The Hunt for the Higgs Boson in the Standard Model

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Annual D.O.E. Review

Starring:

$WH \rightarrow$ leptons, neutrinos, and bottom-quarks
$ZH \rightarrow$ leptons, neutrinos, and bottom-quarks
$H \rightarrow WW^* \rightarrow$ electrons, muons, and neutrinos

The Plot:

Suggested over 35 years ago by theorists to explain how particles get their mass in the Standard Model, the Higgs boson has been on high-energy experimentalists' most-wanted list every since.

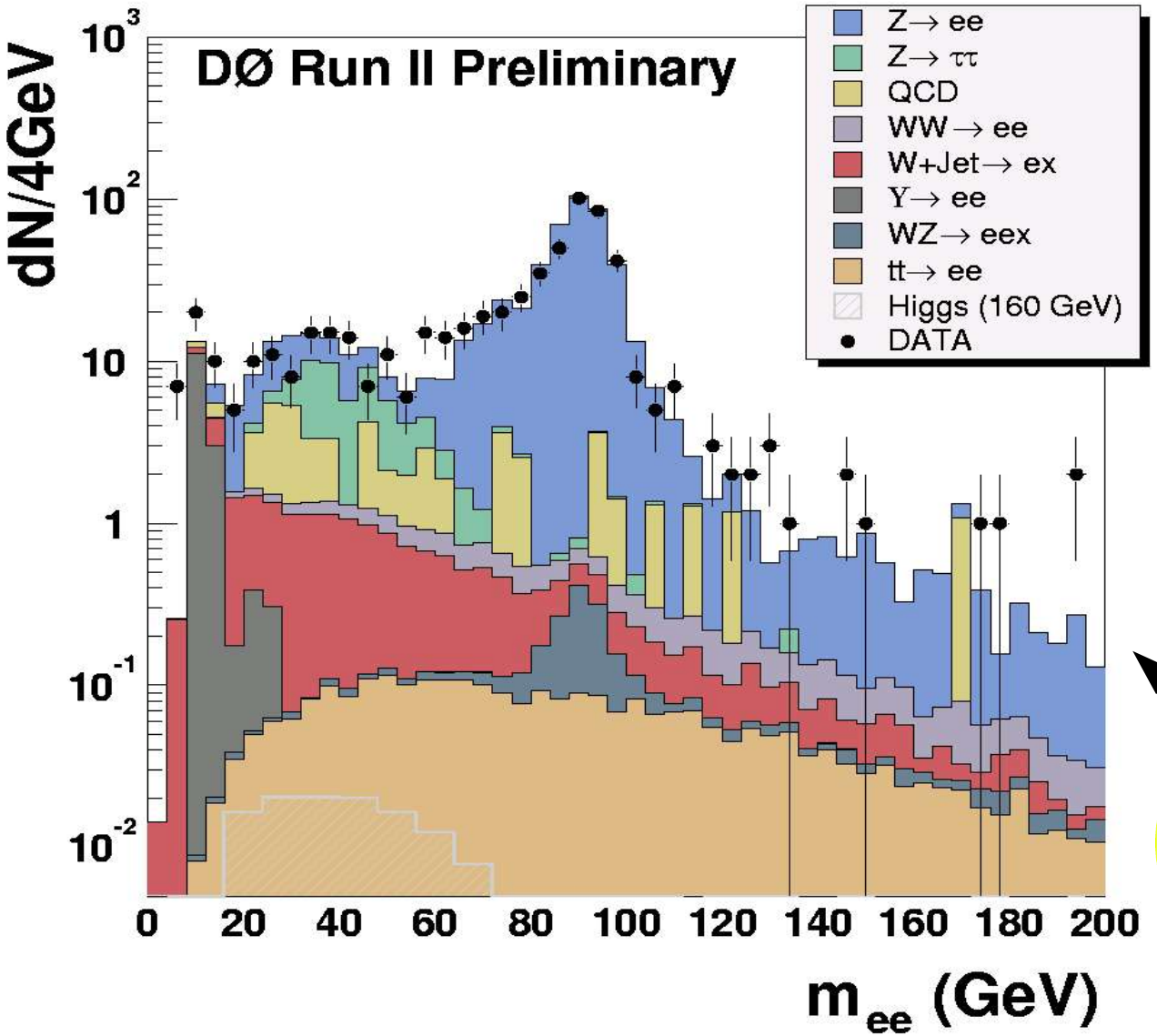
The DØ experiment is searching for the Higgs boson, and is already placing new limits on its production.

The final piece of the Standard Model is still missing...

Search for Higgs →WW*

Invariant mass of two electrons in data compared to Monte Carlo

1



If the Higgs is "heavy" (>~140 GeV), it will decay primarily to pairs of W bosons.

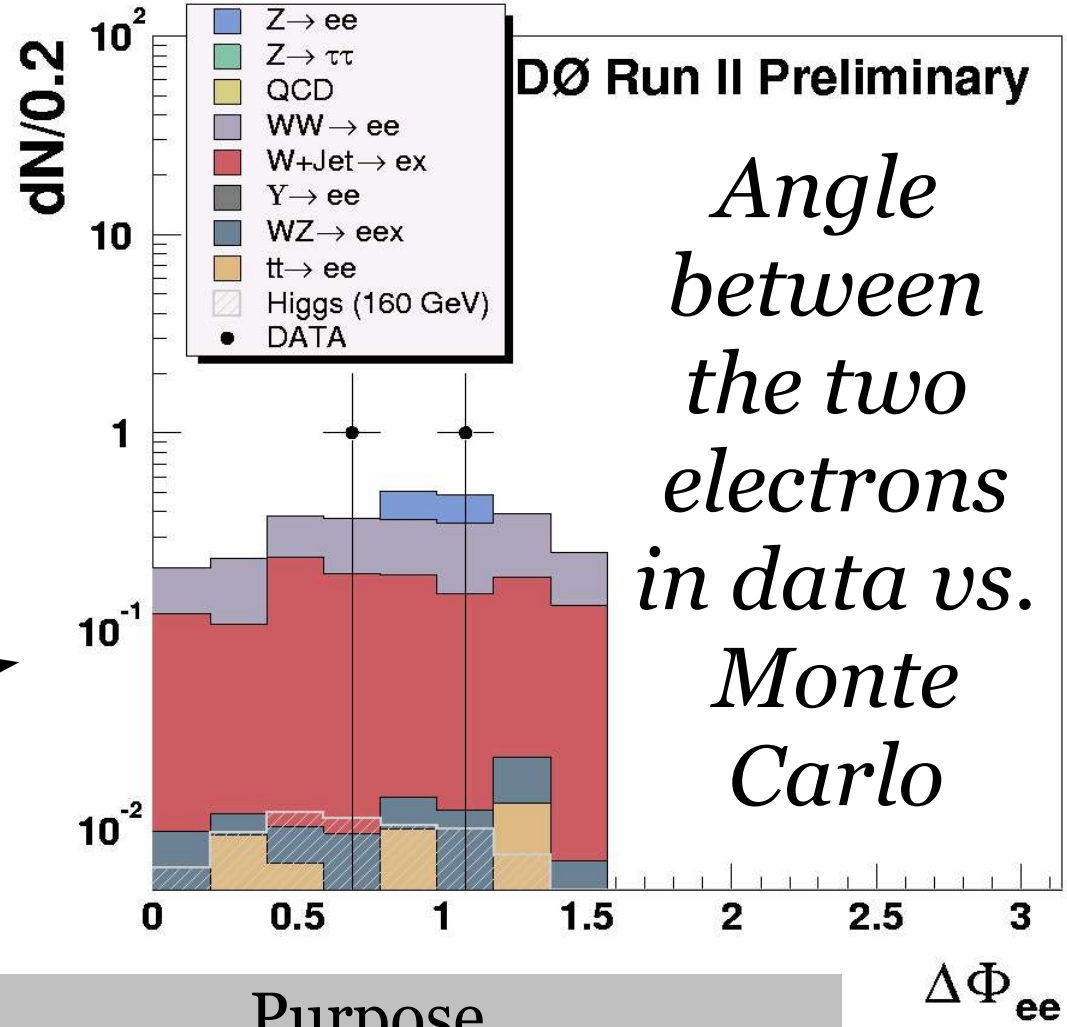
DØ is placing new limits on the excess production of W boson pairs.

First, we verify the agreement of two leptons and missing E_T data with Monte Carlo

