DIS 2016

Measurement of the underlying event at 13 TeV with the CMS experiment

Ada Solano
Univ. of Torino and INFN

On behalf of the CMS Collaboration

Outline

CMS-PAS-FSQ-15-007: Underlying event measurements with leading particles and jets in pp collisions at √s = 13 TeV

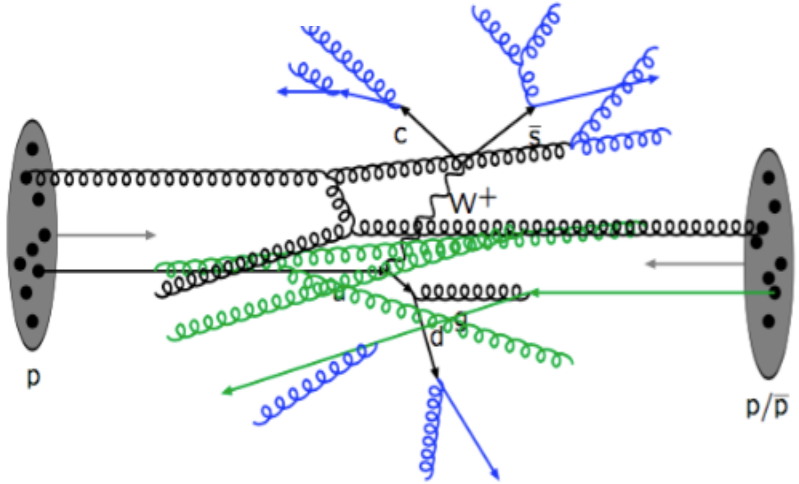
- **Underlying events and Observables**
- **Event selection and analysis**
- **MC samples**
- **Unfolding and Systematics**
- **Results**
- **Summary and Conclusions**

+ a reminder to

CMS-PAS-TOP-15-017: Underlying event measurement with ttbar+X events with pp collision data at √s = 13 TeV

that has been presented by Buğra Bilin in yesterday's afternoon session of WG4 – Heavy Flavours

Underlying events @ LHC



[+ colour reconnection, hadronisation, etc..
+ pile-up]

pp collisions at the LHC:

- hard scattering
- softer partonic scatters (MPI)
- initial- and final- state radiation (ISR/FSR)
- beam remnants and soft rescattering of beam remnants (BR)

UE: additional activity on top of the hard scattering

Hadronic activity at the high luminosities of the LHC is dominated by the UE

⟶ **accurate understanding needed for precise measurements of SM and BSM**
[top-quark measurements as an example]

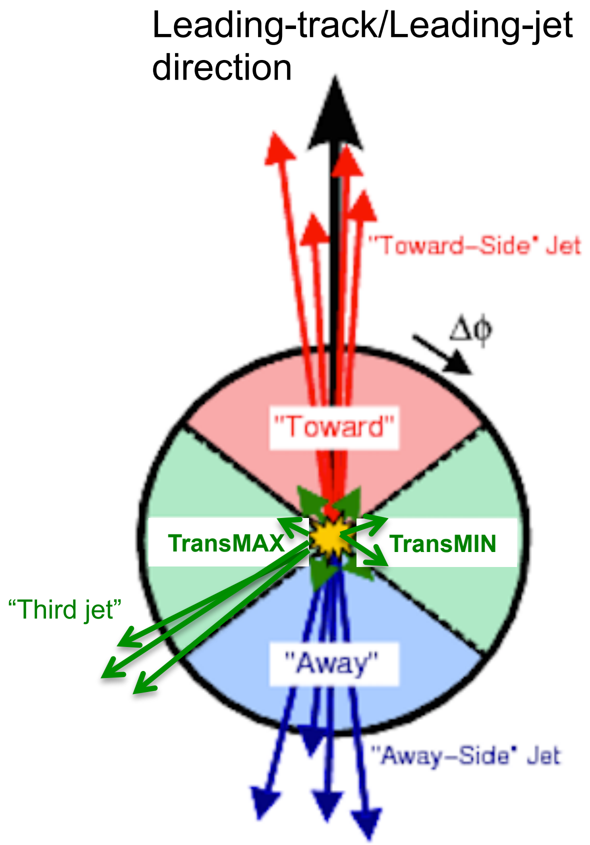
The UE consists of semi-hard and low-momentum processes

⟶ phenomenological description

⟶ **detailed understanding crucial for MC tuning**
[for the latest tunes by CMS see EPJ C76 (2016) 155]

UE observables

Particle properties in **regions transverse** to the **direction of hard scattering products**



Transverse regions: $60^o < |\Delta\phi| < 120^o$:

- **TransMAX:** maximum activity side, often containing a 3rd jet ➔ **MPI/BR + ISR/FSR**
- **TransMIN:** minimum activity side ➔ **MPI/BR**

TransAVE = (TransMAX + TransMIN)/2

TransDIF = TransMAX – TransMIN ➔ ISR/FSR

Observables:

- average charged-particle multiplicity density **(particle density) : $<N_{ch}>/[\Delta\eta\ \Delta(\Delta\phi)]$**
- average transverse-momentum scalar sum density **(energy density) : $<\Sigma p_T>/[\Delta\eta\ \Delta(\Delta\phi)]$**

Event selection and analysis

CMS-PAS-FSQ-15-007

- **Data sample:**
  - July 2015 data, $\sqrt{s}$ = 13 TeV, L = 218 nb^{-1}
  - Low pile-up: <PU> = 1.3
  - ZeroBias trigger: only coincidence of both beam pick-up timing devices - BPTX
- **Vertex requirement:**
  - Exactly one primary good vertex
  - Good vertex = within 10 cm in *z*-direction and 2 cm in *xy*-plane from nominal IP; at least 5 degrees of freedom (*dof* > 4)
- **Track requirements:**
  - High quality tracks (σ_{p_T}/p_T <0.05) with $p_T \geq 0.5$ GeV within $|\eta| < 2$
  - Cut on the impact parameter in order to remove secondary decays
- **Jet requirements:**
  - Built with the same previous track selection in $|\eta| < 2.5$, using the SISCone jet algorithm with distance parameter R = 0.5
  - $p_T^{jet} \geq 1$ GeV within $|\eta| < 2$

❖ **Leading track/jet: highest $p_T \geq 0.5$ ($p_T^{jet} \geq 1$) GeV within $|\eta| < 2$**

❖ **All final-state charged-particles with $p_T \geq 0.5$ GeV in $|\eta| > 2$ used for average particle/energy density calculation in transverse regions**

MC samples

CMS-PAS-FSQ-15-007

❑ PYTHIA8

Lund string hadronisation model; p_T-ordered parton shower; MPI and parton showers interleaved in one common sequence of decreasing p_T values

- New CMS tune **CUETP8M1** [EPJC 76 (2016) 155]:
  - validation and correction with PU 1.3
  - PU systematics without PU
- **Monash**: comparison with corrected data

❑ HERWIG++

Cluster hadronisation model; angular-ordered parton shower; MPI model similar to PYTHIA but no interleaving with parton showers

- New CMS tune **CUETHS1:**
  - model dependency systematics
  - comparison with corrected data

❑ EPOSv1.99

Soft-parton dynamics described in terms of virtual quasi-particle states as in Gribov's reggeon field theory, with multi-pomeron exchanges accounting for MPI

- model dependency sistematics
- comparison with corrected data

Unfolding and systematics

CMS-PAS-FSQ-15-007

❖ Data correction

Measured observables are corrected for detector effects and selection efficiencies, to reflect primary charged-particle activity.
An iterative Bayesian unfolding technique is used for correction, based on response matrices that correlate generated and reconstructed level observables.
Response matrices are constructed from PYTHIA8+CUETP8M1 simulated events.

