Recent Minimum Bias and UE measurements at CMS at 13 TeV

Juan M. Grados Luyando

on behalf of the CMS Collaboration

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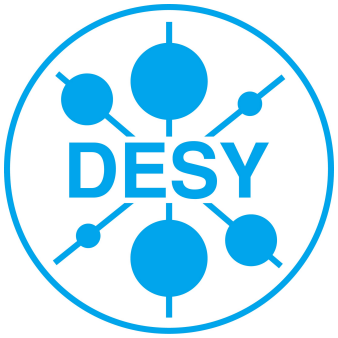
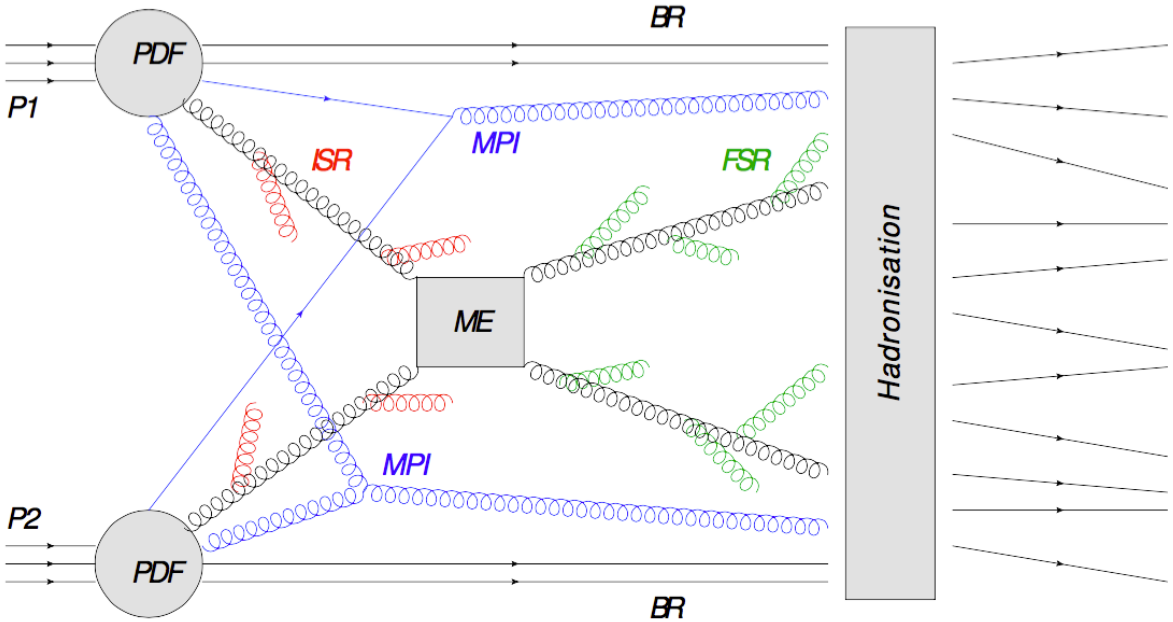
San Cristobal de las Casas, Chiapas, Mexico



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)

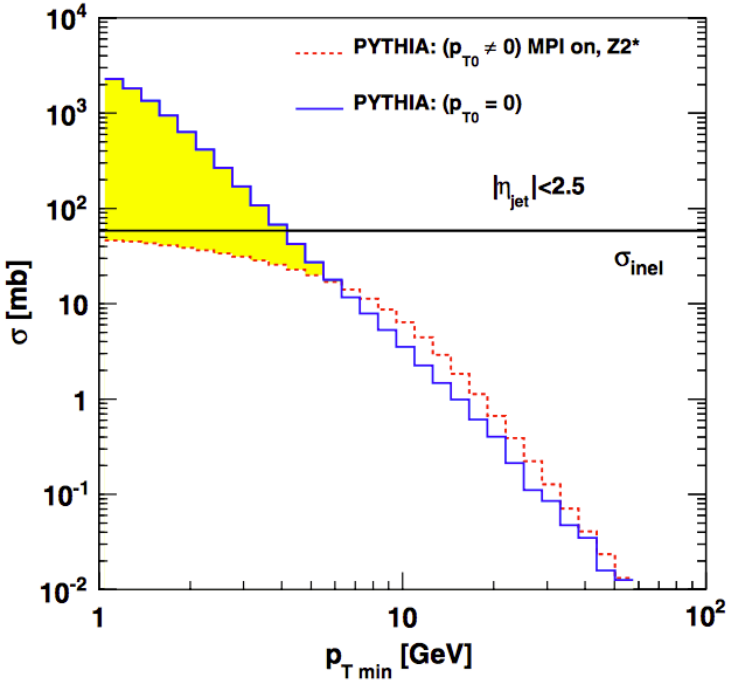
With all this we can constrain and tune the models

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

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

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

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



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

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

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

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**

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 **p_T leading particle/jet** events.

Minimum Bias analysis

- 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

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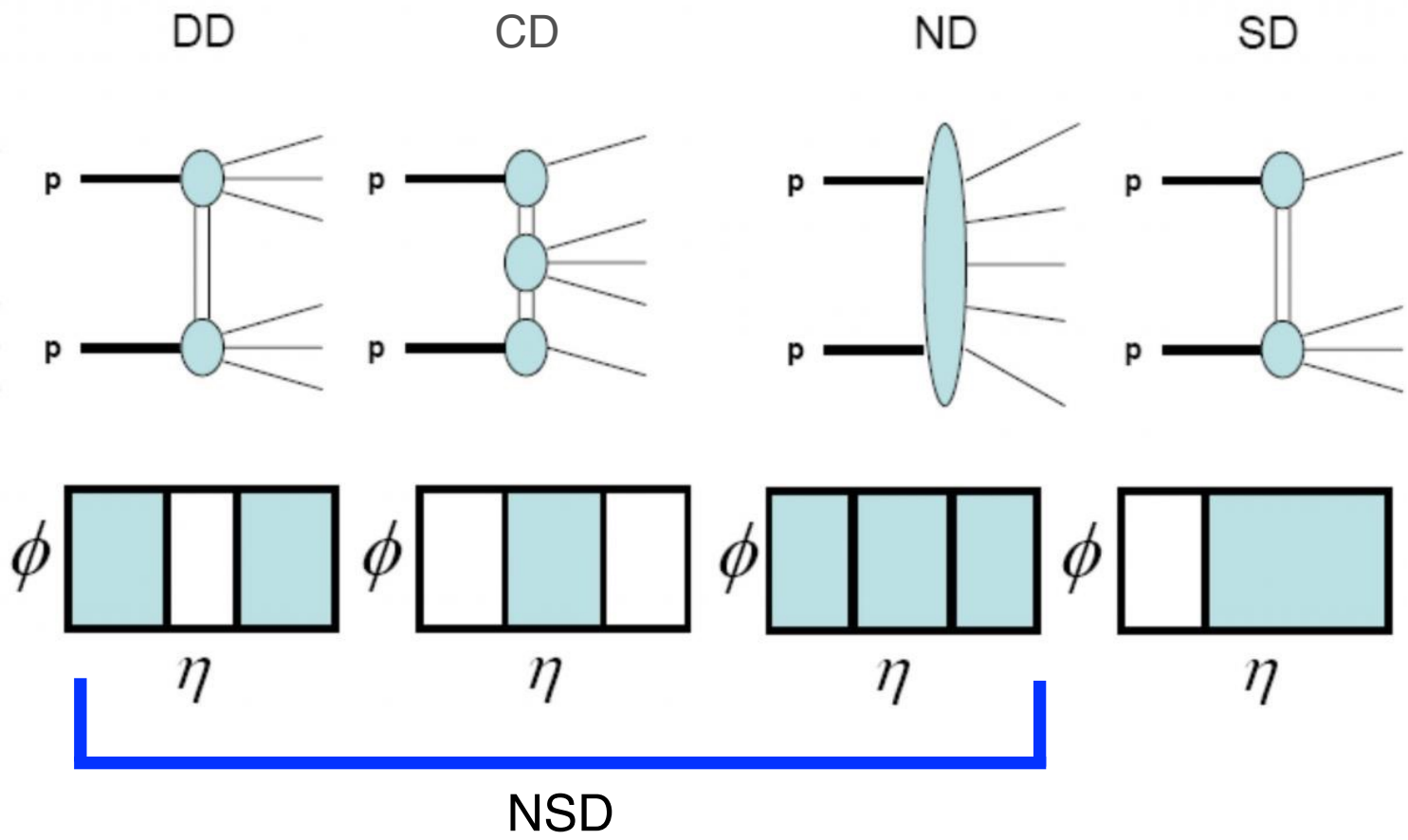


