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ALPGEN

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

M. Mangano, M. Moretti, R. Pittau, F. Piccinini and A. Polosa

JHEP 0307:001,2003.

- Ready-to-use exact LO calculation (based on the ALPHA code) for multiparton final states in hadronic collisions (SM)

  ALPHA: F. Caravaglios and M. Moretti, Phys. Lett. B **358** (1995) 332

- Parton-level event generation (weighted and unweighted)
  - mass term included
  - stable/unstable heavy particles avaliable.
  - routines for decays of heavy particles avaliable. full spin correlation in the narrow width approximations
  - coulor structure of the event in the leading $1/N_c$ approximation
- Interface to Herwig/Pythia for the evolution of the partonic final state through parton shower (jets and hadrons)

Up to now available processes

- $W^*Q\bar{Q} + n\text{-}jets$
  1. $W^* = l\nu_l$ only $O(\alpha_W)$ contibutions,
  2. $Q = top, bottom$
  3. description of top quark decay with spin correlation taken fully into account (infinitely narrow width approximation, $\Gamma_t = 0$).
  4. option for anomalous $V + A$ interaction in top decay.
- $W^* + n\text{-}jets$
- $Z^*/\gamma^* Q\bar{Q} + n\text{-}jets$ $(Z^*/\gamma^* = l\bar{l}, \nu\bar{\nu})$
- $Z^*/\gamma^* + n\text{-}jets$
- $Q\bar{Q} + n\text{-}jets$
- $Q\bar{Q}Q\bar{Q} + n\text{-}jets$
- $Q\bar{Q} + H + n\text{-}jets$
- $n\text{-}jets$
- $n_W + n_Z + n_H + n\text{-}jets$
  1. description of V-boson and top quark decay with spin correlation taken fully into account (infinitely narrow width approximation, $\Gamma = 0$).
  2. Z decay channel can be selected
  3. Higgs decay: to be released (v.2.0).
  4. $\Gamma_V = 0$ and a 'tuned' slice in $m_{jj'}$ cutted away to preserve gauge invariance
  5. four EW scheme provided (four free parameters, including higgs sector, others from tree-level relationships to preserve gauge invariance). Experienced users can override defaults.

- Single Top: to be released (v.2.0)
- $H + n$-$jets$:to be released (v.2.0) (gluon fusion, $m_t \to \infty$ limit)

Up to 8 final partons allowed (although not all the contributing partonic process are always accounted for). This restriction can be removed if required from physics studies.

Validation

An extended series of comparisons among avaliable packages (AMEGICC++, ComHEP, HELAC/PHEGAS/JetI, MadEvent) has been performed in MC_4 Wshop. See the web page *http://agenda.cern.ch/displayLevel.php?fid=152* for full detayls.

Validation against data

Tevatron W + multi-jet data

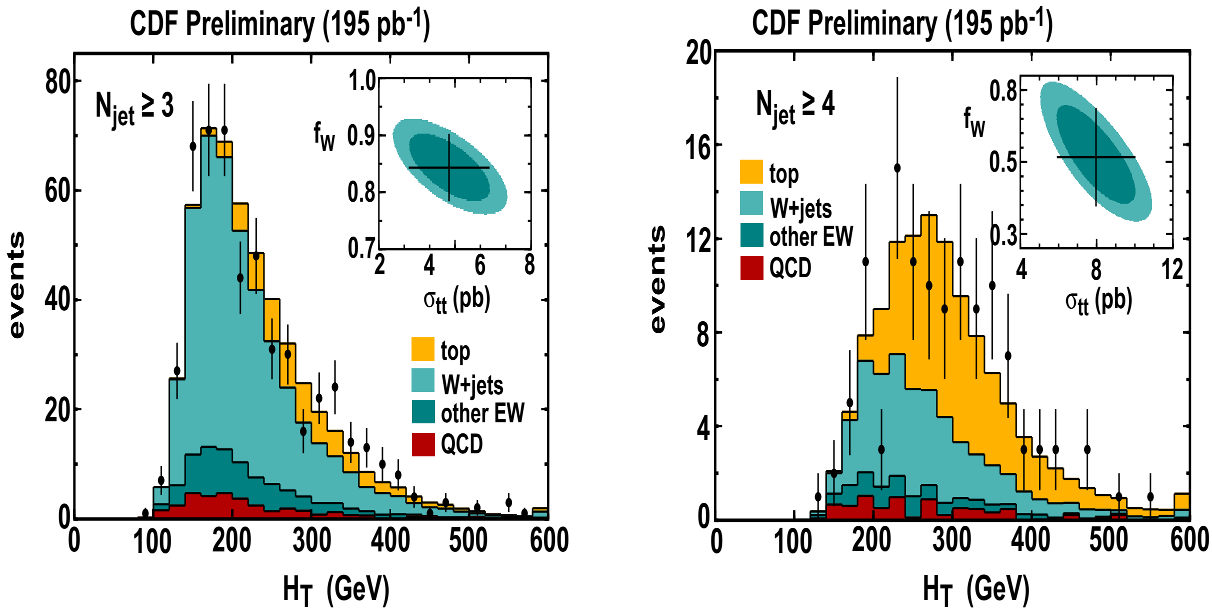
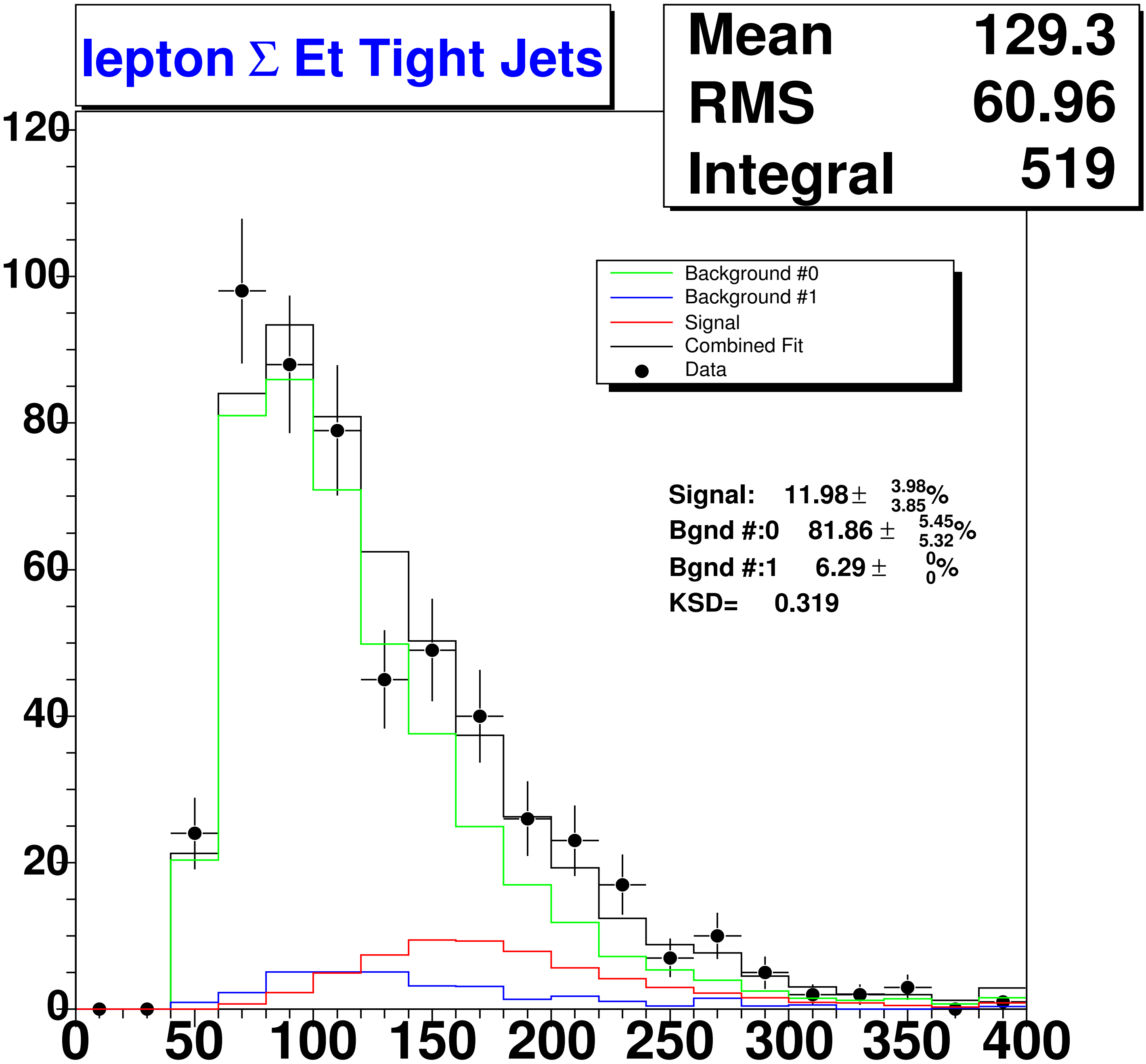


