Multi-parton interactions & the underlying event

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- *HERA: Underlying event in DIS*
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- *LHC?: Underlying event in* pp
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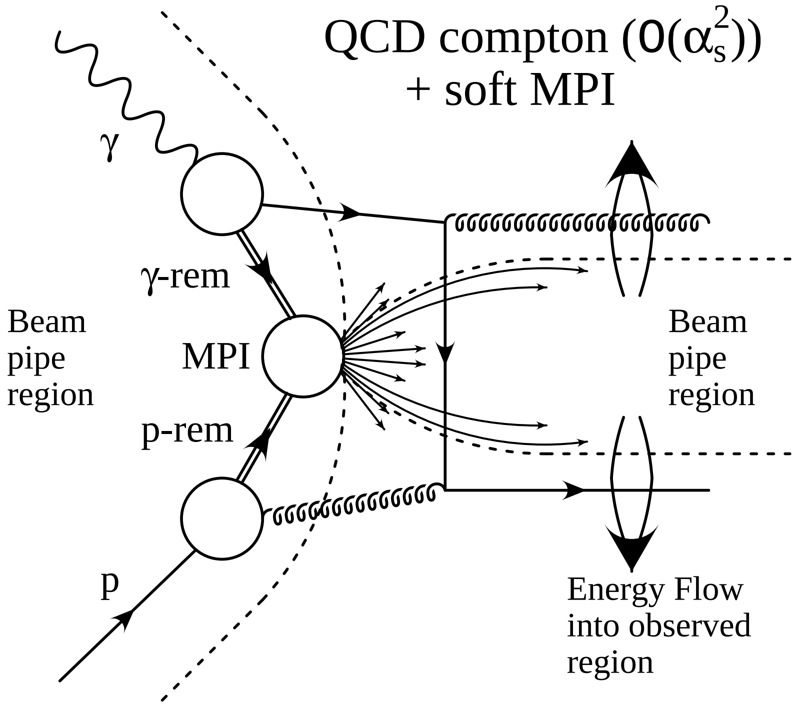


Introduction

- What is the underlying event? (*a working definition:*)
  - **all energy flow not associated with the primary process**

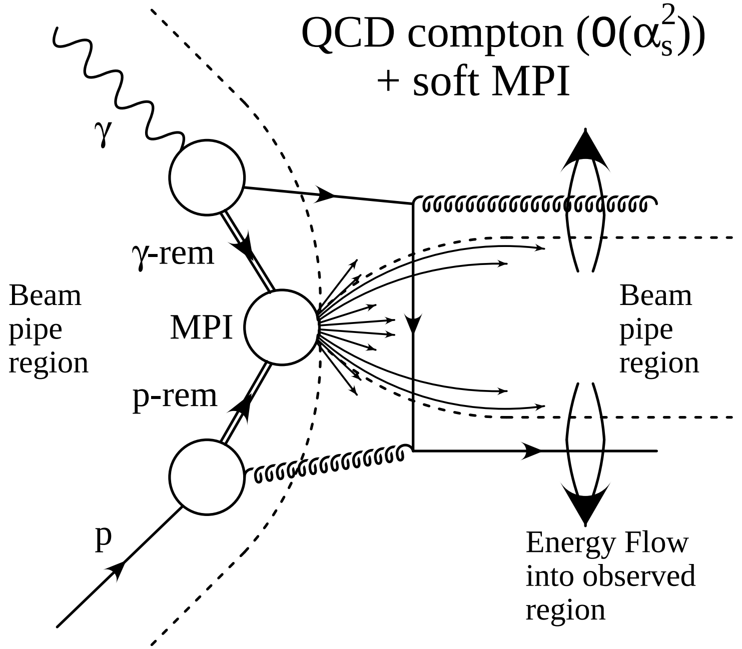
- What is the primary process?!
  - a parton-parton interaction, which (beyond PDFs) is completely insensitive to the incoming particles and beam remnants.
  - includes all coherent radiation (to all orders) associated with that interaction
  - this assumes perfect universality - the source of the partons irrelevant.

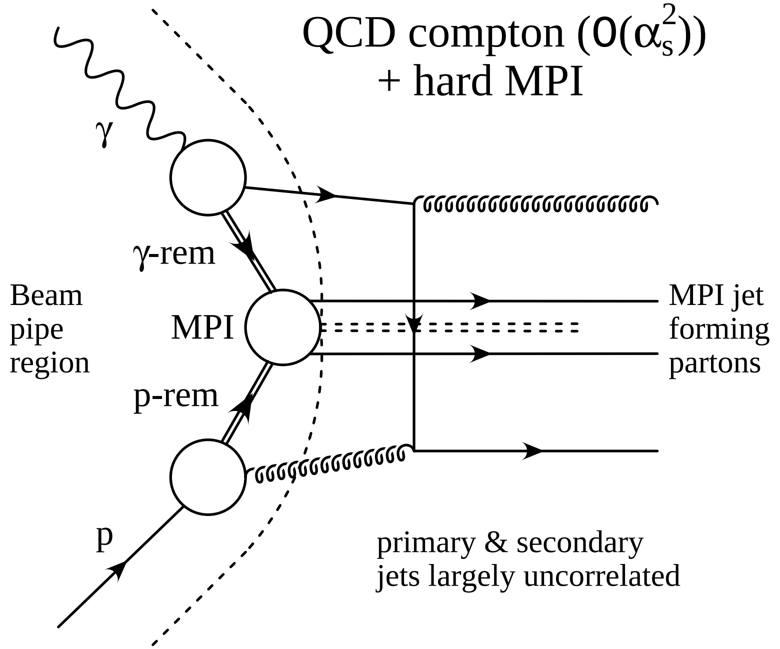
- What else could affect or contribute to the observable energy flow?
  - secondary remnant-remnant interactions - multi-parton interactions (MPIs)
  - multiple-scattering as a primary parton re-scatters off the remnants
  - any other environmental effects that might affect primary scattered partons.

