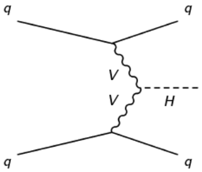
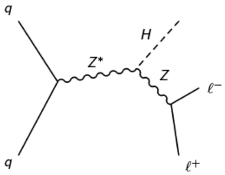
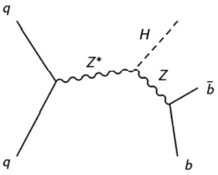
Combination of Invisible Higgs Direct Measurements

Paper - HIG-13-030, PASs: HIG-13-013, HIG-13-018, HIG-13-028

P. Dunne
on behalf of the H→invisible analysis groups







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CMS AN -2013/333

The Compact Muon Solenoid Experiment

Analysis Note

The content of this note is intended for CMS internal use and distribution only

04 October 2013 (v2, 02 December 2013)

Search for $Z(\to \ell\ell)H(\to \text{invisible})$ at $\sqrt{s}$ = 7 and 8 TeV

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Abstract

A search for decays to invisible particles of a Higgs boson at the Large Hadron Collider using the CMS experiment is presented. This search is performed for a standard model-like Higgs boson produced in association with a Z boson. The Higgs boson mass range between 115 GeV and 300 GeV is studied. The results are interpreted to place limits on the branching fraction to invisible particles of the SM Higgs boson, which could provide evidence for the production of dark matter particles. The search uses the full 2011 and 2012 data samples at 7 TeV and 8 TeV, respectively.

Available on CMS information server

CMS AN -2012/403

The Compact Muon Solenoid Experiment

Analysis Note

The content of this note is intended for CMS internal use and distribution only

25 October 2012 (v11, 02 December 2013)

Search for an Invisible Higgs Boson

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Abstract

In this analysis note, we describe a search for invisible decay modes of a Higgs boson, produced in vector boson fusion. The search is performed using the full 8 TeV dataset collected during 2012, with an integrated luminosity of 19.6 fb^{-1}. Events are selected with a dedicated trigger based on the vector boson fusion tag jet topology, together with large missing transverse energy. The offline selection makes further use of the tag jet topology. The dominant backgrounds from $Z \to \nu\nu$, $W \to l\nu$ where the charged lepton goes unidentified, and QCD multijet production are estimated from data. Minor backgrounds are estimated from Monte-Carlo. An expected limit on the invisible branching fraction of the 125 GeV boson is presented, together with expected limits on the production cross-section times invisible branching fraction for additional Higgs bosons.

Search for invisible Higgs decay in Z($b\bar{b}$) H(inv) with 2012 dataset

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Abstract

A search for a Higgs boson produced in association with a Z boson, with Higgs decays into invisible particles and Z decays into a pair of b jets is presented. Full 2012 8 TeV dataset is analyzed and 95% confidence level upper limit on the product of ZH production cross section and Higgs invisible branching fraction is evaluated for Higgs boson mass range from 105 to 150 GeV. For an invisible Higgs boson of mass 125 GeV, the observed (expected) upper limit on the product of ZH production cross section times the invisible branching ratio is 1.82 (1.99) times the standard model ZH production cross section.

Introduction

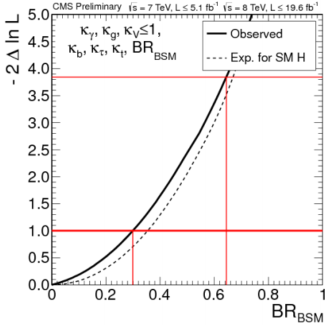
Motivation

- Many BSM theories predict invisible final states of the Higgs:
  - SUSY, Extra Dimensions, etc.
- Direct searches must be performed in channels where the Higgs recoils against a visible system

Outline

- The CMS Higgs to invisible results in the following three channels have already been approved:
  - VBF (HIG-13-013), Z($\ell\ell$)H(inv) (HIG-13-018), Z($b\bar{b}$)H(inv) (HIG-13-028)
- These results have been combined for a paper (HIG-13-030)
- Today's talk is an approval for this combination and its interpretation in a Higgs portal dark matter model.

