Searches for Third Generation Scalar Quarks

at CDF in Run I

and

Status and Prospects for Run II

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Outline

- Motivation
- Tevatron and CDF
- Review on Run 1 searches and prospects for Run 2
- Current status
- Conclusion

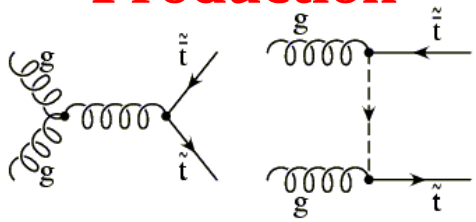
Why Search for $\tilde{t}$ and $\tilde{b}$

- Stop may be light due to large top quark mass which give rise to large mixing between the left- and right-handed stop weak eigenstates => large mass splitting between the two mass eigenstates $\tilde{t}_1$ and $\tilde{t}_2$
- Sbottom may be light to due to large mass splitting between $\tilde{b}_1$ and $\tilde{b}_2$ at high tan(β)
- Stop and sbottom are produced strongly at Tevatron => relatively large cross section compared to slepton, chargino, neutralino,…
- Prediction of production and decay mechanisms are model dependent

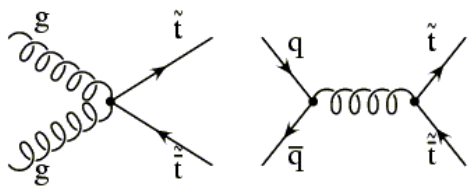
$\tilde{t}$, $\tilde{b}$ Production and Decay

Production

MSSM



***Rp*C**



or

SM t prod. followed by $t \rightarrow \tilde{t}_1 \tilde{\chi}^0_1$

Decay

$\tilde{b}_1 \rightarrow b \tilde{\chi}^0_1$

$\tilde{t} \rightarrow t_1 \tilde{\chi}^0_1$

$\tilde{t}_1 \rightarrow b \tilde{\chi}^{+/-}_1 \rightarrow b\, l\, \nu\, \tilde{\chi}^0_1$

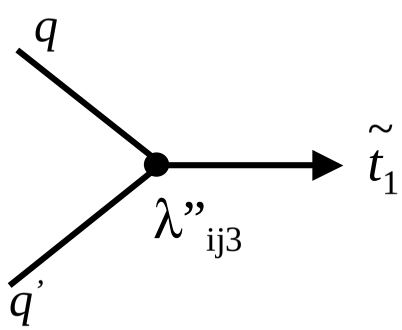
$\tilde{t}_1 \rightarrow b\, l\, \tilde{\nu}$

