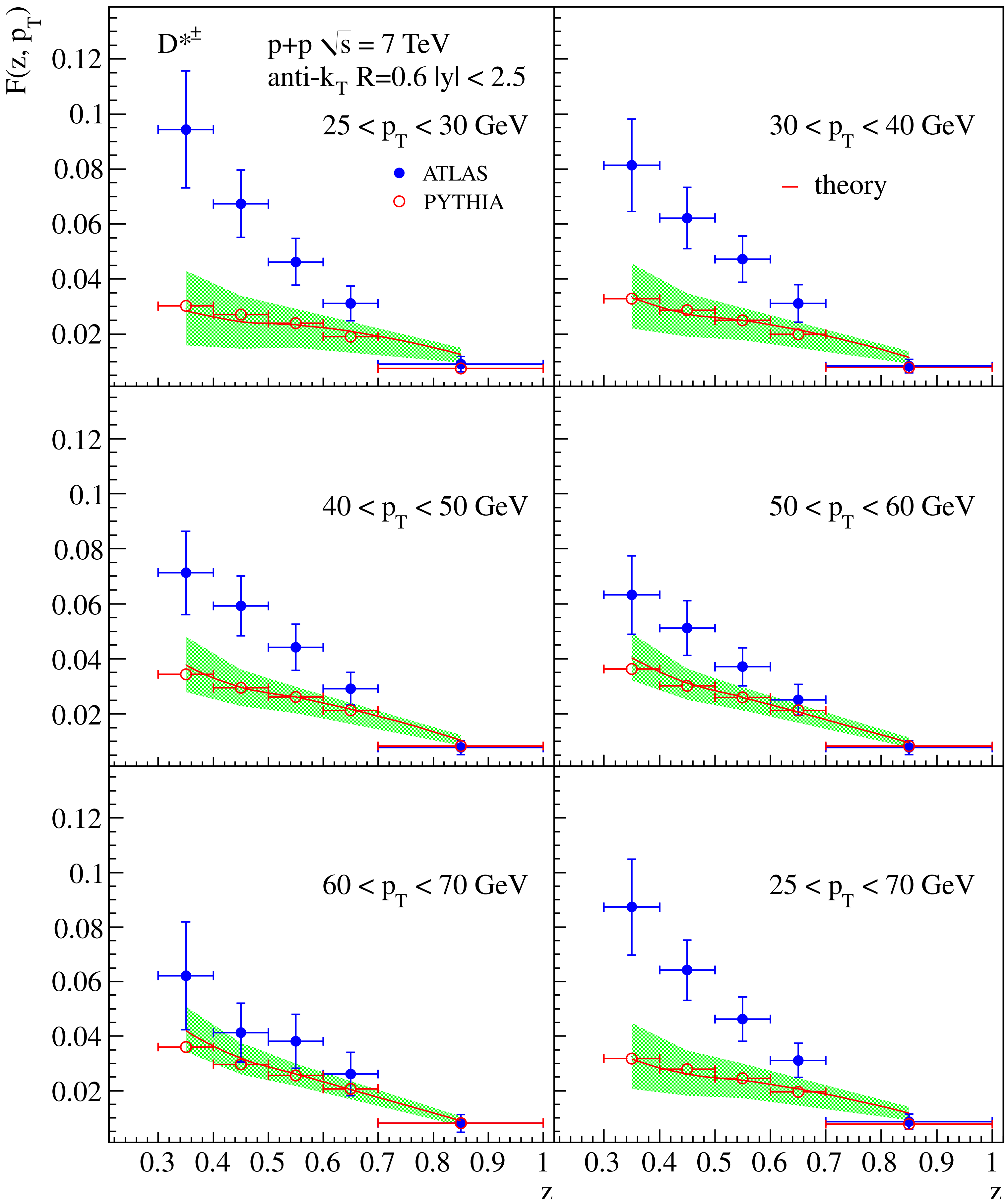
Chien, Kang, FR, Vitev, Xing `15 (exclusive FJF)

