ALPGEN

http://mlm.home.cern.ch/mlm/alpgen

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hep-ph/0206293

- Ready-to-use exact LO matrix element calculations for multiparton final states in hadronic collisions
- Parton-level event generation (weighted/unweighted)
  - mass terms and finite width effects
  - spin correlations, also in decays like $t \rightarrow bW(\rightarrow f\bar{f}')$
  - cross section exact to all orders in $1/N_c$, colour structure to $O(1/N^2)$
  - EW/QCD interferences available for key processes
- Evolution of the parton level final state through parton shower and hadronization phases, using Herwig or Pythia
- Code available in F77, as well as in a version with some F90 routines (transparent to the user, preferred for CPU performance if compiler available)

Available processes

- **WQQ**+N jets, **Z/γ+QQ**+N jets (Q=c,b,t), $N \leq 4$
- **W**+ N jets, **Z/γ**+ N jets, $N \leq 6$
- **W**+**c**+ N jets, $N \leq 5$
- **QQ** + N jets (Q=c,b,t), $N \leq 6$
- **QQQ'Q'** + N jets (Q,Q'=b,t), $N \leq 4$
- N jets, $N \leq 6$
- QQ+**Higgs**+ N jets (Q=b,t), $N \leq 4$
- n**W** + m**Z** + p**Higgs** + N jets, $N < n+m+p+N \leq 8$, $N \leq 3$
- n **γ** + N jets, $N < n+N \leq 6$

In progress:

- single top production
- Higgs plus multijets, via the ggH vertex

Validation against other codes:

W+jets:

X-sects (pb)	Number of jets						
$e^-\bar{\nu}_e + n$ QCD jets	0	1	2	3	4	5	
ALPGEN	3904(6)	1013(2)	364(2)	136(1)	53.6(6)	21.6(2)	8
AMEGIC++	3905(4)	1014(3)	370(2)				
CompHEP	3947.4(3)	1022.4(5)	364.4(4)				
GR@PPA	3906.37 (4)	1046.85 (5)					
HELAC/PHEGAS/JetI	3786(81)	1021(8)	361(4)	157(1)	46(1)		
MadEvent	3902(5)	1012(2)	361(1)	135.5(3)	53.6(2)		

Wbb+jets:

X-sects (pb)	Number of jets				
$e^-\bar{\nu}_e + b\bar{b} + n$ QCD jets	0	1	2	3	4
ALPGEN	9.34(4)	9.85(6)	6.82(6)	4.18(7)	2.39(5)
AMEGIC++	9.42(5)	9.92(10)			
CompHEP	9.415(5)	9.91(2)			
HELAC/PHEGAS/JetI	9.88(11)	12.68(9)			
MadEvent	9.32(3)	9.74(1)	6.80(2)		

More examples on the MC4LHC Wshop web page: http://agenda.cern.ch/fullAgenda.php?ida=a031457

jets:

X-sects (mb)	Number of jets				
jets	2	3	4	5	6
ALPGEN	331.7(3)	22.49(7)	4.81(1)	1.176(9)	0.330(1)
AMEGIC++	330.9(3)	24.2(3)			
ComHEP	334.8(1)	22.79(7)			
HELAC/PHEGAS/JetI	331(3)	22.6(3)	4.7(1)	0.9(1)	
MadEvent	329(1)	22.3(1)	4.86(2)		

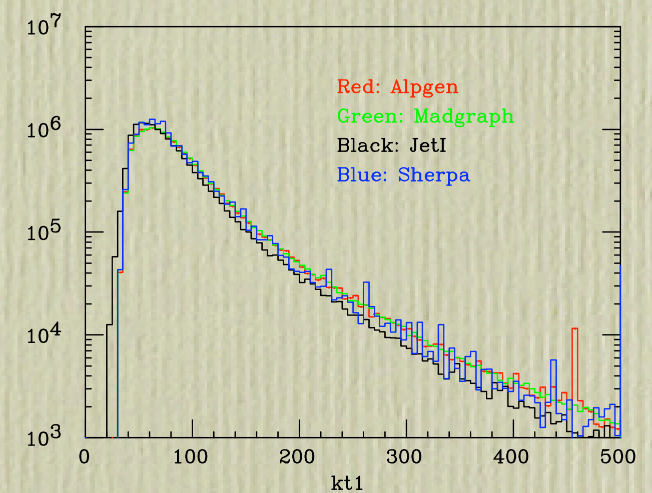
Validation against other codes: selection of colour flows

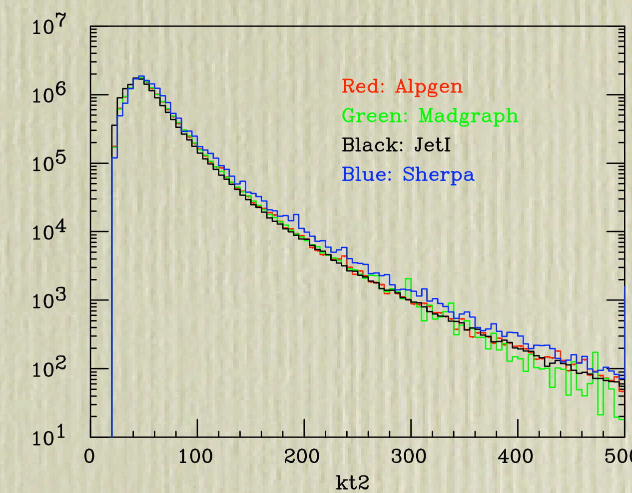
To compare the determination of colour flows in different codes we analysed the distributions of the k_T variables. For each colour-connected pair of partons we define

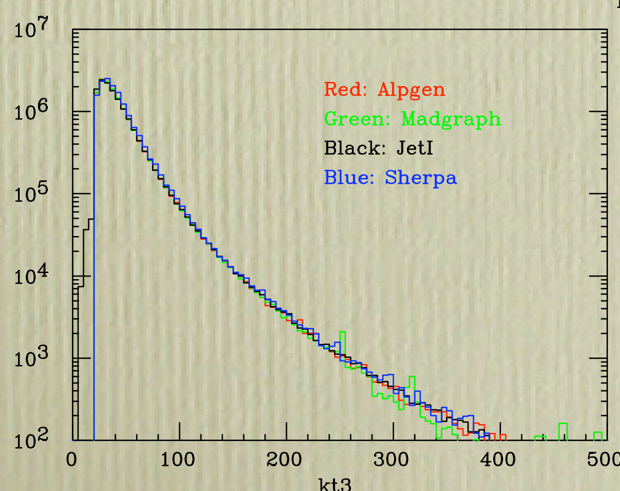
$$k^2_{ij} = p^2_{T,i} \text{ if } i \text{ final state and } j \text{ incoming parton}$$

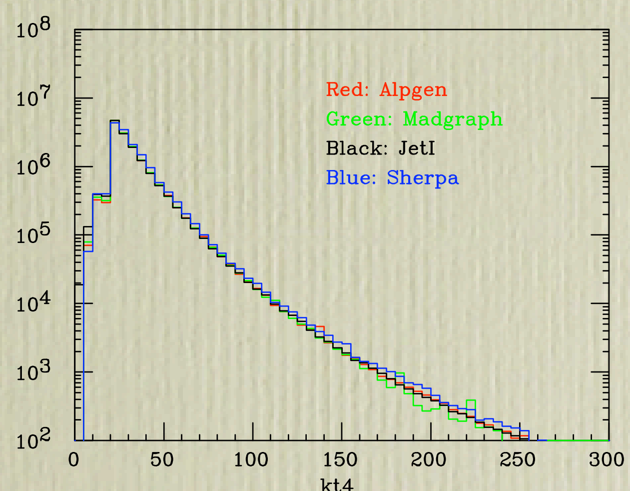
$$k^2_{ij} = \min(p^2_{T,i}, p^2_{T,j}) \times \Delta R(i,j) \text{ if } i,j \text{ outgoing partons}$$

