Search for low mass Higgs at the Tevatron (ZH and $H \to \gamma\gamma$)

Michele Giunta

Introduction

Tevatron, CDF, D0

Higgs Processes

Tools

$ZH \to \nu\nu b\bar{b}$

$ZH \to \ell\ell b\bar{b}$

$H \to \gamma\gamma$

Conclusions

Backup

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Michele Giunta

on behalf of the CDF and D0 Collaborations
Fermilab

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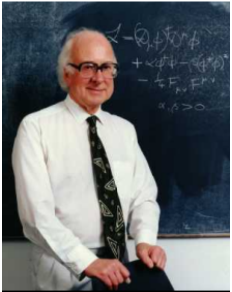
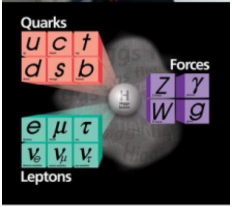
Introduction

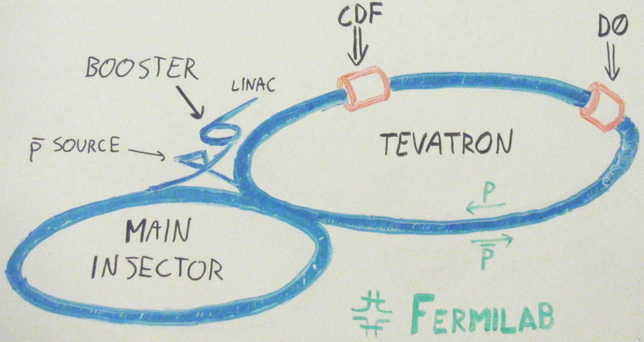
- The **Standard Model** needs the Higgs mechanism to generate the boson and fermion masses
- The SM cannot predict M_H, but can infer it from M_W, M_{top}
  - This allows us to set model dependent constraints based on the measured values of M_W and M_{top}
  - Current global fits constrain $M_H < 163\ GeV/c^2$ at 95% CL
- LEP excluded at 95%CL an Higgs with $M_H < 114\ GeV/c^2$ by direct searches
- Tevatron can observe/exclude the Higgs in $M_H \in [100; 200]\ \mathrm{GeV}/c^2$ which covers the region allowed by the SM fits and LEP



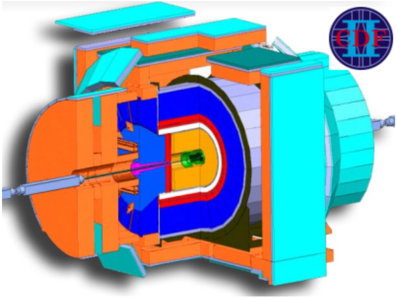


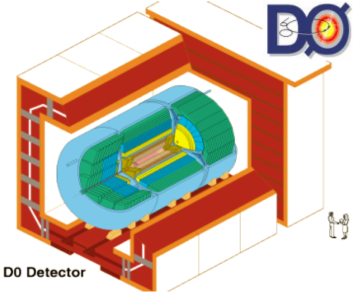
Tevatron

- Fermilab is located near Chicago, USA
- Tevatron: hadronic collider accelerating p and $\bar{p}$ in opposite directions (6 km circle)
- $\sqrt{s} = 1.96\ TeV$ is the highest energy available today for HEP collisions



The CDF and D0 Detectors

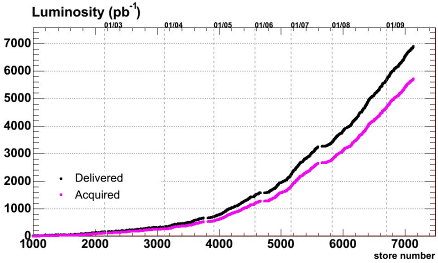




- Interaction vertex silicon detectors (b-jet tagging)
- Trackers in a magnetic field (lepton ID)
- EM and Hadronic calorimeters (jets, $e^{\pm}$, γ)
- Muon detectors systems wrap the detectors

Integrated luminosity ∀ experiment

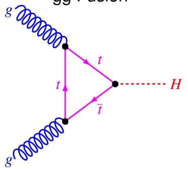
- The Tevatron has delivered so far almost 7 fb^{-1} of data
  - more than 9 fb^{-1} by the end of 2010
  - up to 12 fb^{-1} if running in 2011
- Each experiment has about 6 fb^{-1} of data on tape
- Analyses presented here use 2.1 to 4.2 fb^{-1}



