ATLAS Monte Carlo generator tunes to LHC data

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The ATLAS detector

General purpose detector designed to cover all the expected physics channels at LHC using p-p collisions with energies up to 14 TeV and Pb-Pb collisions at 5.5 TeV/nucleon.

MC modelling and tunes

MC event modelling needed both for **experimental understanding of QCD, V +jets, etc. as backgrounds to new physics**, and to **allow highest-tech theory/data comparisons**.

Some parts of MC simulation are very predictive – ME (especially at NLO), parton shower, QED, etc. – while those based on non-perturbative QCD are less robust. Hadronisation, “underlying event” in particular. These have **parameters to be tuned to data**.

Event simulation has two roles: **to use and test our ability to calculate QCD**, and **to parameterise observables**. Both are useful, but we need to be careful about which we are doing. **Don't “tune away” failures in predictive parts**.

MC generators in ATLAS

ATLAS uses a multitude of event generator codes, in the appropriate scenarios:

- ▶ General purpose: PYTHIA, HERWIG, Pythia 8, Sherpa, Herwig++
- ▶ Multi-jet QCD: AlpGen, Sherpa, MadEvent
- ▶ NLO (in α_s): MC@NLO, POWHEG, Herwig++
- ▶ **Soft QCD: PHOJET, PYTHIA, HERWIG+JIMMY, Herwig++**
- ▶ Other: HIJING, BlackMax, Charybdis, Protos, ExHuME, HORACE...

Initial interest is in tuning general purpose QCD to fit **minimum bias QCD** and **underlying event** ATLAS observables. For optimal simulation of QCD pile-up and signal-process UE respectively.

Tuning infrastructure

PYTHIA and HERWIG+JIMMY are main ATLAS QCD workhorse generators – for now. Most experience in tuning PYTHIA, which has *many* params, HERWIG+JIMMY is more restrictive.

Pre-LHC tuning rounds: MC08 and MC09. Mostly-manual tunes, based on CDF UE and min bias data. MC09 significantly changed from MC08, including change of PDF from CTEQ6L1 to MRST LO*. PYTHIA MC09c tune used Professor tool to improve colour-reconnection – since then all ATLAS tuning has been based on the Rivet/Professor tool combination (see previous talk).

Infrastructure also exists to use fast detector simulation to tune to pre-unfolding data – in practice not required as detector understanding has been better than anticipated.

Tuning data

- ▶ Minimum bias from CDF and ATLAS: defined for ATLAS by 1 MBTS hit on each side. Diffractive contribution reduced via $N_{\text{ch}} \geq 6$ requirement
- ▶ Underlying event from CDF 1 & 2 with track-jet, calo-jet, and $Z \rightarrow \text{leptons}$ alignment
- ▶ Underlying event from ATLAS with leading track alignment, min bias trigger
- ▶ $\sqrt{s} = 900 \text{ GeV} \& 7 \text{ TeV}$, track $p_{\perp} > 500 \text{ MeV}$, $|\eta| < 2.5$ for all ATLAS results

Underlying event
analysis topology

PYTHIA AMBT1

First LHC-data tune of PYTHIA was from ATLAS: AMBT1 (ATLAS Minimum Bias Tune #1).

Focus on ATLAS min bias data, also including CDF min bias results. Test stability of pre-LHC energy evolution fit of multiple parton interactions (MPI) cutoff scale:

$$p_{\perp}^{\min} = \text{PARP}(82) \left(\frac{\sqrt{s}}{1.8 \text{ TeV}} \right)^{\text{PARP}(90)}$$

Other parameters: strength of colour reconnection (and suppression of high-momentum CR) and hadronic matter distribution (double-Gaussian).

Data used:

- ▶ diffractive-reduced min bias data with $N_{\text{ch}} \geq 6$
- ▶ low-stats ATLAS UE
- ▶ plus pre-LHC MB/UE data from CDF Runs I & II

PYTHIA AMBT1 params

Parameter	Meaning	MC09c	AMBT1
PARP(62)	ISR cutoff (GeV)	1.0	1.025
PARP(93)	$k_{\perp}^{\text{prim}}$ cutoff (GeV)	5.0	10.0
PARP(77)	Fast-string CR suppression	0.0	1.016
PARP(78)	CR strength	0.224	0.538
PARP(82)	$p_{\perp}^{\text{min}}$	2.31	2.292
PARP(83)	Inner matter fraction	0.8	0.356
PARP(84)	Inner matter rel. width	0.7	0.651
PARP(90)	Energy evolution exp.	0.24	0.250

$p_{\perp}^{\text{min}}$ and energy evolution as for MC09(c) – compatible with Tevatron. Matter distribution: first tune since MC08 so change expected. Non-zero fast-string CR suppression preferred.

