High-Q^2 physics at the LHC

Frank Krauss

Institute for Theoretical Physics
TU Dresden

DIS 2006, KEK, 23.4.2006

Outline

Reminder: Physics @ LHC

- Many interesting signals:
  Higgs (or alternative EWSB), SUSY, ED's, ...
- But: Severe backgrounds in nearly all channels,
  (almost always with large influence of QCD)
  $\Longrightarrow$ depend on detailed understanding of QCD.
- Examples:
  - Central jet-veto in VBF (Higgs)
  - Multi-jet backgrounds for SUSY (e.g. Z+jets)
- Todays signals = tomorrows backgrounds.

Scope of this talk

- YES: maybe lots of interesting physics at LHC
- BUT: (nearly) nothing comes for free:
  - A signal is what remains after background subtraction.
  - How well do we understand bread-and-butter physics?
- SO: I won't talk too much about Higgs, BSM, etc..

  I'll talk about our understanding of QCD

as far as I can tell.

Fitting PDFs

Motivation

- PDFs are basic input for cross section calculations
- PDFs so far mainly determined from DIS data
- Uncertainties remain, typically around 5%-10%, larger for instance in high-Q^2 gluons
- Prepare for inclusion of LHC data in fits
- Ongoing projects: FastNLO & NLO@Grid

see talks by M.Wobisch and D.Clement

Fitting PDFs

Input of hadron colliders

- PDFs usually measured in DIS,
  Input of hadron colliders: gluon @ high Q^2.
- Sensitivity through

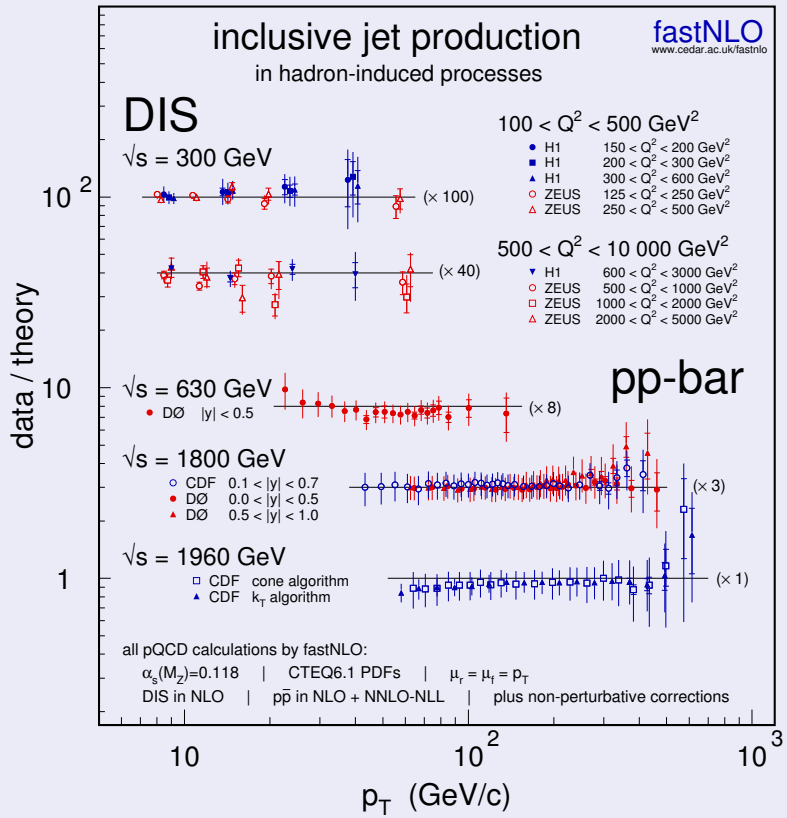
$$\sigma_{pp\to X}(s) = \int \mathrm{d}x_1 \mathrm{d}x_2 f_i(x_1,\, Q_F^2) f_j(x_2,\, Q_F^2) \hat{\sigma}_{ij\to X}(\hat{s},\, \mu_R^2)\,,$$

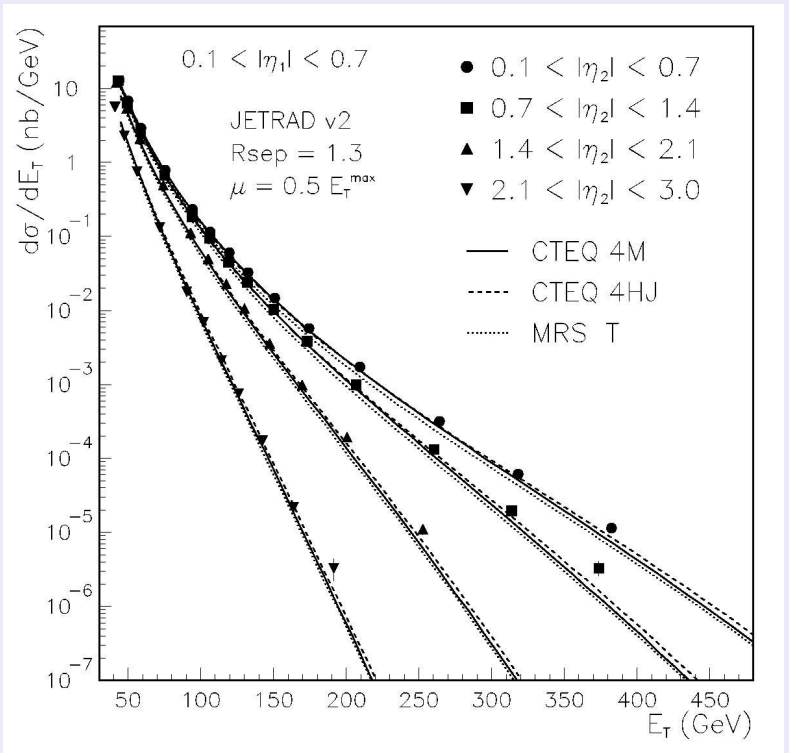
where $f_{i,j}$ = PDFs, $\hat{s} \sim x_1 x_2 s$.

- Idea for extraction of PDF: Compare σ @ NLO with data.
- Problem: Duration of NLO calculation.

Fitting PDFs

Quality of theory vs. data





Data from CDF, PRD64 (2001) 012001

Fitting PDFs

Idea for acceleration

hep-ph/0510324 by T.Carli, G.Salam, F.Siegert

- Replace integration by summation (MC integration):

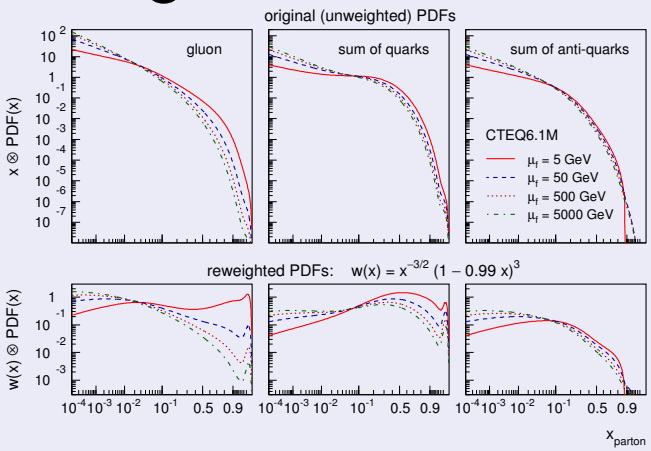
$$\sigma = \sum_{x_1,\, x_2,\, Q^2} \mathcal{W}_{\hat{\sigma}} \cdot \mathcal{W}_{\mathrm{PDF}}$$

- Bin $\hat{\sigma}$ in 2 dims $\Longrightarrow \mathcal{W}_{\hat{\sigma}}$
- Bin $f_i(x_1,\, Q_F^2) f_j(x_2,\, Q_F^2)$ in 3 dims $\Longrightarrow \mathcal{W}_{\mathrm{PDF}}$
- Interpolate in between
- Pre-calculate $\mathcal{W}_{\hat{\sigma}}$ and use for fast evaluation/fitting of PDF

