Unburied Higgs

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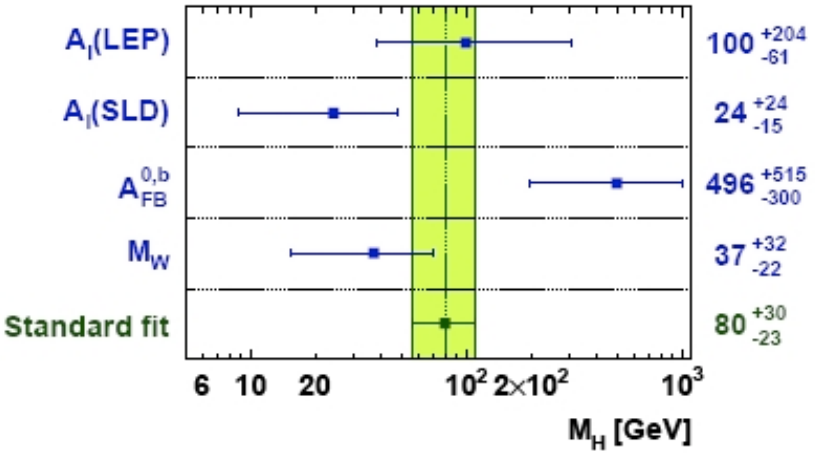
Based on AA,Bellazzini,Csaki,Weiler [0906.3026] ,
AA,Krohn,Shelton,Thallapillil,Wang [1006.0xxx]

Intro

- Within the standard model, Higgs has to be heavier than 114.4 GeV according to the LEP experiment
- But the limit can be much weaker if Higgs decays to a multiparticle final state
- Actually, Higgs mass well below 115 GeV is suggested by electroweak precision observables, and also by naturalness in popular extensions of the standard model



Summary of LEP Higgs constraints

Assuming SM production cross section, and $BR(H \to xx) = 1$

Decay Channel	**Limit**	
$h \to \not{E}$	114 GeV	
$h \to \tau\overline{\tau}$	115 GeV	
$h \to jj$	113 GeV	
$h \to WW^*$ or ZZ^*	110 GeV	
$h \to AA \to 4b$	110 GeV	
$h \to AA \to 4\tau$	110 GeV	(oven fresh!)
$h \to AA \to 4c, 4g$	86 GeV	
$h \to$ anything	82 GeV	

see Chang,Dermisek,Gunion,Weiner [0801.4554] for review

- Invisible and two-body decay channels very well constrained
- Constraints on four- and more body decay channels typically not much better than the model independent OPAL constraint, with the exception of the 4b and 4τ channels
- Typically, the multiparticle channels are weakly constrained not because of fundamental reasons but because nobody looked

