Pythia8 Tunes in CMS

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LHC-EW WG: Jets and EW Bosons
20 June 2018
CERN

α_s Consistency in ME and PS and PDF Choices

- PDF and α_s appear in ME, PS, and MPI models.
- α_s in at (N)NLO and LO are typically very different.
- Traditionally, perturbative order of the PDF is matched to the order of the ME.
- Matched/merged calculations capture some higher order corrections w.r.t. the formal order of the ME calculation.
- Using the same PDF set and α_s value in the ME and in the simulation of the PS components advocated in *B. Cooper et al., EPJ C72 (2012) 2078*, and by *HERWIG7* and *SHERPA* (especially when PS is matched/merged to higher-order MEs).
  - e.g. If ME is at NLO, then use $N^{\geq 1}LO$ PDF in ME and PS.
  - Some processes may be affected more.

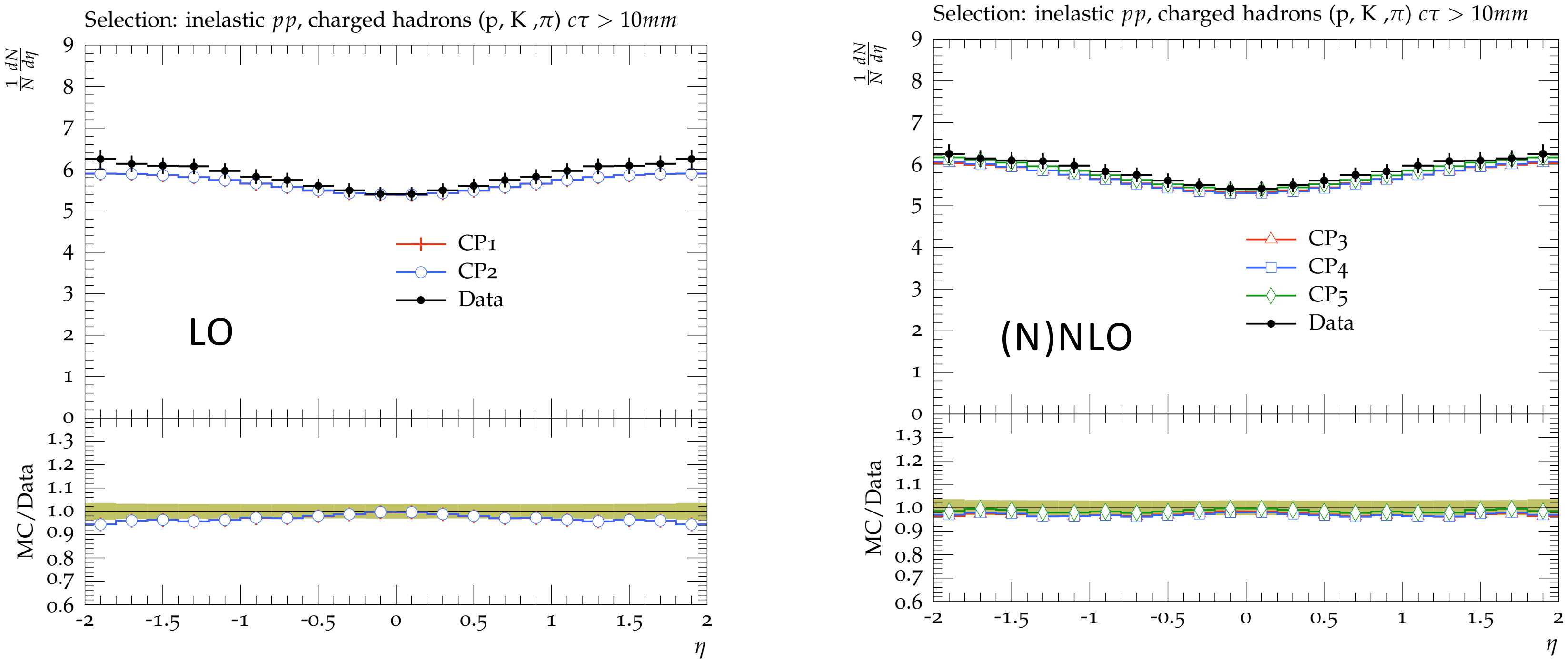
α_s Consistency in ME and PS and PDF Choices

- However, for MPI, better to choose a LO PDF to assure a physical small-x gluon distribution (unless this is assured by the specific PDF set).
- Different strategies are adopted
  - CMS & ATLAS tunes traditionally based on LO PDFs.
  - PYTHIA tunes are mostly based on LO PDFs.
  - Sherpa tunes are based on NNLO PDFs.
  - HERWIG7 provide tunes based on NLO PDFs (in which MPI is still based in LO PDF).

α_s Consistency in ME and PS and PDF Choices – MinBias and Underlying Event

→ test the effect using different PDF orders of NNPDF3.1 sets in Pythia8 among other parameter variations.

