UNIVERSITÀ
DEGLI STUDI DI TRIESTE

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MONTE CARLO TUNING IN CMS

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WHY MONTE CARLO TUNING?

Monte Carlo (MC) simulation codes describe hadron-hadron collisions with models based on several components

- **Hard scattering**: particles from hadronization of partons whose kinematics are predicted using perturbative matrix elements (MEs) + initial-state radiation (ISR) and final-state radiation (FSR)
- **Underlying events**: beam-beam remnants (BBR) and particles arising from soft multiple-parton interactions (MPI)

Standard MC event generators, such as PYTHIA8, HERWIG, and SHERPA have adjustable parameters to control the behavior of their event modeling.

A set of these parameters, which has been adjusted to better fit some aspects of the data, is referred to as a tune

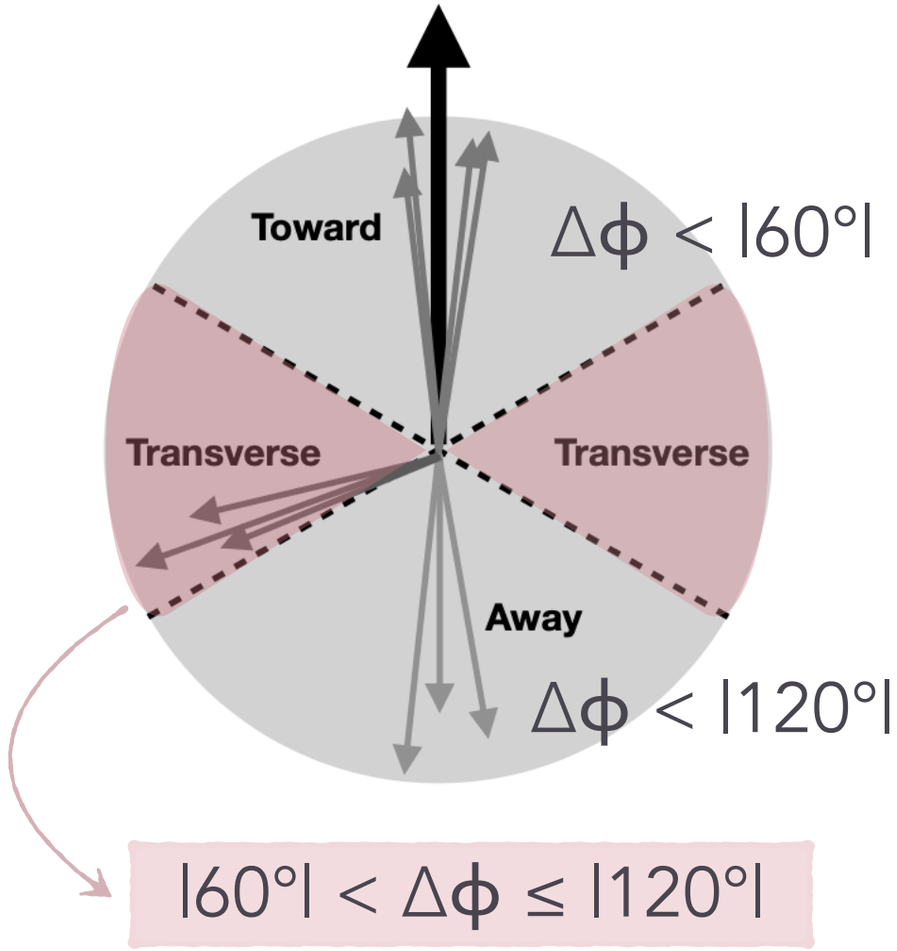
OBSERVABLES SENSITIVE TO UE

- The new CMS PYTHIA8 tunes are extracted by fitting observables sensitive to UE
  - Charged-particle multiplicity
  - Charged-particle scalar-p_T sum (p_T^{sum}) densities

To define UE-sensitive regions in the η-ϕ space

$\Delta\phi = \phi - \phi_{max}$

Tunes extraction in transMIN and transMAX regions, defined as the transverse region having the maximum (minimum) of either the number of charged particles, or scalar p_T^{sum}



NEW CMS PYTHIA8 (CP) TUNES AT 13 TEV

New tunes distinguished according to the order of the parton distribution functions (PDF) set used

