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PDFs and Monte Carlo Tunings

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Summary

- Introduction
- PDFs
- Underlying Event
- Matrix Element Matching
- Conclusions

Introduction

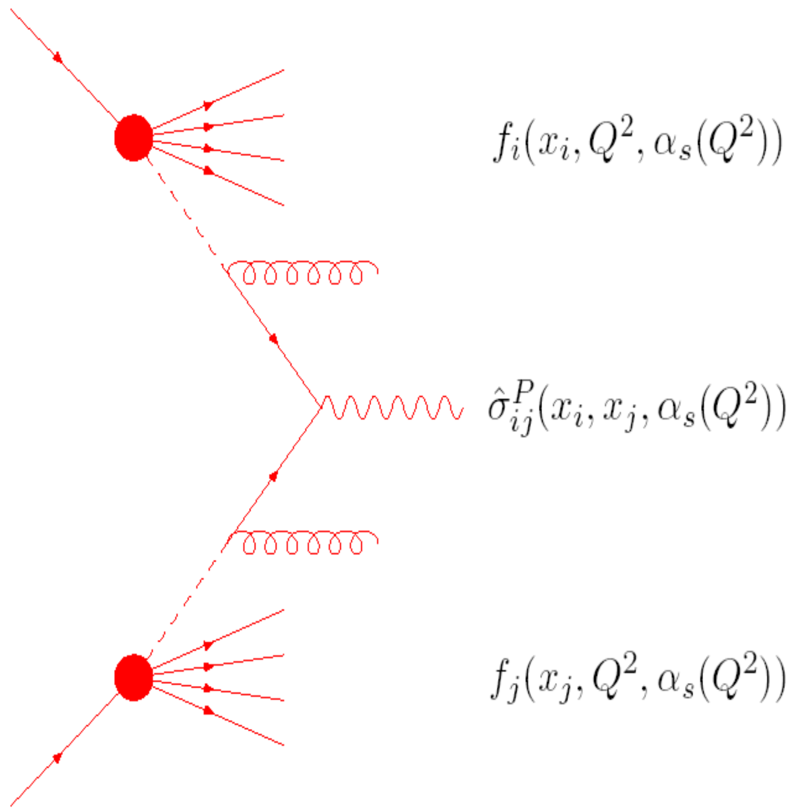
- Most of the recent talks I've seen on using Tevatron experience for the LHC have concentrated on
  - PDFs
  - Underlying Event
- While these are both important rather than repeat things from one of Robert Thorne, Craig Buttar or Rick Field's talks I'll concentrate on other Monte Carlo related issues.
- The main one is matching parton showers and higher order matrix elements.

PDFs

- So the basic issues for PDFs from the Tevatron to the LHC are probably best summarised in Robert Thorne's talk at on 'Expectations from the early LHC data' at the IOP meeting on 'LHC - the first year of physics.'
- I'm by no means an expert on PDFs so I will recap the basics and point out the potential problems.

PDFs

- The PDFs are a non-perturbative input to all cross sections at the LHC.
- They are universal, once they have been measured at one experiment they can be evolved using perturbative evolution to higher energies to predict LHC cross sections
- The results of many experiments go into the fits, ZEUS/H1, CDF/D0 and many earlier DIS/fixed target experiments.

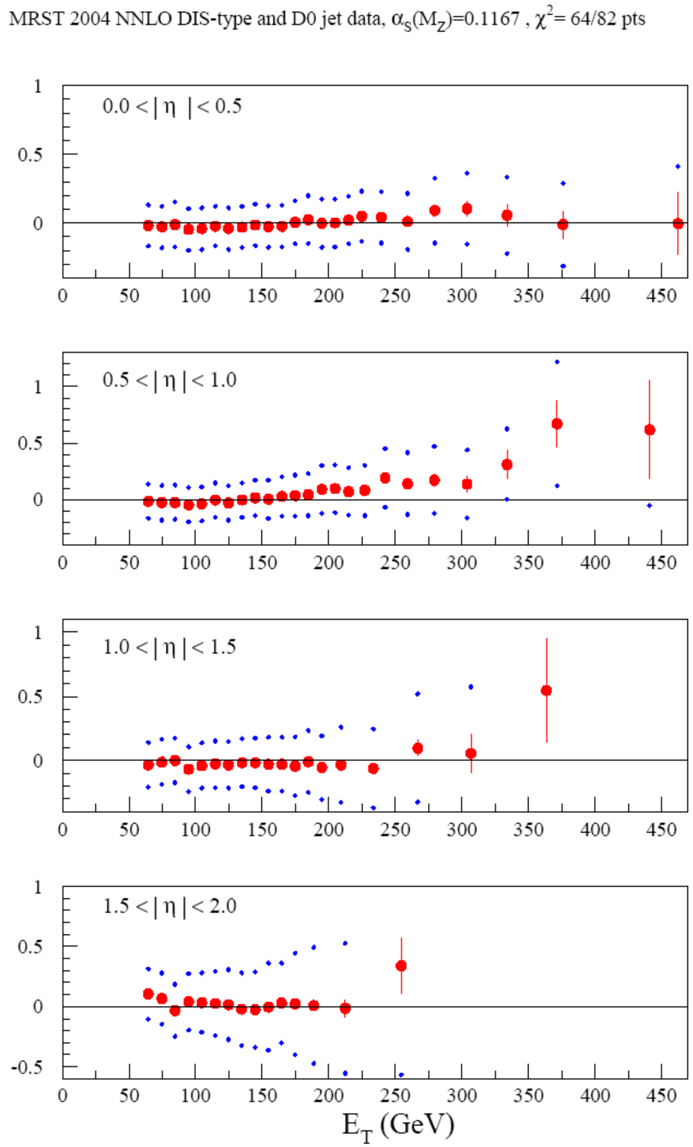


PDFs

- The main input from the Tevatron into the PDFs are
  - W asymmetry
  - High p_T jet cross section
- In general performing the fit is something of an art, in particular the calculation of the error.

