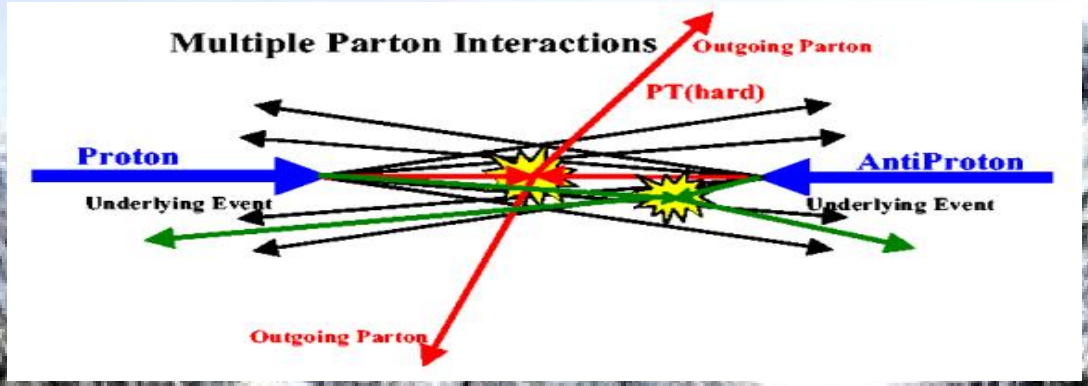


Minimum Bias and UE Measurements at CMS

Rajat Gupta

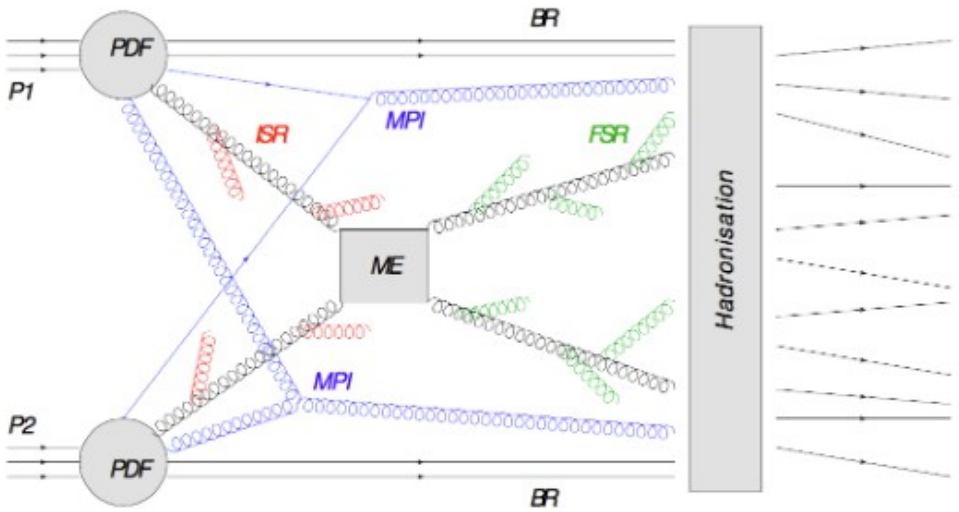
Panjab University Chandigarh (India)
On behalf of the CMS Collaboration

MPI2017: 9th International Workshop on Multiple Partonic Interactions at the LHC,
Shimla (India)
11-15 Dec 2017,

Outline

- Introduction to Minimum Bias and Underlying Event
- MB : Identified Charged Hadron Spectra at 13 TeV
- UE Measurement at 13 TeV
- Results and Summary

Minimum Bias (MB) and Underlying Event (UE)



Minimum Bias (MB)

- Very loose trigger conditions.
- Dominated by low p_T QCD processes.
- Sensitive to saturation effects of cross-section and MPI.
- Possibility to understand the different components of particle production.
- improve the modelling of various key ingredients of
- MC hadronic event generators, such as MPI, parton hadronization, and other final-state effects

Measurement of p_T spectra of charged hadrons identified via energy deposition in Si detectors (FSQ-16-004)

Underlying Event (UE)

pp collisions @ LHC
- hard scattering
- softer partonic interactions (MPI)
- initial and final state radiation (ISR and FSR)
- beam beam remnants (BBR)

UE : additional activity on top of the hard scattering

Importance of UE

- These processes can't be completely described by perturbative QCD, and require phenomenological models, whose parameters are tuned by means of fits to data.
- Same sign WW production from MPI can mimic final state of same sign dilepton SUSY searches.
- It can affect isolation criteria applied to photons and charged leptons.

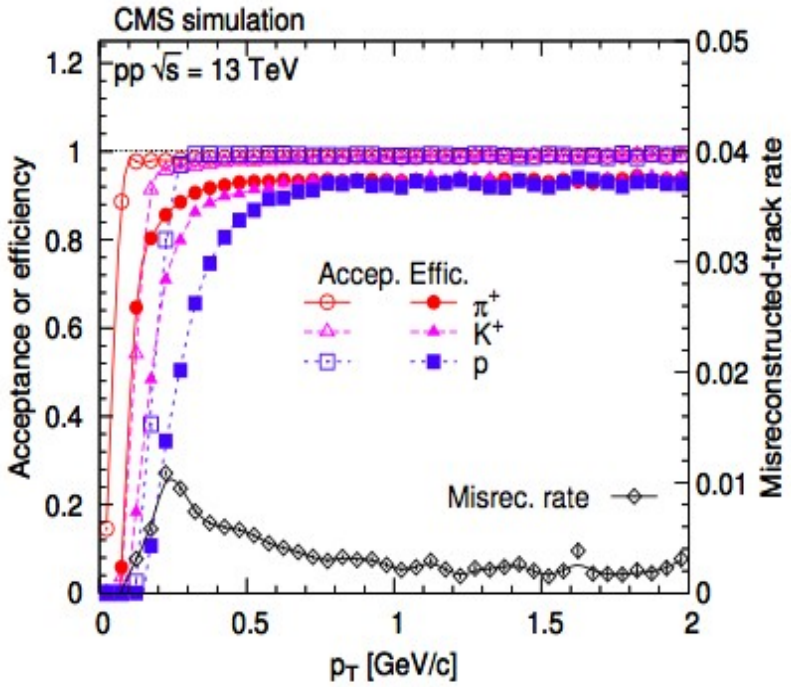
Presented for p_T leading track/jet (FSQ-15-007) & Using p_T of dimuon pair (FSQ-16-008)

Identified charged particle spectra (π,K,p) at 13 TeV

- Event Selection
  - Zero Bias, in line with previous Minimum Bias analysis
  - main goal is to show inelastic spectra and multiplicity dependence
  - HF is not used in analysis, but showing traditional (double sided) selection
    - in order to compare with previous measurements at lower energies

arXiv:1706.10194
Submitted to Physical Review D

- Minimum Bias Tracking
  - Low p_T and low fake rate tracking
  - used successfully in previous spectra and multiplicity papers
  - Iterative: hits on found tracks and successively removed
  - Cluster shape filter is used for both pixels and strips