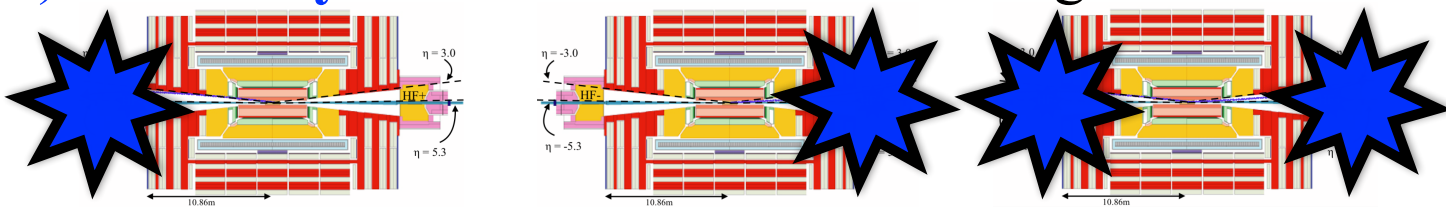
Phase space definition at stable particle level

(A) At least 1 charged particle $\begin{cases} p_T > 0.5 \text{ GeV} \\ |\eta| < 2.4 \end{cases}$

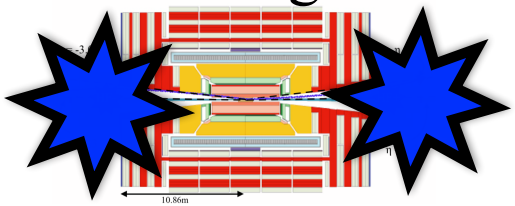
Forward region
$3 < |\eta| < 5$

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

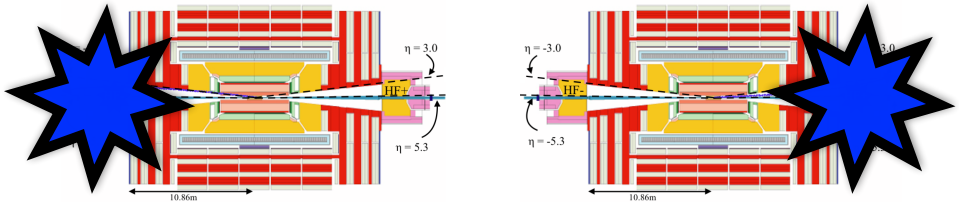
- **Inclusive**: (A)
- **Inelastic enhanced**: (A) + **Activity** in **at least one** Forward Region



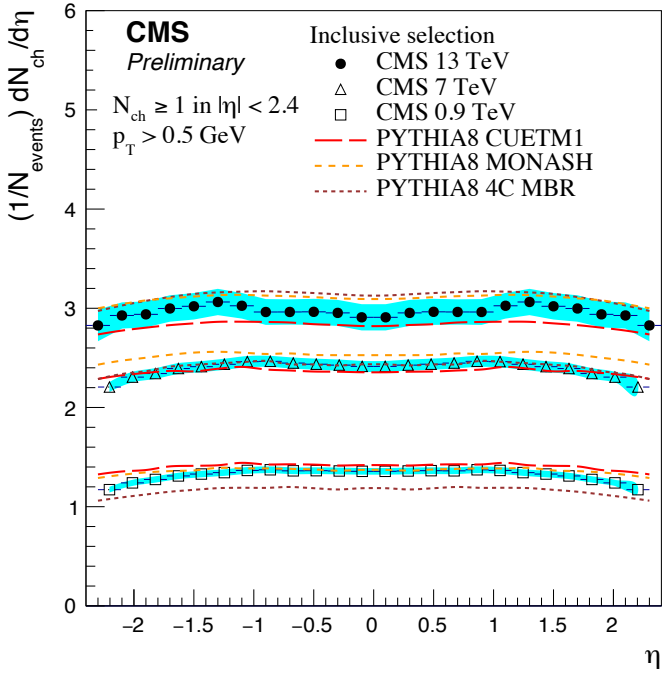
- **NSD enhanced**: (A) + **Activity** in **both** Forward Regions

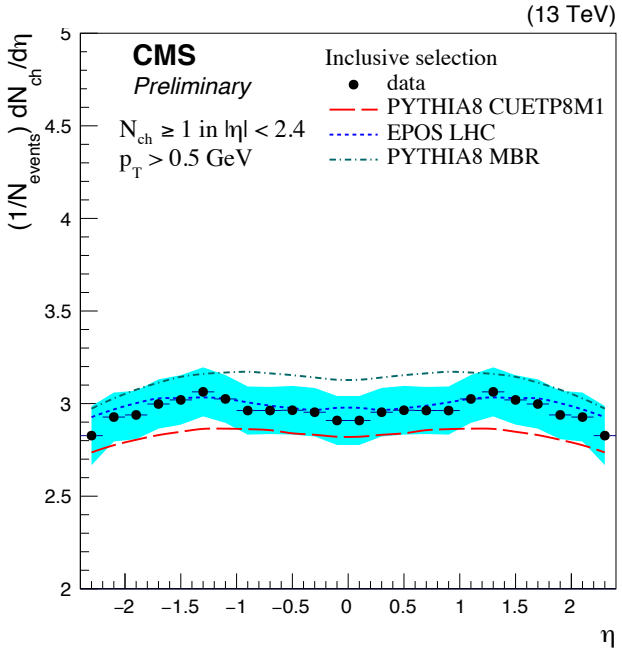


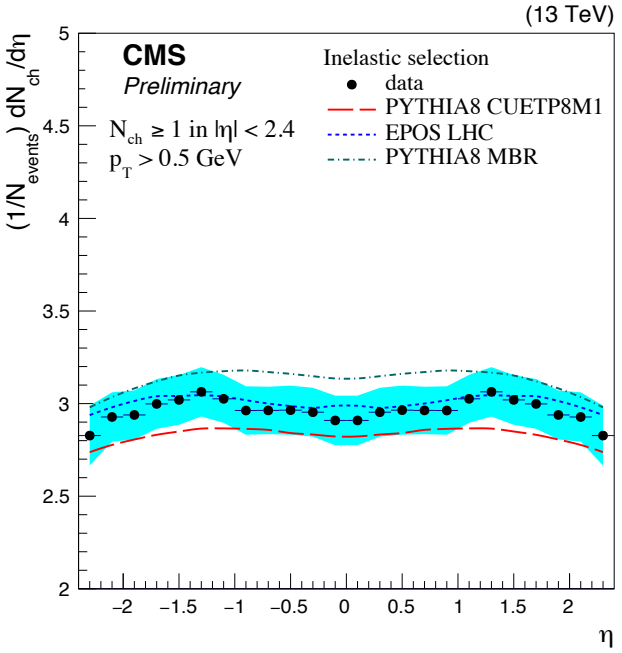
- **SD enhanced**: (A) + **Activity** in one Forward Region **and** **Veto** in the other side