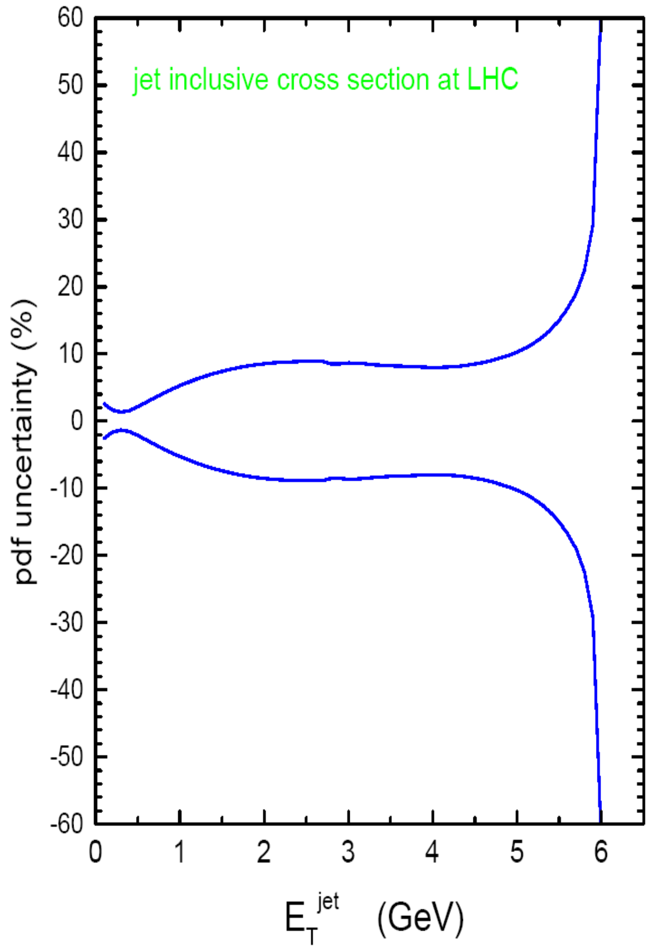
PDFs

- The main thing to be learnt from the Tevatron is related to the error on the PDFs.
- There are two possible causes for an excess of high E_T jets
  - New physics
  - high-x gluon PDF
- At the Tevatron there was an excess due to gluon PDF, established by looking at non-central rapidity
- High-x gluon PDF effects forward jet production but new physics doesn't.

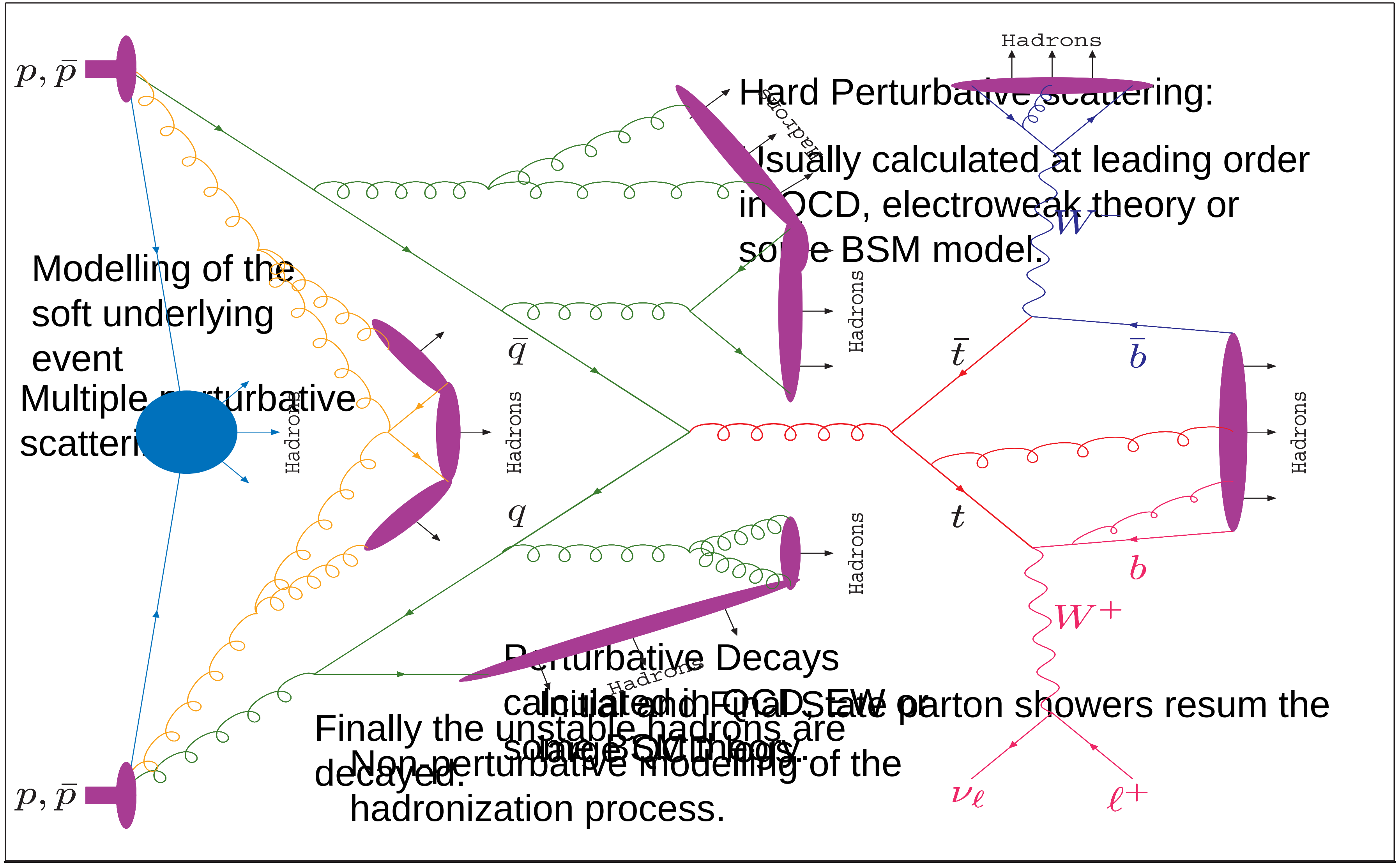


PDFs

- This has lead to the development of PDF sets including an estimate of the error.
- However at the LHC it will be important to look at both forward and central jet production in order to disentangle the new physics and PDF effects.
- There are other potential problems, such as small-x effects, at the LHC.



A Monte Carlo Event



Hard Perturbative scattering:

Usually calculated at leading order in QCD, electroweak theory or some BSM model.

Modelling of the soft underlying event

Multiple perturbative scattering.

Perturbative Decays calculated in QCD, EW or some BSM theory.

Initial and Final State parton showers resum the large QCD logs.

Finally the unstable hadrons are decayed.

Non-perturbative modelling of the hadronization process.

Monte Carlo Event Generators

- The different event generators use different approximations or models for the different stages of the event.
- However the overall strategy is the same.
- All the programs have a (large) number of parameters.
- In general the hope is that if the parameters are tuned at one energy/collider they can be used at other machines (universality.)
- However not all experiments probe all the parameters.

Monte Carlo Parameters

- We use the parton shower to evolve from the high energy of the collision to a low energy where we use the non-perturbative models.
- This should ensure the universality of the parameters just like the PDFs.
- In general if the parameters are energy dependent then there is some missing physics in the evolution.

Monte Carlo Parameters

Parameters	Experiments/Colliders
Hadronization	LEP
Final-State Shower	LEP
Underlying Event	Tevatron/HERA
Initial-State Shower	Tevatron
Matrix Element Matching Procedures	Tevatron
Hadron Decays	B factories/Tevatron/LEP

Monte Carlo Parameters

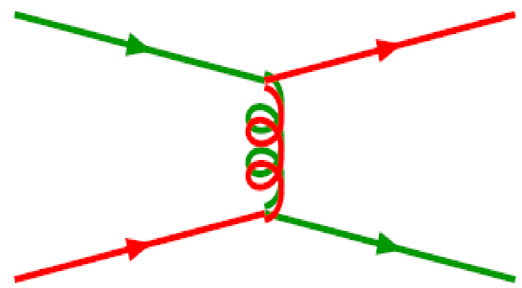
- Most of the parameters relating to the hadronization and final-state parton shower are tuned to LEP data.
- Many of them, in particular the rates for the production of particular hadrons are hard/impossible to measure in hadron collisions.
- However the parameters relating to the underlying event and initial-state shower must be tuned to Tevatron data.