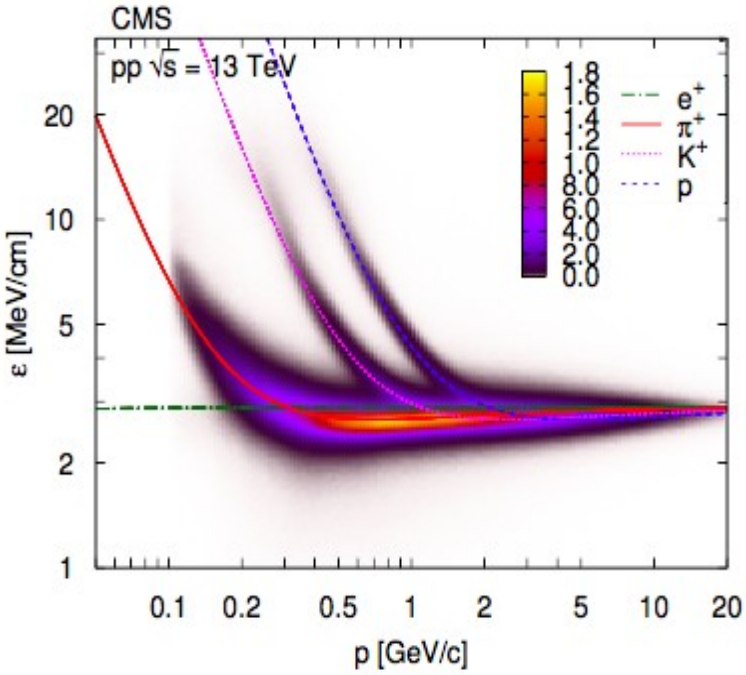


special tracking algorithms extend reconstruction capabilities down to p_T ~ 0.1 GeV

Acceptance : flat (96-98 for p_T > 0.4 GeV

Reconstruction eff : 80-90%

Mis-reconstructed track rate: Very small, 1% for p_T < 0.2 GeV



- Distributions of ln ε as a function of total momentum p for +ve particles.
- Identified from the energy deposited in the silicon tracker and the reconstructed particle trajectory.

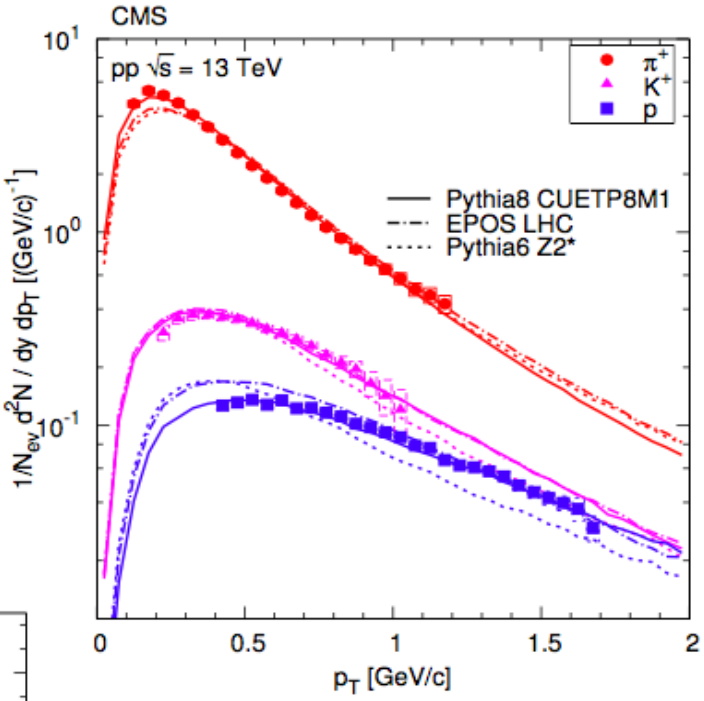
Identified charged particle spectra (π,K,p) at 13 TeV

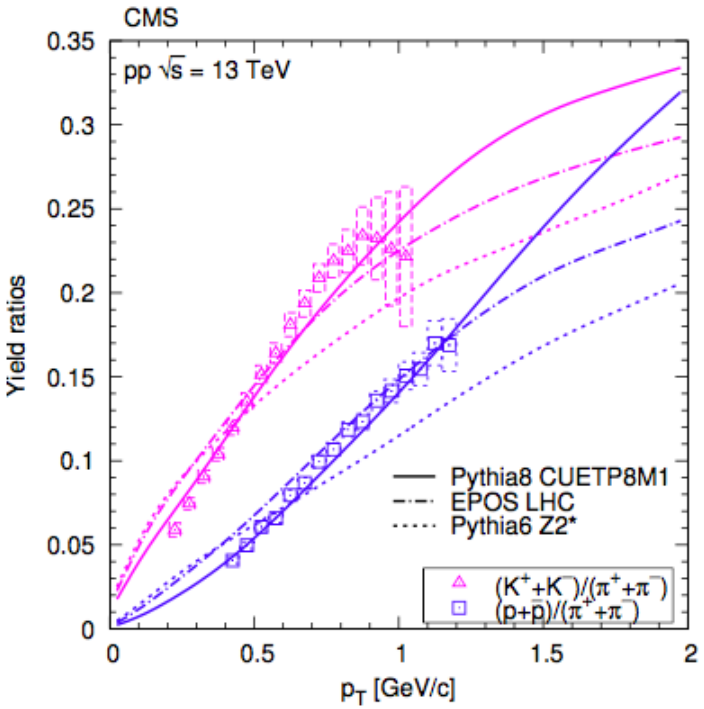
arXiv:1706.10194

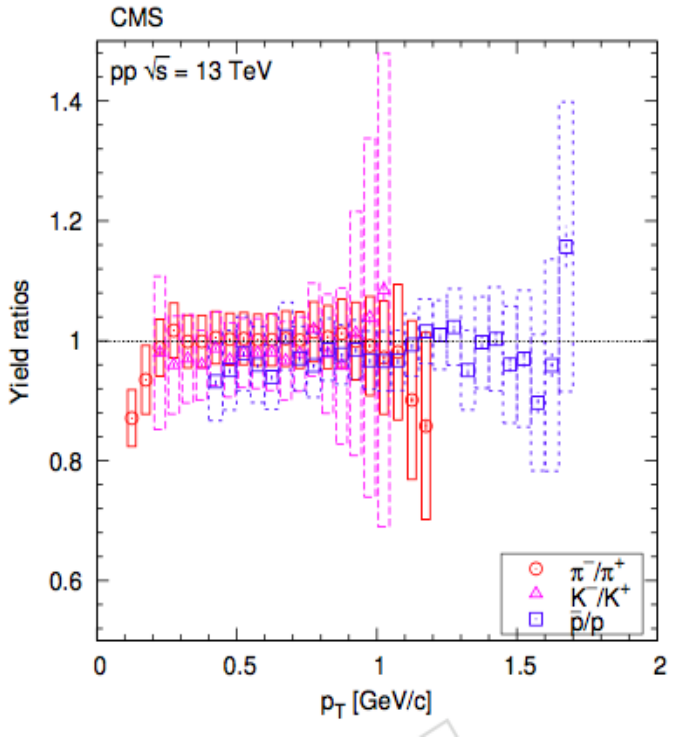
Submitted to Physical Review D

- Measured :
  - p_T spectra, average $\langle p_T \rangle$, ratio of particle yields
- Selection:
  - |y| < 1
  - K : p < 1.05 GeV
  - π : p < 1.2 GeV
  - p : p < 1.7 GeV

- pions are described well by all three generators
- kaons are best modelled by PYTHIA8 and EPOS.
- For protons only PYTHIA8 gives a good description.