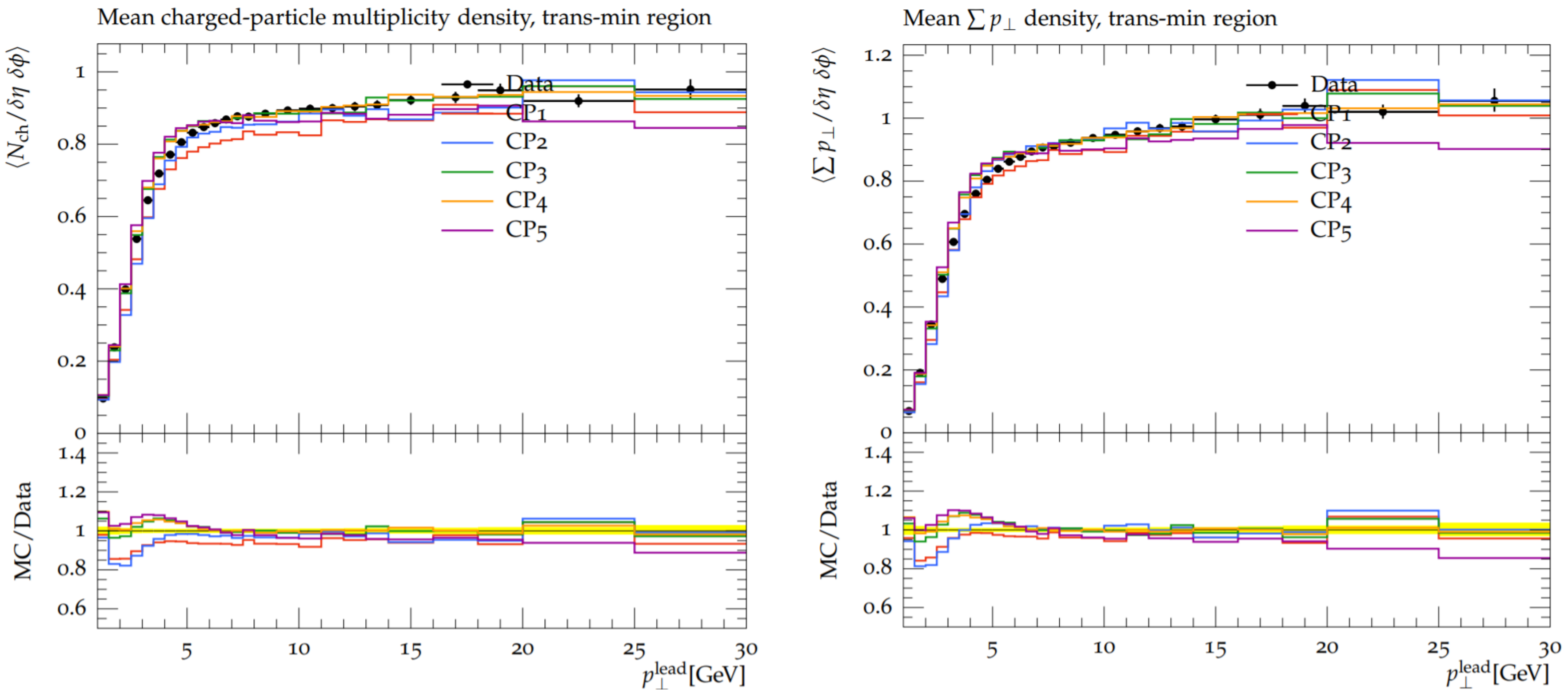
CP1,2: LO (α_s =0.130)
CP3 : NLO (α_s =0.118)
CP4,5: NNLO (α_s =0.118)



Rivet:CMS_2015_I1384119, 0 Tesla, |η|<2, √s=13 TeV

- Min-bias data are described at the same level by tunes with LO, NLO, and NNLO NNPDF3.1 sets.

α_s Consistency in ME and PS and PDF Choices – MinBias and Underlying Event



Rivet: ATLAS_2017_I1509919, |η|<2.5, p_T>0.5 GeV with at least 1 of the charged particle p_T > 1 GeV, √s=13 TeV

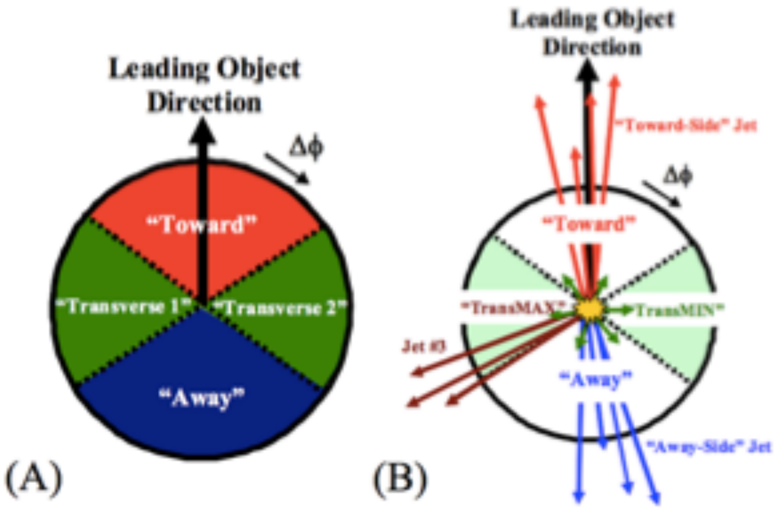
- UE data are described at the same level by tunes with LO, NLO, and NNLO NNPDF3.1 sets.

