CMS Underlying Event and Double Parton Scattering Tunes

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Manisha Lohan
(On behalf of CMS Collaboration)
Panjab University, Chandigarh (India)

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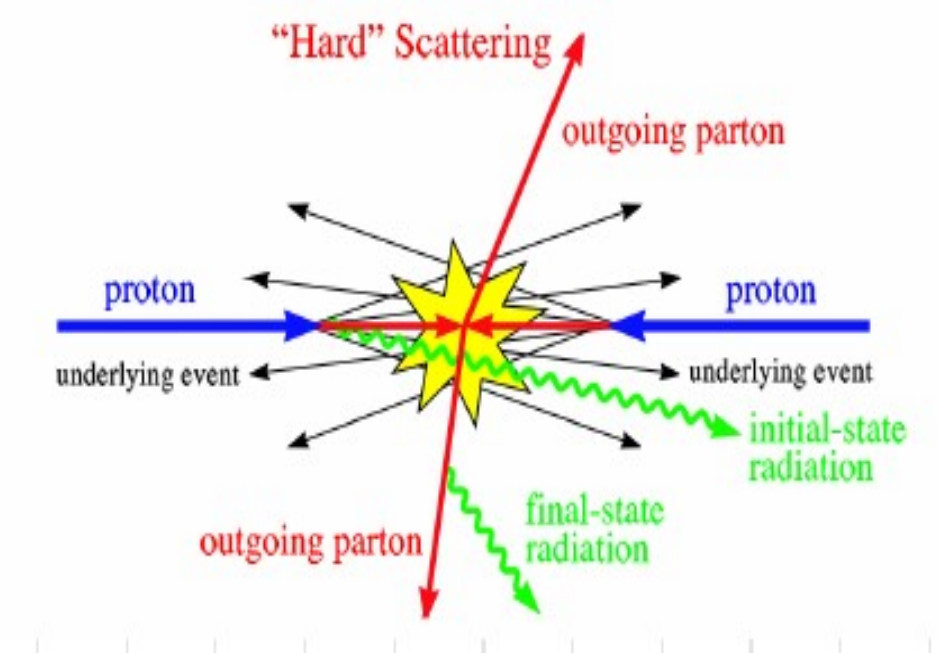
Underlying Event & Double Parton Scattering

Underlying Event (UE) : Anything that does not originate from hard scatter outgoing partons.



Components of UE :

- Initial State Radiation (ISR).
- Final State Radiation (FSR).
- Multiple Parton Interactions (MPI).
- Beam Beam Remnants (BBR).

Importance of UE :

- Better modeling of MC simulation.
- To probe hadron production.

Double Parton Scattering (DPS) : Two hard collisions per pp interaction.

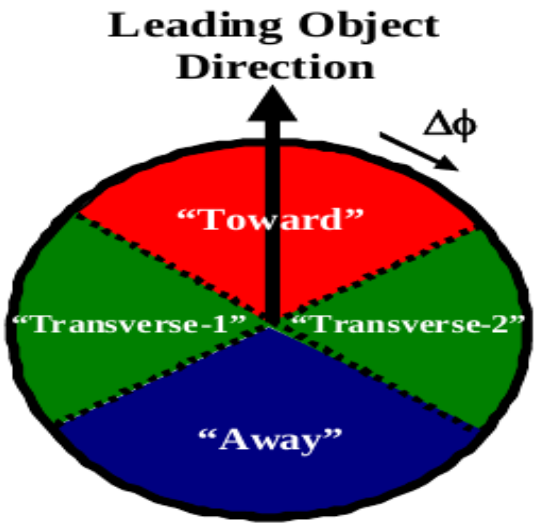
Effective Cross-section Parameter of DPS

$$\sigma_{DPS} = \frac{\sigma_a \sigma_b}{\sigma_{eff}}$$

Single Parton Scattering (SPS) Cross-section.

