Searching for new phenomena at Tevatron

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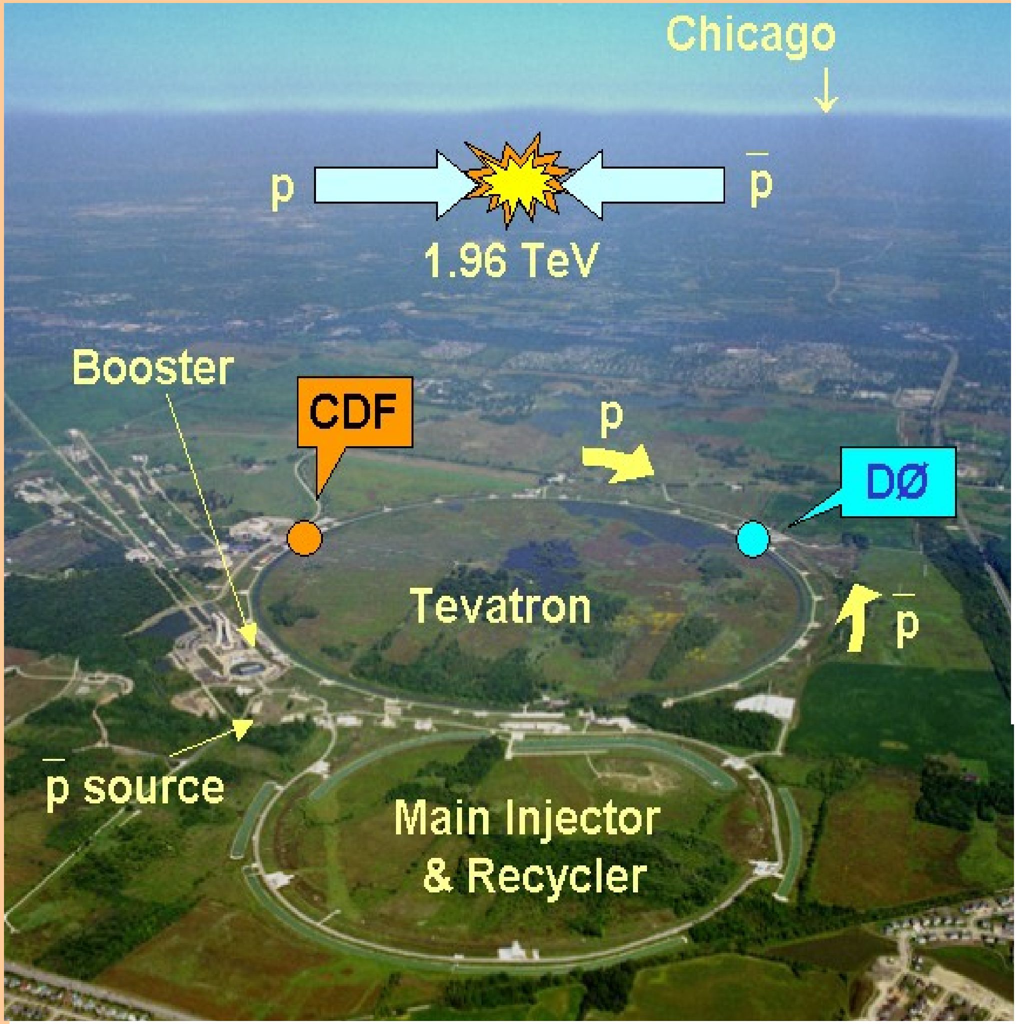
on behalf of CDF & D∅ collaborations

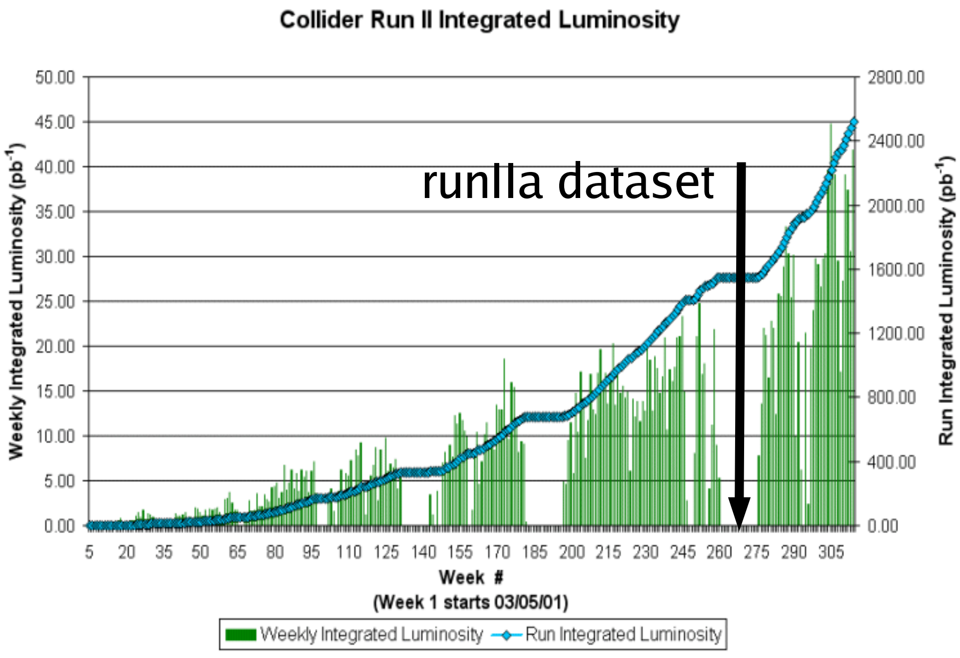
5th workshop “Flavor in the Era of LHC”

Overview

- TeVatron, CDF & DØ detectors
- Where might new physics show in flavor physics ?
- Searches for sparticles pair production
- Higgs bosons searches
- New physics in top decays
- Conclusions

The TeVatron





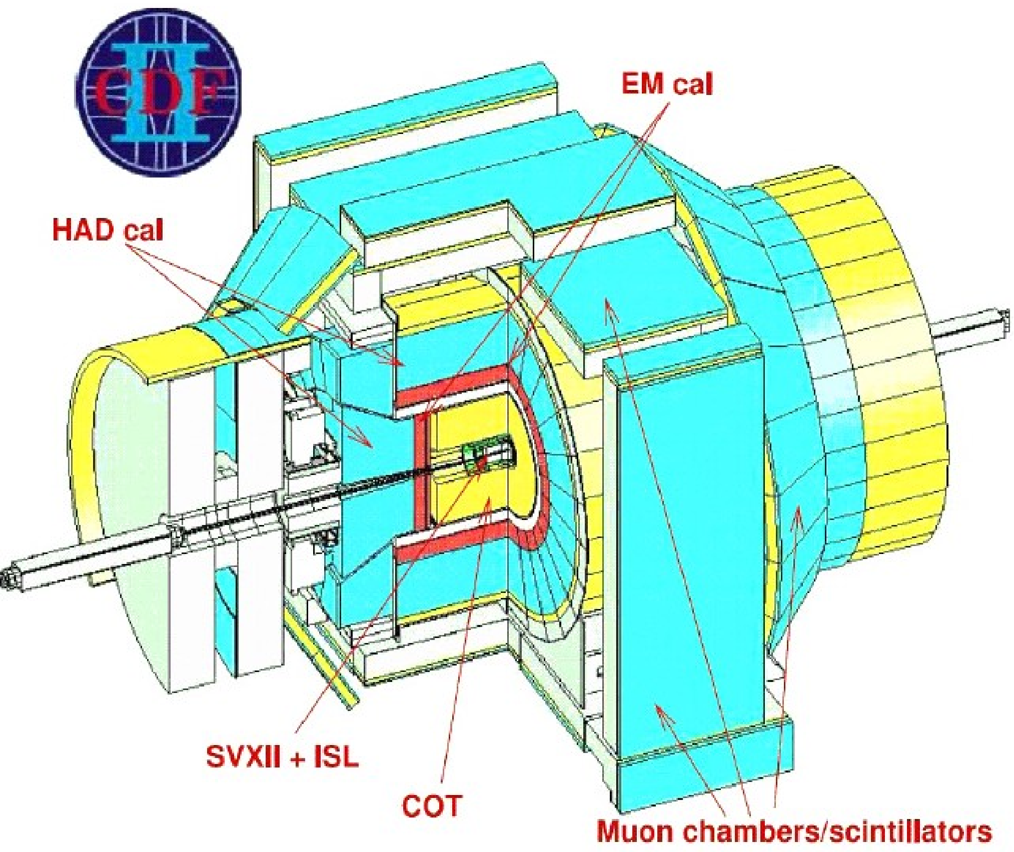
Data taking efficiency: 85-90%

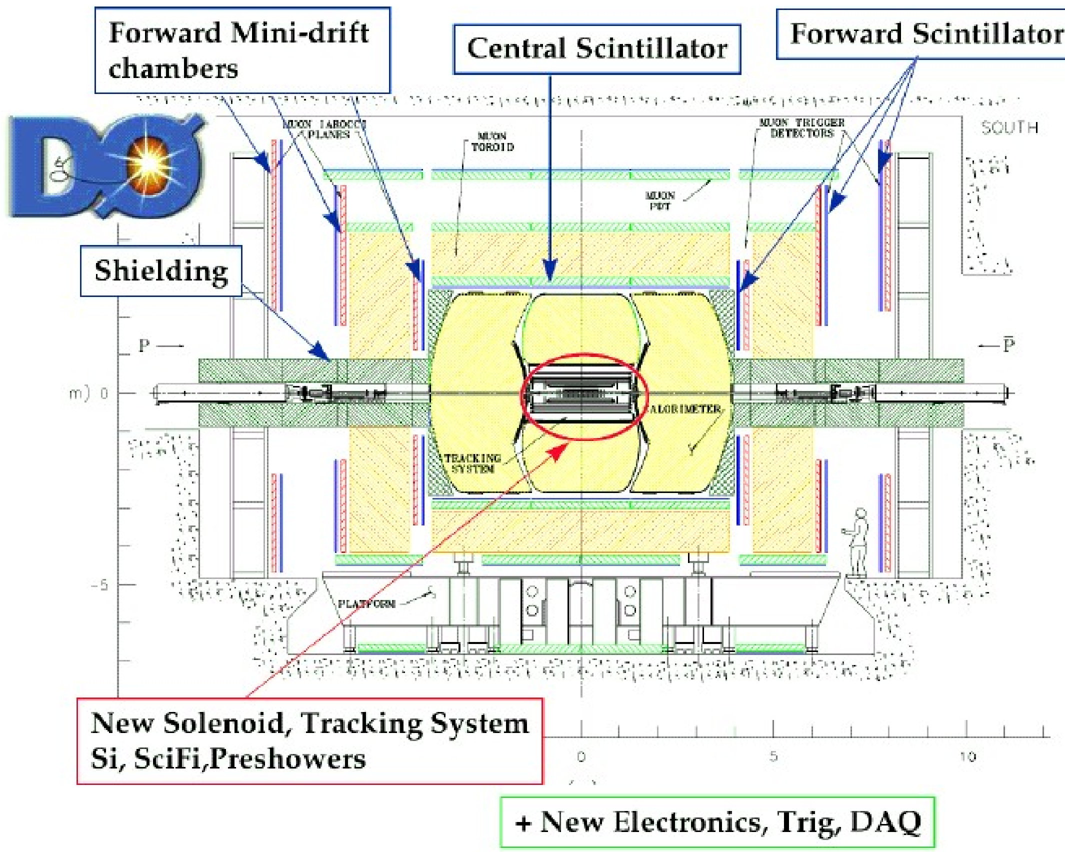
run IIa dataset: 1.2 fb^{-1}

Peak luminosity record

285E30 cm^{-2}/s^{-1} (February 2007)

DØ and CDF detectors



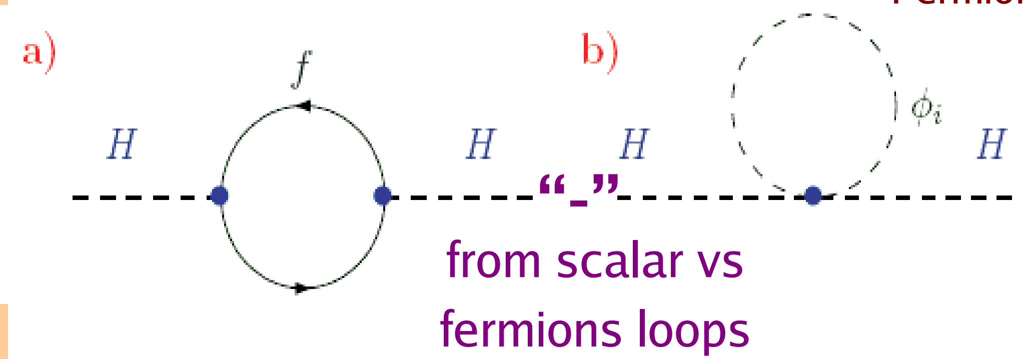


Multipurpose detectors able to reconstruct (and identify) e, μ, τ, light and heavy jets, missing transverse energy $\not{E}_T$

Where might new physic show up in Flavor Physics? The MSSM example

SUSY in a nutshell

- SUSY relates bosons to fermions. But it requires a complete set of new particles ("s"-particles): can not "only" relate known bosons to known fermions
- One of the main appeals: it solves naturally the hierarchy problem provided that $m_{Fermion}$ close to m_{Scalar}



$$= \Delta M_H^2 = \frac{\lambda_f^2 N_f}{4\pi^2}\left[(m_f^2 - m_S^2)\log\left(\frac{\Lambda}{m_S}\right)\right]$$

Quadratic divergences cancel out, only logarithmic ones remain !

