Searching for the SM Higgs with τ leptons at the Tevatron

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on behalf of CDF and D0 collaborations

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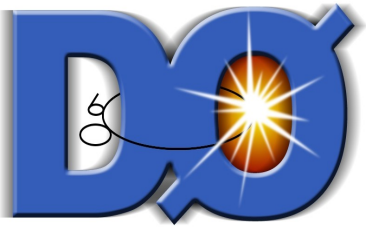


Higgs searches with τ leptons

- **BR(H→ ττ) ~ 10%** for $m_H < 135$ GeV/c^2

  - measure branching ratio

  - sensitive to different production mechanisms

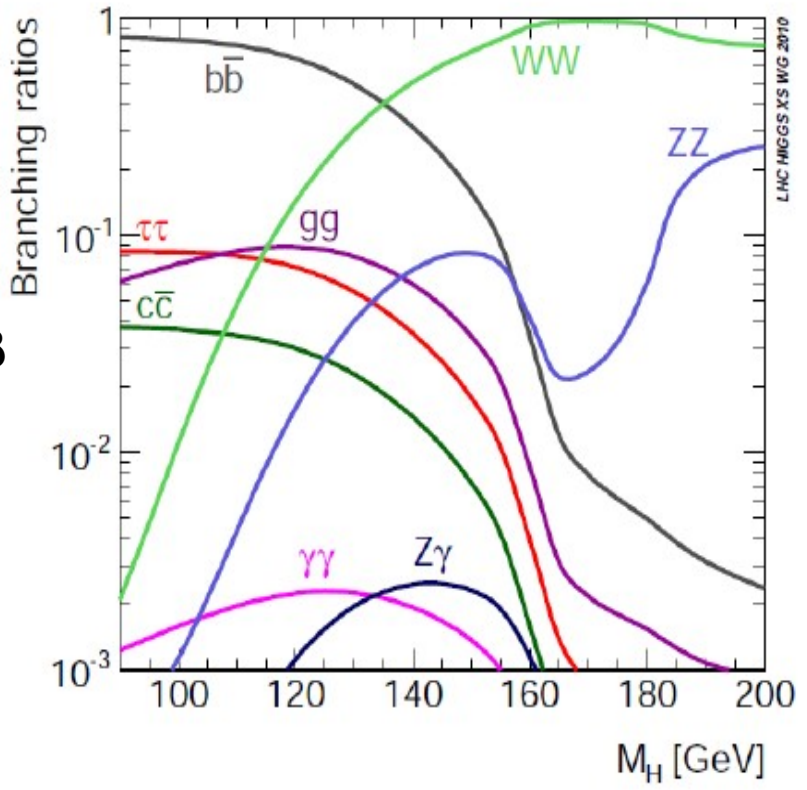
  - in MSSM, gg → H cross section enhanced for high tanβ

    increased sensitivity in this channel

    <u>Analysis presented today:</u>

    H → ττ + jets

    ZH → llττ / WH→lvττ



- Including channels with τs into main analyses (e/μ final states) **increases acceptance**

  higher backgrounds → limited sensitivities

  <u>Analysis presented today:</u>

  H → WW → τνlν

  WH → τνbb

τ experimental signature

- τ lifetime: 0.29 ps
  → reconstruct in the detector only decay products

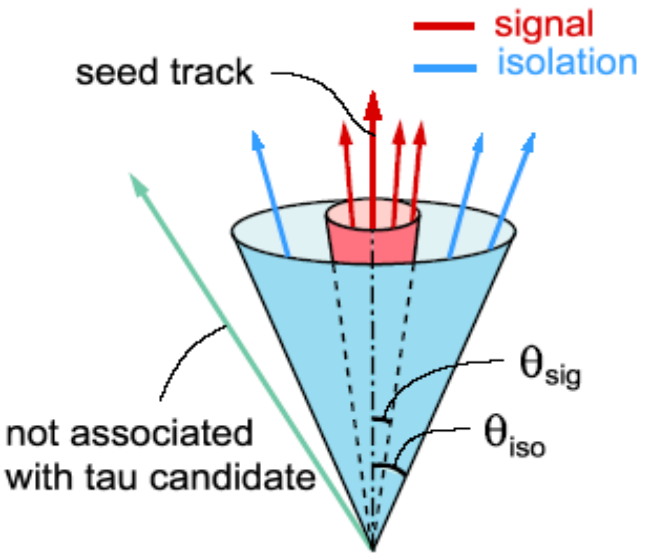
- τ decays produce neutrinos
  - only visible energy reconstructed
  - softer energy spectrum of decay products

- BR(τ → lνν): 35% and BR(τ → hadron ν): 65%
  - e/μ decays are indistinguishable from prompt ones
  - hadronically decaying τs
    - narrow, isolated jet in the calorimeter
    - jet → τ fake rate non-negligible, and difficult to model

Decay Mode	Final Particles	BR
Leptonic	$e^-\bar{\nu}_e\nu_\tau$	17.8%
	$\mu^-\bar{\nu}_\mu\nu_\tau$	17.4%
Hadronic 1-prong	$\pi^-\nu_\tau$	11.1%
	$\pi^-\pi^0\nu_\tau$	25.4%
	$\pi^-2\pi^0\nu_\tau$	9.2%
	$\pi^-3\pi^0\nu_\tau$	1.1%
	$K^-\nu_\tau$	0.7%
	$K^-\pi^0\nu_\tau$	0.5%
Hadronic 3-prong	$2\pi^-\pi^+\nu_\tau$	9.5%
	$2\pi^-\pi^+\pi^0\nu_\tau$	4.4%

