ttH in non-bb modes at the LHC

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Introduction

- ttH production is an important target for the Higgs program
  - only direct probe of the top Yukawa coupling
  - compare to coupling extracted from gluon-gluon fusion production, γγ decay: "tree" versus "loop" measurement
- Massive final state (≥ 470 GeV)
- Here: review studies of ttH production, detected in modes other than H ⟶ bb
  - all assumed as SM Higgs
- Many thanks to EF background custodians, and to Sergei Chekanov for helping us with signal simulations

Theoretical Notes

- We're after the Higgs-top coupling κ
- But we measure a cross section ratio $\sigma_{exp}/\sigma_{theory} \propto \kappa^2$
- We need theoretical cross section uncertainties on $\sigma(ttH)$, and differential quantities, at the level of the experimental ones
  - LHC Higgs x-sec WG gives $^{+5.9}_{-9.3}$% (scale), ± 8.9% (PDF+α_s) @NLO; ≈ 8% error on coupling common to all channels; improvements needed
- In addition we may need reliable predictions for differential distributions for backgrounds (a la HNNLO)

Cross-Sections

- Determined with Madgraph and aMC @NLO
- Significant scale dependence even at NLO (~5-10%)

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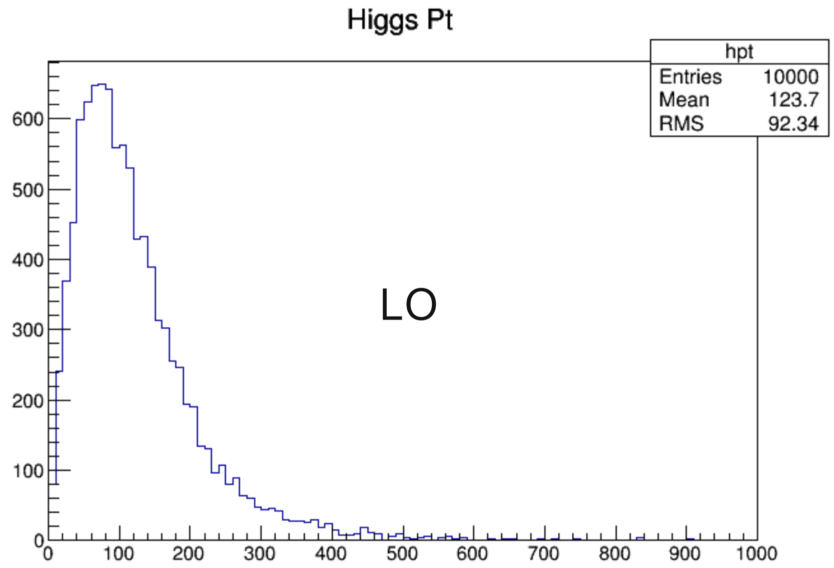
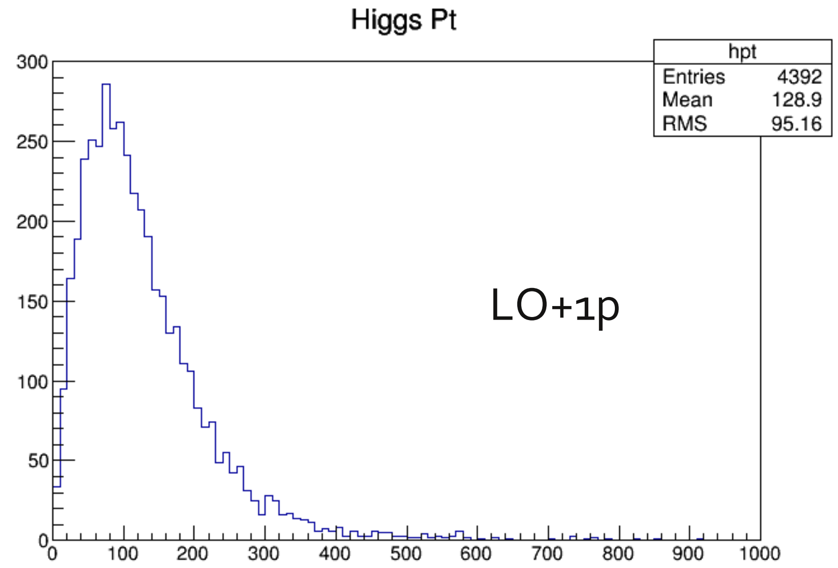
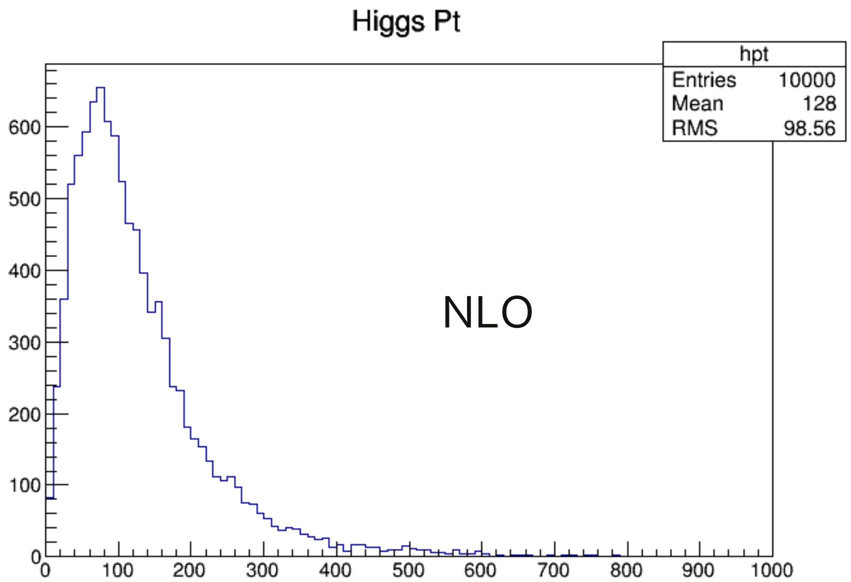
Good agreement with LHC Higgs XS WG (611 fb) → σ (NLO) for ttH

