Combination Discussion

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Topics

- Motivation
- Combination: Why? What?
- Orthogonality
- Nuisance parameter over-constraints
- B-Tagging systematics

Motivation

- Goal is a paper with combined ttH results from Run I data
  - Increase sensitivity to Higgs by combining multiple channels
  - Study features in ttH specific channels before putting them in full Higgs combination
  - Analysis provides direct constraint on ttH vertex that is otherwise only present in loops in other analyses in combination: increase sensitivity to new physics tests in couplings combination
- Essential to prepare roadmap and avoid potential pitfalls
  - Orthogonal selections for signal and control regions
  - Understand correlated systematics
  - Understand signal contributions in each channel

Combination: What?

- Start with the individual likelihoods $\mathcal{L}_i(\mu, \theta_i) = \mathcal{L}_i^0(\mu, \theta_i) \times \prod_j^{M_i} \mathcal{A}(\theta_{ij})$
  - θ_i are the set of nuisance parameters used in channel i
  - $\mathcal{L}_i^0$ is the "body" of the likelihood (eg $P(N_{obs}|\lambda(\mu, \theta_i))$)
  - $\mathcal{A}(\theta_{ij})$ are prior constraints for each θ_{ij} (commonly unit gaussian)
- Build a combined likelihood $\mathcal{L}(\mu, \theta) = (\prod_i^N \mathcal{L}_i^0(\mu, \theta_i)) \times (\prod_j^M \mathcal{A}(\theta_j))$
  - $\theta = \theta_1 \cup \theta_2 \cup ... \cup \theta_M$ is now the set of all $unique$ nuisance parameters
  - Some θ_{ij} are shared (correlated) between channels
- Combination requires orthogonality: $\mathcal{L}_i^0$ should be independent
  - Includes overlap between control regions (commonly ignored), and between CRs and SRs (some analyses SR is subsets of another's CR)
  - Overlap between data would artificially enhance sensitivity

Orthogonality

Lepton multiplicity	$H \to b\bar{b}$	$H \to WW$	$H \to \gamma\gamma$
$\ell^{\pm}\ell^{\mp}$ (OS)	x	x ($t\bar{t} \to \ell\nu\ell\nu + H \to WW \to jets$ or $t\bar{t} \to jets + H \to WW \to \ell\nu\ell\nu$)	x
1ℓ	x		x
0ℓ	x		
$\ell^{\pm}\ell^{\pm}$ (SS)		x	
$3\ell/4\ell$		x	

- Given smart lepton ID, orthogonality can be achieved through lepton decay mode
  - Different lepton ID can lead to overlap
  - Exception is OS $\ell\ell$, though jet multiplicity is different
- Lepton / jet overlap removal may be important if jet defs are different
  - Electrons no problem (electrons prioritized), but muon removal in OL cases may be an issue
- $\gamma\gamma$ discussed earlier, but not sure if strictly defined to be orthogonal
  - Veto on diphoton events to be strict?

Object ID

Lepton Definitions

bb		WW	
Electron	Muon	Electron	Muon
$p_T > 25$ GeV		$p_T > 20$ GeV	
-	${p_T}^{\mu} > 20$ GeV for 7 TeV		
Tight++, author 1 or 3	Combined muID, author 12	Tight++	Combined STACO
Absolute track and calo iso		Relative isolation	
		$\|d_0/\sigma(d_0)\| < 3, \|z_0 \sin\theta\| < 0.5$mm	

- Differences in p_T cut, isolation, muon algorithm, vertexing
- WW also looks at looser leptons for third lepton veto to reject WZ
- Jet definitions could affect lepton orthogonality given overlap removal
  - bb jets: anti-kt R=0.4, LCW, JVF $>$ 0.5
  - WW jets: anti-kt R=0.4, EM, (JVF $> 0.5|||\eta| > 2.5||p_T > 50$ GeV

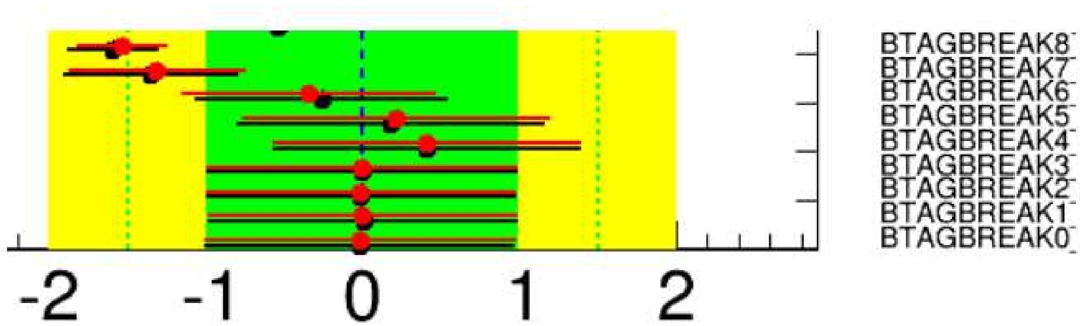
OS $\ell\ell$ orthogonality

- Final states
  - bb: 4j, 4b, 2ℓ
  - WW: 6j, 2b, 2ℓ
- bb includes 2-tag, ≥ 4-jet CR which will include 6-jet WW final state
- W$\rightarrow$c+jet will have ~ 20% tag rate, so potential overlap with bb's 3-tag ≥ 4-jet SR