- In this talk we shall talk exclusively about MPIs and the underlying event

Introduction - MPIs

- MPIs may range from being v. soft (“underlying event”) upto hard (jet forming)



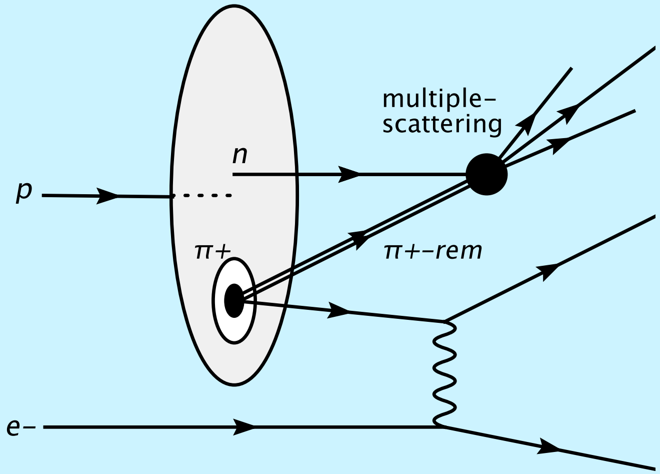


- thus possible MPI signatures (softest $\Rightarrow$ hardest) are a low-E_T pedestal, increased production of (incoherent) mini-jets or an excess of 4-jet events.
- experimentally, it’s difficult to differentiate MPIs from HO pQCD corrections

Motivation

- MPIs can interfere with many types of physics analysis so must be understood:
  - they reduce rapidity gap survival probability
  - they affect isolation criteria (e.g. for muons)
  - they lead to larger charged/particle multiplicities
  - affect jet profiles/pedestals and increase jet energy scale
  - potentially increase jet rates and affect jet angular correlations

- Multiple-scattering affects:
  - leading baryon E_T spectra

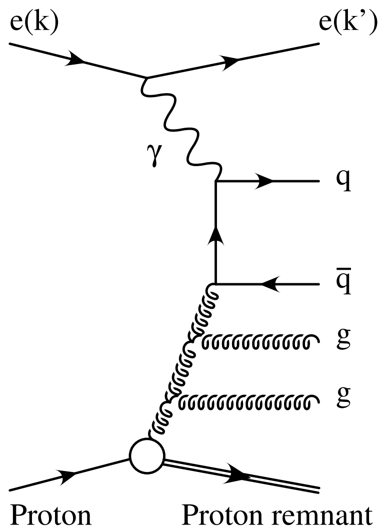


- And MPIs at the LHC will be far more prevalent
- to find (most) new physics must understand QCD background, including:
  - the primary interaction...
  - ...plus the secondary interactions...
  - ...from the multiple particle interactions per bunch crossing!
- MPIs affect what analyses can be done and...
- what triggering strategies should be employed

- MPIs may lead to a greater understanding of p e.g. multi-parton correlated SFs?

