Event modelling at the CMS experiment

Paolo Gunnellini
on behalf of the CMS Collaboration

DIS 2017
Birmingham
April 2017, England
Outline

- Brief introduction
- Before and during Run II situation
- Considered measurements for CMS tunes
- Tuning value of $\alpha_S$
- Validation plots at 13 TeV
- Conclusions
The underlying event at the LHC

Hadronisation modelling

Parton Shower (initial and final state radiation)

Beam remnants, primordial $k_T$

Multiple parton interactions (Underlying Event)

From Frank Siegert
A hard $pp$-collision at the LHC can be interpreted as a hard scattering between partons, accompanied by the underlying event (UE) consisting of:

- Initial and final state radiation
- Beam Remnants
- Multiple Parton Interactions (MPI)
- Hadronization

Many processes are included in the nomenclature "UE" at different scales:

- Double Parton Scattering (DPS)
- Diffractive processes
- Semi-hard multiparton interactions
How do we deal with that?

Monte Carlo event generators (PYTHIA, HERWIG, SHERPA..)

Parameters need to be adjusted (tuned) to describe data

- MPI
  - e.g. $p_T^0 = p_T^{\text{ref}} \cdot (E/E_{\text{ref}})^\epsilon$
  - Proton matter distribution profile
  - Colour reconnection

- Primordial $k_T$
  - e.g. Width of the gaussian used for modelling the parton primordial $k_T$ inside the proton

- Parton shower
  - e.g. Strong coupling value
  - Regularization cut-off
  - Upper scale

- Hadronization
  - e.g. Length of fragmentation strings
  - Strange baryon suppression

How does one tune all these?

- Choice of parameter ranges and sensitive observables
- Predictions for different parameter choices and interpolation of the MC response
- Data-MC difference and minimisation over parameter space
Why do we actually tune?

Not only for fun!

1. Correct description of the data
   - Pile-up simulation
   - Evaluation of detector effects and unfolding
   - Estimation of background (in MC-driven approach)
   - Models are not "allowed" to fail

2. Good physics predictions
   - Correct evaluation of physics effects
   - Models are "allowed" to fail

The danger is overtuning!
Before Run II data: trying to predict

Charged particle mult. in the MAX reg. @ 0.9 (left) and 7 (right) TeV

New tunes!
- PYTHIA 8 (CUETP8)
- HERWIG++ (CUETHpp)

Better constrain of the energy extrapolation
CR changes with the choice of the PDF

Rising part and plateaux region are well predicted by the new tunes

(EPJC 76 (2016) 155)
After Run II data: the outcome

CMS Preliminary \( \sqrt{s} = 13 \text{ TeV} \)

\[ \text{TOP:} \quad \frac{dN}{d\eta} \]


\[ \text{BOTTOM:} \quad N_{\text{ch}} \text{ vs } p_T^{\text{lead}} \]


None of the tunes reproduce the data perfectly!

The energy dependence of the MPI fitted to lower energies is not optimal

\[ p_T^0 = p_T^{\text{ref}} \cdot (E/E_{\text{ref}})^\epsilon \]
Similar strategy used for obtaining CUETP8M1 (BUT..without energy dependence)

GEN-14-001, EPJC 76 (2016) 155

Two types of measurements considered for the fit:

- UE observables (charged particle multiplicity and $p_T$ sum) at 13 TeV in MIN and MAX region as a function of leading track $p_T$
- Charged particle multiplicity as a function of $\eta$ in MB collisions

CUETP8M2T4: New UE/MB tune at 13 TeV

TOP-16-021, CMS-GEN-XXX: paper in preparation
Considered measurements

Measurement of UE observables in the transverse region by CMS

**Transverse regions: $60^\circ < |\Delta \phi| < 120^\circ$:**

- **TransMAX**: maximum activity side, often containing a 3rd jet $\Rightarrow$ MPI/BR + ISR/FSR
- **TransMIN**: minimum activity side $\Rightarrow$ MPI/BR

