NORTHERN ILLINOIS UNIVERSITY

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Search for SM Higgs boson in the four lepton channel with DØ detector using 9.8 fb^{-1} of data

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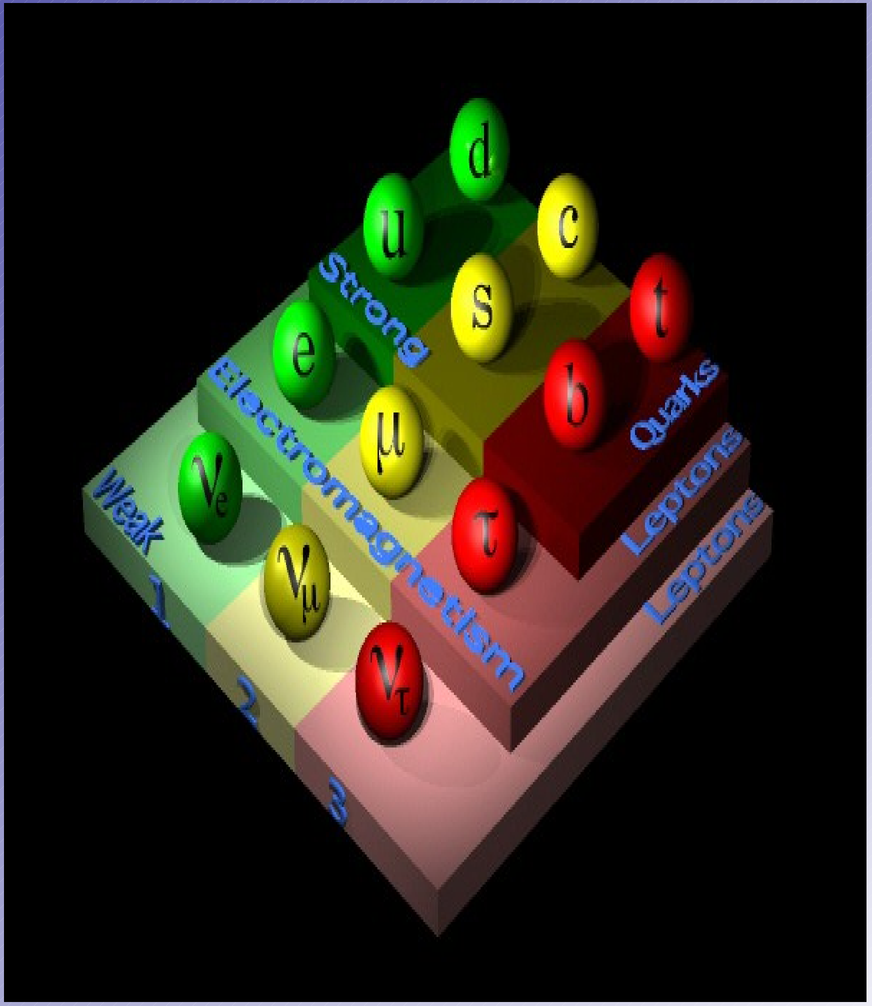
OUTLINE

1) The Standard Model
2) Higgs boson branching ratios
3) Higgs boson searches
4) ZZ $\rightarrow$ 4 lepton analysis
5) Event selection
6) Cross section calculation
7) Higgs search and limits calculation
8) Conclusions

The Standard Model

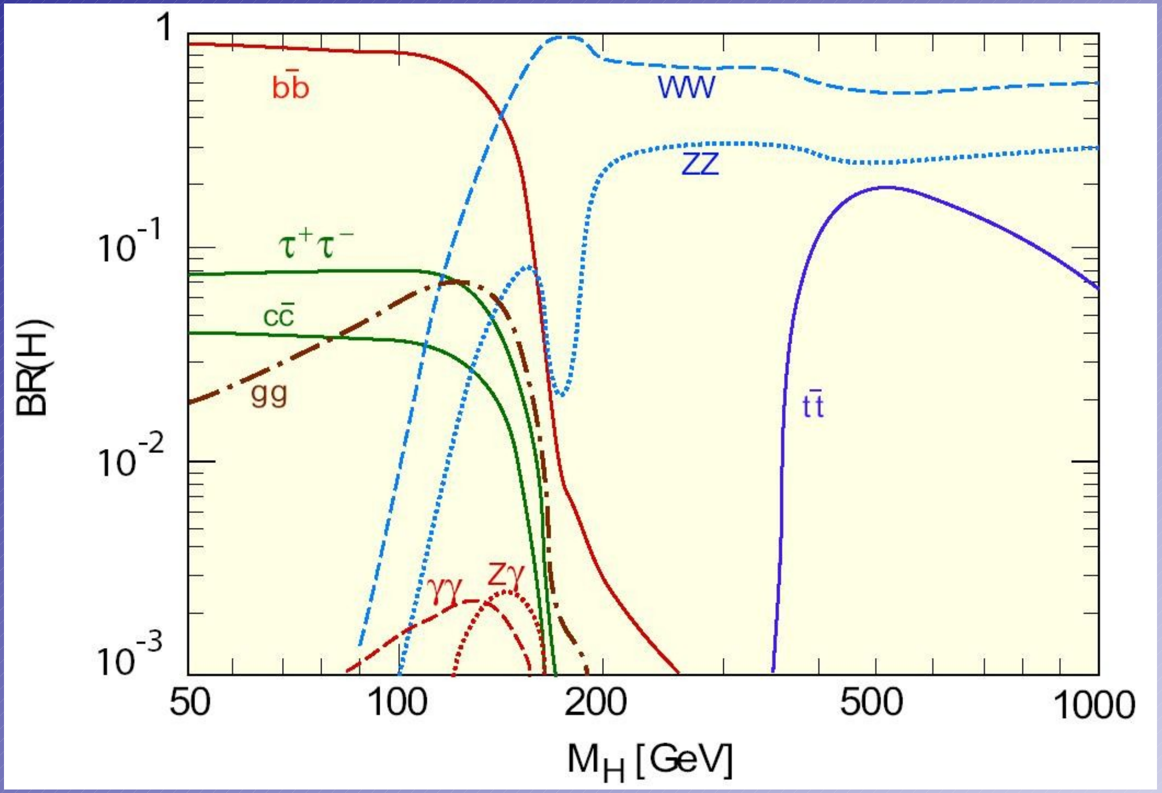
- One of the greatest scientific achievements in History;
- Contains almost everything we know on particles and forces;
- Has its predictions successfully confirmed through decades of experiments: W & Z bosons, bottom and top quarks, gluons;
- Problems: gravity, too many parameters, hierarchy problem, matter-antimatter asymmetry, dark matter & dark energy;

Higgs boson is a fundamental piece of SM!



