SEARCH FOR AN INVISIBLE DECAYING HIGGS BOSON IN DILEPTON EVENTS AT CDF

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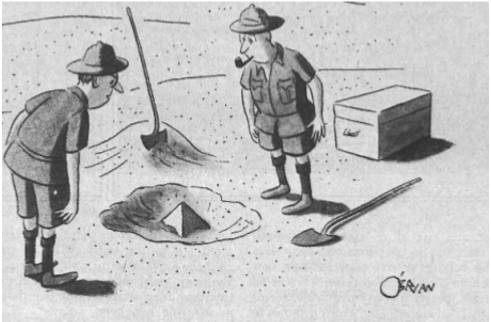
Introduction: What are we searching for?

Aim: Search for an (Exotic) Higgs boson that decays in an unexpected way to invisible particles.



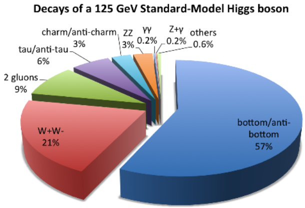
"This could be the discovery of the century. Depending, of course, on how far down it goes."

Introduction: Invisible Higgs Decays

The Higgs particle interacts directly with the known elementary particles with a strength related to their masses.

$\Rightarrow$ If it is kinematically accessible, decays to heavy particles are more likely than those to lightweight particles.

- 60% bottom quark antiquark pairs
- 21% W particles
- 9% two gluons
- 5% tau lepton antilepton pairs
- 2.5% charm quark antiquark pairs
- 2.5% Z particles
- 0.2% two photons γ
- 0.15% a photon and a Z particle



Introduction: Why it's so interesting?

What type of particle is it?

- After the discovery of Higgs boson at LHC, the main task will be to establish its properties.
- Many BSM models incorporate Invisible decay of Higgs boson that is significantly different from zero:
  Fourth Generation Neutrino, SUSY, Extra-Dimension.
- To observe an Higgs decay to invisible it will be indication of *New Physics*.

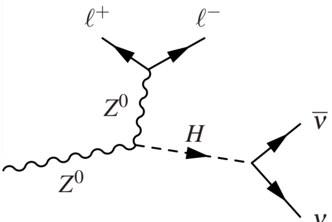
How can we search for this events?

What forms the baseline?

If Higgs boson decays to weakly interacting and neutral particles,
Final state will only be the $\not{E}_T$.

Anyway:

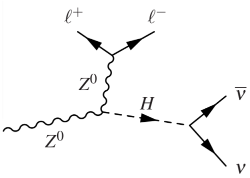
- 5% of Higgs particles are expected to be produced along with a W or Z particle.
- 6% of Z particles decay to an e^+e^- pair or a $\mu^+\mu^-$ pair



- One of the easiest signature to study this process is when H is produced in association with a $Z \rightarrow ll$

The Signal Process

We look for such signal process in a sample of $Z - resonant$ dileptons, using a dataset corresponding to $9.7\ fb^{-1}$ of CDF data.



$ZH \rightarrow ll\nu\nu$ has a clean signature:

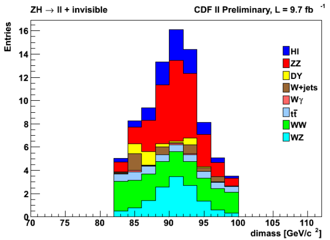
- 2 Leptons at $Z-$mass
- Missing $\not{E}_T$ from Higgs
- No jets

We will investigate ZH signal assuming SM production and $BR(H \rightarrow \nu\nu) = 100\%$.

We investigate Higgs mass hypothesis from 115 to 150 GeV/c^2.

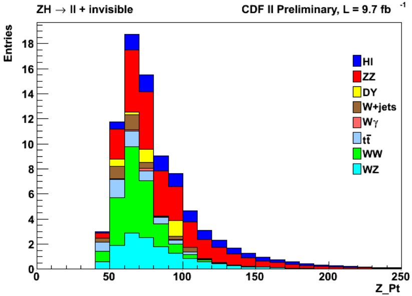
Event Selection: Reconstruct $Z \rightarrow ll$

- In order to reconstruct the final state $Z \rightarrow ll$:
  - Exactly two leptons, opposite charge and same flavor
  - Reconstructed invariant mass: $82 \leq M_{ll} \leq \ 100GeV/c^2$
  - Different reconstructed lepton categories for electrons, muons and high-quality tracks



Event selection: Require $Z \to ll$ to be boosted

- In order to account of the recoil against the Higgs boson, events are required to be boosted:
  - Consider as a signal region $p_T(ll) \geq 45\,GeV$
  - $30 \leq p_T(ll) \leq 45\,GeV$ events considered as a control sample

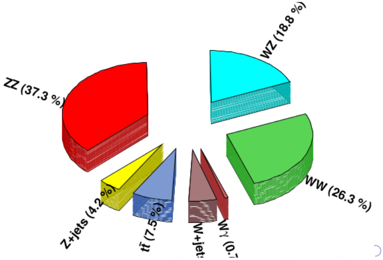


Composition of the selected Data Sample

A $Z - resonant$ dilepton sample is composed by several other processes events, which are background contribution to our search.

