LHC Potential for
ZH→*ll* + invisible Search

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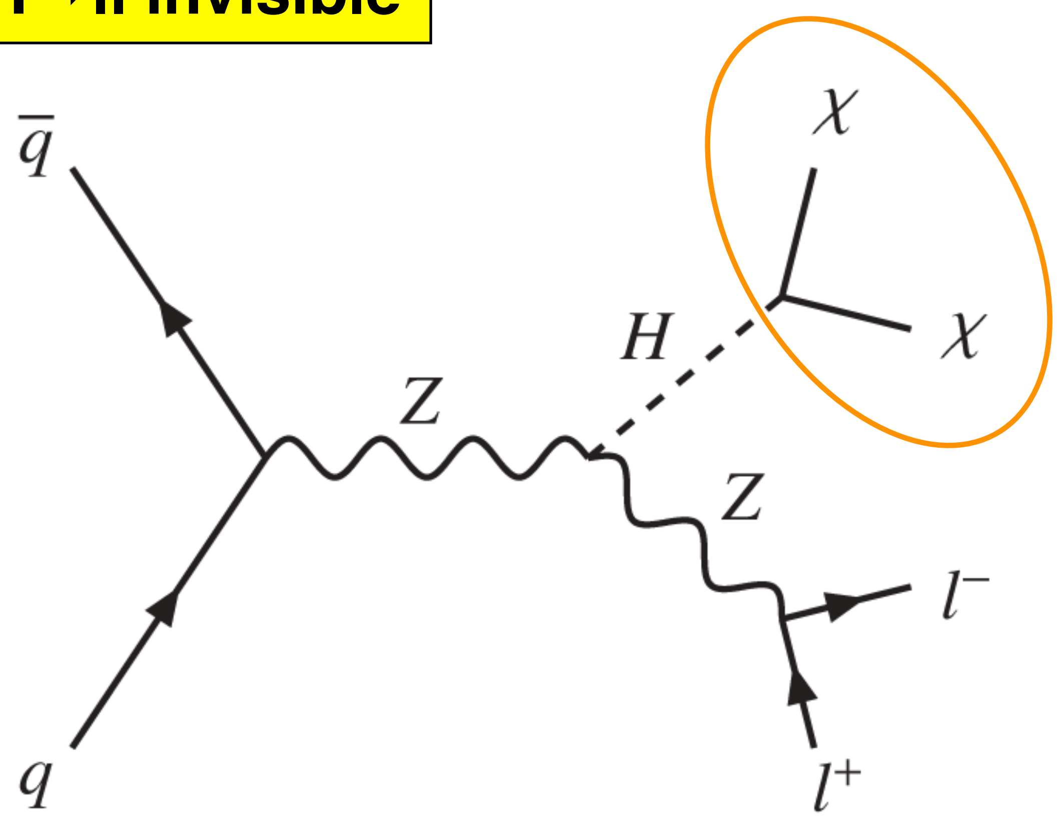
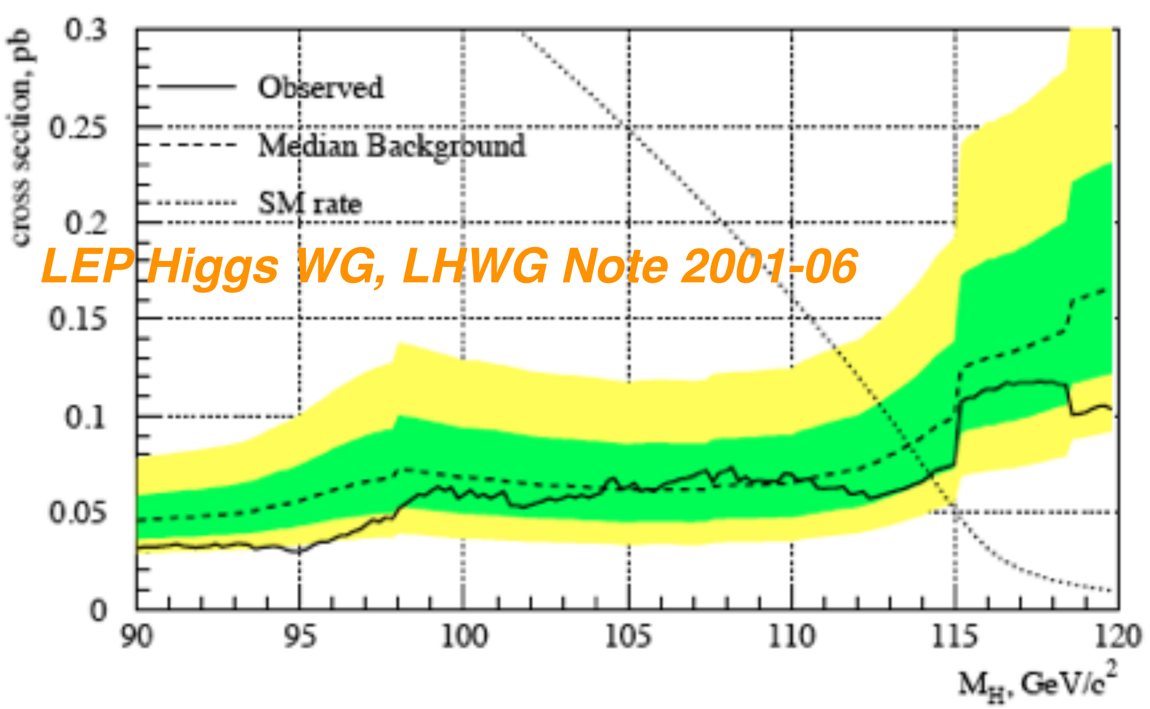
ZH(→ll+inv.) Search @ LHC

ZH→ll invisible



- **DIRECT search for the invisible decays of Higgs**; BSM process
- **Cut-based analysis using Z+E_T^{miss} final state.**
- **Has one of the highest sensitivities among direct H(→inv) search channels.** **(cf. other channels; VBF, monojet, W+E_T^{miss})**



