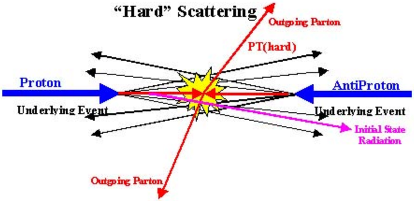
Deutsches Elektronen-Synchrotron
(DESY), Hamburg

Event modelling at the CMS experiment

Paolo Gunnellini
on behalf of the CMS Collaboration

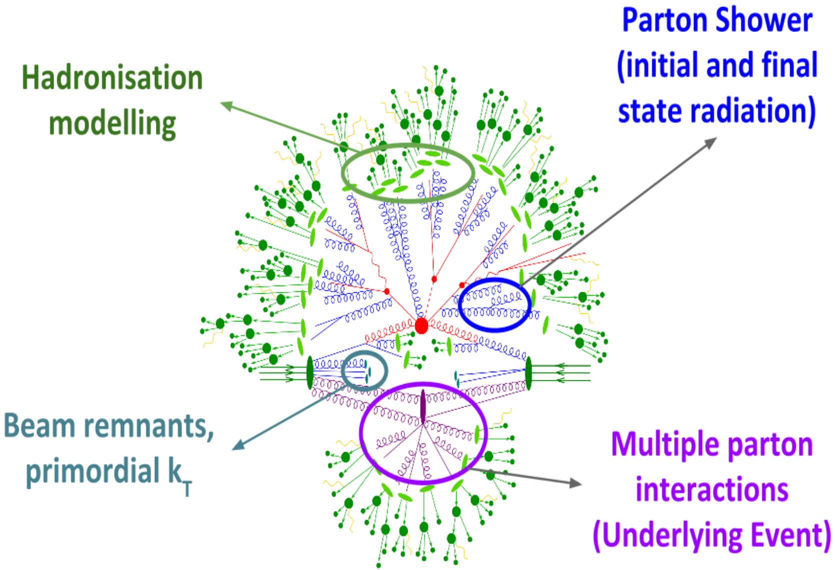
DIS 2017
Birmingham
April 2017, England

Outline

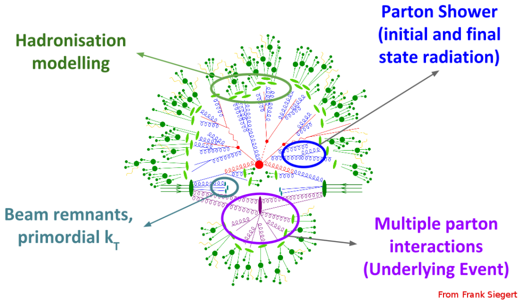


- Brief introduction
- Before and during Run II situation
- Considered measurements for CMS tunes
- Tuning value of α_S
- Validation plots at 13 TeV
- Conclusions

The underlying event at the LHC



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
- Multiple Parton Interactions (MPI)
- Beam Remnants
- 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. $p_T^0 = p_T^{ref} \cdot (E/E_{ref})^{\epsilon}$
  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?

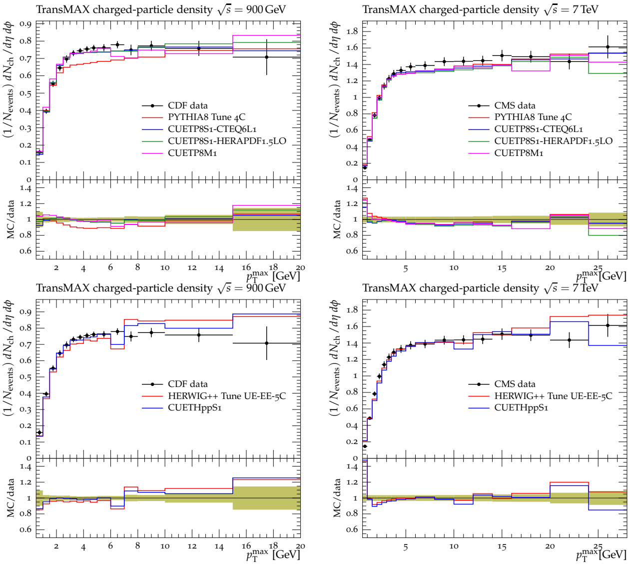
Not only for fun!