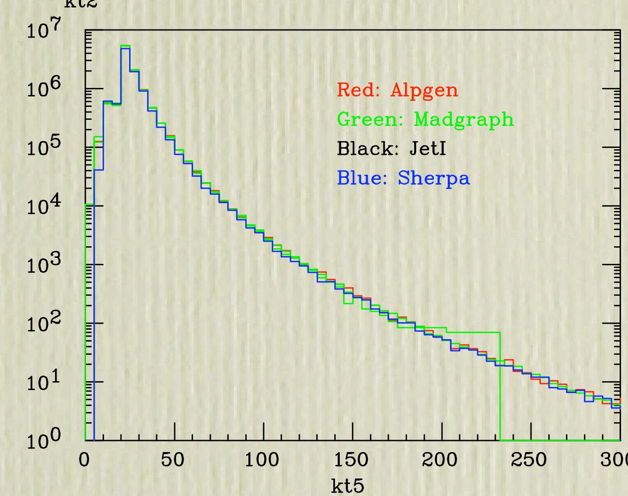
and then order the k_{ij} from the largest (k_{T1}) to the smallest (k_{Tn}). In the case of **gg→ggg**, for example, there will be 5 pairings



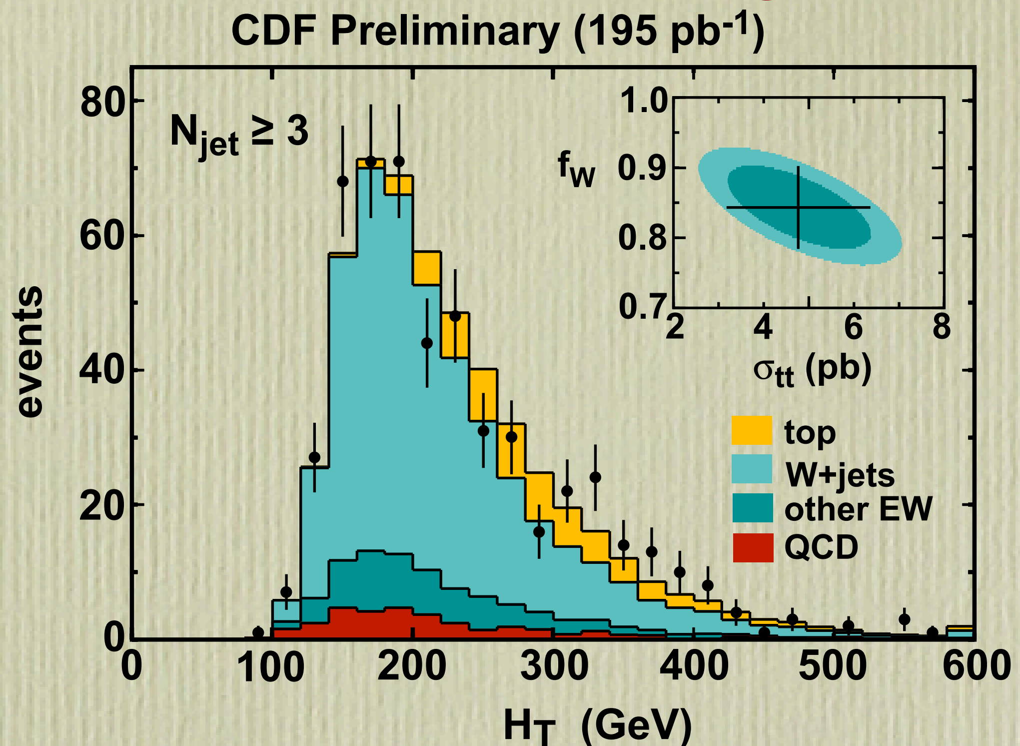


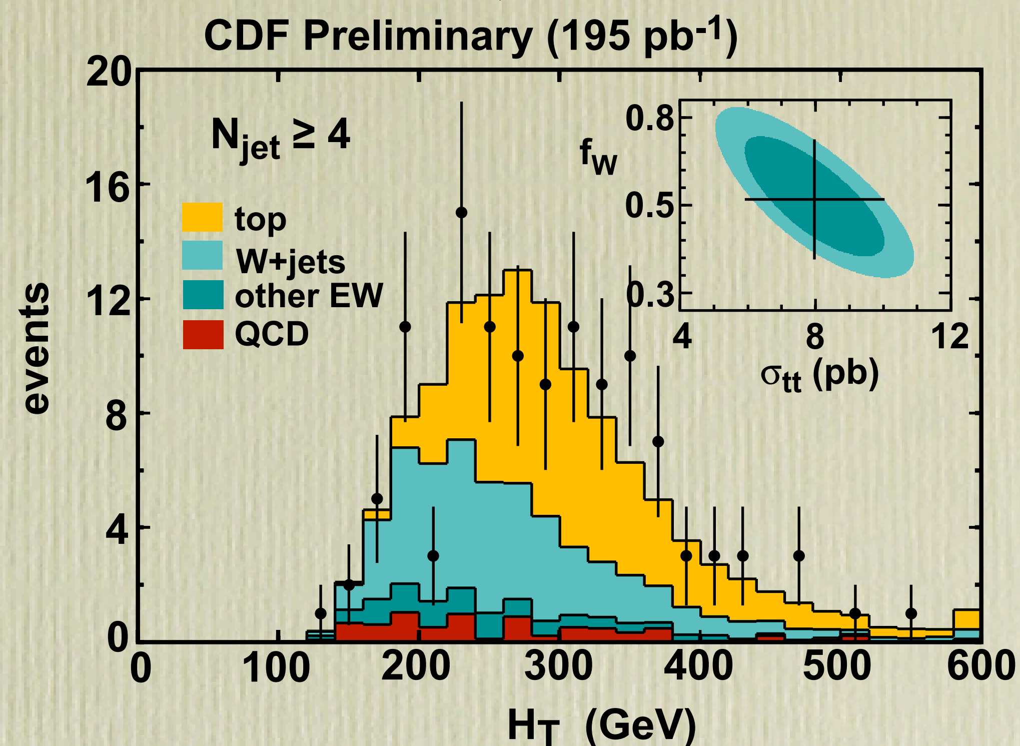


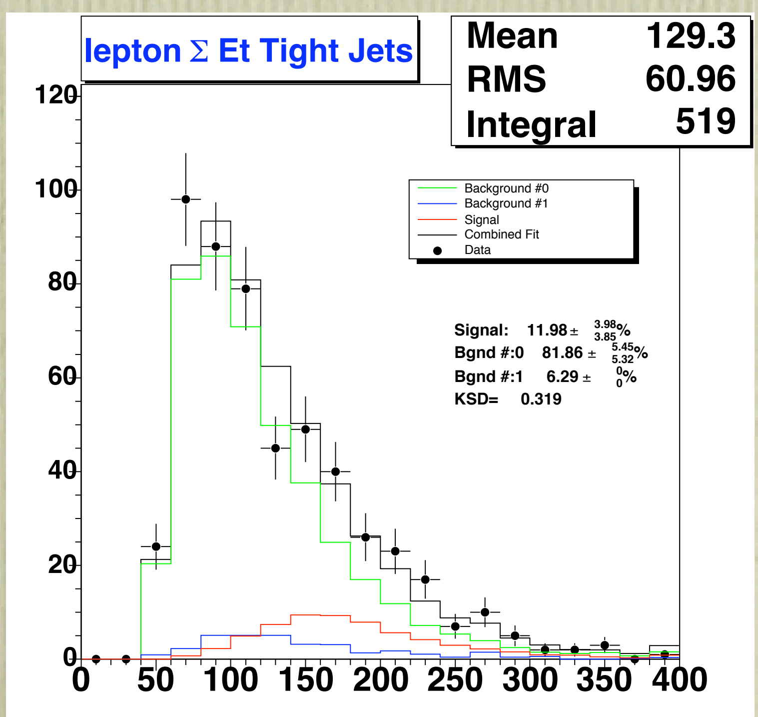


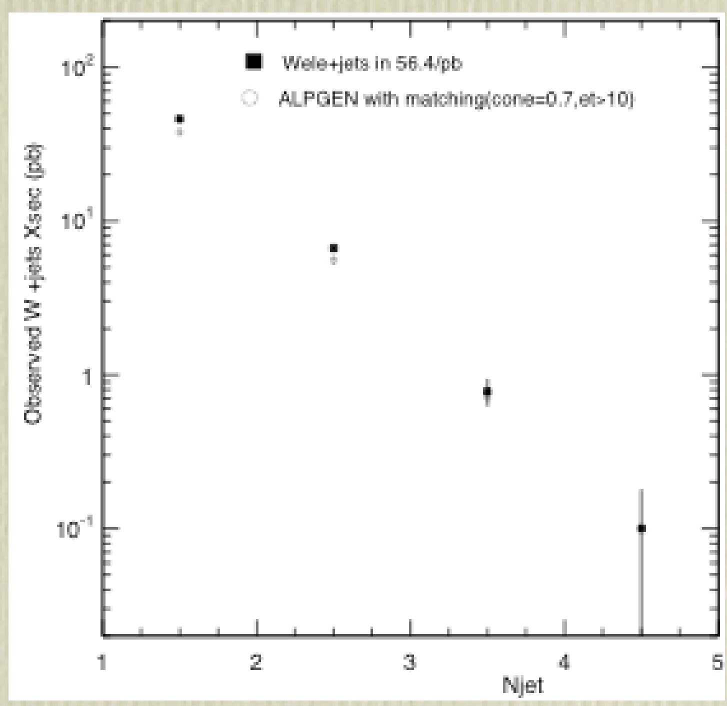


Validation against Tevatron W+multijet data

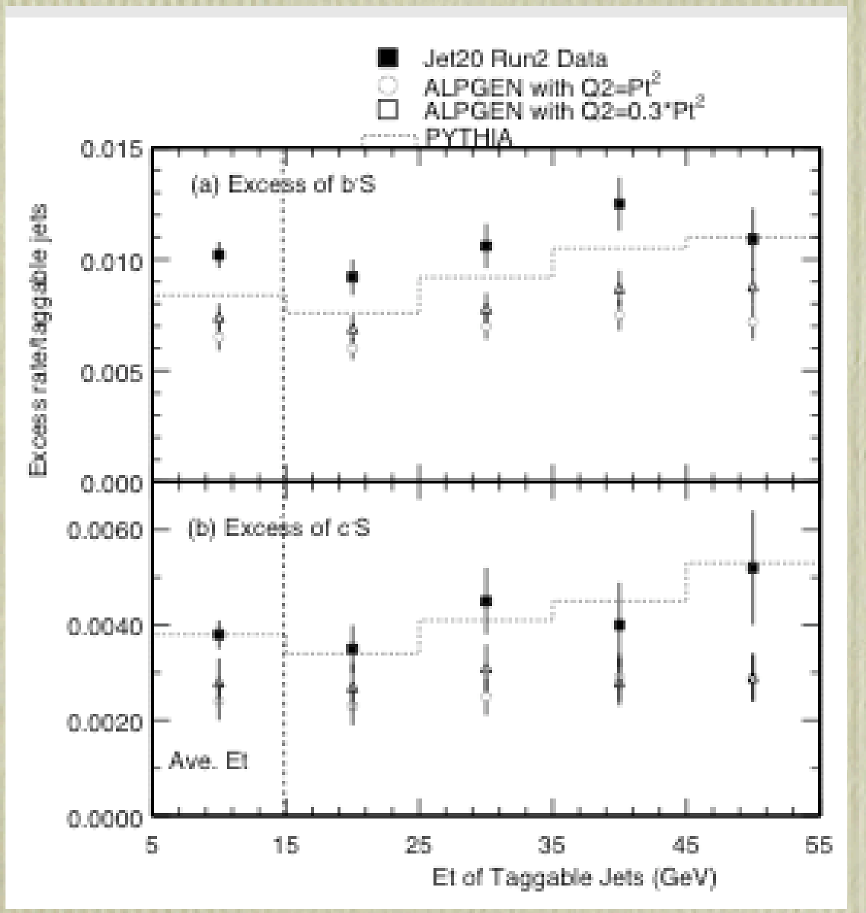


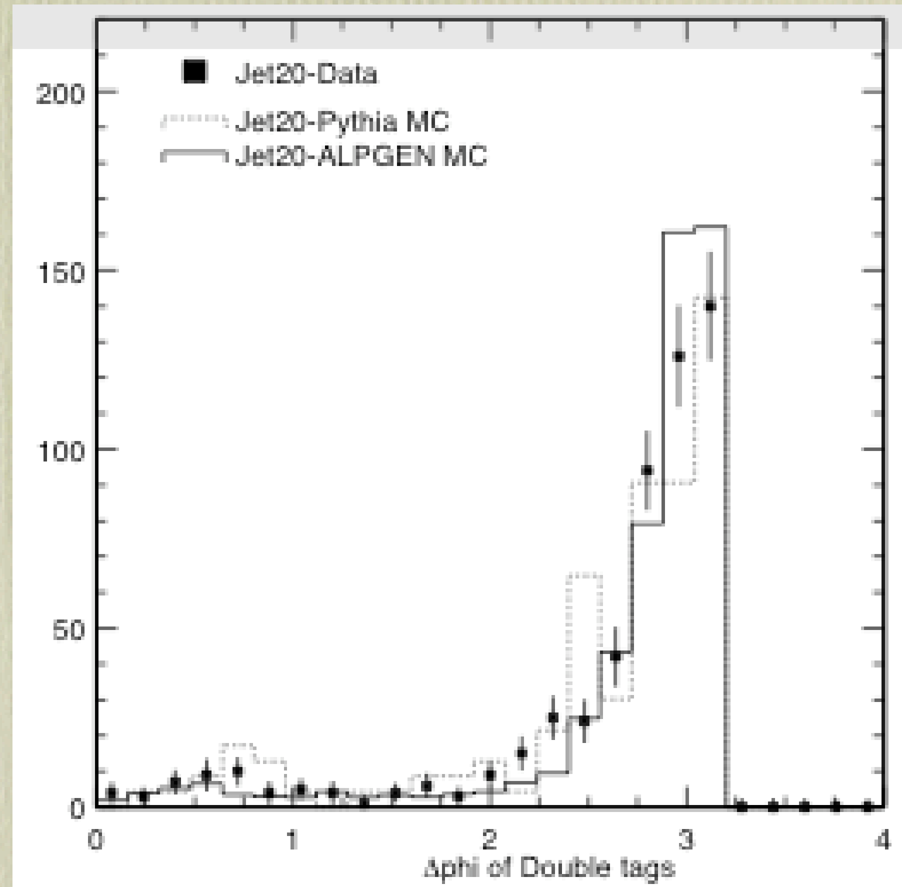






Validation against Tevatron: heavy flavour content of inclusive dijet data





~30% low, consistent with NLO effects

How the code runs

- Well documented in the accompanying text file
- Straightforward compilation of executable for selected process
- Selection of kinematical cuts, PDF set, renormalization scale through input cards
- User routines to implement additional (possibly complex) generation cuts, and initialization of histogramming and analysis routines
- 3 steps:
  - generation of weighted event sample
  - unweighting
  - processing (shower+hadronization) through Herwig/Pythia

```
~/alpgen> tar -zxvf v133.tgz
```

.....

```
~/alpgen> ls
2Qlib/    History.txt   QQhwork/      phjetwork/    wcjetlib/    wqqwork/
2Qwork/   Makefile      alplib/       pylib/        wcjetwork/   zjetlib/
4Qlib/    Njetslib/     ft90V.tar.gz  v133.tgz      wjetlib/     zjetwork/
4Qwork/   Njetswork/    herlib/       vbjetslib/    wjetwork/    zqqlib/
DOCS/     QQhlib/       phjetlib/     vbjetswork/   wqqlib/      zqqwork/
```

```
~/alpgen> cd wjetwork
~/alpgen/wjetwork> make wjetgen
```