35% τ_l

65% τ_h

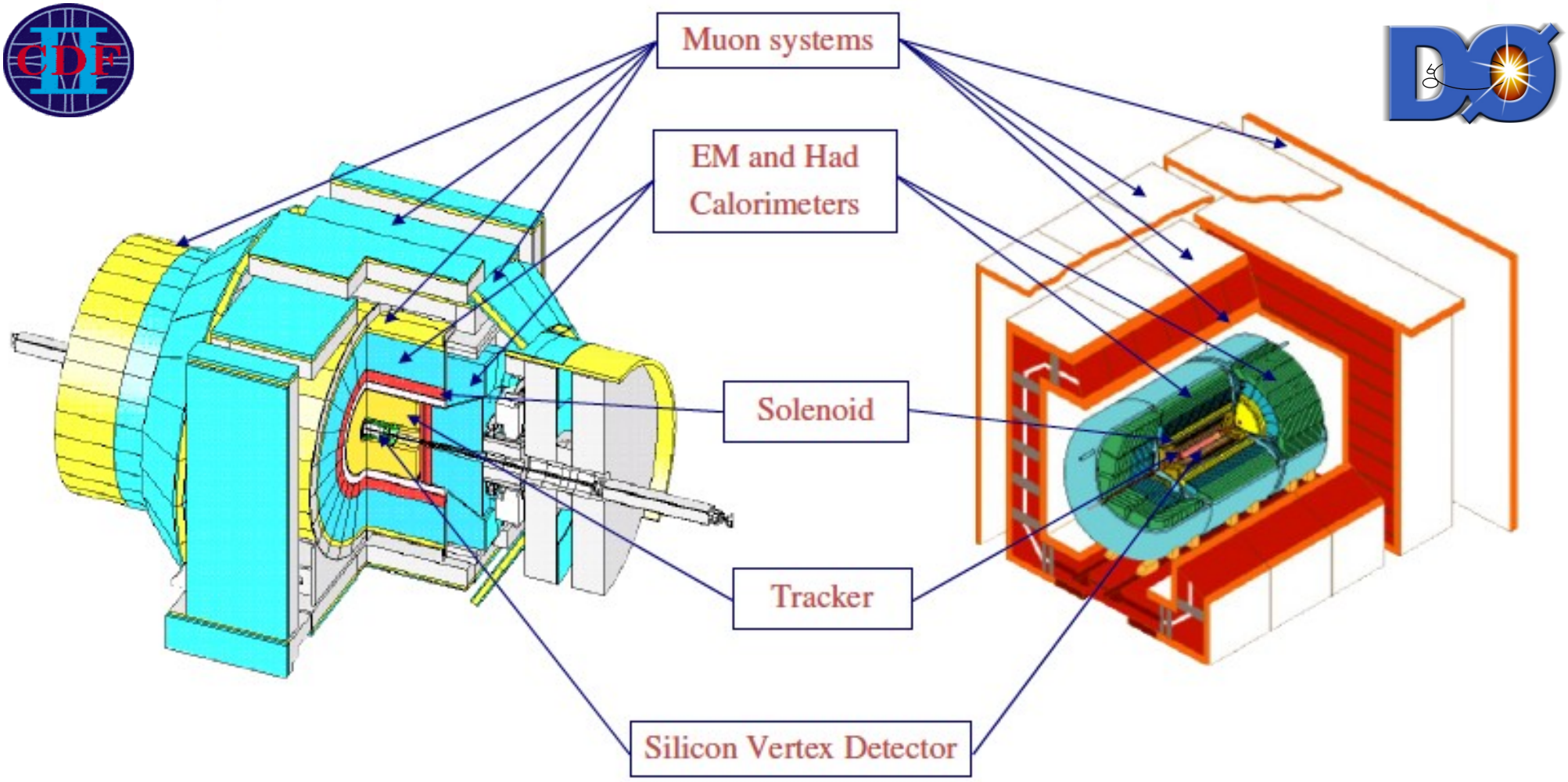


The Tevatron

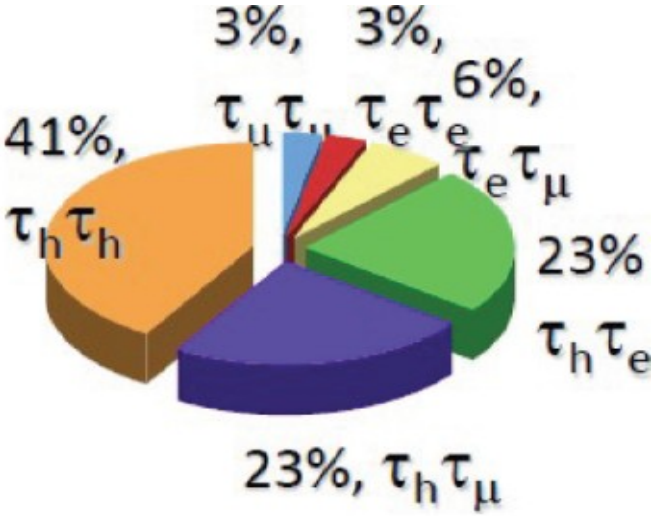
Tevatron ($p\bar{p}$ collider, $\sqrt{s}$ = 1.96 TeV) is doing great:

- weekly integrated luminosity ~ 50 pb^{-1}
- 11.5 fb^{-1} delivered (> 9.5 fb^{-1} on tape per experiment)

<u>Analysis presented today:</u> **5.5 fb^{-1} < $\int L$ < 8.2 fb^{-1}**



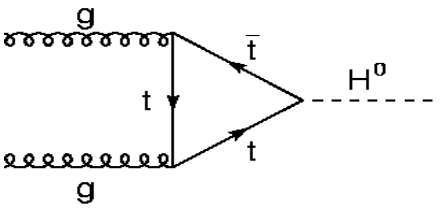
$H \rightarrow \tau\tau$ + jets



- Sensitive at low masses - BR($H \rightarrow \tau\tau$) ~ 10%
- Many decay modes
  - only **hadronic τ + lepton** final state (BR: 46%) explored
- Sensitive to **many production mechanisms**:

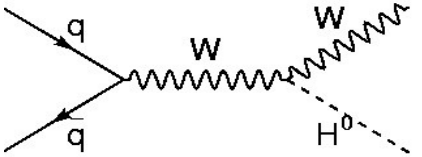
Gluon fusion:

~ 77% of total cross section, irreducible main background ($Z \rightarrow \tau\tau$)



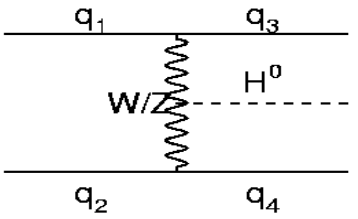
Associated Production:

~ 18% of total cross section, extra jets in event improve S/B



Vector Boson Fusion (VBF):

~ 5% of total cross section, jet kinematics provide extra discrimination



H → ττ + jets: Event Selection

➢ **One identified e/μ + one hadronic τ**

- opposite charge, E_T > 10-15 GeV (CDF/D0)

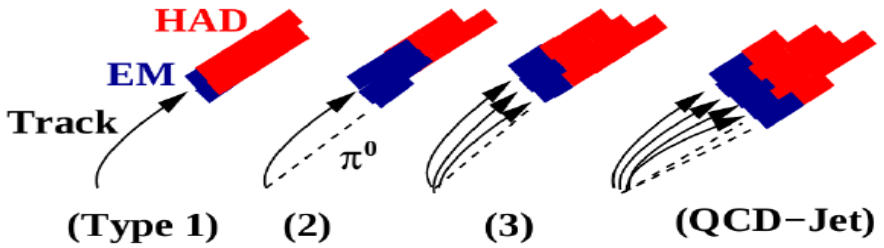
- <u>Multivariate technique to distinguish τ from jets:</u>

  Improve efficiency by ~15%

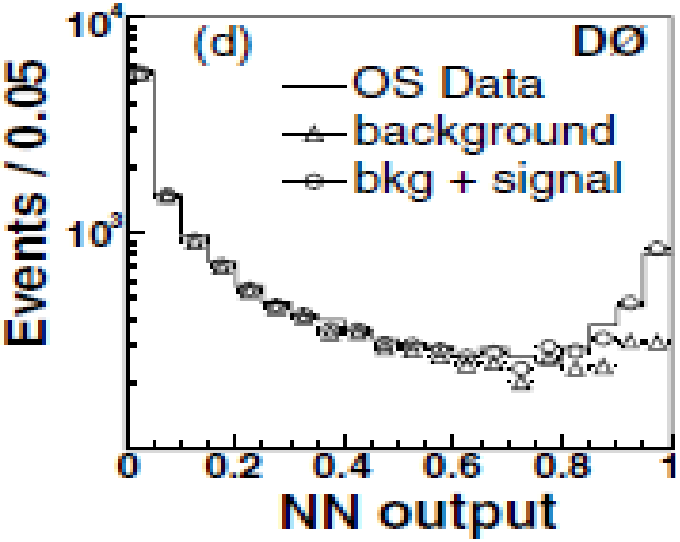
  CDF: train Boosted Decision Tree separately for 1-3 prongs

  D0: reconstruct different decay modes using NN

  - $\tau \rightarrow \pi^{\pm} \nu$, $\tau \rightarrow \pi^{\pm} \pi^0 \nu$, $\tau \rightarrow \pi^{\pm} \pi^{\pm} \pi^{\pm} (\pi^0)$



$Z/\gamma^* \rightarrow \tau\tau$: NN output for Data, background and background + signal



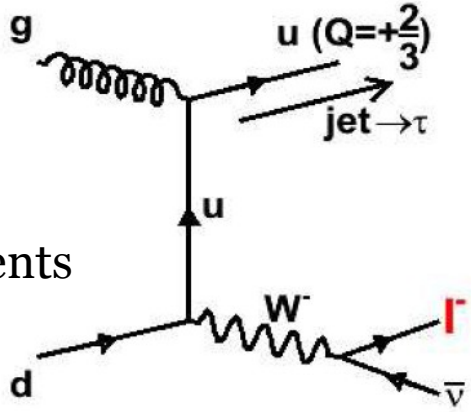
➢ **Reject events with extra e/μ** (suppress $Z/\gamma^* \rightarrow ee/\mu\mu$)

➢ **Jet Selection:**

- **DO : 2 jets** (E_T > 20 GeV $|\eta| < 3.4$)
- **CDF: 1 and 2 jets** (E_T > 20 GeV, $|\eta| < 2.5$)

