Overview of Exotic Physics at CDF-II

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Outline:

- Subgroups in CDF Exotic Physics
- Model Based / Signature Based Searches
- Supersymmetry
- Results and Possibilities for Run II

Run II Exotics Group

- Three physics working groups:
  - Supersymmetry (SUSY)
  - Higgs
  - "VEGY" – Very Exotic Group
- Other working groups involved with specific types of searches.
  - lepton + track
  - Gauge symmetry-breaking SUSY in diphoton events
  - Multi-lepton signal searches
  - Jet probability algorithms (used in flavour tagging)
  - Missing E_T/SUSY

Run II Exotics Group

- Exotics also involved with several technical subgroups, dealing with datasets, triggers, code, etc.
- Much overlap with other software and hardware groups.
  - τ, γ, e, μ groups
  - Calorimetry
  - Tracking
  - Heavy flavour tagging

Model-based and Signature-based searches

- Run II exotics searches to be carried out with both model-based and signature-based methods:
  - Model-based: begin with model, choose signature, calculate background, evaluate limit. Best optimized, but model may become outdated with later results.
  - Signature based: begin with signature, publish acceptance and cross-section limit. If inconsistent with SM, result can be used to test various models.

Supersymmetry: Partial Motivation

- For the standard model Higgs boson, corrections to Δm_H^2 proportional to Λ^2, the energy scale for new physics.
  - Fermion loop: $\Delta m_H^2 = \frac{g^2}{16\pi^2}(-2\Lambda^2 + 6m_f^2 \ln(\Lambda/m_f) + \cdots)$
  - Boson loop: $\Delta m_H^2 = \frac{g^2}{16\pi^2}(+2\Lambda^2 - 4m_s^2 \ln(\Lambda/m_s) + \cdots)$
- Without new physics near the TeV scale, next known scale for new physics is M_{GUT}
- This results in $m_H \sim 15$ orders of magnitude above experimentally favoured values.
- Supersymmetric models postulate a fermion (boson) partner for each boson (fermion) in the Standard Model.

Supersymmetry: Higgs

- Δm_H^2 contributions from superpartner pairs become
  - $\Delta m_H^2 = \frac{g^2}{16\pi^2}(6m_f^2 \ln(\Lambda/m_f) - 4m_s^2 \ln(\Lambda/m_s)) + \cdots)$
- Each supermultiplet requires equal fermionic and bosonic degrees of freedom.

Supersymmetry: Unification

- Coupling constants in gauge theories scale with energy, depending on the particle spectrum, number of generations, and Higgs doublets.
  - $\frac{1}{\alpha_i(Q)} = \frac{1}{\alpha_i(Q)} + \frac{b_i}{2\pi}\log(M/Q)$
- In the standard model, with $N_g = 3$ and $N_H = 1$
  - $b_1 = \frac{4N_g}{3} + \frac{N_H}{10} = 4.1$
  - $b_2 = -\frac{22}{3} + \frac{4N_g}{3} + \frac{N_H}{6} = -\frac{19}{6}$
  - $b_3 = -11 + \frac{4N_g}{3} = -7$
- Evolving the coupling constants from Z-pole to high energy – no unification.

Supersymmetry: Unification

- With SUSY, with $N_g = 3$ and $N_H = 2$
  - $b_1 = 2N_g + \frac{3N_H}{10} = 6.6$
  - $b_2 = -6 + 2N_g + \frac{N_H}{2} = 1$
  - $b_3 = -9 + 2N_g = -3$
- Coupling constants meet around 10^{16} GeV!
- Many variations on this due to different SUSY models.

Sparticle Production at Tevatron

- As a $p\ \bar{p}$ collider, the Tevatron can produce sparticles via electroweak or QCD interactions.
- Electroweak:
  - $q\ \bar{q}' \rightarrow W^{\pm} \rightarrow \tilde{\chi}_1^{\pm}\ \tilde{\chi}_2^{o}$
  - $q\ \bar{q} \rightarrow Z^{o} \rightarrow \tilde{\chi}_1^{+}\ \tilde{\chi}_1^{-}$.
- QCD:
  - $q\ \bar{q}, g\ g \rightarrow \tilde{g}\ \tilde{g}, \tilde{q}\ \bar{\tilde{q}}$
- $\tilde{t}$, and possibly $\tilde{b}$, thought to be less massive than other squarks, and more likely to be produced.
- Single sparticles produced if R-parity violated.
- Slepton cross-section low.

