Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

UNIVERSITÀ
DEGLI STUDI
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Summary of the VBS Polarization Workshop

Laboratoire Leprince-Ringuet, Palaiseau, 10-12 October 2018

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VBS and the importance of "being polarized"

Importance of studying the phenomenology of polarized VBS at the LHC
(talk by D. Zeppenfeld and A. Ballestrero)

- both for SM and BSM/new physics searches
  ("NP can be just around the corner (a few TeV)", cit. J.J. Sanz-Cillero)
- gives direct access to EWSB mechanism, hopefully in a model indep. way

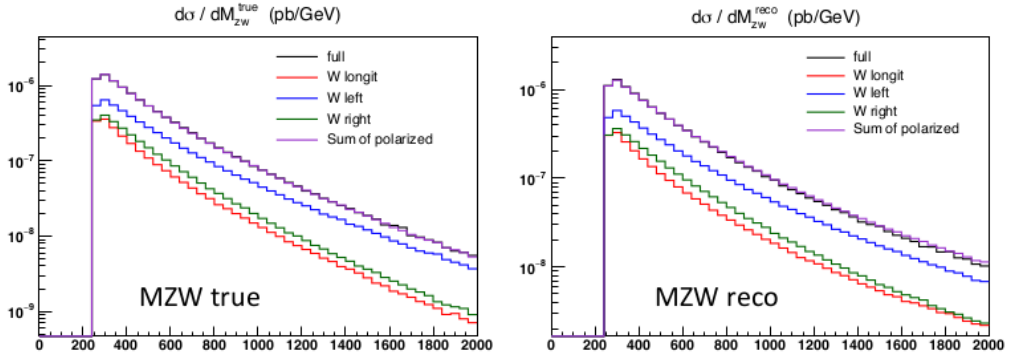
What do we need?

- to be as realistic as possible (leptonic cuts, reconstruction, ...)
- to be as precise as possible (interferences, NLO, ...)
- to exploit the best analysis and experimental techniques
- to take advantage of methods employed for similar processes ($t\bar{t}$, diboson, ...)
- to find discriminating variables to disentangle longit/transv

Phenomenological studies

E. Maina talk: polarized VBS within SM and beyond

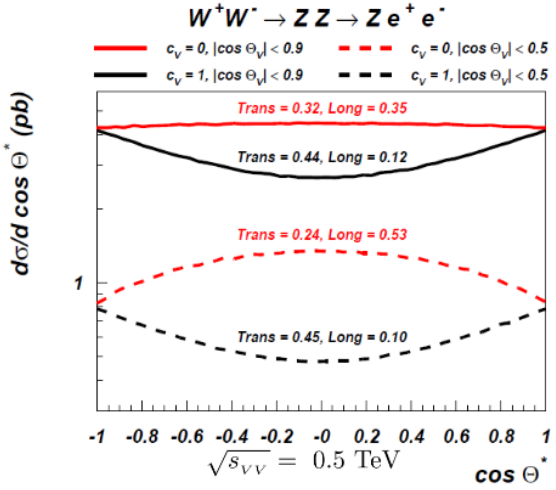
LO EW $\mathcal{O}(\alpha^6)$ with PHANTOM for polarized W^+W^+, W^+W^-, W^+Z, ZZ (fully lept.)
$\rightarrow$ found good prescription for (singly) polarized signals, OS projections:
$\sum_\lambda d\sigma_{\mathrm{pol.}\lambda}/dX \approx d\sigma_{\mathrm{full}}/dX$ at % level accuracy



going more and more realistic:

$\rightarrow$ ν reconstruction
$\rightarrow$ small longitudinal
LHC@13TeV: hard to pick it out of the total cross-section

A. Belyaev talk: LH13 report on new physics searches



Longitudinal/transverse component and sensitivity to c_V (HVV anomalous coupling). Model-independence.

