

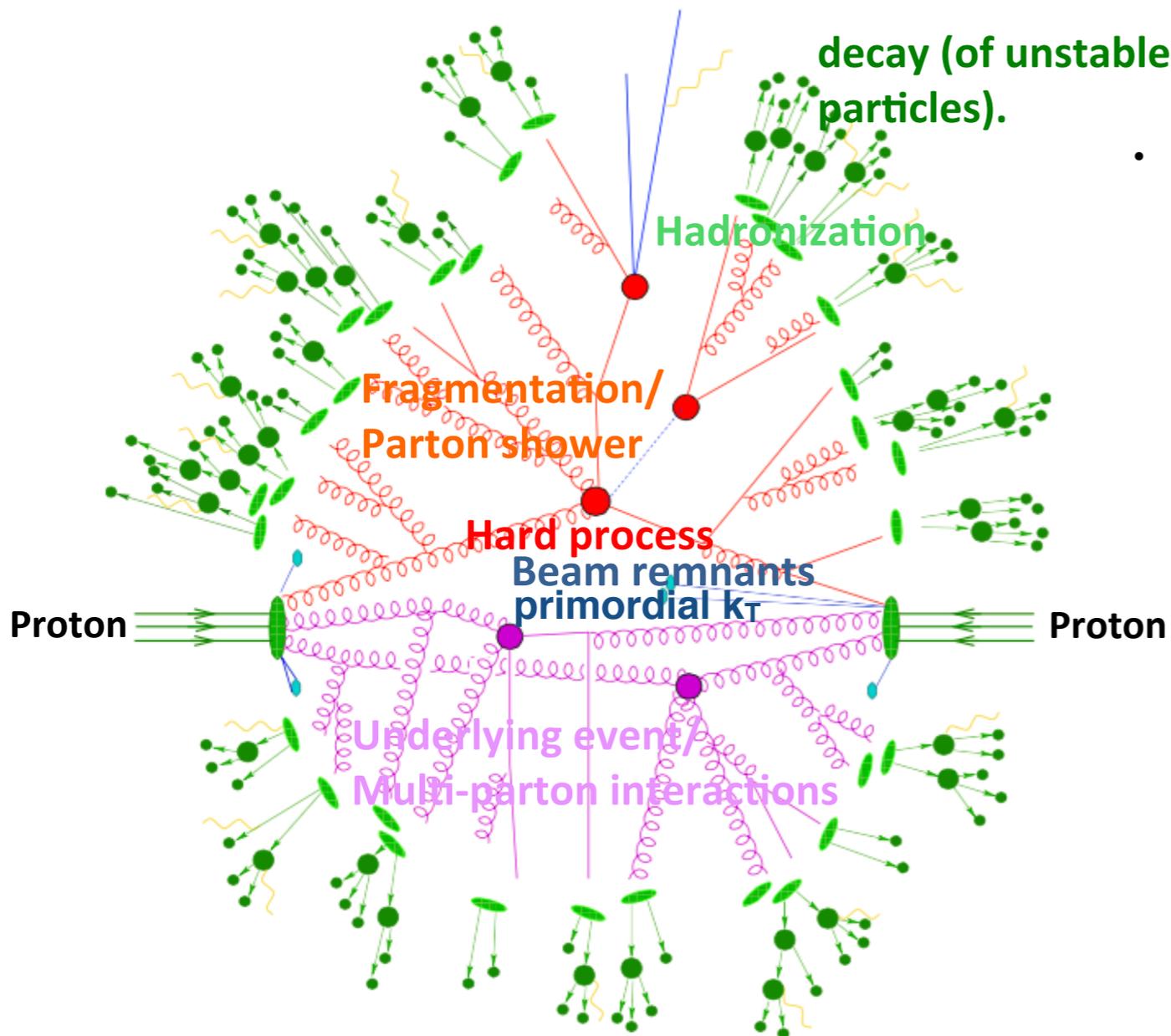
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Institute of High Energy Physics
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Underlying Event and Multi-Parton Interactions Tuning in CMS

Efe Yazgan
for the CMS Collaboration

ATLAS-CMS-MC2017: ATLAS-CMS Monte Carlo Generators Workshop,
2-5 May 2017, CERN

Event Modeling



F. Krauss

- **Underlying Event (UE):** activity in addition to the hard process + initial/final state radiation + hadronization (+ beam remnants, diffractive processes, ..)
- Main contribution from color exchanges between *beam particles* ==> modeled by *multiple Parton Interactions (MPI)* with some free parameters.
- Small number of additional jets, i.e. Double Parton Scattering (DPS)
- Many soft interactions modifies the final state: increased particle multiplicity, p_T sum, ...

Need to tune the adjustable parameters in MCs.

Pythia8 Tunes

- Monash tune

- MPI parameters \Leftarrow UE pp(pbar) data.
- Primordial $k_T \Leftarrow p_T(Z \rightarrow ll)$
- Parton shower \Leftarrow Event shapes in ppbar
- Hadronization \Leftarrow Particle multiplicities in hadronic Z decays in e^+e^- data.

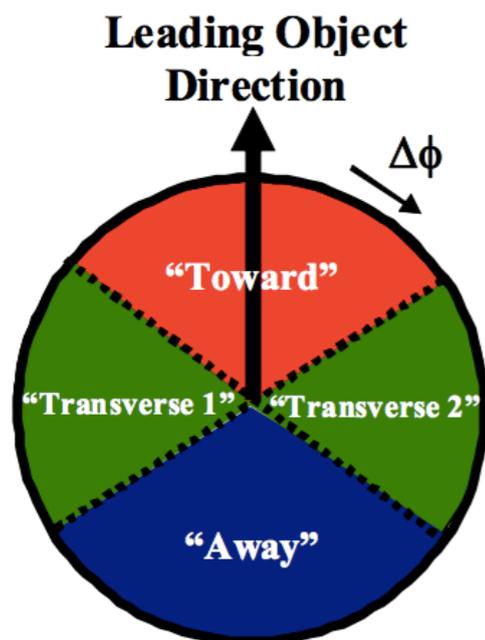
Skands, Carrazza, Rojo,
EPJ C 74 (2014) 3024

- Refine the Monash tune by optimizing MPI and color reconnection parameters using

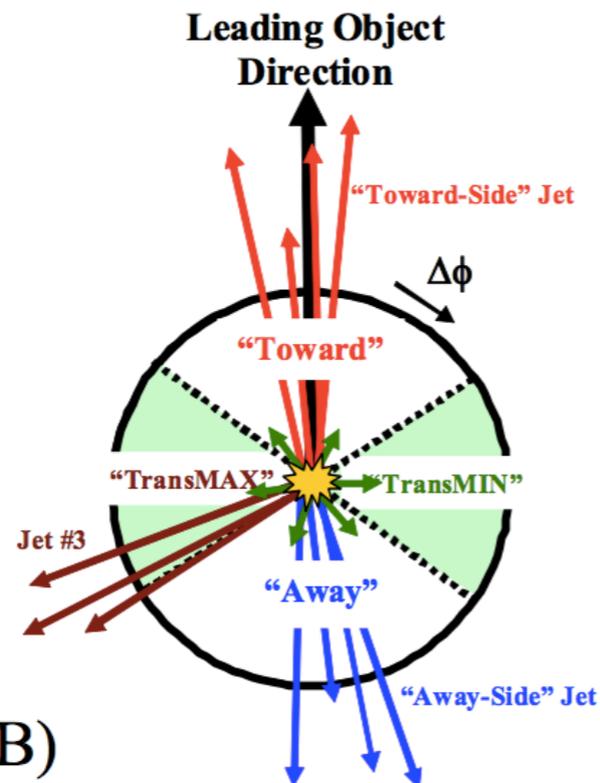
- UE data (e.g. $p_T > 0.5$ GeV, $|\eta| < 2$): Charged-particle and energy densities in e.g. TransMIN and TransMAX regions vs leading charged particle p_T , ...
- MB data ($p_T > 0$): Charged-particle η distribution, ...

$$\frac{\langle \eta_{ch} \rangle}{\Delta\eta\Delta(\Delta\phi)}$$

$$\frac{\langle \Sigma p_T \rangle}{\Delta\eta\Delta(\Delta\phi)}$$



(A)



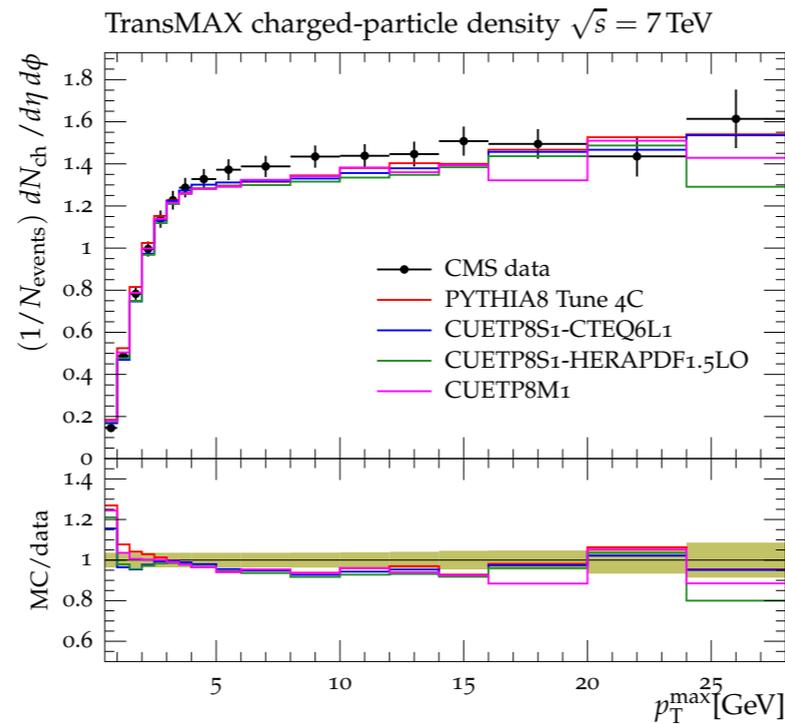
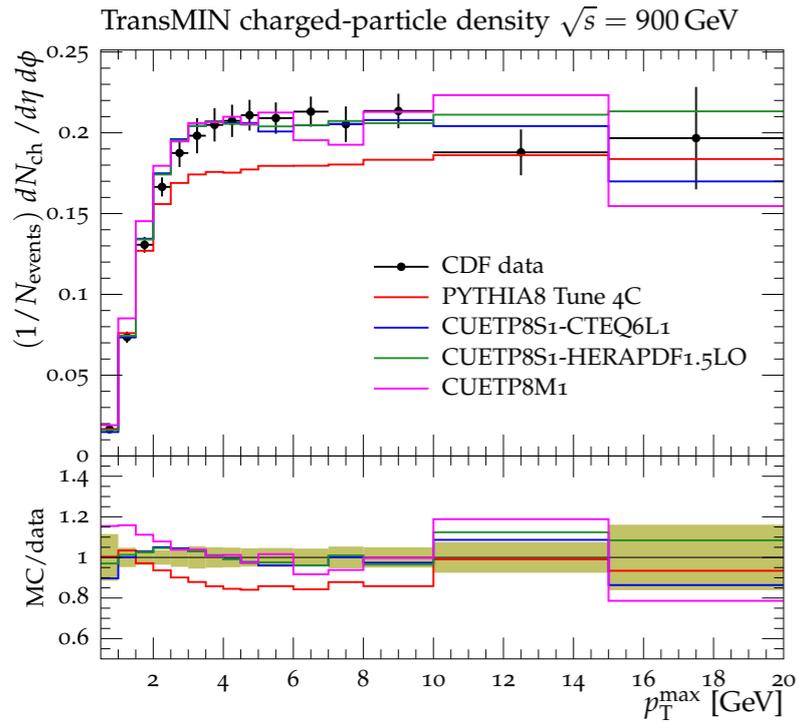
(B)

