ttH / tH Experimental Status

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on behalf of the ttH LHC Higgs XS WG

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Overview of the ttH WG I

- Short bi-weekly reports from the different decay channels
  - Channels have very different signatures / experimental approaches
  - Meetings covering ttH signal, important backgrounds (tt+bb, ttV, etc)
  - Background modelling is very important for ttH/tH search
  - Still to come: meetings on tH signal and background MC treatments

- https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGTTH
  - Summaries from meetings linked

- Reports from experiments (both CMS and ATLAS)
  - Highlight important issues from each experiment
  - Comparison of treatment of uncertainties
  - Identify room for improvement towards Run-2 with priority list

- Arranged a group of experimentalists from both experiments to work on open issues which have risen from discussions

Overview of the ttH WG II

- $t\bar{t}H$ smallest cross section of four Higgs production mechanisms
  - $\sigma(t\bar{t}H)$ @ 8 TeV = 130 fb → ~ 2600 events with 20 fb^{-1}

- **$t\bar{t}H$ suffers from very large background due to $t\bar{t}$+X**
- Ratio of $t\bar{t}H$ to $t\bar{t}$ significantly increases with higher luminosity

- **Very different signatures and analysis related issues**
- **Topical meetings to address each individually**

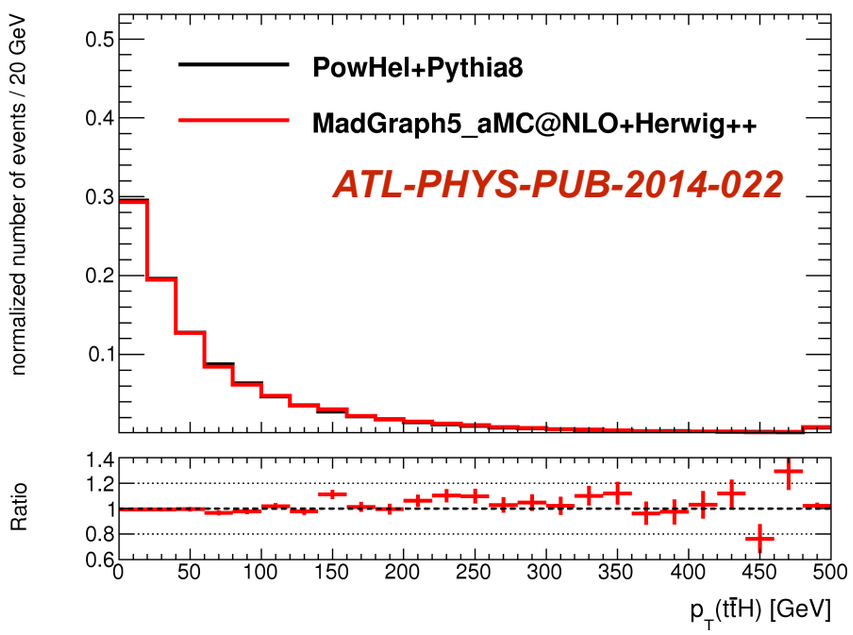
Higgs Decay	Branching (%)
H → bb	58%
H -> WW / ZZ / ττ	30%
H → γγ	0.2%

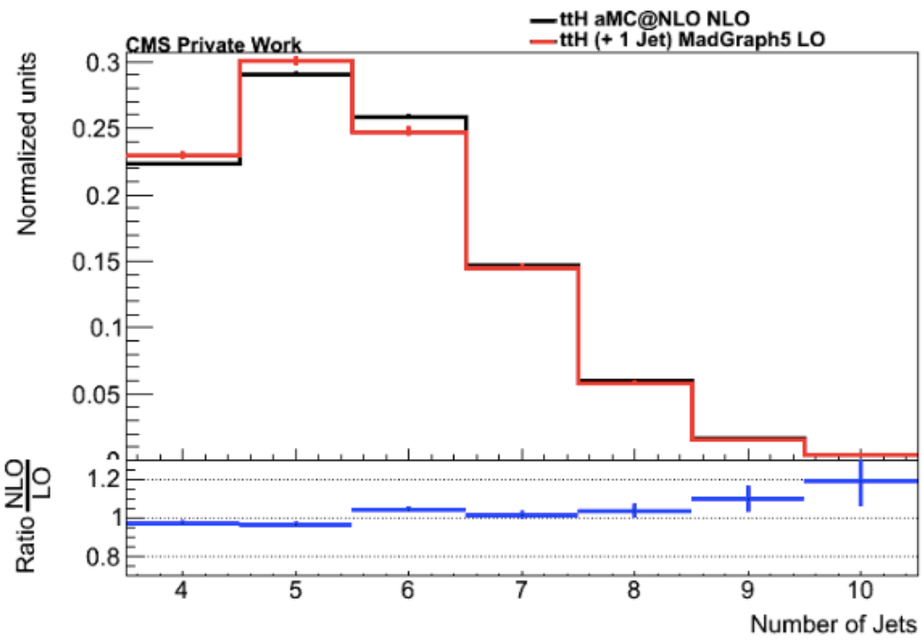
- Largest branching fraction, large background from $t\bar{t}$+HF
- Multilepton final states, small backgrounds from $t\bar{t}$+V, VZ+HF and $t\bar{t}$+jets (w/ fake leptons)
- Small branching fraction, clean signature

ttH Signal Modelling

- Talks on ttH signal modelling
  - **CMS: LO Pythia6.4.26 / ATLAS: NLO PowHel+Pythia8**
  - In both experiments, this is not the leading source of uncertainty for Run-I
    - Might be larger issue with higher luminosity
  - **Need to assess a way of uniform theory systematics / scale choices**