$\theta_V, \theta^*_\ell, \sqrt{s_{VV}}$ variables: defined at a VV scattering level
$\rightarrow$ extension of the definition of such variables to $pp \rightarrow jjVV$.
So far ZZ investigated, but extensions to WZ and other relevant channels expected.

Status of Monte Carlo generators: polarized predictions

Not all generators full *spin matrix density* $\rho_{\lambda\lambda'}$ and off-shell effects (approx.: diagonal $\rho_{\lambda\lambda'}$, NWA, production $\times$ decay, BW smearing ..., see talk by C. Bittrich)
Usually in experiments reweighting employed to produce samples with definite pol.
More accurate predictions needed.

$\rightarrow$ MADGRAPH (M. Zaro): no effort in polarization studies so far. `MADSPIN` packages: spin correl. preserved, BW smearing. Generation of polarised on-shell V possible, polarised off-shell V cumbersome. Alternatively: `DECAY` package (old releases only).

$\rightarrow$ POWHEG (A. Karlberg): VBF/VBS processes (fully leptonic) up to NLO QCD accuracy, with PS matching. Polarization separation not implemented.

$\rightarrow$ VBFNLO (D. Zeppenfeld): provides a handle for pol. separation: pol. distributions not available, but (in principle) feasible for fully leptonic (LO, NLO QCD).

$\rightarrow$ WHIZARD (J. Reuter): full spin density matrix, SMEFT & simplif. models implemented. Polarized on-shell V bosons (NWA only, cascade decay): implemented.

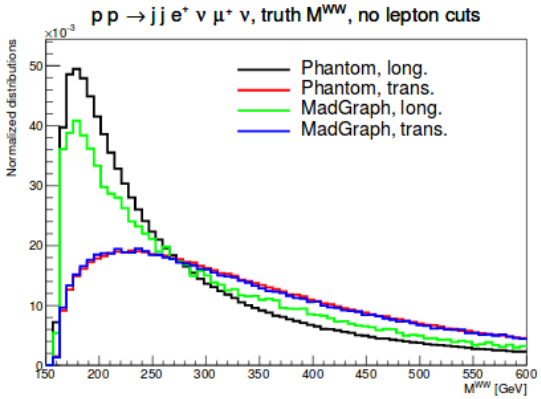
$\rightarrow$ PHANTOM (E. Maina, A. Ballestrero): capable of simulating polarized samples for any VBS process, at LO EW (extension to QCD amp. expected). All spin correl., off-shell effects (OSP). Polarizations defined in the lab. frame.

* for WZ scattering: `WZDECAY` (by C. Bittrich), generator indep. tool to decay V bosons with definite pol. (in NWA).

Status of Monte Carlo generators: first comparisons

J. Novak's talk

`PHANTOM` vs `MadGraph-MADSPIN` comparison for polarized processes: discrepancies arise. Due to different ways of treating spin-correlations? Preliminary work (Jakob): still to investigate.