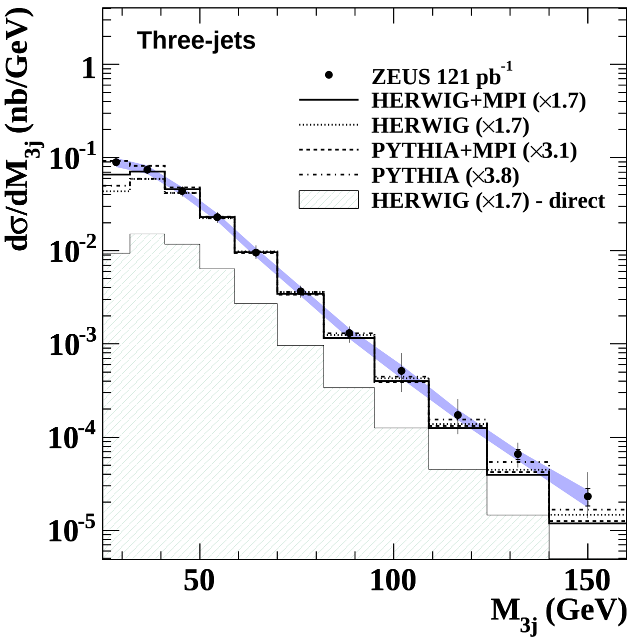
Underlying event in γp - multi-jets

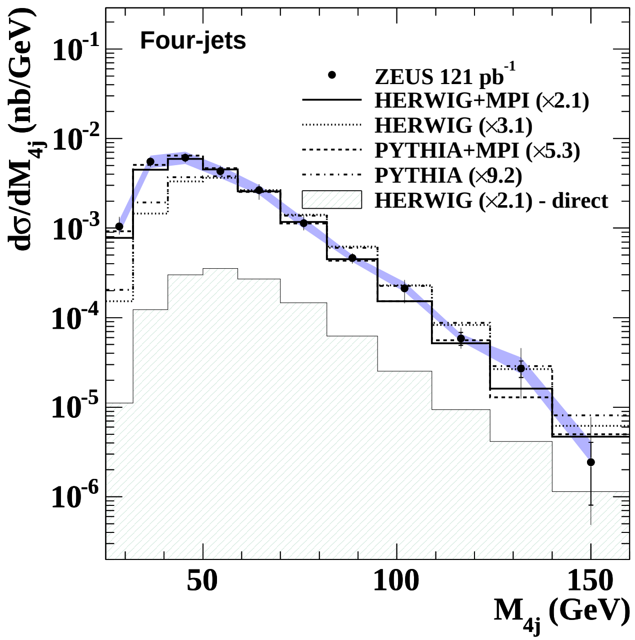
- Here we study: $\gamma p \to$ 3+ or 4+ jets ($E_T^{\text{jet}} > 6$ GeV)
- γ may act like a point-like (direct) or composite object (resolved)
- MPIs only present in resolved (hadron-hadron-like) process
- Multi-jets generated by QCD processes (*see figure right*)...
- ...and hard-MPIs? Note: soft underlying event changes jet energy scale and so, given some E_T^{jet} criteria, affects jet rates.

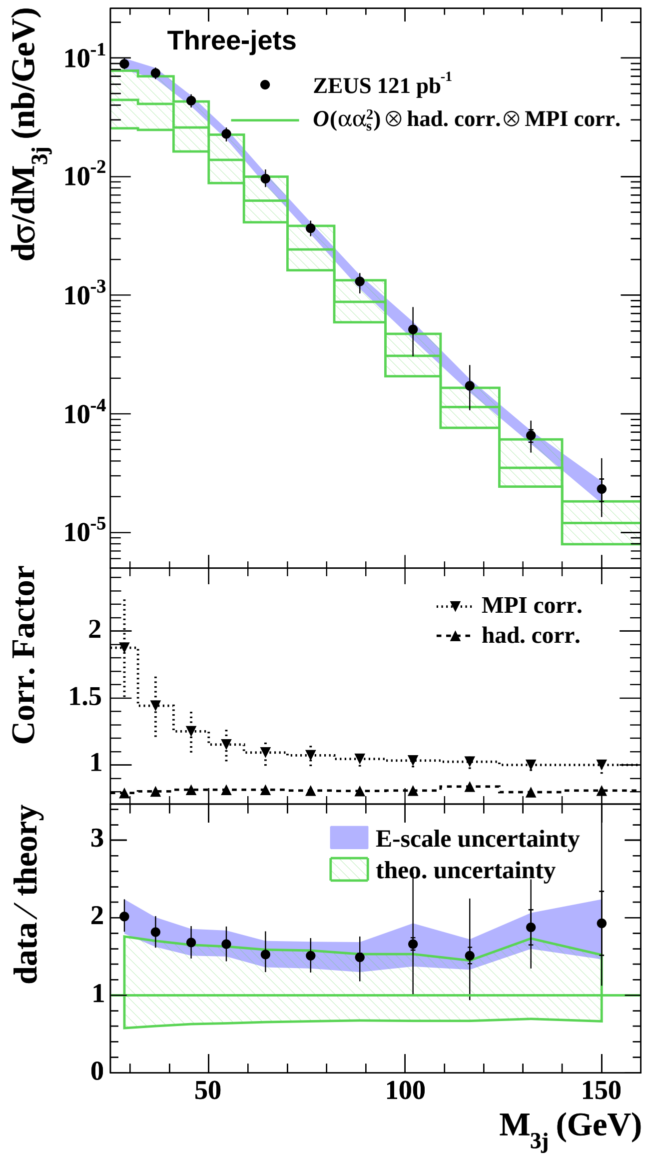


- Variables looked at:
  - M_{nj}: invariant mass of the n-jet system. Compared to MCs with and without MPIs and LO pQCD.
  - x_γ^{obs}: which approximates x_γ, the fraction of γ's momentum transferred to the hard interaction (i.e. the jets). At LO, $x_\gamma = 1$ (direct) & $x_\gamma < 1$ (resolved) - however ambiguous at HOs. Compared to MCs with and without MPIs
- events studied in two M_{nj} regions: ($25 \leq M_{nj} < 50$ GeV) & ($M_{nj} \geq 50$ GeV)

