Latest results from Tevatron collider experiments

Quarks 2010 International seminar

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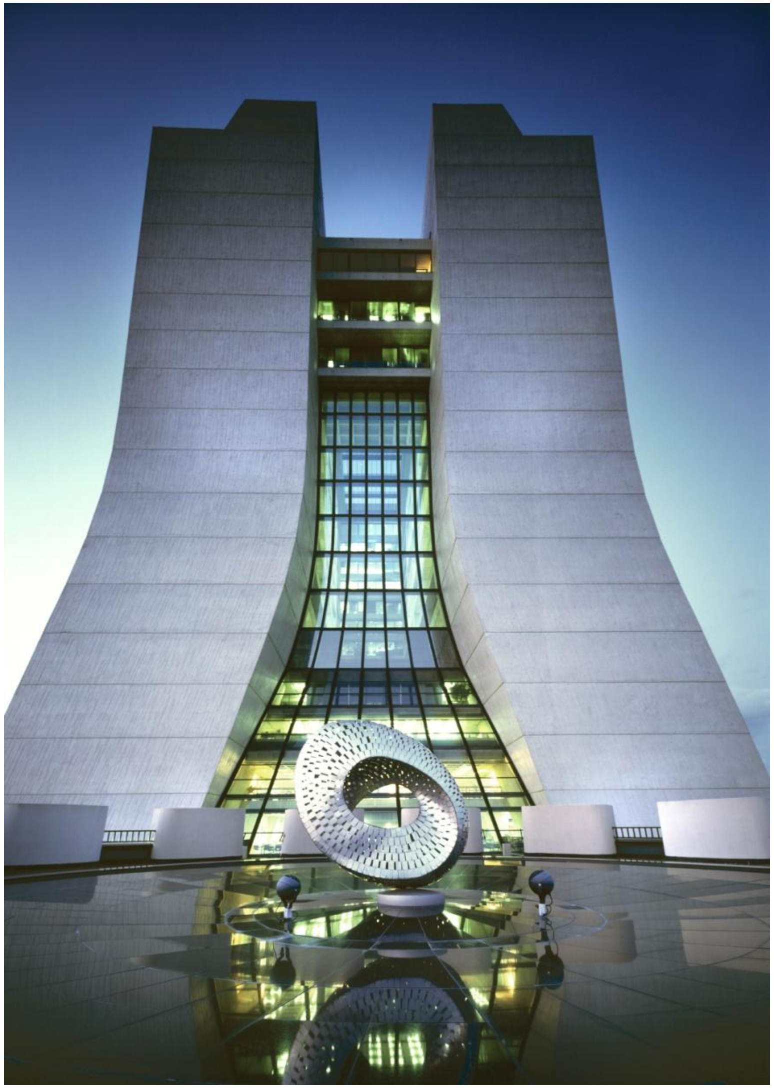
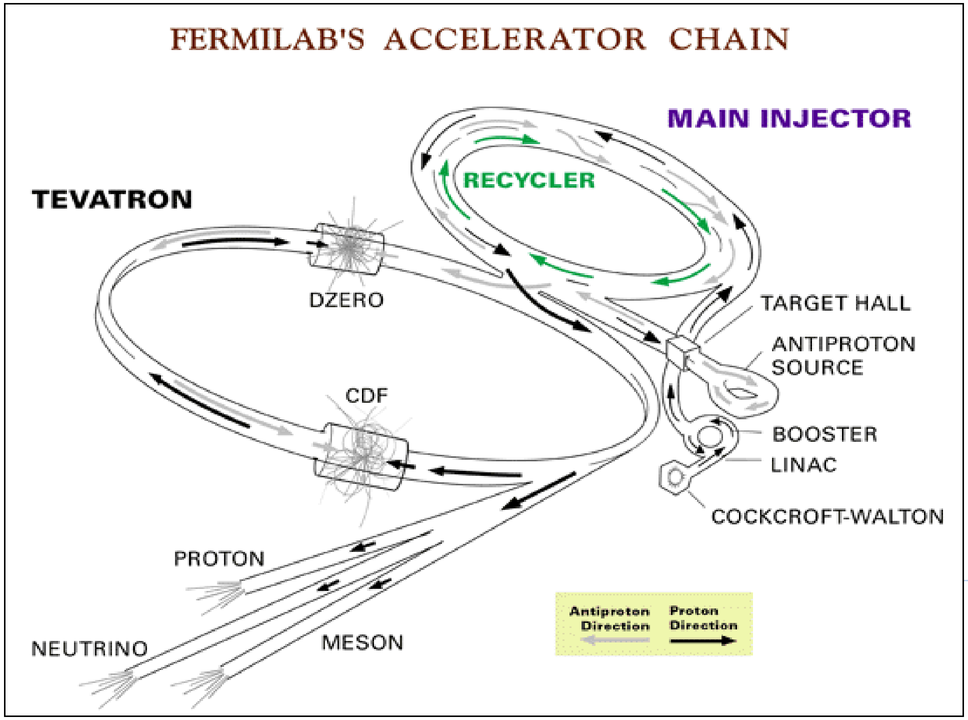
Outline

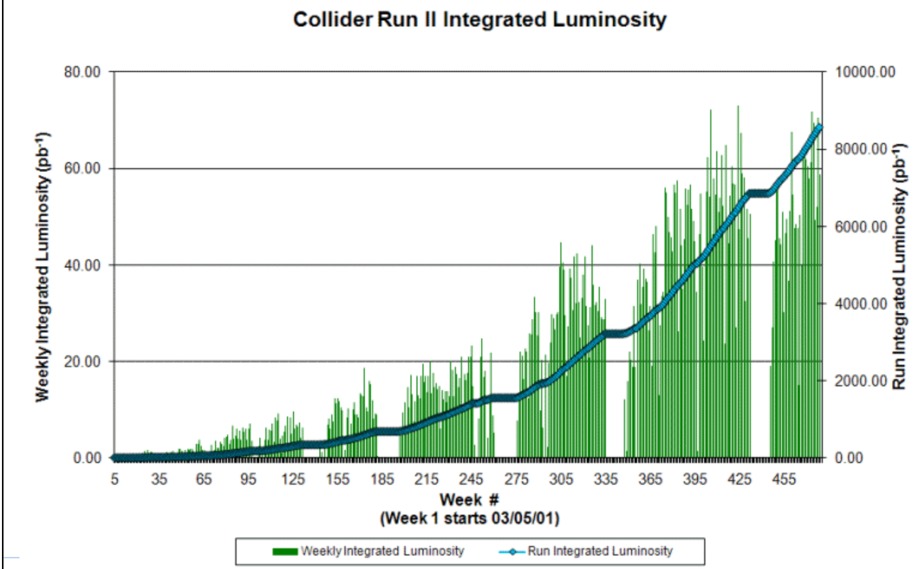
- ➢ The Tevatron collider
- ➢ Experiments and data
- ➢ Higgs (SM and SUSY) searches
- ➢ Electroweak physics
- ➢ QCD physics
- ➢ b-physics
- ➢ New Phenomena searches
- ➢ Tevatron perspectives
- ➢ Summary

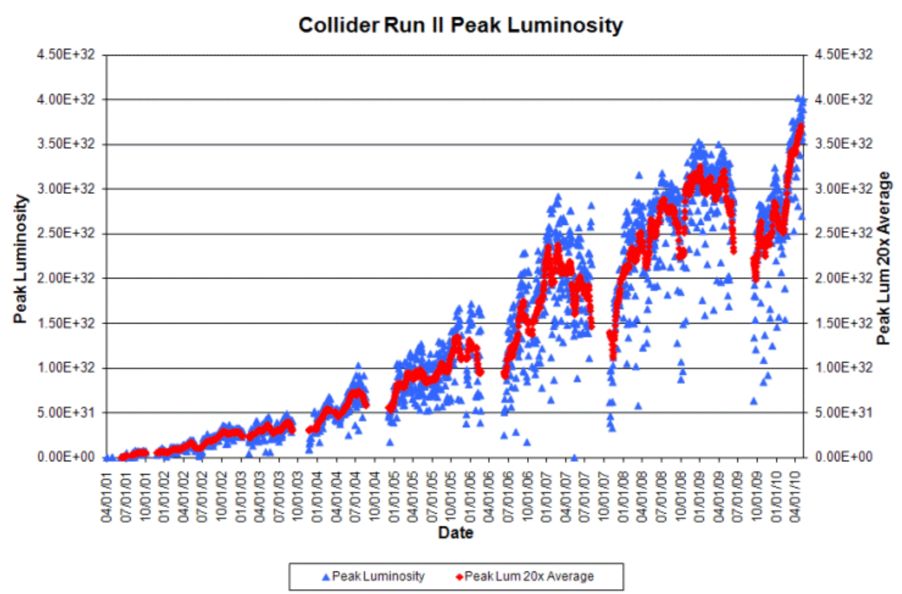
(top physics will be covered in additional presentation by L. Dudko)



The Tevatron collider







1.96 TeV center of mass energy

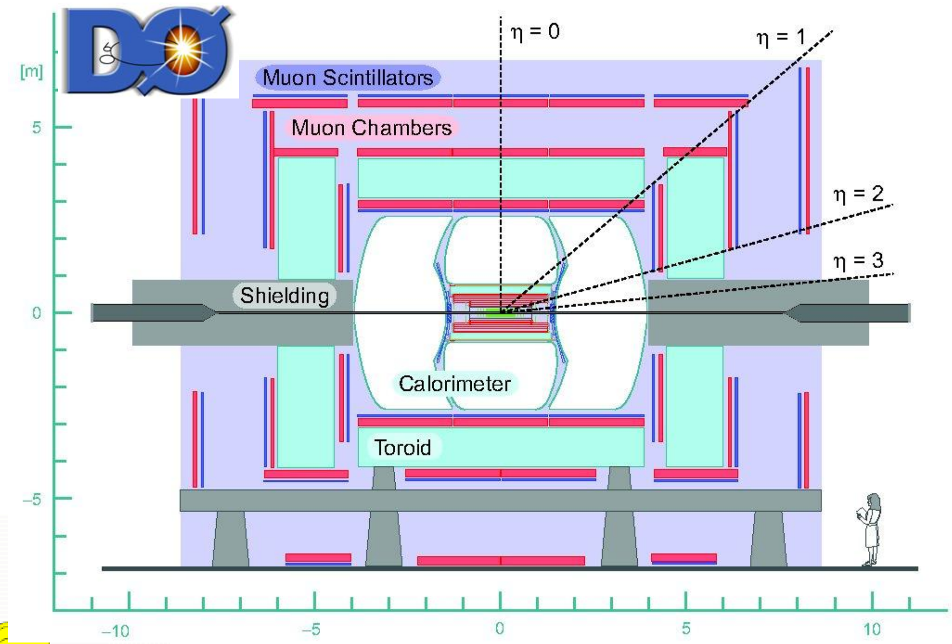
$4\cdot10^{32}$ $cm^{-2}sec^{-1}$ peak instantaneous luminosity

In stores ~120 hours peer week

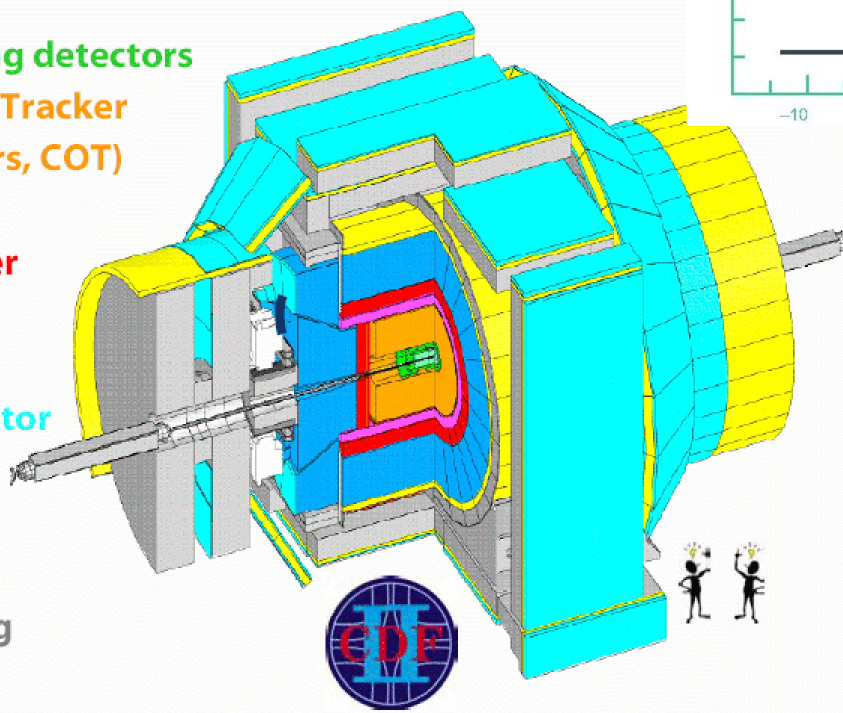
Total 8.6 fb^{-1} luminosity delivered in Run II

