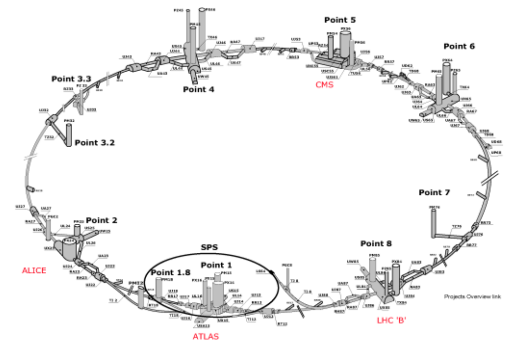
Signal Modeling in tHq analyses at ATLAS



Andrey Loginov[1]

1 Yale University

LHC Higgs XS ttH (tHq Modeling)

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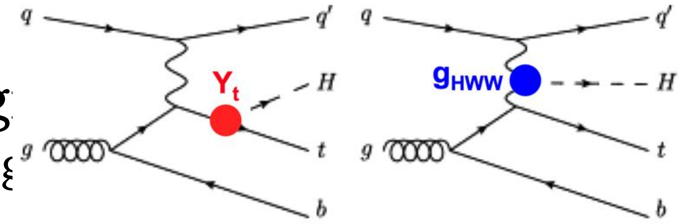
Introduction

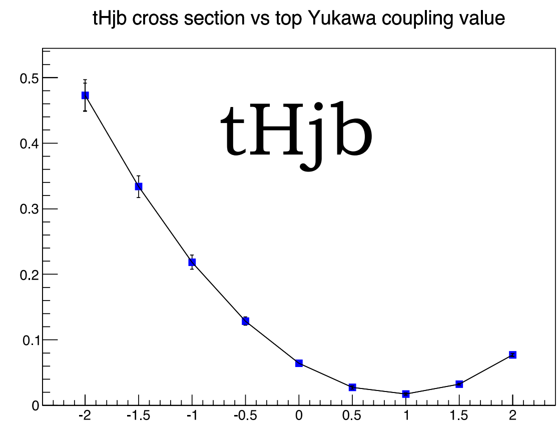
- ATLAS performed tH search as a part of ttH (diphoton) effort
  - Considered both tHjb and tWH contributions
    - A number of checks / validations have been performed
      - Will cover some of them
  - Close collaboration with aMC@NLO_MG5 team
    - Thanks very much to Rikkert Frederix and Fabio Maltoni

ttH & tH



- **tH** => Strong interference between tH diag
  - Sensitive to the relative sign of ttH (Y_t) and WWH (g couplings
- ATLAS performed ttH & tH analysis in
  H → γγ [arXiv:1211.3736v2 [hep-ph]]

	$\sigma^{LO}(pp \to thj)$ [fb]		$\sigma^{LO}(pp \to thjb)$ [fb]	
	$c_F = 1$	$c_F = -1$	$c_F = 1$	$c_F = -1$
8 TeV	17.4	252.7	5.4	79.2
14 TeV	80.4	1042	26.9	363.5



- **ATLAS Analysis selection**
  - Same trigger and photon selection requirement as in H to diphoton
  - $p_T^e > 15$ GeV, $p_T^\mu > 10$ Ge, $p_T^j > 25$ GeV
- **Hadronic** channel: **5/6j, ≥1/≥2 b-tags, lepton veto**
  - Optimization
    - Suppress non-Higgs processes
    - High purity of ttH w.r.t. non-ttH Higgs processes (ggF)
- **Leptonic** channel : **$N_{lep} \geq 1$, $M_{e\gamma}$ veto, $N_{btag} \geq 1$, minimal MET**
  - Optimization: High ttH signal efficiency

ttH & tH, $H \rightarrow \gamma\gamma$

- Run 1 ATLAS paper published in PLB
  - **Physics Letters B 740 (2015) 222-242**
    - arXiv:1409.3122 [hep-ex]
  - μ(ttH) > 6.7xSM (4.9xSM) excluded (expected)
  - **Top Yukawa coupling limits**
    - **c_t < -1.3 && c_t > +8.0 are excluded**

