Soft QCD and Forward Physics at CMS

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on behalf of CMS Collaboration
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Outline

1. Studies of 2 b-jet + 2 jet production in proton-proton collisions at $\sqrt{s} = 7$ TeV
2. Azimuthal angle decorrelation of jets widely separated in rapidity in pp collisions at $\sqrt{s} = 7$ TeV
3. Leading charged particles and leading charged-particle jets at small p_T in pp collisions at $\sqrt{s} = 8$ TeV
4. Pseudorapidity dependence of the energy and transverse energy density at $\sqrt{s} = 13$ TeV
5. Pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV

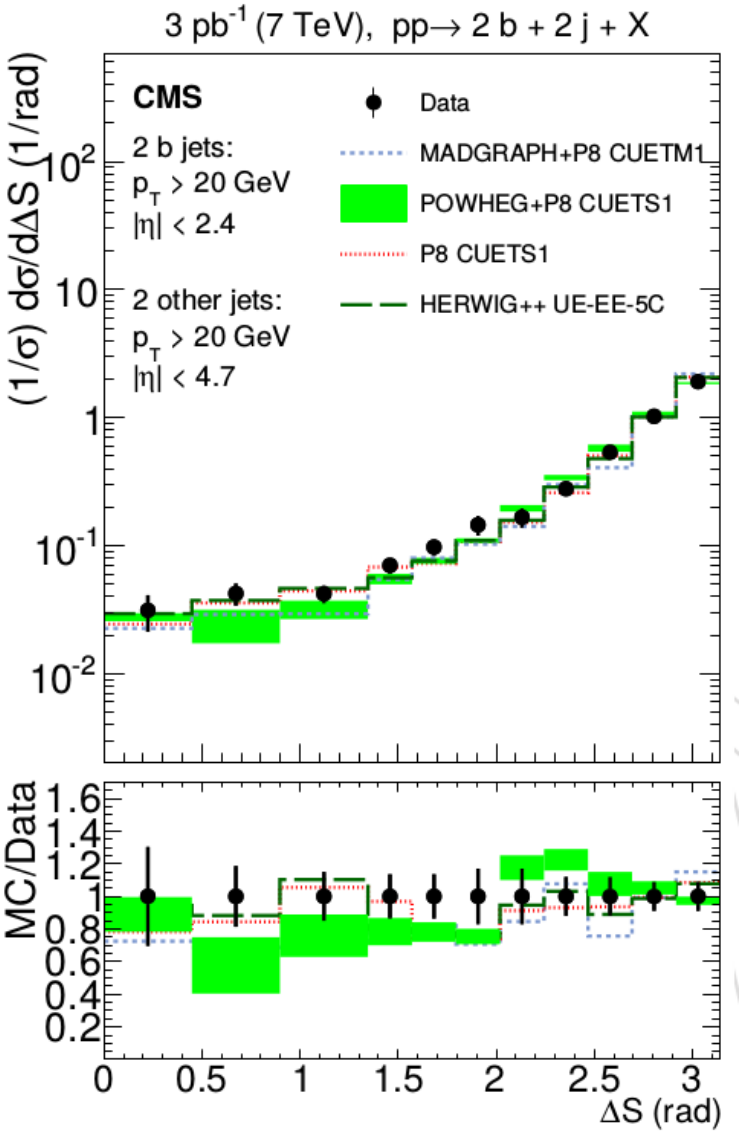
Studies of 2 b-jet + 2 jet production in proton-proton collisions at $\sqrt{s} = 7$ TeV

- 4 jets required with $p_T > 20$ GeV : 2 b-jets with $|\eta| < 2.4$ and 2 jets with $|\eta| < 4.7$
- $\sigma(pp \to 2b + 2j + X) = 69 \pm 3(stat) \pm 24(syst)nb$
- Measurement of DPS signal using correlations:

$$\Delta S = arcos\left(\frac{\overrightarrow{p_T}(bottom_1, bottom_2).\overrightarrow{p_T}(light_1, light_2)}{|\overrightarrow{p_T}(bottom_1, bottom_2)|.|\overrightarrow{p_T}(light_1, light_2)|}\right)$$

Preliminary Result: FSQ-13-010; Submitted to Phys. Rev. D

Studies of 2 b-jet + 2 jet production in proton-proton collisions at $\sqrt{s} = 7$ TeV



- Normalized cross sections unfolded to the particle level as a function of ΔS
- All MC describe the data reasonably well
- Other observable display similar behaviour
- Predictions with MPI off yield worst agreement
- Results demonstrate sensitivity of correlation variables to DPS in multi-jet scenarios with heavy-quarks

Azimuthal angle decorrelation of jets widely separated in rapidity in pp collisions at $\sqrt{s} = 7$ TeV

- Measurement of the azimuthal angle between the most forward and the most backward jets (Mueller-Navelet).
- CMS allows for a higher coverage up to 9.4 units of rapidity.
- The decorrelation arises from the presence of higher-order processes.
- Search for BFKL-like effects.

