Measurement of the Minimum Bias, Underlying Events and Double-Parton Scatterings

Ankita Mehta

on behalf of the CMS Collaboration

Panjab University India

XXXIX International Conference on High Energy Physics

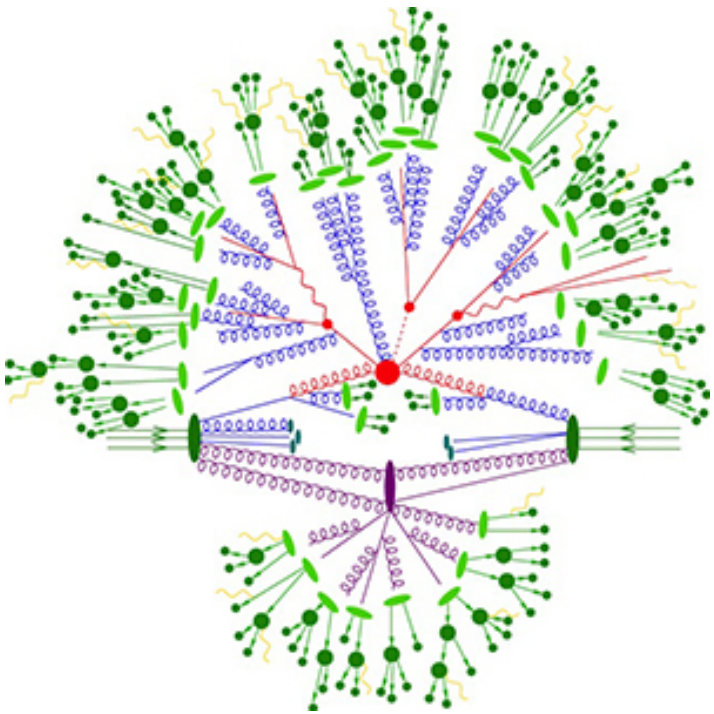
Coex, Seoul

07 July 2018

Overview

Hadron-Hadron Collision → Hard scattering b/w partons $\bigoplus$ UE activity

Important to study soft & semi-hard interactions @ LHC



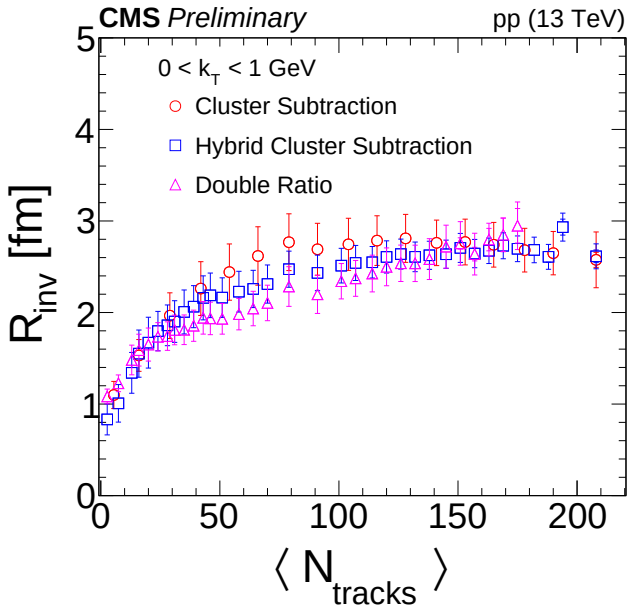
1. Recent Measurements from CMS @ 13 TeV → Different Aspects of Particle Production
2. Minimum Bias Data (MB) Analysis
   - BEC of Charged Hadrons (CDS Record 2318575)
   - Charged Particle Spectra in MB events (CERN-EP-2018-187)
3. UE Activity using Z Boson Events (arXiv:1711.04299)
4. DPS Studies using same-sign WW events (CDS Record 2257583)
5. Summary

