New Results for Winter 2011

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University of Manchester

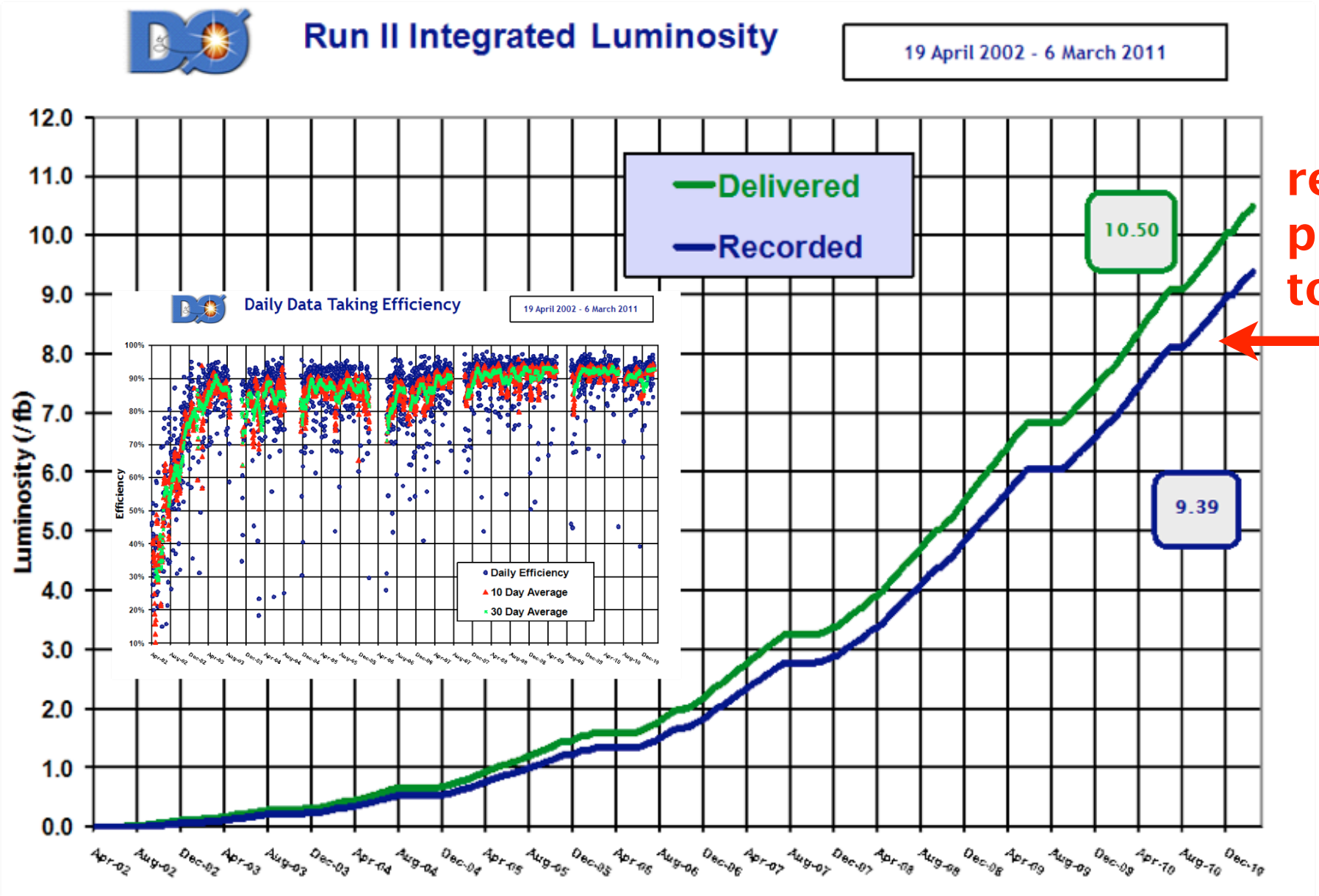
Joint Experimental-Theoretical Seminar

Fermilab, March 11, 2011

The DØ Collaboration

487 physicists from 20 countries

Many Thanks to Accelerator Division!



results presented today

DØ Physics Program

Competitiveness

- high x_T gluons
- single top production
- EW processes, couplings
- ....

Complementarity

- $t\bar{t}$ spin correlations
- $t\bar{t}$ FB asymmetry
- W asymmetry
- ....

Hints& Excesses

- t' quark search
- $t\bar{t}$ FB asymmetry
- CP violation in B_s

Legacy

- top mass
- top properties
- W mass

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Higgs

Hints& Excesses

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Legacy

- top mass
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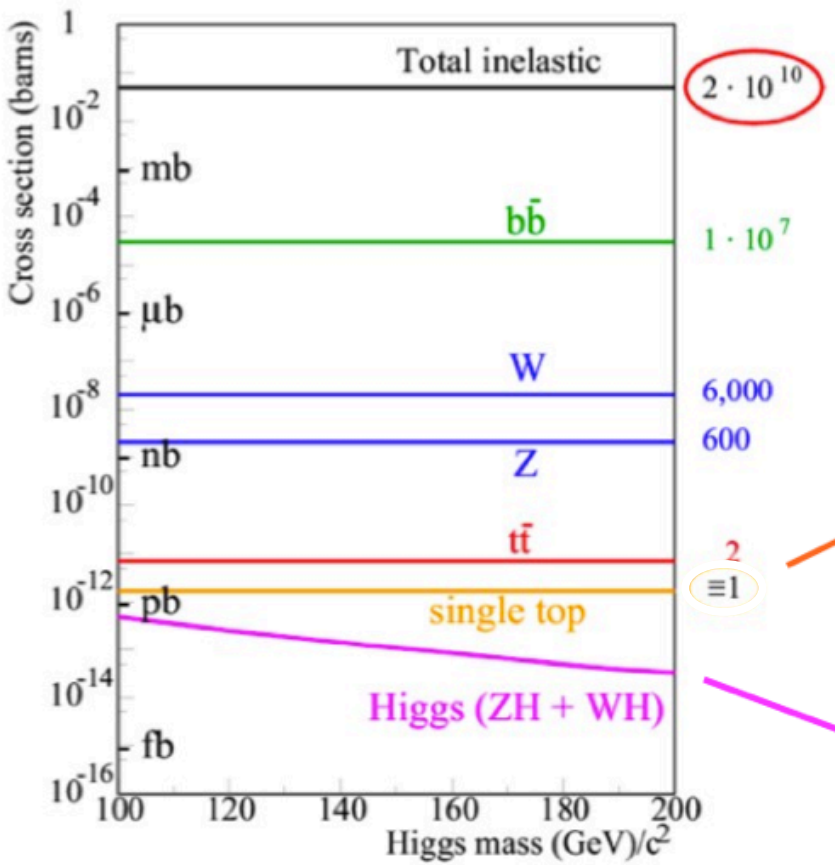
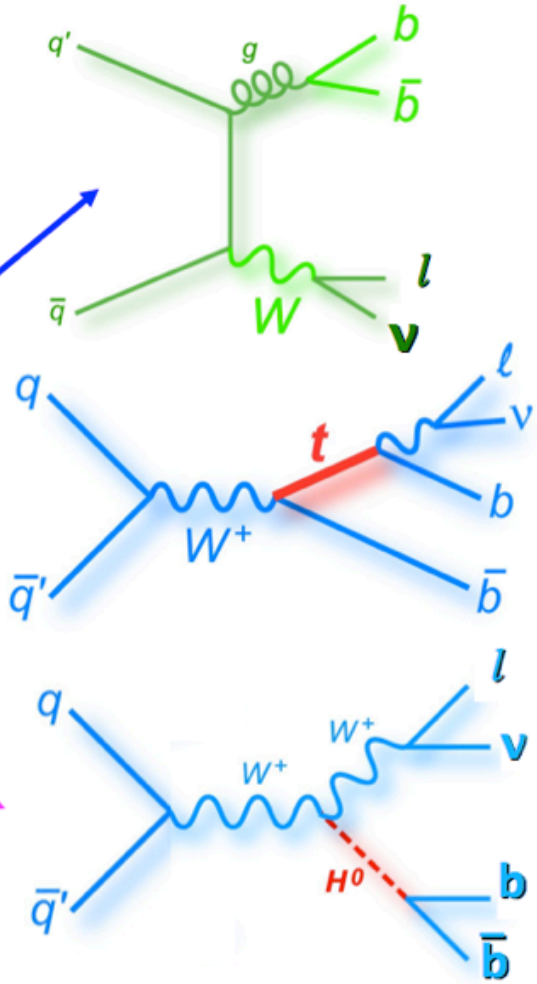
Outline



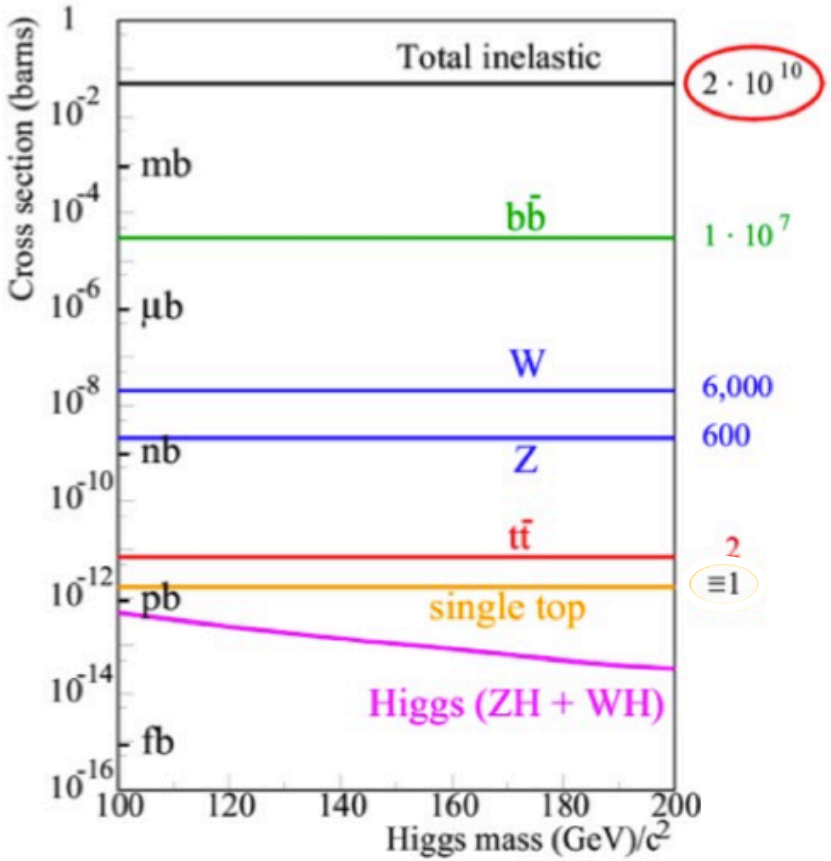


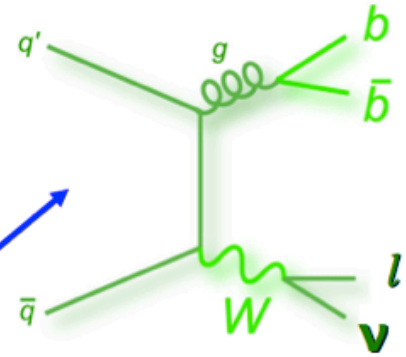
W, Z bosons

top quark

Higgs boson

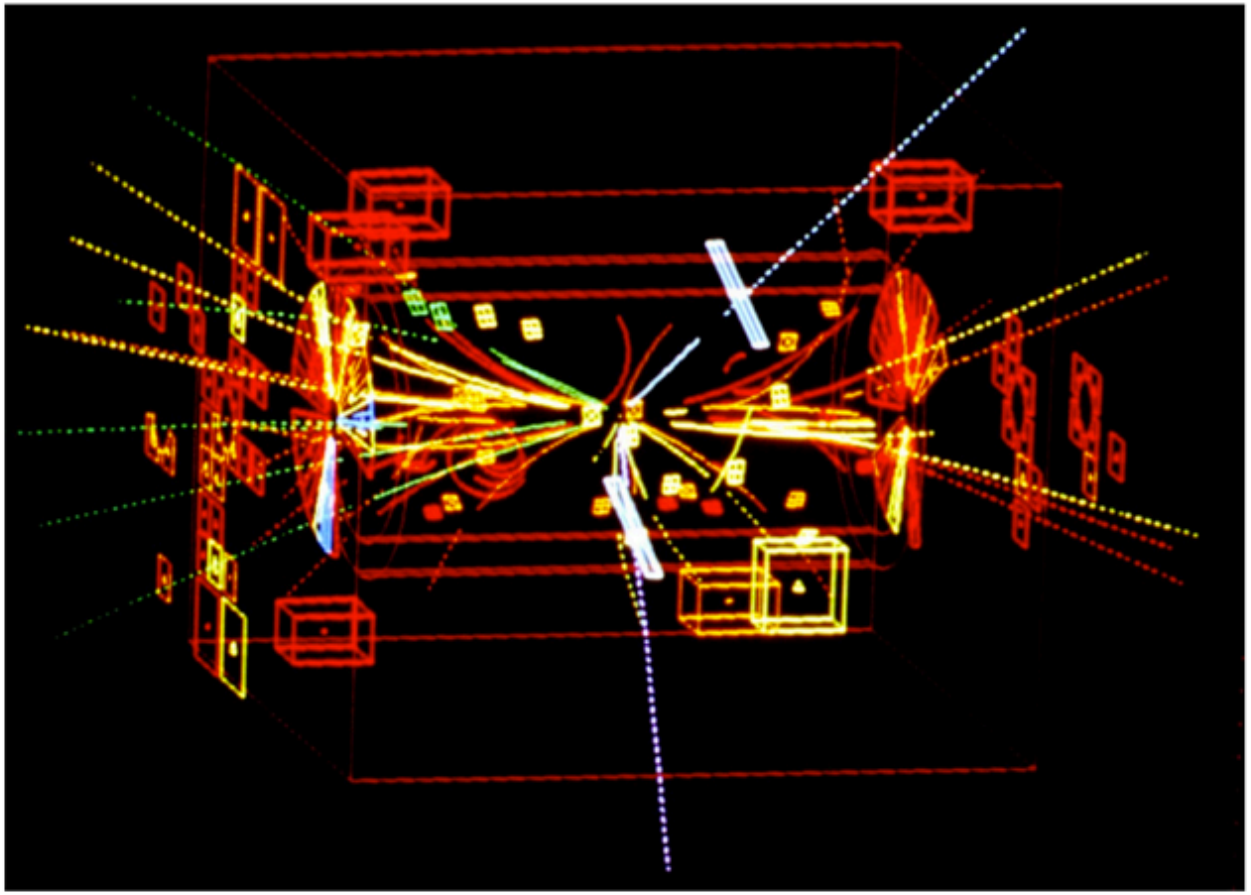
Outline





W, Z bosons

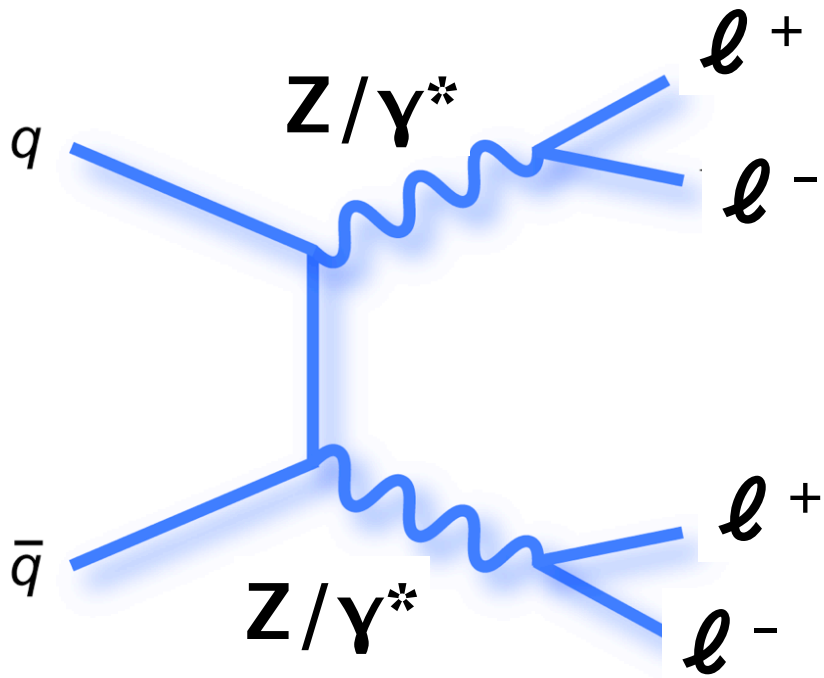
Electroweak Interaction



1983, UA1 experiment, $\sqrt{s}$=540 GeV

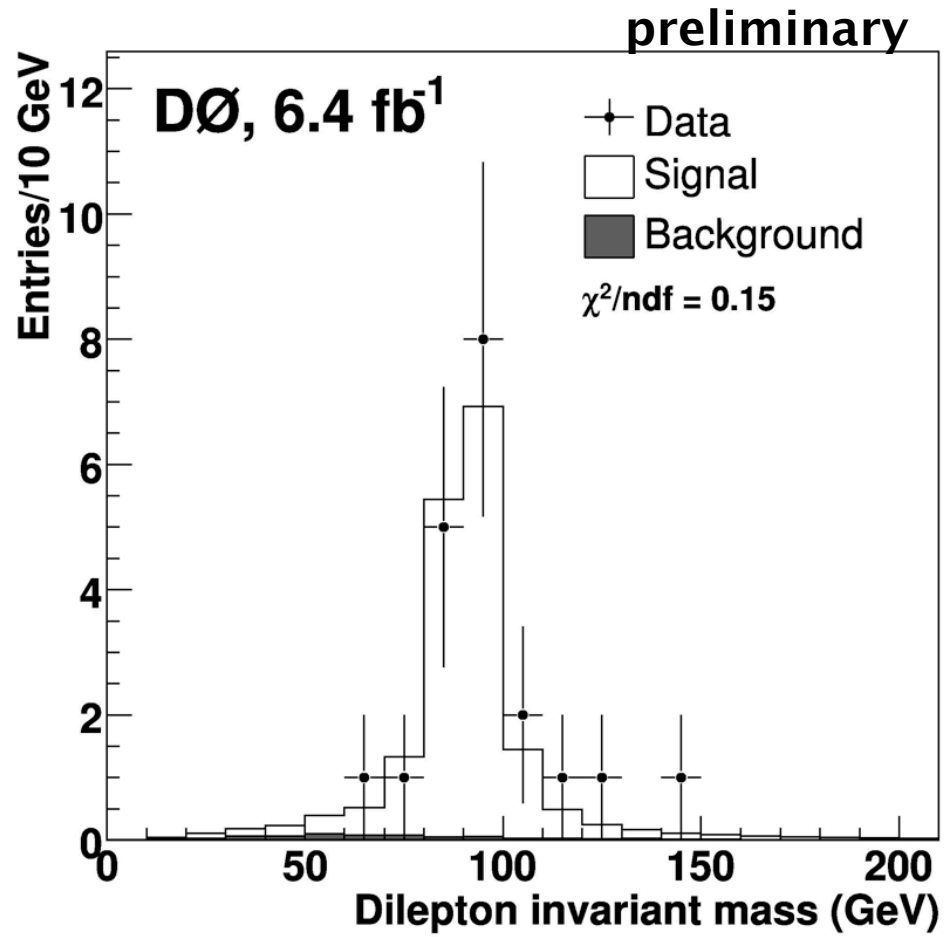
discovery of Z boson at $\bar{p}p$ accelerator SPS (CERN, Geneva)

ZZ→ℓ ℓ ℓ ℓ Production



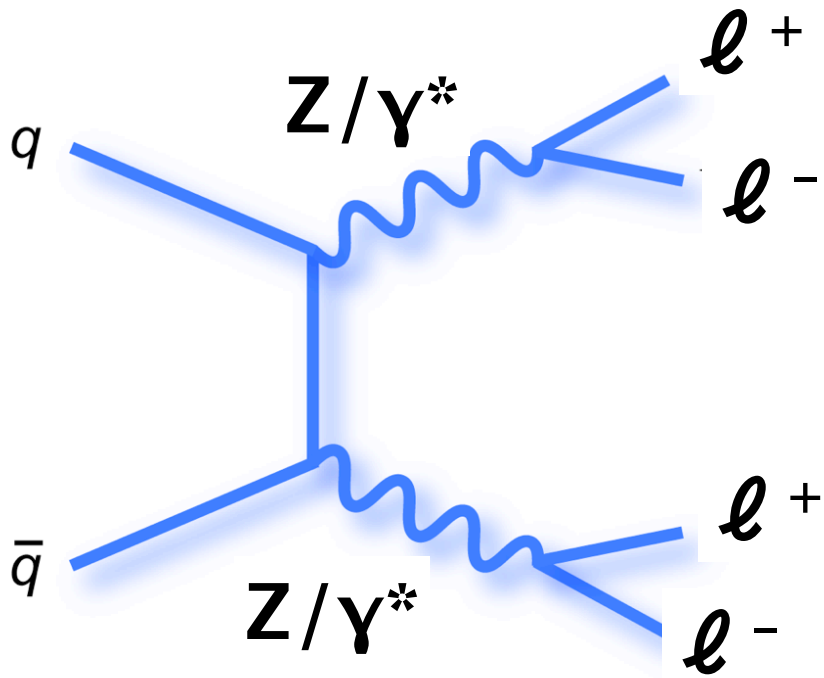
important background
to H→ZZ searches

eeee, eeμμ, μμμμ



NEW

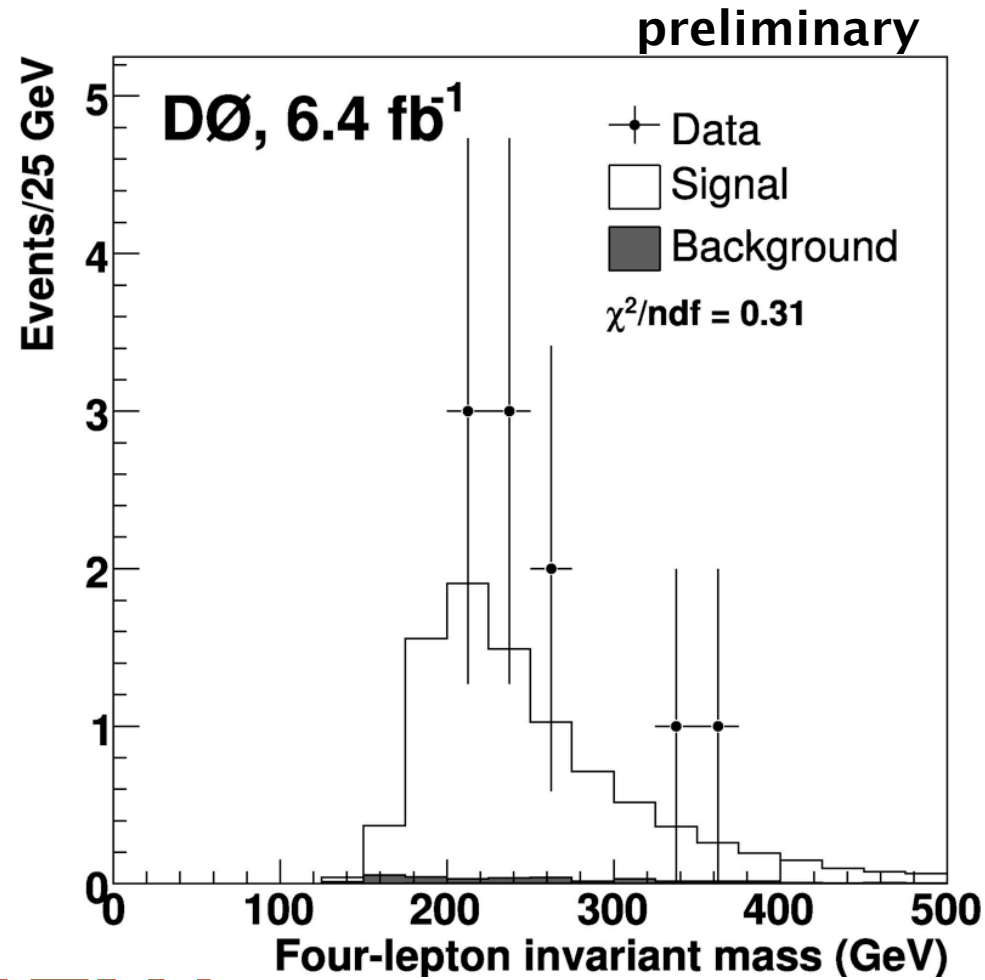
ZZ→ℓ ℓ ℓ ℓ Production



important background to H→ZZ searches...

- data: 10 events
- signal: 8.73±0.45
- background: 0.35±0.04 (jets faking electrons, muons in jets, top pair production)

eeee, eeμμ, μμμμ



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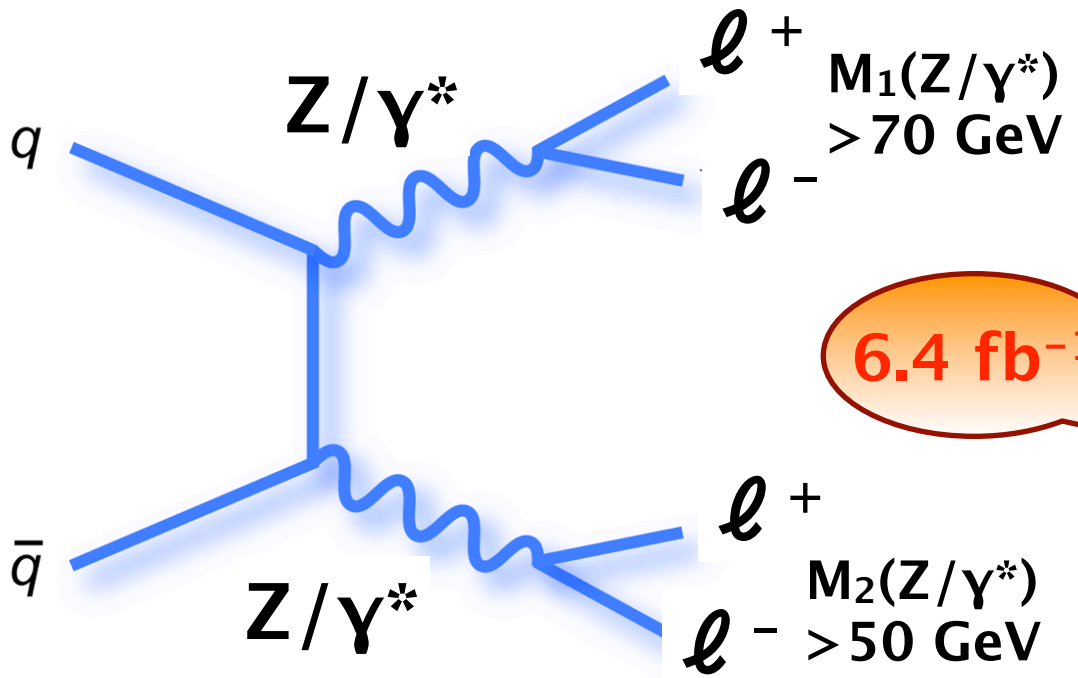
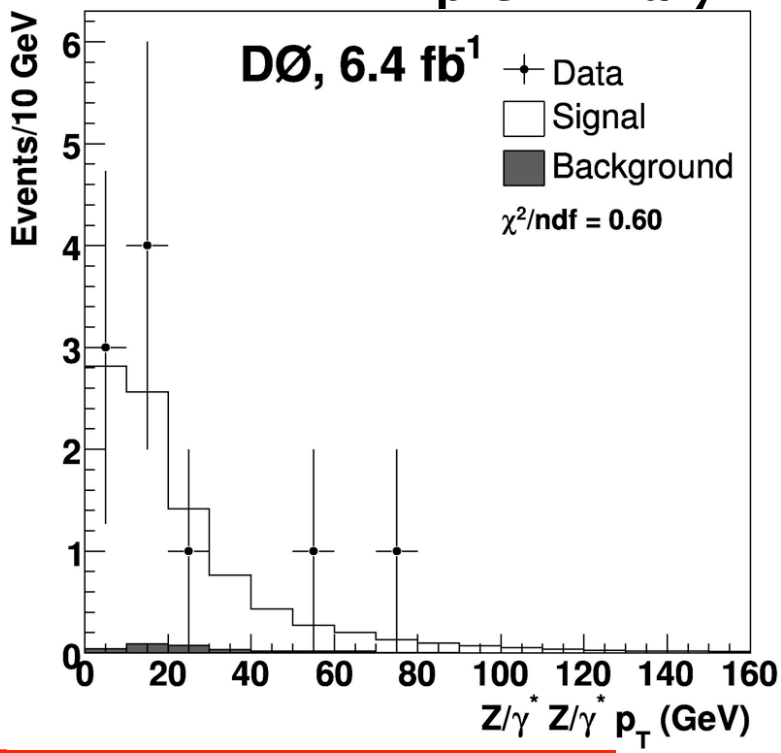


6.4 fb^{-1}

eeee, eeμμ, μμμμ

preliminary

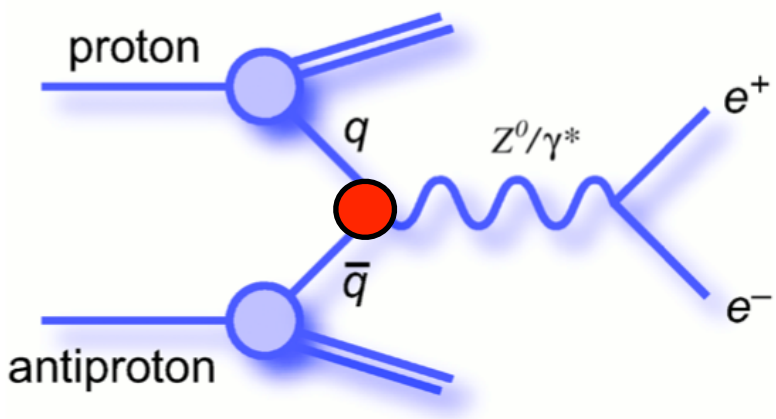


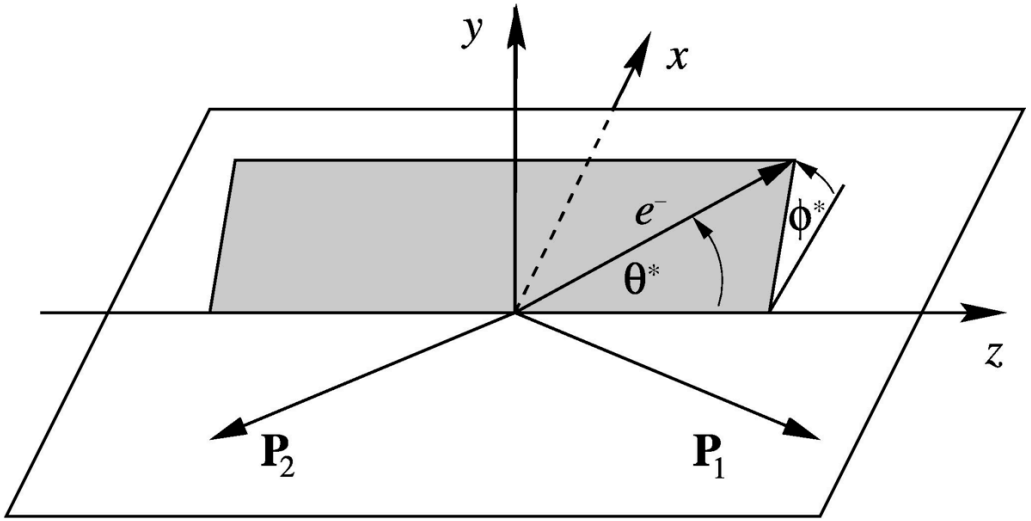
SM: $\sigma(Z/\gamma^* Z/\gamma^*) = 1.4 \pm 0.1$ pb

$$\sigma(p\bar{p} \to Z/\gamma^* Z/\gamma^*) = 1.35^{+0.50}_{-0.40}\,(\text{stat}) \pm 0.15\,(\text{syst})\ \text{pb}$$

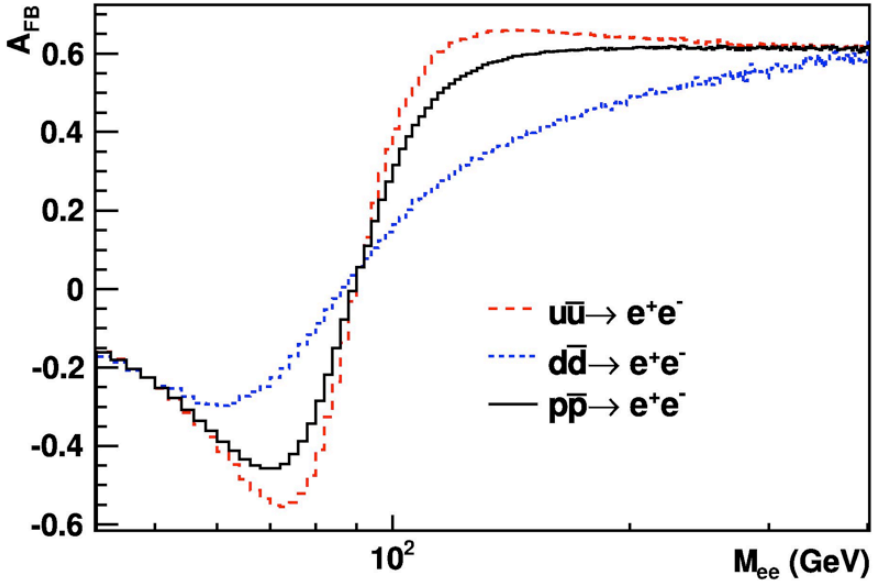
- smallest cross section measured at hadron collider
- most precise measurement
- examine kinematic distributions

Z Boson–Quark Couplings





$$g_V^f = I_3^f - 2Q_f \cdot \sin^2\theta_W$$
$$g_A^f = I_3^f$$



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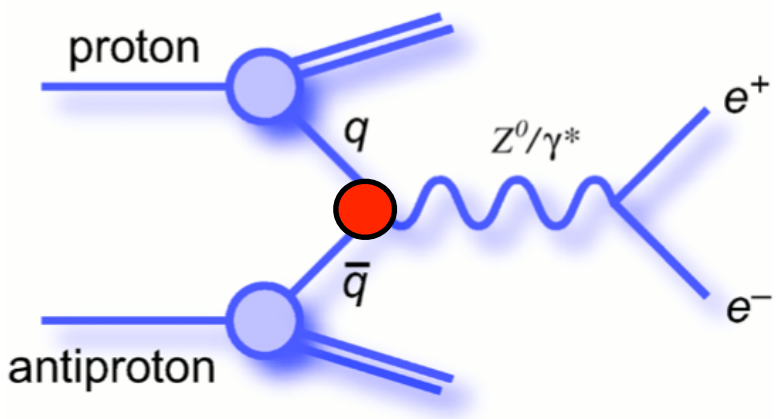

