Sensitivity to polarized VBS and doubly charged Higgs bosons at future hadron colliders

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FCC-hh meeting

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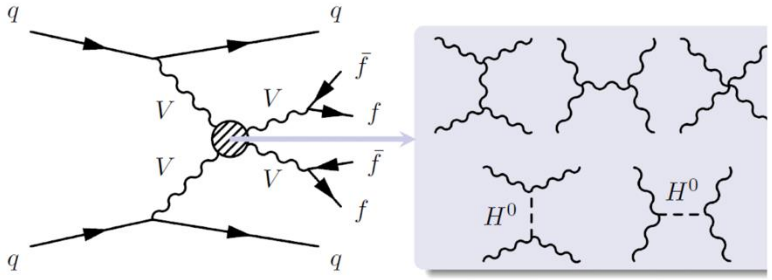
Vector Boson Scattering (VBS)

- ➔ Important measurements to fully explore electroweak symmetry breaking
  - ◆ Longitudinally polarized VBS is unitarized by the presence the SM Higgs boson
- ➔ Important window for physics beyond the Standard Model (SM)
- ➔ Our study explores the scattering of two same-sign W bosons ($W^{\pm}W^{\pm}jj$) at the FCC-hh
  - ◆ $W^{\pm}W^{\pm}jj$ has the largest electroweak to strong production cross-section ratio among VBS processes
  - ◆ Sensitive to BSM models such as the doubly charged Higgs model

- ➔ We want to test the sensitivity to all $W^{\pm}W^{\pm}jj$ polarization states at $\sqrt{s}$ = 27, 50 and 100 TeV
- ➔ Longitudinal VBS has not yet been observed at the LHC
- ➔ Projections at the HL-LHC indicate a limited possibility of observation



Polarized $W^{\pm}W^{\pm}jj$ at the LHC and HL-LHC

- Access to longitudinally polarized $W^{\pm}W^{\pm}jj$ is challenging at the LHC
  - Cross-section is very small (less than 10% of the total $W^{\pm}W^{\pm}jj$ scattering cross-section)

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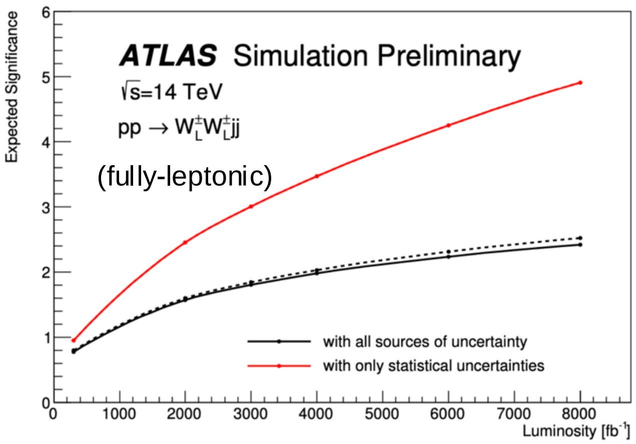

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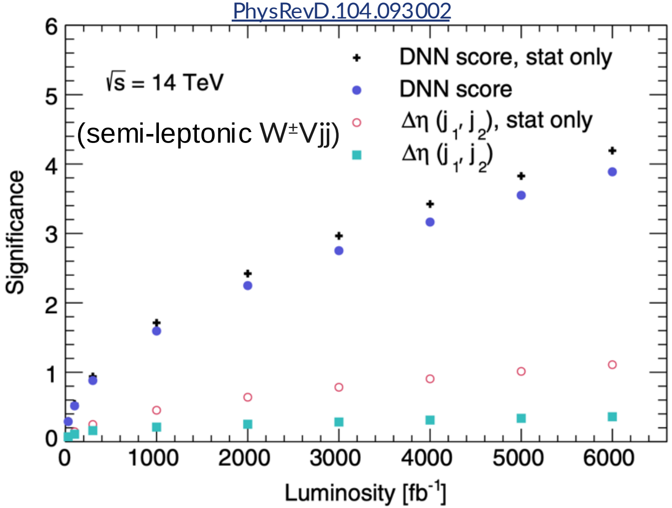


Expected significance at the HL-LHC with 3000 fb^{-1} of data is below 5σ

Polarized ssWW scattering at future hadron colliders

➔ This analysis only considers the fully-leptonic final state

➔ Provides a more detailed follow-up to a study performed for the 2021 US Snowmass process

- The expected sensitivity to longitudinal polarizations was found to be 17% for a 100 TeV FCC-hh machine