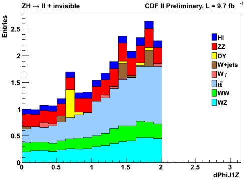
- **Z/γ* + jets**: fake $\not{E}_T$ in the event.
- **ZZ**: irreducibile SM background, exactely same decay mode, different Z recoil (wrt ZH).
- **WW**: $l\nu l\nu$ non resonant final-state.
- **WZ**: missing one lepton from leptonic decay mode ($lll\nu$).
- **W γ** : γ faking a lepton.
- **W+jets**: jet faking a lepton.
- **t$\bar{t}$** : ll+jets final state characterized by large hadronic activity.

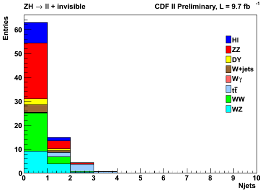
Process	Events in $9.7fb^{-1}$
Z + jets	3.1 ±1.2
WW	3.1 ±1.2
WZ	19.2 ±1.8
ZZ	27.2 ± 2.9
W γ	0.5 ± 0.5
W + jets	3.8 ± 0.6
t $\bar{t}$	5.5 ± 0.9
Total Background	73.0 ± 4.0
ZH (m_H = 125 GeV/c^2)	8.1 ± 1.2

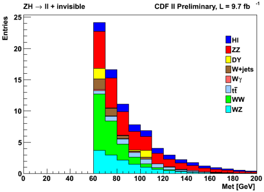


Reduce spurious background boosted events

- No jets reconstructed that have $E_T \geq 15\,GeV$ a, with $\Delta\phi \geq 2.0$ from the Z
- Selected Signal Region with $\not{E}_T \geq 60\,GeV$



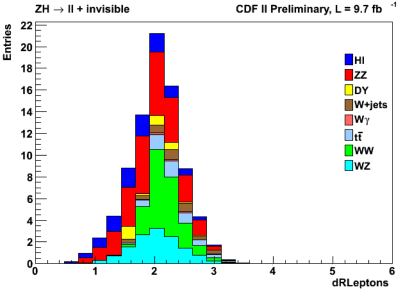




Final discriminant $\Delta R(ll)$

Requiring $\not\!\!E_T \geq 60\,GeV$

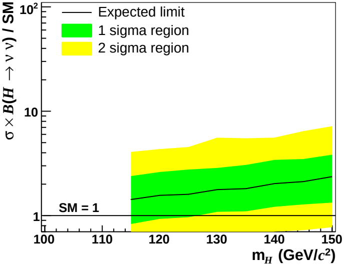
We chose as Final Discriminant the kinematic variable $\Delta R(ll)$.

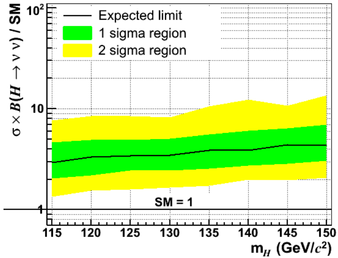


$(Z \to ll)(H \to \nu\nu)$ production Limit Calculation

Statistics-only and including Systematics Limits

Using a Bayesian approach we set a 95% confidence level upper limit on $\sigma(ZH) \; \times \; BR(H \to \nu\nu)$.





Upper limit on $\sigma(ZH)_{SM}$	115 GeV/c^2	120 GeV/c^2	125 GeV/c^2	130 GeV/c^2	135 GeV/c^2	140 GeV/c^2	145 GeV/c^2	150 GeV/c^2
$-2\sigma/\sigma_{SM}$	1.36	1.55	1.60	1.65	1.73	1.98	1.96	2.08
$-1\sigma/\sigma_{SM}$	2.04	2.19	2.47	2.44	2.56	2.75	2.87	3.06
Median$/\sigma_{SM}$	2.95	3.32	3.44	3.49	3.86	3.89	4.39	4.37
$-1\sigma/\sigma_{SM}$	4.65	4.90	4.90	5.08	5.56	6.07	6.42	6.97
$-2\sigma/\sigma_{SM}$	7.73	8.51	8.49	8.21	10.55	12.34	10.75	13.71

Conclusion

Further improvements

Up to now:

- We are able to reproduce kinematic variable's plots in the signal region.
- Limits with systematics uncertanties look too high.

We are going to explore

- How to model correctly the Z+jets and W+jets backgrounds.
- If we need to include Shape Systematics.
- Much discussion of whether we can reinterpret this analysis as dark matter or other new physics search.

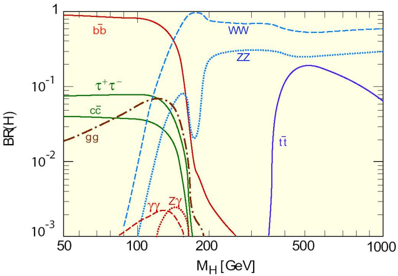
Thank you!

