Summary: EW multi-boson production

- Aims formulated last year
- General progress and activities
- Current stage
- Outlook

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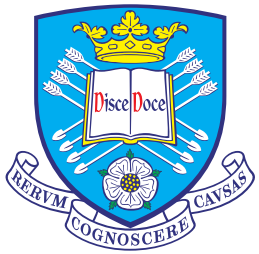


The University Of Sheffield.

Last year's outlook: Multibosons Objectives

> Three main topics:

- Discuss and/or converge on ***discrepancies in the measurements***
- Discuss between ATLAS, CMS and Theory Community on ***future application of EFT***, and converge on matters concerning anomalous couplings
- Consolidate and Comine: Summary plots with common style, ***Documentation of recommendations, Combination efforts*** (long-term)

> Ideas for documentation effort (yellow report)

- Overview of current results of ATLAS/CMS results (very brief, since there are 1-2 review papers already)
- Prospectives for dibosons at LHCb
- Overview of Generators / MC for diboson (including new calculations and pub-data/MC comparisons)
- Description of EFT models (+Relations between those (translating them back and forth!)
- Add relations between EFT parameters and other direct models?
- Add instructions on how to combine / use ZZ as example / preparation *between* experiements, whilst in the same group combinations between ATLAS internal analysis would be evaluated

> Taken from last year's workshop and it's summary

- https://indico.cern.ch/event/678694/

- ***So what has happened since then?***

Last year's activities

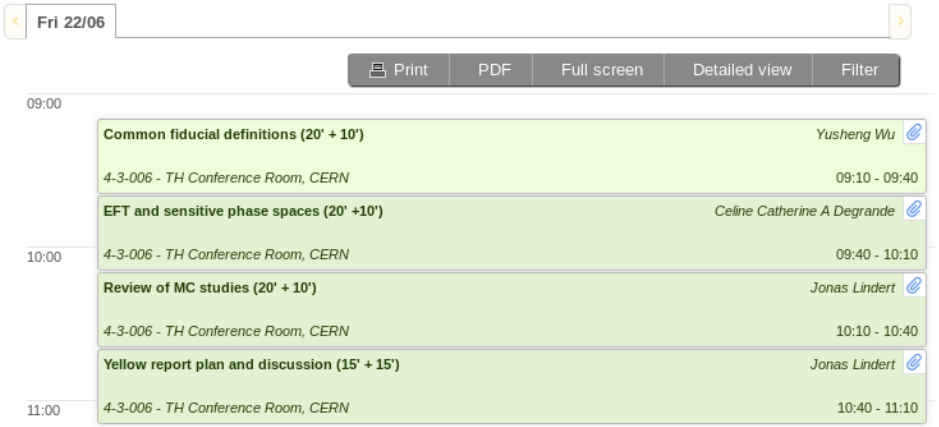
> Relatively regular meetings

- About 10 since last year (excluding small discussions for specific projects)

> Some change in convenors/YR editors

- Incoming ATLAS: Louis Helary, Shu Li (Kristin Lohwasser, Yusheng to stay as editors)
- Incoming CMS: Pietro Vischia (Chia Ming to stay on) [relatively recent and after other changes over the summer]

> Halftime!



Discuss / converge on measurements

> **Two different approaches:**

1) Aposterio: extrapolations between the measurements

example: ZZ (slightly different pairing, pT cuts and Z-Mass window)

Binnings in GeV:

ATLAS	0, 5, 15, 25, 35, 45, 55, 65, 75, 85, 100, 125, 150, 200, 250, 1500
CMS	0, 25, 50, 75, 100, 150, 200, 300
Combined	0, 25, 50, 75, 100, 150, 200, 300

Challenges:

ATLAS published $\frac{d\sigma}{dx}$, CMS published $\frac{1}{\sigma}\frac{d\sigma}{dx}$

I quickly read CMS data off plots with exponential y-axes — very inaccurate *(apologies!)*

Stefan Richter

Converge on measurements: Aposteriori

Intrapolation matrix I relating the histogram c in the intersecting phase space to that in the experiment's phase space, e

$$c_i = I_{ij} e_j \tag{1}$$

$$I_{ij} = M_{ij}\, \varepsilon_j\, \phi_i \tag{2}$$

M_{ij} describes the *bin migrations*:

$$M_{ij} = \frac{P(\text{in intersection bin } i \cap \text{in experiment bin } j)}{\sum_{i'} P(\text{in intersection bin } i' \cap \text{in experiment bin } j)} \tag{3}$$