Figure 1:

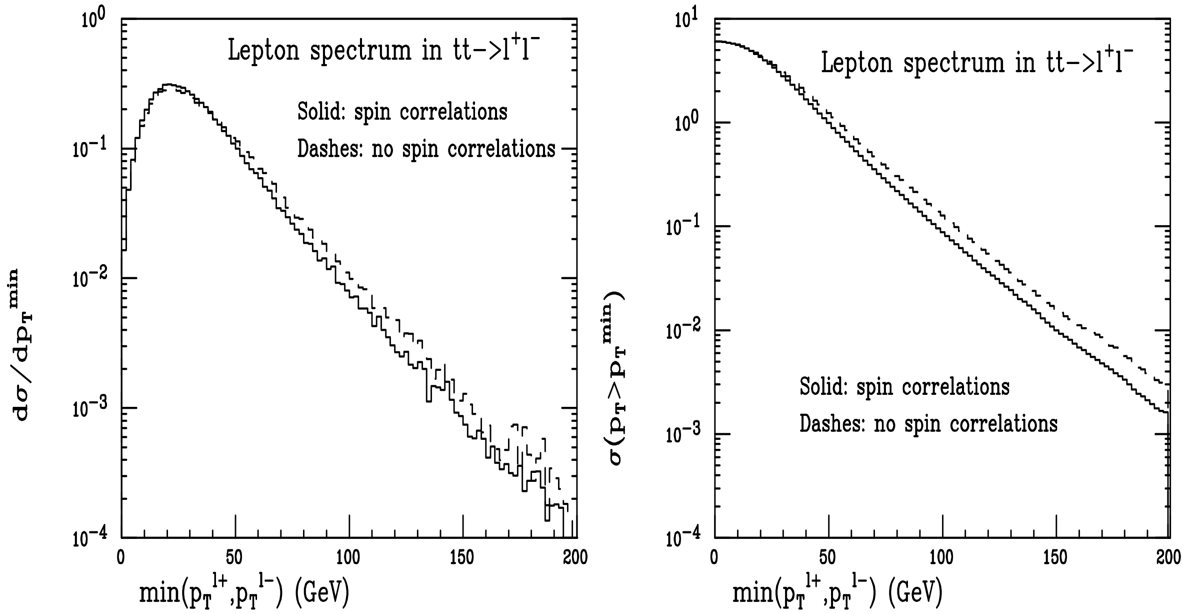

lepton Σ Et Tight Jets
Mean 129.3
RMS 60.96
Integral 519
Background #0
Background #1
Signal
Combined Fit
Data
Signal: 11.98 ± 3.98/3.85 %
Bgnd #:0 81.86 ± 5.45/5.32 %
Bgnd #:1 6.29 ± 0/0 %
KSD= 0.319
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400

Running Alpgen

- Inputs
  - Generation cuts on light (and heavy) quarks are specified as input. $p_T > 0$ $\Delta R > 0$ mandatory to avoid divergent cross sections.
  - option for forward/backward (up to two in opposite directions) jets.
  - Other cuts can be specified in a standalone subroutine.
  - Utilities to plot distributions avaliable.
  - PDF set and α_S scale
- the code compute the cross section and pre-unweighted events are dumped on disk.
  - a priori knowledge of maximum weight not required
  - off-line optimization of the unweighting procedure. (In practice one can lower the maximum weight provided that the distribution are unbiased by the procedure)
  - better (statistycally more accurate) assesment and study of showering effects
- events are unweighted and processed through the parton shower (interface to Herwig and Pythia).
  - event weight is given by the (modulus-squared) matrix element
  - for accepted events only, the coulor flow is reconstructed
    1. For the *given* external coulors all contributing *charge flow* are computed (infinite N_c limit).
    2. a specific charge flow is selected (randomly, according to the relative weight. subleading $1/N_c$ interferences neglected) and feeded to the parton shower
- At this stage the user can choose to force decay of heavy particles

(top, V-bosons, Higgs in progress) full spin correlation is included in the decay.