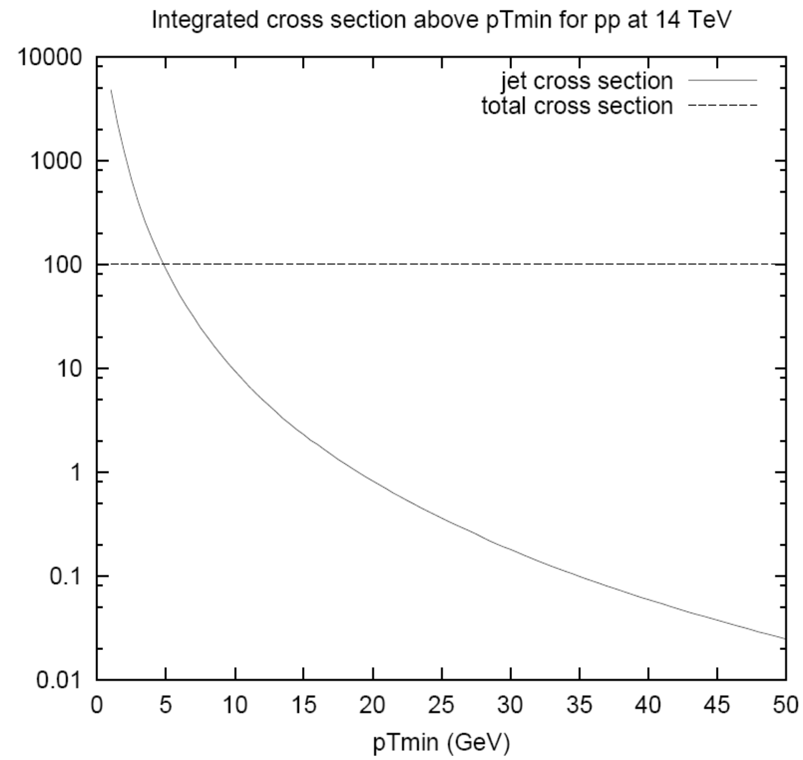
Multiparton Interaction Models

- The cross-section for 2→2 scattering is dominated by t-channel gluon exchange.
- It diverges like

$$\frac{d\sigma}{dp_\perp^2} \approx \frac{1}{p_\perp^4} \quad \text{for} \quad p_\perp \to 0$$

- This must be regulated used a cut of p_{Tmin}.
- For small values of p_{Tmin} this is larger than the total hadron-hadron cross section.
- More than one parton-parton scattering per hadron collision



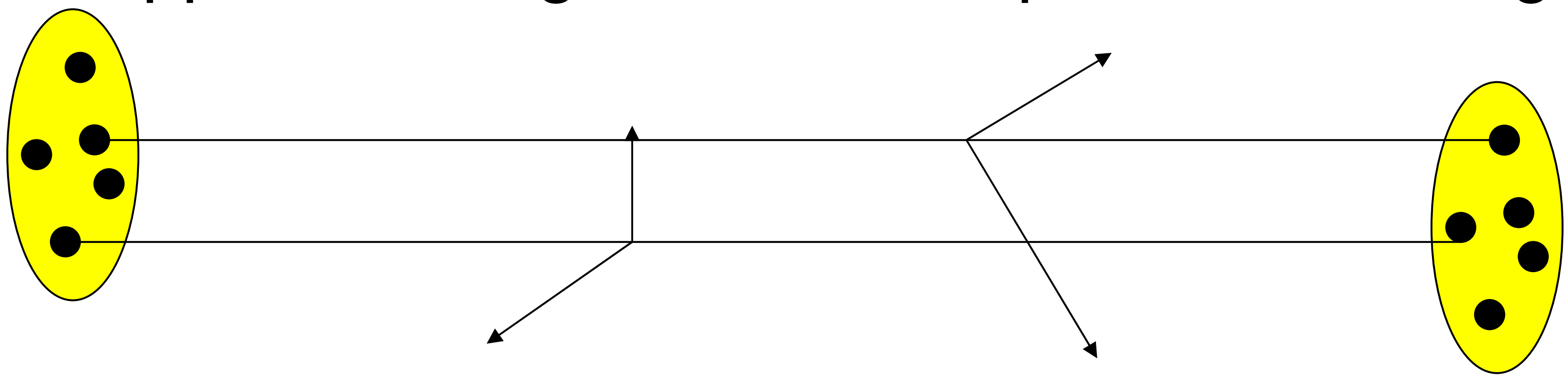


Multiparton Interaction Models

- If the interactions occur independently then follow Poissonian statistics

$$P_n = \frac{\langle n \rangle^n}{n!} e^{-\langle n \rangle}$$

- However energy-momentum conservation tends to suppressed large numbers of parton scatterings.



- Also need a model of the spatial distribution of partons within the proton.

Multiparton Interaction Models

- In general there are two options for regulating the cross section.

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}p_\perp^2} \propto \frac{\alpha_s^2\left(p_\perp^2\right)}{p_\perp^4} \rightarrow \frac{\alpha_s^2\left(p_\perp^2\right)}{p_\perp^4}\theta\left(p_\perp - p_{\perp\min}\right) \quad \text{simpler}$$