- **CP1**: NNPDF3.1 PDF set at LO, with α_s values used for simulation of MPI, hard scattering, FSR, and ISR equal to, respectively, 0.13, 0.13, 0.1365, and 0.1365
- **CP2**: same as CP1 but with α_s values all equal to 0.13
- **CP3**: NNPDF3.1 PDF set at NLO, with α_s all equal to 0.118
- **CP4**: NNPDF3.1 PDF set at NNLO, same values of α_s as CP3
- **CP5**: same settings as CP4, but with ISR emissions ordered according to rapidity

PARAMETERS CONSTRAINED

Only five parameters are constrained for the new CMS tunes

Parameters related to the hadronization and BBR are kept fixed to the values of the Monash 2013 tune

Parameter description	Range considered
MPI threshold [GeV], `pT0Ref`, at $\sqrt{s} = \sqrt{s_0}$	1.0–3.0
Exponent of $\sqrt{s}$ dependence, ϵ	0.0–0.3
Matter fraction contained in the core	0.1–0.95
Radius of the core	0.1–0.8
Range of color reconnection probability	1.0–9.0

- Threshold parameter for the regularization of the divergence of the cross section at low p_T ($\sqrt{s_0}$ = 7 TeV)
- Smaller values of `pT0Ref` result in larger MPI contributions because of a higher MPI cross section
- The energy dependence is parameterized using a power law function with a reference energy parameter s_0 and an exponent ε

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- The overlap distribution between the two colliding protons is modeled according to a double-Gaussian functional form with two parameters. An inner, denser part, the so-called core, and an outer less dense part are identified.

- The matter fraction refers to the fraction of quark and gluon content enclosed in the core

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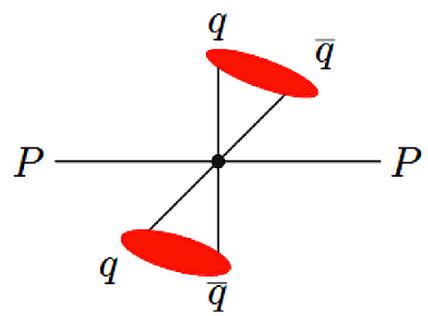


- Determines the amount of simulated color reconnection (CR)

- A small (large) value of the CR parameter tends to increase (reduce) the final particle multiplicities

TUNES EXTRACTION

- Tunes are determined by generating sets of predictions using the RIVET and the PROFESSOR frameworks with around 150 different choices of the five parameter values used in the event simulation.
- The predictions form a grid in the five-dimensional parameter space which is fitted using a third-order polynomial function.

Functions that parametrize the dependence of the predictions in bin i on the tuning parameters