- In $t\bar{t}+$ jets the top quarks are generated on shell
- spinors $\sim$ to exact matrix element for the decay $t \rightarrow bf\bar{f}'$ are used
- In so doing all spin correlations between top decay products are exactly taken into account (*even for particles coming from distinct decays*)



From partons to jets

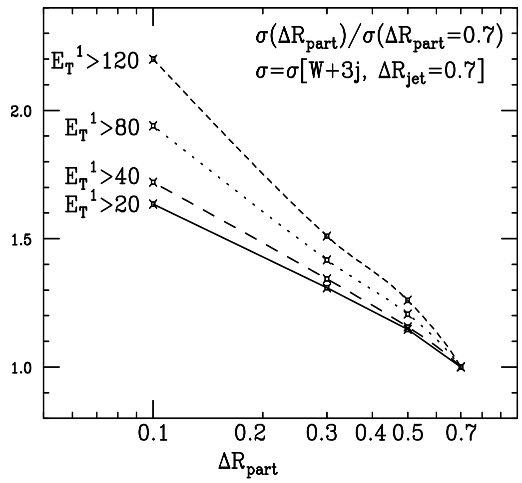
- Parton-level cuts are just a computational device (to avoid ME blow up) results should be insensitive

  One could start from softer parton-level cuts

- Due to softer cuts some events are obatined as:
  - two (or more) hard partons are clustered in the same jet
  - one (or more) jet is obtained from hard PS radiation
  - double counting (suppressed by $O(\alpha_S)$)
  - ME soft/collinear divergencies not dumped by Sudakov suppression

- Ideally the final jet cross-section should be independent of the parton-level generation cuts, even in the limiting case $p_{T min} \to 0$ and $\Delta R_{cut} \to 0$

Example: $W + 3$ jets at Tevatron



Cross section for $W + 3$ jets at Tevatron as a function of generation cuts (ΔR_{parton} $E_{T parton}$). The soft/collinear divergence is clearly seen

N.B. final cuts are the same for all the above points

Towards matching of ME & PS

For e^+e^- physics a solution has been proposed

S. Catani et al., JHEP 0111 (2001) 063

L. Lönnblad, JHEP 0205 (2002) 046

which avoids double counting and shifts the dependence on the resolution parameter beyond NLL accuracy

The method consists in separating arbitrarily the phase-space regions covered by ME and PS, and use vetoed parton showers together with reweighted tree-level matrix elements for all parton multiplicities

Proposal to extend the procedure to hadronic collisions but the proof is still missing

F. Krauss, JHEP 0208 (2002) 015

The CKKW procedure has been successfully tested on LEP data

e.g. S. Catani et al., JHEP 0111 (2001) 063

R. Kuhn et al., hep-ph/0012025

F. Krauss, R. Kuhn and G. Soff, J. Phys. G26 (2000) L11

Recent work for hadronic collisions

- `Herwig` (P. Richardson)
- `Pythia` (S. Mrenna)

  S. Mrenna and P. Richardson, hep-ph/0312274

- `SHERPA with APACIC++/AMEGIC++` (F. Krauss and A. Schälicke)

An alternative proposal

M.L. Mangano, FNAL MC Workshop, October 2002

- generate event sample ($p_T > p_{Tmin}$ $\Delta R > \Delta R_{min}$
- shower the event and reconstruct particle clusters (jets) with a cone algorithm
  - Note: these clusters are just a computational device to define the sample. they don't need to coincide with "experimental" jet Namely you can input $p_{Tmin} = 20$GeV and $\Delta R > 0.5$ as cuts for the partonic ME and then analize the sample requiring $p_{Tmin} = 40$GeV and $\Delta R > 0.7$ for final jets.
- define the matching of a parton (LO matrix element) and a cluster as follows: a parton match a cluster if the separation ΔR between the parton and the cluster is smaller than $\Delta\bar{R}$ (an arbitrary fixed quantity $\Delta\bar{R} \sim \Delta R_{min}$
- reject the event if more than one parton match the same cluster or if a parton doesn't match any cluster
- for *exclusive* samples also events with number of clusters different (larger) from number of partons are rejected
- Let's stress again that we have different parameters: a) $p_T^{(partons,matching)}$ $\Delta R^{(partons,matching)}$ which should not affect σ and distributions (efficiency can however depend on the choice made). b) p_{Tjets}, ΔR_{jets} and any other cuts

used in the analysis σ depends only on this set of parameters.

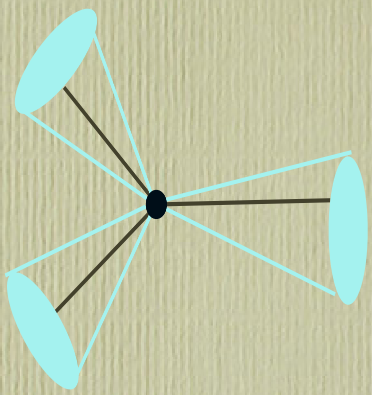
One still expects not better than LL accuracy. However we expect a strongly reduced NLL sensitivity. From the practical point of view it is enough that these residual effects are smaller than the other systematics of the calculation

Ideally the whole prescription leads to samples independent from generation cuts. In practice the dependece from generation cuts is a measure of the success of the matching prescription

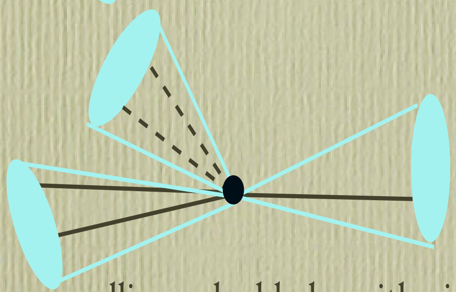
Few examples of matching:

hard parton

parton emitted by the shower



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

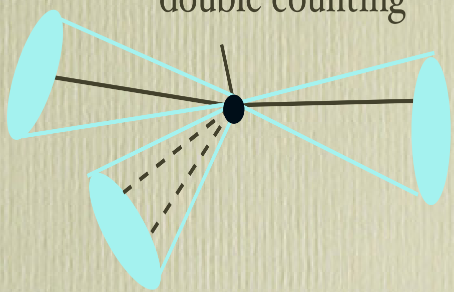


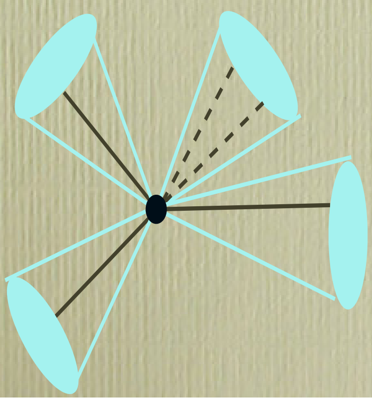
collinear double-logarithmic double counting

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.