UE Measurements

Observables : Average charged particle multiplicity ($<N_{ch}>$) and average scalar sum of p_T of the charged particles ($<\Sigma p_T>$).



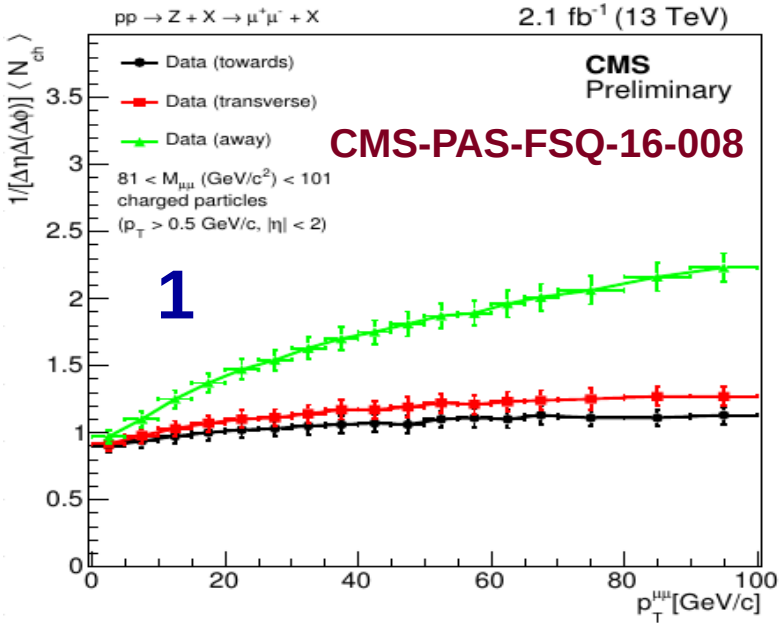
Regions of Measurements

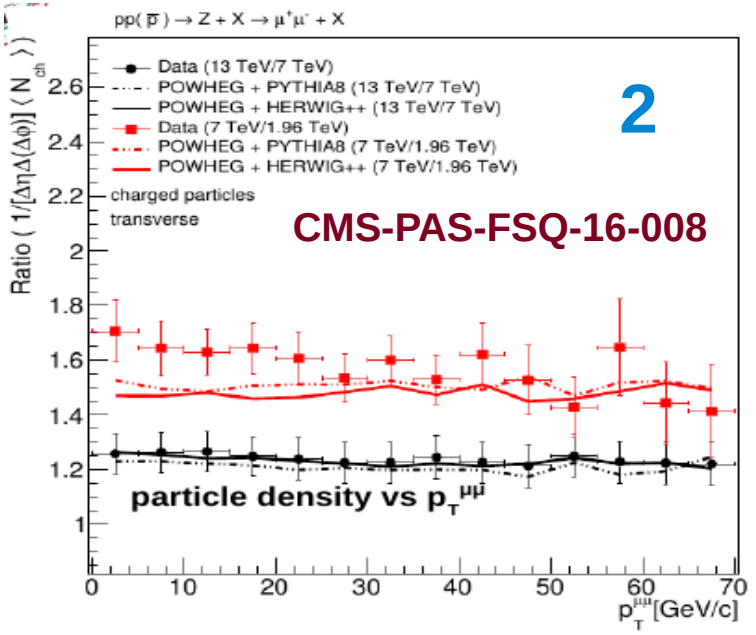
- Towards : $|\Delta\Phi| < 60^0$
  $\Delta\Phi$ - (the leading object, charged particle)
- Away Region : $|\Delta\Phi| > 120^0$
- Transverse : $60^0 < |\Delta\Phi| < 120^0$
  - TransMax : Maximum value of UE observable.
  - TransMin : Minimum value of UE observable.