Polarization	Signal Strength		
	$\sqrt{s} = 27$ TeV	$\sqrt{s} = 50$ TeV	$\sqrt{s} = 100$ TeV
μ_{LL}	1 ± 0.39	1 ± 0.22	1 ± 0.17
μ_{LT}	1 ± 0.11	1 ± 0.10	1 ± 0.04
μ_{TT}	1 ± 0.08	1 ± 0.05	1 ± 0.02

- Boosted Decision Tree (BDT) variable to distinguish the signal NEW
- Theory uncertainties NEW
- Expected limits on doubly charged Higgs model parameters using the Georgi-Machacek (GM) model as the BSM benchmark NEW

Signal and background samples

- Both signal and background events are simulated using Madgraph5 v3.4.1 + Pythia v8.306
- Delphes is used for the simulation of detector effects
- Background processes include: $W^{\pm}W^{\pm}jj$ QCD, $W^{\pm}Zjj$ QCD, $W^{\pm}Zjj$ EW, tZq processes
  - Detector-specific background processes (charge-flip, fakes) are ignored

- These events are simulated for a 27 TeV, 50 TeV, and 100 TeV FCC-hh collider and are scaled to an expected integrated luminosity of 30 ab^{-1}
- Events for longitudinal, transverse, and mixed $W^{\pm}W^{\pm}jj$ polarization were simulated separately
  - Cross-sections were validated to ensure that they added up to the inclusive cross-section

Event selection and systematic uncertainties

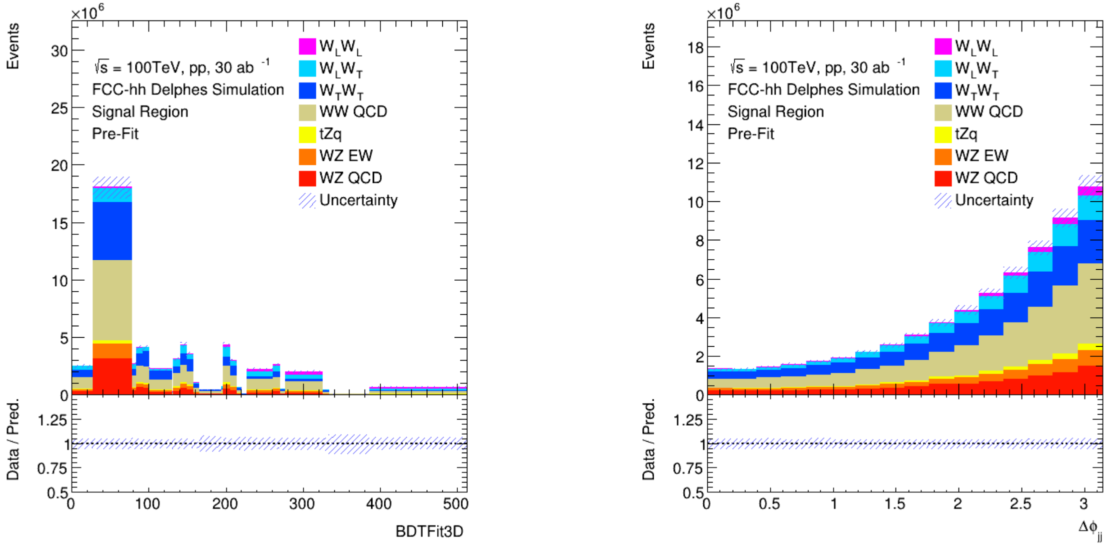
Selection type	Requirement
Number of leptons	Exactly 2 same-charge leptons
Lepton p_T	$p_T \geq 15$ GeV
Number of jets	≥ 2
Jet p_T	$p_T \geq 50$ GeV
Di-lepton invariant mass	$M_{ll} \geq 60$ GeV
$Z-$veto	$\lvert M_{ll} - M_Z \rvert > 10$ GeV
Di-jet invariant mass	$M_{jj} \geq 2$ TeV
Missing transverse momentum	$E_T^{miss} \geq 50$ GeV

- Only electrons or muons are considered

- Sources of systematic uncertainties:
  - Luminosity uncertainty (2%)
  - MC statistical uncertainties
  - PDF+α_s uncertainties
  - QCD scale uncertainties

Maximum-likelihood fit

- BDTs were trained to isolate the individual polarizations and the backgrounds
- We used a binned maximum-likelihood fit to the BDTs and the $\Delta\phi_{jj}$ distribution
- Sensitivity is determined from the uncertainty on the signal strength parameters