Pythia8 Tunes

- Monash tune
  - MPI parameters <== UE pp(pbar) data.
  - Primordial kT <== pT(Z—>ll)
  - Parton shower <== Event shapes in ppbar
  - Hadronization <== Particle multiplicities in hadronic Z decays in e+e- data.
- Refine the Monash tune by optimizing MPI and color reconnection parameters using
  - UE data (e.g. pT> 0.5 GeV, | η | < 2): Charged-particle and energy densities in e.g. TransMIN and TransMAX regions vs leading charged particle pT, …
  - MB data (pT > 0): Charged-particle η distribution, …

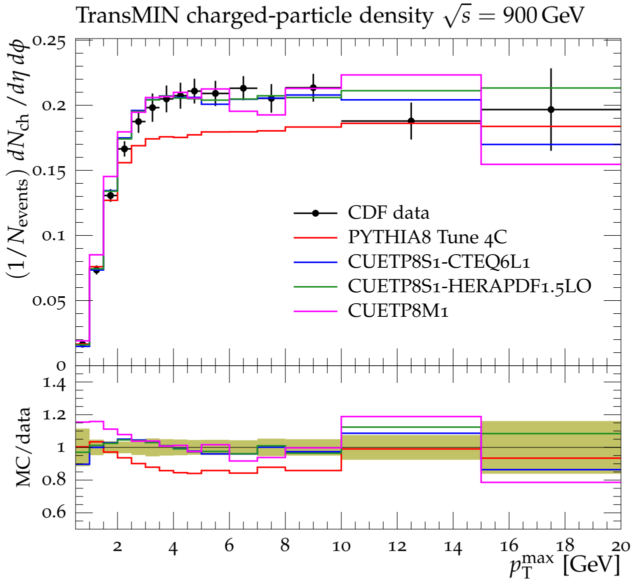
$$\frac{<\eta_{ch}>}{\Delta\eta\Delta(\Delta\phi)}$$

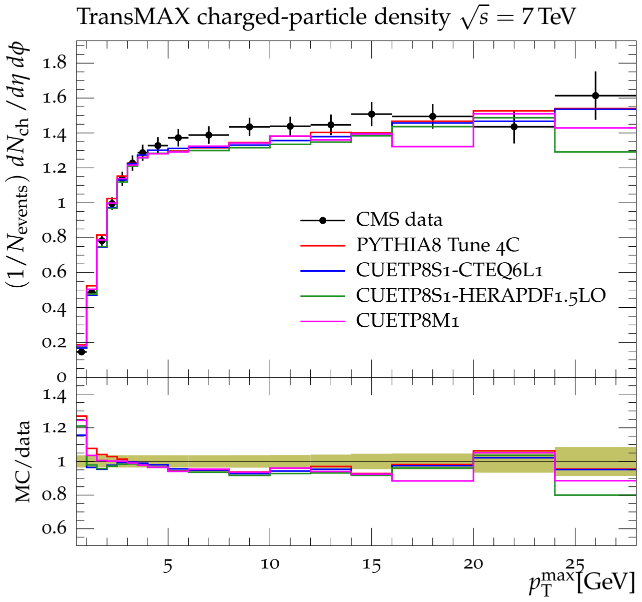
$$\frac{<\Sigma p_T>}{\Delta\eta\Delta(\Delta\phi)}$$



- Transverse: 60 < |Δϕ| < 120
  - TransMax: maximum activity side <== MPI/BR & ISR/FSR
  - TransMin: minimum activity side <== MPI/BR
  - TransAve = (TransMax + TransMIN)/2
  - TransDIF = TransMax - TransMIN <== ISR/FSR