$\text{TransAVE} = (\text{TransMAX} + \text{TransMIN})/2$

$\text{TransDIF} = \text{TransMAX} - \text{TransMIN} \Rightarrow$ ISR/FSR

**Observables:**

- average charged-particle multiplicity density (particle density): $<N_{ch}>/[\Delta \eta \Delta (\Delta \phi)]$
- average transverse-momentum scalar sum density (energy density): $<\Sigma p_T>/[\Delta \eta \Delta (\Delta \phi)]$

**MAX and MIN regions included in the tune**

CMS-PAS-FSQ-15-007
Considered measurements

Measurement of charged-particle multiplicities by ATLAS and CMS

→ ATLAS measurement: $p_T > 500$ MeV (100 MeV)

→ CMS measurement: any particle $p_T (> 0$ MeV)

Not included in the tune
arXiv:1602.01633

Included in the tune
PLB 751 (2015) 143
Measurement of charged-particle multiplicities by CMS

(A) At least 1 charged particle \[ \begin{align*}
& \frac{p_T}{ > 0.5 \text{ GeV}} \\
& |\eta| < 2.4
\end{align*} \]

- **Activity**: at least 1 particle with \( E > 5 \text{ GeV} \)
- **Veto**: no particle with \( E > 5 \text{ GeV} \)

- **Inclusive**: (A)

- **Inelastic enhanced**: (A) + **Activity** in at least one Forward Region

- **NSD enhanced**: (A) + **Activity** in both Forward Regions

- **SD enhanced**: (A) + **Activity** in one Forward Region and **Veto** in the other side

Not included in the tune

CMS-PAS-FSQ-15-008
The starting point of the Underlying Event tune

Top events are important background for searches (e.g. ttH)
**Low jet multiplicity is sensitive to ME and matching to PS**
**High jet multiplicity is sensitive to PS (i.e. UE tune)**

![CMS Preliminary 2.2 fb⁻¹ (13 TeV)](image)

Dilepton

\[ p_T^{\text{jets}} > 30 \text{ GeV}, |\eta^{\text{jets}}| < 2.4 \]

- Data
- Powheg v2+Pythia8
- Powheg v2+Herwig++
- MG5\_aMC@NLO+Pythia8 [FxTx]
- MG5\_aMC@NLO+Pythia8 [MLM]

Any considered prediction overestimates the jet multiplicity, when jets come from the parton shower!

**Effect seen also at 8 TeV**

arXiv:1610.04191, TOP-12-041, TOP-16-011, TOP-16-021
The starting point of the Underlying Event tune

Need for improvement of the jet multiplicity in top events → tune of $\alpha^{ISR}_S$ and $h_{damp}$

$\rightarrow h_{damp}$ is an internal parameter inside the POWHEG ME simulation, which regulates the amount of additional hard radiation

**Results**

$\alpha^{ISR}_S = 0.1108^{+0.0144}_{-0.0142}$

$h_{damp} = 1.581^{+0.658}_{-0.585}$
The new Underlying Event Tune

The fit includes five histograms for the UE and MB measurements!

TransMIN charged particle density $\sqrt{s} = 13$ TeV

PYTHIA8.219

PDF set: NNPDF30_lo_as_0130

ISR $\alpha_S = 0.1108$ (previous slide)

MultipartonInteractions:ecmPow=0.25208 (from CUETP8M1)

Baseline: Monash tune

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tuning Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MultipartonInteractions:pT0Ref</td>
<td>1.0-3.0</td>
</tr>
<tr>
<td>MultipartonInteractions:expPow</td>
<td>0.4-10.0</td>
</tr>
<tr>
<td>ColourReconnection:range</td>
<td>0.0-9.0</td>
</tr>
</tbody>
</table>

TOP: chg part. mult. in trans MIN region

BOTTOM: $dN/d\eta$

CMS-GEN-XXX in prep.
Performance of the new tune

Charged particle mult. in the MIN region and \(dN/d\eta\) @13 TeV

The new tune has a better description of the plateau region

Rising part of the spectrum seems to prefer a double gaussian matter distribution profile

Performance of the new tune

Charged particle mult. in the MIN region and $dN/d\eta \ @13 \ TeV$

CMS Preliminary, 281 nb$^{-1}$ (13 TeV)

CMS Preliminary, 85.6 nb$^{-1}$ (13 TeV)

Single-diffractive enhanced observables and inelastic cross sections not well described

NEED FOR TUNING DIFFRACTIVE PART OF THE SIMULATION!

