



SUSY2003

Searches for new Particles and Phenomena at CDF

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Outline



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- Status of CDF, Tevatron
- Physics results already in hand
 - **Dijet resonances:** E6 diquarks, RS graviton LED, excited quarks, W' ...
 - **Dilepton resonances:** Z' , RS graviton
 - **Champs:** long lived charged particles
 - **1st Generation Leptoquarks:** $eejj$ and $\nu\nu jj$ channels
 - **Excited electrons:** $ee^* \rightarrow ee\gamma$
 - **Photon-rich signatures:** γMET , $\gamma\gamma$, $\gamma\gamma\ell$ and $\gamma\ell$, more
 - **Doubly-charged particles:** $H^{\pm\pm} \rightarrow e^\pm e^\pm, \mu^\pm \mu^\pm$
 - **Stop:** search results and prospects
- Physics results finishing soon
- Concluding remarks

See also parallel talks

A. Pompos: Search for SUSY at CDF

C. Neu: Search for the Higgs Boson

S. Lee: Search for SUSY with Photons

K. Ikado: Search for the Z' and ED

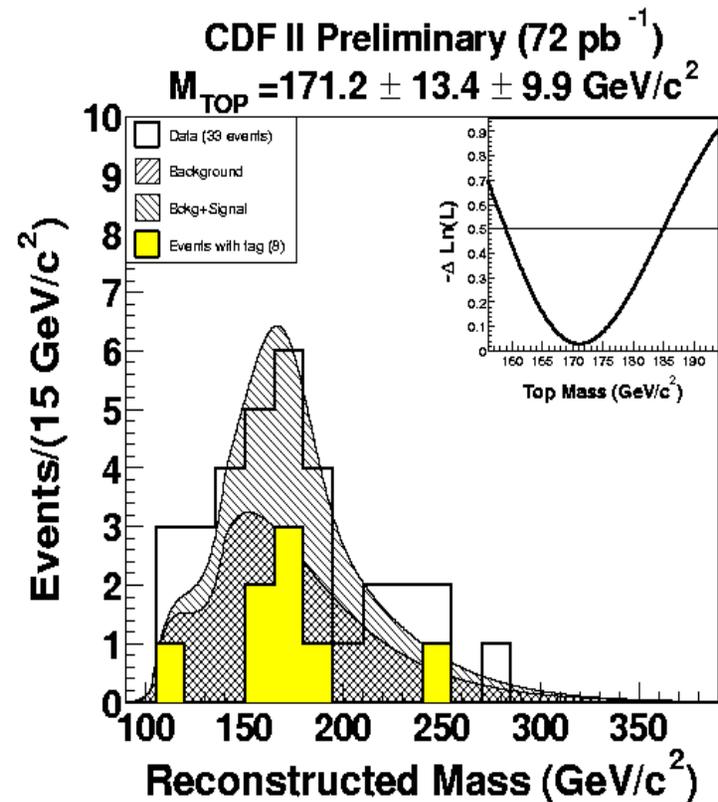


How is CDF doing?



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- Commissioning the detector (mostly done)
 - >2 years of effort already
 - Some pieces still under study
- Re-establish baseline physics program
 - W, Z
 - QCD
- More elaborate tools and techniques now re-established: same capabilities as Run I
 - Precision tracking and B-tagging
 - Missing Energy
 - Top mass (re)measurement good indicator
- Searches for new physics underway!





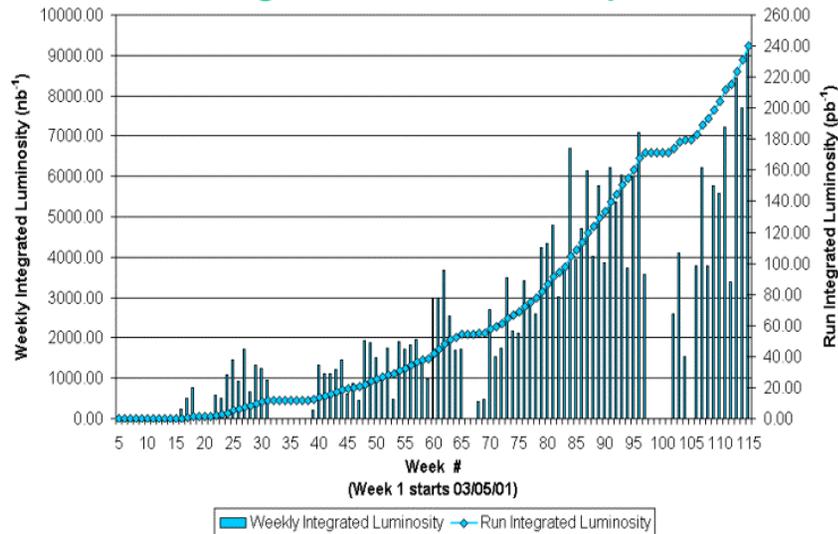
How is the Tevatron doing?



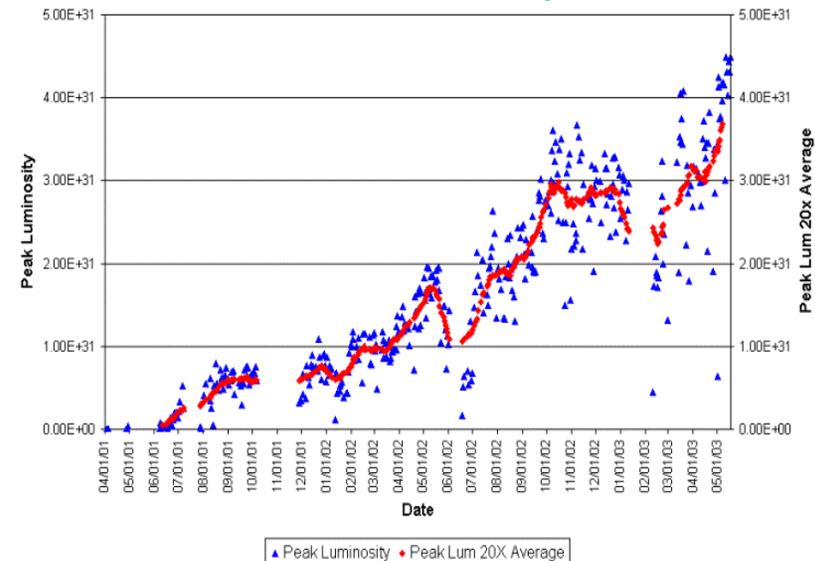
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- Accelerator is running much better
- Several records broken recently
 - One week Luminosity: $>9 \text{ pb}^{-1}$
 - a new Inst. luminosity record of 4.5×10^{31}
 - record number protons to pbar target, pbar stacking rates, etc.
- Slowly ramping up... Run II is going!
- Long term luminosity projections currently being reviewed

Integrated Luminosity



Peak Luminosity





CDF Searches; Run I vs. Run II



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- Better coverage for leptons and silicon tracking
 - Muon coverage greatly increased
 - Electron covers out to $\eta < 2.4$
 - Silicon acceptance (hence B-tagging) increased by almost x2.0

	e	μ	τ	j	b	c
CDF $ \eta $ range	2.4	2.0	2.0	3.0	2.0	2.0

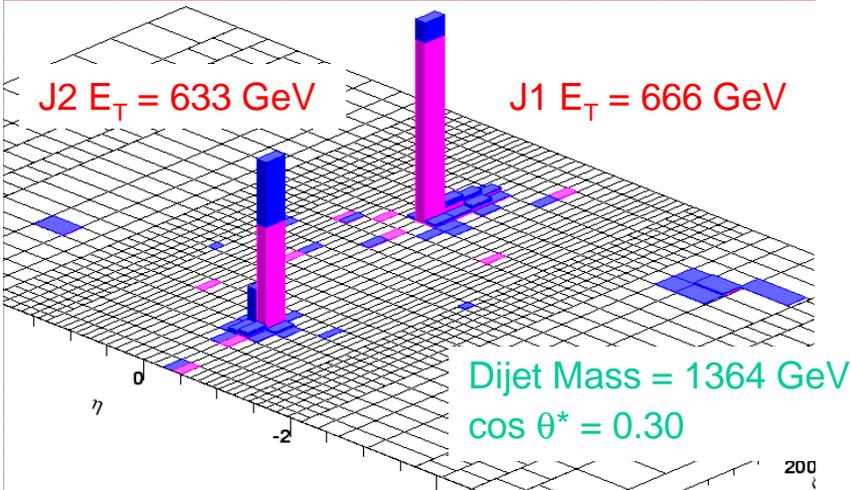
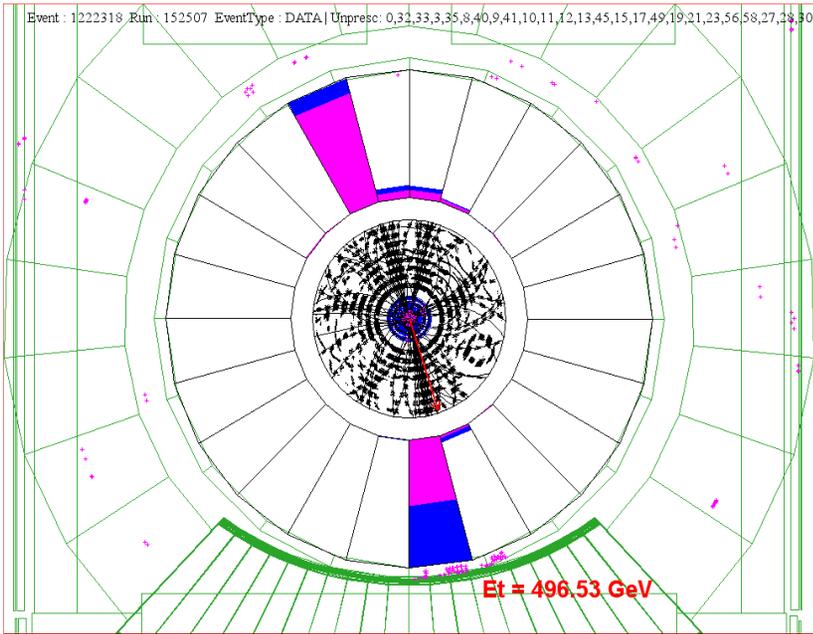
- Missing Transverse Energy (MET) well understood
- B tagging and displaced track triggers
 - Displaced track triggers working well
 - 2D b-tag available and working as expected
- Tau finding and reconstruction
 - Improvements are important for high $\tan\beta$ regions
 - Reduced fake rate compared to Run I
- CDF running as advertised (!)