ε_j is like an *efficiency*:

$$\begin{aligned} \varepsilon_j &= \frac{\sum_{i'} P(\text{in intersection bin } i' \cap \text{in experiment bin } j)}{P(\text{in experiment bin } j)} \\ &= P(\text{in any intersection bin} \mid \text{in experiment bin } j) \leq 1 \end{aligned} \tag{4}$$

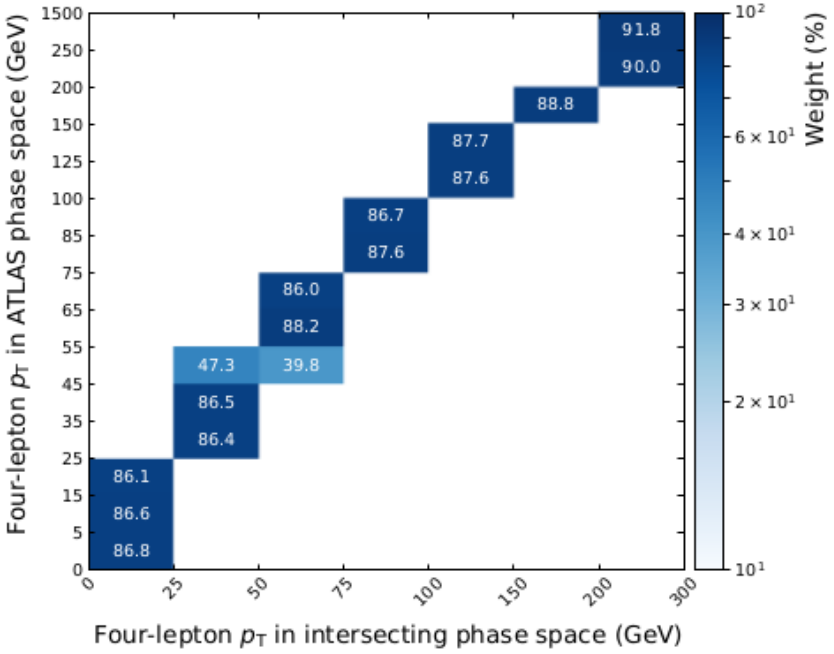
ϕ_i corrects for events falling in the "intersection", but not the experiment's phase space (only possible if it's not truly the intersection!):

$$\phi_i = \frac{P(\text{in intersection bin } i)}{\sum_j P(\text{in intersection bin } i \cap \text{in experiment bin } j)} \geq 1 \tag{5}$$

