Soft gluon resummation in Dijet correlation at colliders

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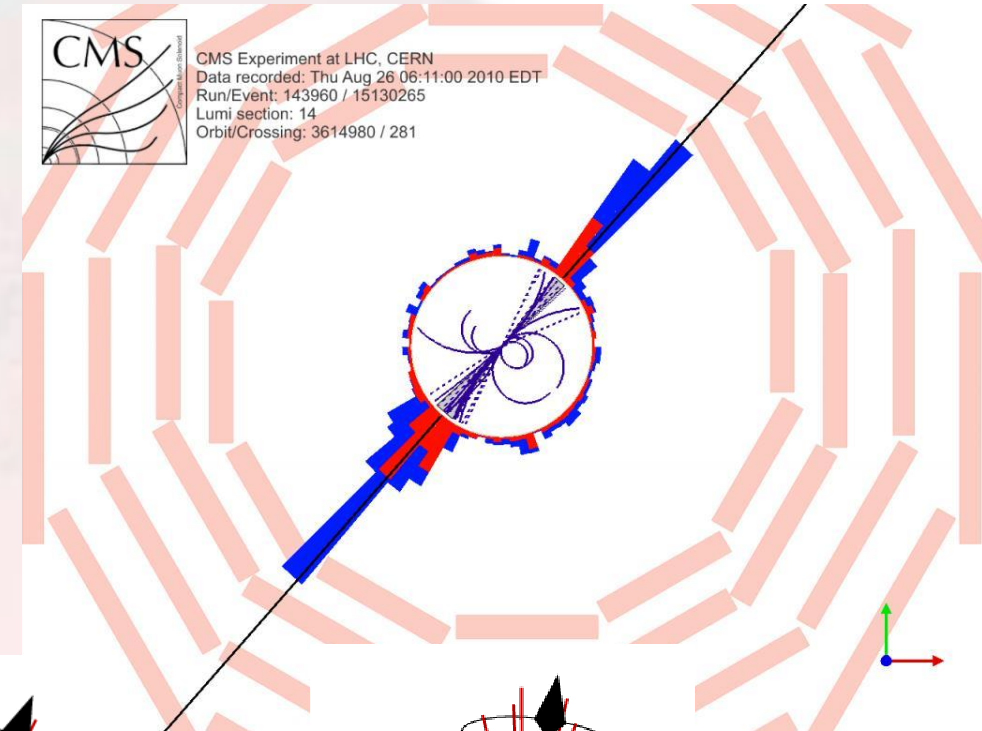
Ref: Peng Sun, C.-P. Yuan, Feng Yuan, PRL 113, 232001 (2014); to be published.

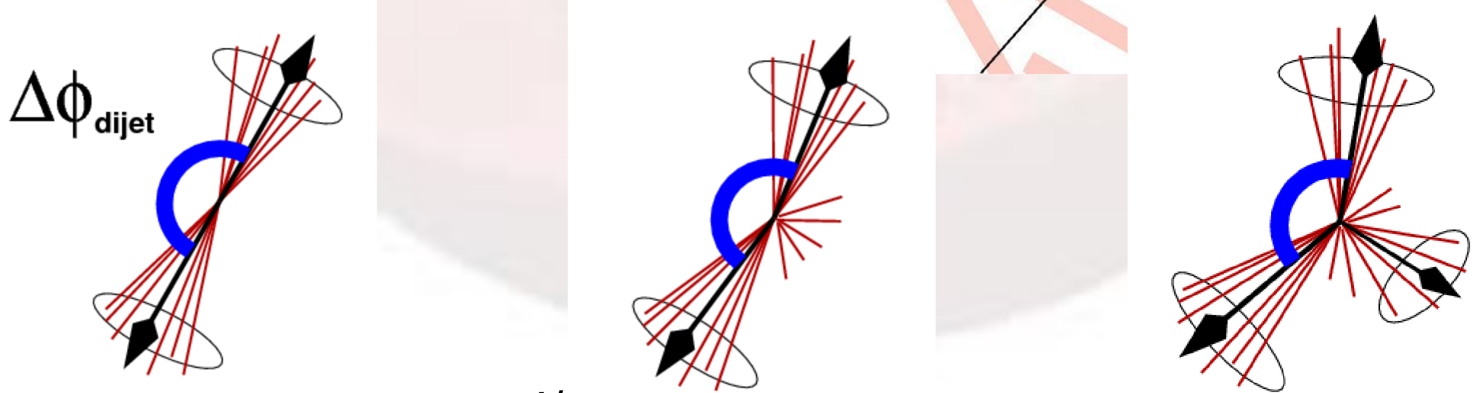
Outlines

- Experiments at Tevatron and LHC
- Soft gluon resummation
  - Collins-Soper-Sterman
- Dijet correlation
- Comparison between theory and data

