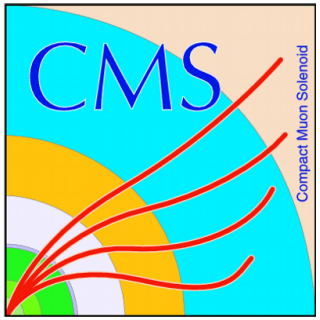


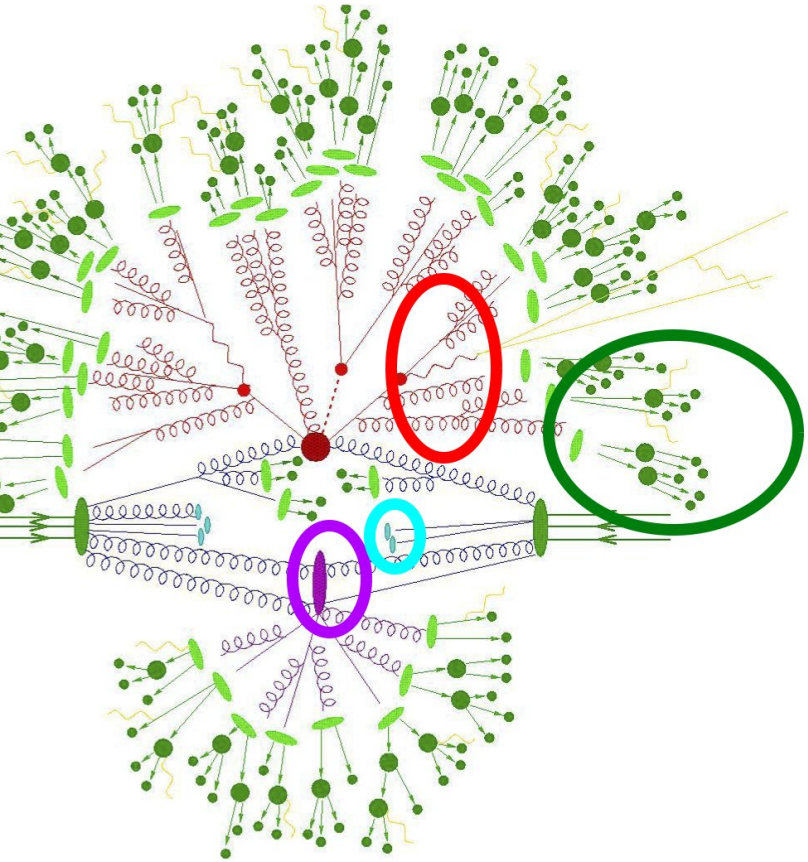
QCD Monte-Carlo model tuning studies with CMS data at 13 TeV

Daniela Dominguez *... on behalf of CMS collaboration*

Deutsches Elektronen Synchrotron

April 2018

Introduction & Tuning: basic concepts



A pp collision at the LHC can be interpreted as a **hard scattering** between partons accompanied by *underlying event* (UE) consisting of:

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

These contribution are not always calculable using pQCD

⇓

There are free phenomenological parameter to determine!!! (***TUNING!!***)

The underlying event (UE) at the LHC

Many processes are included in the nomenclature *UE* at different scales, i.e.:

1. Semi-hard multiparton interactions
2. Double Parton Scattering (DPS)
3. Diffractive processes

How we deal with that?

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

Parameters need to be adjusted (tuned) to describe data:

- MPI : $p_T^0 = p_T^{ref}(E/E_{ref})^{\epsilon}$
  Primordial k_T, i.e: width of the Gaussian used for modeling the parton primordial k_T inside the proton
- Colour reconnection
- Parton shower Strong coupling value, Regularization cut-off upper scale
- Hadronization Length of fragmentation strings

Tuning Strategy

Rivet+Professor

https://professor.hepforge.org/

- Choice of parameter ranges and sensitive observable.
- Predictions for different parameter choices and interpolation of the MC response.
- Data-MC difference and minimization over parameter space.

Before Run II

UE observable used

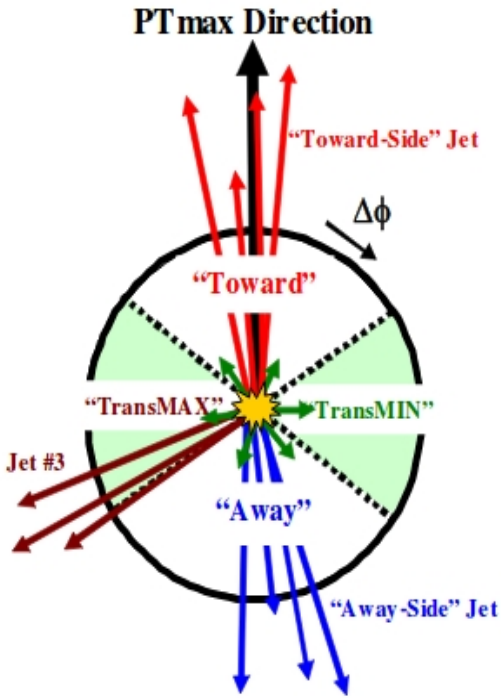
during RunII ..until now

UE observable & charge particle multiplicity in MB events used.