Detectors and data

- **Vertexing**
- **Precision tracking**
- **Calorimetry**
- **Muon system**
- **Hermetic → Missing E_T**

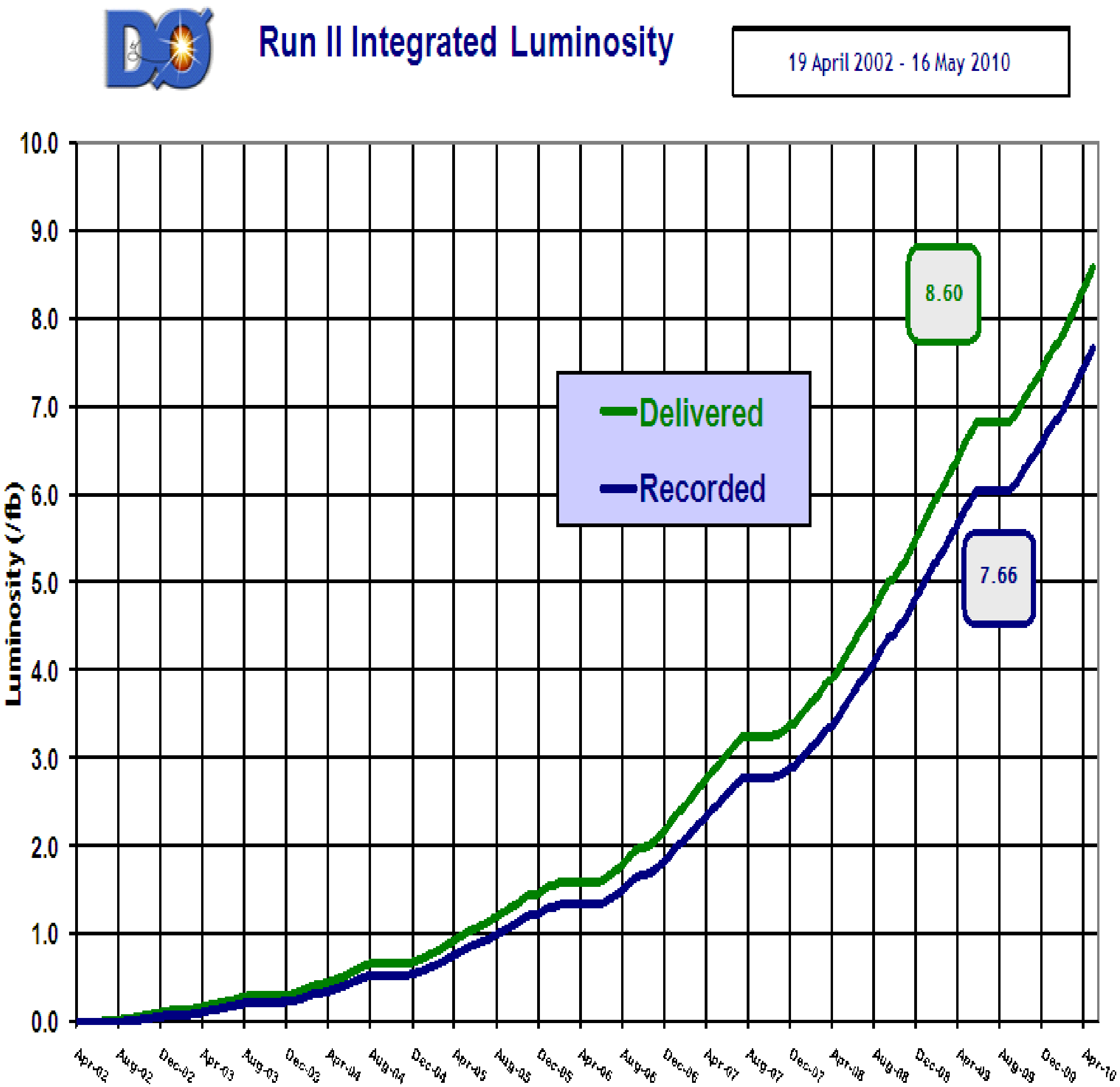


- Silicon tracking detectors
- Central Outer Tracker (drift chambers, COT)
- Solenoid Coil
- EM calorimeter
- Hadronic calorimeter
- Muon scintillator counters
- Muon drift chambers
- Steel shielding



- **CDF has better track momentum resolution and displaced track triggers at Level1**
- **DØ has finer calorimeter segmentation and a muon system extending farther forward**

Detectors and data



At the middle of May DØ has ~7.7 fb^{-1} written to tapes

Typical week integrated luminosity ~50-60 pb^{-1}

On average ~92% data taking efficiency

Most results published ~3 fb^{-1}

Many results published ~5 fb^{-1}

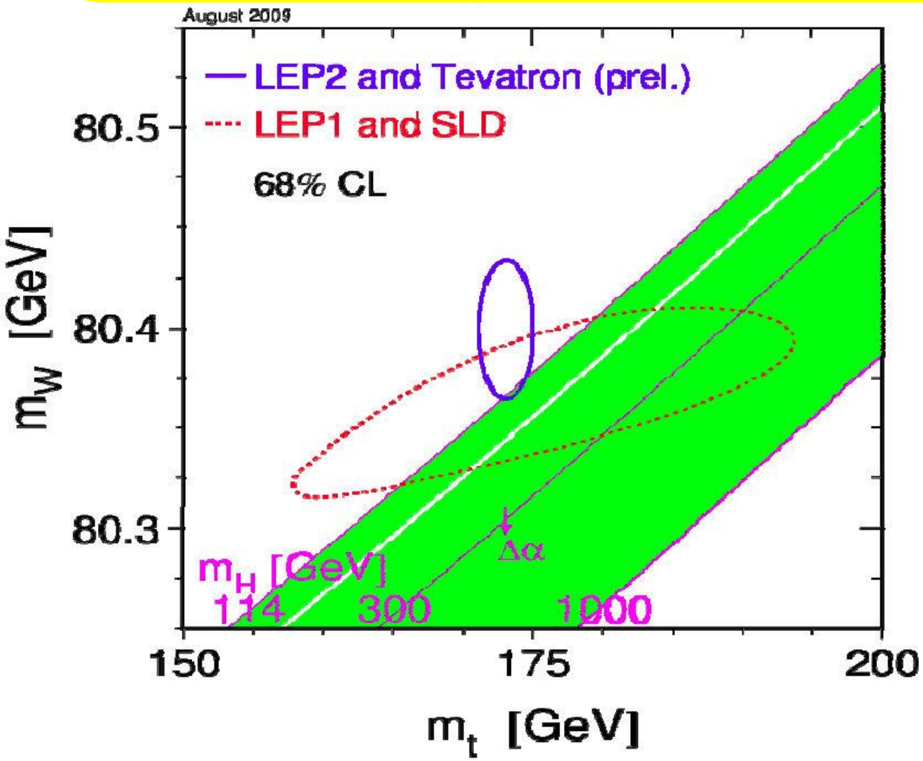
Preliminary results ~6 fb^{-1}

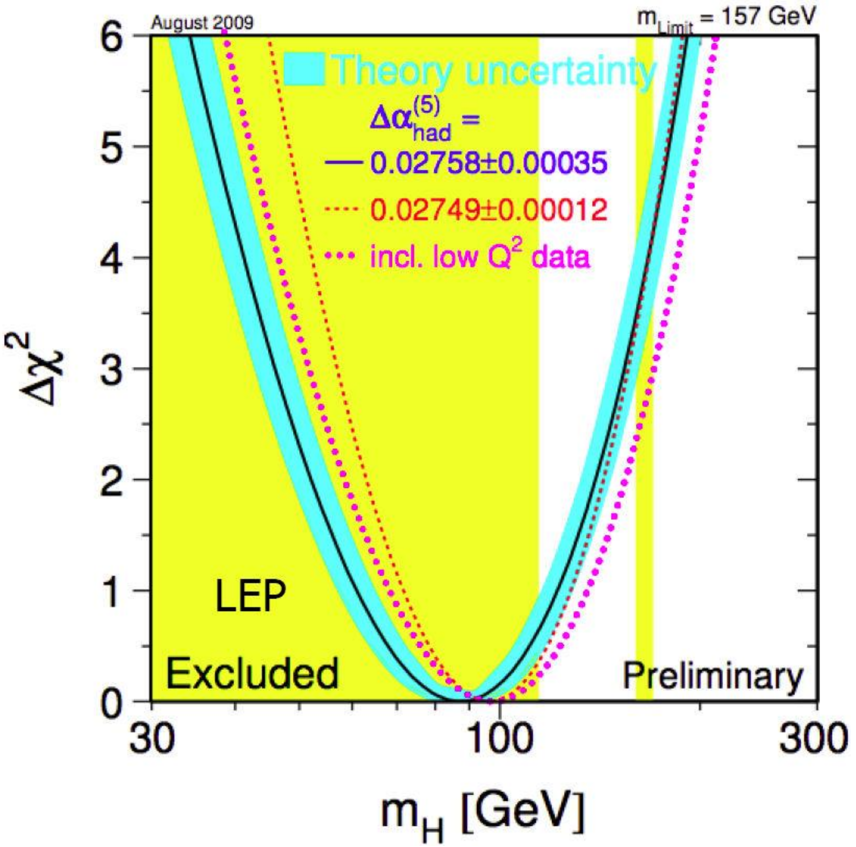
Searching for SM Higgs

Direct searches at LEP: M_H >115 GeV (95% CL)

Precision EW fits: M_H< 157 GeV
(185 GeV with direct LEP limit, 95% CL)