Underlying event in γp - multi-jets

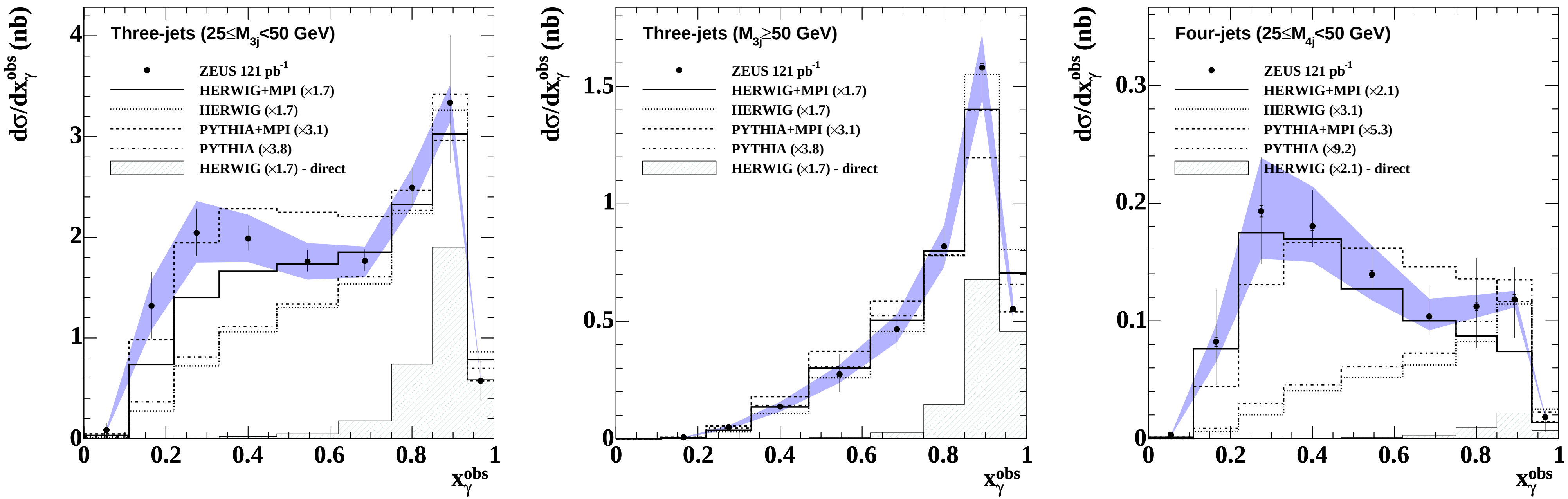






- both 3- and 4-jet mass distributions fall exponentially
- MC without MPIs fails to describe low M_{nj} regions
- adding MPIs helps description of M_{nj} (*see* M_{4j})
- highest order pQCD in γp only LO for 3-jet process
- shown here corrected for hadronisation and MPI effects
- largely describes M_{3j} data but theo. uncertainty large
- description greatly improved by MPI corrs.

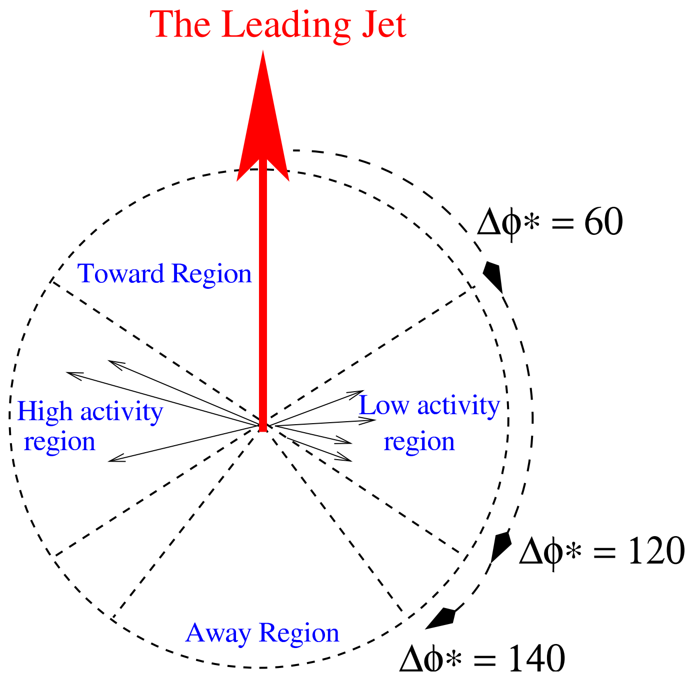
Underlying event in γp - multi-jets

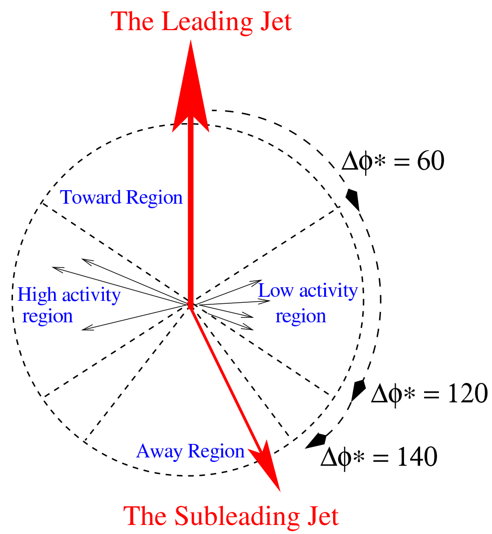


- all MC models describe high mass data reasonably well.
- MCs without MPIs don't describe low $x_\gamma^{\rm obs}$ region at low mass.
- the discrepancy between the MC without MPIs and the data is larger for 4-jets.
- introducing MPIs into the MCs improves the description.
- note: predicted influence of MPIs very sensitive to tunable parameters in models.
- low mass 4-jet data some of the most MPI sensitive ZEUS data. **However**...
- ...always issue: really MPIs or HO effects not modelled by parton-showers?

