Joint Experimental-Theoretical Seminar at Fermilab

(Wine & Cheese Seminar)

December 4$^{\mathrm{th}}$ (2009)

$\not\!\!E_T$+Jets at CDF

– Results across the program –

Óscar González

CIEMAT (Spain)

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Outline of the talk

Measuring what is not observed
to detect what is undetectable

- **Some historical background**
- **Experimental context**
- **The CDF approach to $\not\!\!E_T$+jets: sample and tools**
- **The analyses:**
  - $\Rightarrow$ **Standard-Model Measurements (Dibosons)**
  - $\Rightarrow$ **Top physics**
  - $\Rightarrow$ **Higgs searches**
  - $\Rightarrow$ **Searches of New Physics**

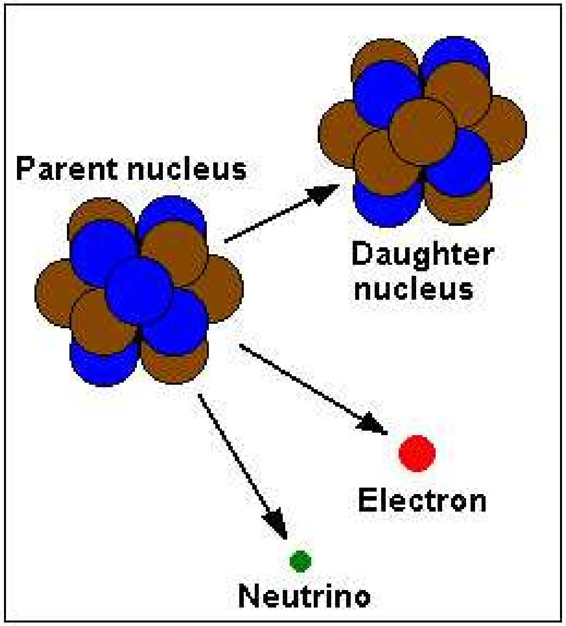
Instead of focusing on the latest results, I will give an overview of several analysis focused on $\not\!\!E_T$+jets final states.

- **Summary**

What is behind $\not\!\!E_T$? Historical background

In 1930, W. Pauli postulated the existence of an undetected particle that would be present in the β-decay.

This particle would allow to conserve energy, (linear and angular) momentum against experimental observation, which suggested those quantities were not conserved.



Beta decay

- **E. Fermi called this particle *neutrino*.**
- **Its existence proved: conservation laws which are apparently violated may be a "particle detector".**
- **Same idea was extensively used to "detect" the presence of neutrinos in the final/initial state.**

At high energies at e^+e^- colliders (where the initial energy is very well known) "missing energy" is used in different kind of analysis:

$\Rightarrow$ **Identify processes with neutrinos or other undetected particles.**
$\Rightarrow$ **Improve (kinematic) reconstruction of the final state.**
$\Rightarrow$ **For SM studies and searches of "New Physics".**

$\not{E}_T$ at hadron colliders

At hadron colliders, this *missing energy* is not very useful:

Fraction of the final-state escapes detection along the beam-pipe.

Those escaping particles have small momentum on the plane perpendicular to the beam directions (*transverse*).

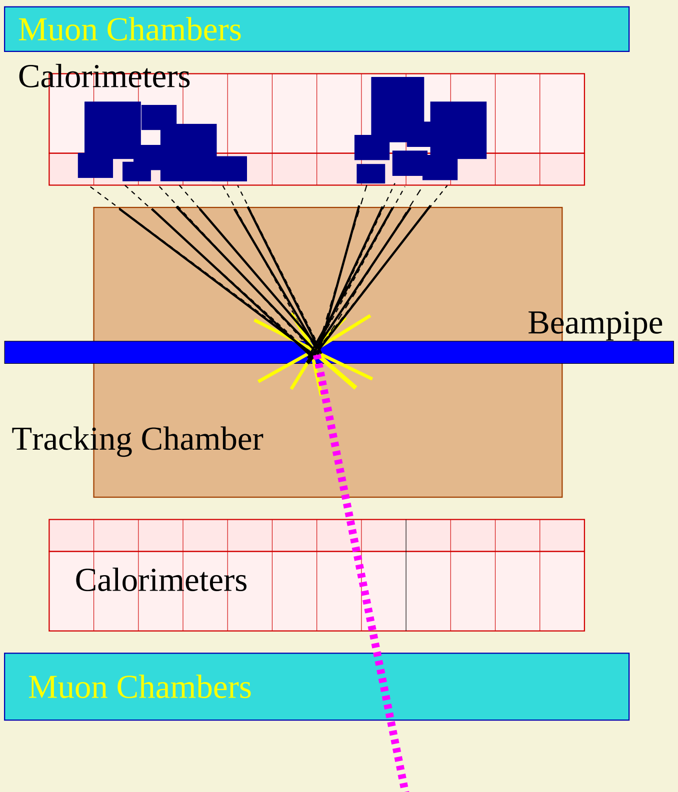
Transverse momentum (which is basically 0 in the initial state) expected to be conserved.

We define "missing transverse energy" as:

$$\not{E}_T = \sqrt{\left(\sum p_x\right)^2 + \left(\sum p_y\right)^2}$$

where the sums run over all measured "particles" (by default, energy deposits in the calorimeters).

$\not{E}_T$ is significantly different from 0 if there are particles with large transverse momentum that are not detected (or not properly measured).

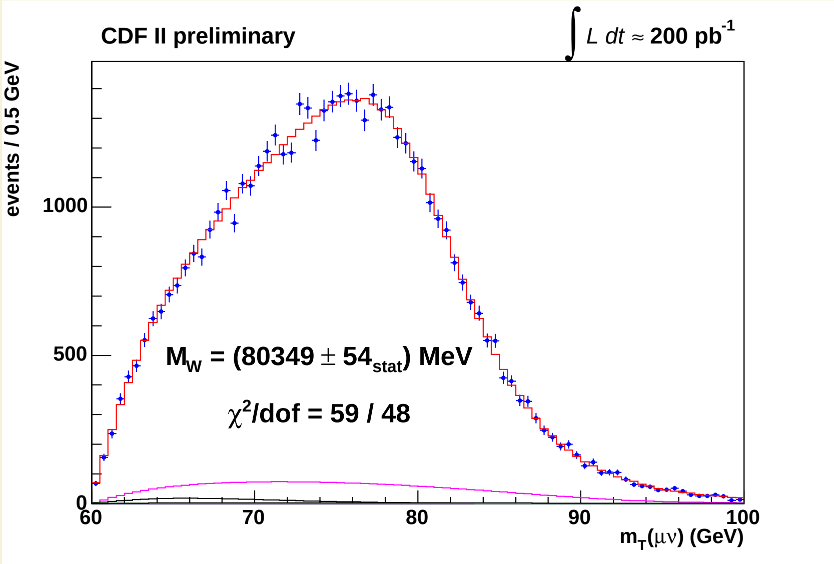


$\not\!\!E_T$ at hadron colliders (II)

- Since the $\not\!\!E_T$ is defined as the magnitude of a vectorial (2-D) quantity, it has an associated azimuthal angle ($\phi_{\not E_T}$).

- These quantities have been effectively used since the $Sp\bar{p}S$ experiments, especially to identify W events.

- As in e^+e^- experiments, the "neutrino" information is used to reconstruct the event kinematics, and physical quantities (as the W mass).



- Also used in searches of striking events that may provide hints of new escaping particles.

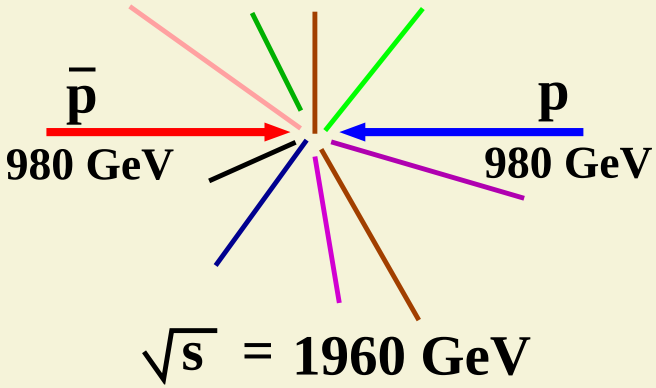
$\Rightarrow$ Quantity difficult to reconstruct: very sensitive to detector effects.

$\Rightarrow$ A lot of progress in the last years to try to get all the possible outcome from events at hadron colliders containing $\not\!\!E_T$ as the main variable to identify the interesting events.

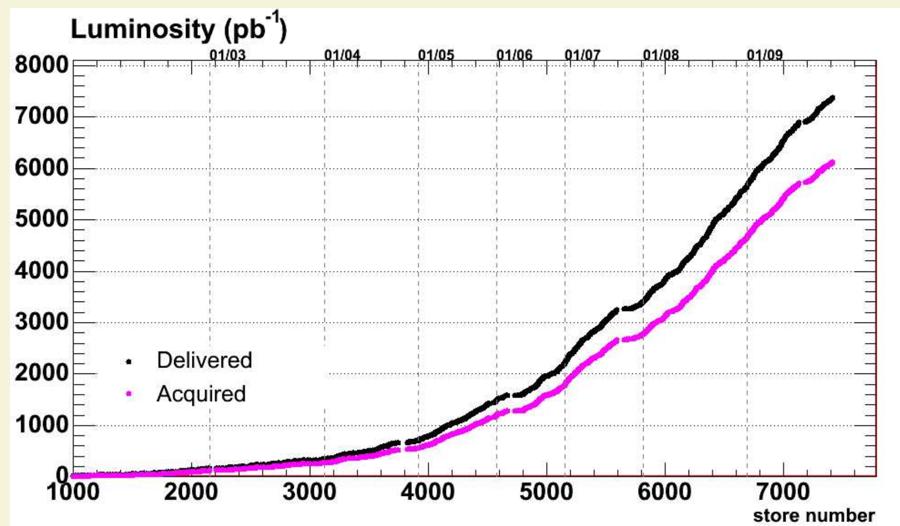
$\Rightarrow$ And it has become a reference for all kind of analysis.

The Tevatron collider

- **The most energetic accelerator in the world (until last week).**
- **Colliding protons and antiprotons**



- **More than 6 fb^{-1} collected by CDF until now.**
- **Data sample sensitive to processes far beyond previously explored regions.**
- **This large datasample would not be possible without the incredible effort of the FNAL AD (Thanks a lot!).**



- **Results here cover luminosities up to 3.6 fb^{-1}.**

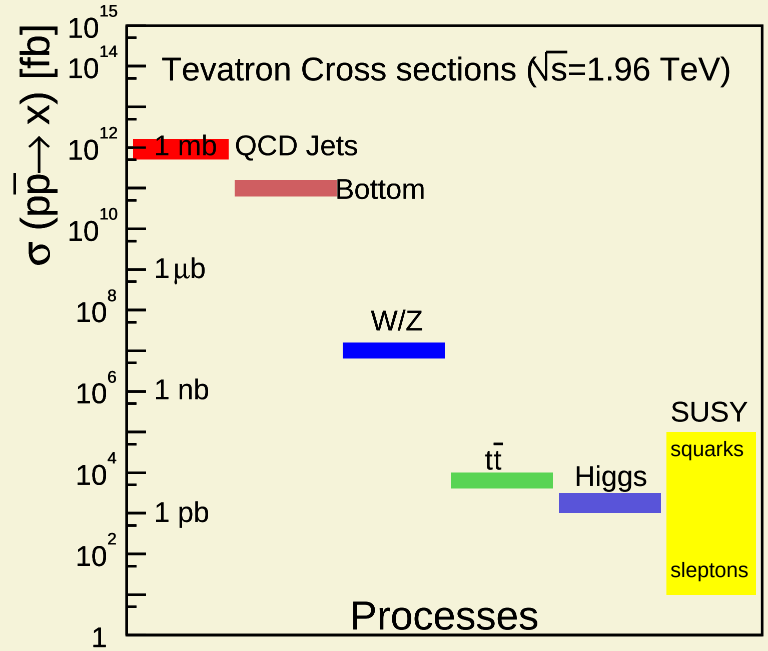
$\not\!\!E_T$ Processes at the Tevatron

- In the Standard Model the only particles producing $\not\!\!E_T$ are the neutrinos.

- Difficult to produce at the Tevatron collisions: the events containing $\not\!\!E_T$ are very sensitive to low-rate processes.

- $\not\!\!E_T$ is one of the primary variables (second to the presence of charged leptons) employed to reduce the main backgrounds.

- Non-physics (cosmics, beam-related) background is easily removed.

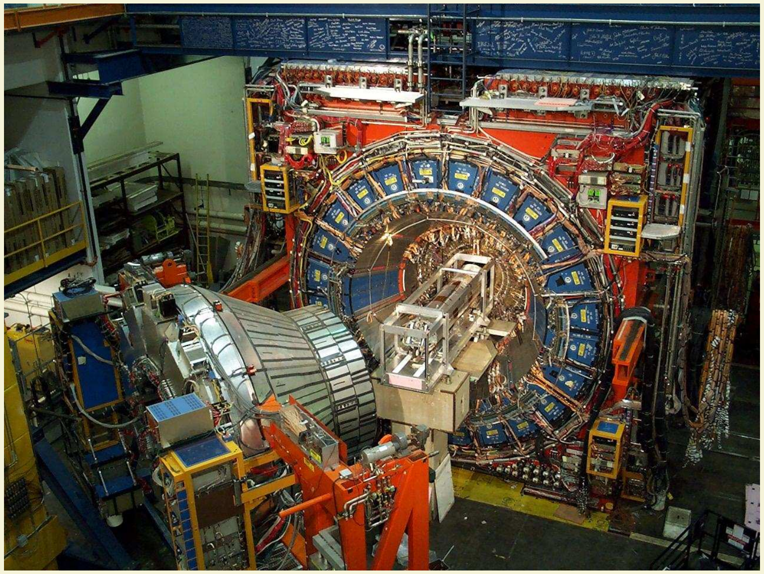


- The final state with $\not\!\!E_T$+jets is really attractive:
  - ⇒ Study rare processes (e.g. when no charged leptons are expected).
  - ⇒ Identify final states with quarks and "missing particles".
  - ⇒ Selection of events even at the trigger level.