D-meson
jet fragmentation function

Comparison to ATLAS data
and PYTHIA simulations
at $\sqrt{s} = 7\,\mathrm{TeV}$

Using FFs from
Kneesch, Kniehl, Kramer, Schienbein - '08

ZMVNFS, $e^+e^- \to DX$
$\mu,\ \mu_J,\ \mu_G \gg m_Q$



Chien, Kang, FR, Vitev, Xing `15 (exclusive FJF)

D-meson
jet fragmentation function

Comparison to ATLAS data
and PYTHIA simulations
at $\sqrt{s} = 7\,\mathrm{TeV}$

Using FFs from
Kneesch, Kniehl, Kramer, Schienbein - '08

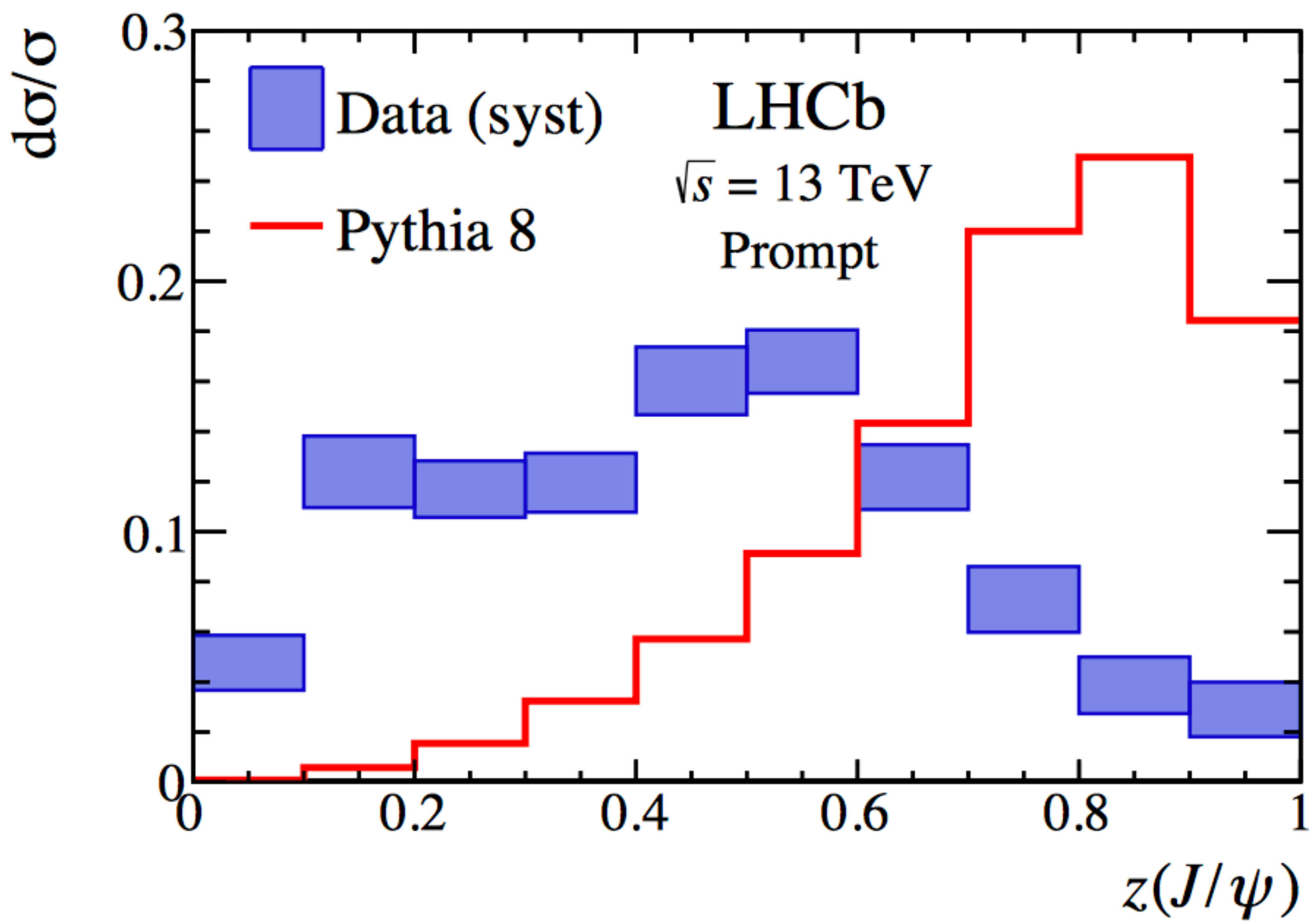
ZMVNFS, $e^+e^- \to DX$
$\mu,\ \mu_J,\ \mu_G \gg m_Q$

