# Recent Minimum Bias and UE measurements at CMS at 13 TeV

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on behalf of the CMS Collaboration

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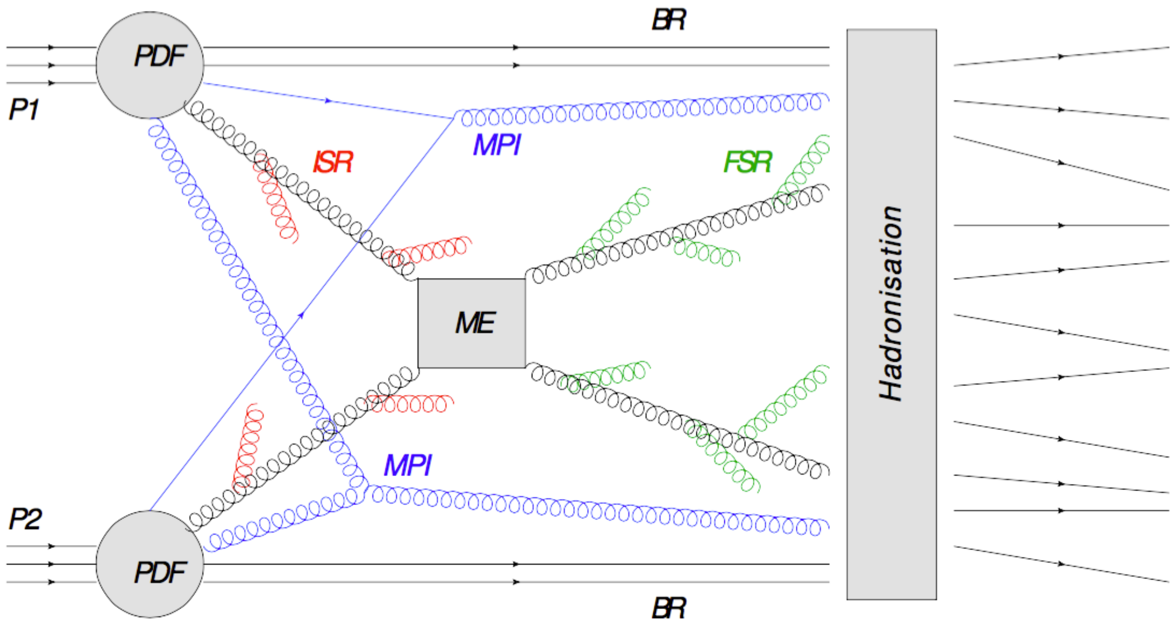
**Nagoya, Japan**

# Motivation 1/2

- Study the different components of particle production




- Also study soft processes:
  - Small scales
  - Small x
- Study transition from perturbative to non-perturbative region

⇓

**Saturation effects**
(taming of the cross section)

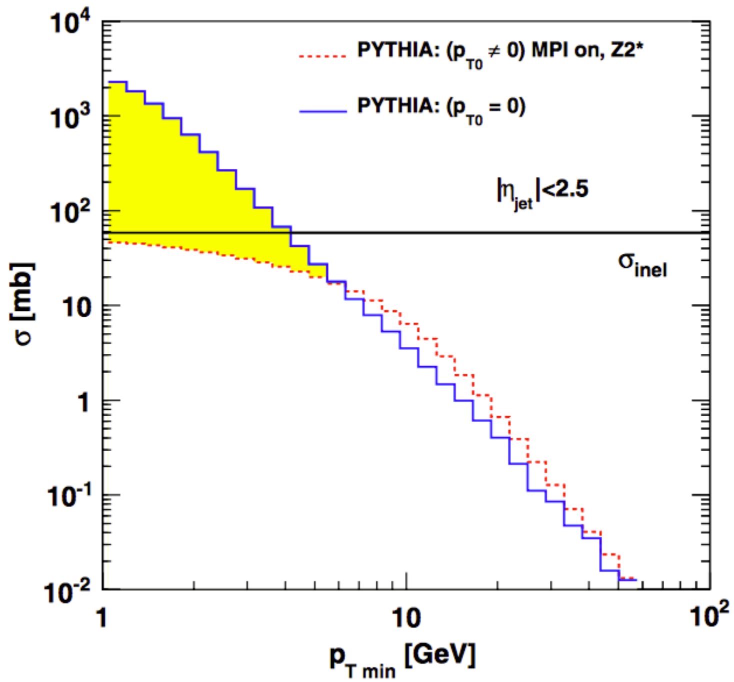
**With all this we can constrain and tune the models**

# Motivation 2/2 Saturation effects (taming of the cross section)

The total 2 → 2 partonic cross section is divergent for $p_T \to 0$

$$\frac{d\sigma_{2\to 2}}{dp_T^2} \propto \frac{\alpha_s^2(p_T^2)}{p_T^4}$$

$$\Rightarrow \sigma(p_T) > \sigma_{inel}$$





10.1103/PhysRevD.86.117501
10.1016/j.cpc.2015.01.024


PYTHIA8: fix this divergence by introducing a regulator $p_{T,0}$

$$\frac{d\sigma_{2\to 2}}{dp_T^2} \propto \frac{\alpha_s^2(p_T^2)}{p_T^4} \to \frac{\alpha_s^2(p_T^2 + p_{T,0}^2)}{(p_T^2 + p_{T,0}^2)^2}$$

and interpreting the remaining excess as Multi-partonic interactions (MPI)

$$< n_{MPI} >= \sigma(p_T)/\sigma_{inel}$$

This motivates the measurement of $p_T$ for the leading charged particle.

# Analyses

## Minimum Bias (MB)

- Very loose trigger conditions.
- Dominated by low transverse momentum QCD processes.
- Sensitive to saturation effects of cross section and MPI.

Presented for **different final state events** and **identified particle species**

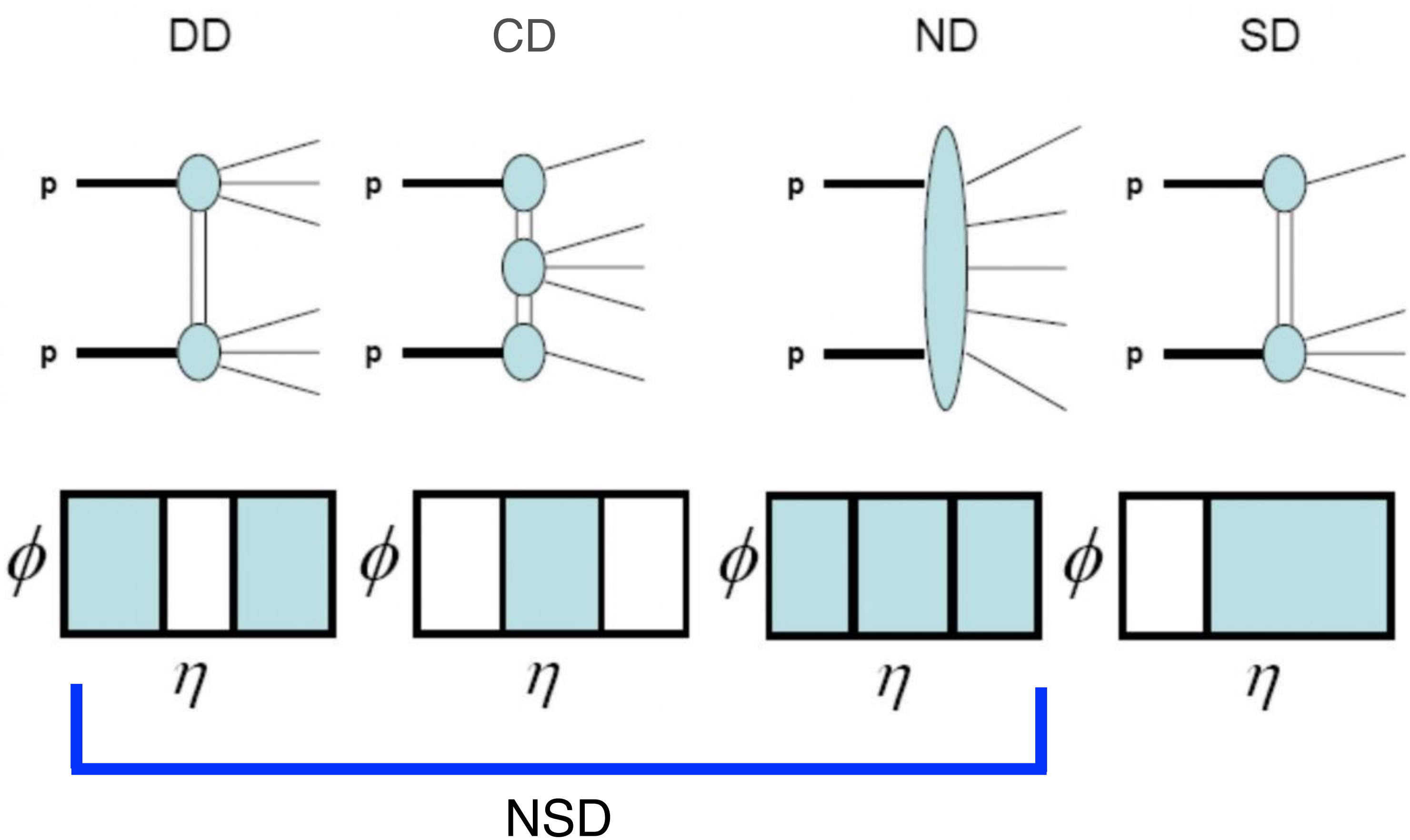
## Underlying Event (UE)

- Events with reference object: leading particle/jet above certain $p_T$ threshold, Z boson, etc.
- Selection of activity regions w.r.t. reference object.
- Sensitive to MPI, Beam remnants, ISR/FSR.

