SUSY-2005 Conference

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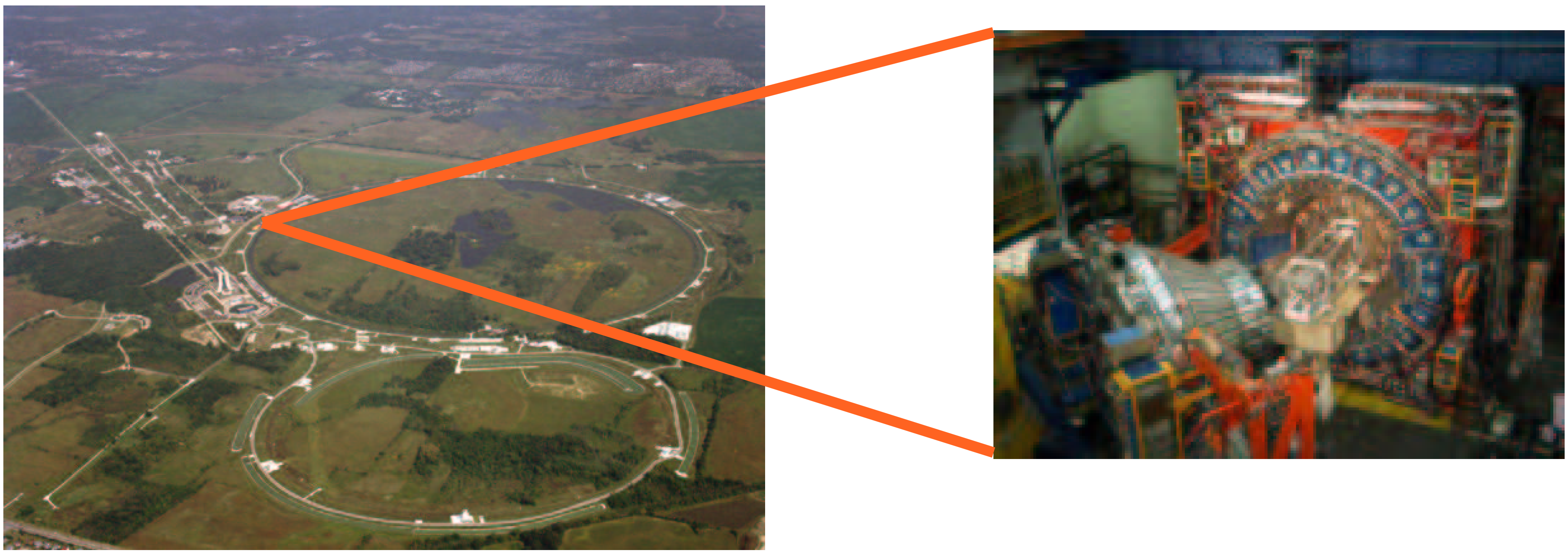
(On behalf of the CDF Collaboration)

Search of the Scalar Top and Bottom at CDF in Run II



Outline of the talk

- Supersymmetry at the Tevatron Collider
- The CDF detector in Run II
- Motivations for searching for s-bottom and s-top
- Experimental tools for performing the searches
- S-bottom searches at CDF:
  - $\Rightarrow$ Search of s-bottom from gluino decays
  - $\Rightarrow$ Direct search of s-bottoms
- S-top searches at CDF:
  - $\Rightarrow$ Search of $\tilde{t} \rightarrow c\tilde{\chi}$
  - $\Rightarrow$ Search of s-top in R-parity violating models
- Summary and perspectives for the future

Supersymmetry at the Tevatron Collider

- Supersymmetry (SUSY) is a symmetry between bosons and fermions which is introduced as an exact symmetry at high energies in theoretical models.
- For each fermion a boson is required to exist (and viceversa)

The quantum number

$$R_p = (-1)^{2S+3B+L}$$

allows to distinguish between particles ($R_p = 1$) and s-particles ($R_p = -1$)

In R-parity conserving SUSY (i.e. interactions conserve R_p)

$\Rightarrow$ The s-particle with smaller mass (LSP) cannot decay and is stable.

$\Rightarrow$ The SUSY particles are produced in pairs.

LSP would not be electrically (or colorly) charged [cosmological motivations].

In R-parity violating SUSY:

$\Rightarrow$ All s-particles may decay

$\Rightarrow$ Decays into leptons are common

These (and other) assumptions simplify the optimization of the experimental search, but it makes the results more model-dependent.

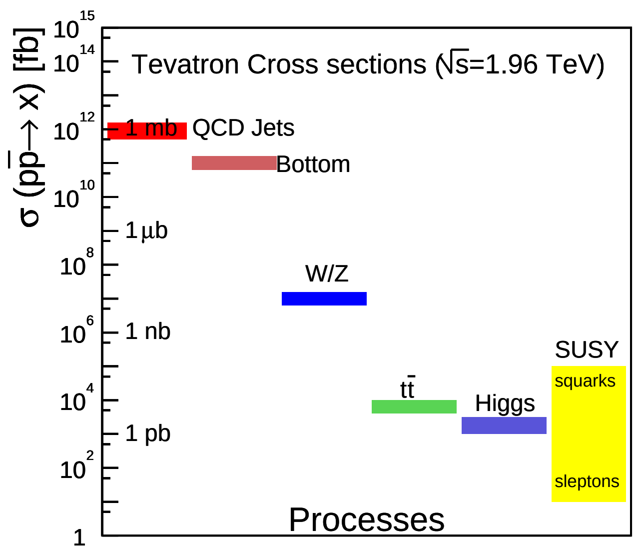
Experimental remarks on searches

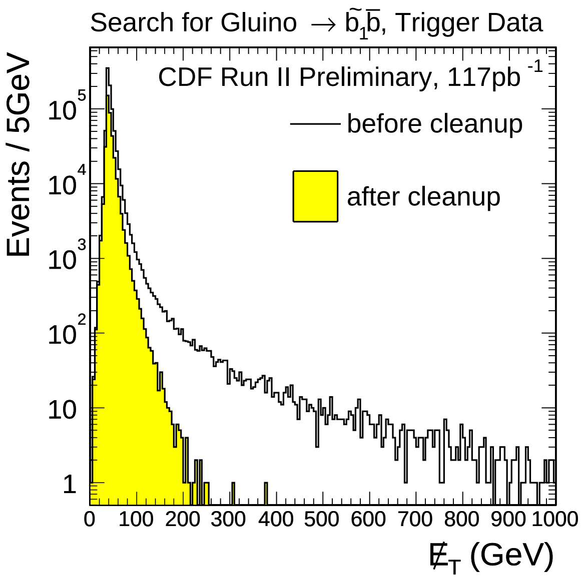
Although the way the search is performed depends on the specific analysis, Supersymmetric searches usually have several reference points:

- **Presence of leptons due to the decays.**
- **Presence of momentum-unbalance in the transverse direction ($\not{E}_T$) associated to undetected particles.**
- **For different reasons (model-dependent) the third generation plays an important rôle in searches for hints of SUSY and other extensions of the Standard Model.**

All these properties are exploited in order to reduce the Standard Model (SM) backgrounds in a hadron collider, where QCD jet production buries all the other processes.