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

- * TransMax: maximum activity side \Leftarrow MPI/BR & ISR/FSR
- * TransMin: minimum activity side \Leftarrow MPI/BR
- * TransAve = (TransMax + TransMIN)/2
- * TransDIF = TransMax - TransMIN \Leftarrow ISR/FSR

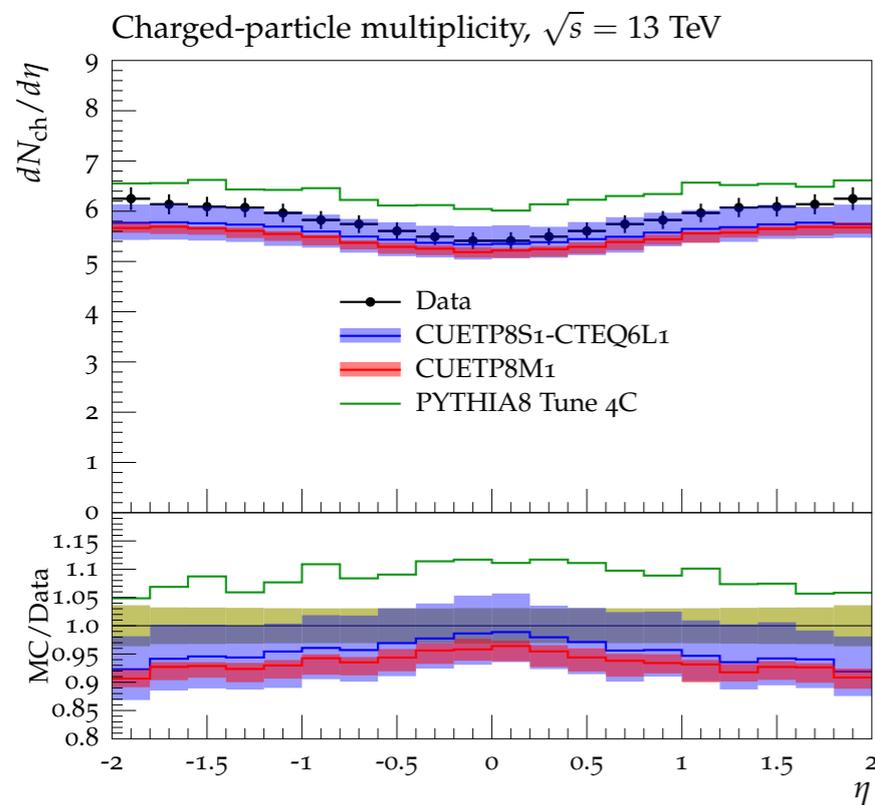
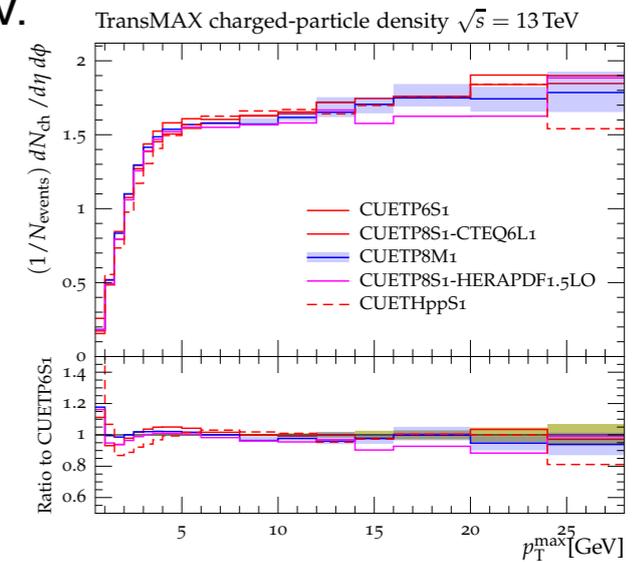
Energy-Dependent Pythia8 Tuning for run II using Tevatron and 7 TeV CMS Data

EPJ C 76 (2016) 155

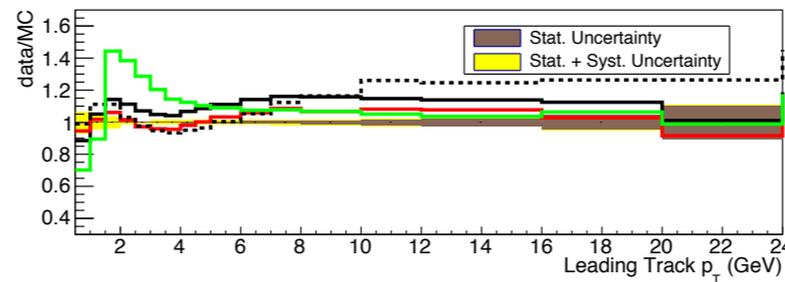
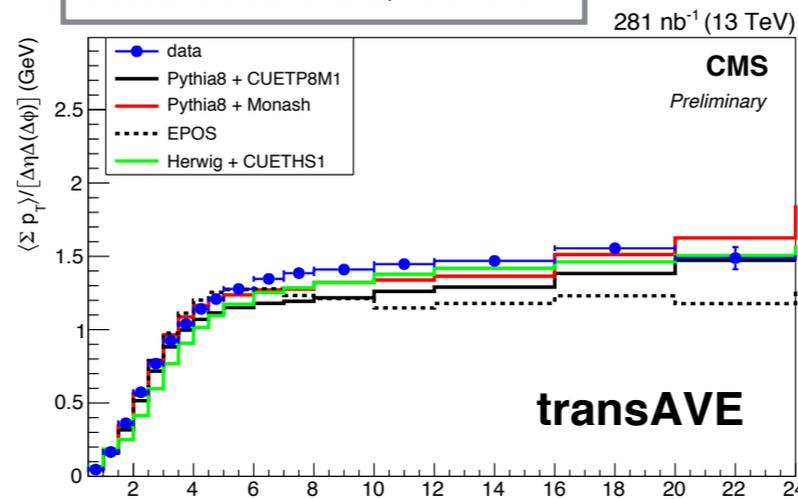


- First CMS tunes by simultaneously fitting UE data at $\sqrt{s} = 0.9, 1.96,$ and 7 TeV: CUETP8 (Pythia), CUETHpp (Herwig++) with various PDFs.

- Predict 13 TeV.

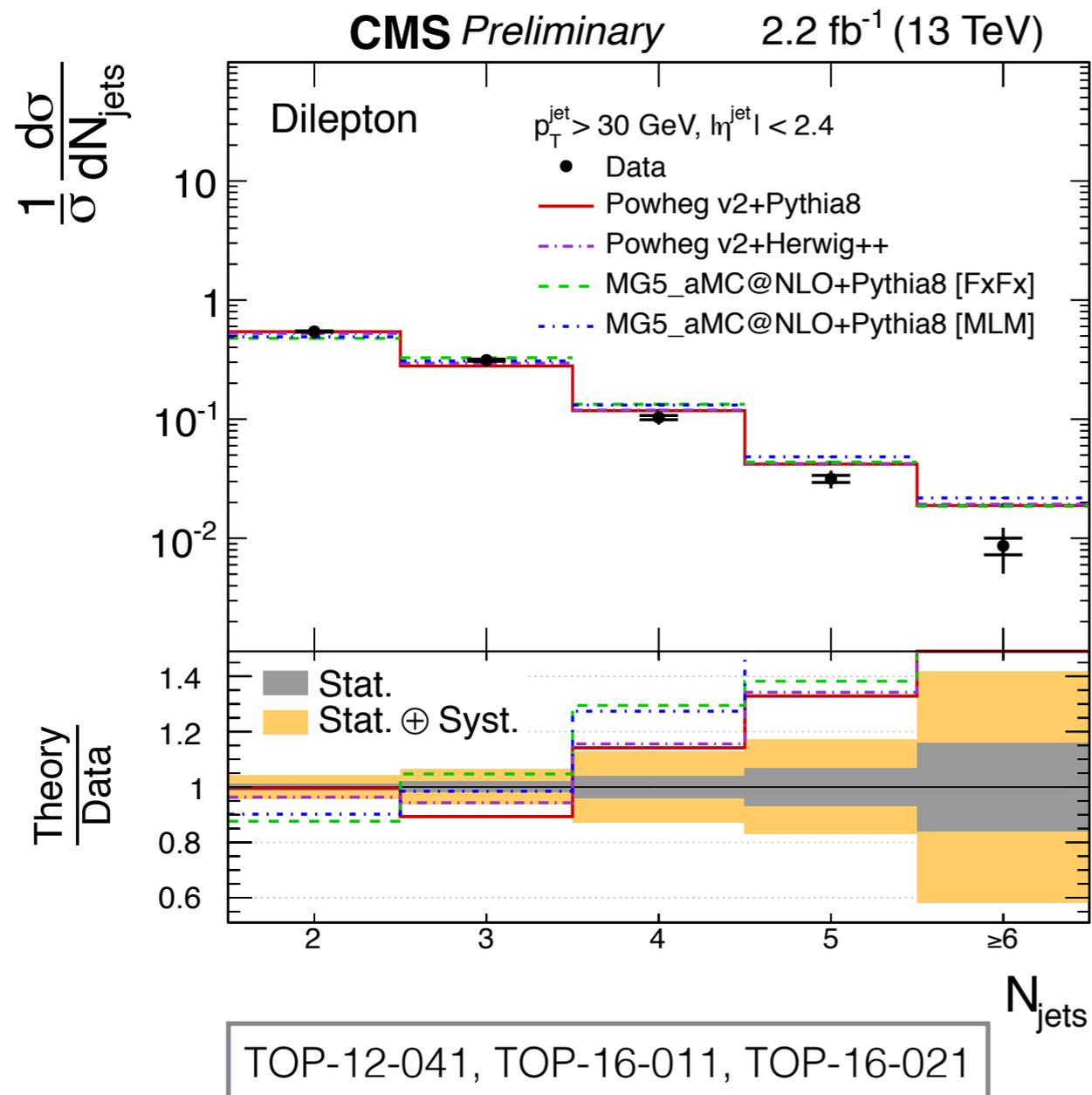


CMS-PAS-FSQ-15-007



* None of the tunes describe the data perfectly

Jet Multiplicity in Top Quark Pair Events



- Predictions overshoot the data for large jet multiplicities when out of the box parameters are used (in Monash-based tunes)
- Effect also observed with 8 TeV data.