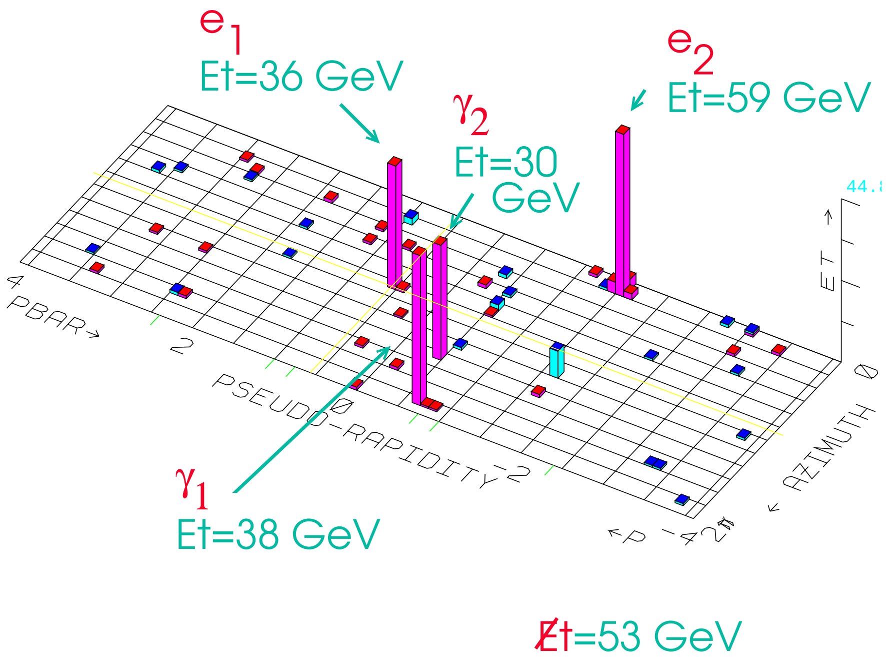
Signals at CDF

- In models where $\tilde{\chi}_1^o$ is LSP, sparticles can decay via:
  - $\tilde{\chi}_2^o \to Z^o\ \tilde{\chi}_1^o \to l^+\ l^-\ \tilde{\chi}_1^o$ or $q\ \bar{q}\ \tilde{\chi}_1^o$
  - $\tilde{\chi}_1^\pm \to W^\pm\ \tilde{\chi}_1^o \to l^\pm \nu\ \tilde{\chi}_1^o$
  - $\tilde{g} \to q\ \bar{q}\ \tilde{\chi}_i^o$ or $q\ \bar{q}'\ \tilde{\chi}_i^\pm$
  - $\tilde{q} \to q\ \tilde{\chi}_i^o$
  - $\tilde{t} \to c\ \tilde{\chi}_1^o$ or $\to b\ \tilde{\chi}_1^+$ if allowed.
- Resulting signals include $\not{E}_T$, such as:
  - Trilepton signal: $\tilde{\chi}_2^o\ \tilde{\chi}_1^\pm \to l^+\ l^-\ l^\pm + \not{E}_T$
  - Jets, $\not{E}_T$, possibly leptons, from squarks and gluinos.

Signals at CDF

- Competes with SM backgrounds producing neutrinos.
  - Drell-Yan pair production + fake lepton main trilepton background.
  - $Z \rightarrow \nu\ \bar{\nu}$ + jets background also produce jets and $\not{E}_T$.
  - $t\ \bar{t} \rightarrow b\ \bar{b}\ l^+ l^- + \not{E}_T$ background for dileptons, jets, $\not{E}_T$.
- In GMSB, with $\tilde{G}$ as LSP:
  - $\tilde{\chi}_1^o \rightarrow \gamma\ \tilde{G}$; neutralino signal becomes photon and $\not{E}_T$.
  - No significant physics background for $\gamma\ \gamma\ \not{E}_T + X$, main background from fake photons.
- R-parity violation: B and L non-conservation.
  - e.g. $\tilde{g} \rightarrow \bar{c}\ \tilde{c_L} \rightarrow \bar{c}\ e^+ d$ giving 2 electrons, 4 jets.
  - Possible long-lived, stable, charged LSPs.

