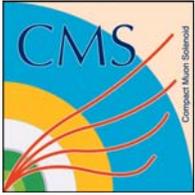


A study on AlpGen and Sherpa in Z+jets events

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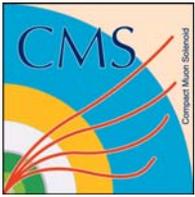
*HERA-LHC workshop
CERN
27-05-2008*



Outline



- The Matrix Element – Parton Shower matching problem
- Two different approaches to the matching:
 - CKKW (Catani, Kuhn, Krauss, Webber), the SHERPA way
 - MLM (M. Mangano), the AlpGen way
- Production of Z+jets events at LHC (14 TeV)
 - Sherpa and its systematics
 - AlpGen and its systematics
 - A comparison between the two



Introduction

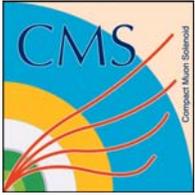


- This work is part of my "*MCnet short term studentship*" work at University College London (UCL), supervised by Prof. Jon Butterworth
- the RIVET package has been used for this comparison
<http://projects.hepforge.org/rivet/trac/wiki/>
 - RIVET (*Robust Independent Validation of Experiment and Theory*) is part of the CEDAR (*Combined e-Science Data Analysis Resource*) [1] project
 - It will be used by the JetWeb[2] facility to make comparison between theory and experimental data stored in the HEP-DATA [3] database
 - It can be used also as a standalone tool for MC validation/tuning and comparison with experimental results

[1] J.M. Butterworth *et al.* "**The CEDAR Project**", hep-ph/0412139

[2] <http://jetweb.cedar.ac.uk/>

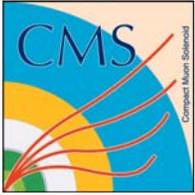
[3] <http://hepdata.cedar.ac.uk>



RIVET



- Interface to many generators is provided by the separate AGILE library <http://projects.hepforge.org/agile/>
- RIVET is a C++ package, with two main kind of objects
 - *Projections*: these classes calculate event observables. Projections are handled through a smart caching system avoiding the same observable being calculated twice for the same event
 - *Analyses*: rivet analyses distributed in the release are mainly intended to reproduce at the generator level experimental results corrected for detector effects. User analyses can of course also be written to compare/tune different event generators
- The default RIVET plot output format is AIDA-xml, the same used when exporting experimental results from HEP-DATA database
- Version 1.0 has been released on 11-02-2008



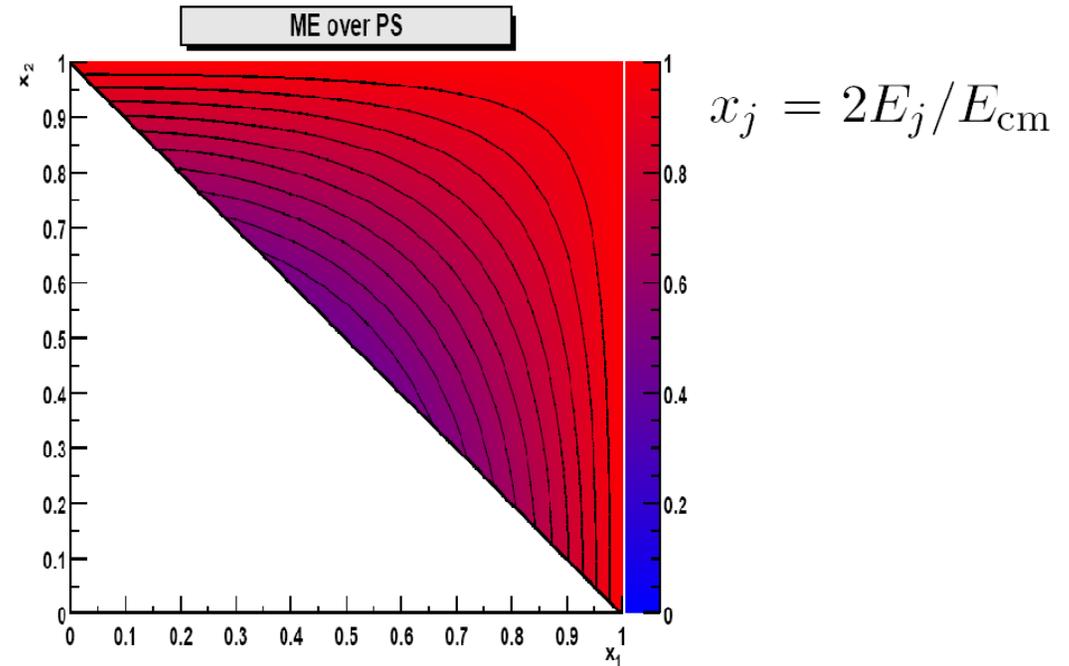
The ME-PS matching problem



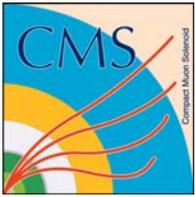
$$\frac{d\sigma_{\text{ME}}}{dx_1 dx_2} \sim \left| \begin{array}{c} \text{diagram 1} \\ \text{diagram 2} \end{array} \right|^2 + \left| \begin{array}{c} \text{diagram 3} \\ \text{diagram 4} \end{array} \right|^2$$

$$\frac{d\sigma_{\text{PS}}}{dx_1 dx_2} \sim \left| \begin{array}{c} \text{diagram 1} \\ \text{diagram 2} \end{array} \right|^2 + \left| \begin{array}{c} \text{diagram 3} \\ \text{diagram 4} \end{array} \right|^2$$

The diagrams show two types of parton interactions: a quark-gluon vertex (top row) and a quark-gluon vertex with a ghost loop (bottom row). In the ME diagrams, the gluon lines are wavy and red, while in the PS diagrams, they are curly and red. Blue lines represent quarks.



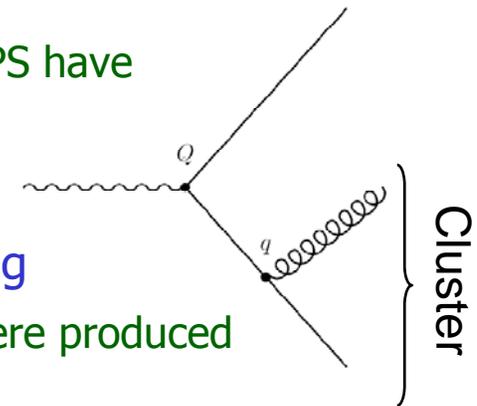
- The PS response coincides with the ME in the soft/collinear region $x_i \sim 1$
- The divergence of the cross section in this region is tamed in the PS using a cutoff and a reweighting factor called Sudakov form factor
- It would be very convenient to use the ME to predict hard parton configuration and the PS to describe the evolution of jets
- BUT beware double counting and holes in the phase space!

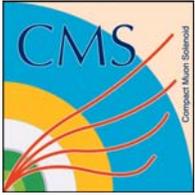


SHERPA approach to the matching: CKKW



- Jet production and jet evolution regions are well separated using a k_t measure ($y = \min(P_{t_1}^2, P_{t_2}^2) * \Delta R^2 / D^2$) cutoff $y_{\text{cut}} = Q_{\text{cut}}^2 / E_{\text{cm}}^2$
- The following recipe is used:
 - Calculate the ME cross sections for all the desired parton multiplicities; y_{cut} is used to cutoff divergences; a fixed α_s^{ME} is used
 - events are produced according to the ME cross sections and a “shower history” is reconstructed through k_t clustering until a $2 \rightarrow 2$ process is found
 - In other words this answers to the question: “How could a PS have produced this parton configuration?”
 - A running coupling correction weight is applied
 - Apply a Sudakov form factor correction for each clustering
 - The effect of this correction is to weight the event as if it were produced by a PS
 - Evolve the event with a PS, vetoing emission above the cut

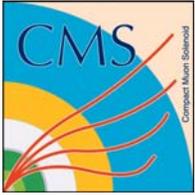




AlpGen approach to the matching: MLM



- The MLM algorithm proceeds exactly as the CKKW up to the reweighting of α_s
- Events are fully showered using a conventional shower (PYTHIA or HERWIG)
- Partons are clustered into jets (with a cone algorithm in the AlpGen implementation)
- Jets are matched to original partons
 - If not all the jets match to the original partons event is rejected
- This effectively reproduces Sudakov reweighting
- Effectively vetoes PS emission above the merging scale



Z+jets event generation

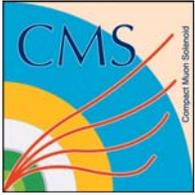


- SHERPA

- SHERPA-MC-1.0.11 was used
- $pp \rightarrow e^+ e^- +$ up to 3 jets at 14TeV
- CTEQ6l pdf
- No underlying event
- $66. \text{ GeV} < \text{mass}(e^+ e^-) < 116. \text{ GeV}$
- Matching parameter $Q_{\text{cut}} = 20\text{GeV}$

- AlpGen

- V2.13 was used
- $pp \rightarrow e^+ e^- + n$ jets ($n = 0, 1, 2, 3$) at 14TeV
- CTEQ6l pdf
- $66.\text{GeV} < \text{mass}(e^+ e^-) < 116. \text{ GeV}$
- - Matching parameters:
 - $E_t(\text{clus}) = 25 \text{ GeV}$
 - $R(\text{clus}) = 0.7$
 - $\eta_{\text{max}} = 5$
- Pythia and Herwig UE was switched off