Indirect Result from Visible Decays



From HIG-13-005

- Observed (expected) limit of 64% (67%) at 95% C.L. on BR_{inv} for a 125 GeV Higgs (HIG-13-005)
  - Combination between direct and indirect methods is being investigated e.g. talk by M. Zanetti

Datacards

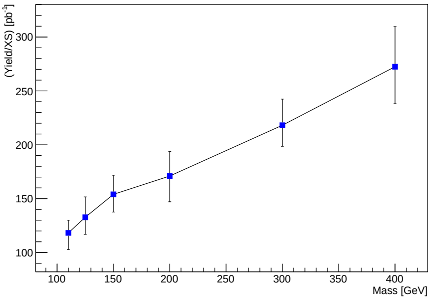
- All three channels have signal MC at different mass points

Channel	Mass Points/GeV
$Z(\ell\ell)H(inv)$	105, 115, 125, 135, 145, 175, 200 & 300
$Z(b\bar{b})H(inv)$	105, 115, 125, 135, 145 & 150
VBF	110, 125, 150, 200, 300 & 400

- New VBF datacards were produced for 115,135 and 145 GeV
  - Nuisances are linearly interpolated between mass points.
  - Signal yields are interpolated using the method described below.

Signal Yield interpolation

- $N_{Signal} = eff. \times acc. \times \mathcal{L}\sigma$
- Luminosity is constant
- Yield over cross-section is thus proportional to efficiency times acceptance
  - YR2 cross-sections from LHC-HXSWG were used



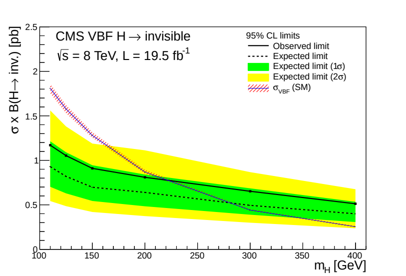
Combination Method

- The cards for the three channels were checked by the combinations group and combined using the standard Higgs combination tool
- The following uncertainties were considered correlated between channels in decreasing order of importance:

Nuisance	Analyses which it affects	Limit change on removal
Jet energy scale	VBF, $Z(\ell\ell)H(inv)$	-5.9%
PDF uncertainties	VBF, $Z(b\bar{b})$, $Z(\ell\ell)H(inv)$	-4.2%
QCD scale	VBF, $Z(b\bar{b})$, $Z(\ell\ell)H(inv)$	-1.7%
Luminosity	VBF, $Z(b\bar{b})H(inv)$, $Z(\ell\ell)H(inv)$	-0.8%
Jet energy resolution	VBF, $Z(\ell\ell)H(inv)$	<0.1%
Unclustered energy scale	VBF, $Z(b\bar{b})H(inv)$, $Z(\ell\ell)H(inv)$	<0.1%
Muon identification efficiency	VBF, $Z(\ell\ell)H(inv)$	<0.1%
Electron identification efficiency	VBF, $Z(\ell\ell)H(inv)$	<0.1%

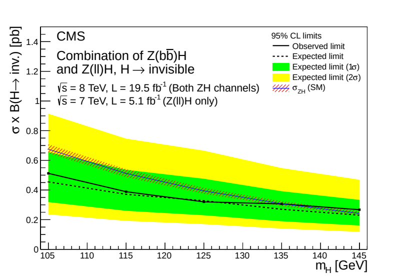
Separate results: Cross-Section limits

VBF - update of approved plot



- Observed (expected) limit of 67% (52%) at 95% C.L. on BR_{inv} for a 125 GeV Higgs

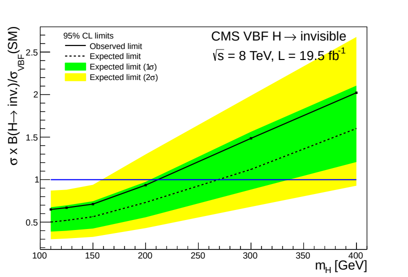
ZH - for approval



- Observed (expected) limit of 81% (83%) at 95% C.L. on BR_{inv} for a 125 GeV Higgs