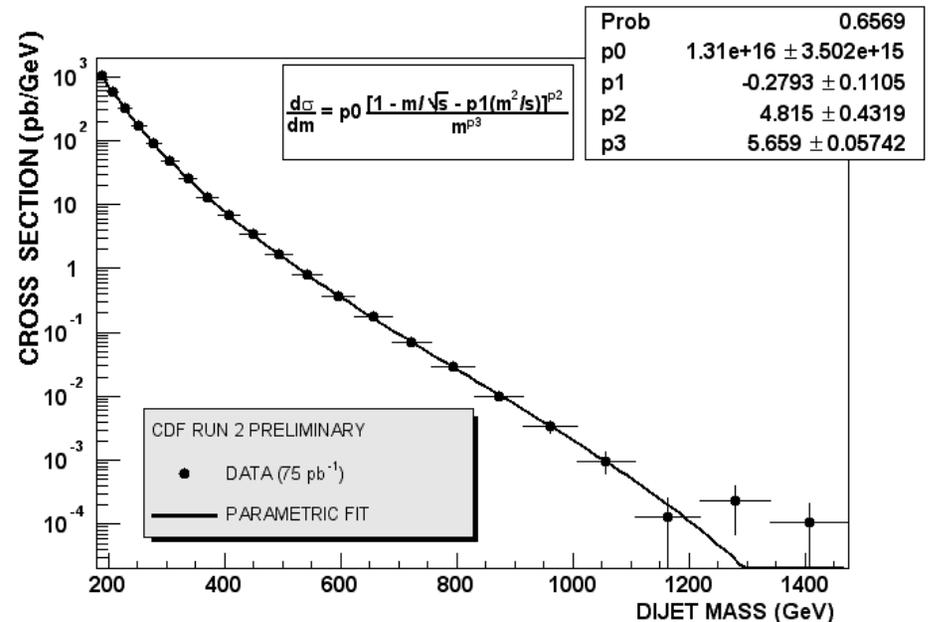
High Mass Dijet Events



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- Highest mass event so far (at left)
- We search for resonances in dijets
 - Assume a narrow width
 - Cleanup includes requirement of MET/sqrt(MET) < 6
 - Simple parameterization (not theory)
- Limits set on a variety of models



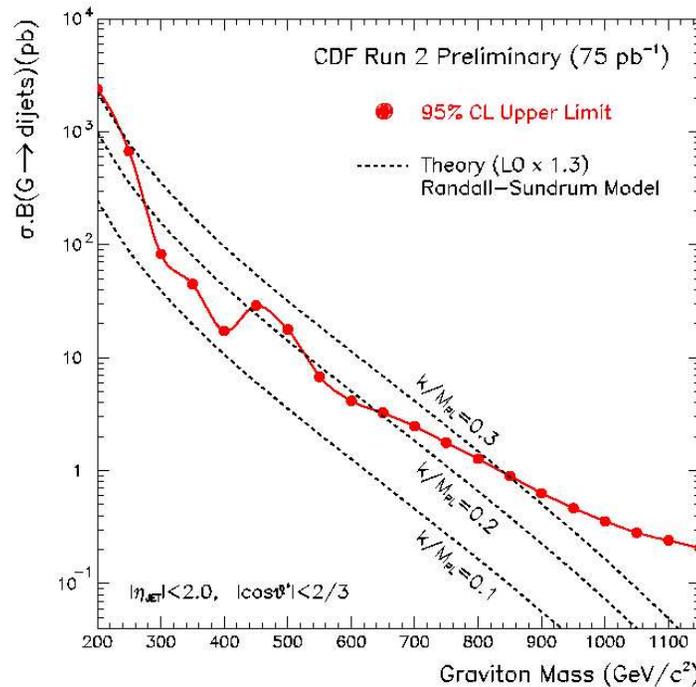
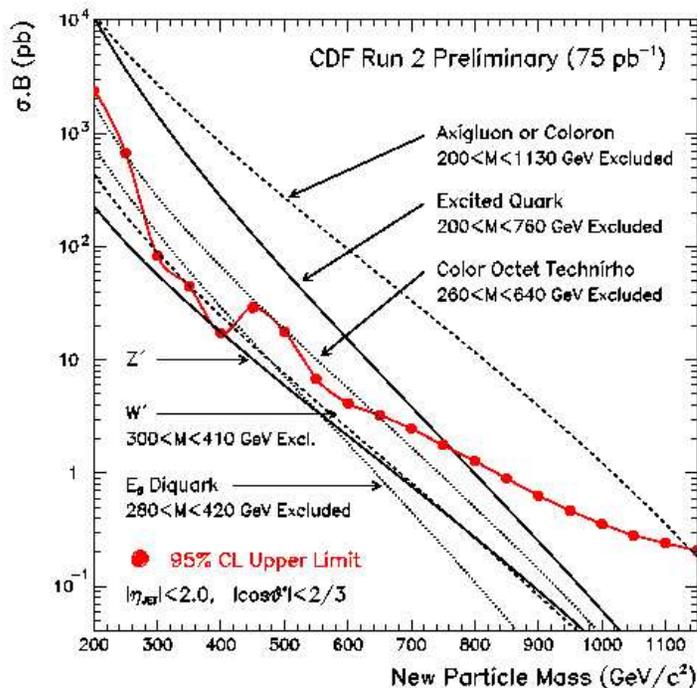


New Particles decaying to Dijets



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- Axiguons or flavor universal colorons
 $200 < m < 1130 \text{ GeV}/c^2$
- Excited quarks
 $200 < m < \text{and } 760 \text{ GeV}/c^2$
- Color octet techni-rho
 $260 < m < 640 \text{ GeV}/c^2$
- E6 Diquarks
 $280 < m < 420 \text{ GeV}/c^2$
- W'
 $300 < m < 410 \text{ GeV}/c^2$
- RS Graviton ($k/M_{\text{pl}}=0.3$)
 $220 < m < 840 \text{ GeV}$



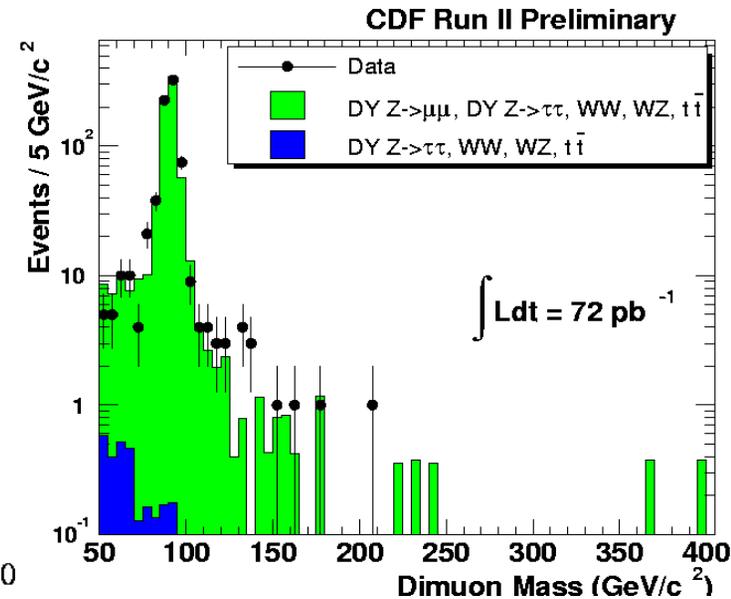
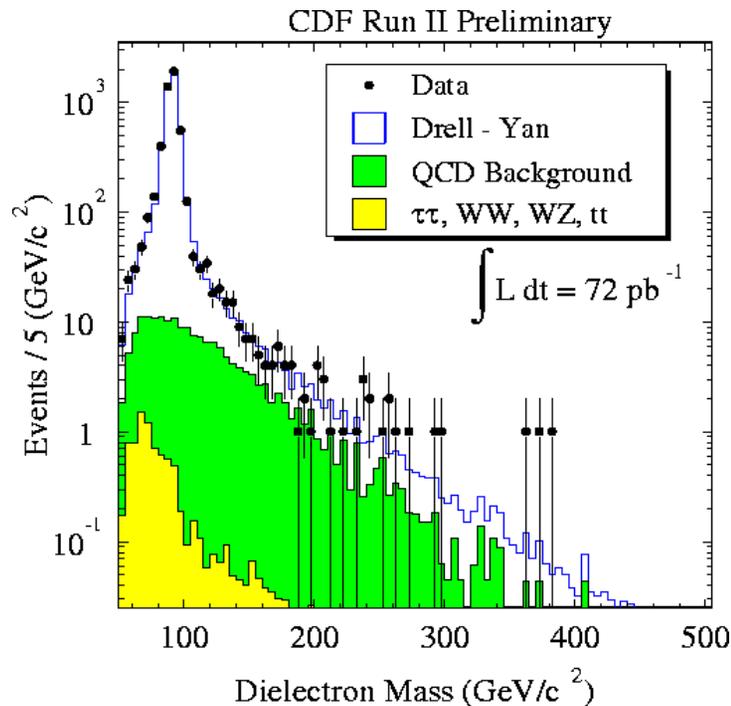
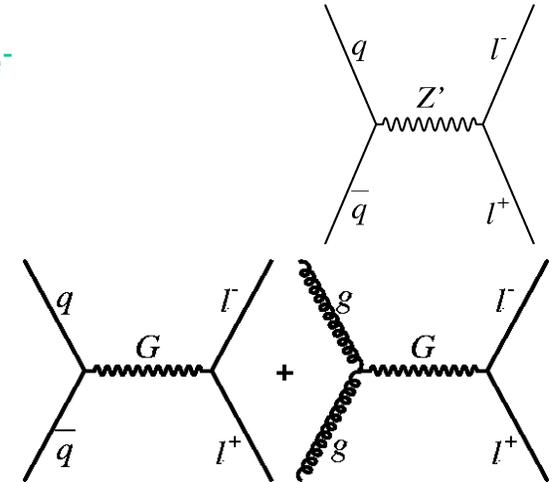


High-Mass Drell-Yan à $\mu^+\mu^-$, e^+e^-



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- Search in high-mass region for Z' (or G_{RS}) à $\mu^+\mu^-$, e^+e^-
 - Assume a narrow resonance
 - Muon $p_T > 25$ GeV/c, electron $E_T > 25$ GeV
- Backgrounds include
 - Drell-Yan, QCD, diboson, tt , bb
 - Cosmic ray backgrounds significant but controllable