Sample	σ (LO)	σ (NLO)	Scale uncert
ttH	428 fb	610 fb	+5.4% -8.8% (NLO)
ttll	(+ up to 2 partons) 74.5 fb	74.1 fb	+57% -24% (LO)
ttW	(+ up to 3 partons) 754 fb	741 fb	
ttWW	10.41	in progress	

ttH – Higgs Pt

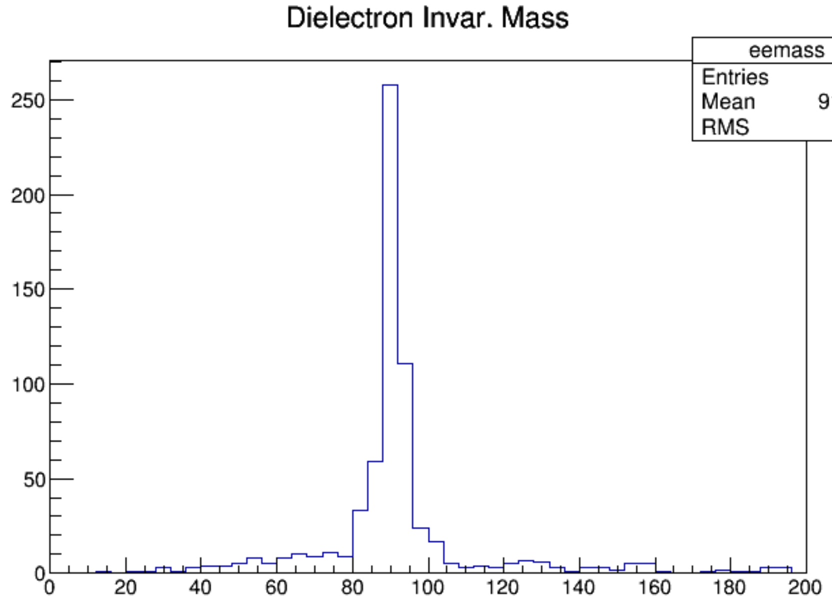


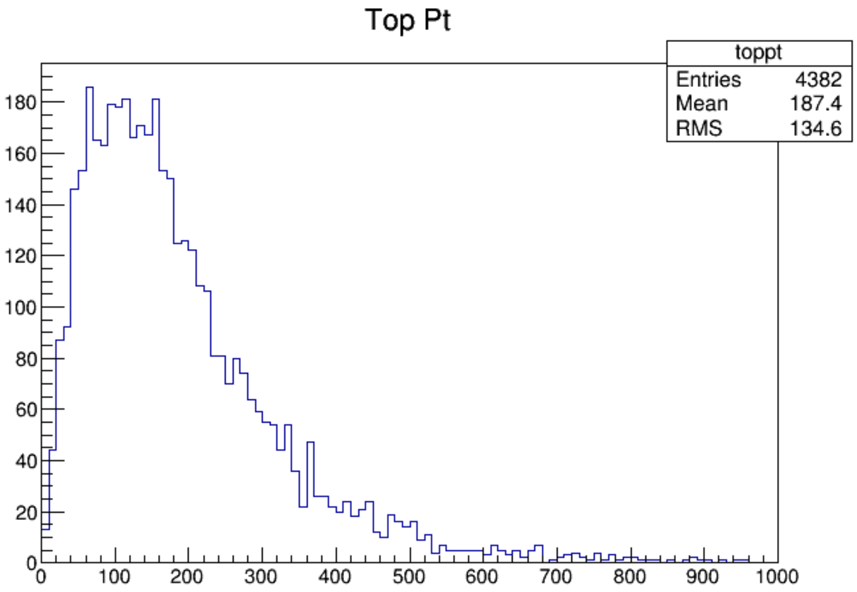


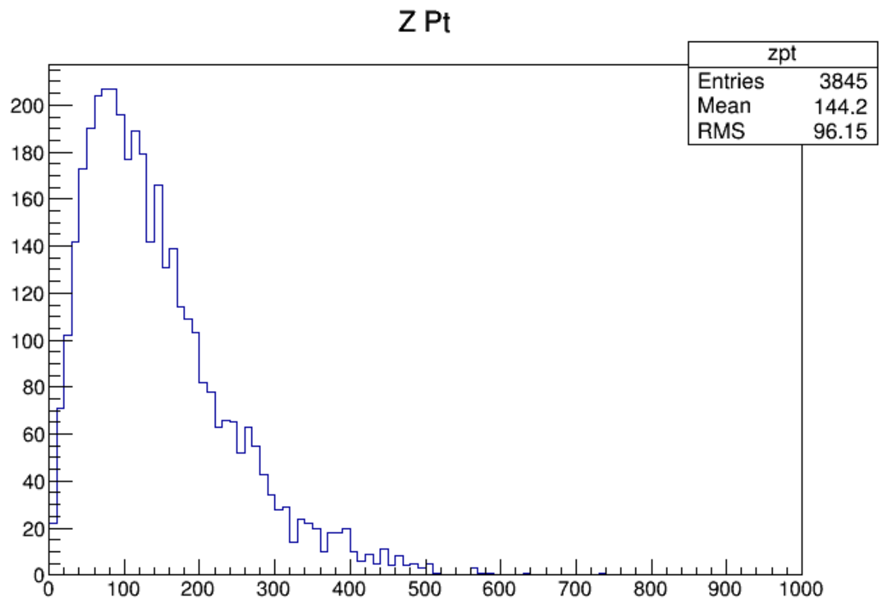


- Higgs kinematics not strongly affected by higher order corrections
- Small NLO scale uncertainty may be sufficient
  - But PDF uncertainty significant, also

ttZ Pt Distributions







- Kinematics similar to ttH
  - Aside from M_{ll}, of course
- Large LO scale uncertainty
  - Need NLO calculations
  - NLO samples would be useful
  - Too computationally intensive (for Snowmass

H → γγ

- Small branching ratio, but high acceptance & detection efficiency, resonance peak

