# Standard Model Higgs boson searches in challenging channels using the full CDF dataset

Elisabetta Pianori
*on behalf of CDF collaboration*

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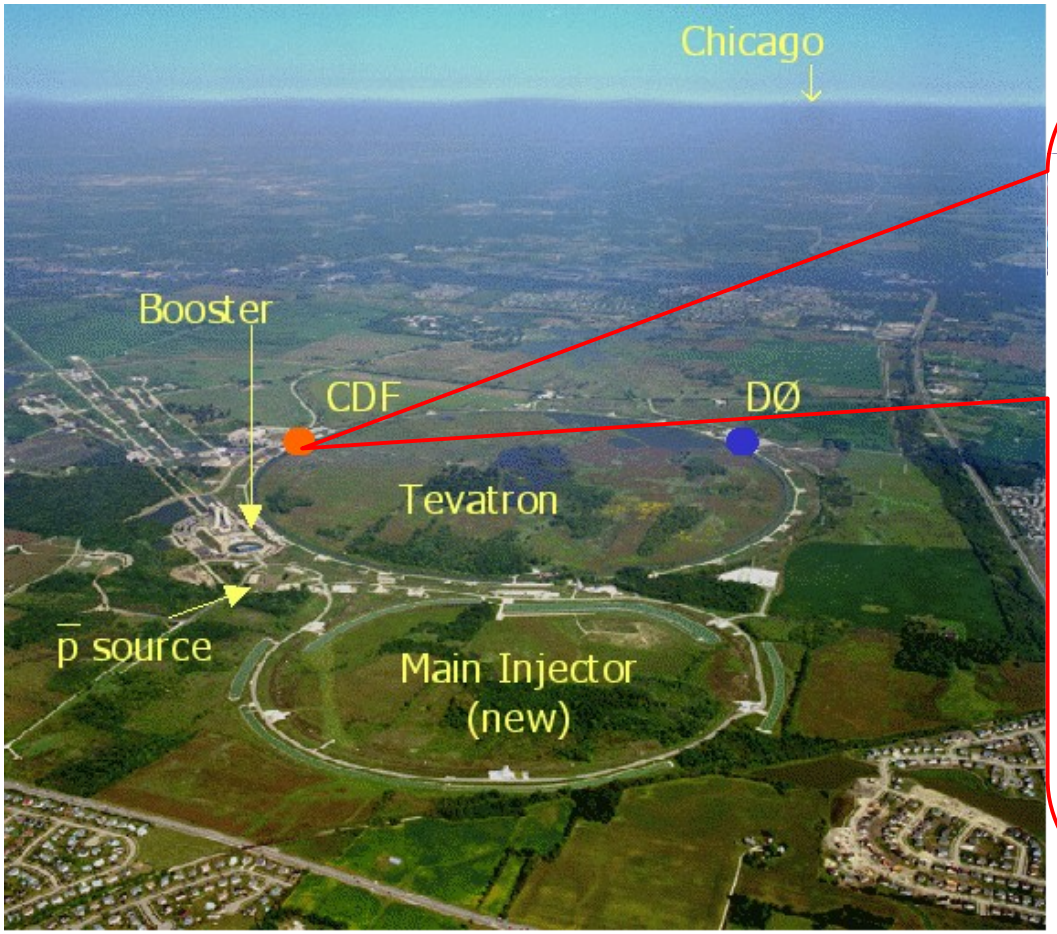
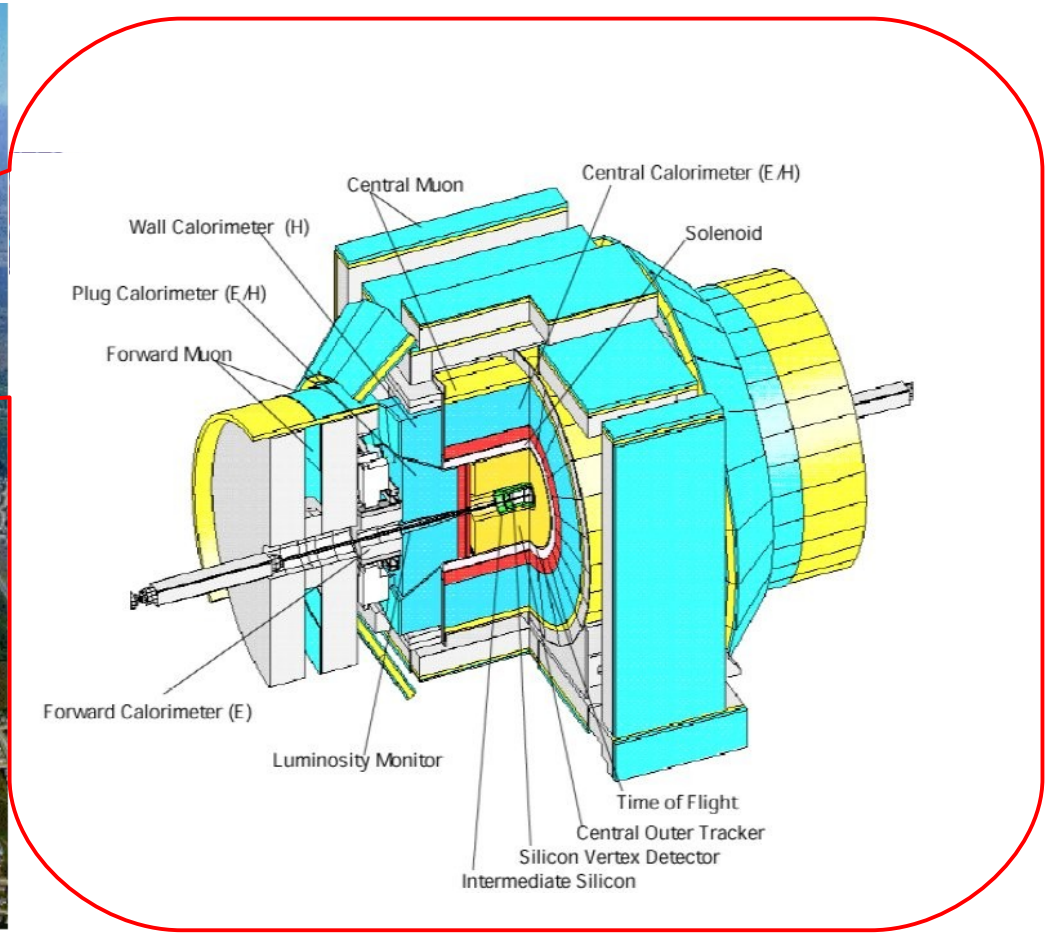
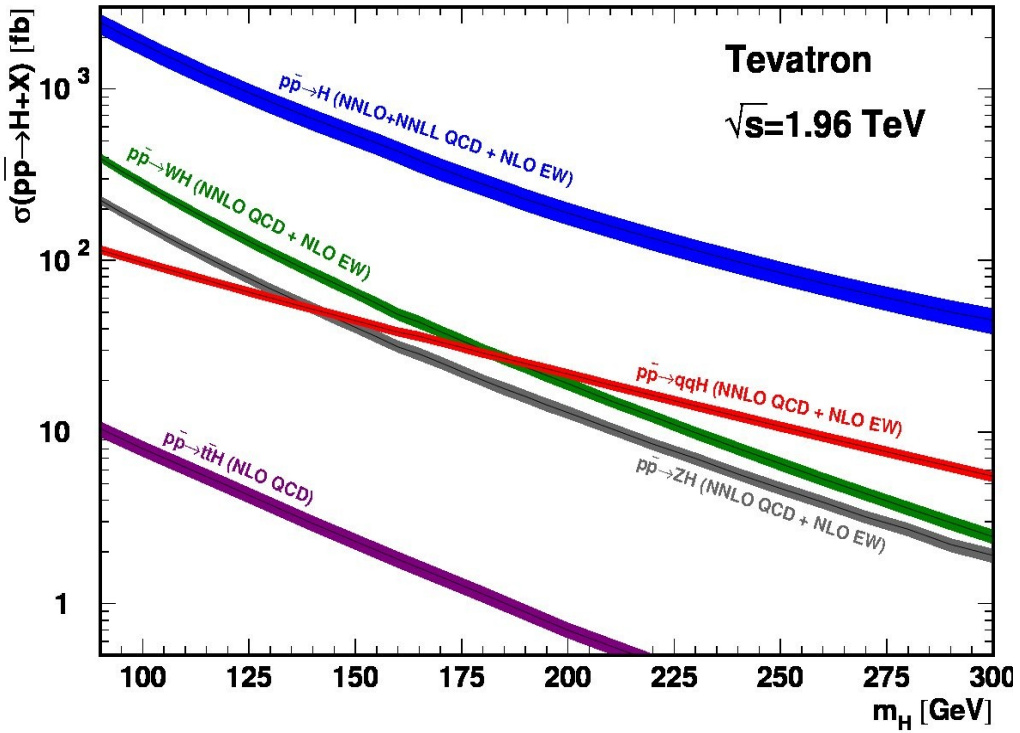
# Tevatron and CDF

