Looking for invisible Higgs signal at the LHC

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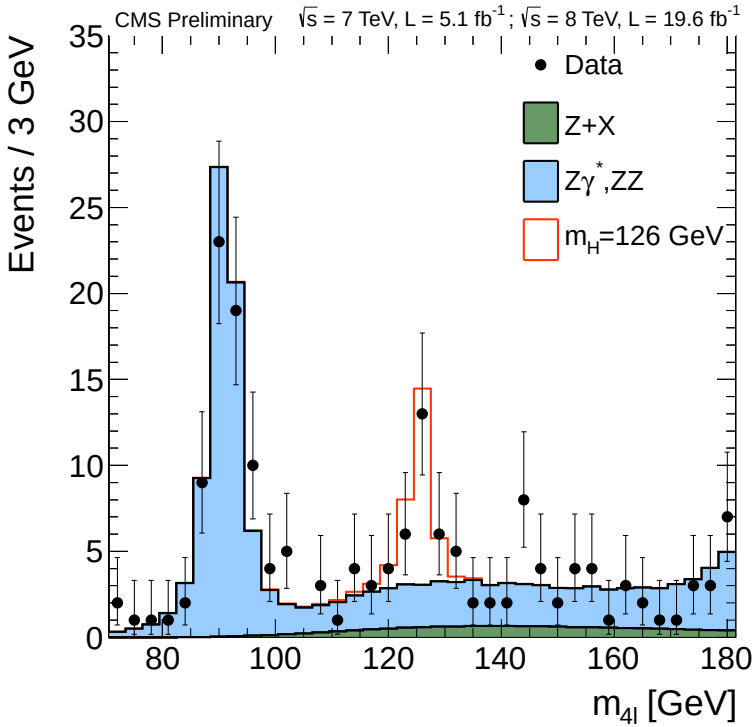
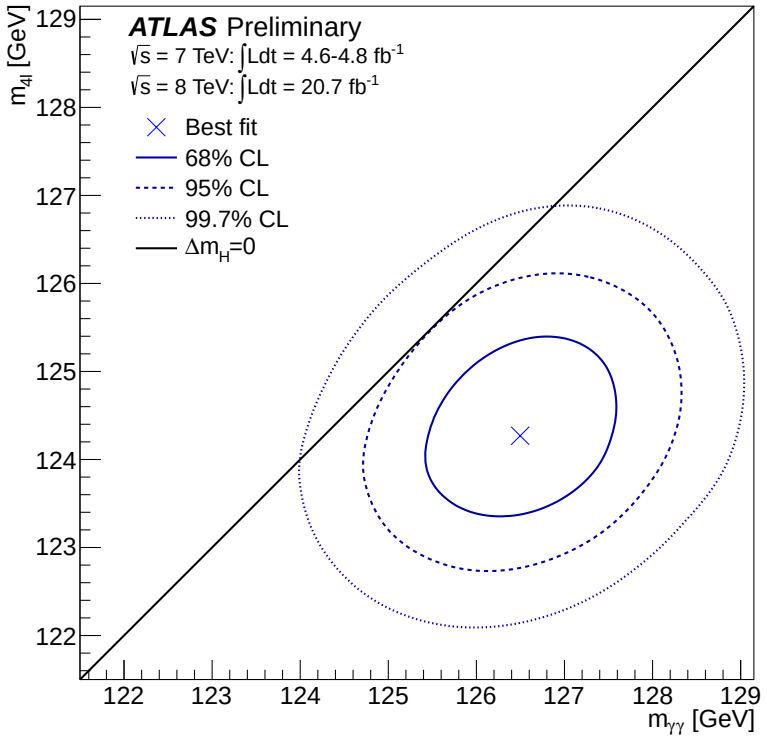
Outline

- Higgs at the LHC
- Invisible Higgs decays
- Invisible Higgs signal: Analysis and Results
- Conclusion