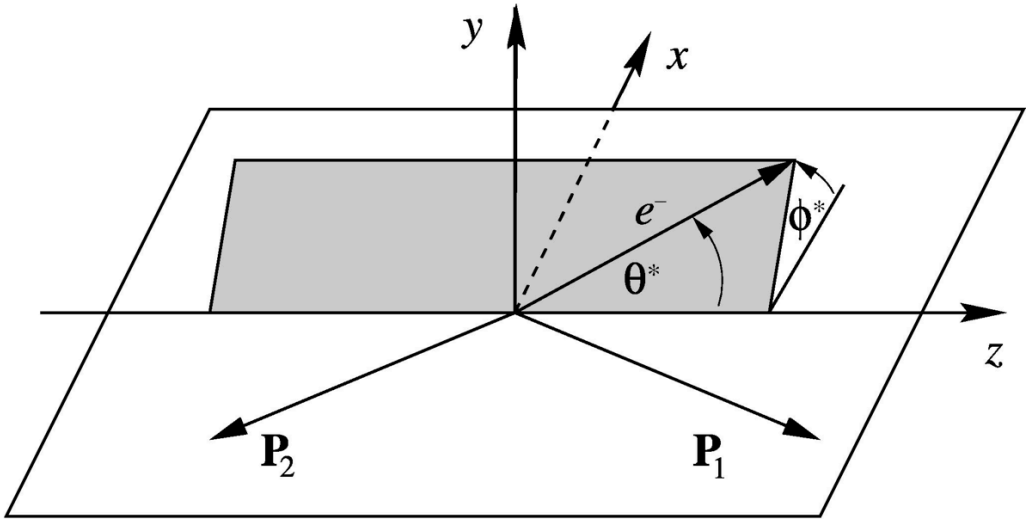

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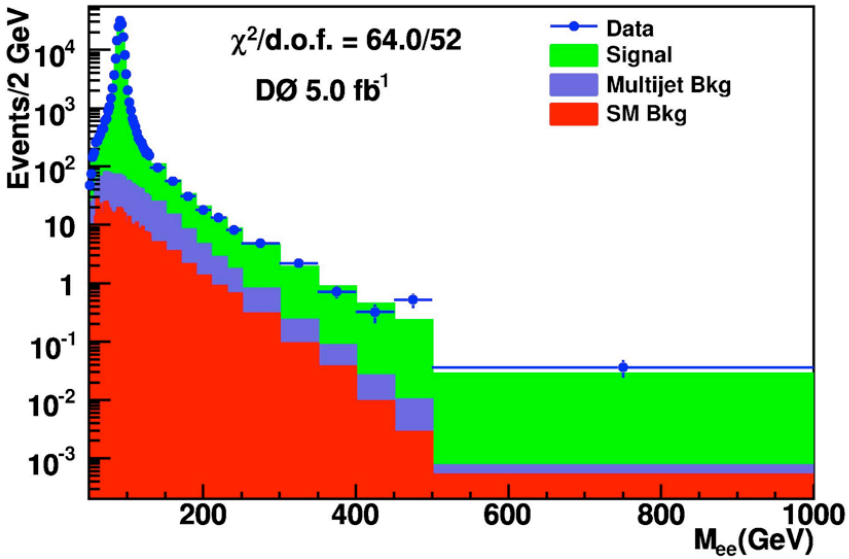

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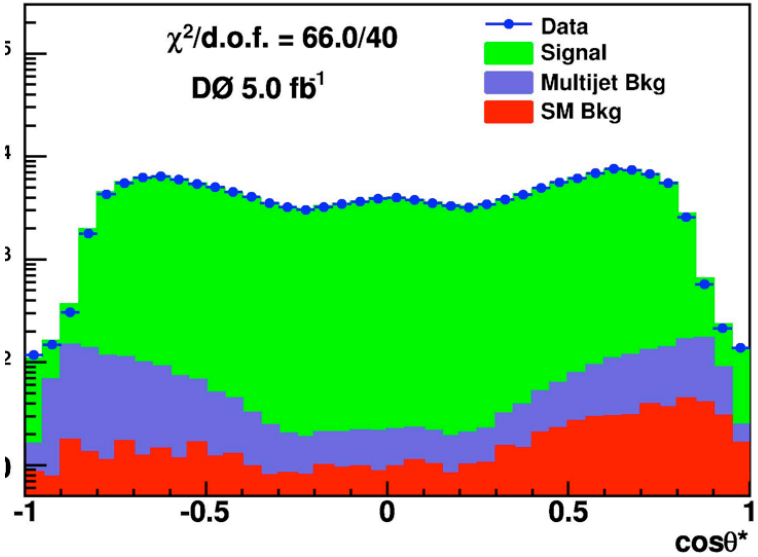

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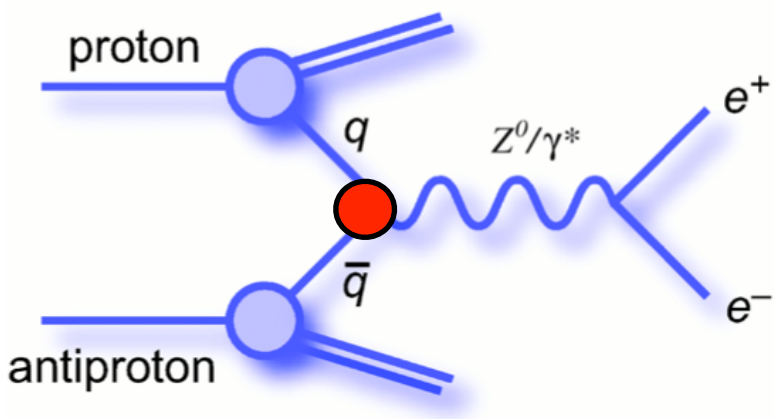

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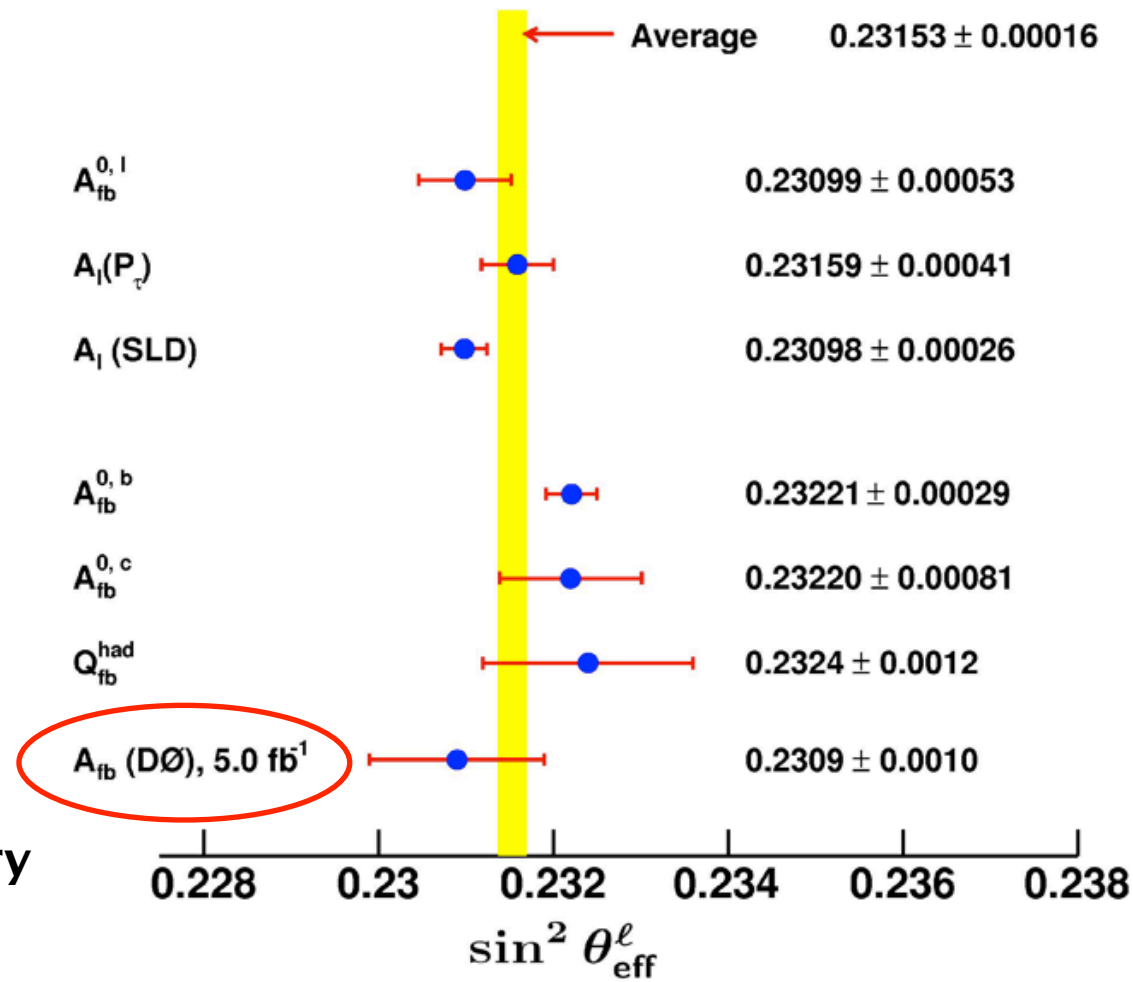
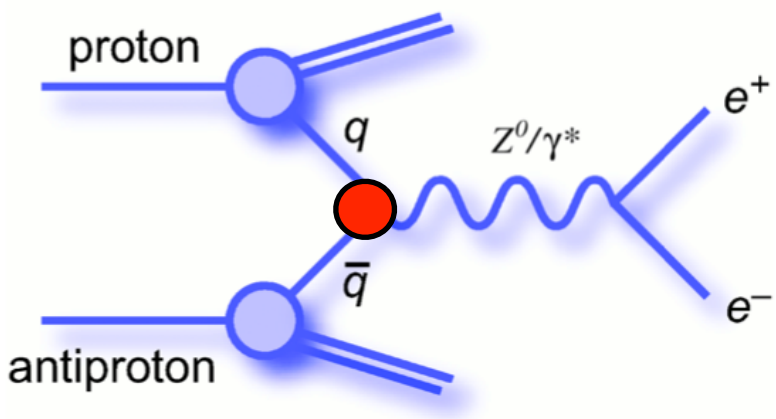


5.0 fb^{-1}

preliminary

Z Boson–Quark Couplings



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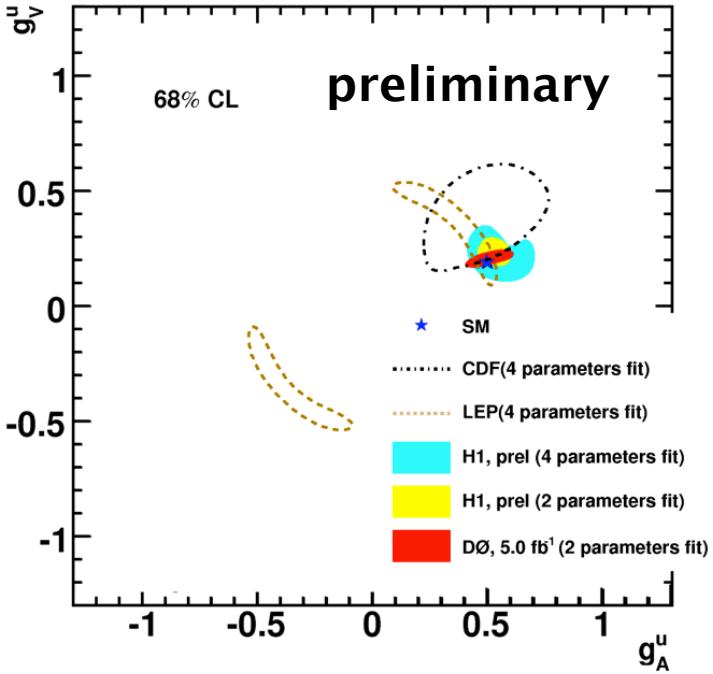

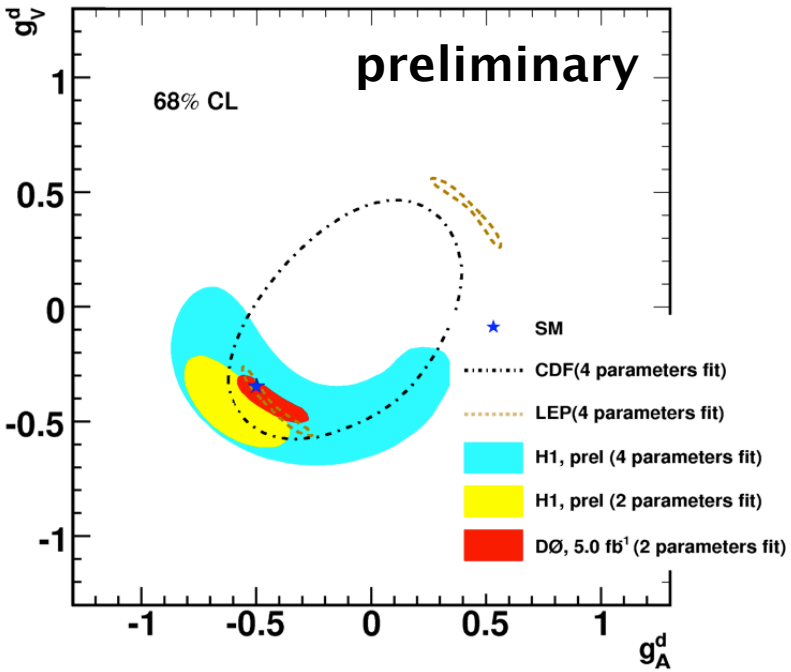

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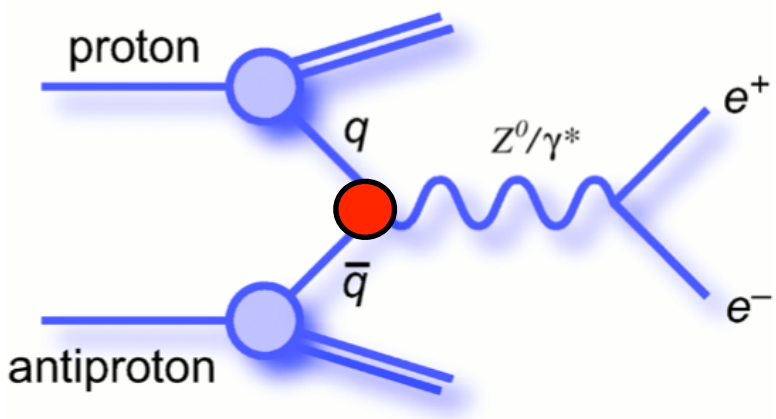

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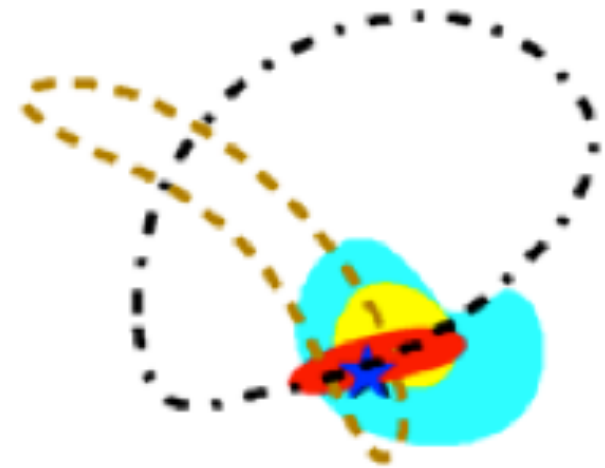
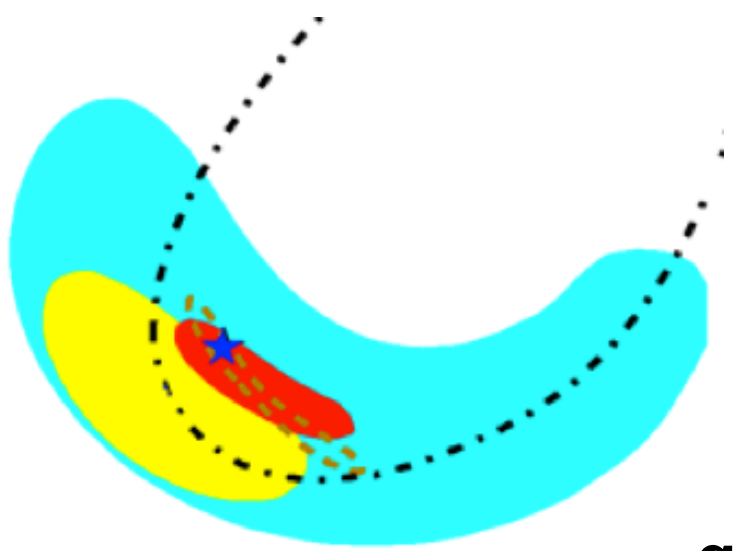
g^u_V



g^u_A

g^d_V



g^d_A

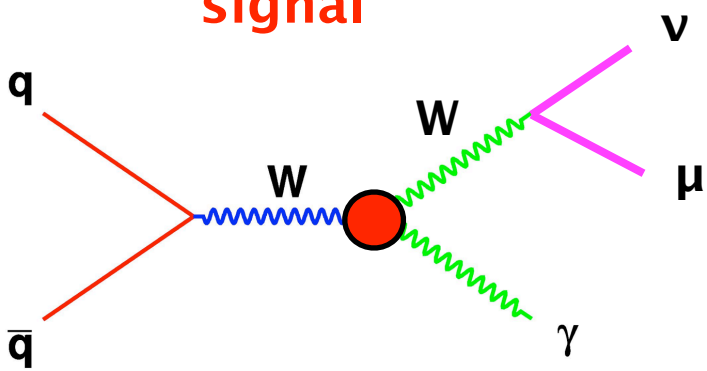
5.0 fb^{-1}

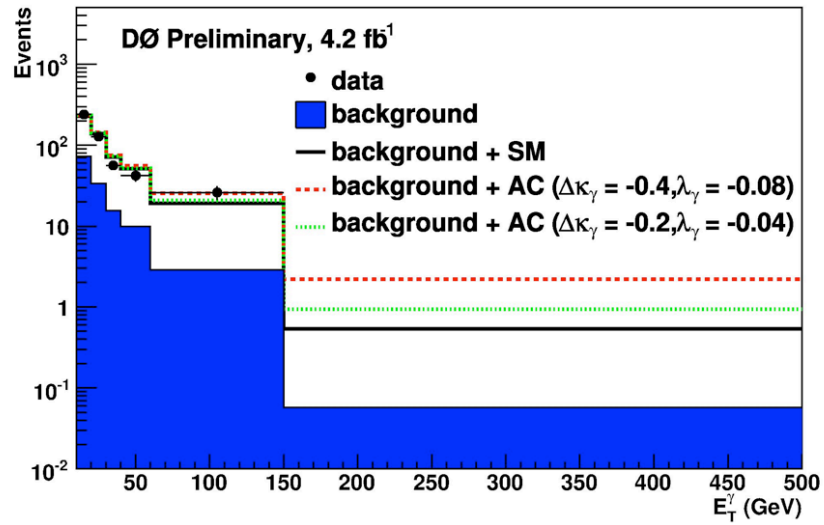
WWγ Couplings

analyse non-abelian gauge structure

4.2 fb^{-1}

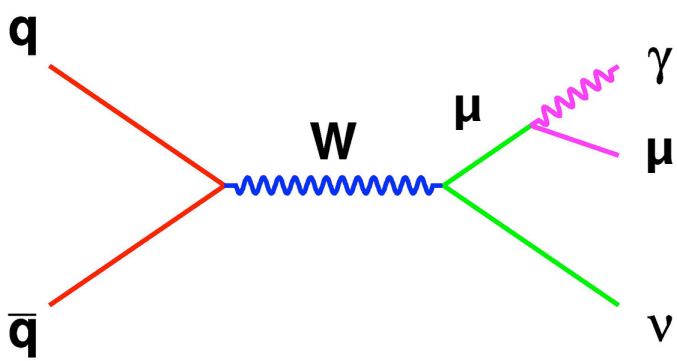
signal



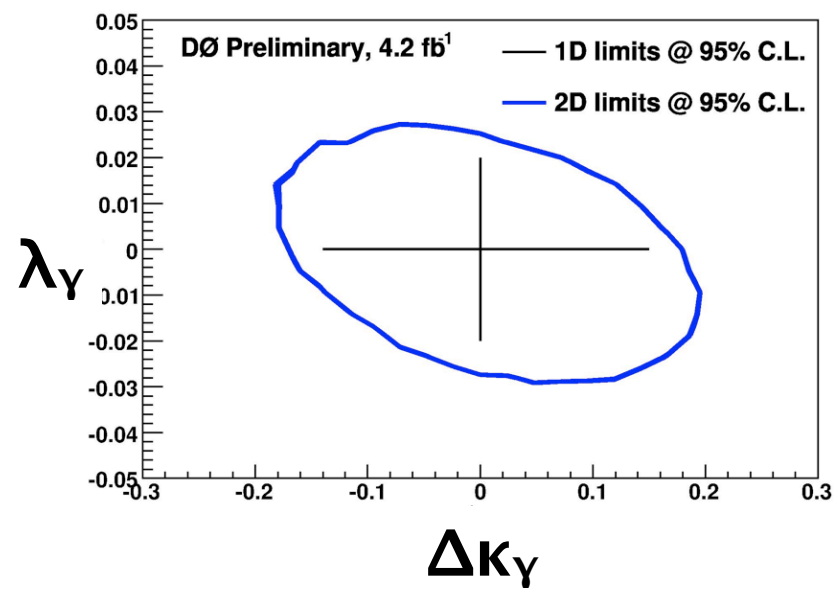


cross section in agreement with SM

background

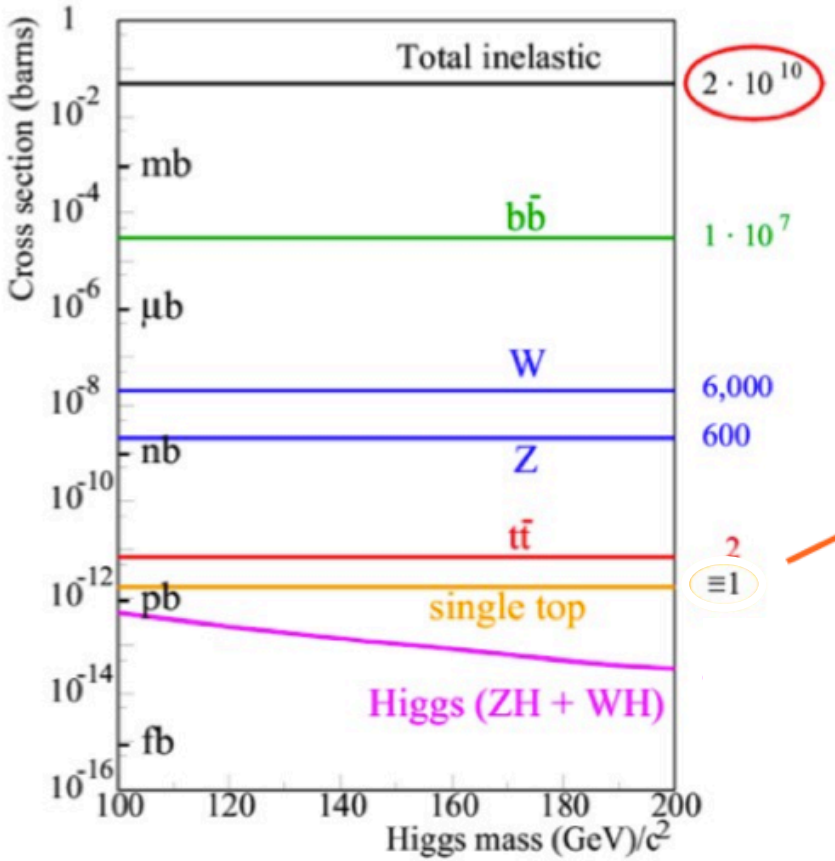


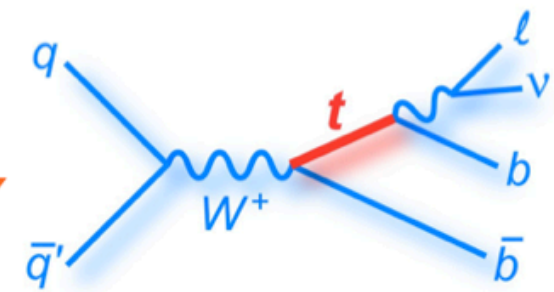
strongest limits on anomalous couplings from Tevatron



background rejection:
tight cut on transverse mass $M_T(\mu,\gamma,MET)$

Outline



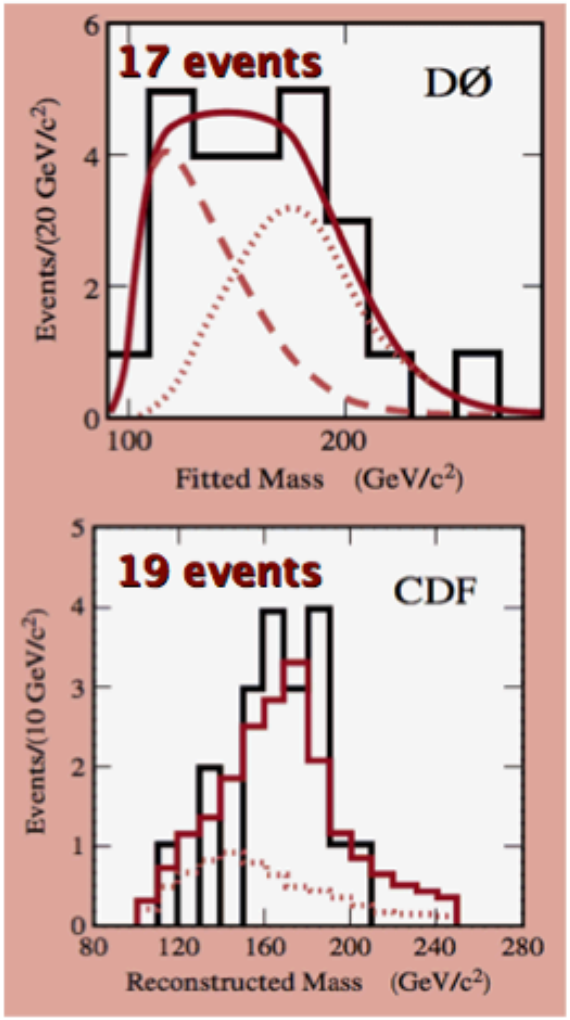


top quark

Top Quark

discovery

PRL 74, 2632 (1995)
PRL 74, 2626 (1995)



1995, CDF and DØ experiments, Fermilab

Top Quark

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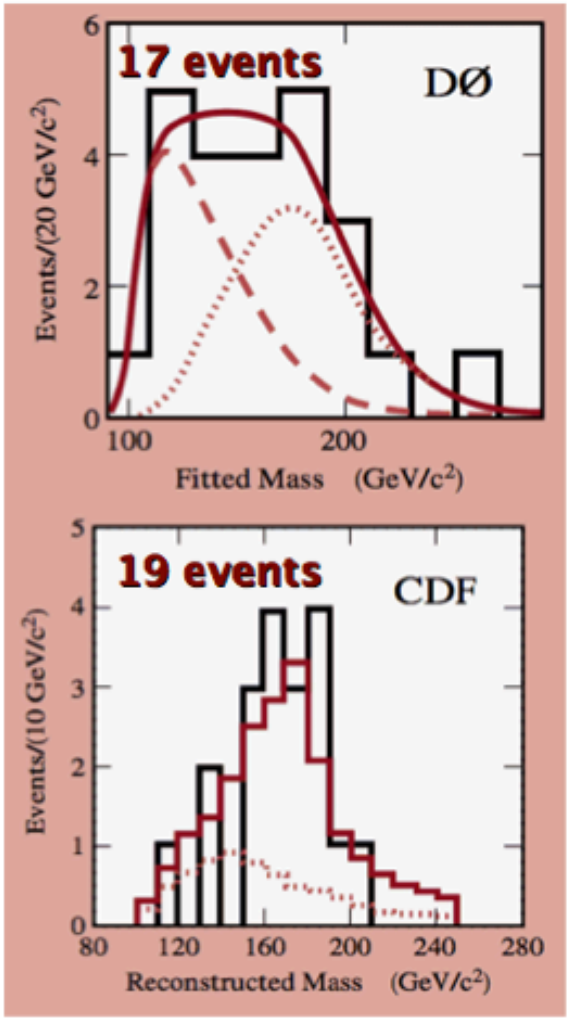
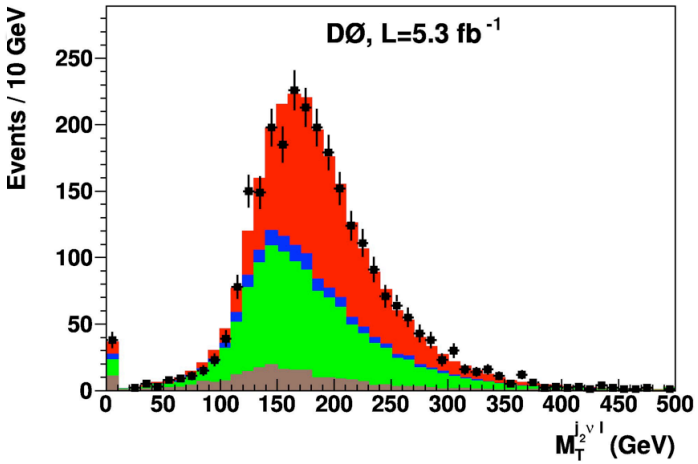


1995, CDF and DØ experiments, Fermilab

today

~1000 events



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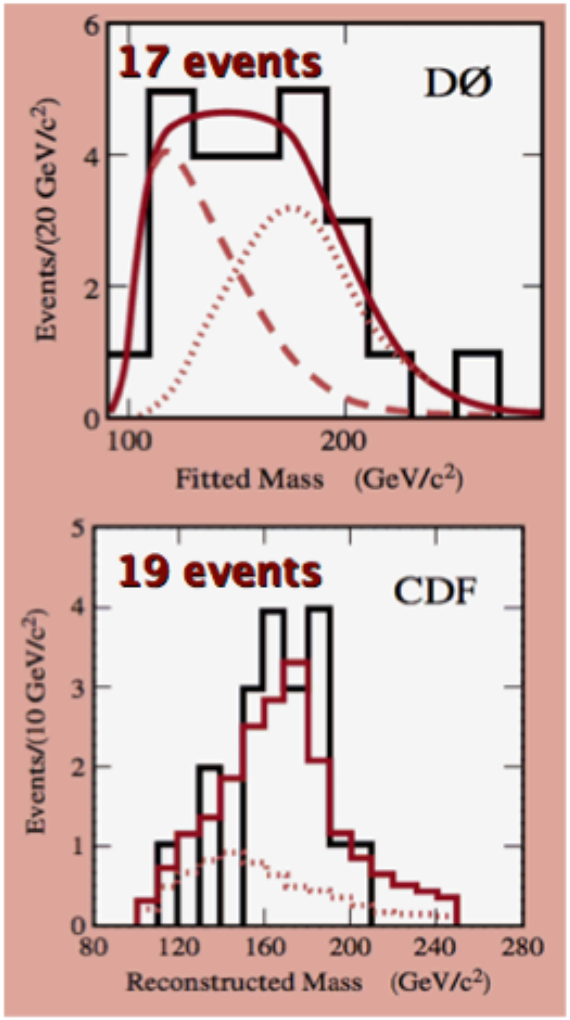

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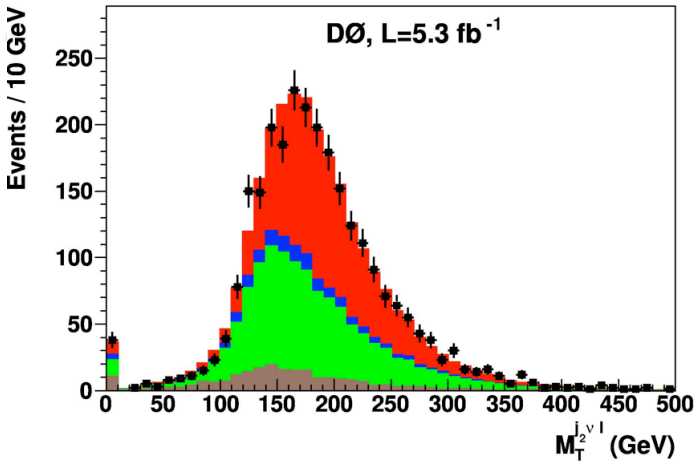
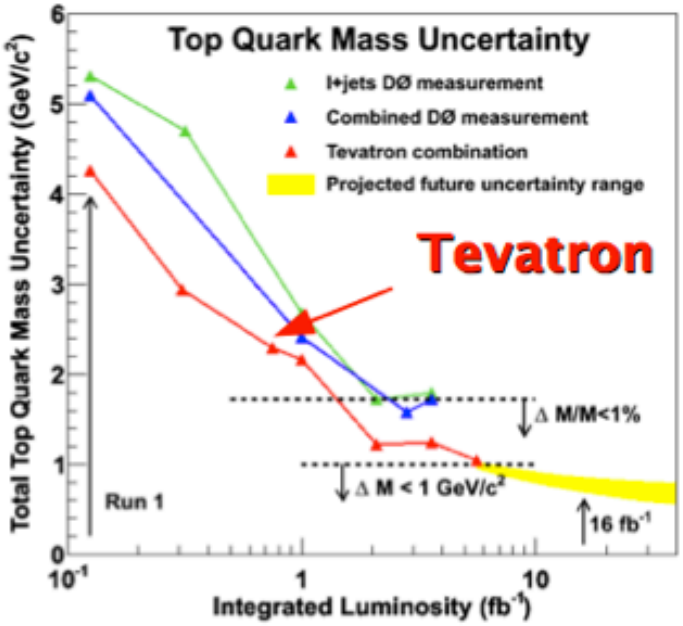


precision



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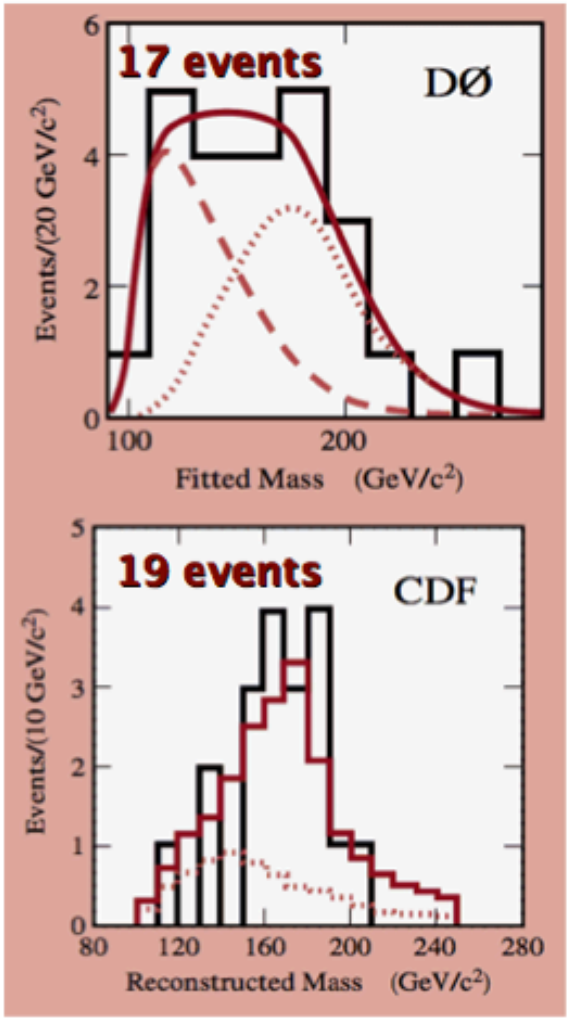