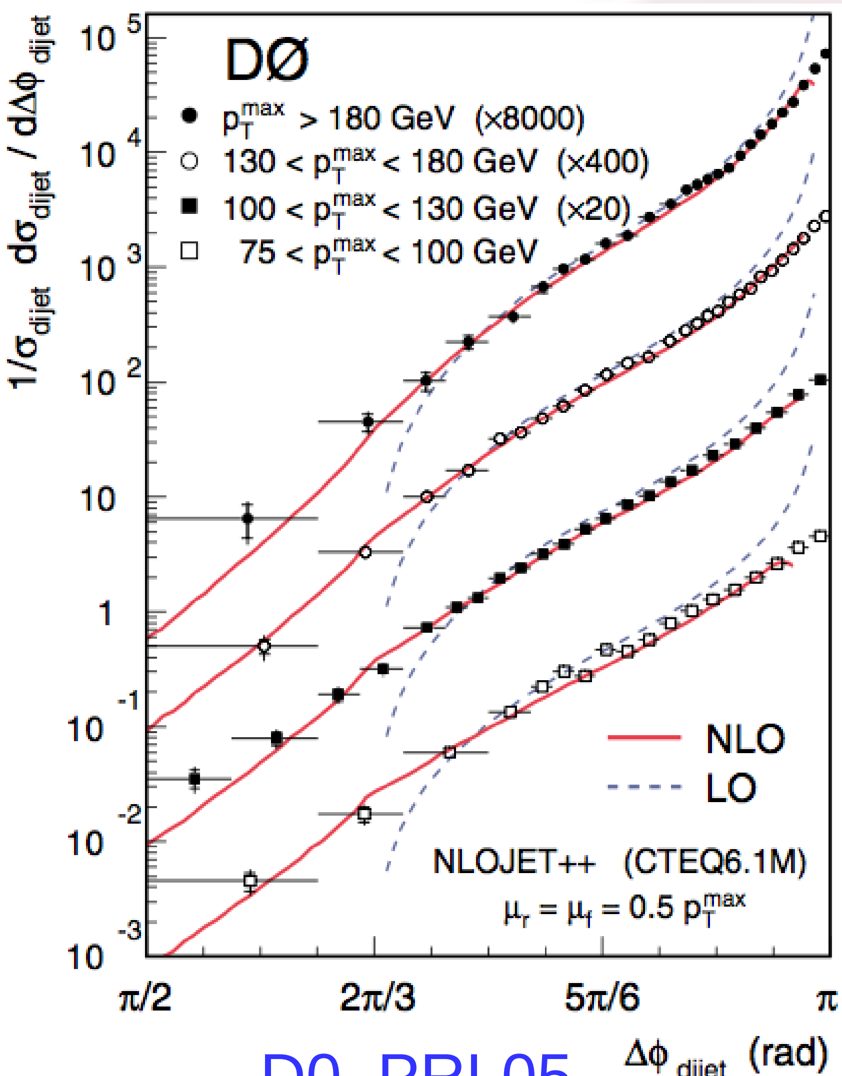
Dijet production at the hadron colliders

- Most abundant events
- Almost back-to-back
- De-correlation comes
  - Hard gluon jet
  - Soft gluon radiation

