Higgs (+X) production: current bottlenecks and future prospects

Mauro Donegà - Les Houches

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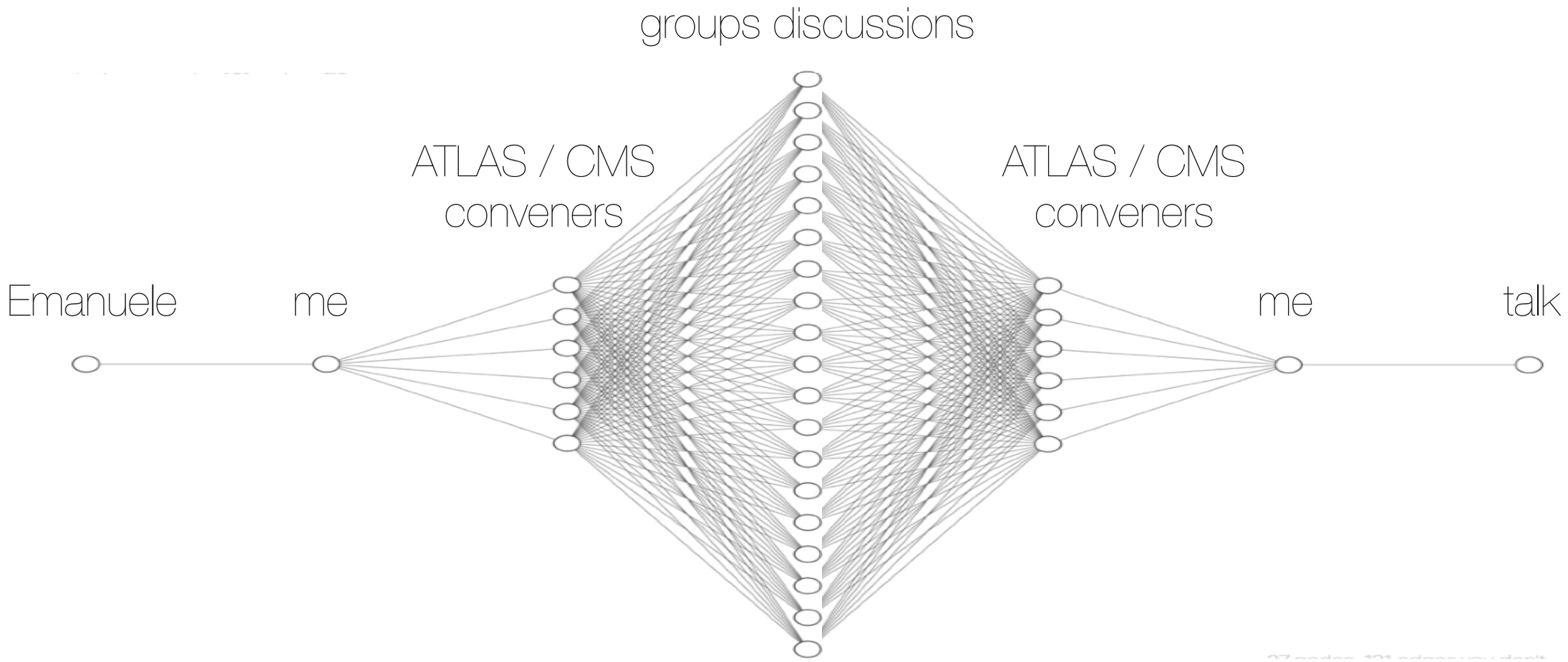
Acknowledgments

The making of this talk…



It’s a lossy compression process, all imprecisions/misunderstandings are my own

Thanks to all people who provided material for this talk !