- Detector effects cause "fake $\not\!\!E_T$" to appear adding uninteresting events to the sample:
  - ⇒ Jet mis-measurement is the main source, causing "multijet background".
  - ⇒ Kinematics help to reduce the background and enhance the signals.

The CDF detector

Standard multi-purpose detector to exploit all the potential of the Tevatron collisions

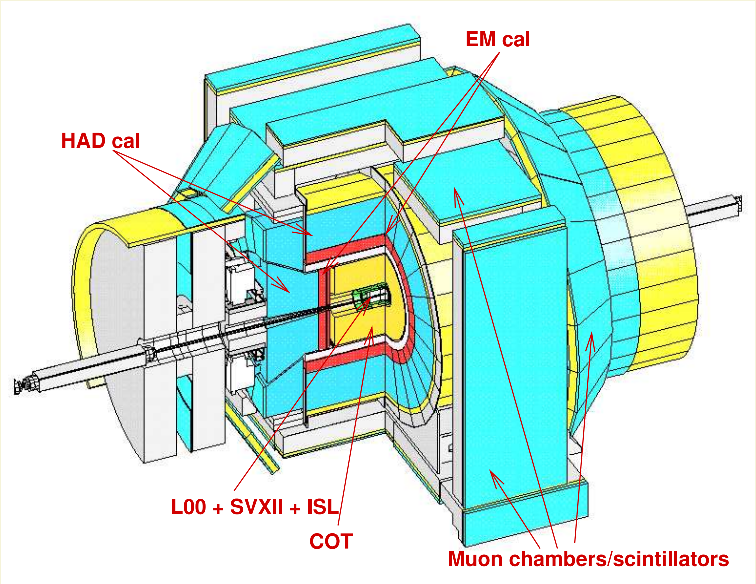


- **Silicon detectors**
  - ⟶ Precision vertex detection
  - ⟶ Displaced decays: heavy-flavour tagging

- **Drift chamber** (in a solenoidal magnetic field of 1.4 T)
  - ⟶ Charged particles up to $\eta \sim 1.5 - 2$

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

  - ⟶ High efficiency and excellent resolution



- **Sampling calorimeters**
  - ⟶ $\sim 4\pi$ coverage (fundamental for $\not\!\!E_T$)
  - ⟶ Jets and electron reconstruction

- **Muon detectors**
  - ⟶ Covering up to $\eta \sim 1.5$

The $\not{E}_T$+jets samples at CDF

- To select events online, the most important variable is the $\not{E}_T$ recontructed at the several trigger levels:

  ⇒ Resolution of the $\not{E}_T$ increases as level increases.
  ⇒ Thresholds increase, reducing the trigger rate.
  ⇒ Additional selection helps to control the rate with lower threshold.

- This defines the main sets for $\not{E}_T$+jets:

  ⇒ Inclusive $\not{E}_T$
  ⇒ $\not{E}_T$+dijet
  ⇒ $\not{E}_T$+b-jet(s) (using the displaced-track trigger)

- For some analysis, a multijet trigger is also available.

For the Run IIb, CDF upgraded his calorimeter trigger in order to improve resolution (mainly in $\not{E}_T$ reconstruction at the lower trigger levels)

⇒ Increased purity of the $\not{E}_T$-based samples.
⇒ Increased acceptance for interesting signals.
⇒ Made possible to run triggers at highest instantaneous luminosities.

See Gene Flanagan's W&C talk on Jun 5$^{\text{th}}$ 2009 for more details

Tools for analyses with $\not\!\!E_T$+jets

The $\not\!\!E_T$ used at the trigger and reconstructed level using the calorimeter towers is not a final representation of the real missing transverse momentum.

Corrections are needed:

- $\longrightarrow$ For mismeasurement of the jets (jet-energy scale)
- $\longrightarrow$ For muons, whose energy deposits are not their actual p_T

After these corrections, $\not\!\!E_T$ is close to the transverse momentum of missing/unmeasured particles but additional information helps to separate events with real or fake $\not\!\!E_T$.

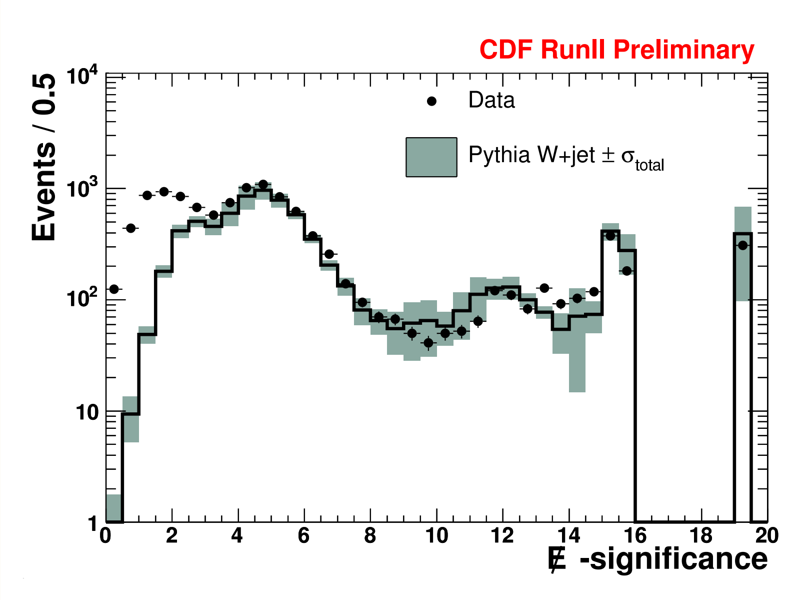
- **MET-Model:** Topology of the event is used to compute significance of observed $\not\!\!E_T$:

$\longrightarrow$ Parameterized resolution of objects

$\longrightarrow$ Identification of real-$\not\!\!E_T$ event candidates

$\longrightarrow$ Angular variables help in discrimination

The calculated significance was validated in a W+jet(s) sample.



Tools for analyses with $\not\!\!E_T$+jets (II)

- **Track-MET:** Reconstruct the $\not\!\!E_T$ using the tracks in the event

Assumes neutrals and out-of-acceptance particles may be neglected (or follow similar pattern to tracks).

$\longrightarrow$ **Magnitude is not directly the missing p_T.**

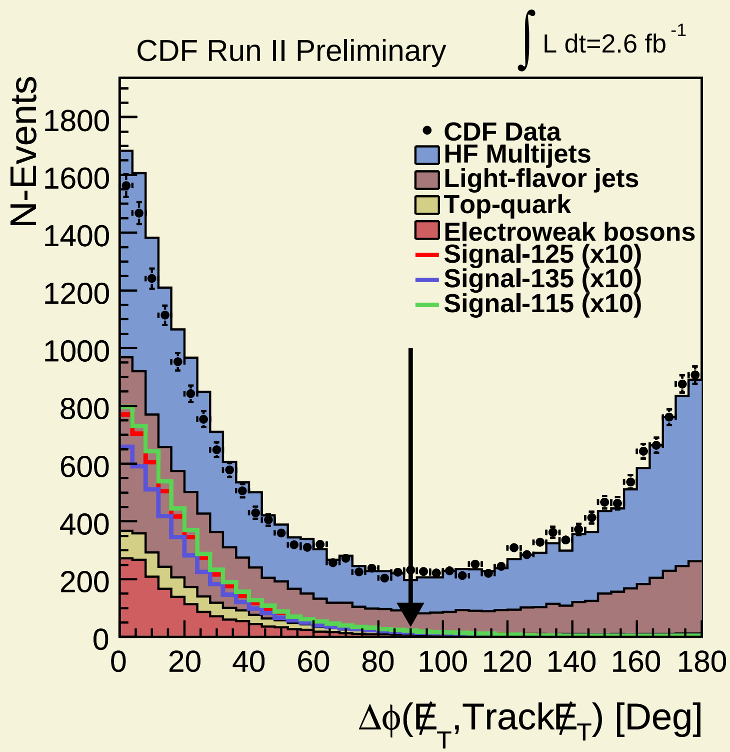
$\longrightarrow$ **Direction reflects neutrino direction.**

$\longrightarrow$ **Used before by DØ, e.g. Phys.Rev.Lett. 97 (2006) 16180.**

Expect that the difference in azimuth between track-MET and the "standard" $\not\!\!E_T$ is small if $\not\!\!E_T$ is due to hard missing particles.

Correlation between the angles is lost for fake-$\not\!\!E_T$ events.

Track-MET variables are currently extensively used in $\not\!\!E_T$ analyses, either as cut variables or as inputs to a neural net separation of events with real versus fake $\not\!\!E_T$.



SM Processes and sample composition

- **Processes with real $\not\!\!E_T$ are normally estimated with Monte Carlo:**

Top processes (mainly top-pair production)

They are dominant in the final selections, especially with multijet requirements.

W+jet(s)

Very common if no (loose) lepton is vetoed. The hadronic-tau component is (sometimes) hard to reduce.

Z+jet(s)

Especially bad is $Z \to \nu\bar{\nu}$ which is usually an irreducible background for searches.

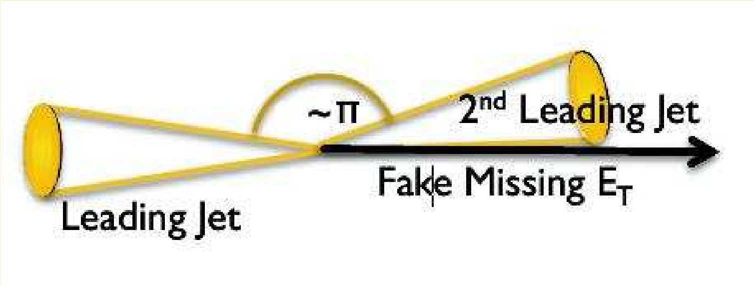
Dibosons

- **Processes with fake $\not\!\!E_T$: Multijets**

Appear from the mismeasurement of the energy of one (or more) jet(s).

Populated by QCD-produced multijets whose cross section is much larger than any process with real $\not\!\!E_T$

Semileptonic decays of hadrons lead to the same topology (underestimation of the energy).



This is the dominant component of the $\not\!\!E_T$+jets sample before any optimization.

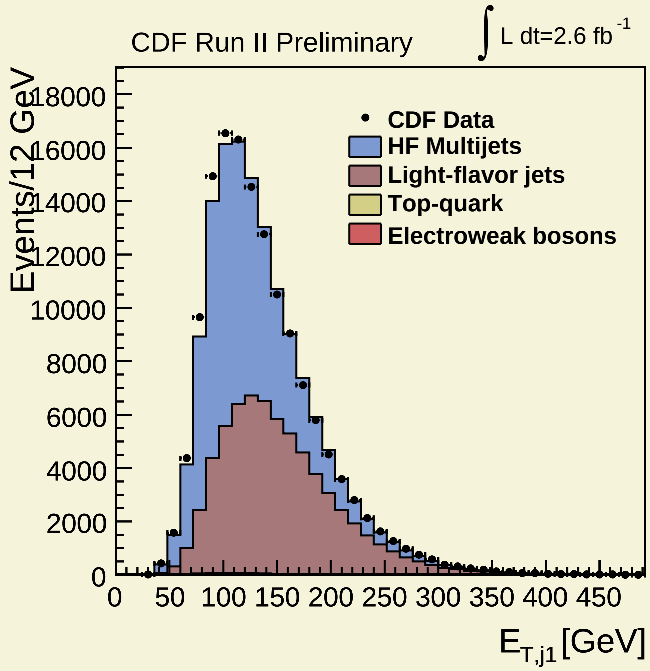
Multijet background from data

The huge cross section of QCD processes makes its estimation difficult.

- **Monte Carlo techniques were used in the past:**
  - ⇒ **Time (and CPU) intensive generation.**
  - ⇒ **Only practical for very tight selections, and small datasamples.**
  - ⇒ **Advantages of MC lost due to waste of resources.**
  - ⇒ **Small samples are used for checks.**

Data-based methods have become the only practical option

- **Extrapolation from control regions:**
  - ⇒ **Using control region(s) the shapes/normalization for the background are obtained.**
  - ⇒ **Assumption that kinematics are similar between control and signal region.**
  - ⇒ **Suitable when only few kinematic variables are interesting (e.g. resonances).**



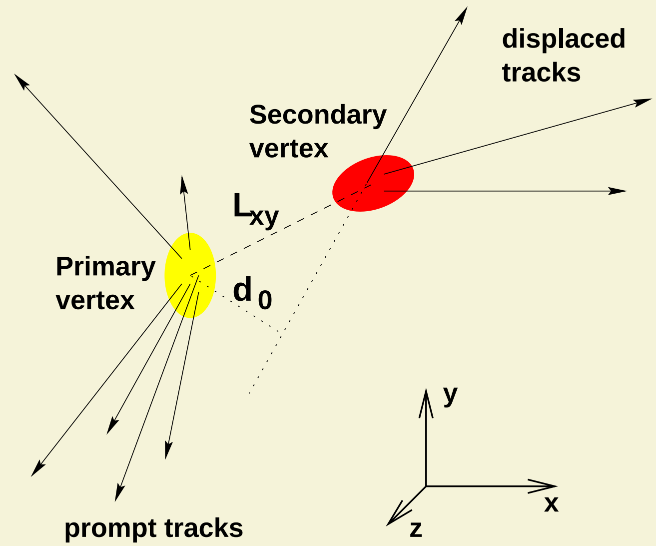
- **In analyses with heavy-flavour tagging:**
  - ⇒ **Commonly a tag-rate parametrization is used.**
  - ⇒ **Kinematics given by similar sample with no tags.**

Heavy-flavour tagging at CDF

The goal of b-tagging is to enhance the presence of signal by identifying heavy-flavour jets in the final state.

