

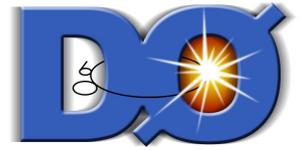


Searches for new physics at the Tevatron

F.D. Snider
Fermilab

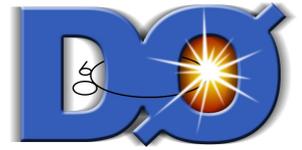
on behalf of the
CDF and D0 collaborations

Hadron Collider Physics Symposium
La Biodola, Isola d'Elba
May 25, 2007



New physics program

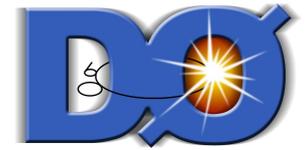
- Tevatron collider provides excellent opportunity to search for physics beyond the SM
- CDF and D0 have broad programs directed finding evidence for new physics: (aside from Higgs, NP related to top)
 - Supersymmetry
 - New gauge bosons
 - Large extra dimensions
 - Long-lived particles
 - Leptoquarks
 - Compositeness
 - Technicolor
 - Signature-based searches



New physics program

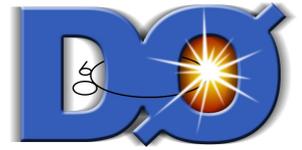
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Both experiments have recent results based on $\sim 1 \text{ fb}^{-1}$ or more in most of these areas



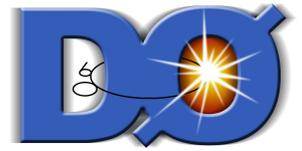
New physics program

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 - CDF and D0 have broad programs directed finding evidence for new physics: (aside from Higgs, NP related to top)
 - Supersymmetry
 - New gauge bosons
 - Large extra dimensions
 - Long-lived particles
 - Leptoquarks
 - Compositeness
 - Technicolor
 - Signature-based searches
- Will focus on a selection of the recent results covering some of these areas
- Can ask questions about any
- Discussed in earlier talk



Searches for supersymmetry

- Supersymmetry (SUSY)
 - Provide a possible solution to the hierarchy problem, a natural candidate for dark matter, stabilizes the mass of the Higgs,...
 - Lightest particles might be created at the Tevatron
 - CDF, DØ have extensive programs to search for evidence of SUSY
 - Standard signatures with good sensitivity to SUSY decays
 - Chargino/neutralino: Tri-leptons
 - Squarks/gluinos: Jets + missing energy
 - Stop/sbottom: Jets + missing energy + B-tag
 - Stable particles (although more broad than SUSY alone)
 - Charged and neutral
 - Indirect searches via rare decays
 - $B_s \rightarrow \mu^+ \mu^-$



Searches for supersymmetry

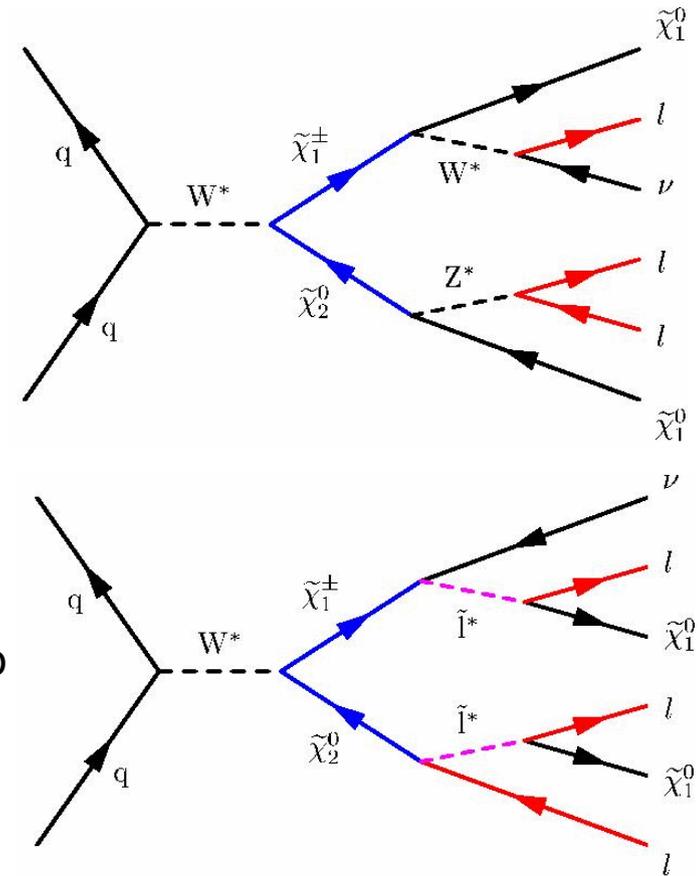
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Discussed in earlier talk

Chargino/neutralino search

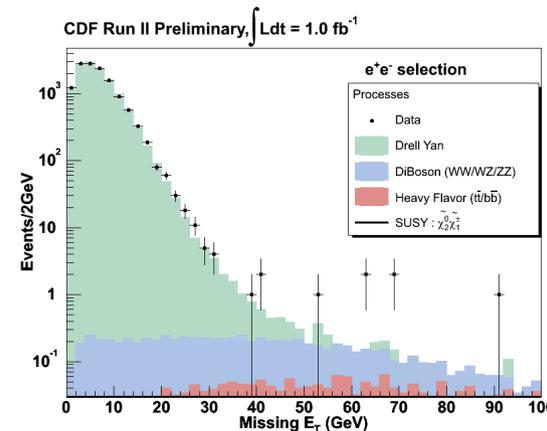
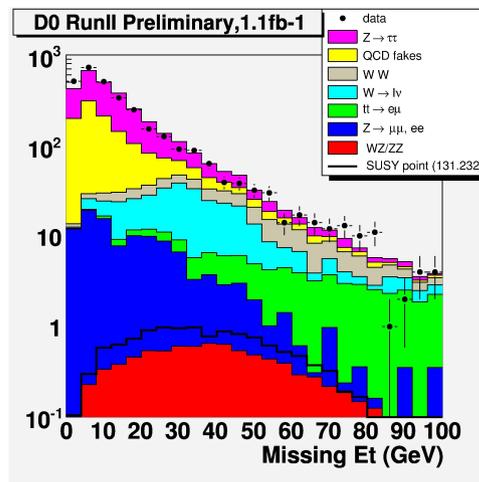
- Minimal SUSY models
 - Lightest neutralino, chargino are lowest lying mass states
 - Lightest neutralino is LSP
- Search for associated production of chargino + neutralino
 - Slepton/WZ-mediated decay channels:
 - Final state = tri-leptons + lightest neutralino
 - Neutralino escapes undetected
 - Missing energy
 - Very clean experimental signature
 - Considerable effort in both experiments devoted to tri-lepton searches



Chargino/neutralino search

- Basic strategy:
 - Identify two good electrons/muons + loose lepton ID for third
 - e.g., Lower Pt requirement, allow isolated track (includes hadronic taus), drop requirement altogether
 - Many different analyses
 - Main background: di-bosons, Drell-Yan + conversion
 - Study background in control regions

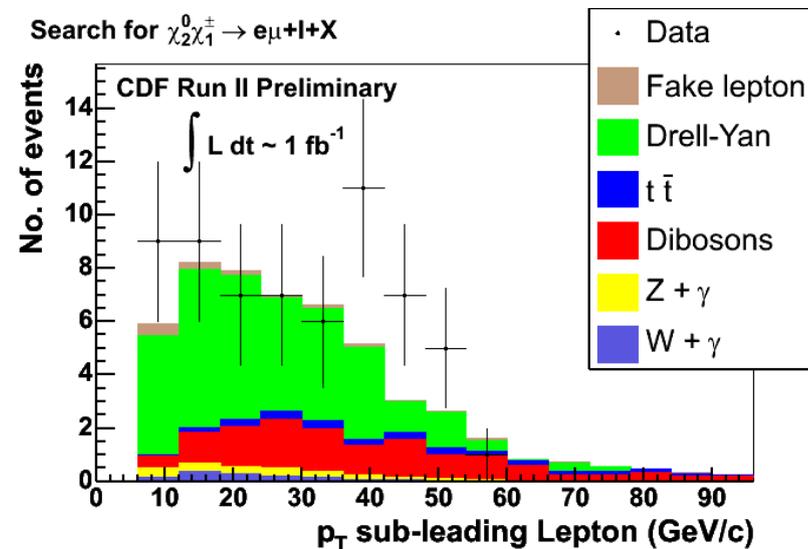
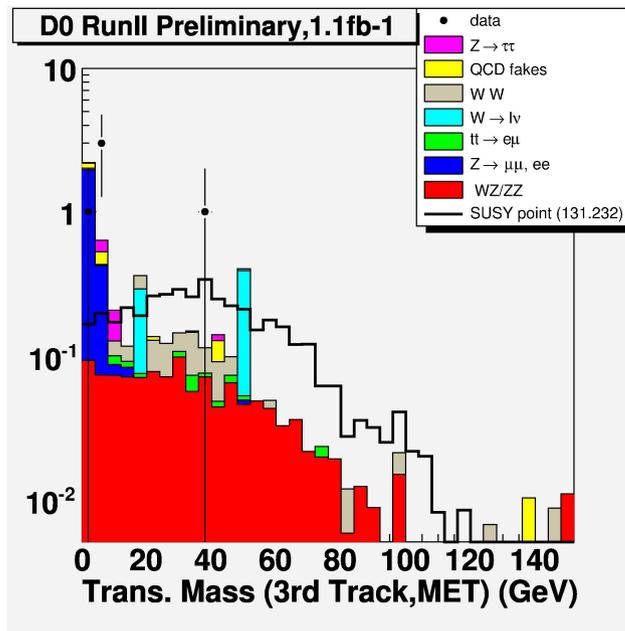
Missing Et
before applying
most cuts