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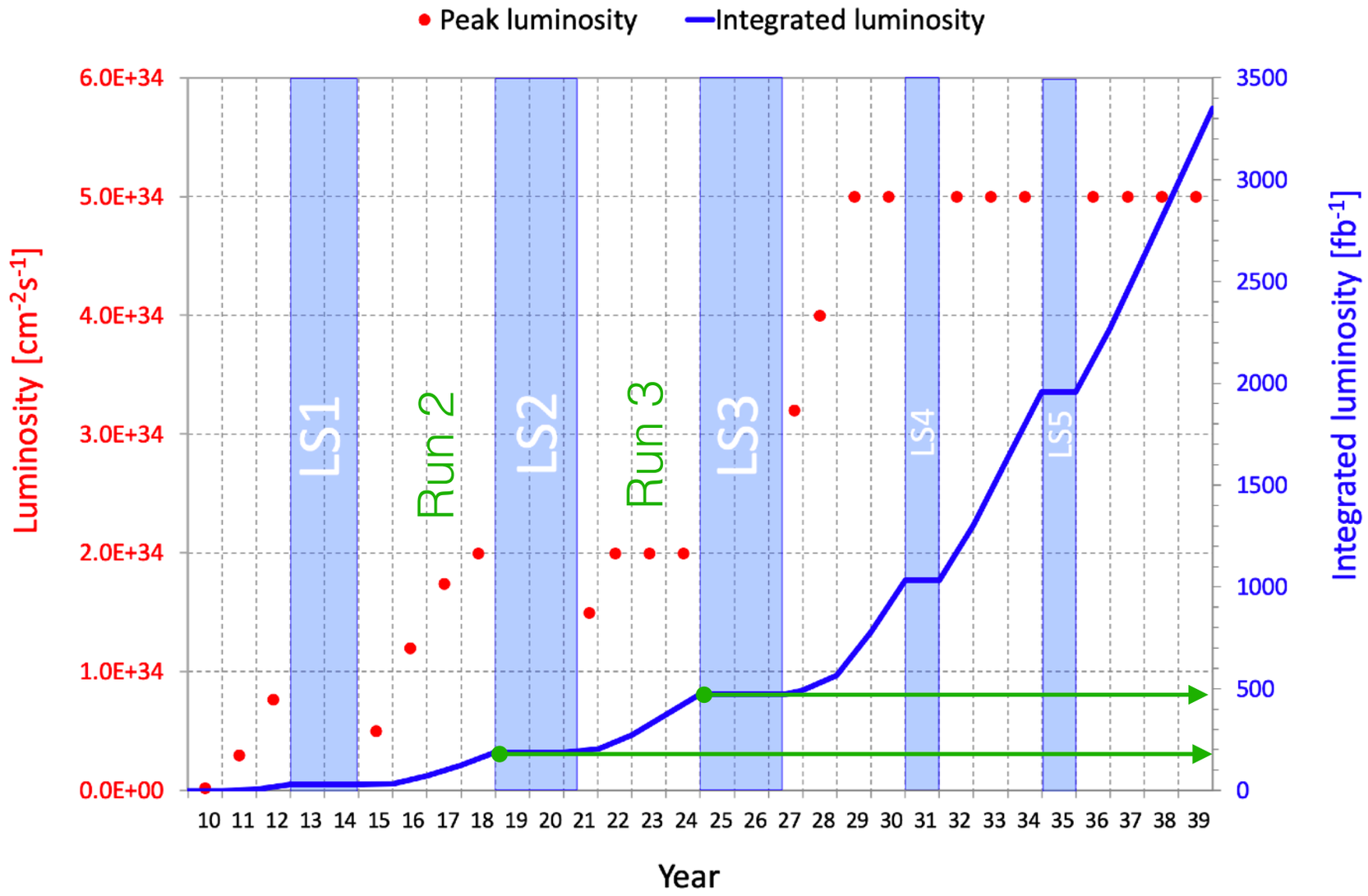
Overview



LHC lumi in perspective:

Run 2 ~150/fb
Run 3 ~300/fb Tot ~450/fb

In the following mostly questions with this luminosities in mind.