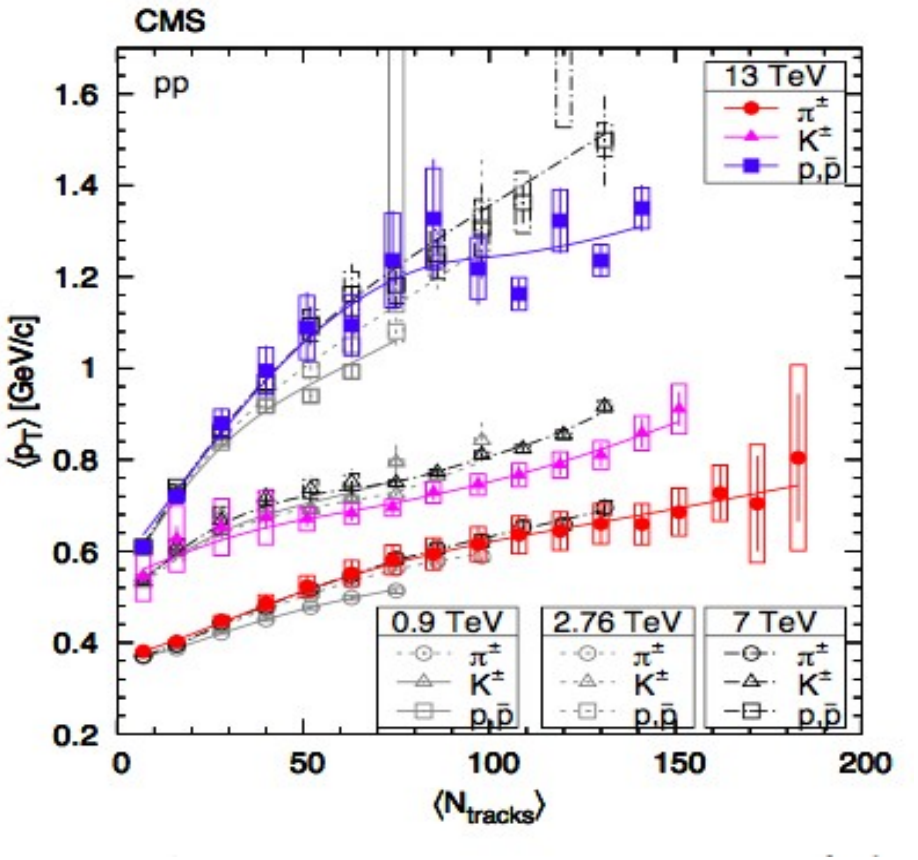


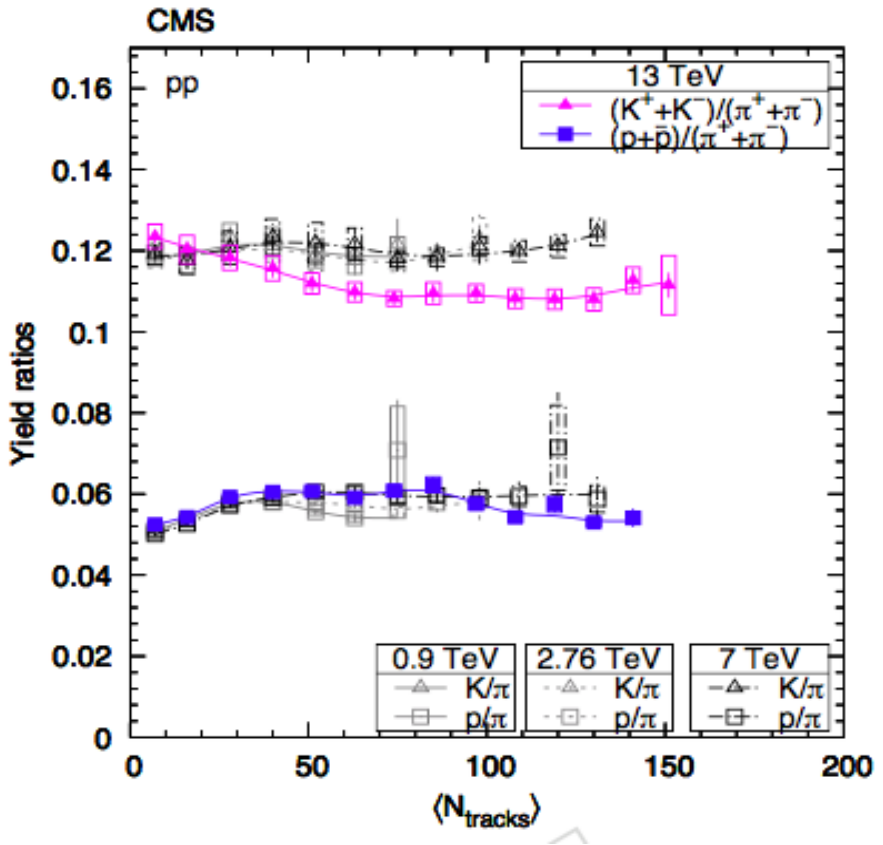


- Only PYTHIA8 is able to predict both the K/π and p/π ratios as a function of p_T.
- The ratios of the yields for oppositely charged particles are close to one (backup), as expected at this center-of-mass energy in the central rapidity region.

Identified charged particle spectra (π,K,p) at 13 TeV

arXiv:1706.10194 *Submitted to Physical Review D*



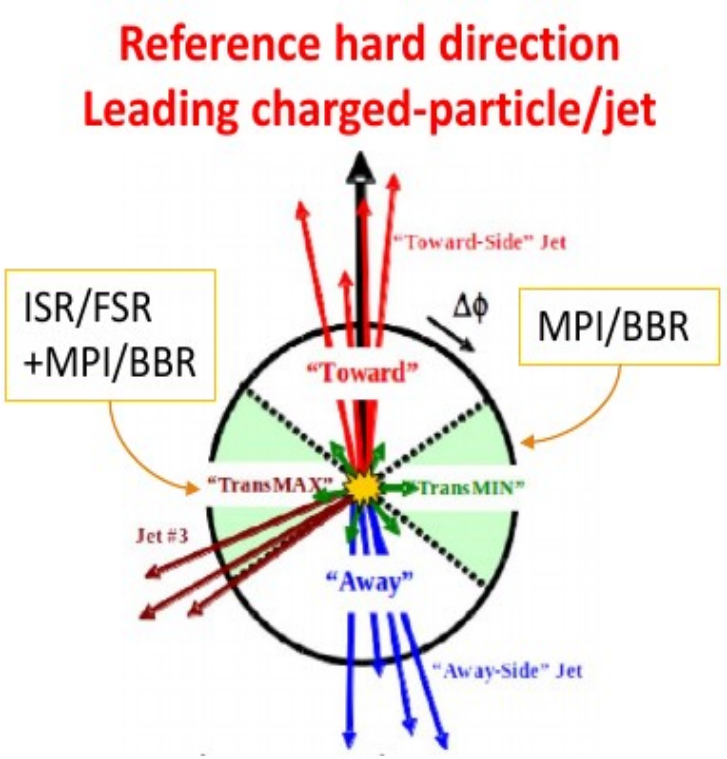


Average p_T of identified charged hadrons and ratios of particle yields in the range |y| < 1 as a function of the corrected track multiplicity for |η| < 2.4, for pp collisions at at √s = 13 TeV (filled symbols) and at lower energies (open symbols)

both ⟨pT⟩ and yield ratios show only a mild dependence on the center-of-mass energy.

