

# Future perspectives for same-sign WW with DELPHES

Xavier Janssen<sup>1</sup>, Ankita Mehta<sup>2</sup>

VBSCan Meeting

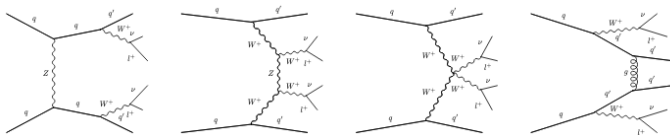
Helsinki, Finland

<sup>1</sup>Eötvös Loránd University, Budapest <sup>2</sup>University of Antwerp

February 21, 2020

# VBS with same-sign WW

- ssWW produced in association with two jets via the EW interaction
- Same-sign lepton events  $\rightarrow$  reduces contribution from strong production of WW  $\rightarrow$  clean experimental signature



## Longitudinal WW scattering

- VBS scattering amplitude dominated by transverse gauge components
- An excess of events w.r.t. SM expectation in the longitudinally polarized channel would point to new interactions in EWSB sector
- Projection studies performed by ATLAS & CMS for the HL-LHC scenario for same-sign WW & WZ channels

- Same-sign  $W^\pm W^\pm \rightarrow e^\pm \mu^\pm$  events simulated using PHANTOM (version 1\_5\_1\_b) event generator
- Both W bosons polarized  $\rightarrow$  three possible final state configurations: **LT+TL**, **TT**, & **LL**  $\rightarrow$  **based on OSP scheme applied to both bosons**
- Events are hadronized using PYTHIA 8 CUETP8M1 tune
- Hadronized events are processed with DELPHES fastsim package to model CMS detector response corresponding to LHC Run-II operations
- VBS-sensitive observables are compared for the three boson polarization states at generator level & post-fastsim
- A BDT classifier is trained using a set of VBS-sensitive variables
- A maximum-likelihood fit is performed on the shape of the BDT classifier to extract the expected significance for the LL final state

## Selection cuts

- Leptons:  $p_T > 20$  GeV,  $|\eta| < 2.5$ ,  $\Delta R(\text{lep,lep}) > 0.3$  &  $m_{ll} > 200$  GeV
- $p_T^{\text{miss}} > 40$  GeV
- Jets:  $p_T > 30$  GeV,  $|\eta| < 4.5$ ,  $\Delta R(\text{jet,jet}) > 2.5$  &  $m_{jj} > 500$  GeV
- $\Delta R(\text{jet,lep}) > 0.3$

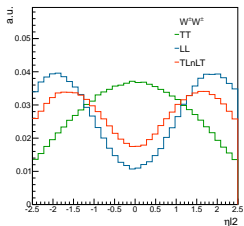
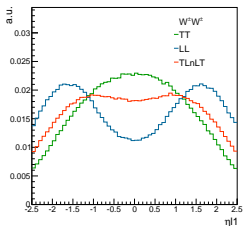
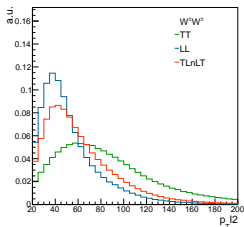
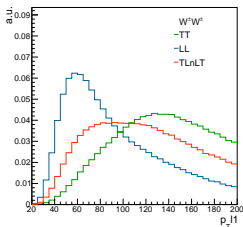
**cross section values for different categories for two W boson charge configurations**

final state	Cross section (fb)	
	$W^+W^+jj$	$W^-W^-jj$
TL/LT	0.168	0.052
LL	0.048	0.015
TT	0.575	0.177

