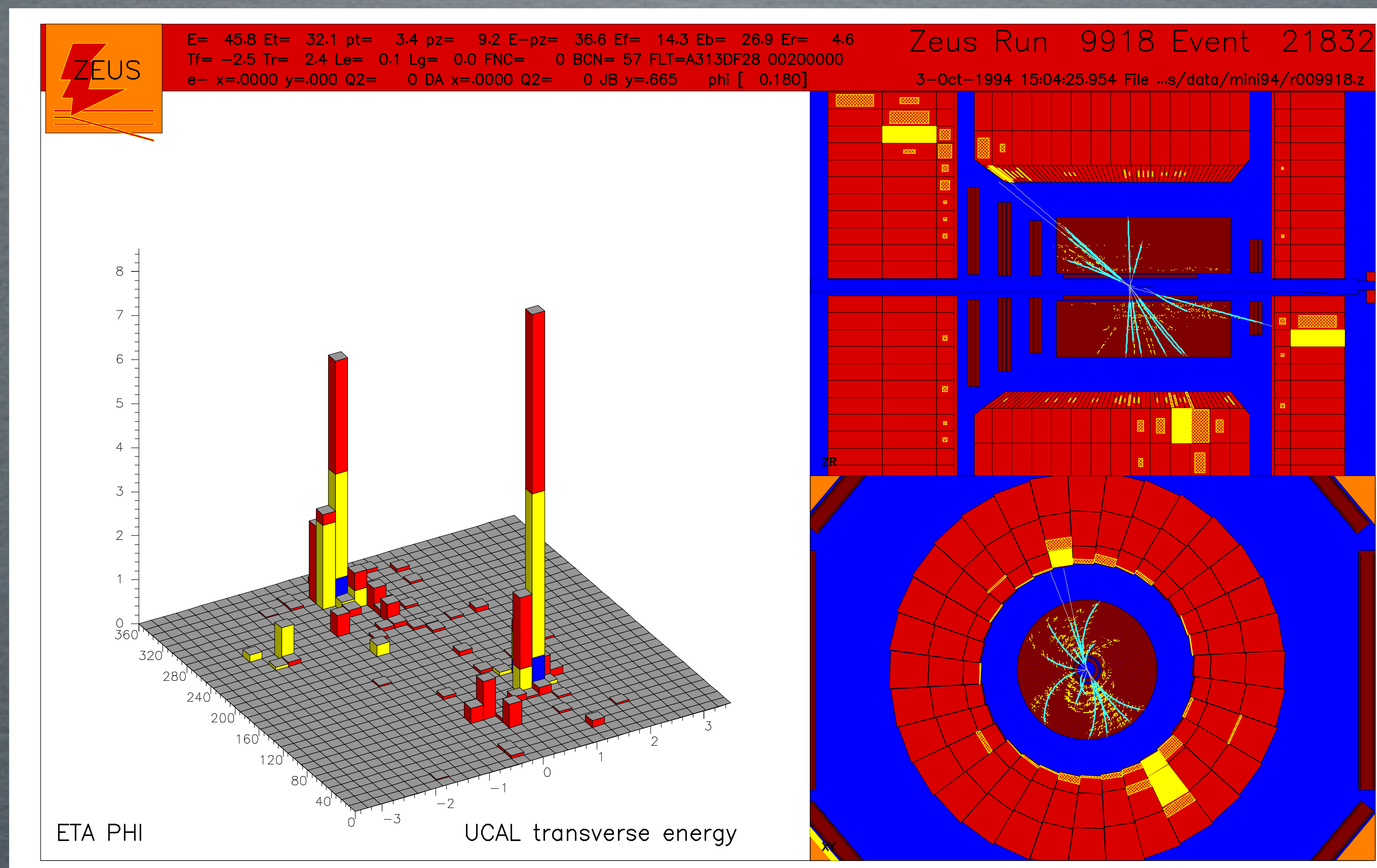
Azimuthal decorrelations between jets in QCD



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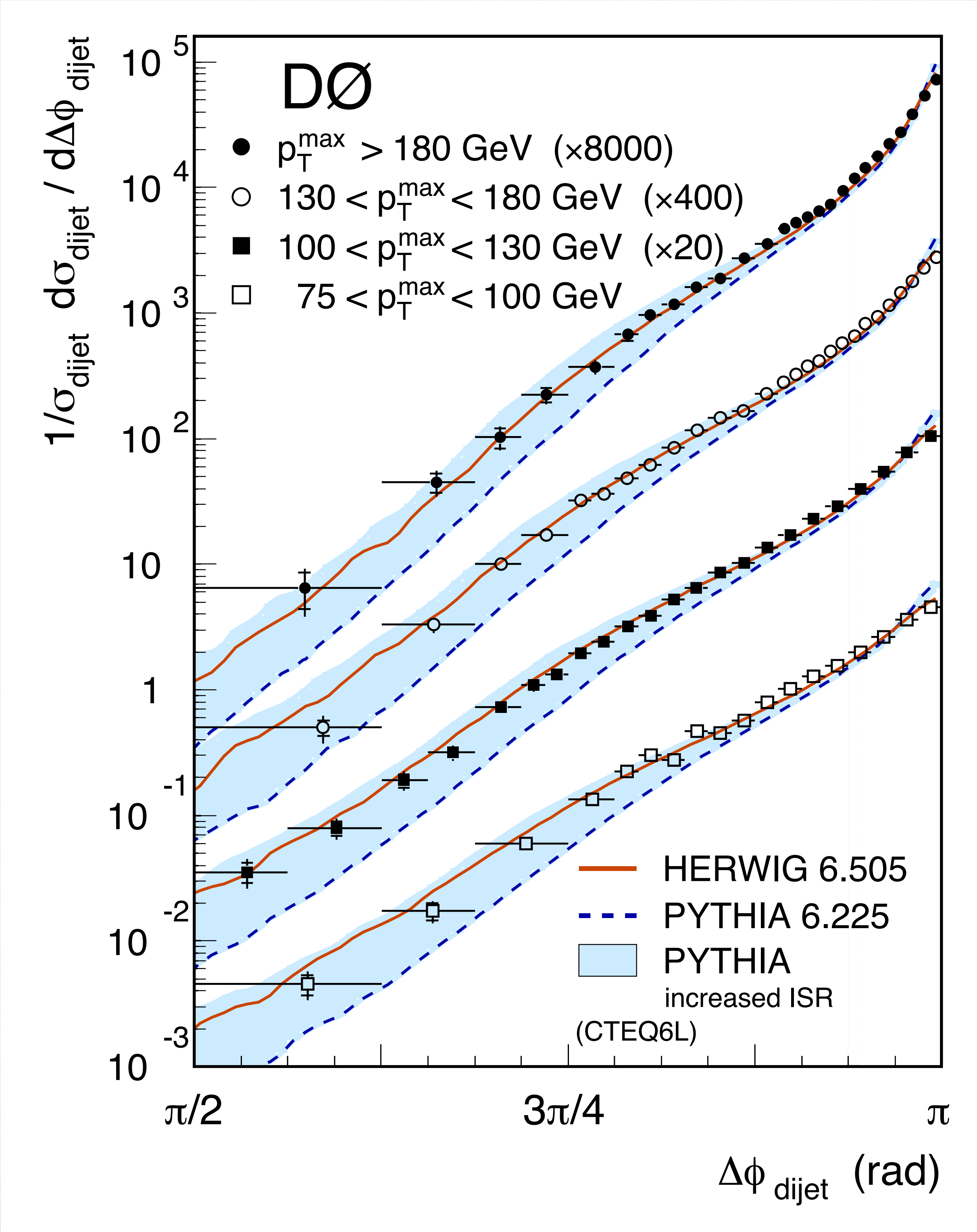
Outline

- Azimuthal decorrelations in QCD hard processes
- Dijets in the back-to-back region
- Phenomenology of azimuthal decorrelations in DIS
- Joining soft-collinear and BFKL resummation?