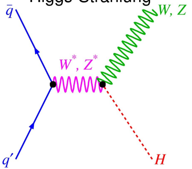
The record store initial luminosity achieved is $3.7 \cdot 10^{32} cm^{-2} s^{-1}$

Production of Higgs and Backgrounds

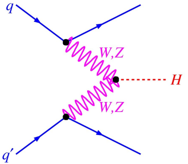
gg Fusion

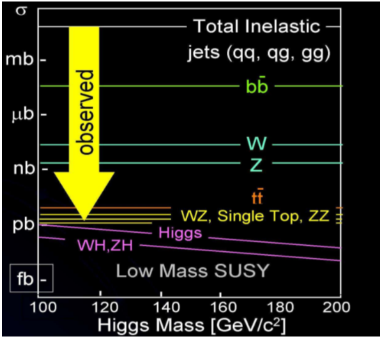


Higgs-Strahlung



WZ Fusion





- The Higgs production cross section at the Tevatron is below 1 *pb*
- Background rates are 6 to 9 orders of magnitude larger
- Tevatron close to the picobarn sensitivity!

Higgs Production and Decay at Tevatron

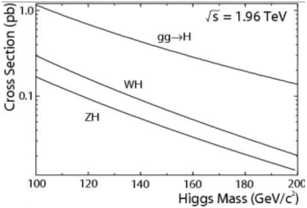
We need a good signature to trigger on

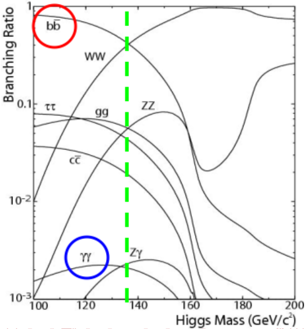
High mass Higgs $(135 < M_H < 200)$

- gg fusion, Higgsstrahlung, VBF $\to H \to WW \to \ell\nu\ell\nu$

Low mass Higgs $(M_H < 135)$

- $gg \to H \to b\bar{b}$ too challenging
- $qq' \to VH \to Vb\bar{b}$ (Higgsstrahlung) [V= W,Z]
  - $(H \to b\bar{b})\ (W \to \ell\nu)$
  - $(H \to b\bar{b})\ (Z \to \ell^+\ell^-)$
  - $(H \to b\bar{b})\ (Z \to \nu\nu)$
- $H \to \gamma\gamma$ (H_f Fermiophobic)

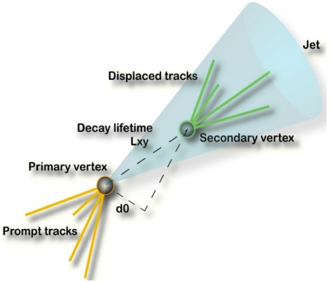


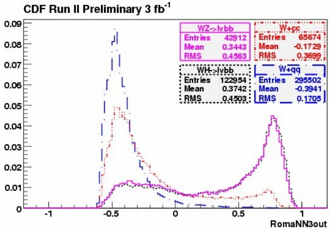


Tools for Analysis

Increase efficiency/acceptance/rejection

- Efficient triggers
- Lepton ID: exploit high and low S/B lepton categories
- Jet b-taggers (low mass $H \rightarrow b\bar{b}$):
  - discrete taggers (CDF) SecVtx and Jet Probability algorithms
  - flavor separators (CDF, D0) jets are separated into b, c, and light using NN discriminants





Use Multivariate analysis techniques

- Neural Networks (NN), Boosted Decision Trees (BDT)
  train to separate signal/background MC

Combine, combine, combine

- Channels, Experiments

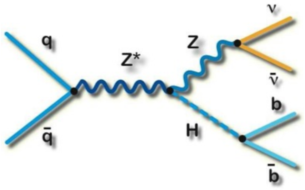
$ZH \to \nu\nu b\bar{b}$ (1/3)

Final state with only two visible objects (high-energy jets), but a large $\not{E}_T$(energy imbalance from neutrinos)

Trigger: on the $\not{E}_T$+ jets (2 or 3)

Signal: $ZH \to \nu\nu b\bar{b}$ and $WH \to (l)\nu b\bar{b}$

Backgrounds: W/Z+jets, top ($t\bar{t}$, single), dibosons, QCD with instrumental $\not{E}_T$(data driven)