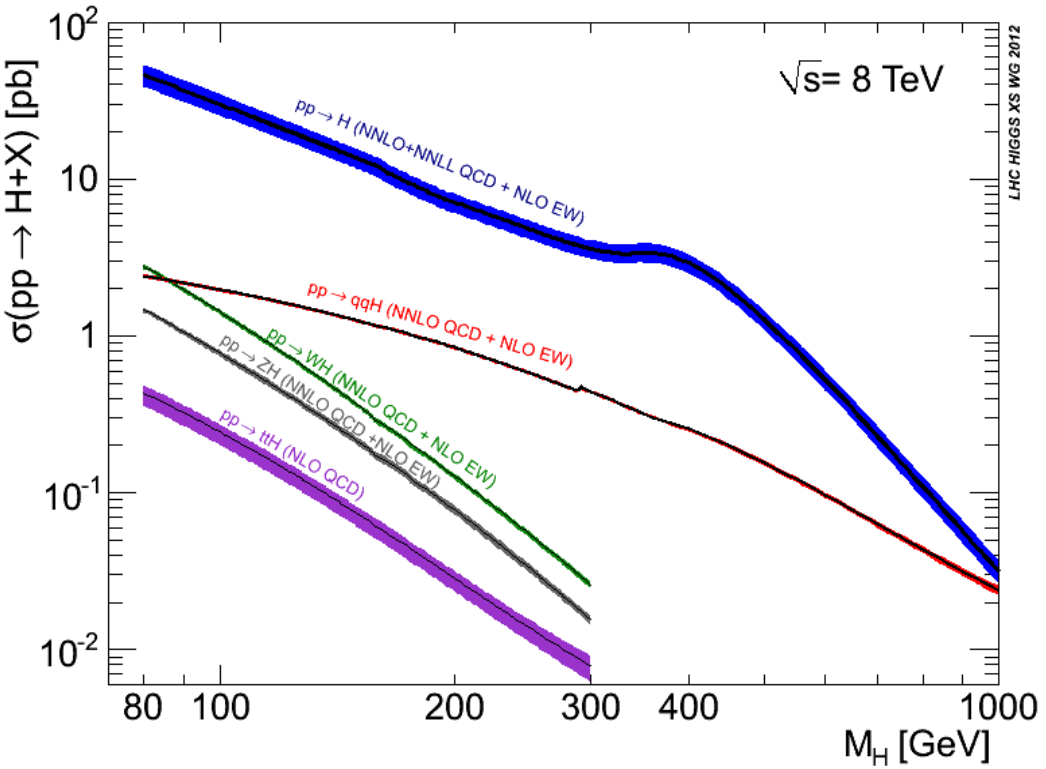
- $p\bar{p}$ collider, $\sqrt{s}$ = 1.96 TeV, $L_{peak}$ = 4.3 $10^{32}$ $cm^{-2}$ $s^{-1}$
- ~12 $fb^{-1}$ delivered before shut down, Sept 2011, ~ 10 $fb^{-1}$ collected
- Analyses presented today: 8.3 $fb^{-1}$ < $\int L$ < 10 $fb^{-1}$



# Higgs Production at the Tevatron




$p\bar{p}$ versus pp $\rightarrow$ different relative contribution of production mechanisms

| | Tevatron | 8 TeV LHC |
|---|---|---|
| $\sigma_{ggH}$ - gluon fusion | 0.95 pb | 19.52 pb |
| $\sigma_{VH}$ - associated production | 0.21 pb | 1.09 pb |
| $\sigma_{VBF}$ -vector boson fusion | 0.07 pb | 1.56 pb |

$m_H = 125\ \mathrm{GeV}/c^2$

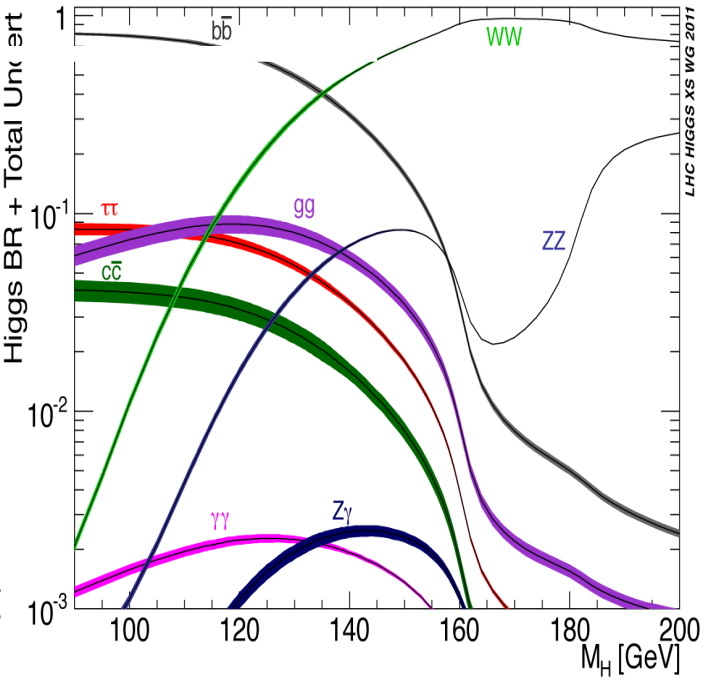
# Higgs search strategy at the Tevatron

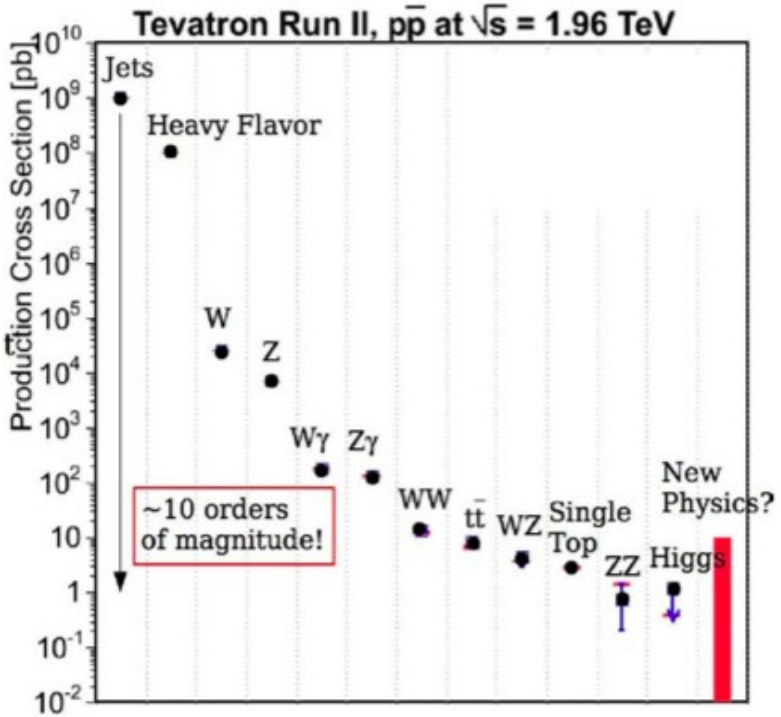
$\sigma$ (ggH) $\cdot$ B.R. (H $\rightarrow b\bar{b}$ ) ~ 0.5 pb
- overwhelmed by QCD

$\sigma$(VH) $\cdot$ B.R. (H $\rightarrow b\bar{b}$ ) ~ 0.1 pb
- leptons from W/Z decays help to reduce background