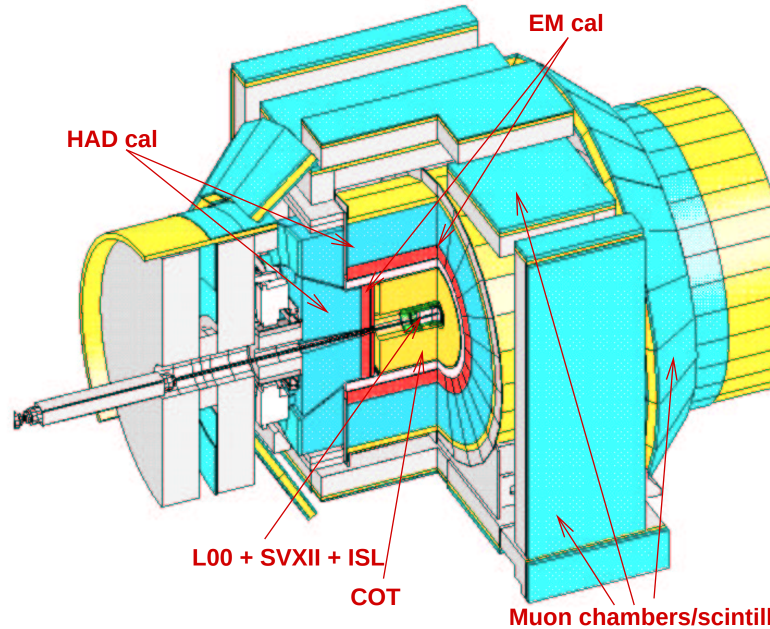
Challenge: lepton ID, $\not{E}_T$ reconstruction and b-jet tagging





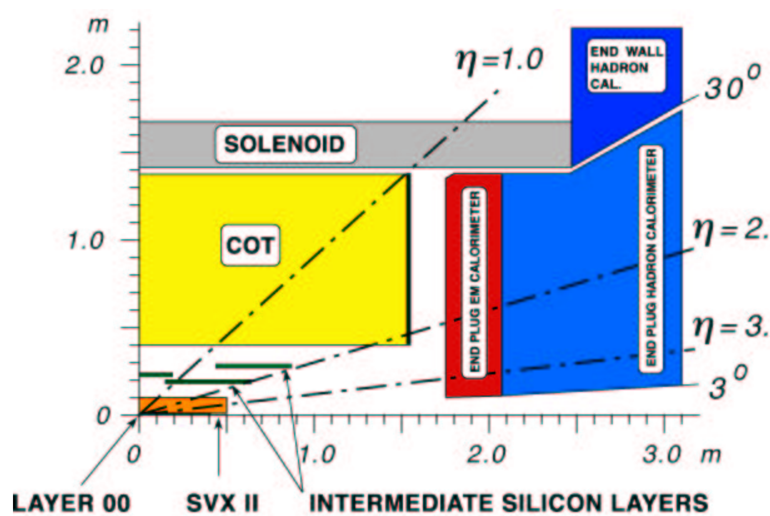
The CDF detector is located in the B0 collision hall at the Tevatron.

It is a multipurpose detector designed to study the collisions at Tevatron using several kinds of subcomponents, mainly:



- **Silicon detectors for high-precision tracking needed for b-jet tagging.**

- **A central tracking chamber used in charged-particle and vertex reconstruction (lepton ID, b-jet tagging, $\not\!\!E_T$)**



- **A central and two plugs calorimeters to measure the "visible" energy in the final state ($\not\!\!E_T$, lepton ID, jets).**

- **Muon chambers to identify muons.**

- **Trigger system in 3 levels for data adquisition and filtering.**

Why looking for s-bottoms and s-tops?

- The cross section for producing colored particles is very high at a hadron collider. The main parameter "reducing" this cross section is the mass of the particles.
- The mass eigenstates are different to the parity eigestates.
- Mass states from important "mixing" (third generation):
- Masses are given by

$$m_{\tilde{q}}^2 = \frac{1}{2}\left[m_{\tilde{q}_L}^2 + m_{\tilde{q}_R}^2 \pm \sqrt{(m_{\tilde{q}_L}^2 - m_{\tilde{q}_R}^2)^2 + 4m_q^2 f(A_q, \mu, \tan\beta)}\right]$$

where $f(A_q, \mu, \tan\beta)$ is:

$\Rightarrow$ large for down-type quark if $\tan\beta$ is large.

$\Rightarrow$ large for up-type quark if $\tan\beta$ is small.

We expect then:

- The scalar top has a light mass eigenstate due to the large mass of the top.
- For $\tan\beta$ large, we expect a light scalar bottom.

Both are good candidates for being the lightest s-quark state

More on the s-bottom and the s-top: decays

- For the s-top, due to the large mass of top, we may find kinematic constrains forbidding the decay into top and another particle.

The model-dependent decay would provide the signature, e.g.:

$\Rightarrow \tilde{t} \to c\tilde{\chi}$ (m-SUGRA motivated)

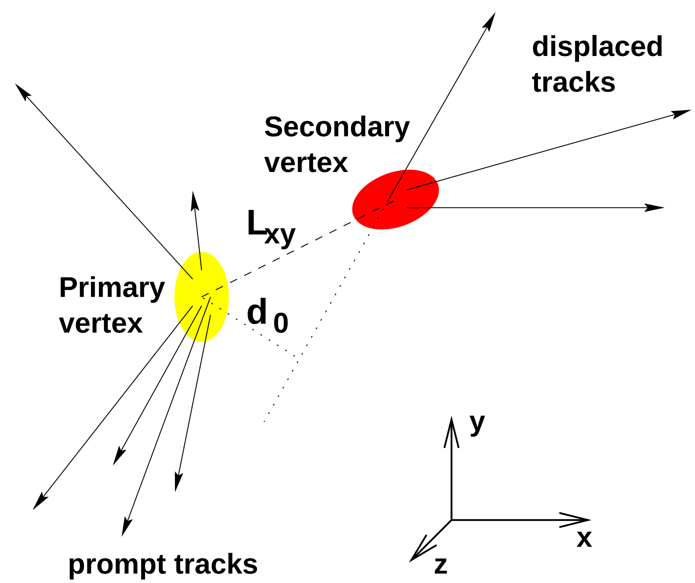
$\Rightarrow \tilde{t} \to bl\tilde{\nu}$ (top-like decay)

$\Rightarrow R_p$ violating decays as $\tilde{t} \to b\tau$

- For the s-bottom, the decay ($\tilde{b} \to b\tilde{\chi}$) makes the final state very rich in b-jets and undetected particles.

The typical signature includes $\not{E}_T$ and b-jets

At CDF the most common methods to tag heavy-flavored jets is based on the long life-time of heavy hadrons yielding displaced tracks and vertices.