$\tilde{t}_1 \rightarrow c\, \tilde{\chi}^0_1$

$\tilde{\chi}^0_1$ or $\tilde{\nu}$ is LSP

decay signature :
HF jets,
leptons,
large MET

***Rp*V**

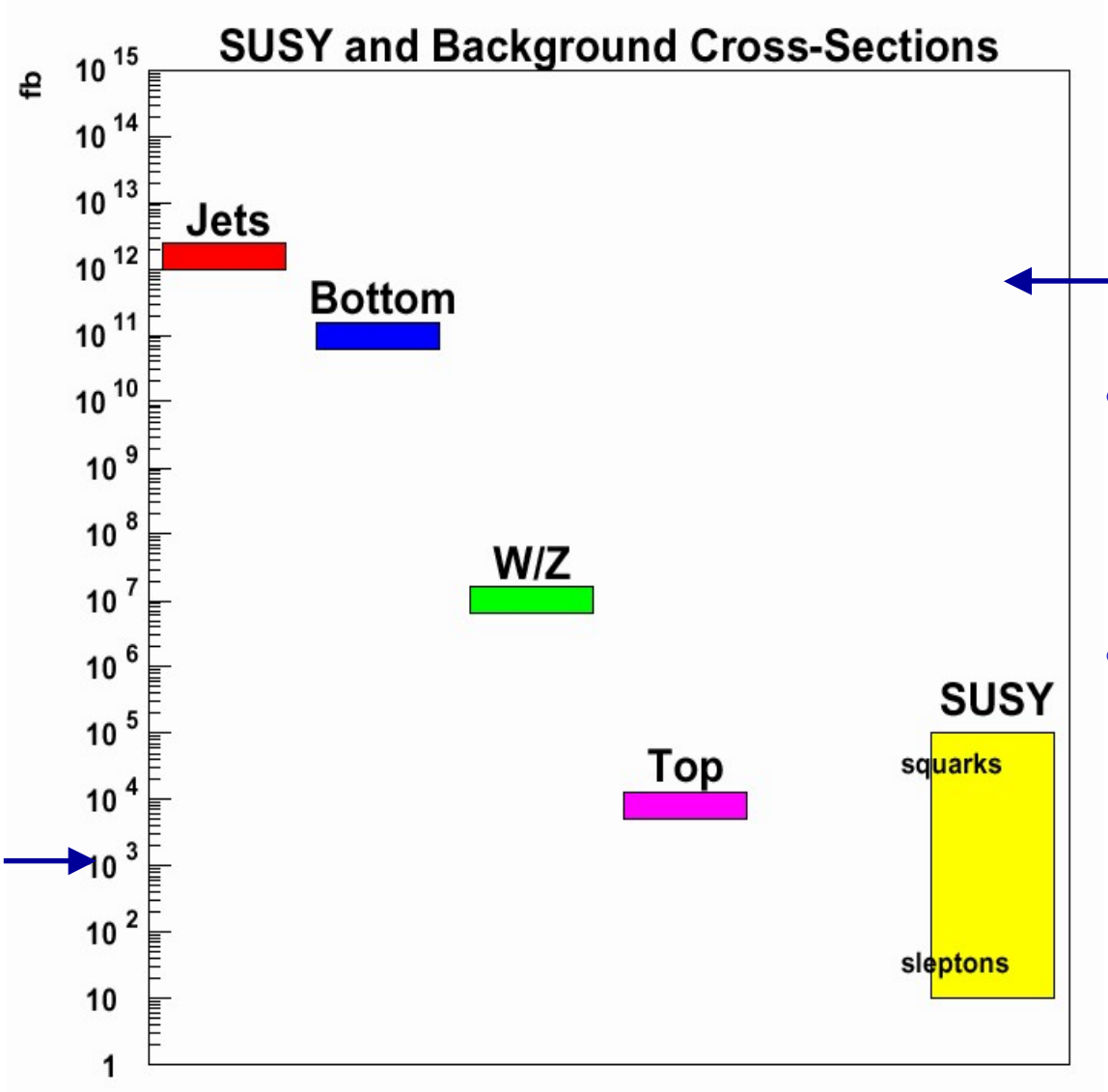


$\tilde{t}_1 \rightarrow b\, l$

$\tilde{t}_1 \rightarrow q\, q'$

*Rp*V decay signature :
small MET

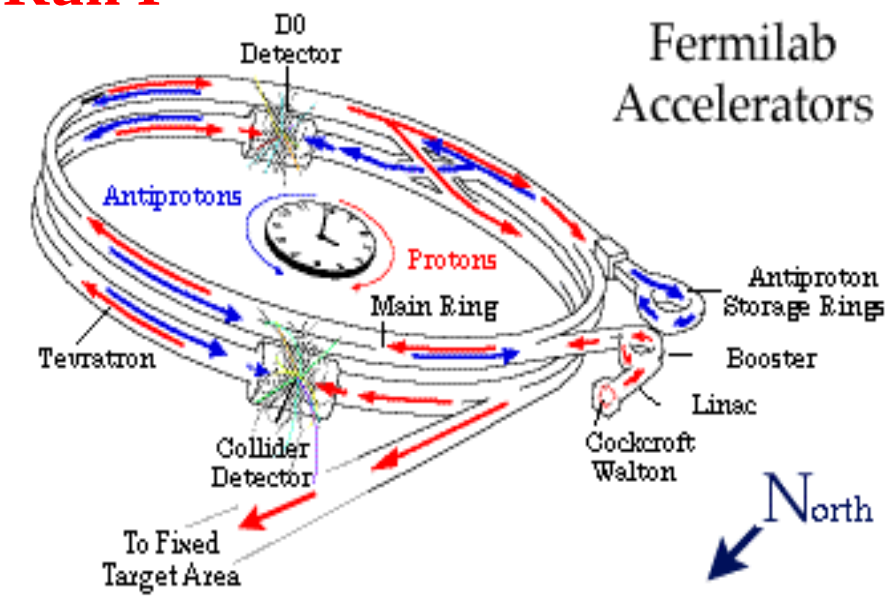
Relative Yields at the Tevatron



- If SUSY exists, it may be within reach at the Tevatron
- Need to make use of the unique signatures of SUSY production and decay to suppress background

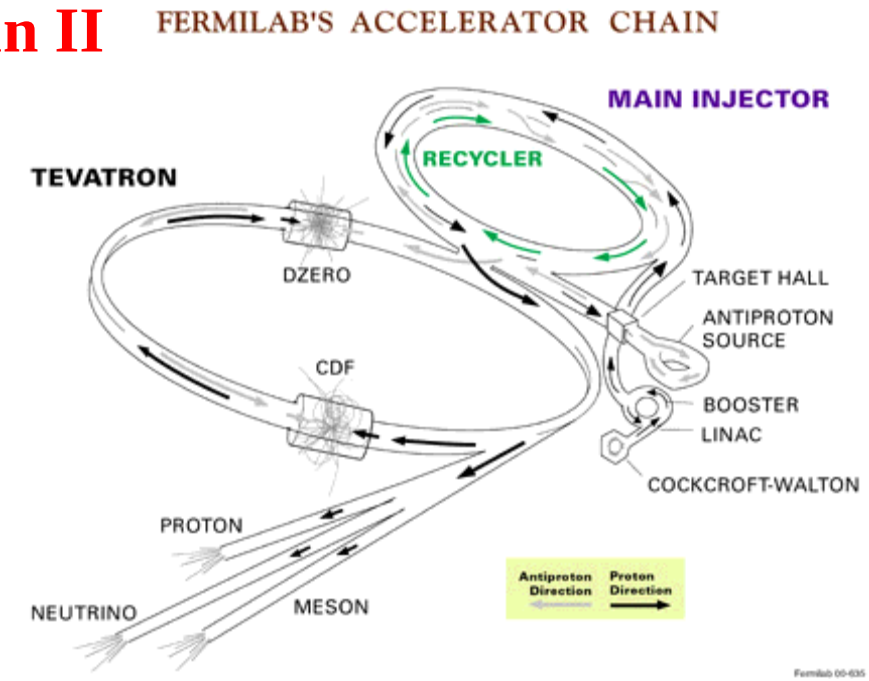
Tevatron - Run I & Run II

Run I



- Collide proton-antiproton at 1.8 TeV center of mass energy
- 6x6 proton-antiproton bunches
- Crossing time every 3.5 μs
- Inst. Lumi. ~10^{30}-10^{31} $cm^{-2}s^{-1}$
- CDF collected about ~100 pb^{-1} of data

