New Physics Searches at CDF

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On behalf of the CDF Collaboration

Outline

- The CDF detector and the Tevatron
- Physics event generation/simulation at CDF

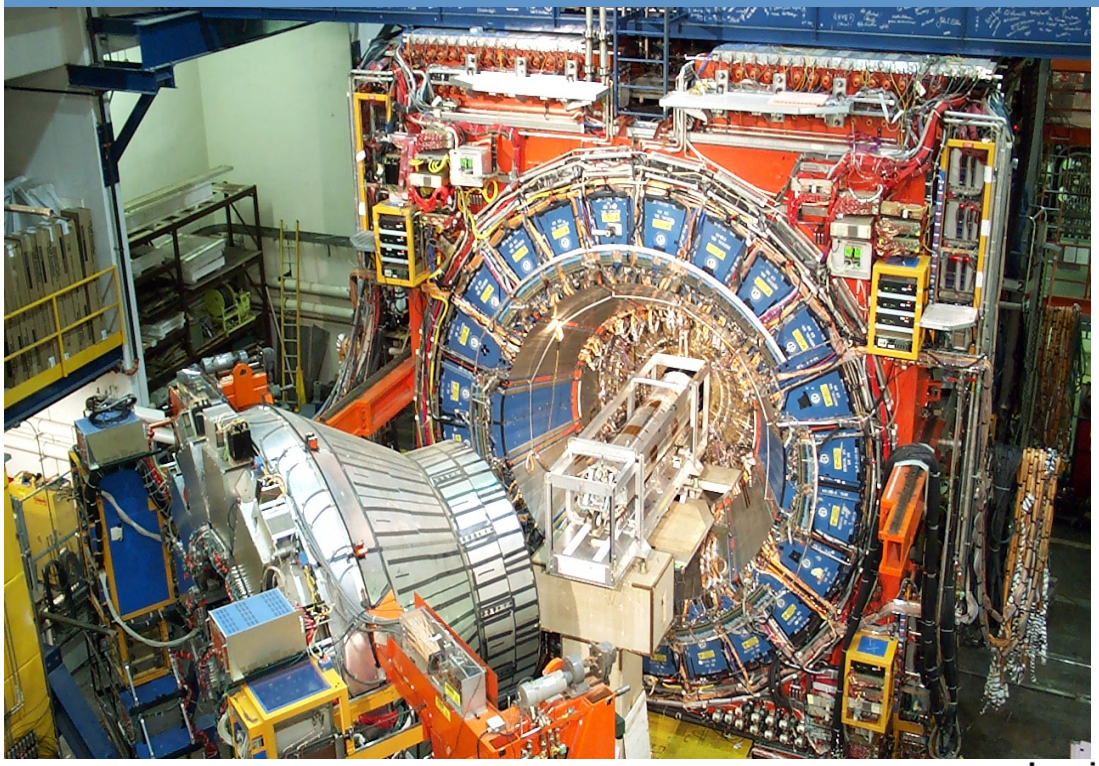
- Signature-based searches
  - High-mass resonances
  - Photon-based signatures

- Model-based searches
  - Supersymmetry
    - Gaugino pair production
    - Squark/gluino production
  - Maximal flavor violation

MC4BSM 09

UC Davis

The CDF Experiment



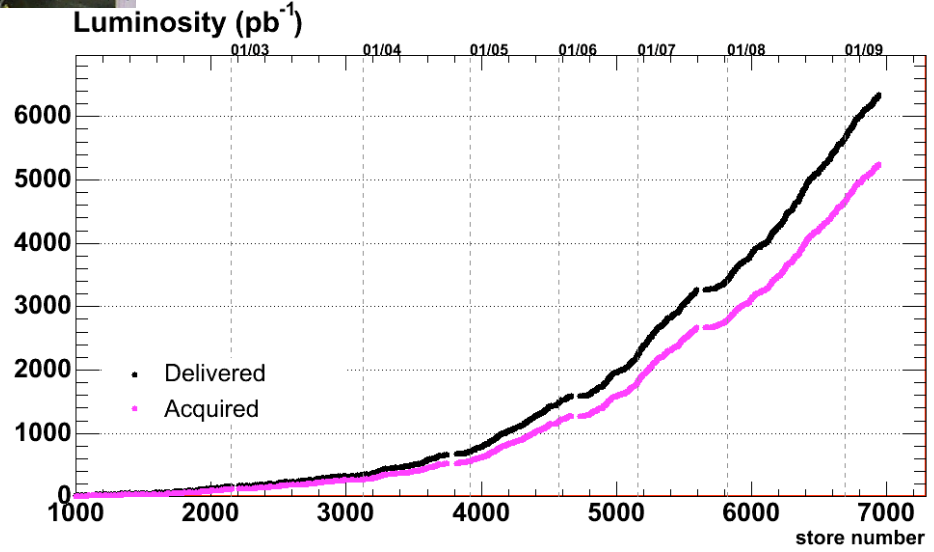
Tevatron: proton-antiproton collisions at 1.96 TeV