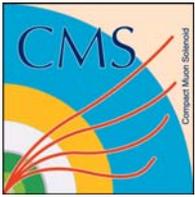


Analysis

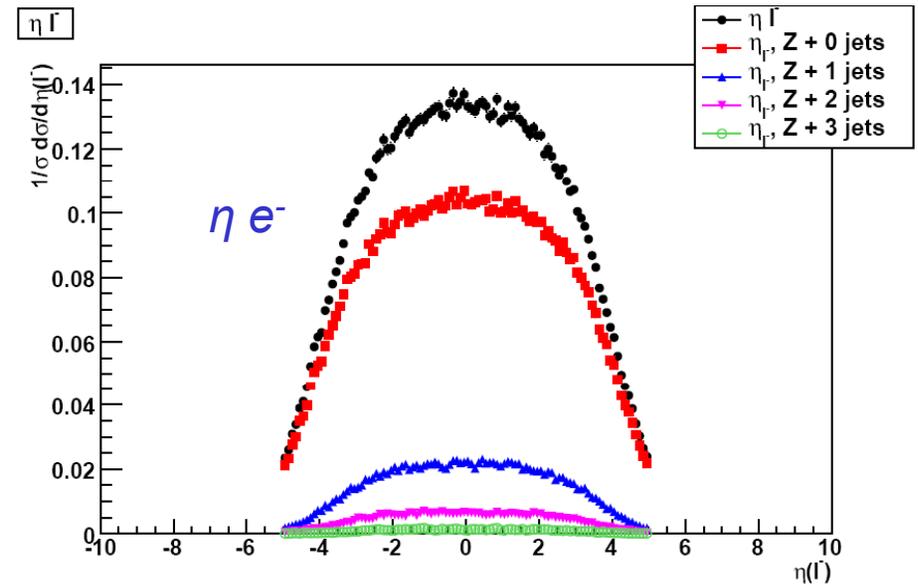
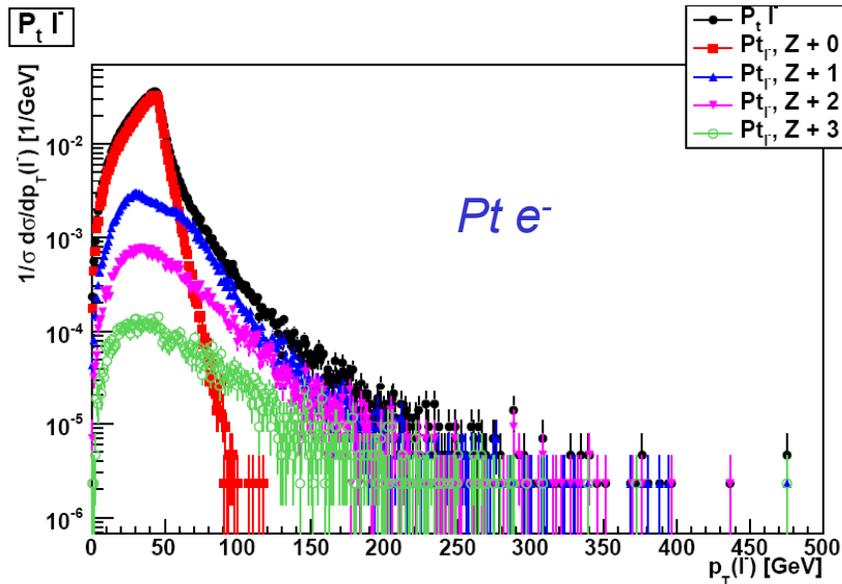
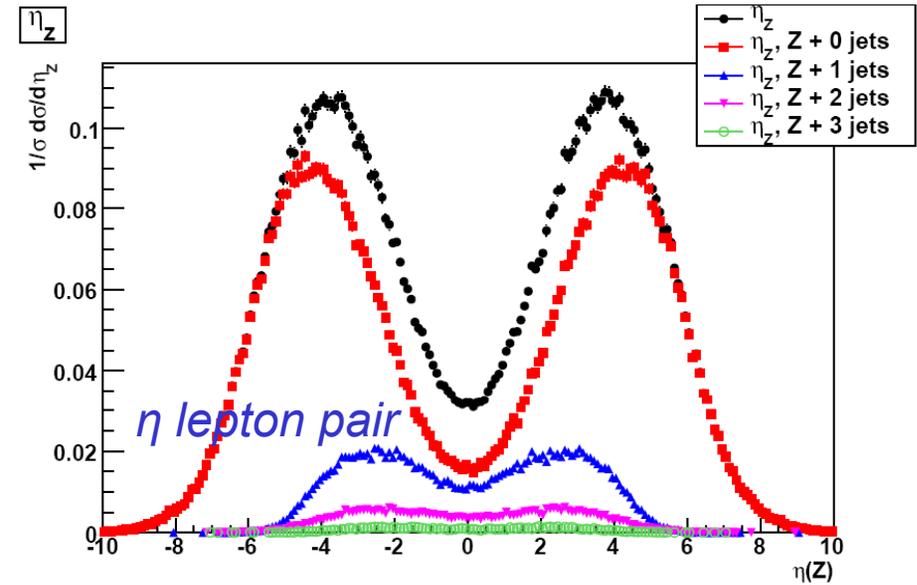
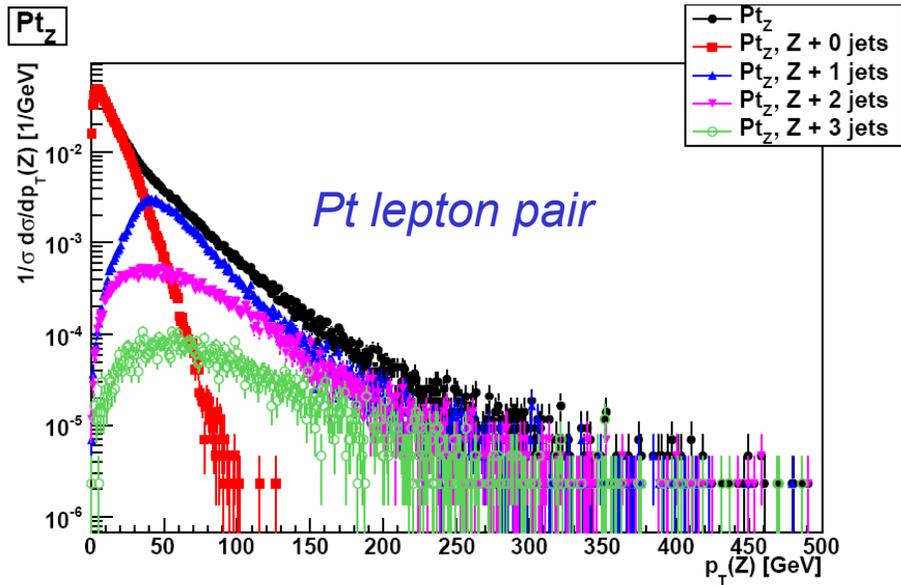


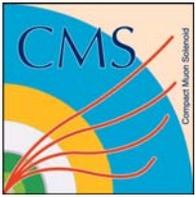
- Final state particles with $|\eta| < 5$ were selected
- No pt cut on the final state particles
- Kt jets were reconstructed using the FastJets package by M. Cacciari, G. Salam
 - $P_{tmin} = 30 \text{ GeV}$, $D = 0.4$
- $\Delta R_{ll} > 0.2$, $\Delta R_{lj} > 0.4$, $\Delta R_{jj} > 0.7$

- Many lepton and jet observables have been calculated
- For each generator a collection of observables is shown and the effect of a change in the matching parameters and in the scale choice is described
- A comparison between AlpGen and Sherpa is shown



