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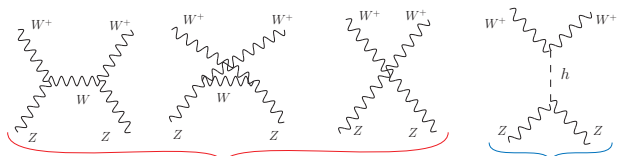
# Polarized Weak Bosons in VBS at the LHC

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## Gauge/unitarity cancellations in scattering of on-shell longitudinal weak bosons



The diagrams illustrate the scattering of two on-shell longitudinal weak bosons,  $W^+$ , into two  $Z$  bosons. The first three diagrams represent contact and  $s$ -channel  $W$  exchange, which are grouped by a red bracket. The fourth diagram represents  $t$ -channel  $h$  exchange, grouped by a blue bracket.

$$-\frac{s}{v^2}(1 - \cos \theta) + \frac{s}{v^2}(1 - \cos \theta)$$

- ▶ Longitudinal cross section depends on the specific realization of **ElectroWeak Symmetry Breaking** mechanism (EWSB).
- ▶ New physics/new resonances could interfere with the SM: **ideal process where to search for BSM effects**.

Important to provide accurate theory predictions for polarized VBS, to be used in LHC experimental analyses.

## ► Other production mechanisms:

Theory studies on polarized  $W$  and  $Z$  bosons at the LHC in different SM production mechanisms:  $V$ +jets [Bern et al. 1103.5445, Stirling et al. 1204.6427], diboson, single- $t$ ,  $t\bar{t}$ ,  $VH$  [Stirling et al. 1204.6427].

Interference and leptonic cuts effects investigated in [Stirling et al. 1204.6427, Belyaev et al. 1303.3297].

More recent studies on polarization observables, mainly for diboson [Aguilar-S. et al. 1508.04592, Baglio et al. 1810.11034].

## ► Specific for VBS:

Polarized signals and lepton cuts effects in fully lept. VBS with SM dynamics [Doroba et al. 1201.2768, Stirling et al. 1204.6427, Ballestrero et al. 1710.09339, 1907.04722]

Studies on polarized bosons produced in VBS with BSM dynamics [Han et al. 0911.3656, Brass et al. 1807.02512, Ballestrero et al. 1710.09339, 1907.04722].

Determining pol. fractions with machine learning techniques [Searcy et al. 1510.01691, Lee et al. 1812.07591, 1908.05196].

- ▷ Many (approximated) methods to treat spin correlations and off shell effects relative to weak bosons.
- ▷ Increasing interest in polarized VBS is pushing forward the separation of polarized signals in available Monte Carlo tools.

**MG5\_aMC@NLO** Generation of polarized on shell  $V$  possible (up to NLO+PS) in SM and several BSM models. Spin correlated decays computed with MadSpin package or via decay chain (NWA). On going work [talk by Barque F., VBScan @ Istanbul 2019].

**WHIZARD** Simulation of polarized on shell  $V$  bosons possible (NWA, cascade decay) [talk by Reuter, VBScan Polarization Workshop @ LLR 2018], within SM or SMEFT.

**PHANTOM** Generation of polarized  $V$  bosons in  $2 \rightarrow 6$  processes, including all spin correl. and off shell effects (OSP) possible at LO EW signal in SM, Higgsless and Singlet Extension. Foreseen extension to QCD bkg at LO (Ballestrero et al.).

**WZDECAY** Generator independent package for decaying polarized  $V$ 's in NWA (only for WZ scattering) [talk by Bittrich, VBScan Polarization Workshop @ LLR 2018].

VBS measured with LHC@13TeV data in  $W^\pm W^\pm$  [CMS 1709.05822, ATLAS 1906.03203],  $W^\pm Z$  [ATLAS 1812.09740, CMS 1901.04060] and  $ZZ$  [CMS 1708.02812], with fully leptonic decays. Measured also in the semileptonic channel [CMS 1905.07445, ATLAS 1905.07714].

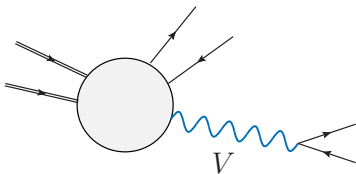
Polarization measurements with LHC@8TeV data in  $W + \text{jets}$  [ATLAS 1203.2165, CMS 1104.3829],  $Z + \text{jets}$  [CMS 1504.03512, ATLAS 1606.00689] and  $t\bar{t}$  [CMS 1605.09047, ATLAS 1612.02577].