Energy-Dependent Pythia8 Tuning for run II using Tevatron and 7 TeV CMS Data

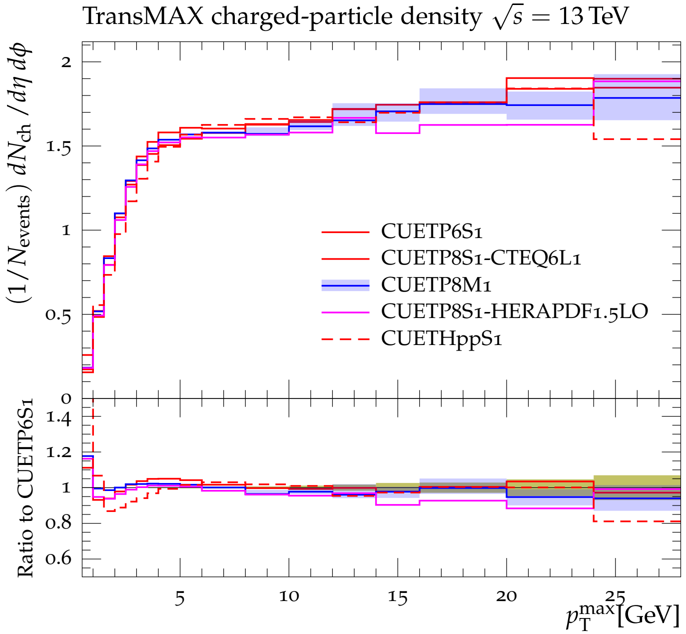


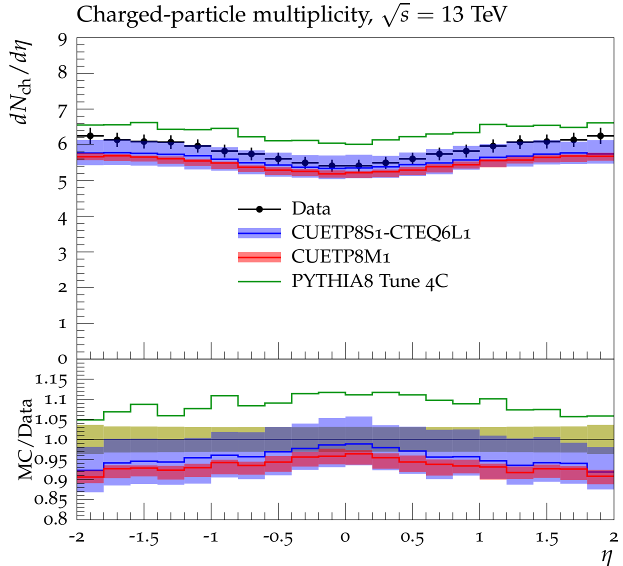


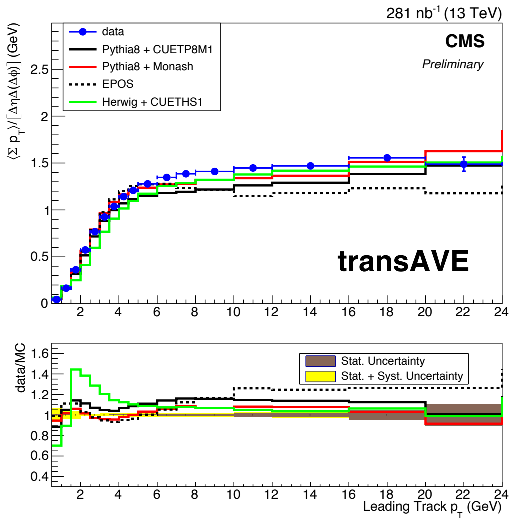
EPJ C 76 (2016) 155

→ First CMS tunes by simultaneously fitting UE data at √s = 0.9, 1.96, and 7 TeV: CUETP8X, CUETHpp with various PDFs.

→ Predict 13 TeV.







CMS-PAS-FSQ-15-007

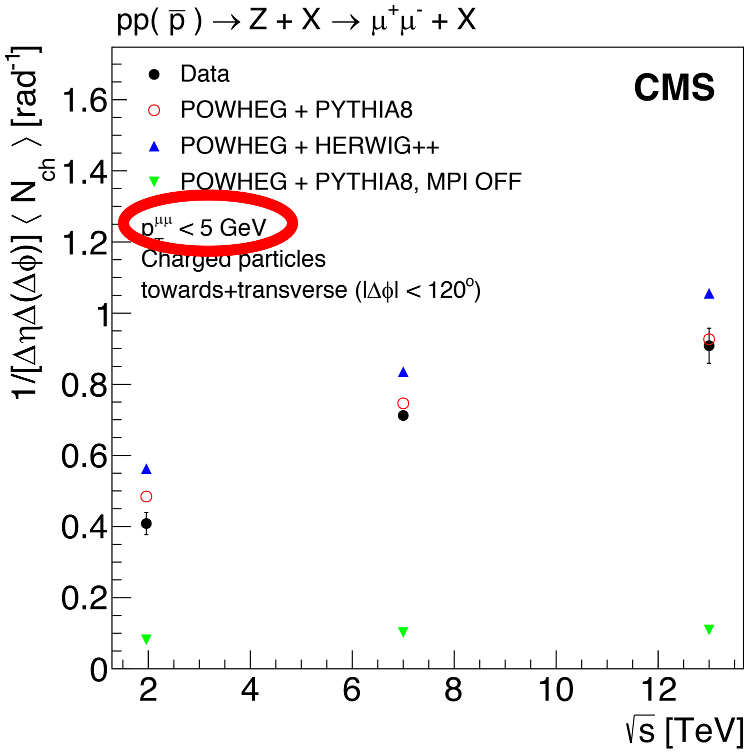
None of the tunes describe the data perfectly

Standard Setups for CMS Monte Carlo at Run II – Pythia8 Tunes

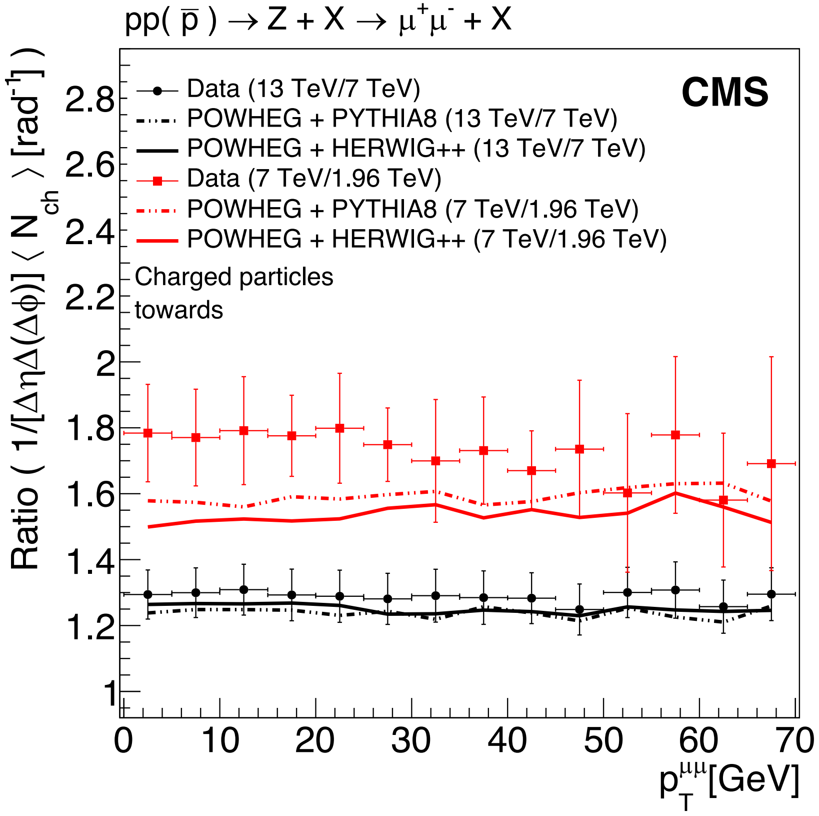
- Until 2017 analyses (except 2016 ttbar), CUETP8M1 tune [*] based on the Monash tune was used.
  - α_s and shower parameters kept as in Monash → $\alpha_s^{ISR/FSR}$=0.1365 despite the prefered values of 0.130 in LO and 0.118 in NLO matrix elements/ PDF sets.
    - α_s^{FSR} in Monash → by fitting Pythia8 predictions to LEP event shape measurements and α_s^{ISR} is just assumed to be the same as α_s^{FSR}.
    - α_s^{MPI} = 0.130 set to the value prefered in the LO PDF set.
  - Revisited the shower parameters
    - Starting from parton shower in ttbar events → CUETP8M2T4 tune.
    - Using a NNLO PDF set in PS → CP5 (and CP0-4 tunes).