Tuning Model Parameters in CMS Run II

- Charged particle multiplicity and pT-sum densities (in the transverse region) ==> Can not constrain MPI and shower ISR simultaneously.
- First, tune shower α_s^{ISR} (==> perturbative parameter that determines inclusive event properties)
 - ttbar jet kinematics ==> Sensitive to shower α_s^{ISR} but not so much to the UE.
 - Nominal ttbar simulation: Powheg+Pythia8 ==> include hdamp in the tuning.
- Then fit UE & MinBias data at 13 TeV to tune MPI parameters.
- Verify the tune with MinBias, DPS, UE, Drell-Yan, W/Z+jets, ... data.

Jet Multiplicity at $\sqrt{s} = 13$ TeV and Shower α_s+h_{damp} Tuning

CMS-PAS-TOP-16-021

- POWHEG: h_{damp} (h_{damp}) is the model parameter that controls ME/PS matching and effectively regulates the high- p_T radiation by damping real emissions generated by POWHEG with a factor of $h_{\text{damp}}^2 / (p_T^2 + h_{\text{damp}}^2)$. The default value is equal to the top-quark mass $m_t = 172.5$ GeV used in simulation.
- PYTHIA 8: `SpaceShower:alphaSvalue` (α_s^{ISR}) is the value of the strong coupling at m_Z used for the initial-state shower. The default value is $\alpha_s^{\text{ISR}} = 0.1365$ obtained from tuning to LEP event shapes [22] is kept for the final-state shower.

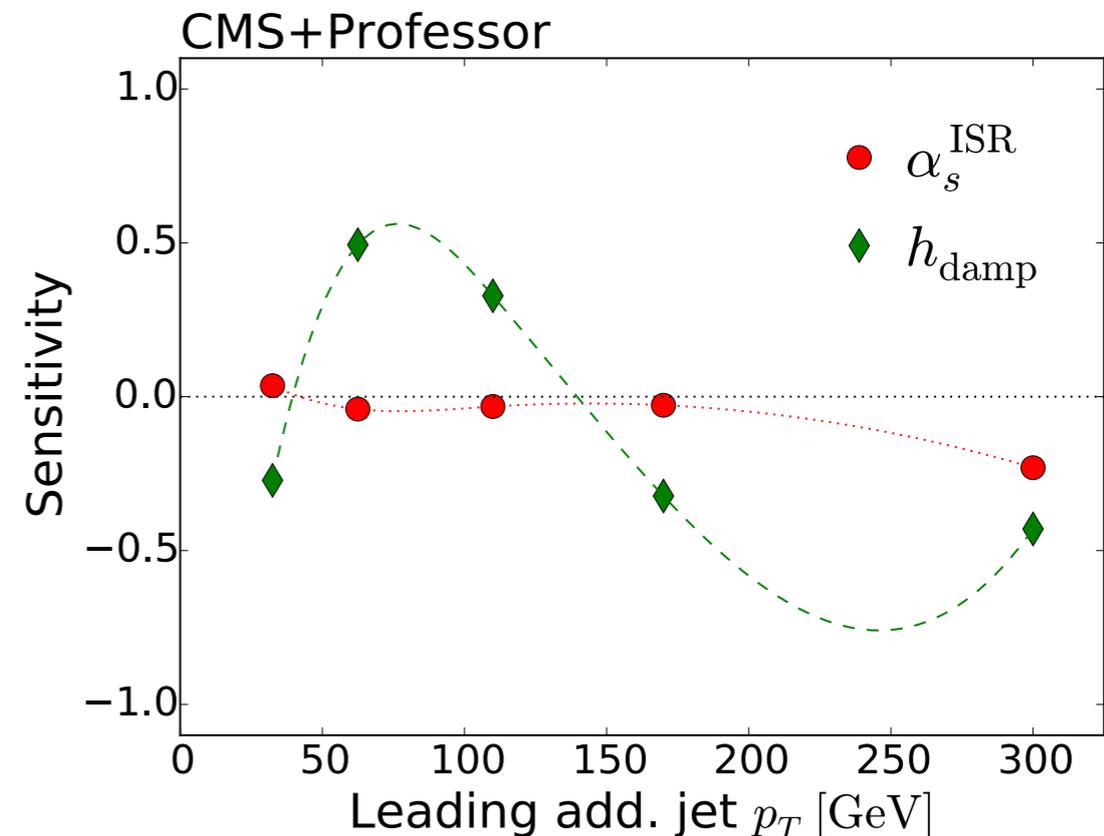
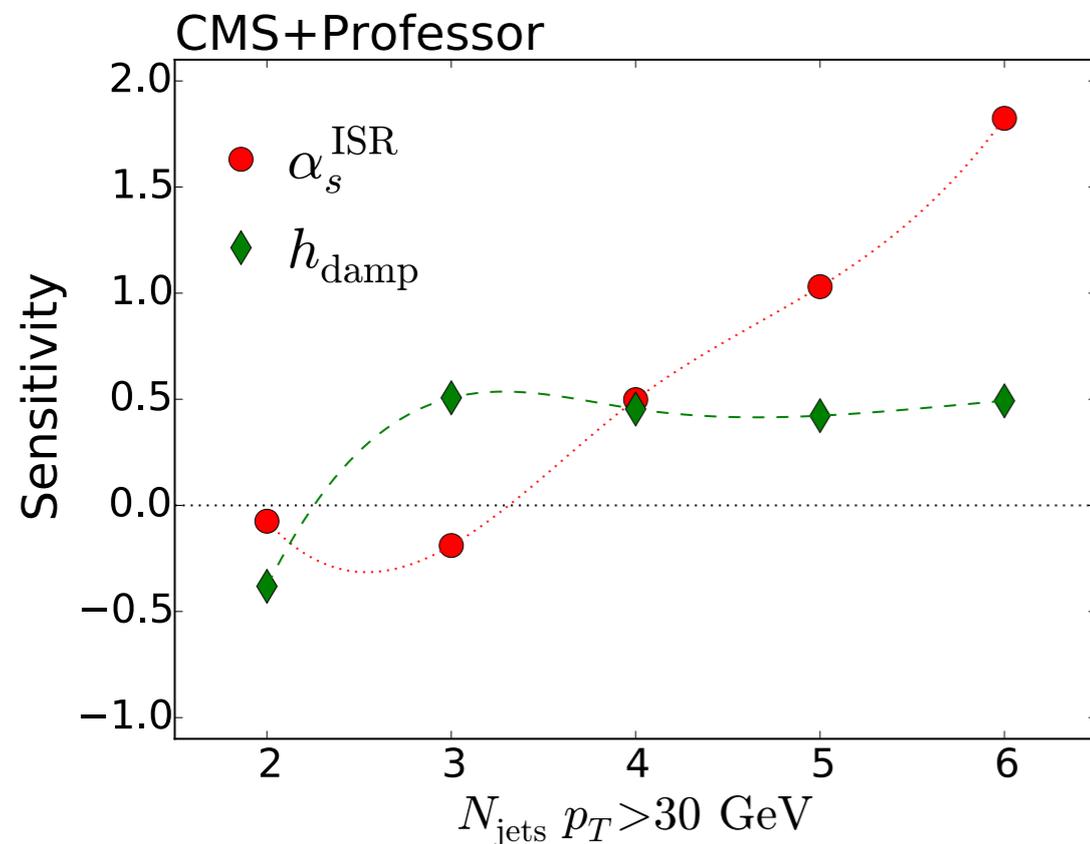
- 2-/3-jet events
- Lead. add. jet p_T

- $N_{\text{jets}} > 3$ where jets predominantly originate from the parton shower in Powheg+Pythia8