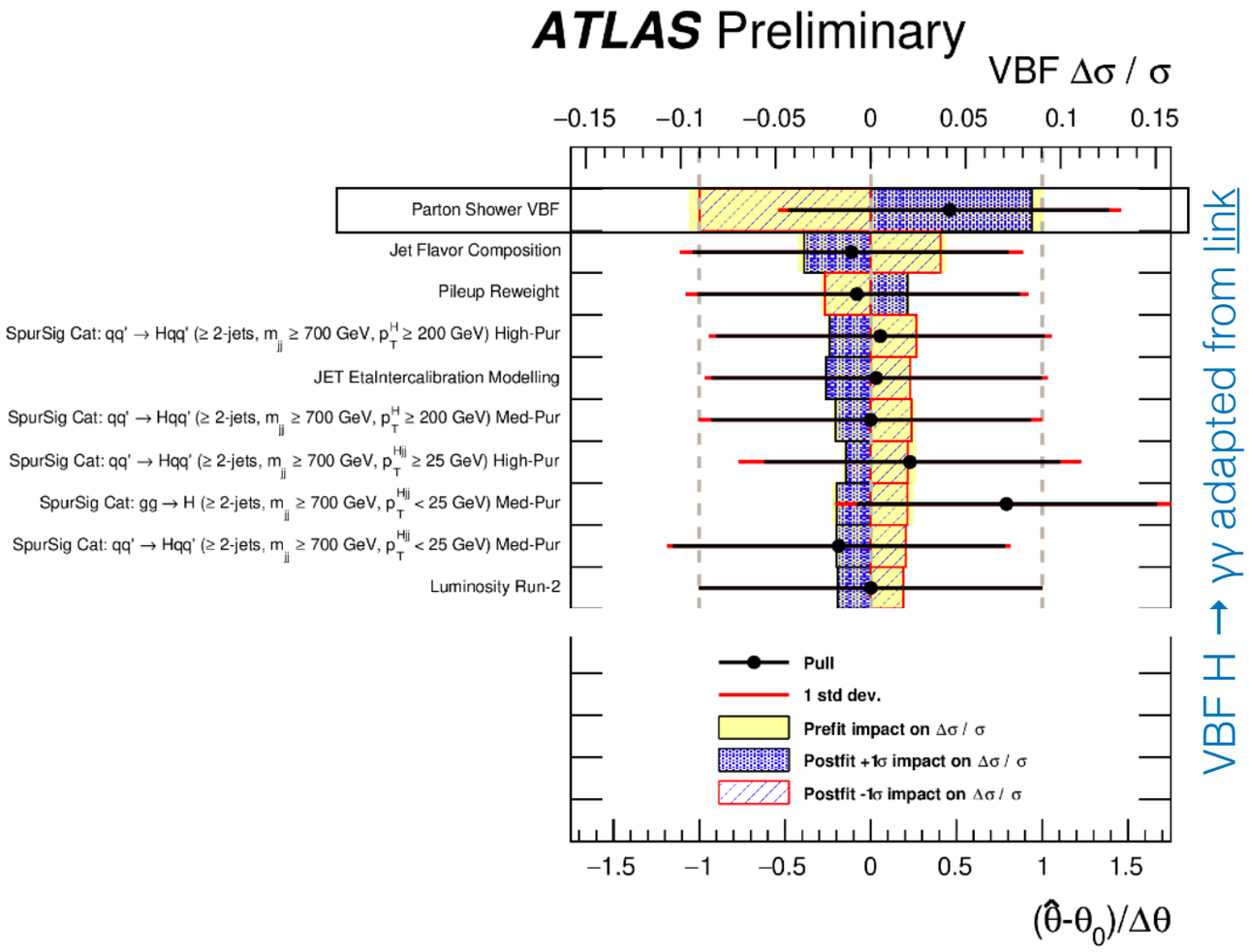
Parton Shower Uncertainies

Experiments often end up using the difference between Pythia and Herwig as "parton shower uncertainty", which is "not a rigorous method", and in some cases leads to quite large uncertainties. How meaningful are these systematic uncertainties ?

