Searches for Low-Mass Higgs at the Tevatron (WH and $t\bar{t}H$ Final States)

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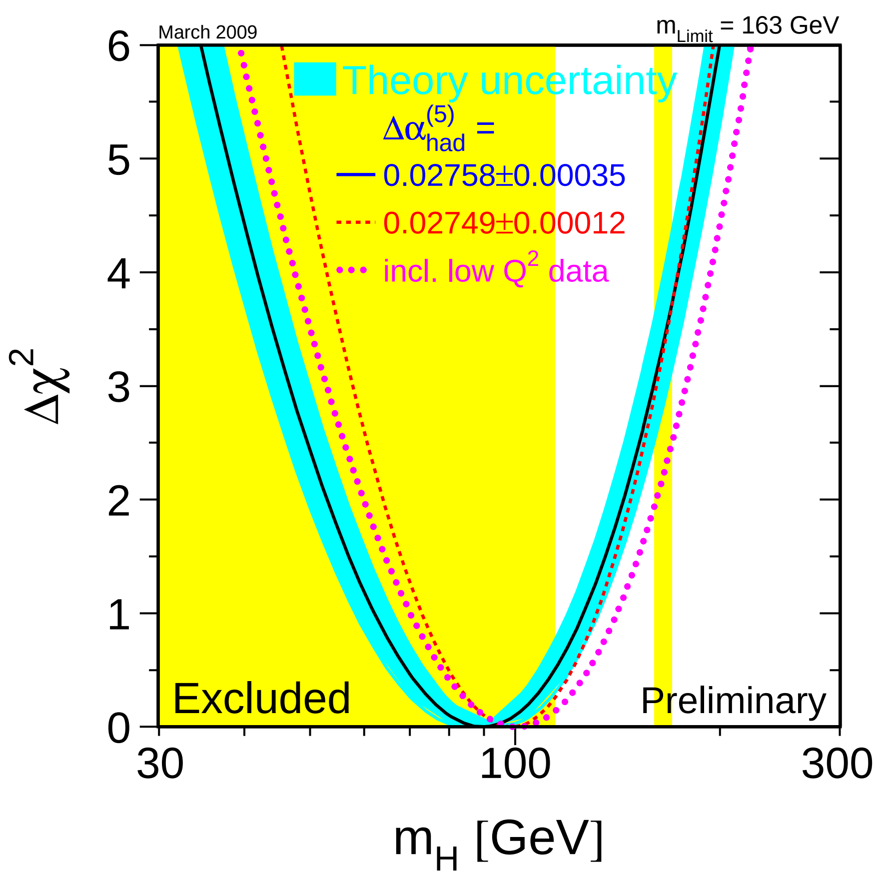
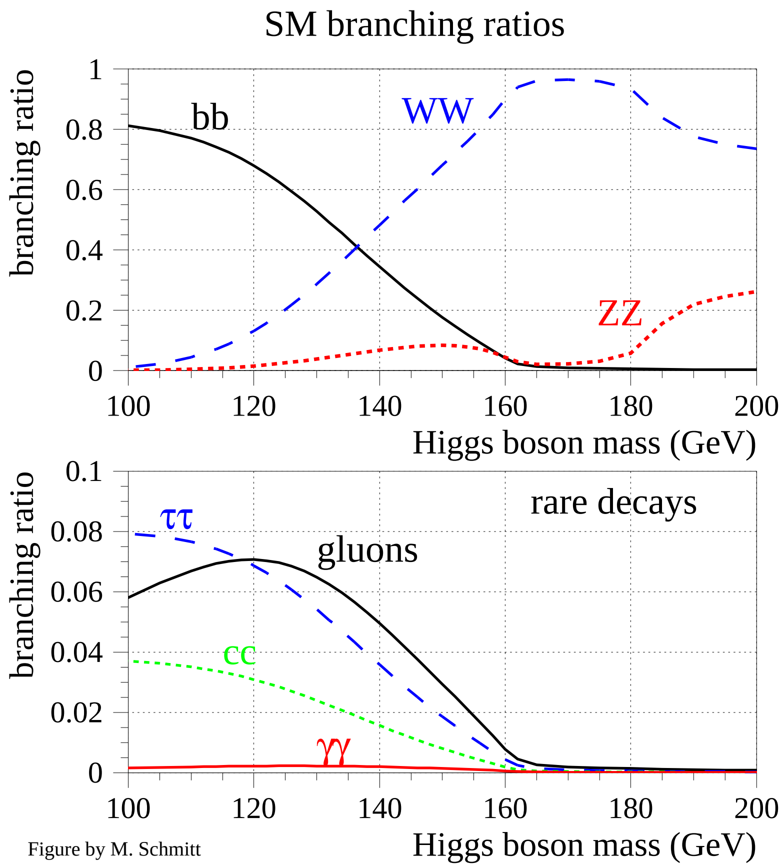
The Higgs Boson

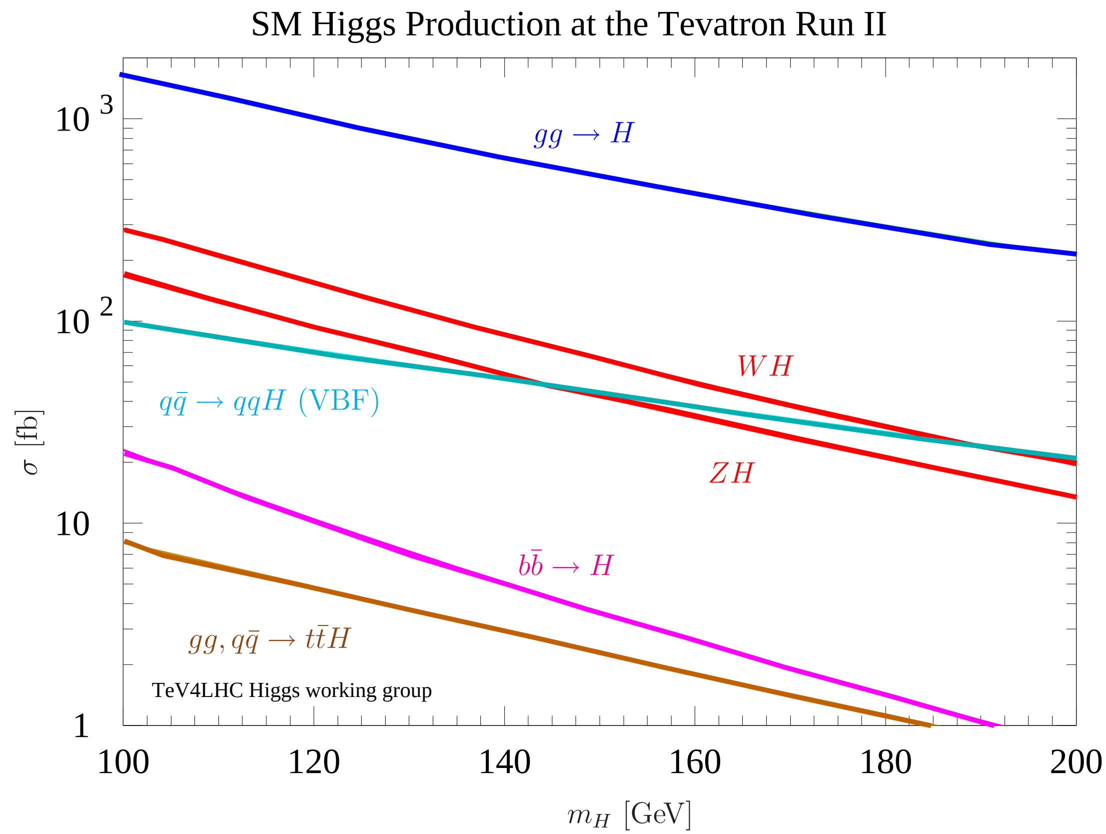
- In the Standard Model, matter particles interact by exchange of gauge bosons.
  - Couplings, masses, and widths are all interrelated in a predictable way.
  - It is extraordinarily successful.
- The Higgs is the last remaining piece of the Standard Model (SM) puzzle:



  - Generates the mass of W and Z.
  - Matter particles obtain mass by coupling to Higgs.
  - Mass of the Higgs Boson m_H not determined by theory.
  - Precision measurements of electroweak observables indirectly constrain m_H.
  - Fit favors low-mass Higgs?