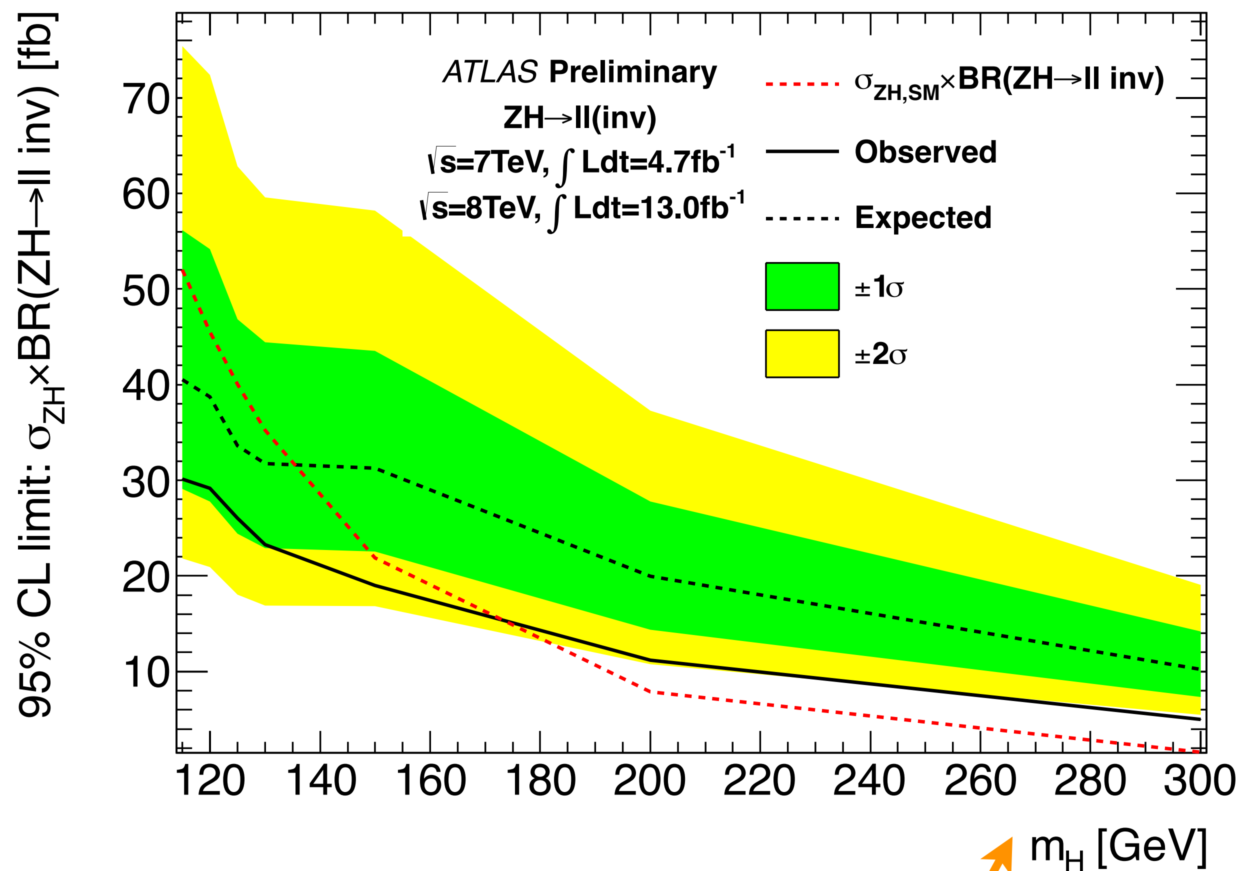
LEP Higgs WG, LHWG Note 2001-06

- LEP apparently has no sensitivity for m_H > ~120 GeV
- **Complementary approach to the Higgs coupling studies**

ATLAS-CONF-2013-034

ATLAS Moriond Results

- **First results at Moriond EW and onwards** using the full 2011 & 2012 HCP dataset (4.7 fb^{-1} + 13.0 fb^{-1})



- The first direct search for the invisible Higgs at the LHC. **<u>BR(H→inv)<0.65@95% CL obs.</u>**
- Also showed interpretations for “another” Higgs scenario

Samples for Snowmass Studies

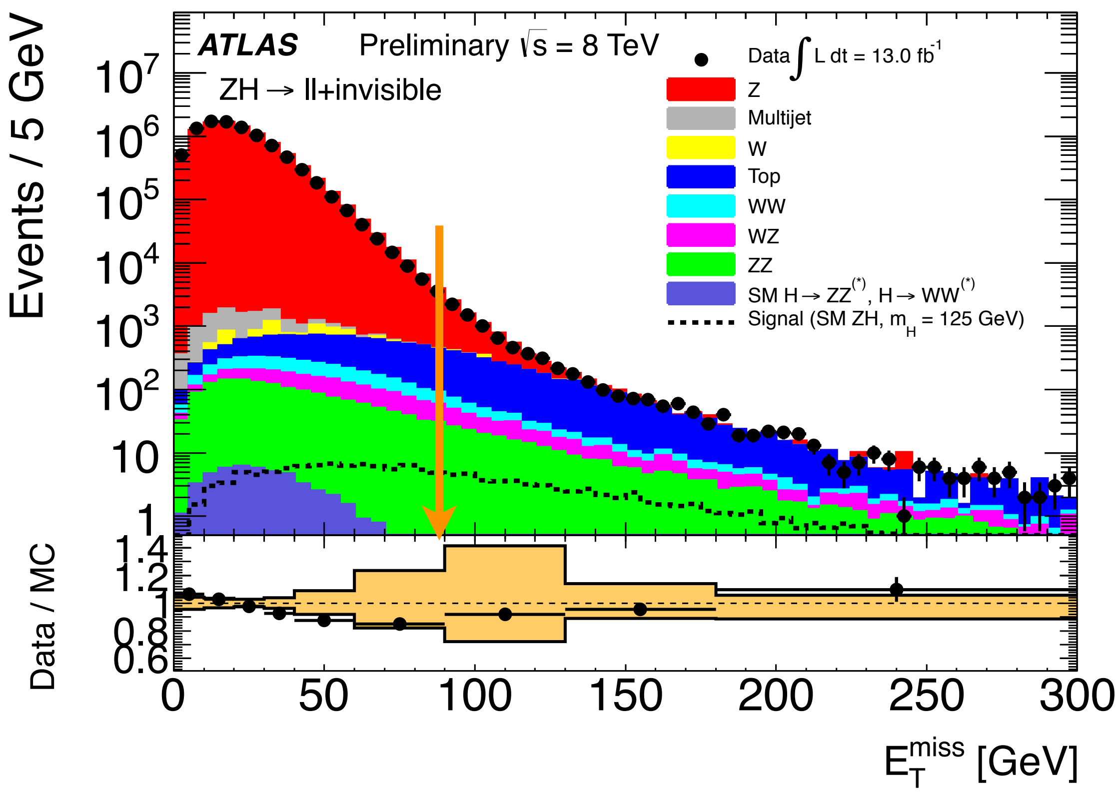
- Used Delphes samples produced by the Snowmass production team (Thank you so much)