.....

```
~/alpgen/wjetwork> ./wjetgen < input
```

.....

```
~/alpgen/wjetwork> more input
1        ! imode
w2j        ! label for files
1          ! initial state (1=pp, -1=ppbar)
7000d0 5   ! beam energy in CM frame and PDF set
2         ! total number of final-state QCD partons
10 2.5 0.4     ! ptmin(jet), etamax(jet), deltaRmin(j-j)
0d0 10d0 0d0 0d0    ! ptmin(lept), etamax(lept), deltaRmin(lep-j) etmiss
1 1d0         ! iqopt, qfac
0 ! start with: 0=new grid, 1=previous warmup grid, 2=previous generation grid
100000 3  ! Nevents/iteration,  N(warm-up iterations)
200000        ! Nevents generated after warm-up
0           ! 1: change default random number seed, 0: keep default seed
```

Cuts

Output X-section:

```
starting generation of  200000. events
average ph-space eff=  0.763166531
avgwgt(pb)=  3178.20734+-  32.006895 maxwgt=  2515129.
unwgt eff =  0.00126363583

 sub-processes:

jproc= 1  total(pb):   282.130733+-  11.3287542
jproc= 2  total(pb):   1233.34552+-  18.2051845
jproc= 3  total(pb):   1242.03163+-  17.7375565
jproc= 4  total(pb):   179.702951+-  6.0569746
jproc= 5  total(pb):   16.4178309+-  1.11904302
jproc= 6  total(pb):   46.2057652+-  3.42308665
jproc= 7  total(pb):   46.5521103+-  2.79104957
jproc= 8  total(pb):   0.323972239+-  0.0872834294
jproc= 9  total(pb):   19.396208+-  3.81907925
jproc= 10  total(pb):   15.4420863+-  1.66302312
jproc= 11  total(pb):   8.47149271+-  1.69881266
jproc= 12  total(pb):   12.8351352+-  1.21279599
jproc= 13  total(pb):   30.4713529+-  5.73240435
jproc= 14  total(pb):   31.0083254+-  13.0661118
jproc= 15  total(pb):   13.8722242+-  1.37630917

cumulated cross-section:
avgwgt(pb)=  3190.53357+-  22.5646735
```

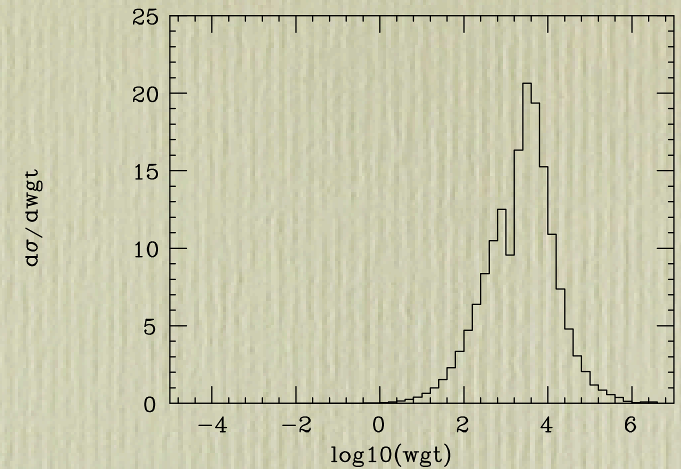
Output files:

```
w2j.grid1  -> trained phase-space integration grid
w2j.par    -> info on grid, max weight, etc
w2j.stat   -> overall run statistics, by subprocess
w2j.top    -> histograms for sample distributions
w2j.wgt    -> list of generated weighted events
```

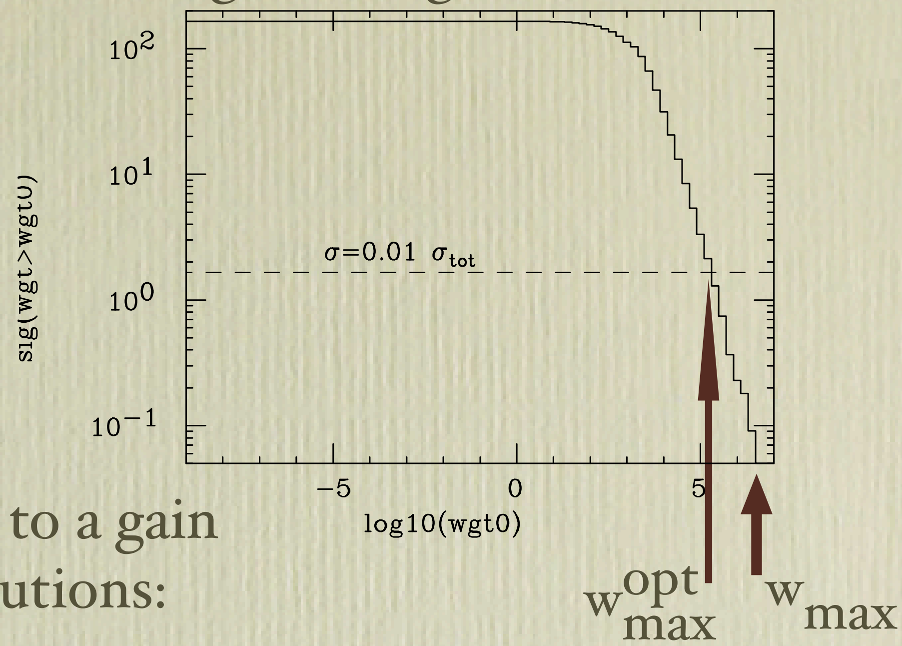
- Weighted event sample (run option imode=1):
  - pre-unweighted during generation using 0.01 maxwgt
  - store to file wgt, random number seeds, and control bits for sanity check
  - wgt distribution saved to file
- Unweighting (run option imode=2):
  - unwgt based on max wgt (possible to change this for optimization, having looked at the weight distribution)
  - generate colour flow information, write events to file
- Shower evolution:
  - link Herwig/Pythia to a set of Les Houches Accord interfacing routines, and run the executable on the unweighted event file. Process output as usual

