Shower Variations and Tuning

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[Part of Les Houches proceedings, Bellm, Hoang, Lönnblad, Plätzer, Prestel, Samitz, AS]

QCD@LHC 2018, 27th - 31st August 2018, Dresden, Germany
1. Motivation
2. Parton Shower variations
3. Generator tuning vs. parton-shower variations
4. Summary
“Without error estimation any experimental parameters determination is useless”

Experimental Techniques in Nuclear Physics
Dorin N. Poenaru, Walter Greiner
Current situation

$\Delta_{MC} = |\text{Pythia} - \text{Herwig}|$

ttH production observation

Jet threshold: 25 GeV

Uncertainty obtained from PYTHIA8 to HERWIG7 comparison:

- $ttH(\gamma\gamma)$ PS modelling uncertainty values 8% in signal and 4% in background.
- $ttH(\text{multilepton})$ PS uncertainty with about 10% uncertainty for both signal and background.
  - multilepton $\equiv H \rightarrow WW^*, H \rightarrow \tau\tau, H \rightarrow ZZ^*$ without $ZZ^* \rightarrow 4\ell$.
- $ttH(b\bar{b})$ PS uncertainty with about 6% uncertainty for signal and 4 to 10% for background.

<table>
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<tr>
<th>Uncertainty source</th>
<th>$\Delta\sigma_{tt\bar{H}} / \sigma_{tt\bar{H}}$ [%]</th>
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<tr>
<td>Theory uncertainties (modelling)</td>
<td>11.9</td>
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<td>$tt +$ heavy flavour</td>
<td>9.9</td>
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<td>$ttH$</td>
<td>6.0</td>
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<td>Non-$ttH$ Higgs boson production modes</td>
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<td>Other background processes</td>
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<td>Experimental uncertainties</td>
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<td>Fake leptons</td>
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<td>Jets, $E_T^{miss}$</td>
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<td>Electrons, photons</td>
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<td>Luminosity</td>
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<td>$\tau$-lepton</td>
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<td>Flavour tagging</td>
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<td>MC statistical uncertainties</td>
<td>4.4</td>
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</tbody>
</table>
Current situation

$$\Delta_{MC} = |\text{Pythia} - \text{Herwig}|$$

**Issues & uncertainties**

- Correlations to LHC data already in PDF fits
- Correlations between $\alpha_s(M_Z)$, $M_{\text{top}}$, $g(x)$
- (Gu)estimation of nonperturbative effects:
  - Different event generators & tunes, different orders, different ...
  - Incoherent among ATLAS, CMS, Tevatron, ...
- Conventional scale variation by factors of $\frac{1}{2}$, 2 and $1\sigma$ assumption
- Central scale choice ...!
Introduction – what is the problem?

Inclusive jets: NNLO & scale choice

anti-kt, R=0.4, 13 TeV

QCD scale choice: \( \mu_R = \mu_F = p_{T\text{jet}} \)
- for small \( p_T \) better agreement with NNLO

QCD scale choice: \( \mu_R = \mu_F = p_{T\text{,max}} \)
- for small \( p_T \) better agreement with NLO

ATLAS

\( L = 81 \text{nb}^{-1} \cdot 3.2 \text{fb}^{-1} \)
\( \tilde{s} = 13 \text{ TeV} \)
anti-k_{t} R=0.4

Data
NLO QCD
@ \( k_{\text{EW}} \) @ \( k_{\text{NP}} \)
NNLO QCD
@ \( k_{\text{EW}} \) @ \( k_{\text{NP}} \)
NLO
MMHT 2014 NLO
NNLO
MMHT 2014 NNLO

Klaus Rabbertz
Dresden, Germany, 27.08.2018

QCD@LHC 2018

See João Pires talk or a workshop:
Taming Unphysical Scales for Physical Predictions
Introduction – what is the problem?
Shower Variations

Recently all MC generators started provide shower variations:

**Parton-shower Variations**

- **Pythia 8** [S. Mrenna, P. Skands, Phys.Rev. D94 (2016) no.7, 074005]
Tuning:

- Helps constrain parameters that cannot be fixed by theory considerations
- Parameters in hadronization models are commonly extracted at lepton colliders and then used unchanged at hadron colliders
- Encodes the global picture of previous measurements into the MCEG

• Despite automatized tools like Professor still more art then science, one has to be very careful during the procedure.
Generator tuning vs. parton-shower variations

Methodology

• MC generators @ LO:
  • Herwig 7 (H7)
  • Pythia 8 (P8)

• Default Parton Showers
  • H7 – angular
  • P8 – pT ordered

• Hadronization
  • H7 cluster model
  • P8 string model

Disclaimer

“We do not attempt to provide a theoretical answer to the question of defining uncertainties. Instead, we provide a phenomenological study of some cross-talk, in hopes of gaining insight for the future.”
 Generator tuning vs. parton-shower variations

Procedure

• **Data:** only LEP 91 GeV (all observables in the backup)

• **Parameters which we tune:**
  • Main parameters of non-perturbative hadronization $\sim 3$
  • Parton shower cut-off

• **Two sets of tunes**
  • Central – tune with $\alpha_s(M_Z)$, variation band: $\xi = 2$, $\alpha_s(M_Z) \rightarrow \alpha_s(\{\frac{1}{\xi}, 1, \xi\} M_Z)$ without tuning.
  
