Yellow report precision EWK, status and plans

The LHC-EWWG Multiboson subgroup conveners

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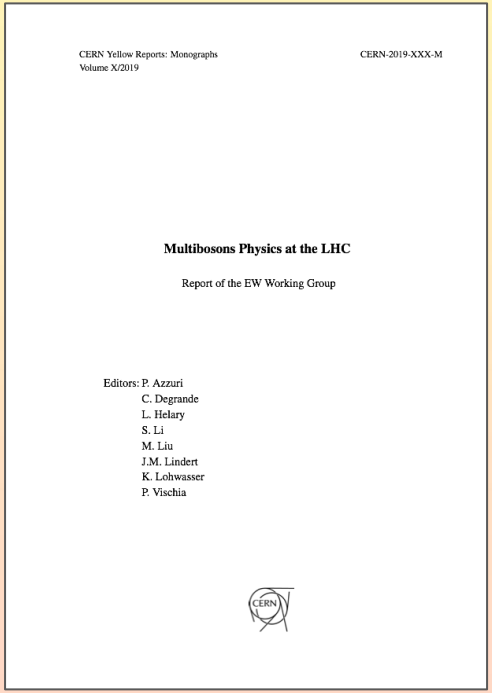
LHC EWWG summer meeting - 3rd July 2019

YR status

gitlab: https://gitlab.cern.ch/lhcewkwg/lhcewkwg-multiboson/Report2018



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Multibosons Physics at the LHC

Report of the EW Working Group

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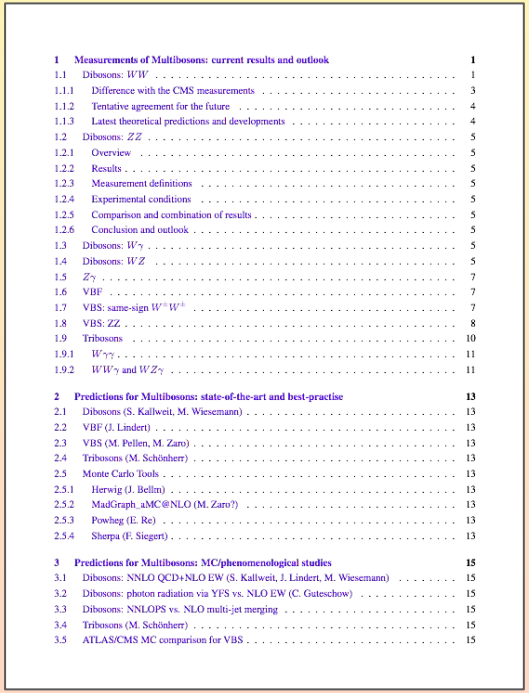

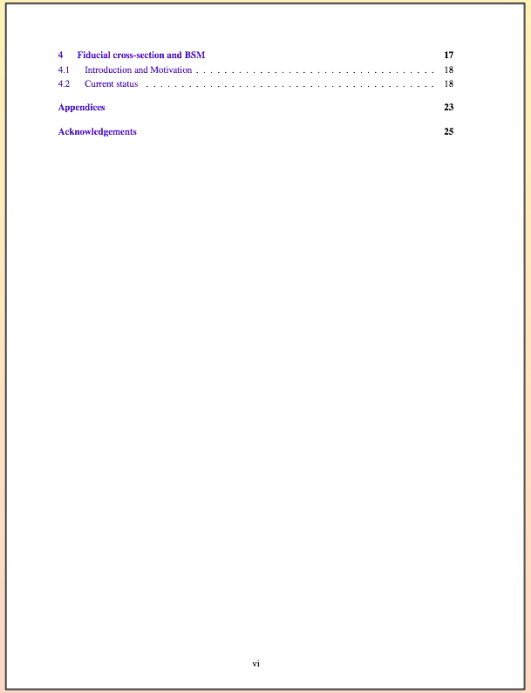

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1. Measurements of Multibosons: current results and outlook
2. Predictions for Multibosons: state-of-the-art and best-practise
3. Predictions for Multibosons: MC/phenomenological studies
4. Fiducial cross-section and BSM

1. Measurements of Multibosons: current results and outlook

What's there

- WW (ATLAS, CMS, comparisons)
- WZ (CMS)
- VBS ssWW (ATLAS, CMS)
- ZZ (ATLAS CMS) and ZZ VBS
- Tribosons (Wγγ WWγ, WZγ)

How can I contribute?