UE Observable

Transverse regions: $60° < |\Delta\phi| < 120°$

- *"transMAX"* and *"transMIN"* Charge Particle Density: number of charged particles ($p_t > 0.5 GeV, |\eta| < 0.8$)
- *"transMAX"* and *"transMIN"* Charged PTsum Density: scalar p_t sum of charged particles



TransMAX
max.jet activity, often contains the 3rd jet
sensitive to MPI/BR + ISR/FSR
TransMIN
min. jet activity, sensitive to MPI/BR
TransAVE, TransDIF
$= (TransMAX + TransMIN)/2$
$= (TransMAX - TransMIN)/2$

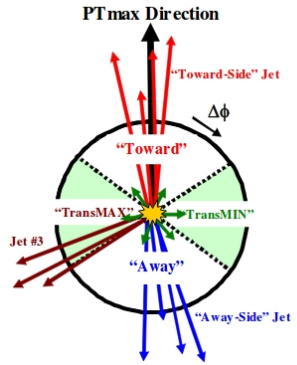
TransMIN sensitive to MPI & BR
TransAVE, TransDIF sensitive to ISR/FSR

Key observable:

$$\frac{<N_{ch}>}{\Delta\eta\Delta(\Delta\phi)}, \frac{\sum <p_t>}{\Delta\eta\Delta(\Delta\phi)}$$

CMS UE Tunes

based on Tevatron & LHC $\sqrt{s} = 7 TeV$ data



PYTHIA 6.4 Tune CUETP6S1 - CTEQ6L or HERAPDF1.5LO
Start with Tune $Z2*-lep$ and tune to the CDF PTmax *transMAX* and *transMIN* UE data at 300 GeV , 900 GeV, and 1.96 TeV and the CMS PTmax *transMAX* and *transMIN* UE data at 7 TeV.

HERWIG++ Tune CUETHS1-CTEQ6L: Start with the Seymour & Siodmok UE-EE-5C tune and tune to the CDF PTmax *transMAX* and *transMIN* UE data at 900 GeV, and 1.96 TeV and the CMS PTmax *transMAX* and *transMIN* UE data at 7 TeV.

PYTHIA 8 Tune CUETP8S1, CTEQ6L or HERAPDF1.5LO
&
PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO

details next slide

First CMS Tunes (RunI LHC)

Pythia8 UE Tunes with RunI LHC + Tevatron Data

$p\bar{p}$ collisions with $\sqrt{s} = 0.9, 1.96, 7$ TeV

using *transMAX* , *transMIN* charged-particle and $\sum p_T$ densities as observable for performing the tune (EPJC 76 (2016) 155)

CUETP8S1

PYTHIA8 Parameter	Tuning Range	Tune 4C	CUETP8S1	CUETP8S1
PDF	—	CTEQ6L1	CTEQ6L1	HERAPDF1.5LO
MultipartonInteractions:pT0Ref [GeV]	1.0–3.0	2.085	2.101	2.000
MultipartonInteractions:ecmPow	0.0–0.4	0.19	0.211	0.250
MultipartonInteractions:expPow	0.4–10.0	2.0	1.609	1.691
ColourReconnection:range	0.0–9.0	1.5	3.313	6.096
MultipartonInteractions:ecmRef [GeV]	—	1800	1800*	1800*
χ^2/dof	—	—	0.952	1.13

* Fixed at Tune 4C value.

Reference tune Pythia 8 Tune 4C

EPJ C 74 (2014) 3024

using different PDF sets:

CTEQ6L, HERAPDF1.5LO

CUETP8M1

PYTHIA8 Parameter	Tuning Range	Monash	CUETP8M1
PDF	—	NNPDF2.3LO	NNPDF2.3LO
MultipartonInteractions:pT0Ref [GeV]	1.0–3.0	2.280	2.402
MultipartonInteractions:ecmPow	0.0–0.4	0.215	0.252
MultipartonInteractions:expPow	—	1.85	1.6*
ColourReconnection:range	—	1.80	1.80**
MultipartonInteractions:ecmRef [GeV]	—	7000	7000**
χ^2/dof	—	—	1.54

* Fixed at CUETP8S1-CTEQ6L1 value.
** Fixed at Monash Tune value.