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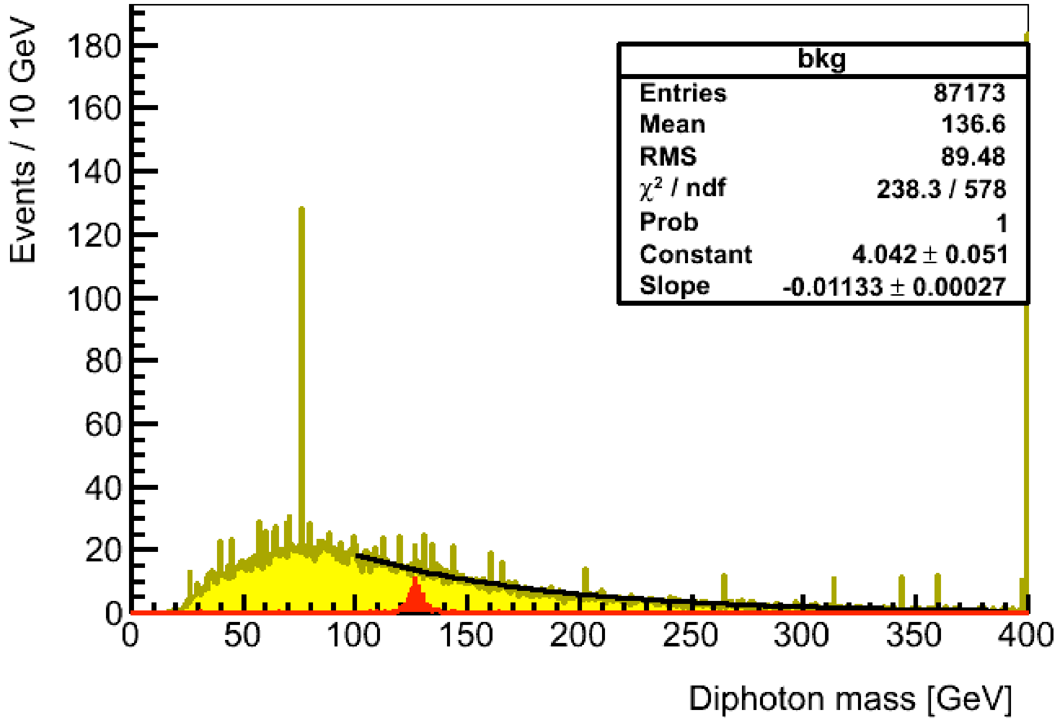
- Select semileptonic tt decays
- Modeling challenge: jet → photon fake rates
  - fake rate derived from Snowmass γ+jet MC, energy scaling with published ATLAS parametrization
  - eff vs. rejection may not be best we can do
- Background dominated by smooth tt+jets

1 e or μ, p_T > 25 GeV	MET > 30 GeV
≥ 1 b-tag	2 photons, p_T > 30 GeV
≥ 3 jets, p_T > 35 GeV, $|\eta|$ < 2.7	10 GeV γγ mass window

$H \to \gamma\gamma$

- Project 20 – 30 % stat uncertainty at 3000 fb^{-1} depending on assumed jet rejection
- Statistics-dominated even for HL-LHC



Scenario	Signal	Bkg
Conservative	138	863
Optimistic	137	256

In line with previous ATLAS projections

ttH → multileptons

- Many Higgs decays with leptons in final state
  - WW, ττ, ZZ, μμ
- Exploit by searching for the multileptons + b-jets + light jets signature
  - 2ℓ same-sign, 3ℓ, 4ℓ are possibilities
- Here we show some projections of 3ℓ
  - 300 fb^{-1} with μ=50
  - 3000 fb^{-1} with μ=140
- Using privately-generated 14 TeV Madgraph+Pythia 6 samples for ttH, ttW, ttll, ttWW