Missing Et
in Z events

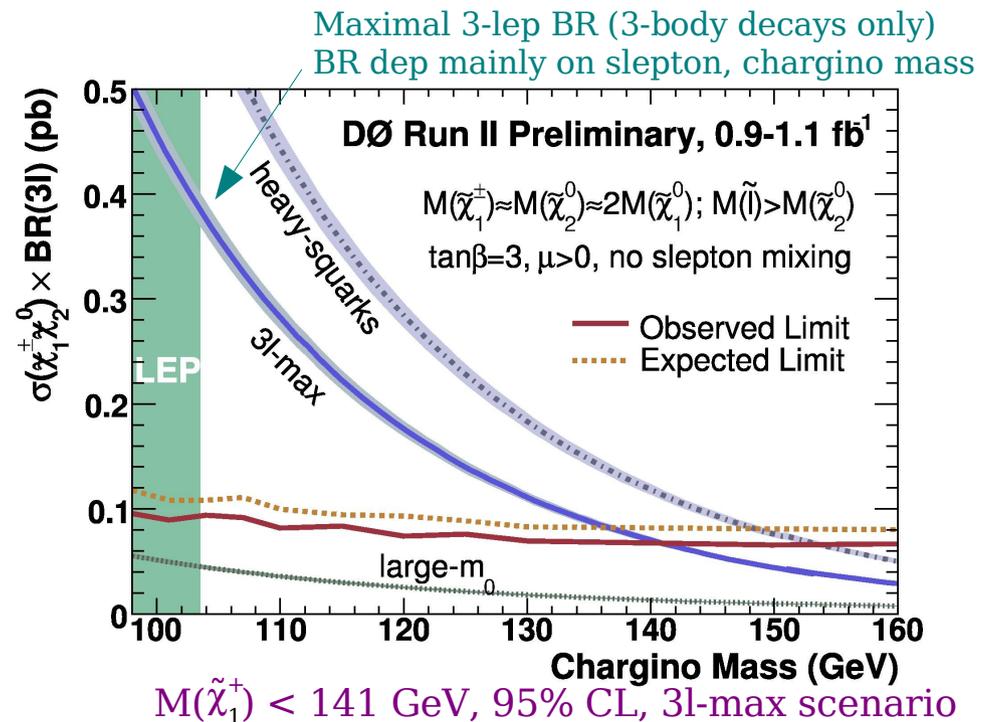
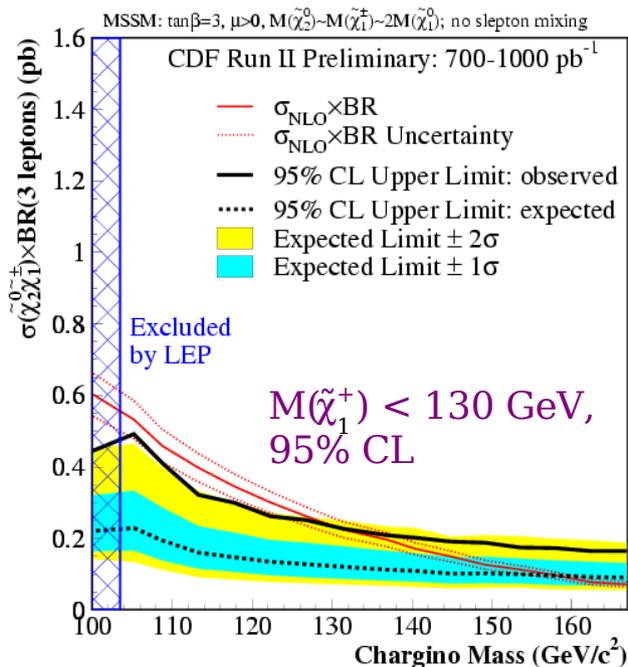
Chargino/neutralino search

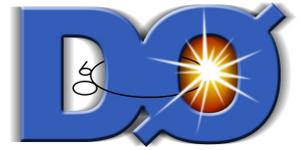
- Observed data consistent with expectations from background



Chargino/neutralino search

- Each experiment combines results from all channels
- Set limits using mSUGRA-inspired MSSM model
 - $m(\tilde{\chi}_1^+) \approx m(\tilde{\chi}_2^0) \approx 2m(\tilde{\chi}_1^0)$, no slepton mixing





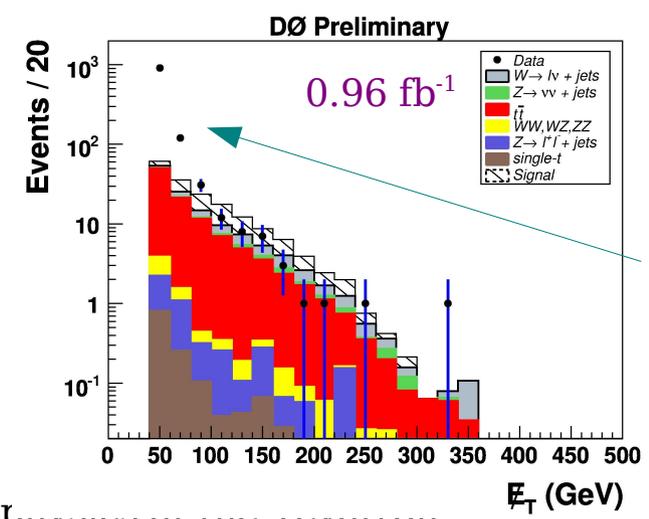
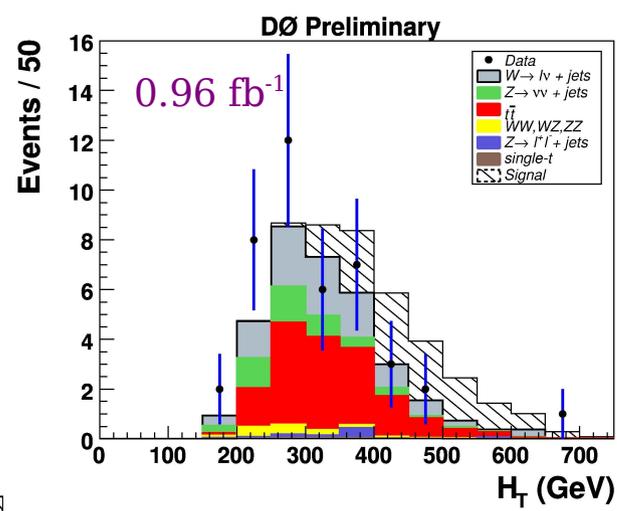
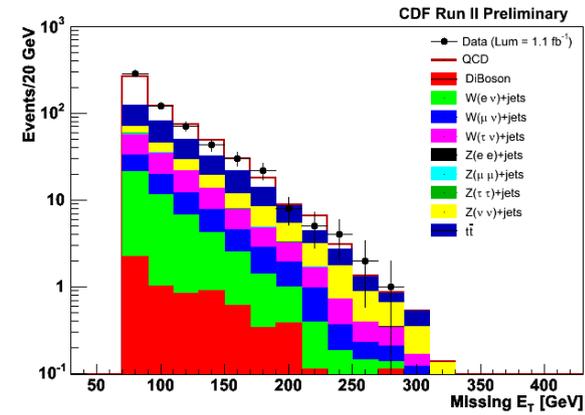
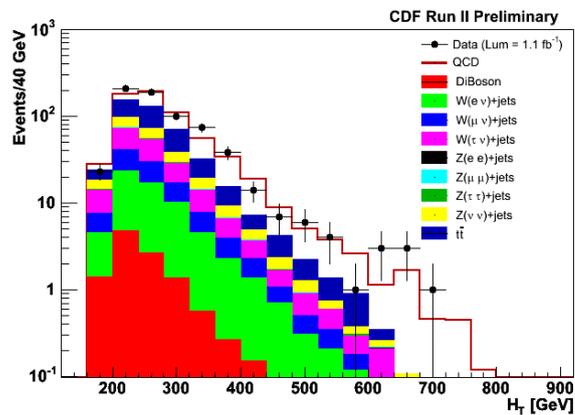
Squarks and gluinos

- Pair produced via $q\bar{q}$, gg
 - Large production cross sections if sufficiently light
 - Squarks corresp to light quarks tend to have similar masses
- Decay signature
 - Jets (acoplanar) + missing energy
 - Search for signatures consistent with lighter of squark, gluino
- Large background from QCD, W/Z + jets
 - Similar strategies, variables used to optimize signal sensitivity
 - N_{jets} , E_t , MET, H_t (scalar sum E_t), angles between jets, multi-jet mass
 - Selection differs across mass range of interest.



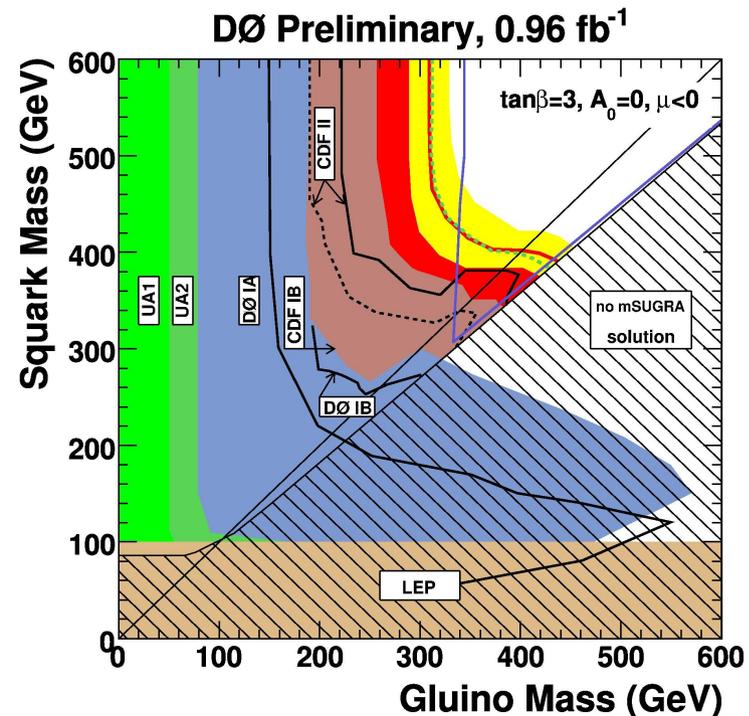
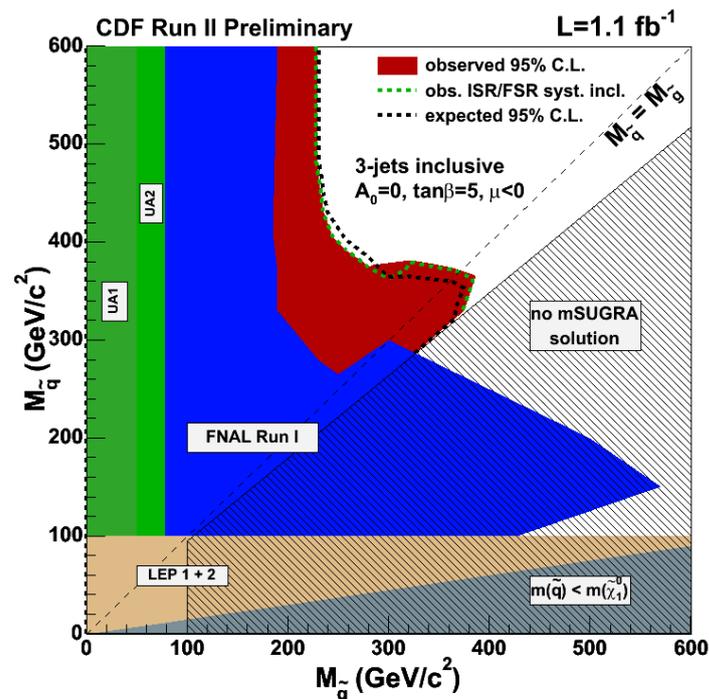
Squarks and gluinos

- Observed events consistent with background



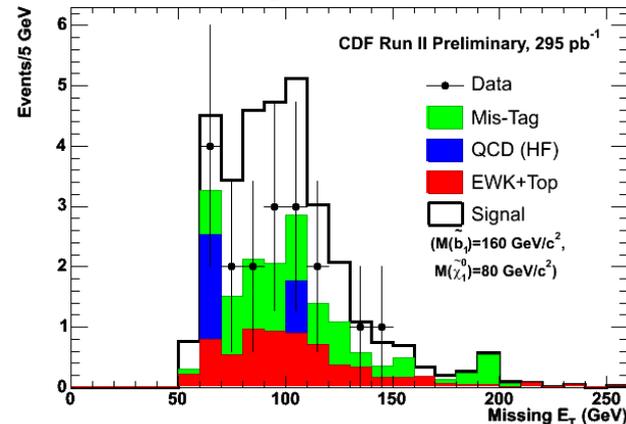
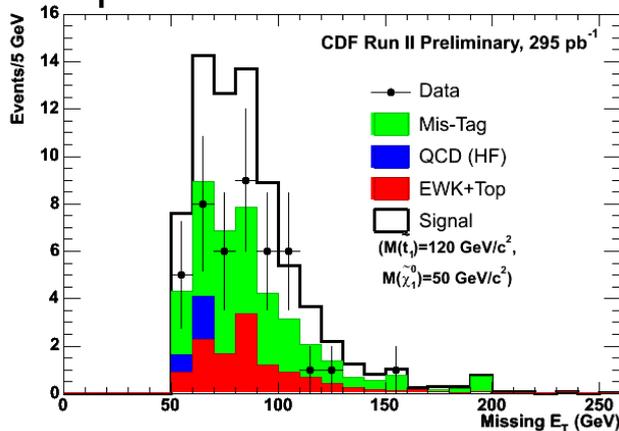
Squarks and gluinos