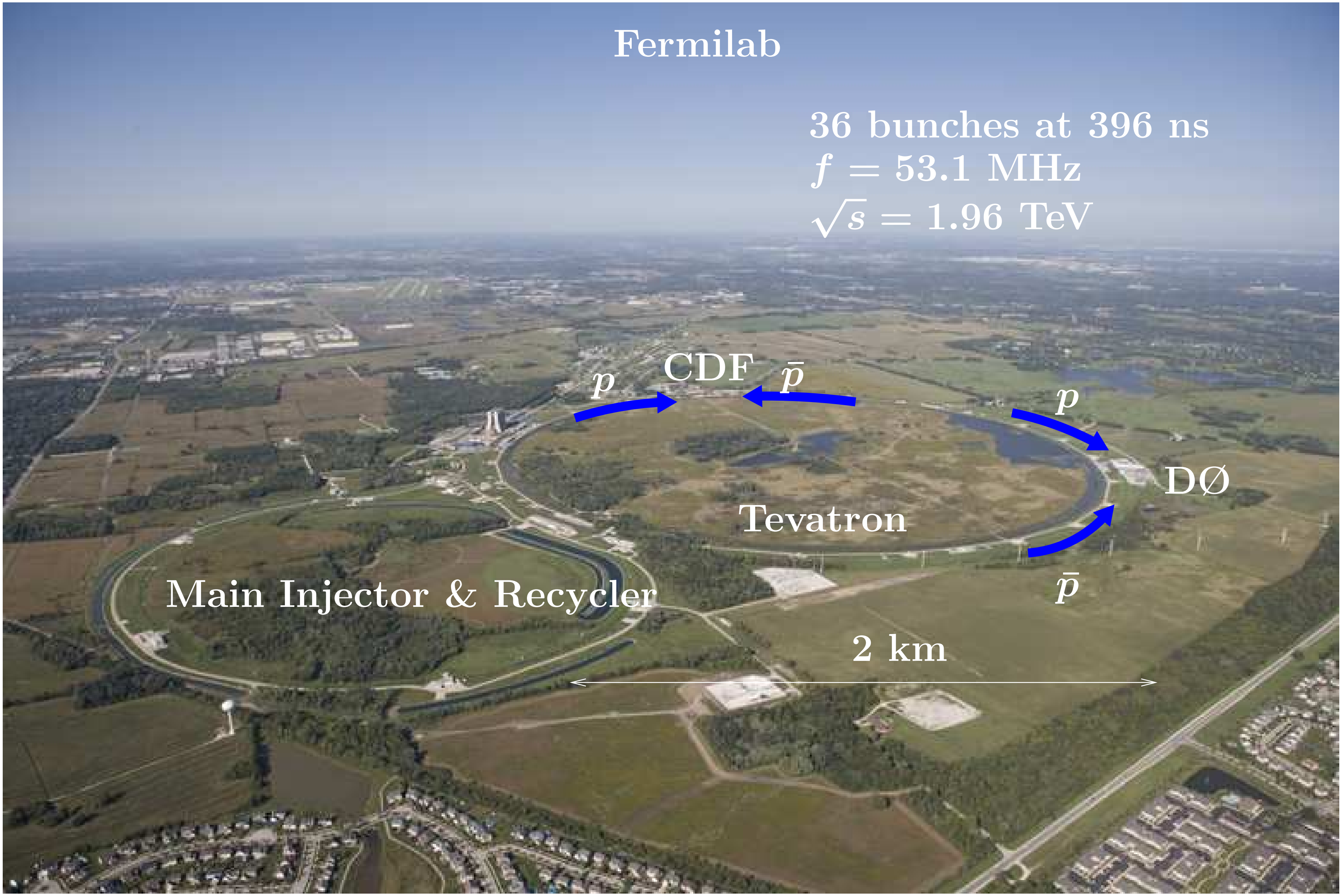
Low-Mass Higgs



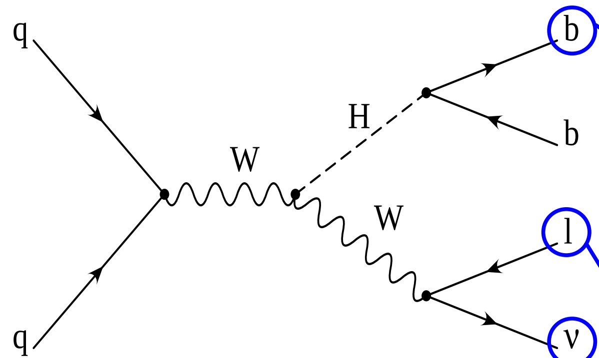


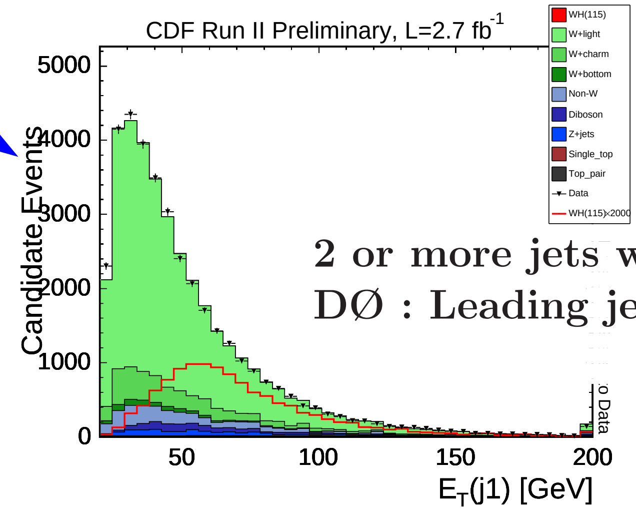
- At low-mass $gg \to H \to b\bar{b}$ swamped by $\sigma(q\bar{q} \to b\bar{b}) \sim 10^6$ pb.
- Primary low-mass sensitivity: $WH \to l\nu bb$ (muon and electron).
- Additional sensitivity: $WH \to \tau\nu bb,\ VH \to qqbb,\ t\bar{t}H$.