**TT configuration has the largest production cross section**

# Lepton kinematic distributions: Generator-level -I

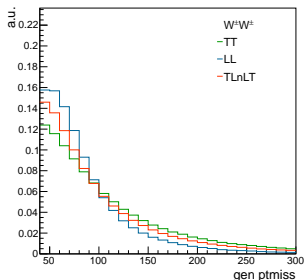
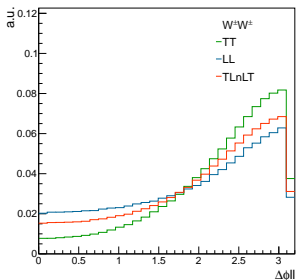
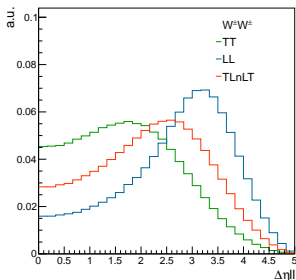
- comparisons based on the LHE-level information
- lepton collections merged and then  $p_T$ -ordered;  $p_T^{\text{miss}}$  from neutrinos



- Softer  $p_T$  spectrum for leptons from longitudinally polarized W bosons
- Leptons in the central regions from transverse polarized W bosons

# Lepton kinematic distributions: Generator-level-II

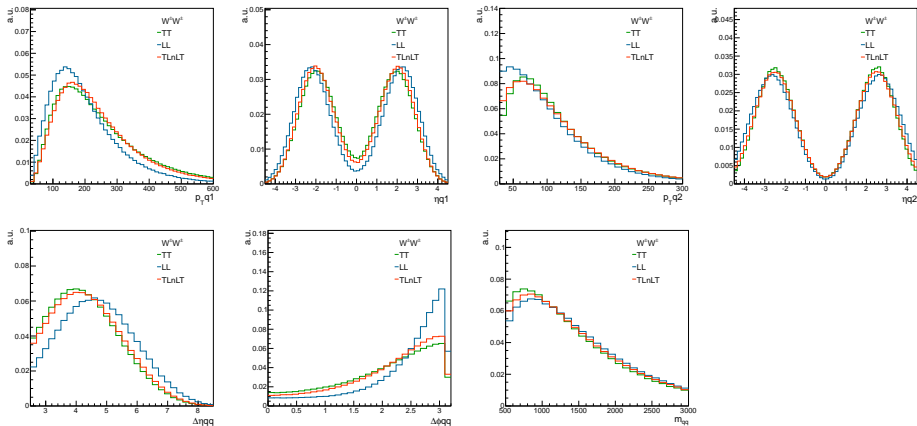
- Dilepton angular observables  $\rightarrow$  sensitive to W polarization
- $\eta$ -difference between the two leading leptons ( $\Delta\eta_{ll}$ )
- Azimuthal angular separation between the two leptons  $\Delta\phi_{ll}$



- $\Delta\eta_{ll}$  looks quite sensitive to boson polarizations
- Somewhat softer  $p_{\text{T}}^{\text{miss}}$  spectrum for the LL configuration

# Jet kinematic distributions: Generator-level

- Leading and subleading jet kinematics & dijet angular variables



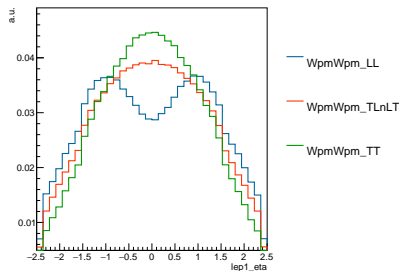
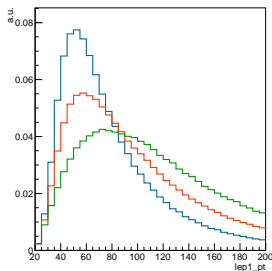
- Softer  $p_T$  spectrum of the two-leading jets for the LL configuration
- $\Delta\phi_{qq}$  looks most-sensitive to boson polarizations

# Reconstructed lepton & $p_T^{\text{miss}}$ distributions-I

DELPHES to simulate CMS detector response corresponding to LHC Run-II  
Check sensitivity of the variables after detector reconstruction step