Event: $2\,e + 2\,\gamma + \not{E}_t$



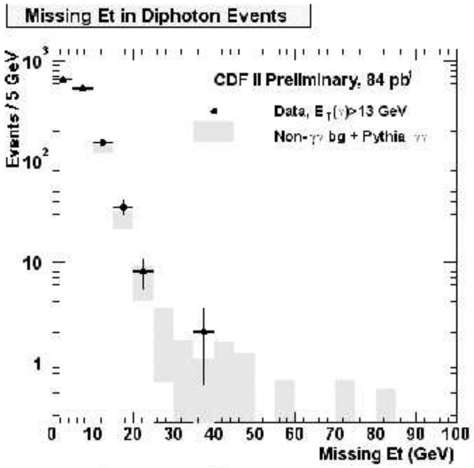
Famous "$\gamma\gamma$ missing E_T" event from CDF Run II TDR.

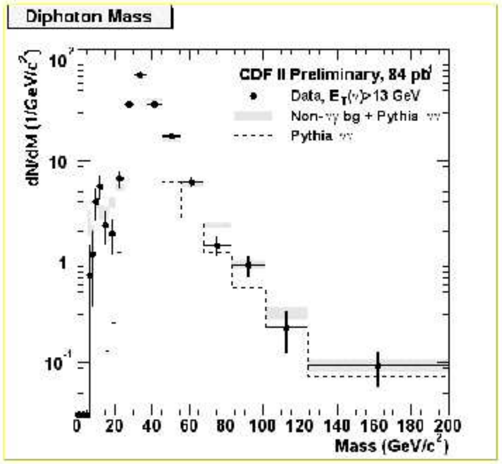
Follow Up on Run I Anomalies

Searches for new physics in the diphoton sample

Sample selection (84 pb^{-1})

- 2 central photons $E_T >$ 13 GeV
- cosmic rays and beam halo rejection
- Observed 1365 events (95 events with $E_T >$ 25 GeV)

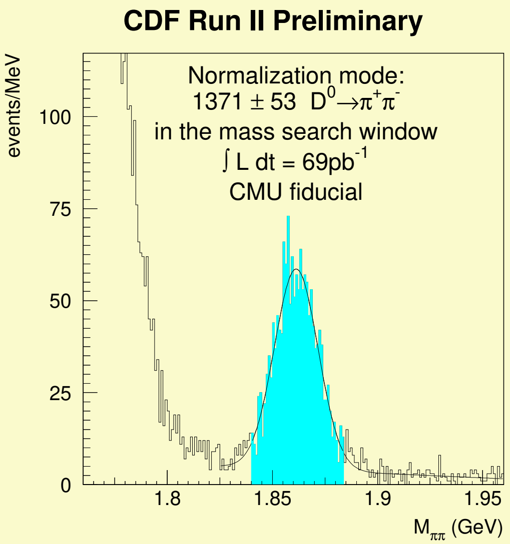


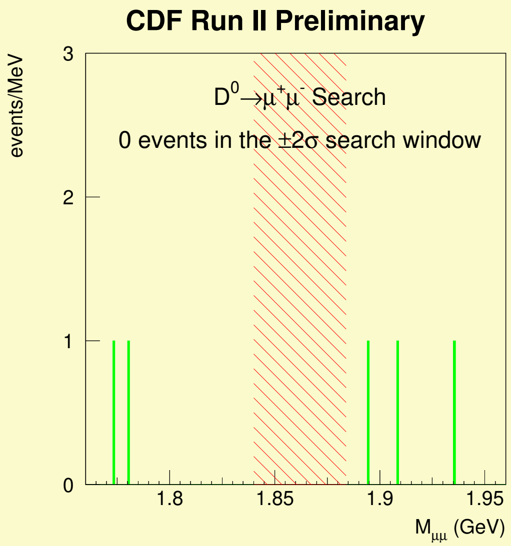


Diphoton + Lepton Events

	Obs.	Exp. $E_T^\gamma > 13\ GeV$	Exp. $E_T^\gamma > 25\ GeV$
$e\gamma\gamma$	0	$0.27 \pm 0.10 \pm 0.14$	$0.04 \pm 0.03 \pm 0.02$
$\mu\gamma\gamma$	0	$0.04 \pm 0.007 \pm 0.02$	$0.007 \pm 0.005 \pm 0.004$