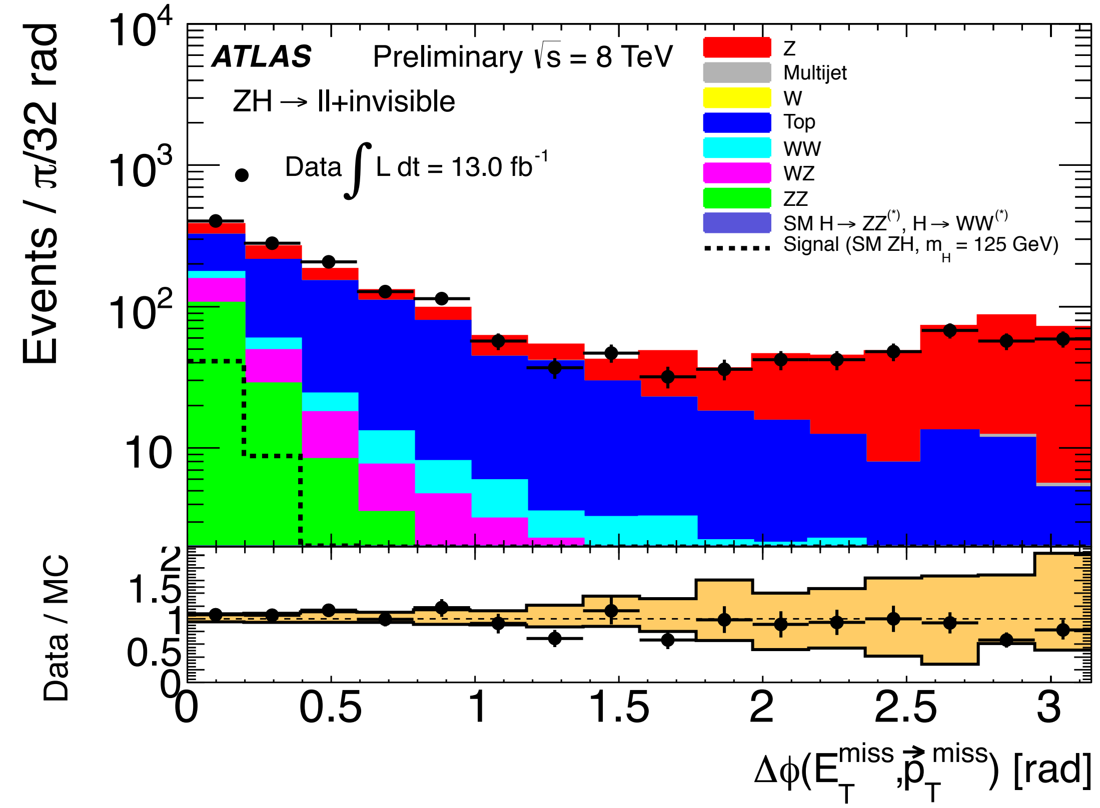
- **Background:**
  - **ZZ/WZ/WW(&Zγ,Wγ):** BB samples with 5 H_T slices
  - **Top:** ttbar (tt samples) with 5 H_T slices, single top (tj, tB samples) to be added for the next round (though almost negligible for this channel)
  - **Z/W+jets:** B samples with inclusive H_T production
- **Signals:**
  - **ZH→ll+inv. signals:** produced with MadGraph5 & ran Delphes v. 3.0.9 with different pileup conditions (0, 50, 140)

ATLAS Event Selection

ATLAS event selection used for Moriond

ATLAS-CONF-2013-011





- 2 opposite-sign lepton w/ $76 < M_{ll} < 106$ GeV; 3rd lepton veto ($p_T > 7$ GeV)
- **$E_T^{miss} > 90$ GeV**
- **Fractional p_T difference ($|E_T^{miss} - p_T^{ll}| / p_T^{ll}$) < 0.2**
- **$d\phi(E_T^{miss}, E_T^{miss,trk}) < 0.2$**
- $d\phi(l,l) < 1.7$
- **$d\phi(Z, E_T^{miss}) > 2.6$**
- Jet veto ($p_T > 20$ GeV, $|\eta| < 2.5$)

