DPS Measurements at CMS

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Outline
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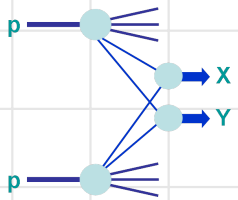
Double-Parton Scattering

- Simultaneous occurring of two hard partonic interactions in a single pp collision →**Double-Parton Scattering** (DPS)
- Large parton densities and small-x values @ LHC → Substantial probability for the manifestation of DPS (hardest instance of MPI)



- $\sigma_{XY}^{DPS} = \frac{m\sigma_X\sigma_Y}{2\sigma_{eff}}$, m = 1 (2) for identical (different) processes
- σ_{eff} → **Effective cross section parameter of DPS**
- Expected to be independent of process type & collision energy

Importance of DPS processes

- Could provide information about hadron structure in transverse plane
- Understanding of background contributions to interesting SM & BSM processes

W+2jets (JHEP03(2014)032)

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

γ+3jets (CMS PAS FSQ-12-017)

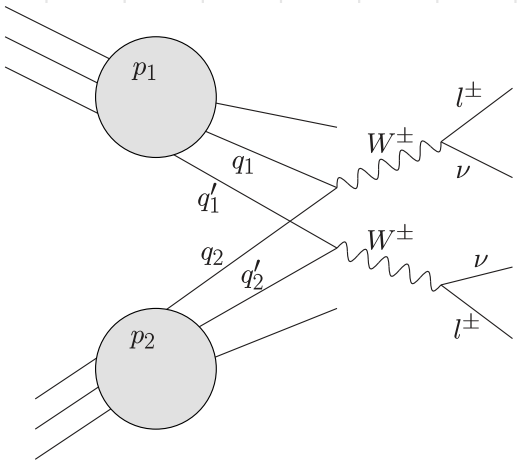
Double J/ψ (JHEP09(2014)094)

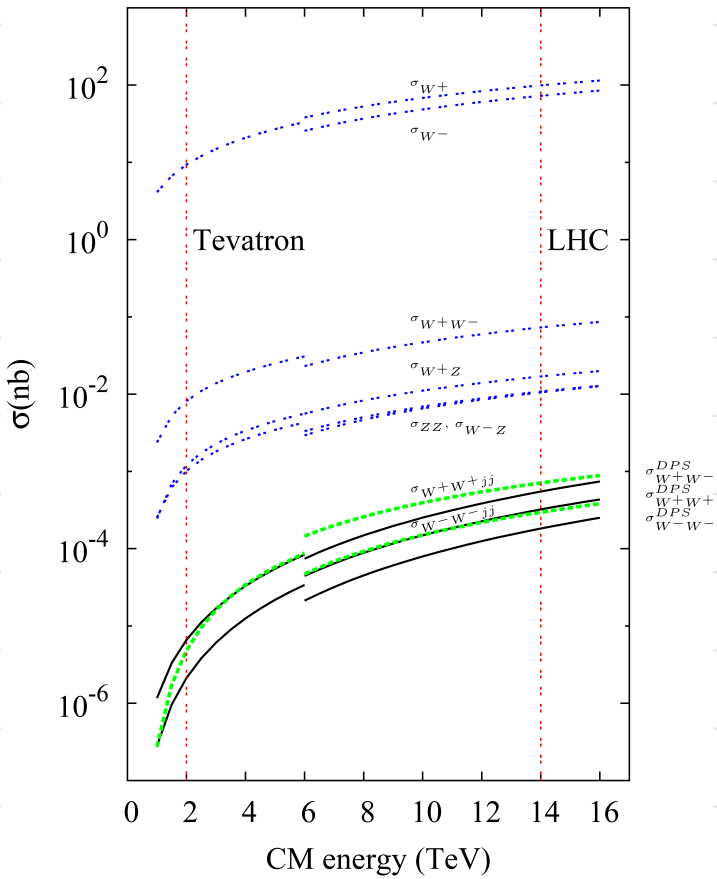
4jets (Phys.Rev.D89(2014)092010)