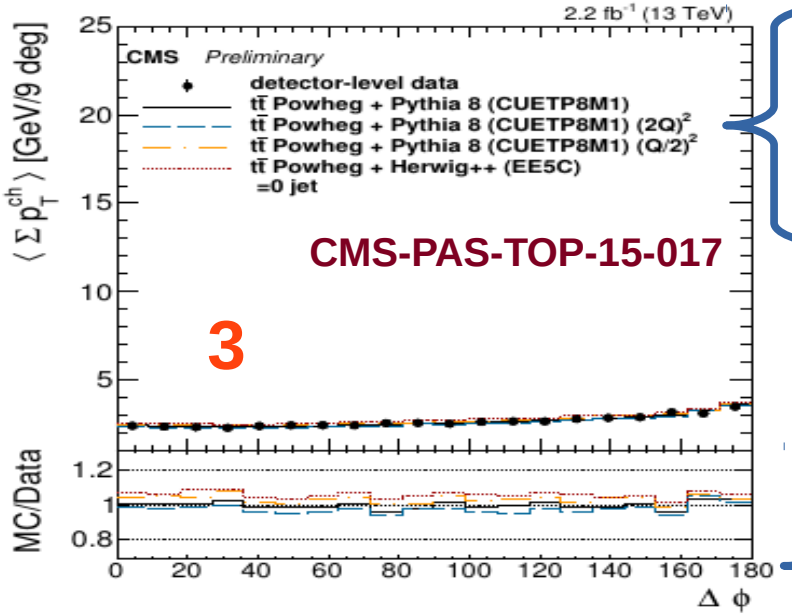
UE measurements at CMS experiment :

- Leading Charged Particles @ 13 TeV – **CMS-PAS-FSQ-15-007.**
- Leading Jets @ 13 TeV – **CMS-PAS-FSQ-15-007.**
- Drell-Yan Events @ 13 TeV – **CMS-PAS-FSQ-16-008, arxiv:1711.04299v1 [hep-ex].**
- ttbar Events @ 13 TeV – **CMS-PAS-TOP-15-017.**

Results of UE Measurements







- ✔ **Away Region - Fast rise in UE activity due to recoiling hadronic activity.**
- ✔ **Towards and Transverse Region - Slow growth due to large spatial separation.**

- ✔ **25-30% rise from 7 to 13 TeV.**
- ✔ **60-80% rise from 1.96 TeV to 7 TeV.**

- ✔ **Average value of scalar sum of p_T of the charged particle vs ΔΦ distribution is sensitive to the scale, Q; Pythia8 and Herwig++ interfaced with Powheg fit the data very well.**