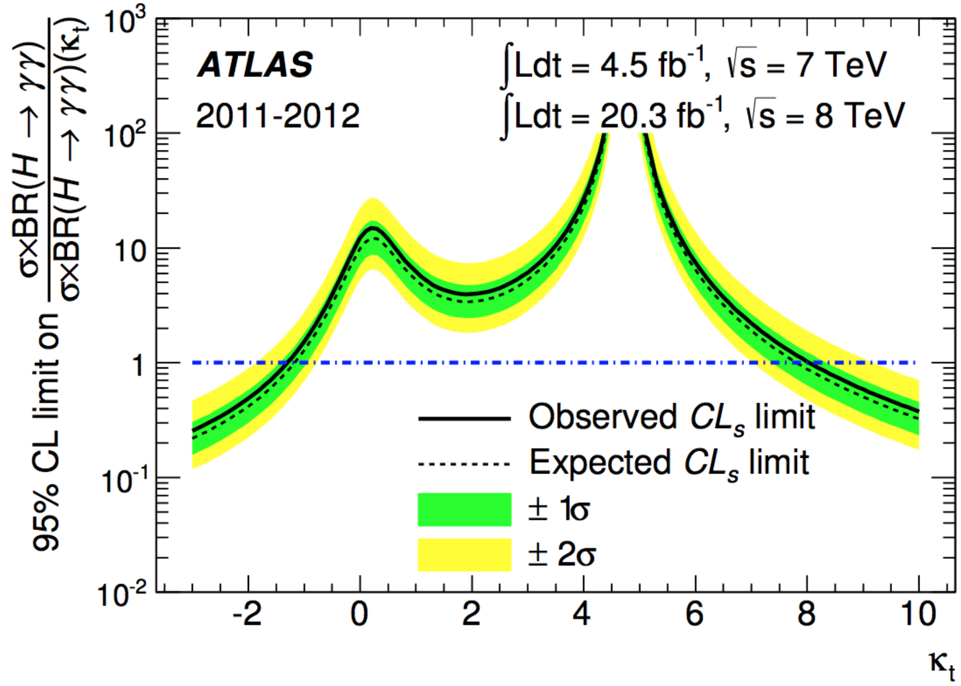
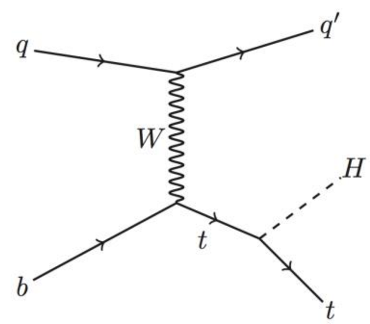


Fig. 6: Observed and expected 95% CL upper limits on the inclusive Higgs production cross section with respect to the SM cross section times BR($H \rightarrow \gamma\gamma$) for different values of κ_t at m_H = 125.4 GeV, where κ_t is the strength parameter for the top quark-Higgs boson Yukawa coupling. All Higgs boson production processes are considered for the inclusive production cross section. The expected limits are calculated for the case where κ_t = +1. The CL_s alternative hypothesis is given by continuum background plus SM Higgs boson production.

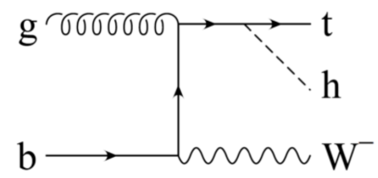
Category	N_H	ggF	VBF	WH	ZH	$t\bar{t}H$	$tHqb$	WtH	N_B
7 TeV leptonic selection	0.10	0.6	0.1	14.9	4.0	72.6	5.3	2.5	$0.5^{+0.5}_{-0.3}$
7 TeV hadronic selection	0.07	10.5	1.3	1.3	1.4	80.9	2.6	1.9	$0.5^{+0.5}_{-0.3}$
8 TeV leptonic selection	0.58	1.0	0.2	8.1	2.3	80.3	5.6	2.6	$0.9^{+0.6}_{-0.4}$
8 TeV hadronic selection	0.49	7.3	1.0	0.7	1.3	84.2	3.4	2.1	$2.7^{+0.9}_{-0.7}$