- Common RIVET routine for your favourite process which lacks it

What's in the making

- A few final states (Zγ, Wγ, VBS WZ)
- Phase space agreements
- Brief review of procedures and possible agreements
  - Use similar generators where possible? (but differences reported even with the same ones, see later slides)
  - Systematics: particularly the ones connected with generators (some are treated differently across experiments)
  - Unfolding: publish useful material (response+correlation matrices, etc), describe well the procedures

Review on measurements

Idea behind: Review and **agree on procedures and phase spaces** to allow at least for

→ a comparison of partial results

→ facilitate a combination of results for Full-Run 2 (without having to re-derive information)

This is common practice in LHC Higgs XS and LHC Top WGs

Could allow to have “ATLAS+CMS” rivet routines that can also be used by theorists to provide latest and greatest theory for comparisons (see also later slides on first ATLAS/CMS MC comparisons)

Examples are : **Z-mass window in ZZ production**

Current status: each experiment quotes extrapolation factor into the other experiements fiducial phase space

Review on measurements: WW as an example

Always better agreement of CMS versus ATLAS (possibly because of the stricter jet veto in ATLAS)
→ but hard to compare results (different phase space, different binning).

Agreement on simplified phase space (https://indico.cern.ch/event/607366/):

Cuts:
Two leptons (pT>25 GeV, |η|<2.5)
MET> 20 GeV
no jets (with pT>30 GeV and |η|<4.5)

Binnings:

Leading lepton pT	{ 27.,40.,50.,60.,70.,80,90,100.,110,130,150.,175,220,300,999}
pT(ll)	{ 30.,35.,40.,45,50.,55,60.,65,70.,75,80.,90,105,140,200,999}
m(ll)	{ 55.,75, 85,95.,110.,125,140.,160.,185,220,280.,380,600,1500}

Review on measurements: WW as an example

2015+2016 data only, on arXiv: https://arxiv.org/abs/1905.04242
Optimisations for full Run-2 possible

