Standard Model 힉스 Searches

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thanks to Gregorio Bernardi, Matt Herndon, Karl Jakobs, Sasha Khanov, Mark Kruse and the CDF and DØ Higgs Groups.

Higgs in a Nutshell

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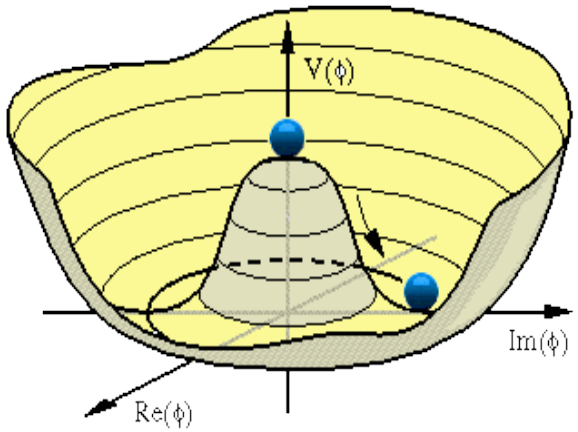
In the Standard Model, the Higgs field is a complex scalar field, V(ϕ):



Through electroweak symmetry breaking, the gauge bosons (W, Z) acquire mass.

A single Higgs boson with spin 0 appears.
The only free parameter is its mass.

LEP's Legacy

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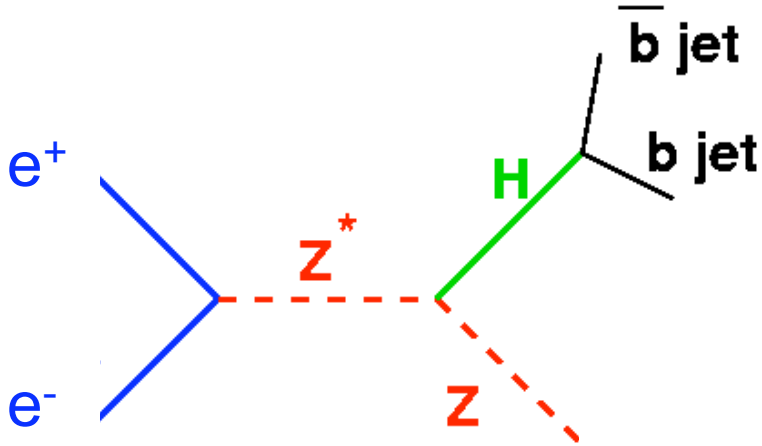
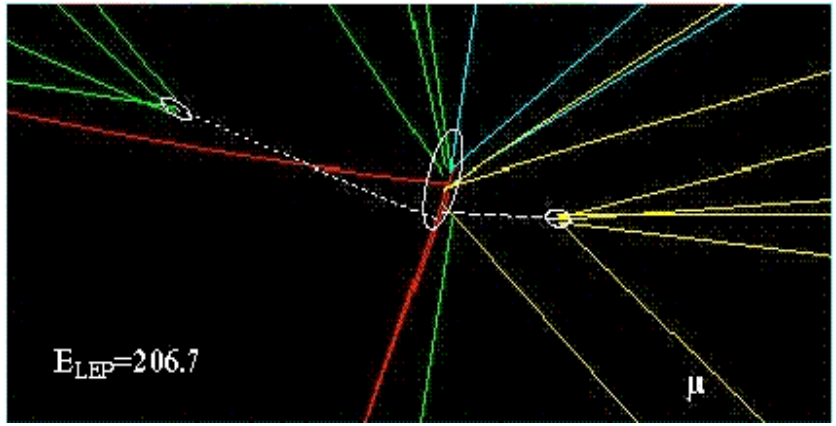
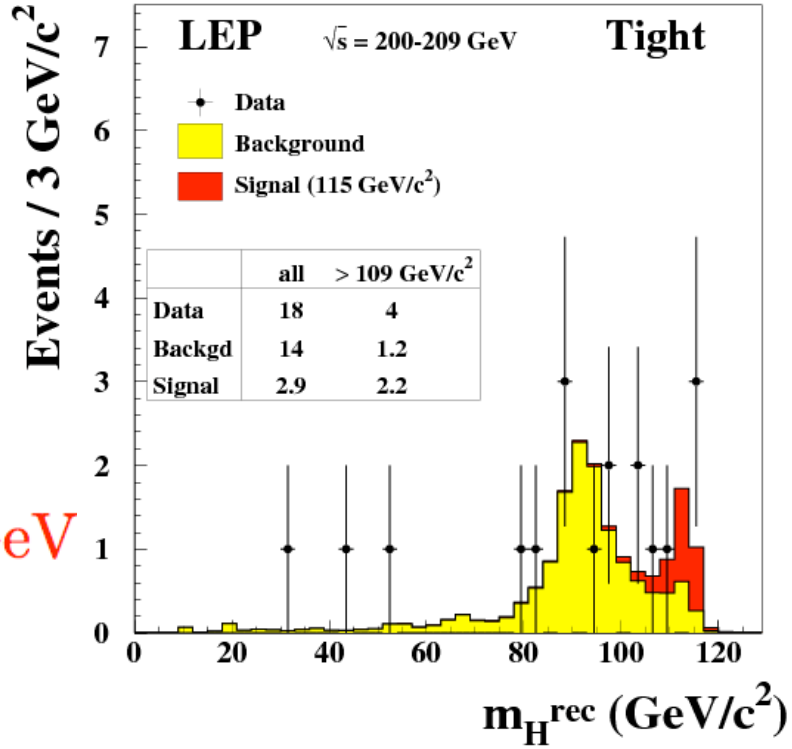


$$\sqrt{s} - m_Z = 206.6 - 91.2 = 115.4 \text{ GeV}$$



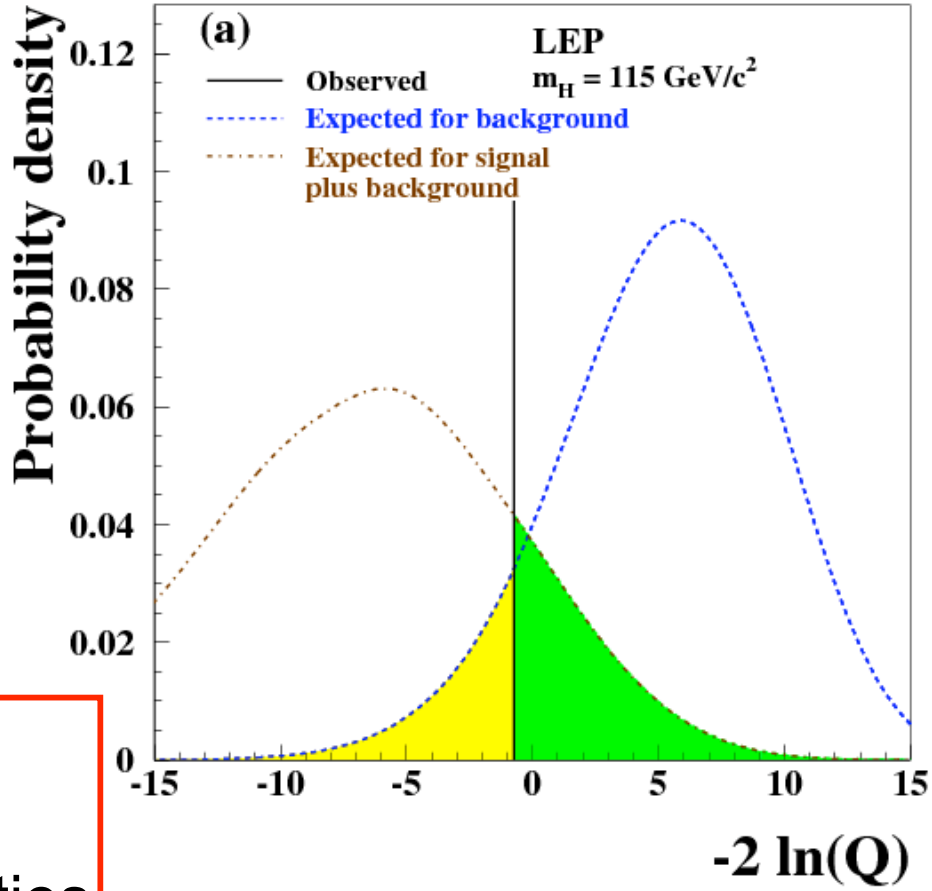


Search for the Standard Model Higgs boson at LEP
Phys. Lett. B565 (2003) 61.

LEP's Legacy

Ratio of Poisson Likelihoods:

$$Q(m_H) = \frac{L_{s+b}}{L_b}$$



probability density obtained using MC toy experiments and statistical/systematic uncertainties

$m_H \geq 114.4$ GeV @ 95% CL

slightly more s+b like

Stalking the Higgs

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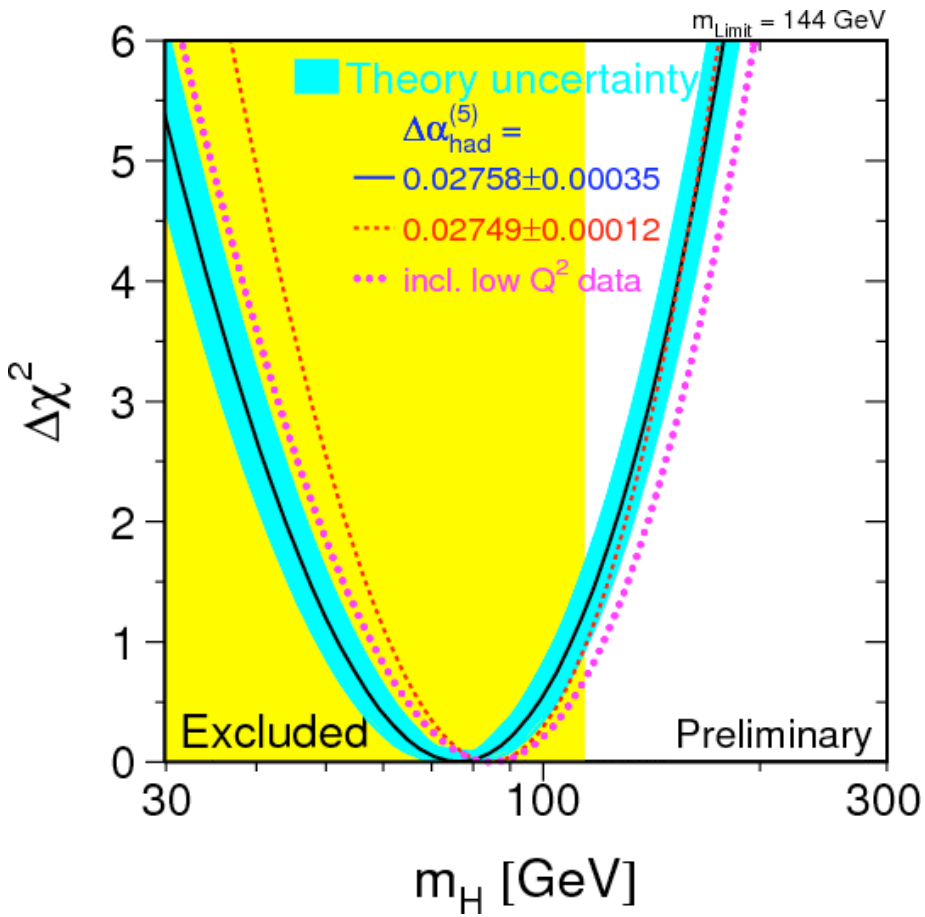
A light Higgs might be around the corner (if the SM is correct)



$$m_H = 76 \pm {}^{36}_{24}\ \text{GeV}$$

$$m_H < 182\ \text{GeV, with direct limit}$$

$$m_H < 144\ \text{GeV, w/o direct limit}$$

→ Robin Erbacher, Pierre Petroff

Production at the Tevatron..

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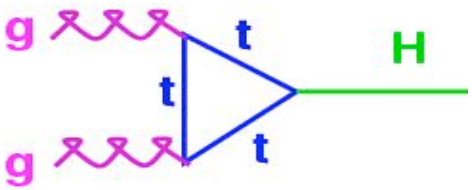
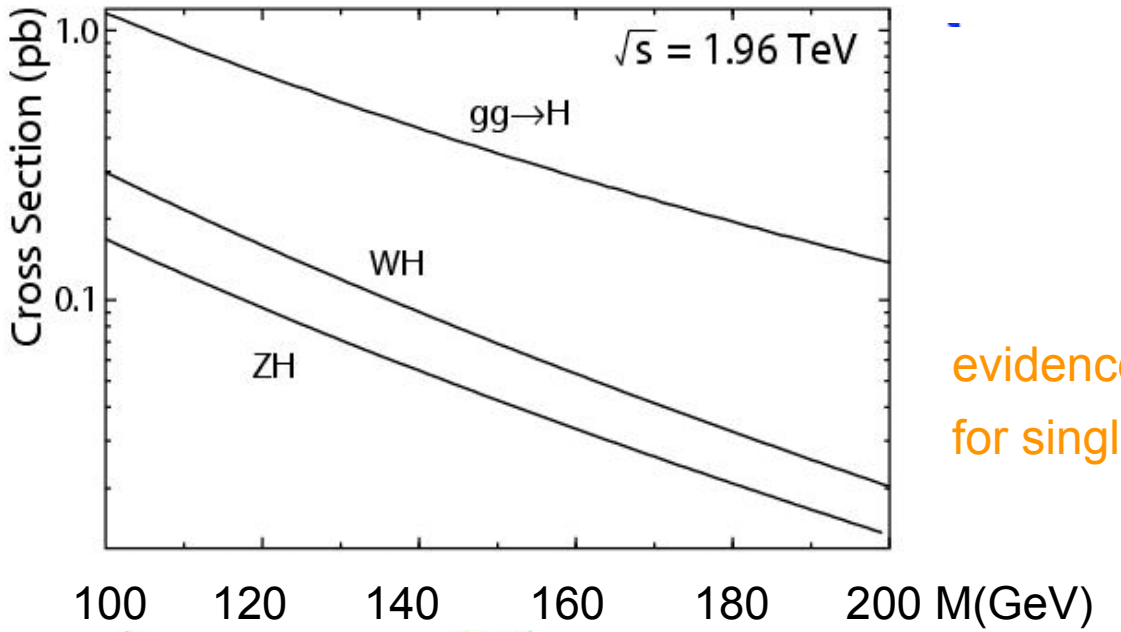
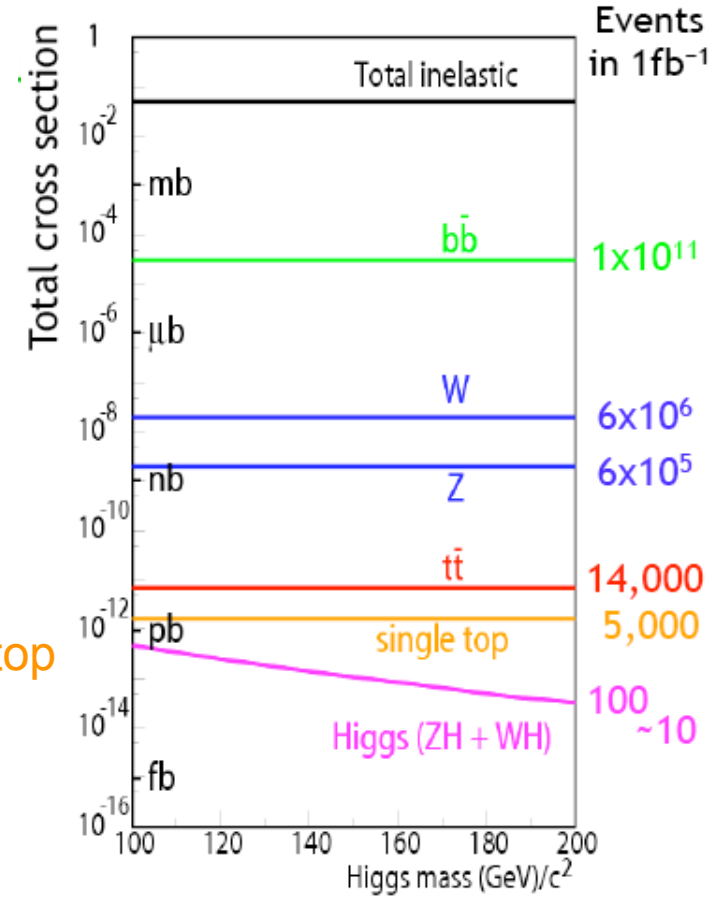
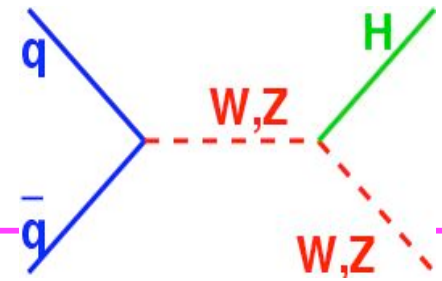




