Need for unintegrated parton correlation functions, not parton densities, in event generators

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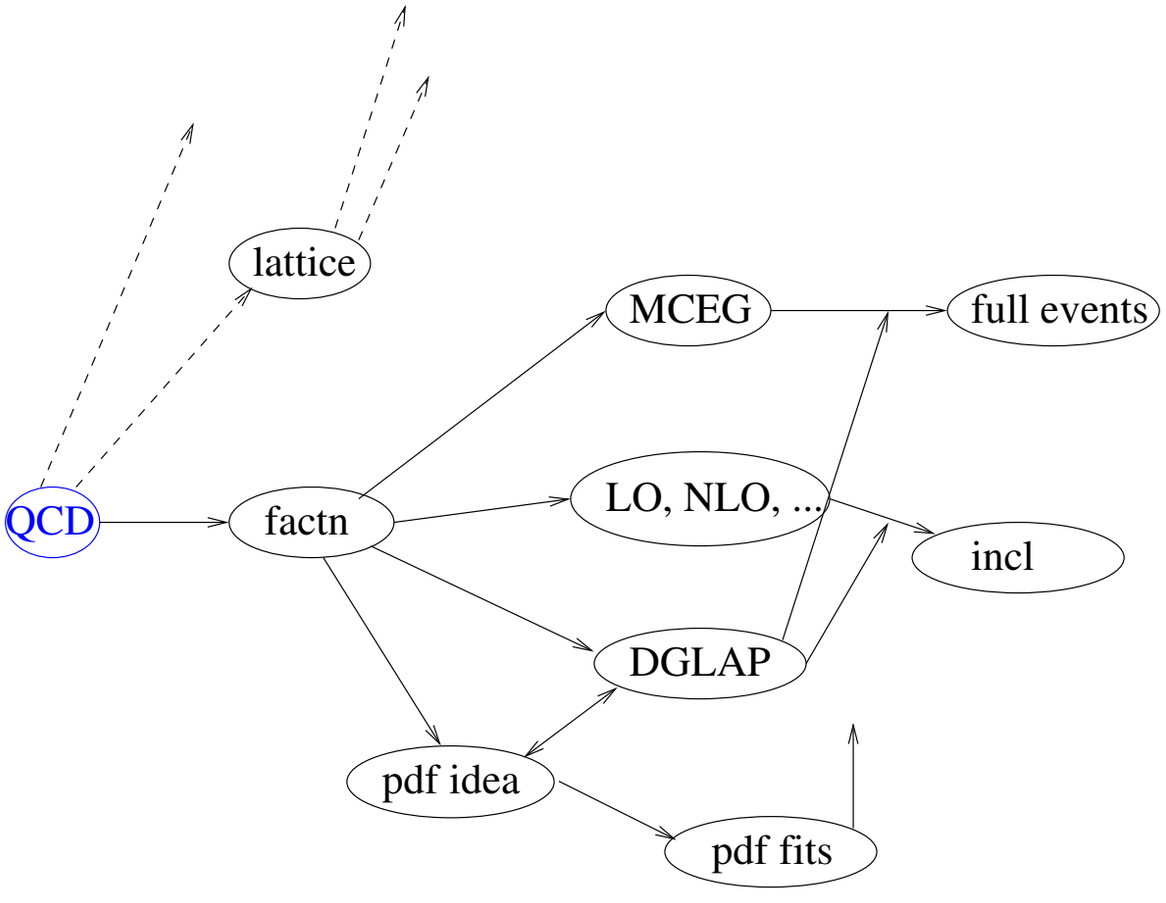
- Big extrapolation to $\sqrt{s} = 14\,\mathrm{TeV}$
- Questions:
  - Do MCEGs really implement QCD?
  - Or, how well?
  - What are the danger points?

Summary

- Standard arguments (for MCEG) are only approximate, if taken literally.
- Reformulate argument *from beginning*