Presented for **Z boson production** events.

- Four different event selections based on activity in forward region
  - **Inclusive** sample
  - **Inelastic** enhanced sample
  - **Non Single Diffractive** (NSD) enhanced sample
  - **Single Diffractive** (SD) enhanced sample

CMS-PAS FSQ-15-008



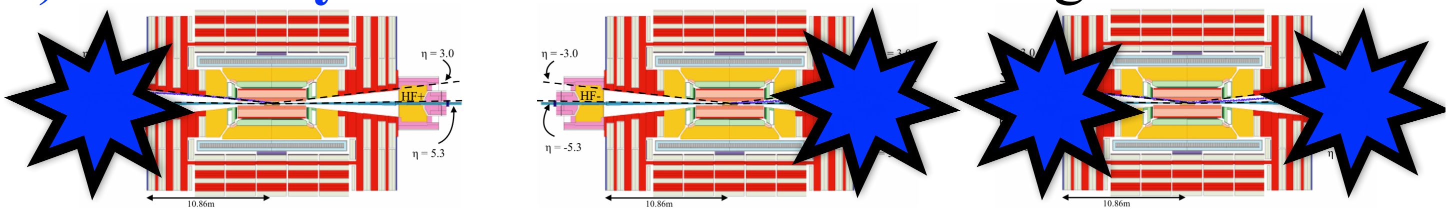
# Phase space definition at stable particle level η spectra

(A) At least 1 charged particle $\left\{ \begin{array}{l} p_T > 0.5 \text{ GeV} \\ |\eta| < 2.4 \end{array} \right.$

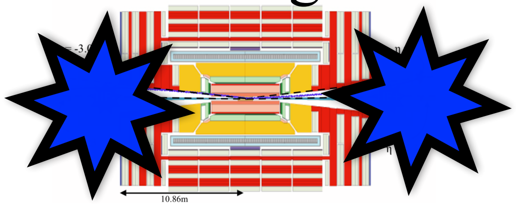
Forward region
$3 < |\eta| < 5$

- ✦ **Activity**: at least 1 particle with E > 5 GeV
- ✦ **Veto**: no particle with E > 5 GeV

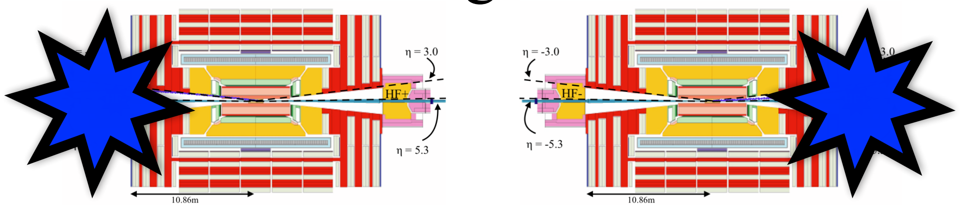
- **Inclusive**: (A)
- **Inelastic enhanced**: (A) + **Activity** in **at least one** Forward Region



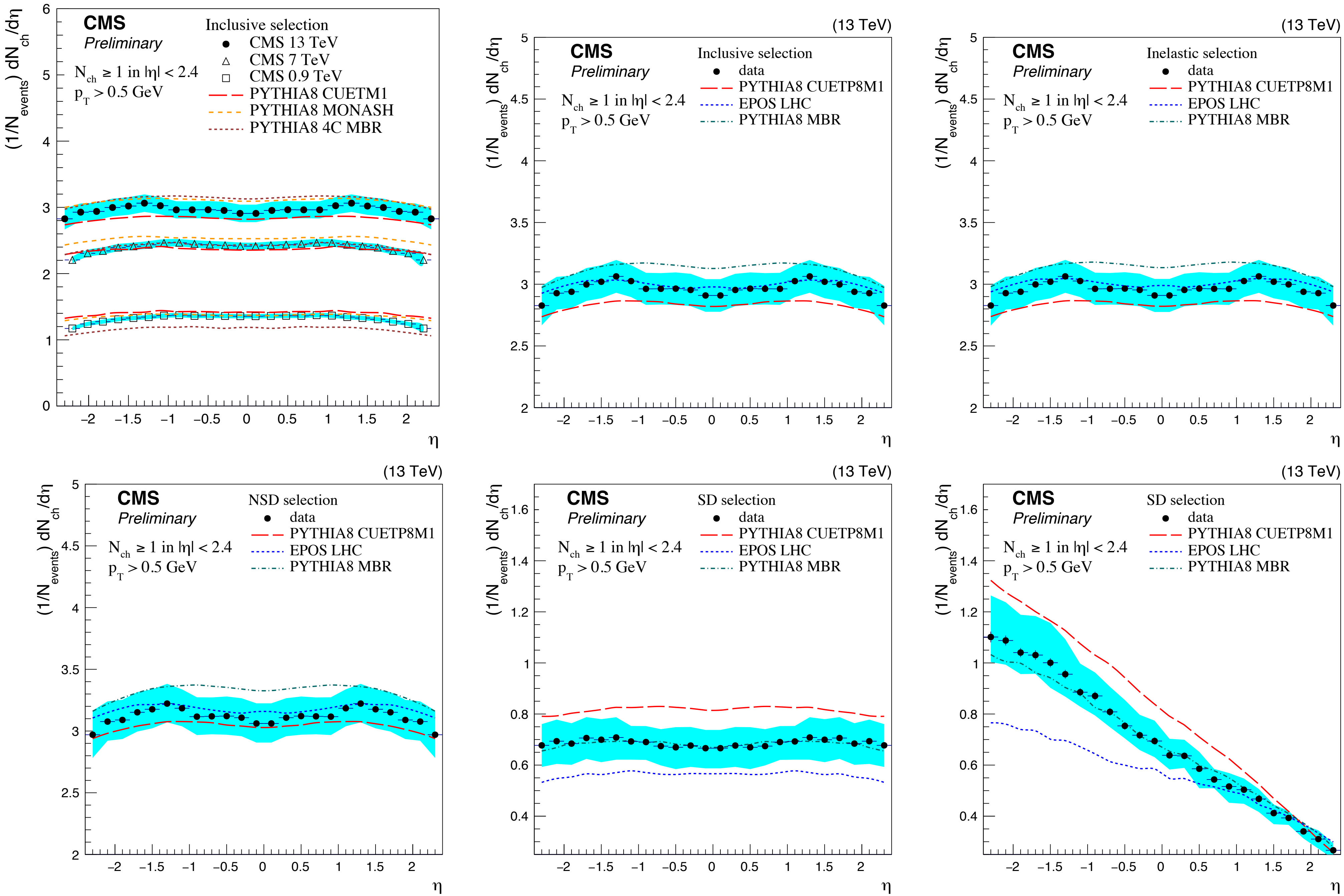
- **NSD enhanced**: (A) + **Activity** in **both** Forward Regions



- **SD enhanced**: (A) + **Activity** in one Forward Region **and** **Veto** in the other side