Single-top (+H) MC

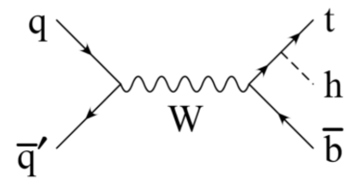
- tWH and tHjb Samples
  - Neglected the s-channel
- tW sample is used to validate aMC@NLO production of tWH process
- Documented in ATL-PHYS-PUB-2014-022



t-channel (tHqb)



WtH-production



s-channel production

$tHj(b)$, tWH and tW samples, $\sqrt{s}$=8 TeV, m$_H$ = 125 GeV, m$_t$ = 172.5 GeV				
Process	$tHj(b)$		tWH	tW
ME gen.	MadGraph5 v1.5.12	MadGraph5_aMC@NLO v2.1.0 with MadSpin	MadGraph5_aMC@NLO (LO/NLO) v2.1.0 with and w/o MadSpin	MadGraph5_aMC@NLO v2.1.0, MC@NLO v4.06
ME PDF	CT10	CT10	CT10	CT10
Ren./Fac. scale	75 GeV	75 GeV	default dynamic	default dynamic
PS/UE gen.	Pythia8 v.8.175, Herwig++ v2.6.3	Herwig++ v2.6.3, Herwig v6.520, Pythia6 v6.427	Herwig++ v2.6.3	Herwig v6.520
PS/UE PDF & Tune	Herwig++: MRSTMCal [69] & UE-EE-4 [70]; Pythia8: CT10 & AU2; Pythia6: CTEQ6L1 & AUET2B [71, 10]; Herwig6: CT10 & AUET2 [72]			

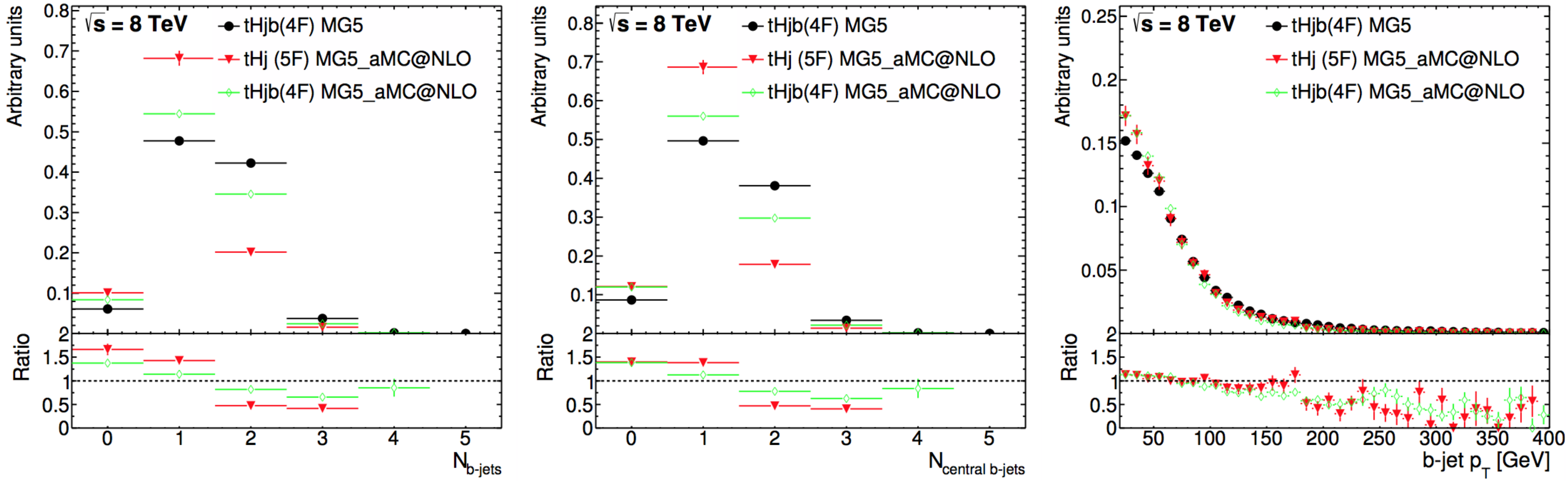
tHjb Strategy (as discussed @fall 2013)