The Tevatron

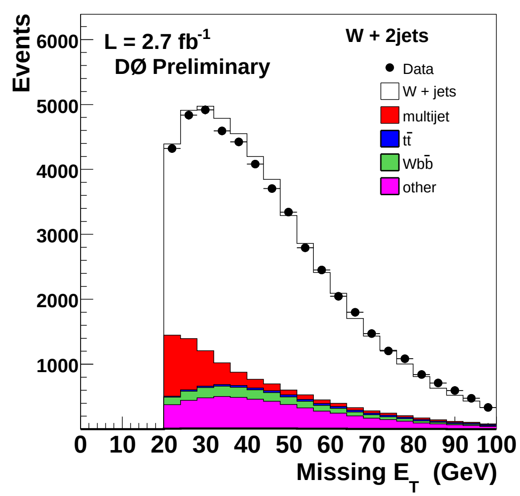


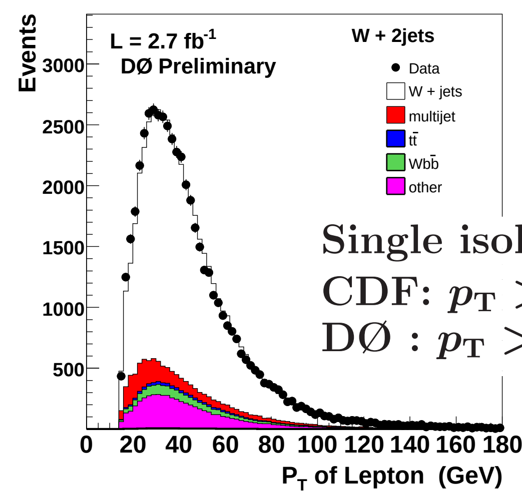
$WH \to l\nu bb$ Selection





2 or more jets with $p_T > 20$ GeV
DØ : Leading jet $p_T > 25$ GeV

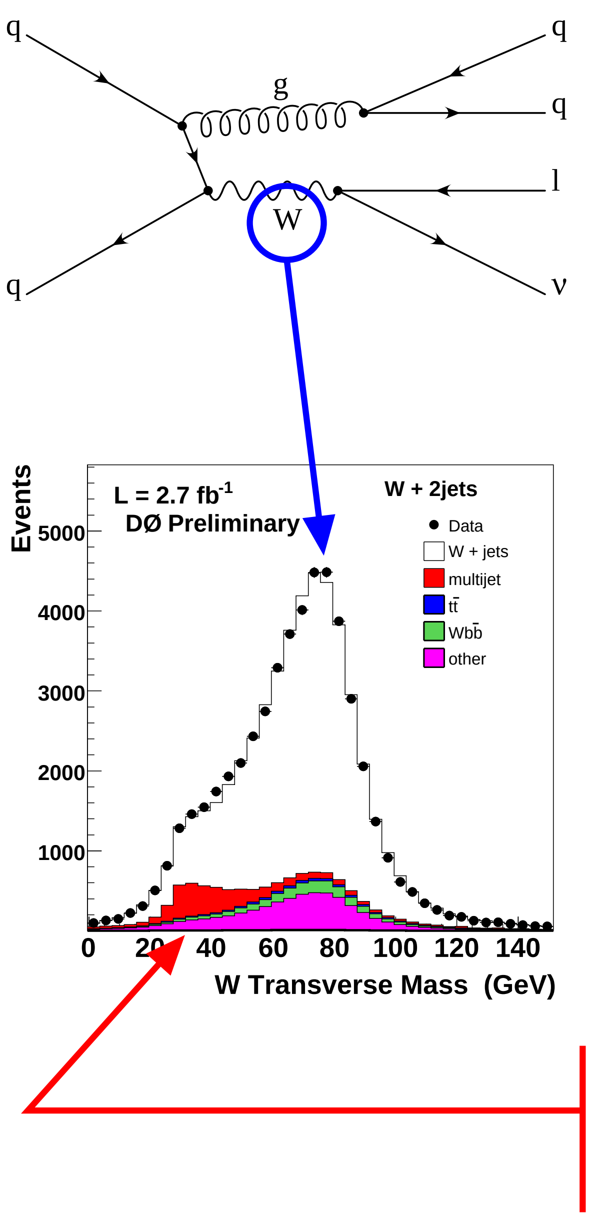




Single isolated lepton
CDF: $p_T > 20$ GeV
DØ : $p_T > 15$ GeV

Missing Transverse Energy $\not{E}_T$
CDF: $\not{E}_T > 20$ GeV, 25 GeV for forward electron
DØ : $\not{E}_T > 20$ GeV for muon, 25 GeV for electron

$WH \to l\nu bb$ Background

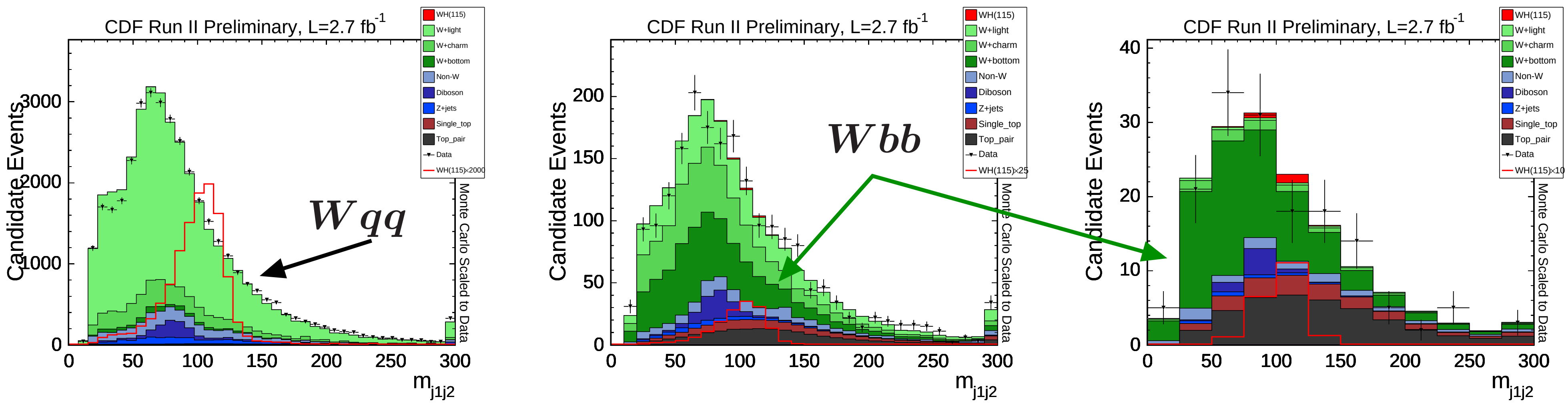


- SM backgrounds modeled with MC generation plus GEANT detector simulation.
  - Primary background W+jets.
  - Diboson production: WW, WZ, ZZ.
  - Single-top, $t\bar{t}$, and Z+jets.
- Both CDF and DØ measure instrumental background from misidentified multijet events in data.
  - Lepton efficiency ε_l well-understood independently.
  - Obtain multijet enhanced sample based on $\not{E}_{\mathrm{T}}$.
  - Measure fake rate ε_j of jets which pass loose lepton id to also pass tight id.
  - Allows bin-by-bin prediction of multijet:

$$N = \frac{\varepsilon_l \cdot N_{\mathrm{loose}} - N_{\mathrm{tight}}}{\varepsilon_l - \varepsilon_j}$$