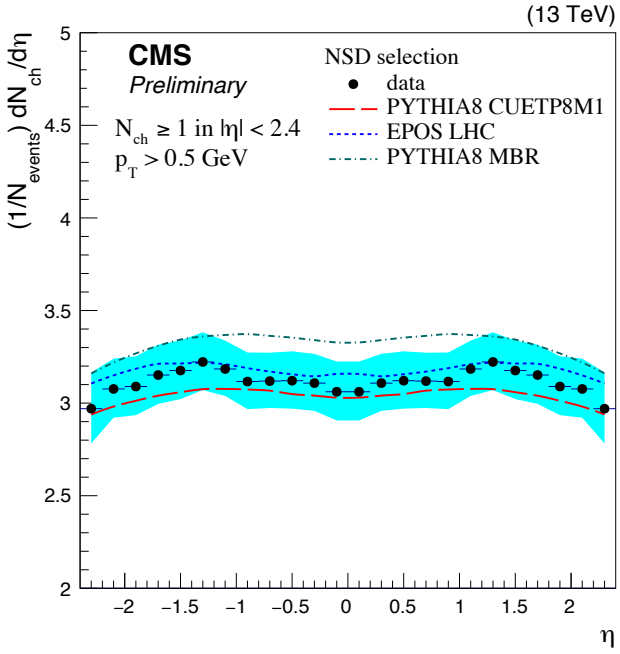


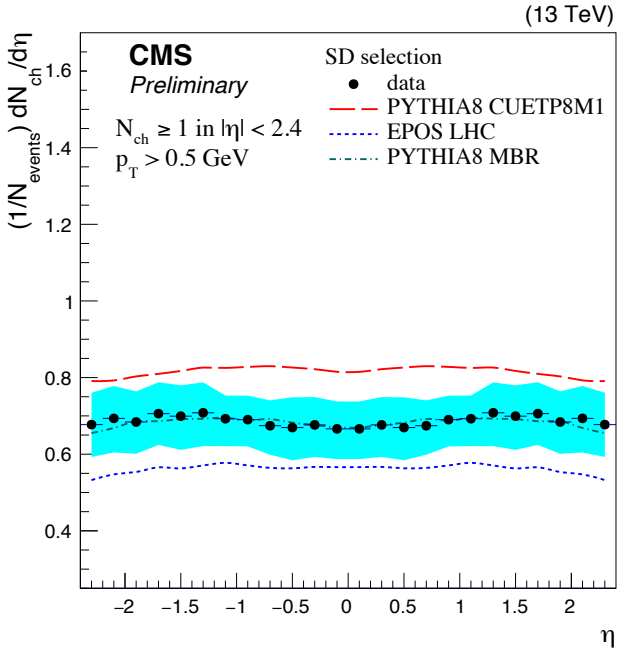
Minimum Bias analysis results

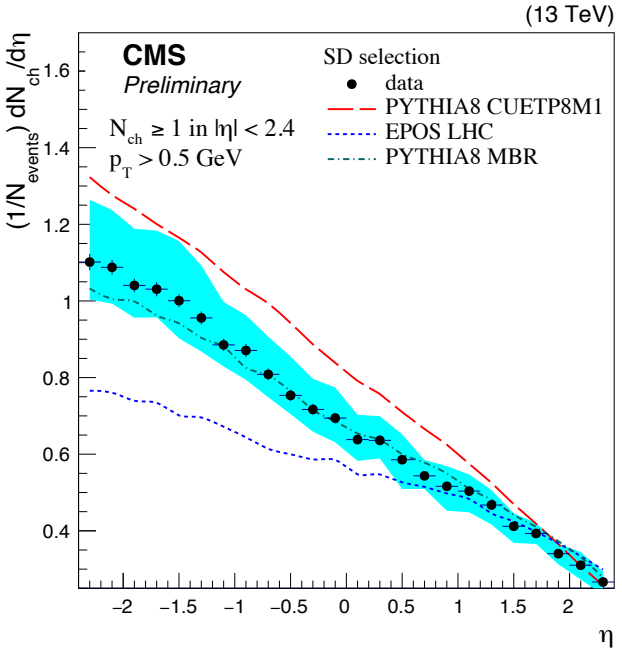












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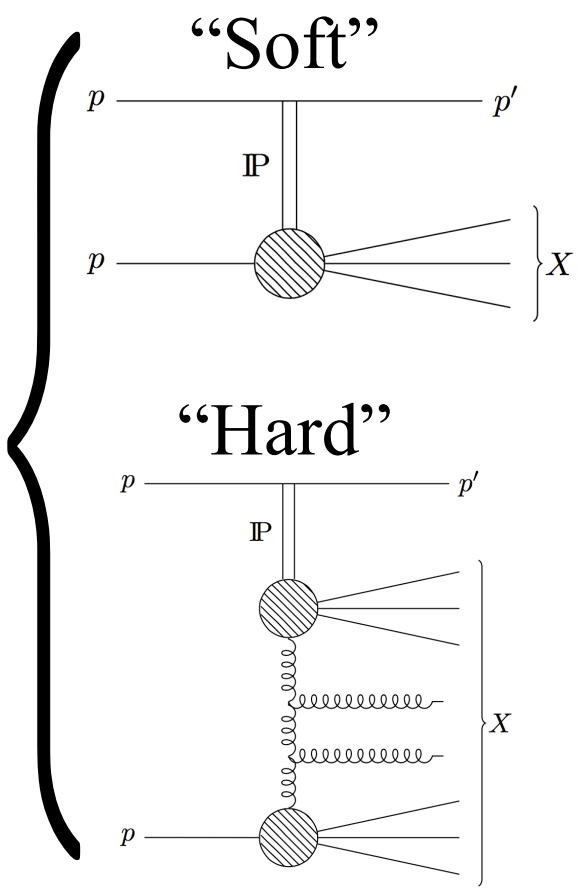
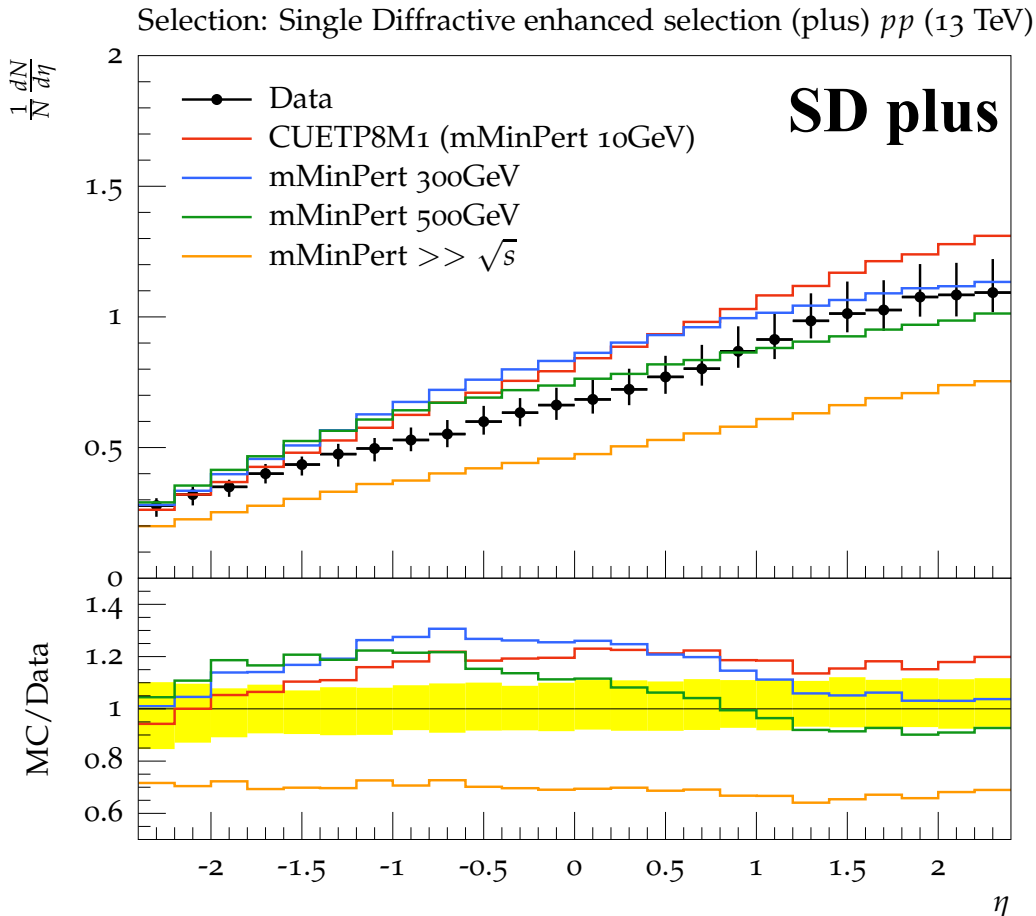
Soft and hard components have a smooth **transition** at a certain value. In PYTHIA8 the **minimum Diffractive Mass** of the system **produced perturbatively** can be chosen.