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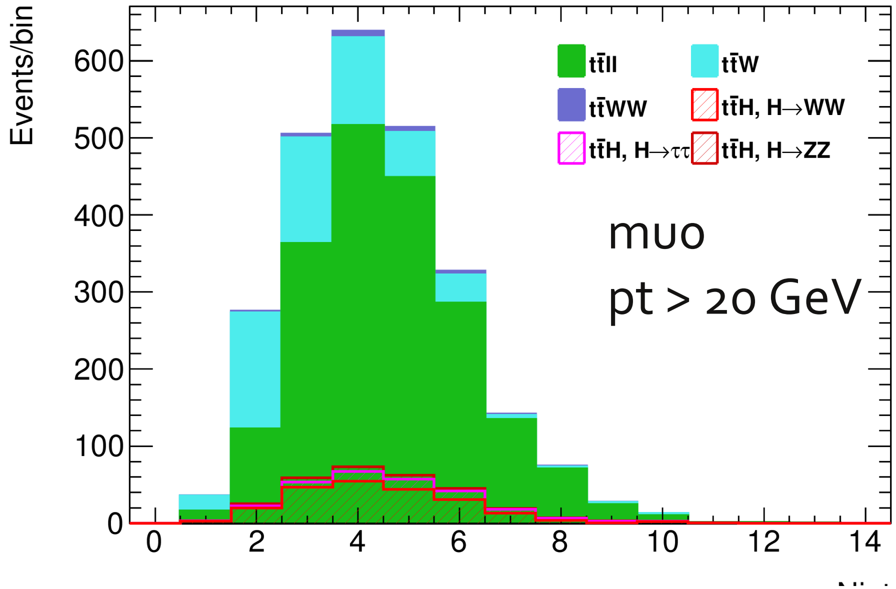
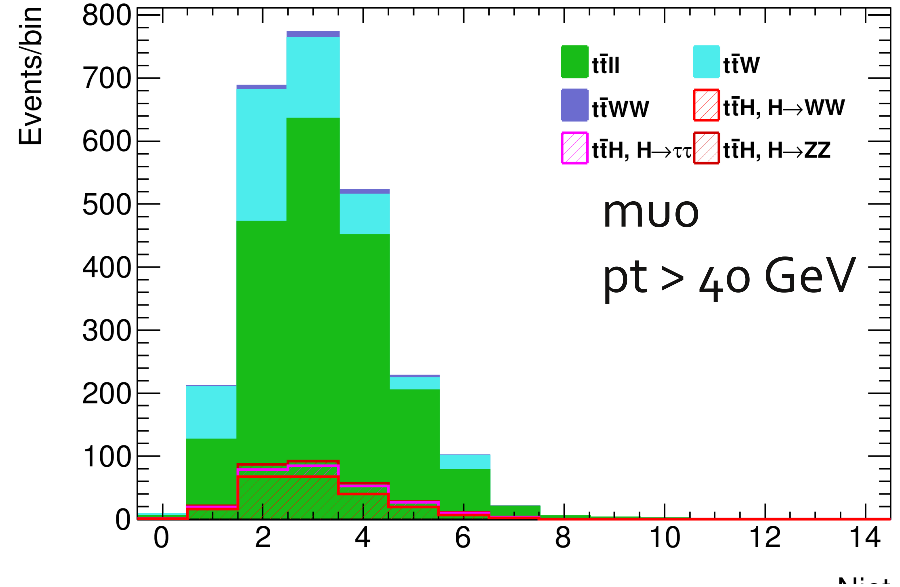
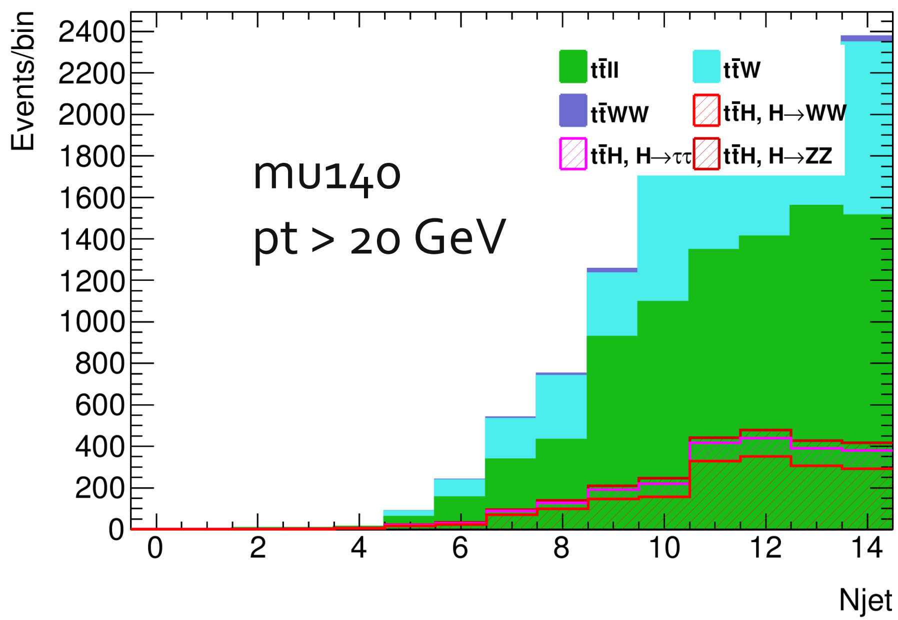
Pileup and Jets