1. Wide range of validation plots for the CUETP8M2T4 tune
2. Comparison to double parton scattering and underlying event observables
3. Tuning studies for Herwig7 and Sherpa

Stay tuned!
CMS has a great interest on Monte Carlo models and follows closely tuning issues during LHC Run II

A new PYTHIA 8 tune is ready after first RunII data!

- It is able to describe UE and MB observables at the same time and uses a lower value of ISR $\alpha_S$, tuned to jet multiplicities in top events
- Cross checks with other observables suggest that the new tune behaves very well in general at 13 TeV
- At 7 TeV, it is also performing well
CMS has a great interest on Monte Carlo models and follows closely tuning issues during LHC Run II

A new PYTHIA 8 tune is ready after first RunII data!

- It is able to describe UE and MB observables at the same time and uses a lower value of ISR $\alpha_S$, tuned to jet multiplicities in top events
- Cross checks with other observables suggest that the new tune behaves very well in general at 13 TeV
- At 7 TeV, it is also performing well

THANKS FOR YOUR ATTENTION
BACKUP SLIDES
ATLAS released a CONF NOTE with a new tune for improving the description of soft QCD observables

<table>
<thead>
<tr>
<th>√s</th>
<th>Measurement type</th>
<th>Rivet name</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 TeV</td>
<td>MB</td>
<td>ATLAS_2016_I1419652 [3]</td>
</tr>
<tr>
<td>13 TeV</td>
<td>INEL XS</td>
<td>MC_XS [5]</td>
</tr>
<tr>
<td>7 TeV</td>
<td>MB</td>
<td>ATLAS_2010_S8918562 [11]</td>
</tr>
<tr>
<td>7 TeV</td>
<td>INEL XS</td>
<td>ATLAS_2011_I89486 [4]</td>
</tr>
<tr>
<td>7 TeV</td>
<td>RAPGAP</td>
<td>ATLAS_2012_I1084540 [15]</td>
</tr>
<tr>
<td>7 TeV</td>
<td>ETFLOW</td>
<td>ATLAS_2012_I1183818 [14]</td>
</tr>
<tr>
<td>8 TeV</td>
<td>MB</td>
<td>ATLAS_2016_I1426695 [16]</td>
</tr>
</tbody>
</table>

- Need to improve the description at the new energy
- Focus on total inelastic cross section, dN/dη and particle multiplicities at different energy
- Choice of double gaussian matter distribution profile
- First attempt to include diffractive parameters in the procedure

Table 1: Tuning parameters and sampling range

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sampling range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MultipartonInteractions:pT0Ref</td>
<td>1.00 – 3.60</td>
</tr>
<tr>
<td>MultipartonInteractions:ecmPow</td>
<td>0.10 – 0.35</td>
</tr>
<tr>
<td>MultipartonInteractions:coreRadius</td>
<td>0.40 – 1.00</td>
</tr>
<tr>
<td>MultipartonInteractions:coreFraction</td>
<td>0.50 – 1.00</td>
</tr>
<tr>
<td>BeamRemnants:reconnectRange</td>
<td>0.50 – 10.00</td>
</tr>
<tr>
<td>Diffraction:PomFluxEpsilon</td>
<td>0.02 – 0.12</td>
</tr>
<tr>
<td>Diffraction:PomFluxAlphaPrime</td>
<td>0.10 – 0.40</td>
</tr>
</tbody>
</table>

ATL-PHYS-PUB-2016-017