Higgs at the LHC



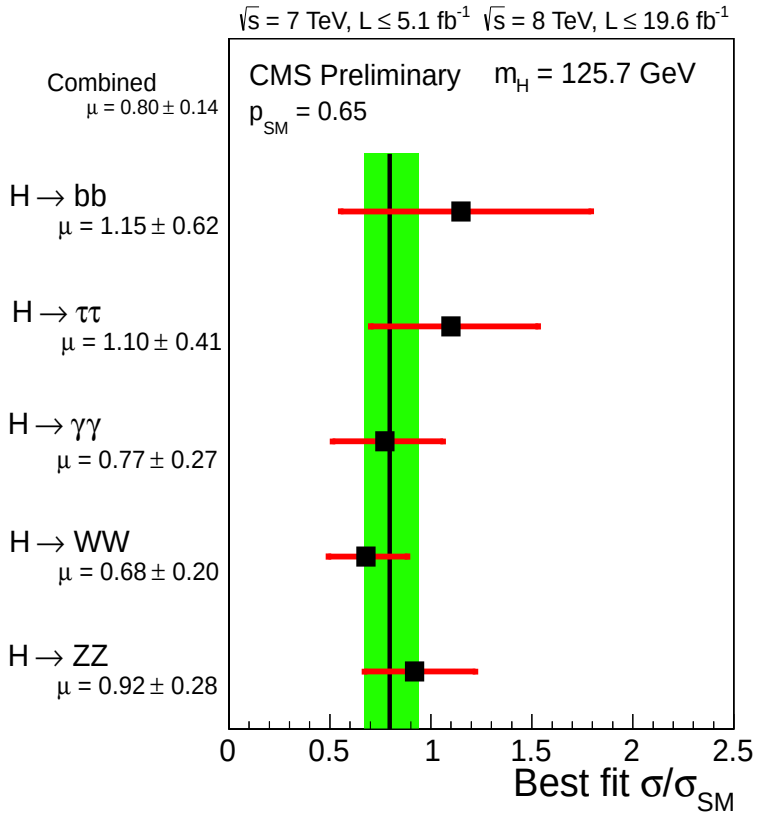


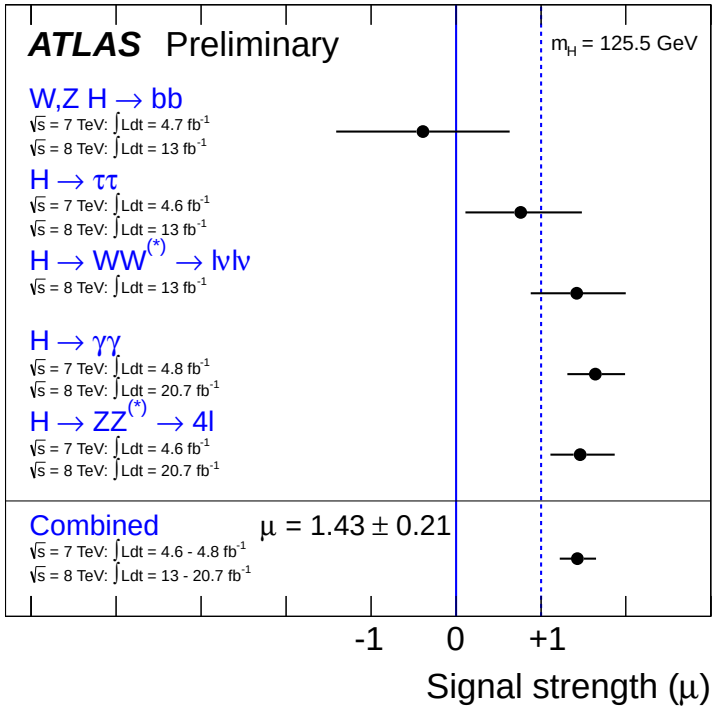
ATLAS: $\mathrm{m_H} = 125.5 \pm 0.2(stat)^{+0.5}_{-0.6}(syst)$

CMS : $\mathrm{m_H} = 125.7 \pm 0.3(stat) \pm 0.3(syst)$

Is it the SM Higgs?