CDF: multi-purpose collider detector

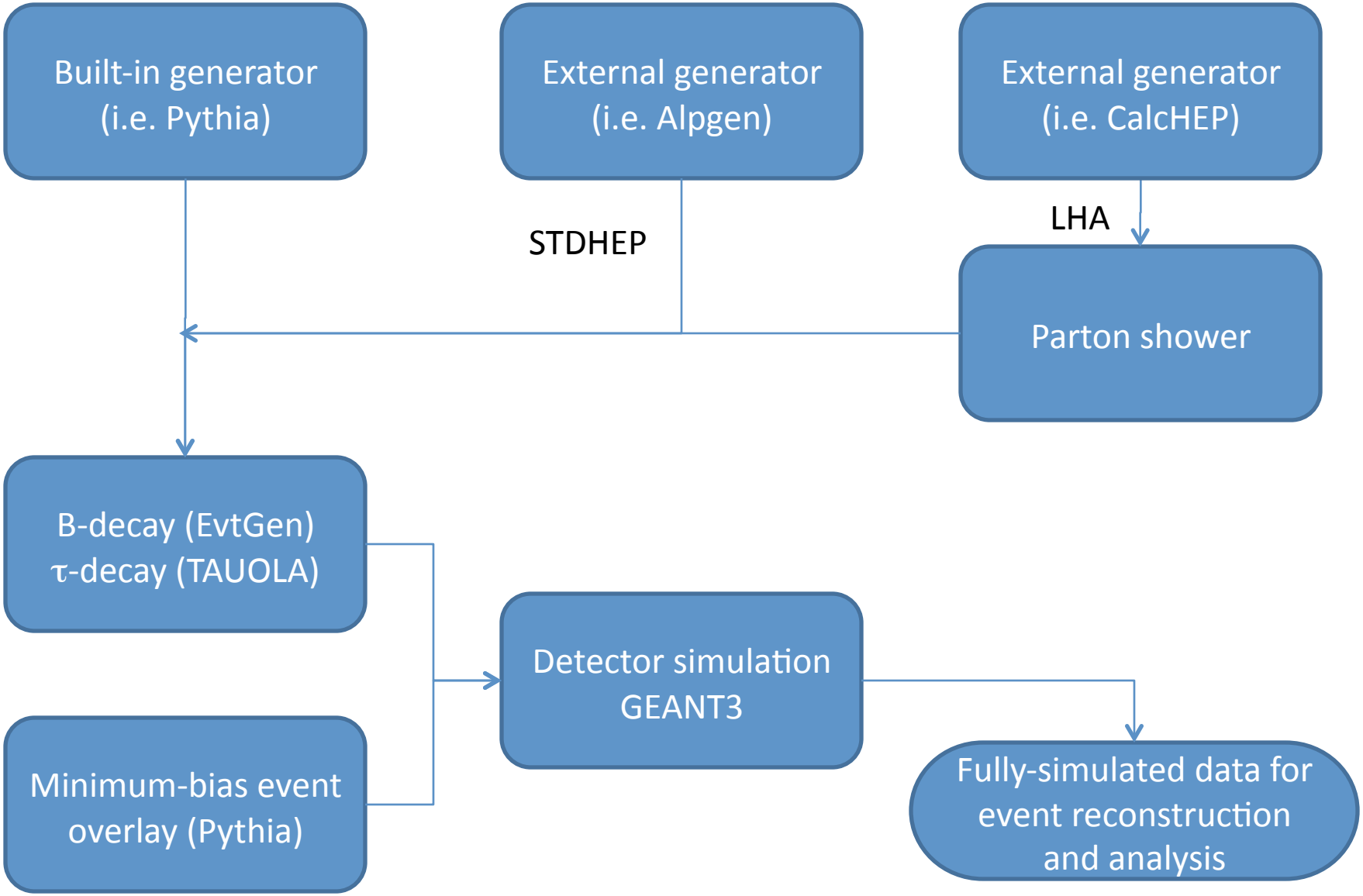
Tevatron has delivered over 6/fb so far in Run II