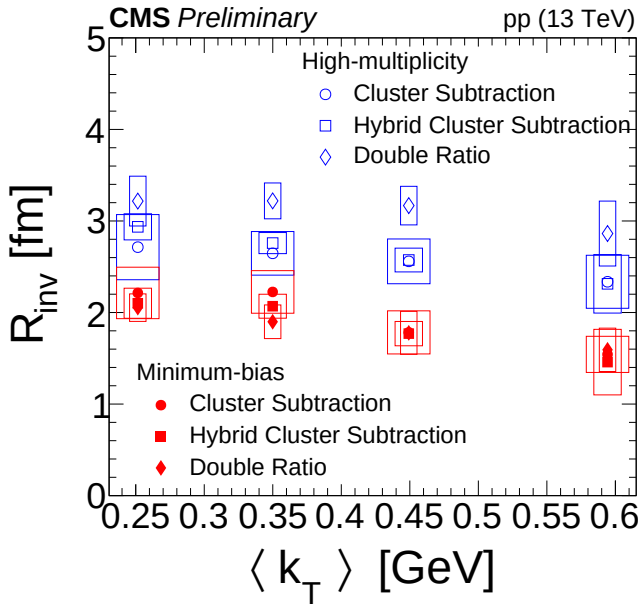
Hard Interaction | Beam-Beam Remnants (BBR) | Multiple-Parton Interactions (MPI) | Initial State & Final State Radiations (ISR & FSR)

Correct description of the data → Requires tuning of MC event generators → Precise physics predictions

Bose-Einstein Correlations (BEC) of Charged Hadrons (CDS Record 2318575)

- BEC : Probes the size and shape of the particle emitting region in high-energy collisions
- Correlation functions extracted using double ratios & two data-driven (cluster subtractions & hybrid cluster subtraction) methods
- Homogeneity lengths (R_{inv}) studied as a function of particle multiplicity (N_{tracks}) at the particle level, average pair transverse momentum (k_T) & mass (m_T)



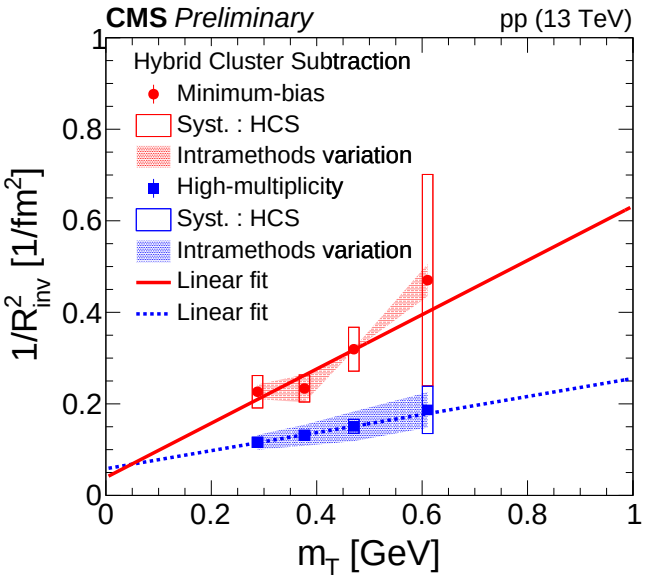


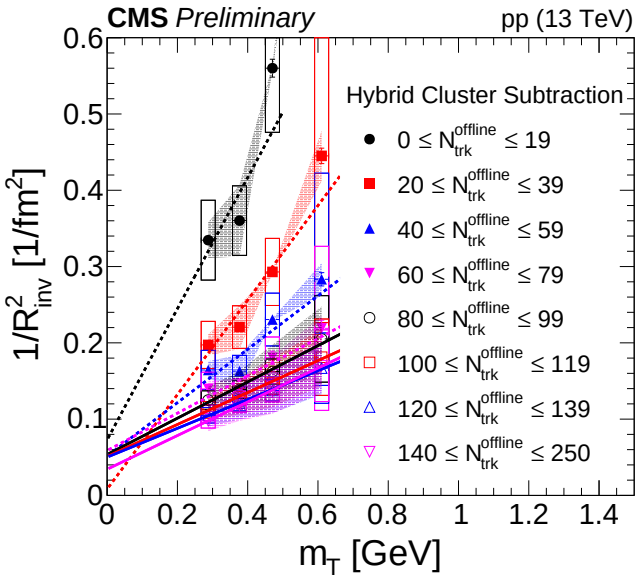
- R_{inv} increases with $\langle N_{tracks} \rangle$ & saturates at higher values
- R_{inv} decreases with increasing k_T $\rightarrow$ Emitting source was expanding prior to decoupling