New global fit of D-meson FFs:

Anderle, Kaufmann, FR, Stratmann, Vitev - in preparation

Quarkonium-in-jet fragmentation

- Quarkonium-in-jet fragmentation proposed in *Baumgart, Leibovich, Mehen, Rothstein `14*
  Bain, Dai, Hornig, Leibovich, Makris, Mehen `16
- J/ψ-in-jet measurement from LHCb *arXiv: 1701.0511*



$p_T > 20\,\mathrm{GeV}$

$2.5 < \eta < 4$

$R = 0.5$

- Semi-inclusive in-jet fragmentation $pp \to (\text{jet}\ J/\psi)X$
  Kang, Qiu, FR, Xing, Zhang - in preparation

Los Alamos NATIONAL LABORATORY EST. 1943

J/psi fragmentation functions

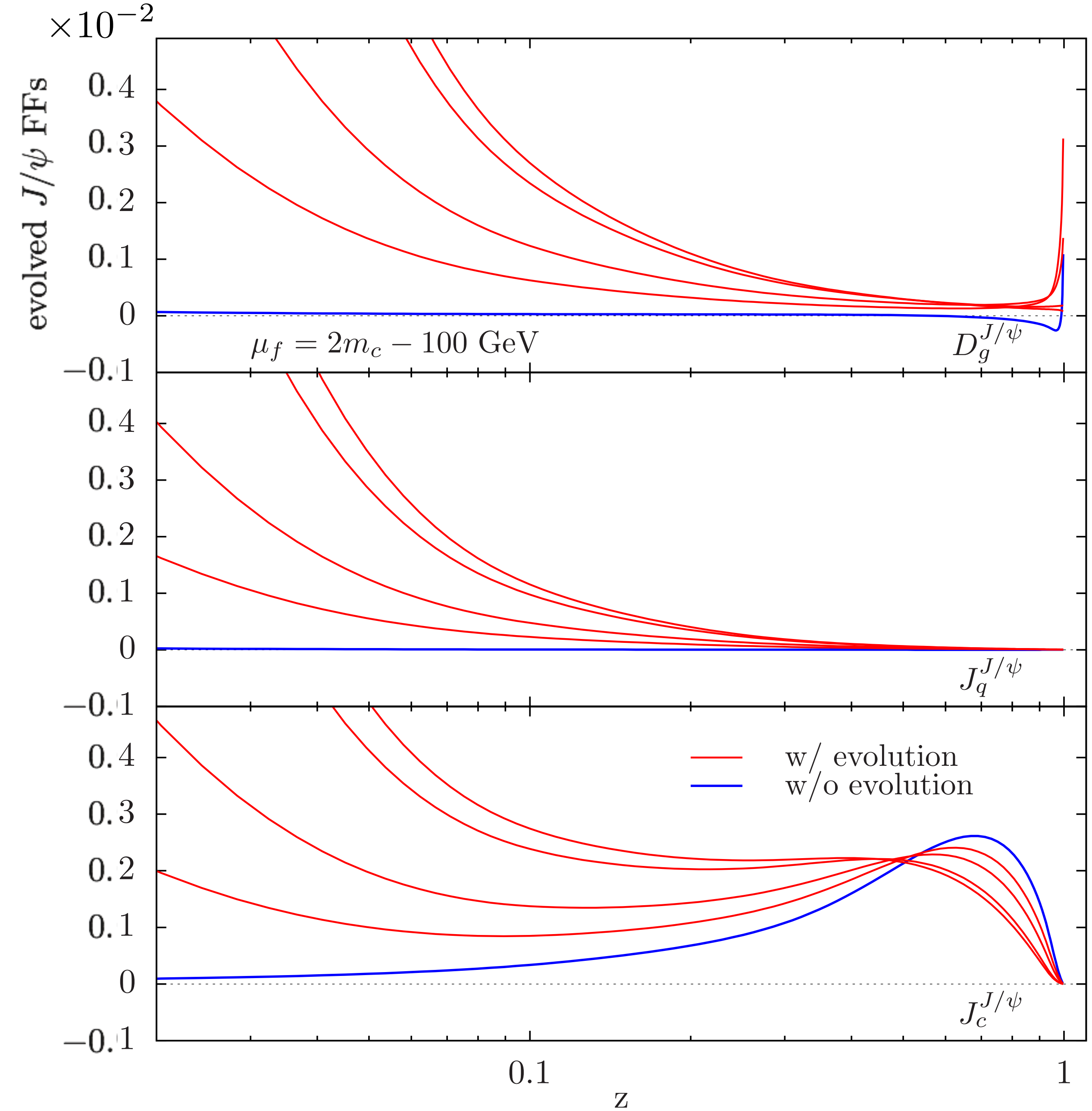
Single-parton FFs:

$$D_{i\to J/\psi}(z) = \sum_{n_\lambda} \pi\alpha_s\, \hat{d}_{i\to Q\bar{Q}(n_\lambda)}(z)\, \langle \mathcal{O}^{J/\psi}_{Q\bar{Q}(n_\lambda)} \rangle$$

perturbatively calculable

NRQCD LDMEs

… evolution again with DGLAP in Mellin moment space



LDMEs: *Butenschoen, Kniehl `14*

Braaten, Yuan `93, Kang, Qiu, Sterman `12, Ma, Qiu, Zhang `13 …

Los Alamos NATIONAL LABORATORY EST. 1943

J/psi siFJF

$$\frac{d\sigma^{pp\to(\text{jet}\,J/\psi)X}}{dp_T d\eta dz_h} = \sum_{a,b,c} f_a \otimes f_b \otimes H_{ab}^c \otimes \mathcal{G}_c^h$$

where $$\mathcal{G}_i^h(z, z_h, \omega_J, \mu) = \sum_j \int_{z_h}^1 \frac{dz_h'}{z_h'} \mathcal{J}_{ij}(z, z_h', \omega_J, \mu) D_j^h\left(\frac{z_h}{z_h'}, \mu\right)$$

evolved FFs

Los Alamos NATIONAL LABORATORY EST. 1943

J/psi siFJF

$$\frac{d\sigma^{pp\to(\mathrm{jet}\,J/\psi)X}}{dp_T d\eta dz_h} = \sum_{a,b,c} f_a \otimes f_b \otimes H_{ab}^c \otimes \mathcal{G}_c^h$$

where $\mathcal{G}_i^h(z, z_h, \omega_J, \mu) = \sum_j \int_{z_h}^1 \frac{dz_h'}{z_h'} \mathcal{J}_{ij}(z, z_h', \omega_J, \mu) D_j^h\left(\frac{z_h}{z_h'}, \mu\right)$