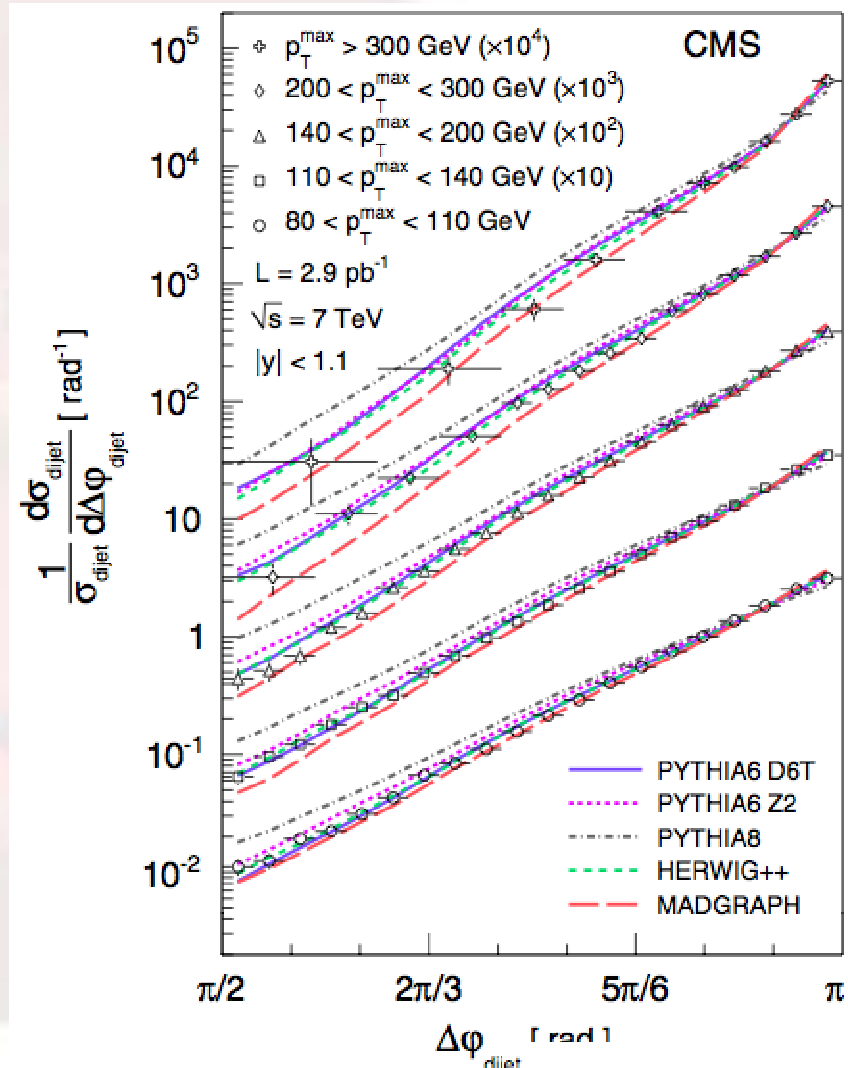




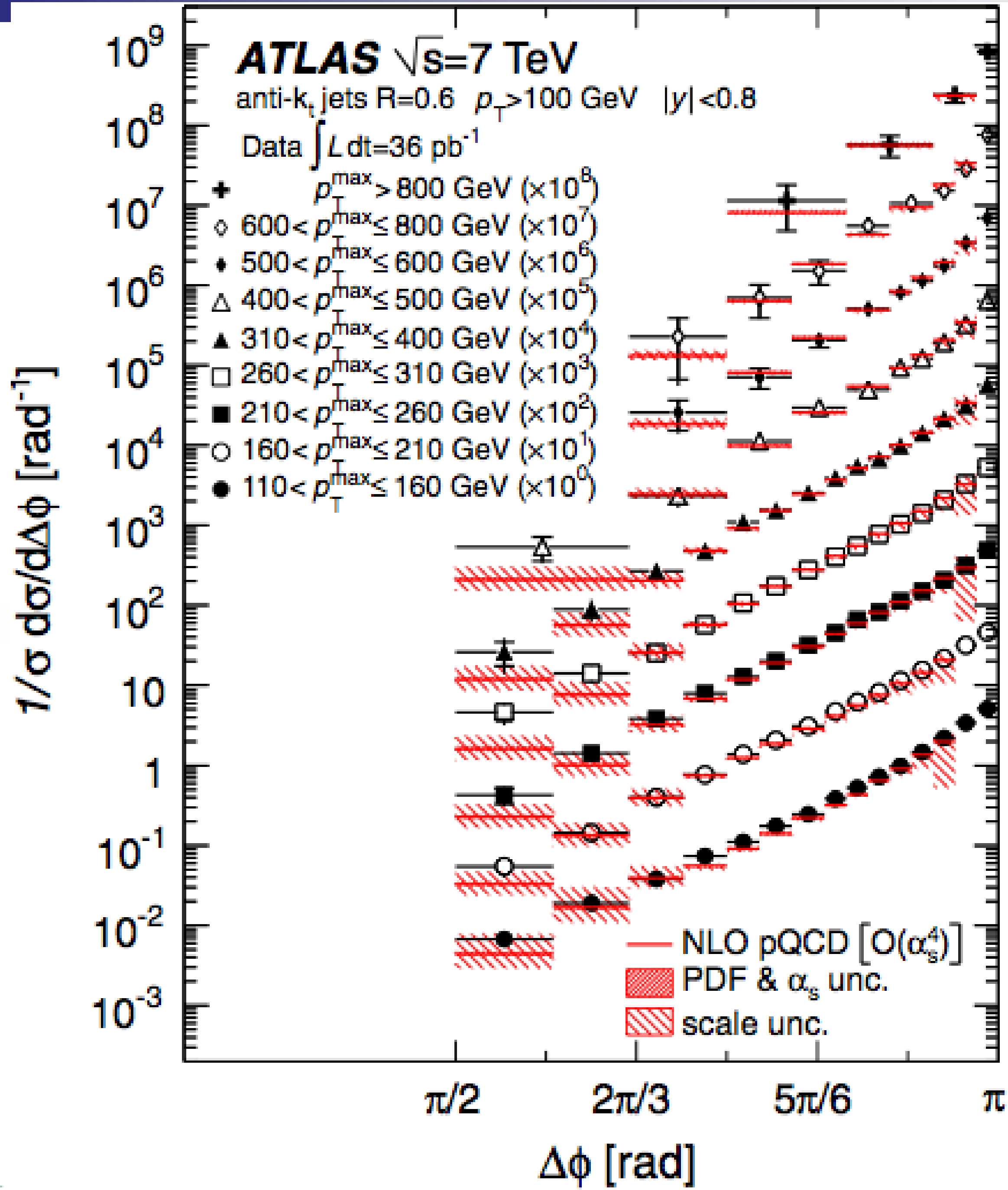
Beautiful data from Tevatron/LHC



D0, PRL05



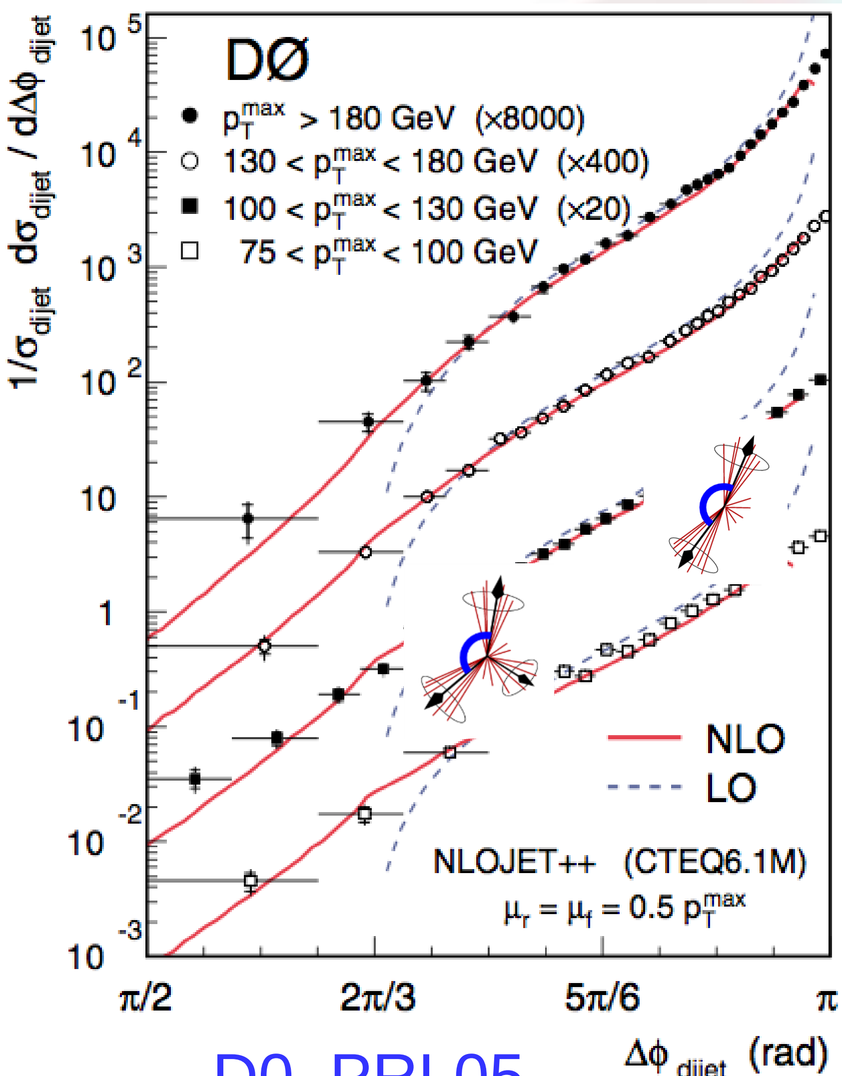
CMS, PRL11



ATLAS √s=7 TeV
anti-k_t jets R=0.6 p_T>100 GeV |y|<0.8
Data ∫L dt=36 pb^-1
p_T^max > 800 GeV (×10^8)
600< p_T^max ≤ 800 GeV (×10^7)
500< p_T^max ≤ 600 GeV (×10^6)
400< p_T^max ≤ 500 GeV (×10^5)
310< p_T^max ≤ 400 GeV (×10^4)
260< p_T^max ≤ 310 GeV (×10^3)
210< p_T^max ≤ 260 GeV (×10^2)
160< p_T^max ≤ 210 GeV (×10^1)
110< p_T^max ≤ 160 GeV (×10^0)
NLO pQCD [O(α_s^4)]
PDF & α_s unc.
scale unc.
1/σ dσ/dΔφ [rad^-1]
Δφ [rad]
π/2
2π/3
5π/6
π

