Merging multijet ME's with shower MC's: some studies of systematics

Michelangelo Mangano
TH Division, CERN
Nov 16, 2002

What systematics??

- In the generation of parton level samples to be processed through a shower evolution, we need to keep the *parton-level cuts not harder than the jet cuts*, else we loose the advantage of the correct description of hard, large-angle emission by the ME calculation
- So a reasonable starting point is to set
  - $p_{T\,parton} > p_{T\,min} = E_{T\,jet}^{min}$ *and* $\Delta R(parton\text{-}parton) > \Delta R_{cut} = \Delta R_{jet}$
- However these thresholds may not be sufficient to guarantee full generation efficiency. Parton configurations not passing these cuts might still give rise to hadronic final states passing the final jet cuts. For example, a jet below threshold might be pushed above thanks to some extra underlying event energy. As a result, one should start from softer parton-level cuts,
  - $p_{T\,min} < E_{T\,jet}^{min}$ *and* $\Delta R_{cut} < \Delta R_{jet}$
- A good, stable, *parton $\to$ shower merging algorithm* would give jet X-sections which, aside form the "efficiency effects" mentioned earlier, should be independent of the parton-level generation cuts, and in particular should converge to a finite answer for $p_{T\,min} \to 0$ *and* $\Delta R_{cut} \to 0$. The X-section should only depend on the jet-level cuts (ΔR_{jet} *and* E_{Tjet})

- Unfortunately our standard implementations of merging:

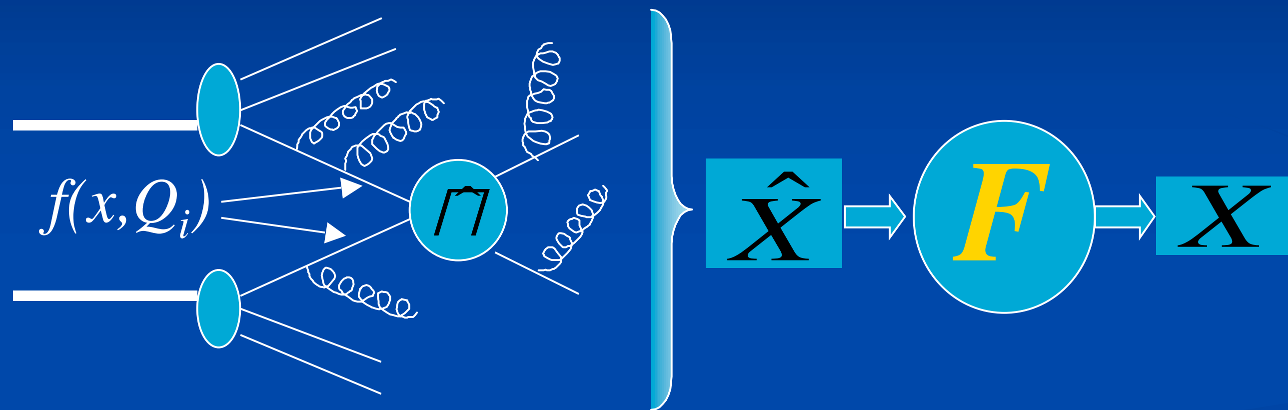
  Alpgen/Madgraph/CompHep/Grappa/etc

  $\oplus$ Herwig/Pythia/etc

  do not guarantee this stability.
- Partial solutions exist, implemented in either low-multiplicity cases, or in e^+e^-
- Goal of this study is to understand to which extent this is a problem, how large are the uncertainties, and propose some simple prescription to deal with the issue while we wait for more complete solutions

Factorization Theorem

$$\frac{d\sigma}{dX} = \sum_{j,k} \sum_{\hat{X}} f_j(x_1,Q_i)\, f_k(x_2,Q_i)\, \frac{d\hat{\sigma}_{jk}(Q_i,Q_f)}{d\hat{X}}\, F(\hat{X} \to X; Q_i,Q_f)$$



$$f_j(x,Q)$$

- sum over all initial state histories leading, at the scale Q, to:

$$\vec{p}_j = x\,\vec{P}_{proton}$$

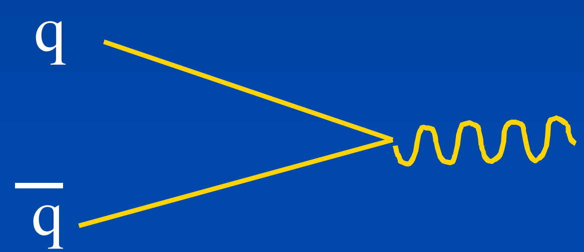
$$F(\hat{X} \to X; Q_i,Q_f)$$

- transition from partonic final state to the hadronic observable (hadronization, fragm. function, jet definition, etc)
- Sum over all histories with ***X*** in them

Q^2 choice for shower evolution

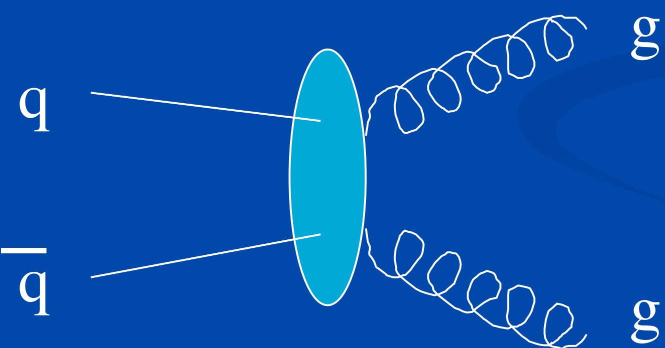
The choice is almost unambiguous for final states with 1 or 2 partons:

Ex:



Z, W □ $Q^2 = \hat{s}$

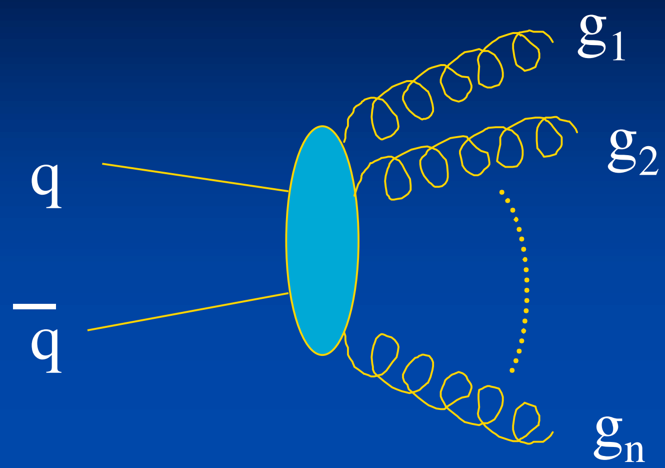
Ex:



$Q^2 \quad p_T^2 \quad -t$

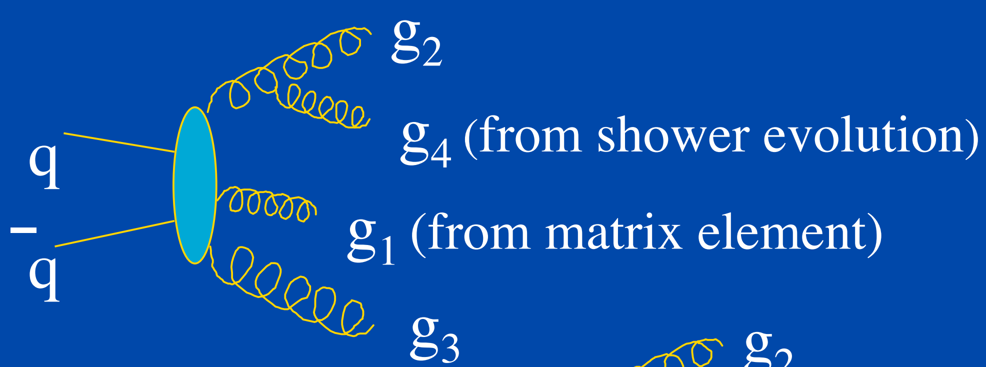
□ the factorization theorem is easily implemented, due to the existence of a single scale

The choice is more difficult in more complex cases



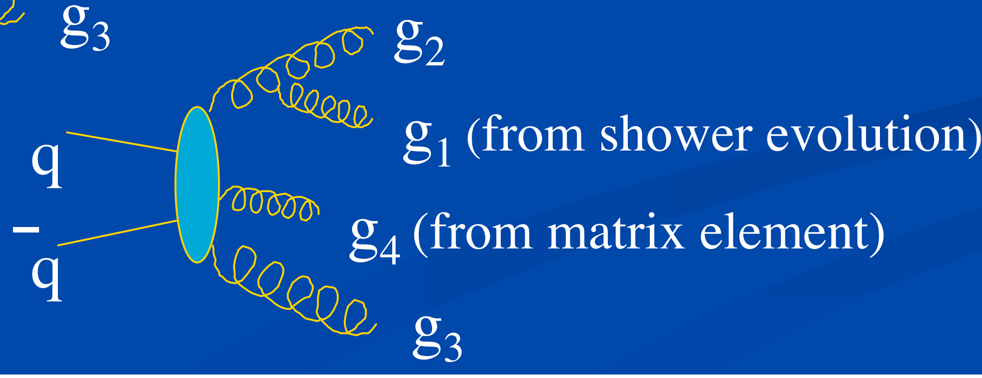
If $p_{T1} << p_{T2} << \dots << p_{Tn}$, or $(p_i+p_j)^2$ varying significantly for different (i,j)

- Ambiguous implementation of the factorization theorem
- Potential problem of double counting:

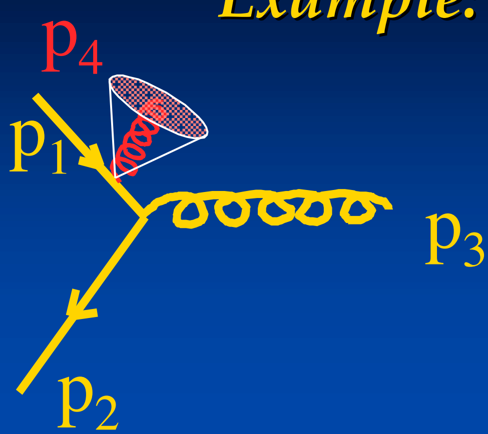


with $p_{T1} << p_{T4} << p_{T2}, p_{T3}$

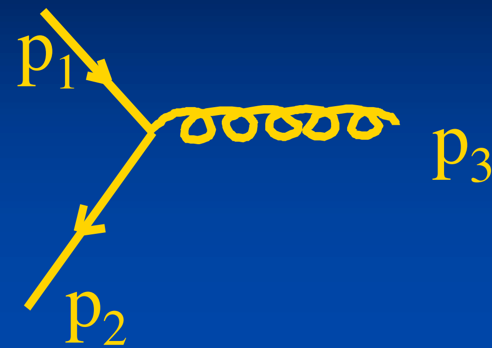
versus



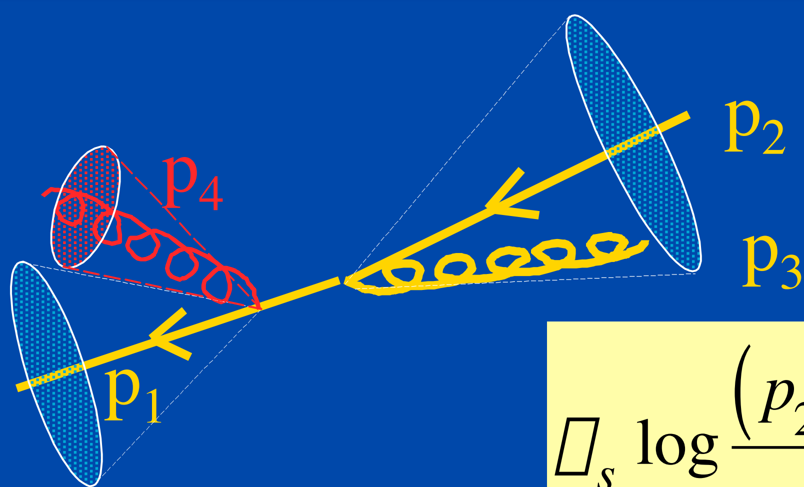
Leading vs subleading double counting
Example: corrections to 3-parton final states



is of $O(\alpha_s)$ relative to the LO process



unless:



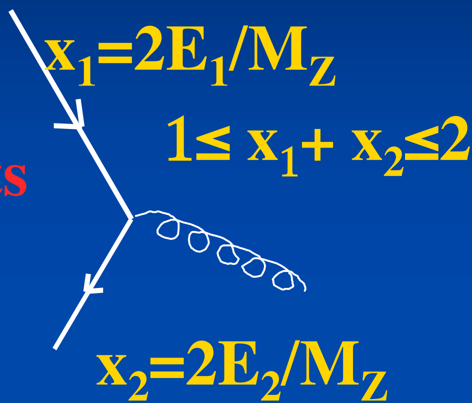
which gives a contribution to $\sigma_{3\text{-jet}}$ of order

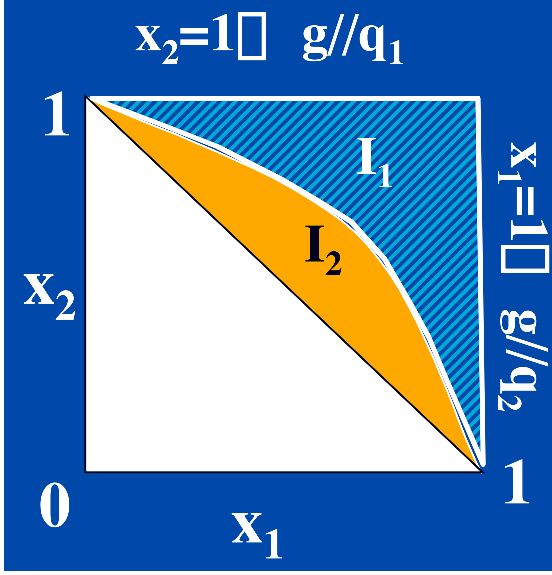
$$\alpha_s \log \frac{(p_2 + p_3)^2}{E_{T\,jet}^2} \approx \alpha_s \left(\log \frac{p_T^{\max}}{p_T^{\min}} + \log \frac{1}{\Delta R} \right)$$

Double counting is sub-leading provided ΔR and $p_T^{\max} / p_T^{\min}$ are not too large

Progress towards solutions
(I) matrix element corrections

Ex: $Z^0 \to$ 3 jets





I_1: ph.space covered by angular-ordered emission

I_2: ph.space NOT covered by angular-ordered emission

Algorithm: (*M.Seymour*)

• generate events in I_2 with (finite!) probability:

$$P = \frac{\int_{I_2} |M(Z \to q\bar{q}g)|^2}{\sigma(I_1) + \sigma(I_2)}$$

and distributions given by

$$|M(Z \to q\bar{q}g)|^2$$

• Use (qqg) matrix element to correct MC weights in I_1

Drawback:

• requires analytic representation of the phase-space domain generated by the angular-ordering prescription

Progress towards solutions (II) vetoed showers

(Catani, Krauss, Kuhn, Webber)

• Generate samples of different jet multiplicities according to exact tree-level ME's, with N_{jet} defined using a k_{perp} algorithm

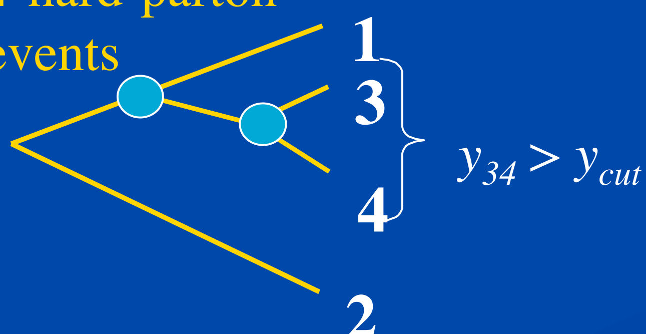
$$y_{ij} = \frac{2\min\left\{E_i^2, E_j^2\right\}\left(1 - \cos\theta_{ij}\right)}{s} \geq y_{cut} = \frac{Q_{cut}^2}{s}$$

• Reweight the matrix elements by vertex Sudakov form factors, assuming jet clustering sequence defines the colour flow

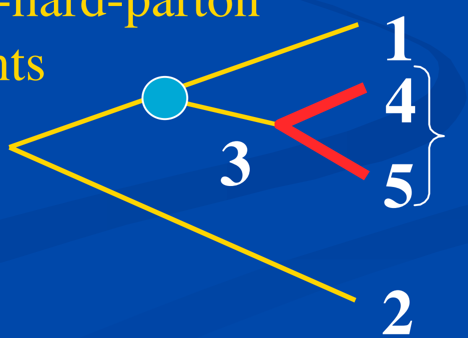
• Remove double counting by vetoing shower histories (i.e. y_{ij} sequences already generated by the matrix elements)

• Fully successfull for e^+e^- collisions, being extended to hadronic collisions

From the sample of 4-hard-parton events



From the sample of 3-hard-parton events



● : **Sudakov correction**

Study of ΔR_{part} and $E_{T\,jet}$ systematics

- We shall consider the case of W+3 jets. Hadronic jets defined by:

$$\Delta R_{jet} = 0.7 \quad \text{and } E_{T\,jet} > 20\ \text{GeV}$$

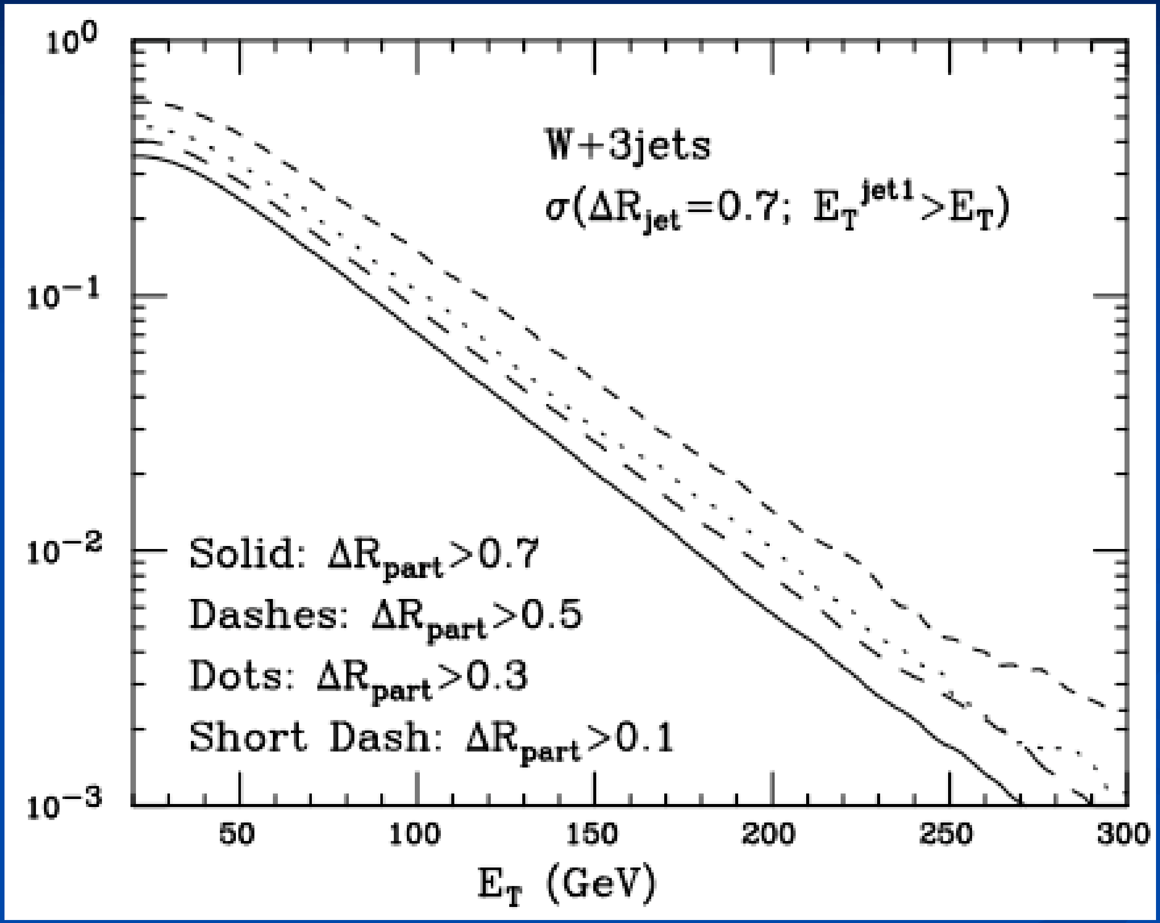
- Generate Alpgen samples of W+3-parton ME events*, using different parton-level thresholds:

ΔR_{part}	0.7	0.5	0.3	0.1	0.7	0.7	0.4
$p_{T\,min}$	20	20	20	20	15	10	15
σ(pb)	0.58	0.79	1.17	2.10	1.34	3.78	2.21

- In the following we study the jet cross-sections obtained by showering these different samples through Herwig

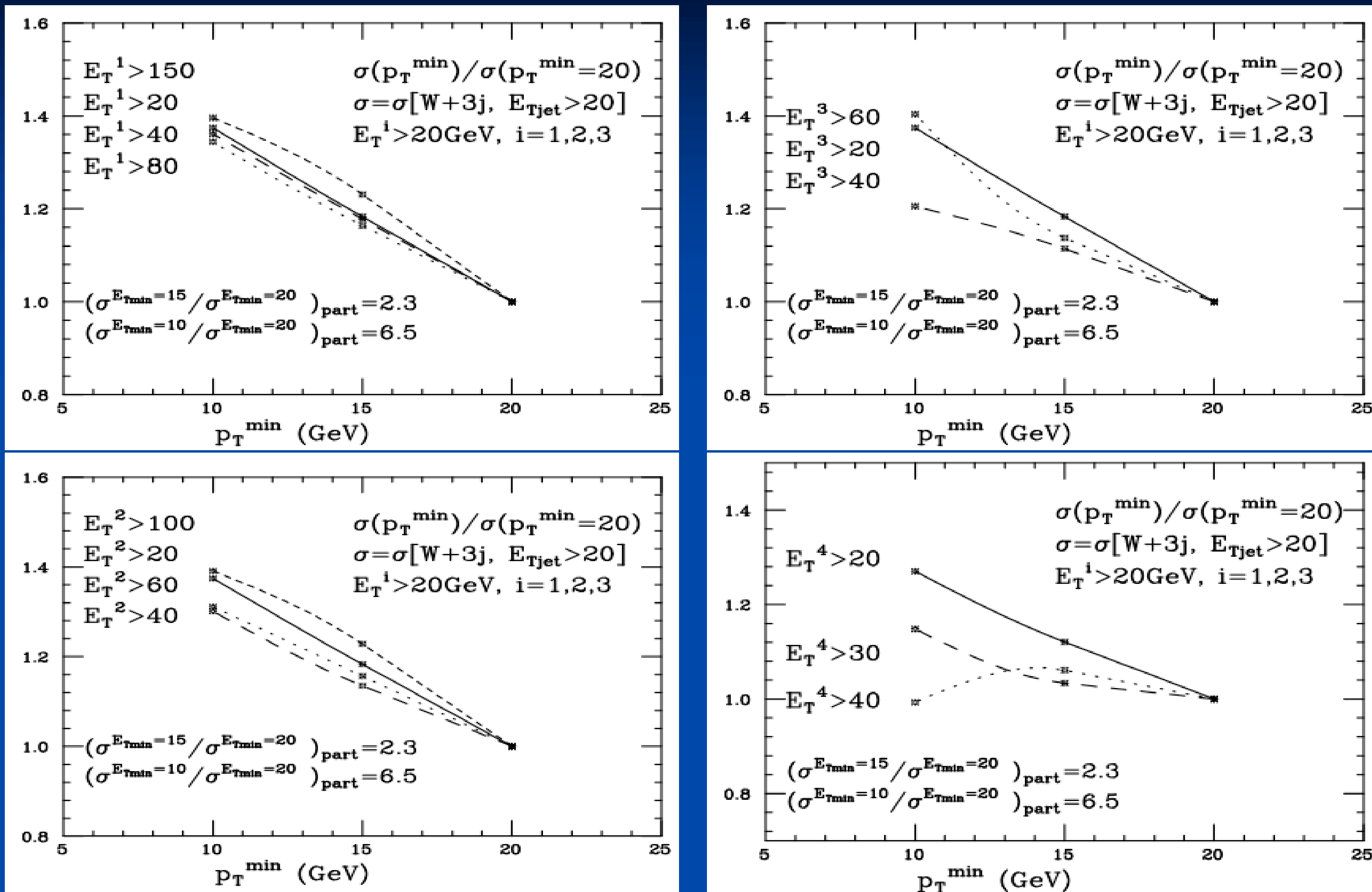
* for simplicity, and for other reasons, we only generated the q-qbar > W ggg subprocesses