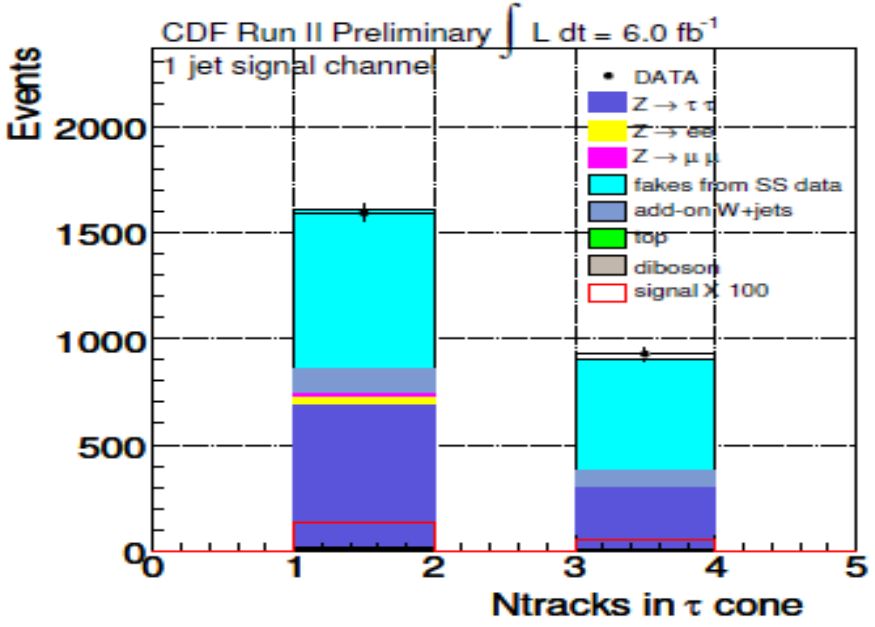
H → ττ + jets: Background Estimation

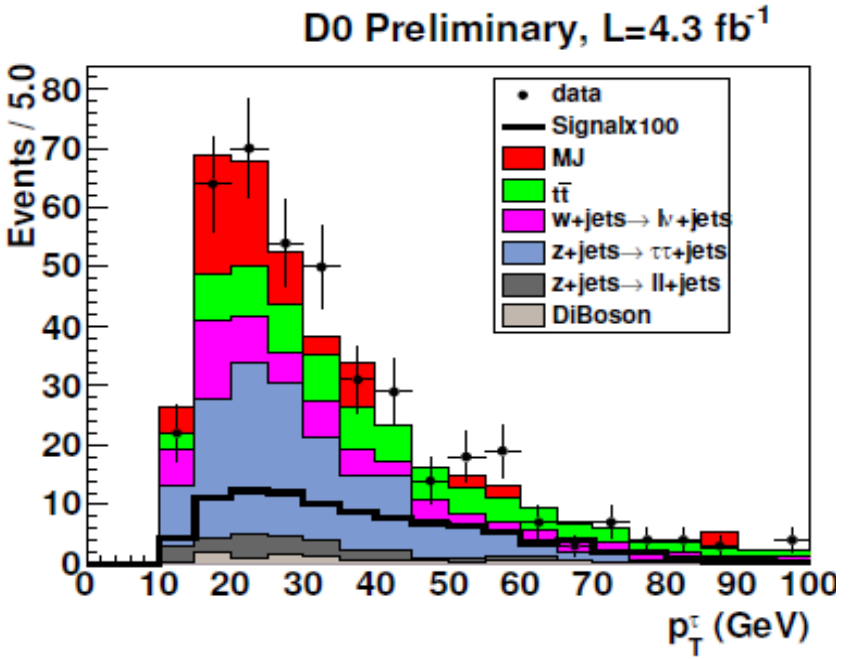
- Irreducible $Z/\gamma^* \rightarrow \tau\tau$ estimated from Monte Carlo
  - also other small background ($Z/\gamma^* \rightarrow ee/\mu\mu$, top, di-boson)



- Fake background: described with data-driven method
  - include γ+jets and multijet production
  no charge correlation between lepton candidates → use same sign events

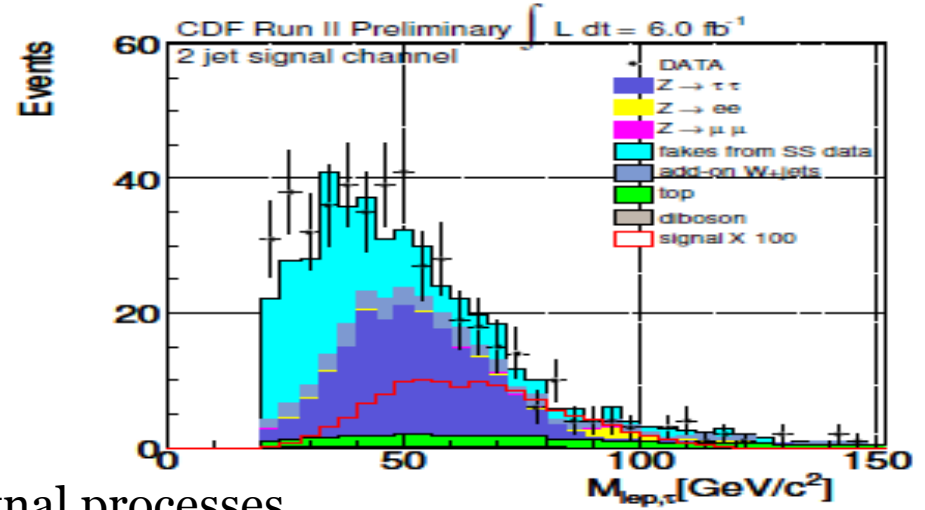
- W+jets
  - charge correlation between lepton candidates → described using MC





Distinguishing Signal From Background

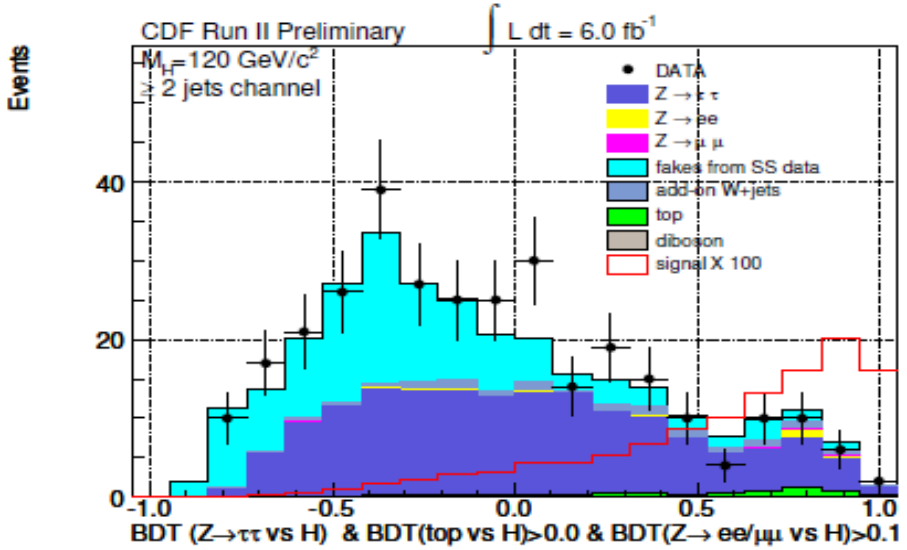
- Signal peak on top of the Drell-Yan background
  - neutrinos and detector resolution
    broaden Z and Higgs mass distribution
  → Z/H peaks not distinguishable

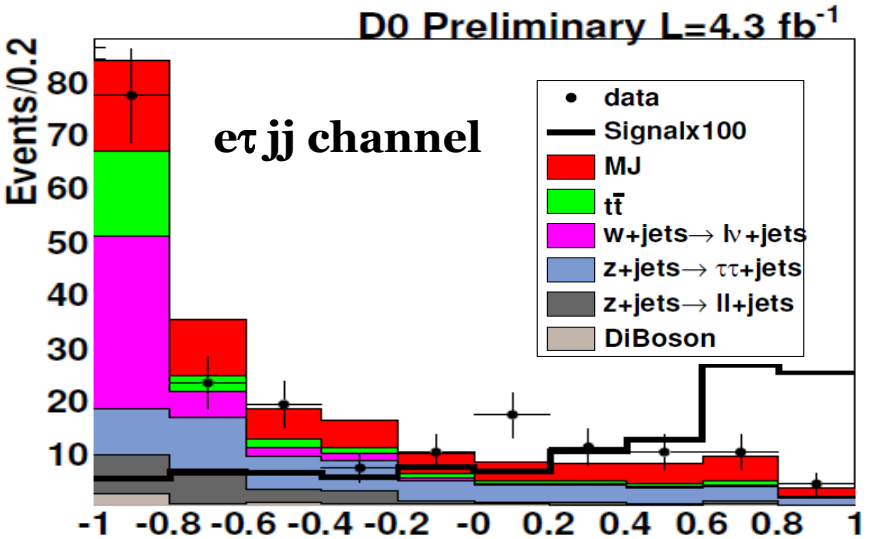


- Use multivariate techniques
  - exploit different kinematics of background and signal processes

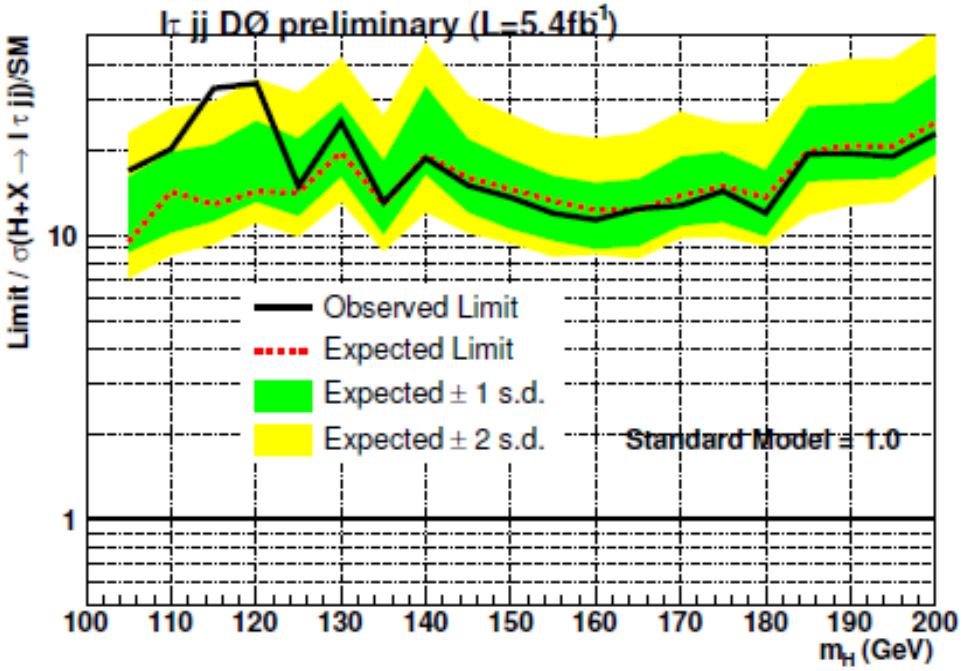
D0: BDTs to separate each signal process from each background, in different mass regions
Output of BDTs used as input of final discriminant