Value of the measured observable in bin i

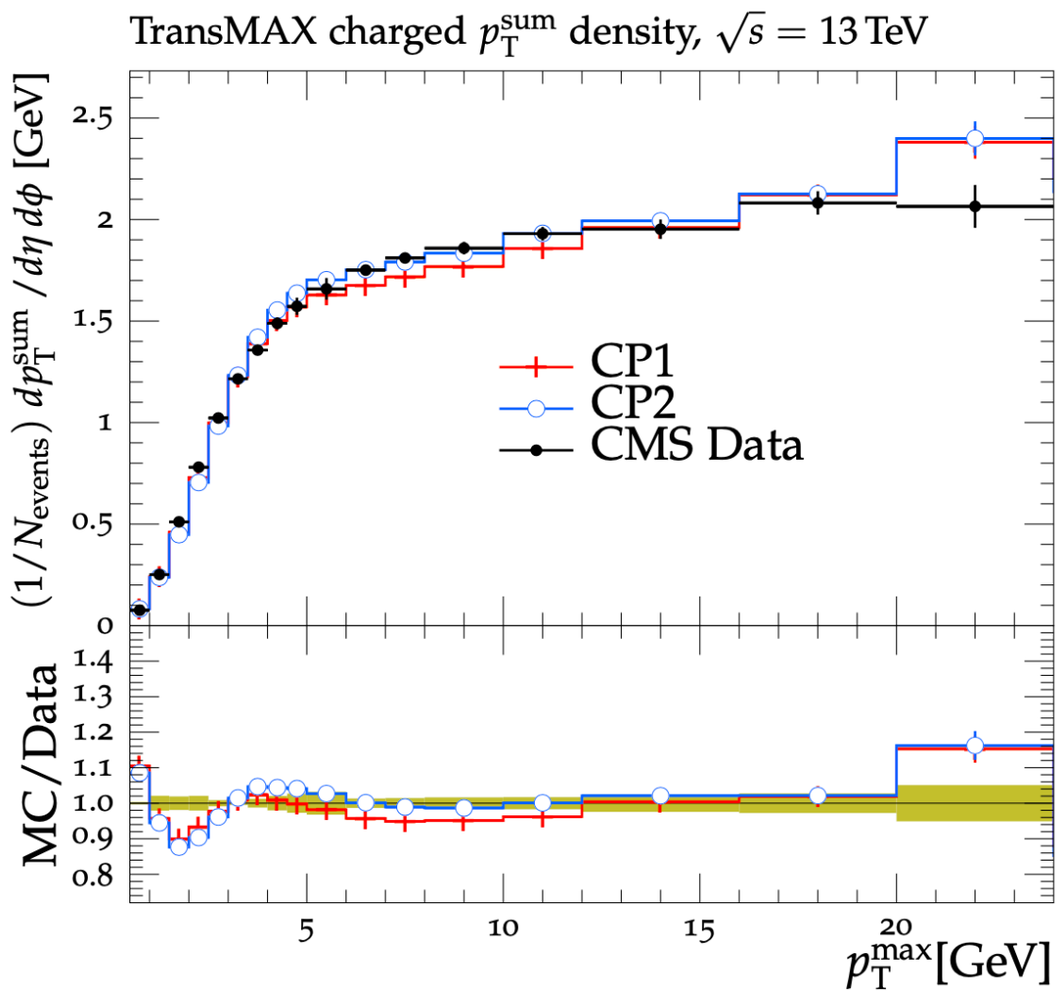
$$\chi^2(p) = \sum_{O_j} \sum_{i} \frac{(f_{i,O_j}(p) - R_{i,O_j})^2}{\Delta^2_{i,O_j}}$$