❖ Systematic uncertainties

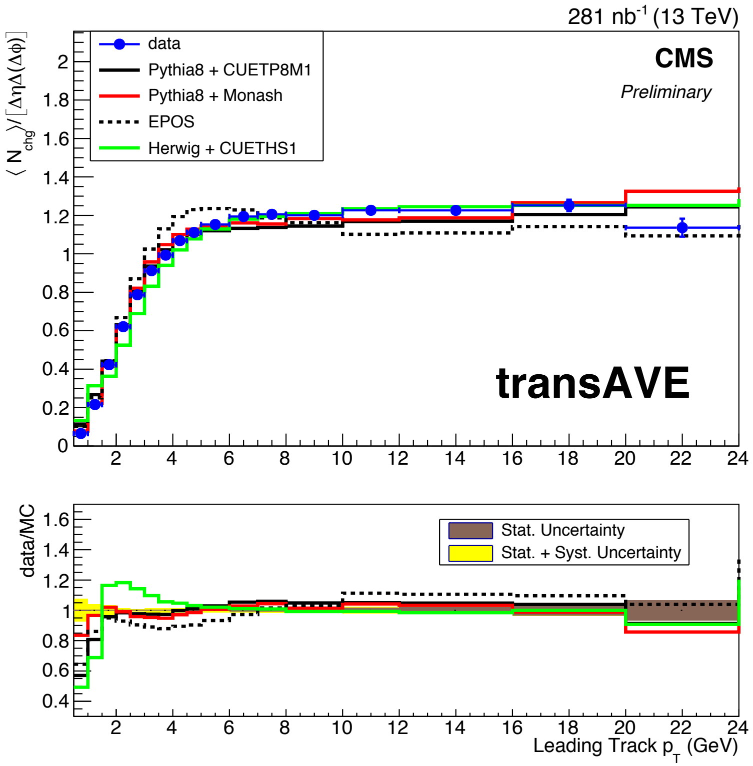
- Model dependency of data correction with different MCs
- Pile-up:
  effect of unfolding with and without PU
- Tracking efficiency/fake mismodeling:
  reduction of efficiency by 3.9% and increasing of fakes by 50%
- Impact parameter variation
- Vertex *dof* variation to 2 and 6 (from 4)

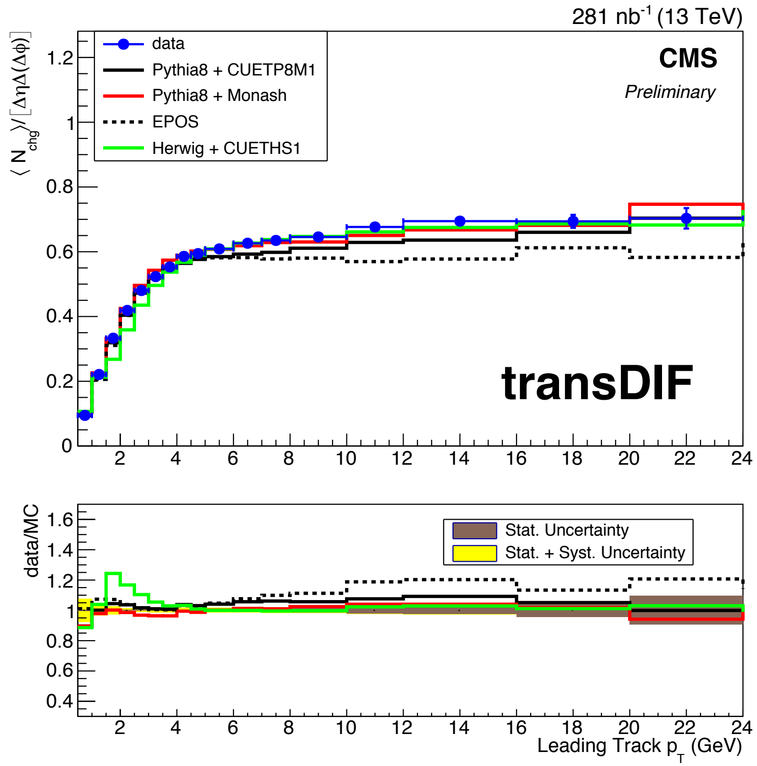
Results

Particle densities – leading track

CMS-PAS-FSQ-15-007

Average charged-particle multiplicity density: $\langle N_{ch} \rangle / [\Delta\eta\ \Delta(\Delta\phi)]$