evolved FFs

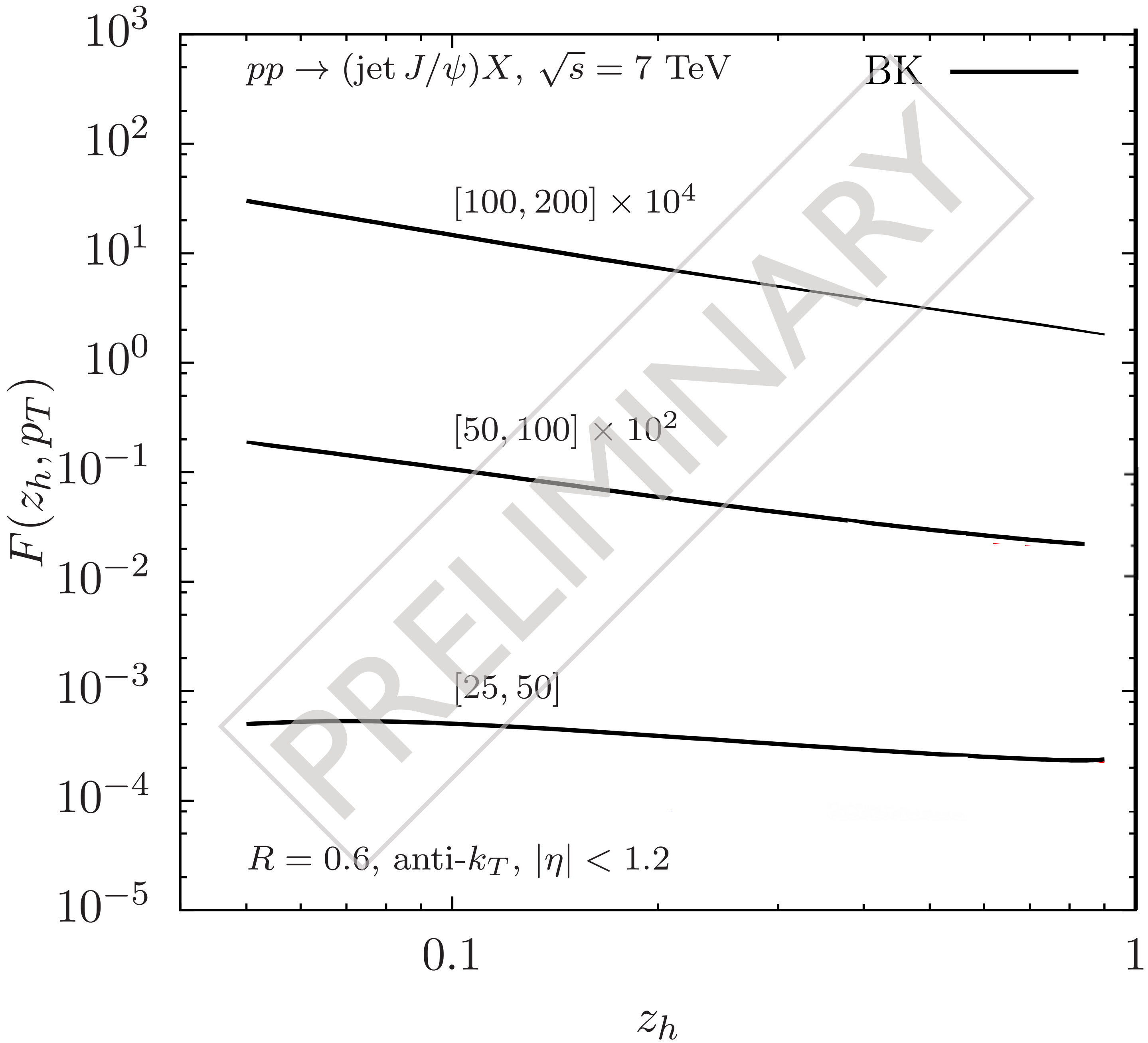
Take Mellin moments wrt z_h :

$$\int_0^1 dz_h\, z_h^{N-1} \mathcal{G}_i^h(z, z_h, \omega_J, \mu) = \sum_j \mathcal{J}_{ij}(z, N, \omega_J, \mu) D_j^h\,(N, \mu)$$