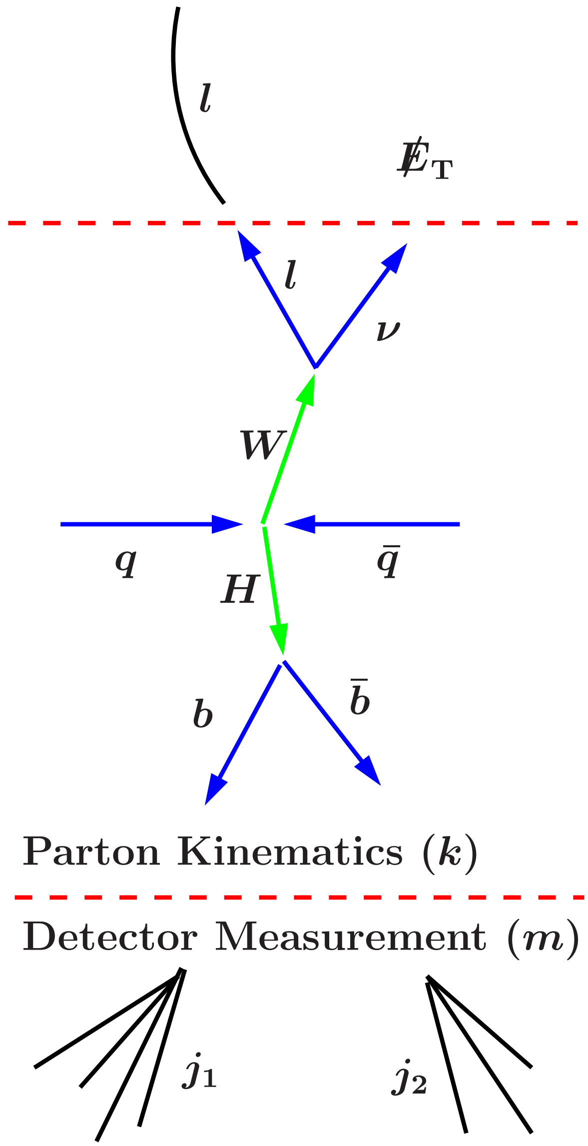
b-Tagging Requirements

No b-tag **Single b-tag** **Double b-tag**



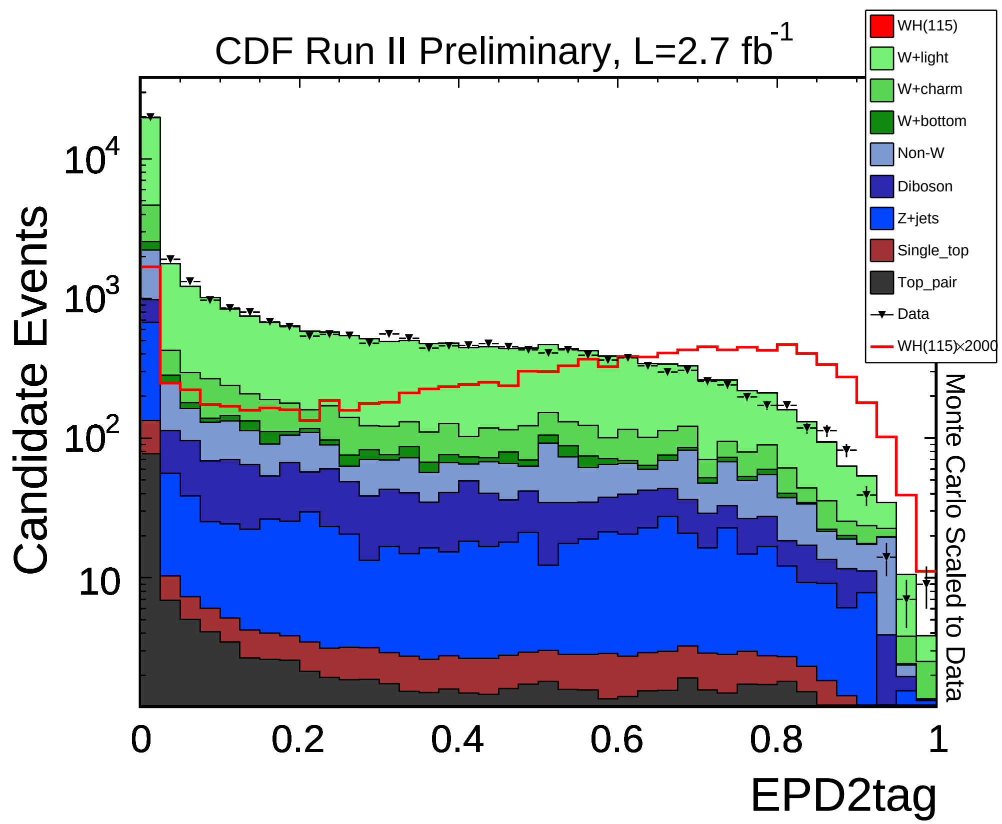
- CDF and DØ b-tagging algorithms discriminate light-jets from b-jets:
  - ▷ b-hadrons are slow to decay, and so b-jets often have a secondary vertex.
  - ▷ b-quark is heavy, so b-jets are wider, with higher invariant mass and multiplicity.
- Select orthogonal b-tag channels to optimize $S/\sqrt{B}$.
- Signal contribution still small after b-tagging, use multivariate techniques.

Matrix Element (ME)

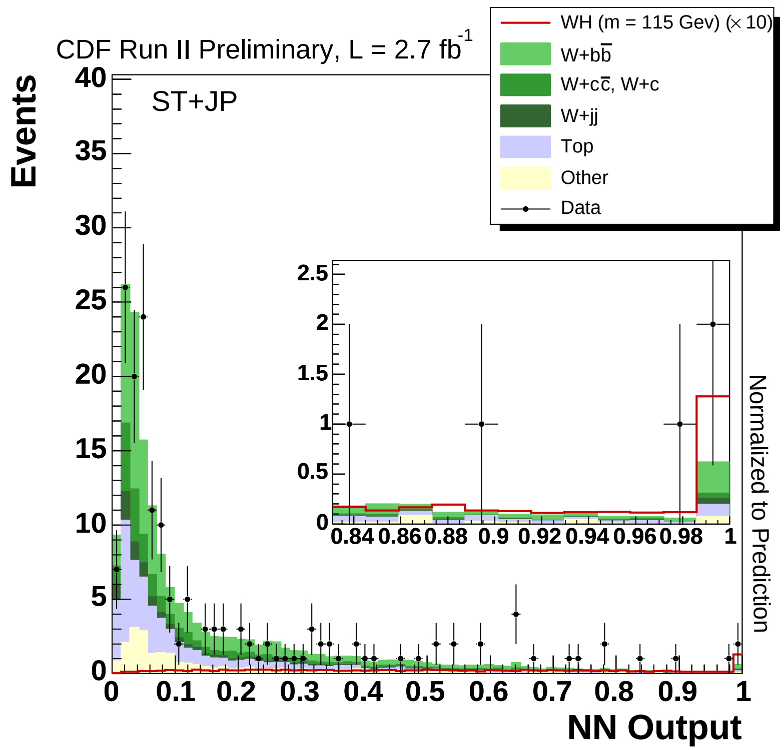


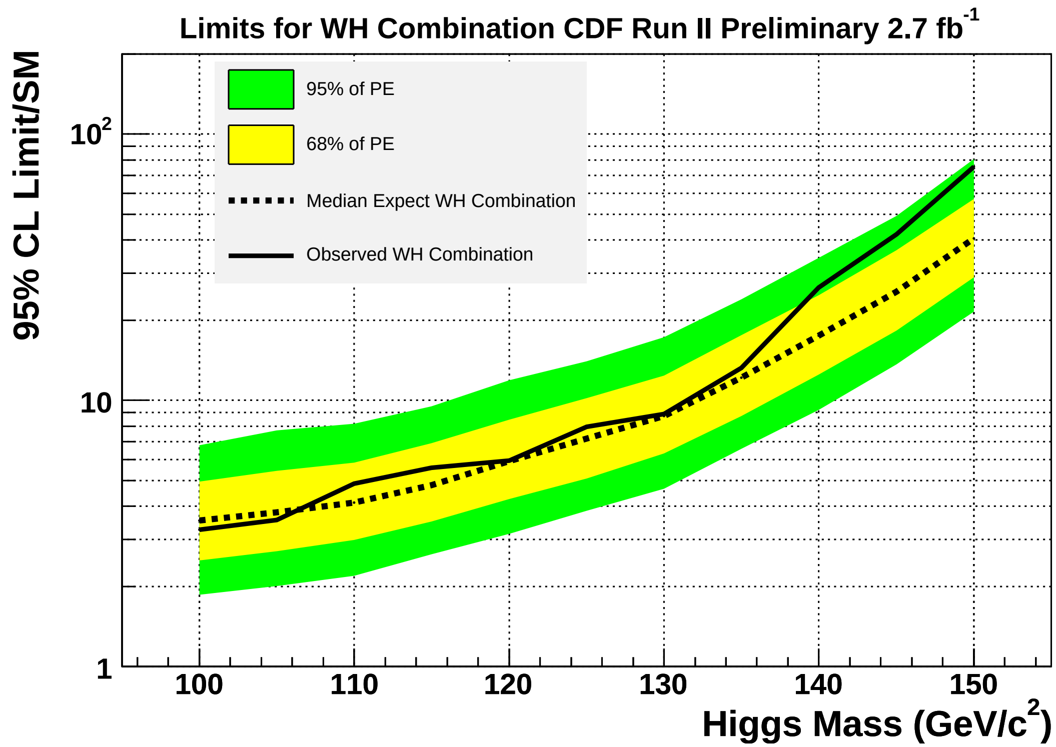
- Both CDF and DØ use ME discriminant to make full use of event kinematics.

$$p(m) = \int dk \cdot |\mathcal{M}(k)|^2 \cdot T(k,m)$$



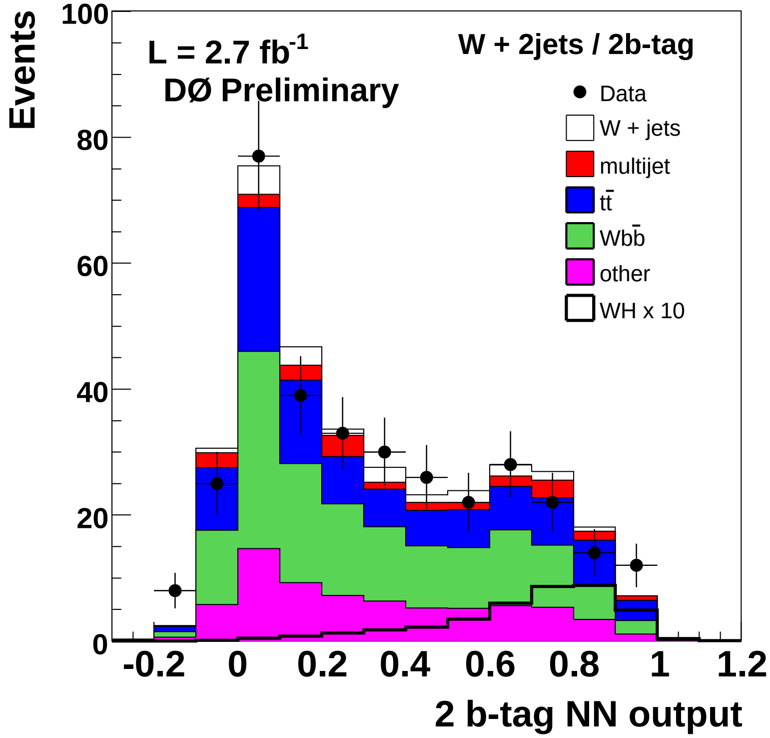
CDF combined $WH \rightarrow l\nu bb$ Results

