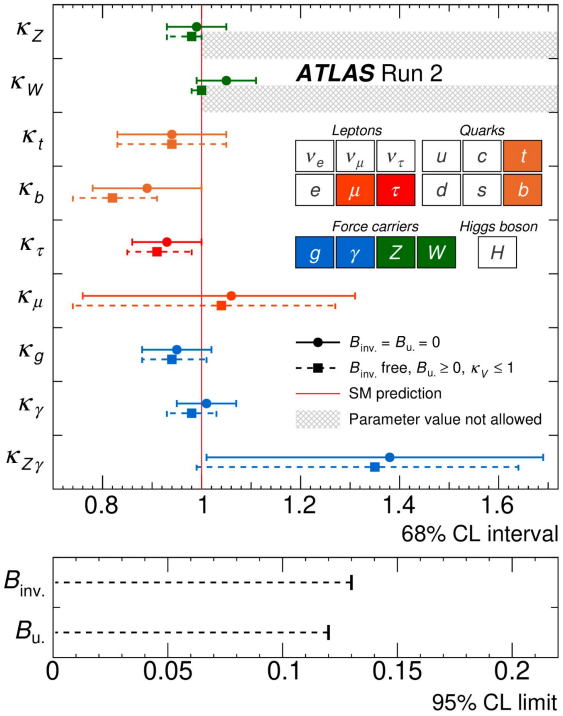
Standard Model Higgs

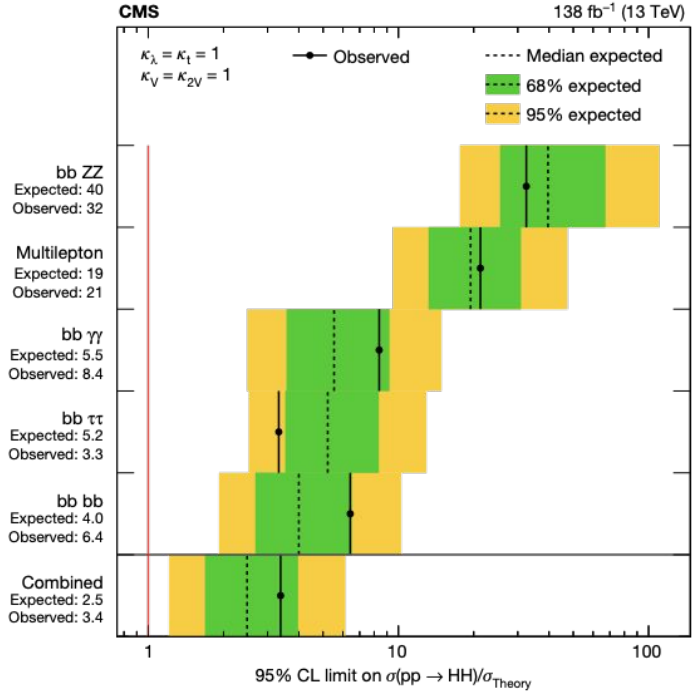
Mauro Donegà, Karsten Köneke
Les Houches 2023

Thanks to the many people who provided input: ATLAS and CMS Higgs & HDBS groups, Saptaparna Bhattacharya, Andrew Hamilton, Clemens Lange, Meng Lu, Zach Marshall, Andrea Valassi