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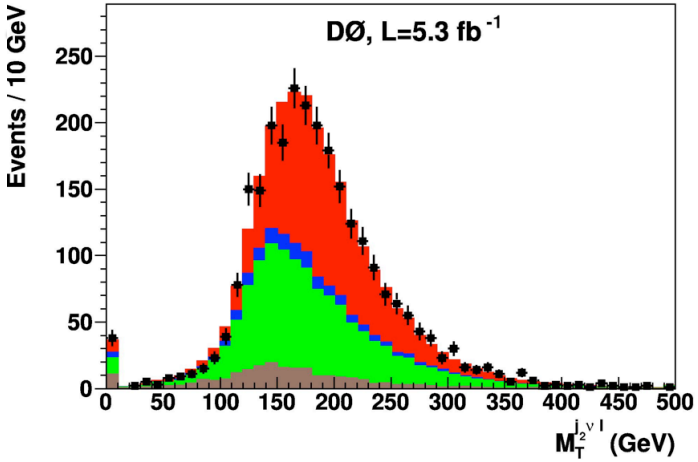
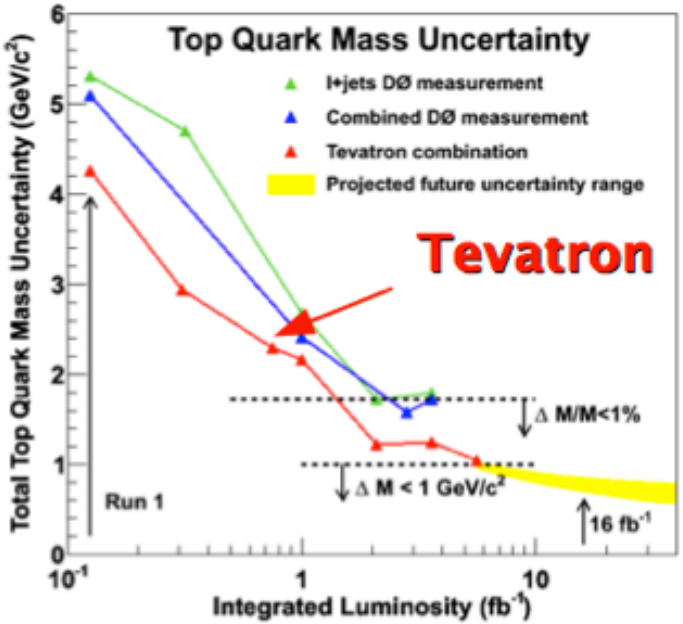


hints & excesses

precision

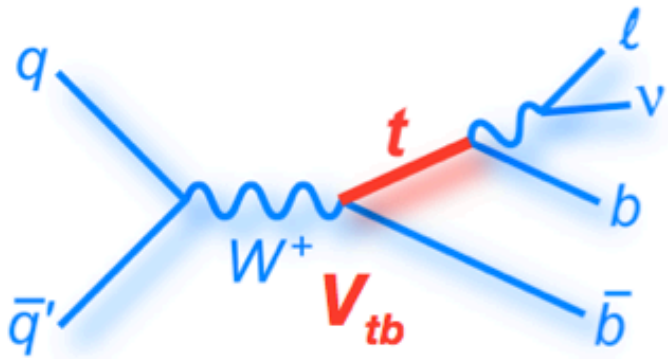


searches

Single Top Quark Production

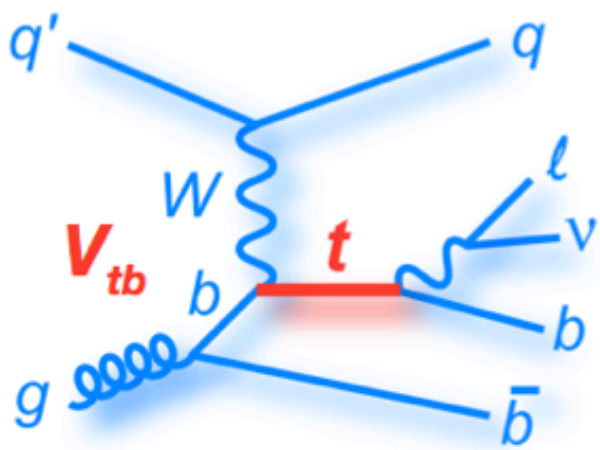
direct measurement of $|V_{tb}|$

s-channel: $\sigma_{tb} = 1.04 \pm 0.04$ pb
NNNLO$_{approx}$, $m_{top} = 172.5$ GeV

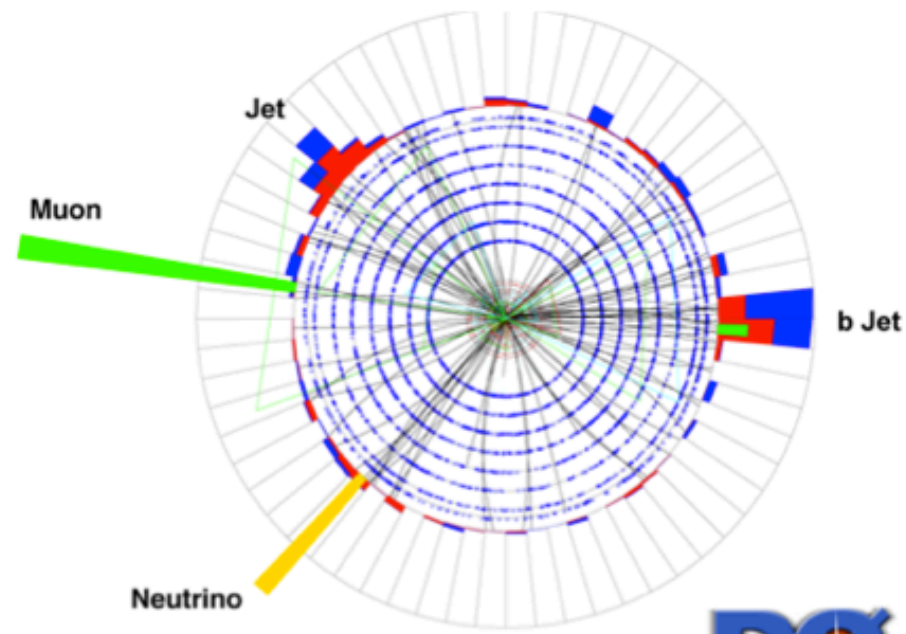


$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

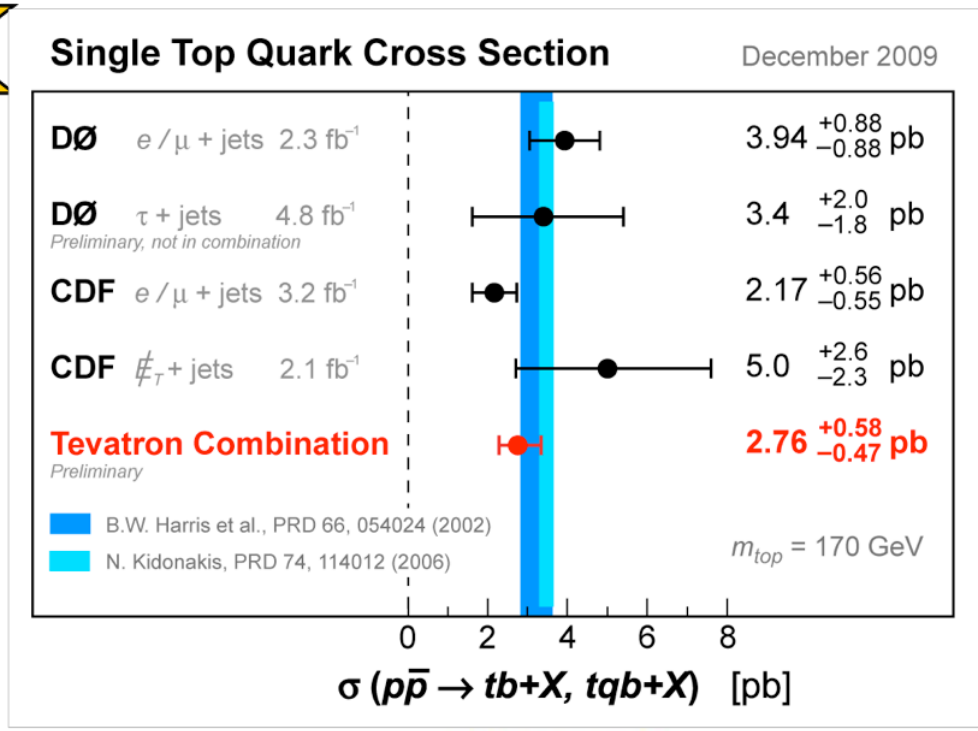
t-channel: $\sigma_{tb} = 2.26 \pm 0.12$ pb
NNNLO$_{approx}$, $m_{top} = 172.5$ GeV



- jets
- lepton
- missing E_T
- b-jets

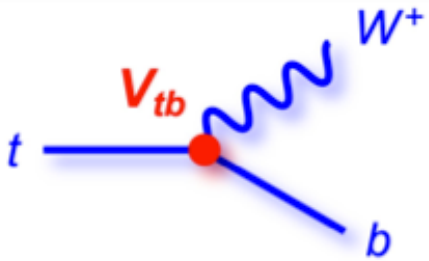


Single Top Quark Observation



to do:

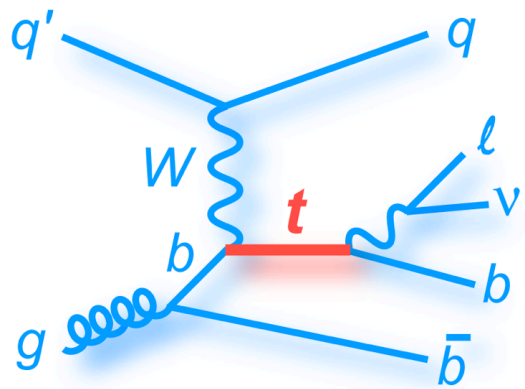
- remove s/t channel constraint that could be changed by new physics (additional quark generation, new heavy bosons, FCNC, anomalous top quark couplings)
- measure t-channel separately
- measure s-channel separately

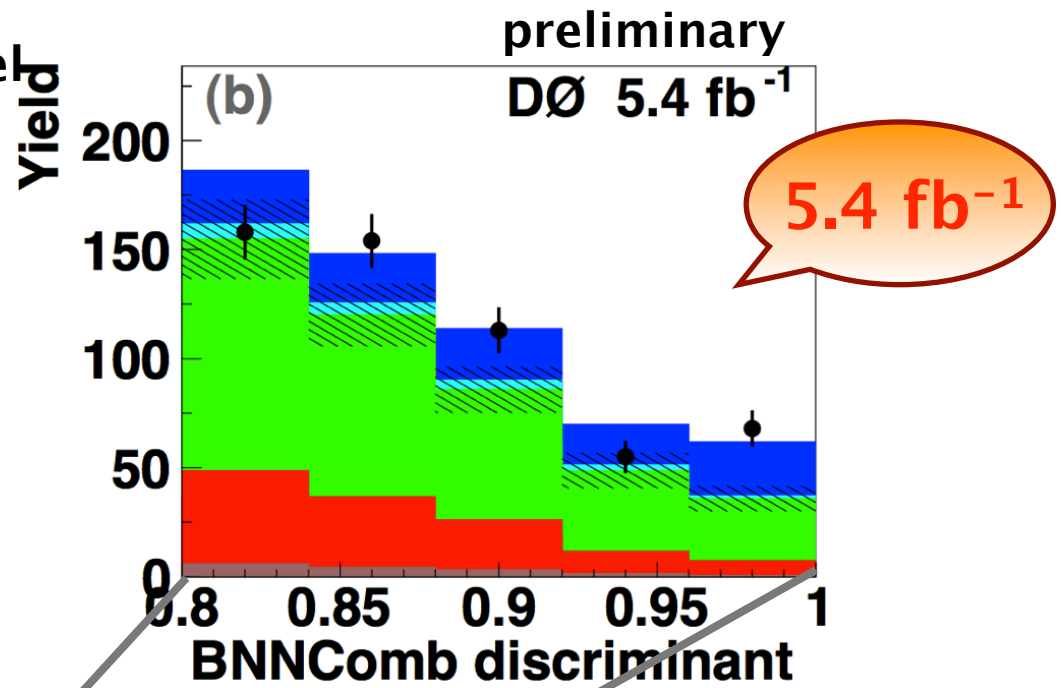


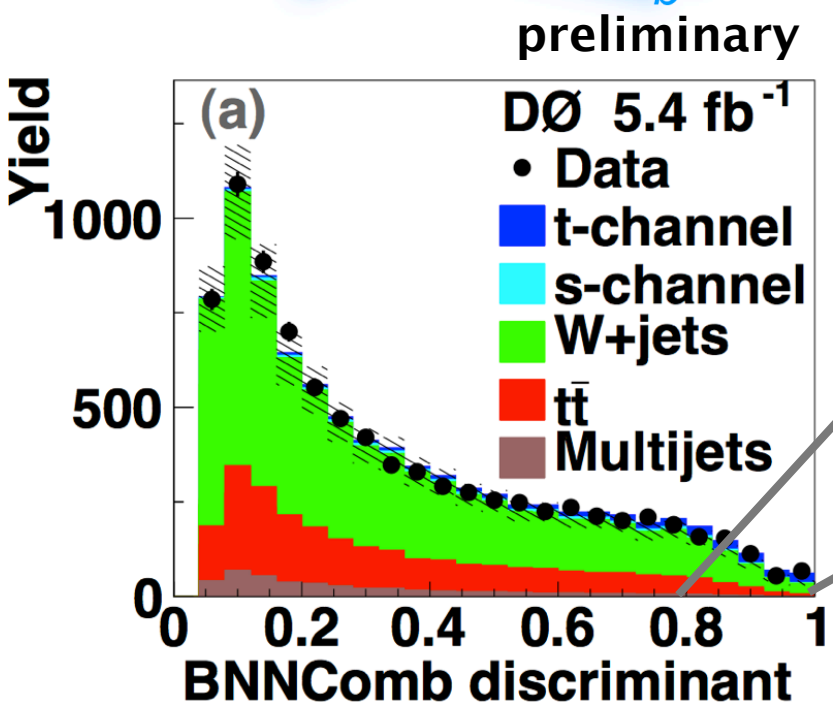
$$|V_{tb}| = 0.88 \pm 0.07$$

Single Top t-channel

- 2, 3, 4 jets with 1, 2 b tags
- train multivariate analysis for t-channel
- double data set





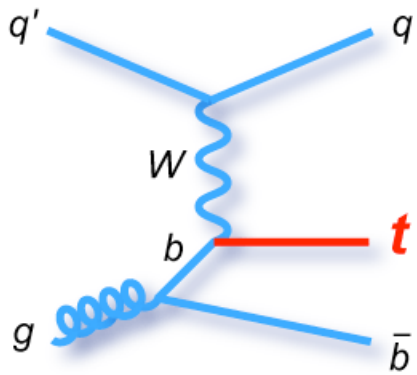


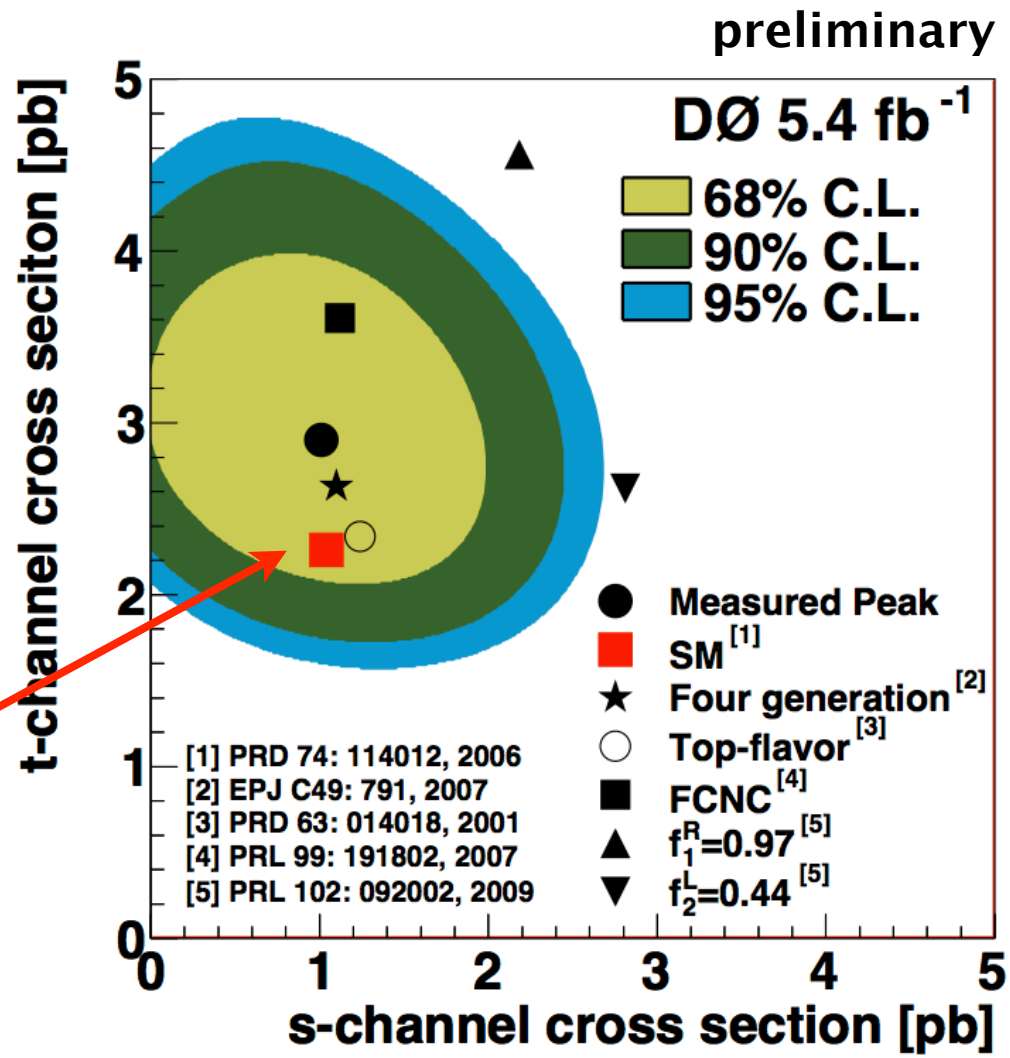
$\sigma_{tb} = 2.26 \pm 0.12$ pb

$NNNLO_{approx}$, $m_{top} = 172.5$ GeV

σ(t-channel)=2.90±0.59 pb

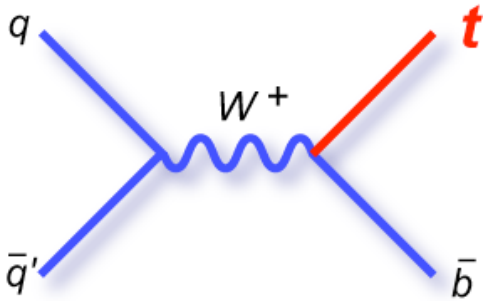
Single Top s- vs. t-channel





5.4 fb^{-1}

SM



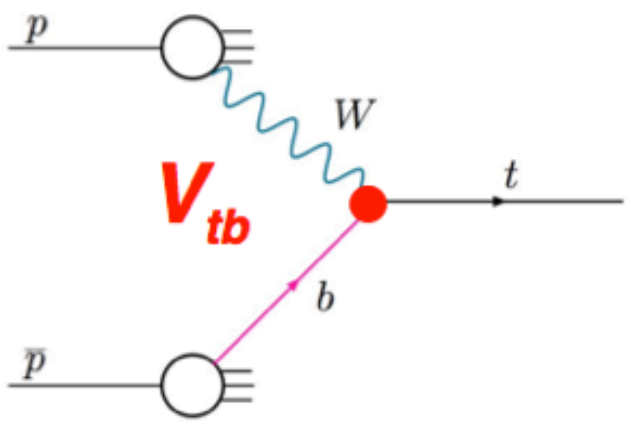
good agreement with Standard Model

Top Decay Width

t-channel cross section:

σ(t-channel) = 2.14 ± 0.18 pb
NLO, m_t = 170 GeV

NEW



Top Decay Width

t-channel cross section:

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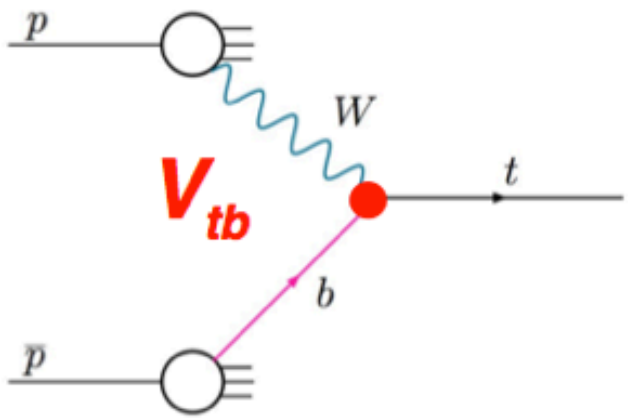
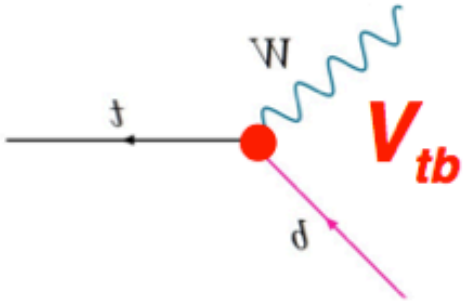
NLO, m_t = 170 GeV



partial decay width:

$\Gamma(t \to Wb)$ = 1.26 GeV
NLO, m_t = 170 GeV

NEW



Top Decay Width

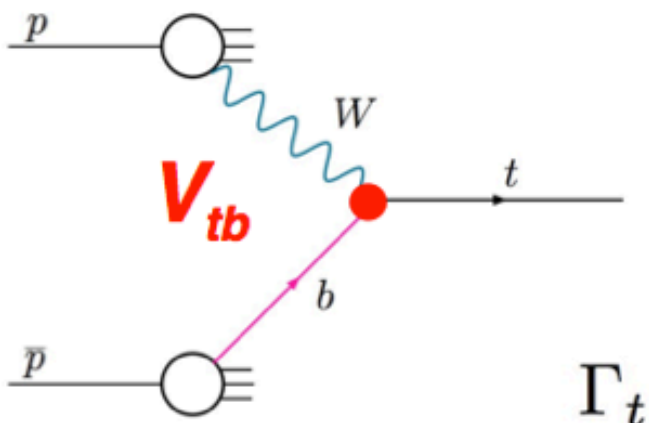
t-channel cross section:

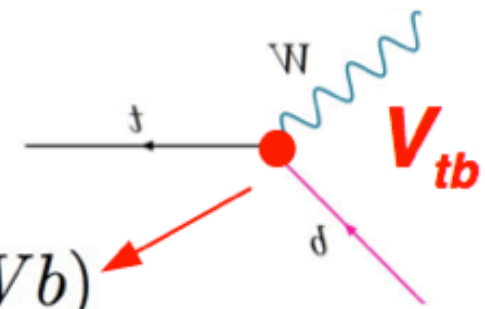
σ(t-channel) = 2.14 ± 0.18 pb
NLO, m_t = 170 GeV

partial decay width:

Γ(t→Wb) = 1.26 GeV
NLO, m_t = 170 GeV

NEW





$$\Gamma_t = \frac{\Gamma(t \to Wb)}{\mathcal{B}(t \to Wb)}$$

$t\bar{t}$ production

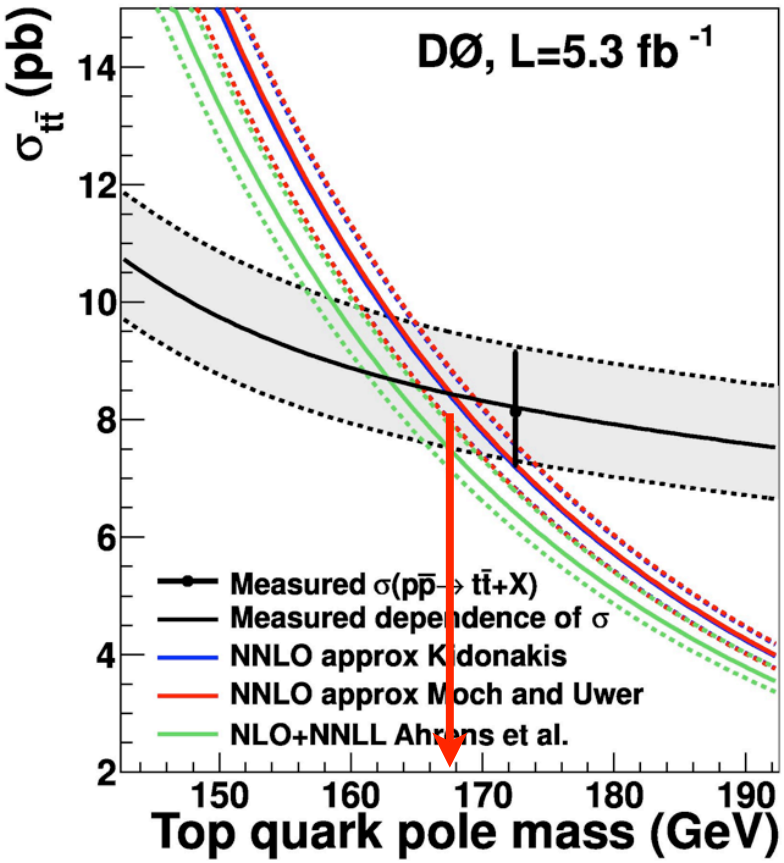
assume that coupling in top production and decay is the same

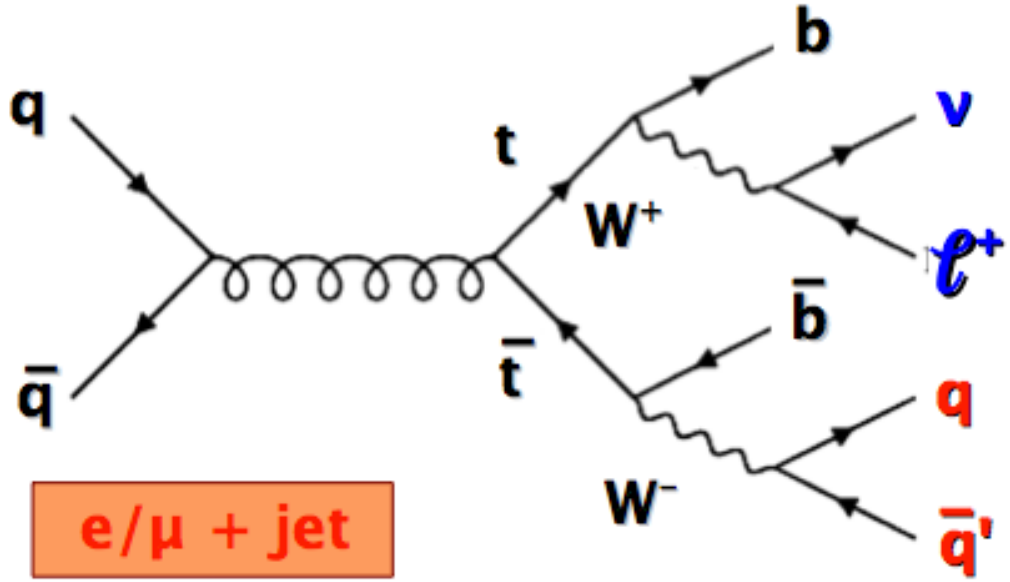
$$\Gamma_t = 1.99^{+0.69}_{-0.55}\ \mathrm{GeV}$$

$$\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}\ \mathrm{s}$$

⇒ **most precise determination**

Top Cross Section and Mass





5.3 fb^{-1}

NEW

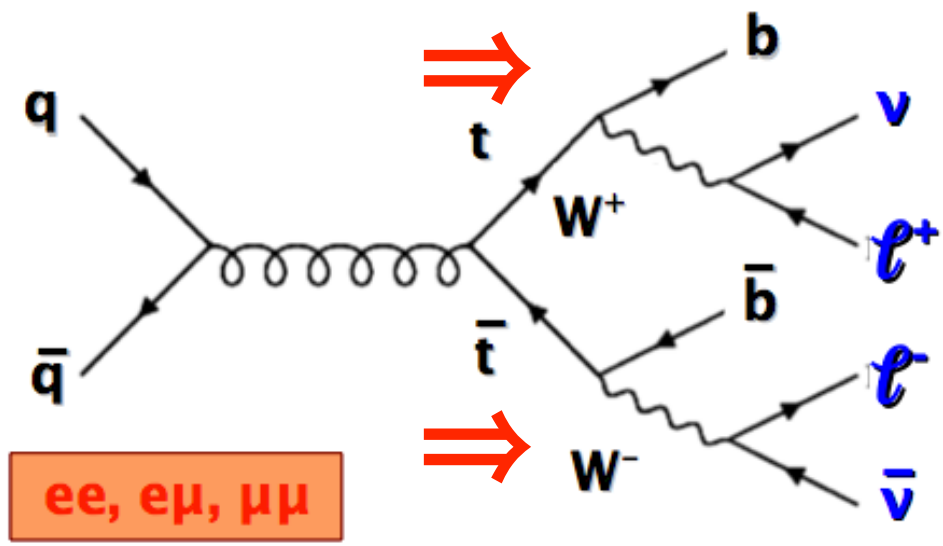
±3.1%

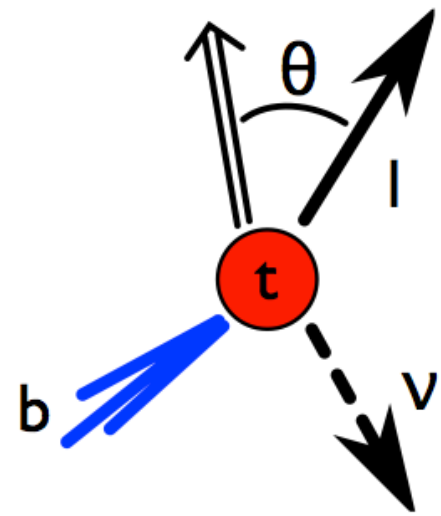
$$m_t^{pole} = 167.5^{+5.4}_{-4.9}\ \text{GeV}$$

$\overline{\text{MS}}$ mass: ±3.0%

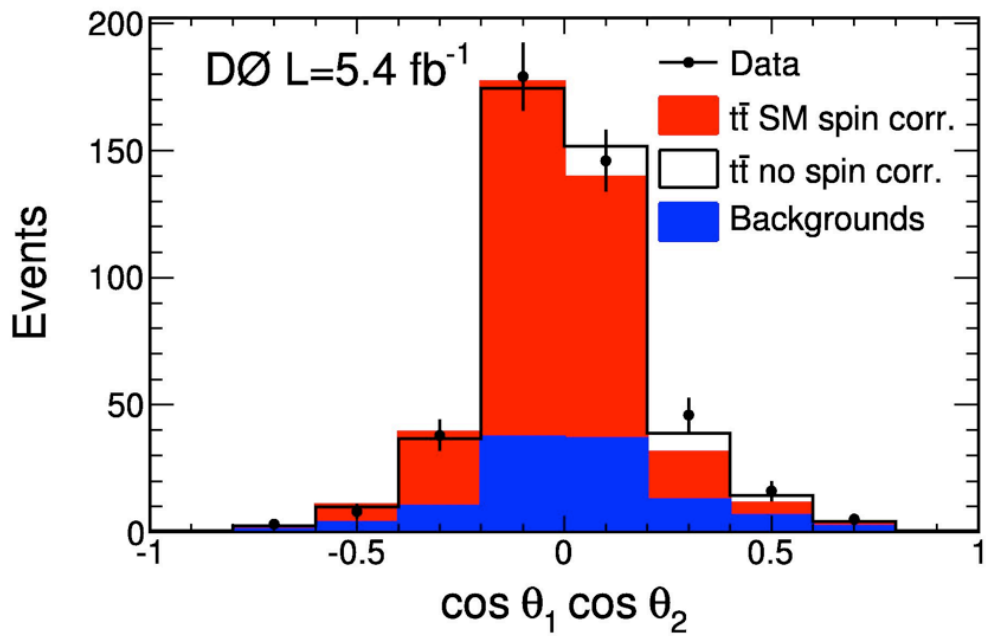
$$m_t^{\overline{MS}} = 159.9^{+5.1}_{-4.4}\ \text{GeV}$$

Top Pair Spin Correlations





5.4 fb^{-1}



correlation strength:

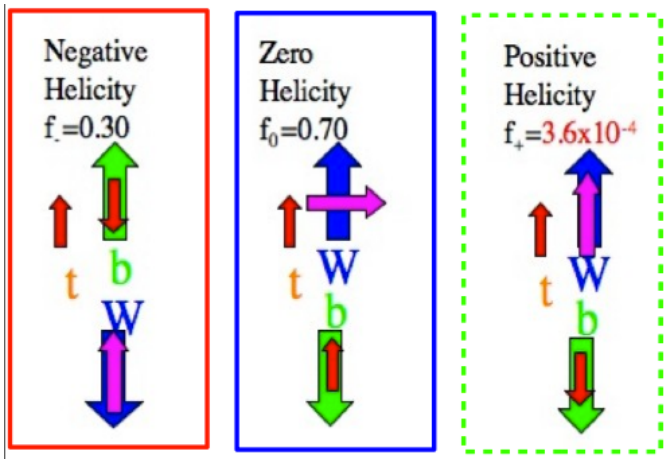
$$C = 0.10^{+0.45}_{-0.45}\ (\text{stat+syst})$$