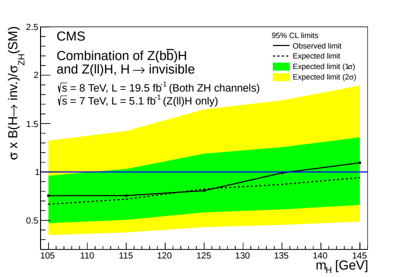
Separate results: Direct

VBF - update of approved plot



- Observed (expected) limit of 67% (52%) at 95% C.L. on BR_{inv} for a 125 GeV Higgs

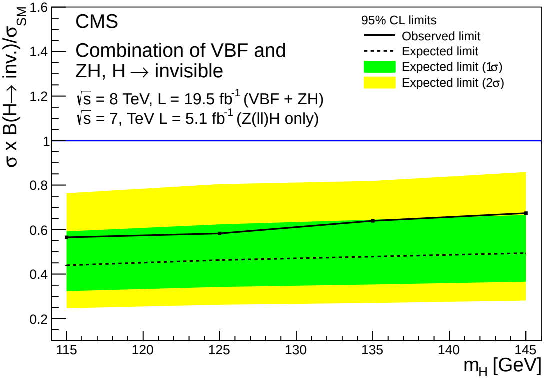
ZH - for approval



- Observed (expected) limit of 81% (83%) at 95% C.L. on BR_{inv} for a 125 GeV Higgs

Combined Results

For approval

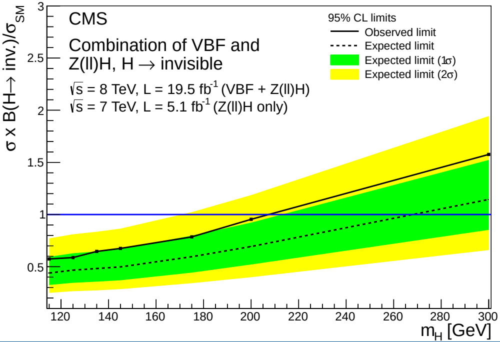


- Observed (expected) limit at 125 GeV is 58(46)%

High mass combination

- Z($\ell\ell$)H(inv) and VBF both have datacards up to 300 GeV
- The same combination method as used above was used to combine these two channels between 115 and 300 GeV

For approval as additional material



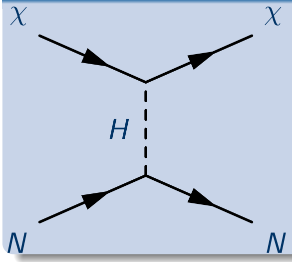
Changes to Plots Since CWR

- Legends have been made consistent across all combinations plots.
- The legend of the final combination plot has been moved further from the blue 'SM' line.
- Square brackets are now used for all units.
- YR2 Cross-sections are now used where YR3 cross-sections were used before.
- Theory uncertainties have been removed from the fit in the $\sigma\mathcal{B}(H \rightarrow inv.)$ plots and a theory uncertainty band has been added to σ_{SM}.

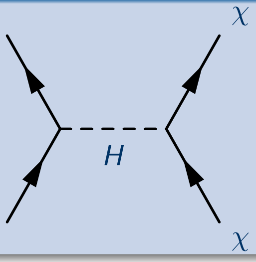
Signatures of Dark Matter (DM)

- If DM couples to the Higgs the following diagrams are possible

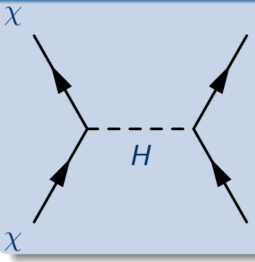
Direct Detection - e.g. LUX



Invisible Higgs - LHC



Annihilation - e.g. WMAP



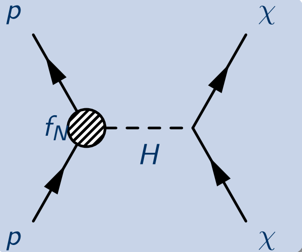
- Limits on $\mathcal{B}(\mathrm{H}\rightarrow\mathrm{inv.})$ can therefore be used to constrain the coupling
- These constraints are directly comparable to those from other experiments

Dark Matter Interpretation - Model

- We use the Higgs portal DM model as described in Phys.Lett. B709 (2012) 6569
- This allows us to translate $\mathcal{B}(H \to inv.)$ to a DM-nucleon cross-section
- Three spin scenarios are considered for the DM particle:
  - scalar, vector, Majorana fermion