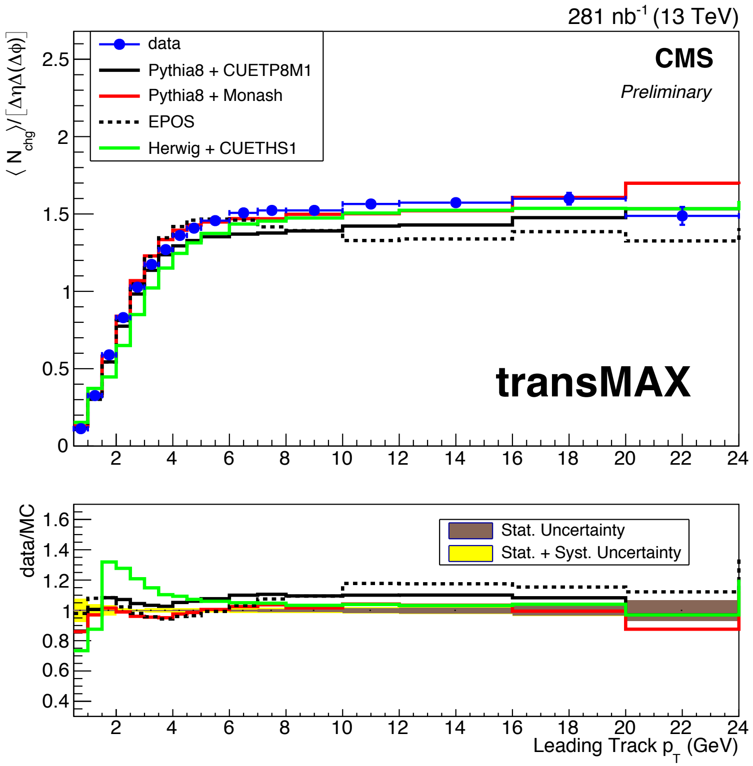


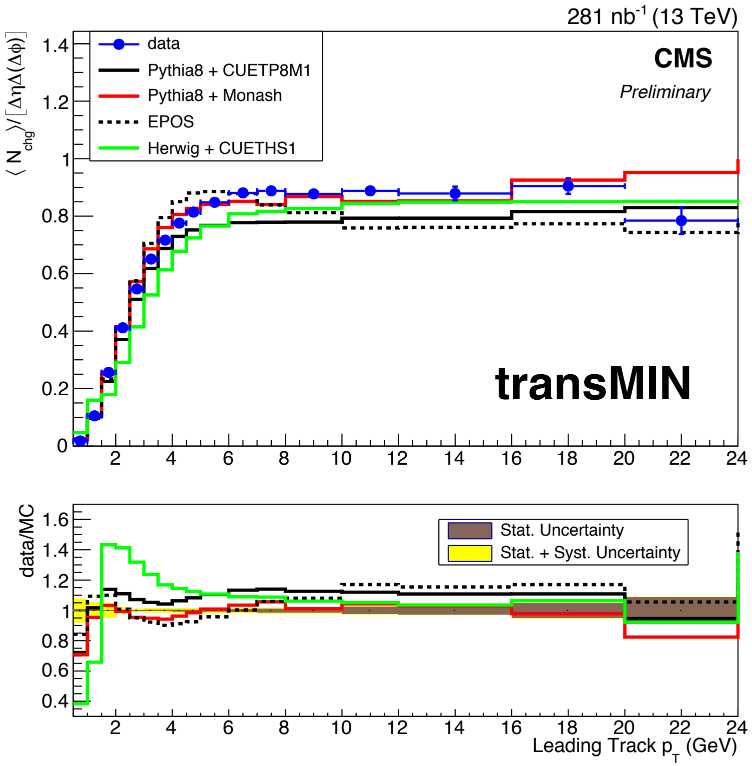
Best performing: PYTHIA8 Monash and CUETP8M1
HERWIG has problems in the rising region
EPOS has problems in the plateau

Particle densities – leading track

CMS-PAS-FSQ-15-007

Average charged-particle multiplicity density: $\langle N_{ch}\rangle/[\Delta\eta\ \Delta(\Delta\phi)]$



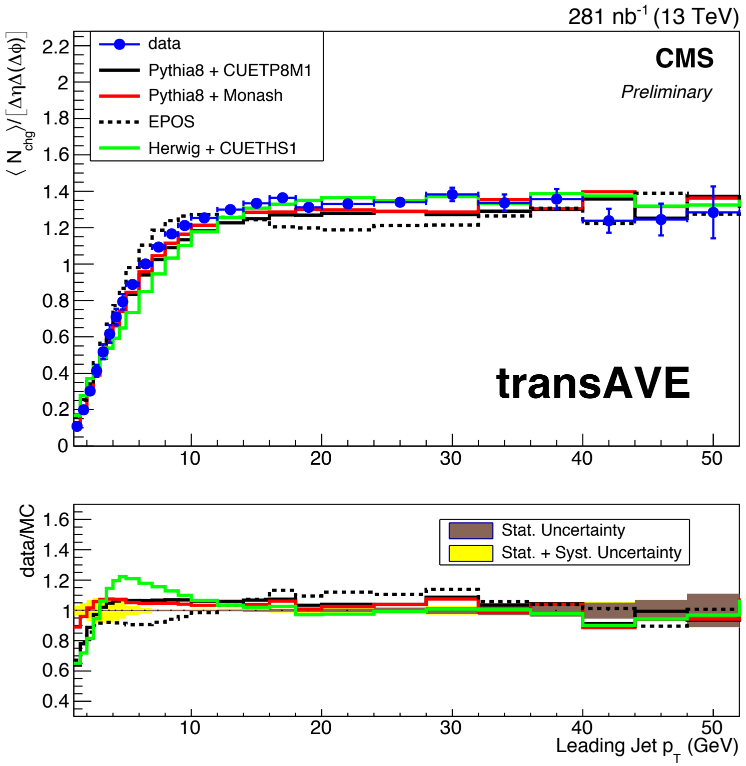


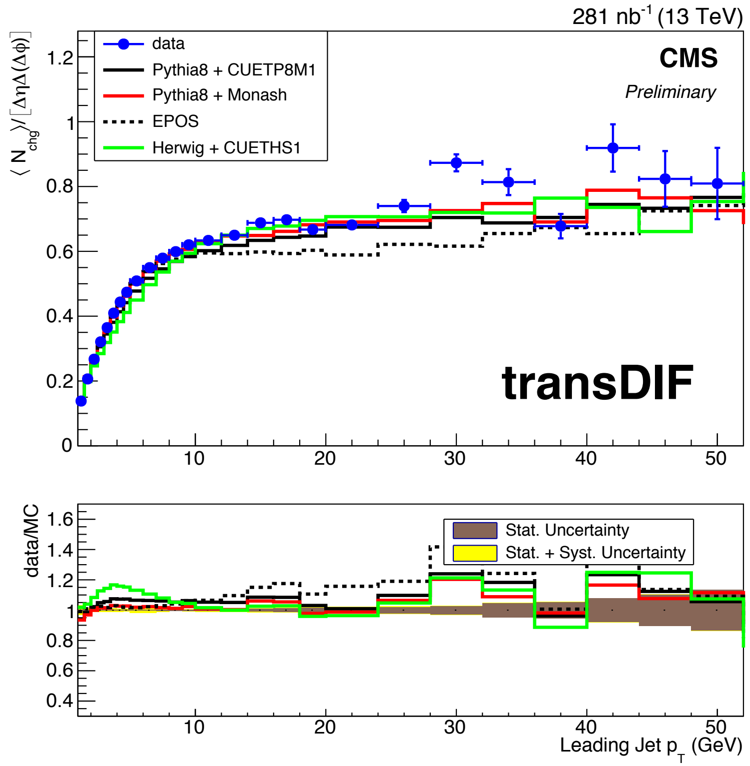
Best performing: PYTHIA8 Monash and CUETP8M1

Particle densities – leading jet

CMS-PAS-FSQ-15-007

Average charged-particle multiplicity density: $\langle N_{ch} \rangle / [\Delta\eta\, \Delta(\Delta\phi)]$





