New MC calculators & processes in the ATLAS software

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Outline

"New MC calculators"?

- Baseline and work horse for many years: Parton showers like Herwig and Pythia
- But: Large phase space for hard higher-order emissions at Tevatron and LHC
- Parton shower approximations (soft/collinear) not valid anymore
  $\Rightarrow$ Need precision from higher-order matrix elements

$\Downarrow$

This talk restricted to generators incorporating ME corrections from higher-order QCD

Only tools available in ATLAS are discussed

POWHEG

Main idea: Two ingredients for NLO accuracy

Radiation pattern of first emission

- Parton shower will only give approximation
- But: We know how to ME-correct its first emissions (for nearly 20 years in fact!)

$\Rightarrow$ Application of correction weight (always positive)

$$w \sim \left(\frac{\mathcal{R}}{\mathcal{B}}\right) \Big/ \left(\frac{\alpha_s}{2\pi}\mathcal{K}\right)$$

With shower splitting kernel $\mathcal{K}$ and real ($\mathcal{R}$) and Born ($\mathcal{B}$) matrix elements

NLO cross section for Born kinematics event

- Virtual (loop) matrix elements
- Integrated real emission term
- (Subtraction procedure)

$\Rightarrow$ Differential NLO weight for each event (almost always positive)

$$\bar{\mathcal{B}} = \mathcal{B} + \mathcal{V} + \int \mathrm{d}\Phi_1 \mathcal{R}$$

More details in talk by E. Re on Thursday

POWHEG: Availability in ATLAS

Standalone Powheg + Pythia/Herwig+Jimmy

- Parton level events generated by standalone Powheg packages:
  - `POWHEG-w`
  - `POWHEG-z`
  - `POWHEG-hvq`
- Read into the ATLAS software using Les-Houches event format
- Shower/hadronisation/MPI done by Herwig+Jimmy or Pythia
- Mainly used for $t\bar{t}$ in ATLAS, but W and Z samples also exist

Herwig++

- Herwig++ version 2.4.2 is available in in Atlas
- Comes with built-in POWHEG generators for:
  - W and Z production
  - $gg \rightarrow$Higgs
  - $W/Z + H$
- No central ATLAS production yet, but used for some top studies

MC@NLO

Main idea

- Use parton shower approximation to subtract infrared divergences from real MEs
  $\Rightarrow$ Shower events starting either from Born or real kinematics
- Weights for these two samples adjusted accordingly

$\Rightarrow$ cross section and hardest emission correct to $\mathcal{O}(\alpha_s)$

- Per construction produces events with negative weights
- Implementation is shower dependent
- Several processes implemented using both Pythia and Herwig showers

Availability in ATLAS

- All ATLAS samples use the Herwig shower
- Standalone production of parton level events
- samples available for W/Z production, (single) top production, diboson production, $gg \rightarrow$ Higgs
- W/Z mainly used for inclusive cross section studies

BlackHat+Sherpa

Features

- Pure parton level calculation
- No connection to shower/hadronisation
- Full NLO corrections for $V + 3$ jets

Tools used in this NLO calculation

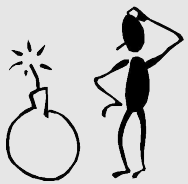
- Tree-level matrix elements for Born and real [Sherpa]
- Automated Catani-Seymour real and integrated subtraction terms [Sherpa]
- Optimised phase space integration [Sherpa]
- Virtual one-loop matrix elements [BlackHat]

Availability in ATLAS

- Readily produced ntuple files available on the Grid
- So far only W+3 jets, soon Z+3 jets
- Factorisation and renormalisation scale $\mu = H_T$
- Cuts: $|\eta_e| < 2.5$, $p_{\perp,e} > 20$ GeV, $p_{\perp,\nu} > 20$ GeV, $m_{\perp,W} > 20$ GeV, $p_{\perp,\text{jet}} > 25$ GeV, $|\eta_{\text{jet}}| < 3.0$
- Events are inclusive with respect to the following jet definitions:
  - Siscone $R = 0.4$
  - anti-$k_\perp$ $R = 0.4,\ 0.5,\ 0.7$
- Soon samples which allow variation of scales/PDFs

ME+PS: Main idea

Problem



- Want matrix element correction beyond first emission
- Traditional reweighting as above not feasible for higher orders

Idea

Start from parton-level events of different multiplicities and apply parton shower to them.