→ **Associated production: main low mass channel**

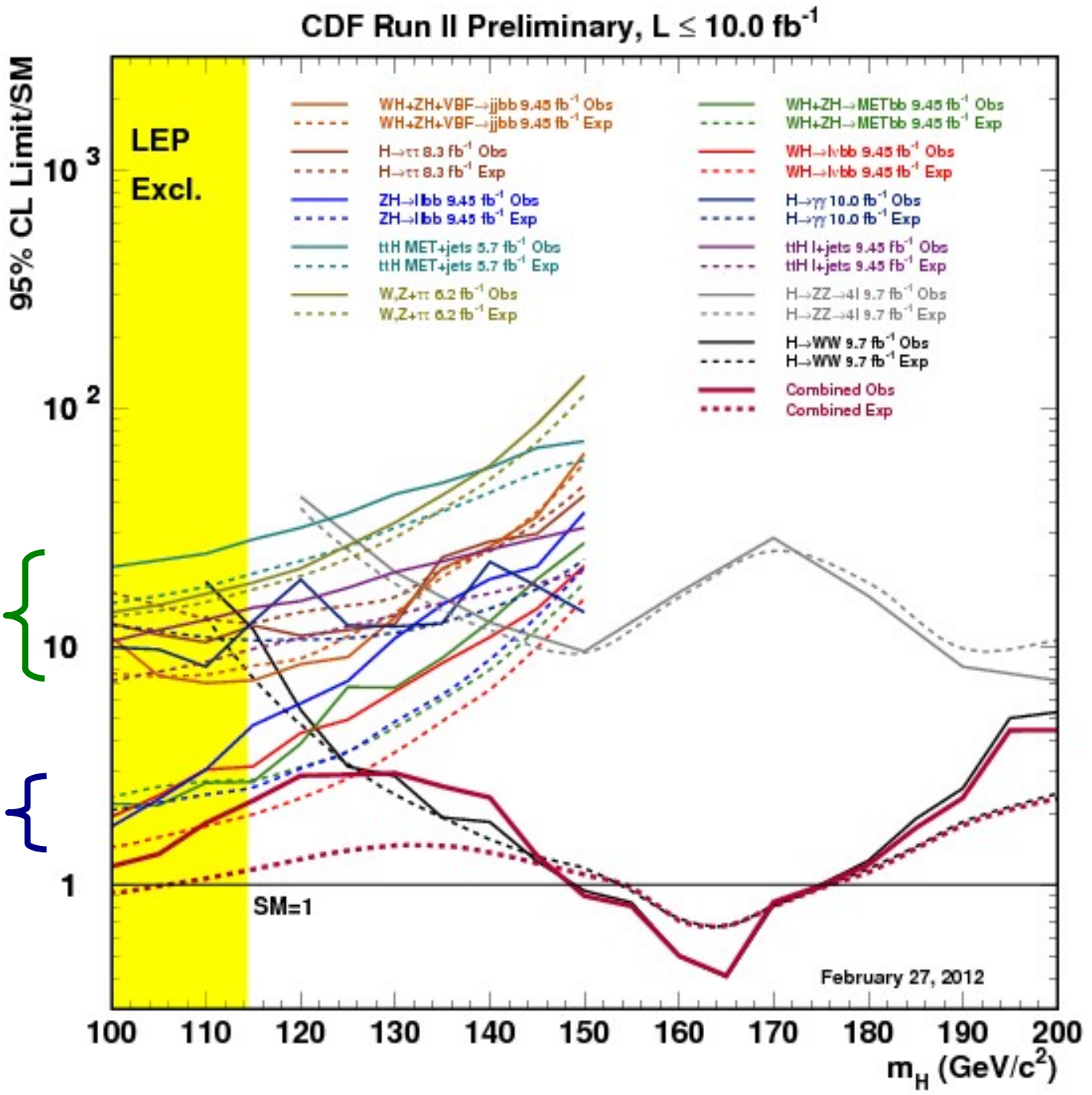
**Signal from background separation is challenging**
inelastic cross section ~ 70 mb




**Strategy:**
- Search in many optimized channels
- Combine channels to achieve best sensitivity

# Higgs search strategy at the Tevatron




More Challenging Channels:

- Expected limit > 10 $\sigma_{S.M}$
- Combined limit > ~5 $\sigma_{S.M}$

Primary Channels:

- $H \rightarrow b\bar{b}$
- Associated VH production
- Expected limit ~ 1.5 -2 $\sigma_{S.M}$

# Search for H → γγ

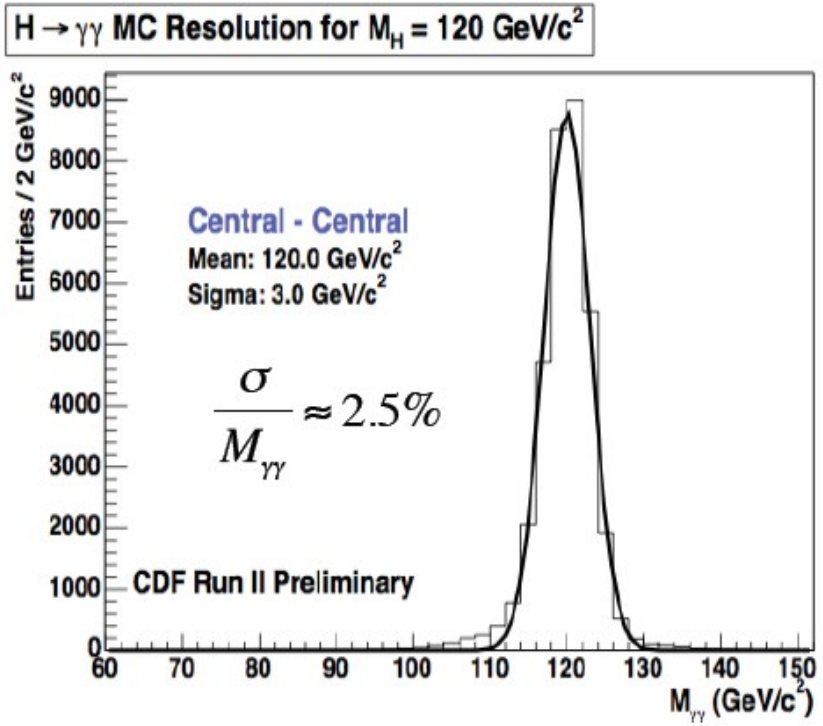
- Search for a narrow resonance on a continuous background

**Advantages:**

- mass resolution: ~ 3 GeV
- include ggH, VH and VBF
- Sensitivity ~ constant over a wide mass range

**Challenge:**

- max B.R. ($H \rightarrow \gamma\gamma$) = 0.2% at $m_H$=120 GeV/c²
  → maximize acceptance




**Photon ID:**

Central Photon (C): $|\eta| < 1.05$, use NN trained to reduce $\pi/\eta$ faking $\gamma$

Forward Photon (P): $1.2 < |\eta| < 2.8$, cut based ID

Central Conversion (C'): use electrons from $\gamma$ conversion

**Data split in 4 channels:** CC, CP, CC', C'P

# H → γγ Signal and Background modeling

**Signal**: PYTHIA MC

**Background:**

Prompt photons production +fakes photons

**Background Modelling:**

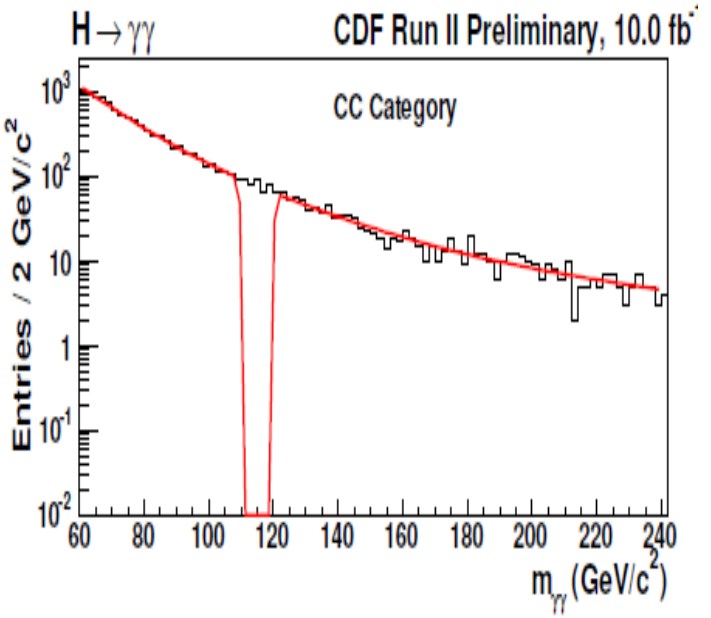
- Fit to sidebands of signal region

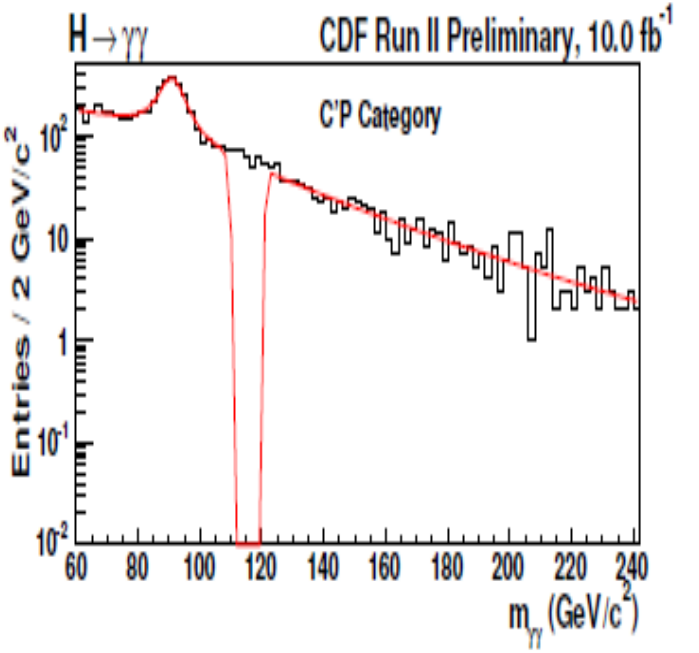
  Signal region: 12 GeV window centered at $m_H$ to be tested