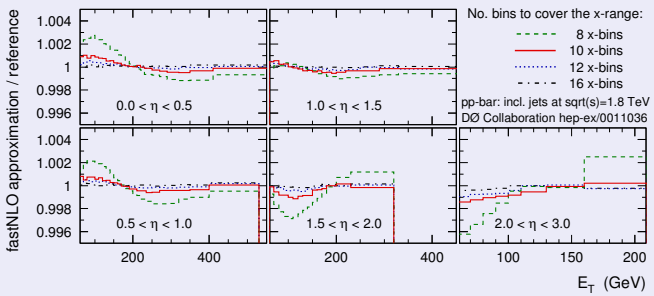
Fitting PDFs

FastNLO

Flattening the PDFs

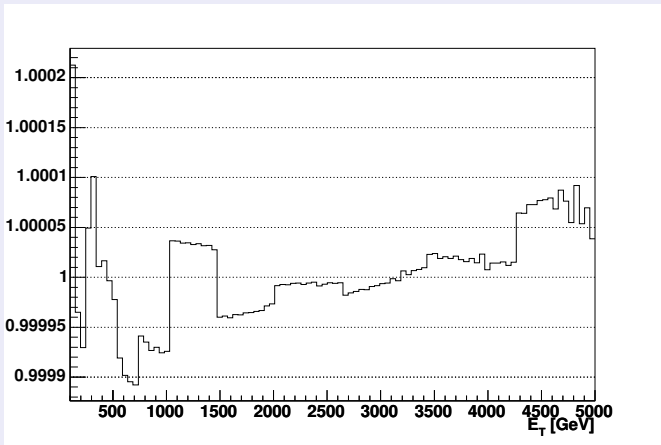


Accuracy of Grid interpolation

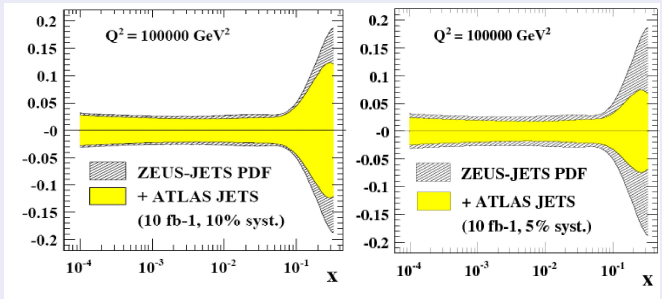


NLO@Grid

Accuracy of Grid interpolation



Impact on gluon PDF



Defining jets

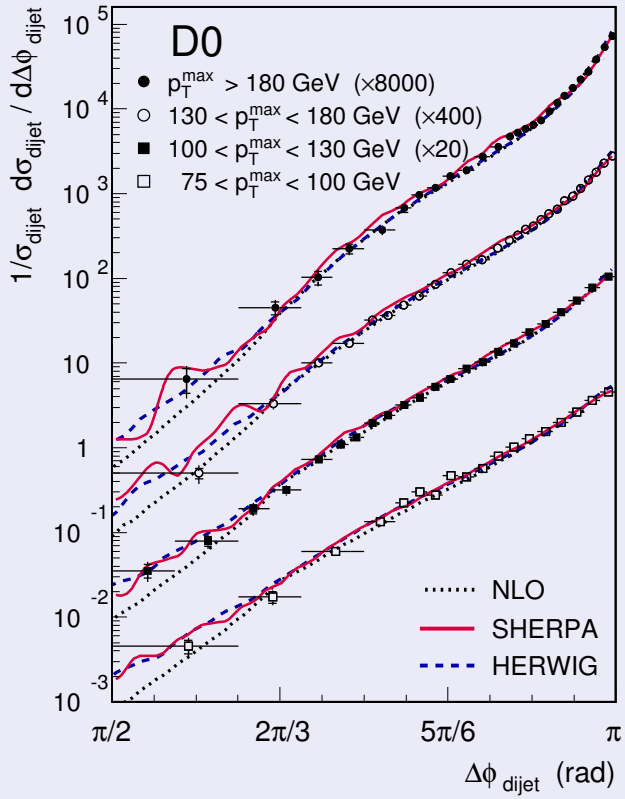
Motivation

- (Nearly) all physics signals are with jets:
  - VBF: Two forward "tag"-jets
  - gluinos: 4 jets + $E\!\!\!/$
- Large systematic uncertainties (steeply falling spectra)
- Need to define jet with good properties
  (better than "bunch of hadronic energy")

Defining jets

Theory vs. data from Tevatron

Data from D0, PRL 94 (2005) 221801, plot by M.Zielinski



Defining jets

Algorithms

- Cone algorithms (iterative, midpoint)
  Basic idea/algorithm
  - Find high E_T bins
  - Cone in ϕ-η around them with radius R
  - Cluster to jet (add momenta)
  - Differences in treatment of overlapping cones
- $k_\perp$-algorithms
  Basic idea/algorithm
  - Define "$k_\perp$-metric" (with "radius" R)
  - Cluster until $k_\perp^{ij} \leq k_\perp^{\rm crit}$

Defining jets

Work by D.Benedetti *et al.*, in hep-ph/0604120

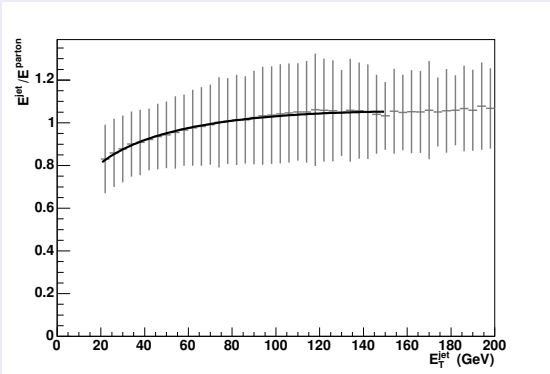
Criteria

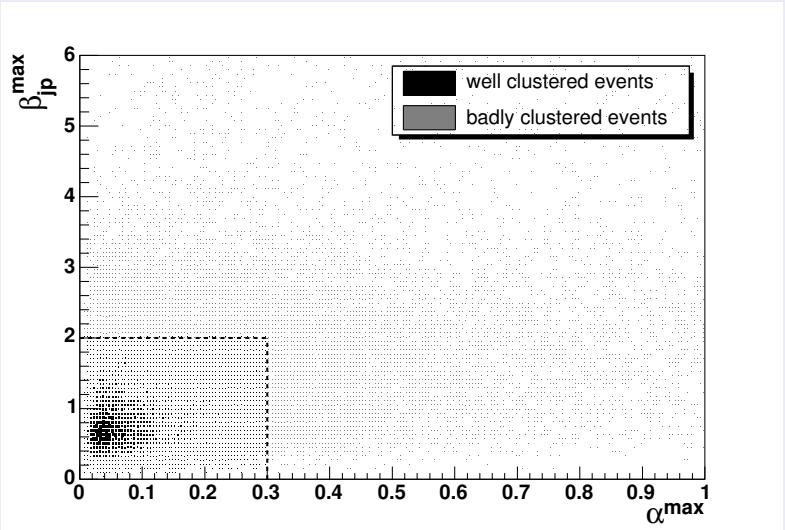
- Angular distance α^i_{jp}:

  $\Delta R(p^i, j^i)$ of i th parton p to its jet j

- Energy difference β^i_{jp}:

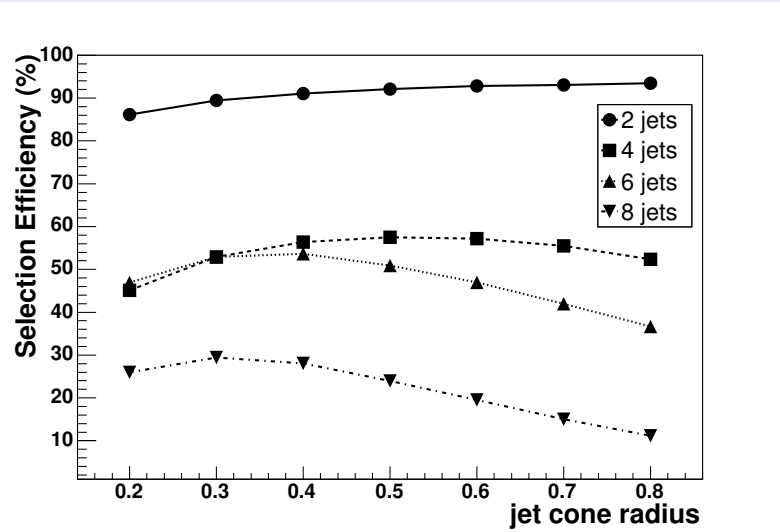
  Distance in σ from fitted curve

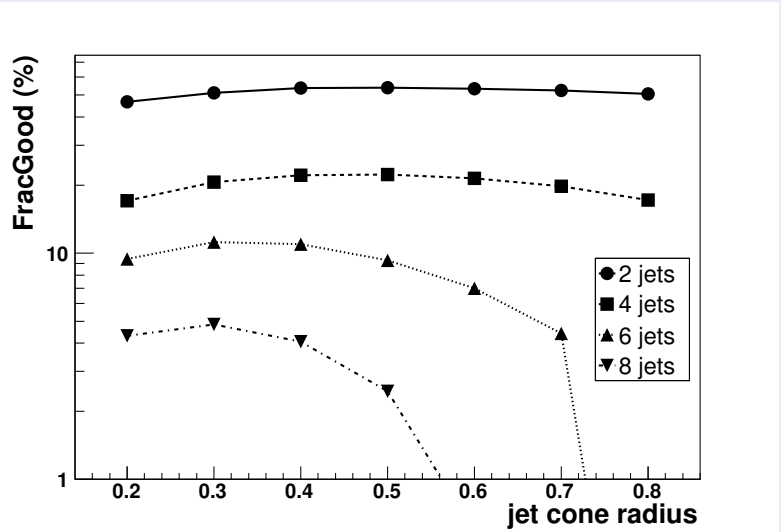




Defining jets: Testing the iterative cone-algorithm

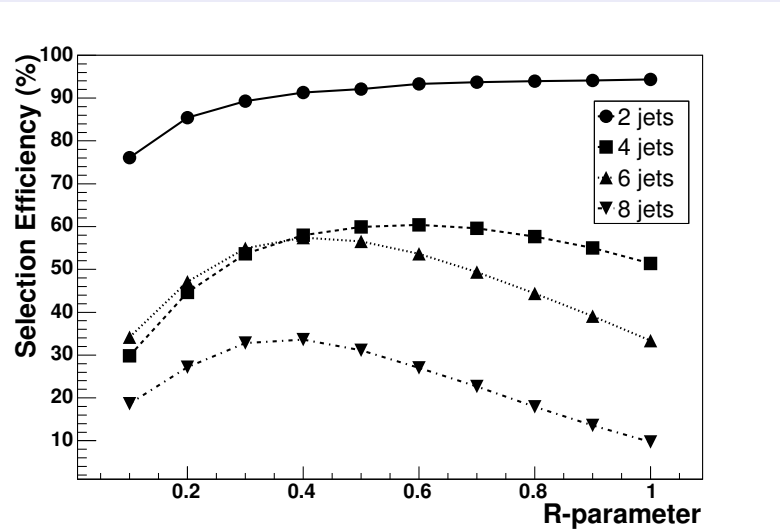
Selected/well-clustered & selected events in $t\bar{t}H$

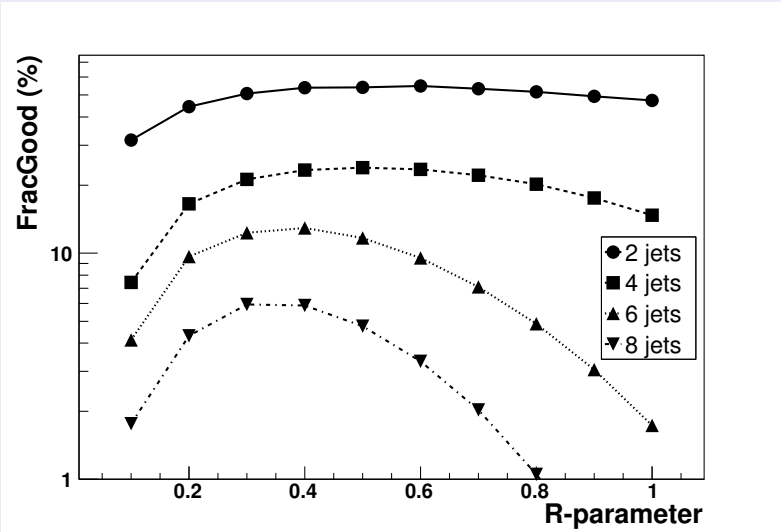




Defining jets: Testing the $k_\perp$-algorithm

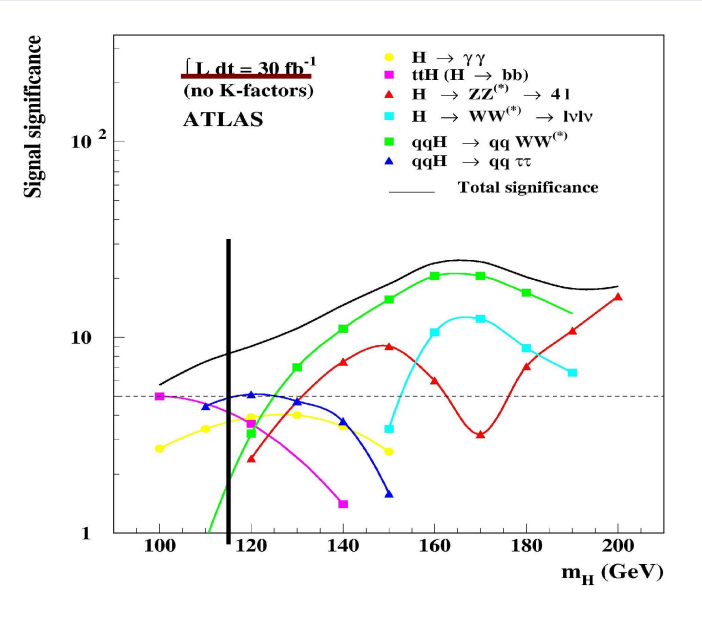
Selected/well-clustered & selected events in $t\bar{t}H$



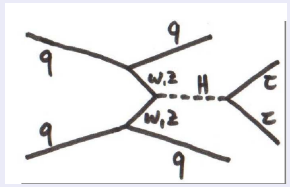


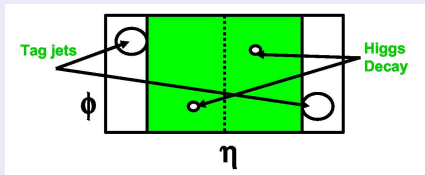
Multijets: Motivation

Higgs searches



Central jet veto in VBF

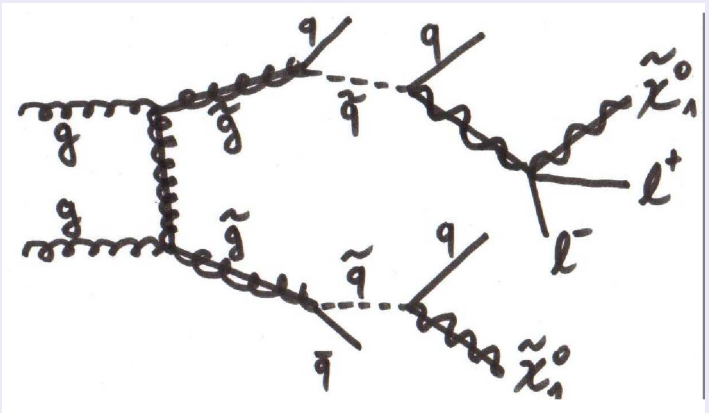




- Signal/background ratio depends on central jet veto.
  (rapidity gap between two "tagging jets",
  $\Longrightarrow$ beautiful signal at leading order)
- But: How many jets come at higher orders?
  $\Longrightarrow$ currently studied.