evidence
for single top





one in ~10^{12} events will be a Higgs boson

Search Strategy at the Tevatron

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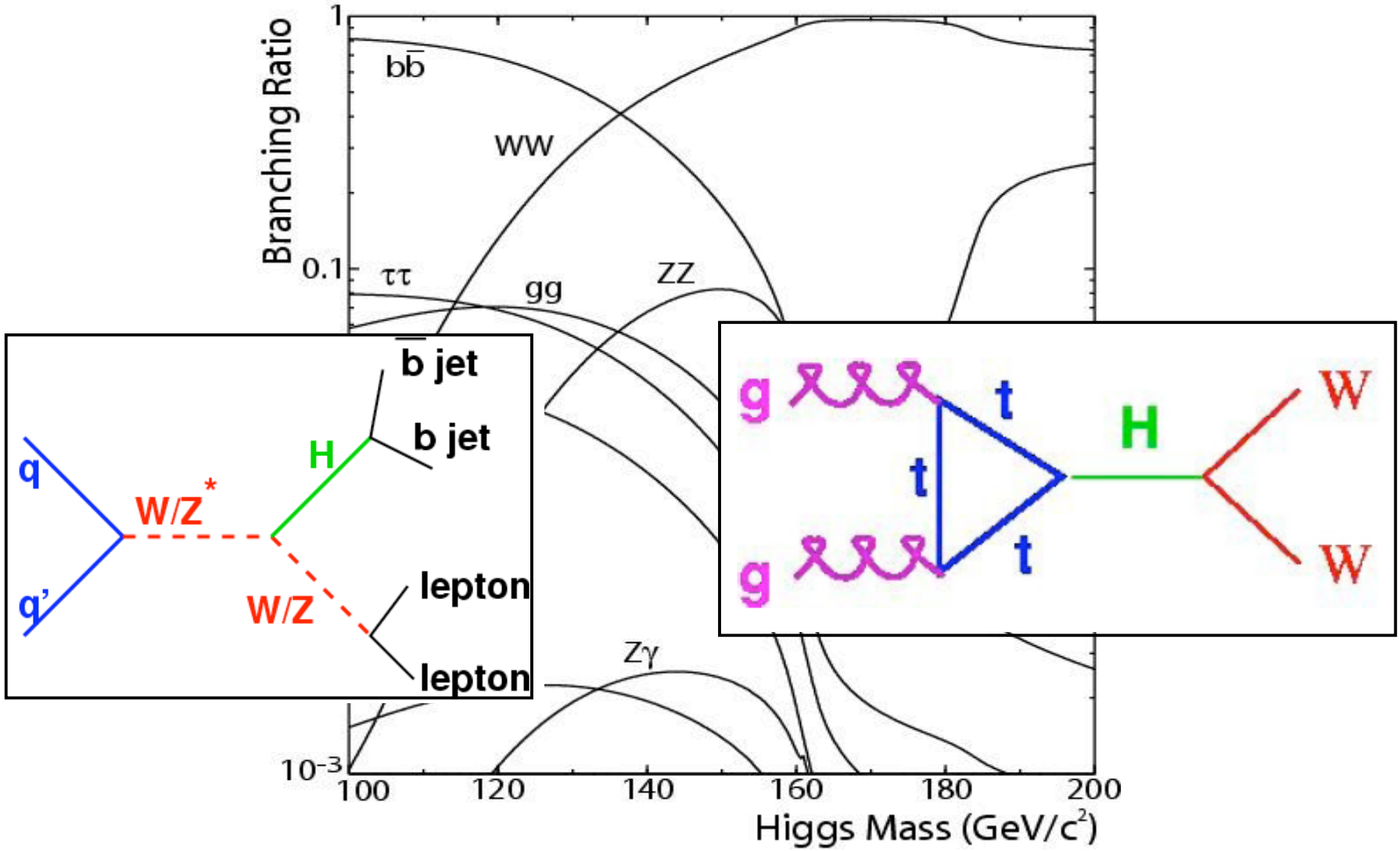

The Tools

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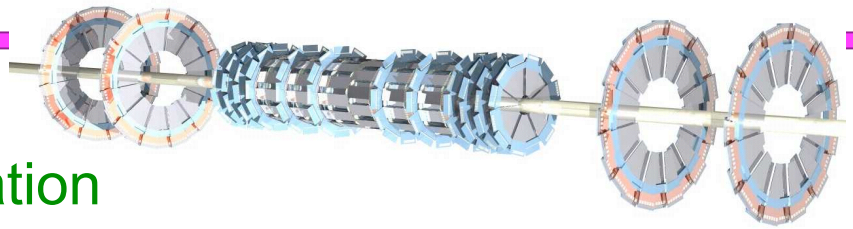
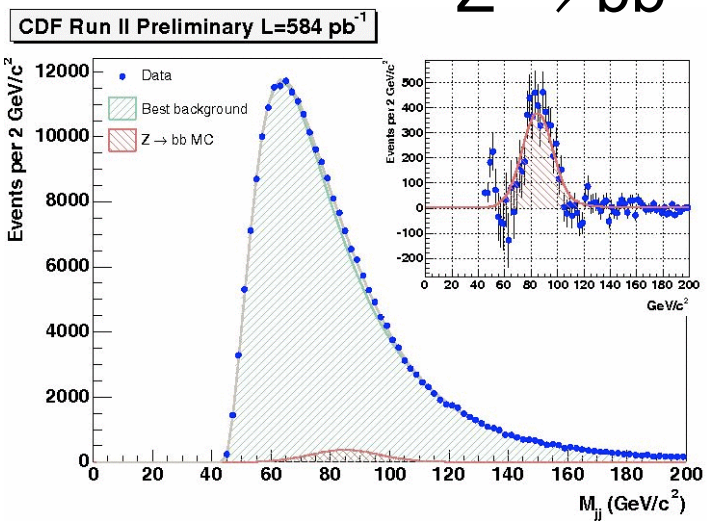
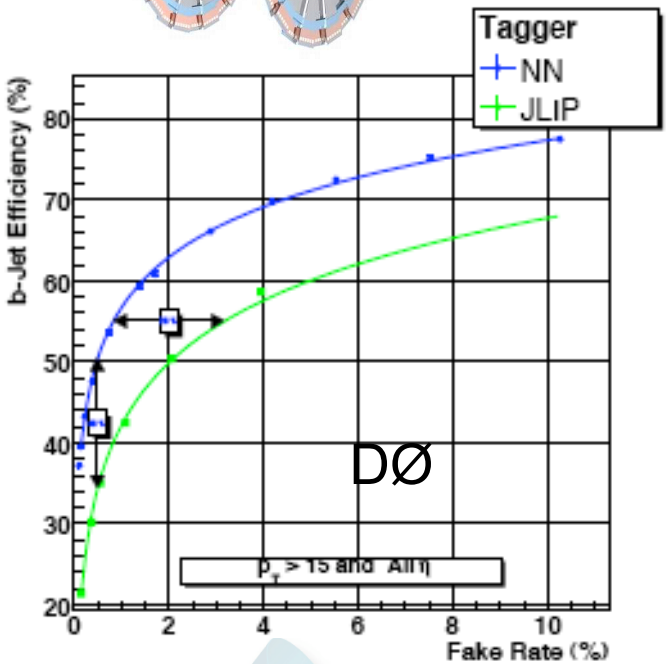


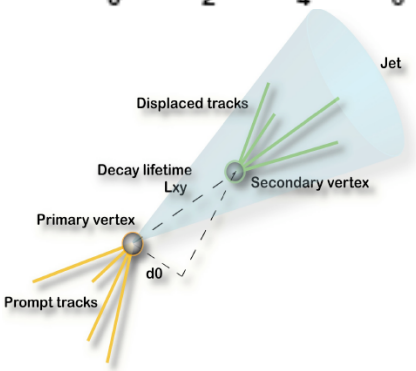
- for all masses:
  lepton identification
- at low masses:
  Neural Net b tagging
  di-jet mass resolution

$Z \rightarrow bb$



di-jet mass distribution for
b tagged jets





Background

- Electroweak background: W(+jets), Z(+jets), WW, WZ, ZZ, also tt and single top

  kinematic distributions using Monte Carlos:
  PYTHIA (LO + parton shower)
  ALPGEN (LO+MLM parton shower/matrix element matching)
  COMPHEP (LO, fixed order matrix element)
  MCFM (NLO)
  MC@NLO (NLO)

  normalised using (N)NLO cross-sections and k factors
  verified by data

Jet production (QCD) and instrumental background

  data using control samples and/or PYTHIA

Typical signal/background ratio of 1/100 in final distributions:
requires advanced analysis techniques (e.g. NN, Limit Setting..)

Data Set

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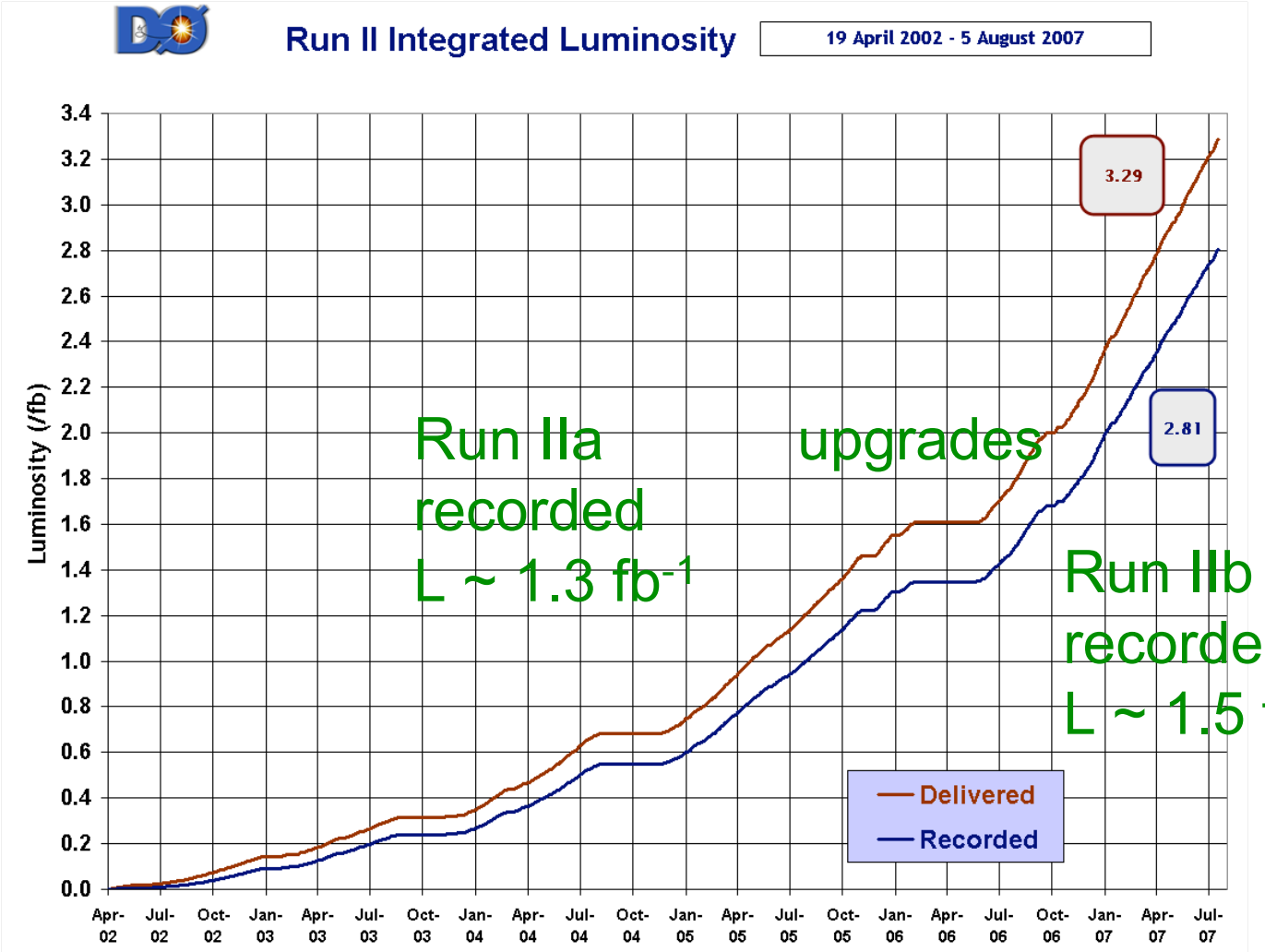

2.8 fb^{-1}

similar for CDF

$WH \rightarrow \ell\nu b\bar{b}$

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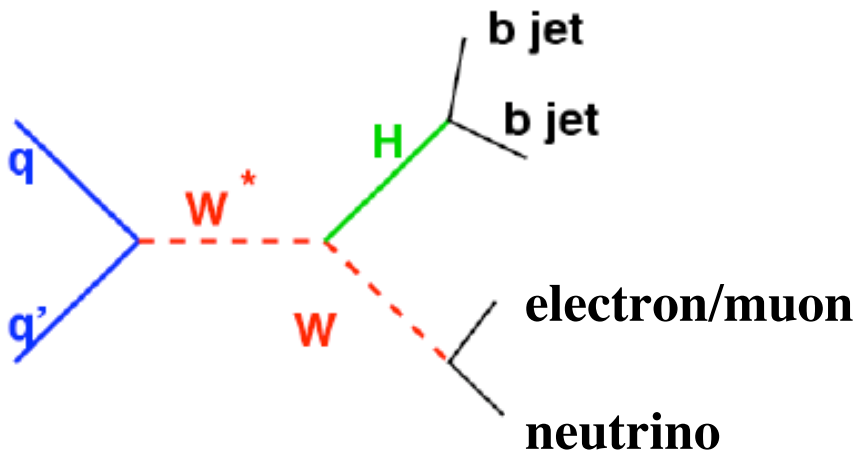

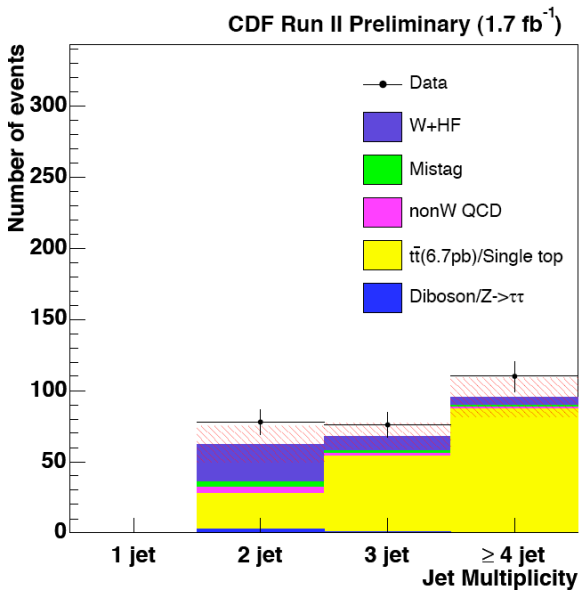

2 b tags

- Basic selection
  - one or two tagged b-jets
  - electron or muon with $p_T > 15$ GeV (CDF/DØ)
  - $E_T^{miss} > 20$ GeV

Top pairs: yesterday's signal is today's background..!