⇒ New particles masses should not be much higher than TeV

⇒ Can be produced "on-shell" at the Tevatron/LHC! (direct searches)

⇒ *B* physics : they can also contribute to penguin diagrams

The MSSM Higgs sector

- **SUSY requires at least 2 Higgs doublets** (to cancel higgsino contribution to triangle anomalies, structure of superpotential)

MSSM: exactly 2 doublets
⇒ 1 couples to down (up) quarks with vev v_d (v_u): $\tan\beta = v_d/v_u$.

NB: if $\tan\beta \approx 40 \Rightarrow \lambda_{top} \approx \lambda_{bottom}$... large $\tan\beta$ regime appealing

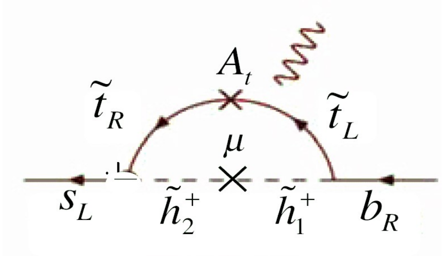
⇒ After EW breaking: 5 Higgs bosons remain:
- 3 neutral : h/H (CP-even) and A (CP-odd) (convention: $m_H > m_h$)
- 2 charged : H^+, H^-

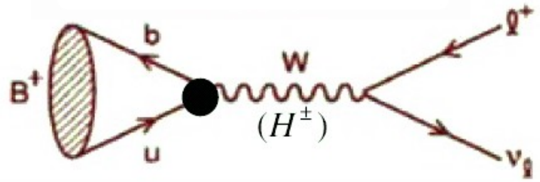
- In susy models, Higgs sector has only 2 parameters, usually M_A and $\tan\beta$, at tree level

⇒ M_h, M_H and $M_{H\pm}$ are function of M_A and $\tan\beta$ at tree level, more model dependent after radiative corrections
⇒ ∀ MSSM parameters, M_h < 135 (150) GeV/c^2. A light Higgs boson must exist if MSSM is realized!

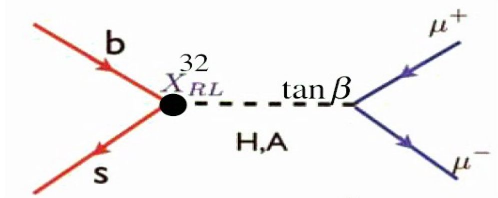
Connection with flavor physics

- In MFV models, no new source of FCNC appear at tree level!
- *B* physics, some examples :
  - Penguins: $b \to s\,\gamma$
  - Charged Higgs in $B^+ \to \tau^+ \upsilon$
  - B_s mixing: some few ps^{-1} less than in SM
  - BR($B_s \to \mu\mu$)





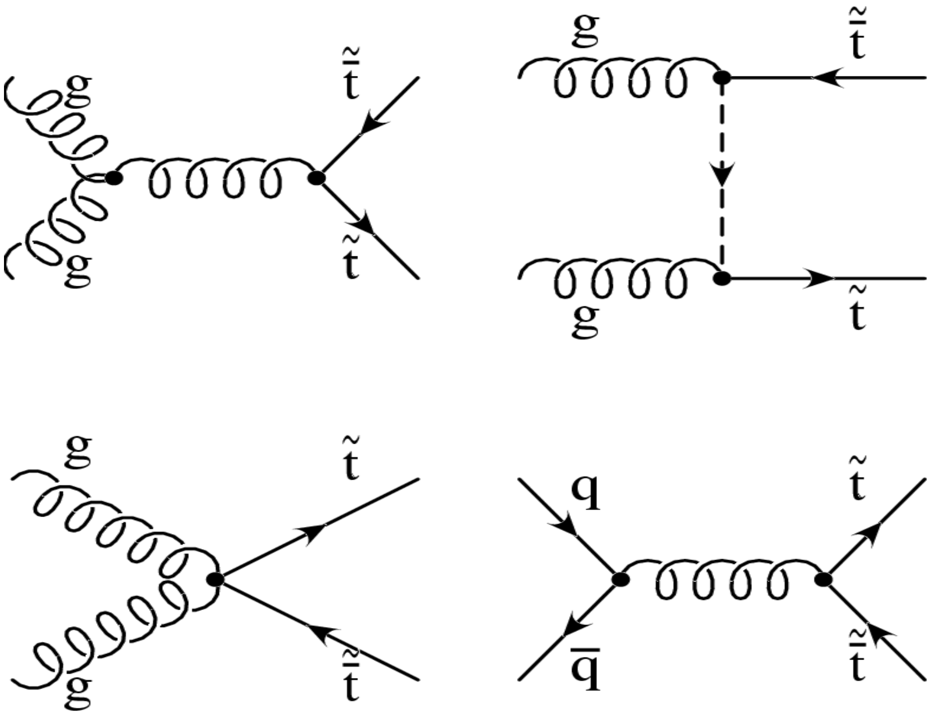
Up to 2 orders of magnitude higher than in SM! ($BR_{SM} = 10^{-9}$)



$$BR(B_S \to \mu^+\mu^-)^{SUSY} \propto \frac{|X_{RL}^{32}|^2 \tan\beta^2}{m_A^4} \propto \frac{|\mu A_t|^2 \tan\beta^6}{m_A^4}$$

- Top quark: the Wtb vertex is not alone anymore, 2Higgs Doublet Models provide H^+tb. Change in the top production (single top) and/or in the top decay ($t \to Hb$ + $t \to Wb$) depending on the H vs top mass.

Search for pair production of super-particles (RPC)



Squarks and gluino production

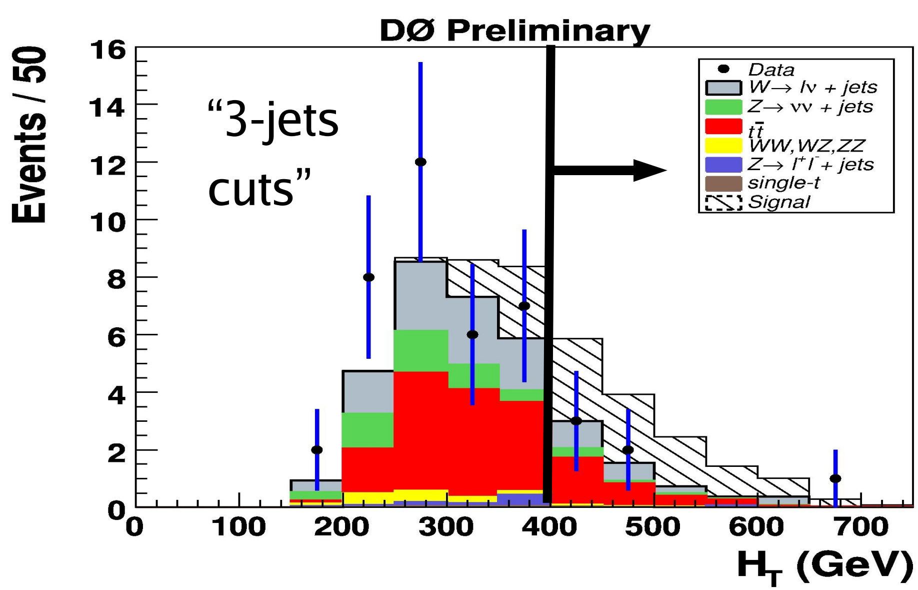
Interpret results in mSugra models:

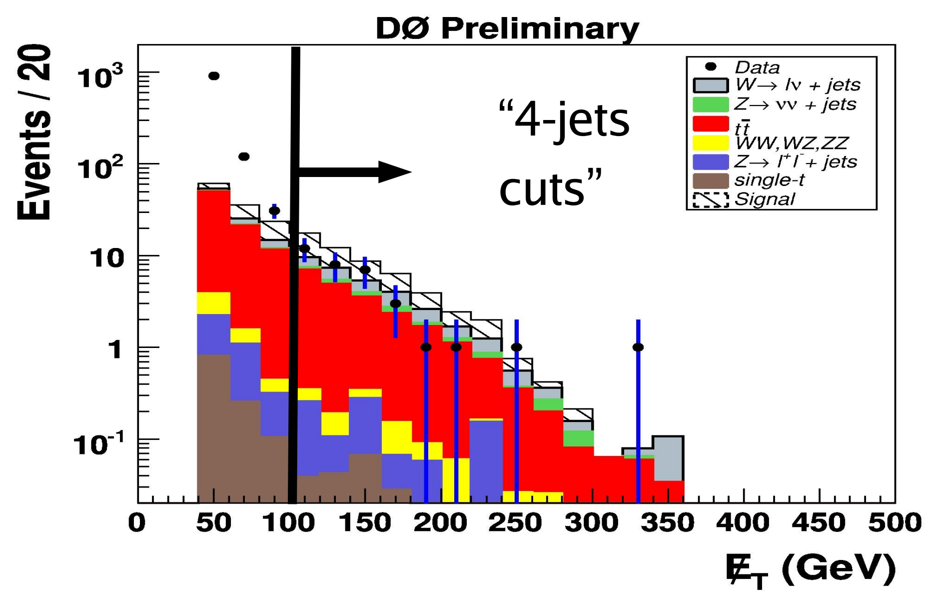
- assume all squarks (except stop) masses are nearly degenerate and
- if gluinos lighter than squarks $\Rightarrow \tilde{g} \rightarrow q\,\bar{q}\,\tilde{\chi}_1 0$
- If squarks lighter than gluinos $\Rightarrow \tilde{q} \rightarrow q\,\tilde{\chi}_1^0$

DØ preliminary
1 fb^{-1}

Three analyses depending on the mSugra parameters

- low m_0 : $\tilde{q}\tilde{\bar{q}}$ production dominates, 2 jets + $\not{E}_T$
- intermediate m_0 : $\tilde{q}\tilde{g}$ production dominates, 3 jets + $\not{E}_T$
- high m_0 : $\tilde{g}\tilde{g}$ production dominates, 4 jets + $\not{E}_T$





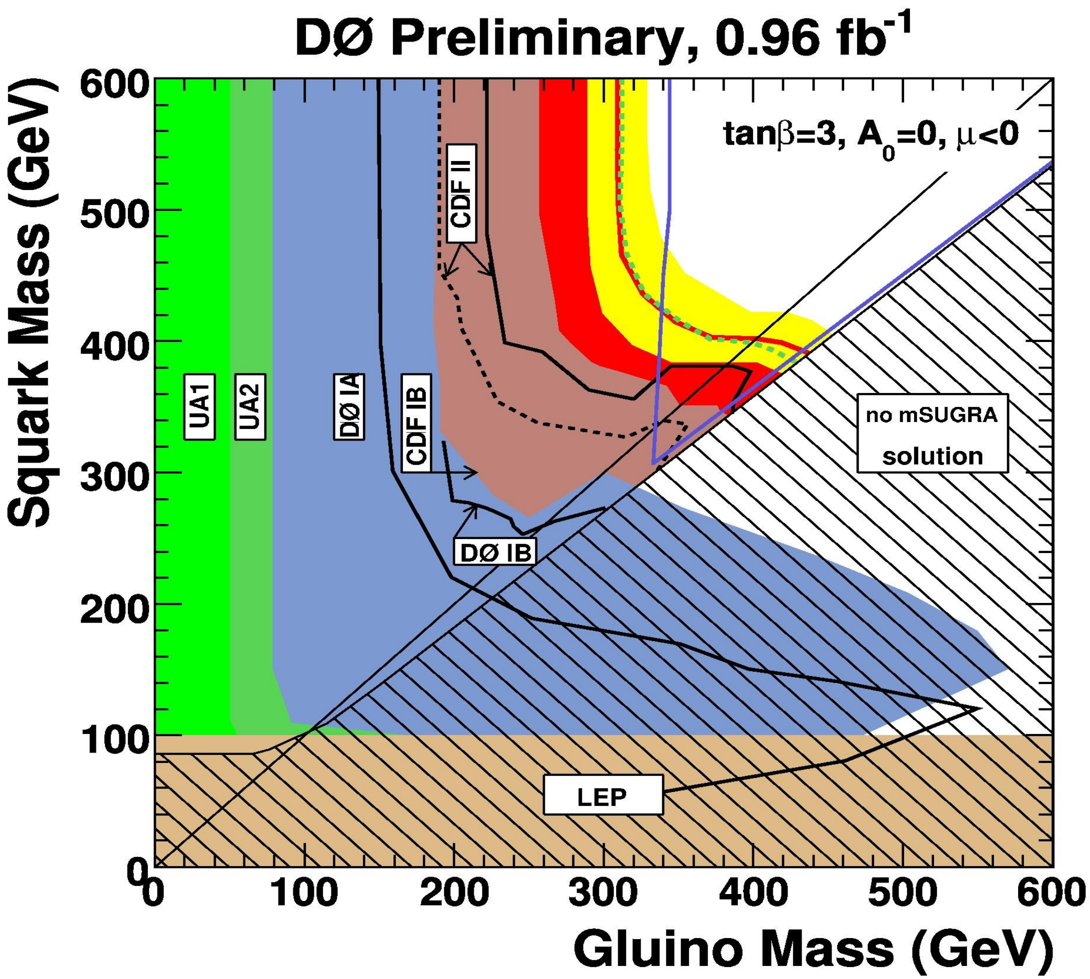
Squarks, gluinos production

Interpret results in mSugra model with: $\tan\beta = 3$; $A_0 = 0$; $\mu < 0$

Analyses optimized for benchmarks :

Analysis	$(m_0, m_{1/2})$ GeV	$(m_{\tilde{g}}, m_{\tilde{q}})$ GeV
"dijet"	(25,165)	(416,375)
"3-jets"	(188,145)	(380,380)
"gluino"	(500,100)	(296,542)

$$M_{\tilde{g}} > 289 \text{ GeV}$$
$$M_{\tilde{q}} > 375 \text{ GeV}$$



Sbottom pair production

high tanβ lead to a large separation of sbottom mass eigenstates (large X_b):
one sbottom could be light enough to be produced and detected at Tevatron.