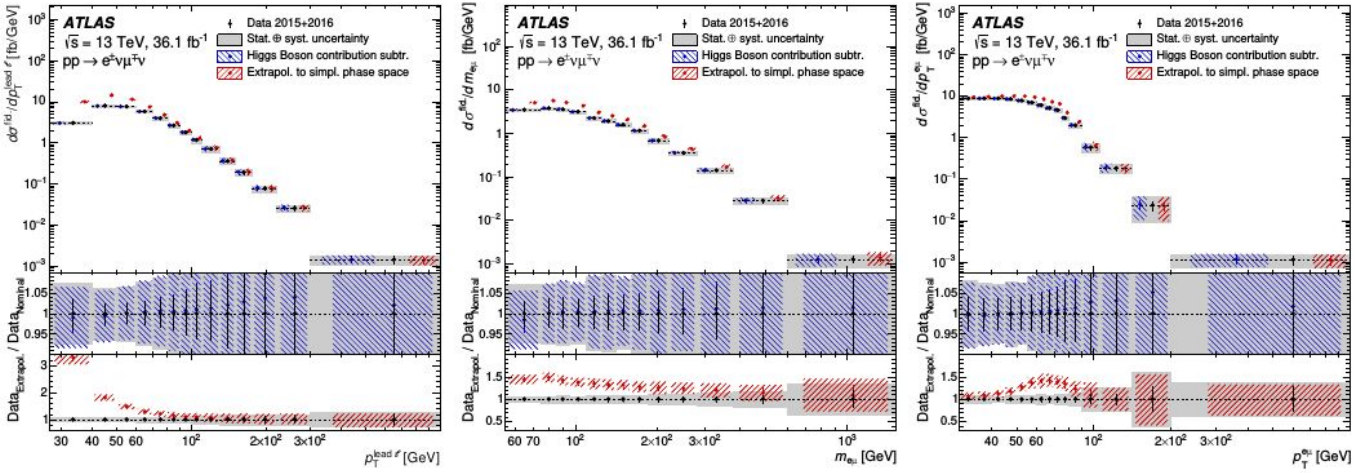
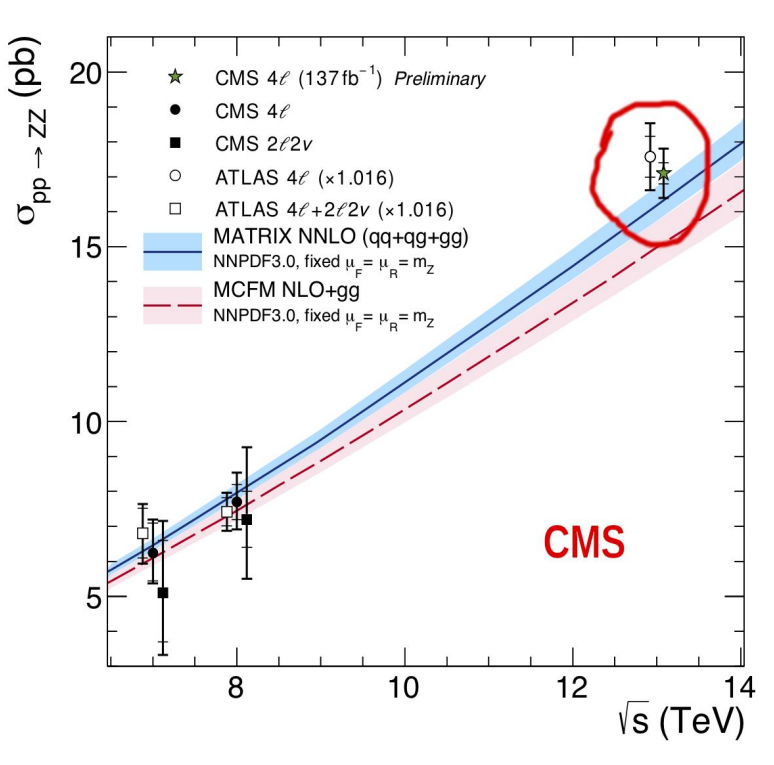


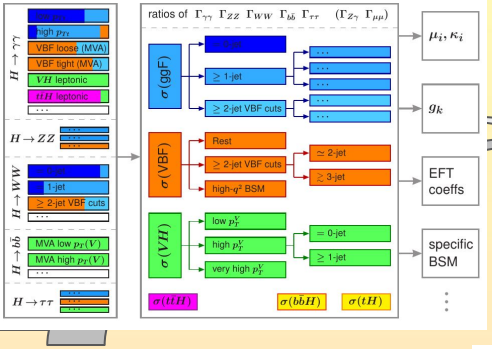
Figure 15: Extrapolated unfolded fiducial cross-sections of $WW \to e\mu$ production as a function of $p_{\mathrm{T}}^{\mathrm{lead}\,\ell}$, $m_{e\mu}$, and $p_{\mathrm{T}}^{e\mu}$. The nominal cross-section values are shown as points with error bars giving the statistical uncertainty and solid bands indicating the size of the total uncertainty. The nominal measurements are extrapolated to measurements without the expected Higgs boson contribution and measurements in a simplified phase space. The simplified phase space is defined by requiring exactly one electron and muon ($p_{\mathrm{T}}^{\ell} > 25$ GeV, $|\eta_{\ell}| < 2.5$), no jets ($p_{\mathrm{T}}^{\mathrm{jet}} > 30$ GeV, $|\eta_{\mathrm{jet}}| < 4.5$) and $E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV.