Measured boson polarizations in  $WZ$  [ATLAS 1902.05759] with LHC@13TeV data.

No polarization measurements in VBS yet, but work in progress.

# Polarizations of $W$ and $Z$ bosons

A **natural** definition for resonant diagrams, in the unitary gauge.



$$\begin{aligned}
 \mathcal{A}^{\text{unpol}} &= \mathcal{P}_\mu \frac{-g^{\mu\nu} + k^\mu k^\nu / M_V^2}{k^2 - M_V^2 + iM_V \Gamma_V} \mathcal{D}_\nu \\
 &= \mathcal{P}_\mu \frac{\sum_{\lambda'} \epsilon_{\lambda'}^\mu \epsilon_{\lambda'}^{*\nu}}{k^2 - M_V^2 + iM_V \Gamma_V} \mathcal{D}_\nu \\
 &\rightarrow \mathcal{P}_\mu \frac{\epsilon_\lambda^\mu \epsilon_\lambda^{*\nu}}{k^2 - M_V^2 + iM_V \Gamma_V} \mathcal{D}_\nu = \mathcal{A}_\lambda
 \end{aligned}$$

At the cross section level,

$$|\mathcal{A}^{\text{unpol}}|^2 = \underbrace{\sum_{\lambda} |\mathcal{A}_\lambda|^2}_{\text{incoherent sum}} + \underbrace{\sum_{\lambda \neq \lambda'} \mathcal{A}_\lambda^* \mathcal{A}_{\lambda'}}_{\text{interference terms}} \rightarrow |\mathcal{A}_\lambda|^2 \propto \text{polarized cross section}$$

If **no lepton cuts applied**, interferences vanish (integration over full lepton azimuth  $\phi$ ):

$$\frac{1}{\sigma} \frac{d\sigma}{d \cos \theta} = \frac{3}{8} f_L \left( 1 + \cos^2 \theta - \frac{2(c_L^2 - c_R^2)}{(c_L^2 + c_R^2)} \cos \theta \right) + \frac{3}{8} f_R \left( 1 + \cos^2 \theta + \frac{2(c_L^2 - c_R^2)}{(c_L^2 - c_R^2)} \cos \theta \right) + \frac{3}{4} f_0 \sin^2 \theta,$$

$c_R$  and  $c_L$  couplings  $Vf\bar{f}$ ,  $\theta$  antifermion angle in the  $W^+/Z$  rest frame, w.r.t. the boson direction in the lab.  $f_0, f_L, f_R$ : pol. fractions that sum to 1.

If **lepton cuts applied**, analytic expression for  $d\sigma/d \cos \theta$  doesn't hold anymore:  
interferences don't vanish (cannot integrate over the full  $\phi$  range).

In VBS, at LO EW,  $\mathcal{O}(\alpha^6)$ :

many diagrams cannot be interpreted as *production*  $\otimes$  *propagator*  $\otimes$  *decay* of a  $W/Z$ .

Needed for gauge invariance, but for them impossible to separate polarizations.

Strategy:

1. select only resonant contributions;
2. apply On Shell proj. and/or invariant mass cuts on decay prod. around  $M_{W/Z}$ ;
3. separate polarizations in the propagators and square the amplitude.

Parton level studies with PHANTOM MC (LO EW) in the fully leptonic channel:

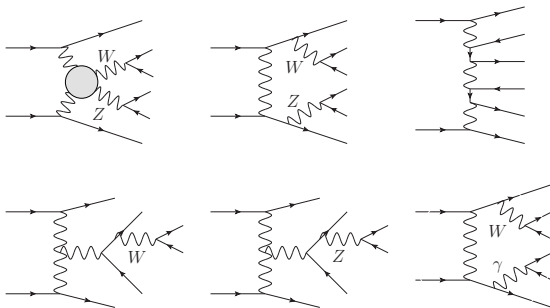
- ▷  $W^+W^-: pp \rightarrow jj \mu^+ \nu_\mu e^- \bar{\nu}_e$  [Ballestrero, Maina, GP, 1710.09339]
- ▷  $W^+W^+: pp \rightarrow jj \mu^+ \nu_\mu e^+ \nu_e$
- ▷  $ZZ: pp \rightarrow jj \mu^+ \mu^- e^+ e^-$  [Ballestrero, Maina, GP, 1907.04722]
- ▷  $W^+Z: pp \rightarrow jj \mu^+ \nu_\mu e^+ e^-$  [Ballestrero, Maina, GP, 1907.04722]

This talk. Including lepton cuts and neutrino reconstruction effects.

