Spotting an Invisible Higgs at 7 TeV

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Y. Bai, P. Draper, JS, arXiv:1112.4496

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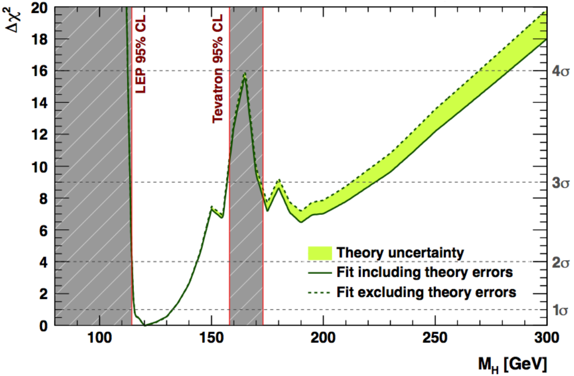
Hints for a light Higgs

Have had indirect evidence for some time that a light SM-like Higgs may be the most likely scenario...

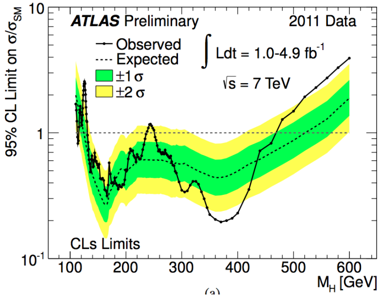


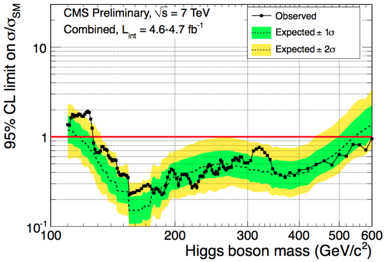
Best fit m_h from precision electroweak

(GFitter, 1107.0975)

Hints for a light Higgs

...now echoed by recent direct results from Atlas and CMS:





Atlas and CMS limits on the Standard Model Higgs

Hints for a light Higgs

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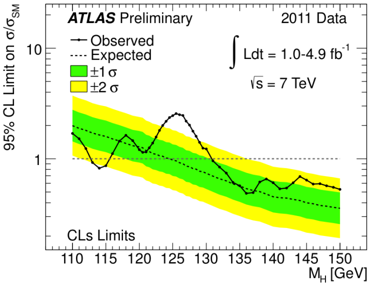
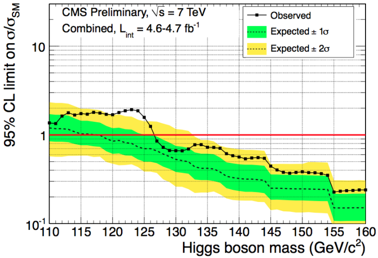
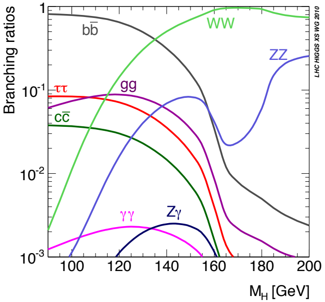




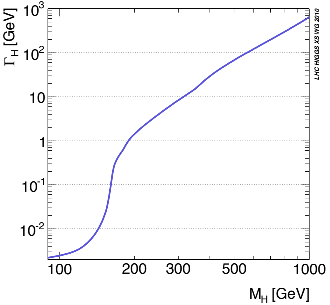
Atlas and CMS limits on the Standard Model Higgs

A light Higgs is *narrow*

For $m_h \lesssim 2m_W$: SM width is tiny...



SM Higgs branching ratios



SM Higgs total width

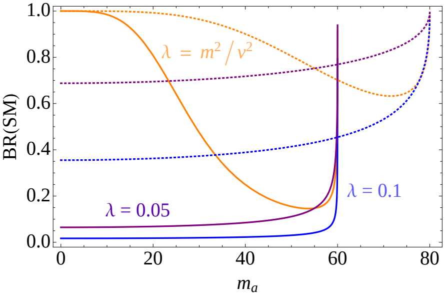
...which makes a SM-like Higgs particularly sensitive to existence of new light degrees of freedom

A narrow Higgs and physics beyond the SM

- Light SM Higgs means
  even weak couplings to new light degrees of freedom can disrupt branching fractions by $\mathcal{O}(1)$