Results: m_T Dependence

Hydrodynamic Models

- Intercept connected with the geometrical size of the source (at freeze-out)
- Slope connected to the flow component, bigger slope (bigger flow) for lower multiplicities

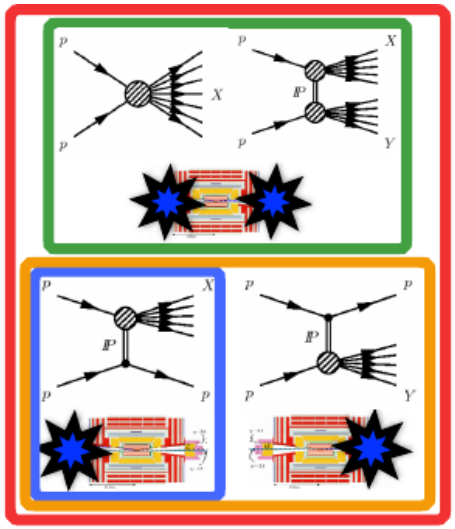


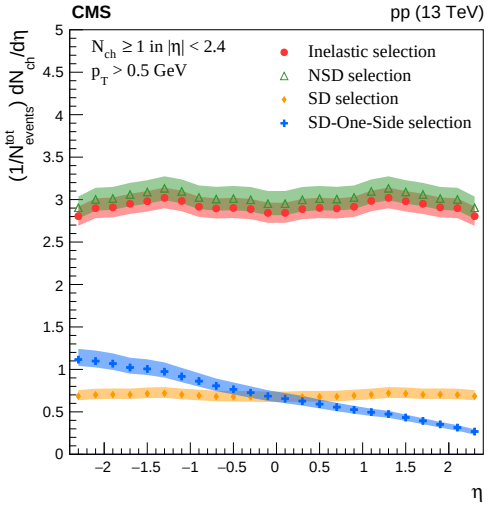


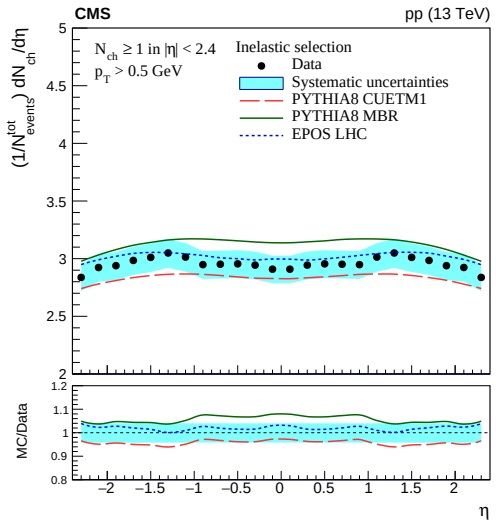
- Expansion in the low multiplicity region is faster than in the high multiplicity region
- Collective flow decreases with increasing multiplicity & saturates ~ 80