Quarkonium-in-jet fragmentation

- semi-inclusive in-jet fragmentation $pp \to (\text{jet}\, J/\psi)X$

  Kang, Qiu, FR, Xing, Zhang - in preparation



LDMEs:

Butenschoen, Kniehl `14

Outline

- Inclusive jets — *Kang, FR, Vitev `16*
- The jet fragmentation function — *Kang, FR, Vitev `16*
- Conclusions — *Chien, Kang, FR, Vitev, Xing `15*

Kang, Qiu, FR, Xing, Zhang - in preparation

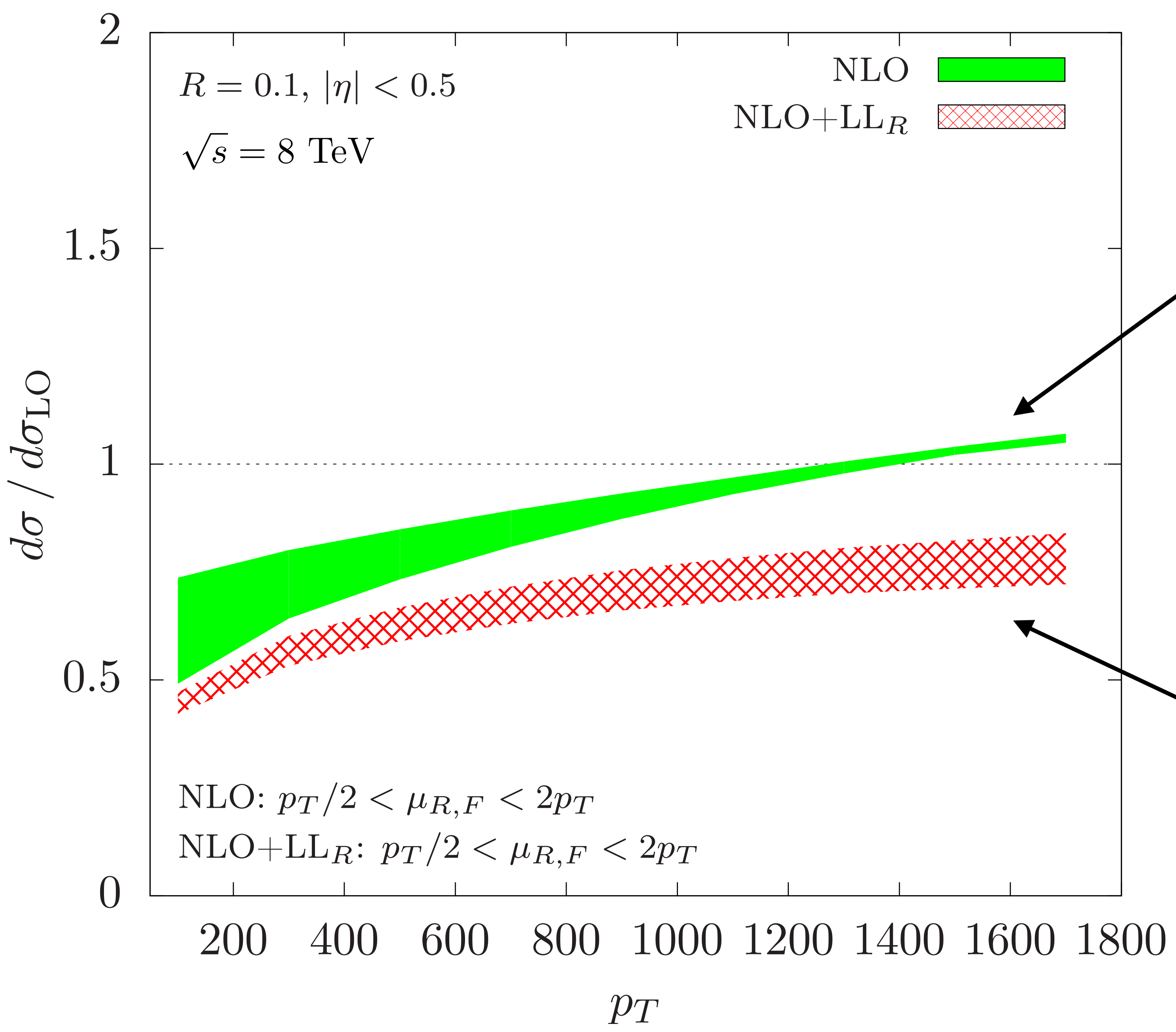
Conclusions

- (Semi-) inclusive jet observables in SCET
- Longitudinal hadron-in-jet distribution
- New constraints for global fits of FFs/ LDMEs

