14th Course on Physics at the LHC 2025

Vector Boson Scattering: Electroweak production of same-sign W boson pairs ($W^{\pm}W^{\pm}$) in association with two jets

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Introduction

- This research presents groundbreaking measurements of the production cross sections for polarized same-sign boson pairs
- This research focusses on investigating the electroweak production of same-sign W boson pairs ($W^{\pm}W^{\pm}$) in association with two jets at the LHC
- This analysis concentrates on the leptonic decay mode: $W^{\pm}W^{\pm} \rightarrow l^{\pm}\nu l'^{\pm}\nu$, where both W bosons decay into electrons or muons.
- Focuses on probing the electroweak (EW) symmetry breaking mechanism by analyzing the production of polarized same-sign W boson pairs at the LHC.

Background of the study

This study revolves around understanding the electroweak (EW) symmetry breaking mechanism and searching for physics beyond the Standard Model (BSM).

Probing Electroweak Symmetry Breaking

- The paper's introduction emphasizes that Vector Boson Scattering (VBS) processes are crucial for investigating the mechanism of electroweak (EW) symmetry breaking.

Probing Beyond the Standard Model (BSM) Physics:

- The introduction states that even after the Higgs boson discovery, new physics models (BSM) could still contribute to EW symmetry breaking. These models predict modifications to VBS cross sections, particularly for longitudinally polarized W and Z bosons, through changes in Higgs boson couplings or the presence of new resonances.

Materials and Methods

CMS Detector at LHC: CMS is designed to detect a wide range of particles produced in proton-proton collisions.

- The pp collisions occurred at a center-of-mass energy of 13 TeV, corresponding to an integrated luminosity of 137 fb^-1. This data was collected during the LHC operating periods in 2016, 2017, and 2018.
- The measurements were conducted based on the data collected by the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC).

Materials and Methods...

- The CMS detector features a superconducting solenoid generating a 3.8 T magnetic field, with various subdetectors for particle tracking and calorimetry.

- Events were selected based on stringent requirements to isolate the $W^{\pm}W^{\pm}$ topology and suppress background processes. Some of this are:

Materials and methods....

Variable	Requirements
Leptons	Exactly 2 same-sign leptons, PT> 25/20GeV
Jet Transverse Momentum	>50 GeV
Absolute difference b/w Di-electron invariant mass and Z boson mass	>15 GeV
Di-electron invariant mass	>20 GeV
Missing Transverse Momentum	>30 GeV
b quark veto	Required
Maximum Lepton Variable	<0.75
Di-jet invariant mass	>500 Gev
Absolute difference in pseudorapidity b/w jets	>2.5

Background Simulation and Signal

Monte Carlo (MC) Event Generators were used to simulate signal and background processes.

- Three independent sets of simulated events for each process are needed to match the data-taking conditions in the various years.
- All generated events are processed through a simulation of the CMS detector based on Geant4 and are reconstructed with the same algorithms used for data.
- Additional pp interactions in the same and nearby bunch crossings, referred to as pileup, are also simulated

Background Simulation and Signal....

Signal Simulation (Polarized W±W±):

- WL±WL±, WL±WT±, and WT±WT± processes simulated separately using MADGRAPH5_aMC@NLO.

Background Simulation:

- EW WZ and QCD-induced WZ/ W±W± processes simulated with MADGRAPH5_aMC@NLO.

Pileup Simulation:

- Additional proton-proton interactions (pileup) are simulated and adjusted to match data (average ~23-32 interactions).

Reconstruction

CMS Particle-Flow (PF) Algorithm:

- Reconstructs and identifies individual particles by combining information from all sub-detectors.

Jets:

- Clustered from PF candidates using the anti-kT algorithm (distance parameter 0.4).
- Calibrated for detector response and pileup effects (charged-hadron subtraction).

Reconstruction…

Electrons and Muons:

- Reconstructed by associating tracks with ECAL clusters (electrons) or muon system tracks (muons).

Extracting Polarization Information

Kinematic Differences: Different W boson polarization states (WL vs. WT) lead to distinct kinematic distributions for leptons, jets, and pTmiss

- WL bosons tend to be radiated at smaller angles, resulting in lower pT compared to WT.