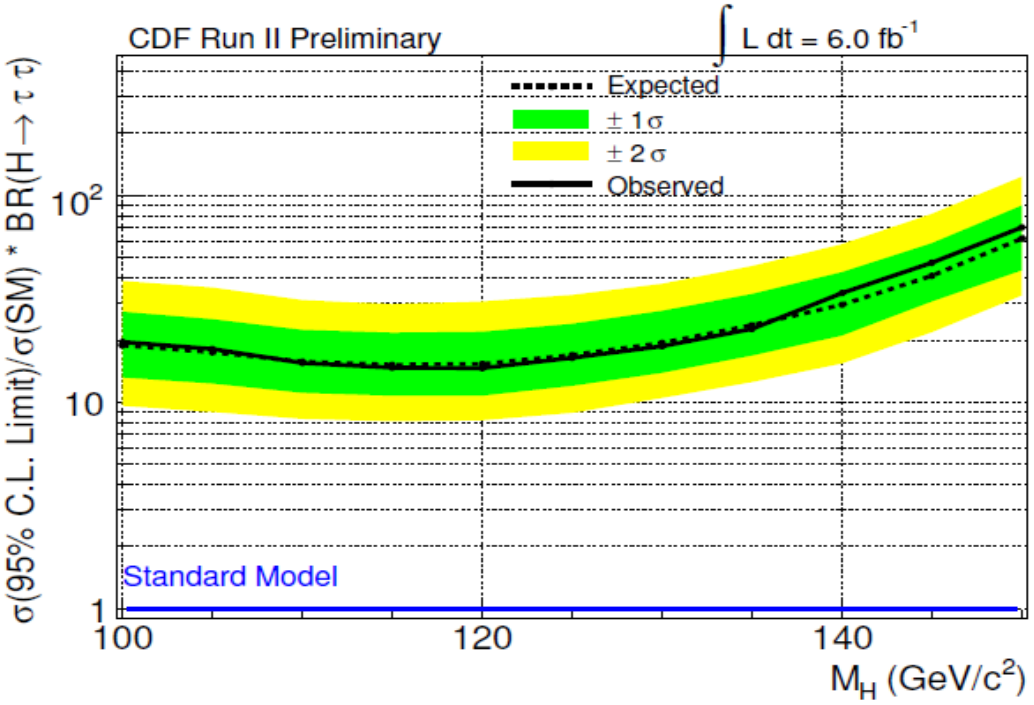
CDF: Use BDT to reduce fakes, W+jets and Z → ee/μμ contributions
Final discriminant trained against Z → ττ





$H \rightarrow \tau\tau$ + jets : results





Limit at @ m_H =115 GeV/c²

Obs (Exp) = 32.8 (12.8) $\sigma_{S.M.}$

Limit at @ m_H =115 GeV/c²

Obs (Exp) = 14.7 (15.2) $\sigma_{S.M.}$

Sensitivity in a wide mass region
- include also $H \rightarrow WW$ decays

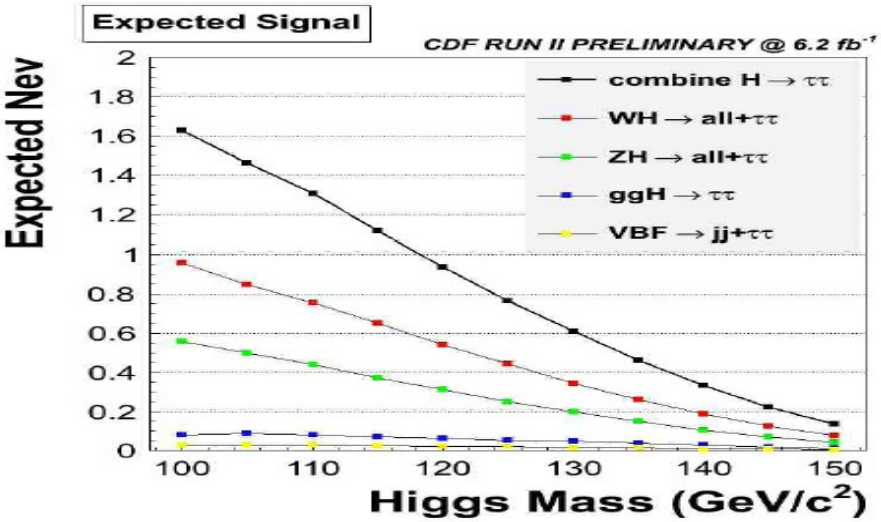
CDF has a dedicated analysis for high mass (later in this talk)

NEW

$ZH \rightarrow ll\tau\tau / WH \rightarrow l\nu\tau\tau$

- Include all tau decay modes
  -5 channels:
  lll, llτ_h , e $\mu\tau_h$, lτ_h τ_h , 4 leptons (any type)

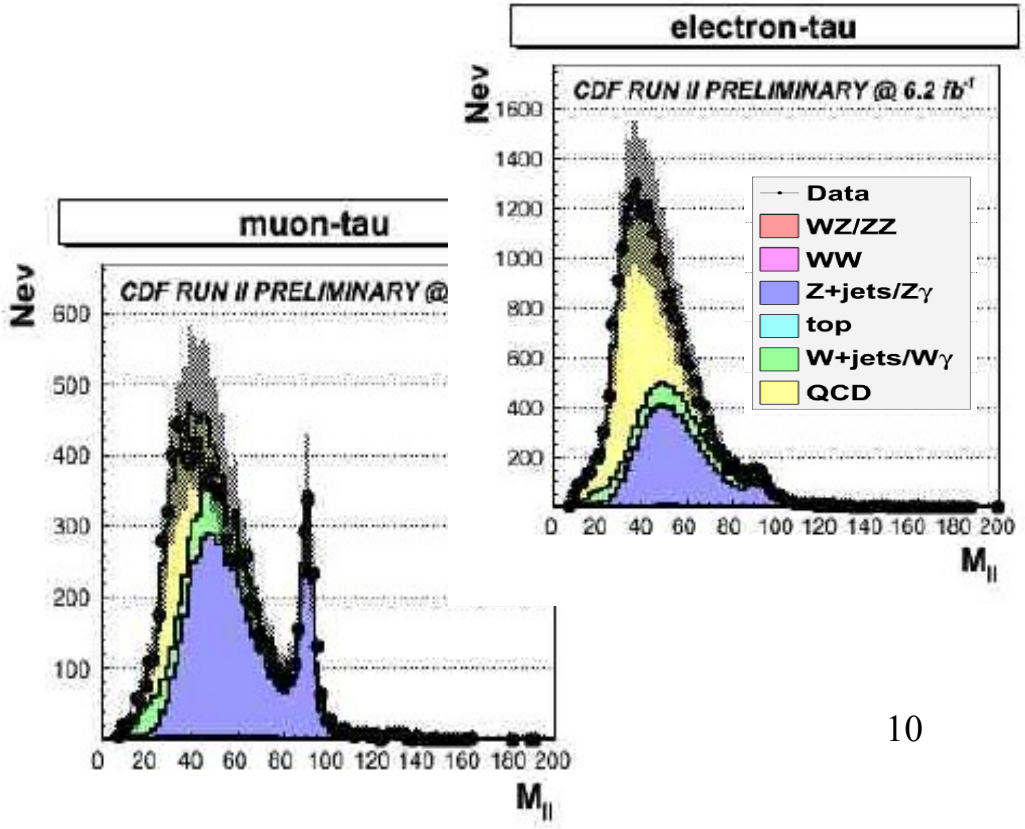
- $|\sum Q| = 1$ (NL=3), $|\sum Q| = 0$ (NL=4)



Most sensitive channel: **llτ_h**

- Dominant backgrounds: DY and Multijet
  - model Multijet from same sign data (|Sum Q| =3)
  - model all other backgrounds with Monte Carlo
    jet $\rightarrow\tau$ fake rate systematic is dominant one (30%)

- Contol region:
  - di-lepton samples
  - tri-lepton, MET/$\sqrt{\sum E_T}$ < 1.



