Status of the Yellow Report of the Multiboson Group

- **ATLAS:** Joany Manjarres Ramos, (Kristin Lohwasser), Shu Li
- **CMS:** Philip Chang, Roberto Covarelli, (Pietro Vischia)
- **Theory**: Jonas Lindert and Celine Degrande

LHC EW WG General Meeting
09/10/2020

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CERN-2019-XXX-M

Multibosons Physics at the LHC

Report of the EW Working Group

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CERN

Draft exists since quite some time but progress has been rather slow recently.

1. Measurements of Multibosons: current results and outlook

Green -> done/in good shape

Yellow -> is assigned and being worked on

Orange -> needs to be updated (and possibly reassigned?)

Red -> needs to be reassigned

(Re)discussion needed on scope:

Reviews vs. Recommendations vs. joint (sub)-phase-space definitions

1. Measurements of Multibosons: current results and outlook

Towards a combination of ATLAS/CMS measurements

Full Run2 (2015 – 2018) measurements on-going/about to be available in many VV channels :

- ❑**Which measurements to combine ?**
- ❑**How to express the results of each experiments in order to facilitate the combination ?**

[Taken from Corinne Goy's slide during MB subgroup meeting on 16/07/20]

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E.g. for WZ

Possible combinations

- Integrated cross-sections
  - $\sigma(WZ)$, $\sigma(W^+Z)$
  - Ratio: $\sigma(W^+Z)/\sigma(W^-Z)$
- Differential distributions
- Polarization fractions
- EFT, aGC
  - Limits
  - Diff distributions

Points to consider

- Phase Space
  - Fiducial phase-space
  - Total phase-space
- Common source of systematics

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Systematics – experimental

- Luminosity
  - Magnitude on the WZ cross-section :
    - ATLAS : 2.2% (stat: 1.6 %)
    - CMS : 2.8% (stat: 2.1 %)
  - Typically vanishes in ratios
  - Between ATLAS/CMS
    - "The largest contribution to the uncertainty comes from the extrapolation of the calibration from the low-luminosity vdM scans to the high-luminosity physics data-taking regime "

    from : ATLAS-CONF-2019-021 : **Luminosity determination in** p p **collisions at** sqrt(s) = **13TeV using the ATLAS detector at the LHC**

    → Potentially large correlation
  - Between years 2015 – 2018
    - "and are partially correlated between years"

Systematics – theoretical & modelling

- **Electroweak Physics constants** :
  - MZ, MW, Branching Ratios, alpha_qed : small if not tiny
- **PDFs + alpha_s :** PDF4LHC prescription
  - ATLAS : CT10 set
  - CMS : NNPDF3.0 set
- **QCD scales:** μF and μR, central value and variations
- **Parton Shower**
  - Pythia/Herwig
- **Pile-Up (& Underlying events)**
  - Uncertainty on the predicted inelastic cross-section
  - ATLAS : takes the diff between measured and predicted
  - CMS : 5% on the predicted cross-section

Usually, not considered as a th & mod error

- Correlation : Experiments / Year / Channels

+ backgrounds

1. Measurements of Multibosons: current results and outlook

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Full Run2 (2015 – 2018) measurements on-going/about to be available in many VV channels :

- ❑**Which measurements to combine ?**
- ❑**How to express the results of each experiments in order to facilitate the combination ?**

[Taken from Corinne Goy's slide during MB subgroup meeting on 16/07/20]

Our aim is to discuss this in detail in the YR for individual channels:
currently work on WZ and WW