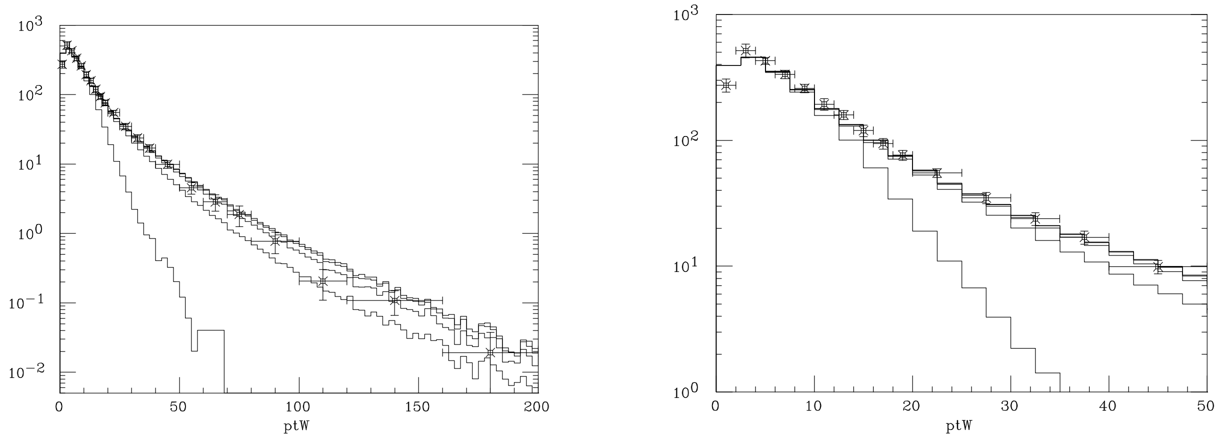


Figure 2: $p_{T,W}$ spectrum. The points represent run I CDF data. The curves correspond to the subsequent inclusion of samples with higher multiplicity, form the $W+0$ jet, up to the $W+4$ jets case. The right plot is the same as the left one, with an enhanced low-p_T scale.

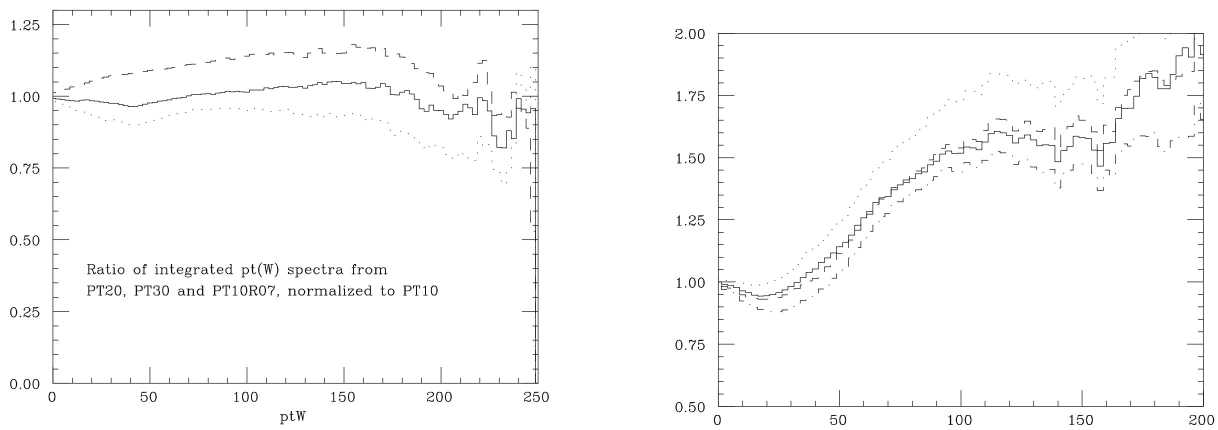


Figure 3: Effect of different genertaion cuts on the integrated $p_{T,W}$ spectrum. The right panel shows the ratios of the samples generated with PT20, PT30 and PT10R07, divided by PT10. The right panel shows all four samples divided by a plain (no ME correction) HERWIG W sample.

PT10, PT20, PT30 : $P_T > 10, 20, 30 GeV$, $\Delta R > 0.4$

PT30R07 : $P_T > 30$, $\Delta R > 0.7$

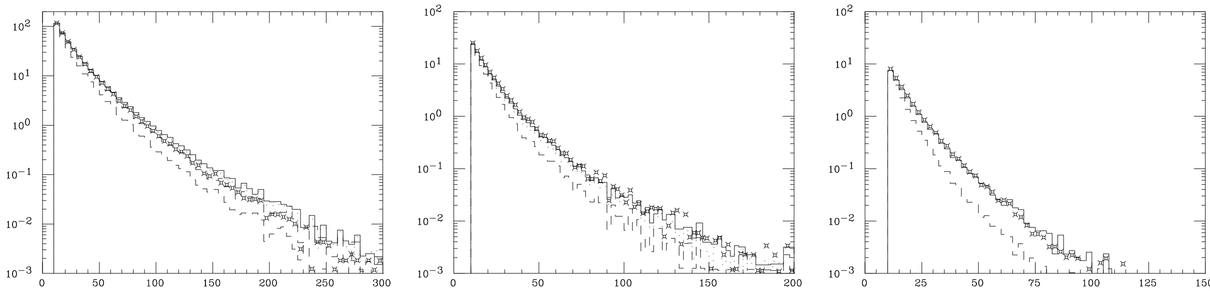


Figure 4: Inclusive jet/cluster E_T spectra, obtained via from an inclusive sample (plotted points) and by adding exclusive samples, for $N_j = 1, 2, 3$.