Backup slides

Introduction: The Higgs Coupling

The Higgs field gives mass to all of the known massive particles:
all the quarks, all the charged leptons, the W and Z particle, and even the neutrinos.
The Higgs coupled to masses:

$$\frac{m_f}{v}(\phi f\overline{f}) + gm_W(\phi W^- W^+) + \frac{g}{2 \cdot cos\theta_W} m_Z(\phi ZZ) \quad (1)$$



Background Modeling

Background processes modeling:

- W+jets background modeled from data.
- Z+jets background modeled from data .
- All other processes are modeled using MC simulations.

Background processes validation:

- WW/W+jets modeling validated in a sample of $e - \mu$ events with significant $(\geq 20\, GeV)$ $\not\!\!E_T$.
- W γ/ W+jets modeling validated in a sample of Same Sign leptons.
- Z+jets fit procedure validated in different kinematic regions:
  - $30 \geq p_T(ll) \geq 45\, GeV/c$ indipendent sample.
  - Events with exactely one jet in *veto* cone.

Systematic Uncertainties

Syst. Unc.	Z+jets	WW	WZ	ZZ	W γ	W+jets	$t\bar{t}$	ZH
XSec_ DIBOSON		6.0%	6.0%	6.0 %				
XSec_ WGAMMA					10.0%			
XSec_ TTBAR							10.0%	
XSec_ ZH								5.0 %
NLO_ ACCEPT_ DIBOSON			5.0 %	5.0%				
NLO_ ACCEPT_ WGAMMA					5.0%			
NLO_ ACCEPT_ TTBAR							10.0%	
NLO_ ACCEPT_ ZH								10%
Luminosity		5.9%	5.9%	5.9%	5.9%		5.9%	5.9%
Conversion					10.0%			
JES_ ZJETS	28%							
JES_ DIBOSON		1.0%	4.0%	2.0 %				
JES_ WGAMMA					3.0%			
JES_ TTBAR							4.0 %	
JES_ ZH								1.0%
ISR_ FSR								8.0%
Fake rates						15.0%		
Lepton_ ID_ ZJETS	3.0%							
Lepton_ ID		3.0%	3.0%	3.0%			3.0%	3.0%
Trigger_ EFF_ ZJETS	2.0%							
Trigger_ EFF		2.0%	2.0%	2.0%			2.0%	2.0%

$(Z \to ll)(H \to \nu\nu)$ production Limit Calculation

Evaluate the limit using a Bayesian approach (MCLIMIT) using as binned likelihood to be fitted:

$$\mathcal{L} = (\prod_i \frac{{\mu_i}^{n_i} e^{-\mu_i}}{n_i!}) \cdot \prod_c e^{-\frac{{S_C}^2}{2}} \tag{2}$$

where

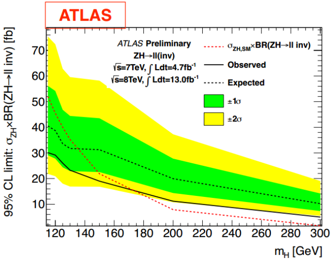
$$\mu_i = \sum_k \alpha_k [\prod_c (1 + {f_k}^C \cdot S_C)]({N_k}^{Exp})_i + f(x_j; \overrightarrow{a}) \tag{3}$$

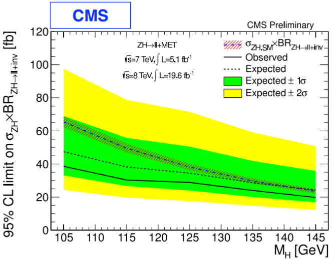
Fitted parameters:

Parameters	Symbol	Fit Status	Notes
ZH production cross section	α_{ZZ}	free	assuming $BR(H \to \nu\nu) = 100\%$
$Z + jets$ modeling parametrization	$\overrightarrow{a}$	$semi-$free	Constrained to float in specific ranges
Systematics nuisance parameters	S_C	constrained	Gaussian prior, as prescribed in limit calculation

Are we competitive with CMS[1]/ATLAS[2]?

No, we are not.





Limits	$H \rightarrow inv$ for $m_{Higgs} = 125\, GeV$	
CMS:	$\sigma_{ZH} \times BR(ZH \rightarrow ll\, inv) < 45 fb(exp)$	(1)CMS PAS HIG-13-018
CMS:	$\sigma_{ZH} \times BR(ZH \rightarrow ll\, inv) < 36 fb(obs)$	
ATLAS:	$\sigma_{ZH} \times BR(ZH \rightarrow ll\, inv) < 38 fb(exp)$	(2) ATLAS-CONF-2013-011
ATLAS:	$\sigma_{ZH} \times BR(ZH \rightarrow ll\, inv) < 28 fb(obs)$	

So Why?

1) Complements other Higgs searches at CDF
2) M. Bauce nearly brought this to completion (*data sample*, *code* already exist), we are trying to finishing it up