1. Measurements of Multibosons: current results and outlook
ATLAS and CMS common (sub) phase-space definitions

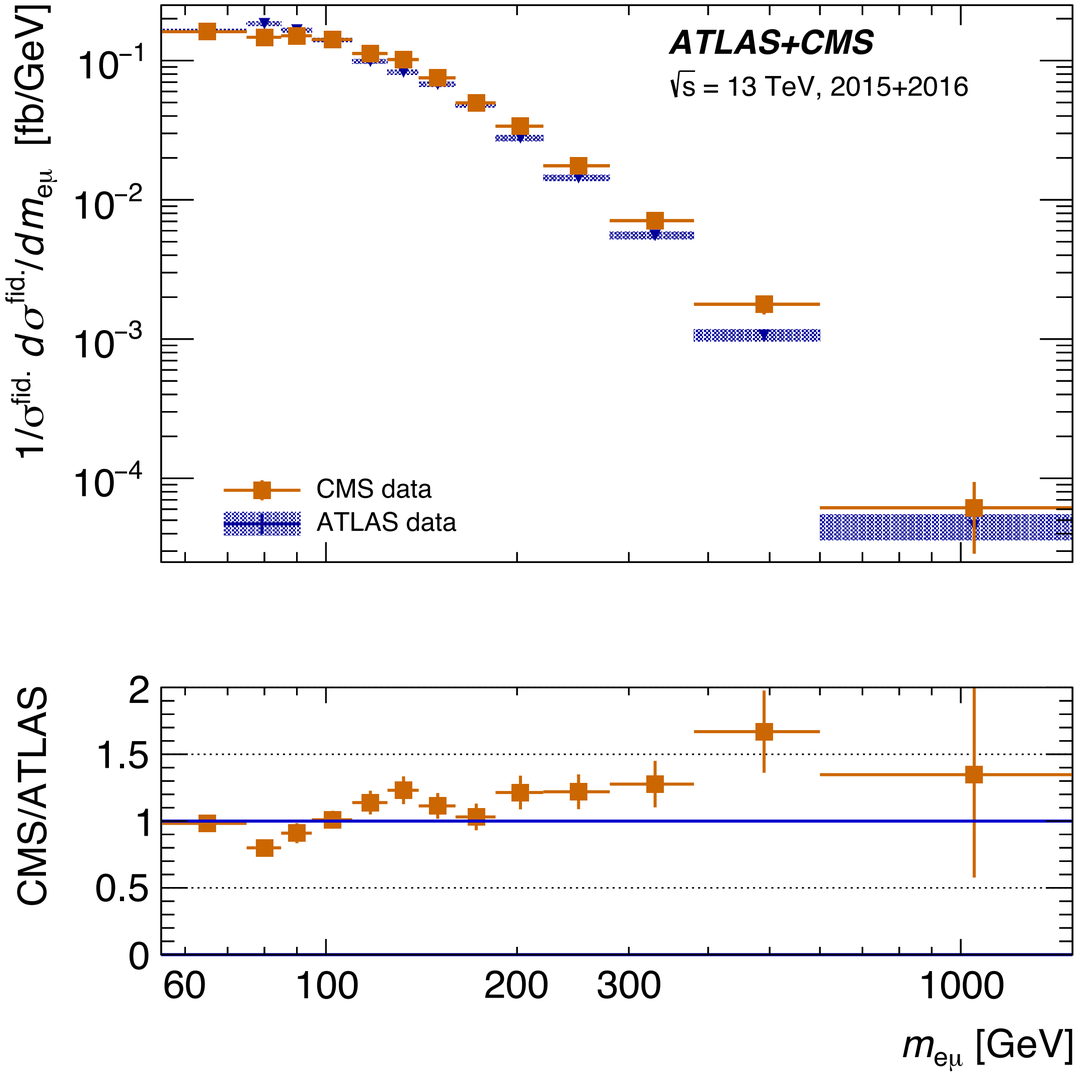
> **ATLAS measurement at 13 TeV (36 /fb, 2015-2016 data)**
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2017-24/
  - https://www.hepdata.net/record/ins1734263
  - https://rivet.hepforge.org/analyses/ATLAS_2019_I1734263

> **CMS measurement at 13 TeV (36/fb, 2015-2016 data)**
  - http://cds.cern.ch/record/2714766

> **Very different cuts, as per usual, but plenty of nice differential distributions**

> **Additional information available for both experiments: common phase space**

> **Based on discussion in LHC-EWWG MB in Feb. 2017 (and followed up)**
  - https://indico.cern.ch/event/607366/