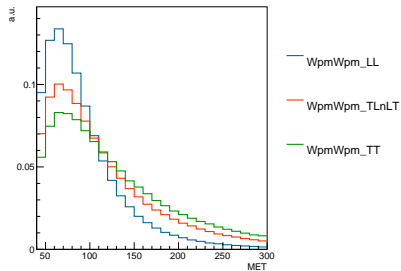
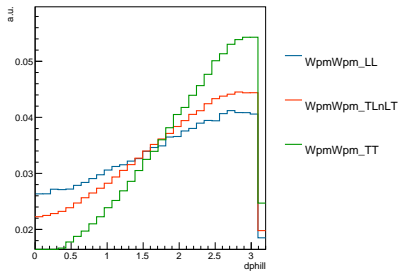
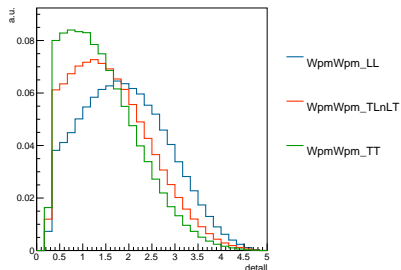
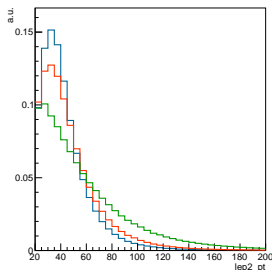
## Selection cuts (CMS-PAS-SMP-14-008)

- $p_T^l > 20$  GeV,  $|\eta^l| < 2.5$  &  $\Delta R(ll) > 0.3$ ;  $p_T^{\text{miss}} > 40$  GeV
- At least 2 jets with  $p_T > 30$  GeV &  $|\eta| < 4.5$ ;  $m_{jj} > 500$  GeV &  $\Delta\eta_{jj} > 2.5$
- $\Delta R(ll, \text{jet}) < 6.0$





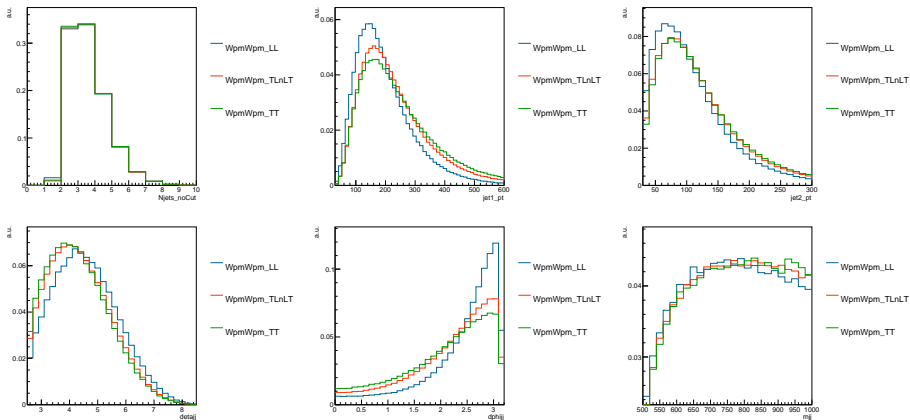
# Reconstructed lepton & $p_T^{\text{miss}}$ distributions-II



All distributions look compatible with generator-level observations

# Reconstructed jet distributions-I

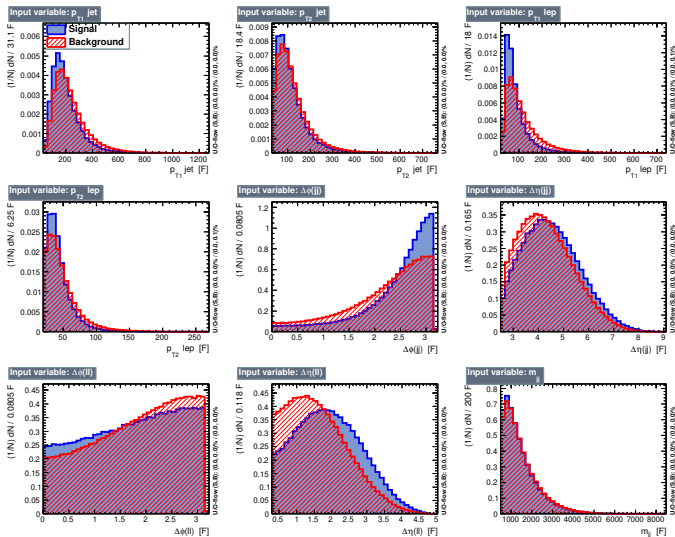
## Inclusive jet multiplicity & jet kinematics