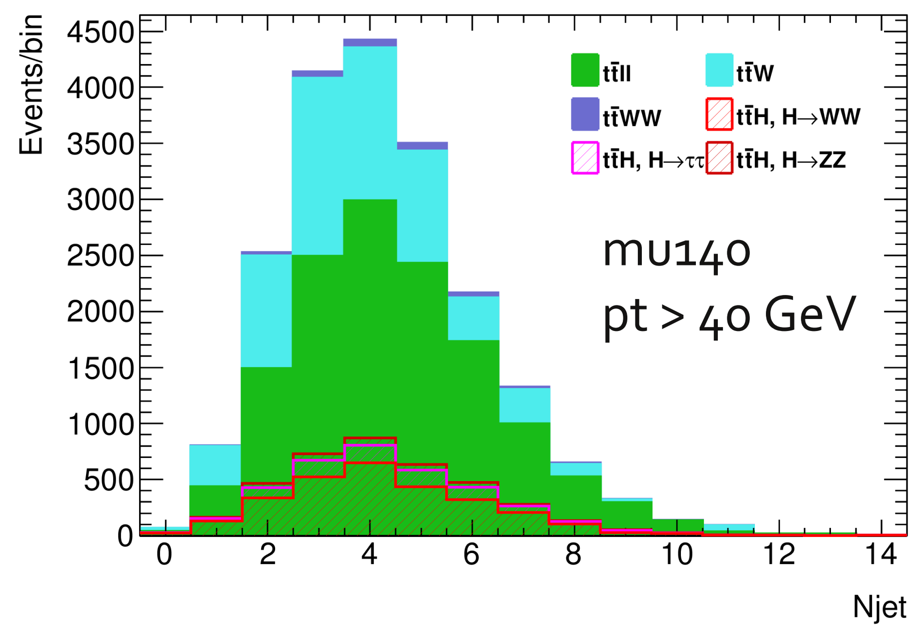
- Pileup simulation has a huge effect on # of jets, but Delphes does not include any of our experimental tricks to reduce the impact on analyses
  - in particular ATLAS uses a jet-vertex association via track counting which is expected to be somewhat robust
- Jet counting difficult to use
- Not using $\not{E}_T$ at this point