AMBT1 tune constraints

PYTHIA tunes vs. ATLAS min-bias data ($N_{\text{ch}} \geq 6$)

At 900 GeV

PYTHIA tunes vs. ATLAS min-bias data ($N_{\text{ch}} \geq 6$)

At 900 GeV

PYTHIA tunes vs. ATLAS min-bias data ($N_{\text{ch}} \geq 6$)

At 7 TeV

PYTHIA tunes vs. ATLAS min-bias data ($N_{\text{ch}} \geq 6$)

At 7 TeV

PYTHIA tunes vs. ATLAS underlying event data

PYTHIA tunes vs. ATLAS underlying event data

HERWIG+JIMMY AUET1

Main MC09 JIMMY tune was just an update of the manual MC08 tune from the CTEQ6L to MRST LO* PDF. Also a CTEQ6.6 NLO PDF tune using Professor. $\Rightarrow$ an updated tune similar to AMBT1 required.

BUT... JIMMY model only valid for secondary scattering in the presence of a hard interaction: can do underlying event but not min bias.

Hence a separate tune type for HERWIG+JIMMY: focus solely on UE data from CDF and ATLAS $\Rightarrow$ "AUET1" tune.

HERWIG+JIMMY AUET1 (ctd.)

Fitting weights strictly ordered: ATLAS > CDF, 7 TeV > 900 GeV, transverse > toward/away. Also, $p_{\perp}^{\text{sum}} > N_{\text{ch}}$ observable: JIMMY has no colour reconnection model (and hadronisation details not included in the tune.)

Use manual version of PYTHIA energy evolution ansatz:

$$\text{PTJIM} = \text{PTMIN0} \left(\frac{\sqrt{s}}{1.8 \text{ TeV}} \right)^{\text{EXP}}$$

Tune PTMIN0 and EXP, plus hadronic matter distribution width PRRAD. Other params tweaked manually, particularly PTRMS (primordial $k_{\perp}$). 3 PDFs: LO*, CTEQ6L & CTEQ66.

HERWIG+JIMMY AUET1 params

Parameter	Meaning	MC09 LO*	—— AUET1 LO* CTEQ6L1	—— CTEQ6.6
Parameters fixed before numerical tuning				
ISPAC	ISR scheme	0	2	2
PTRMS	Prim. $k_{\perp}$ (GeV)	0	1.2	1.2
QSPAC	ISR cut-off (GeV/c)	2.5	2.5	2.5
Tuned cutoff meta-parameters				
PTJIM0	MPI cut-off (GeV/c)	3.6	2.86	2.65
EXP	MPI evolution	0.274	0.273	0.277
Tuned JIMMY parameters				
PRRAD	Proton radius (GeV ²)	2.2	1.69	1.90
PTJIM(7)	MPI cut-off (7 TeV)	5.22	4.14	3.86
PTJIM(10)	MPI cut-off (10 TeV)	5.76	4.56	4.26
PTJIM(14)	MPI cut-off (14 TeV)	6.32	5.00	4.68

Again mostly stable $p_{\perp}^{\min}$ and energy evolution. Note that MPI cut-off is ordered by magnitude of gluon PDF at low- x .

AUET1 tune constraints (for LO* PDF only)

AUET1 vs. CDF underlying event data

Showing low- $p_{\perp}$ track jet UE at 1800 GeV only: others in fit

Transverse N_{ch}

Transverse $p_{\perp}^{sum}$

AUET1 vs. ATLAS underlying event data

900 GeV

7 TeV

AUET1 vs. ATLAS underlying event data

900 GeV

7 TeV

AUET1 vs. ATLAS underlying event data

900 GeV

7 TeV

Summary

- ▶ PYTHIA AMBT1 and HERWIG+JIMMY AUET1 tunes from ATLAS give a good description of ATLAS soft QCD physics without severely compromising Tevatron agreement.
- ▶ Rough agreement of main MPI cutoff and energy-scaling exponent between PYTHIA/JIMMY, and between the pre-LHC and LHC tunes.
- ▶ Room for improvement:
 - PYTHIA: final state shower and hadronisation not tuned to LEP data... improvements definitely possible. Also, better description of hadron collider jet shapes possible with recent PYTHIA versions.
 - HERWIG: tuning to LEP not tried for a long time, can maybe use extra parameters for beam remnant fragmentation to better balance the momentum distribution among final-state particles.
 - More generators: external work on Pythia 8, Herwig++ and Sherpa very promising: will be used in ATLAS.