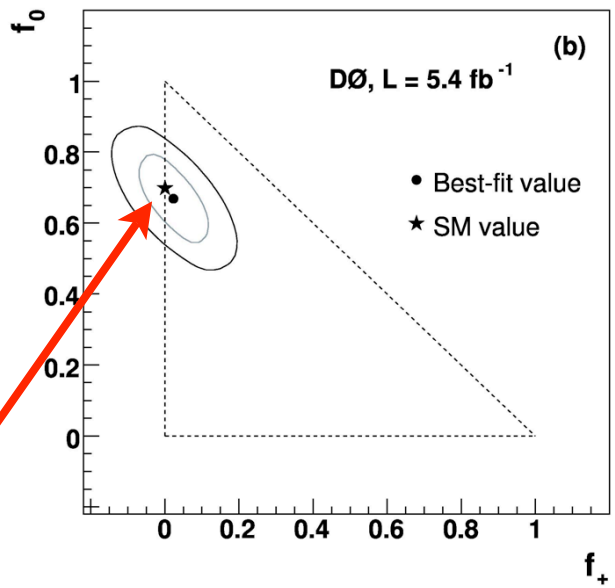
NLO QCD: $C = 0.777^{+0.027}_{-0.042}$

agreement within 2 sd

W from Top Decay Properties

W helicity fractions
study V-A Wtb coupling

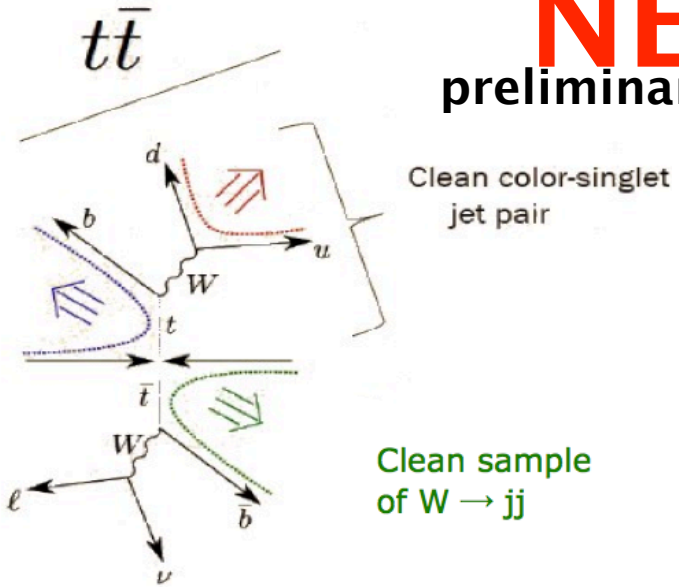


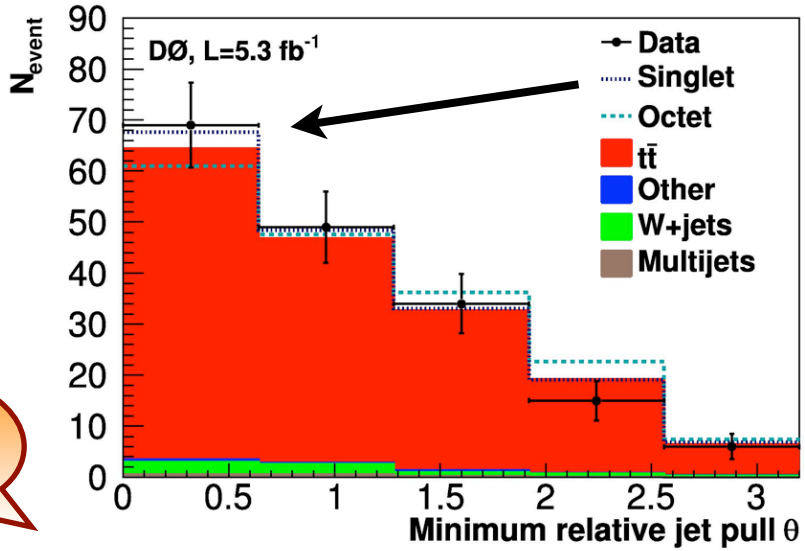


5.4 fb^{-1}

colour flow

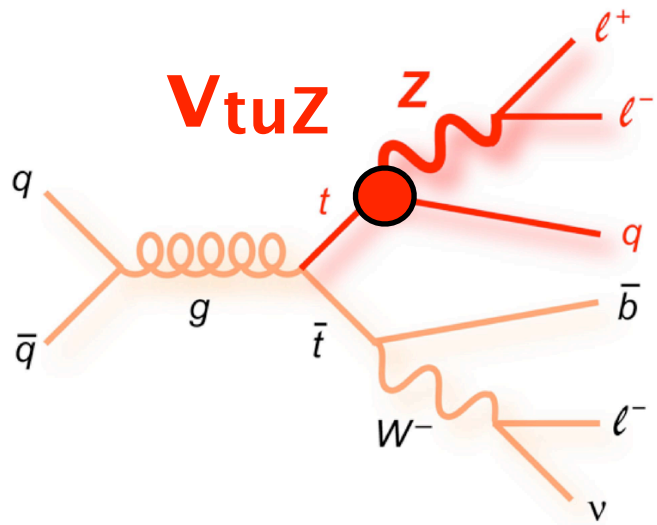
NEW
preliminary



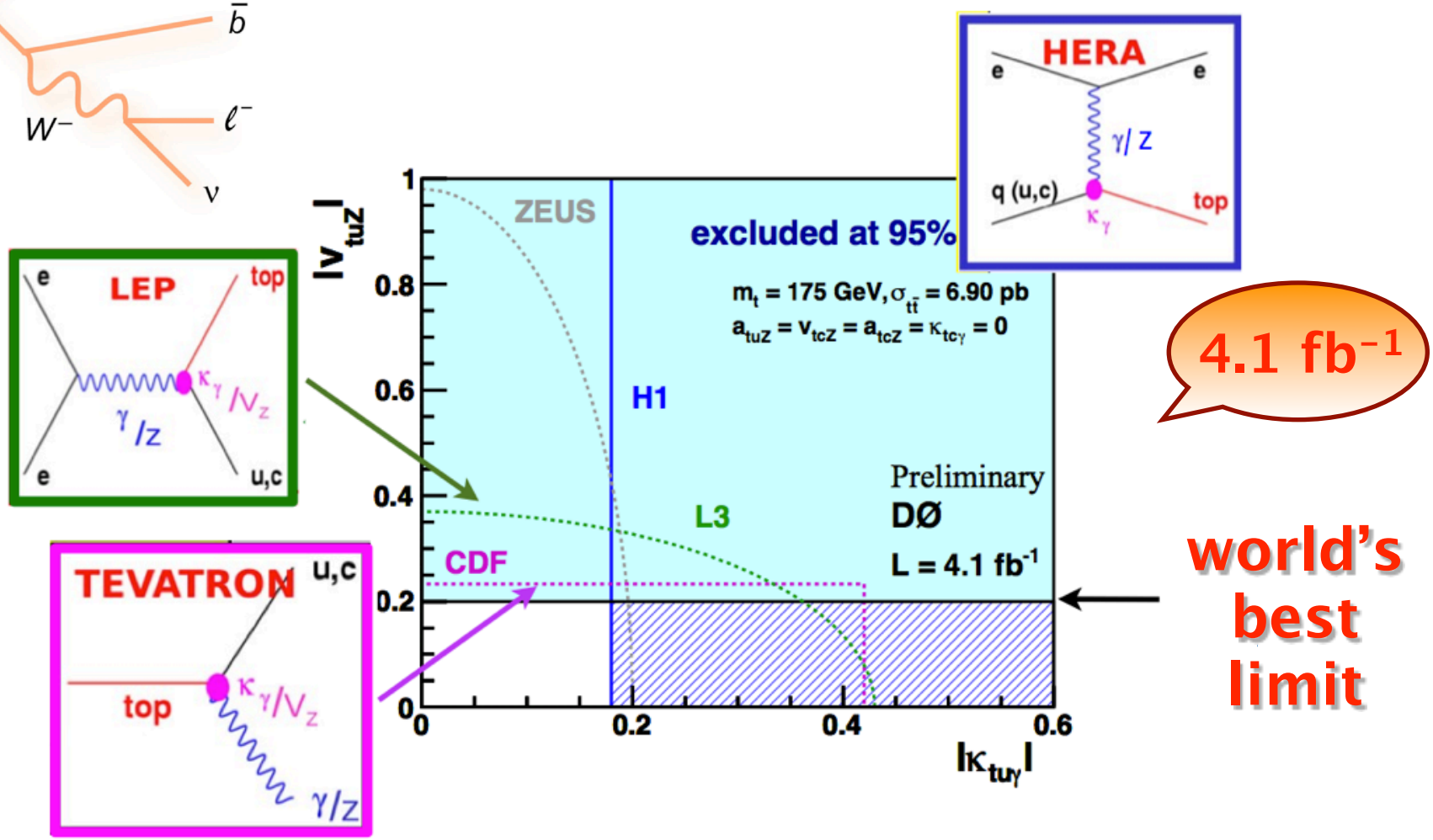


5.3 fb^{-1}

Search for FCNC



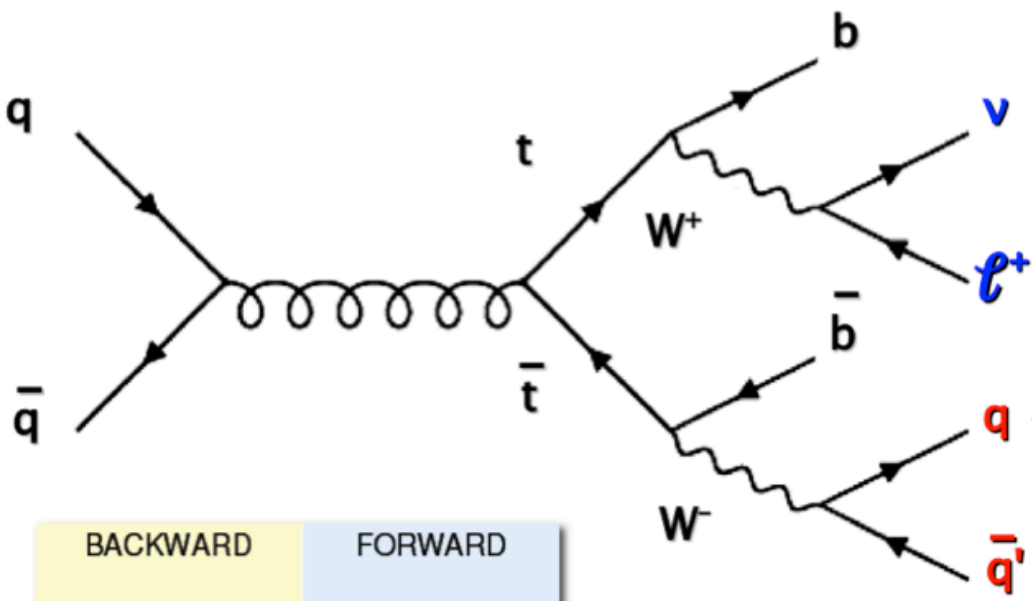
NEW

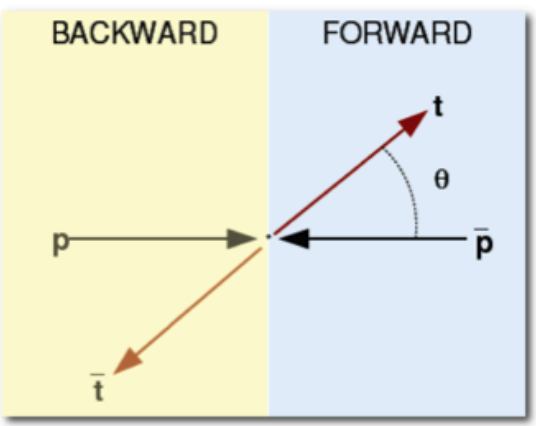


4.1 fb^{-1}

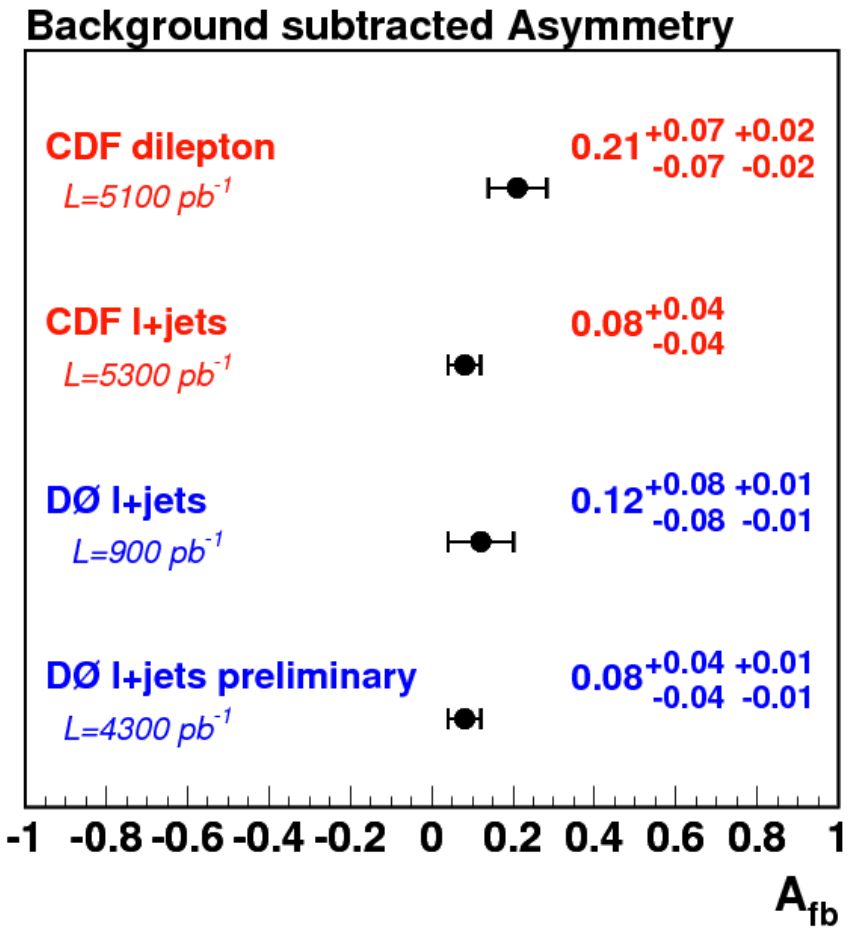
world's best limit

Forward Backward Asymmetry



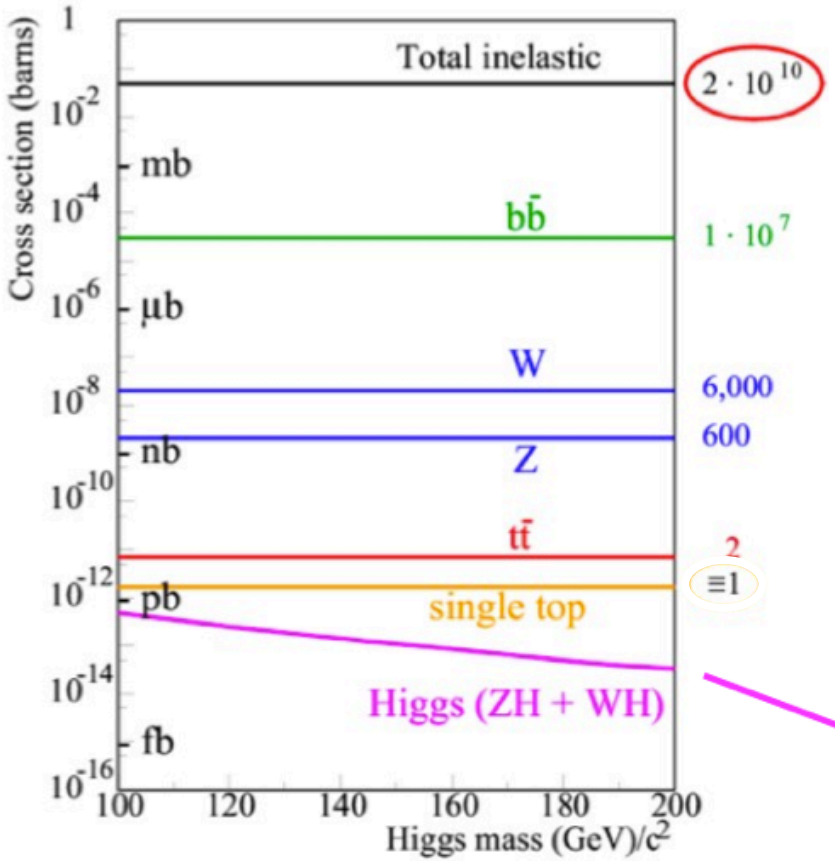


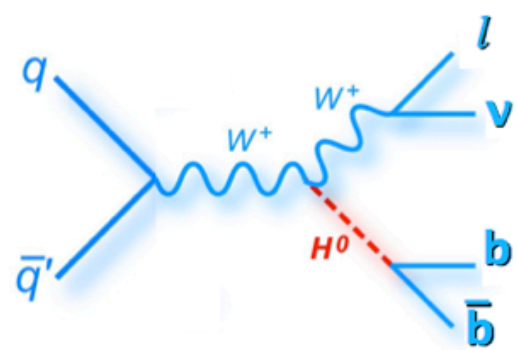
$$A_{fb} = \frac{F - B}{F + B}$$



new DØ measurement is on its way!

Outline

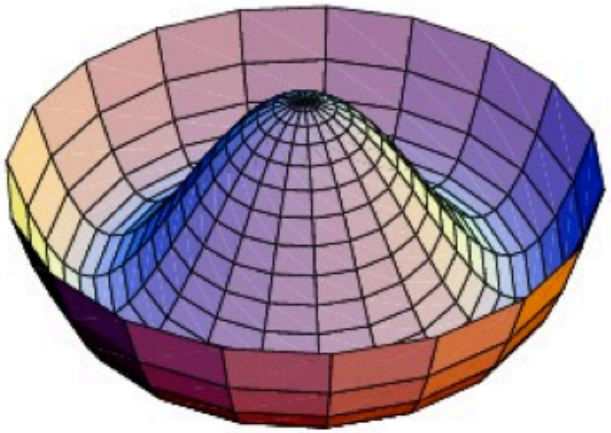




Higgs boson

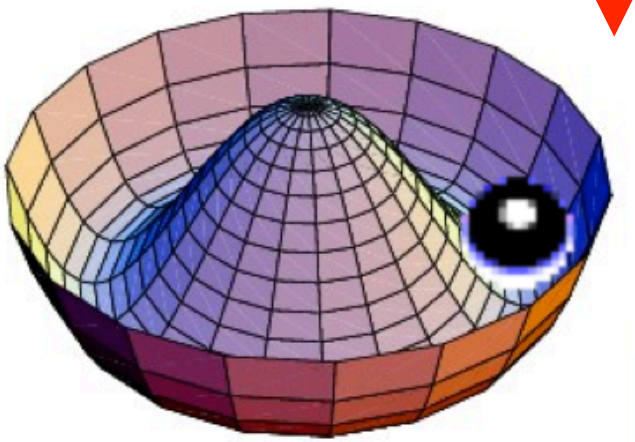
The Higgs Potential

Higgs potential:



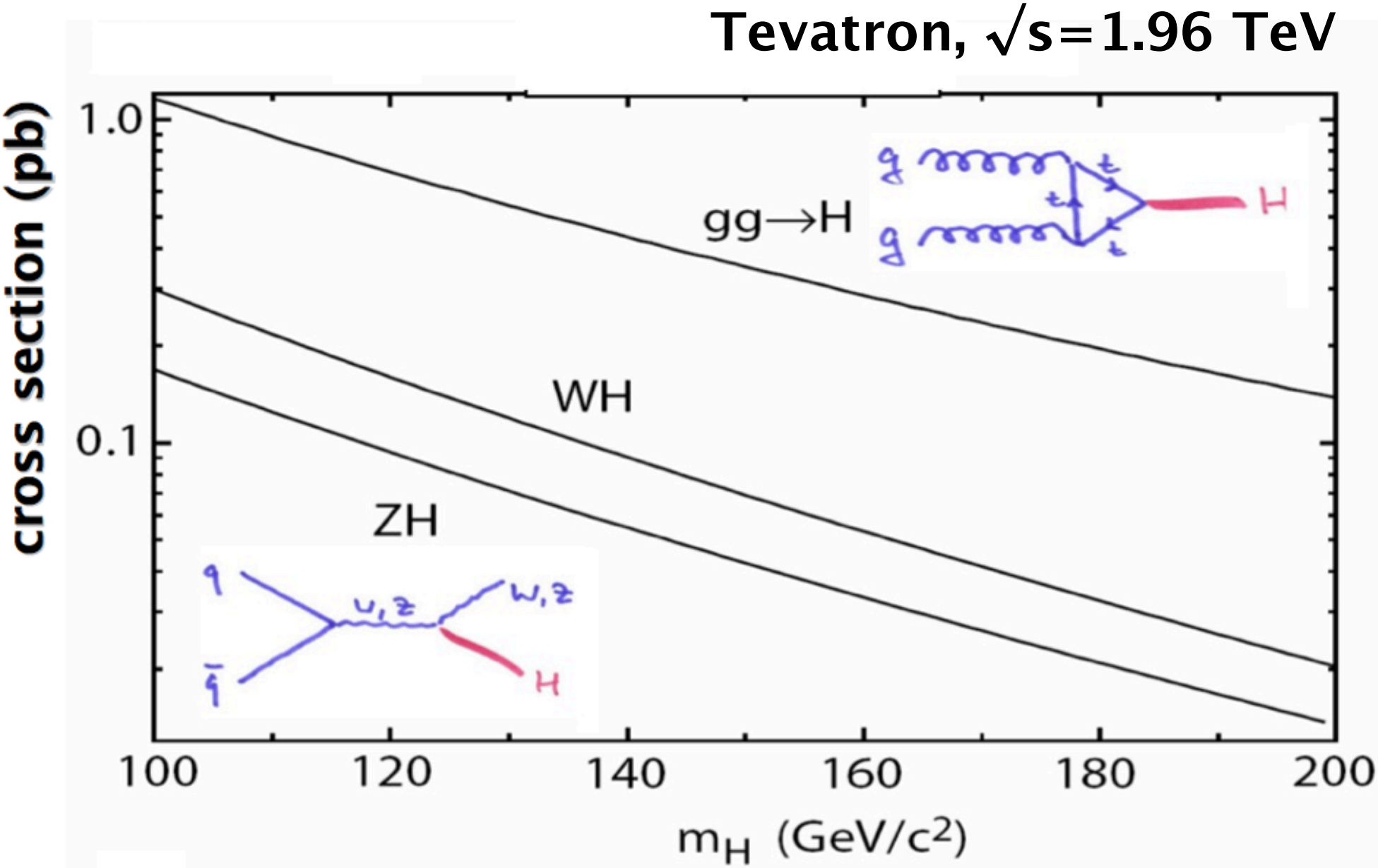
spontaneous symmetry breaking

Higgs ground state:

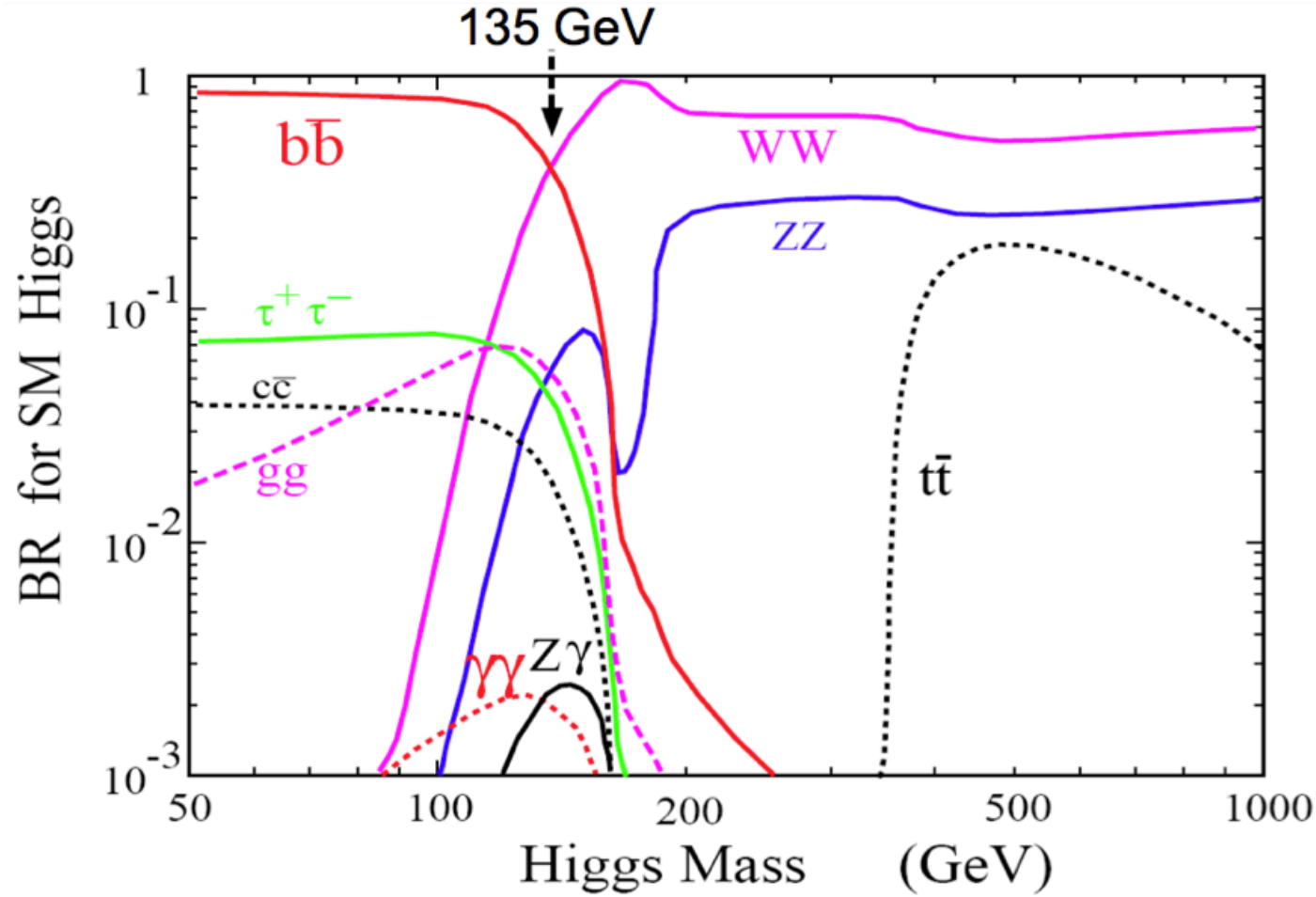


$$
\begin{aligned}
\mathcal{L} = & -\frac{1}{2} \mathrm{Tr}\left(W_{\lambda\rho} W^{\lambda\rho}\right) \\
& - \frac{1}{4} B_{\lambda\rho} B^{\lambda\rho} \\
& + W^{+}_{\lambda} W^{-\lambda} m_W^2 \left(1 + \frac{H}{v}\right)^2 \\
& + \frac{1}{2} Z_\lambda Z^\lambda m_Z^2 \left(1 + \frac{H}{v}\right)^2 \\
& + \left\{ \bar{\psi} \frac{i}{2} \gamma^\lambda D_\lambda \psi + h.c. \right\} \\
& - \bar{\psi} M \psi \left(1 + \frac{H}{v}\right) \\
& + \frac{1}{2} \partial_\lambda H \partial^\lambda H - \frac{1}{2} m_H^2 H^2 \left[1 \right. \\
& \left. + \frac{H}{v} + \frac{1}{4} \left(\frac{H}{v}\right)^2 \right]
\end{aligned}
$$