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)

with various PDFs

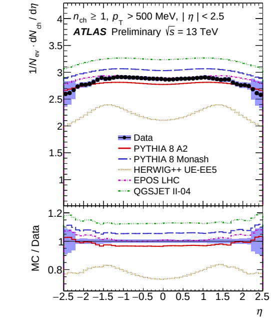
Better constrain of the energy extrapolation

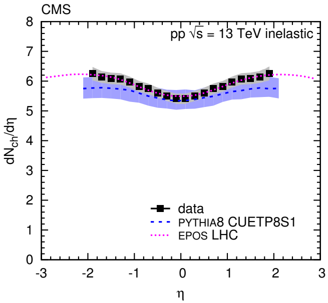
CR changes with the choice of the PDF

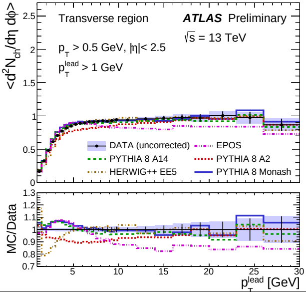
Rising part and plateaux region are well predicted by the new tunes

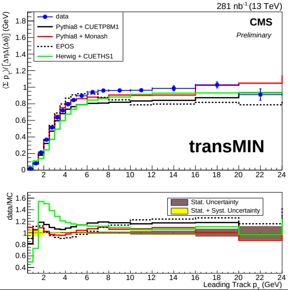
(EPJC 76 (2016) 155)

After Run II data: the outcome









$\sqrt{s}$ = 13 TeV

TOP:
dN/dη

ATLAS-CONF-2015-028, PLB 751 (2015) 143

BOTTOM:
N_{ch} vs p_T^{lead}

ATLAS-PHYS-2015-019, CMS-FSQ-15-007

None of the tunes reproduce the data perfectly!

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

$$p_T^0 = p_T^{ref} \cdot (E/E_{ref})^{\epsilon}$$

CMS retuning effort

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:

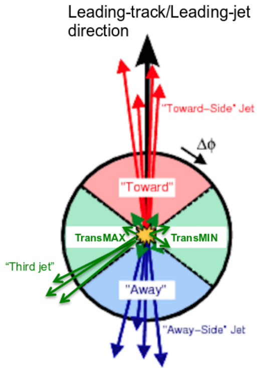
- UE observables (charged particle multiplicity and p_T sum) at 13 TeV in MIN and MAX region as a function of leading track p_T
- Charged particle multiplicity as a function of η in MB collisions

- 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: $60^o < |\Delta\phi| < 120^o$:

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

TransAVE = (TransMAX + TransMIN)/2

TransDIF = TransMAX – TransMIN ➔ 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)

$$\frac{1}{N_{\rm ev}} \cdot \frac{dN_{\rm ch}}{d\eta}, \quad \frac{1}{N_{\rm ev}} \cdot \frac{1}{2\pi p_{\rm T}} \cdot \frac{d^2 N_{\rm ch}}{d\eta d p_{\rm T}}, \quad \frac{1}{N_{\rm ev}} \cdot \frac{dN_{\rm ev}}{dn_{\rm ch}} \quad \text{and} \quad \langle p_{\rm T} \rangle \text{ vs. } n_{\rm ch}$$

Not included in the tune

arXiv:1602.01633

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

Included in the tune

PLB 751 (2015) 143

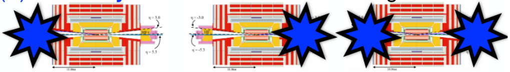
Considered measurements

Measurement of charged-particle multiplicities by CMS

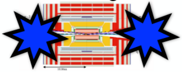
(A) At least 1 charged particle $\begin{cases} p_T > 0.5 \text{ GeV} \\ |\eta| < 2.4 \end{cases}$

- ✦ **Activity**: at least 1 particle with $E > 5$ GeV
- ✦ **Veto**: no particle with $E > 5$ GeV

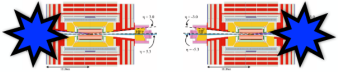
- **Inclusive**: (A)
- **Inelastic enhanced**: (A) **+ Activity** in **at least one** Forward Region