Examples: leading systematics in many VBF analyses and limiting progress

Source	$\Delta\mu_{\mathrm{VBF}}/\mu_{\mathrm{VBF}}$ [%]
Data statistics	12.5
Total systematics	17.8
Experimental uncertainties	8.8
Missing ET	4.7
MC statistics	3.1
Jet energy scale	2.2
Luminosity	1.9
Modelling of pile-up	1.7
b-tagging	1.6
Jet energy resolution	1.4
Misidentified leptons	0.9
VBF signal theory uncertainties	14.4
Background theory uncertainties	7.7
ggF Higgs	5.2
Top-quark	3.3
WW	2.5
Z+jets	1.9
Total	22

VBF H→WW*→eνμν link



VBF H → γγ adapted from link

The modelling of systematics for parton showers was discussed in 2019, is there any progress that could be used by the experiments ?

H → WW*: VBF matching

Estimate the uncertainty related to the matching between the matrix element and the parton shower for ggF and VBF production:

compare MadGraph_aMC@NLO+H7 vs. Powheg+H7
uncertainty of 8% out of a total 18% (almost as big as parton shower)

Matching uncertainties should be very small - maybe a generation issue ?
Should we expect such a difference ?

Are we double counting ? are we including in “matching uncertainty” also some parton shower uncertainty component ?

(ongoing test: μ_R/μ_F scale variations band and compare with different generators with same parton shower)

Higgs + HF modeling and uncertainties

ggH+bb can be an important (peaking) background to e.g. ttH(H→γγ) and HH→γγbb, and, for lack of better knowledge, we often apply a 100%.

It would be worth to look into how good we expect ggF+HF to be modeled, and how to estimate reasonable uncertainties on this.