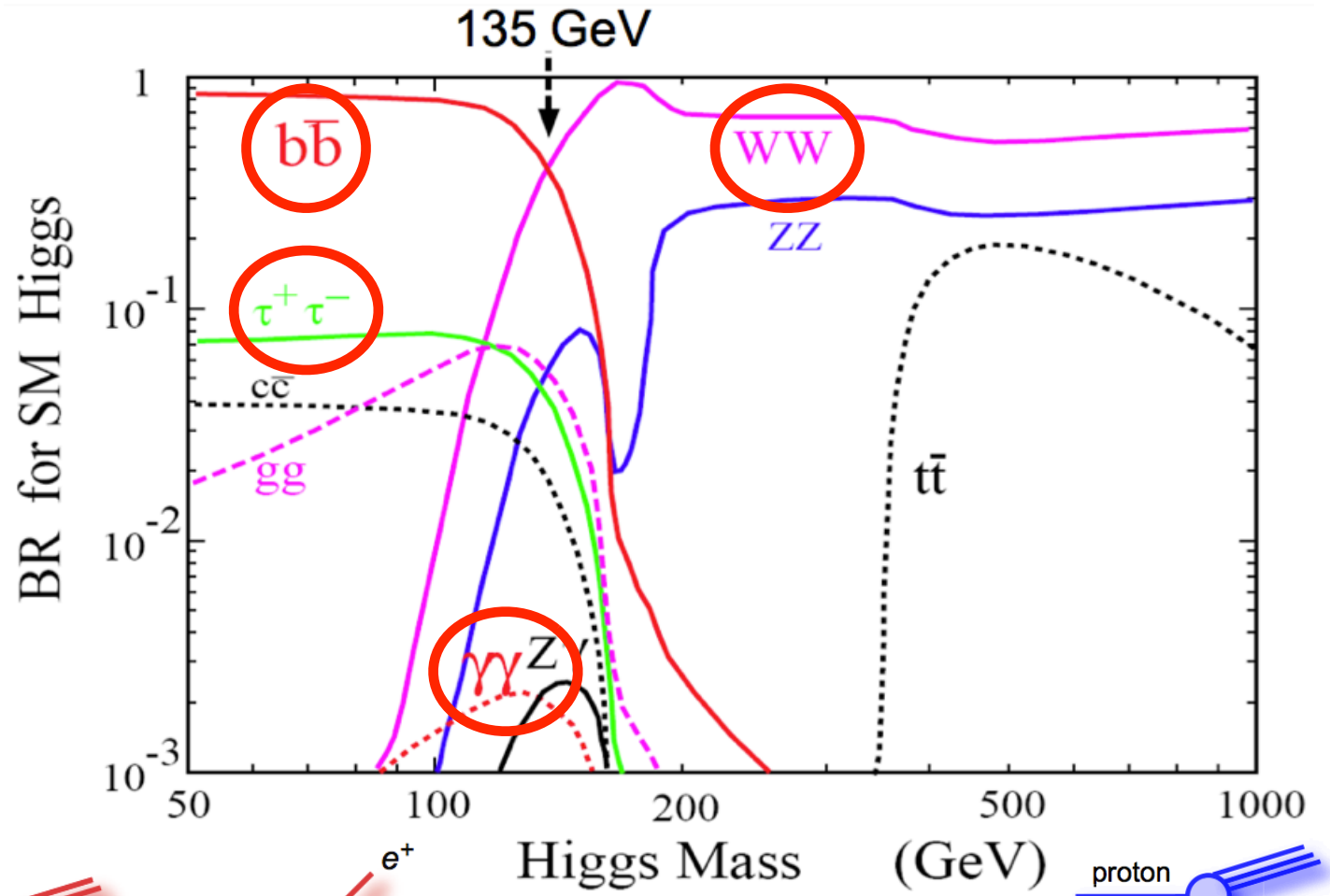
SM Higgs Production

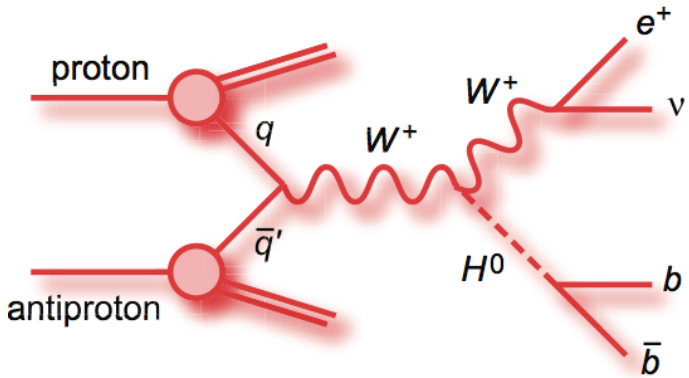


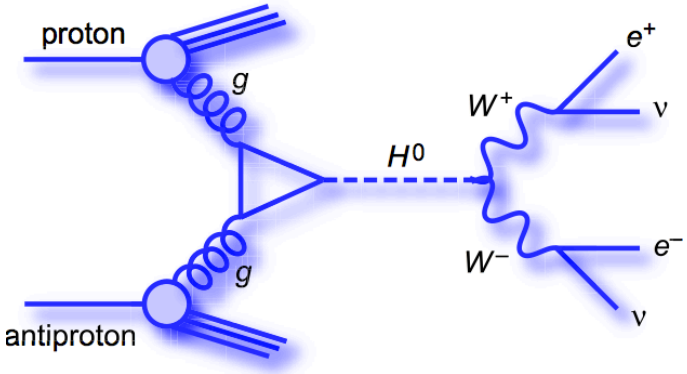
SM Higgs Decays



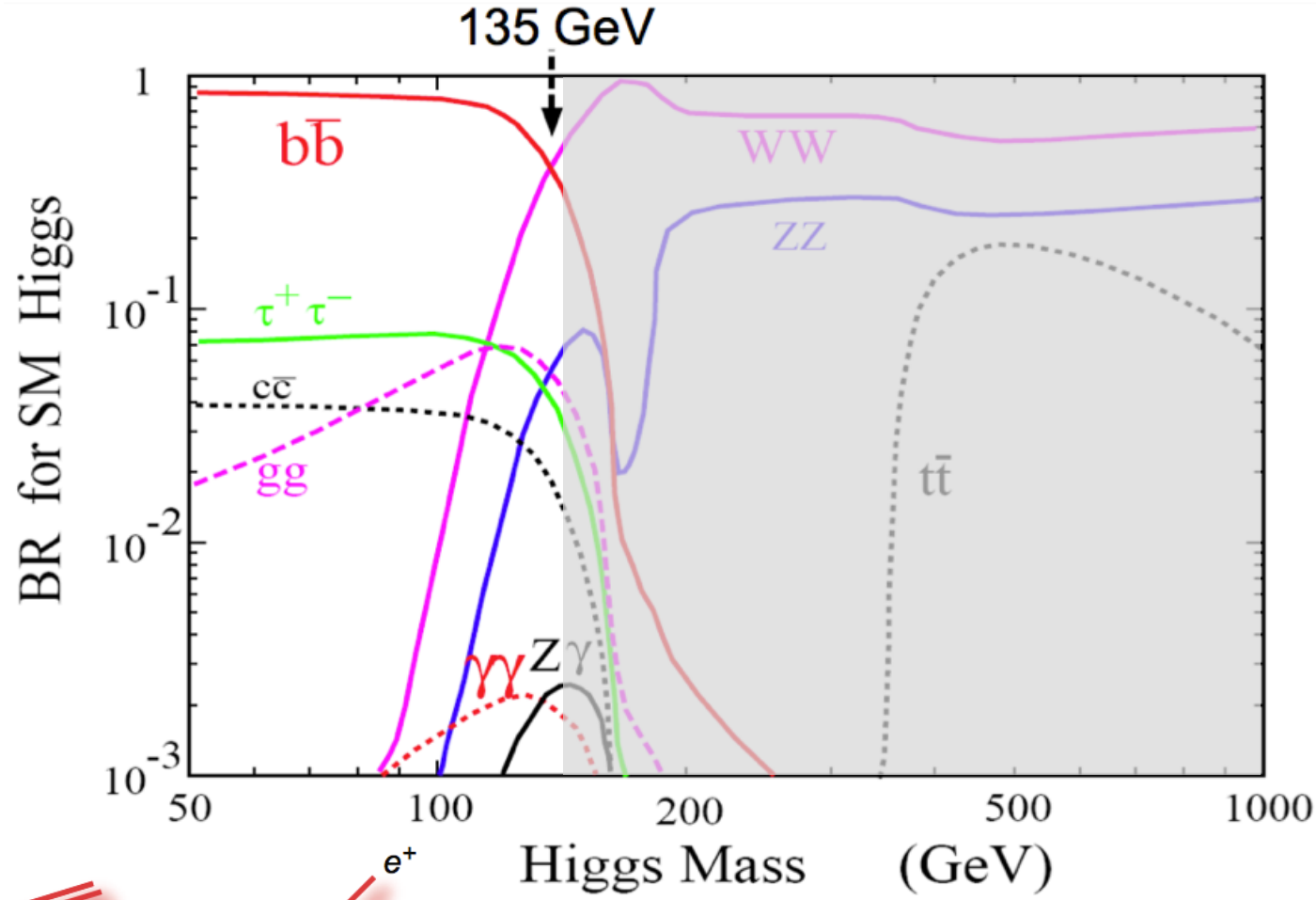
SM Higgs Decays

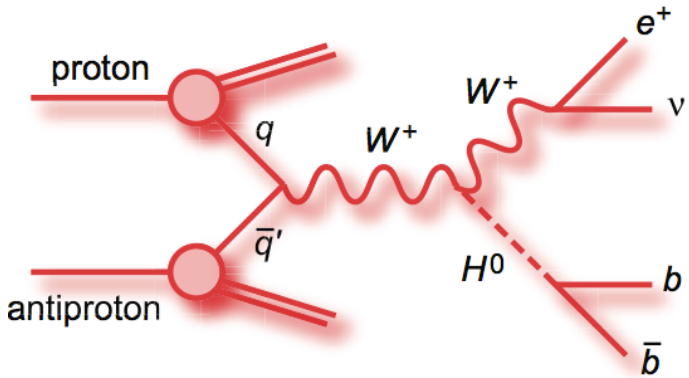






Low Mass Higgs Searches

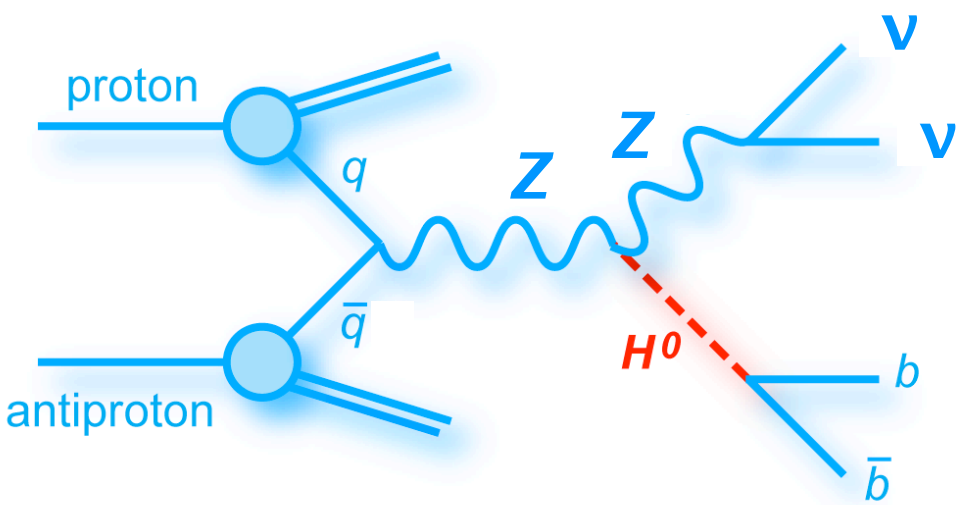


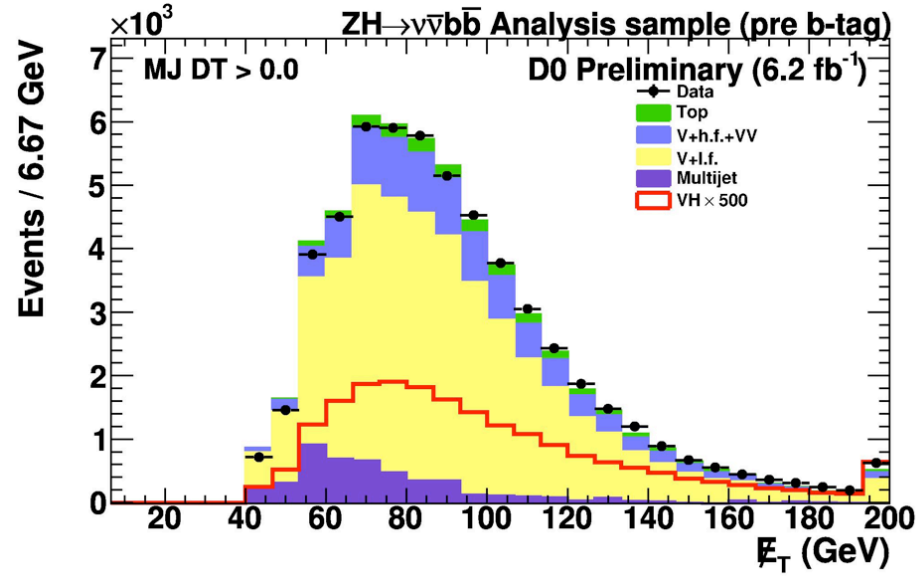


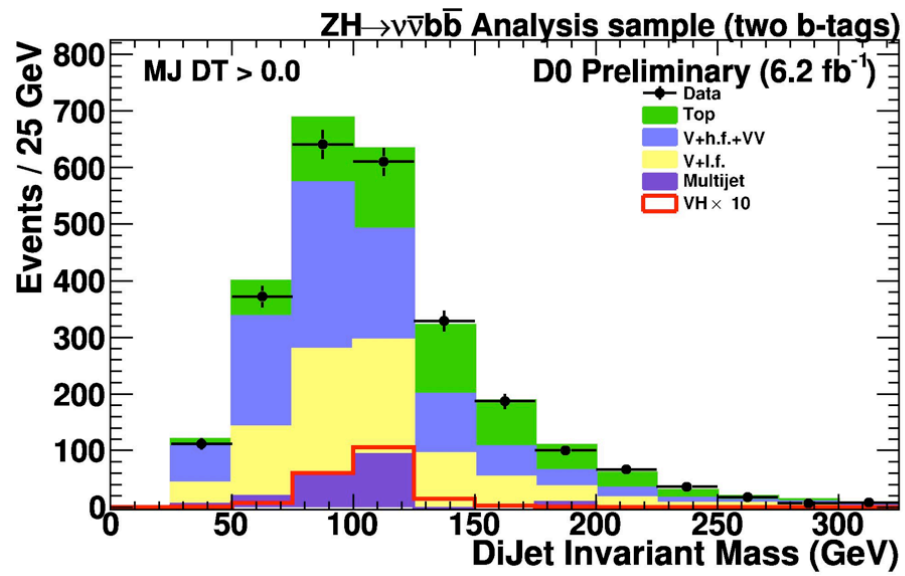
Associated ZH Production

- new improved b-tagging
- b-tag information (NN) used in final discriminant

→ increase of sensitivity by 14%



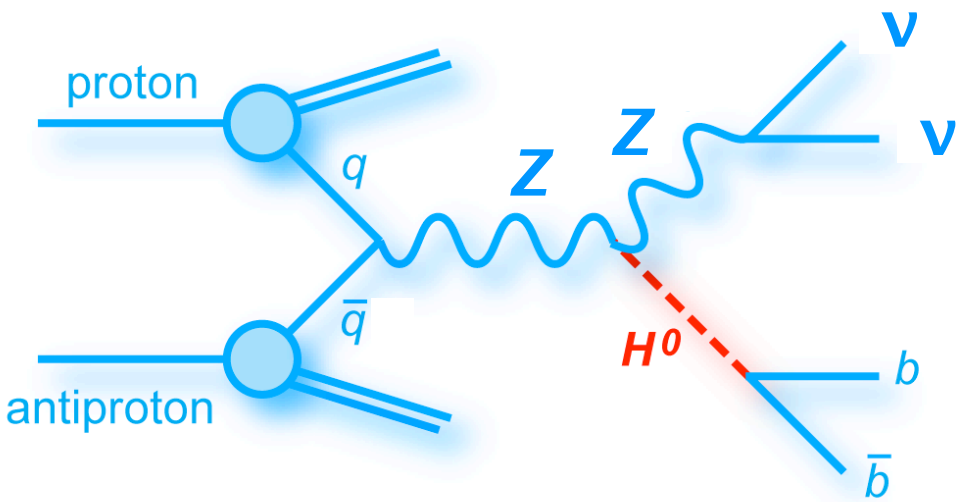


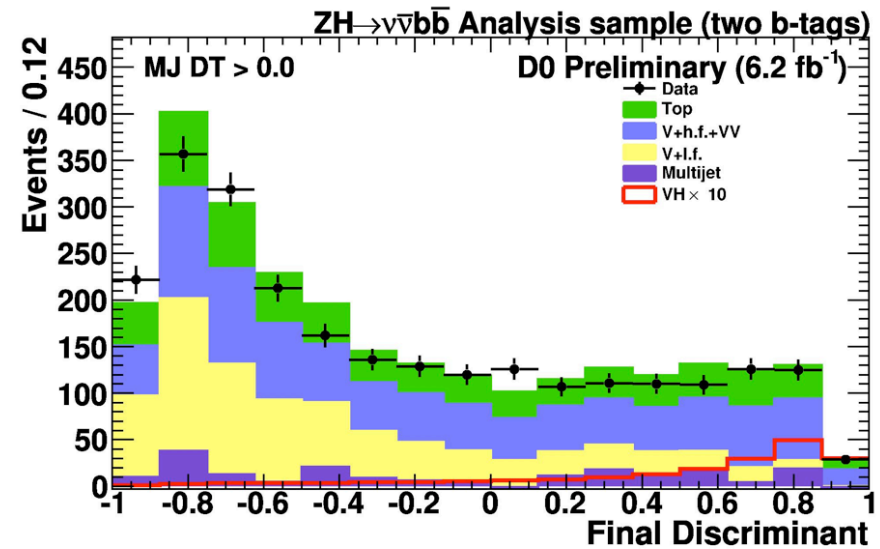


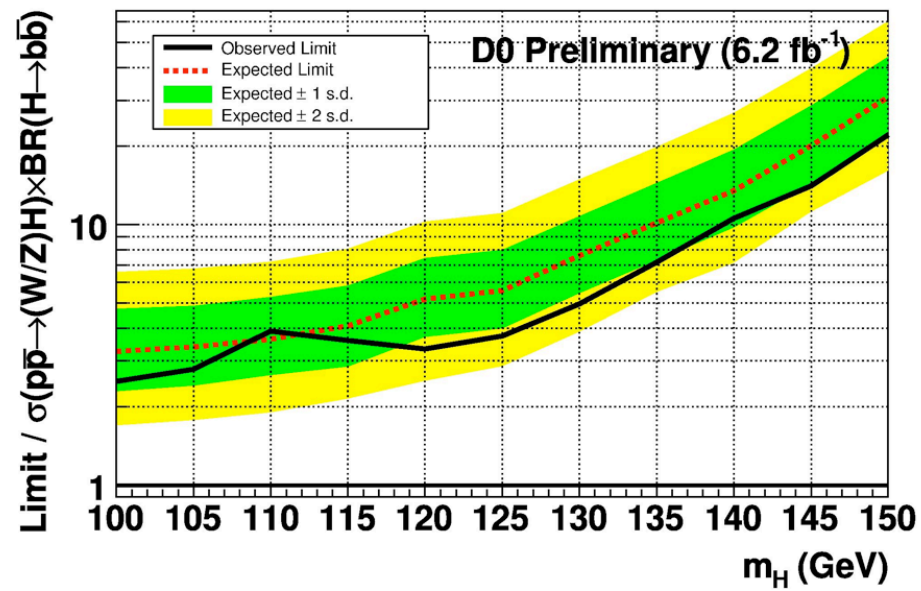
Associated ZH Production

6.2 fb^{-1}

- form BDT using 20 kinematic variables
- use sample with 1 and 2 b-tags separately







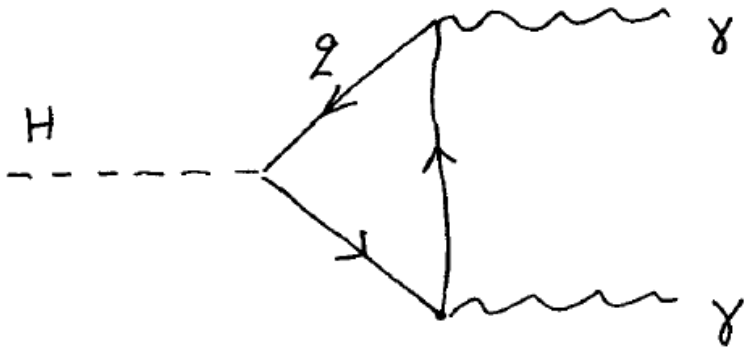
m_H=115 GeV, 95% CL

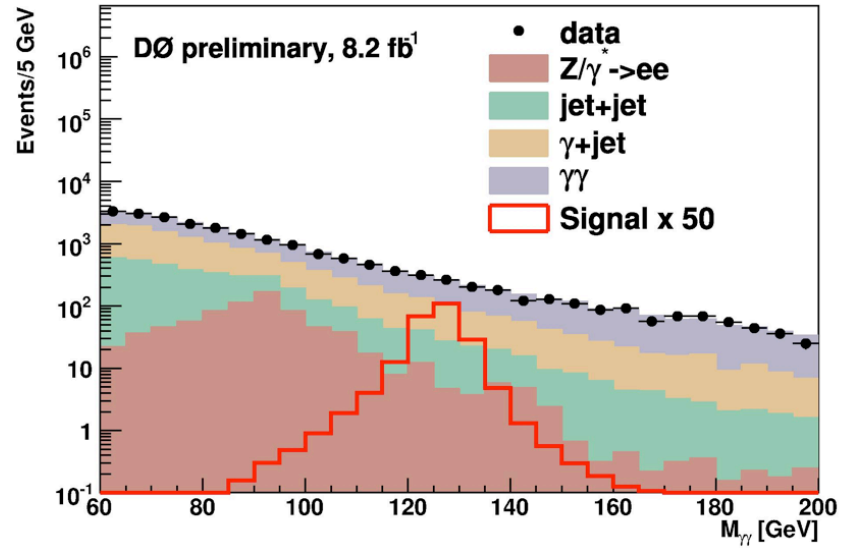
expected: 4.0×SM

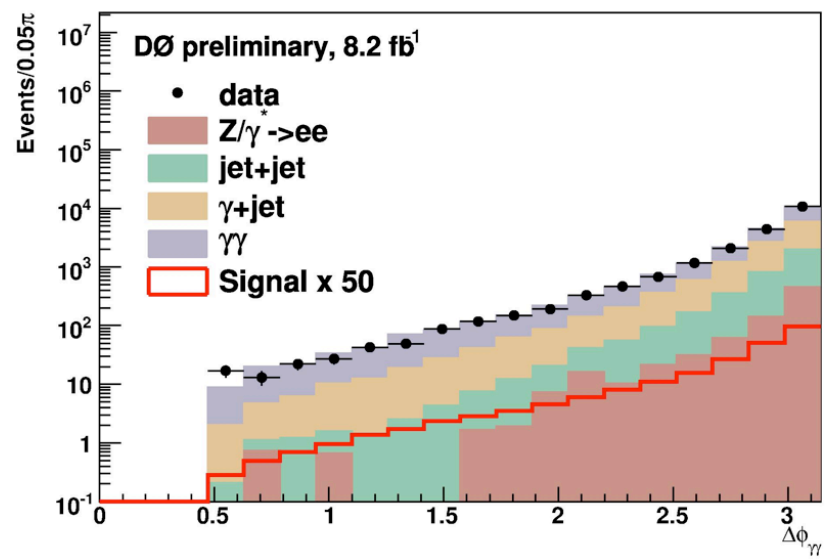
observed: 3.4×SM

Search for H→γγ Production

- double data set
- include angular information
- good understanding of SM γγ cross section