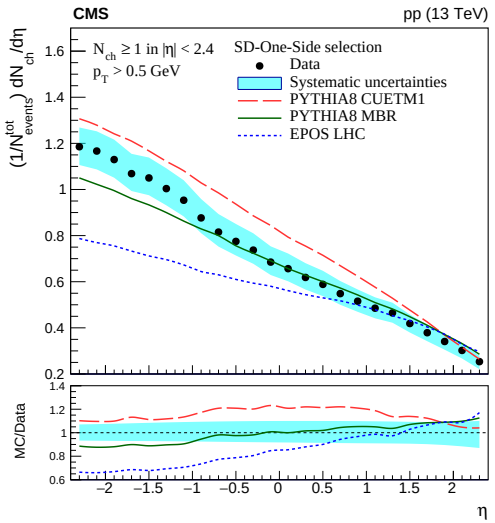
Charged Particle Spectra in MB events

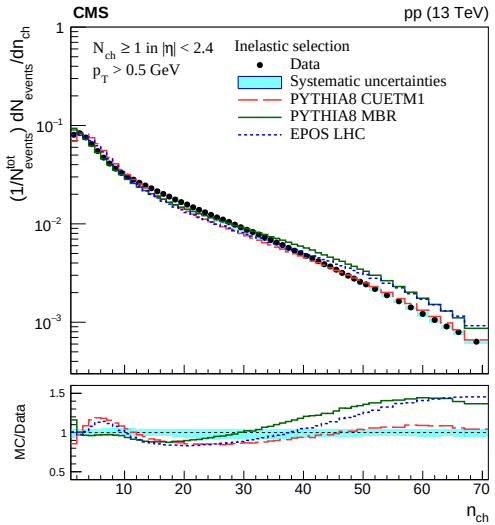
- Diffraction → Exchange of color-neutral object
- Three event categories: Inelastic, NSD-enhanced, SD-enhanced