Reference tune Pythia 8 Monash

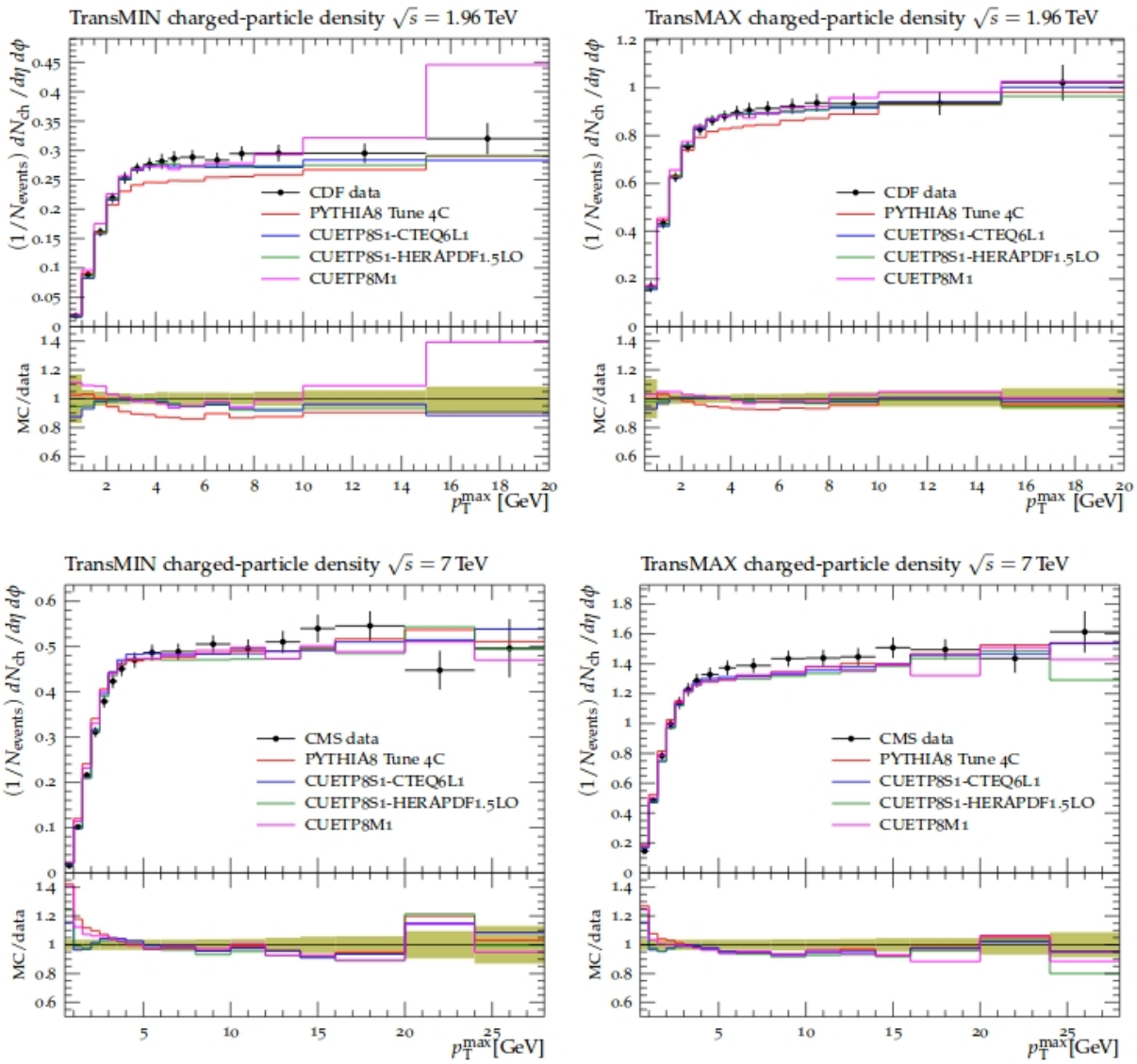
JHEP 10 (2013) 113

one PDF set: NNPDF2.3LO PDF

only varying MPI- energy dependence parameters.

RunI LHC & Tevatron data

Charged particle mult. in the MIN reg (left) and MAX reg. (right) for CDF and LHC RunI data



Different versions changing PDF sets

Good description of MB and UE observable, as well as variables measured in the forward region and in the jet sector

Rising part and plateau region are well predicted by the new tune

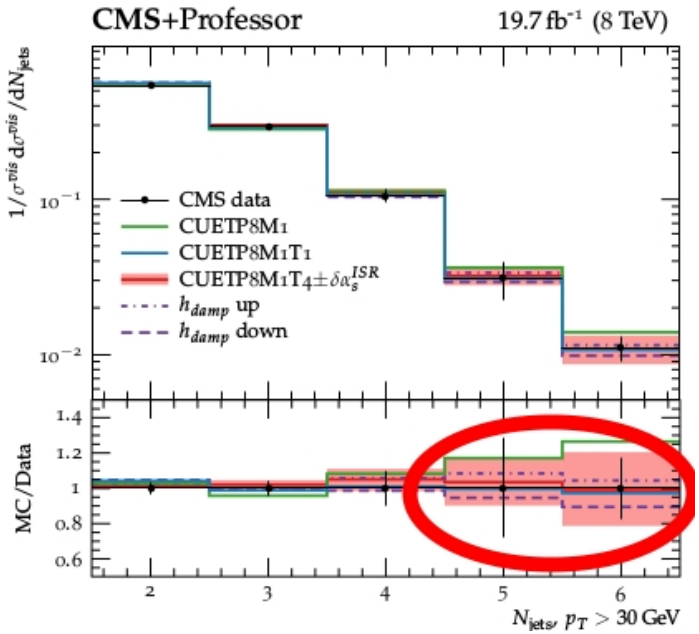
(EPJC 76 (2016) 155)

Extrapolating results to RunII LHC Data

CUETP8M1 performance with RunII data

Good performance → confirmation of the understanding of the energy dependence cut off of the partonic cross section
Not optimal performance → inaccuracy of energy extrapolation included in the tune, need for a better PDF sets, etc ...