Introduction

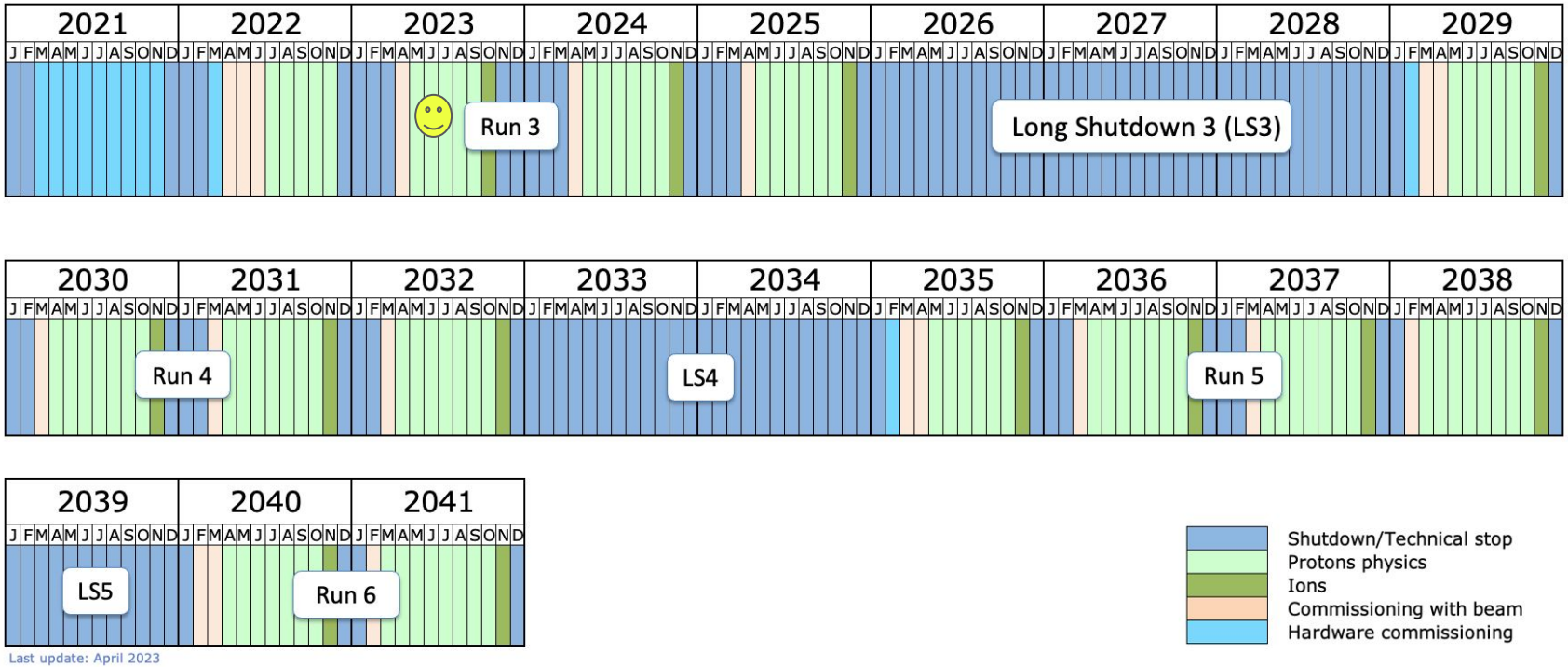
Several Higgs results have appeared since the last Les Houches workshop (see e.g. ATLAS an CMS) - happy to setup up specific discussion if interesting in any particular one !





→ 95% CL upper limit reaching 1xSM in Run 3

The road ahead



Introduction

The list of topics for possible exercises can be found at:

https://phystev.cnrs.fr/wiki/2023:topics#session_1 → **Standard Model Higgs:**

These topics also overlap with the activities of the LHCHWGs.
In particular you can find the WG2 list at:

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG2#Topics

and a LH style list of topics on CP:

https://docs.google.com/document/d/1qX5Ypq0Frw47HzltEqtxEt8PG9NM3Z5vkl8BGT2OZtk/edit#

Flavour algorithms

IRC safe flavour-aware algorithms in experimental measurements:

- What can we do with these tools ?
- Comparison with anti-kt in unfolding ?
- VHbb (or cc): g→bb effect on Data/MC scale factors for merged (non merged) jets ?
- Can these algorithms help in the calibration procedures of boosted taggers ? g→bb vs Hbb
  → see also Andreas/Simone talk on single b-jet
- FCCee: what is the effect of these algorithms in strange tagging ? link