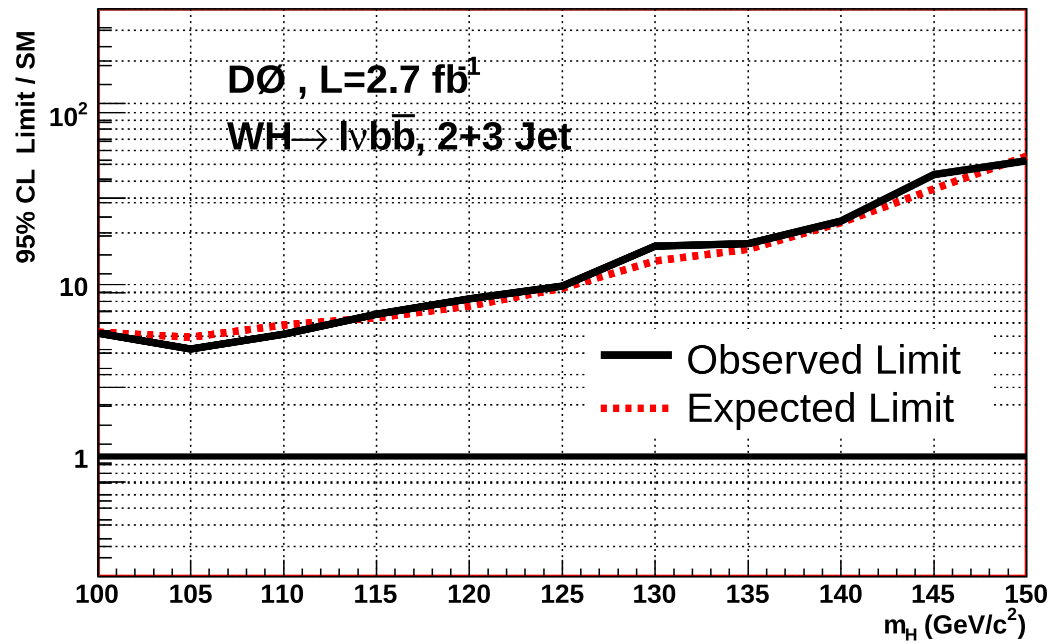




- CDF has two analyses with different multivariate discriminants:
  - ▷ Artificial Neural Network (NN), and
  - ▷ Matrix-Element + Boosted Decision Tree (ME+BDT)
  - ▷ NN and ME+BDT combined with genetic algorithm.
- At $m_H = 115$ GeV observed limit is $5.6\times$SM (4.8 expected).

DØ $WH \rightarrow l\nu bb$ Results

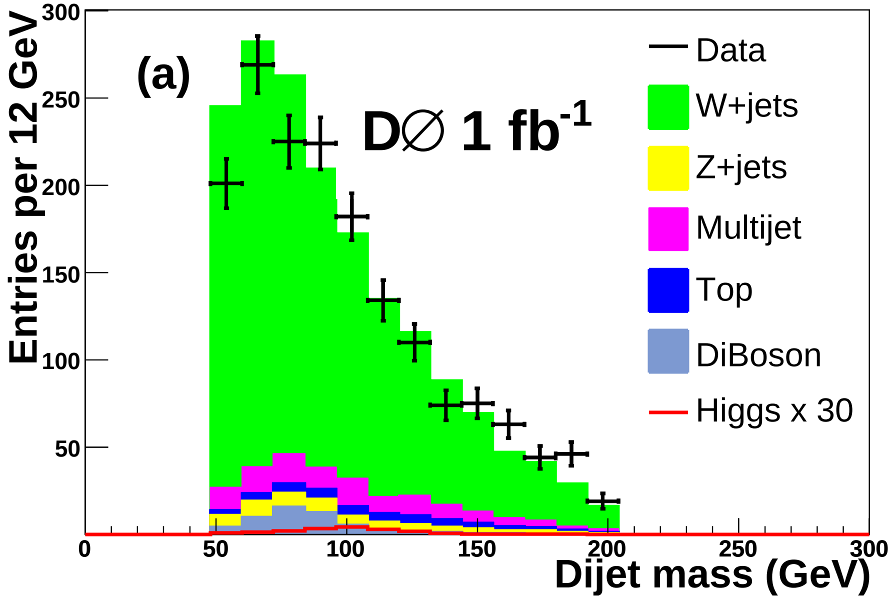




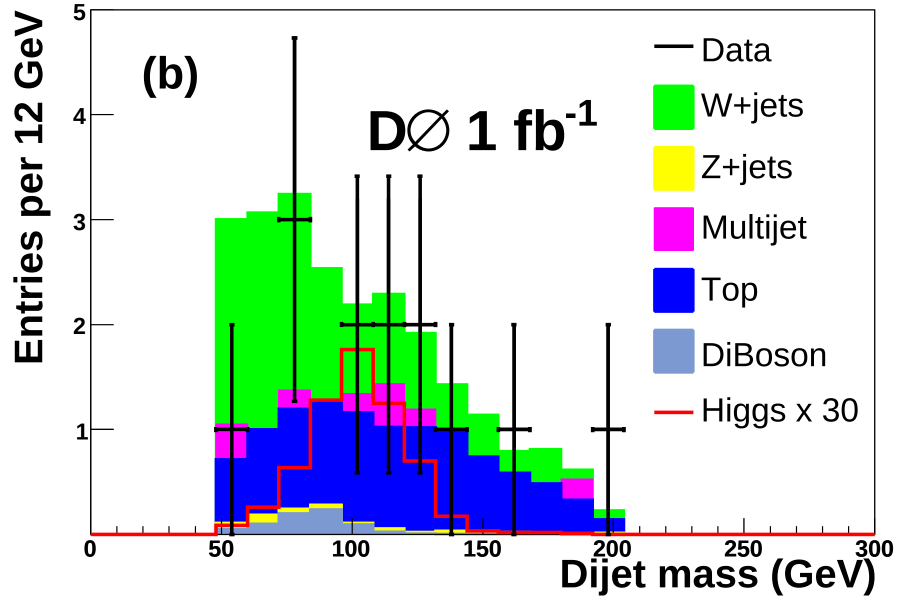
- DØ analyses trains NN using ME as additional input.
- At $m_H = 115$ GeV observed limit is $6.7\times$SM (6.4 expected).