Jet counting







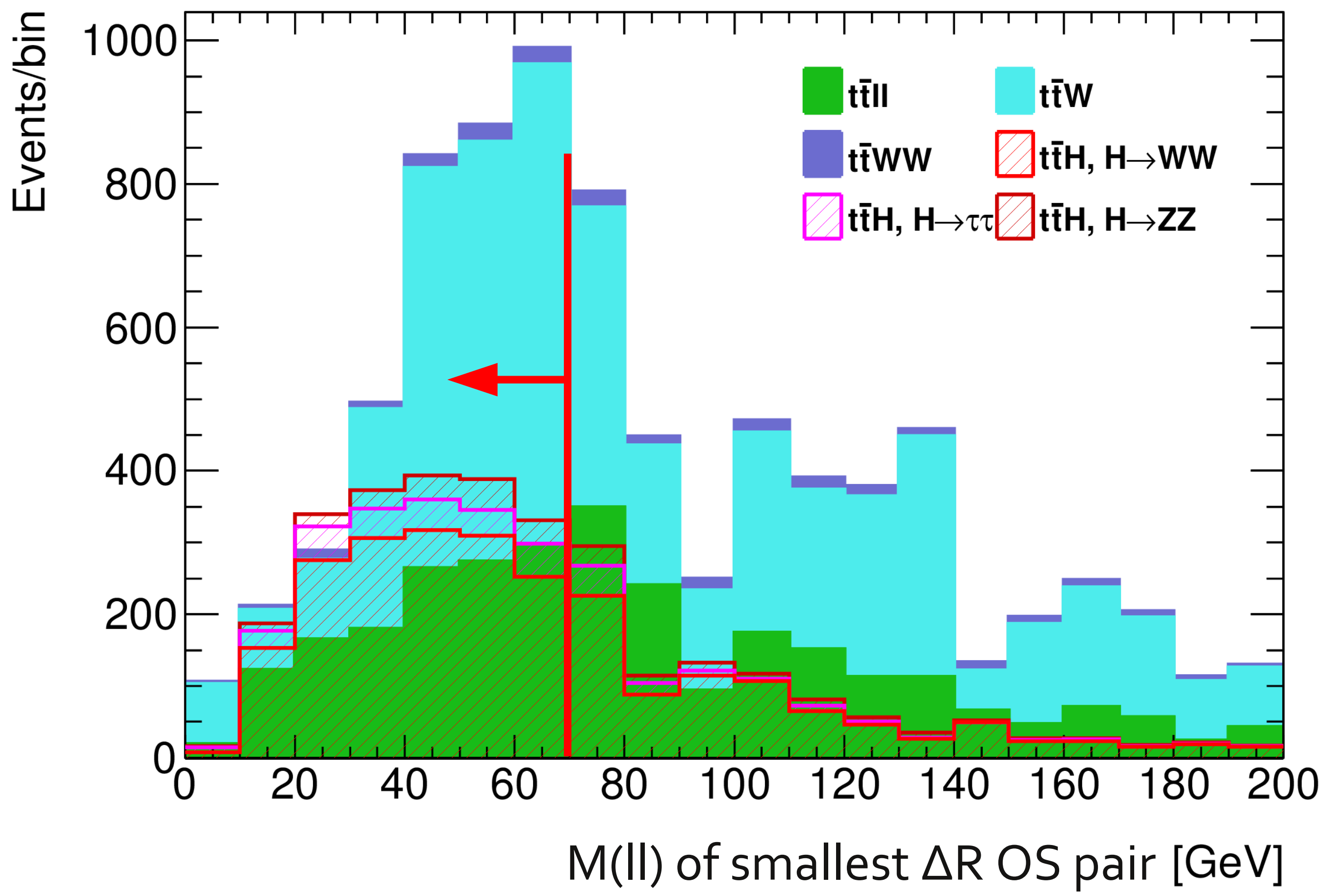


3-lep selection

- Event selection:
  - 3 leptons >= 20 GeV, none between 10 and 20
  - >= 1 b-tag
  - opposite sign, same flavor lepton pairs within 10 GeV of Z pole rejected
  - M(ll) of OS lepton pair with smaller $\Delta R < 70$ GeV
- No jet selection applied here; jet counting unreliable without better modeling
  - assume that counting is applied in the *real* analysis to remove e.g. WZ, ZZ, with 50% efficiency for signal and same S/B
- Assume ttZ, ttW backgrounds normalized from data

Using Higgs Spin Correlation

- Long-established technique in $H \to WW \to \ell\nu\ell\nu$ analysis: leptons close together, small M(ll)



3-lep Results

- Stat only precision on σ/σ_{SM} :
  - 13% @ 300 fb^{-1}
  - 4% @ 3000 fb^{-1}
  - Systematics-limited “immediately”?
- Detector uncertainties almost certainly dominated by jets and b-tagging
  - in a real analysis with jet counting, energy scale and pileup rejection systematics will become critical; perhaps this can be avoided for a tradeoff in statistics
- Theoretical uncertainties significant

$H \rightarrow \tau\tau$

- Dedicated study @ 14 TeV, scaled to 300 fb^{-1}
- Explores $\tau_l\tau_h$ and $\tau_h\tau_h$ final states

Boddy, Farrington, Hays PRD 86, 073009

  - some overlap between $\tau_l\tau_h$ and multilepton analysis