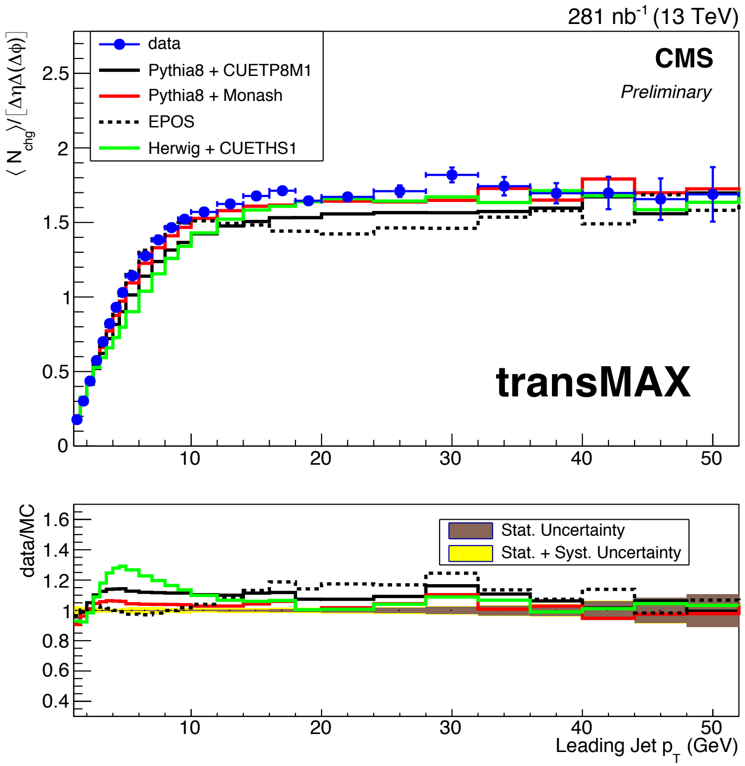
Higher activity in the plateau in the presence of a leading jet

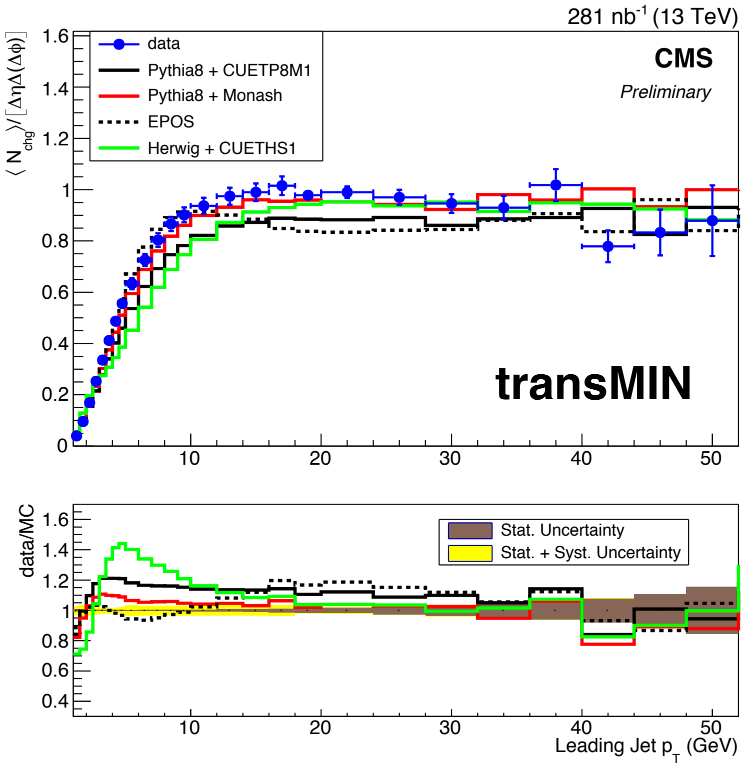
Best performing: PYTHIA8 Monash and CUETP8M1

Particle densities – leading jet

CMS-PAS-FSQ-15-007

Average charged-particle multiplicity density: $\langle N_{ch} \rangle / [\Delta\eta \, \Delta(\Delta\phi)]$





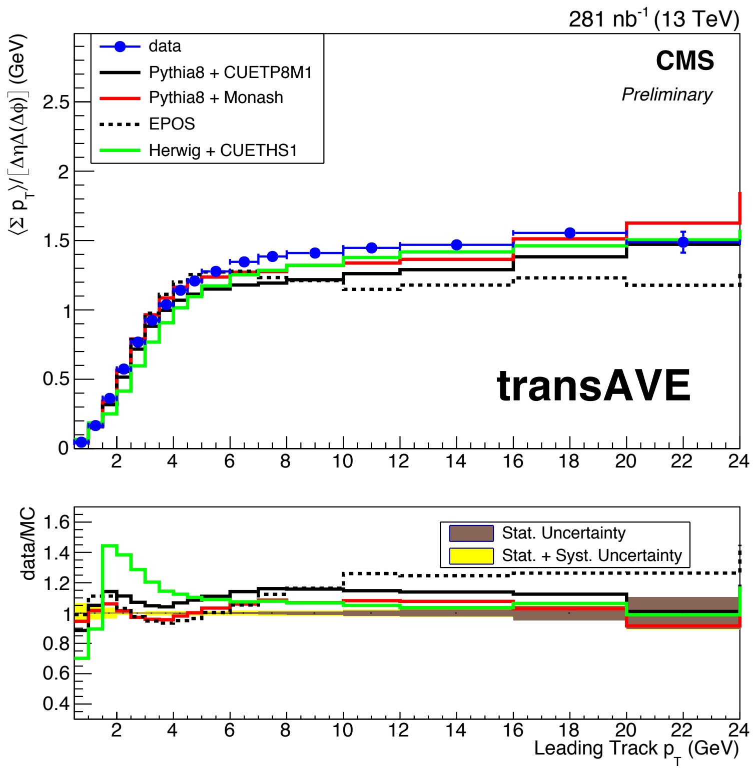
Higher activity at the plateau in the presence of a leading jet

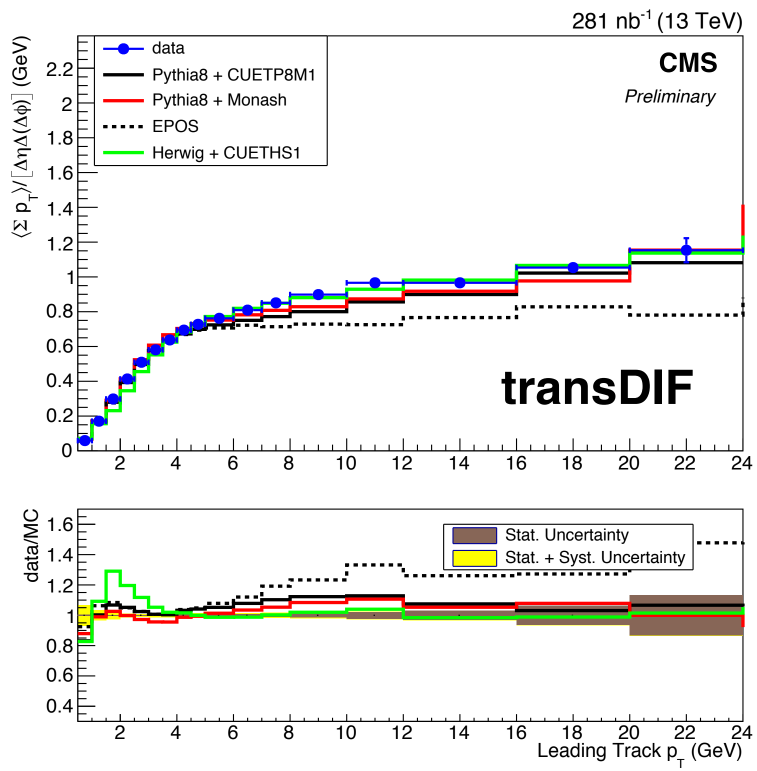
Best performing: PYTHIA8 Monash and CUETP8M1