Performance of Pythia8 Old UE Tunes

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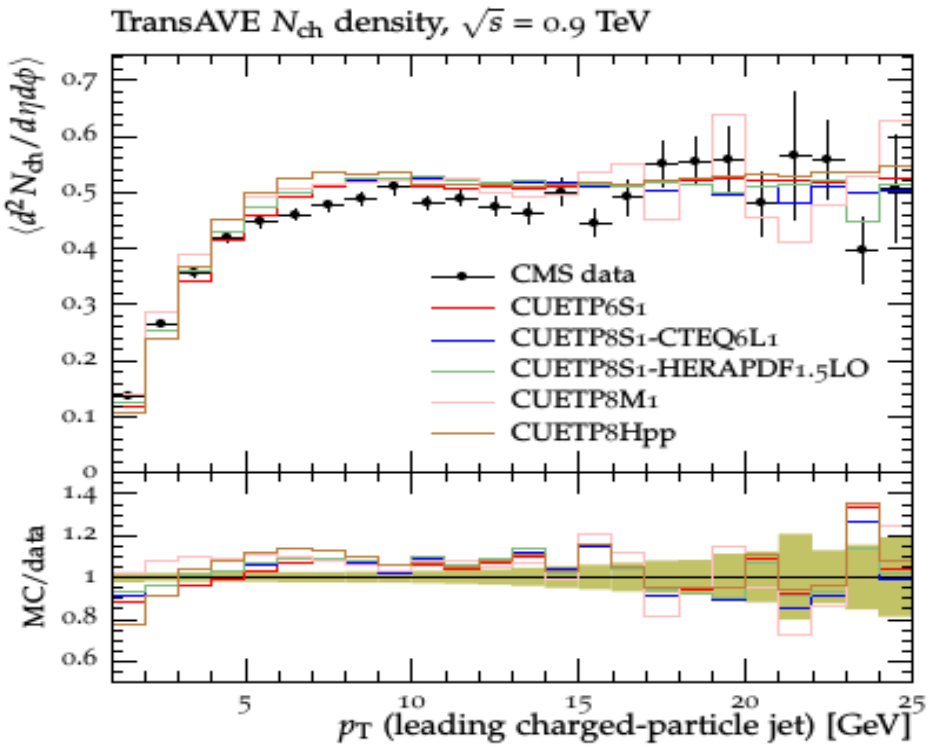
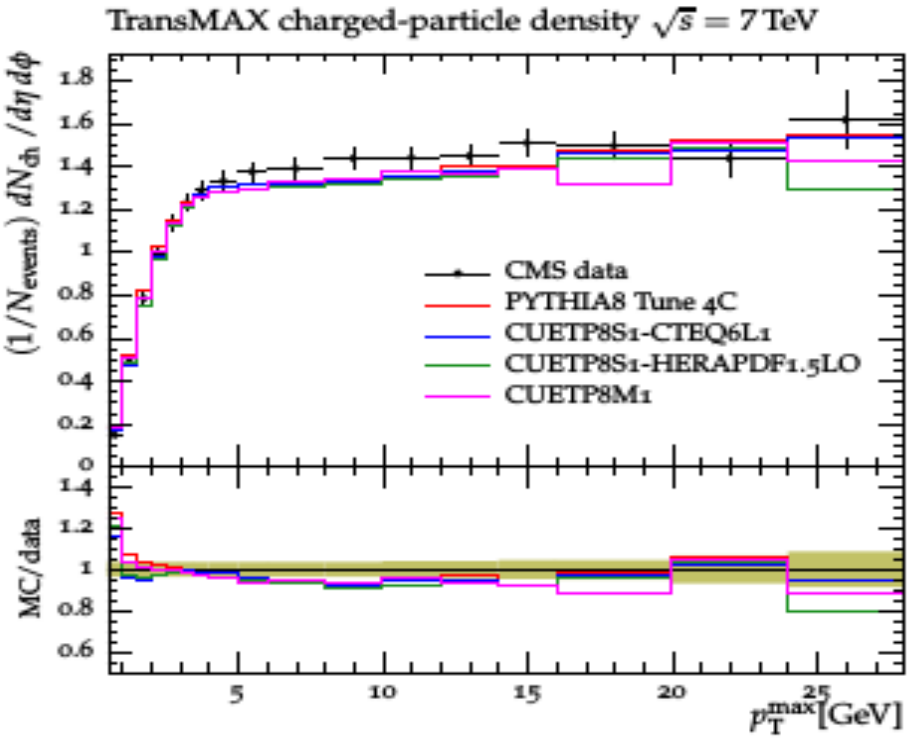
Tune : Specified set of parameters adjusted to better fit the data.





✔ ***Requires tuning.***

How Tuning is Done?

Tuning : The tuning is performed by minimizing a function, χ^2.

$$\chi^2(p) = [x - \mu(p)]^T C^{-1} [x - \mu(p)]$$

- **X → Data values**
- **μ (p) → MC prediction for parameter, p.**
- **C → Covariance Matrix.**

Pythia8 Tuning

- By fitting UE data i.e. Charged-particle and energy densities in TransMIN and TransMAX regions vs leading charged particle p_T at various energies, charged particle η distribution (dN/dη vs η).
- Refine tunes CUETP8M1 (Pythia8), CUETP8S1 (Pythia8), CUETP8Hpp etc. using **Monash as a baseline.**
- With different PDFs i.e. CTEQ6L1, HERAPDF etc.