Final state $bb\,\tilde{\chi}_1^0\tilde{\chi}_1^0$

assume $B(\tilde{b}\rightarrow b\tilde{\chi}_1^0)$=100%

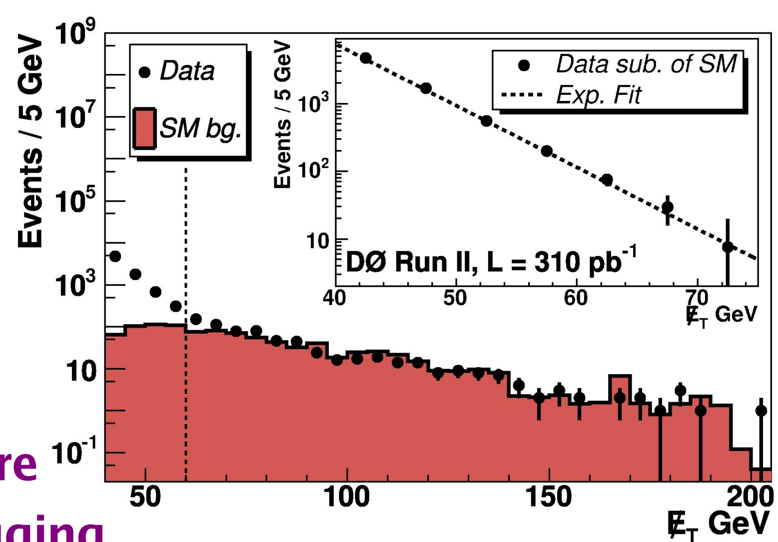
Backgrounds

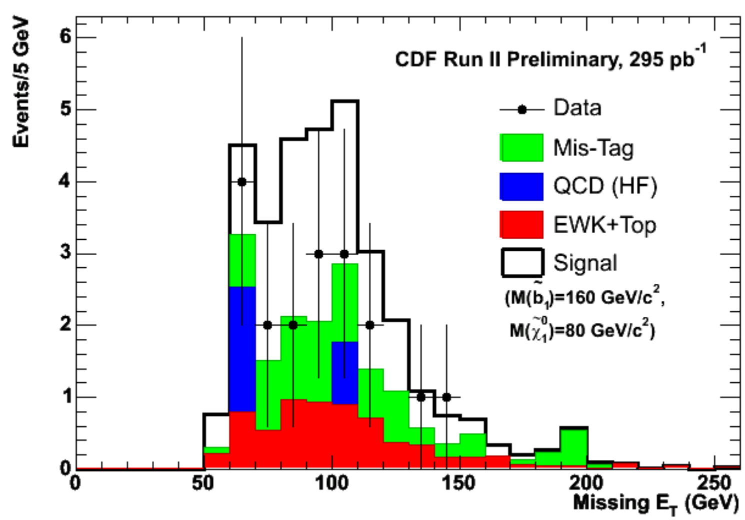
Fake b-jets, QCD multijet, top, EW

Event selection

2, 3 jets high pT jet & large $\not{E}_T$
no isolated hard lepton
1 jet is identified as a b-jet
cuts adapted to the scenario

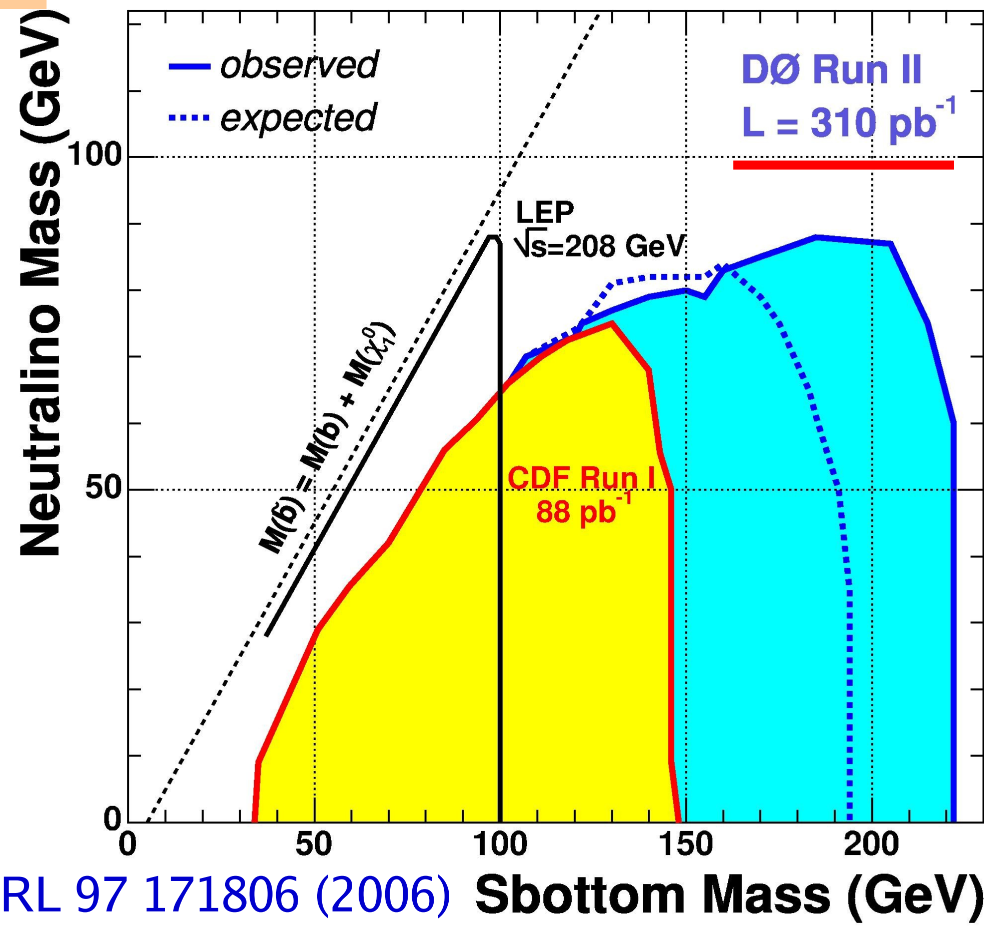
Before b-tagging





After b-tagging

Sbottom pair production



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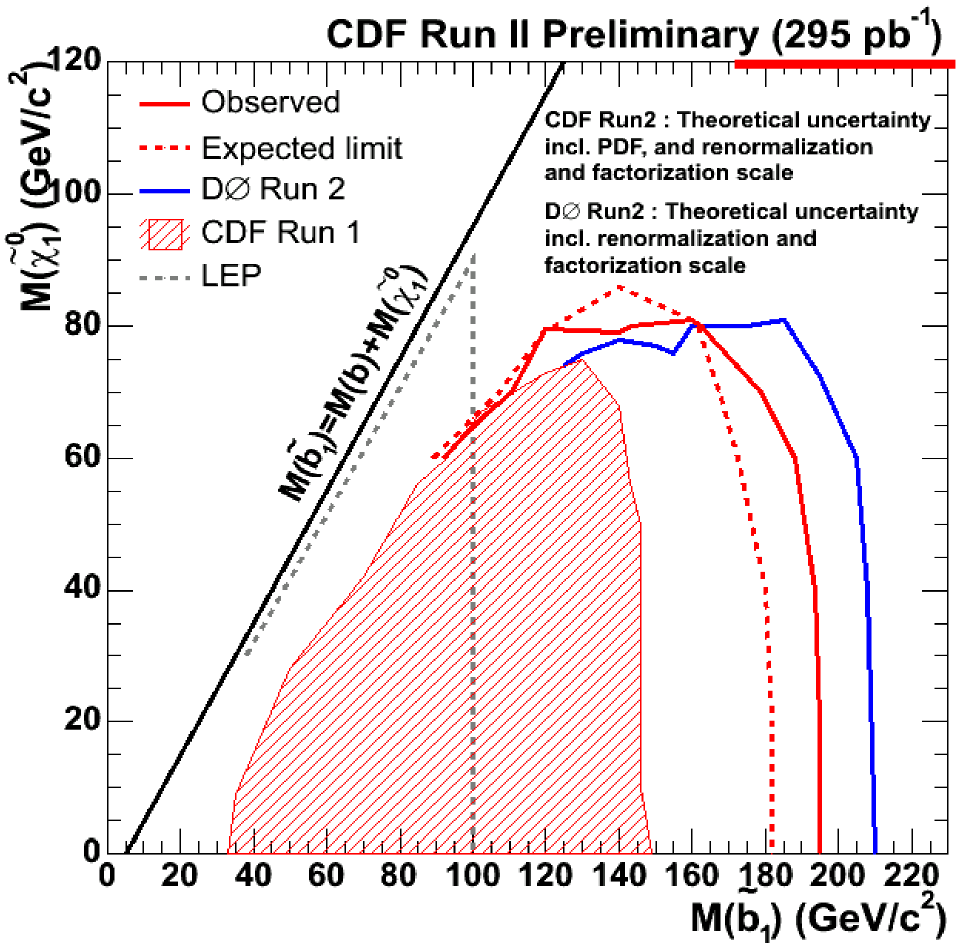


Stop pair production

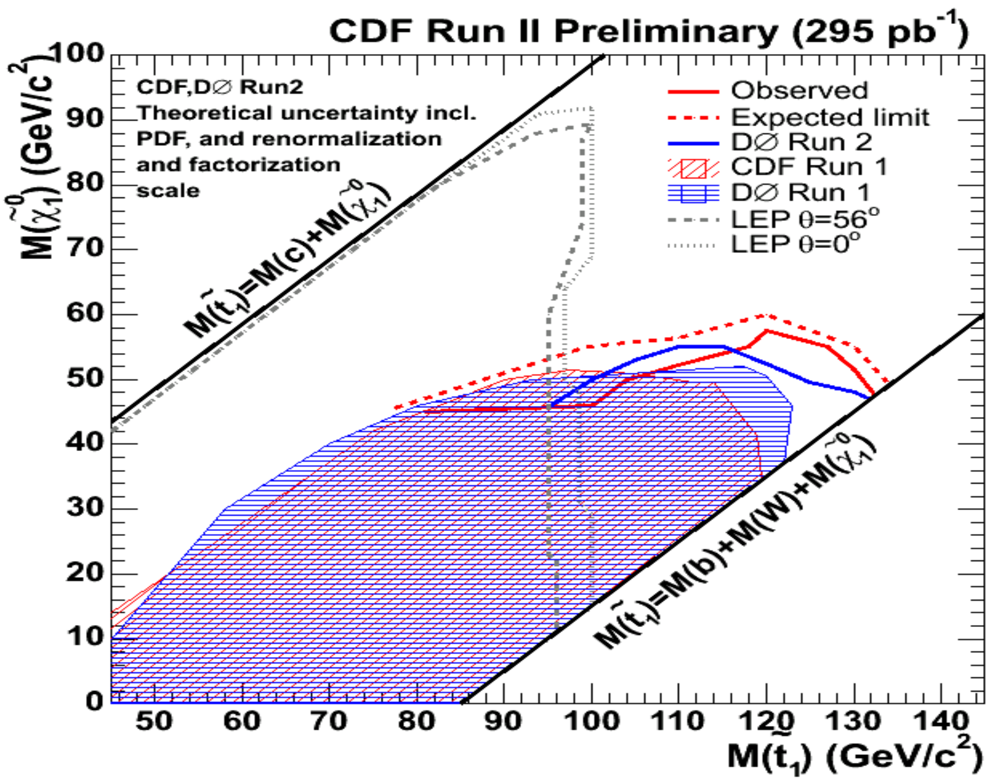
large stop mixing parameter X_t (no need for large tanβ), one stop mass eigenstate could have a very low mass: channel t χ_1^0 forbidden, if $stop_1$ mass small enough look for c χ_1^0