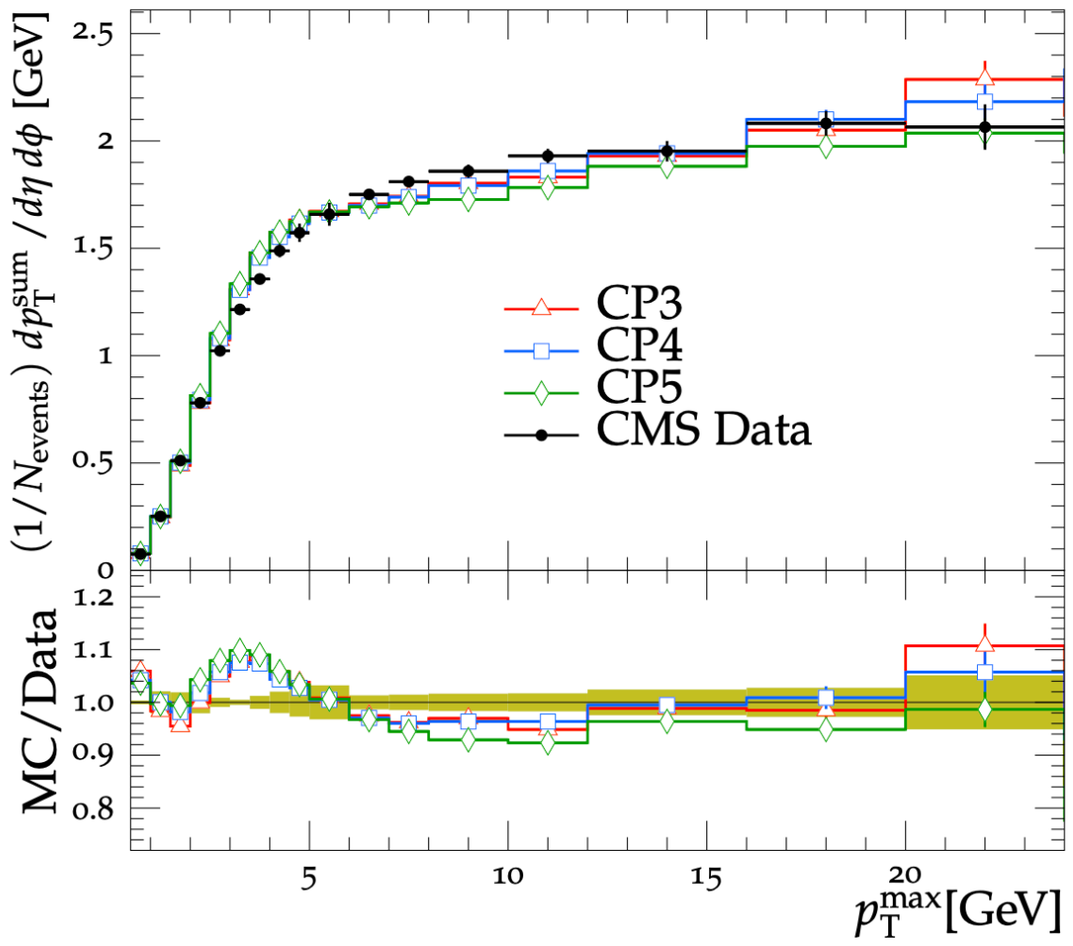
Observables

Total experimental uncertainty of R_i

TUNES COMPARISONS

TransMAX charged p_T^{sum} densities, as a function of the transverse momentum of the leading charged particle, p_T^{max}