# Minimum Bias analysis results η spectra



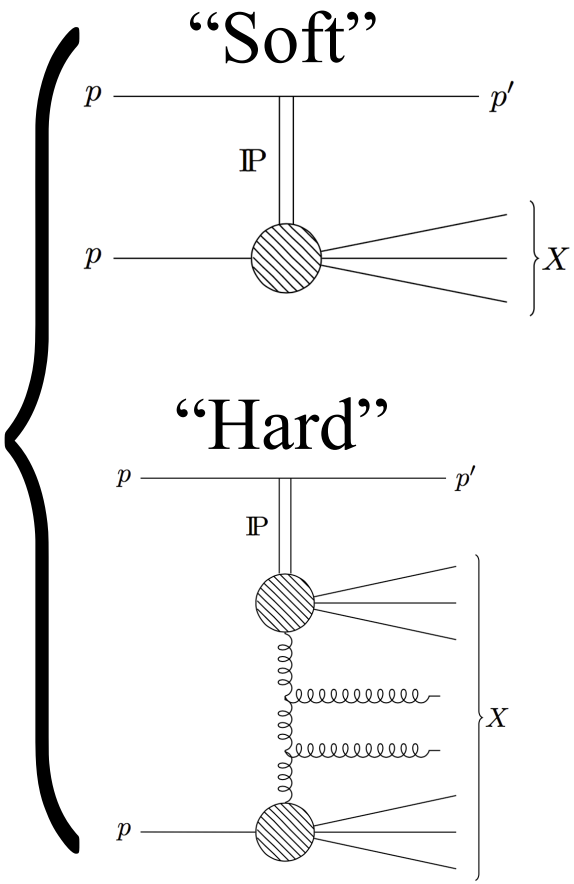

CMS PAS FSQ-15-008

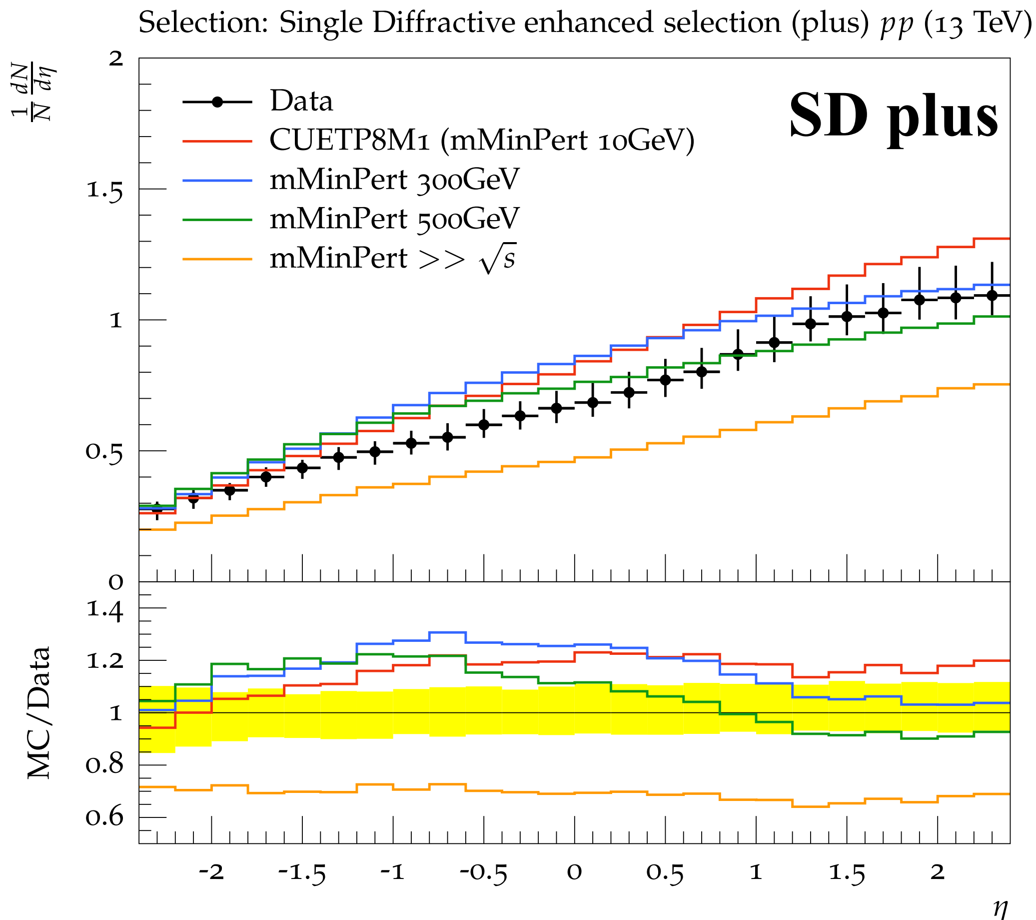
**Soft** **and** **hard** components have a smooth **transition** at a certain value. In PYTHIA8 the **minimum Diffractive Mass** of the system **produced** **perturbatively** can be chosen.

if **minDiffMass** > $\sqrt{s}$
then
**No Perturbative** description at all

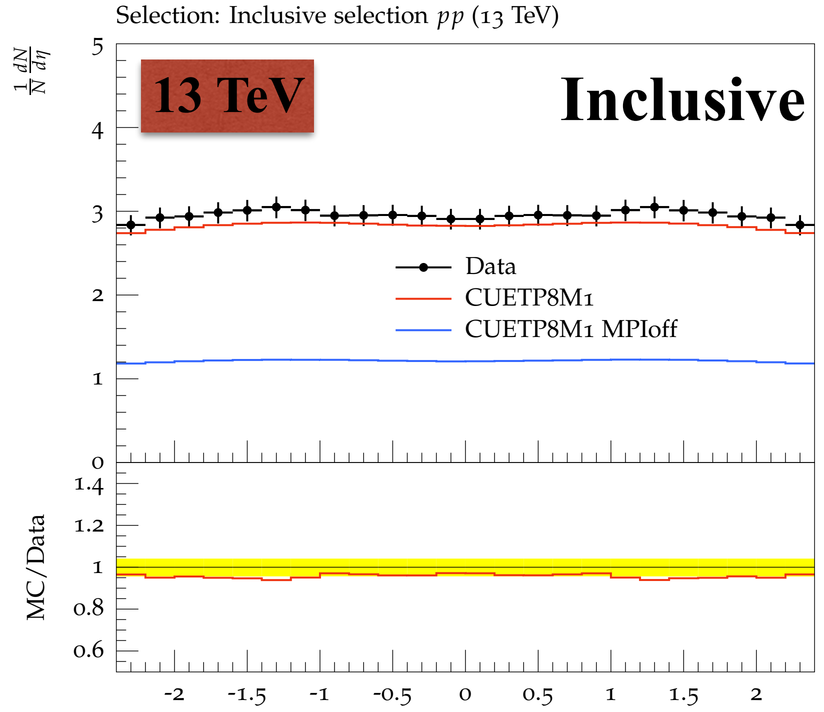
Sensitivity to high mass diffractive systems.

What are the contributions for the Single Diffractive component?



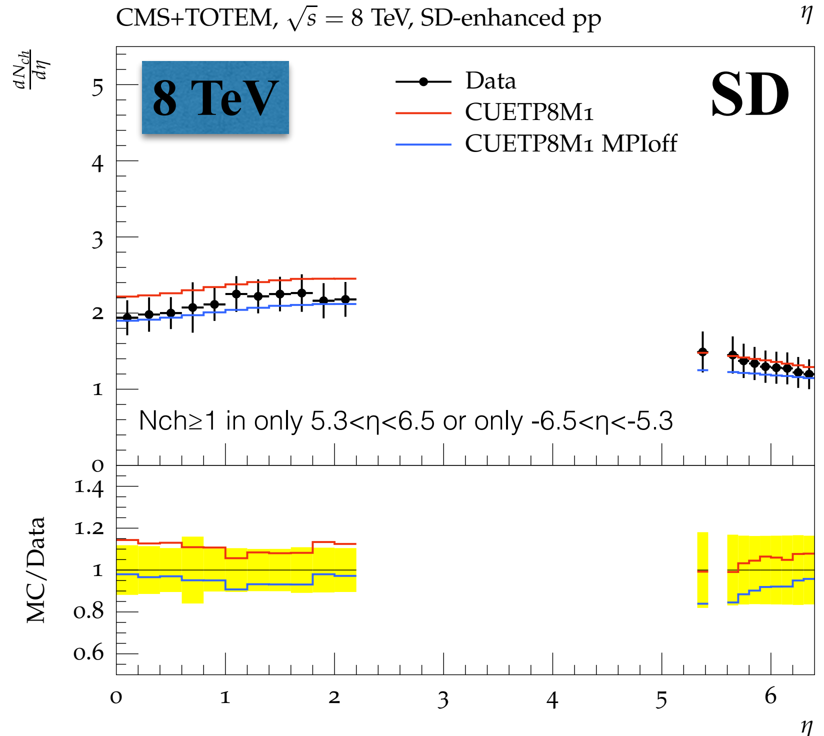
# Effects of **MPI** in the different diffractive enhanced samples