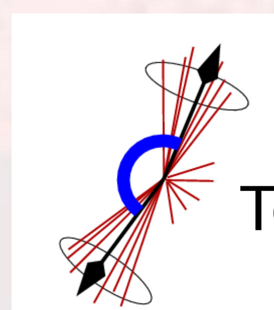
ATLAS, PRL11

QCD calculations



D0, PRL05

- Fixed order calculations divergent around π, where soft gluon radiation dominate
- All order resummation is needed to understand the physics around here
  - Two separate scales $P_T >> q_T$



Leading P_T

Total $q_T \approx P_T \mathrm{Sin}(\Delta\phi)$

Sudakov Large Double Logarithms

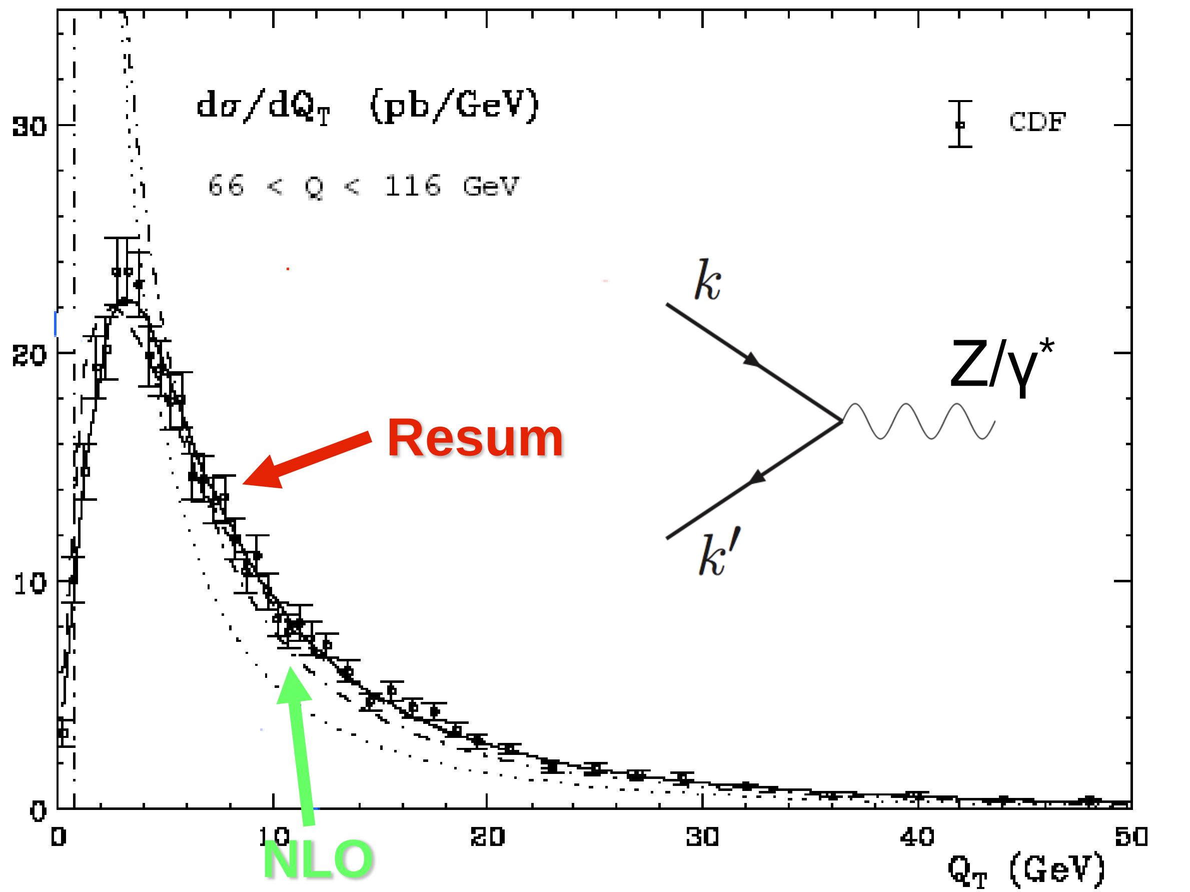
Sudakov, 1956

- Differential cross section depends on Q_1, where $Q^2 \gg Q_1^2 \gg \Lambda^2_{QCD}$

$$\frac{d\sigma}{dQ_1^2} = \frac{1}{Q_1^2} f_1 \otimes f_2 \otimes \sum_i \alpha_s^i \ln^{2i-1} \frac{Q^2}{Q_1^2} + \cdots$$

- We have to resum these large logs to make reliable predictions
  - Q_T: Dokshitzer, Diakonov, Troian, 78; Parisi Petronzio, 79; Collins, Soper, Sterman, 85
  - Threshold: Sterman 87; Catani and Trentadue 89

How Large of the Resummation effects



Kulesza, Sterman, Vogelsang, 02

Collins-Soper-Sterman Resummation

- $\sigma(P_T,Q)=H(Q)\, f_1(k_{1T},Q)\, f_2(k_{2T}, Q)\, S(\lambda_T)$
- Large Logs are resummed by solving the energy evolution equation of the TMDs

$$\frac{\partial}{\partial \ln Q} f(k_\perp, Q) = (K(q_\perp,\mu) + G(Q,\mu)) \otimes f(k_\perp, Q)$$

- K and G obey the renormalization group eq.

$$\frac{\partial}{\partial \ln \mu} K = -\gamma_K = \frac{\partial}{\partial \ln \mu} G$$

(Collins-Soper 81, Collins-Soper-Sterman 85)

CSS Formalism (Drell-Yan)