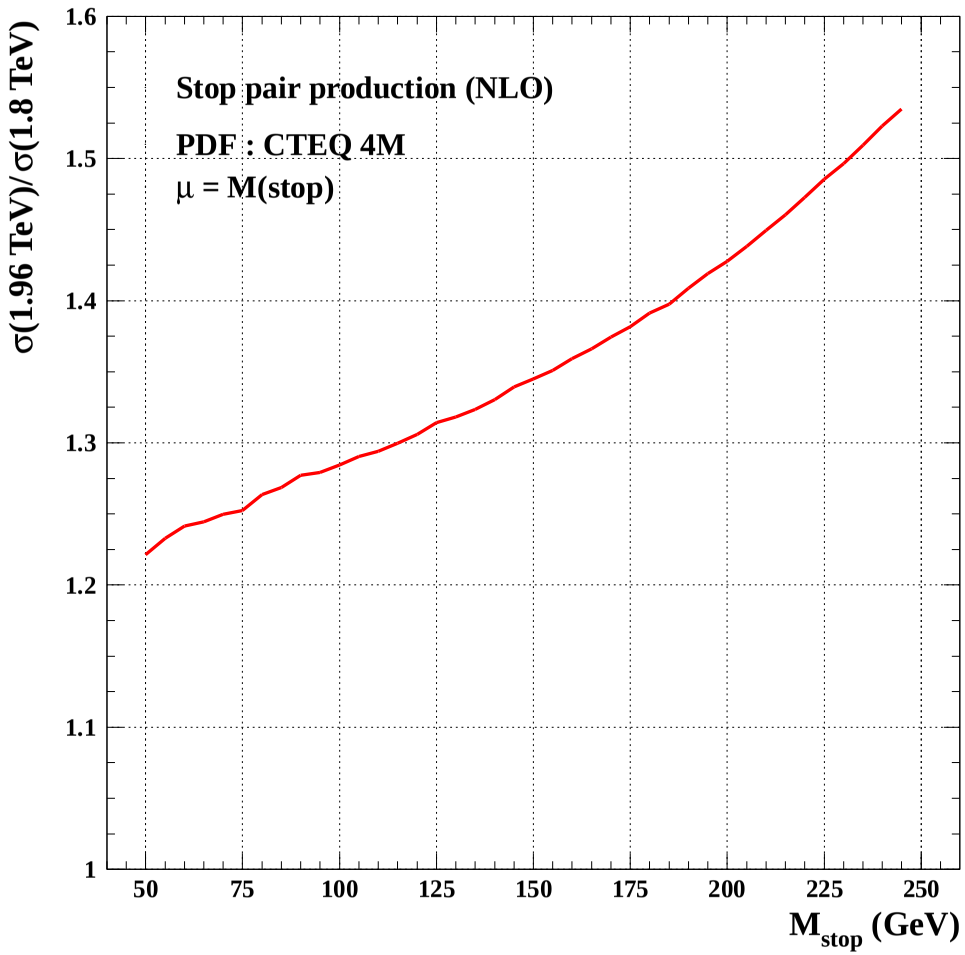
Run II



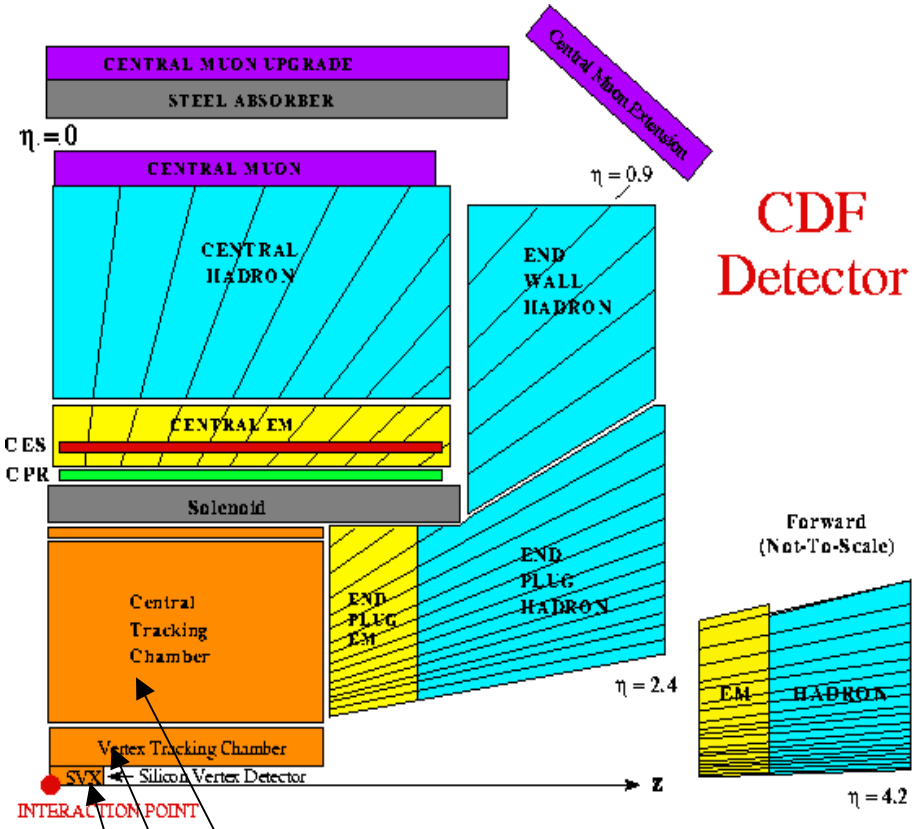
- Center of mass energy = 2 TeV
- Colliding bunches: 36x36 / 108x108 (bunch spacing: 396 / 132 ns)
- Design inst. Lumi ~ 10^{32} $cm^{-2}s^{-1}$)
- Started delivering luminosity in summer 2001

Stop Production Cross Section

- Modest increase in energy compare to Run I, but substantial increase in stop production cross section



CDF - Run I & Run II



CDF Detector

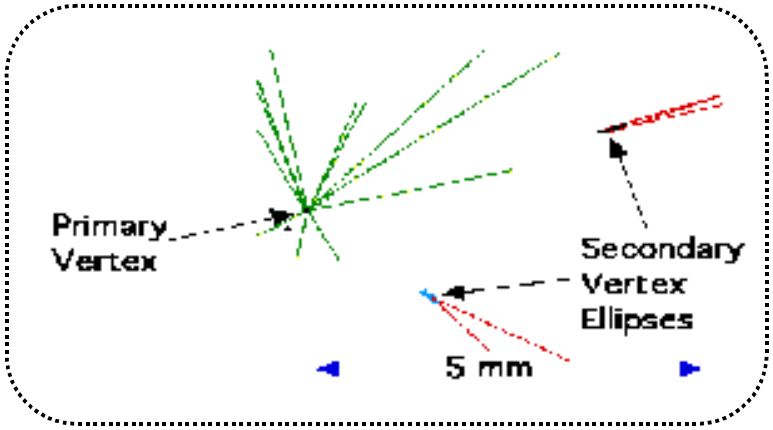
- Tracking Detectors
- EM Calorimeter
- Had Calorimeter
- Muon Detectors

- Tracking + Cal => e, τ, jets, MET
- Tracking + Cal + Muon detectors => μ
- Tracking (SVX) => Secondary Vertex (to tag b and c jets)