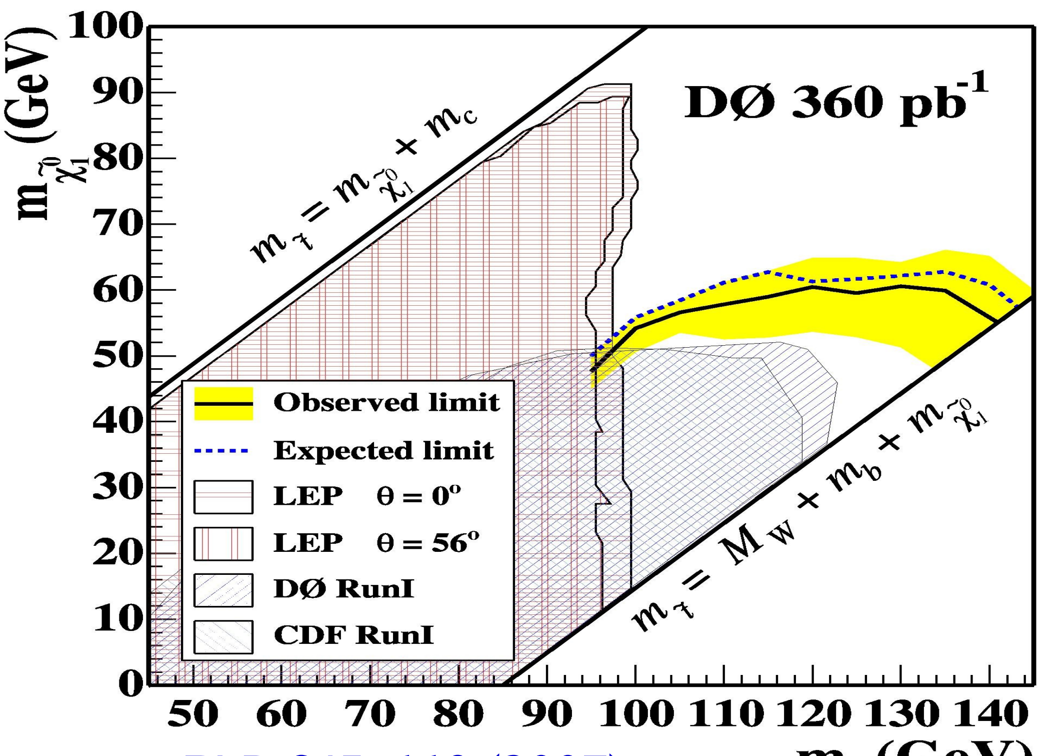
Final state cc $\tilde{\chi}_1^0 \tilde{\chi}_1^0$

assume $B(\tilde{t} \to c\tilde{\chi}_1^0)=100\%$

Very similar to previous analysis

different cut optimization + c quark instead of b quark (lower efficiency)





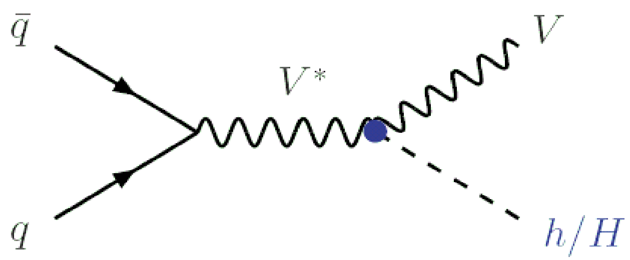
PLB 645, 119 (2007)

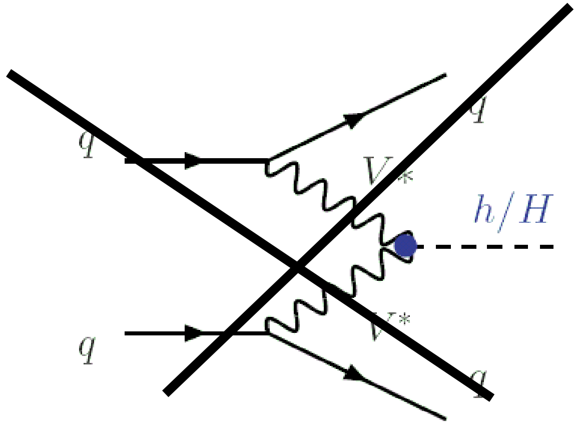
Direct searches of Higgs bosons at Tevatron

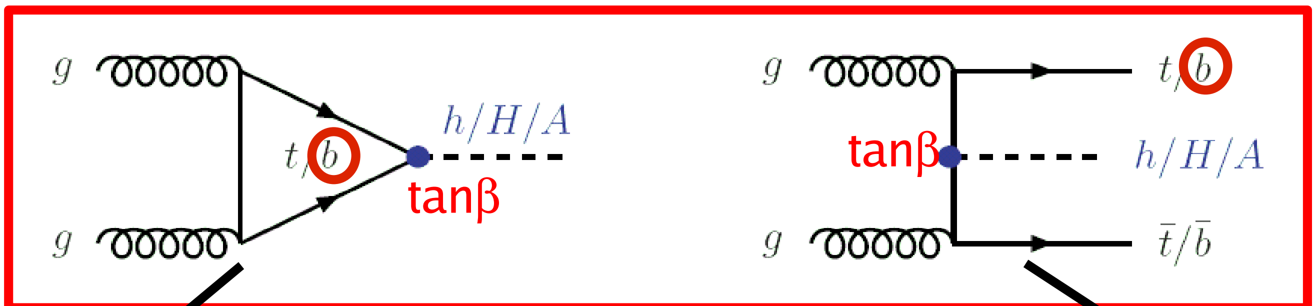
Higgs bosons Production at Tevatron

No particular enhancement in MSSM, use only for SM searches

Very small, not tried yet







If tanβ >> 1
$\mathcal{B}(\Phi \to bb) \approx 90\%$
$\mathcal{B}(\Phi \to \tau\tau) \approx 10\%$
where $\Phi \equiv h/H/A$

At LO

enhancement in $\tan^2\beta \times 2$

SM : $h \to WW^*$
Susy : $h/H/A \to \tau\,\tau$
bb out of reach
(QCD background)

2 higgs with same mass
if tanβ >> 1

Both $h/H/A \to bb$ and $h/H/A \to \tau\,\tau$ possible
very small BR in SM but one b jets helps to discriminate vs QCD!

SM Higgs bosons searches

Search strategy:

Low mass (m_H < 135 GeV/c^2): $\ell \equiv e/\mu$

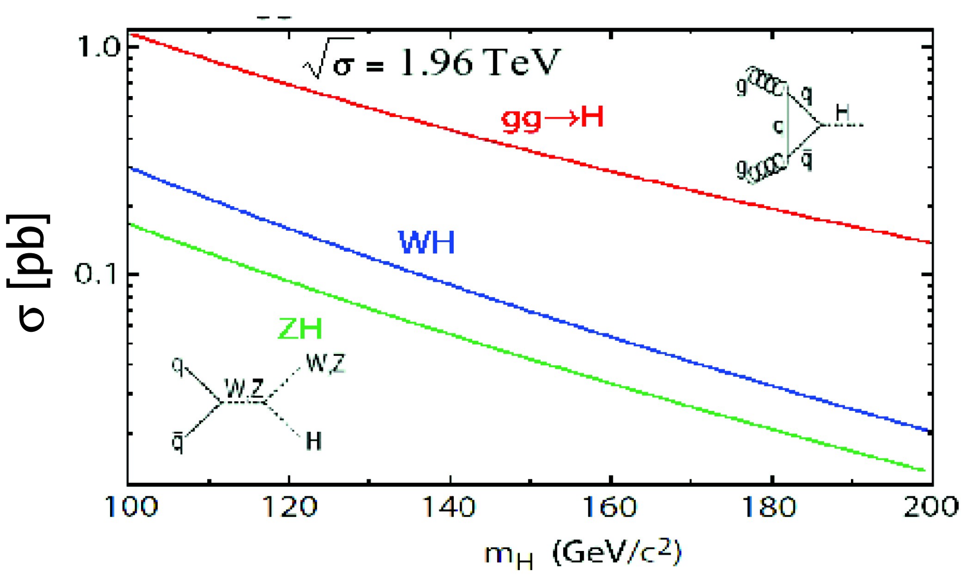
- ZH : $Z \to \ell\ell$ / $\upsilon\upsilon$ and $H \to bb$
- WH : $W \to \ell\upsilon$ and $H \to bb$
  - ℓ can also be undetected
- $H \to WW^* \to \ell\upsilon\ell\upsilon$

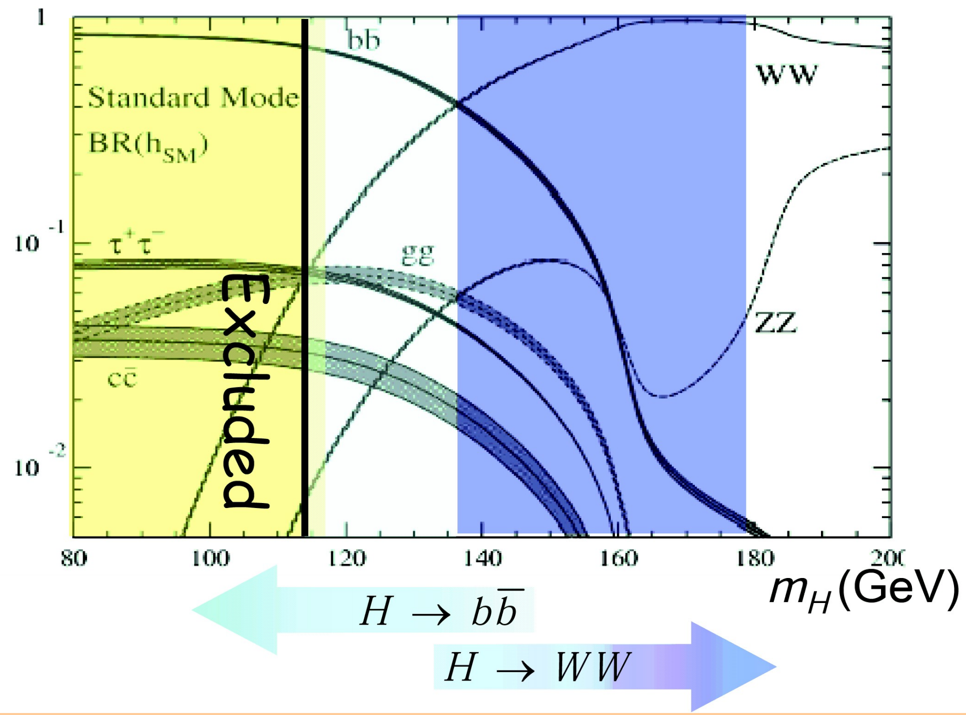
Higher mass: most of the sensitivity comes from $H \to WW^*$

Signature & Tools :