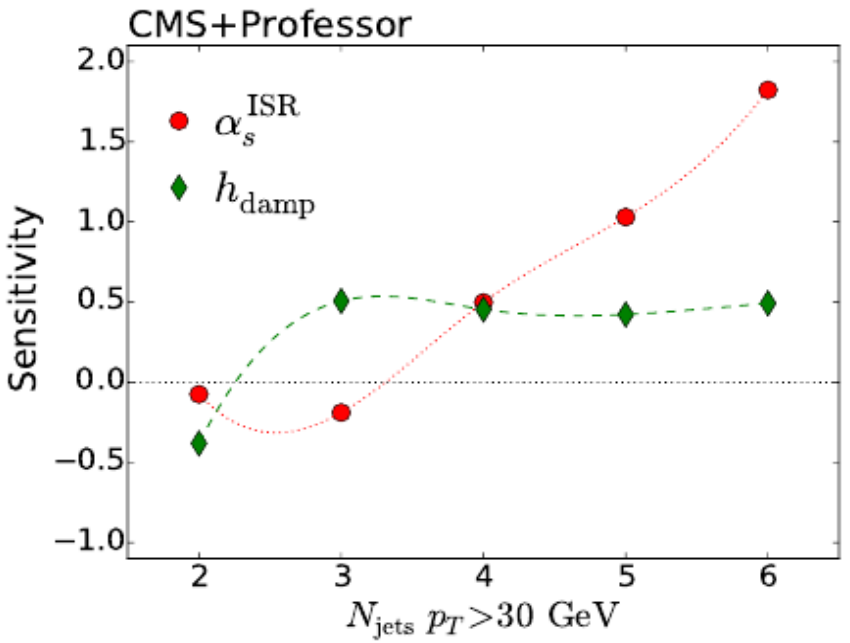
Top Quark specific Pythia8 Tune – CUETP8M2T4

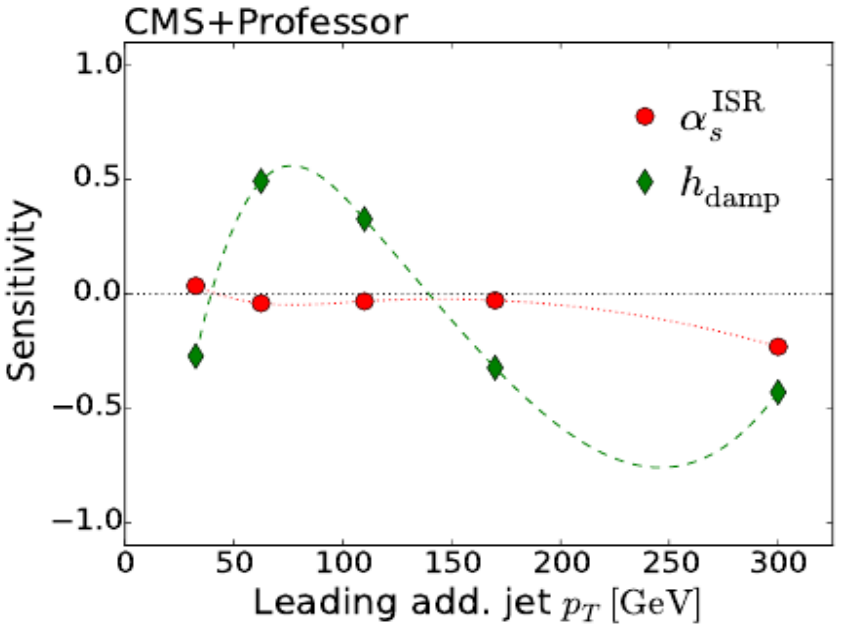
Motivation : To describe high jet multiplicity events in ttbar events.