The tune describe quite well the MB and UE, as well as variables measured in the forward region and in the jet sectors....
BUT the performance is not optimal!



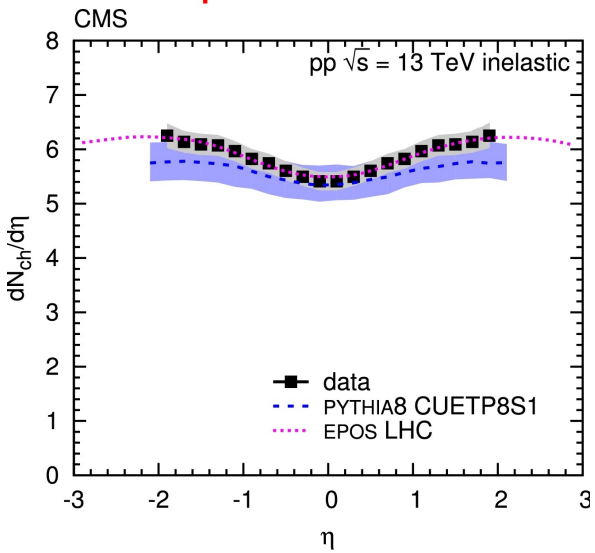
Jet multiplicity in top events was overestimated

This effect present in both 8TeV and 13TeV data

TOP-16-021

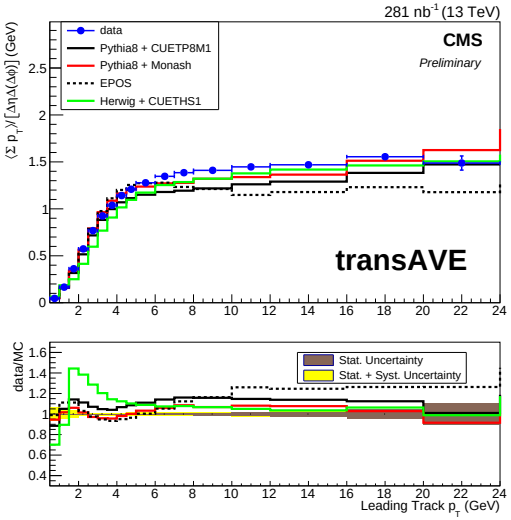
CUETP8M1 performance with RunII data (II)

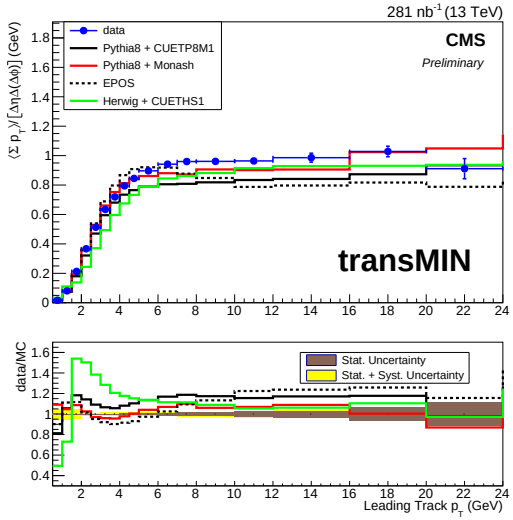
None of the tunes reproduce the data perfectly!



$\sqrt{s} = 13$ **TeV**

TOP plot:
$dN/d\eta$
PLB 751 (2015) 143
BOTTOM plots:
N_{ch} vs p_T^{lead}
CMS-FSQ-15-007





Need for new Tune!!!

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

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

Re-Tuning efforts to describe RunII LHC

based on $\sqrt{s} = 8$ TeV Data

CUETP8M2T4 Tune

The following parameters are tuned to the jet multiplicity measured in dilepton events at 8 TeV:

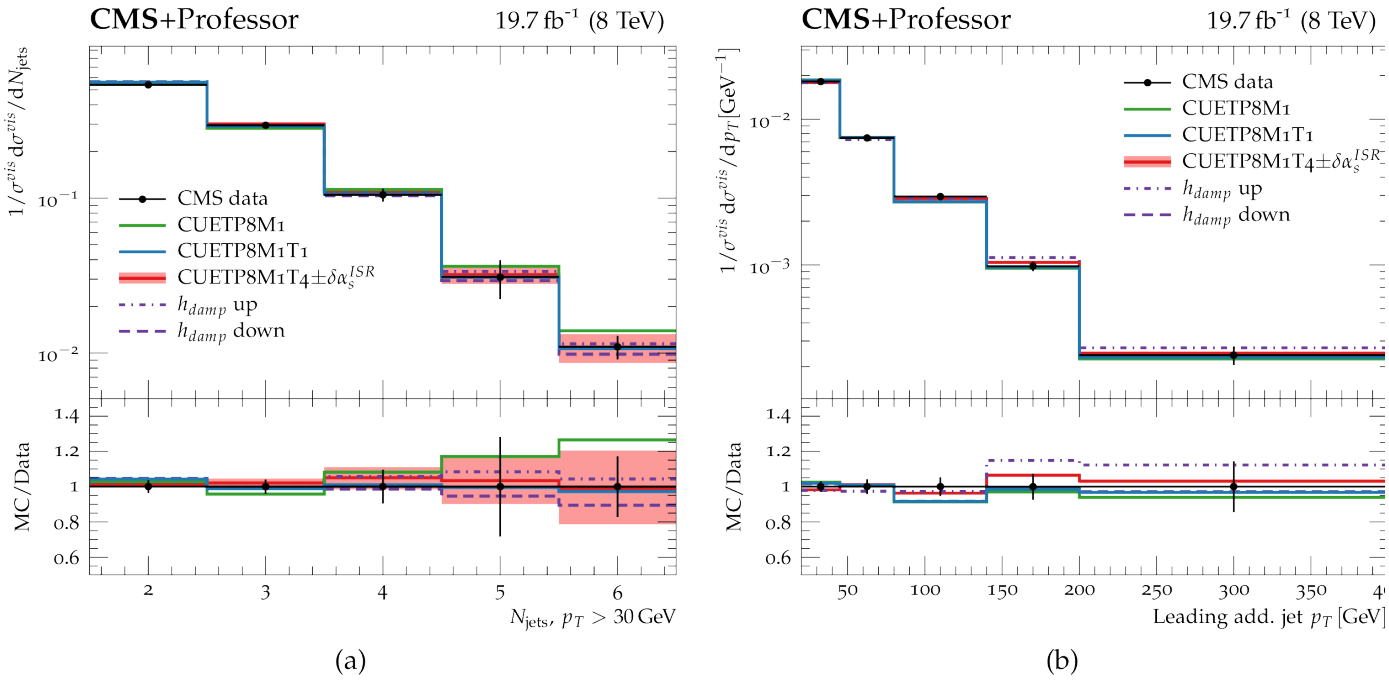
- POWHEG: h_{damp}, controls ME/PS matching and effectively regulates the high-pt radiation by damping real emissions generated by POWHEG
- Pythia8 SpeceShower:alphaSvalue (α_S^{ISR}), value of the strong coupling at m_Z used to initial-state shower.

STEP 1 POWHEG+Pythia8 in top events (8 TeV Data):
Using jet multiplicity and p_t of the additional jet distributions, parameters are tuned: α_S **is tuned to lower values (**0.1108**)**
UE parameters are fixed using values from CUETP8M1

CUETP8M1T4 (intermediate tune)

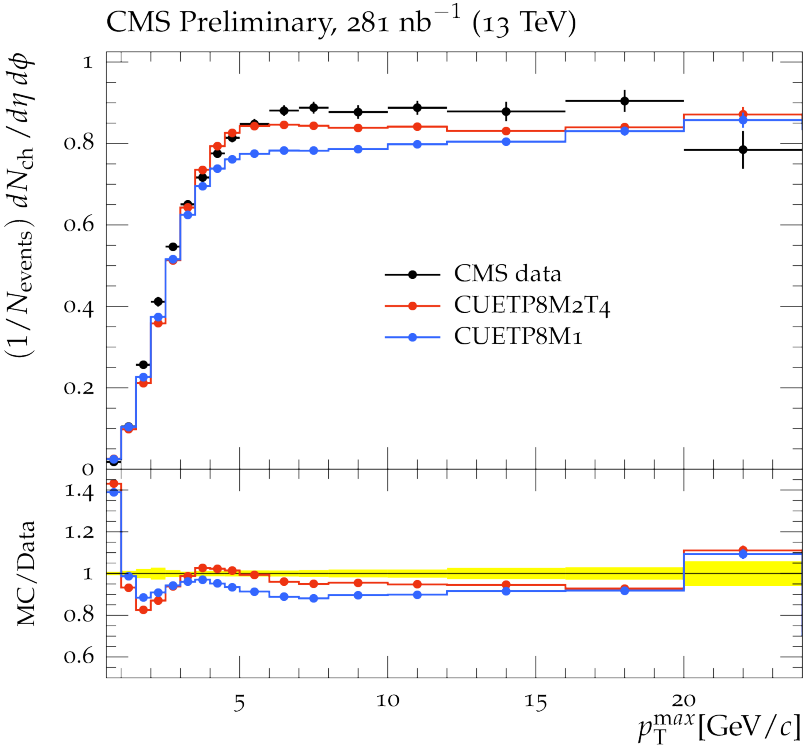
STEP 2 Pythia8 in UE/MB using 13 TeV Data:
Once the α_S (ISR) is extracted (fixed to $\alpha_S = 0.1108$), a new UE/MB tune is derived.
Parameter of energy dependence fixed to the value in CUETP8M1 (no energy dependence).
CUETP8M2T4.