Search for Higgs →WW*

2

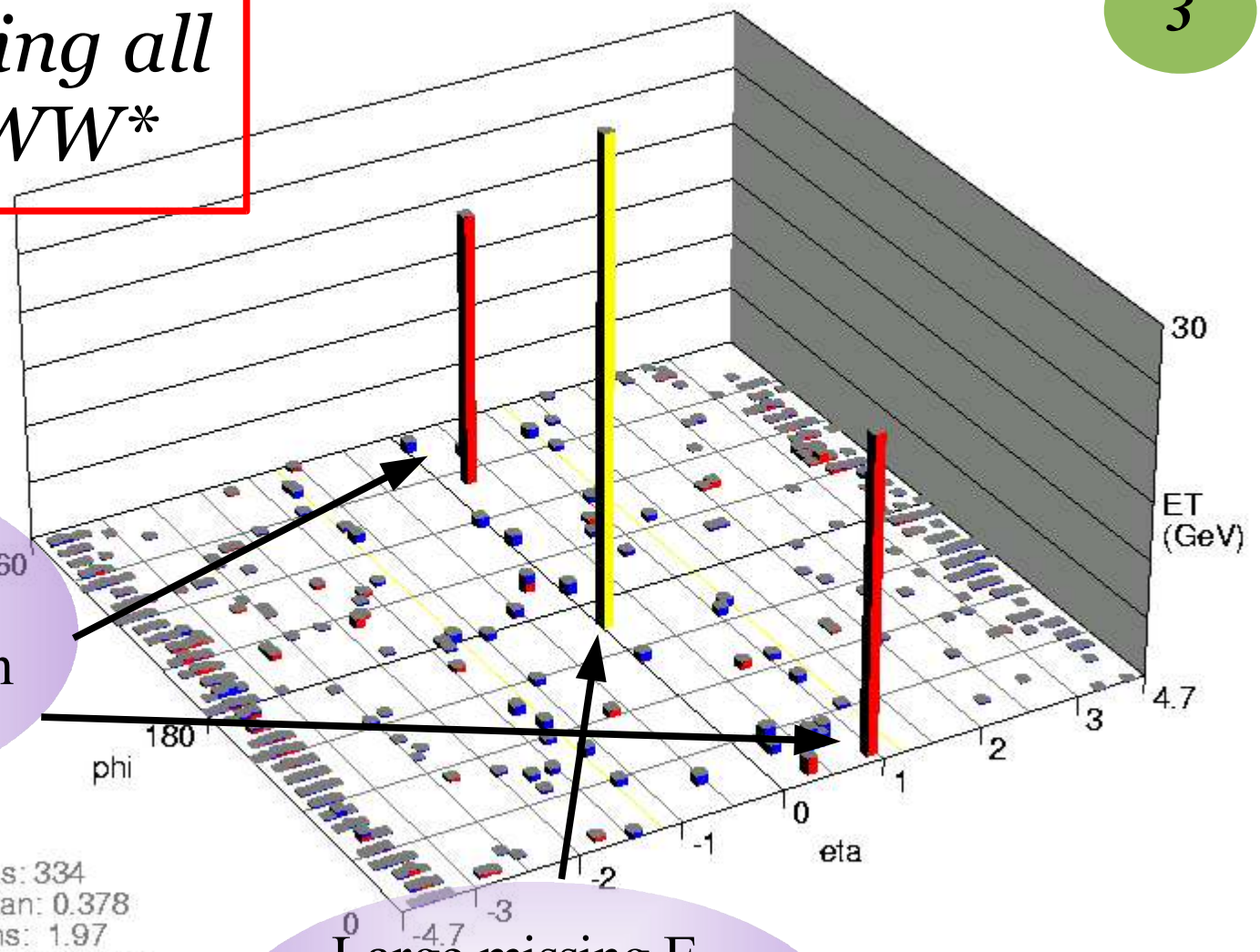
Next, we make more selective cuts to reduce the backgrounds



Requirement	Purpose
Large missing E_T (>20 GeV)	*Select events with W bosons*
Invariant mass < 80 GeV	*Reduce Z background*
Large H_T (>100 GeV)	*Reduce QCD and Y backgrounds*
Veto on large number of jets	*Reduce top-quark background*
Small angle between electrons	*Reduce WW background*

Search for Higgs →WW*

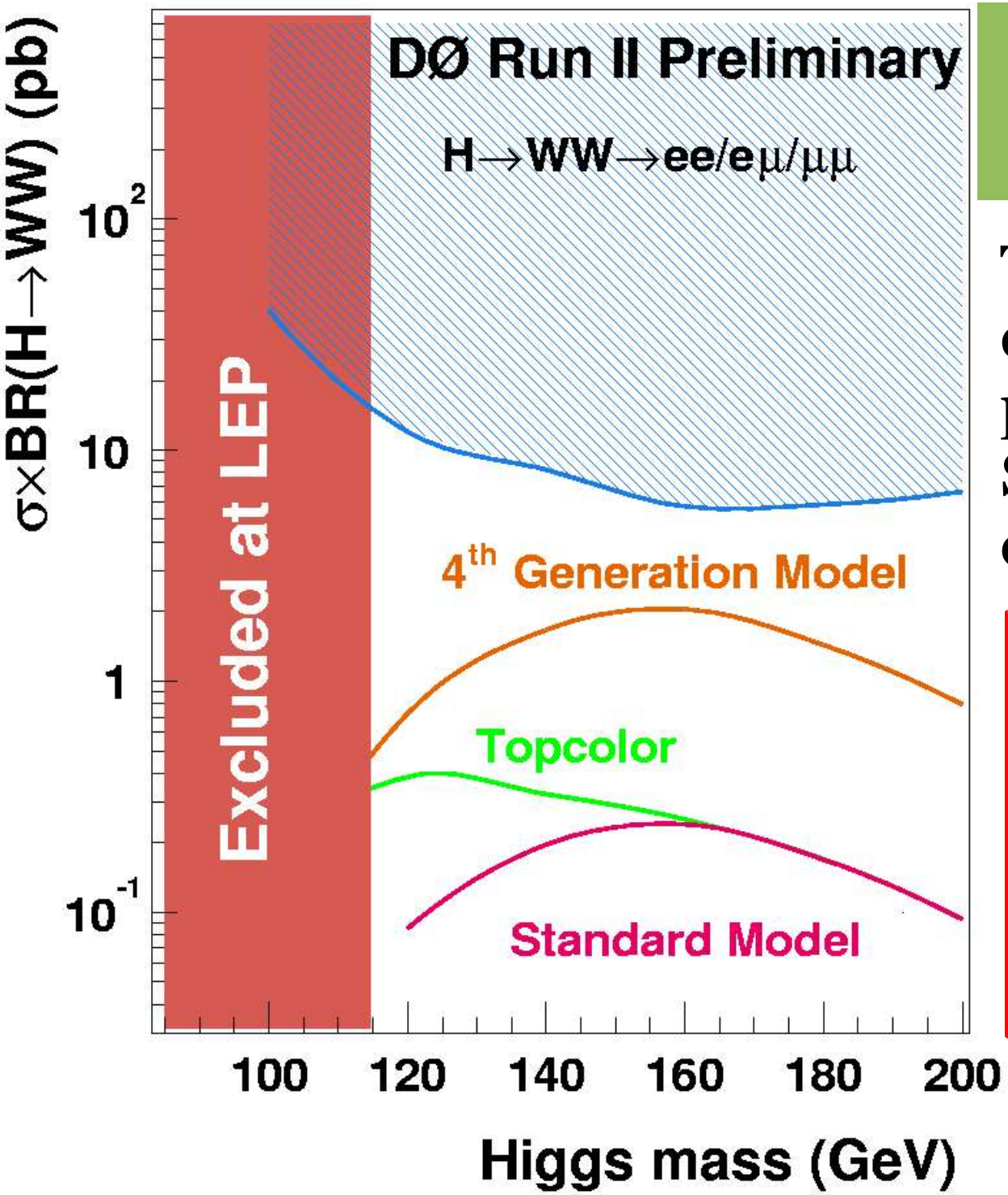
*An event passing all criteria for WW**



Two electrons (one from each W) Small angle between them!

Large missing E_T from two neutrinos (one from each W)

Search for Higgs →WW*



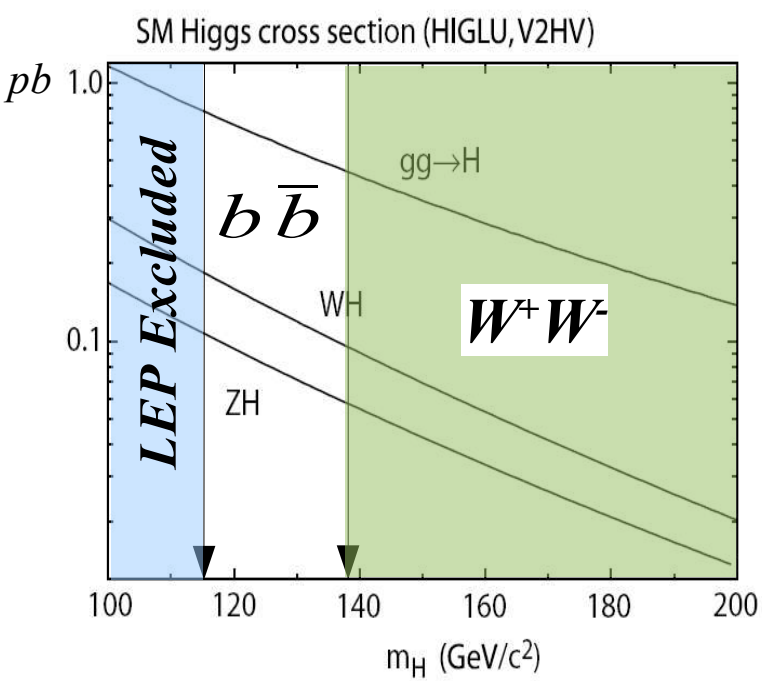
The limits are compared to predictions from the Standard Model and other theories

New limits have been placed on the production of Higgs bosons decaying to WW*

W and Z + jets with b-tagging: *Background to a light Higgs boson*

1

Higgs boson production and decay in the SM



A light (<~140 GeV) Higgs in the Standard Model (SM) decays primarily to bottom quarks.

We search for the Higgs in association with either a W or Z boson (to reduce the huge QCD background).

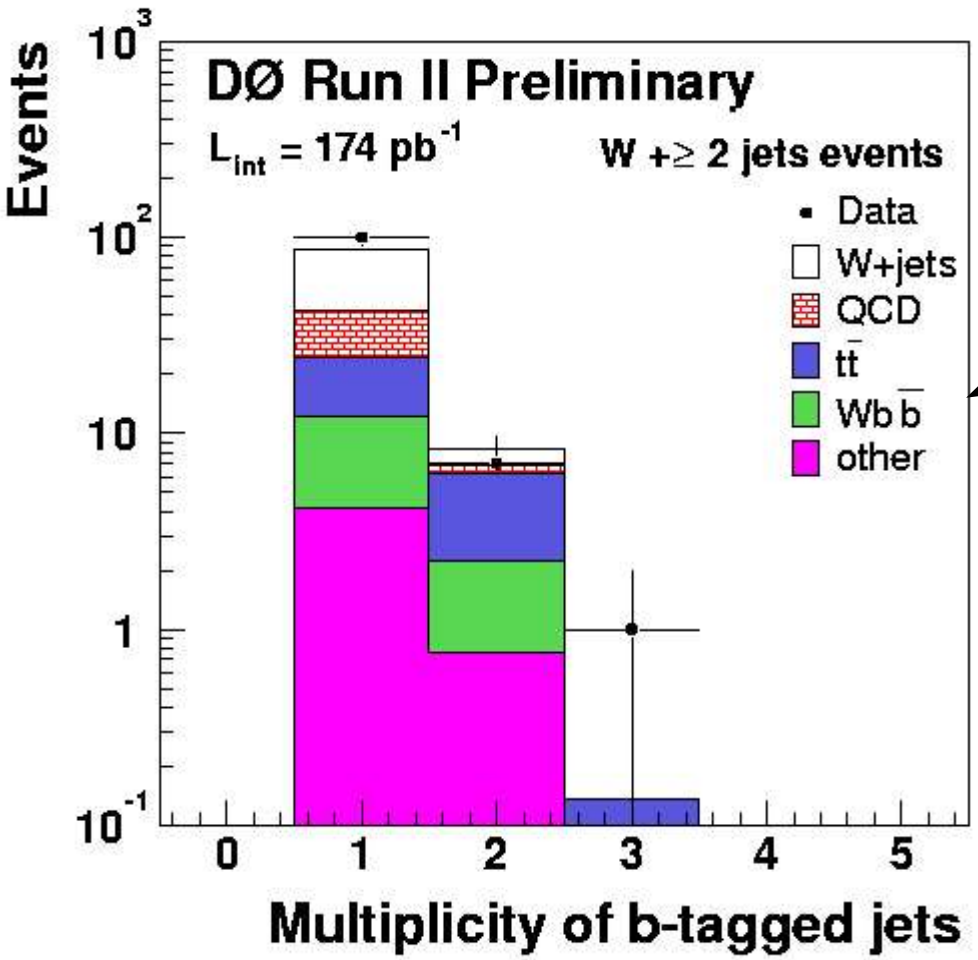
Understanding W (and Z) production with b-jets is crucial to a search for SM Higgs.