- Study of modelling of different generators
  - Studies of modelling from MadGraph5_aMC@NLO+MadSpin with nominal samples
    - Reasonable agreement found between two generators
  - **Need to include Sherpa and Powheg**





- CMS: NLO prefers more jets

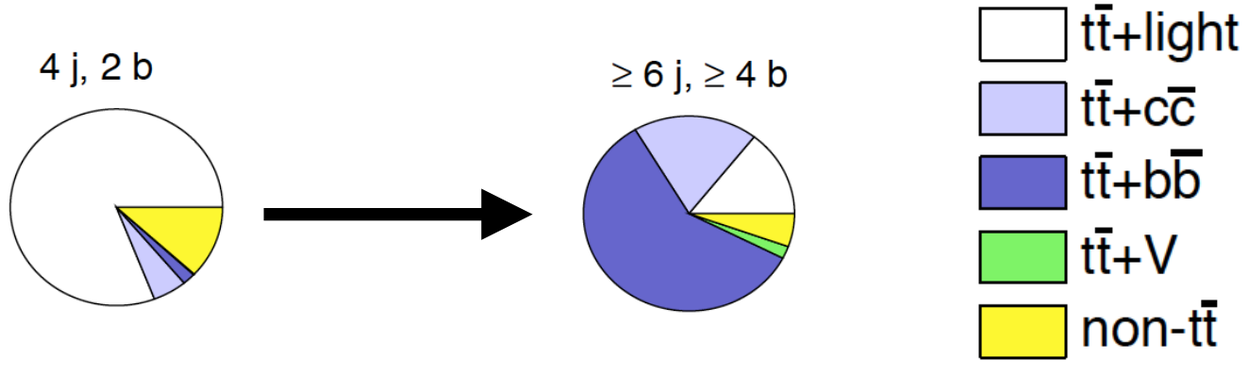
- **Need to continue study of NLO ttH MC generators**

ttH(bb): tt+jets background I

- **Largest source of uncertainty on the ttH(bb) analysis is tt+jets modelling**
  - **tt+bb and tt+cc normalization + top/ttbar pT re-weighting**

- Treatment of tt+jets slightly different between ATLAS (NLO+PS) and CMS (LO ME+PS)
  - CMS treats tt+b also separately in fitting procedure
  - Ad-hoc treatment of normalization uncertainties for tt+bb/b and tt+cc (50 %)
  - Clear improvement can be made here

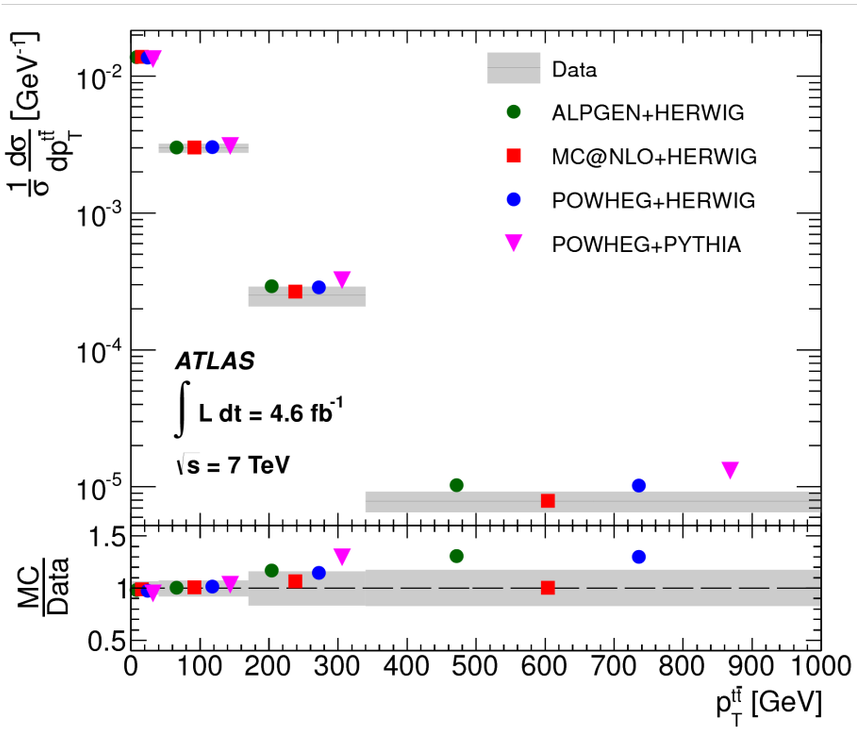
- Fitted regions in ttH(bb) single lepton:



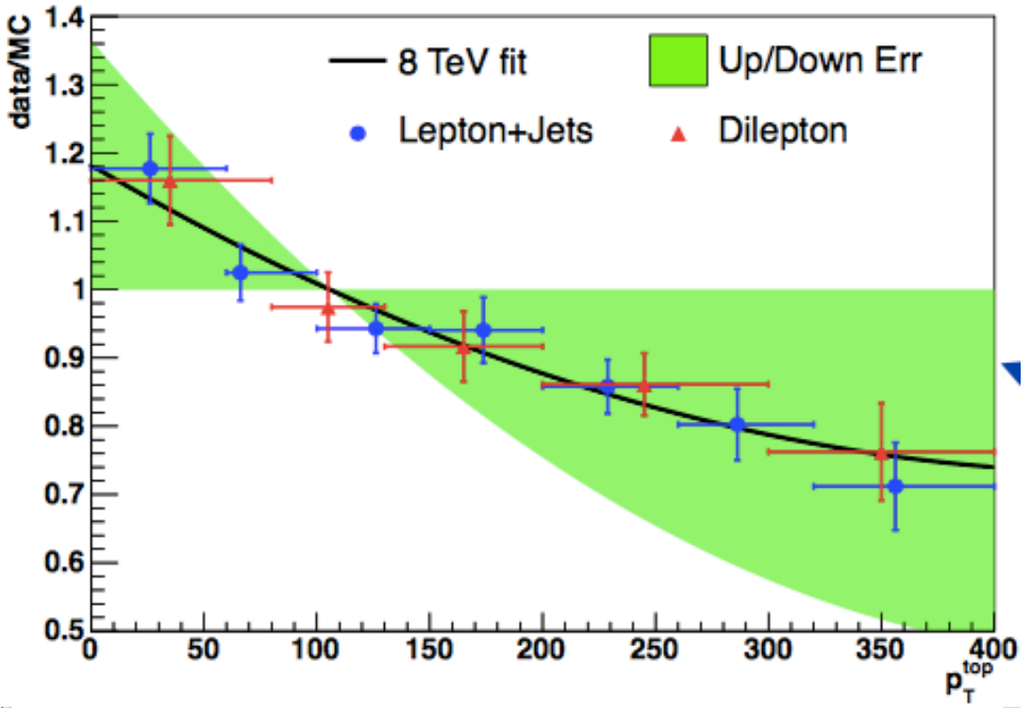
- Both experiments re-weight from differential top measurements (top pT)
  - ATLAS also re-weights based on ttbar pT spectrum
  - Thoroughly discussed experimental treatment and associated systematics

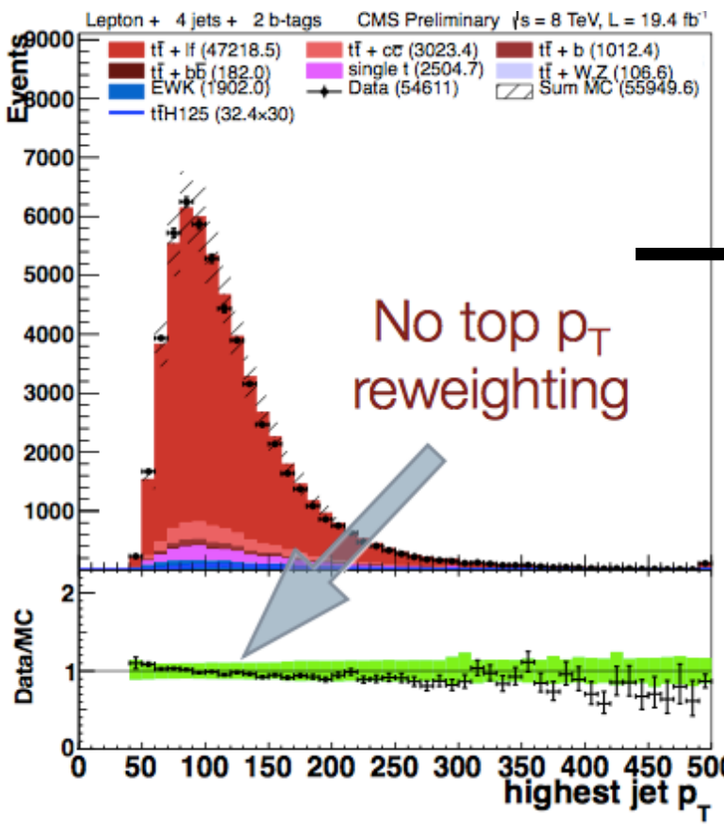
ttH(bb): tt+jets background II

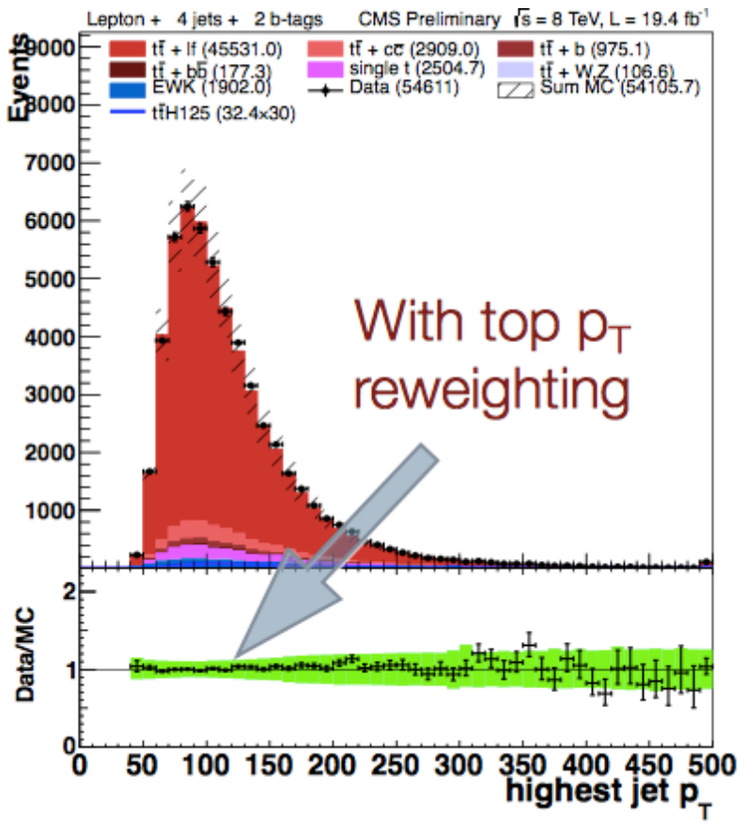
- CMS re-weights top pT from top differential cross section measurement
- ATLAS does a sequential ttbar pT x top pT re-weighting