[*] CMS Collaboration, Eur. Phys. J. C 76 (2016) 155

UE activity (vs √s) in Z+Jets Events



arXiv:1711.04299

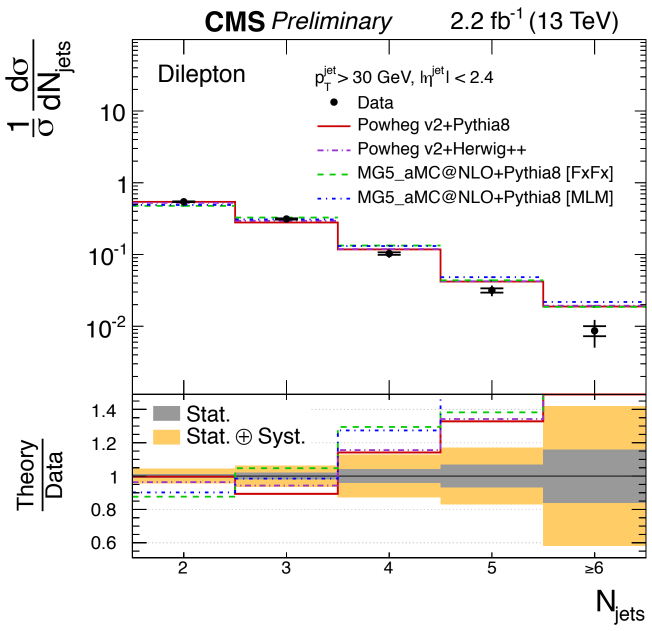


- pT($\mu\mu$) < 5 GeV → Mainly MPI
  - very small contribution from radiation
- UE activity ~doubles w/ logarithmic increase from √s=1.96 to 13 TeV.
- Powheg+Pythia8 provides better description.

- The increase in UE from 7 to 13 TeV is described well by simulations but underestimate the UE evolution from 1.96 to 7 TeV

Universality of UE tested up to a scale of ~ 90 GeV

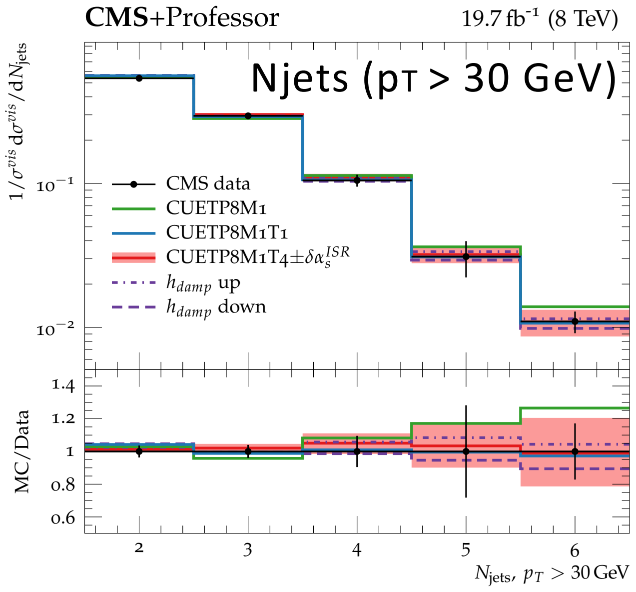
CUETP8M2T4 Event Tune



- Predictions overshoot the data for large jet multiplicities when out of the box parameters are used (in Monash-based tunes: α_s^{ISR}=0.1365)
- Effect also observed with 8 TeV data.