Thinking about combinations

- Anomalous Couplings
  - The latest ATLAS+CMS combination seems to be the 7 TeV one (**CMS-PAS-SMP-15-001**, PAS only!)
  - In the meantime, many results constrain much more the trilinear and quartic couplings
  - When do we want to produce the next combination?
  - Go for a 13 TeV one, skipping 8-TeV-only one
    - Would including 8 TeV results in 13 TeV combination be worth (sensitivity-wise) the pain of implementing it?
- Cross sections
  - Is it time to combine our measurements (extrapolated to the full phase space) in each production mode?
  - Agreements on phase space would make things easier
  - Plots of evolution with c.m.e. are supercool, but they all contain split ATLAS and CMS points: they could include a third point
- Concert with SMP-Combination (CMS) strategies and details!
  - These combinations already discussed within SMP-Comb?



Inspired by Higgs STXS: Useful benchmarks!



[LHC EWWG Working group proposal]

Step towards making

global fits easier ?

→ and basis to start EFT investigations

- ***Keep just (differential) cross sections and measure (but in BSM phase space)***
- Profit from advantages of being **useful tool, interface, benchmark**

Multiboson Production		
Final state	Object	Selection requirements
WW	**leptons**	p_T >25 GeV, $\|\eta\| < 2.5$
	neutrinos	$(\sum \vec{p}_\nu) > 30$ GeV
	jets	no jets with p_T >30 GeV and within $\|\eta\| < 5.0$
	final BSM region	$m_{\ell\ell}$: 380-600 GeV, >600 GeV
WZ	**leptons**	$p_{T,\text{lead}}$ >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	$m_{T,W}$ >30 GeV (see Eq. **??**), $\Delta(m_Z, m_{\ell\ell})$ <15 GeV
	final BSM region	$m_{T,WZ}$: 380-600 GeV, >600 GeV (see Eq. **??**)
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	m_{WZ}: 0.8-1.0 TeV, >1.0 TeV
$W\gamma$	**leptons**	p_T >35, $\|\eta\| < 2.5$
	photons	E_T >25, $\|\eta\| < 2.5$, $\Delta R(\ell, \gamma) > 0.7$
	neutrinos	$(\sum \vec{p}_\nu) > 30$ GeV
	bosons	$m_{T,W}$ >50 GeV
	final BSM region	$p_{T,\gamma}$: 25-60 GeV, 60-90 GeV, 90-150 GeV, >150 GeV
$Z(\to \ell\ell)\gamma$	**leptons**	p_T >35, $\|\eta\| < 2.5$
	photons	E_T >25, $\|\eta\| < 2.5$, $\Delta R(\ell, \gamma) > 0.4$
	bosons	$\Delta(m_Z, m_{\ell\ell})$ <10 GeV
	final BSM region	$p_{T,\gamma}$: 100-250 GeV, >250 GeV
$Z(\to \nu\nu)\gamma$	**photons**	E_T >25, $\|\eta\| < 2.5$, $\Delta R(\ell, \gamma) > 0.4$
	neutrinos	$(\sum \vec{p}_\nu) > 30$ GeV
	final BSM region	$p_{T,\gamma}$: 100-250 GeV, >250 GeV