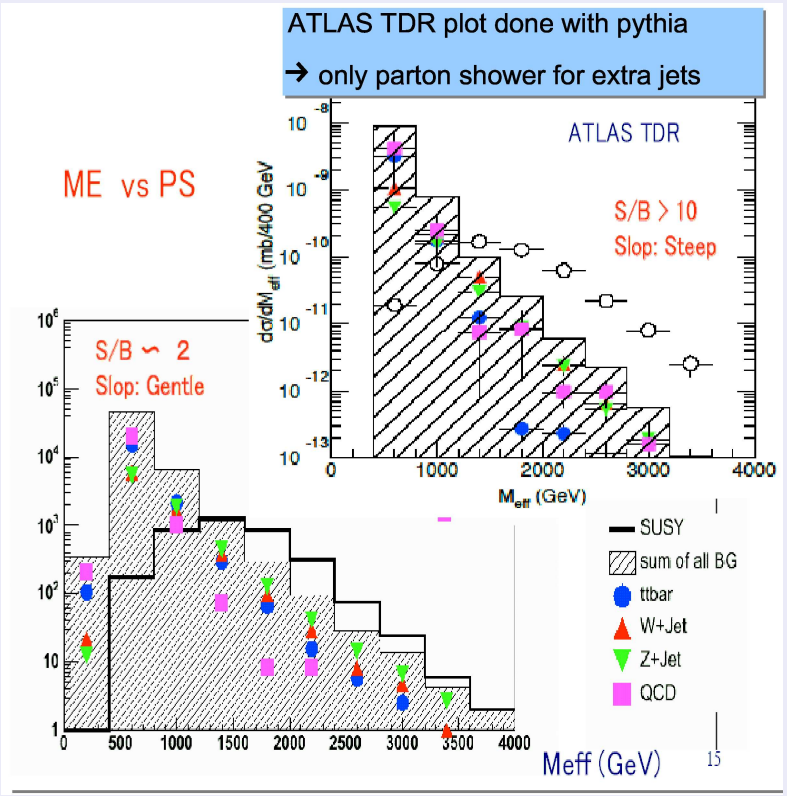
Multijets: Motivation

SUSY searches



- Large $\sigma_{\rm prod}$
- Many hard jets.
- $M_{\rm eff} = \sum p_\perp^{\rm hard}$.

Quick Discovery?



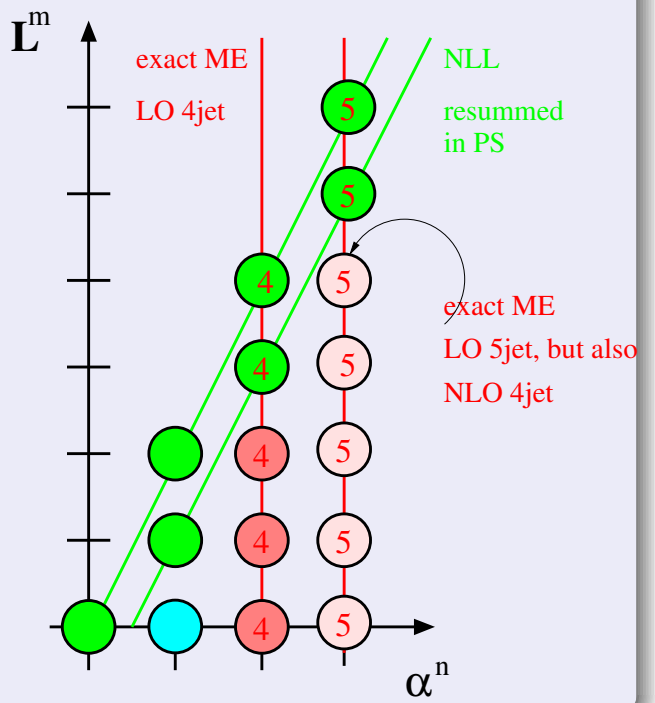
Multijets: MC-Comparison

Introducing SHERPA

T.Gleisberg, S.Höche, F.K., A.Schälicke, S.Schumann and J.C.Winter, JHEP **0402** (2004) 056

- New event generator in C++;
- Matrix elements @ LO, combined with parton shower

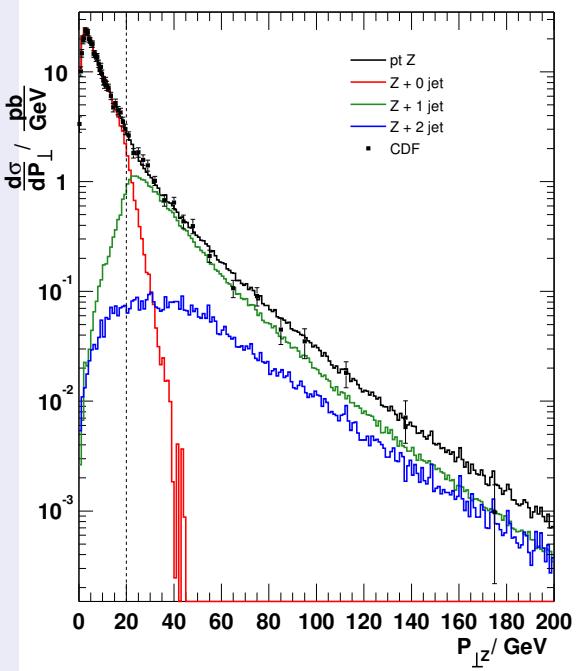
  (S.Catani *et al.* JHEP **0111** (2001) 063
  F.K., JHEP **0208** (2002) 015);
- Hadronization by Pythia;
- Underlying event a la Pythia (old version), showers added.

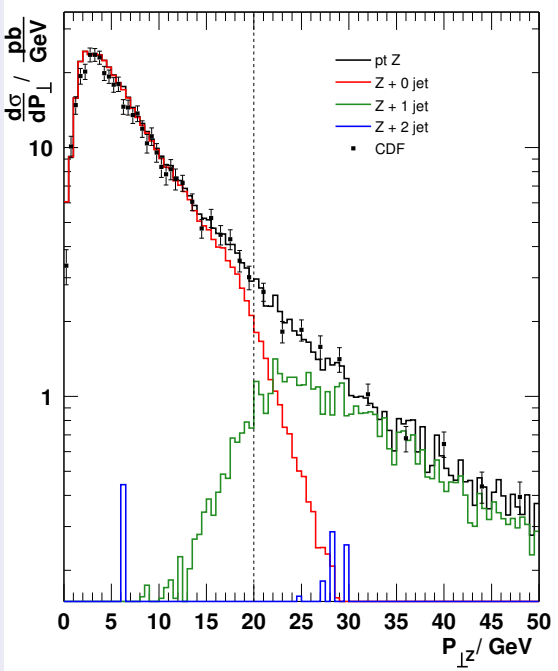


Multijets: MC-Comparison

$p_\perp$ of Z-bosons in $p\bar{p} \longrightarrow Z + X$ @ Tevatron

Data from CDF, Phys. Rev. Lett. 84 (2000) 845

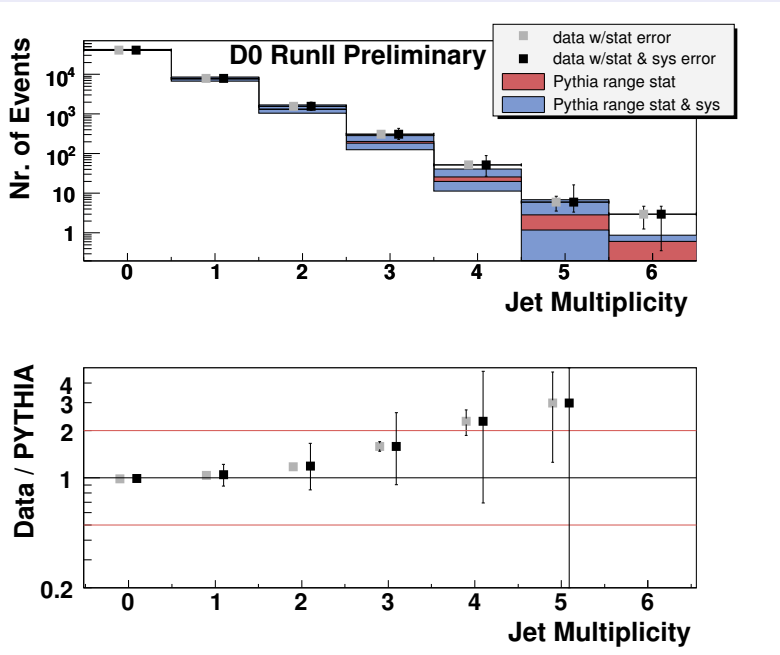


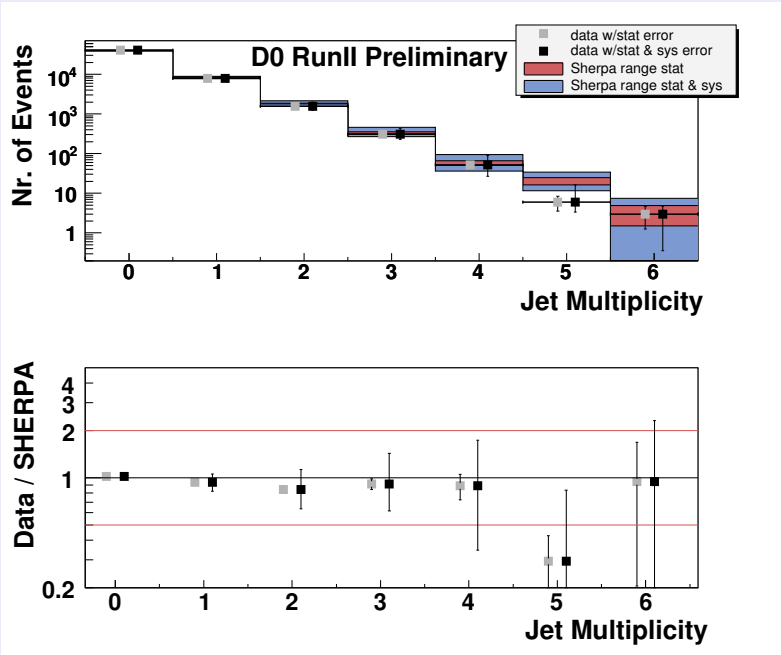


Multijets: MC-Comparison

Jet rates in $p\bar{p} \longrightarrow Z + X$ @ Tevatron

(D0-Note 5066)