Signal strength $\mu = \frac{\sigma}{\sigma_{SM}}$



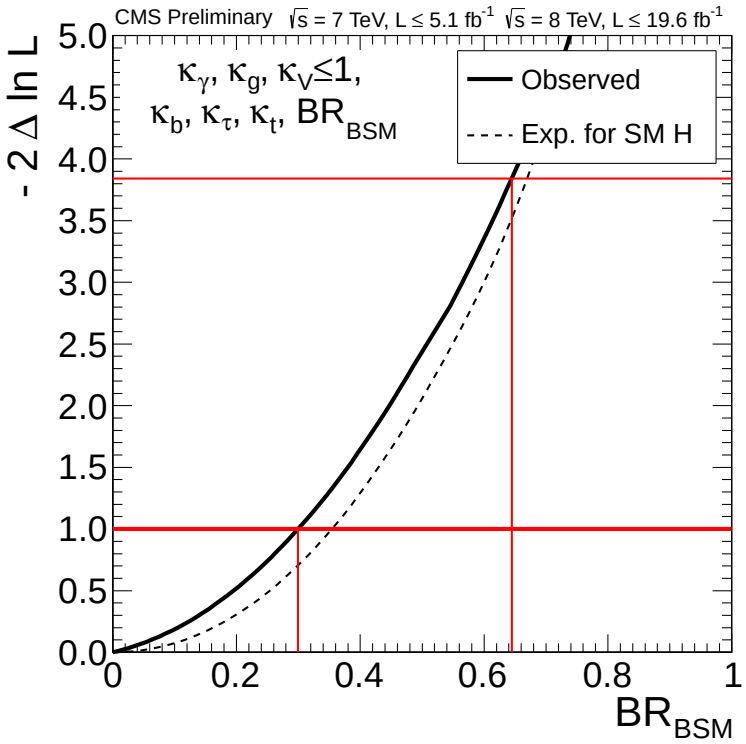


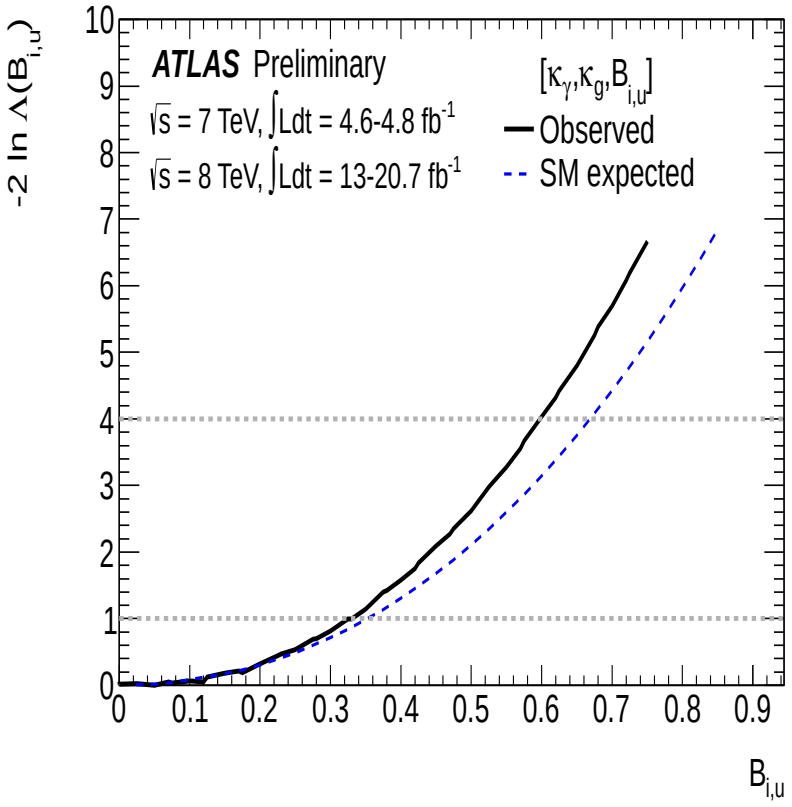
$$\mu = 0.80 \pm 0.14 \;\Rightarrow\; H \rightarrow H_{SM}$$

Spin and parity measurement favour SM hypothesis

Non SM decay of Higgs?

$$\Gamma_H = \Gamma_{SM} + \Gamma_{BSM} \Rightarrow BR_{BSM} = 1 - BR_{SM}$$





CMS: $(BR)_{BSM} <$ **0.64 @ 95% C.L.**

Invisible Higgs decays:Models

$$H \to \chi\chi$$

$$\begin{aligned}
\chi\chi &= ZZ \to \nu\bar{\nu}\nu\bar{\nu} \quad \text{very tiny,} \\
&= \tilde{\chi}_1^0\tilde{\chi}_1^0, \tilde{\nu}\tilde{\nu} \\
&= \nu_H\nu_H \\
&= \text{graviscalars in extra dimension models}
\end{aligned}$$