  • Retune – similar but variation band: $\alpha_s(M_Z) \rightarrow \alpha_s(\{\frac{1}{\xi}, 1, \xi\} M_Z)$ with tuning.
Results: Distributions used in the tune

1) both generators are able to fit the data
2) as expected, the scale variations of the central tune are much larger then after retune
3) distributions are normalised to unity → scale variations are artificially reduced at the center
4) Closer look some imperfections:
   - H7 has problem with large y23 (small -ln(y23)) this is due switched off matching to $O(\alpha_s)$. P8 had it on.
   - In P8 for large y23 scale variation not reduced by the retuning (expected hadronization in P8 can not compensate for scale change in hard jets)
   - In H7 it is possible large mass clusters decay isotropically to two lighter clusters ending up as a jets
Results: Distributions used in the tune

Thrust minor ($E_{CMS} = 91.2$ GeV)
(the thrust calculated wrt. the axis out of the event plane spanned by the thrust and thrust major axes)

1) both generators are able to fit the data

2) as expected, the scale variations of the central tune are much larger than after retune

3) distributions are normalised to unity → scale variations are artificially reduced at the center

4) Closer look some imperfections:

- large ln(Tminor) region, corresponding to large activity out of the event plane driven sensitive to hard effects $O(\alpha_s^2)$
as expected, the scale variations of the central tune are much larger than after retune.

2) Similar pattern as for y23
Results: Distributions NOT used in the tune

Charged multiplicity at a function of energy

1) In H7 no surprises as expected, the scale variations of the central tune are much larger then after retune.
Results: Distributions **NOT** used in the tune

Charged multiplicity at a function of energy

1) In P8 there is a surprise!

2) Tuning has scarified this bin in order to fit many others in other distributions
Results: Distributions **NOT** used in the tune

**Charged multiplicity at a function of energy**

1) In P8 there is a surprise!

2) Tuning has scarified this bin in order to fit many others in other distributions

3) Solution add full multiplicity distribution from L3 → similar results as for H7
Results: Distributions **NOT** used in the tune

200 GeV
Summary

1) Using retuned scale variations gives a better estimate of the uncertainties in the predictions of shower/hadronisation models. Before retuning the variation quite be quite different (H7 conservative, P8 optimistic), after the retune size of variation similar.

2) This does however not mean that it gives a better estimate of the uncertainties in general.

3) An interesting exercise to make, as it can increase our understanding of how the models behave and how the tunings work in more detail, for example we have shown that:
   - not using leading order matrix element matching in H7 can be compensated also in the hard regions by non-perturbative parameters in the hadronisation.
   - similarly, in P8 it is possible to compensate some shortcomings in the description of several event shapes at the expense of an accurate description of the total multiplicity.
Thank you for your attention
Backup slides
Observables used in the tune process

A_2004 := ALEPH_2004_S5765862
L_2004 := L3_2004_I652683

/A_2004/d01-x01-y01 1 # Charged multiplicity
/A_2004/d102-x01-y01 1 # Thrust minor
/A_2004/d110-x01-y01 1 # Jet mass difference
/A_2004/d118-x01-y01 1 # Aplanarity
/A_2004/d133-x01-y01 1 # Oblateness
/A_2004/d141-x01-y01 1 # Sphericity
/A_2004/d149-x01-y01 1 # Durham jet 2->1
/A_2004/d157-x01-y01 1 # Durham jet 3->2
/A_2004/d165-x01-y01 1 # Durham jet 4->3
/A_2004/d187-x01-y01 1 # 1-jet fraction
/A_2004/d195-x01-y01 1 # 2-jet fraction
/A_2004/d203-x01-y01 1 # 3-jet fraction
/A_2004/d211-x01-y01 1 # 4-jet fraction
/A_2004/d54-x01-y01 1 # Thrust
/A_2004/d62-x01-y01 1 # Heavy jet mass
/A_2004/d70-x01-y01 1 # Total jet broadening
/A_2004/d78-x01-y01 1 # Wide jet broadening
/A_2004/d86-x01-y01 1 # C-parameter
/A_2004/d94-x01-y01 1 # Thrust major
- Thrust Minor $T_{\text{minor}}$ : The minor axis is perpendicular to both the thrust axis and the major axis, $\vec{n}_{Mi} = \vec{n}_T \times \vec{n}_{Ma}$. The value of thrust minor is given by

$$T_{\text{minor}} = \frac{\sum_i |\vec{p}_i \cdot \vec{n}_{Mi}|}{\sum_i |\vec{p}_i|}.$$ 

- Thrust $T$ : The thrust [25] axis $\vec{n}_T$ maximises the quantity

$$T = \max_{\vec{n}_T} \left( \frac{\sum_i |\vec{p}_i \cdot \vec{n}_T|}{\sum_i |\vec{p}_i|} \right),$$

where the sum extends over all particles in the event.

- Thrust Major $T_{\text{major}}$ : The thrust major vector, $\vec{n}_{Ma}$, is defined in the same way as the thrust vector, but with the additional condition that $\vec{n}_{Ma}$ must lie in the plane perpendicular to $\vec{n}_T$,

$$T_{\text{major}} = \max_{\vec{n}_{Ma} \perp \vec{n}_T} \left( \frac{\sum_i |\vec{p}_i \cdot \vec{n}_{Ma}|}{\sum_i |\vec{p}_i|} \right).$$