- TMDs, spin-asymmetries inside jets …

Los Alamos NATIONAL LABORATORY EST. 1943

LL_R DGLAP evolution



Vanishing, unphysical scale dependence

Note: same at NNLO (large-N_c)
Currie, Glover, Pires `16

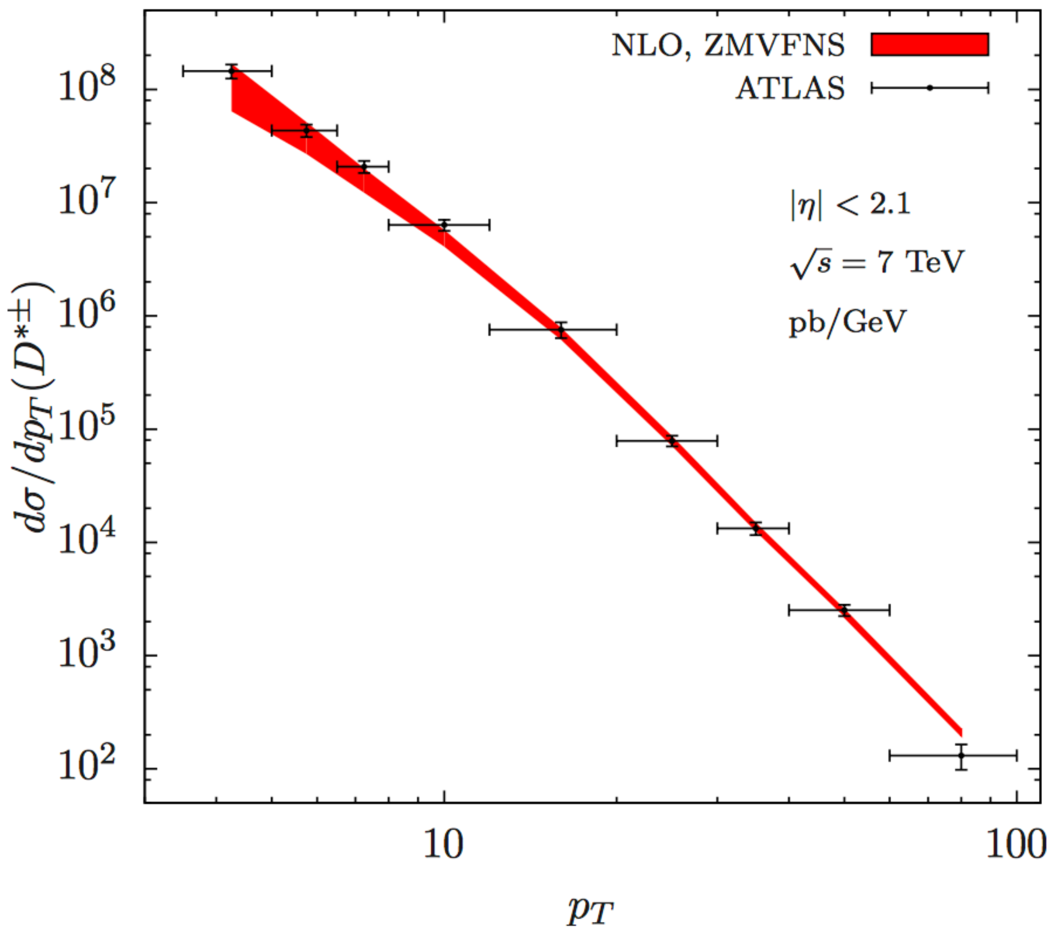
Additional final state factorization

