SM@LHC Electroweak Session Discussion

Alessandro Tricoli, Stefano Pozzorini, Emanuela Barberis

SM@LHC 2017, Amsterdam

Topics of discussion

Focus on few selected topics that came up during discussion/questions (rather review talk) that may affect transversally all EW (and QCD) processes at the interface between Experiment/Theory

1. W mass
2. Drell-Yan
3. V+jets
4. Di-bosons

We thank all speakers for very nice and informative talks

We also thank all who contributed to the lively discussions

Thanks to the organisers for arranging such a nice meeting!

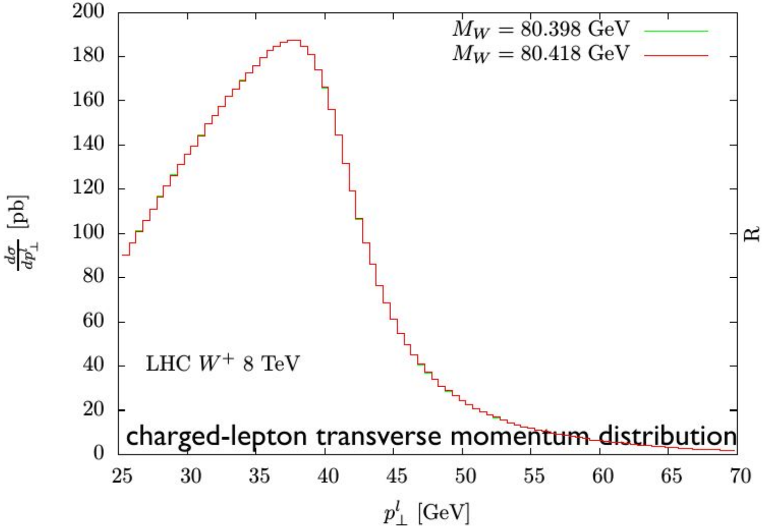
W-mass

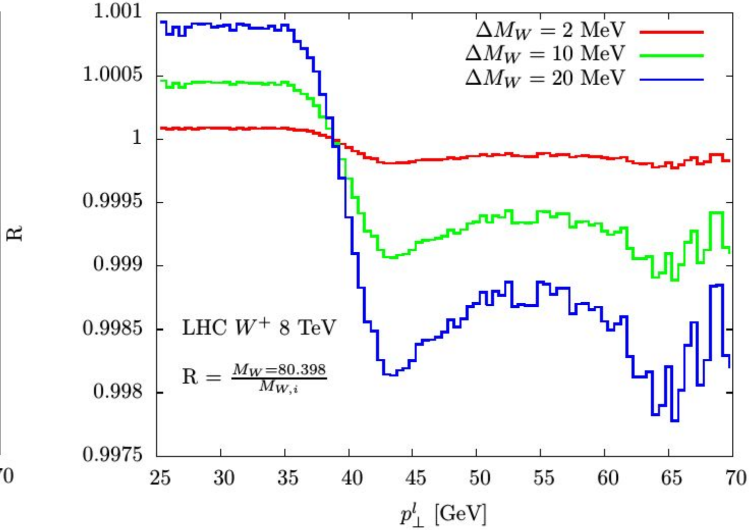
2017 LHC (ATLAS)