Underlying Event (UE) Observables

Underlying Event study using Leading Track/Jet:



Spatial Distribution of tracks is categorized by azimuthal separation $\Delta\Phi = \Phi_{track} - \Phi_{leading\ track/jet}$

1. $|\Delta\Phi| > 120^0$ (away)
2. $60^0 < |\Delta\Phi| < 120^0$ (transverse)
3. $|\Delta\Phi| < 60^0$ (towards).

UE observable:

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

Average Scalar sum of transverse momenta
$\langle \Sigma p_T \rangle / [\Delta\eta\Delta(\Delta\varphi)]$

transMAX(TransMIN): activity in maximum (minimum) activity side of transverse region

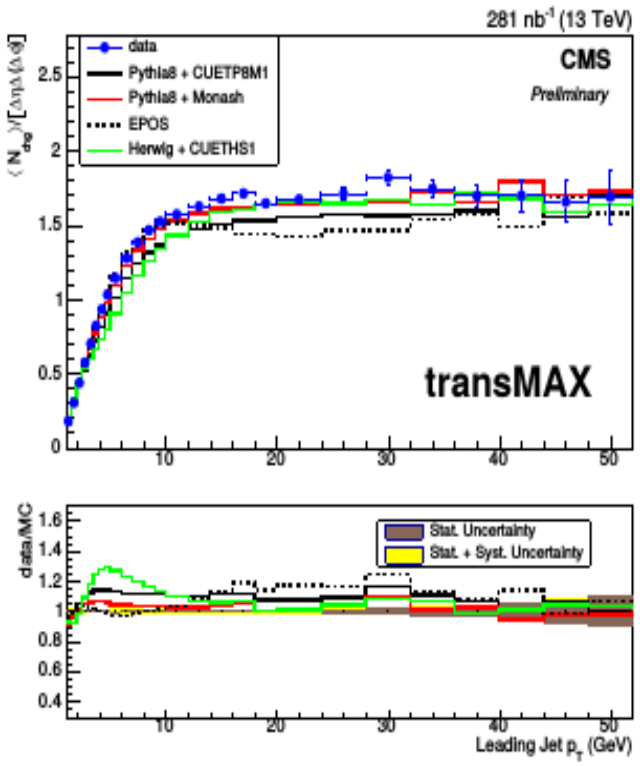
transAVE: (TransMAX+TransMIN)/2

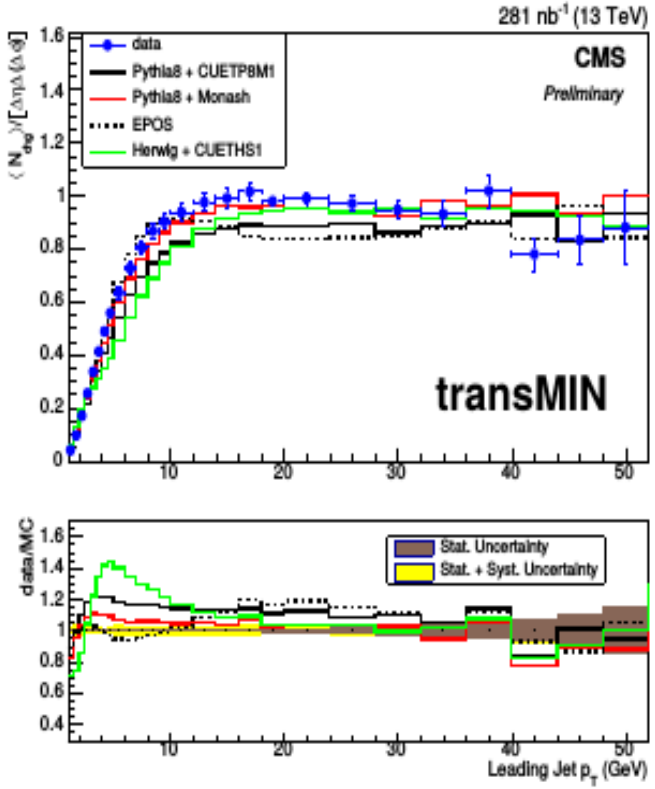
transDIF: (TransMAX-TransMIN)
Sensitive to ISR/FSR

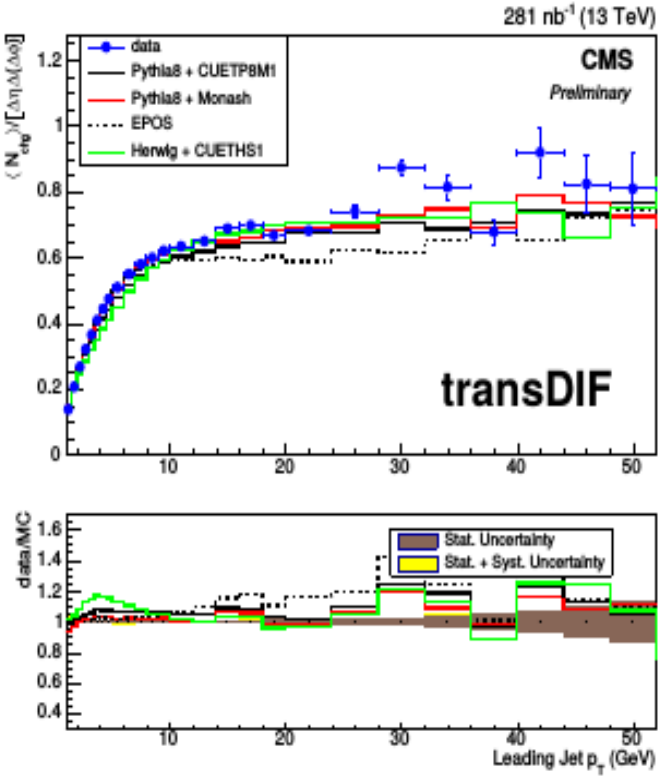
Underlying event with leading particle and Jet @ 13 TeV

CMS-PAS-FSQ-15-007

- Average Particle density vs leading jet p_T for charged particles : $p_T > 0.5$ GeV and $|\eta| < 2$.







two different regimes:

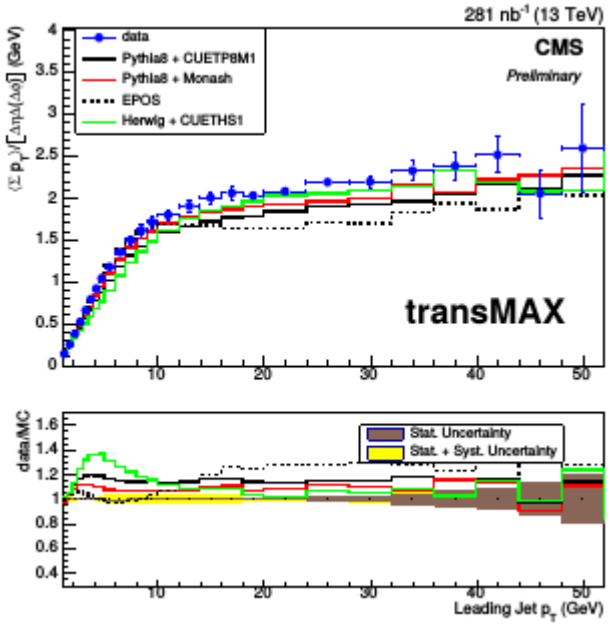
- At low p_T : sharp rise due to increase of the MPI activity.
- At higer p_T : MPI activity saturates, slow increase due to the ISR and FSR contributions.

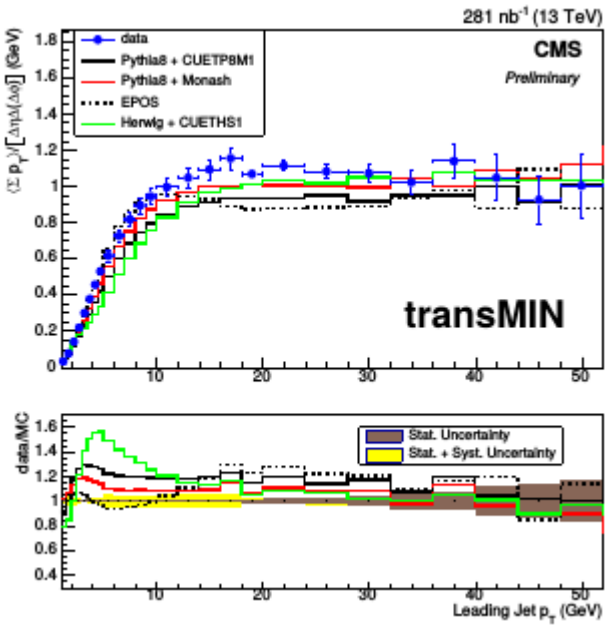
TransMIN flatter at higher p_T (MPI saturated) than transMAX and transDIF (ISR/FSR increase)

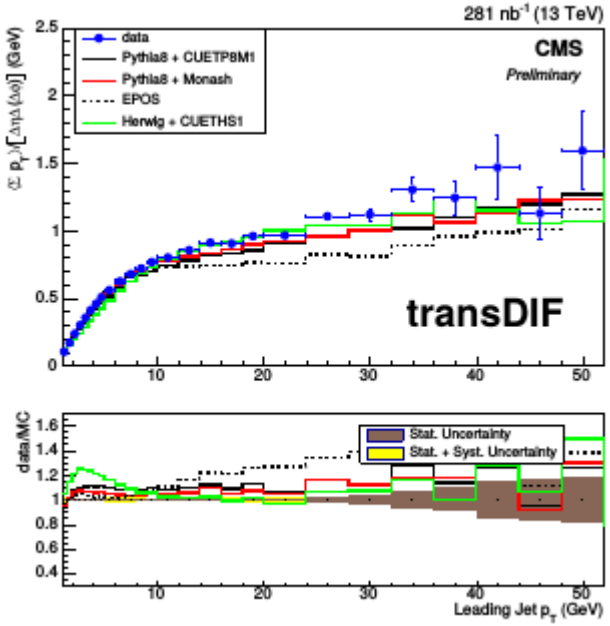
Underlying event with leading particle and Jet @ 13 TeV

CMS-PAS-FSQ-15-007

- Average p_T sum vs leading jet p_T for charged particles – p_T > 0.5 GeV and $|\eta| < 2$.







Qualitative behavior described by the simulations:

- Level of agreement is 10-20% in the plateau region.
- Larger difference between models in the low p_T regions.

→ Data better described by Pythia8 Monash and CUETP8M1

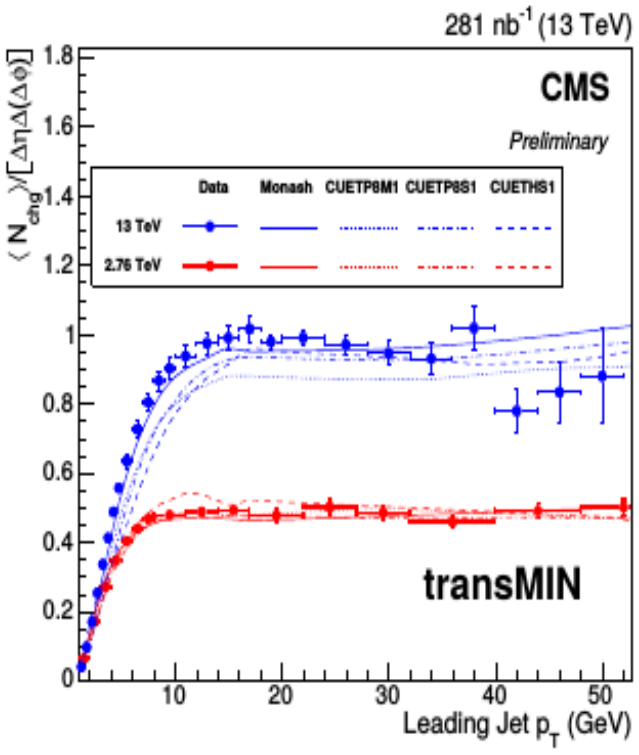
HERWIG + CUETHS1 fails in the low p_T region (lack of diffractive events)

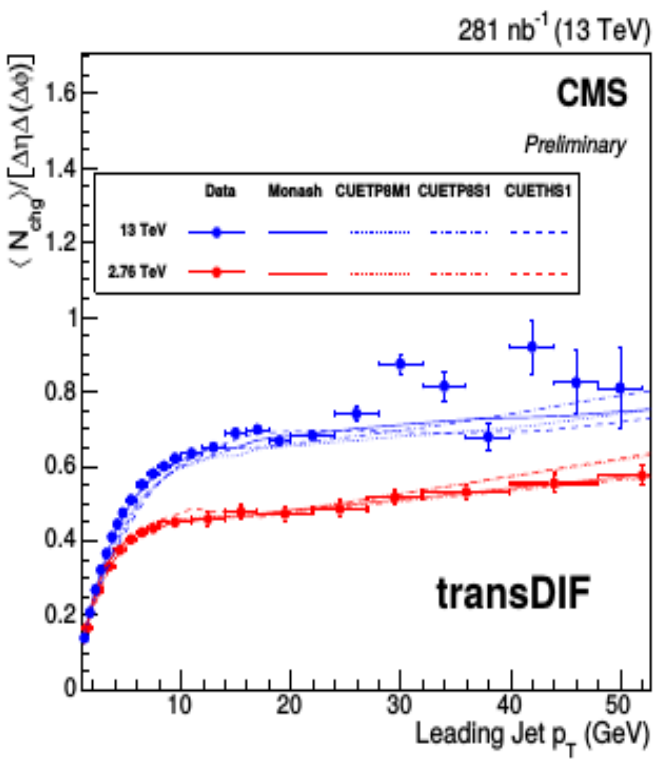
EPOS describes the rising part but fails to describe the plateau.