- Set limits within mSUGRA framework
 - Exclude gluino < 309 GeV (any squark mass)
 - Exclude squark < 391 GeV (any gluino mass)



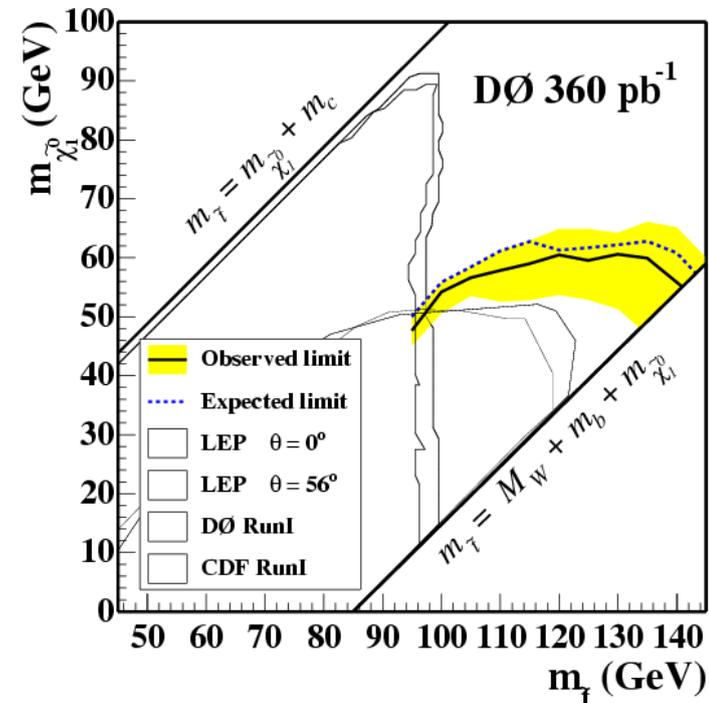
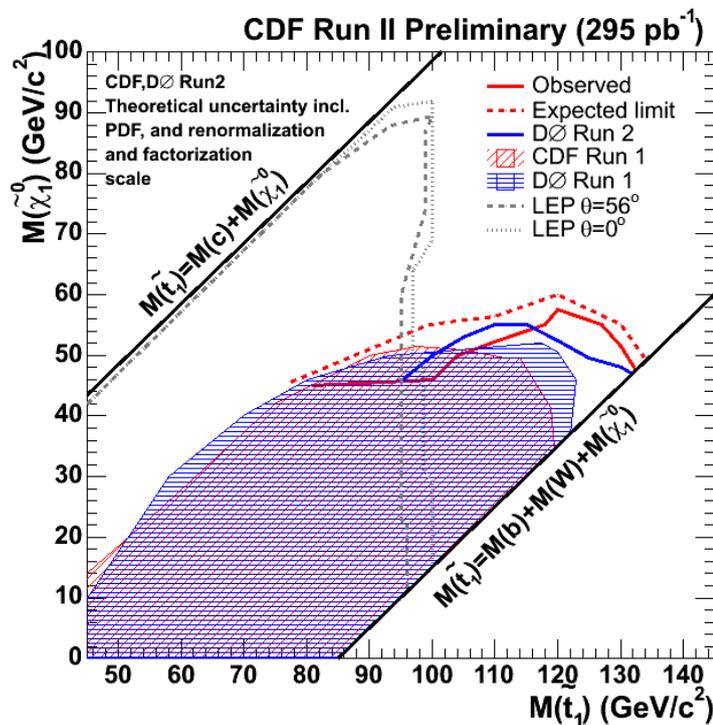
Stop and sbottom

- Strong mixing due to large Yukawa coupling
 - Can be light
 - NLSP in large region of mSUGRA parameter space
- Pair produced. Decay mode depends on mass.
 - Search in $\tilde{t} \rightarrow c \tilde{\chi}_1^0$ and $\tilde{b} \rightarrow b \tilde{\chi}_1^0$
 - Similar analysis to that for generic squark, except add B-tag
- Optimize selection for three mass ranges



Stop and sbottom

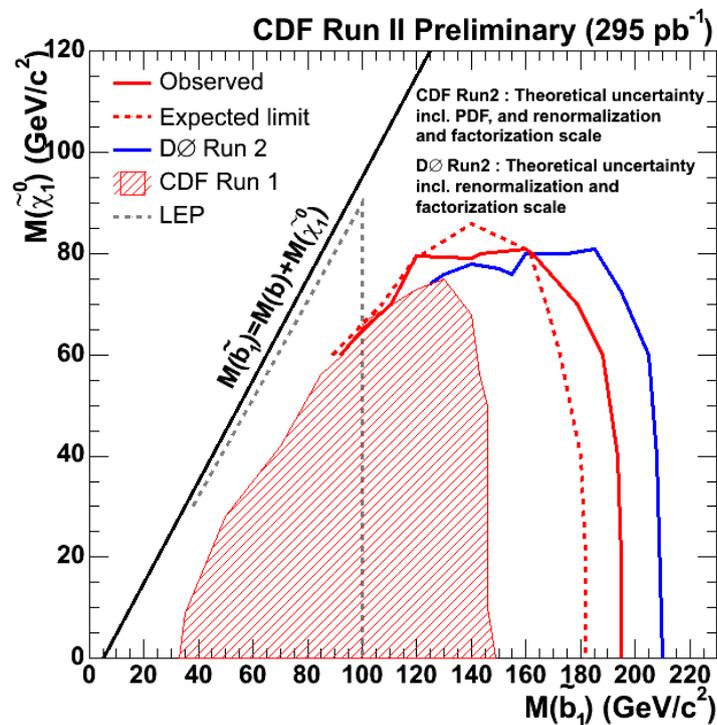
- Observe no excess over expected background
 - Set limit in $M(\text{stop})$ vs. $M(\tilde{\chi}_1^0)$ plane





Stop and sbottom

- Observe no excess over expected background
 - Set limit in $M(\text{sbottom})$ vs. $M(\tilde{\chi}_1^0)$ plane





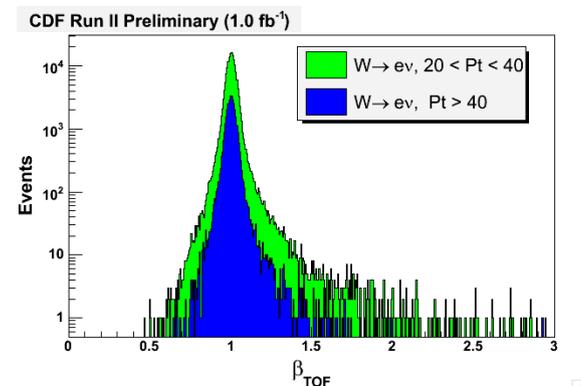
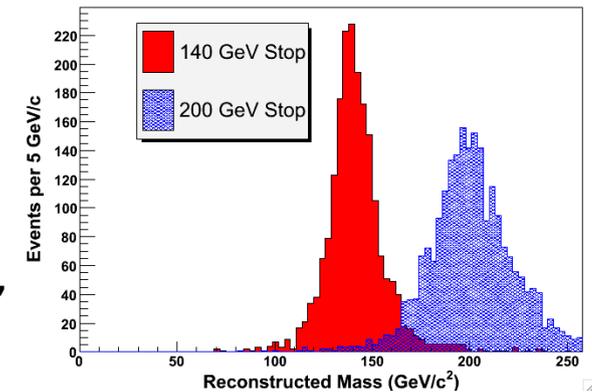
Long-lived particles

- Various models predict long-lived massive particles due to:
 - Weak coupling (e.g., NLSP in SUSY models with GMSB)
 - Kinematic constraints, barrier (e.g., chargino in SUSY with AMSB)
 - New symmetry (e.g., gluino in split-SUSY, LSP stop in ED models)
- Can be charged/neutral, decay inside/outside detector
- Several searches performed
 - Charged (CHAMP)
 - Escapes detector, looks like a slow muon
 - Neutral
 - Decays inside detector
 - Delayed photon
 - Delayed jets



Search for CHAMPs

- Long-lived charged particles
 - Lose energy primarily via ionization (+ low energy hadronic interactions if colored)
 - Highly penetrating: reconstruct (and trigger detector) as muons
 - Distinctive signature
 - High Pt, low velocity, highly ionizing “muons”
- CDF search in 1 fb^{-1}
 - Measure velocity (β) via TOF detector + timing from tracking detector
 - Calculate mass from momentum and β
 - Study resolution function
 - W electrons and muons in control regions

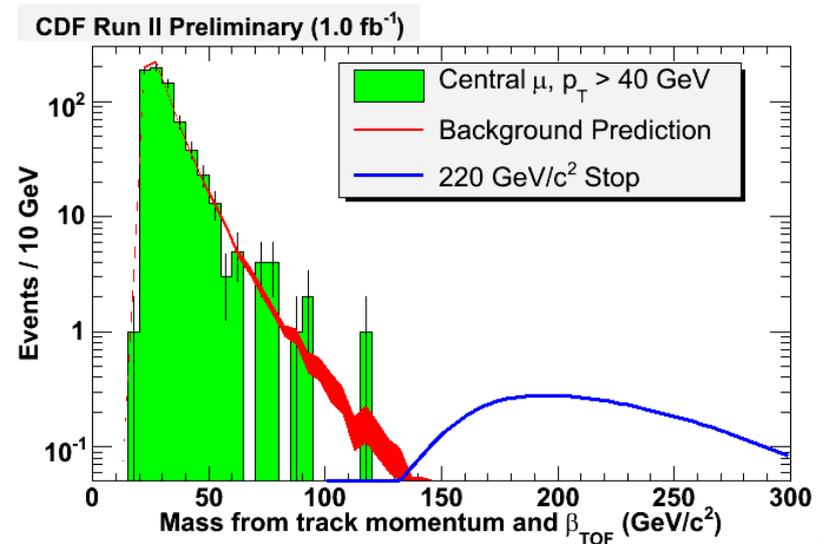


Search for CHAMPs

- Observed events consistent with expected background
- Set model independent limits
 - For fiducial CHAMP (at 95% CL)
 - Strongly interacting: $\sigma < 48$ fb
 - Weakly interacting: $\sigma < 10$ fb

Relevant to some R-hadron, stable chargino

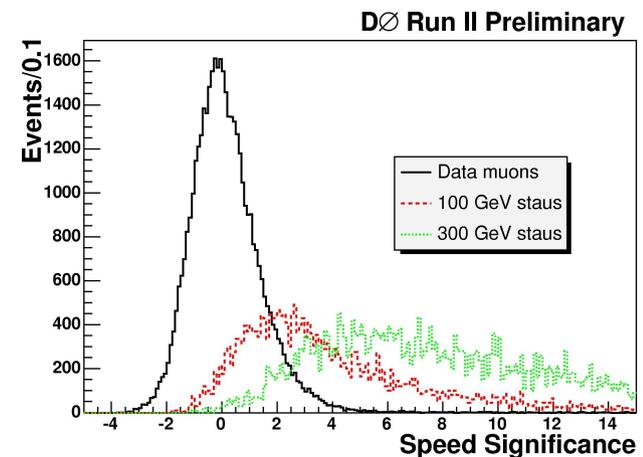
- Set limit on stable stop squark
 - $M > 250$ GeV at 95% CL