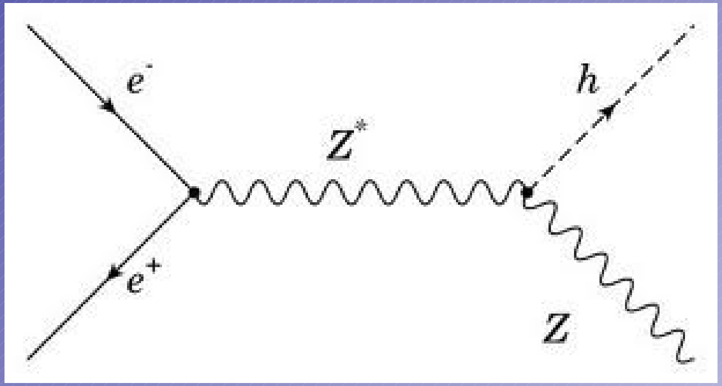
Higgs BR's

Higgs branching ratios as a function of the Higgs mass tell us which decays to expect and where:



LEP Searches

LEP performed Higgs searches in electron-positron collisions up to $\sqrt{s} = 209$ GeV.

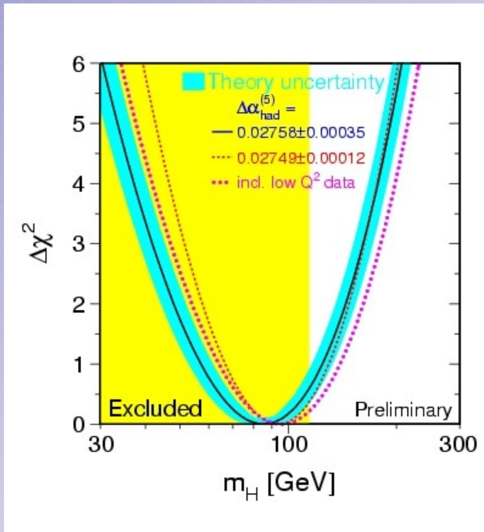


Signal signatures were:

* four jets, from $h \to b\bar{b}$ & $Z \to q\bar{q}$;
* two taus and two jets, from $h \to b\bar{b}$ & $Z \to \tau^-\tau^+$ or $h \to \tau^-\tau^+$ $Z \to q\bar{q}$;
* two jets and missing $E_{T\ (MET)}$, from $h \to b\bar{b}$ & $Z \to \nu\bar{\nu}$;
* two leptons and two jets, from $h \to b\bar{b}$ & $Z \to l^-l^+$.

LEP did set a limit on Higgs masses at 95% confidence level of

$$M_H > 114.4 \text{ GeV}$$

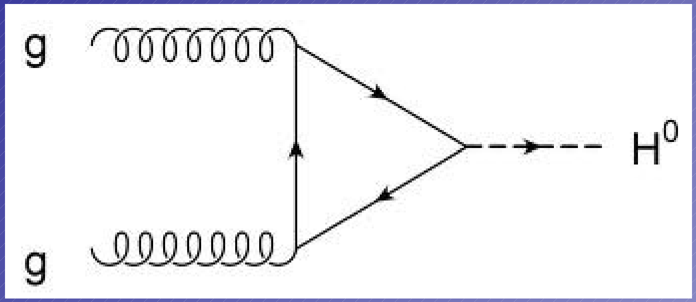


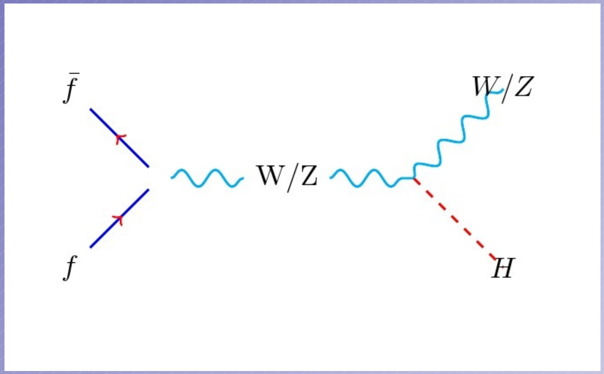
Tevatron Searches

Tevatron performed Higgs searches in proton-antiproton collisions up to $\sqrt{s} = 1.96$ TeV.

Collected ~ $10 fb^{-1}$ of data up to shutdown in November 2011.

Hadron colliders provide a number of process that produce Higgs:





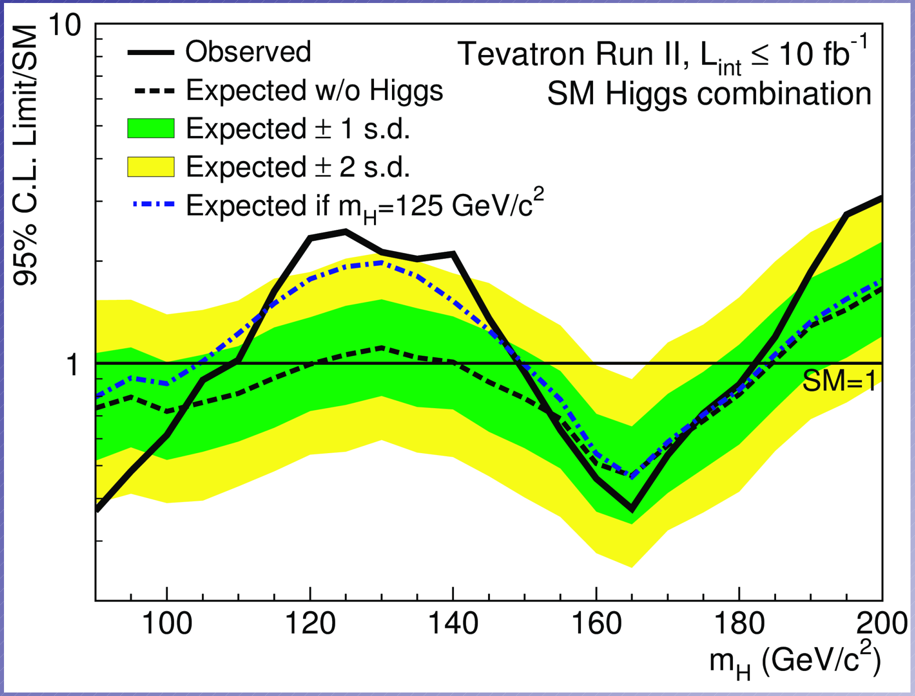
At the Tevatron, the main process involving Higgs were:

* two b-jets, lepton plus missing E_T (MET) from $p\bar{p} \to W^{\pm}H$ or $p\bar{p} \to ZH$

* two b-jets and two leptons from $p\bar{p} \to ZH$
* two taus from $h \to \tau^- \tau^+$
* four isolated leptons from $p\bar{p} \to H \to ZZ \to 4\,leptons$.

Tevatron Searches

D0 and CDF collaborations excluded the 147 – 180 GeV & 100 – 103 GeV mass windows at 95% confidence level and found a 2.5σ excess of events between 115 and 135 GeV:



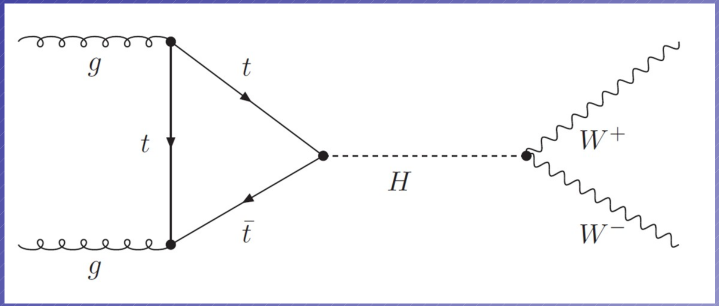
Next we will review searches at LHC and the discovery of a Higgs-like particle ~ 125 GeV on both experiments

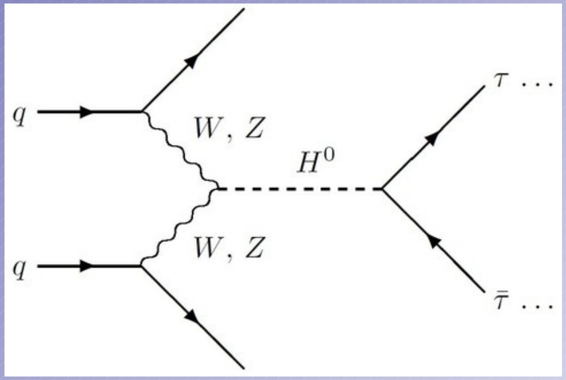
LHC Searches

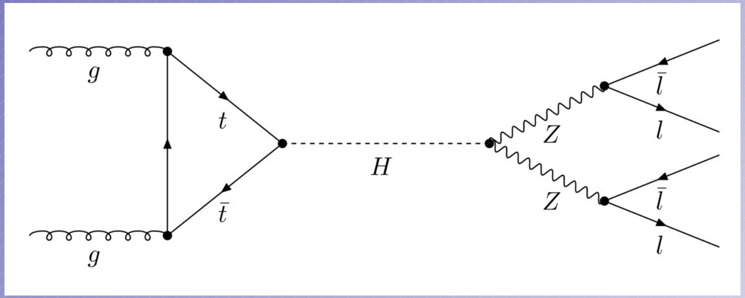
CMS and ATLAS searched for Higgs in proton-proton collisions up to $\sqrt{s} = 8$ TeV, having accumulated 5.3 and 5.8 fb^{-1} each up to August 2012.

At the LHC, the main process involving Higgs are:

* two photons from $h \to \gamma\gamma$
* four leptons from $h \to ZZ$
* jets from weak vector boson fusion together with $h \to \tau^- \tau^+$, $h \to \gamma\gamma$ and $h \to WW$



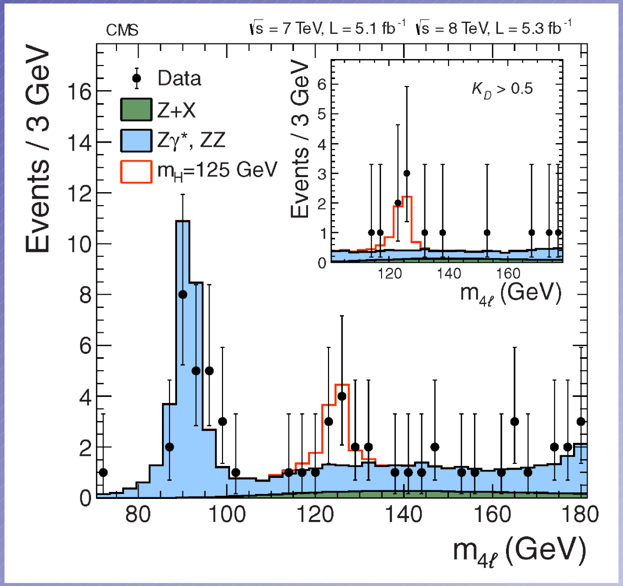




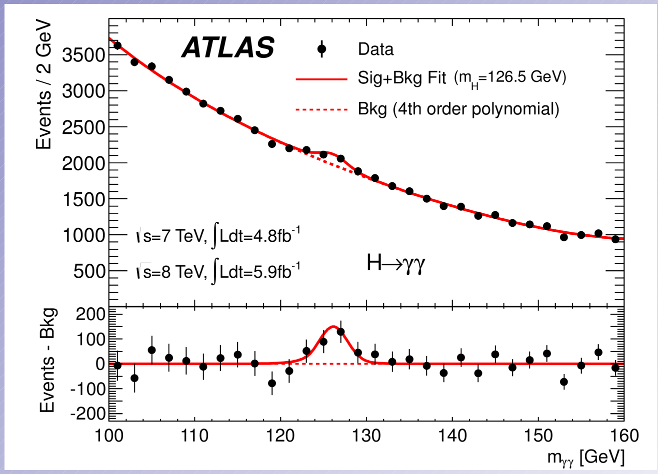
LHC Searches

CMS and ATLAS reported last Summer a discovery of a Higgs-like particle ~ 125 GeV.