Optimized unweighting: example W+3 jet events

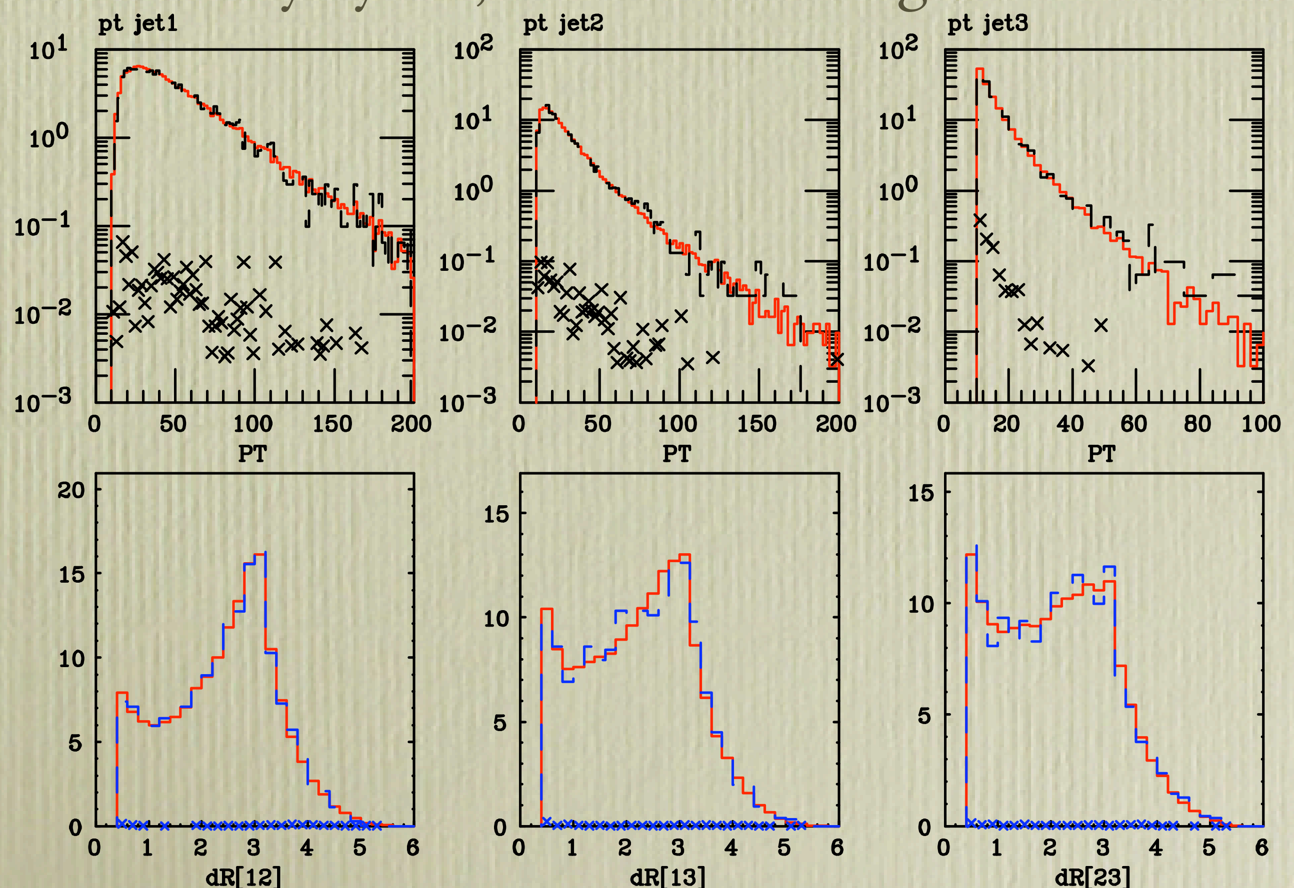
Weight distribution:



Weights integral distribution:



Unweighting w.r.t. the optimal max weight leads to a gain in efficiency by ~10, without affecting the distributions:



Red histo: optimal unweighting

Dark histo: w_{max} unweighting

x: distribution of events with $w>w_{max}$

No discernible bias!

Some examples of performance:

(F77, xlf on 1.8GHz Mac G5; F90 version is typically 2-5 times faster)

$(Z \rightarrow e^+e^-)$+N jets, $p_T>30$ GeV, $|\eta|<2.5$

N=4: 120' for 10M wgt events, unw eff=5×10^{-4} ⇒ 5K events = $1fb^{-1}$ (σ=5pb)

N=5: 300' for 10M wgt events, unw eff=3×10^{-4} ⇒ 3K events = $2fb^{-1}$ (σ=1.4pb)

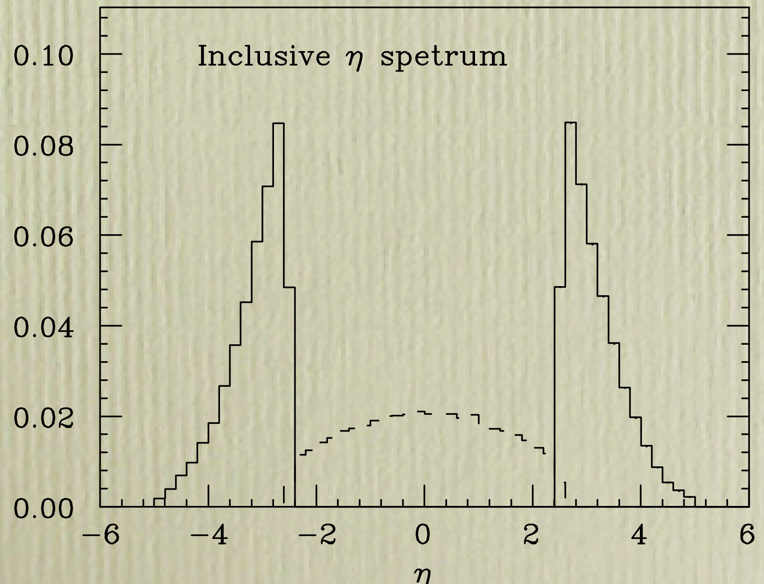
$100fb^{-1}$ ⇒ 200 hr (N=4) and 150hr (N=5) **< 1week on 1 CPU**

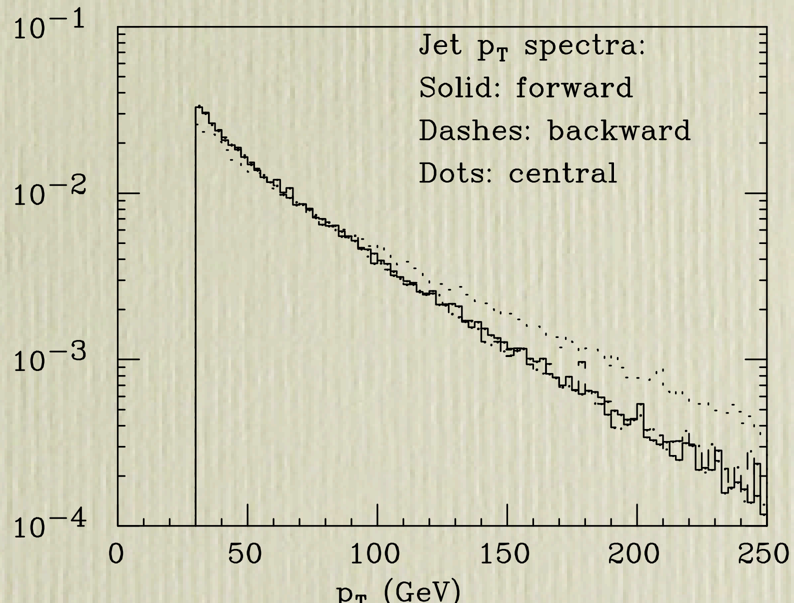
$(Z \rightarrow l^+l^-)$+**3 jets,** $p_T>30$ GeV, $-5<\eta_1<-2.5$, $2.5<\eta_2<5$, $|\eta_3|<2.5$

(asymmetric cut option is hard-wired, no effort required to the user)

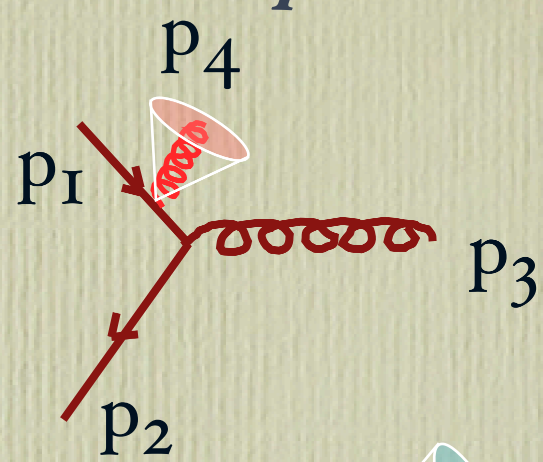
360' for 100M wgt events, unw eff=5×10^{-5} ⇒ 5K events = $12fb^{-1}$ (σ=0.4pb)