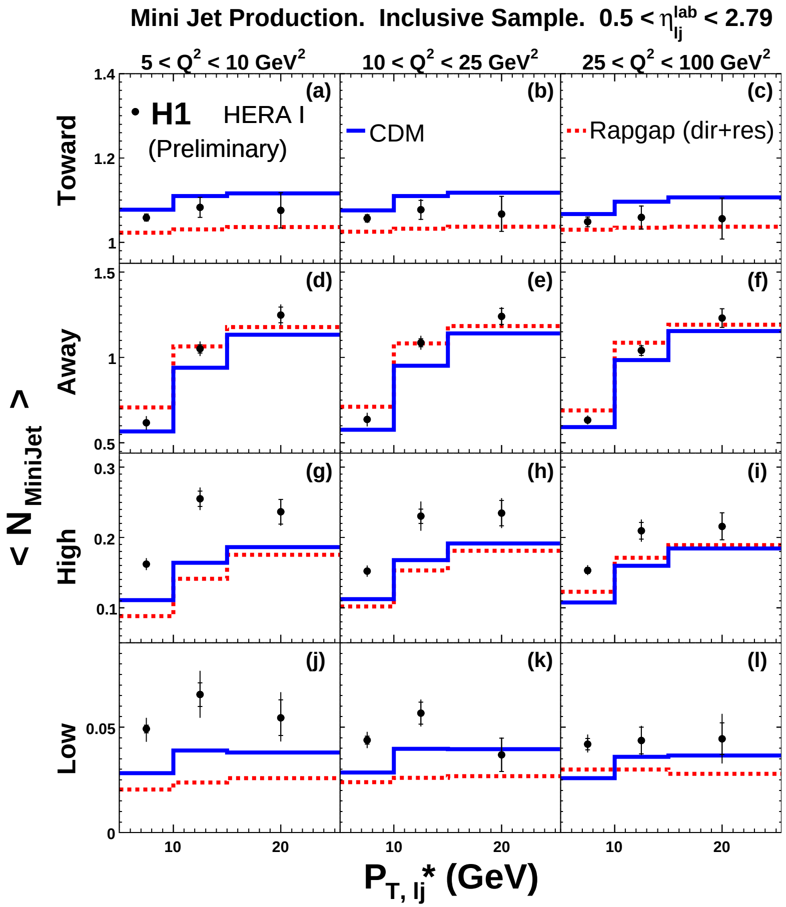
Underlying event in DIS - mini-jets

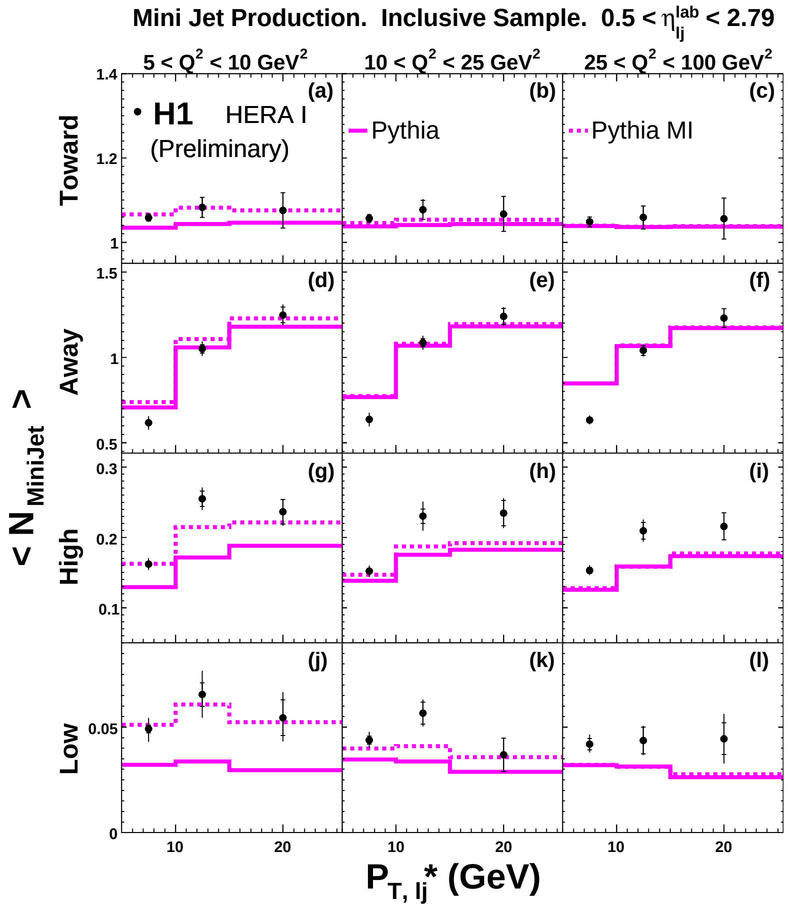
- resolved processes suppressed by virtuality, Q^2.
- are we even sensitive to MPIs/underlying event in DIS?
- Strategy:
  - select DIS events ($5 < Q^2 < 100$ GeV^2)
  - select hardest jet in HCM ($P_T^{\text{jet}} > 5$ GeV)
  - define 4 regions (*see figure right*)
  - $\sum$ of particle E_T defines low/high activity regions
  - measure average mini-jet multiplicity, $< N_{\text{minijet}} >$.
  - where mini-jets have $P_T^{\text{jet}} > 3$ GeV...
  - ...and $< N_{\text{minijet}} >= \frac{\sum^{N_{\text{events}}} N_{\text{minijet}}}{N_{\text{events}}}$
- transverse regions - sensitive to incoherent energy flow.
- can further reduce coherent radiation by requiring back-to-back subleading jet (*see figure right*)
  - select dijet events ($P_T^{\text{jet}} > 5$ GeV)
  - with subleading jet in "away region"
  - repeat procedure...