- For instance, a new scalar a coupled through $\Delta\mathcal{L} = -\lambda|H|^2 a^2$ can easily dominate over SM decays

- Signatures depend on further couplings of a



solid, $m_h = 120$ GeV; dotted, $m_h = 160$ GeV

New physics and the Higgs portal

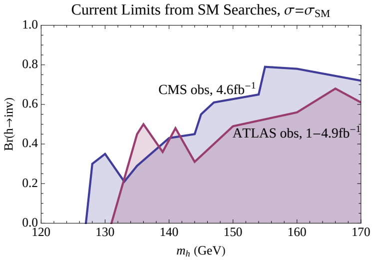
- $h \to aa$ simple example of Higgs portal:
  $|H|^2$ super-renormalizable $\Rightarrow$ leading terms in effective $\mathcal{L}$ coupling other sectors to SM
  - E.g.: NMSSM $\Rightarrow$ a mixes with h and reduces tuning
  - E.g.: dark matter $\Rightarrow$ a is DM or decays to DM
- If new physics is only weakly coupled to SM it may easily be invisible at colliders
  - dark matter
  - gravitinos
  - collider-stable hidden sector matter

$\Rightarrow$ $h \to$ invisible decay mode highly sensitive to existence of new physics and probes broad class of BSM scenarios.

Three ways to spot non-standard Higgs decays

indirect; total width; direct

- Indirect: assuming SM production, SM searches give a lower bound on Γ_{BSM}



Current indirect limits from Atlas and CMS

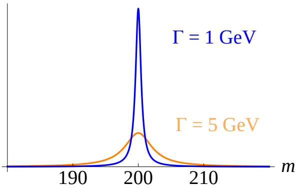
Three ways to spot non-standard Higgs decays

indirect; total width; direct

- Total width: measure total width from lineshape (like Z)

  Low, Schwaller, Shaughnessy, Wagner

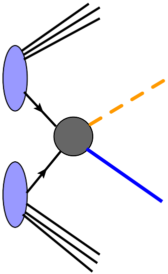
  - statistically expensive
  - Only feasible for $m_H \gtrsim 200$ GeV: experimental resolution



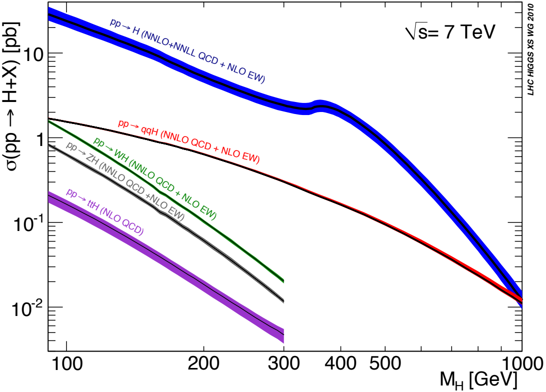
Three ways to spot non-standard Higgs decays

indirect; total width; direct

- Direct: directly measure $\sigma \times BR(h \to BSM)$
  - usually better at low mass: larger σ (BR)
  - will show: can directly constrain $\sigma \times BR(h \to \text{inv}) \geq 0.4$ in the low-energy LHC run



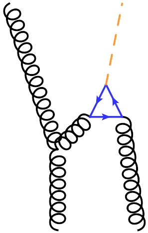
Making an invisible Higgs



- as always, best channel determined by channel-dependent backgrounds as well as rate
- $gg \to hj$, $pp \to Vh$, $qq \to qqh$

Gluon fusion with ISR

- To make final state observable, require recoil against hard ISR jet

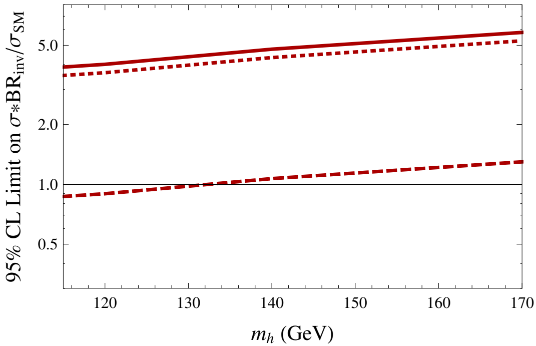


Monojet $+\not{E}_T$:

- irreducible background: $pp \to Zj,\ Z \to \nu\nu$
- largest rate, but m_h not greatly separated from m_Z
- poor S/B makes this channel comparatively insensitive
- however: currently best direct limits on $\sigma \times BR(h \to \text{inv})$

Gluon fusion with ISR

Current (ATLAS 1 fb^{-1}, solid) and projected (20 fb^{-1}) limits on $\sigma \times BR(h \to \text{inv})$ from monojet $+\not{E}_T$

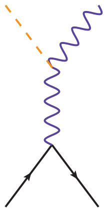


Importance of systematic errors: no improvement in relative systematic error (dotted) and $\sqrt{\mathcal{L}}$ improvements (dashed)

Associated Higgs Production

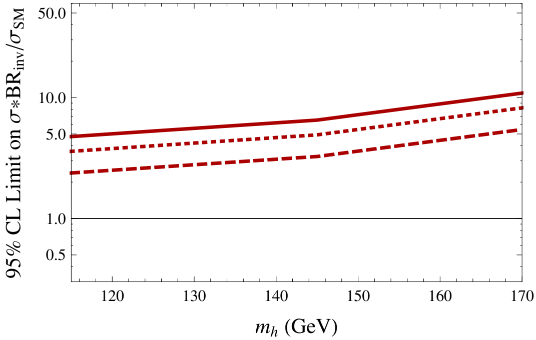
$Z + h, Z \to \ell\ell$

- Cleaner final state with more kinematic variables to separate h from dominant backgrounds VV, $t\bar{t}$
- comparatively strong mass dependence of production cross-section helps constrain m_H
- small production cross-sections limit reach
- current constraints from CMS heavy Higgs searches $H \to ZZ \to \nu\nu\ell\ell$: not optimized for light invisible Higgs



Associated Higgs Production

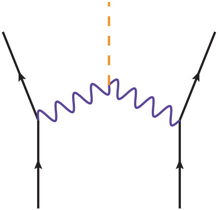
Current (CMS 4.6 fb^{-1}, solid) and projected (20 fb^{-1}) limits on $\sigma \times BR(h \to \text{inv})$ from monojet $+\not{E}_T$



no improvement in relative systematic error (dotted) and $\sqrt{\mathcal{L}}$ improvements (dashed)

Higgs Production through Weak Boson Fusion

Most sensitive channel for $h \to$ invisibles at 14 TeV Eboli, Zeppenfeld, '00



- Electroweak process, but accesses valence PDFs
- Final state: $2j + \not{E}_T$
  - Large missing energy $\not{E}_T > 100$ GeV is triggerable
  - Kinematics of jets set by EW process and distinctive

- Jets should be energetic: $p_{Tj} \gtrsim 30$ GeV, $M_{j_1 j_2} \gtrsim 1$ TeV
- Jets should be widely separated: $\Delta\eta_{j_1 j_2} \gtrsim 4$
- Dominant scattering does not involve QCD $\Rightarrow$ relatively little other jet activity

Signal and Backgrounds

- Large rate of $gg \to h + 2$ jets: contributes to reach despite small acceptance
- Main backgrounds:
  - $Z+$ jets, $Z \to \nu\nu$. Both usual ("QCD") and WBF production are important
  - $W+$ jets, $W \to \ell\nu$ can also contribute when the lepton is lost
  - Contribution from mismeasured QCD
- Estimate regime where mismeasured QCD can be neglected: study 3 jet events using PGS
  - Suppression by 2 orders of magnitude: $Min(\Delta\phi_{j,\not{E}_T}) > 0.5$
  - With $\not{E}_T \gtrsim 100$ GeV, negligible
  - only Gaussian response, but dominance of single jet mismeasurement encouraging

Modelling

- Signal and background are generated in MadGraph and showered in Pythia.
- All processes are normalized to N(N)LO cross-sections
  - Processes where jets are generated by QCD (Z+jets, W+jets, h+jets), we generate matched samples to better approximate true kinematics and normalize to inclusive cross-sections (Black Hat '10, '11)
  - WBF processes where jets originate from EW (hqq, Zqq, Wqq) are normalized using K-factors: (Figy, Palmer, Weiglein '10) for Vqq, obtained from VBFNLO.
- Detector simulation performed with PGS.
  - Approximate losing a lepton: veto central leptons with $p_T > 20$ GeV for electrons and visible hadronic taus and $p_T > 15$ GeV for muons.