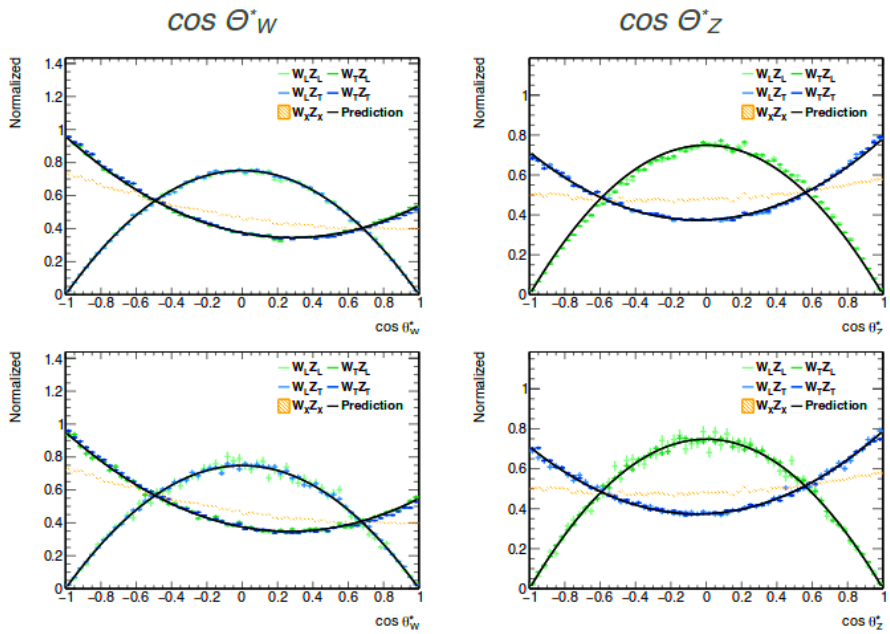


Talk by C. Bittrich

comparison of NWA-`WDECAY` and rewighting methods for normalize polarized templates.

Reweighting:

WZdecay:



EFT and BSM studies

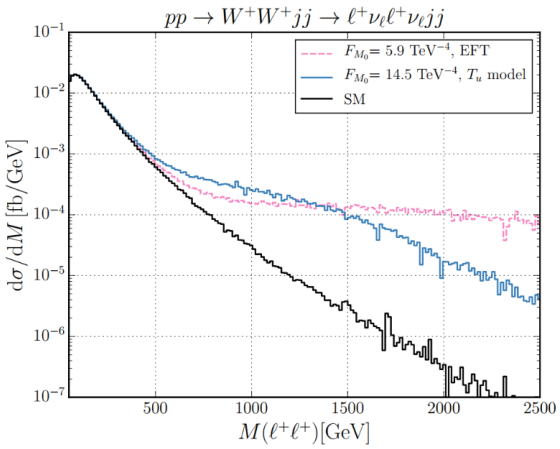
EFT approach:

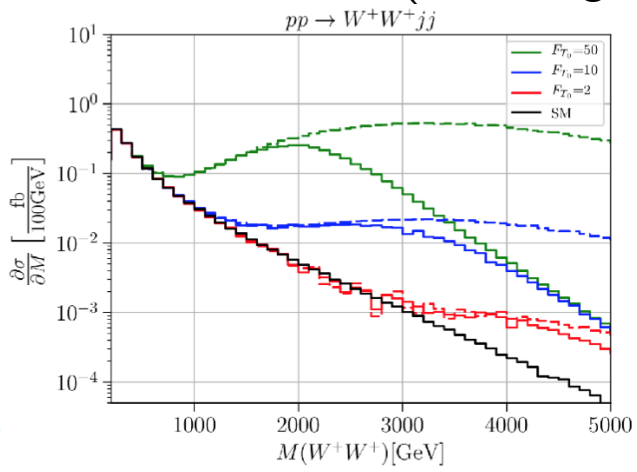
$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \left[\frac{c_i^{(5)}}{\Lambda} \mathcal{O}_i^{(5)} + \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \frac{c_i^{(7)}}{\Lambda^3} \mathcal{O}_i^{(7)} + \frac{c_i^{(8)}}{\Lambda^4} \mathcal{O}_i^{(8)} + \cdots \right]$$

Much interest for BSM in the th. community (talks by D. Zeppenfeld & J. Reuter)

- $dim = 6$ not enough for parameterizing helicity structure of VBS $\rightarrow$ $dim = 8$)
- operators for longit.-longit., mixed and transverse pol.
- unitarization needed (K-matrix,. . .)

Remark: more space for new physics in transverse modes (than longit.)