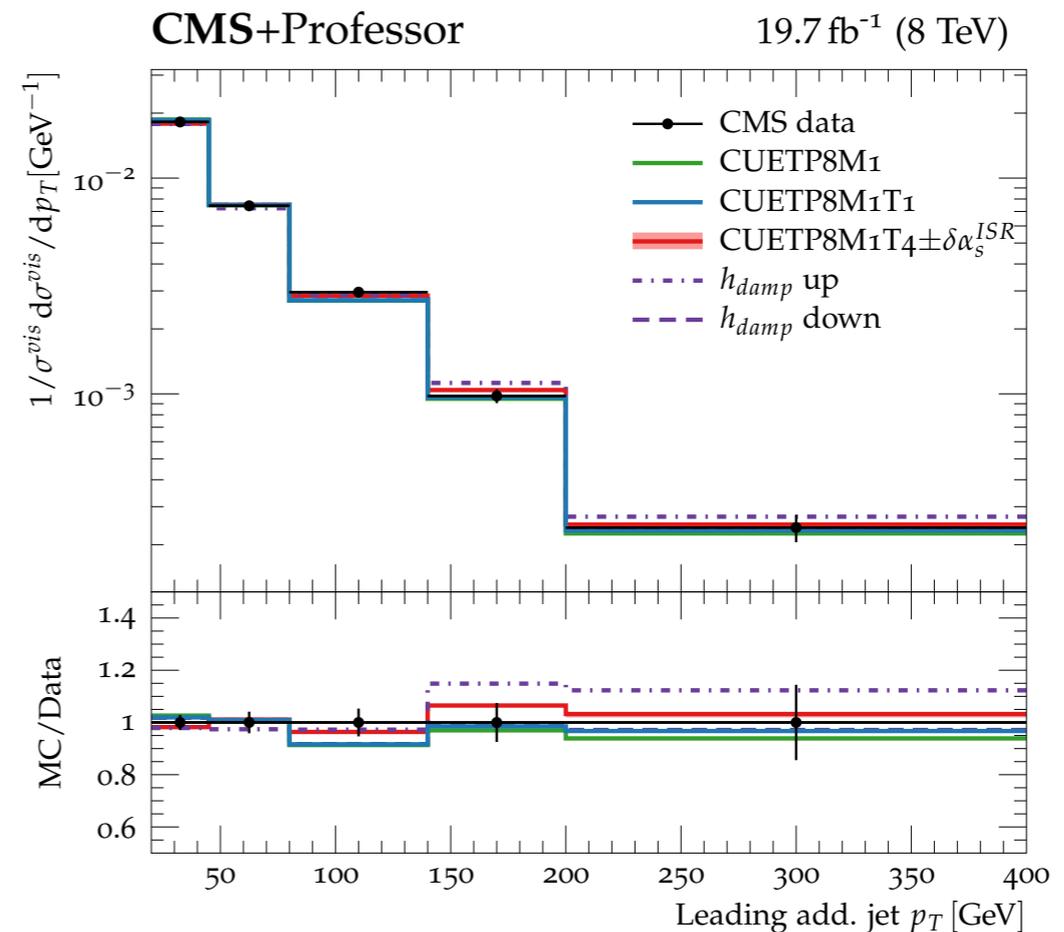
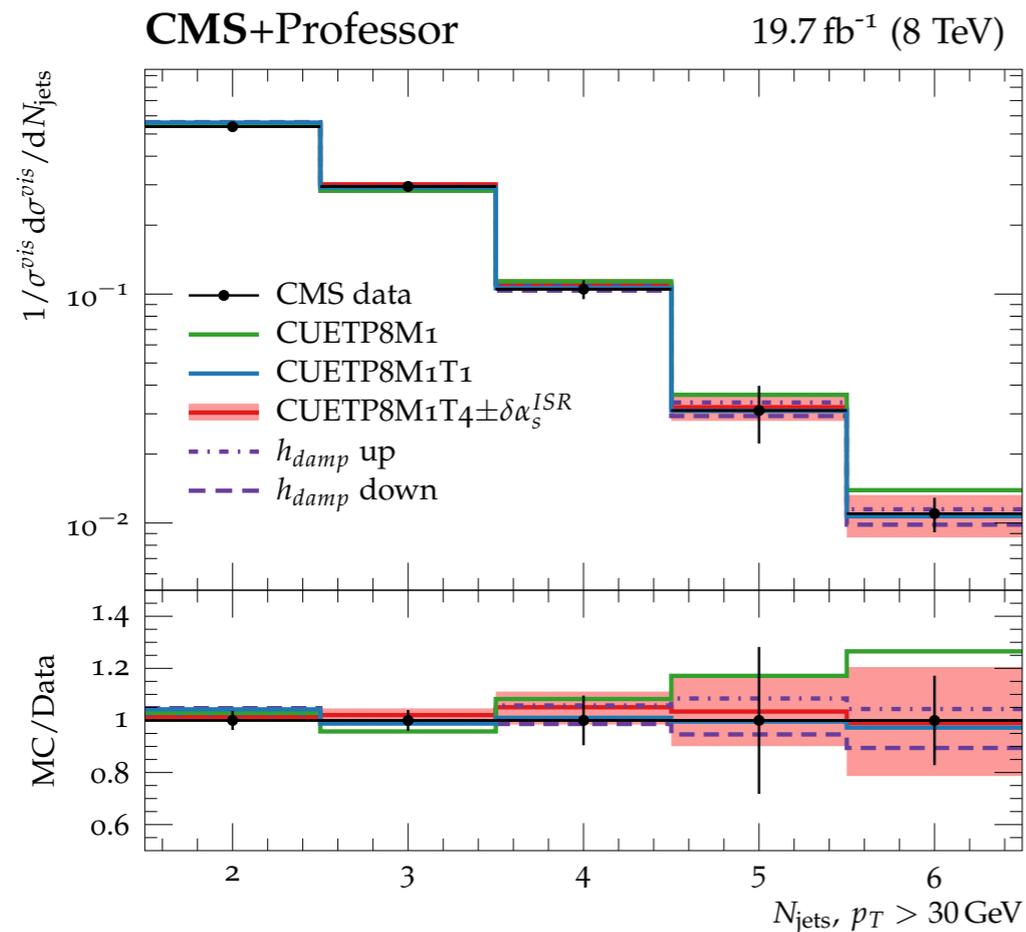
$$S = \frac{dMC(p)}{dp} \times \frac{p_c}{MC(p_c)}$$

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

See also the presentation by James Howarth on Wednesday.



CMS Shower $\alpha_s + h_{damp}$ Tuning



$$\alpha_s^{ISR} = 0.1108^{+0.0145}_{-0.0142}$$

$$h_{damp} = 1.581^{+0.658}_{-0.585} \times m_t$$

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==> Significantly lower shower α_s curing the overshoot of CUETP8M1 at high jet multiplicities.
 ==> Tuning α_s (w/o h_{damp}) using the same data yields $\alpha_s^{ISR} = 0.115^{+0.021}_{-0.019}$

<http://cms-results.web.cern.ch/cms-results/public-results/publications/TOP-12-041/index.html#AddFig>

The New UE Tune

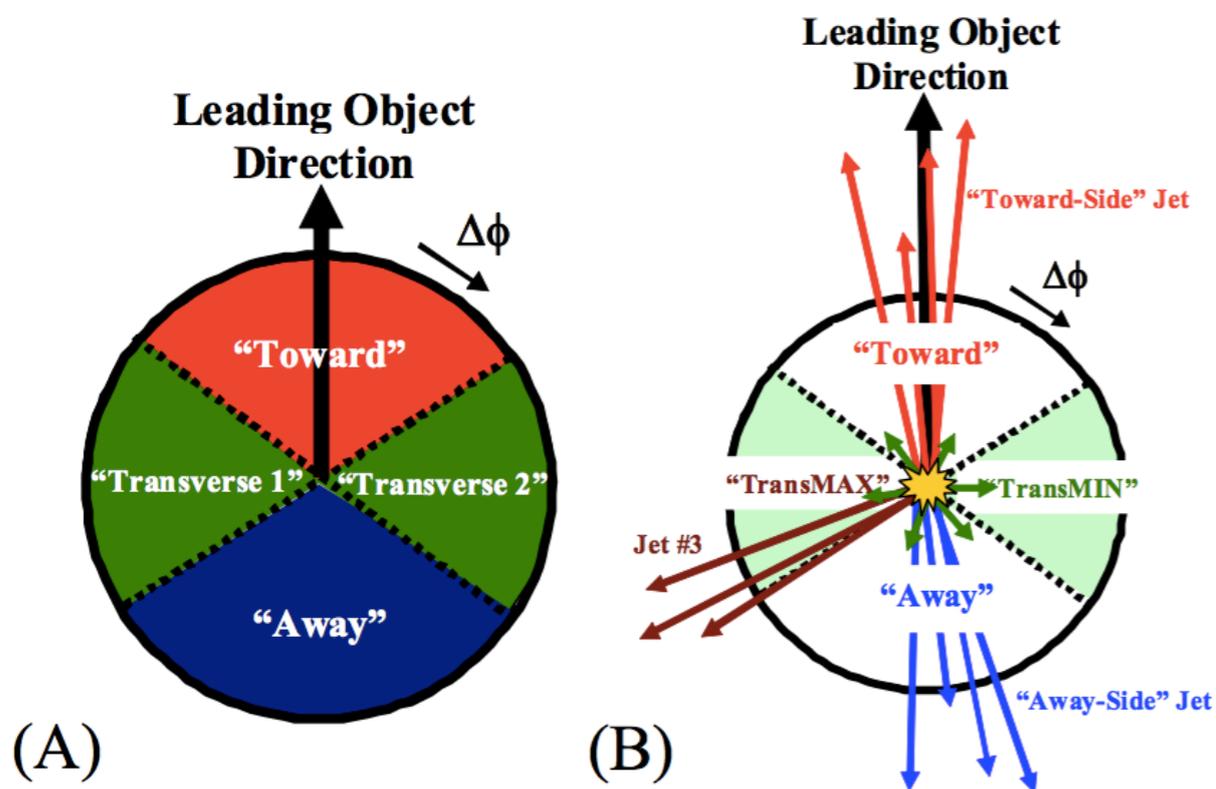
- Fixing the amount of ISR, a new UE tune is derived optimizing MPI parameters ==> Fit to 5 measurements

- UE data ($p_T > 0.5$ GeV, $|\eta| < 2$): Charged-particle and energy densities in TransMIN and TransMAX regions vs leading charged particle p_T .

$$\frac{\langle \eta_{ch} \rangle}{\Delta\eta\Delta(\Delta\phi)}$$

$$\frac{\langle \Sigma p_T \rangle}{\Delta\eta\Delta(\Delta\phi)}$$

- MB data ($p_T > 0$): Charged-particle η distribution.



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

- * TransMax: maximum activity == MPI/BR & ISR/FSR
- * TransMin: minimum activity == MPI/BR
- * TransAve = (TransMax + TransMIN)/2
- * TransDIF = TransMax - TransMIN == ISR/FSR

The New UE Tune

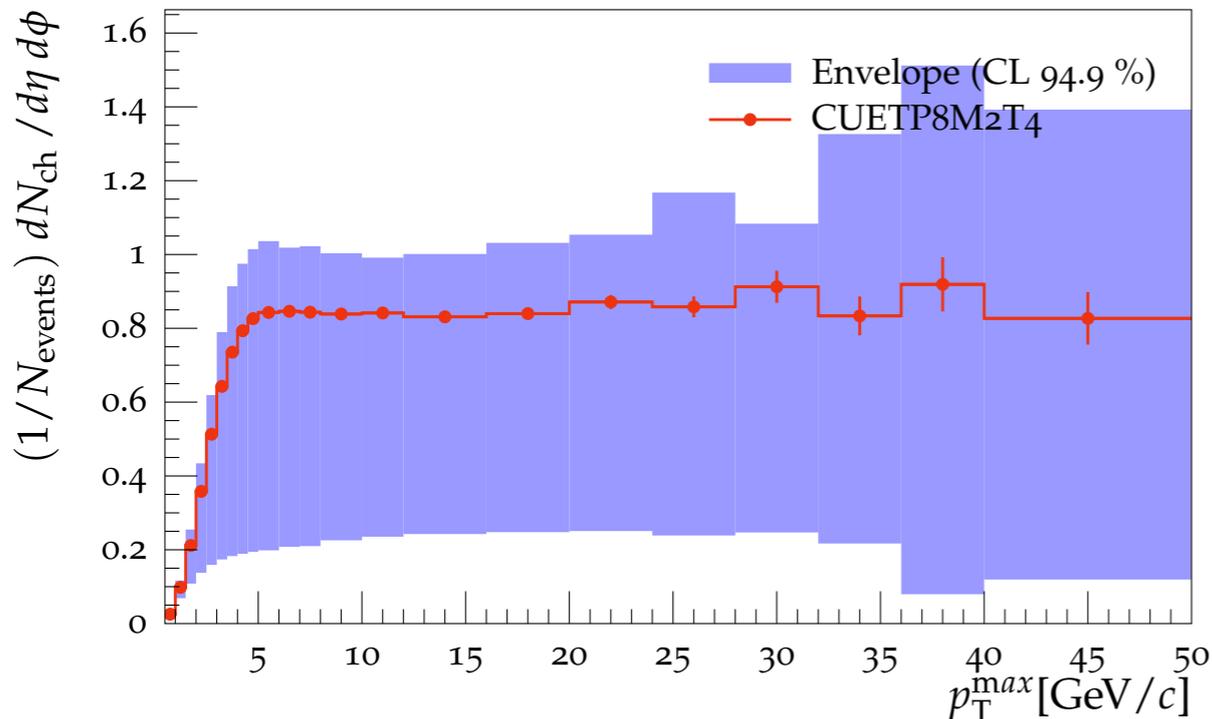
	CUETP8M1	CUETP8M2T4
Tune	pp 14	pp 14
Tune	ee 7	ee 7
MultipartonInteractions ecmPow	0.2521	0.2521
SpaceShower:alphaSvalue	0.1365	0.1108
PDF pSet LHAPDF6	NNPDF23_lo_qed_as_0130	NNPDF30_lo_as_0130
MultipartonInteractions:pT0Ref	2.40	2.20
MultipartonInteractions:expPow	1.6	1.6
ColourReconnection:range	1.8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