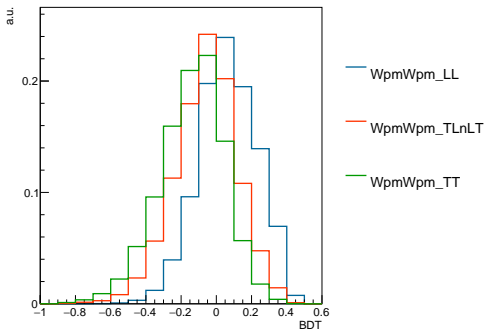
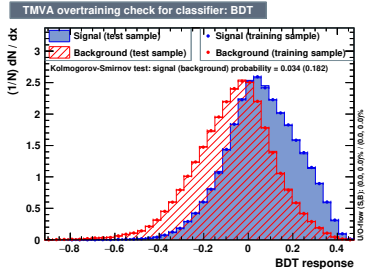
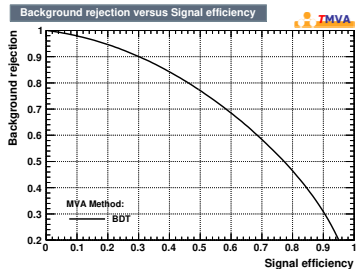
All distributions look compatible with generator-level observations

# BDT classifier training

- BDT is trained with LL as signal against TT & TL/LT backgrounds
- Input variables consist of lepton & jet variables



# BDT classifier output



# Results: ML fit on asimov dataset

- Results with full Run-II luminosity ( $153 \text{ fb}^{-1}$ )
  - Added systematic & statistical uncertainties CMS-PAS-SMP-14-008
  - ML fit on the shape of  $\Delta\phi_{jj} \rightarrow$  expected significance of  $0.39\sigma$
  - ML fit on the shape of BDT classifier  $\rightarrow$  expected significance of  $0.6\sigma$
- used uncertainty structure; also includes bin-by-bin statistical uncertainty

```
##-----  
bin  
process          vbsWW  vbsWW  vbsWW  
                 LL    TlnLT  TT  
process          0      1      2  
rate             -1     -1     -1  
-----  
lumi_13TeV      lnN    1.023  1.023  1.023  
jer             lnN    1.05   1.05   1.05  
jes             lnN    1.03   1.03   1.03  
lepE            lnN    1.02   1.02   1.02  
sigAcc          lnN    1.02   1.02   1.02  
muES            lnN    1.01   1.01   1.01  
muER            lnN    1.01   1.01   1.01  
eLES            lnN    1.01   1.01   1.01  
eLER            lnN    1.01   1.01   1.01  
qcd_LL          lnN    1.03   -       -  
pdf_LL          lnN    1.07   -       -  
qcd_TlnLT      lnN    -       1.03   -  
pdf_TlnLT      lnN    -       1.07   -  
qcd_TT         lnN    -       -       -  
pdf_TT         lnN    -       -       -
```

- Performed some polarization studies using OSP machinery from phantom event generator for same-sign WW events
- Generated events are hadronized & showered using PYTHIA 8 & passed to DELPHES fast simulation package
- Results based on LHC Run-II scenario
- Kinematic distributions show sensitivity towards W boson polarisations even after reconstruction
- Deep machine learning tools or an improved BDT training could be used to enhance sensitivity

extras...

# W boson kinematics: Generator level

