Interpretations of the Run II analyses and implications for BSM physics

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Dedicated reco-level searches

Huge range of dedicated reco-level NP searches
- Extensive supporting material with results to enable reinterpretation
- Inherently model-dependent
- Mitigate with limits in signal grids, efficiency & acceptance for variety of models
  [aspects will be discussed in different WG]

- Limitations on reuse when applied to unanticipated topologies / out of original phase space
- Dependence on accurate detector simulation with limited validation
- Variation of eff/acc not just with object kinematics but multiplicity, presence of other objects...
- How to fully capture model dependence?
SM measurements: differential cross-sections

Various theory papers reinterpreted original ATLAS WW cross-section excess in terms of BSM models.

One such re-interpretation closed gap in SUSY models where mass splittings between EW BSM states small, placing bounds on these scenarios

\[ pp \rightarrow \chi^+\chi^- \rightarrow W^+W^- \chi^0\chi^0 \]

Not assuming SM hypothesis in measurements!
Model-dependence built into systematics and in-situ validation.
SM measurements: EFT fits

Electroweak measurements provide good reinterpretation candidates
- Sensitive to New Phenomena in high-energy tails
- Differential cross-sections particularly sensitive

Unfolded cross-sections and correlations provided but typical so far to characterise NP using EFT at reco-level: assess gain/loss?
SM measurements: EFT fits

Can our aGCs limits be reinterpreted into constraints on masses and couplings of new particles in extensions of the SM?

Concerns:

- For specific model, potentially choose inappropriate energy scale cutoff in deriving aGC: leads to weaker/tighter limits
- Current aGC approaches also do not scan simultaneously over all parameters

Falkowski et al. did show this can work!
SM measurements: EFT fits

LHC WW+WZ data at particle-level used to constrain BSM coefficients

Some discussion in paper about alternative route:
- presentation of full aGC likelihoods by experiments for combinations
- benefit of deriving limits on unfolded data with correlation information
SM measurements: aTGC limits


EW Wjj cross-section data sensitive to aTGCs unfolded in addition to providing reco-level aTGC limits. Can multi-dimensional fits to data improve sensitivity?
SM/Higgs measurements for BSM fits

LHC Higgs data reinterpreted $\rightarrow$ constraints on TGVs

Equivalently:
ATLAS+CMS (WW, WZ, Wγ) production data reinterpreted $\rightarrow$ constraints on Higgs coupling parameters


Complementary constraints from both datasets benefit from combination
SM/Higgs measurements for BSM fits

LHC di-boson (reco-level) kinematic yields used to constrain Higgs couplings: TGV data provides important complementarity

Butter et al., JHEP 1607 (2016) 152

Ellis, Sanz, You, JHEP 1503 (2015) 157

Single coefficient fits
VH production data
TGC data
VH+TGC
Higgs measurements


Reinterpretation of published data as constraint on EFT Wilson coefficients
Ratio of differential cross-section to theory with varied coefficients, CLs limits

Unfolded measurements provide full covariance matrix
Higgs fiducial differential cross-sections have been reinterpreted in terms of specific models e.g. 

Buddenbrock et al., arXiv:1506.00612 (scalar + DM candidate model)

Bishara et al., arXiv:1606.09253 (Charm-quark Yukawas)
Potential to benefit from reinterpretation of SM measurements even where dedicated search topologies exist:

**Fully unfolded double-differential dijet measurements**
- Set 95% CL on compositeness scale for model of contact interactions using unfolded data
- Compositeness scale limits (>7.3 TeV; PDF dependent), of comparable sensitivity to dedicated reco-level search at time (>7.6 TeV)
- Easily reinterpretable, potential for combination with additional datasets
- Demonstration of reusability of “SM” measurements – limitations?
Search for WWW triboson production
- Sensitive to aQGCs

No observation in paper but able to set 95% CL on cross-section and reinterpret in terms of contact interaction:
Particle-level search for events with jets+MET

https://hepdata.net/record/ins1609448
https://www.hepforge.org/archive/rivet/contrib/NEW/ATLAS_2017_I1609448.tar.gz

New approach: search for general phenomena with MET+jets

Unfold distributions sensitive to such unseen new phenomena to particle-level

\[ R_{\text{miss}} = \frac{\sigma(\not{p}_T + \text{jets})}{\sigma(Z \rightarrow \ell^+\ell^- + \text{jets})} = \frac{1}{C_Z} \frac{N(\not{p}_T + \text{jets})}{N(Z \rightarrow \ell^+\ell^- + \text{jets})} \]

Provide:

- experimental statistical and systematic correlations within and between distributions
- theoretical correlations
- framework to determine new correlations with BSM model
- Rivet routine with distributions and fiducial regions defined
- SM numerator and denominator, and facility to replace (should better predictions become available)
Particle-level search for events with jets+MET

\[ \text{arXiv:1707.03263, to appear in EPJC} \]

https://hepdata.net/record/ins1609448

https://www.hepforge.org/archive/rivet/contrib/NEW/ATLAS_2017_I1609448.tar.gz

Unfolded differential cross-sections:
Same data easily interpreted in various models (+high-performing!). Straightforward to combine with further data in future.

Limitations? Re-use cases? More inclusive differential NP measurements in future?

1) Monojet simplified model

2) VBF EFT

3) Higgs $\rightarrow$ invisible model ($gg+VH+VBF$)

$$Br^{\text{exp}}(H \rightarrow \text{inv}) < 59\%; \quad \pm 1\sigma : [47\%, 113\%]$$

$$Br^{\text{obs}}(H \rightarrow \text{inv}) < 46\%$$
Thoughts

Extensive direct dedicated BSM searches at reco-level
- Assessing model independence
- Difficulties in detector simulation, SM rates/uncertainties, validation

SM process measurements already used widely for reinterpretation
Specific BSM models / EFT constraints from SM measurements / combination of EW and Higgs data (reco and unfolded) / Higgs data for EFTs and specific BSM theories / Unfolded measurements where no SM signal present / resonance searches
- Model dependence accounted for [?] in systematics on modelling.
- Need to ensure relevant aux data provided & in consistent way [link with other WG]

Extend concept to unfolded generalised searches for NP
- Use cases of such data? Other generalised unfolded searches valuable?
- Statistical questions: limit of no data, limit of no SM, limit of no BSM expected
- Exploring limitations, assessing model independence

Towards a global picture for LHC BSM limits
- How to combine all BSM search / measurement results in single picture?
- How to make best use of SM measurements as a whole? Measurements missing?
- Characterisation: simplified models exist, neural nets to calculate approximate $\chi^2$, other approaches? Approach an LHC likelihood...

Potential future use of CMS and ATLAS Open data?
- What are needs, use cases, potential interest?
Backup
Workflow for reinterpretation

Provided information for detector-corrected data:
- Fully-corrected data measurements (+uncertainties) [http://hepdata.net]
- Bin-to-bin correlations + any useful auxiliary information (Improved constraints)
- Rivet analysis routine [http://rivet.hepforge.org]
  (Handle object definitions to avoid ambiguity in isolation, jet algorithms, MET definition etc., observable definitions, and binning)

\[
\chi^2 = (\sigma_{\text{data}} - \sigma_{\text{theory}})^T (C_{\text{stat}}^{-1} + C_{\text{syst}}^{-1})(\sigma_{\text{data}} - \sigma_{\text{theory}})
\]
Various tests of model independence of procedure performed.

One example: Injection of BSM dark matter model enhancing MET distribution:

- Causes large changes in numerator and shape of $R_{\text{miss}}$
- Negligible effect on correction factor!
- Such large enhancements are anyway ruled out by the measured data