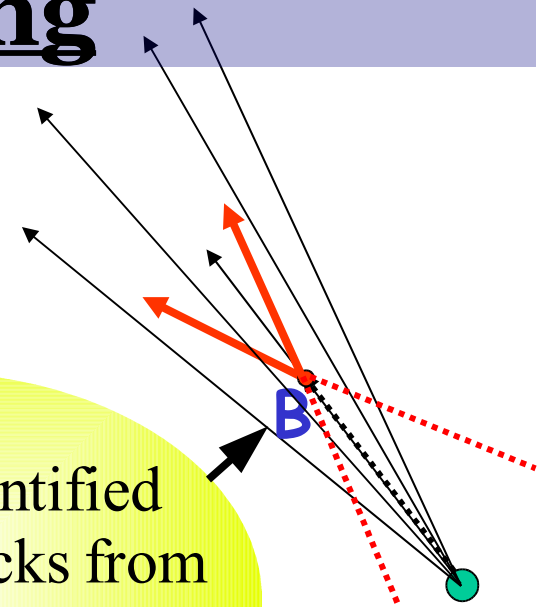
We are making measurements of important Higgs backgrounds

W+jets with b-tagging

2

Number of b-tagged jets in W + ≥2 jet events





b-jets are identified by finding tracks from *secondary vertices* inside jets

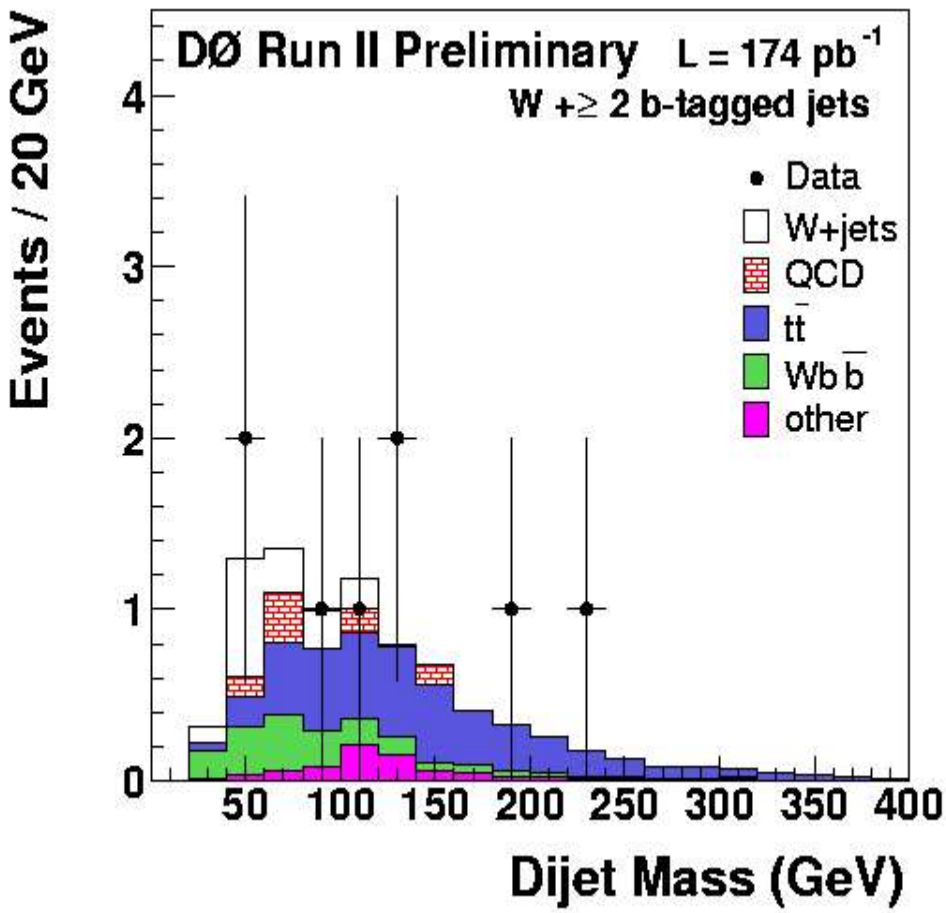
We observe roughly the number of b-tagged jets that we'd expect.

Most of the 8 double b-tagged events are from top-quark events.

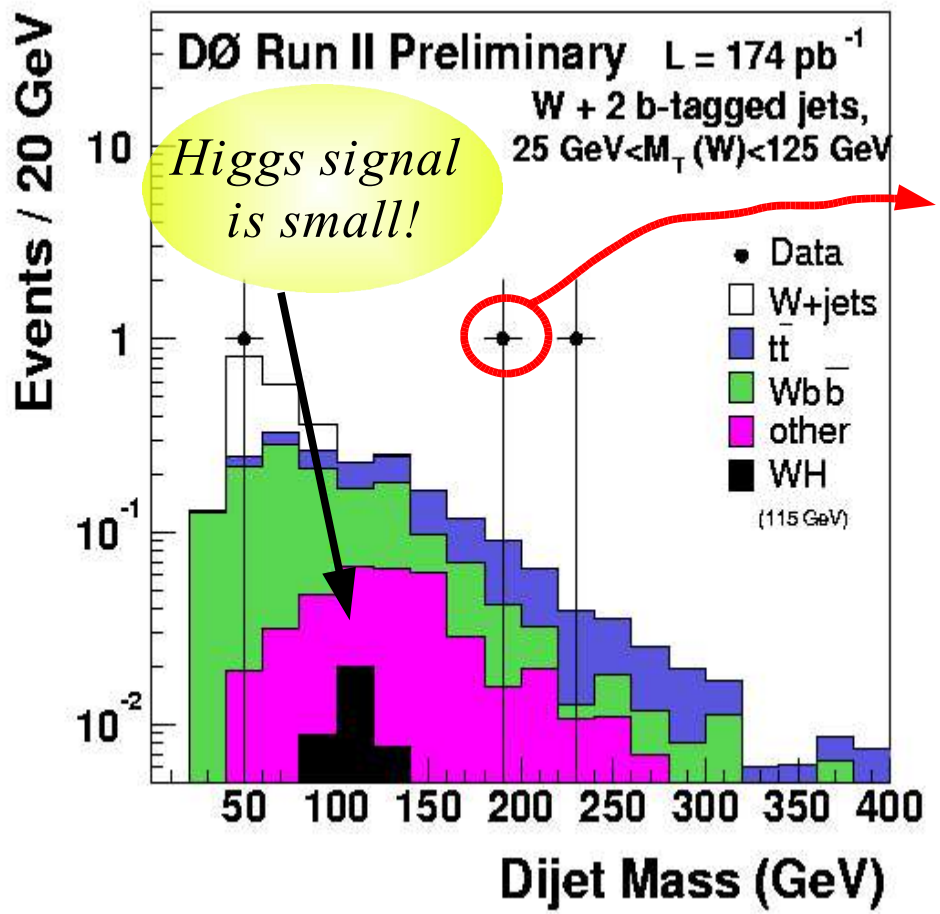
W+jets with b-tagging

3

Invariant mass of ***all*** *double b-tagged events*



Invariant mass of double b-tagged events with ***exactly 2 jets*** *(to reduce $t\bar{t}$ background)*