- **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

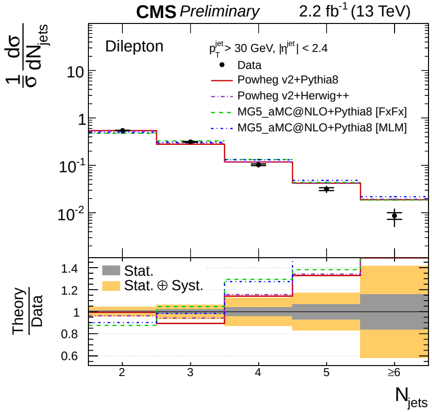
CMS-PAS-FSQ-15-008

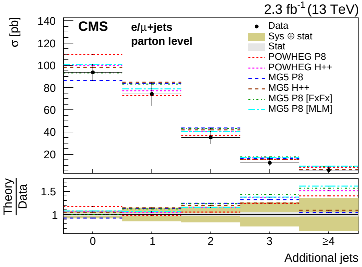
The starting point of the Underlying Event tune

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)





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

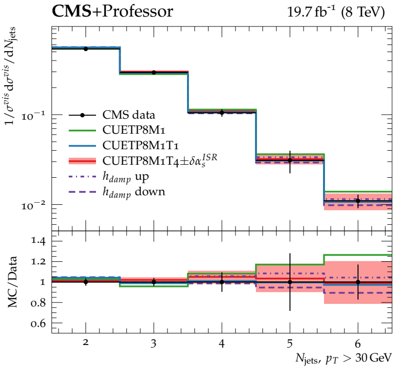
The starting point of the Underlying Event tune

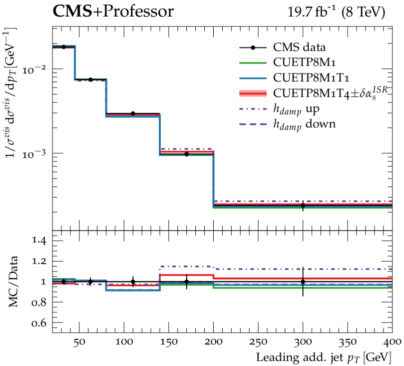
Need for improvement of the jet multiplicity in top events → tune of α_S^{ISR} and h_{damp}

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

Results

$\alpha_S^{ISR} = 0.1108^{+0.0144}_{-0.0142}$ $h_{damp} = 1.581^{+0.658}_{-0.585}$

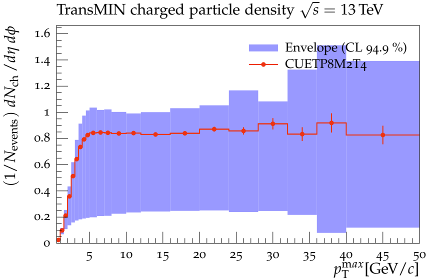


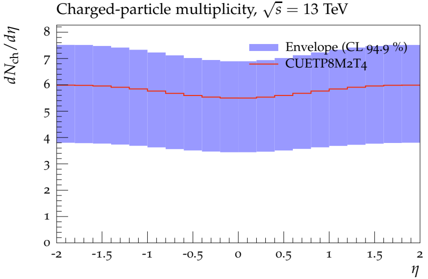


TOP-12-041, TOP-16-021

The new Underlying Event Tune

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





PYTHIA8.219

PDF set: NNPDF30_lo_as_0130

ISR $\alpha_S = 0.1108$ (previous slide)

MultipartonInteractions:ecmPow=0.25208 (from CUETP8M1)

Baseline: Monash tune

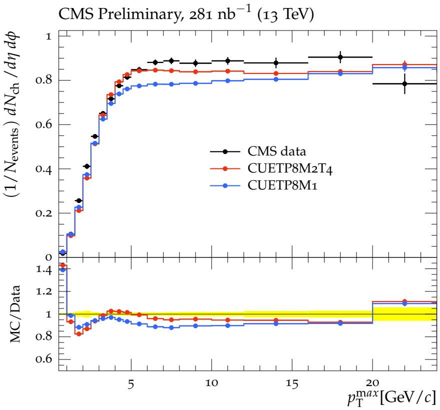
Parameter	Tuning Range
MultipartonInteractions:pT0Ref	1.0-3.0
MultipartonInteractions:expPow	0.4-10.0
ColourReconnection:range	0.0-9.0