DØ $WH \to \tau\nu bb$ Search

No b-tag

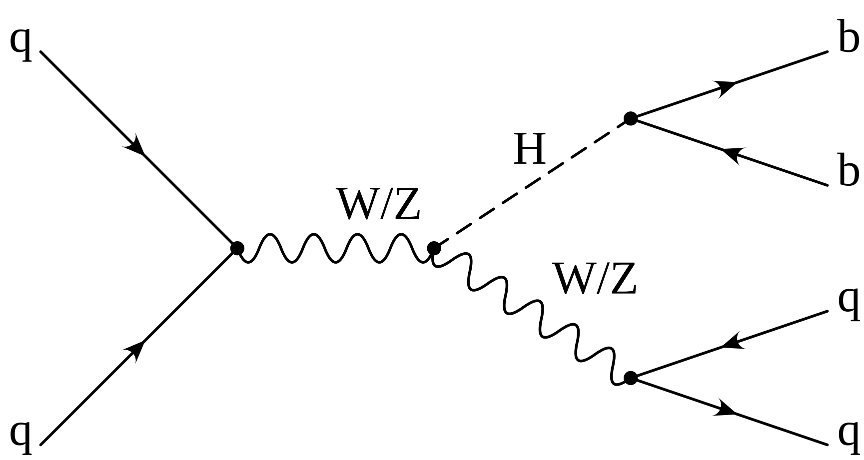


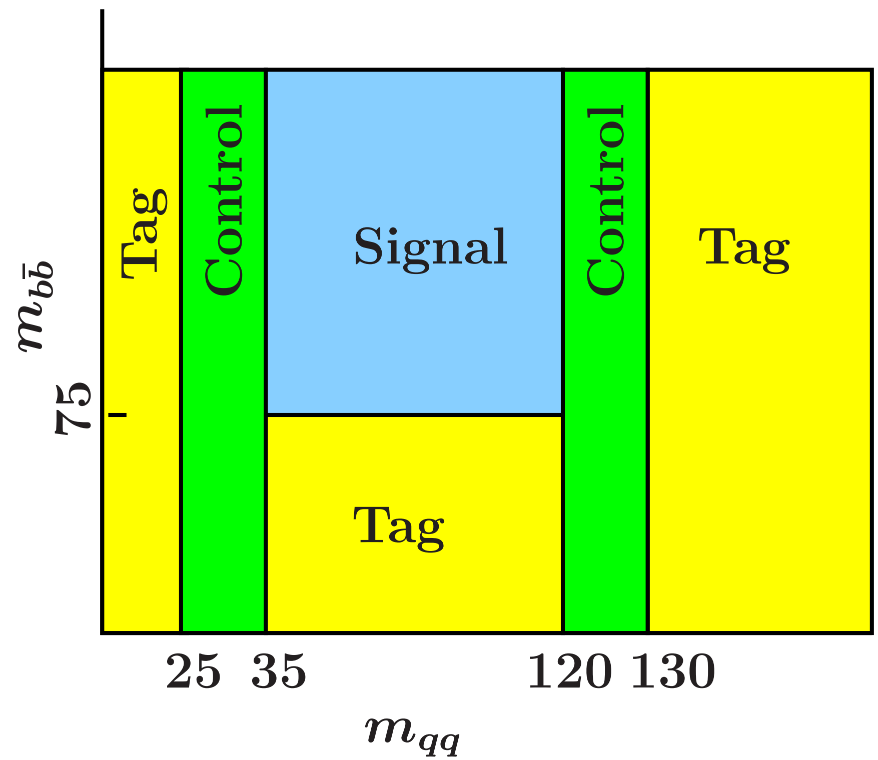
Double b-tag



- Orthogonal selection of hadronic tau decays (electron and muon veto).
  - Tau reconstruction adds additional complexity to analysis.
- Multijet background from data, others from MC simulation.
- Dijet-mass distribution used as final discriminant.
- At $m_H = 115$ GeV observed limit of $35\times$SM (expected 42).

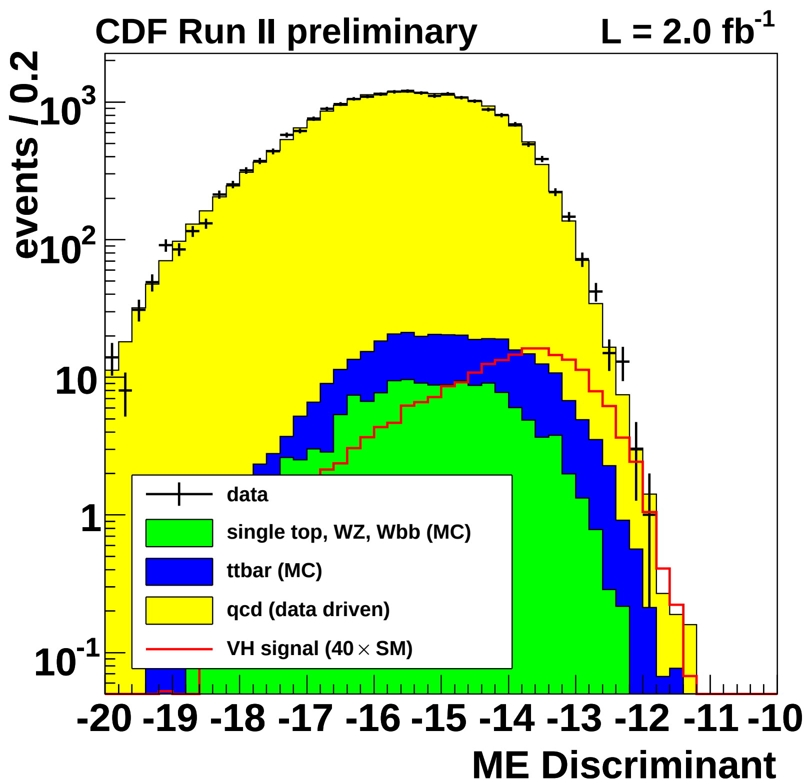
CDF Fully Hadronic VH Search

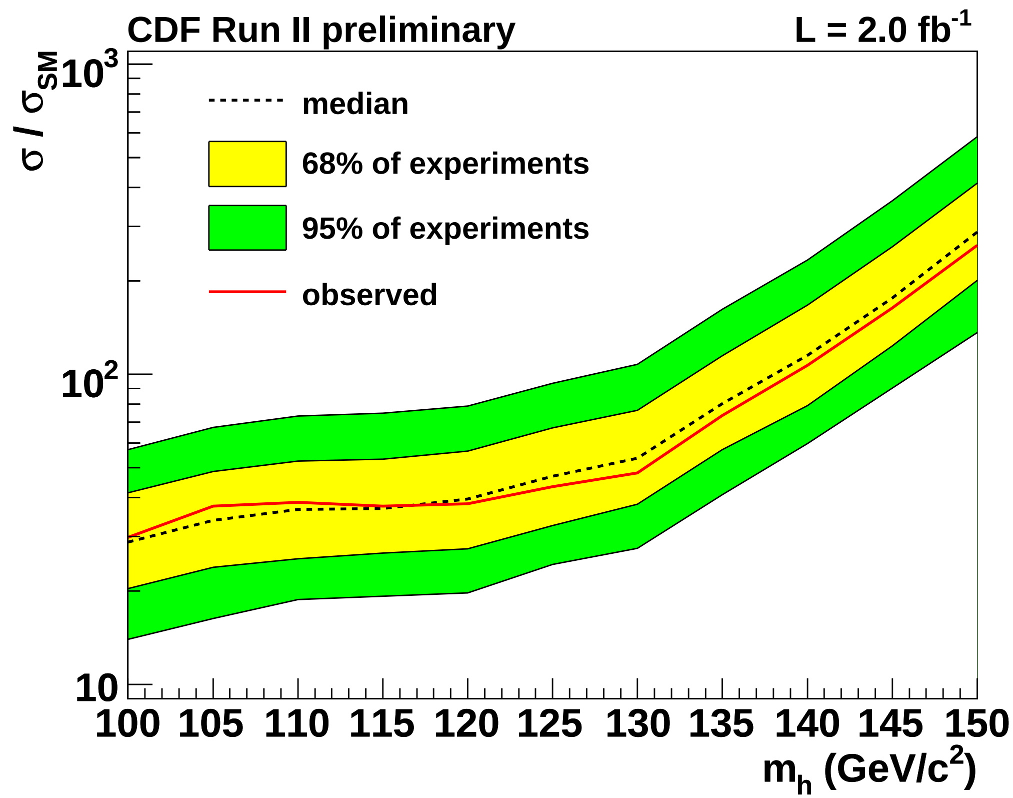




- CDF search for fully hadronic $ZH, WH \rightarrow qqbb$.
- Multijet background estimated from $bjjj$ sample.
- Measure tag-rate in low and high m_{qq} sidebands.
- Extrapolate to m_{qq} signal region using low $m_{b\bar{b}}$ sideband.
- Test with control region (also in 5-jet bin)