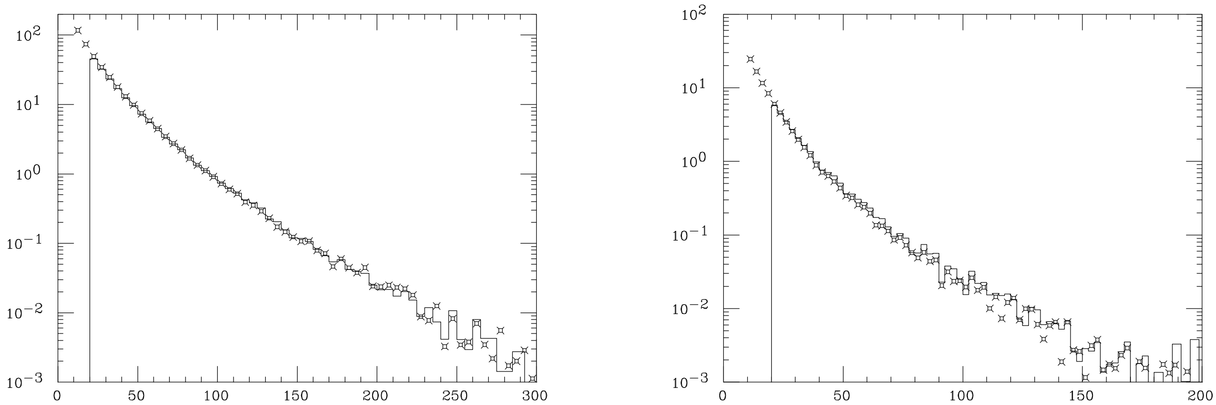


Figure 5: Effect of different generatiaon cuts on the E_T spectrum of the leading (left) and of the second (right) jet/cluster. Solid line obtained with PT20, plots with PT10.

Towards **ALPGEN** v.2.0

Essentially completed (documentation still missing)

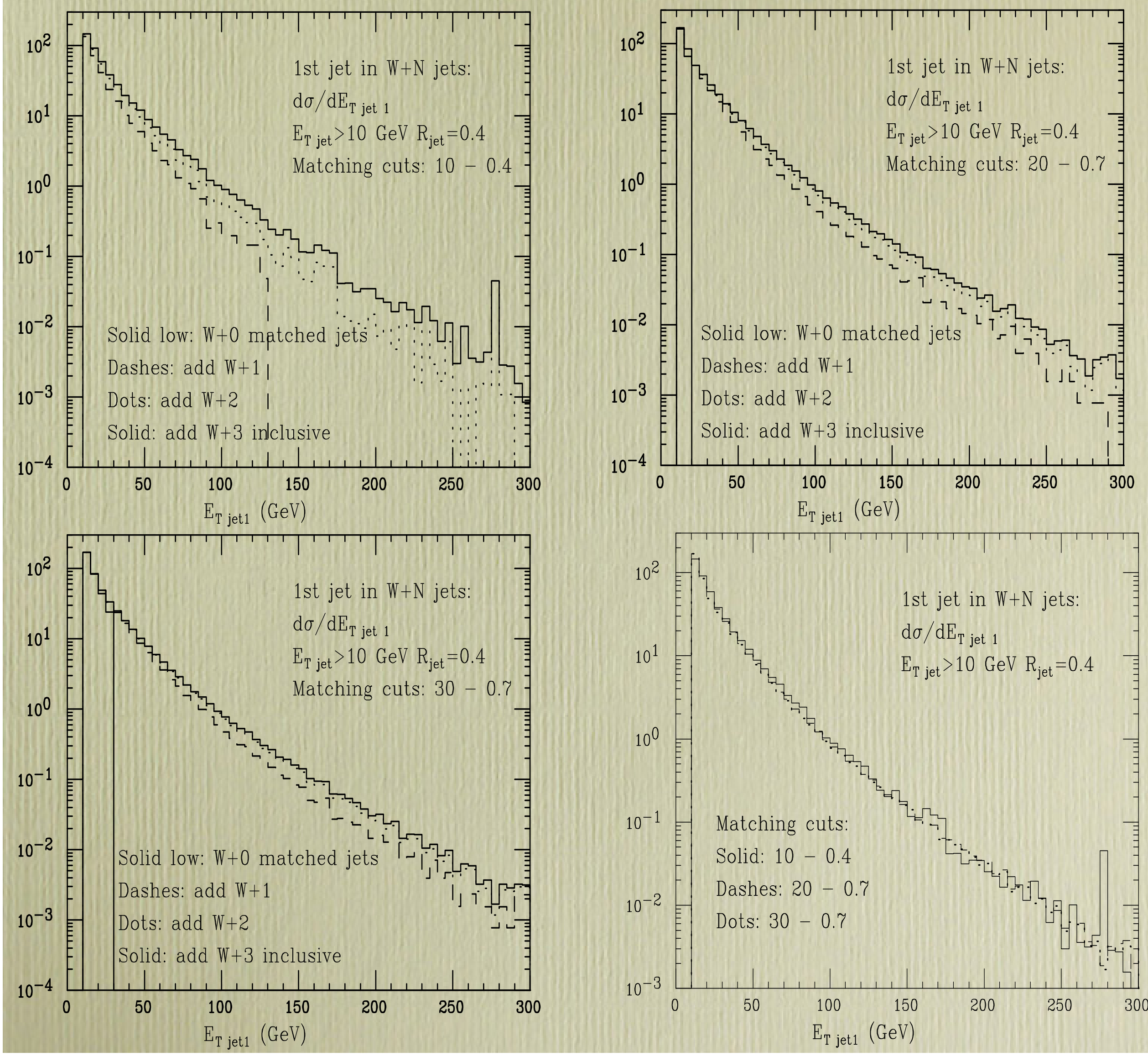
Option for matching and α_S reweighting included

- parton level: as before, but
  1. From the event kinematics and color flow a branching tree is reconstructed using $k_\perp$ algorithm. The scale of α_S is assigned as the minimum $k_\perp$.
  2. Pre-unweighted events are dumped on disk
- Unweighting, done in two stages:
  1. Events are: a) reweighted according to a product of $\alpha_S(k_\perp)/\alpha_S(k_\perp^{(min)})$, one for each branching b) unweighted
  2. unweighted eventes are showered (*no adronization*), ME+PS partons are clustered (cone algorithm implemented , $k_\perp$ option in progress).