....and many more other models

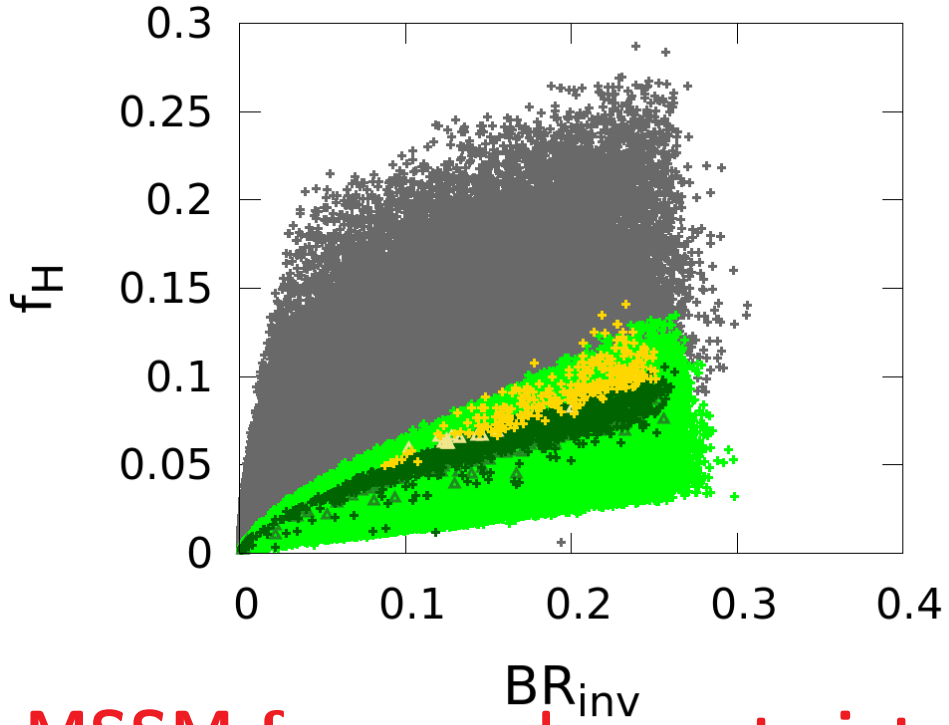
• Higgs Portal models: Higgs is coupled with the Dark matter, acts as a mediator in DM annhilation and scattering, so invisible decay BR and DM scattering cross sections are connected,

$\chi\chi$**=S, V, f**

A. Djouadi, et. al. 1205.3169
G. Belanger et. al.1308.3735

Invisible Decay width

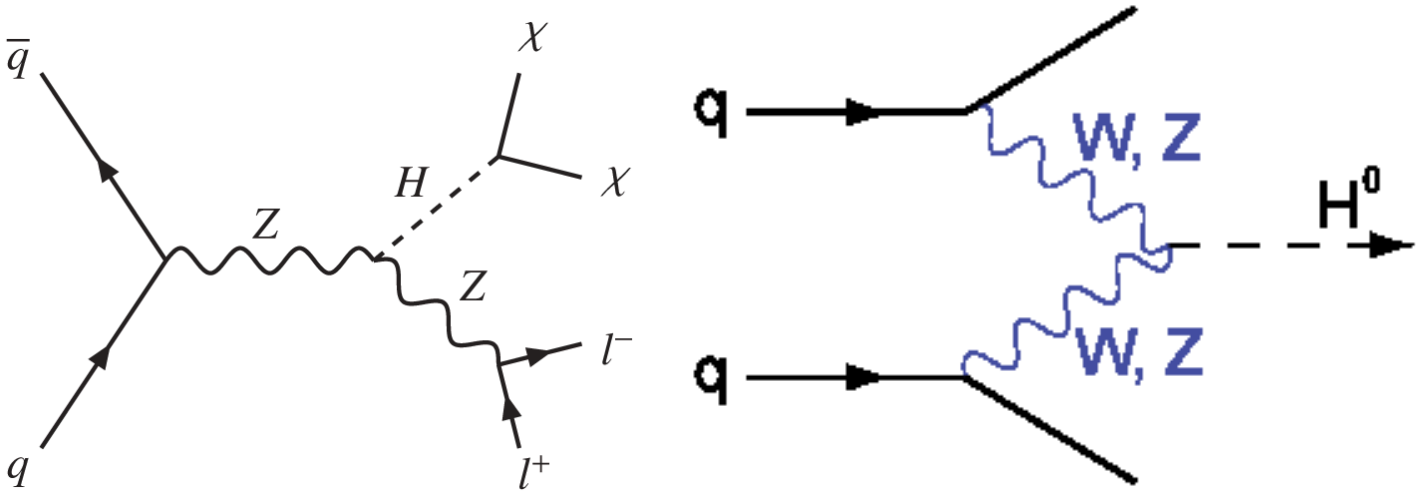
$H \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ in SUSY