$WH \to \ell\nu b\bar{b}$

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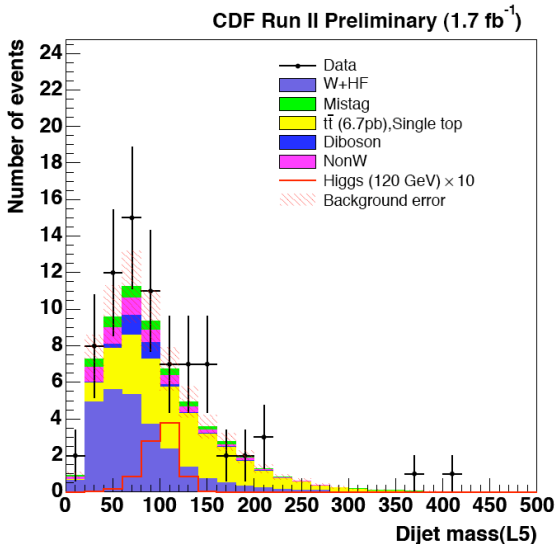
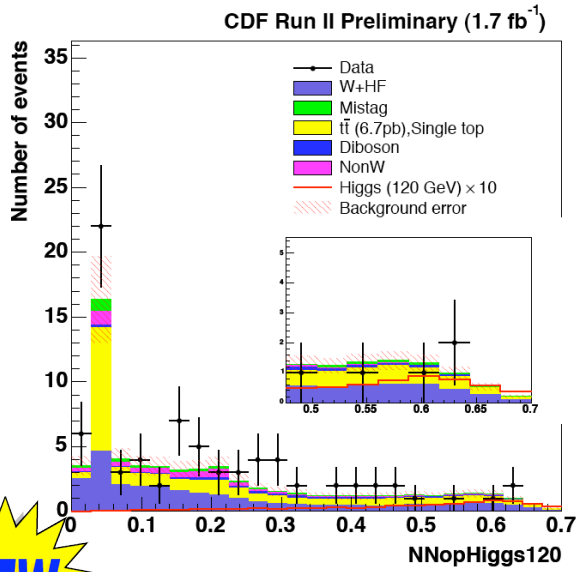


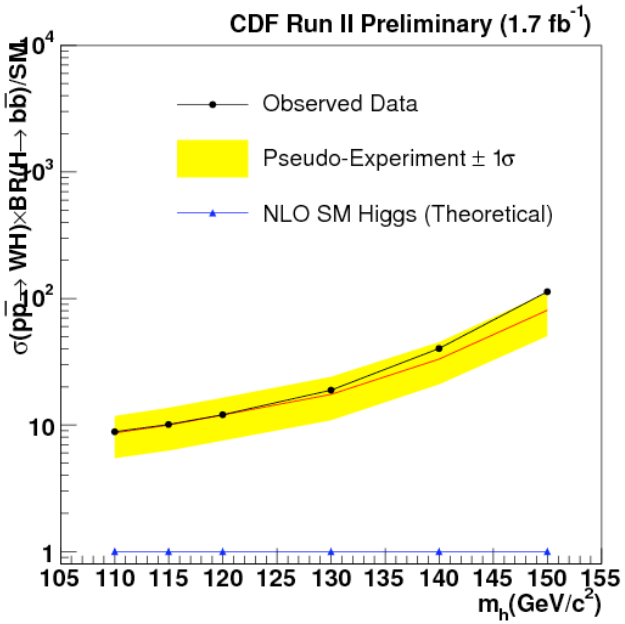


NEW

Neural Network trained on event kinematics

$$L = 1.7 \text{ fb}^{-1}$$

two exclusive samples using different b tagging algorithms



m_H = 115 GeV

$$\frac{\sigma_{95}(L = 1.7 \text{ fb}^{-1})}{\sigma_{95}(L = 1.0 \text{ fb}^{-1})} \simeq 1.7$$

linear in luminosity:
- more b tagging channels
- Neural Net

$WH \rightarrow \ell\nu b\bar{b}$

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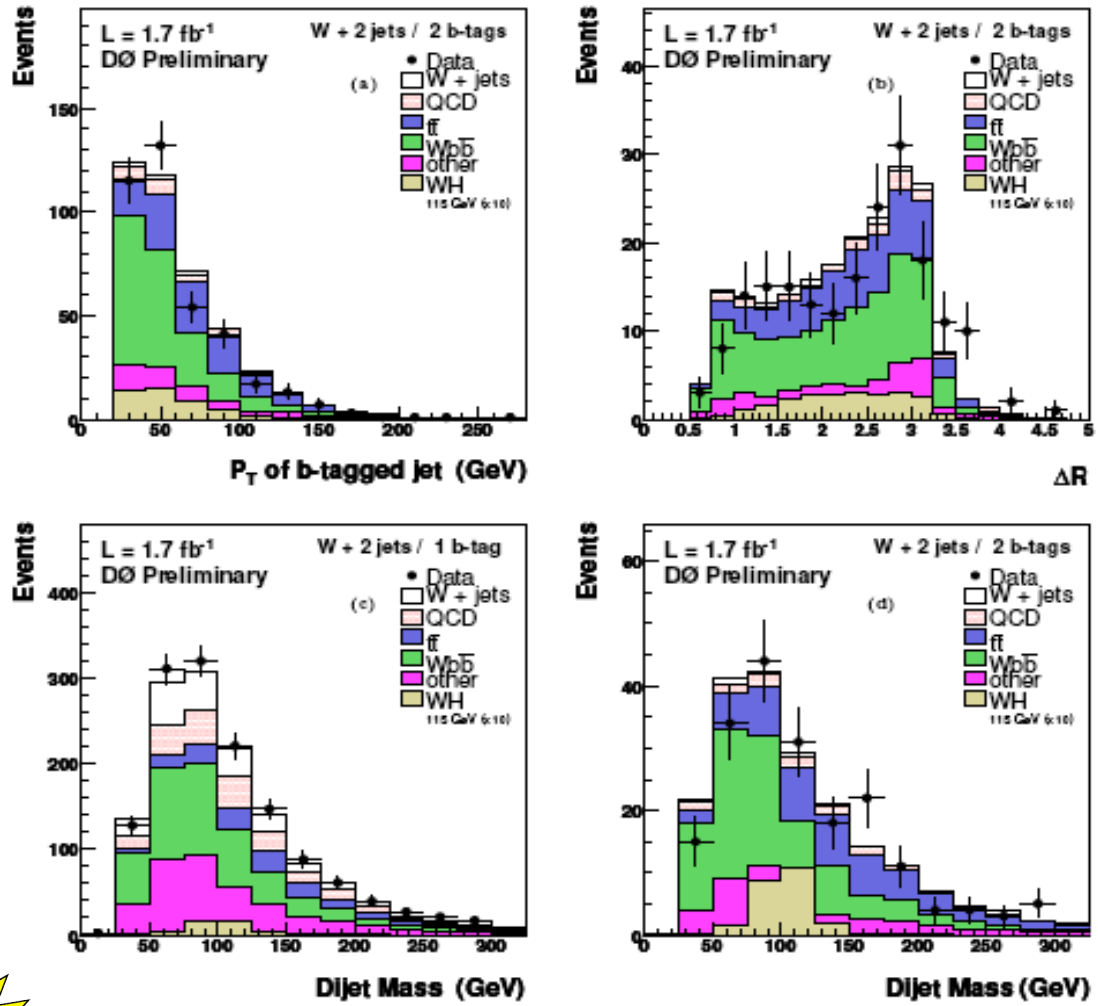
1 'tight' b-tag 2 'loose' b-tags



$$L = 1.7\ \mathrm{fb}^{-1}$$

Four samples:

- electron, muon
- 1 b tag, 2 b tags

major background:

- W plus b-jets
- top pairs

variables used to train Neural Net

NEW

$WH \rightarrow \ell\nu b\bar{b}$

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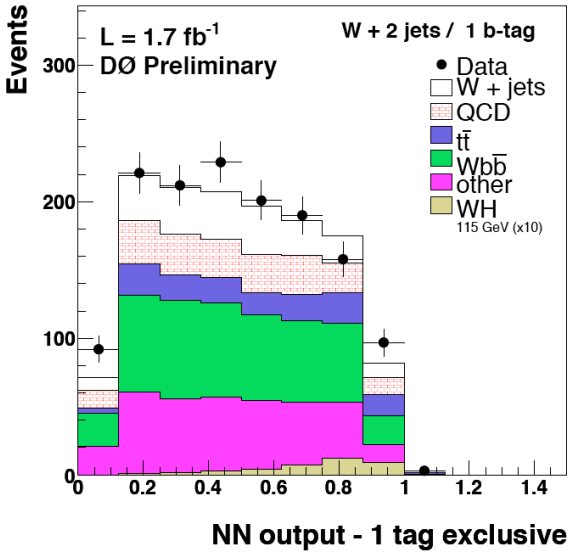
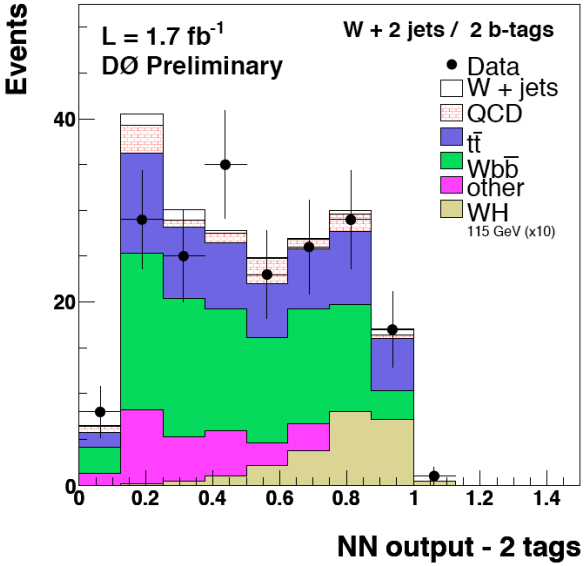
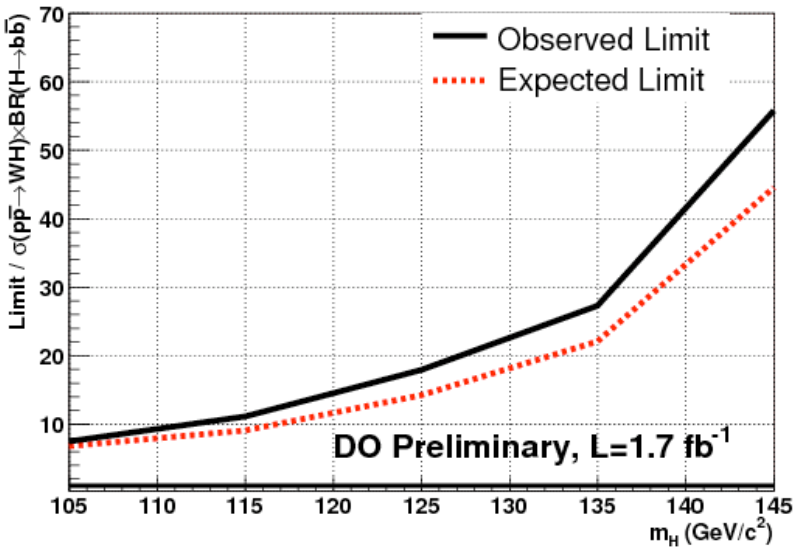


1 b-tag (excl.)



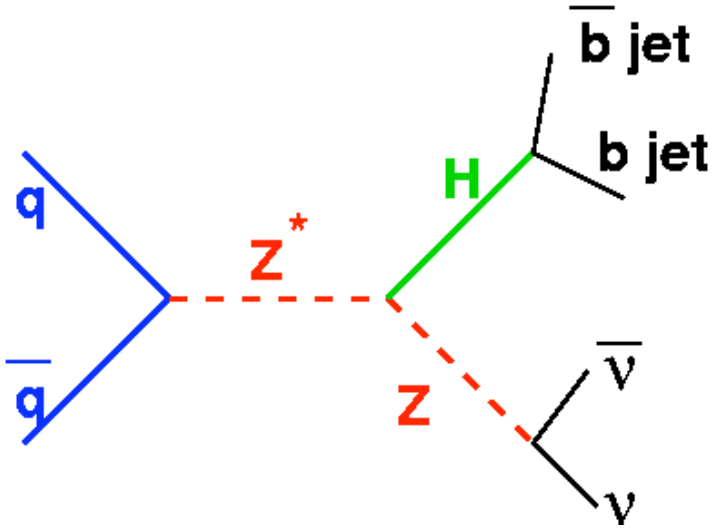
2 b-tags

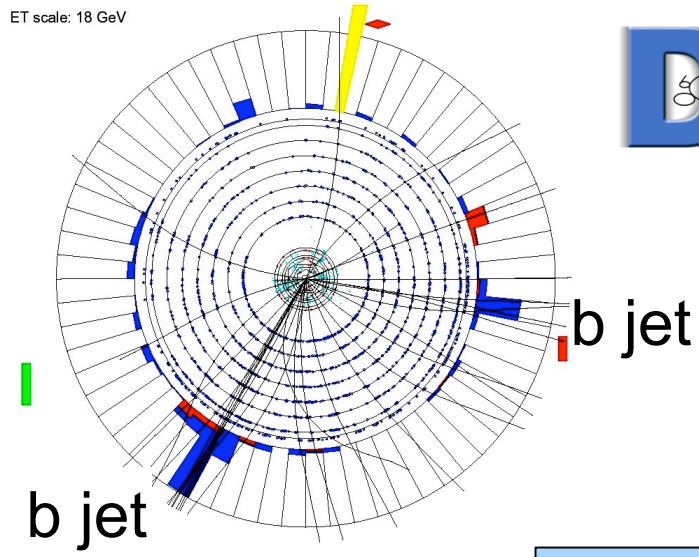
Limit setting using
NN output distributions

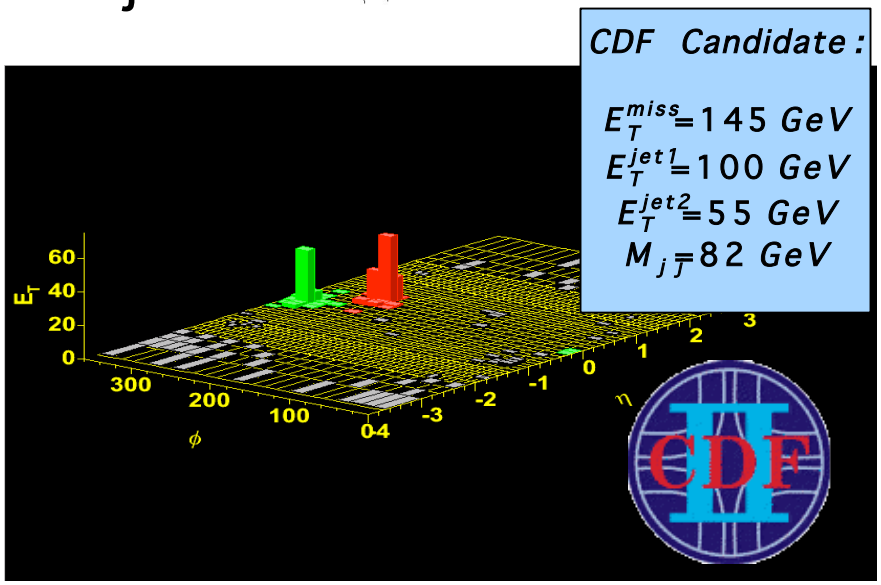


m_H = 115 GeV	CDF exp,obs	DØ exp,obs
σ_{95}/SM	9.95,10.1	9.05,11.1

$ZH \to \nu\nu bb$ $\not{E}_T$ 힉스







Basic selection:

- two acoplanar jets
- ≥ 1 tagged b-jets (CDF)
  2 tagged b-jets (DØ)
- E_T^{miss} > 70 GeV (CDF)
  50 GeV (DØ)