CDF acquires at 80-85% efficiency

Results in this talk use up to 3/fb



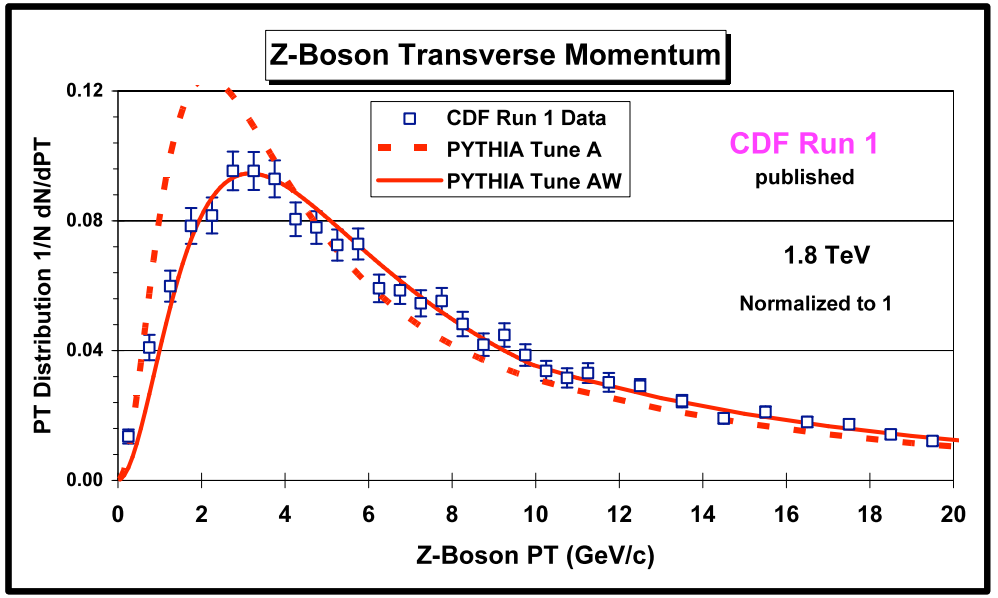
Simulation at CDF



Generators

- Built-in
  - PYTHIA 6.216
  - HERWIG 6.500
  - ISAJET 7.51

- External generators
  - ALPGEN 2.1 (with PYTHIA 6.326)
  - MadGraph/MadEvent
  - WGAMMA/ZGAMMA
  - GRACE/GR@PPA
  - MC@NLO
  - CompHEP
  - CalcHEP
  - MCFM
  - Your favorite generator



CDF PYTHIA samples use Tune A with extra intrinsic k_T (Tune AW)

