



Higgs and BSM at the Tevatron

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on behalf of the CDF & DZero Collaborations

ISMD 2011, September 26 - 30

Tevatron

Tevatron collider at Fermilab

proton anti-proton collisions

$\sqrt{s} = 1.96 \text{ TeV}$

$4 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ peak luminosity



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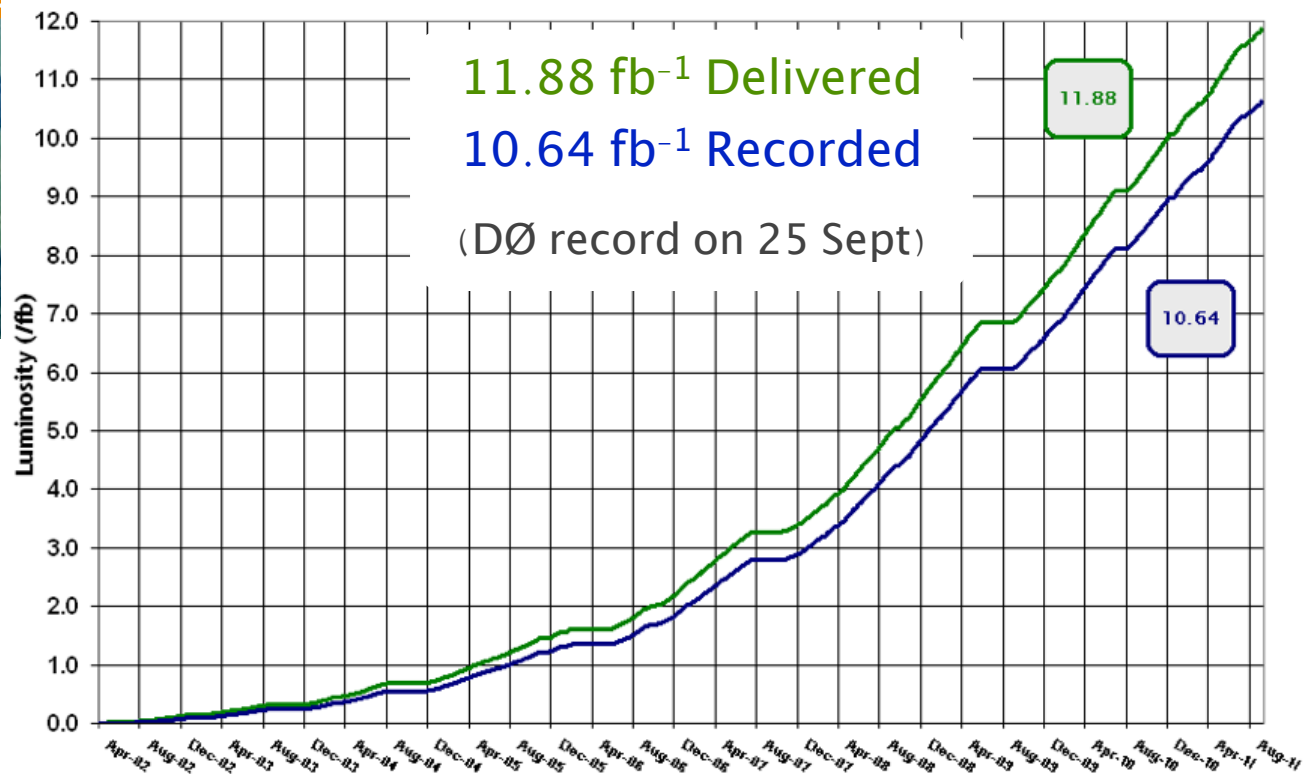
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Run II Integrated Luminosity

19 April 2002 - 25 September 2011



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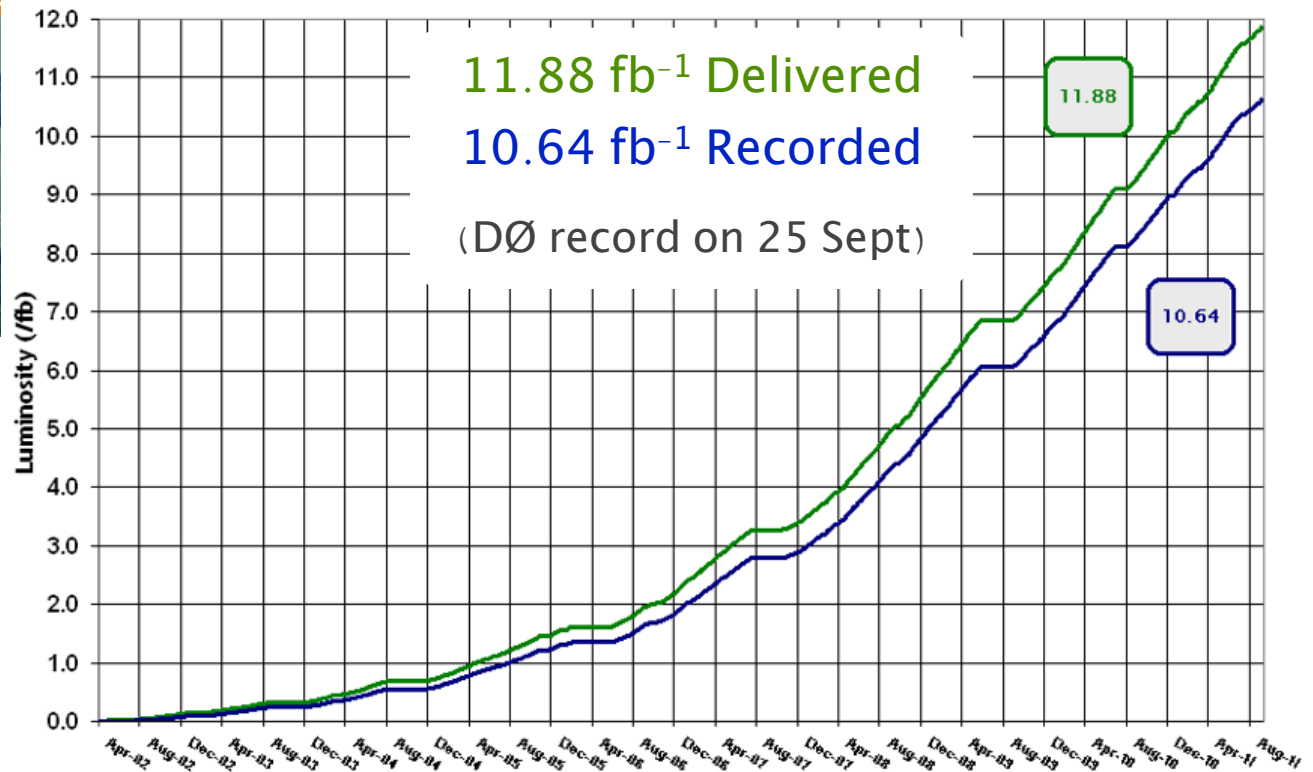
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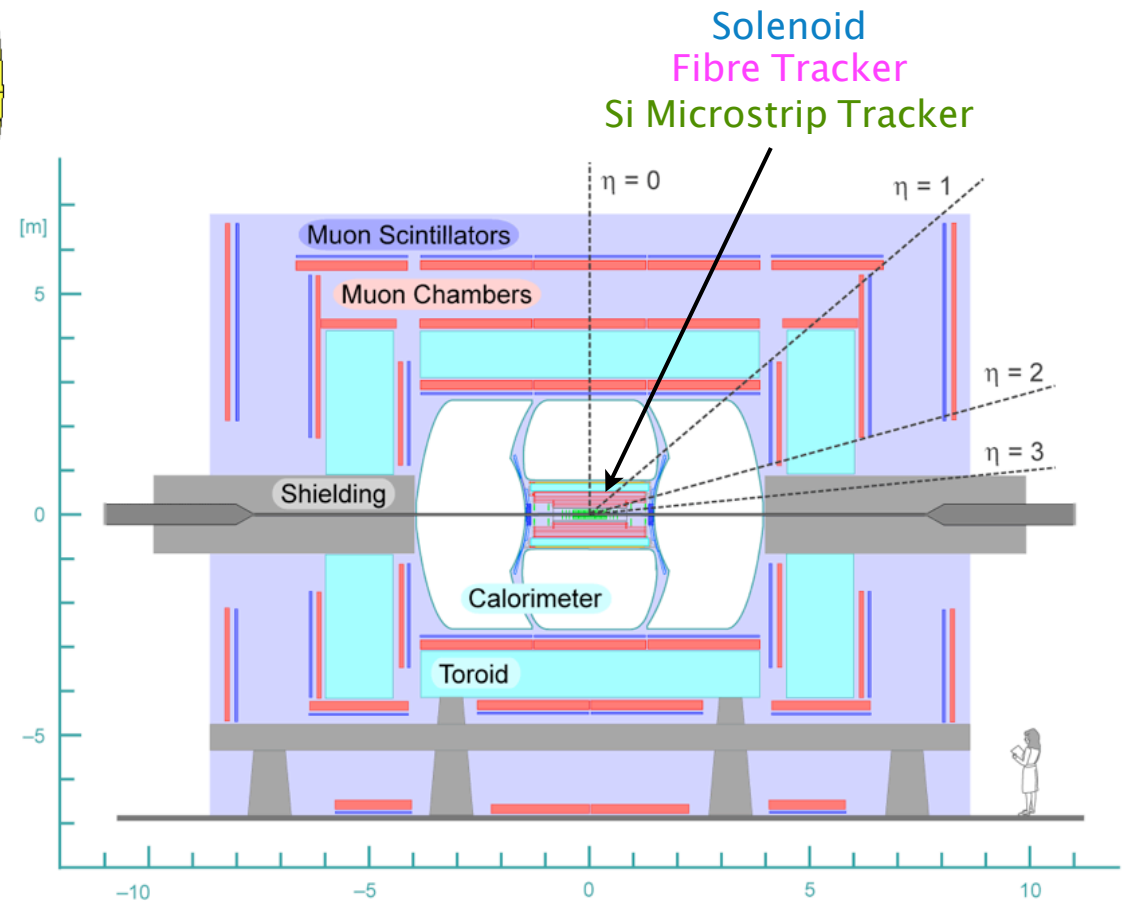
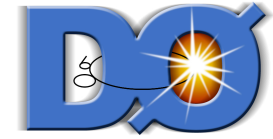
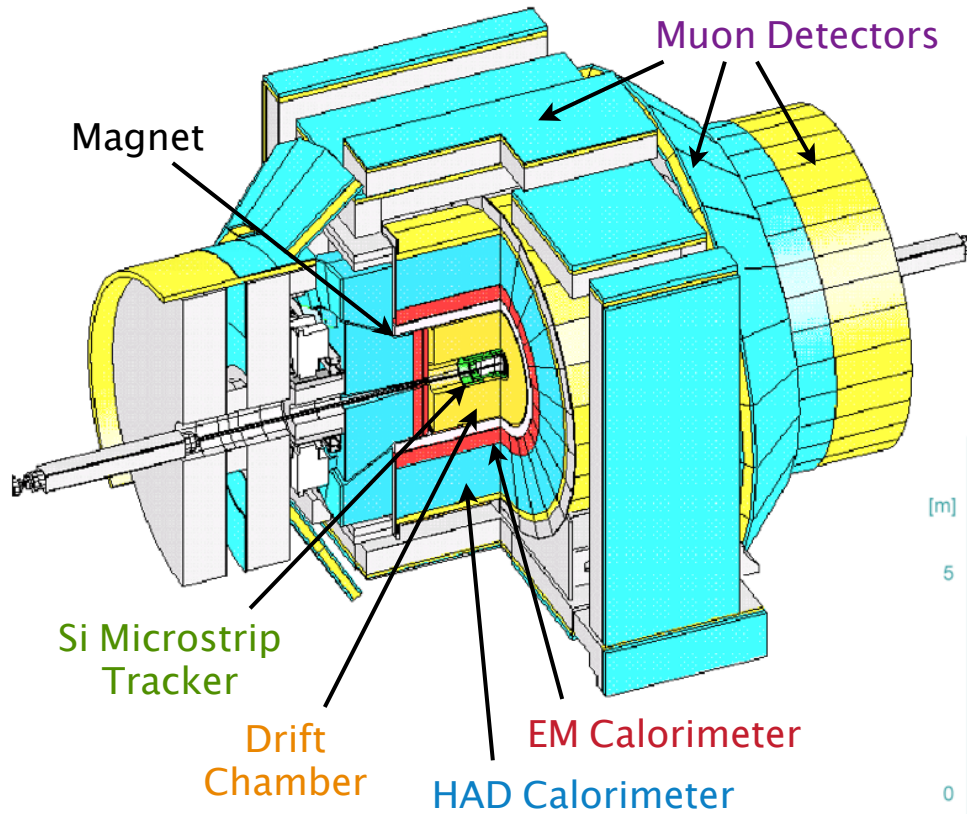
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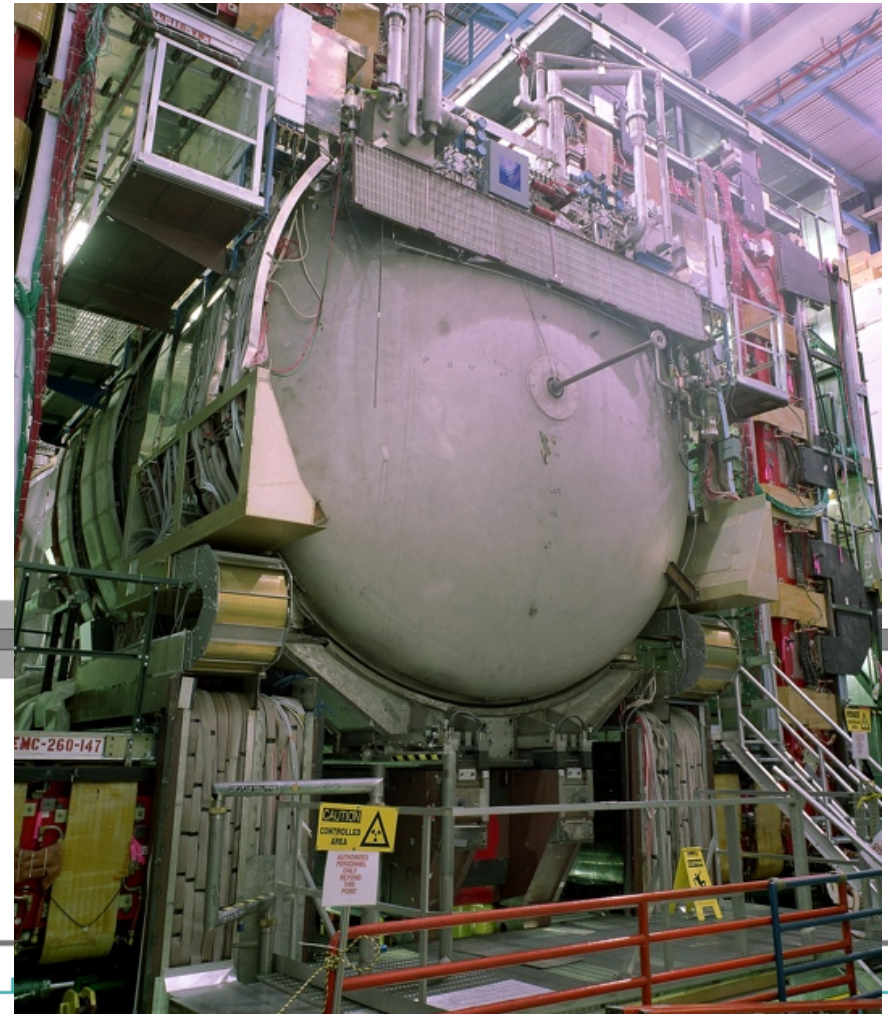
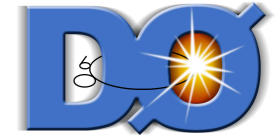
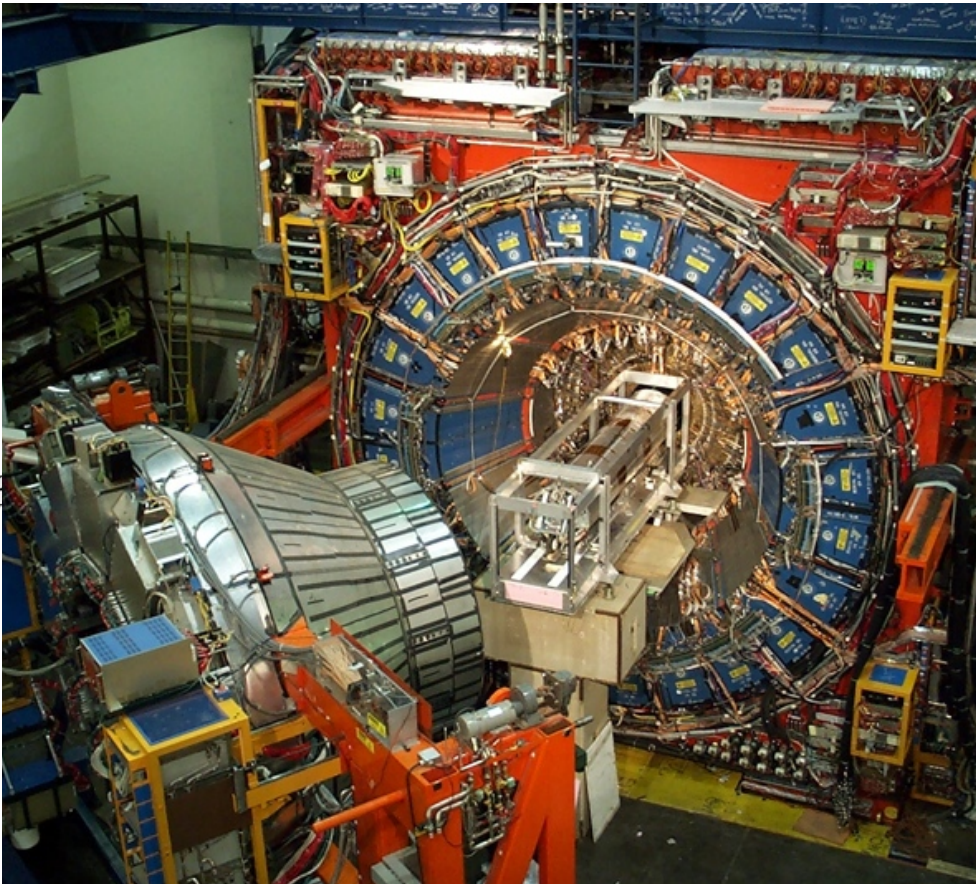
Tevatron operation
ends today