Focus on single polarized signals, but easy to extend to double polarized.

## WZ: setup and separation of resonant contributions

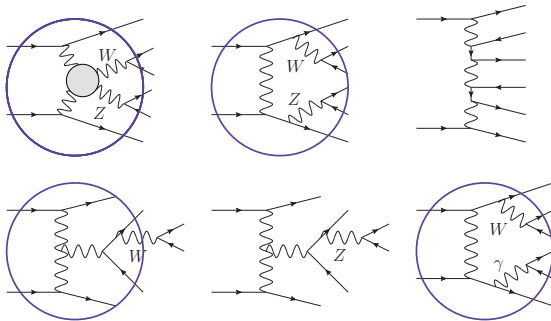
Tree-level contributions at  $\mathcal{O}(\alpha^6)$ :





# WZ: setup and separation of resonant contributions

Tree-level contributions at  $\mathcal{O}(\alpha^6)$ :



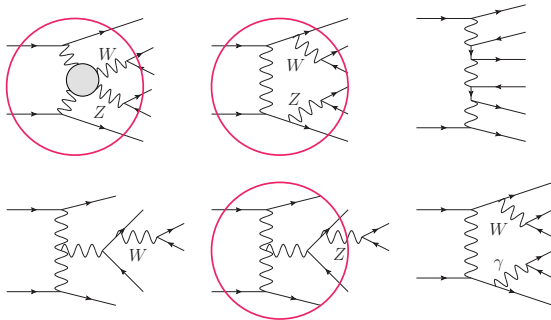
For  $W$  polarization, select  $W$ -res. diagrams, perform a single on shell proj. (OSP1) on the  $W$  to recover (partially) EW gauge invariance.

**No cut needed on  $|M_{\ell\nu\ell} - M_W|$ , thanks to OSP1.**

**We impose a tight cut on  $|M_{e^+e^-} - M_Z|$ , in coherence with what follows.**

# WZ: setup and separation of resonant contributions

Tree-level contributions at  $\mathcal{O}(\alpha^6)$ :



For Z polarization, select Z-res. diagrams, perform a single on shell proj. (OSP1) on the Z to recover (partially) EW gauge invariance  $\rightarrow$  not enough!.

**Required a tight cut on  $|M_{e^+e^-} - M_Z|$ , due to  $\gamma/Z$  mixing in SM.**

**No cut needed on  $|M_{\ell\nu\ell} - M_W|$ .**

## WZ: setup and unpolarized results

**Setup:**  $M_{jj} > 500$  GeV,  $|\Delta\eta_{jj}| > 2.5$ ,  $p_t^j > 20$  GeV,  $|\eta_j| < 5$ ,  $M_{4\ell} > 200$  GeV,  $|M_{\ell^+\ell^-} - M_Z| < 15$  GeV.

Lepton cuts:  $p_t^\ell > 20$  GeV,  $|\eta_\ell| < 2.5$ ,  $p_t^{\text{miss}} > 40$  GeV.

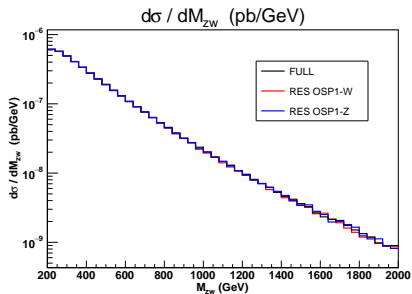
Complex-mass scheme,  $\mu_F = M_{4\ell}/\sqrt{2}$ , NNPDF30\_lo\_as\_0130 PDFs, no  $b$ .

Unpolarized calculation:

resonant OSP1 calculations (either OSP1-W and OSP1-Z) well approximate the full results, both with and without lepton cuts and neutrino reconstruction.

Differential cross-section in the four-lepton invariant mass.

$\lesssim 1\%$  discrepancy bin-by-bin

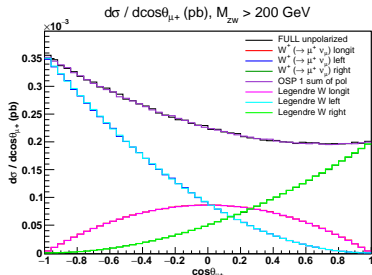


Ready to separate polarizations.