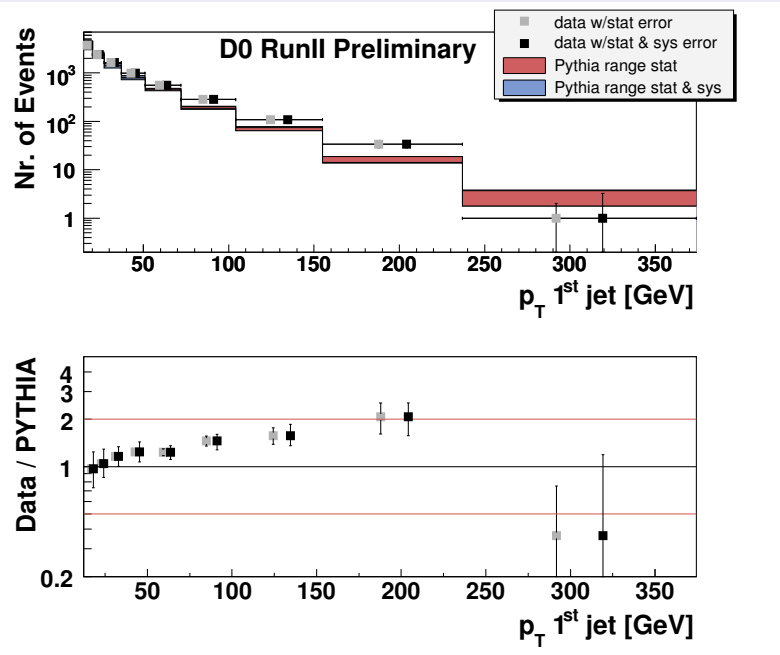


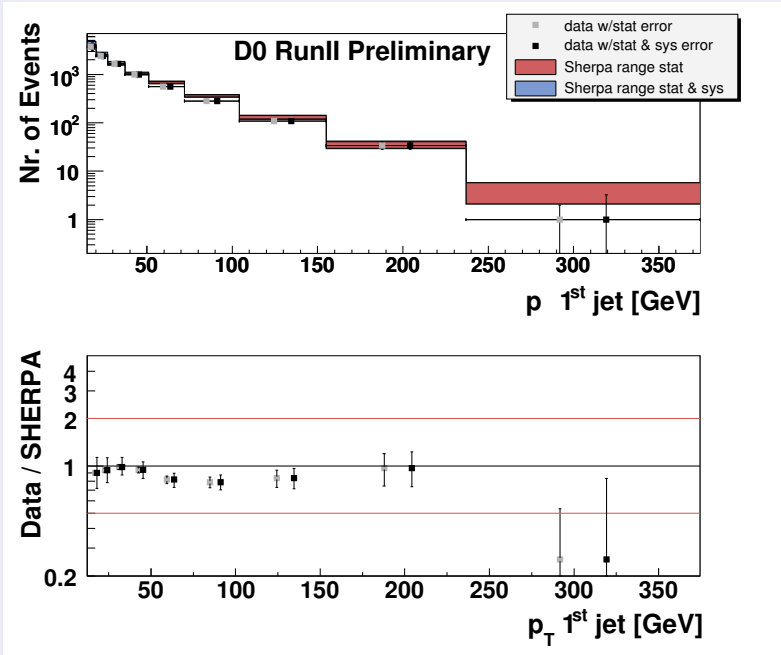


Multijets: MC-Comparison

Jet spectra (1st jet) in $p\bar{p} \longrightarrow Z + X$ @ Tevatron

(D0-Note 5066)

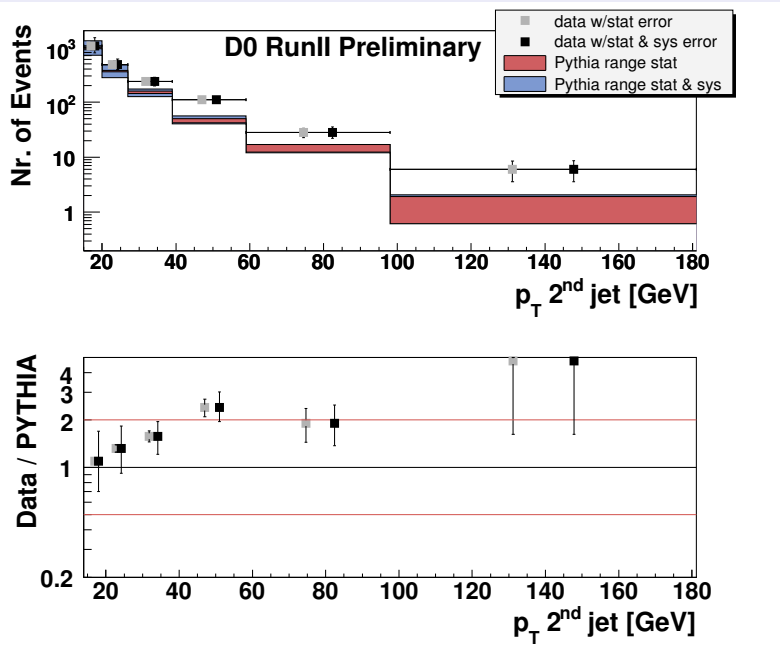


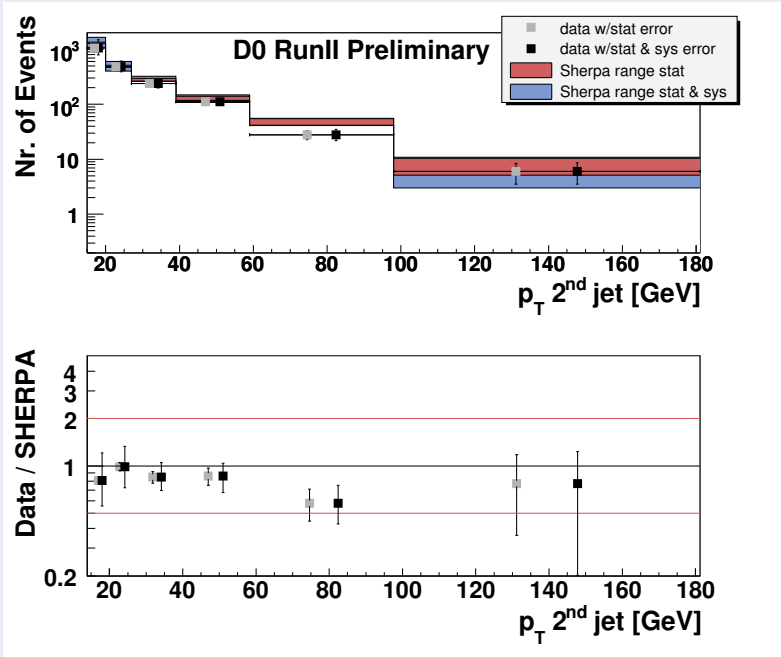


Multijets: MC-Comparison

Jet spectra (2nd jet) in $p\bar{p} \longrightarrow Z + X$ @ Tevatron

(D0-Note 5066)

