TOP-22-006 ARC-Authors Meeting #2: Jan 13, 2023

Summary of status and updates on sensitivity studies

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1: The Ohio State University
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Recap of ARC-authors meeting #1 (Dec 12, 2022)

Overview of status

- Our analysis twiki (with answers 83/86 of the questions) is here
- Questions that we would like to discuss today:

1. Handling of the renormalization/factorization systematics:
   - "L1016: how much shape effects remain after taking the uR and uF envelope? wouldn't it make more sense to treat them independently, to get the full shape effect?"

2. Interpretation of sensitivity:
   - "There are not many figures. Are there others that could be interesting to include, showing the effect of some non-zero WCs on the yields, for example? Currently it is difficult to understand why some WCs are well-constrained while others are not, and what features of the data are exploited in the fit to reach this sensitivity."
   - "About the results: It would be good to present & discuss in the paper what is the "relative" contribution of the individual (groups of) categories to the sensitivity to individual EFT operators. Did you try to study/understand/visualize this in some way? E.g. perhaps one could try to extract for each EFT operator the WC uncertainties arising from the individual (groups of) categories (by including/excluding them individually in the fit), and to use the relative fraction of the corresponding WC uncertainties^2 in the total sum of WC uncertainties^2 as a measure of the relative contribution of each individual (groups of) categories to the sensitivity to individual operators."

2

Done and included in the updated documentation

What we'd like to discuss today

Goal and methodology

- Goal: Understand the WC limits in terms of which bins/categories are important for each WC
- Two approaches:
  - Top-down: Based on the categories of operators and their vertices and which processes they affect
  - Bottom-up: Based on looking at individual bins, comparing the prediction and observation at the 2sigma limits in order to identify bin(s) that contribute most to the sensitivity
    - For this study we created a set of plots to attempt to quantify the effect of each bin, details are in the backup
    - However, we do not propose to include any of these plots in the paper, rather we'd like to focus on the conclusions that these plots (in combination with the "top-down" approach) helped us to reach
- Coming at the problem from both of these directions, we arrived at the following categorization

The 26 WCs in TOP-22006

4fermion

2fermion+bosons

4heavy

The **2lss (mainly 3b** but also 2b) are where we obtain most of the sensitivity to these WCs

(All 4heavy WCs)

2heavy 2lep

All categories except onZ contribute to understanding these WCs

(All 2q2l WCs)

2heavy 2light

"ttlnu-like"

Gain most of our sensitivity from the **2lss** (mostly 2lss+ 2b) via impacts on ttlnu, though not exclusively (are some 3l contributions)

(The other 4 2light2heavy)

"tllq-like"

Gain much of our sensitivity **onZ 2b low j** categories (via the tbqq' vertices that are unique to these WCs), though **2lss** remains non-negligible

(cQq13, cQq83)

2heavyWith Bosons

These 9 WCs have a variety of diverse effects and together contribute to all categories

"ttZ-like"

These WCs have t-t-Z vertices and the lead process affected is ttll. Thus **onZ** categories are important, but note **2lss** is important too (as ttll significantly populates 2lss)

(cpt, cpQM, ctZ)

"tXq-like"

These WCs primarily impact tHq and tllq, and essentially all categories are important

(cpQ3, cbW, cptb)

Affects multiple processes, nearly all categories are important

(ctG, ctp, ctW)

Discussion of 4-heavy (ctt1, cQQ1, cQt1, cQt8)

- Distinguishing characteristic is that most of the sensitivity comes from 2lss, (mainly the 2lss 3b subcategory, though 2b is also important)
- This is one of the more clear-cut categories of WCs, where the sensitivity seems to come from a fairly well-defined subcategory of analysis bins
- To get a quantitative idea of how much of the sensitivity comes from these subset of bins, we reran the fit with only the 2lss bins included
  - The limits with all bins included are about 0.75 of the limits with just 2lss included
  - This shows we would retain most of our sensitivity if only included 2lss bins, so the 2lss bins are indeed important for these WCs
  - However, interesting to note that even for this relatively clear-cut case, we'd still be losing about 1/0.75=33% of our sensitivity if we only looked at this subset of the bins, so even in this "simple" case the full multi-lepton data set is important for our limits