after 26 years
of $p\bar{p}$ collisions

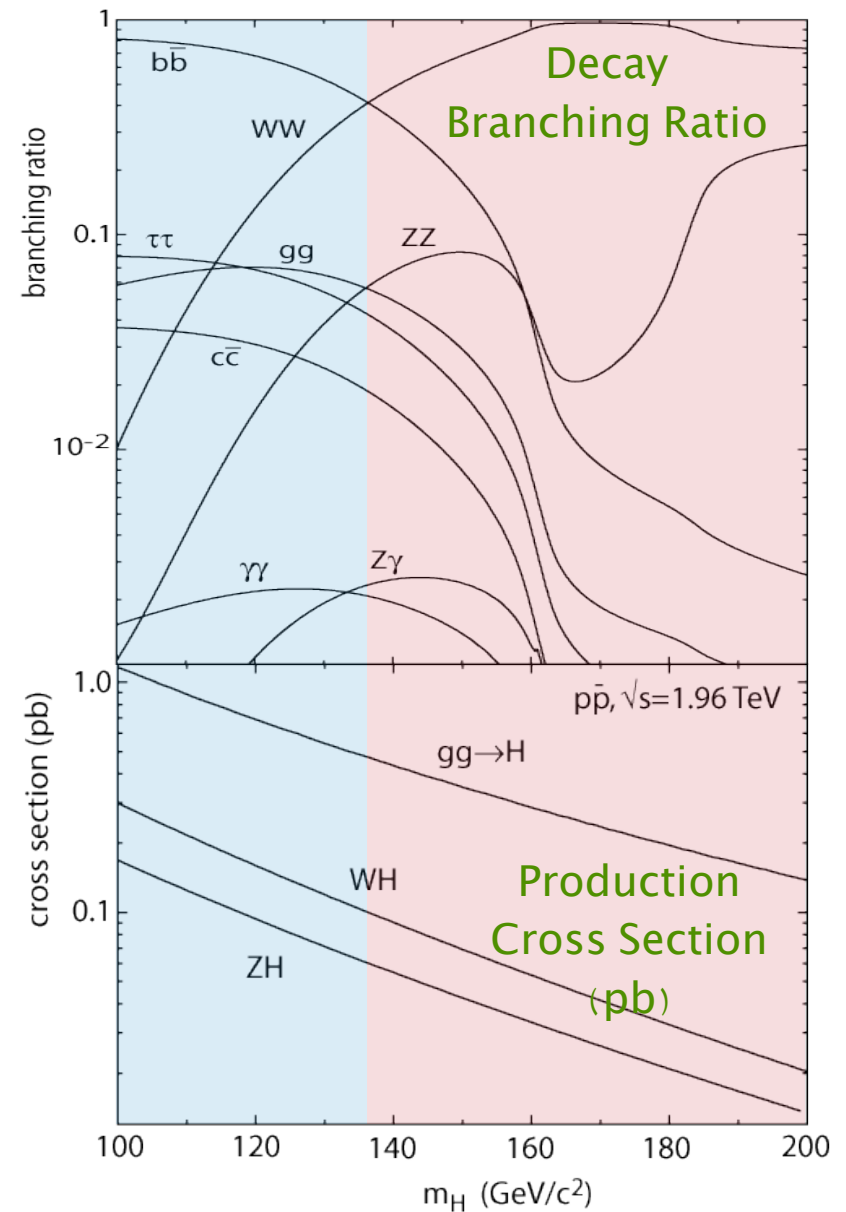
CDF and DØ Experiments



CDF and DØ Experiments

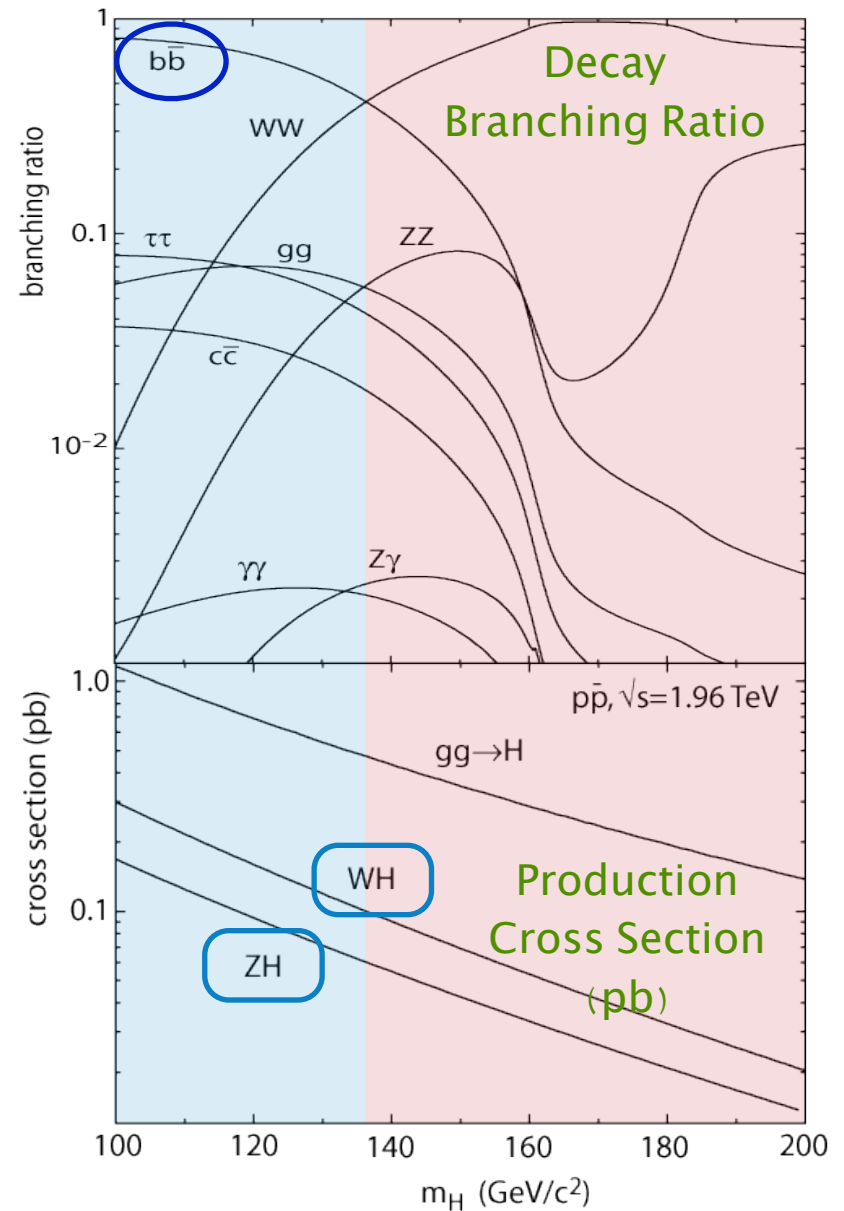
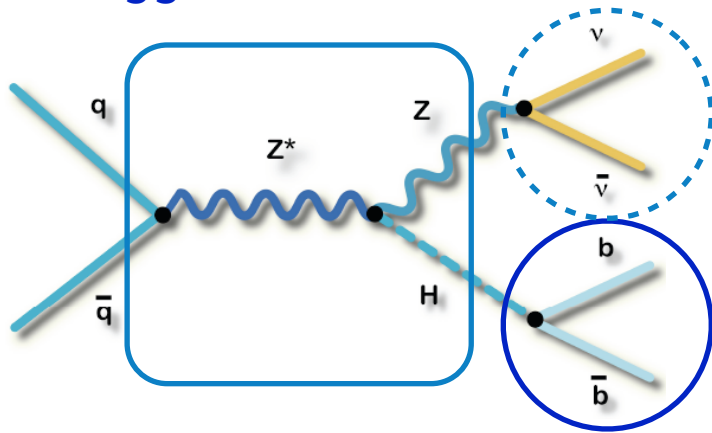


SM Higgs Boson



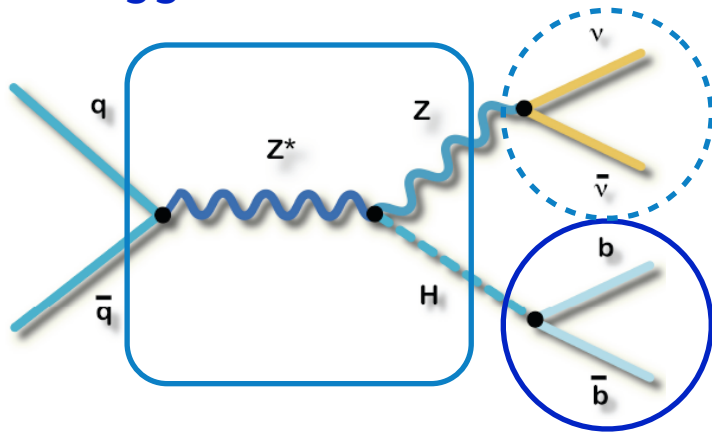
SM Higgs Boson

Low Mass Higgs search

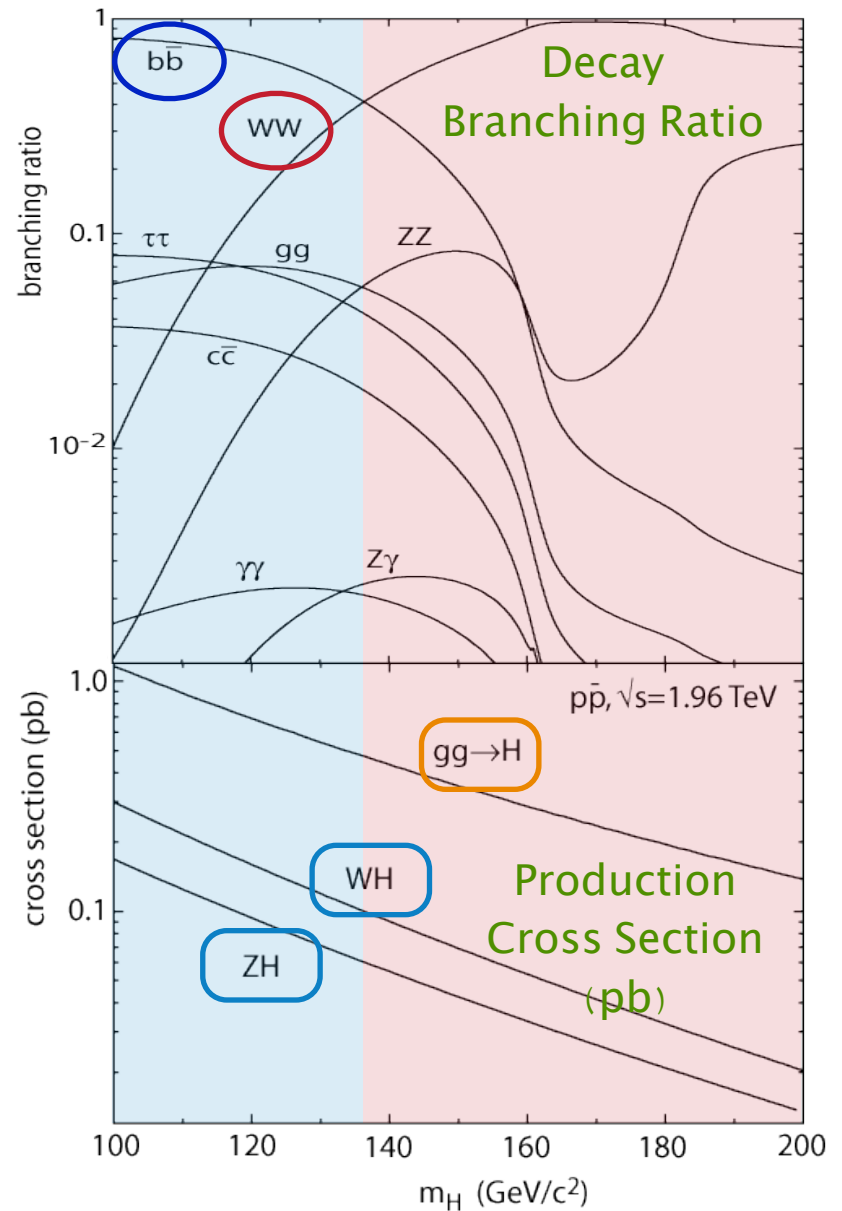
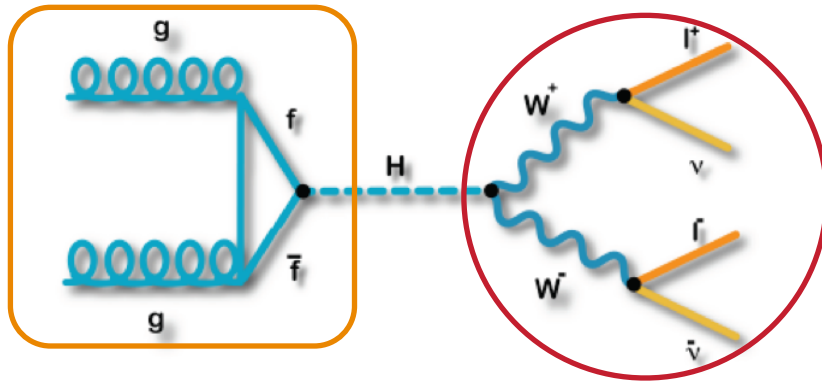


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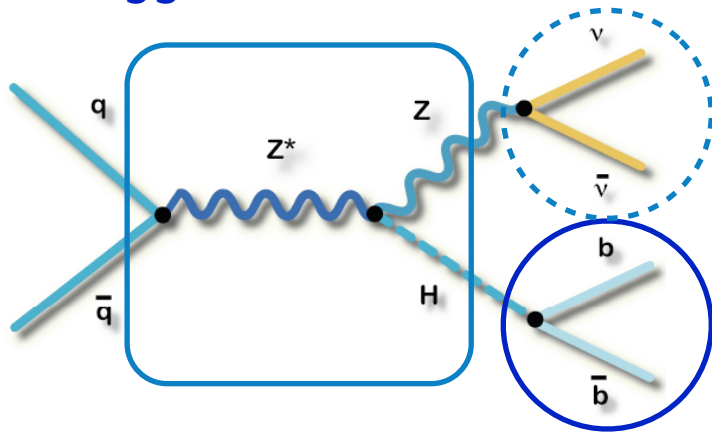