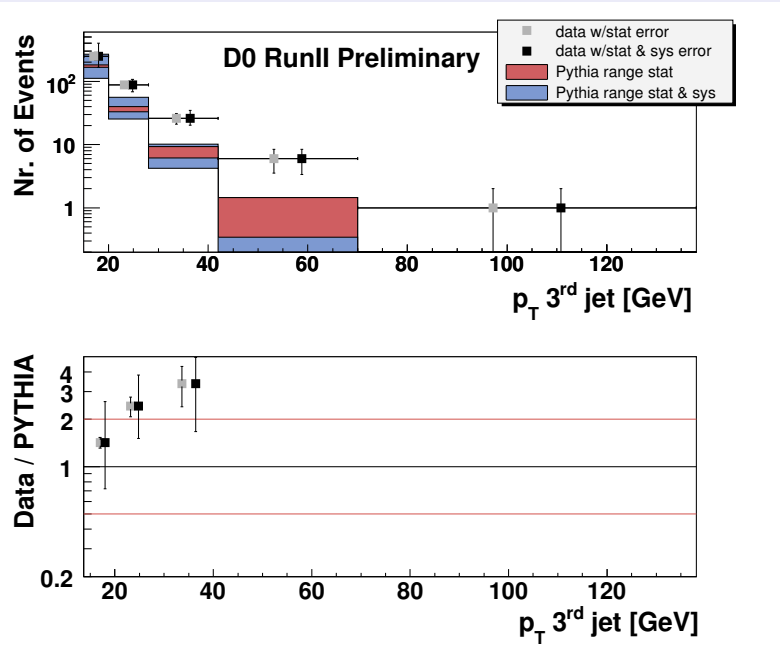


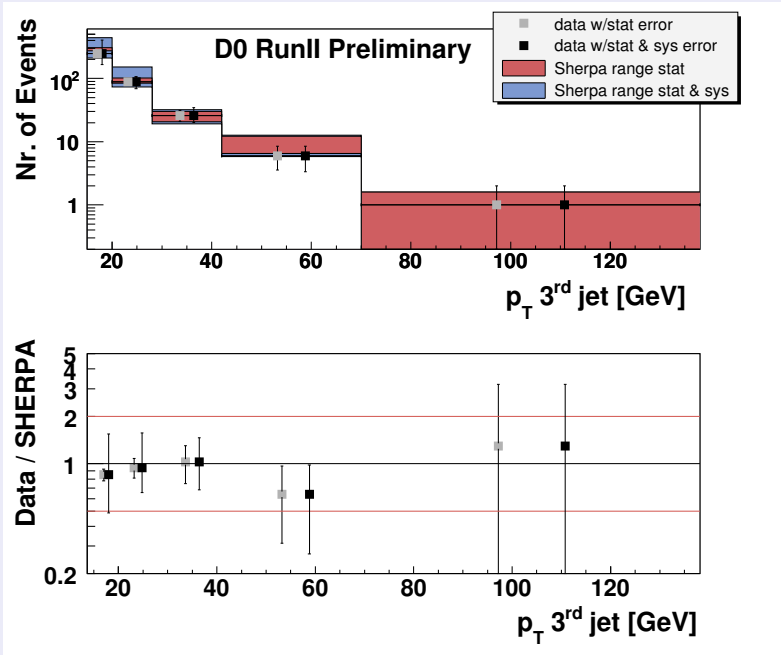


Multijets: MC-Comparison

Jet spectra (3rd jet) in $p\bar{p} \to Z + X$ @ Tevatron

(D0-Note 5066)

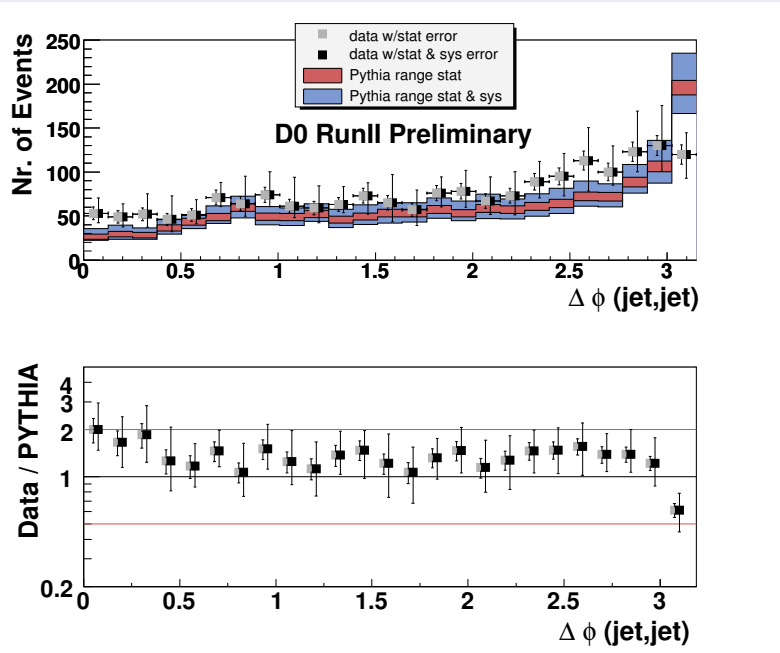


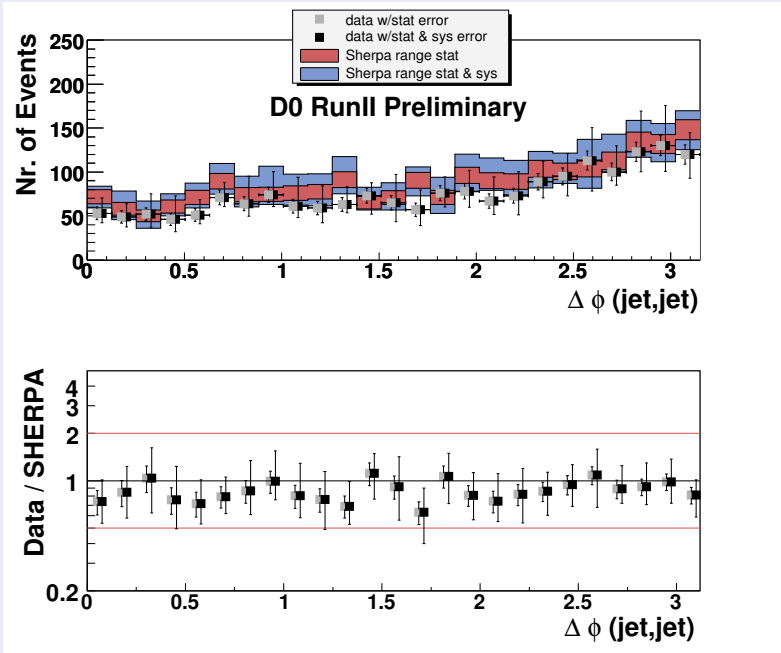


Multijets: MC-Comparison

$\phi_{1.\mathrm{jet},2.\mathrm{jet}}$ in $p\bar{p} \longrightarrow Z + X$ @ Tevatron

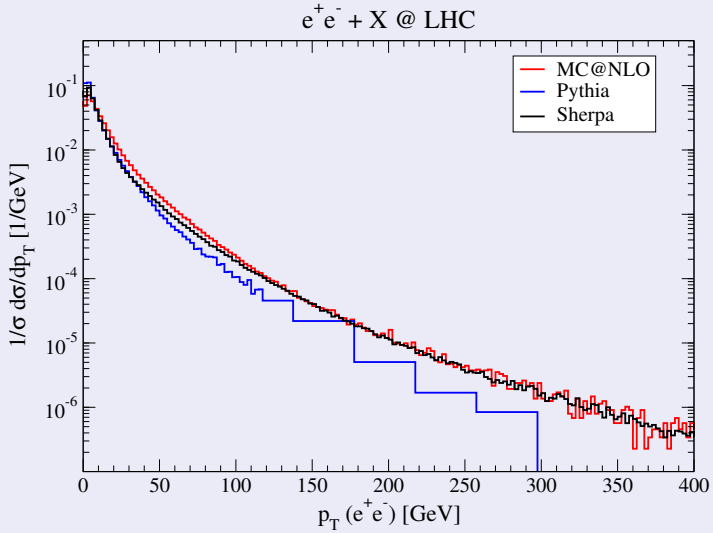
(D0-Note 5066)