Signal cross-talk

- Important to mention how to handle signal contamination between analyses
- H$\rightarrow WW$ signal can enter H$\rightarrow b\bar{b}$ analysis and vice-versa
  - Not the same as the issue with orthogonality
  - It's fine as long as the contamination is taken into account
- For coupling combination this should be dealt with by including corresponding (constant) parameters in front of appropriate signal contribution
  - $\lambda_{tot} = \mu\mu_{pp\rightarrow ttH} \times \sum_{signal} \mu_{H\rightarrow XX}\lambda_{H\rightarrow XX} + \sum_{background} \lambda_i$
  - Parameters $\mu_{pp\rightarrow ttH}$ and $\mu_{H\rightarrow XX}(XX = bb, WW, \gamma\gamma, etc...)$ are constant and allow for technical reparametrization in terms of coupling ratios

Nuisance parameter over-constraints



- Many nuisance parameters (esp b-tagging) pulled / over constrained by control regions
  - Need to understand if they are real and reliable (how often do we see such pulls / constraints in pseudo-data?)
  - How to deal with them in combination (should the constraint propogate to other analyses?)

What are over-constraints?

- Suppose we have two control regions with a free normalization μ_B and a systematic θ with a prior $G(0|\theta, 1)$
  $\mathcal{L}_A(\mu_B, \theta) = P(B_1|\mu_B B_1(1+\epsilon_1\theta)) \times P(B_2|\mu_B B_2(1+\epsilon_2\theta)) \times G(0|\theta, 1)$

- Constraint on θ can be quantified with log likelihood ratio
  $-2\ln\frac{\mathcal{L}(\hat{\hat{\mu}}_B,\theta)}{\mathcal{L}(\hat{\mu}_B,\hat{\theta})} \sim \theta^2(1+\frac{B_1B_2(\epsilon_1-\epsilon_2)^2}{B_1+B_2})$

- Nominal constraint is just from the gaussian: $-2\ln\frac{\mathcal{L}(\theta)}{\mathcal{L}(\hat{\theta})} \sim \theta^2$

- Additional term $\theta^2 \times \frac{B_1B_2(\epsilon_1-\epsilon_2)^2}{B_1+B_2}$ comes from information added by control regions gives the over-constraint
  - Control regions with anticorrelated systematics (ϵ_1 different sign than ϵ_2), such as CRs with different b-tag multiplicities, and large rates B_1, B_2 lead to large over constraints

B-Tagging systematics

Validation (not used in fit)	Signal-depleted	Signal-rich

Lepton+jets:

- H_{Thad} in signal-depleted channels and NN in signal-rich channels.
- Always compare with H_{Thad}-only analysis.

	0 b-tag	1 b-tag	2 b-tags	3 b-tags	≥ 4 b-tags
4 jets	H_{Thad}	H_{Thad}	H_{Thad}		
5 jets	H_{Thad}	H_{Thad}	H_{Thad}	NN	NN
≥ 6 jets	H_{Thad}	H_{Thad}	H_{Thad}	NN	NN

Dileptons:

- m_{bb} (from kinematic fit) in ≥4 jets channels and H_T (sum of H_{Thad} and lepton p_Ts) elsewhere.

	0 b-tag	1 b-tag	2 b-tags	3 b-tags	≥ 4 b-tags
2 jets	H_T	H_T	H_T		
3 jets	H_T	H_T	H_T	H_T	
≥ 4 jets	m_{bb}	m_{bb}	m_{bb}	m_{bb}	m_{bb}

Check consistency between lepton+jets and dilepton analyses whenever possible

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- (slide stolen from Aurelio Juste)
- Such control regions exist in bb analysis (1, 2, 3 b-tagged CRs) and will give the over-constraint on b-tagging sys

B-Tagging cancellation

- H→WW (not ttH) recently implemented method to cancel b-tagging sys using 2-jet CR
  - Introduce b-tagging normalization parameter $\mu_{\mathrm{b-tag}} = \frac{\epsilon^{\mathrm{data}}_{\mathrm{b-tag}}}{\epsilon^{\mathrm{MC}}_{\mathrm{b-tag}}}$ (ratio of b-tagging efficiency in data and MC) and measure this using CRs
  - Impact of b-tagging systematic on analysis reduced to ~ 0
- Method is rather generic and could be applied to ttH analyses
  - Over-constraints would be ∼gone, systematic due to b-tagging efficiency replaced by statistical uncertainty from CR measurement of $\mu_{\mathrm{b-tag}}$

Sensitivity

Expected limits on μ

bb			$\gamma\gamma$		WW		
ll+lj	$\geq$8j	7j	leptonic	hadronic	SS 2l	3l	4l
2.8	13.3	14.2	6.91	13.7	6.8	4.5	13.4
Individual Combinations							
2.69 (Naive)			5.42		3.61 (Naive)		

Full naive combination: 1.86

- $\mu_{\rm up}^{\rm cb} \sim 1.84\sigma^{cb} \sim 1.84/\sqrt{\sum_i 1/\sigma_i^2} \sim 1/\sqrt{\sum_i 1/\mu_{up,i}^2}$
  - Very rough: assumes fully uncorrelated systematics
- Still missing sensitivities from several channels

Summary

- A few issues must be dealt with before combination possible, though these may be straight forward to solve
  - Primarily orthogonality
  - Other issues can be solved along the way (NP correlations / constraints)
- Naive sensitivity is 1.86$\times$SM given channels that have listed expected limits
  - Several channels missing, a lot of room for improvement...