The choices are from the theory community:

- **1st simple choice: MadGraph**
  - Generate **thjb** with a b massive (4F), choose a rather low central ren-fac scale
    - Should give rather accurate predictions at LO for both the 3b and 4b selections without a need for matching
- **2nd simple choice: aMC@NLO**
  - Use in the 5F scheme, **thj**
    - Should give the 3b signature at NLO and the 4b signature at LO accuracy. In addition, this will give the total best normalization
- **3rd choice (a bit of work): aMC@NLO**
  - in the 4F (start from the **thjb** Born with massive b)
    - it has never been looked at
    - This would give both the 3b and 4b signatures at NLO accuracy as well the total normalization

tHjb

- 4F vs 5F, LO vs NLO

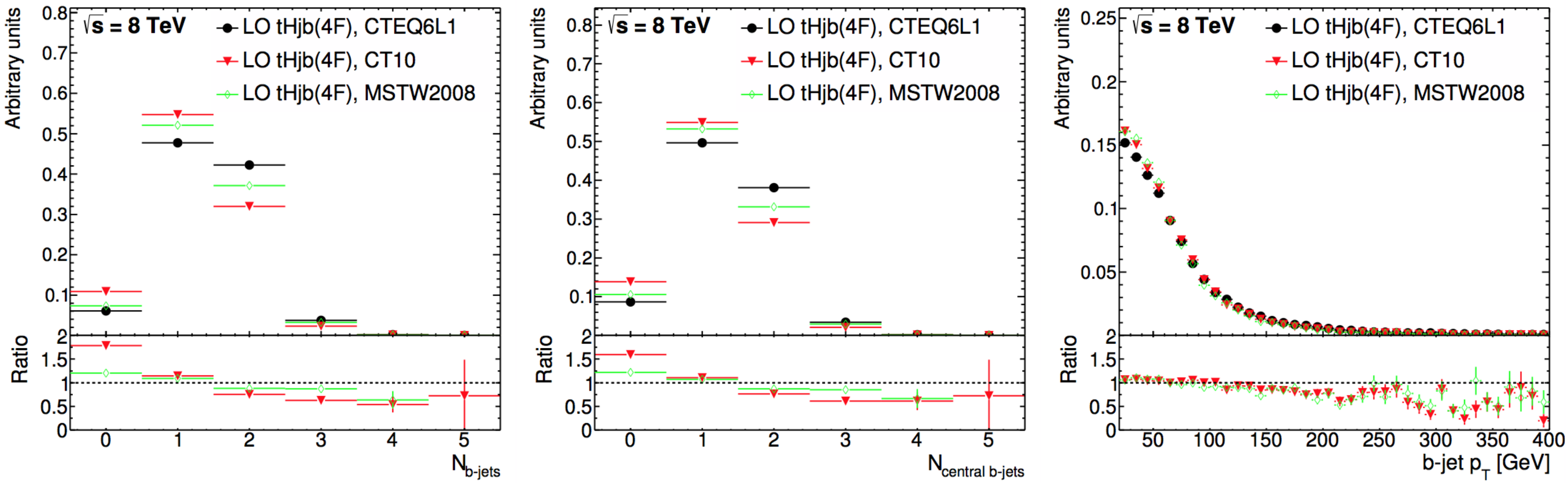


(a) $N_{\rm all}^{b-\rm jet}$ (b) $N_{\rm central}^{b-\rm jet}$ (c) $p_{\rm T}^{b-\rm jet}$