Discussion of 2-heavy-2-lepton (cQl3i, cQlMi, cQei, ctli, ctei, ctlSi, ctlTi)

- Distinguishing characteristic is that the sensitivity comes from essentially everywhere except 3l onZ bins
- To get a quantitative idea of how much of the sensitivity comes from these subset of bins, we reran the fit with the onZ bins excluded, and the limits for these WCs only changed by ~2%
- Similar results had been observed in TOP-19-001
  - However, our limits on these WCs have improved by more than a factor of 2 over the TOP-19-001 results
  - Some of this improvement is due to increased statistics (~25% improvement from statistics alone), and some is due to the improvements in the analysis (differential binning)
  - But overall, the qualitative answer to where the sensitivity is coming from for these WCs (i.e. "everywhere except onZ") has not changed since TOP-19-001

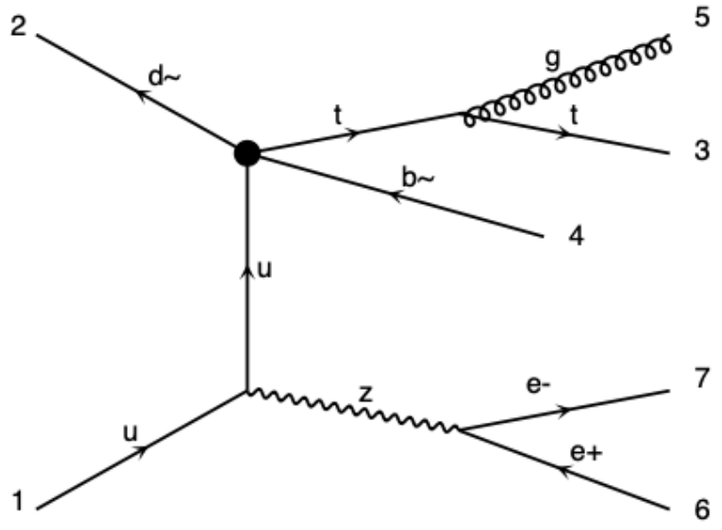
Discussion of 2-heavy-2-light "ttlnu-like" (cQq11, ctq1, cQq81, ctq8)

- These are 4 out of the 6 2-heavy-2-light WCs, and the primary factor driving the sensitivity seems to be their effect on ttlnu, so categories populated by ttlnu are important
- Most of the sensitivity to these WCs seems to come from the 2lss and also the 3l offZ categories
- However, it's not as clear-cut as e.g. the 4-heavy category of WCs, the sensitivity is more spread out
- To get a quantitative idea of how much of the sensitivity comes from these subset of bins, we reran the fit with only the 2lss bins included and only the 2lss bins excluded
    - Lost significant sensitivity in both cases (limits worse by factors of 2-3x), so sensitivity is not coming solely from 2lss
- Running without onZ only results in a loss of ~5% sensitivity, confirming that 2lss and offZ are the primary categories of importance

Discussion of 2-heavy-2-light "tllq-like" (cQq13, cQq83)

- What makes these two WCs unique among the 2-heavy-2-light WCs is that these have t-b-q-q' vertices

- These WCs can thus impact 3l onZ 2b low jet multiplicity final states via tZq diagrams



- Note that the Z in these diagrams are not associated with the EFT vertex (this discussion may sound familiar, as these WCs are the reason why we use lj0pt in these bins instead of ptZ, as we were losing significant sensitivity to these WCs when using ptZ)

- These WCs are similar to the previous set (2-light-2-heavy "ttlnu like") except that here the onZ-2b-low-jet bins are important as well
    - Excluding the onZ bins causes us to lose almost 30% of our sensitivity to these WCs (as opposed to only about 5% lost for their "ttW-like" counterparts)