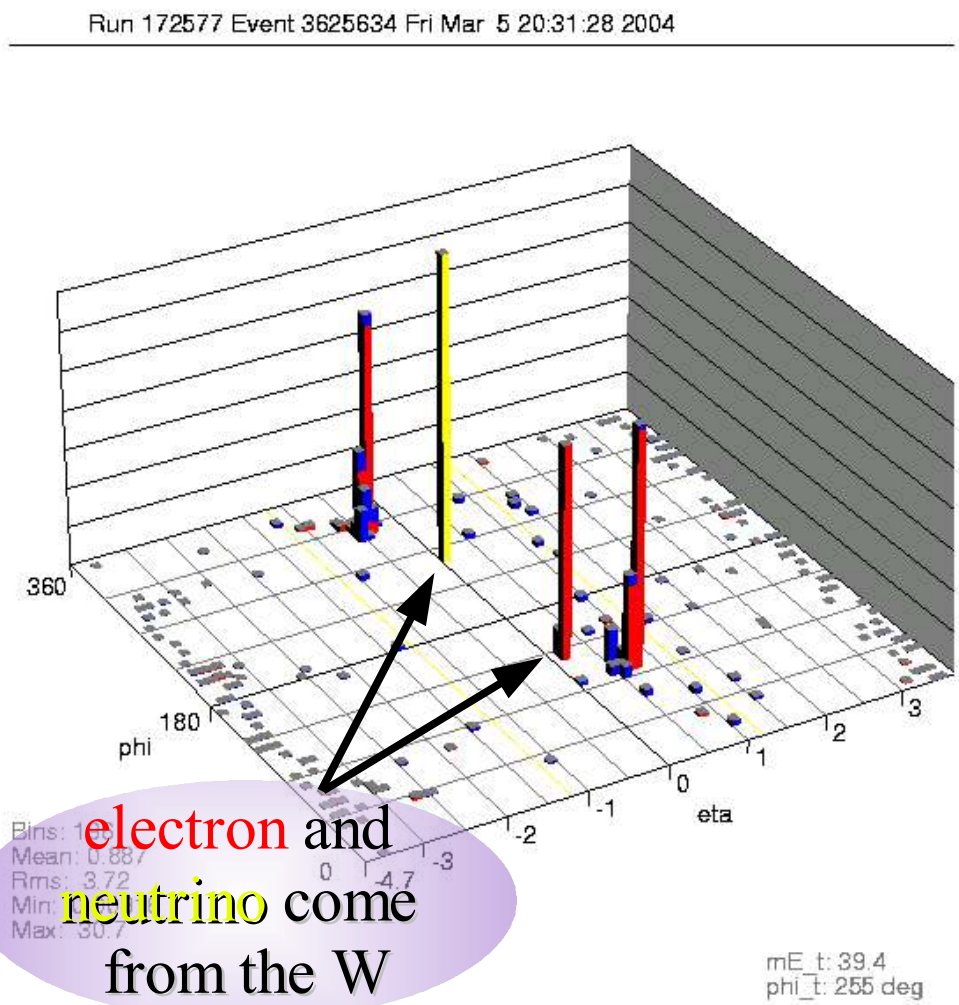


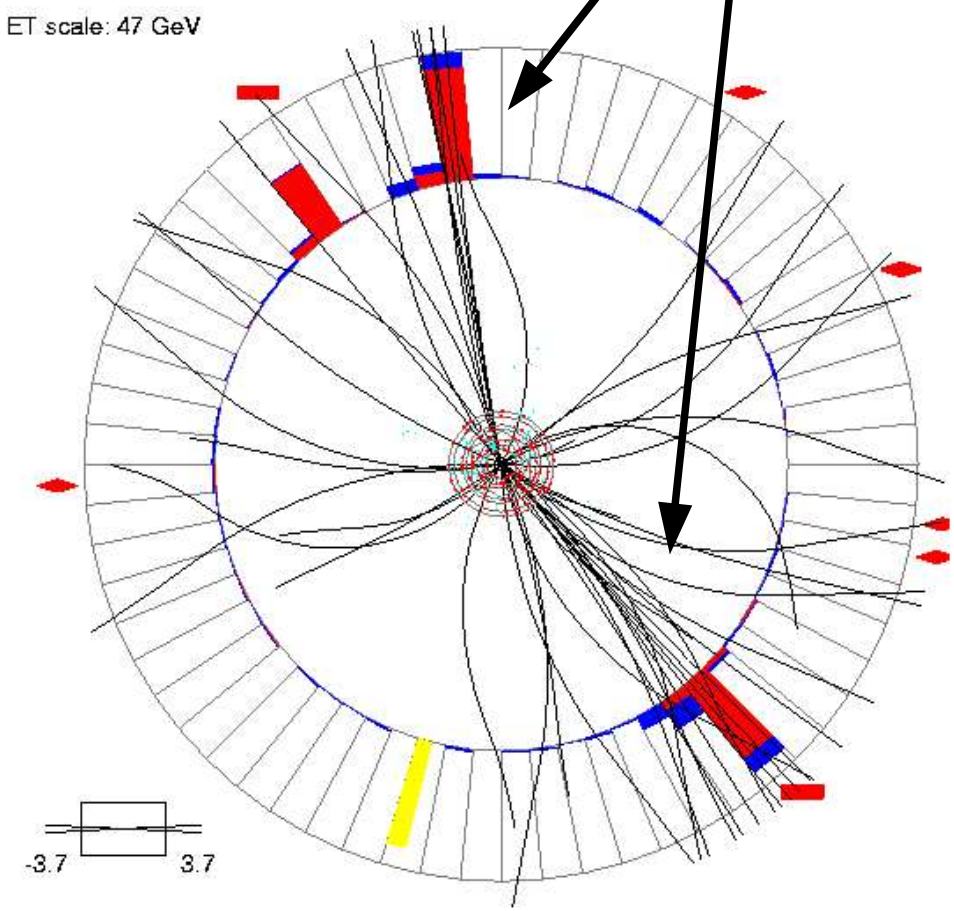
W+jets with b-tagging

4

A double b-tagged W + 2 jets event

Two b-tagged jets!





electron and neutrino come from the W

Z+jets with b-tagging

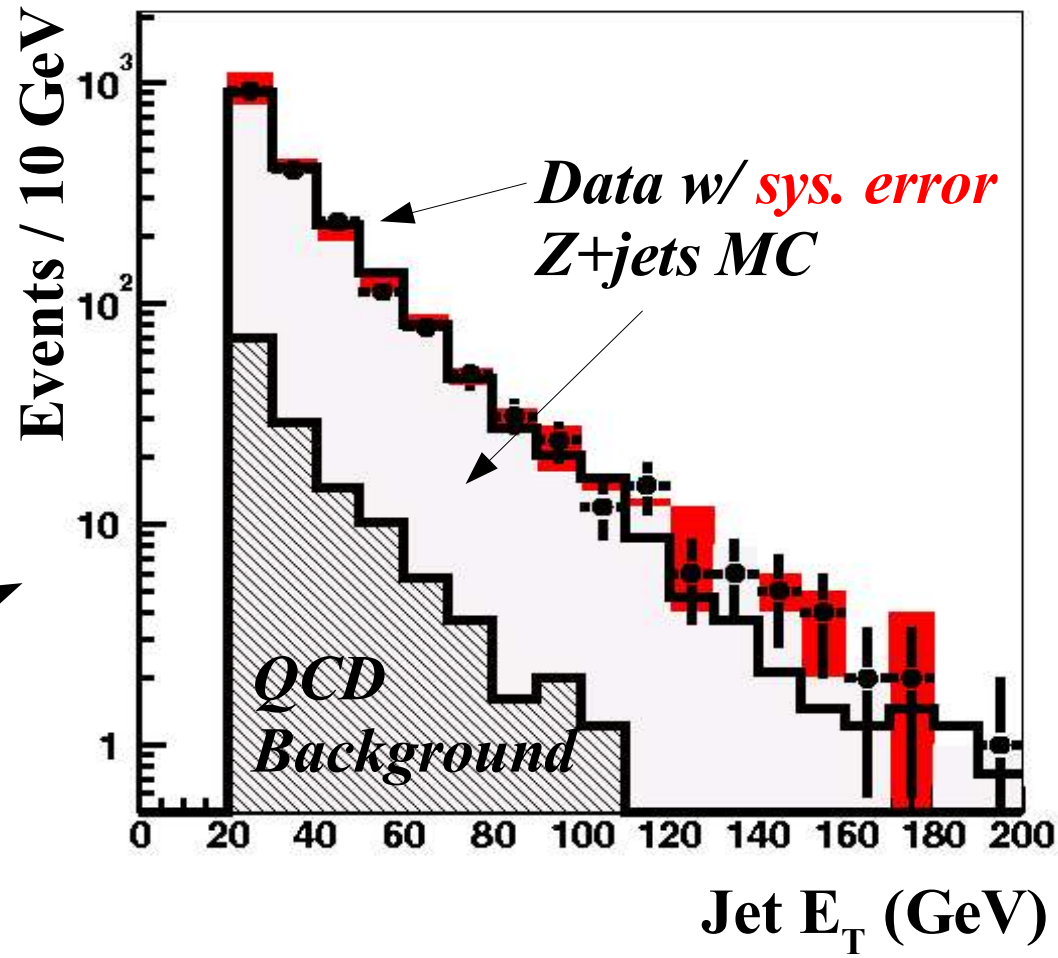
5

A large background to Higgs signals is Z events with b-jets.

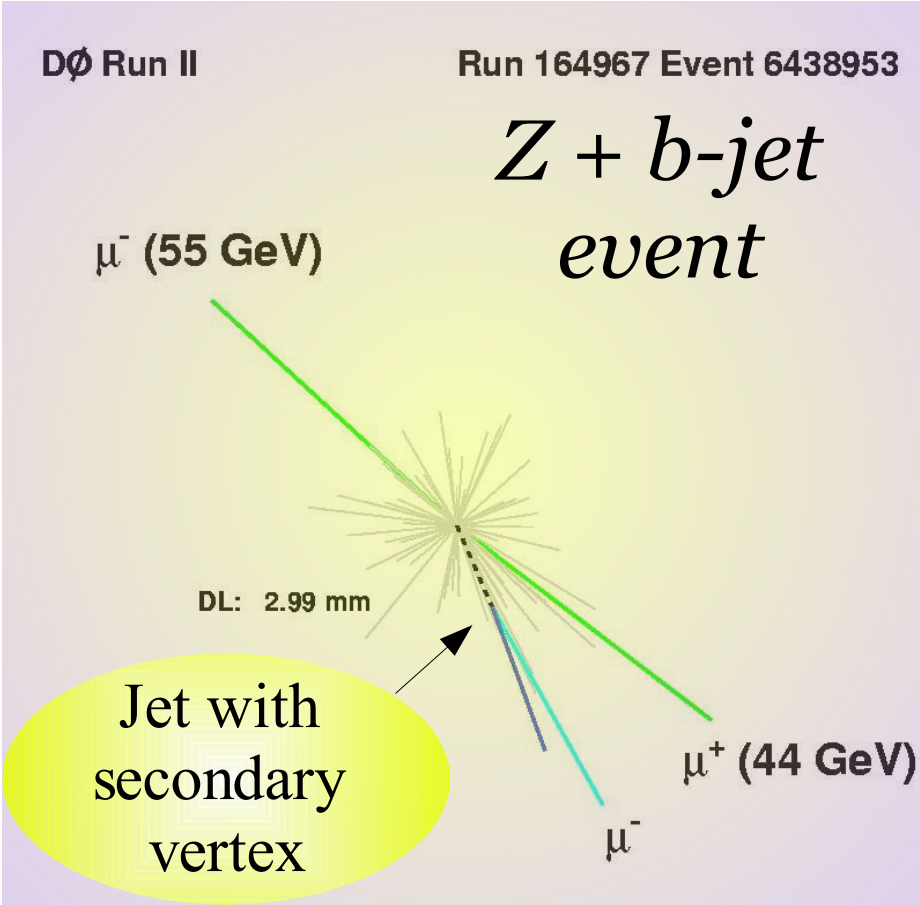
DØ has now studied this process and made a first measurement of its cross-section.