CDF $(2.1\ fb^{-1})$

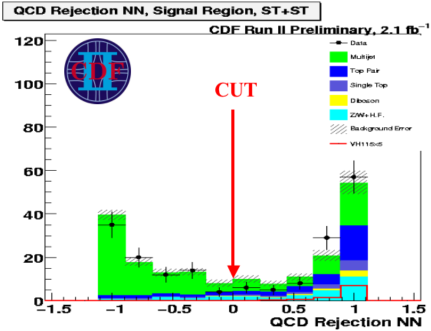
- Preselection: $\not{E}_T$>50 GeV, 2 or 3 high E_t jets, $\Delta R(J_1, J_2) > 1.0$
- 3 exclusive b-tag samples
- QCD-Killer NN used to *cut*
- final NN used to *discriminate*

D0 $(2.1\ fb^{-1})$

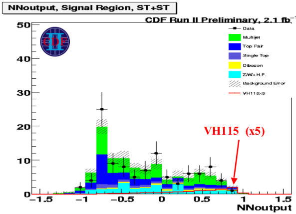
- Preselection: $\not{E}_T$>40 GeV, 2 or 3 jets, $\Delta\phi(j_1, j_2) < 165^o$
- NN b-tagger used w/ asymmetric cuts for best sensitivity
- BDT as final discriminant

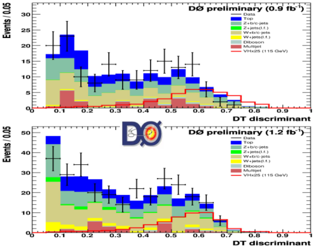
$ZH \to \nu\nu b\bar{b}$ (2/3) CDF QCD-Killer NN

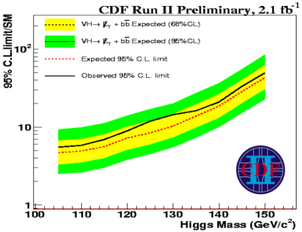
- Use kinematic informations from jets ($\Delta\phi$(jets), $\not{E}_T$, ΔR, etc..)
- Train on MC h.f. QCD and ZH (50%) WH (50%)
- Cut at $NN_{QCDk} > 0$ as part of the selection
- Reject 5% of signals and 65% of QCD



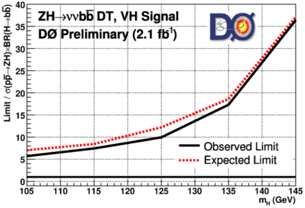
$ZH \rightarrow \nu\nu b\bar{b}$ (3/3)







$N(\sigma_{SM}^{115\ GeV}) < 6.9_{obs}\ (5.6_{exp})$ @95% CL



$N(\sigma_{SM}^{115\ GeV}) < 7.5_{obs}\ (8.4_{exp})$ @95% CL

$ZH \to \ell\ell b\bar{b}$ (1/3)

BR($Z \to \ell\ell$) = 2x3.4% ($\ell = e, \mu$), but:
clean channel, well measured and fully reconstructed final states, only instrumental $\not{E}_T$

Trigger: high-p_T e or μ

Signal: ($Z \to e^+e^-$) ($Z \to \mu^+\mu^-$) $H \to b\bar{b}$

Backgrounds: Z+jets (b,c, light); $t\bar{t}$; dibosons; fake leptons

$M_{\ell^+\ell^-}$ must be compatible with M_Z

Tight and loose lepton definitions to increase sensitivity

CDF (2.7 fb^{-1})

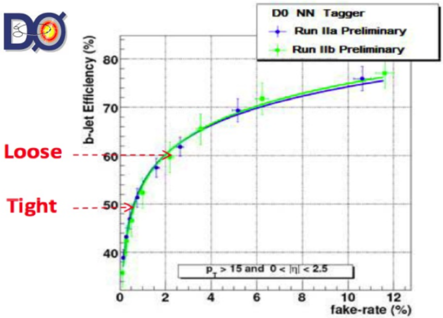
- Identify Z candidates
- set 6 categories: 3 exclusive b-tag categories x2 S/B
- Train (6) 2D-NN to simultaneously separate the signal from $t\bar{t}$ and Z+jet

D0 (4.2 fb^{-1})

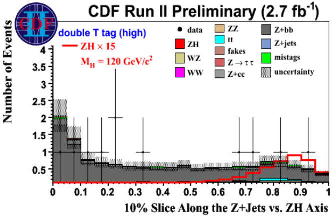
- 4 lepton samples: e, μ each with tight and loose definitions
- NN b-tagging: two categories
- (8) BDTs: 4 lepton x 2 b-tag categories