Precision measurements of m_t and M_W help to tighten these limits



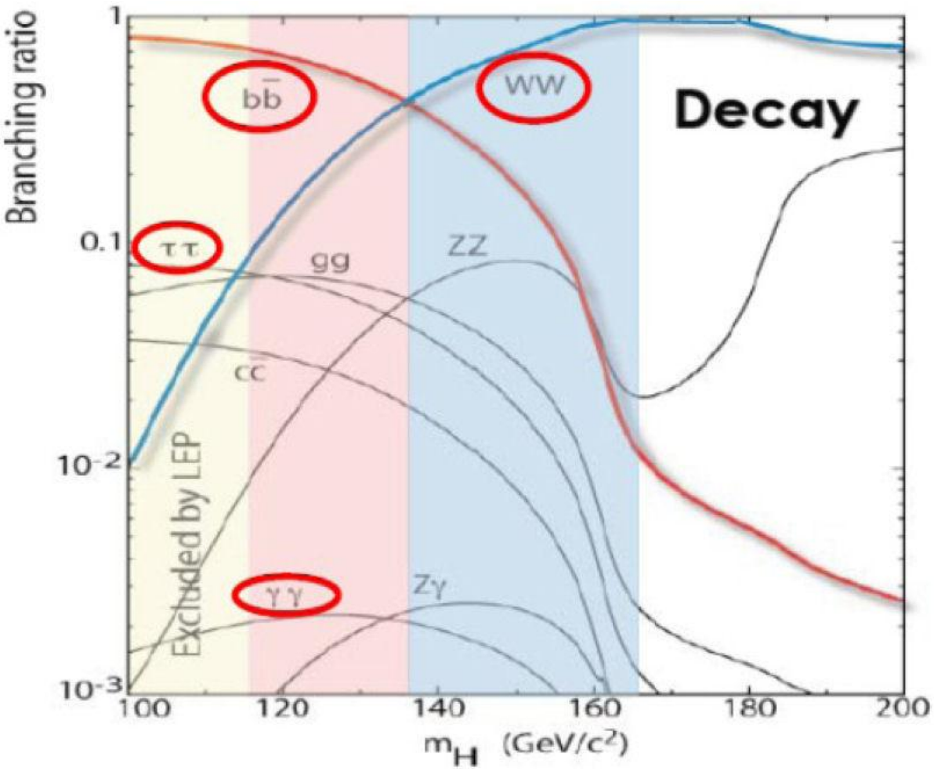


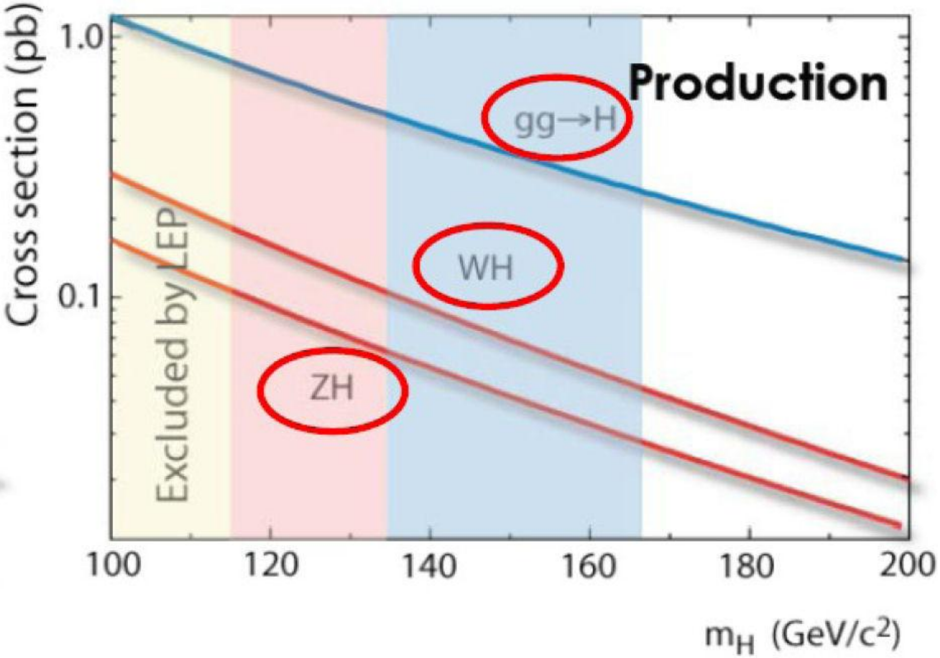
Light Higgs is favored by SM – in the Tevatron sensitivity range!

M_H > 130 GeV

gg→H→WW

Main background: WW production



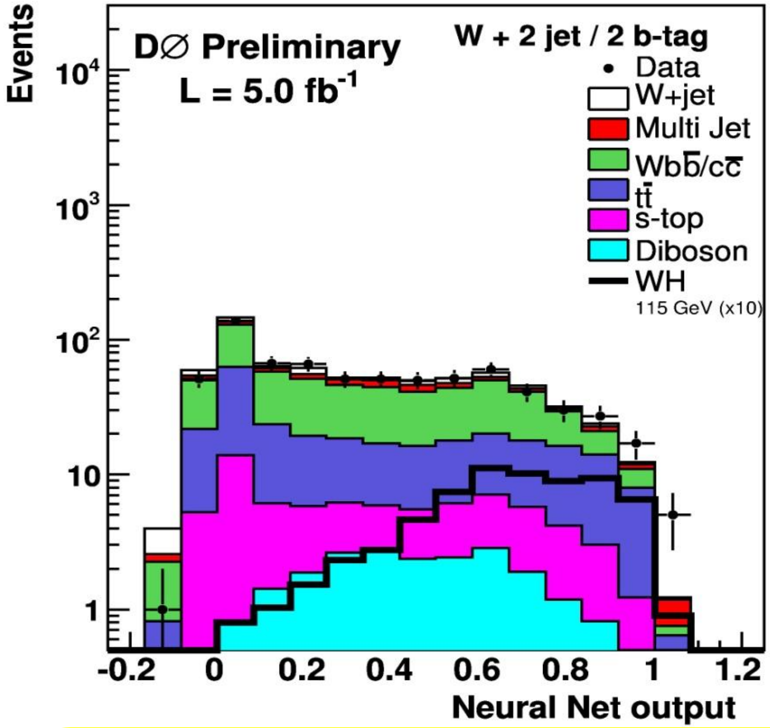


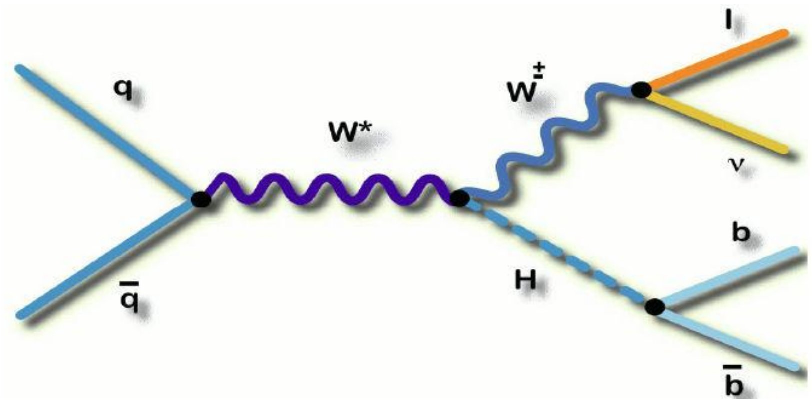
M_H < 130 GeV

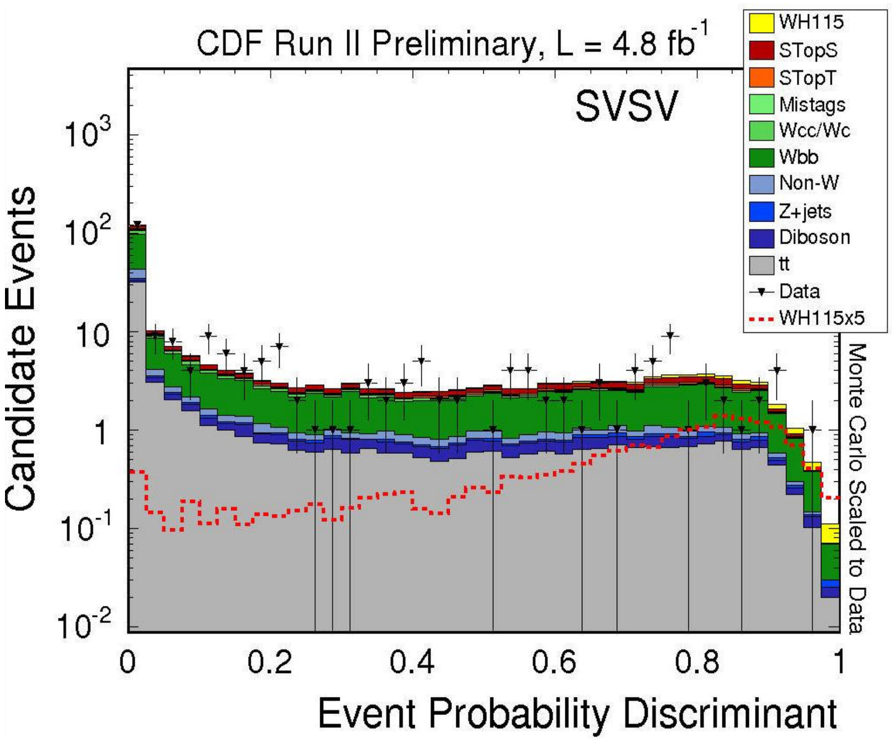
Associated ZH and WH production with H→bb decay

Main backgrounds: Wbb, Zbb, top, W/Z+jets, di-boson, QCD

Searching for SM Higgs: WH→lνbb



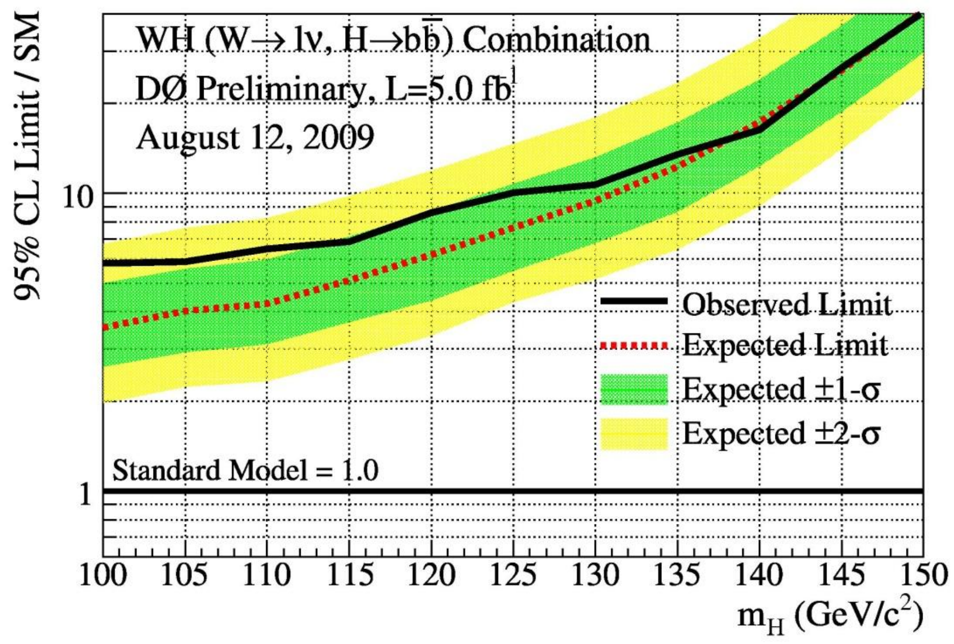


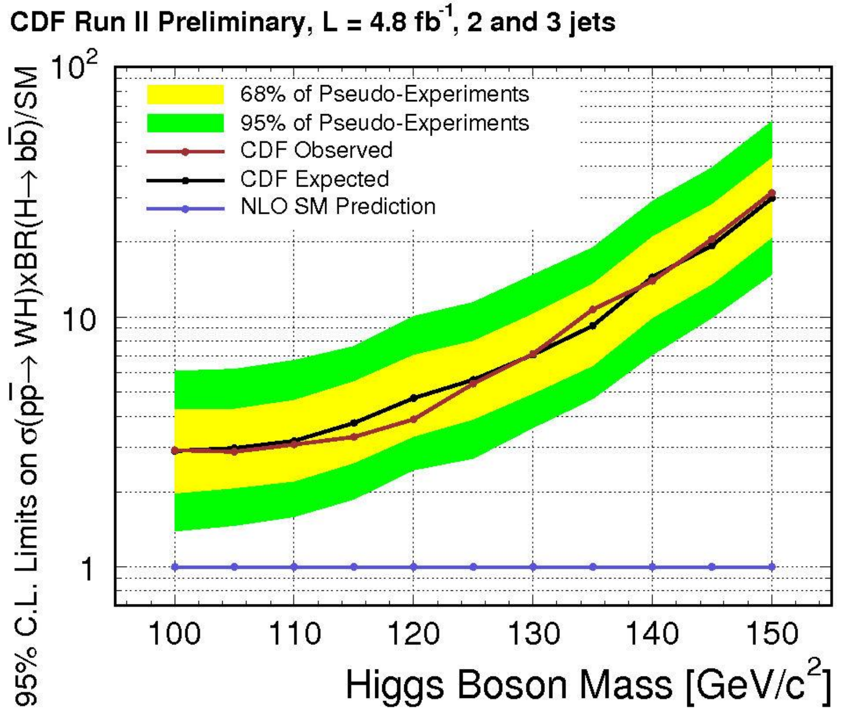


One of the most sensitive channels in the ~110-130 GeV mass range

Isolated single lepton, missing E_T, 2 or 3 high p_T jets with 1 or 2 jets b-tagged

Searching for SM Higgs: WH→lνbb





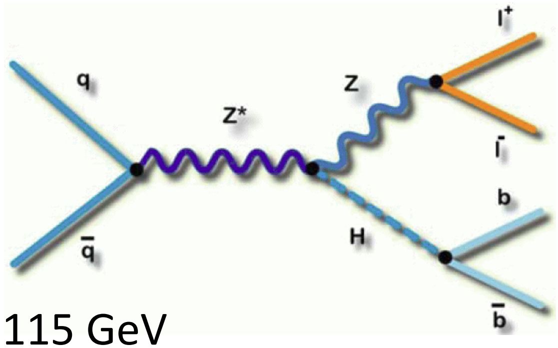
	Lum	Exp/SM	Obs/SM
D0	5.0 fb^{-1}	5.1	6.9
CDF	4.8 fb^{-1}	3.8	3.3