Jets

q/g jet tagging

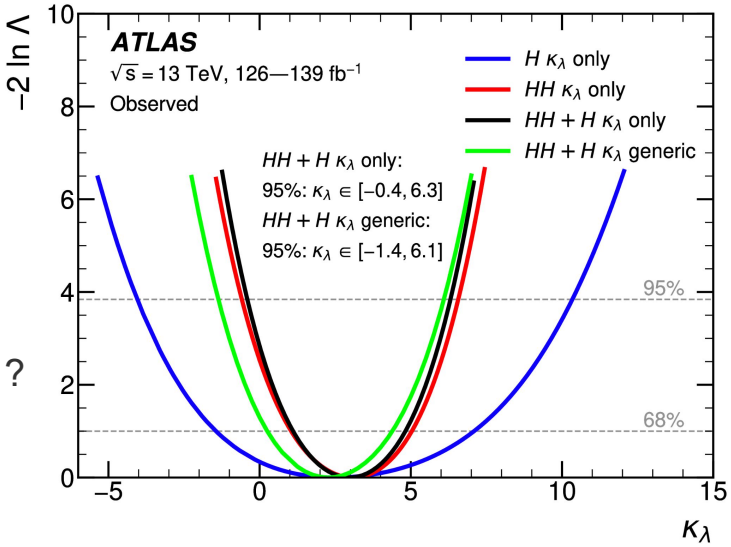
- More and more complex NN approaches (ParticleNets) working with basic events objects (PFcandidate - tracks, clusters). Indicative performance: reject x5 for a signal efficiency of 80%
- Can we convince ourselves that the features they're learning are reliable ?
  Are we sure we're not getting better discrimination from unsound / theory uncertain features?
- Study with Delphes + ParticleNet

→ See Andreas/Simone talk on ParticleNet

Double Higgs

Constraining the Higgs self coupling

- Exploited the sensitivity of single H in constraining k_λ
- Are there other observables that we can use beside p_T?
- Channels beyond ggHH are being explored,
  any more promising process ?
- Can the (very weak) constraints on k_4 help constraining k_3 ?



STXS binning for self-coupling interpretation

- It was not optimised for k_λ, is there something better we can do ?
- Can we optimise some fiducial differential measurement for k_λ ?
- Is there any observable to bin on, that would increase sensitivity to k_λ?
  - “Brute force approach”: study a LR: ME(λ)/ME(SM) as a function of the H kinematics ?

Experiment/Theory efficient information exchange

Publishing Likelihoods: information exchange

- What is the use case ? Re-interpretation ? Combinations ? e.g. HEP / Low E ?
- When is the full likelihood needed ? when are cov mtx enough ?
- ...what do we mean by full likelihood? Are “Simplified Likelihoods” good enough ? (e.g. link)

Publishing Likelihoods: tools

- CMS → plan to release the “combine” package as a generic tool. CMS papers could then appear with a record in HEPDATA containing datacards/workspaces
- ATLAS → work on pyhf json format. Only binned distributions
- Common (human readable) format for datacards
    - effort started in the ROOT group + experiments
    - HS3 (High Energy Physics Statistics Serialization Standard) as emerging community standard?
        - Subscribe to hep-statistics-serialization-standard@cern.ch
        - Discussion in github issue tracker: https://github.com/hep-statistics-serialization-standard/hep-statistics-serialization-standard/issues
    - Common LH2 (Les Houche LikeliHood) format defining the content ?

Experiment/Theory efficient information exchange

“RIVET with efficiencies”

- Add to RIVET the possibility to import weight (xgboost, tensorflow, …)
- It would have some applications:
    - Particle level → “smearing module / Delphes” → Classifier → Analysis category
    - Particle level → Analysis Category
        - (proof of principle trained on ggF H→γγ sample then used to predict analysis category for different input kinematics)

Something along these lines was done on the VBF-W cross section in 2019 (link)

Experiment/Theory efficient information exchange

Can unbinned reweighting with machine learning be useful?