- Re-weightings of top pT agree very well between two collaborations

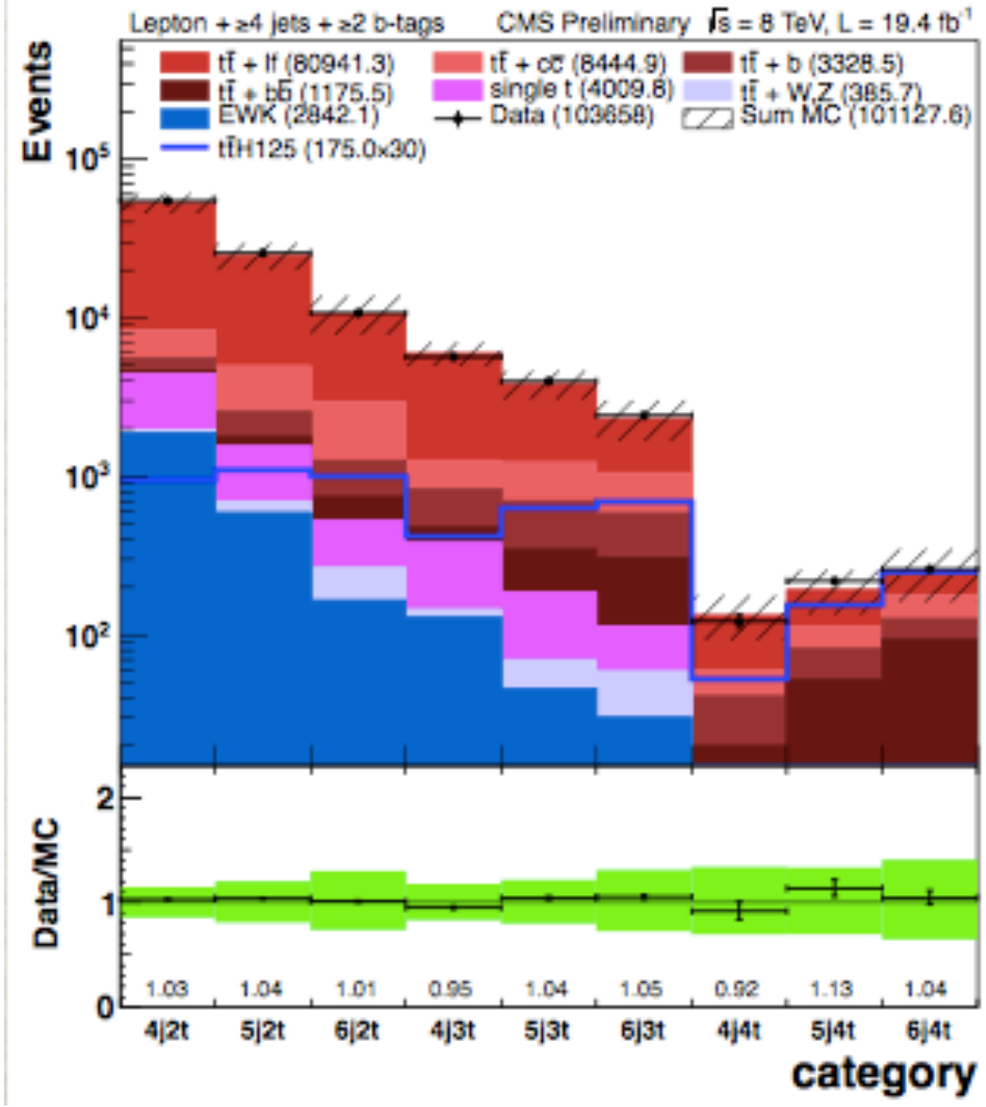




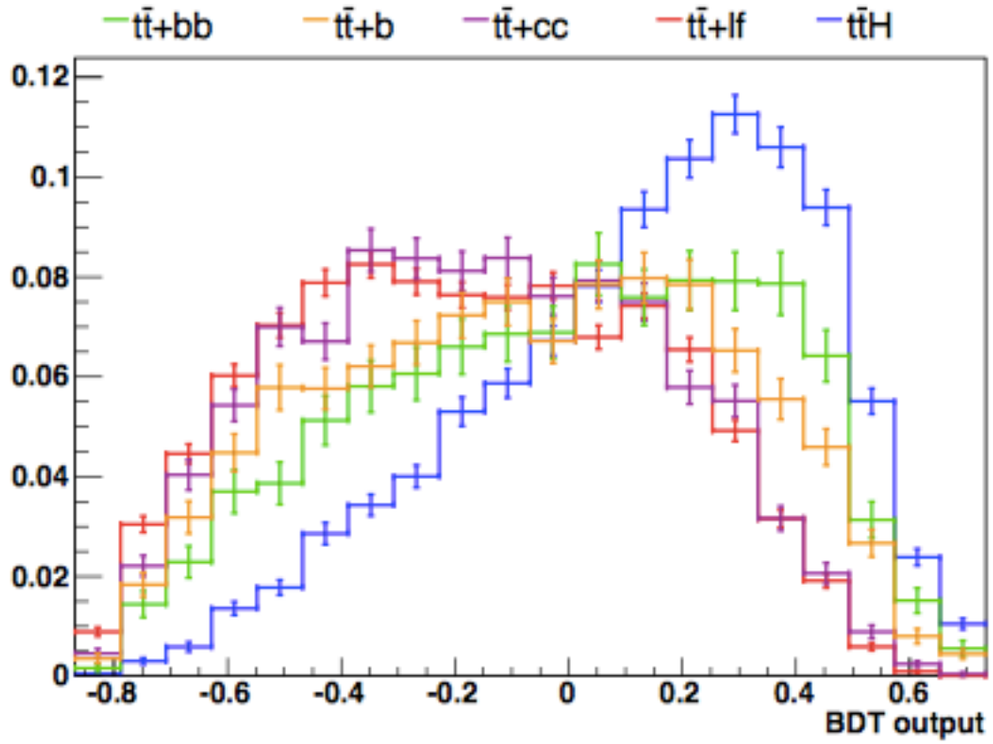


- Data/Prediction agreement significantly improves

ttH(bb): tt+jets background III