High Mass Higgs search

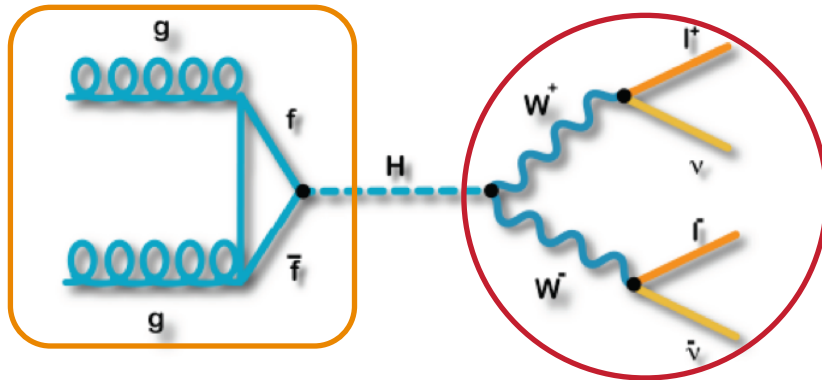


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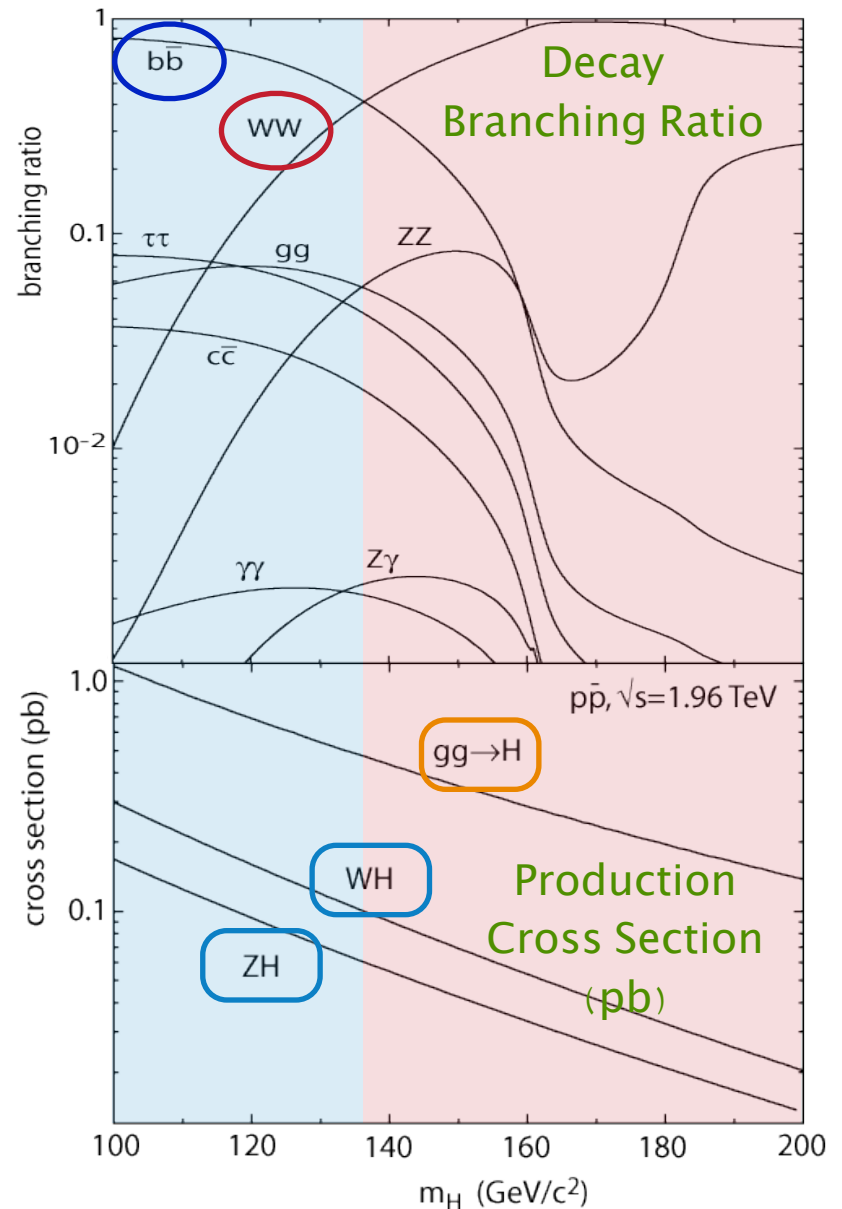
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High Mass Higgs search

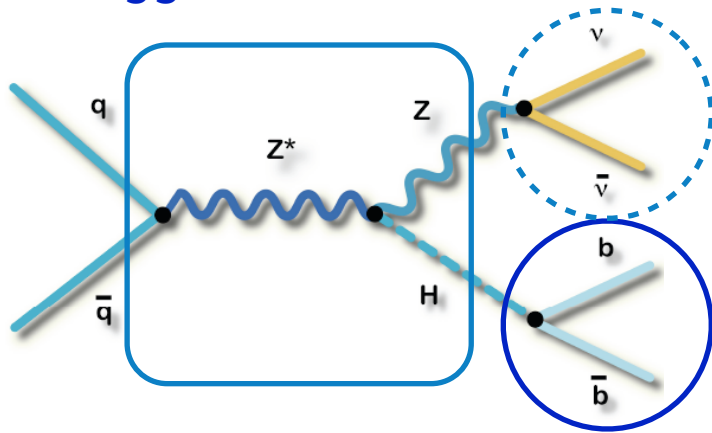


and many more channels included in recent Tevatron Higgs searches



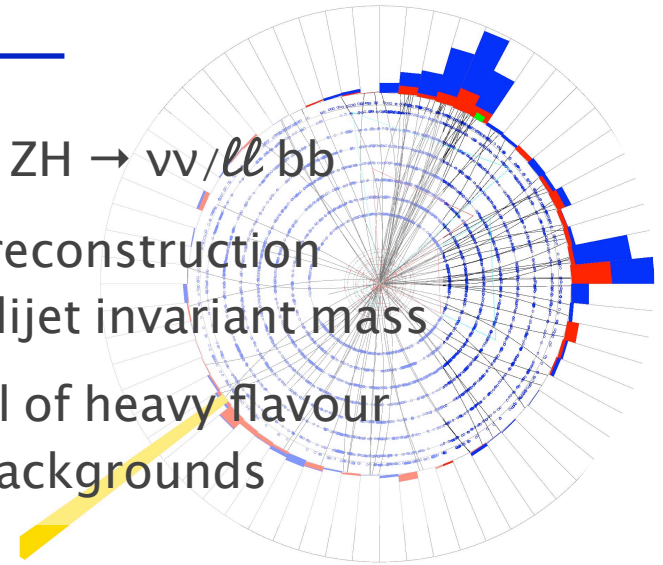
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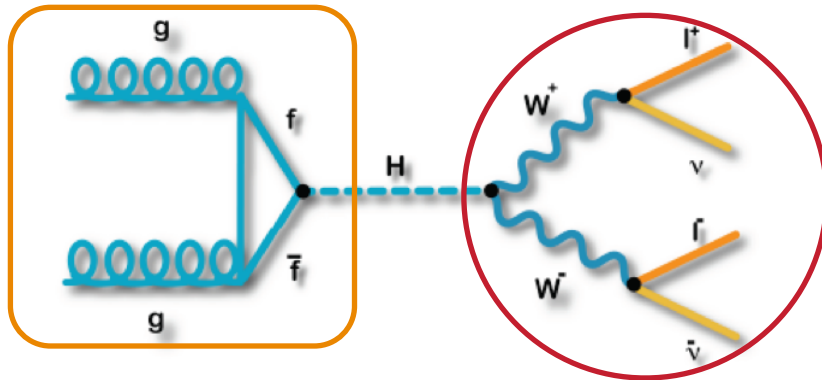


$WH \rightarrow \ell \nu$, $ZH \rightarrow \nu \nu / \ell \ell$, bb

- ▶ Higgs reconstruction using dijet invariant mass
- ▶ Control of heavy flavour (b/c) backgrounds

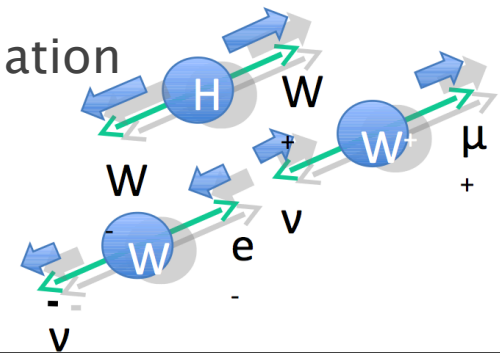


High Mass Higgs search



$gg \rightarrow H \rightarrow WW \rightarrow \ell \nu \ell \nu$

- ▶ Neutrinos in final state \rightarrow missing energy
- ▶ Angular correlation



Higgs Search Strategies

Maximise signal selection

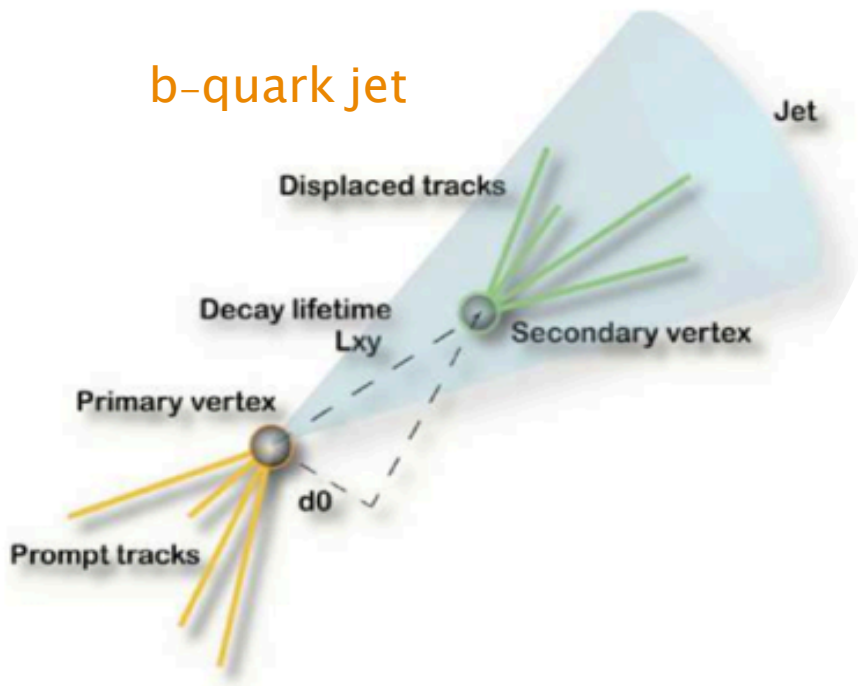
- ▶ Improved object identification algorithms
- ▶ Increased acceptance
- ▶ Exploiting all decay modes

Sophisticated analysis techniques

- ▶ Improved background description and kinematic measurements
- ▶ Dedicated optimisation for categorised sub-samples
- ▶ Multivariate methods

Experiments have always been improving sensitivity of the searches much more than the luminosity projection

Event Selection



Final state objects from Higgs signal

- ▶ leptons
- ▶ b-jets
- ▶ missing E_T

Powerful b-tagging \rightarrow $\times 10^2$ increase in S/B

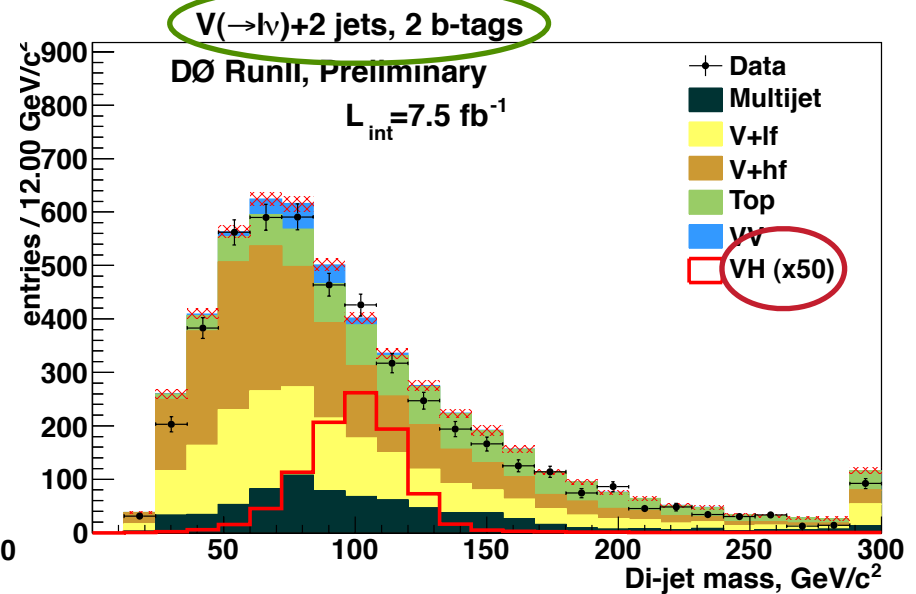
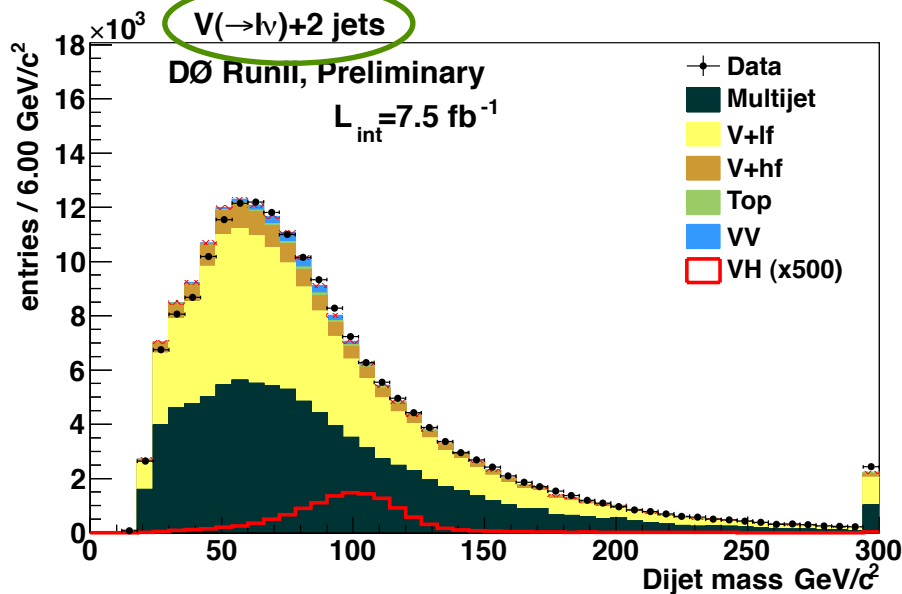
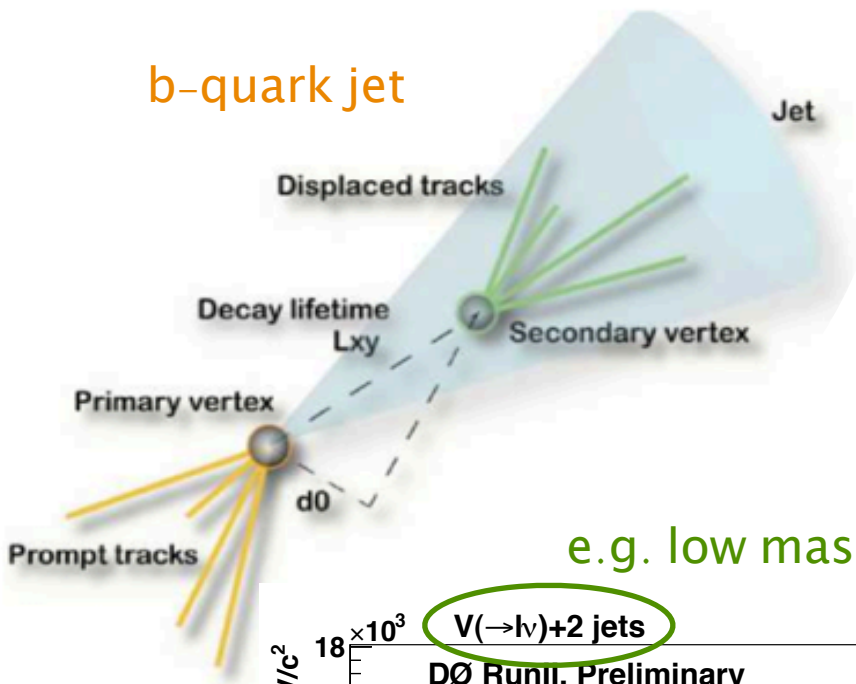
Event Selection

Final state objects from Higgs signal

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e.g. low mass Higgs search in $WH \rightarrow l\nu bb$