Baseline:
Monash tune

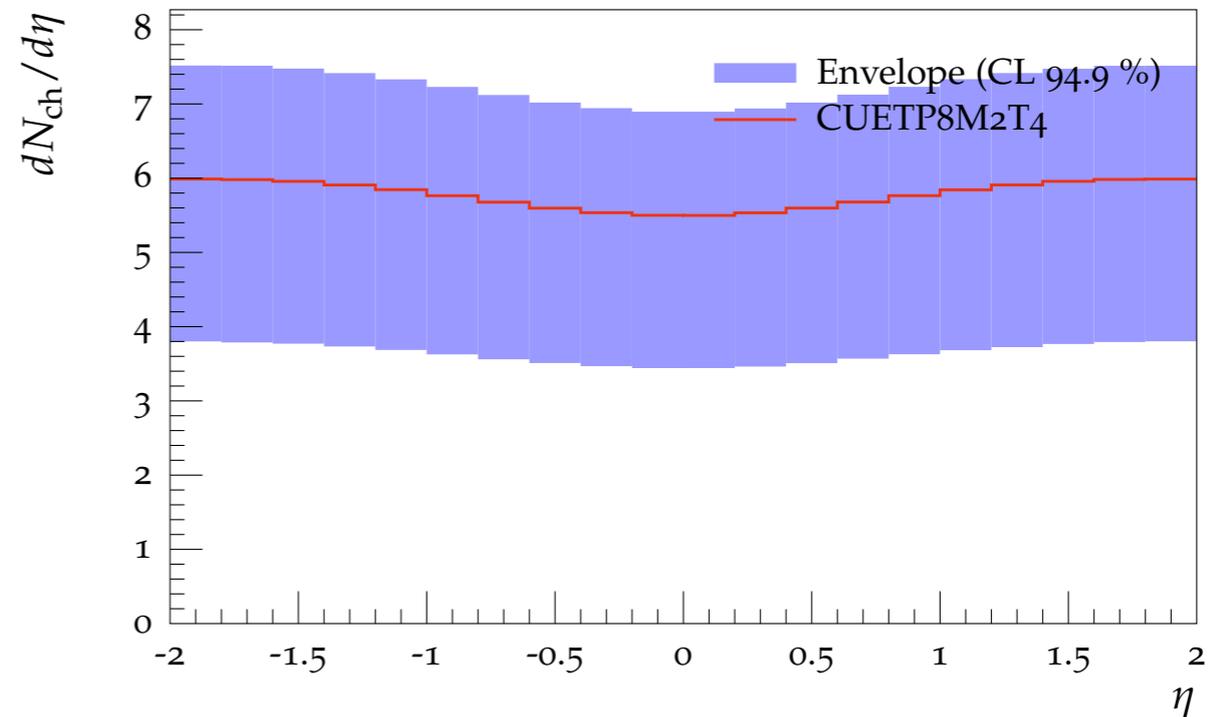
Tuning ranges
1.0-3.0
0.4-10.0
0.0-9.0

* NNPDF3.0LO includes forward charm data from LHCb ==> improves low-x gluon distribution
==> results in smaller low-x than NNPDF2.3LO

TransMIN charged particle density $\sqrt{s} = 13$ TeV

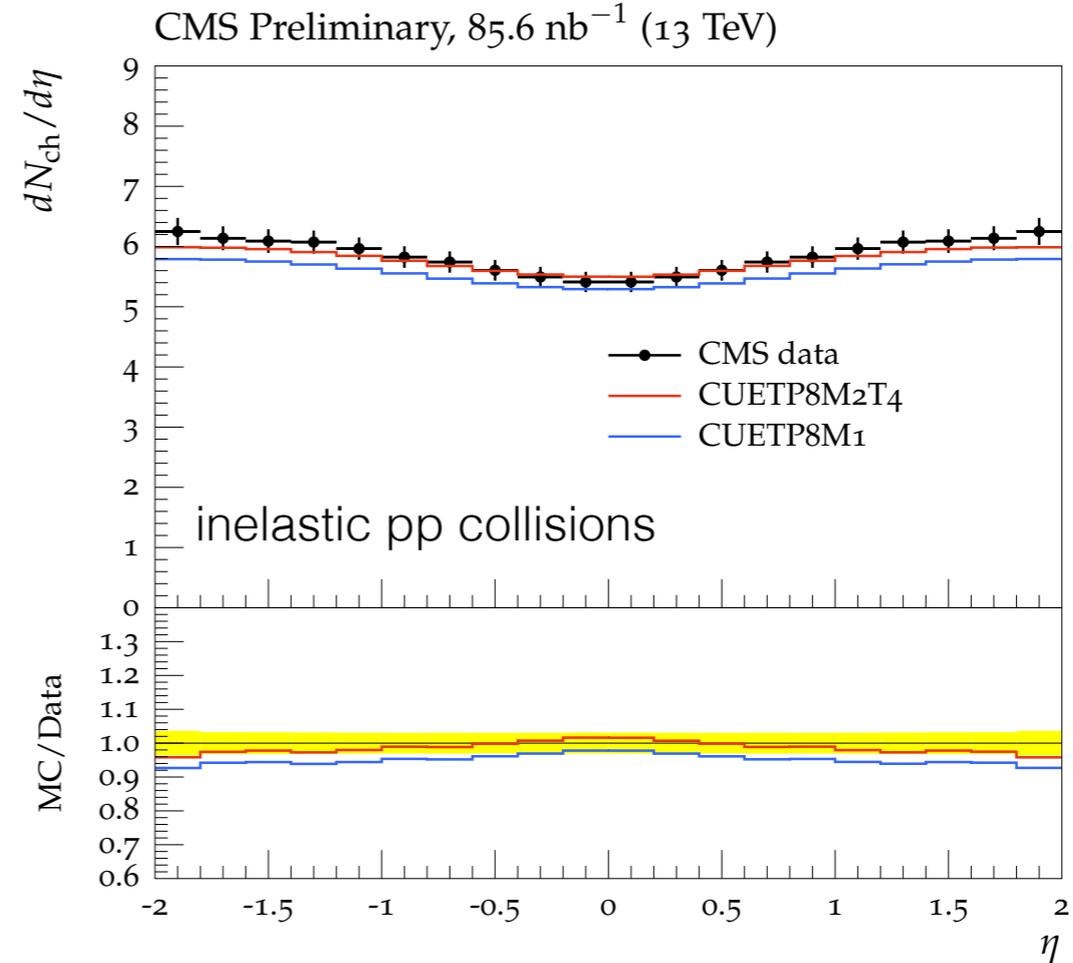
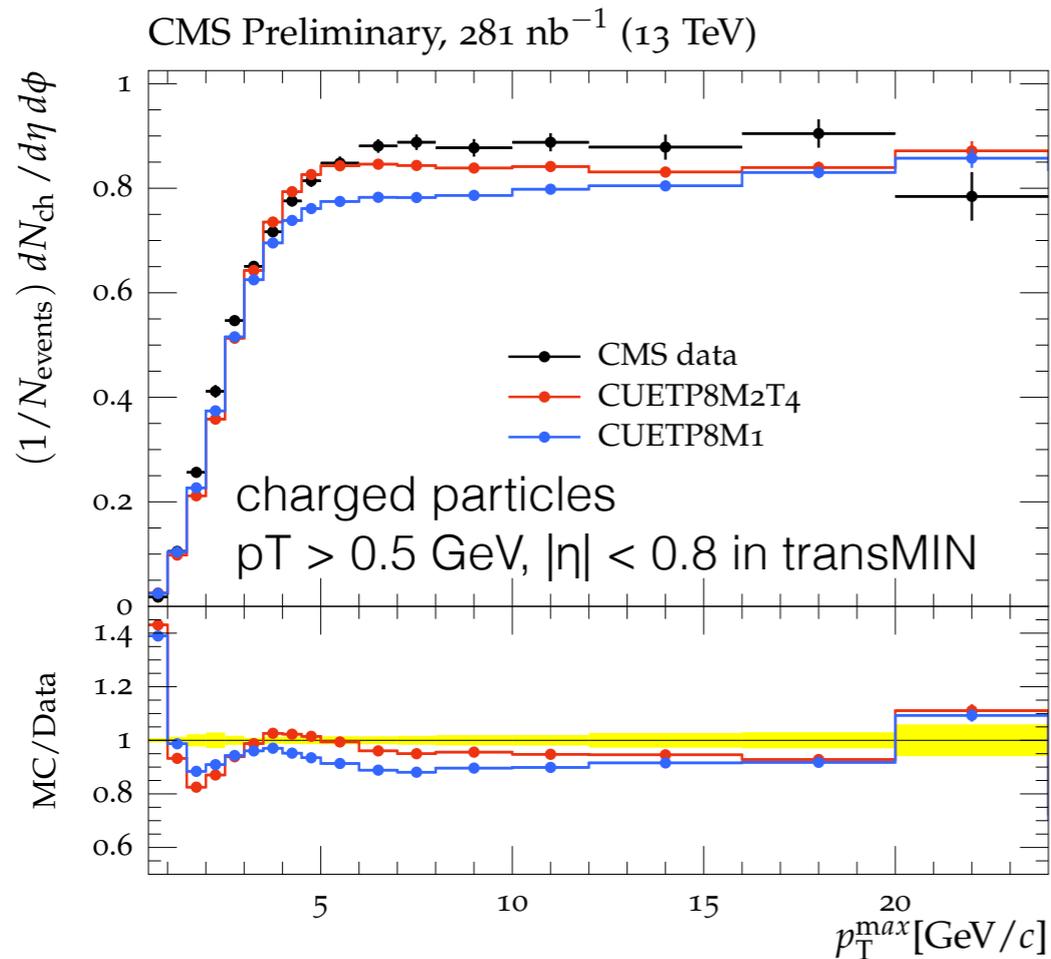