For M_H = 115 GeV

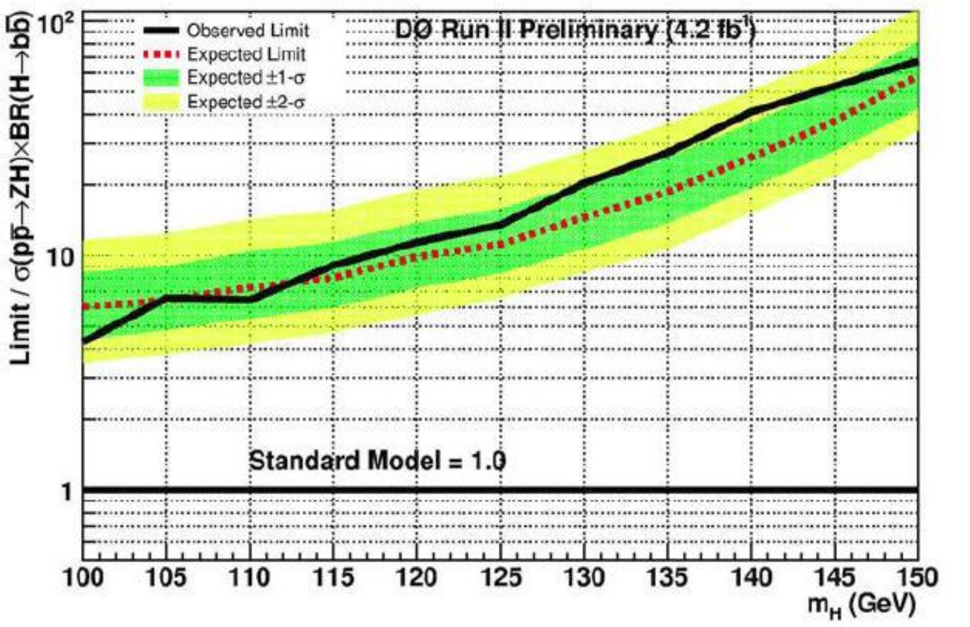
Searching for SM Higgs: ZH→l^+l^- bb

Cleanest channel, but low σ x Br

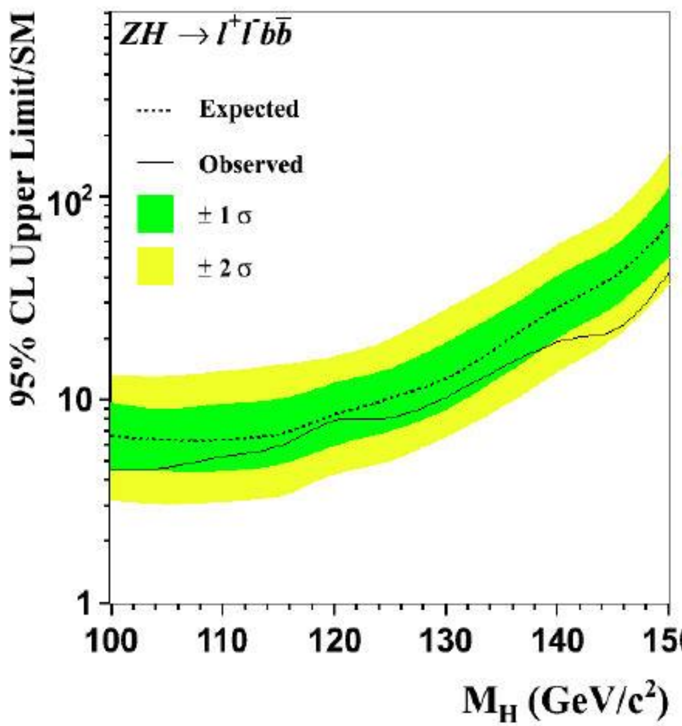
Experiment	Lum	Exp/SM	Obs/SM
D0	4.2 fb^{-1}	8.0	9.1
CDF	4.1 fb^{-1}	6.8	5.9



M_H = 115 GeV



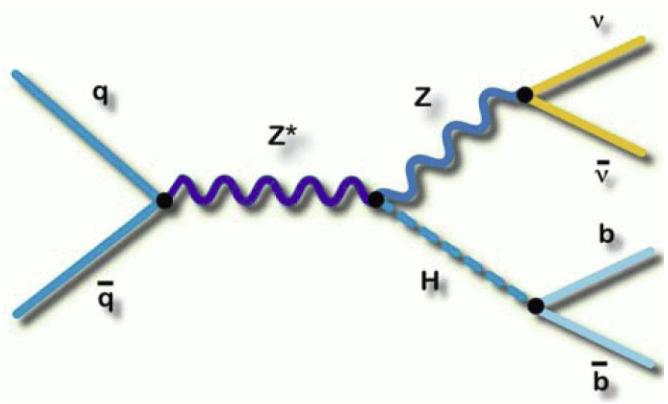
CDF Run II Preliminary (4.1 fb^{-1})



Searching for SM Higgs: $ZH \rightarrow \nu\nu\, bb$

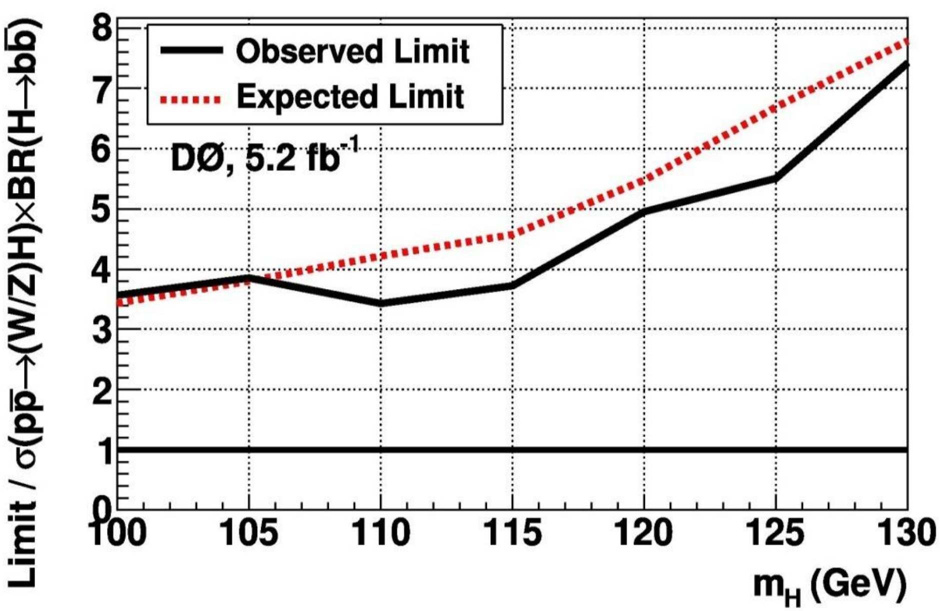
Large σ x Br but also large multijet background

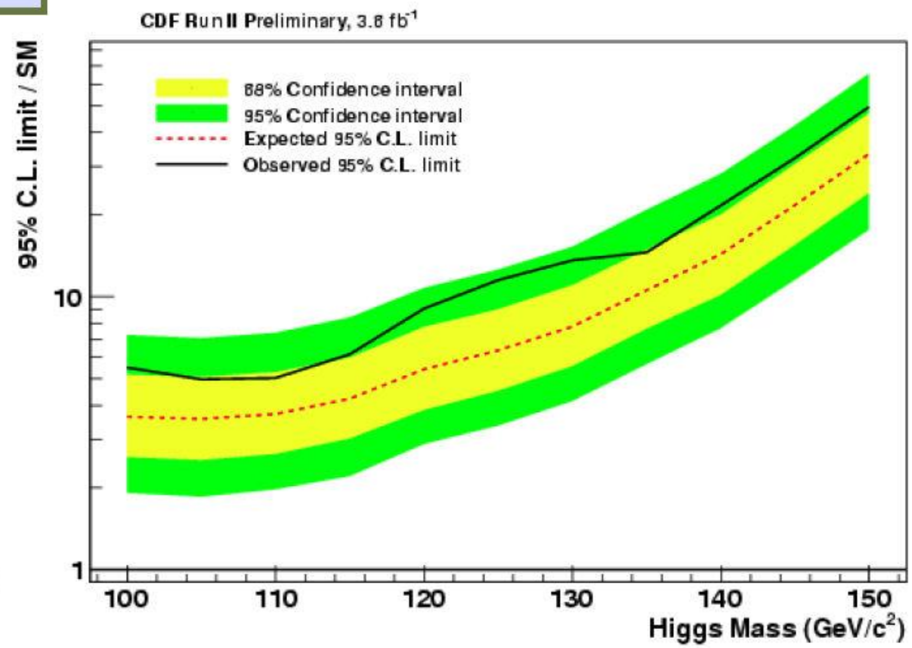
Large contribution from WH with missed lepton ($WH \rightarrow (l)\nu\, bb$)