- The large logs will be resummed into the exponential form factor

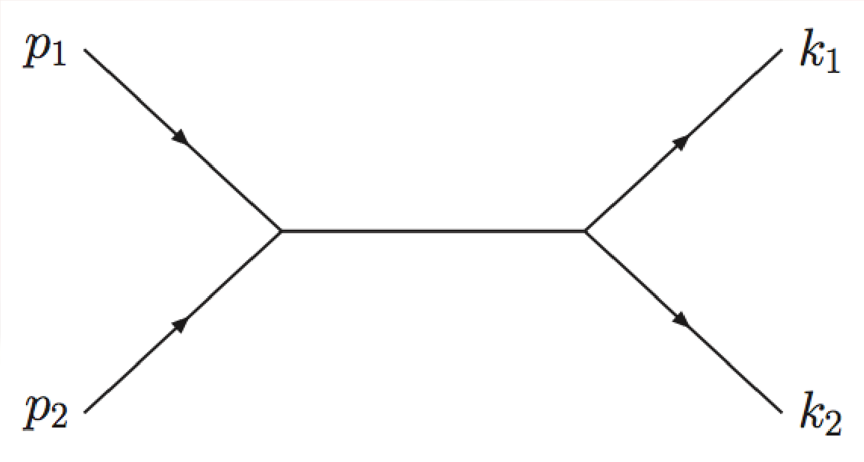
$$W(Q,b) = e^{-\int_{1/b}^{Q} \frac{d\mu}{\mu}\left(\ln\frac{Q}{\mu}A+B\right)} C \otimes f_1 C \otimes f_2$$

  - A,B,C functions are perturbative calculable
  - f_1,f_2 are integrated PDFs

(Collins-Soper-Sterman 85)

Dijet (Leading Double Logs-A)

- Power counting: each incoming parton contributes to a half of the associated color factor



$A^{(1)}=(C_{p1}+C_{p2})/2$

Banfi-Dasgupta-Delenda, PLB 2008
Mueller-Xiao-Yuan, PRD 2013

Next-to-leading Logs (NLL)

- Jet size-dependence (Banfi-Dasgupta 2004)
- Matrix form (Kidonakis-Sterman 1997)

$$x_1\, f_a(x_1, \mu = b_0/b_\perp) x_2\, f_b(x_2, \mu = b_0/b_\perp) e^{-S_{\rm Sud}(Q^2, b_\perp)}$$

$$\mathrm{Tr}\left[\mathbf{H}_{ab\to cd} \exp[-\int_{b_0/b_\perp}^{Q} \frac{d\mu}{\mu} \gamma^{s\dagger}] \mathbf{S}_{ab\to cd} \exp[-\int_{b_0/b_\perp}^{Q} \frac{d\mu}{\mu} \gamma^{s}]\right]$$

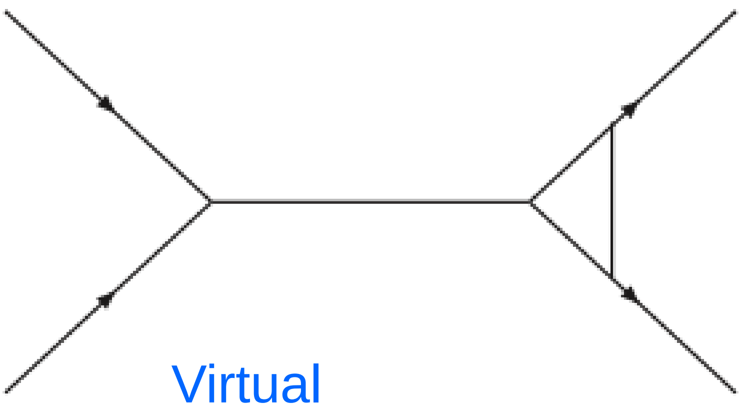
Sun,C.-P. Yuan, F. Yuan, PRL 2014

$$S_{\rm Sud}(Q^2, b_\perp) = \int_{b_0^2/b_\perp^2}^{Q^2} \frac{d\mu^2}{\mu^2} \left[\ln\left(\frac{Q^2}{\mu^2}\right) A + B + D_1 \ln \frac{Q^2}{P_T^2 R_1^2} + D_2 \ln \frac{Q^2}{P_T^2 R_2^2}\right]$$