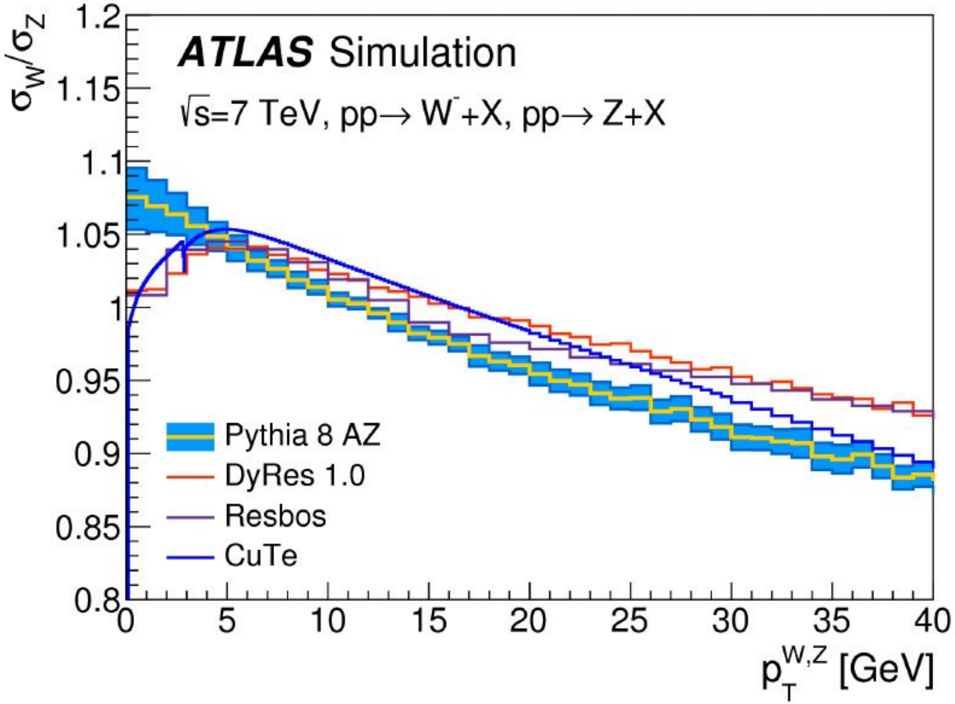
$m_W = 80.370 \pm 0.019$ GeV

MW determination at hadron colliders: observables and techniques

Challenging shape measurement:
a distortion at the few per mil level of the distributions
yields a shift of O(10 MeV) of the MW value



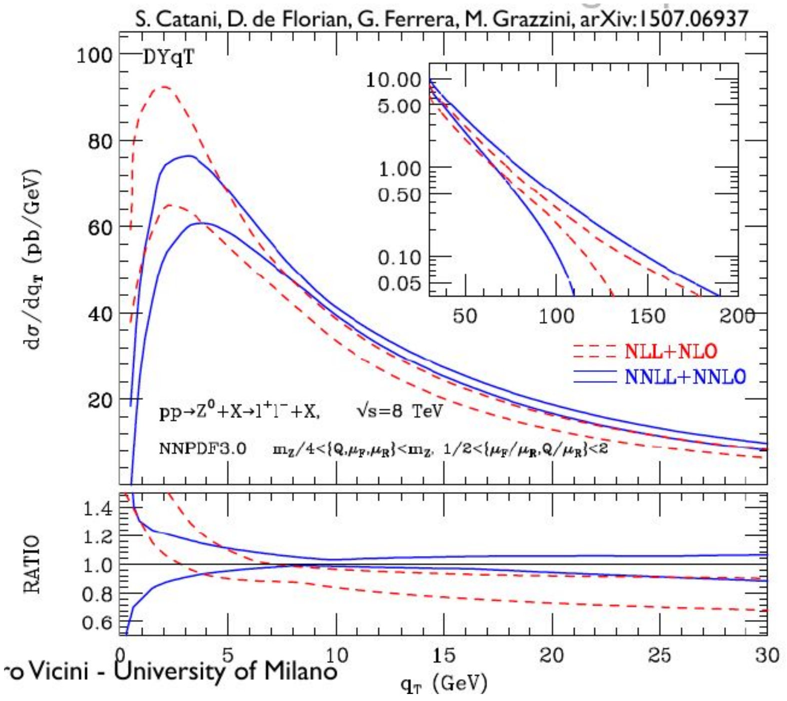




Strategy: reduce TH uncertainty exploiting pp->Z as calibration

Problem: tension between data and NNLO+NNLL in boson-pT shape

Solution: use Pythia with dedicated tune (after careful validation against data)



General questions

- Real tension or neglected TH uncertainty?
- We need more systematic recipes for TH uncertainties in EXP analyses (see A. Vicini)
- Shapes and processes-correlation TH uncertainties are nontrivial but crucial
- Origin of tension (if real)?
- Legitimate to use dedicated Pythia tune?

Answers could benefit various other precision measurements and/or searches!

Questions to theory colleagues

- Can one really extrapolate from Z to W assuming certain cancellations of theory uncertainties (in particular the dreaded scale variations, where resummation needs to be added to the usual suspects)?