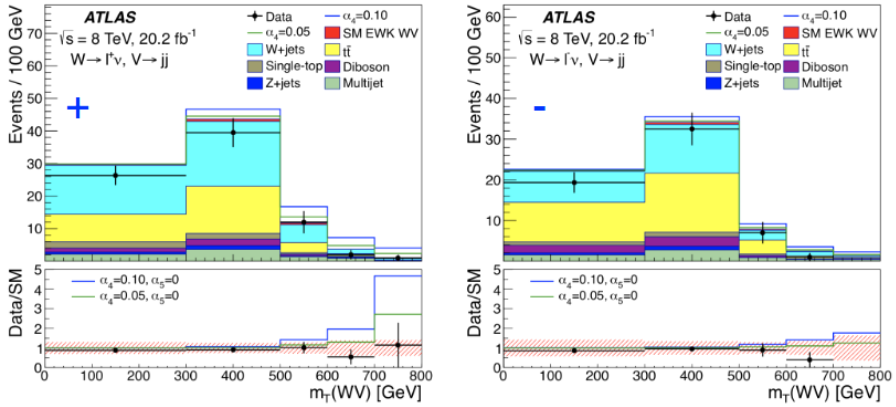


EW$\chi\mathcal{L}$ and chiral expansion (talk by J.J. Sanz-Cillero):
EFT non-linear representation for "SM + something else". What happens when adding new resonances? $\rightarrow$ VBS, DY diboson production.

Status of VBS experimental analyses and measurements

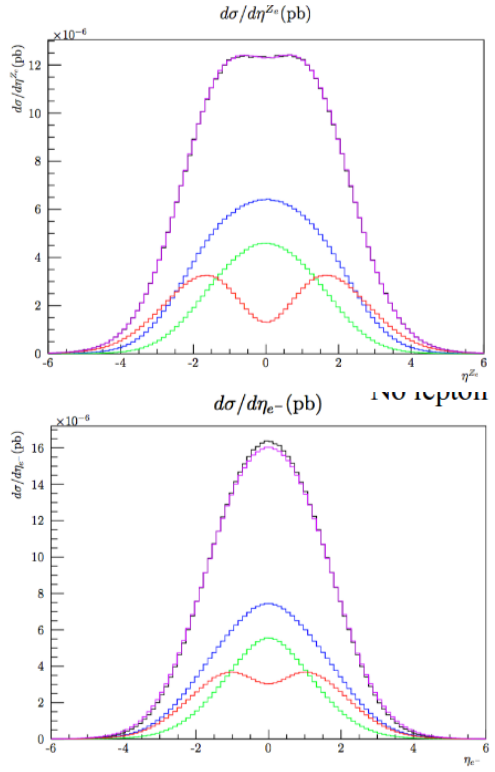
A. Apyan talk: semileptonic, $pp \to jjjj\ell\nu$.

- boosted W/Z tagging, with a merged jet
- pile-up mitgation needed (rapidly improving)
- W+jets and top bkg, see ATLAS 8 TeV
- hard to disentangle WW and WZ
- techniques for jet substructure (being developed)
- no polarization study so far



C. Charlot talk: ZZ scattering in $pp \to jj\ell^+\ell^-\ell'^+\ell'^-$

- good prospects in spite of low cross rate: precise reco of the final state, low red. bkg.
- irreducible QCD bkg description (*e.g.* $gg \to ZZgg$, large th. unc. @ LO+PS)
- First simulations for polarized (singly and doubly) cross-sections in ZZ, simulated with `PHANTOM`
- forward acceptance for $Z_{\rm long}Z_{\rm long}$ (increased sensitivity): to be considered at HL-LHC.

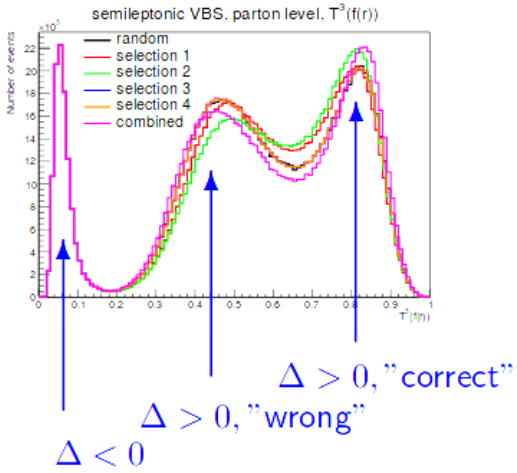


W bosons reconstruction

Discussion of different reco techniques needed: **no a priori selection criterium given**.