Multivariate Techniques (Boosted Decision Trees - BDTs):

- Used to enhance separation between different processes and polarization states.

Extracting Polarization Information

Two Signal BDTs:

- Separates $W_L^{\pm}W_L^{\pm}$ from $W_X^{\pm}W_T^{\pm}$ (where X is any polarization).
- Separates $W_L^{\pm}W_X^{\pm}$ from $W_T^{\pm}W_T^{\pm}$.

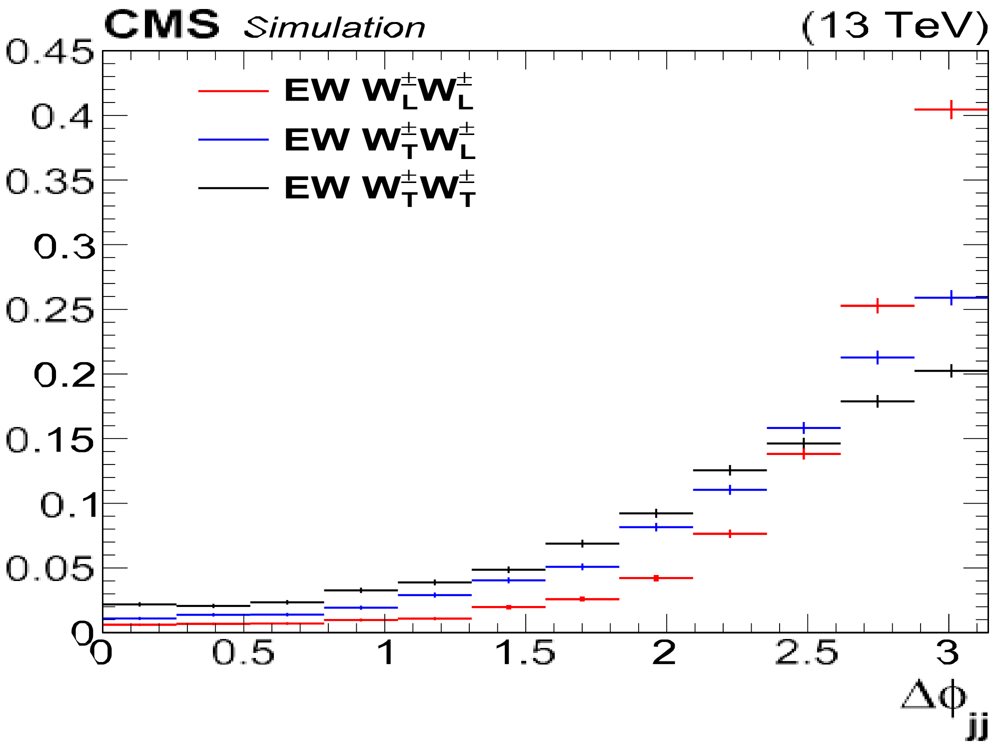
Inclusive BDT:

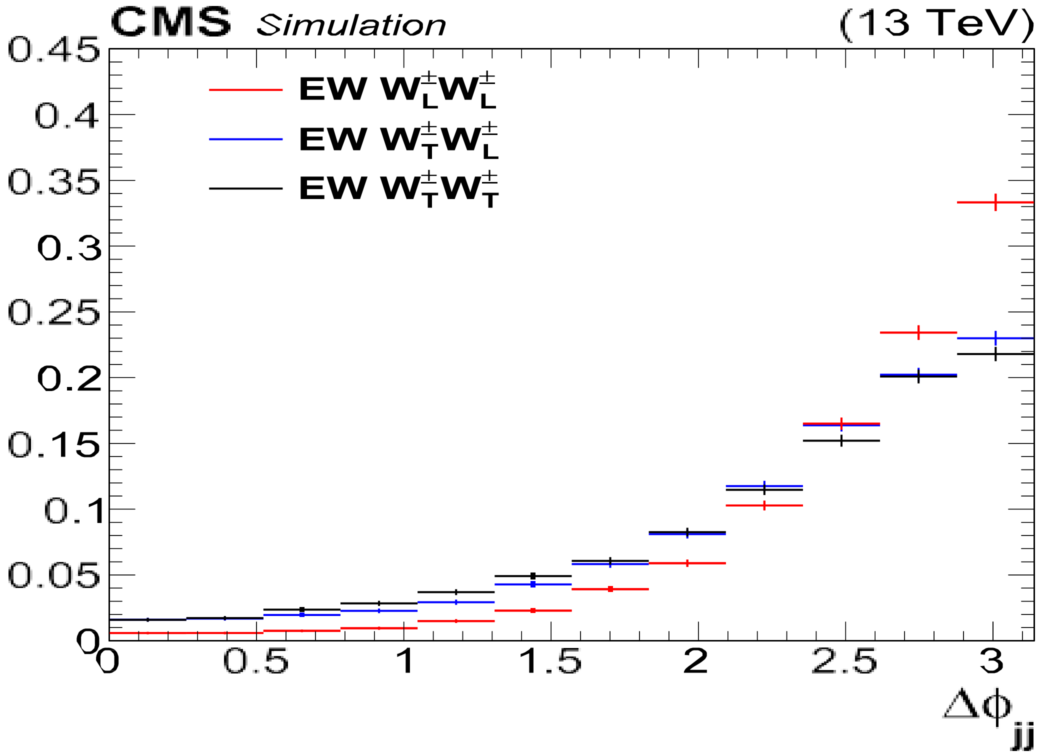
- Trained to distinguish EW $W^{\pm}W^{\pm}$ production from overall SM background processes using variables like m_{jj}, $|\Delta\eta_{jj}|$, $\Delta\varphi_{jj}$, p_T^{j1}, p_T^{j2}, p_T^{l1}, p_T^{ll}, z_{l1}^{*}, z_{l2}^{*}, p_T^{miss}.

Background Estimation

Background contributions are estimated using a combination of methods based on control samples in data and simulation. Important backgrounds include electron charge misidentification and non-prompt leptons.