Central Tracking Chamber

Vertex Tracking Chamber

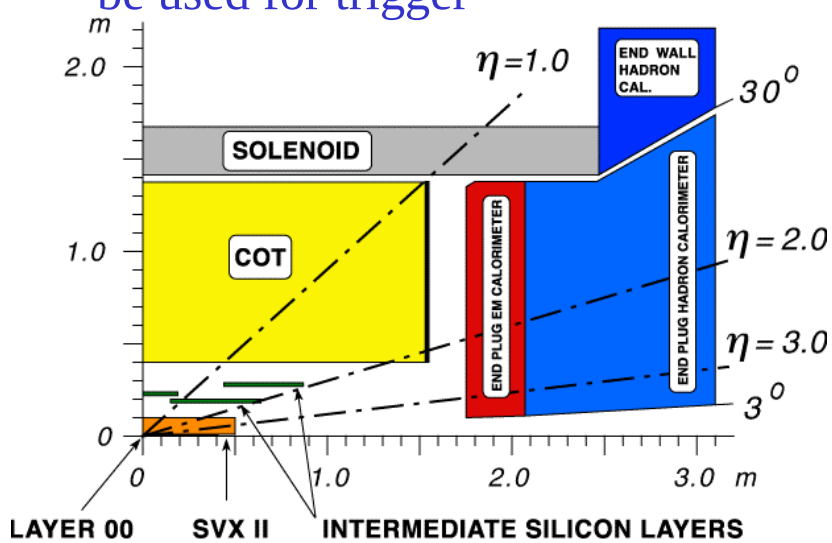
Silicon Vertex Detector (SVX)



CDF - Run II

Upgrades:

- Central Outer Tracker (COT) :
  - More sense wires (improves occup.)
  - Shorter drift time
- Silicon detector :
  - Double Run 1 length (from 51 to 96 cm)
  - Twice number of layers (from 4 to 8), double sided (for 3D tracking)
  - Silicon tracking available in online, can be used for trigger



- New scintillating tile plug calorimeter
  - Faster response (Run 1, gas calorimeter)
- Muon detector
  - Extend coverage, increase trigger region from $|\eta|<0.6$ to $|\eta|<1.5$
- Time of Flight (new)
  - Great time resolution (~100ps)
  - Particle Id, cosmic rejection

- Improve geometrical acceptance for b-tagging from ~60% to ~100%
- Extend lepton tagging region
  - Electron : from $|\eta|<1$ to $|\eta|<2$
  - Muon : from $|\eta|<0.6$ to $|\eta|<1.5$
- Improve trigger cuts to extend kinematics reach in SUSY search.

Review of Run I Searches & Prospects for Run II

Channels searched in Run I

$pp \to \tilde{t}_1\tilde{t}_1$: $\tilde{t}_1 \to b\tilde{\chi}^{+/-}_1 \to bl\nu\tilde{\chi}^0_1$ ($M(t)>M(\tilde{t}_1)>M(\tilde{\chi}^{+/-}_1)$)

$\tilde{t}_1 \to bl\tilde{\nu}$ ($M(\tilde{\chi}^{+/-}_1)>M(\tilde{t}_1)>M(\tilde{\nu})$)

$\tilde{t}_1 \to c\tilde{\chi}^0_1$ ($M(\tilde{\chi}^{+/-}_1)>M(\tilde{\nu})>M(\tilde{t}_1)$) ✓

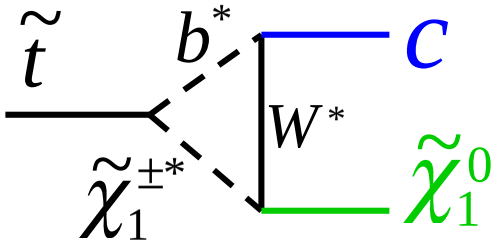
$\tilde{t}_1 \to b\tau$ (RpV decay) ✓

$pp \to t\,t$: $t\,t \to (b\,W)(\tilde{t}_1\ \mathrm{LSP})$

$pp \to \tilde{b}_1\tilde{b}_1$: $b \to b\tilde{\chi}^0_1$ ✓

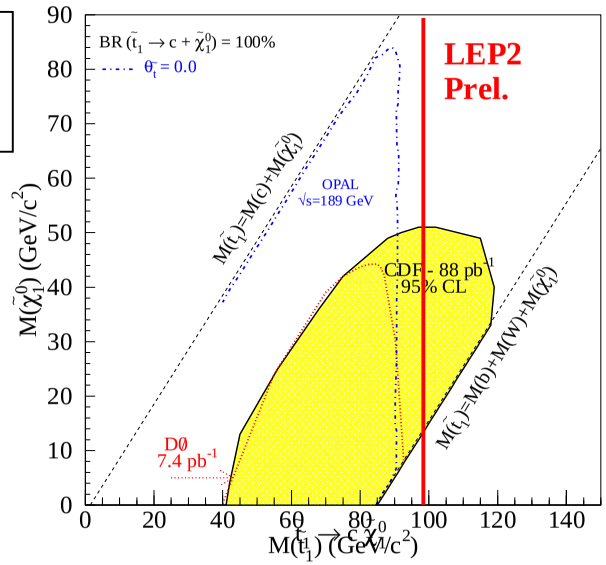
Stop (HF jets + MET)