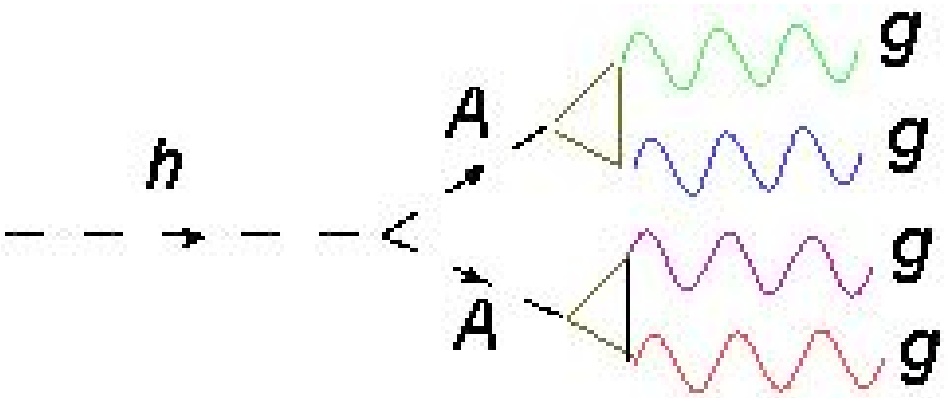
Hidden Higgs models

- $H \to 4b, 4\tau$ in NMSSM, Dermisek,Gunion [hep-ph/0502105,hep-ph/0611142]
- $H \to 6j$ in R-parity violating MSSM Carpenter,Kaplan,Rhee [hep-ph/0607204]
- $H \to 4g$ (Buried Higgs) in SUSY Little Higgs Bellazzini,Csaki,AA,Weiler [0906.3026] , open for $m_h > 86$ GeV
- $H \to 4c$ (Charming Higgs) in SUSY Little Higgs Bellazzini,Csaki,AA,Weiler [0910.0345]
- $H \to$ lepton jets in MSSM+light hidden sector AA,Ruderman,Volansky,Zupan [1002.2952]
- $H \to$ displaced vertices in hidden valley Strassler,Zurek [hep-ph/0605193] , or SM+light RH neutrino Graesser [0705.2190]

Buried in the QCD backyard

Bellazzini,Csaki,AA,Weiler [0906.3026]

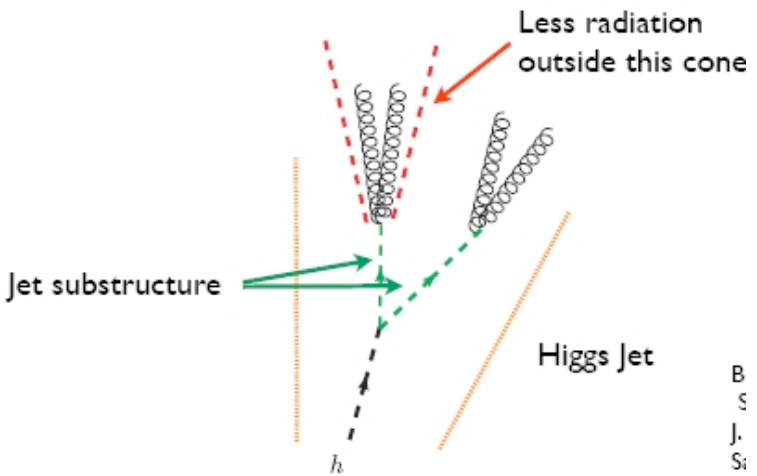
- Higgs dominantly decays to a pair of pseudoscalars A with $m_A < 10$ GeV
- A has sizable Yukawa couplings to the third generation quarks only. For $m_A < 10$ GeV it dominantly decays via loop of off-shell bottom quark to 2 gluons
- In effect, the leading Higgs decay is the cascade $h \to AA \to 4g$



- Typically, branching into standard LHC discovery final states like $h \to \gamma\gamma$ or $h \to \tau\tau$ is strongly suppressed

Buried Forever?

- Because $m_A \ll m_h$, A is boosted, and the 2 gluons from its decay will merge into 1 jet
- The signature of buried Higgs is 2 jets of low invariant mass $\sim m_A \lesssim 10$ GeV
- At the LHC, it semes hopeless at first sight:
  - Gluon fusion $gg \to h$ completely swamped by dijet background
  - VBF channels suffers because of the central jet veto
  - The associated production Vh or tth more promising, but the backgrounds from $V + jets$ and $tt + jets$ are many orders of magnitude larger than the signal
- Nevertheless...



jet substructure may save the day! AA,Krohn,Shelton,Thallapillil,Wang [1006.0xxx]