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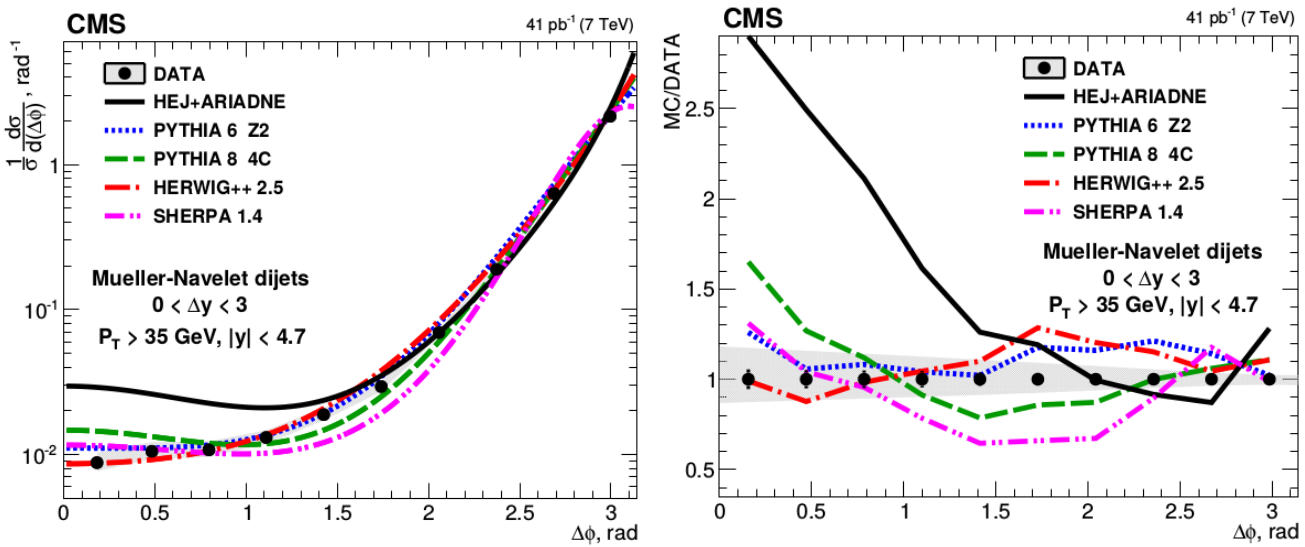
Azimuthal angle decorrelation of jets widely separated in rapidity in pp collisions at $\sqrt{(s)} = 7$ TeV

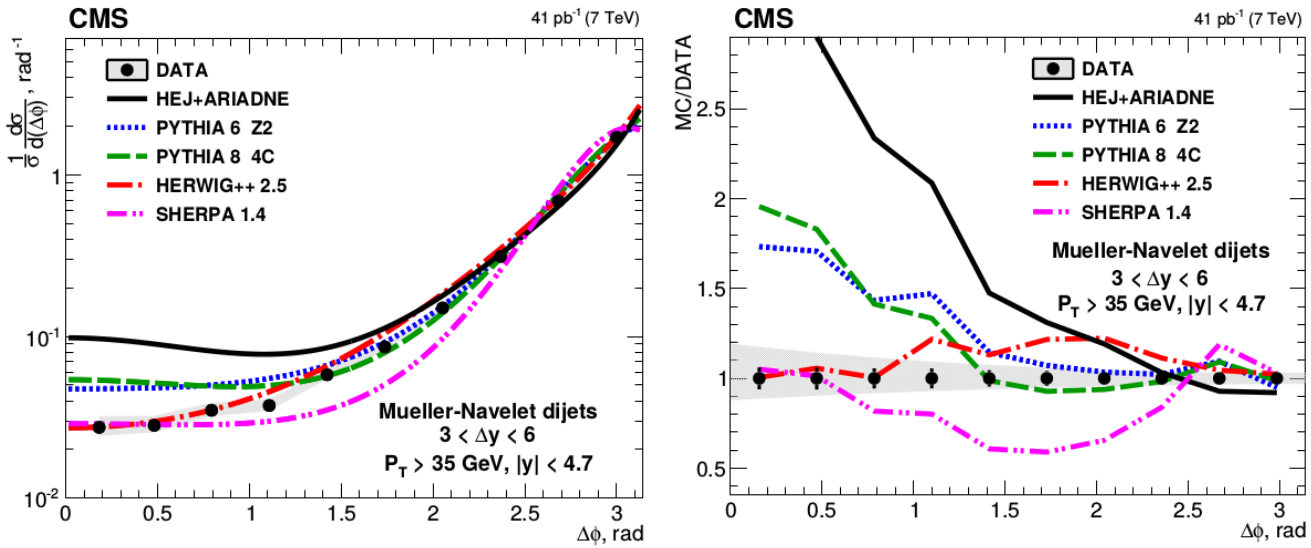
Mueller-Navelet $\Delta\phi$ for dijets with $|y| < 4.7$ and $p_T > 35$ GeV
$0 < |\Delta y| < 3$