Related Work in Run II: $D^0 \to \mu^+\mu^-$ *New!* 69pb^{-1}





expect: 1.7 ± 0.7 events

observe: zero

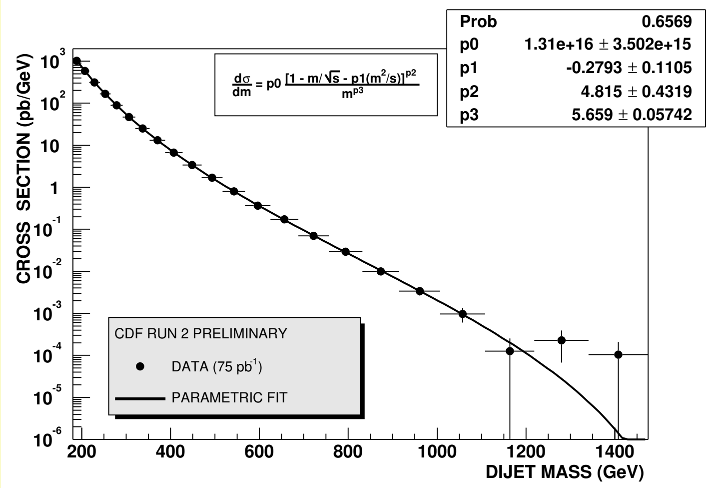
$$BF(D^0 \to \mu^+\mu^-) < 3.1 \times 10^{-6} \quad 95\% \text{ C.L.}$$

Already 2× better than previous limit. $B_s \to \mu^+\mu^-$ results are on the way...

Related Work in Run II: Search for Dijet Resonances

New result from Run II !!

- combine several di-jet samples
- di-jet mass calculated from corrected jet energies



→ fit corrected spectrum to empirical smooth function

→ ratio and residuals show no signs of 'bumps'

Upper limits on $\sigma \cdot B$:

0.3–1.5 pb for masses in the 800-1000 GeV range

⟶ significantly extends exclusion of axigluons and excited quarks.

Related Work in Run II: **Leptoquark Searches**

New result from Run II !!

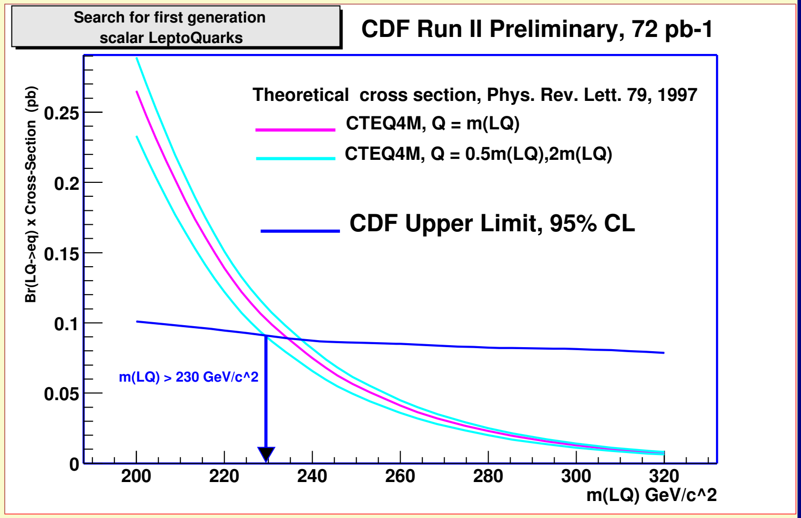
$e^+e^- \, JJ$ channel

(opposite-sign, no $\not{E}_T$)

- demand tight e^+e^-
  $\longrightarrow$ testing lepton ID
  in a jetty environment