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

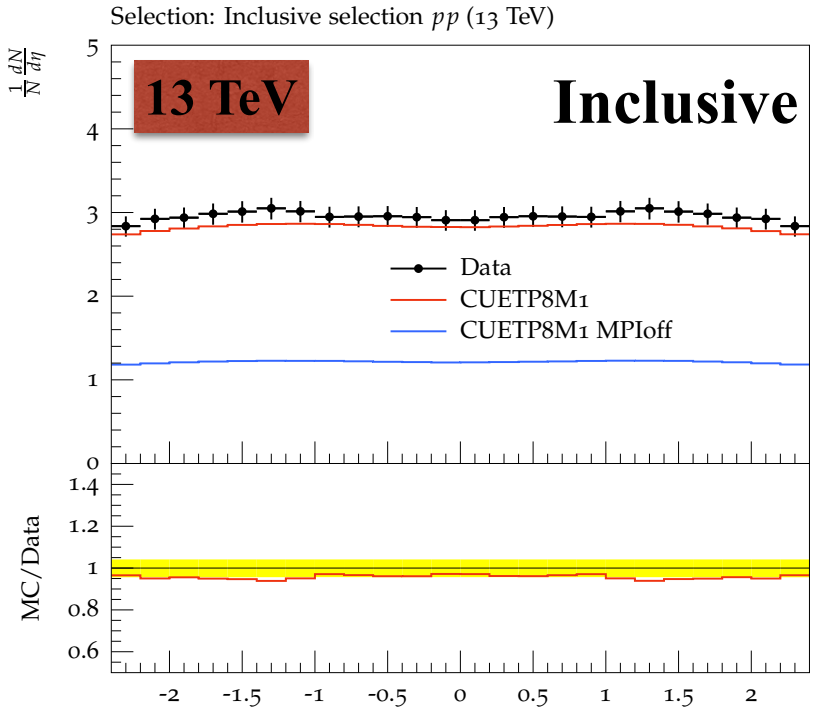
Sensitivity to high mass diffractive systems.

What are the contributions for the Single Diffractive component?





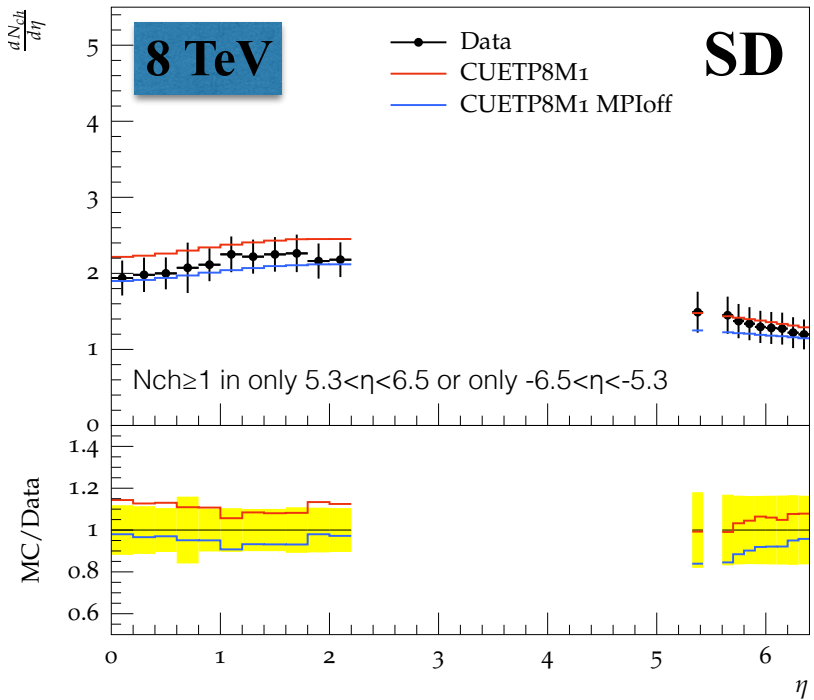
Effects of **MPI** in the different diffractive enhanced samples