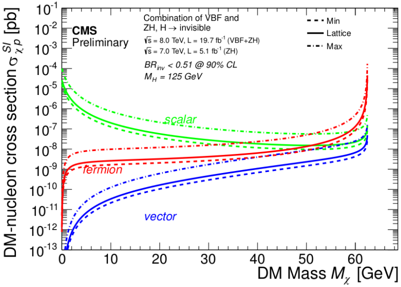
Formulae

- $\mathcal{B}(H \to inv.) = \frac{\Gamma(H \to inv.)}{\Gamma(H)^{SM} + \Gamma(H \to inv.)}$
- $\sigma^{SI}_{S-N} = \frac{4\Gamma(H \to inv.)}{m_H^3 v^2 \beta} \frac{m_N^4 f_N^2}{(M_\chi + m_N)^2}$
- $\sigma^{SI}_{V-N} = \frac{16\Gamma(H \to inv.) M_\chi^4}{m_H^3 v^2 \beta (m_H^4 - 4M_\chi^2 m_H^2 + 12 M_\chi^4} \frac{m_N^4 f_N^2}{(M_\chi + m_N)^2}$
- $\sigma^{SI}_{f-N} = \frac{8\Gamma(H \to inv.) M_\chi^2}{m_H^5 v^2 \beta^3} \frac{m_N^4 f_N^2}{(M_\chi + m_N)^2}$
  - Where f_N is the Higgs-proton coupling and v is the Higgs vacuum expectation

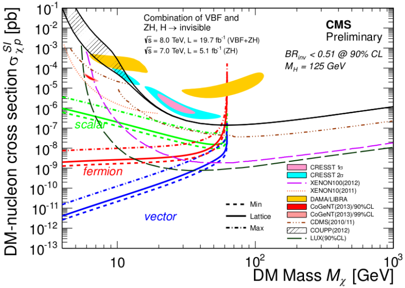


Dark Matter Interpretation - Results

For approval



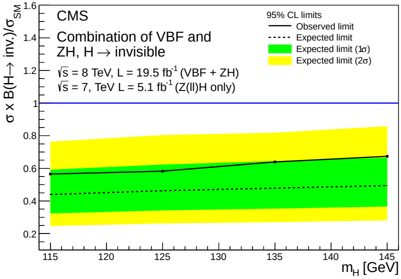
For approval as additional material



- $\mathcal{B}(H \to inv.)$ gives important exclusion in the low mass region
- Clearly we are only sensitive in the region $M_\chi < m_h/2$

Conclusions

- All three H→invisible channels have been combined using the standard Higgs combination tool
- The combined result gives the strongest limit on the invisible branching fraction of the 125 GeV Higgs [58(46)% Observed (expected) 95% C.L. limit at 125 GeV]
- A Higgs portal dark matter interpretation of the above results has been presented and is particularly competitive at low mass



Backup

Previous Limits

- CMS PAS limits on BR_{inv} for a 125 GeV Higgs boson are:
  - VBF: observed (expected) limit of 69% (53%) at 95% C.L.
  - Z($\ell\ell$)H(inv): observed (expected) limit of 75% (91%) at 95% C.L.
  - Z($b\bar{b}$)H(inv): ovserved (expected) limit of 182% (199%) at 95% C.L.
  - CMS indirect limit, from visible channels: observed (expected) limit of 64% (67%) at 95% C.L.
- ATLAS also produce an indirect limit and a limit in the ZH channel:
  - Indirect limit 60% (no expected limit given)
  - ZH: observed (expected) 65% (84%)

VBF changes since PAS

- New MC jet resolution measurement made at recommendation of JetMET
- ttbar cross-section updated from 234.0 $\rightarrow$ 245.8pb
- int. lumi changed from 19.576 $\rightarrow$ 19.494 fb^{-1}
- runMETuncertainty tool bug fixed
- lepton weights and ID efficiency uncertainties incorporated
- WGamma MC added
- Uncertainty correlations properly accounted for
- Plot cosmetics updated