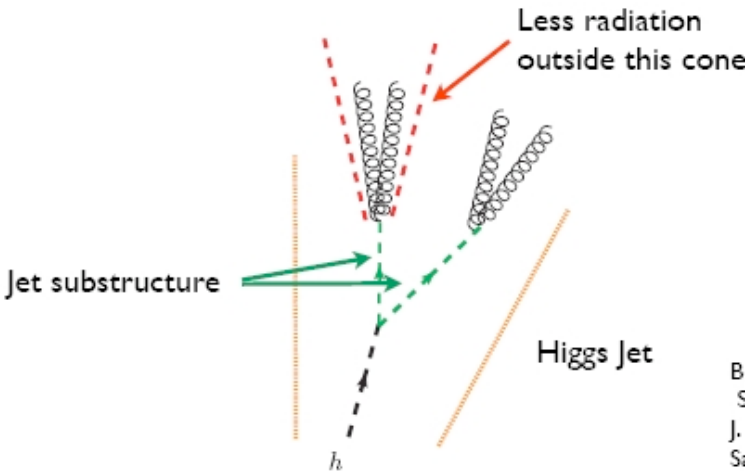
How to dig him out

AA,Krohn,Shelton,Thallapillil,Wang [1006.0xxx] looks at the following 2 channels

- Higgstrahlung: $W + h$
  - At LHC 14 TeV, $\sigma_{Wh} \sim 3$ pb for $m_h \sim 100$ GeV
  - Look at leptonic W boson decays
  - Main background: W+jets, $\sigma_W \sim 200$ nb
- Associated production with top quarks: $t\bar{t}h$
  - At LHC 14 TeV, $\sigma_{tth} \sim 1$ pb, for $m_h \sim 100$ GeV.
  - Look at dileptonic tops
  - Final state: 2 leptons (e or μ), 2 tagged b-jets, and at least 2 ordinary jets
  - Main background: tt+jets, $\sigma_{tt+jets} \sim 1000$ pb, $S/B \sim 1/1000$
  - Note: contrary to the SM case no pesky combinatorics!
  - Other backgrounds like ttZ, Zbb are by far subdominant

This talk: ttH channel only (similar techniques and final signal significance in Wh channel). Assume SM production cross section and 100 percent branching fraction into 4 gluons (caution: both can be suppressed in specific models). Assume $m_A < 10$ GeV so the two gluons to which A decays merge into 1 jet.

Unburied Higgs



- LHC is a very jetty place, and brute force kinematic cuts are not enough
- Concentrate on the kinematic regime where Higgs is boosted, $p_T(h) \gtrsim 150$ GeV, so that 2 jets from Higgs decay are approximately collimated and appear as one `fat jet` in the detector
- Then study the jet substructure, to identify the characteristic kinematics and color flow of buried Higgs It turns out for QCD it is not easy to fake that substructure
- Jet substructure tools successfully earlier applied for the SM Higgs in the $W(H \to b\bar{b})$ channel Butterworth et al [0802.2470] and $t\bar{t}h$ channel, Plehn et al [0910.5472].

Event Generation

- Signal and background are generated with `MadGraph` pipelined to `Pythia 6.4` and `Slowjet`
- ISR, showering, pile-up and underlying event included
- 3 signal samples: $m_h = 80, 100, 120$, and $m_A = 8$ GeV
- The $t\bar{t}$+jets background is matched using MadGraphs native kT-MLM procedure
- Jet clustering is done in `FastJet` and `SlowJet` using the anti-kT scheme (similar results with C/A)
- Results robust under changing model of parton shower (Pythia virtuality-ordered) and choice of matching scheme (shower-kT)

Analysis

For each generated signal and background event

- Cluster all particles into jets of size $R = 0.4$ using the anti-kT algorithm
- Preselection of the dileptonic top sample: events with 2 identified opposite sign leptons + 2 identified b-jets
- Drop leptons and identified b-jets and further cluster remaining untagged jets into fat jets of size $R = 1.5$.
- Trim the fat jets to remove contamination from unrelated soft activity
- Select the hardest fat jet with at least 2 subjets and cut $p_T \gtrsim 130$ GeV
- Find 2 hardest subjets, and cut on their $p_T \gtrsim 40$ GeV