$M(\tilde{\chi}^{+/-}_1) > M(\tilde{\nu}) > M(\tilde{t}_1)$

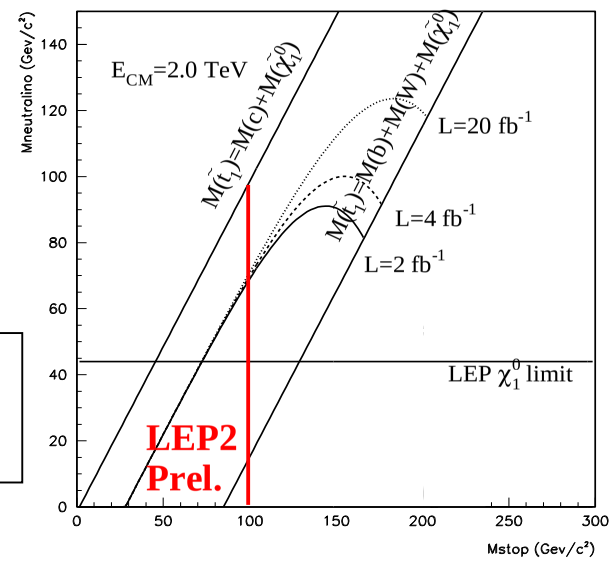


- LSP => $\tilde{\chi}^0_1$, Signature : HF jets, MET
- Selection:
  - 2 or 3 jets (Et>15 GeV, |η|<2)
  - No additional jets (Et>7 GeV, |η|<3.6)
  - MET>45 GeV
  - Cuts on MET-jet, jet-jet angles (reduce fake MET, QCD)
  - Lepton veto
  - >= 1 "c-tag"
- N_{expect}=14.5+-4.2 , N_{obs}=11
- BG : $W(\rightarrow \tau\nu)$ + >= 1 jet, QCD

Run 1 limit

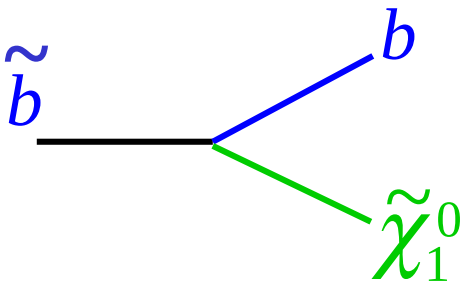


Projection for Run 2

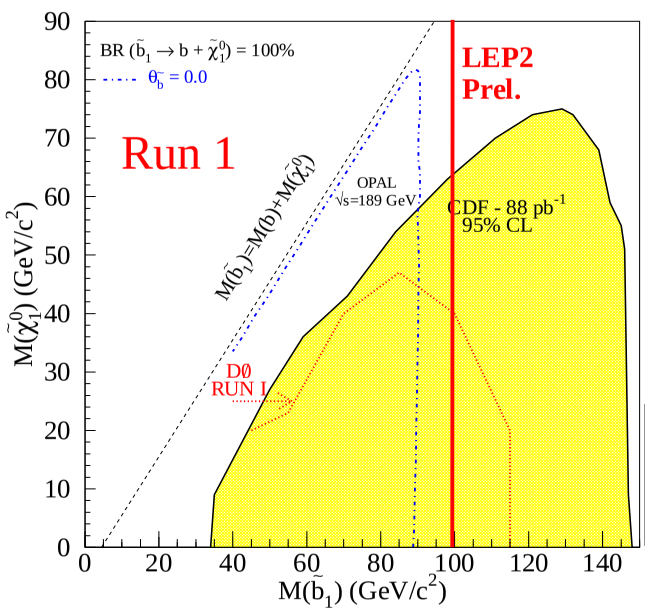


Sbottom (HF jets + MET)

$M(\tilde{b}_1) > M(\tilde{\chi}^0_1)$

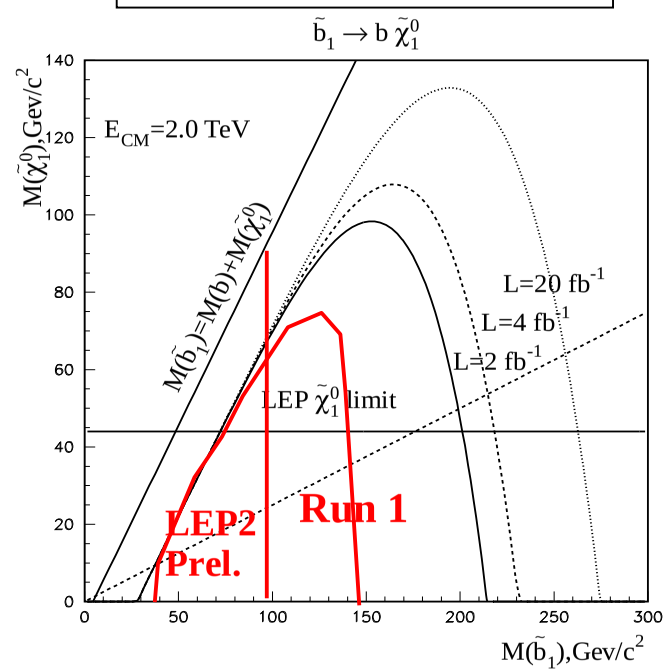


- Sbottom pair produced, *Rp*C decay
- LSP => $\tilde{\chi}^0_1$
- Signature : HF jets, MET
- Selections are similar to $t \rightarrow c\ \tilde{\chi}^0_1$ analysis
- Require >= 1 "b-tag"
- N_{expect}=5.8 +- 1.8 , N_{obs}=5



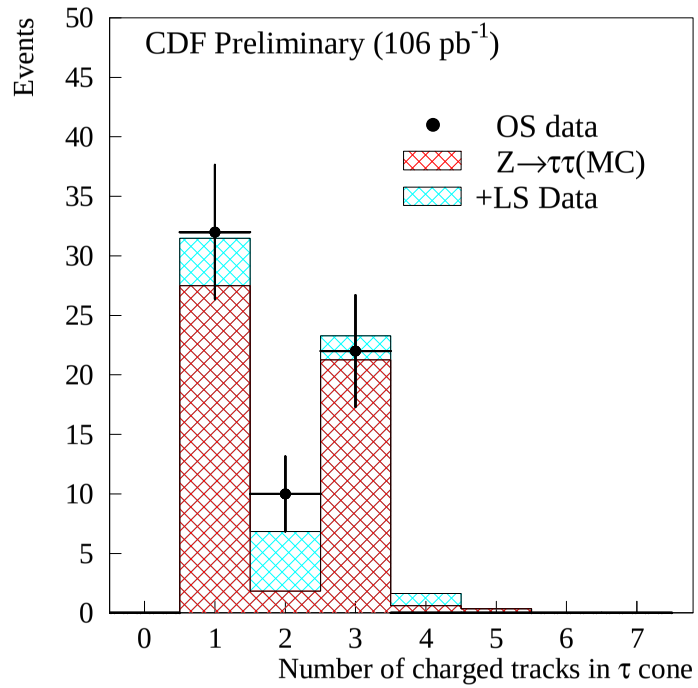
Run 1 limit

Projection for Run 2



Stop (*Rp*V Decay)