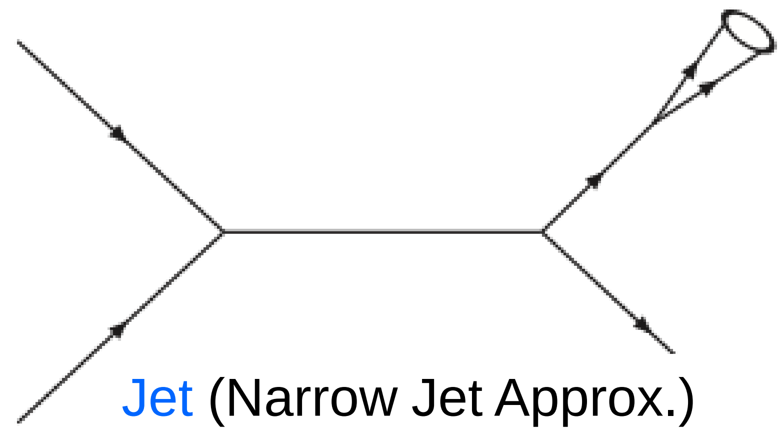
D: color-factor for the jet

R: jet size

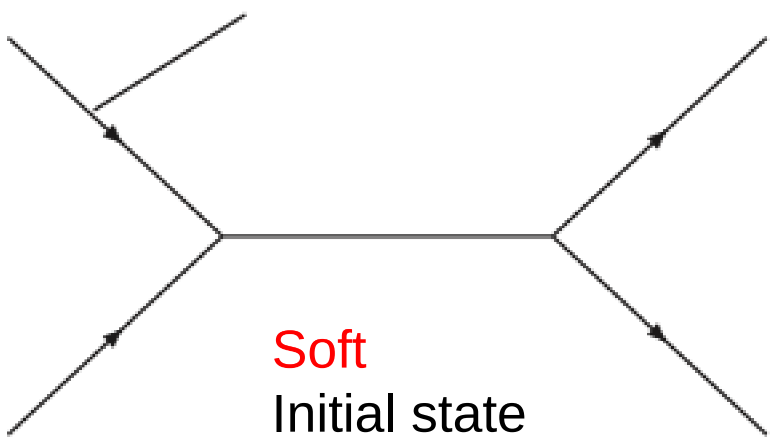
Soft and collinear gluon at one-loop



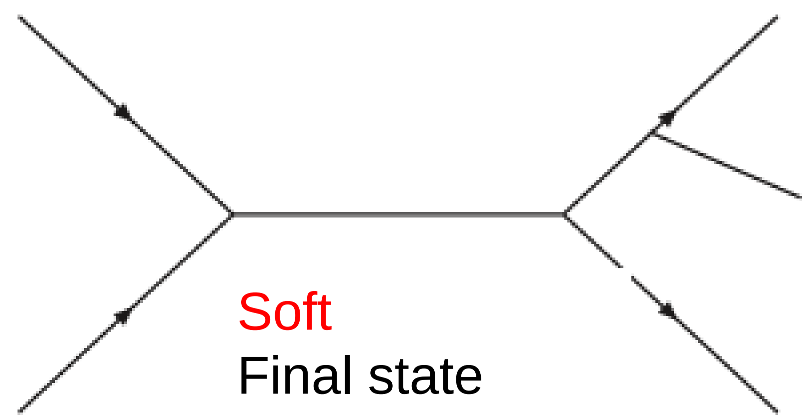
Virtual
Ellis-Sexton 86



Jet (Narrow Jet Approx.)
Jager-Stratmann-Vogelsang 2004



Soft
Initial state



Soft
Final state
(out of jet cone)

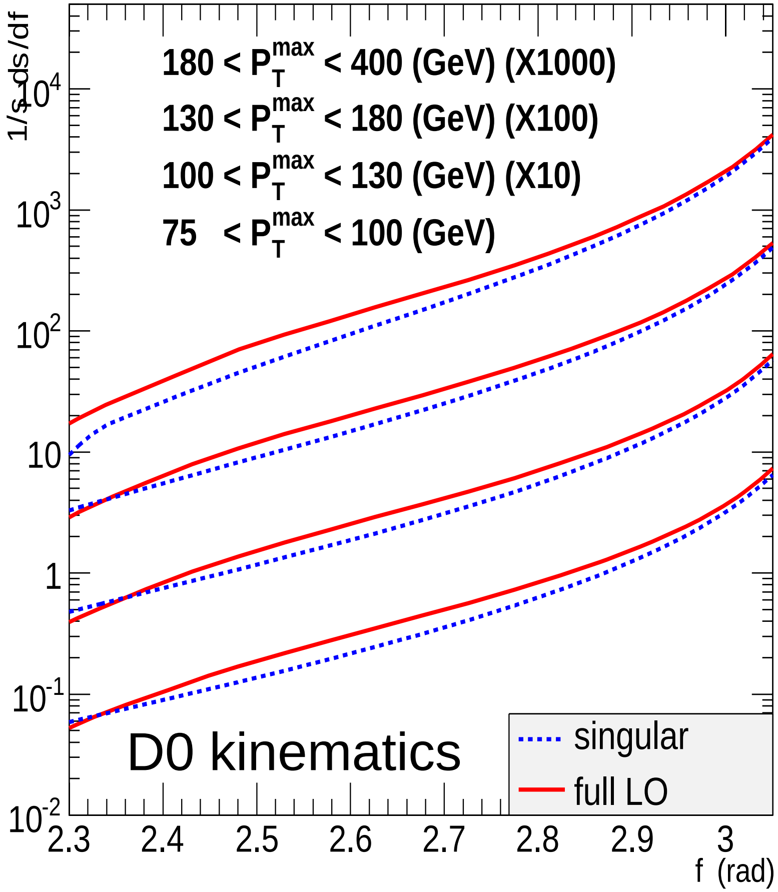
Cross checks

- Divergences cancelled out between virtual, jet, sot contributions (dimension regulation applied)
- Final results :double logs, single logs, ..

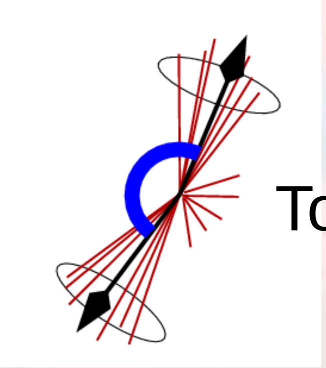
$$W^{(1)}(b_\perp)|_{logs.} = \frac{\alpha_s}{2\pi}\left\{h^{(0)}_{q_iq_j\to q_iq_j}\left[-\ln\left(\frac{\mu^2 b_\perp^2}{b_0^2}\right)(\mathcal{P}_{qq}(\xi)\delta(1-\xi')+\mathcal{P}_{qq}(\xi')\delta(1-\xi))-\delta(1-\xi)\right.\right.$$
$$\left.\times\delta(1-\xi')\left(C_F\ln^2\left(\frac{Q^2b_\perp^2}{b_0^2}\right)+\ln\left(\frac{Q^2b_\perp^2}{b_0^2}\right)\left(-3C_F+C_F\ln\frac{1}{R_1^2}+C_F\ln\frac{1}{R_2^2}\right)\right)\right]$$
$$\left.-\delta(1-\xi)\delta(1-\xi')\ln\left(\frac{Q^2b_\perp^2}{b_0^2}\right)\Gamma^{(qq')}_{sn}\right\}\,, \qquad (71)$$