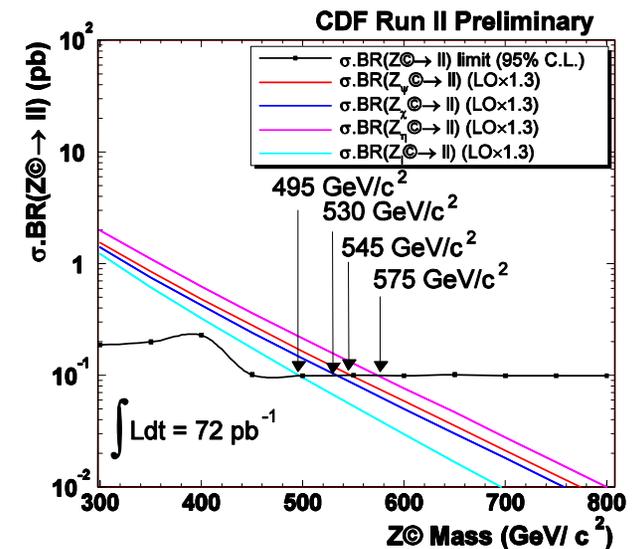
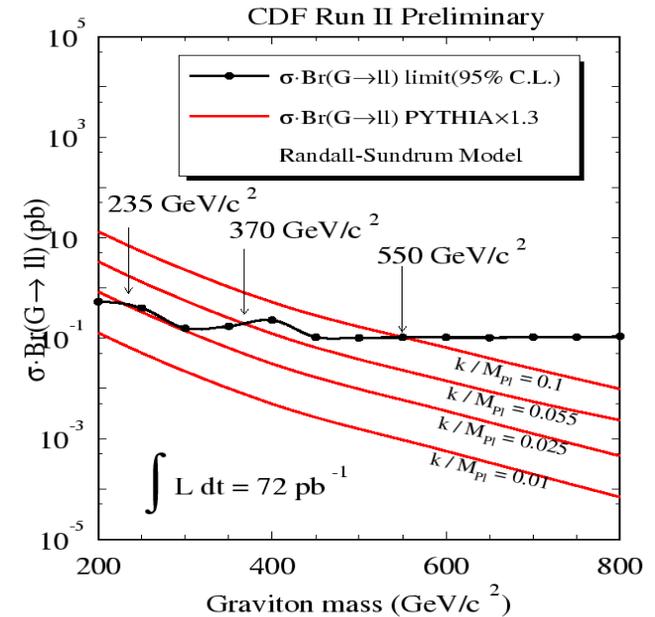
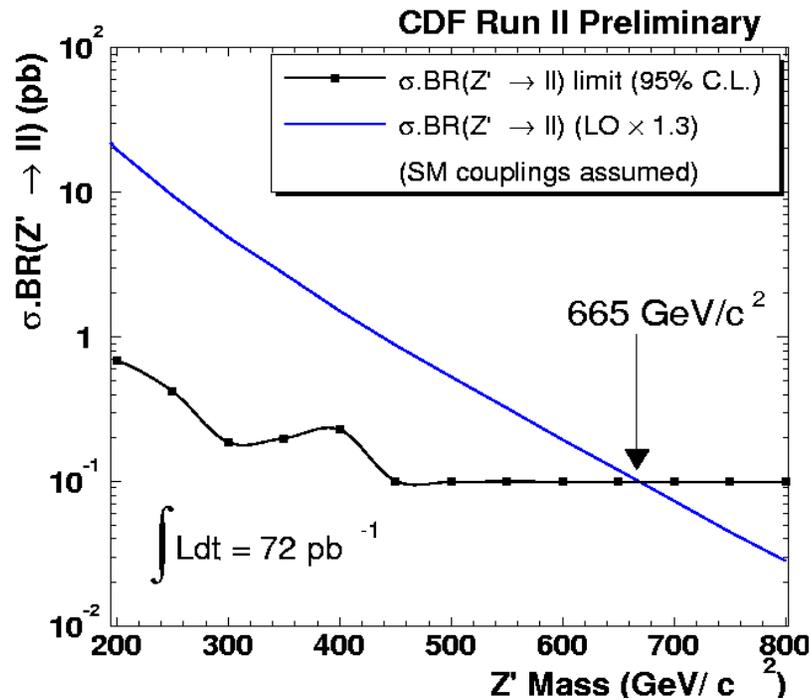




High-Mass Drell-Yan to $\mu^+\mu^-$, e^+e^-



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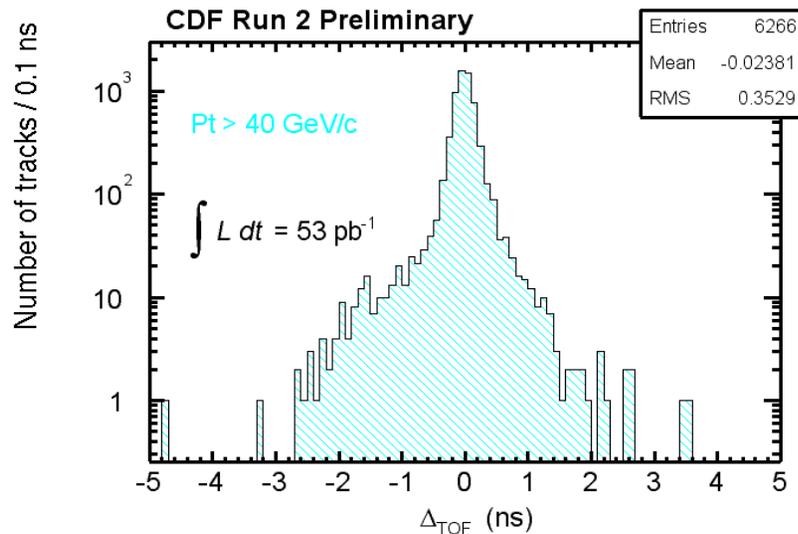
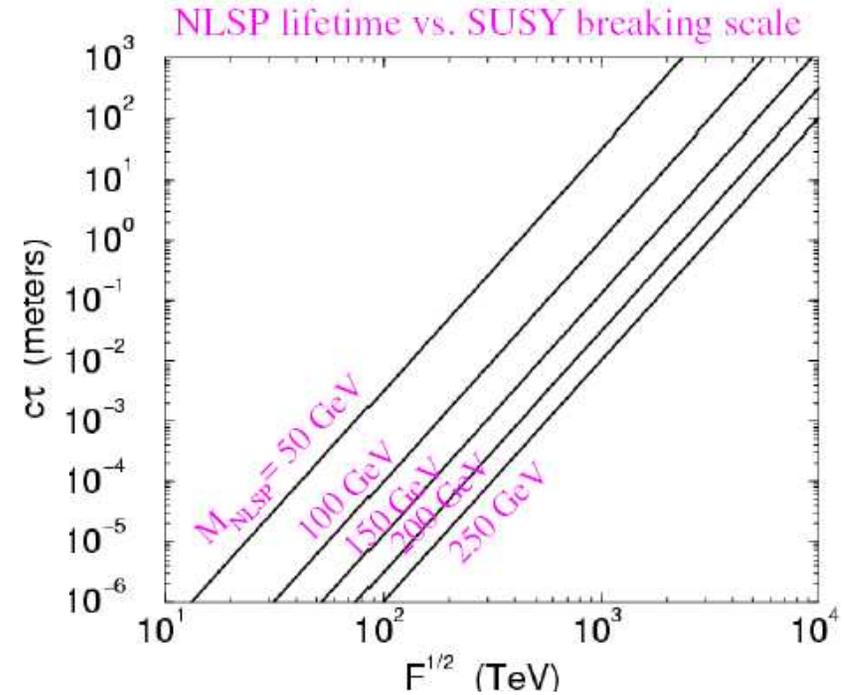


- Limits have been placed on
 - ‘Standard Model’ Z'
 - Randall-Sundrum graviton for $k/M_{Pl} > 0.025$
 - Z' from E6
- Many results slightly exceed Run I
- See talk by K. Ikado (Tuesday)



CHarged **M**assive **P**article **S** -- heavy, slow, and long-lived enough to leave detector

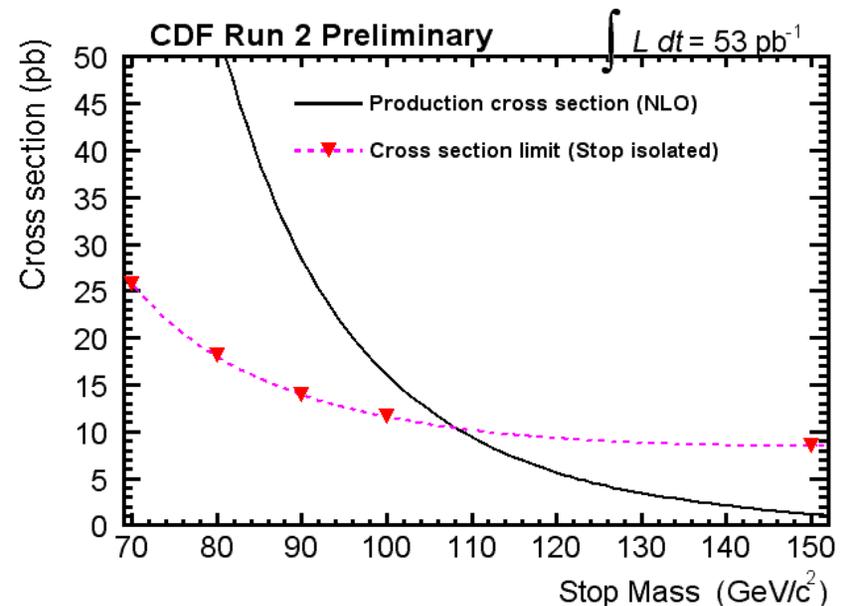
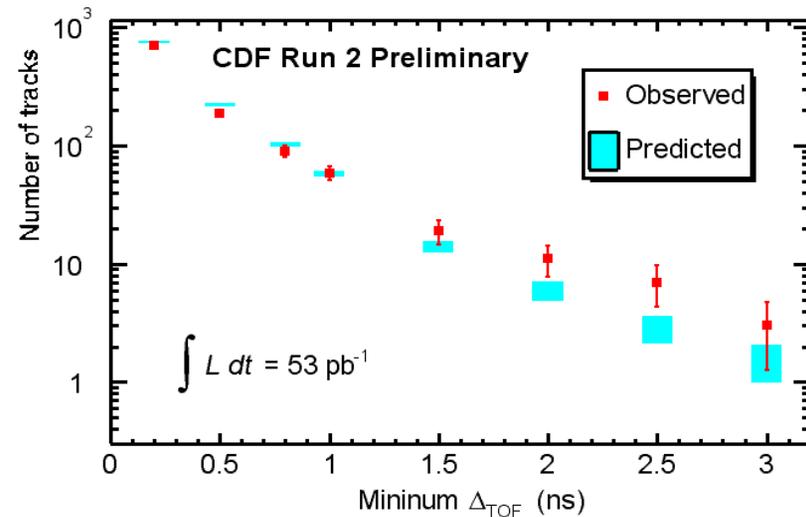
- SUSY breaking scale and lifetime
 - SUSY particle decays to SM partner are \propto to F^{-2}
 - \sqrt{F} not well constrained from $\sim 10\text{TeV}/c^2$ to near GUT scale