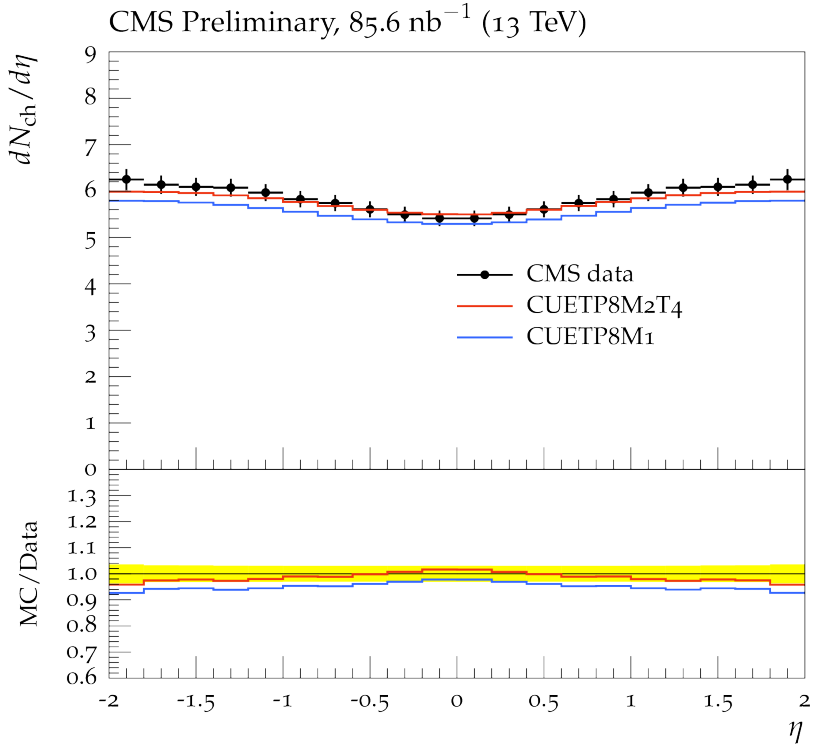
Intermediate tune: CUETP8M1T4 TOP-16-021



Improves the description of $t\bar{t}$ kinematics and overall description of observable at $\sqrt{s} = 8$ TeV & $\sqrt{s} = 13$ TeV. (arXiv:1803.0399)

Charge Particle Multiplicity in the MIN region and $dN/d\eta$ at 13TeV





the new tune describes better the plateau region

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/TOP-16-021/index.html#AddFig

But: Single-Diffractive enhance observable and inelastic cross sections not well described

Need for new tune!

Colour Reconnection tunes efforts

New CR tunes

New tunes are performed with two different CR models:

QCD inspired *(HEP08 (2015) 003)*

Gluon Move *arXiv:1506.09085*

Tuning Strategy

Baseline: CUETP8M2T4 (top specific tune)

Tuning in addition some color reconnection parameters:

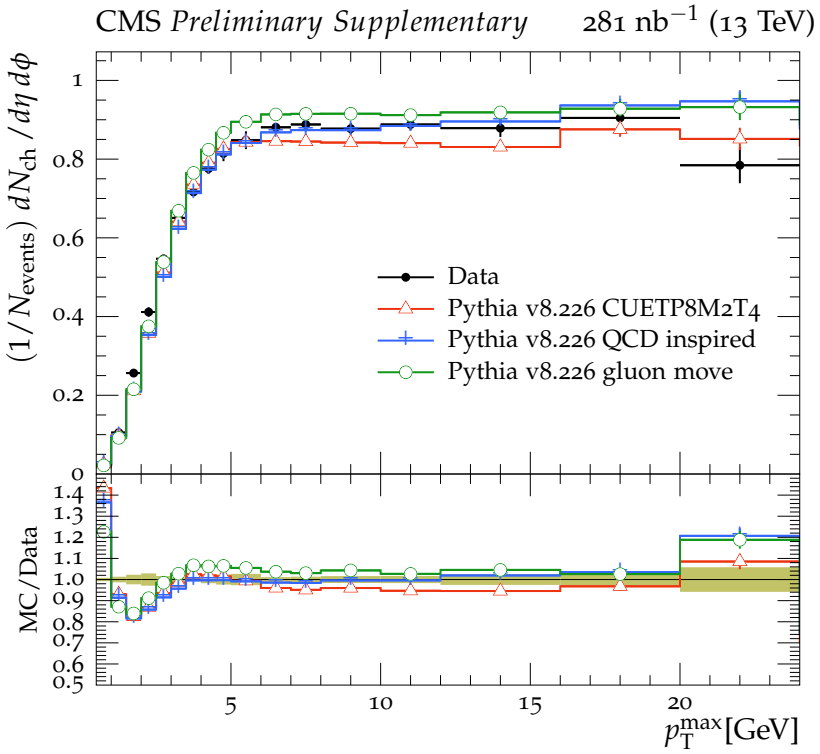
- QCD-inspired model: junctionCorrection, timeDilationPar,m0
- Gluon-move model: m2Lambda