- Move away from the 1D scale factors, which can damage correlations among variables
- “Gain statistics” Morph a low stat alternative sample to a high sta nominal https://arxiv.org/pdf/2007.02873.pdf

Unfolded unbinned cross sections ? How sensitive are they on hyperparameters ?

- Multifold (list of observables all unfolded at the same time) and Omnifold (unfolding at the event level that can be re-binned in any observable).
- Does it work both in simple cases (resonance) and in more complex multiple-scale processes (ttHbb) ? (take two MC and unfold one to the other)

Likelihood free inference beyond arXiv-like examples ? Try some complex case ? (again ttHbb?)

Generators - negative weights

Generators take ~10% of the experiments computing resources. With more precision (gen) and larger datasets (exp), the time required for generation is expected to increase significantly.

- Origin of negatively weighted events: NLO cross sections are not positive definite in local phase space
  - Some events arising from the hard scatter acquire negative weights
- CMS exploring two different strategies for the mitigation of negative weights:
  - MC@NLO-Δ scheme based on dealing with over estimation of MC counter terms in aMC@NLO (arXiv:2002.12716)
  - *Positive resampling*: eliminates negative weights locally in phase space (arXiv:2109.07851)
    - Process independent, preserves physical observables
    - Can we prove that methods like positive reweighting works on the full analysis phase space ?
- The negative weight reduction scheme implemented in Sherpa, based on color correction approximations is implemented in CMS
  - up to 50% reduction observed in various processes, ttV, ttbar, V+jets
  - cross sections and distributions of observables remain unchanged

Generators - GPU

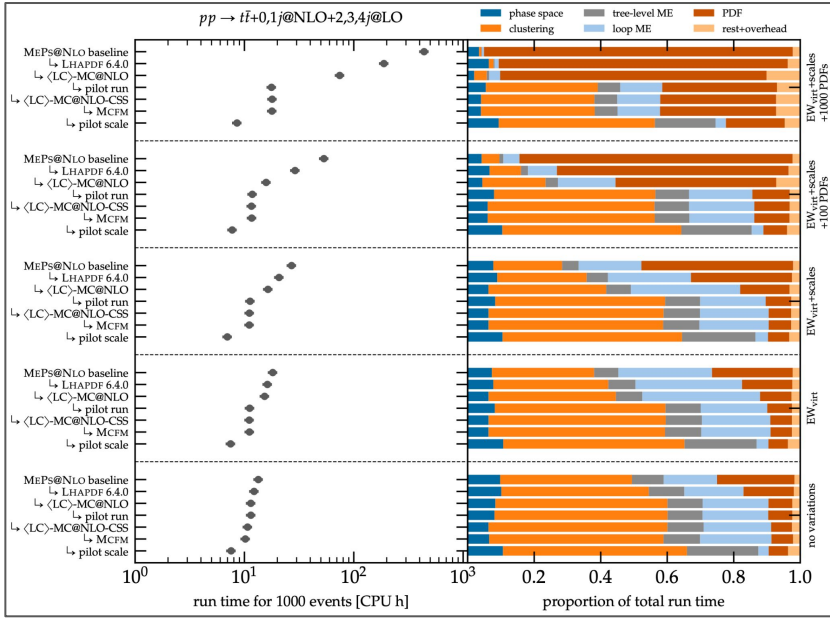
Generation on GPU

MadGraph Authors + ATLAS & CMS generators groups + CERN computing to take advantage of MadGraphGPU:

- MadgraphGPU for users: hands on on how to set it up and run
- MadgraphGPU internals for other MCs: compare what learnt with MadGraph (moving from single to multi event APIs, vectorization and GPUs) to what people in other MCs plan to do (eg SHERPA). Some components may become interchangeable across different MC generators through well defined software APIs.

ATLAS & CMS working on implementing GPU-based event generation in central workflows

ATLAS also in contact with Sherpa to test their GPU-based code, when it will be available.