Substructure variables

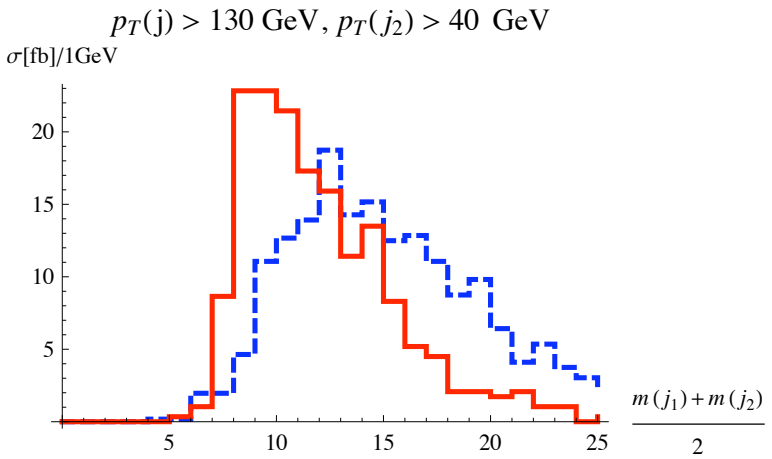
- Signal has 2 subjets with the same and low invariant mass
- QCD radiation favors mass hierarchy and sligthly larger jet masses (after pT cuts)

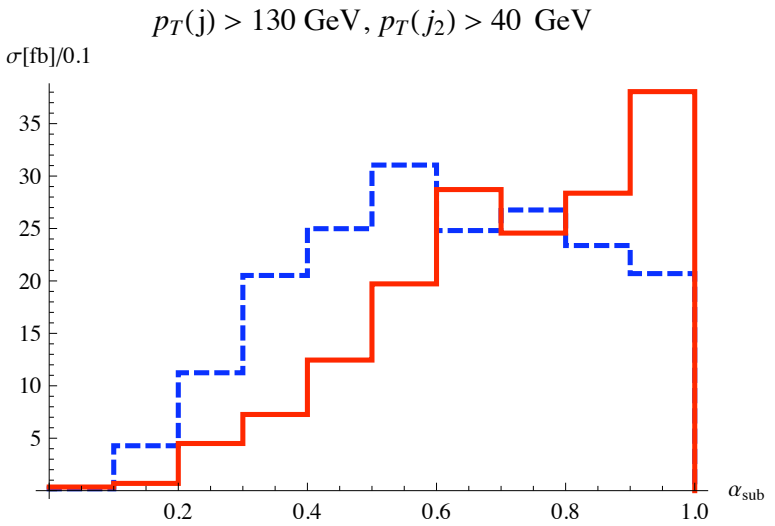
Mean invariant mass:

$$\overline{m} = \frac{m(j_1) + m(j_2)}{2}$$

Mass democracy:

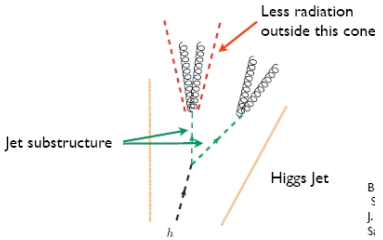
$$\alpha_{sub} = \mathrm{Min}(m(j_1)/m(j_2), m(j_2)/m(j_1))$$