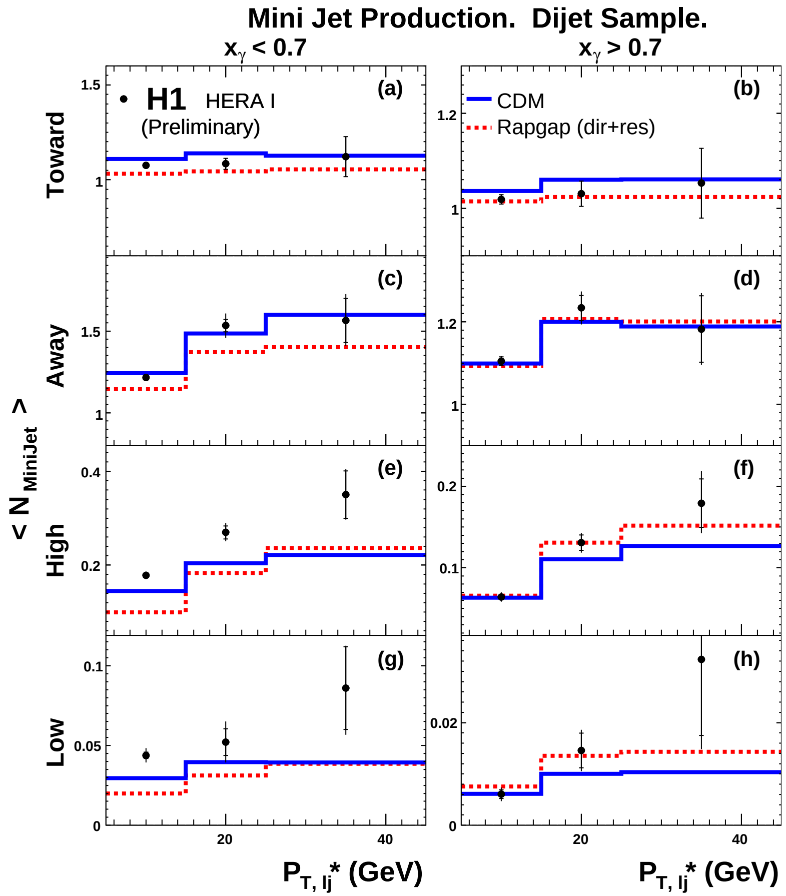
Underlying event in DIS - mini-jets (inclusive)

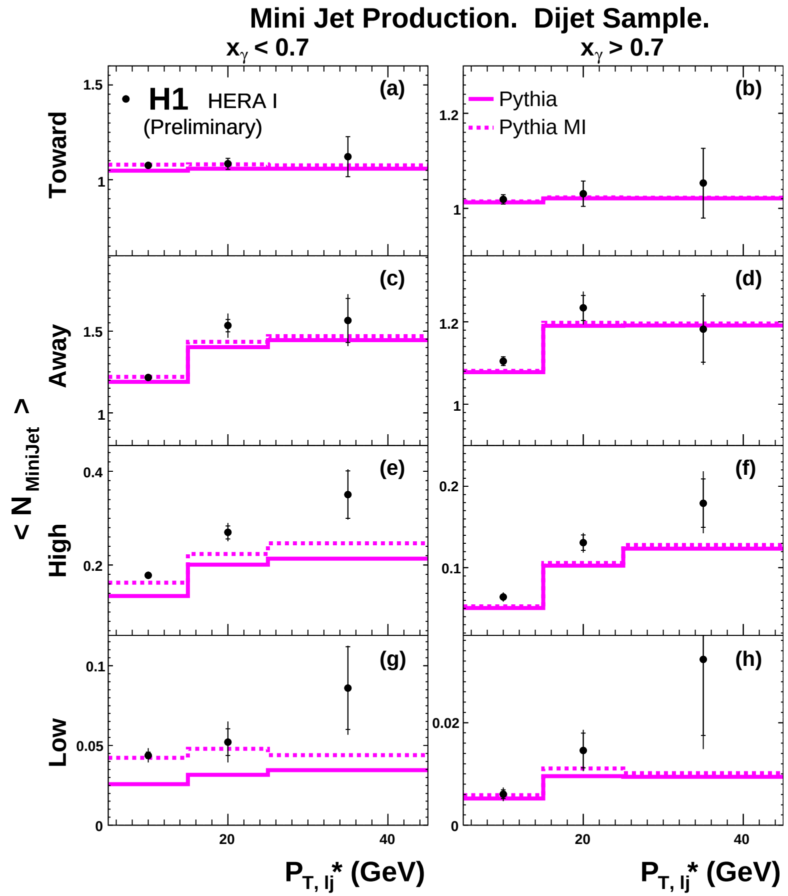




- $< N_{\text{minijet}} > (P_T^{\text{jet1}})$ in the 4 regions. Shown for high η^{jet1} region in 3 Q^2 bins.
- expect larger resolved contribution in high η^{jet1} (forward) region.
- all MC models describe the “towards” and “away” regions reasonably well.
- MPIs improve description of “low” and “high” regions at low Q^2 but not at mid Q^2

Underlying event in DIS - mini-jets (dijets)

