UHH Group meeting

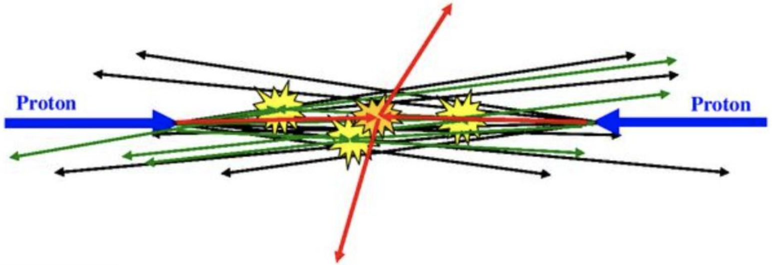
15th May 2019

# Underlying event tunes in CMS

*Paolo Gunnellini*

**OUTLINE:**

- What is the Underlying Event?
- Underlying Event tunes
- Tune choices in CMS

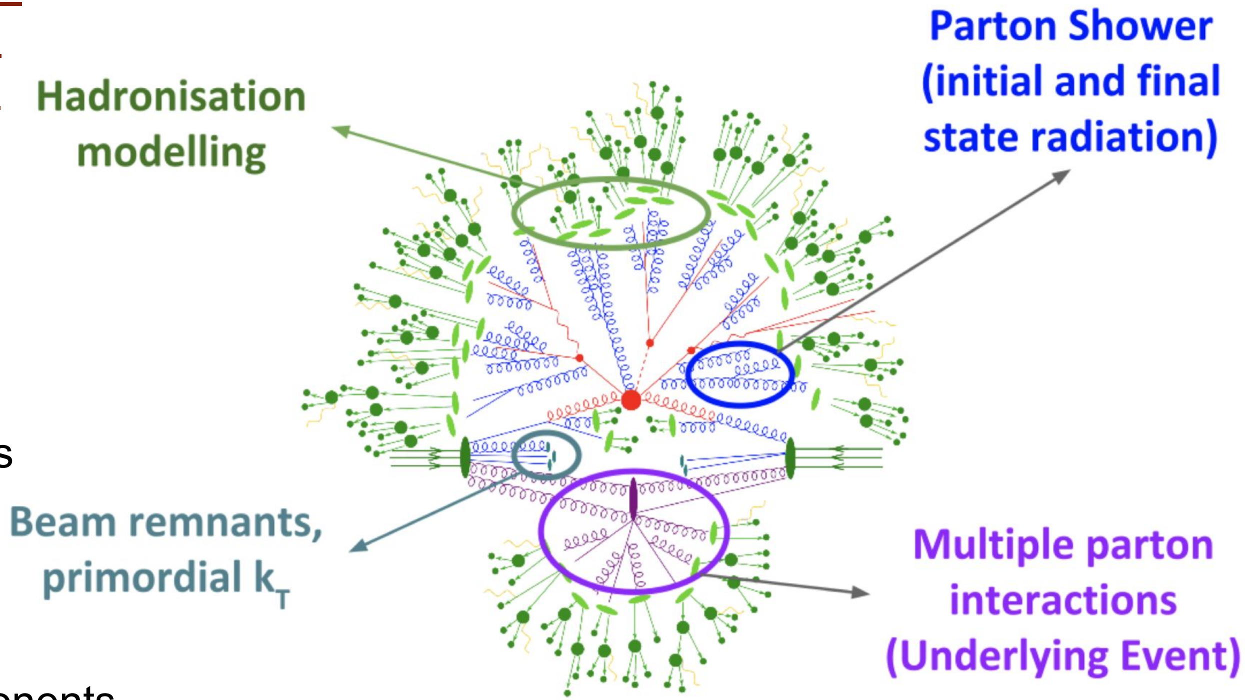


# Introduction: the underlying event

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

- Parton Shower
- Beam remnants
- Multiple Parton Interactions
- Hadronization

Current event generators use phenomenological models to simulate most of these components



# Example of phenomenological model

Partonic cross section diverges as a function of the exchanged transverse momentum