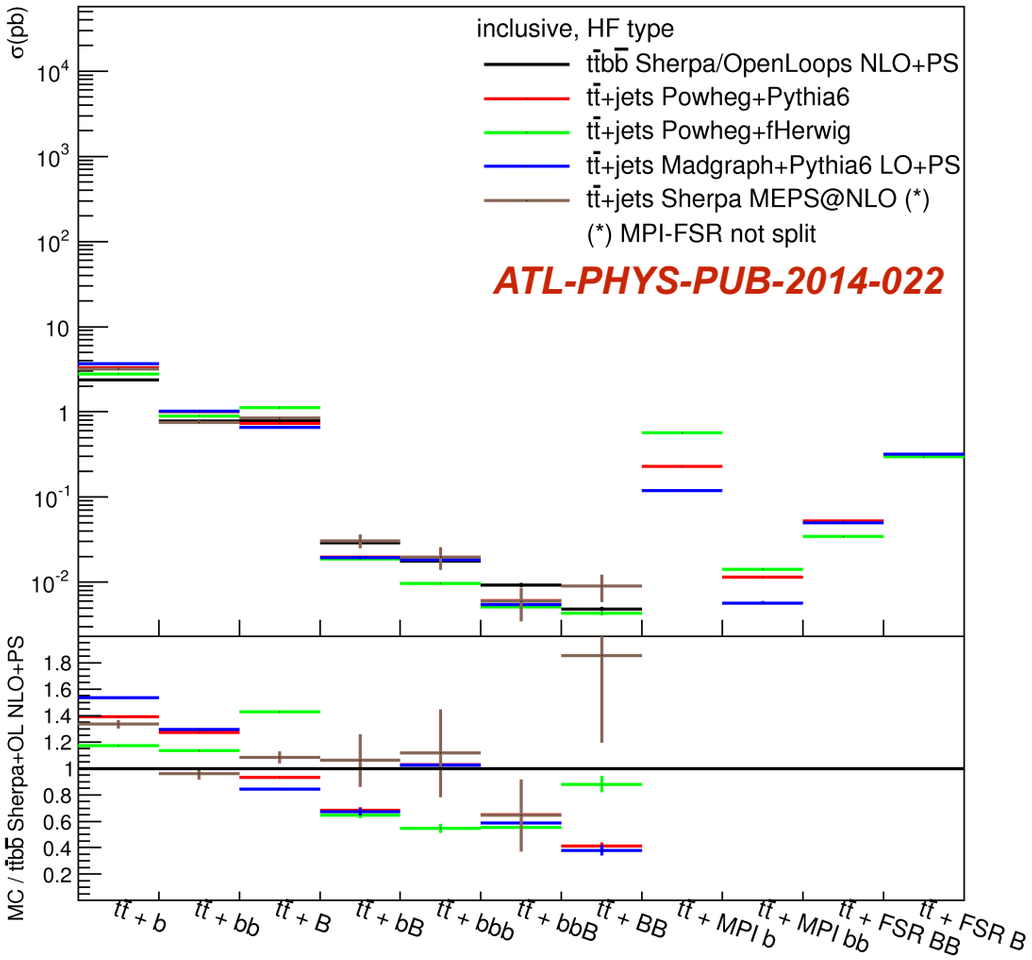
- Signal overwhelmed by tt+bb background in most signal-like regions



- **Exploit kinematic information to separate ttH from tt+bb in both analyses -> modelling crucial**