- **The tagging algorithms identify vertices from long-lived B/D hadrons.**

- **Decay distances ($c\tau \sim 300 - 500\ \mu$m) resolved with silicon detectors.**



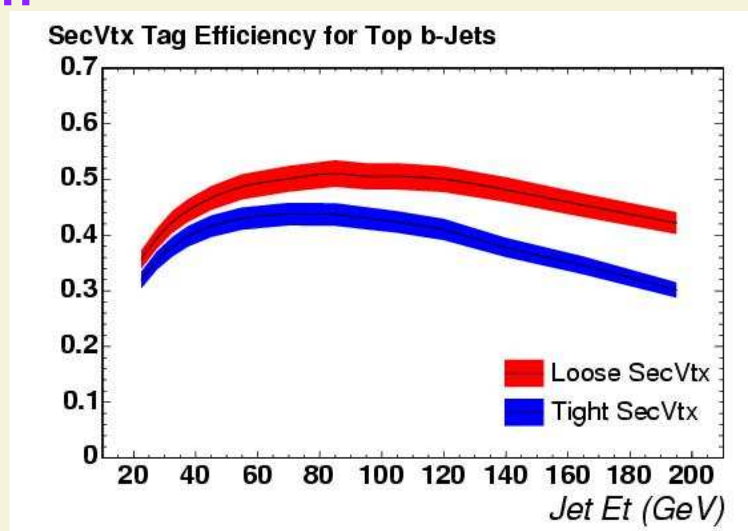
- **Algorithms at CDF based mostly on these properties:**

  $\Rightarrow$ **Reconstruction of secondary vertices**

  $\Rightarrow$ **Displaced tracks and their properties**

  $\Rightarrow$ **NN algorithm combining all the information**

(Lepton-based algorithm also used but not in the analyses covered here)



- **Always contribution from light-flavour jets wrongly tagged as heavy-flavour jets (mistags).**

They are estimated with data.

Multijet background for $\not{E}_T$+b-jet

The more sophisticated method CDF is currently using is the

MUltijet TAg-Rate Estimator (MUTARE)

which is applied to estimate the multijet background

Estimate the amount of expected Heavy-flavour multijet events in a sample using the data at a pre-tag stage (with minimum conditions on “taggability”), with the expression:

$$N^{HF-multijets} = R \times \left(N^{data}_{taggable} - N^{non-multijets}_{taggable}\right) = R \times \left(N^{data}_{taggable} - N^{MC-backgrounds}_{taggable}\right)$$

where R is a rate (parameterized in kinematic and tracking variables) computed in a reference, multijet-enhanced sample as:

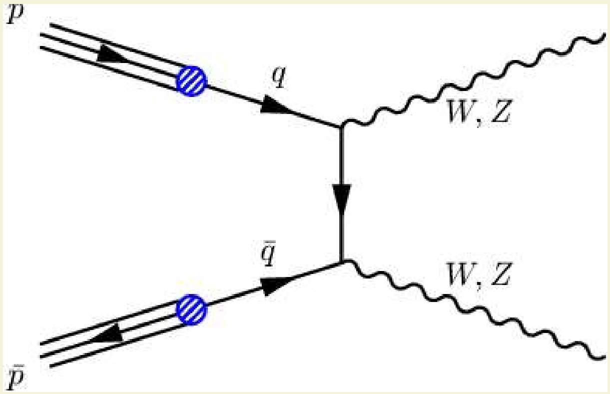
$$R = \frac{N_{tags} - N_{mistags} - N^{non-multijets}_{tags}}{N^{data}_{taggable} - N^{non-multijets}_{taggable}}$$

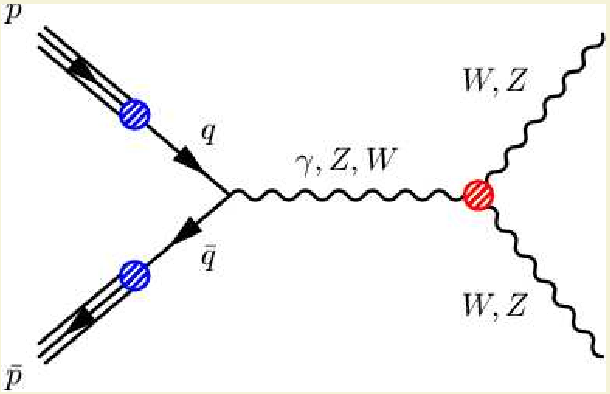
This represents a step forward over the usual tag-rate estimation since it allows to estimate the contributions from multijet and mistags separately.

The Analyses with $\not{E}_T$+Jets

Diboson observation

- Diboson production is one of the main topics in the Tevatron program.
- Directly sensitive to the SM structure (self coupling of the weak bosons).

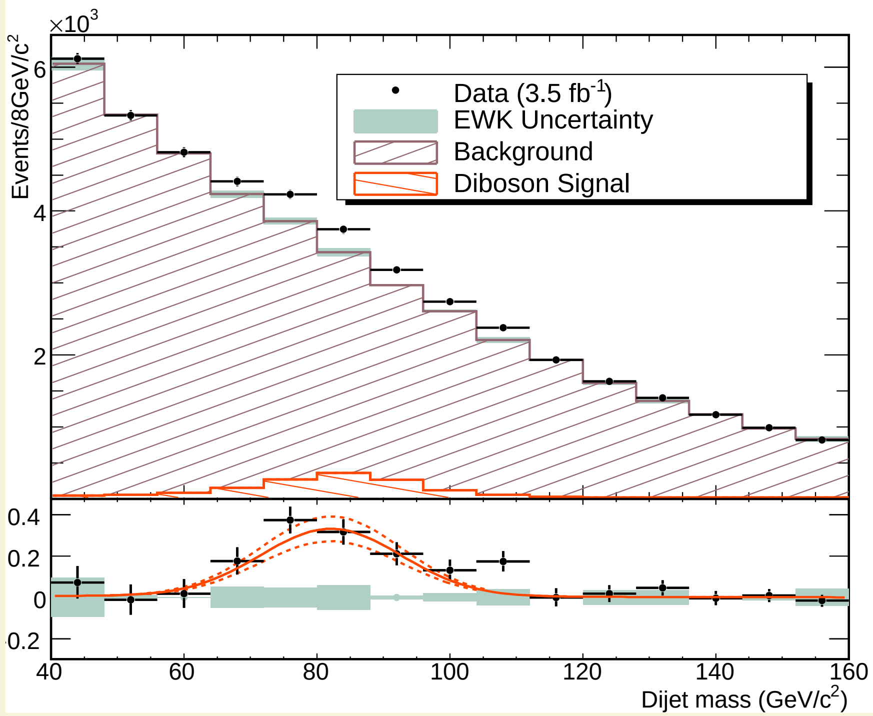




- Channels with leptons already observed, but what about the jet decays?
- Hadronic-decays of diboson are very interesting:
  - $\Rightarrow$ Resonance in dijet mass allows to study jet-energy scale
  - $\Rightarrow$ Sensitive to new physics (more branching ratio than leptonic decays)
  - $\Rightarrow$ Common topology/tools with Higgs searches at Tevatron
- Looking at final state with $\not{E}_T$+jets is very inclusive (high acceptance)
- Sensitive to WW, WZ and ZZ with $Z \rightarrow \nu\bar{\nu}$ and $W \rightarrow l\bar{\nu}$

Diboson observation (II)

- Analysis performed with 3.5 fb^{-1} sample
- Using $\not\!\!E_T$-based triggers.
- Extraction of signal based on template fits: signal, multijets and boson+jets
- Boson+jets extracted from MC
- Multijet from data
  (from $\Delta\phi$(Track-MET, $\not\!\!E_T$) > 1 rad)



- Suppressed using the MET-Model technique.

$1516 \pm 239(\mathrm{stat}) \pm 144(\mathrm{syst})$ **diboson events**

$\sigma = 18.0 \pm 2.8(\mathrm{stat}) \pm 2.4(\mathrm{syst}) \pm 1.1(\mathrm{lum})$ **pb**

- This result was the first observation of diboson with jets in the final state.
- $\not\!\!E_T$+jets analysis more sensitive than the corresponding lepton+jets.
- Published as **Phys. Rev. Lett. 103 (2009) 091803.**

See Gene Flanagan's W&C talk on Jun 5$^{\mathrm{th}}$ 2009 for more details

Top Physics: Cross Section Measurement

- Due to the presence of jets and $\not\!\!E_T$ from W decays, top events may also be studied using the $\not\!\!E_T$+jets sample.

- Measurement of the cross section based on a multijet trigger:

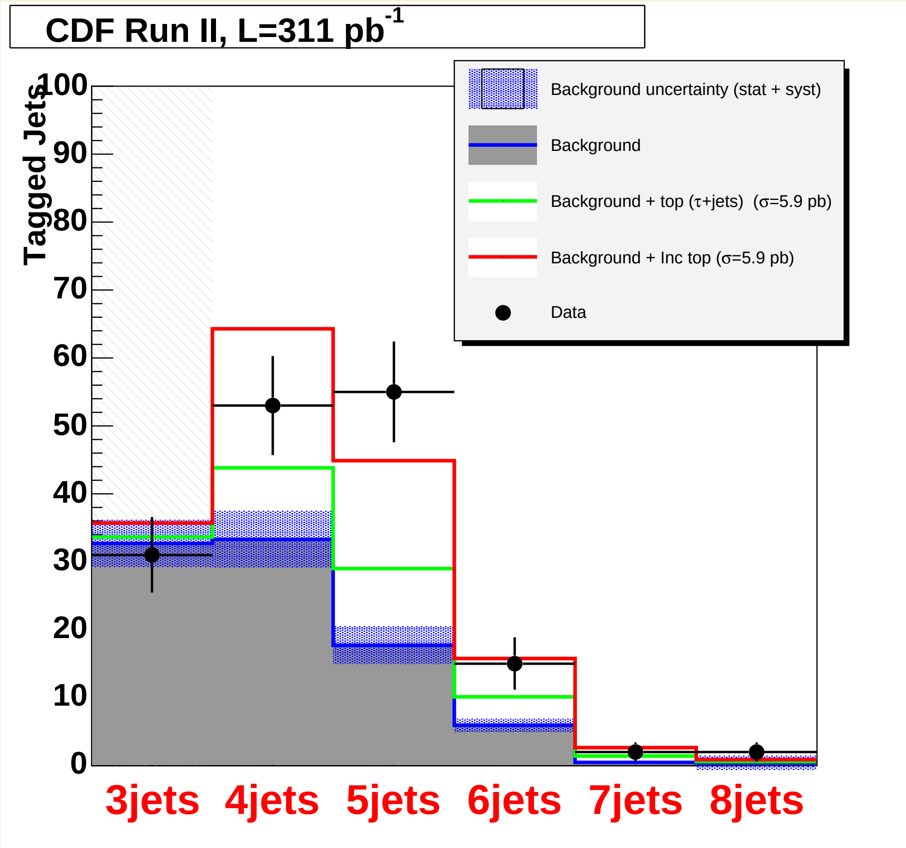
⇒ Three or more jets in the final state.

⇒ Cross section measured counting number of tagged jets.

⇒ $\not\!\!E_T$ requirement to reduce the background.

⇒ Very sensitive to final states with hadronic taus, even without explicit tau reconstruction.

- First CDF analysis using $\not\!\!E_T$ instead of lepton reconstruction to select events where leptons are indeed expected.



$$\sigma(t\bar{t}) = 5.8 \pm 1.2\ (\text{stat})^{+0.9}_{-0.7}\ (\text{syst})\ \textbf{pb}$$ (m(t)=178 GeV/c^2)

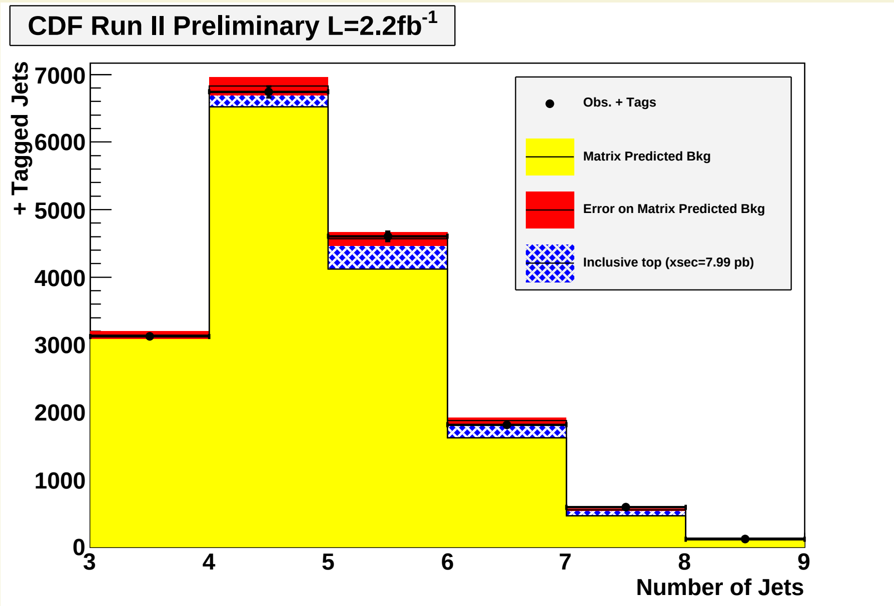
- Published as Phys.Rev.Lett. 96 (2006) 202002

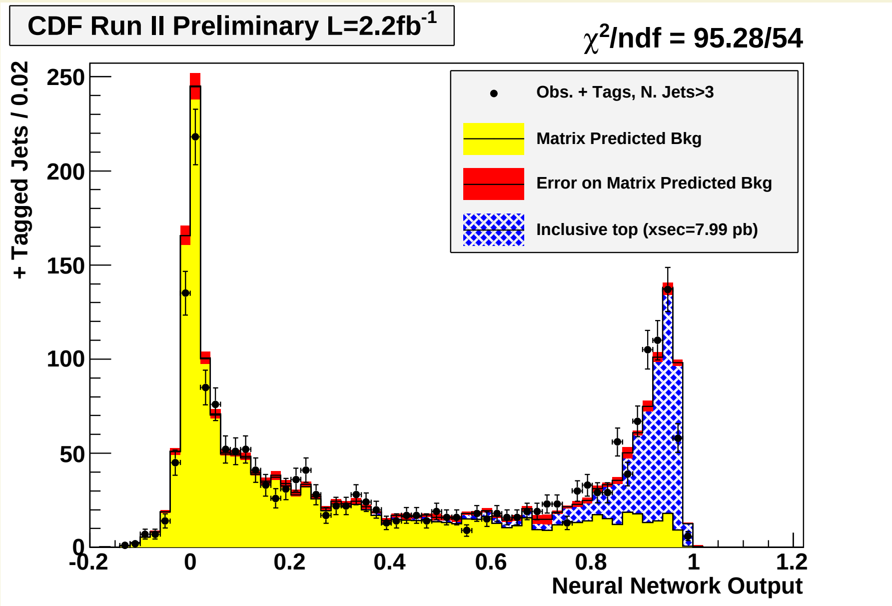
Top Physics: Cross Section Measurement (II)

- Last update of the analysis using 2.2 fb^{-1}.