Energy densities – leading track

CMS-PAS-FSQ-15-007

Average transverse-momentum scalar sum density: $\langle \Sigma p_T \rangle / [\Delta\eta\ \Delta(\Delta\phi)]$



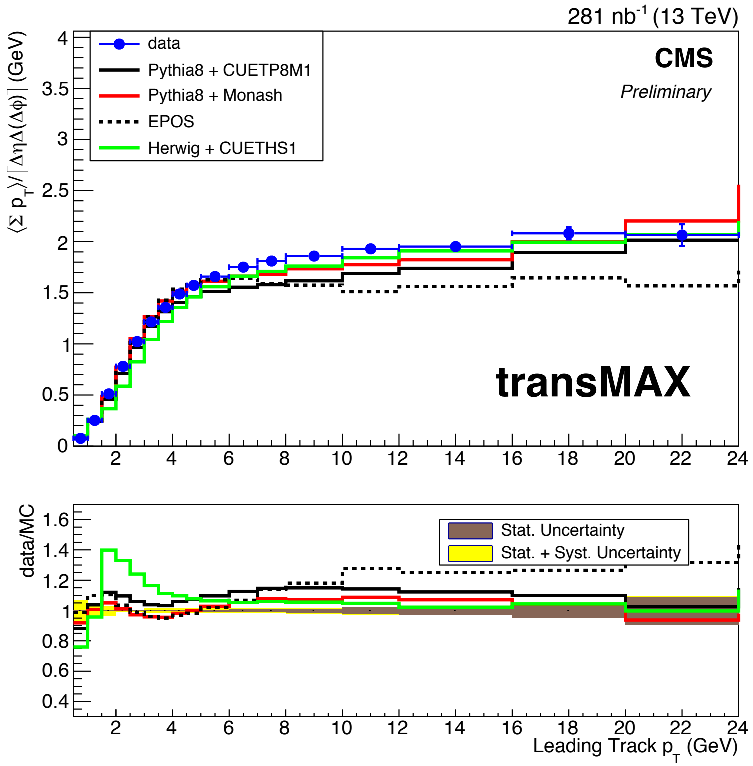


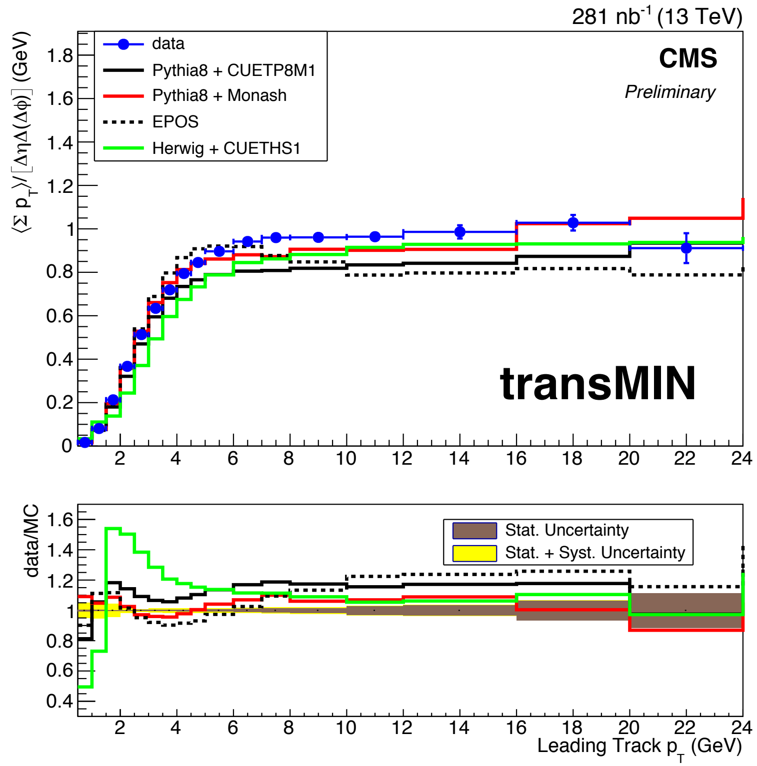
Best performing: PYTHIA8 Monash and CUETP8M1
HERWIG has problems in the rising region
EPOS has problems in the plateau

Energy densities – leading track

CMS-PAS-FSQ-15-007

Average transverse-momentum scalar sum density: $\langle \Sigma p_T \rangle / [\Delta\eta\ \Delta(\Delta\phi)]$