- Assumes same tau efficiency/jet rejection at μ=50
- Worried about systematics after 300 fb^{-1}
  - tau performance in HL-LHC conditions?

Final state	Signal	Bkg	stat unc.
$\tau_l\tau_h$	111	297	24%
$\tau_h\tau_h$	42	126	41%
Naive combo			21%

H → μμ

- Very stat-limited channel, only accessible at 3000 fb^{-1}
- Studied by ATLAS: ATL-PHYS-PUB-2012-004
- Predict ~ 25% stat uncertainty for HL-LHC

Plans

- Further refinement of analyses
  - e.g. include more official background samples for multileptons analysis
- Closer look at systematics
- More theoretical studies, in particular NLO impact
- Combination?

Summary

- Cross section measurement to < 25% @ 300 fb^{-1} certainly plausible
  - will require good understanding of jets in a pileup rich environment and some theoretical input
- Improvement for 3000 fb^{-1} will be systematics-dominated except for γγ, μμ
  - < 20% requires few % uncertainty per jet and theoretical understanding at < 15%
- Translates to Yukawa coupling measurements of O(10%) (perhaps with just with 300 fb^{-1})
  - for HL-LHC sensitivity need to think a bit harder about systematics

Extra

A note on ttV+jets

- ME+PS LO generators strongly suggest that σ(ttV+N jets) decreases slowly with N

N	σ(ttW+Np)
0	321 fb
1	212 fb
≥ 2	221 fb

- As a result, ttW+2j, ttZ corrections are more significant than inclusive σ might lead you to believe