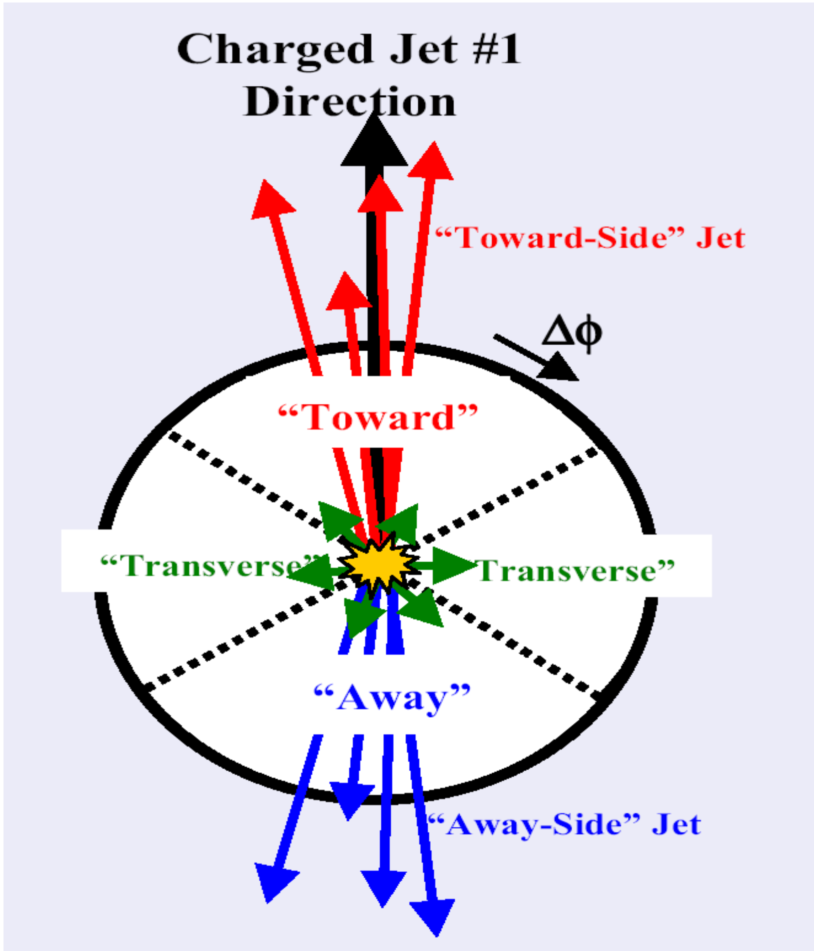
$$\text{or} \rightarrow \frac{\alpha_s^2\left(p_\perp^2 + p_{\perp 0}^2\right)}{\left(p_\perp^2 + p_{\perp 0}^2\right)^2} \qquad \text{more complicated}$$

where $p_{\perp\min}$ or $p_{\perp 0}$ are free parameters of order 2 GeV.

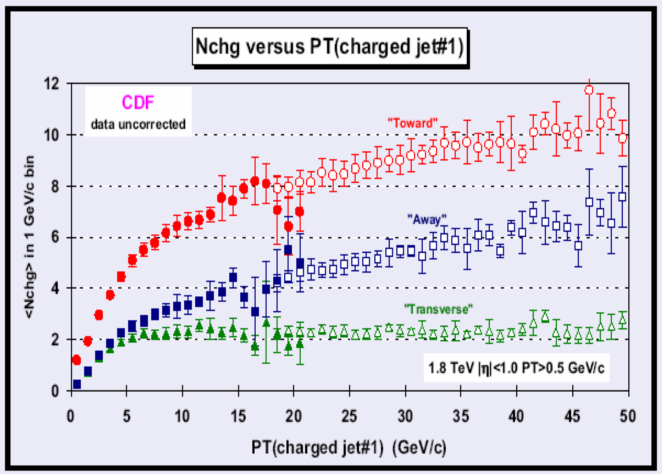
- Typically 2-3 interactions per event at the Tevatron and 4-5 at the LHC.
- However tends to be more in the events with interesting high p_T ones.

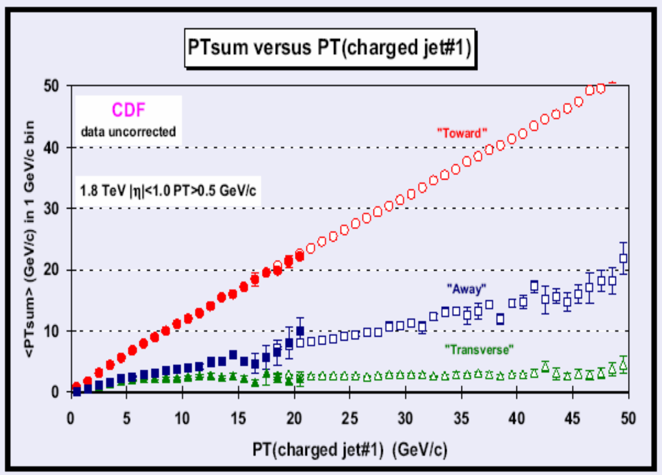
Data

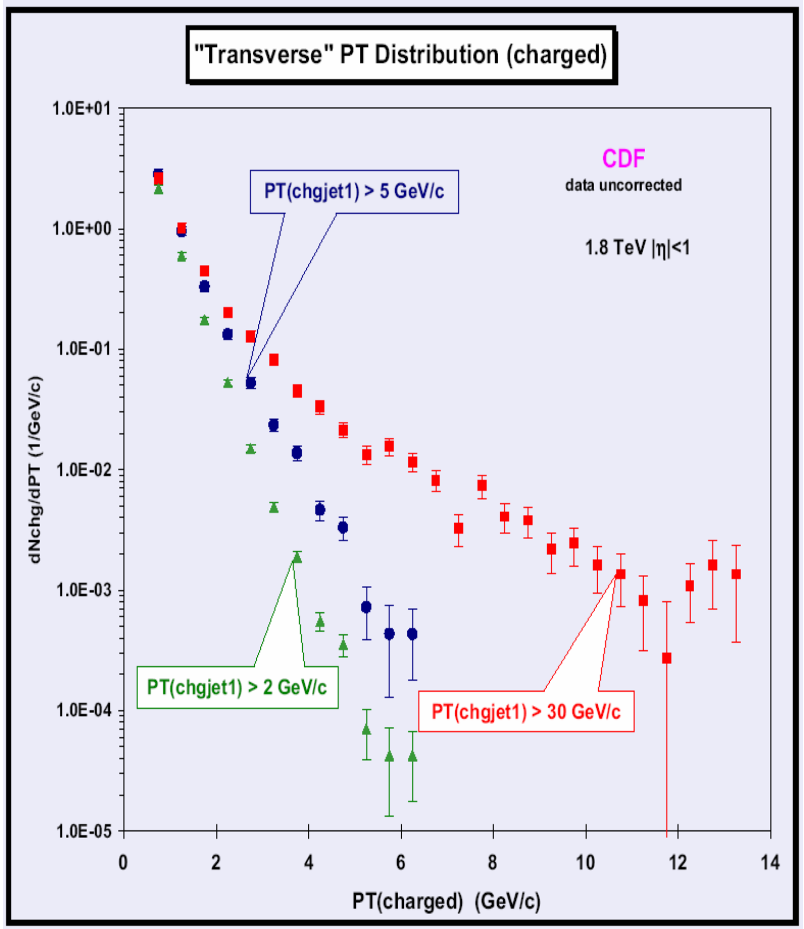
- There have been a lot of studies at the Tevatron of the underlying event.
- Define three regions
  - Toward near the leading jet
  - Away near the second jet
  - Transverse to both jets
- Expect the underlying event in the transverse region.