CMS analyzed 5.1 and 5.3fb-1 at $\sqrt{s} = 7$ $\sqrt{s} = 8$ TeV respectively. The Higgs boson with mass of 125.4 ± 0.4(stat) ± 0.5(sys) GeV was found with a 5.8σ significance:



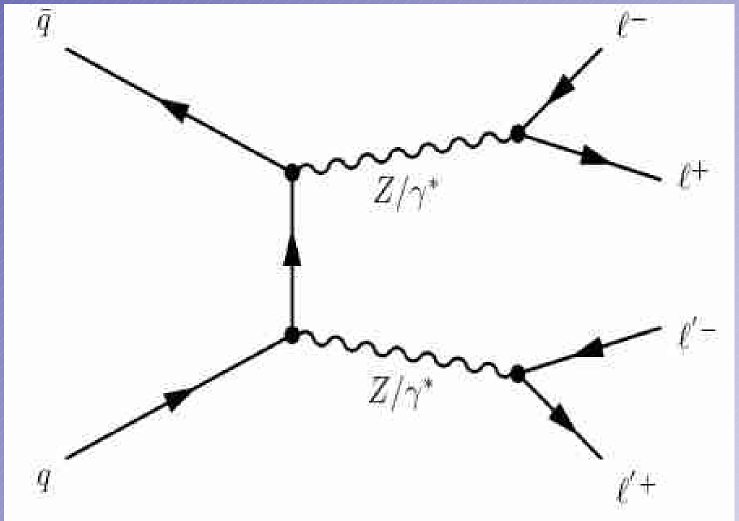
ATLAS analyzed 4.8 and 5.8fb-1 at $\sqrt{s} = 7$ $\sqrt{s} = 8$ TeV respectively. The Higgs boson with mass of 126.0 ± 0.4(stat) ± 0.4(sys) GeV was found with a 5.9σ significance:



D0 ZZ → 4 leptons analysis

$$p\bar{p} \rightarrow Z/\gamma Z/\gamma \rightarrow 4\ leptons$$

* One of the smallest cross sections in SM;
* Very pure signal and little background;
* Opens door for H → ZZ search;
* Results have been accepted for publication on PRD; 🙂



The analysis itself is divided into 3 final states:
ZZ → 4e, ZZ → 2e2μ and ZZ → 4μ.

This 9.8fb^{-1} analysis is an improved extension of previous 6.4fb^{-1} one.

Event selection

Selection criteria used to enhance signal over background
*** 4e final state broken into the number of electrons in the CC: 2, 3, 4 or 1 ICR electron.**
*** 2e2μ final state broken the same way: 0, 1 or 2 CC electrons.**

4e final state:
*** at least 4 "good" electrons;**
*** all electron pT's > 15 GeV;**
*** number of electrons in the CC > 2;**
*** two lepton pairs invariant masses M_{ll} > 30 GeV and $M_{l'l'}$ > 30 GeV.**

2e2μ final state:
*** at least two "good" non-ICD electrons & two "good" muons;**
*** all electron and muons pT's > 15 GeV;**
*** muons must be isolated;**
*** $\cos(\alpha) < 0.96$ between the two muons;**
*** acoplanarity between the two muons > 0.05;**
*** $\Delta z_{DCA} < 3.0$ cm between all muon tracks;**
*** $\Delta R > 0.2$ between all electron-muon pairs;**
*** two lepton pairs invariant masses M_{ll} > 30 GeV and $M_{l'l'}$ > 30 GeV.**

4μ final state:

* at least four "good" muons;
* all muons pT's > 15 GeV;
* muons must be isolated;
* $\Delta z_{DCA} < 3.0$ cm between all muon tracks;
* $\Delta R > 0.2$ between all muon tracks;
* Muon charges must have opposite sign;
* invariant mass of best muon pair > 30 GeV.

Our trigger efficiency for signal is estimated to be close to 100%

Instrumental background

Main background is Z (→ll) + jets and Z (→ll) + γ + jets

Need to determine the probability of a jet be misidentified as a lepton (P_{jl} or fake rate).

We use the tag-probe method: select a di-jet sample in data. The tag jet is the one with $p_T > 15$ GeV and fires a single-jet trigger; the other is the probe one.

Electron fake rate (P_{je}): $\Delta\varphi$(probe,tag) > 3.0 – fills denominator with probe jets

$\Delta\varphi$(e,tag) > 3.0 – fills numerator with electrons

We also apply MET < 20 GeV to suppress W + jets contamination

Muon fake rate ($P_{j\mu}$): $\Delta\varphi$(probe,tag) > 3.0 – fills denominator with probe jets

$\Delta\varphi(\mu$,tag) > 3.0 – fills numerator with muons

Both are $P_{jl} \sim 10^{-3}$

4e final state Z + jets background:

* apply P_{je} to events with 3 electrons with pT > 15 GeV and 1 jet;
* method accounts for Z + γ + jets background;
* overestimates events with 2 electrons and 2 jets misreconstructed as electrons. This contribution was found to be negligible;

4μ final state Z + jets background:

* apply $P_{j\mu}$ to events with 2 isolated muons with pT > 15 GeV and 2 jets;
* method accounts for Z + jets background;

2e2μ final state Z + jets background:

* two different contributions: 2 muons + 1 electron + 1 jet and 2 electrons + 2 jets;
* applying P_{je} to the jet estimates both $Z(\to\mu\mu)$ + jets and $Z(\to\mu\mu) + \gamma$ + jets ;
* applying $P_{j\mu}$ to the jet estimates $Z(\to ee)$ + jets.