- Time Of Flight detector now installed
 $\Delta\text{TOF} = \text{TOF of candidate} - \text{TOF at } c$



- Backgrounds are from cosmic rays and instrumental sources
 - Muon data used as signal sample
 - Checks made on many samples
- Expect $2.9 \pm 0.7(\text{stat}) \pm 3.1(\text{syst})$ events, find 7 (no excess)
- For limit setting, a long-lived stop is assumed
 - Initial state charge ($\sim 53\%$) and re-hadronization probability ($\sim 43\%$) effect $\epsilon_{\text{trigger}}$ ($\sim 6\%$ for 100 GeV stop)
 - $M_{\text{stop}} > 108 \text{ GeV}/c^2$ at 95% CL
 - ALEPH limit is $M_{\text{stop}} > 95 \text{ GeV}/c^2$



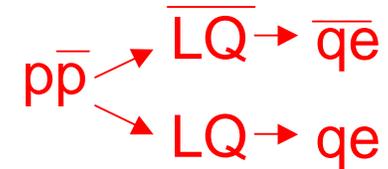


Leptoquarks: $L\bar{L}Q\bar{Q} \rightarrow eejj$



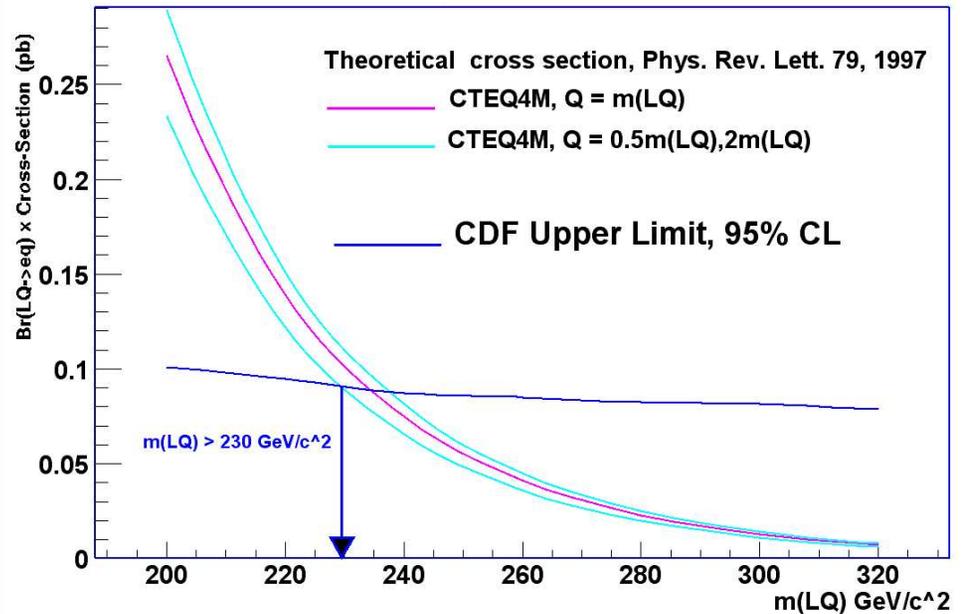
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- Search in di-electron, di-jet data
- Exploit kinematics of leptoquarks by requiring:
 - $E_T(\text{jet1}) + E_T(\text{jet2}) > 85 \text{ GeV}$
 - $E_T(e1) + E_T(e2) > 85 \text{ GeV}$
 - $\text{sqrt}((\sum \text{jet} E_T)^2 + (\sum e E_T)^2) > 200 \text{ GeV}$



- Expect 3.4+3.2 events, observe 0
 - Limit on $m(LQ) > 230 \text{ GeV}/c^2$ at 95% CL
 - Run I CDF+DØ: $M_{LQ} > 242 \text{ GeV}$

CDF Run II Preliminary, 72 pb⁻¹



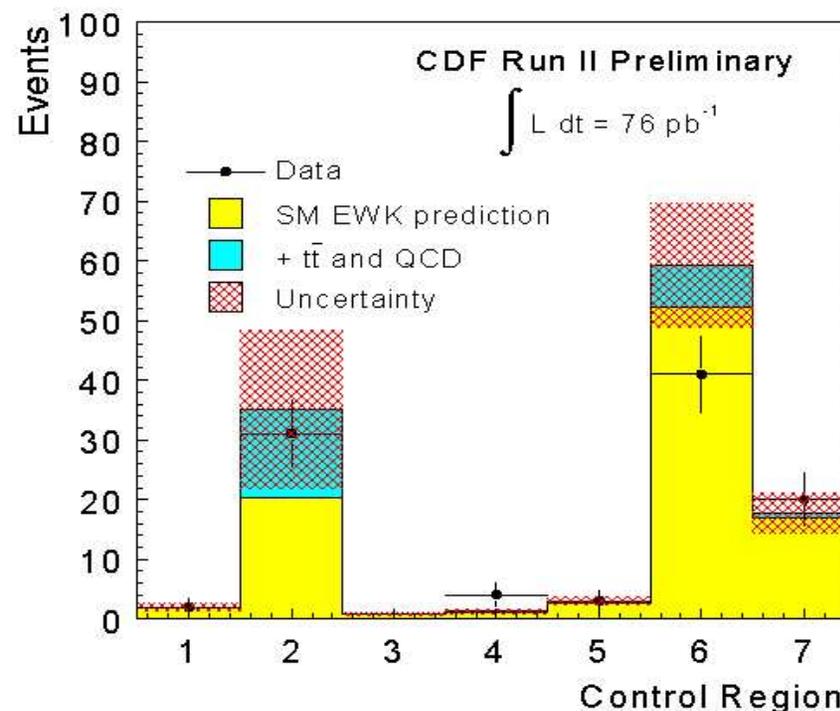


LQLQ à $\nu\nu jj$ and MET



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- For LQLQ à $\nu\nu jj$, we need a very good understanding of Missing Energy (MET)
- MET 'cleanup' includes corrections for...
 - Beam halo cuts
 - Event vertex offset
 - Jet reconstruction
 - Calorimeter timing cuts
 - Corrections due to beam offset
 - Muons
- Control regions studied before 'opening box'
 - $45 < \text{MET} < 55$ (signal is > 55 GeV)
 - $\Delta\phi(\text{jet1}, \text{jet2}) > 165$ (signal is < 165)
 - Number leptons > 0 (signal is $= 0$)



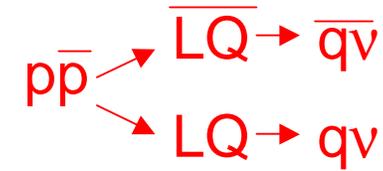


Leptoquarks: $LQLQ \rightarrow \nu\nu jj$



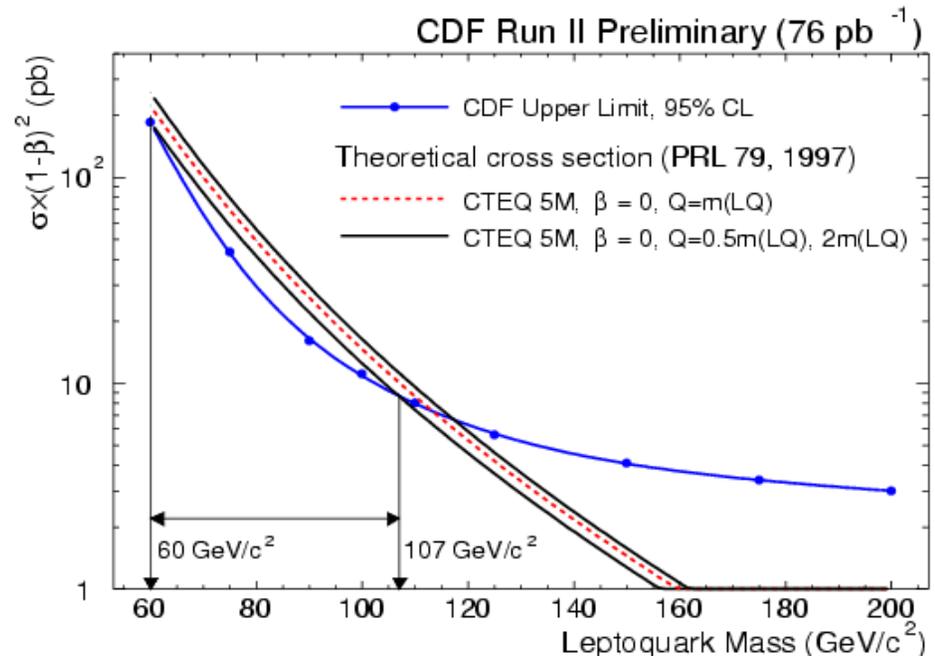
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- Limits set for 1st generation LQ mass $> 107 \text{ GeV}/c^2$
 - Expect $42.5 \pm 7.6(\text{stat}) \pm 7.5(\text{syst})$, see 42 in data
 - Run I limit (D0) $> 98 \text{ GeV}/c^2$
- First step in a program of SUSY results
 - Squark, gluino, or gravitino \rightarrow MET + jets
 - Stop, sbottom \rightarrow MET + heavy flavor jets