E_T^{miss}-related variables

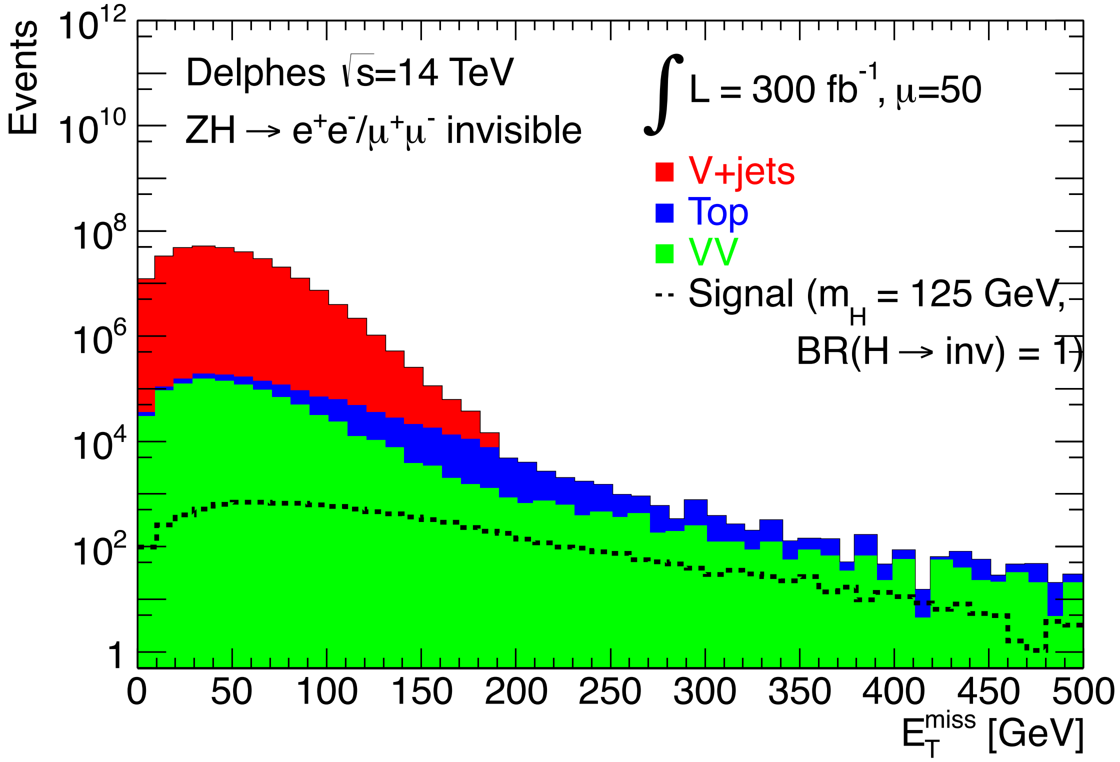
Snowmass Scenarios

- **14 TeV scenarios:** 300 fb^{-1} (pileup μ=50) & 3000 fb^{-1} (pileup μ=140)

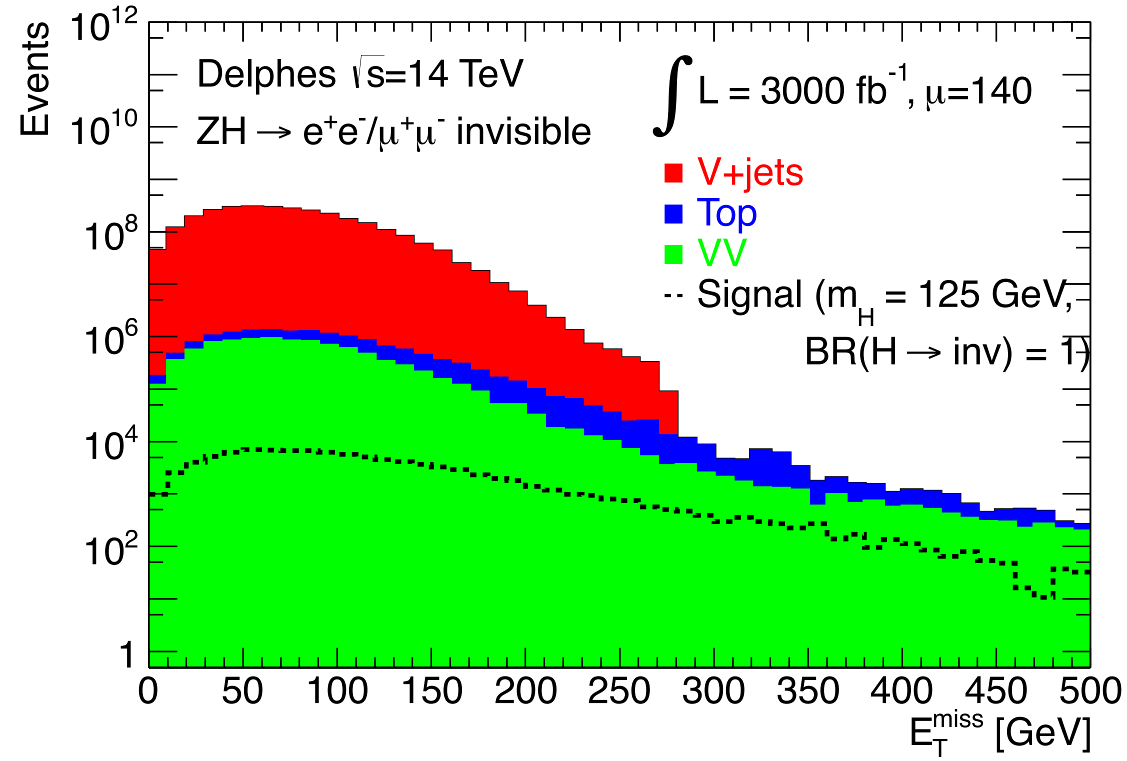
- Made minor modifications to the ATLAS ZH($\rightarrow$ll+invisible) event selection for the following reasons
    - Missing E_T: degradation of resolution due to more pileup
    - Removed dΦ(E_T^{miss}, track p_T^{miss}) cut for now. Detailed investigations are needed for the tracks in Delphes samples.
    - Jet veto threshold: pileup subtraction is not applied in the Delphes samples (which is different from the ATLAS conditions). So, we simply raised the p_T threshold for now.