Experiment	Lum	Exp/SM	Obs/SM
D0	5.2 fb^{-1}	4.6	3.7
CDF	3. fb^{-1}	4.2	6.1

M_H = 115 GeV

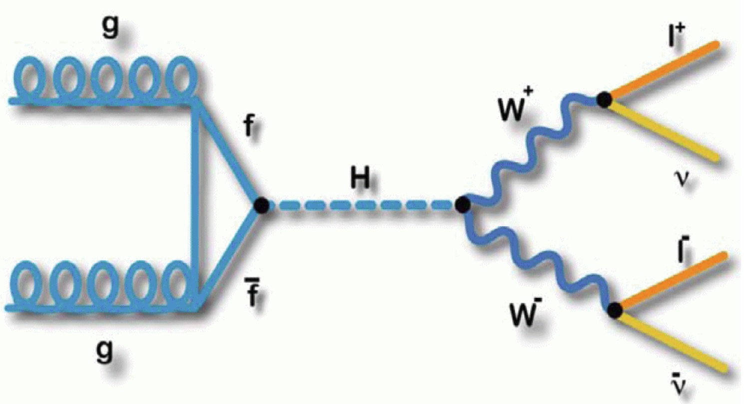


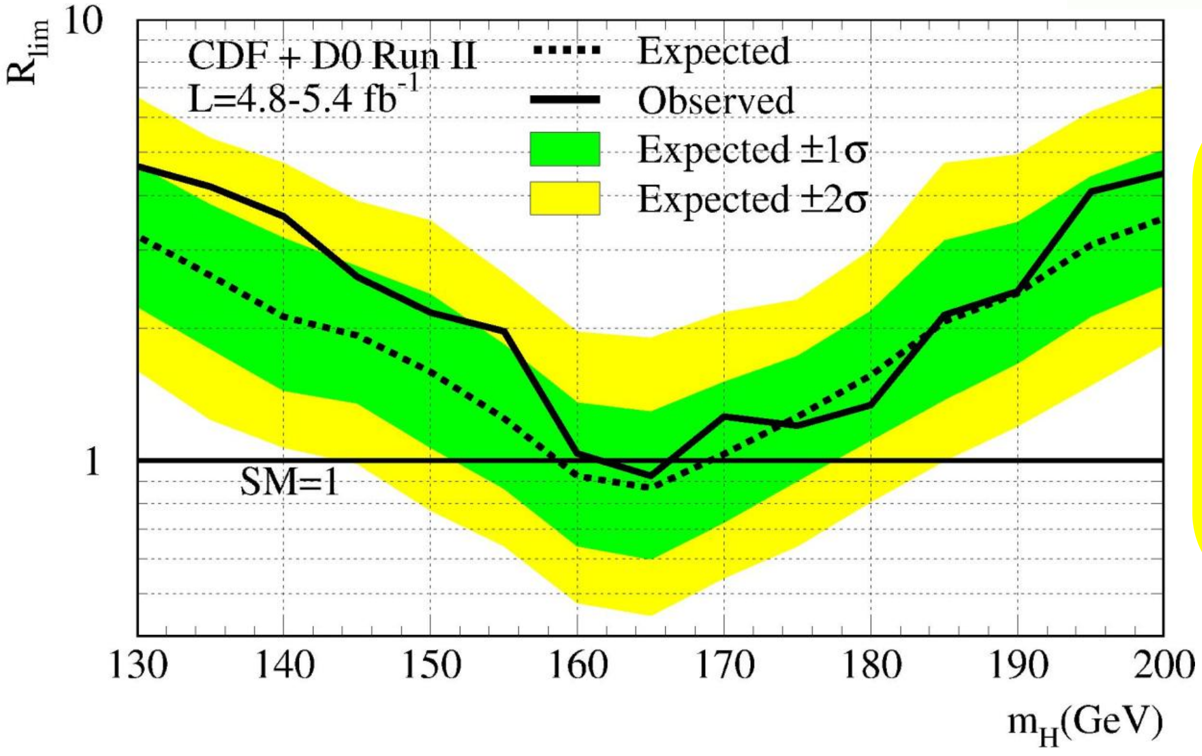


Searching for SM Higgs: H → WW

High mass region M_H>130 GeV
dominant decay mode for Higgs

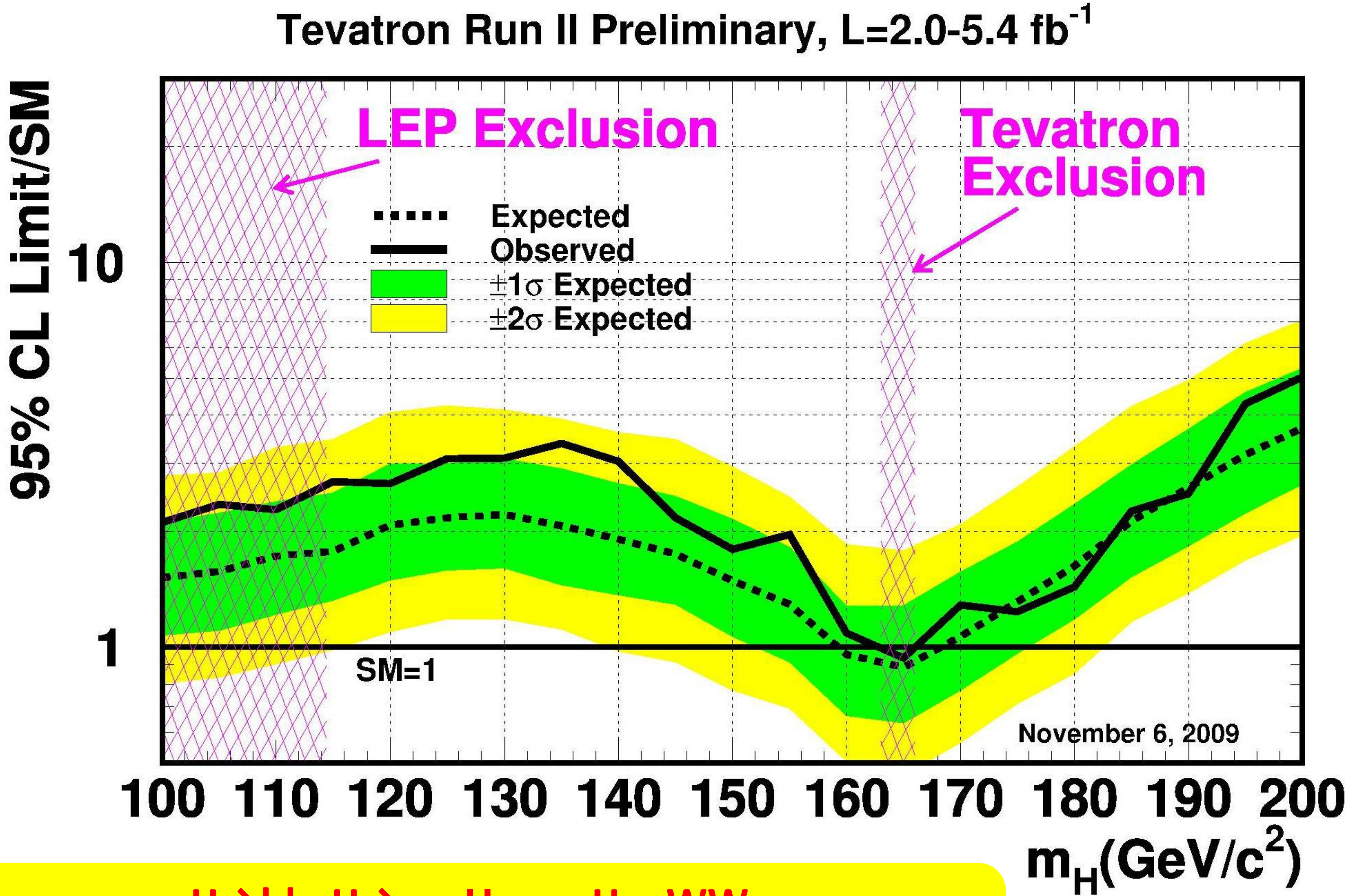
H→WW→lνlν
Clean signature and large σ x Br





Higgs mass from 162 to 166 GeV (159–169 GeV with expected limit) is excluded with 95 % CL

Searching for SM Higgs: Combination



H→bb, H→ττ, H→γγ, H→WW
(90 final states - 36 for CDF, 54 for DØ)

Beyond the SM: MSSM Higgs

- Extended Higgs sector in MSSM: two Higgs doublets, five Higgs bosons (h, H, A, $H^{\pm}$)
- Higgs sector described at LO with two parameters: mass of the A boson (M_A) and tanβ – ratio of the vacuum expectation value of the two Higgs doublets
- Most interesting region at Tevatron: low M_A and high tanβ
- In this region Higgs mostly decays to bb (~90%) and $\tau\tau$ (~10%)

$\phi \rightarrow \tau\tau$

Relatively clean signature but low Br

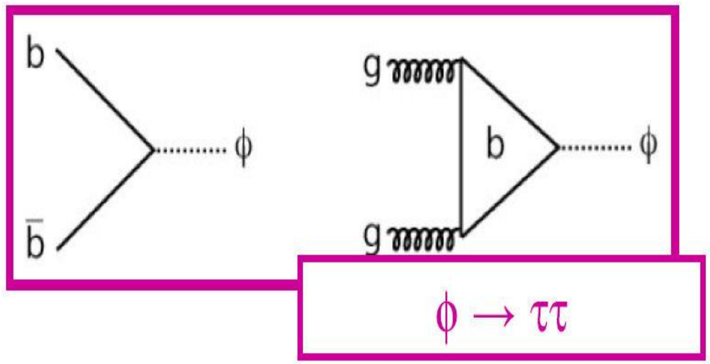
$b\phi \rightarrow b+bb$

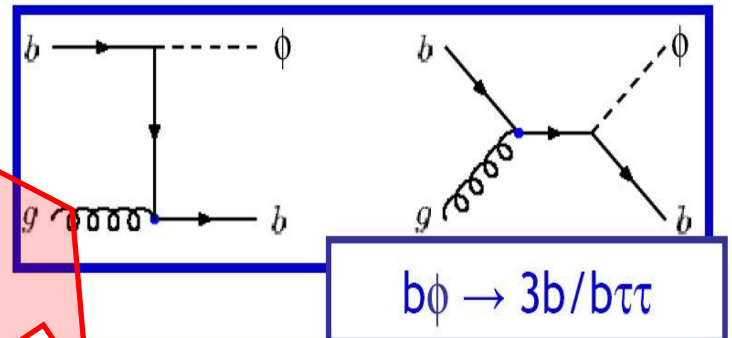
High Br but large multijet background

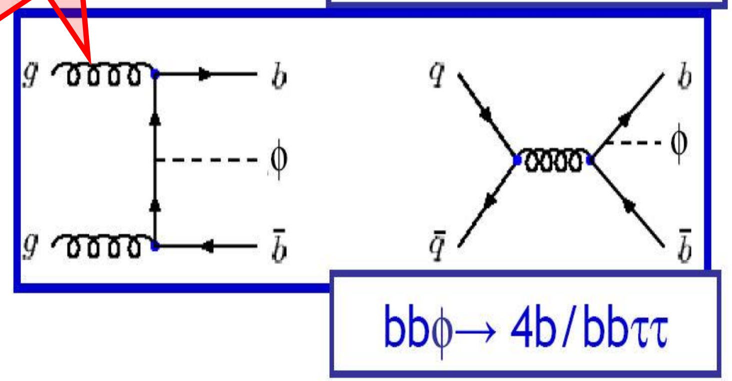
$b\phi \rightarrow b+\tau\tau$

Reduced background, additional sensitivity at low M_A

(h,H,A)$\rightarrow\phi$







Beyond the SM: MSSM Higgs

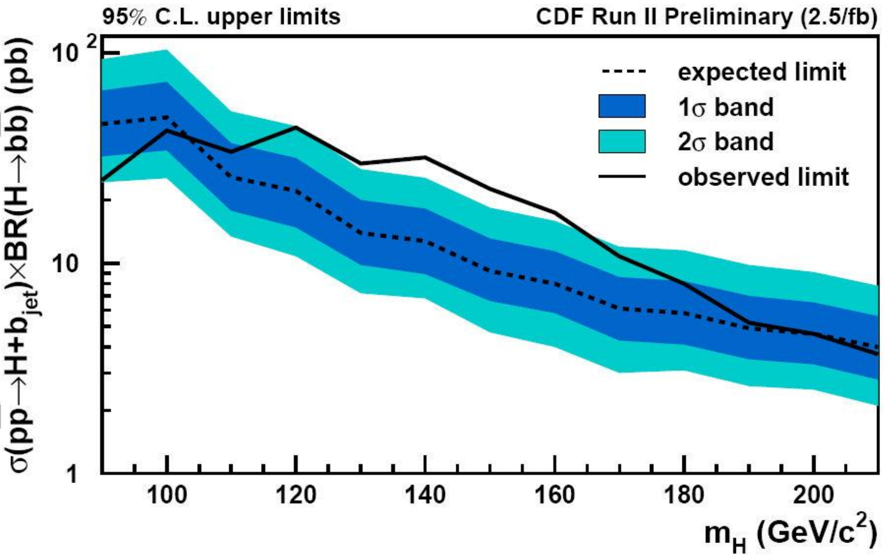
CDF (2.5 fb^{-1})

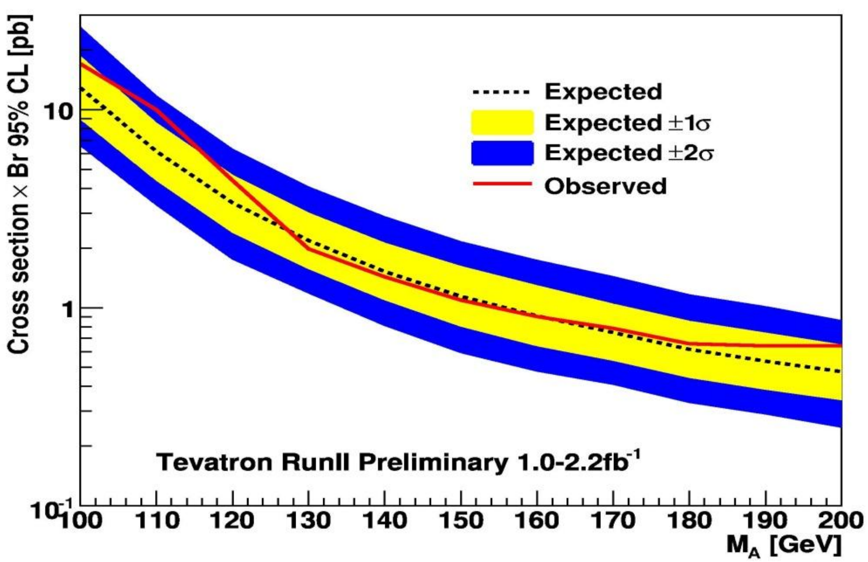
Associated production $b\phi \rightarrow b+bb$