CDF Run II Preliminary

	Events
QCD	7.3
$W \rightarrow e\nu + 2 \text{ jets}$	1.7
$W \rightarrow \mu\nu + 2 \text{ jets}$	8.3
$W \rightarrow \tau\nu + 2 \text{ jets}$	10.3
$Z \rightarrow \mu\mu + 2 \text{ jets}$	0.5
$Z \rightarrow \tau\tau + 2 \text{ jets}$	0.2
$Z \rightarrow \nu\nu + 2 \text{ jets}$	13.4
$t\bar{t}$	0.7
All Data	$42.5 \pm 7.6(\text{stat}) \pm 7.5(\text{syst})$ 42



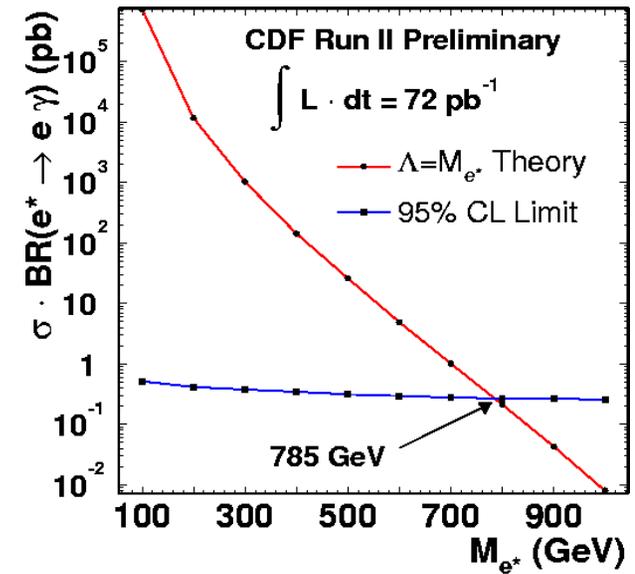
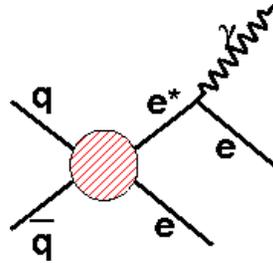
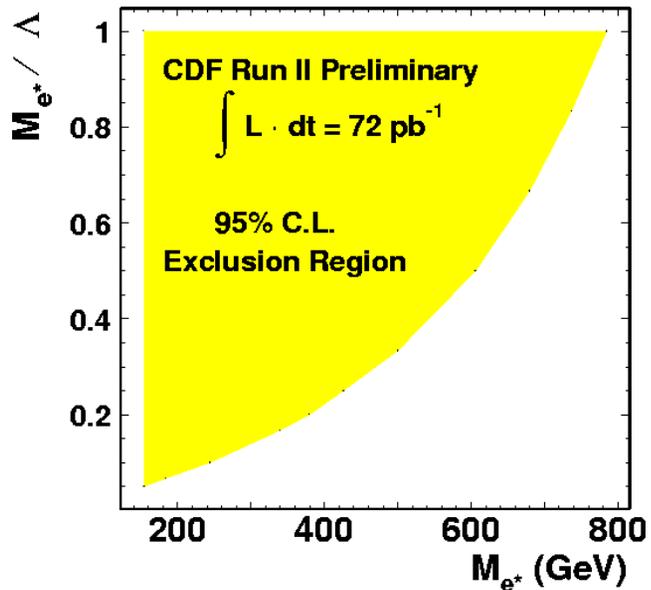
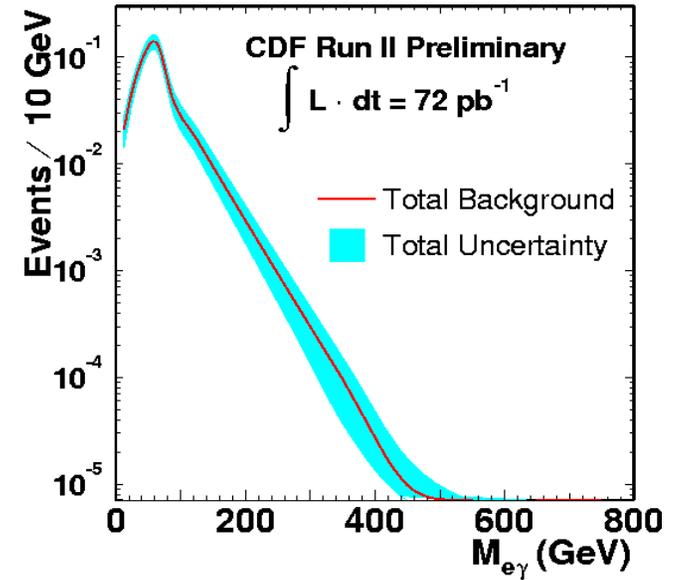


Excited electrons: $e^* \rightarrow e\gamma$



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- Composite electrons can have excited states
 - Signature is $p+p\bar{p} \rightarrow e+e^* \rightarrow e+e\gamma$
- Bkgnd is $Z\gamma$ (dominant), Z +jet, Multi-jet, W +jet
 - 1 event expected with $M_{ee} = M_Z$ (1 event found)
 - 0 events expected with $M_{ee} \neq M_Z$ (0 found)
- 95% CL limit set at 785 GeV/ c^2



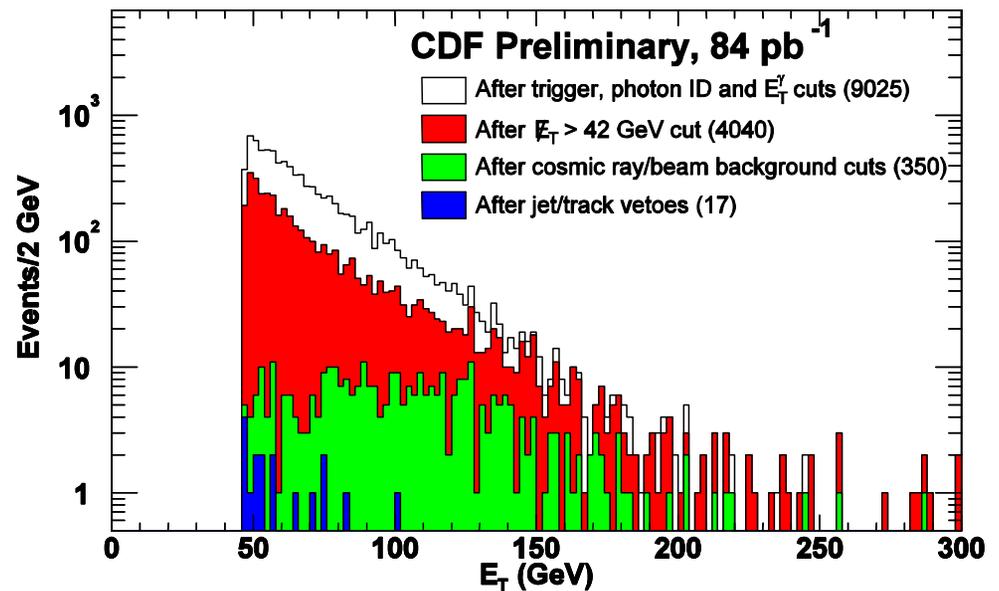
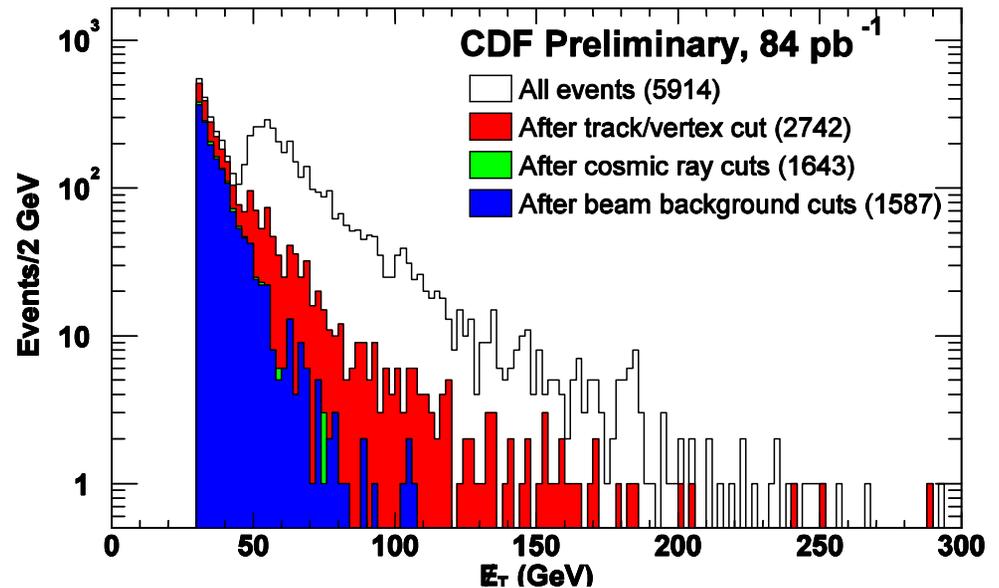


$\gamma + MET$



- Channel is sensitive to LED and Supersymmetry
 - Careful study of MET, cosmics, and beam halo required
 - Backgrounds include $W \rightarrow e\nu$, $Z\gamma \rightarrow \nu\nu\gamma$, cosmics
- Optimize search for $q\bar{q} \rightarrow Z\gamma \rightarrow \nu\nu\gamma$

- 18.0 ± 2.1 events expected,
17 observed
 - 95% CL upper limit is 10.2 events
 - Corresponds to a limit on $A\epsilon\sigma$ of 121 fb or 2.1 times expected $Z\gamma$ contribution
 - Run I result was 3.1 times $Z\gamma$