Signal and backgrounds

Cross-sections (fb) for cuts; $m_h = 120$ GeV

Cuts	qqh	hjj	qqZ	Zjj	qqW	Wjj
Reference cuts	310	650	400	3300	470	3200
WBF selection	14	1.9	6.8	25	7.3	18
$\Delta\phi$	8.9	1.4	2.0	11	2.5	8.9
jet veto	3.9	0.41	0.77	3.1	1.1	2.6

Reference cuts: initial event selection,

- ≥ 2 jets with $p_T > 20$ GeV
- lepton veto
- $\not{E}_T > 90$ GeV, $Min(\Delta\phi_{j,\not{E}_T}) > 0.5$

Signal and backgrounds

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WBF selection cuts: $\not{E}_T > 120$ GeV, 2 leading jets satisfying

- $p_T > 30$ GeV
- $M_{12} > 1200$ GeV
- $|\Delta\eta_{12}| > 4.5$

Signal and backgrounds

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$\Delta\phi_{12} < 1.5$: main cut discriminating WBF h from Z, W

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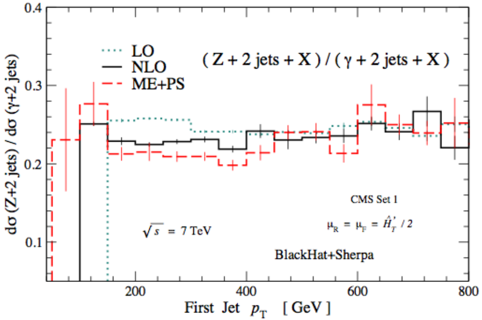
central jet veto: any additional jets with $|\eta| < 2.5$ soft: $p_T < 40$ GeV

Setting limits

- Can't reconstruct mass feature: purely a counting experiment. $\Rightarrow$ systematic uncertainties critical for setting limits
- Theoretical prediction of WBF backgrounds under good quantitative control
- Systematic uncertainties on $Z \to \nu\bar{\nu}+$ jets still uncomfortably large even with state-of-the-art computations
- Modelling from control regions in data offers better precision
  - Natural control sample $Z \to \ell^+\ell^-$ statistics limited
  - New idea pioneered by SUSY jets $+\not{E}_T$ searches at CMS: use reweighted $\gamma+$ jets (CMS PAS SUS-08-002, CMS PAS SUS-10-005)

Reweighting photons for $Z+$ jets

- Ratio $Z + \text{jets} + X/\gamma + \text{jets} + X$ is stable Bern et al, '11
- Expect we are in a kinematic regime where this works
    - $\not{E}_T$ requirement similar to existing studies
    - $\Delta\phi$ cut removes collinear regions
- Achieve $\sim 10\%$ precision



From Bern et al, '11: p_T of leading jet in $2j + \not{E}_T$ search (I)

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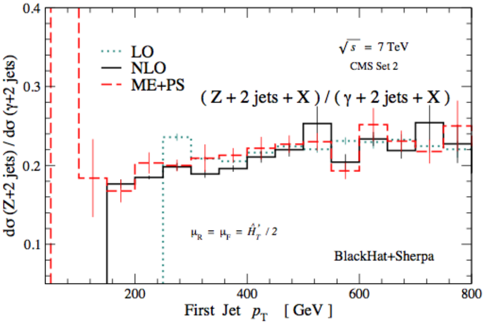

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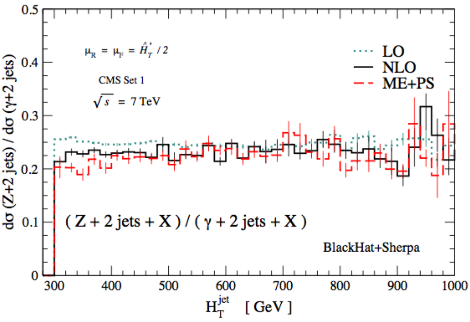
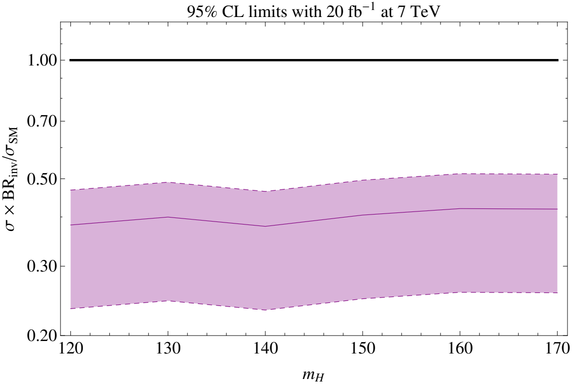