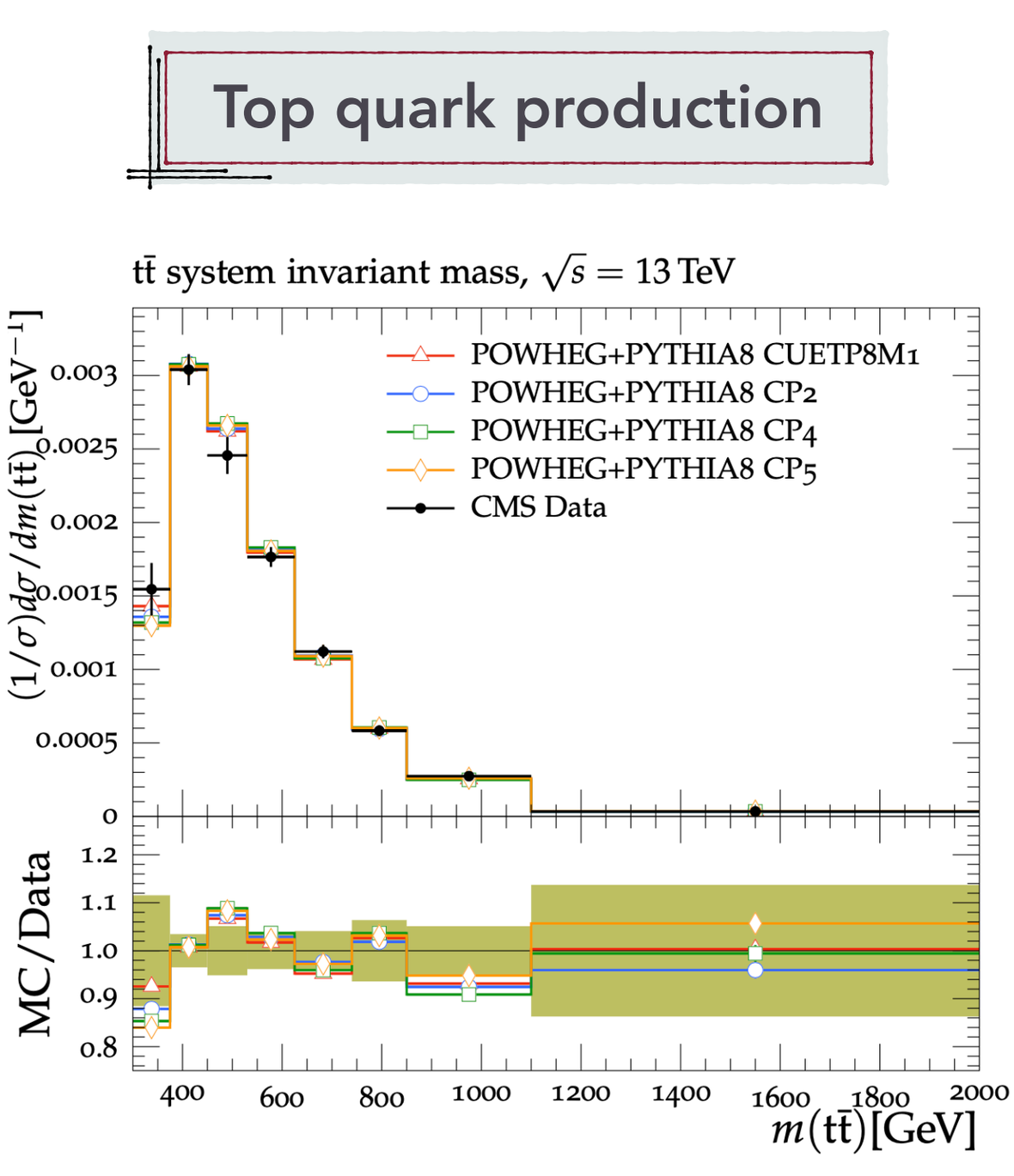


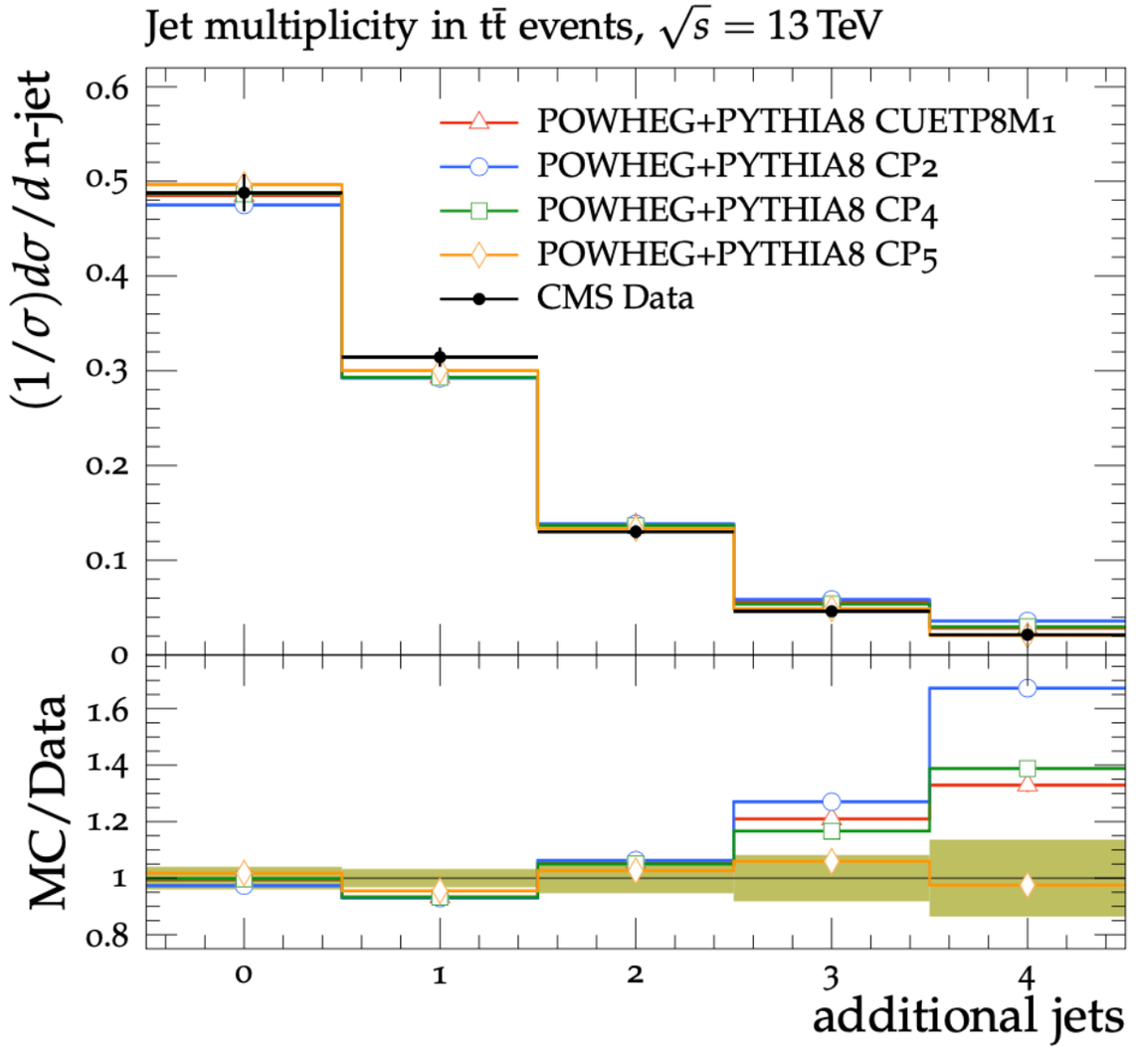
- Predictions from LO tunes are slightly better than higher-order tunes in describing the energy dependence of the considered UE measurements
- In the region of small p_T^{max} values ($p_T^{max} < 3$GeV) predictions do not always reproduce the measurements and exhibit discrepancies up to 20% (contributions from diffractive processes)