-> Regularization through a phenomenological energy-dependent parameter $p_{T0}$

$$\frac{d\hat{\sigma}}{dp_T^2} \propto \frac{\alpha_s^2(p_T^2)}{p_T^4} \quad \Rightarrow \quad \frac{d\hat{\sigma}}{dp_T^2} \propto \frac{\alpha_s^2\,(p_T^2 + p_{T0}^2)}{(p_T^2 + p_{T0}^2)^2}$$

Energy extrapolation is set according to a power-law function:

$$p_T^0 = p_T^{0,ref} \cdot \left(\frac{E}{E_0}\right)^{\epsilon}$$

E = energy
$E_0$ = reference energy
ε = energy exponent (free parameter)
pT0ref = reference pT0 (free parameter)

**Parameters are not theoretically defined**

-> They can be constrained by the available data

-> TUNE: set of adjusted parameters whose predictions describe (some of) the available measurements

$p_T^{0ref}$ values around
1.5-2.5 GeV at ref. energy of 7 TeV
ε values around 0.2

# What can we tune?

- 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?**

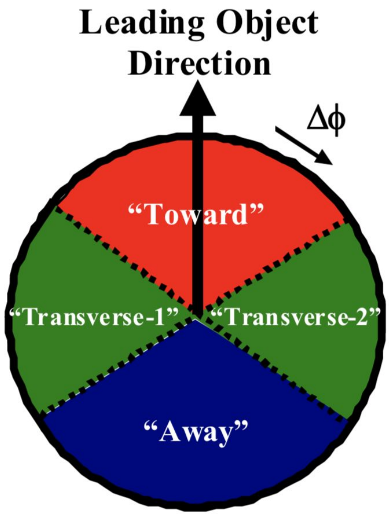
- Choice of parameter ranges and sensitive observables
- Predictions for different parameter choices and interpolation of the MC response
- Data-MC difference and minimisation over parameter space

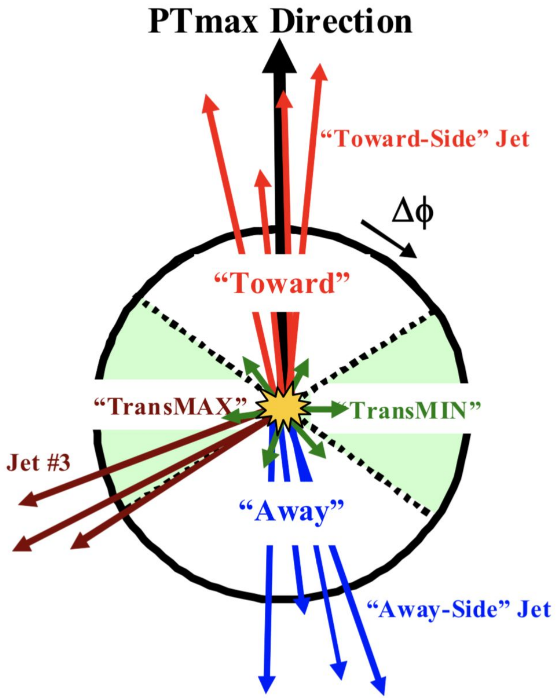
# How can we study the UE activity?

## How to measure the Underlying event contribution?

Definition of a leading object and of its direction ($\phi^{max}$)

Identification of four regions:
- TOWARD: $|\Delta\phi| < 60$
- TRANSVERSE: $60 < |\Delta\phi| < 120$
- AWAY: $|\Delta\phi| > 120$