Search for CHAMPs

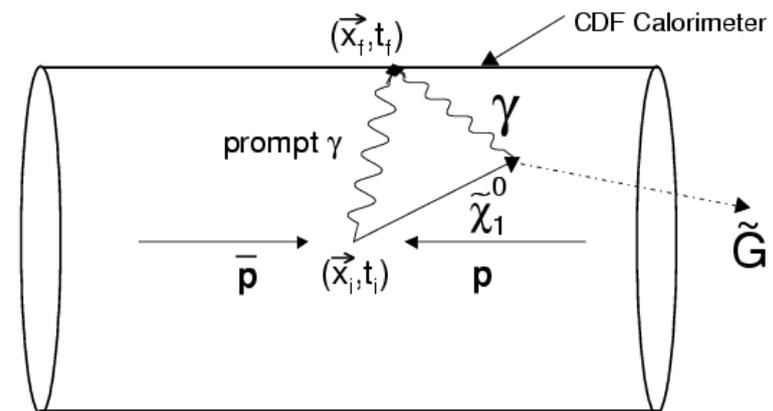
- D0 search for long-lived chargino in 390 pb^{-1}
 - Use timing information from muon scintillators
 - Select candidates based upon speed significance



- Observe no events, expect 0.69 ± 0.05
 - Set limit on mass of gaugino-like chargino $> 174 \text{ GeV}$ at 95% CL

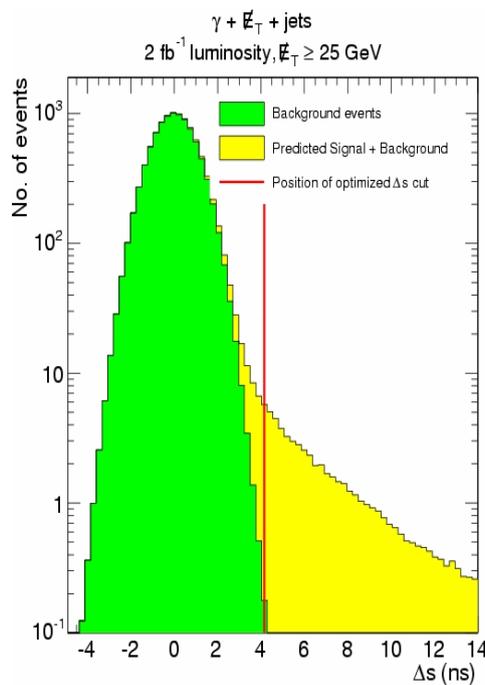
Search for delayed photons

- CDF search for late photon + missing energy + jet
- Benchmark model
 - Neutralino lifetime in GMSB models is free parameter
 - Could decay far from interaction inside detector
 - Chargino+neutralino associated production
 - Gamma from neutralino
 - Missing Et from gravitinos
 - Jet from chargino decay



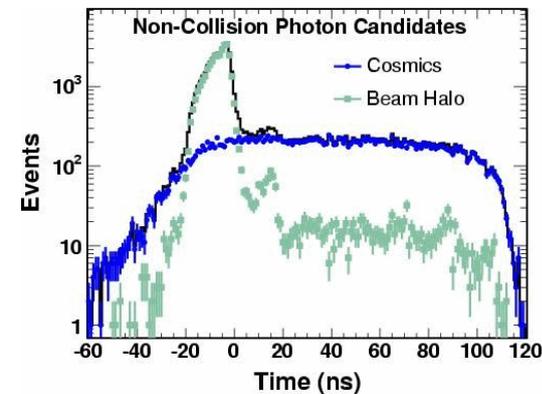
Search for delayed photons

- Measure photon arrival time at calorimeter
- Background from cosmics, beam-halo and event vertex mis-assignments

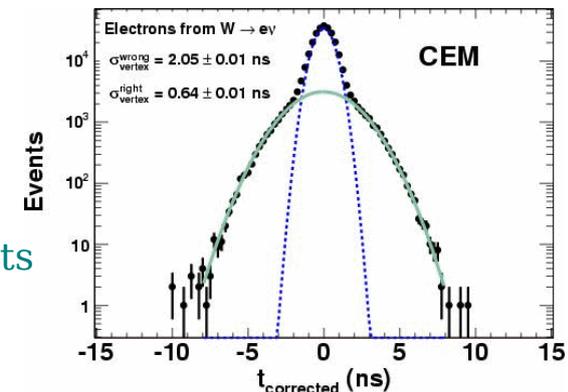


Arrival time for prompt and signal photons + background

Beam halo + cosmics

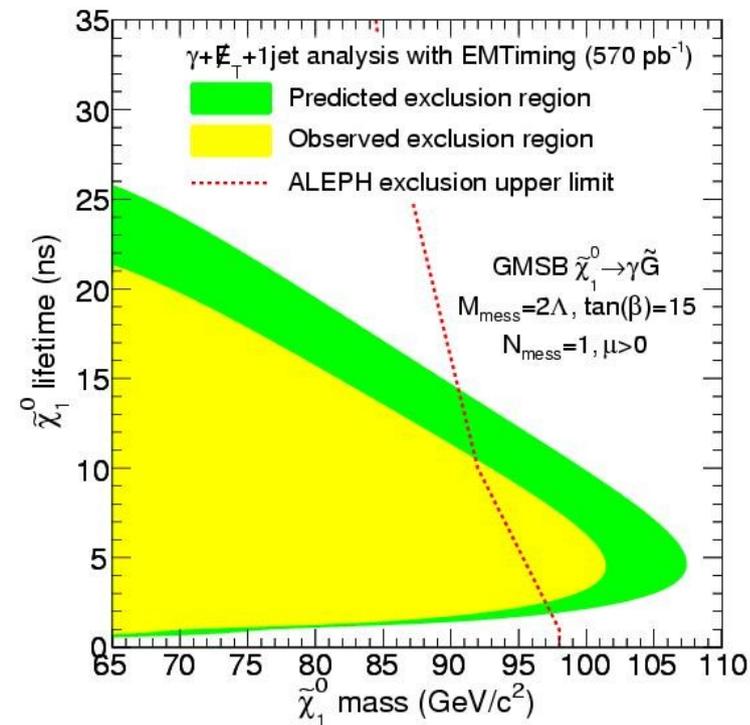
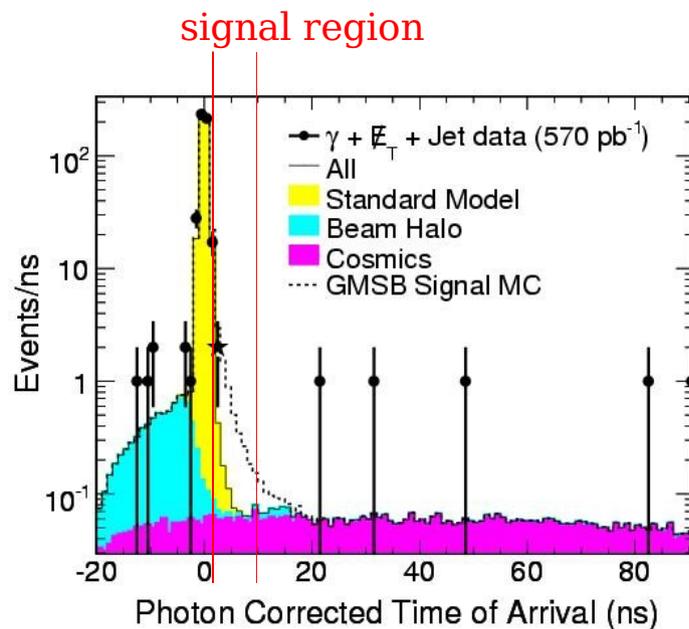


Vertex mis-assignments



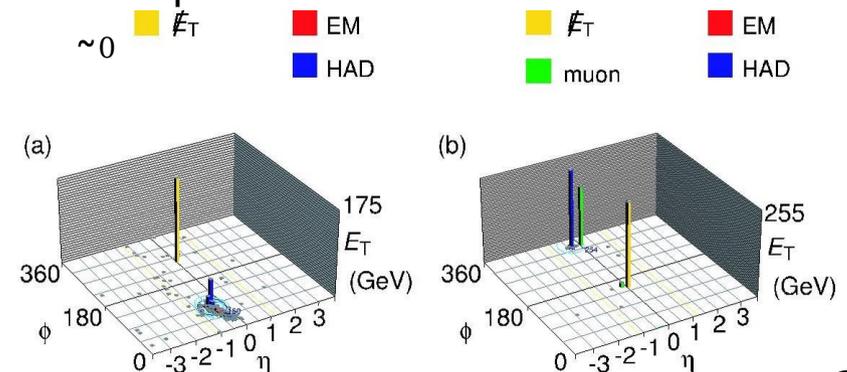
Search for delayed photons

- Observe 2 events, expect 1.25 ± 0.66
 - Set limit in $\tilde{\chi}_1^0$ lifetime vs. $\tilde{\chi}_1^0$ mass plane



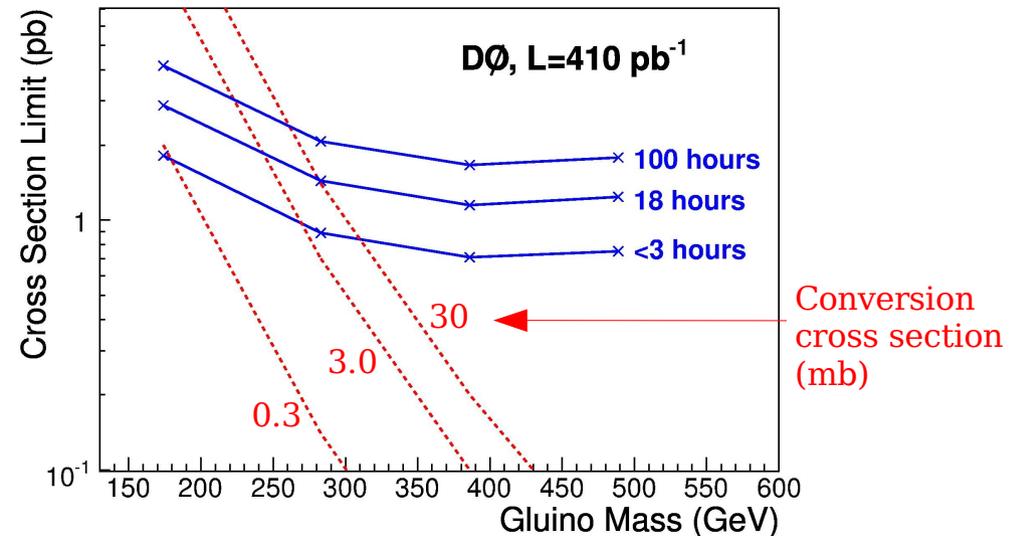
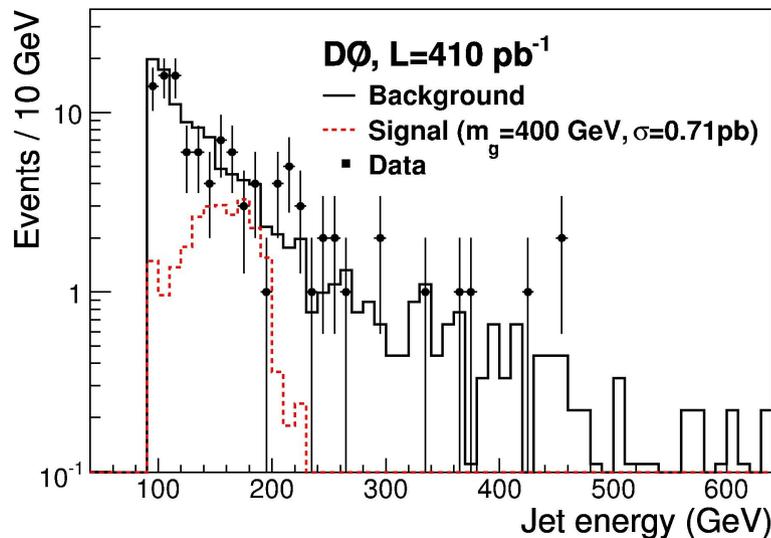
Search for stopped gluinos