$100fb^{-1}$ ⇒ 80 hr **~ 3 days on 1 CPU**

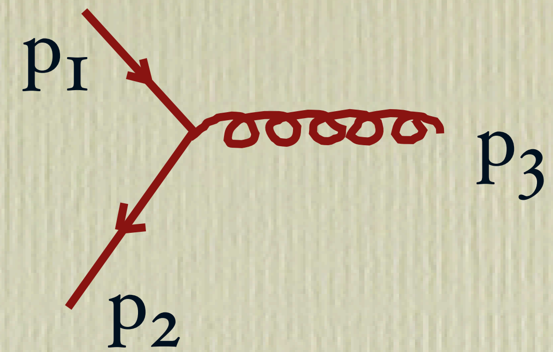


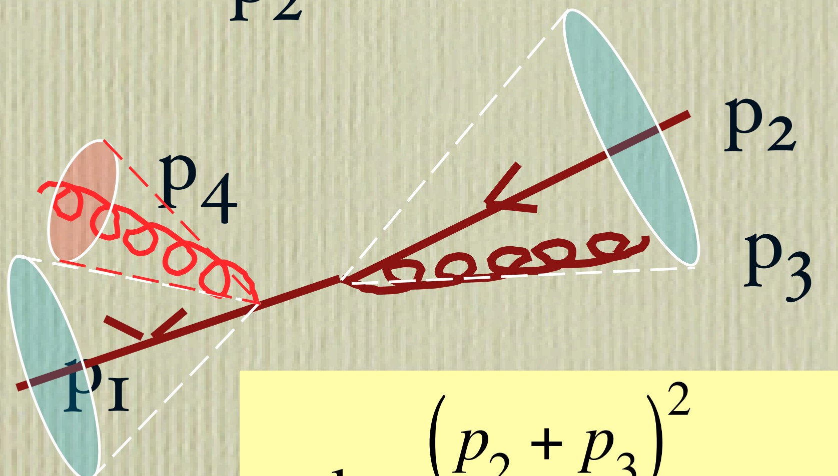


The problem of Leading-log-order double counting



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

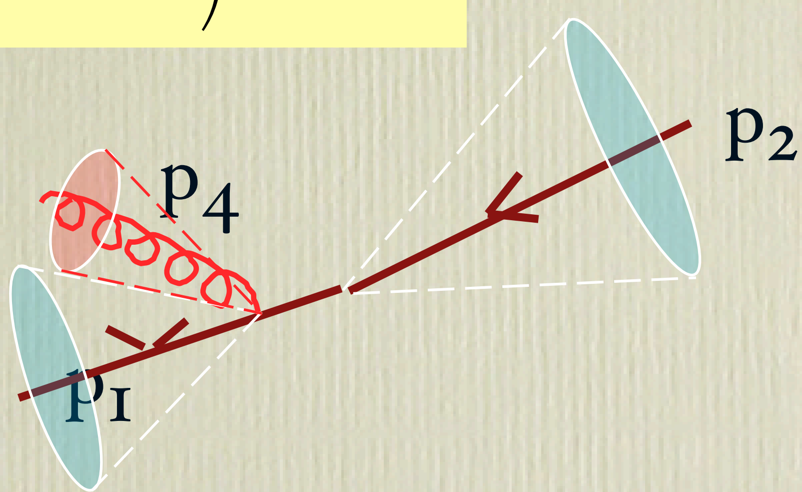




instead gives a contribution to $\sigma_{3\text{-jet}}$ of order

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

Double counting, since this configuration is already generated by showering:



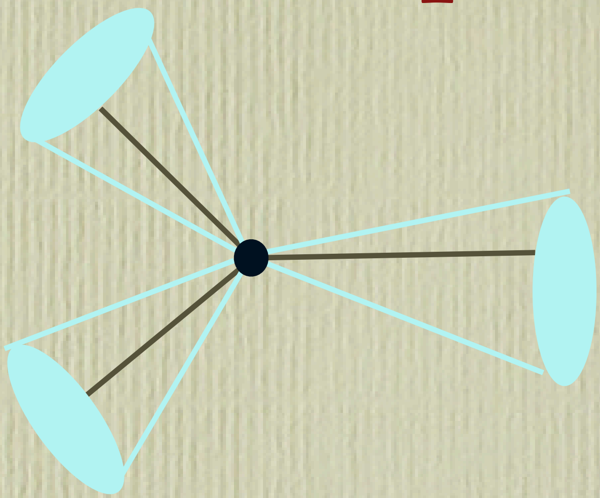
A simple prescription to address this problem

- **Generate parton-level configurations** for a given hard-parton multiplicity N_{part}, with partons constrained by
  - $p_T > p_{T\,min}$ $\Delta R_{jj} > R_{min}$
- **Perform the jet showering**, using the default Herwig/Pythia algorithms
- Process the showered event (before hadronization) with a **cone jet algorithm,** defined by
  - $E_{T\,min}$ and R_{jet}
- **Match partons and jets:**
  - for each hard parton, select the jet with min $\Delta R_{j\text{-}parton}$
  - if $\Delta R_{j\text{-}parton} < R_{jet}$ the parton is "matched"
  - a jet can only be matched to a single parton
  - **if all partons are matched, keep the event, else discard it**
- This prescription defines an **inclusive sample** of $\mathbf{N_{jet}=N_{part}}$ **jets**
- Define an **exclusive N-jet** sample by requiring that the number of reconstructed showered jets $\mathbf{N_{jet}}$ be equal to $\mathbf{N_{part}}$

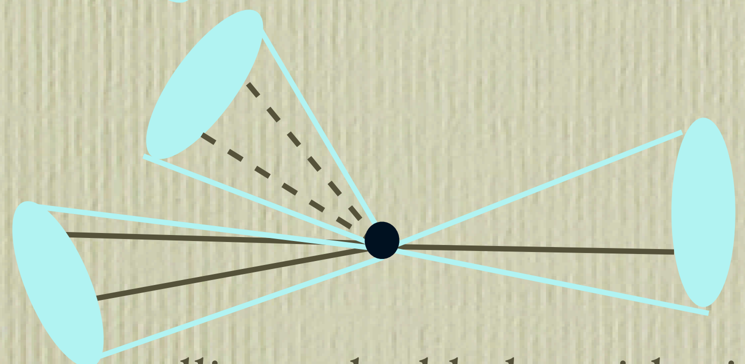
Few examples:

—— hard parton

- - - - parton emitted by the shower



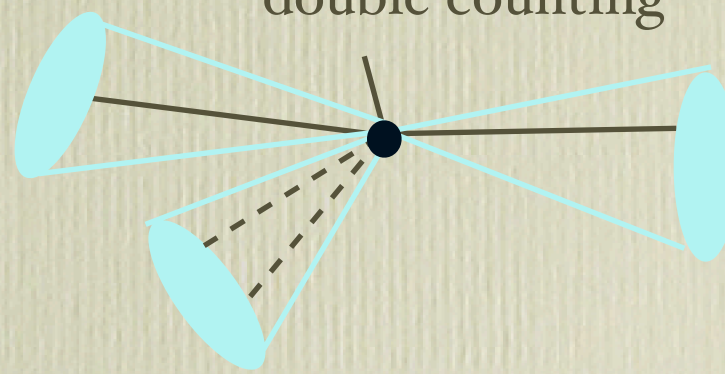
Event matched, $N_{jet}=N_{part}=3$, keep

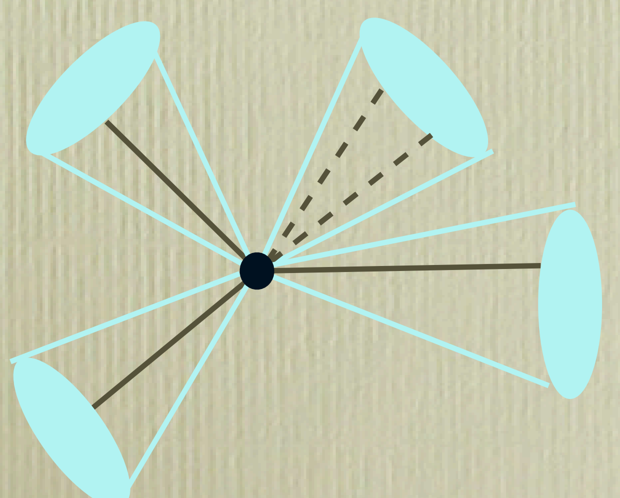


collinear double-logarithmic double counting

NOT matched, $N_{jet}=N_{part}=3$, but $N_{match}=2$ Throw away

soft single-logarithmic double counting





Event matched, $N_{jet}>N_{part}$, keep for inclusive sample, but throw away for exclusive samples.