Snowmass Event Selection

14 TeV 300 fb^{-1} (μ=50)



14 TeV 3000 fb^{-1} (μ=140)



Changes to the cut thresholds

- E_T^{miss} > 90 → 100 GeV
- $|E_T^{miss} - p_T^{ll}| / p_T^{ll}$ < 0.2 → 0.4
- Jet veto p_T threshold : 20→45 GeV

Signal significance without BG uncertainty ~ 1.6 (3.1) for signals w/ BR(H→inv)=10% (20%) at 300 fb^{-1}

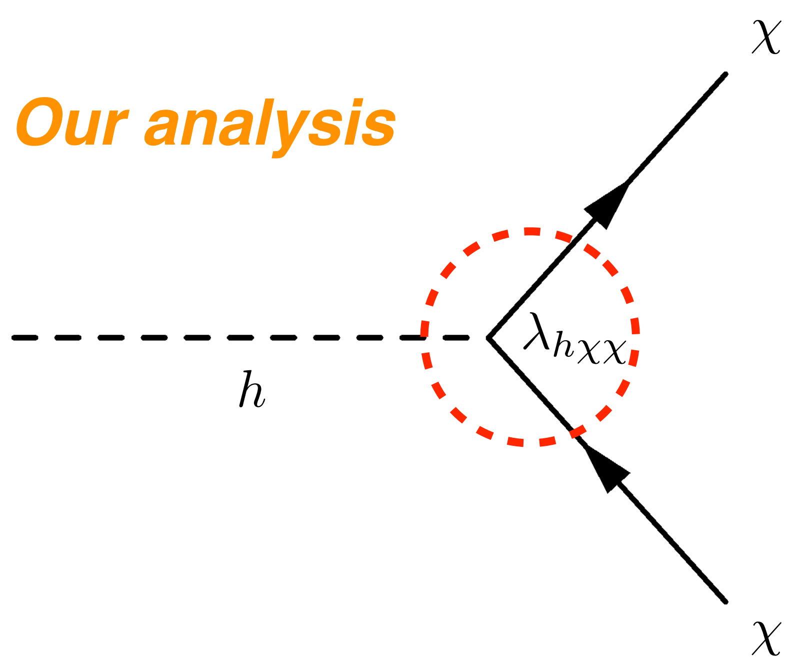
Changes to the cut thresholds

- E_T^{miss} > 90 → 170 GeV
- $|E_T^{miss} - p_T^{ll}| / p_T^{ll}$ < 0.2 → 0.6
- $d\phi(l,l)$ < 1.7 → 0.8
- Jet veto p_T threshold : 20→60 GeV

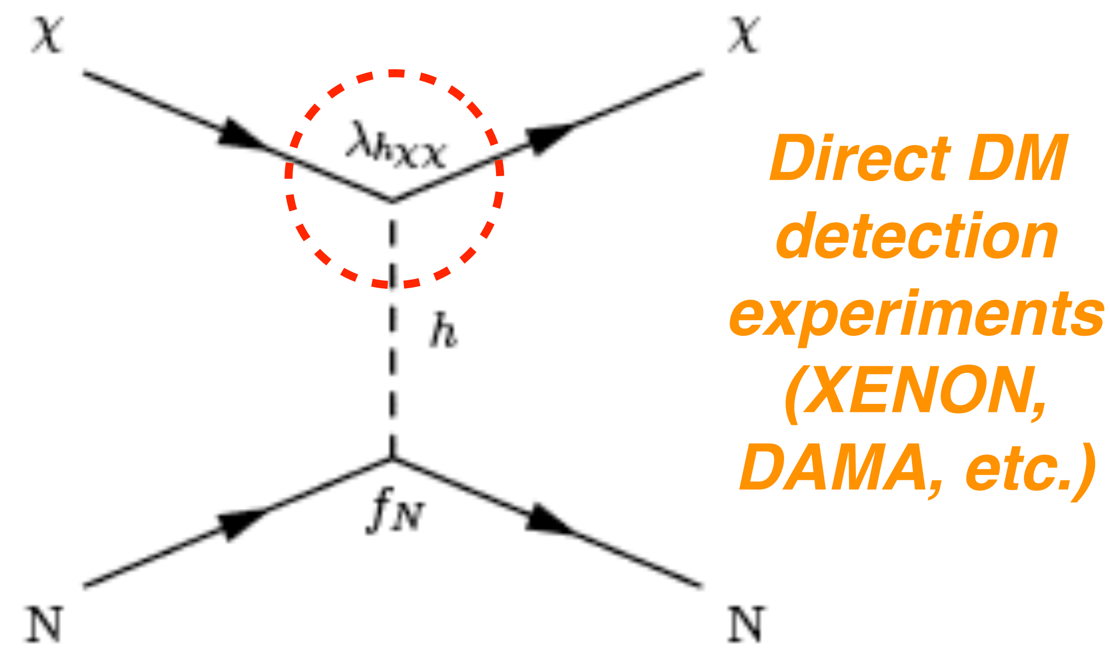
Preliminary

Higgs-Portal Interpretation

Higgs decaying to DM



DM-nucleon scattering in Higgs-portal DM Model



- The limits on BR(H→inv) could be mapped to bounds on the coupling of Higgs-dark matter (DM) & DM-nucleon cross section for Higgs-portal DM models

- The Higgs-portal is a particular type of DM models, where DM interacts through the couplings to Higgs.

Mapping & DM-types

Higgs invisible decay — **Higgs-DM coupling** — **DM-nucleon xsec**

$$\Gamma(h \to \chi\chi) \Leftrightarrow \lambda^2_{h\chi\chi} \Leftrightarrow \sigma_{N\chi}$$

$$BR(h \to \chi\chi) = \frac{\Gamma(h \to \chi\chi)}{\Gamma(h \to \chi\chi) + \Gamma(h \to SM)}$$

We consider three DM types: scalar, vector, majorana fermion

$$\Gamma^{\rm Scalar}(h \to \chi\chi) = \frac{\lambda^{2\,\rm Scalar}_{h\chi\chi} v^2}{64\pi m_h}\left[1 - \left(\frac{2m_\chi}{m_h}\right)^2\right]^{1/2}$$

$$\sigma^{\rm Scalar}_{\chi N} = \frac{\lambda^{2\,\rm Scalar}_{h\chi\chi}}{16\pi m_h^4}\frac{m_N^4 f_N^2}{(m_\chi + m_N)^2}$$

$$\Gamma^{\rm Vector}(h \to \chi\chi) = \frac{\lambda^{2\,\rm Vector}_{h\chi\chi} v^2}{256\pi m_\chi^4 m_h}\left[m_h^4 - 4m_\chi^2 m_h^2 + 12 m_\chi^4\right]\left[1 - \left(\frac{2m_\chi}{m_h}\right)^2\right]^{1/2}$$