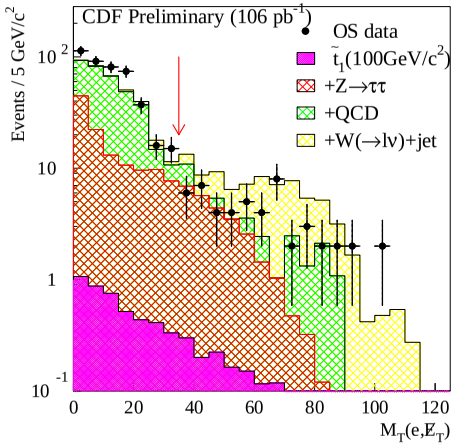
- Stop pair produced thru *Rp*C
- Assume only λ'_{333} and ε_3 are non-zero
  - $\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow (b\ \tau^+)(\bar{b}\ \tau)$ (RpV in 3rd gen., lepton number is violated)
- Selection:
  - $\tau \rightarrow l\nu\nu_\tau$: isolated lep., (Et>10 GeV)
  - $\tau \rightarrow$ haronic decay
    - Id : 1 or 3 pong, ($|\Sigma Q|=1$), $N_{\pi^0} < 3$
    - $M_\tau < 1.8$ GeV, $Pt_\tau > 15$ GeV

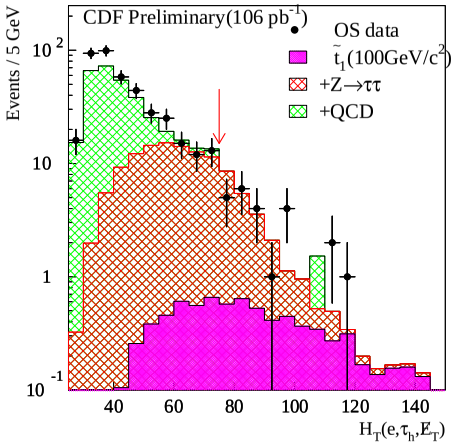


(hadronic tau candidate, w/o #trk cut)

Stop (*Rp*V Decay)

- Additional selections:





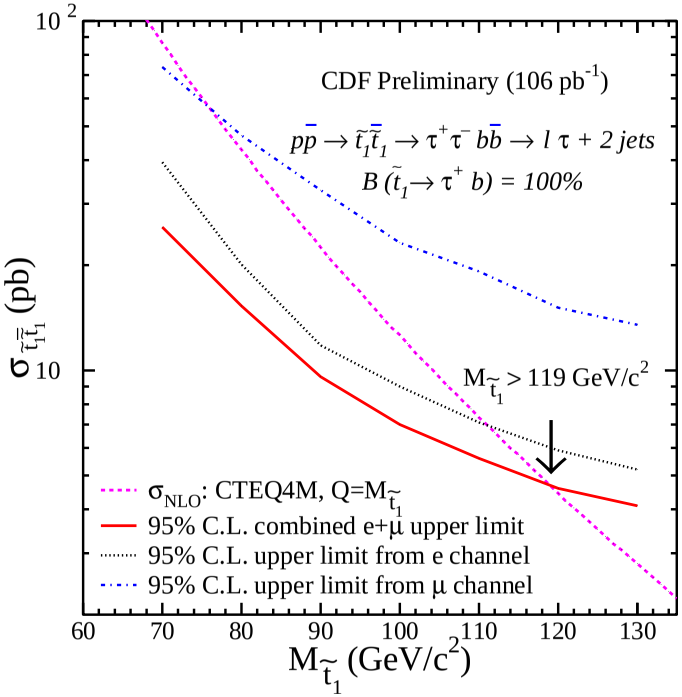
- Mt(l,MET)<35 GeV
- Ht(l,MET,τ_h)>70 GeV

- >= 2 jets, Et>15 GeV

channel	BG	Obs
e	1.92+-0.19	0
μ	1.13+-0.14	0

BG: $Z\rightarrow \tau\tau$

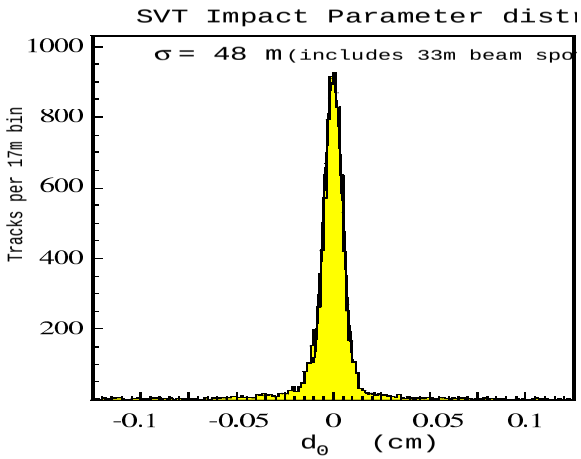
Run 1 limit



(ALEPH: M($\tilde{t}$) > 93 GeV)

CDF Run II Status

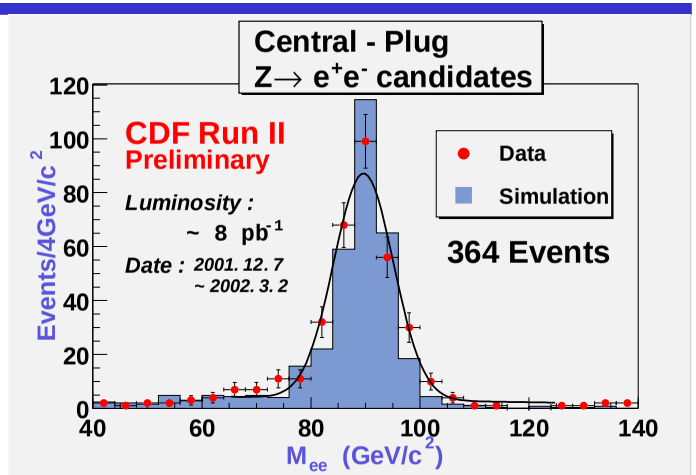
- Summer 2001→present, Tevatron delivered ~50 pb^{-1} integrated luminosity