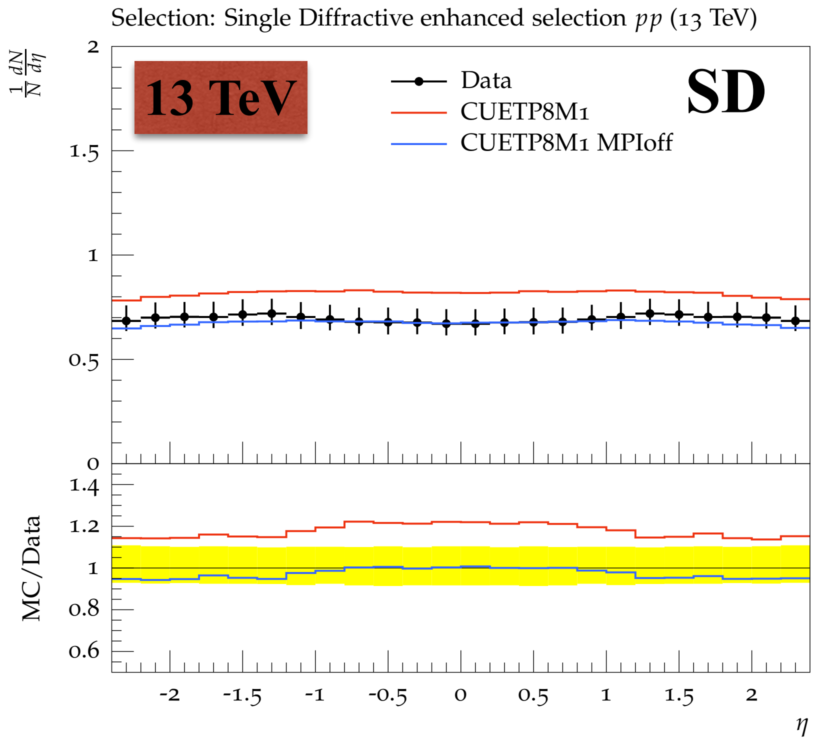



Inclusive selection highly sensitive to MPI

**2/3 of produced particles come from MPI**

**8TeV vs 13TeV**

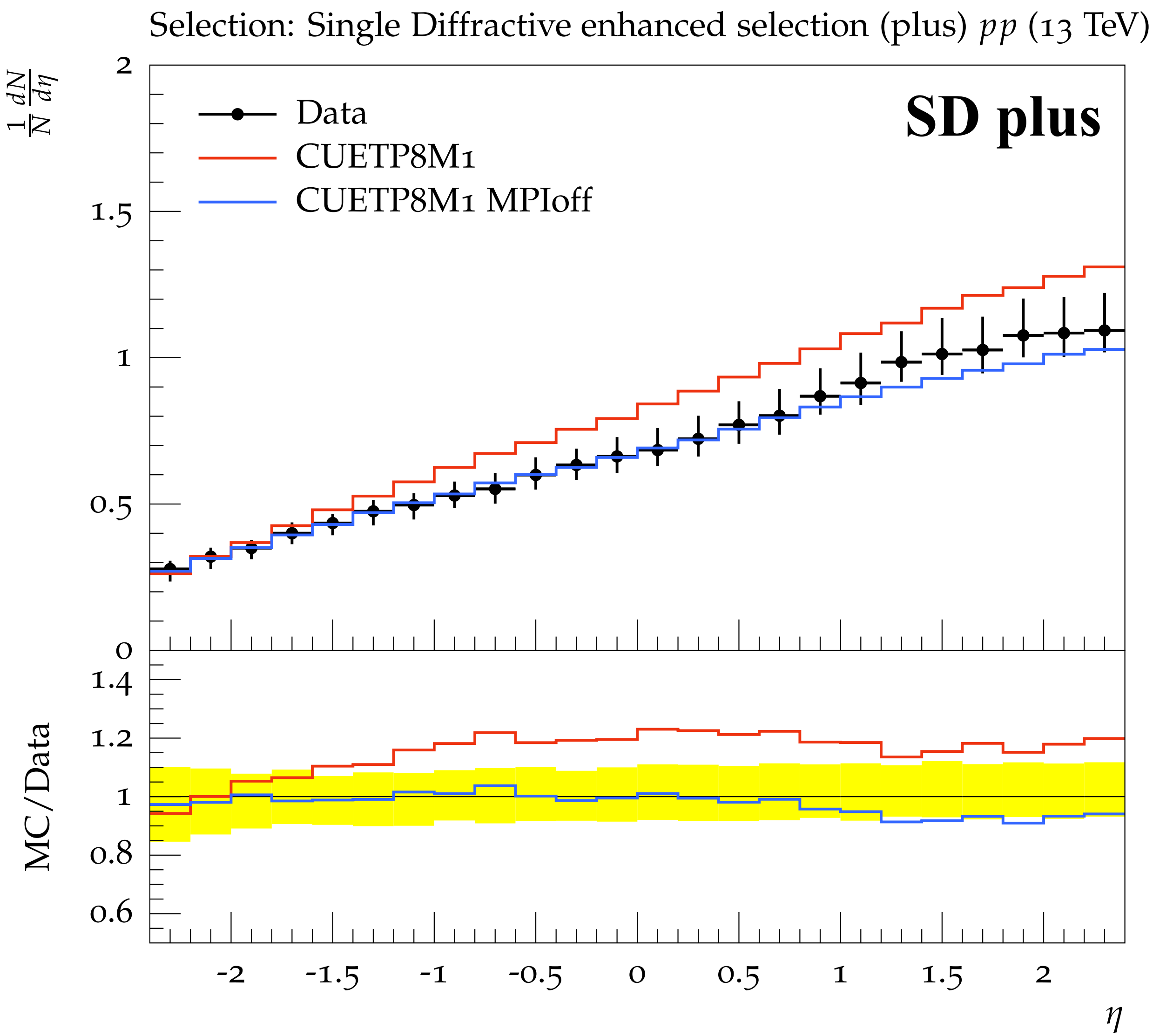


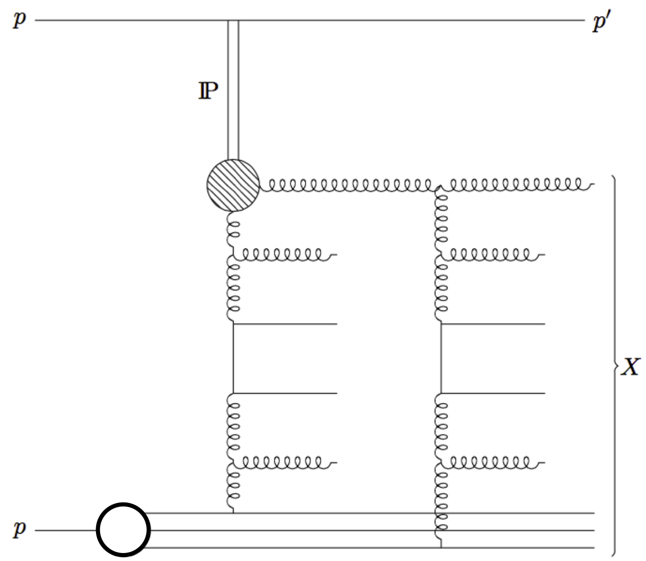




Better described without MPI. Bigger disagreement at 13TeV

# Effects of **MPI** in the different diffractive enhanced samples

Separate SD samples according to the side of the diffractive system.