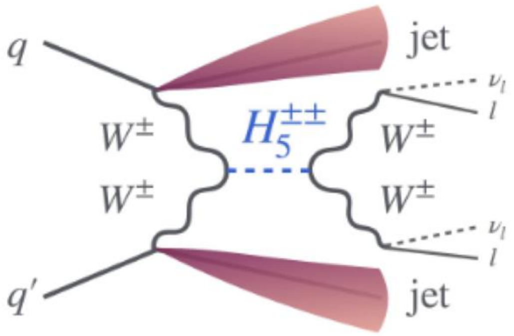


Sensitivity measurement

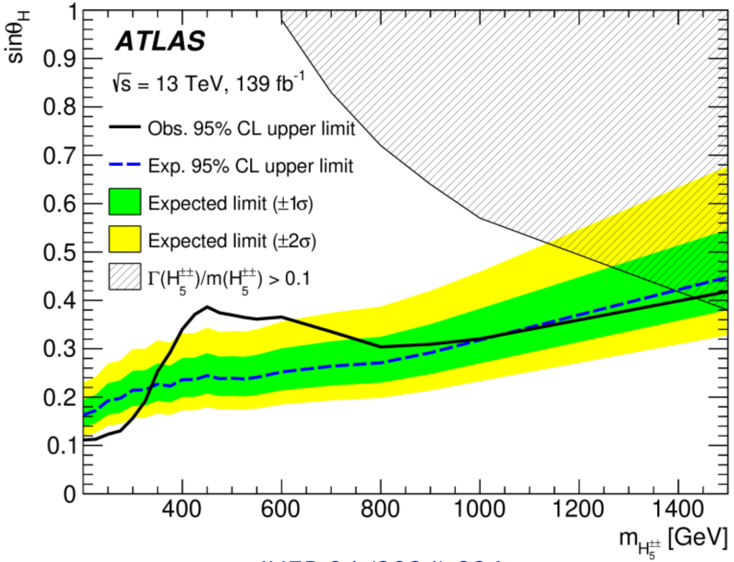
- Significantly improved sensitivity using the BDT variable
- Best sensitivity at 100 TeV
- Uncertainties are largely associated with the theory modelling
- Improved theoretical predictions may result in a better sensitivity

Polarization	Signal Strength: BDT		
	$\sqrt{s} = 27$ TeV	$\sqrt{s} = 50$ TeV	$\sqrt{s} = 100$ TeV
μ_{LL}	1 ± 0.20	1 ± 0.15	1 ± 0.13
μ_{LT}	1 ± 0.12	1 ± 0.085	1 ± 0.080
μ_{TT}	1 ± 0.12	1 ± 0.069	1 ± 0.062
	Signal Strength: $\Delta\phi_{jj}$		
μ_{LL}	1 ± 1.02	1 ± 0.62	1 ± 0.40
μ_{LT}	1 ± 0.45	1 ± 0.42	1 ± 0.14
μ_{TT}	1 ± 0.33	1 ± 0.26	1 ± 0.12

Doubly charged Higgs searches



- The [GM model](#) is a BSM model with extended Higgs sectors
  - Two isospin triplet scalar fields are added to the SM Higgs doublet
  - Scalar potential includes 5-plet states of Higgs bosons: $H_5^{\pm\pm}, H_5^{\pm}, H_5^{0}$
- ATLAS recently saw an excess of events corresponding to 2.5σ at $m_{H_5^{\pm\pm}} = 450$ GeV.
  - $\sin\theta_H > 0.11 - 0.41$ for $200 < m_{H_5^{\pm\pm}} < 1500$ GeV were excluded
- In this analysis, we only look at five $H_5^{\pm\pm}$ masses; 800, 900, 1000, 2000 and 3000 GeV



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Doubly charged Higgs searches at the FCC-hh

- We perform a binned maximum-likelihood fit to the transverse mass (m_T) distribution of the dilepton and $E_{T,miss}$ system

- We're still validating our results
- So far there are indications of better limits than those at the LHC for higher $m_{H_5^{\pm\pm}}$ values

$\sqrt{s}$	$m_{H_5^{\pm\pm}}$	$\sin\theta_H$ limit
100 TeV	900 GeV	0.15
100 TeV	2000 GeV	0.18
100 TeV	3000 GeV	0.24

Summary

- With an integrated luminosity of 30 ab^{-1} at a 100 TeV FCC-hh, we can measure the cross-section of longitudinally polarized $W^{\pm}W^{\pm}jj$ with a relative precision of 13% in the fully leptonic final state.
- The precision is largely limited by the theory modelling.
- The analysis is also progressing towards setting expected limits on doubly charged Higgs bosons in the context of the Georgi-Machacek model. We expect better limits than those set at the LHC.

Additional material

BDT and $\Delta\phi_{jj}$ post-fit distributions