Sherpa, Lepton observables

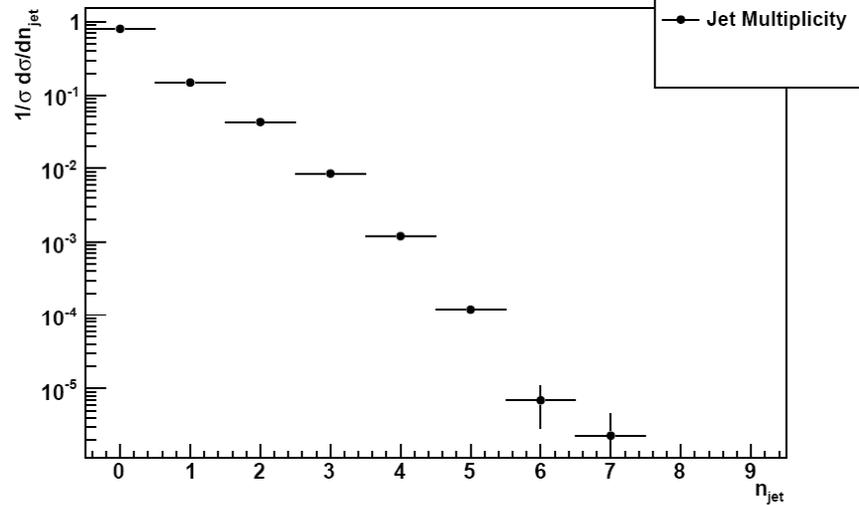




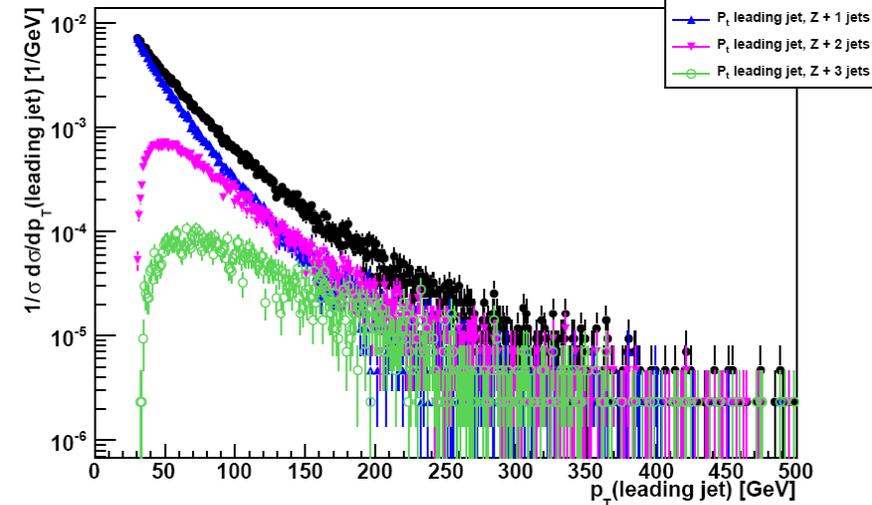
Sherpa, jet observables



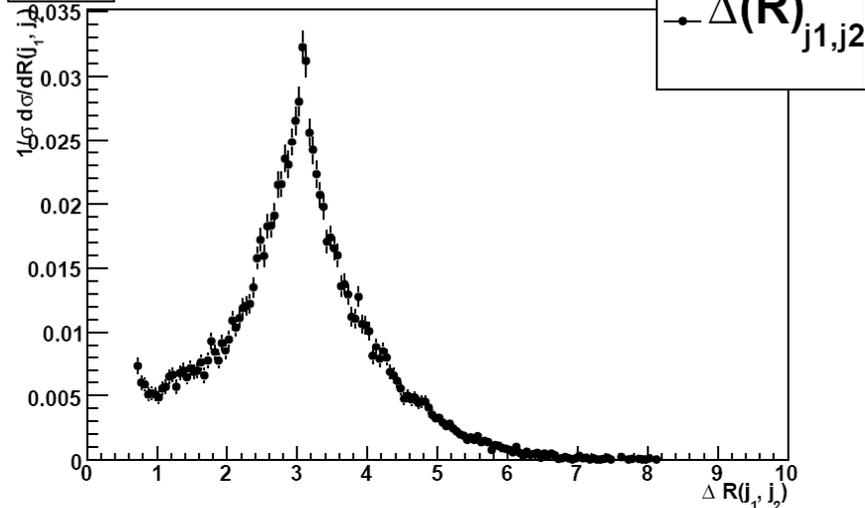
Jet Multiplicity



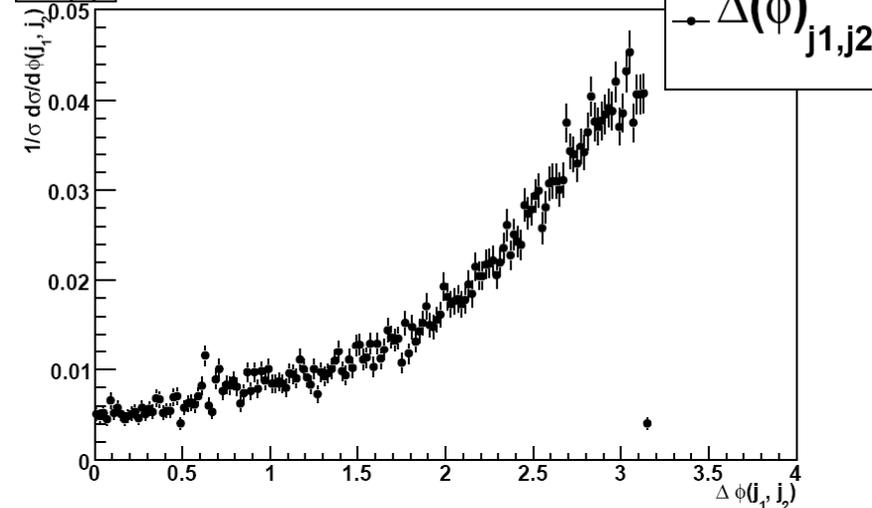
P_t of the leading jet

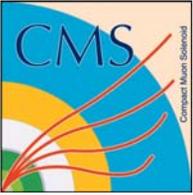


$\Delta(R)_{j1,j2}$



$\Delta(\phi)_{j1,j2}$

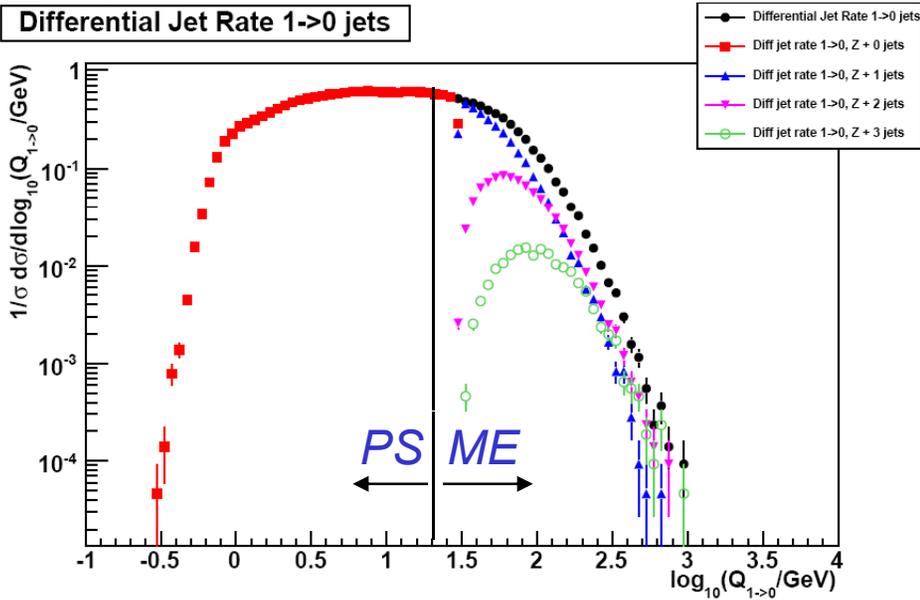




Sherpa, differential jet rates

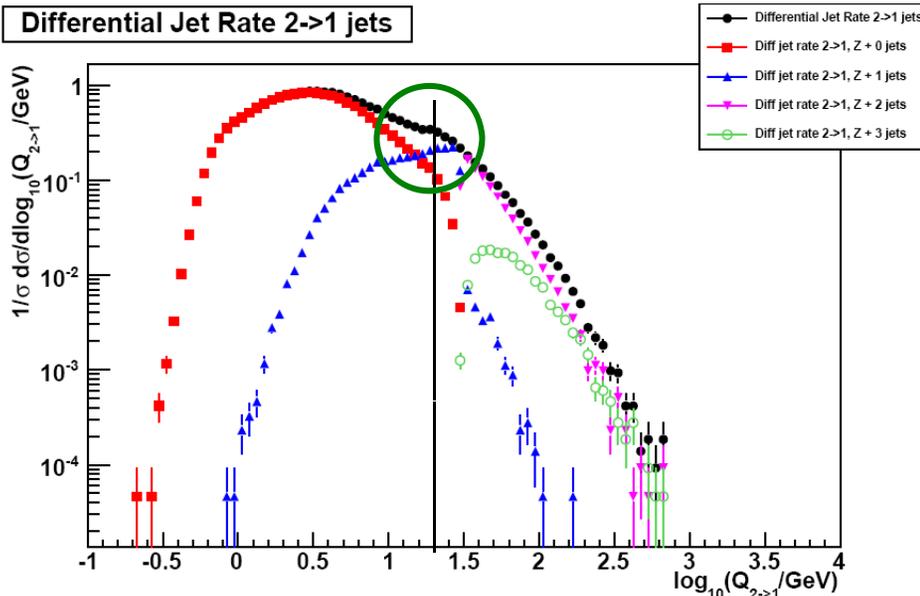


Differential Jet Rate 1->0 jets

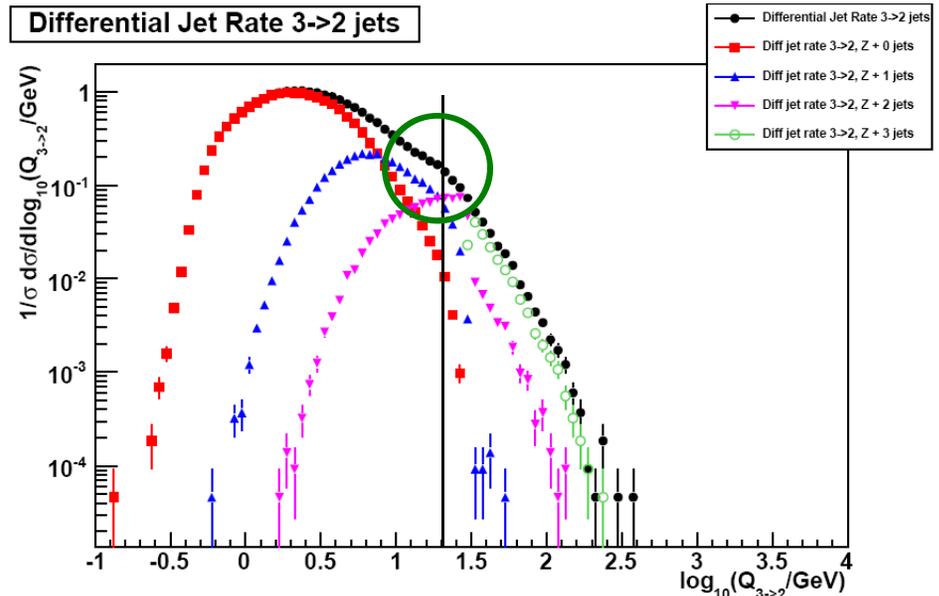


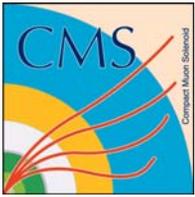
- Distribution of the k_t resolution variable making a n jet turn into a $n-1$ jet event
- Little bumps observed around the resolution cut ($\log_{10}(20) \sim 1.3$)
- The ME kinematics is altered by the PS, so mismatches around the cut can occur

Differential Jet Rate 2->1 jets



Differential Jet Rate 3->2 jets





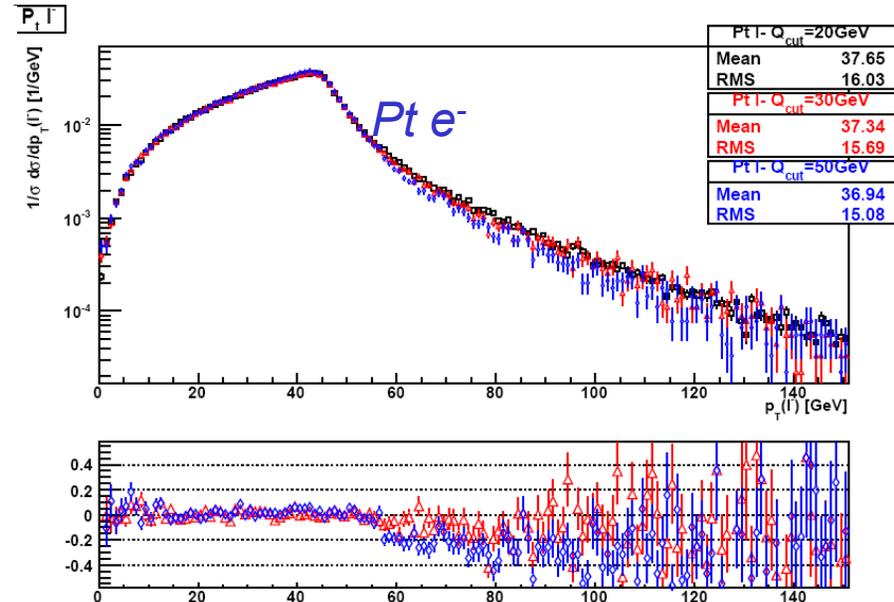
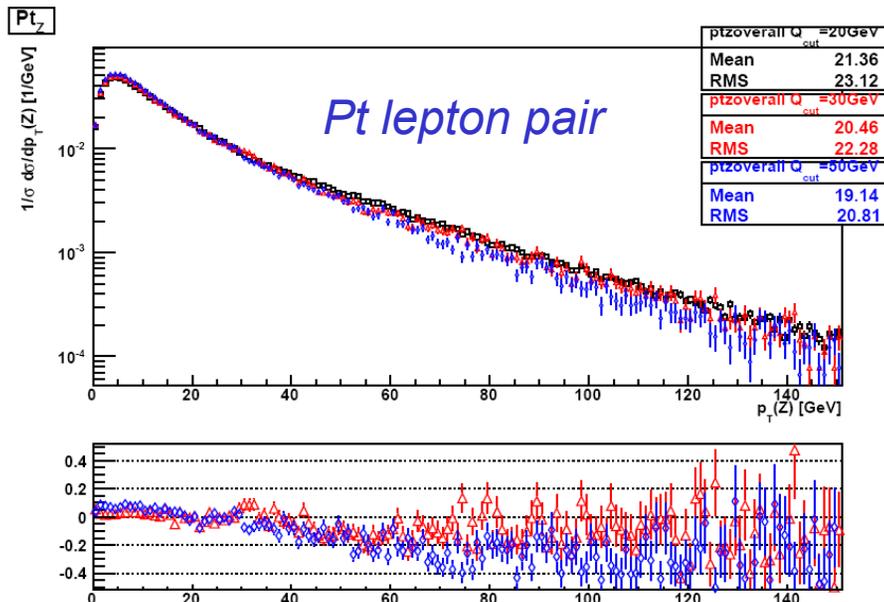
Sherpa systematics: change of the matching scale

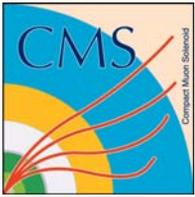


- Three values for Q_{cut} were tried: 20GeV (default), 30GeV, 50GeV
- The effect on the overall cross section is summarized below

$Q_{\text{cut}}=20\text{GeV}$	$Q_{\text{cut}}=30\text{GeV}$	$Q_{\text{cut}}=50\text{GeV}$
1594.1 pb	1411.3 pb	1399.8 pb

- The effect on lepton observables, and the relative difference with respect to the default is shown in the plots below
 - As the Q_{cut} is increased, the ME phase space fraction is reduced
 - Since the ME is responsible for the hardest parton kinematics the increase in the merging scale results in spectra with softer tails

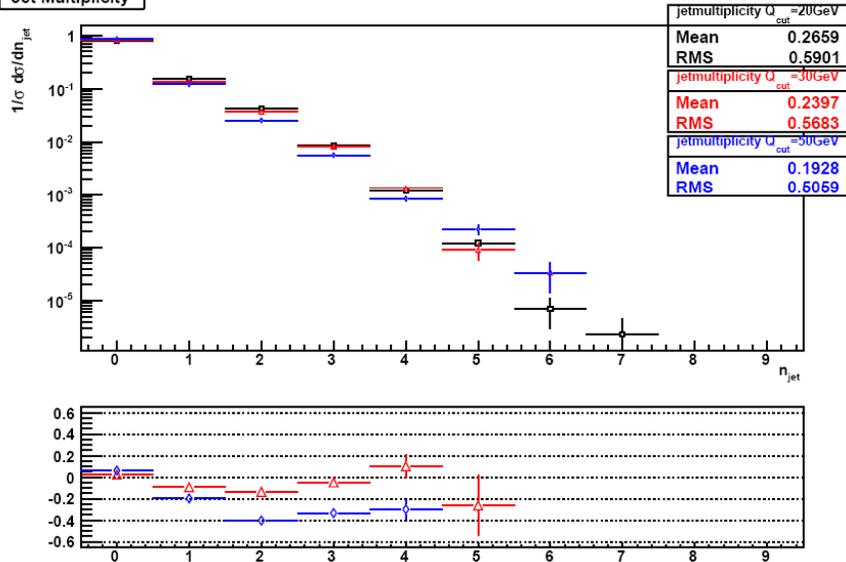




Change of the matching scale (continued)



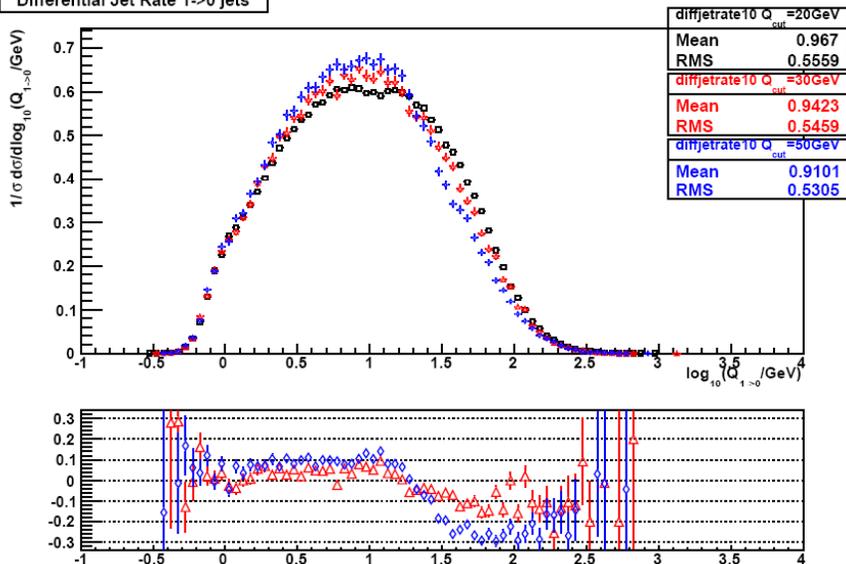
Jet Multiplicity



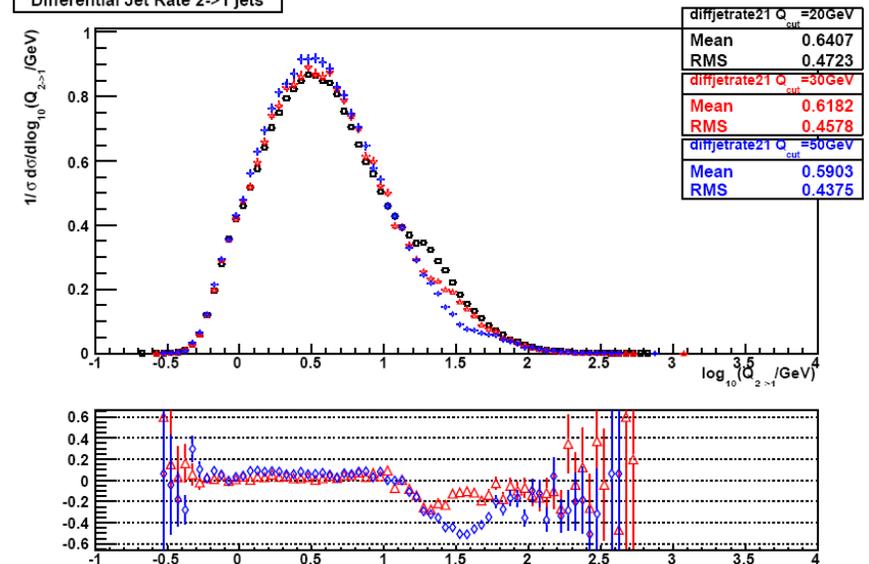
- Jet observables:

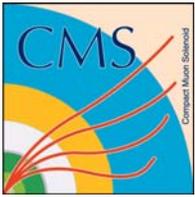
- The mean multiplicity decreases as the merging scale grows
- Diff jet rates are depleted in the ME region, and are enhanced in the PS region
- The smoothest transition seems to be the one for the highest merging scale used

Differential Jet Rate 1->0 jets



Differential Jet Rate 2->1 jets



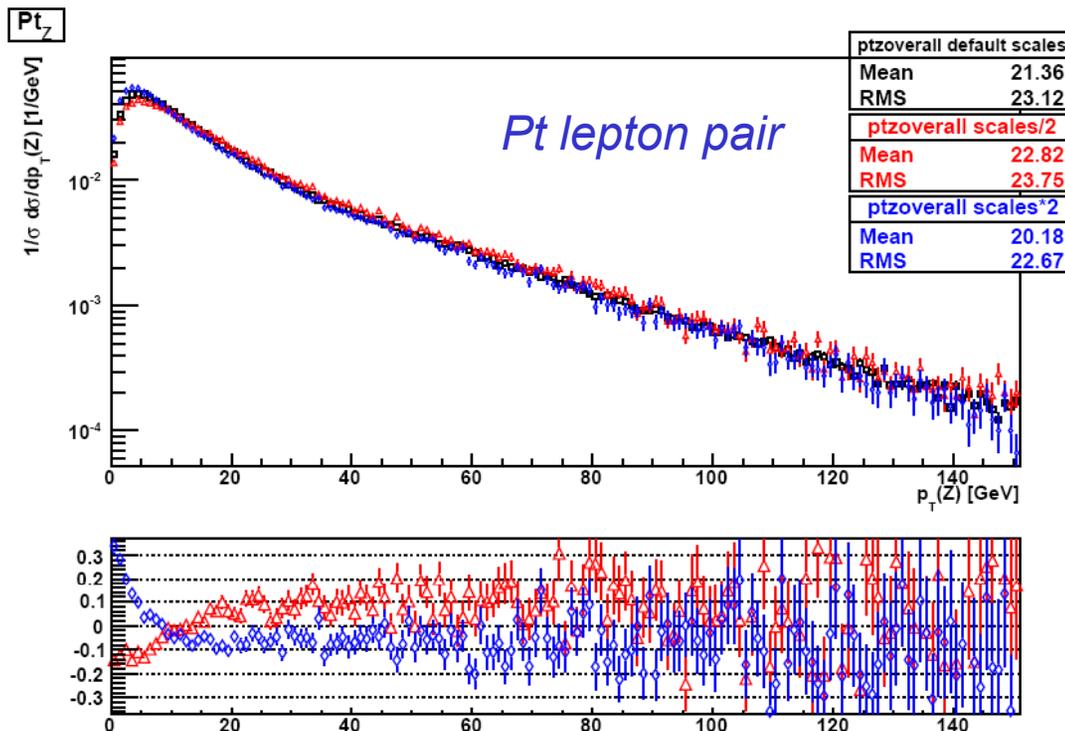


Sherpa systematics: change of scales

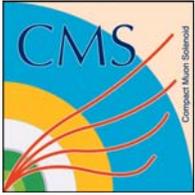


- Sherpa was run with the default choice for renormalization (μ_R) and factorization (μ_F) scales, μ_R and μ_F times 0.5 and μ_R and μ_F times 2
- The effect on the overall cross section is summarized below:

Default scales	Scales*0.5	Scales*2
1594.1 pb	1292.4 pb	1646.5 pb



- The effect is more evident in the first bins where the 0 jet contribution dominates
- The effect changes sign for higher boson pt
- This agrees with previous studies, where it was shown that the LO cross section for 0 jets grows with the scale, while the LO cross section for >0jets decreases as the scale grows [hep-ph/0308195]

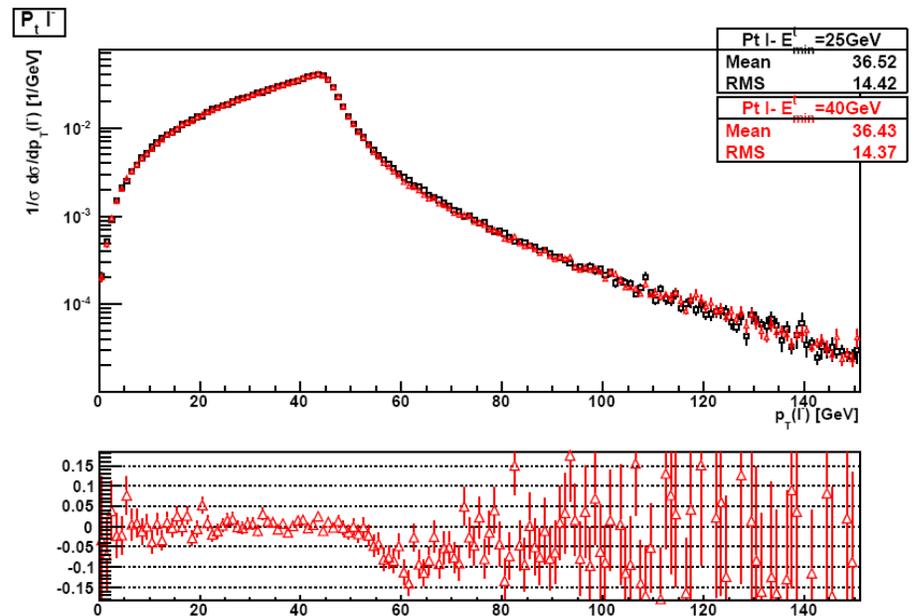
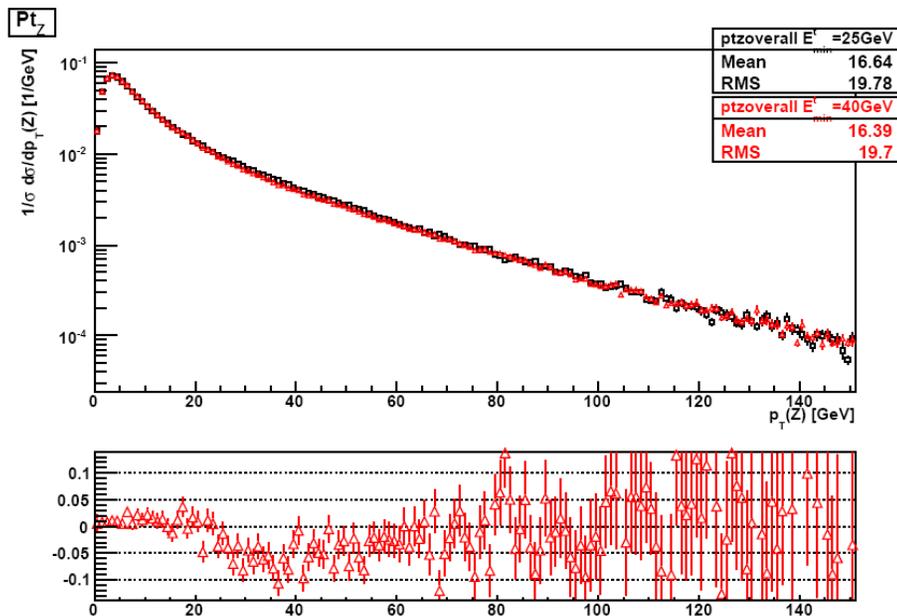


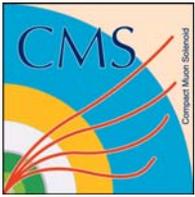
AlpGen systematics, change of the merging scale

- Two values were used for the $E_t(\text{min})$ of the cone algorithm used to steer the matching: 25GeV and 40 GeV
- The overall cross section effect is summarized below

$E_t(\text{min})=25\text{GeV}$	$E_t(\text{min})=40\text{GeV}$
1534.5 pb	1516.4 pb

- The effect on lepton observables is almost negligible



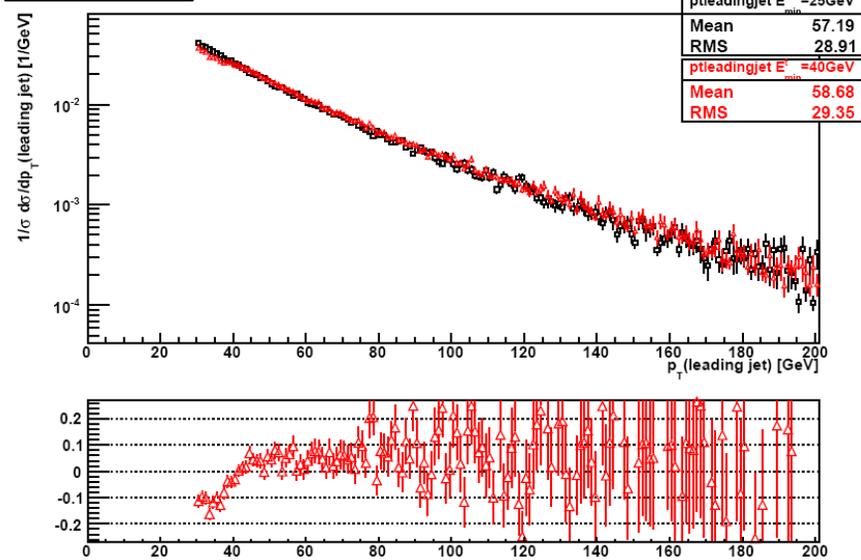


Change of the merging scale (continued)

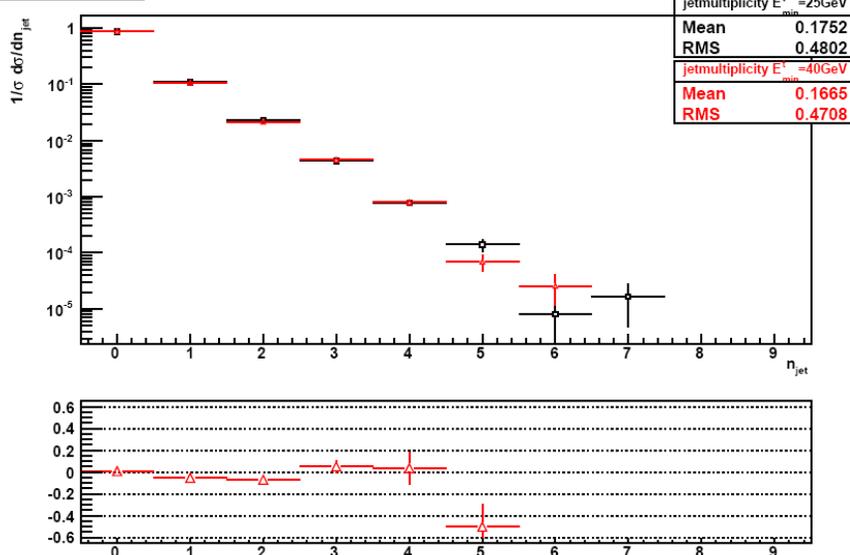


- Leading jet Pt show a bump around 40 GeV for the non-default sample
- Small differences observed in the jet multiplicity
- Differential jet rate plots show some modification at the merging scale