Note an excess at 130-160 GeV region

$\tan\beta \sim 40$ for m_A=90 GeV

$\tan\beta \sim 100$–120 for m_A=110-170 GeV





Tevatron combination for

$\phi \rightarrow \tau\tau$

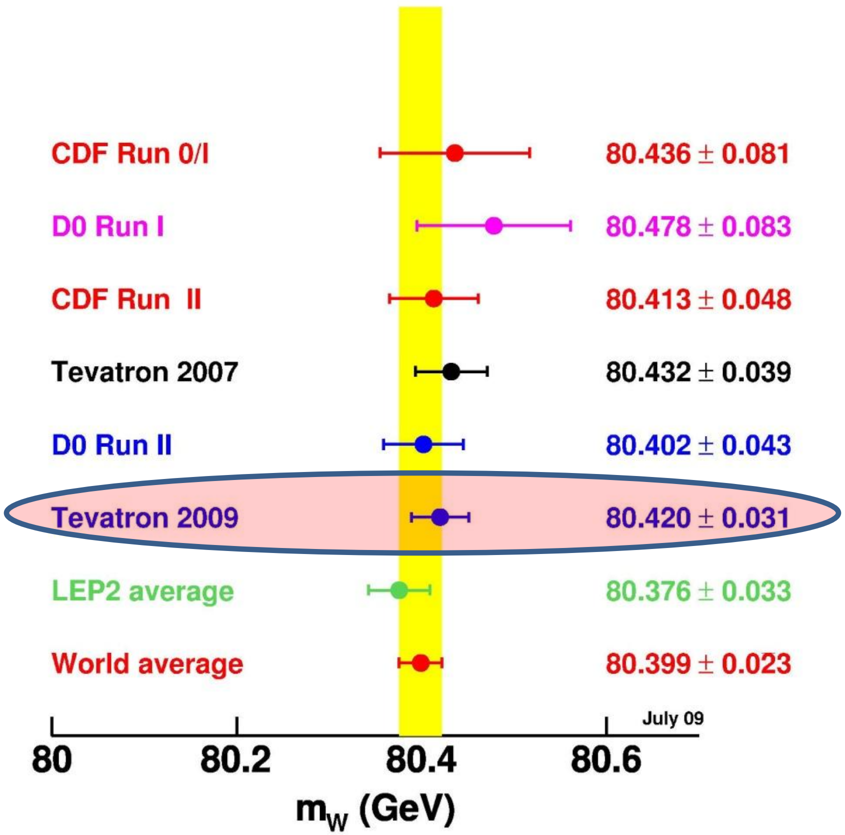
1.8 fb^{-1} for CDF, 2.2 fb^{-1} from DØ

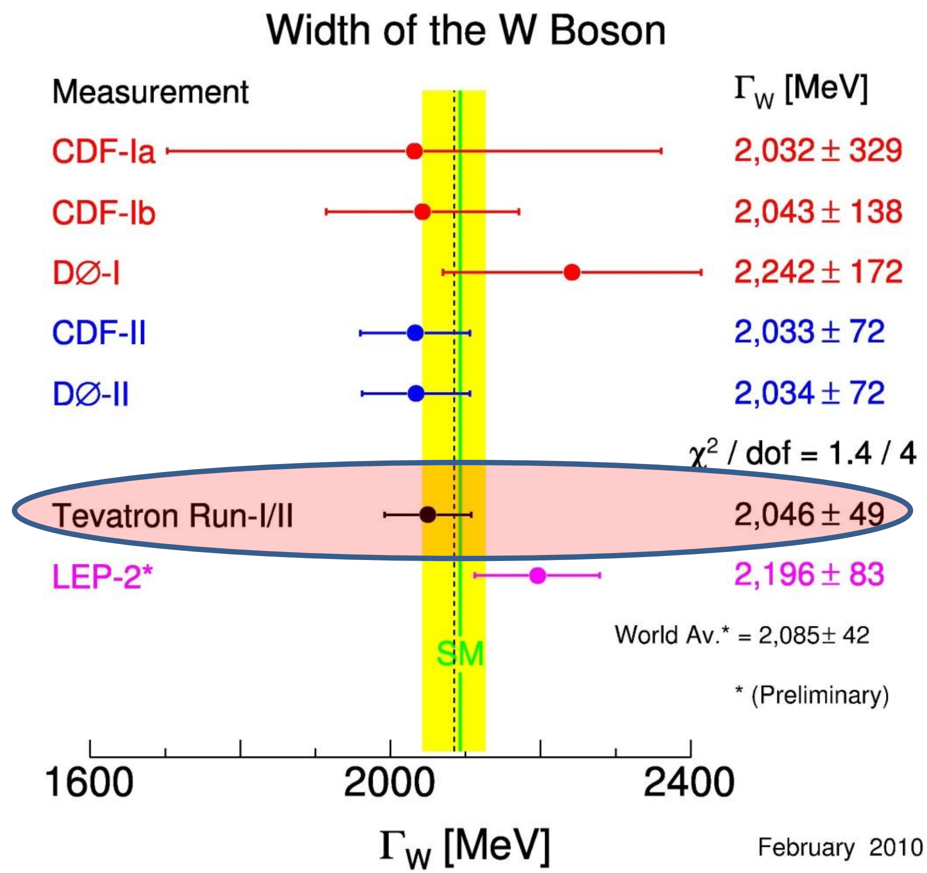
$gg \rightarrow \phi$, $bb\phi$ (CDF), $gg \rightarrow \phi$ (DØ)

No excess of events over SM prediction

$\tan\beta$ ~ 30 at m_A=130-150 GeV

Electroweak physics: W mass and width





Important parameter to constrain Higgs mass

DØ: single experiment most precise W mass measurement

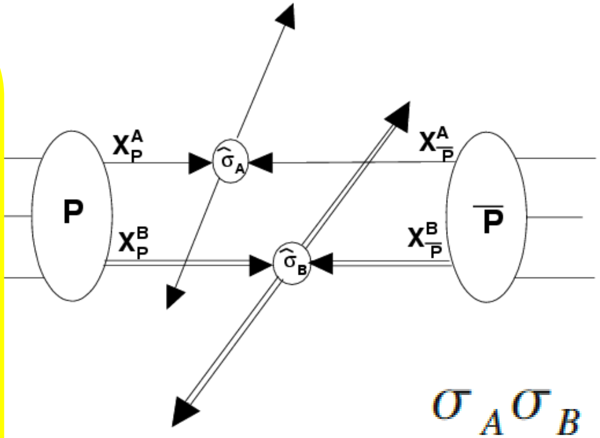
New world averages:

M_W **= 80.399 ± 0.023 GeV**

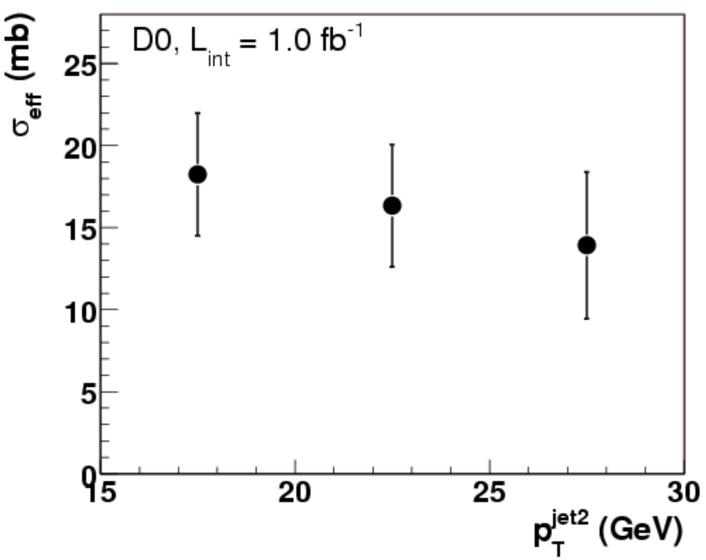
Γ_w **= 2085 ± 42 GeV**

QCD physics: double parton interactions

- Provides insight into parton spatial distributions
  - May impact PDFs
- Double Parton cross-section given on a scaling parameter σ_{eff}
  - Large values → Uniform spatial distribution
- Double Parton interaction can be background to several important rare channels, including Higgs searches



$$\sigma_{DP} = \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$



$(\gamma+jet)_A + (jet+jet)_B \rightarrow (\gamma + 3jets)$ final state

σ_{eff} values in different jet pT bins agree with each other within their uncertainties. (a slight fall can be also suggestive)

$\sigma_{eff}^{(ave)} = 16.4 \pm 0.3(stat) \pm 2.3(syst)$ mb

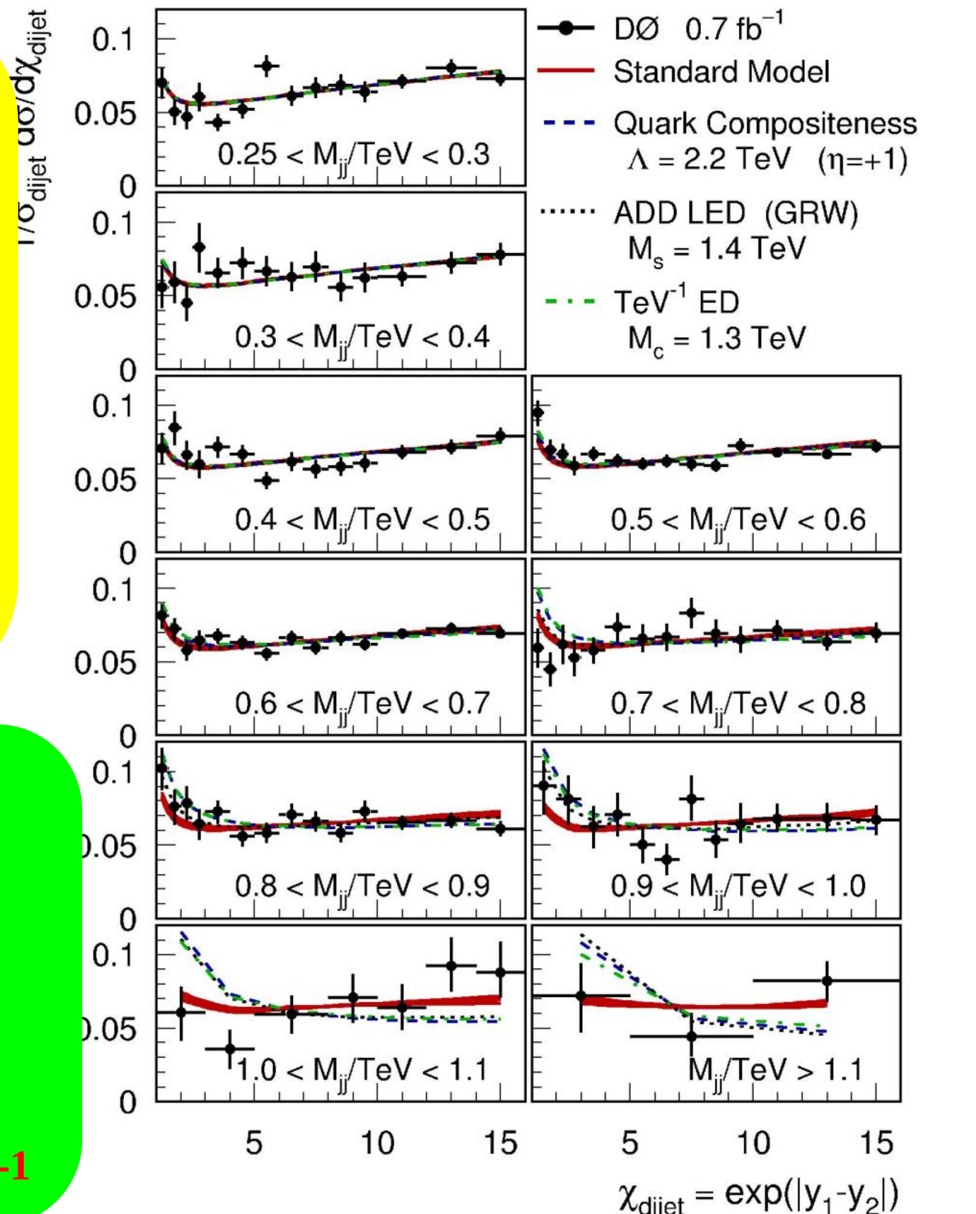
QCD physics: di-jet angular distributions

$$\chi_{dijet} = \exp(|y_1 - y_2|)$$

$$y = 0.5 \ln[(1+\beta\cos\theta)/(1-\beta\cos\theta)]$$

$$\beta = |\vec{p}| / E$$

An excess at small χ_{dijet} would be a sign for new physics



Quark compositeness: L > 2.9 TeV

ADD LED: M_S > 1.66 TeV (GRW),
M_S > 1.97 TeV (HLZ, n_d=3)

