Deutsches Elektronen-Synchrotron
(DESY), Hamburg

Measurement of the underlying event using track-jets with the CMS experiment

Paolo Gunnellini
on behalf of the CMS Collaboration

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Dallas (TX)
USA

Outline

- Introduction
- Analysis strategy and event selection
- Unfolding procedure
- Evaluation of systematics
- Results and MC comparisons
- Summary and Conclusion

NEW!

CMS-FSQ-12-025 To be submitted soon

CMS-FSQ-12-020

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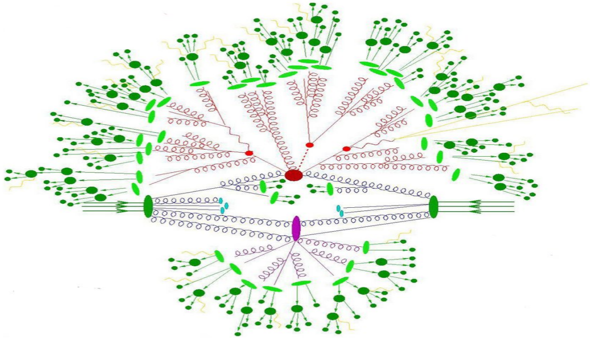


Hard scattering

Initial, Final State Radiation (PS)

Multiple Parton Interaction (MPI)

Beam-beam remnants

Underlying Event

Everything which occurs during the collision, but the hard scattering!

How can we quantify the UE contribution?

Analysis technique

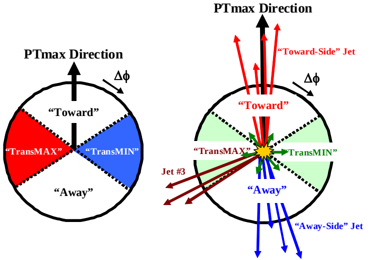
$\rightarrow$ Charged particle multiplicity and p_T sum
as a function of the leading charged particle

$$|\Delta\phi| = |\Delta\phi^{part} - \Delta\phi^{lead}| \rightarrow$$

if $|\Delta\phi| < \pi/3 \rightarrow$ TOWARD region
if $\pi/3 < |\Delta\phi| < 2\pi/3 \rightarrow$ TRANSVERSE region
if $|\Delta\phi| > 2\pi/3 \rightarrow$ AWAY region

MIN and MAX regions are defined by the activity in each of the two transverse regions

- TRANS MIN: sensitive to MPI
- TRANS MAX: sensitive to MPI and PS
- TRANS DIF: sensitive to PS
- TRANS AVE: sensitive to MPI and PS

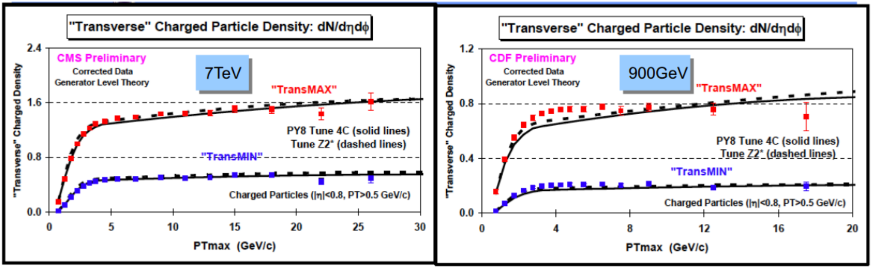


Charged particles in the central region are counted above a certain p_T threshold

Status of the art

→ Understanding of the Underlying Event data is crucial for every analysis using MC predictions

1. UE as a function of the leading charged particle p_T



R.Field, The Tevatron Energy Scan: Findings & Surprises, (September 17,2013), CMS-PAS-FSQ-12-020

How are the MPI implemented in Monte Carlo event generators?

MPI energy extrapolation: regularization of the partonic cross section

$$p_T^0 = p_T^{ref} \cdot \left(\frac{E}{E^{ref}}\right)^{exp}$$

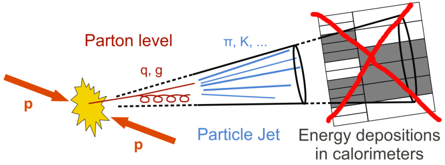
Tunes extracted from these data in CMS (CMS-GEN-14-001)

Why to measure track jets?

1. UE as a function of the leading charged jet p_T

Step forward:

- Measurement reaches higher p_T scales
- Less sensitive to hadronization and shower effects than measurement with leading charged particle



TRACK JETS:
Clustering charged particles measured only in the tracker

Less information but access to low p_T jets

How to cluster them?