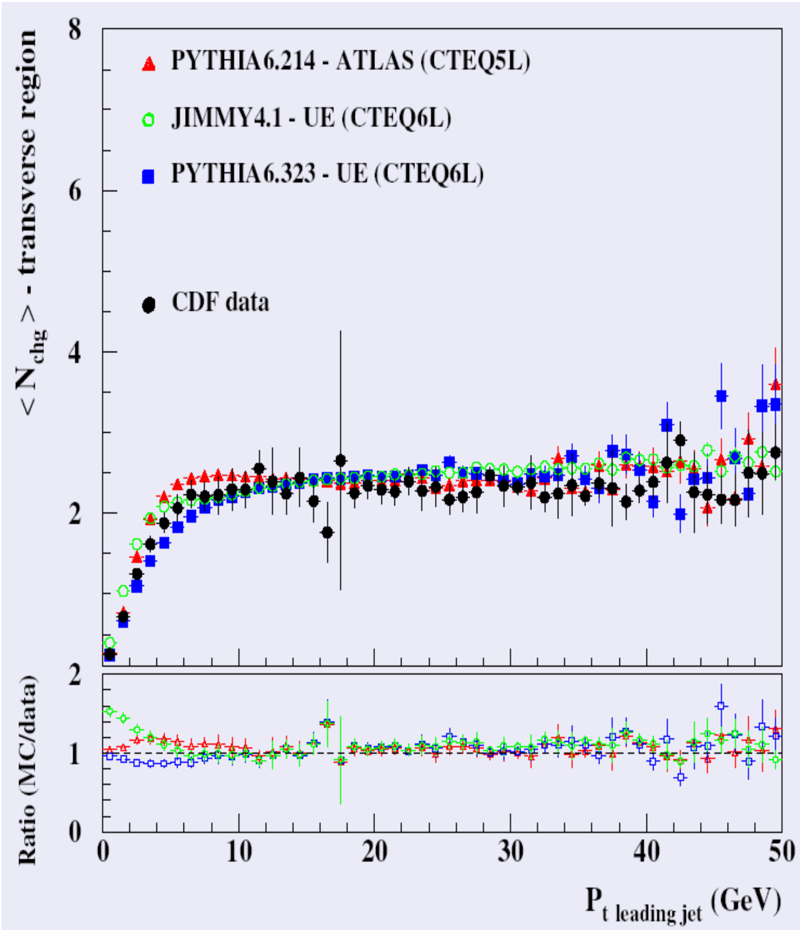
Data

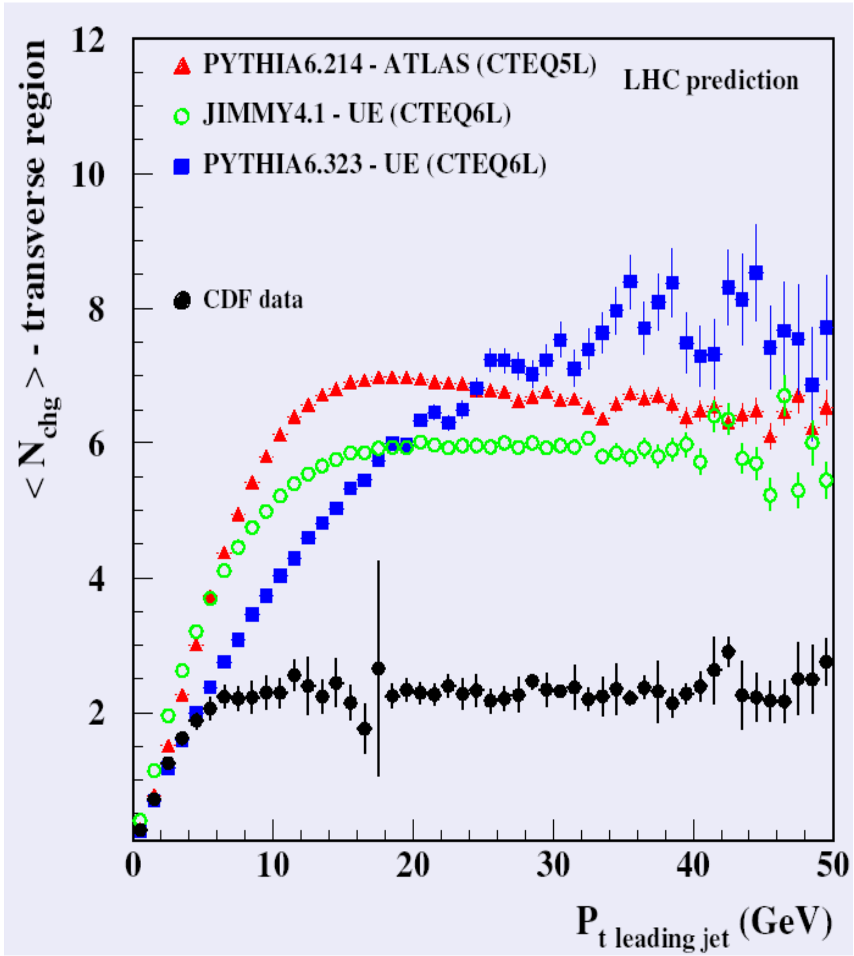

Nchg versus PT(charged jet#1)
CDF
data uncorrected
"Toward"
"Away"
"Transverse"
1.8 TeV |η|<1.0 PT>0.5 GeV/c
<Nchg> in 1 GeV/c bin
PT(charged jet#1) (GeV/c)


PTsum versus PT(charged jet#1)
CDF
data uncorrected
1.8 TeV |η|<1.0 PT>0.5 GeV/c
"Toward"
"Away"
"Transverse"
<PTsum> (GeV/c) in 1 GeV/c bin
PT(charged jet#1) (GeV/c)


"Transverse" PT Distribution (charged)
CDF
data uncorrected
1.8 TeV |η|<1
PT(chgjet1) > 5 GeV/c
PT(chgjet1) > 2 GeV/c
PT(chgjet1) > 30 GeV/c
dNchg/dPT (1/GeV/c)
PT(charged) (GeV/c)

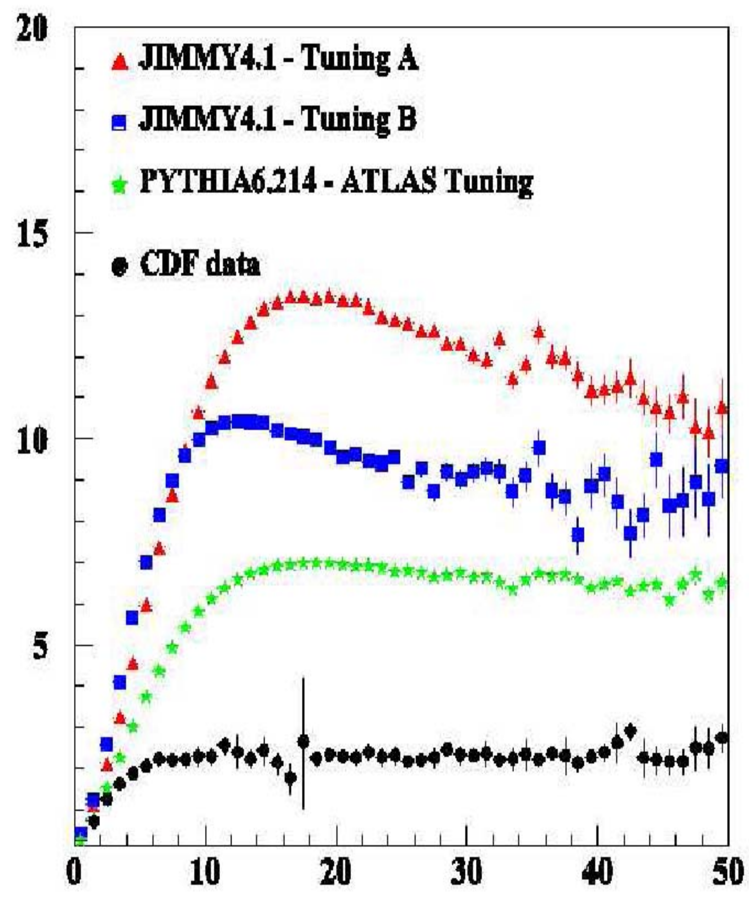
and for the LHC?





and for the LHC?