We compare the jets in Z events to simulations of the Standard Model. *Good agreement!*

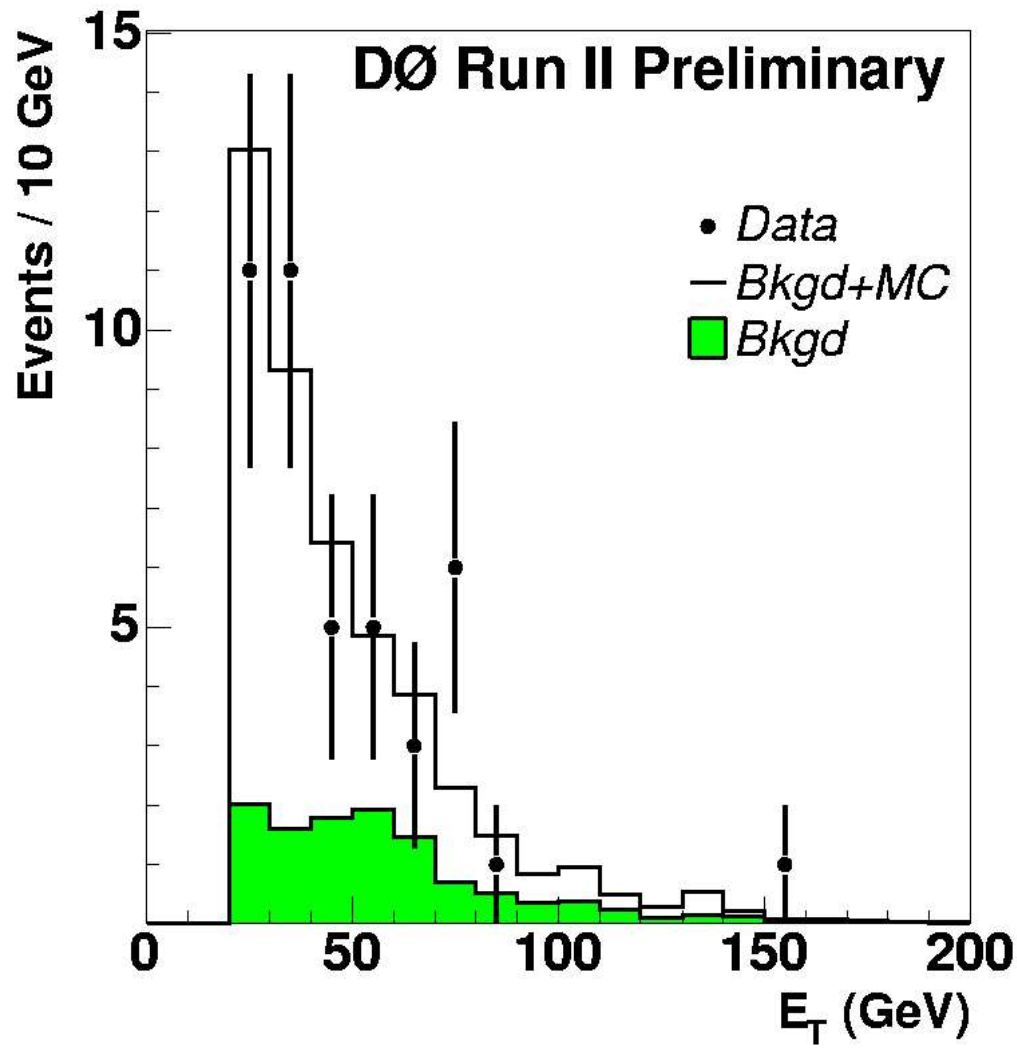
Jets in Z events compared to Monte Carlo



Z+jets with b-tagging



p_T spectrum of b-tagged jets



We have measured the ratio of cross-sections for Z+b / Z+j

The Search for Higgs Bosons Beyond the Standard Model

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Starring:

Doubly-charged Higgs bosons
Supersymmetric Higgs bosons
Fermio-phobic Higgs bosons

The Plot:

Extended theories of Electro-weak Symmetry Breaking predict many kinds of Higgs bosons.

DØ is looking hard for these new Higgs bosons, and has excluded new regions of parameter space in these models.

... and the Higgs could point the way to physics beyond Standard Model.

Search for bb(h,H,A): SUSY Higgs at high tanβ

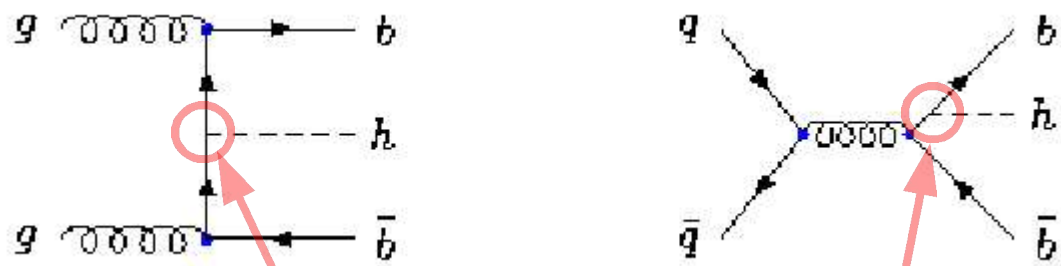
If Supersymmetry (SUSY) is correct, then there are at least *five* Higgs bosons:

h, H, A, H^+, H^-

DØ has completed a search for the neutral Higgs bosons in the context of the Minimal Supersymmetric extension of the Standard Model (MSSM).

We search for a signal from the Higgs in triple b-tagged multi-jet events.

Feynman diagrams for bb(h,H,A) production



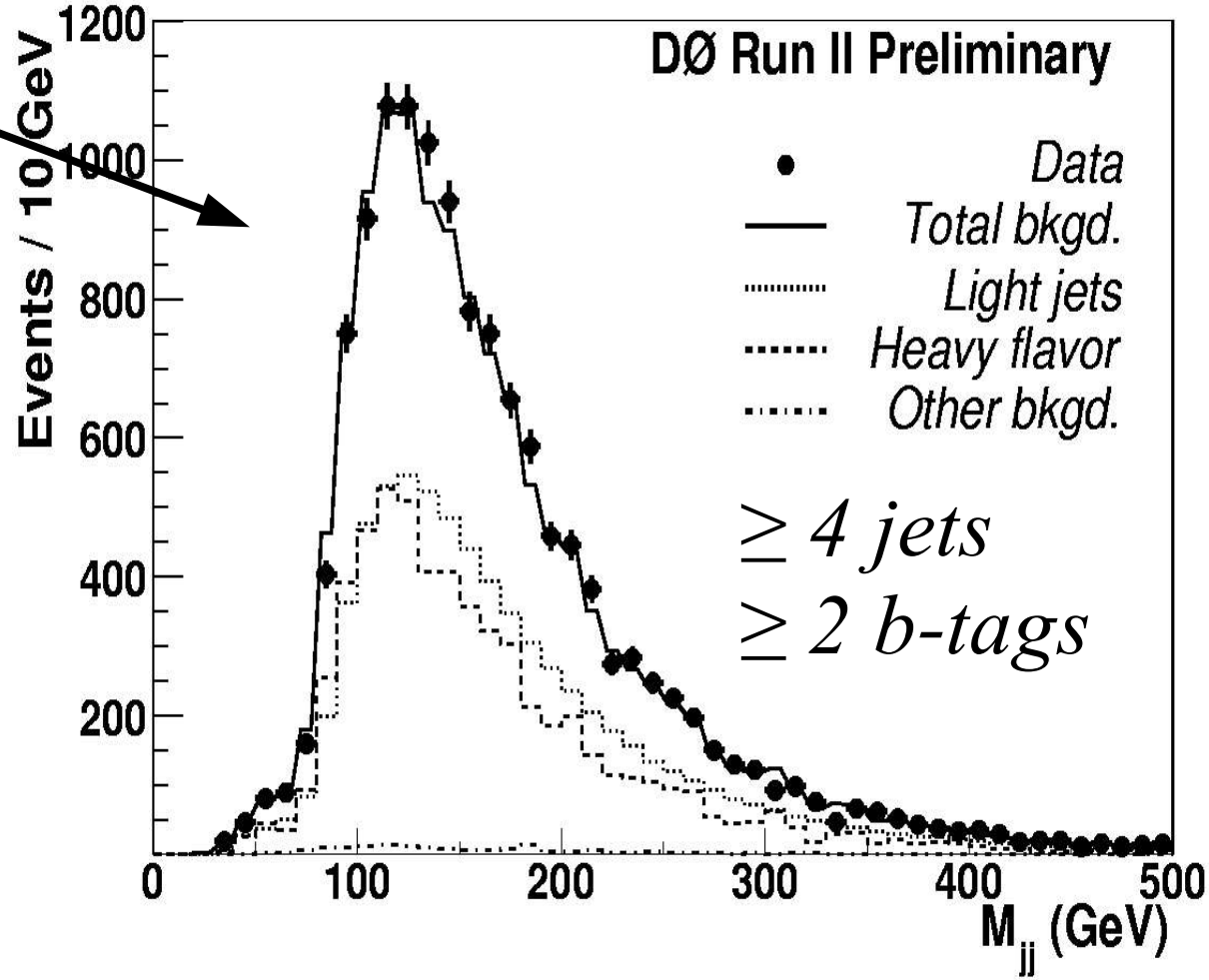
This coupling is proportional to tanβ.
The cross-section is proportional to tan²β!

Search for bb(h,H,A)

2

First, we compare distributions of the double b-tagged events to the Standard Model

Comparison of double b-tagged events with ≥4 jets to Monte Carlo



The ALPGEN Monte Carlo describes the multi-jet heavy-flavor background very well.