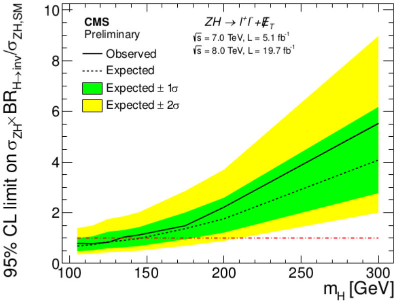
Z(ll)H changes since PAS - presented to PAG 29/10/13

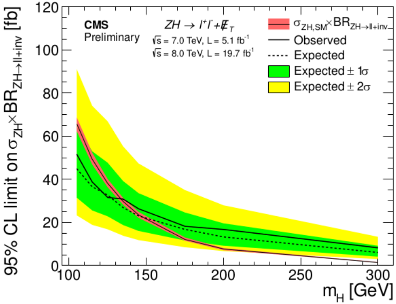
- Original PAS (HIG-13-018) was based on two independent analyses:
  - AN-12-123, historically linked to ZZ analysis (SMP-12-016)
  - AN-13-148, historically linked to H→WW analysis (HIG-13-003)
- These two analyses have been merged (AN-13-333):
- : Lepton ID, b-tagging taken from ZZ analysis
- : MET and M_T definitions from WW analysis Additionally:
- A 1-jet bin has been added
- int. lumi has been updated
- Muon efficiency has been updated (3.5→4.0%)
- 2D shape analysis is used in limit setting for 8 TeV data
- A small change has been made to the data-driven Drell-Yan background

Z(ll)H changes since PAS continued - presented to PAG 29/10/13

- p_T dependent EW corrections added to ZH signal and WZ and ZZ backgrounds
  - ZH correction is taken from Z(bb)H(inv) analysis
  - WZ and ZZ correction parameterized from arxiv:1305.5402
  - Result - reduction in expected yields for both signal and background.
  - This is why observed limit increased (75→83%) even though expected limit decreased (91→86%)
- Generated additional signal mass points at 175, 200 and 300 GeV

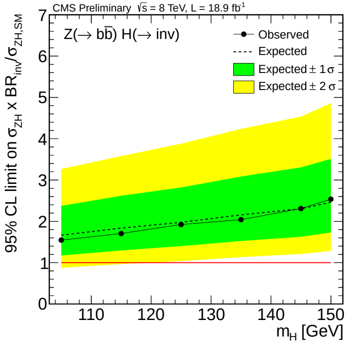
Z(ll)H Final Limit Plots





Z(bb)H changes since PAS

- Apply EW corrections to VV backgrounds to be consistent with Z(ll)H(inv) (2-3% changes to limits due to less background in high p_T tails)
- Unified style and systematic naming with other two analyses



Values used for DM interpretation

Parameter	Value
v	174.0 GeV
m_h	125.0 GeV
m_N	938.95 MeV
Γ_H^{SM}	4.07 MeV
f_N Lattice	0.326
f_N Min	0.260
f_N Max	0.629

VBF uncertainties by background

Source	$Z \to \nu\nu$	$W \to \mu\nu$	$W \to e\nu$	$W \to \tau\nu$	QCD	Other	Total BG	Signal
Statistics in control region	29%	5%	10%	30%	2%	-	10%	-
MC statistics	14%	10%	10%	20%	2%	10%	6%	10%
Method uncertainty	20%	20%	20%	20%	40%	-	17%	-
Jet/MET scale/resolution	2%	$^{+1\%}_{-6\%}$	$^{+15\%}_{-13\%}$	$^{+8\%}_{-4\%}$	$^{+50\%}_{-55\%}$	$^{+9\%}_{-30\%}$	6%	$^{+10\%}_{-12\%}$
Lepton scale/resolution	5%	3%	3%	1%	4%	1%	2%	-
Tau ID efficiency	-	-	-	8%	-	-	1%	-
Electron contamination	-	-	-	1%	-	-	0.2%	-
Luminosity	-	-	-	-	-	2.6%	0.3%	2.6%
Cross-section uncertainty	-	-	-	-	-	8-20%	0.5-1%	-
PDF uncertainty	-	-	-	-	-	-	-	5%
QCD Scale uncertainty	-	-	-	-	-	-	-	4%