Azimuthal decorrelations

- Azimuthal decorrelations between jets are directly sensitive to QCD radiation
- Tuning of MC event generators (PYTHIA DW)



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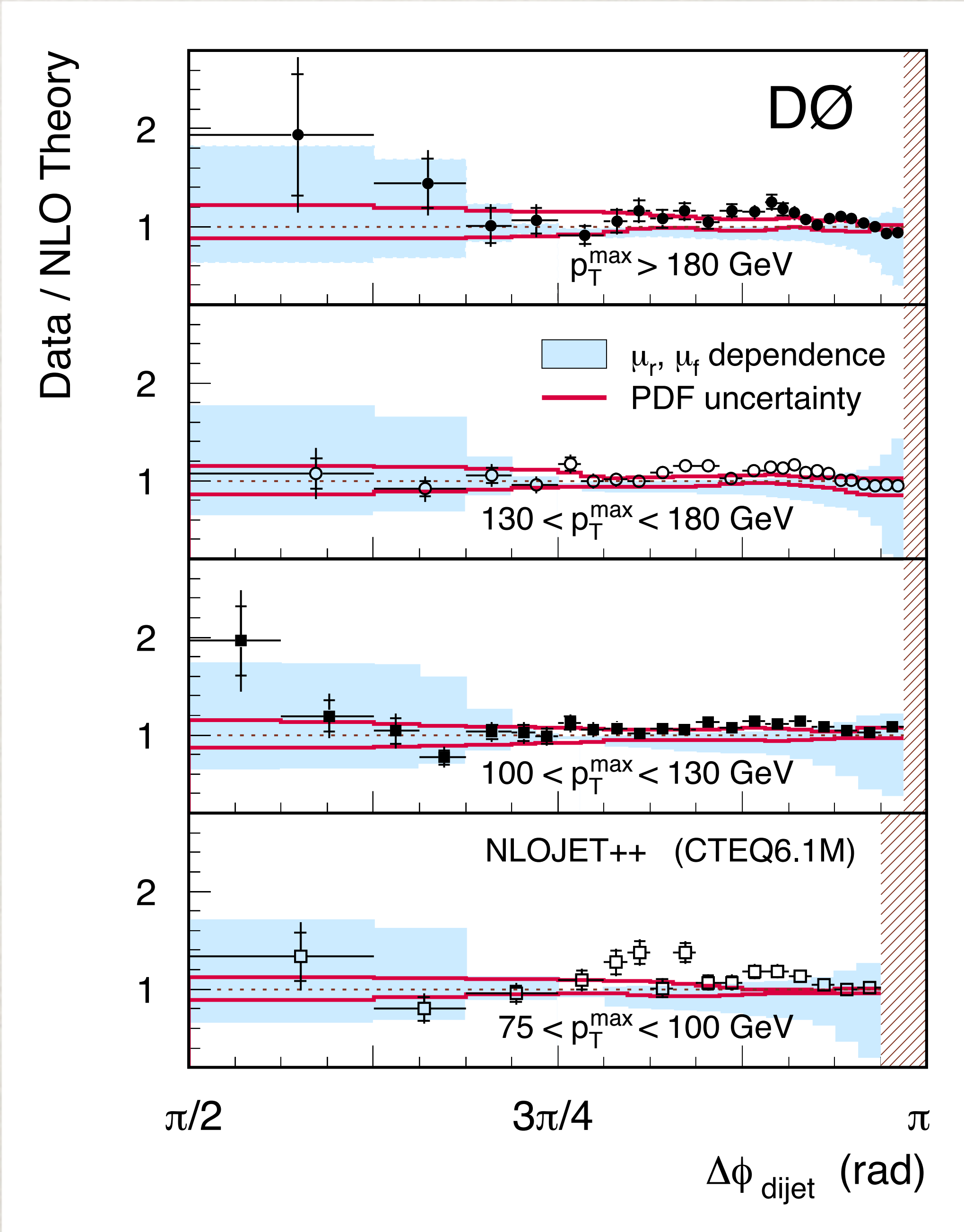

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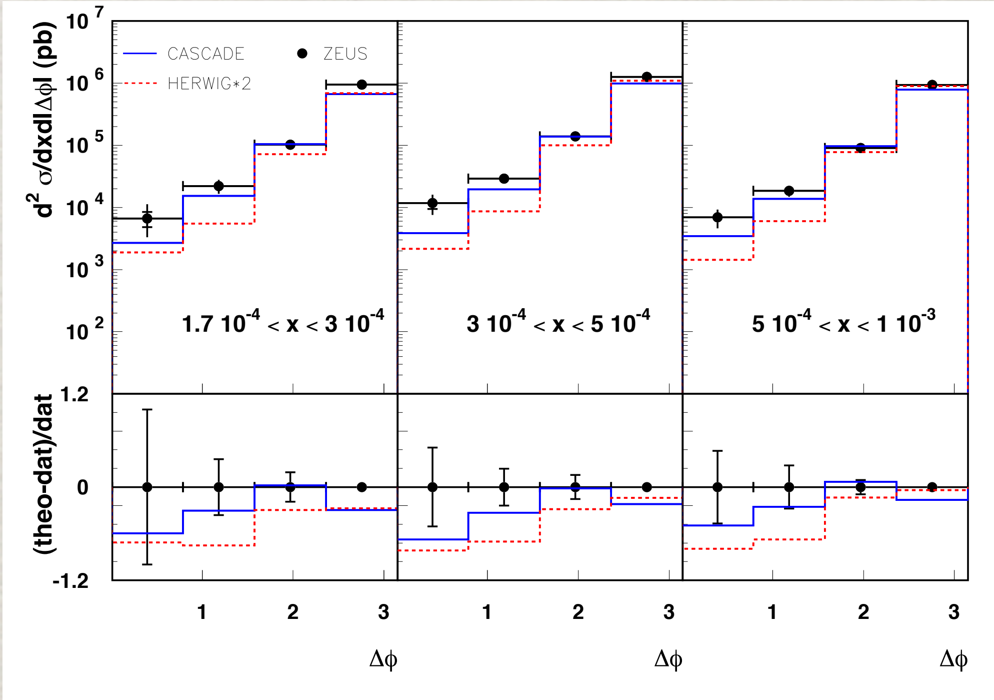
- Access to unexplored regimes of QCD (BFKL, unintegrated parton densities) [Hautmann Jung '08]



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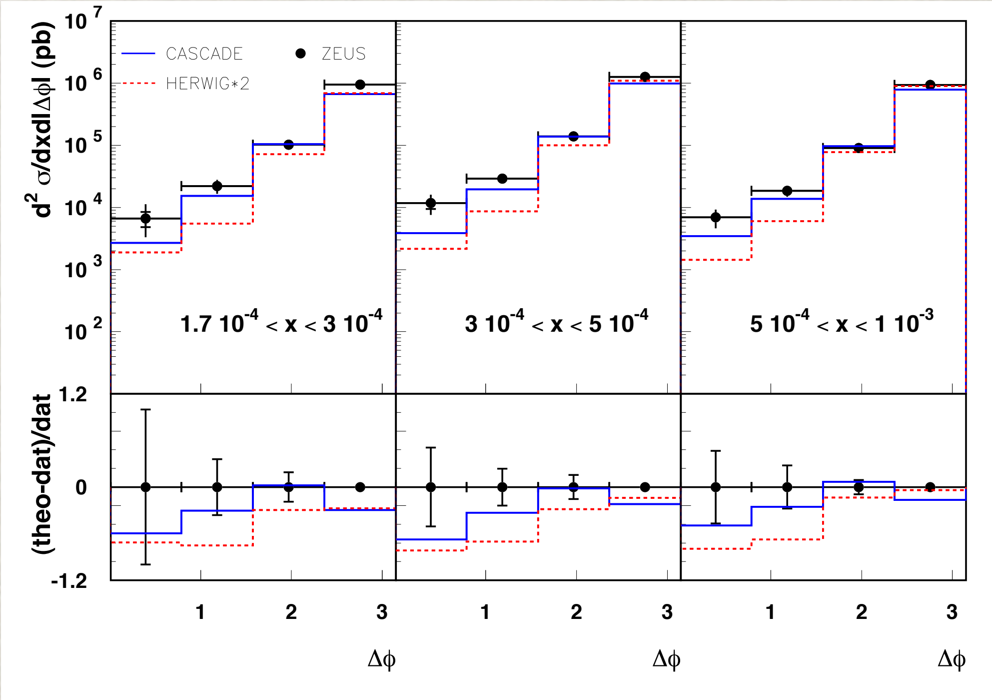
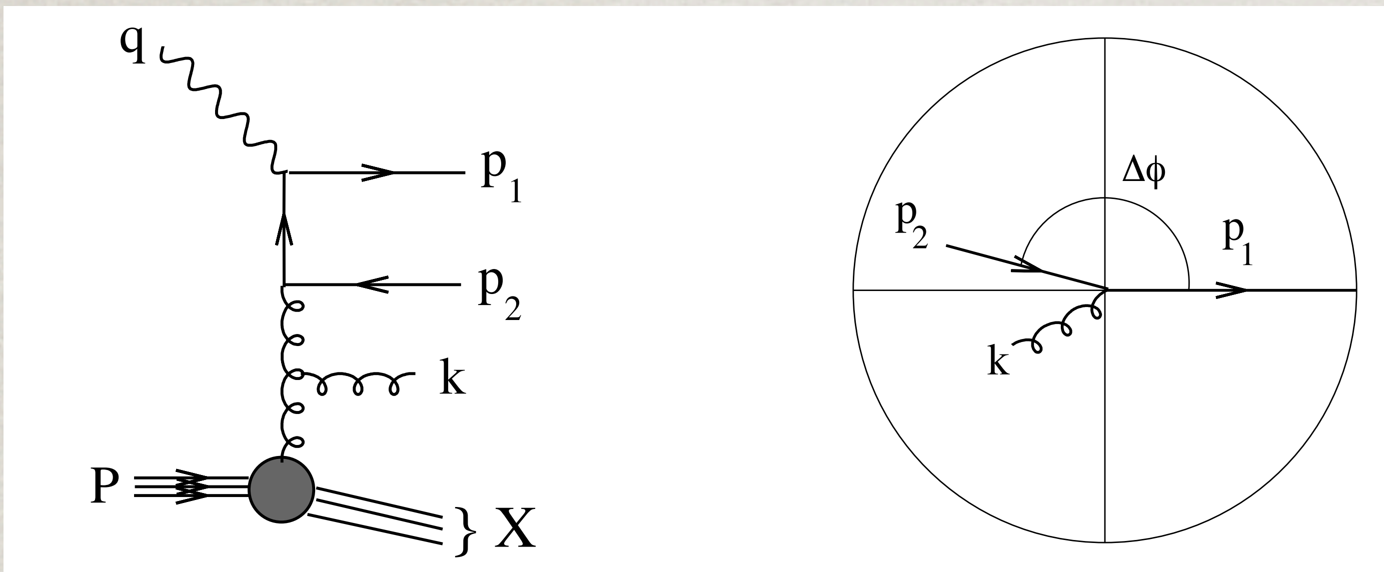