Figure 27: Various b-tagged jet comparisons. $tHjb$: The 4F scheme vs the 5F scheme comparison for LO and NLO samples generated with MadGraph5_aMC@NLO interfaced with Herwig++. Central (all) jets are required to have $|\eta| < 2.5$ ($|\eta| < 4.5$) and $p_{\rm T} > 25$ GeV. The ratio is defined with respect to the LO MadGraph5 sample (shown in black). NLO MadGraph5_aMC@NLO sample produced at the 5F (4F) scheme is shown in red (green).

tHjb

- PDF comparison

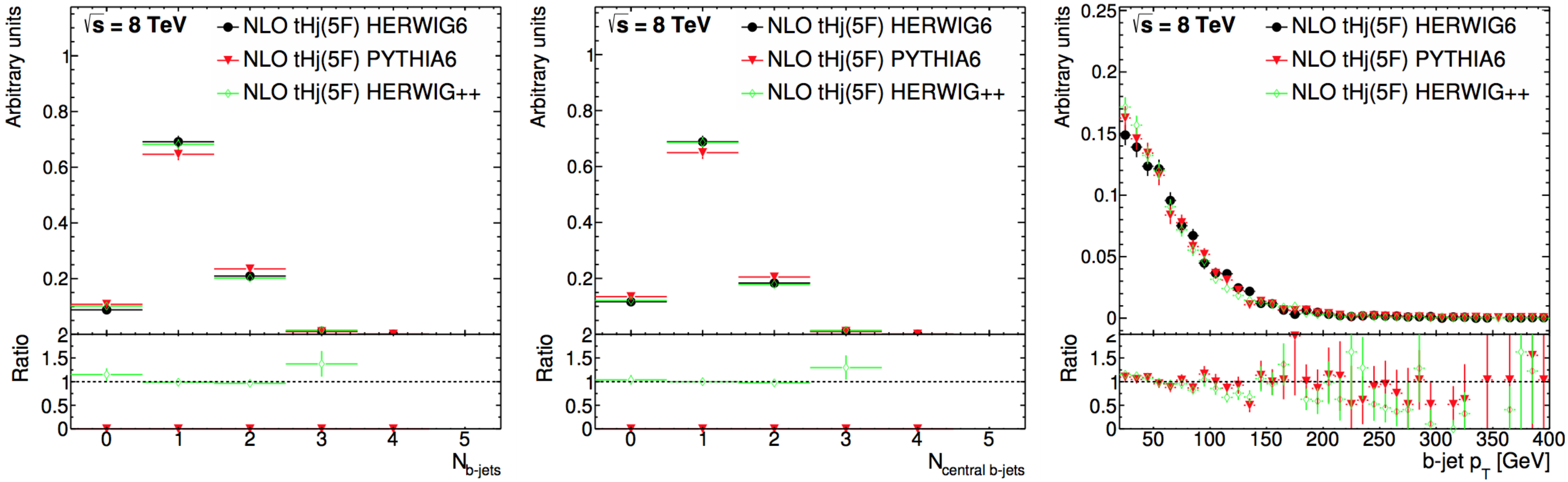


(a) $N_{\mathrm{all}}^{b\mathrm{-jet}}$ (b) $N_{\mathrm{central}}^{b\mathrm{-jet}}$ (c) $p_{\mathrm{T}}^{b\mathrm{-jet}}$

Figure 28: Various *b*-tagged jet comparisons. Comparison of $tHjb$ samples generated with MadGraph5 interfaced with Herwig++ using different PDF sets (CTEQ6L1, CT10, MSTW2008). Central (all) jets are required to have $|\eta| < 2.5$ ($|\eta| < 4.5$) and $p_{\mathrm{T}} > 25$ GeV. The ratio is defined with respect to the LO MadGraph5 sample that uses CTEQ6L1 PDF set (shown in black). The LO MadGraph5 sample that uses CT10 (MSTW2008) PDF set is shown in red (green).