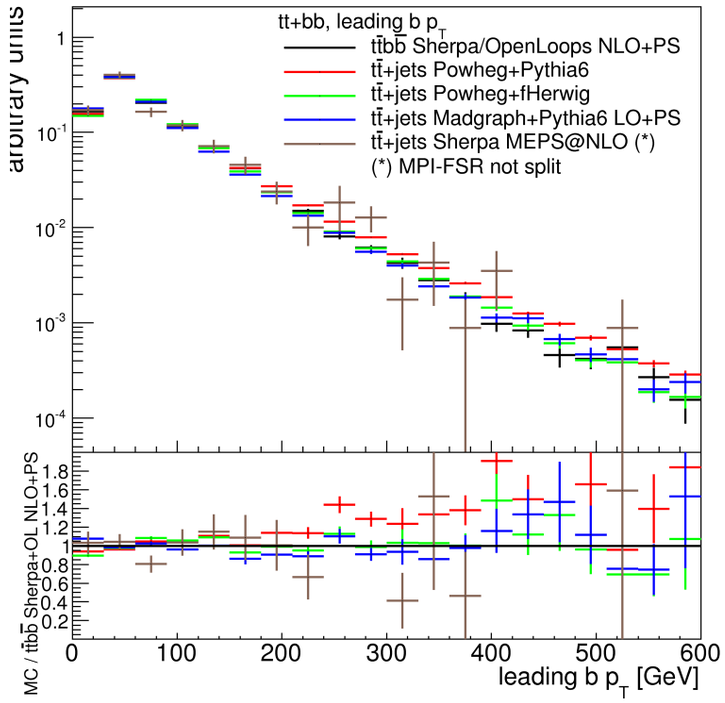
- General agreement in need to move to NLO generators for Run-II.
  - Better theoretical modelling descriptions for tt+jets.
- **Experimental input is required:**
  - Do we need tt+bb at NLO in 4F scheme? How to merge with ttbar+jets?
  - Does tt+jets at NLO in 5F scheme do a good enough job at modelling b-kinematics?

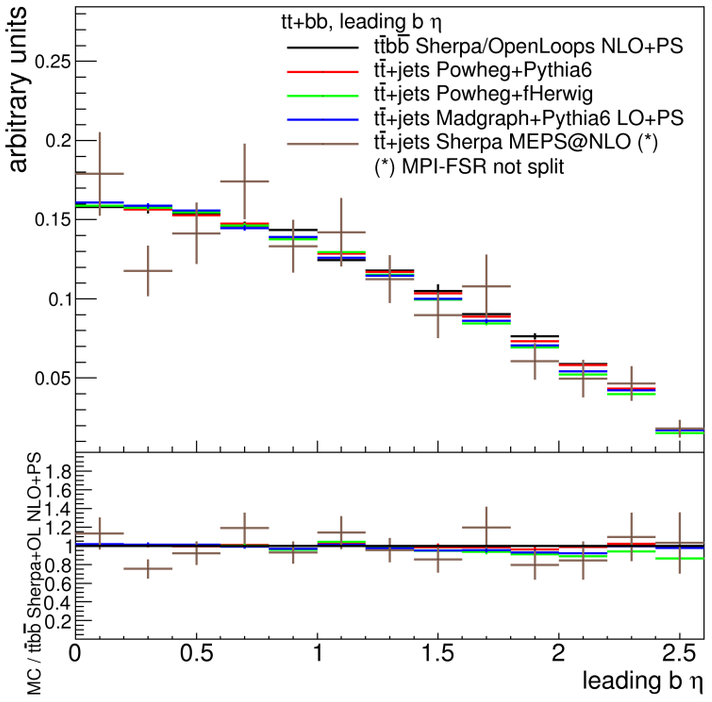
ttH(bb): tt+bb Background Studies



- Studies on-going for tt+bb for 4F vs 5F scheme
- Sherpa+OpenLoops NLO 4F tt+bb compared with NLO+PS and Sherpa MEPS@NLO

- Differences in relative contributions of different categories of tt+b(b) HF





- b-kinematics seem to be similarly modelled - not yet conclusive

- Need to include PowHel tt+bb samples, Madgraph5_aMC@NLO with different merging schemes (FxFx and UNLOPS)
- EW contributions might be significant at tree-level -> should be checked

ttH(γγ)

- Analysis approaches are different between two experiments:
  - ATLAS uses sideband region to understand tt+γγ (less MC dependent), large contribution of non-ttH production mechanisms
  - CMS aims to reduce non-ttH production, however tt+γγ background modelling is more important

- Analyses in Run-I did not need background MC descriptions
  - Background estimated from sideband regions (good to check with MC in Run-II)
  - Statistically limited analysis (CMS: ~ 1 % due to systematics)

- ATLAS H+HF uncertainties very conservative
  - Motivated by tt+HF (ggF+HF) and W+b (VH+HF) <— 100 % uncertainty

- For Run-II: beneficial to have MC modelling at NLO+PS of tt+γγ
  - PowHel collaboration: ttH(H->γγ), tt+1or2 γ at NLO+PS
    - Would like to have it publicly available
  - Significantly help model kinematic distributions for Run-II
  - Need to assess systematics from PS, hadronization effects, etc to clearly see benefit from MC predictions (still unclear how much MC will play a role)
  - Not just a ttH effort - tHq and some BSM searches

ttH(Multilepton)

- The multilepton channel includes several final state signatures:
  - 2 same-sign leptons + b-jets
  - 3 leptons (with no resonant Z->ll)+ b-jets
  - 4 leptons (other than H->ZZ->4l – no resonant Z->ll)+ b-jets