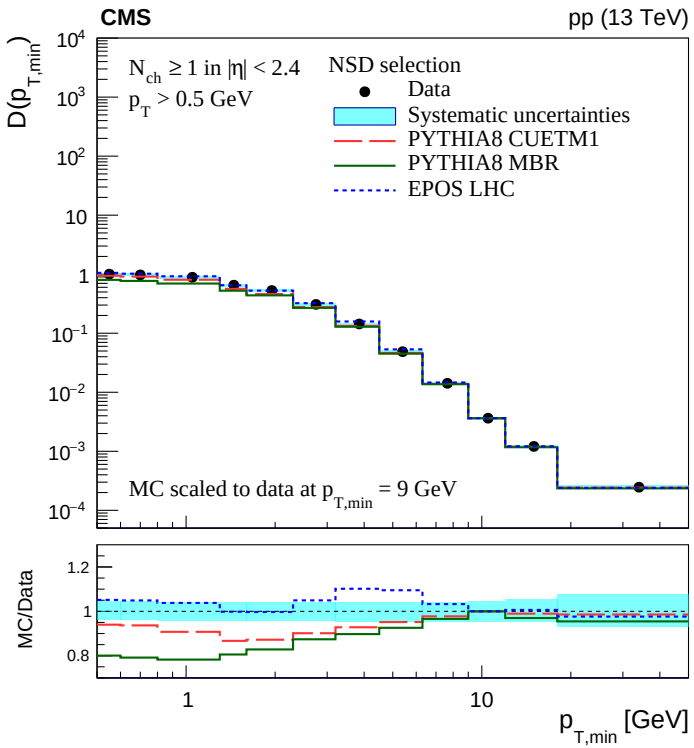


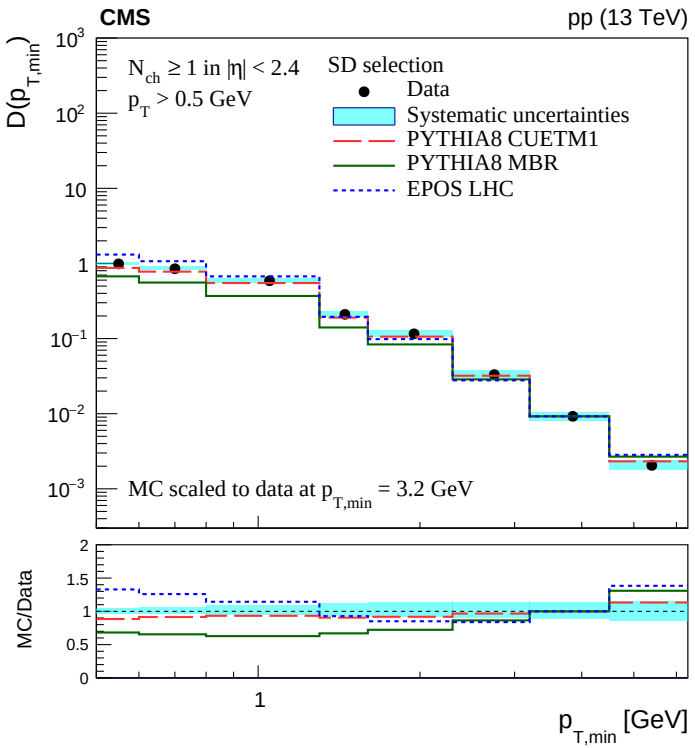


- SD-One-Side enhanced sample → PYTHIA8 MBR4C described the measurements within uncertainties
- Room for improvement in high multiplicity regions (dominated by MPI)

Results

- Integrated p_T spectrum of charged particles → Sensitive to the transition b/w the non-perturbative & perturbative QCD regions

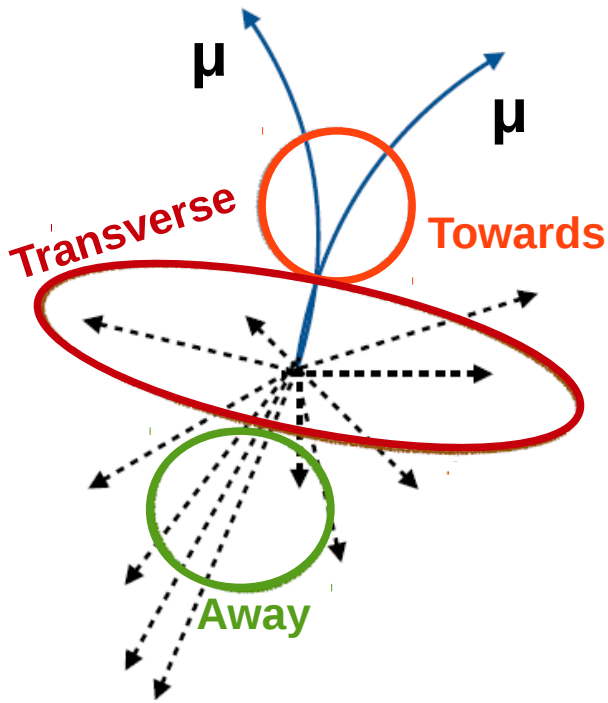




- NSD-enhanced events: EPOS LHC gives the best description, with small fluctuations
- SD-enhanced events: Low p_T region difficult to describe
- Transition b/w the region dominated by particle production from MPI & hard scattering evident from fast change of slope

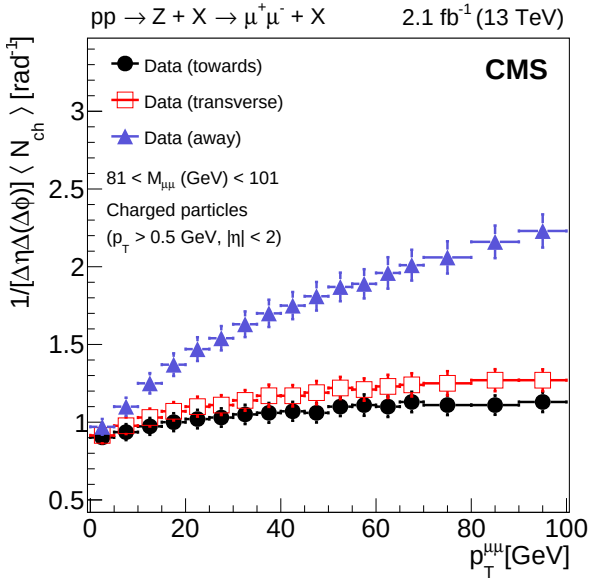
UE activity using Z $\rightarrow \mu\mu$ events (arXiv:1711.04299)