- Pythia 6 and Herwig++ describe the data within uncertainties
- Pythia 8 and Sherpa 1.4, with parton matrix elements matched to LL DGLAP parton showers, show deviations at small and intermediate $\Delta\phi$

Azimuthal angle decorrelation of jets widely separated in rapidity in pp collisions at $\sqrt{(s)} = 7$ TeV

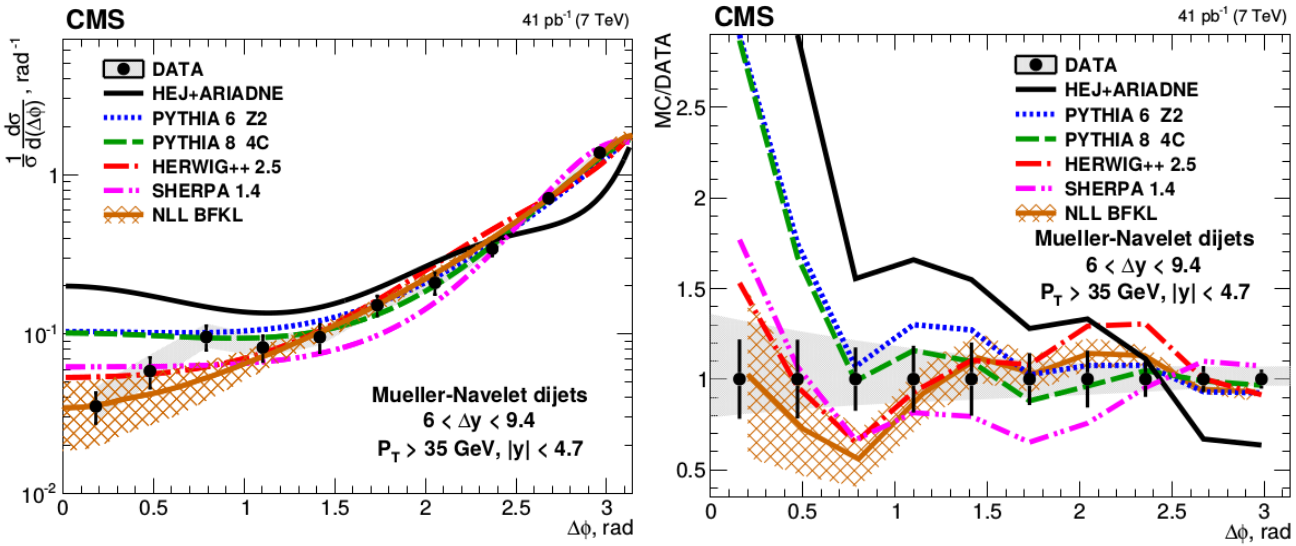
Mueller-Navelet $\Delta\phi$ for dijets with $|y| < 4.7$ and $p_T > 35$ GeV
$3 < |\Delta y| < 6$



- All predictions show deviations beyond experimental uncertainties
- HERWIG ++ provides the best description

Azimuthal angle decorrelation of jets widely separated in rapidity in pp collisions at $\sqrt{(s)} = 7$ TeV

Mueller-Navelet $\Delta\phi$ for dijets with $|y| < 4.7$ and $p_T > 35$ GeV
$6 < |\Delta y| < 9.4$



- Dijets are strongly decorrelated and NNL BFKL is the best description
- SHERPA and HERWIG deviates at intermediate $\Delta\phi$ but are close at lower $\Delta\phi$. PYTHIA 6 and PYTHIA 8 fail for the lower $\Delta\phi$
- Indication that the kinematical domain of the present study lies in between the regions described by the DGLAP and BFKL approaches

Leading charged particles and leading charged-particle jets at small p_T in pp collisions at $\sqrt{s} = 8$ TeV

- Jet production at LHC well described at $p_T > 20$ Gev and $|\eta| < 3$
- Looking for the low p_T particles/jets: transition between pertubative and non-pertubative region
- Both measurements are complentary: jets carry almost all energy from the parton but are sensitive to MPI, initial and final state radiation