- The distribution in $\Delta\phi$ can gives an incredible amount of information on QCD dynamics

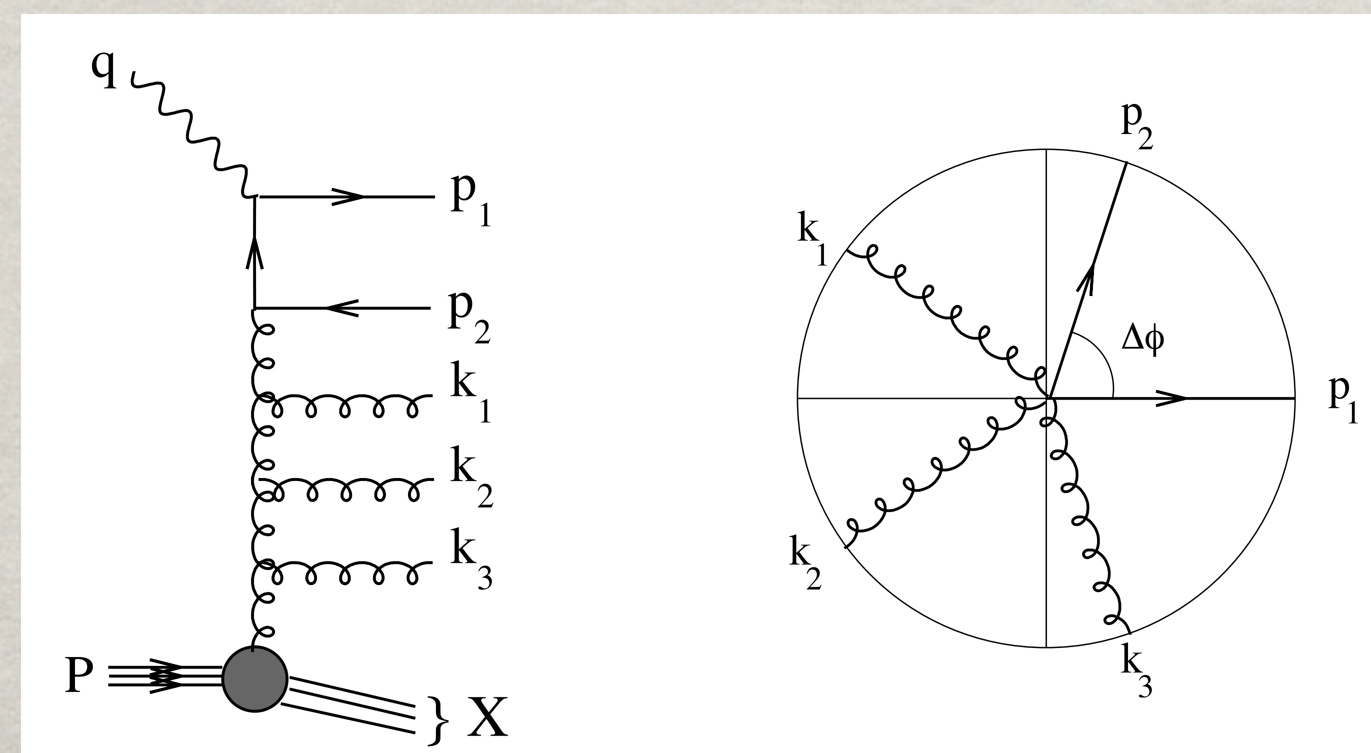
Dijets beyond LO

- Back-to-back region: multiple soft-collinear emissions



$$\Delta\phi \simeq \pi - \frac{|k_t \times p_{t1}|}{p_{t1}^2}$$

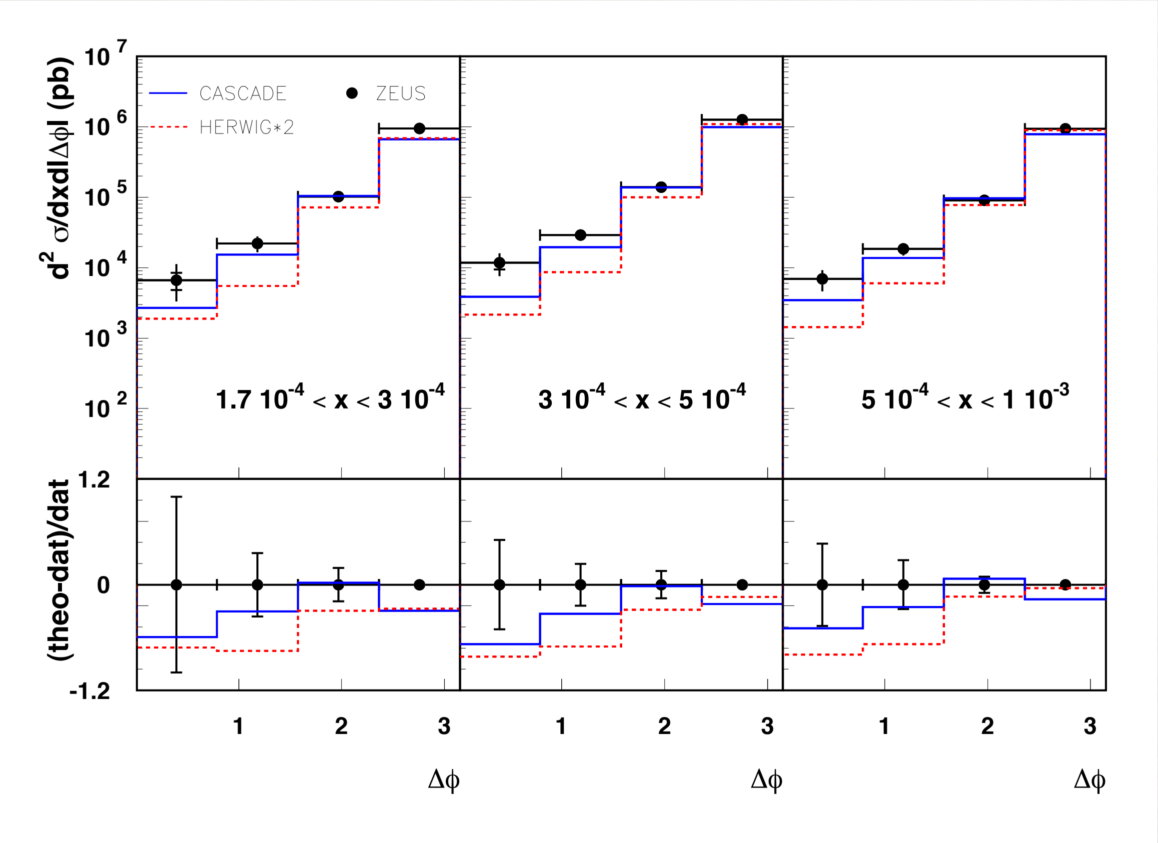
- Small-x regime: large phase space for multiple hard gluons