- Reduction of the background using a Neural-Network approach instead of cut-based selection.

- Same strategy as previous version.





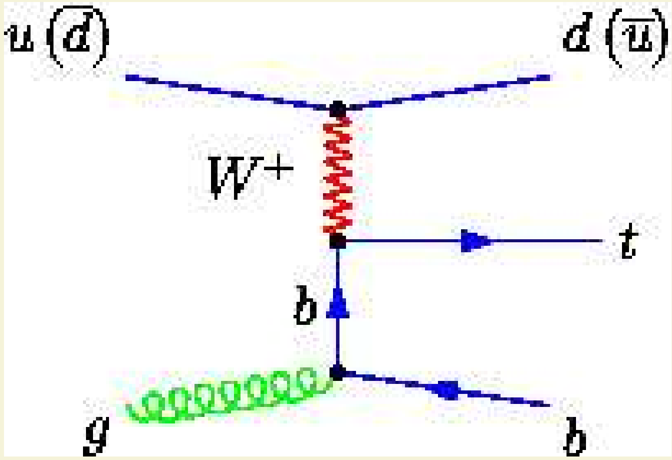
$$\sigma(t\bar{t}) = 7.99 \pm 0.55\ (\text{stat}) \pm 0.76\ (\text{syst}) \pm 0.46\ (\text{lum})\ \textbf{pb}$$ (m(t)=172.5 GeV/c^2)

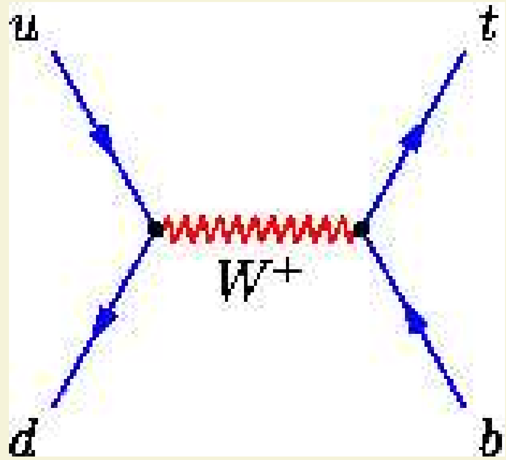
- Uncertainty is comparable to other measurements.

- Sample completely independent to lepton+jets (explicit in the selection).

Top Physics: Single-top observation

- In addition to its use in Top-Pair production, $\not{E}_T$+b-jet(s) is sensitive to single-top processes.





- Mostly intended to cover the remaining events not used in the (traditional) lepton+jets searches.

- Leptons are vetoed (exclusiveness), so sensitivity mostly coming from events with an hadronic-tau.

- Number of discriminating variables is smaller than in the lepton+jets case.

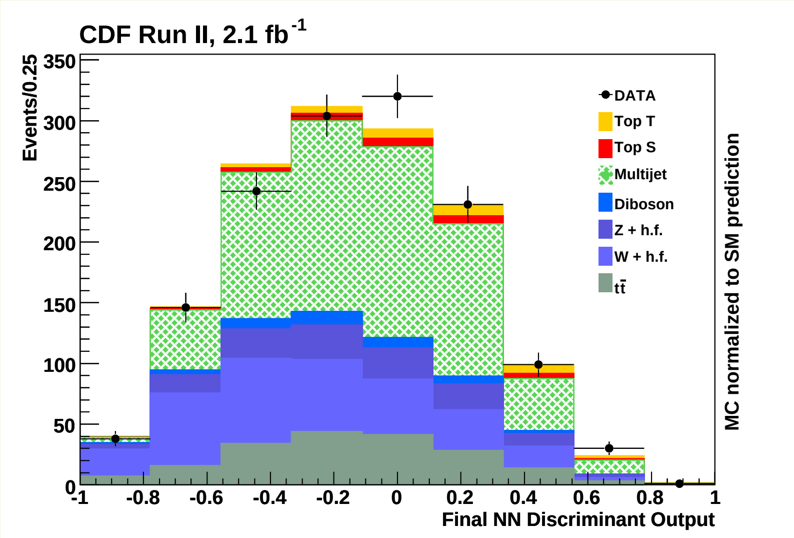
- Note that the $\not{E}_T$-based triggers were also used in the lepton+jets analyses, to gain sensitivity with no triggered leptons.

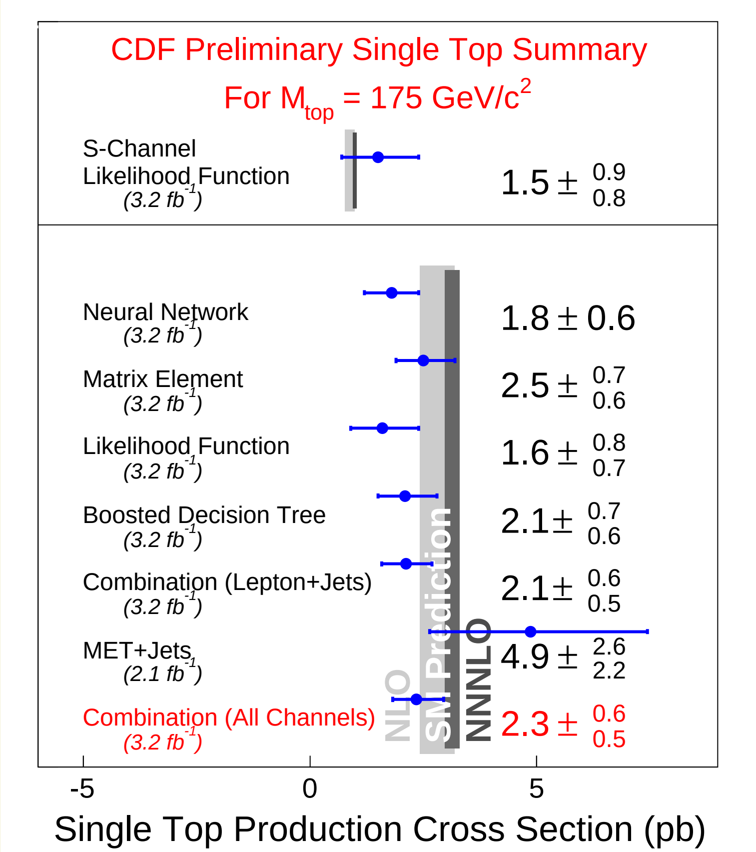
Top Physics: Single-top observation (II)

- **First search using $\not\!\!E_T$+jets done with 2.1 fb^{-1}.**
- **Multijet background estimated with a tag-rate parametrization.**
- **Suppressed using a Neural-Network approach.**
- **Final discrimination with a second NN.**

$\sigma = 4.9^{+2.5}_{-2.2}$ **pb (2.1σ significance)**

$|V_{tb}| = 1.24^{+0.34}_{-0.29}(\mathrm{exp}) \pm 0.07(\mathrm{theory})$



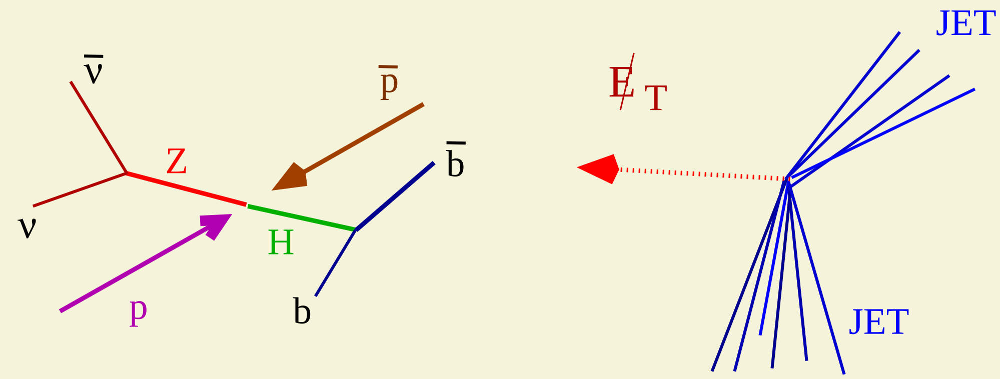


- **Adds visible sensitivity to final combination (completely independent sample) as described in Phys.Rev.Lett. 103 (2009) 092002**

See Fabrizio Margaroli's W&C talk on October 23$^{\mathrm{th}}$ 2009 for details

The SM Higgs Search

- One of the most interesting use of $\not\!\!E_T$+b-jets (e.g. motivated the upgrade of the trigger) is **the search for the SM Higgs, mostly for $ZH \rightarrow \nu\bar{\nu}b\bar{b}$**:



- Fundamental to achieve the Tevatron goals for low-mass Higgs search:

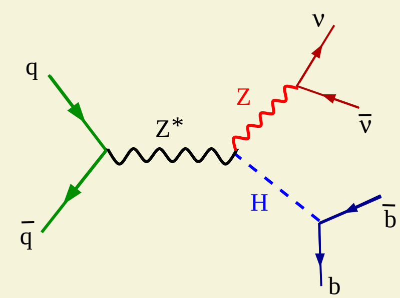
$\Rightarrow$ Large branching ratio of $Z \rightarrow \nu\bar{\nu}$.

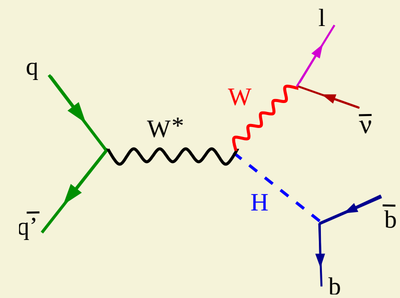
$\Rightarrow$ Exclusive to the lepton+jets searches.

$\Rightarrow$ Cleaner topology than in the single-top case.

$\Rightarrow$ Kinematics (angles) and dijet resonance.

$\Rightarrow$ Also sensitive to WH (missing lepton).

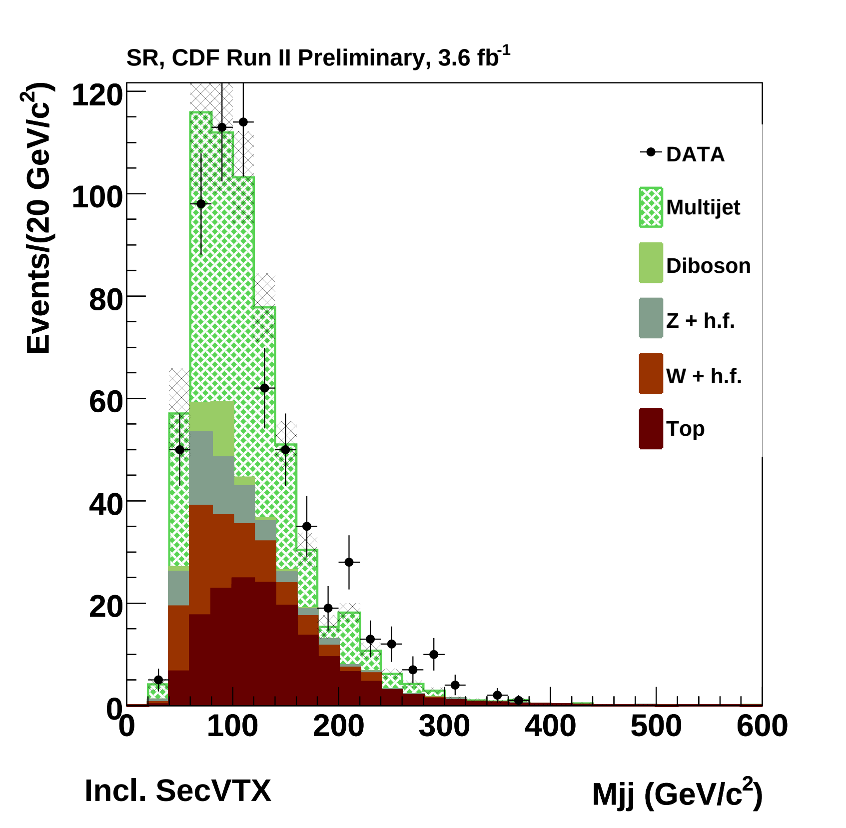


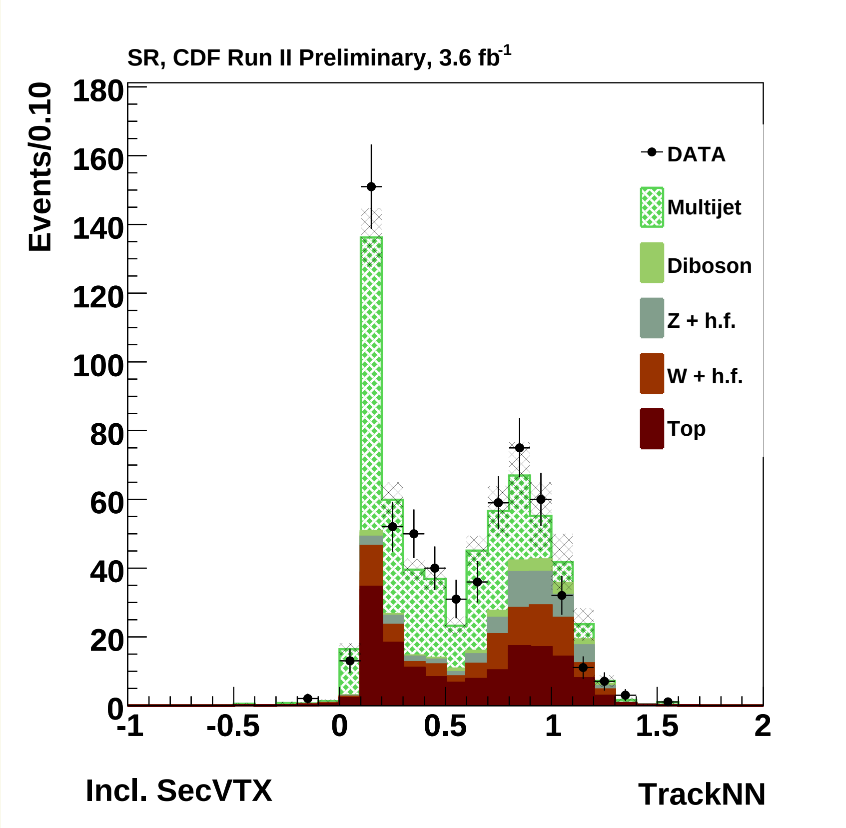


Traditionally considered the second (after WH) most important channel, it has turned out to be the most sensitive in practice due to the large acceptance in a single topology.