Very large speedups (**x2-78**) demonstrated when running ATLAS setup with >100 weights (EW, PDF,...) using *simplified pilot runs and fast PDFs* [https://arxiv.org/abs/2209.00843]

CMS use the MG reweighting module as standalone to perform the reweighting on the final data format

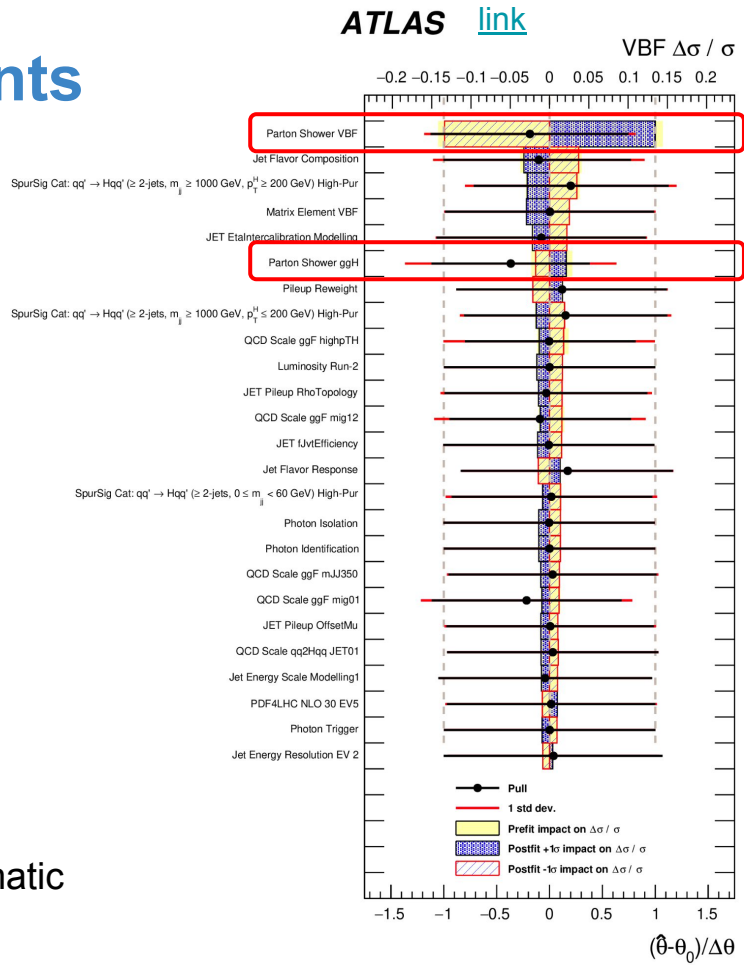
Parton Shower issues and develoments

The limiting systematic on VBF
(and very significant for other Higgs processes):

- Predictions for VBF/VBS processes highly sensitive to PS description, particularly (but not only) for third-jet observables
- Two-point PS uncertainty bands currently used by experiments is a limiting factor in VBF precision measurements
- A clear VBF process PS uncertainty prescription is important for Run-3 measurements and beyond
- What can new showers say on this right now?
- See more in Raoul/Stephen talk

Main experimental combinations start seeing more and more systematic limitations, from PDFs in other phase spaces.

- See approximate-N3LO PDFs in Raoul/Stephen talk

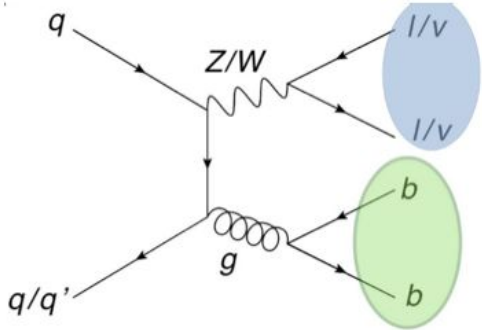


Backgrounds - V+HF for VH→bb

https://indico.cern.ch/event/1207058/

V+heavy-flavour represents the main irreducible background of the VHbb analysis

- Signal extracted from the fit to a NN where the bkg is from MC (starting sample 10^9 evts)
- theory prediction extremely important for accurate signal extraction
- data constrains prediction of V+jets processes very precisely ⇒ MC modelling and choice of systematics variations can impact the measurement significantly