E.g. to be used as benchmark for MC/theory comparisons

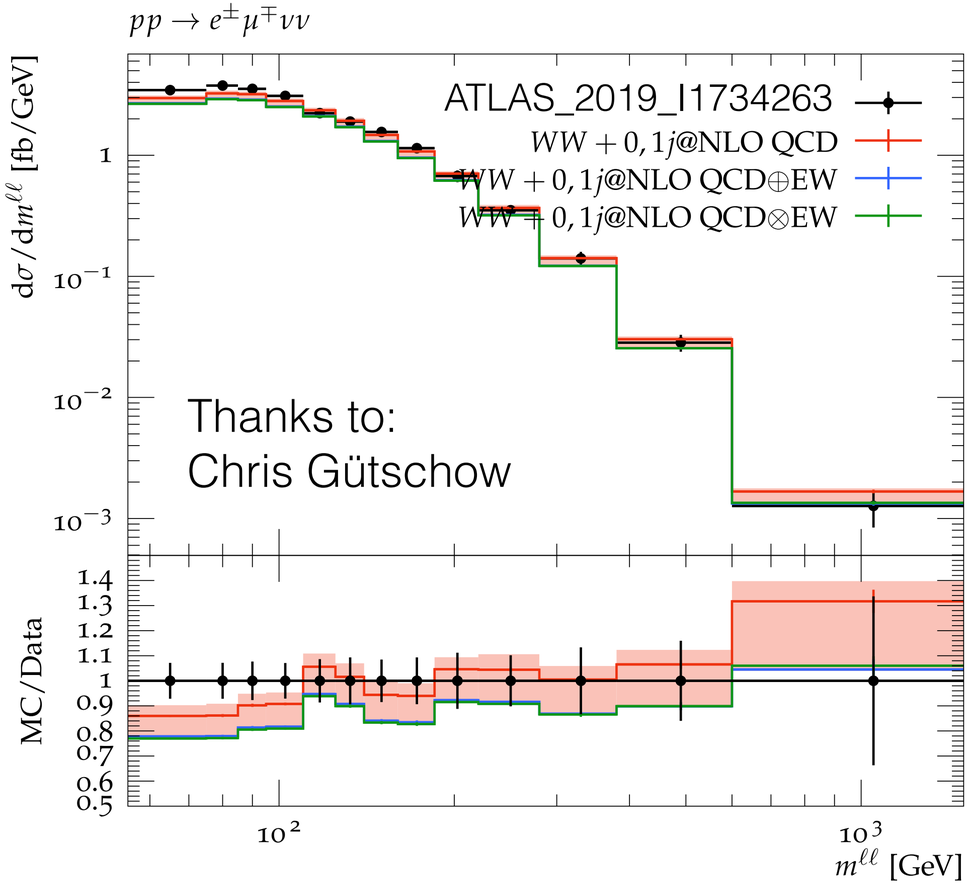
[See Kristin Lohwasser's slide during MB subgroup meeting on 21/07/20]

3. Predictions for Multibosons: MC/phenomenological studies

Use this joint phase-space

Currently being considered:

- NNLOPS from POWHEG+Matrix
- MEPS@NLO QCD(+EW) from Sherpa
  (see also 2005.12128)