Spectrum of the leading-E_T jet (jet1)



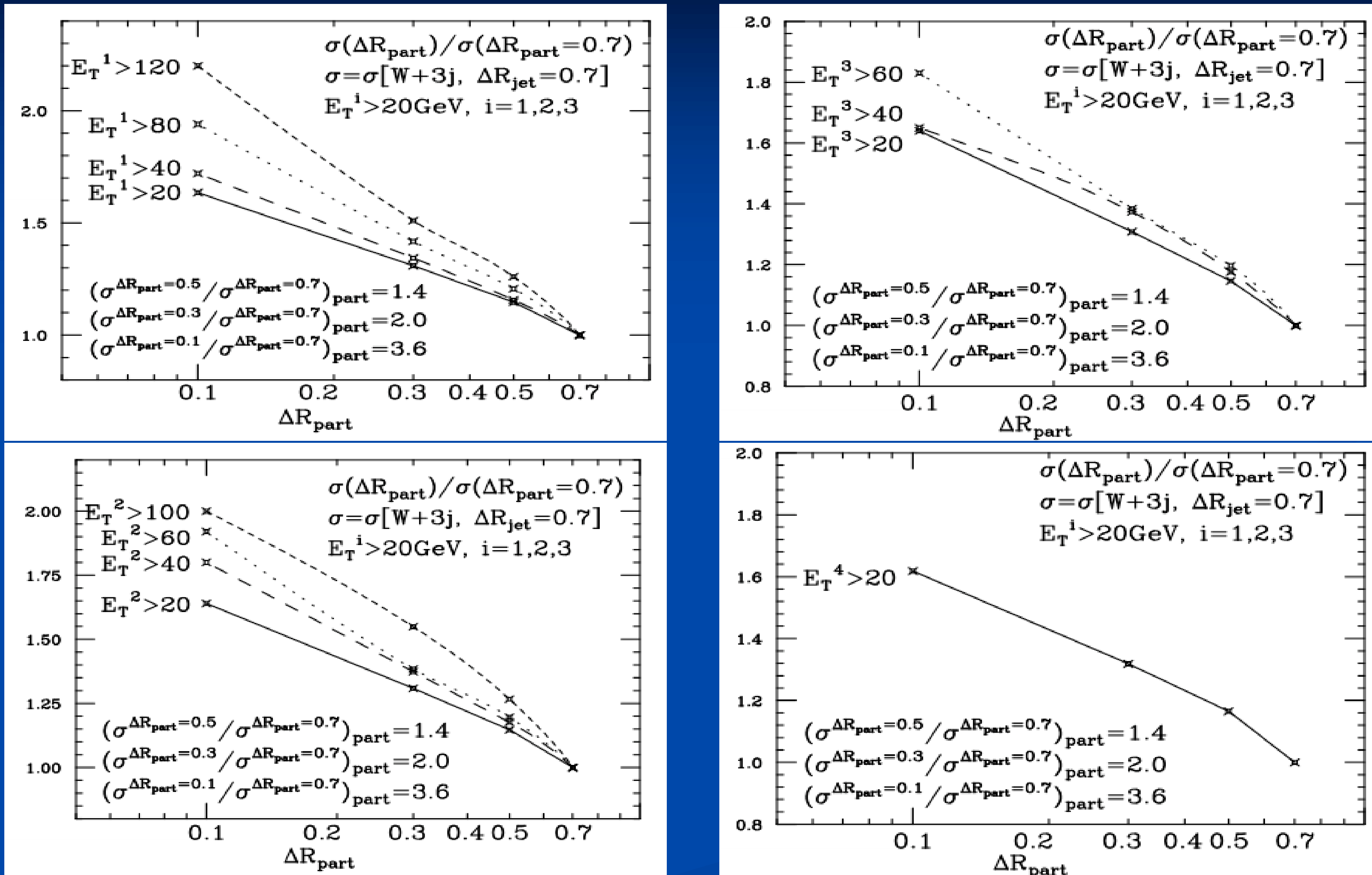
The ΔR_{part} dependence becomes more significant at high E_T, as expected because of larger logs

E_T spectrum dependence on $p_{T\,min}$, for the 4 most energetic jets



Sensitivity to $p_{T\,min}$ at the level of ±20%, in spite of the huge variation in rate before jet reconstruction