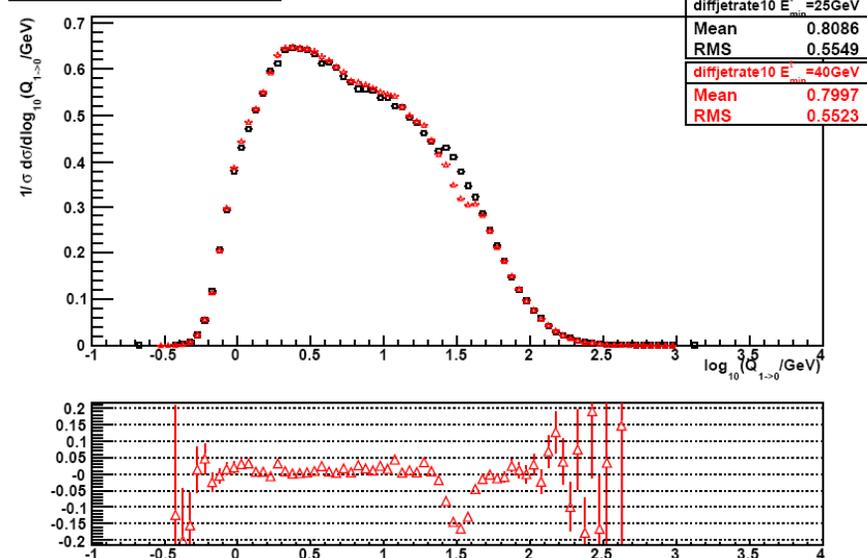
P_t of the leading jet

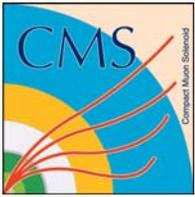


Jet Multiplicity



Differential Jet Rate 1->0 jets



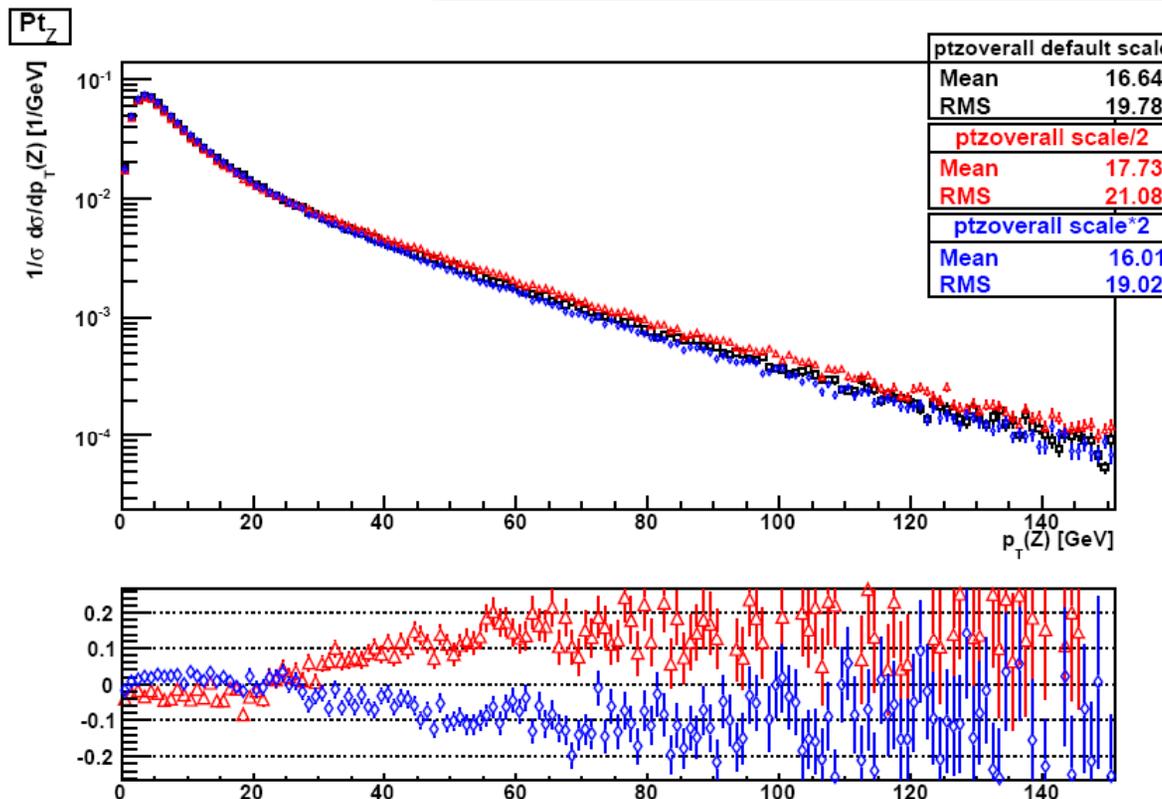


AlpGen systematics, Change of scales

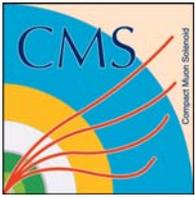


- AlpGen+Pythia was run with the default scale choice, μ_R times 0.5 and μ_R times 2
- The effect on the overall cross section is summarized below:

Default scales	Scale*0.5	Scale*2
1534.5 pb	1449.1 pb	1672.2 pb



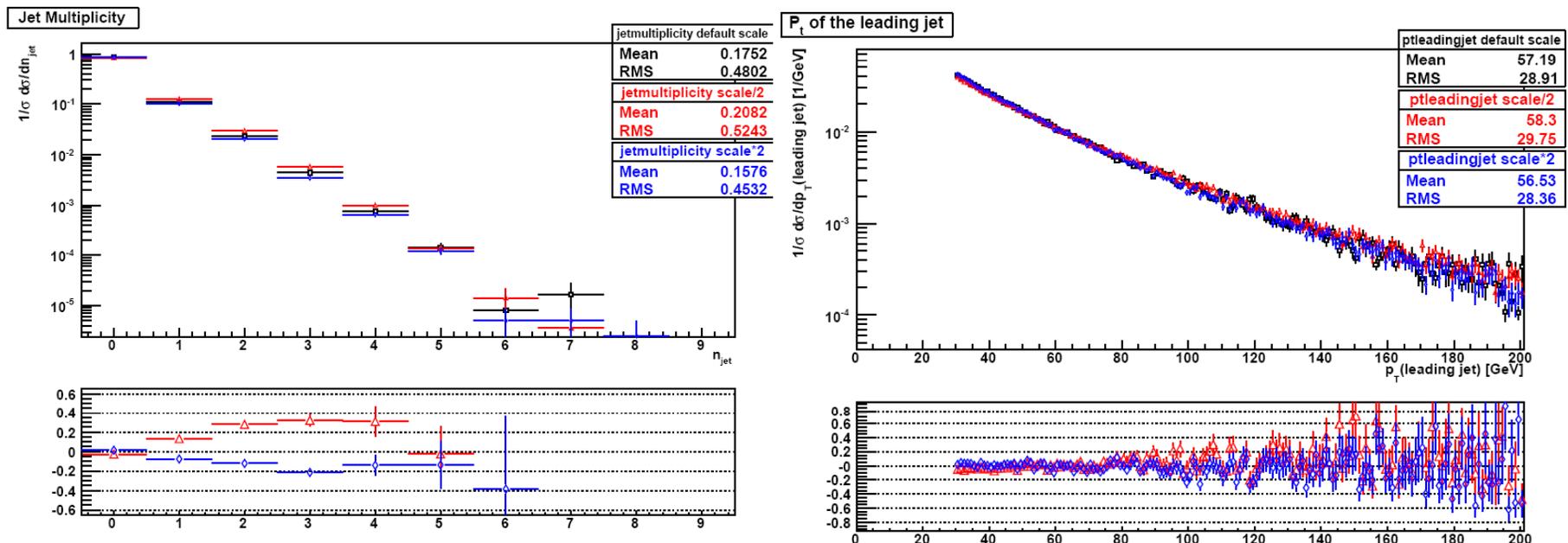
- The effect is similar to the one observed in Sherpa
- The low pt region, dominated by the 0jet contribution seems to be less affected than in Sherpa though

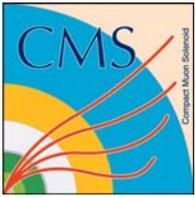


Change of scales (continued)



- The effect on the jet multiplicity:
 - The scales*0.5 sample shows the highest jet multiplicity, while the scales*2 samples shows the smallest
 - This agrees with what was observed in the boson p_t spectrum, where the tail due to >0 jet events was enhanced in the scales*0.5 case and depleted in the scales*2 case
- The effect of the jet p_t spectrum is not very evident





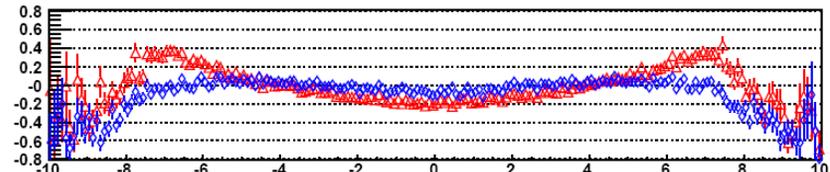
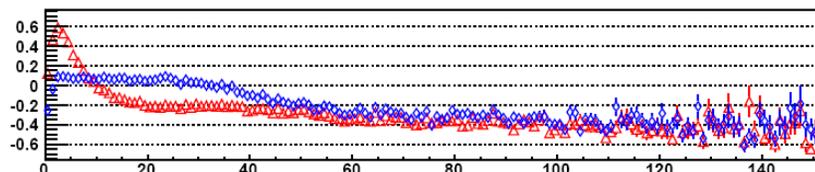
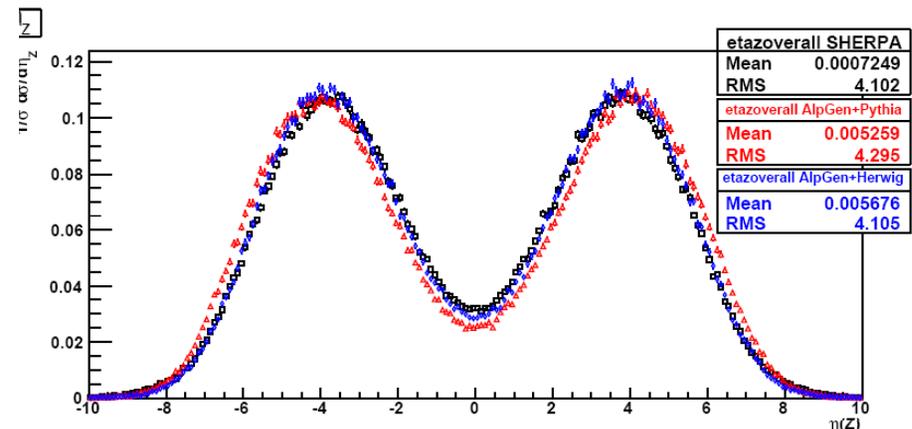
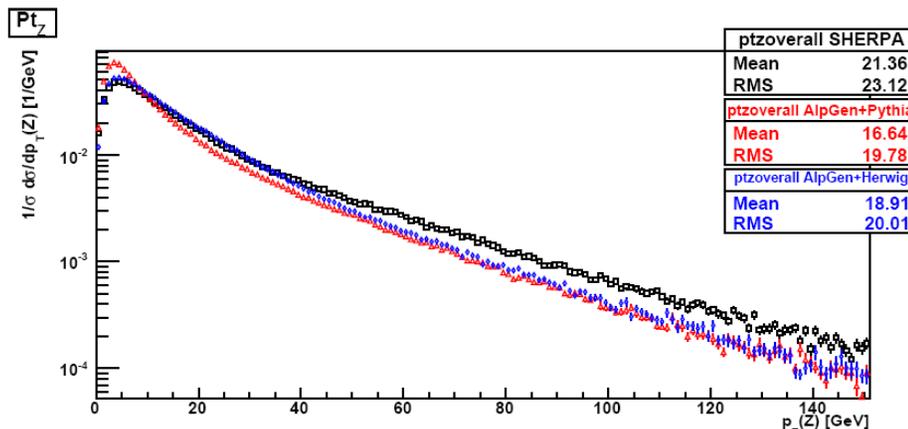
AlpGen-SHERPA comparisons: lepton observables

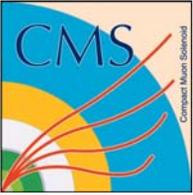


- AlpGen has been showered both with Pythia and Herwig
- The inclusive cross sections are

SHERPA	AlpGen+PYTHIA	AlpGen+Herwig
1594.1 pb	1534.5 pb	1523.0 pb

- Sherpa shows the hardest spectrum, Pythia the softest
 - Differences between Pythia and Herwig are due to the different way the two PS alter the ME kinematics
- The Pt spectrum differences translate into the η spectrum, with PYTHIA showing the less central Z and SHERPA the most central one