Same-sign WW production

Same-sign WW production via DPS

- $\sigma^{\mathrm{DPS}}_{\mathrm{W^{\pm}W^{\pm}}} \approx \sigma^{\mathrm{SPS}}_{\mathrm{W^{\pm}W^{\pm}}}$
- Clean final state with leptonically decaying W bosons

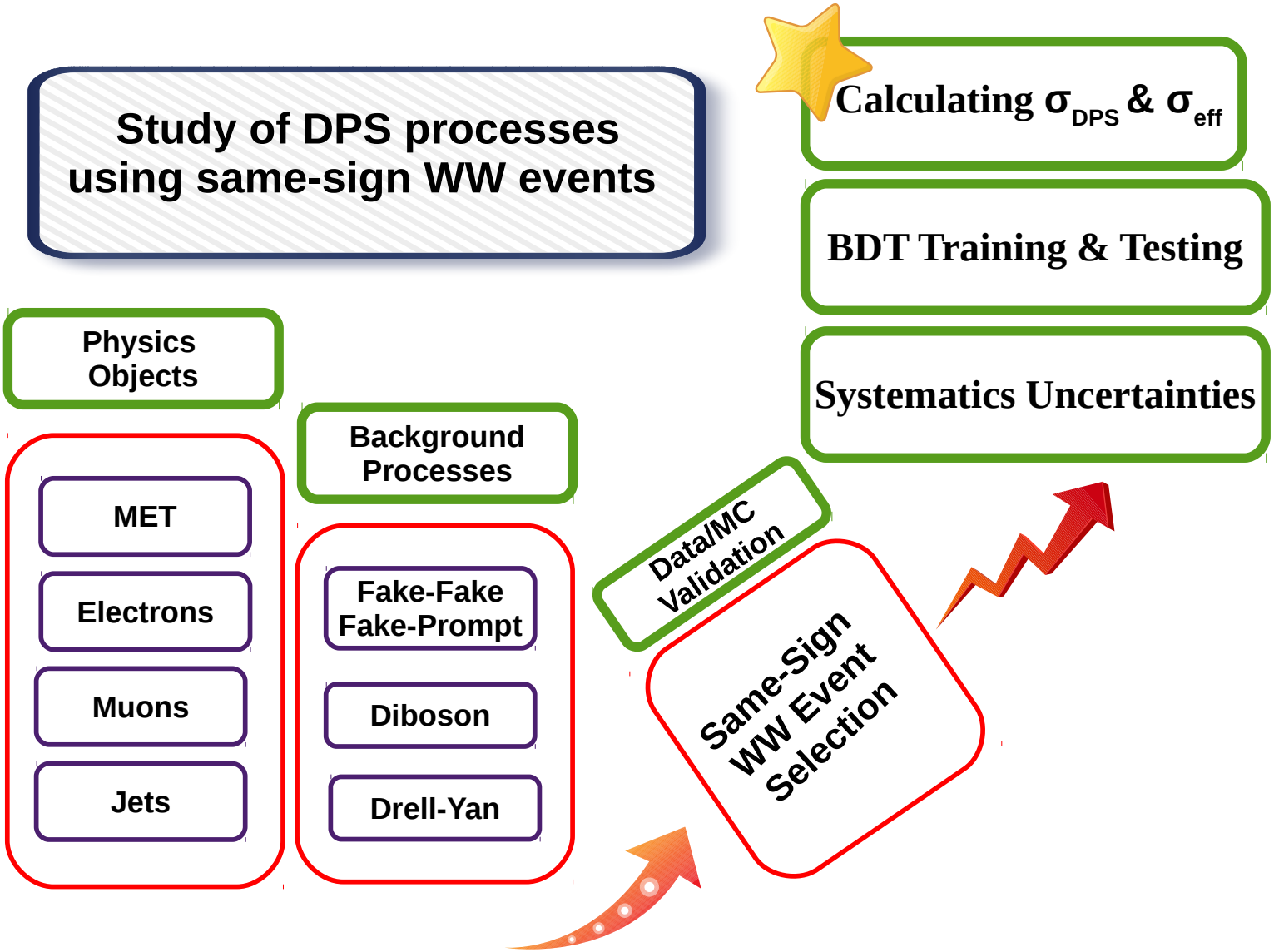




Performed Measurements

- Measurement of double parton scattering in same-sign WW production in pp collisions at $\sqrt{s} = 13$ TeV with the CMS experiment (CMS-PAS-FSQ-16-009)
- Constraints on the double-parton scattering cross section from same-sign W boson pair production in proton-proton collisions at $\sqrt{s} = 8$ TeV (`https://arxiv.org/abs/1712.02280`)