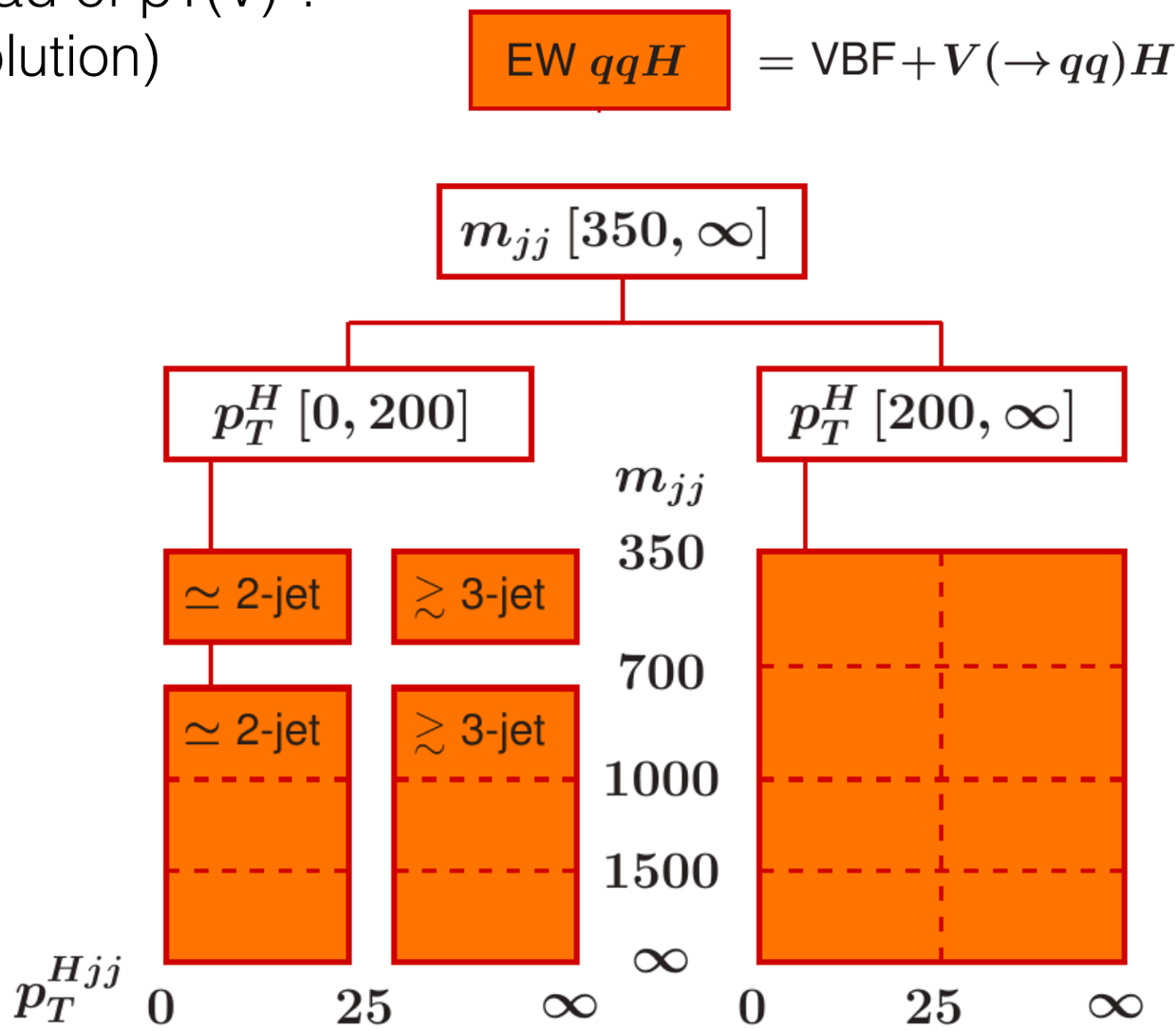
STXS

- Can we improve the binning in view of Run 3 ? and for BSM sensitivity ?
  As we pass the threshold of <100% uncertainty, we could use a finer binning, e.g.:
  - high-pT region
  - Δϕ(jj) for VBF

- In VH shall we test the use of pT(H) bins instead of pT(V) ?
  (pro: bin directly on Higgs, con: worse resolution)

- how to include VBF+gamma in STXS:
  in current scheme all the events with a hard photon will enter ≥ 3j category, while we would like them to enter in the = 2j category, and possibly in a subdivision of it. Shall we add a dedicated handling of photons to accommodate ATLAS VBF+γ ?

- Currently STXS split EW qqH categories by pT(Hjj) (acts as a jet veto and helps separate VBF and ggF). Does the pT(Hjj) binning in the STXS scheme mirror best what is currently done in the analyses so that we have minimal unfolding effects ?



STXS

- From LH2019: where to put the next pTH cuts for VH and ttH STXS 1.x ?
  One option was to have it at 600 GeV
  Re-discuss it in the light of the expected sensitivity with the Run 2+3 statistics.
  (a cut at 500 GeV and move the upper one around 700 GeV ?)

- The distinction between VBF and V(had)H becomes ill-defined at higher orders.
  We enrich in V(had)H the bin EW qqH (VBF+VH) mjj $\in$ [60, 120] GeV
  Anything we can do to better handle the two ?
  How big is the interference between V(had)H and Hjj QCD ?

- VH: would it be useful to bin in:
  m_{VH} : suggested by phenomenologist to increase sensitivity to EFT ?
  (better than the separate ptH / ptV ?)

- VBF:
  optimal observable to increase sensitivity to CP operators ?
  discussion started at LH19, “STXS CP-sensitive binning options for VBF production modes” some proof of principle discussed ($\Delta\varphi$jj)
  Continuing in this direction with more specific tests?

STXS

- how the single top analyses should be incorporated into the STXS framework?
  (we fit all of tH together, rather than keeping tHq and tHW separate)

  Input on how those should be treated in the next stage of STXS?
  e.g. whether they should be fit together with ttH: at the moment splitting the ttH into the pTH bins gives extremely high correlations with tH

- Bins for decay
  "continuous decay observable" definition investigated in LH2019 and abandoned
  Shall we converge on a scheme (e.g. Michael's proposal at WG2) ?