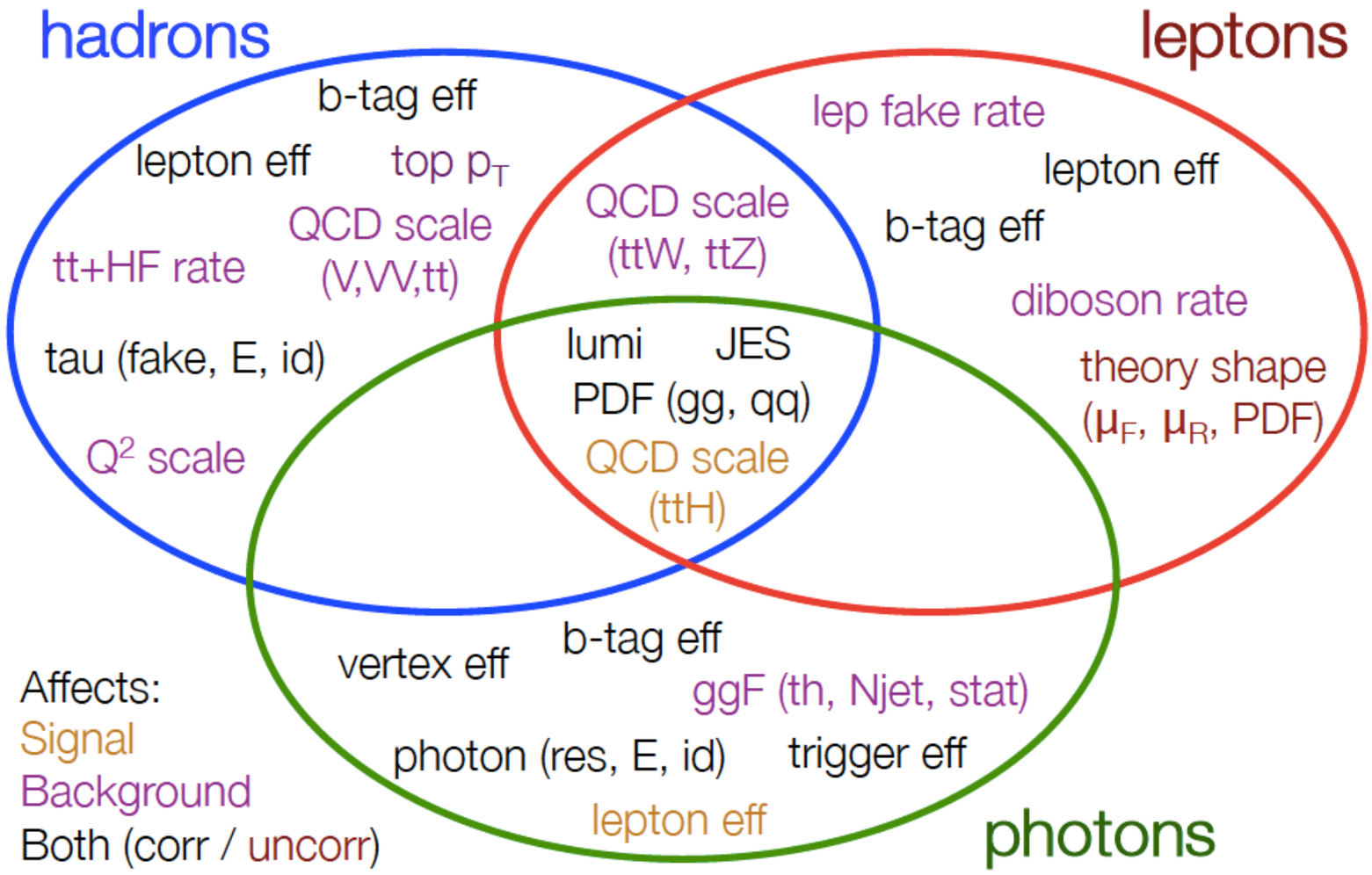
- Data driven (fakes) and MC estimated backgrounds
- Run-I analyses heavily dependent on MC simulations
  - Variations of renormalization and factorization scales, as well as ME/PS threshold taken as systematic uncertainties
  - Largest background contributions include ttV and VZ+HF
  - Discussion of usefulness of uniform recommendation for theory uncertainty treatment

- CMS uses a multivariate technique: modelling important
  - Normalized to data in control regions
  - VZ+bb extrapolation from signal region to control region one of the limiting factors

- **To-do list from experimental side:**
  - Need to quantify the need for multijet NLO simulations (ttV+jets and VV+jets) +heavy b
  - Spin correlation important?
  - Off-shell treatment of ttZ (Z-veto) —> full tt+dilepton simulation incl. off-shell Z/γ^*

ttH Systematics and Correlations

- Meeting to discuss treatment of systematics and correlations within the combination of each experiment
  - How we treat theory systematics between channels
  - Review similarities and differences between the collaborations



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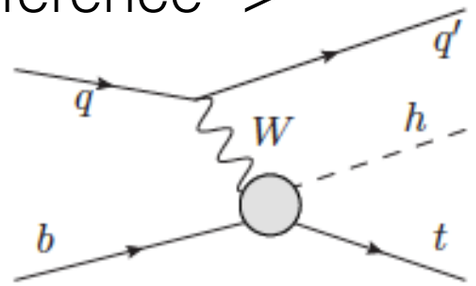
- In general, treatment quite similar
  - ttH analyses are quite different —> most systematics uncorrelated

tH Modelling: Still to Come

- **tH Meetings still to come: Jan 26th and Feb 2nd**

- Experimental measurements of kT (coupling of top-Higgs)
  - CMS: tH(H->bb) with kT=-1 (constructive interference -> enhance tHq cross section)

- Modelling issues:
  - 5F (NLO 3b + LO 4b) vs 4F (NLO 3b and 4b)
  - Validation with tWH channel MC