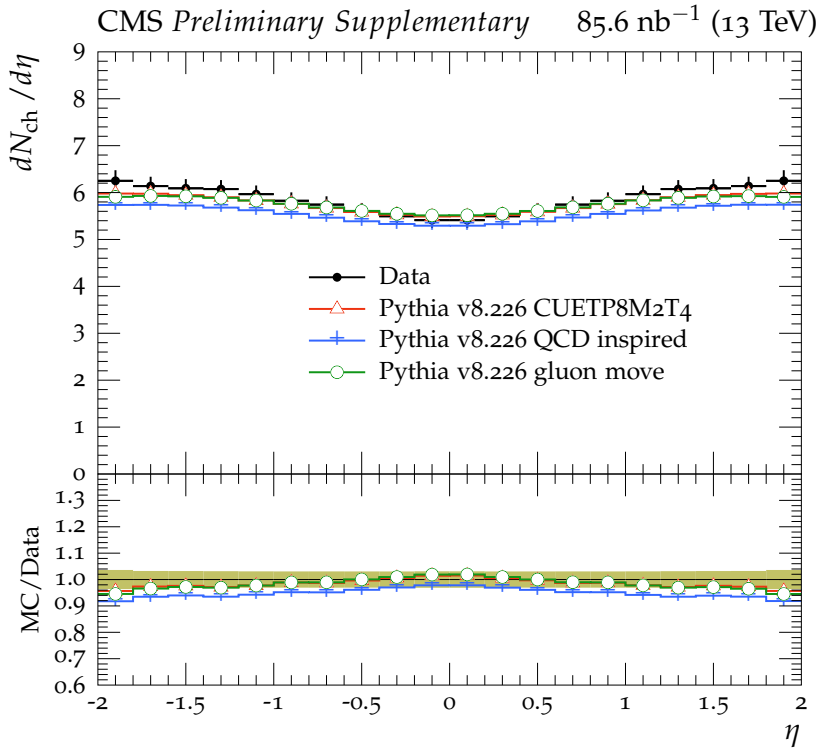
UE/MB observable used at 13 TeV Data.

Very important in model dependence systematic uncertainties in the estimation of the top mass!!!

TOP-17-007

Charge particle multiplicity and pseudorapidity performance for the CR tunes.





Remarks: Very difficult to describe the rising part of the spectrum at 13 TeV

Most recent efforts for Tuning based in $13\,TeV$ Data

The five CP Tunes (CmsPythia Tune)

Strategy

Discussions on the order of PDF sets in parton shower and the matching of the PDF in the PS and in the ME brings the idea of new set of tunes.

1. tuning of ISRα_S values and *hdamp* for POWHEG+PYTHIA8 simulation based on top events. The UE parameters were fixed to CUETP8M1 tune
2. Full UE retuning starting from the new values of ISRα_S and switching to latest NNPDF3.1 set

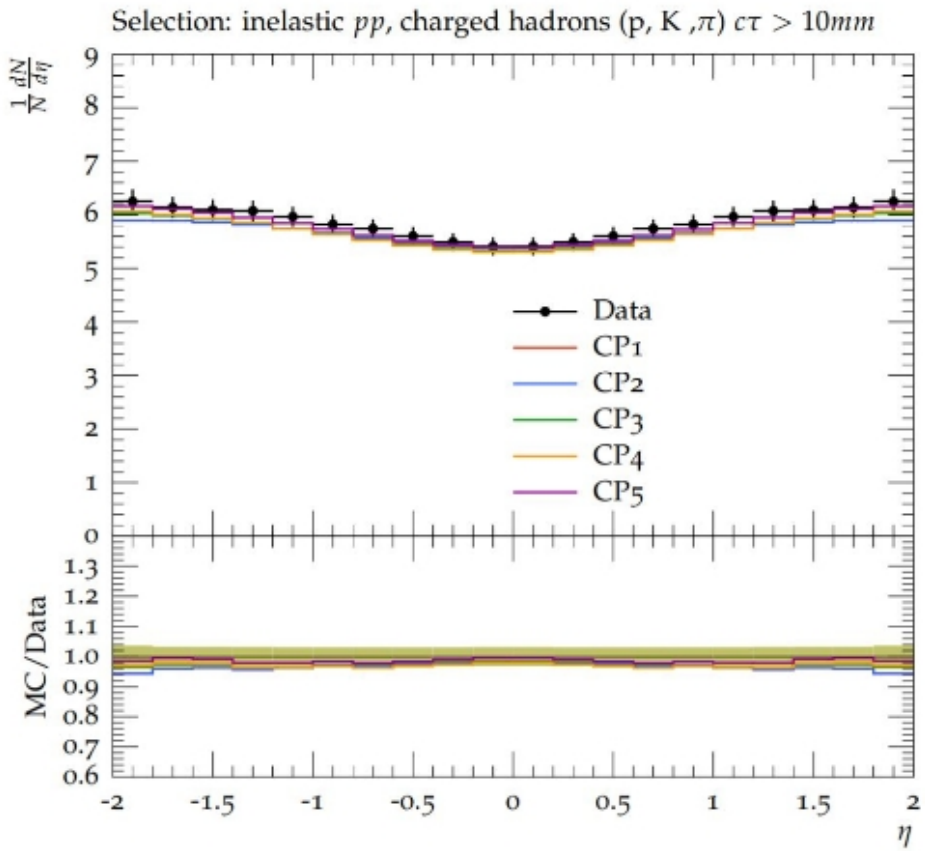
   Main idea: test the effect of using different PDF orders of NNPDF sets in Pythia8 among other parameters variations