E_T spectrum dependence on ΔR_{part} , for the 4 most energetic jets



Much larger sensitivity than in the case of $p_{T\ min}$

Matching partons and jets

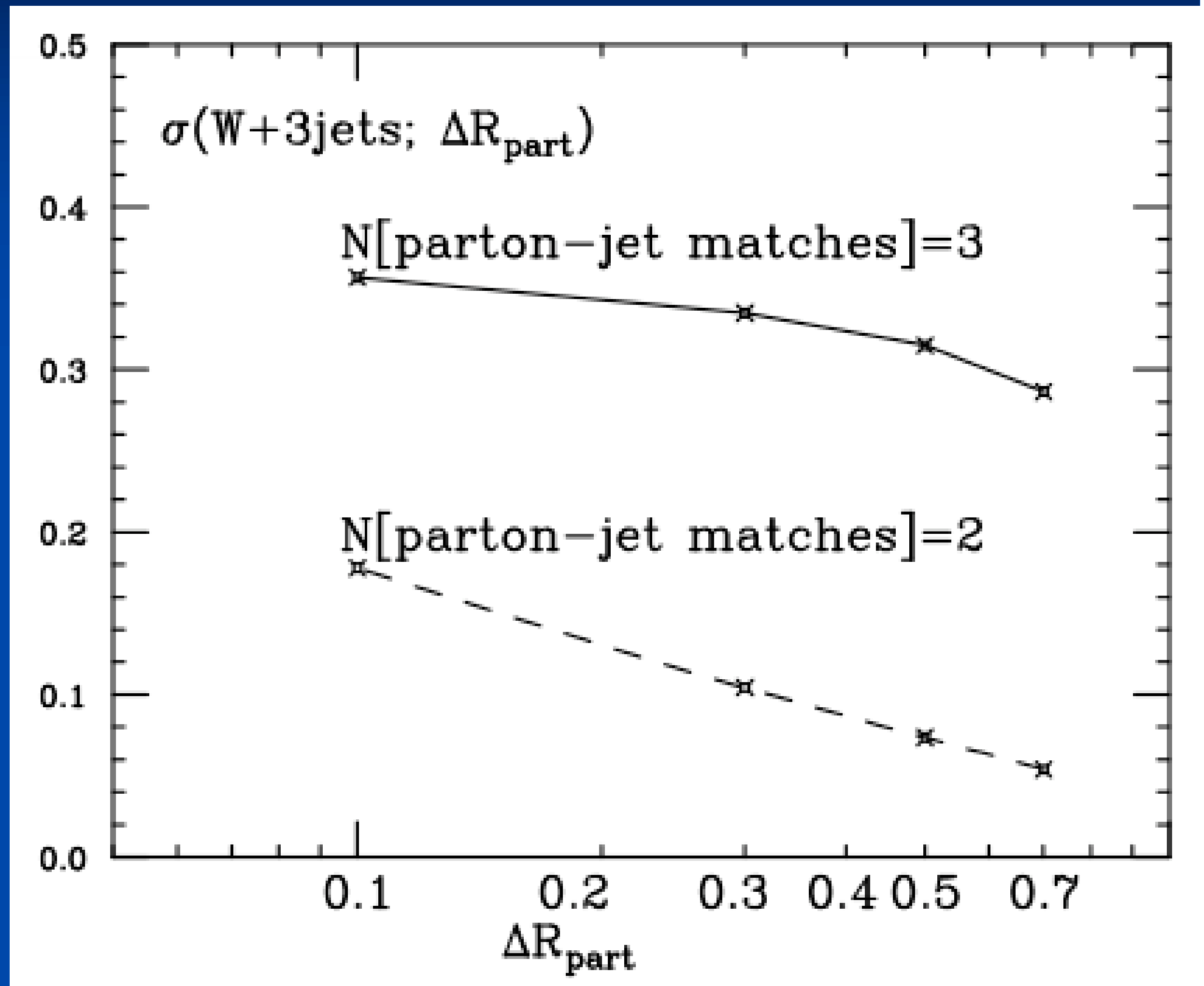
Matching criterion:

N=#(parton-jet) pairs with **□R<** 0.7

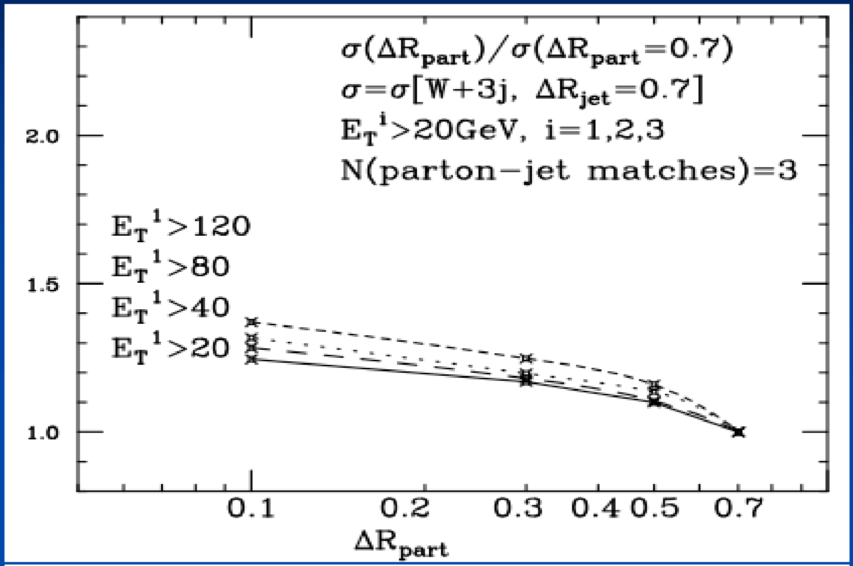
(only 1 jet can be assigned to a given parton)

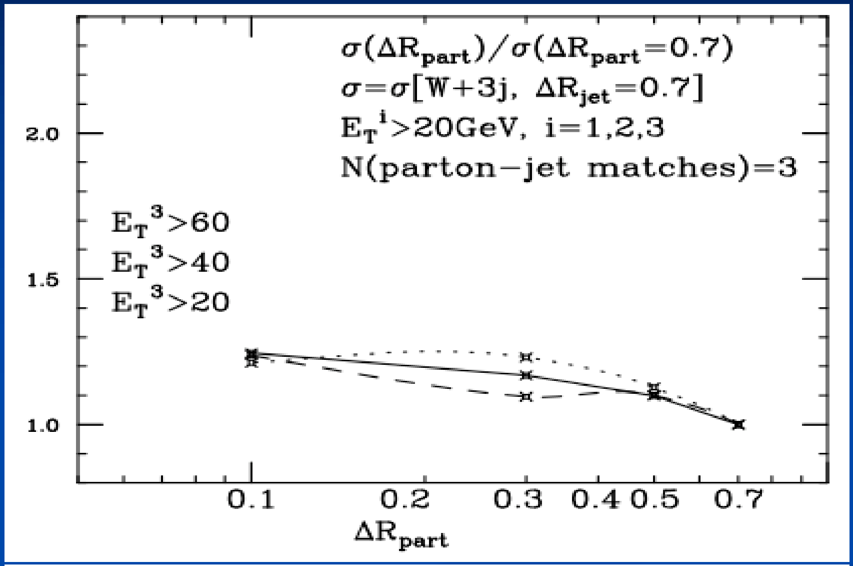
The rate for events with all partons matched by a jet is rather flat, and saturates as