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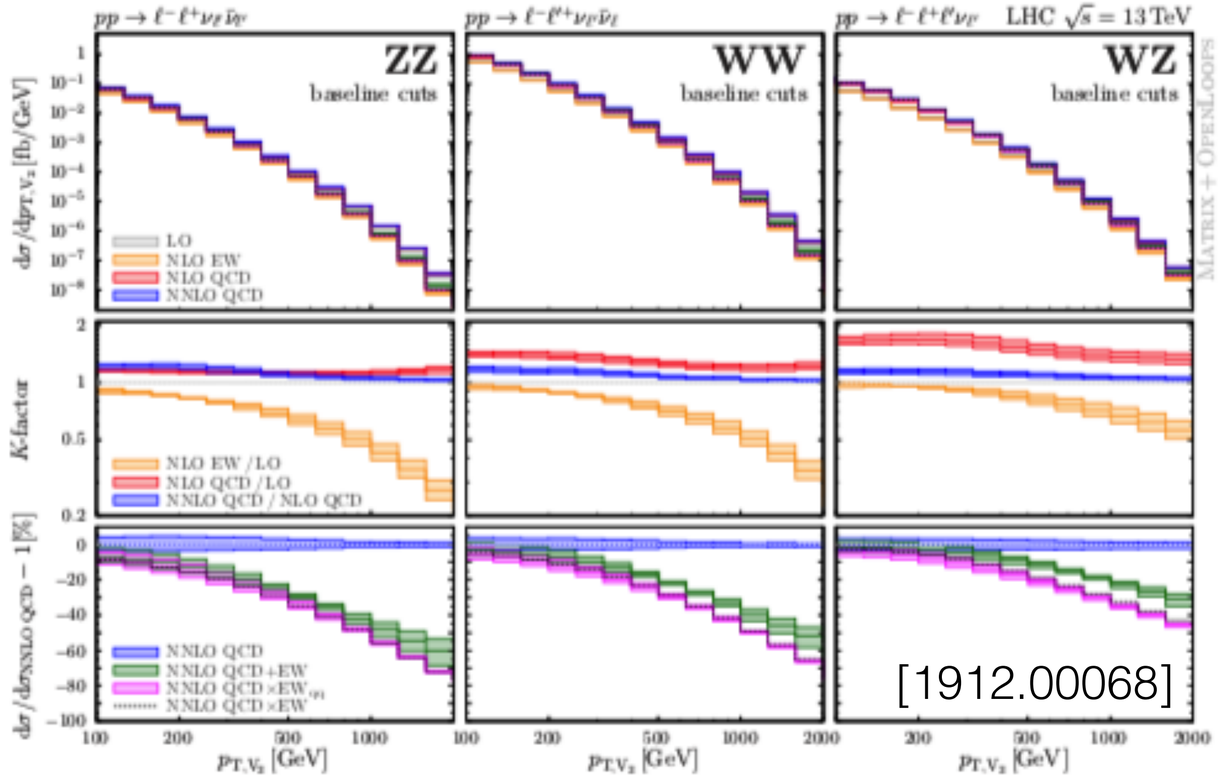
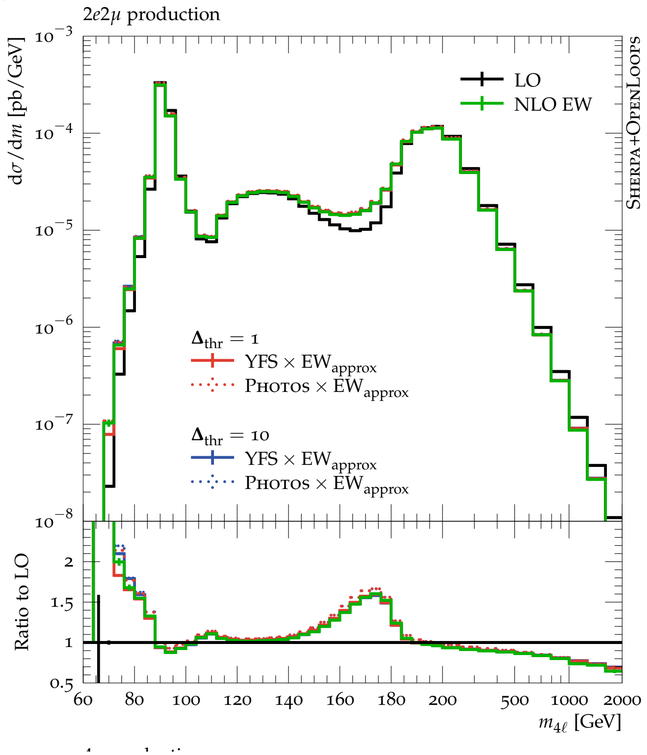
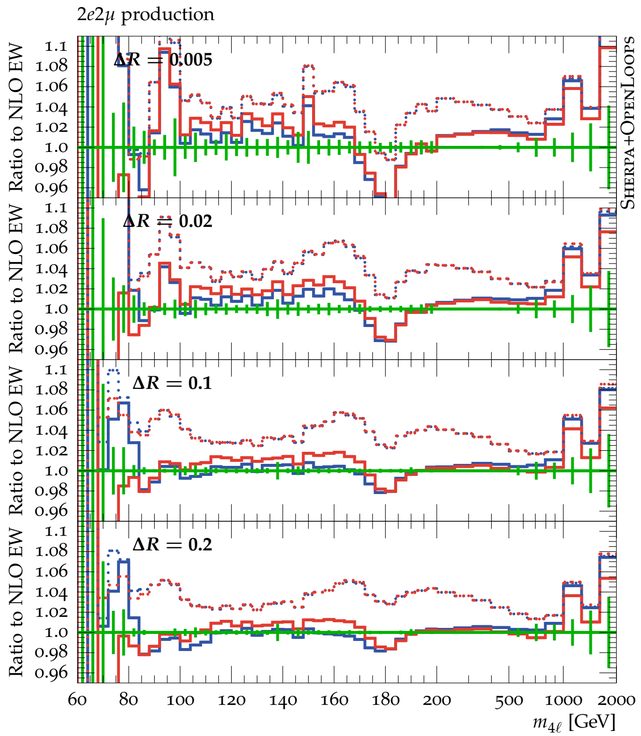


YR contribution:
Discuss recommendations for QCD-EW mixed uncertainties.