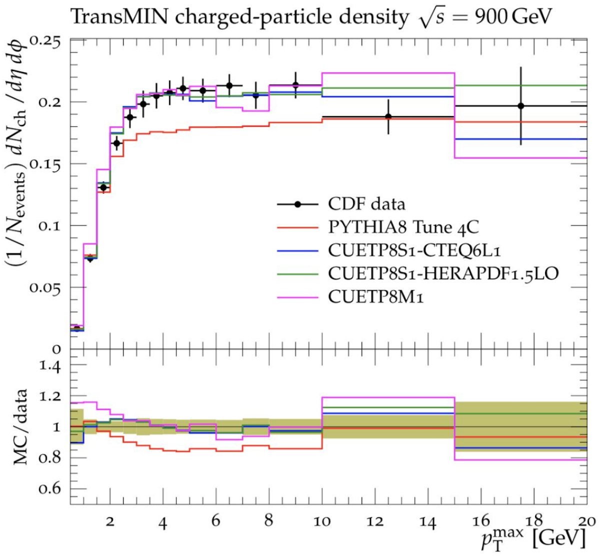

## Observables:
- Charged particle multiplicities
- Average transverse momentum sum (of charged particles)

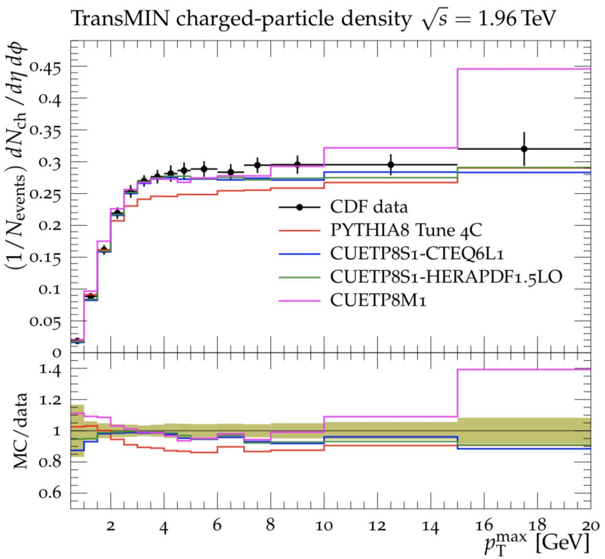
TransMAX and TransMIN denote the transverse regions with the largest and the smallest activity, defined event-by-event

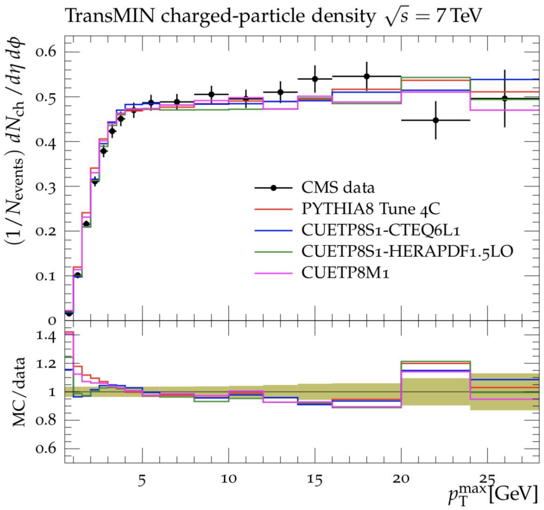
# How well do we understand the UE?

**CMS pre-13 TeV tuning effort: fitting UE observables at different energies for trying to predict UE activity at 13 TeV**

- CUETP8M1: based on Monash tune but focusing on energy dependence of transMIN and MAX observables



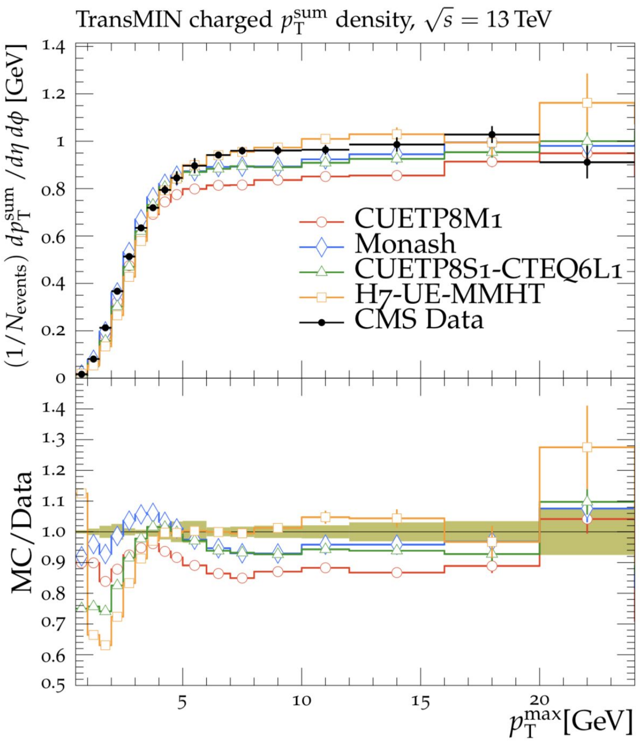




**CMS-GEN-14-001**

Tune 4C: old tune from Pythia8 authors

CUETP8M1: new CMS tune which was used in production at the beginning of RunII

# How well do we understand the UE?




CMS pre-13 TeV tunes do not optimally describe the 13 TeV data:

- Monash tune from Pythia8 authors
- CUETP8M1 (CMS Pythia8 tune)
- Herwig7 tune (UE-MMHT)
- CUETP8S1 (CMS Pythia8 tune based on CTEQ6L1)

None of the tunes (especially the previous CMS tune) is able to give a good description of the UE data.

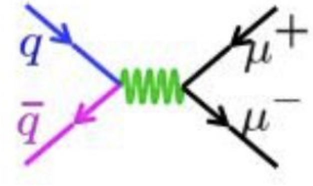
**CMS decided to perform a re-tune of the UE parameters to improve the description of the plateau region of the UE data**

# Tuning strategy

Particular attention is given to improve the performance of “matched configurations”:

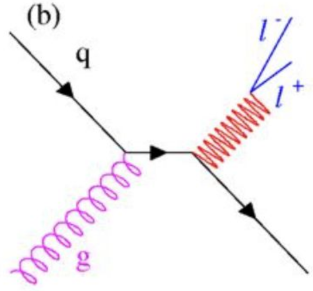
- Higher-order matrix element (POWHEG, MADGRAPH) + UE simulation from P8

Example: Z boson production decaying into two leptons




Leading order: tree-level (the most simple diagram):

- 2 initial partons, 2 leptons in the final state

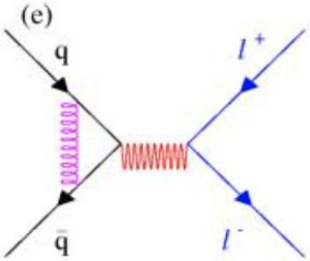



Multileg diagrams: additional real emissions are produced in the calculation

- 2 initial partons, 2 leptons in the final state + ≥ 1 final partons

Next-to-leading order (NLO): virtual corrections (loops) calculated in the matrix element

- 2 initial partons, 2 leptons in the final state (+ virtual corr. in init. and fin. state)




PYTHIA: Generation of leading order diagrams + parton shower + underlying event

Madgraph/aMC@NLO: Generation of multileg and/or NLO diagrams (PS+UE from PY.)

POWHEG: Generation of NLO diagrams (PS and UE from PYTHIA)

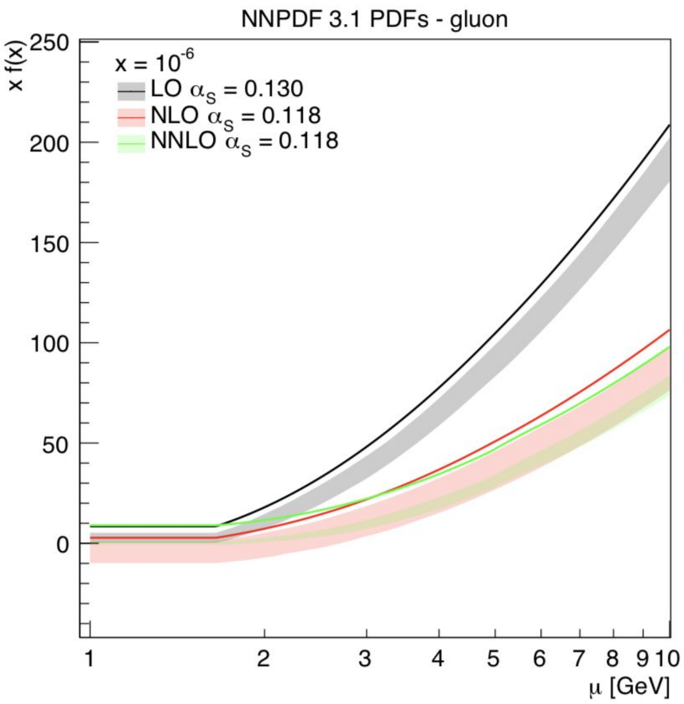
# Tuning strategy

Particular attention is given to improve the performance of "matched configurations":