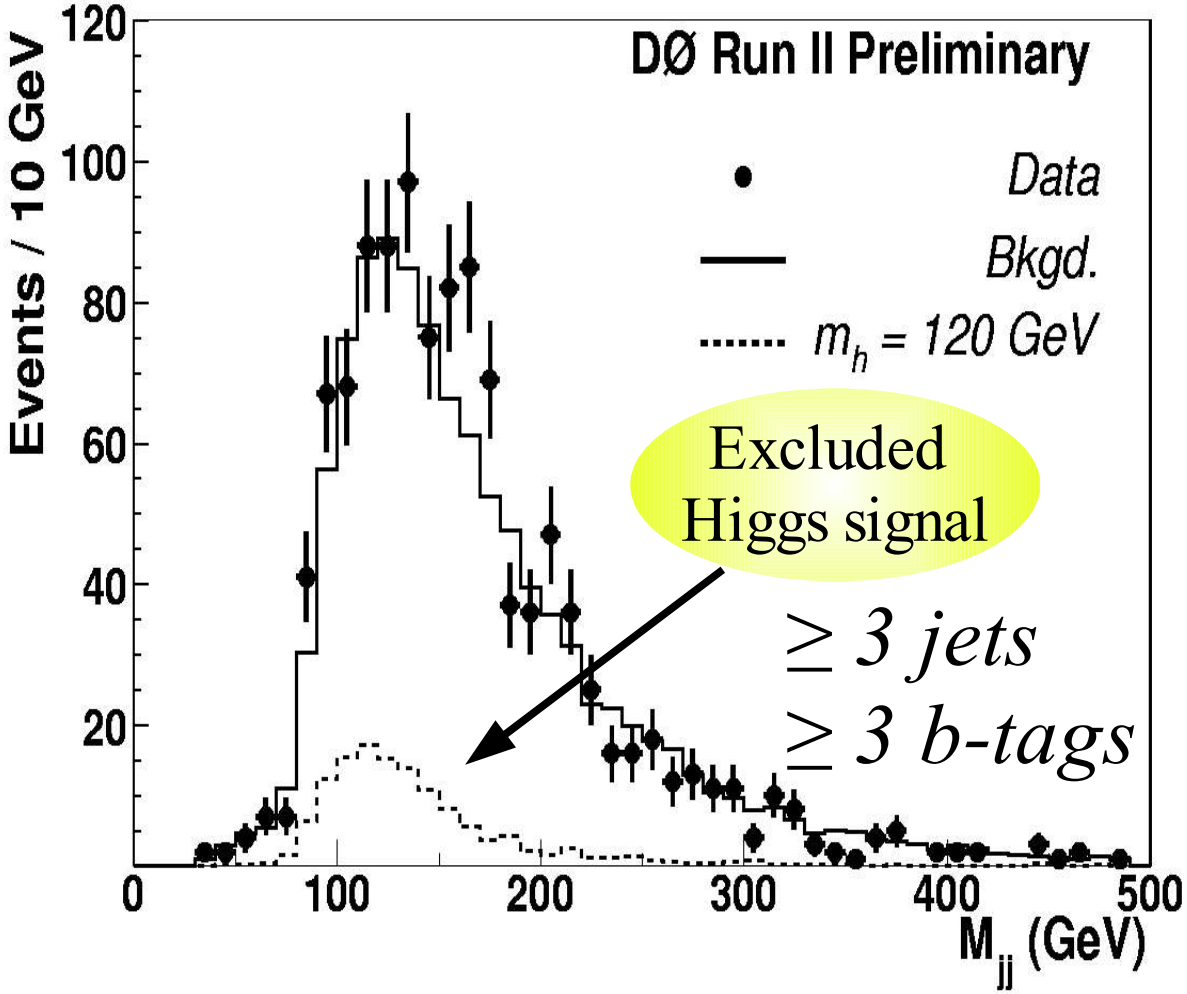
We have measured the normalization factor of data / MC :

1.14±0.02 (stat.)

Search for bb(h,H,A)

3

Comparison of triple b-tagged events to expected background



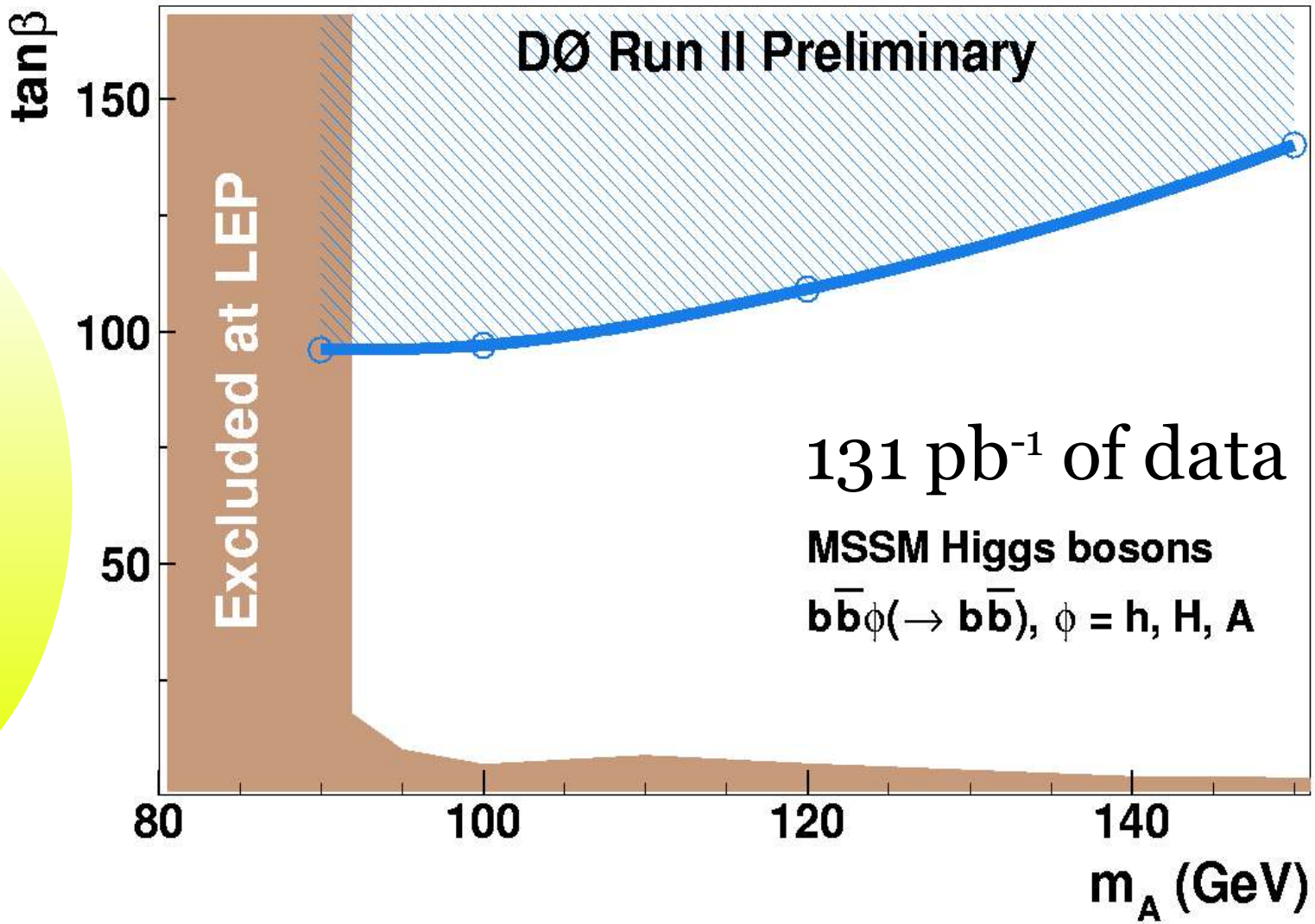
The background shape was extrapolated from double b-tagged data using a tag-rate-function derived on the full multi-jet data sample.

Limits were set on the signal production, using simulated signal shapes, the normalized background, and the observed data.

Search for bb(h,H,A)

4

The limits will continue to improve as new data and better b-tagging are used.



We have constrained the MSSM parameter space by searching for Higgs bosons!

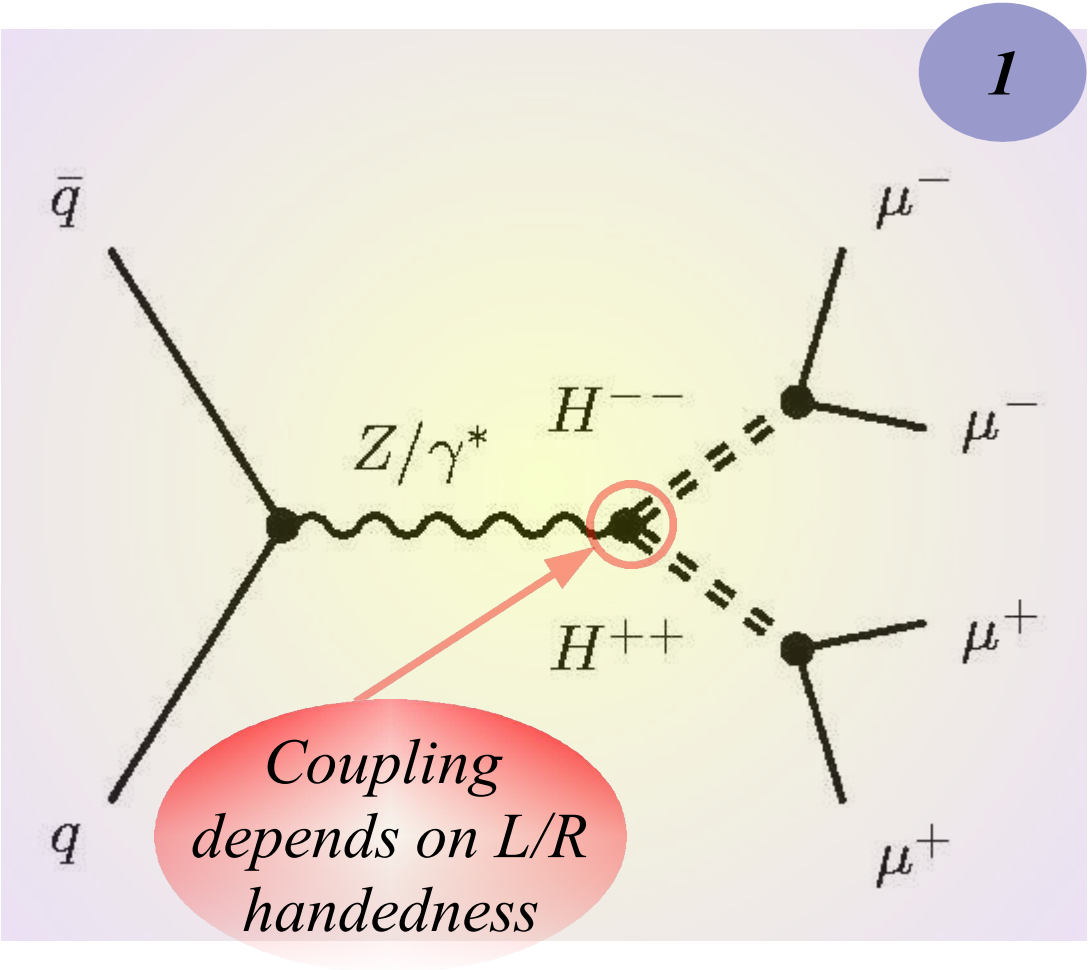
Search for doubly-charged Higgs

Many models predict the existence of Higgs bosons with electric charge of ±2:

- *Left/Right Symmetric*
- *Higgs Triplet*
- *Little Higgs*

We search for decays of the doubly-charged Higgs into **two like-signed muons**.