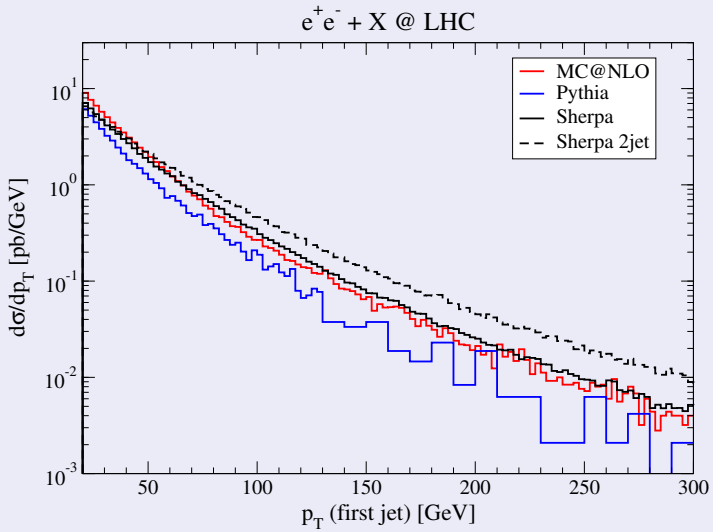




Multijets: MC-Comparison

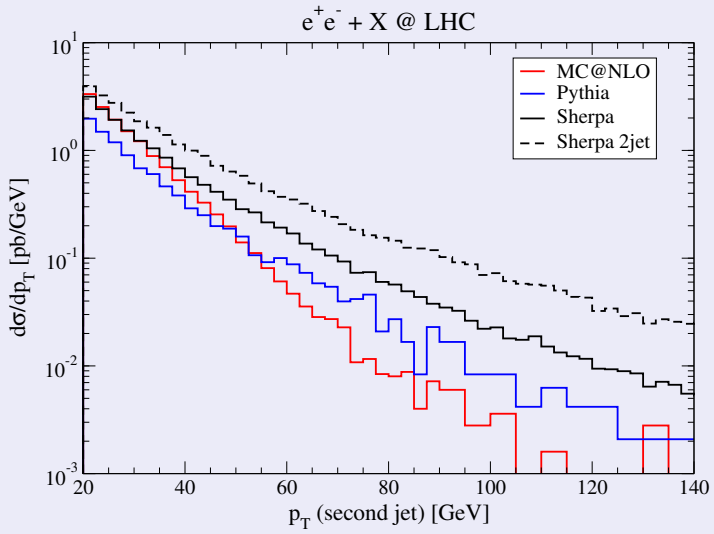
Extrapolation to LHC: $p_\perp^{Z,\mathrm{jet}}$ in $Z+$ jets

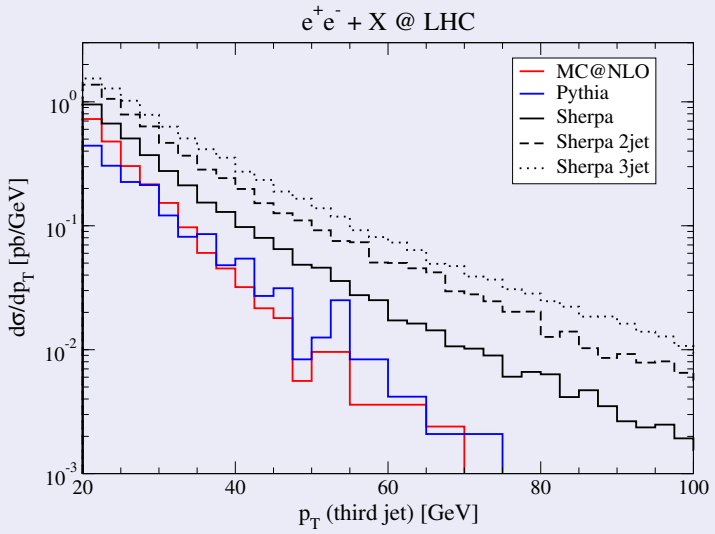




Multijets: MC-Comparison

Extrapolation to LHC: $p_\perp^{Z,\mathrm{jet}}$ in $Z+$ jets





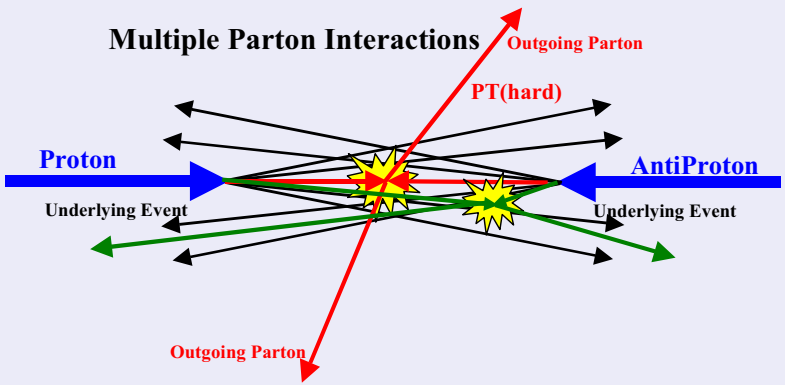
Underlying event

In the following: Data from CDF, PRD 65 (2002) 092002, plots partially from C.Buttar

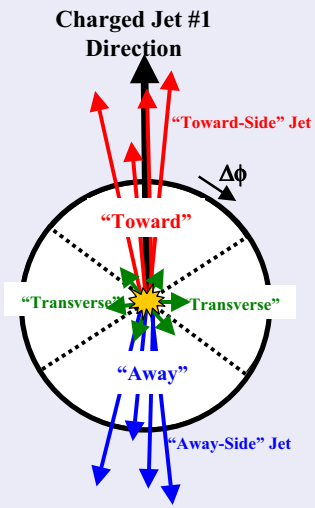
Multiple parton interactions

Model:

- Incoherent parton-parton interactions
- Ordered in $p_\perp$ (or similar)
  $\Longrightarrow$ scales with Q^2 of hard interaction