Sensitivity to Tuning Parameters

CMS-PAS-TOP-16-021

- The impact of the tuning parameters on N_{jets} and leading additional jet p_T can be quantified via the parameter, S.



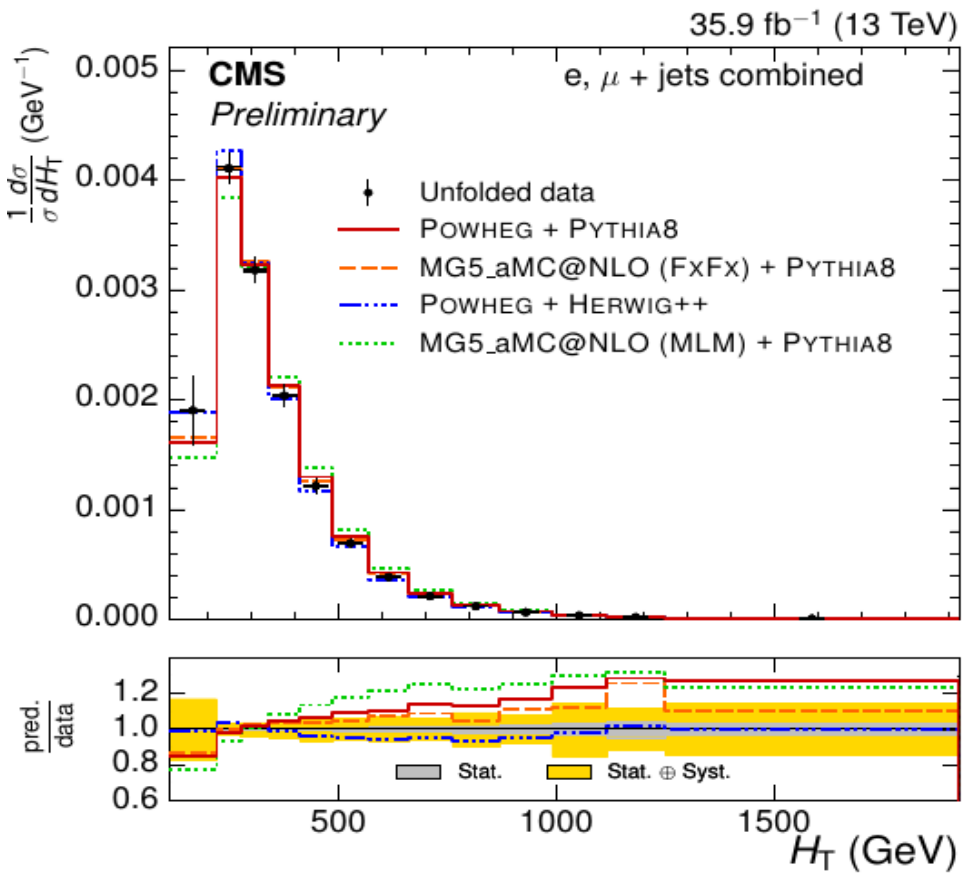


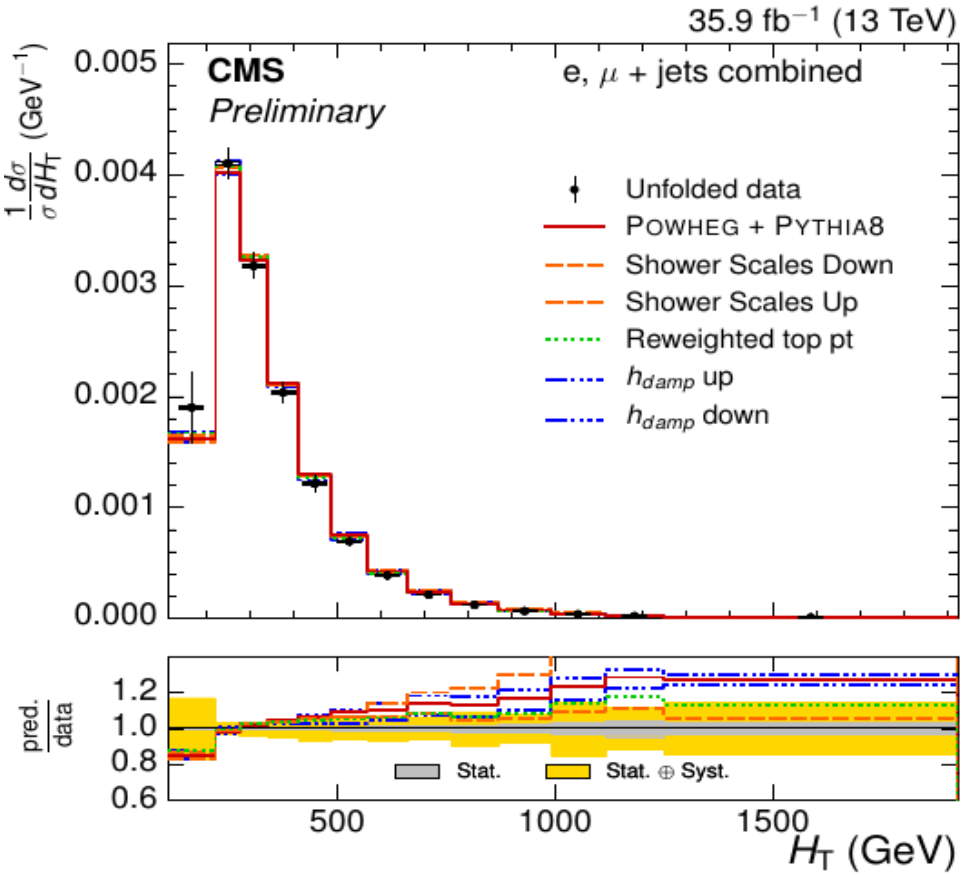
$$S = \frac{dMC(p)}{dp} \times \frac{p_c}{MC(p_c)}$$

bin value for a parameter value p and p_c is a reference parameter point.

- **α_s^{ISR} impacts mostly the higher jet multiplicities.**
- **h_{damp} has a high influence on the ratio of 2-jet to 3-jet events and the leading additional jet p_T .**

Performance of the New Pythia8 Tune with Top Quark Data





- Powheg + Pythia8 (CUETP8M2T4) describes the data very well.
- MG5_aMC@NLO [MLM] and MG5_aMC@NLO [FxFx] + Pythia8 with the new tune do not describe the top quark data perfectly.
- ttbar cross-sections are sensitive to shower scales and h_{damp} parameter.