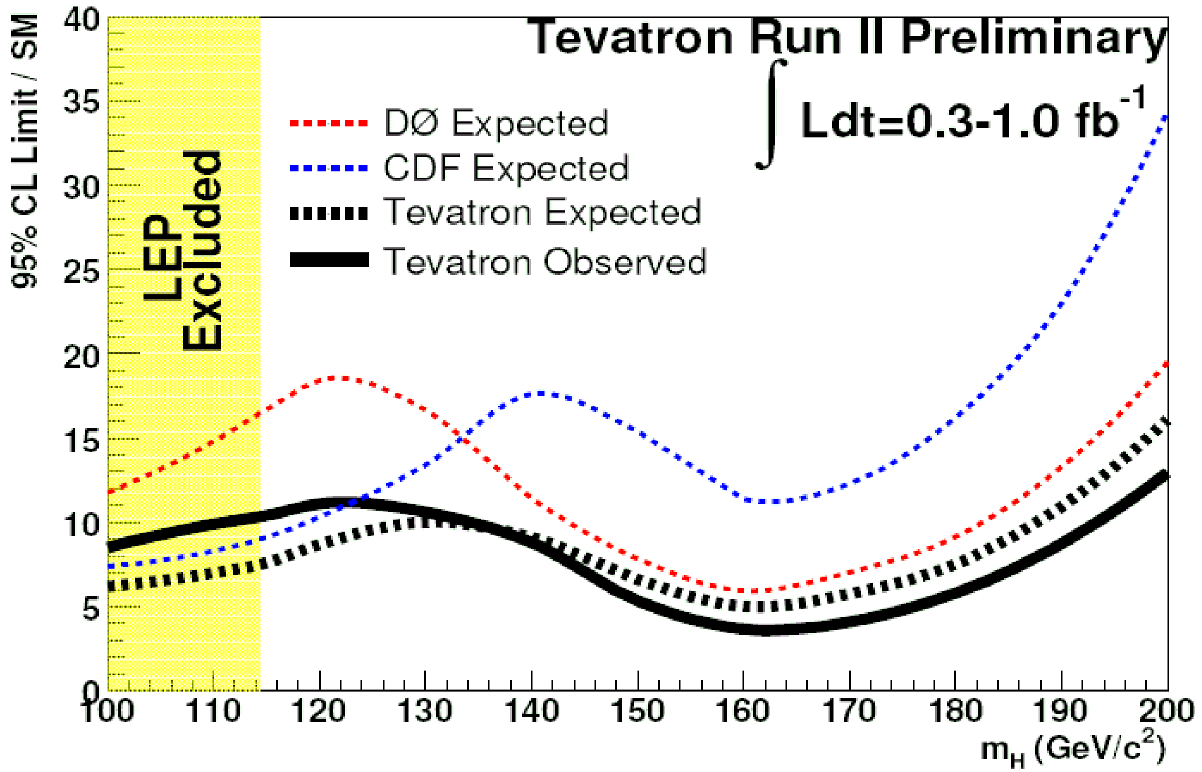
- high pT isolated e/μ, $\not{E}_T$, b jets (b tagging)
- some analyses benefit from multivariate techniques (Matrix element, NeuralNet)

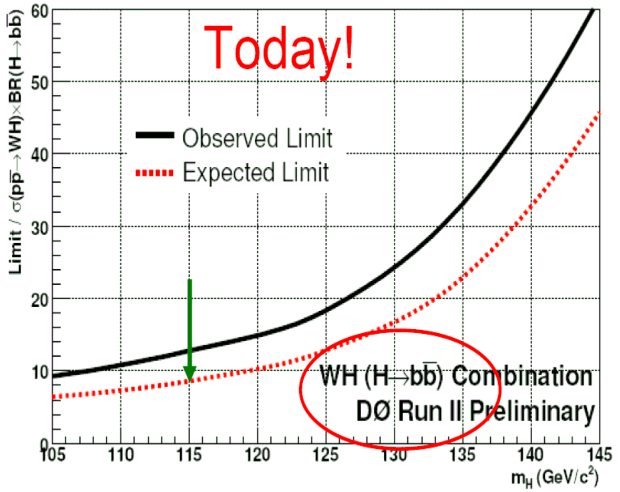
Backgrounds : W/Z bb, W/Zjj, QCD, diboson mainly WW for $H \to WW^*$





First DØ CDF combination (summer 06)





First combination released last summer: not all analyses were ready with 1 fb^{-1}

Perspective:

- combination with the whole 1 fb^{-1} for both experiment
- analyses will benefit from improved b-tagging
- further development of analysis techniques (multivariate)
- new detector features may help (ie: Layer 0 should improve b-tagging)
- statistics!

Searches for h/H/A→ττ

New result, both CDF and D∅, with $1\ fb^{-1}$

Final State ττ(j) with

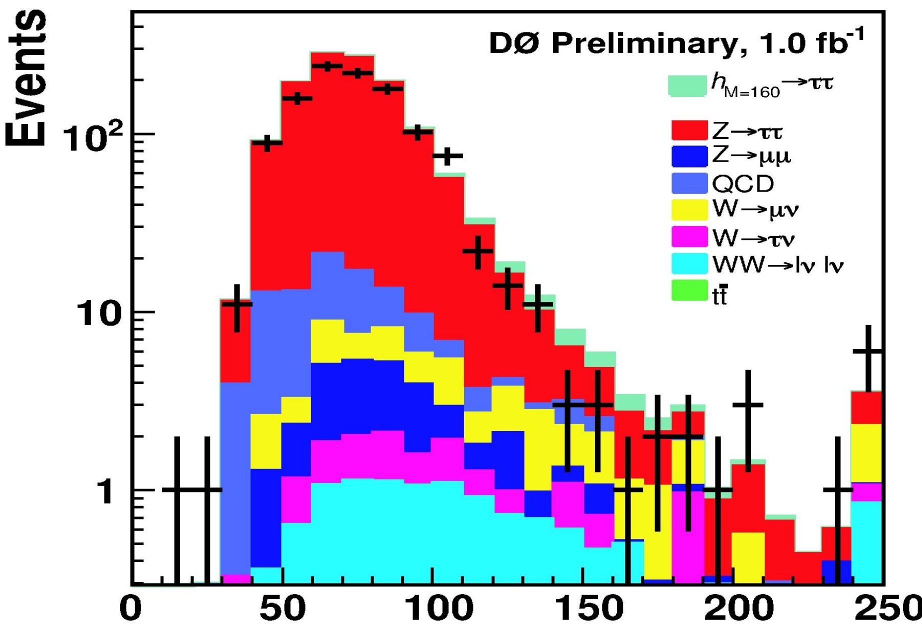
- CDF: $\tau_e\tau_\mu + \tau_e\tau_{had} + \tau_\mu\tau_{had}$
- D∅ : only $\tau_\mu\tau_{had}$ but use a NN to discriminate signal from background

Selection

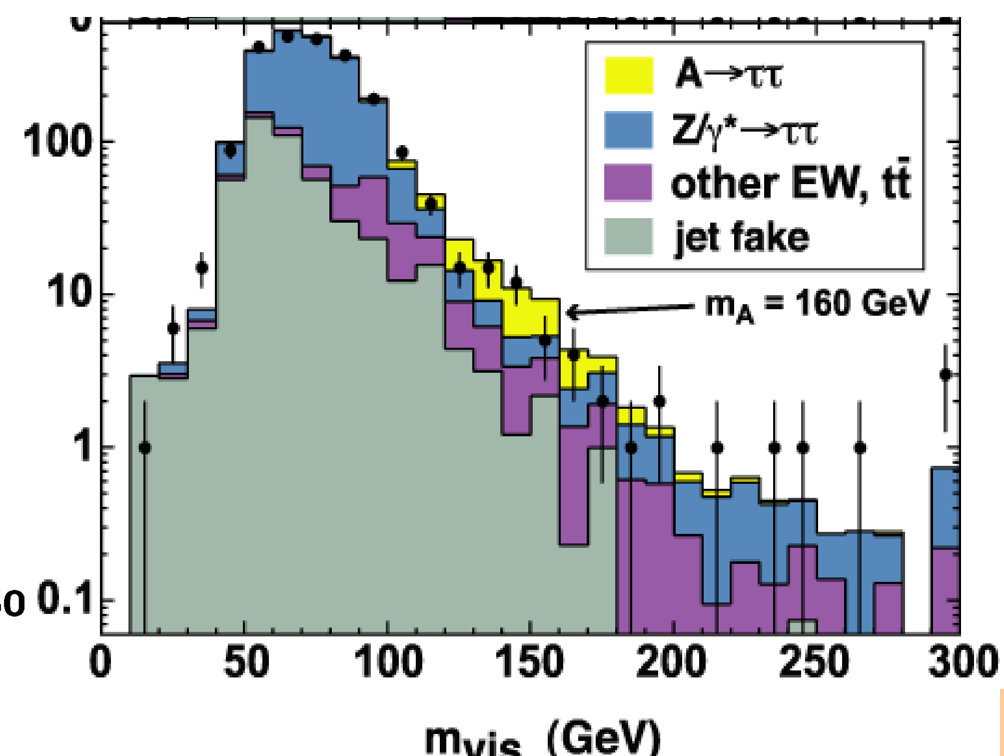
1 (2 for eμ) isolated hard lepton + one hadronic tau (apply NN tau id) with opposite sign. W(j) removed with $\vec{\not{E}}_T$