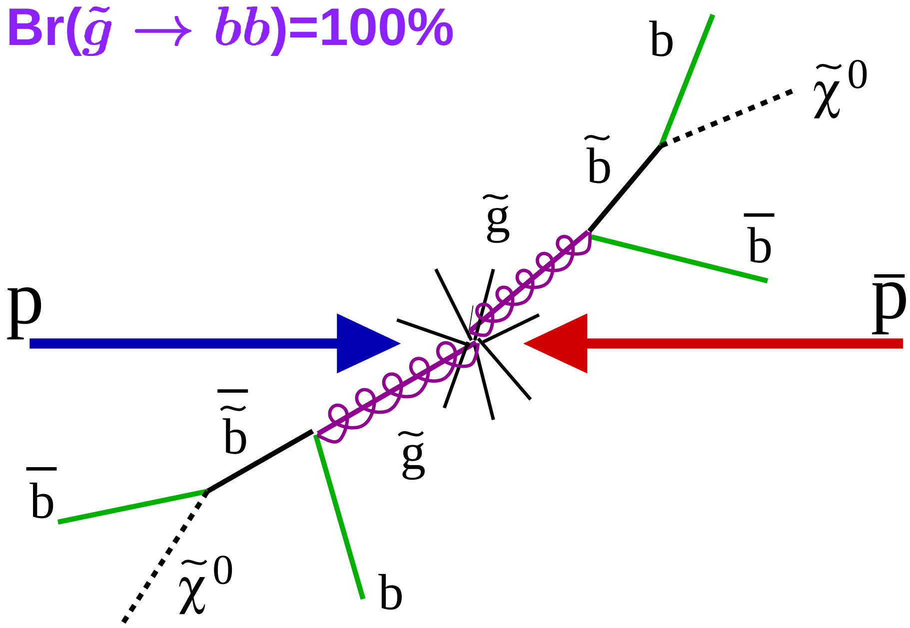
s-bottom at CDF in Run II

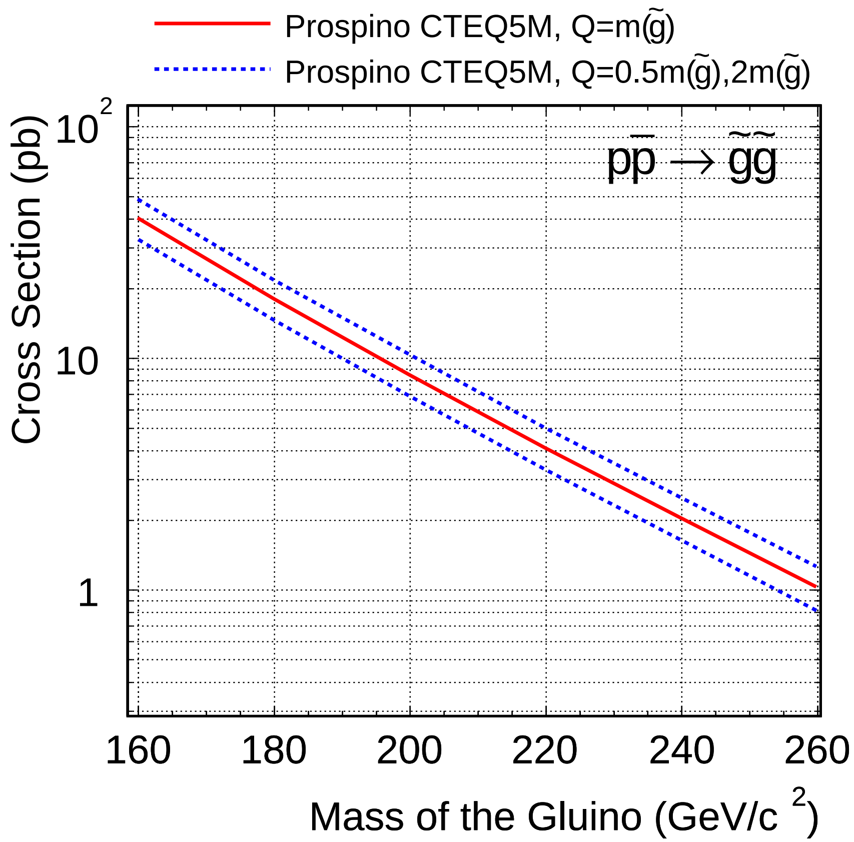
- **Direct s-bottom search suffers from SM background ($b\bar{b}$ production).**
- **A different approach has been considered.**

The idea is to search from s-bottom coming from gluino, which is the particle that is pair-produced in the collision (pro: larger cross section, for same mass).

The gluino will decay into a s-bottom/bottom pair in a decay chain which provides a clean signature.

Br($\tilde{g} \rightarrow \tilde{b}b$)=100%





Search for s-bottom in gluino decays (I)

- **The analysis on gluino-pair production was designed to look for events as:**

$$p\bar{p} \Rightarrow \tilde{g}\tilde{g} + X \rightarrow (b\tilde{b}_1)(b\tilde{b}_1) + X \rightarrow (bb\tilde{\chi}_1^0)(bb\tilde{\chi}_1^0) + X$$