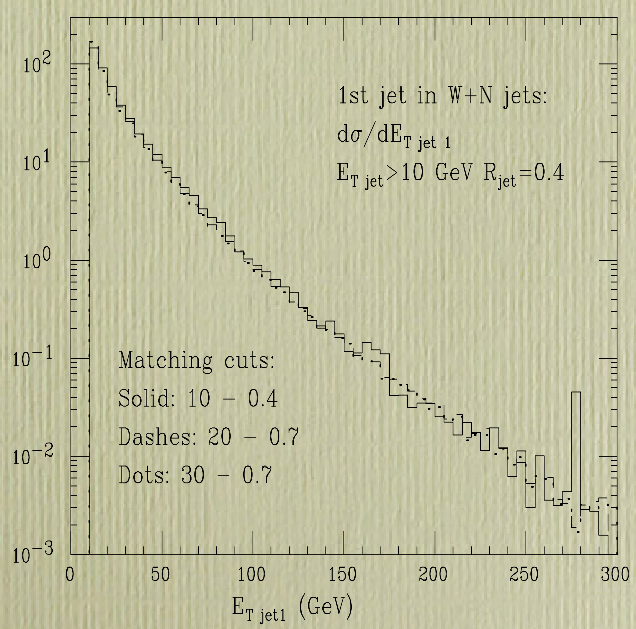
Events which don't fulfill matching prescription are rejected (The PS thus provide Sudakov suppression to ME weights)

3. ME+PS partons are dumped on disk, a new cross section is provided including the effect of α_S reweighting and vetoed showers
4. Exclusive samples of arbitrary jets multiplicities can now be consistently added (the highest multiplicity sample is an inclusive one). *this step, adding toghether separate samples, has to be performed by the user*
5. as a final step events are *adronized*

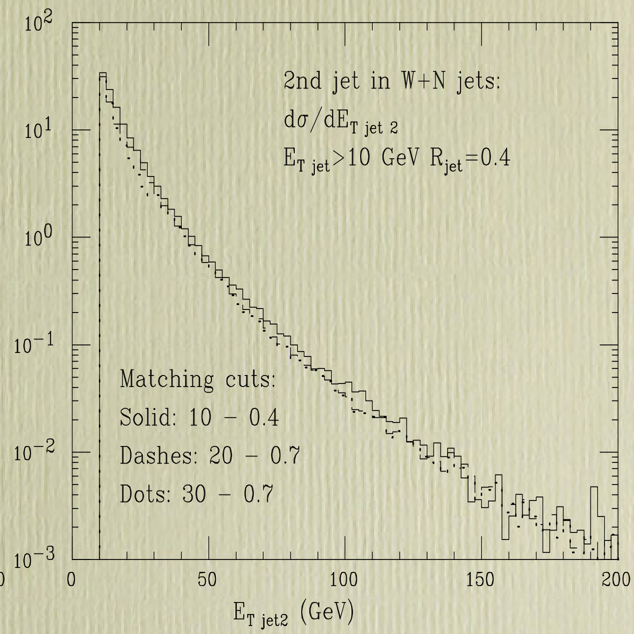
Leading-jet[10,0.4] Et distribution: multijet composition with different matchings



Comparison of resulting spectra for leading and second-leading jet in inclusive samples defined by different matchings