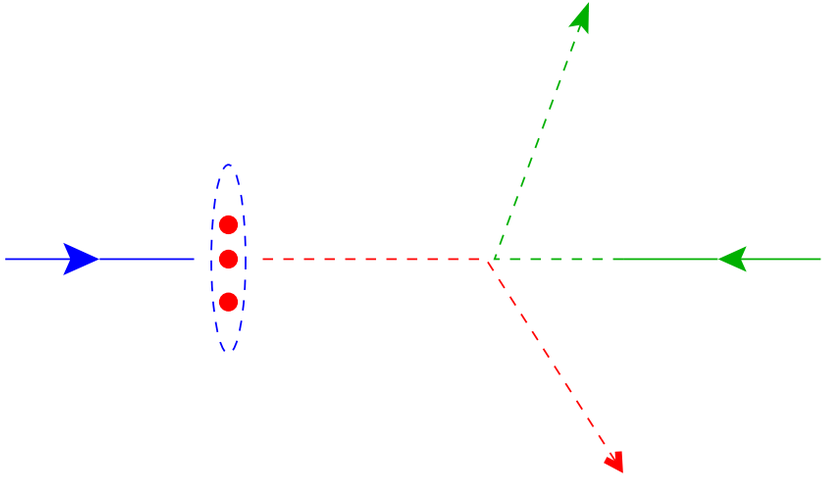
$\Longrightarrow$ parton correlation functions not pdfs
& new kinds of factorization

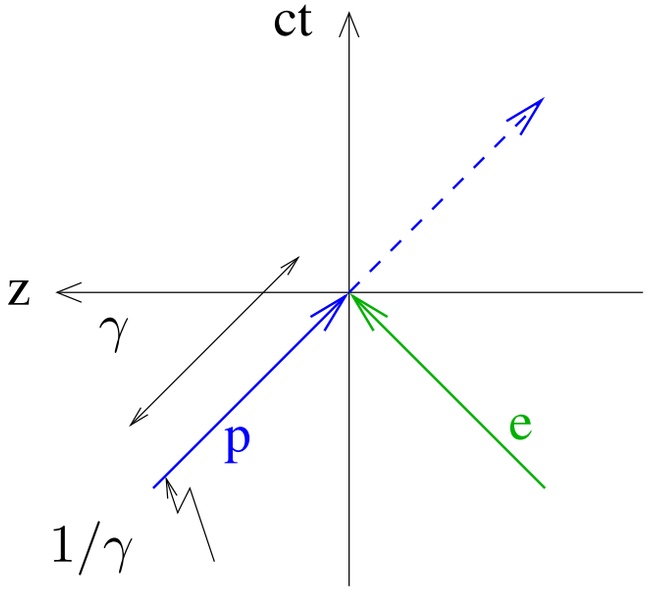
- Problems likely in hadron-hadron case


lattice
QCD
factn
MCEG
full events
LO, NLO, ...
incl
DGLAP
pdf idea
pdf fits

DIS basics

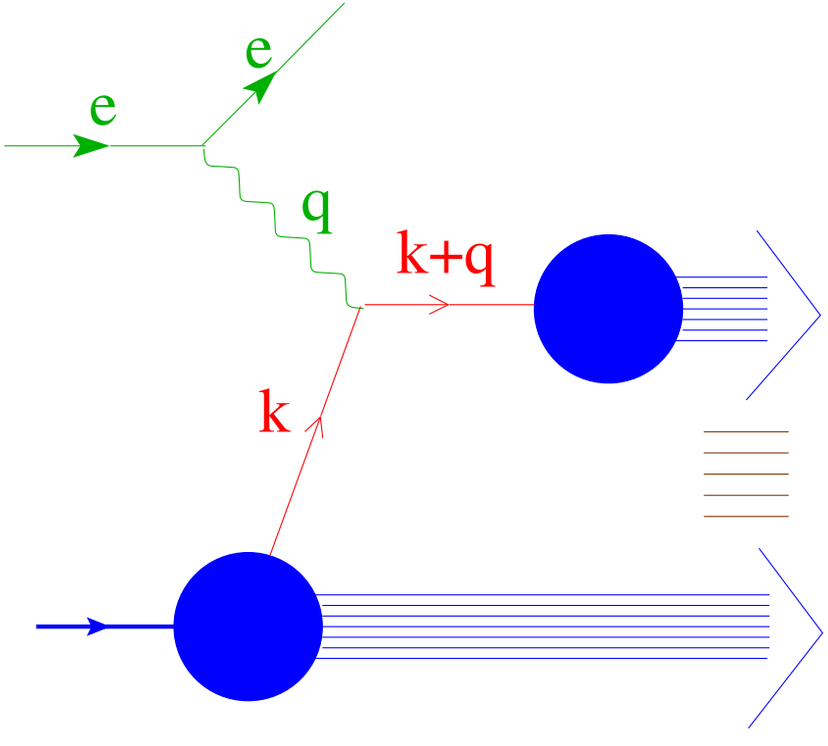
Roughly:





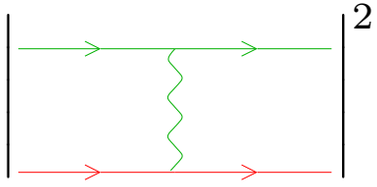
- Large s, Q
- Time dilation; Lorentz contraction
- $\gamma = E/m$
- Approximately independent scattering on approximately free constituents

Convert to field theory: Basic parton model

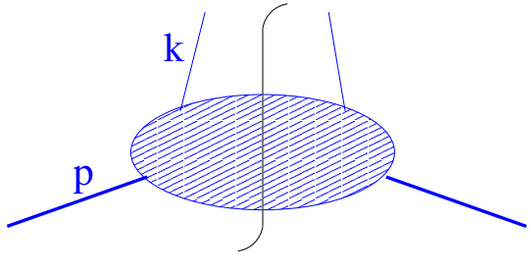


- Neglect k^2, $k_\perp^2$, $(k+q)^2$, w.r.t. Q^2.
- I.e., the partons are approximated on-shell, etc in hard scattering
- But *not* in hadronic part
- Large component: $k^+ \simeq x_{\rm Bj} p^+$

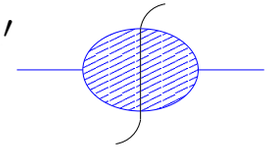
Field theory implementation of parton model for F_2, etc



$\times \quad \int \mathrm{d}k^- \, \mathrm{d}^2 k_T$



$\times \quad \int dk^{+\prime}$



on-shell $eq \to eq$ $\times$ pdf $\times$ 1

In Breit (brick-wall) frame:

$$p^\mu = \left(p^+,\, M^2/2p^+,\, 0_T\right), \qquad q^\mu = \left(-xp^+,\, Q^2/(2xp^+),\, 0_T\right),$$

approximated kinematics in hard scattering

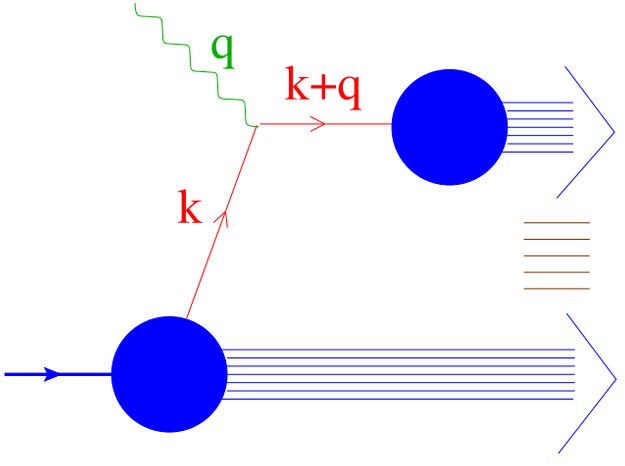
$$k^\mu \simeq \left(xp^+,\, 0,\, 0_T\right), \qquad k^\mu + q^\mu = \left(0,\, Q^2/(2xp^+),\, 0_T\right)$$

But true value:

$$k^+_{\text{true}} = xp^+ + \frac{M_j^2 + k_T^2}{2(q^- + k^-)}$$

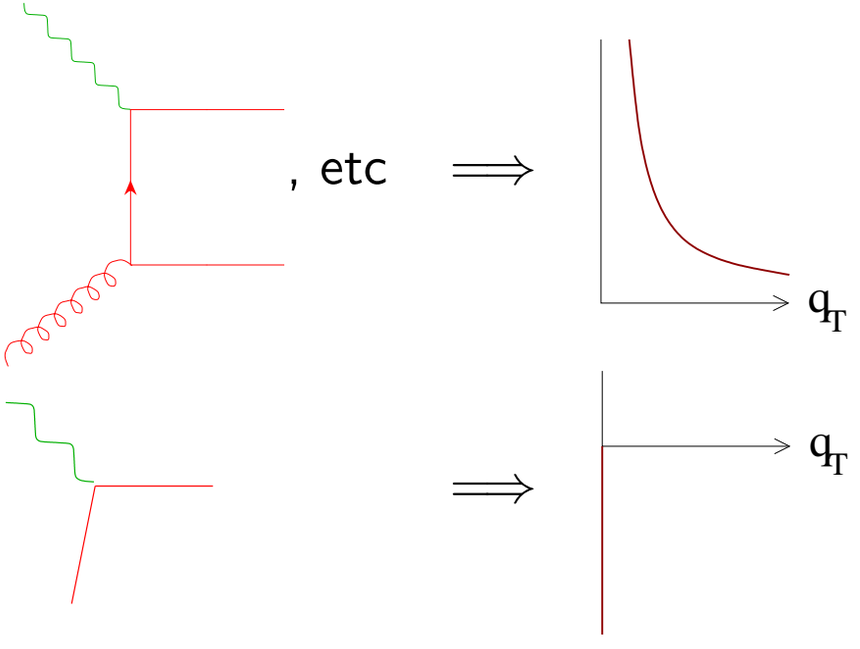
Large M_j or $k_T^2 \Longrightarrow$ large change in k^+