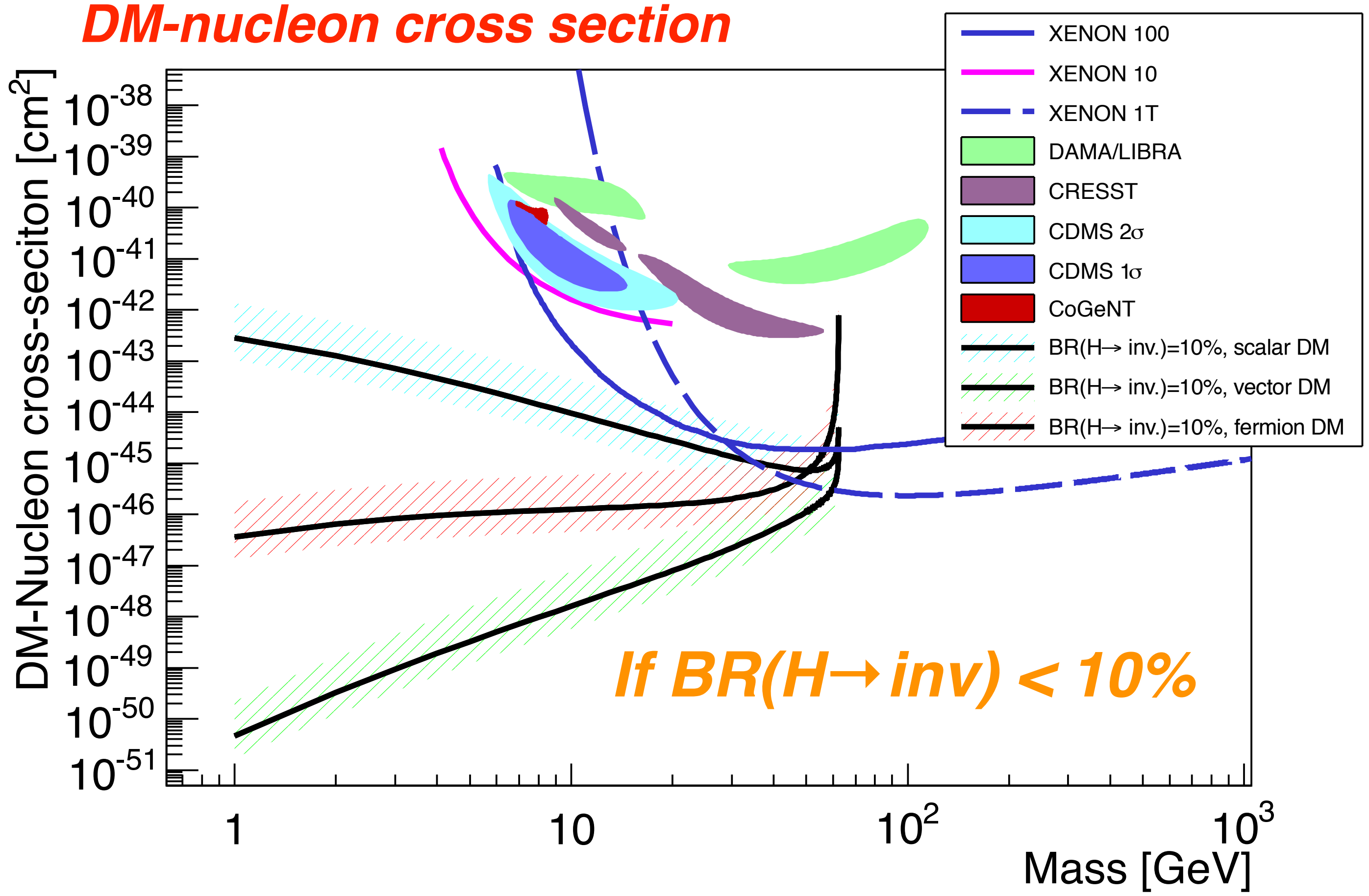
$$\sigma^{\rm Vector}_{\chi N} = \frac{\lambda^{2\,\rm Vector}_{h\chi\chi}}{16\pi m_h^4}\frac{m_N^4 f_N^2}{(m_\chi + m_N)^2}$$

$$\Gamma^{\rm Majorana}(h \to \chi\chi) = \frac{\lambda^{2\,\rm Majorana}_{h\chi\chi} v^2 m_h}{32\pi\Lambda^2}\left[1 - \left(\frac{2m_\chi}{m_h}\right)^2\right]^{3/2}$$