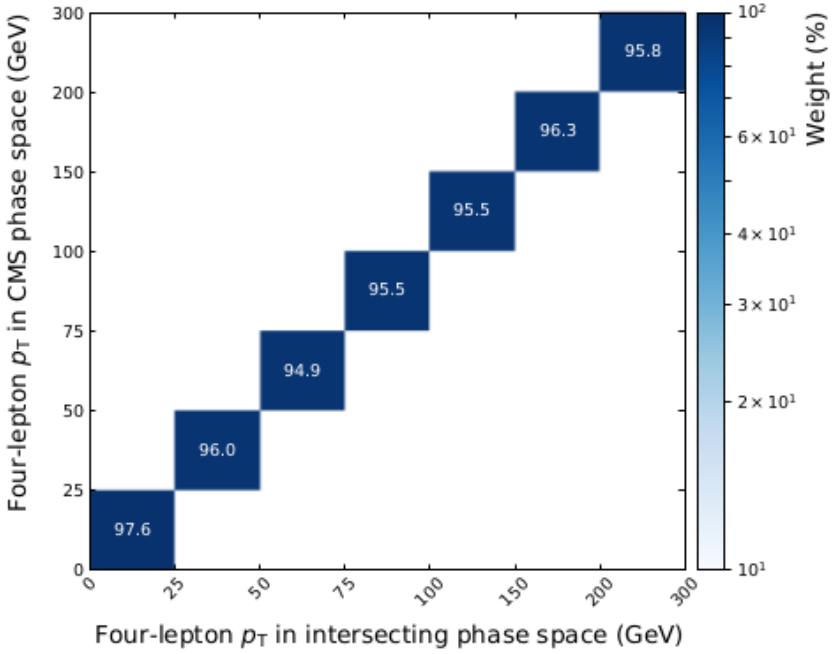
Stefan Richter

Converge on measurements: Aposteriori

ATLAS → intersection



CMS → intersection

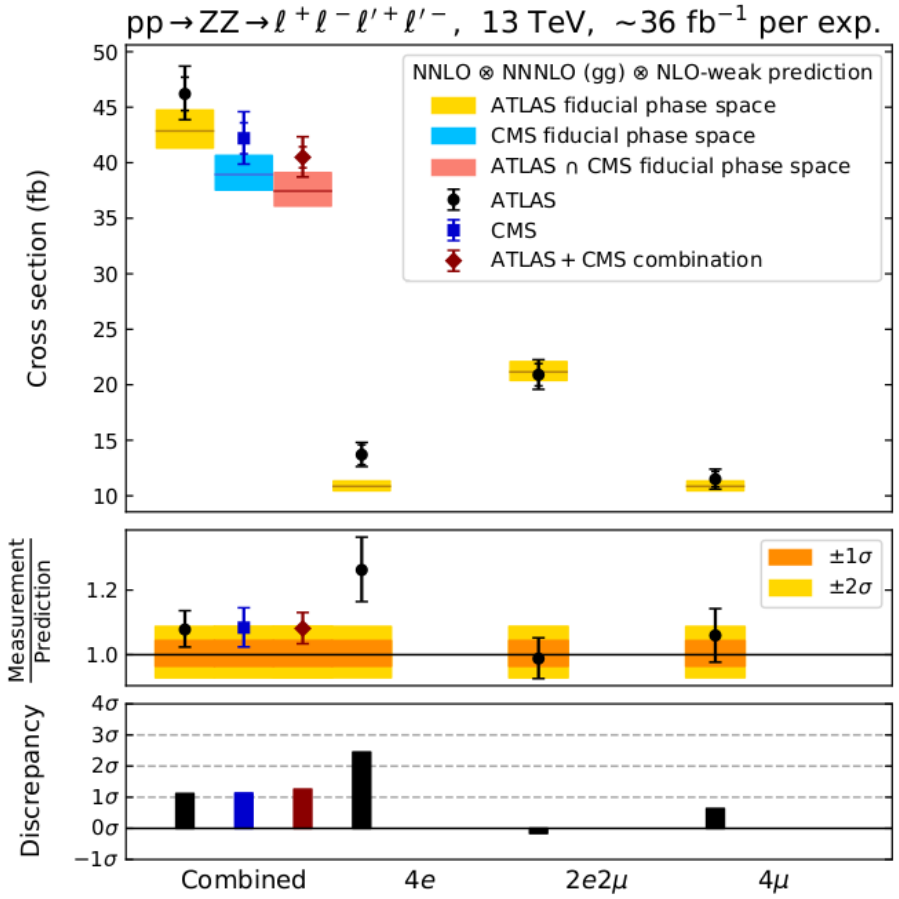


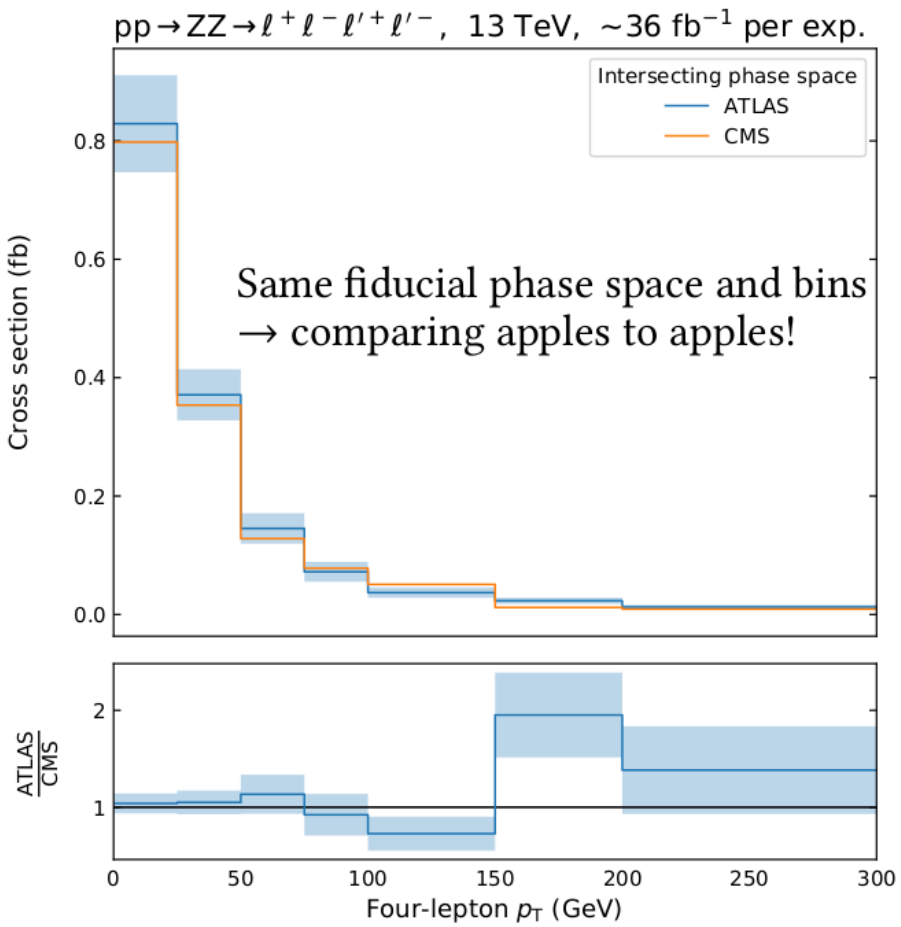
Using SHERPA pp → $\ell^+\ell^-\ell'^+\ell'^-$ + {0, 1} jets @ NLO + {2, 3} jets @ LO