TeV^{-1} ED: M_C > 1.59 TeV

DØ, 0.7 fb^{-1}

b-physics: $B^0_{s,d} \to \mu\mu$

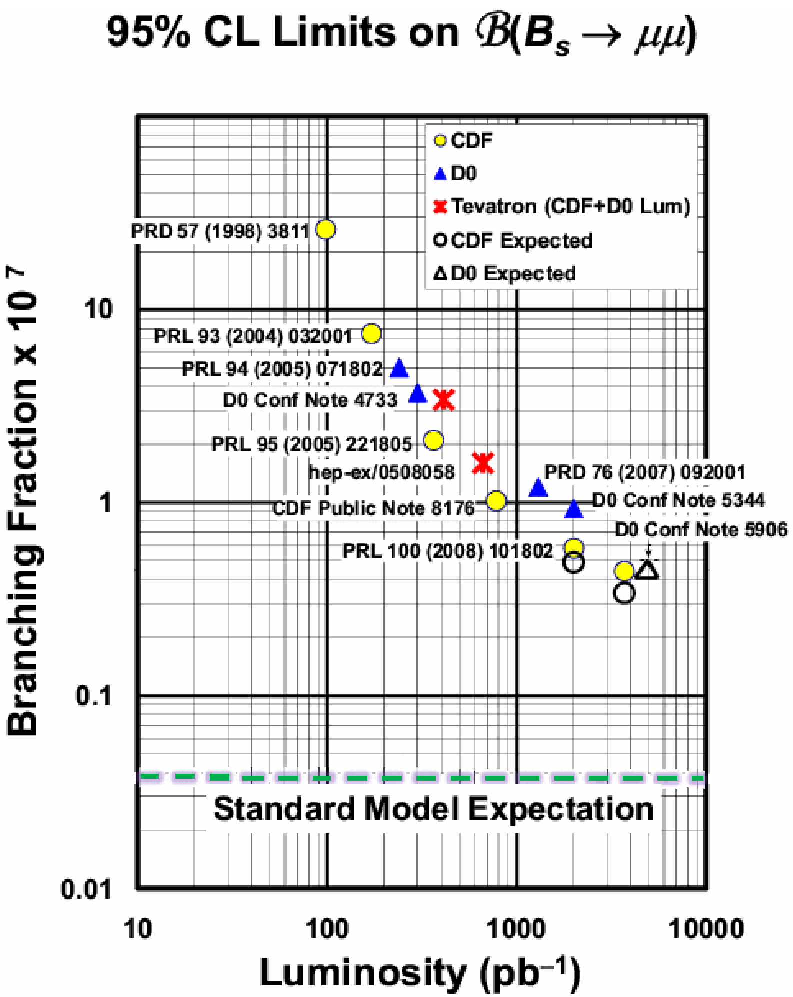
- FCNC processes highly suppressed in SM
  $(3.86\pm0.57) \times 10^{-9}$ (B^0_s), $(1.00\pm0.14) \times 10^{-10}$ (B^0_d)
- Highly sensitive to BSM physics – for example in MSSM $Br(B^0_{s,d} \to \mu\mu) \sim (\tan\beta)^6$

New limits from DØ and CDF

DØ (5 fb^{-1}): $4.3(5.3) \times 10^{-8}$ 90%(95%) CL (B^0_s)

CDF(3.7 fb^{-1}): $3.6(4.3) \times 10^{-8}$ 90%(95%) CL (B^0_s)

$6.0(7.6) \times 10^{-9}$ 90%(95%) CL (B^0_d)



Like-sign di-μ charge asymmetry

- Observed CP violation in the K^0 and B^0_d systems is not sufficient to explain matter-antimatter asymmetry of the universe – presence of additional sources of CP violation beyond the standard model
- Charge asymmetry measurement is a sensitive way to discover "anomalous" CP violation

Like sign dimuon charge asymmetry of semileptonic B decays: $A^b_{sl} = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$

One muon comes from direct semileptonic decay $b \to \mu^- X$, second muon comes from direct semileptonic decay after neutral B mixing: $B^0 \to \bar{B}^0 \to \mu^- X$

Non-zero values of A^b_{sl} means that the semileptonic decays of B^0 and $\bar{B}^0$ are different. It occurs only due to CP violation in mixing in the B systems

SM prediction of the A^b_{sl} : $(2.3^{+0.5}_{-0.6}) \times 10^{-4}$ - below the sensitivity of current experiments

DØ latest measurement: 6.1 fb^{-1} statistics

The high energy provides access to mass states beyond the reach of B-factories
Periodic reversal of the DØ solenoid and toroid polarities results in a cancellation of most detector-related asymmetries

Like-sign di-μ charge asymmetry

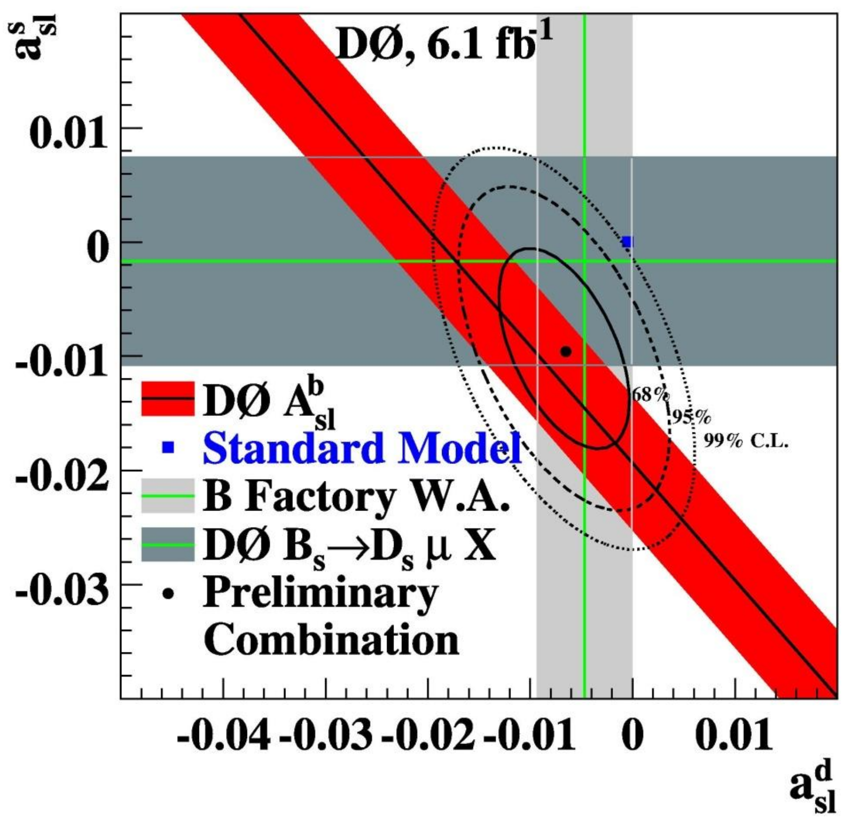
$$A=\frac{N^{++}-N^{--}}{N^{++}+N^{--}}, \quad a=\frac{n^{+}-n^{-}}{n^{+}+n^{-}}$$

$$a=k\times A_{sl}^{b}+a_{bkg}, \quad A=K\times A_{sl}^{b}+A_{bkg}$$

Sources of background

- Kaon and pion decays or punch-through
- Proton punch-trough
- False track associated with muon track
- Asymmetry in muon reconstruction

All background contributions were measured directly from data



A^{b}_{sl} = -0.00957±0.00251(stat)±0.00146(syst)

~3.2σ difference from the SM prediction

$$a_{sl}^{q}=\frac{\Gamma(\bar{B}_q^0\to\mu^{+}X)-\Gamma(B_q^0\to\mu^{-}X)}{\Gamma(\bar{B}_q^0\to\mu^{+}X)+\Gamma(B_q^0\to\mu^{-}X)}, \quad q=d,s$$

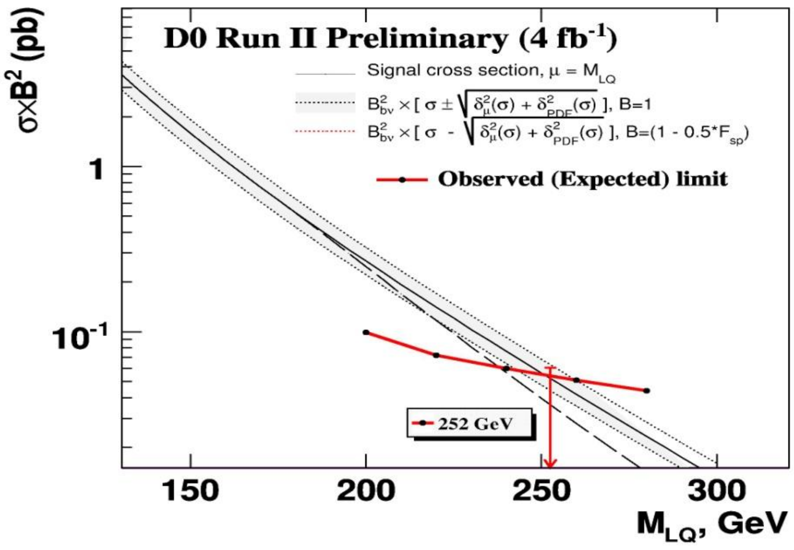
$$A_{sl}^{b}=0.506\times a_{sl}^{d}+0.494\times a_{sl}^{s}$$

New Phenomena searches

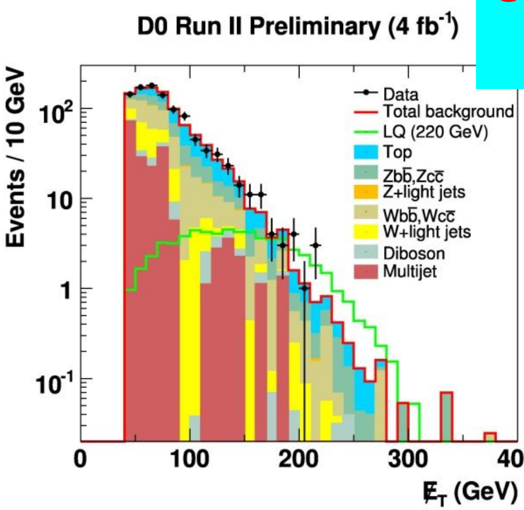
Many BSM searches progressing at the Tevatron

- Supersymmetry
- Leptoquarks (all generations)
- Technicolor
- Large extra dimensions
- Compositeness
- Extra gauge bosons
- MIS

… and many more



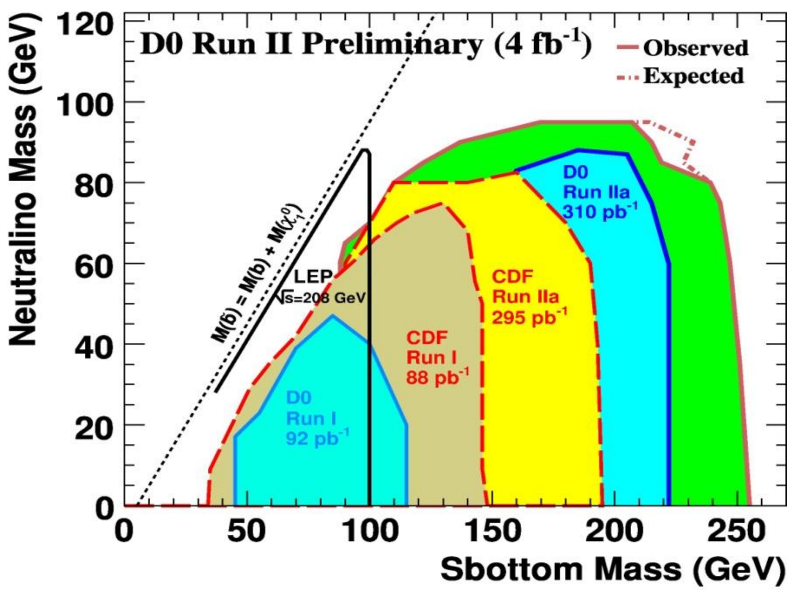
3rd generation leptoquarks DØ (4 fb^{-1})