→ SISCone algorithm:

- No seed for jet clustering
- Find all stable cones from the measured particles
- Stop the procedure where only stable cones are present and all particles are associated to a jet

Measurement of the Underlying Event at 2.76 TeV in *pp* collisions with the CMS experiment

Analysis and event selection

- Data used
  - Special runs at 2.76 TeV in March 2011
  - Three different triggers: Minimum Bias + two jet triggers (at different p_T thresholds)
- Vertex requirement
  - Only one reconstructed primary vertex within 10 cm along the longitudinal direction from the nominal interaction point
- Track requirement
  - High quality tracks with $p_T > 0.5$ GeV in $|\eta| < 2.0$
  - Cut on the impact parameter in order to remove secondary decays
- Jet requirement
  - Leading track-jet with $p_T > 1$ GeV in $|\eta| < 2.0$ clustered with SIsCone R = 0.5
  - Built with the same previous track selection in $|\eta| < 2.5$

Unfolding and systematics

Data unfolded to the stable particle level

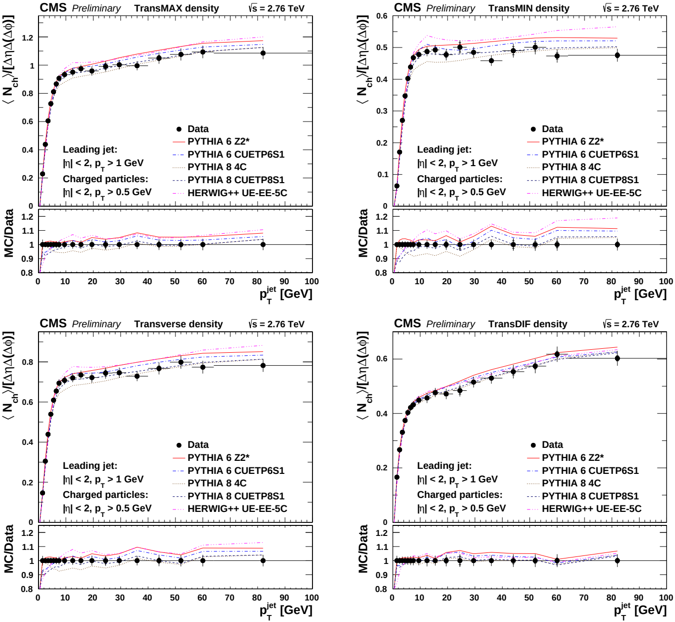
- 4D response matrices
- Profile of the distributions extracted after event-by-event unfolding

→ **Several systematic effects are evaluated in the measurement**

Source	Systematic uncertainty (%)	Source	Systematic uncertainty (%)
Impact Parameter Sig.	2-4	Dead Channel	0.1
Track sel.	0.2	Beamspot	0.2
Fake Mis-modelling	0.4-0.5	Material Budget	1.0
Model dep.	1-4	Tracker Alignment	0.2-0.3

Dominant effects are the model dependence and the impact parameter significance

Results: charged particle multiplicity



TransMIN region has a flatter plateau

Rise and plateau well described by the available models

Best performing CUETP8S1

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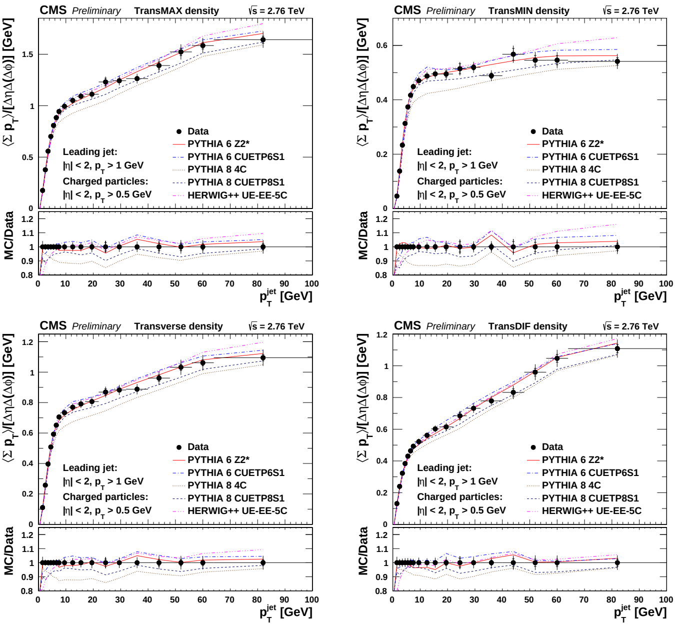
TOP: MAX, MIN
BOTTOM: AV, DIFF