Other backgrounds must be noticed

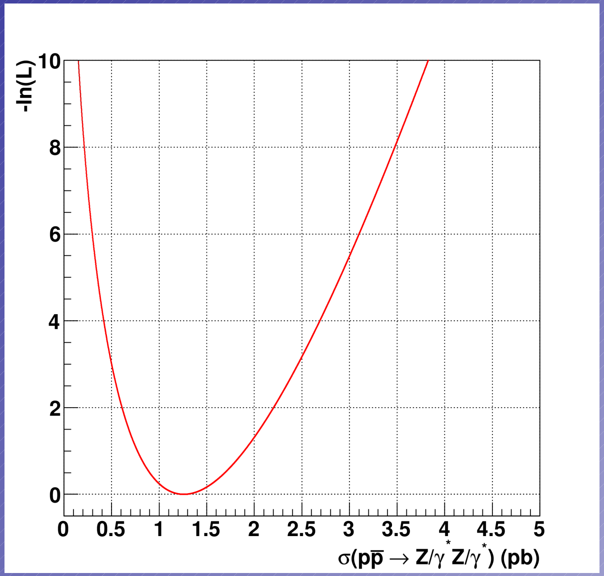
* ttbar: small contribution in 2e2μ final state;
* beam halo and cosmic ray muon: beam halo interactions and cosmic rays muons can produce events with four lepton in the final state;
* migration/misreconstruction: lepton pairs coming from low mass Z/γ^* production. Wrong pairings (leptons wrongly assigned to Zs) can still pass selection cuts and end up as a signal. Affects 4e and 4μ.

After applying these selection criteria we end up with 15.31 signal events, 1.49 background events and 13 candidate events in the data sample.

final state	observed events	expected signal ZZ	QCD background	migration background	tt background	cosmic background
4e	5	4.12	0.61	0.09	0.00	0.00
4mu	3	4.26	0.12	0.03	0.00	< 0.01
2e2mu	5	6.93	0.59	0.01	0.04	< 0.01

Cross section calculation

To find the cross-section,we minimize the negative Log-likelihood:



$$\sigma(pp \to Z/\gamma^* Z/\gamma^*) = 1.26^{+0.44}_{-0.36}(stat.)^{+0.17}_{-0.15}(syst.) \pm 0.08(lumi)\, pb$$

Using MCFM we correct for $\sigma(pp \to Z/\gamma^* Z/\gamma^*)/\sigma(pp \to ZZ)$, combine with $ZZ \to ll\nu\nu$ cross section to obtain:

$$\sigma(pp \to ZZ) = 1.32^{+0.29}_{-0.25}(stat.) \pm 0.12(syst.) \pm 0.04(lumi)\, pb$$

In agreement with SM value of 1.43 pb

Higgs search and limits calculation

In Summer 2012 both D0 and CDF collaborations reported evidence of the Higgs boson.
CMS and ATLAS reported its discovery with a mass of ~ 125 GeV.

Higgs search in the four lepton final state is the last piece of the Higgs program on D0. We perform such search here.

Two production mechanisms studied:
gg → H → ZZ → 4leptons
ZH production via H → ττ, H → WW and H → ZZ with subsequent decays to four leptons in the end.

Both simulated using PYTHIA.

Use the same method as in the pp → ZZ cross section measurement: divide the analysis into 3 final states, 4e, 4μ and 2e2μ and apply the same selection criteria.

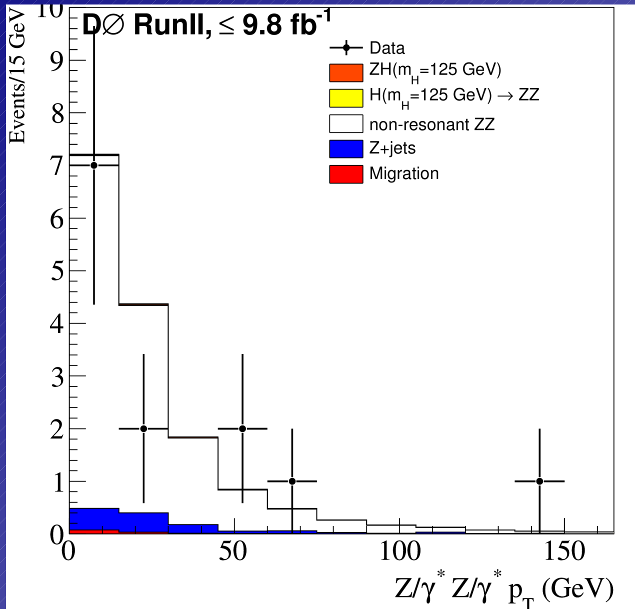
Higgs search yields

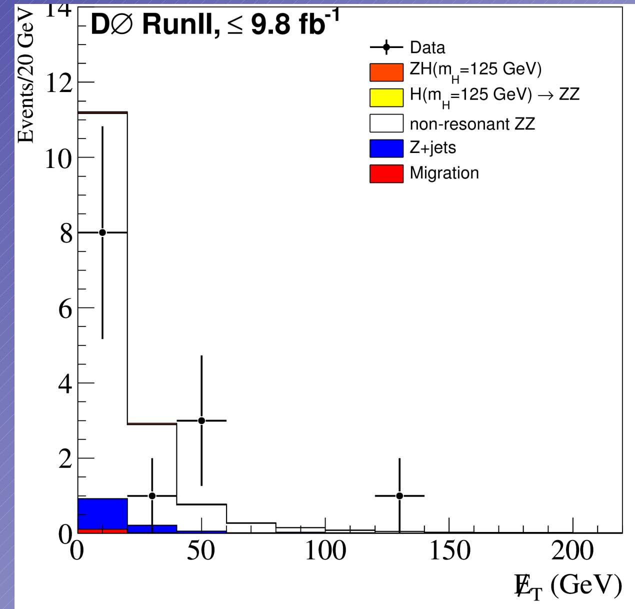
$M_H = 125$ GeV yields in all final state channels:

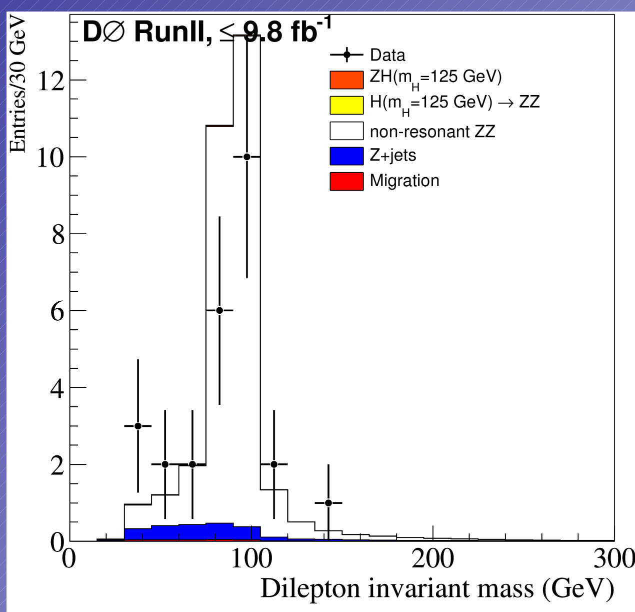
channel	yield
ZH 4e, 4CCnoICR	0.010
ZH 4e, 3CCnoICR	0.006
ZH 4e, 2CCnoICR	0.003
ZH 4e, 1ICR	0.008
ZH 4μ	0.033
ZH 2e2μ, 0CC	0.001
ZH 2e2μ, 1CC	0.015
ZH 2e2μ, 2CC	0.036
ZH, H → WW	0.041
ZH, H → ZZ	0.024
ZH, H → ττ	0.044
ZH, other H decays	0.005
ZH total	0.114
gg → H → ZZ 4e, 4CCnoICR	0.004
gg → H → ZZ 4e, 3CCnoICR	0.001
gg → H → ZZ 4e, 2CCnoICR	< 0.001
gg → H → ZZ 4e, 1ICR	0.002
gg → H → ZZ 4μ	0.007
gg → H → ZZ 2e2μ, 0CC	< 0.001
gg → H → ZZ 2e2μ, 1CC	0.002
gg → H → ZZ 2e2μ, 2CC	0.007
gg → H → ZZ total	0.026
Signal total	0.137

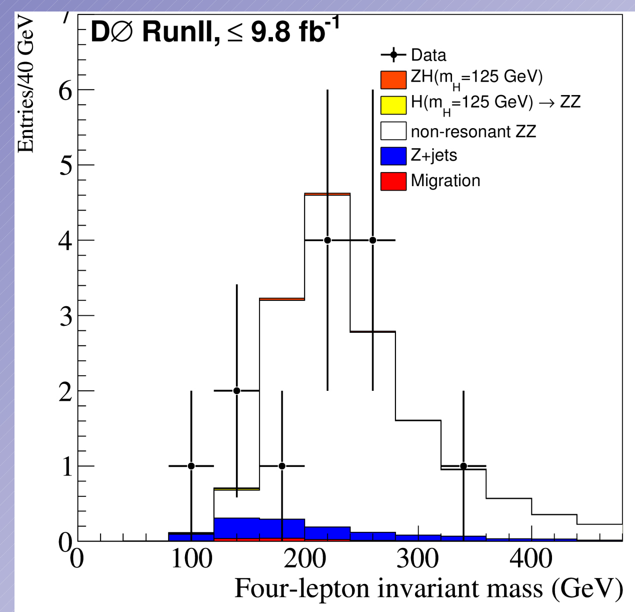
final state	observed events	Signal m_H = 125 GeV	expected non-resonant ZZ	QCD background	migration background	tt background	cosmic background
4e	5	0.035	4.12	0.61	0.09	0.00	0.00
4mu	3	0.040	4.26	0.12	0.03	0.00	< 0.01
2e2mu	5	0.062	6.93	0.59	0.01	0.04	< 0.01