J. Novak's talk: tried various reconstruction methods for WW in semi and fully leptonic channel. Efficiency evaluated ($p_z^\nu(reco)/p_z^\nu(true)$).

Processes with one only neutrino ($pp \to jjjj\ell\nu$):
Ljubljana variable, to visualize the whole range of reco relative error.
Fair results, need to find an optimal selection for VBS events.



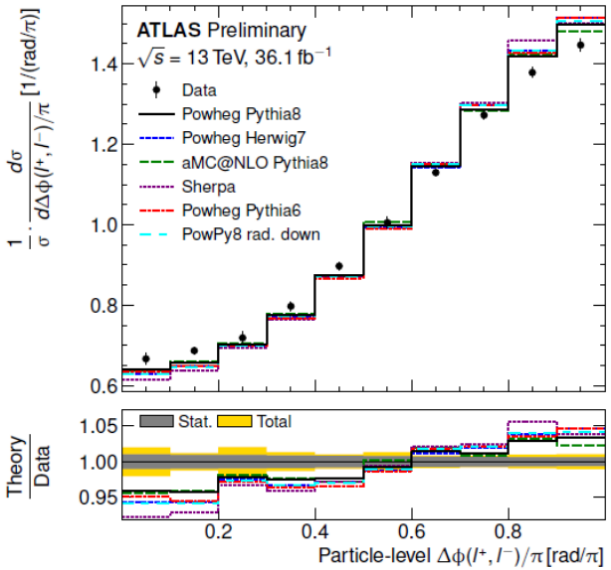
Processes with 2 neutrinos ($pp \to jj\ell'\nu'\ell\nu$): based on MAOS reconstruction, different effects on different polarizations: to be improved. Still much work to do here.

C. Bittrich's talk: proposed ν reco in WZ scattering (ATLAS): min ($\mathrm{Re}\ p_z^\nu$).

Beyond VBS

Top studies (single-t, $t\bar{t}$), talk by M. Komm:

- Many polarization/spin-related available in $t\bar{t}$/single-t events
- W helicity in decays, single t polarization, structure of tWb coupling etc.
- tantalizing result in ATLAS ttbar spin correlation



Diboson production talk by E. Sauvan:
polarizations in inclusive WZ diboson prod. (ATLAS 2018).
Agreement of pol. fractions (defined in the WZ CoM system) with SM predictions (NLO+PS, NNLO), possible effects of EW corrections $\rightarrow$ extension to $jjWZ$

VBF Higgs talk by M. Slawinska:
s-channel Higgs only, Higgs rest frame.
Preliminary results for HVV coupling modifications in VBF.
Aim: polarized VV from the H decay.

Talk by A. Belyaev: th. predictions for triple Higgs production in VBF: very sensitive to HVV deviations (at 100 TeV). SM Large unitarity cancellations $\rightarrow$ NP searches.

Outlook

Starting point for collaboration among different groups (TH & EXP)

Interest in polarization is rapidly increasing

More discussion needed:

- polarized signals in Monte Carlo generators:
  different approx., polarized samples at LO, going NLO QCD (and EW)
- ν reconstruction:
  hard work, of primary importance at the LHC
- common targets for VBSCan:
  further discussions after this meeting, future joint work
- further investigation of all fully leptonic channels in VBS/VBF
- polarizations in semileptonic channel:
  MC simulation, data analysis and experimental techniques
- more work on the description of VBS bkg's (t, QCD, ...)

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the speakers
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all the participants

Stay tuned!