Charged-particle multiplicity, $\sqrt{s} = 13$ TeV



TOP-16-021, GEN-17-001 in preparation

Performance of the New CMS Tune

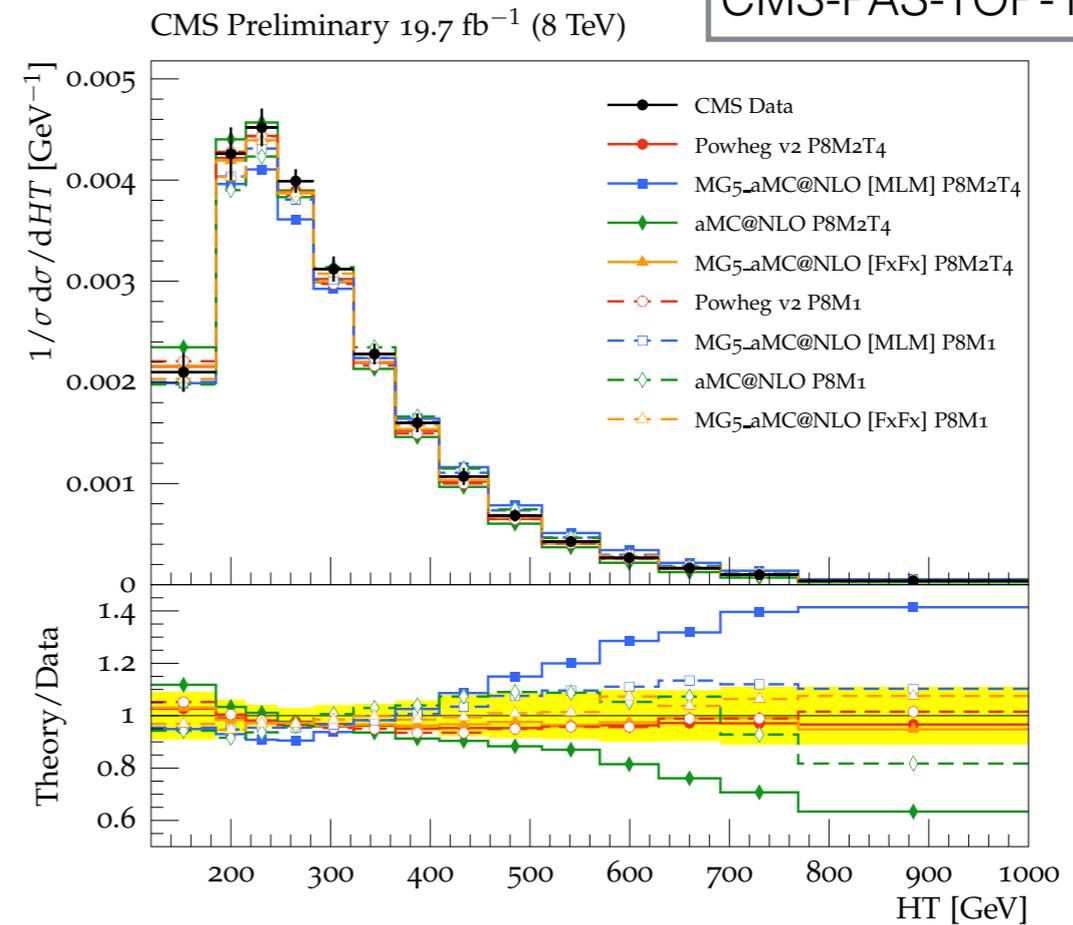
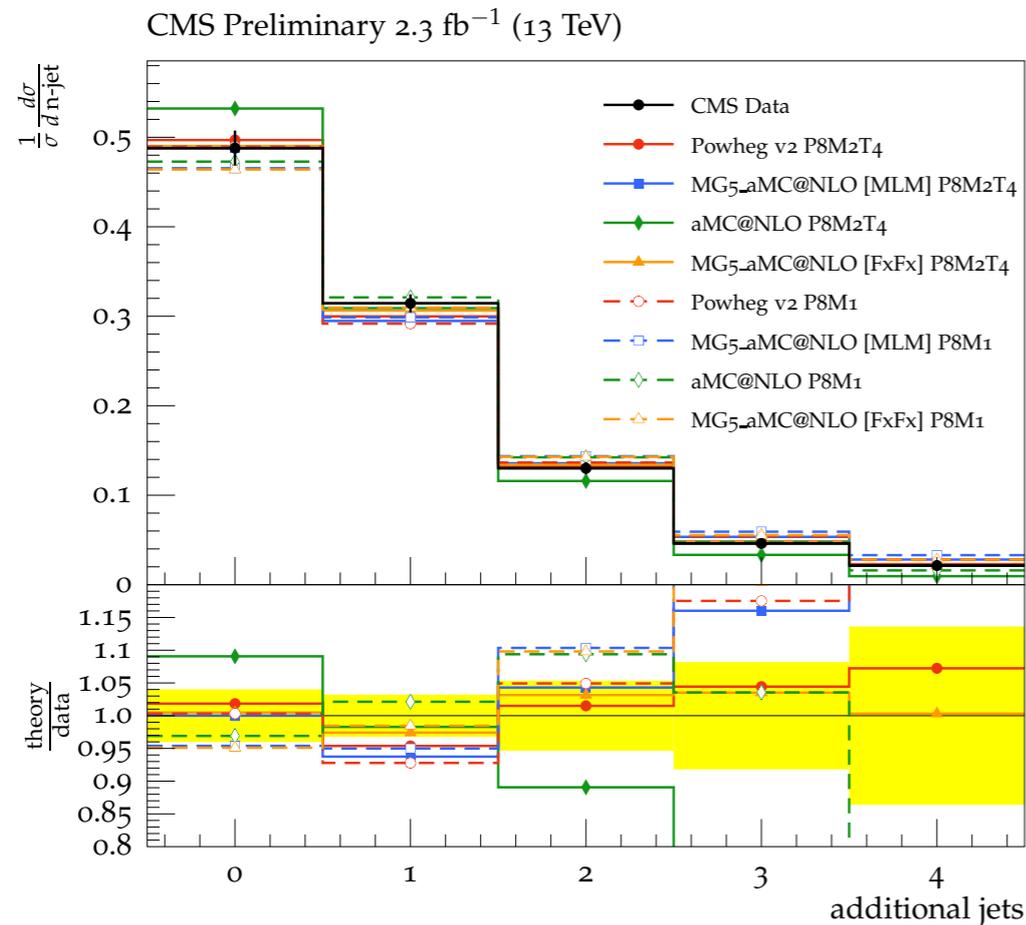


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- New tune describes UE and MB data at $\sqrt{s} = 13 \text{ TeV}$ simultaneously
- Performs well at $\sqrt{s} = 7 \text{ TeV}$ as well.
- Provides a better description of the plateau
- Single-diffractive enhanced observables and inelastic cross sections not well described
- Comparisons with other processes, UE and DPS observables and tuning for Herwig7 and Sherpa coming soon.

Performance of the New CMS Tune with Top Quark Data

CMS-PAS-TOP-16-021



- Powheg+Pythia8 with the new tune describes the top quark data very well (except top p_T)
- MG5_aMC@NLO [FxFx] with the new tune describes the data as well as Powheg+Pythia8 (top p_T and except gap fraction).
- MG5_aMC@NLO [MLM] and aMC@NLO + Pythia8 with the new tune does not describe the top quark data in general.
- Global event variables do not get modified significantly with the change of α_s^{ISR} (except Mg5_aMC@NLO [MLM] and aMC@NLO).
- Comparisons with W/Z+jets simulated using different configurations coming soon.

Existing (Main) CMS Run II MC Configurations and the New Tune

ME+PS	NLO	LO	PS
aMC@NLO + Pythia8	= 0 jet	= 1 jet	≥ 2 jets
Powheg + Pythia8	= 0 jet	= 1 jet	≥ 2 jets
MG5_aMC@NLO + Pythia8 [MLM]	-	≤ 3 jets	≥ 4 jets
MG5_aMC@NLO + Pythia8 [FxFx]	≤ 2 jets	= 3 jets	≥ 4 jets

- FxFx and MLM have better accuracy for additional jets.
- Different values of α_s for LO and NLO matrix elements.
- Different shower parameters/tuning uncertainties.
 - Different ME-PS schemes.
 - Different jet emission probability.

Show α_s Tuning in Different Configurations

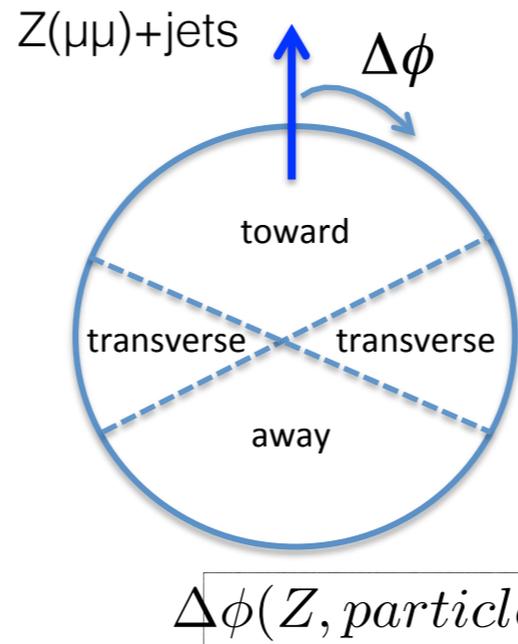
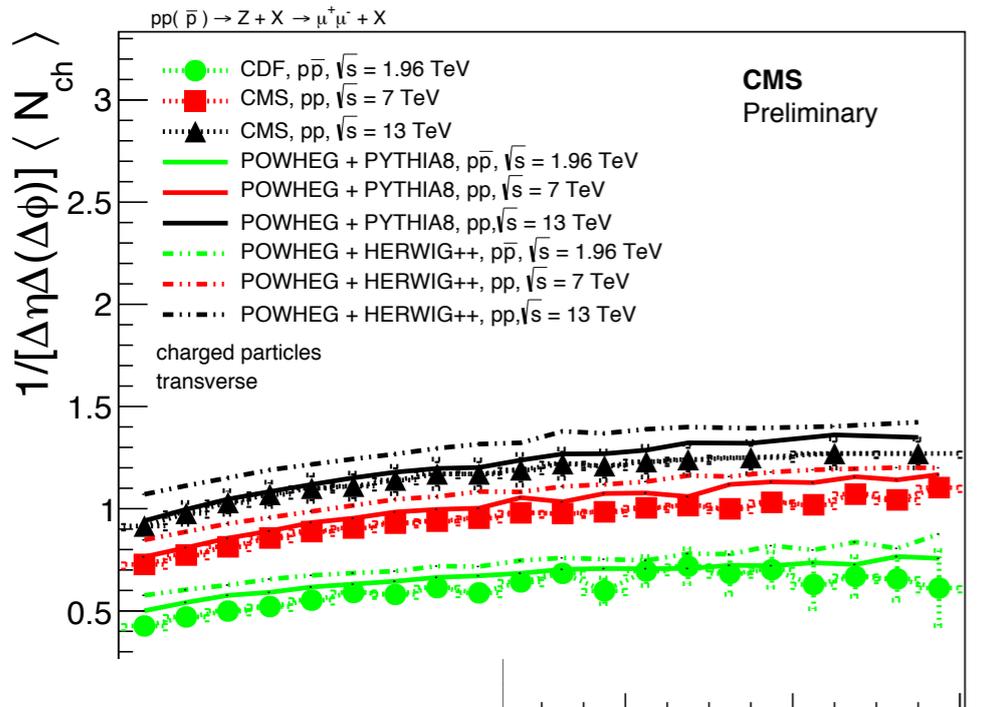
- Powheg is less sensitive to tuning of the shower α_s than MG5_aMC@NLO+Pythia
- Not trivial to directly predict the outcomes of using the optimized shower α_s in other configurations (esp. matched/merged).
 - Consistency of the α_s value in the PS and ME may be important for matched/merged emissions (see Cooper et al. EPJ C72 (2012) 2078 that advocates this for MLM).
 - Powheg+Pythia ==> N/A: first emission is handled by Powheg (down to ~ 1 GeV), all subsequent emissions by Pythia
 - MG5_aMC@NLO + Pythia [FxFx & MLM] ==> applies to first ~ 3 emissions.
 - aMC@NLO + Pythia [w/o merging] ==> applies to first emission
 - Different α_s values may be needed for matched and unmatched emissions.
- Further studies ongoing to ensure FxFx and MLM will behave better than Powheg and MC@NLO as expected from additional ME accuracy .