- Why are NNLO+NNLL calculations worse than simple parton shower when compared to data? Could this be due to oversimplication of ansatz assuming a sophisticated calculation of a single observable provides more accuracy than a model generating event-by-event kinematics of multiple soft gluon emission? Or is this mostly due an as yet poorly understood treatment of heavy flavours? These play an important role at the LHC, and the contributions are not at all the same for W (charm, strangeness) and Z (bottom).

- How can one solve the bottlenecks in the theory used by PDF fits? Scale variations, parton shower effects, etc

- Is there a way to extrapolate the discrepancies seen between NNLO QCD and data for the Z angular coefficients to the W boson? Presumably experiments need to do the W measurements themselves but the accuracy will always be worse than for Z bosons.

Drell-Yan - I

Many experimental cross sections available by LHC experiments, is this the time to discuss combination of LHC results to (a) compare results in a systematic way (b) strengthen interpretations , e.g. Weinberg angle extraction, PDF ?

- ***Is a extrapolation to a common phase space diluting experimental results?***
- ***Is definition of common phase space for future measurements possible?***

Current approach:

- Each experiment compares/combines DY measurements, e.g. electron and muon channels at different c.m.e. and carries out its own data interpretation
- Delegation to PDF fitting groups the study of compatibility between different experiment results

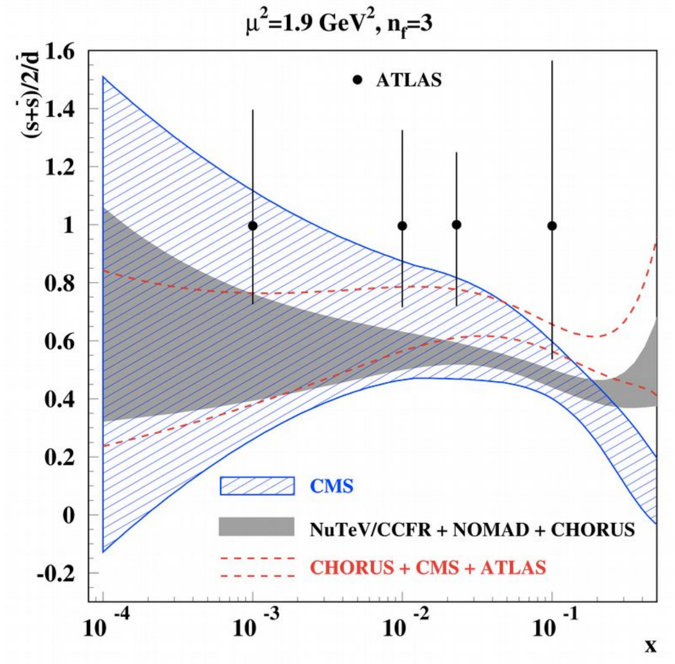
Drell-Yan - II

Is there a risk of over-interpreting data absorbing theory/modeling uncertainties into interpretations?

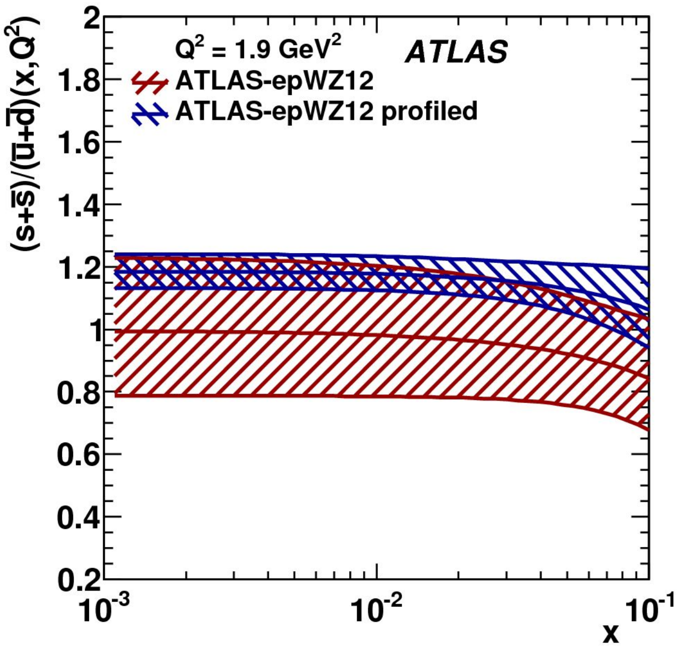
- ***non-perturbative effects into alpha-strong***
- ***scale uncertainties into PDF fits? e.g. gluon-PDF from*** p_T^Z
- ***is strange-quark enhanced at LHC? Is there tension with neutrino-beam data?***
  - LHC experiments often show impact of a specific dataset on PDF interpretation, fitting a specific dataset together with HERA data (HERAFitter tool)
    - ATLAS claims that W/Z data point towards a strange-quark enhancement
  - ABM claims that correlations between strange-quark and d-quark sea may absorb apparent effect of strange enhancement