CMS-PAS-TOP-12-041 (dilepton 8 TeV),
CMS-PAS-TOP-16-011 (dilepton 13 TeV),
CMS-PAS-TOP-16-008 (l+jets 13 TeV)

CMS-PAS-TOP-16-021



Tune α_s^{ISR} using 8 TeV ttbar Njets and jet pT data —>

$$\alpha_s^{ISR} = 0.1108^{+0.0145}_{-0.0142}$$
$$h_{damp} = 1.581^{+0.658}_{-0.585} \times m_t$$

with **SpaceShowerRapidityOrdering=on** *(special care of options needed for the emissions produced by the PS)*

==> Significantly lower shower α_s cures the overshoot of CUETP8M1 at high jet multiplicities.
==> UE and min-bias are described better
==> POWHEG+PYTHIA8: generally consistent with data, with residual differences covered by theory uncertainties.

arXiv:1803.0399

CUETP8M2T4 Event Tune

Table 3: The parameters of the old tune (CUETP8M1) and the new tune (CUETP8M2T4). The parameter (in italic) relative to the energy dependence of the partonic cross section cutoff (ECMPOW) is fixed to the value of CUETP8M1 in the fit of the new tune. In the new tune, the ISR α_s is fixed to the value extracted from the $t\bar{t}$ events described previously.

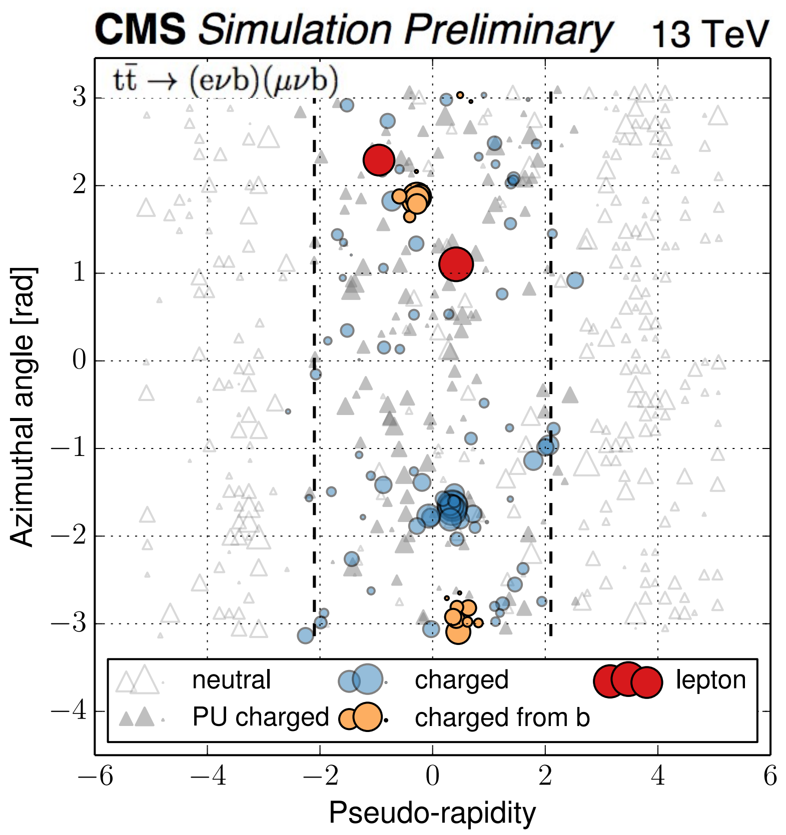
	CUETP8M1	CUETP8M2T4
Tune	pp 14	pp 14
Tune	ee 7	ee 7
MultipartonInteractions ecmPow	0.2521	0.2521
SpaceShower:alphaSvalue	0.1365	0.1108
PDF pSet LHAPDF6	NNPDF23_lo_qed_as_0130	NNPDF30_lo_as_0130
MultipartonInteractions:pT0Ref	2.40	2.20
MultipartonInteractions:expPow	1.6	1.6
ColourReconnection:range	1.8	6.6