UE Event in Hard Processes

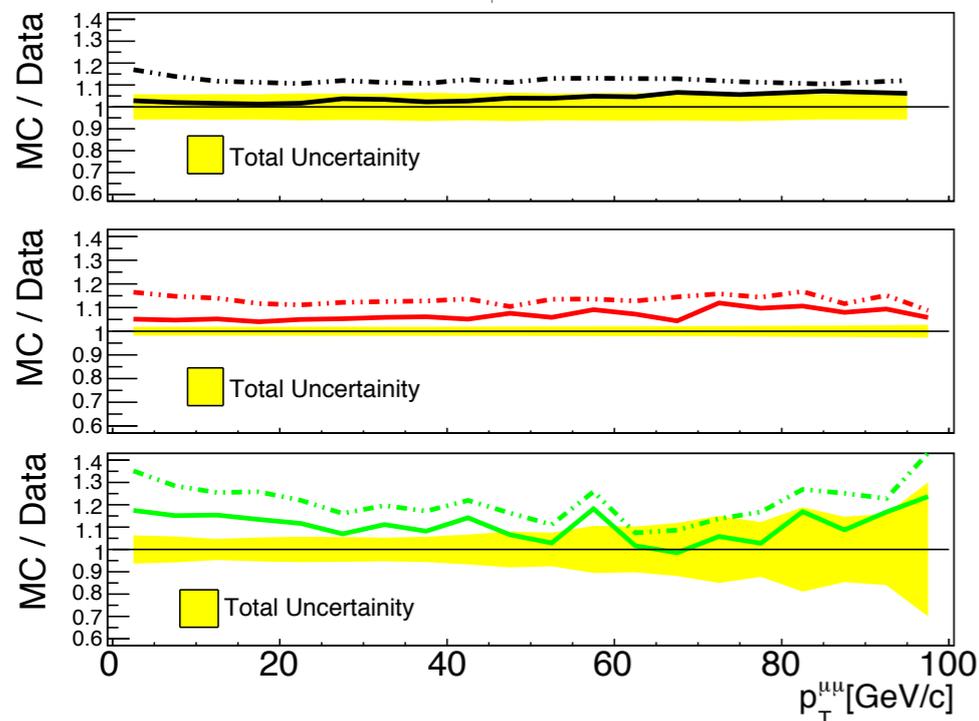
- Z+jets and ttbar measurements
 - to understand the sensitivity to different hard processes and
 - scale dependence ==> expected to increase with increased momentum transfer and
 - systematic uncertainties related to the modelling of the UE (esp. in top mass measurements).
 - Possibility of separating MPI from the radiation contribution. [CMS EPJ C72 (2012) 2080, Kumar et al. PRD93 (2016) 054019]

UE in Z+jets Events

CMS-PAS-FSQ-16-008



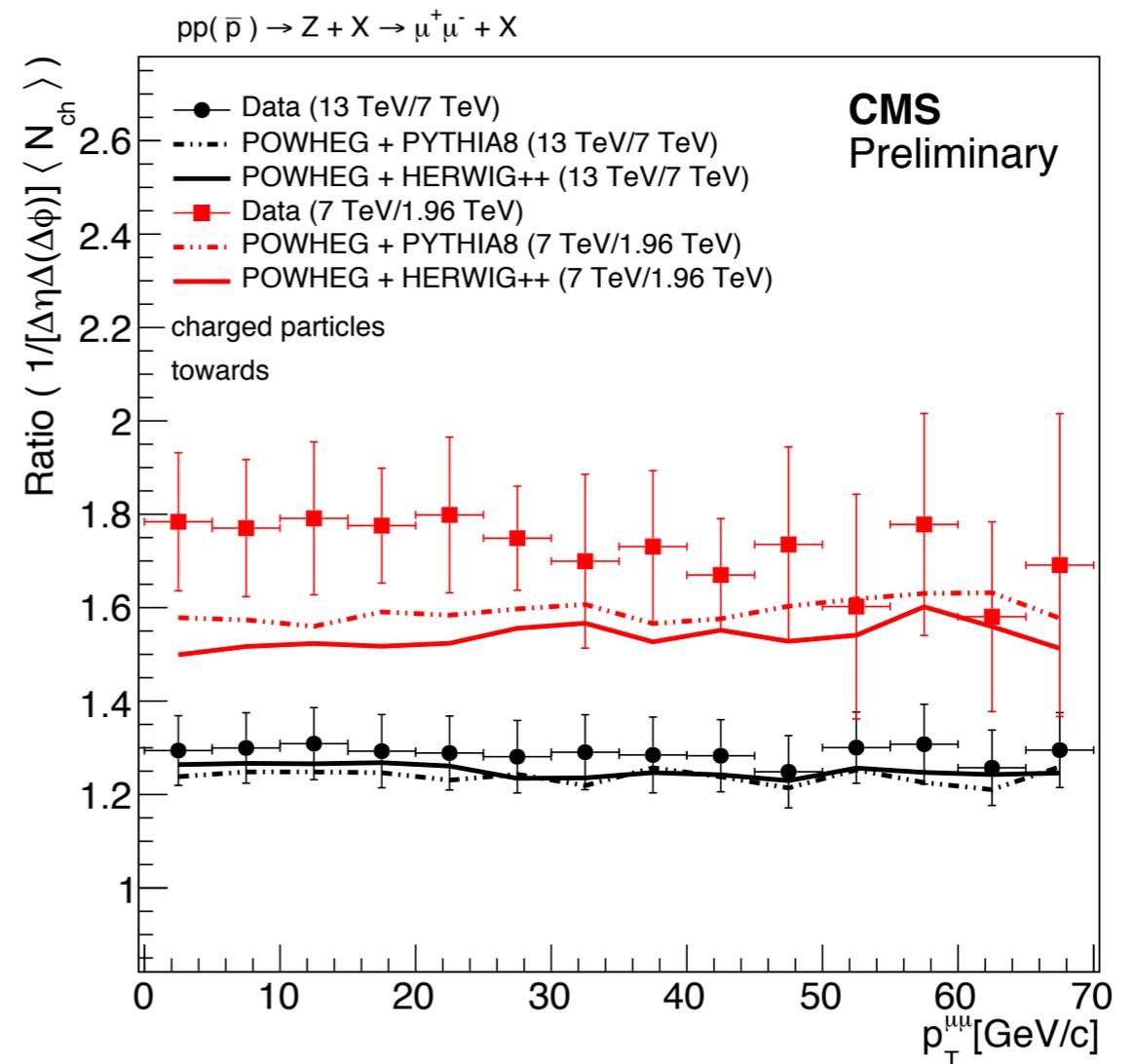
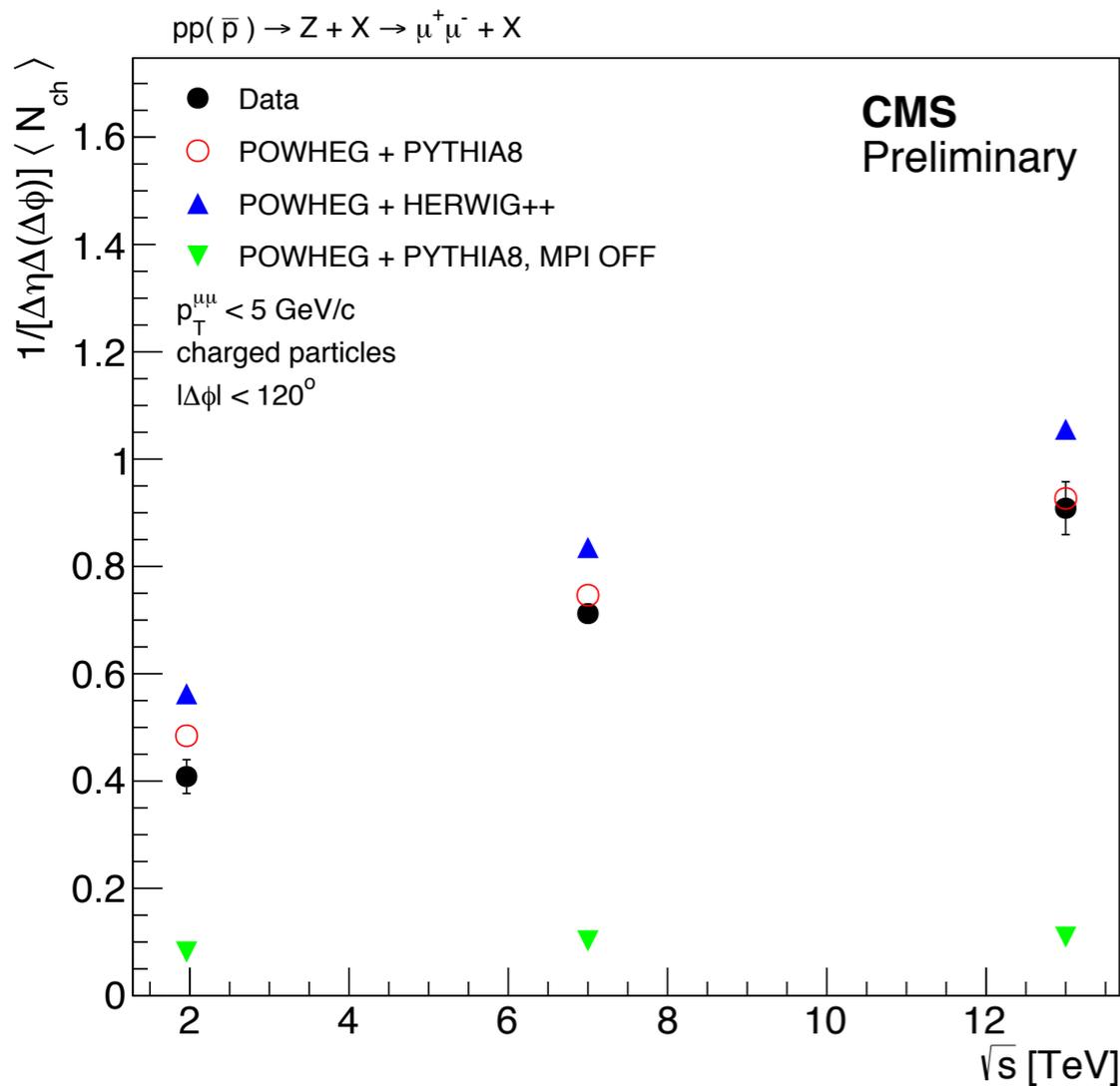
$p_T(\text{ch}) > 0.5 \text{ GeV}, |\eta| < 2$