Online silicon tracks' impact parameter

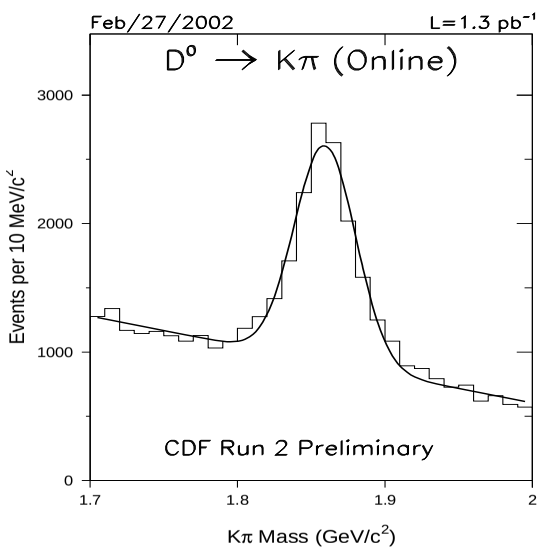
$\sigma = 48\ \mu m$

Including beam spot spread



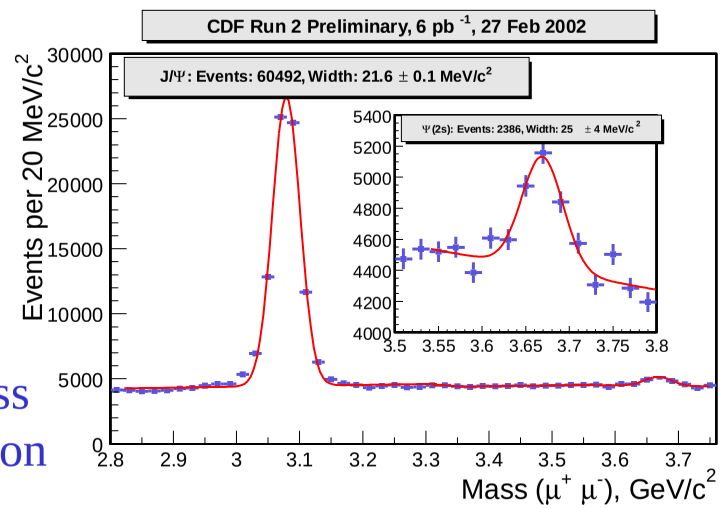
$Z \rightarrow e^+e^-$

1 electron in central, 1 electron in plug



Online silicon tracks match to COT tracks

100μm<d0<1 mm



Invariant mass from two muon tracks

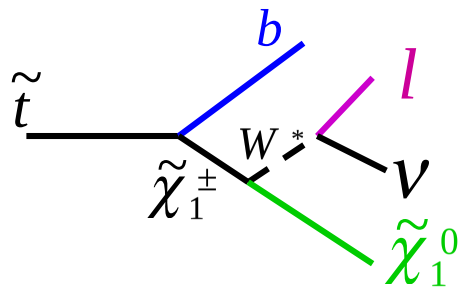
Conclusion

- CDF has searched for $\tilde{t}_1$ and $\tilde{b}_1$ in various channels of production and decays in Run 1, but has not found them yet
- Have excluded some parts of SUSY parameter space
- Started Run II data taking, detectors are performing well, physics analyses are underway
- Tevatron's goal:
  - By end of 2002 : deliver L ~200 pb^{-1}
    - Although not substantially greater than Run I, but with improve in detectors' performances, and increase in production cross section, we believe that CDF can still make an impact on $\tilde{t}$, $\tilde{b}$ searches
  - Run 2a (by 2004) L ~2 fb^{-1}
  - Run 2b (2004→2007+) L ~15 fb^{-1}
- Run 2 data will allow CDF to greatly extend its searches for $\tilde{t}$, $\tilde{b}$ and other SUSY particles

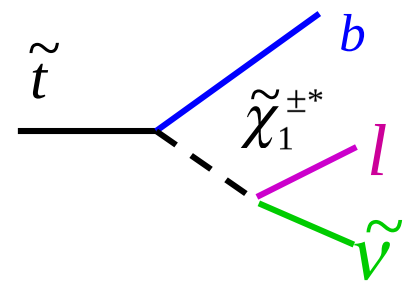
Stop (Leptons + HF jets + MET)

- Stop pair produced, *Rp*C decay

$M(t)>M(\tilde{t}_1)>M(\tilde{\chi}^{+/-}_1)$



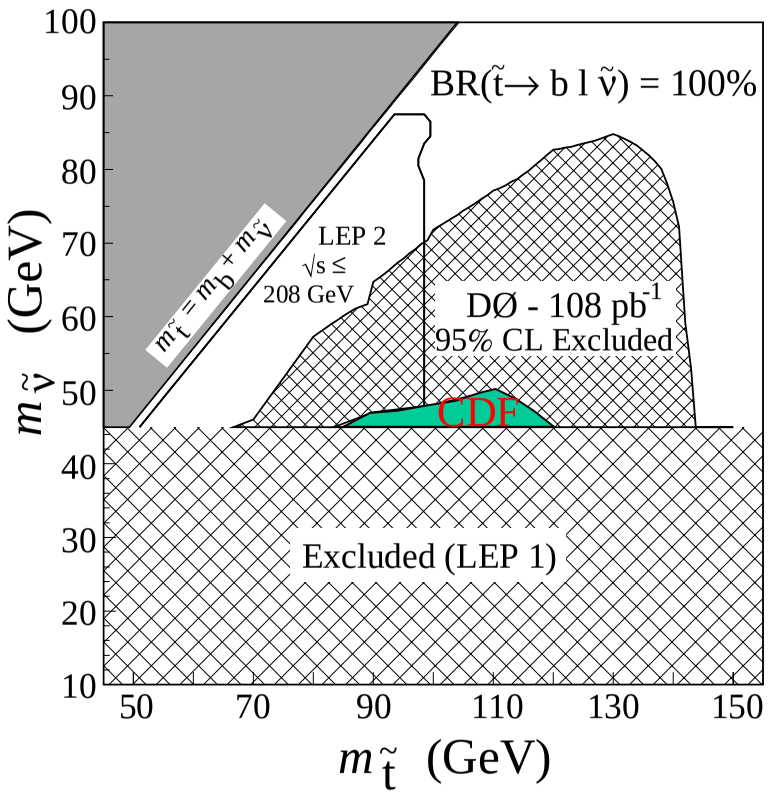
$M(\tilde{\chi}^{+/-}_1)>M(\tilde{t}_1)>M(\tilde{\nu})$