pMSSM framework, constraints from LEP, flavour physics, DM, Higgs...

G. Belanger, et .al. 1308.3735

Invisible Higgs signal:ZH and VBF



M_H=125 GeV

ZH : $\ell^+\ell^- + \not{E}_T, b\bar{b} + \not{E}_T$

vbfH : 2 jets + $\not{E}_T$

	σ(pb) 8 TeV	σ(pb) 14 TeV
ZH	0.4	0.83
vbfH	1.73	4.3

$$R_{inv} \equiv \sigma_H^{BSM} BR(H \to inv)/\sigma_H^{SM}$$

Simulation:Tools

- **ZH :** `Madgraph+PYTHIA6`
- **VBF productions(Signal+Background):** `MadGraph`
- **Backgrounds:** `PYTHIA6` **and** `PYTHIA6+Madgraph`
- **Jet Reconstruction:** `FastJet`, **anti** K_T **with R =0.5**
- **Jet Substructure:** `FastJet`, **R=1.2**

Background cross sections:

	$t\bar{t}$	W+jets	Z+jets	QCD
8 TeV	160	$\sim 10^4$	$\sim 10^3$	$\sim 10^6$
14 TeV	500	$\sim 10^5$	$\sim 10^4$	10^9

ZH: $\ell^+\ell^- + \not{E}_T$

Backgrounds: ZZ $(\to (\ell\ell)(\nu\bar{\nu})$**, WZ** $\to \ell\nu\nu\bar{\nu}$**,**
$t\bar{t} \to (\ell\nu b)(\ell\nu\bar{b})$**, WW**

Selections:

- **Leptons:** $p_T^\ell > 10$ **GeV and** $|\eta_l| < 3$**. Isolation:** $E_T^{ac} \leq 0.2 p_T^\ell$**.**
$E_T^{ac} = \sum p_T^j (\Delta R(l,j) \leq 0.2)$
- **Jet veto,** $p_T > 30$ **GeV and** $|\eta| < 4$**.**
- $\cos\phi_{\ell\bar{\ell}} > 0$**,** $M_T^{l\bar{l}} >$ **150 (200) GeV for 8 (14) TeV.**

$M_T^{l\bar{l}} = \sqrt{p_T^{ll} \not{E}_T \left(1 - cos\phi(E_T^{ll}, \not{E}_T)\right)}$**.** $\Rightarrow$ **used in CMS**

- $\not{E}_T >$**100 GeV.**
- $|M_Z - m_{\ell\bar{\ell}}| < 10$ **GeV.**

R.Godbole, MG,K.Mazumdar,S.Moretti,D.P.Roy, PLB,'03.
D.Ghosh, R.M.Godbole, MG, K. Mohan D. Sengupta, 1211.7015
Y. Bai et. al.1112.4496

ZH: $\ell^+\ell^- + \not{E}_T$

Process	8 TeV		14 TeV	
	Production C.S[pb]	After Cuts C.S[fb]	Production C.S[pb]	After Cuts C.S[fb]
ZZ	4.79	6.7	10.1	17.6
WZ	12.6	1.8	47.3	3.8
WW	33.8	0.3	69.4	2.3
$t\bar{t}$	115	0.1	480	0.95
Total Bg		8.9		24.7
ZH	0.3	2.3	0.64	5.6
$S/\sqrt{B}$	$\mathcal{L}$=**20** fb^{-1}	**~3.5**	$\mathcal{L}$=**50** fb^{-1}	**~8**

D.Ghosh, R.M.Godbole, MG, K. Mohan, D.Sengupta, PLB '13(1211.7015)

ZH: $b\bar{b} + \not{E}_T$

Method (a): b-jets are identified using jet reconstruction algorithm and matching, taking care b-jet efficiency.