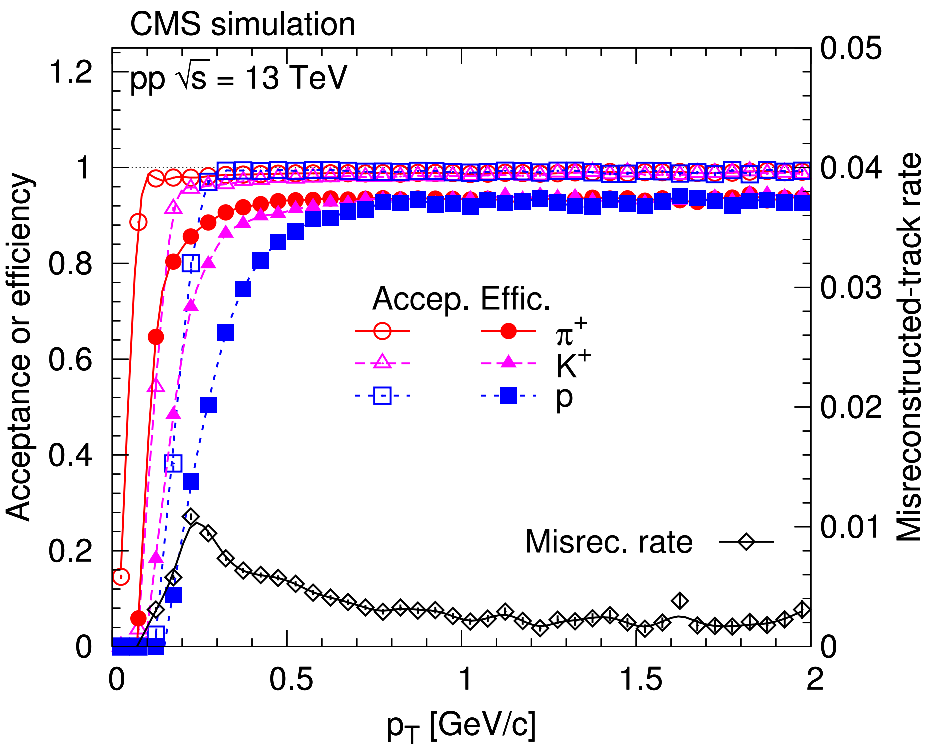


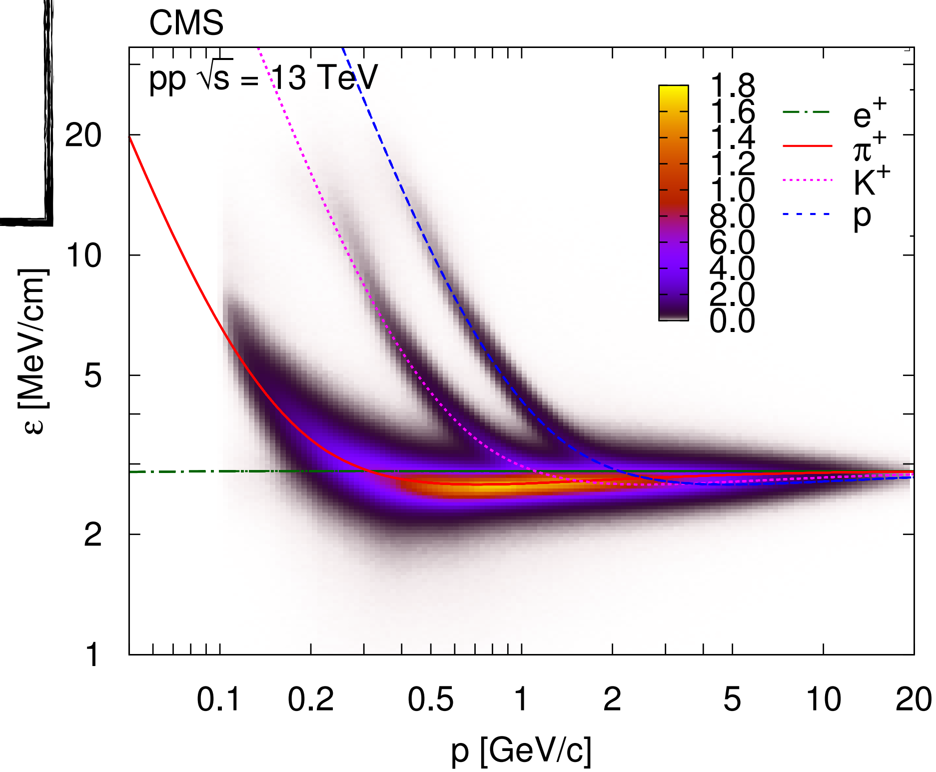




This is the first time we see indications of MPI in the diffractive system

# Identified charged particle spectra: pion , kaon and proton at $\sqrt{s}$ = 13 TeV

Special tracking algorithms extend reconstruction capabilities down to $p_T \approx 0.1$GeV




Identified from the energy deposited in the silicon tracker and the reconstructed particle trajectory.

**arXiv:1706.10194**

*Submitted to Physical Review D*

Measured:

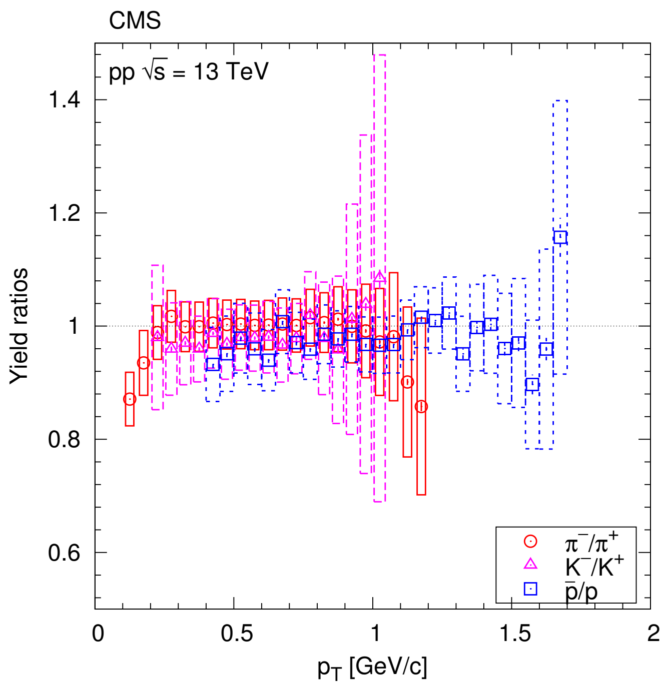
- $p_T$ spectra
- Average $\langle p_T \rangle$
- Ratio of particle yields