Analysis Strategy



Constraints on the double-parton scattering cross section from same-sign W boson pair production in proton-proton collisions at $\sqrt{s} = 8$ TeV

First results on DPS measurements @ 8TeV with 19.7 fb^{-1} of pp collisions data

Event Selection

- 2 same-sign leptons ($\mu\mu$ or eμ) with $p_T(l_{1/2}) > 10/20$ GeV
- $E_T^{miss} > 20$ GeV; $m_{ll} > 20$ GeV; Veto on additional leptons
- $\mu\mu$ final state
  - $m_{\mu\mu} \notin [75,105]$ GeV; $|\vec{p}_{T_{\mu_1}}| + |\vec{p}_{T_{\mu_2}}| > 45$ GeV
- eμ final state
  - No b-tagged jets with $p_T > 30$ GeV & $|\eta| < 2.1$

Background Processes

- **Data driven estimate of QCD multijets, W+jets & semileptonic $t\bar{t}$ events**
- Diboson (WZ, ZZ, WW) processes estimated from MC
- W$\gamma^{(*)}$ estimated from MC with normalization derived from data
- DY process estimated from MC (negligible for $\mu\mu$ final state)

Multivariate Analysis: Boosted Decision Trees (BDT)

Variables Used: $e\mu$ final state

- $p_{\mathrm{T}} l_{1,2}$
- $p_{\mathrm{T}} l_1 l_2$
- $p_{\mathrm{T}}^{\mathrm{miss}}$
- $\Delta\eta(l_1, l_2)$
- $\Delta\phi(l_2, p_{\mathrm{T}}^{\mathrm{miss}})$
- $\Delta\phi(l_1, l_2)$
- $\Delta\phi(l_1 l_2, p_{\mathrm{T}}^{\mathrm{miss}})$

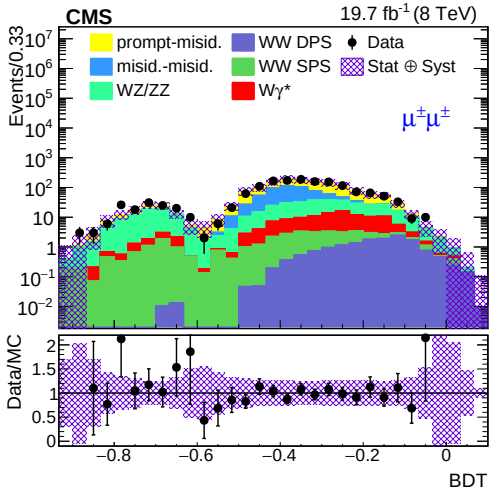
Variables Used: $\mu\mu$ final state

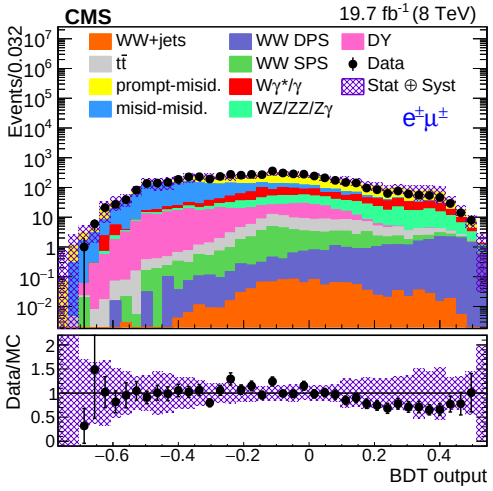
- $p_{\mathrm{T}} \mu_{1,2}$
- $p_{\mathrm{T}}^{\mathrm{miss}}$
- $\Delta\phi(\mu_{1/2}, p_{\mathrm{T}}^{\mathrm{miss}})$
- $\Delta\phi(\mu_1, \mu_2)$
- $\mathrm{m_T}(\mu_{1/2}, p_{\mathrm{T}}^{\mathrm{miss}})$
- $\mathrm{m_T}(\mu_1, \mu_2)$