Kinematic distributions

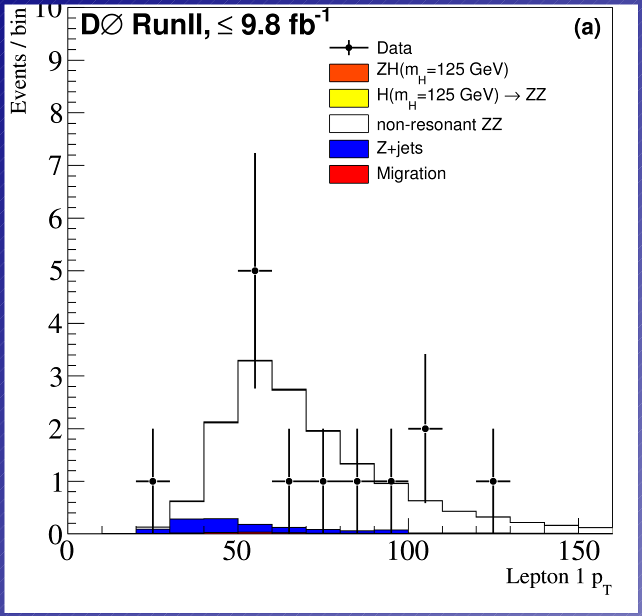


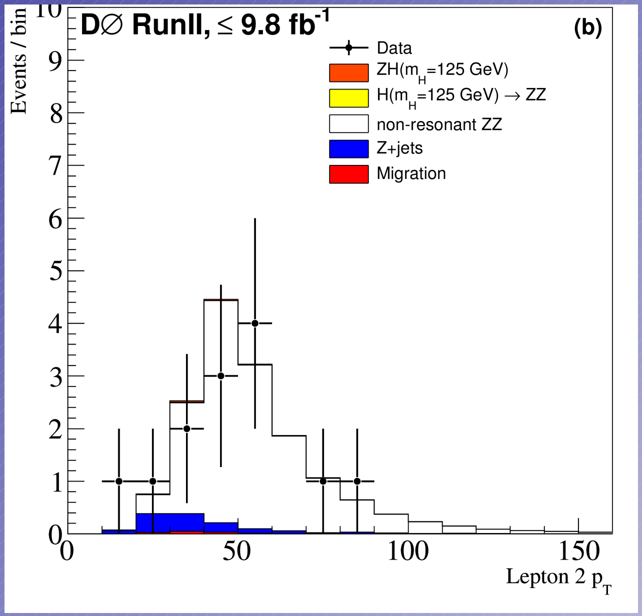


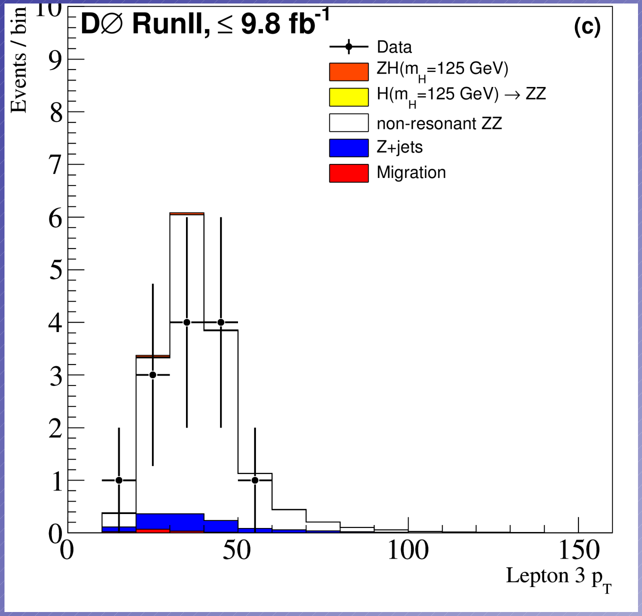


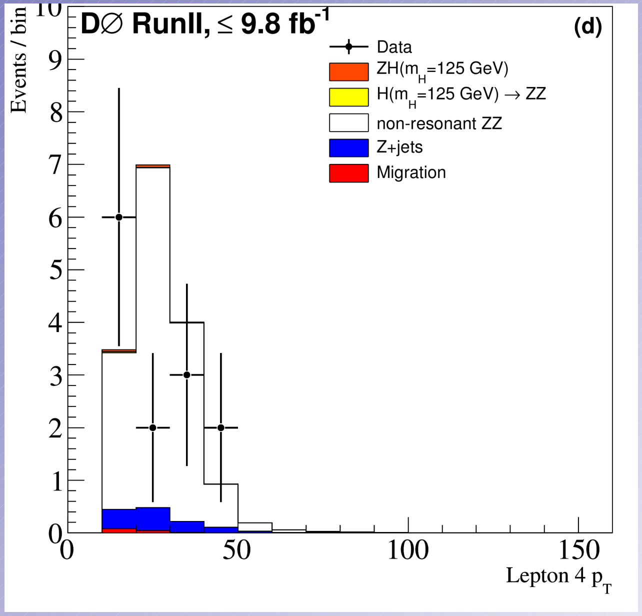


Kinematic distributions









Limits setting

Examine Higgs masses 115 – 200 GeV in increments of 5 GeV.

Use COLLIE to do limits calculation.

COLLIE uses a CLs method: a log-likelihood ratio (LLR) test statistic is formed using Poisson probabilities for number of signal, background and observed events.

Confidence levels are derived by integrating the LLR using both CL_{s+b} and CL_b.

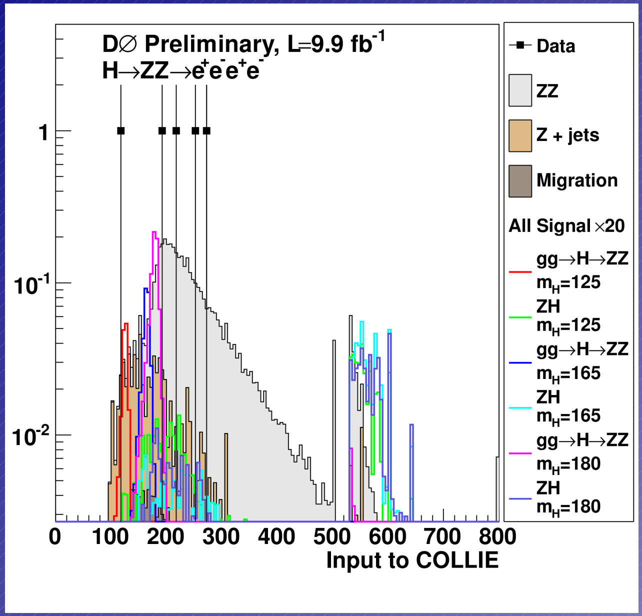
Excluded cross section is obtained when $CL_s = CL_{s+b}/CL_b < 0.05$.

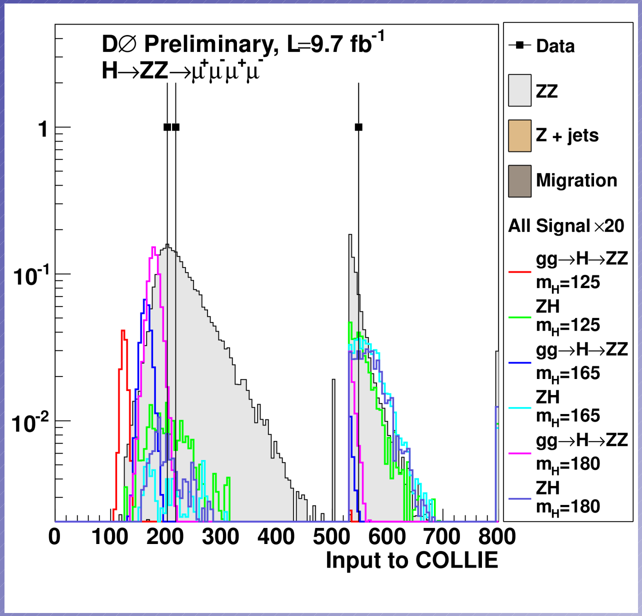
Need a variable to set limits: four-lepton mass the natural choice
For $gg \rightarrow H \rightarrow ZZ$.

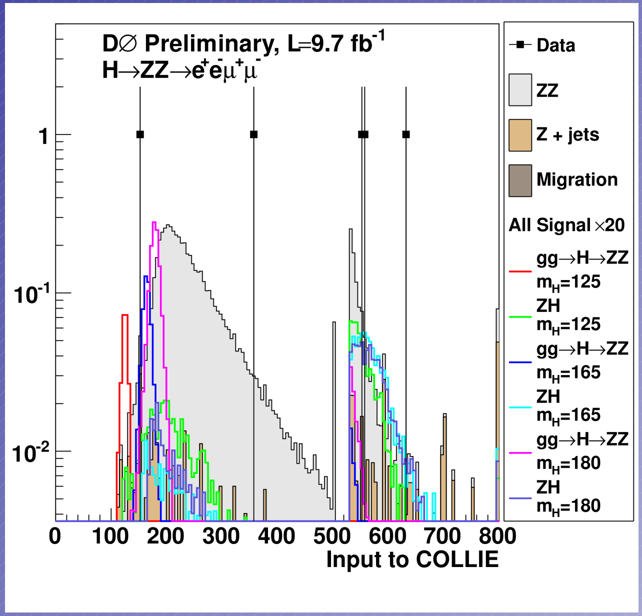
ZH production has no such peak! Large MET instead. No backgrounds have a real source of MET.