TUNES VALIDATION

Comparisons of the predictions obtained with the new tunes to various experimental measurements performed by CMS have been performed

Top quark production



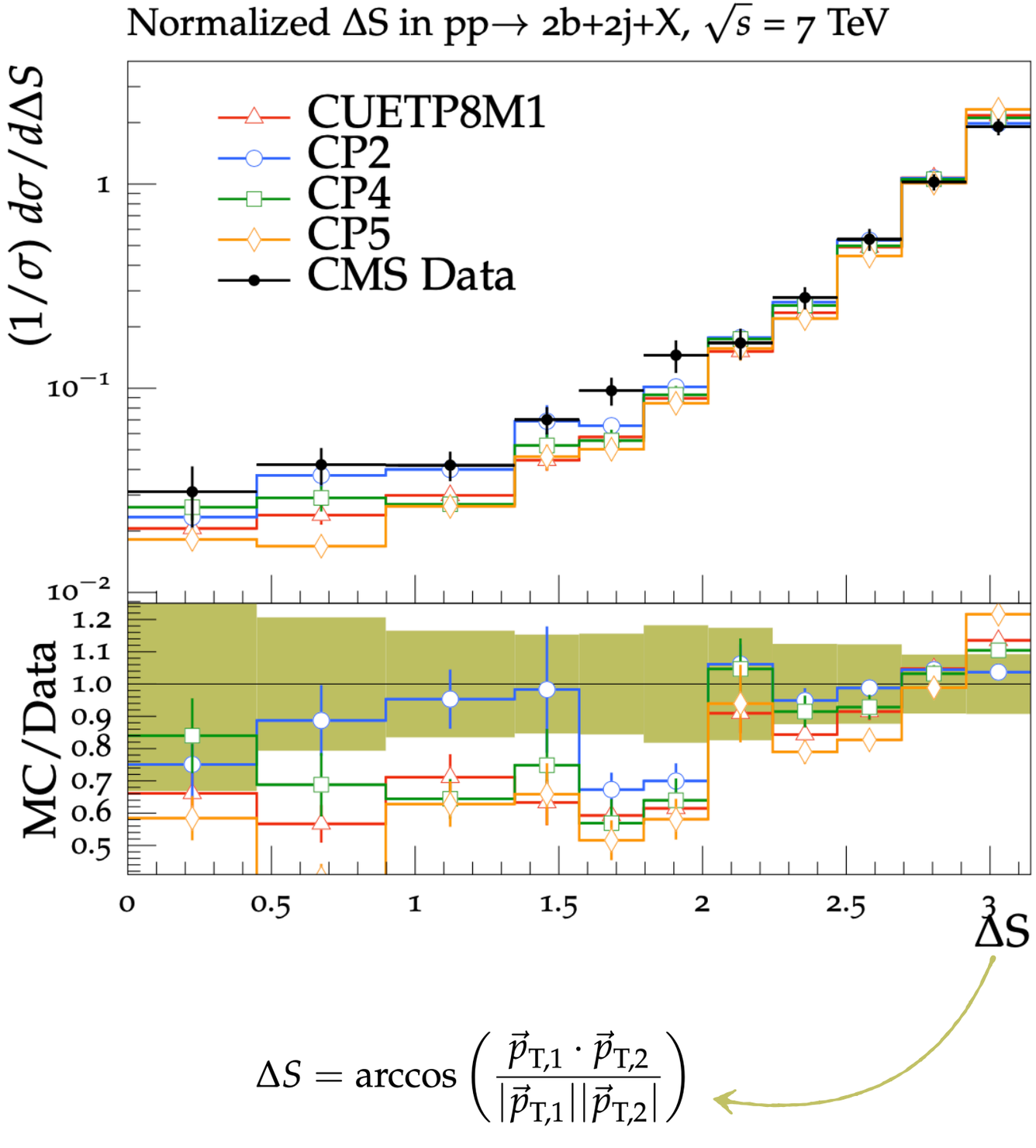


- Overestimation of data at high jet multiplicity
- Better agreement using CP5 tune