- After matching, combine the exclusive event samples to obtain an **inclusive sample containing events with all multiplicities**
- The definition of generation cuts, and of jet cuts after the shower, are required as operative options to generate the sample, but **the physics obtained form the inclusive sample should not depend on them**. The inclusive sample so obtained can be used for any analysis, where possibly different jet definitions will be employed
- The extent to which results depend of the initial generation cuts is a measure of the success of the matching prescription

Some examples: W+multijets

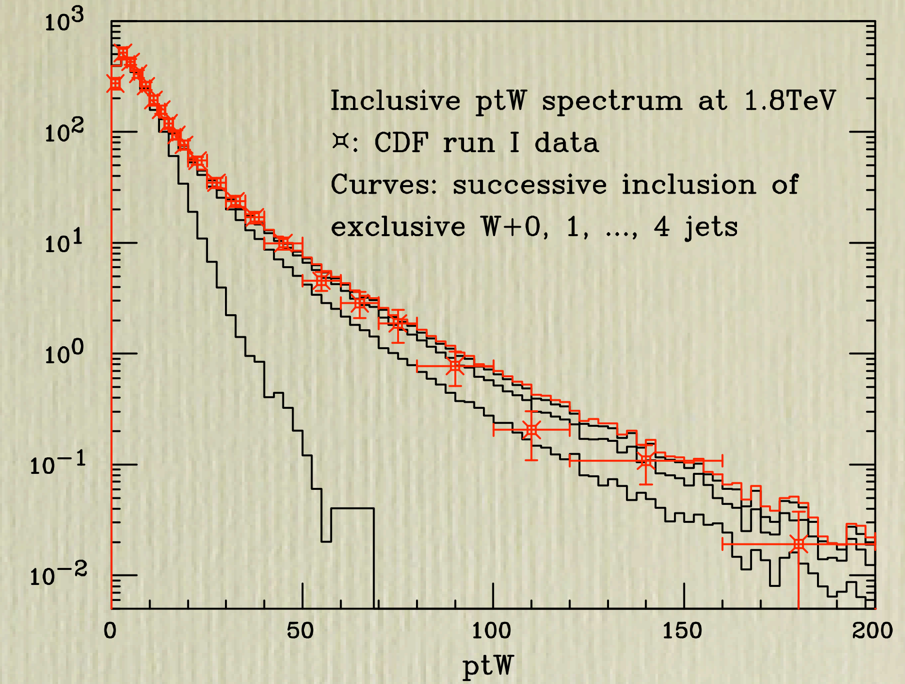
Define parton-level samples using

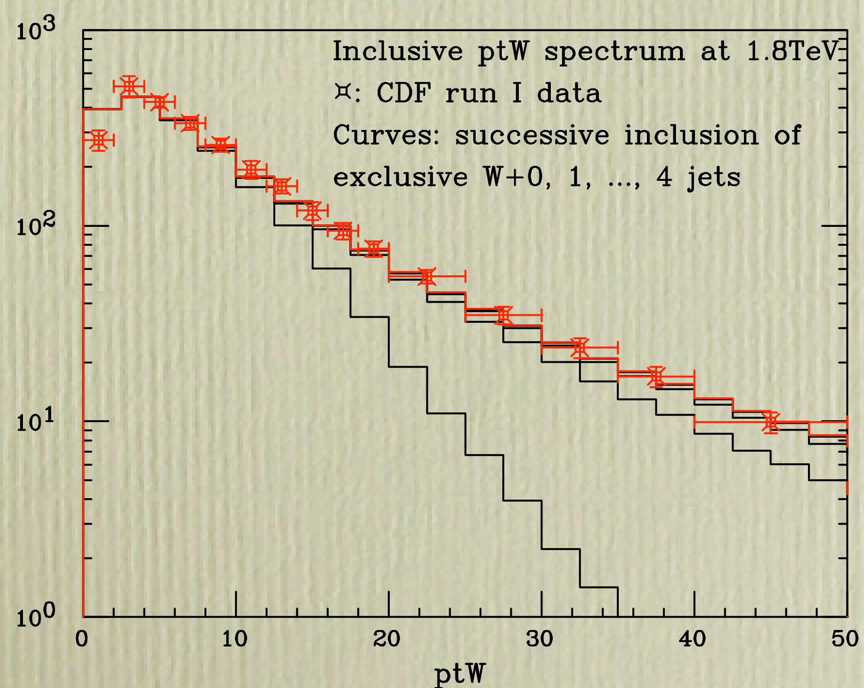
p_{Tmin} = 10, 20, or 30 GeV (PT10, PT20, PT30)

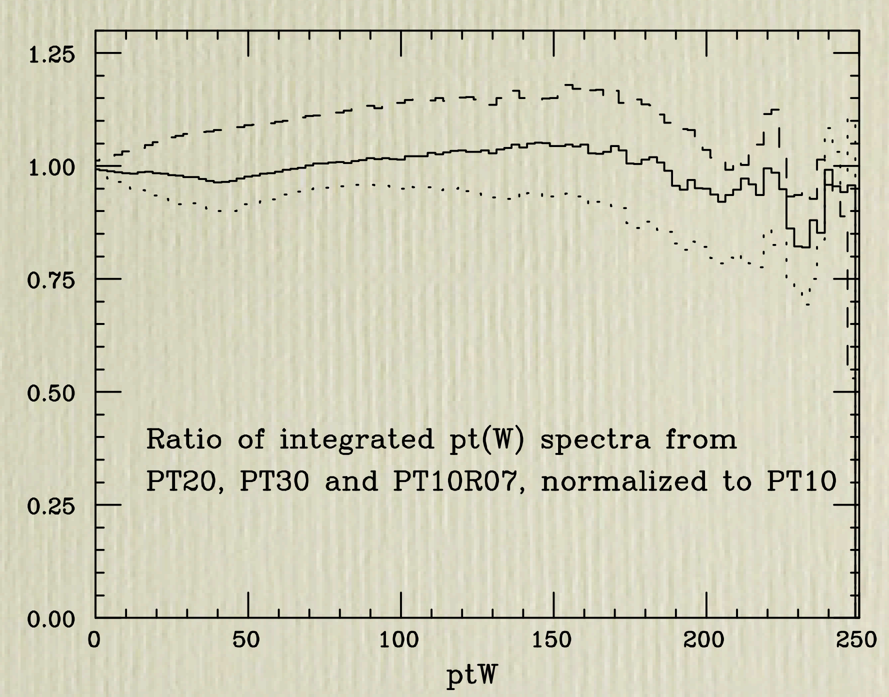
R_{jj}=0.4 or 0.7 (PT10R07)

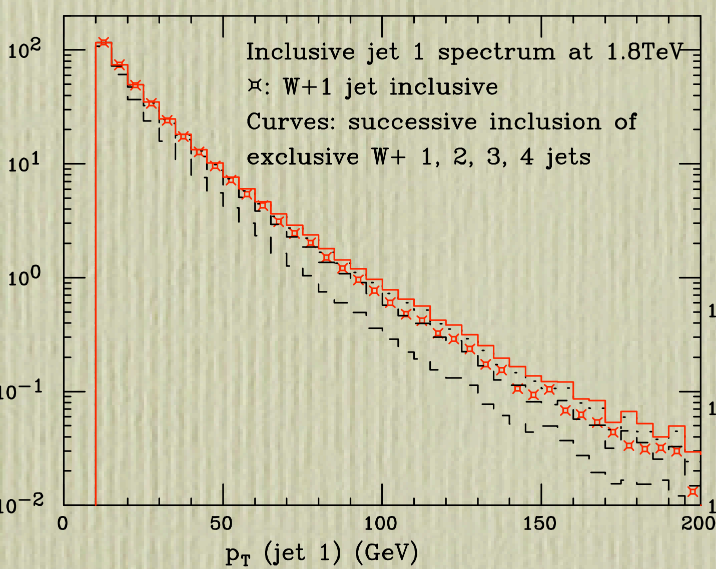
Shower and reconstruct jets using R_{cone}=0.4