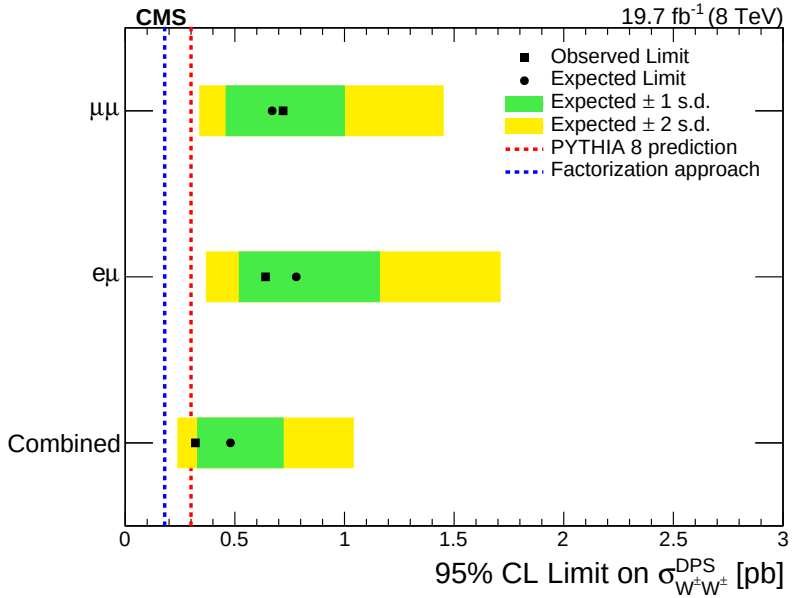
Training & testing samples

- Signal: DPS OS events for training & SS events from MC sample for testing
- Background: WZ, Fake-fake & Prompt-Fake events (both OS & SS)

Results







- **BDT trained using kinematic variables of two leptons**
- **Shape of the BDT discriminant is used to extract the limits**

- **Limits improved after combined results from two final states**
- **Results in agreement with MC predictions**

Measurement of double parton scattering in same-sign WW production in pp collisions at $\sqrt{s} = 13$ TeV with the CMS experiment

Event Selection

- 2 same sign leptons ($\mu\mu$ or eμ) with $p_T(l_{1/2}) > 25/20$ GeV
- $E_T^{miss} > 15$ GeV
- $N_{jets} < 2$ ($p_T > 30$ GeV)
- $N_{bjets} = 0$ ($p_T > 25$ GeV)
- Veto on additional leptons & hadronically decaying τs

Background Processes

- WZ: Estimated from MC; Shape & normalization uncertainty from 3l control region
- Jet induced backgrounds: Estimated from data; Shape & scale uncertainties from variations in fake rate & MC closure tests
- Wγ^*, ZZ, WW,& WWW $\rightarrow$ estimated from MC
- Z $\rightarrow \tau\tau$ estimated by measuring charge flip probability of electrons

Multivariate Analysis: Boosted Decision Trees (BDT)