TUNES VALIDATION

Double parton scattering

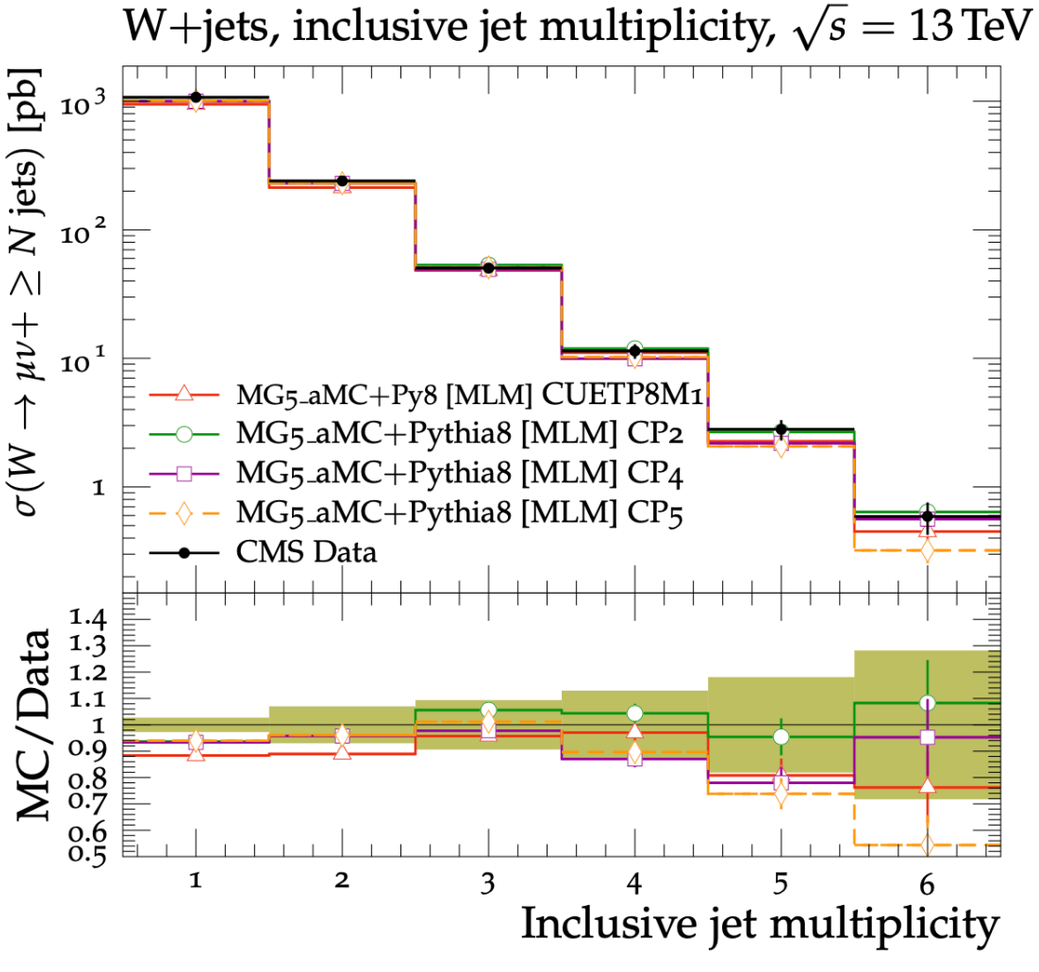
- Predictions from CP2 (LO PDF) describe the central values better than CP4 and CP5 (NNLO PDF set), or old tune CUETP8M1
- CP4 describe DPS observables better than CP5
- By removing the rapidity ordering for the PS emissions (CP4) simulation produces more radiation, decreasing correlation between jet pairs. This reduced correlation mimic a DPS event by producing low values of ΔS.