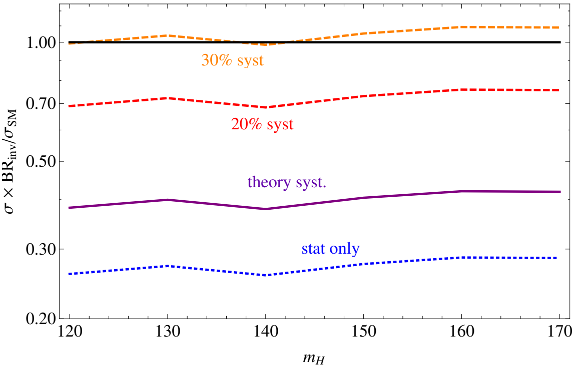
From Bern et al, '11: event H_T in $2j + \not{E}_T$ search (I)

Projected limits from $\not{E}_T+$ forward jets



Projected 95% CL limits on $\sigma \times BR(h \to inv)$ at 20 fb^{-1} including 5% uncertainty on WBF processes and 10% on Drell-Yan

Projected limits from $\not{E}_T +$ forward jets



Projected 95% CL limits on $\sigma \times BR(h \to inv)$ at 20 fb^{-1}
as a function of systematic error

Conclusions

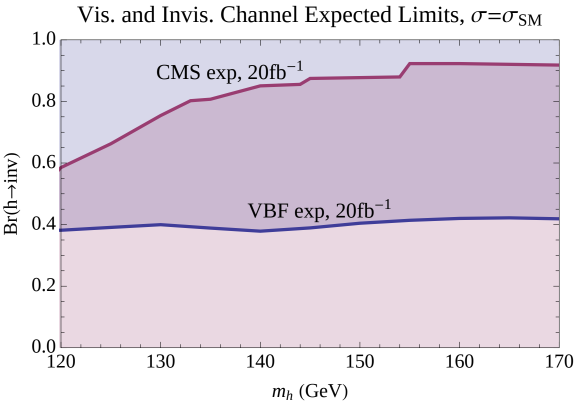
- Entering a new era in Higgs physics: detailed measurements of Higgs properties
  - Decays of a light SM-like Higgs a natural and generic place to expect BSM physics
  - Rare decays important for constraints on dark matter, non-minimal SUSY, ...
  - Direct measurements of BSM widths: cross check production mechanisms

Conclusions

- Performed comprehensive update of $h \rightarrow$ invisibles in the WBF channel
  - First study at low LHC $\sqrt{s}$
  - utilize advances in signal and background cross-section calculations
  - With 10 fb^{-1}/experiment, probe $BR(h \rightarrow \text{invisible}) > 0.4$
  - Enough to be interesting? Yes!
  - Reach can be extended by including $Z + h$
  - Keys: systematics, triggers

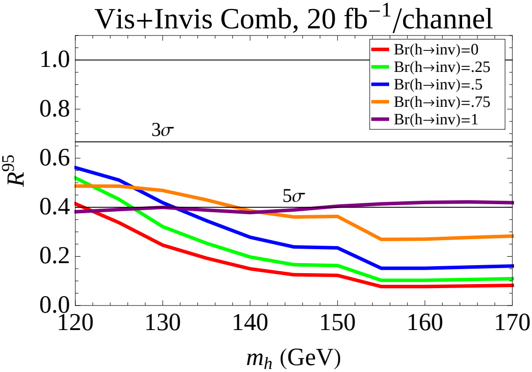
Backup: Combination with visible modes

Visible and invisible limits probe complementary parts of parameter space:



Backup: Combination with visible modes

Invisible branching fractions dilute signal significance:



Combination in quadrature with visible modes (used CMS):
reasonable approximation to careful results