Drell-Yan - II (strange-quark)

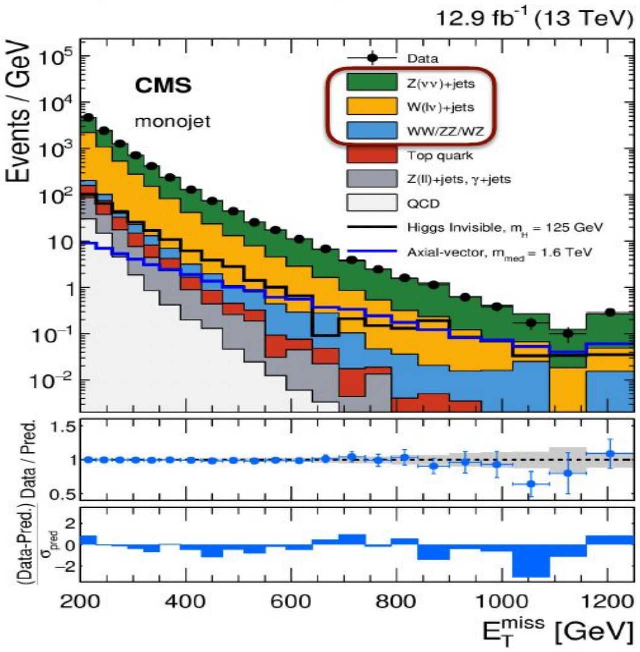
ABM12 study (using old (2011) ATLAS result at 7 TeV) shows good agreement between LHC and NuTeV/CCFR+NOMAD+CHORUS



Latest ATLAS 7 TeV DY measurement interpretation by ATLAS [ArXiv:1612.03016] confirms previous indications of strange-quark enhancement