3. Predictions for Multibosons: MC/phenomenological studies





[2007.15360]

YR contribution:
Summary of published study

Possible extension:
compare against 2005.12146
(POWHEG-BOX-RES
VV@NLO QCD+EW)

3. Predictions for Multibosons: MC/phenomenological studies

Now public from both sides:

ATLAS:
http://cdsweb.cern.ch/record/2737267

CMS:
https://cds.cern.ch/record/2730973

Based on analysis from VBSCan:
arXiv:1803.07943

Significant differences can be traced back to different recoil schemes.

Comparisons of nominal and alternative samples-I

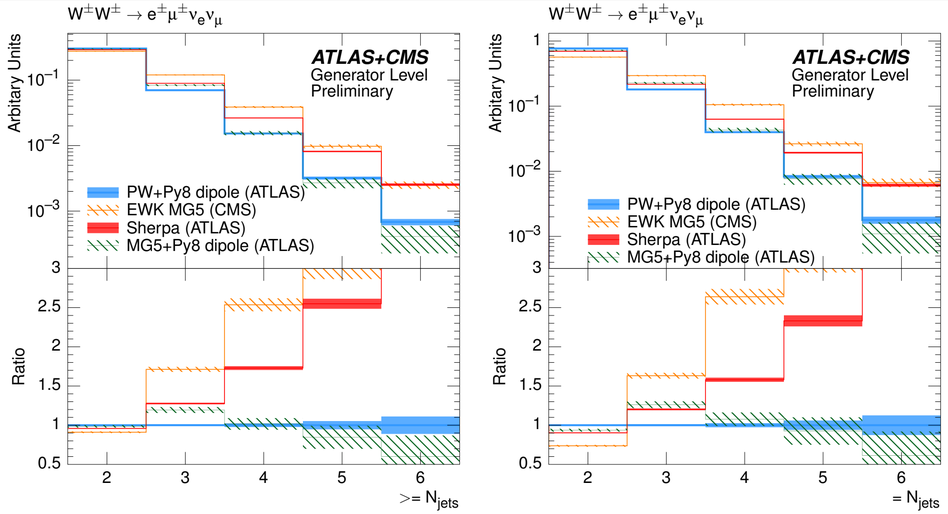


Figure: Comparison of the inclusive and exclusive jet multiplicities for the nominal and alternative samples. All uncertainty bands are statistical only. The samples have been normalised to unity.

- Ratios are computed w.r.t POWHEG+PYTHIA8-DIPOLE-RECOIL (ATLAS) sample.
- POWHEG+PYTHIA8-DIPOLE-RECOIL (ATLAS) sample predicts a much lower inclusive & exclusive jet multiplicities compared to the other samples with the exception of the MG5_AMC@NLO+PYTHIA8-DIPOLE-RECOIL (ATLAS), that also uses the dipole-recoil scheme.

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Comparisons of nominal and alternative samples-II