Different strategies in place for ATLAS and CMS, but in the end still large data/MC discrepancies

CMS

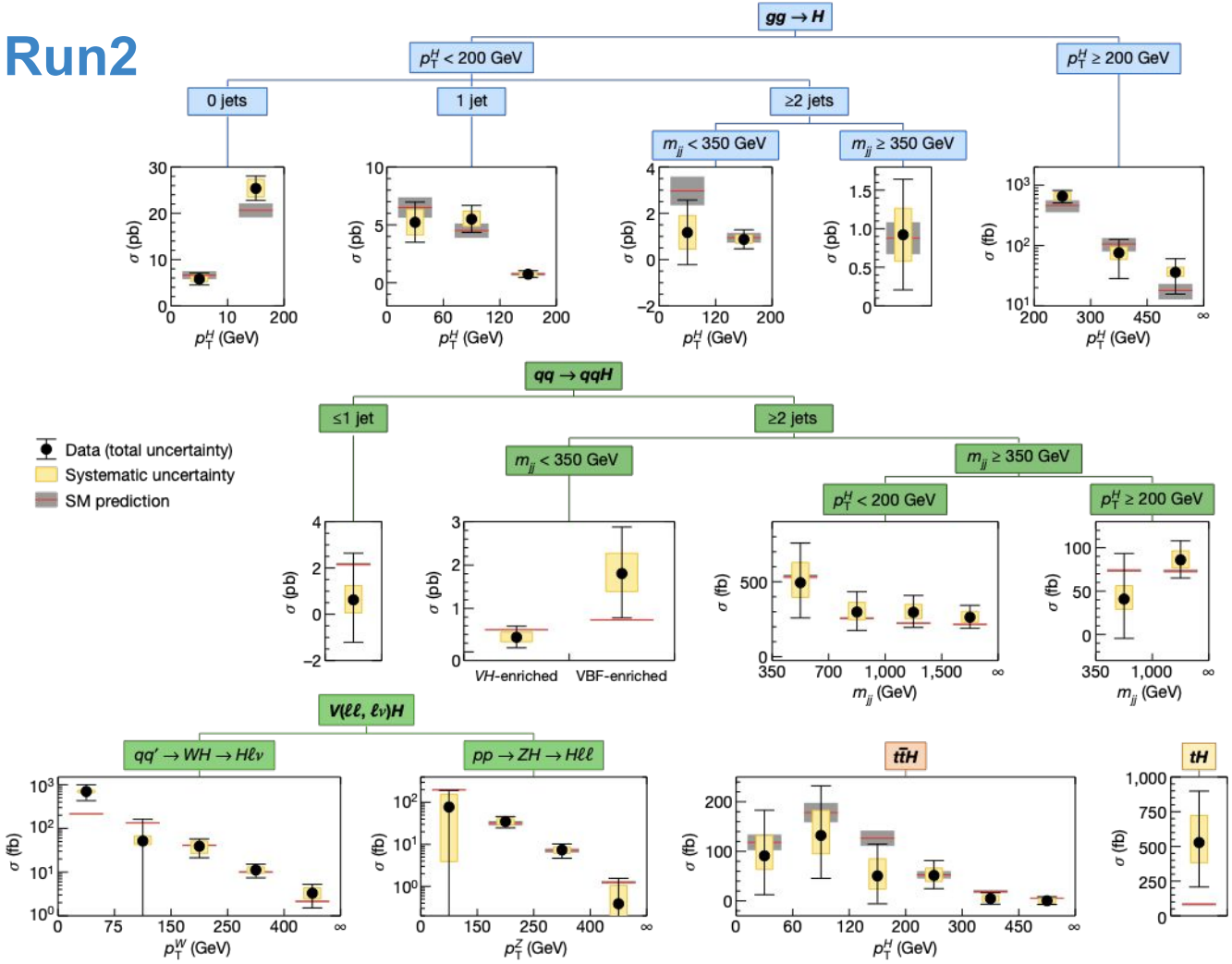
- (2016) LO MadGraph with MLM matching: reweighted to NLO in etabb + Xsec reweighted to NNLO QCD + NLO EWK in $p_T(V)$
- (2017/18) NLO MadGraph with FxFx matching: Xsec reweighted to NNLO QCD + NLO EWK in $p_T(V)$
  - Still o(30-40%) scale factor on the normalization

ATLAS

V+hf modelled with Sherpa 2.2.1 and now Sherpa 2.2.11.