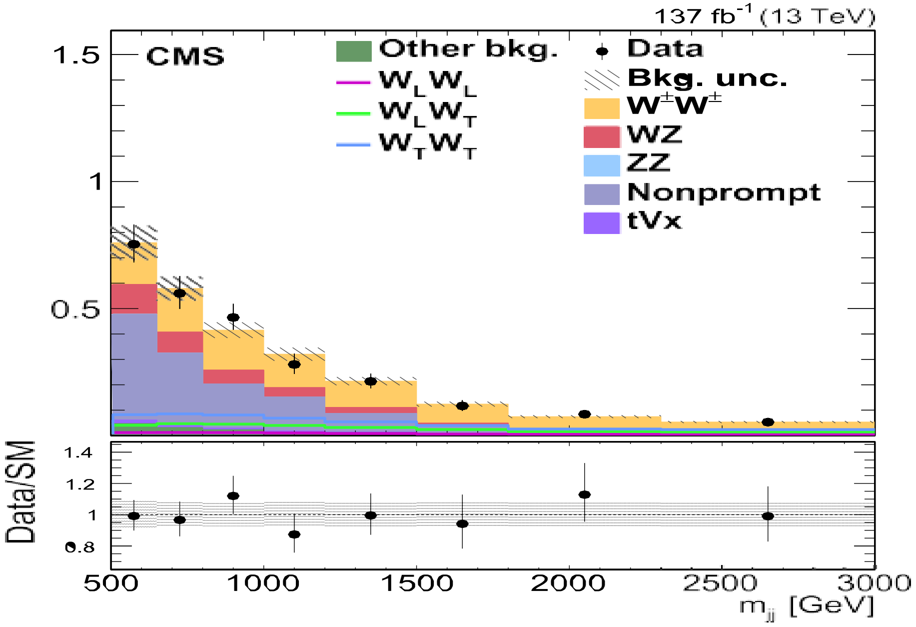
Background Estimation…

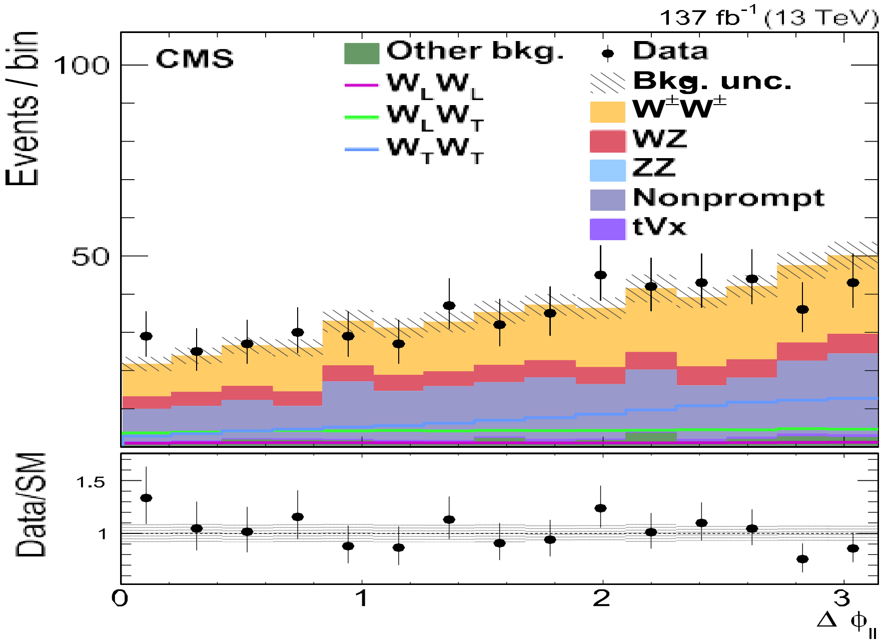




Results - Cross Section Measurements

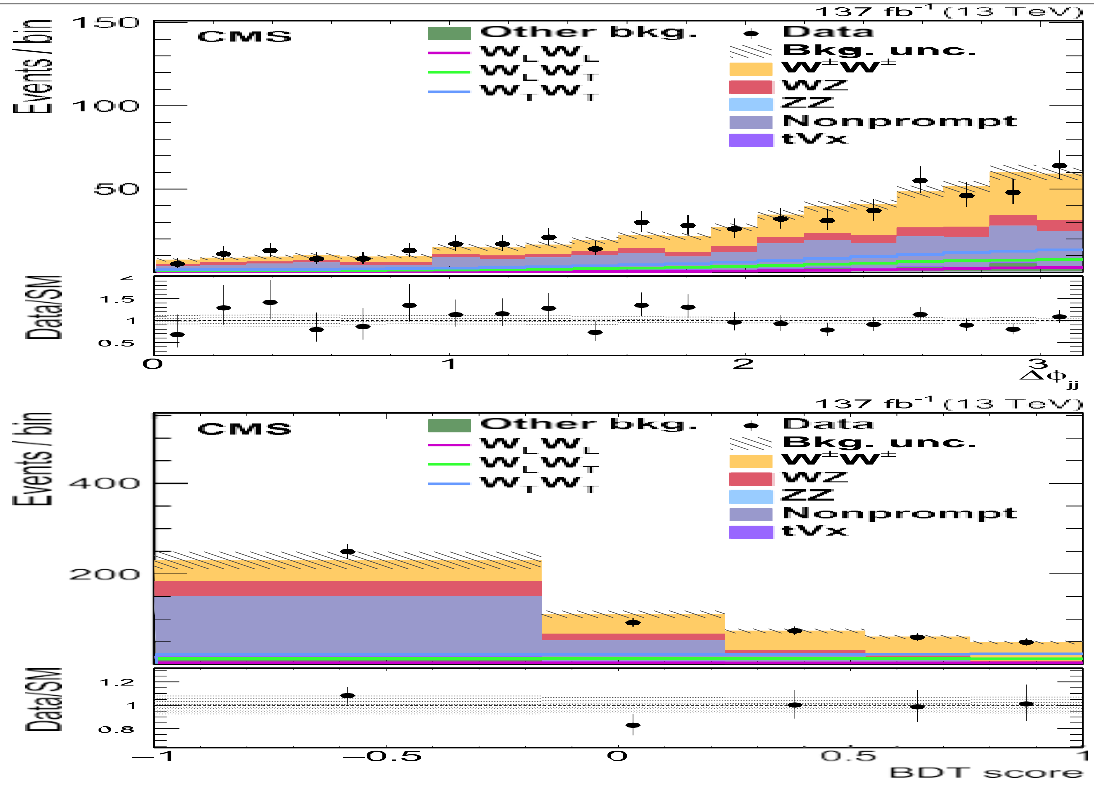
Maximum-Likelihood Fits: Binned maximum-likelihood fits are performed using the W±W± SR and the WZ, nonprompt lepton, tZq, and ZZ CRs.