We assume 100% branching ratio to muons when setting limits.

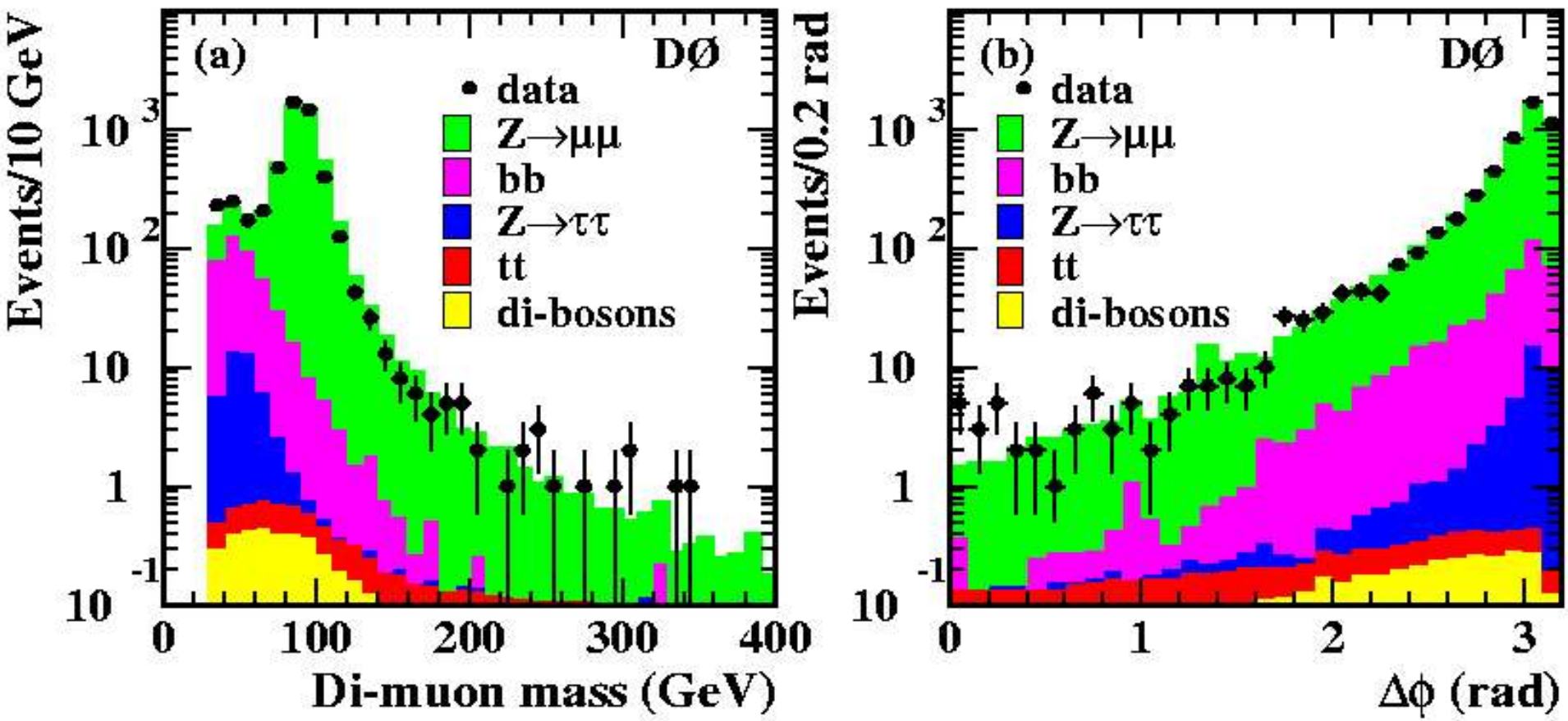


Feynman diagram for the production of doubly-charged Higgs

Search for doubly-charged Higgs

Comparisons of mass and Δφ distributions of the di-muon data to Monte Carlo

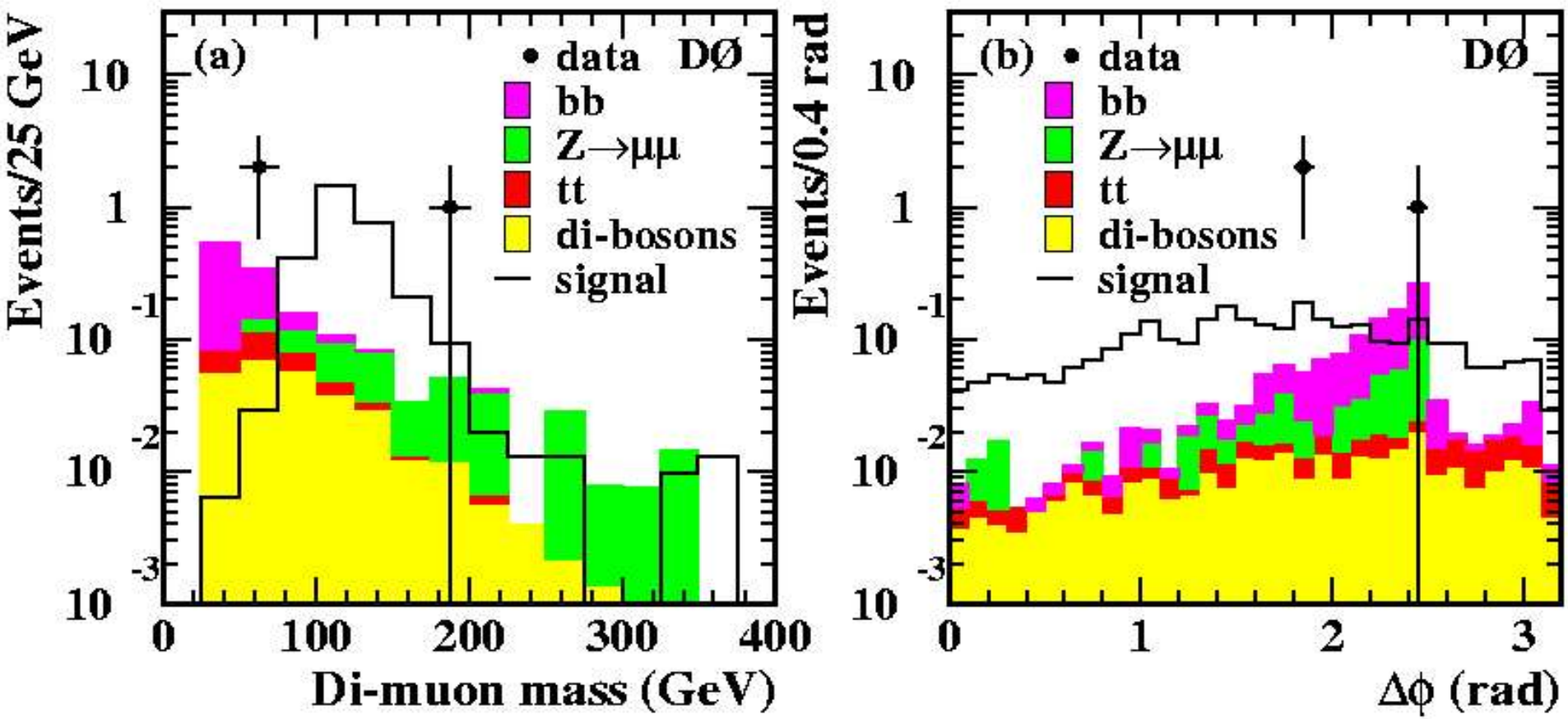
First, we compare distributions before requiring like-signed muons. *Good agreement!*



Search for doubly-charged Higgs

Comparisons of mass and Δφ distributions of the like-signed and isolated di-muon data to Monte Carlo

No sign of an excess in events with isolated and like-signed muons.