Vectorboson Fusion		
Final state	Object	Selection requirements
Z VBF / Zjj	**leptons**	$p_{T,\text{lead}}$ >25 GeV, $\|\eta\| < 2.5$
	jets	$p_{T,j1}$ >55 GeV, $p_{T,j1}$ >40 GeV, $\|\eta\| < 4.5$
	bosons	$\Delta(m_Z, m_{\ell\ell})$ <10 GeV
	further jets	p_T >25 GeV, none in interval between leptons
	event	p_T^{balance} <0.15 (see Eq. **??**)
	final BSM region	m_{jj}: 0.8-1.2 TeV, >1.2 TeV
Vectorboson Scattering		
Final state	Object	Selection requirements
WW VBS / $WWjj$ same-sign	**leptons**	p_T >20 GeV, $\|\eta\| < 2.5$, same-sign
	jets	$p_{T,j1}$ >30 GeV, $p_{T,j1}$ >30 GeV, $\|\eta\| < 4.5$, $\Delta\eta_{jj}$ >2.5
	final BSM region	m_{jj}: 0.25-0.5 TeV, >0.5 TeV
$Z\gamma$ VBS / $Z\gamma jj$	**leptons**	p_T >35, $\|\eta\| < 2.5$
	photons	E_T >75, $\|\eta\| < 2.5$, $\Delta R(\ell/j, \gamma) > 0.4$
	bosons	$\Delta(m_Z, m_{\ell\ell})$ <10 GeV
	jets	$p_{T,j1}$ >30 GeV, $p_{T,j1}$ >30 GeV, $\|\eta\| < 4.5$, $\Delta\eta_{jj}$ >3.0
	final BSM region	m_{jj}>0.5 TeV
WZ VBS /	**leptons**	$p_{T,\text{lead}}$ >25 GeV, p_T >15 GeV, $\|\eta\| < 2.5$
	neutrinos	$(\sum \vec{p}_\nu) > 30$ GeV
	jets	$p_{T,j1}$ >55 GeV, $p_{T,j1}$ >40 GeV, $\|\eta\| < 4.5$
	bosons	$\Delta(m_Z, m_{\ell\ell})$ <25 GeV
	further jets	p_T >25 GeV, none in interval between leptons
	event	p_T^{balance} <0.15 (see Eq. **??**)
	final BSM region	m_{WZ}: 0.8-1.0 TeV, >1.0 TeV
ZZ VBS / $ZZjj$	**leptons**	p_T >25 / 15 / 10 GeV (leading leptons), $\|\eta\| < 2.5$
	jets	$p_{T,j1}$ >55 GeV, $p_{T,j1}$ >40 GeV, $\|\eta\| < 4.5$
	bosons	$\Delta(m_Z, m_{\ell\ell})$ <25 GeV
	further jets	p_T >25 GeV, none in interval between leptons
	event	p_T^{balance} <0.15 (see Eq. **??**)
	final BSM region	m_{WZ}: 0.8-1.0 TeV, >1.0 TeV

Consistent comparisons/combinations

- For **any** consistent comparison/combination:
  Common definitions are useful if not strictly *needed*

- Discussed and not found to be too different, but not (yet) put into writing
  - Common pre-defined RIVET routines could be helpful here too
  - As definitions of formats on how to to put stuff into HEP data
    (and what systematic sources to quote)

- All of this would be work to be very difficult to do post-factum
  - (if we measured completely different things in Run-2 and then decided to combine/compare -> "*good luck!*")

Object (Truth) Definition in ATLAS and CMS
—
LHC EWWG Multiboson

Overview by LHC EWWG Multiboson

ATLAS public documents

- A public document from ATLAS side exist
  https://cds.cern.ch/record/2022743

- Motivation: More precise measurements and theory predictions -- use observables that allow:
  - Accurate comparison of theoretical and experimental results
  - Unambiguous comparison to future measurements possible
  - Minimal knowledge of experimental or model-dependent definitions of the final state objects.

- Based on the stable particles that enter in the detector and their physical parents
- Minimal extrapolation but simple and streamlined fiducial region (i.e. same η-range for electrons and muons)

Lepton definition

- Use promt leptons → no association to W, Z.. mother particles needed
- Definition using mother particles are equivalent (where information is availabl but *not model-independent → **use prompt leptons**
- What about QED Final state radiation (FSR)? → leads to different leptons
  - **Born leptons:** leptons prior to FSR - defined by LO diagram in α_{QED}
    Not strictly physical, neglect interference between initial and final state QED radiation in W/Z
  - **Bare leptons:** leptons "after QED FSR", depend on technical details of implementation of QED radiation on MC generators
  - **Dressed leptons:** using a cone of dR<0.1 around bare lepton and adding all prompt photons to lepton can remedy model-dependence of final state leptons, negligible impact of ISR photons
    Dressed lepton measurements can be directly combined! (difference electron-muon < 0.1%)