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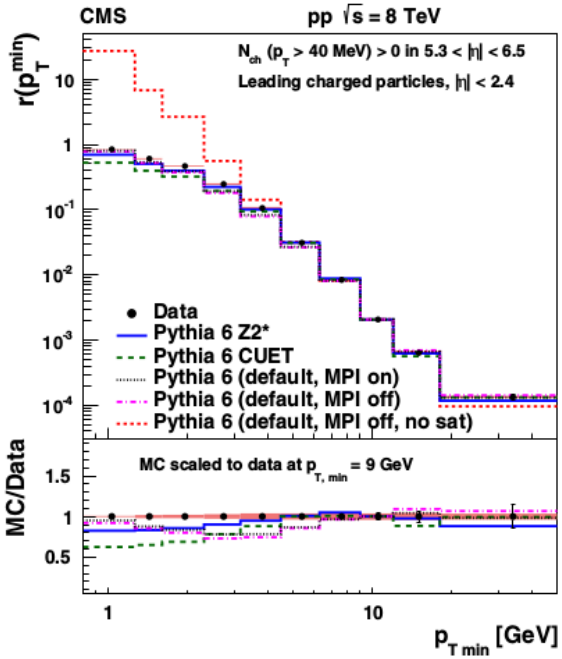
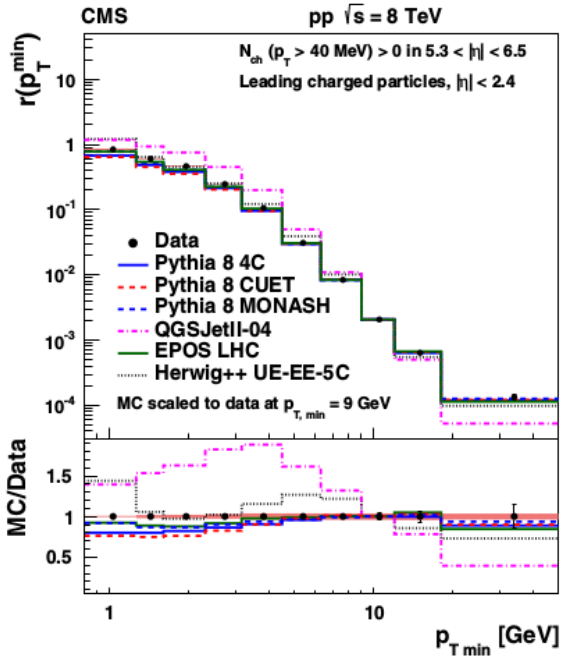
Leading charged particles and leading charged-particle jets at small p_T in pp collisions at $\sqrt{s} = 8$ TeV