Results…

2.



137 fb⁻¹ (13 TeV)
CMS
Other bkg.
Data
Bkg. unc.
$W^{\pm}W^{\pm}$
WZ
ZZ
Nonprompt
tVx
$W_L W_L$
$W_L W_T$
$W_T W_T$
Events / bin
Data/SM
$\Delta\phi_{jj}$
BDT score

Results

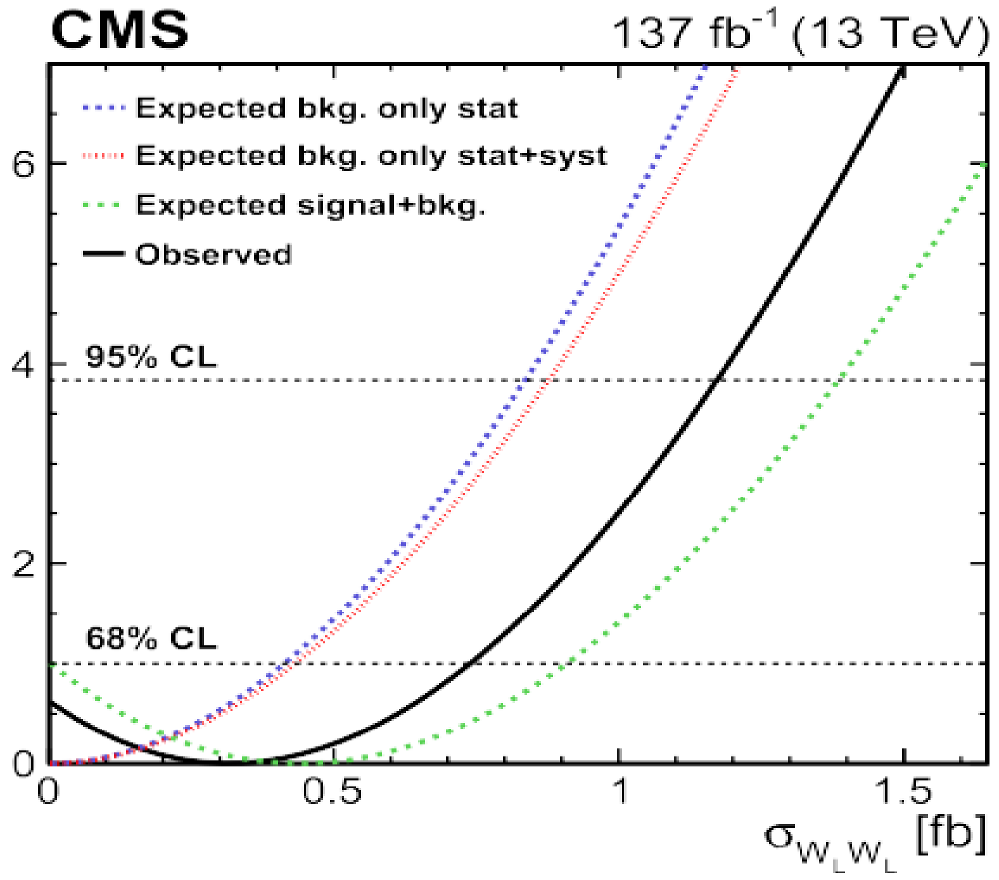
Two Separate Fits:

- Simultaneous measurement of WL±WL± and WX±WT± cross sections.
- Simultaneous measurement of WL±WX± and WT±WT± cross sections.

Observations

- Observed (expected) 95% Confidence Level upper limit on the production cross section for longitudinally polarized same-sign W±W± boson pairs (WL±WL±): 1.17 (0.88) fb.
- Electroweak production of W±W± boson pairs with at least one W boson longitudinally polarized (WL±WX±) is measured with an observed (expected) significance of 2.3 (3.1) standard deviations.

Observations…



Thank You!