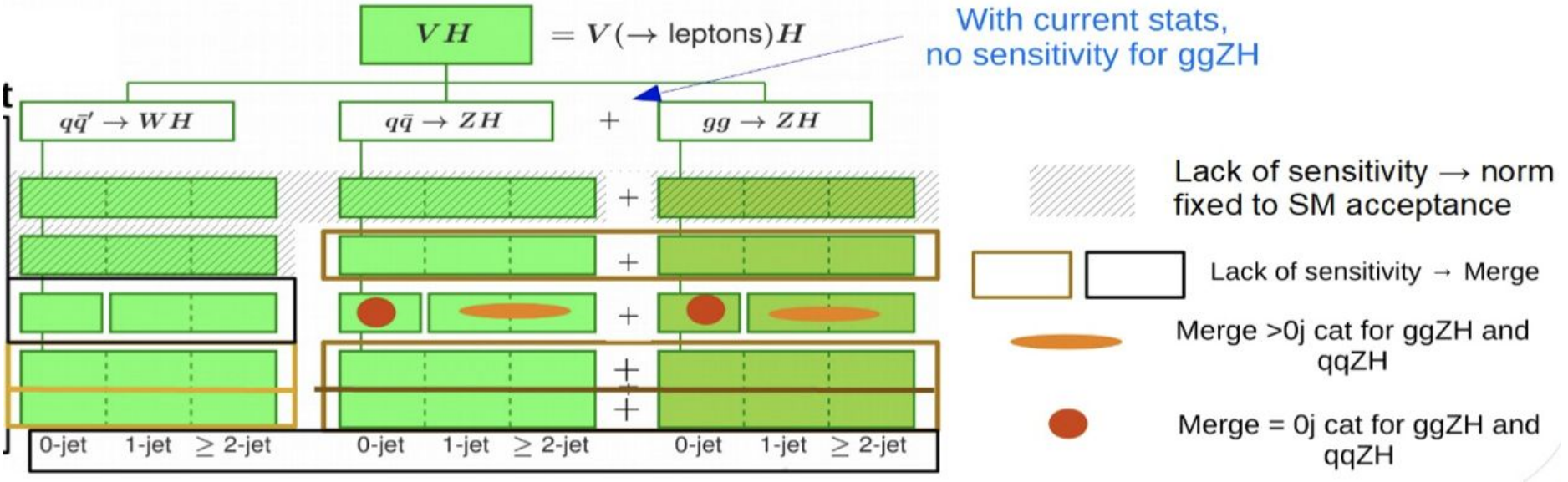
- underestimation of the overall yield and Sherpa 2.2.11 shows a severe mismodelling of the vector boson pT in the relevant range of 75-400 GeV requiring correction factors of up to 1.5-2 at high $p_T(V)$
- enabling NLO electroweak corrections worsens the agreement further
- the alternative MC sample currently under study, MG_aMC@NLO+Pythia8 with FxFx merging, shows very large differences to Sherpa 2.2.11 in the prediction of number of jets at high $p_T(V)$