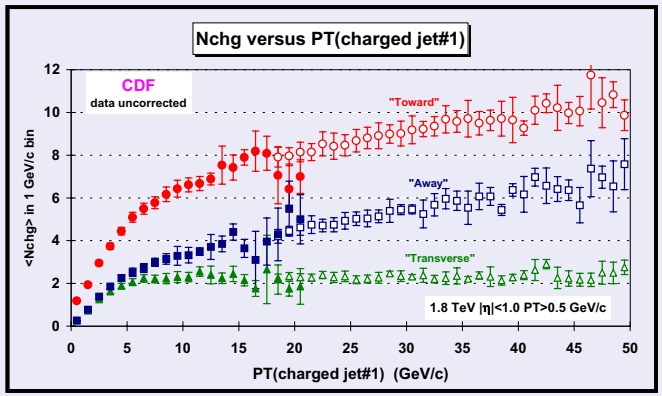


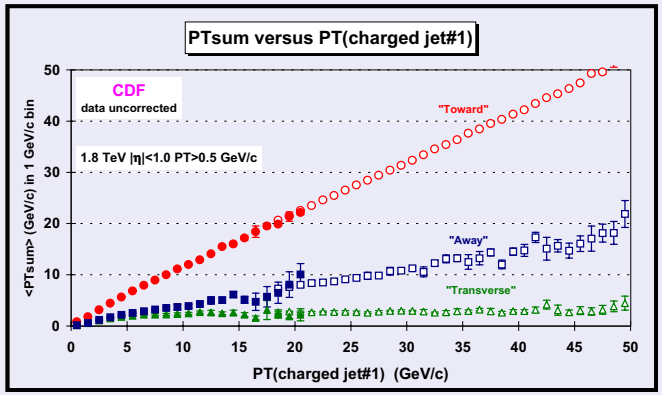
Observables



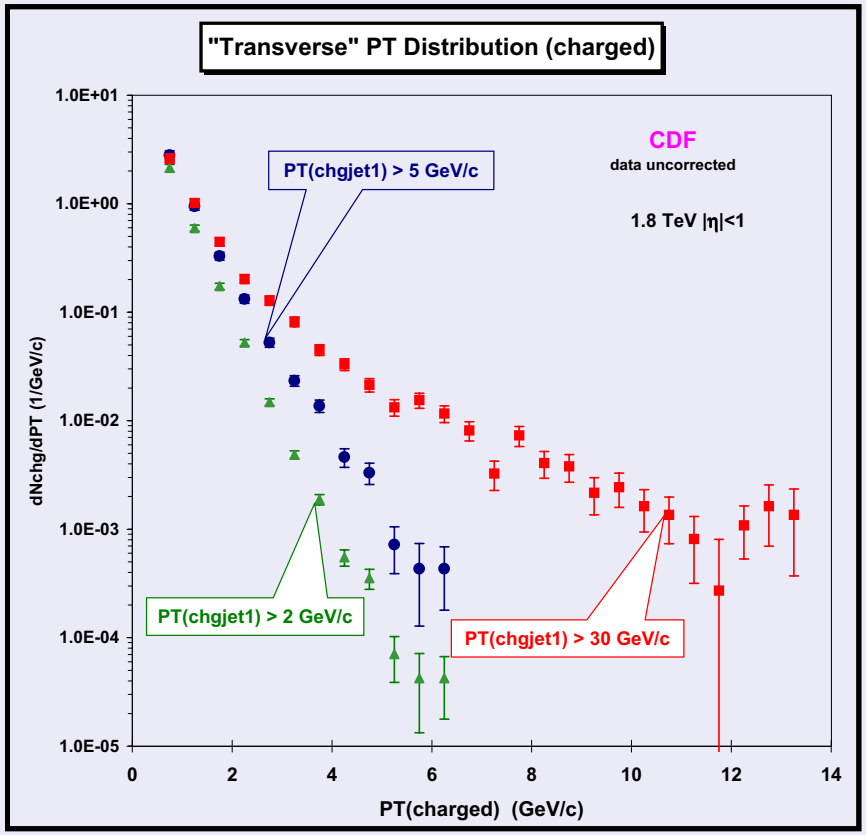
Underlying event

Compare 3 regions



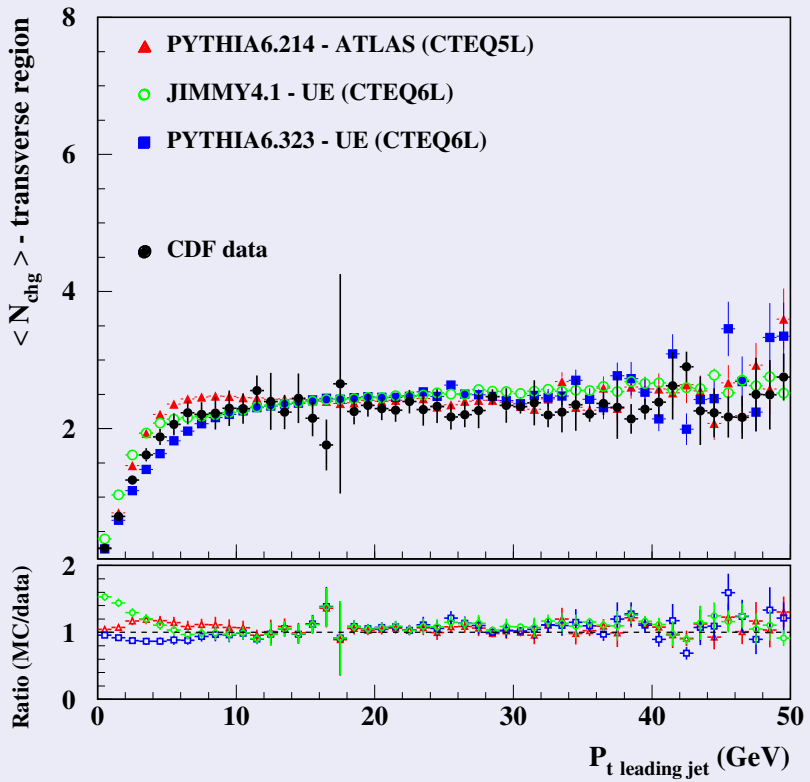


$p_\perp$ @ Tevatron, transverse

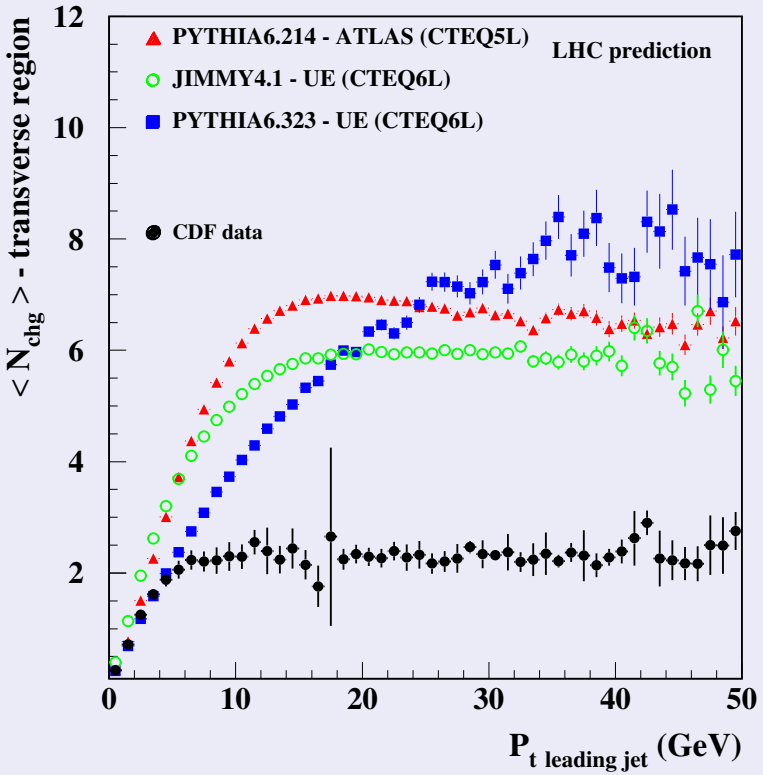


Underlying event

From Tevatron ...

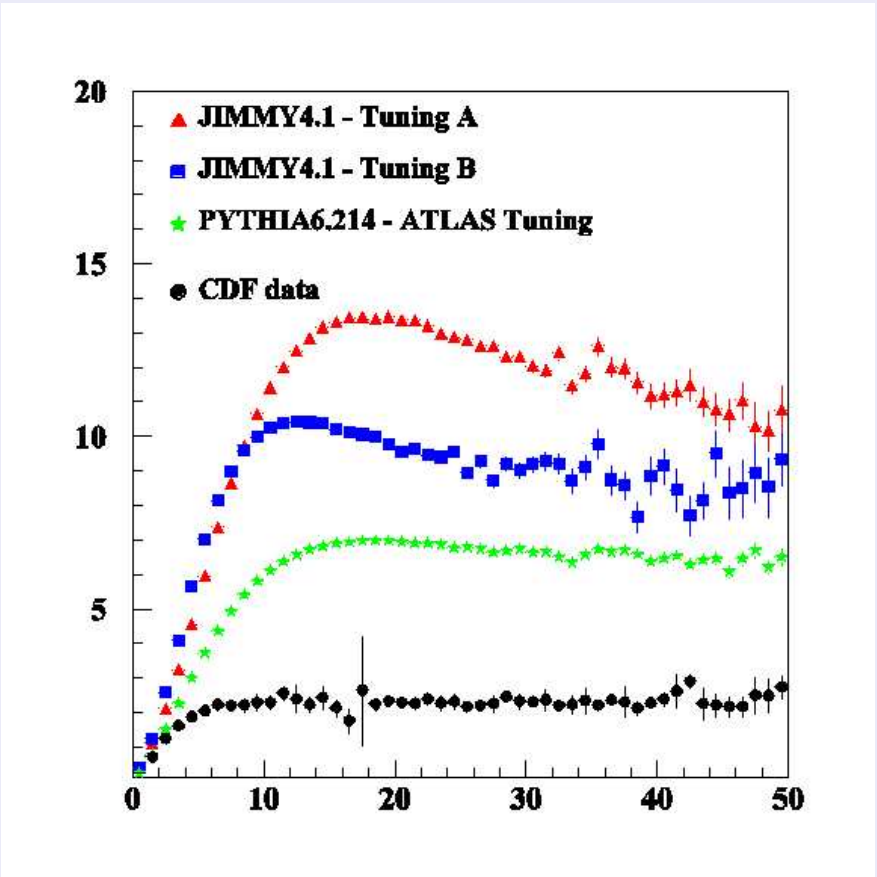


... to LHC ...



Underlying event

. . . or is it rather this?



Summary

- Success of LHC probably depends on detailed understanding of QCD
- The first few years of LHC running are a great time for QCD-addicts
- There is leeway for an improved understanding of QCD - on all levels between theory and experiment
- There are still puzzles and problems to be resolved -
  - from technicalities:
    sufficient precision in PDFs, jets and their definitions, multijets (a personal selection)
  - to basics:
    underlying event, interplay of soft & hard QCD ...