- Split-SUSY predicts long-lived gluino
 - If lifetime > 10 s of nsec, some will escape detector while others will stop in the material of the detector
 - Approx 20% - 30% for D0 detector
 - Decay to $g\tilde{\chi}_1^0$ or $q\bar{q}\tilde{\chi}_1^0$ will produce out-of-time “jet” + missing energy
 - Differentiate using transverse shower shape
 - Also background from beam halo



Stopped gluinos

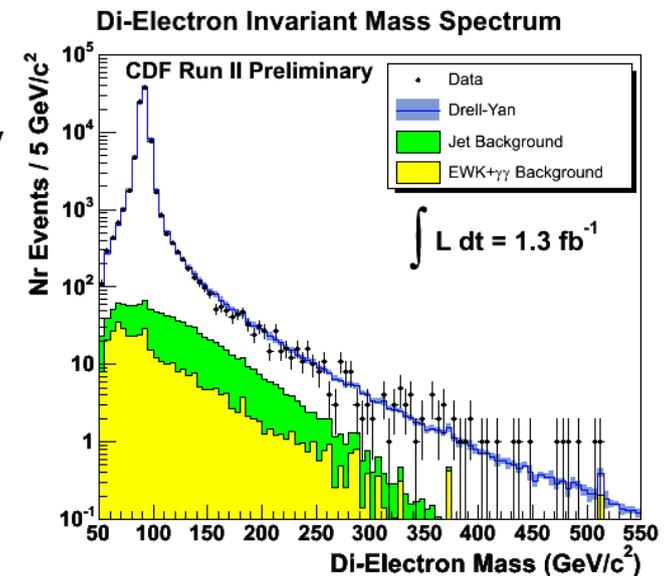
- Jet spectrum sensitive to gluino mass
 - Observe no excess over expected background
 - Sensitive to lifetimes $> 30 \mu\text{s}$; modeled up to 100 hrs
 - Set limits as a function of gluino mass and rate at which they convert from neutral to charged in detector material





Search for new gauge bosons

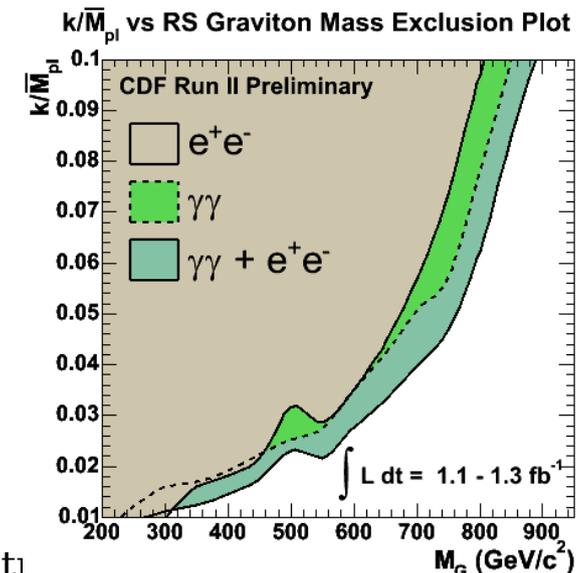
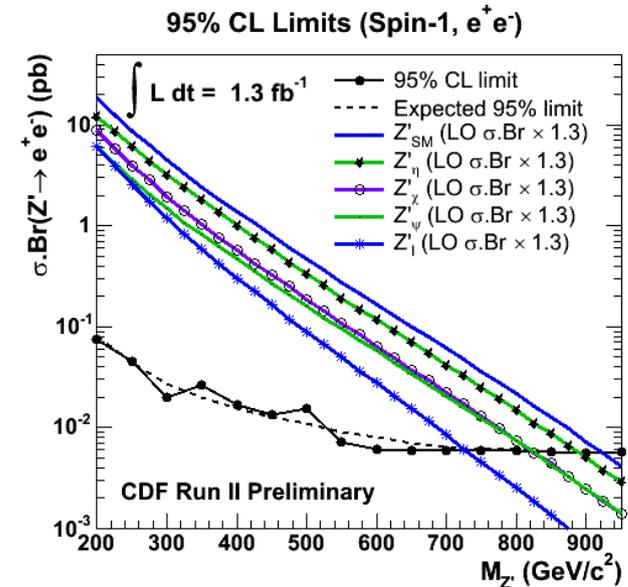
- New gauge bosons appear in many models
 - GUT models that produce new U(1) symmetries: neutral spin-1 (Z')
 - Randall-Sundrum models: new neutral spin-2 particles (R-S gravitons)
 - Both cases can decay to di-electrons
- CDF search for narrow resonances in e^+e^- mass spectrum
 - Based on 1.3 fb^{-1}
 - Select two good electrons with $E_t > 25 \text{ GeV}$
- Background
 - Dominated by Drell-Yan
 - Smaller contribution from di-jet, W+jet, $W+\gamma$, $\gamma\gamma$

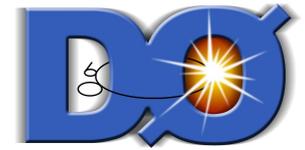




Search for new gauge bosons

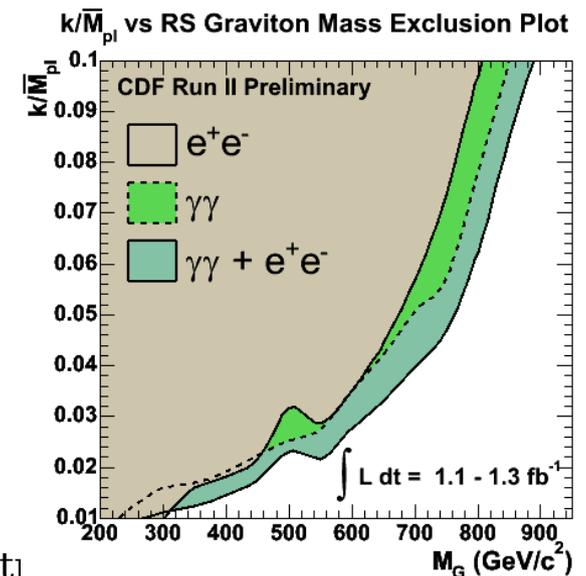
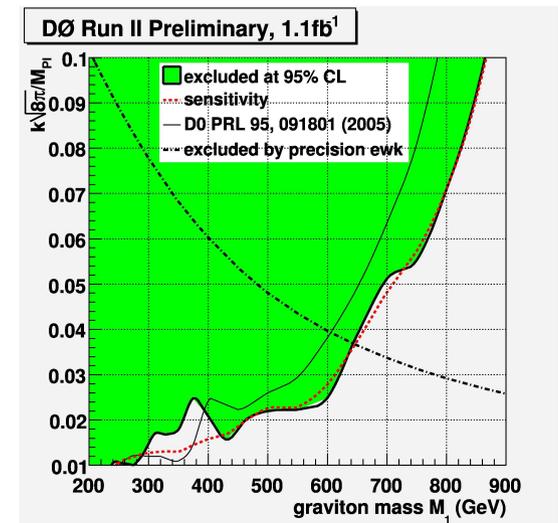
- No observed excess over background
 - Set limits on
 - SM Z' + E_6 (GUT) Z'
 - SM Z' excluded below 923 GeV at 95% CL
 - E_6 : $Z_I > 729$, $Z_\psi > 822$, $Z_\chi > 822$,
 $Z_\eta > 891$ GeV
 - R-S gravitons
 - Combine results with previous di-photon analysis with previous di-photon results
 - Set limit in plane of graviton mass and ratio of warping scale / effective Planck mass





Search for new gauge bosons

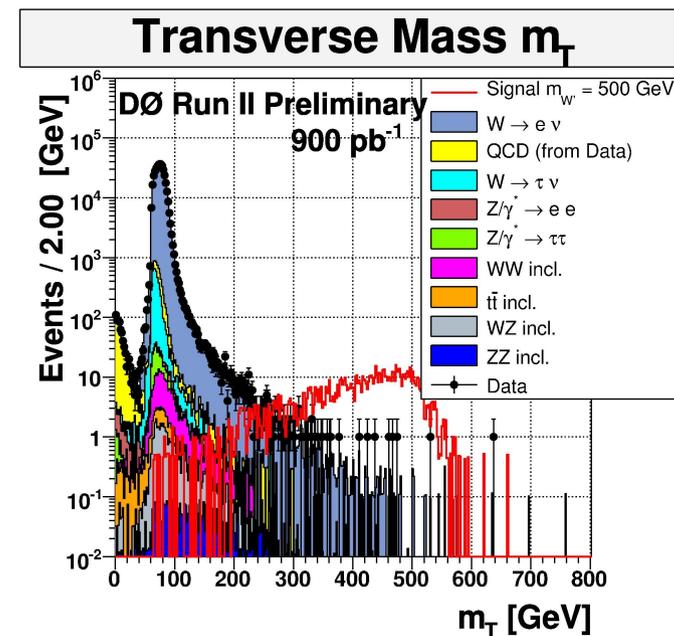
- Also an R-S graviton search result from DØ in 1 fb^{-1} (from last summer)
 - Also searched in di-electron + di-photon mass spectrum
 - Similar analysis
 - No observed excess over background
 - Set limits

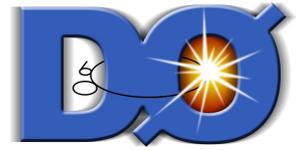




Search for new gauge bosons

- D0 search for $W' \rightarrow e\nu$ decays (from last summer)
 - Measure transverse mass distribution
 - Main background from $W \rightarrow e\nu$
 - Exclude W' with mass < 965 GeV at 95% CL



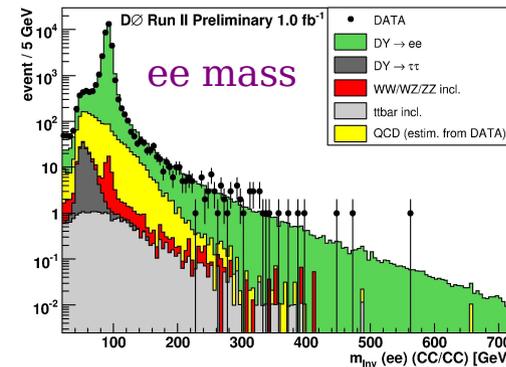


Search for excited electrons

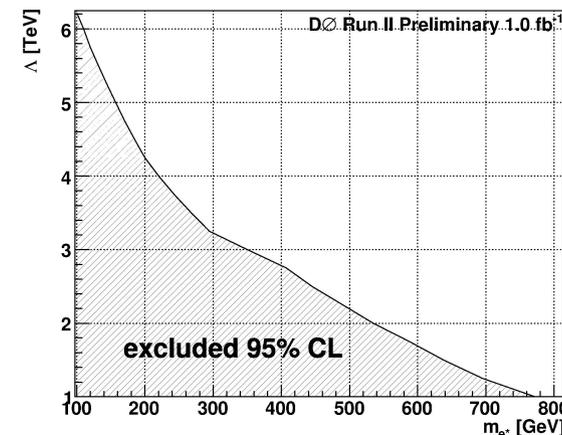
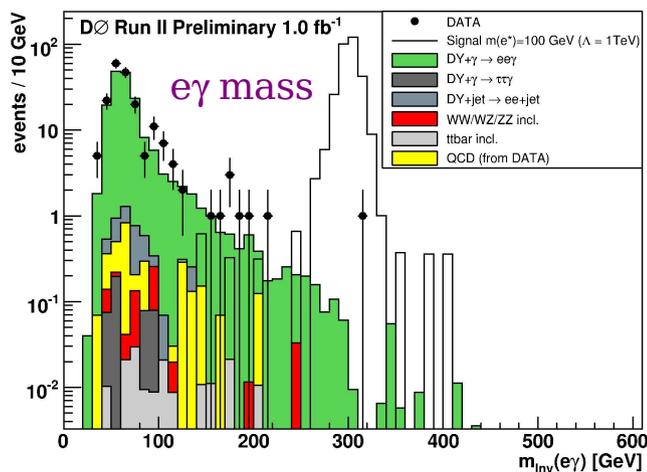
- Excitations of SM particles appear in a number of models
 - Additional degrees of freedom via composite sub-structure or extra dimensions
 - Compositeness:
 - Excited states produced via contact interactions between sub-structure particles
 - Excited electron production rate depends on mass, compositeness scale, Λ
- D0 search for excited electrons in 1.0 fb^{-1} : $pp \rightarrow ee^* \rightarrow ee\gamma$
 - Trigger on single or di-electron trigger
 - Require isolated electrons with $E_t > 25 \text{ GeV}$, $E_t > 15 \text{ GeV}$ + isolated photon with $E_t > 15$
 - Background: dominated by Drell-Yan $\rightarrow ee+\gamma$, QCD