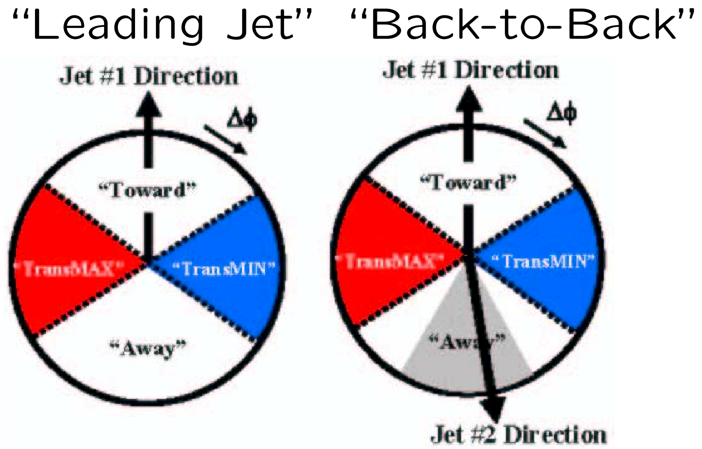


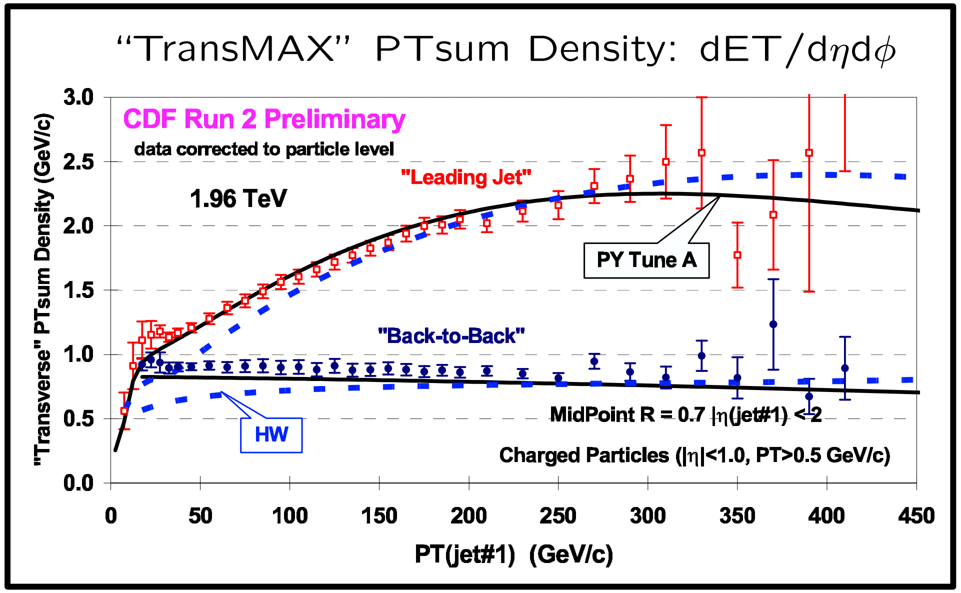


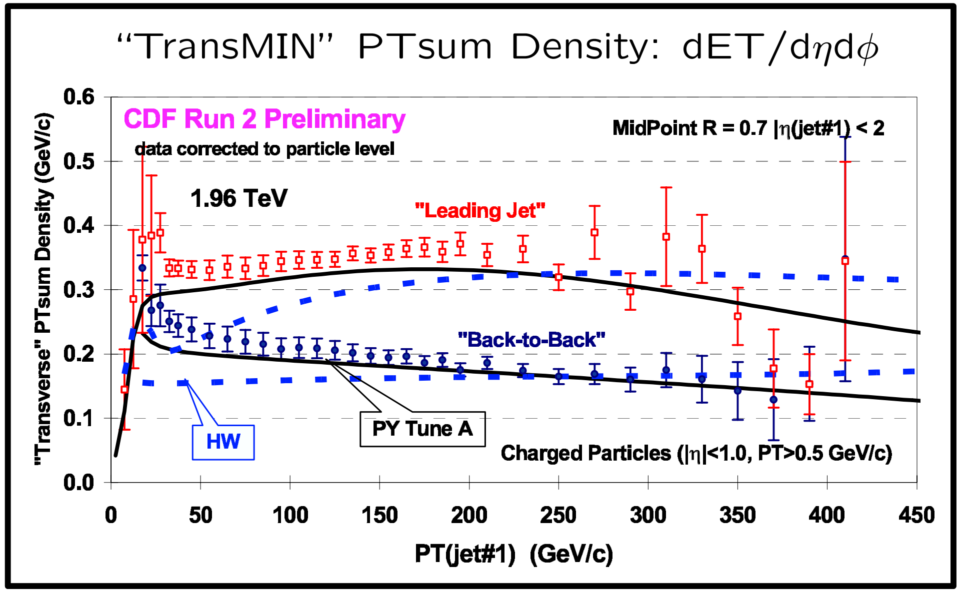
- $< N_{\text{minijet}} > (P_T^{\text{jet1}})$ in the 4 regions in two x_γ regions.
- “towards” and “away” regions again largely described by all MC models
- more activity in “low” and “high” regions at low x_γ (resolved enriched)
- low x_γ description generally improved by the inclusion of MPIs

Underlying event in $p\bar{p}$ - transverse P_T

- Tevatron underlying event most relevant for LHC
- analysis of “transverse” regions (*see figure right*)
- plot hadronic P_T sums compared to MC models
- HERWIG (no MPIs) below the low-PT(jet#1) data
- best description by PYTHIA with MPIs (“Tune A”)