CMS-PAS-TOP-16-021

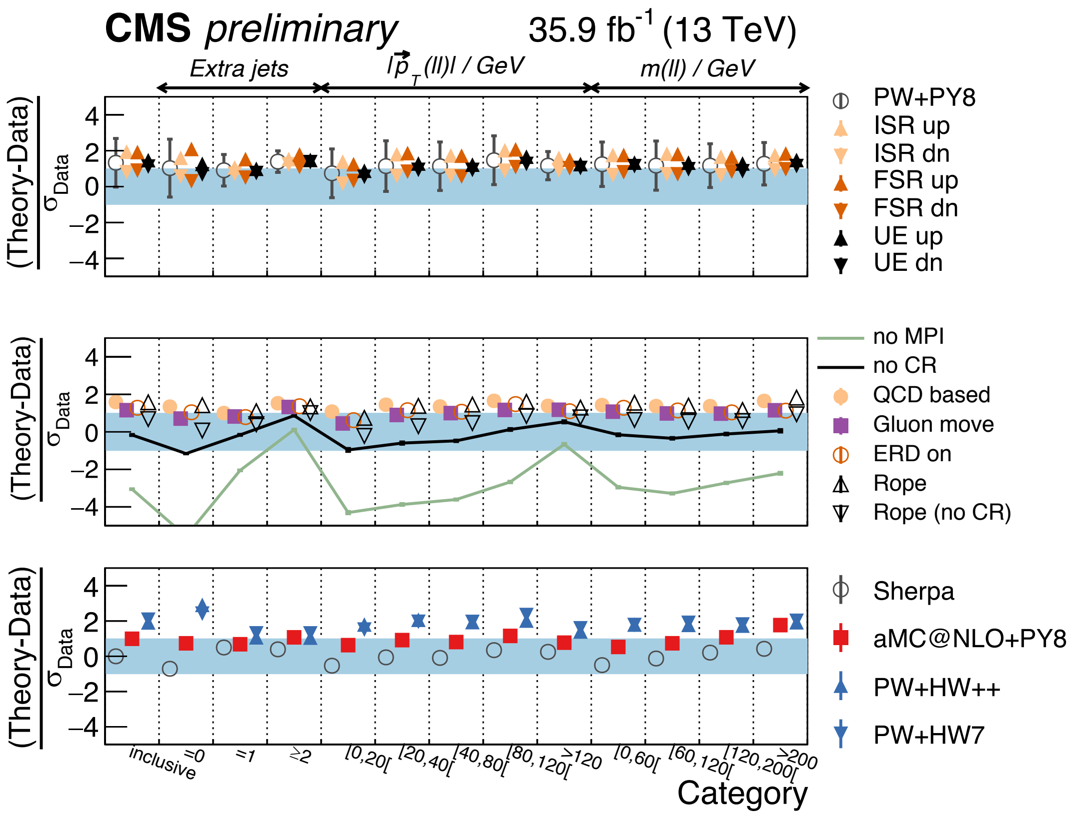
Underlying Event in ttbar Events

CMS-PAS-TOP-17-015

- Observables/categories enhance sensitivity to the modeling of MPI, color reconnection, and $\alpha_s^{FSR}(M_Z)$ in Pythia8.
  - Among the parameters with the largest impact on the ttbar modeling.
  - Data disfavor default settings in HERWIG++, HERWIG7, and SHERPA → Need tuning.
  - Choice of NLO ME generator (Powheg or MG5_aMC@NLO[FxFx] + Pythia8) does not impact the UE in ttbar.