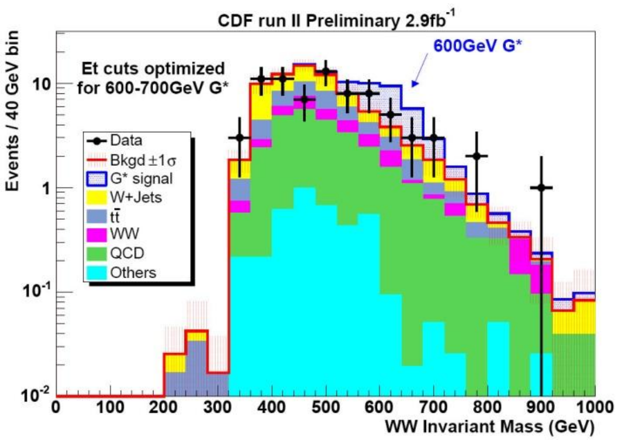
$LQ_3 \rightarrow \nu b$ or $\tilde{b}_1 \rightarrow b\tilde{\chi}^0_1$

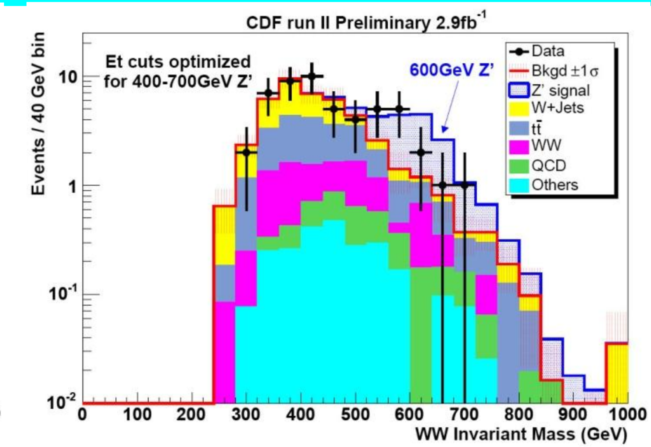
Final state: $b\bar{b}$+MET

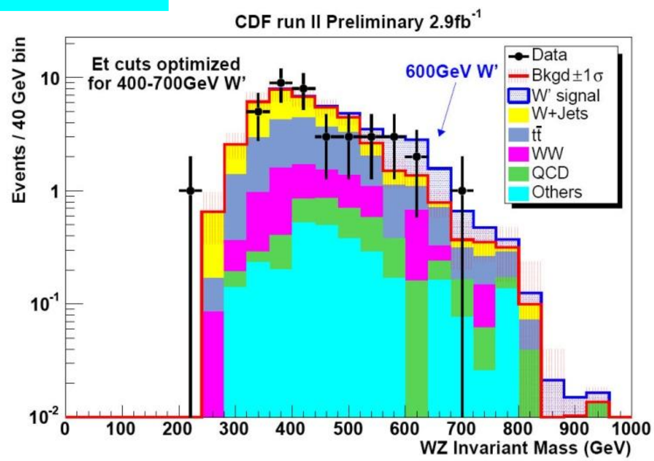
M_{LQ}>252 GeV for β=0



WW and WZ resonances (CDF, 2.9 fb^{-1})





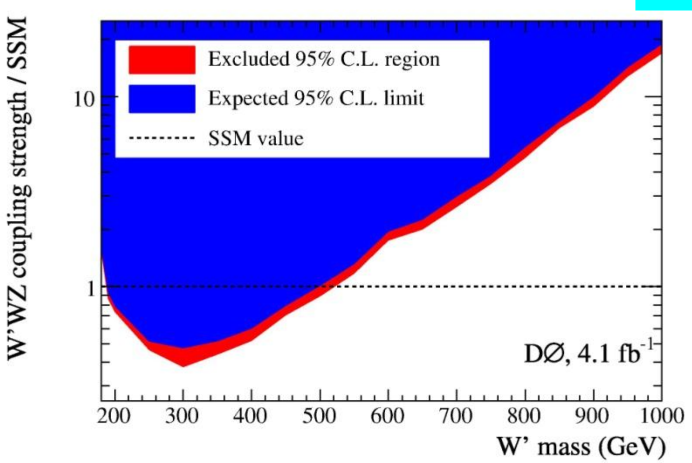


$M(G^*) > 607$ GeV
(95% CL, $k/M_{PL}=0.1$)

$247>M(Z')>545$ GeV
(95% CL)

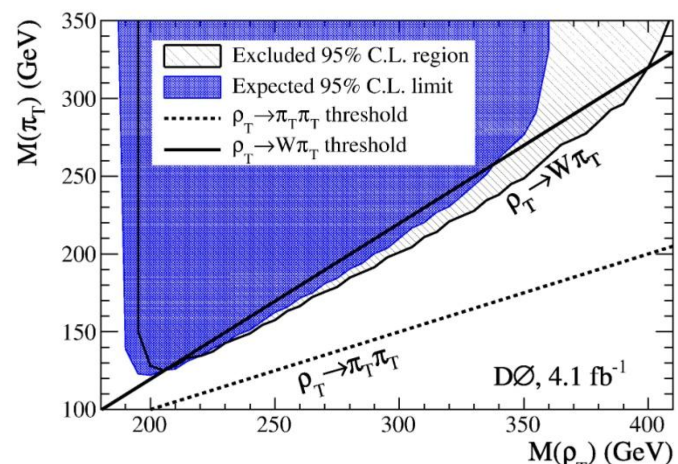
$284>M(W')>515$ GeV
(95% CL)

WZ resonances (DØ, 4.1 fb^{-1})

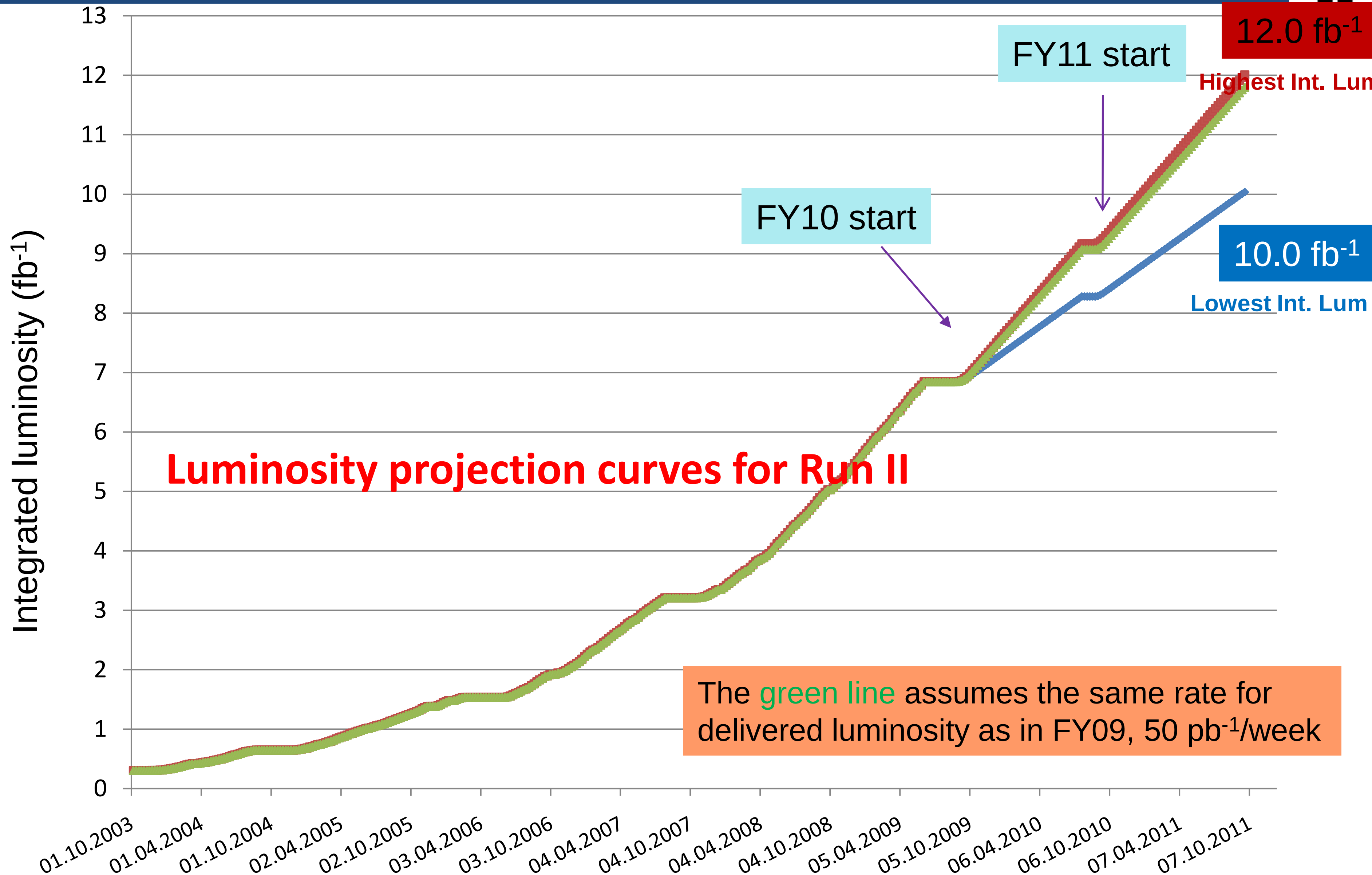


$188>M(W')>520$ GeV
(95% CL)

$208>M(\rho_T)>408$ GeV
(95% CL,
$M(\rho_T)<M(\pi_T)+M(W)$)



Tevatron perspectives



Summary

- Tevatron is performing extremely well: ~12 fb^{-1} by 2011
- Experiments are collecting and analyzing data smoothly
  - Many discoveries and precision measurements
  - ~200+ studies in progress publishing 1-2 papers per week
- Some hints of the physics beyond the standard model:
  - Like-sign di-μ charge asymmetry (needs to be confirmed)
- SM (and beyond) Higgs searches is in a very active stage
  - Excluded at 95% CL Higgs with mass 162-166 GeV
  - Proceeding to exclude wider mass range or… to discover the Higgs!
- Currently Tevatron run is expected to proceed at least till late 2011 and discussion of the extension of the Tevatron run for another few years is in progress: looking with excitement forward for continuing exciting physics results from the Tevatron experiments!

Backup slides

- **Excursions from the SM can be described via effective Lagrangian:**

$$\frac{L_{WWV}}{g_{WWV}} = g_V^1 (W^+_{\mu\nu} W^\mu V^\nu - W^+_\mu V_\nu W^{\mu\nu}) + k_V W^+_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W^+_{\lambda\mu} W^\mu_\nu V^{\mu\lambda}, \quad V = Z, \gamma$$

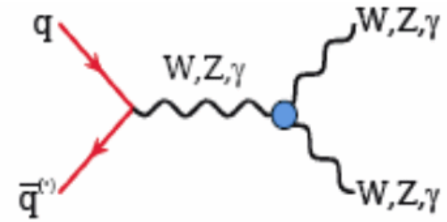
- **In SM** $g_V^1 = k_V = 1, \quad \lambda_V = 0$

- **Anomalous Triple Gauge Couplings (TGC) increase production cross-sections, particularly at high values of the boson p_T**

- **W magnetic dipole and quadrupole moments:**

$$\mu_W = \frac{e}{2M_W}(g_\gamma^1 + k_\gamma + \lambda_\gamma)$$

$$q_W = -\frac{e}{M_W^2}(k_\gamma - \lambda_\gamma)$$



$q\bar{q}' \rightarrow W^{(*)} \rightarrow W\gamma$: $WW\gamma$ only

$q\bar{q}' \rightarrow W^{(*)} \rightarrow WZ$: WWZ only

$q\bar{q} \rightarrow Z/\gamma^{(*)} \rightarrow WW$: $WW\gamma, WWZ$

$q\bar{q} \rightarrow Z/\gamma^{(*)} \rightarrow Z\gamma$: $ZZ\gamma, Z\gamma\gamma$

$q\bar{q} \rightarrow Z/\gamma^{(*)} \rightarrow ZZ$: $ZZ\gamma, ZZZ$

Absent in SM

Latest DØ result for TGC:

$$k_\gamma = 1.07^{+0.16}_{-0.20}, \quad g_Z^1 = 1.05 \pm 0.06$$

$$\lambda = 0.00^{+0.05}_{-0.04}$$

$$\mu_W = 2.02^{+0.08}_{-0.09} \times (e/2M_W)$$

$$q_W = -1.00 \pm 0.09 \times (e/M_W^2)$$