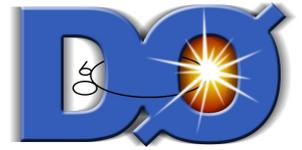
Search for excited electrons

- Background estimates checked in ee final state
- Observed $e\bar{e}\gamma$ data consistent with background
 - Set limits in $\Lambda - (e^* \text{ mass})$ plane



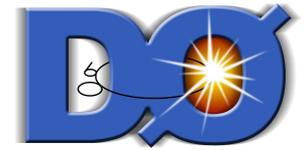
- Exclude $m(e^*) < 756 \text{ GeV}$ for $\Lambda = 1 \text{ TeV}$





Summary

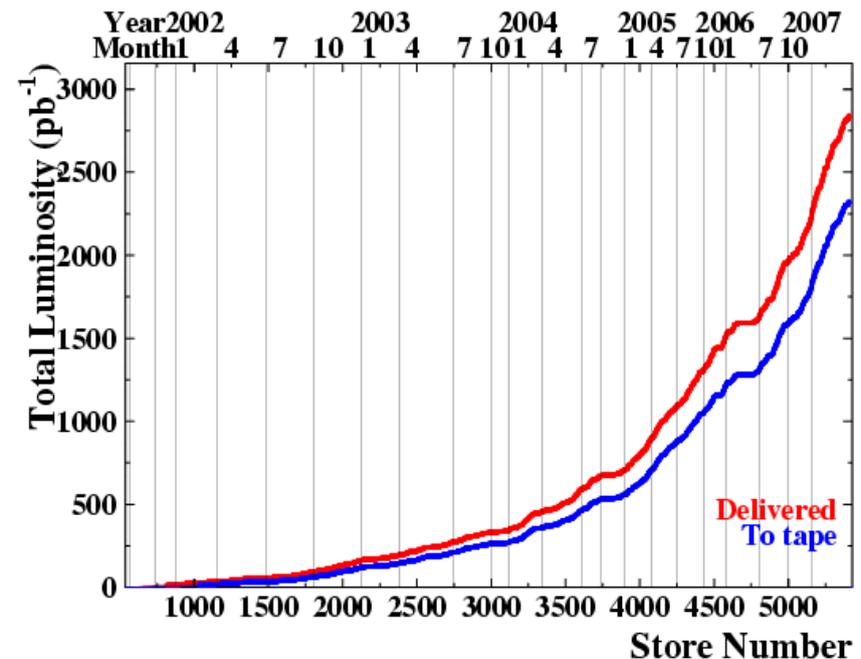
- CDF and D0 have searched for numerous signals for new physics
 - Recent results reveal no evidence for physics beyond the SM
 - Most of these analyses based upon about 1 fb^{-1}
- Both experiments analyzing $2+ \text{ fb}^{-1}$ of data currently in hand



Summary

- Have been doubling the dataset annually over the past several years
 - Have double the dataset for which results have currently been presented
 - Anticipate around 3.5 fb⁻¹ on tape by this time next year

Stay tuned!

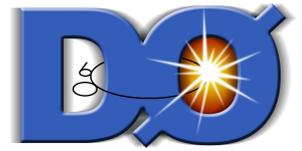




The end



Backup slides



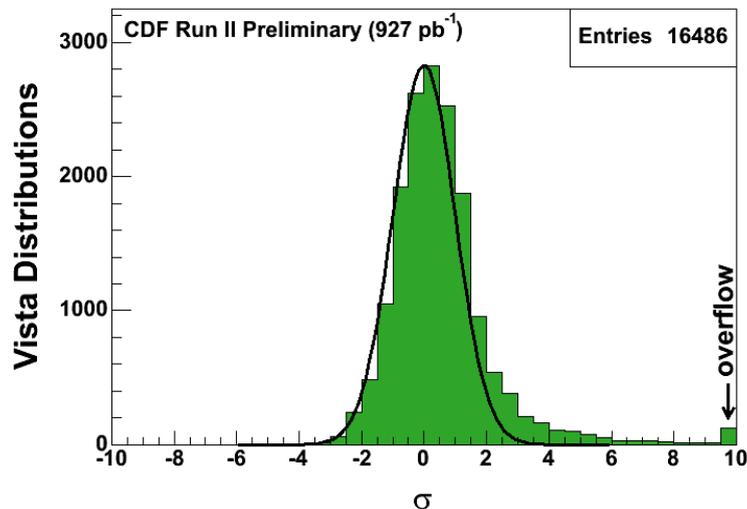
Signature-based search: Vista/Sleuth

- Asks a very basic question on a global scale:
 - Is what we see consistent with the SM?
- Vista algorithm:
 - Define physics objects (electron, muon, tau, jet, missing E_t ,...)
 - Filter events of interest (high Pt)
 - Estimate background (from MC)
 - Simulate detector response
 - Fit for experimental, theoretical correction factors
 - Accounts for deficiencies in SM prediction and detector simulation
 - 44 parameters in correction model with physically intuitive meanings
 - e.g., object mis-identification efficiencies

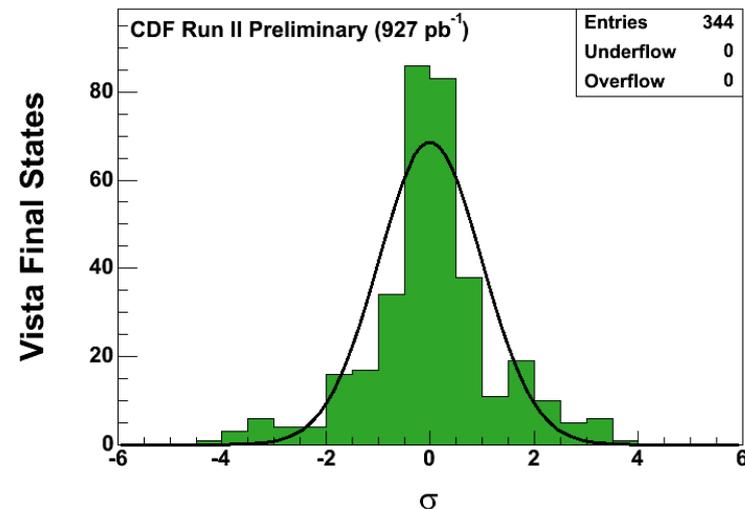
Signature-based search: Vista/Sleuth

- Vista identifies final states with significant discrepancies between SM prediction + correction model and data
 - Fit is across 16,486 kinematic distributions

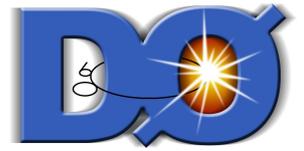
Deviation of kinematic distrib
from predictions



Deviation of final states
from predictions

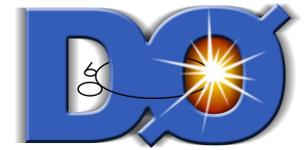


No significant outliers, so no evidence of new physics



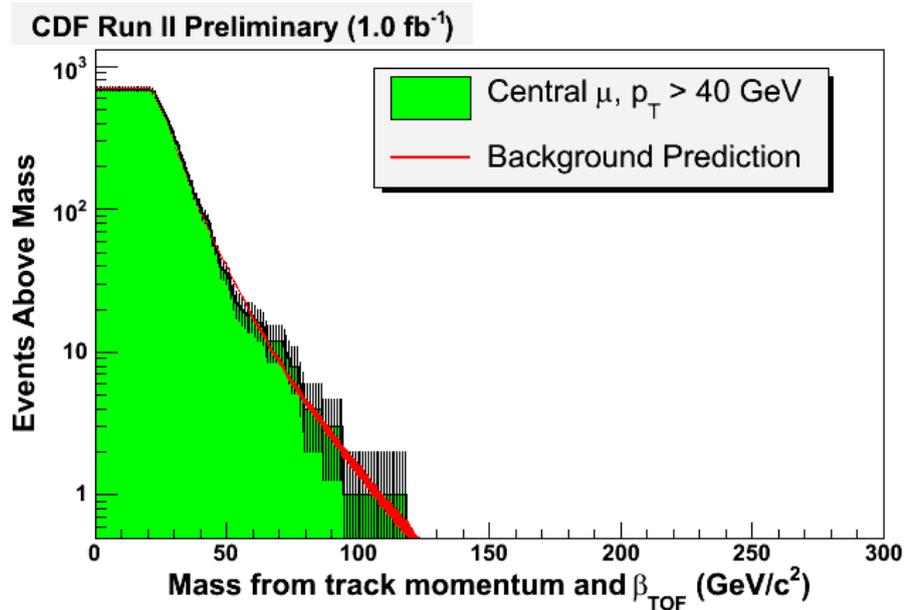
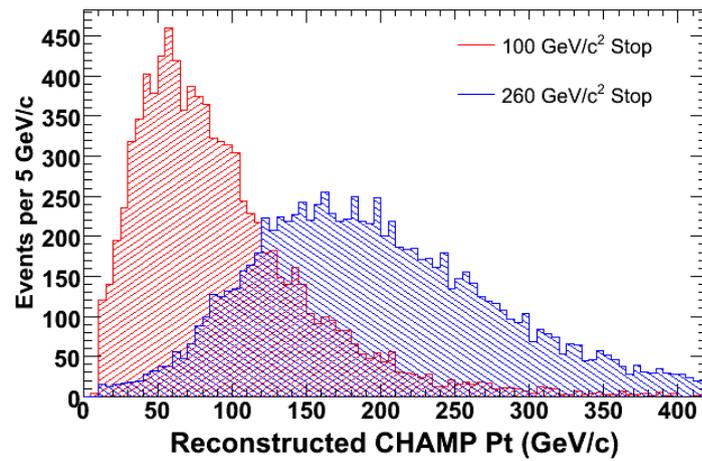
Signature-based search: Vista/Sleuth

- Sleuth
 - Search high-Pt tails of select distributions (about 100)
- Assumes new physics:
 - will appear predominantly in one exclusive final state
 - at high Pt
 - as an excess of data over SM prediction
- Search for discrepancies, calculate probability that the SM would produce a region at least as interesting as the most interesting observed in the data
 - $P = 0.46$
 - So no evidence for new physics in selected 100 distribution