Discussion of 2-heavy-with-bosons

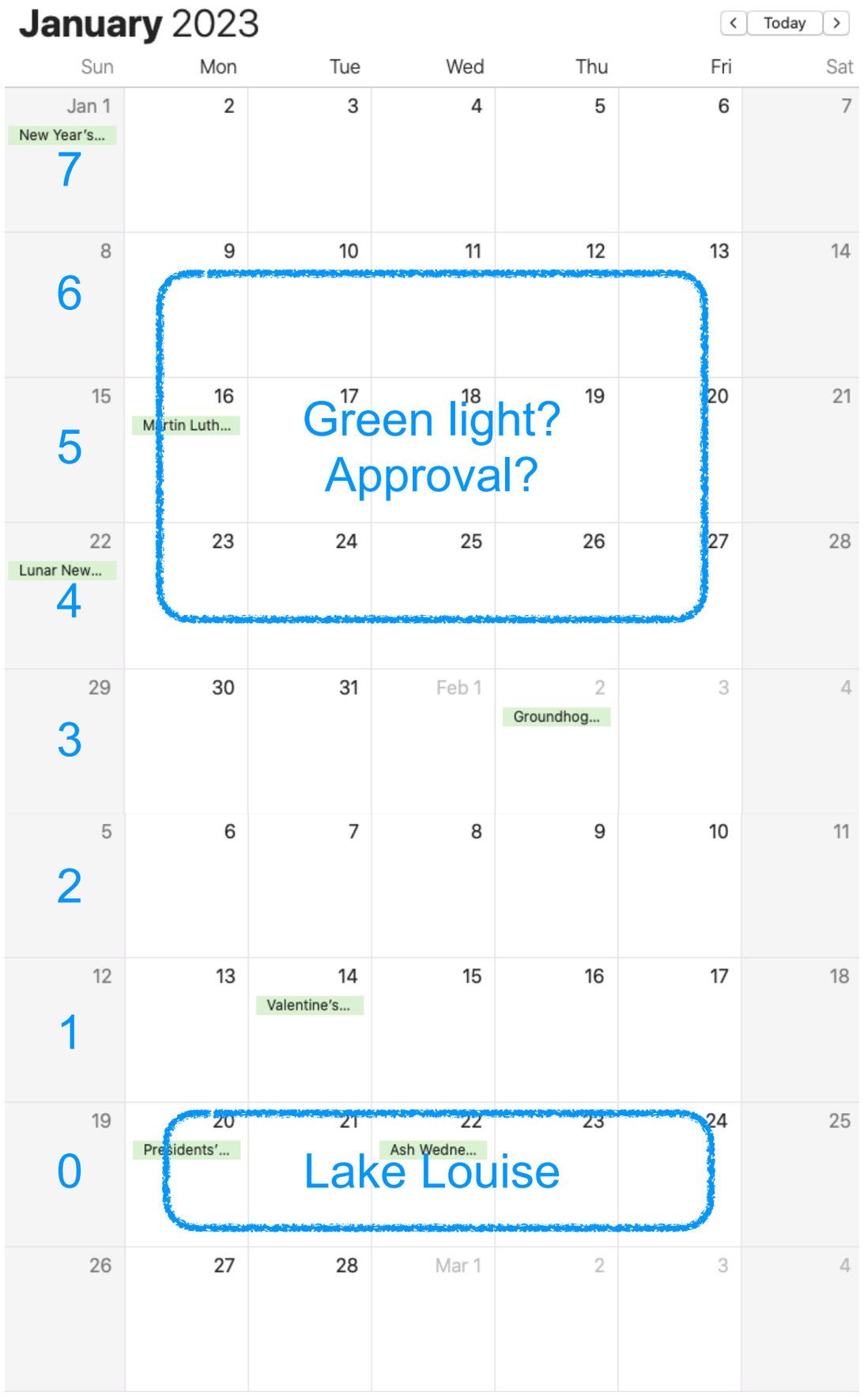
- These WCs are very diverse and are challenging to categorize definitively
- "**ttZ-like**": The onZ categories are important for these WCs, but note other categories (especially 2lss) are also important because ttZ populates 2lss when we lose a lepton (ctZ, cpt, cpQM)
- "**tXq-like**": Affects tHq and tllq, and these WCs have important contributions from across many bins (cpQ3, cptb, cbW)
- "**Affects multiple processes**": The remaining WCs affect multiple processes and have diverse effects across the full set of multi lepton categories
    - ctG: Primarily affects ttH but also has significant impacts on ttll, ttlnu, tttt thus many categories are important (for multiple reasons)
    - ctp: Primarily affects ttH and tHq (also tttt), most categories are important (though onZ is not extremely significant, only lose about 5% of sensitivity when onZ is excluded)
    - ctW: Affects multiple processes, but note this WC also has significant interference with ctZ leading to a strong linear correlation in the fit, so at the ctW 2sigma limits ctZ is also turned on, making the categorization of the effects challenging to disentangle