The SM Higgs Search (II)

- Shared tools and knowledge with the related single-top and SUSY searches.
- Improved selection in order to maximize acceptance (~ 4 Higgses per fb^{-1})
- Last analysis blessed with 3.6 fb^{-1} of good data.





- Track-MET variables used in specific NN (good agreement with expectations)
- It is used as input variable for final NN discriminant.

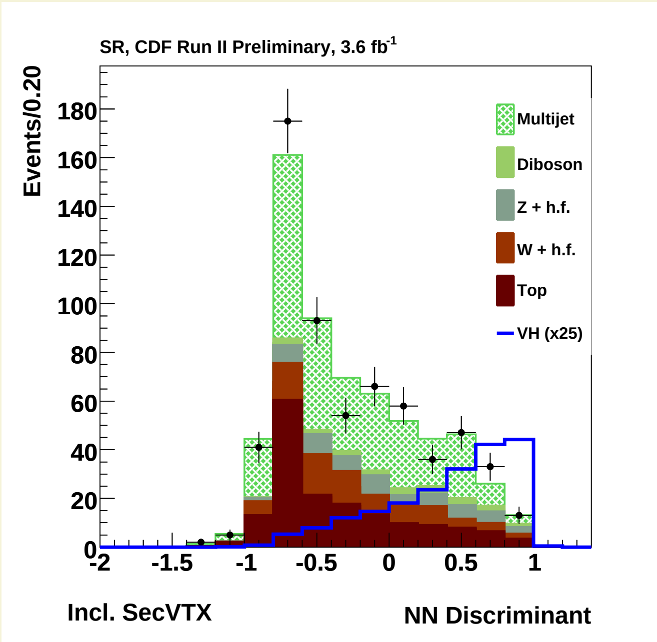
The SM Higgs Search (III)

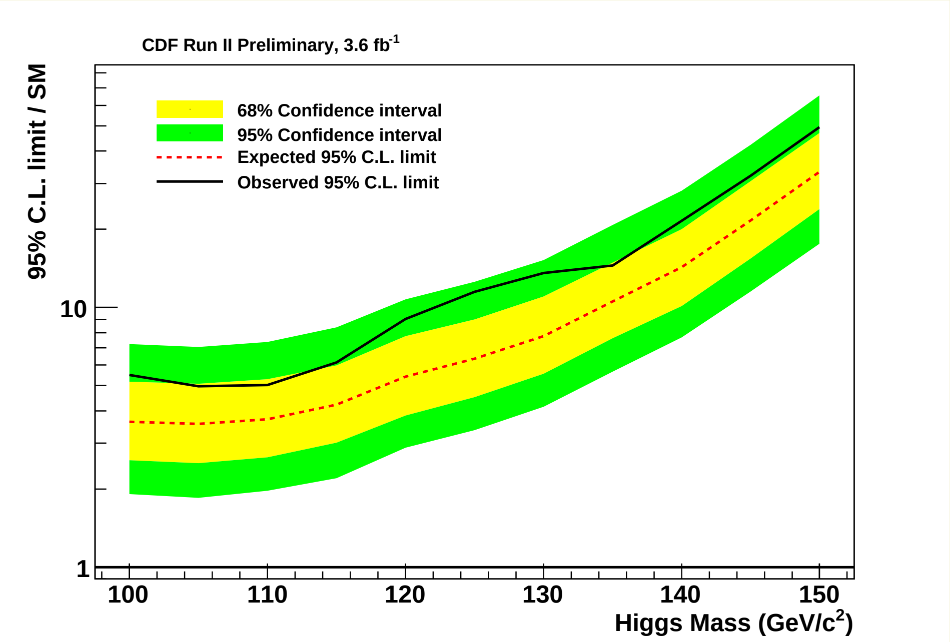
⇒ **Additional sensitivity gained by splitting the final events in different tagging categories (associated to the tagger classes and the number of tags).**

⇒ **Used in latest combination.**

CDF Run II Preliminary, 3.6 fb^{-1}

Process	Excl. ST	ST+ST	ST+JP
QCD + Mistags	1593 ± 63	55 ± 9	120 ± 14
Single Top	73 ± 13	14 ± 3	11 ± 2
Top Pair	209 ± 25	45 ± 7	42 ± 5
Diboson	60 ± 11	8 ± 2	7 ± 2
W+H.F.	499 ± 216	18 ± 10	33 ± 15
Z+H.F.	180 ± 77	18 ± 8	18 ± 8
Exp. Background	2476 ± 300	166 ± 22	259 ± 28
Observed	2397	157	233
$ZH \to \nu\nu bb$ ($MH = 115$ GeV)	3.5	1.6	1.3
$WH \to (l)\nu bb$ ($MH = 115$ GeV)	3.1	1.4	1.2
$ZH \to (ll)bb$ ($MH = 115$ GeV)	0.1	0.1	0.1
Exp. Signal	6.7	3.1	2.6





See Fabrizio Margaroli's W&C talk on October 23th 2009 for details

Search of New Physics

- In spite of the success of the SM results (also confirmed in the $\not{E}_T$+Jets sample), there are still some open questions about Nature and about the reasons why the SM works so nicely:

  $\longrightarrow$ Hierarchy of scales and fermion masses
  $\longrightarrow$ Why three generations
  $\longrightarrow$ Composition of Dark Matter and Energy
  $\longrightarrow$ Gravity at the particle (quantum) level
  ...

- The answers to these questions may be summarized in the existence of "New Physics" (i.e. something beyond the SM).

- (Some of the) New-Physics particles might be Weakly-Interacting and in practice escape detection.

- Especially true for Dark Matter candidates.

- If Tevatron produces these particles, they provide additional events with $\not{E}_T$.

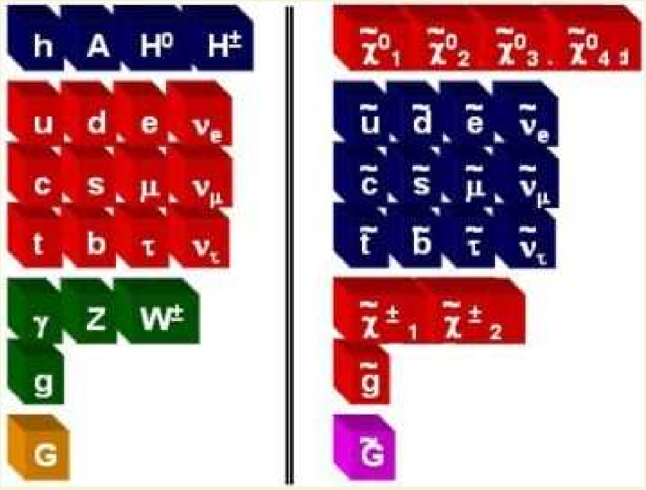
- Other option is New Physics enhancing neutrino production.

SUSY in the $\not\!\!E_T$+jets channel

- Supersymmetry (SUSY) makes Nature invariant under the transformation

bosons ⇔ fermions

- For this to be satisfied we require a supersymmetric partner for each known (or to be known) particle.



This symmetry is commonly introduced since it solves some weak points of the SM (on the theoretical side).

The quantum number: $R_p = (-1)^{2S+3B+L}$
is 1 for particles and -1 for superparticles.

In R_p-conserving models, the lightest supersymmetric particle (LSP) is stable and weakly-interacting (Dark Matter?) and appears in the final state as $\not\!\!E_T$.

If masses are reachable at the Tevatron, squarks and gluinos are produced via the strong interaction:

$$p\bar{p} \rightarrow \tilde{q}\tilde{q}X \rightarrow q\tilde{\chi}^0 q\tilde{\chi}^0 X \text{ } (\not\!\!E_T\text{+2 jets})$$

$$p\bar{p} \rightarrow \tilde{g}\tilde{q}X \rightarrow q\bar{q}\tilde{\chi}^0 q\tilde{\chi}^0 X \text{ } (\not\!\!E_T\text{+3 jets})$$

$$p\bar{p} \rightarrow \tilde{g}\tilde{g}X \rightarrow q\bar{q}\tilde{\chi}^0 q\bar{q}\tilde{\chi}^0 X \text{ } (\not\!\!E_T\text{+4 jets})$$

SUSY in the $\not\!\!E_T$+jets channel (II)

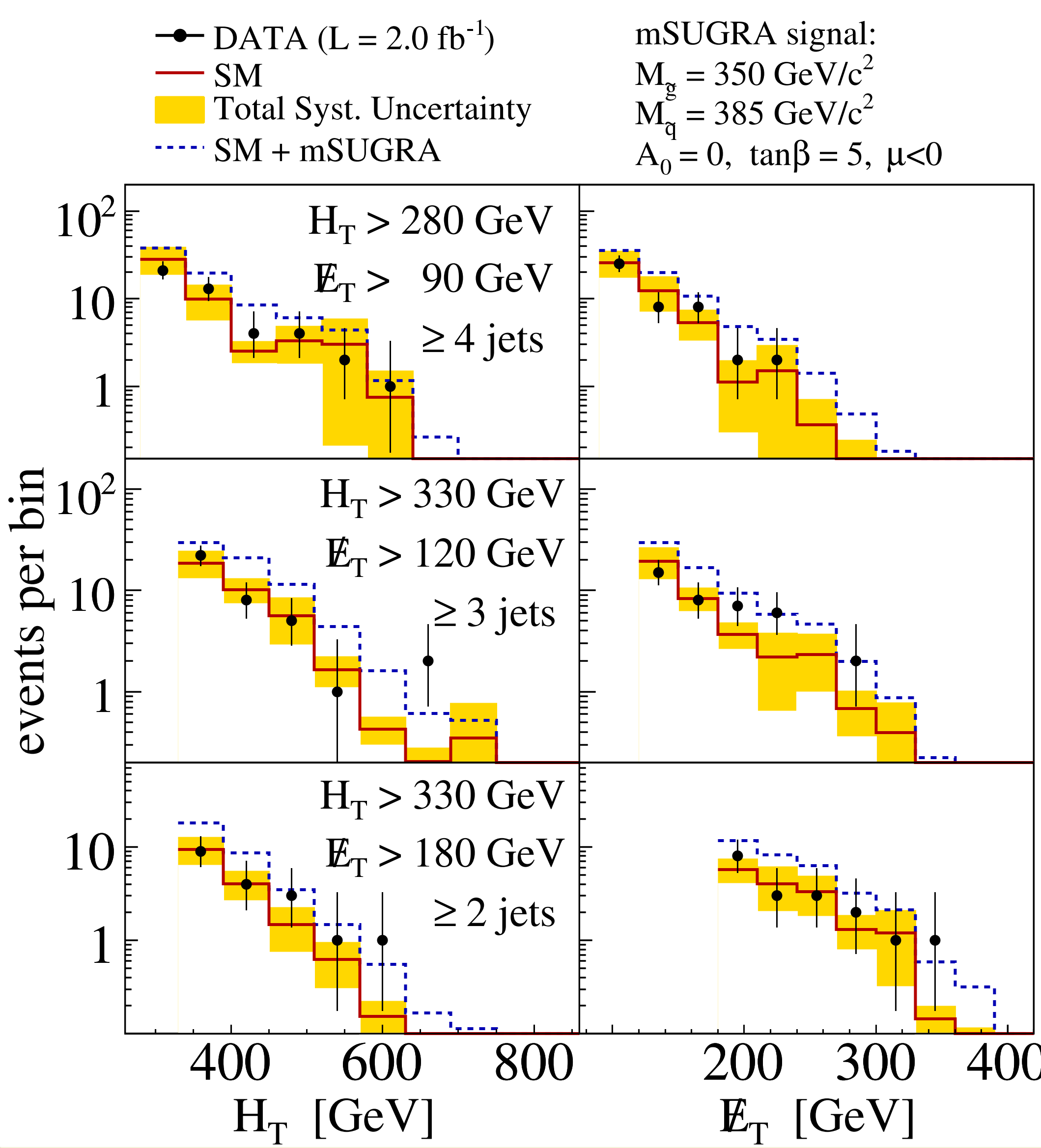
- **Search has been performed optimizing for each of the final states.**
- **Optimization variables:**