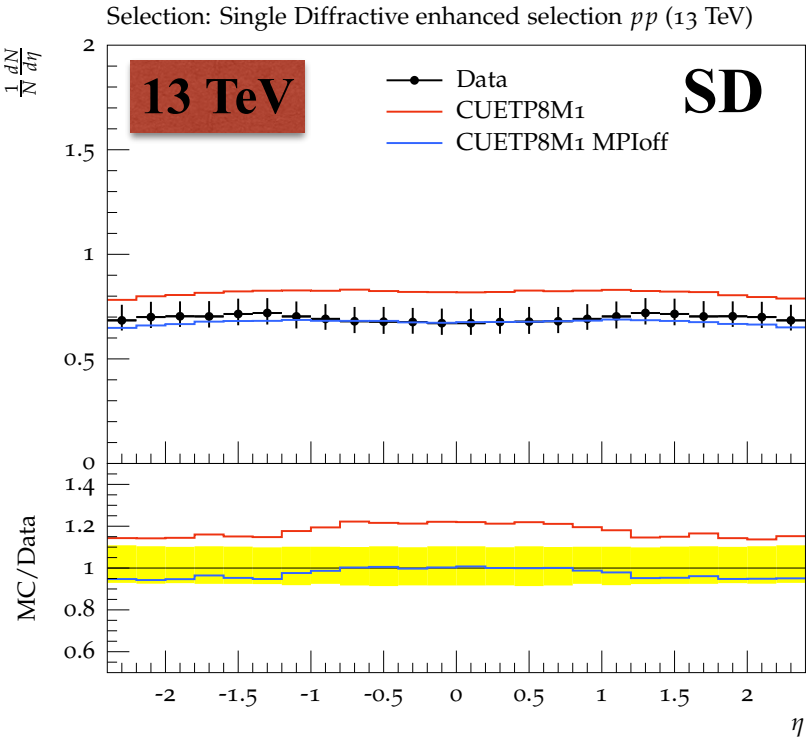


Inclusive selection highly sensitive to MPI

2/3 of produced particles come from MPI

8TeV vs 13TeV

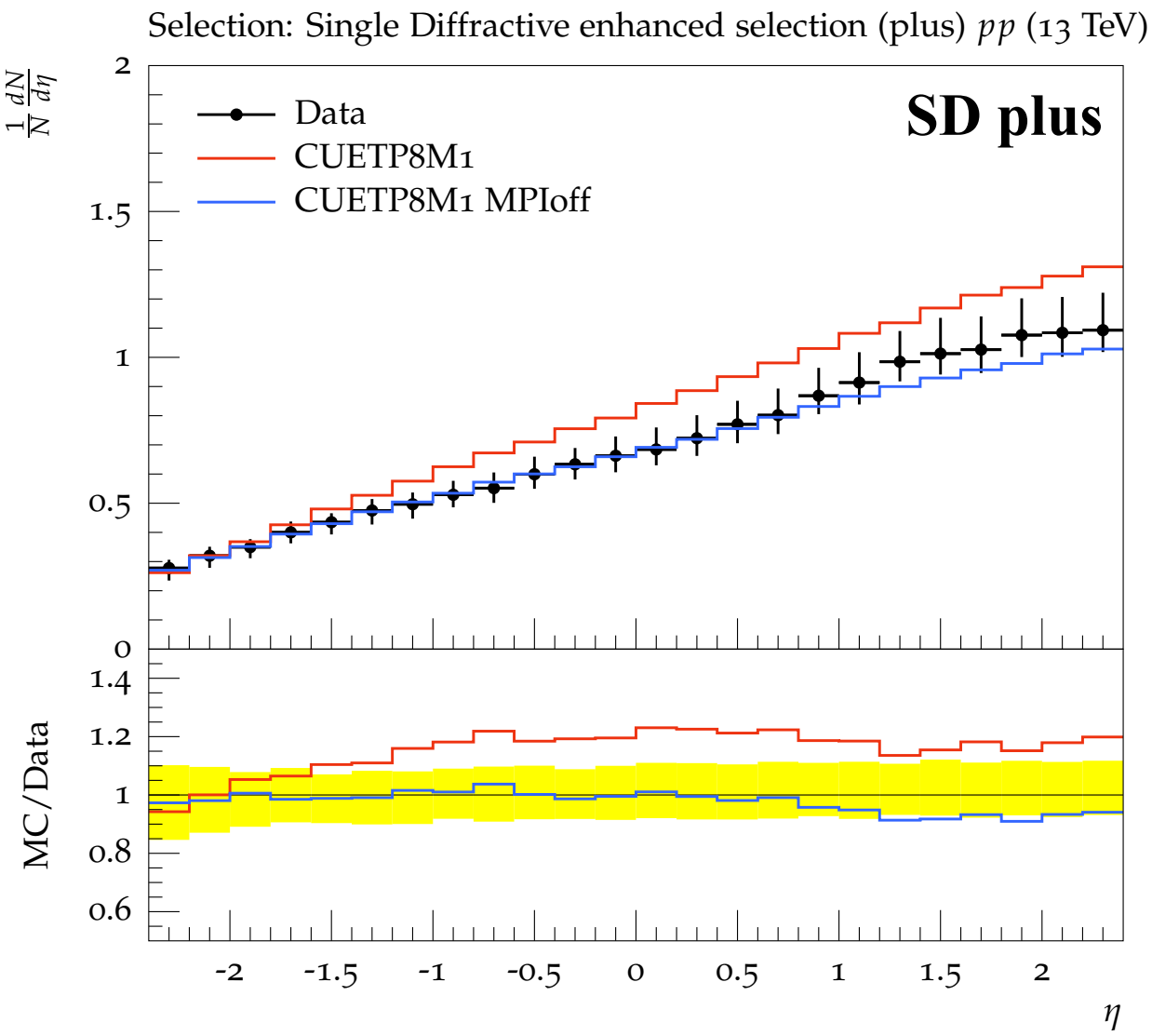


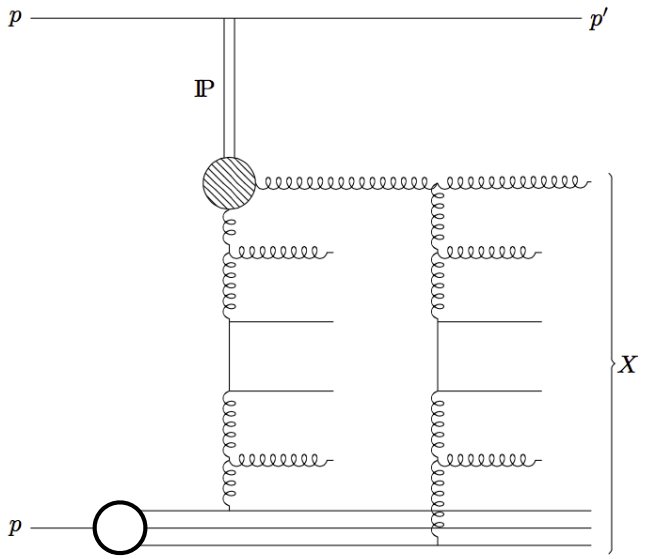


Better described without MPI. Bigger disagreement at 13TeV

Effects of **MPI** in the different diffractive enhance samples

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



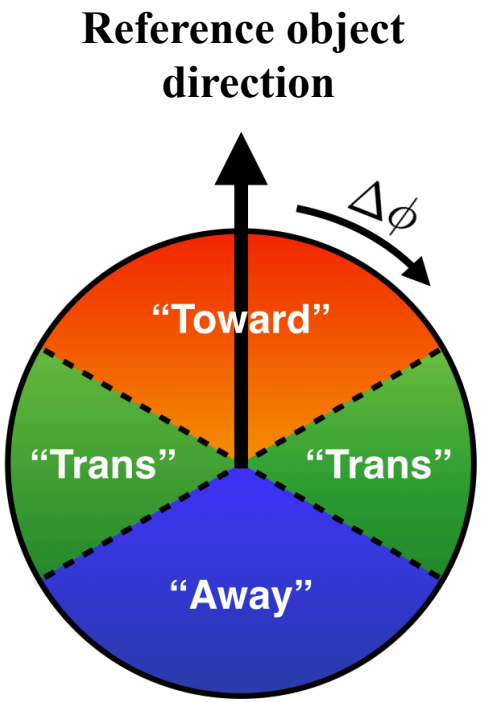


This is the first time we see indications of MPI in the diffractive system

Underlying event analysis

Four main regions of interest:

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

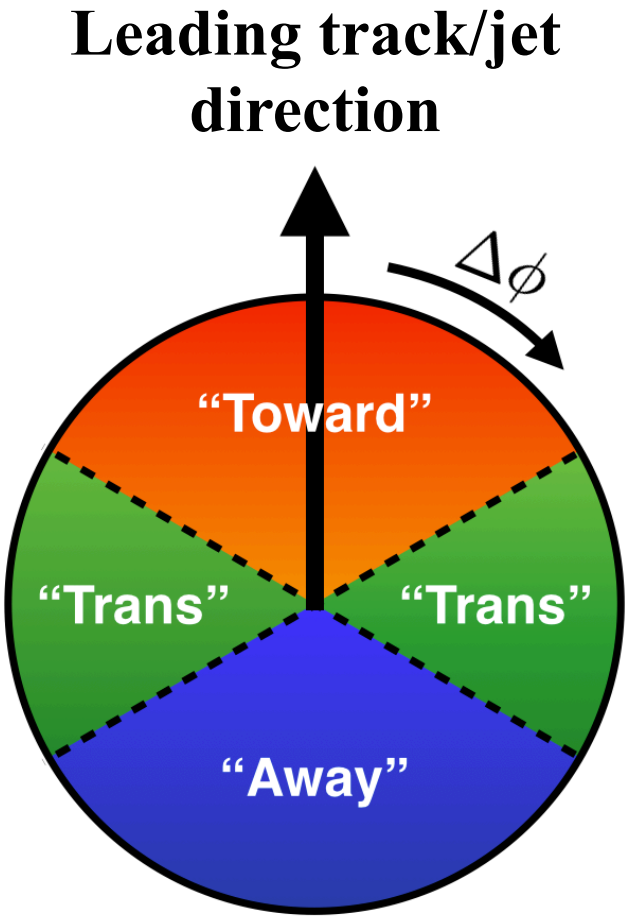


Where $\Delta\phi = \phi_{Reference\ object} - \phi_{Any\ track}$

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



Focuses on Transverse regions

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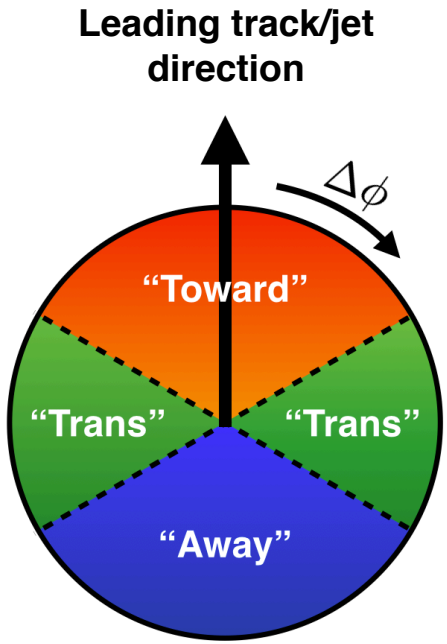
$Leading\ p_T\ track/jet$