  Fit function: sum of two exponentials multiplied
  by fraction-degree polynomial
  add Breit-Wigner function to model Z (only P)

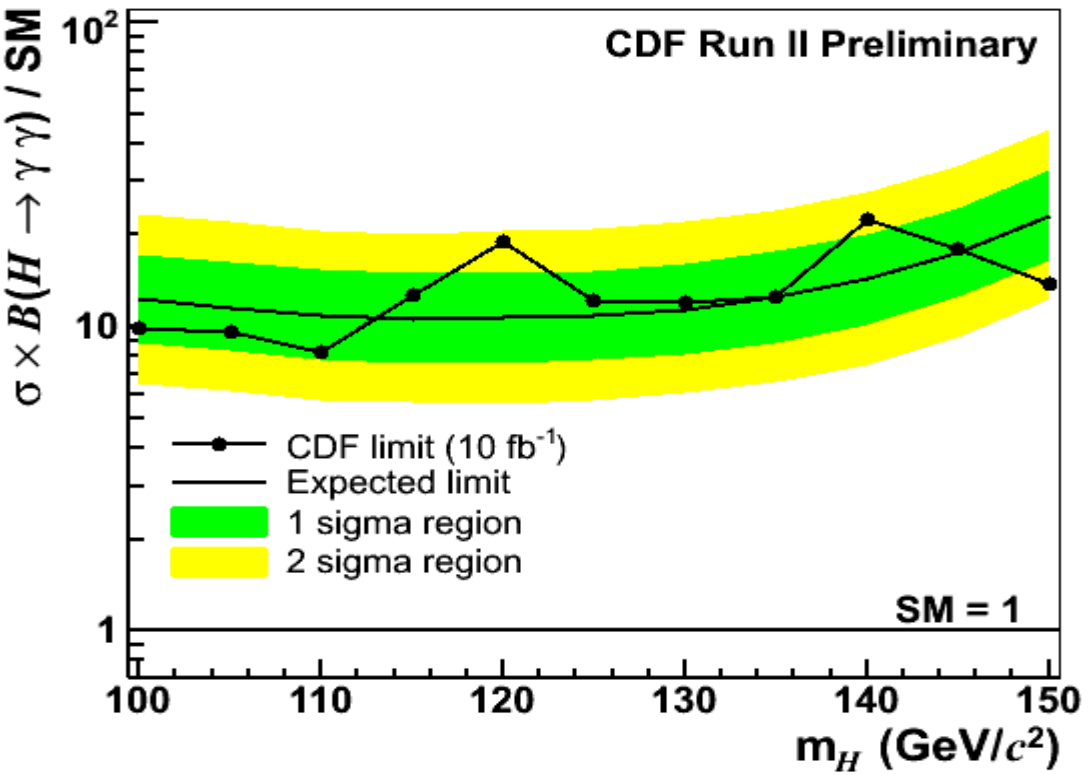
- Extrapolate fit into signal region → background yield

  fluctuate parameters of the fit to estimate
  background rate uncertainty in signal region:
  2.8%(CC) - 6.1% (CP)



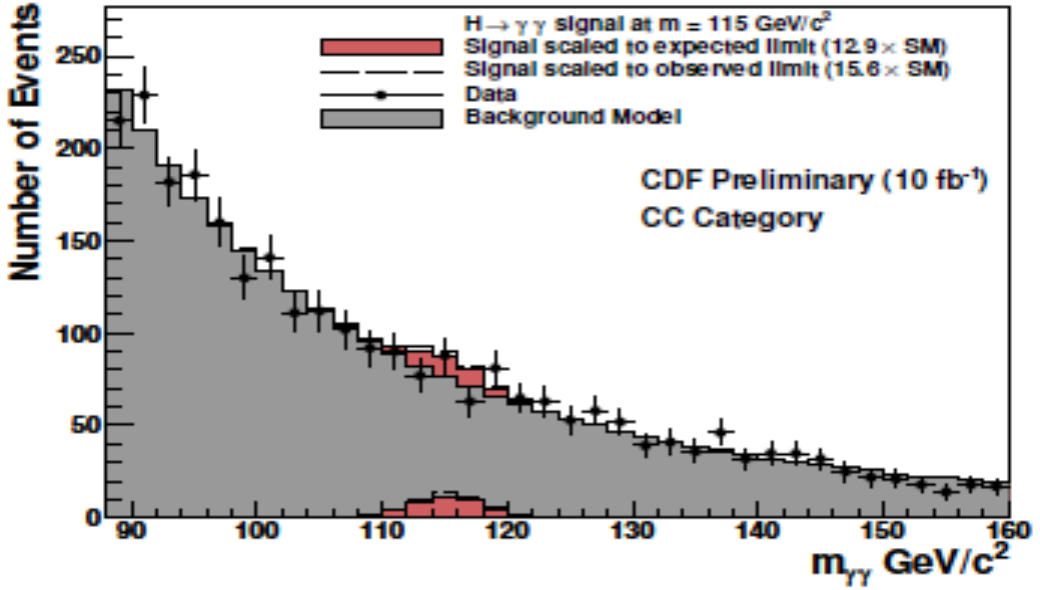



# Result for H → γγ search




Limit at @ $m_H$ =125 GeV/c²

Obs (Exp) = 12.2(10.8) $\sigma_{S.M.}$



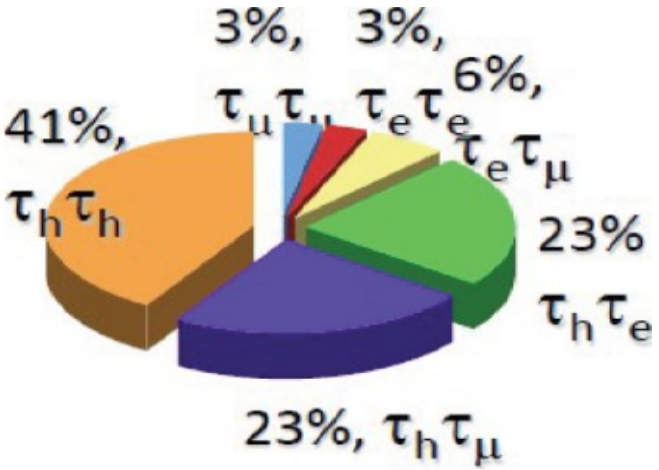

Signal @ $m_H$ =115 GeV/c²

Scaled by expected limit: 10.6 $\sigma_{S.M}$

# Search for H → ττ+jets

- At low masses BR(H → ττ) ~ 10%

- Many decay modes, only two explored:
  - **e\μ + $\tau_{had}$** (BR: 46%)
  - **e + μ** (BR: 3%)




**Event Selection:**

| e\μ + $\tau_{had}$ | e + μ |
|---|---|
| e\μ $p_T \geq 10$ GeV/$c$<br>$\tau_{had} p_T \geq 15(20)$ GeV/$c$ | e $p_T \geq 10$ GeV/$c$<br>μ $p_T \geq 10$ GeV/$c$ |
| Opposite Charge | |
| ≥ 1 jet | |

Classify events by numbers of jet:

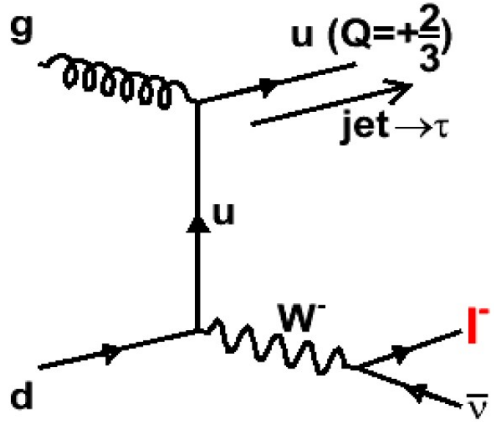
| | e or μ + $\tau_{had}$ | | e + μ | |
|---|---|---|---|---|
| | 1 jet | 2 jets | 1 jet | 2jets |
| $\sigma_{ggH}$ | 72.6 % | 33.5% | 58.4% | 32.2% |
| $\sigma_{VH}$ | 21.7% | 48.8% | 36.9 % | 52.2% |
| $\sigma_{VBF}$ | 5.7% | 17.7 % | 4.7 % | 15.6% |