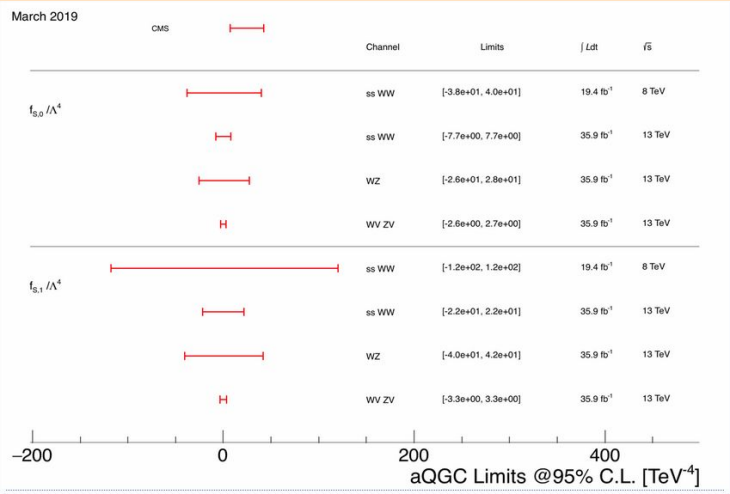
Jet flavour

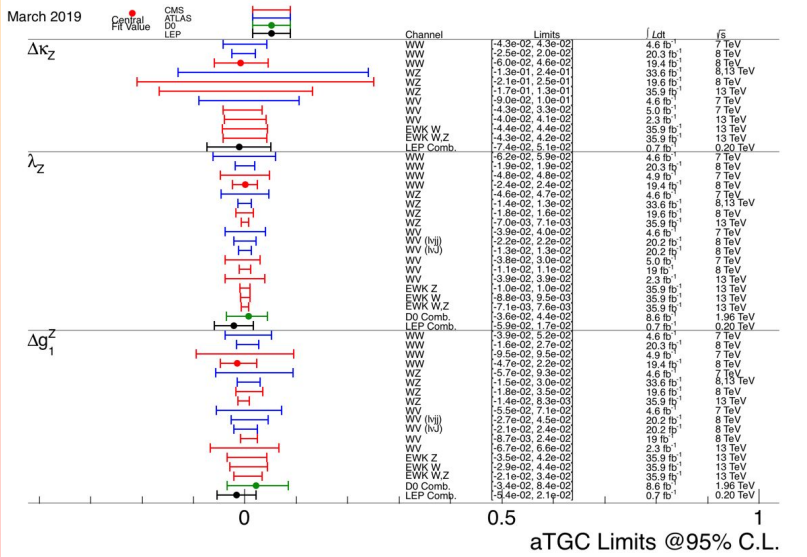
- **Ghost association:**
  - HF hadrons do not fullfill lifetime criterium for stable particles → excluded from jet finding
  - Can be *included* nonetheless as infinitifely small momentum particles (i.e. do not change pT)
  - Can then be associated to a jet → ghost-association
  - HF jet is:
    - A b-jet if contains at least 1 ghost-associated b-hadron
    - A c-jet if contains at least 1 ghost-associated c-hadron but no b-hadron

- How is this implemented in e.g. Rivet?

Status of the anomalous couplings Summary Plots

- Matthew Herndon and Marc-Andre Pleier in charge of updating them
- Latest plots can be found in the [CMS public twiki]
- Plots are up-to-date to before SM@LHC
  - Analyses with a factor of 200 worse in sensitivity have been removed
- Criteria for inclusion/exclusion never really discussed
  - To keep the number of measurements in a given plot to a reasonable level
  - So far, some cutoff relative to the best measurement for a particular operator
- Help or comments on style always very welcome!