- acceptance/efficiency effects as a function of the parametrizations:
  - κ_λ in single-Higgs ggF : we have a parametrisation on k_λ that only affects the normalisation, we should move to a parametrisation that depends on the kinematics to be able to compute the effects on the acc/eff. Status / plans ?
  - similar effect for the requirements on the minimum invariant mass m_{34} in H—>4l,
  introduce an additional dependence of the signal acceptance on the BSM coupling parameters

STXS

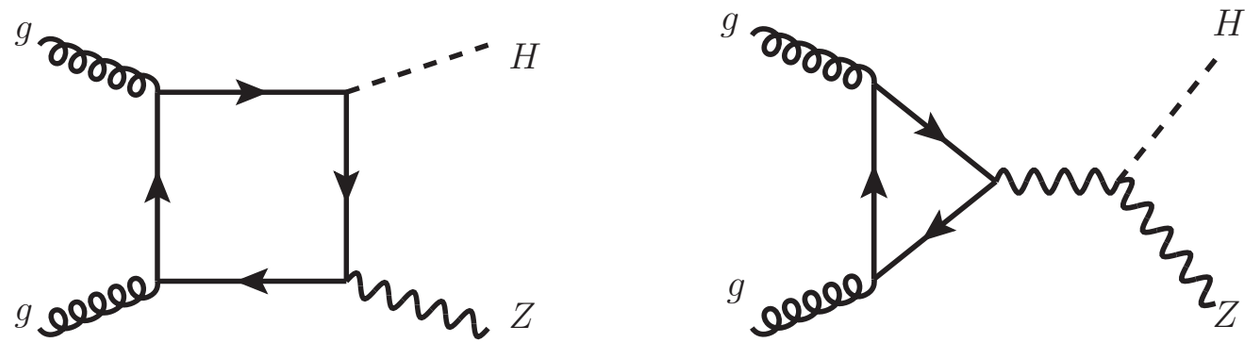
- Role of dashed separation (uncertainties vs future measurements):
  Converging towards:
  - future analyses can use the dashed boundaries (values to be agreed)
  - and recommendation for how to correlate the uncertainties from analyses not using the dashed boundaries so that everything is consistent.

Modeling uncertainties for MVA-based selections:

(very) Often we use MVA-based selections to measure Higgs processes with better statistical precision:

- Are the “standard” input modeling uncertainties (scale variations and the normalisation+migration scheme) fully sufficient? Or will there be other recommendations?
- for specific region of the phase space (e.g. some slices of m_jj where we know the MC modeling is poor) can we use different approaches ? (e.g. injecting some ad-hoc m_jj variation and check the impact on the MVA score - just to get the feeling of the sensitivity)

gg → ZH



A precise modeling of ggZH is important for the VH analysis of VH.

So far relied on POWHEG matched to the Pythia 8 PS to simulate events at LO+PS, scaling the LO total cross-section to (state-of-the-art) NLO(EFT)+NLL , but

- the modeling of differential distribution is only at LO
- the perturbative QCD uncertainties induced by analysis cuts (e.g. jet-vetoes, pT(H) cuts, etc.) rely on the LO+PS simulation.

Project at LH2019 (“A study of loop-induced ZH production with up to one additional jet”): check impact of the simulation of higher jet multiplicities at matrix element level, comparing gg → ZH SHERPA (MEPS 0-1j, and LO+PS 0j) vs. POWHEG+Pythia8 (LO for 0j) and got comparable results + shows the importance of a merged 0,1-jets prediction for the modeling of the high pT(ZH) regime

No reduction of scale uncertainties on STXS predictions w.r.t. inclusive LO sample.
Is there a timeline for NLO?

(Technical question: standard STXS Rivet routine doesn't run on Sherpa since Higgs and V-boson are not explicitly present in the generator record. Is there a work around it?)

t(t)H

- How to report acceptances for different processes (i.e. ttH, tHq, tWH)?
  - the separation between them at higher order becomes unclear
  - selections made on MVA classifiers makes it difficult to report an acceptance

- EW corrections to ttH relevant processes (ttH, ttW, ttZ, ttbb)
  - what is the status / plans ?

- Single-top Higgs production:
  - 4FS vs 5FS: currently 4FS as nominal sample, difference used as systematic uncertainty but very large (knowing that the difference doesn't make sense in some region of the phase space). In ttbb we compare 4FS vs 5FS predictions (b from ME, vs. b from PS) POWHEG can do both and take care of the overlap - do we have the same for single top production ?