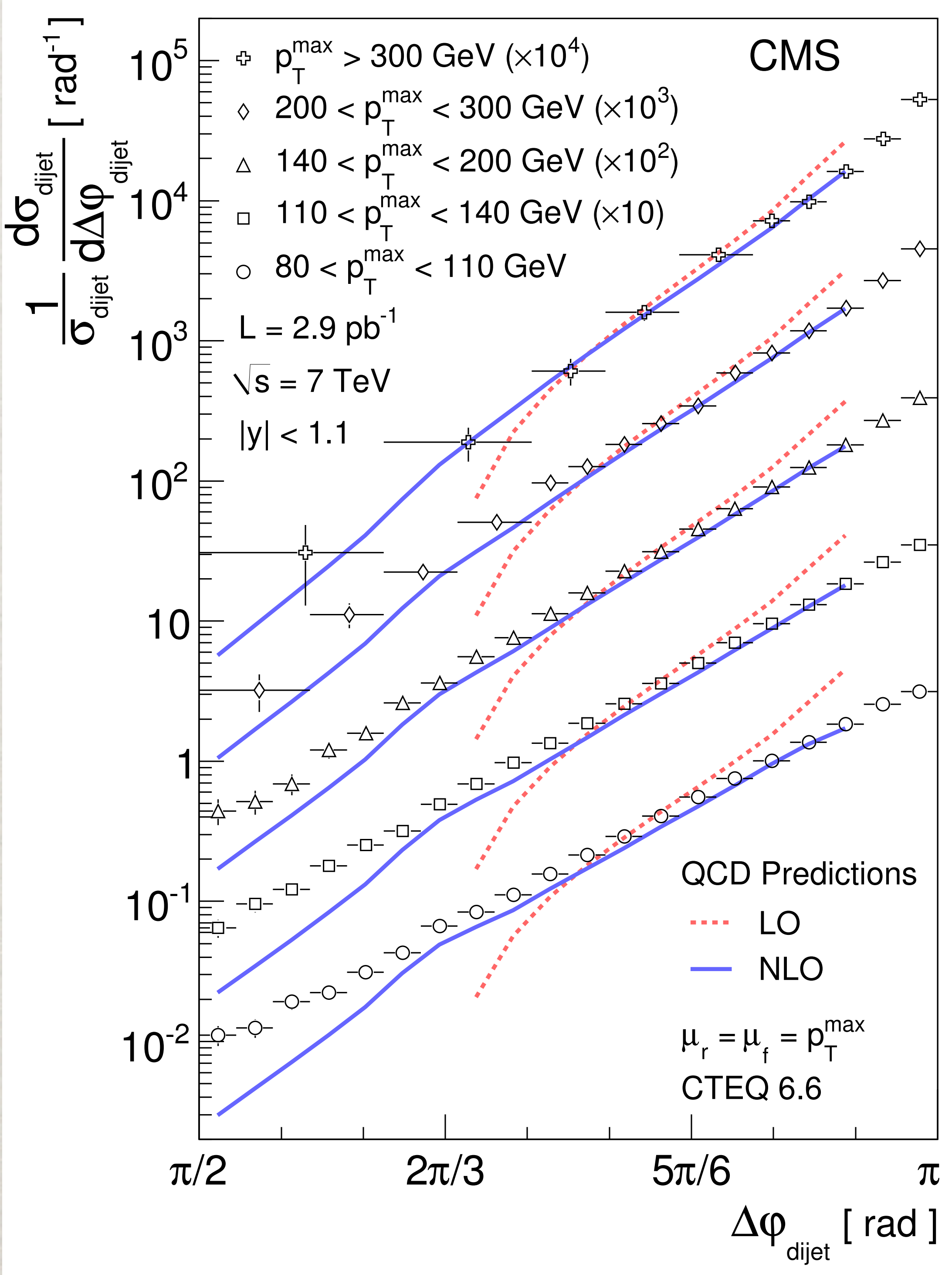


$$\Delta\phi \simeq \frac{2}{5}\pi \lesssim 1$$

Comparison theory vs data

- Fixed order QCD predictions fail both for small and large $\Delta\phi$
- Problems at large $\Delta\phi$ also for BFKL inspired approaches

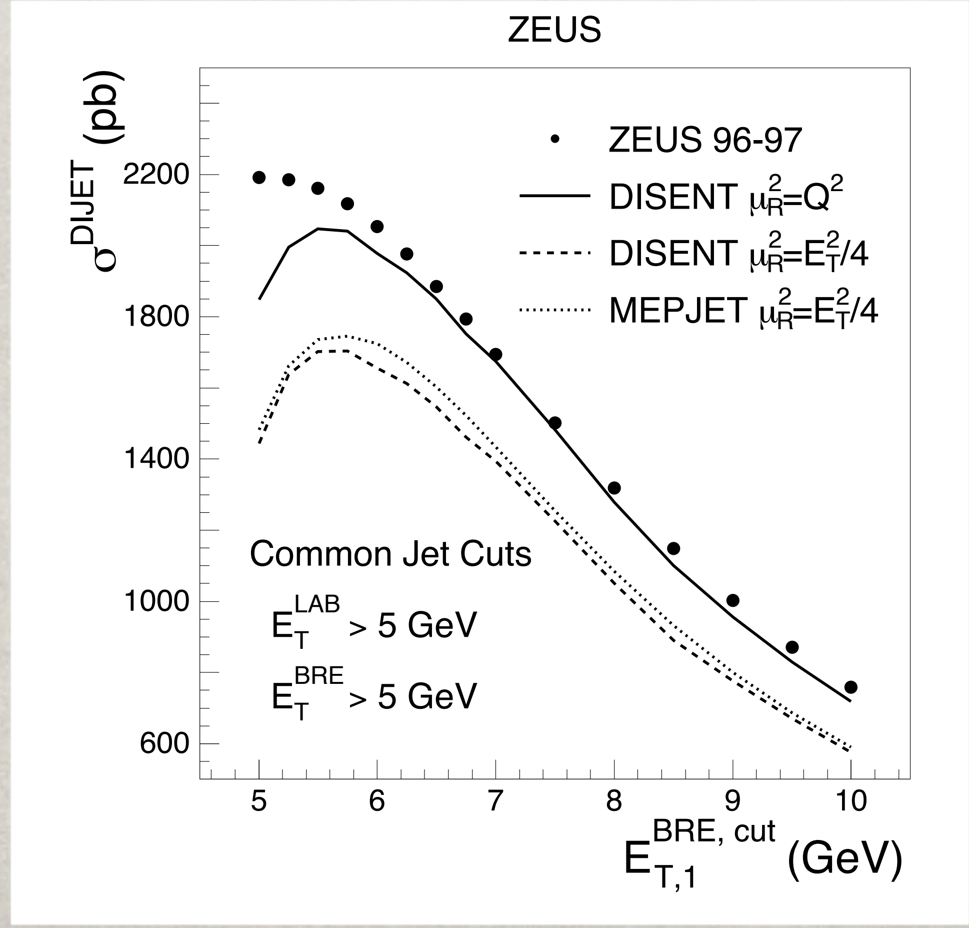


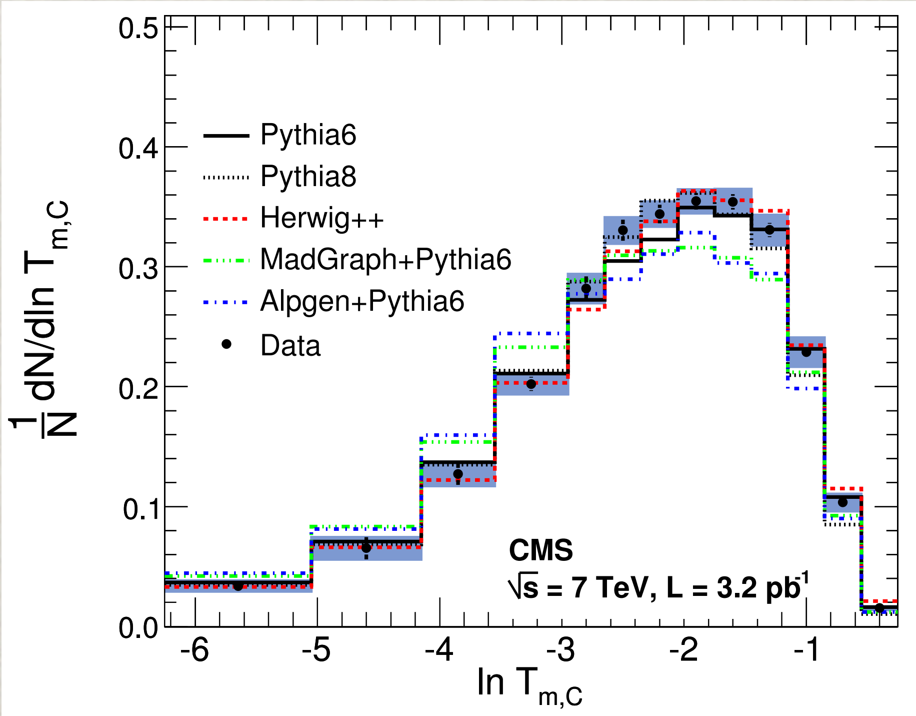


Neither NLO nor BFKL account for large $\ln(\pi - \Delta\phi)$ terms which dominate the distribution at $\Delta\phi \sim \pi$