Generate using CTEQ5L PDFs

Reweight in x, Q^2 to estimate systematics with CTEQ6 eigenvectors

Signature-Based Searches

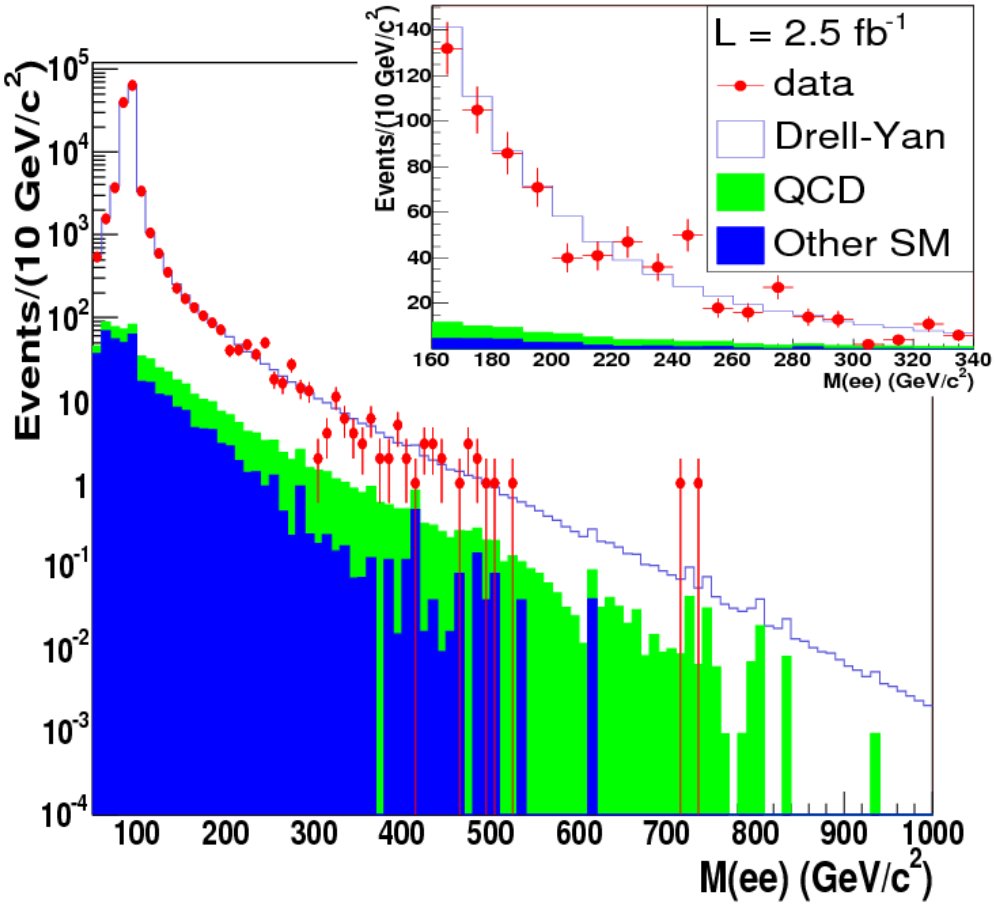
Dielectron Resonances

Signature of new heavy resonances (Z', RS graviton)