# Background Estimation

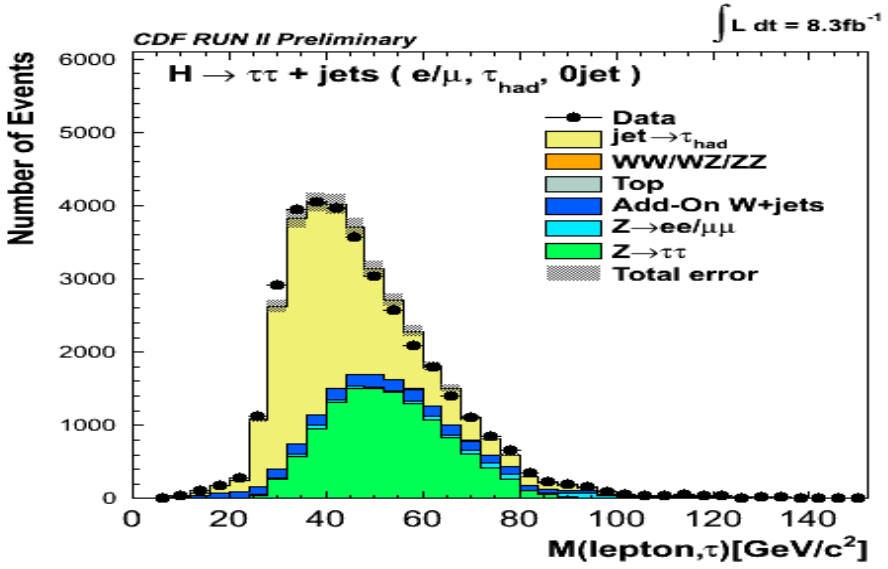
- Main background $Z/\gamma^* \rightarrow \tau\tau$: ALPGEN MC
  $Z/\gamma^* \rightarrow ee/\mu\mu$, top, di-boson : MC

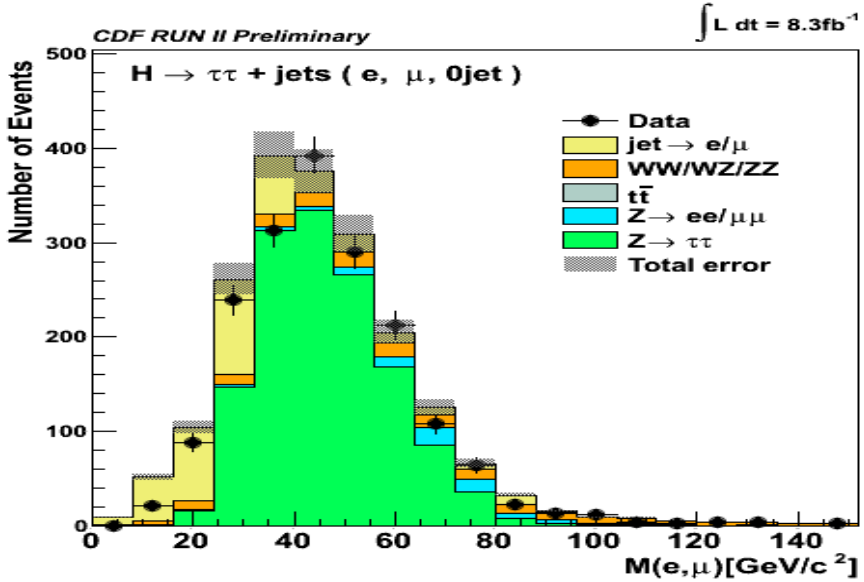
- MultiJet background: Same Sign data events

- W+jets:
  included in SS sample
  because of charge correlation, $N_{OS} > N_{SS}$
  → correct for excess of W+jets OS events



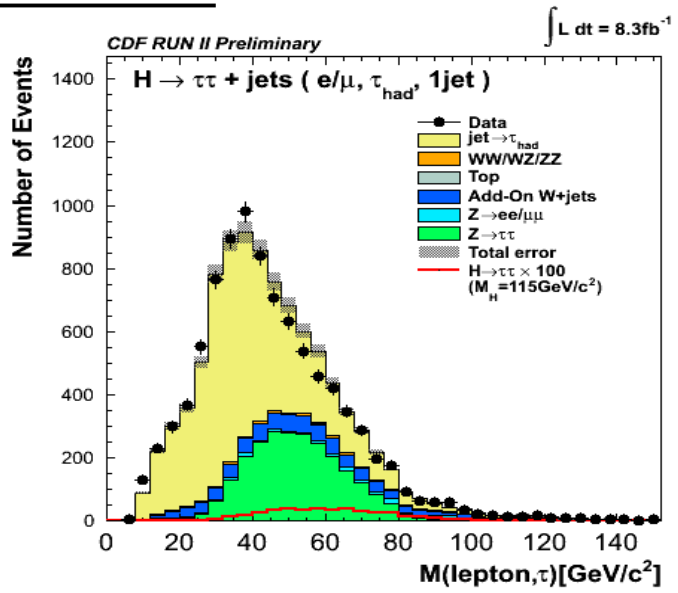

Test background modeling in 0 jet bin



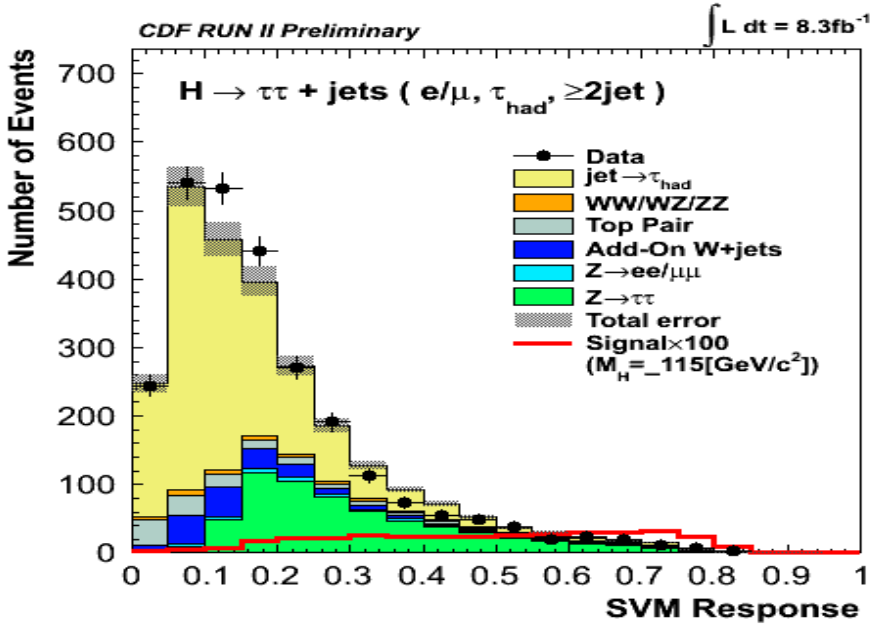



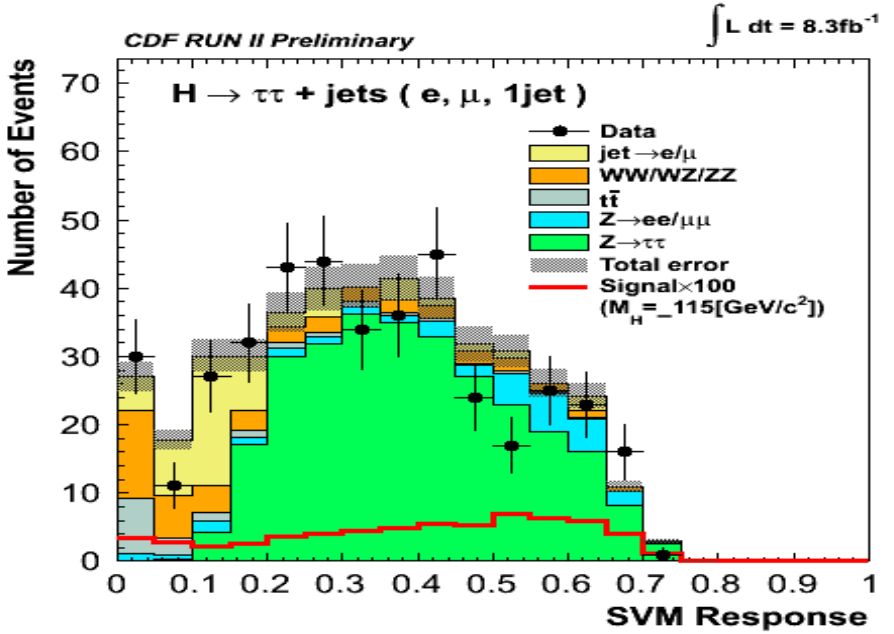
# Discriminant

- Signal peak on top of Drell-Yan background
  neutrinos and detector resolution
  broaden Z and Higgs mass distribution
  → **Z/H peaks not distinguishable**