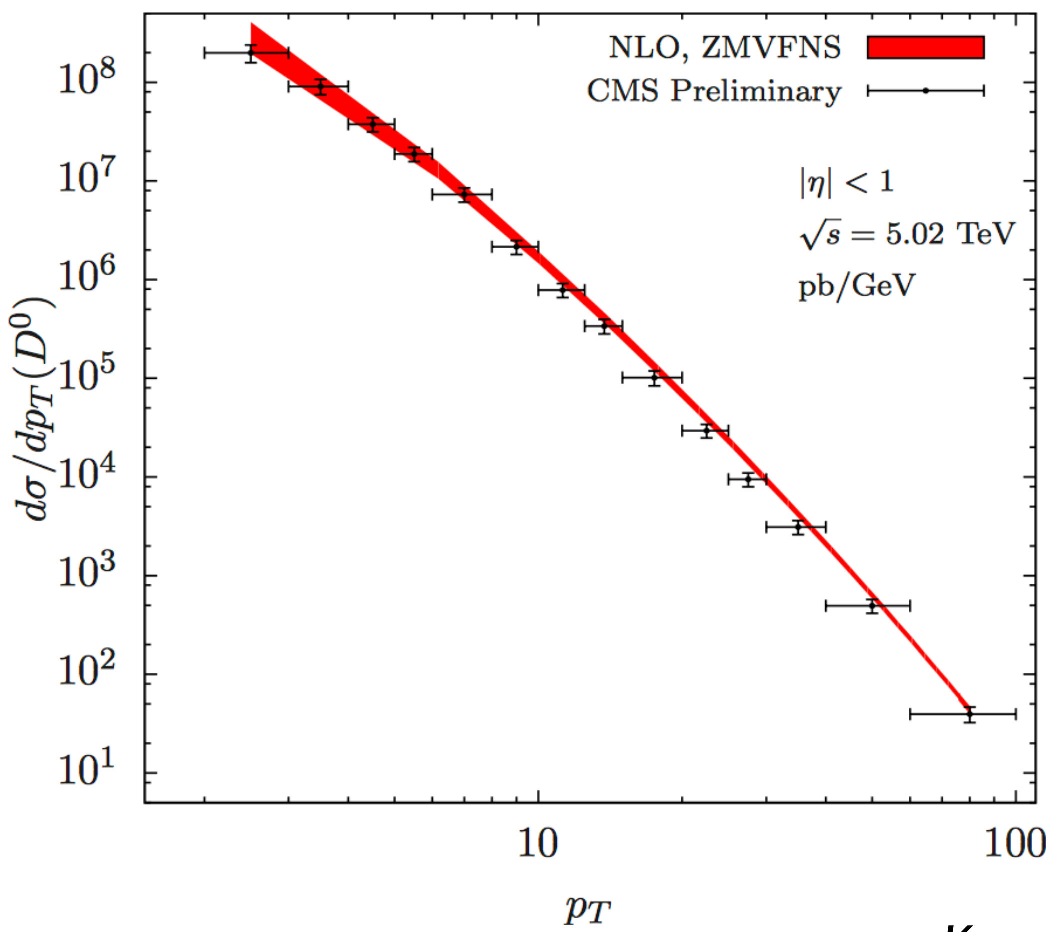
see also
Dasgupta, Dreyer, Salam, Soyez `15, `16

Inclusive D-meson production in pp

NLO + ZMVFNS FFs from

Kneesch, Kniehl, Kramer, Schienbein - '08





Kang, FR, Vitev `16

Los Alamos NATIONAL LABORATORY EST. 1943