Effect of approximated kinematics



- Inclusive cross section:
  - Use of pdf $f(x)$ when $k^+ \neq xp^+$
  - Compensate by NLO, etc, for value of cross section
- MCEG (or other treatment of detailed final state):
  - Need "jet" final state (conditional) probabilities, *given* k, and *given* $k+q$
  - Need to reassign parton kinematics after event generation (non-factorizing)
  - OK at LLA
  - But how to formulate in general?

Distributions in conventional NLO corrections

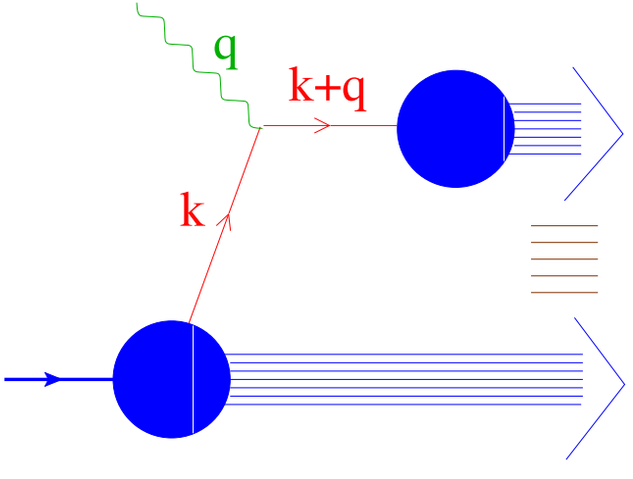


- $\Longrightarrow$ terms like $\left(\frac{1}{q_T^2}\right)_+$
- Distribution/generalized fn.: needs integral with smooth fn.
- Valid only for $\alpha_s(Q)$-expansion of incl. cross sections, etc.

Restart derivation from beginning

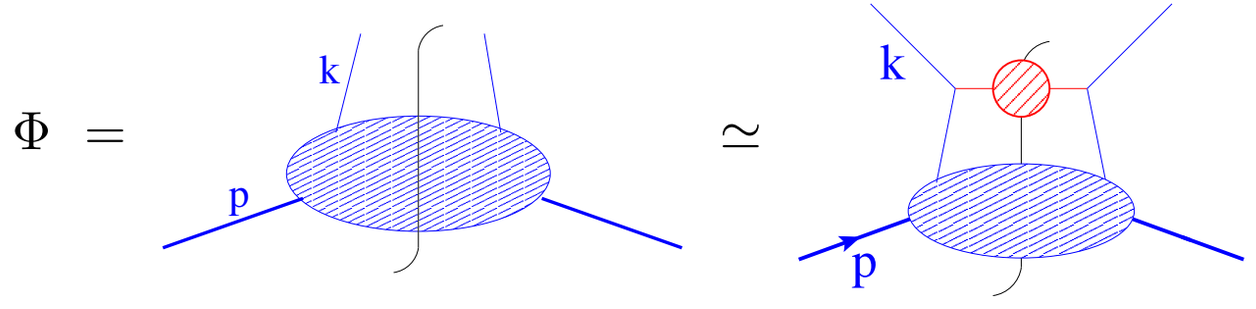
Aim: precise formulation without ad hoc "fudges".
Definite objects for probabilities
No redefinitions/reassignments after construction

First attempt, ignoring QCD complications:



- $\mathrm{d}\sigma_{\mathrm{PM}} = \int \mathrm{d}^4k\, \Phi(k,p)\, J(k+q)$
- Φ and J are parton correlation functions (in proton and vacuum)
- Can be differential in final state
- No approximations on parton kinematics
- New factorization theorems for σ, Φ, and J:
  - Inclusive in terms of usual pdf's
  - Differential in terms of differential pCf's (Hence showering algorithm)