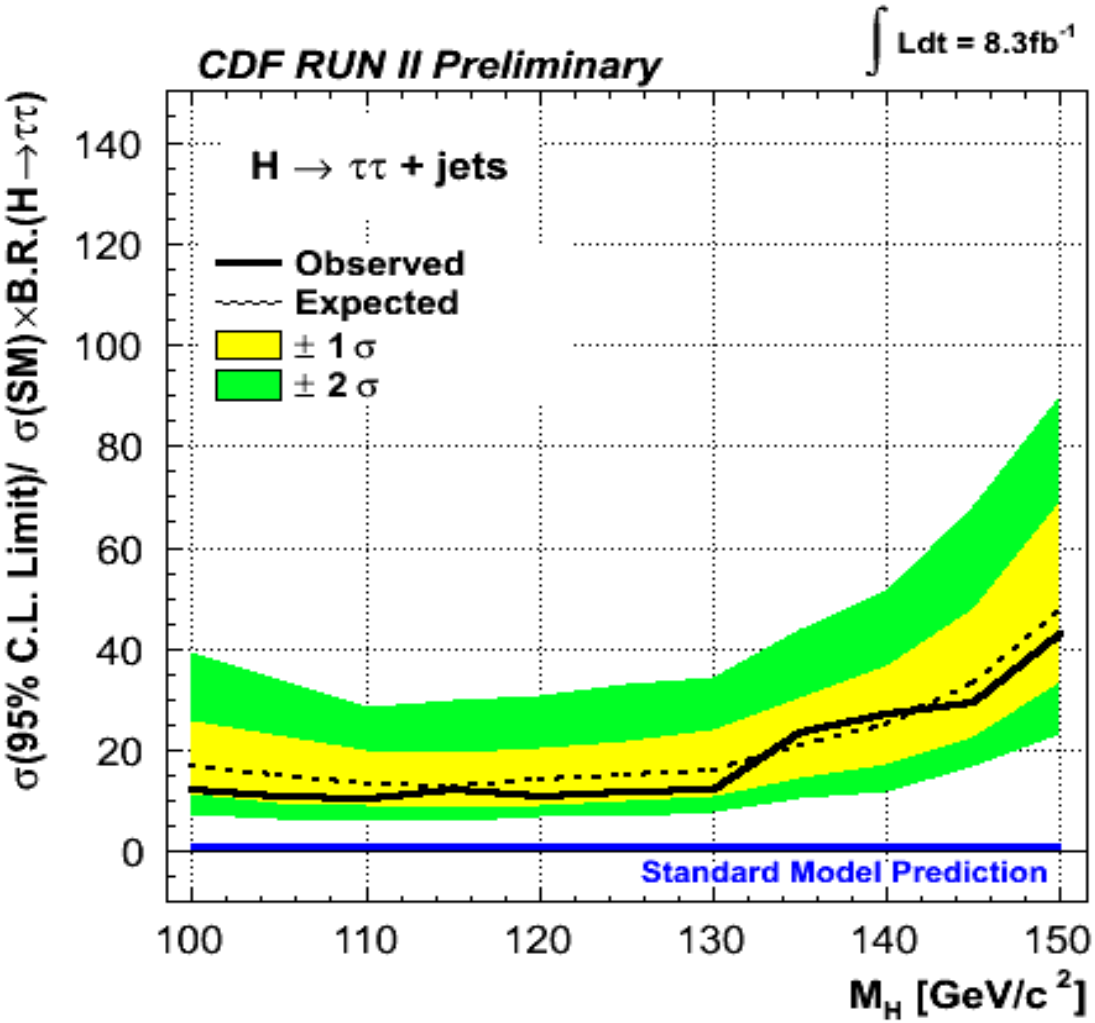



- Use multivariate technique (Support Vector Machine)
  - train a different SVM to separate each individual background process from signal
  -final discriminant: minimum value in any SVM classifier



# Result for H → ττ + jets search




Limit at @ $m_H$ =125 GeV/$c^2$

Obs (Exp) = 11.7(14.8) $\sigma_{S.M.}$

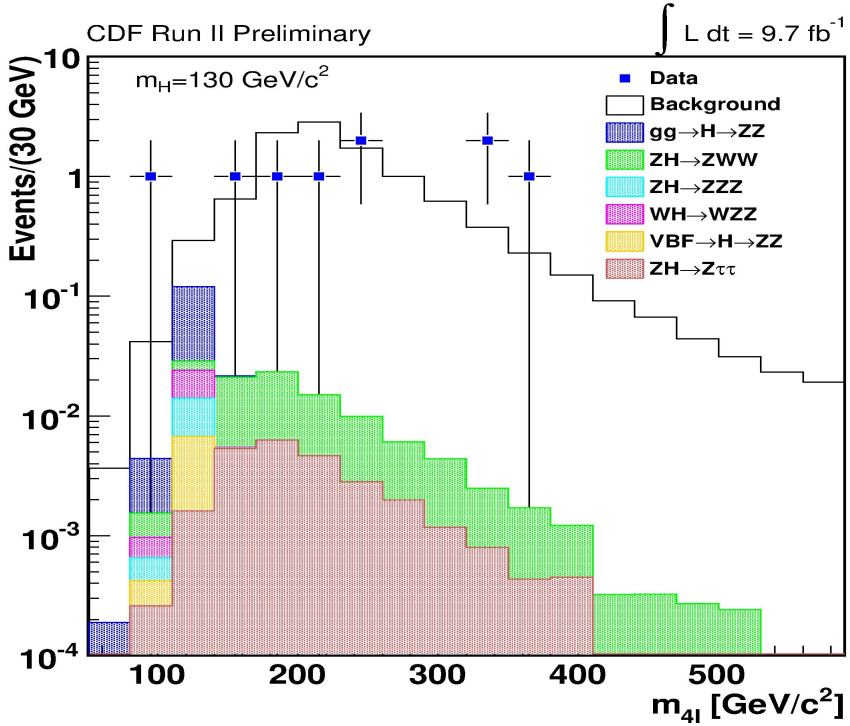
# Search for $H \rightarrow ZZ^{(*)} \rightarrow 4$ leptons

- Clean channel but small signal rate

- Two same flavor/opposite charged pairs of isolated leptons
  - $P_T > 20$ GeV/c (triggering lepton)
  - $P_T > 10$ GeV/c (other leptons)
  - no cut on $M_{ll}$

- Include ZH production, $H \rightarrow WW/\tau\tau$
  ~ double signal yield

- Backgrounds:
  non-resonant $ZZ^{(*)}$ SM : PYTHIA MC
  $Z\gamma$ + jets/Z+2jets: data-driven estimate
  shape from Bauer MC



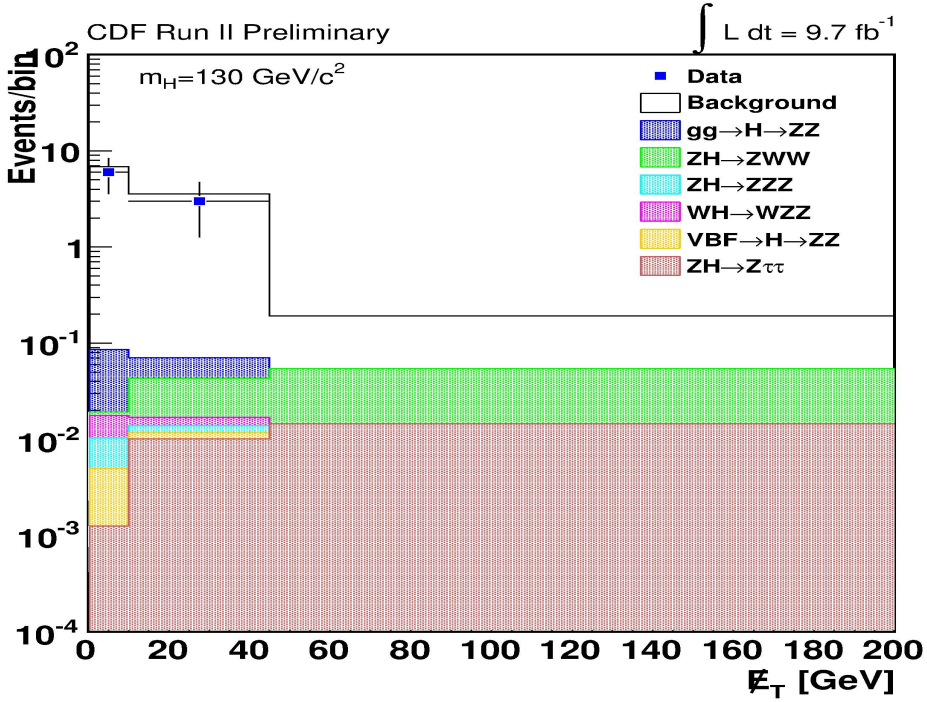

| CDF Run II Preliminary | $\int \mathcal{L} = 9.7$ fb$^{-1}$ |
|---|---|
| Contribution | Yields |
| $ZZ$ | $10.59 \pm 1.34$ |
| Fakes | $0.39 \pm 0.19$ |
| Total Background | $10.98 \pm 1.34$ |
| Higgs Process $m_H$ =130 GeV/$c^2$ | |
| $gg \rightarrow H \rightarrow ZZ$ | 0.09 |
| $WH \rightarrow WZZ$ | 0.01 |
| $ZH \rightarrow ZZZ$ | 0.01 |
| VBF $H \rightarrow ZZ$ | 0.01 |
| $ZH \rightarrow ZWW$ | 0.07 |
| $ZH \rightarrow Z\tau\tau$ | 0.03 |
| Data | 9 |