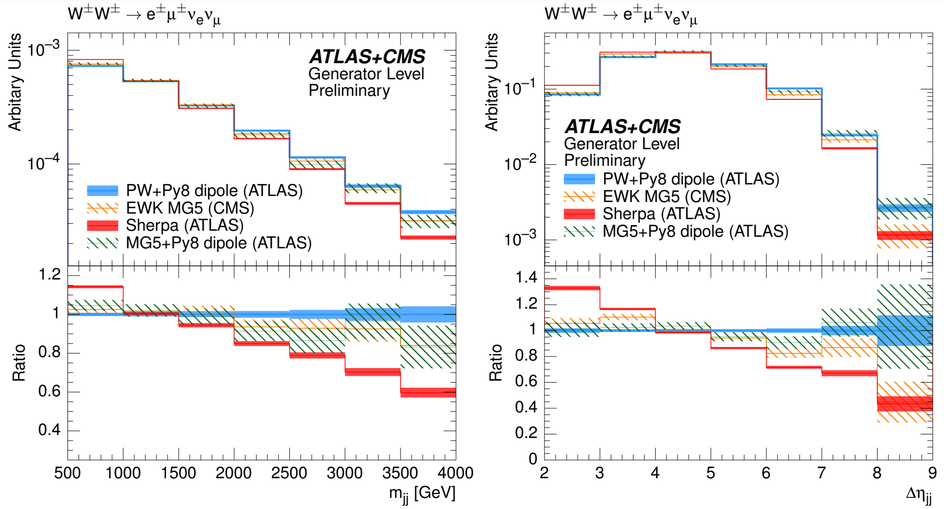

Figure: m_{jj} & $\Delta\eta_{jj}$ are compared for the nominal and alternative samples. All uncertainty bands are statistical only. The samples have been normalised to unity.

- Ratios are computed w.r.t POWHEG+PYTHIA8-DIPOLE-RECOIL (ATLAS) sample.
- m_{jj} distribution is the softest for the SHERPA (ATLAS) sample and falls off much quicker than the others, whilst the other samples are more similar.
- MG5_AMC@NLO+PYTHIA8 (CMS) sample tends to exhibt a slight smaller rapidity gap compared to the dipole samples.

3. Predictions for Multibosons: MC/phenomenological studies

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ATLAS:
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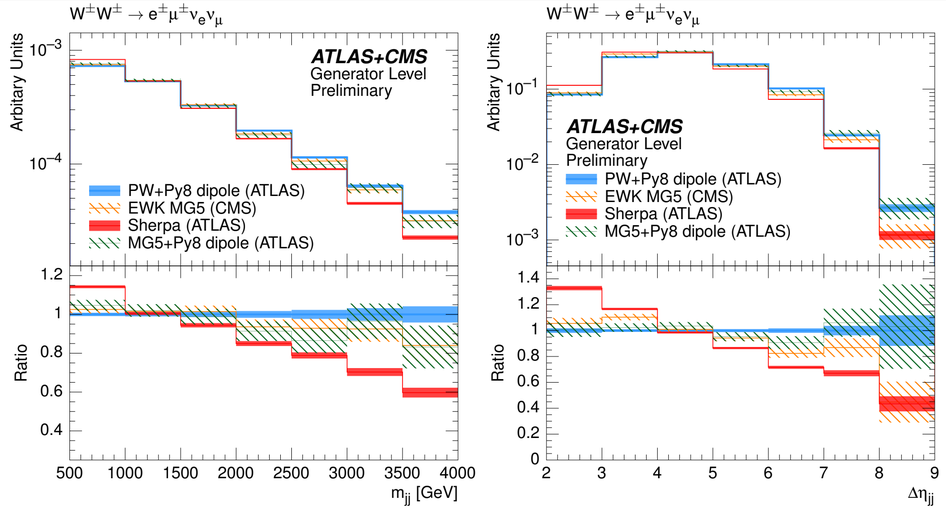
Based on analysis from VBSCan:
arXiv:1803.07943

Establishes technical and organisational proof-of-concept for such comparisons!

Comparisons of nominal and alternative samples-II



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4. Fiducial cross-section and BSM

Survey of EFT and multibosons

- Systematic review of multiboson processes:
  - → which operators do they constrain?
  - → how sensitive are they (relatively speaking, also w/r to other processes)
- "Toy" exercise
- Define processes

What can be gained from combination?

Class A:	**Diboson production**		
	A1: $WW(\to \ell^+\ell^-\nu\bar{\nu})$	A2: $WZ(\to \ell^+\ell^-\ell\nu)$	A3: $ZZ(\to \ell^+\ell^-\ell^+\ell^-)$
	A4: $W\gamma(\to \ell\nu)$	A5: $Z\gamma(\to \ell\ell\gamma)\gamma$	A6: $Z\gamma(\to \nu\nu\gamma)\gamma$
Class B:	**vector-boson fusion (VBF)**		
	B1: $Zjj(\to \ell^+\ell^-$	B2: $Wjj(\to \ell\nu$	
Class C:	**vector-boson scattering (VBS)**		
	C1: $W^\pm W^\pm\ jj(\to \ell^\pm\ell^\pm\nu\bar{\nu})jj$	C2: $WZ\ jj$	C3: $WZ\ jj$ (QCD)
	C4: $ZZ\ jj$	C5: $ZZ\ jj$ (QCD)	C6: $Z\gamma\ jj$
	C7: $W^\pm W^\mp\ jj$	C8: $W^\pm W^\mp\ jj$ (QCD)	