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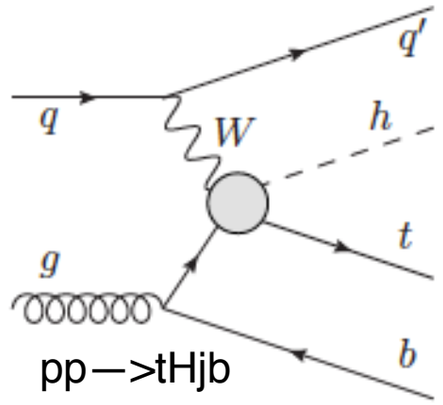

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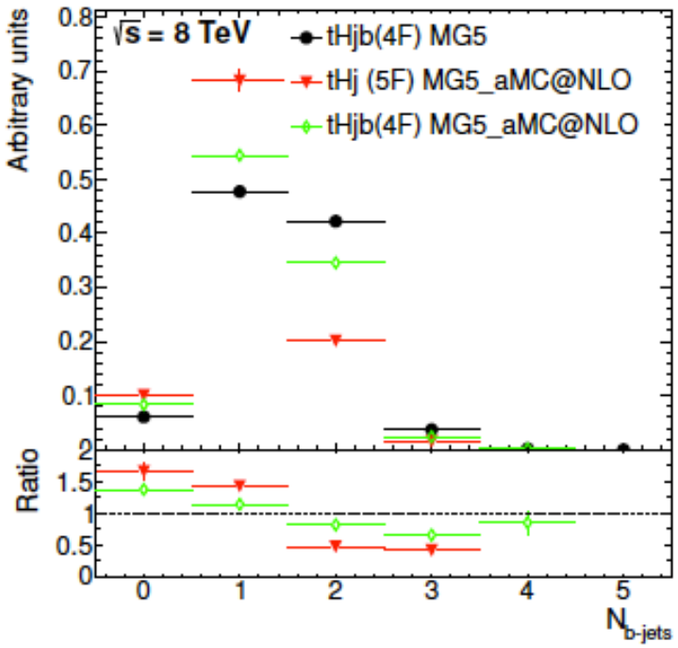

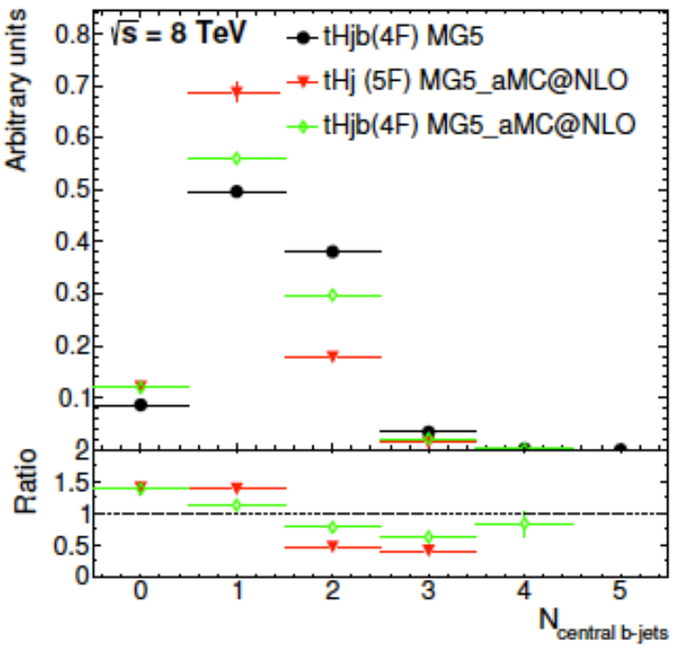

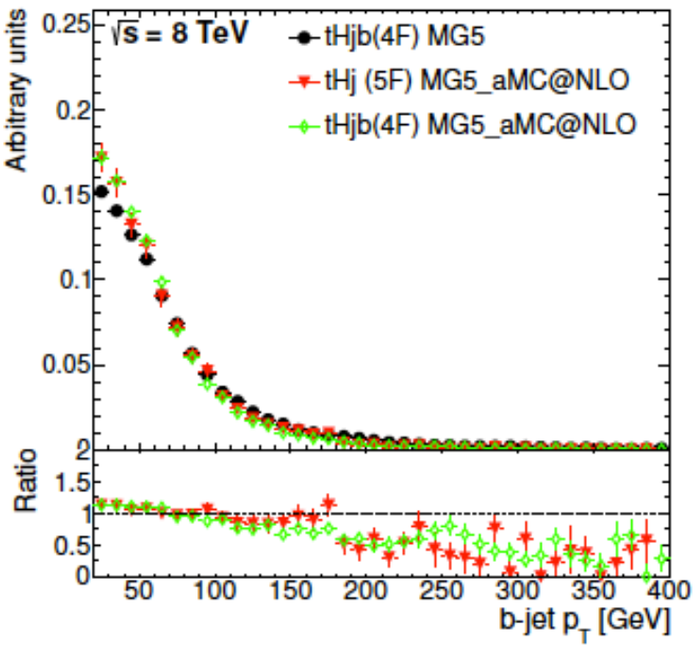

- 4F scheme predicts more and harder b-jets than 5F since the spectator b-quark at LO.
- In the NLO 4F calculation kinematics: NLO

Outlook from Experimental Side

- ttH LHC Higgs XS WG has been very busy

- Many talks from both experiments on a full range of topics
  - Discussions of ttH signal and background modelling
  - Largest sources of systematics for Run-I analyses
  - Identifying sources of improvement and where work is needed for Run-II
  - **Brought together a group of experimentalists to study all the wonderful tools our theory collaborators have been working on!**
  - Many studies currently on-going in various areas

- Look forward to continued discussion over the coming months!