Method (b): b-jets are identified using Jet substructure technique.

Backgrounds: ZZ, $\mathrm{Zb\bar{b}}$**, WZ,** $\mathrm{t\bar{t}}$**,** $\mathrm{Wb\bar{b}}$**.**

Selections:

- **b jet selection, Jet reconstruction/Jet substructure**
- **Veto events with leptons**
- $|M_{b\bar{b}} - M_Z| <$ **30 GeV.**
- $\not{E}_T >$**70 GeV**
- $M_T(b\bar{b}, \not{E}_T) >$**200 GeV.**
- **No un-tagged jet activitiy,** $R_T = \frac{p_{T_{b_{j_1}}} + p_{T_{b_{j_2}}}}{H_T} >$**0.9**

ZH: $b\bar{b} + \not{E}_T$

$\sqrt{S}$=8 TeV

Process	Prod. C.S[pb]	After Cuts C.S [fb] b jet cluster	After cuts C.S[fb] b jet substructure
ZZ	4.79	**2.26**	**1.92**
WZ	12.6	0.38	0.36
$\nu\bar{\nu}b\bar{b}$	16	**3.1**	**1.33**
$t\bar{t}$	115	0.48	0.52
W$b\bar{b}$	50.5	0.54	0.16
Background		6.76	4.29
ZH	0.3	0.8	0.72
S/$\sqrt{B}$ $\mathcal{L} = 20fb^{-1}$		**~2**	**~2**

D.Ghosh, R.M.Godbole, MG, K. Mohan, D.Sengupta, PLB '13(1211.7015)

ZH: $b\bar{b} + \not{E}_T$ 14 TeV

$\sqrt{S}$=14 TeV

Process	Production C.S[pb]	After Cuts C.S [fb] b jet cluster	After cuts C.S[fb] b jet substructure
ZZ	10	5.56	2.47
WZ	26.7	3.5	1.44
$\nu\bar{\nu}b\bar{b}$	47.3	12.9	3.04
$t\bar{t}$	476	3.92	0.16
W$b\bar{b}$	112	4.2	1.08
Background		30.	8.19
ZH	0.64	2.	1.1
S/$\sqrt{B}$ $\mathcal{L} = 100 fb^{-1}$		∼**4**	∼**4**

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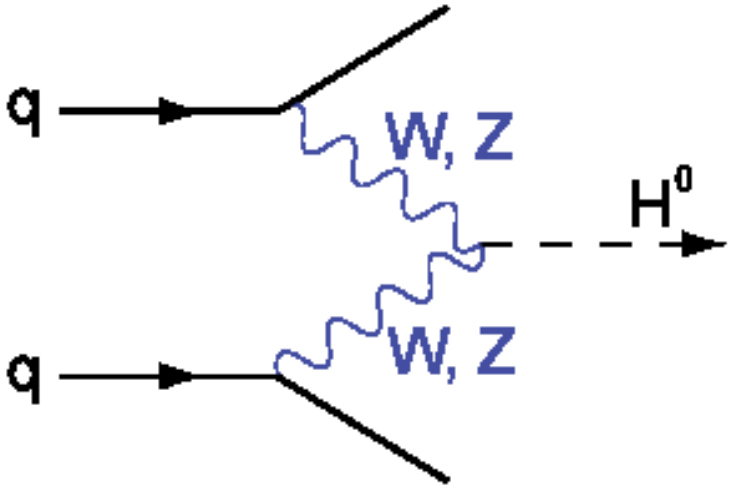
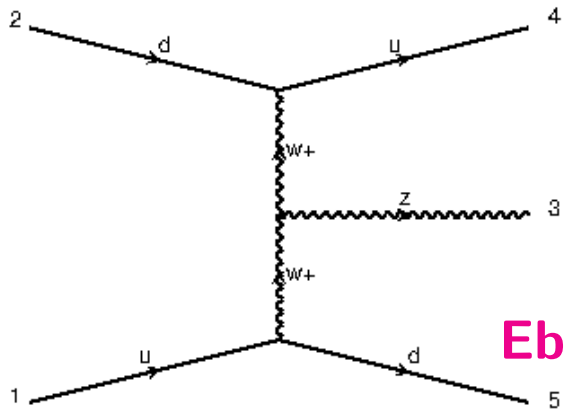
VBF: 2 jets + $\not{E}_T$



gg $\rightarrow$ H+2jets, $\rightarrow$ 2 jets + $\not{E}_T$



Main backgrounds: W+2jets, Z+2jets,
W+3jets, Z+3jets

Eboli, Zeppenfeld, 2000, A.Nikitenko et.al '01
Y. Bai et.al 1112.4496
D.Ghosh, R.M.Godbole, MG, K. Mohan, D.Sengupta, PLB '13(1211.7015)