- Problem is that unlike the PDFs and the parton shower we don't know what the energy dependence should be.
- Makes it hard to extrapolate to the LHC as the lever arm in energy we have from CERN experiments and the Tevatron isn't large enough.



Hard Jet Radiation

- The parton shower is designed to simulate soft and collinear radiation.
- While this is the bulk of the emission we are often interested in the radiation of a hard jet.
- This is not something the parton shower should be able to do, although it often does better than we expect.
- If you are looking at hard radiation HERWIG/PYTHIA will often get it wrong.

Hard Jet Radiation

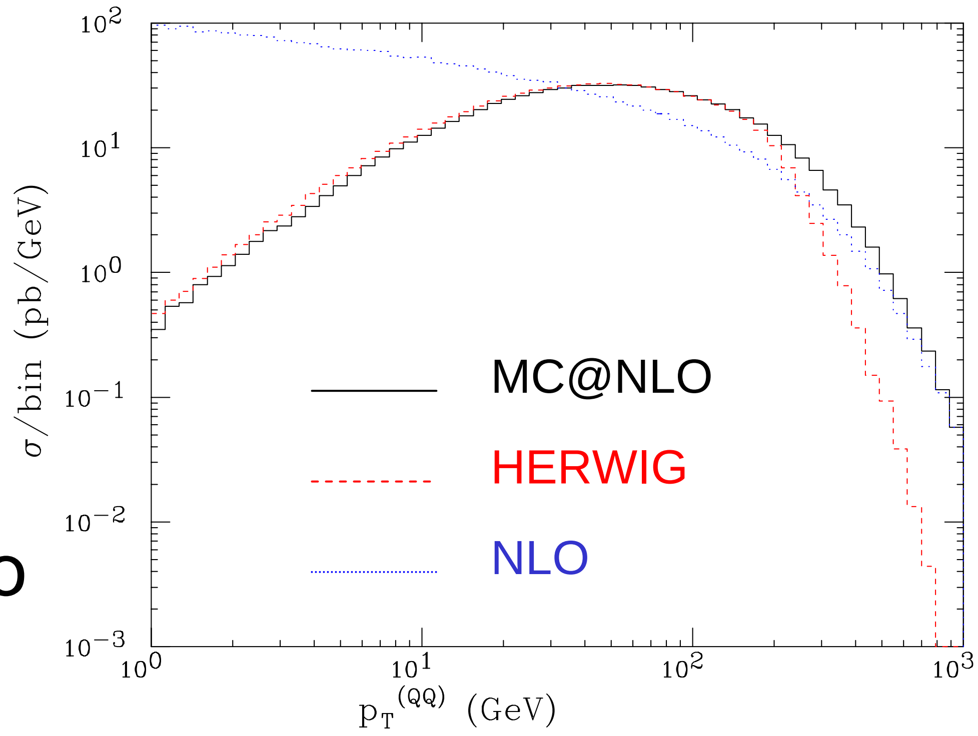
- There has been a lot of work in this area in the last 5 years.
- In order to test the new approaches and tune new parameters we must compare and tune with Tevatron data.
- The conventional approaches give good agreement with LEP data it is only in hadron collisions where it is possible to have a lot of additional hard radiation that these techniques are needed.

Hard Jet Radiation

- There have been a number of developments
  - NLO Simulation, MC@NLO
  - Multi-Jet matching
    - MLM procedure
    - CKKW and variants
- For the NLO simulation there are no new approximations/parameters so I will concentrate on the multi-jet matching.

MC@NLO

- Idea is to include the hardest emission as in a NLO calculation and get the total cross section to NLO accuracy.
- Rigorous calculation so no new parameters, just the normal ones in the event generator.



S. Frixione, P. Nason and B.R. Webber, JHEP 0308(2003) 007, hep-ph/0305252.

Multi-Jet Leading Order

- While the NLO approach is good for one hard additional jet and the overall normalization it cannot be used to give many jets.
- Therefore to simulate these processes use matching at leading order to get many hard emissions correct.
- I will briefly review the general idea behind this approach and then show some results.

Hard Jet Radiation: General Idea

- Parton Shower (PS) simulations use the soft/collinear approximation:
  - Good for simulating the internal structure of a jet;
  - Can't produce high p_T jets.
- Matrix Elements (ME) compute the exact result at fixed order:
  - Good for simulating a few high p_T jets;
  - Can't give the structure of a jet.
- We want to use both in a consistent way, i.e.
  - ME gives hard emission
  - PS gives soft/collinear emission
  - Smooth matching between the two.
  - No double counting of radiation.
- All the schemes involve matching between the matrix element and parton shower at some p_T scale.

Two approaches

CKKW

- Simulate N jet partonic state.
- Apply weight factors for probability that no jets emitted above matching scale.
- Generate shower vetoing radiation above the matching scale.
- The weight factors ensure the different samples can be added.

MLM

- Simulate partonic N jet state.
- Generate parton shower.
- Require that all the jets above the matching scale after the shower have an associated pre-shower parton.
- For each N the shower doesn't add any more jets.
- Rejection ensures that samples with different numbers of jets can be summed