Converge on measurements: Aposteriori

> Nice test of competability

- Information of channel split not available from CMS side unfortunately
- Comparing apples-with-apples also for fiducial distribution





Converge on measurements: Apriori Compromises

> Example: WW analysis

- Relatively extensive discussions beforehands
- Communication on binning and convergence!
- Compromises on selection (i.e. additional work put into further publishing measurements / distributions extrapolated into the agreed phase space)
- Should be intersting to see how well this worked
- However: both papers still in progress :-)
- STAY TUNED!

Discuss / converge on measurements: Documentation

> **Contacted different analysis teams/editors inside collaboration and asked for contributions → Review and Ideas for *common* ATLAS/CMS approaches**

- Status so far – needs to be iterated (for consistency)
- Still a few processes missing (need re-poking!)

Future application of EFT: Goals

- Define common fiducial cross-sections and observables to constraint NP (SMEFT, other?) with multiboson processes
  - Compare Atlas/CMS cuts and observables: which one are the best to constraint NP
- Motivate combination between experiments, channels and observables
  - Ex : WW, WZ, WA all sensitive to the same 3 CP conserving dim-6 operators

C. Degrande

Future application of EFT

Pro

- Can be a first point of reference for any further limit setting fits (i.e. proof that the limits agree)
- easier to combine (i.e. everyone knows what to expect and how to use it)
- Experimental work is rather low (once phase space is fixed)
- Little model dependence for fiducial and differential cross-sections
- Need a region that both Atlas and CMS can either measure or extrapolate to with minimal theory dependence + common binning for distributions.

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C. Degrande

Future application of EFT

Con

- could be quite some work to create them : converge between experiments
- motivation could be weak : why not just measure differential cross-sections? (production channels are already split efficiently)
- Extra care for the definitions of particles/processes
- not sure what can be gained

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C. Degrande

Future application of EFT: Other issues

- **Theorists quote limits based on "control plot"**
  - Without detector corrections, could be up to 50% wrong (reco efficiency!!!)
  - No way to compare to theory results or experimental results on equal footing
  - Hard for theorists to give concrete suggestions that might be adapted by experiments
- **Difference between limits between experiments**
  - Hard to debug if people are gone - hard to redo limits (if based on detector-level), result is ~gone
- **What operators to study?**
  - Seen cases, where just a couple are tested as example -- but are these those, where measurement can provide the best input / is most important?
  - Could give overall picture to guide people, which operators are best checked for which measurements → but for this need benchmark regions
- **Can answer whether an approach is better than the "benchmark"**
  - E.g. BDT study with STXS has shown, that not necessarily better than BDT trained for EFT
  - Allows experiments to shine, and show where they are better than average
- **What happens if we "see" something?**
  - E.g. Is it due strong production mismodelling (i.e. MBI+2jets) ?

Future application of EFT: First proposal

> Rough average between ATLAS/CMS phase spaces
> Any of these regions should be statistics dominated

Vectorboson Fusion		
Final state	Object	Selection requirements
Z VBF / Zjj	**leptons**	$p_{\mathrm{T,lead}}$ >25 GeV, $\|\eta\| < 2.5$
	jets	$p_{\mathrm{T,j1}}$ >55 GeV, $p_{\mathrm{T,j1}}$ >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	$p_{\mathrm{T}}^{\mathrm{balance}}$ <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	$p_{\mathrm{T,j1}}$ >30 GeV, $p_{\mathrm{T,j1}}$ >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, $\|\eta\| < 2.5$, $\Delta\mathrm{R}(\ell/j, \gamma) > 0.4$
	bosons	$\Delta(m_Z, m_{\ell\ell})$ <10 GeV
	jets	$p_{\mathrm{T,j1}}$ >30 GeV, $p_{\mathrm{T,j1}}$ >30 GeV, $\|\eta\| < 4.5$, $\Delta\eta_{jj}$ >3.0
	final BSM region	m_{jj}>0.5 TeV
WZ VBS /	**leptons**	$p_{\mathrm{T,lead}}$ >25 GeV, p_{T} >15 GeV, $\|\eta\| < 2.5$
	neutrinos	$(\sum \vec{p}_{\nu}) > 30$ GeV
	jets	$p_{\mathrm{T,j1}}$ >55 GeV, $p_{\mathrm{T,j1}}$ >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	$p_{\mathrm{T}}^{\mathrm{balance}}$ <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	$p_{\mathrm{T,j1}}$ >55 GeV, $p_{\mathrm{T,j1}}$ >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	$p_{\mathrm{T}}^{\mathrm{balance}}$ <0.15 (see Eq. **??**)
	final BSM region	m_{WZ}: 0.8-1.0 TeV, >1.0 TeV