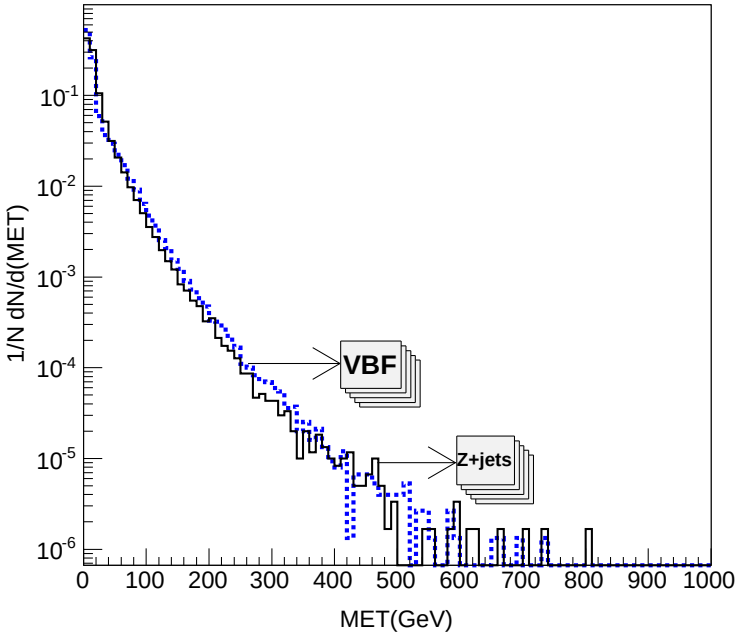
VBF: 2 jets + $\not{E}_T$

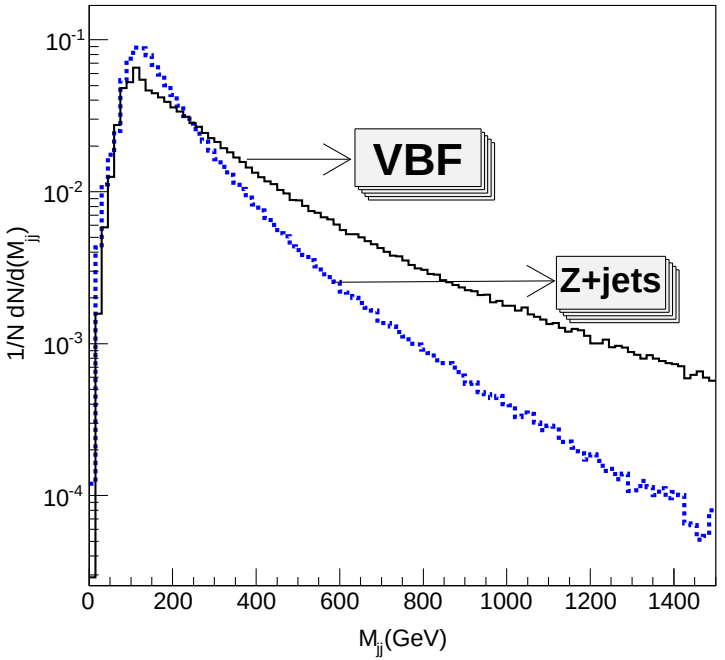
Event Selections:

- **VBF selections:** $|\eta_{j1} - \eta_{j2}| = |\Delta\eta| >$**4,**$\eta_{j1} \times \eta_{j2} <$**0.**
- **Central Jet veto: no jets with** $p_T > 40$ **GeV in the rapidity gap region between two jets.**
- **Lepton veto(LV): Since Signal is free of any leptonic presence.**
- **Selection of** $\not{E}_T$**:** $\not{E}_T >$**100 (170) GeV for 8 (14)TeV.**
- **Dijet invariant mass** M_{jj} **:** $M_{jj} >$**1400 (1800) GeV for 8 TeV (14 TeV).**