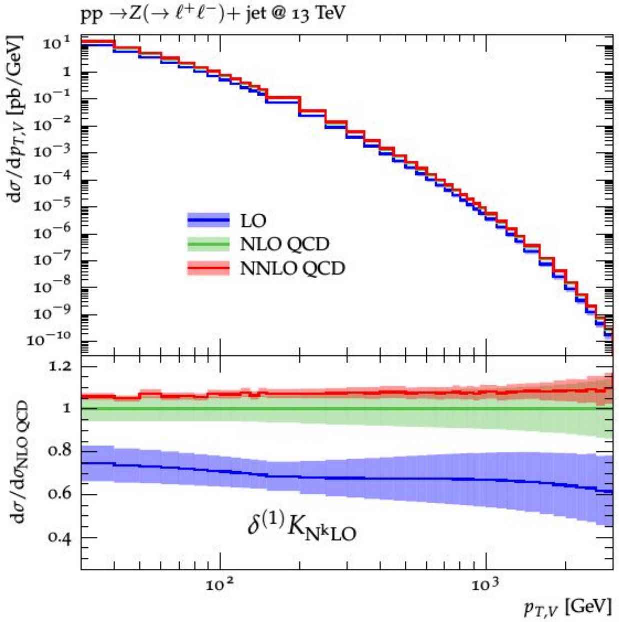


V+jets for MET+jet searches

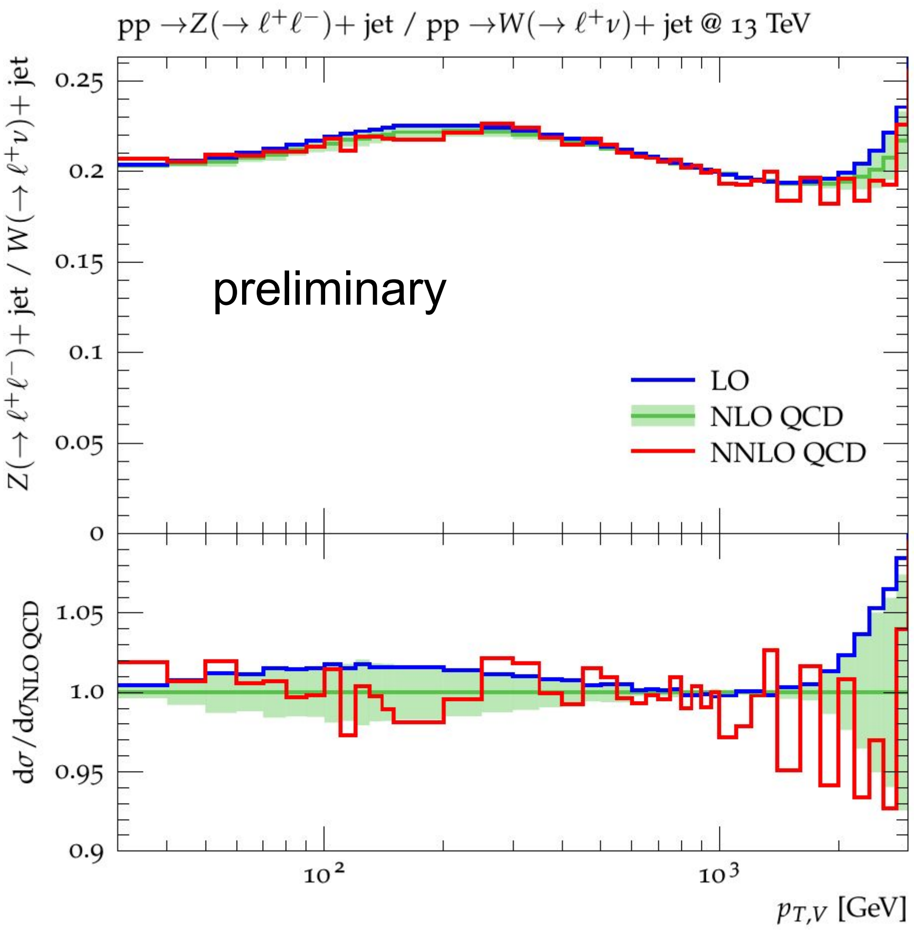


- percent precision at very high pT
- require precise Z(vv)+jet background
- TH extrapolation from W+jet & gamma+jet

NNLO QCD + (N)NLO EW

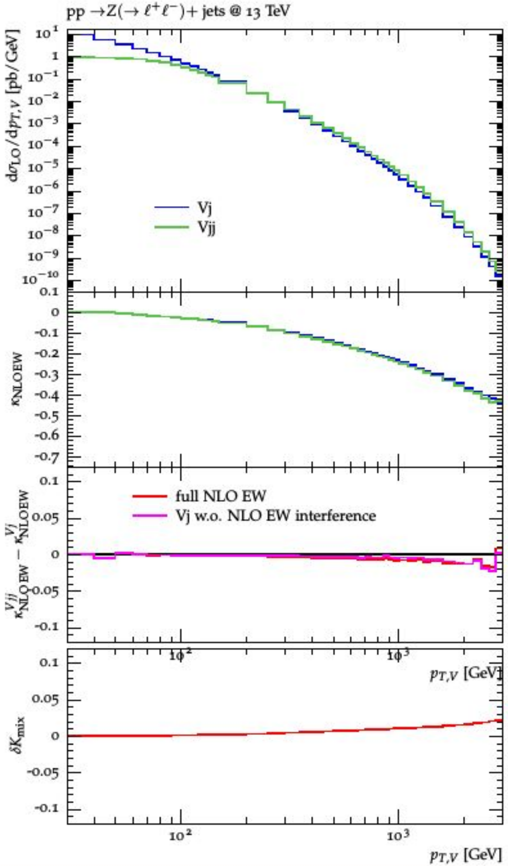


- Correlation across V+jet processes?
- EW+QCD vs EWxQCD combination?
- Validation through precision measurements?