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

Underlying event analysis

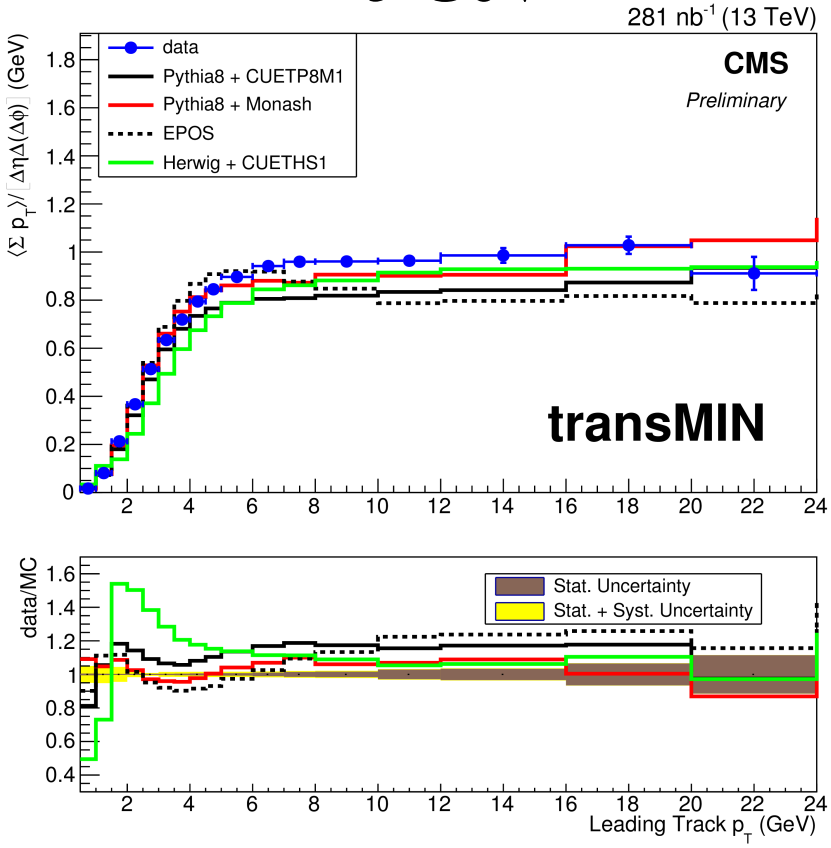
Leading p_T track/jet

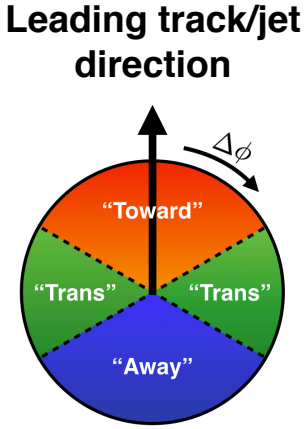
TransMIN: region with a lower activity

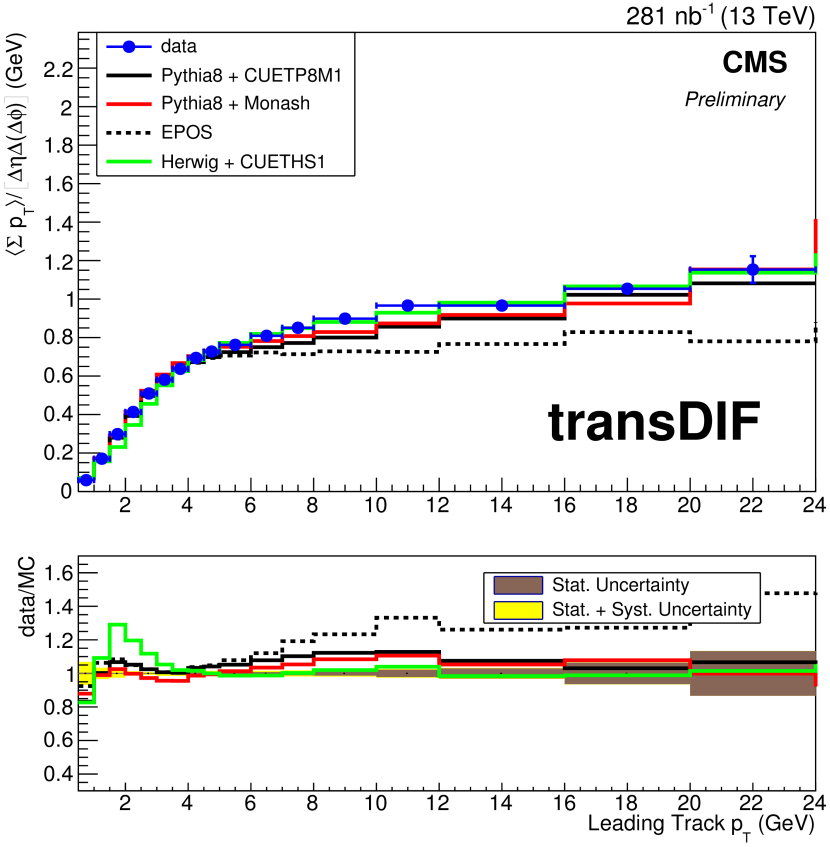
TransDIF: TransMAX - TransMIN

Saturation of MPI activity related to the impact parameter ~ 5 GeV

After ~ 5 GeV constant rise originating from increasing ISR activity.