- LSP => $\tilde{\chi}^0_1$ or $\tilde{\nu}$
- Signature : HF jets, leptons, MET
- Selection:
  - >= 1 isolated lepton, Pt > 10 GeV
  - >= 2 jets (Et_1>12 GeV, Et_2>8 GeV)
  - MET > 25 GeV
  - >= 1 "b-tag"
- Reject events w/ 2 isolated opp. charged leptons (reduce Drell-Yan)
- Cuts on MET-jets angles (reject fake MET)

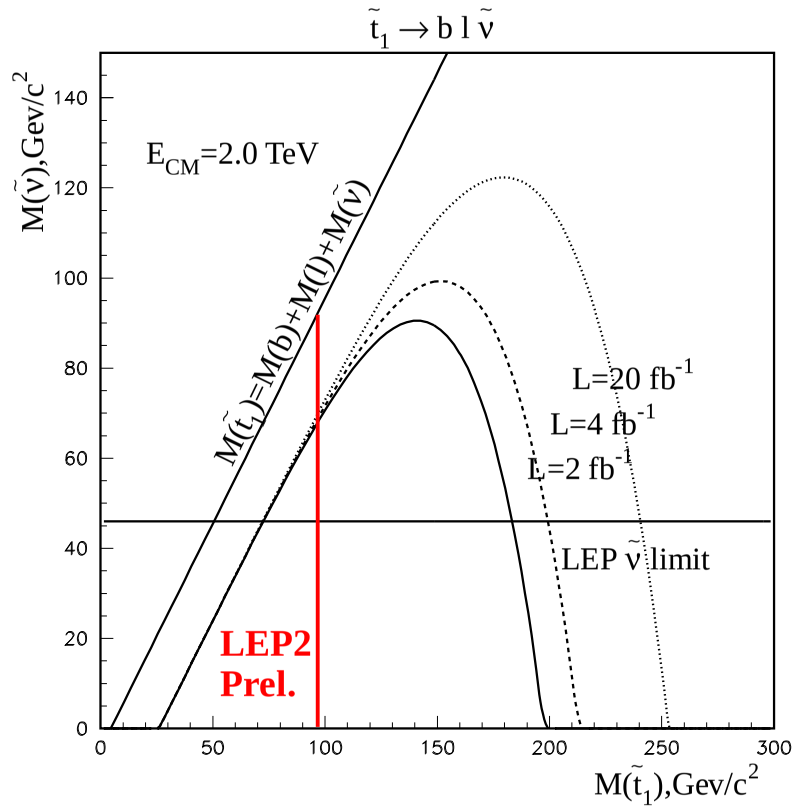
Stop (Leptons + HF jets + MET)

- Results:
  - N_{expect}=87.3 +- 8.8 , N_{obs}=81
- Backgrounds:
  - $W(\rightarrow l\nu)$ + >=2jets, tt , fake leptons



Run 1 limit

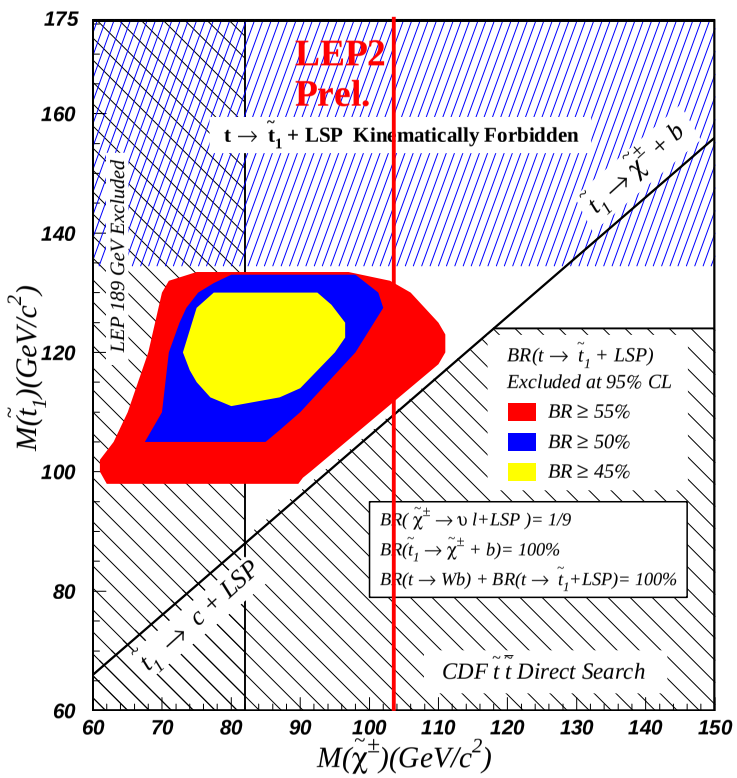
Projection for Run 2



Top Decays to Stop

- $t\,\bar{t} \rightarrow (bW)(\tilde{t}_1\ \mathrm{LSP})$
  - $\tilde{t}_1 \rightarrow b\tilde{\chi}^+_1 \rightarrow b\ q\ q'\ \mathrm{LSP}$
- Signature : HF jets, MET
- Selection:
  - Central e,μ(from W) w/ Pt>20 GeV
  - MET>45 GeV
  - Mt(l,MET)>40GeV (reject non-W)
  - Pt(l,MET)>50 GeV (reject W+jets)
  - >=3 jets ($Et_{1,2}$>20GeV, Et_3>15GeV)
  - >= 1 "b-tag"
- N_{expect}=9.5 , N_{obs}=9
- BG : $t\,\bar{t} \rightarrow (bW)(bW)$

Run 1 limit



M(LSP) = 40 GeV