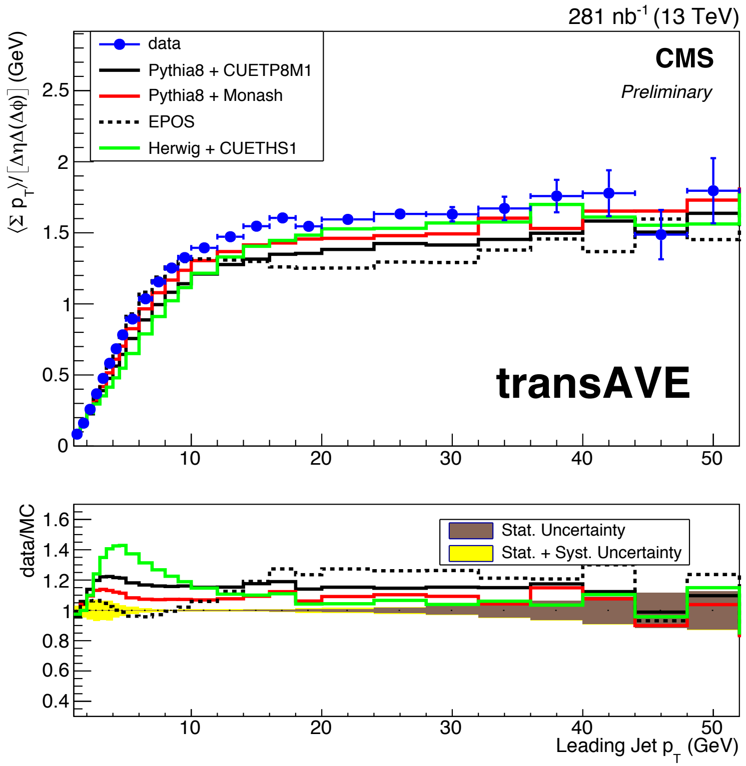
TransMIN region has a flatter plateau

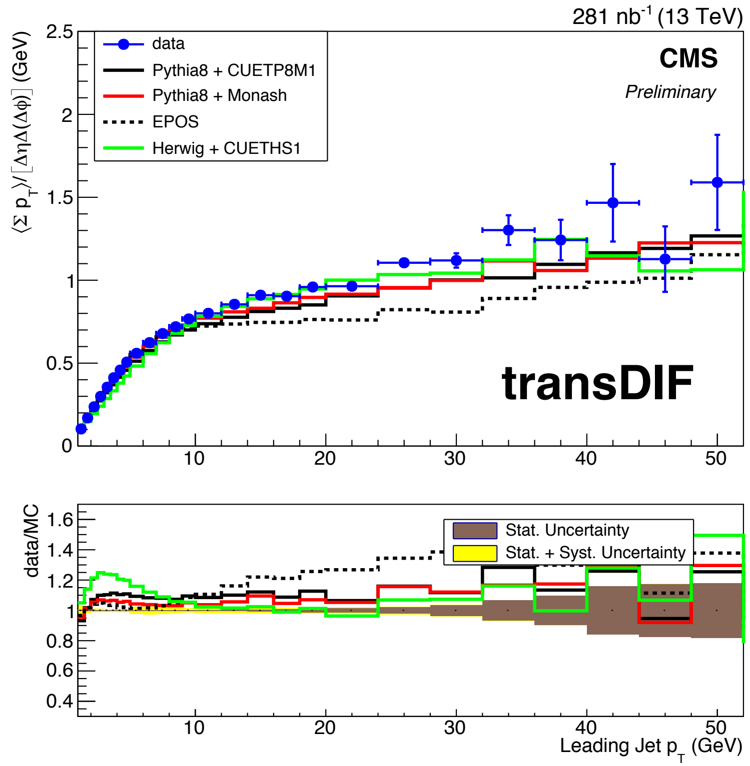
Best performing: PYTHIA8 Monash and CUETP8M1

Energy densities – leading jet

CMS-PAS-FSQ-15-007

Average transverse-momentum scalar sum density: $\langle \Sigma p_T \rangle / [\Delta\eta\ \Delta(\Delta\phi)]$





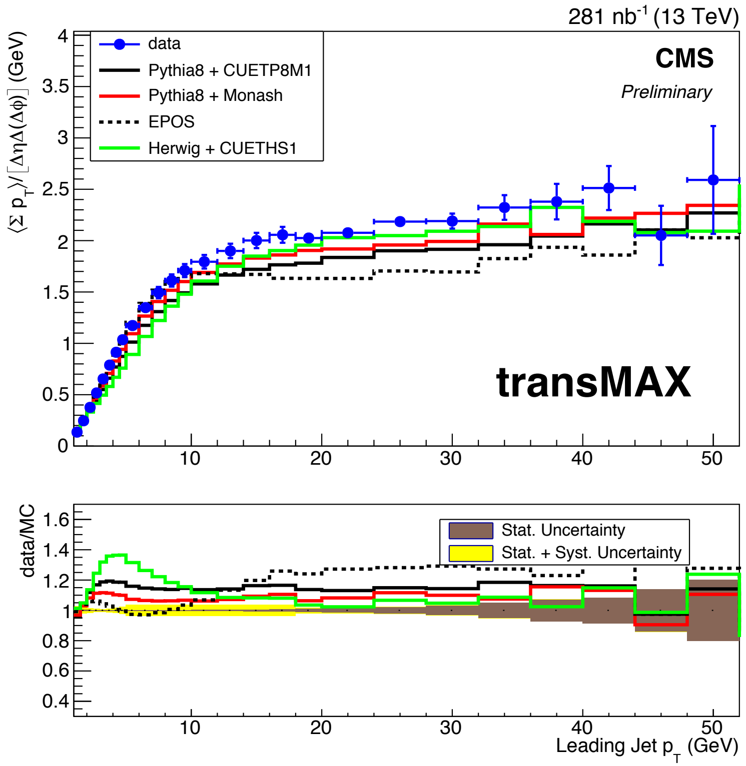
Higher activity at the plateau in the presence of a leading jet

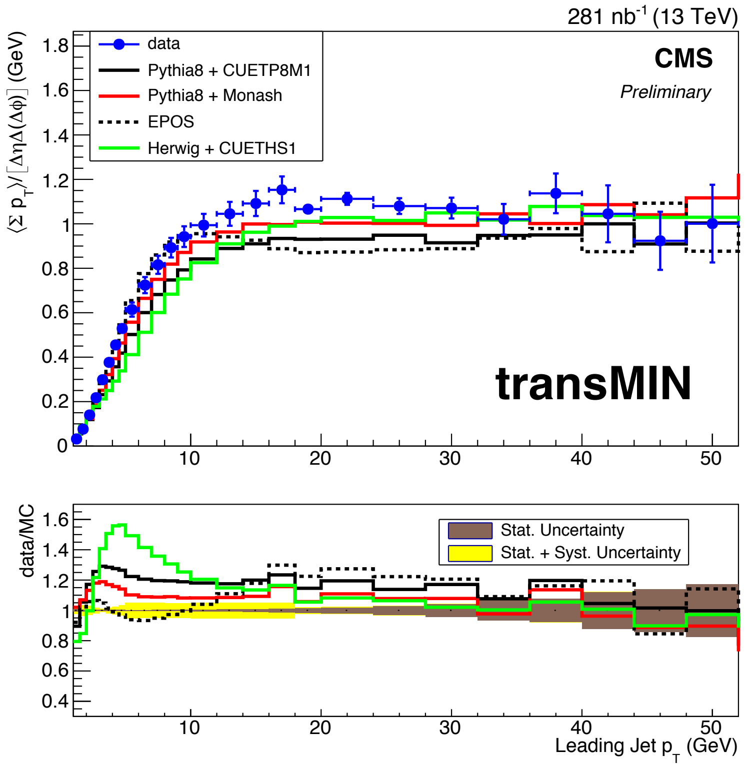
Best performing: PYTHIA8 Monash and CUETP8M1

Energy densities – leading jet

CMS-PAS-FSQ-15-007

Average transverse-momentum scalar sum density: $\langle\Sigma p_T\rangle/[\Delta\eta\ \Delta(\Delta\phi)]$