# Result for $H \rightarrow H \rightarrow ZZ^{(*)} \rightarrow 4$ leptons

Discriminant: distribution in $M_{4l}$-MET plane

- no real MET in $H \rightarrow ZZ$ events
- real MET in $ZH \rightarrow ZWW \rightarrow ll\ lv\ lv$

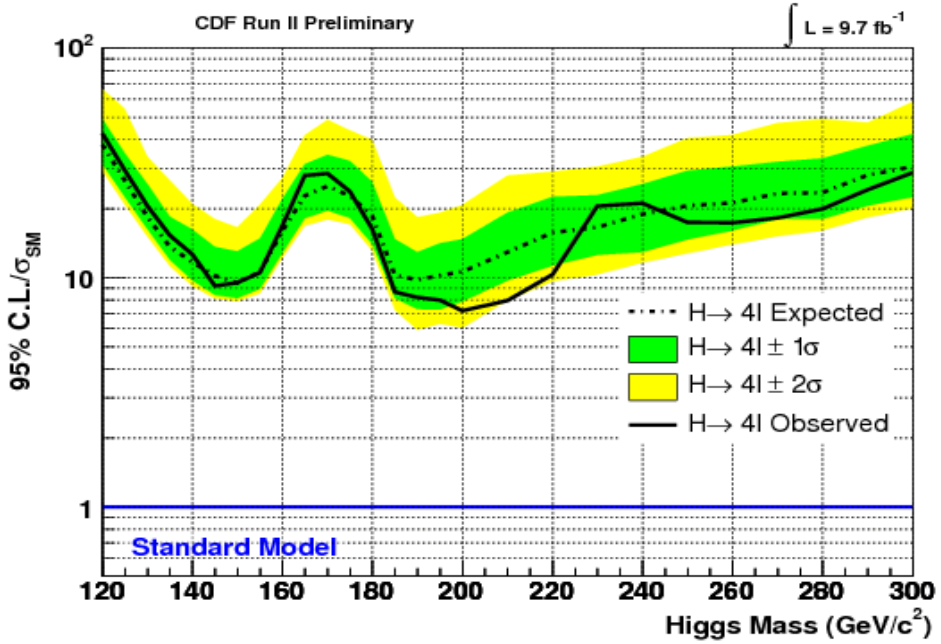
$\rightarrow$ improve limit by 10-15 %




Search performed for $120 < m_H < 300$ GeV/$c^2$

Limit at @ $m_H$ =130 GeV/$c^2$

Obs (Exp) = 20.5 (18.3) $\sigma_{S.M.}$



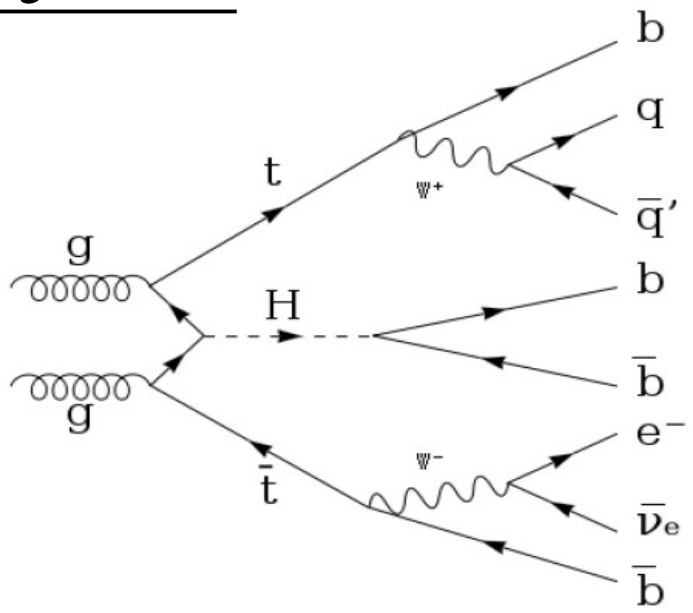
# Search for ttH production: lepton + jets

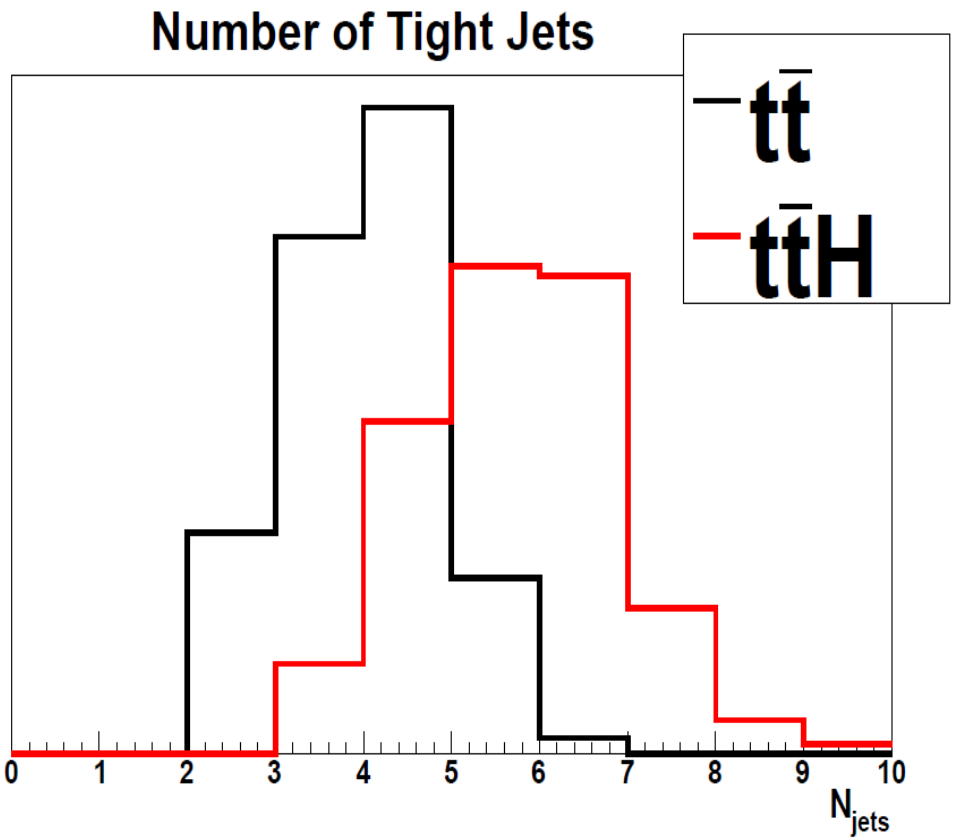
- $\sigma(ttH) = 4.3$ fb ( $m_H = 125$ GeV/$c^2$ )

- Include all hadronic decays of the Higgs
  $H \to b\bar{b}$, $H \to WW$, $H \to \tau\tau$

- Event Selection:
  - e/μ with $P_T > 20$ GeV/c
  - at least 4 jets ($E_T > 20$ GeV $|\eta| < 2.0$)
  - at least 2 b-quarks in final state