NEW

$ZH \rightarrow ll\tau\tau / WH \rightarrow l\nu\tau\tau$

- $MET/\sqrt{\sum E_T} > 1.$

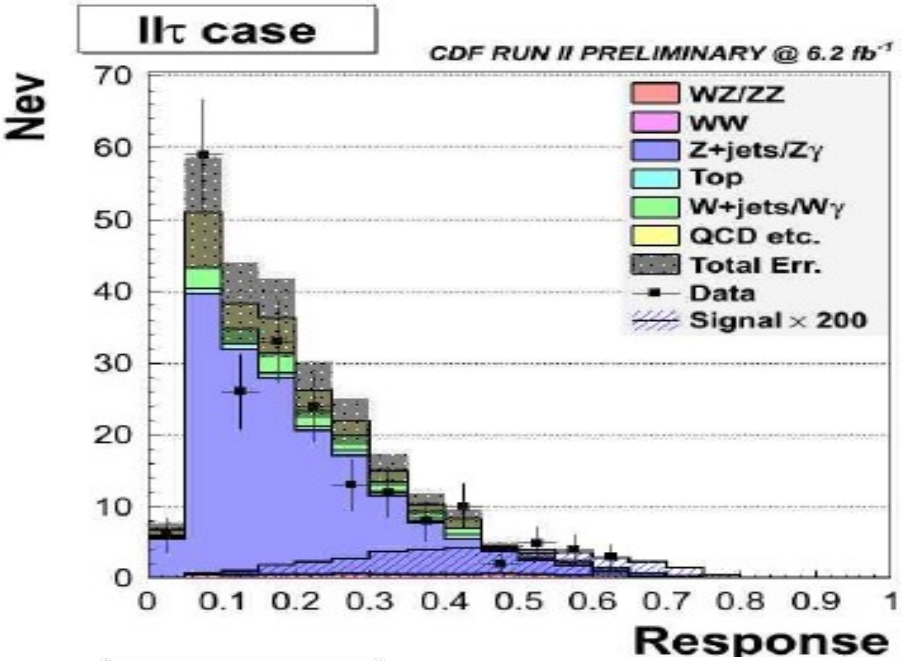
  reduce DY and Multijet background contributions

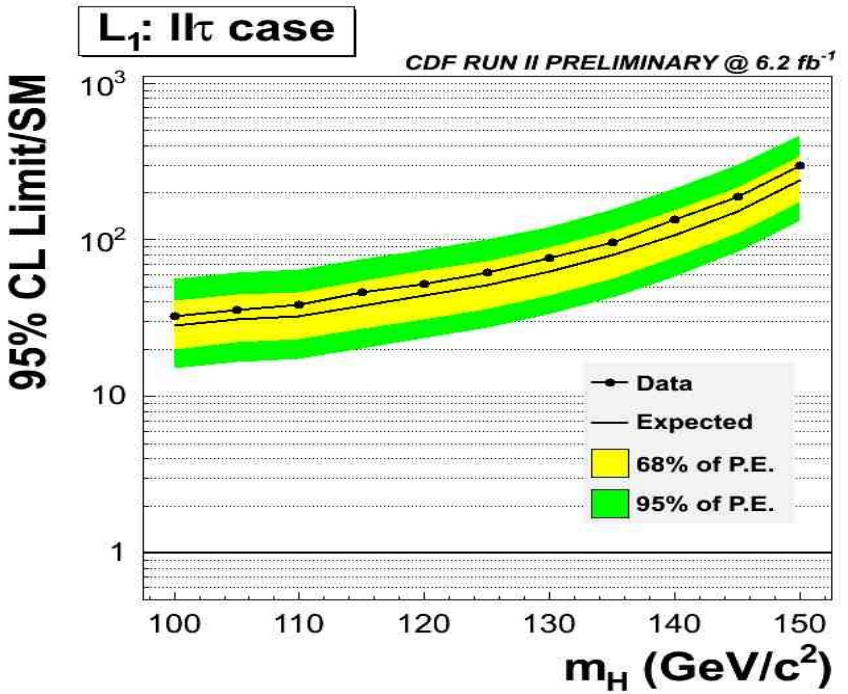
- Use **Support Vector Machine** to discriminate
  - effective when training on low statistic samples
  - separate events in two regions with an hyperplane

Limit at @ m_H =115 GeV/c²

Obs (Exp) = 46 (38.2) $\sigma_{S.M.}$

- $e\mu\tau_h$, $l\tau_h\tau_h$ channels comparable sensitivity





NEW

$ZH \rightarrow ll\tau\tau/WH \rightarrow l\nu\tau\tau$

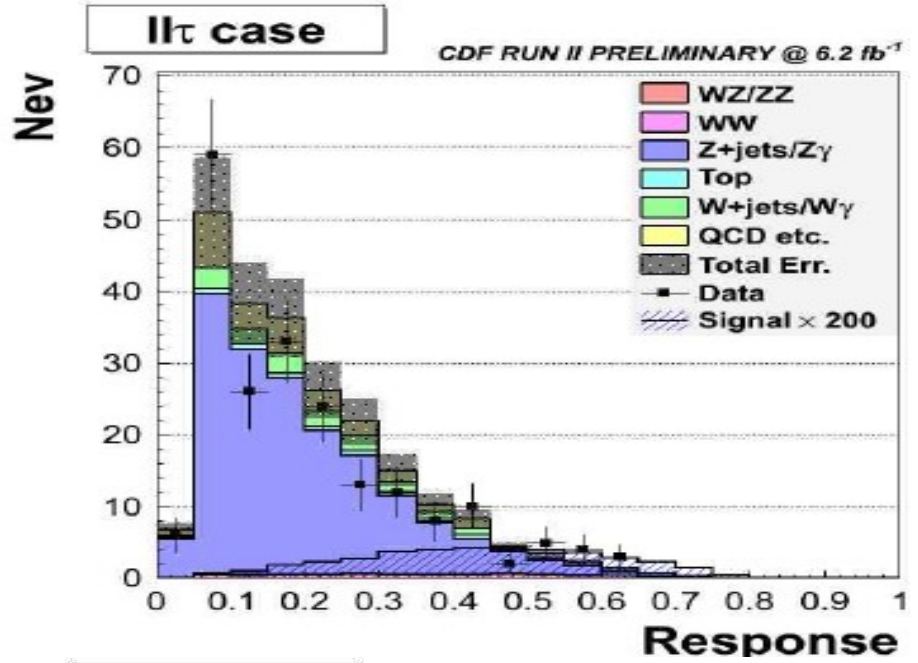
- $MET/\sqrt{\sum E_T} > 1.$

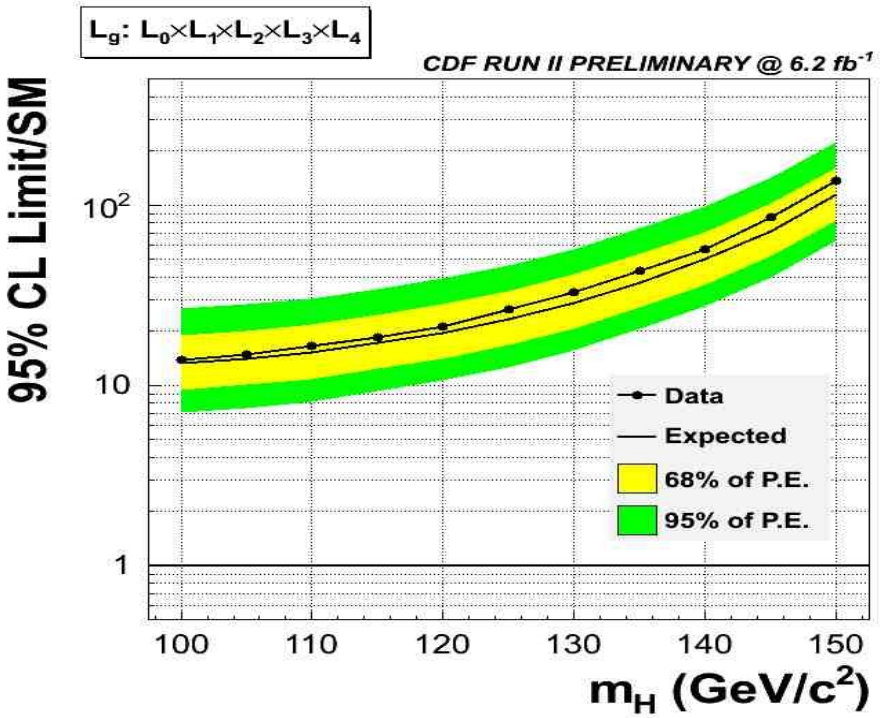
  reduce DY and Multijet background contributions

- Use **Support Vector Machine** to discriminate
  - effective when training on low statistic samples
  - separate events in two regions with an hyperplane