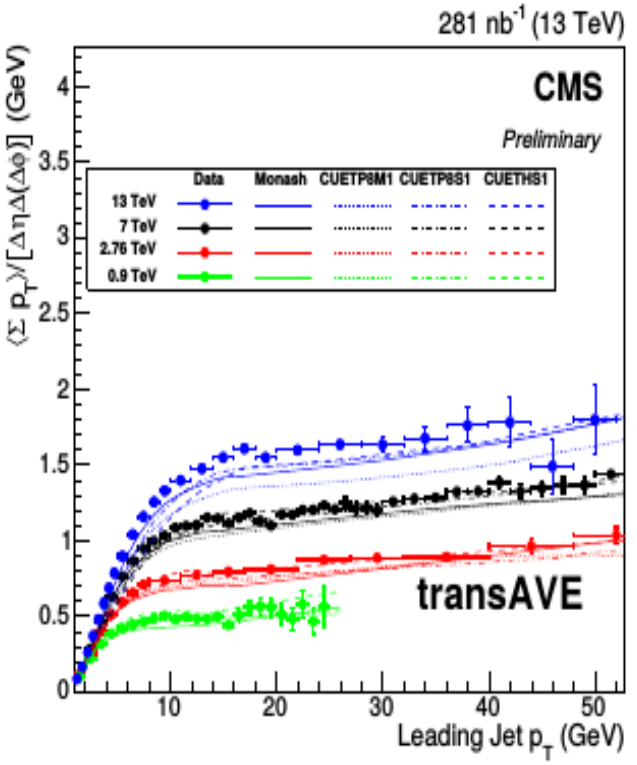
Underlying event with leading particle and Jet @ 13 TeV

CMS-PAS-FSQ-15-007

- p_T sum density vs leading jet p_T : energy dependence 2.76 TeV → 13 TeV







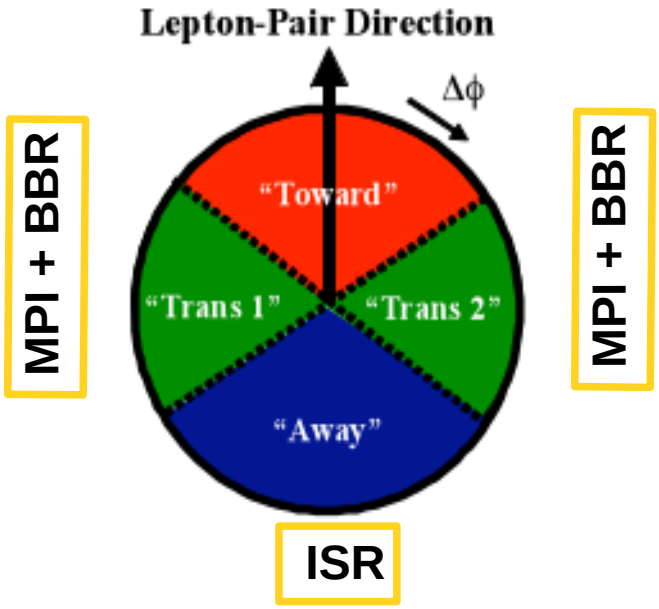
Strong energy dependence well reproduced by the different models

- Increase of the parton densities at smaller momentum fraction.
- transMIN shows a stronger rise than transDIF

→ MPI activity grows faster with CM energy than activity from ISR and FSR.

Underlying Event (UE) Observables

Underlying event using Drell-Yan process with muonic final state:

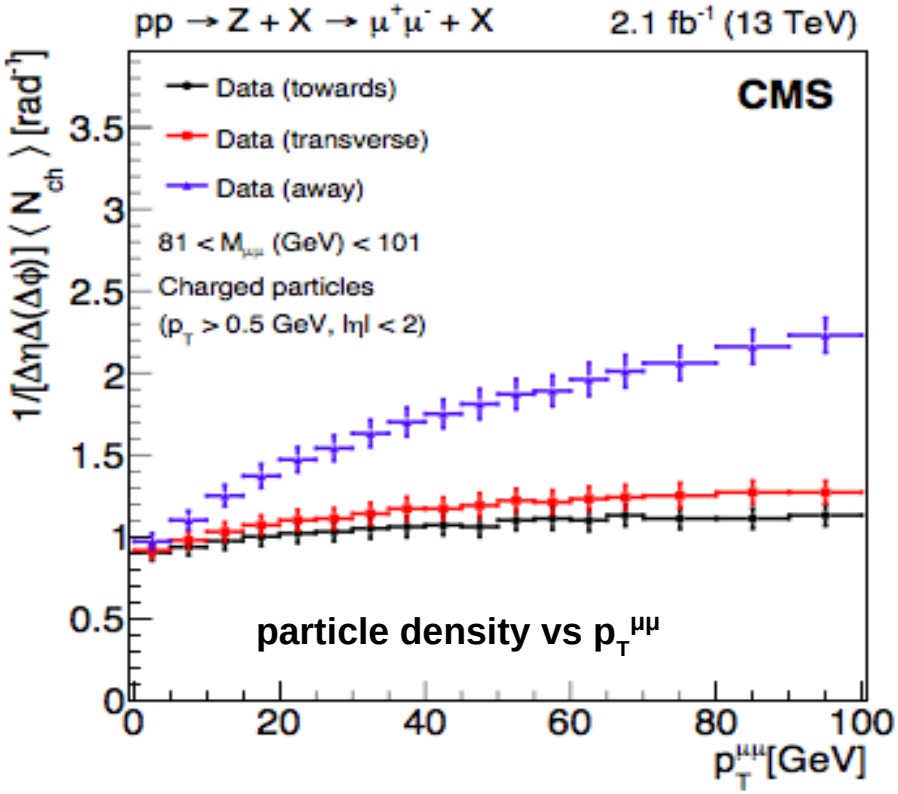


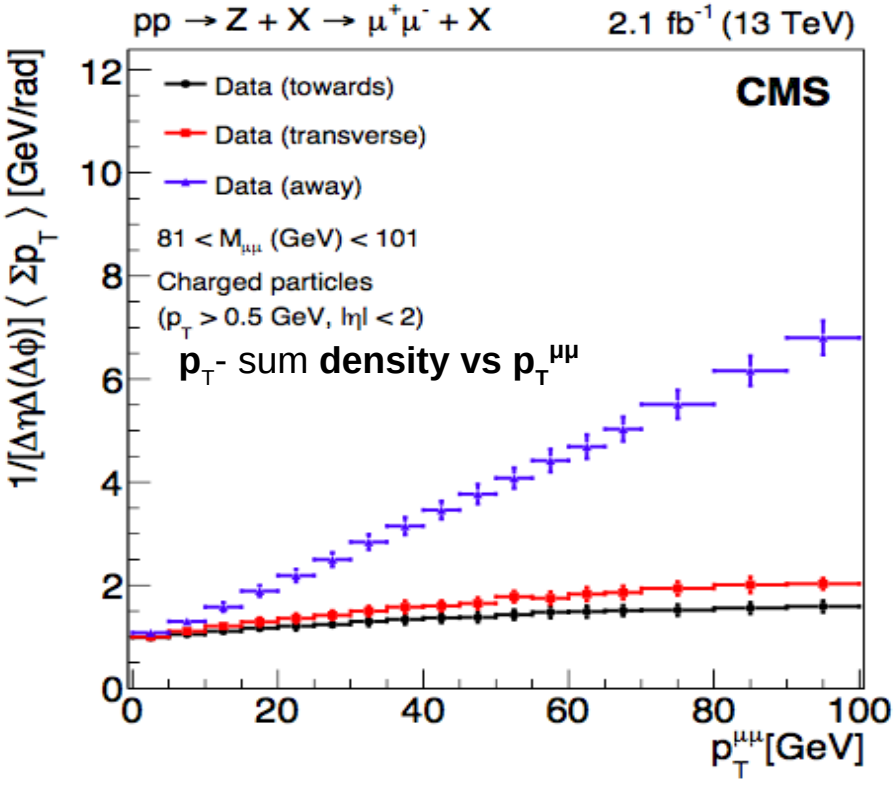
- 2 muons from Z leptonic decay with p_T > 10 & 20 GeV, $|\eta| < 2.4$ & $81 < M_{\mu\mu} < 101$ GeV
- charged particles with $p_T > 0.5$ GeV & $|\eta| < 2$ in the towards, transverse and away region.
- Test the process universality of the underlying event activity.
- No Final-State Radiation → more direct access to MPI and Initial-State Radiation
- Test the universality of the tunes interfaced with different event generators.

ArXiv:1711.04299 (submitted to JHEP)

These observables are studied as a function of $p_T^{\mu\mu}$ in narrow mass window (around Z resonance i.e 81-101 GeV), in away, towards and transverse regions.

Results





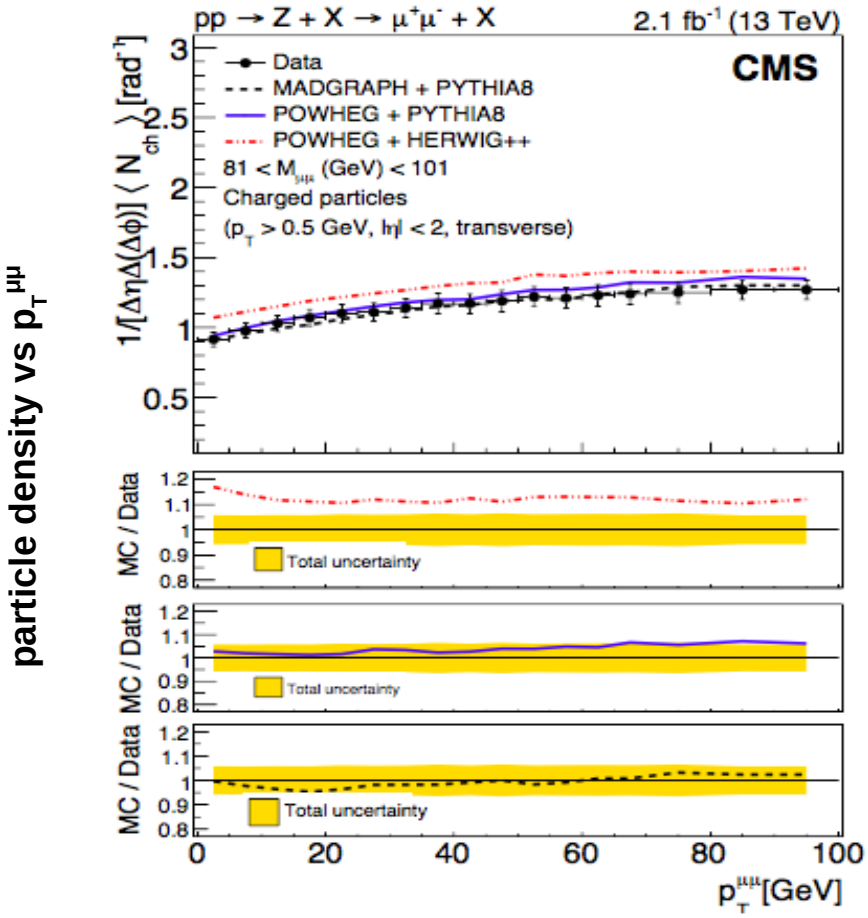
- Away : fast rise in UE activity due to recoiling hadronic activity (ISR).
- Towards and transverse : slow growth (due to large spatial separation).
- All activities equal as $p_T^{\mu\mu} \longrightarrow 0$: difference in UE activity for different regions is due to varying radiation contribution.

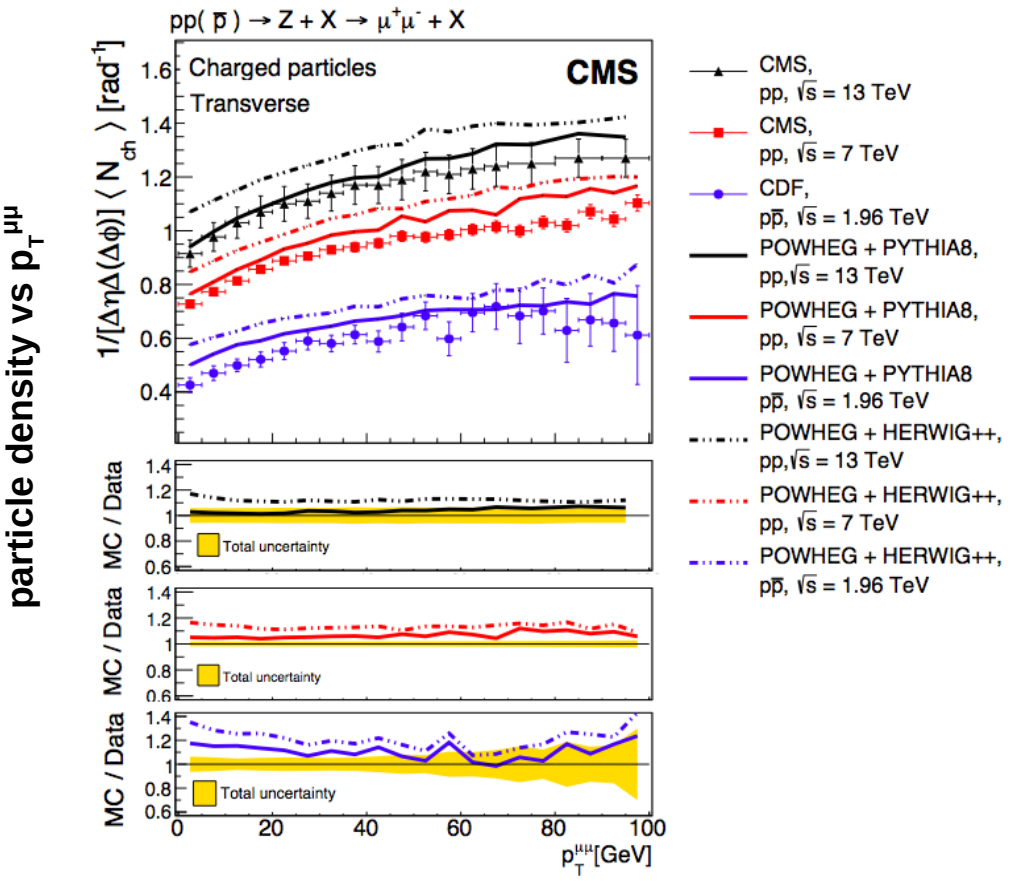
ArXiv:1711.04299 (submitted to JHEP)