- Pure sample of $t\bar{t}$



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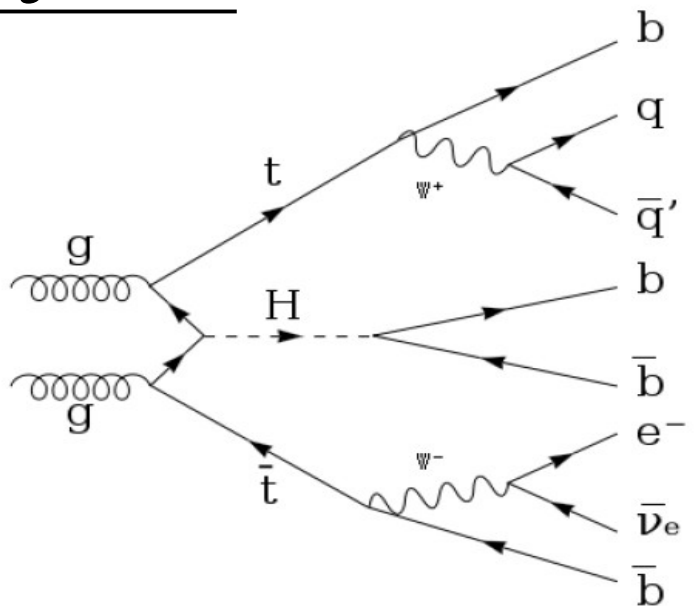
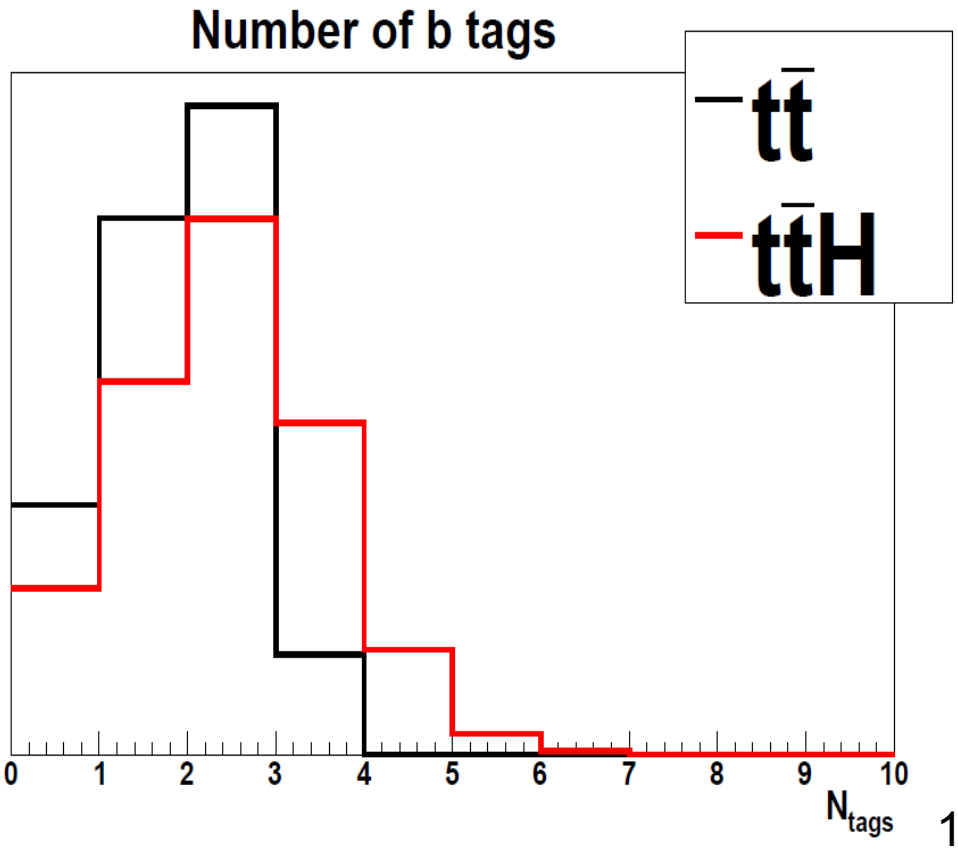
- Pure sample of $t\bar{t}$

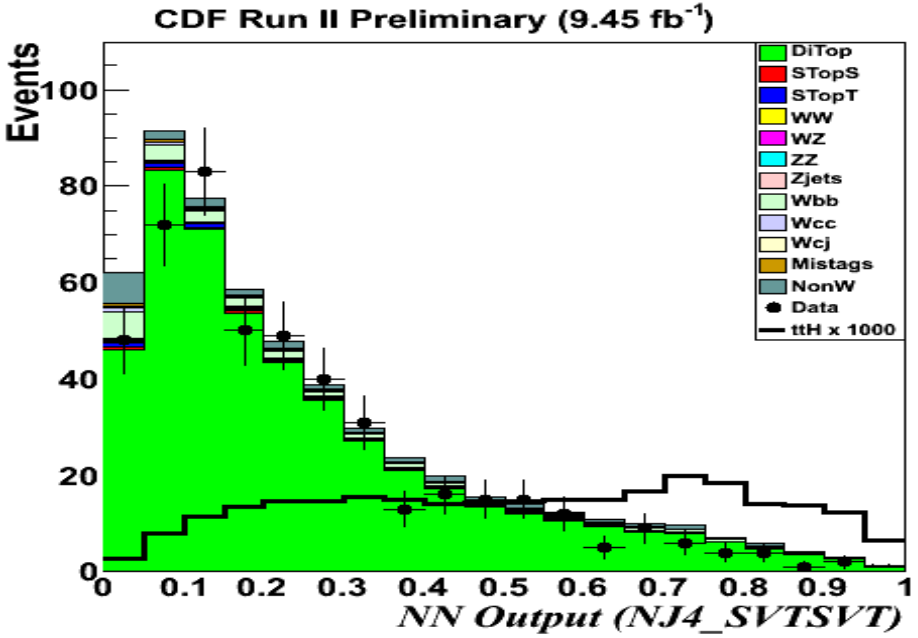
- Classify events by:
  number of jets: 4, 5, ≥ 6 jets
  number of b-tagged jets: 2 or ≥ 3



# Results for ttH production: lepton +jets

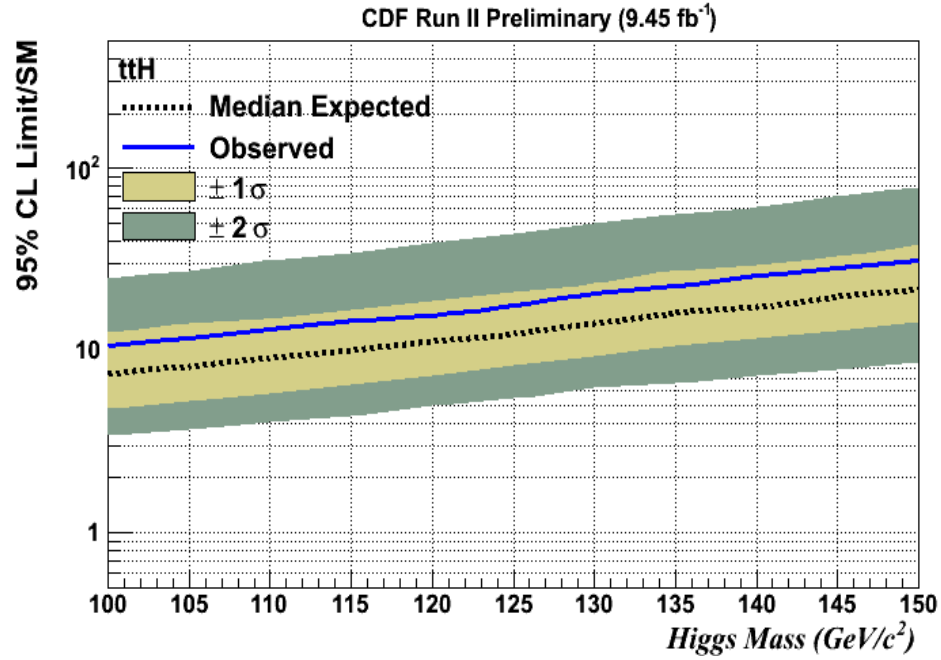
- Neural Network discriminant:
  - one for event category




Limit at @ $m_H$ =125 GeV/c²

Obs (Exp) = 17.6 (12.36) $\sigma_{S.M.}$

NN trained only for one mass points
→ very smooth limit



# Summary and conclusion

**Presented the status of $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ$, $H \rightarrow \tau\tau$ + jet and ttH at CDF**

**Challenging channels contribute to the overall CDF sensitivity:**

- combined expected sensitivity comparable to one of the main analyses

**Tevatron experiments pioneered these channels:**

first data analyses back into 2008-2010

**4$^{th}$ of July:**

**ATLAS and CMS discovered a new particle in $\gamma\gamma$ and ZZ final states**

**m ~ 125-126 GeV/c$^2$**

**→Measure its properties to determine its nature (is it really a Higgs boson?)**

**Tevatron results still matter:**

**currently provide a unique window in $H \rightarrow b\bar{b}$ modes**

→ *see Wei-Ming Yao and Satish Desai talks this afternoon*