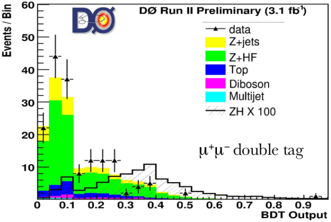
$ZH \to \ell\ell b\bar{b}$ (2/3) D0 b-tag NN

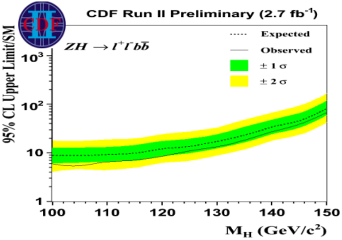
- Continuous variable returning a value depending on jet secondary vertex and track kinematics
- Allows to tune the workpoint(s) for the specific analysis
  - **Single tag:** one tight, one non-tagged
  - **Double tag:** two loose at least
- Can potentially use the whole spectrum as a discriminant



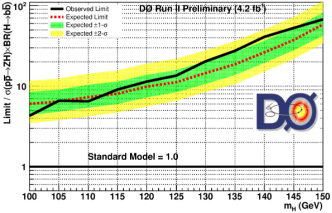
$ZH \to \ell\ell b\bar{b}$ (3/3)







$N(\sigma_{SM}^{115\ GeV}) < 7.1_{obs}\ (9.9_{exp})$ @95% CL



$N(\sigma_{SM}^{115\ GeV}) < 9.1_{obs}\ (8.0_{exp})$ @95% CL

$H \to \gamma\gamma$ (1/2)

Production: Higgsstrahlung, VBF. No gg fusion (top loop) if Fermiophobic (FP)
BR($H \to \gamma\gamma$) = 0.2 % @ 120 GeV (SM)
BR($H_f \to \gamma\gamma$) = 2.8 % @ 120 GeV (FP models)

Trigger: diphoton

Backgrounds: DY($qq \to ee$); γ+jet; dijet

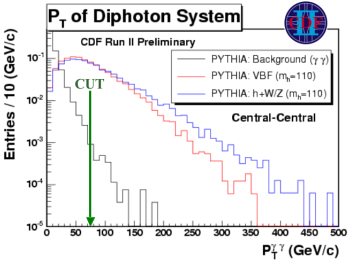
CDF ($3.0\ fb^{-1}$)

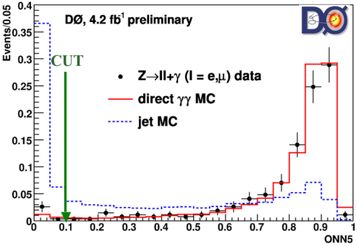
- select with $p_t(\gamma\gamma) > 75$ GeV
- BG model from data fit excluding the probed M_H
- Signal model from MC gives a narrow peak
- Final discriminant: $M_{\gamma\gamma}$

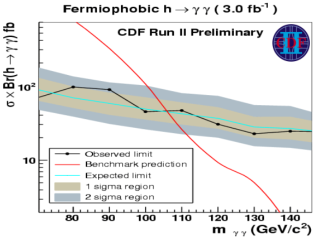
D0 ($4.2\ fb^{-1}$)

- Select with $p_t(\gamma\gamma) > 35$ GeV, veto if tracks match EM clusters
- Cut on a NN separates γ from jets
- Final discriminant: $M_{\gamma\gamma}$
- (SM limit: 15.8 x σ_{SM})

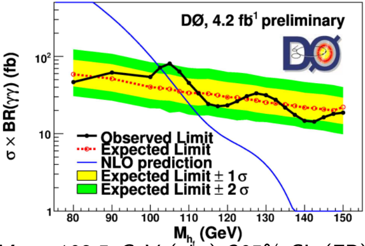
$H \to \gamma\gamma$ (2/2)





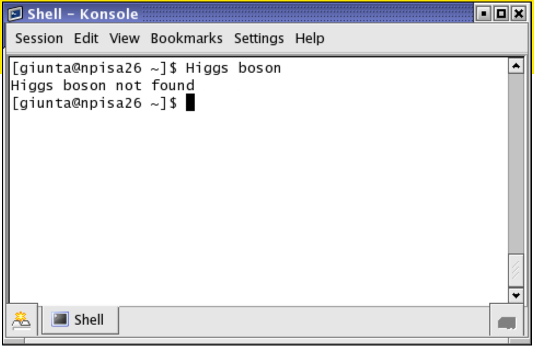


$M_H > 106\ GeV$ (obs) @95% CL



$M_H > 102.5\ GeV$ (obs) @95% CL (FP)

Conclusions



- Tevatron did NOT find the Higgs (yet?), but is starting to be sensitive in the SM Higgs cross section region even at low masses (2 or 3 times σ_{SM})
- Tevatron sensitivity improves faster than $\sqrt{\int L}$ due to new and finer techniques
- **This search gets exiting right now!** And remember: finding no Higgs could be even more intriguing than finding one!