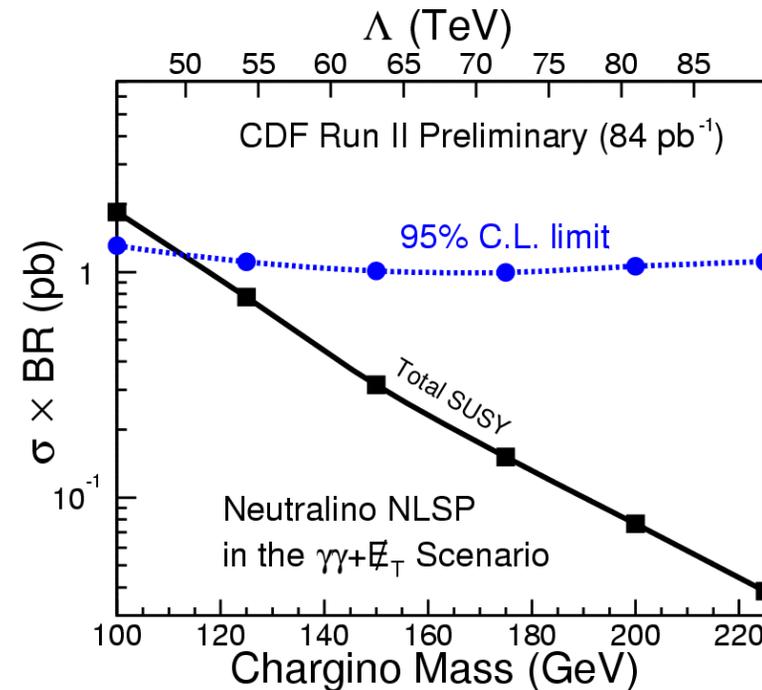
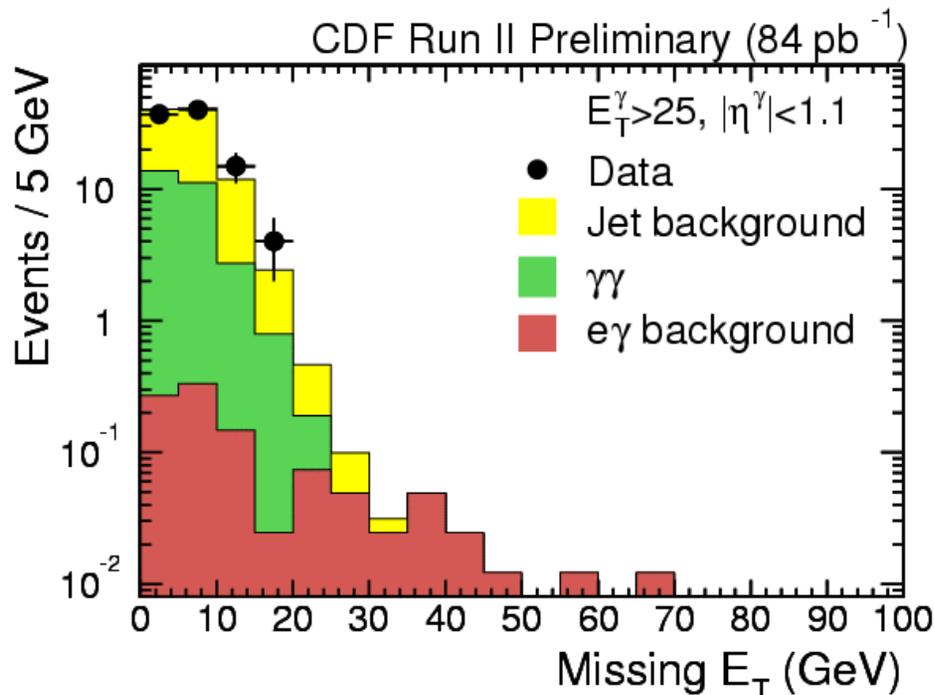


GMSB $\gamma\gamma$ MET



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- Neutralino as NLSP yields signatures of $\gamma\gamma$ MET from gaugino pair production
- Backgrounds from fake (QCD) and real photons ($W\gamma$, Wj , $Z\tau$, $\tau\tau$, diboson...)
 - Two methods to estimate bkgnd; from MET resolution and Pythia $\gamma\gamma$, or sidebands
 - 2 ± 2 expected background for limits; 2 events observed
- Lower limit on mass of lightest chargino $> 113 \text{ GeV}/c^2$ at 95% CL



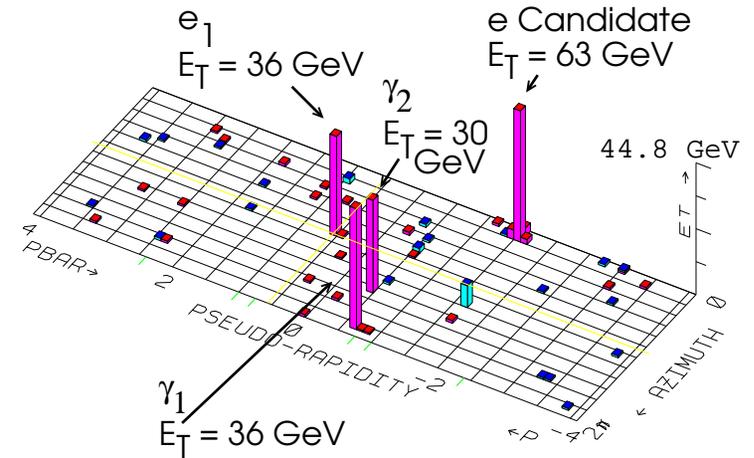


$\gamma\ell$ and $\gamma\ell$



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- Motivated by Run I, many searches are underway
- Searched for $\gamma\ell$ in 84 pb^{-1}
 - $> 20 \text{ GeV}$ lepton, $> 13 \text{ GeV}$ photons, isolated
 - 0.27 events expected in electron channel, less in muon
 - 0 events observed in muon or electron channels
- Run II $W\gamma$, $Z\gamma$ cross section measured for $E_T(\gamma) > 7 \text{ GeV}$, $\Delta R > 0.7$:
 - $\sigma(W\gamma \rightarrow \mu\gamma) = 19.8 \pm 4.5(\text{stat}) \pm 2.4(\text{sys}) \pm 1.2(\text{lum}) \text{ pb}$ (SM: $\sigma(W\gamma) = 18.7 \pm 1.3 \text{ pb}$)
 - $\sigma(W\gamma \rightarrow e\gamma) = 17.2 \pm 3.8(\text{stat}) \pm 2.8(\text{sys}) \pm 1.0(\text{lum}) \text{ pb}$
 - $\sigma(Z\gamma) = 5.8 \pm 1.3(\text{stat}) \pm 0.7(\text{sys}) \pm 0.3(\text{lum}) \text{ pb}$ (SM: $\sigma(Z\gamma) = 5.3 \pm 0.4 \text{ pb}$)
 - All are consistent with Standard Model
- No $ee\gamma\gamma\text{MET}$ events yet, but we are looking!



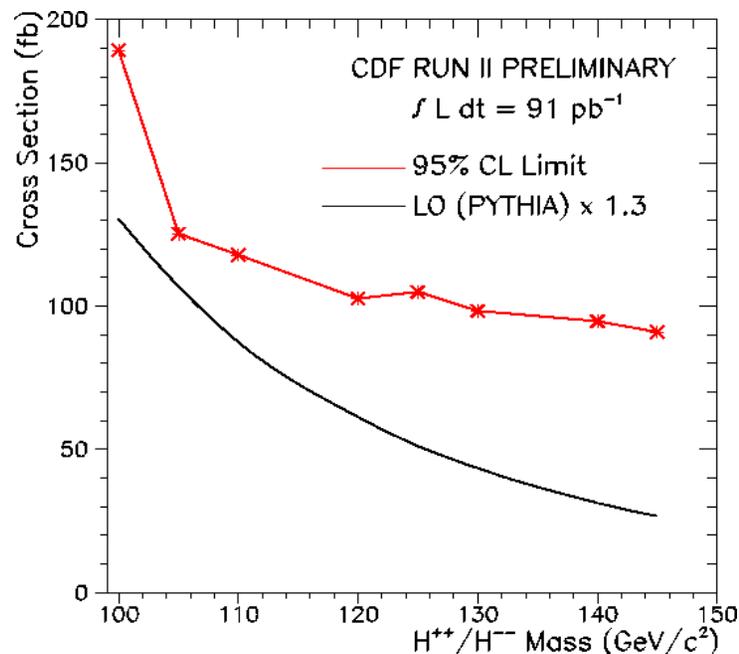
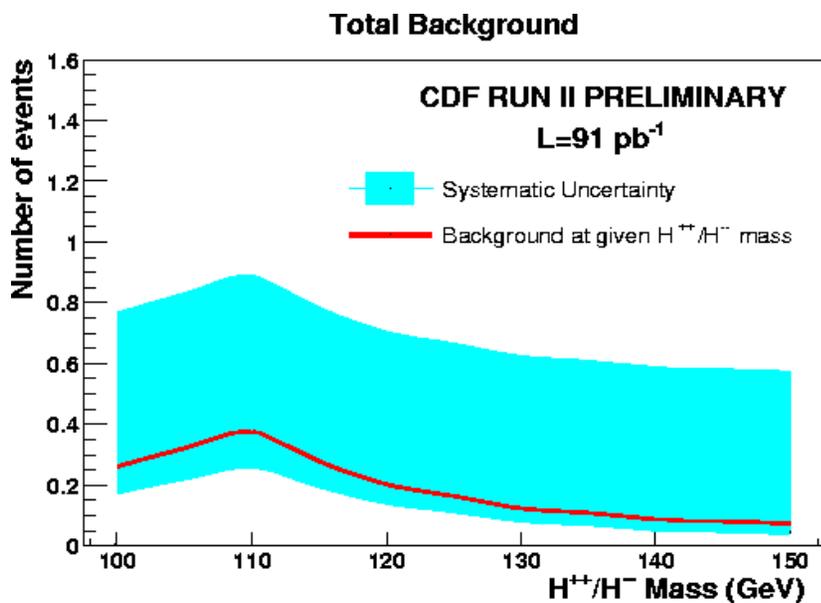
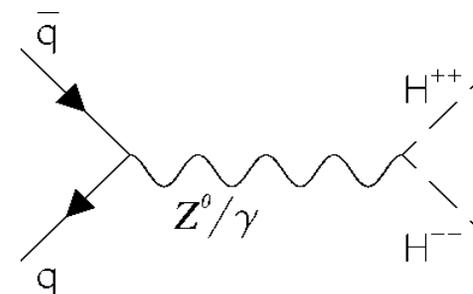


Doubly-Charged Particles à e^+e^-



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- Arise in models with a Higgs triplet
 - Naturally occur in Left-Right models: $SU(2)_L \times SU(2)_R$
 - SUSY LR models predict low-mass H^{++} (~ 0.1 to 1 TeV)
- Use same-sign electrons, search for resonance
 - Low mass region ($< 80 \text{ GeV}/c^2$) used to check backgrounds
- 0 events seen in 91 pb^{-1}
 - Cross section limit set at 95% CL