2. Predictions for Multibosons: state-of-the-art and best-practise

What's in the making

- Review of Theory status of
  - **VV** (Kallweit/Wiesemann)
  - **VBF** (Lindert)
  - **VBS** (Pellen/Zaro)
  - **Tribosons** (Schönherr)

- Review of MC tools for multibosons
  - Herwig (Bellm)
  - MG5_aMC@NLO (Zaro?)
  - Powheg (Re)
  - Sherpa (Siegert)

3. Predictions for Multibosons: MC/phenomenological studies

Talk by J. Lindert

Talk by M. Schönherr

Talk by K. Lohwasser

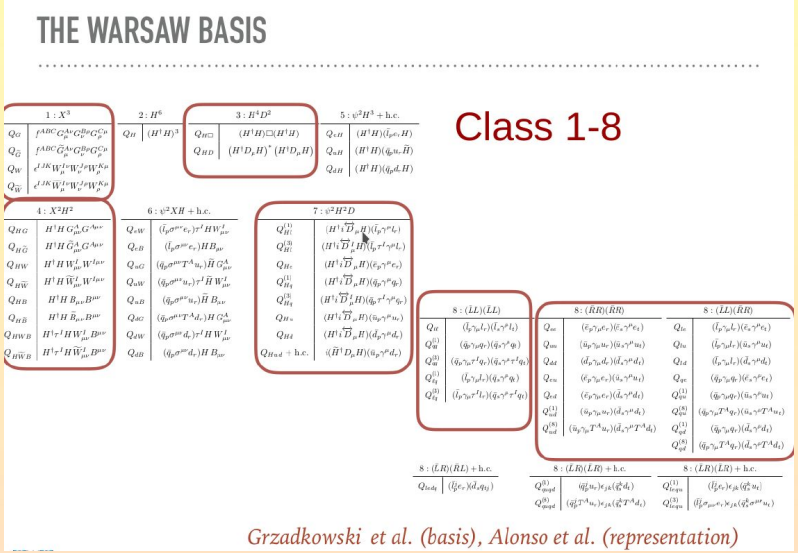
4. Fiducial cross-section and BSM

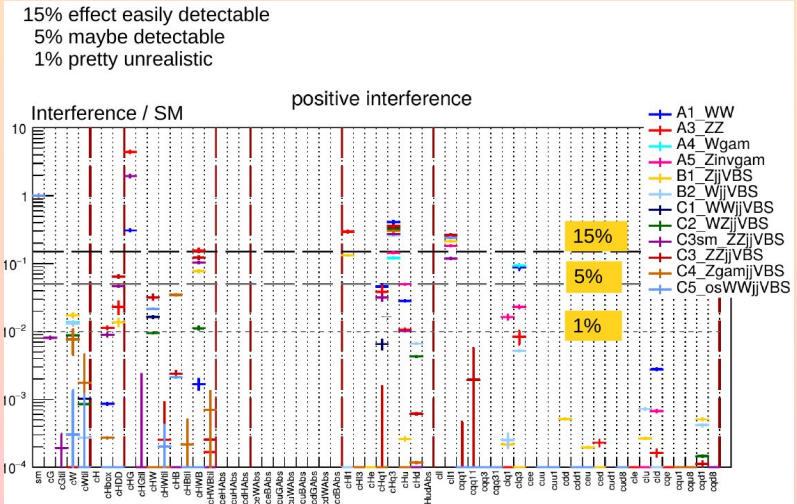
- Recommendation for how to treat DimO6 SMEFT theory (Warsaw basis)

- Which operators interesting for which process?
  (survey using rough phase spaces)

- Use benchmark phase spaces?

  R. Gomez Ambrosio,
  K. Lohwasser
- C. Degrande





Summary

- Yellow Report: things are marching, expect draft **end of summer**
  - Some items need contribution (RIVET routines, MC comparisons)

- Combinations: discussions should start/continue
- Simulators show differences, sometimes even when the setup should be equivalent
  - 4 leptons: YSF and Photos yield some differences…
  - VBS comparisons using RIVET show striking differences in ssWW
  - Call for volunteers to check other processes in CMS/ATLAS/Theory comparison
    - VBF processes could be equally interesting (mjj modelling) -> esp. b/c of BDT usage -> V+jets group ?
    - ZZ -> 4l lineshape (difficult to get the contributions right, and similar issues as WW)
  - The more people can provide comparison studies, the better we can understand what is going on!