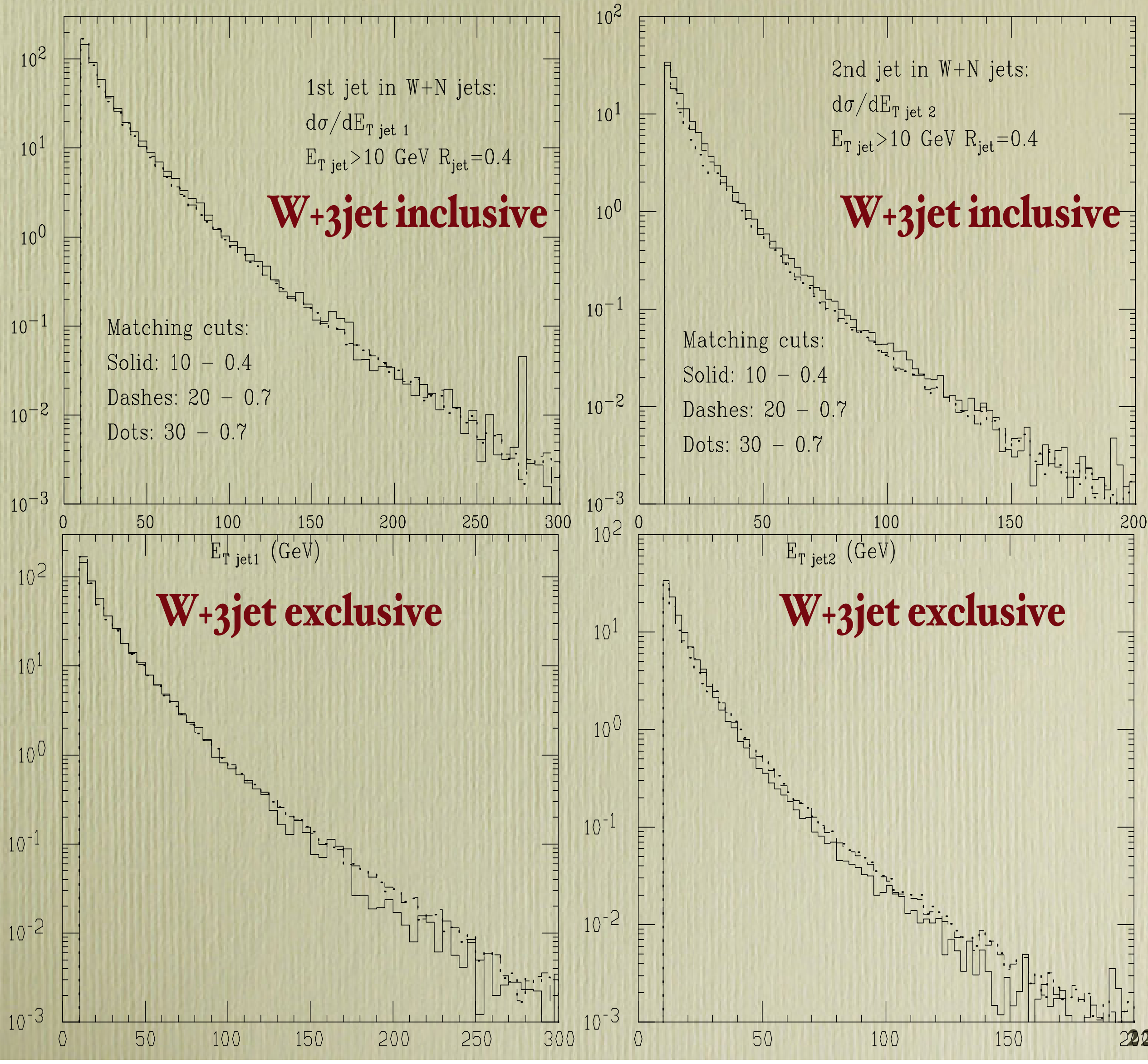


Leading jet



Second-E_T jet

Impact of treating inclusively/exclusively the highest-multiplicity sample



- matching systematic $20 - 30\%$ level (smaller on distributions, might depend on the process)
- one can use the relatively small dependence on matchin presription to actually impose harder cuts at generation level (useful for efficiency)

New packages in ALPGEN v2.0

- Single Top
- Higgs + jets (effective ggH vertex, $m_t \to \infty$ limit)
- $t\bar{t} + n_\gamma \gamma + n_j$ jets, in progress

Higgs + jets, azimutal correlation and rapidity gap studies [a] with the new ALPGEN

work in progress V. Del Duca, M. Mangano, R. Pittau, F. Piccinini and A. Polosa

- Azimutal correlation
  1. helpful to discriminate between CP odd/even higgs (dip at $\Delta\phi_{jj'} = \pi/2$ for standard higgs
  2. distintive signature of gluon fusion mechanism (no dip for VBF)
  3. potential signature of new physics
- Rapidity Gap useful to discriminate VBF higss versus gluon fusion higgs
  1. color coherence inhibit central jet emission in VBF process $\to$ tool to enhance VBF content of the signal

[a] Zeppenfeld, Baur, Plehn, Rainwater, Del Duca, Kilgore, Oleari, Odagiri, Dokshitzer, Khoze, Sjostrand . . . , see JHEP 0405 (2004) 64 for an extensive set of reference

mini-jet veto: mostly parton level studies

azimutal decoherence (induced by soft emission)
studied only with the pure PS approach (Odagiri)

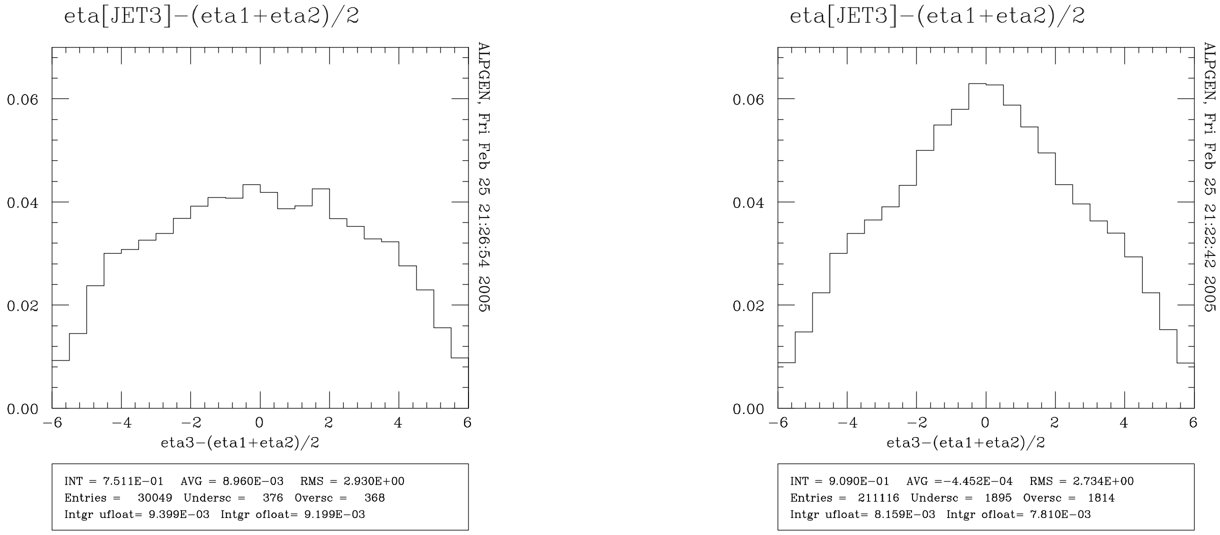


Figure 6: $\eta_3 - \frac{\eta_2+\eta_1}{2}$, jets ordered according p_T. left $ME_{pp\to H+2jets}$ + PS, right $ME_{pp\to H+3jets}$ + PS . Gluon fusion production mechanism ($m_t \to \infty$ limit)

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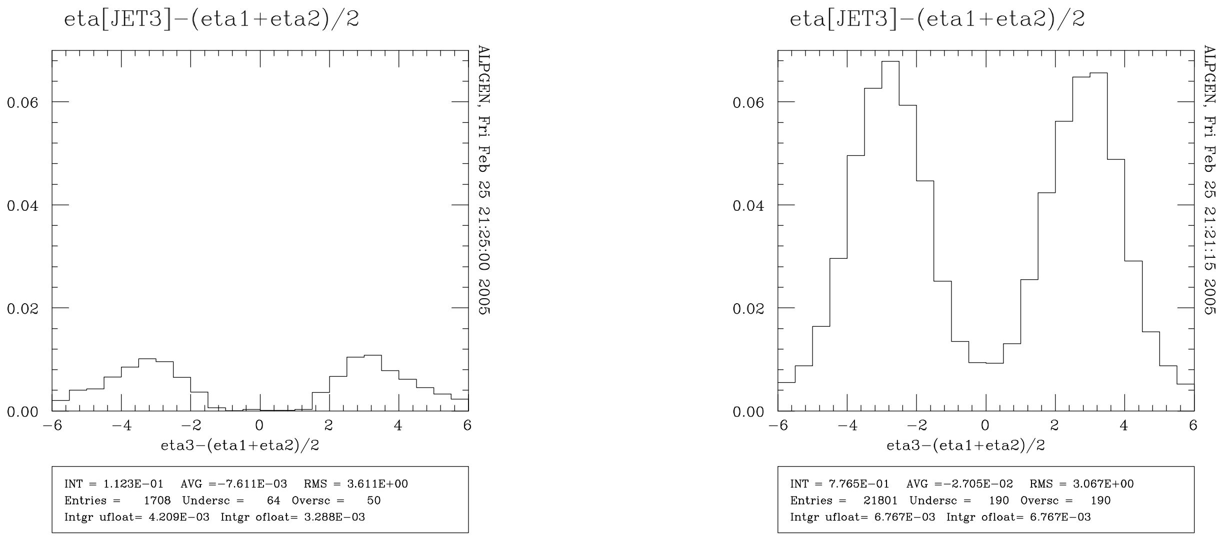

Figure 7: $\eta_3 - \frac{\eta_2+\eta_1}{2}$, jets ordered according p_T. left $ME_{pp\to H+2jets}$ + PS, right $ME_{pp\to H+3jets}$ + PS. Vector boson fusion production mechanism.