COMBINED Limit at @ m_H =115 GeV/c^2

Obs (Exp) = 18.5 (17.3) $\sigma_{S.M.}$



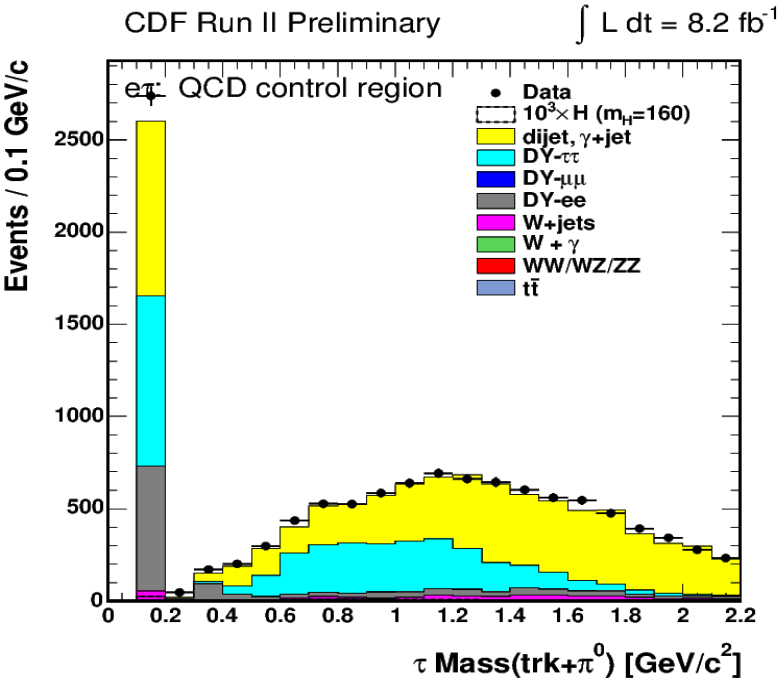


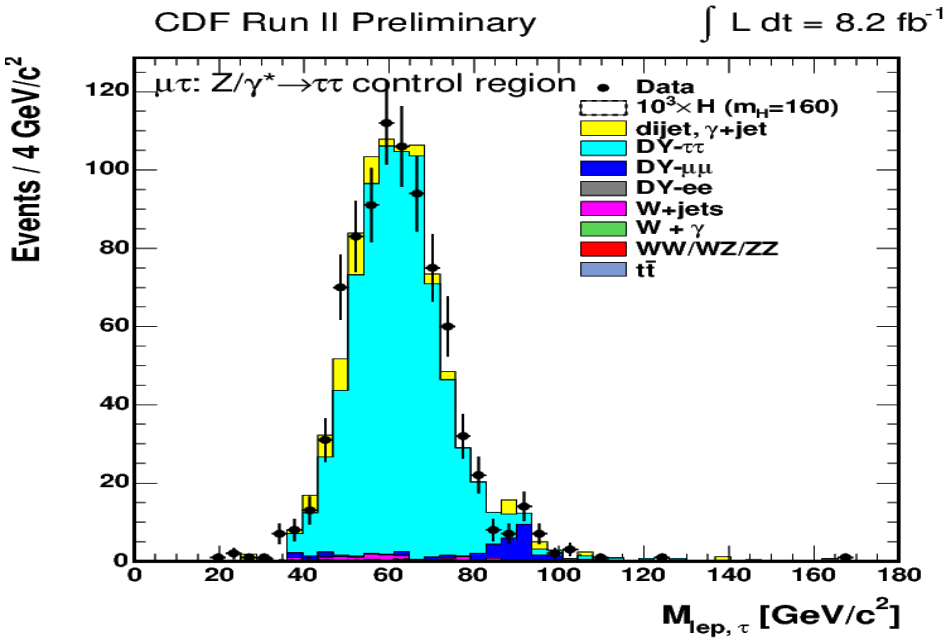
$H \rightarrow WW \rightarrow l\nu\tau\nu$

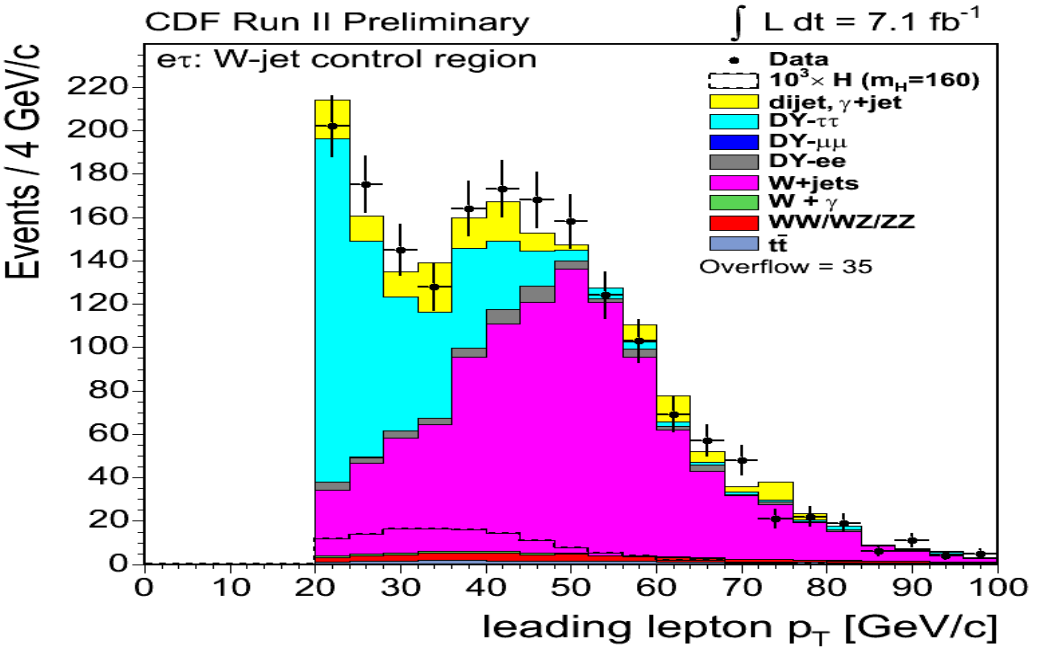
- e/μ (E_T > 20 GeV), hadronic tau candidate (E_T> 15 GeV)

- Backgrounds: $Z/\gamma^* \rightarrow \tau\tau$, W+jets and Multijet
  - fake rate of $e \rightarrow \tau$, $\mu \rightarrow \tau$, jet $\rightarrow \tau$ from MC
  - same sign data events to model events with double fakes
    γ + jets, multijets production

- Topological cut to reduce backgrounds
  → Invert them to define control regions