STXS in Run2


gg → H
p_T^H < 200 GeV
p_T^H ≥ 200 GeV
0 jets
1 jet
≥2 jets
m_{jj} < 350 GeV
m_{jj} ≥ 350 GeV
σ (pb)
σ (fb)
p_T^H (GeV)
qq → qqH
≤1 jet
≥2 jets
m_{jj} < 350 GeV
m_{jj} ≥ 350 GeV
p_T^H < 200 GeV
p_T^H ≥ 200 GeV
Data (total uncertainty)
Systematic uncertainty
SM prediction
VH-enriched
VBF-enriched
m_{jj} (GeV)
V(ℓℓ, ℓν)H
qq′ → WH → Hℓν
pp → ZH → Hℓℓ
tt̄H
tH
p_T^W (GeV)
p_T^Z (GeV)

STXS for Run3

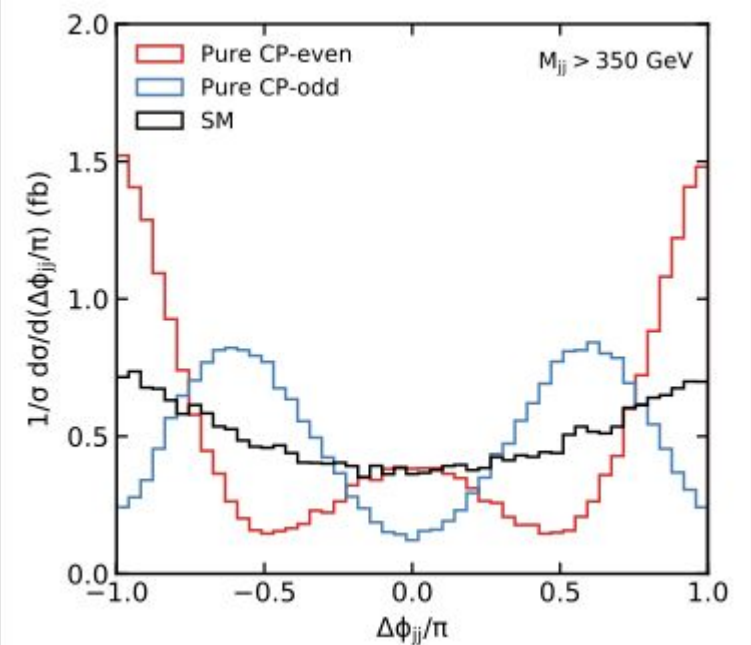
v1.2 too aggressive binning (required merging bins for lack of sensitivity)



STXS for Run3

v1.3 strategy could be less aggressive: just add more bins at high $p_T(V)$, e.g. 400-600 GeV, and split more $p_T(V)$ bins also in n_{Jet} ?

Add bins to highlight specific observables ? (e.g. CP-sensitive binning)



Extension of stage 1.1 with a binning of [−π, −π/2, 0, π/2, π] in Δϕjj for Mjj >350 GeV (pT >100GeV) in both high and low pHT branches.

See LS2019: arxiv.org:2003.01700 and recent summary at VBF workshop: link

Try new observables ?

What about VH ?

STXS for Run3

Integrating decays in STXS

Example: a generator produces a Higgs decay with a bb-pair of 110 GeV and an e+e- pair of 5 GeV. What process is this? If we want to define decay bins, we should be able to tell for each event where it belongs:

- $H \to ZZ^* \to (Z \to bb)(Z \to ee)$?
- $H \to Z\gamma^* \to (Z \to bb)(\gamma^* \to ee)$?
- $H \to bb$+EW correction$\to bb\gamma^* \to bb(\gamma^* \to ee)$

Some avenues have already been tried :

- 0 st edition: informal discussion, Les Houches 2017
- 1 st edition: STXS/fiducial meeting, 17th May 2018
- 2 nd edition: Les Houches, 12th June 2019
- 3 rd edition: LHC Higgs XS WG workshop, 17th October 2019
- 4 th edition: LHC Higgs XS WG2 STXS/fid meeting, 1st July 2020
- 5 th edition: LHC Higgs XS WG workshop, 9th Nov 2020

Michael Duehrssen had a concrete set of cuts to be tried (talk - WG2).

Check them out ? New ideas ?

Summary

We collected several topics interesting for the experimental community, but the list is clearly not exhaustive.

Sign up for your favourite topic, or propose a new one !