$ZH \rightarrow \nu\nu bb$

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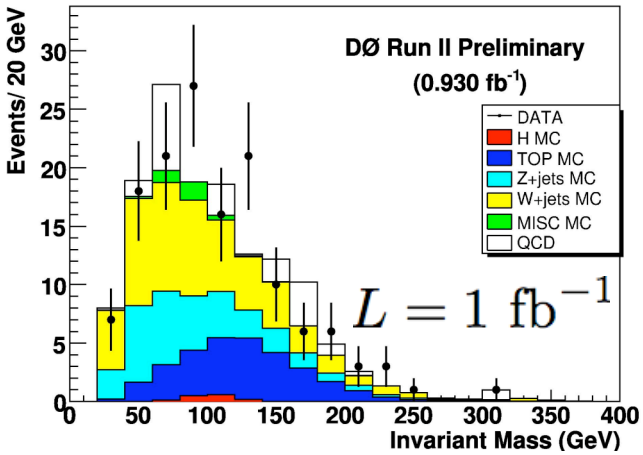
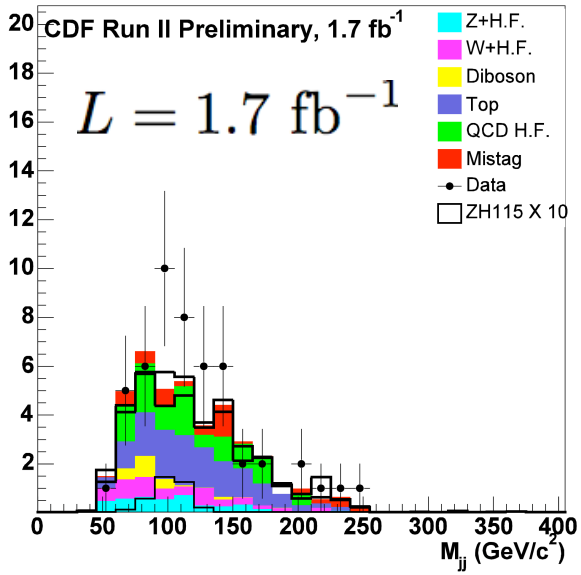
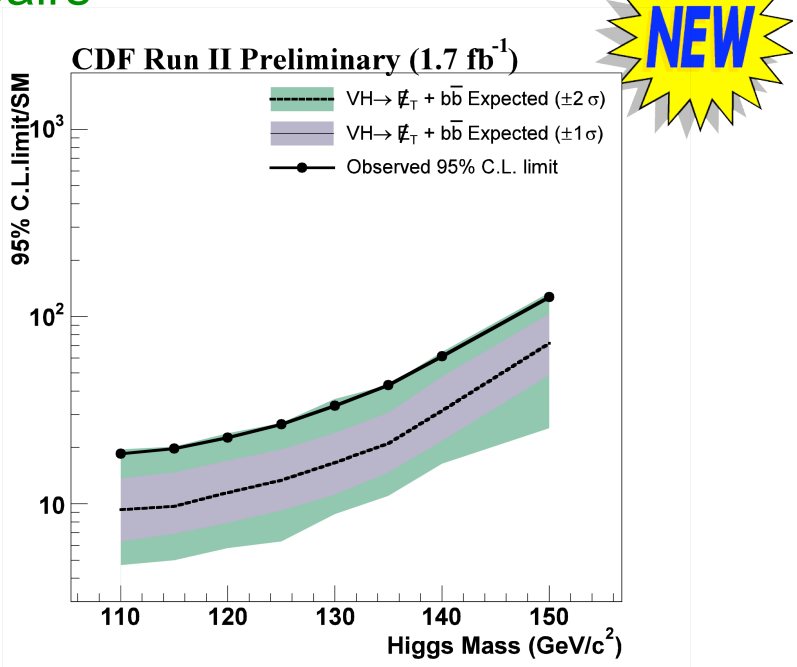


Dijet Mass, SR, L+L



Backgrounds :

- W+heavy flavour jets
- Z +heavy flavour jets
- top pairs



same sensitivity as WH channel:

m_H=115 GeV: σ_{95}/SM=9.7(exp),19.7(obs)

$ZH \rightarrow \ell^+\ell^- bb$

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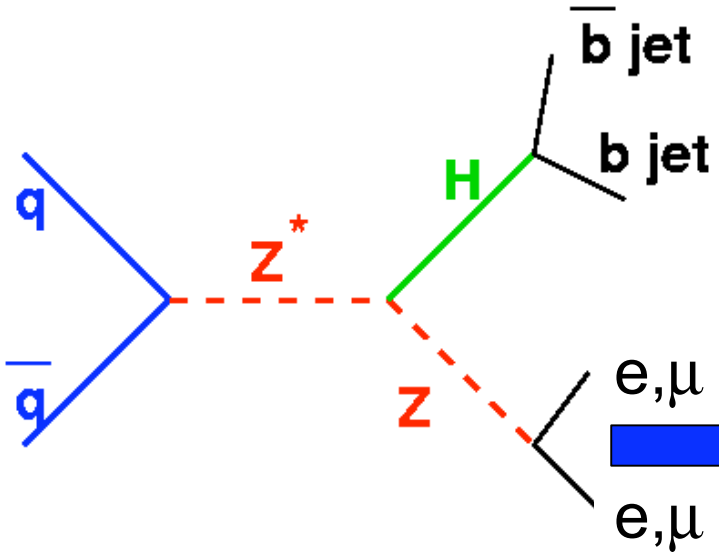
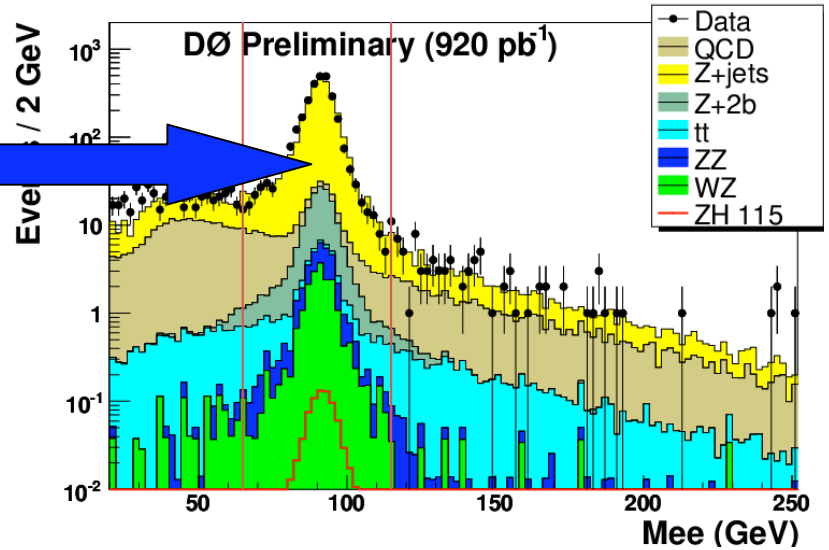




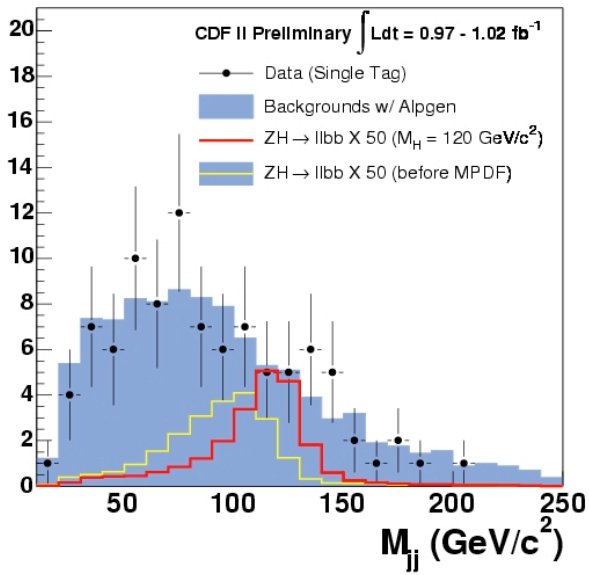
Basic selection:

-require two isolated muons or electrons in Z mass window

-one or two tagged b jets

$ZH \to \ell^+\ell^- bb$ 힉스

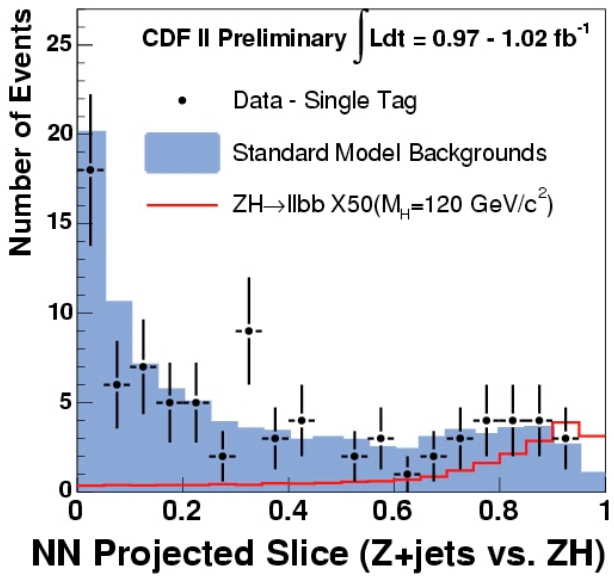
$L = 1\ \mathrm{fb}^{-1}$

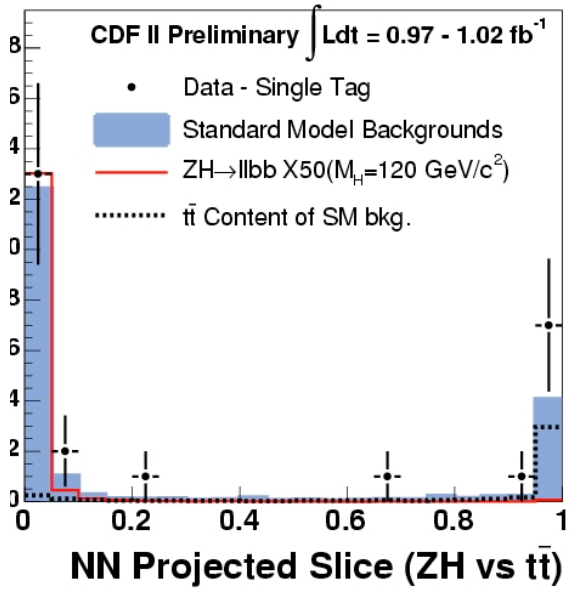


Separate NN trained to reject two main background processes:

Z + jets

top pairs





NN di-jet correction:

E_T^{miss} variables

E_T, η, φ of both jets

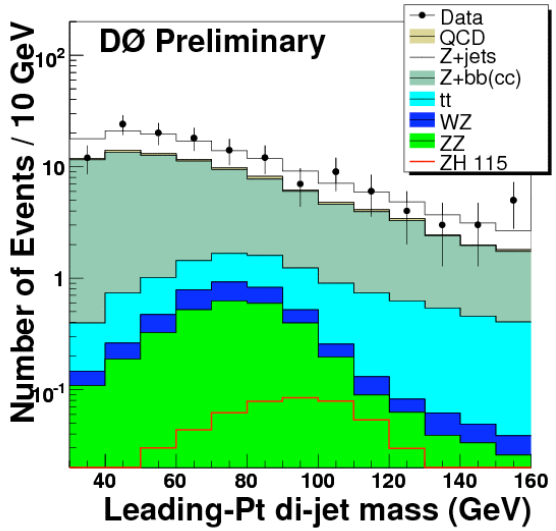
M=115 GeV: σ_{95}/SM = 16(exp),16(obs)

$ZH \to \ell^+\ell^- bb$ 힉스

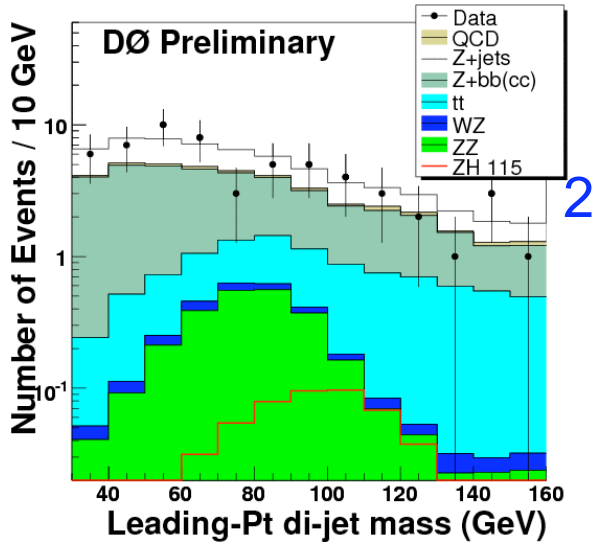
$L = 1.1\ \mathrm{fb}^{-1}$

NEW

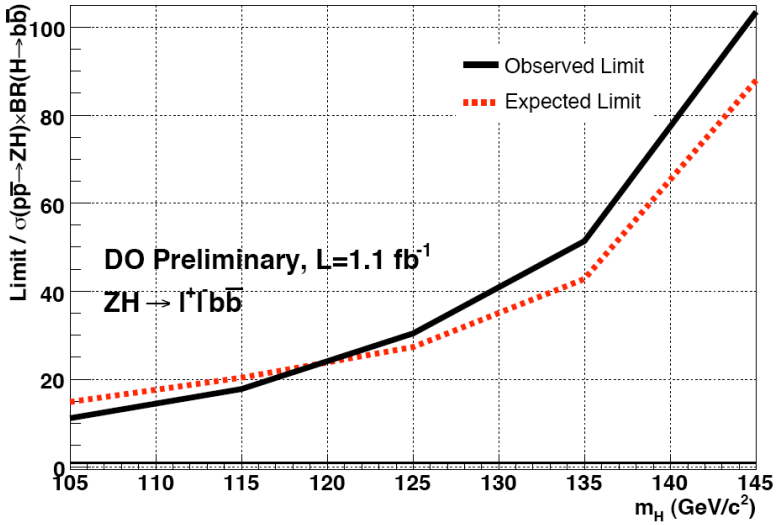
- NN trained based on kinematics
- ZZ is irreducible background



1 'tight' b tag

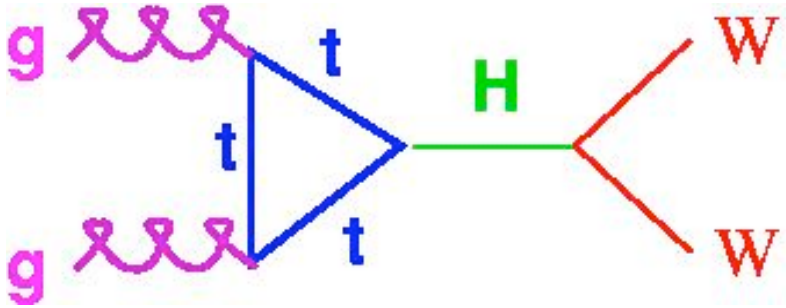


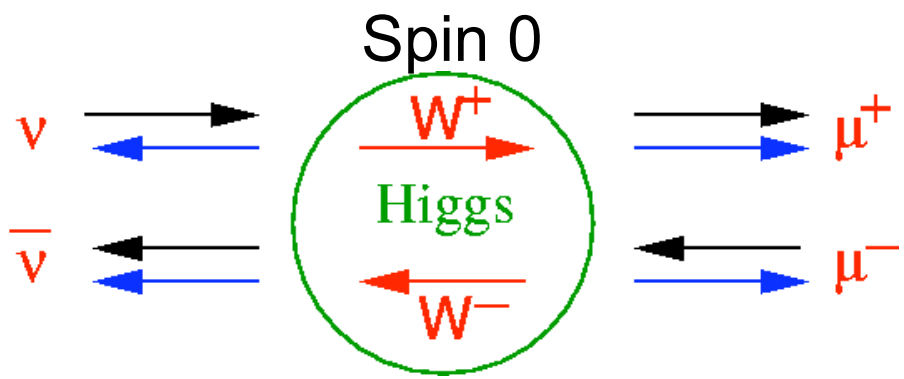
2 'loose' b tags



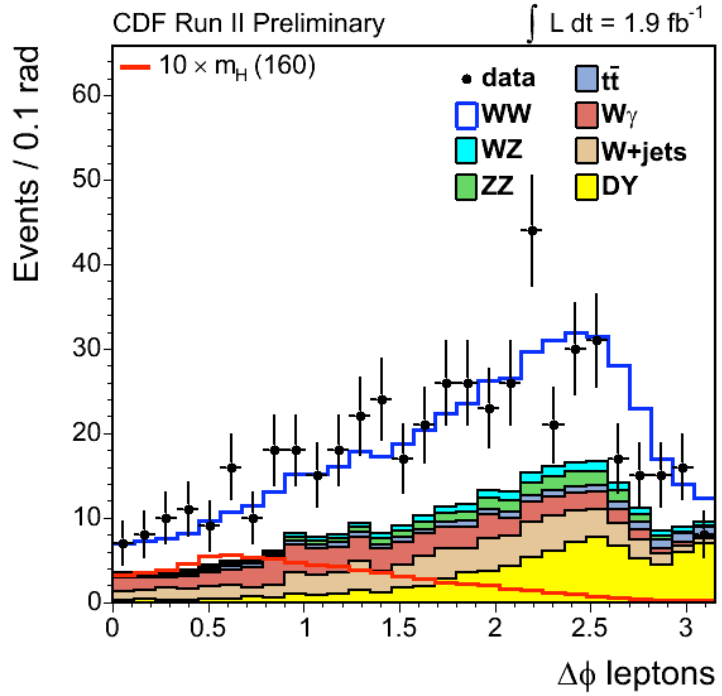
- M=115 GeV:
  σ_{95}/SM=20.4 (exp), 17.8 (obs)
- all channels important for final sensitivity