IR sensitive jet observables

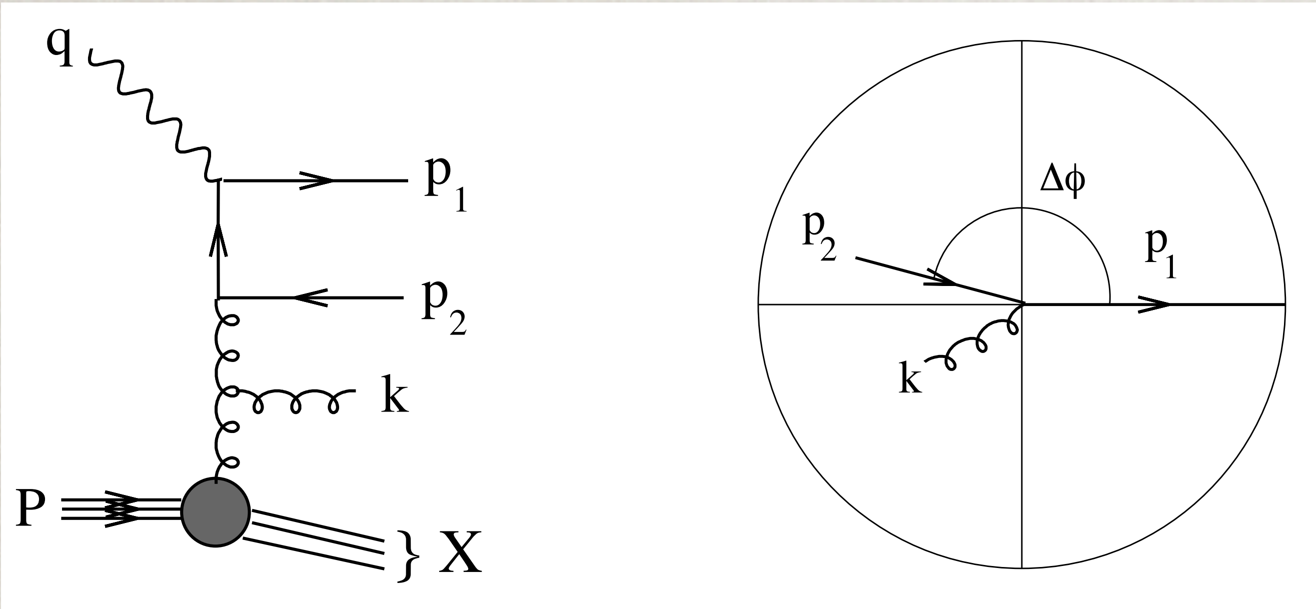
- The physics underlying azimuthal decorrelations at $\Delta\phi \sim \pi$ is present in many jet cross sections [AB Dasgupta '03]
  - dijet rates with symmetric E_t cuts
  - jet transverse energy imbalance $\Delta E_t = |E_{t1} - E_{t2}|$
  - event shape distributions with jets as inputs
  - jet cross sections developing an infrared sensitivity





Soft-collinear effects (I)

- Radiation outside the jets $\Leftrightarrow p_{\mathrm{jet},1} = p_1$ and $p_{\mathrm{jet},2} = p_2$



$$\Delta\phi \simeq \pi - \frac{k_t}{p_{t1}} |\sin\phi|$$

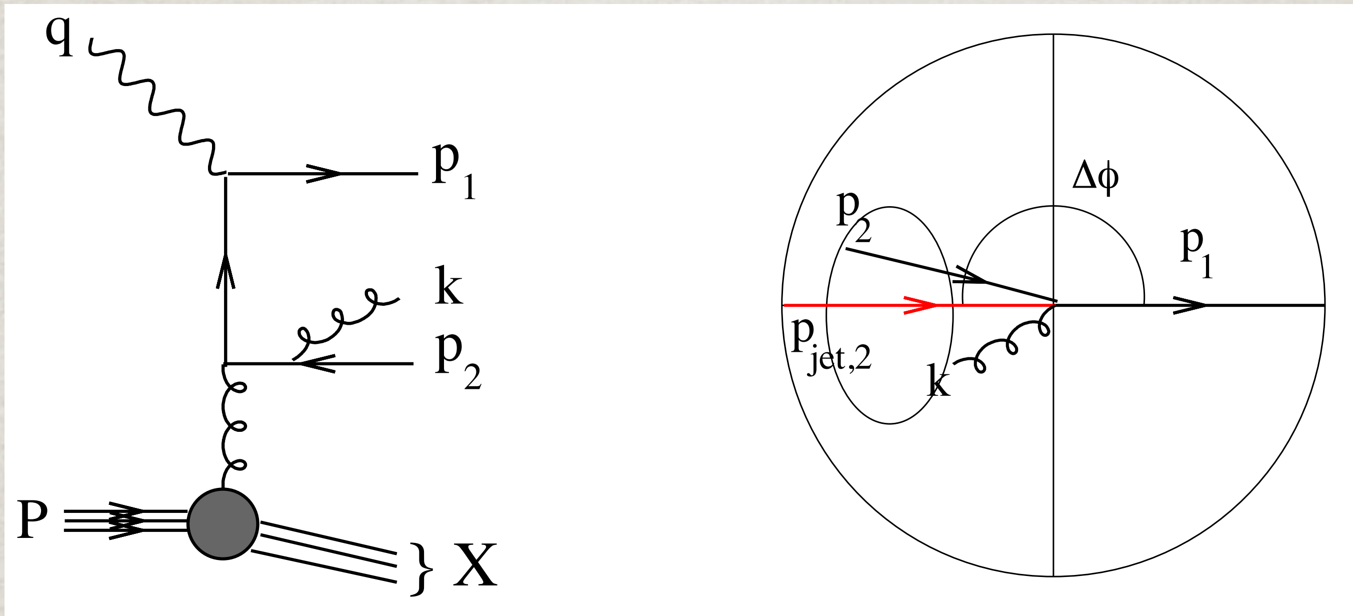
- Multiple gluon emissions collinear to the beam give

$$|\pi - \Delta\phi|_{\mathrm{in}} \simeq \frac{1}{p_{t,\mathrm{jet}}} \left| \sum_{i \notin \mathrm{jets}} k_{ti} \sin\phi_i \right|$$

- Same as ϕ^* in Drell-Yan $\Rightarrow$ first transverse momentum resummations involving coloured particles in final state

Soft-collinear effects (II)

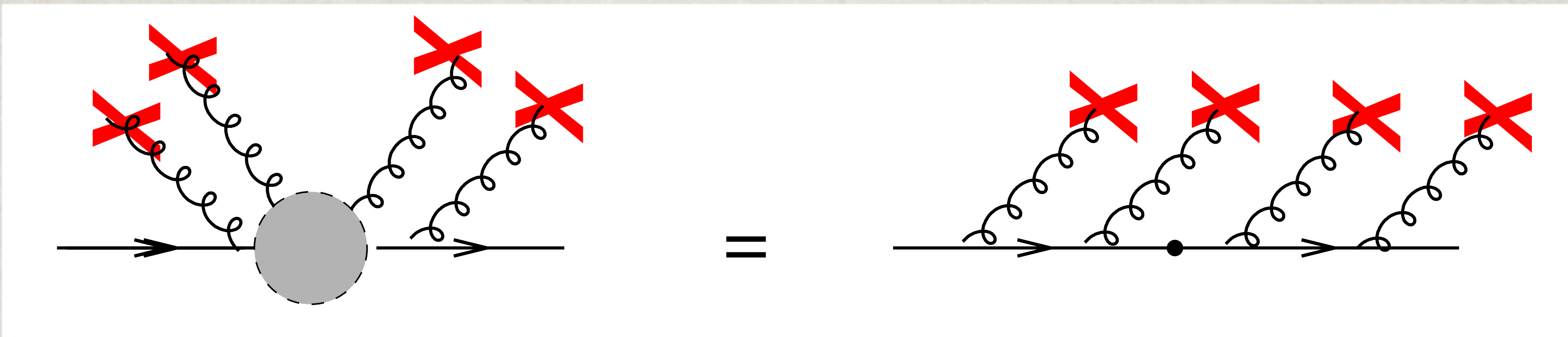
- Radiation inside one jet $\Leftrightarrow p_{\mathrm{jet},1} = p_1$ but $p_{\mathrm{jet},2} \neq p_2$



- If one uses a vectorial recombination scheme $\vec{p}_{t,\mathrm{jet}} = \vec{p}_{t2} + \vec{k}_t$ the two jets remain back-to-back, i.e. $\Delta\phi = \pi$
- Azimuthal decorrelation is insensitive to radiation inside the jets, i.e. it is a non-global observable
- What is so special about non-global observables?