pp →Z(→ ℓ+ℓ−)+ jet / pp →W(→ ℓ+ν)+ jet @ 13 TeV
Z(→ ℓ+ℓ−)+ jet / W(→ ℓ+ν)+ jet
preliminary
LO
NLO QCD
NNLO QCD
dσ/dσNLO QCD
p_T,V [GeV]

Mixed QCD-EW uncertainties



Bold estimate:

Consider real $\mathcal{O}(\alpha\alpha_s)$ correction to V+jet

$\simeq$ NLO EW to V+2jets

and we observe

$$\left.\frac{d\sigma_{\mathrm{NLO\,EW}}}{d\sigma_{\mathrm{LO}}}\right|_{V+2\mathrm{jet}} - \left.\frac{d\sigma_{\mathrm{NLO\,EW}}}{d\sigma_{\mathrm{LO}}}\right|_{V+1\mathrm{jet}} \lesssim 1\%$$

strong support for

- factorization
- multiplicative QCD x EW combination

Estimate of non-factorising contributions

(correlated)

$$\delta K^{(V)}_{\mathrm{mix}}(x) \quad = \quad 0.1\left[K^{(V)}_{\mathrm{TH},\oplus}(x,\vec{\mu}_0) - K^{(V)}_{\mathrm{TH},\otimes}(x,\vec{\mu}_0)\right]$$

(tuned to cover above difference of EW K-factors)

Di-bosons - I

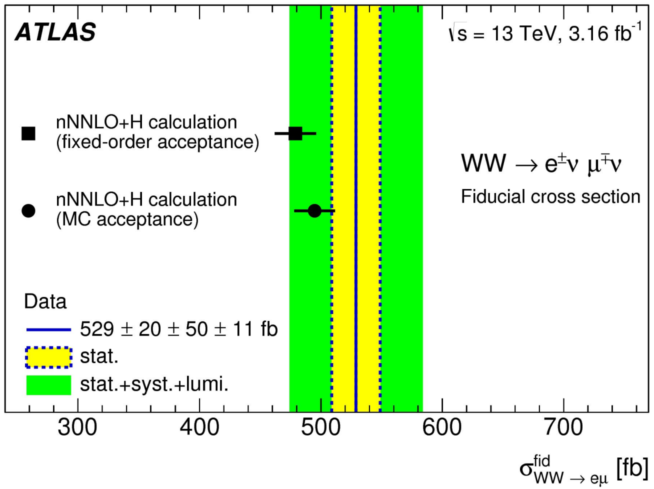
Do we have MC/calculations that allow us to assess in a coherent and systematic way theory uncertainties on Di-boson cross sections and differential distributions?

- ***include fixed-, high-order calculations, resummation, EW corrections***
- ***Allow to assess coherently scale, PDF and possibly at particle level (vs parton)***

Current approach:

- Use an NLO MC to compare results to or to correct fiducial cross section to total cross sections
  - This turned out to be at times dangerous, e.g. jet veto modeling in WW using Powheg
- Take highest possible order in calculation per process and add processes together ignoring interference
  - e.g. in WW: NNLO for qq, NLO for non-resonant gg, N3LO for gg->H->WW

Di-bosons - I (WW example)



Use of best calculations available on market

- e.g. in WW: NNLO for qq, NLO for non-resonant gg, N3LO for gg->H->WW

$pp \to WW$ sub-process	Order of α_s	σ^{tot}_{WW} [pb]	A [%]	$\sigma^{fid}_{WW\to e\mu}$ [fb]
$q\bar{q}$ [9,13]	$\mathcal{O}(\alpha_s^2)$	111.1 ± 2.8	16.20 ± 0.13	$422\ ^{+12}_{-11}$
gg (non-resonant) [33]	$\mathcal{O}(\alpha_s^3)$	$6.82\ ^{+0.42}_{-0.55}$	$28.1\ ^{+2.7}_{-2.3}$	44.9 ± 7.2
$gg \to H \to WW$ [67][30]	$\mathcal{O}(\alpha_s^5)$ tot. / $\mathcal{O}(\alpha_s^3)$ fid.	$10.45\ ^{+0.61}_{-0.79}$	4.5 ± 0.6	11.0 ± 2.1
$q\bar{q}$ + gg (non-resonant) + $gg \to H \to WW$	nNNLO+H	$128.4\ ^{+3.5}_{-3.8}$	$15.87\ ^{+0.17}_{-0.14}$	478 ± 17