  - tWH wish-list: can we have a centrally supported code for Diagram Removal (DR) and Diagram Subtraction (DS) procedures ? can it be implemented including central handling of the overlaps in MadSpin ?

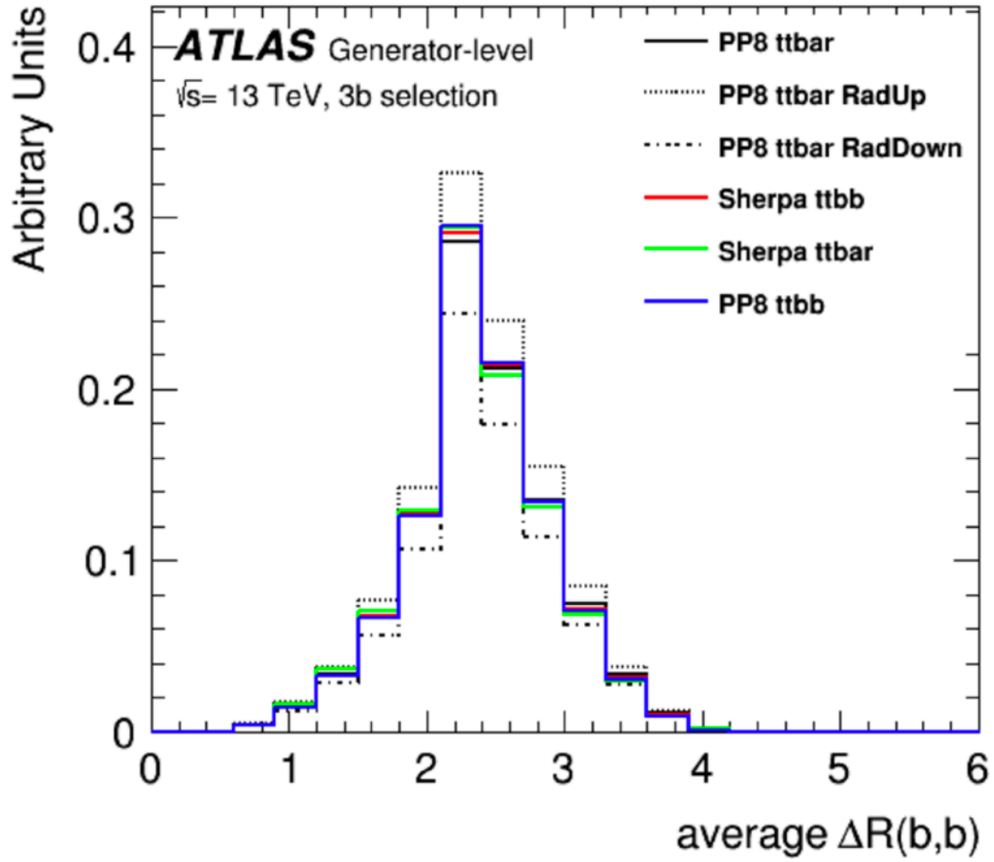
  - tHq bottle-neck: large fraction of negative weights in MG5_MC@NLO leading to large CPU requirements.