Diboson 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**	$p_{\mathrm{T,lead}}$ >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. **??**), $\Delta(m_Z, m_{\ell\ell})$ <15 GeV
	final BSM region	$m_{\mathrm{T},WZ}$: 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, $\|\eta\| < 2.5$, $\Delta\mathrm{R}(\ell, \gamma) > 0.7$
	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
$Z(\to \ell\ell)\gamma$	**leptons**	p_{T} >35, $\|\eta\| < 2.5$
	photons	E_{T} >25, $\|\eta\| < 2.5$, $\Delta\mathrm{R}(\ell, \gamma) > 0.4$
	bosons	$\Delta(m_Z, m_{\ell\ell})$ <10 GeV
	final BSM region	$p_{\mathrm{T},\gamma}$: 100-250 GeV, >250 GeV
$Z(\to \nu\nu)\gamma$	**photons**	E_{T} >25, $\|\eta\| < 2.5$, $\Delta\mathrm{R}(\ell, \gamma) > 0.4$
	neutrinos	$(\sum \vec{p}_{\nu}) > 30$ GeV
	final BSM region	$p_{\mathrm{T},\gamma}$: 100-250 GeV, >250 GeV

Future application of EFT: Progress

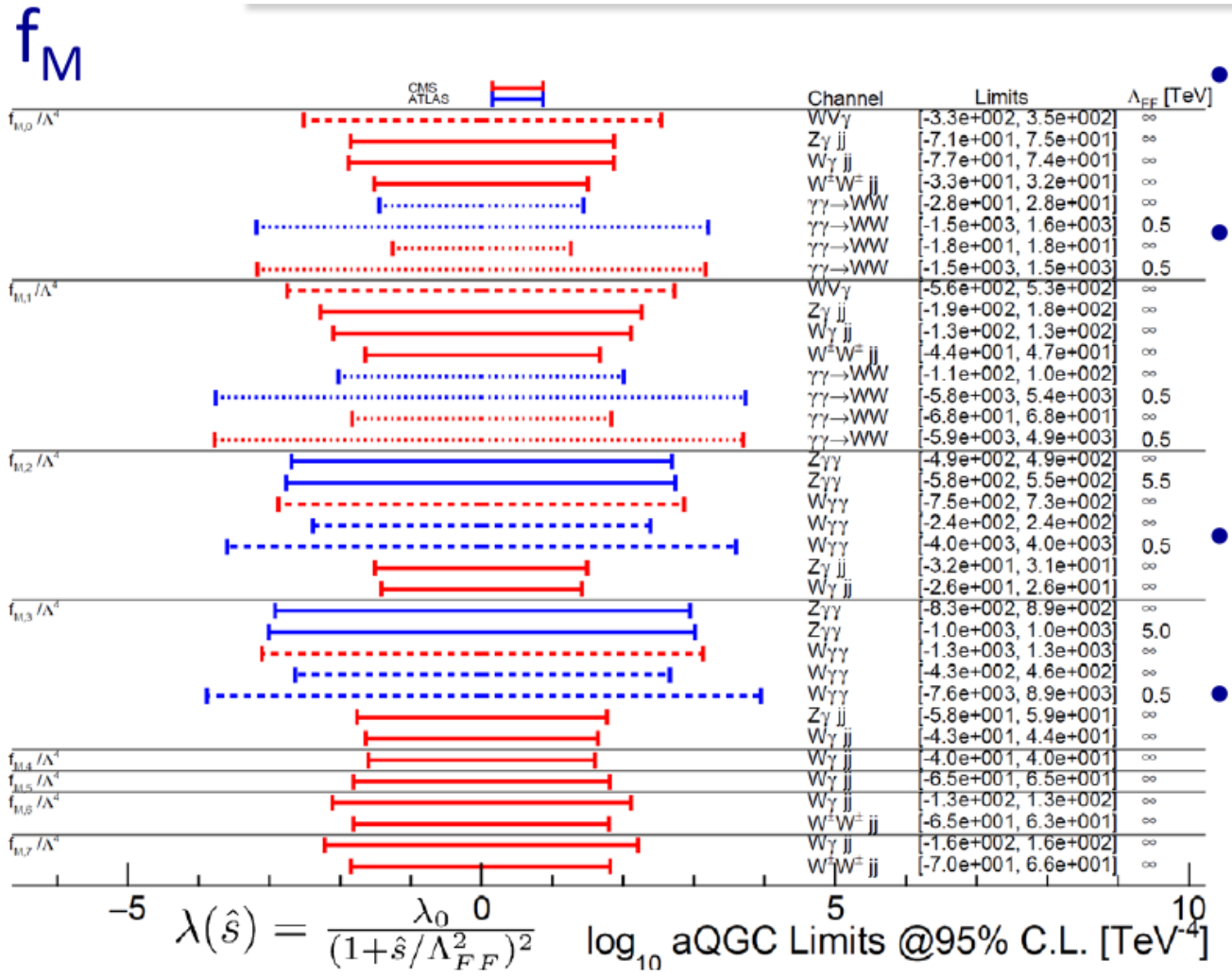
> Current status

- Reported by Raquel Gomez yesterday
- Studying impact of operators in SMEFT Warsaw basis framework
  → full dimension-6 Lagrangian (including the Higgs, top)
- Studying linear terms (→ need to investigate more, will have discussion next year)
- Compromises on selection (i.e. additional work put into further publishing measurements / distributions extrapolated into the agreed phase space)

> Questions to be answered

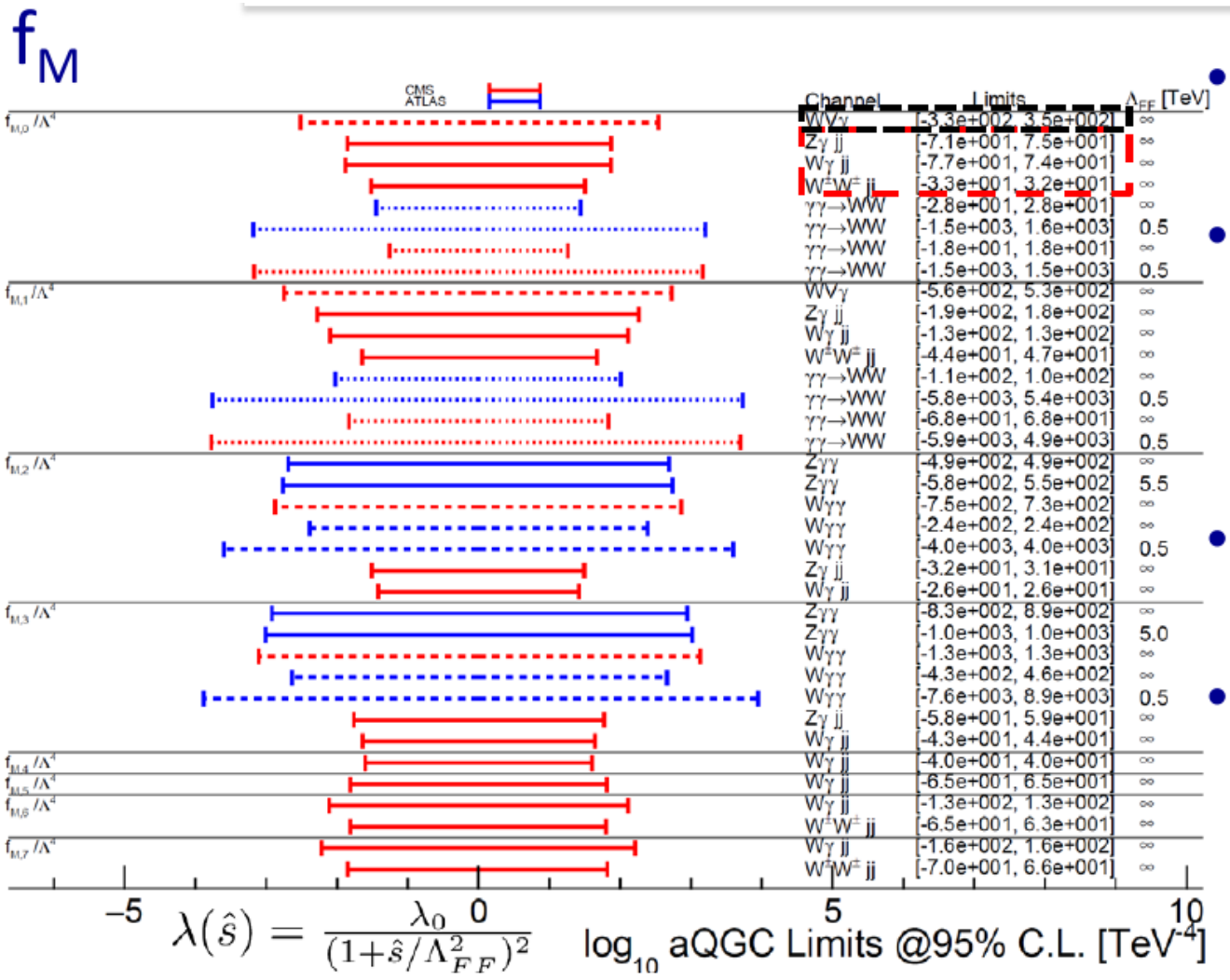
- What is affected by how much?
- Which processes “overlapp” and should/could be combined
- Can we convince the experiements to agree on some BSM phase space?