- Higher-order matrix element (POWHEG, MADGRAPH) + UE simulation from P8

Phenomenological studies show that:

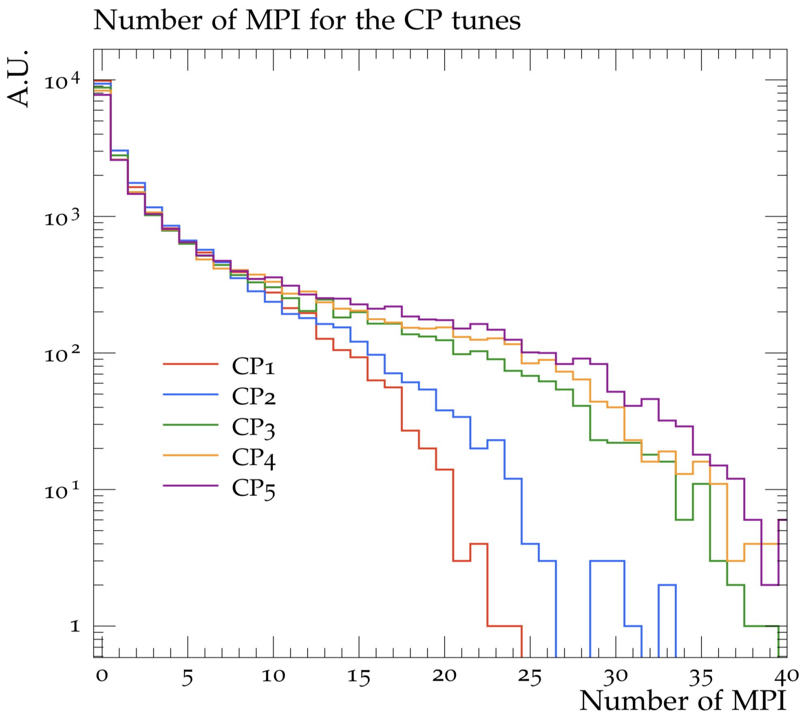
- Higher-order matrix element simulation works best when using a PDF of the same order
- Higher-order matrix element simulation works best when the parton shower attached to it uses the same PDF order and same value of the strong coupling




**TUNES USING DIFFERENT ORDERS OF NNPDF3.1 PDFs:**

- CP1-2 (LO PDF, strong coupling = 0.13)
- CP3 (NLO PDF, strong coupling = 0.118)
- CP4-CP5 (NNLO PDF, strong coupling = 0.118)

# Different tunes for different PDF orders




Differences in the gluon distribution for the different PDF sets need to be compensated by a larger amount of multiple parton interactions (MPI)

$$\frac{d\hat{\sigma}}{dp_T^2} \propto \frac{\alpha_s^2\left(p_T^2 + p_{T0}^2\right)}{\left(p_T^2 + p_{T0}^2\right)^2}$$