sensitive to **MPI**

sensitive to **ISR** of hard process

Underlying event analysis

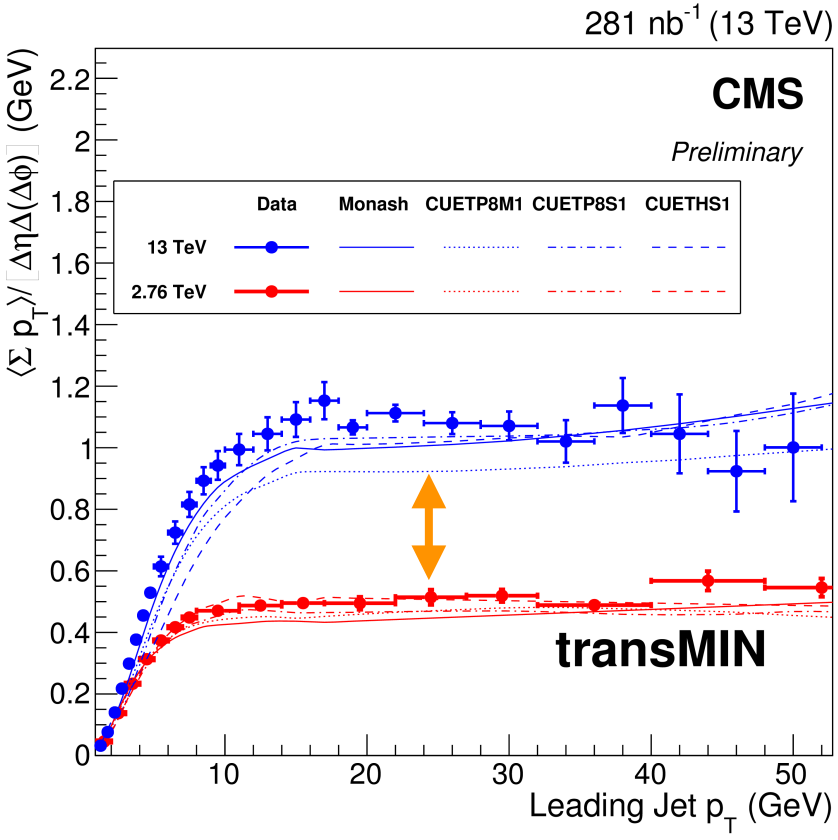
Leading p_T track/jet

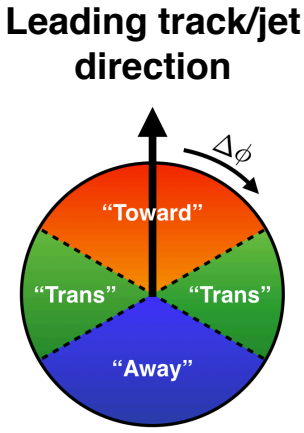
TransMIN: region with a lower activity

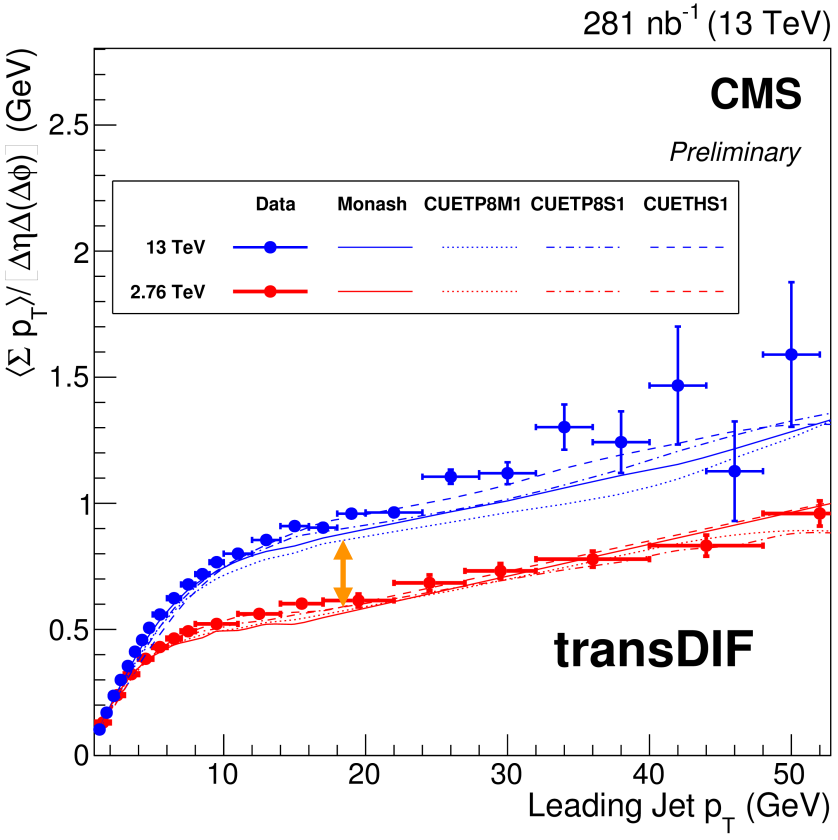
TransDIF: TransMAX - TransMIN

Energy dependence

MPI activity grows more with √s than that from ISR







sensitive to **MPI**

sensitive to **ISR** of hard process

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.
- 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 $\sqrt{s}$.
- We have reasonable good models for MB/UE
  - Still some discrepancies for the energy dependence and SD diffractive component.

Thanks for your attention

Additional Material

Track and vertex selection

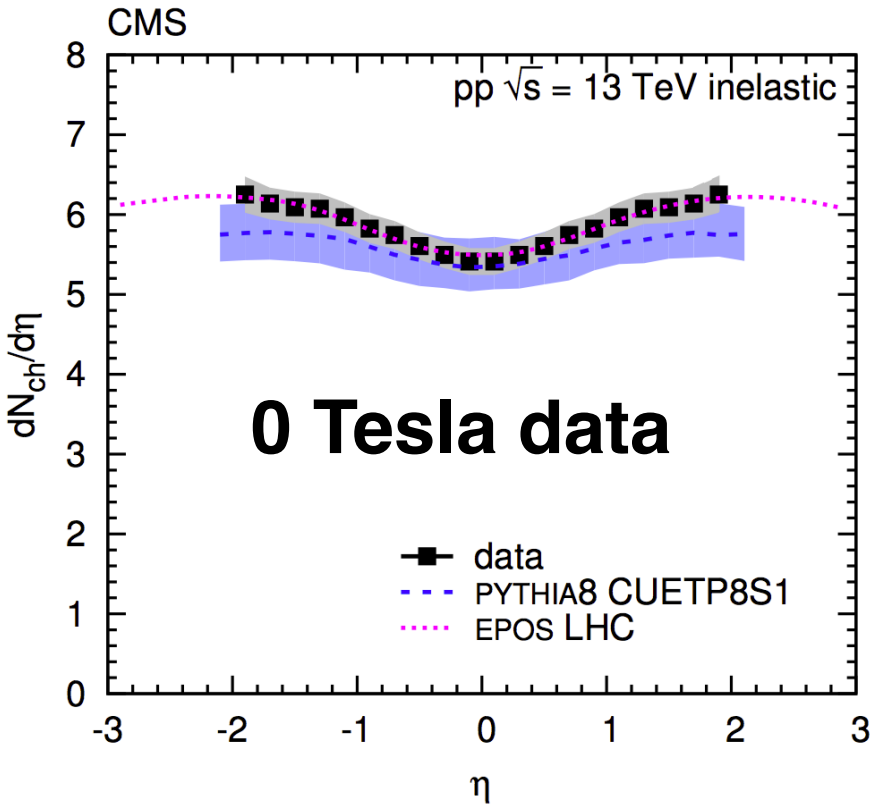
Track selection:

- Quality = 2 (high purity tracks)
- $p_T > 0.5$GeV
- $|\eta| < 2.4$
- $\sigma_{p_T}/p_T < 0.1$
- $|dxy|/\sigma xy < 3$
- $|dz|/\sigma z < 3$
- At least 3 pixel hits for $|\eta| < 1$
- At least 2 pixel hits for $|\eta| > 1$

Only events with exactly one good vertex are keept

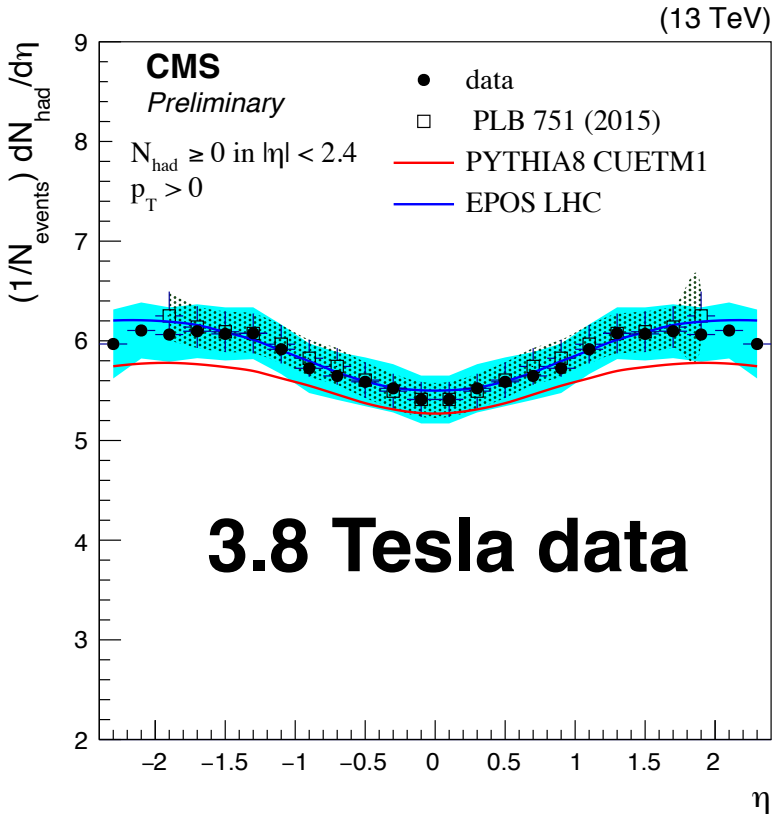
Good vertex:

- At least 2 tracks fulfilling the **Track selection except pT cut**
- Valid vertex
- $|z| < 15$ cm w.r.t. Beam spot
- $\rho < 0.2$ cm w.r.t. Beam spot