Summary

- We propose to include a few paragraphs in the paper that describe the categorization presented on slide 4 (with details included from slides 5-9)

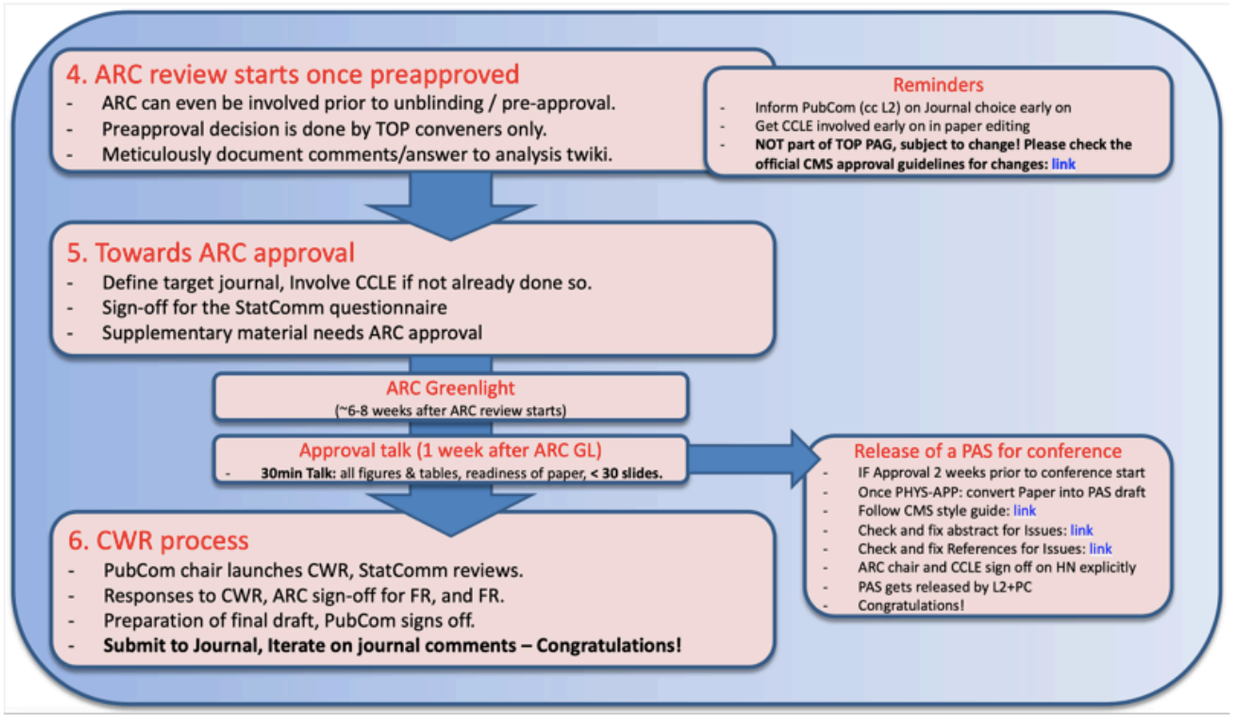
- We do not propose to include any of the "figure of merit" plots (explained in backup) that were used in the "bottom-up" approach to the determinations of the categorization