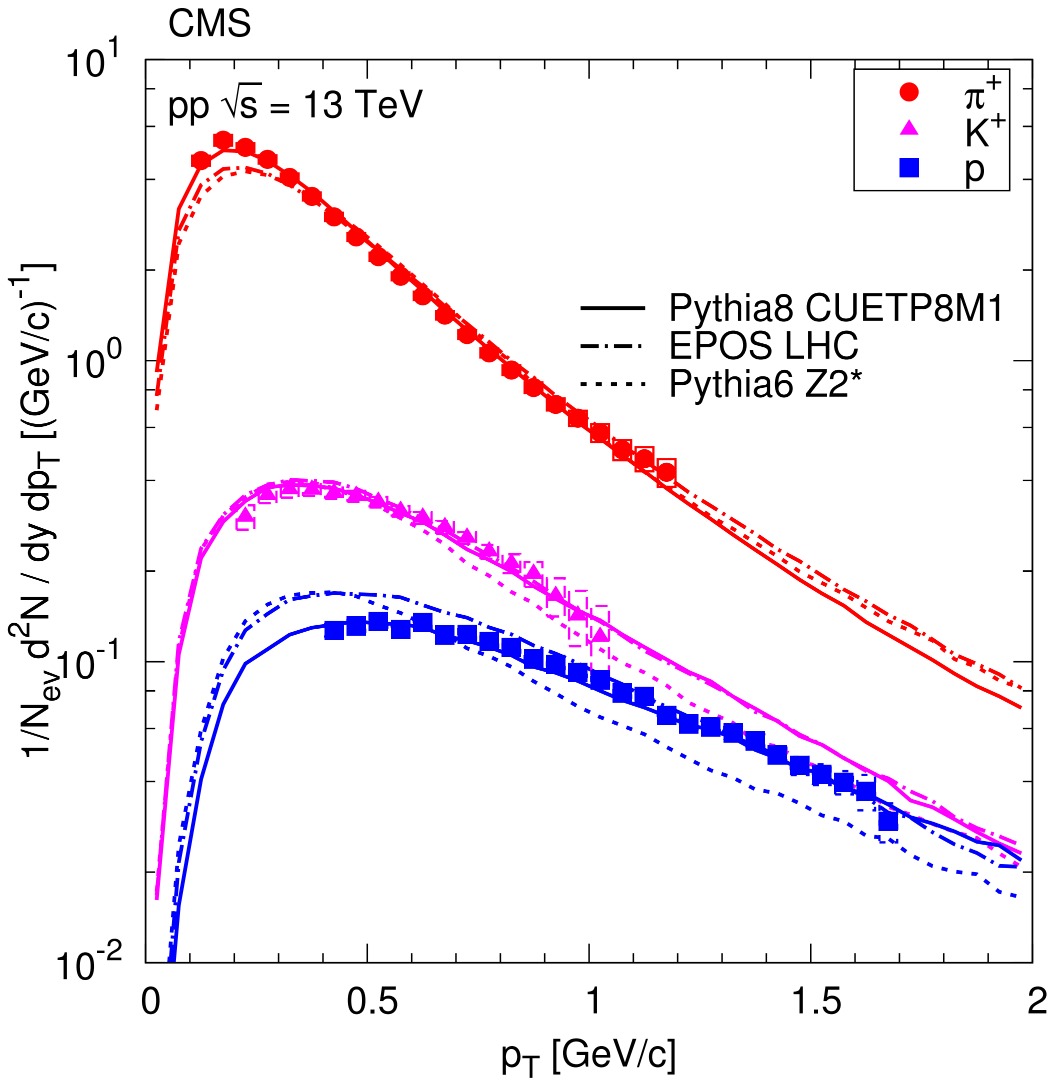
|y| < 1

K: p < 1.05 GeV

$\pi$: p < 1.2 GeV

p: p < 1.7 GeV



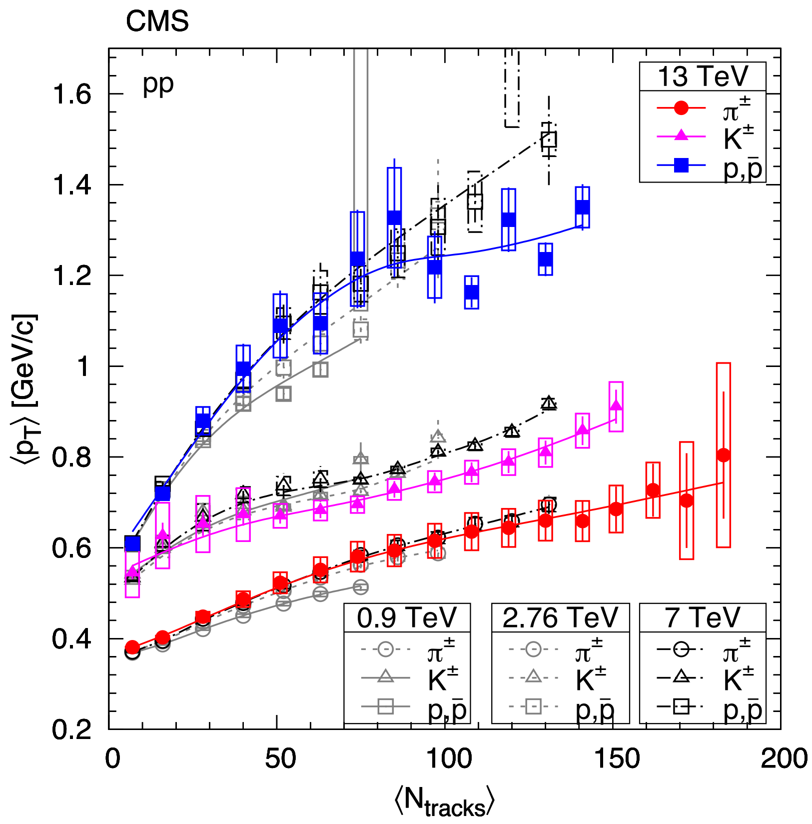

$\pi$ well described by compared generators

K best described by PYTHIA8 and EPOS

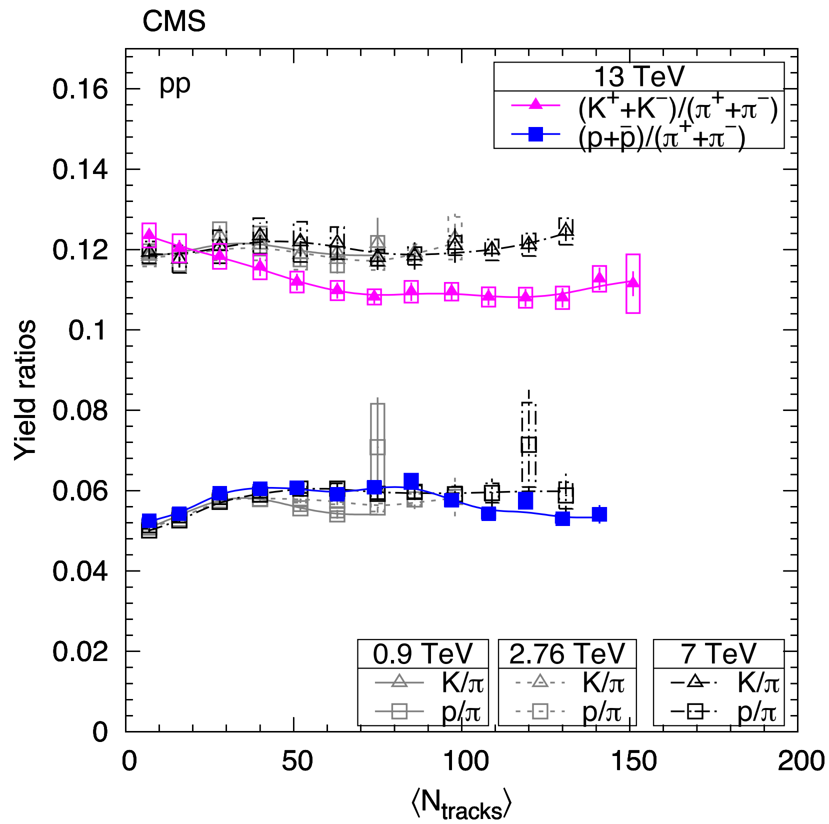
p best described PYTHIA8

Comparison to lower-energy pp data

c.m.e. of 0.9, 2.76 and 7 TeV




Track-multiplicity dependence of ⟨ $p_T$ ⟩




Track-multiplicity dependence of the particle yield ratios

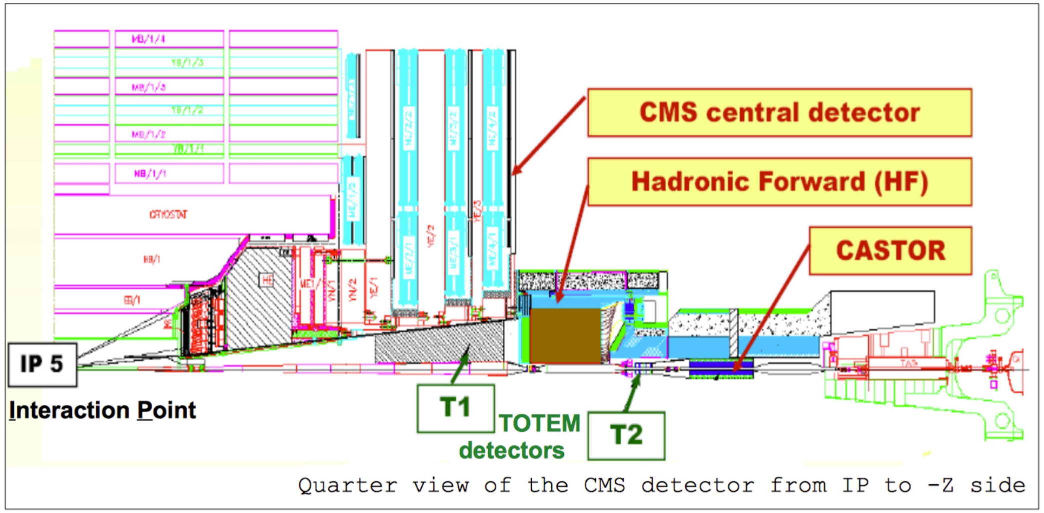
**Similar dependences on the particle multiplicity independently of c.m.e.**

# Inclusive energy spectrum in very forward direction in pp collisions at $\sqrt{s} = 13$ TeV

CASTOR calorimeter

$-6.6 < \eta < -5.2$

**Total** energy deposition
as well as
separated **electromagnetic**
and **hadronic** components




Events selected with fractional momentum loss of the proton $\xi > 10^{-6}$

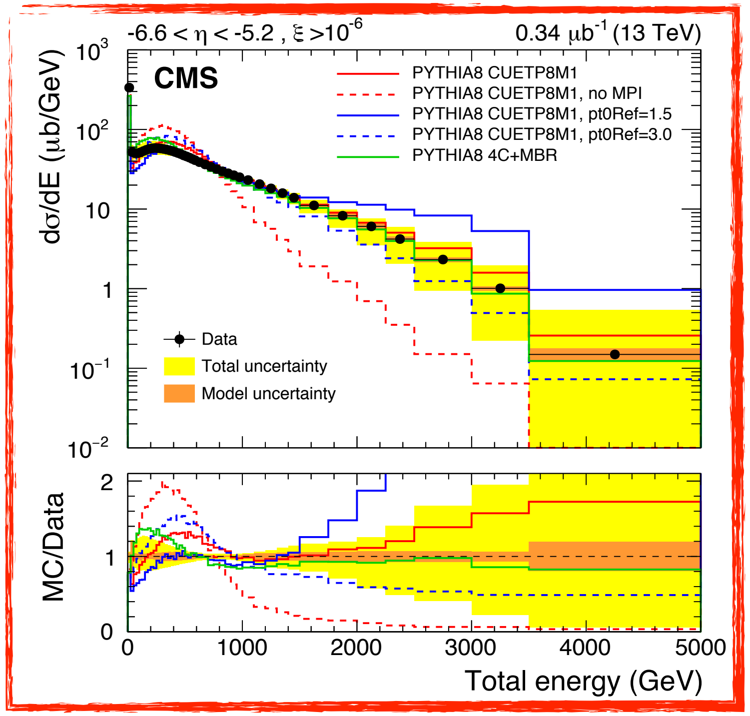
where: $\xi_X = M_X^2/s,\ \xi_Y = M_Y^2/s$