- Experimentally clean signature & absence of QCD FSR *(Accepted by JHEP)*
- **Observables: Charged-particle density & $\sum p_T$ density**



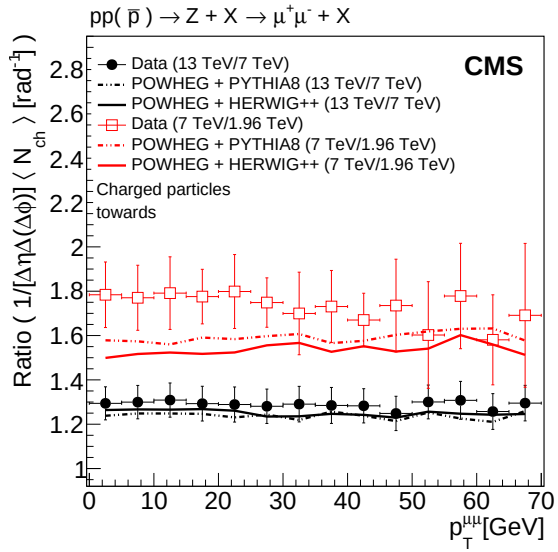
Phase-space Regions

- $|\Delta\phi(\mathrm{Z}, \mathrm{ch.particle})| < 60°$: *Towards* $\rightarrow$ **Sensitive to MPI/UE**
- $|\Delta\phi(\mathrm{Z}, \mathrm{ch.particle})| > 120°$: *Away*
- $60° < |\Delta\phi(\mathrm{Z}, \mathrm{ch.particle})| < 120°$: *Transverse* $\rightarrow$ **Sensitive to MPI/UE**

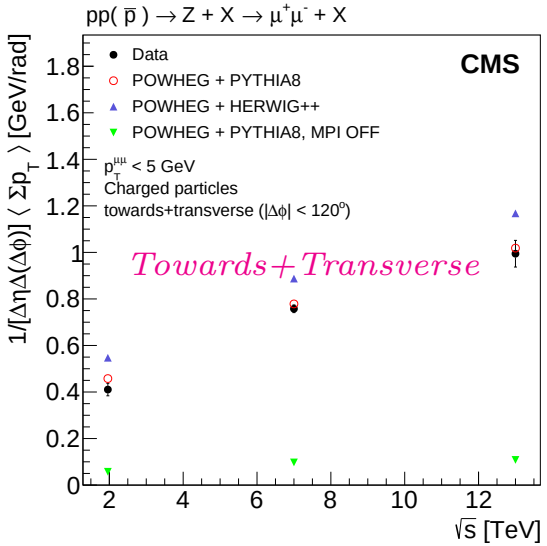


Energy Dependence of UE Activity

- Current results are compared with those @ 1.96 TeV (CDF) & 7 TeV (CMS)
- 60–80% rise from 1.96 TeV to 7 TeV → Simulations predict a slower rise with $\sqrt{s}$
- 25–30% rise from 7 TeV to 13 TeV → Best described by POWHEG+PYTHIA8 & POWHEG+HERWIG++

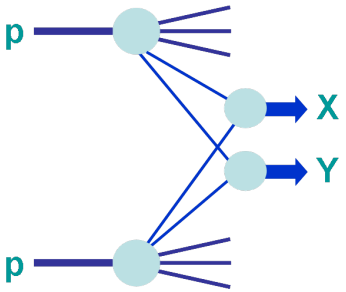


- Upper cut on $p_T^{\mu\mu}$ → UE activity mainly from MPI
- Better description: POWHEG+PYTHIA8
- POWHEG+HERWIG++ overestimates the data



Double-Parton Scattering (DPS) (CDS Record 2257583)