# WZ: separating W polarizations

## No lepton cuts, no $\nu$ reconstruction.

Analytic cross-section in  $\cos\theta_{\mu}$  known:  
expand in first 3 Legendre poly. to extract  
pol. fractions.

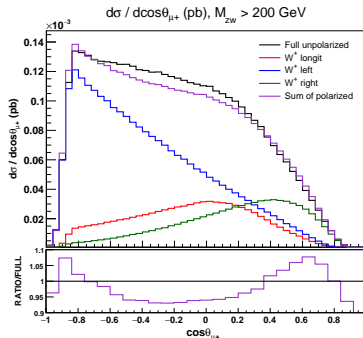


Very good agreement between MC and  
Legendre expansion of the full for pol.  
fractions and distributions (< 1% discrep.).

Sum of polarized components equals the  
full, as interferences vanish and  
non-resonant effects are negligible

## Lepton cuts, $\nu$ reconstruction.

Legendre expansion of the full is  
meaningless.

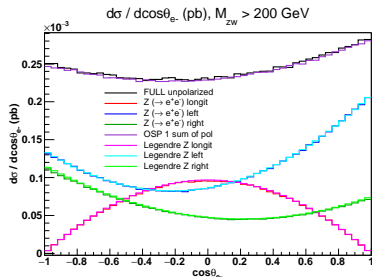


Interferences among polarizations don't  
vanish: **small but non negligible (few  
percent)**.

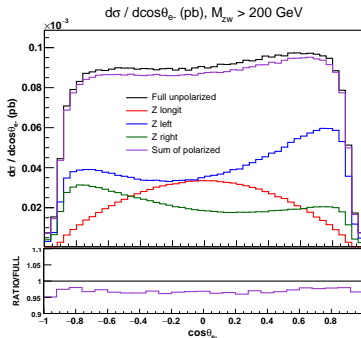
Different polarization modes are affected  
differently by the cuts and  $\nu$  reco.

Analogous results for Z polarizations (from  $\cos\theta_e$  distributions).

No lepton cuts, no  $\nu$  reconstruction.



Lepton cuts,  $\nu$  reconstruction.

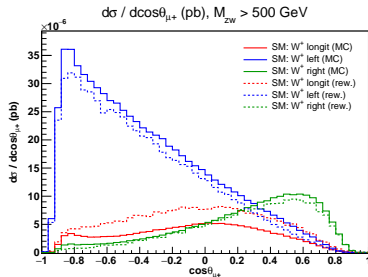


Smaller interferences in the presence of lepton cuts and  $\nu$  reco., as  $\cos\theta_e$  is not affected directly by  $\nu$  reco.

# Reweighting VS pol. amplitudes (1)

Consider the  $W^+$  boson polarization in  $W^+Z$  ( $W^+ \rightarrow \mu^+ \nu_\mu$ ).

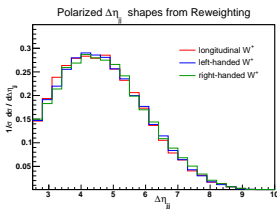
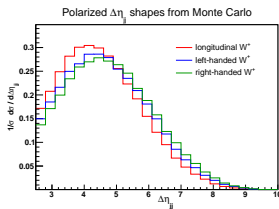
**Reweighting:** from full unpol. events (no lepton cuts), compute pol. fractions in  $W$   $\{p_t, \eta\}$  regions. Assign probability for the  $W$  of being longit., left or right, depending on  $\cos\theta_\mu$  analytic shape (and pol. fractions), to obtain 3 separated *polarized* samples.



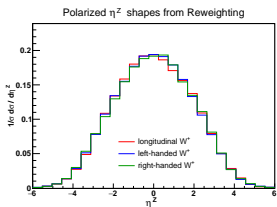
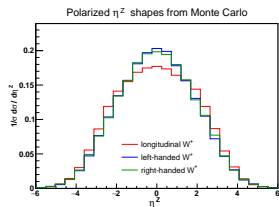
- ▷ Large statistics required (unpol. generation).
- ▷ Compared to polarized amplitudes, **reweighting is very inaccurate in reproducing pol. cross sections:** up to 70% discrep. for longit., for  $M_{WZ} > 500$  GeV.
- ▷ Interferences completely **neglected**.
- ▷ Inaccuracy proved also if compared with NWA + polarized decays (WZDECAY), **[work by C. Bittrich]**

# Reweighting VS pol. amplitudes (2)

Reweighting washes out dependence of polarized signals on other kinematic variables (other than  $\cos\theta_{\mu^+}$ ).