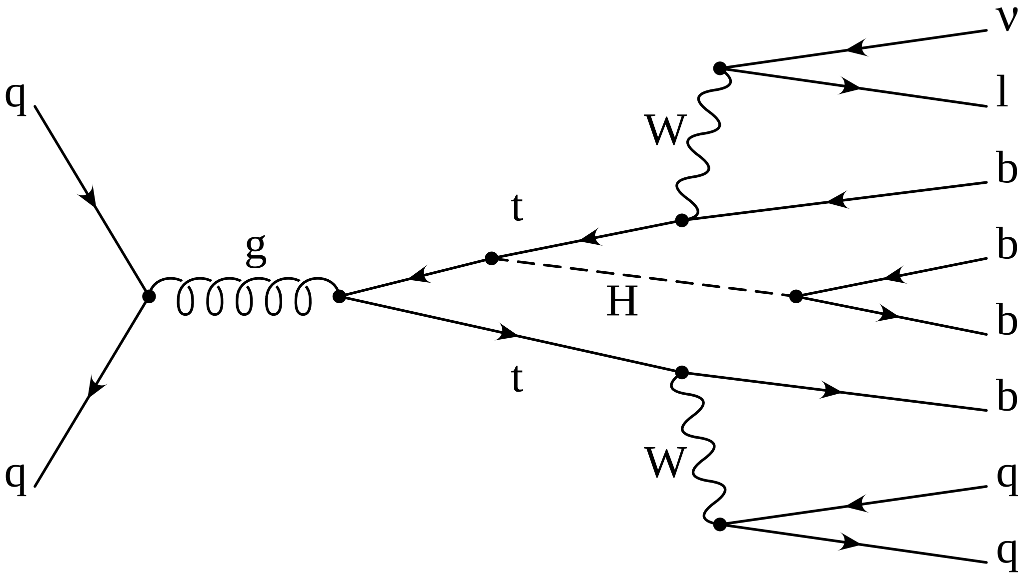
CDF Fully Hadronic VH Search

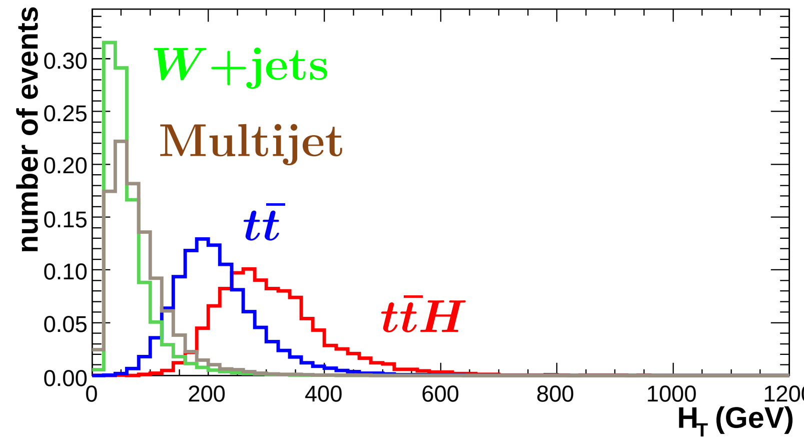




- Large signal but even larger background: matrix-element discriminant.
- At $m_H = 115$ GeV observed limit of $38\times$SM (expected 37).

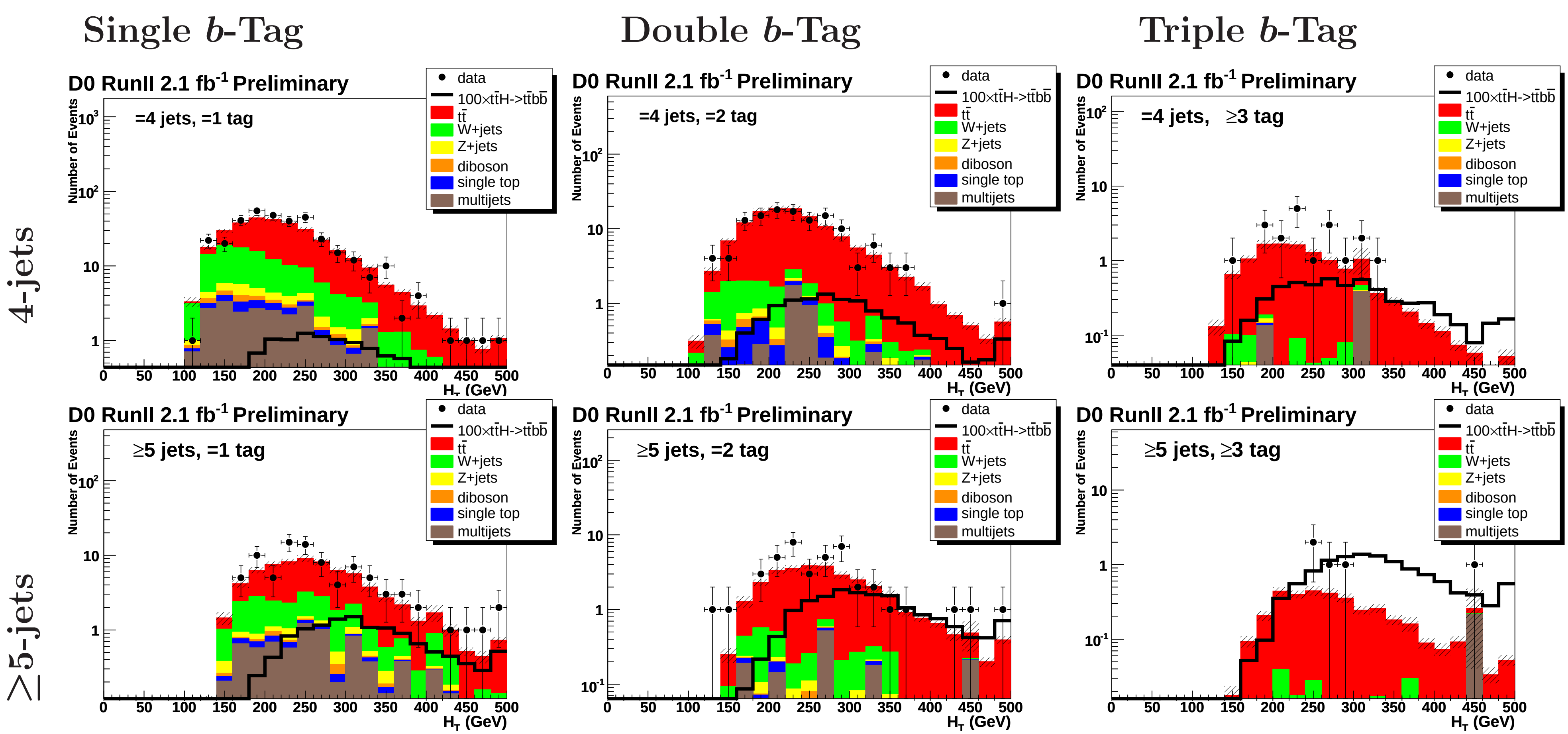
DØ $ttH \to ttbb$ Search





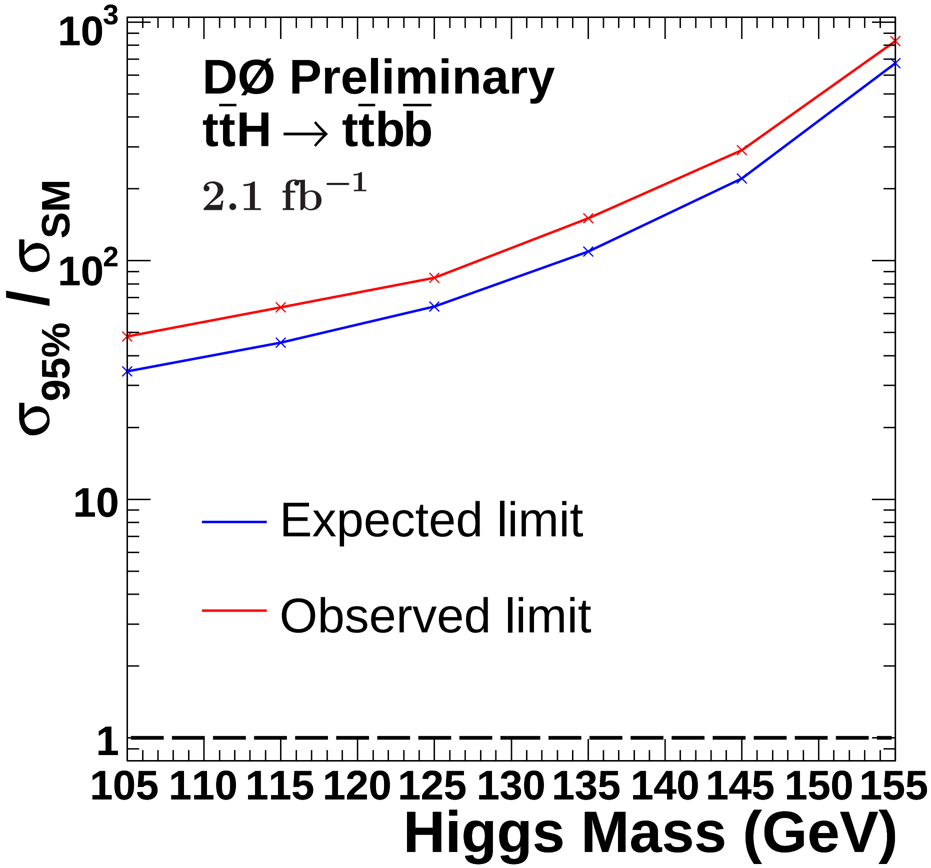
- ttH has crowded final state:
  - four b-quarks, two light-quarks, a lepton and neutrino.
- Primary backgrounds: $t\bar{t}$, W+jets, and multijet.
- Kinematic variables discriminate between signal/background:
  - Number of jets, and number with b-tags.
  - H_{T}, scalar sum of p_{T} from first four or five leading jet.
  - H_{T} outperforms e.g. dijet invariant mass.