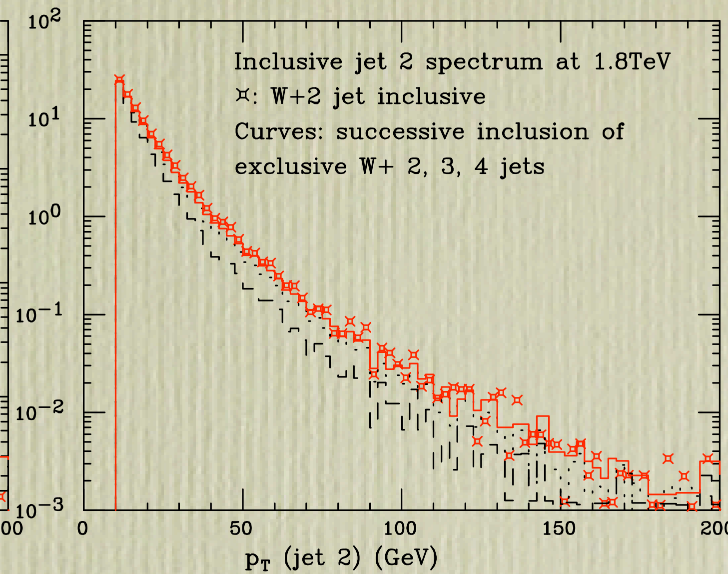
Study dependence of inclusive W and inclusive jet spectra on generation parameters

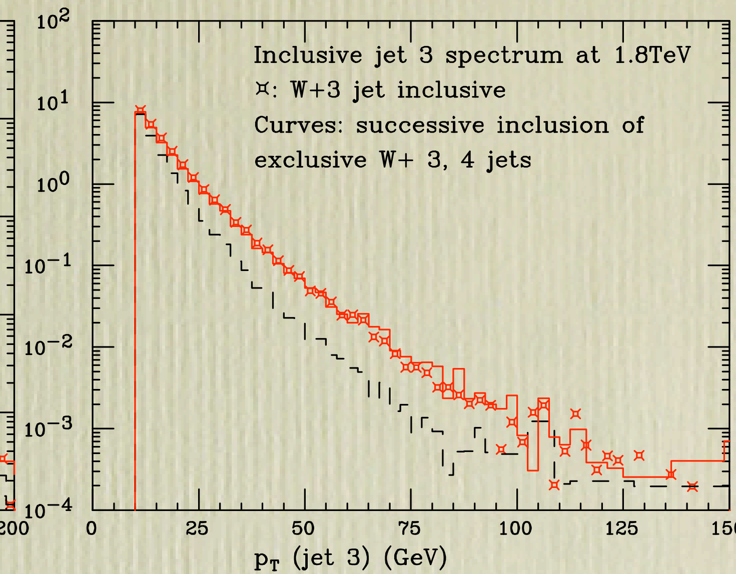


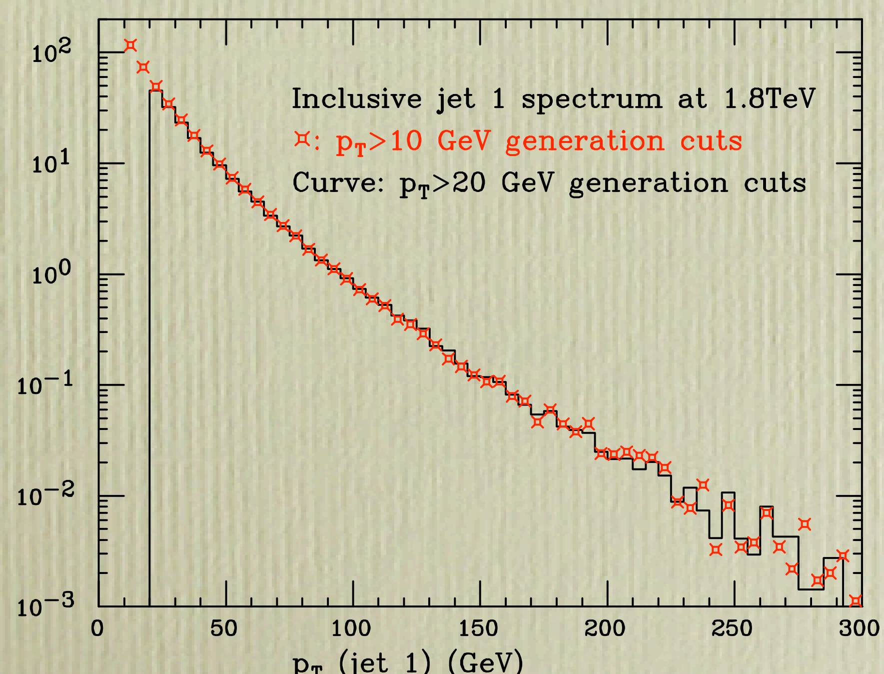


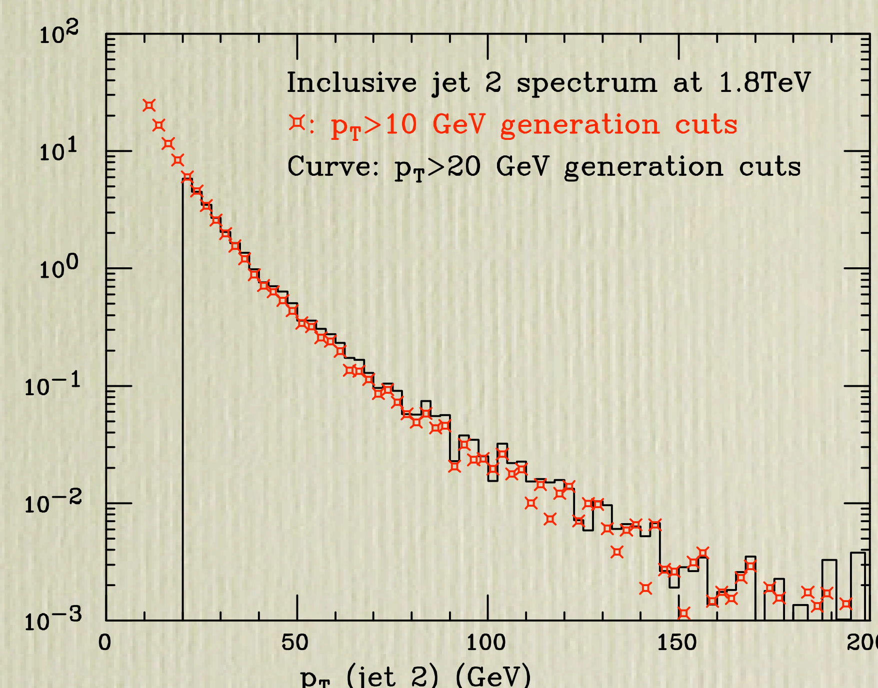



Inclusive jet 1 spectrum at 1.8TeV
¤: W+1 jet inclusive
Curves: successive inclusion of
exclusive W+ 1, 2, 3, 4 jets
p_T (jet 1) (GeV)


Inclusive jet 2 spectrum at 1.8TeV
¤: W+2 jet inclusive
Curves: successive inclusion of
exclusive W+ 2, 3, 4 jets
p_T (jet 2) (GeV)


Inclusive jet 3 spectrum at 1.8TeV
¤: W+3 jet inclusive
Curves: successive inclusion of
exclusive W+ 3, 4 jets
p_T (jet 3) (GeV)


Inclusive jet 1 spectrum at 1.8TeV
¤: p_T>10 GeV generation cuts
Curve: p_T>20 GeV generation cuts
p_T (jet 1) (GeV)


Inclusive jet 2 spectrum at 1.8TeV
¤: p_T>10 GeV generation cuts
Curve: p_T>20 GeV generation cuts
p_T (jet 2) (GeV)