

Minimum bias and underlying event measurements with CMS

Benoît Roland (DESY)
on behalf of the CMS collaboration

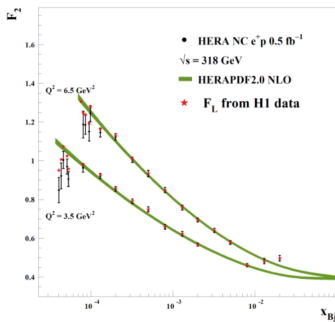
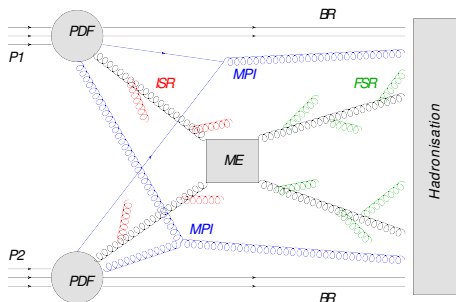
DIS 2017 Workshop

3-7 April 2017
Birmingham, UK

Motivation

- We want to probe **the dynamics** of hadron production ...
... investigate the behavior of its **different components** ...
... as well as their **universality**
- We want to get an insight in the **non-perturbative** QCD regime ...
... and in the behavior of QCD at **small-x**
- We want to probe the **transition scale** between ...
... the perturbative and non-perturbative regions
- We study **different observables** sensitive ...
... to **specific components** of the hadron production
 - inclusive observable: charged particle density in minimum bias events
 - differential observables: charged particle and energy densities
with respect to the direction of the leading object
in hadronic events and Drell-Yan events

Description of the hadron production



- Parton densities **at small x and small scale**
- **The Hard Scattering** \rightarrow described by pQCD at fixed order
- **Initial-State Radiation** and **Final-State Radiation**
 - \rightarrow account for higher order emissions
 - \rightarrow described by QCD-evolution-inspired Parton Shower
- **Several Soft to Semi-Hard Scatterings: Multiple Partonic Interactions**
 - \rightarrow described by pQCD-inspired phenomenological models
- **MPI** have their own **ISR** and **FSR**
- Beam Remnants
- Hadronisation

Underlying Event

Tuning of the model parameters based on experimental data

Phenomenology of the low- p_T region

- total $2 \rightarrow 2$ **partonic cross section**: $\sigma(p_T) \propto 1/p_T^2$
 - is **divergent towards low p_T** and eventually becomes **larger than σ_{inel}**
- At LHC energies: $\sigma(p_T) > \sigma_{inel}$ already for $p_T \sim 5$ GeV
 - ➔ **Cross section needs to be tamed in the low p_T region**
- In PYTHIA: the rise of the $2 \rightarrow 2$ partonic cross section is controlled by:

- an infrared cutoff p_{T0} tuned to data:**

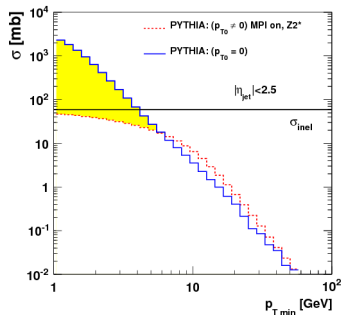
$$\sigma(p_T) \propto \frac{1}{p_T^2 + p_{T0}^2}$$

energy dependence parametrised by a power law:

$$p_{T0}(\sqrt{s}) = p_{T0}(\sqrt{s_0}) \left(\frac{\sqrt{s}}{\sqrt{s_0}} \right)^\alpha$$

- multiple partonic interactions (MPI):**

$$\langle n_{MPI} \rangle = \sigma(p_T) / \sigma_{inel}$$



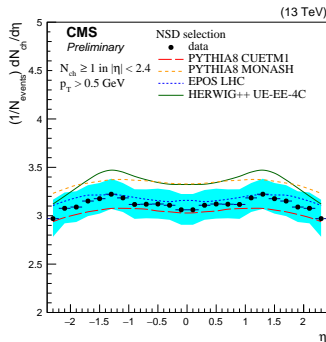
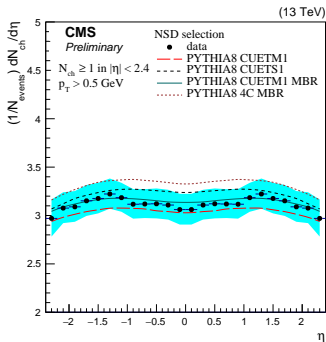
[Phys. Rev. D 86 (2012) 117501]

Charged particle pseudorapidity density at 13 TeV - NSD

[CMS-PAS-FSQ-15-008]

- Results corrected to primary charged particles - $N_{ch} \geq 1$ - $p_T > 0.5$ GeV - $|\eta| < 2.4$
- Different event categories based on the **activity in the forward region** $3 < |\eta| < 5$