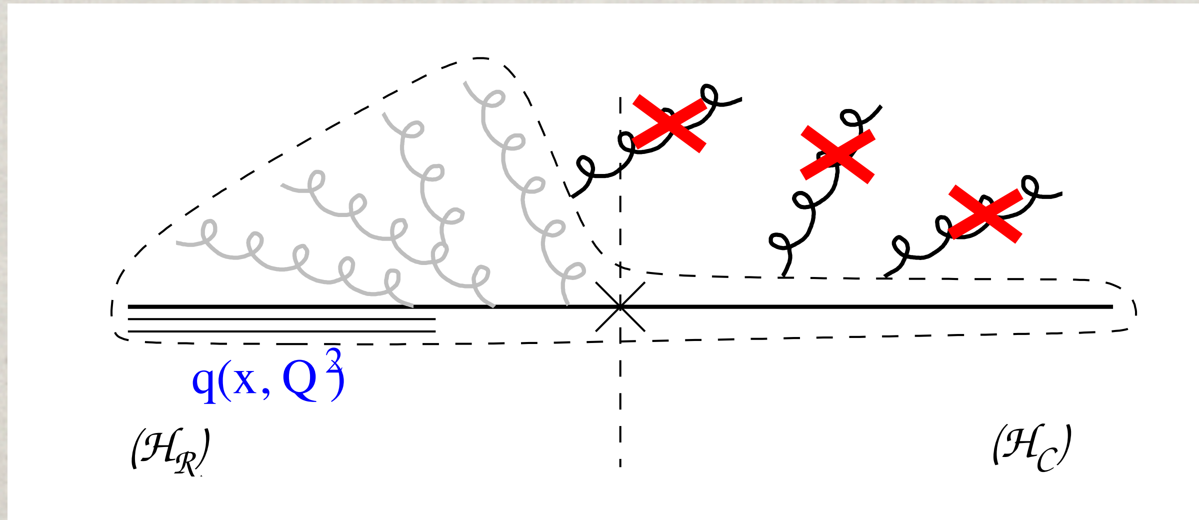
Non-global logarithms

- Soft-collinear resummations heavily rely on independent emission approximation for QCD radiation



- This picture breaks down for non-global observables

[Dasgupta Salam '01]

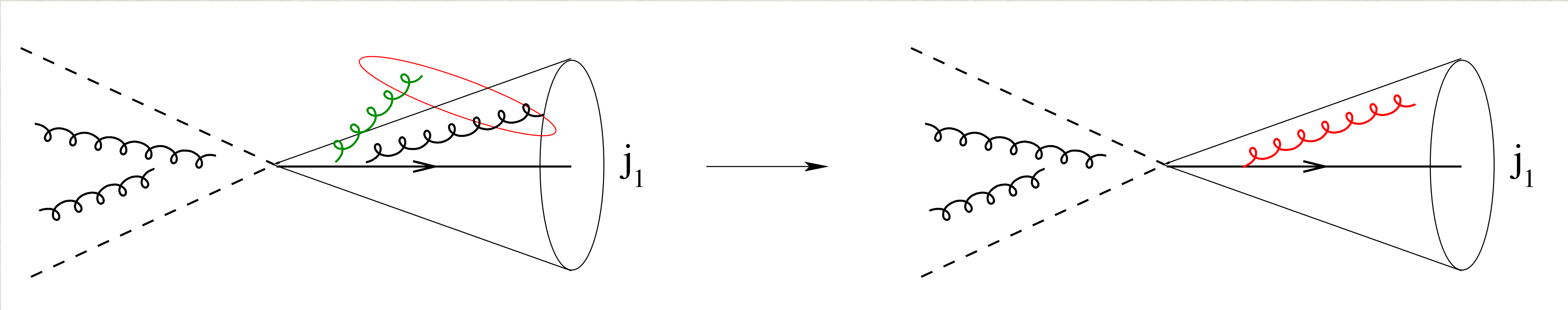


- New soft large-angle contributions arise when harder gluons emit a softer gluon in the observed region

Non-global logs in jets

- All observables involving jets are in principle affected by non-global logarithms [AB Dasgupta '03]

- Non-global logarithms depend on the jet algorithm and on the recombination scheme (maximal for anti-kt and reduced for clustering algorithms) [Appleby Seymour '02]



- For clustering algorithms there are further clustering logarithms that spoil independent emission as well! [AB Dasgupta '05]

Who's afraid of NG logs?

Who's afraid of NG logs?

- Non-global logs are soft large-angle non-abelian contributions resummed by solving a non-linear equation

  [Dasgupta Salam '01]
  [AB Marchesini Smye '02]

- Dynamics of NG logs is understood both in the context of interjet energy flow and of jet cross sections (e.g. dependence on jet algorithm and jet radius)

  [Dasgupta Salam '02]
  [AB Dasgupta Khelifa-Kerfa Marzani '10]

- Clustering logarithms can be computed numerically and analytically estimated as a power series in the jet radius

  [AB Dasgupta '05]
  [Delenda Appleby AB Dasgupta '06]

- NG and clustering logs have a small impact on transverse momentum resummations

  [AB Dasgupta '03]

Global is better

- Non-global jet cross sections have various drawbacks
  - Resummation of NG logs can only be performed in the large N_c limit

    [Dasgupta Salam '01]
    [AB Marchesini Smye '02]

  - Predictions for non-global observables depend heavily on the details of the observation region (jet algorithm, recombination scheme, jet radius, etc.)

    [Dasgupta Salam '02]
    [AB Dasgupta Khelifa-Kerfa Marzani '10]

- Global observables are not sensitive to the details of the interjet region, except from universal soft anomalous dimensions, a.k.a. the fifth form factor

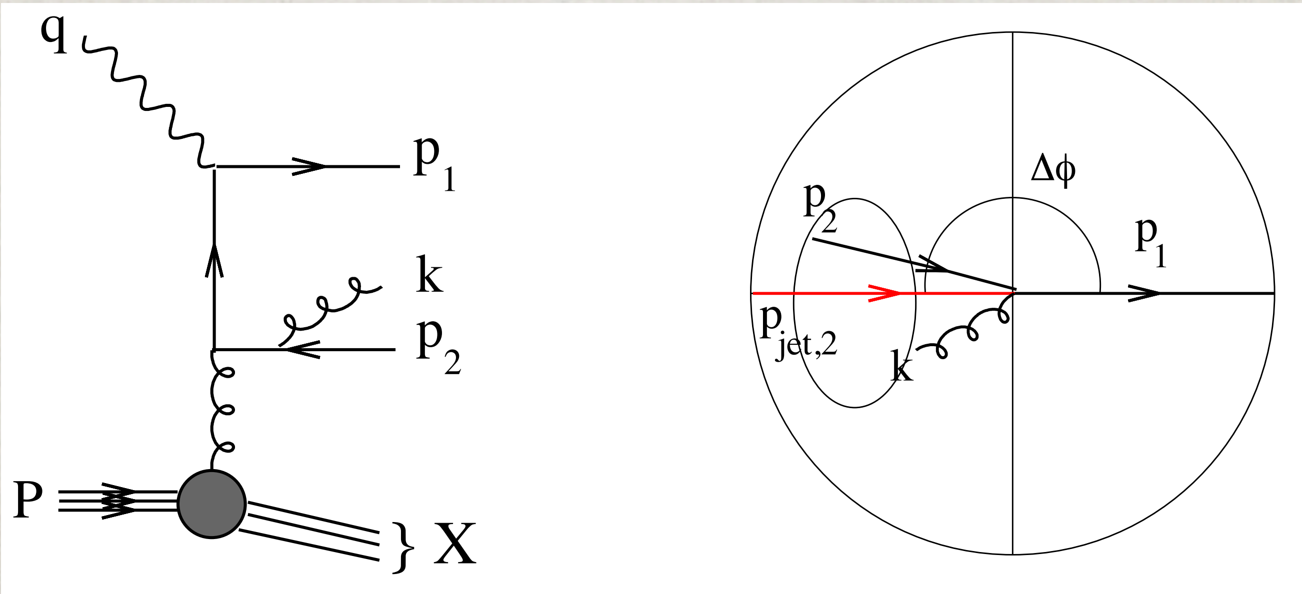
  [Kidonakis Oderda Sterman '98]
  [AB Salam Zanderighi '05]
  [Dokshitzer Marchesini '06]

- Is it possible to devise global dijet cross sections?