Backgrounds

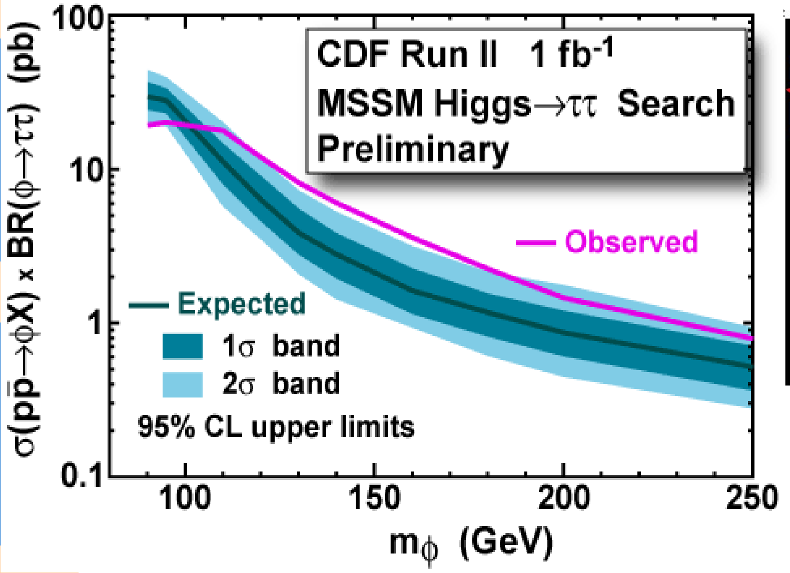
main Z→ττ, QCD, Z→ee, Z→μμ, di boson

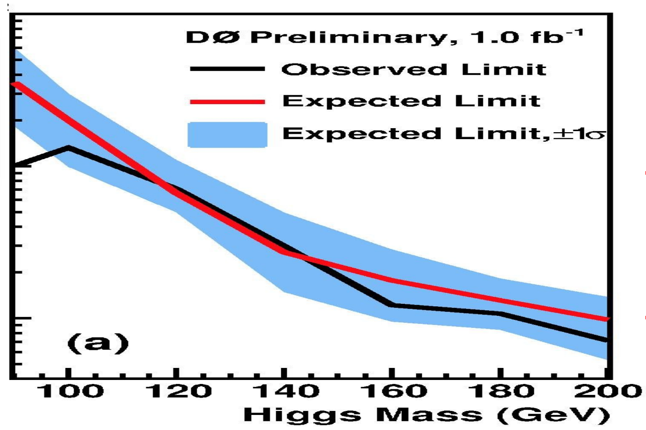


$$m_{vis} = |P^{vis}_{\tau_1} + P^{vis}_{\tau_2} + \not{P}_t|$$



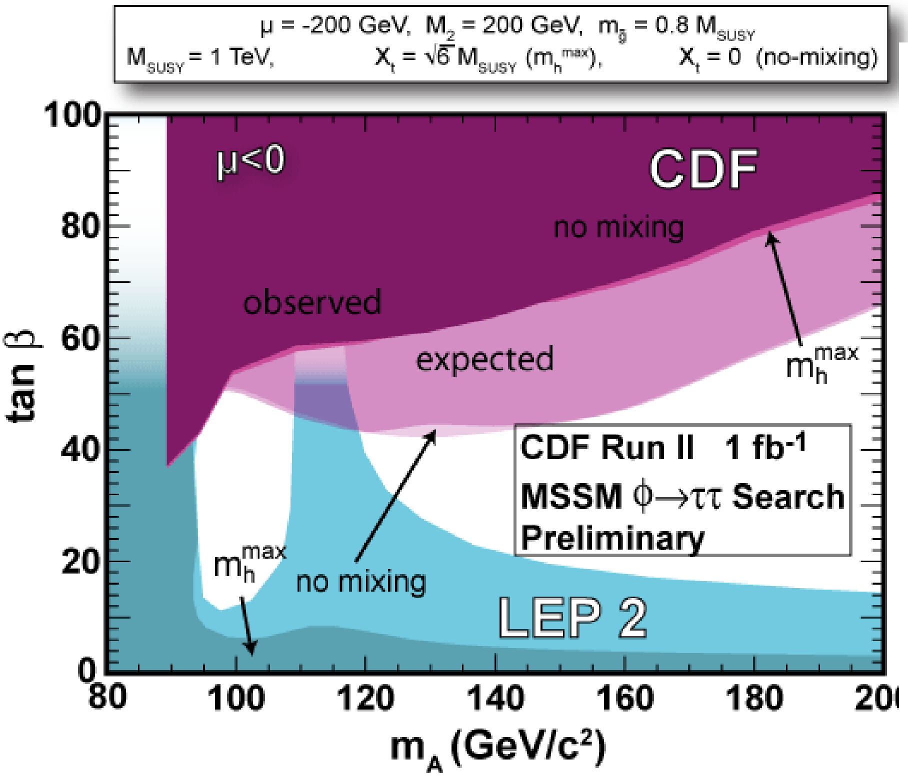
Searches for h/H/A→ττ

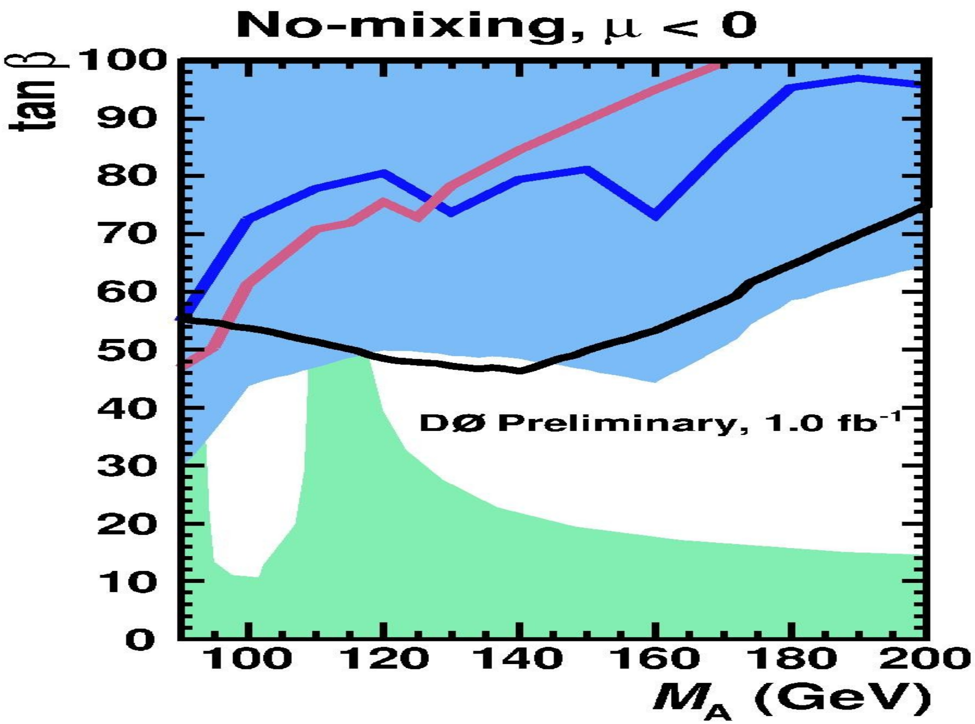




- CDF: 2 σ excess at high masses
- D∅ : no excess

CDF&D∅ have comparable sensitivities





Searches of h/H/Ab→ττ b

DØ only, 344 pb^{-1} — Final State ττb(j) with $\tau_\mu \tau_{had}$ b

Selection

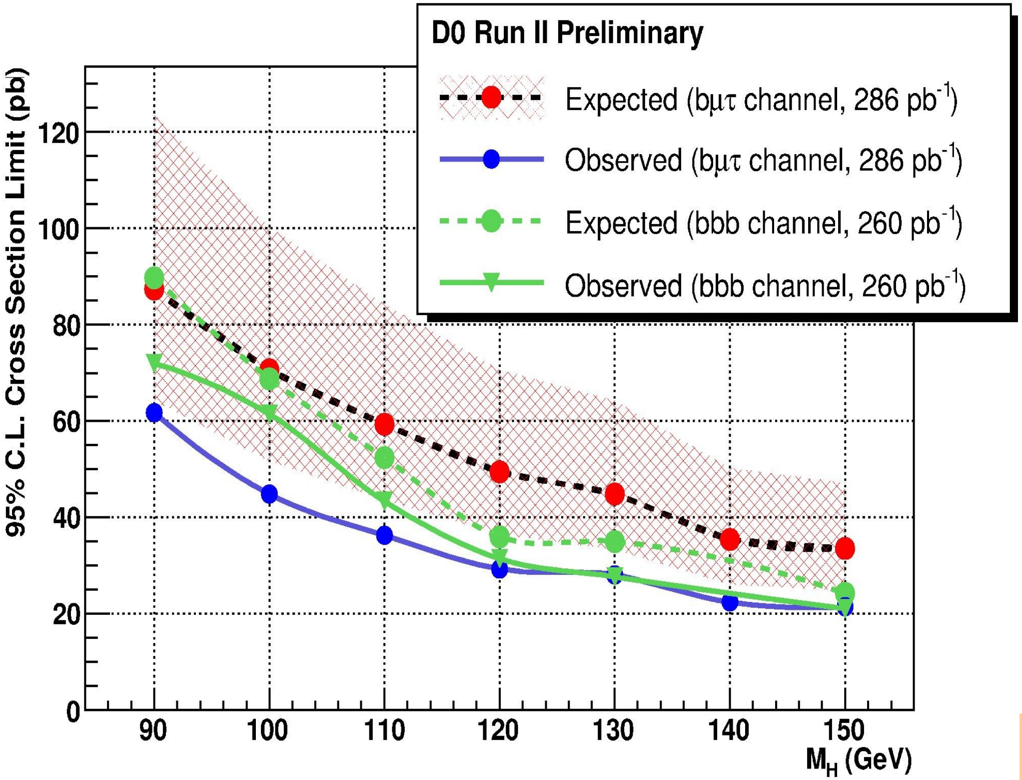
1 isolated hard muon + one hadronic tau (apply NN tau id) with opposite sign + 1 tagged b jet.

ttbar events are discriminate with the help of an NN

Backgrounds

Z(j), QCD, ttbar

Exp: 6.8 bkg evts ; Obs: 3



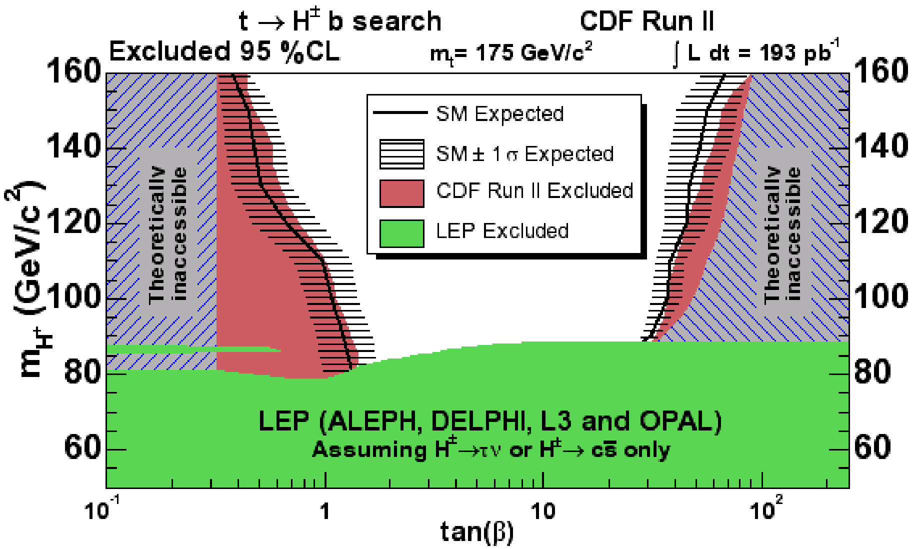
Less sensitive than previous slide but some lessons can be drawn:

- nearly as sensitive as hb→bbb with 300 pb^{-1} though the BR is 9 times smaller
- hb→bbb suffer froms a large QCD multijet production difficult to predict. With higher statistics, ττb will probably be more sensitive than hbb!
- new bbb result expected soon, both from CDF and DØ

CDF H^+ searches

If $m_{H+} < m_{top}$ then the decay $t \rightarrow b\,H^+$ compete with the SM $t \rightarrow b\,W^+$

Use the top samples. Look for excess of events over SM predictions

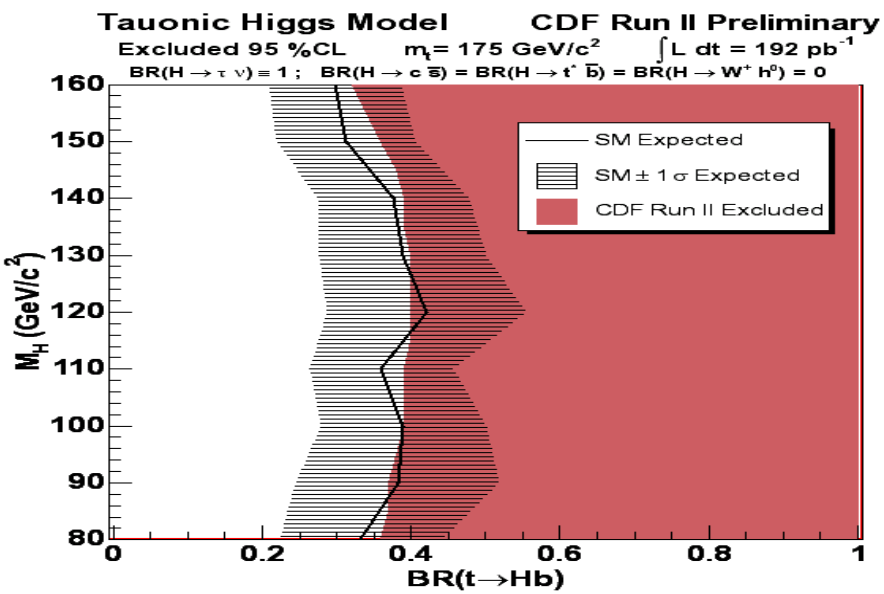


Limits in several scenarii, cover different H^+ decays. Left plot:

Maximal mixing scenario

200 pb^{-1}

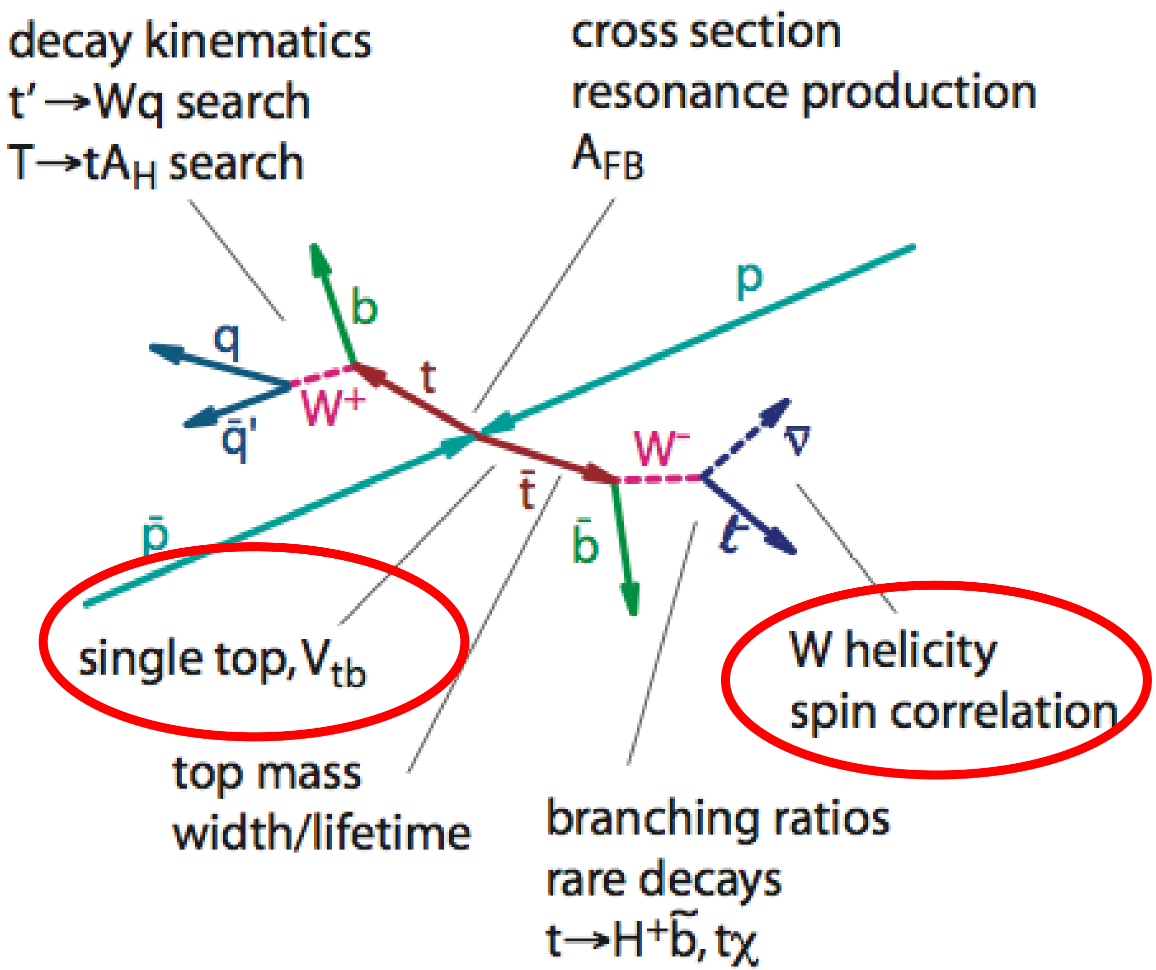
Phys. Rev. Lett. 96, 042003 (2006)



large $\tan\beta$ case :