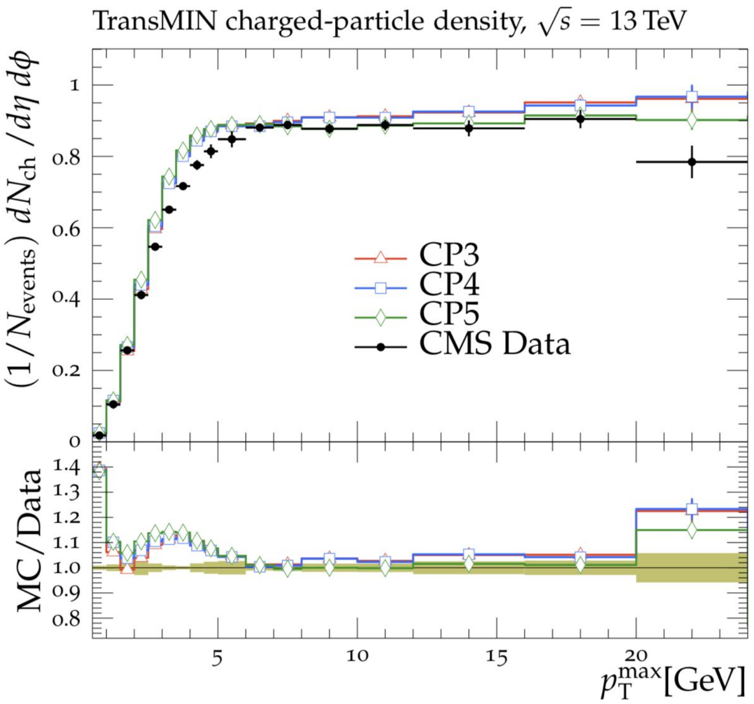
NNLO PDF -> lower gluon PDF -> More MPI -> Lower pT0Ref
LO PDF -> lower gluon PDF -> Less MPI -> Higher pT0Ref

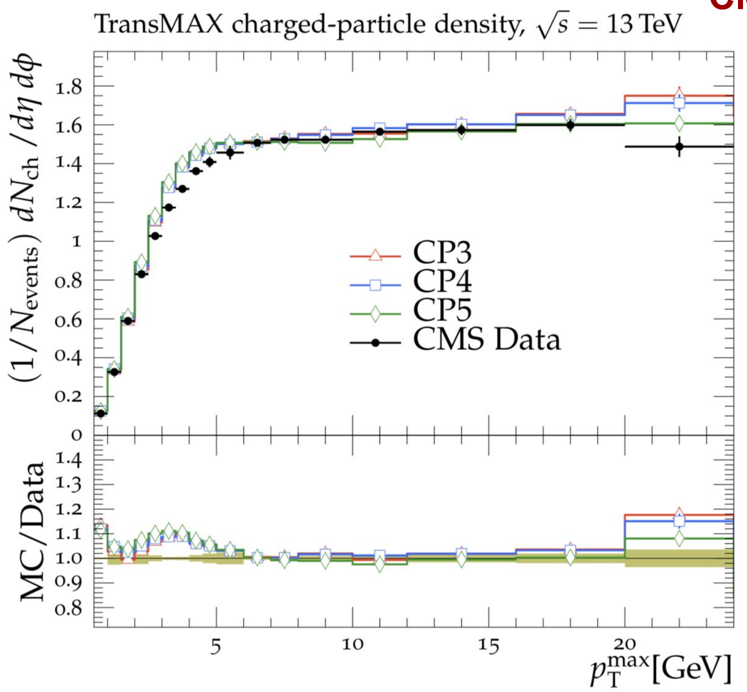
| Tune | pT0Ref paramater |
|---|---|
| CP2 (LO) | 2.3 (GeV) |
| CP3 (NLO) | 1.5 (GeV) |
| CP5 (NNLO) | 1.4 (GeV) |

# How well do we understand the UE?

Tunes based on UE data at 1.96, 7 and 13 TeV -> description of UE data improves (especially at 13 TeV)
-> Tunes using higher-order PDF sets (NLO, NNLO) have the same performance as LO PDF sets