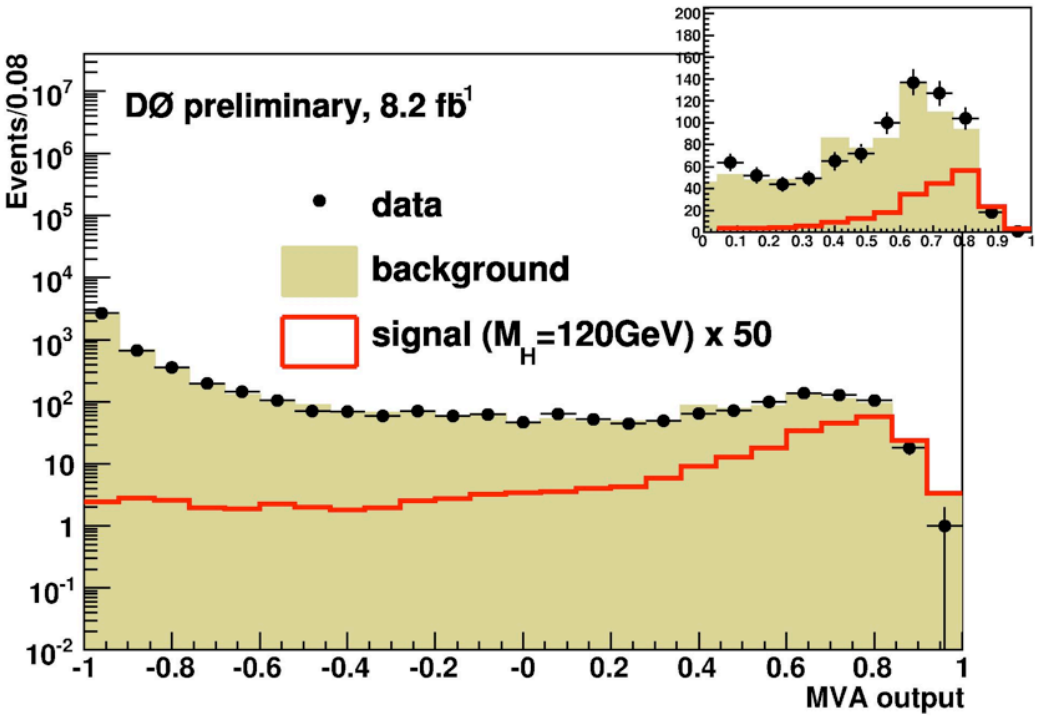




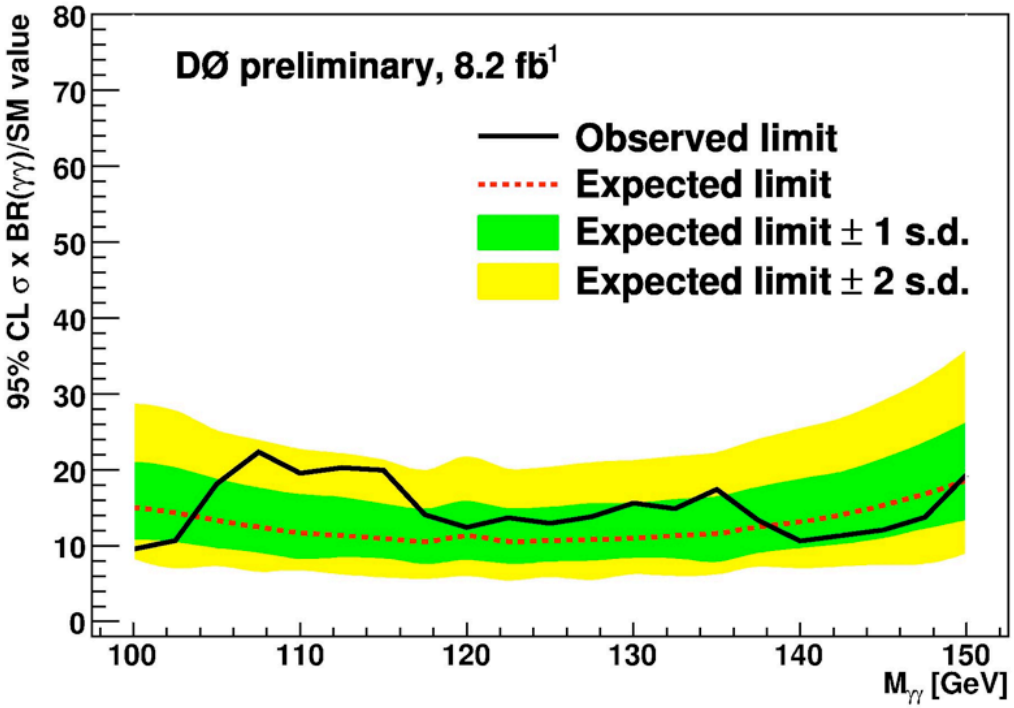


+ E_T of leading 2 photons + $p_T^{\gamma\gamma}$ ⇒ BDT

Search for H→γγ Production



8.2 fb^{-1}



m_H=115 GeV, 95% CL

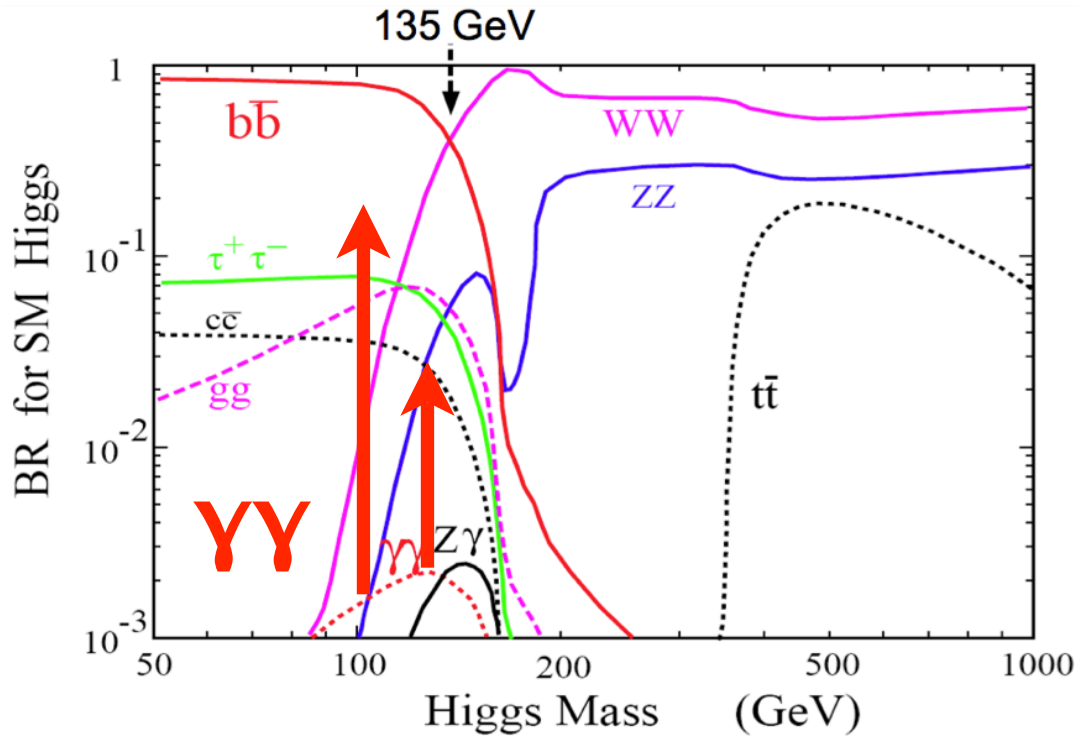
expected: 11×SM

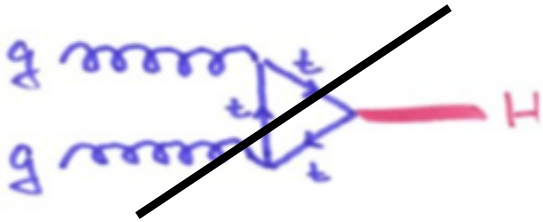
observed: 20×SM

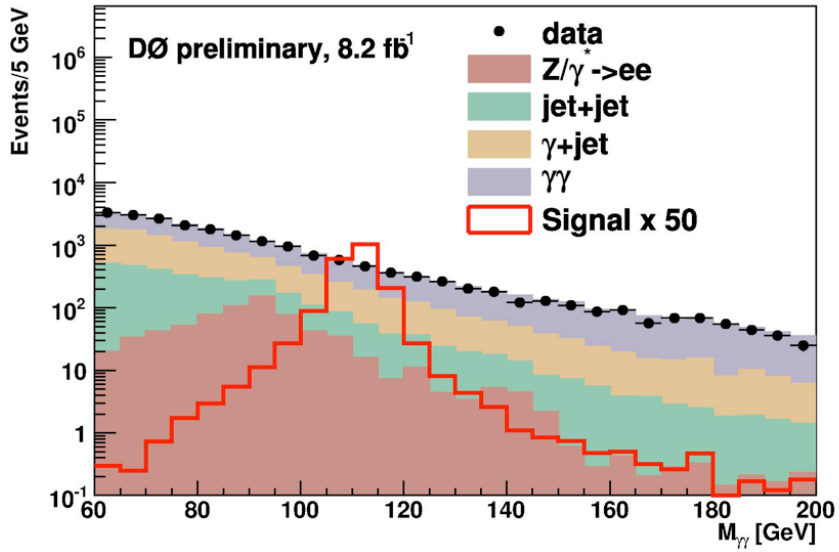
70% increase of sensitivity

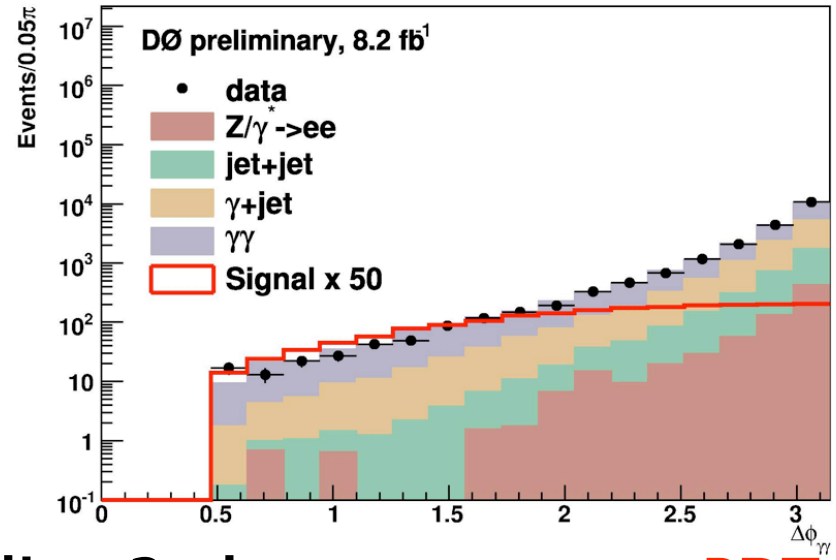
Search for Fermiophobic H→γγ

same analysis technique as for SM search



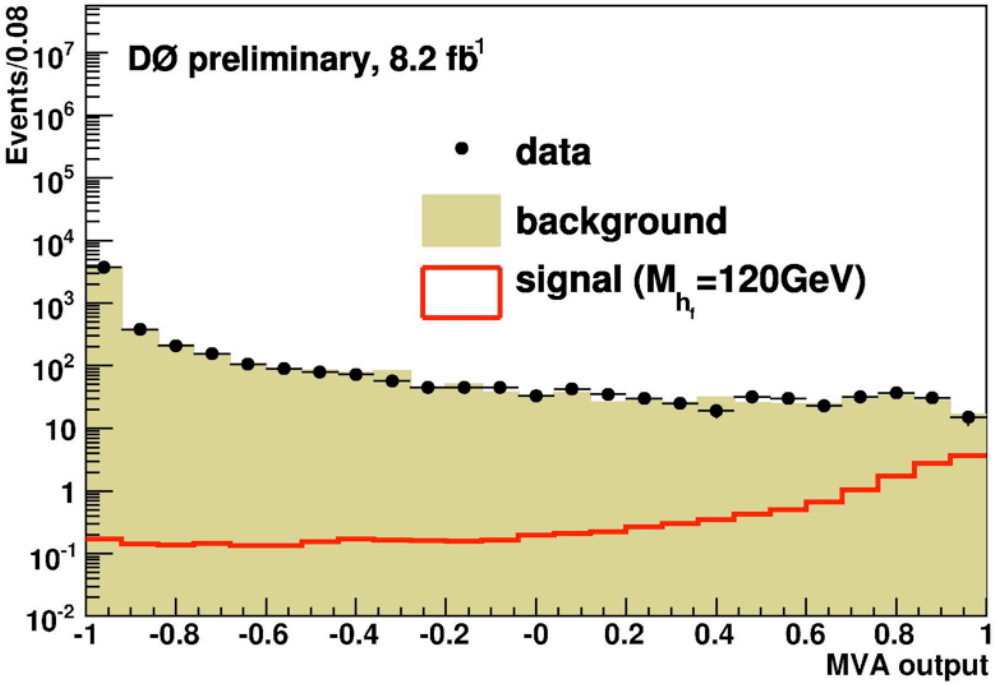




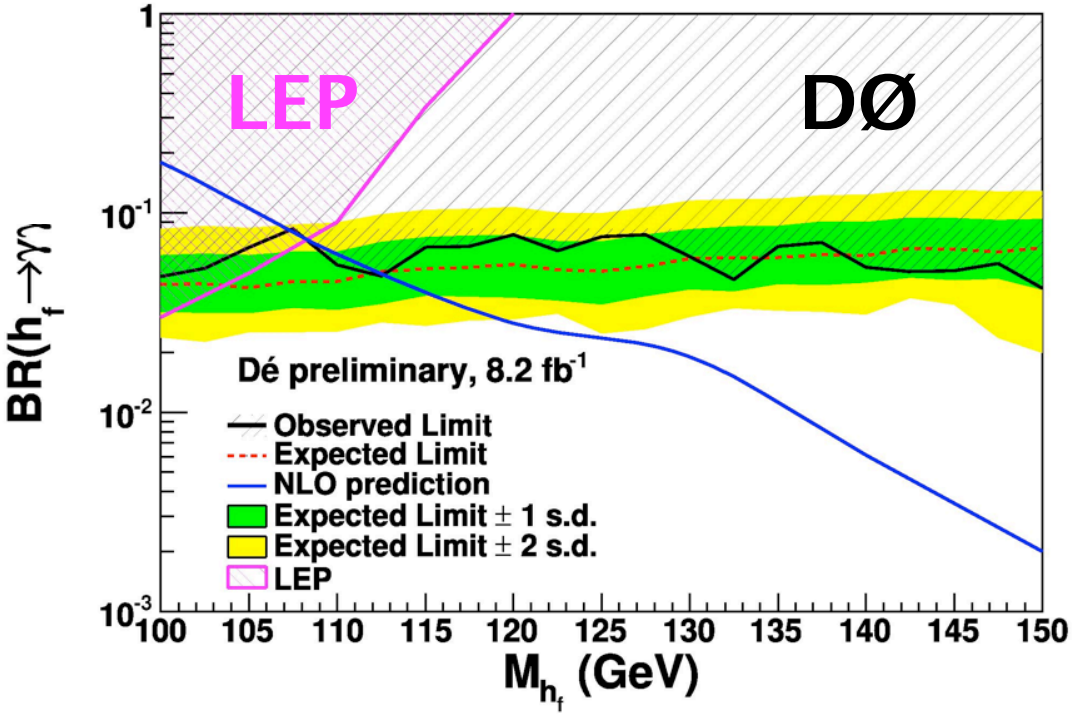


+ E_T of leading 2 photons + $p_T^{\gamma\gamma}$ ⇒ BDT

Search Fermiophobic H→γγ



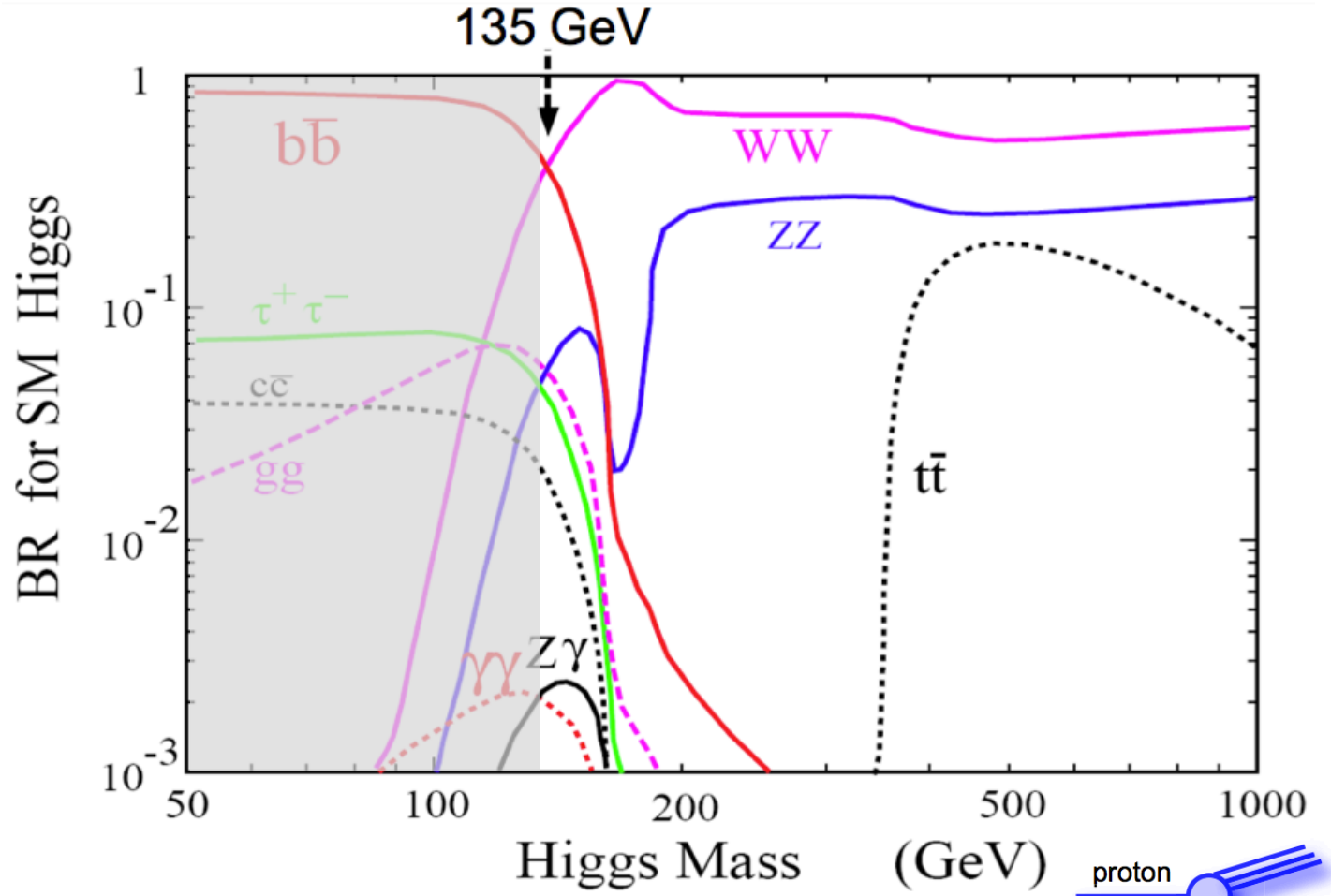
8.2 fb^{-1}

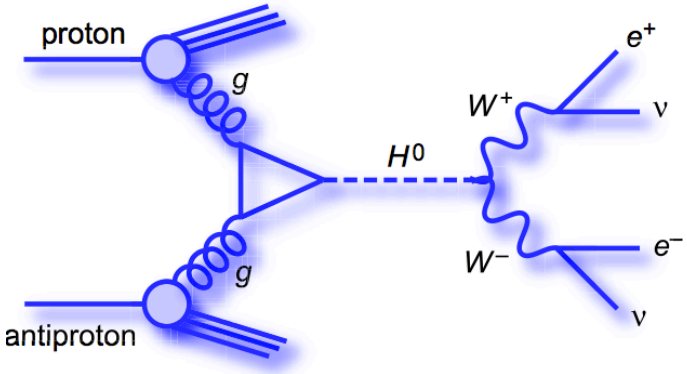


$M_{h,f}$ > 113 GeV, 95% CL

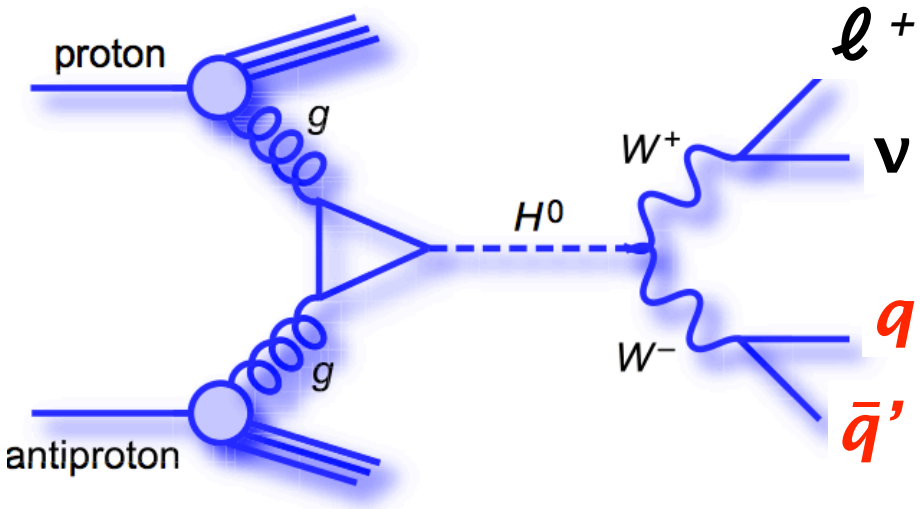
best limit

High Mass Higgs Searches

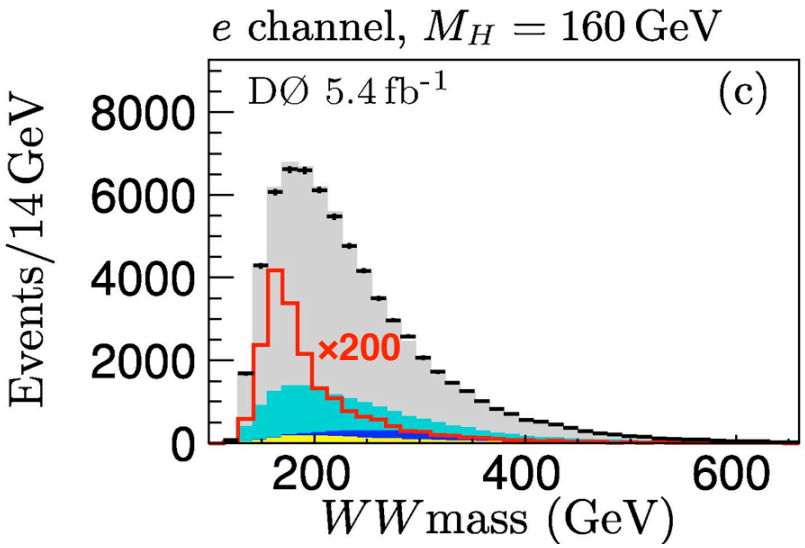




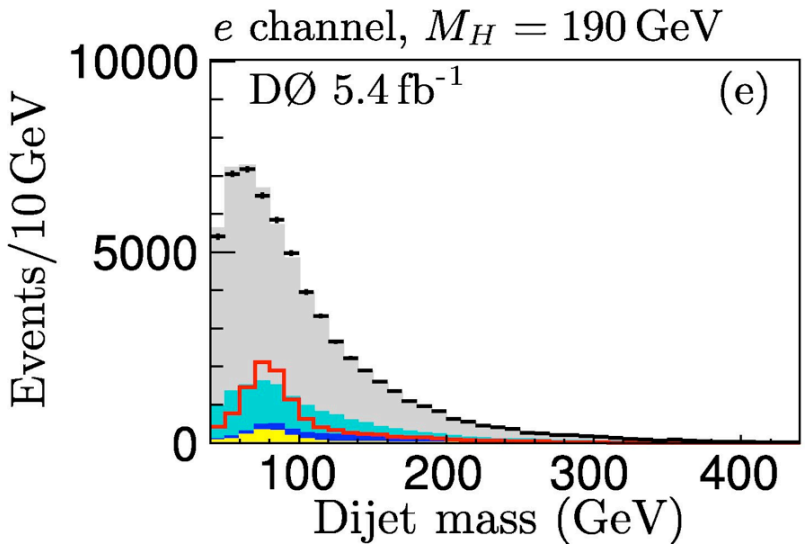
Search for H→WW→lνqq̄



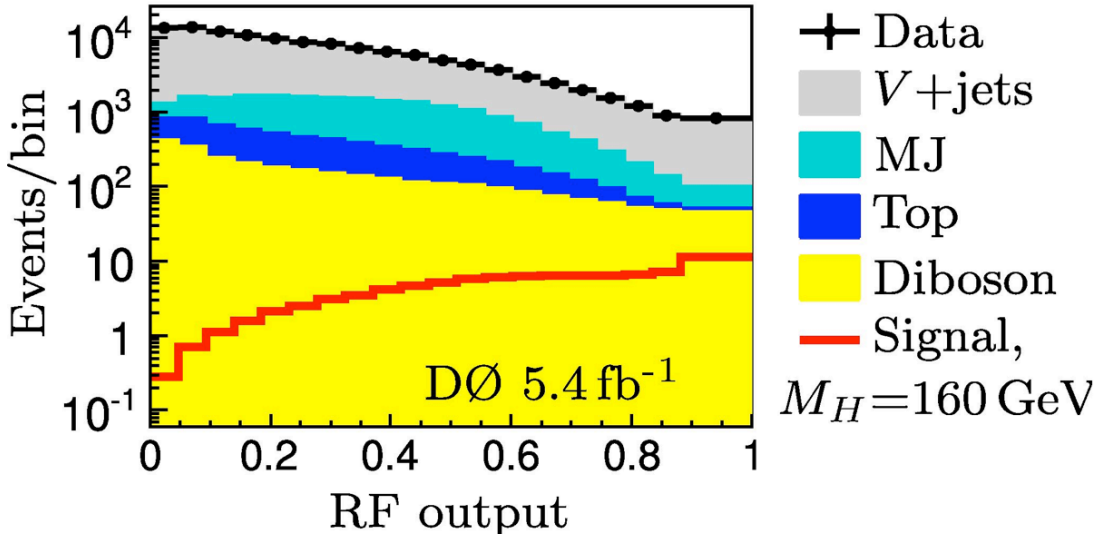
– reconstruct Higgs mass



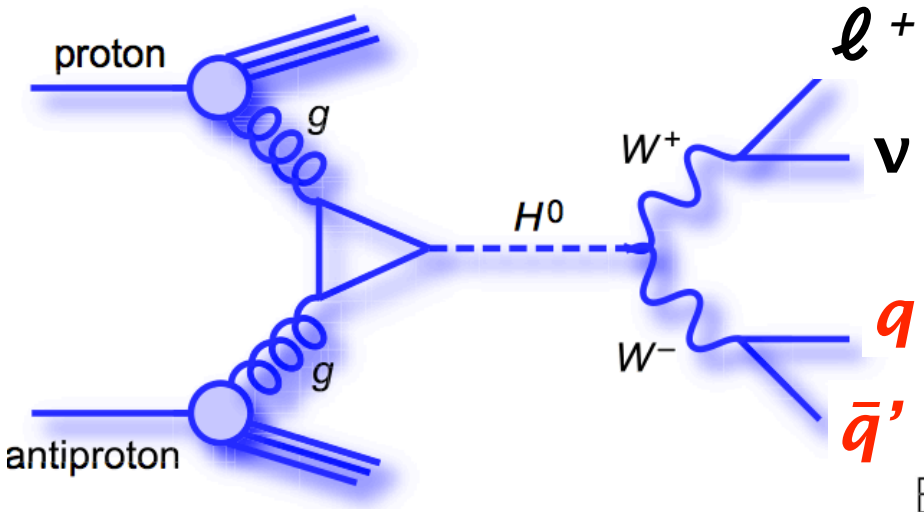
– reconstruct W mass



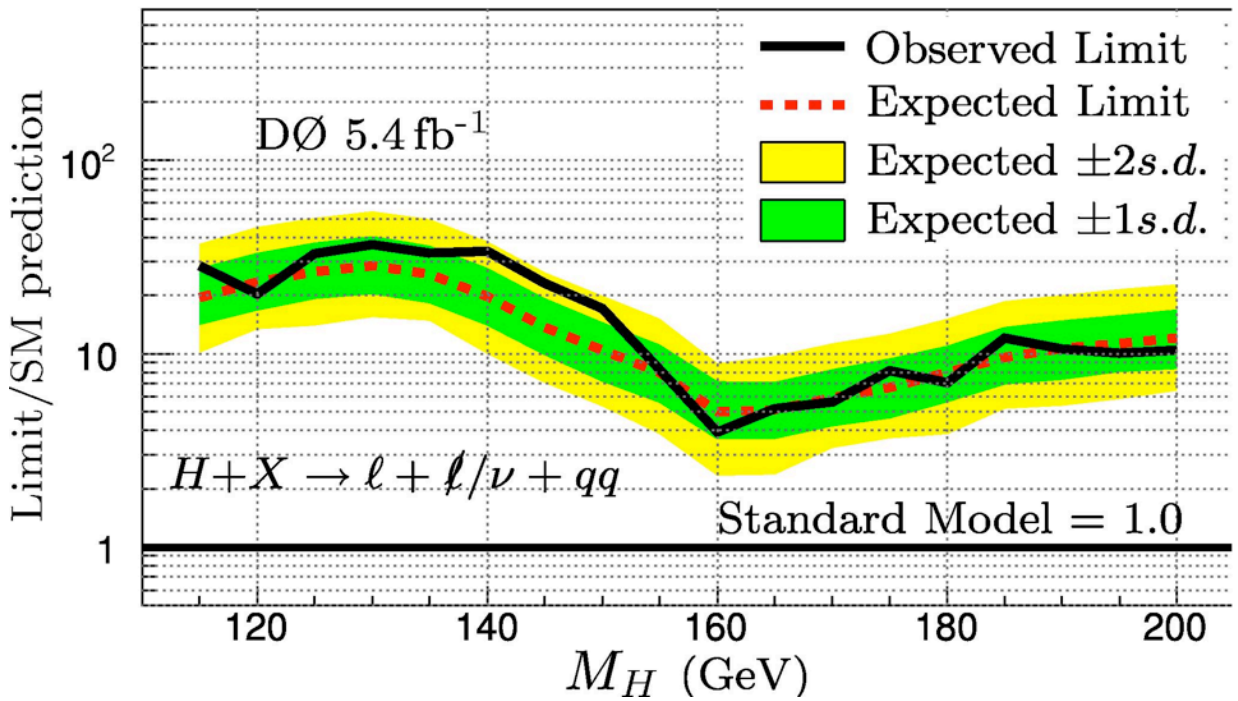
– combine 30 variables to discriminant



Search for H→WW→lνqq̄



5.4 fb^{-1}

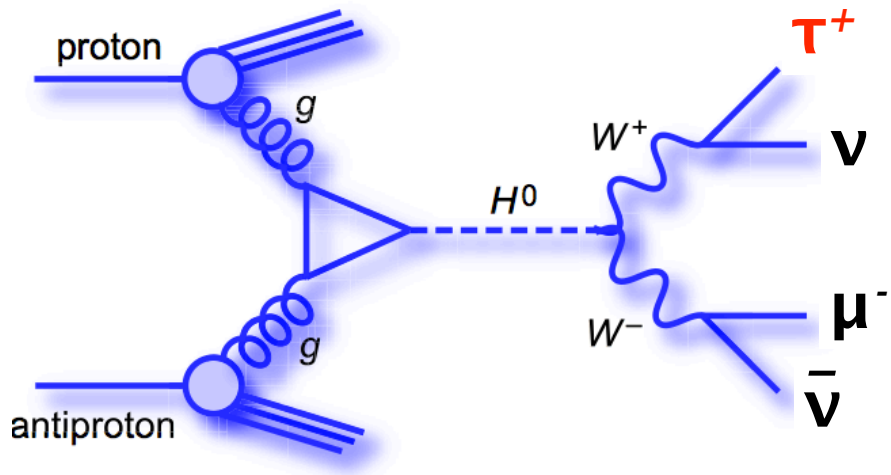


m_H=160 GeV, 95% CL

expected: 5.0×SM

observed: 3.5×SM

Search for $H \to WW \to \tau_h \mu \nu\nu$

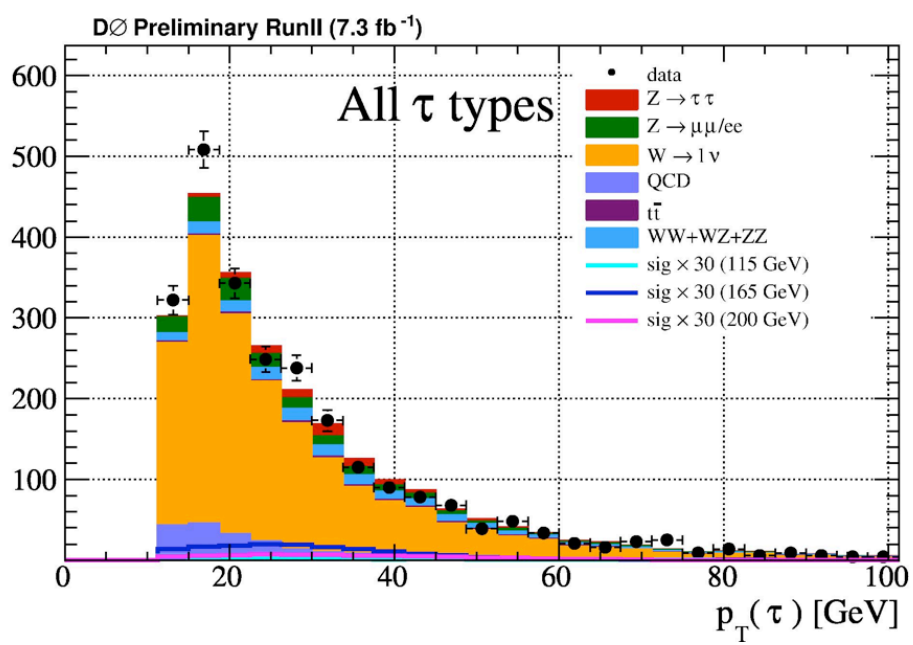


NEW

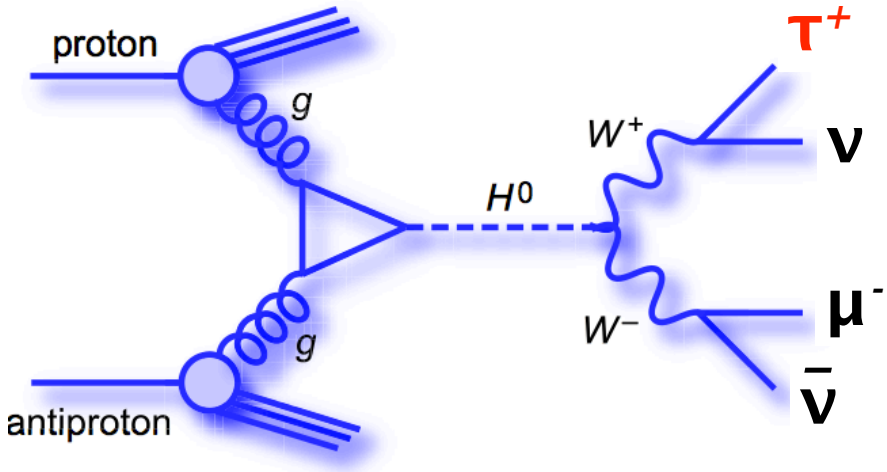
identification of hadronic tau leptons:

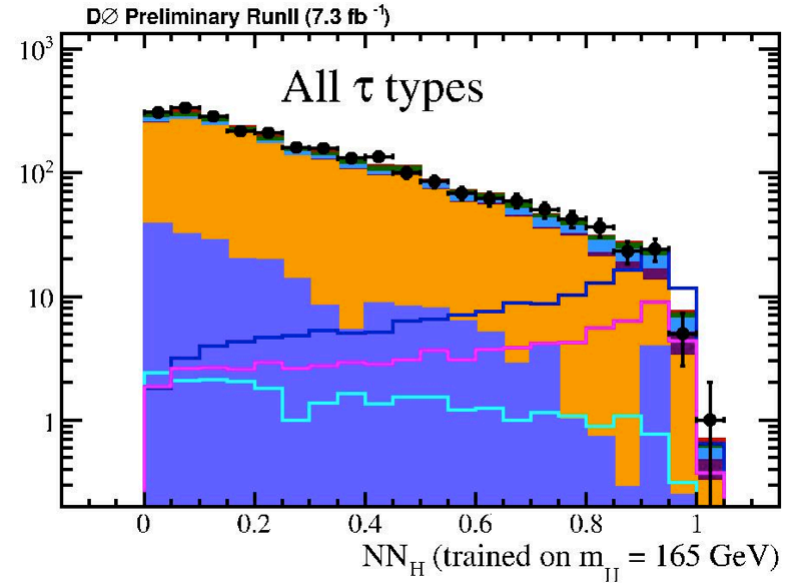
- **use neural network to separate from quark and gluon jets**
- **variables: shower shape, isolation, correlation between tracking and calorimeter energy measurement**

0-jet, 1-jet bins

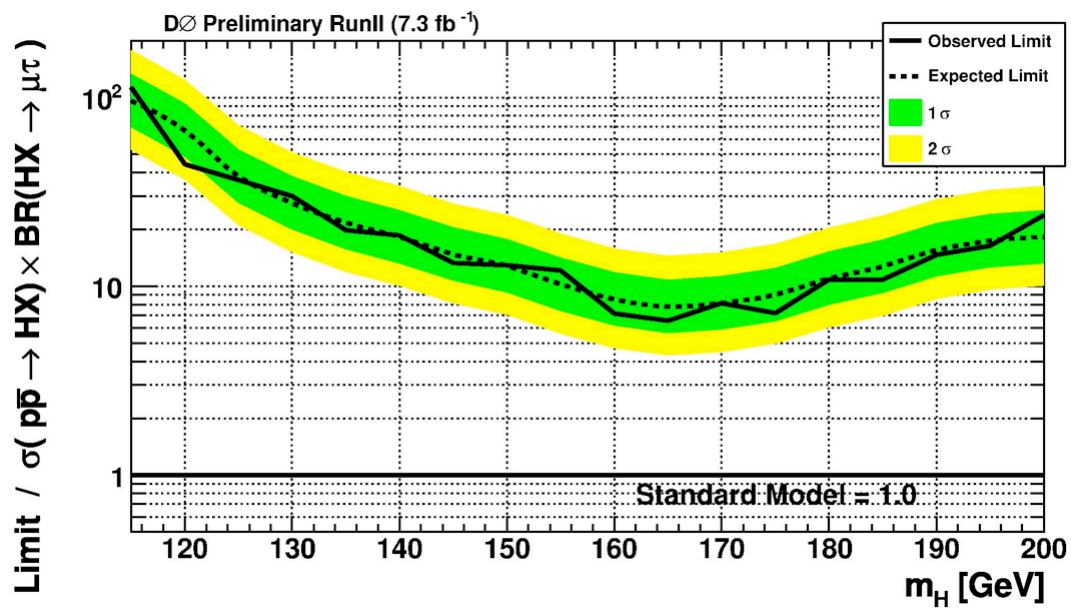


Search for $H \to WW \to \tau_h \mu \nu\nu$





use neural network to separate signal from background



7.3 fb^{-1}

m_H=165 GeV, 95% CL

expected: 7.8×SM

observed: 6.6×SM

Search for $H \to \tau_e \tau_h jj$, $\tau_\mu \tau_h jj$

$q\bar{q} \to H(\to b\bar{b})\ Z(\to \tau\tau)$

$q\bar{q} \to Z(\to \ell\ \ell)\ H(\to \tau\tau, WW)$

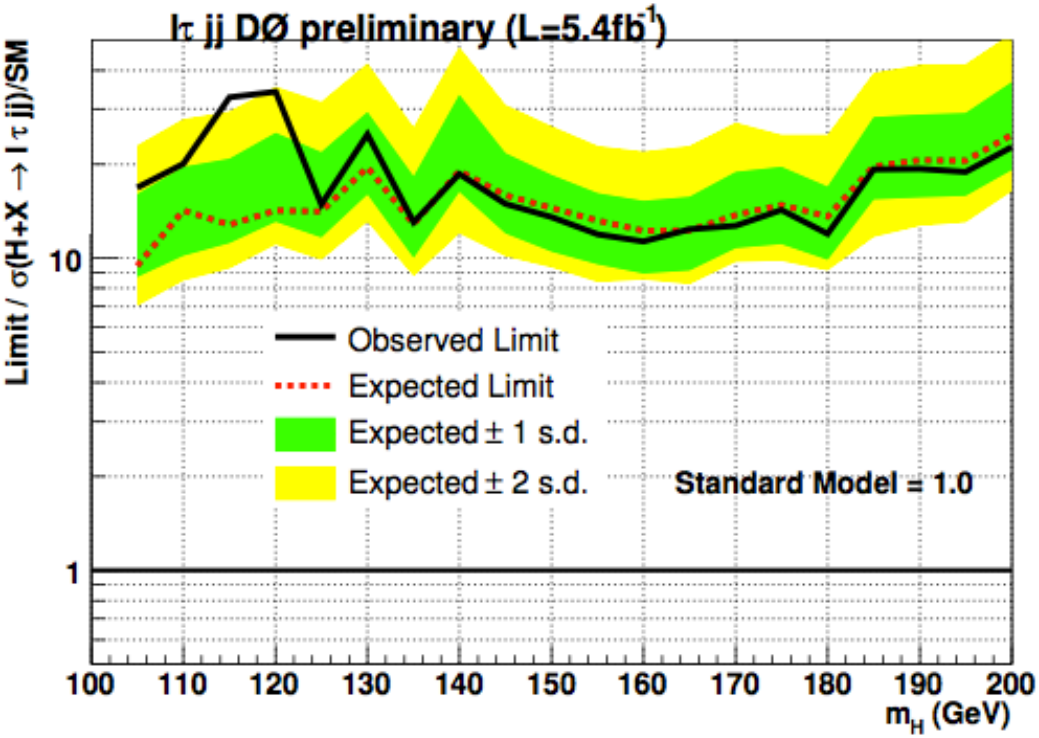
$q\bar{q} \to W(\to \ell\ \nu)\ H(\to \tau\tau, WW)$

$gg \to H(\to \tau\tau, WW) + \geq 2$ jets

$q\bar{q}' \to q\bar{q}'\ H(\to \tau\tau, WW)$

5.4 fb^{-1}

Boosted Decision Tree using 17 variables

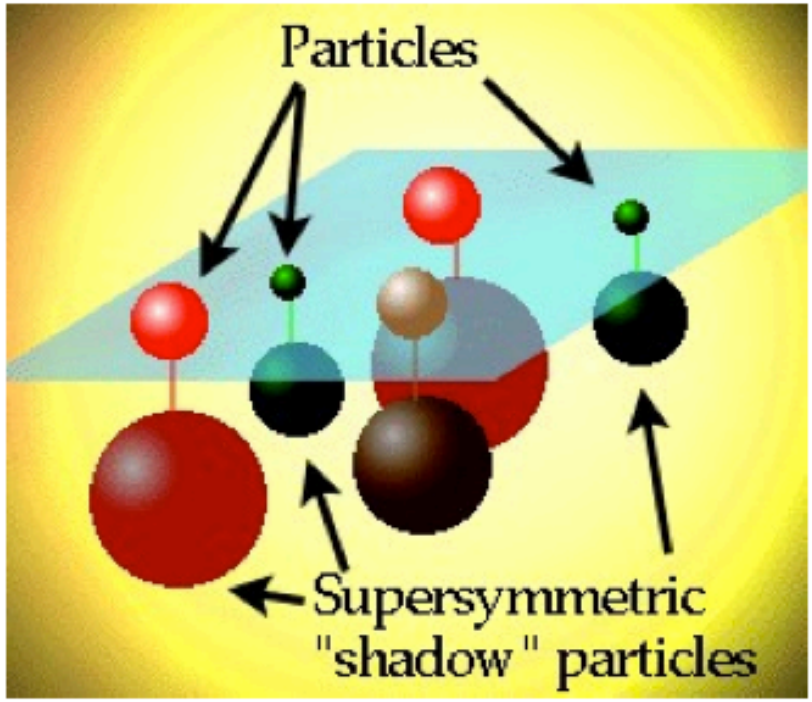


m_H=165 GeV, 95% CL

expected: 13×SM

observed: 13×SM

Supersymmetry

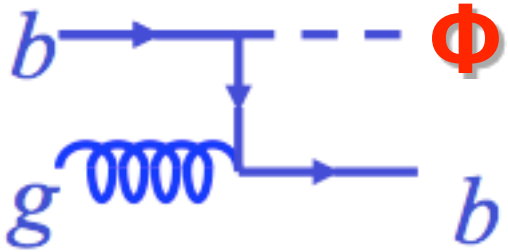


Name	Spin	Superpartner	Spin
Electron	1/2	Selectron	0
Muon	1/2	Smuon	0
Tau	1/2	Stau	0
Neutrino	1/2	Sneutrino	0
Quark	1/2	Squark	0

Name	Spin	Superpartner	Spin
Graviton	2	Gravitino	3/2
Photon	1	Photino	1/2
Gluon	1	Gluino	1/2
$W^{+,-}$	1	$Wino^{+,-}$	1/2
Z^0	1	Zino	1/2
Higgs	0	Higgsino	1/2

H^0, A^0, H^+, H^-, ...

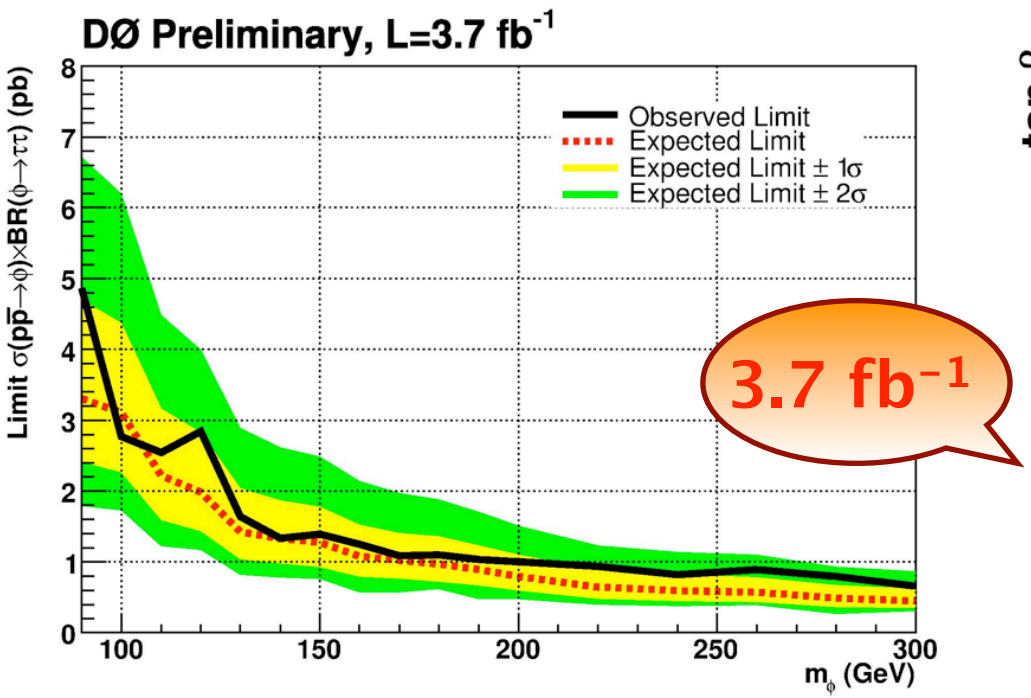
Search for $p\bar{p} \to \Phi b \to \tau_e \tau_{had} b$

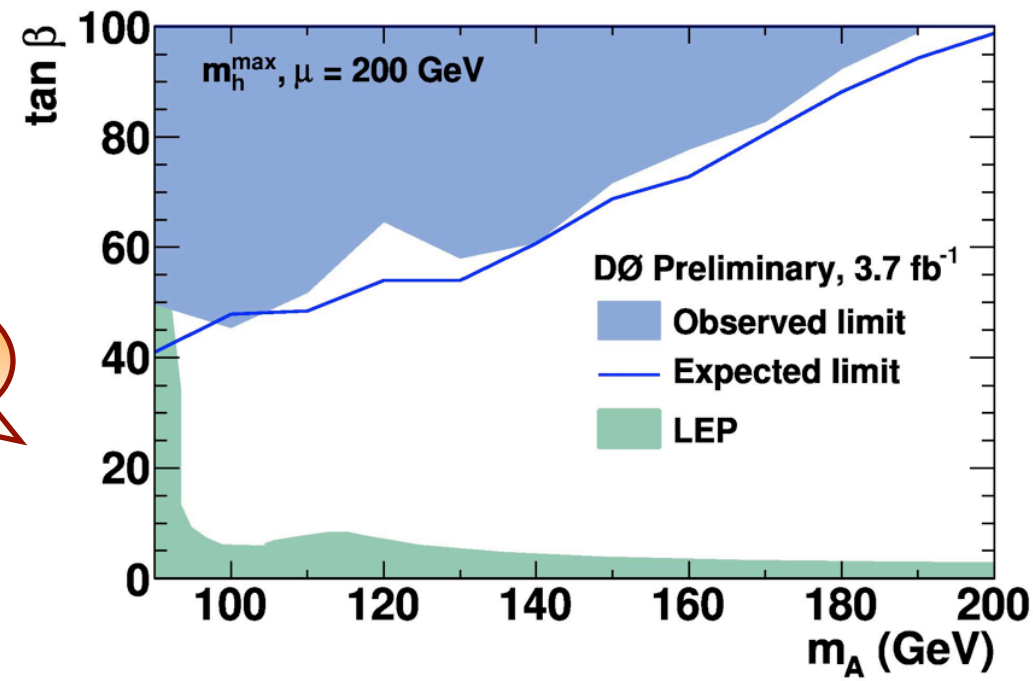


$\Phi = h^0, H^0, A^0$

NEW

scenario:
Minimal Supersymmetric Standard Model (MSSM)

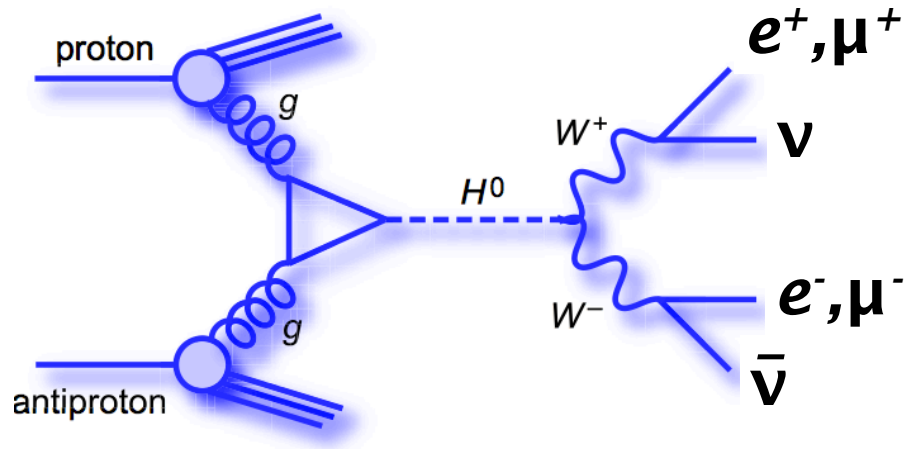


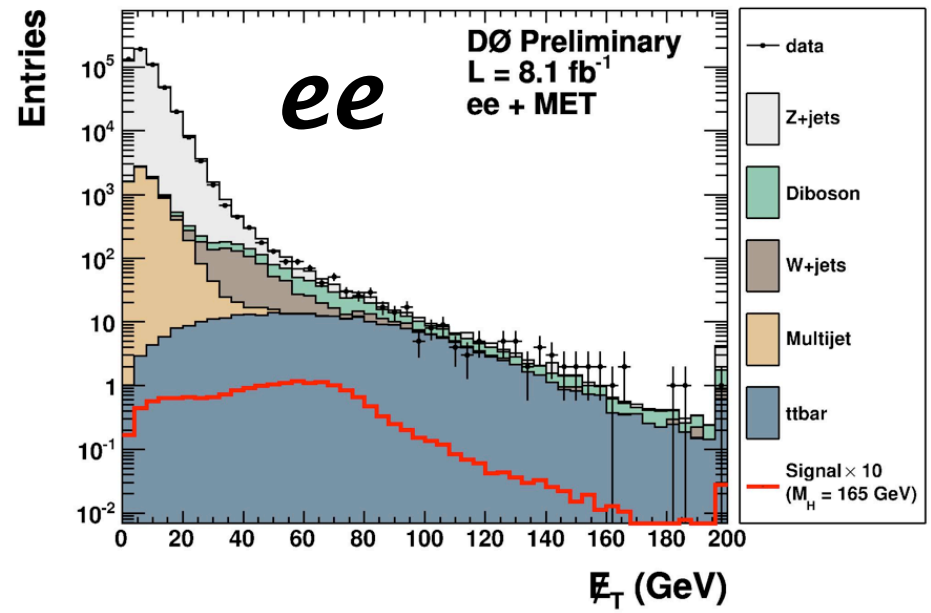


- no hint for physics beyond the SM
- will be combined with $\Phi b \to \tau_\mu \tau_{had} b$, $\Phi \to b\bar{b}$, $\Phi b \to b\bar{b}b$

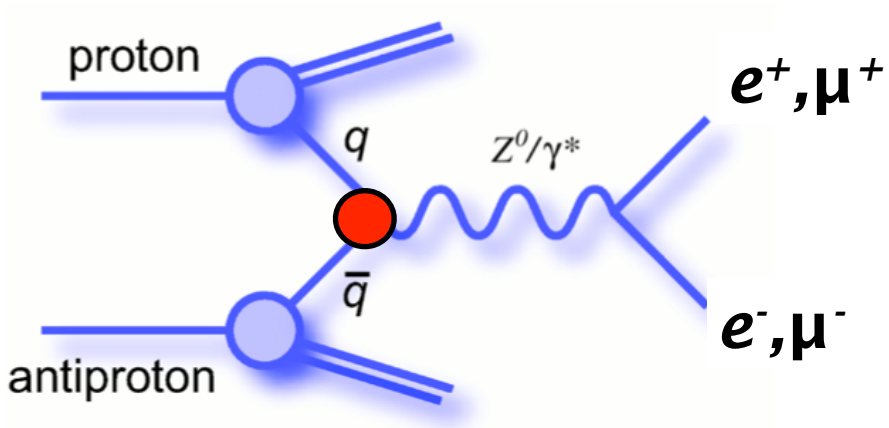
Search for H→WW→ee, eμ, μμ

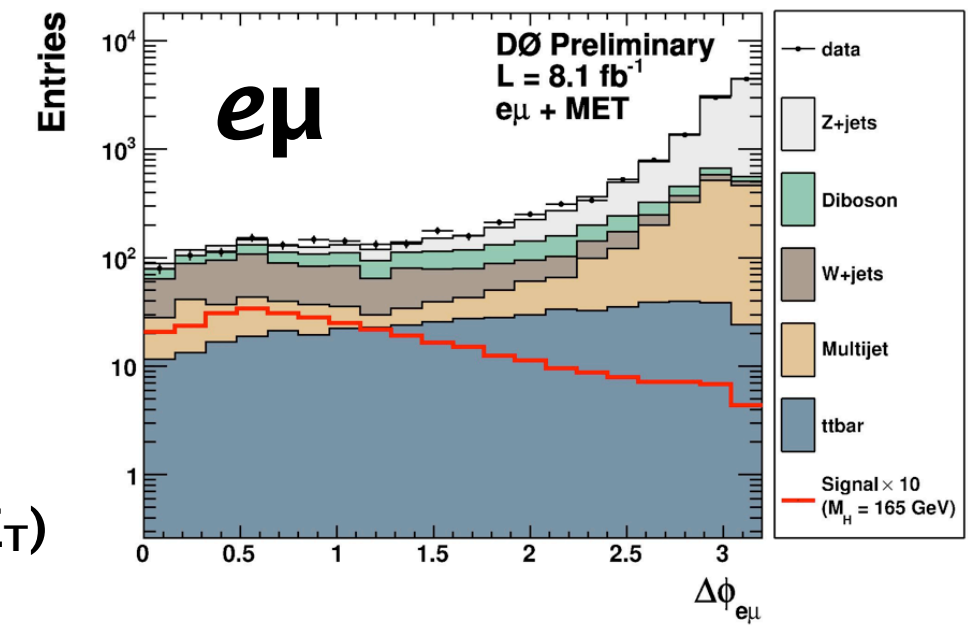
signal





background



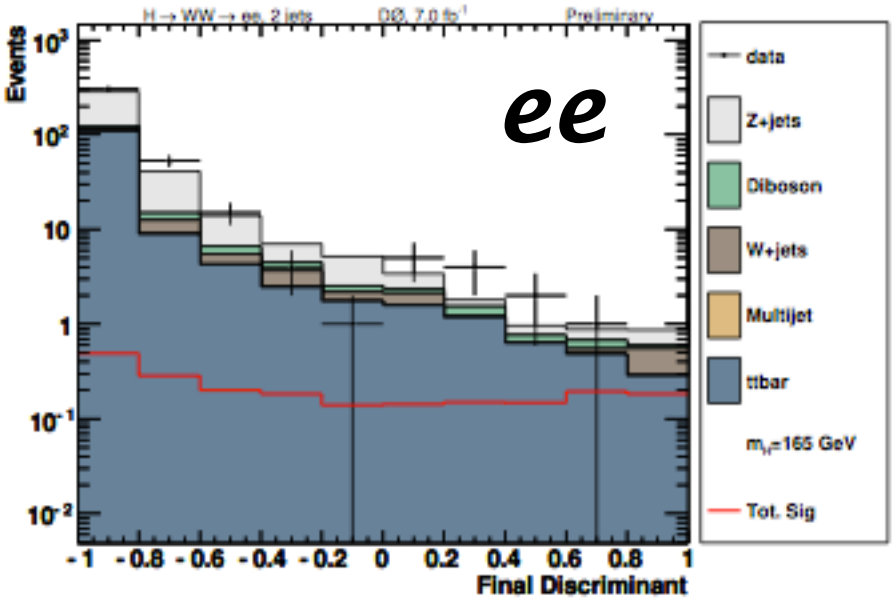


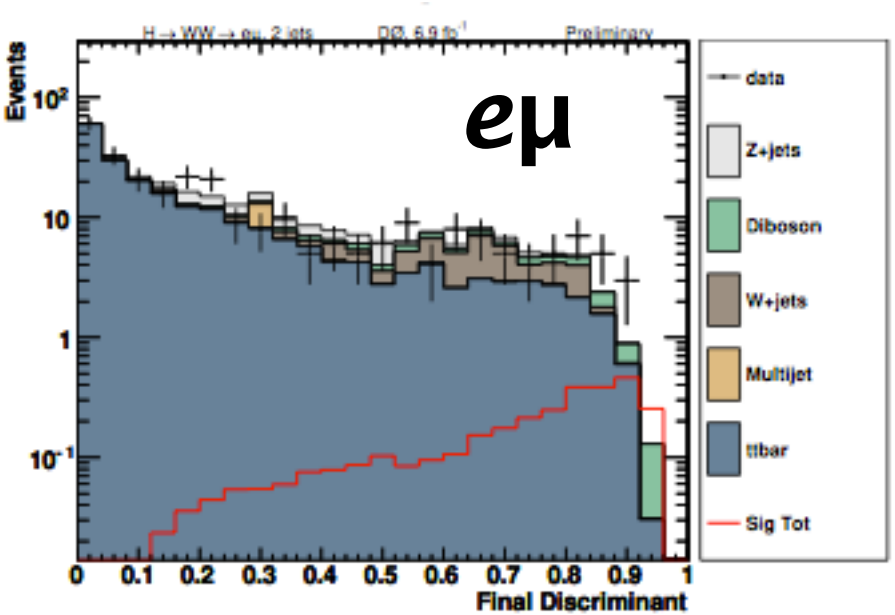
background rejection

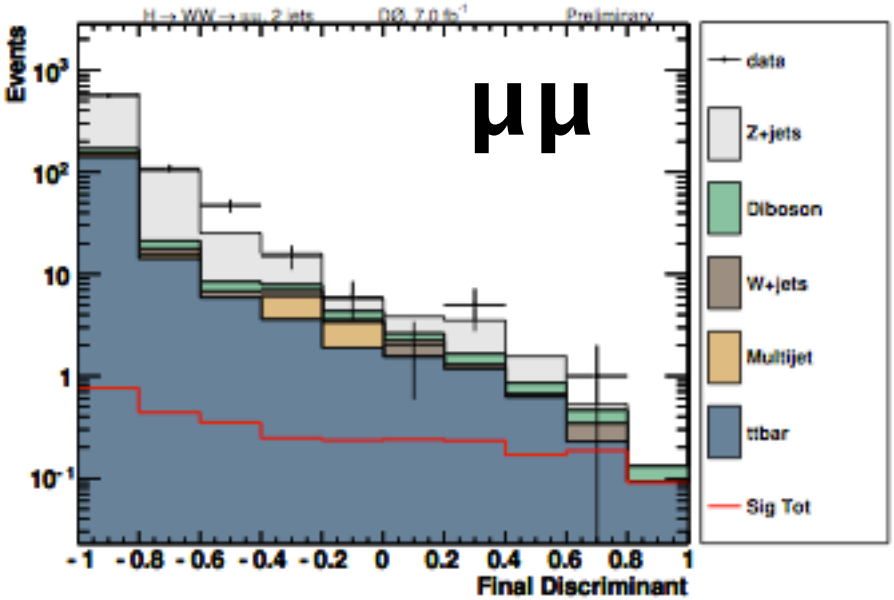
- eμ: minimal transverse mass $M_T(e/\mu,\not{E}_T)$
- ee, μμ: BDT discriminant **NEW**