Background (Blue) x 1, Signal(Red) x 100

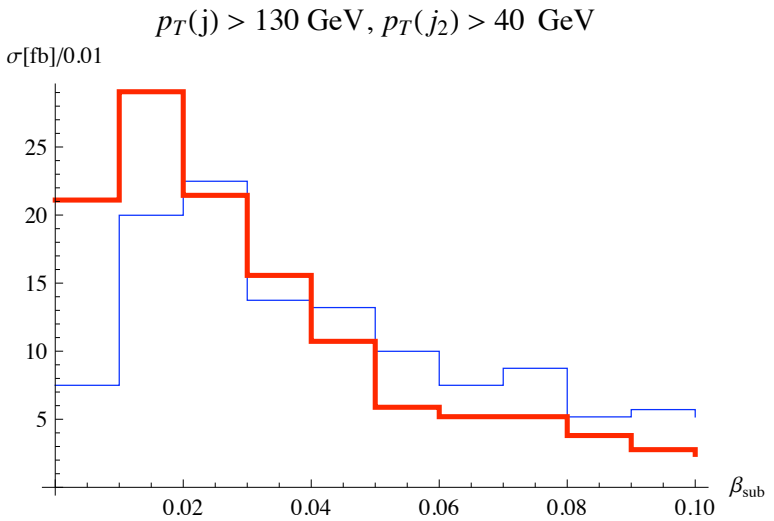
Color flow variables

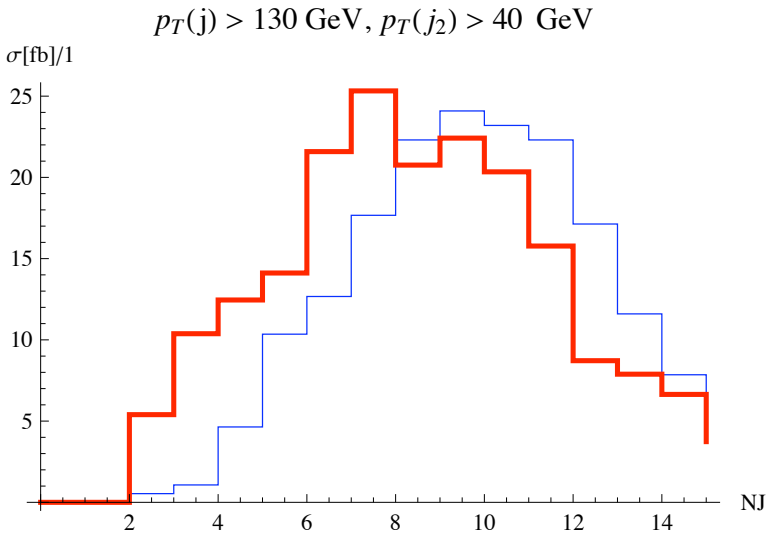


- Signal is color singlet until pseudoscalar decay at $\sim$ 10 GeV: expect less radiation between jets

$$\beta_{sub} = \frac{p_T(j_3)}{p_T(j_1) + p_T(j_2)}$$

$NJ(j, p_{th})$ = Number of subjets with $p_T > p_{th}$ inside the hardest fat jet

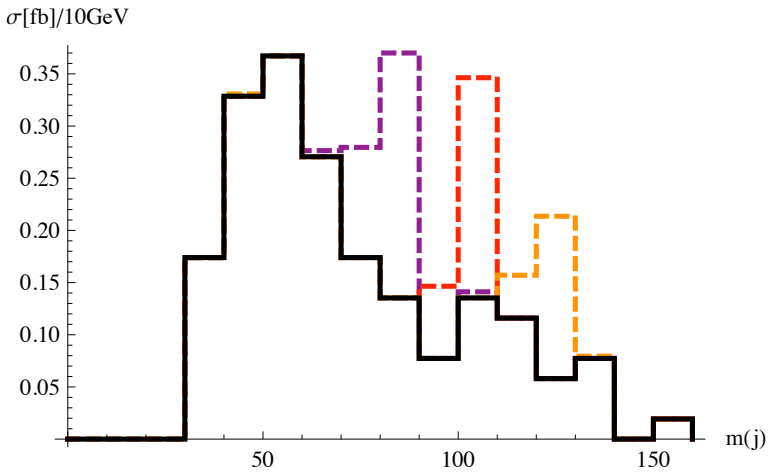




Background (Blue) x 1, Signal(Red) x 100

Bump Hunting

- Cut on mass democracy $\alpha_{sub} \gtrsim 0.7$ on color flow $\beta_{sub} \lesssim 0.03$,
- After all cuts, signal displays a clear peak in the invariant mass of the fat jet, while background sharply drops at high masses



Background (black)
Signal + Background (purple $m_h = 80$ GeV, red $m_h = 100$ GeV, orange $m_h = 120$ GeV)

	$m_h = 80\,\mathrm{GeV}$	$m_h = 100\,\mathrm{GeV}$	$m_h = 120\,\mathrm{GeV}$
$pp \to hW$	6.7	7.6	6.8
$pp \to ht\bar{t}$	6.1	6.1	7.1

Conclusions

- ☺ With the help from methods of jet substructure a light Higgs boson decaying via a cascade $h \to AA \to 4g$ into 2 light jets can be discovered at the LHC with sufficiently large integrated luminosity