Search for doubly-charged Higgs

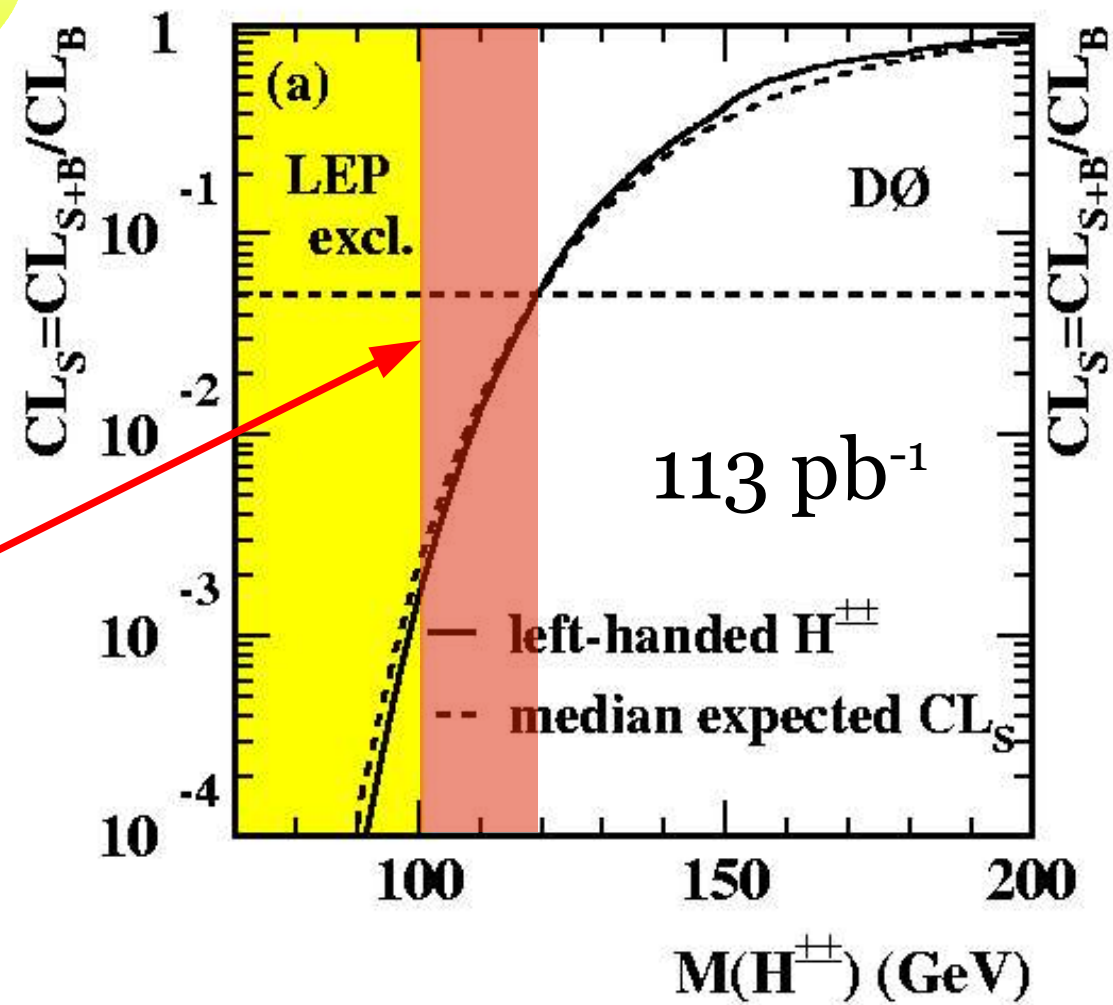
4

These limits will improve when the full data set is included!

Confidence Limit set as a function of doubly-charged (left-handed) Higgs mass

We have placed new lower limits on the masses of doubly-charged Higgs bosons:

$$m_{H^{L}_{++}} > 118.4 \text{ GeV}$$
$$m_{H^{R}_{++}} > 98.2 \text{ GeV}$$



Search for Higgs → γγ

1

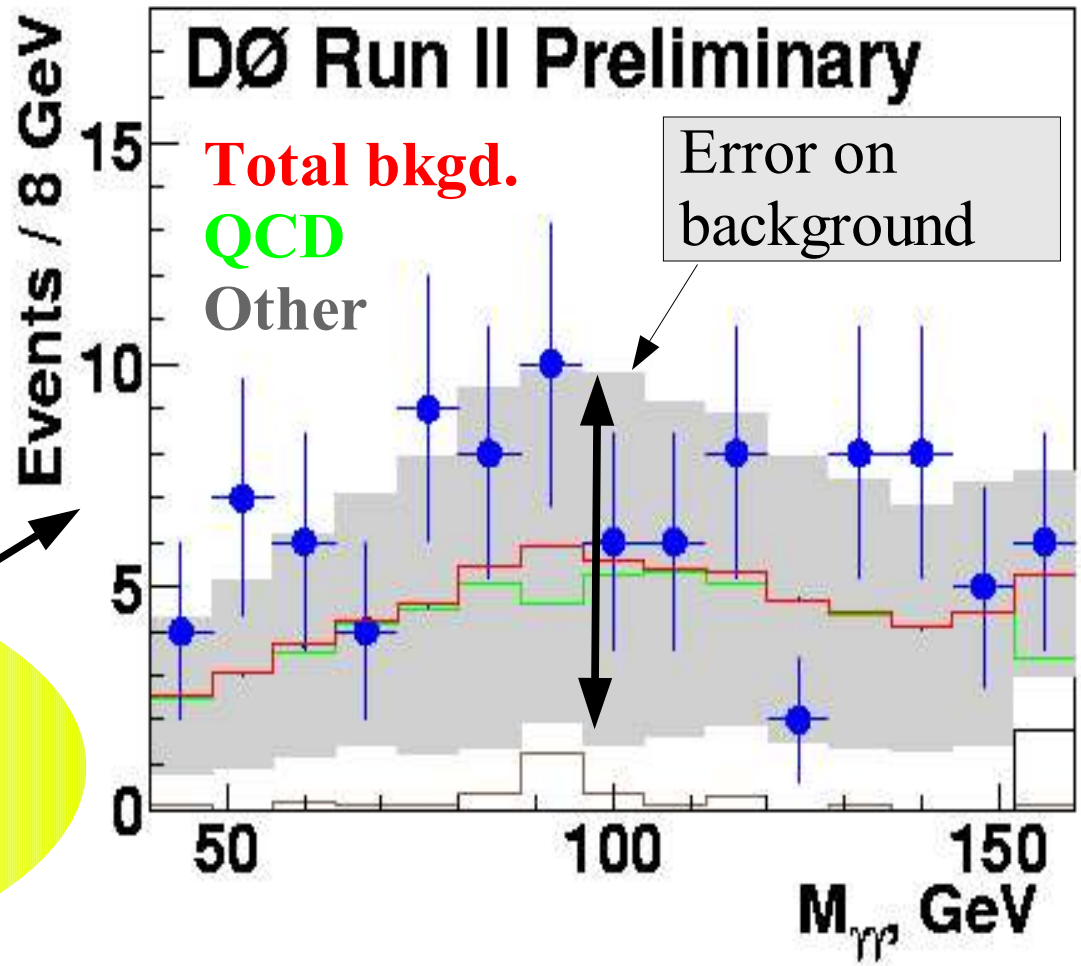
Some models predict an enhanced branching fraction of Higgs bosons to photons:

- *Top-color Higgs*
- *Fermio-phobic Higgs*

We search for decays of the Higgs into **two photons**.

We compare the distributions to expected backgrounds are see... *decent agreement.*

Invariant mass of photon pairs in the central and end-cap Calorimeters

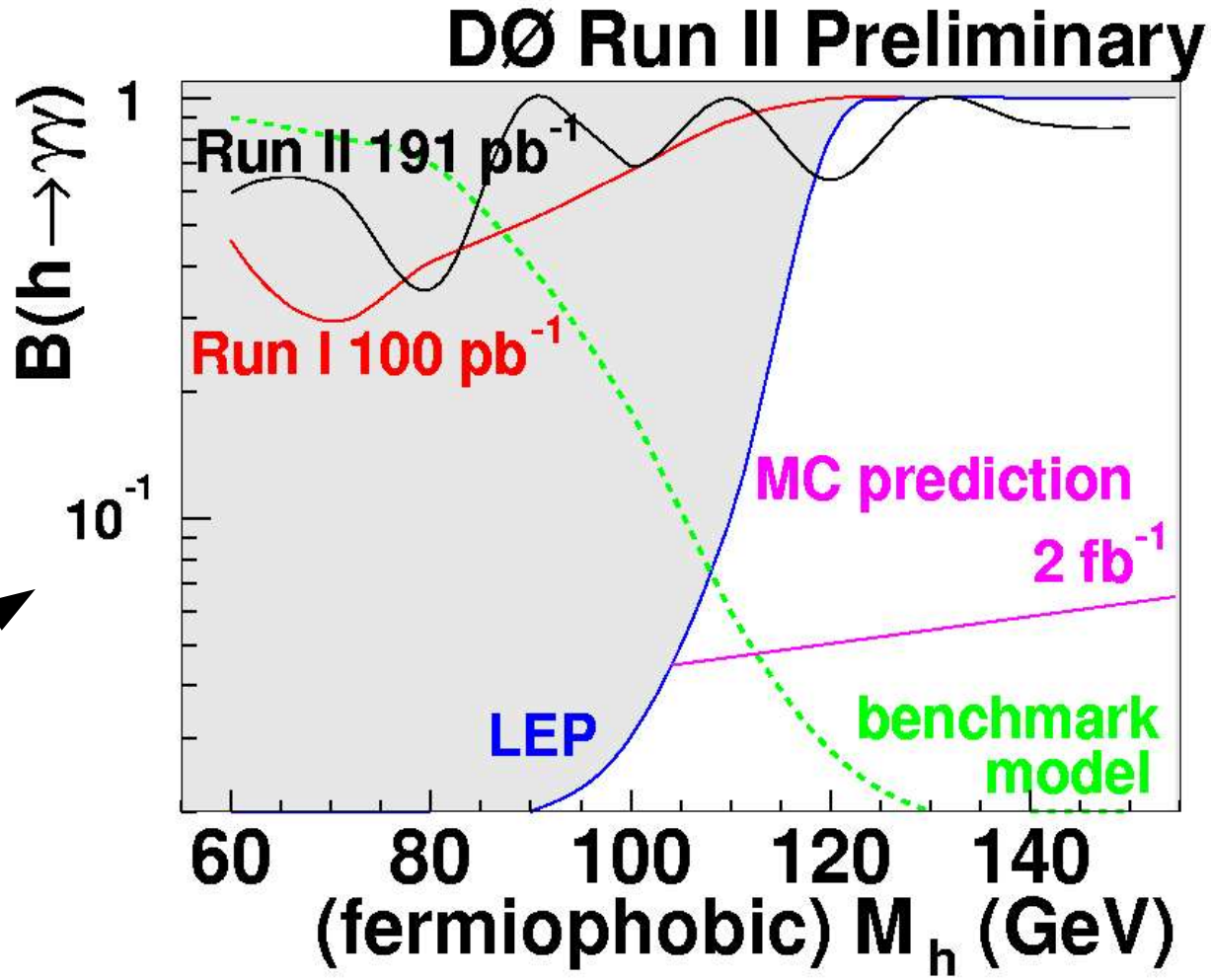


Search for Higgs → γγ

2

We are able to exclude a light Higgs boson which only decays to photons.

Limits set on the branching ratio of Higgs to photons as a function of the Higgs mass



The limits have surpassed the Run I results!