Backup Slides

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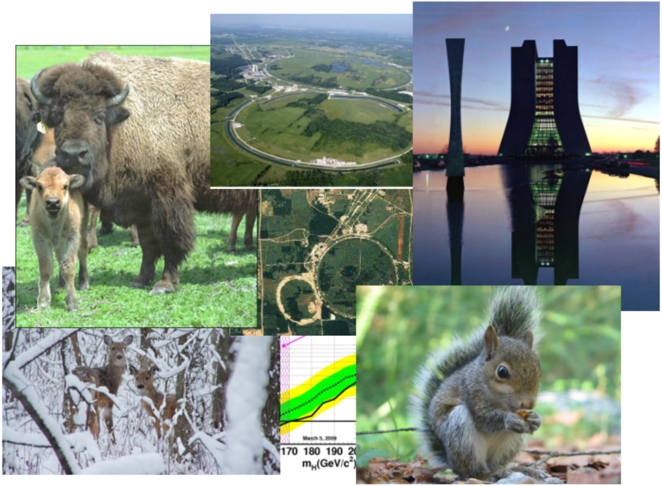
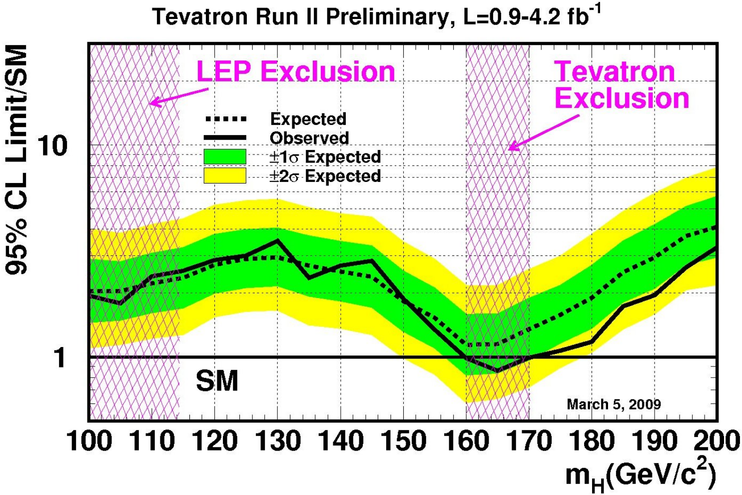


Cross Sections and BRs (HDECAY)

m_H (GeV/c^2)	$\sigma_{gg\to H}$ (fb)	σ_{WH} (fb)	σ_{ZH} (fb)	σ_{VBF} (fb)	$B(H \to b\bar{b})$ (%)	$B(H \to \tau^+\tau^-)$ (%)	$B(H \to W^+W^-)$ (%)
100	1861	286.1	166.7	99.5	81.21	7.924	1.009
105	1618	244.6	144.0	93.3	79.57	7.838	2.216
110	1413	209.2	124.3	87.1	77.02	7.656	4.411
115	1240	178.8	107.4	79.07	73.22	7.340	7.974
120	1093	152.9	92.7	71.65	67.89	6.861	13.20
125	967	132.4	81.1	67.37	60.97	6.210	20.18
130	858	114.7	70.9	62.5	52.71	5.408	28.69
135	764	99.3	62.0	57.65	43.62	4.507	38.28
140	682	86.0	54.2	52.59	34.36	3.574	48.33
145	611	75.3	48.0	49.15	25.56	2.676	58.33
150	548	66.0	42.5	45.67	17.57	1.851	68.17
155	492	57.8	37.6	42.19	10.49	1.112	78.23
160	439	50.7	33.3	38.59	4.00	0.426	90.11
165	389	44.4	29.5	36.09	1.265	0.136	96.10
170	349	38.9	26.1	33.58	0.846	0.091	96.53
175	314	34.6	23.3	31.11	0.663	0.072	95.94
180	283	30.7	20.8	28.57	0.541	0.059	93.45
185	255	27.3	18.6	26.81	0.420	0.046	83.79
190	231	24.3	16.6	24.88	0.342	0.038	77.61
195	210	21.7	15.0	23	0.295	0.033	74.95
200	192	19.3	13.5	21.19	0.260	0.029	73.47

Tevatron Combined SM Higgs Limits



Detectors pics