- main bg $Z \to e^+e^- + \mathrm{ISR}$
  $\longrightarrow$ understood

total background	3.39 ± 3.15
observed	zero



$\sigma \times Br$ *sensitivity to* ~ 0.1 pb *for* 72 pb^{-1}

Related Work: Z' Searches in e^+e^- and $\mu^+\mu^-$ channels

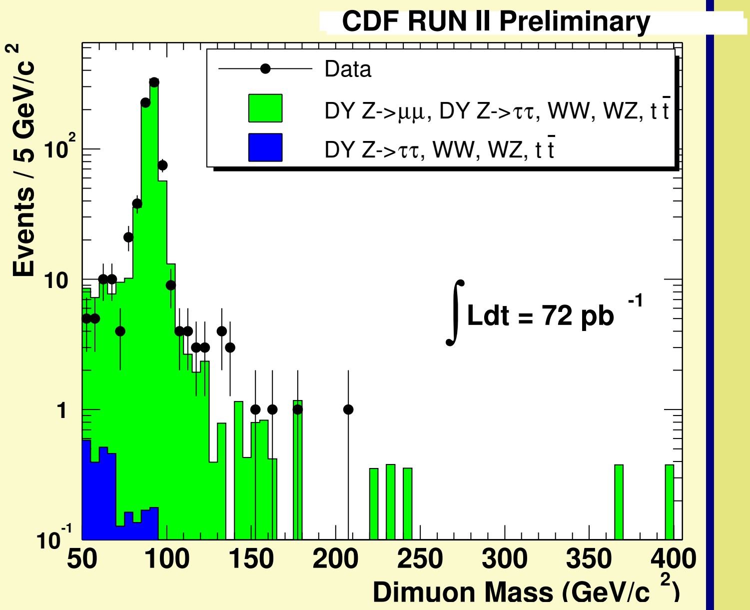
New result from Run II !!

- two tight leptons
  $\longrightarrow$ understand lepton ID

- eliminate QCD and CR backgrounds, leaving DY processes

- define mass region $M_{\ell^+\ell^-} > 150$ GeV

total expected background	5.2 ± 0.3
observed	4

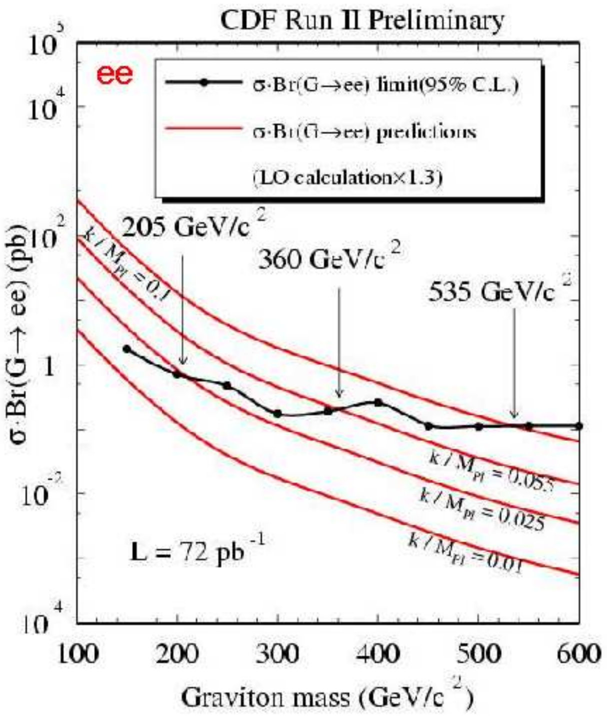


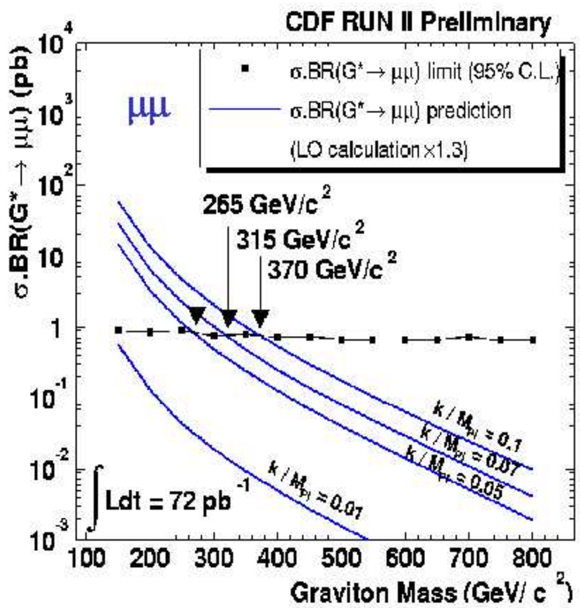
sensitivity to $\sim$ 1pb (μ) $\sim$ 0.1pb (e)

muons	$M_{Z'} > 455$ GeV
electrons	$M_{Z'} > 650$ GeV

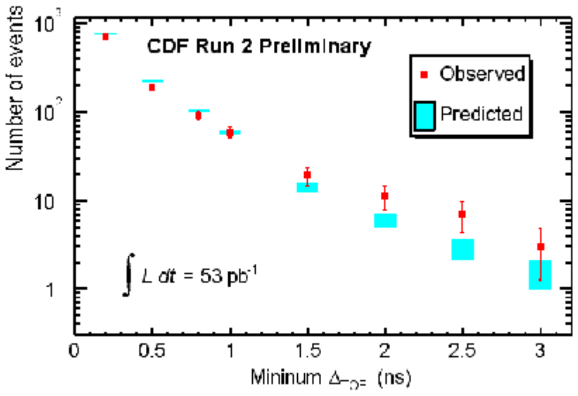
Work proceeds with low-p_T multilepton sample – more challenging...