$$\not\!\!E_T$$

$$E_{T,\mathrm{j(s)}}$$

$$H_T = \sum E_{T,\mathrm{jet}}$$

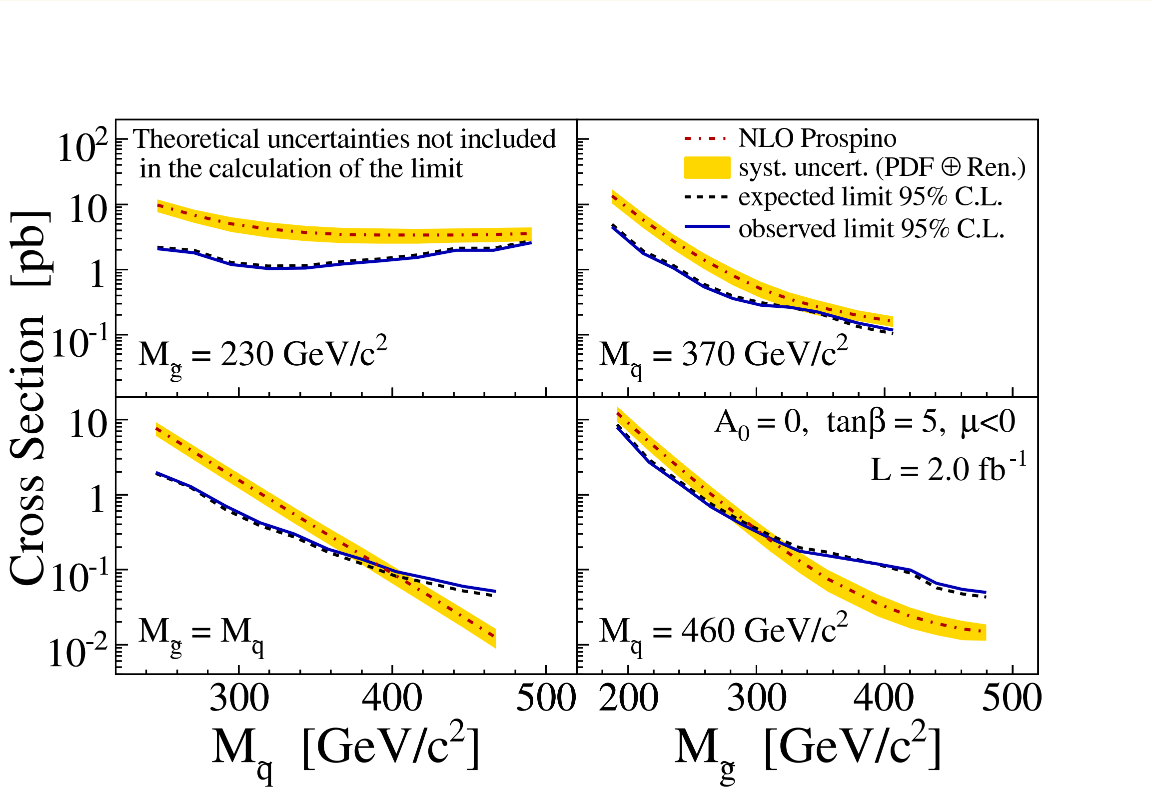
- **In the analysis, multijet background was estimated using huge amount of QCD MC.**
- **Top and W/Z+jets also important.**
- **Optimization performed with cuts for different topologies.**

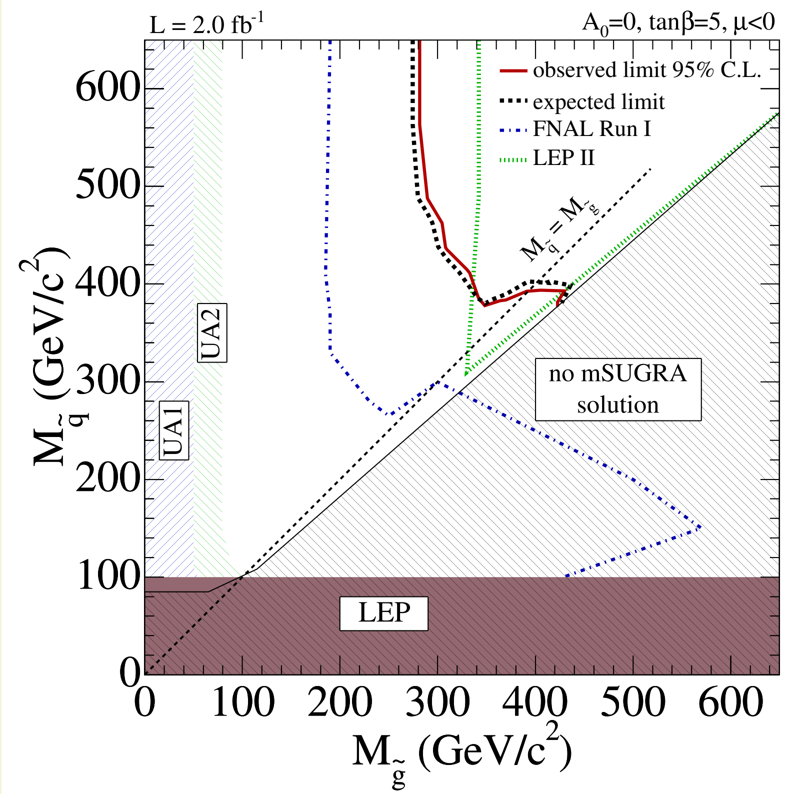


- **Final number of events:**

Events (2 fb^{-1})	2-jets	3-jets	4-jets
Total SM	16 ± 5	37 ± 12	48 ± 17
Observed	18	38	45

Since no hint of SUSY was found, limits were set:





- In the mSUGRA interpretation, excluding regions not accessed by LEP.
- gluinos: $m > 280$ GeV$/c^2$ for all squark masses.
- squarks: $m > 380$ GeV$/c^2$ for all gluino mass.
- Published as Phys.Rev.Lett. 102 (2009) 121801
- Analysis is currently being combined with the DØ equivalent.

SUSY with $\not{E}_T$ and HF-tagging

- Particular properties of the third generation fermions (much more massive) make it (sometimes) more sensitive to the New Physics.

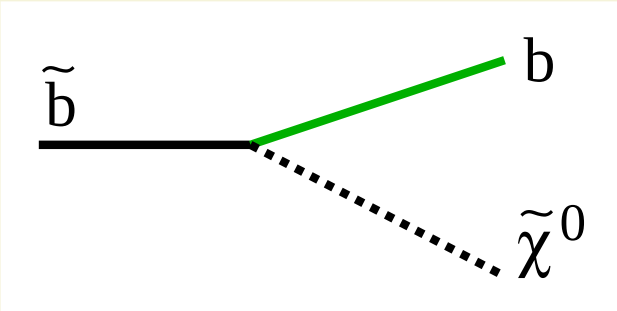
- In the context of SUSY this usually means that third-generation scalars tend to be lighter than the other scalars (due to large mixing).

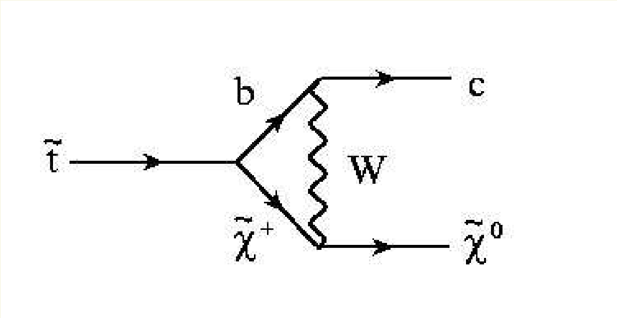
- One additional advantage of the third generation is that SM particles (top, bottom and tau) are

  $\Rightarrow$ Harder to produce (i.e. less background)

  $\Rightarrow$ Easier to identify (in the case of jets)

- Sensitivity to $\not{E}_T$+heavy-flavour jets is enhanced with decays:





- This motivates the extended use of the $\not{E}_T$+b-jet (i.e. with heavy-flavour tagged jet) sample in searches of SUSY or other extensions of the SM.

  $\Rightarrow$ $\not{E}_T$ is coming from the LSP (neutralino)

  $\Rightarrow$ Heavy-flavour jets coming from b and c quarks in the decays.

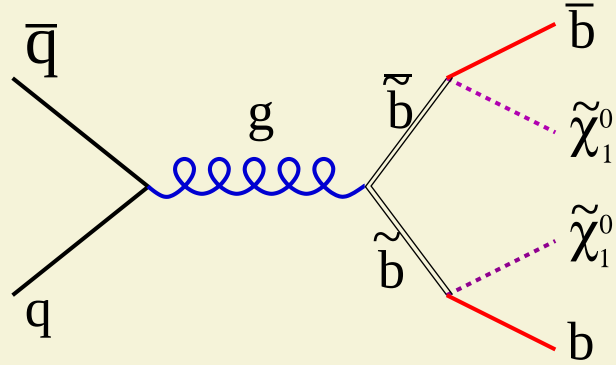
Search for scalar bottoms

- Due to mixing of chirality states, the sbottom may be the lightest coloured SUSY particle (at large $\tan\beta$).

$$m^2_{\tilde{b}_{1,2}} = \frac{1}{2}[m^2_{\tilde{b}_L} + m^2_{\tilde{b}_R} \pm \sqrt{(m^2_{\tilde{b}_L} - m^2_{\tilde{b}_R})^2 + 4m^2_b(A_b - \mu\tan\beta)^2}]$$

- LSP is neutralino (Dark matter candidate)

- The sbottom decay is 100% to bottom and neutralino.

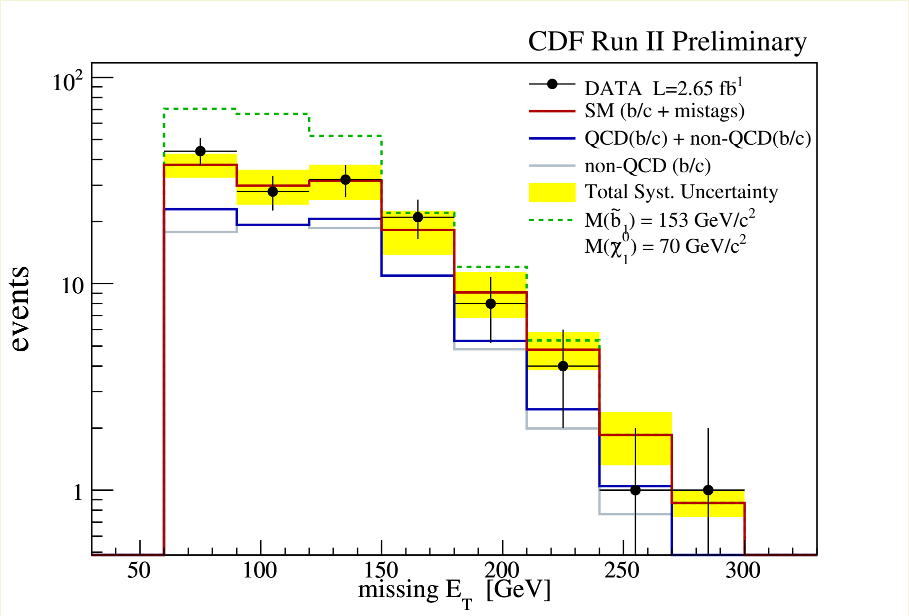


$\not{E}_T$+2 b-jets

- Background dominated by multijet and mistags (using the MUTARE method)

- Others are estimated with MC

- Optimization based on
  - $\Rightarrow$ Kinematics: $\not{E}_T$, $\sum E_T$ (jets)
  - $\Rightarrow$ b-tagging of jets (secondary vertices)



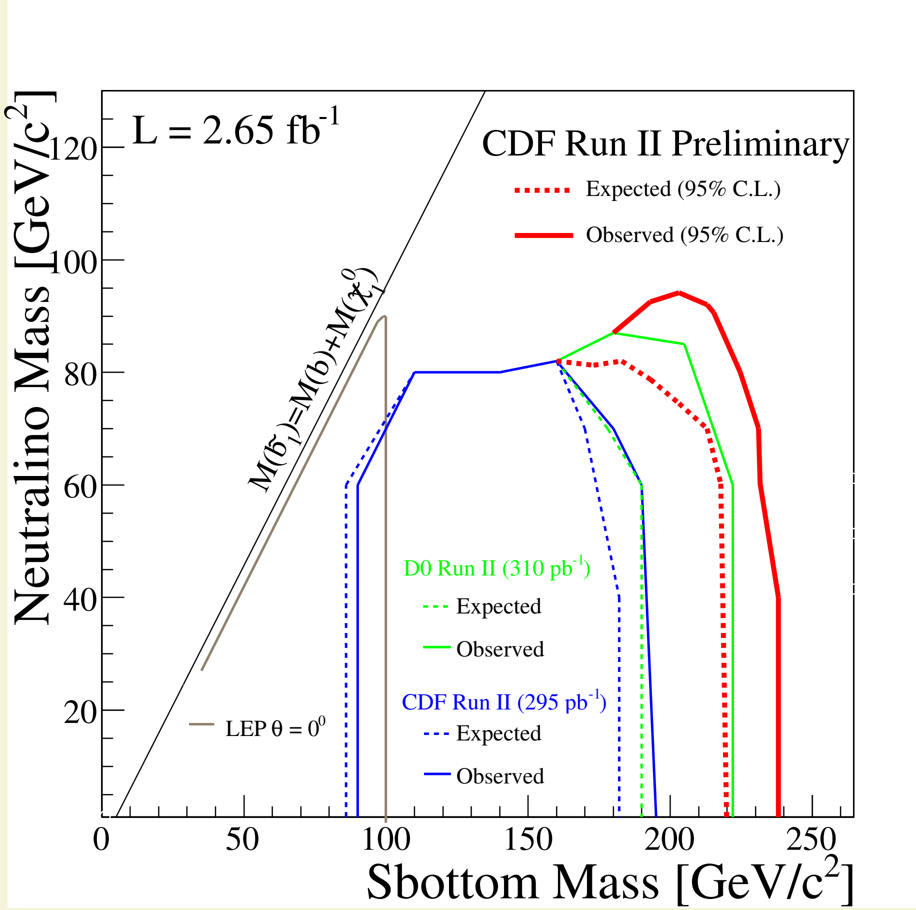
Search for scalar bottoms (II)

- Two cut-based optimizations performed (depending on the mass difference between the sbottom and the neutralino).