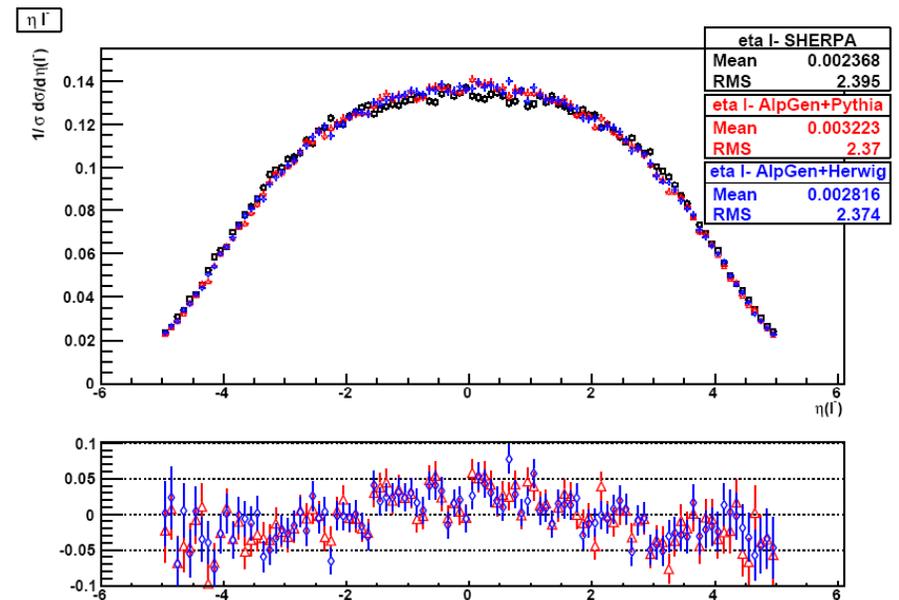
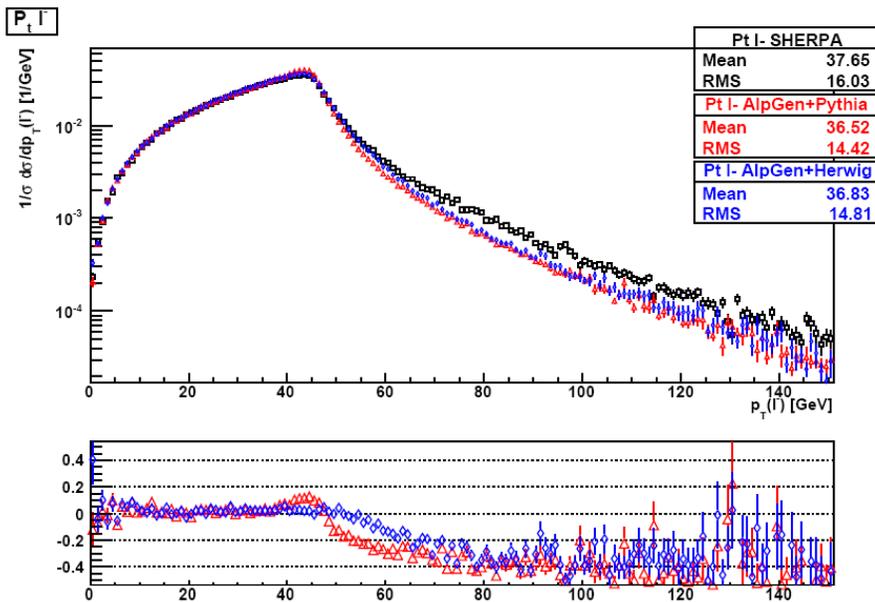


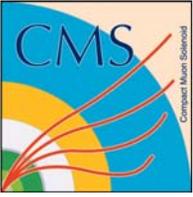


Lepton observables (continued)



- As for the Z spectrum, the $e^- P_t$ spectrum is harder for Sherpa and softer for Pythia
- The $e^- \eta$ are similar (within 8%)

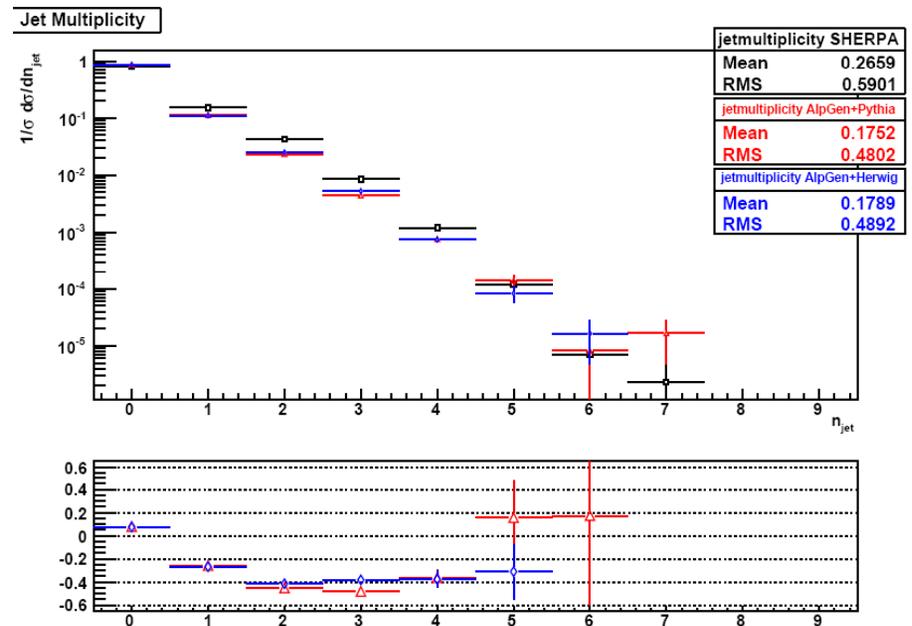
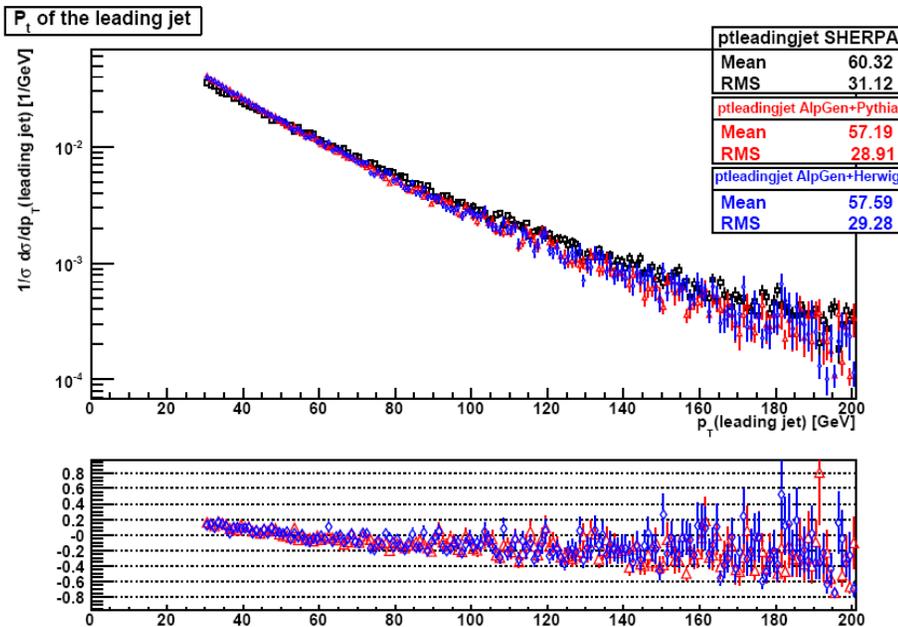


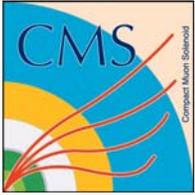


AlpGen-SHERPA comparisons: jet observables



- Sherpa shows a harder leading jet spectrum
- The jet multiplicity is maximum for Sherpa and minimum for AlpGen+Pythia

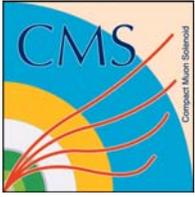




Conclusions

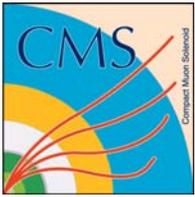


- AlpGen and SHERPA implement two different approaches to the matching of ME and PS predictions
- A study of the “theoretical uncertainties” has been carried out for both generators, varying the matching parameters and the scales
 - The change on the shape of the distributions is similar for the two generators when changing the scales
 - When changing the matching parameters AlpGen shows minor changes in the shape of the distributions than Sherpa
- When comparing AlpGen with SHERPA, some not negligible differences have been spotted:
 - The boson lepton and jet spectra are harder for SHERPA
 - The Sherpa mean jet multiplicity is higher than the AlpGen one
- It might be interesting to see how differential jet rates look on data, and see how well the MC can reproduce these plots, since these observables are very sensitive to the way in which the phase space is filled



Backup





The PS formulae



$$d\mathcal{P}_{a \rightarrow bc} = \frac{\alpha_s}{2\pi} \frac{dQ^2}{Q^2} P_{a \rightarrow bc}(z) dz$$

where $P_{q \rightarrow qg} = \frac{4}{3} \frac{1+z^2}{1-z}$,

$$P_{g \rightarrow gg} = 3 \frac{(1-z(1-z))^2}{z(1-z)},$$

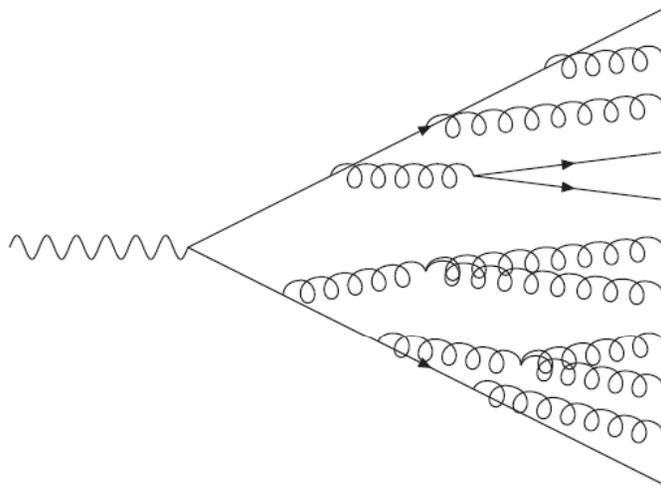
$$P_{g \rightarrow q\bar{q}} = \frac{n_f}{2} (z^2 + (1-z)^2) \quad (n_f = \text{no. of quark flavours})$$

Divergencies are tamed with a cutoff.

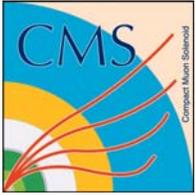
Evolving the shower a big splitting probability will turn into big probabilities for successive branchings. If we want to conserve total probability the splitting probability $a \rightarrow bc$ at scale Q has to be multiplied by the probability that that splitting did not happen before (at $> Q$).

This “non branching probability” is the

“Sudakov form factor”



$$d\mathcal{P}_{a \rightarrow bc} = \frac{\alpha_s}{2\pi} \frac{dQ^2}{Q^2} P_{a \rightarrow bc}(z) dz \exp \left(- \sum_{b,c} \int_{Q^2}^{Q_{\max}^2} \frac{dQ'^2}{Q'^2} \int \frac{\alpha_s}{2\pi} P_{a \rightarrow bc}(z') dz' \right)$$



The ME-PS matching problem



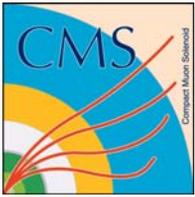
- Matrix Element calculations:

- ✓ Can be done with up to several partons in the final state, as long as tree level results are asked for
- ✓ Describe well separated jets configurations
- ✗ Run into troubles in the soft and collinear regions
- ✗ Can't describe the internal structure of jets

- Parton Shower calculations:

- ✓ PS is universal, given the basic hard process the PS recipe will produce reasonable parton configurations
- ✓ The use of Sudakov form factors ensures controlled behavior in the soft and collinear region, so jet evolution is well described
- ✗ Cannot steer the shower evolution too much, some regions of the phase space are not efficiently filled, e.g. well separated parton configurations

- A combined use of the two approaches is desirable, BUT beware double counting and holes in the phase space



PYTHIA approach to the matching: ME corrections



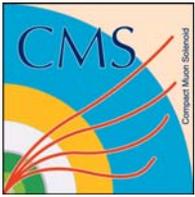
- Let's consider the LO $e^+e^- \rightarrow qq\bar{q}$ and the NLO real emission one $e^+e^- \rightarrow qq\bar{q}g$

$$W^{\text{ME}} = \frac{1}{\sigma(\text{LO})} \frac{d\sigma(\text{LO} + g)}{d(\text{phasespace})}$$

- If the shower populates the phase space according to W_{PS} , then a factor $W_{\text{ME}}/W_{\text{PS}}$ needs to be applied
- W_{ME} is substituted to W_{PS} in the Sudakov form factor

$$W_{\text{actual}}^{\text{PS}}(Q^2) = W^{\text{ME}}(Q^2) \exp \left(- \int_{Q^2}^{Q_{\text{max}}^2} W^{\text{ME}}(Q'^2) dQ'^2 \right)$$