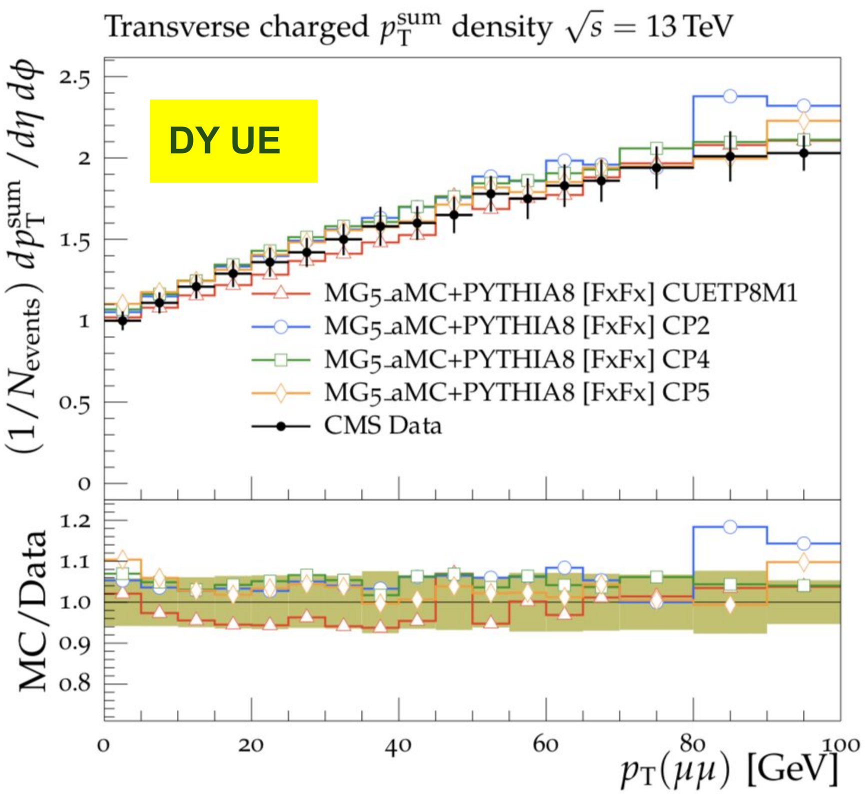
**CMS-GEN-17-001**

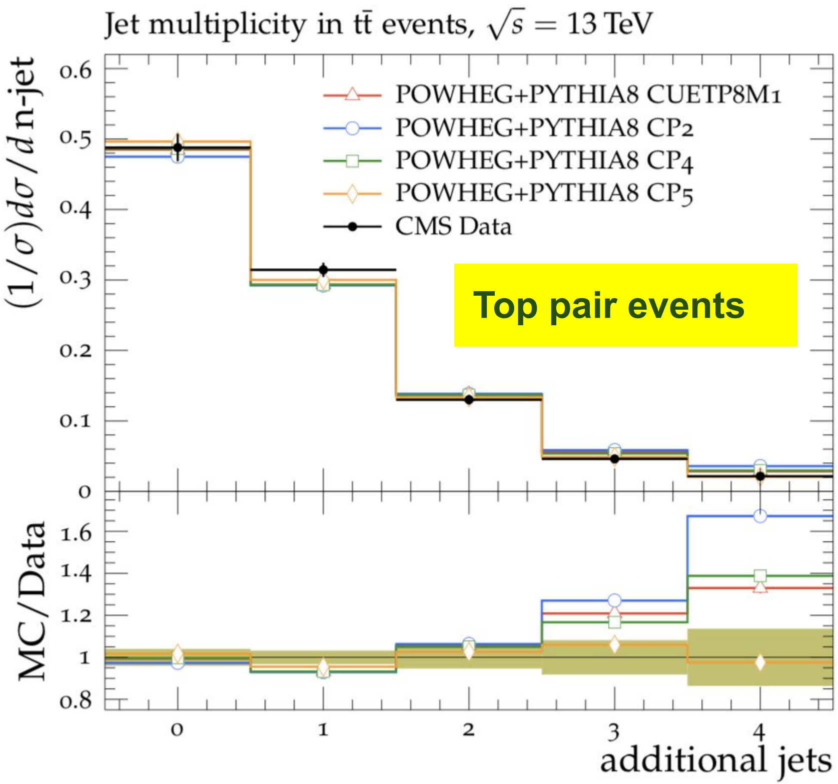


# How well do we understand other observ.?

**CMS-GEN-17-001**



# Summary

- Tuning Monte Carlo event generators is important to constrain the free parameters of the implemented phenomenological models

- We have a lot of UE data measured at different energies available for tuning
  - They are measured with high precision
  - Current simulation is challenged to describe all of them

- Many attempts to describe them with different generators, PDF sets, settings

- CMS uses a tune [CP5] based on NNLO PDF set:
  - It describes UE observables as well as tunes using LO PDF sets
  - It improves the description of data when UE simulation is matched to higher-order matrix elements

# Why do we actually tune the parameters?

## 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

**Danger is overtuning!!**