▷  $\Delta\eta_{jj}$   
(pseudorapidity separation between the two jets)

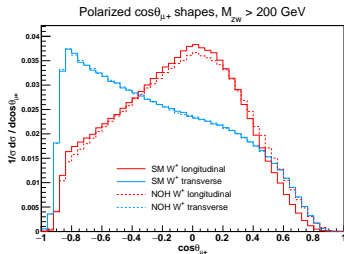
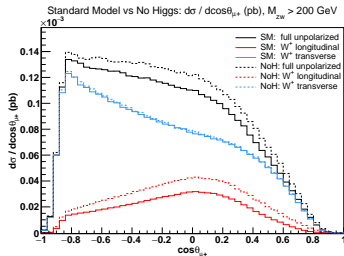


▷  $\eta^Z$   
(pseudorapidity of the  $e^+e^-$  system)

# Extracting polarization fractions (1): intro

Target: model independent extraction of polarized cross-sections from LHC data (no prior knowledge of underlying theory).

**Standard Model vs Higgsless SM (NoH, extreme BSM th.), all cuts and  $\nu$  reco.**



Here shown  $\cos\theta_{\mu}$  for a polarized  $W$ . Similar results for  $\cos\theta_e$  for a polarized  $Z$ .

1. Transverse (coherent sum) better than left and right (interf. minimized).
2. Transverse component doesn't discriminate between the two models (neither in shape, nor in cross-section,  $\lesssim 3\%$  discrep.).
3. Longitudinal component shows mild differences in shape, and (as expected) a huge difference in total cross-section.



## Extracting polarization fractions (2): strategy

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### Strategy 1

Fit full NoH (our “BSM data”) with SM templates: longit., transv, interference.  
 $\chi^2$ -minimz., relying on the shape similarity of both longit. and transv.

$$f(\cos\theta_\ell)_{\text{full}}^{\text{noh}} = \sum_{\lambda=0,T} C_\lambda f(\cos\theta_\ell)_\lambda^{\text{sm}} + C_I f(\cos\theta_\ell)_{\text{interf}}^{\text{sm}} \quad (3 \text{ free parameters})$$

### Strategy 2

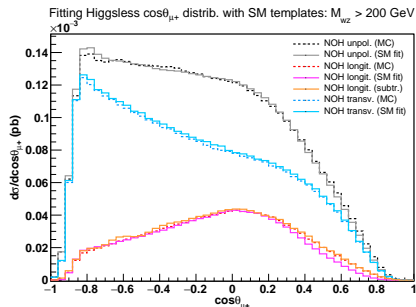
Subtract SM transverse distrib. and interference from the full NoH, relying on the cross-section similarity of the transverse. Even interf. similar in the two models.

Performed both procedures for  $W$  pol. and for  $Z$  pol..

In the following only results for  $W$ . Results for  $Z$  are even better, as they are not affected directly by  $\nu$  reco.

Considered both the whole fiducial volume, and more exclusive kinematic regions.

## Extracting polarization fractions (3): results



Fit and subtraction results in the complete fiducial region:

Fit works well ( $\approx 4\%$  underestim. of longit. cross-section).

Subtraction works slightly better ( $\approx 3\%$  overestim. of longit. cross-section).

The two methods give accurate results even in more exclusive kinematic regions ( $\lesssim 4\%$  discrep.).

kinematic region	Cross sections [ $ab$ ] for a polarized $W^+$					
	Longitudinal			Transverse		
	MC	Fit	Subtr.	MC	Fit	Subtr.
$M_{WZ} > 200$ GeV	46.90	44.93	48.37	133.10	135.16	131.73
$M_{WZ} > 1000$ GeV	4.71	5.20	4.73	5.50	4.79	5.47
$M_{WZ} > 200$ GeV, $p_t^W > 400$ GeV	4.81	4.79	4.84	9.12	9.26	9.03
$M_{WZ} > 200$ GeV, $ \eta_W  > 3$	1.74	1.70	1.73	0.83	0.83	0.82

Good description of VBS processes with polarized  $W/Z$  bosons (single polarized signals) in the fully leptonic channel, at LO EW, with and without lepton cuts.

Rewighting procedure is inaccurate.

Progress in the model independent extraction of pol. fractions from data.

On going work from other research groups.