$H \to WW \to \ell\nu\ell\nu$ 힉스





Higgs: small $\Delta\varphi(l,l)$
WW: large $\Delta\varphi(l,l)$



Basic selection:

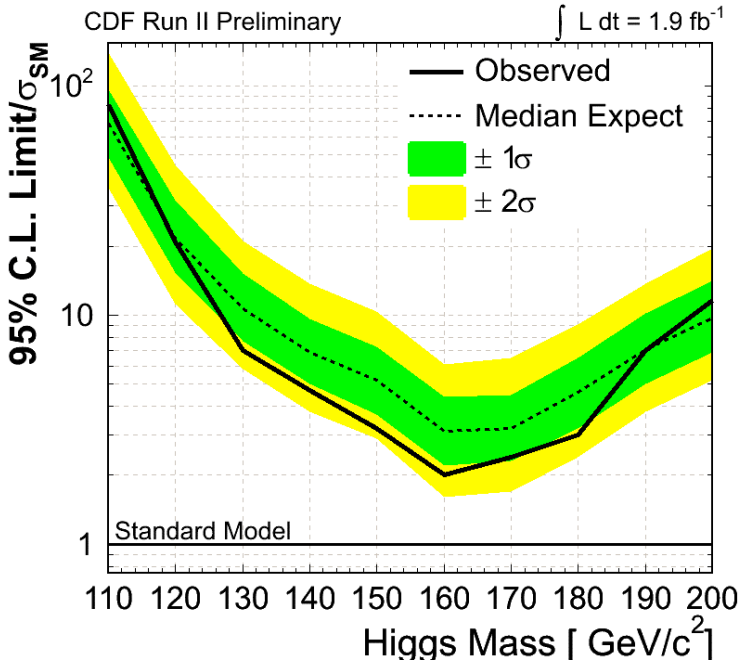
- two isolated leptons
- large E_T^{miss}

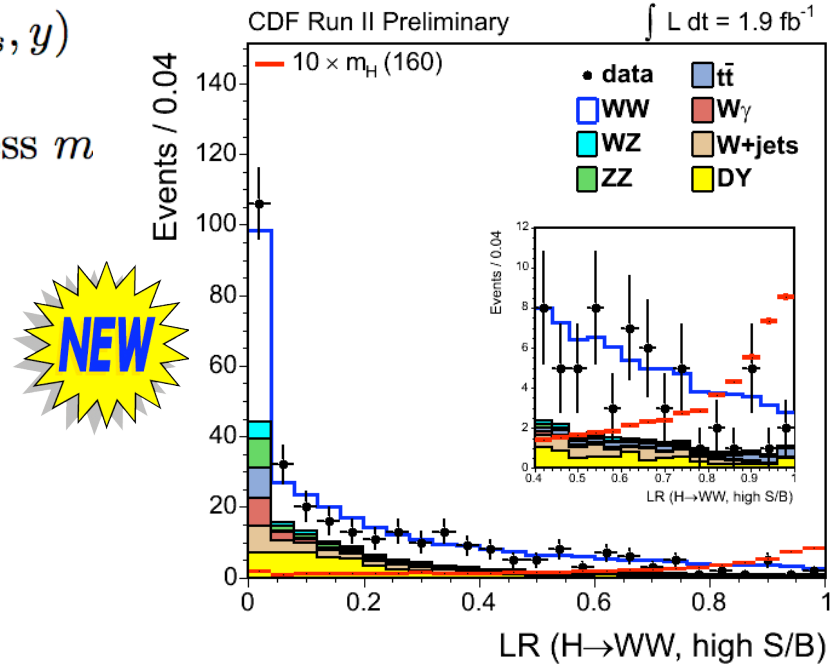
$$L = 1.9 \text{ fb}^{-1}$$

$H \to WW \to \ell\nu\ell\nu$ 힉스

$$P_m(\vec{x}_{obs}) = \frac{1}{\langle\sigma_m\rangle} \int d^n\sigma_m^{theory}(y)\epsilon(y)G(\vec{x}_{obs}, y)$$

P_m : Event-by-event probability for process m
y : true lepton kinematics, incl. neutrinos
$\vec{x}_{obs}$: observed kinematics
ϵ : lepton efficiencies
G : detector resolution function





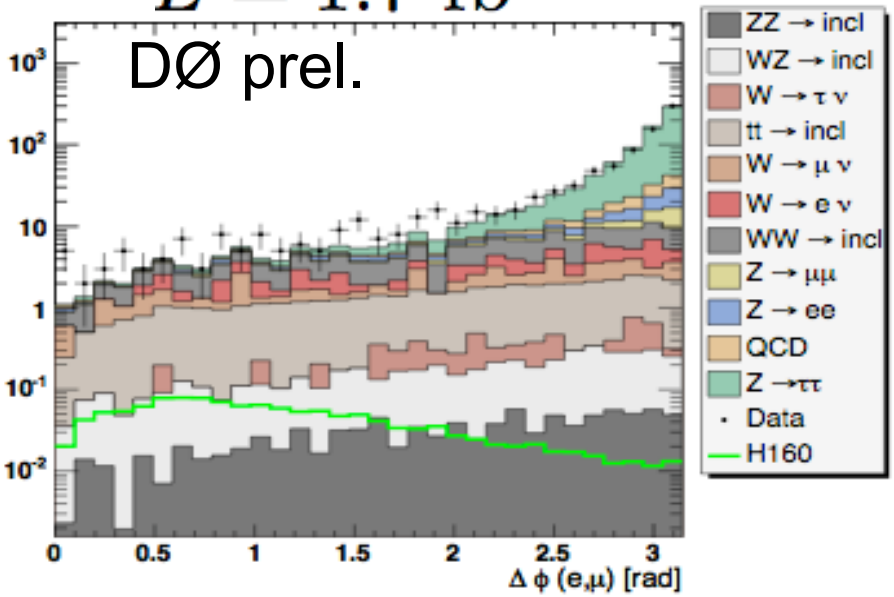
$$LR(m_H) = \frac{P_{Higgs}(m_H)}{P_{Higgs}(m_H) + \sum_{bg=WW,WZ,tt,..} f_{bg}P_{bg}}$$

Matrix Element Technique (→top)

most sensitive at high masses

$H \to WW \to \ell\nu\ell\nu$ 힉스

$L = 1.7\ \mathrm{fb}^{-1}$

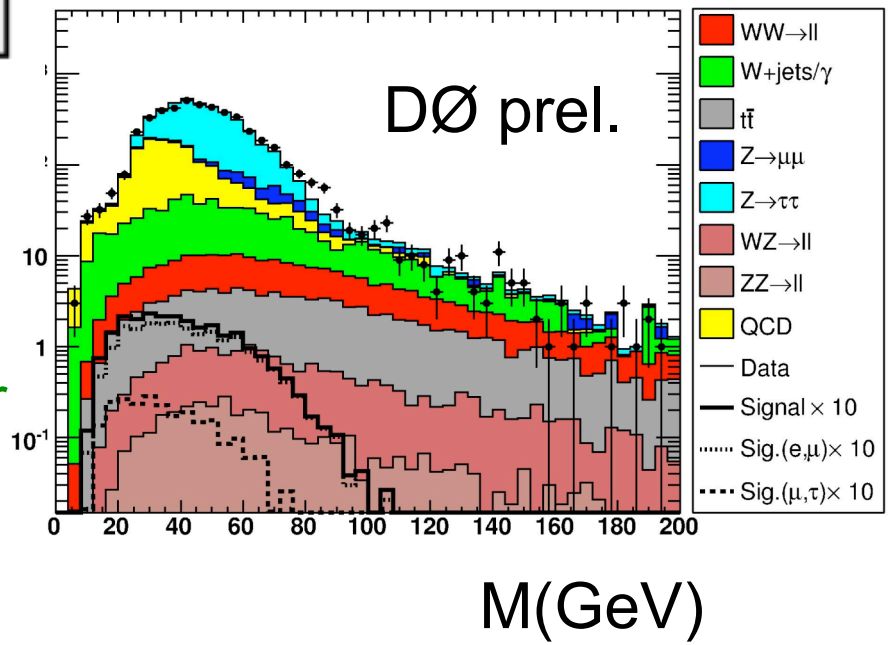


μe final state

NEW

normalised to $Z \to \tau_e \tau_\mu$

$L = 1\ \mathrm{fb}^{-1}$



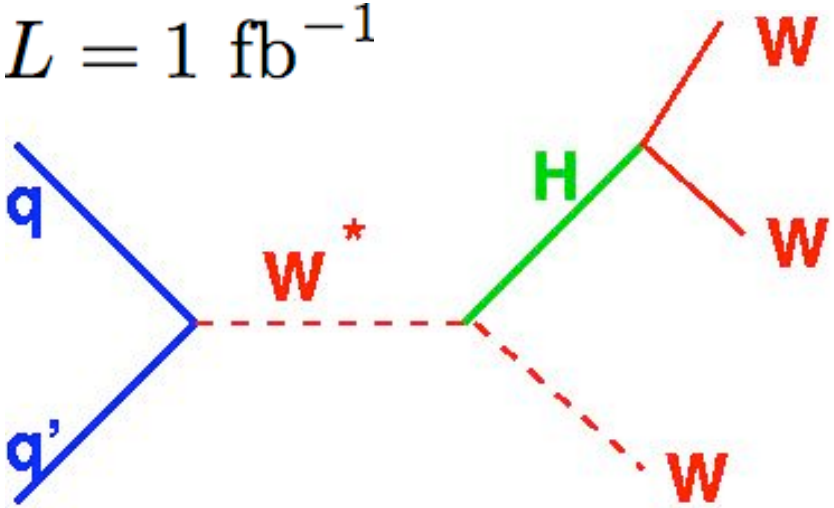
NEW

$\mu\tau_{had}$ final state

- hadronic tau reconstruction challenging at hadron collider
- $Z \to \tau_\mu \tau_{had}$ has been observed
- adds sensitivity

$HW \to WWW \to \ell\nu\ell\nu + X$ 힉스

$L = 1\ \mathrm{fb}^{-1}$



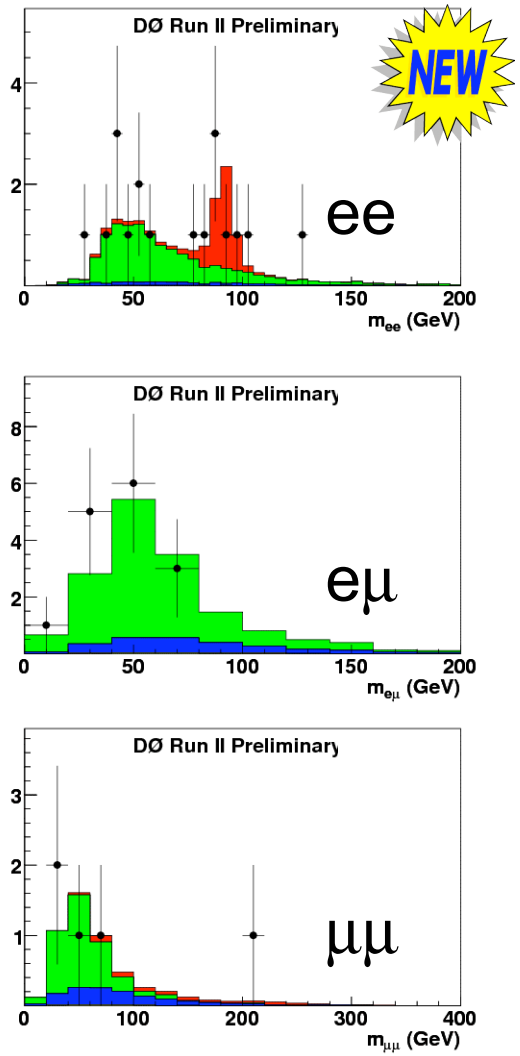
→ X (h,l)

→ e or μ

same charge

→ e or μ

di-lepton mass



Selection:
- two isolated leptons (electrons,muons)
- both leptons have p_T > 15 GeV
- kinematic likelihood selection

Charge mis-identification ('flips') from data:
- muons: solenoid vs toroid
- electrons: solenoid vs Δφ(track,calorimeter)

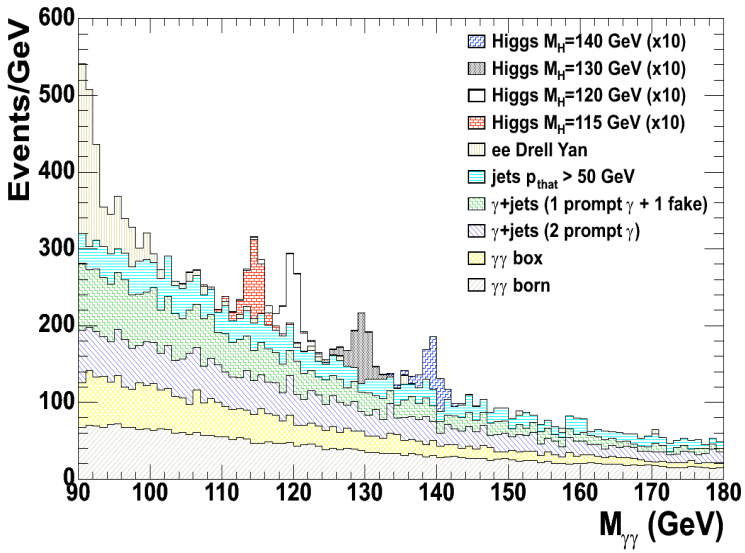
relatively low background,
important at intermediate masses, σ_{95}/SM(exp) ~ 20

Limit Setting

LEP: low background, small systematics
Tevatron/LHC: high background, large systematics

Background only (b) and signal plus background (s+b) hypotheses are compared to data using Poisson likelihoods.

Probability density function is obtained through Gaussian smearing.



Systematic uncertainties are included in the likelihood ('profile likelihood')

Background is constrained by maximising profile likelihood ('sideband fitting').