4. Fiducial cross-section and BSM

Survey of EFT and multibosons

- "General" BSM regions with high sensitivity (based on experimental measurements)
  → Projections / general cuts

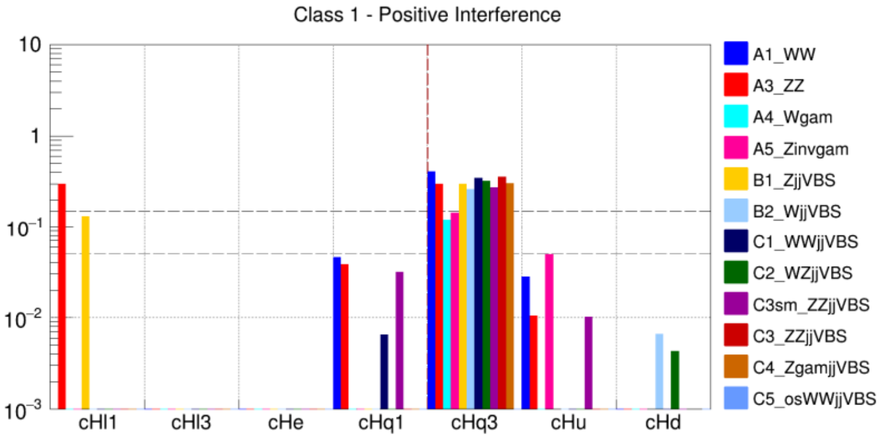
Diboson Production		
Final state	Object	Selection requirements
WW	**leptons**	p_{T} >25 GeV, $\|\eta\| < 2.5$
	neutrinos	$(\sum \vec{p}_{\nu}) > 30$ GeV
	jets	0 or 1 jet with p_{T} >30 GeV and within $\|\eta\| < 5.0$
	final BSM region	BSM1: 0 jet, $m_{\ell\ell}$ >600 GeV BSM2: 1 jet, $m_{\ell\ell}$ >600 GeV BSM3: 0 jet, $p_{T,\ell_{\mathrm{lead}}} > 400$ GeV BSM4: 1 jet, $p_{T,\ell_{\mathrm{lead}}}$ >400 GeV
WZ	**leptons**	$p_{\mathrm{T,lead}}$ >25 GeV, p_{T} >15 GeV, $\|\eta\| < 2.5$
	neutrinos	$(\sum \vec{p}_{\nu}) > 30$ GeV
	jets	no b-jets with p_{T} >30 GeV and within $\|\eta\| < 5.0$
	bosons	$m_{\mathrm{T},W}$ >30 GeV (see Eq. 21), $\Delta(m_Z, m_{\ell\ell})$ <15 GeV
	final BSM region	BSM1: $m_{\mathrm{T},WZ}$: >600 GeV (see Eq. 22) BSM2: $m_{3\ell} > 1250$ GeV
ZZ	**leptons**	p_{T} >25 / 15 / 10 GeV (leading leptons), $\|\eta\| <$ 2.5
	bosons	$\Delta(m_Z, m_{\ell\ell})$ <25 GeV
	final BSM region	BSM1: $m_{ZZ} > 1.0$ TeV
$W\gamma$	**leptons**	p_{T} >35, $\|\eta\| < 2.5$
	photons	E_{T} >25, $\|\eta\| < 2.5$, $\Delta\mathrm{R}(\ell, \gamma) > 0.7$
	neutrinos	$(\sum \vec{p}_{\nu}) > 30$ GeV
	bosons	$m_{\mathrm{T},W}$ >50 GeV
	final BSM region	$p_{\mathrm{T},\gamma}$: 25-60 GeV, 60-90 GeV, 90-150 GeV, >150 GeV