- * Powheg (MiNLO): 2 jets from ME +
- * Pythia8 with CUETP8M1 agreement w/ data within
 - * 10% @ $\sqrt{s}=7, 1.96 \text{ TeV}$
 - * 5% @ $\sqrt{s}=13 \text{ TeV}$
- * Herwig++ with EE5C agreement w/ data within
 - * 20-40% @ $\sqrt{s}=1.96 \text{ TeV}$
 - * 10-20% @ $\sqrt{s}=7 \text{ TeV}$
 - * 10-15% @ $\sqrt{s}=13 \text{ TeV}$

Dominant uncertainty: tracking efficiency

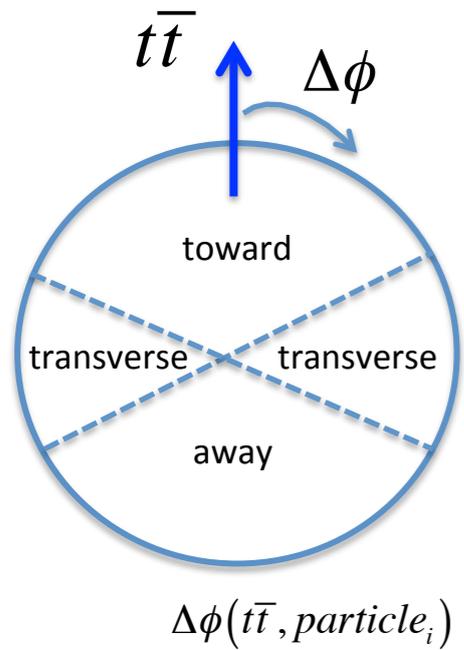
UE in Z+jets Events



- $p_T(\mu\mu) < 5$ GeV \implies Mainly MPI
 - very small contribution from radiation
- The UE activity \sim doubles w/ logarithmic increase from $\sqrt{s}=1.96$ to 13 TeV.
- Powheg+Pythia8 provides a better description.

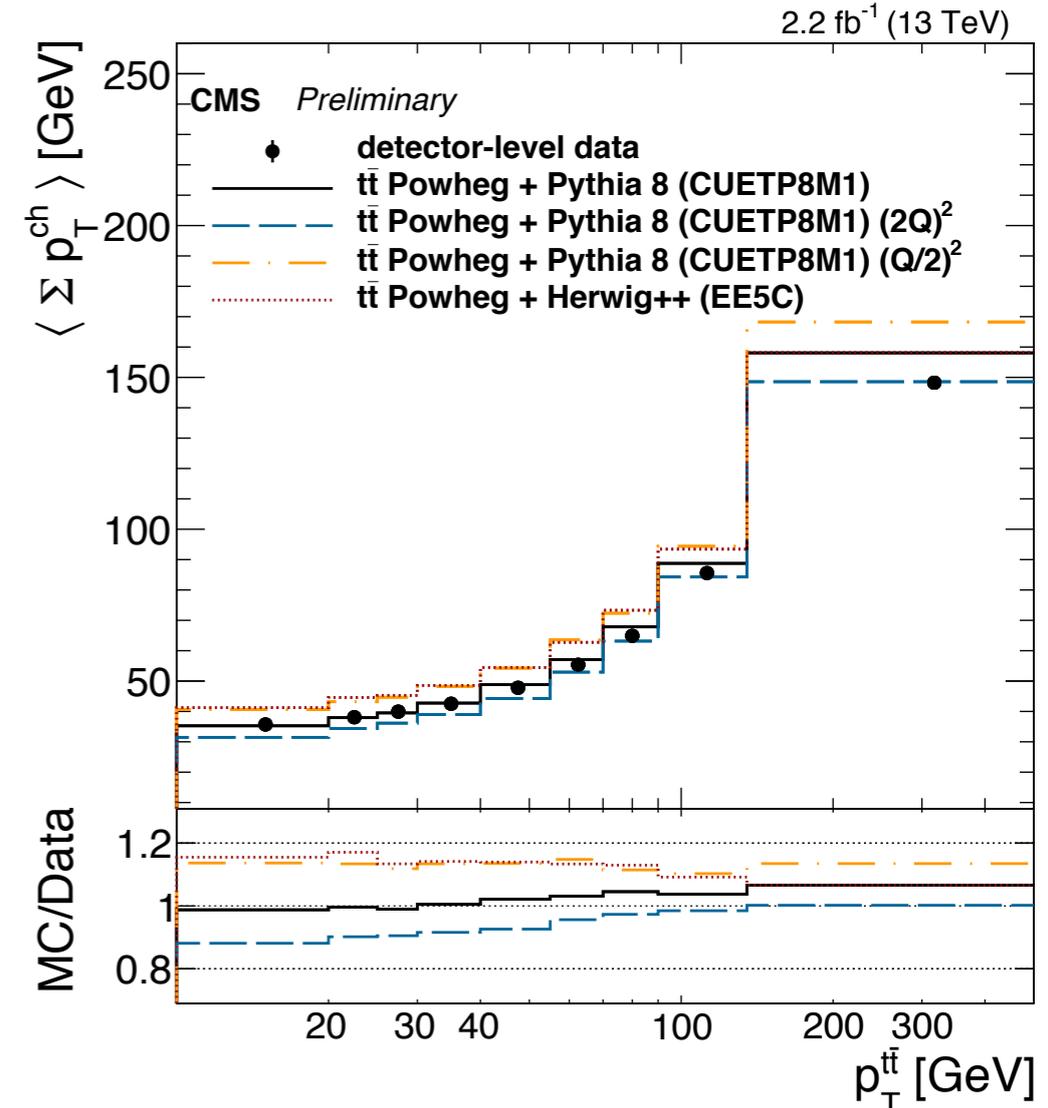
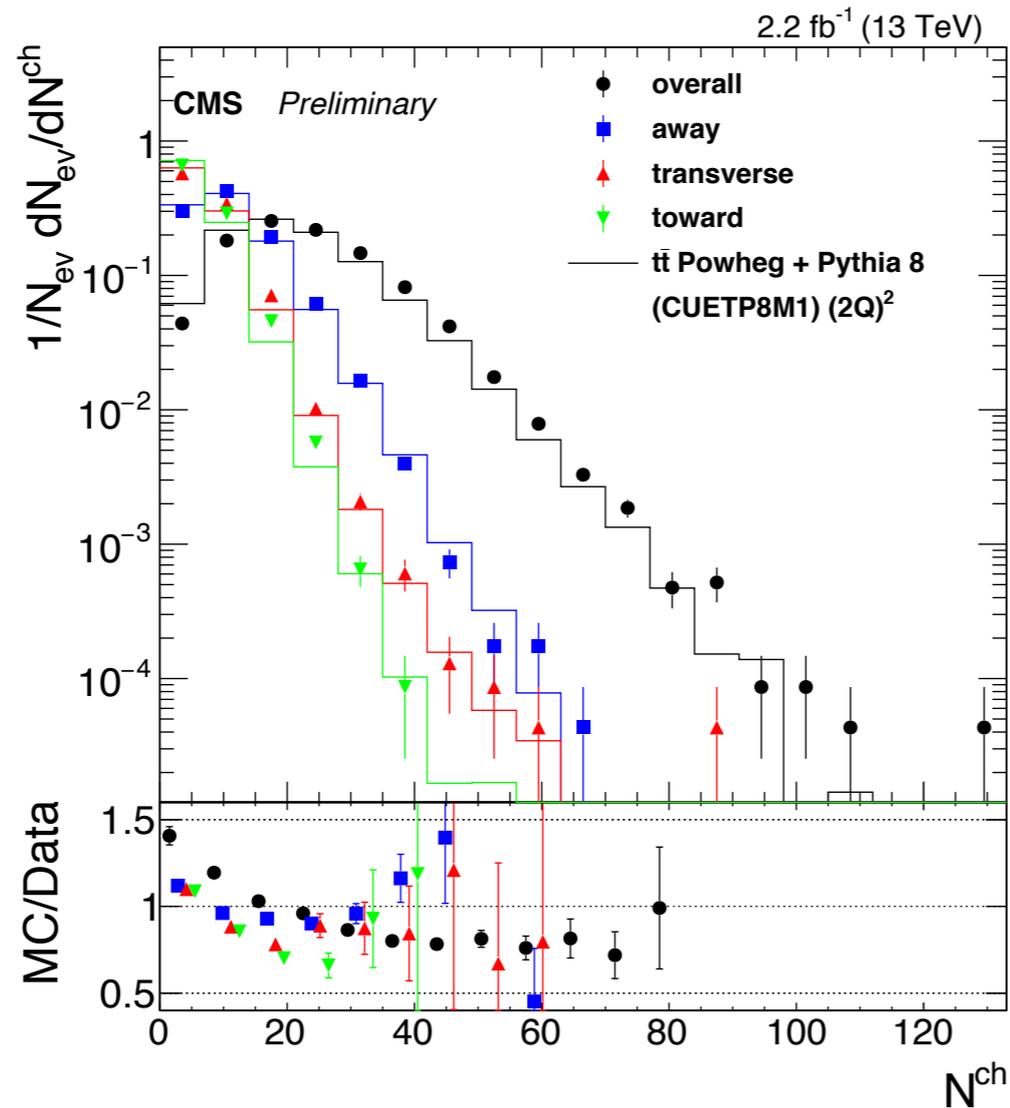
- The increase in UE from 7 to 13 is described well by simulations but underestimate the UE evolution from 1.96 to 7 TeV.

UE in ttbar Events



$p_T(\text{ch}) > 0.5 \text{ GeV}, |\eta| < 2.1$

CMS-PAS-TOP-15-017



- Fair agreement between Powheg + Pythia8 CUETP8M1 tune predictions.
- UE is sensitive to QCD scales / ISR.
- A complete measurement of UE in ttbar events may lead to more precise top mass with better understood systematics.

Summary and Conclusions

- A new CMS Pythia8 tune is ready
 - with lower shower α_s tunes to jet kinematics in top quark pair events.
 - It describes UE and MB observables well
 - Powheg+Pythia8 and MG5_aMC@NLO [FxFx] with the new tune provide good description of all top quark distributions (except top p_T).
 - Comparisons with other processes and configurations in the works.
 - Further studies ongoing to understand tuning in matched/merged configurations.
- Ongoing efforts to measure UE in Z+jets and top quark pair events.