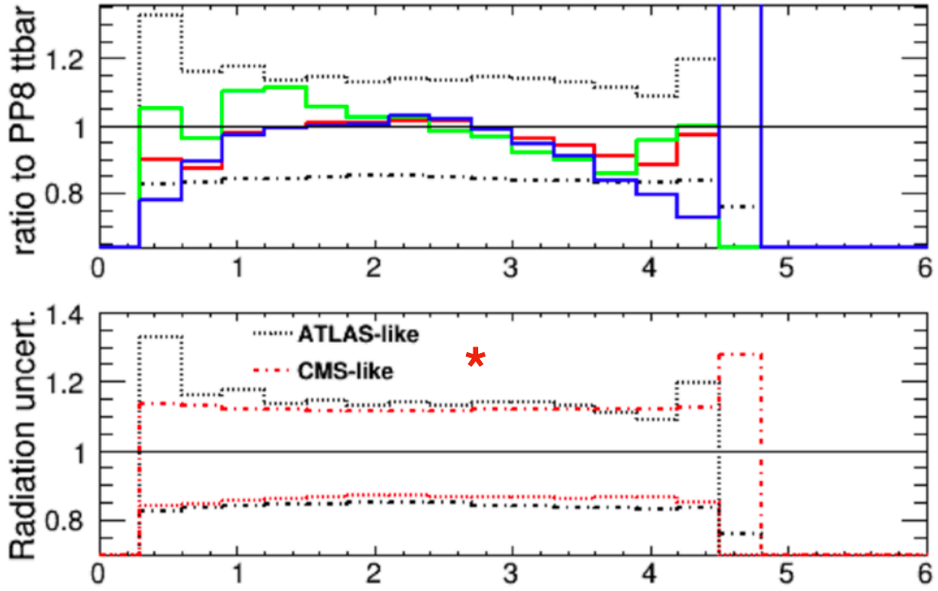
ttbb

POWHEG+Pythia8 vs. Sherpa: we observe some different modeling especially for angular variables

(these are used in MVAs, if badly modelled they can lead to biases in classifications)

Any project / work in progress to understand the differences ?





Average opening angle between two b-jets

Knowing where the differences come from, can we obtain smaller systematics ?

* The **RadiationUp** variation has the renormalisation and factorisation scales decreased by a factor of two, the Var3c upward variation of the A14 parameter set and the hdamp parameter doubled to equal 3 times the top quark mass. The **RadiationDown** variation has the renormalisation and factorisation scales increased by a factor of two, the Var3c downward variation and the nominal value of hdamp. Additionally, the up and down radiation uncertainty is calculated following the **CMS** approach, under which the renormalisation scale, factorisation scale and PDF tune variations are each taken individually and their difference to the nominal is summed in quadrature, without changing hdamp

ttbb

- How to merge ttbb with tt+light flavour and tt+charm to have consistent sample for full ttHbb analysis phase space ?

- CP odd effects on ttbb background and virtual corrections on ttbb (https://arxiv.org/pdf/2104.04277.pdf) for future (CP) analyses:

  - currently these CP effect can be simulated on (inclusive) ttbar with MCFM.
  - Can they be ported to some ttbb simulation, so that they could be accounted for in the Higgs CP analysis targeting ttH/H->bb ?

ttV

Improving experimental understanding for ttW and usage of ttW differential measurements in ttH multilepton:

- Which observables are the most interesting ones for the theory community to understand the ttW process better?
  ttW predicted lower than what ATLAS/CMS measure: can we trust the differential predictions ? Any measurement in ttV that can help tuning the predictions ?

- ttW and ttZ normalisation to data derived at very low jet multiplicity below the expected number of jets from born level process. How precise are the theoretical predictions in this region? / how to best do extrapolation uncertainties

Miscellanea

- Issue encountered in H—>γγ*—> llγ
  - no “blessed” theory numbers e.g. from HXSWG
  - γ*-> ll by parton shower. Shall we trust it ?
  - Pythia 8 used for phase space

Interpretations

Differential measurements for MSSM interpretation:

At the moment we basically have a look up table that given a set of parameters gives back the cross sections, could we use some shape information ?

Currently we only use coupling modifiers to constrain MSSM (link), but if we could get the impact on kinematic/shape we could include also the differential measurement in the interpretation.

Go beyond the k-framework for BSM interpretation → could the STXS workspaces (that include more kinematics information) be useful for BSM interpretation ?

How to improve Exp-Th information exchange ?

Result reporting:

- How to report acceptances ? what kind of uncertainties on the acceptance factor might be useful to report, as well (if relevant) any correlation scheme.

How to improve Exp-Th information exchange:

- publish likelihoods (e.g. link)
- provide nD likelihood sliced in 2D scans ? gaussian approximations around minimum ?
- classifier to map gen-level to final event class ?

Discussion

Beyond this discussion, we can request a slot for Thursday or Friday afternoon to address questions on specific topics (e.g. STXS)