Pt recombination scheme

- Sensitivity to radiation inside the jets with the p_t weighted recombination scheme ⇒ global observable!

[AB Dasgupta '08]



$$\phi_{\mathrm{jet},2} = \frac{p_{t2}\,\phi_2 + k_t\,\phi}{p_{t2}+k_t} \quad \Rightarrow \quad \Delta\phi = \pi - \frac{k_t}{p_{t1}}\left|\sin\phi - (\pi-\phi)\right|$$

- Novel kind of one-dimensional momentum cancellation

$$|\pi - \Delta\phi|_{\mathrm{out}} \simeq \frac{1}{p_{t,\mathrm{jet}}}\left|\sum_{i\in\mathrm{jets}} k_{ti}\sin^3\phi_i\right|$$

Soft gluon resummation

- Resummation of soft-collinear gluons is performed in b space with the same phylosophy as for ϕ^* in DY

$$\frac{1}{\sigma}\frac{d\sigma}{d\Delta} = \frac{2}{\pi}\int_0^\infty db \cos(b\Delta) \times \underbrace{\frac{f_1(\mu_F/\bar{b})}{f_1(\mu_F)}\frac{f_2(\mu_F/\bar{b})}{f_2(\mu_F)} e^{-R_{\rm in}(\bar{b})}}_{\rm initial\ state\ (DY-type)} \times$$

$$\times \underbrace{e^{-R_{\rm out}(\bar{b})}}_{\rm final\ state} \times \underbrace{\frac{{\rm Tr}[He^{-\Gamma^\dagger t(\bar{b})}Me^{-\Gamma t(\bar{b})}]}{{\rm Tr}[HM]}}_{\rm soft\ large-angle}$$

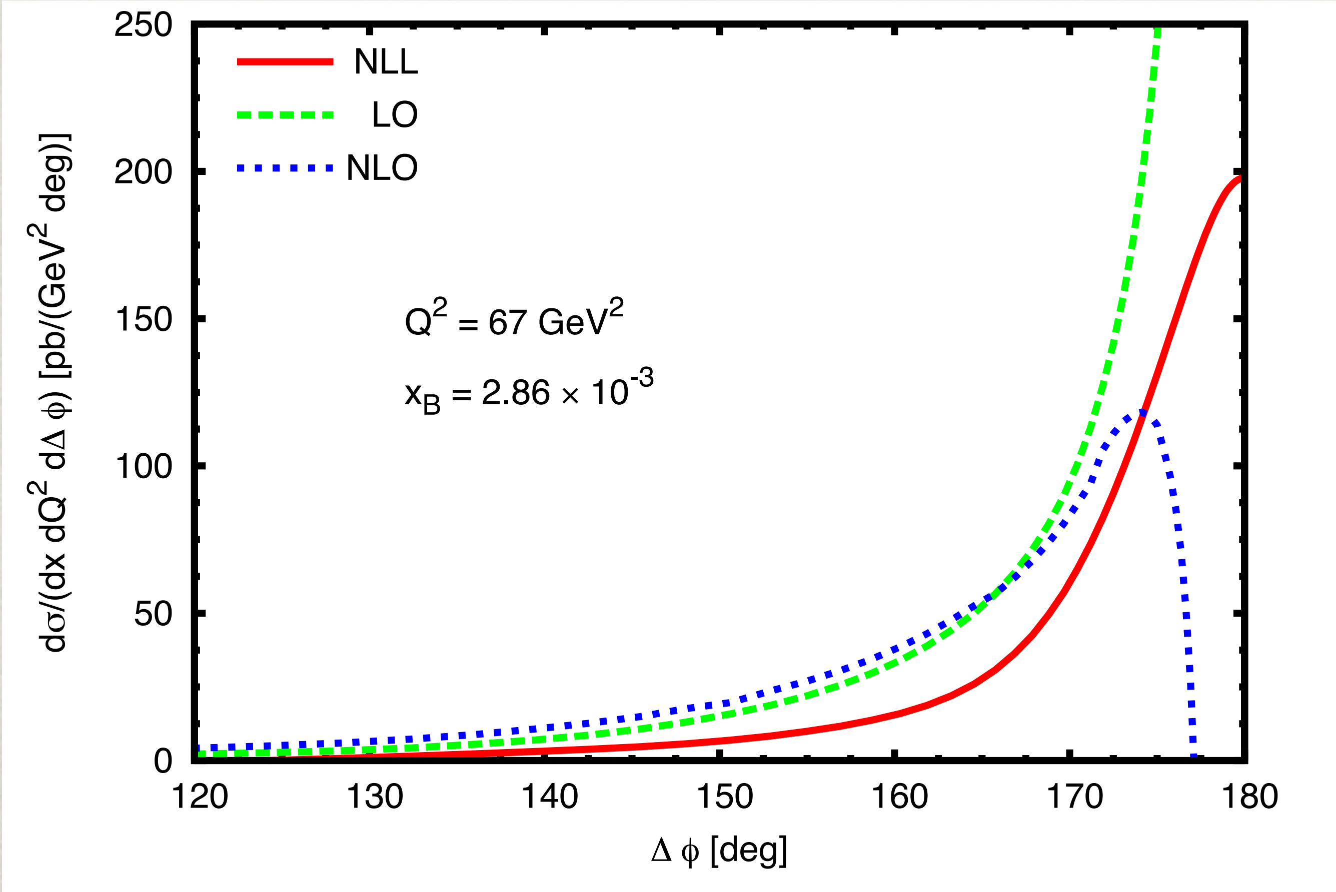
- Novel Sudakov exponent $R_{\rm out}(\bar{b})$ accounting for soft-collinear radiation inside the outgoing jets

$$R_{\rm out}(\bar{b}) = \sum_i C_i \int_0^Q \frac{dk_t}{k_t}\frac{2\alpha_s(k_t)}{\pi}\int_0^{\ln\frac{E_i}{k_t}} d\eta \times$$

$$\times\, \Theta\left[\frac{2}{3}\left(\frac{E_i}{p_t}\right)^2 \frac{k_t}{p_t} e^{-2\eta}|\sin\phi|^3 - \frac{1}{\bar{b}}\right] \simeq \frac{C_{\rm out}}{3}\frac{\alpha_s}{\pi}\ln^2\bar{b}$$