Leading charged particle within $|\eta| < 2.4$ and $p_T > 0.8$ GeV

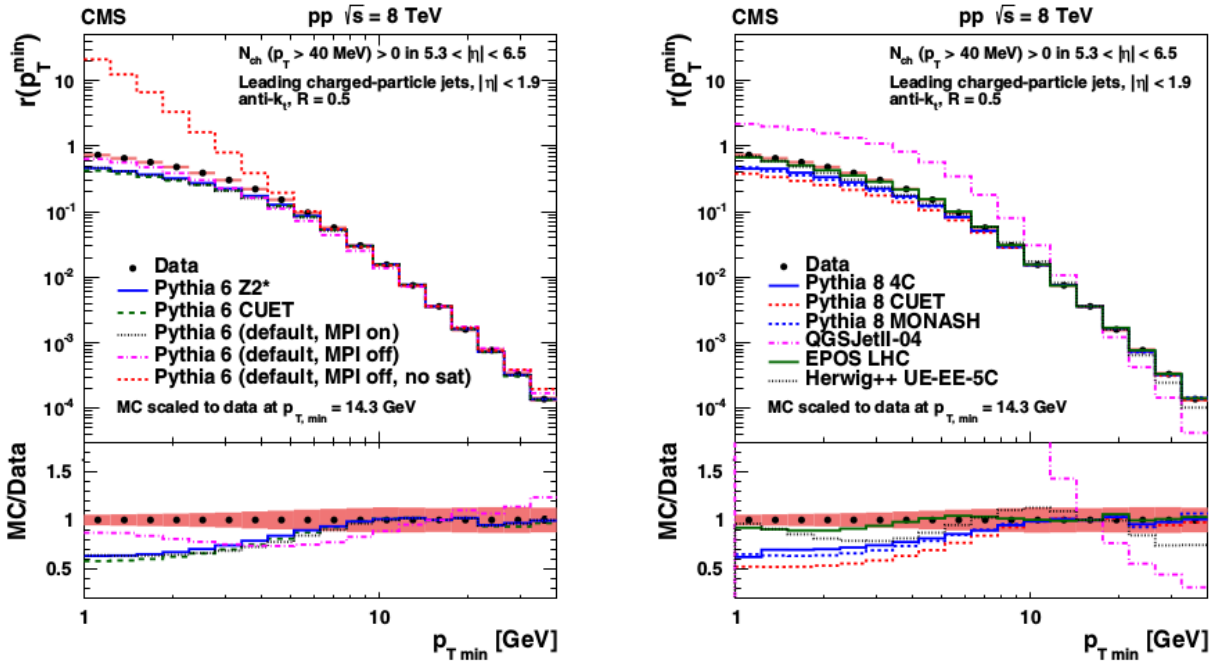




- EPOS is the best description, deviates only 10% from data at very low p_T
- HERWIG does not describe the transition between low and high p_T
- PYTHIA does not predict the correct shape at low p_T

Leading charged particles and leading charged-particle jets at small p_T in pp collisions at $\sqrt{s} = 8$ TeV

Leading charged particle jet within $|\eta| < 1.8$ and $p_T > 1$ GeV



- EPOS is the best description, deviates only 10% from data at very low p_T
- Similar conclusions for HERWIG and PYTHIA as in previous slides
- The region around 1 GeV is relatively flat: help to improve the description of the transition

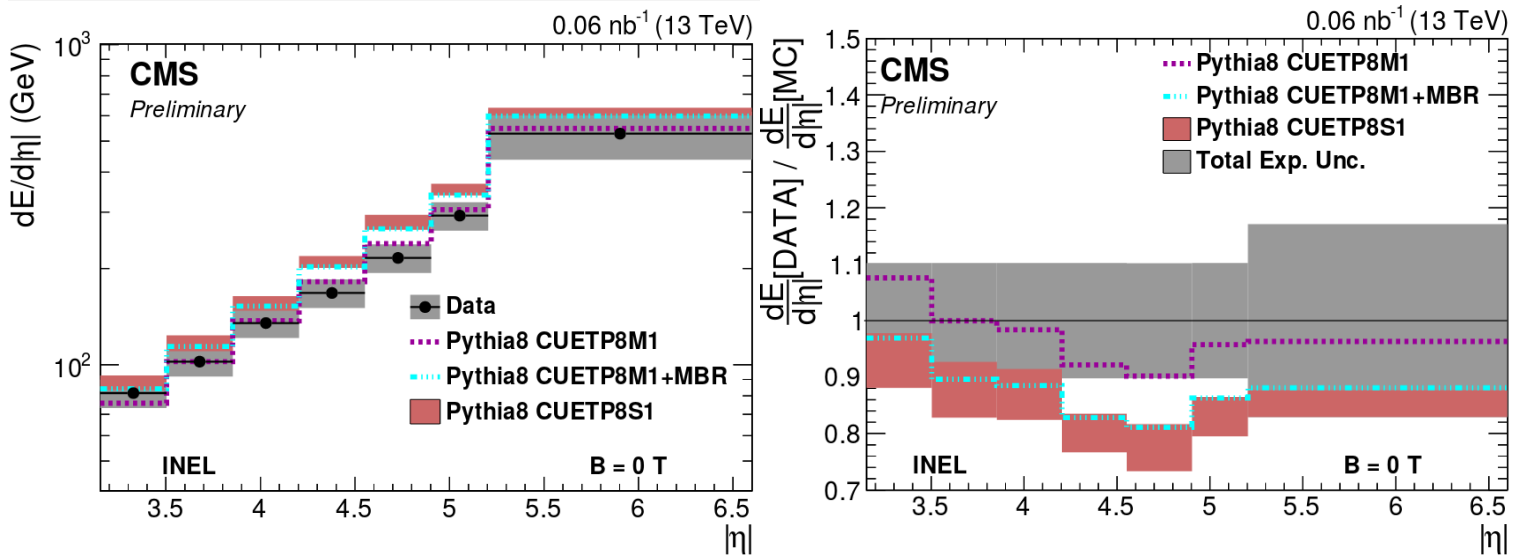
Pseudorapidity dependence of the energy and transverse energy density at $\sqrt{s} = 13$ TeV

- Measuring the energy flow $dE/d\eta$ and transverse energy density $dE_T/d\eta$ in the range $3.15 < |\eta| < 6.6$
- Explore the basic characteristics of the underlying event and MPI as function of pseudorapidity
- Study the soft particle production in the beam fragmentation region $\eta' = \eta - y_{beam} \simeq 0$