tHjb

- Shower comparisons

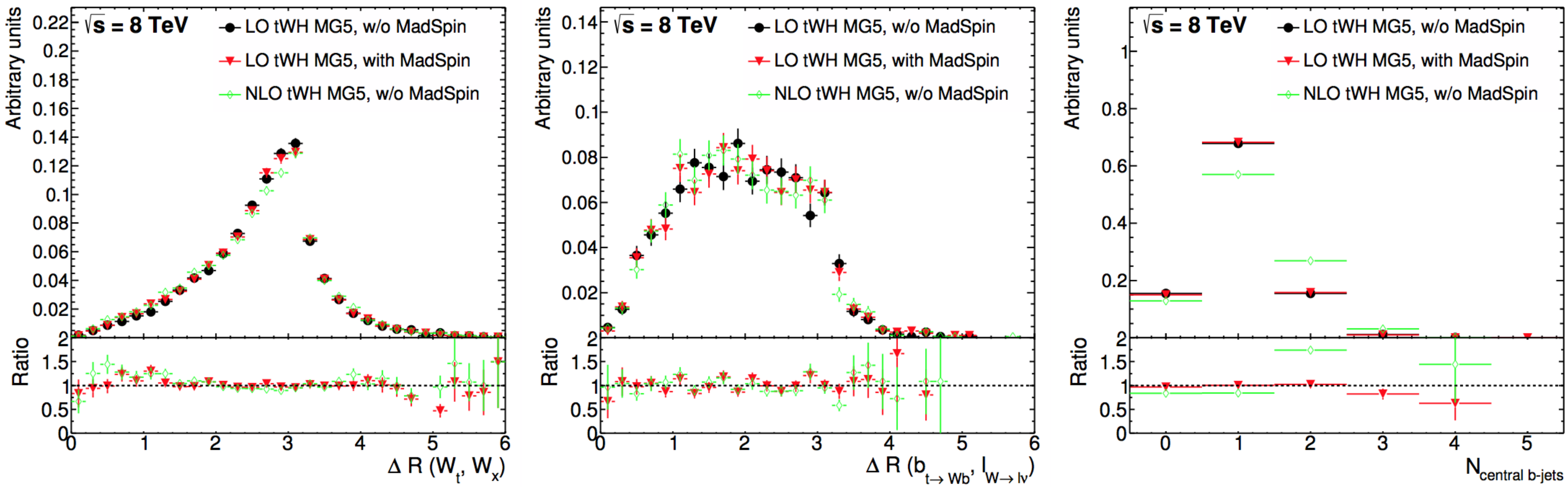


(a) $N^{b-\mathrm{jet}}_{\mathrm{all}}$ (b) $N^{b-\mathrm{jet}}_{\mathrm{central}}$ (c) $p^{b-\mathrm{jet}}_{\mathrm{T}}$

Figure 29: Various *b*-tagged jet comparisons. Comparison of $tHjb$ NLO 5F-flavor samples generated with MadGraph5_aMC@NLO interfaced with different shower programs (Herwig, Pythia6 and Herwig++). Central (all) jets are required to have $|\eta| < 2.5$ ($|\eta| < 4.5$) and $p_T > 25$ GeV. The ratio is defined with respect to the MadGraph5_aMC@NLO sample showered with Herwig (shown in black). MadGraph5_aMC@NLO sample showered with Pythia6 (Herwig++) is shown in red (green).

tWH

- Not compatible with MadSpin
  - Uses diagram removal to remove overlap with ttH
  - Not a part of the official aMC@NLO package