Quark channel: $q_iq_j \to q_iq_j$

Compared to full calculations



$$\frac{\alpha_s}{2\pi^2}\frac{1}{q_\perp^2}\sum_{ab,a'b'}\sigma_0\int\frac{dx_1'}{x_1'}\frac{dx_2'}{x_2'}x_1' f_a(x_1',\mu)x_2' f_b(x_2',\mu)$$
$$\times\Big\{h^{(0)}_{a'b'\to cd}\,[\xi_1\mathcal{P}_{a'/a}(\xi_1)\delta(1-\xi_2)+\xi_2\mathcal{P}_{b'/b}(\xi_2)\delta(1-\xi_1)$$
$$+\delta(1-\xi_1)\delta(1-\xi_2)\delta_{aa'}\delta_{bb'}\left((C_a+C_b)\ln\frac{Q^2}{q_\perp^2}+C_c\ln\frac{1}{R_1^2}+C_d\ln\frac{1}{R_2^2}\right)]$$
$$+\delta(1-\xi_1)\delta(1-\xi_2)\delta_{aa'}\delta_{bb'}\Gamma^{ab\to cd}_{sn}\Big\}\ , \qquad (10$$

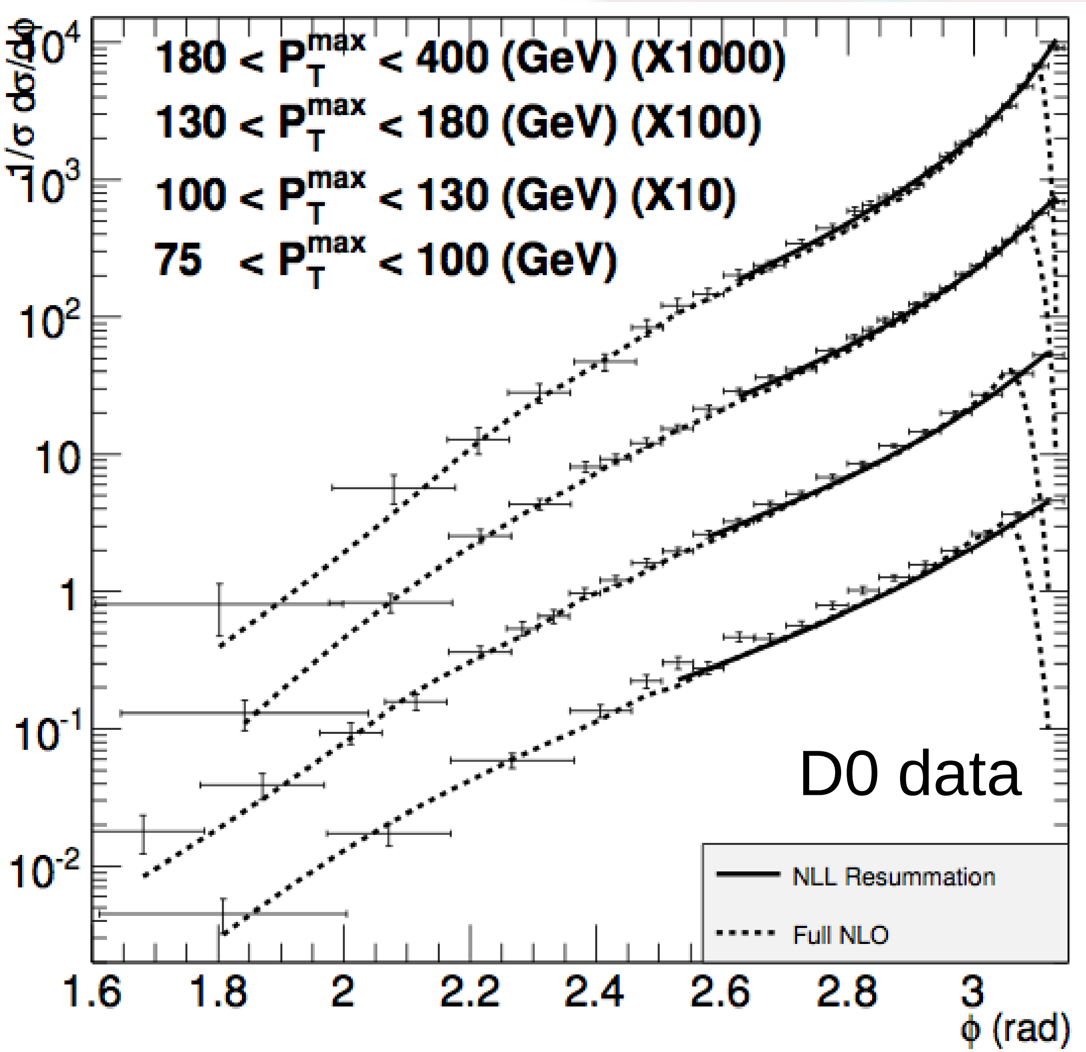


Leading P_T

Total $q_T \approx P_T \mathrm{Sin}(\Delta\phi)$

full LO: Nagy 2002, NLOJET++

Compared to the data

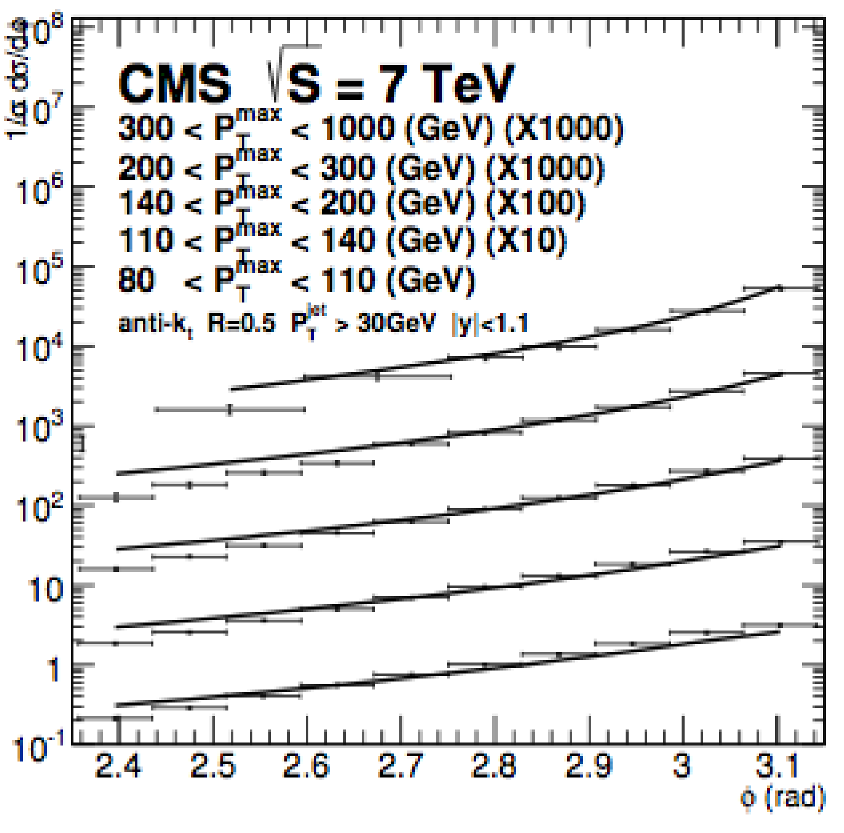


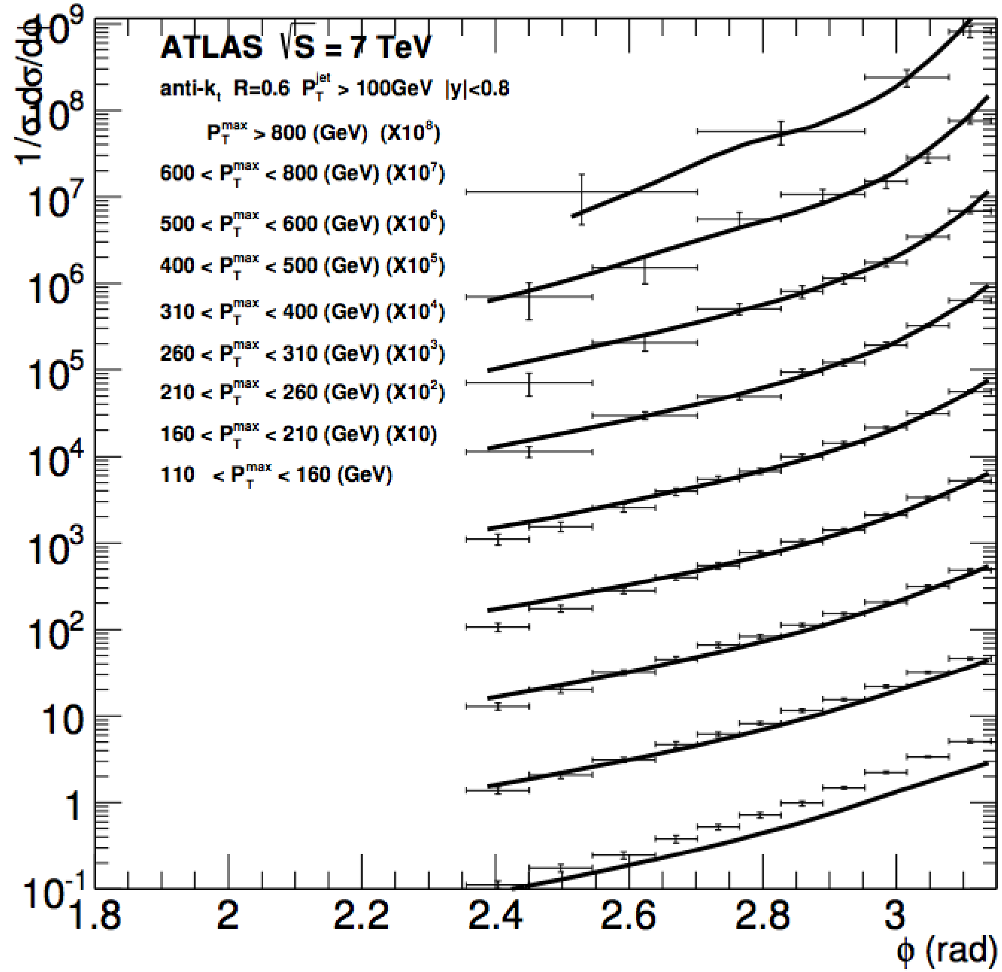
NLL Resummation:
Sun,C.P.Yuan, F.Yuan, PRL2014

$$x_1 f_a(x_1, \mu = b_0/b_\perp) x_2 f_b(x_2, \mu = b_0/b_\perp) e^{-S_{\mathrm{Sud}}(Q^2, b_\perp)}$$