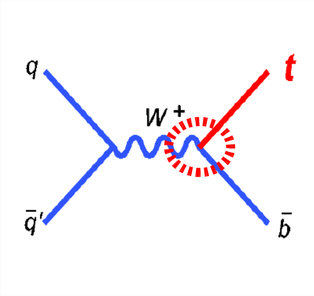
$Br(H^+ \rightarrow \tau\nu) = 100\ \%$ and one can put a limit on the $Br(t \rightarrow b\,H^+)$

New phenomena in top decays



Single top production

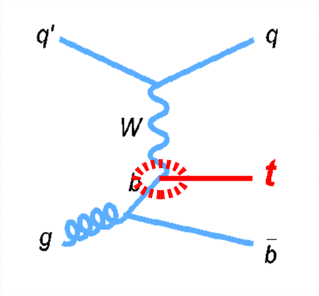
s-channel (tb)



- $\sigma_{NLO} = 0.88 \pm 0.11$ pb (*)
- previous limits (95% C.L.):

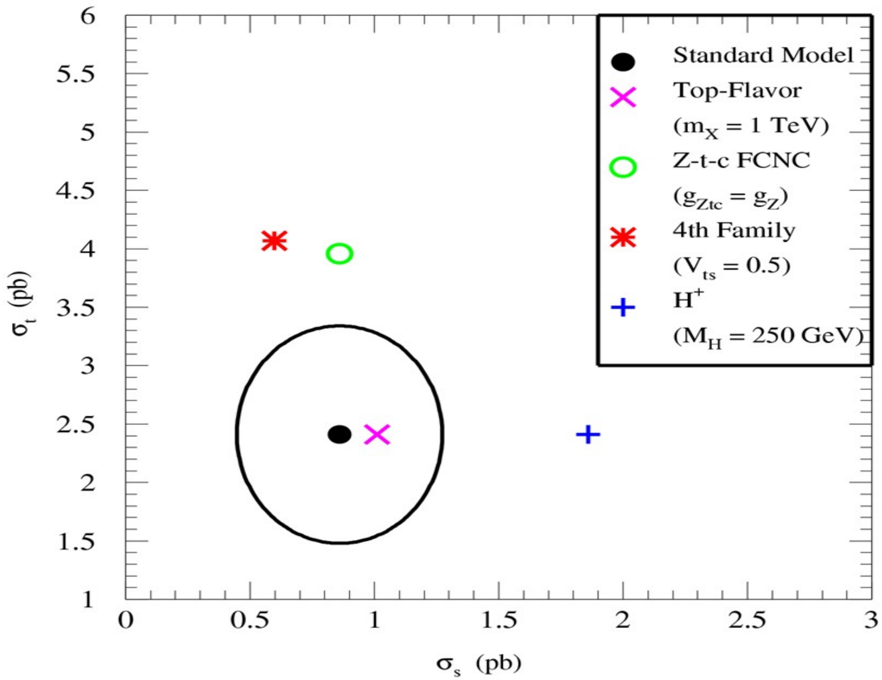
Run II DØ: < 5.0 pb (370 pb^{-1})
Run II CDF: < 3.1 pb (700 pb^{-1})

t-channel (tqb)



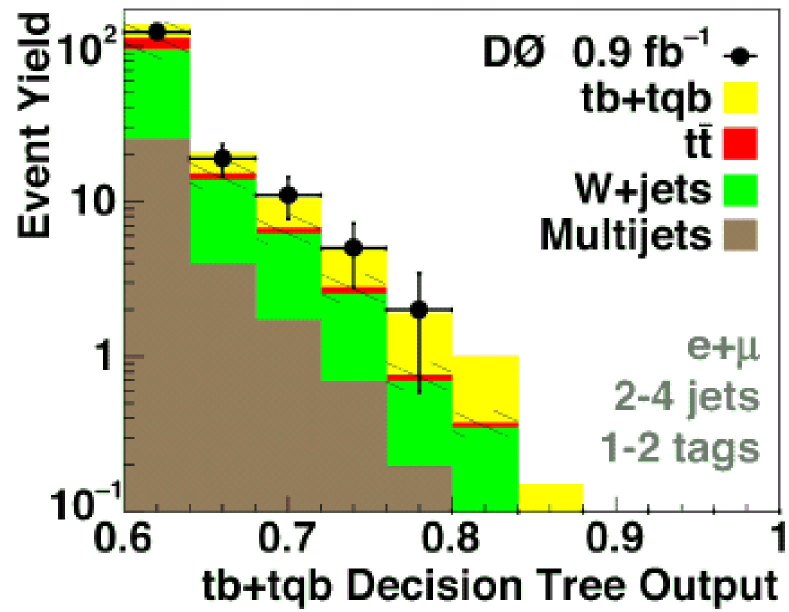
- $\sigma_{NLO} = 1.98 \pm 0.25$ pb(*)
- previous limits (95% C.L.):

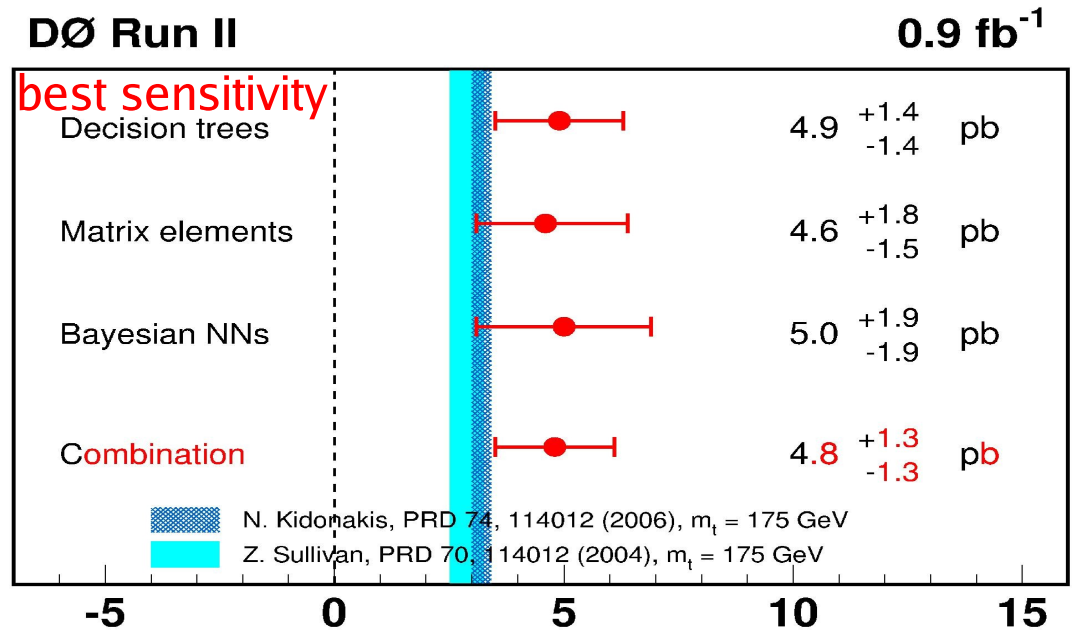
Run II DØ: < 4.4 pb (370 pb^{-1})
Run II CDF: < 3.2 pb (700 pb^{-1})



- Standard Model
  - Rate $\propto |V_{tb}|^2$
  - Spin polarization: V-A
- Beyond the Standard Model
  - Sensitive to a 4^{th} generation
  - Flavor changing neutral currents
  - Additional heavy charged bosons
    - W' or H$^+$
- New physics can affect s-channel and t-channel differently

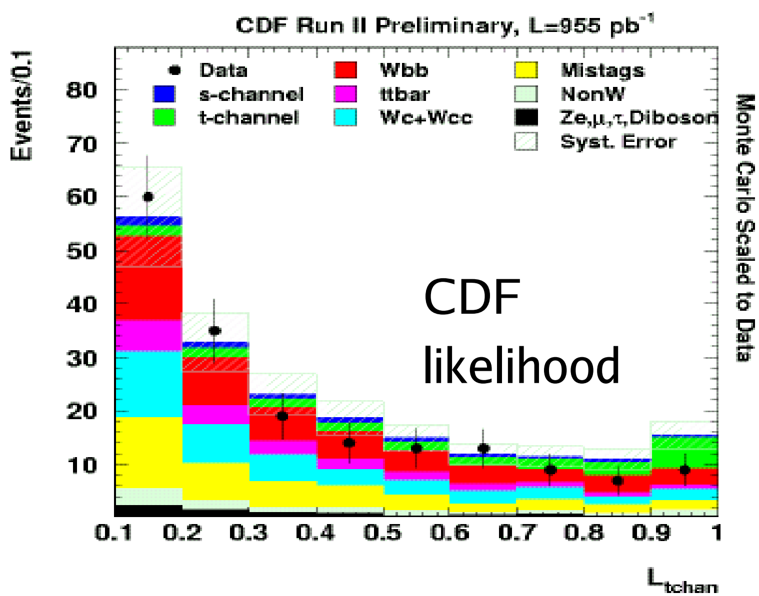
Single top evidence





DØ significance: 3.5 σ

Compatibility with SM : 11 %

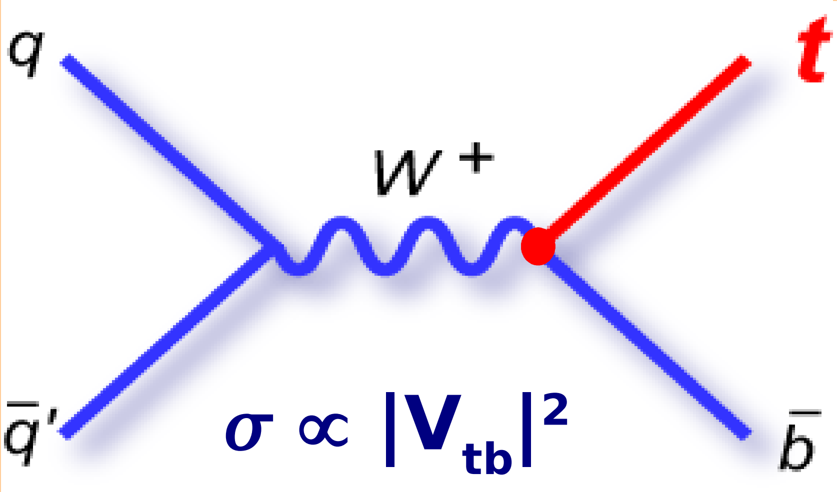


CDF is checking the agreement of their measurement:

- Likelihood : $\sigma < 2.7$ pb @ 95%CL
- Neural Net : $\sigma < 2.6$ pb @ 95%CL
- Matrix element : $\sigma = 2.7^{+1.5}_{-1.3}$ pb (2.3 σ)

NN and ME same sensitivity

Single top production

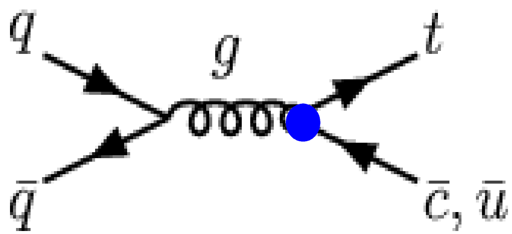


Strength of the coupling is proportional to $|V_{tb}|$, in SM $|V_{tb}| \sim 1$. Can use the single top production to measure V_{tb} ! Assuming SM top decay, no FCNC, CP conservation in the Wtb vertex, we measure

$$| V_{tb}\, f_1^L| = 1.3 \pm 0.2$$

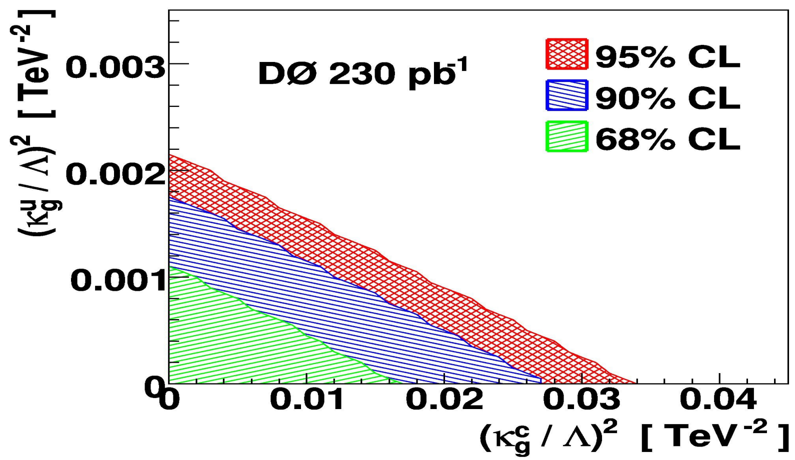
assuming $f_1^L = 1$ (SM) $\Rightarrow$ $| V_{tb}| > 0.68$ @ 95% CL