Preliminary result: CMS-PAS-FSQ-15-006

Pseudorapidity dependence of the energy and transverse energy density at $\sqrt{s} = 13$ TeV

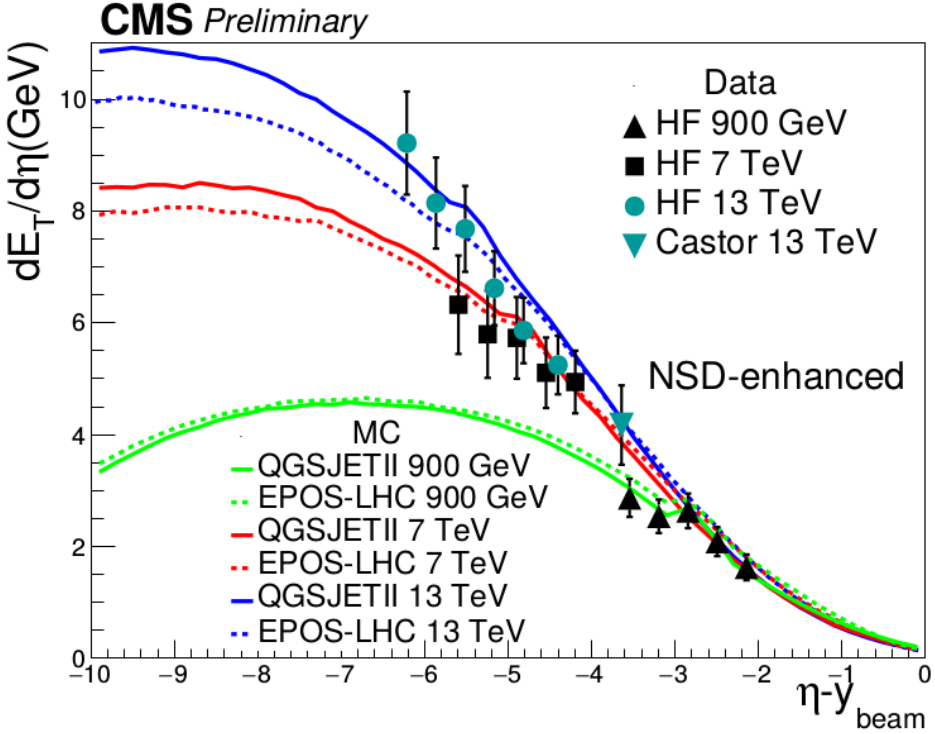
Energy flow for the soft-inclusive inelastic selection $3.15 < |\eta| < 6.6$
$\xi = M^2/s > 10^{-6}$ - requiring activity on at least one side of HF or in CASTOR



- Pythia 8 cuetp8s1 gives the best description.

Pseudorapidity dependence of the energy and transverse energy density at $\sqrt{s} = 13$ TeV

Transverse energy flow as function of shifted pseudo-rapidity, $\eta' = \eta - y_{beam}$.
At least two particles in the range $3.9 < |\eta| < 4.4$, at least one on each side of the detector.



- Soft particle production in the region $\eta' \simeq 0$ is independent of the $\sqrt{s}$