- **The signal region is defined by**

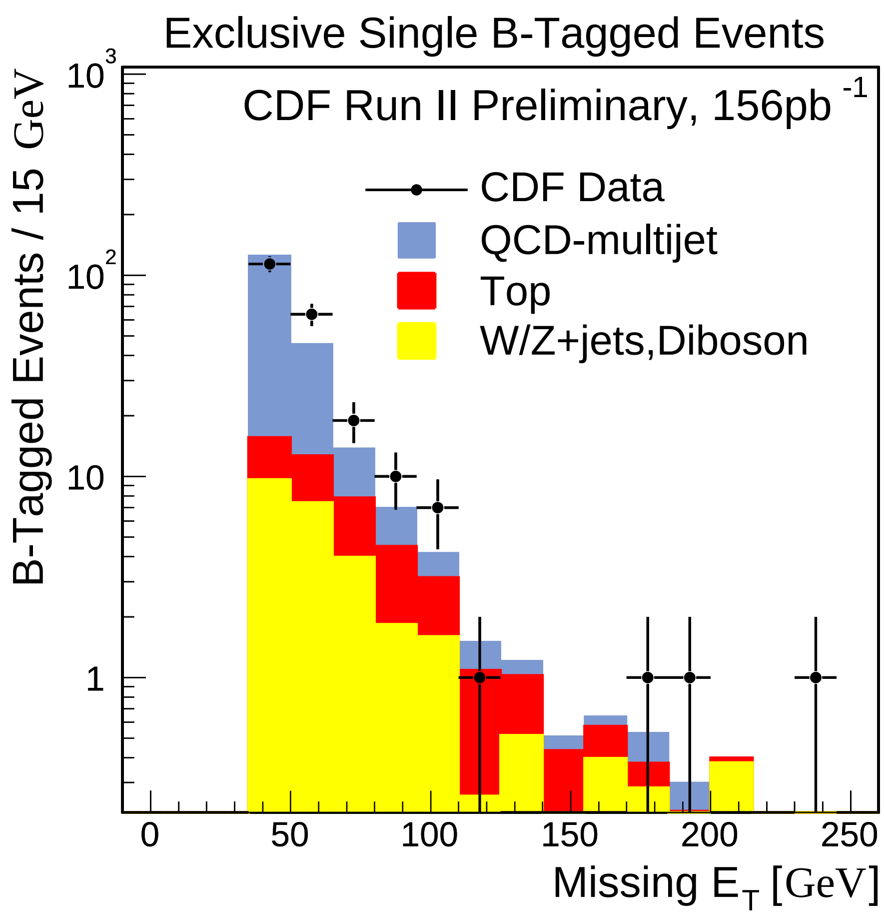
→ $\not{E}_T > 80$ **GeV.**

→ **No isolated leptons.**

→ **3 or more jets with**

$E_T > 15$ **GeV and** $|\eta| < 2$.

→ **Specific cuts to reduce background from multijet production: cuts on azimuthal angle between jets and** $\not{E}_T$.

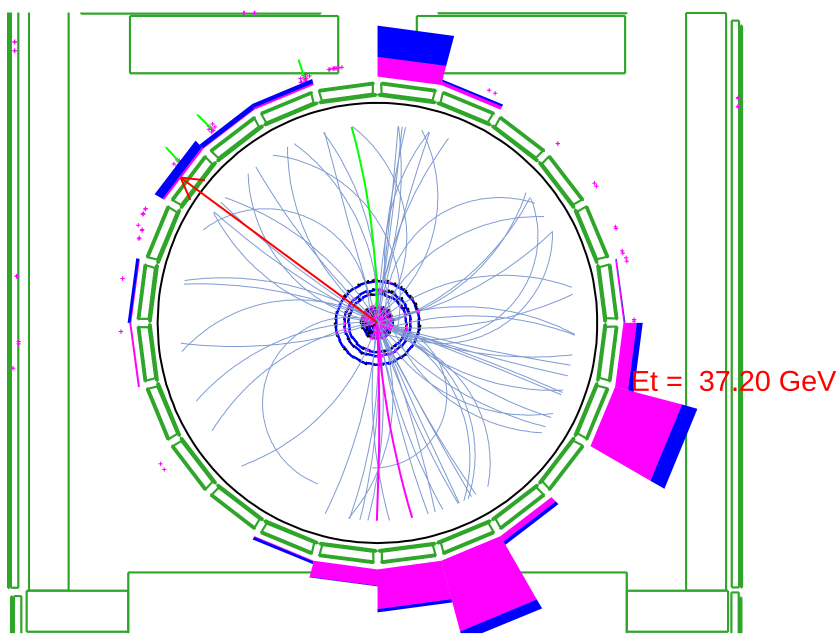


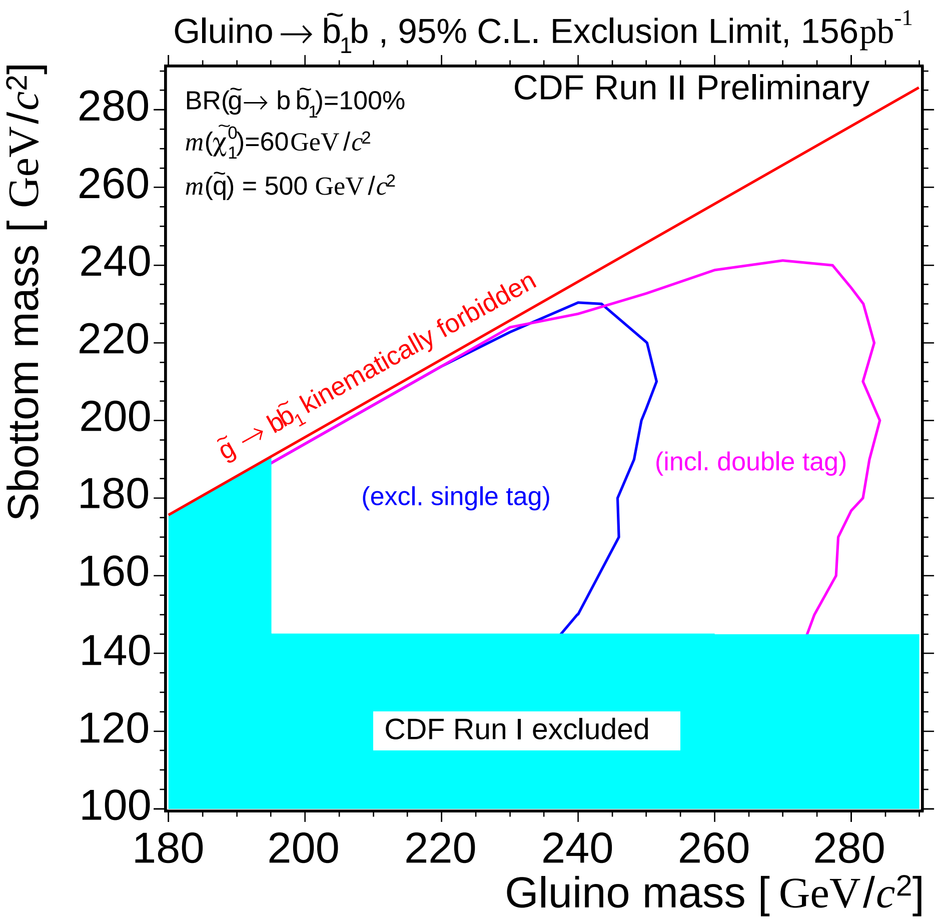
- **Further SM background is reduced by requiring tagged b-jets.**

Search for s-bottom in gluino decays (II)

- Signal region separated in exclusive single-tag and inclusive double-tag bins.
- The requirement of a second tag reduces the background while keeping most of the signal due to the 4 b-jets that are expected in the signal.
- Data in agreement with expected Standard Model background.

b-tags	Observed events	Expected background
=1	21	16.4 ± 3.7
$\geqslant 2$	4	2.6 ± 0.7