What's next:

## Fully leptonic channel.

- ▶ Polarized weak bosons in VBS main backgrounds: QCD bkg, top,  $t\bar{t}$ , ...
- ▶ NLO QCD (straightforward) and EW (more involved [Baglio et al. 1810.11034]).
- ▶ Systematic modeling of doubly polarized signals.
- ▶ Further investigation of model independence of angular shapes, more refined fit.

## Semileptonic channel.

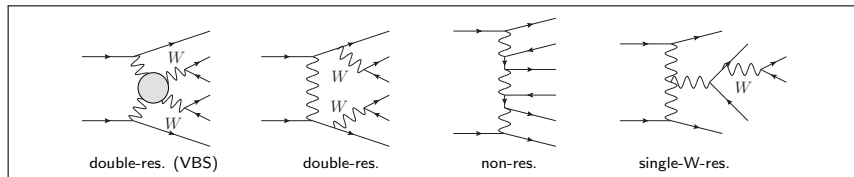
Larger SM cross section than fully lept., dominated by bkg's: EW sgn. is  $\approx 5\%$  of the total in the fiducial region [CMS 1905.07445]  $\rightarrow$  longitudinal  $< 1\%$ .

- Definition and simulation of polarized signals.
- Need to separate  $W$  and  $Z$  from jet substructure.

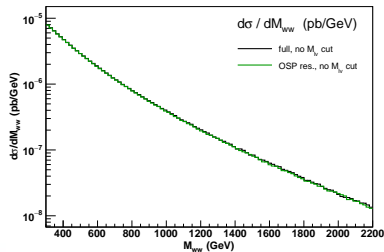
BACKUP

# WW - separating resonant contributions

Setup:  $M_{jj} > 600$  GeV,  $|\Delta\eta_{jj}| > 3.6$ ,  $\eta_{j1} \cdot \eta_{j2} < 0$ ,  $M_{4\ell} > 300$  GeV.



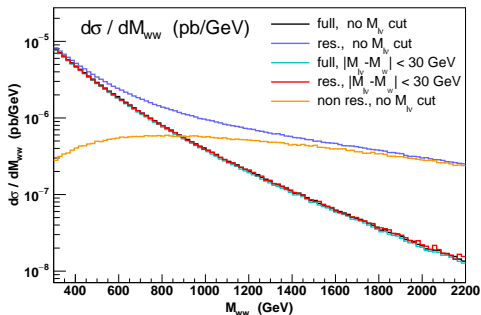
Select **only double-resonant** diagrams, perform **double On Shell projections** on the  $W$ 's  
 $\rightarrow$  **recovered EW gauge invariance**, without any cut on  $|M_{\ell\nu} - M_W|$ .

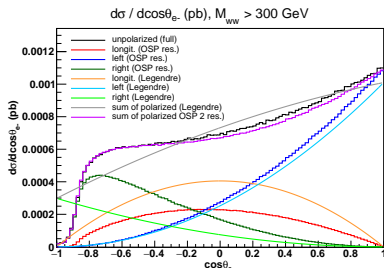
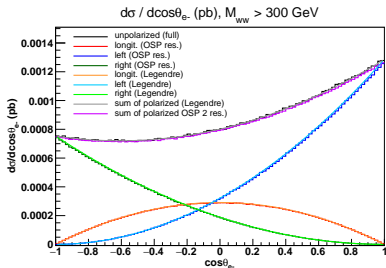


OSP unpolarized  $\sigma$  and distributions reproduce full calculation results with 1% accuracy, **even with minimal lepton cuts** ( $p_t^\ell > 20$  GeV,  $|\eta_\ell| < 2.5$ ).

Remark: if no OSP, resonant contrib. require a tight cut on  $|M_{\ell\nu} - M_W|$   
 $\rightarrow$  **large cancellation between res. and non-res. in the full computation.**

Large cancellation between res. and non-res. in the full computation:





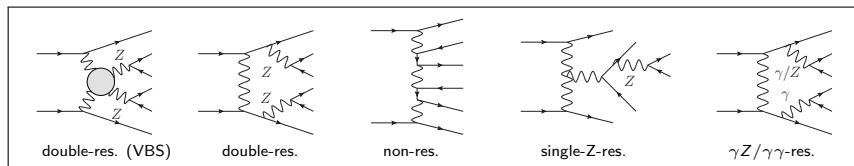
Very good agreement between MC and Legendre expansion of the full for pol. fractions and distributions ( $< 1\%$  discrep.).

Sum of polarized components equals the full, as interferences vanish and non-resonant effects are negligible

Legendre expansion of the full is meaningless.