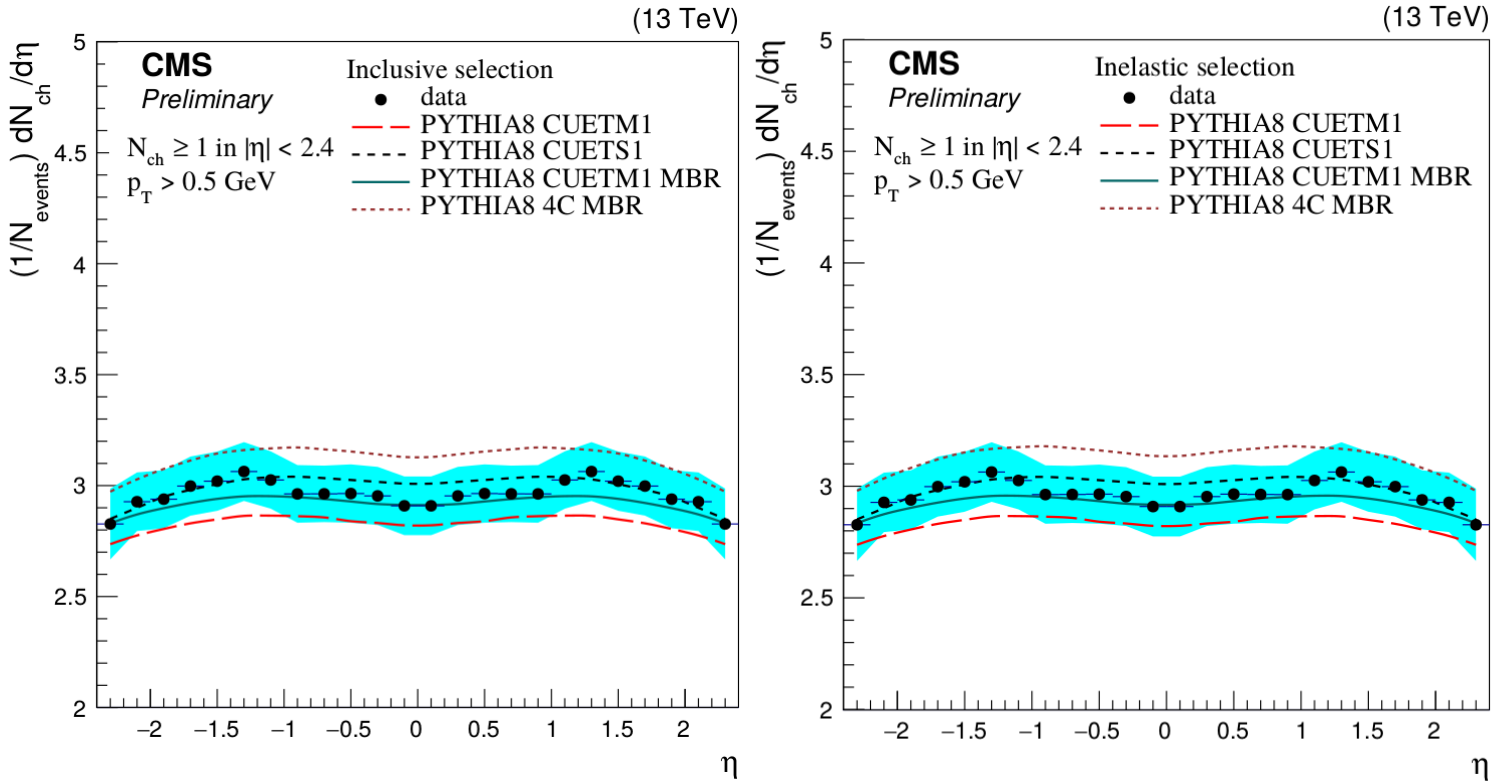
Pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV

- Pseudorapidity distribution of charged particles $dN_{charged}/d\eta$ for $|\eta| < 2.4$ and $p_T > 0.5$ GeV
- Measurement performed for several scenarios: inclusive, inelastic enhanced, non-single diffractive dissociation and single diffractive dissociation.
- Needed to understand the Underlying Event properties at low energies.

Preliminary result: CMS-PAS-FSQ-15-008

Pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV

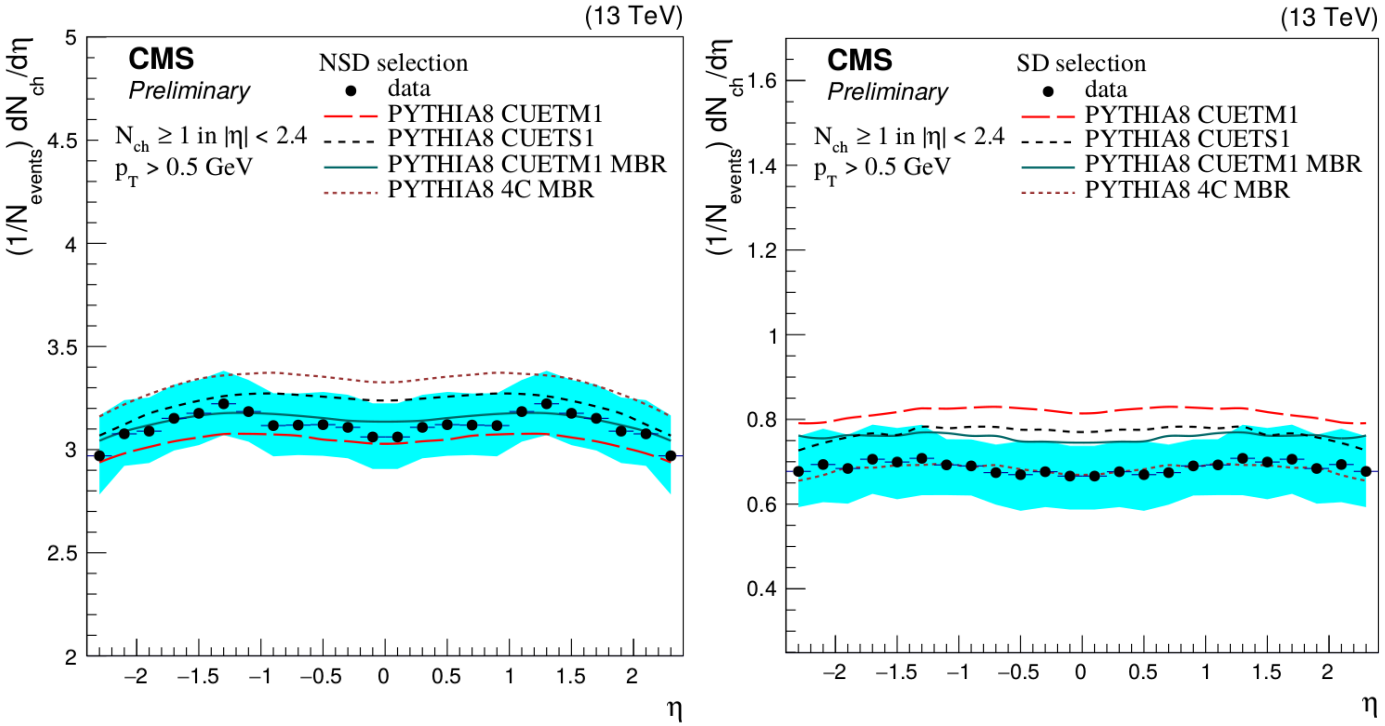
Inclusive: at least one particle with $p_T > 0.5$ GeV and $|\eta| < 2.4$
Inelastic: activity in $-5 < \eta < -3$ or $3 < \eta < 5$ with $p_T > 5$ GeV