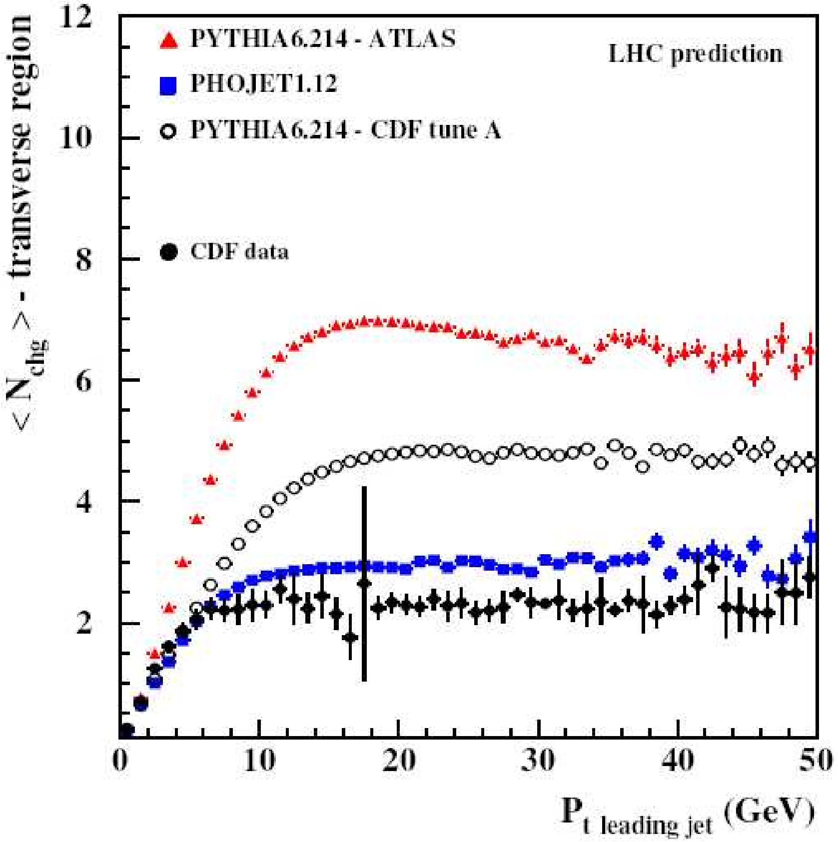


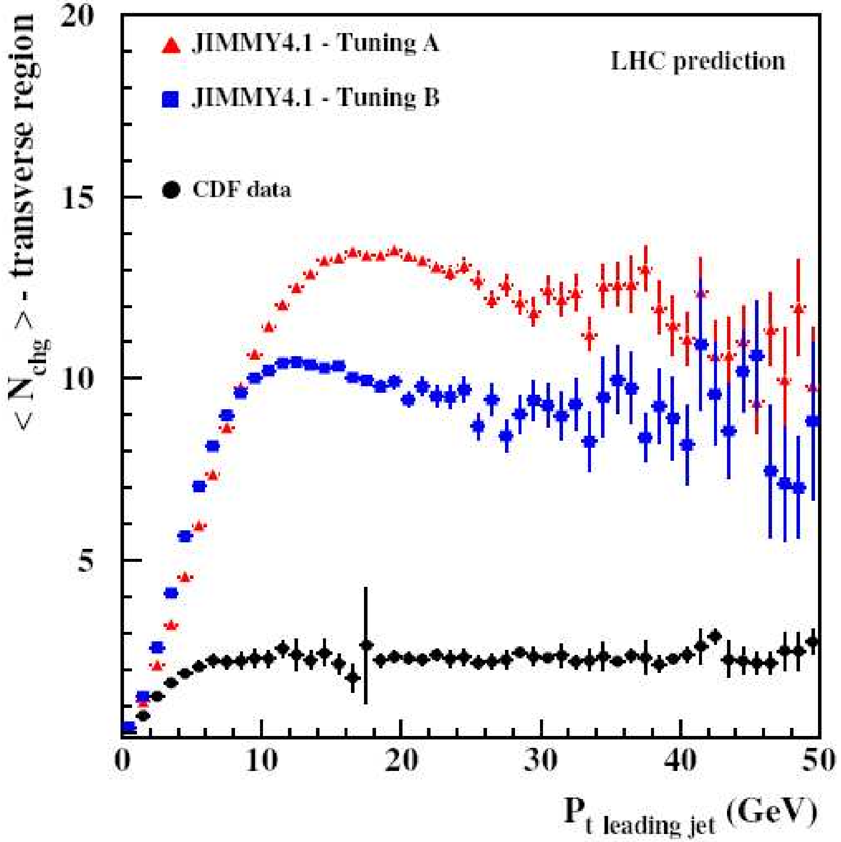


- R. Field [CDF Collab.], AIP Conf. Proc. **828** (2006) 163

Underlying event at the LHC?

- What will the underlying event be like at the LHC? Can we say anything presently?





- Clearly, LHC extrapolations based on tunes to current data disagree
- certainly first LHC data will provide an interesting test for the current models
- but beyond just being a background for physics it will be interesting if MPI events can be used constructively to gain further insight into e.g. proton structure.

Summary

- the topic of MPIs is presently very relevant. From practical considerations:
  - they interfere with what physics analyses can be done
  - they interfere with what triggering strategies can be employed

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- at HERA, MPIs are possible in resolved photon interactions
- resolved processes suppressed with increasing Q^2 and x_γ.
- low-Q^2 multi-jet γp data suggestive of large MPI contribution at low M_{nj} & low x_γ.
- furthermore, influence of MPIs predicted to grow with jet multiplicity.
- HERA DIS mini-jet data also suggestive of MPIs at lowish-Q^2 (upto $\mathcal{O}(10)$ GeV^2)
- however, always question whether MPIs or HO effects/soft physics?

- at the Tevatron, the picture is the same.
- particle P_T sums are in excess of MC prediction without MPIs
- description can be remedied by the inclusion of MPIs

- But as for the LHC, extrapolations to the relevant energies have large uncertainties
- LHC data will provide an interesting test of the models
- but beyond just being a background for physics, it will be interesting if MPI events can be used constructively to gain further physical insights