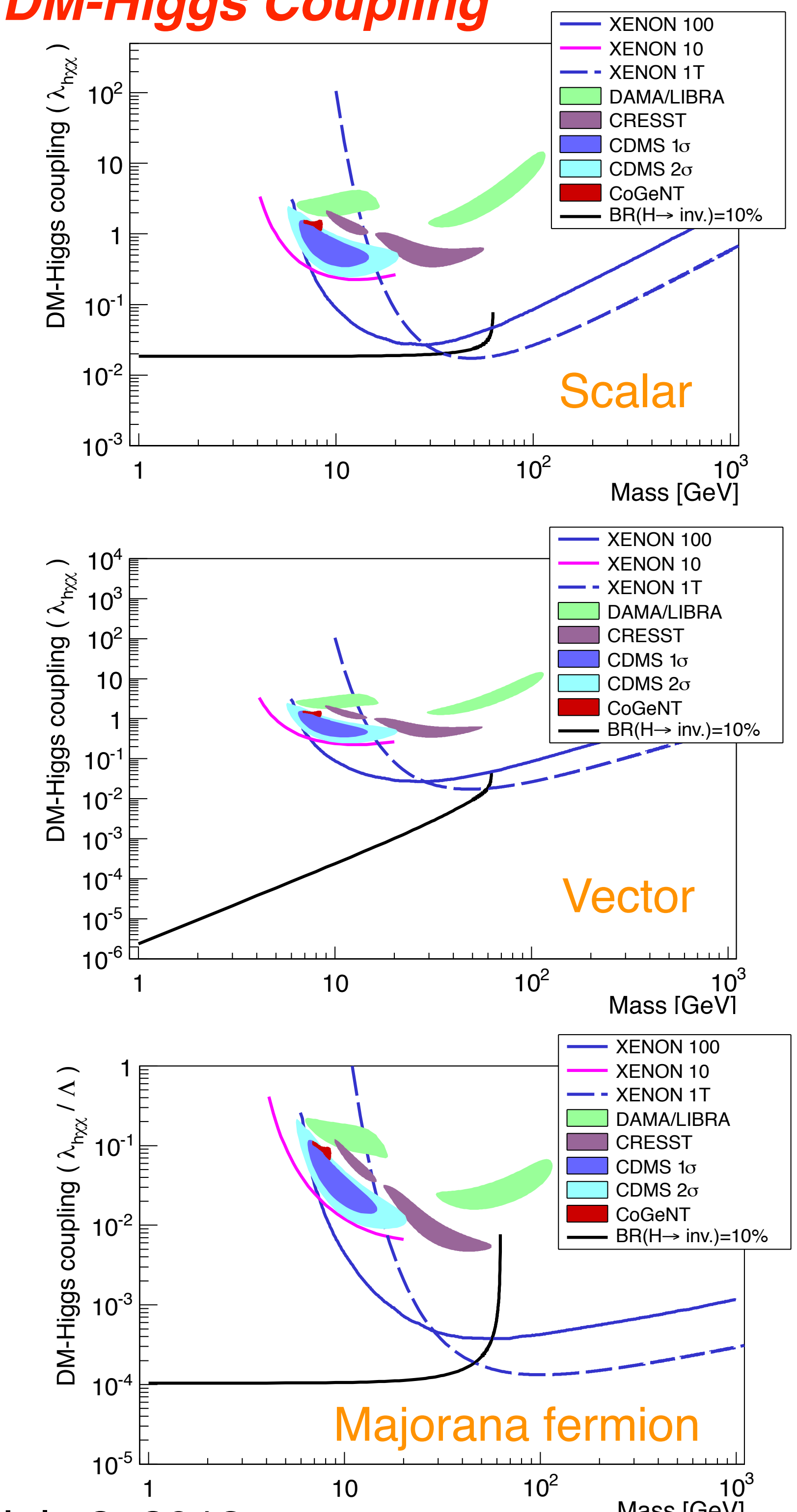
$$\sigma^{\rm Majorana}_{\chi N} = \frac{\lambda^{2\,\rm Majorana}_{h\chi\chi}}{4\pi\Lambda^2 m_h^4}\frac{m_\chi^2 m_N^4 f_N^2}{(m_\chi + m_N)^2}$$

BR(H→inv) to Higgs-Portal

DM-nucleon cross section



DM-Higgs Coupling



- Mapped BR(H→inv)=10% line (as a benchmark) to Higgs-portal DM interpretation
- Very good sensitivity in $m_\chi < m_H/2$ region
- Uncertainty from the nucleon form factor is shown (left plot)