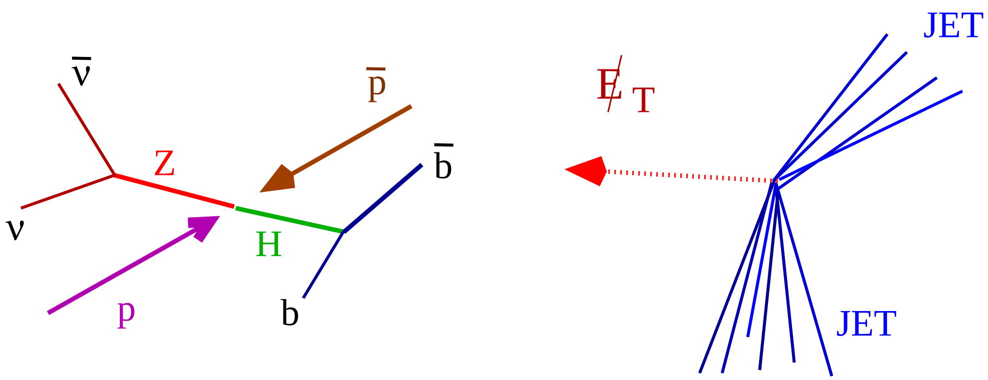


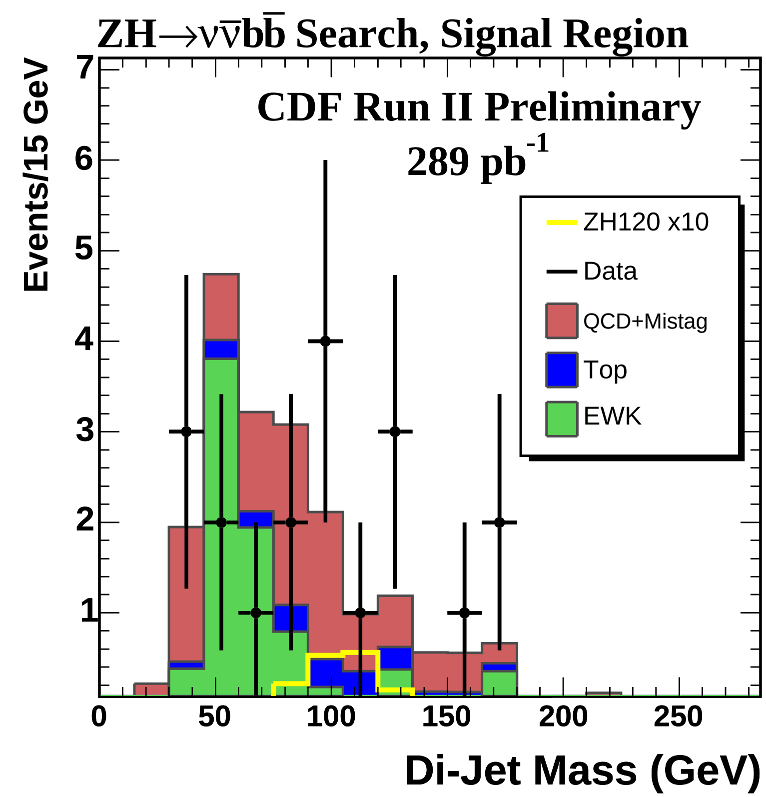
The expected signature for direct s-bottom production

$$\tilde{b}\bar{\tilde{b}} \rightarrow b\bar{b} + \not{E}_T$$

is closely related to that of the Higgs in the $ZH \rightarrow \nu\bar{\nu}b\bar{b}$:

(CDF analysis reported at this conference by V. Vesprémi)





The differences in topology are expected from different kinematics (masses, decays).

Optimization may be different, but not much since selection should exploit differences with identical SM backgrounds.

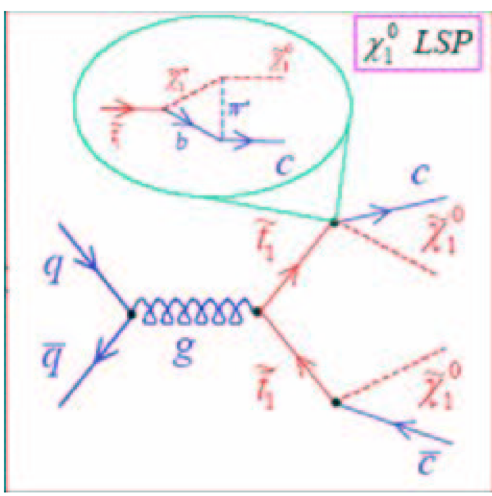
We are currently working on setting limits on direct s-bottom production.

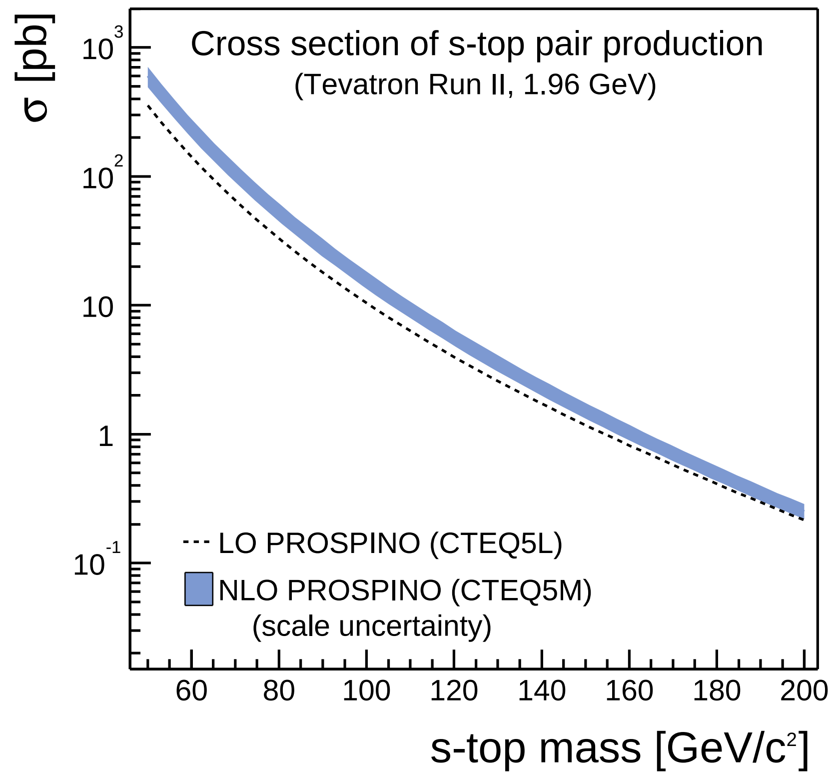
The s-top searches are mainly driven by the assumption that the decay to top is forbidden (otherwise those events are observed as excess on the top production containing events with anomalous kinematics, due to the neutralinos).

The signature is dependent on the model, but typically includes b-jets, $\not{E}_T$ and leptons.

- **Common tools to the searches of s-bottom.**
- **Large cross section in region of interest ($m_{\tilde{t}} \sim 100 - 180$ GeV/c^2)**

Within mSUGRA-based models, a preferred decay is into a charm quark and LSP (which is loop-suppresed in absence of FCNC).