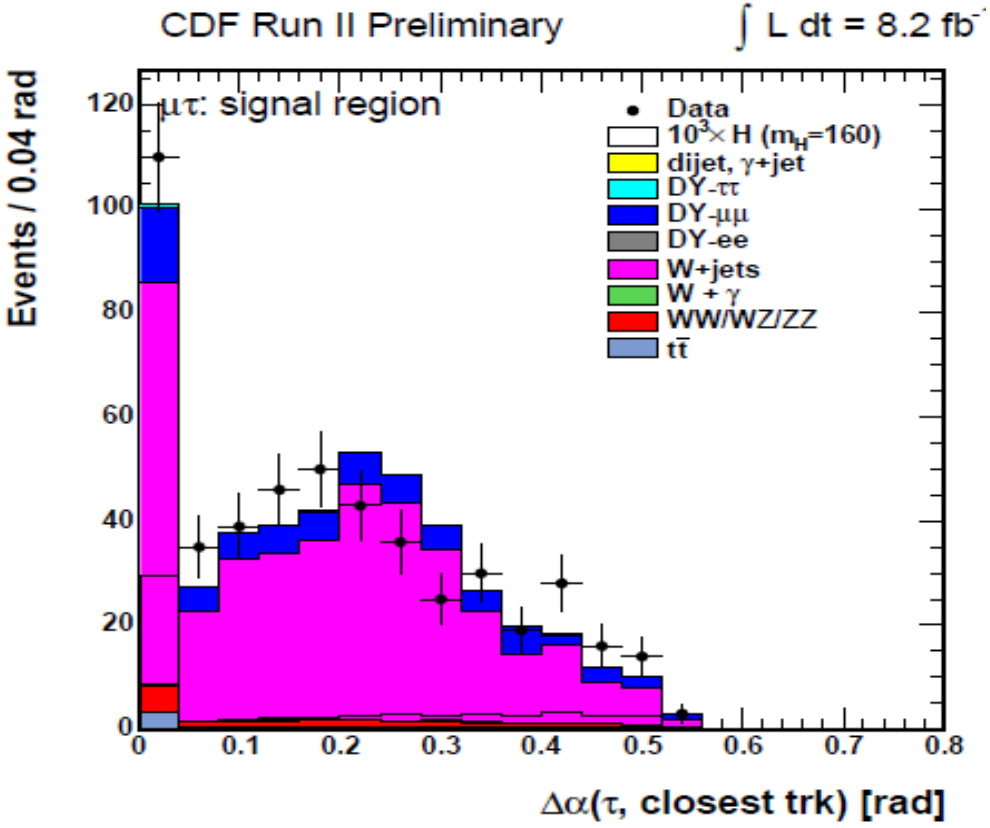


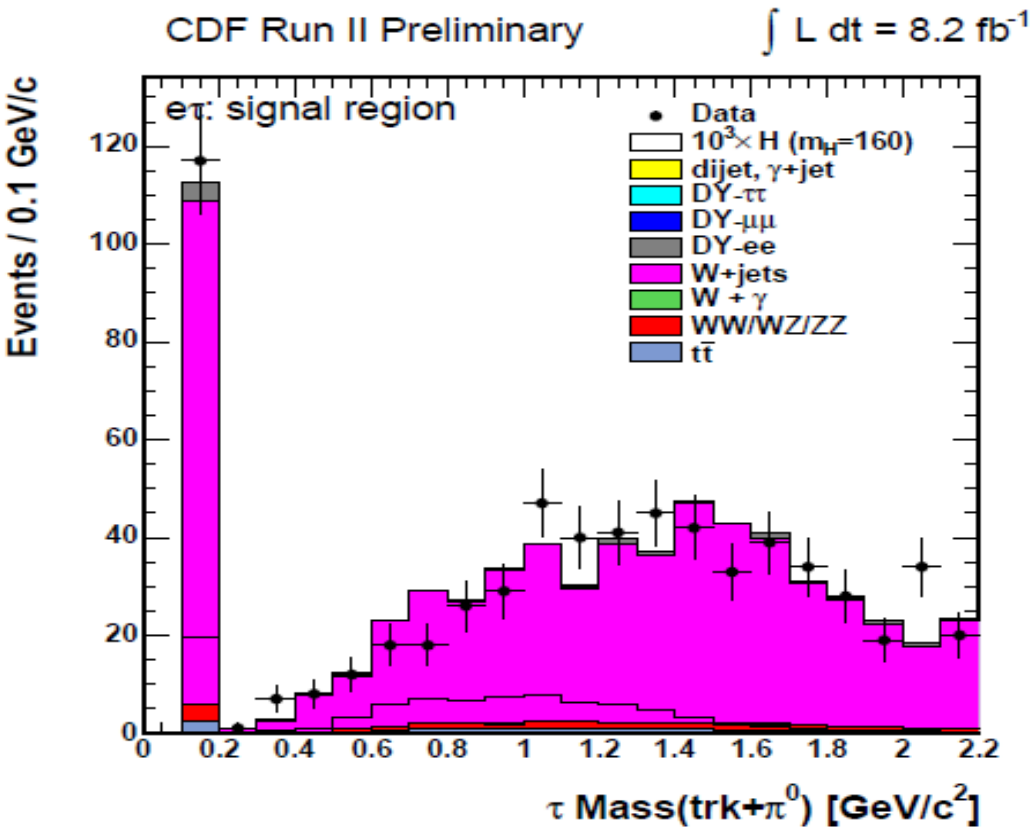


$H \rightarrow WW \rightarrow l\nu\tau\nu$

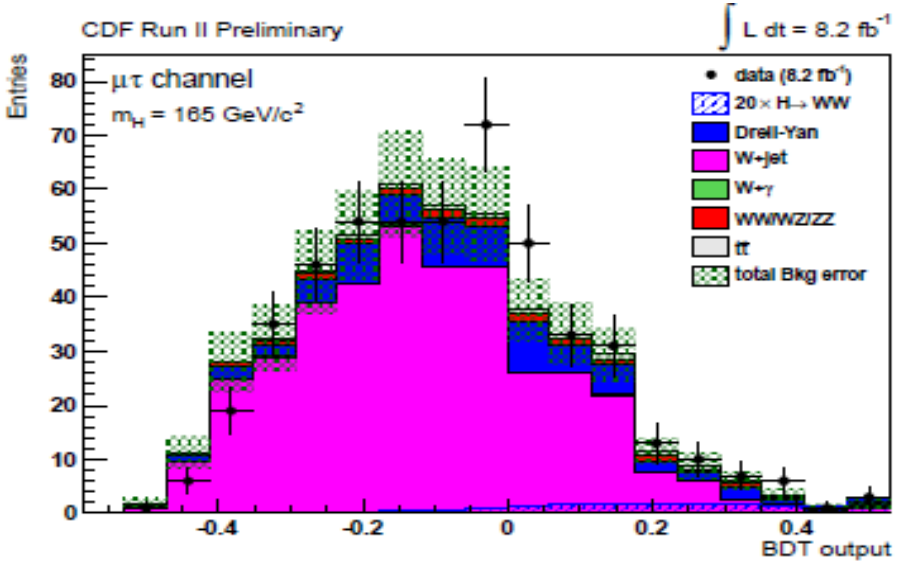
- After selection, W+jets is dominant background
  - no Higgs mass reconstruction

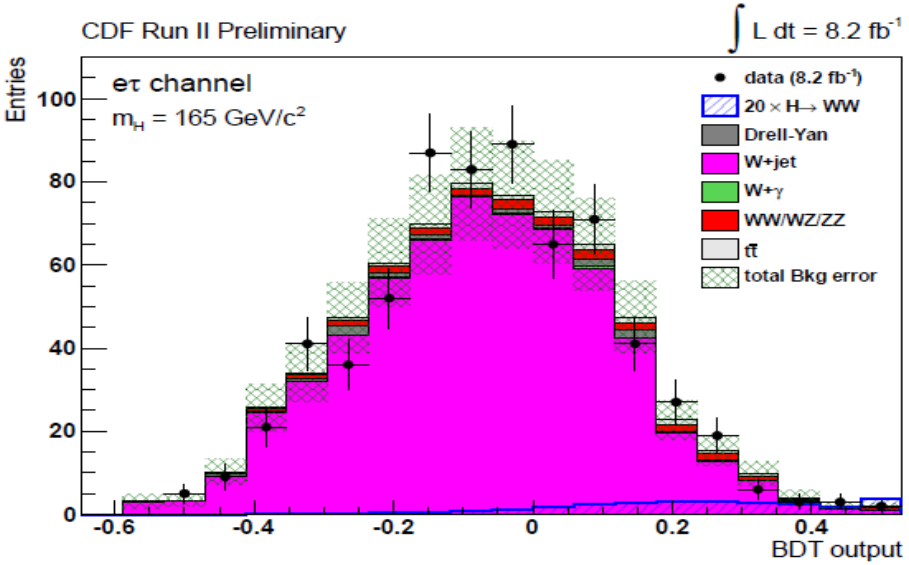
- Use Boosted Decision Tree to discriminate
  - exploit kinematical differences
  - add tau specific variables: help separate real/fake taus





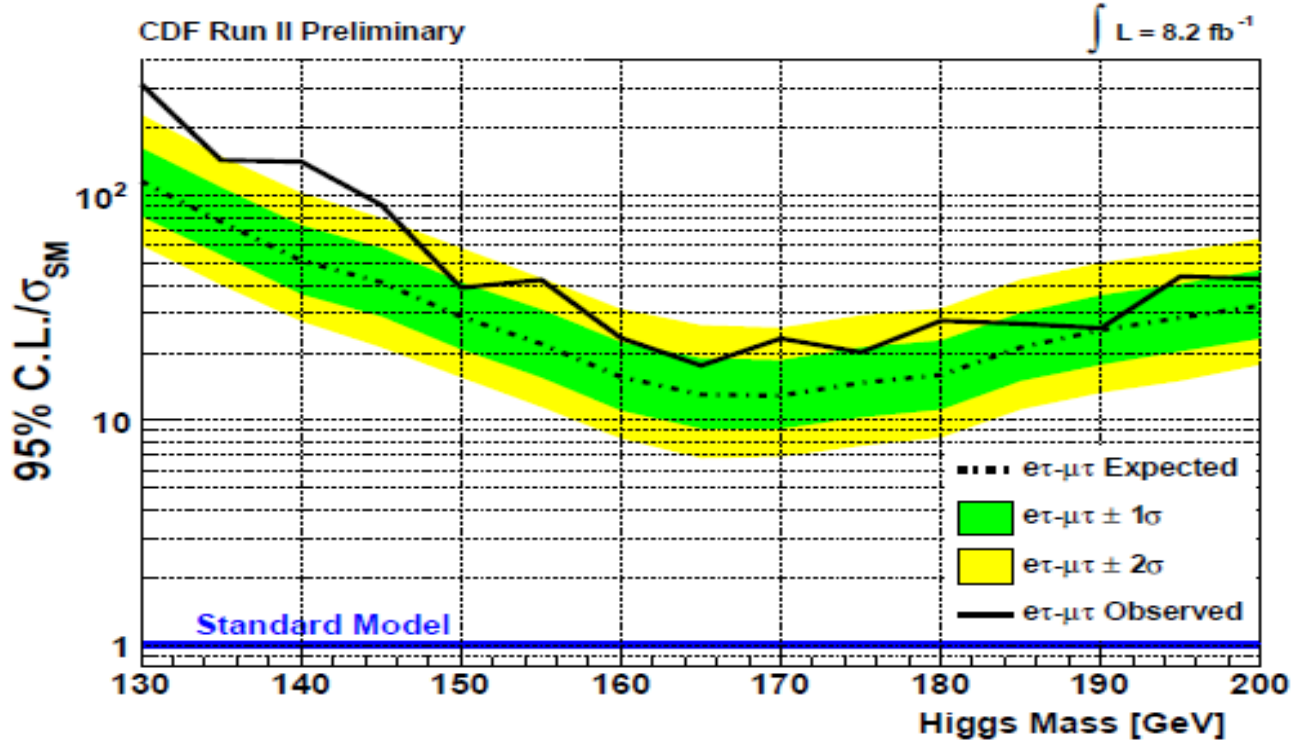
$H \rightarrow WW \rightarrow l\nu\tau\nu$