- Two hard parton-parton interactions in a single pp collision→**DPS**



- $\sigma_{XY}^{DPS} = \frac{m\sigma_X\sigma_Y}{2\sigma_{eff}}$ ⇒ Assumed factorization of DPDFs
- σ_{eff} ⇒ Predicted to be independent of process type & collision energy

Importance of DPS Processes

- Provide information about hadron structure in transverse plane
- Estimation of background contributions for interesting SM & BSM processes

W+2jets (JHEP03(2014)032)

4jets (Phys.Rev.D89(2014)092010)

γ+3jets(CDS Record 2007815)

2bjet+2jet (Phys.Rev.D94(2016)112005)

Double J/ψ (JHEP09(2014)094)

Same-sign WW (JHEP02(2018)032), (CDS Record 2257583)

More Channels Waiting To Be Explored !!

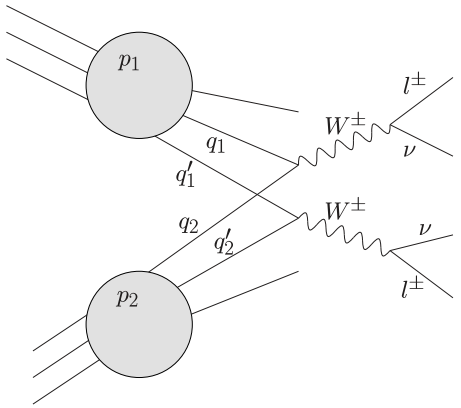
Why DPS using Same-Sign WW

- $\sigma_{W^\pm W^\pm}^{DPS} \approx \sigma_{W^\pm W^\pm}^{SPS}$ & a clean final state with leptonically decaying W bosons

DPS in Same-Sign WW Production

Event Selection

- 2 same-sign leptons ($\mu\mu$ or eμ): $\mathrm{p_T}(l_{1/2}) > 25/20$ GeV
- $p_{\mathrm{T}}^{\mathrm{miss}} > 15$ GeV
- $\mathrm{N_{jets}} < 2$ ($\mathrm{p_T} > 30$ GeV)
- $\mathrm{N_{bjets}} = 0$ ($\mathrm{p_T} > 25$ GeV)
- Veto on additional leptons & τ_{had}



Signal & Background Processes

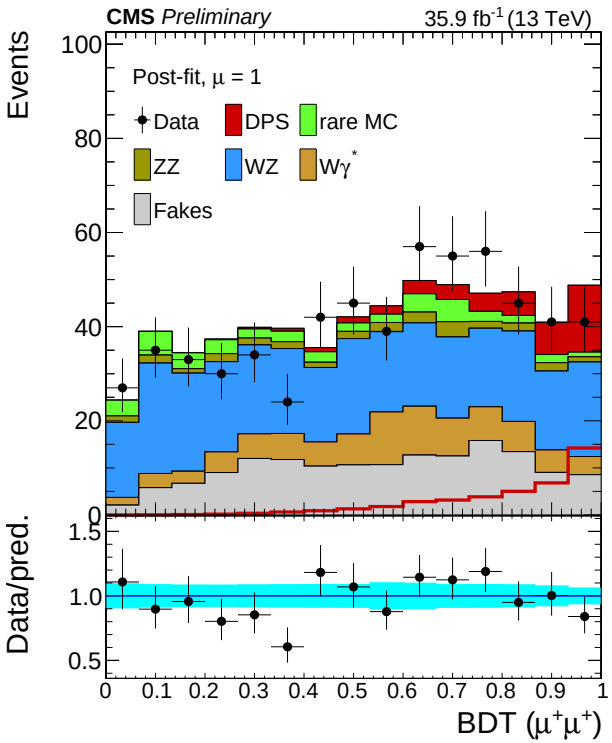
- PYTHIA8 (CUETP8M1 TUNE) Signal sample
- Backgrounds: WZ, Jet induced backgrounds, Diboson, Triboson & $\mathrm{Z} \to \tau\tau$