- UE activity does not start from zero due to hard scale set by event around Z resonance (MPI activity already saturated)

UE in DY – avg particle density vs dimuon p_T

ArXiv:1711.04299 (submitted to JHEP)

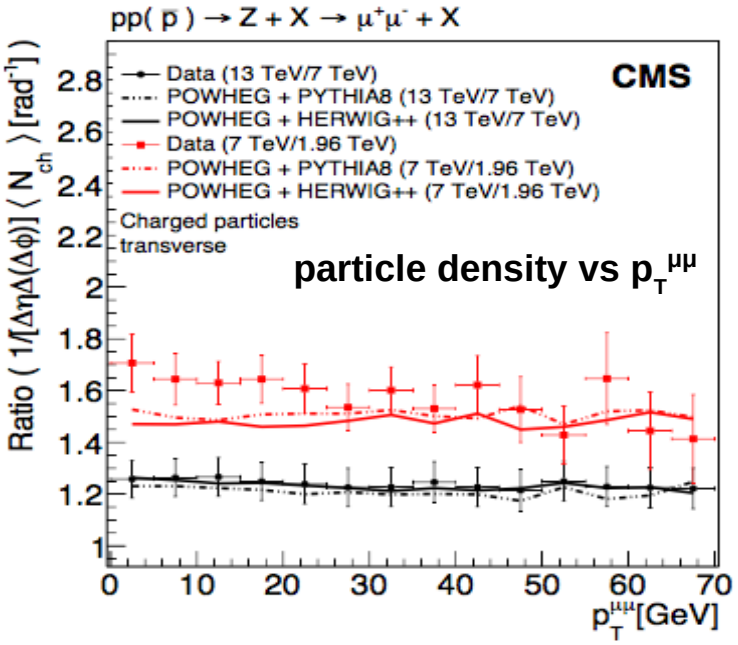


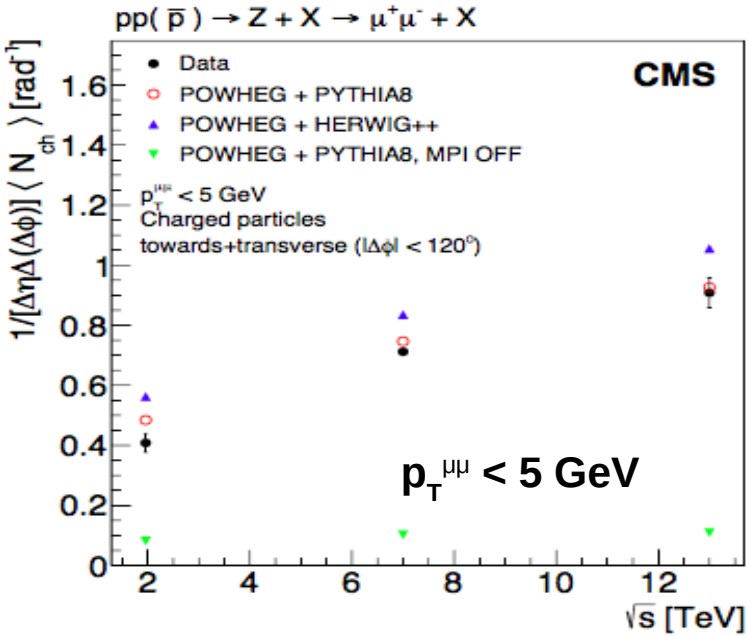


- POWHEG + HERWIG++ EE5c: overestimates UE activity by 10-15% in all regions
- POWHEG + PHYTHIA8 CUETP8M1: describes the data within 5%
- MADGRAPH + PYTHIA8 CUETP8M1: gives the best description

- 1.96 TeV → 7 TeV → 13 TeV:
- POWHEG + HERWIG++ EE5c: overestimates data by 40 to 10%.
- POWHEG + PHYTHIA 8 CUETP8M1: describes data within 10 to 5%.

UE in DY : activity at different energies





- To quantify increase in UE : ratios are calulated $(UE)_{13(7)\ TeV}$ / $(UE\ activity)_{7(1.96)\ TeV}$ for both simulation and data.
- 25-30% rise from 7 to 13 TeV , models in good agreement.
- 60-80% rise from 1.96 TeV to 7 TeV, models predict lower increase particularly at lower p_T

- At low dimuon p_T : underlying event activity dominated by MPI contributions.
- Average particle and energy density for dimuon p_T as a function of CM energy in the combined towards and transverse region.

ArXiv:1711.04299 (submitted to JHEP)

- POWHEG + PYTHIA8 Without MPI : contribution from radiation very small.
- Increase of MPI activity well reproduced by POWHEG + PYTHIA8.
- Overestimated by POWHEG + HERWIG++.

Conclusion

- The yields and spectra of identified hadrons for laboratory rapidity |y| < 1 have been studied as a function of the event charged particle multiplicity in the range |η| < 2.4.
- The PYTHIA8 CUETP8M1 event generator reproduces most features of the measured distributions; EPOS LHC also gives a satisfactory description of several aspects of the data.
- As observed in lower energy data, the average p_T and the ratios of particle yields are strongly correlated with the event particle multiplicity at LHC energies.
- Measurement of UE activity at 13 TeV using inclusive Z Boson event and leading jet/track at 13 TeV is presented.
- Underlying event measurements
  - Probe the dynamics of hadron production with increasing precision.
- Sensitivity to the parton densities at small x and small scale,
- Various observables enable to measure these different components independently from each other.
- The Results are valuable inputs to further constrain phenomenological models used to describe the particle production at low p_T.


Thank You


Backup
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CMS Publications

- Measurement of charged pion, kaon, and proton production in proton-proton collisions at √s= 13 TeV, arXiv:1706.10194
- Underlying Event Measurements with Leading Particles and Jets in proton-proton collisions at √s= 13 TeV, CMS-PAS-FSQ-15-007.
- Measurement of the underlying event using the Drell-Yan process in proton-proton collisions at √s = 13 TeV, ArXiv:1711.04299