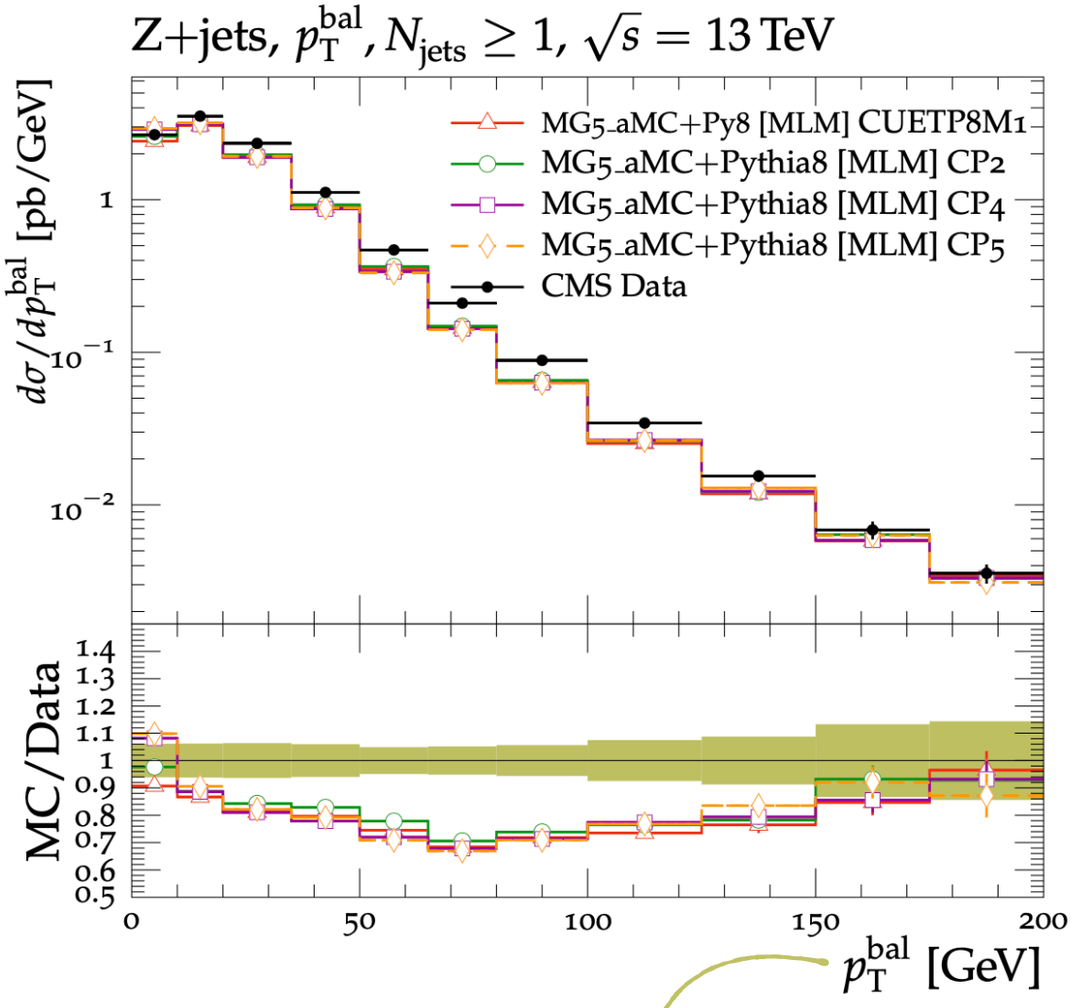


TUNES VALIDATION

W(+jets) and Z(+jets) production

- The k_T–MLM predictions of the jet multiplicity have little sensitivity to UE and PS tunes
- All the tunes provide a good description of this observable, with a slightly better agreement for the CP2





$$p_T^{\,bal} = |\vec{p}_T(Z) + \textstyle\sum_{jets} \vec{p}_T(j_i)|$$

- p_T balance is sensitive to PS and UE
- Differences between the tunes are significant below ≈20 GeV

SUMMARY AND CONCLUSIONS

- A new set of tunes for the underlying-event (UE) simulation in the PYTHIA8 generator has been obtained by fitting various measurements sensitive to soft and semihard multipartonic interactions
- A significant improvement in the description of UE measurements at 13 TeV is observed with respect to predictions from old tunes
- For the first time, predictions based on higher-order PDF sets are shown to give a reliable description of UE measurements, with similar level of agreement as predictions from tunes using LO PDF sets
- CP5 tune chosen for the official CMS MC Run2 production