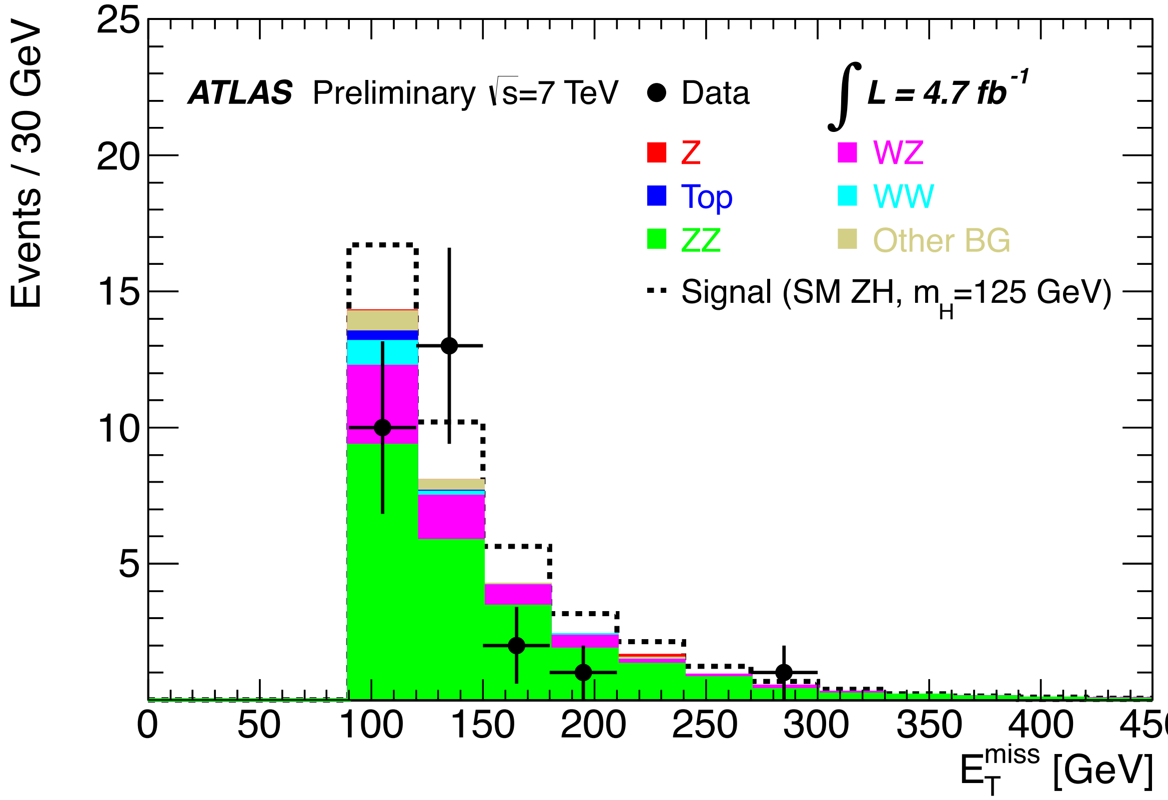
Summary & Plans

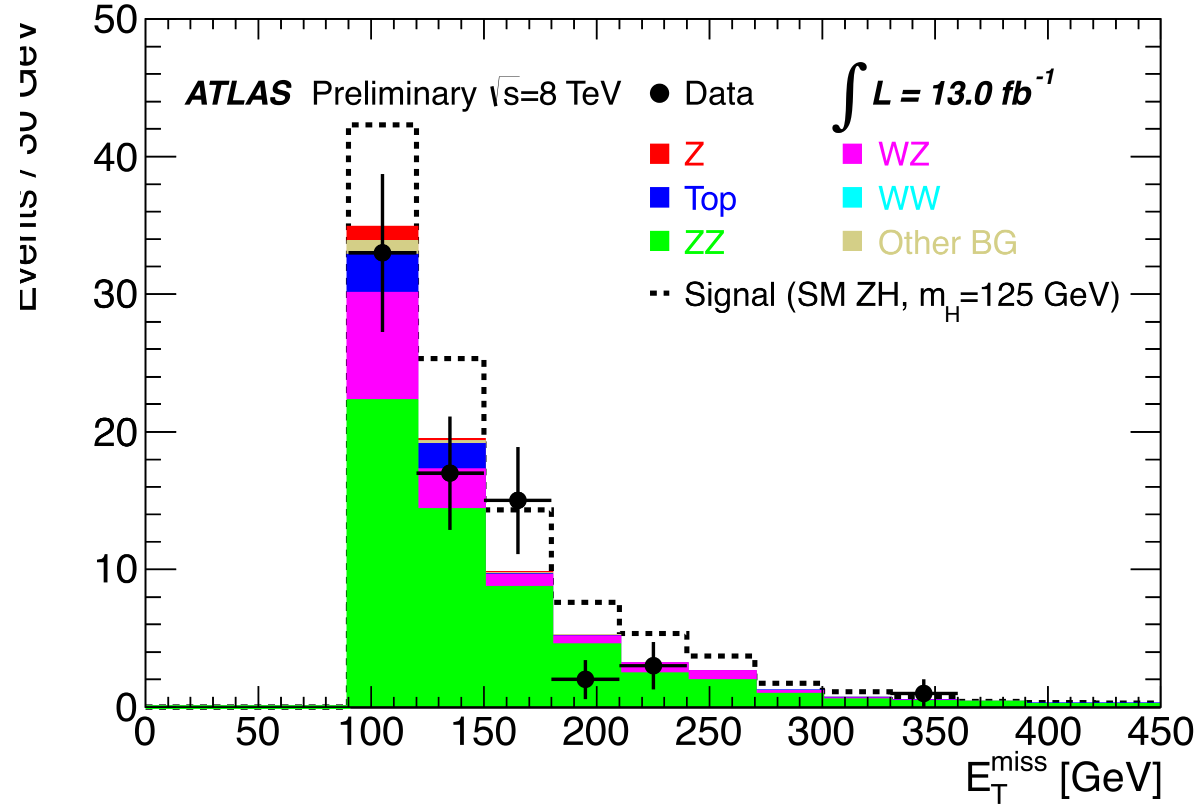
- Showed preliminary studies on the prospects of LHC for ZH→ll +invisible channel.
- Considered benchmark luminosities & μ-values proposed by the Snowmass committee.
- As this channel significantly relies on the performance of Missing E_T, improving the pileup suppression in the Missing E_T calculation would have quite an impact on the signal sensitivity.
- As long as E_T^{miss} is under control, the main background is ZZ. The systematics of ZZ will be the key component for the signal sensitivity.
- Detailed investigations are ongoing, and expected limits for the Snowmass scenarios are to be provided.

backups

Moriond Results

From Moriond CONF note





- Consistent with the SM predictions.
- Limits are set on the two scenarios as mentioned in the next slide.

Data Period	2011 (7 TeV)	2012 (8 TeV)
ZZ	$23.5 \pm 0.8 \pm 2.5$	$56.5 \pm 1.2 \pm 5.7$
WZ	$6.2 \pm 0.4 \pm 0.7$	$13.9 \pm 1.2 \pm 2.1$
WW	$1.1 \pm 0.2 \pm 0.2$	used $e\mu$ data-driven
Top quark	$0.4 \pm 0.1 \pm 0.4$	used $e\mu$ data-driven
Top quark, WW and $Z \to \tau\tau$ ($e\mu$ data-driven)	used MC	$4.9 \pm 0.9 \pm 0.2$
Z	$0.16 \pm 0.13 \pm 0.09$	$1.4 \pm 0.4 \pm 0.7$
W + jets, multijet	$1.3 \pm 0.3 \pm 0.2$	$1.4 \pm 0.4 \pm 0.3$
Total BG	$32.7 \pm 1.0 \pm 2.6$	$78.0 \pm 2.0 \pm 6.5$
Observed	27	71

Moriond Results

From Moriond CONF note

Process	Estimation method	Uncertainty (%) 2011	2012
ZH Signal	MC	7	6
ZZ	MC	11	10
WZ	MC	12	14
WW	MC	14	not used
Top quark	MC	90	not used
Top quark, WW and $Z \to \tau\tau$	$e\mu$ CR	not used	4
Z	ABCD method	56	51
W + jets, multijet	Matrix method	15	22

- ZZ, WZ are dominated by the jet systematics & theory uncertainty
- Z uncertainty comes from both the statistical and systematical uncertainty.