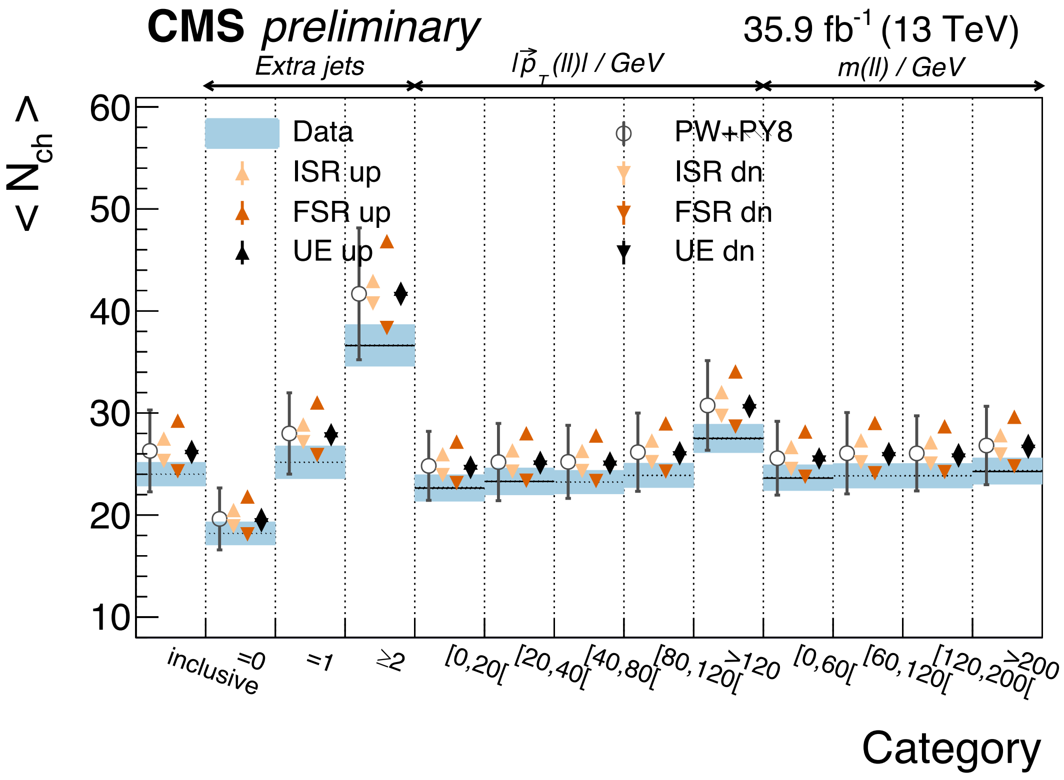


$< \Sigma p_T > \ [GeV]$



Underlying Event in ttbar Events

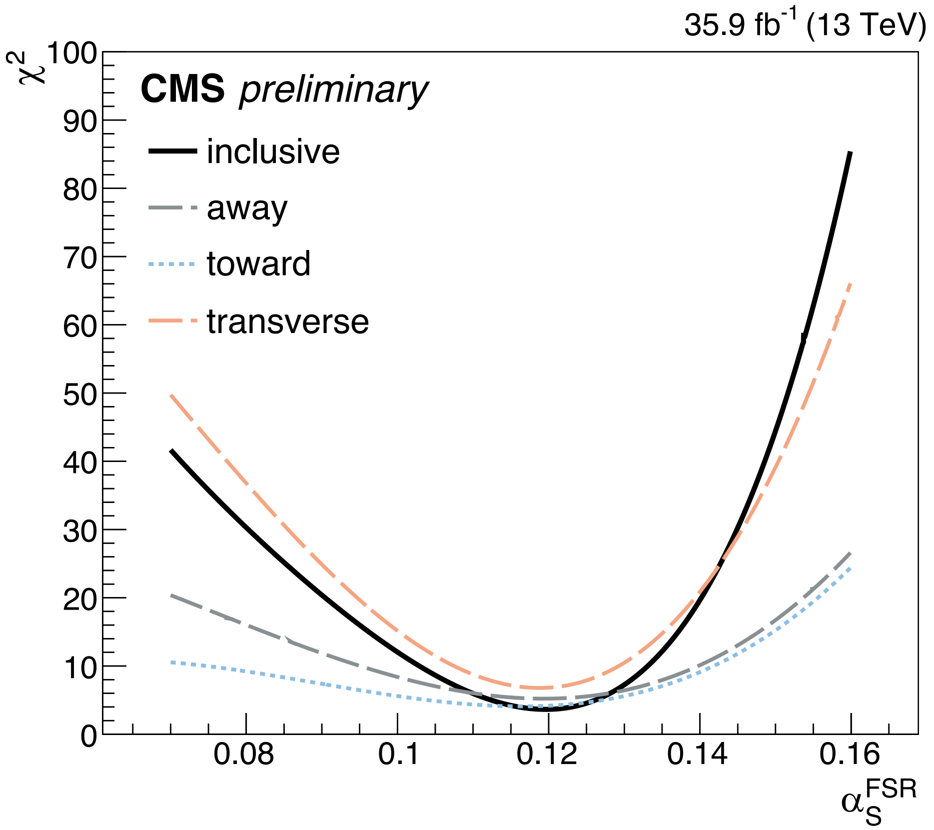
- Test the universality of the UE hypothesis to scales up to $2m_t$ than the ones UE models are usually tuned.
  - Measurements in categories of m(ll) indicate that it should be valid at even higher scales.



CMS-PAS-TOP-17-015

- The measurements will be used to improve the assessment of systematic uncertainties in future measurements.

Underlying Event in ttbar Events



CMS-PAS-TOP-17-015

- Data prefer lower $\alpha_s^{FSR}(M_Z)$ than *assumed* in Monash.
  - Similar result from jet substructure in ttbar events [CMS-PAS-TOP-17-013]

$\lvert\vec{p}_T(\ell\ell)\rvert$ region	Inclusive	Away	Toward	Transverse
Best fit α_S^{FSR}	0.120	0.119	0.116	0.119
68% CI	[-0.006,+0.006]	[-0.011,+0.010]	[-0.013,+0.011]	[-0.006,+0.006]
95.45% CI	[-0.013,+0.011]	[-0.022,+0.019]	[-0.030,+0.021]	[-0.013,+0.012]

Uncertainties ~√2 variation of μ_R.

Summary

- α_s in parton shower and UE event in ttbar events (and also jet shapes of ttbar events) prefer a value of ~0.111-0.120.
- UE/Min-Bias data are described at the same level by tunes with LO, NLO, NNLO PDF NNPDF3.1 sets.
  - Higher order NNPDF3.1 sets (with α_S=0.118) can be consistently used in the ME and Pythia8.
- Different phase space regions probing ISR, FSR, CR, MPI, parton shower investigated.
  - For top quark measurements, a factorized parton shower and hadronization uncertainties to understand each source better.
  - Probing Z boson and top quark differential spectra and UE to understand and improve event modeling.
  - Universality of the UE tunes tested at ~M(Z) and up to scales larger than 2 x m(top).
  - Collision energy dependence of the UE tunes tested.
  - PDFs with negative weights can cause some inconvenience in extreme phase-space regions.
- An improved Pythia8 tune based on NNLO NNPDF3.1 set is being used for ≥ 2017 CMS measurements. The details of the tune and data/MC comparisons will be published soon.

Common LHC tunes

- to ease comparisons between experiments.

PYTHIA parameter
PDF Set
$\alpha_s(M_Z)$
SpaceShower:rapidityOrder
MultipartonInteractions:ecmRef [GeV]
α_s^{ISR} value/order
α_s^{FSR} value/order
α_s^{MPI} value/order
α_s^{ME} value/order
MultipartonInteractions:pT0Ref [GeV]
MultipartonInteractions:ecmPow
MultipartonInteractions:coreRadius
MultipartonInteractions:coreFraction
ColorReconnection:range

Fixed – parameters to be decided
(considering ME-PS consistency?, and the results of CMS TOP-16-021 and TOP-17-013, TOP-17-015, indicating $\alpha_s^{ISR}= \alpha_s^{FSR}$ ~0.118? and ?)

parameters to be determined
(any other important parameter?)

Common LHC tunes – parameters to be determined and from which measurements

Parameter description	Name in PYTHIA 8
MPI cutoff, p_{T0}^{ref}, at $\sqrt{s} = \sqrt{s_0}$	MultipartonInteractions:pT0Ref
Exponent of $\sqrt{s}$ dependence, ϵ	MultipartonInteractions:ecmPow
Matter fraction contained in the core	MultipartonInteractions:coreFraction
Radius of the core	MultipartonInteractions:coreRadius
Range of colour reconnection probability	ColorReconnection:range

- Measurements to be used?
  - UE data (e.g. pT> 0.5 GeV, $|\eta| < 2$): Charged-particle and energy densities in e.g. TransMIN and TransMAX regions vs leading charged particle pT, …
  - MB data (pT > 0): Charged-particle η distribution
- Measurements at √s=13 TeV and/or at √s=7 TeV and/or at √s=1.96 TeV ?

Common LHC tunes – One or More tunes?

- (N)NLO and LO tunes?
- With different PDF sets, NNPDF, CT?
- Focus only on Pythia in the beginning?