- Optimizing on $\not\!\!E_T$ and $\sum E_{T,\mathrm{jet}}$

- Final numbers:

CDF Preliminary $(2.65\ \mathrm{fb}^{-1})$	Expected	Observed
low ΔM	133.8 ± 25.2	139
high ΔM	47.6 ± 8.3	38



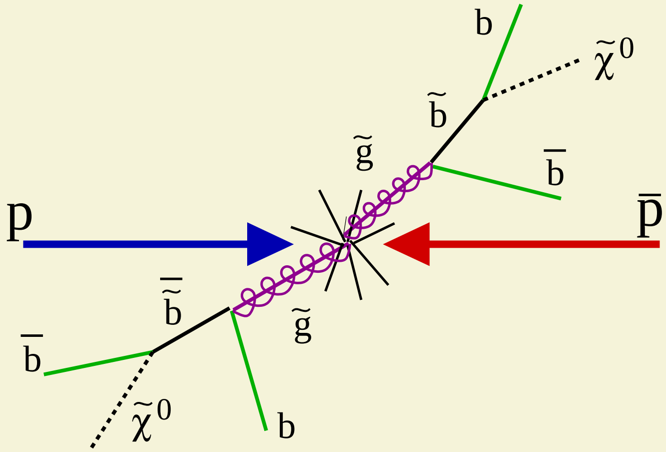
- Good agreement with the SM expectations.

- No hint of sbottom (or new physics) in this sample.

- This analysis has extended the previous limit towards larger $m(\tilde{b})$.

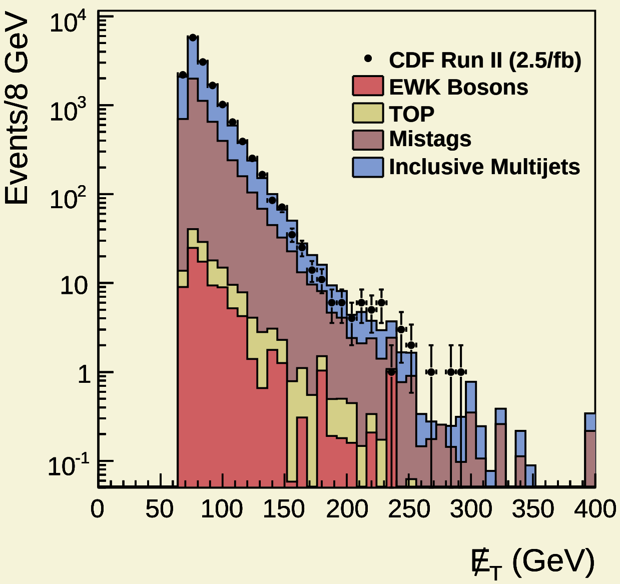
Scalar bottom from gluino decays

An alternative way is to look for the presence of sbottoms from gluino decays:

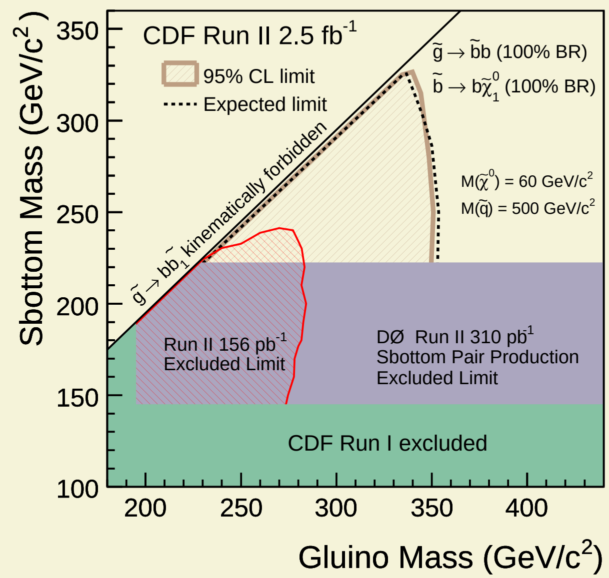


- Higher cross section
- Low-background signature: $\not{E}_T$+4 b-jets
- Larger model dependence
- Adds dependence on $m(\tilde{g})$
- Results are very competitive for $m(\tilde{g}) \sim m(\tilde{b})$

The analysis performed two optimizations (depending on the mass difference)



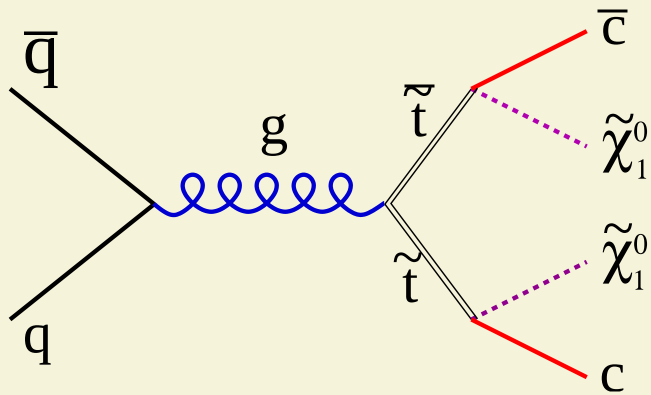
	Large Δm Optimization	Small Δm Optimization
Electroweak bosons	0.17 ± 0.05	0.5 ± 0.3
Top-quark	1.9 ± 1.0	0.6 ± 0.4
Light-flavor jets	1.0 ± 0.3	0.6 ± 0.1
HF Multijets	1.6 ± 0.8	0.7 ± 0.3
Total expected SM	4.7 ± 1.5	2.4 ± 0.8
Observed	5	2
Optimized $\tilde{g}$ signal	14.9 ± 5.0	8.5 ± 2.8



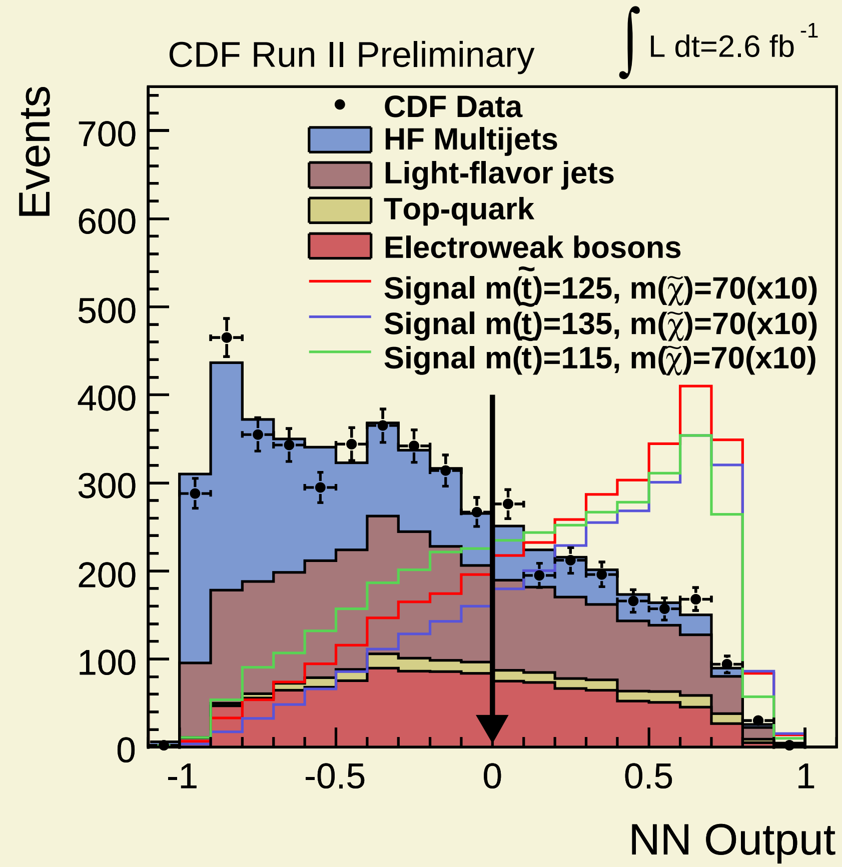
- Good agreement with SM predictions: competitive limit set.
- Published as **Phys.Rev.Lett. 102 (2009) 221801**

Scalar top in $\not\!\!E_T$ and charm-tagging

- For low-mass scalar top, the decay $\tilde{t} \rightarrow c\tilde{\chi}^0$ may dominate



- Again we have $\not\!\!E_T$+ (heavy-flavour) jets.
- Similar tools as those described above: MUTARE, Track-MET.
- In this case however:
  - ⇒ Charmed jets instead of bottom
  - ⇒ Tagging should focus on properties of charm hadrons
  - ⇒ Background dominated by QCD multijets and mistags (reduced using NN approach).

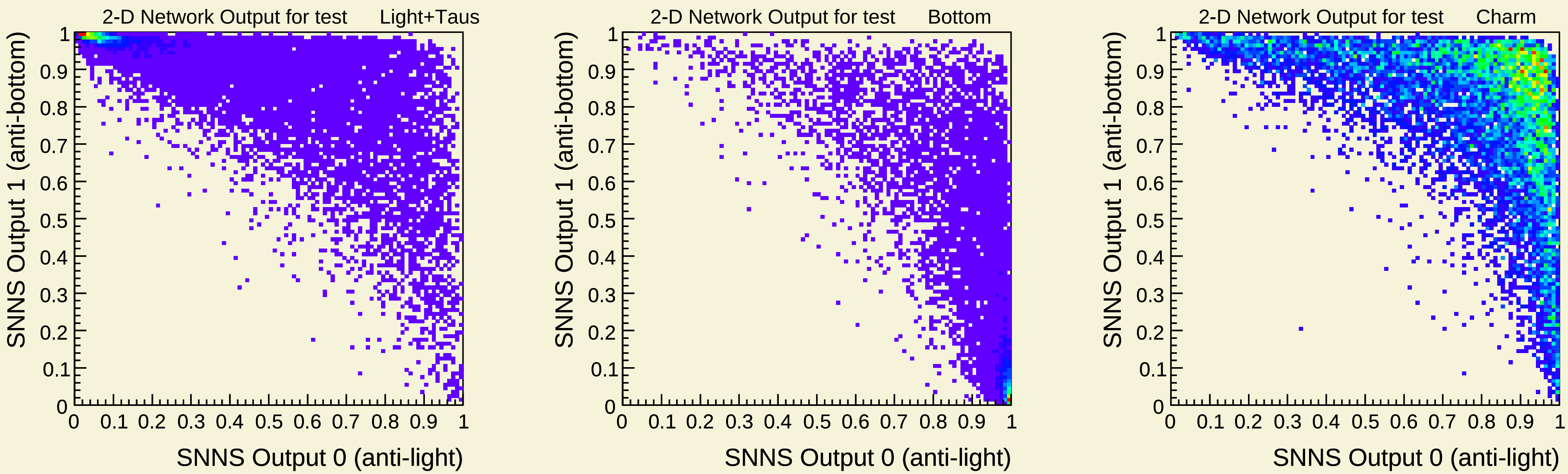


Scalar top in $\not{E}_T$ and charm-tagging (II)

Recent CDF search exploited properties for charm-tagging of jets to reduce background from bottom jets.

Using a Charmed-Hadron Analysis-Oriented Separator (CHAOS)

which is a 2-D Neural-Network allowing to select a high-purity sample of charmed-jets.



- **Using a SNNS NN with 22 variables.**
- **Discriminating for charm cutting on the sum of the outputs ($O_0 + O_1 > 1.65$).**
- **Accepting 30% of charm jets and $\sim 5\%$ of bottom or light jets.**

Scalar top in $\not\!\!E_T$ and charm-tagging (III)

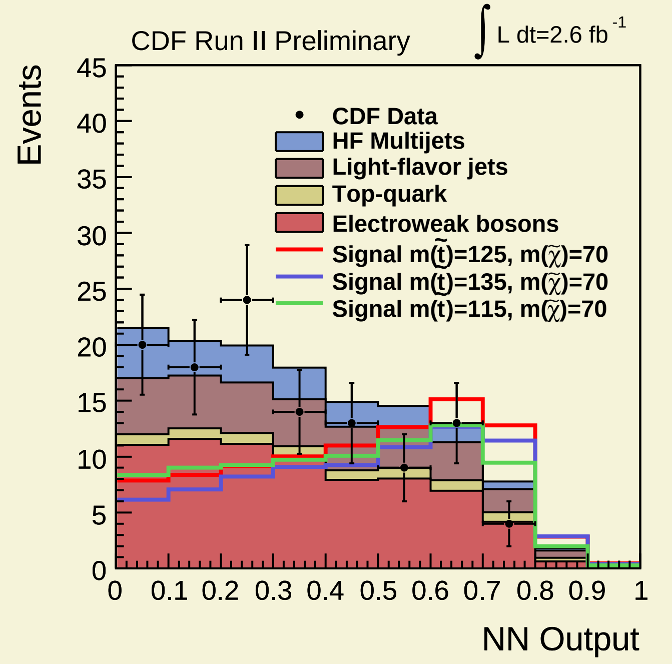
- Applying CHAOS to select events in the final region we are left with a reduced number of events.