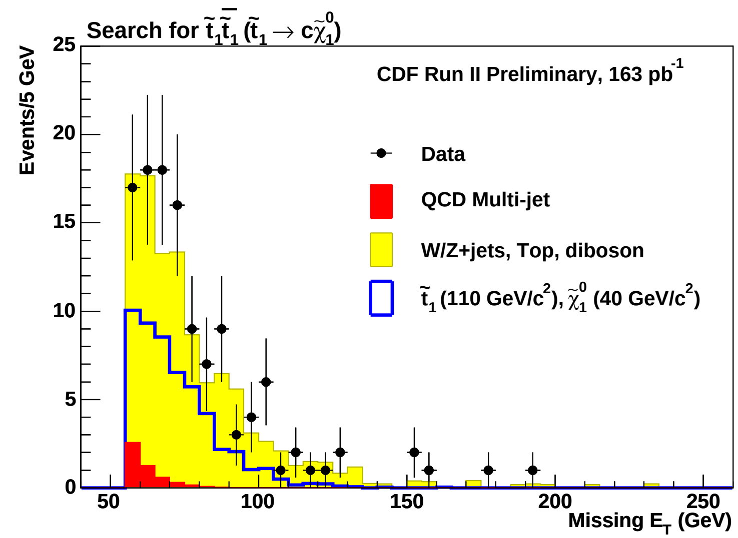


s-top in the $c\tilde{\chi}$ channel (I)

Assuming that decay to be 100% of the s-top branching ratio, the signature is

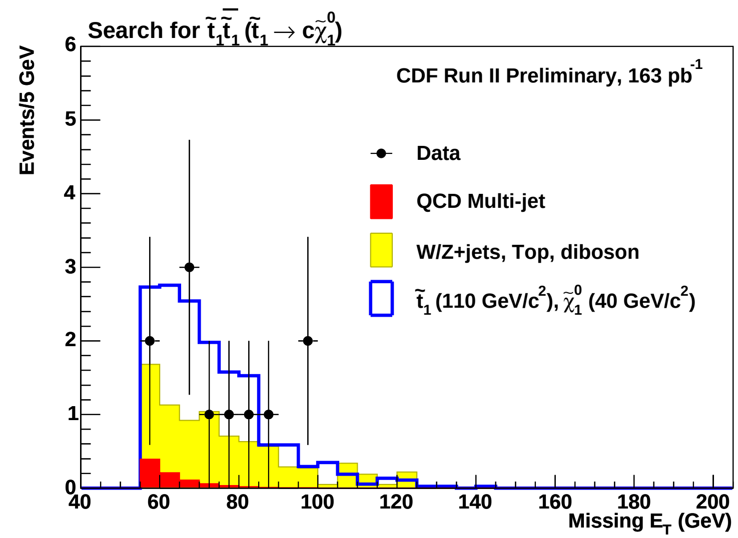
$$p\bar{p} \Rightarrow c\bar{c} + \not{E}_T$$

which may be identified as 2 tagged c-jets and some $\not{E}_T$.



$\Rightarrow$ **Looser tagger used for charmed jets.**

$\Rightarrow$ **Uses probability method for a jet to contain tracks from a secondary vertex (instead of reconstructing the vertex itself).**



The dominant SM background is the production of electroweak bosons (with addition of jets), for the selection before and after tagging.

Remark: **This analysis is also sensitive to direct s-bottom pair production.**

Signal region selection:

⇒ $\not{E}_T > 55$ GeV

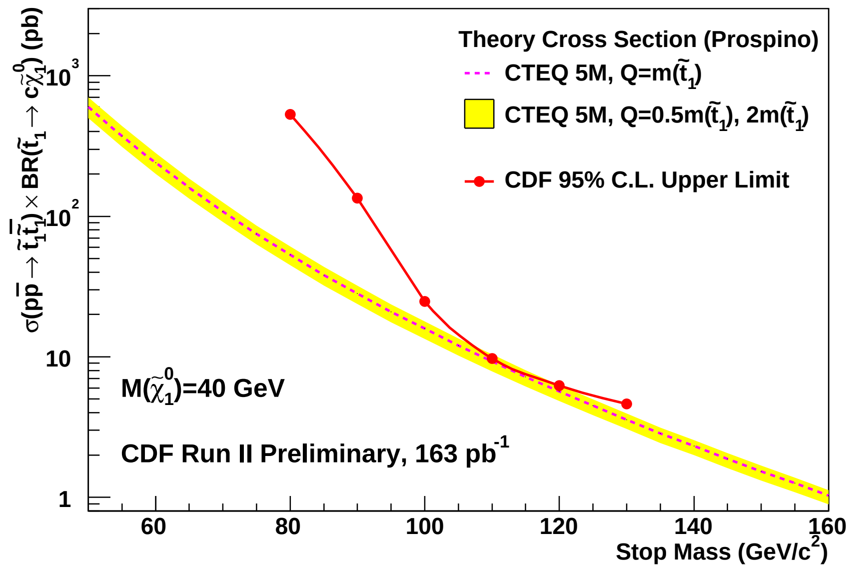
⇒ 2 jets with

$$E_T > 15 \text{ GeV and } |\eta_{j1(2)}| < 1, 1.5$$

⇒ No more than 3 jets with

$$E_T > 10 \text{ GeV and } |\eta| < 3.6.$$

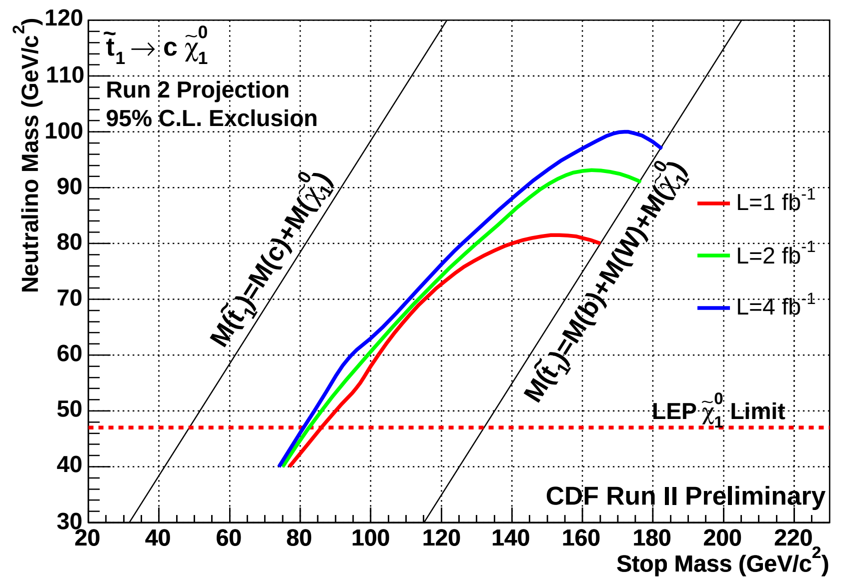
⇒ Kinematic cuts and lepton rejection



This selection yields:

Expected from SM: $8.3^{+2.3}_{-1.7}$

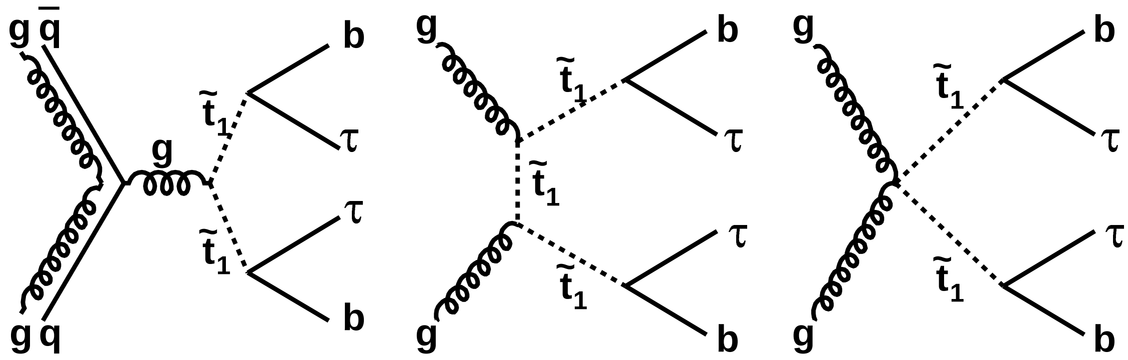
Observed: 11 events



With the current performance it is not possible to set a limit (better than those obtained in Run I, ~ 120 GeV/c^2).

Proyection studies show that with larger datasamples this analysis will be able to explore a large region in the kinematic plane.

- In models for which R_p is not conserved, a possible decay of the s-top is into a b quark and a τ lepton:



- The signature is (in principle) very clean since production of τ with jets has a "reasonable" cross section.
- The complication comes from the identification of the hadronic decay of the τ, which represents most of the branching ratio:
- Assuming 100% decay of $\tilde{t} \to b\tau$ the following reductions are expected:

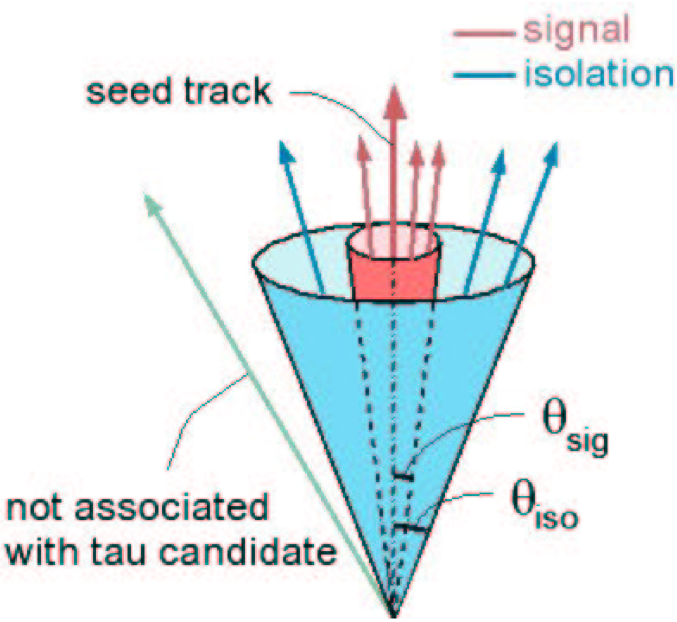
  $\Rightarrow \sim 12\%$ for doubly-leptonic decay

  $\Rightarrow \sim 44\%$ for leptonic + hadronic decay

For a reasonably acceptance, events with hadronic decays should be included.

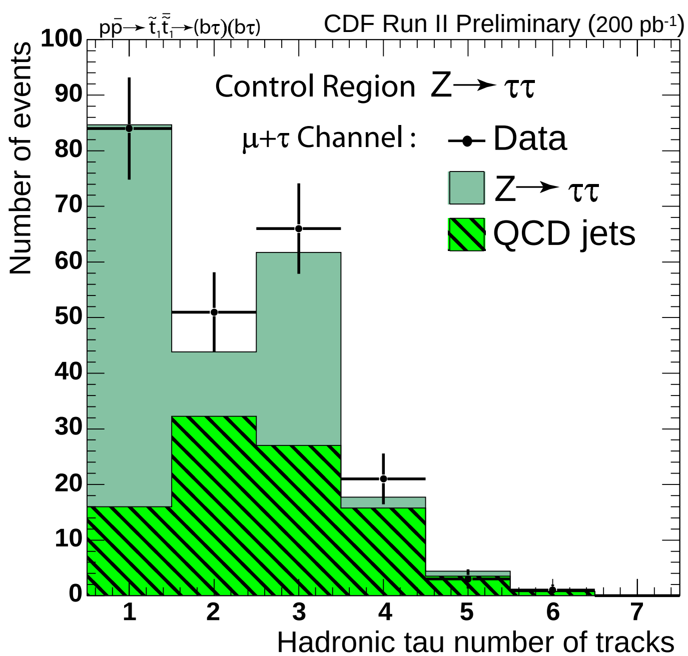
Tau identification at CDF

CDF is putting a lot of effort in hadronic-tau reconstruction with high purity and efficieny.



- **Intended for isolated τ which may be used in several analyses testing the SM predictions and in searches.**
- **Purity: the reduction of contamination from hadrons which pass the τ ID selection.**
- **The big challenge is the efficient identification of τ's in the trigger.**

- **In the s-top analysis, the $Z \rightarrow \tau\tau$ signal is used as a control sample for checking the performance of the hadronic- τ identification.**
- **This process represents the main background for the analysis.**



s-top in R-parity violating decays (I)

The analysis selects events with:

- **One identified lepton (e, μ) of $p_T > 10$ GeV/c.**
- **One τ (hadronic decay) with $p_T > 15$ GeV/c.**
- $p_{T,l} + p_{T.\tau} + \not{E}_T > 85$ **GeV/c**

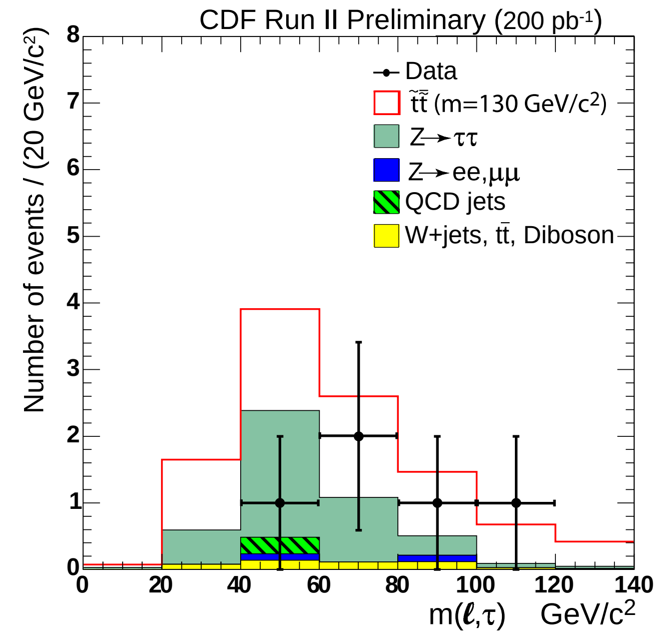
(where $p_{T.\tau}$ is the visible p_T of the hadronic τ)