Di-bosons - II

Theorists recommendation: move away from aTGC/aQGC formalism with Form Factors and embrace SMEFT formalism for constraining new physics entering VV couplings

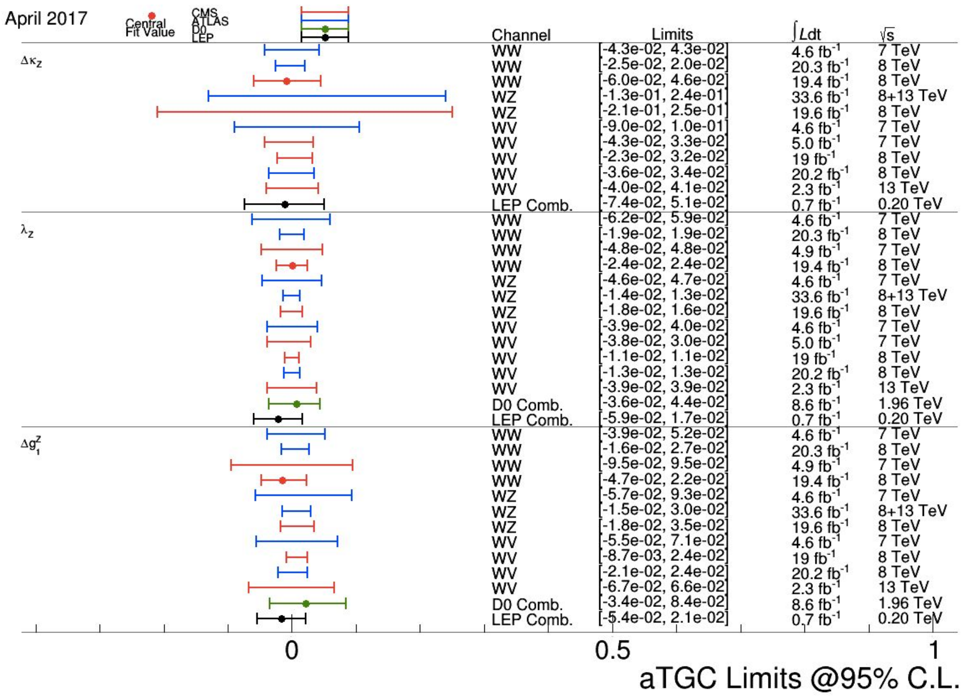
Current experimentalist approach:

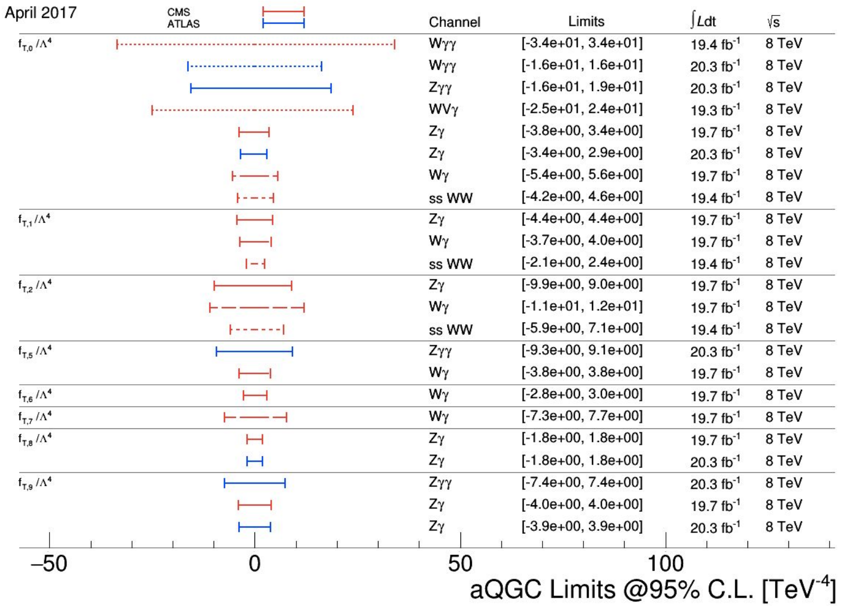
- Limits set on anomalous coupling formalism with or without Form Factors to ensuring unitarity (different methodologies for unitarity restoration)
- Conversion of aTGC/aQGC to EFT formalism