BDTs trained against the WZ background process using 11 input variables

- $p_{\mathrm{T}}\, l_{1,2}$, $p_{\mathrm{T}}^{\mathrm{miss}}$, $\eta_1 \times \eta_2$, $|\eta_1 + \eta_2|$
- $\mathrm{M_{T2}^{ll}}$, $\mathrm{m_T(l_1, p_T^{miss})}$, $\mathrm{m_T(l_1, l_2)}$
- $\Delta\phi(l_1, l_2)$, $\Delta\phi(l_2, p_{\mathrm{T}}^{\mathrm{miss}})$, $\Delta\phi(l_1 l_2, l_2)$

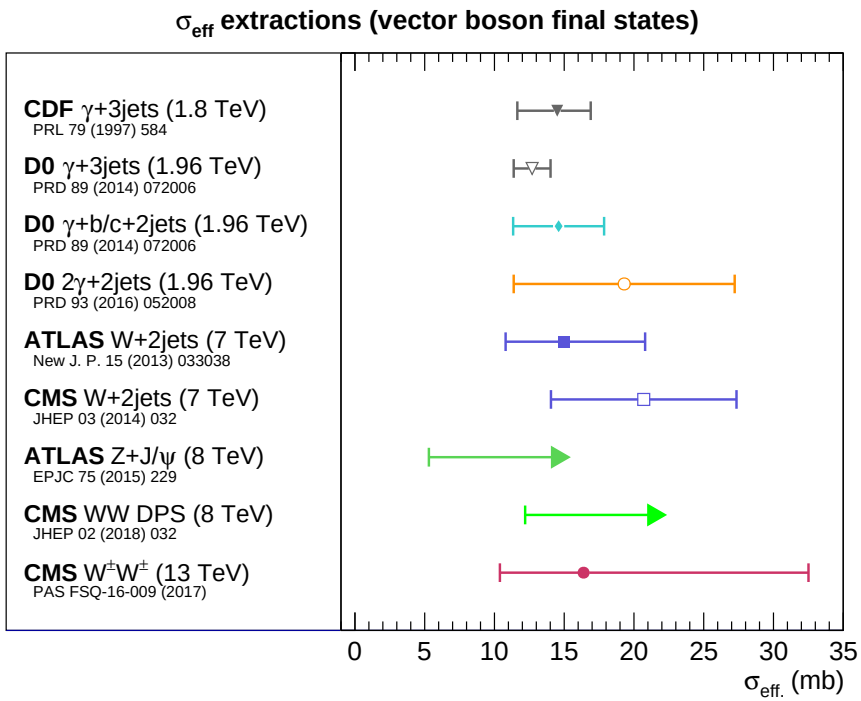
Results

- Shapes of BDT → Fitted using a likelihood fit for e^+e^+,e^-e^-,$\mu^+\mu^+$,$\mu^-\mu^-$



	expected	observed
$\sigma^{\text{pythia}}_{\text{DPSWW}}$	1.64 pb	$1.09^{+0.50}_{-0.49}$ pb
$\sigma^{\text{factorized}}_{\text{DPSWW}}$	0.87 pb	
significance for $\sigma^{\text{pythia}}_{\text{DPSWW}}$	3.27 σ	2.23 σ
significance for $\sigma^{\text{factorized}}_{\text{DPSWW}}$	1.81 σ	
UL in the absence of signal	< 0.97 pb	< 1.94 pb

2σ sensitivity → I$^{\text{st}}$ time in WW DPS



Summary

- Unique measurements of charged-particle spectra in different event categories → Important input for MC tuning
- Consistent results from three different correlations functions (with different dependence on MC simulations) used to study BEC
- Homogeneity lengths increase with increasing track multiplicities → Consistent with hydrodynamical calculations
- Observed change in UE activity in Z boson events from 7 → 13 TeV → Best described by POWHEG + PYTHIA8 & POWHEG + HERWIG++
- Overall good description of UE activity by simulations → Universality of UE tunes
- 2σ sensitivity observed in DPS with same-sign WW analysis