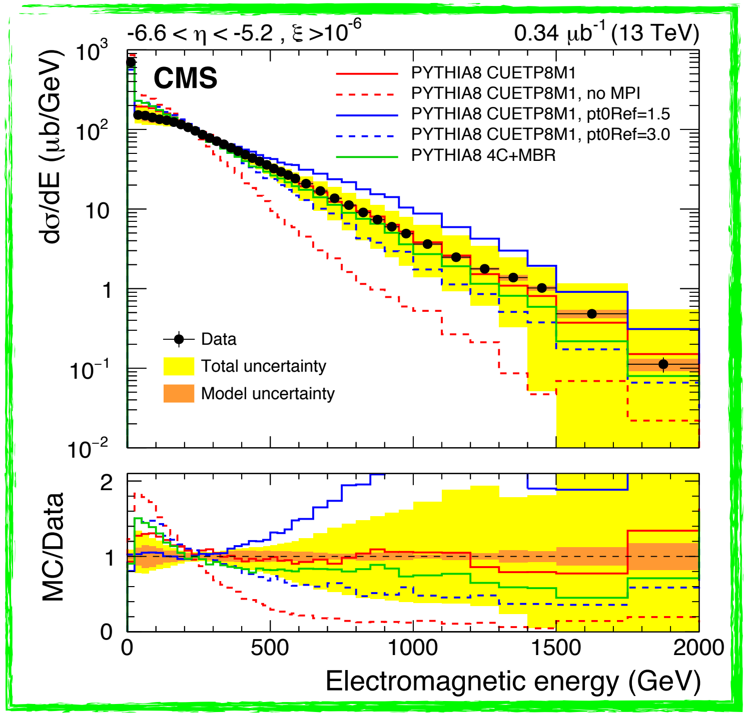
$$\xi = \max(\xi_X, \xi_Y)$$

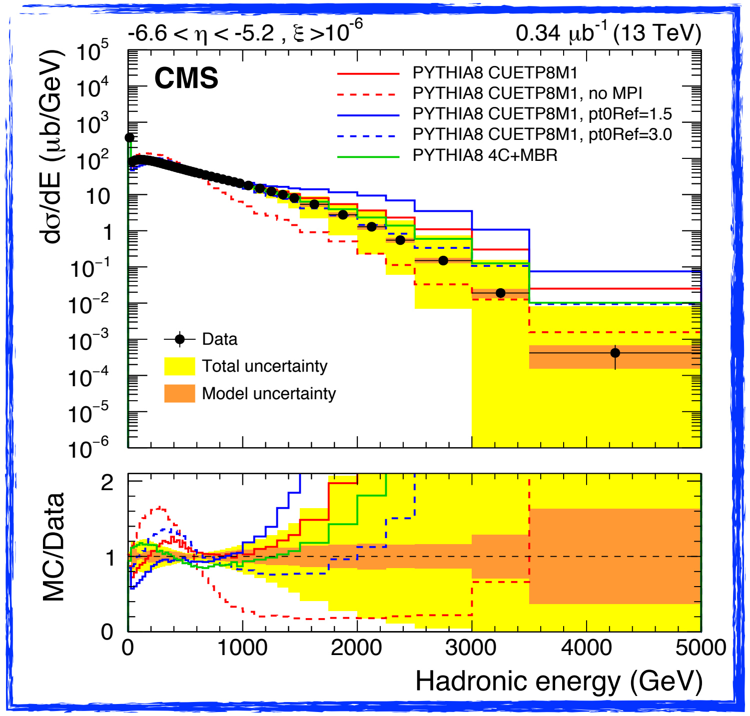
$M_{XY}$: the invariant mass of the two systems separated by the largest rapidity gap in the event.

10.1007/JHEP08(2017)046

- **Peak at zero** reflects the presence of **diffractive** events
- **Total** and **hadronic** spectra exhibit peaks at **300** and **100GeV** respectively
- Predictions sensitive to the $p_{T0}$ parameter of PYTHIA8
- **MPI** is a key aspect to describe the spectrum



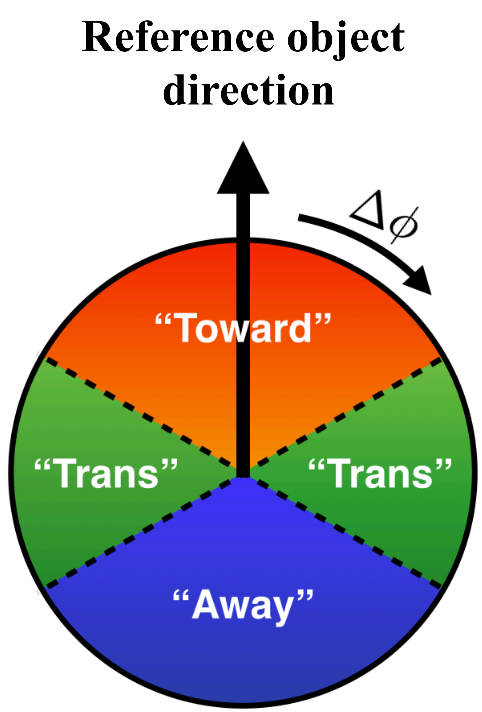



# Underlying event analysis

Four main regions of interest:

- Towards $|\Delta\phi| < 60^\circ$
- Away $|\Delta\phi| > 120^\circ$
- Transverse $60^\circ < |\Delta\phi| < 120^\circ$

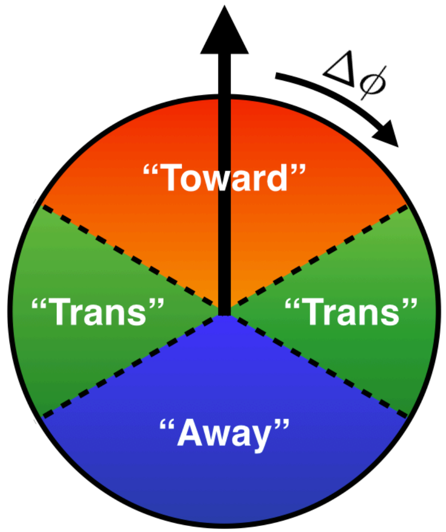



Where $\Delta\phi = \phi_{Reference\ object} - \phi_{Any\ track}$

Measured observables:

- **Particle density** $\longrightarrow \langle N_{ch}\rangle/[\Delta\eta\Delta(\Delta\phi)]$
- **Energy density** $\longrightarrow \langle \Sigma p_T\rangle/[\Delta\eta\Delta(\Delta\phi)]$

# Underlying event analysis




Transverse regions **separated** by the **amount of activity** and with that **four observables** are constructed

**TransMAX**: region with a higher activity → sensitive to **MPI** and **ISR** of hard process

**TransMIN**: region with a lower activity → sensitive to **MPI**

**TransDIF**: TransMAX - TransMIN → sensitive to **ISR** of hard process

**TransAVE**: (TransMAX + TransMIN)/2

$Z\ boson\ (\rightarrow \mu^+\mu^-)$

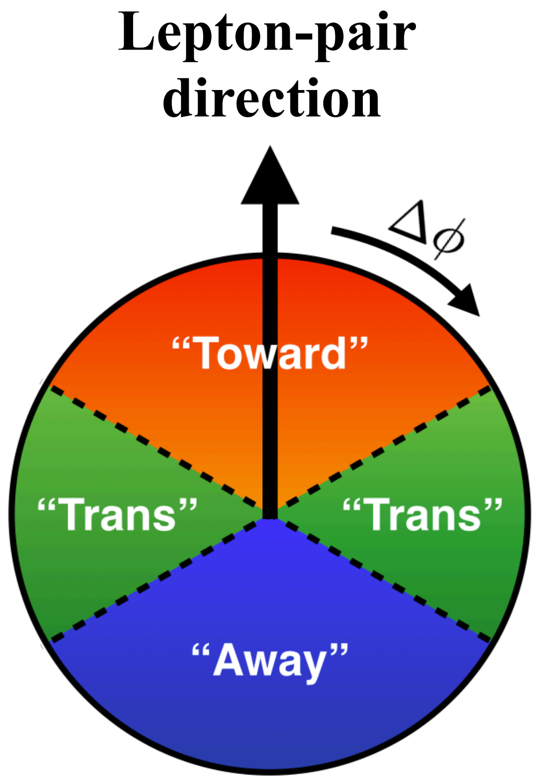
**CMS-PAS FSQ-16-008**

Measurement of activity vs $p_T^{\mu\mu}$

Initial scale in Z-boson events set by invariant mass of lepton-pair:

$$81 - 101\ \mathrm{GeV}/c^2$$

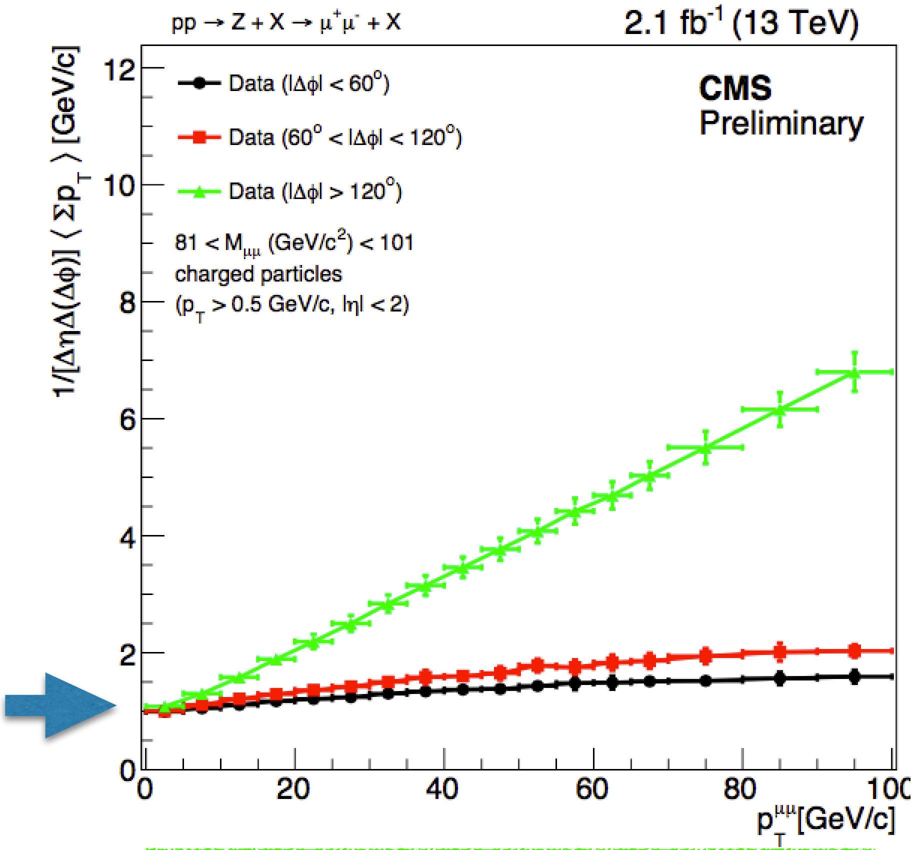
at that scale the maximum overlap of pp collision is reached