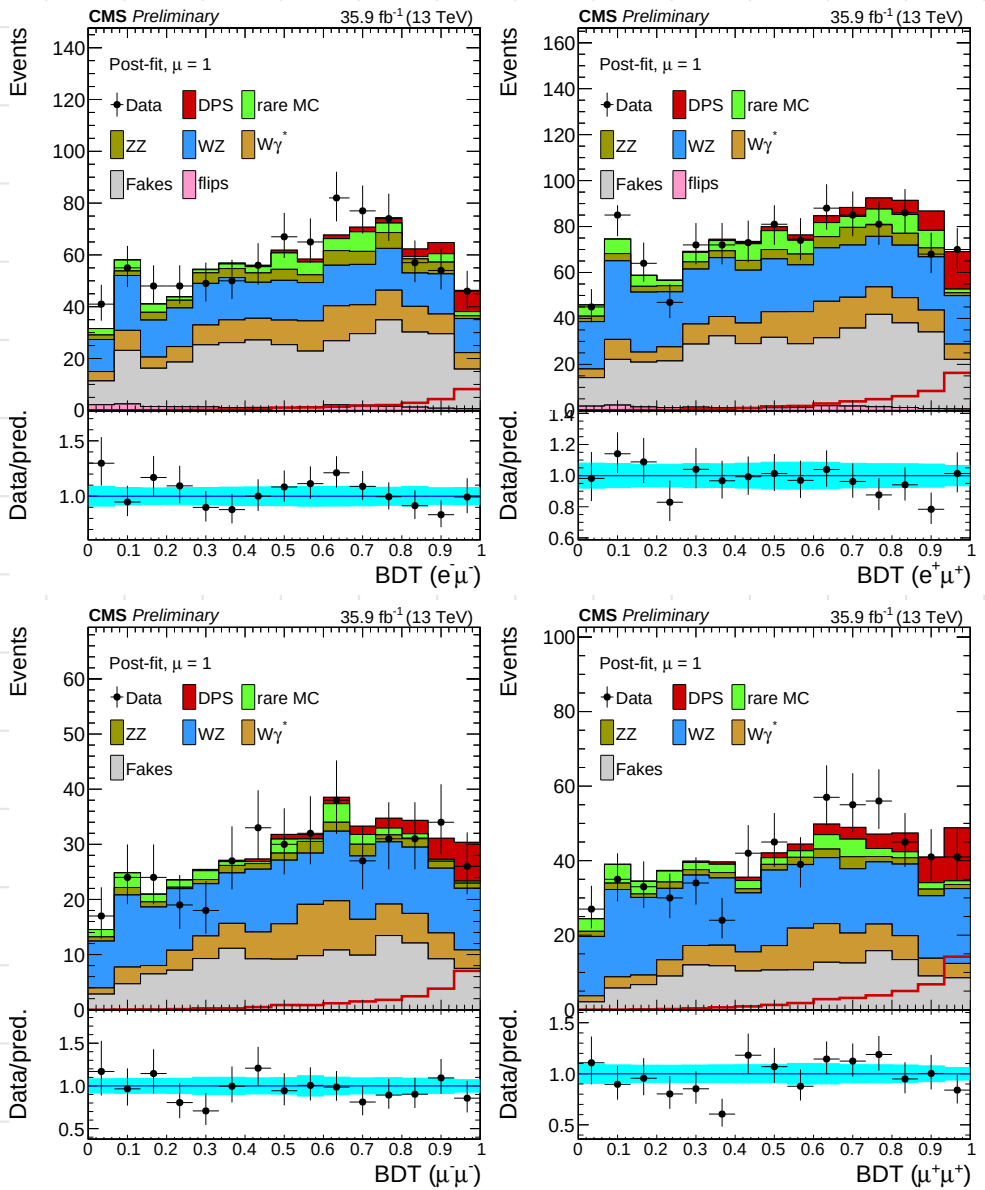
Variables Used

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

Training & Testing Samples

- Signal: DPS events from MC sample
- Background: WZ events from MC sample

Results-I



- Shapes of BDT $\rightarrow$ fitted using a likelihood fit for e^+e^+,e^-e^-,$\mu^+\mu^+$,$\mu^-\mu^-$
- Dividing into charge configurations maximizes the sensitivity

	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 $\rightarrow$ I$^{\text{st}}$ time in WW DPS**

Summary

- DPS measurements → Important to understand partonic structure of hadrons & for new physics searches @ LHC
- Various channels being probed to perform DPS measurement at LHC
- **Same-sign WW emerges as a golden channel to search for DPS**
- **More data @ 13Tev → Possible to see first DPS signal in same-sign WW events**