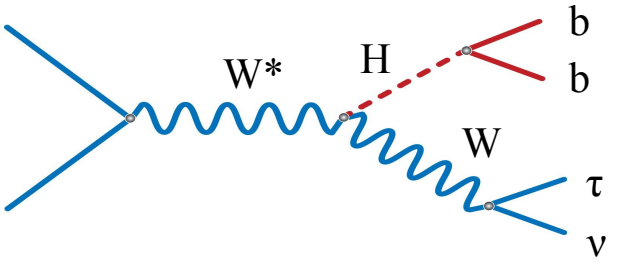
Limit at @ m_H =160 GeV/c²

Obs (Exp) = 23.3 (15.6) $\sigma_{S.M.}$



WH → τνbb

- WH → lνbb: one of the most sensitive channels at the Tevatron
  target e/μ final state, not optimized for hadronic tau



Challenges:
- trigger
- identification (τ ID efficiency ~ 40-60%)
- jet → τ fake rate non-negligible, and difficult to model

=> add ~ 10% to main channels acceptance, but S/B limits sensitivity

- Basic selection:

  Identified τ , E_T > 12 GeV (D0)/ 25 GeV (CDF), |η| < 2. (D0)/ 1. (CDF)

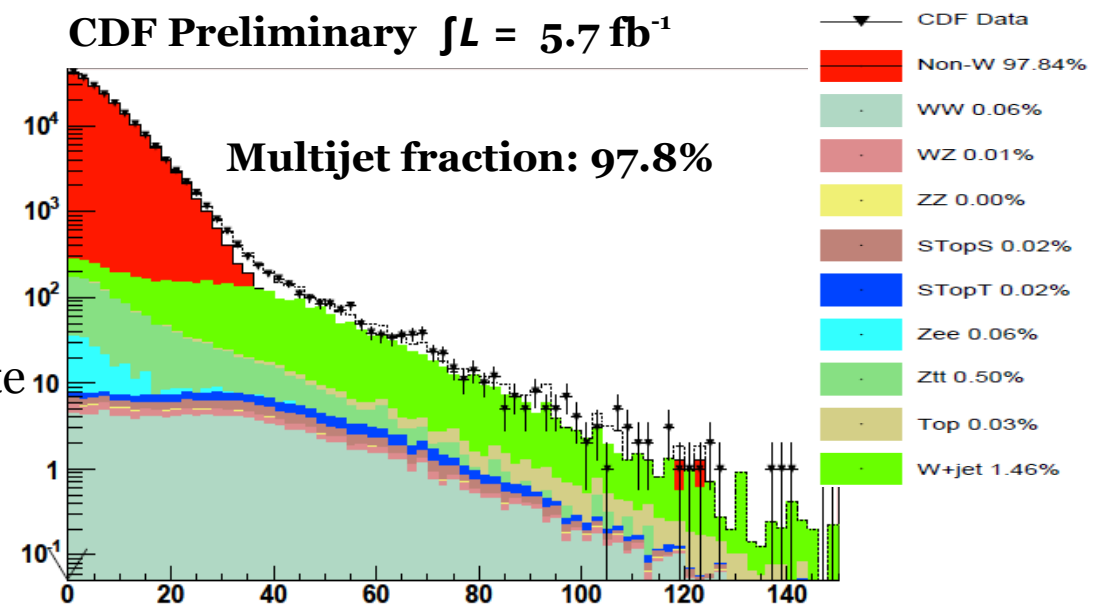
  2 high P_T jets, b-tagged, large MET

Sample dominated by Multijet production
- use data-driven model

D0 : invert NN cut on identified tau candidate

CDF: identified tau candidate, 2 tracks

All other backgrounds: modeled by MC

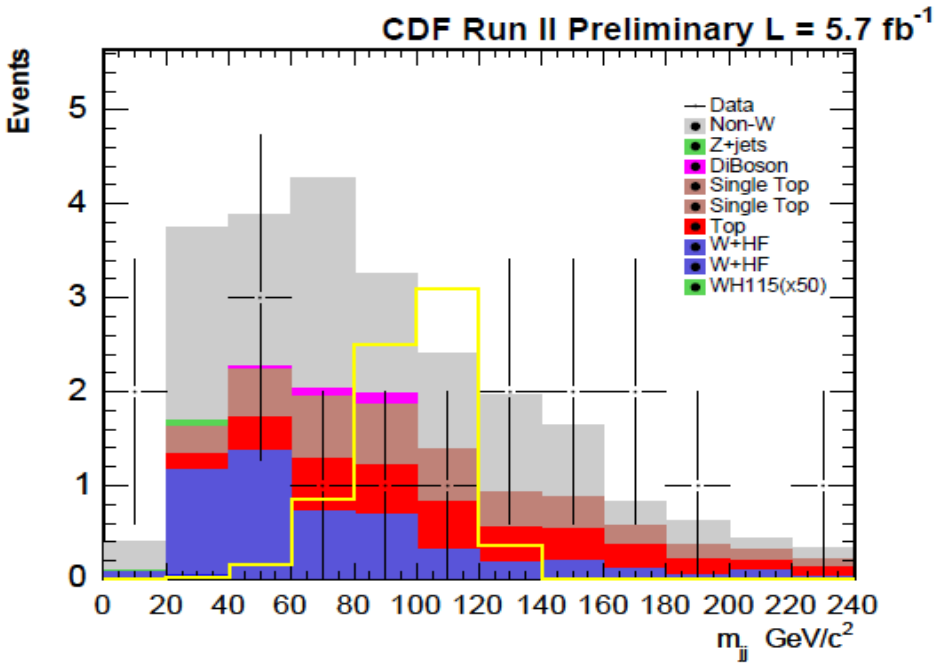


$WH \rightarrow \tau\nu bb$

➢ Reduce Multijet contribution:

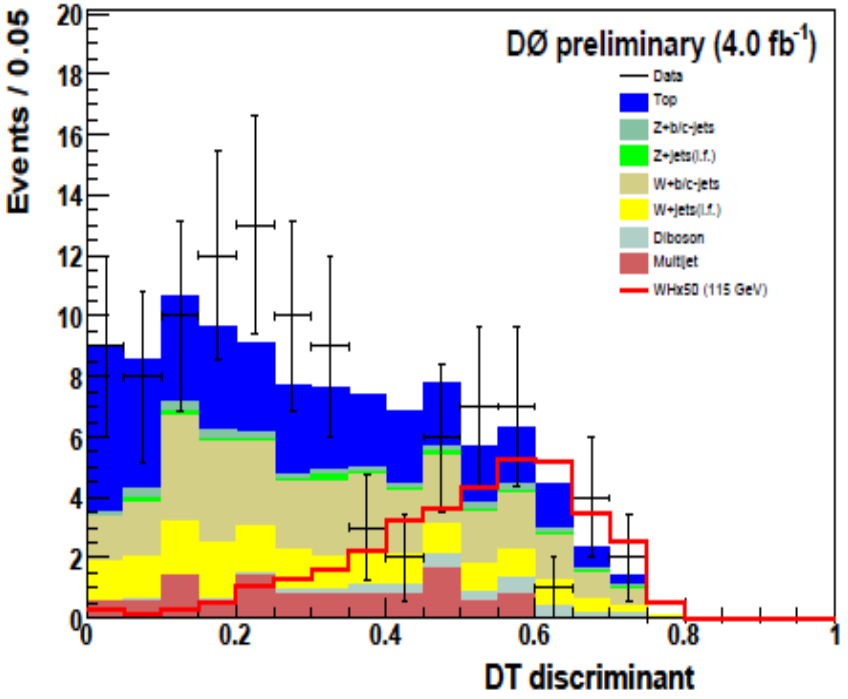
CDF:

- optimize cut on MET Perpendicular for each sub-samples classified by number of b-tagged jets
- fit di-jet mass



D0:

- MET Significance > 4.5
- Delta Phi(Missing P_T, MET) < 2.
- Use BDT to separate signal and background



Limit at @ m_H =115 GeV/c^2

Obs (Exp) = 22.4 (14.1) $\sigma_{S.M.}$

Summary

- Presented most recent Higgs searches at the Tevatron with τ leptons
  - many different analysis, one of which has never been performed before

- Analyses with τ leptons are challenging:
  lower selection efficiency
  Multijet background has significant contribution
  → limited sensitivity, but every channel counts in combination

- Not all data available analyzed yet => Stay tuned for more results

BACK UP

$H \rightarrow WW \rightarrow l\nu\tau\nu$: Control regions

QCD region:

$M_{\tau l} > 20$ GeV/c^2 , MET > 20 GeV

$Z/\gamma^* \rightarrow \tau\tau$ region:

$M_{\tau l} > 20$ GeV/c^2 , MET < 20 GeV, $\Delta\phi_{\text{l-MET}} < 0.5$

W+jets region:

$M_{\tau l} > 20$ GeV/c^2 , MET > 20 GeV, $\Delta\phi_{\tau l} < 0.5$