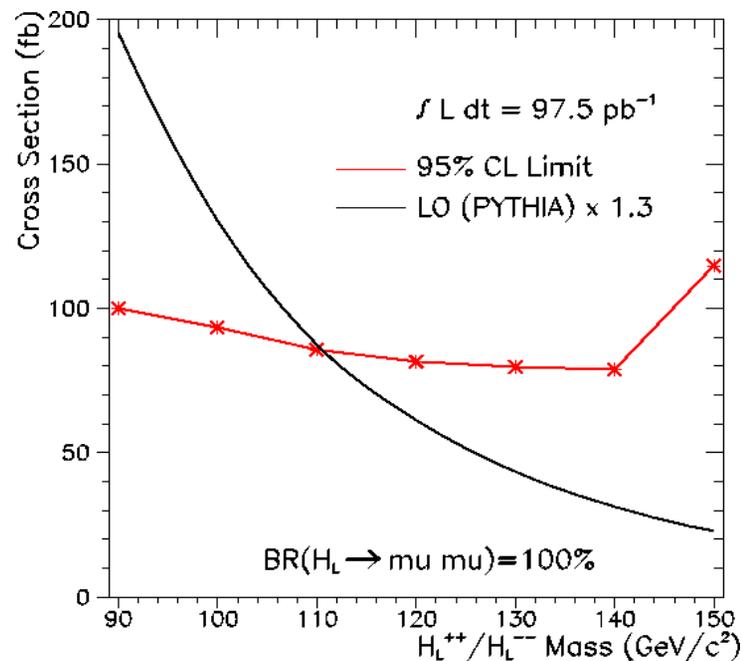
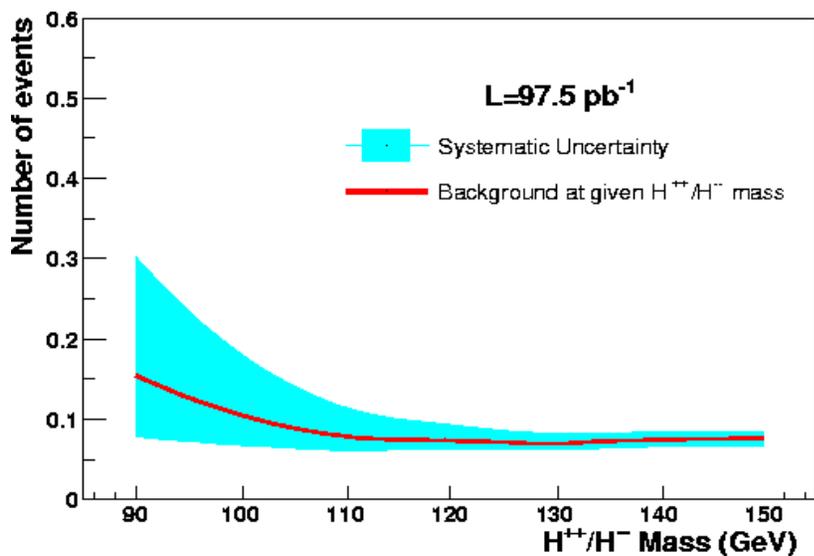
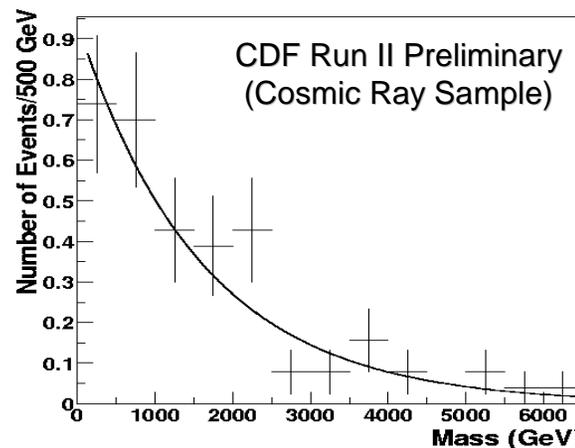


Doubly-Charged Particles à $\mu^\pm\mu^\pm$



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- H^{++} à $\mu^\pm\mu^\pm$ backgrounds
 - Cosmics dominate high end
 - W+jets are dominant below ~ 100 GeV/c²
- $3^{+0.4}_{-0.3}$ events expected, 2 observed (160, 760 GeV)
- $M_{H^{++}} > 110$ GeV/c² at 95% CL
 - LEP limit is 100 GeV/c²

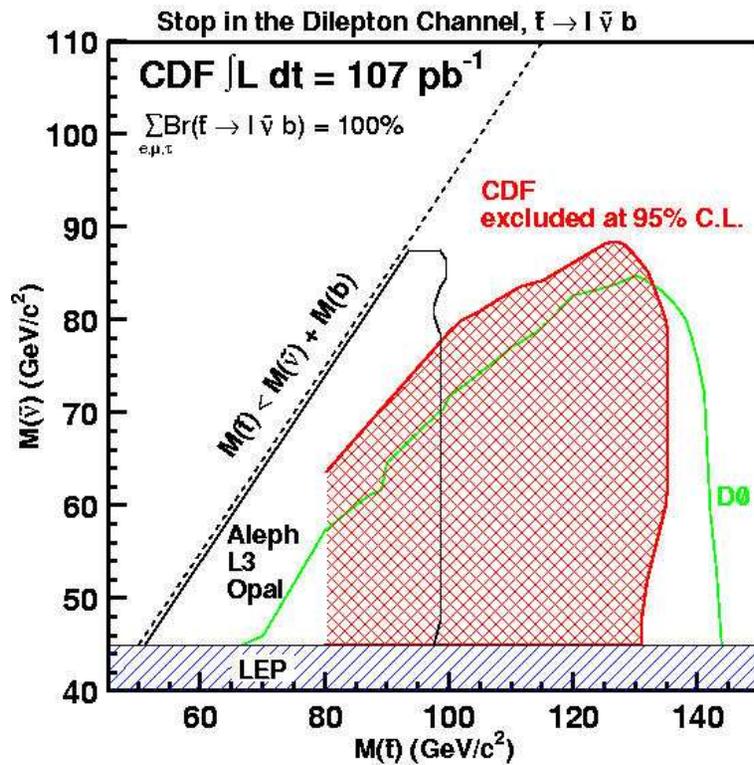




Stop à dileptons



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(Run I result)

- Assume stop à $b\bar{l}\nu$ (equal l Br)
Search for:
 - 2 opposite sign dileptons
 - ≥ 1 jet
 - Missing Energy
- Backgrounds include $t\bar{t}$, Drell-Yan + jets, di-bosons, 'fake' leptons, heavy flavor...
- Two blind analyses performed:
 - For small Δm , $p_T(\ell 2) > 6 \text{ GeV}$
 - For large Δm , $p_T(\ell 2) > 10 \text{ GeV}$

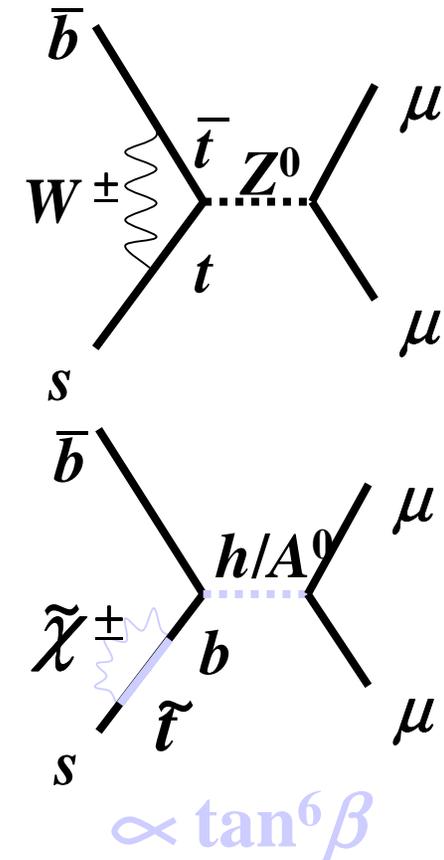
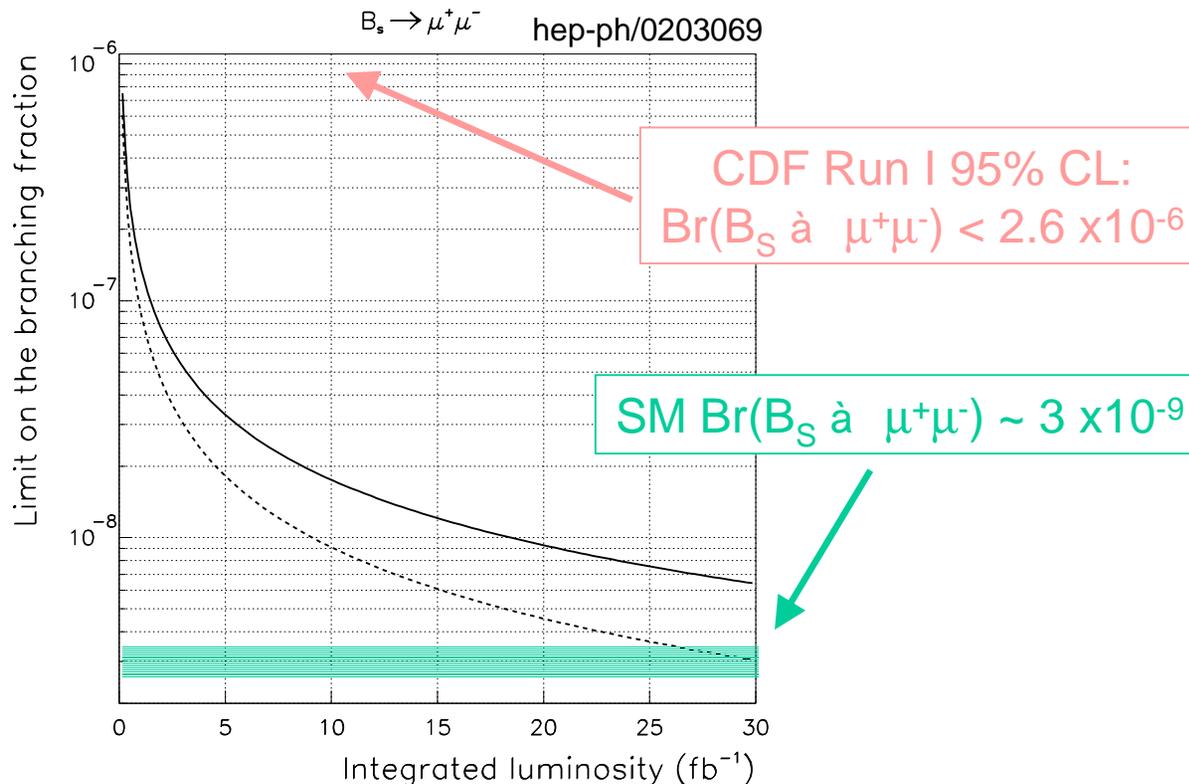
Δm	Data	Bkgnd	Signal
Small	0	1.5 ± 0.5	5.7 ± 2.1
Large	0	2.1 ± 0.5	8.2 ± 3.1



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



- Rare decay rates can be modified by new physics
 - Standard Model $\text{Br}(B_s \rightarrow \mu^+ \mu^-) \sim 10^{-9}$
 - SUSY diagrams can modify the $\text{Br}(B_s \rightarrow \mu^+ \mu^-)$ to be $\sim 10^{-8}$ or even 10^{-7}
- Requires precision tracking, understanding of fakes
- Search is underway...first results in a few weeks!