4. Fiducial cross-section and BSM

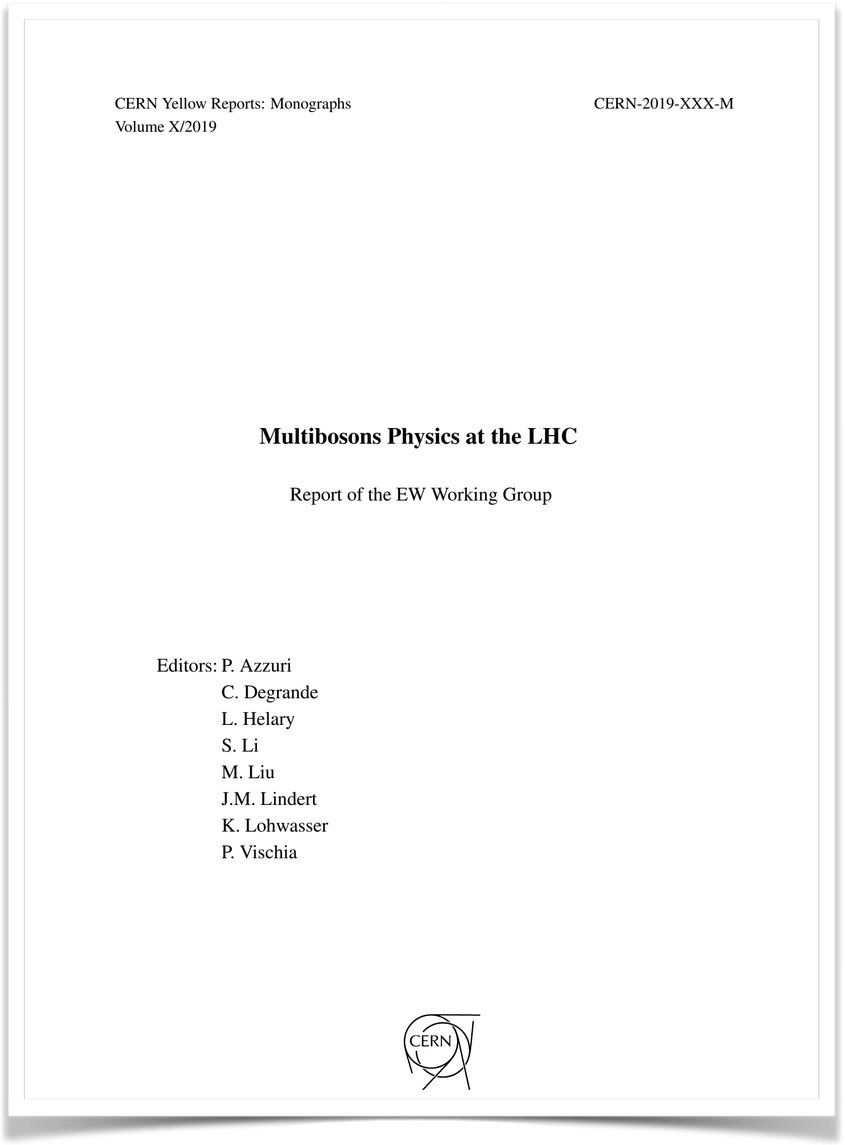
Survey of EFT and multibosons

Coefficient	A: Diboson production						B: VBF		C: Vectorboson scattering							
Class 1	A1: WW	A2: WZ	A3: ZZ	A4: $W\gamma$	A5: $Z\gamma$ ($\ell\ell\gamma$)	A6: $Z\gamma$ ($\nu\bar{\nu}\gamma$)	B1: Zjj	B2: Wjj	C1: $W^{\pm}W^{\pm}$ jj	C2: WZ jj	C3: WZ jj (QCD)	C4: ZZ jj	C5: ZZ jj (QCD)	C6: $Z\gamma$ jj	C7: $W^{\pm}W^{\mp}$ jj	C8: $W^{\pm}W^{\mp}$ jj (QCD)
c_G											✓		✓			✓
$c_{\tilde{G}}$											✓		✓			✓
c_W	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$c_{\widetilde{W}}$	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Class 2																
c_H													✓			✓
Class 3																
$c_{H\Box}$	✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓
c_{HD}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Class 4																
c_{HG}	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
$c_{H\tilde{G}}$	✓		✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
c_{HW}	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	
$c_{H\widetilde{W}}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
c_{HB}			✓		✓	✓				✓	✓	✓	✓	✓	✓	
$c_{H\tilde{B}}$			✓		✓	✓				✓	✓	✓	✓	✓	✓	✓
c_{HWB}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
$c_{H\widetilde{W}B}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

- General “affectedness” (above)
- Specific % sensitivity w/r to the SM (still working on better presentation)
- Comparison with current MB limits: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC



Outlook



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Most important: need to focus attention!