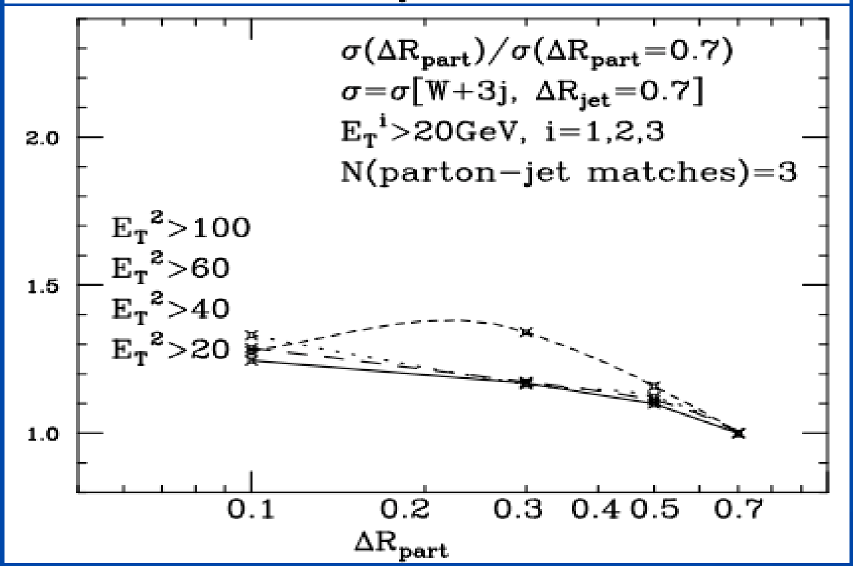
□R_{part}->0

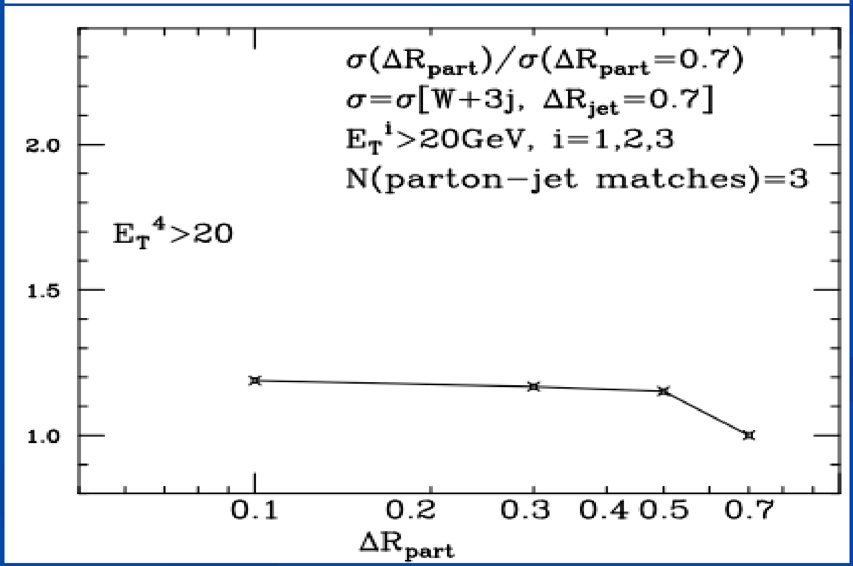


Cone dependence of Et distributions for events with N_{match}=3





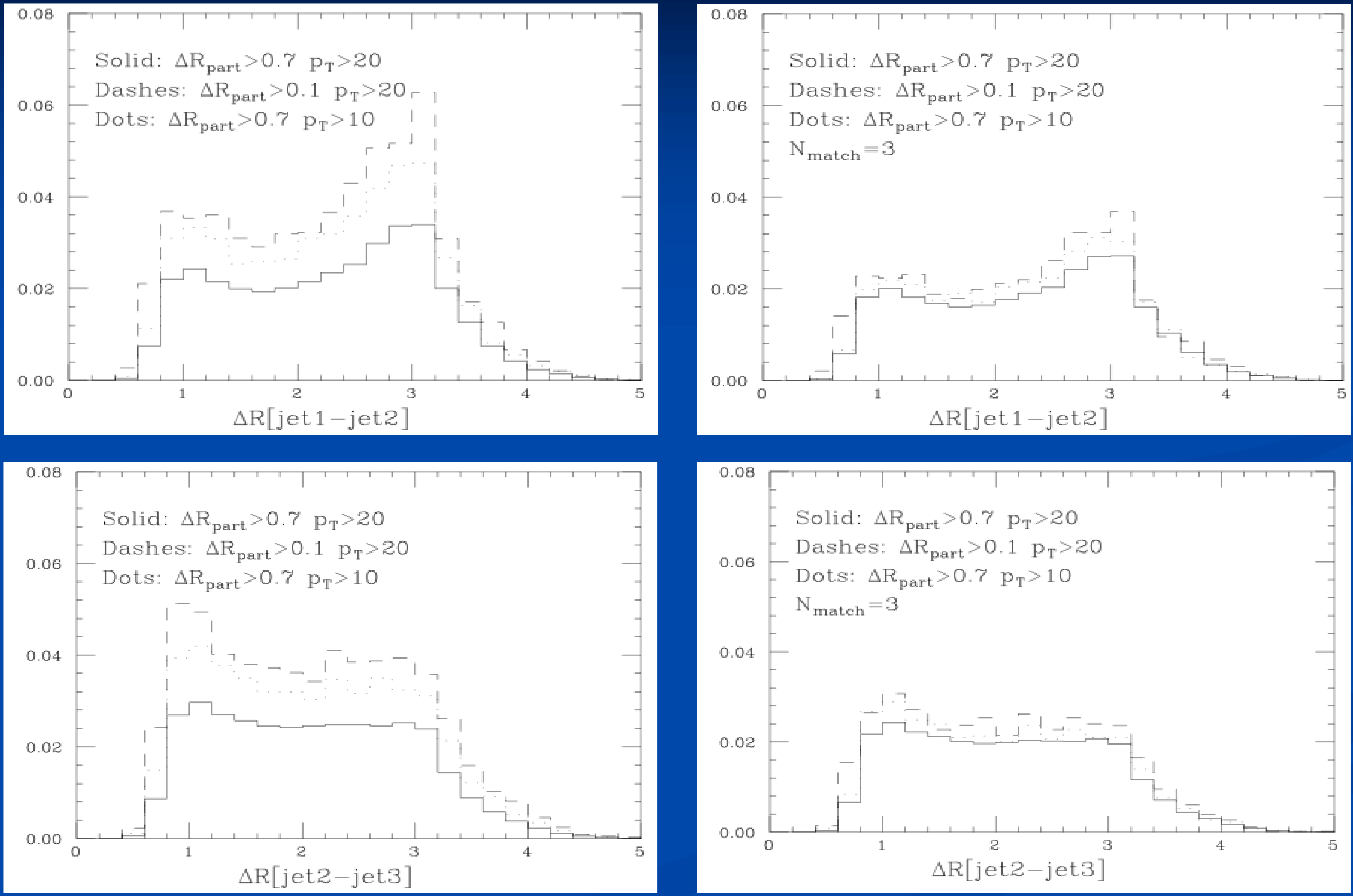




The prescription N_{match}=3 gives a much smaller uncertainty and, even more important, leads to a saturation of the rate at small ΔR_{part} :