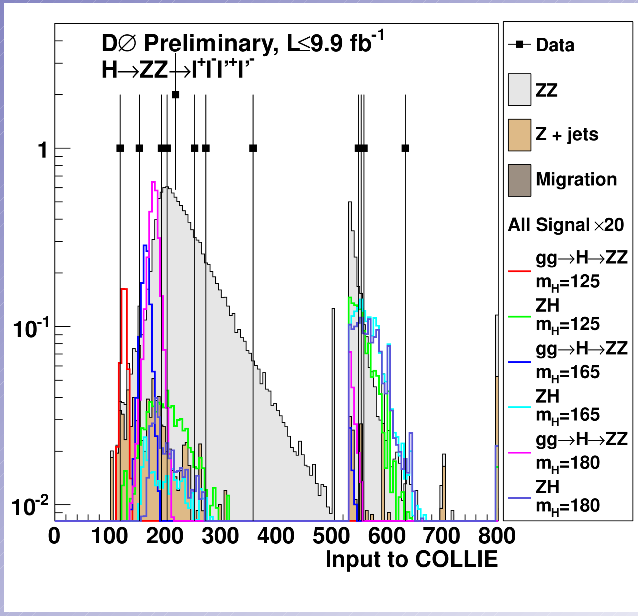
Method: for events with MET < 30 GeV four-lepton mass is used; for events with MET > 30 GeV MET is used.

Collie inputs





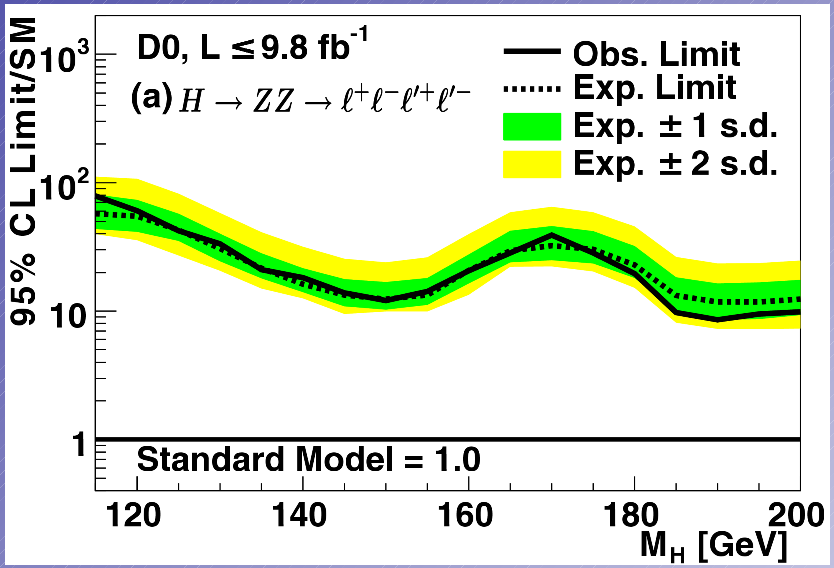


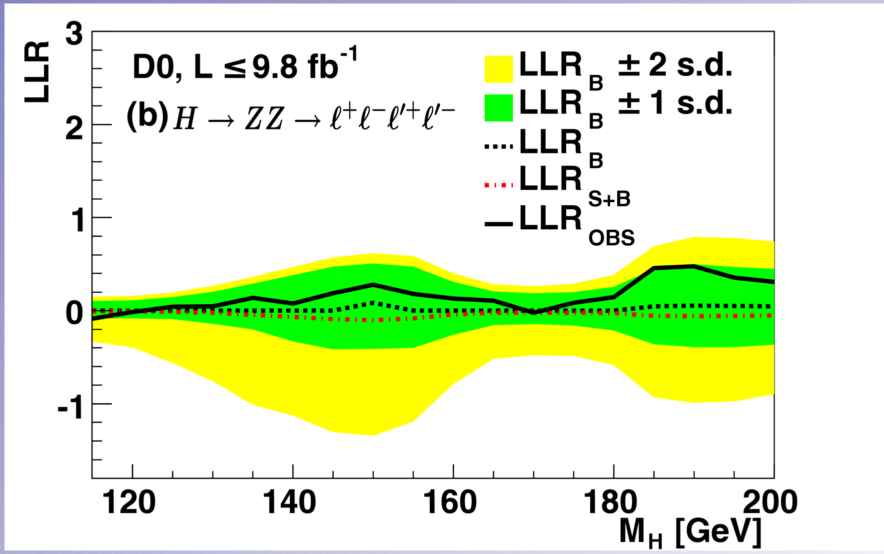


Limits results

COLLIE takes yields and their stat. uncer. plus associated systematics to provide exp. and obs. limits as function of Higgs mass:

mH (GeV)	expected	observed
115	57.3	78.9
120	54.9	60.6
125	42.8	42.3
130	30.6	33.5
135	21.5	21.0
140	16.2	18.2
145	13.4	13.9
150	12.4	12.1
155	13.4	14.2
160	20.8	20.6
165	29.6	28.3
170	32.3	39.0
175	30.4	28.4
180	22.9	19.6
185	13.3	9.7
190	11.8	8.6
195	11.8	9.5
200	12.4	9.9





Conclusion

*** We successfully performed a cross section measurement of $\mathbf{ZZ \rightarrow 4}$ leptons channel, finding as the final result:**

$$1.32^{+0.29}_{-0.25}(stat.) \pm 0.12(syst.) \pm 0.04(lumi)\ pb$$

*** We extended the analysis to search for SM Higgs boson between 1115 and 200 GeV. At a Higgs mass of 125 GeV, we set expect to set a limit of 43 times the SM and set a limit of 42 times the SM at 95% confidence level.**