Factorization for pCf and showering



- – Like factorization for σ or F_2
  – But can be differential in final-state
  – Replaces showering
  – Evolution (virtual only)
- See hep-ph/0411332

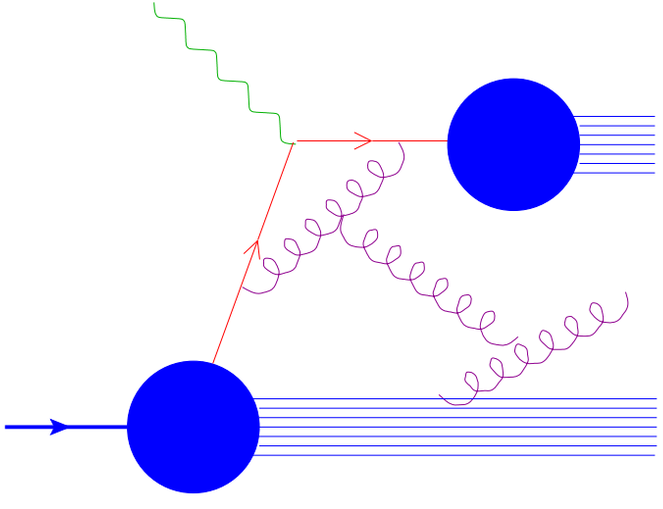
✓ Exact treatment of kinematics in factorization formula

- Approximations only in values of hard scattering and kernels

✓ Distributions are ordinary functions, not $(1/q_T^2)_+$, etc

QCD

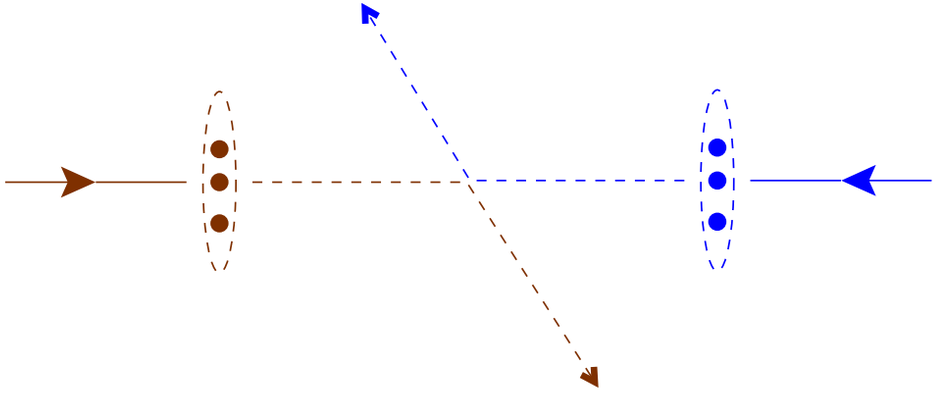
At parton-model level of approximation, have gluon exchanges:

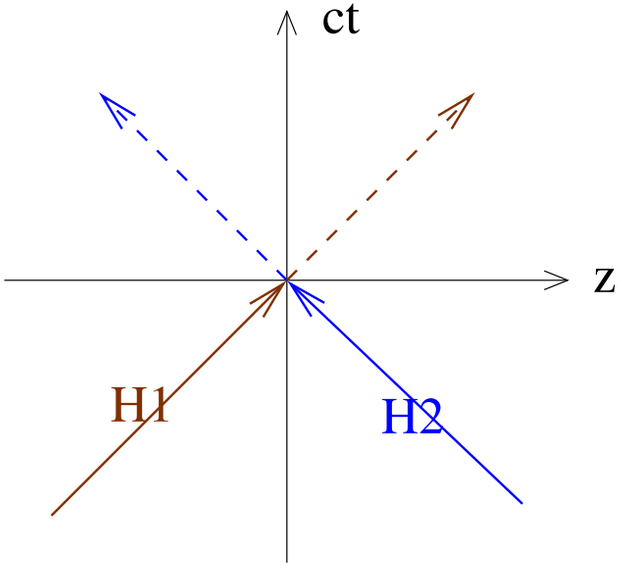


- Gauge invariance issue
- Correct proof of factorization gives
  - Wilson lines in operators
  - Directions of Wilson lines
  - Collins-Soper eq. (or similar) for direction-dep.
- Need to do this precisely, completely
- Separation of final-state kinematics?