Combining the results

Tevatron experiments use LEP CL_s (modified frequentist) and Bayesian methods

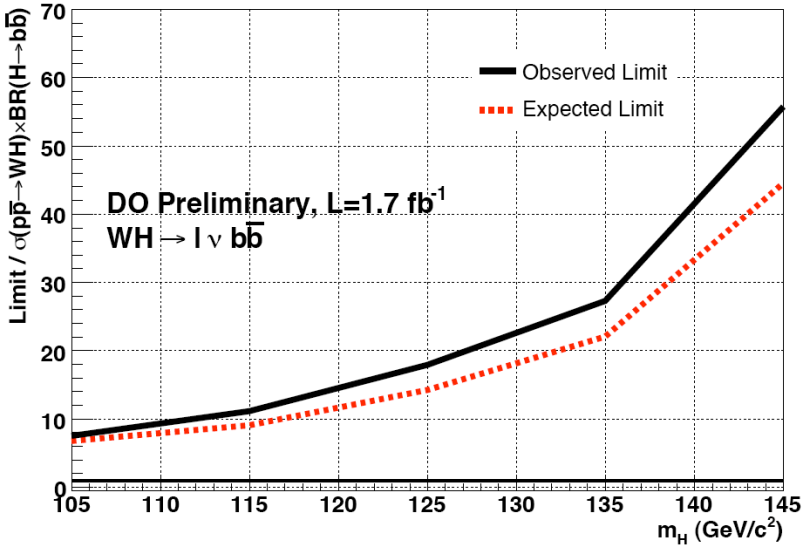
Systematics, including correlations, taken into account:

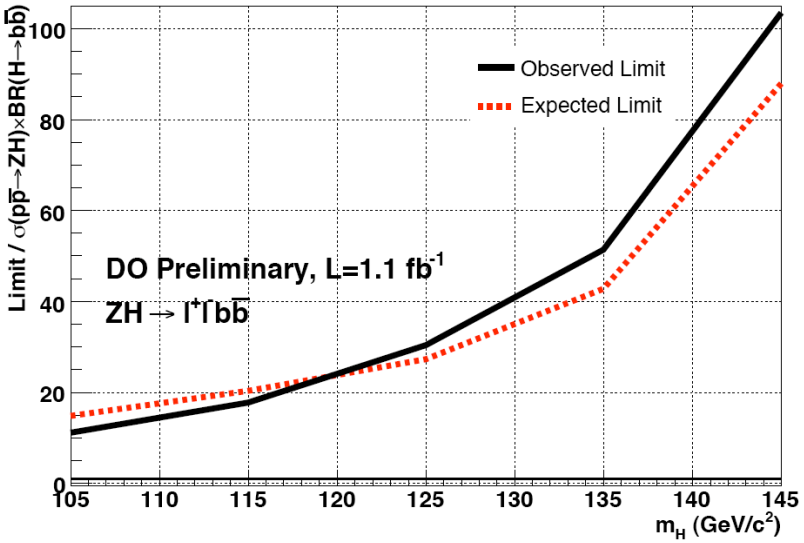
Main systematics (depending on channel):

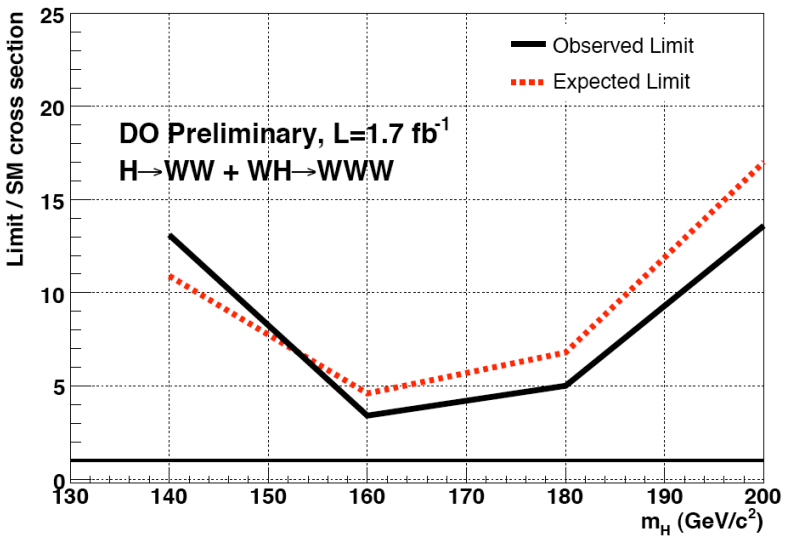
- luminosity and normalisation
- QCD background estimates
- input background cross-sections
- jet energy scale and b-tagging
- lepton identification

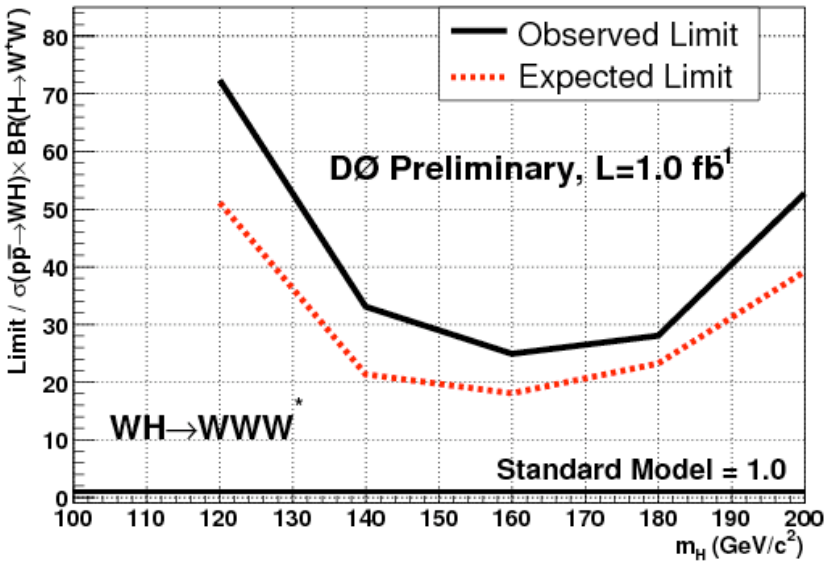
Limit setting approaches agree to within 10%

Putting it all together (DØ)









Putting it all together (CDF)

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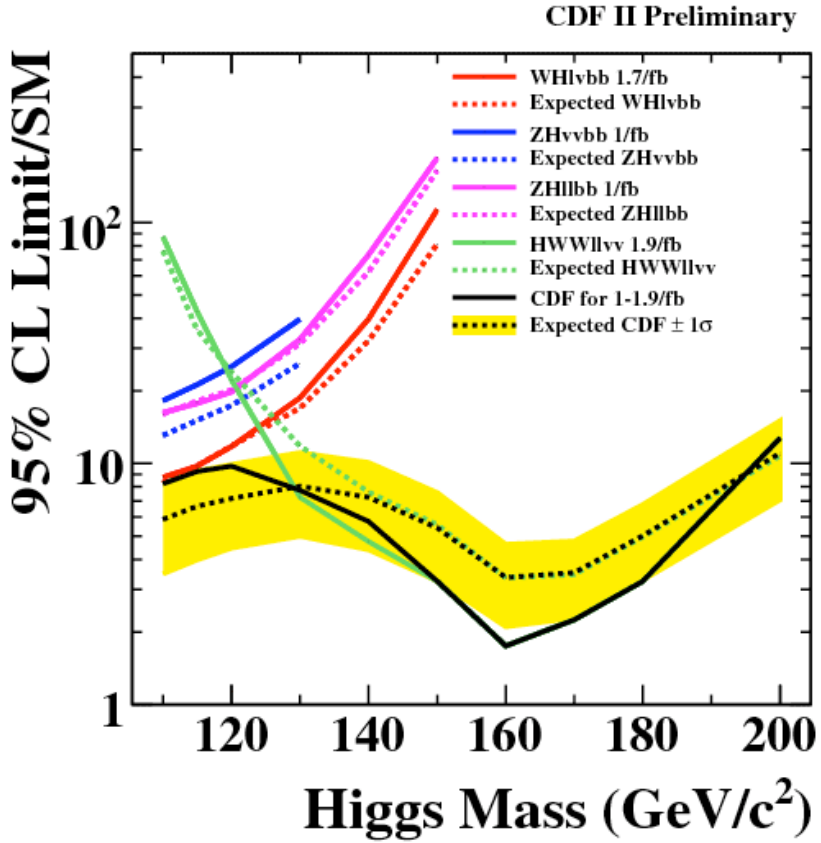
- new CDF ννbb result not included yet



Putting it all together (CDF)

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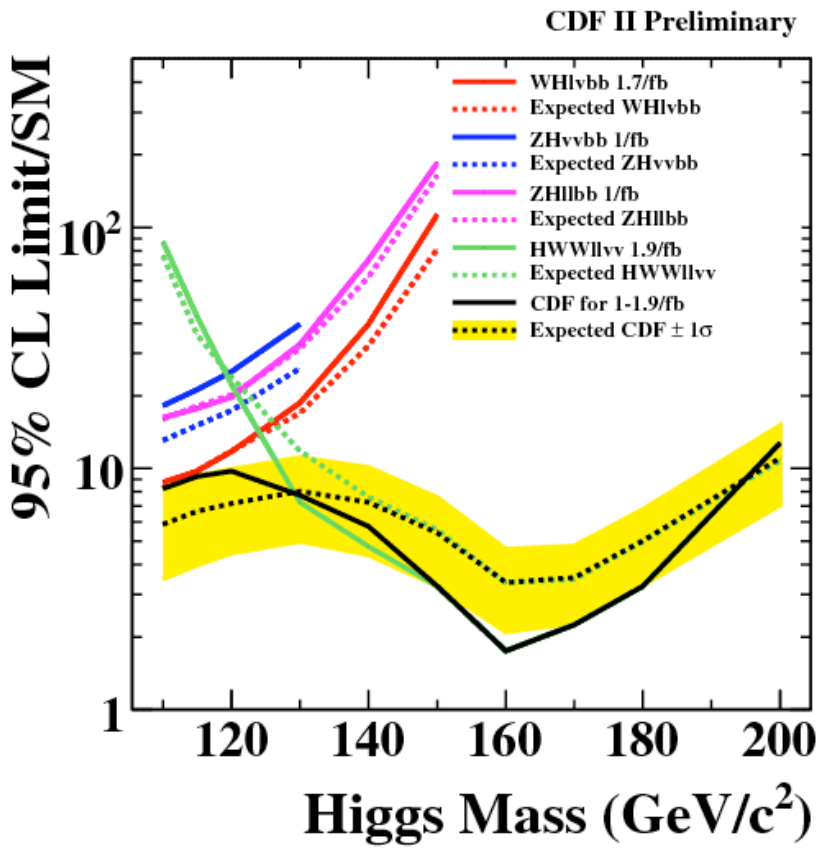
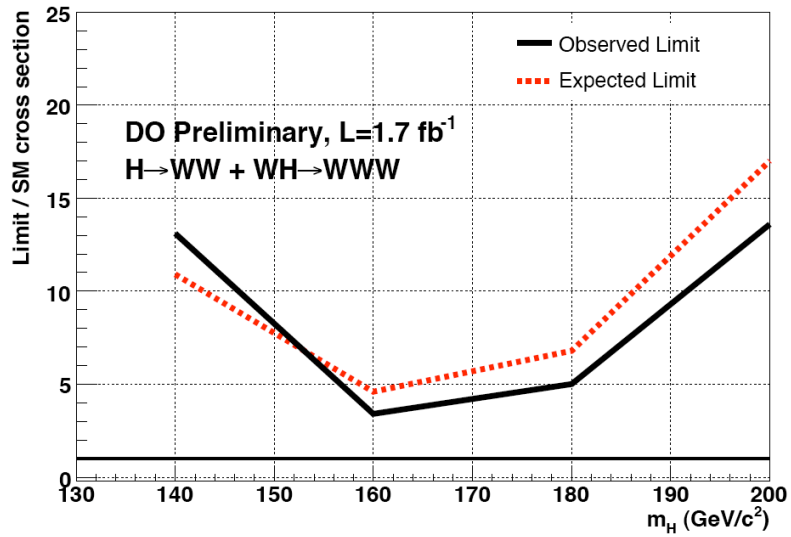


- new CDF ννbb result not included yet

- Tevatron combination in progress



watch 160 GeV…

Tevatron Combination

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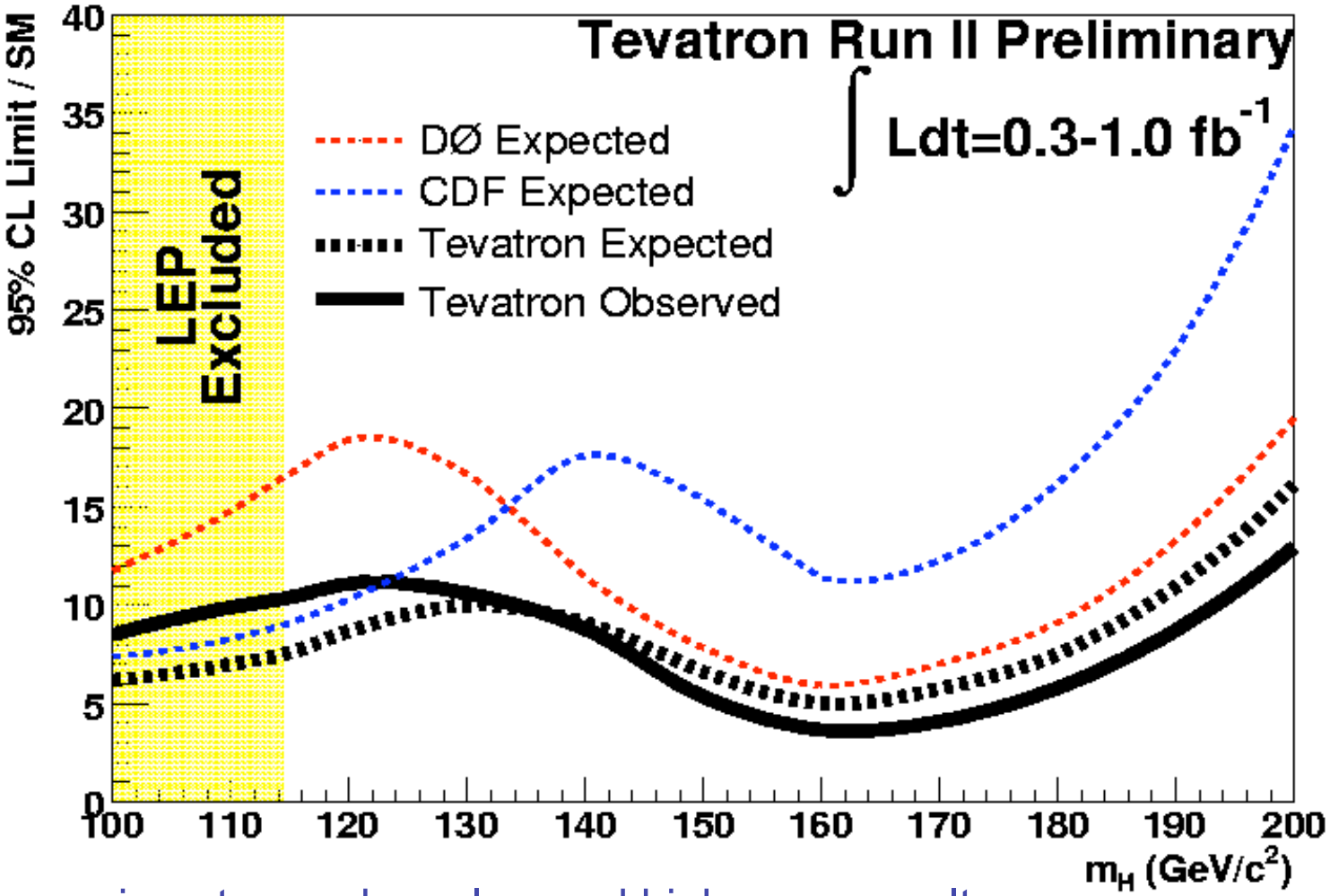
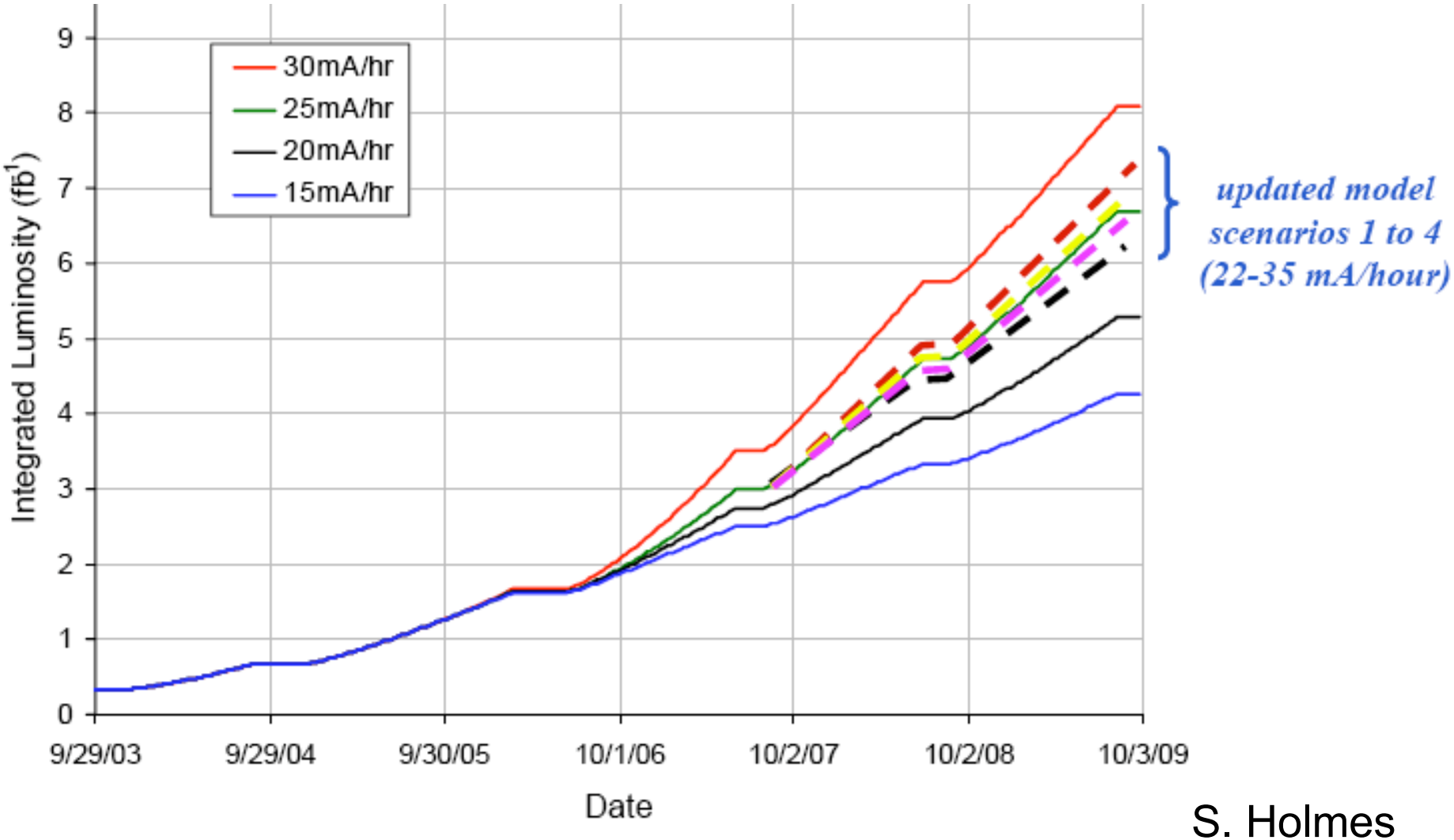
to be updated..