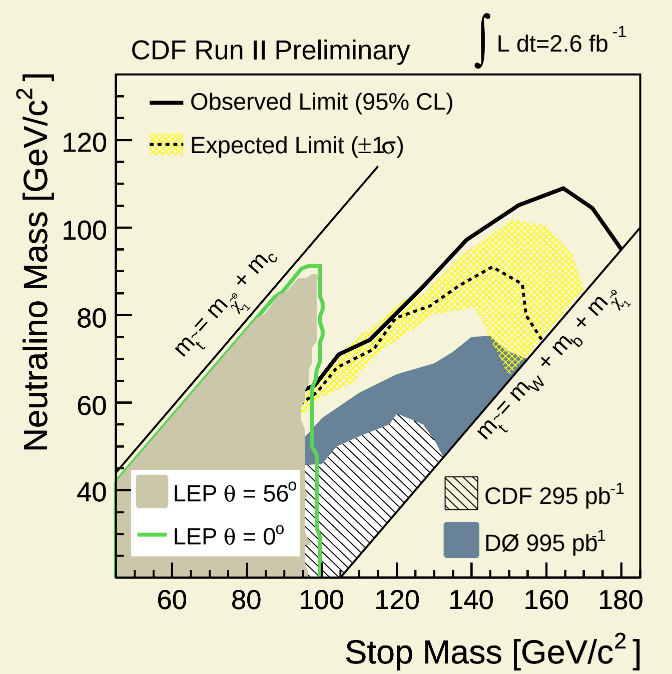
- And shape of the NN are different, so we used it to enhance the sensitivity (following Higgs-analysis experience).

CDF Run II Preliminary 2.6 fb^{-1}

	Final Region
W/Z + jets production	60.9 ± 26.6
Diboson production	10.7 ± 1.9
Top pair production	4.6 ± 1.3
Single top production	3.2 ± 0.8
HF QCD Multijets	20.4 ± 15.2
Light-flavour contamination	32.2 ± 12.7
Total expected	132.0 ± 24.4
Observed	115
Signal m($\tilde{t}$)=125, m($\tilde{\chi}^0$)=70	90.2 ± 23.9
Signal m($\tilde{t}$)=135, m($\tilde{\chi}^0$)=70	78.0 ± 20.7
Signal m($\tilde{t}$)=115, m($\tilde{\chi}^0$)=70	82.4 ± 21.8

- No hint of scalar tops but sensitivity greatly extended.

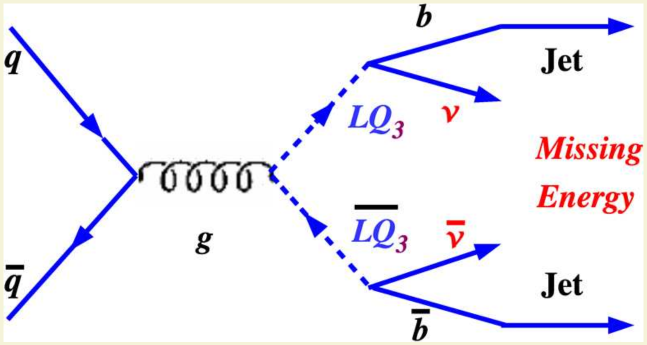


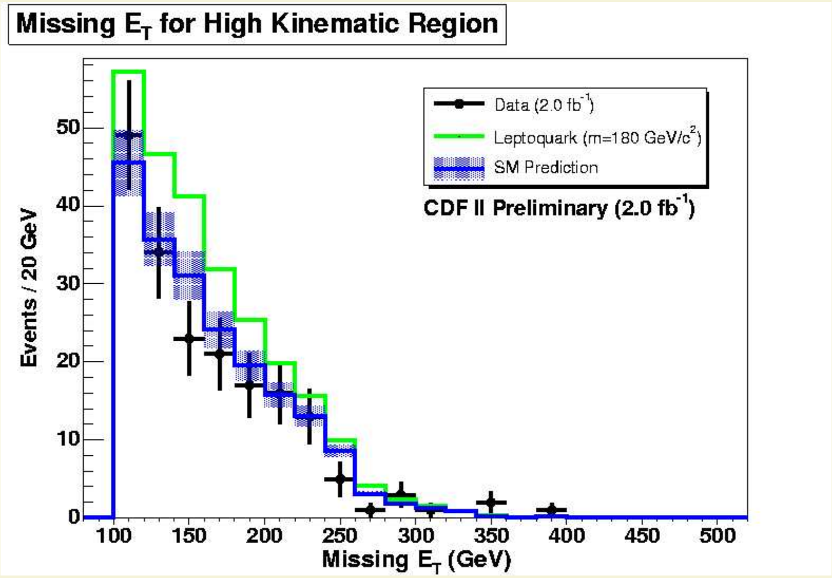


Leptoquark searches

- The $\not{E}_T$+Jets topology is also a final state for leptoquarks that decay into quarks and neutrinos.

This search is inclusive to all the families.





⇒ Data-driven estimation of QCD and EWK.

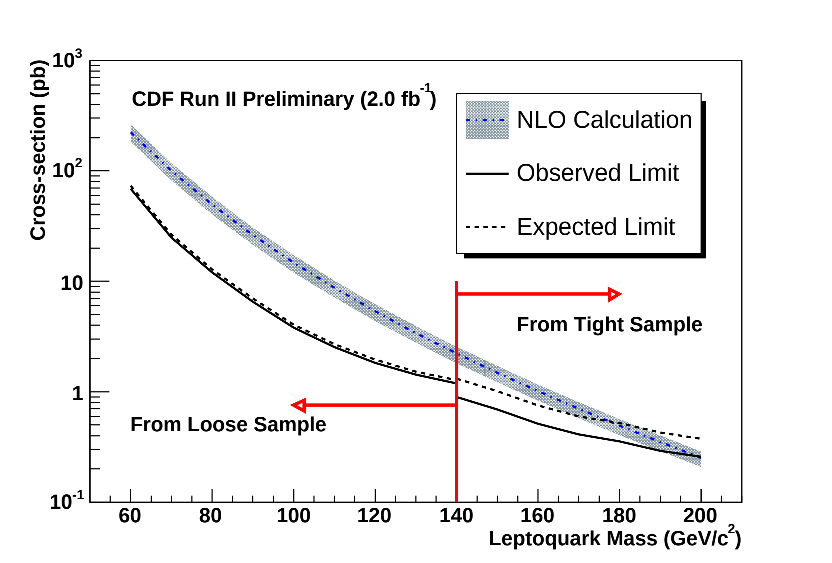
⇒ Analysis is a generic signature search.

⇒ No hints of Leptoquarks.

⇒ At 95% CL:

$M_{LQ} > 190$ GeV/c^2 (1^{st} or 2^{nd} generation)

$M_{LQ} > 178$ GeV/c^2 (3^{rd} generation)

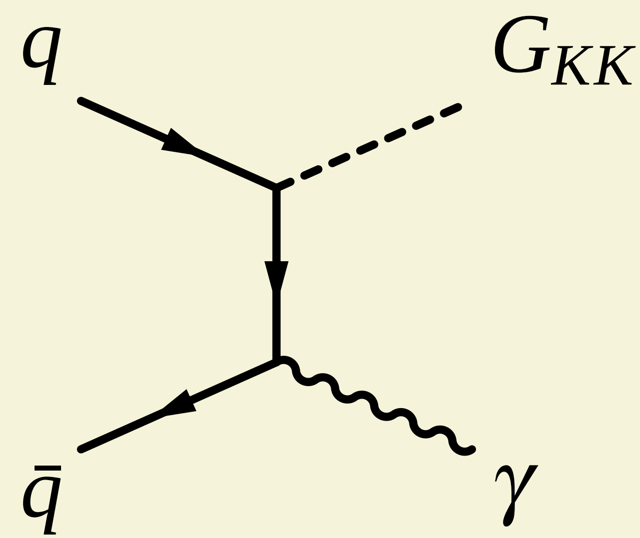


- Leptoquark and SUSY searches share the $\not{E}_T$ + dijet final state and both analyses may be used to constrain both types of models.

LED and $\not\!\!E_T$+jet

If gravity propagates in $4+n$ dimensions (as a difference to the other interactions, confined in 3+1 dimensions), **the effective Planck scale could be small (~ 1 TeV) and gravity becomes comparable in strength to the electroweak interaction.**

The typical "golden channel" for this at Tevatron is the production of a single high-E_T photon and $\not\!\!E_T$ (from the graviton, identified as a Kaluza-Klein mode)



However, a gluon (instead of the photon) would produce a single-jet event with topology:

$\not\!\!E_T$+1 jet

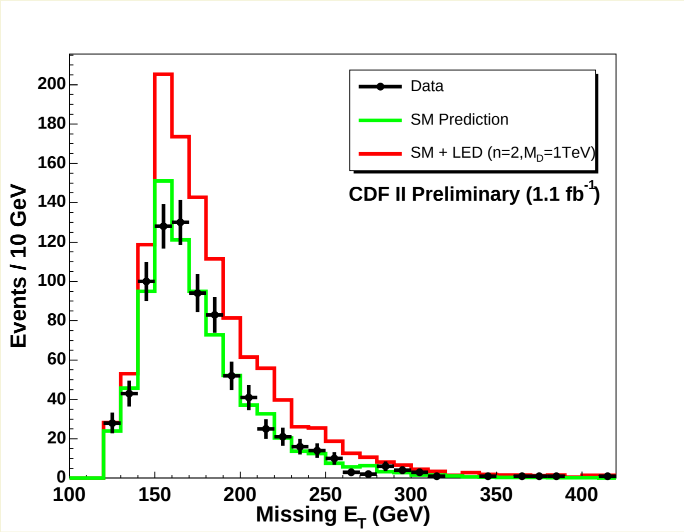
Tight selection to achieve a high final sensitivity:

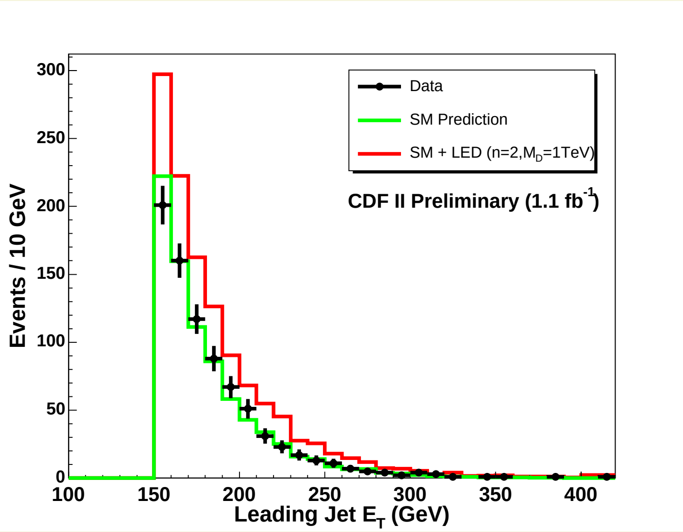
- $\Rightarrow E_{T,jet} > 150$ GeV
- $\Rightarrow \not\!\!E_T > 120$ GeV
- $\Rightarrow$ No second jet with $E_T > 60$ GeV or third jet with $E_T > 20$ GeV

Multijet background estimated by extrapolating 2-jet events into the region in which the second jet is lost.

LED and $\not\!\!E_T$+jet (II)

- **Observing 809 events (for 808 ± 62 expected).**

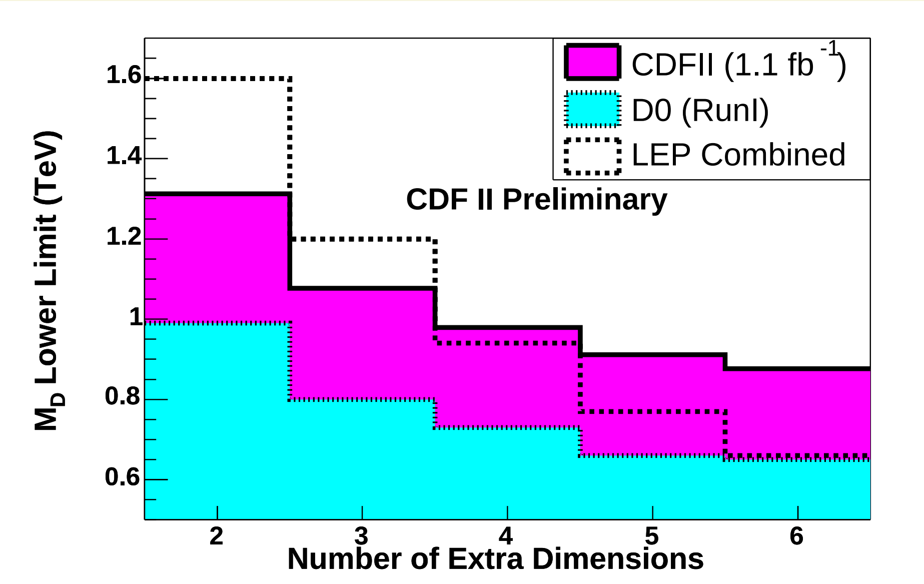




- **Setting 95% C.L. (lower) limits on the $4+n$ dimensional Planck scale M_D related to the "standard" one by:**

$$M_{Pl}^2 \sim R^n M_D^{n+2}$$

- **Tevatron results are the best for large number of LED.**



- **Published as Phys.Rev.Lett. PRL 101 (2008) 181602**

- **Analysis used to measure the invisible width of the Z ($\Gamma = 466 \pm 42$ MeV)**

Summary

- Presented results and status of tools to analyze the $\not\!\!E_T$+jets sample.
- The $\not\!\!E_T$+jets sample is used broadly across the different High-p_T Physics Groups of CDF.
- In the last 2-3 years many improvements related to this sample and associated analysis:

  $\Rightarrow$ Improved trigger to increase acceptance and purity.

  $\Rightarrow$ New tools for background estimation (using data).

  $\Rightarrow$ New tools to reduce fake-$\not\!\!E_T$ background events.

  $\Rightarrow$ Sample used to recover lepton+jets events for:

  – non-trigger leptons.

  – not reconstructed leptons.

- All these provided great improvements in sensitivity of the results.
- Performance of analyses is beyond expectations we had a few years ago.
- Especially true for searches: dibosons, single-top, Higgs and New Physics.

These results really show this sample has a lot of potential for physics at hadron colliders.