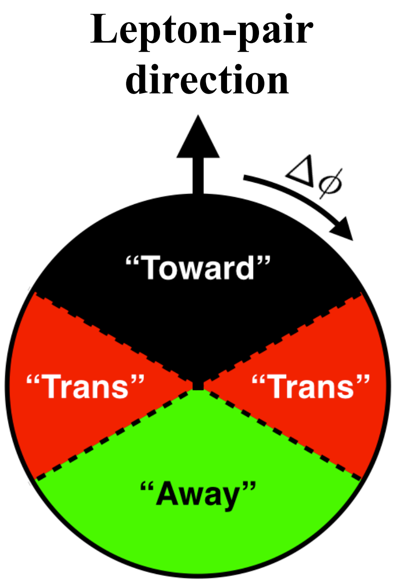



$\Rightarrow$ MPI is maximal $\Rightarrow$ **changes in UE activity (mainly) due to ISR**

# Underlying event analyses

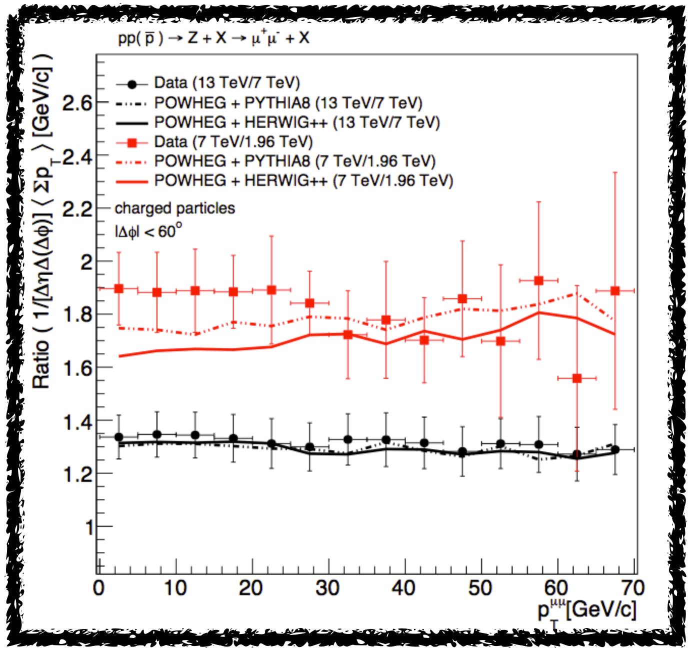
## $Z$ boson $(\to \mu^+\mu^-)$

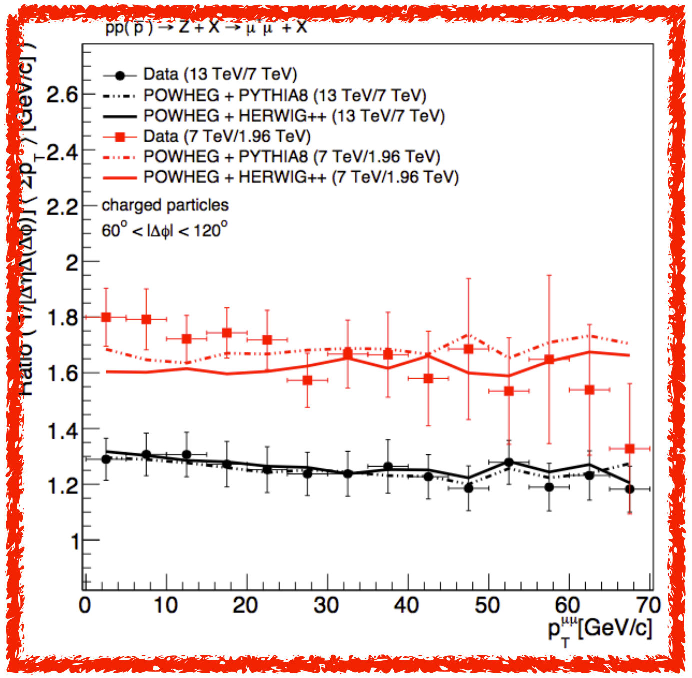



Recoil hadronic activity highly correlated with $p_T^{\mu\mu}$

**Energy dependence**




- MC's predict slower rise of UE activity for increasing $\sqrt{s}$
- Better agreement for higher $p_T^{\mu\mu}$ values

# Underlying event analyses — $Z$ boson $(\to \mu^+\mu^-)$

For events with $p_T^{\mu\mu} < 5$ GeV$/c$

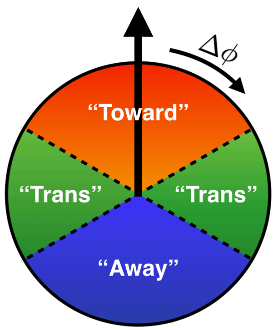
**Energy dependence**

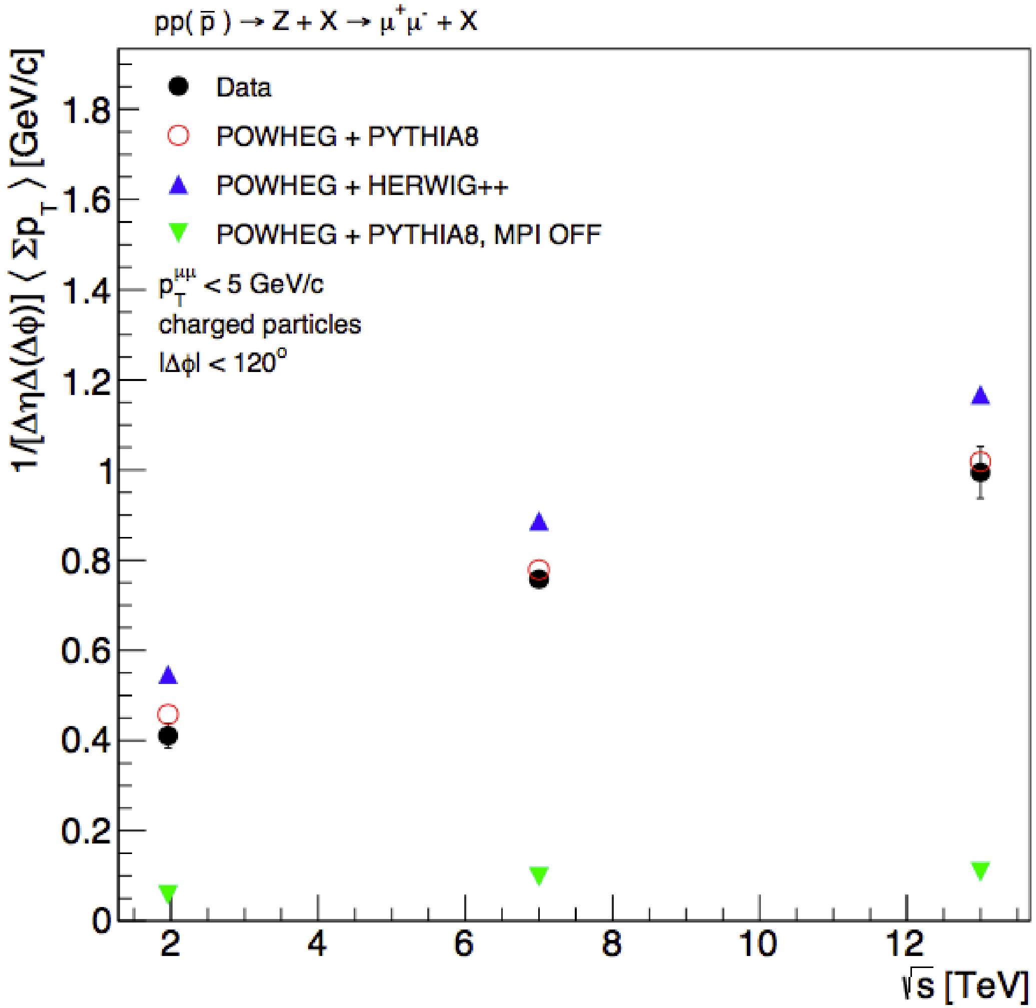
the radiation is reduced

$\Rightarrow$ UE activity is mainly from MPI

- Logarithmic increase with $\sqrt{s}$.
- POWHEG able to describe trend.
- Better description when hadronized with PYHTIA8.

**Lepton-pair direction**




For these events Towards and Trans regions have similar activity

# Summary

- **Phenomenological** studies for **Minimum Bias** events help to **constrain** and understand the **models**
  - Studies of **SD** show sensitivity to **soft** and **hard** diffractive processes.
  - Hints of **MPI in diffraction** were found.
  - Average $p_T$ is found to increase with particle mass and event multiplicity.
- Measurements of **UE** activity in different event topologies allow us to **separate MPI from PS**
  - Energy dependence studies show different rise in activity for MPI and ISR as function of $\sqrt{s}$.
- Many other MB measurement have been performed by the CMS Collaboration
  - More phenomenological studies help to understand the underlying processes and to constrain the current models

# Summary

List of latest MB and UE results by CMS

Preliminary:
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/FSQ/index.html

Published:
http://cms-results.web.cern.ch/cms-results/public-results/publications/FSQ/index.html

Thanks for your attention