VBF: 2 jets + $\not{E}_T$

$\not{E}_T$ and M_{jj} distributions





VBF: 2 jets + $\not{E}_T$

Process	8 TeV		14 TeV	
	Production CS[pb]	After cuts CS[fb]	Production CS[pb]	After cuts CS[fb]
W+2jets(VBF)	76.5	4.5	167.9	6.3
W+2jets	18700	5.8	45900	18.7
W+3jets	10260	< 1	21000	13
Z+2jets(VBF)	19	6	43.2	6.7
Z+2jets	6000	16.5	14000	11.2
Z+3jets	2772	8.3	7300	17.8
tbW	140	< 1	611	< 1
Total Background		41.1		74
hjj(VBF)	1.73	7.3	4.3	8.7
hjj	6.7	1.2	24.5	1.3
Signal		8.5		10

D.Ghosh, R.M.Godbole, MG, K. Mohan, D.Sengupta,1211.7015

Results:Summary

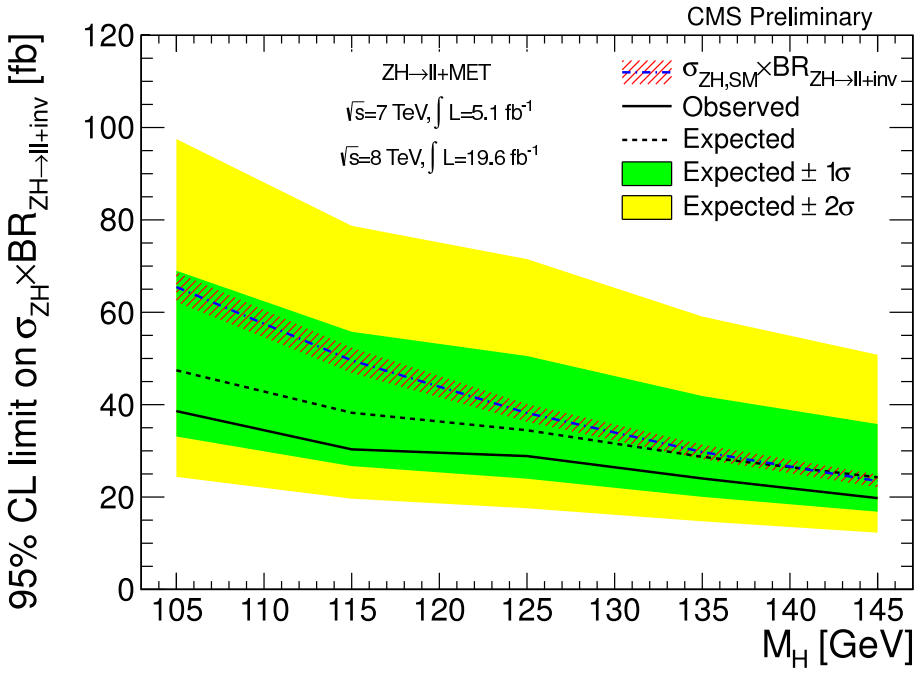
$\mathrm{BR_{inv}}$ **sensitivity at** 5σ

Process	8 TeV (20 fb^{-1})	14 TeV (30 fb^{-1})	14 TeV (100 fb^{-1})
VBF	**0.34**	**0.33**	**0.17**
$Z(\rightarrow l^+l^-)H$	**0.58**	**0.32**	**0.18**
$Z(\rightarrow b\bar{b})H$**(substructure)**	–	–	**0.50**
$Z(\rightarrow b\bar{b})H$**(b-jet cluster)**	–	–	**0.55**

Possible to measure invisible BR as low as 30% at 14 TeV LHC

Invisible Higgs Search at the LHC:CMS and ATLAS

PP $\rightarrow ZH \rightarrow (\ell^+\ell^-) + \not{E}_T$



CMS: BR(H→ inv) <0.75% @ 95% C.L, CMS - PAS-HIG 13-018
ATLAS: BR(H→ inv) <0.65% @ 95% C.L, ATLAS CONF 2013-011

Conclusion

- Invisible Higgs decay width still a window to confirm the existence of BSM physcis.

- Invisible decay width and DM are connected, Higgs as a portal

- LHC may find invisible decay of Higgs signal in future, about 30% at low luminosity and 17% at high luminosity.