Search for H→WW→ee, eμ, μμ

- analyse 0, 1, and ≥ 2 jets **NEW**
- final BDT discriminant
- improvements up to 15-40% besides gain in luminosity



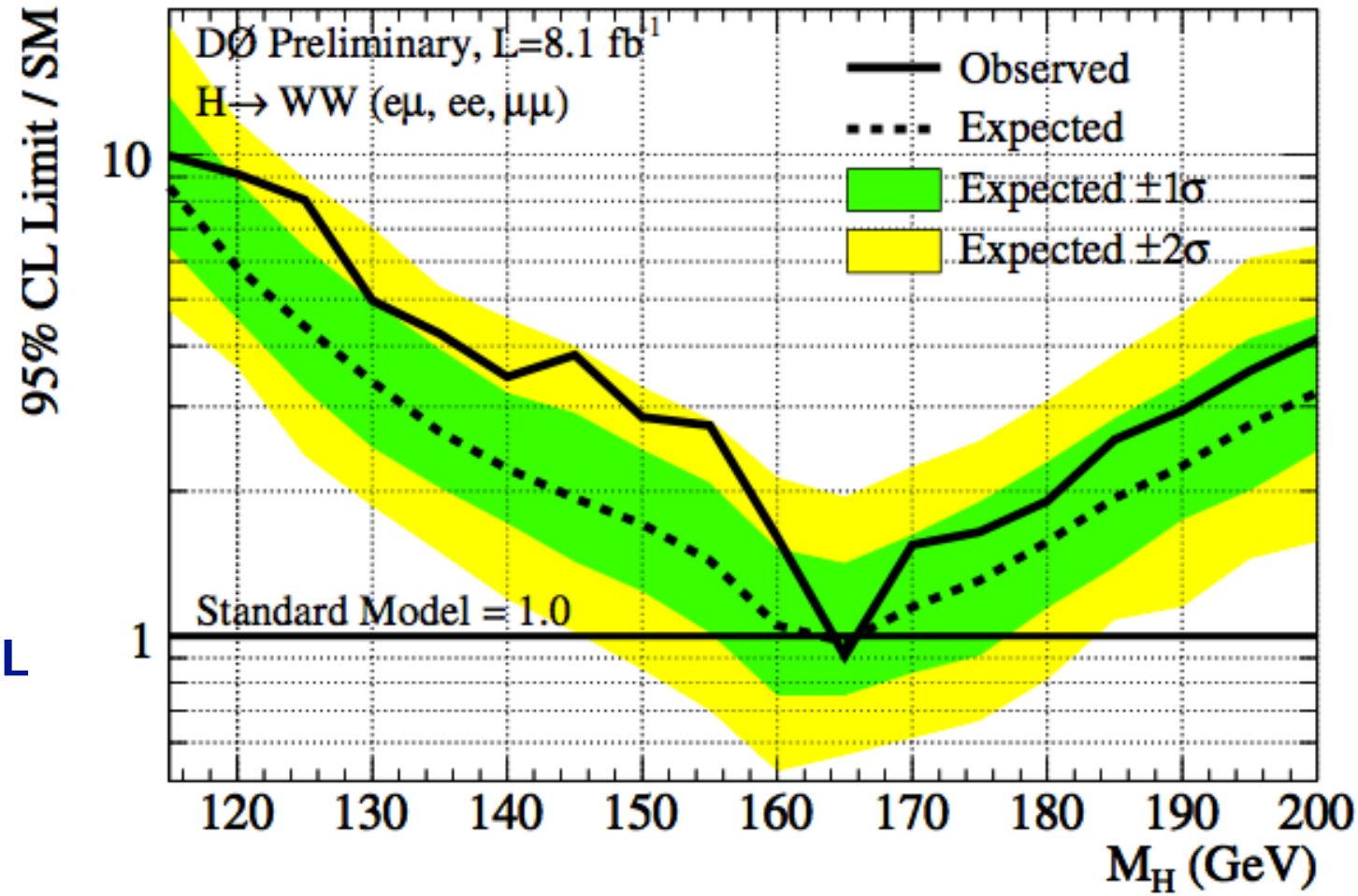




Search for H→WW→ee, eμ, μμ

8.1 fb^{-1}

ee+eμ+μμ



m_H=165 GeV, 95% CL

expected: 0.97×SM
observed: 0.91×SM

exclusion at 95% CL for M_H=165 GeV

exclusion in one channel for the first time!

SM Higgs Combination

5.3–8.2 fb^{-1}

$H \to W^+W^- \to \ell^\pm \nu \ell^\mp \nu$
0/1/2+ jet

$H \to W^+W^- \to \ell \nu q \bar{q}$

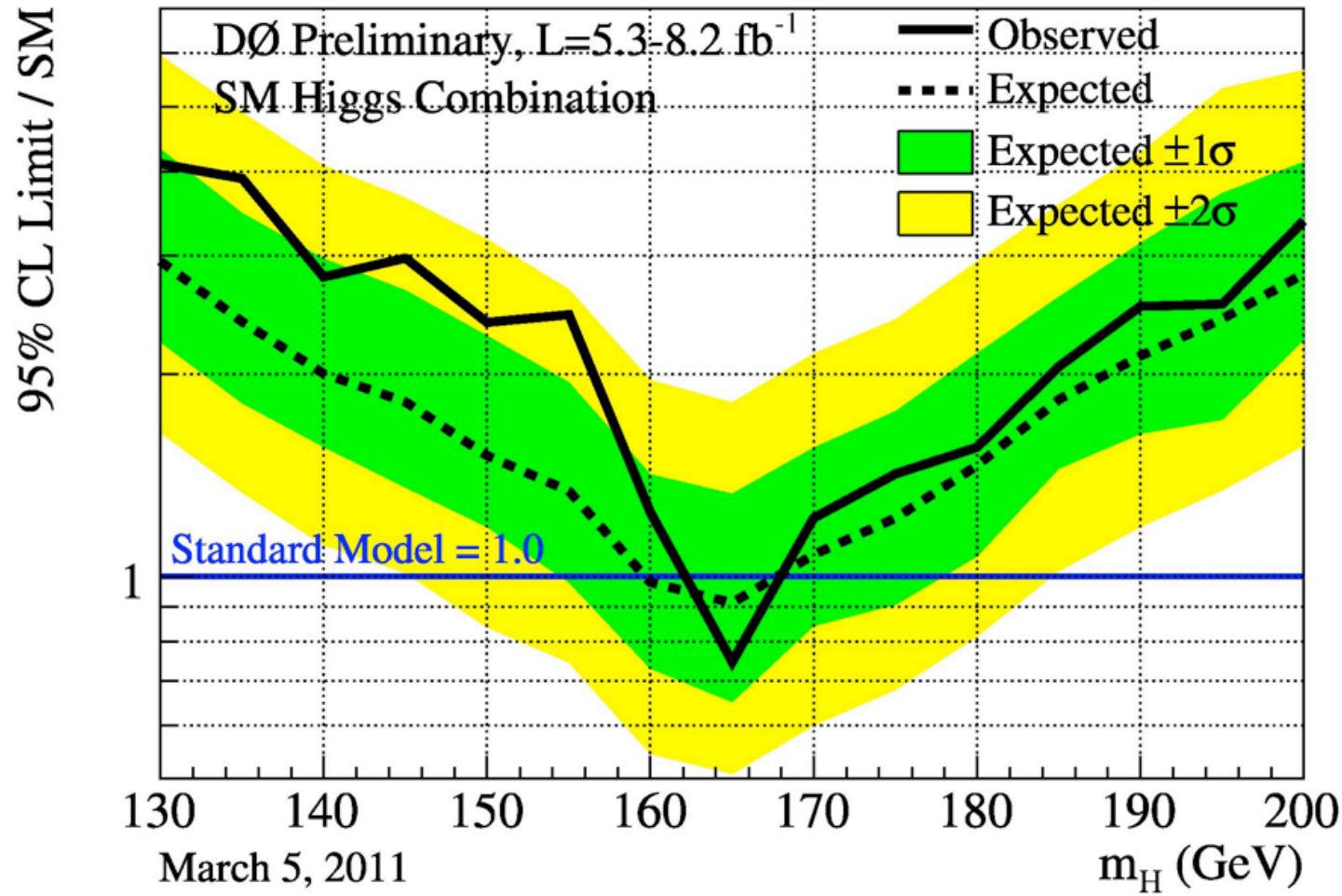
$H + X \to \mu^\pm \tau^\mp_{had} + \leq 1j$

$H + X \to \mu^\pm \tau^\mp_{had} jj$

$H + X \to e^\pm \tau^\mp_{had} jj$

$VH \to \ell^\pm \ell^\mp + X$

$H \to \gamma\gamma$



m_H=165 GeV, 95% CL

expected: 0.91×SM
observed: 0.75×SM

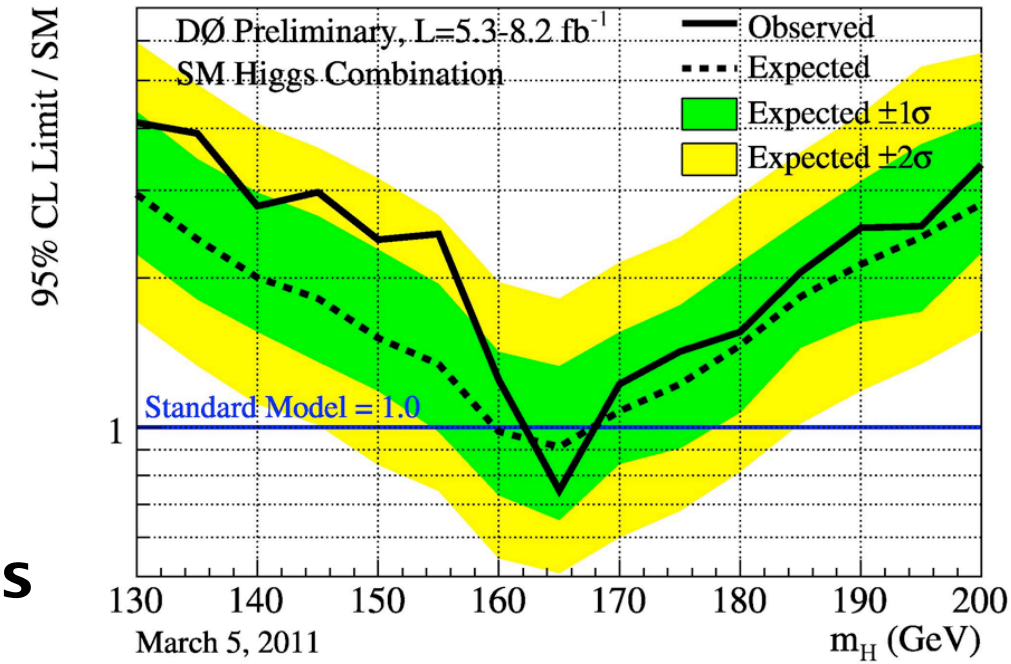
exclusion at 95% CL for 163 < M_H < 168 GeV
exclusion by a single experiment for the first time!

Conclusions

- many new results representing a broad spectrum of physics
- many analyses are performed for the first time
- data set up to 8.2 fb^{-1}

→ first SM Higgs exclusion of a single experiment as CDF
→ first SM Higgs exclusion of a single channel: H→WW

- Tevatron Higgs combination close to be ready
- more results expected within the next days
- many more exciting results are ahead of us!



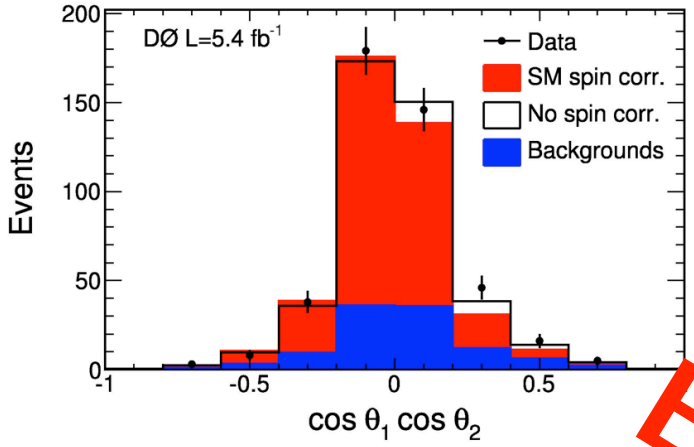
- public web page for DØ results for Winter 2011 conferences:

http://www-d0.fnal.gov/Run2Physics/ResultsWinter2011.html

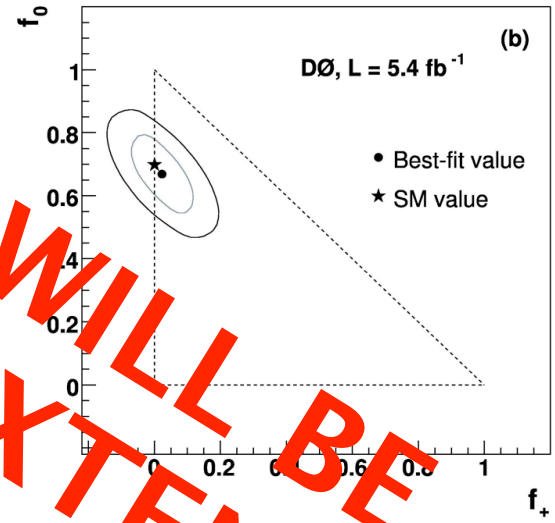
Backup

Recent Top Quark Results

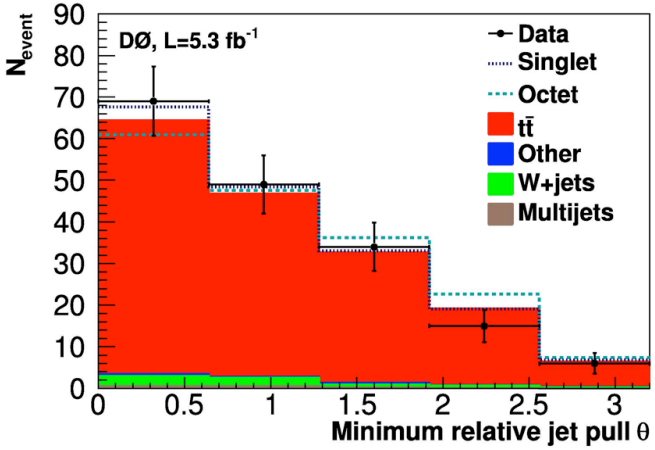
$t\bar{t}$ spin correlation



W helicity fractions

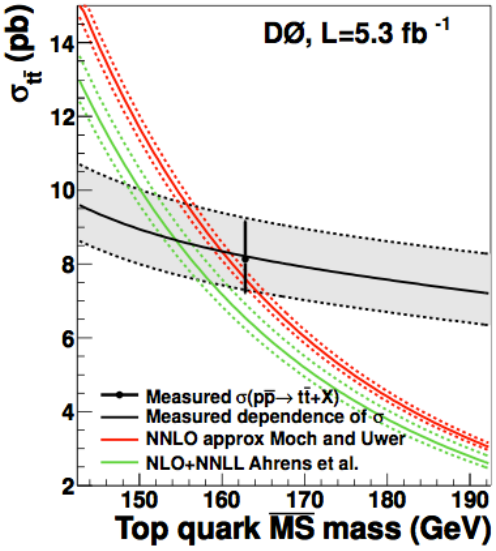


colour flow

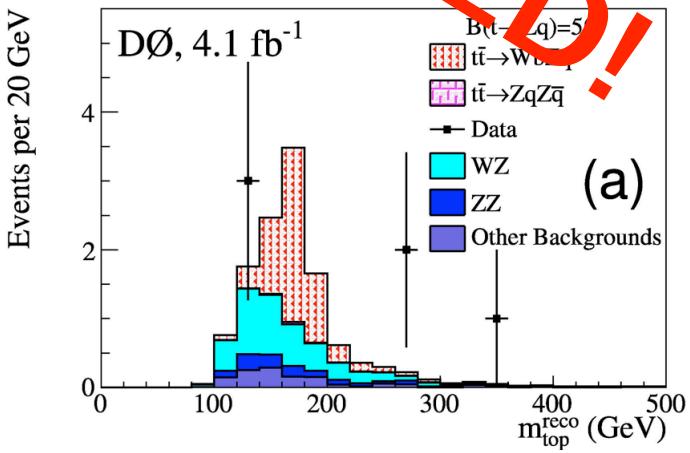


WILL BE EXTENDED!

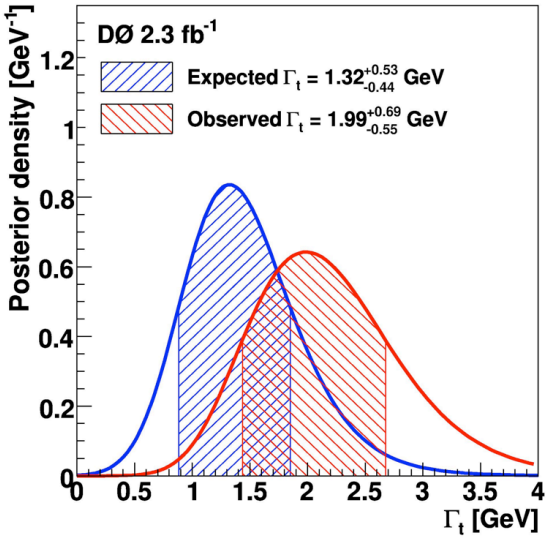
pole&$\overline{\text{MS}}$ mass



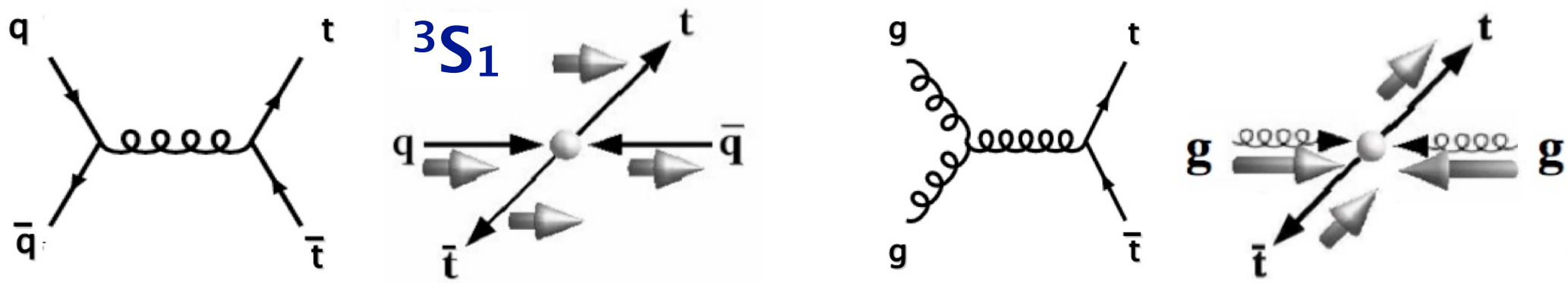
search for FCNC decays



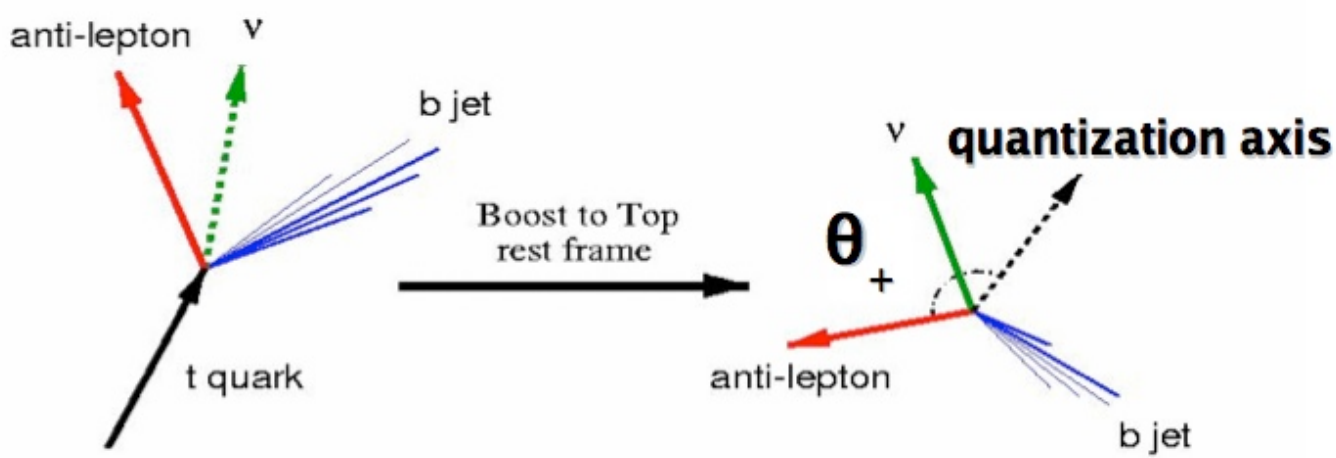
width



Top Pair Spin Correlations



Tevatron LHC

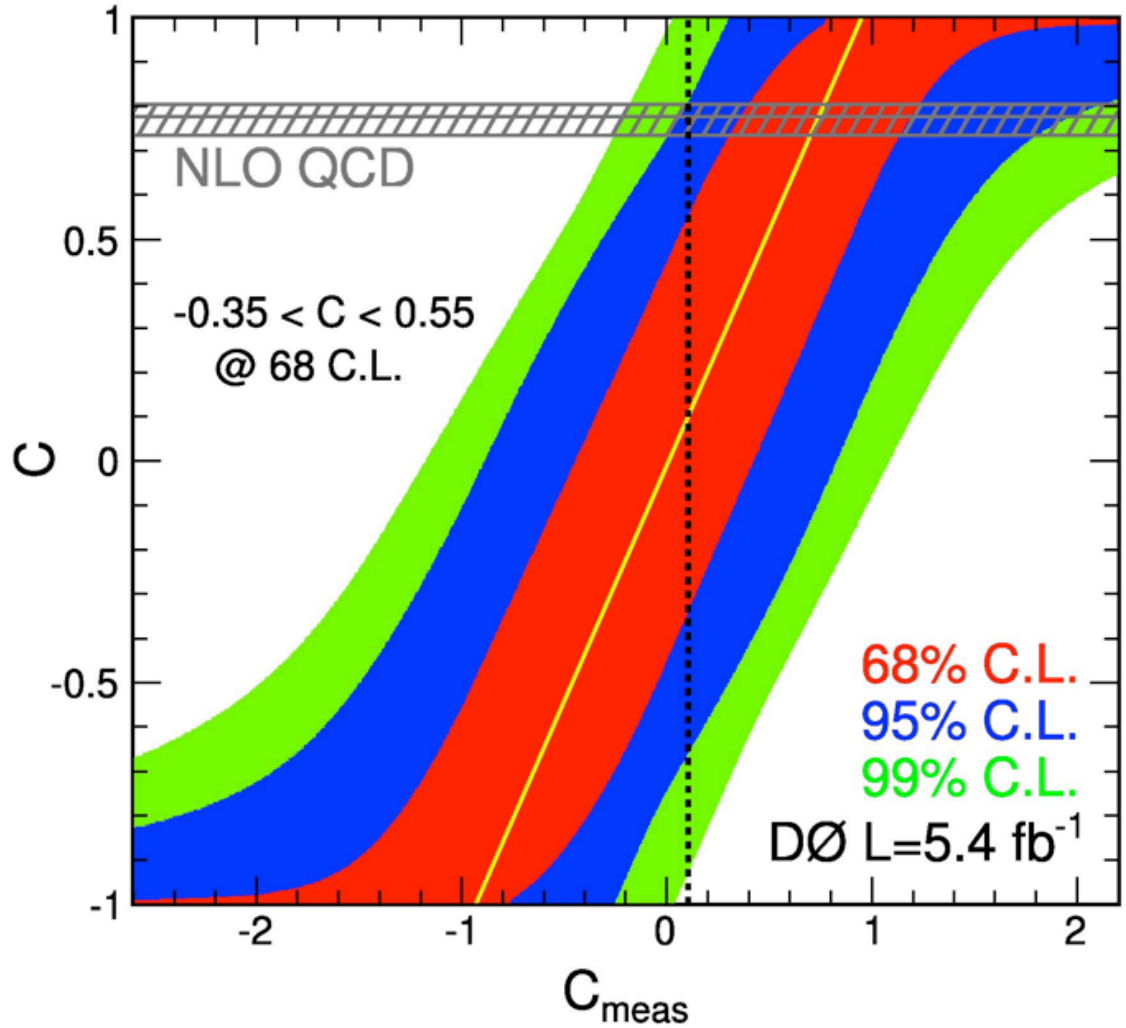


$$K = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$

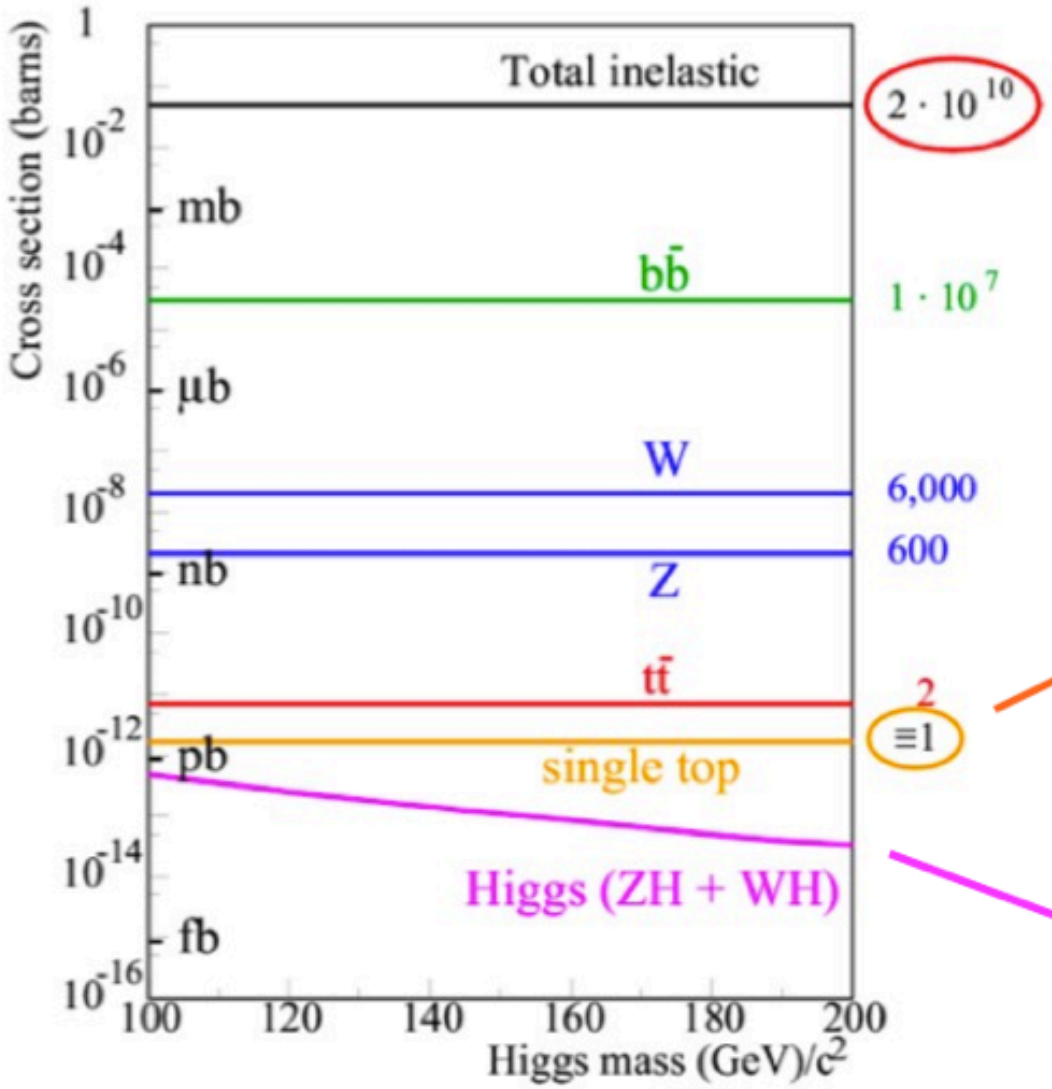
completely complementary to LHC who measure a different parameter