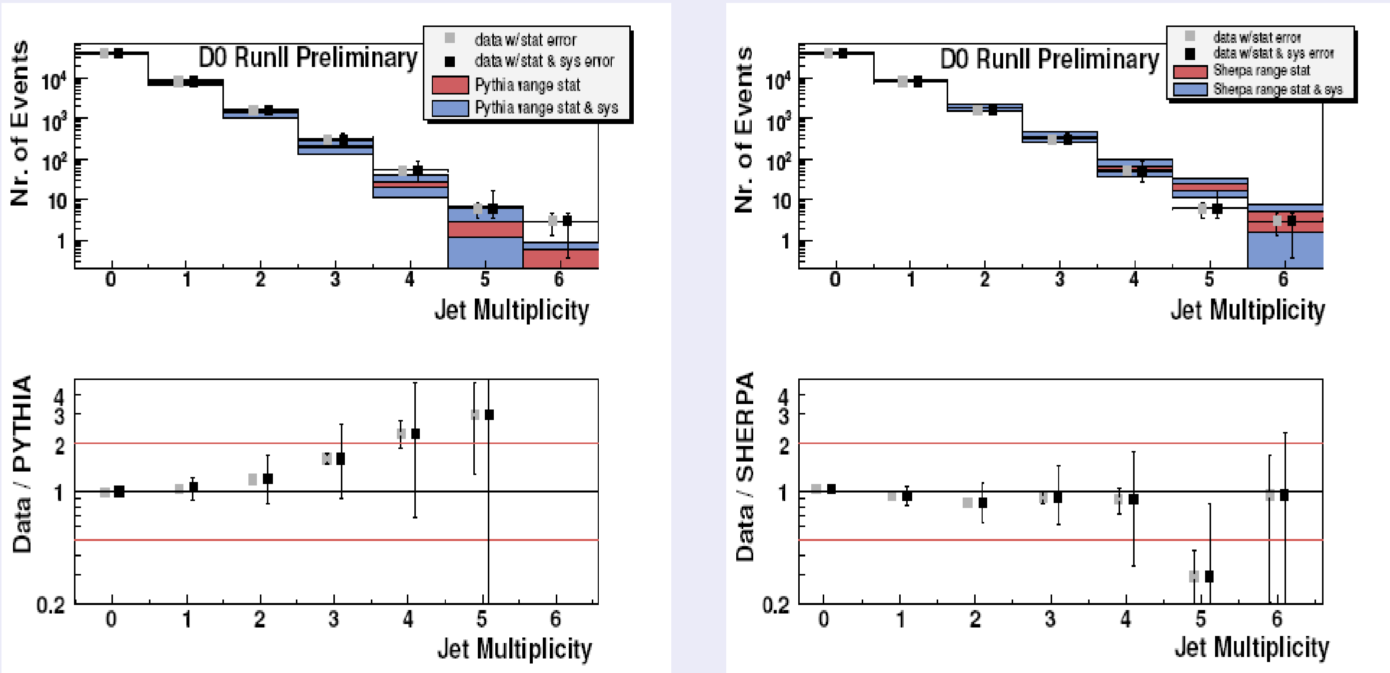
Two approaches

- While the CKKW approach is more rigorous the approaches are similar and the MLM method is easier to implement.
- The rejection of events without a match between the pre- and post-shower jets in the MLM approach plays the same role as the weight factors and veto in the CKKW approach.

CKKW results for Z +jets

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

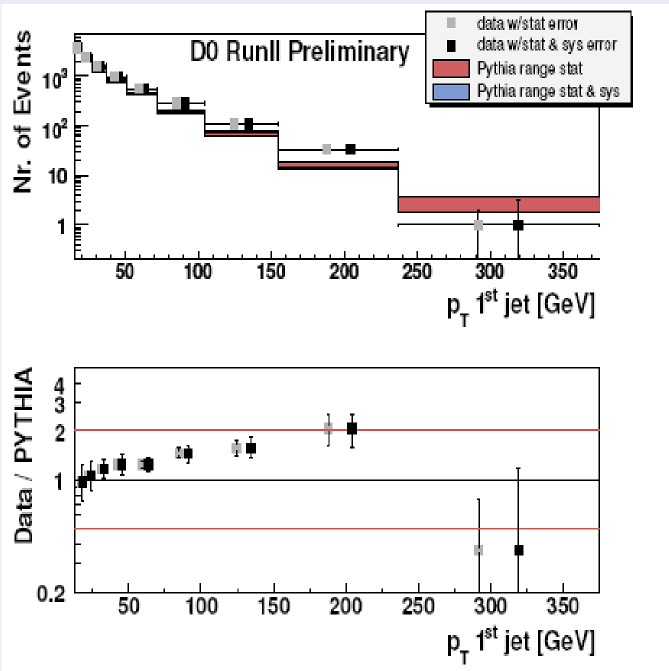
(D0-Note 5066)

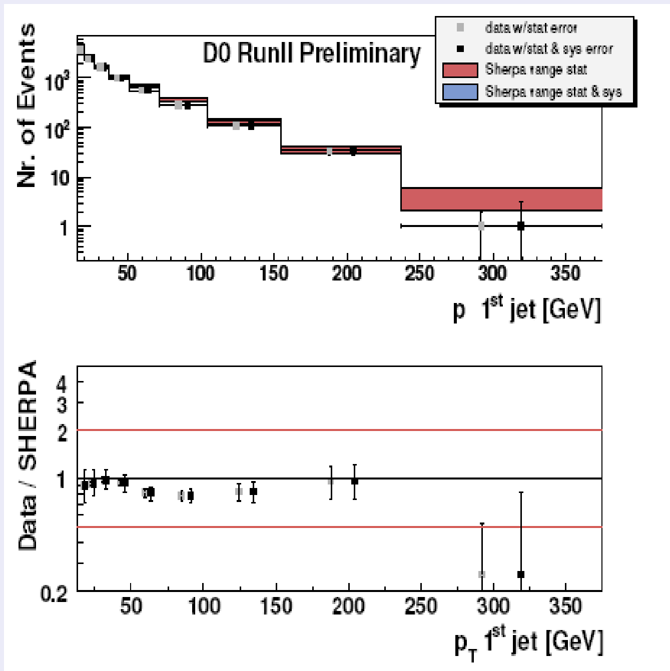


CKKW results for Z +jets

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

(D0-Note 5066)