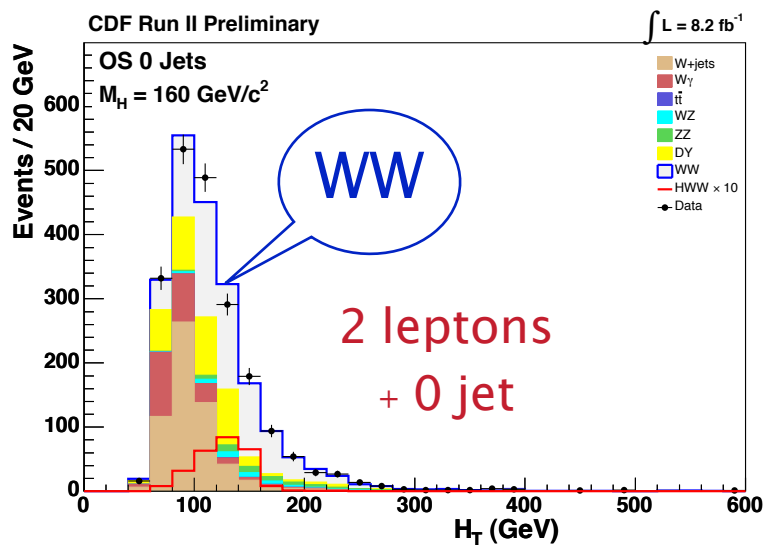


Event Categories

Make sub-samples based on signatures

→ optimise analyses for different S/B and background compositions

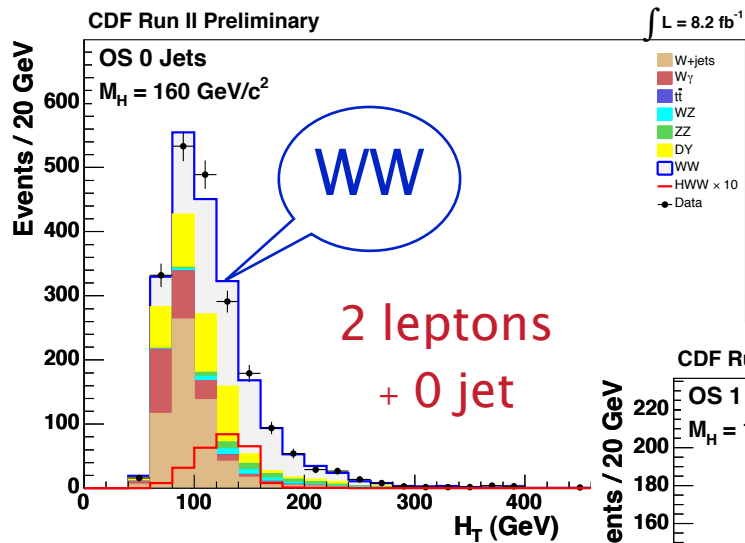
Event Categories



e.g. $gg \rightarrow H \rightarrow WW$
(H_T = scalar sum of
lepton and missing E_T)

Make sub-samples based on signatures
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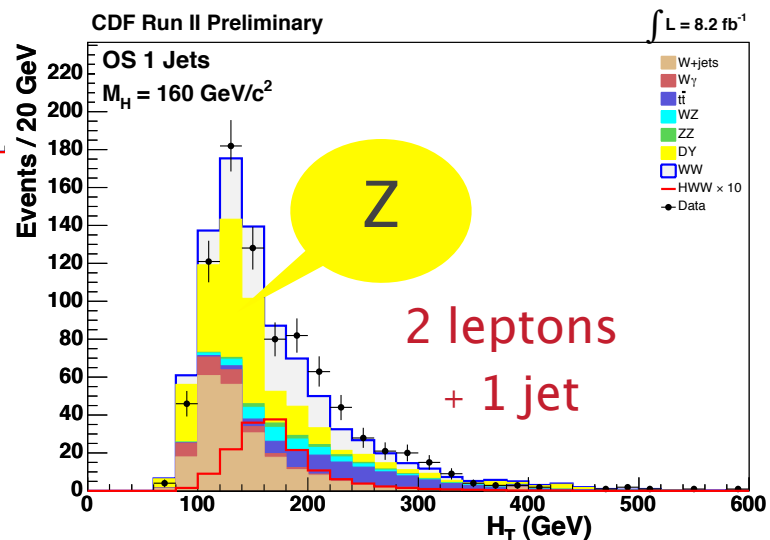
Event Categories



2 leptons
+ 0 jet

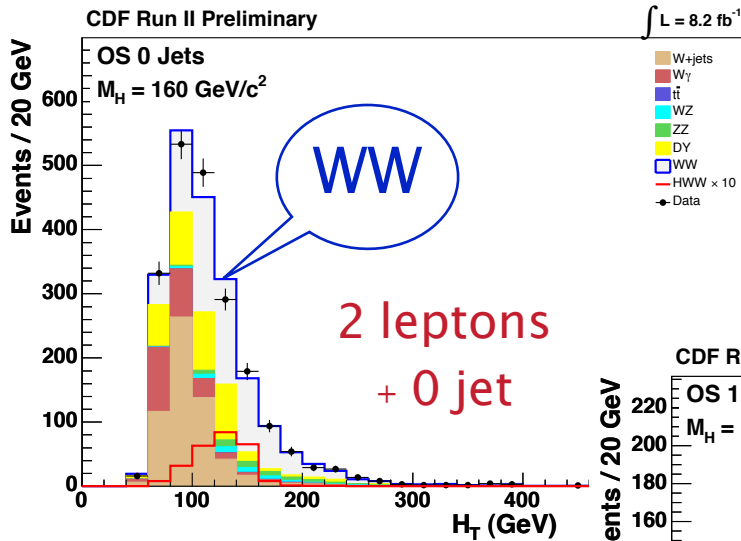
e.g. $gg \rightarrow H \rightarrow WW$
 $(H_T = \text{scalar sum of lepton and missing } E_T)$

Make sub-samples based on signatures
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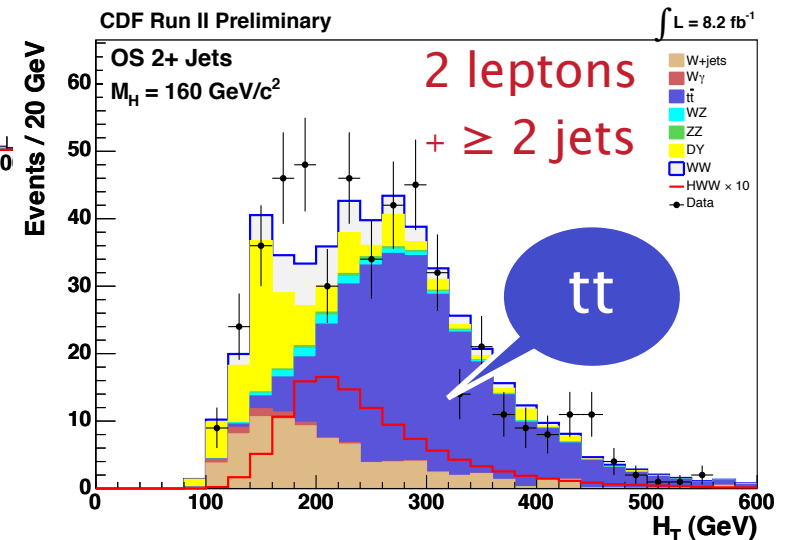
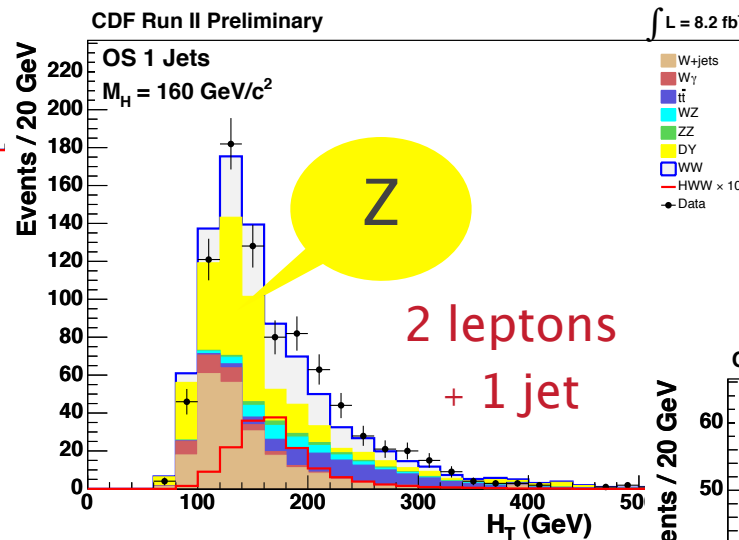
2 leptons
+ 1 jet

Event Categories

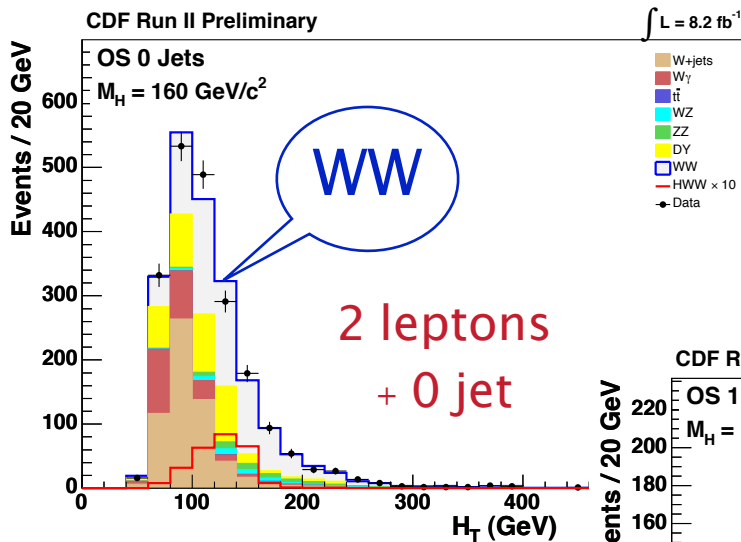


e.g. $gg \rightarrow H \rightarrow WW$
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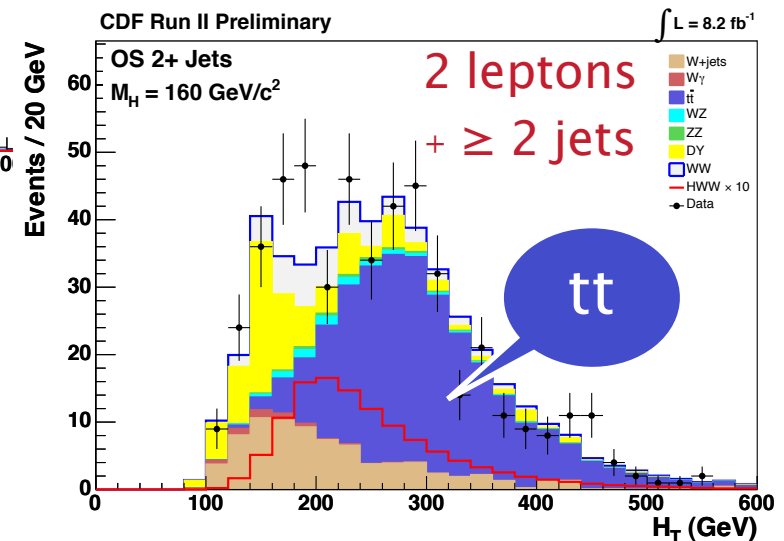
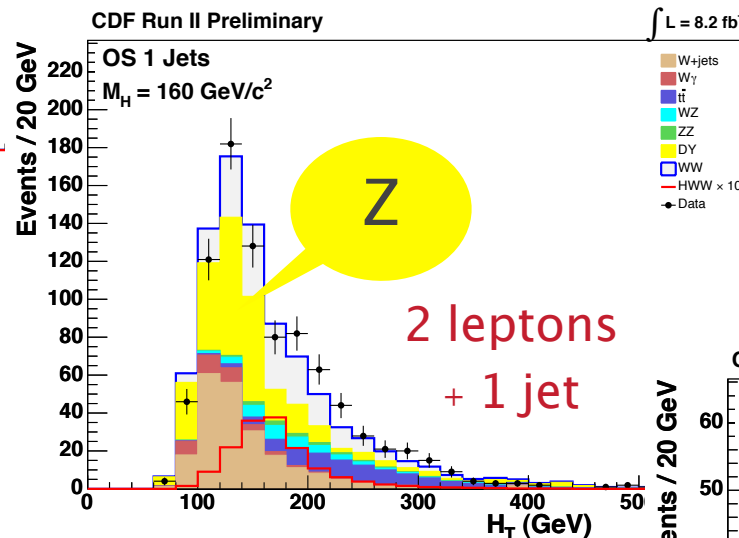
Make sub-samples based on signatures
 → optimise analyses for different S/B and
 background compositions



Event Categories



e.g. $gg \rightarrow H \rightarrow WW$
 $(H_T = \text{scalar sum of lepton and missing } E_T)$



Categories based on:

- ▶ lepton flavour
- ▶ number of (b-tag) jets
- ▶ kinematic regions

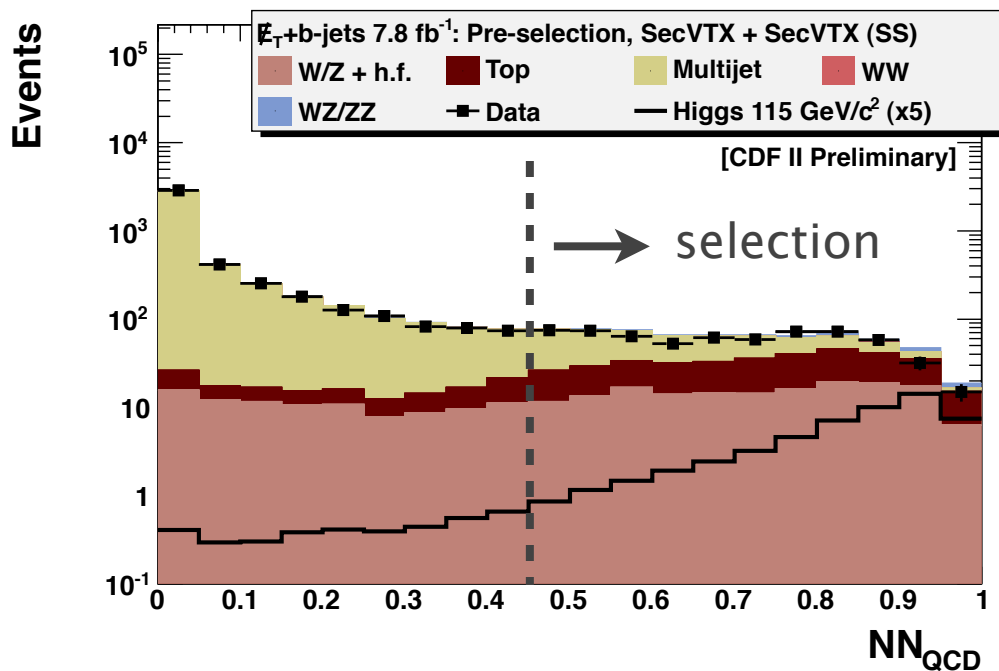
Make sub-samples based on signatures
 \rightarrow optimise analyses for different S/B and background compositions

Multivariate Techniques

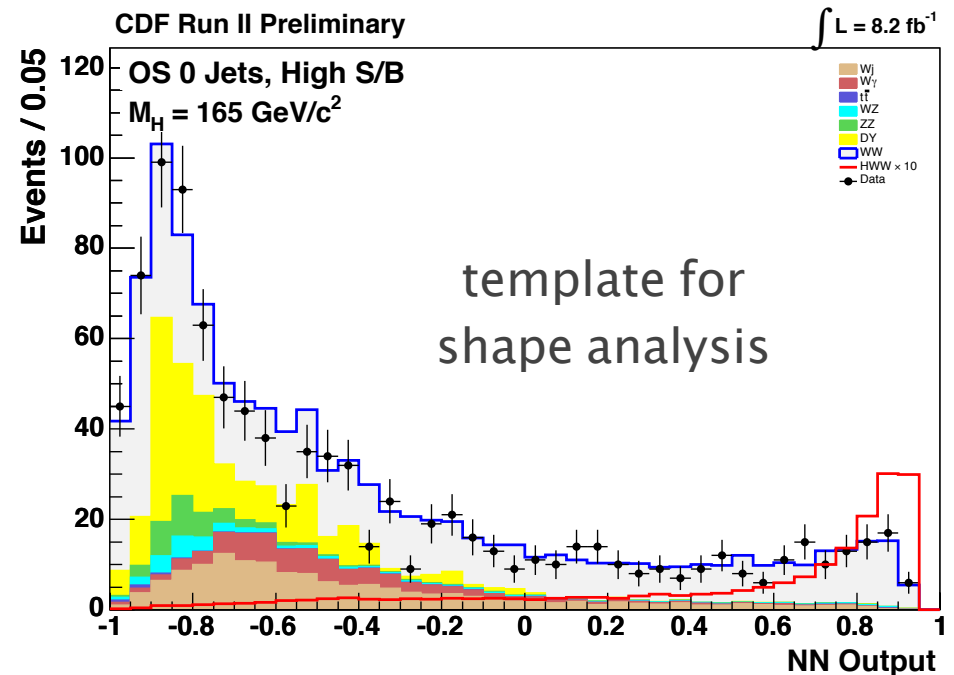
Multivariate analysis

- ▶ Single discriminant combining many variables
- ▶ Maximum signal / background separation
- ▶ ~20% gain in sensitivity

multijet discriminant for $ZH \rightarrow \nu\nu b\bar{b}$



final discriminant for $gg \rightarrow H \rightarrow WW$



Uncertainties

Experimental and theoretical uncertainties affect:

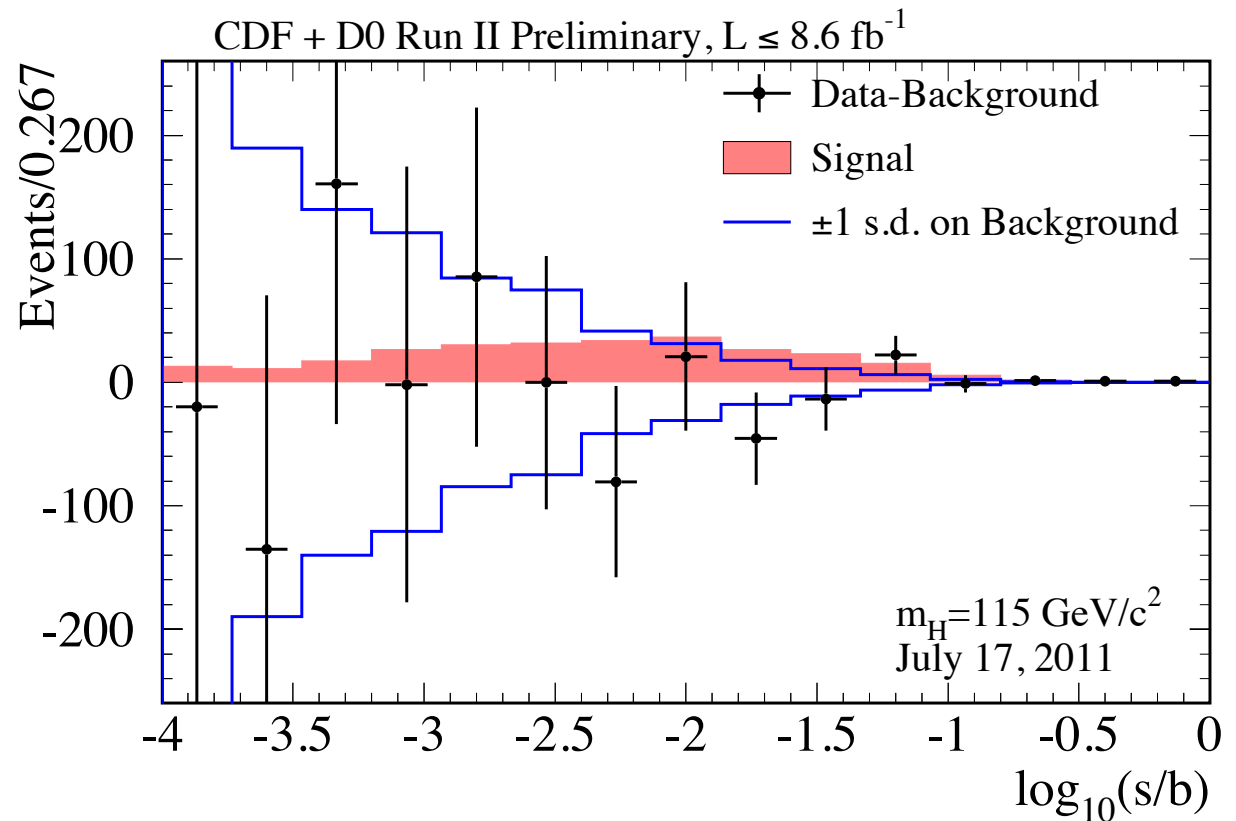
- ▶ predicted yields
- ▶ kinematic shapes

Main sources

- ▶ signal cross section
- ▶ selection efficiency
- ▶ energy resolution
- ▶ background modelling

Correlation across channels
taken into account

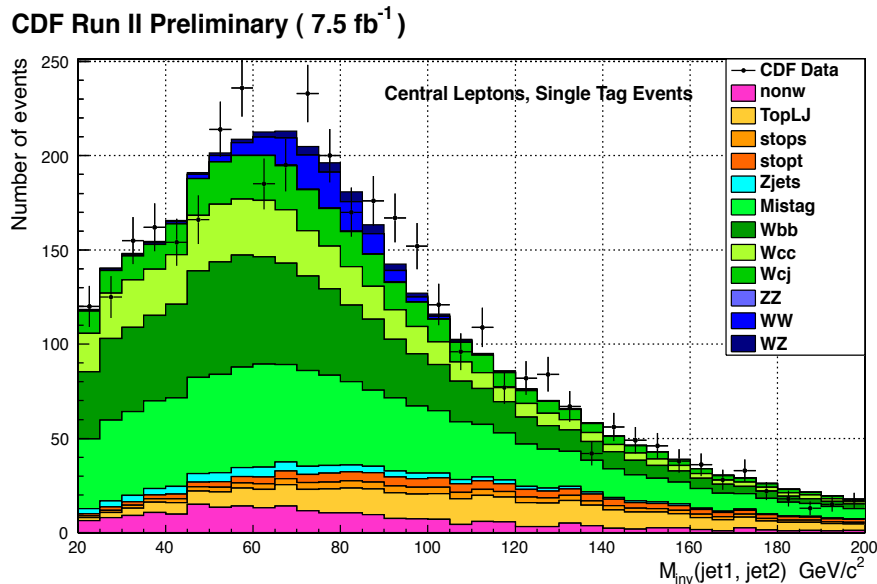
Background subtracted data



Background Modelling

Background prediction and crosschecks

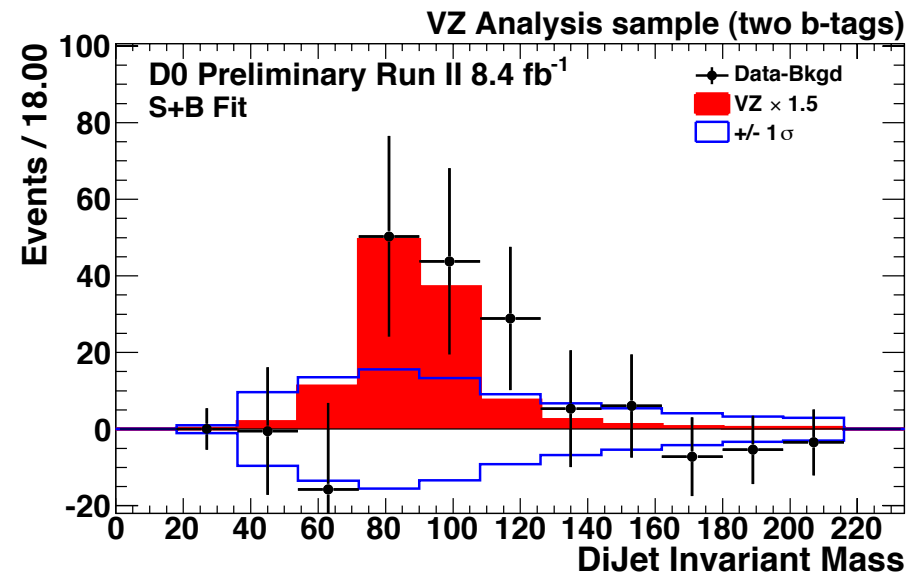
- ▶ W/Z production → enriched control regions for crosschecks
- ▶ Fake lepton (multijet) → data-driven estimation
- ▶ diboson (WW/WZ/ZZ) → measurement of SM cross section



WW/WZ in 1 lepton + 2 b-jets

$1.085 \pm (0.26/0.40) \times \text{SM}$

3.0 σ significance

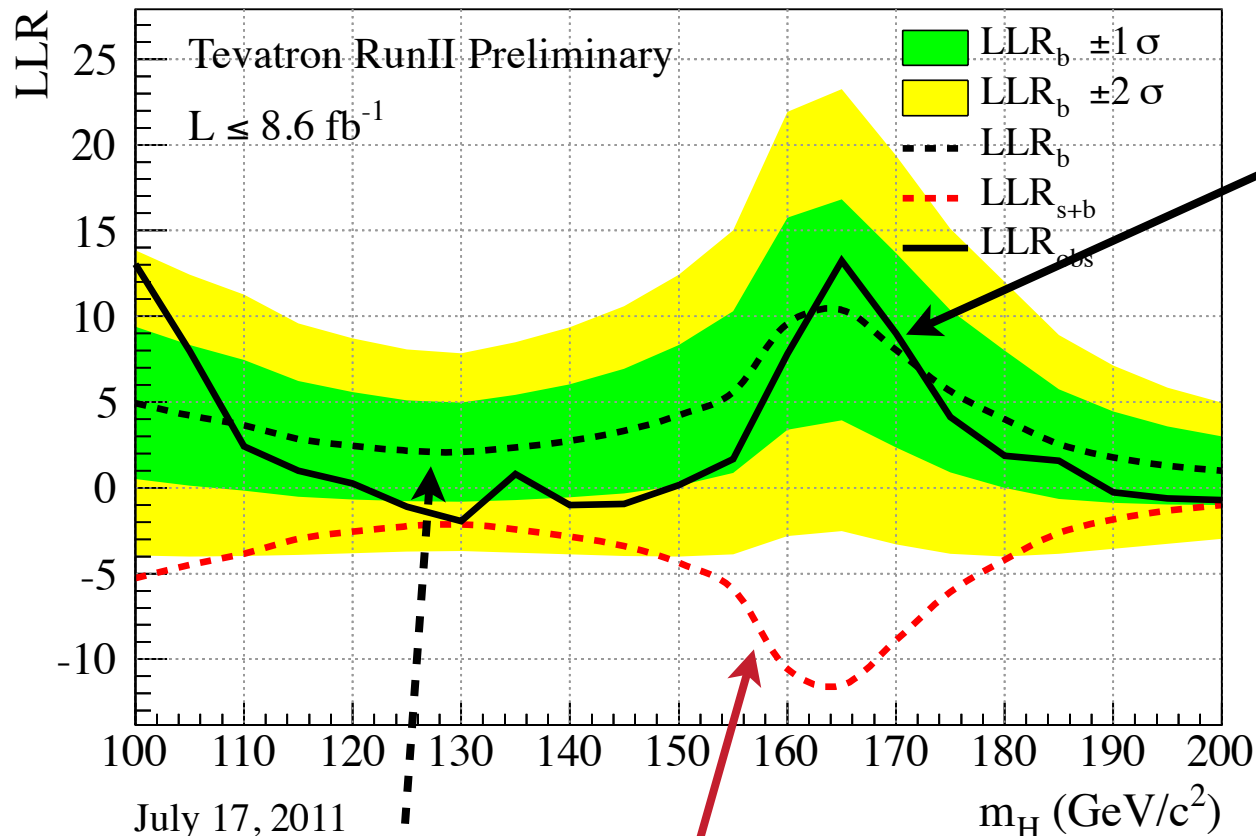


WZ/ZZ in 0 lepton + 2 b-jets

$1.5 \pm 0.3 \text{ (stat)} \pm 0.4 \text{ (syst)} \times \text{SM}$

2.8 σ significance

Sensitivity to Higgs Signal



Data

Log-Likelihood Ratio (LLR)

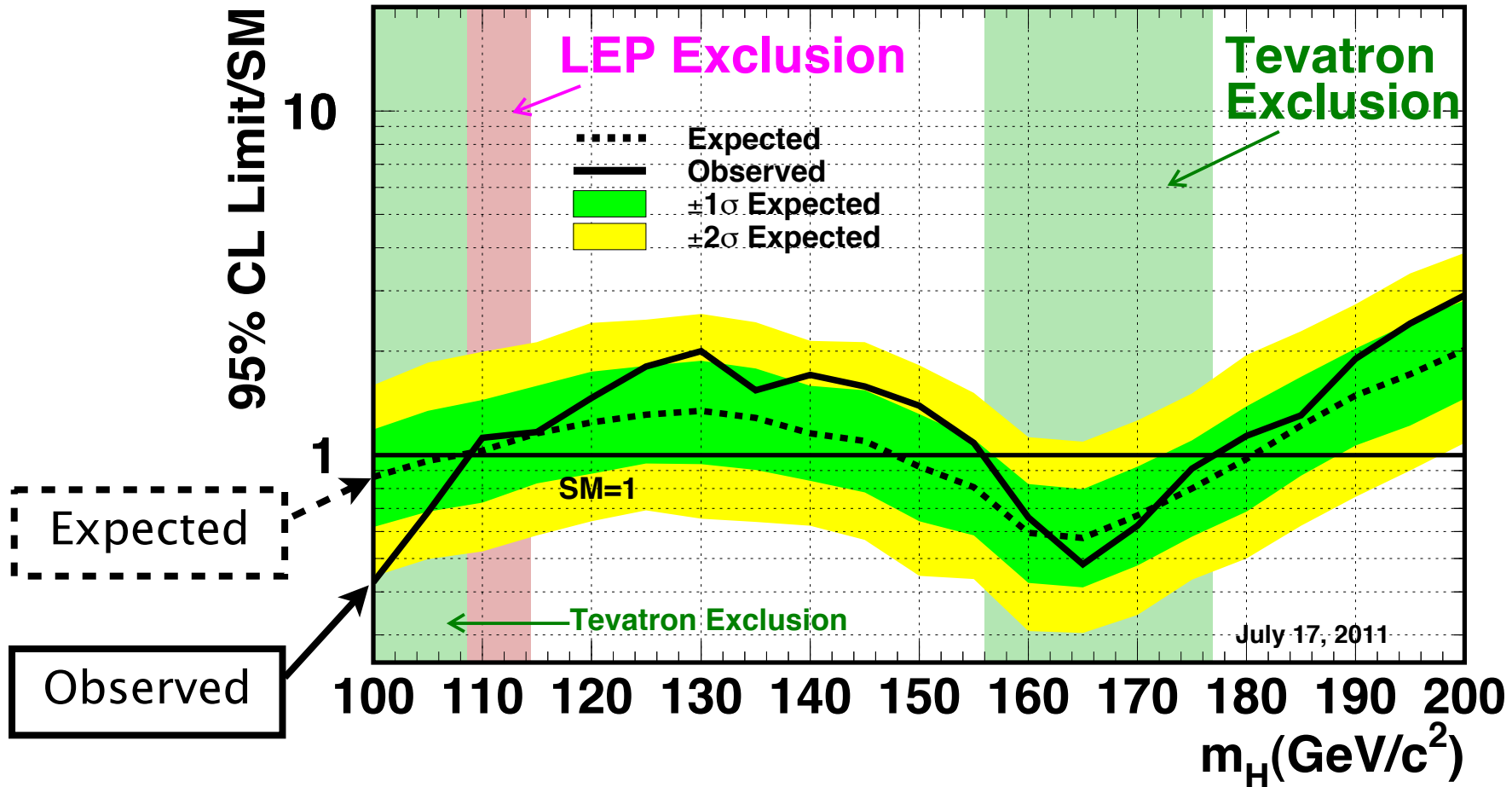
- ▶ Separation between LLR_b and LLR_{s+b} translates to sensitivity
- ▶ Data follows LLR_b curve within the uncertainty bands

Background only
 (LLR_b)

Signal + Background
 (LLR_{s+b})