At least one particle with $E > 5$ GeV in **both** forward regions \rightarrow **NSD enhanced sample**

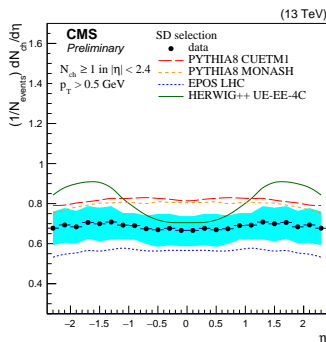
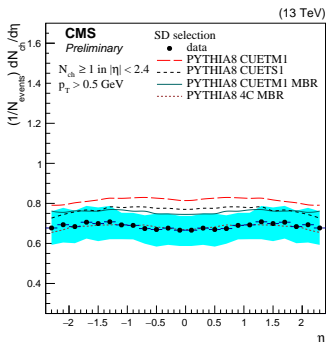


- ➔ **PYTHIA8** with different tunes and **EPOS LHC** show similar agreement with the data
- ➔ **HERWIG++ (version 6.521) UE-EE-4C** is not able to describe the measurement
- ➔ difficult to describe **simultaneously** the density in the central and most forward regions

Charged particle pseudorapidity density at 13 TeV - SD

- Results corrected to primary charged particles - $N_{ch} \geq 1$ - $p_T > 0.5$ GeV - $|\eta| < 2.4$

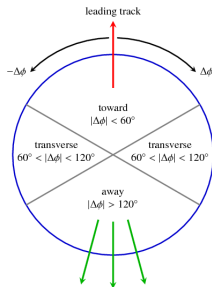
At least one particle with $E > 5$ GeV in **only one** of the forward regions,
no activity on the other side \rightarrow **SD enhanced sample**



- \rightarrow particle density ~ 4 times smaller \rightarrow **correlation** between the central and forward regions
PYTHIA8 4C MBR gives the best description
HERWIG++ (version 6.521) UE-EE-4C has no diffractive component
- \rightarrow **Larger model dependence not covered by the systematic uncertainties**

Underlying event measurements - strategy

- Underlying Event: activity not attributed to the hardest partonic scattering
Initial-State Radiation, **Final-State Radiation**, **Multiple Partonic Interactions**, proton remnants
- Experimentally: final-state hadrons can not be identified as coming from one of these processes
→ define 3 regions in φ with respect to the **direction of the leading object**



Towards region ($|\Delta\varphi| < 60^\circ$) and **Away region** ($|\Delta\varphi| > 120^\circ$)

→ dominated by the **leading object** and the **hadronic recoil**

Transverse region ($60^\circ < |\Delta\varphi| < 120^\circ$)

→ **most sensitive to the UE activity**

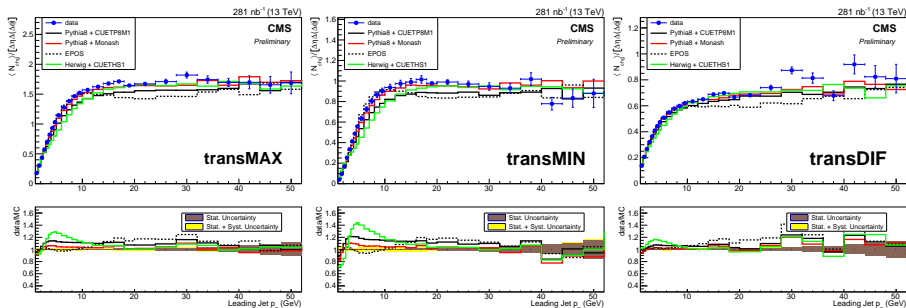
Separate activity from **Radiation** and **Multiple Partonic Interactions**

- **TransMIN**: transverse region with the **lowest** activity → **MPI**
- **TransMAX**: transverse region with the **highest** activity → **MPI** + **Radiation**
- **TransDIF**: difference between TransMAX and TransMIN → **Radiation**
- **TransAVE**: average between TransMAX and TransMIN

Underlying event with leading particles and jets at 13 TeV

[CMS-PAS-FSQ-15-007]

- Average particle density versus leading jet p_T for charged particles - $p_T > 0.5$ GeV - $|\eta| < 2$

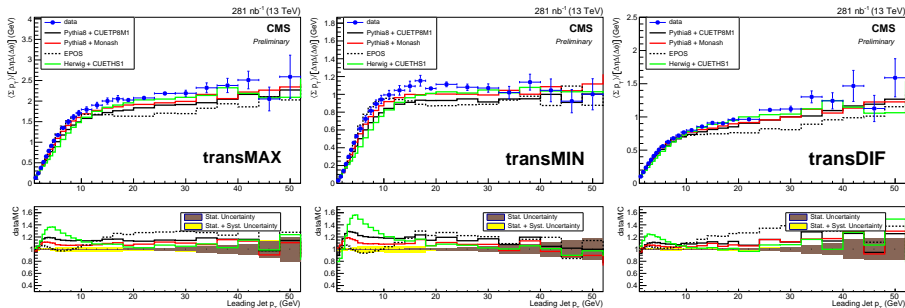


2 different regimes:

- at low p_T : sharp rise due to the increase of the MPI activity
 - at higher p_T : MPI activity saturates, slow increase due to the ISR and FSR contributions
- TransMIN flatter at high p_T (MPI saturated) than TransMAX and TransDIF (radiative increase)

Underlying event with leading particles and jets at 13 TeV

- Average energy density versus leading jet p_T for charged particles - $p_T > 0.5$ GeV - $|\eta| < 2$



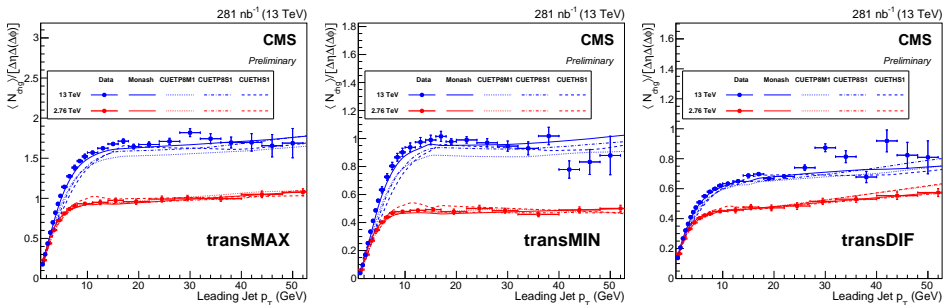
qualitative behavior described by the predictions:

- level of agreement of 10 - 20% in the plateau region
- **larger difference** between models in the **low p_T** region

➔ 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 particles and jets at 13 TeV

- Average particle density versus leading jet p_T - energy dependence 2.76 TeV \rightarrow 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

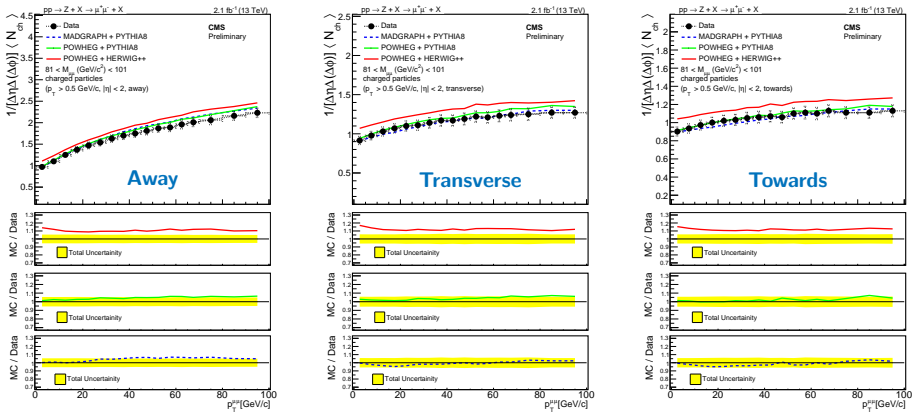
→ MPI activity grows faster with \sqrt{s} than activity from ISR and FSR

New results!

[CMS-PAS-FSQ-16-008]

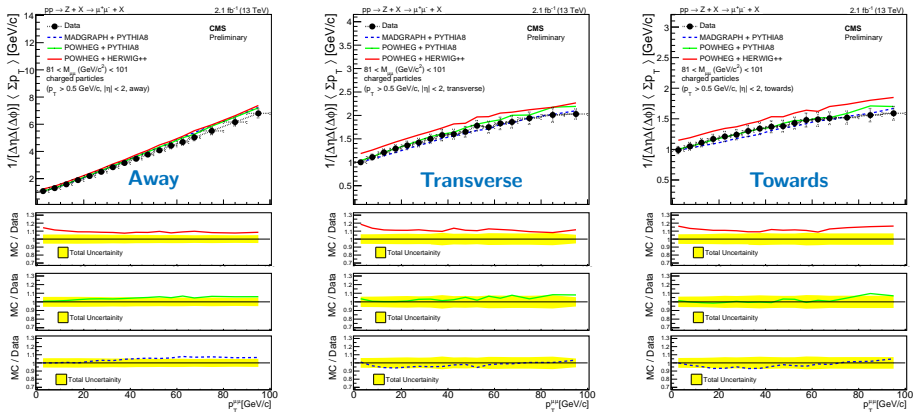
- 2 muons from Z leptonic decay with $p_T > 10$ and 20 GeV, $|\eta| < 2.4$ and $81 < M_{\mu\mu} < 101$ GeV
average particle and energy densities for charged particles with $p_T > 0.5$ GeV and $|\eta| < 2$
in the towards, transverse and away regions
- test the **process universality** of the underlying event activity
test the underlying event activity at **higher scale**
no **Final-State Radiation** → more direct access to **Initial-State Radiation** and **MPI**
test the **universality of the tunes** interfaced with different event generators
 - MADGRAPH (Z + up to 4 partons at LO) + PYTHIA8 CUETP8M1
 - POWHEG (Z + up to 2 partons at NLO) + PYTHIA8 CUETP8M1
 - POWHEG + HERWIG++ EE5C