Current aTGC overview plots (example from a talk)



- All results use full 8 TeV datasets
- Trend that exclusive outperforms VBS, which is better than VVV
- Note **strong** impact of unitarisation
- Fair comparison requires some work

Example slides



- All results use full 8 TeV datasets
- Trend that exclusive outperforms VBS, which is better than VVV
- Note **strong** impact of unitarisation
- Fair comparison requires some work

Current plans for updates

> **for overview over operators:**
- Plot only best / second best constraints
  (same color – hatched/non-hatched for ATLAS/CMS to distinguish experiments)

> **For overview over sensitivities**
- Plot only ONE operator for different channels
- (could add rough conservative combination? Or estimate of combination?)

> **Slightly low on manpower**
- (again lost some over the year)

- https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SummaryPlots
- Mailing list: LHC-EWWG-MB-SummaryPlot@cern.ch
- Currently concentrating on limit summary plots
  (in future perhaps also cross sections)

Theory comparisons

> **Comparison of Theory Codes to describe Multiboson measurements**
- What are the differences?
- What are issues?
- What are strengths/weaknesses?
- What are recommendations for experiments?

> **NNLOPS vs. multi-jet merging for WW**
- (M. Wiesemann, E. Re – Powheg, J. Lindert, Alan Price, F. Krauss – Sherpa)

> **NLO EW for WW & ZZ vs. YFS for line-shape**
- (by Alan Price - Sherpa)

Theory comparisons: Concluded projects

> **NLO EW for VVV**
(Marek Schoenherr)
https://indico.cern.ch/event/765404/contributions/3177059/attachments/1735708/2807338/WWW_MarekSchoenherr.pdf)

Triboson production

- triboson production clean testbed to test EW quartic couplings
- contribs from

signature	process	resonance structure
0 SFOS	$e^- \mu^+ \mu^+ \bar{\nu}_e \nu_\mu \nu_\mu$	WWW
1 SFOS	$e^- e^+ \mu^+ \bar{\nu}_e \nu_e \nu_\mu$	$WWW + WZZ$
	$e^- e^+ \mu^+ \bar{\nu}_\mu \nu_\mu \nu_\mu$	WZZ
	$e^- e^+ \mu^+ \bar{\nu}_\tau \nu_\tau \nu_\mu$	WZZ
2 SFOS	$e^- e^+ e^+ \bar{\nu}_e \nu_e \nu_e$	$WWW + WZZ$
	$e^- e^+ e^+ \bar{\nu}_{\mu/\tau} \nu_{\mu/\tau} \nu_e$	WZZ

  and $e \leftrightarrow \mu$
- exchange $+ \leftrightarrow -$ for $W^+W^-W^-$ production
- main backgrounds: $t\bar{t}W$, $tWW \Rightarrow$ apply jet veto
  WZ in 1, 2 SFOS $\Rightarrow$ req. large $\not{p}_T$, $m_{\ell\ell}^{\text{SFOS}} \not\approx m_Z$