Tevatron SM Higgs Limits

Tevatron Run II Preliminary, $L \leq 8.6 \text{ fb}^{-1}$



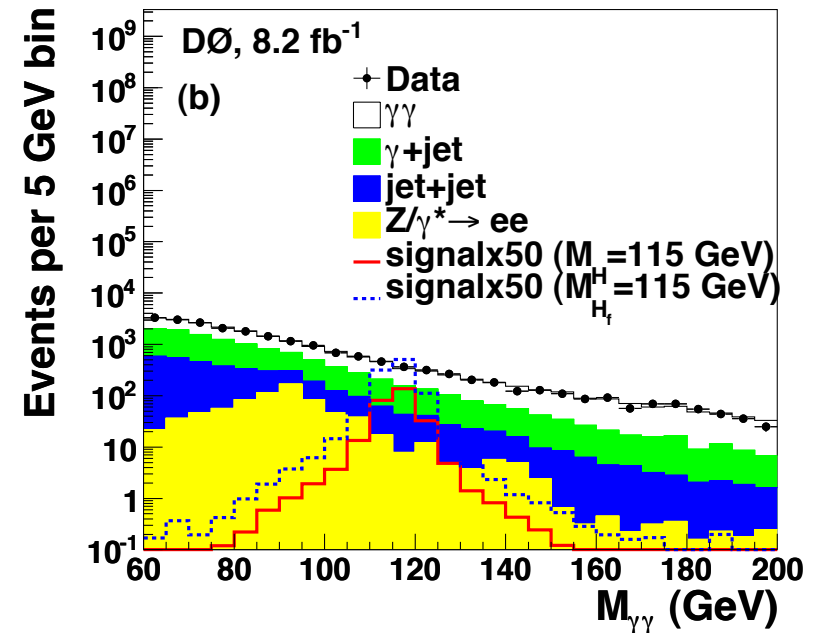
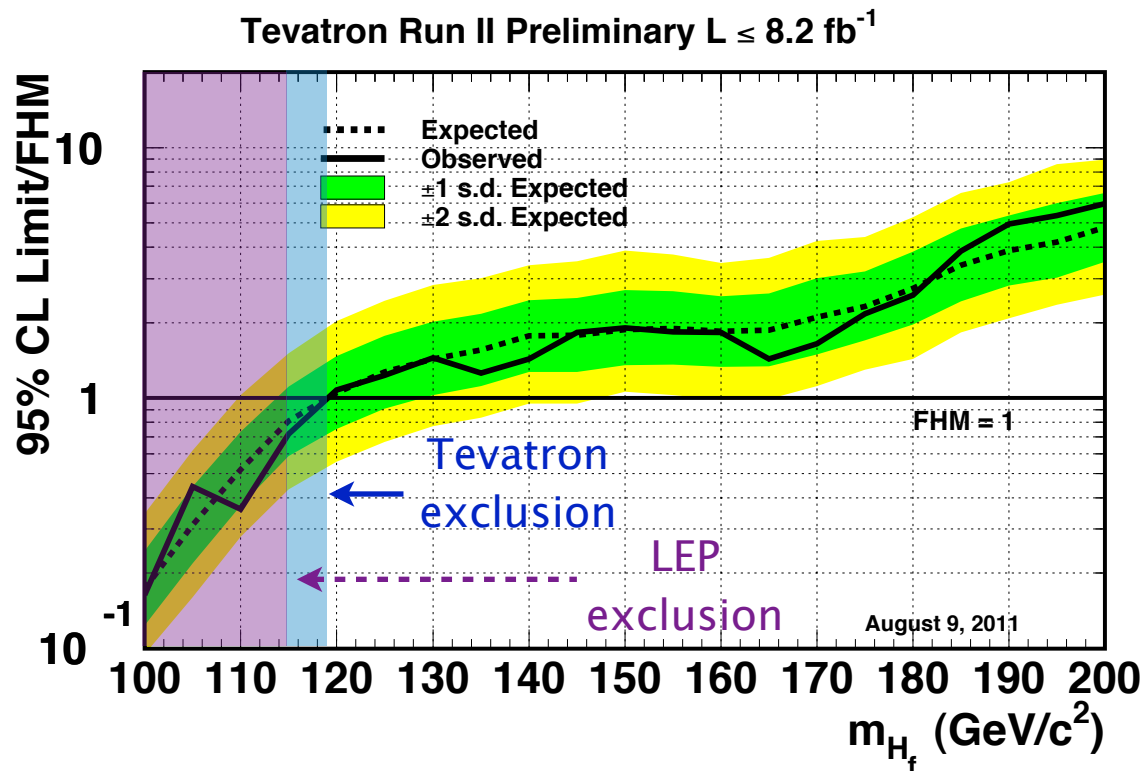
Exclude mass ranges 100–109 and 156–177 GeV

(ATLAS/CMS exclusion: 146–232/145–216 GeV and higher masses)

Fermiophobic Higgs

Coupling to fermions heavily suppressed

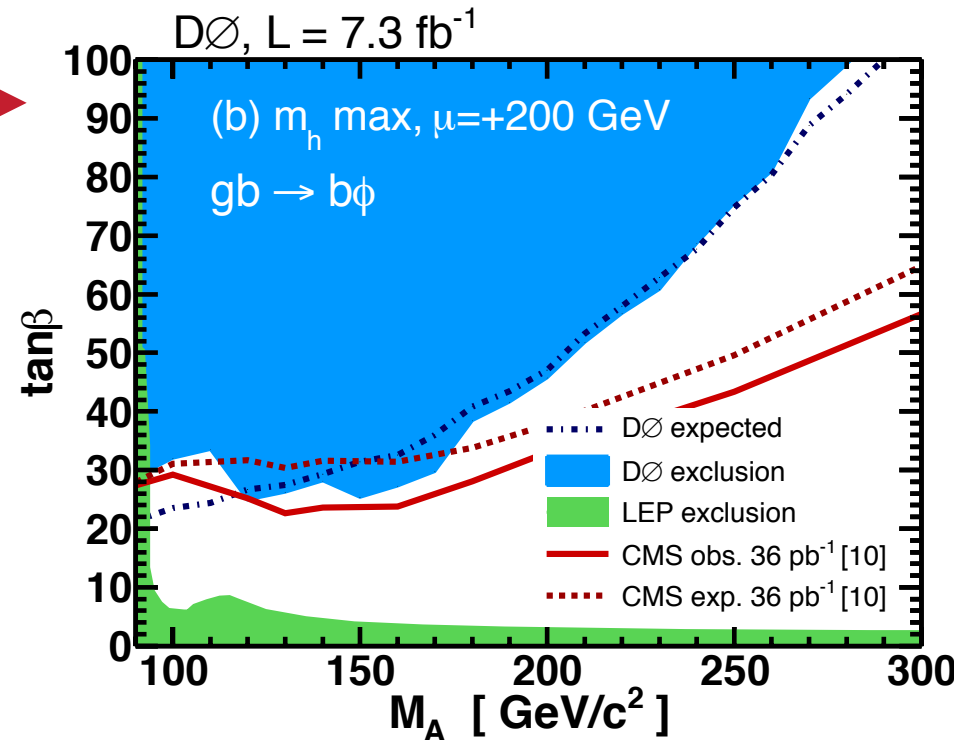
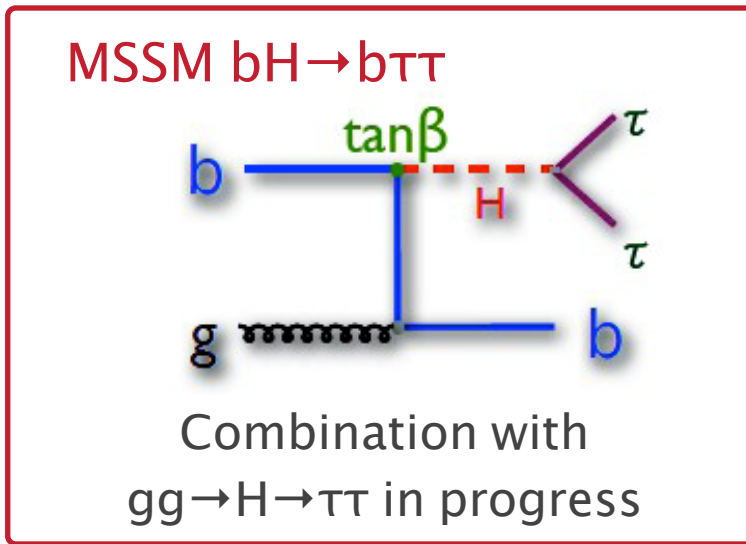
- ▶ No gluon fusion (via top loop)
- ▶ Branching fraction to WW and $\gamma\gamma$ dominates at low mass (no $H \rightarrow bb/\tau\tau$ decays)



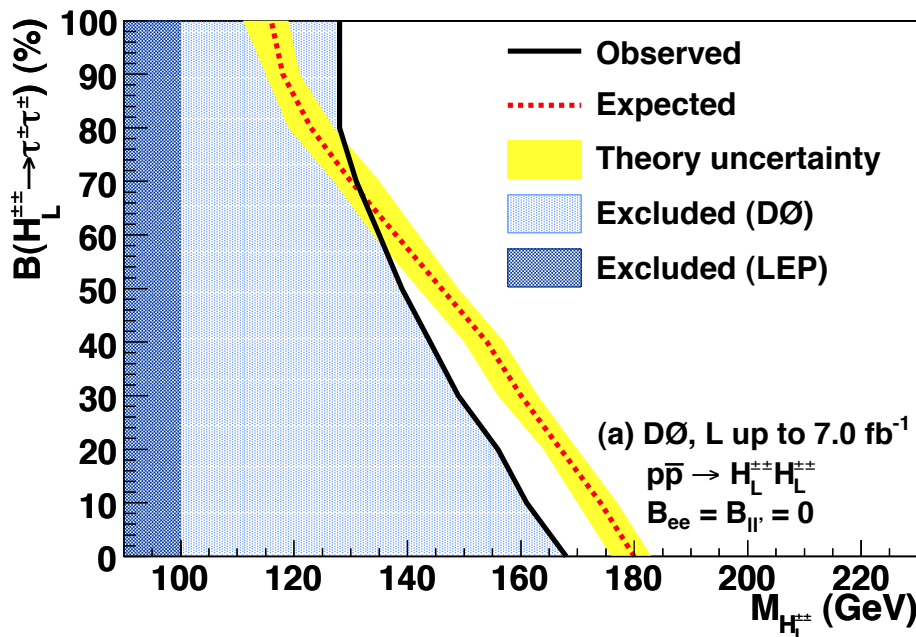
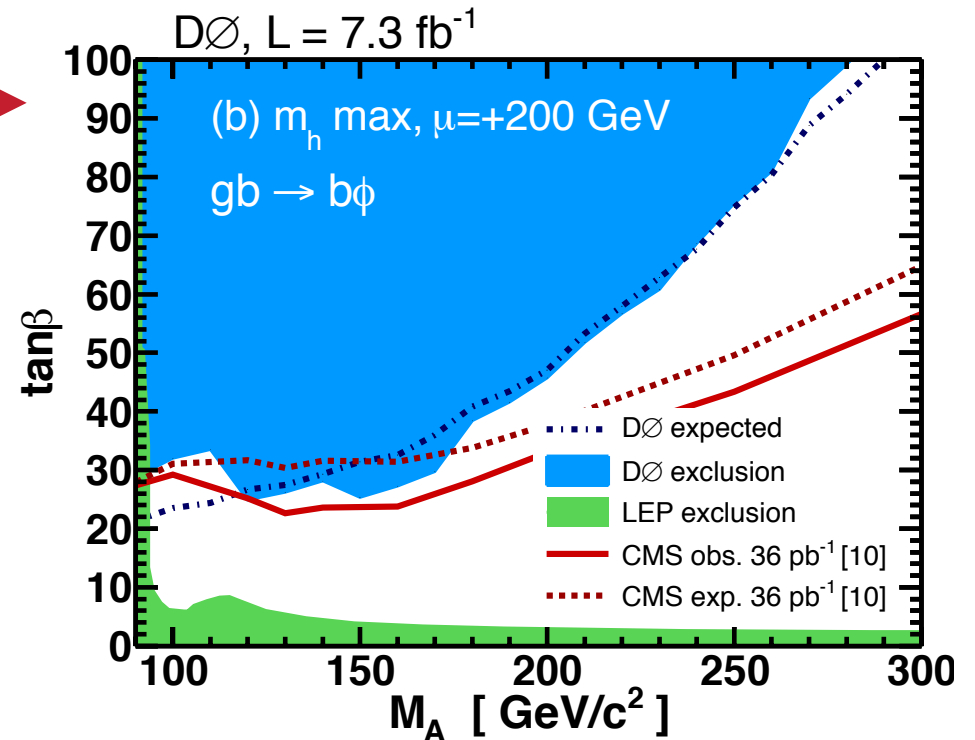
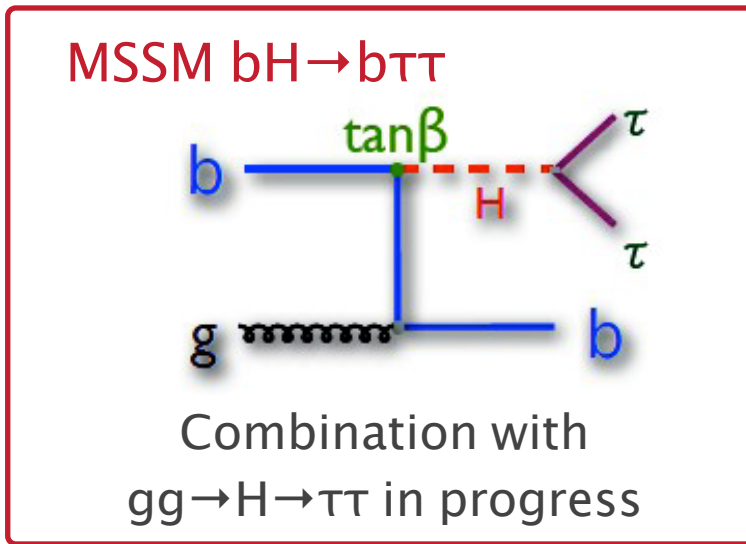
Tevatron combination
for Fermiophobic Higgs
(Summer 2011)

Exclude $M \leq 119 \text{ GeV}$

BSM Higgs with Taus



BSM Higgs with Taus

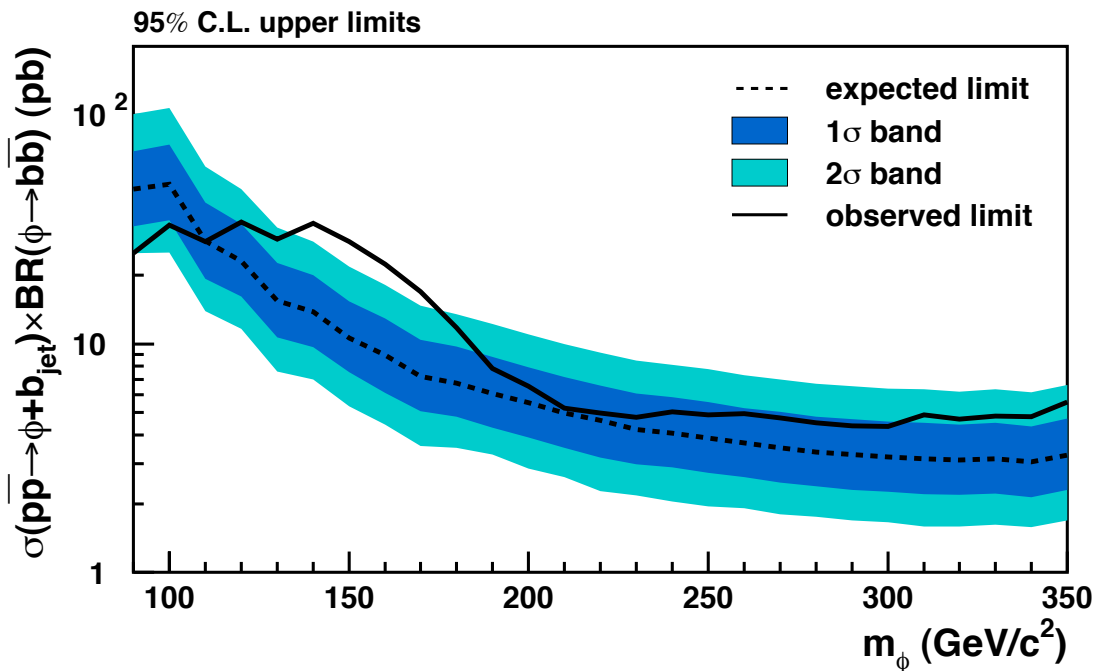
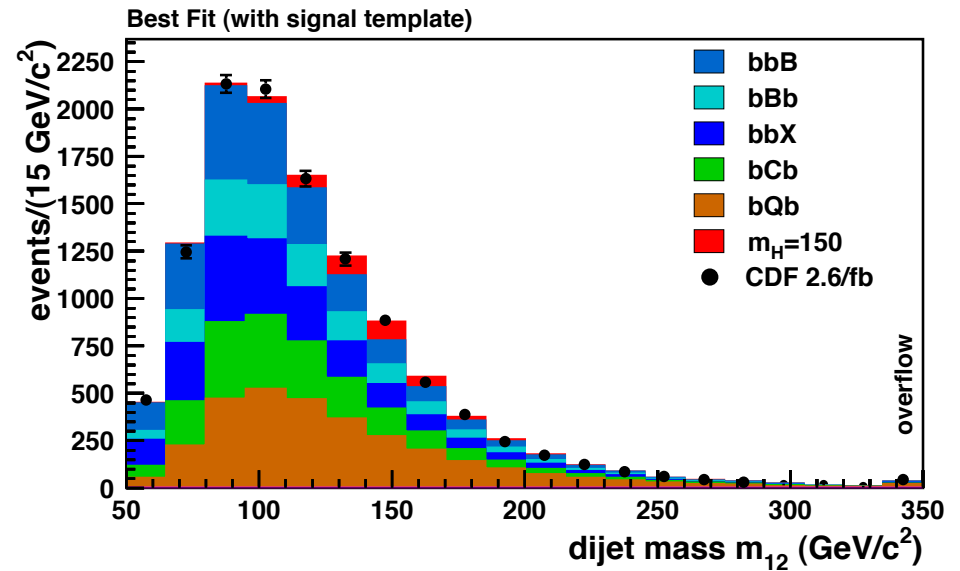
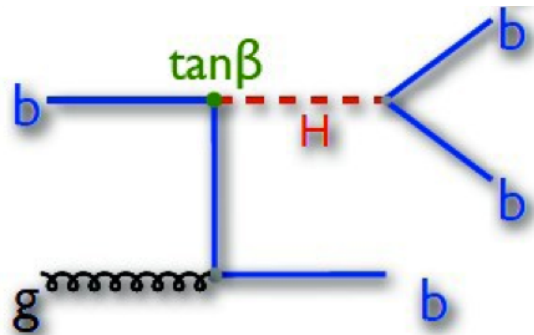