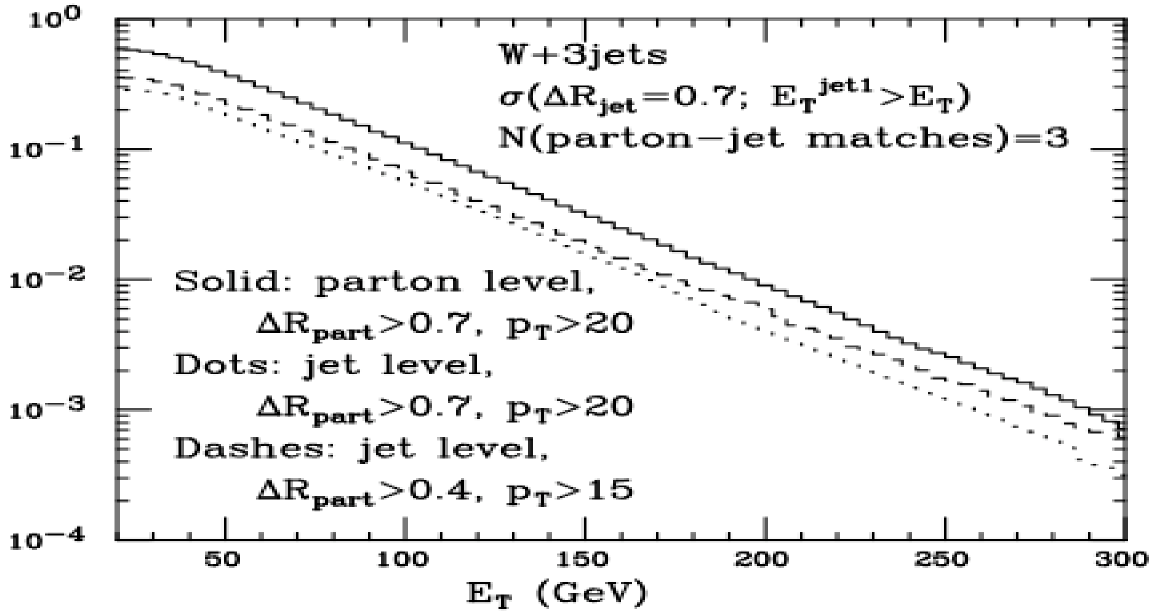
ΔR_{part}	0.7	0.5	0.3	0.1	0.7	0.7	0.4
$p_{T\ min}$	20	20	20	20	15	10	15
σ(partons)	0.58	0.79	1.17	2.10	1.34	3.78	2.21
σ(all N_{match})	0.35	0.40	0.46	0.58	0.42	0.48	0.51
σ(N_{match}=3)	0.29	0.31	0.33	0.36	0.31	0.32	0.36

Some distributions

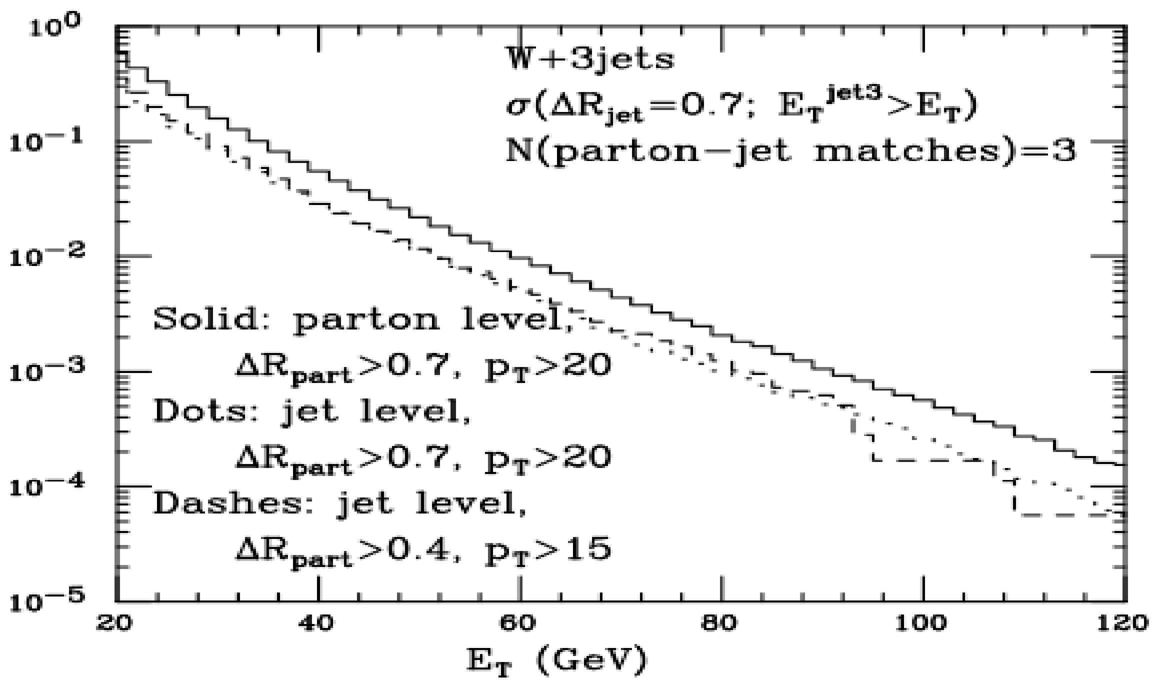


Some more distributions

Jet 1:



Jet 3:



Conclusions

- The merging of parton level multijet events into shower MC's leads to a new type of systematics, typically not explored in previous Tevatron studies (w. exception of the study of NLO inclusive jet rates)
- The size of this systematics, for the case studied here, is at the level of 40-50% if one does not apply any rejection algorithm
- A simple rejection algorithm, based on the matching of all ME partons with some jet, reduces strongly this uncertainty, to the level of 10-20%
- Some shape dependence in the jet E_T distributions is however still present
- This systematics is suitable to be addressed with the data, and to allow for "tuning"

(Update on Alpgen)

- V1.1 released few weeks ago, with F90 implementation for all processes and Pythia interface
- Will include single-charm final states in W+jets
- Will allow for hadronic decays of W, plus allow labeling for mu and taus (current version has only electorns)
- Debugging Njet processes (with Njet up to 4, and #(quark pairs)=0,1,2)
- Debugging □+jets and □QQ+jets processes