- We are interested to hear the feedback and ideas of the ARC



Timeline

- Documentation needs to be frozen for one week between GL and approval
- When to aim for approval?
- We're aiming to present the analysis at Lake Louise
- Could potentially make it through CWR prior to the conference if we move quickly

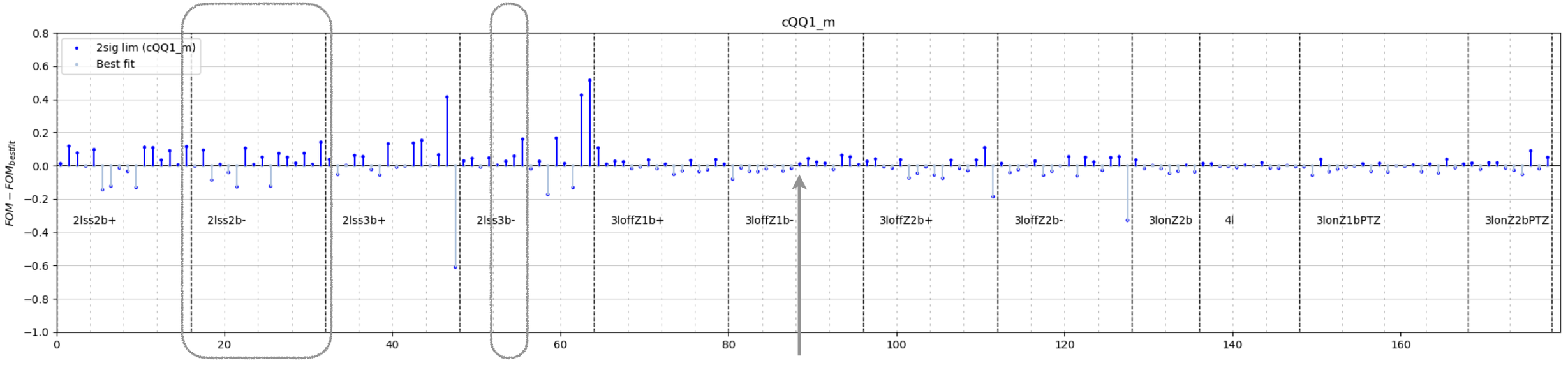


Backup

Explanation of of the FOM metric

- Define a figure of merit (FOM) that indicates how much a particular bin contributes to setting the 2sigma limit, and look for trends across bins
  - Define as FOM = $|N_{\text{pred}} - N_{\text{obsv}}|/\sigma_{\text{tot}}$, where σ_{tot} is the total uncertainty on the prediction, i.e. $\sigma_{\text{tot}} = \sqrt{\text{Fit uncty}^2 + \text{N}_{\text{pred}}}$
  - Evaluate this FOM at best fit and at +2sig and -2sig limits
  - We're looking for bins where the FOM is significantly larger (i.e. worse) at the +2sig or -2sig limit than it is at the best fit point, as this would provide information about which bin(s) are the reason that the fit hit 2sigma at the given value of the scanned WC
  - We thus subtract the FOM at the best fit from the +2sig and -2sig limits and then look at the results per bin

Example FOM plot



These are the bins in the 2lss 2b- category

These are the 4 lj0pt bins in the 5j subcategory of the 2lss 3b- category

This is the first lj0pt bin in the 4j subcategory of the 3l offZ 1b- category

← Some notes on how to read the plot

- We have 26 WCs that each have a +2sigma and -2sigma limit, so in total there are 52 FOM plots to consider
- We thus examined the plots in order to look for trends that would help us to understand which bins (or categories of bins) contribute most to the sensitivity for each WC (or category of WCs)

A few examples from the total set of 52 FOM plots