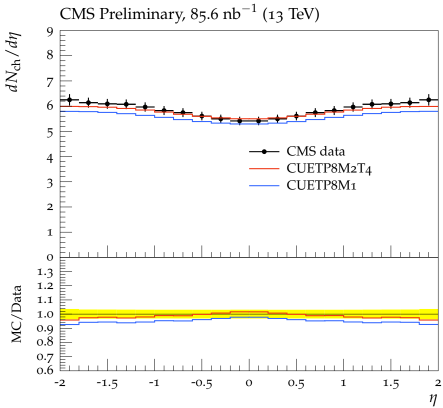
TOP: chg part. mult. in trans MIN region
BOTTOM: dN/dη

CMS-GEN-XXX in prep.

Performance of the new tune

Charged particle mult. in the MIN region and dN/dη @13 TeV





The new tune has a better description of the plateau region

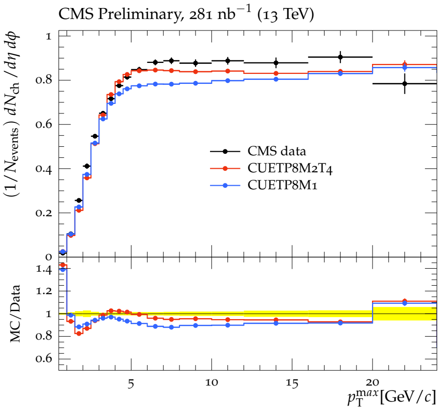
Rising part of the spectrum seems to prefer a double gaussian matter distribution profile

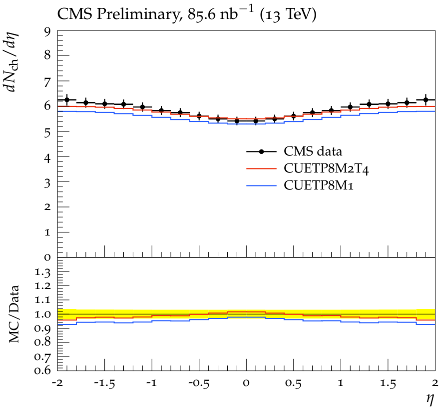
NEW!

CMS-FSQ-15-007 | PLB 751 (2015) 143 | CMS-TOP-16-021

Performance of the new tune

Charged particle mult. in the MIN region and dN/dη @13 TeV





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

NEED FOR TUNING DIFFRACTIVE PART OF THE SIMULATION!

CMS-FSQ-15-007 | PLB 751 (2015) 143 | CMS-TOP-16-021

Coming soon..

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-GEN-XXX in prep.

Summary and conclusion

- 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 α_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

Summary and conclusion

- 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 α_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 retuning effort

ATLAS released a CONF NOTE with a new tune for improving the description of soft QCD observables

$\sqrt{s}$	Measurement type	Rivet name
13 TeV	MB	ATLAS_2016_I1419652 [3]
13 TeV	INEL XS	MC_XS [5]
7 TeV	MB	ATLAS_2010_S8918562 [11]
7 TeV	INEL XS	ATLAS_2011_I89486 [4]
7 TeV	RAPGAP	ATLAS_2012_I1084540 [15]
7 TeV	ETFLOW	ATLAS_2012_I1183818 [14]
900 GeV	MB	ATLAS_2010_S8918562 [11]
2.36 TeV	MB	ATLAS_2010_S8918562 [11]
8 TeV	MB	ATLAS_2016_I1426695 [16]

Parameter	Sampling range		
`MultipartonInteractions:pT0Ref`	1.00	–	3.60
`MultipartonInteractions:ecmPow`	0.10	–	0.35
`MultipartonInteractions:coreRadius`	0.40	–	1.00
`MultipartonInteractions:coreFraction`	0.50	–	1.00
`BeamRemnants:reconnectRange`	0.50	–	10.0
`Diffraction:PomFluxEpsilon`	0.02	–	0.12
`Diffraction:PomFluxAlphaPrime`	0.10	–	0.40

Table 1: Tuning parameters and sampling range

- 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

ATL-PHYS-PUB-2016-017