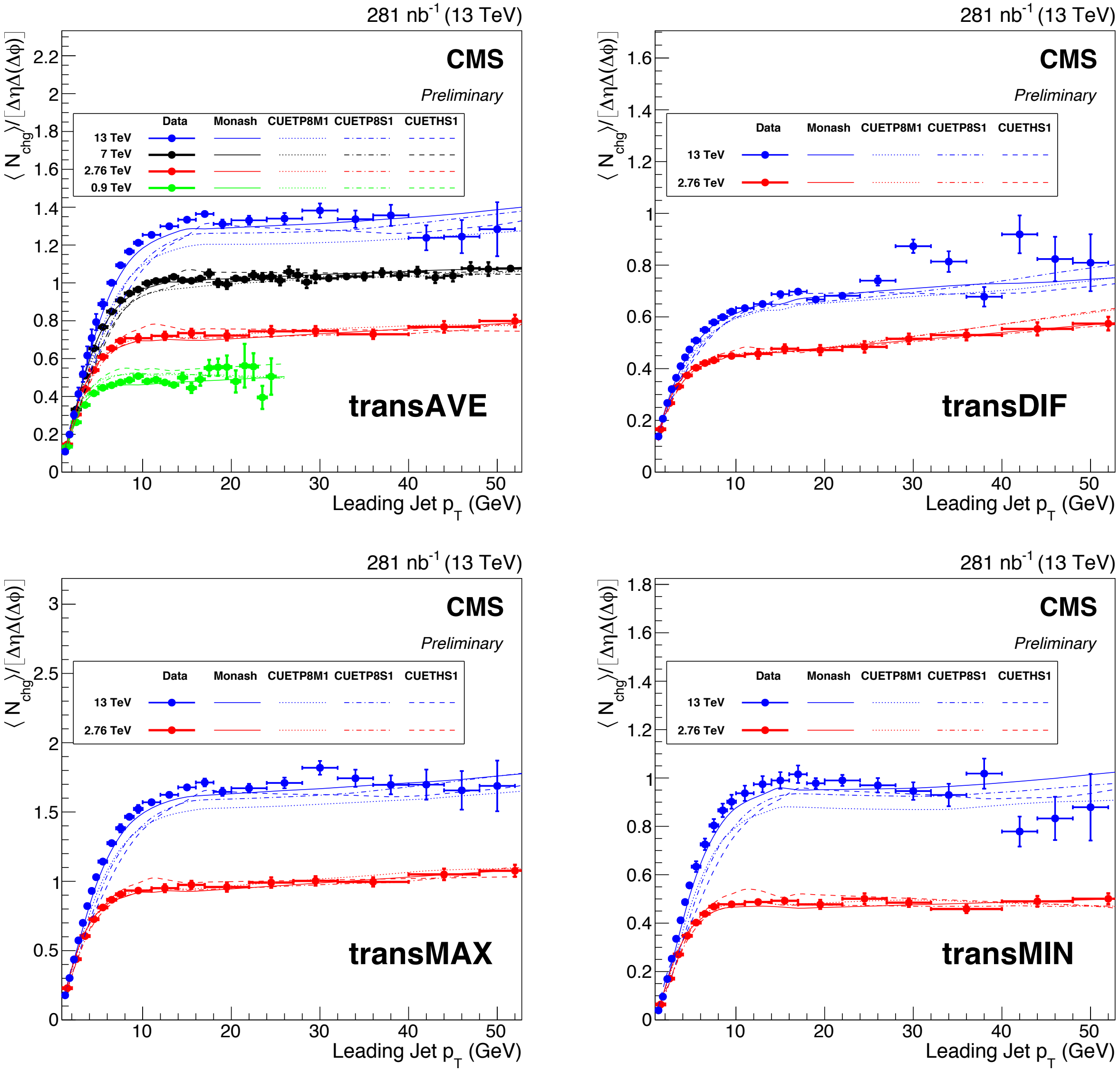


Higher activity at the plateau in the presence of a leading jet
TransMIN region has a flatter plateau

Best performing: PYTHIA8 Monash and CUETP8M1

√s dependence – particle densities

CMS-PAS-FSQ-15-007

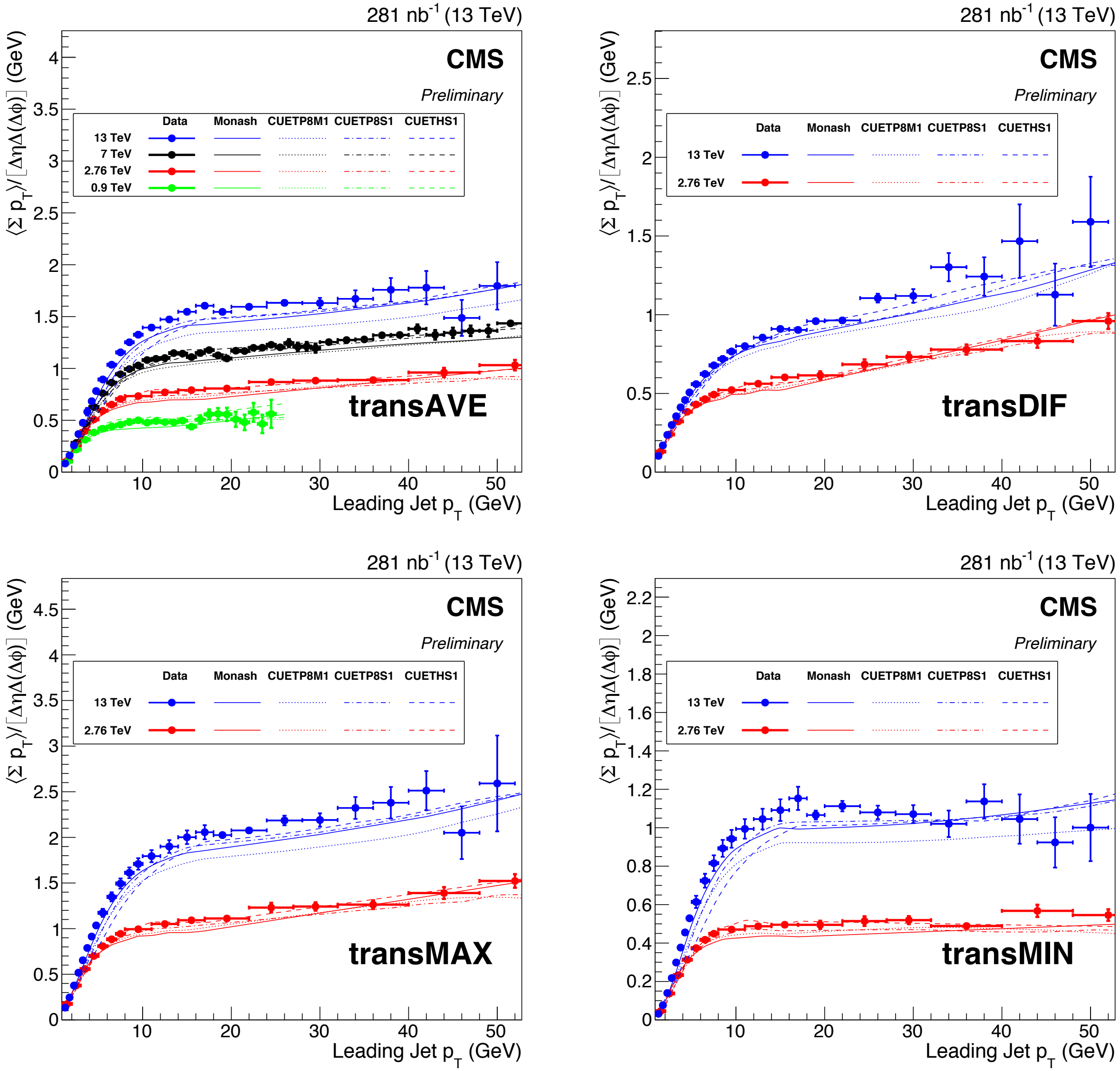


Strong rise of UE activities with centre-of-mass energy, as predicted by MCs

TransMIN densities show a stronger √s dependence than TransDIF ones, indicating that the activity coming from MPI grows more with √s than that from ISR and FSR

√s dependence – energy densities

CMS-PAS-FSQ-15-007



Strong rise of UE activities with centre-of-mass energy, as predicted by MCs

TransMIN densities show a stronger √s dependence than TransDIF ones, indicating that the activity coming from MPI grows more with √s than that from ISR and FSR