$$\mathrm{Tr}\left[\mathbf{H}_{ab\to cd} \exp[-\int_{b_0/b_\perp}^{Q} \frac{d\mu}{\mu} \gamma^{s\dagger}] \mathbf{S}_{ab\to cd} \exp[-\int_{b_0/b_\perp}^{Q} \frac{d\mu}{\mu} \gamma^{s}]\right]$$

Full NLO: Nagy 2002, NLOJET++

At the LHC


CMS $\sqrt{S}$ = 7 TeV
300 < P_T^{max} < 1000 (GeV) (X1000)
200 < P_T^{max} < 300 (GeV) (X1000)
140 < P_T^{max} < 200 (GeV) (X100)
110 < P_T^{max} < 140 (GeV) (X10)
80 < P_T^{max} < 110 (GeV)
anti-k_t R=0.5 P_T^{jet} > 30GeV |y|<1.1
$1/\sigma\, d\sigma/d\phi$
ϕ (rad)


ATLAS $\sqrt{S}$ = 7 TeV
anti-k_t R=0.6 P_T^{jet} > 100GeV |y|<0.8
P_T^{max} > 800 (GeV) (X10^8)
600 < P_T^{max} < 800 (GeV) (X10^7)
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210 < P_T^{max} < 260 (GeV) (X10^2)
160 < P_T^{max} < 210 (GeV) (X10)
110 < P_T^{max} < 160 (GeV)
$1/\sigma\, d\sigma/d\phi$
ϕ (rad)

Summary

- Soft gluon resummation for dijet correlation at the next-to-leading logarithmic order agrees well with the experimental data, which extend the kinematic reach of fixed order perturbative calculations
- Extending to EW boson plus jet production will be interesting to follow
  - Higgs+Jet, Sun, C.-P. Yuan, F. Yuan, 1409.4121