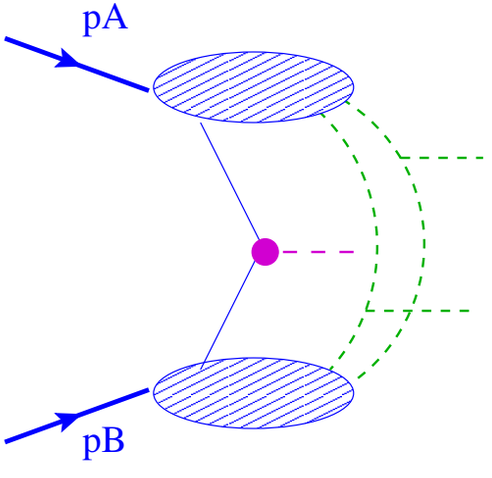
Hadron-hadron I

Parton model generalization:

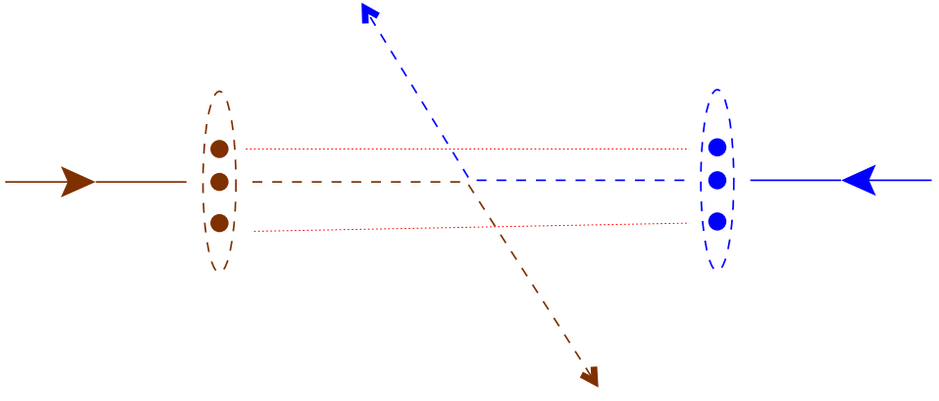


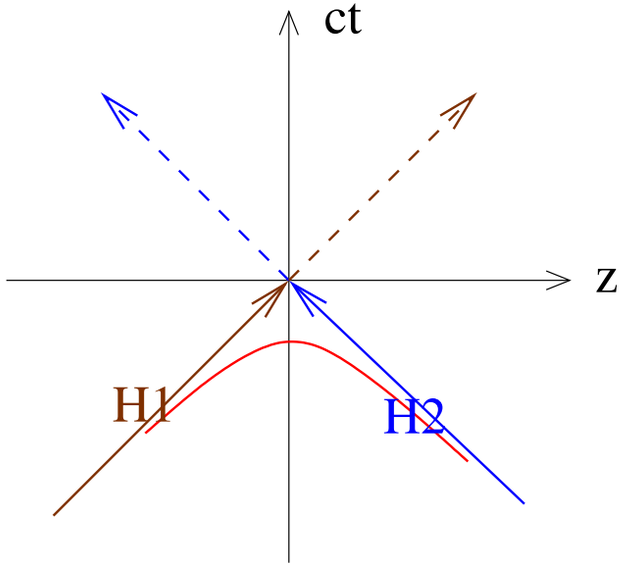


But extra exchanges are leading power:



Hadron-hadron, with spectator-spectator ints.





- Standard factorization needs cancellation of spectator-spectator interactions,
- which are not just soft interactions

Hadron-hadron: factorization status

- – Proof of factorization for DY (inclusive). [CSS, Bodwin]
  – No published proof for jet-jet. [As far as I know.]
  – Counterexamples for diffractive hard scattering.

- Full cross section (with final-state):
  – No ordinary factorization
  – Cf. PYTHIA multiple interactions
  – Momentum- or coordinate-space formulation?

Conclusions

At level of quality needed for LHC:

- Need to properly & precisely formulate logic: QCD $\longrightarrow$ MCEG
- $\Longrightarrow$ use of parton correlation functions (vacuum, target)
- Several factorization theorems:

Inclusive	—	value of σ
	—	value of pCf
Differential in f.s.	—	for σ and pCf
	$\Longrightarrow$	showering

- Complete formulation in non-gauge theory model
- Techniques exist for extension to QCD
- Beware: Non-factorization in hadron-hadron collisions