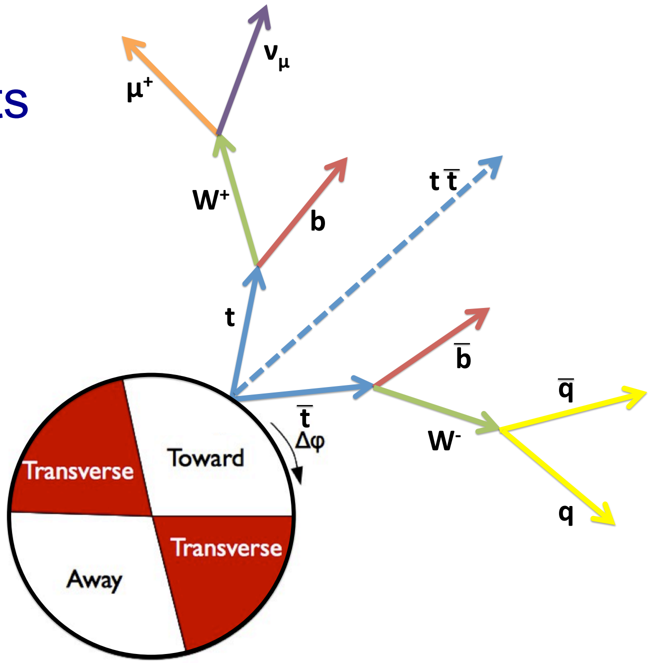
UE – leading ttbar system

CMS-PAS-TOP-15-017

Important to verify the “universality” of the UE tunes in hard process events

UE activity measured at 13 TeV in ttbar events in the μ+jets channel (2.2 fb^{-1})

ttbar system used as leading object

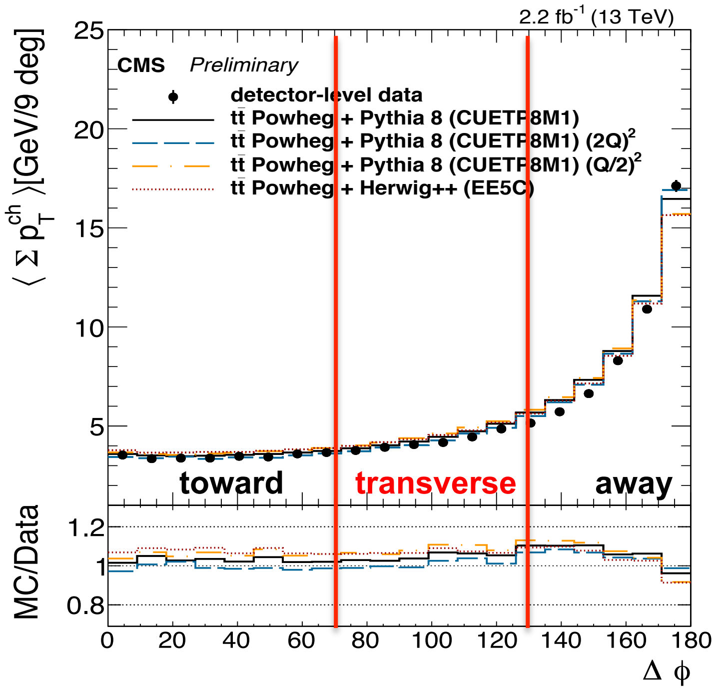


Data compared with:

- POWHEG & PYTHIA8 (CUETP8M1)
- POWHEG & HERWIG++ (EESC)

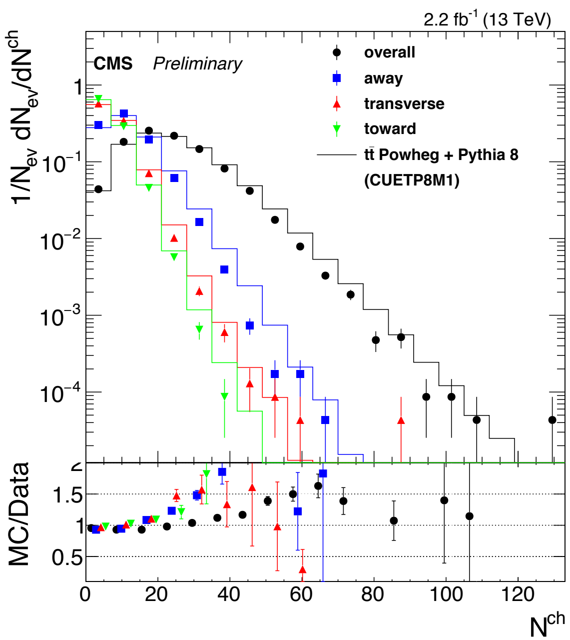
UE observables – leading ttbar

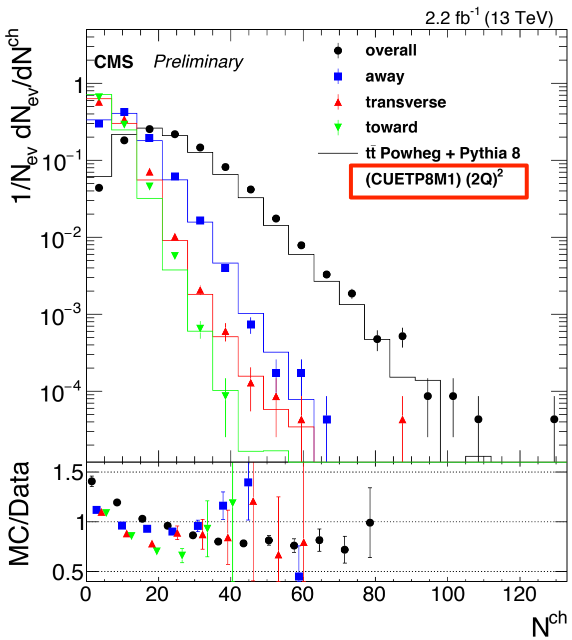
CMS-PAS-TOP-15-017



Good description of the UE observable $<\Sigma p_T^{ch}>$ in the transverse region with both PYTHIA8 (CUETP8M1) and HERWIG++ (EESC), which were tuned using datasets with different 'leading object' topology

MC predicts more charged particle multiplicity than in the data. A better agreement can be obtained doubling the scale





Please refer to Bilin's talk for more details

Summary and conclusions

- ✓ Underlying events have now been measured by CMS at 0.9, 2.76, 7, and 13 TeV, offering a large collection of data which can help to better understand these processes and improve the tuning of MC generators, required for precision measurements of SM and searches for new physics
- ✓ Measurements of TransAVE, TransMAX, TransMIN and TransDIF densities have been presented as a function of the leading-track/leading-jet p_T, fully corrected for detector effects and selection efficiencies.
  Results have been compared to different MCs and PYTHIA8 with Monash tune is presently the one best performing
- ✓ A comparison of data at 0.9, 2.76, 7, and 13 TeV shows:
  - strong $\sqrt{s}$ dependence
  - stronger dependence in TransMIN than TransDIF densities, suggesting that MPI activity rises more than ISR/FSR with respect to $\sqrt{s}$
- ✓ The underlying event activity has also been measured in ttbar+X events, supporting the universality of UE tunes

Backup slides

CMS detector