Stable long lived charge particles with **pT > 0 GeV**

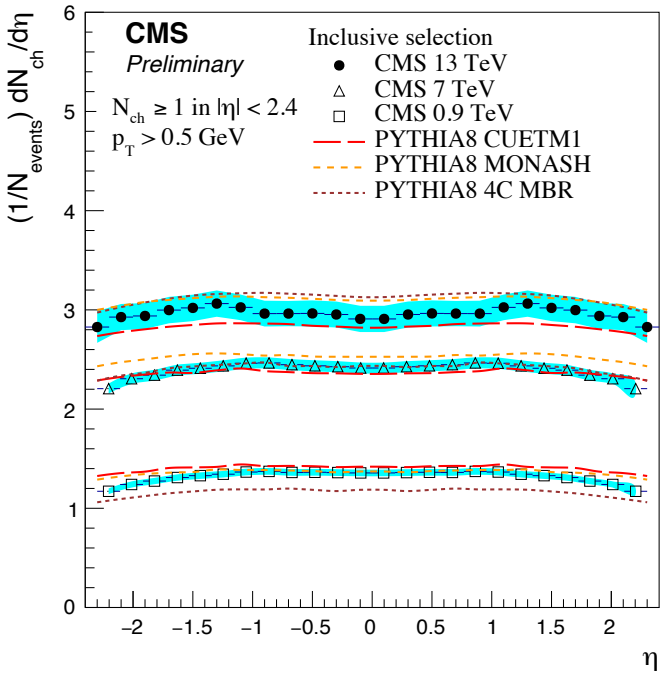
10.1016/j.physletb.2015.10.004

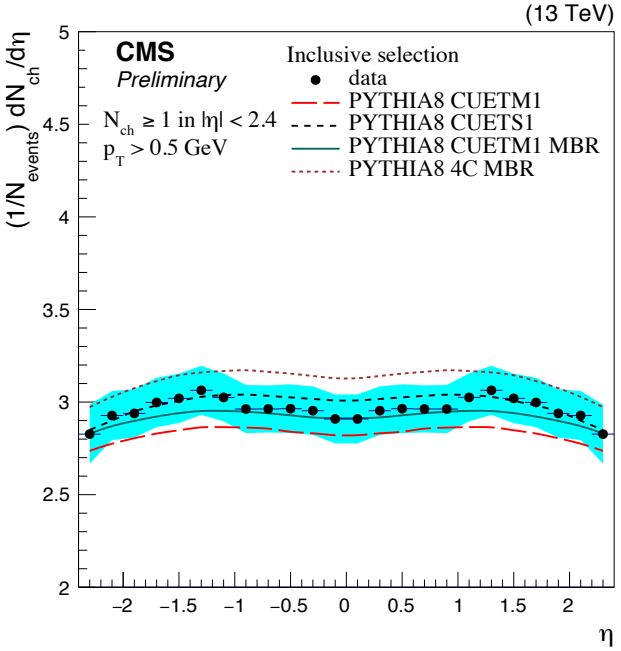


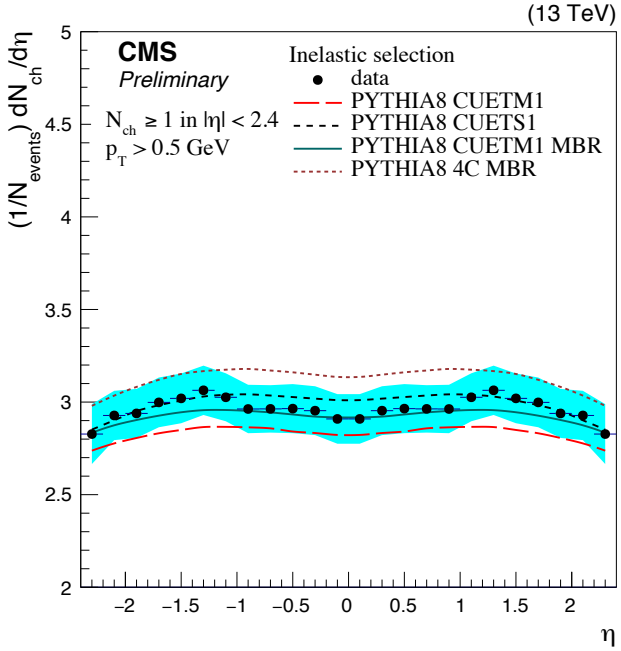
Extrapolation from **pT > 0.5 GeV —> pT > 0 GeV**

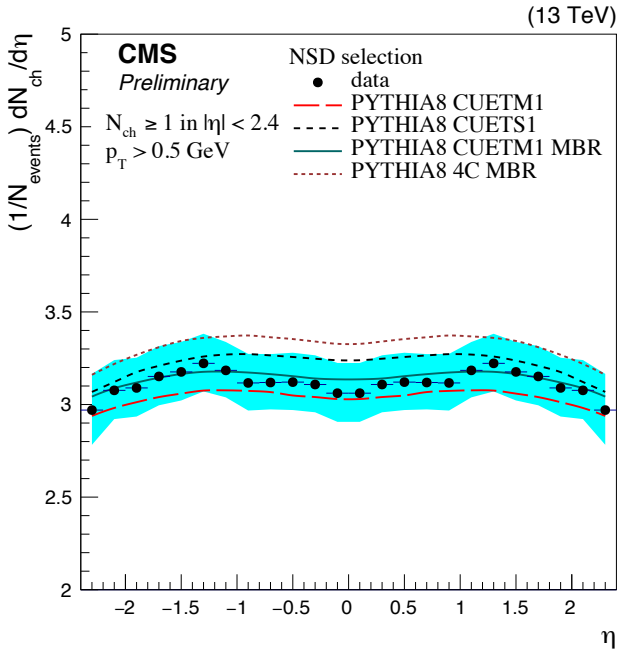
(bigger uncertainties due to extrapolation)

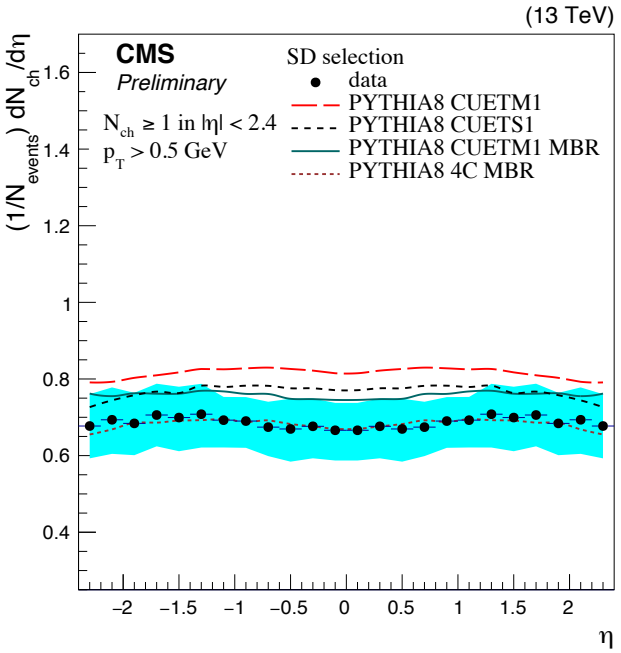
Good agreement in results even with different experimental conditions and different track reconstructions algorithms

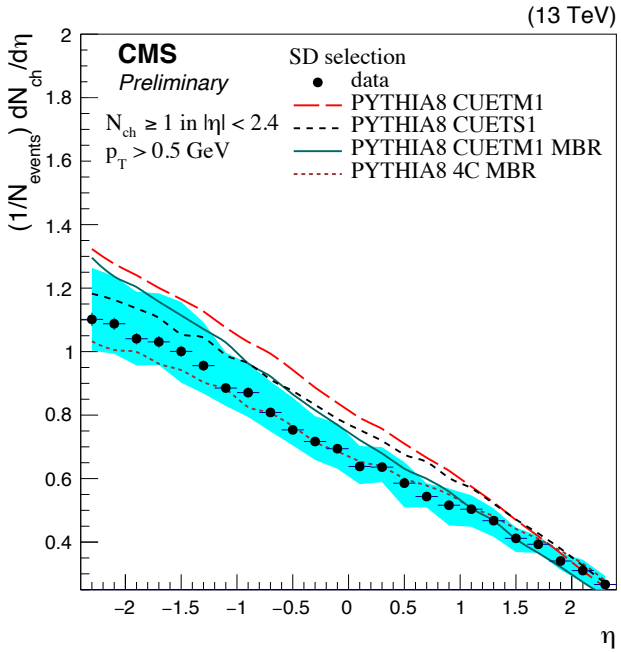












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