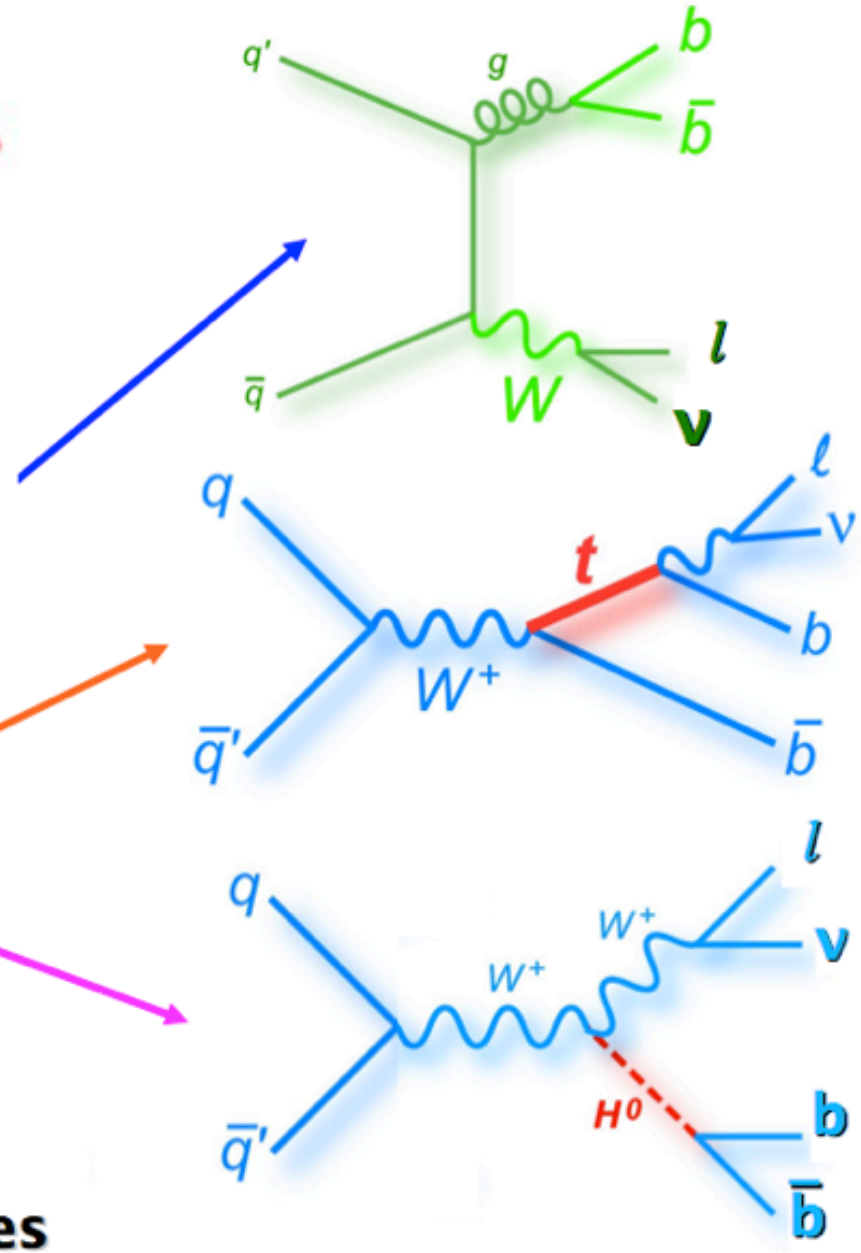
Spin correlations

only dilepton channel



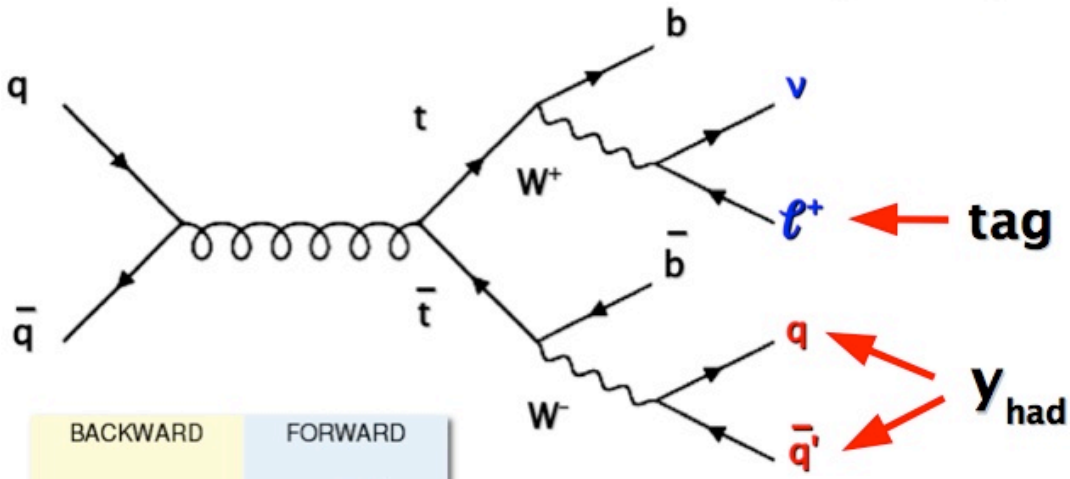
Single Top Quark Production

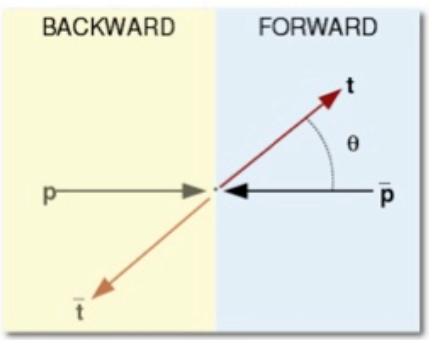




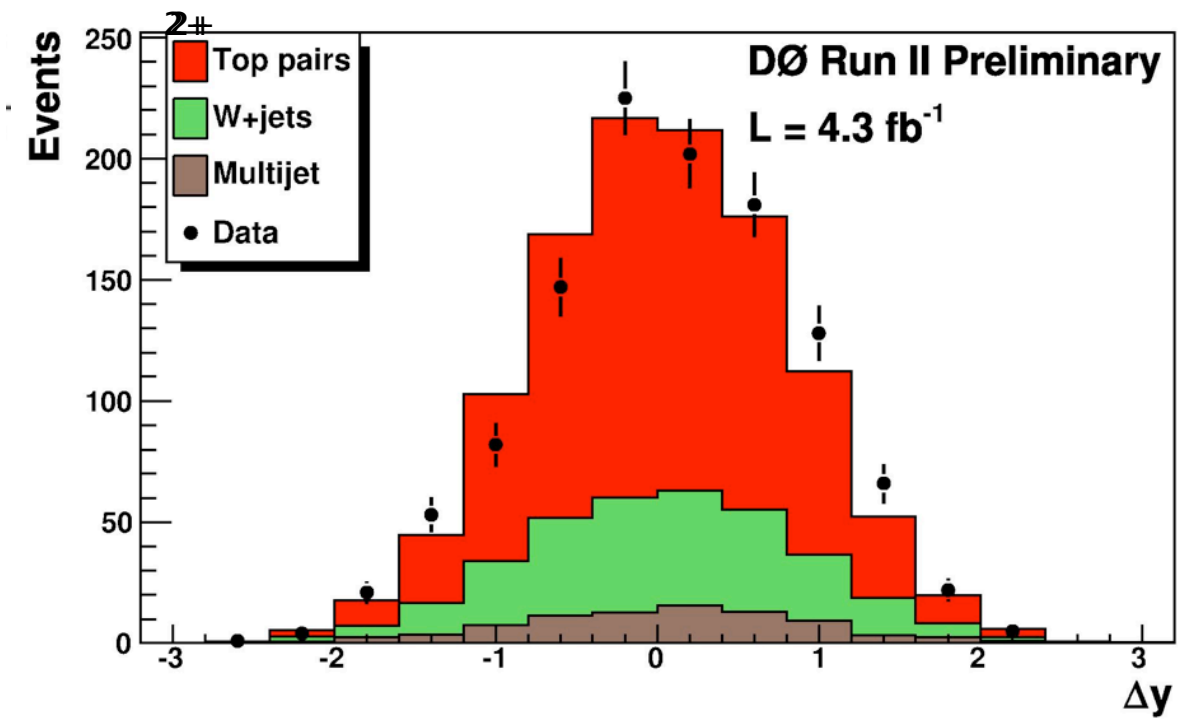
⇒ **multivariate analysis techniques**

Forward Backward Asymmetry





$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$



A_{fb} = (8 ± 4(stat) ± 1(syst))%

$A_{fb}^{predicted}$ = $(1^{+2}_{-1}$(syst))%

- statistically limited
- complementary to LHC who cannot measure this

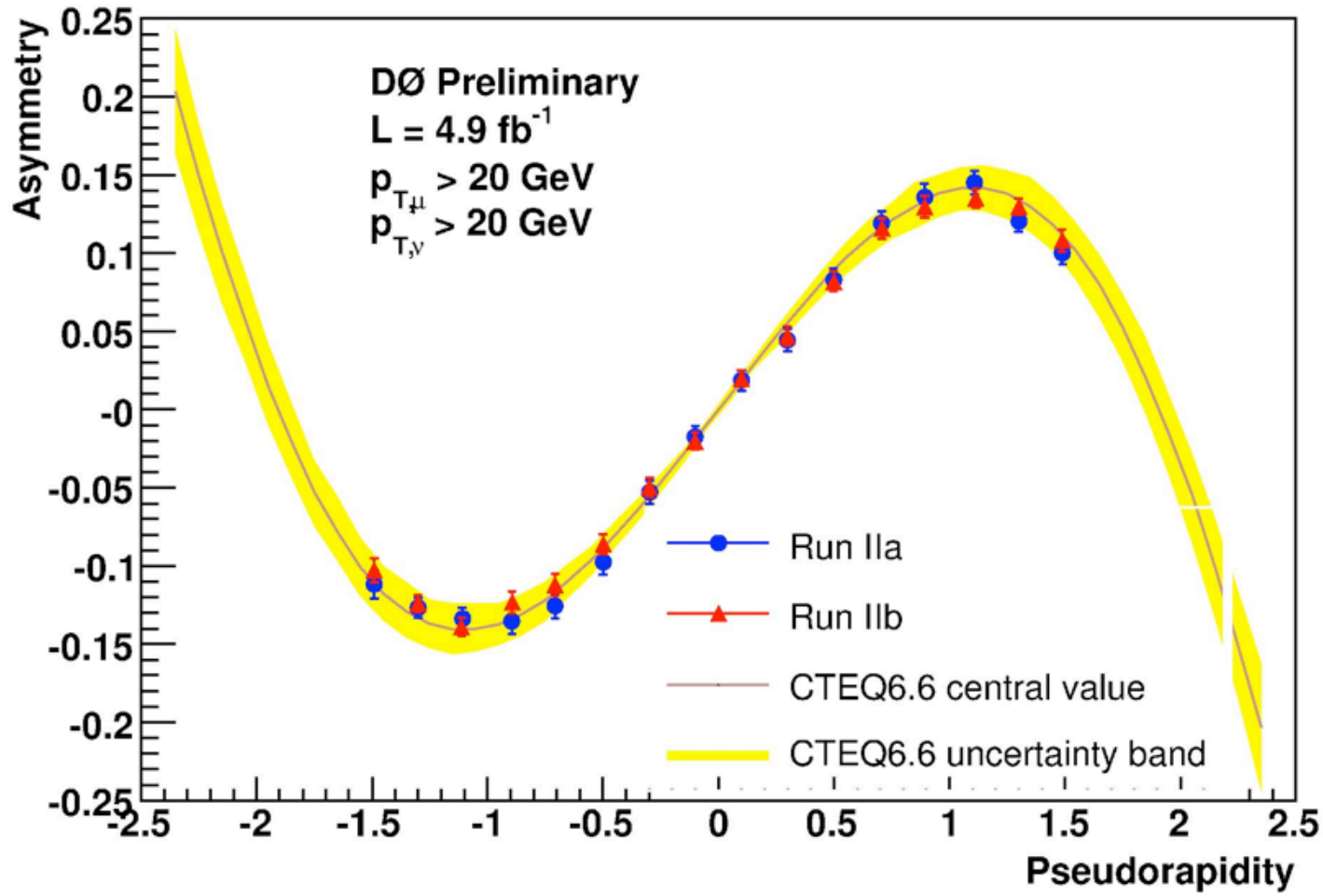
Muon Charge Asymmetry

$$u + \bar{d} \rightarrow W^+ \rightarrow \mu^+ + \nu_\mu$$
$$\bar{u} + d \rightarrow W^- \rightarrow \mu^- + \bar{\nu}_\mu$$

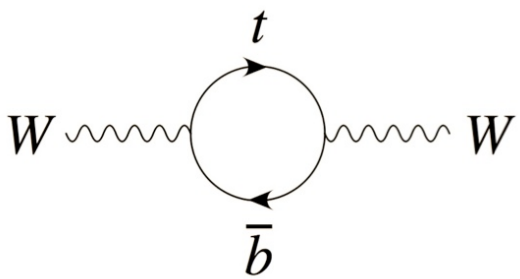
$$A(\eta_\mu) = \frac{N_{\mu^+}(\eta) - N_{\mu^-}(\eta)}{N_{\mu^+}(\eta) + N_{\mu^-}(\eta)}$$

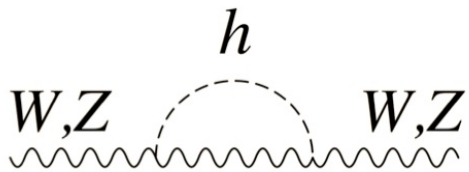
valence up quark tends to have higher momentum fraction of proton than valence down quark

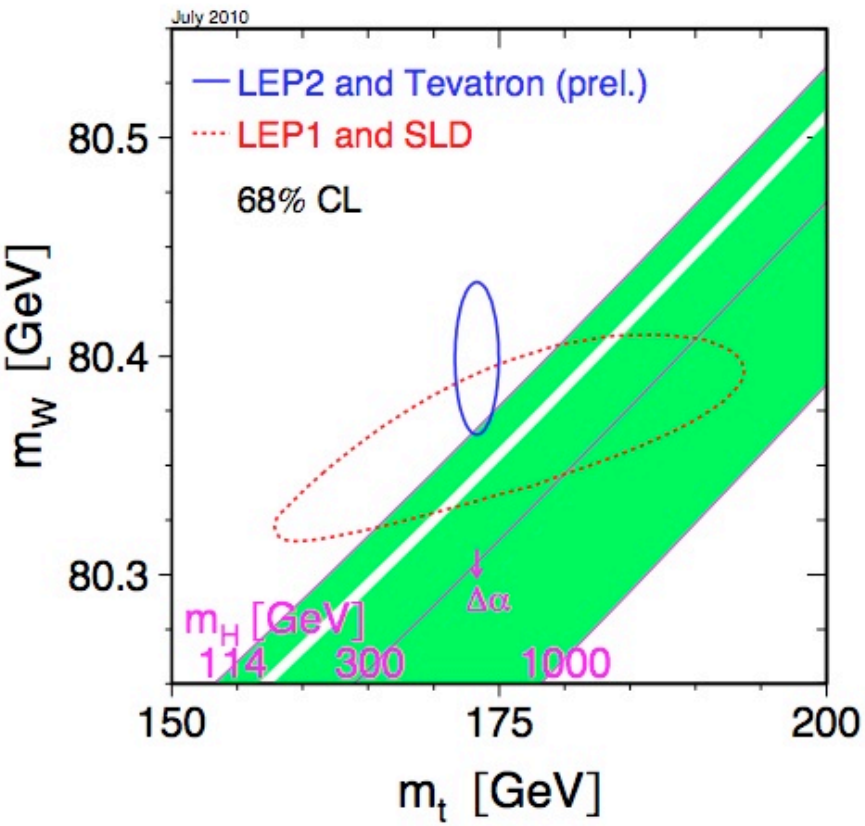
- can constrain pdfs
- cannot be done at the LHC where sea quarks are analysed



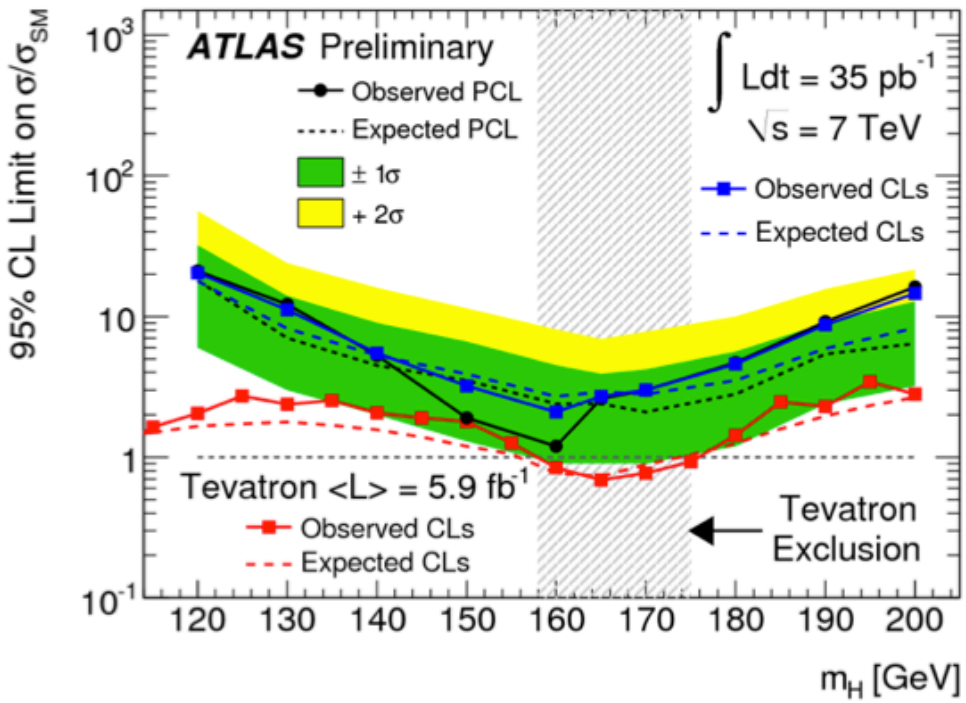
Self-consistency of the SM

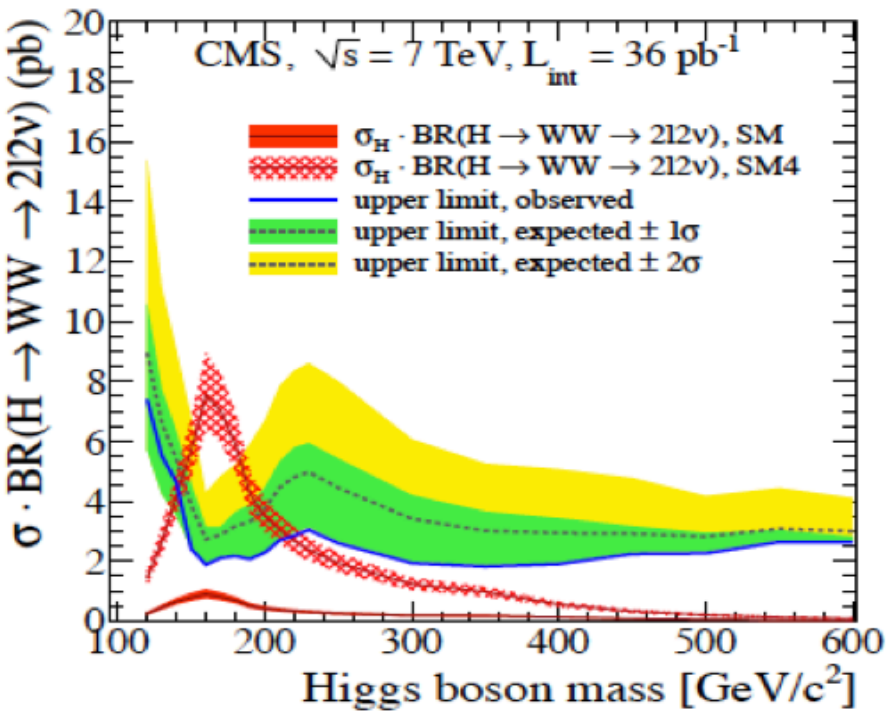




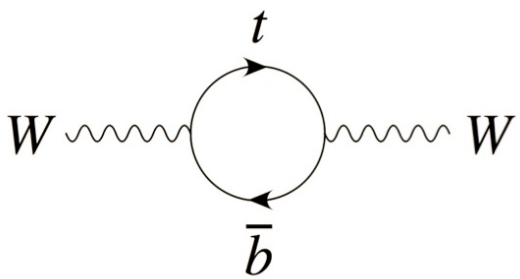


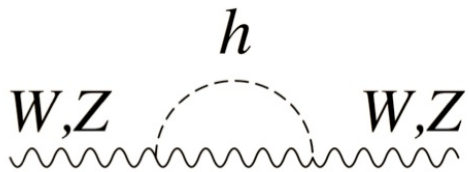
LHC Higgs Searches

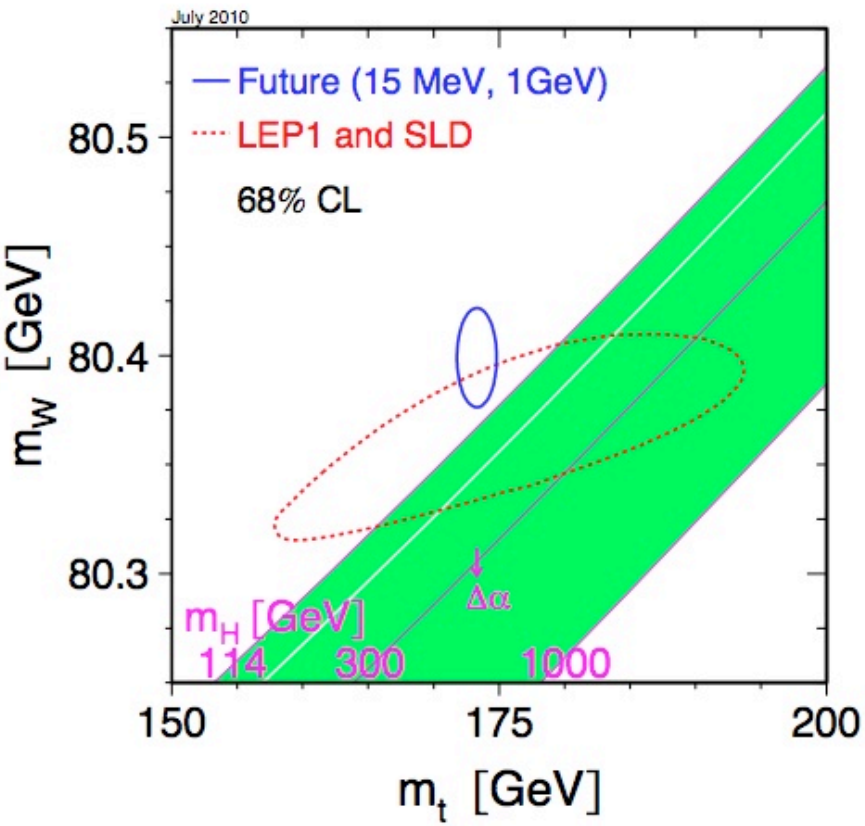




Self-consistency of the SM

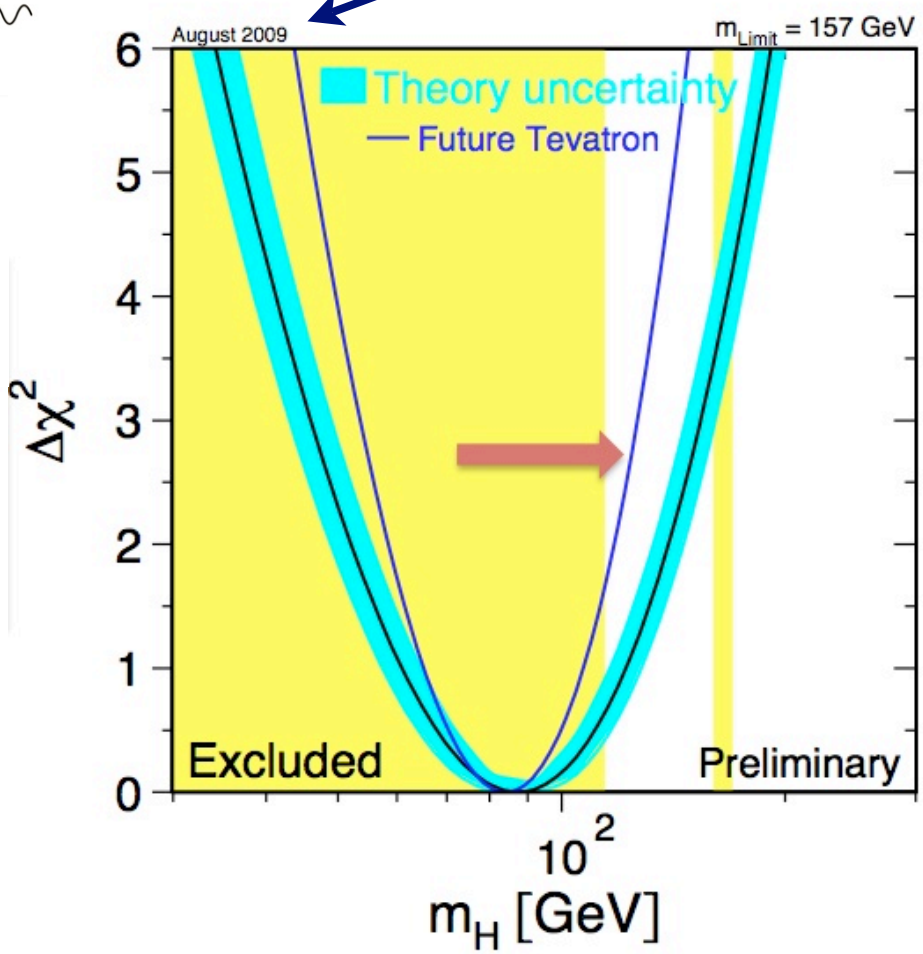






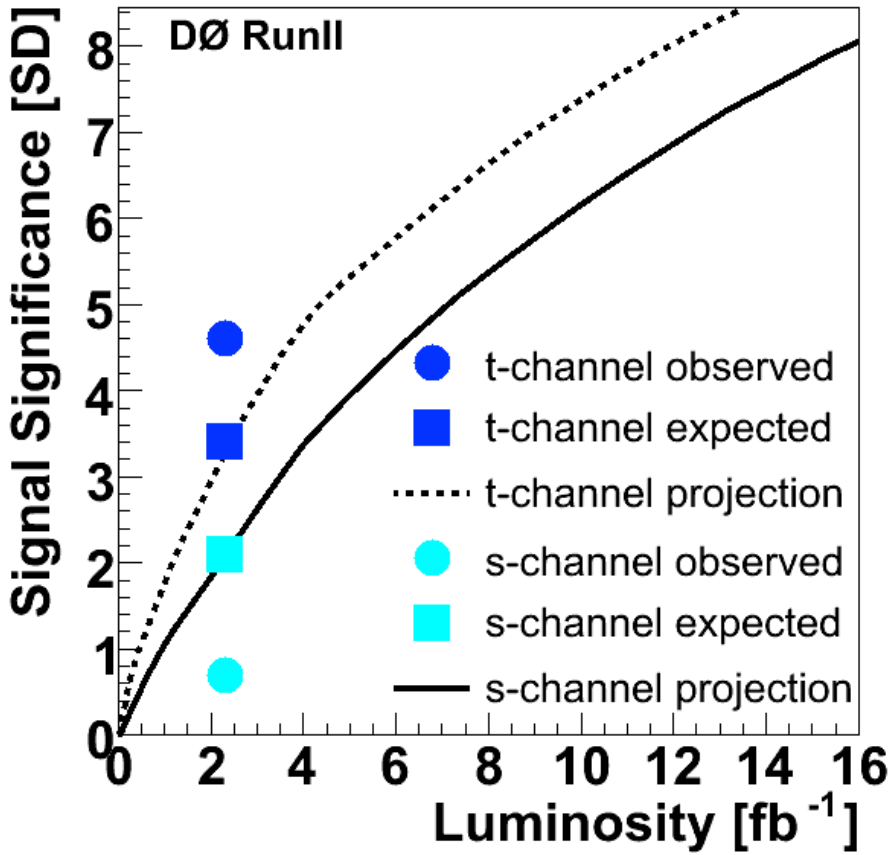
Improved W mass measurement is critical

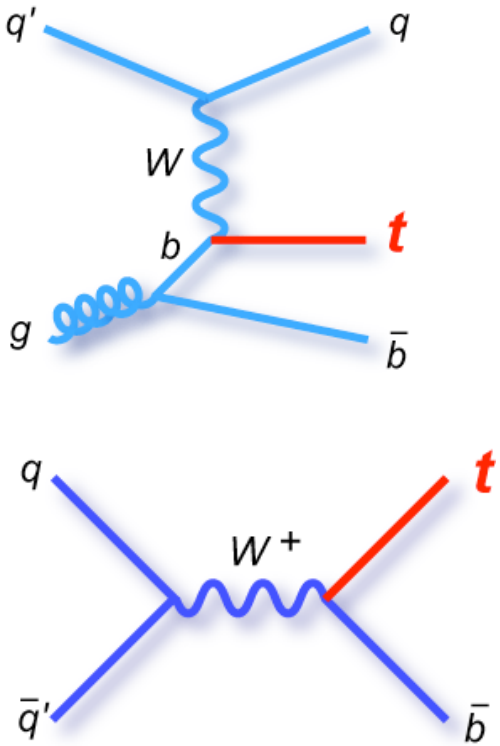
assume precision of top mass: 1 GeV
assume precision of W mass: 15 MeV



m_H < 117 GeV at 95% CL
at current minimum

Single top production





s-channel:

signal significance at 10fb^{-1}: 6σ

should increase with a dedicated MVA trained on s-channel only

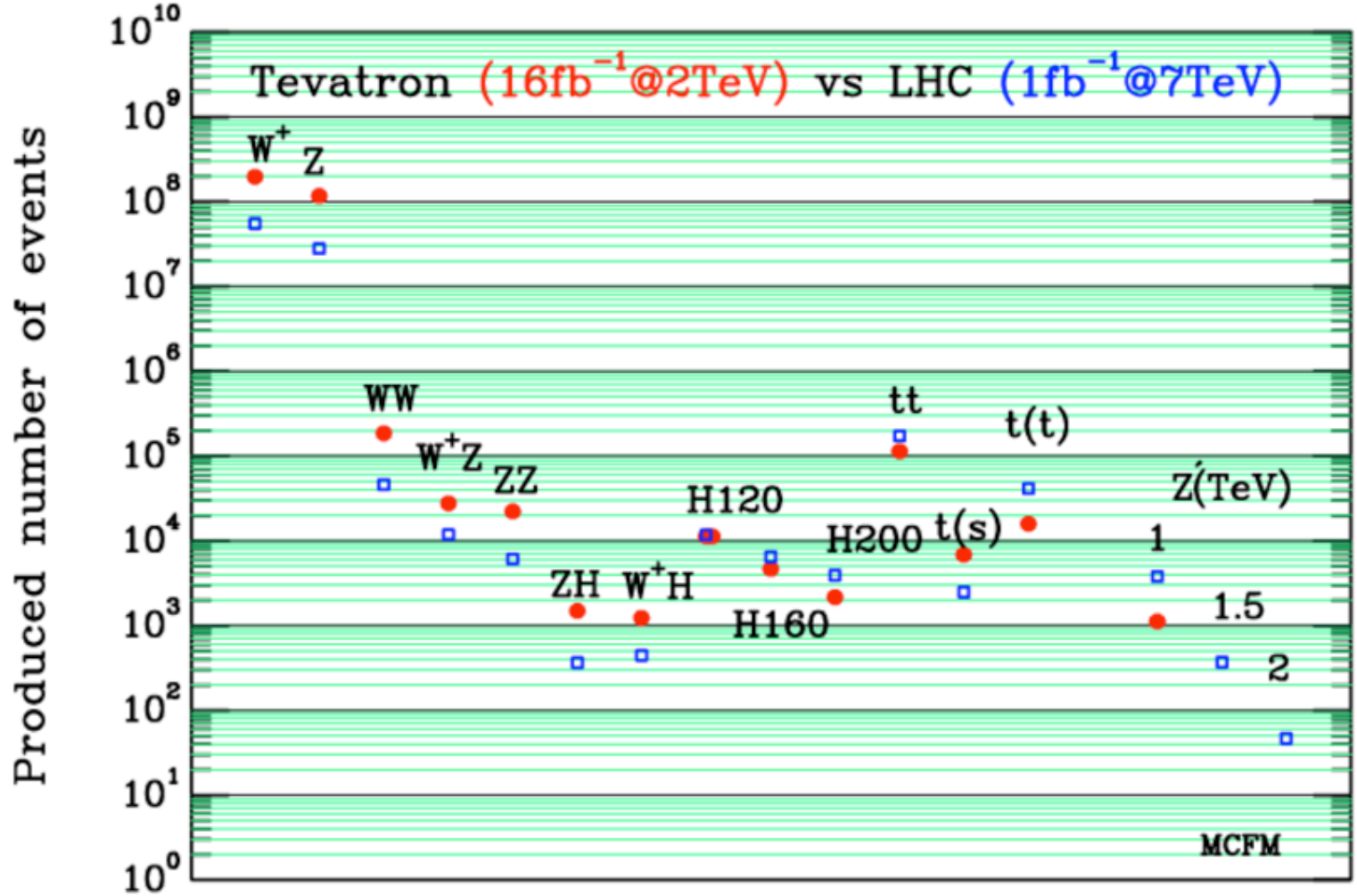
sensitivity to new physics...

s-channel@LHC:

3σ signal significance with 10-30fb^{-1} at $\sqrt{s}$=14 TeV!

→ competitive for a long time!

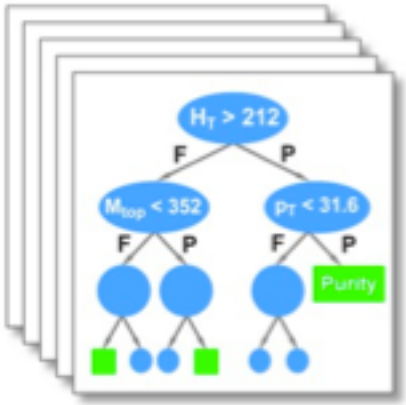
Competition



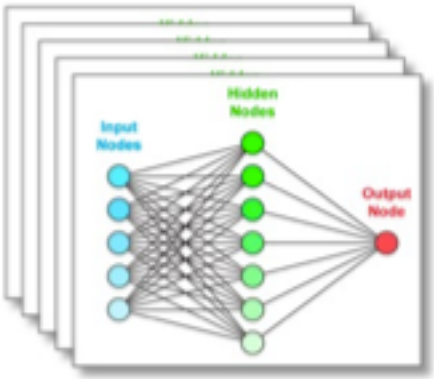
similar size of electroweak samples: top, W, Z

Mulitvariate Analyses

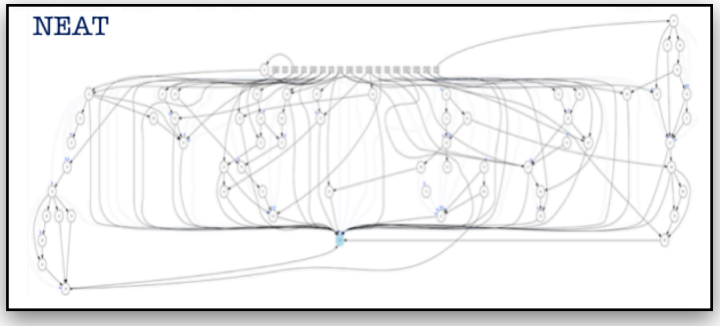
Boosted Decision Trees



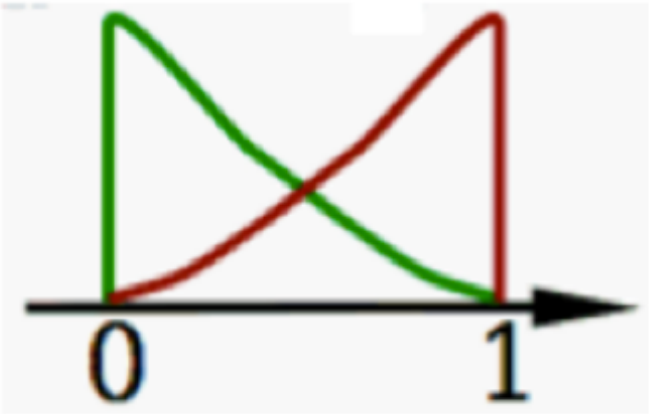
Boosted Neural Networks



Neuroevolution of Augmenting Topologies



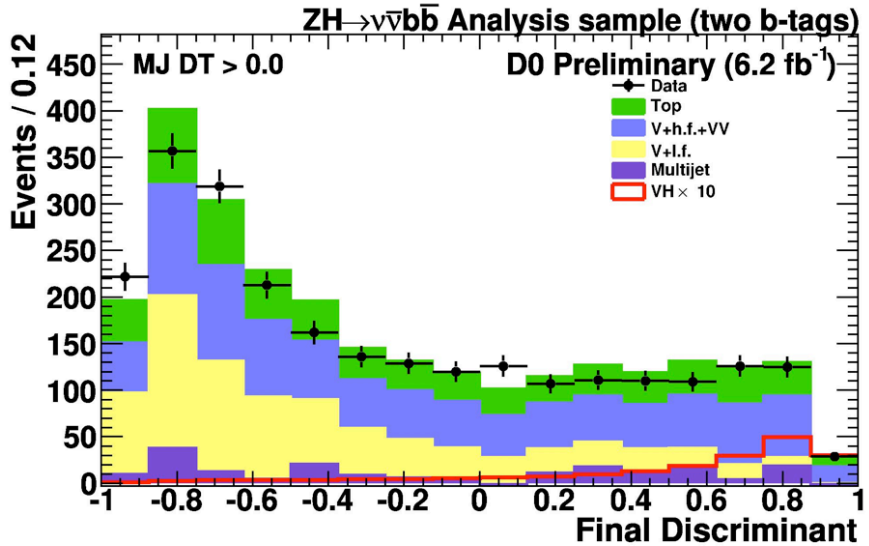
background **signal**

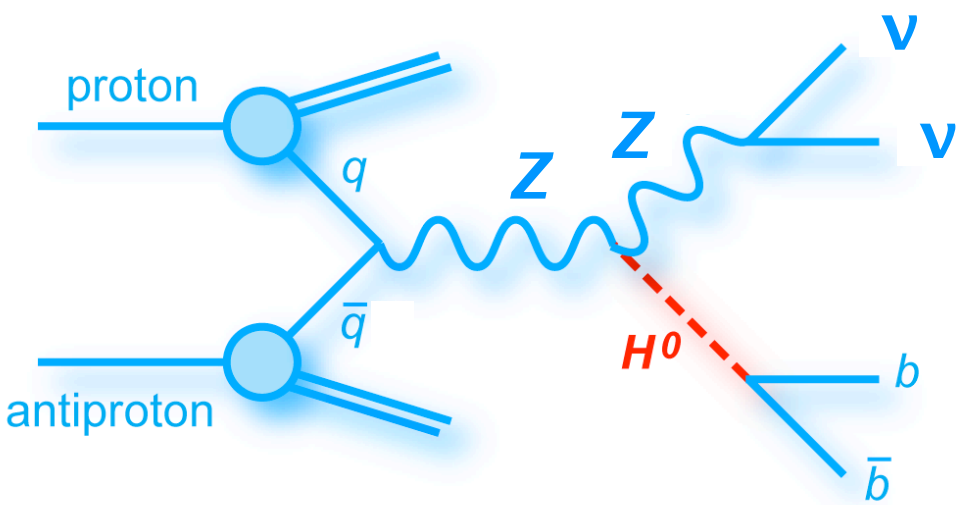


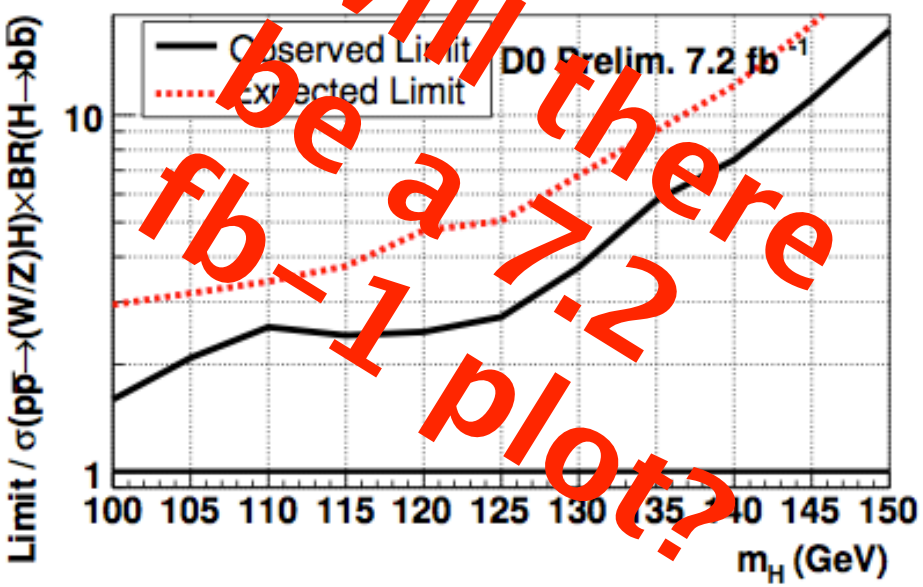
Associated ZH Production

7.2 fb^{-1}

- 2fb^{-1} more data
- form BDT using 20 kinematic variables
- use sample with 1 and 2 b-tags separately







will there be a 7.2 fb^{-1} plot?

m_H=115 GeV, 95% CL

expected: 3.8×SM

observed: 2.4×SM