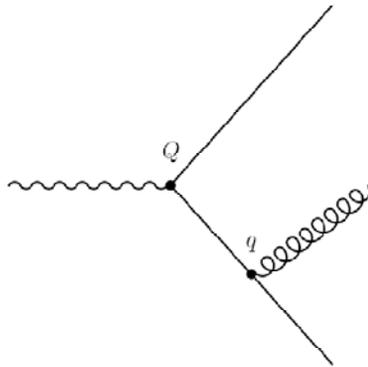
- In the hard region, where the Sudakov ~ 1 , the ME results holds, in the soft region, where $W_{\text{ME}} \sim W_{\text{PS}}$ the PS result holds



CKKW (continued)

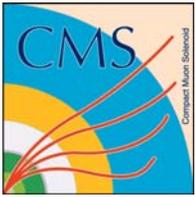


- For each internal line in the “shower history” connecting scale i to scale k reweight events with a factor $\Delta_i(q_j, q_{MS}) / \Delta_i(q_k, q_{MS})$
- For each external line reweight events with a factor $\Delta_i(q_j, q_{MS})$
 - $\Delta_k(q_i, q_j)$ is the Sudakov form factor associated to clustering k , connecting scales q_i and q_j



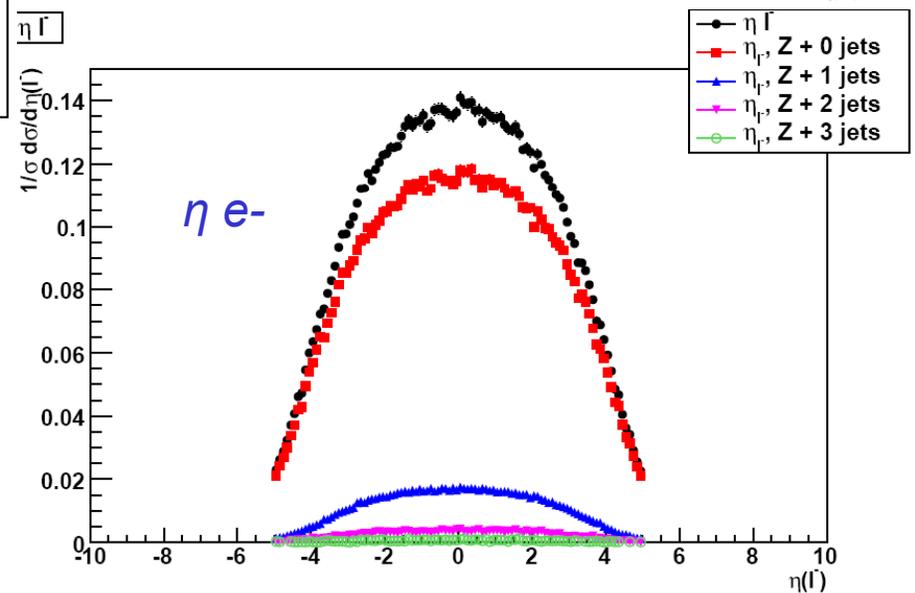
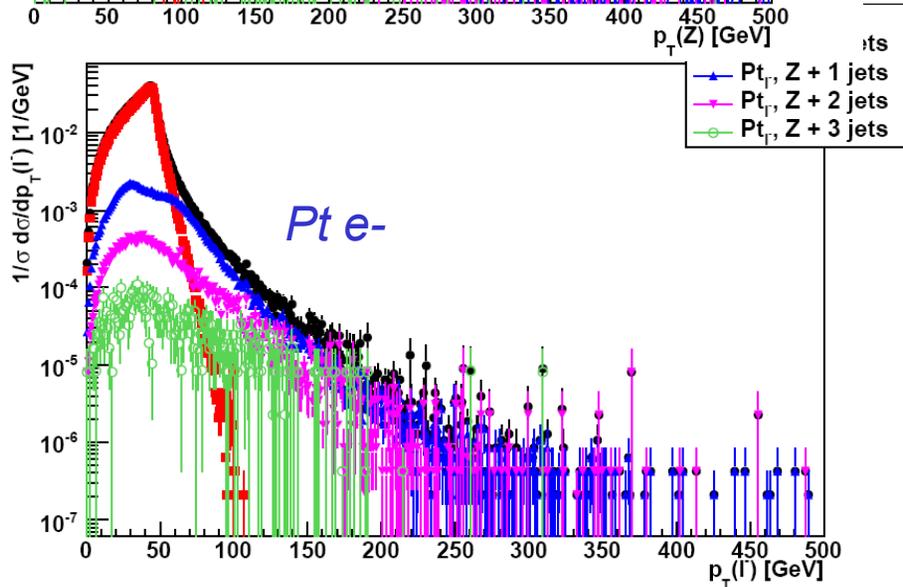
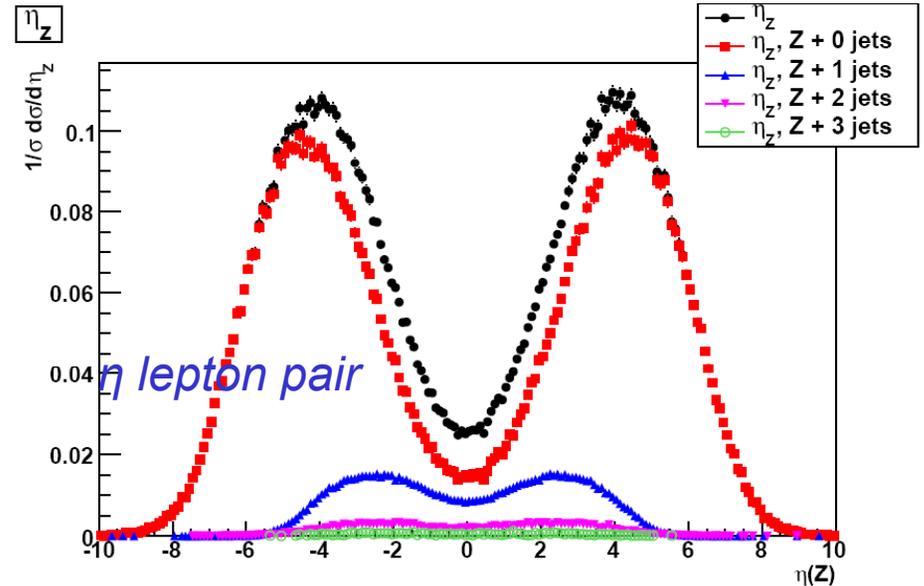
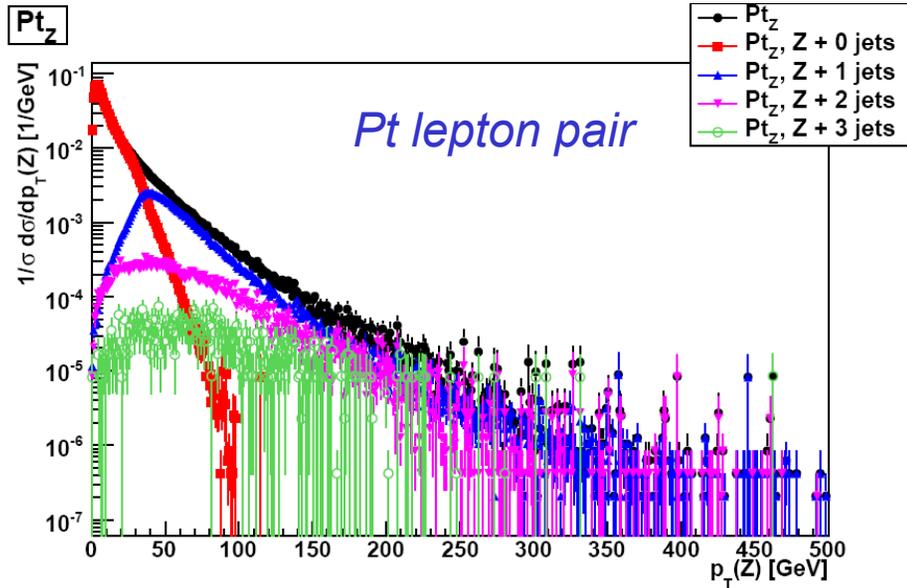
$$\mathcal{W} = \Delta_q(Q_{\text{jet}}, Q) \frac{\Delta_q(Q_{\text{jet}}, Q)}{\Delta_q(Q_{\text{jet}}, q)} \frac{\alpha_s(q)}{\alpha_s(Q_{\text{jet}})}$$
$$\Delta_q(Q_{\text{jet}}, q) \Delta_g(Q_{\text{jet}}, q)$$

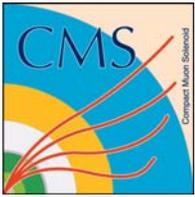
- The net effect of this procedure is similar to what is achieved with the Pythia’s ME corrections: the splitting functions present in the Sudakov form factor are replaced by their ME version
- The PS is then applied to the weighted events, with a VETO on hard (above the merging scale) emission