CmsPythia tunes at 13 TeV

Tune	PDF set & running order, $\alpha_S(M_Z)$	ISR/FSR α_S
CP0	NNPDF30 at LO/LO, 0.13	0.1108/0.1365
CP1	NNPDF31 at LO//LO, 0.1365	0.13
CP2	NNPDF31 at LO/LO, 0.13	0.13
CP3	NNPDF31 at NLO/NLO, 0.118	0.118
CP4	NNPDF31 at NNLO/NLO, 0.118	0.118
CP4	NNPDF31 at NNLO/NLO, 0.118	0.118

Minimum Bias events

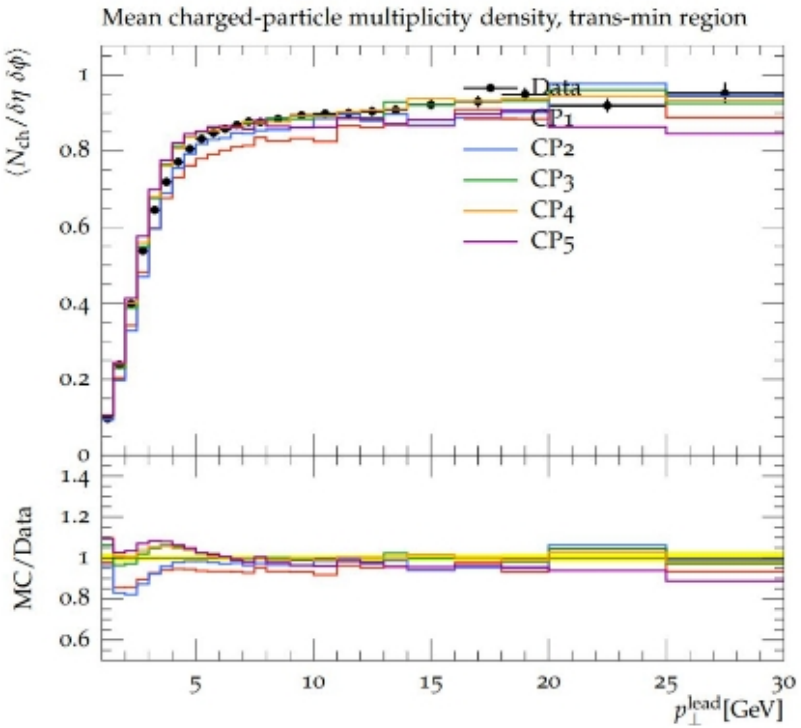
Rivet: CMS_2015_I1384119, 0 Tesla, $\sqrt{s} = 13$ TeV, $|\eta| < 2$

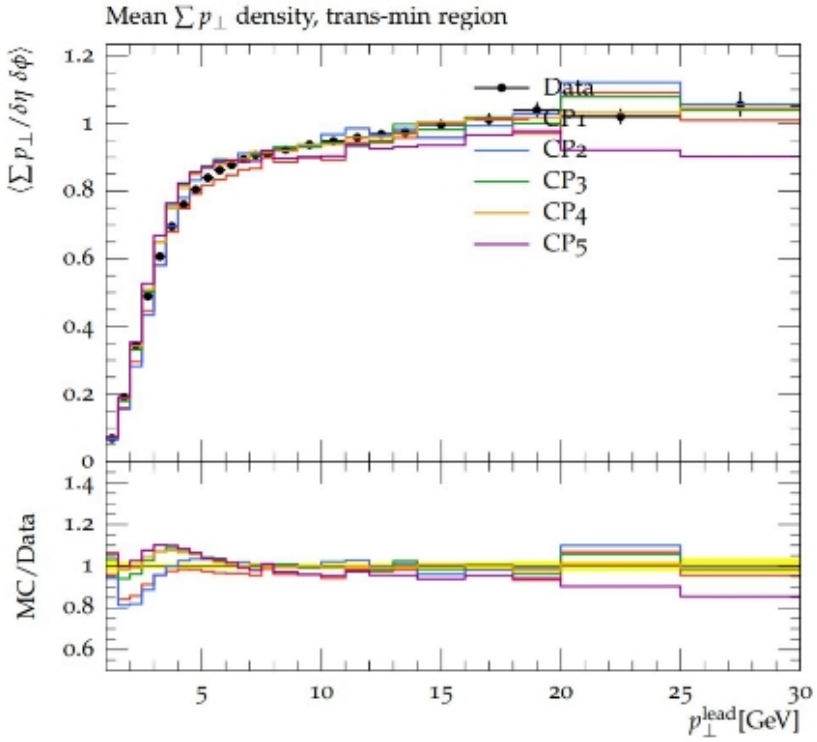


Underlying event

Rivet: ATLAS_2017_I1509919, $\sqrt{s} = 13$ TeV, $|\eta| < 2.5$, $p_T > 0.5$GeVb with at least one of the charged particle with $p_T > 1$GeV

Distributions most sensitive to MPI, biggest problems not using a LO PDF.





The data are described at the same level by tunes with LO, NLO, and NNLO PDF NNPDF3.1 sets.

Summary and conclusion

Monte Carlo models contain free phenomenological parameters that need to be tuned to describe properly new data.

- New Tunes in CMS used in LHC data Run II were presented.
- New Tunes for Pythia8 are ready and show good performance at 13 TeV data (also at 8 TeV).
- Effects on different choices of PDF and α_S in UE simulation are investigated.

Thanks for your attention!!!!