Interferences among polarizations don't vanish: small but non negligible (few percent). Different polarization modes are affected differently by the cuts.

Setup:  $M_{jj} > 500$  GeV,  $|\Delta\eta_{jj}| > 2.5$ ,  $M_{4\ell} > 200$  GeV,  $M_{\ell+\ell-} > 40$  GeV.



Select **only ZZ-resonant** diagrams: **double On Shell projections not enough to give reliable results**, due to  $\gamma$  effects. Mainly for  $ZZ \rightarrow ZZ$  processes.

Required tight cut on  $|M_{\ell+\ell-} - M_Z|$

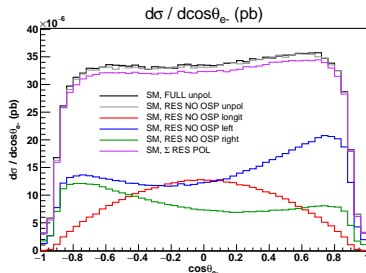
OSP: no substantial effect on ZZ-resonant with  $|M_{\ell+\ell-} - M_Z| < 15$  GeV ( $\ell = e, \mu$ ).

→ full results described at the % level, with and without lepton cuts ( $p_t^\ell > 20$  GeV,  $|\eta_\ell| < 2.5$ ). See figure in next slide (gray vs black curve).



In the absence of lepton cuts, Legendre expansion of the full works well, as in *WW*.

In the presence of lepton cuts,



1. Res. diagrams (unpol., no OSP) reproduce the full within 1% (total and diff.).
2. Sum of single polarized distrib. reproduces the full within few percent.
3. Different polarization modes are affected differently by the cuts.

# Single On Shell projection (OSP1)

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To cure (at least partially) gauge violation given by the selection of  $Z/W$ -resonant diagrams, we perform an **On Shell projection of the  $Z/W$  boson** (OSP1).

Details of OSP1: for the process  $pp \rightarrow V(\rightarrow \ell\bar{\ell}) + X$ , it conserves  $X$  4-momentum, the  $V$  3-momentum in the lab frame and the  $\ell$  direction in the  $V$  rest frame, modifying the initial parton 4-momenta in order to conserve the total 4-momentum.

# Neutrino reconstruction for $WZ$ (1)

One neutrino in the final state: require  $M_{\ell\nu} = M_W$  to determine the longitudinal momentum  $p_z^\nu \rightarrow$  two solutions:

$$p_{z1,2}^{\nu, \text{reco}} = \frac{p_z^\ell \xi \pm \sqrt{\Delta}}{p_\ell^{t2}},$$

$$\text{where} \quad \Delta = p_z^{\ell 2} \xi^2 - p_t^{\ell 2} \left[ E^{\ell 2} p_t^{\nu 2} - \xi^2 \right], \quad \xi = \frac{M_W^2}{2} + \mathbf{p}_t^\ell \cdot \mathbf{p}_t^\nu.$$

If transverse mass of the  $\ell^+ \nu_\ell$  system ( $M_t^{\ell\nu}$ ) is larger than  $M_W$ , then  $\Delta < 0$ , we need to recover a unique real solution. If  $M_t^{\ell\nu} < M_W$ , then  $\Delta > 0$ : in such case we need to choose one of the two real solutions.

Several criteria: we investigated how different reconstruction schemes act on unpolarized events, computed with full matrix-elements at LO EW, with VBS cuts.

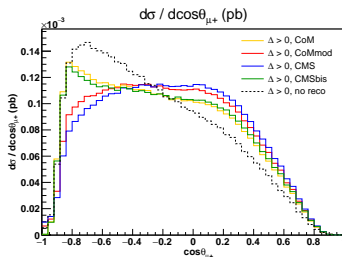
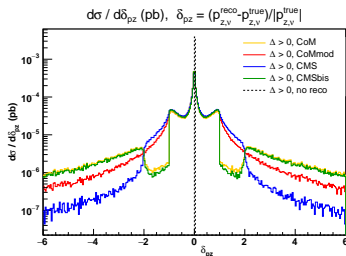
How do we choose the best one? Choose the one which:

1. minimizes the RMS of  $\delta_{p_z} = \frac{p_z^{\nu, \text{reco}} - p_z^{\nu, \text{true}}}{|p_z^{\nu, \text{true}}|}$  (highest central peak, lowest tails)
2. reconstructs  $\cos \theta_{\ell^+}^{\text{reco}}$  distributions shapes as similar as possible to  $\cos \theta_{\ell^+}^{\text{true}}$  ones