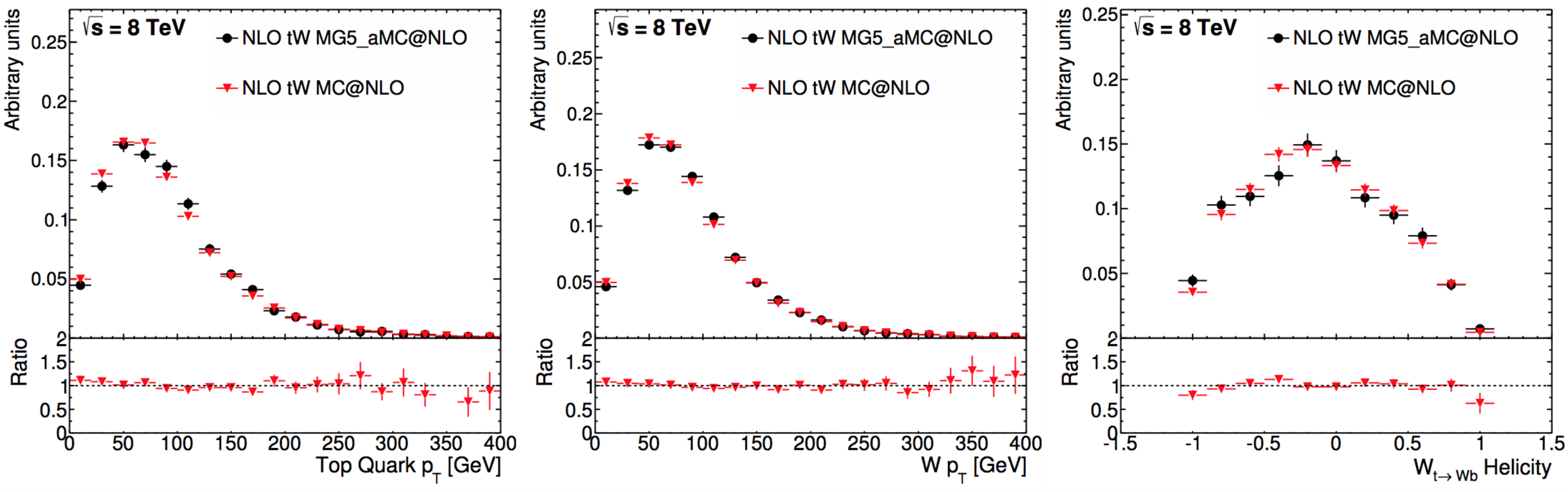


(a) $\Delta R(W_t, W_x)$ (b) $\Delta R(b_t, \ell_W)$) (c) $N^{b-\text{jet}}_{\text{central}}$

Figure 30: Various tWH comparisons. Red: tWH generated at LO with MadSpin, black: tWH generated at LO without MadSpin (top decays are done in Herwig++), green: tWH generated at NLO without MadSpin (top decays are done in Herwig++). All samples are generated with MadGraph5_aMC@NLO and showered with Herwig++. W_t is the W from $t \to Wb$. W_x is the other W. b_t is the b from $t \to Wb$. ℓ_W is a lepton from W. Central jets are required to have $|\eta| < 2.5$ and $p_T > 25$ GeV. The ratio is defined with respect to the LO tWH sample without MadSpin.

tW

- As tWH @ NLO is a new process, need to validate it somehow
  - Generate without the Higgs boson and compare to the "official" ATLAS tW sample
  - Same kind of code as for tWH



(a) p_T^{top} (b) p_T^{W} (c) W-helicity

Figure 31: tW comparisons. Red: MC@NLO, Black: MadGraph5_aMC@NLO. The ratio is defined with respect to the MadGraph5_aMC@NLO tW sample.

Outlook

- Single-top plus Higgs modeling in a decent shape for Run 1
  - Tools got improved since then
    - E.g. we can now generate tHq @ 4F scheme in aMC@NLO_MG5 at NLO
  - Some improvements would be welcome
    - tW(H) not compatible with MadSpin
      - Didn't see a major effect in the distributions we looked at… Any feedback / suggestions from the theory community?
- Thanks very much to the theory community…
  - For all the help and expertise
- …and to our colleagues from CMS
  - For being our colleagues (aka competitors) from CMS ;)