UE in DY - average particle density versus dimuon p_T



- at low p_T : no sharp rise, **MPI activity already saturated** (hard scale $M_{\mu\mu}$)
- at higher p_T : **slow increase** of the **ISR activity** in the transverse and towards regions
sharp increase of the **ISR activity** in the away region (recoiling hadronic activity)
- similar activities in the 3 regions as dimuon $p_T \rightarrow 0$
→ similar MPI activities in the 3 regions → **different behaviors due to varying ISR**

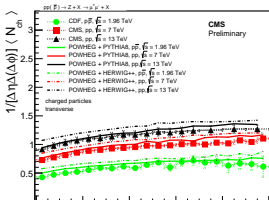
UE in DY - average energy density versus dimuon p_T



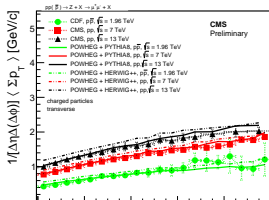
- ➔ **POWHEG + HERWIG++ EE5C** overestimates the activity by 10-15% in all regions
- POWHEG + CUETP8M1** describes the data within 5%
- MADGRAPH + CUETP8M1** gives the best description

UE in DY - transverse activity at different energies

average particle density



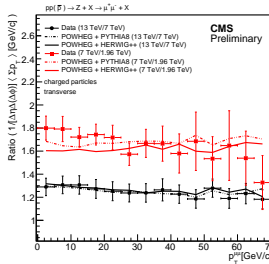
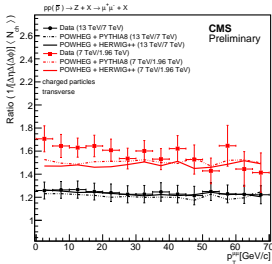
average energy density



1.96 TeV \rightarrow 7 TeV \rightarrow 13 TeV

POWHEG + HERWIG++ EE5C
overestimates data by 40 to 10%

POWHEG + CUETP8M1
describes data within 10 to 5%



increase in densities

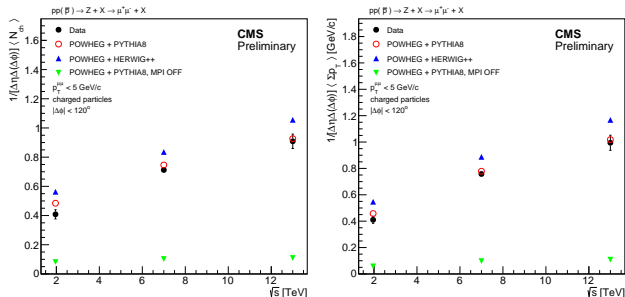
25-30% from 7 to 13 TeV
models in good agreement

60-80% from 1.96 to 7 TeV
models predict lower increase
particularly at low p_T

UE in DY - MPI activity at different energies

at low dimuon p_T : underlying event activity dominated by MPI contributions
and similar in transverse and towards regions

→ average particle and energy densities for dimuon $p_T < 5$ GeV versus \sqrt{s}
in the combined transverse and towards regions



POWHEG + PYTHIA8 without MPI → contributions from radiation very small

increase of MPI activity well reproduced by **POWHEG + CUETP8M1**

overestimated by **POWHEG + HERWIG++ EE5C**

Conclusion

- Minimum bias and underlying event measurements
probe the dynamics of hadron production with increasing precision
- Sensitivity to the **parton densities at small x and small scale**,
Initial-State Radiation, **Final-State Radiation** and **Multiple Partonic Interactions**
- Various observables enable to measure these different components
independently from each other
- Results are valuable inputs to further constrain phenomenological models
used to describe the particle production at low p_T

Thanks for your attention!

Back up

- Underlying Event Measurements with Leading Particles and Jets in proton-proton collisions at $\sqrt{s} = 13$ TeV, CMS-PAS-FSQ-15-007.
- Measurement of the underlying event using the Drell-Yan process in proton-proton collisions at $\sqrt{s} = 13$ TeV, CMS-PAS-FSQ-16-008.
- Measurement of pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV by the CMS experiment, CMS-PAS-FSQ-15-008.