# Neutrino reconstruction for $WZ$ (2)

$$\delta_{p_z} = \frac{p_z^{\nu, \text{reco}} - p_z^{\nu, \text{true}}}{|p_z^{\nu, \text{true}}|}$$

$$\cos \theta_{\ell+}$$



Our choice (yellow line):

For  $\Delta > 0$ :

if  $p_{z1}^{\nu} \cdot p_{z2}^{\nu} < 0$ , choose the one such that  $p_z^{\ell} \cdot p_z^{\nu, \text{reco}} > 0$

if  $p_{z1}^{\nu} \cdot p_{z2}^{\nu} > 0$ , choose the one such that the partonic CoM invariant mass is minimized (natural choice at the LHC, due to PDFs).

For  $\Delta < 0$ :

substitute  $M_W$  with  $M_t^{\ell\nu}$  (this sets  $\Delta = 0$ ), the (unique) solution is  $p_z^{\nu} = p_z^{\ell} \frac{p_t^{\nu}}{p_t^{\ell}}$

# Fit and subtraction results: polarized $W^+$

kinematic region	Cross sections [ab] for a polarized $W^+$					
	Longitudinal			Transverse		
	MC	Fit	Subtr.	MC	Fit	Subtr.
$M_{WZ} > 200 \text{ GeV}$	46.90	44.93	48.37	133.10	135.16	131.73
$M_{WZ} > 500 \text{ GeV}$	16.06	15.89	16.42	38.14	38.23	37.83
$M_{WZ} > 1000 \text{ GeV}$	4.71	5.20	4.73	5.50	4.79	5.47
$M_{WZ} > 200 \text{ GeV}, p_t^W > 200 \text{ GeV}$	13.49	13.09	13.78	43.90	44.26	43.51
$M_{WZ} > 200 \text{ GeV}, p_t^W > 300 \text{ GeV}$	7.89	7.81	7.93	19.61	19.66	19.40
$M_{WZ} > 200 \text{ GeV}, p_t^W > 400 \text{ GeV}$	4.81	4.79	4.84	9.12	9.26	9.03
$M_{WZ} > 200 \text{ GeV},  \eta_W  < 1$	17.65	15.07	18.41	62.61	65.16	61.83
$M_{WZ} > 200 \text{ GeV}, 1 <  \eta_W  < 2$	19.42	19.36	19.95	55.91	55.70	55.35
$M_{WZ} > 200 \text{ GeV}, 2 <  \eta_W  < 3$	8.09	8.17	8.27	13.76	13.88	13.72
$M_{WZ} > 200 \text{ GeV},  \eta_W  > 3$	1.74	1.70	1.73	0.83	0.83	0.82

# Fit and subtraction results: polarized $Z$

kinematic region	Cross sections [ab] for a polarized $Z$					
	Longitudinal			Transverse		
	MC	Fit	Subtr.	MC	Fit	Subtr.
$M_{WZ} > 200 \text{ GeV}$	56.27	54.88	57.75	122.24	124.46	120.96
$M_{WZ} > 500 \text{ GeV}$	18.35	17.59	18.63	35.46	36.30	35.26
$M_{WZ} > 1000 \text{ GeV}$	4.90	4.73	4.91	5.37	5.54	5.39
$M_{WZ} > 200 \text{ GeV}, p_t^Z > 200 \text{ GeV}$	13.97	13.58	14.30	37.91	38.31	37.59
$M_{WZ} > 200 \text{ GeV}, p_t^Z > 300 \text{ GeV}$	8.16	8.13	8.29	17.05	17.11	16.93
$M_{WZ} > 200 \text{ GeV}, p_t^Z > 400 \text{ GeV}$	4.94	4.84	4.99	7.92	8.05	7.92
$M_{WZ} > 200 \text{ GeV},  \eta_Z  < 1$	19.22	18.32	19.99	62.76	63.69	61.95
$M_{WZ} > 200 \text{ GeV}, 1 <  \eta_Z  < 2$	22.41	22.42	23.03	45.42	45.59	45.08
$M_{WZ} > 200 \text{ GeV}, 2 <  \eta_Z  < 3$	11.72	11.51	11.76	13.31	13.72	13.22
$M_{WZ} > 200 \text{ GeV},  \eta_Z  > 3$	2.92	2.83	2.94	0.71	0.89	0.71