Theory comparisons: Concluded projects

Results for LHC EW WG

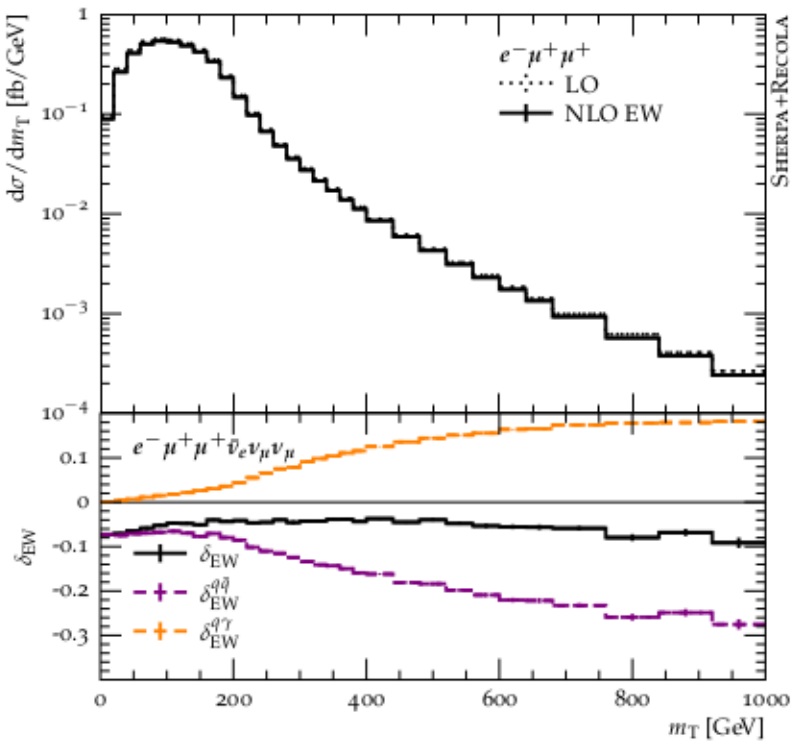
:807

Selection	Cut	Value
general	$p_{\mathrm{T}}(\ell)$	$[20\,\mathrm{GeV}, \infty)$
	$y(\ell)$	$[-2.5, 2.5]$
	$\Delta R(\ell, \ell)$	$[\mathbf{0.1}, \infty)$
	$\Delta\phi(\not{p}_{\mathrm{T}}, \ell\ell\ell)$	$[\mathbf{2.5}, \pi]$
0 SFOS	$\mathbf{m}_{\ell\ell}^{\mathrm{SF}}$	$[\mathbf{20}\,\mathrm{GeV}, \infty)$
	$\mathbf{m}_{\ell\ell}^{\mathrm{eeSS}}$	$[\mathbf{0}, \mathbf{m_Z} - \mathbf{15}\,\mathrm{GeV}] \wedge [\mathbf{m_Z} + \mathbf{15}\,\mathrm{GeV}, \infty)$
1 SFOS	$\not{p}_{\mathrm{T}}$	$[\mathbf{45}\,\mathrm{GeV}, \infty)$
	$m_{\ell\ell}^{\mathrm{SFOS}}$	$[\mathbf{0}, \mathbf{m_Z} - \mathbf{35}\,\mathrm{GeV}] \wedge [\mathbf{m_Z} + \mathbf{20}\,\mathrm{GeV}, \infty)$
2 SFOS	$\not{p}_{\mathrm{T}}$	$[\mathbf{55}\,\mathrm{GeV}, \infty)$
	$m_{\ell\ell}^{\mathrm{SFOS}}$	$[\mathbf{0}, \mathbf{m_Z} - \mathbf{20}\,\mathrm{GeV}] \wedge [\mathbf{m_Z} + \mathbf{20}\,\mathrm{GeV}, \infty)$

- similar selection as before (differences marked in **red**)
- otherwise same setup as above

Theory comparisons: Concluded projects

Results for LHC EW WG – 0 SFOS channel ($e^-\mu^+\mu^+$)



- similar findings as before
  - modest EW corrections in $q\bar{q}$ channel
  - rel. large corrections from γ-induced jet production

  $\rightarrow$ large accidental cancellations

  $\rightarrow$ net NLO EW correction small
- large dependence on fiducial phase space definition and observable

Theory comparisons: Documentation

> **Editors for YR documentation “State-of-the-art & best practise”:**

> - VV: M. Wiesemann, S. Kallweit
> - VBS: M. Zaro, M. Pellen

> VBF-V to be determined

ATLAS/CMS MC comparisons

> Comparison of MC used by ATLAS/CMS

- So far particular interest for VBS measurement (where cross section is often determined as signal-strength x SM prediction)
- Using general theory-Rivet routines (close to ATLAS/CMS phase space)

> Good progress for ssWW

(Ankita Mehta, Xavier Janser, Marjorie Shapiro)

- Yoda files from CMS for signal and control regions
- Comparisons for signal and QCD background
- ATLAS has distributions but is waiting for the release of a PUB note to share yoda files

> WZ VBS: First discussions

(Kenneth Long, Karolos Potaminos)

Summary

> Progress over the year

- Started on documentation of different processes for ATLAS/CMS
- Started work on quantifying sensitivities to a genuine EFT Lagrangian (should also formulate this as explicit recommendation)
- Theory comparisons progressing very well
  Work on ATLAS/CMS MC comparisons started

> Some hope to have Full Run-2 recommendations

- Though some problems with manpower

BACKUP