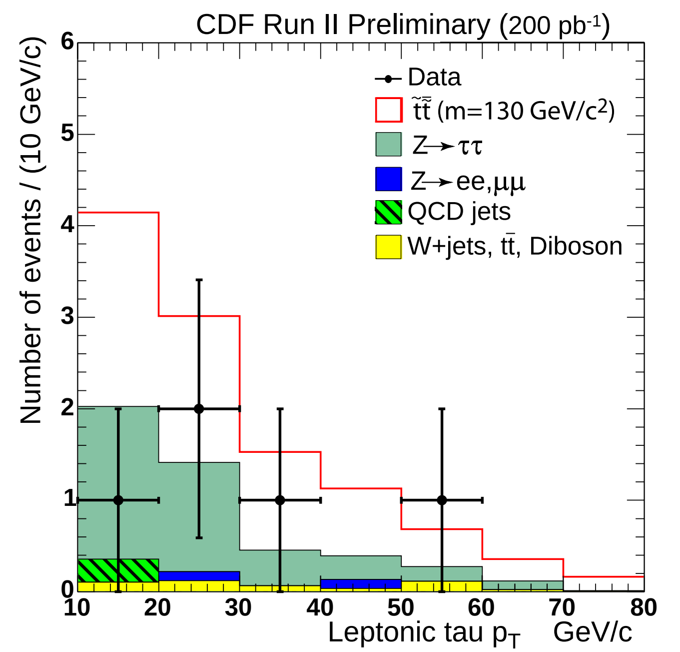
And defines a "primary" signal region for events having

- **At least two jets with**

  $E_T > 15$ **GeV and** $|\eta| < 2.4$.
- $M_T(l, \not{E}_T) < 35$ **GeV/c^2**

Auxiliary regions are defined by inverting the requirement on the transverse mass. Those not dominated by W+jets background are used to set a limit.



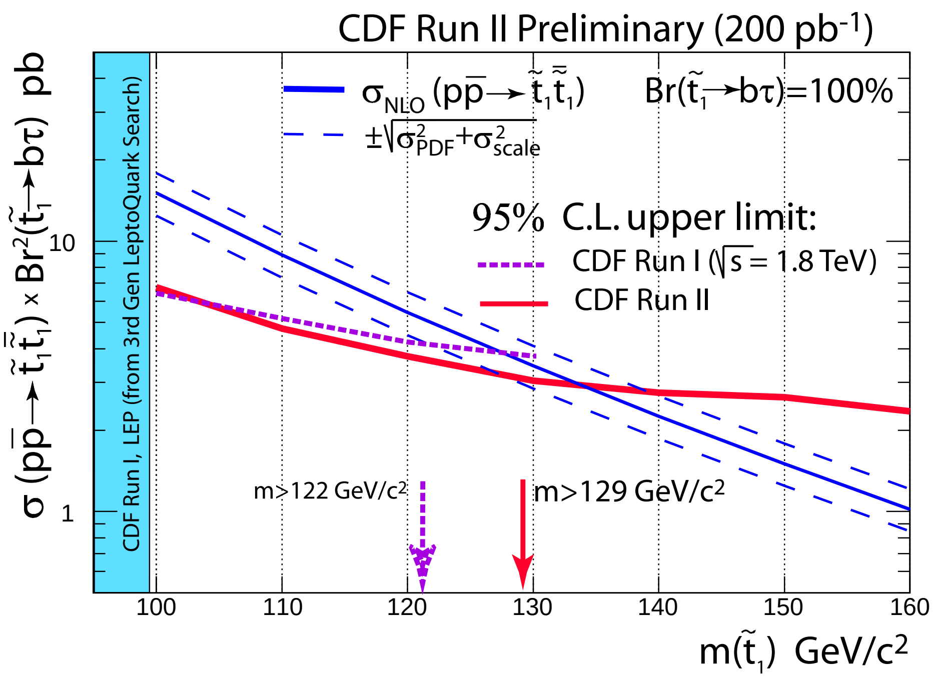


With the described selection we obtained the following result (in the "primary" signal region):

	$e+\tau$	$\mu+\tau$	total
Expected (SM):	2.6 ± 0.6	2.2 ± 0.5	4.8 ± 0.7
Observed:	2	3	5

- No excess observed
- This applies also to the other signal regions.
- Limits are set on the s-top pair-production cross section (and s-top mass).

As a remark, this process yields the same signature as the production of a pair of leptoquarks (scalar, third generation).



The mass limit for the leptoquark is the one extracted for the scalar top (for heavy gluino)

Summary and perspectives for the future

- Large activity at CDF looking for new physics based on Supersymmetry
- Strong motivation for detecting SUSY with the production of s-bottom and s-top pairs at the Tevatron collider:

$\Rightarrow$ They might be the lightest scalar quark states (i.e. higher cross section)

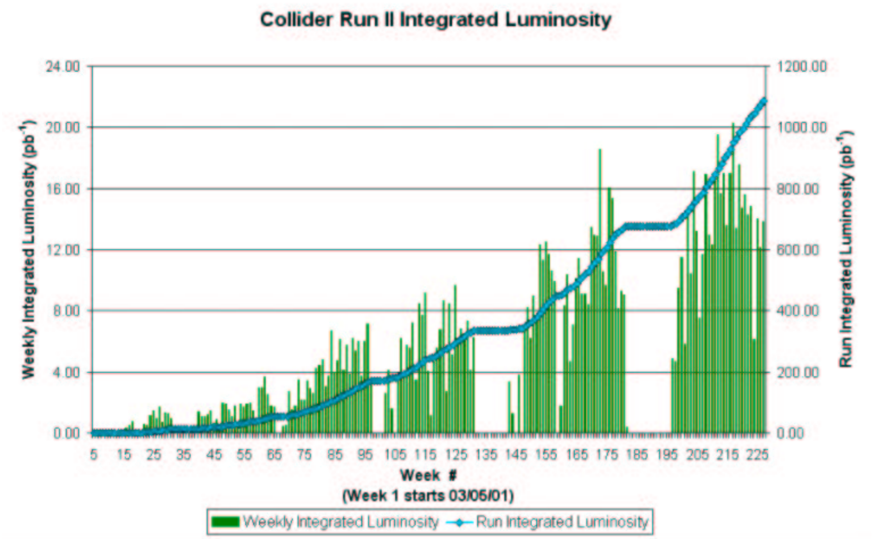
$\Rightarrow$ Distinctive signatures allows to reduce the SM background

Third generation objects (b-jets, τ's)

Leptonic final states from decays

Missing E_T from ν's and neutralinos

High jet (and b-jet) multiplicities



$\tilde{b}$ and $\tilde{t}$ are experimentally very attractive

- No hint of Supersymmetry [yet], but we'll keep trying:
- Expected to have ~ 1 fb^{-1} for analysis at the end of this year.
- We are becoming sensitive to regions never explored (or even approached) in any experiment.