both experiments now have low and high mass results

The near future…



S. Holmes

and finally: from Chicago to Geneva

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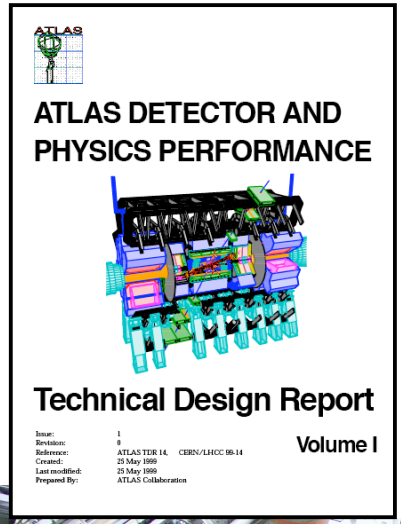

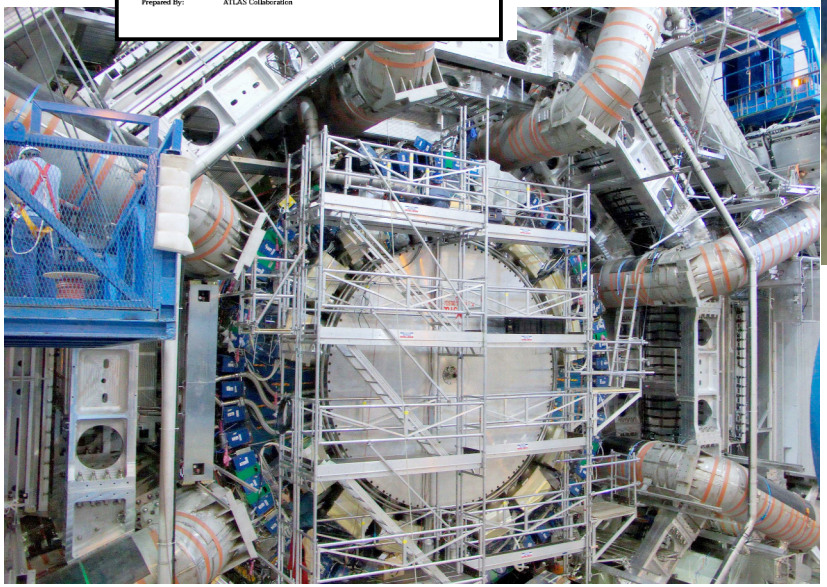

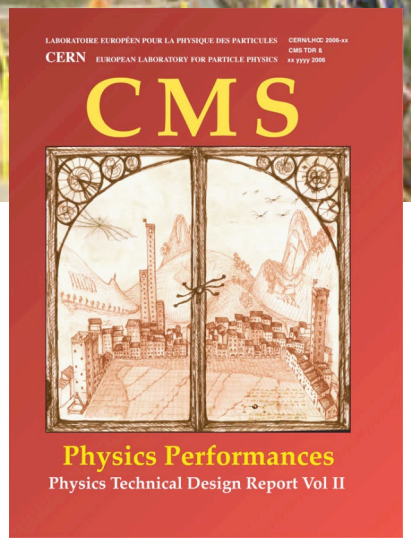

Production at the LHC

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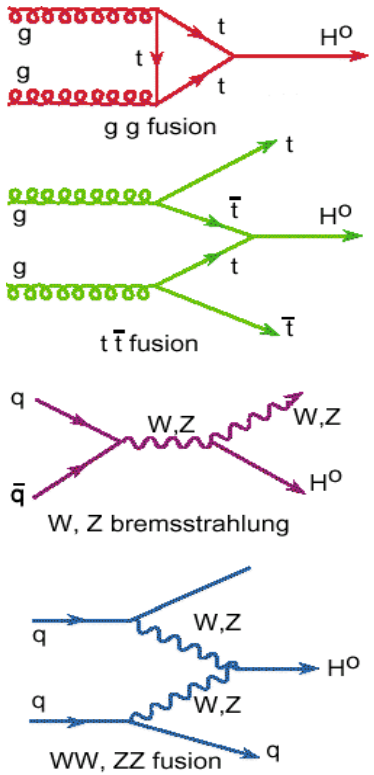

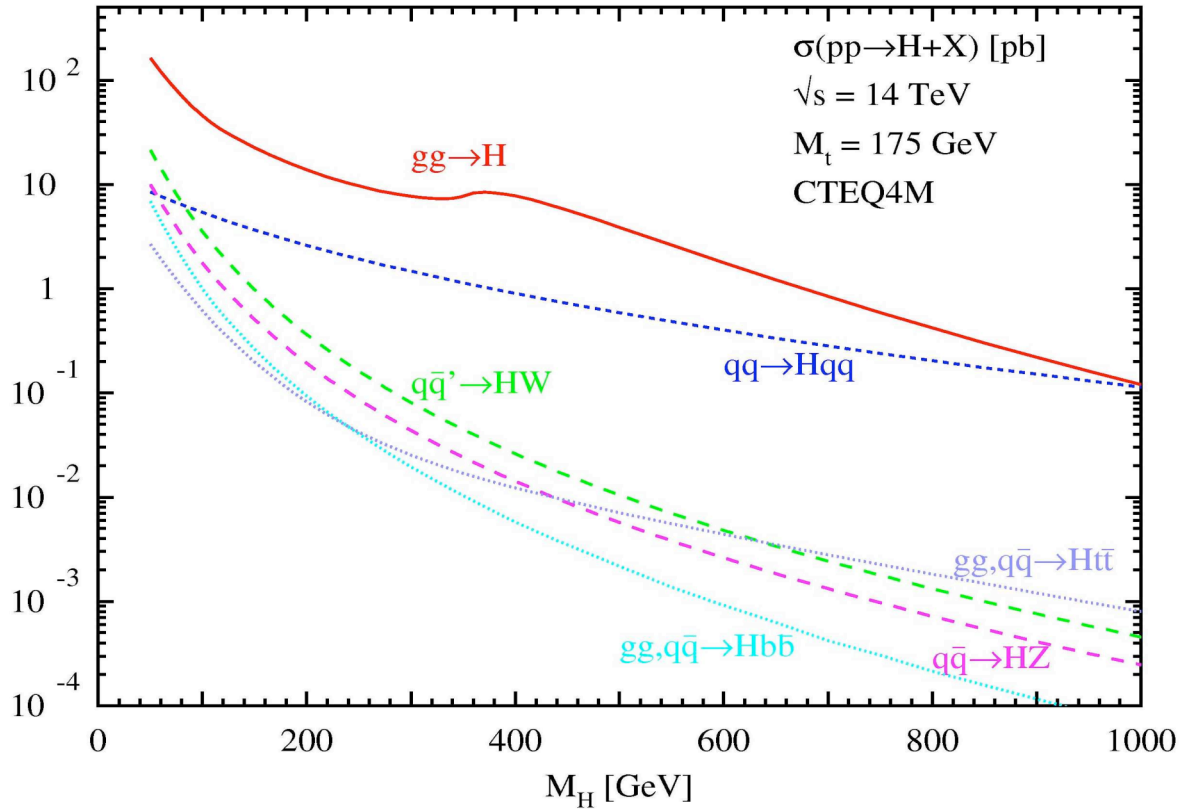

Two orders of magnitude larger than at the Tevatron

..and Decay

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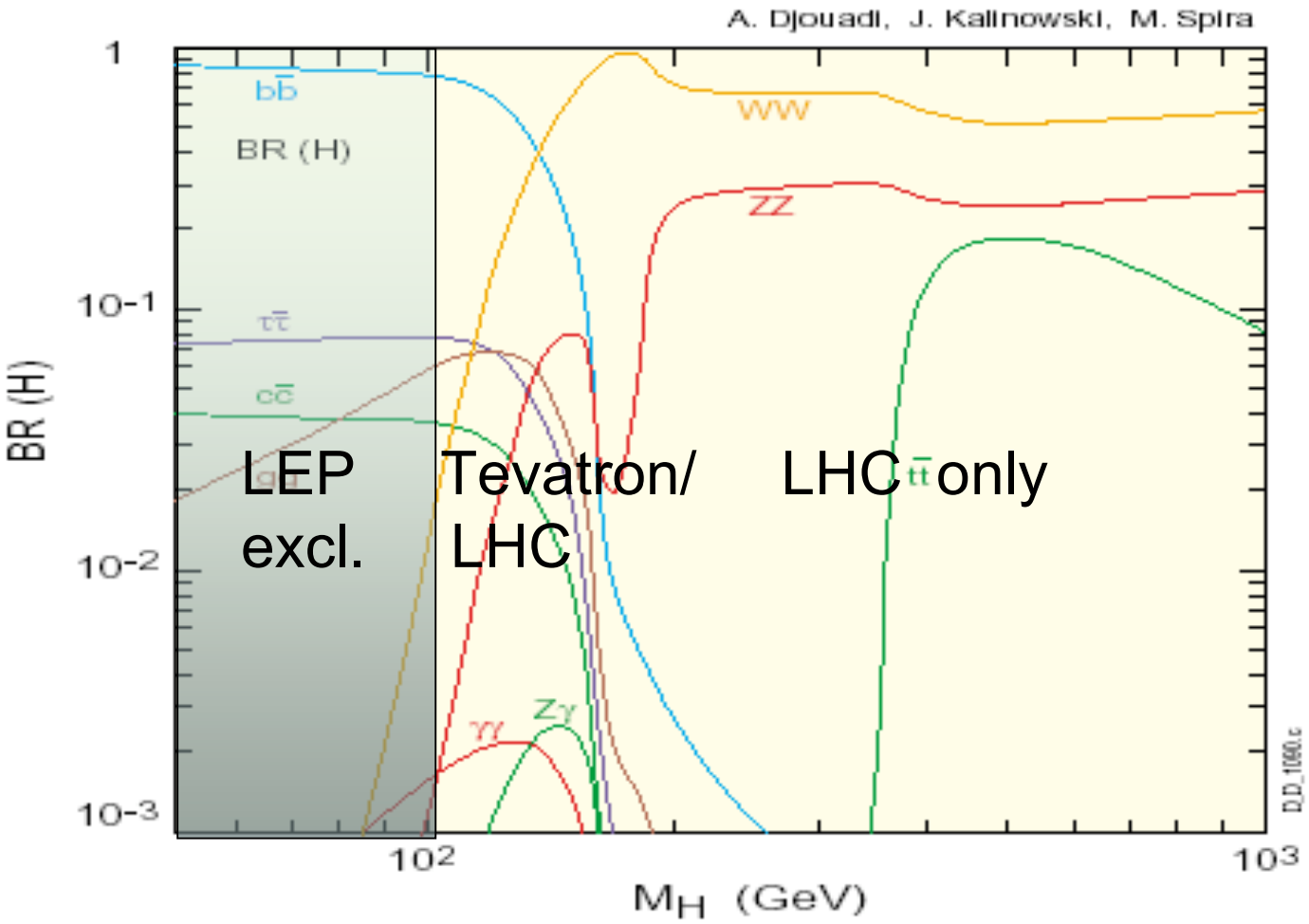
A. Djouadi, J. Kalinowski, M. Spira
BR (H)
1
10-1
10-2
10-3
bb̄
WW
ZZ
ττ̄
cc̄
γγ
Zγ
LEP excl.
Tevatron/ LHC
LHC tt̄ only
10²
10³
M_H (GeV)

H → γγ

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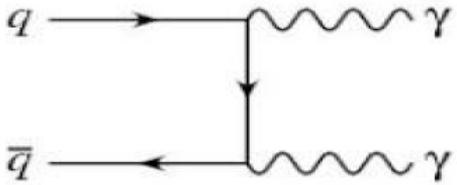
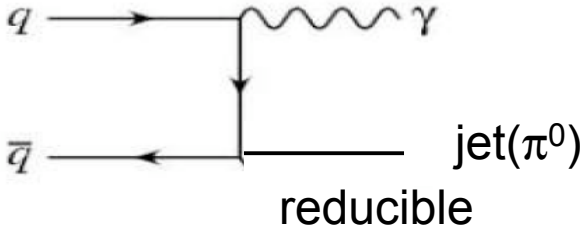
small BR ~ 0.002, but clear signature

main background:

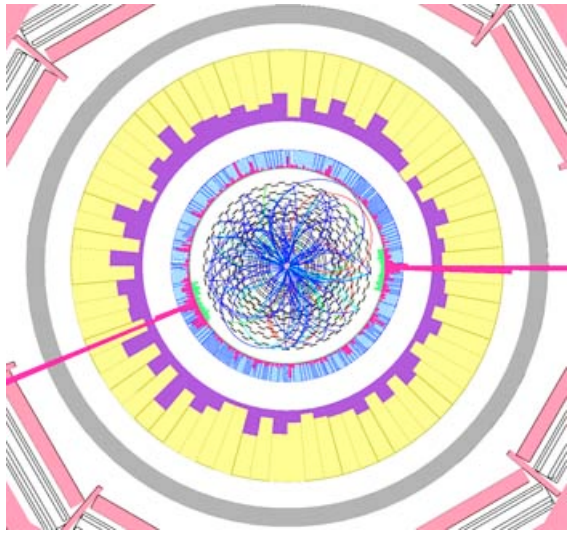
$\sigma_{H\to\gamma\gamma}/\sigma_{pp\to\gamma\gamma} \simeq 10^{-3}$