Form Factor $$f \rightarrow f\left(1+\frac{s}{\Lambda}\right)^{-p}$$

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_{i=WWW,W,B,\Phi W,\Phi B} \frac{c_i}{\Lambda^2}\mathcal{O}_i + \sum_{j=1,2} \frac{f_{S,j}}{\Lambda^4}\mathcal{O}_{S,j} + \sum_{j=0,\ldots,9} \frac{f_{T,j}}{\Lambda^4}\mathcal{O}_{T,j} + \sum_{j=0,\ldots,7} \frac{f_{M,j}}{\Lambda^4}\mathcal{O}_{M,j}$$

Di-bosons - II (aTGC and aQGC Examples)





Di-bosons - II

Theorists recommendation: move away from aTGC/aQGC formalism with Form Factors and embrace SMEFT formalism for constraining new physics entering VV couplings

(a) ...However, limits set in tails of distributions, e.g. pT distributions

- *How well do we model tails of distributions (e.g. large high-order QCD and EW corrections)*
  - *How dangerous are the tails*

(b) ...However how can we properly assess impact of multiple operators on a process (Multi-Dim. limit settings)?

- *See interplay between Dim-8 and Dim-6 operators in QGC*

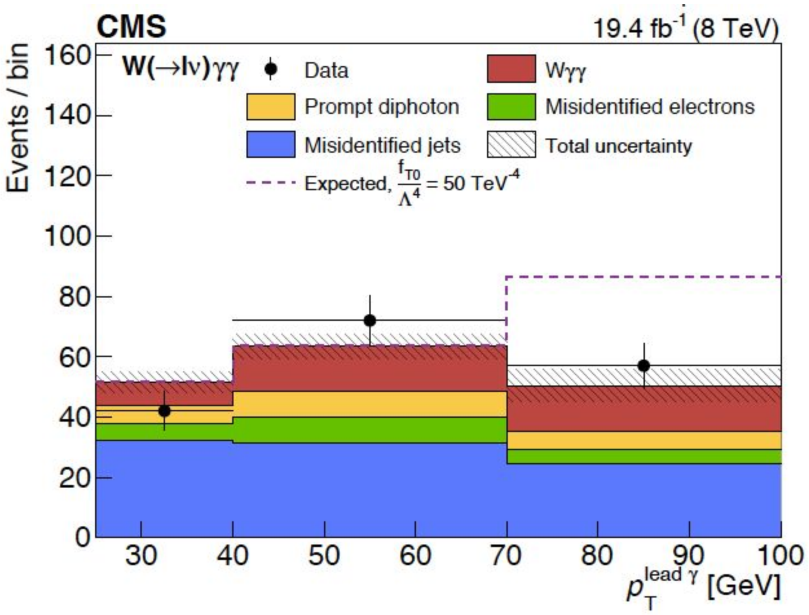
(c) Should experiments interpret their results? How can ensure results be reinterpreted?

- Should experimentalists provide more unfolded distributions (concerns about model dependence) or efficiency correction maps, as done in searches?
- Should theorists develop fast detector simulations that emulate LHC detector performances?

Di-bosons - II (Wγγ Example)

Current experimentalist approach:

- Limits mostly set on detector level distributions on 1 or 2-operators at a time ignoring other operators



$W\gamma\gamma$	Expected (TeV^{-4})	Observed (TeV^{-4})
$f_{M,2}/\Lambda^4$	$[-549, 531]$	$[-701, 683]$
$f_{M,3}/\Lambda^4$	$[-916, 950]$	$[-1170, 1220]$
$f_{T,0}/\Lambda^4$	$[-26.5, 27.0]$	$[-33.5, 34.0]$
$f_{T,1}/\Lambda^4$	$[-34.5, 34.8]$	$[-44.3, 44.8]$
$f_{T,2}/\Lambda^4$	$[-74.6, 73.7]$	$[-93.8, 93.2]$

Thank you