CMS-PAS-TOP-16-014

Comparison of UE and DPS Tunes

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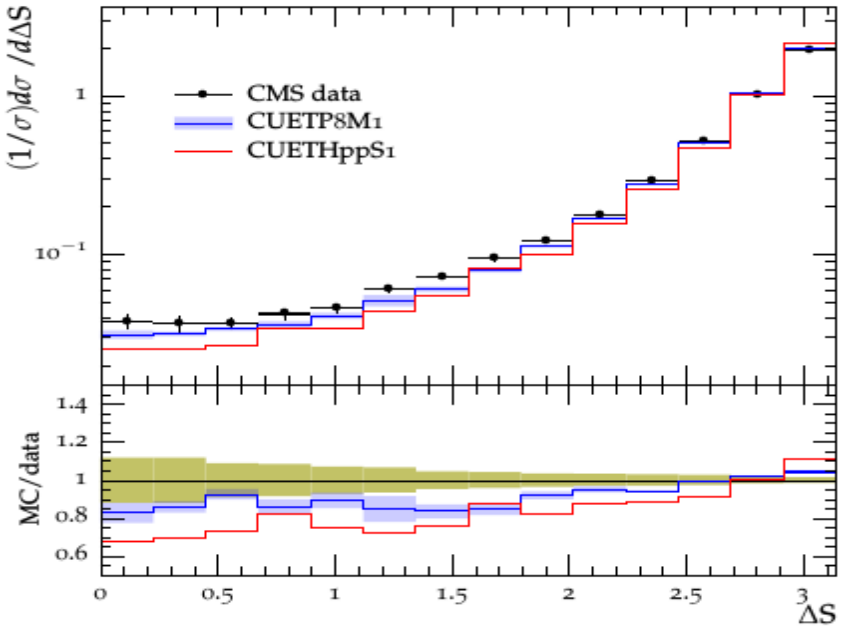
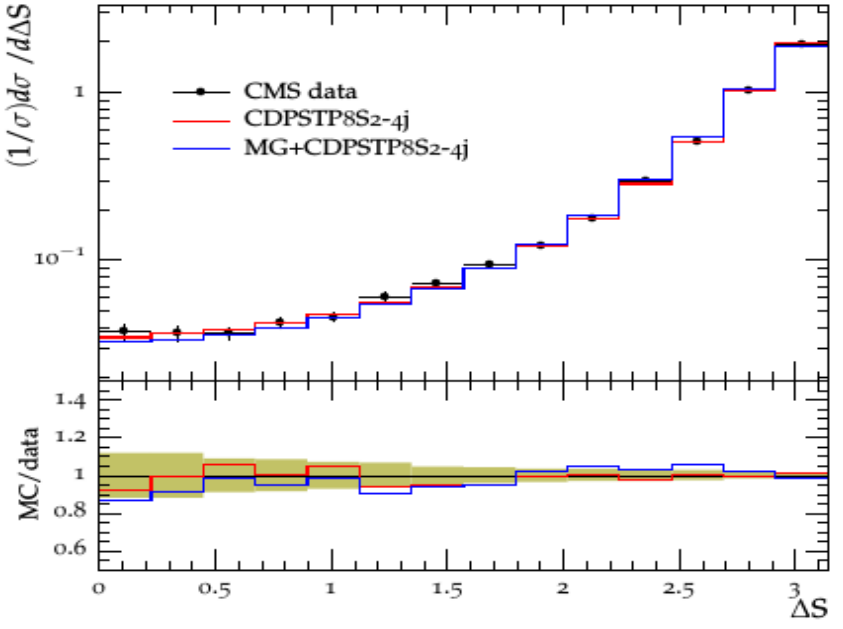
CMS Tune	σ_{eff}(mb) at 7 TeV
CUETP8S1-CTEQ6L1	$27.8^{+1.2}_{-1.3}$
CUETP8S1-HERAPDF1.5LO	$29.1^{+2.2}_{-2.0}$
CUETP8M1	$26.0^{+0.6}_{-0.2}$
CUETHppS1	$15.2^{+0.5}_{-0.6}$
CDPSTP8S1-4j	$21.3^{+1.2}_{-1.6}$
CDPSTP8S2-4j	$19.0^{+4.7}_{-3.0}$

- CMS DPS tunes give value of σ_{eff} ~ 20 mb but CMS UE tunes give bit higher value in the range of 26 – 29 mb.

- ***CMS DPS tunes (right) tend to provide good description of data (for DPS sensitive observables) as compared to CMS UE tunes (left).***





Summary

- UE activity shows strong growth with increase in centre-of-mass energy.
- Comparison of UE activity has been done in different regions, shows fast rise in away region as compared to towards and transverse regions.
- Top quark specific Pythia8 tune, CUETP8M2T4 along with Powheg describes the UE data very well.
- CMS UE tunes do not describe the data as well as done by CMS DPS tunes for DPS sensitive observables.
- Results of ongoing analyses which requires UE modeling, can provide important input for tuning.