CHAMPs

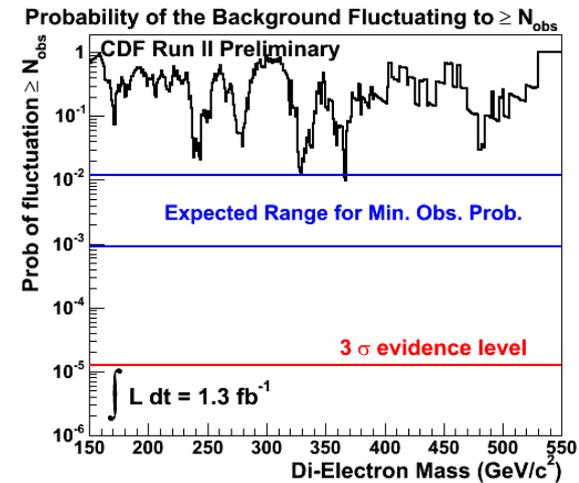
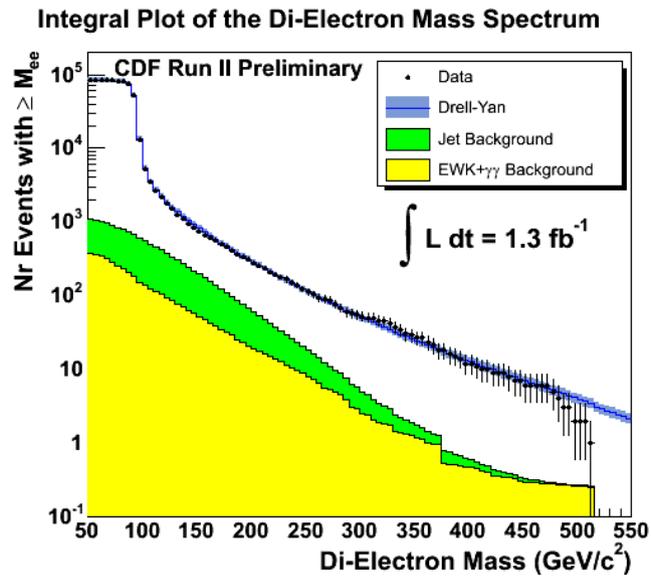
Observed and predicted integral track mass distribution

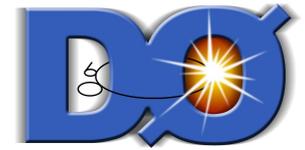


Track momentum distribution for stable stop quarks produced at CDF



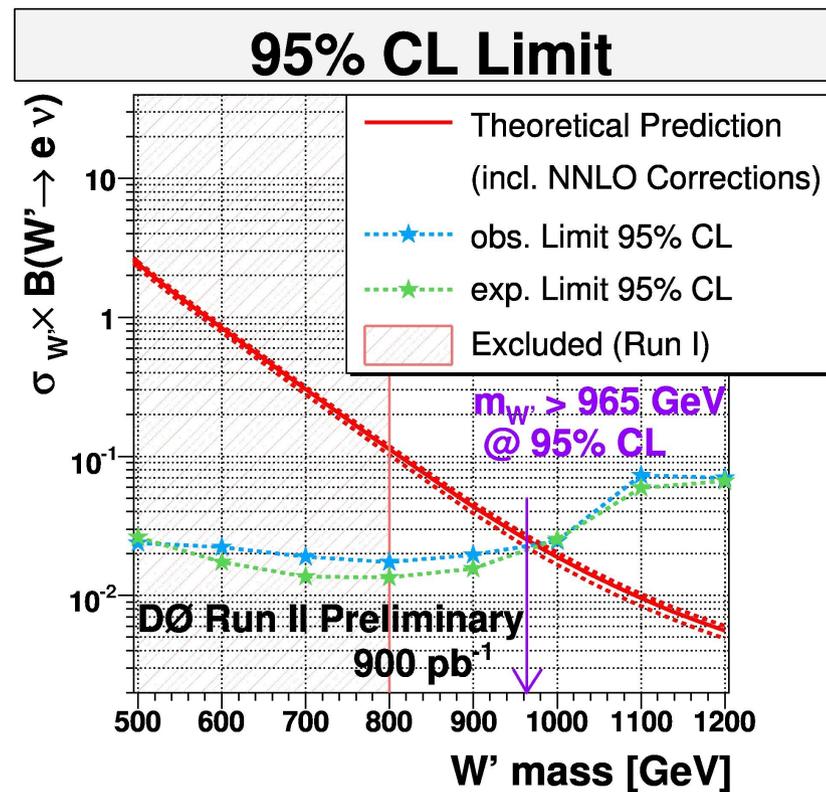
Search for new gauge bosons





Search for new gauge bosons

- Limit on W' production cross section \times BR



$$B_s \rightarrow \mu^+ \mu^-$$

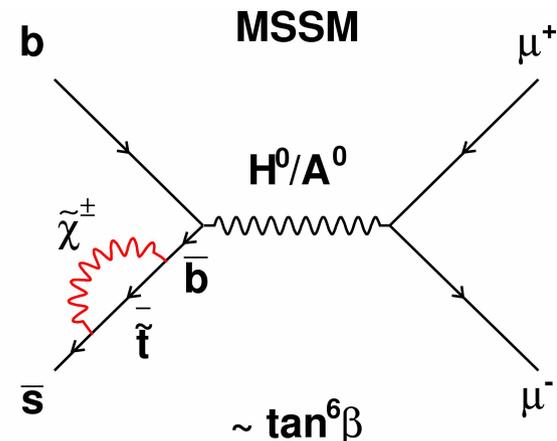
- The decay $B_s \rightarrow \mu^+ \mu^-$ highly suppressed in SM

- BR expected to be $(3.42 \pm 0.54) \times 10^{-9}$

A.J. Buras, Phys. Lett. B 566, 115 (2003)

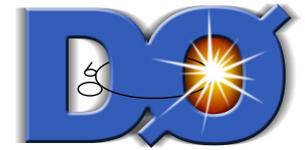
- New physics can enhance the rate

- MSSM: additional terms $\propto \tan^6 \beta$



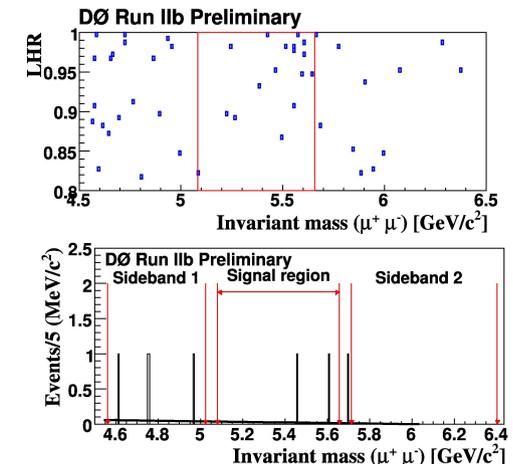
- D0 has new result of search for $B_s \rightarrow \mu^+ \mu^-$ based upon 2 fb^{-1}

- First 2 fb^{-1} result from the Tevatron



$$B_s \rightarrow \mu^+ \mu^-$$

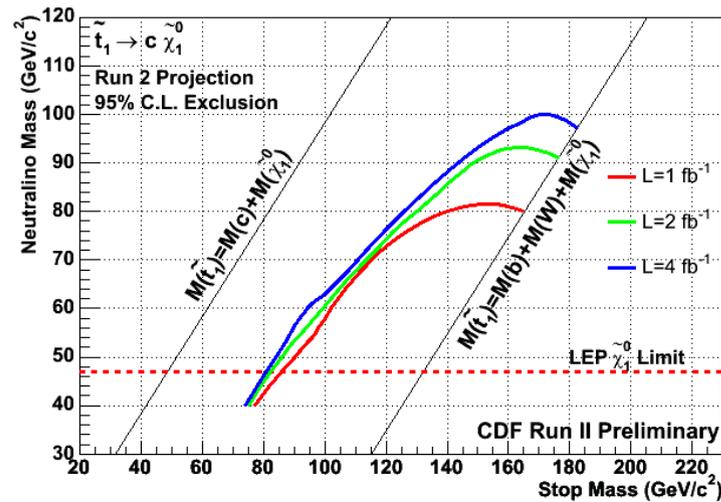
- Both analyses
 - Use event-by-event likelihood ratio to enhance signal discrimination
 - D0: isolation, pointing angle, decay length significance, B and muon impact parameter, vertex fit probability
 - CDF: isolation, opening angle, probability of decay length
 - Normalize BR to $B_d \rightarrow J/\psi K$, $J/\psi \rightarrow \mu^+ \mu^-$
- D0 result (2 fb^{-1}):
 - 0.8 ± 0.2 expected, 1 observed in Run Iia
 - 1.5 ± 0.5 expected, 2 observed in Run Iib
 - $B(B_s \rightarrow \mu^+ \mu^-) < 7.5(9.3) \times 10^{-8}$ at 90% (95%) CL
- CDF (0.78 fb^{-1}): $B(B_s \rightarrow \mu^+ \mu^-) < 8.0 \times 10^{-8}$ (1.0×10^{-7}) at 90% (95%) CL
- Outlook: Tevatron will probe down to 2×10^{-8} (actually less!)





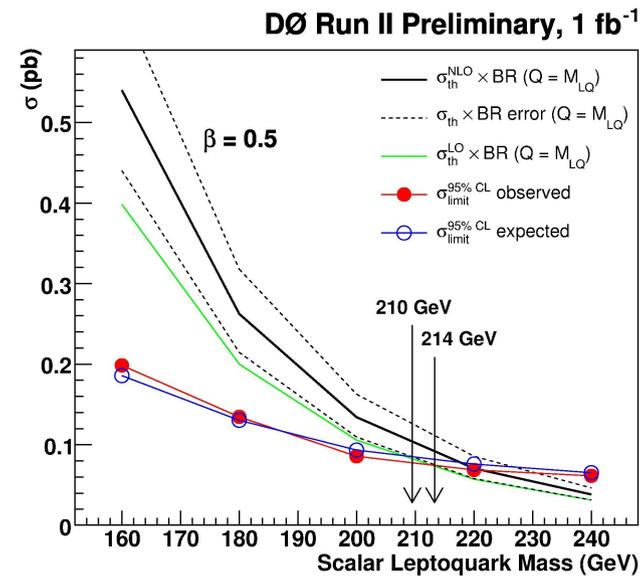
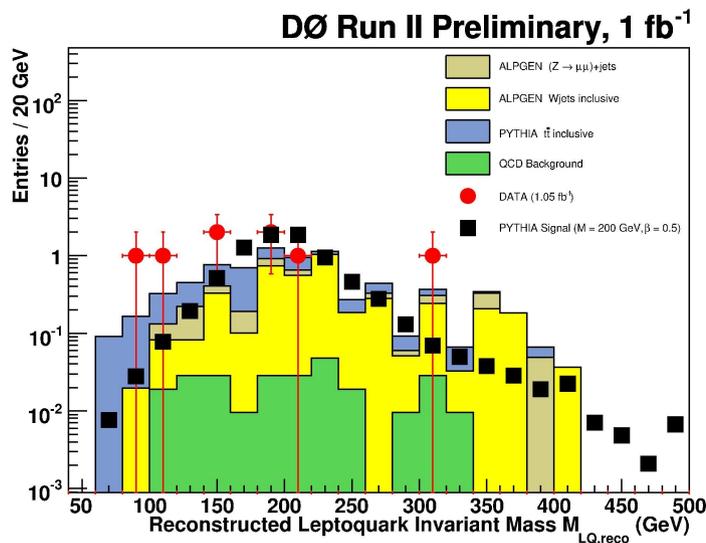
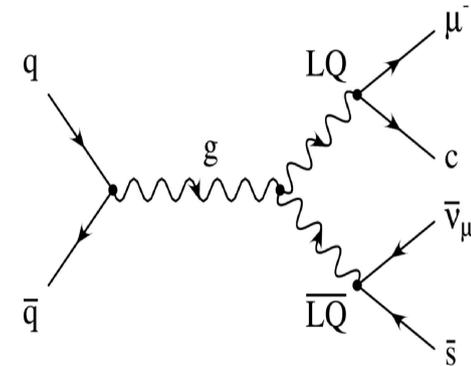
Stop and sbottom