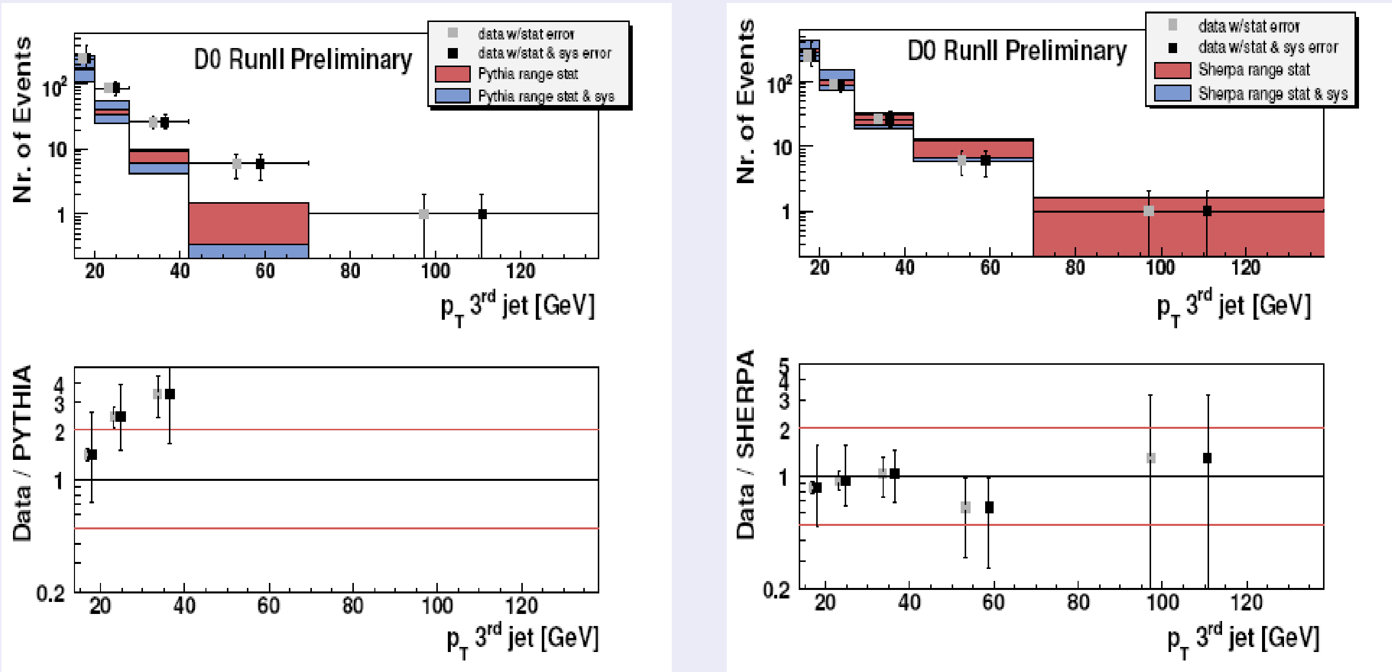




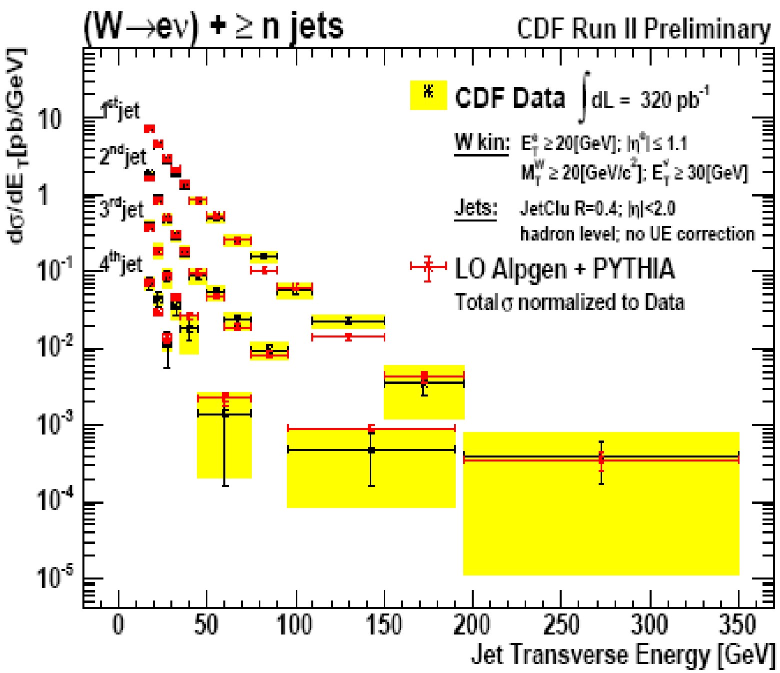
CKKW results for Z +jets

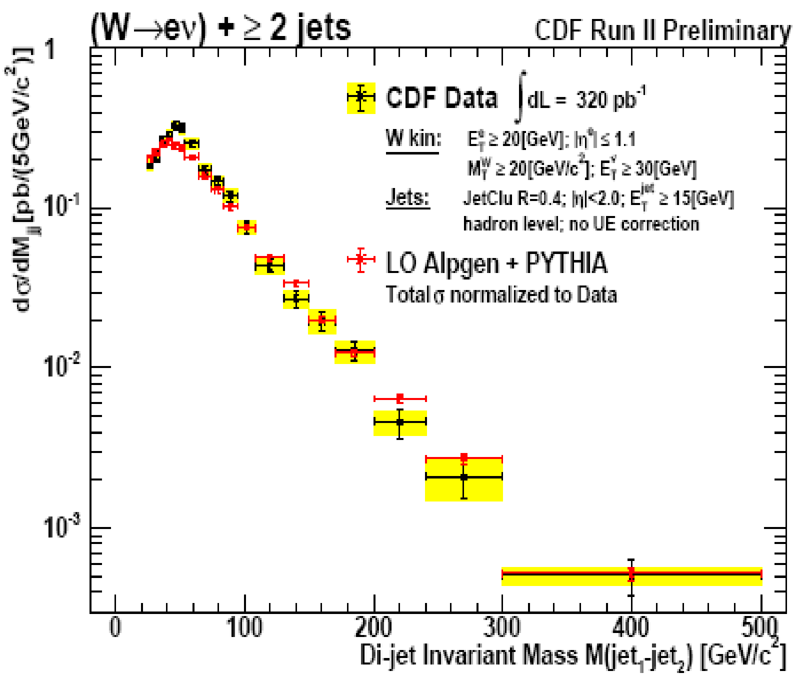
Jet spectra (3rd jet) in $p\bar{p} \rightarrow Z + X$ @ Tevatron

(D0-Note 5066)



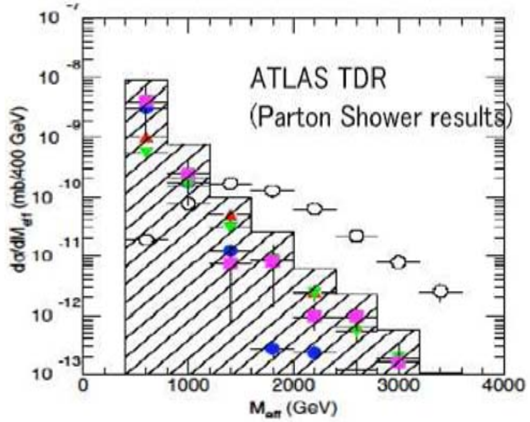
MLM Method for W+jets

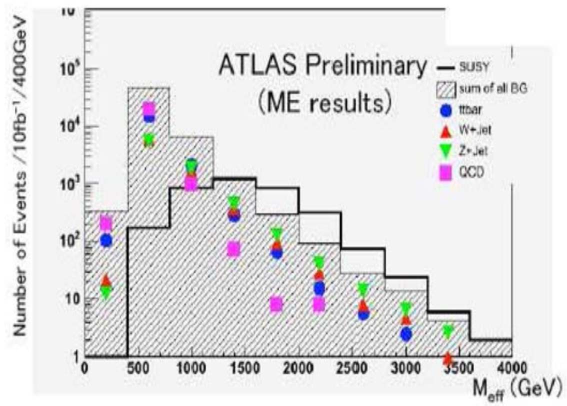




LHC

- So we need to use these new tools for the simulation of multi-jet final states.
- Important for a more realistic estimate of LHC backgrounds.





$$M_{eff} = E_T^{miss} + \sum_i P_{T,i}^{jet}$$

Conclusions

- So there is a lot to learn from the Tevatron for the LHC.
- Some things can been directly applied, where we understand the energy dependence.
- However I think that particularly in using event generators the most important thing is that the good practice developed by the Tevatron experiments continue.
- In particular use the right tool for a given analysis rather than PYTHIA for everything.