Doubly charged Higgs boson
 $H^{++} H^{--} \rightarrow \tau^+ \tau^+ \tau^- \tau^-$
 (also in muons)
 Best limits in τ final states

BSM Higgs with b-quarks

Challenging final state with 3 b-jets

→ unique opportunity
at the Tevatron



Both CDF and DØ experiments
observe $\sim 2\sigma$ deviation at
 $\sim 120-150$ GeV

→ Tevatron combination planned
using increased datasets

Searches for Exotics

New phenomena searches at the Tevatron

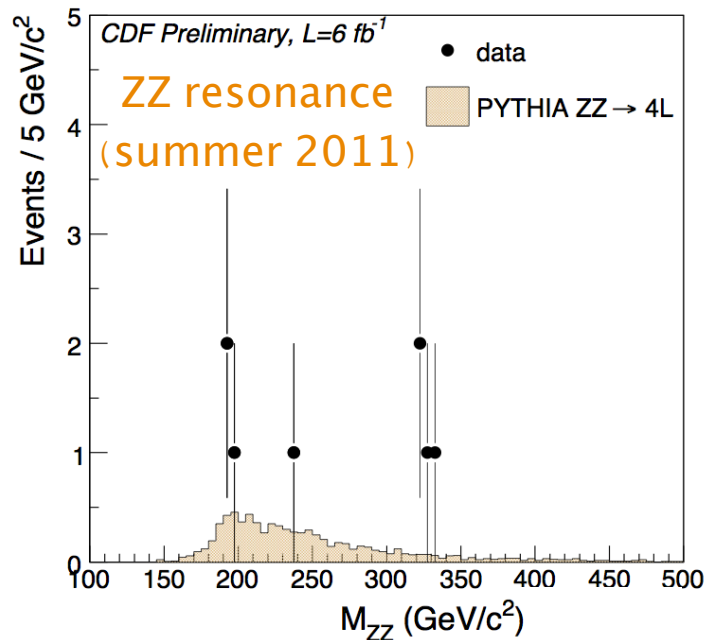
SUSY, leptoquarks, large ED,
excited quarks, t' , W' , Z' , quirks,
hidden valleys, RS Graviton,
FCNC, new heavy gauge bosons,
model independent searches...

Many “first limits” came from the Tevatron
– some are still competitive with the LHC

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New phenomena searches at the Tevatron

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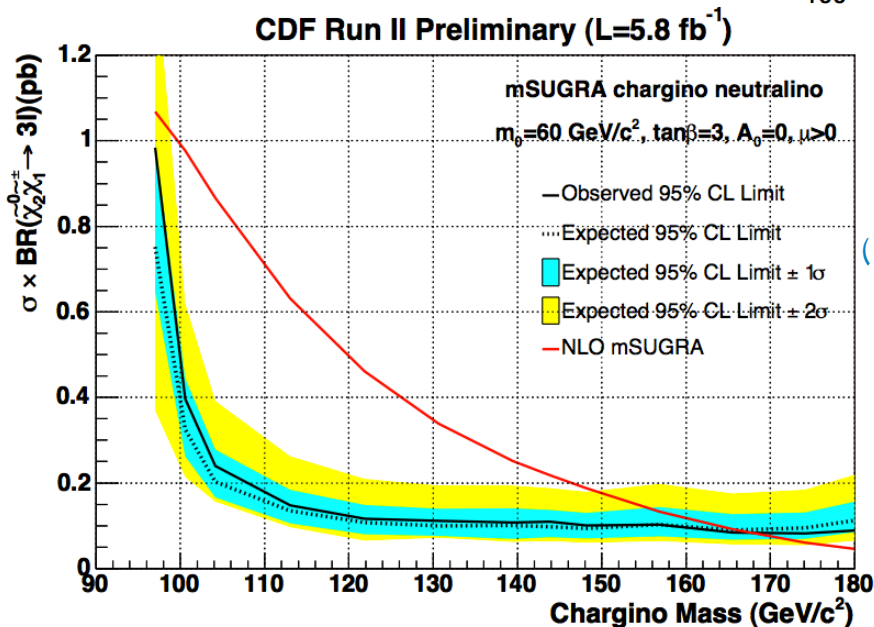
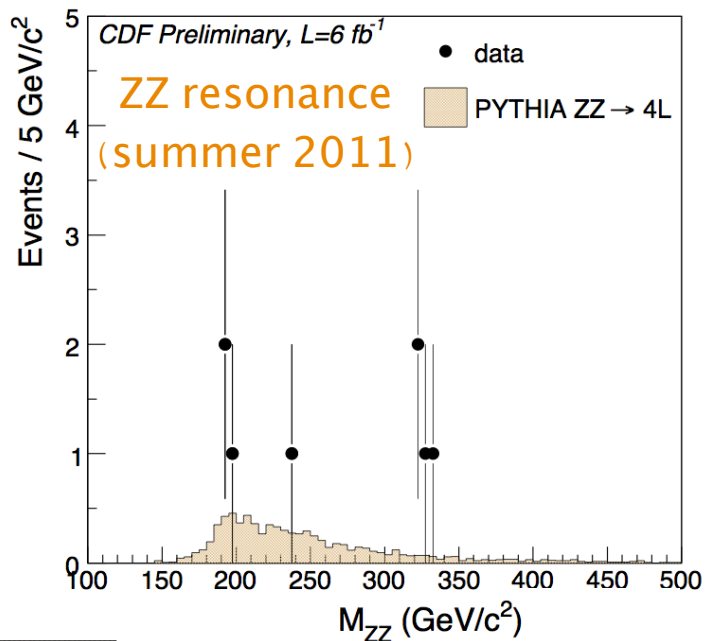


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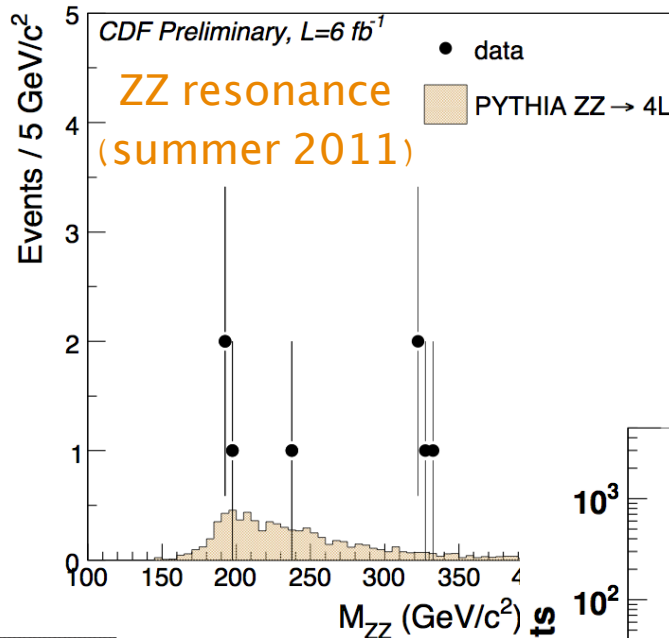
Trilepton search (summer 2011)

Many “first limits” came from the Tevatron – some are still competitive with the LHC

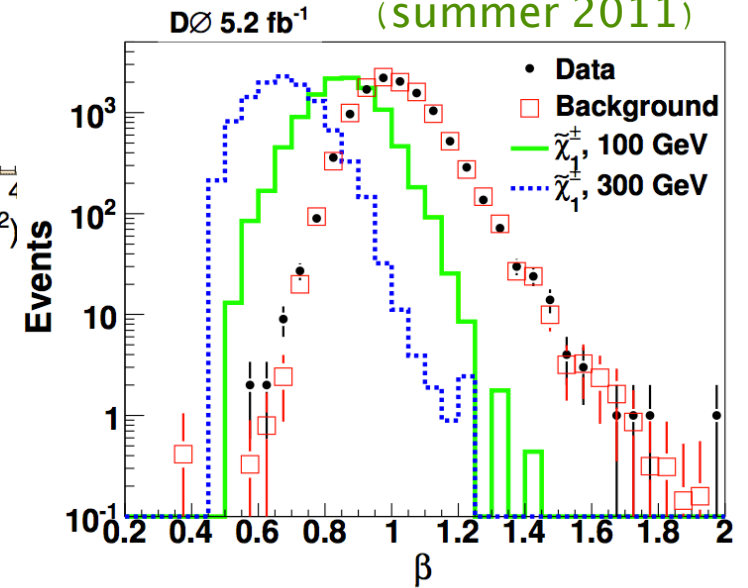
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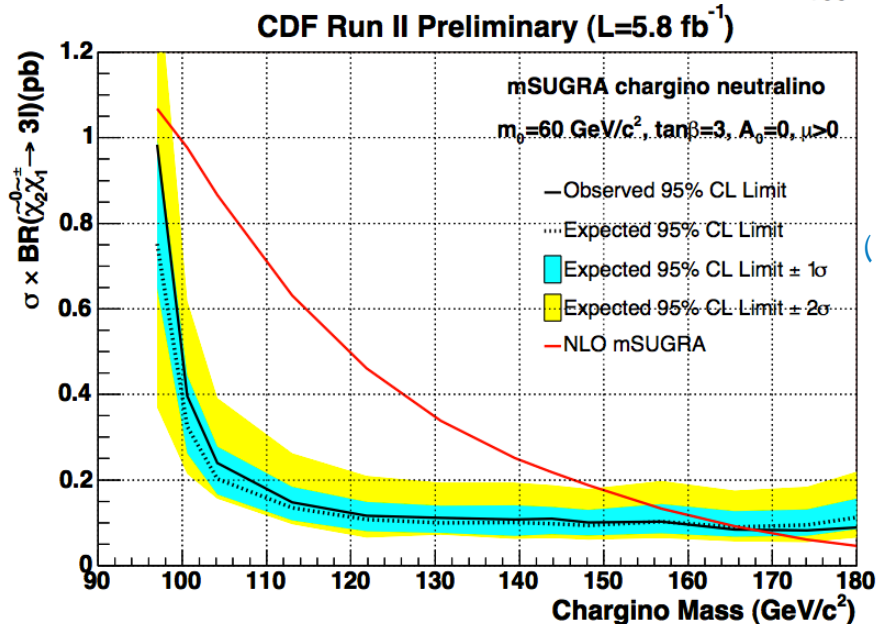
SUSY, leptoquarks, large ED, excited quarks, t' , W' , Z' , quirks, hidden valleys, RS Graviton, FCNC, new heavy gauge bosons, model independent searches...



Charged massive long-lived particles (summer 2011)



Trilepton search (summer 2011)

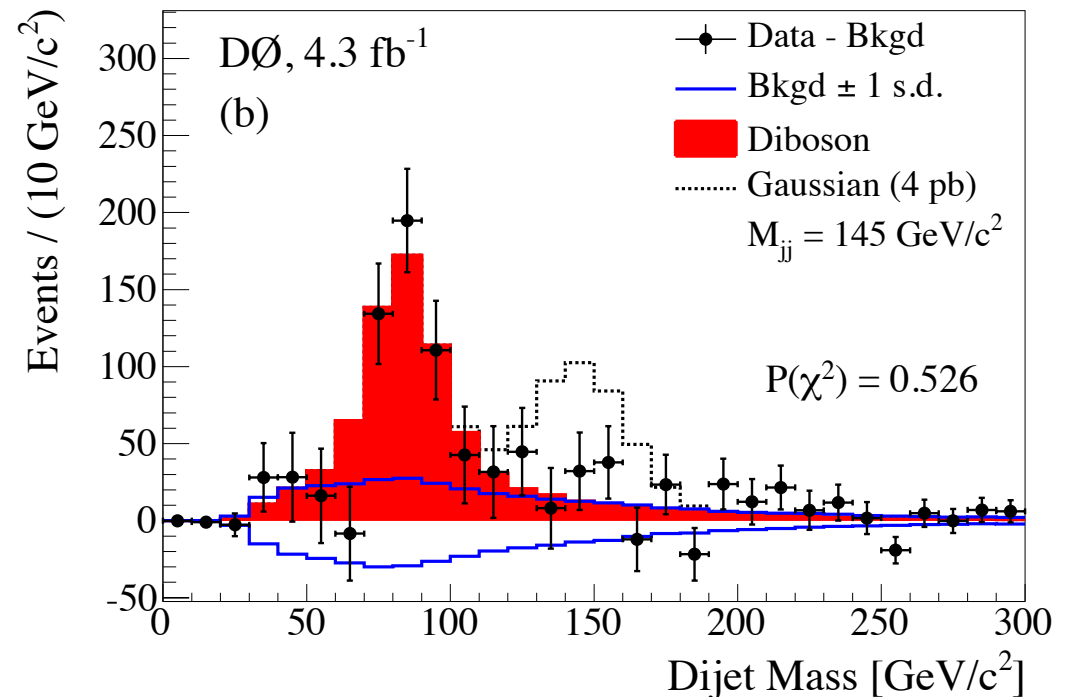
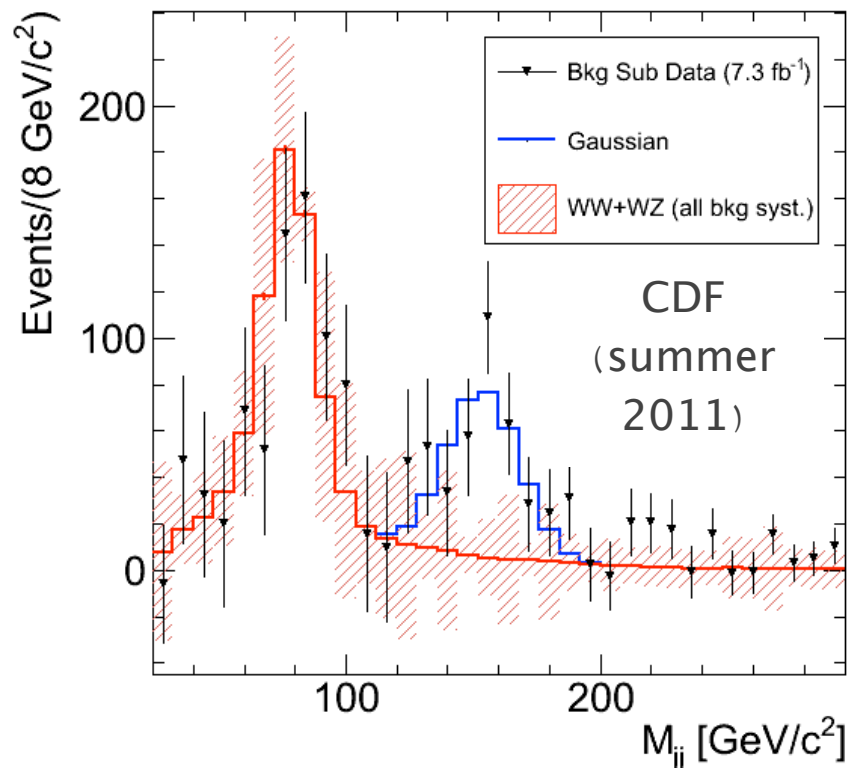


Many “first limits” came from the Tevatron – some are still competitive with the LHC