- Best description with PYTHIA 8 tune CUETP8S1 and PYTHIA 8 MBR tune CUETP8M1

Pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV

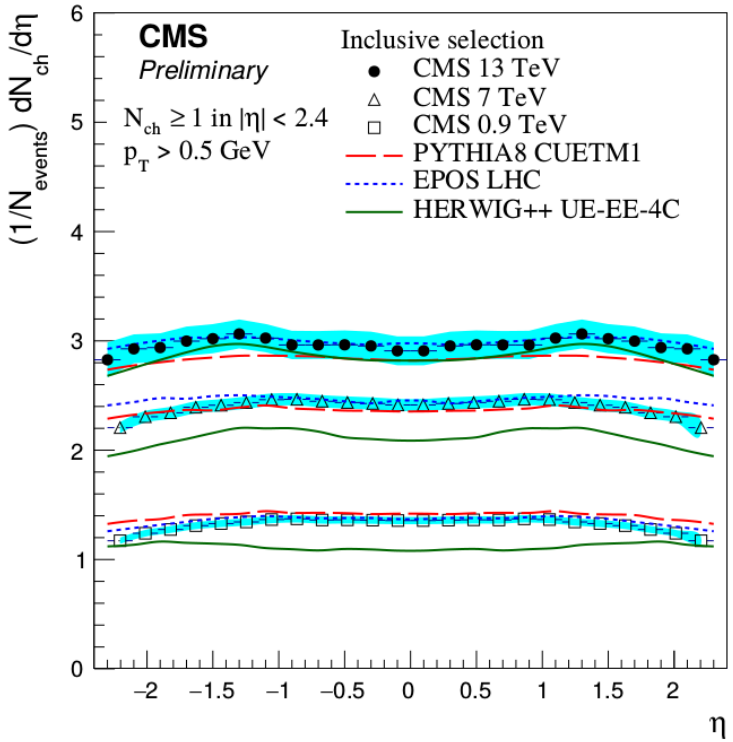
NSD: activity in $-5 < \eta < -3$ and $3 < \eta < 5$ with $p_T > 5$ GeV
SD: activity in $-5 < \eta < -3$ or $3 < \eta < 5$ and veto the other with $p_T > 5$ GeV



- PYTHIA 8 MBR with tune CUETP8M1 gives the best description of the NSD scenario
- PYTHIA 8 MBR with tune 4C describe the SD scenario well

Pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV

Inclusive scenario for several center-of-mass energies: 0.9, 7 and 13 TeV



- Good description by Pythia 8 tune CUETP8M1 and EPOS LHC at 3 distinct centre-of-mass energies.

Conclusions

- CMS has carried out several soft QCD and Forward Physics measurements at different centre-of-mass energies 7, 8 and 13 TeV
- Jets and charged particles were studied, specially at low p_T
- Large rapidity intervals were studied, taking advantage of the almost hermetic detector
- These measurements helped to shed light in several open QCD topics: Underlying Event (UE), Multi Parton Interactions (MPI), Double Parton Scattering (DPS), Single and Non-Single diffractive dissociation, Jet Correlations and transition between perturbative and non-pertubative QCD
- More studies are being produced with 13 TeV