Single top can also be produced via new sources of FCNC

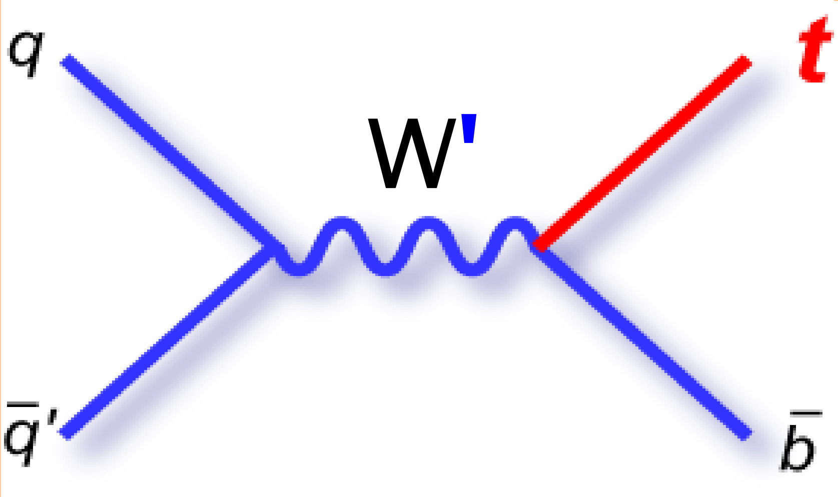


gtu(c) vertex strength $\propto K^{u(c)}/\Lambda$

D∅ , 200 pb^{-1}, performed a generic search



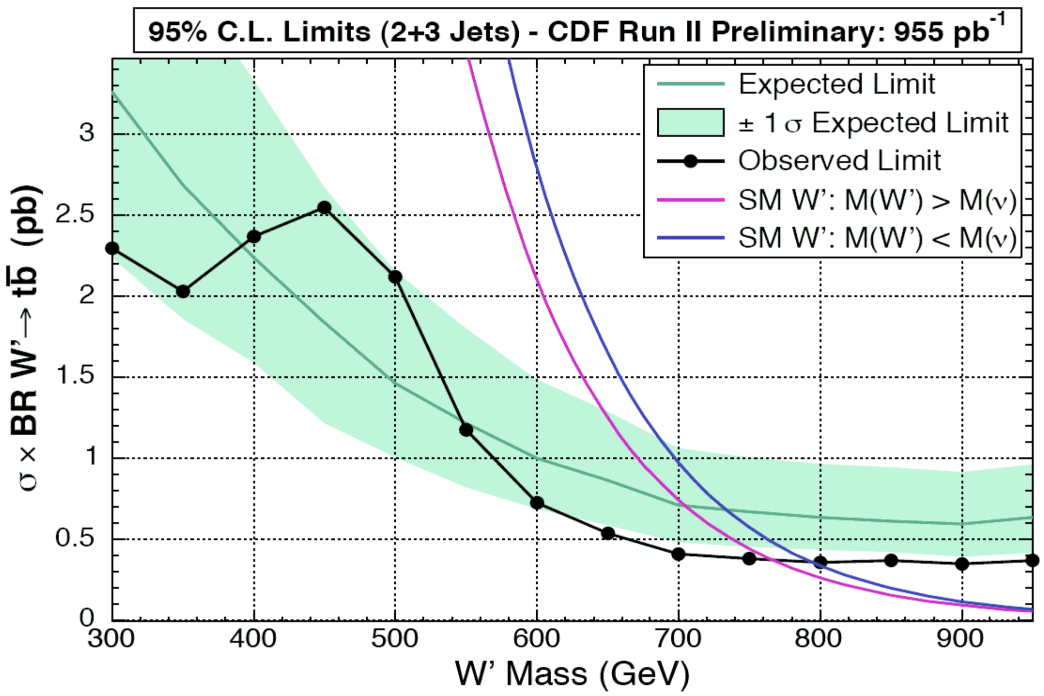
Single top production W'



Resonant production of single top from W' :

$$W' \rightarrow tb \rightarrow Wbb$$

Search for an excess in Wbb invariant mass assuming W' as SM-like coupling to fermions



CDF, 1 fb^{-1}, using single top samples and tools.

Limits @ 95 % CL:

if $M(\nu_R) < M(W')$

$M(W') > 760\ GeV/c^2$

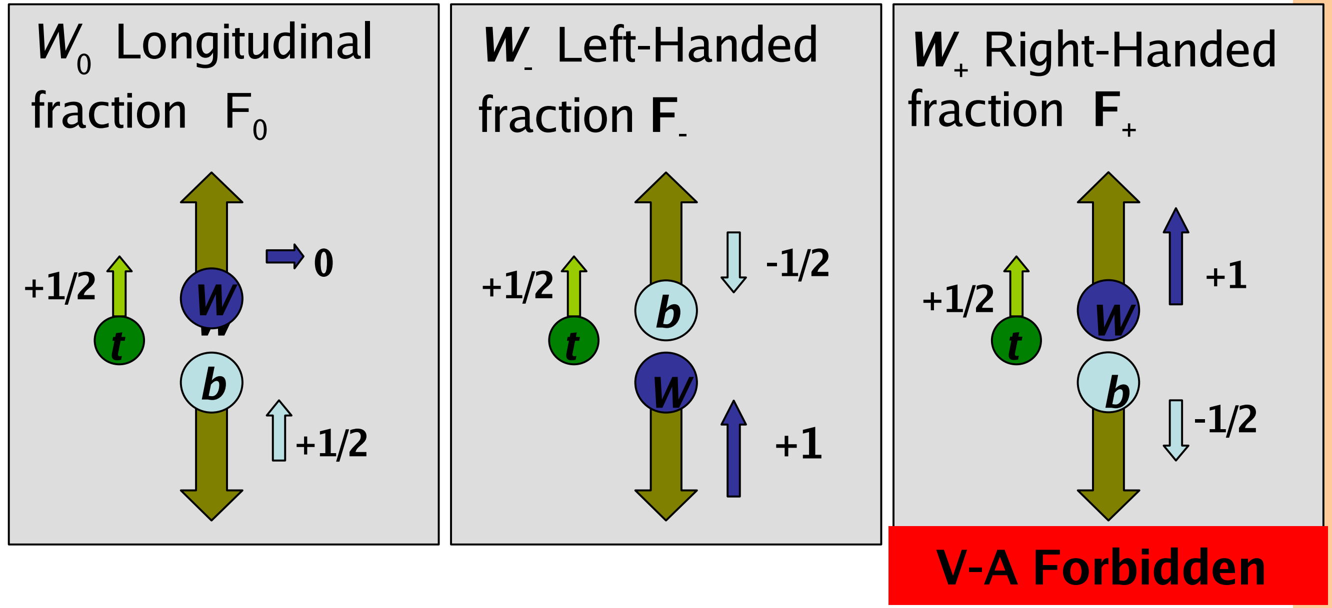
if $M(\nu_R) > M(W')$

$M(W') > 790\ GeV/c^2$

W helicity measurement

In top decay W helicity is determined by the V-A structure of the EW sector and the mass of the particles involved:

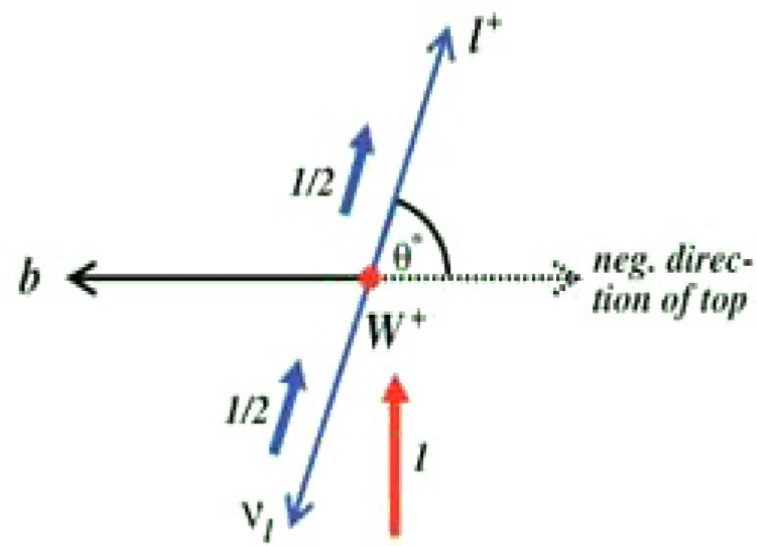
- 70 % longitudinal
- 30 % left handed
- 0 % right handed

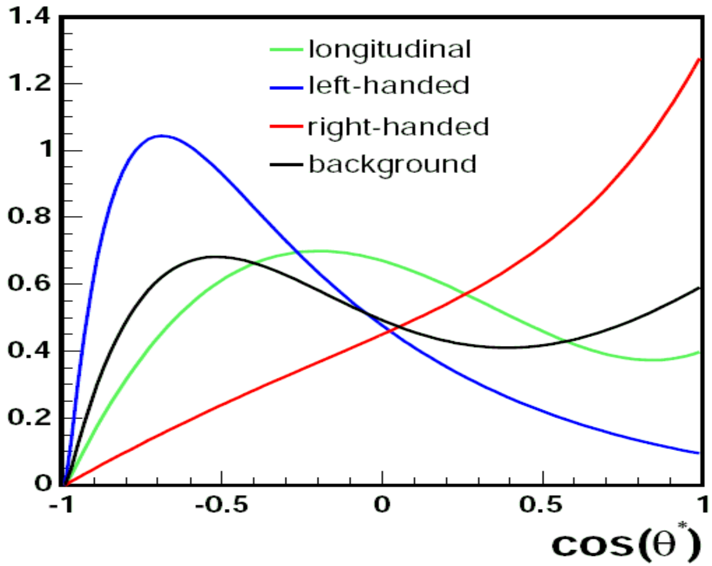


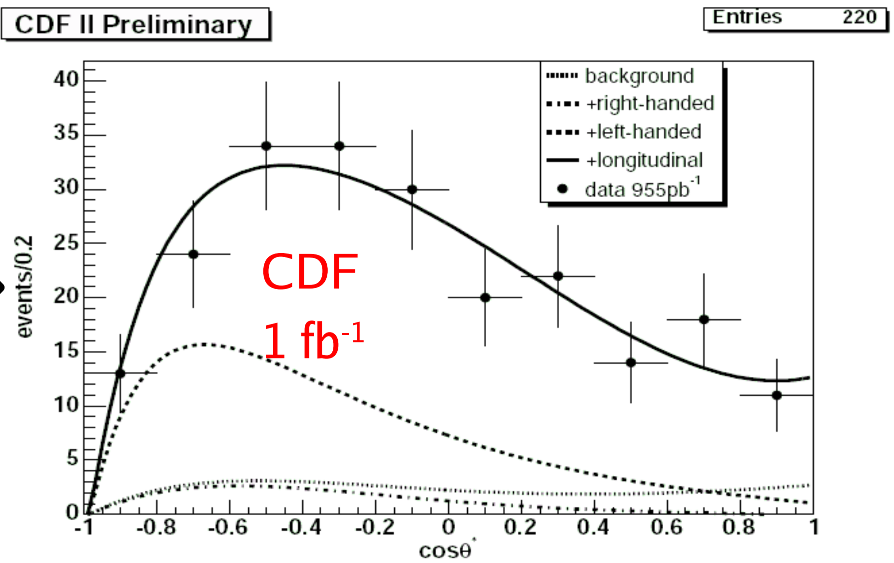
Use the top quark samples with leptonic decays to measure the different polarization contributions:

- 3 techniques : cos θ* , M_{lb}^2 p_T lepton

- 2 different top quark samples:
 lepton + jets and dilepton







Results:

- CDF (1 fb^{-1}), sample lepton+jet only ($\cos\theta^*$)

  $f_0 = 0.61 \pm 0.13$ (f_+ fix to zero) in agreement with SM $f_0 = 0.70$ & $f_+ = 0$

  $f_+ < 0.11$ @ 95 % CL

- CDF (700 pb^{-1}), samples lepton+jets and dileptons (M_{lb}^2) - PRL **98**, 072001 (2007)

  $f_+ < 0.09$ @ 95 % CL

- DØ (370 pb^{-1}), samples lepton+jets and dileptons – PRD **75**, 031102 (2007)

  $f_+ < 0.23$ @ 95 % CL

Conclusions

Different ways to search for new phenomena:

- direct detection of new particles
- study of the Higgs sector
- top decay
- *B* physics

We are surveying all those sectors at Tevatron, only a small subset of results was shown here... see:

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

http://www-cdf.fnal.gov/physics/physics.html

but so far, no significant sign of new physics

The best is yet to come:

- tools for object identification have been improved (for instance b id)
- Tevatron is doing well and integrated luminosity should increase quickly!