Results: charged transverse momentum sum



TransMIN region has a flatter plateau

Rise and plateau well described by the available models

Best performing P6 Z2*

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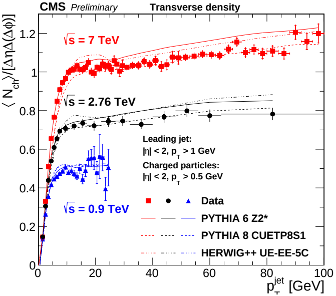
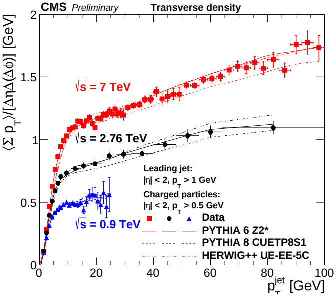
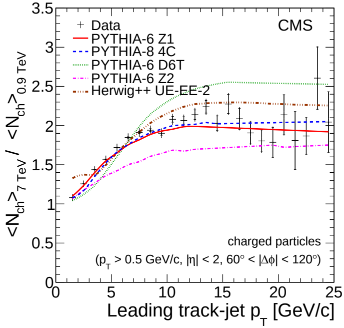
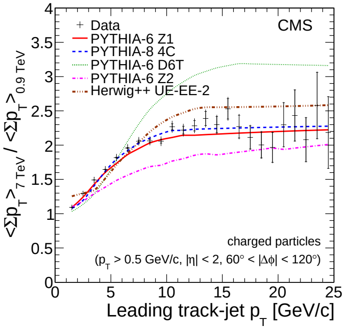
TOP: MAX, MIN
BOTTOM: AV, DIFF

Underlying event measurements at different energies









TransAV region

UE data at 0.9, 2.76 and 7 TeV

Only the new tunes are able to reproduce very well the energy dependence!

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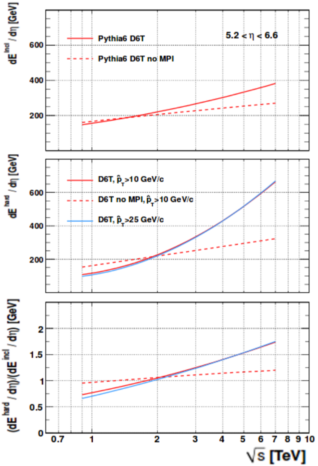
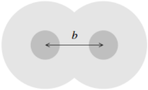
TOP: Nch, p_T sum in AV. region
BOTTOM: Ratio 7/0.9 TeV for Nch and p_T sum

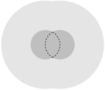
Energy density at forward rapidities (CASTOR region $-6.6 < \eta < -5.2$) in Min. Bias events compared to hard ones



Minimum bias (inclusive events)
- ➔ energy density not much affected by MPI
- ➔ non-diffractive dominated event sample



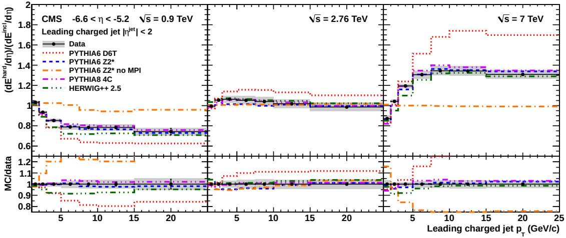
Hard scale $\hat{p}_T$
- ➔ energy flow strongly affected by MPI
- ➔ use the central leading charged jet with p_T > 1 GeV/c and $|\eta|$ < 2

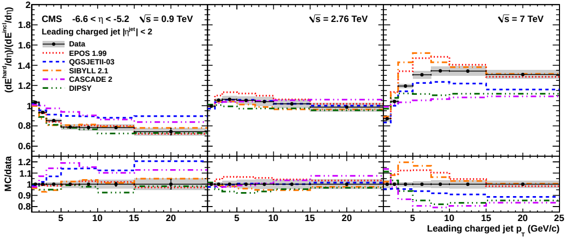


Compute ratio of energy densities
- ➔ able to factorize MPI contributions
- ➔ minimizes systematic uncertainties

Look at behavior of ratio as function of p_T scale and at relative energy flow as function of $\sqrt{s}$

Underlying Event measurements at forward rapidities (II)





Hard/inclusive energy density ratio vs leading charged jet p_T at different energies

- Hard: presence of a jet in $|\eta|<2$ with $p_T>1$ GeV
- Inclusive: no request in the central region

Different behaviour at $\sqrt{s}=0.9$ and 7 TeV

Data corrected to hadron level

Systematic uncertainty $\approx$ 4.7-3.6 %

Pythia Z2* and 4C & H++ 2.5 describe the data, P6 D6T predicts too much MPI.

None of the cosmic ray models describe the data correctly. JHEP 04 (2013) 072

Summary and conclusions

- CMS offers a large collection of data, sensitive to UE at different collision energies
- Current models are able to reproduce well the measured distributions
- Models specialized in describing UE data at different energies

We are ready to predict the UE at 13 TeV

THANK YOU
FOR THE ATTENTION

Projections at 13 TeV

Charged particle multiplicity and p_T sum at 13 TeV

$\rightarrow$ Projections of UE observables for the different tunes