Several issues to solve

- Definition of shower evolution on top of higher-order ME

Solution:
α_s reweighting,
Truncated shower

- Double counting of emissions: e.g. $2 \to 2 +$ shower vs. $2 \to 3$ ME
- Higher-order ME's are not finite
- Higher-order ME's are inclusive

Solution:
Phase space slicing,
Additional jet vetos (= Sudakov form factor)

MLM matching

Shower evolution

- Reweighting of α_s for each branching in k_T clustering
- Parton level events are fed into Pythia or Herwig
- Py/Hw determine **starting scales based on kinematics and colours**
- Upper cutoff given by scale of the hard process

Phase space slicing and jet vetos

- ME's regularised using simple **cone finder** with k_T cut
- After shower jets constructed using a slightly different cone algorithm
- **Matching**: If there is a parton which is not matched by a jet, the event is rejected
- **Jet veto**: If there is an additional jet, the event is rejected as well

MLM matching: Available setups

Alpgen+Herwig

- **Alpgen** ME generator version 2.13
- Interfaced to **Herwig+Jimmy**
- cteq6l1 used as default PDF
  Some interest in using it with LO*, opinions?
- factorisation scale $\mu^2 = m_V^2 + p_{\perp,V}^2$
- usually two separate samples for light jets (u, d, s, c) and b-quarks
  Tricky bit: Overlap removal... tool for that in progress
- Available processes:
  - QCD jet production up to $2 \to 6$ for both light and b quarks
  - $W \to \ell\nu$ (ℓ=e, μ, τ) + up to 5 jets
  - $Z \to \ell\ell$ + up to 5 jets
  - $Z \to \nu\nu$ + up to 5 jets
  - Possibly γ+jets in the future
  - Variations of factorisation scale and matching parameters available for systematics studies

Helac+Pythia

- **Helac** matrix element generator
- Parton level events in Les Houches format fed into **Pythia**
- Starting to be used for γ+jets production with up to 5 jets

CKKW-like merging with truncated showers

Shower evolution

- Starting scales determined by backward clustering in **shower scheme**:
  - Clustering criterion given by shower measure
  - Clustering kinematics given by inverted shower kinematics

  $\Rightarrow$ ME final state in shower language
- Showering off **intermediate legs** possible ("truncated shower")
- Reweighting of α_s for each branching in shower clustering
- **Logarithmic accuracy preserved**

Phase space slicing and jet vetos

- **Specialised jet criterion** Q resembling soft/collinear divergences of QCD
- ME's regularised using $Q > Q_{\text{cut}}$
- Jet veto: Shower emissions with $Q > Q_{\text{cut}}$ lead to rejection of event

CKKW-like: Availability in ATLAS

Sherpa 1.2.2 available in MC10 production

- High multiplicity ME generator Comix
- Shower based on Catani-Seymour dipole picture
- **Improved CKKW merging using truncated showers**
- Combined QCD+QED merging possible
- Hadronisation and MPI models built-in
- Interfaced directly in ATLAS software, no need to write out event files
- Optionally event files in HepMC format can be read in

Available processes

Just recently started production of MC10 samples:

- $W \to \ell\nu$ (ℓ=e, μ) + up to 5 jets
- $Z \to \ell\ell$ + up to 5 jets
- Variations of factorisation scale and matching parameters for systematics studies

Next plans:

- QCD jet production with up to $2 \to 6$ jets
- γ + jets with up to 5 jets

Conclusions and outlook

Conclusions

- **Many approaches** exist to account for higher-order QCD corrections in a **more precise** manner than in traditional parton showers
- Implementations exist and are available in ATLAS

Use them!

Outlook

- Automated POWHEG implementations appear
- Combination of the POWHEG and ME+PS approaches
  $\Rightarrow$ **jack-of-all-trades algorithm** "MENLOPS"
  cf. talk by Keith Hamilton on Thursday