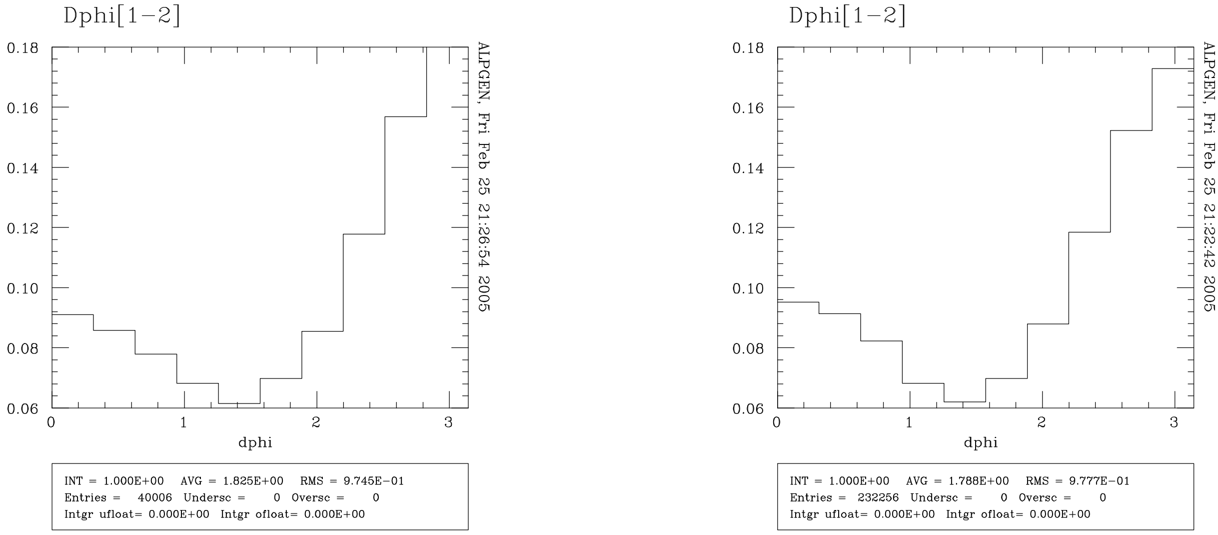

Figure 8: jet-jet distance in the transverse plane, $\Delta\phi_{j_1 j_2}$, jets ordered according p_T. left $ME_{pp\to H+2jets}$ + PS, right $ME_{pp\to H+3jets}$ + PS . Gluon fusion production mechanism ($m_t \to \infty$ limit)

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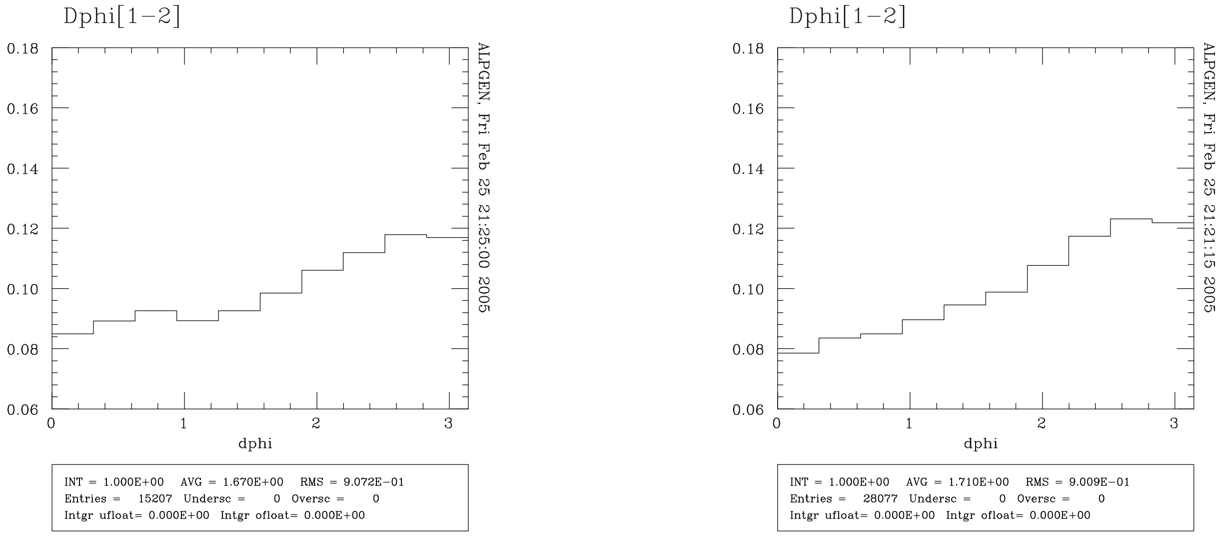

Figure 9: jet-jet distance in the transverse plane, $\Delta\phi_{j_1 j_2}$, jets ordered according p_T. left $ME_{pp\to H+2jets}$ + PS, right $ME_{pp\to H+3jets}$ + PS. Vector boson fusion production mechanism.

- Azimutal correlation
  1. correlation only mildly affected by soft/collinear radiation
  2. asimmetry arounf $\pi/2$ enhanced
  3. ME mandatory, showering important
- Rapidity Gap
  1. radiation pattern fairly stable in VBF (amount of central radiation larger but still small as compared to total); impact of showering smooth
  2. radiation pattern stable as well in gluon fusion; central jet emission enhanced by ME contribution; impact of showering smooth