AlpGen+Pythia, default settings

- Lepton observables



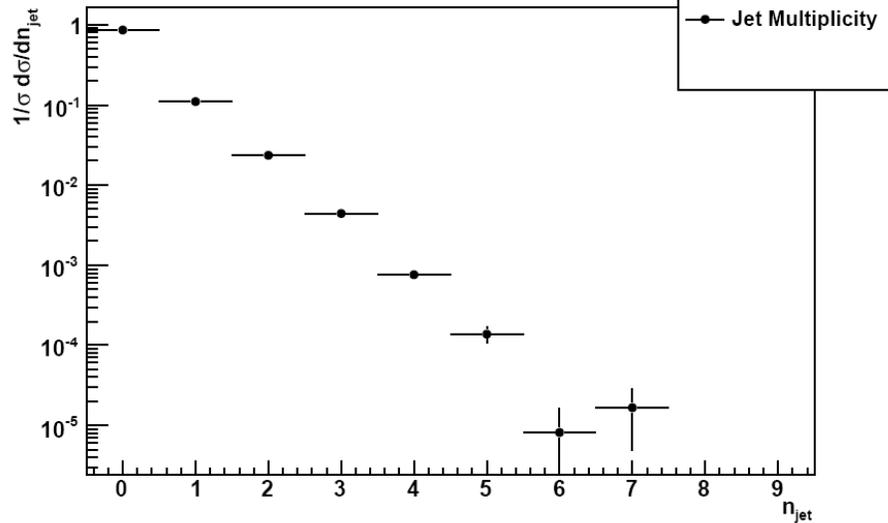


AlpGen+Pythia, default settings

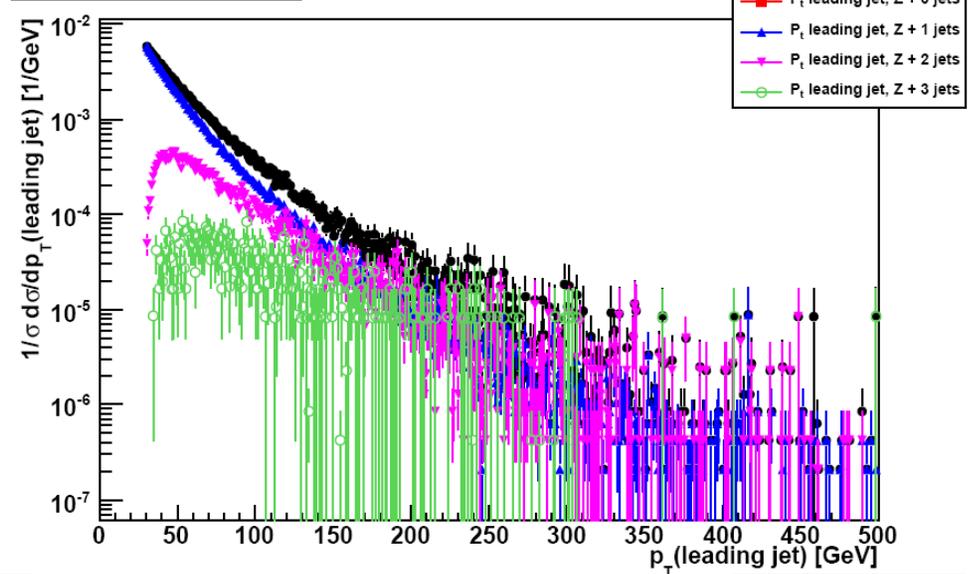
- Jet observables



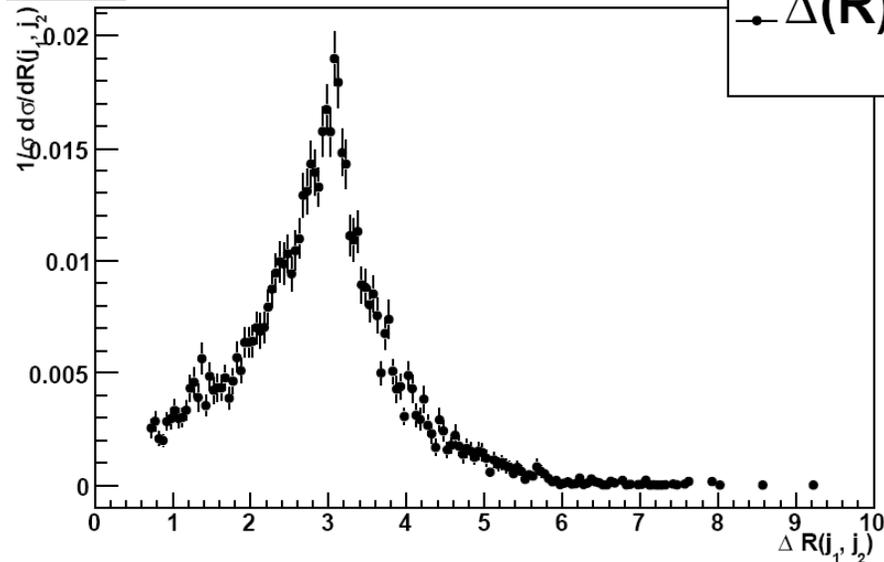
Jet Multiplicity



P_t of the leading jet

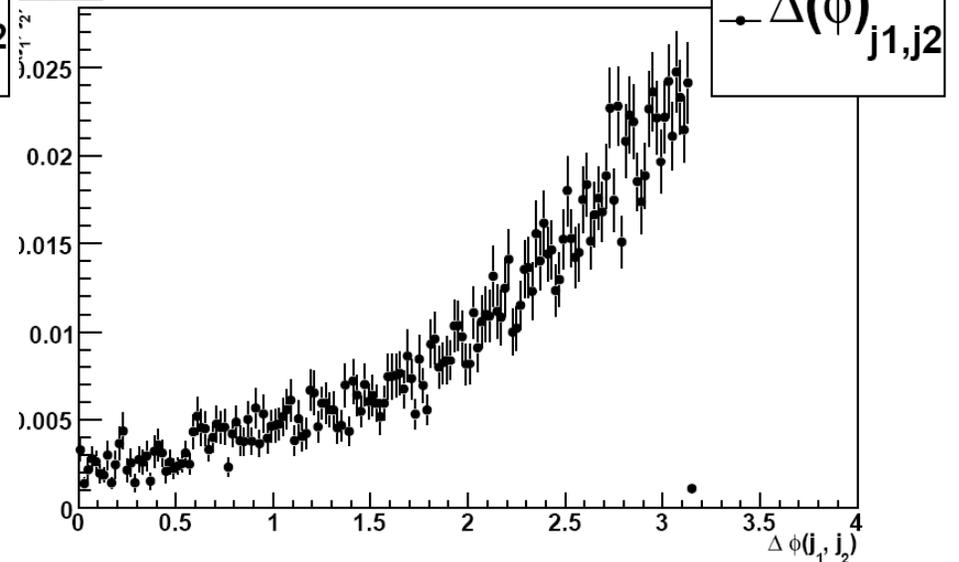


$\Delta(R)_{j1,j2}$

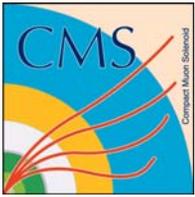


$\Delta(R)_{j1,j2}$

$\Delta(\phi)_{j1,j2}$



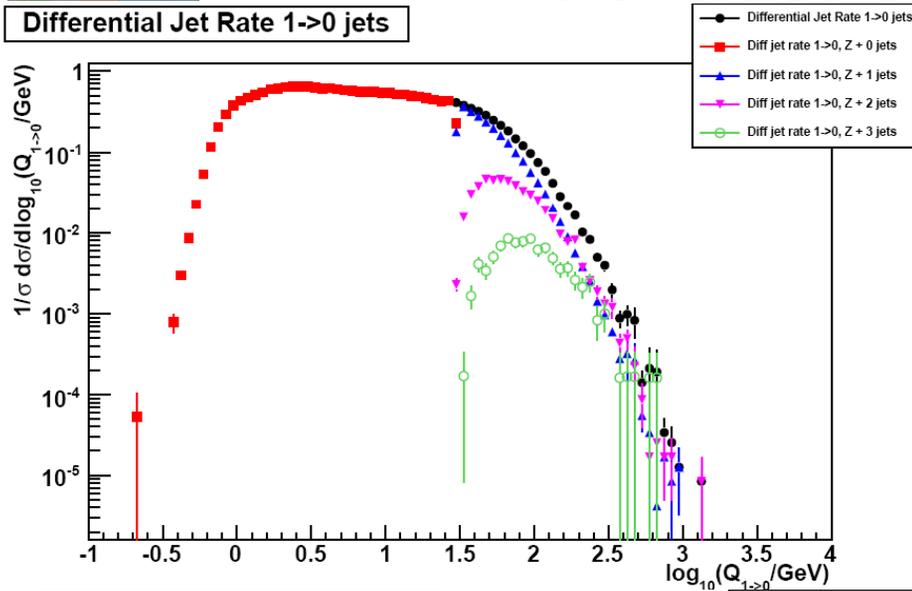
$\Delta(\phi)_{j1,j2}$



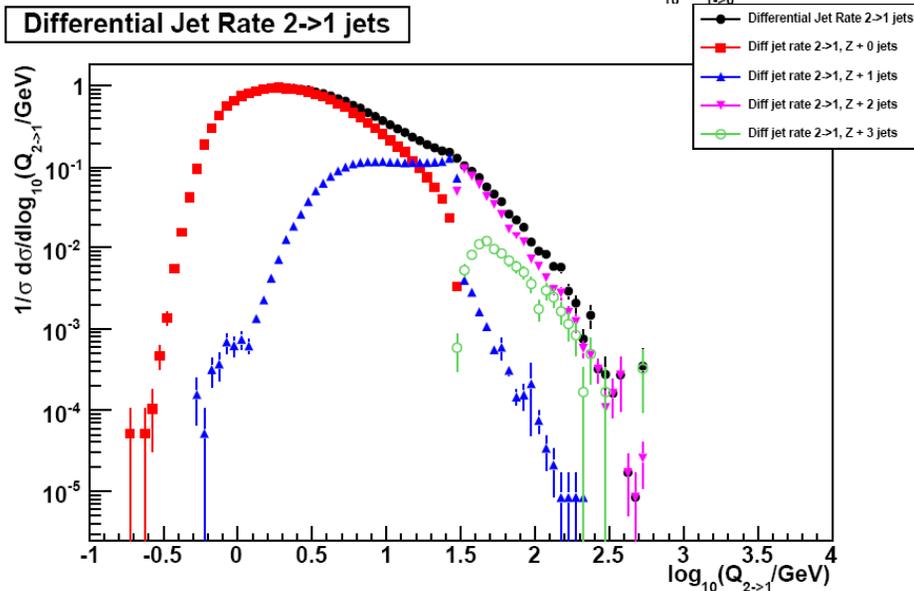
AlpGen+Pythia, default settings



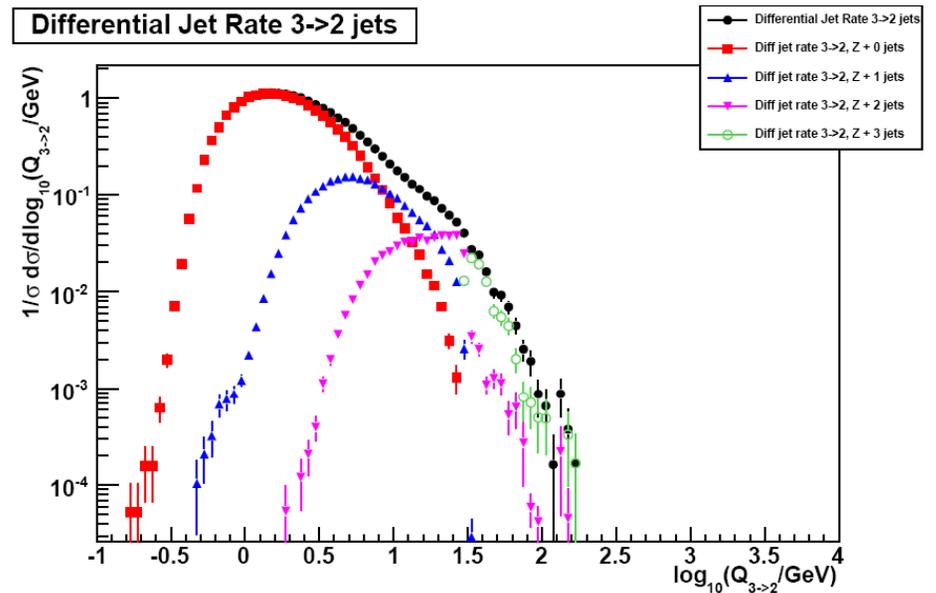
Differential Jet Rate 1->0 jets

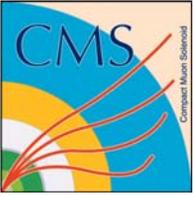


Differential Jet Rate 2->1 jets



Differential Jet Rate 3->2 jets





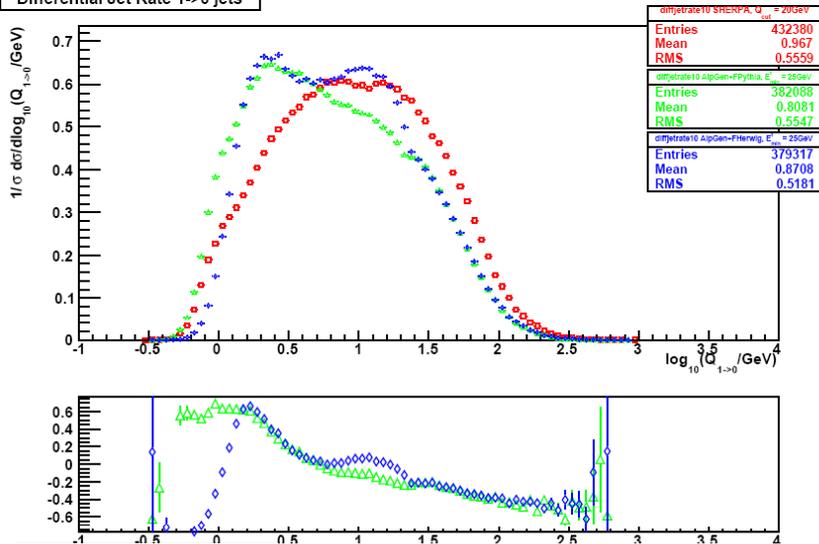
Jet observables (continued)



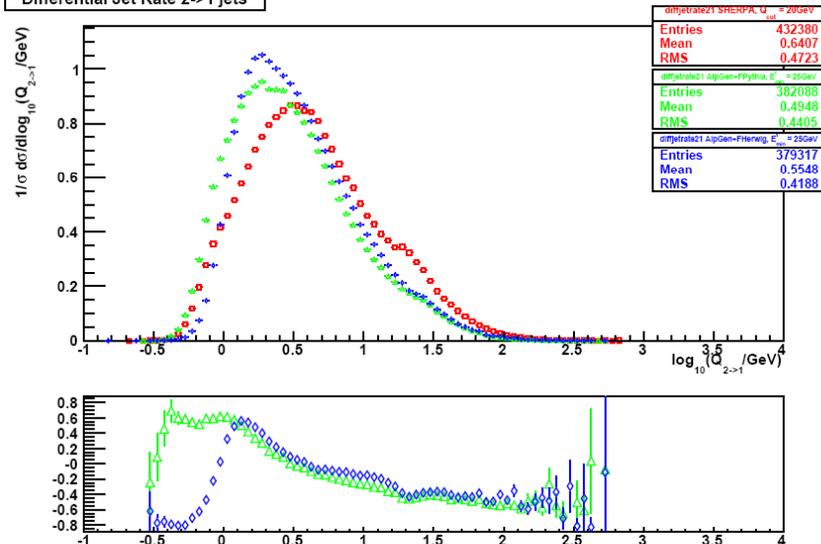
- The differential jet rates show many differences:

- AlpGen+Pythia and AlpGen+Herwig show similar rates for 2→1 and 3→2 transition, while the shape is quite different for 1→0
- Sherpa always fills the ME region more
- This seems to be in agreement with the harder spectra observed for sherpa, since the ME is responsible for the hardest parton kinematics

Differential Jet Rate 1→0 jets



Differential Jet Rate 2→1 jets



Differential Jet Rate 3→2 jets