Dijet phenomenology in DIS

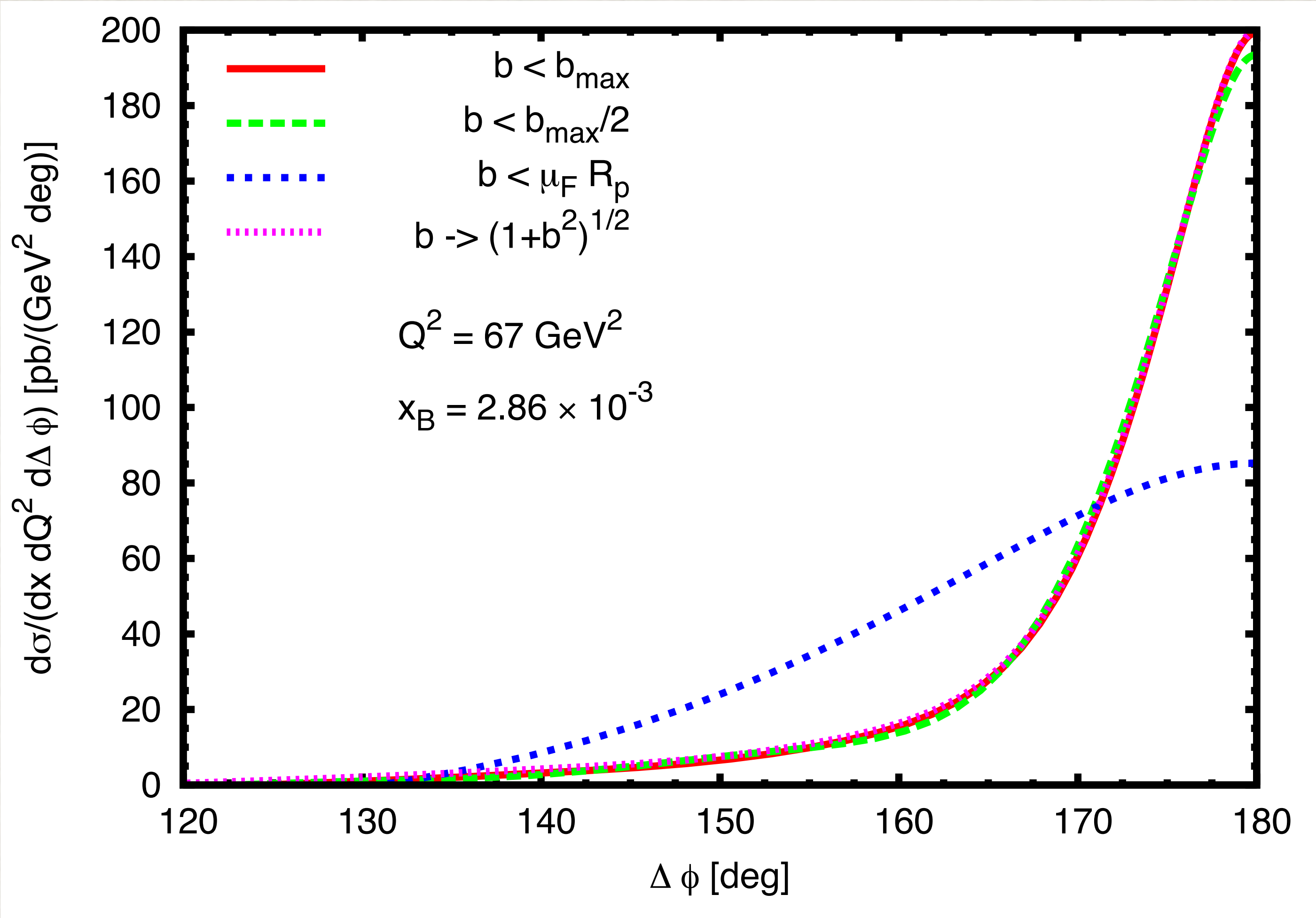
- Dijet events with $p_{t,\mathrm{jet}}^{\mathrm{HCM}} > 5\mathrm{GeV}$ and $-1 < \eta_{\mathrm{jet}}^{\mathrm{lab}} < 2.5$



- Both LO and NLO predictions diverge at $\Delta\phi \sim \pi$
- Resummation approaches a plateau for $\Delta\phi \sim \pi$, as expected for one-dimensional cancellations

Non-perturbative effects

- Size of non-perturbative effects $\Leftarrow$ change in prescriptions to perform the b integration

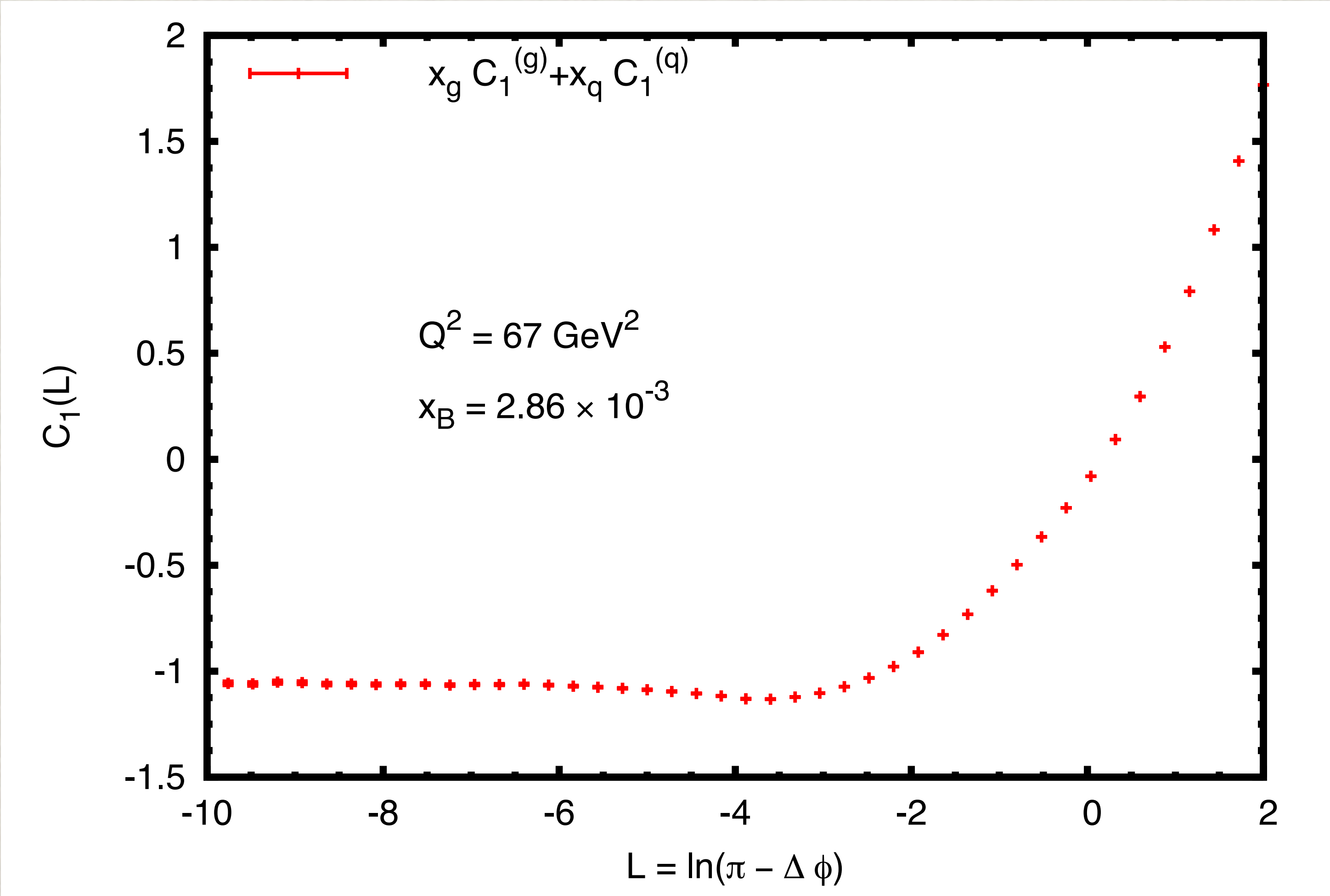


- Cutting off the b integral at a scale corresponding to the size of the proton gives a huge difference $\Rightarrow$ high sensitivity to intrinsic transverse momentum of the proton

Problems at small x

- The height of the plateau at $\Delta\phi \sim \pi$ is determined also by resummation coefficient constant

$$\Sigma(L) \sim (1 + C_1(L))\,\Sigma_{\rm res}(L) \qquad C_1(L) = \Sigma_1(L) - H_{12}L^2 - H_{11}L$$



- At the largest value of x_B the coefficient constant becomes larger than one ⇒ resummation of small-x effects in C_1?

Complementary approaches

- Summary of all-order resummation of azimuthal decorrelations at small and large $\Delta\phi$

Soft-collinear resummation

- Plateau (random walk) around $\Delta\phi = \pi$
- Hard emissions only at fixed order
- Described by shower MC at Tevatron (large x), not at HERA (small x)
- Analytical calculations at NLL+NLO

Small-x resummation

- Unintegrated parton distributions at $\Delta\phi = \pi$
- Multiple hard emissions via BFKL or CCFM
- Described at HERA by CASCADE, no results for hadron colliders yet
- No analytical control over MC accuracy

Conclusions

- Azimuthal dijet decorrelations are rich in information on QCD dynamics at soft and hard scales
- In the quasi back-to-back region it is possible to resum multiple soft-collinear enhancements $\Rightarrow$ first transverse momentum resummation with final-state coloured particles
- Sensitivity to intrinsic transverse momentum of the proton and to multiple hard gluon emissions (BFKL)
- Description of LHC data requires a joint effort from different QCD communities