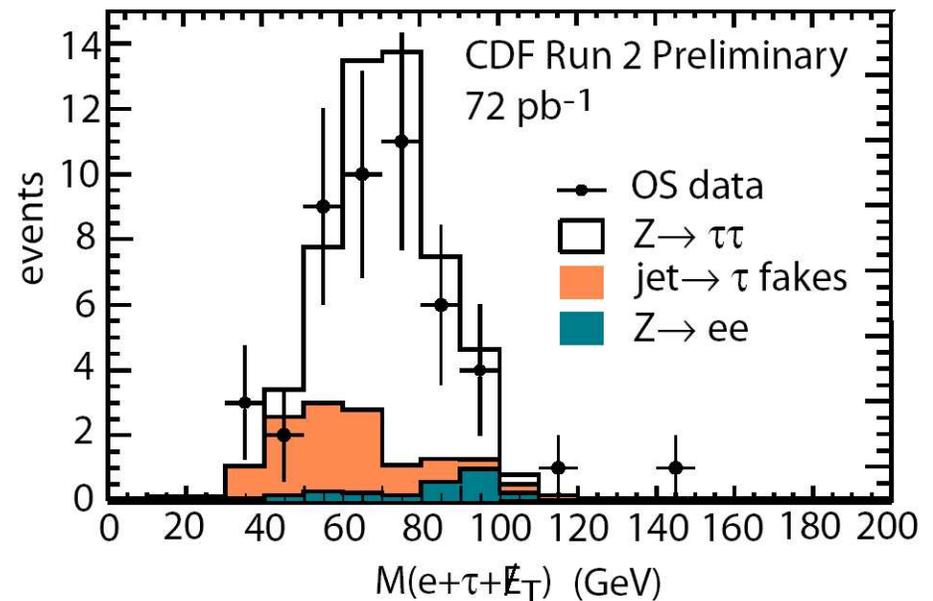
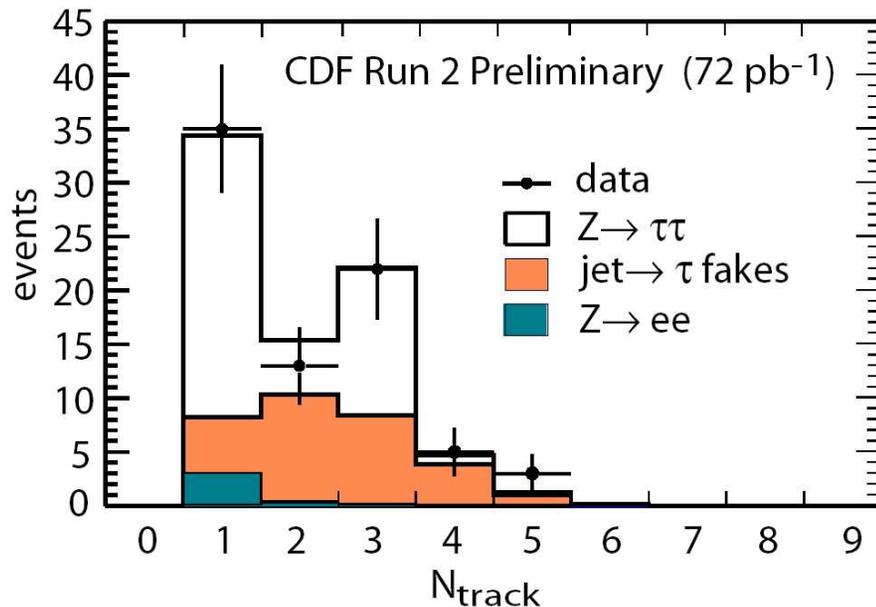


Tau reconstruction: $Z \rightarrow \tau\tau$



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- Improved tau finding in Run II
 - Complete set of tau and di-tau triggers
 - Revised tau finding algorithm
- Hadronic tau charged track multiplicity
 - Data fit to MC signal plus jet-induced fakes
 - Clear indication of tau in 1 and 3 track bins
- Mass plotted for opposite-sign data
- Finding $Z \rightarrow \tau\tau$ is a stepping stone to tau related SUSY and Higgs searches





Conclusion?



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Overall, the detector is working well, and a multitude of searches for new phenomena are underway!

- Results new to SUSY 2003 include searches in
 - Dijet resonances: E6 diquarks, RS graviton LED, excited quarks, W' ...
 - Dilepton resonances: Z' , RS graviton
 - Champs: long lived stop
 - 1st Generation Leptoquarks: $eejj$ and $vvjj$ channels
 - Excited electrons: $ee^* \rightarrow ee\gamma$
 - Photon-rich signatures: γMET , $\gamma\gamma$, $\gamma\gamma\ell$ and $\gamma\ell$, more
 - Stop: search results and prospects
 - Doubly-charged particles: $H^{\pm\pm} \rightarrow e^\pm e^\pm, \mu^\pm \mu^\pm$
- Many more to come!



All critical components are working well

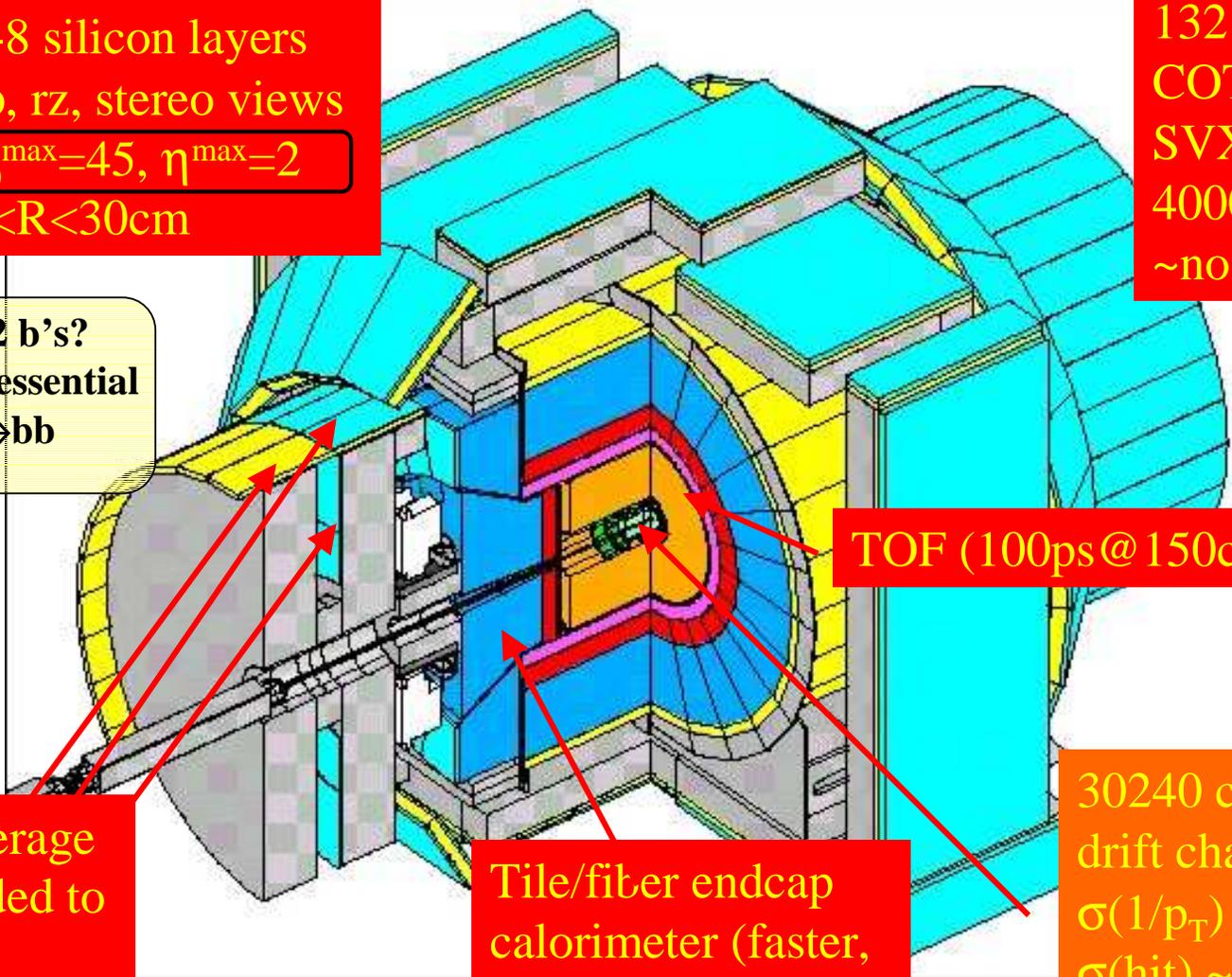


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7-8 silicon layers
 $r\phi$, rz, stereo views
 $z_0^{\max}=45$, $\eta^{\max}=2$
 $2 < R < 30\text{cm}$

132 ns front end
COT tracks @L1
SVX tracks @L2
40000/300/70 Hz
~no dead time

2 b's or not 2 b's?
Double tags essential
for M_{top} , $H \rightarrow b\bar{b}$



TOF (100ps @ 150cm)

μ coverage
extended to
 $\eta=1.5$

Tile/fiber endcap
calorimeter (faster,
larger F_{samp} , no gap)

30240 chnl, 96 layer
drift chamber
 $\sigma(1/p_T) \sim 0.1\%/GeV$
 $\sigma(\text{hit}) \sim 150\mu\text{m}$