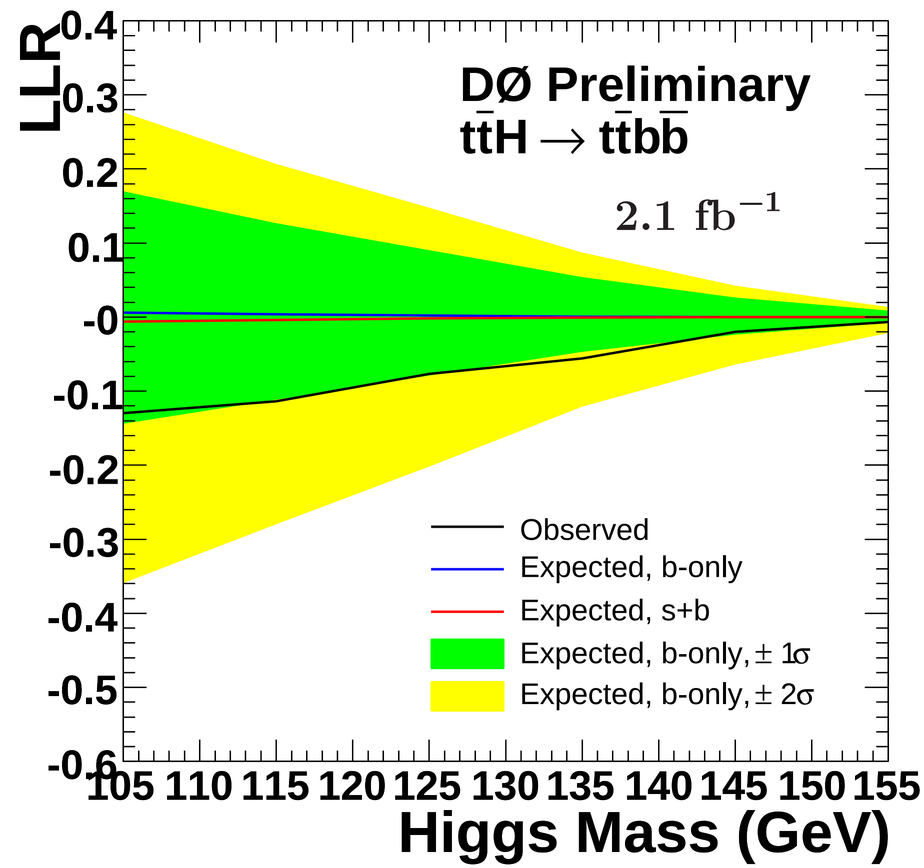
DØ $ttH \to ttbb$ H_T



- Look for signal excess in H_T, binned in number of jets and b-tags.
- 1-tag and 2-tag bins constrain background, improve limit.

DØ $ttH \rightarrow ttbb$ Results





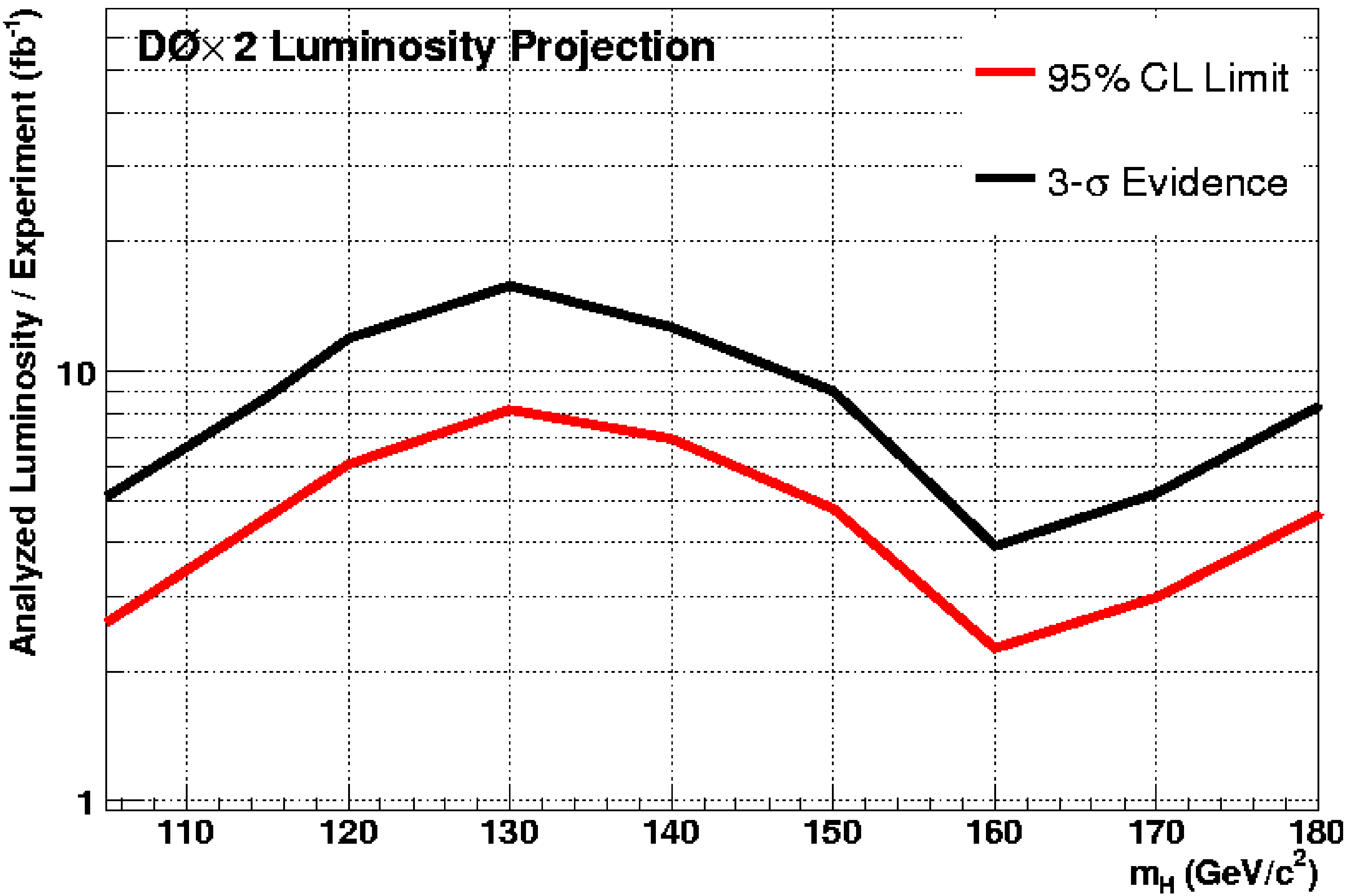
- At $m_H = 115$ GeV observed limit of $64 \times$SM (expected 45).

Outlook

- Tevatron is reaching for SM sensitivity to a low-mass Higgs.
- The accelerator is providing collisions at an astonishing rate:
  - ▹ Could reach 10 fb^{-1} analyzed with 2011 running.
- Both CDF and DØ continue improving faster than $\sqrt{L}$:
  - ▹ Optimizing analyses using advanced multivariate techniques.
  - ▹ Gaining additional efficiency from looser selections.
  - ▹ Adding additional channels to combination.
- A low-mass Higgs is a challenge for the LHC as well.
- It is shaping up to be a fascinating race:
  - ▹ Mature, well-understood Tevatron reaching as far as it can.
  - ▹ New LHC racing to overcome problems, understand data.

(Backup Slides Follow)

Projections



Projections