Limits : R-S Graviton





CHArged Massive ParticleS

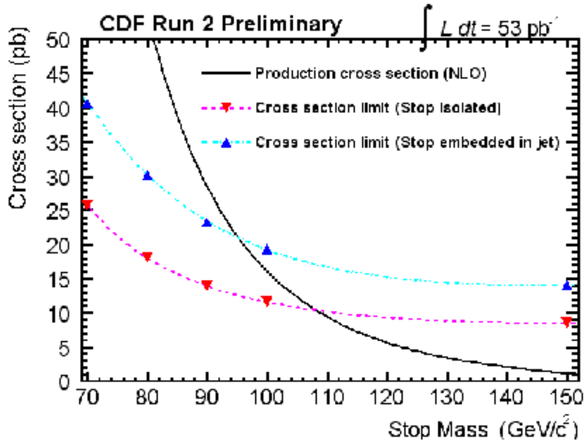


Predicted/observed events in the signal region (statistical uncertainties only).
The counting experiment required Δ(TOF) > 2.5 ns.
This point has a background prediction of

2.9 +/- 0.7 (stat) +/- 3.1 (sys), with 7 observed.

Backgrounds:
- instrumental
- cosmic rays (negligible for Δ(TOF) > 2.5)

Interesting NLSP cases in GMSB
- stop or stau as the lightest SM partners
- stop - strongly interacting
- stau - weakly interacting



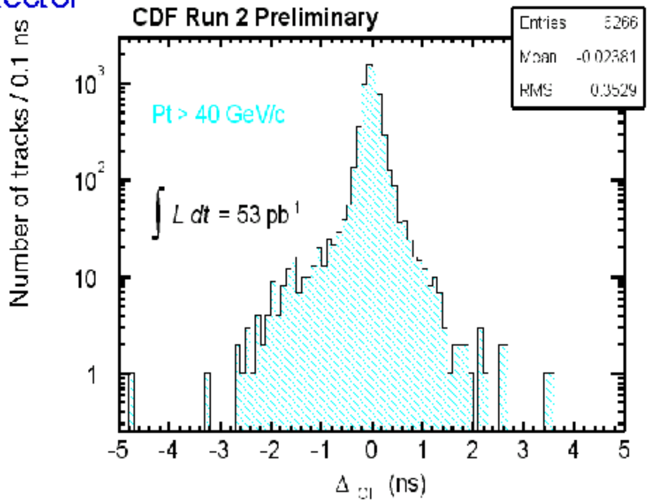
M(stop) > 108 GeV at 95% CL. (isolated stop)
M(stop) > 95 GeV at 95% CL. (non isolated stop)

LEP m(stop) > 95 GeV/c^2

Simona Rolli, Les Arcs March 2003 21

CHArged Massive ParticleS

- Long lived particles escaping the CDF detector
  - looking at high pt muon trigger
- Isolated, slow moving
  - $p_t > 40$ GeV/c to have full tracking efficiency
  - long time of flight through the detector
- TOF measurement
  - RunII TOF system provides sensitivity to higher $\beta\gamma$ than dE/dx (LEP searches)
  - event t_0 from tracks with $P_T > 20$ GeV/c
    - tested with W electron sample
  - Looking for tracks with high $TOF_{tracks} - t_0$



Possibilities for Run II

- With luminosity, sensitivity, and energy increasing for run II, better results expected.
  - Greater mass reach
  - Smaller cross-sections, branching ratios
- Run II results being presented at recent meetings based on first 70-120 pb^{-1}.
- Expect 250 pb^{-1} by summer's end!

Possibilities for Run II

- If SUSY cross-sections $\sim 0.1 - 1$ pb, might expect up to 200 - 4000 events. (Not taking background and inefficiencies into account.)
- After 2 years of data collection, enough data to report preliminary results should be available.
- Many SUSY models and parameter choices exist – trends towards signature-based, model-independent analyses.
- Theoretical expectations for SUSY put new physics just within the reach of Tevatron – if SUSY valid, should start to see something.
- We should expect the unexpected.