W+dijet

Measurement of WW/WZ $\rightarrow \ell\nu jj$ production

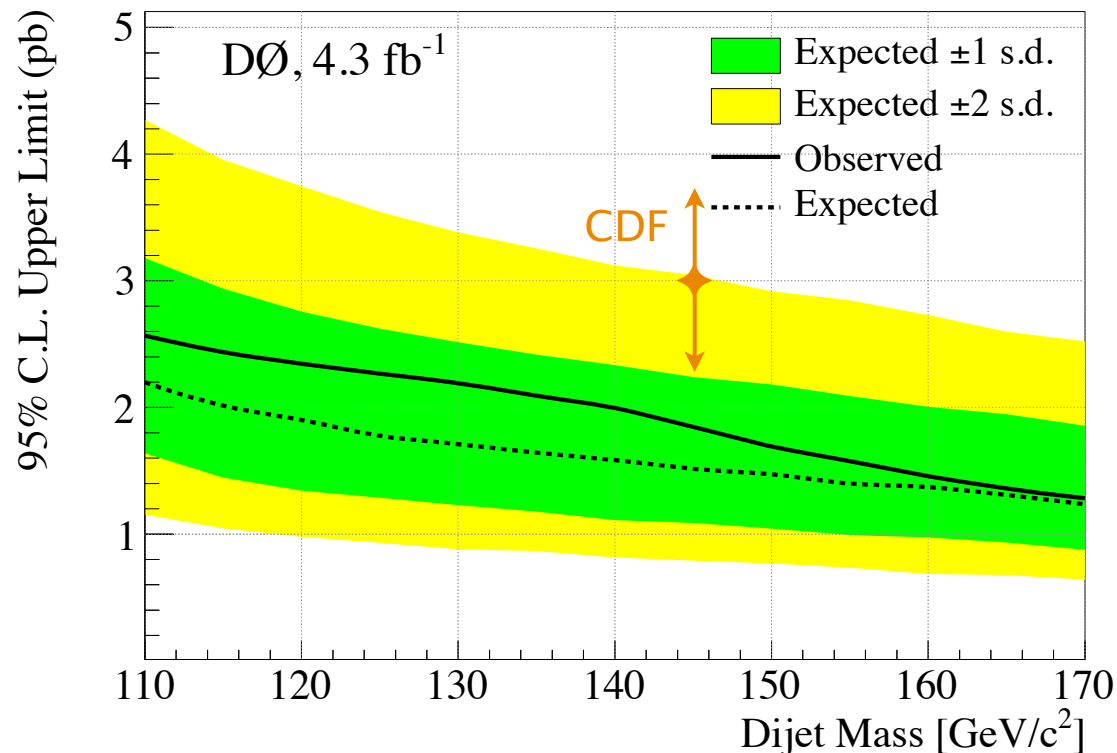
- ▶ Cross section measured (2009) using dijet mass resonance around W/Z mass
- ▶ CDF observed an excess of events at a higher mass (published in 2011)
- ▶ No significant deviation at DØ



W+dijet

Results from the two experiments

- ▶ **CDF** measures 4.1 (3.3) σ significance using 7.3 (4.3) fb^{-1} of data, equivalent to 3.0 ± 0.7 pb at $M = 145$ GeV
- ▶ **DØ** observes good agreement between data and the SM prediction, setting an upper limit at 1.85 pb



A_{FB} in Top

Forward-backward asymmetry, “ A_{FB} ” in $t\bar{t}$ production

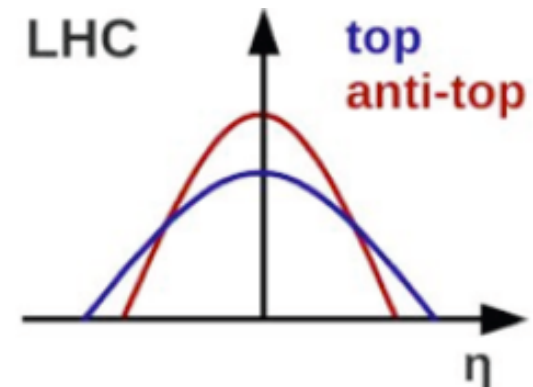
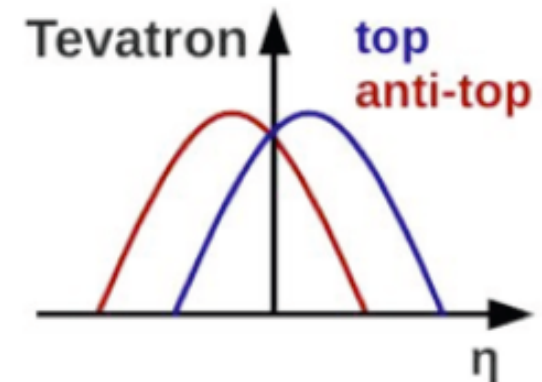
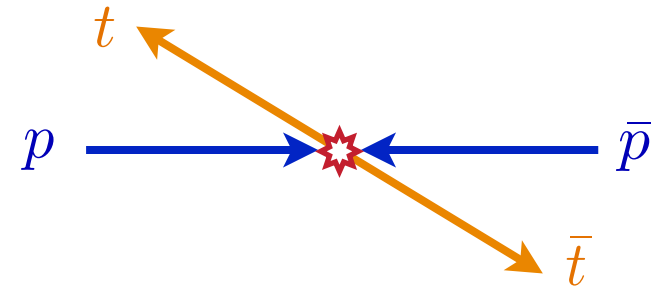
- ▶ Top/anti-top prefers the direction of incoming quark/anti-quark
- ▶ Unique measurement at the Tevatron

Define A_{FB} ,

$$A_{FB}^{t\bar{t}} = \frac{N_{\Delta y > 0} - N_{\Delta y < 0}}{N_{\Delta y > 0} + N_{\Delta y < 0}}$$

expressed in terms of number of events with given rapidity difference, $\Delta y = y(t) - y(\bar{t})$

SM predicts $A_{FB} = 0$ at LO, \sim few % at NLO



A_{FB} in Top

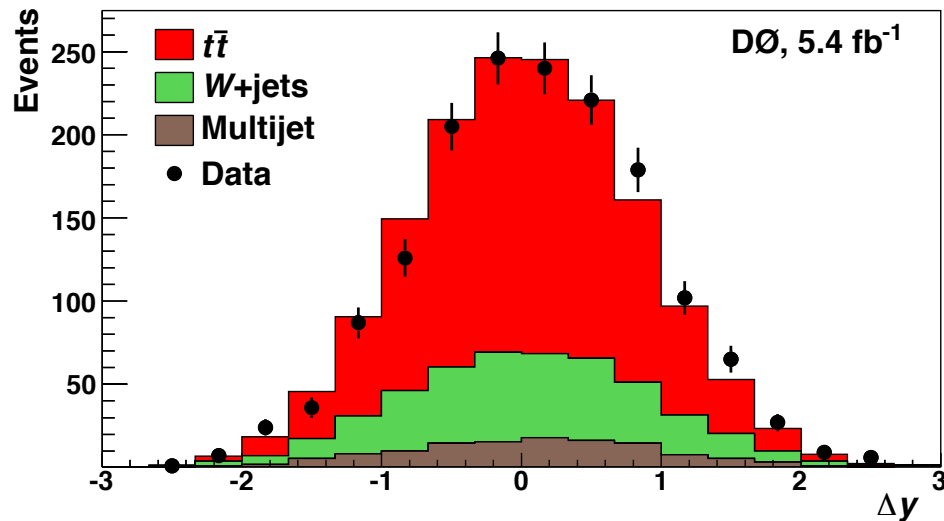
Both CDF and DØ observe deviation from the theoretical NLO prediction (after unfolding)

CDF: 0.201 ± 0.065 (stat) ± 0.018 (syst)

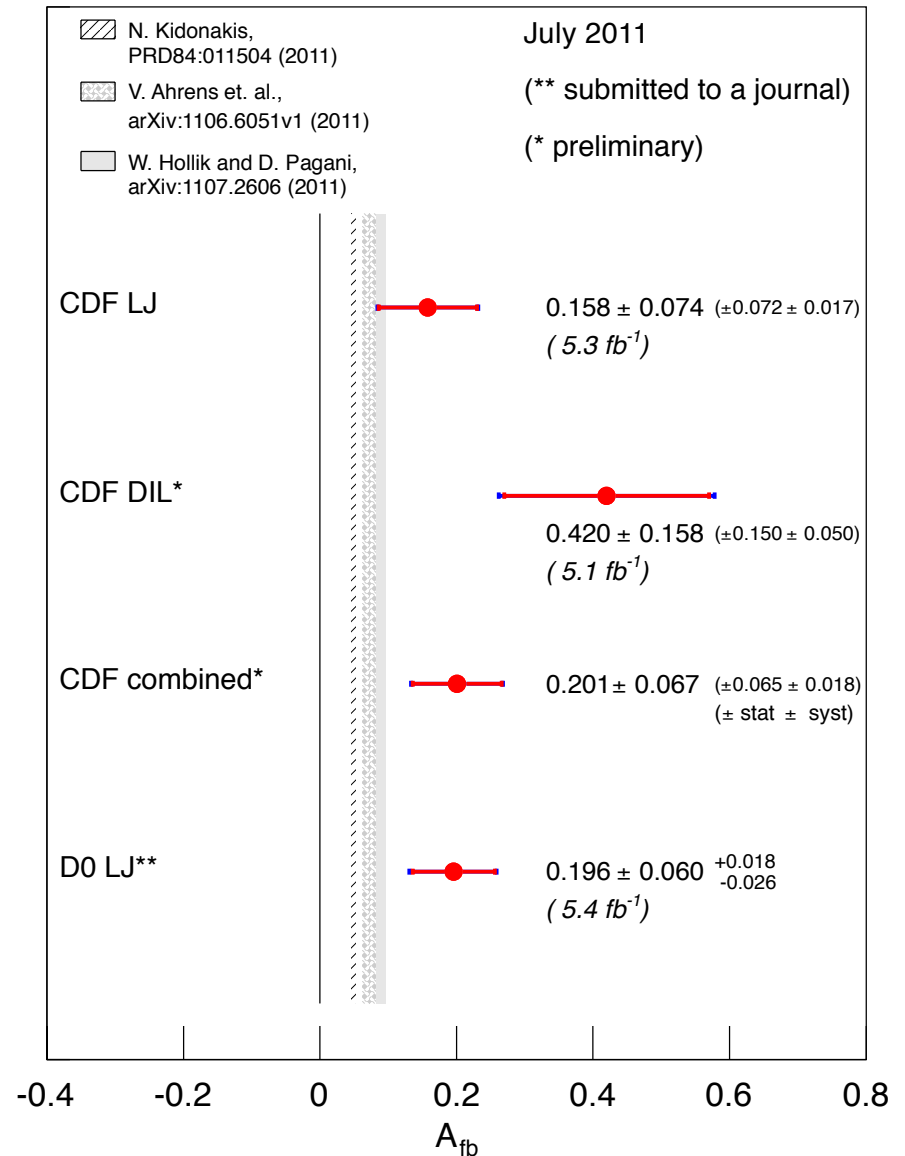
DØ: 0.196 ± 0.060 (stat) $\pm 0.018-0.026$ (syst)

MC@NLO: 0.05 ± 0.001

→ 3-4 σ significance



A_{fb} of the Top Quark



Dimuon Charge Asymmetry



CP violation in mixing in semi-leptonic decay of $b\bar{b}$

- ▶ One B meson oscillates to give the like charged muon pair

Measure like sign dimuon charge asymmetry

$$A_{\text{sl}}^b = \frac{N_{b\bar{b}}^{++} - N_{b\bar{b}}^{--}}{N_{b\bar{b}}^{++} + N_{b\bar{b}}^{--}}$$

SM predicts very small asymmetry, $A \sim 0$

Precise measurement possible at DØ because of the periodic change of magnet polarity

Dimuon Charge Asymmetry

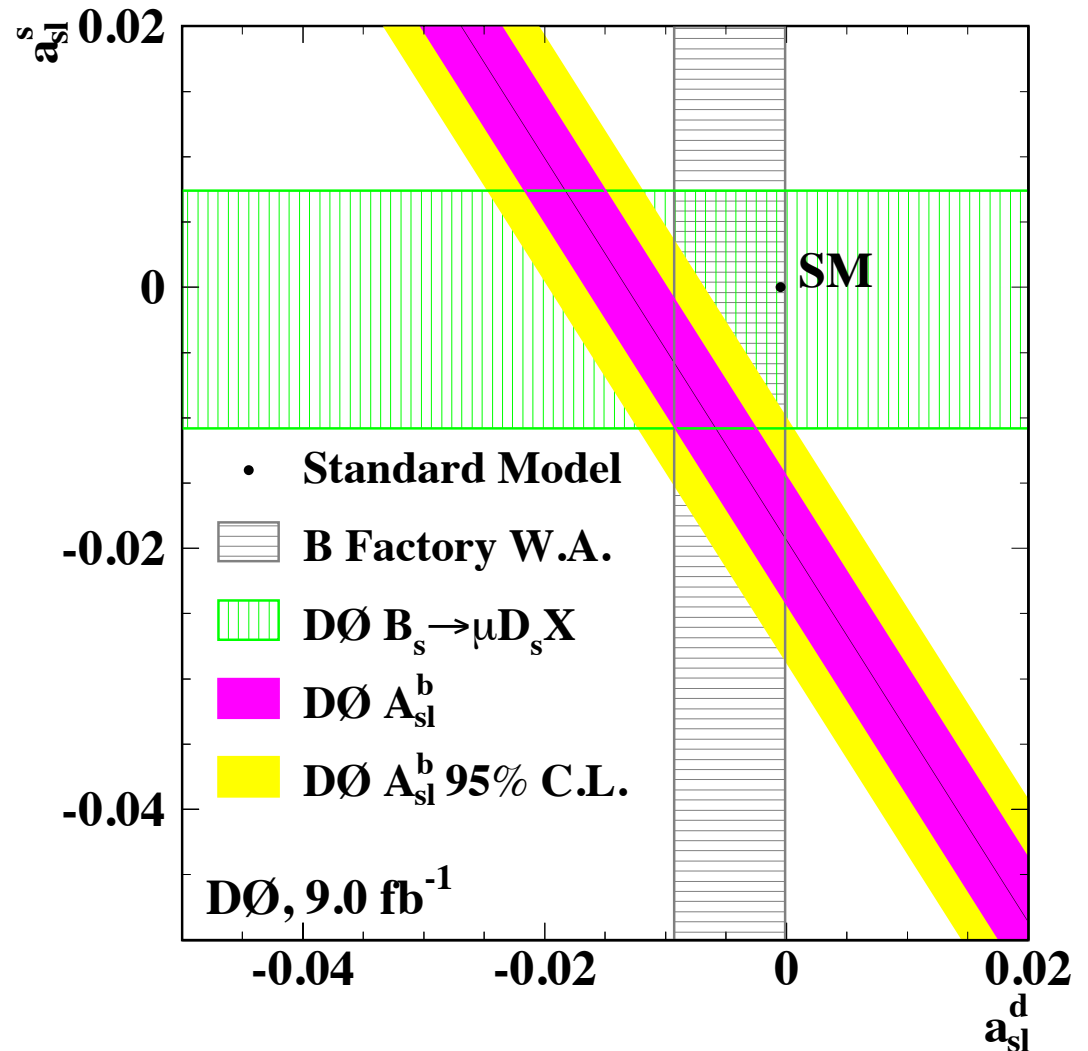
Evidence for anomalously large CP violation

→ first reported in 2010

Latest measurement using 9.0 fb^{-1} (2011)

- ▶ 3.9σ away from SM
- ▶ Consistent with past results
- ▶ Impact parameter dependence within expectation

$$A_{sl} = -0.787 \pm 0.172 \text{ (stat)} \pm 0.093 \text{ (syst)} \%$$



Conclusions



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Final results from the Tevatron are expected by ICHEP 2012

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References

General Tevatron results pages

CDF: <http://www-cdf.fnal.gov/physics/physics.html>

DØ: <http://www-d0.fnal.gov/Run2Physics/WWW/results.htm>

Searches for the Standard Model and Beyond Standard Model Higgs boson

CDF: <http://www-cdf.fnal.gov/physics/new/hdg/Results.html>

DØ: <http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm>

Tevatron combination: http://tevnpbwg.fnal.gov/results/SM_Higgs_Summer_11/index.html

Others

W+2jet CDF: PRL 106,171810(2011), http://www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html

DØ: PRL 107, 011804 (2011)

Top AFB CDF: PRD 83, 112003 (2011), CDF Note 10584, DØ: arXiv:1107.4995 (accepted by PRD)

Dimuon charge asymmetry

DØ: PRD 82, 032001, (2010), PRL 105, 081801 (2010), [arXiv:1106.6308](http://arxiv.org/abs/1106.6308) (accepted by PRD)

W +dijet: CDF-DØ Comparison