- Future prospects for stop search (CDF)



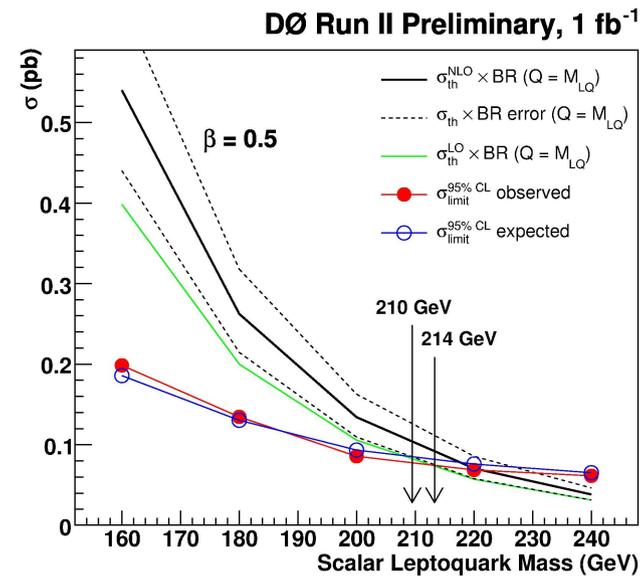
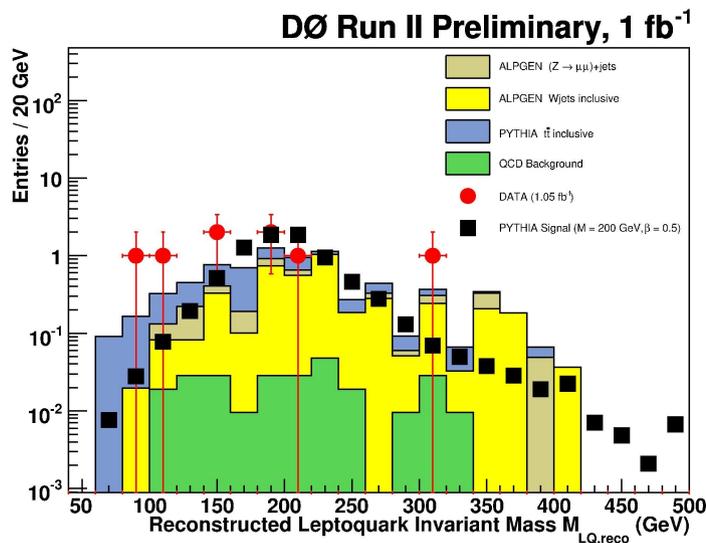
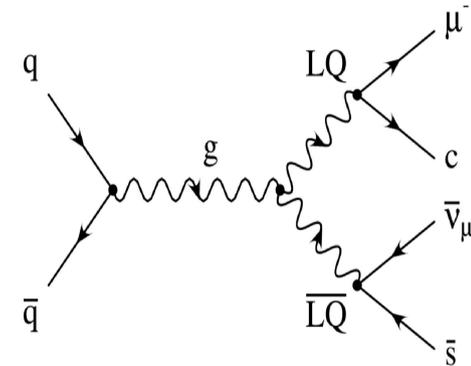
Lepto-quarks

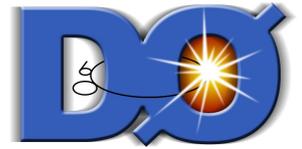
- DØ 2nd gen lepto-quark



Lepto-quarks

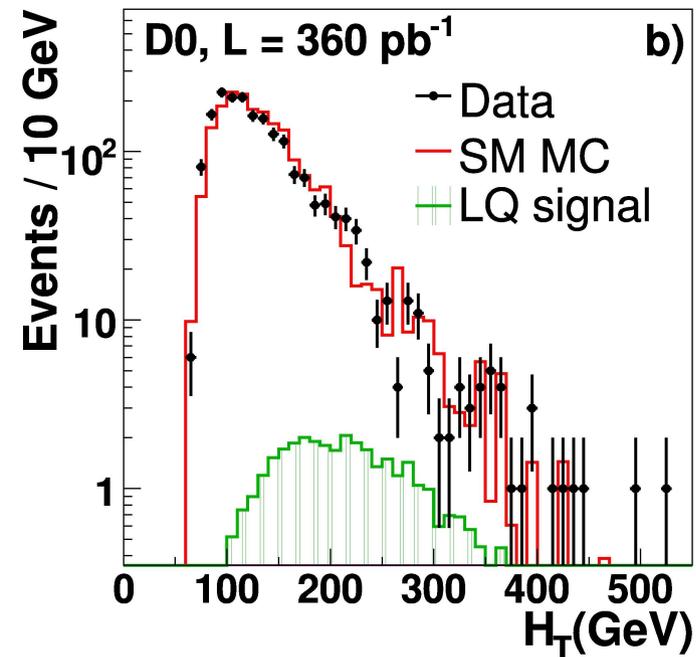
- DØ 2nd gen lepto-quark





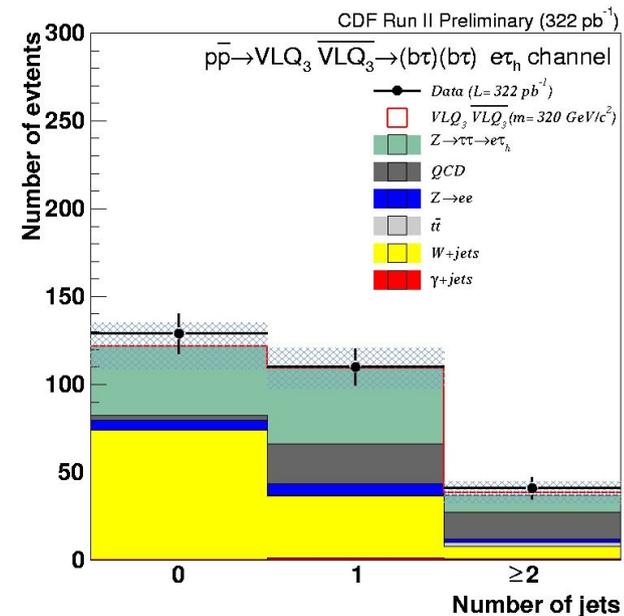
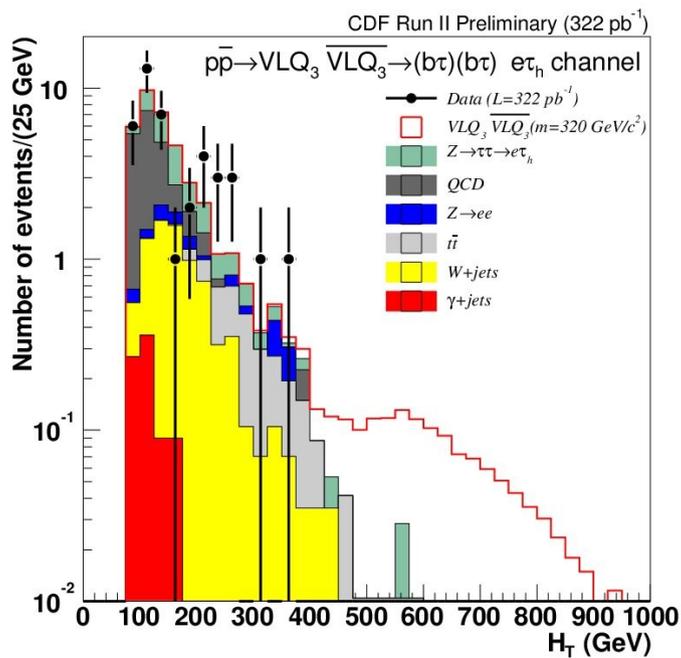
Lepto-quarks

- D0 3rd generation search



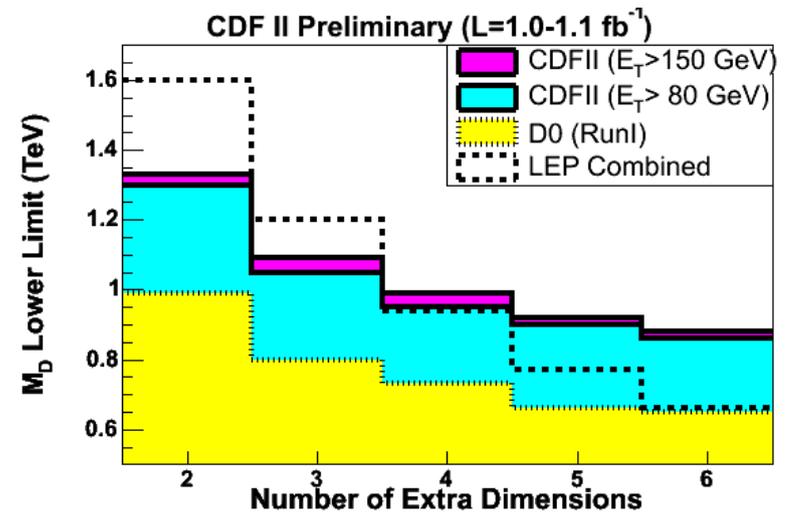
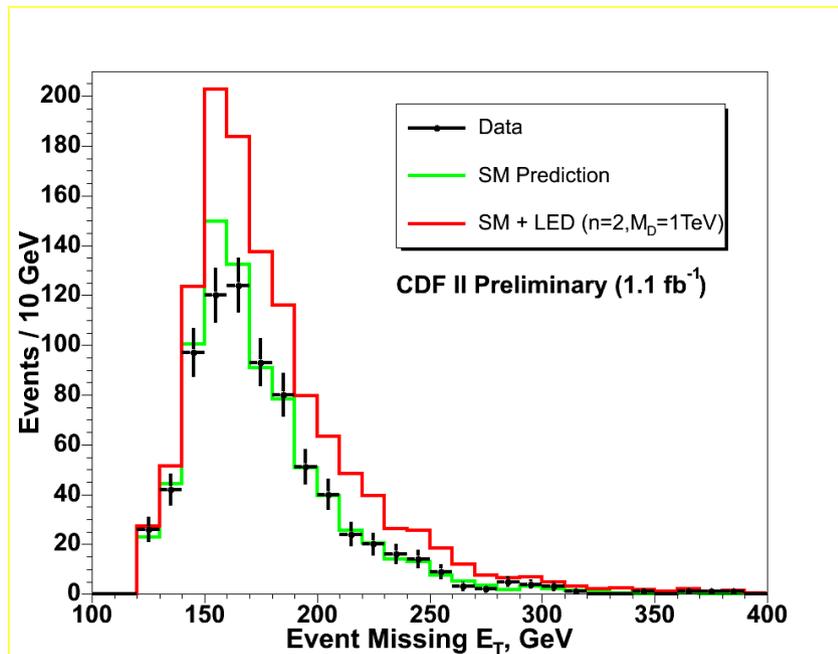
Lepto-quarks

- CDF 3rd generation search



Extra dimensions

- CDF: jet(s) + MET
- ADD models: direct prod of $g+G$



Extra dimensions

- D0: di-lepton/di-photon search for R-S gravitons
- DY + direct gamma-gamma + instrumental

and Z peak for latter