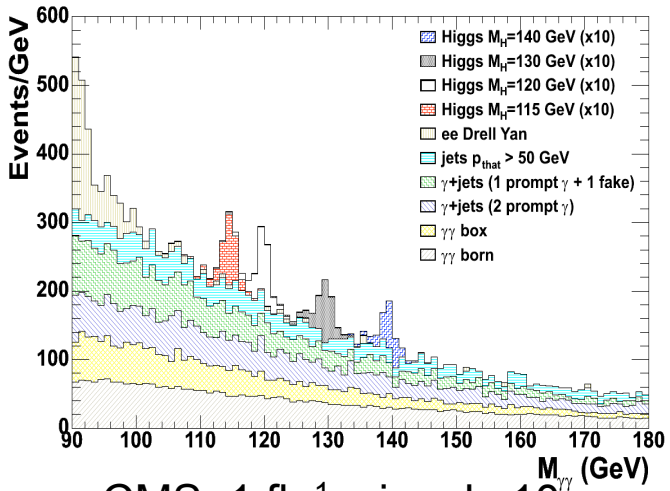


$\sigma_{H\to\gamma\gamma}/\sigma_{pp\to\gamma+jet} \simeq 10^{-6}$



reducible

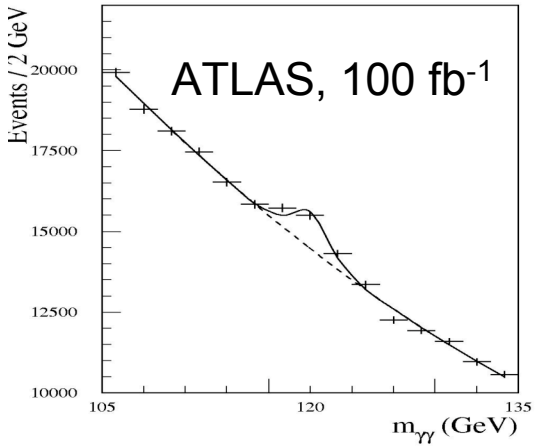




CMS, 1 fb^{-1}, signal x10

Tools:

- photon id (incl. conversions)
- γ/jet separation
- very good energy resolution



H → ZZ → 4 leptons

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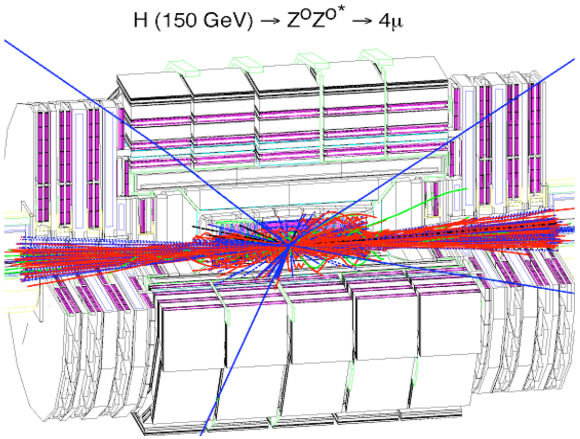
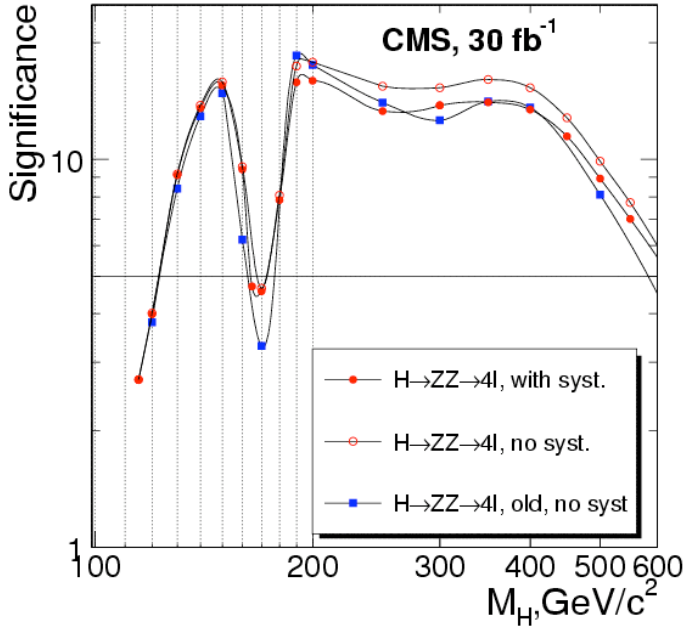
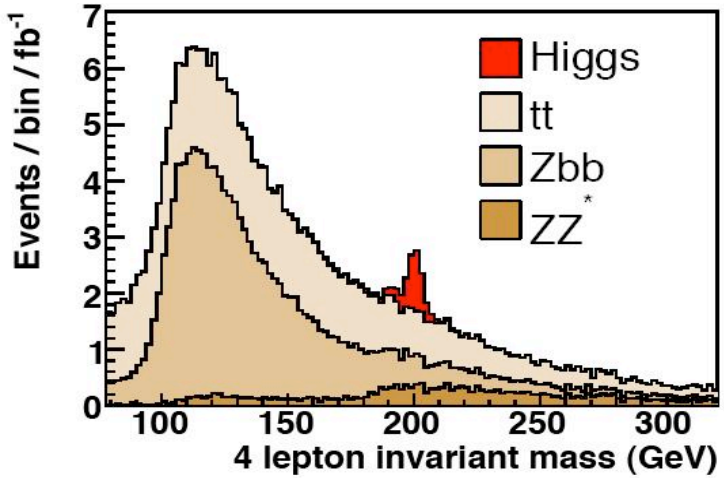
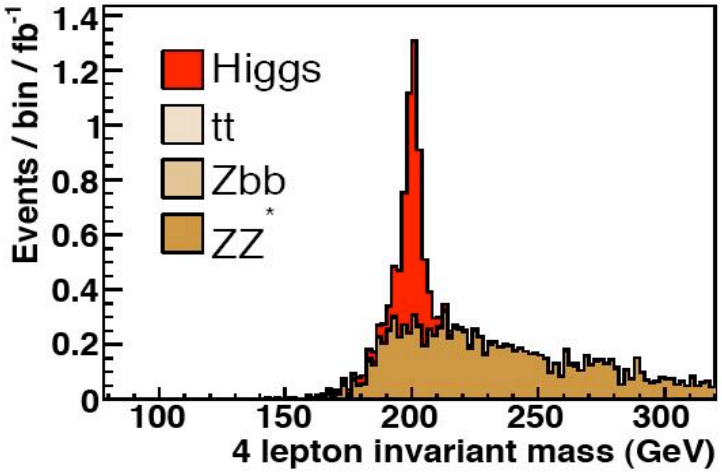




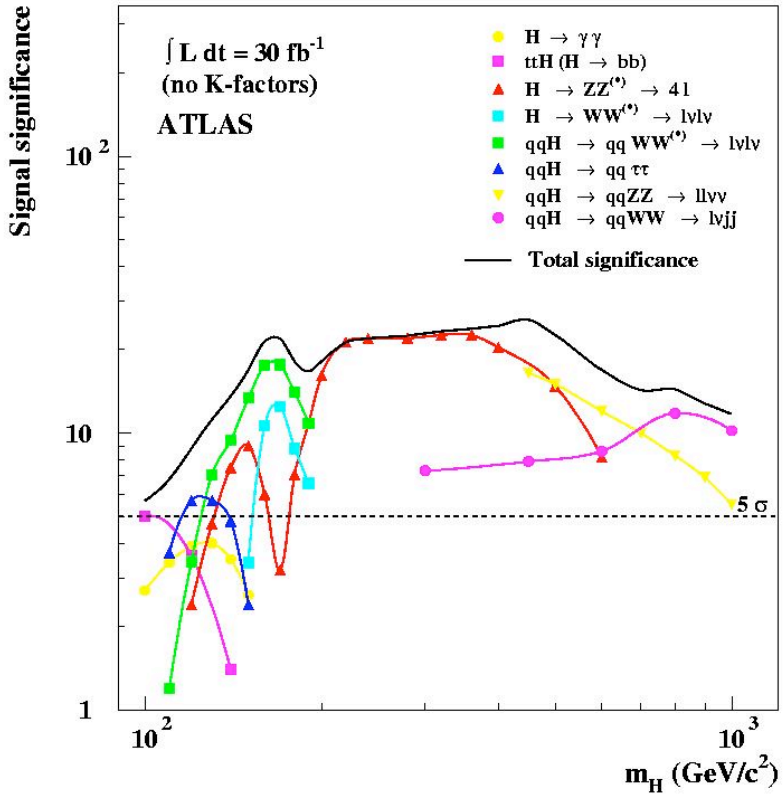
'golden channel'



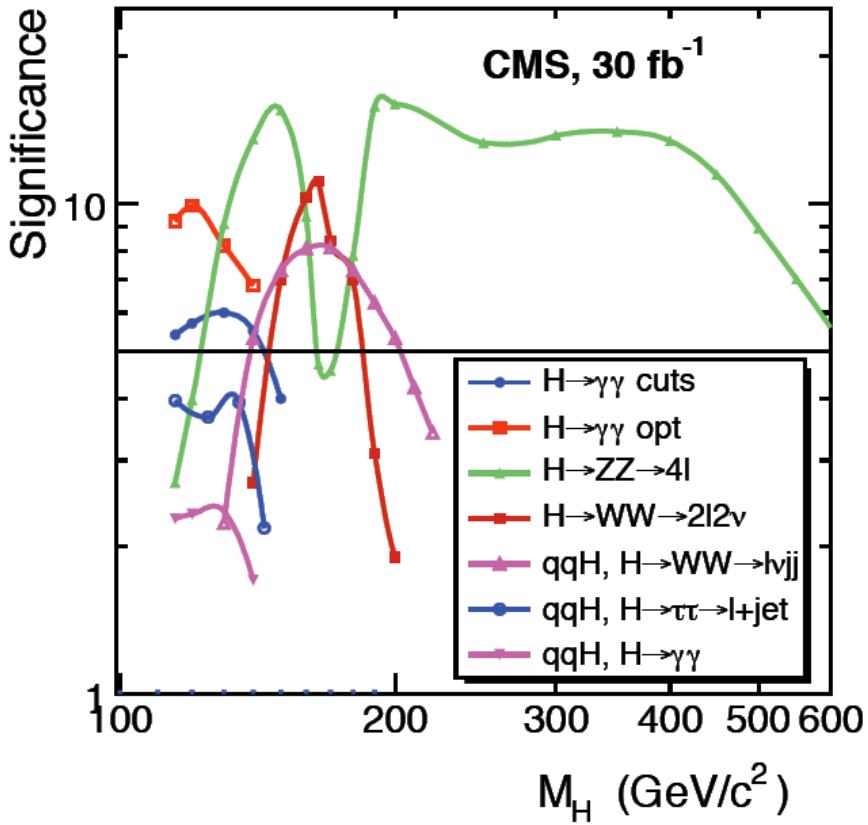


LHC Discovery Potential

2003, no k factors



2006, k factors



updates in progress

Summary

힉스

LEP limit is M_h>114.4 GeV.

Tevatron experiments are searching for Standard Model Higgs in the mass range 100-200 GeV.
Preliminary results for 2 fb^{-1} data set.

In many channels, limits improve linearly with luminosity due to improved calibrations and analysis techniques.

Final data set expected to be 6-7 fb^{-1} per experiment.

Stay tuned for the Higgs,
register for Lepton-Photon 2009.

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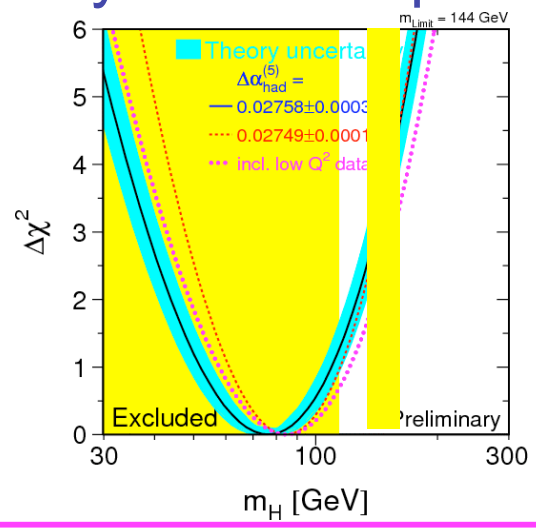

LEP's Legacy

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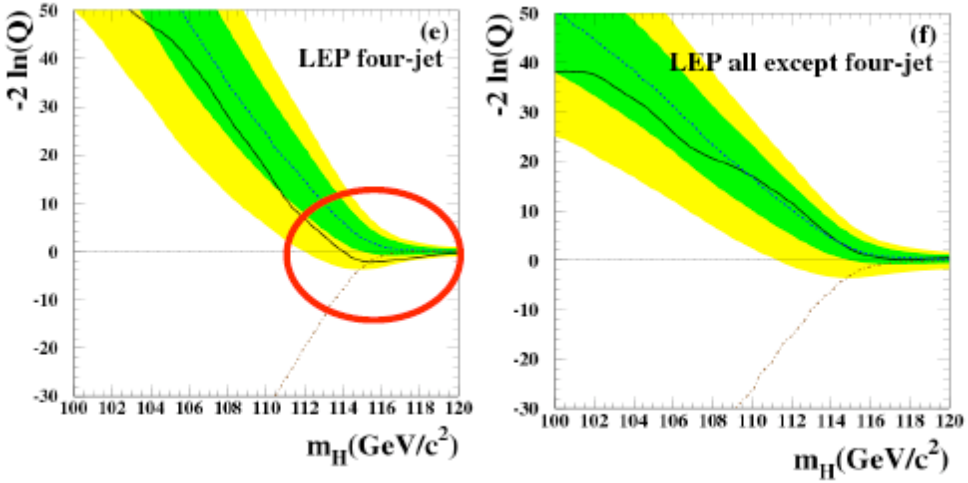
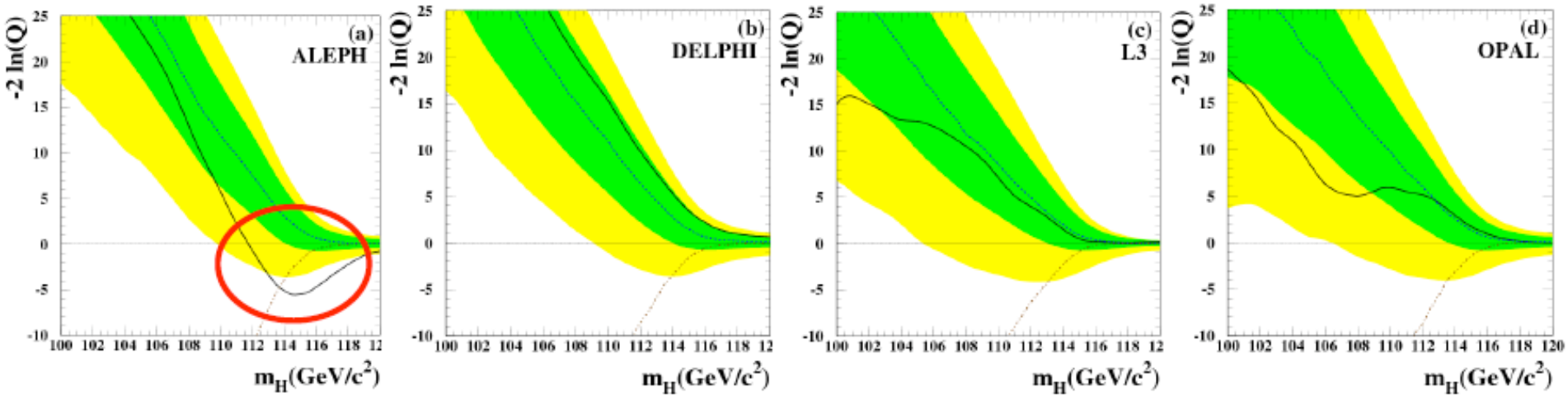
The effect is mainly due to

- four-jet channel
- ALEPH events