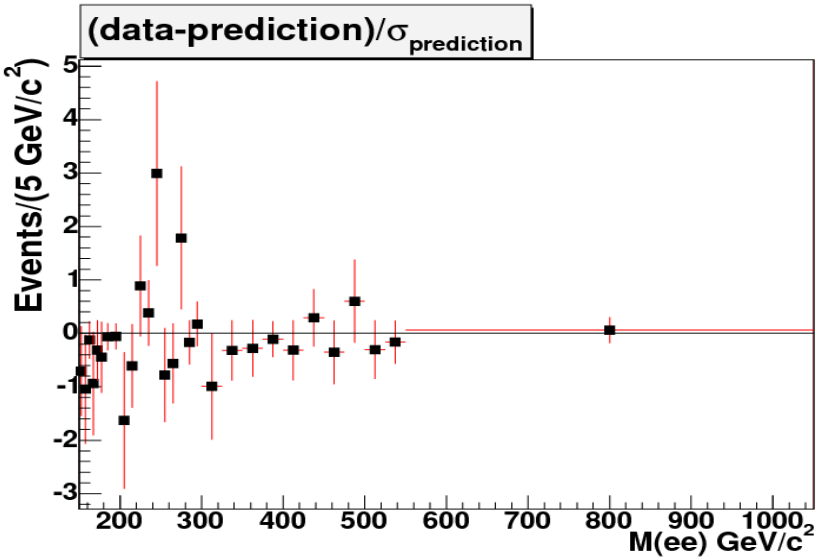
Two electrons with $E_T > 25$ GeV

DY : PYTHIA with mass-dependent NNLO k-factor, normalized to Z
QCD : data-driven

CDF Run II Preliminary



CDF Run II Preliminary

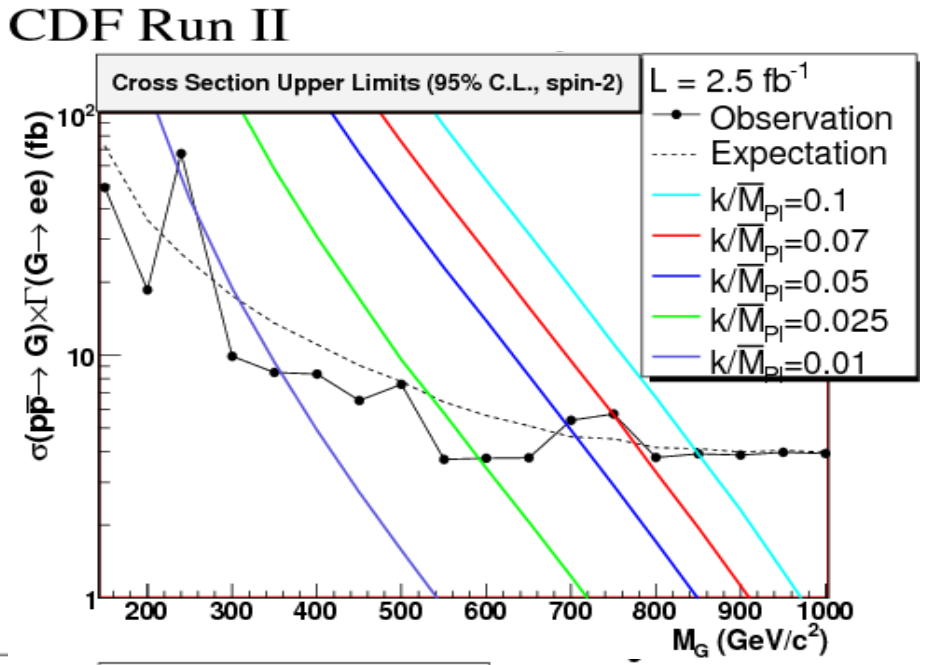


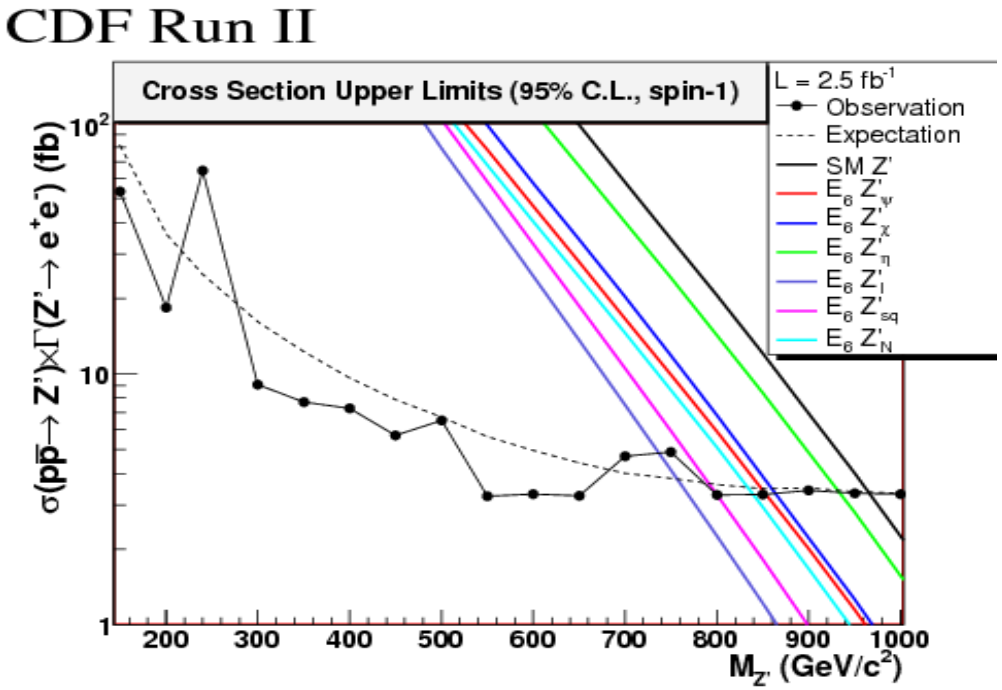
3.8σ excess at 240 GeV
Including trials factor, 2.5σ

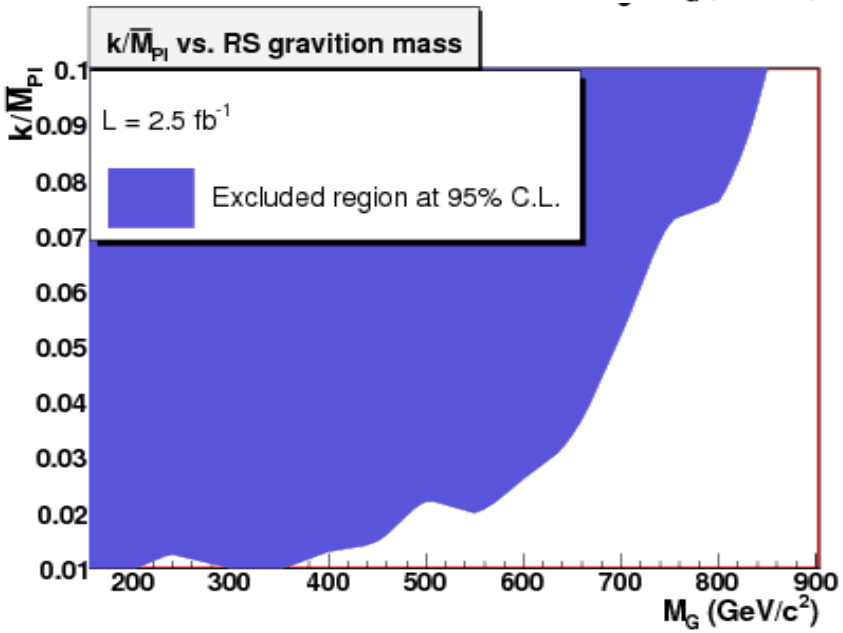
Dielectron Mass Limits

Mass limits for a variety of signal models
- SM-like Z' : M > 966 GeV
- RS graviton (k/Mpl = 0.1) : M > 850 GeV

Cross sections : PYTHIA x k-factor 1.3







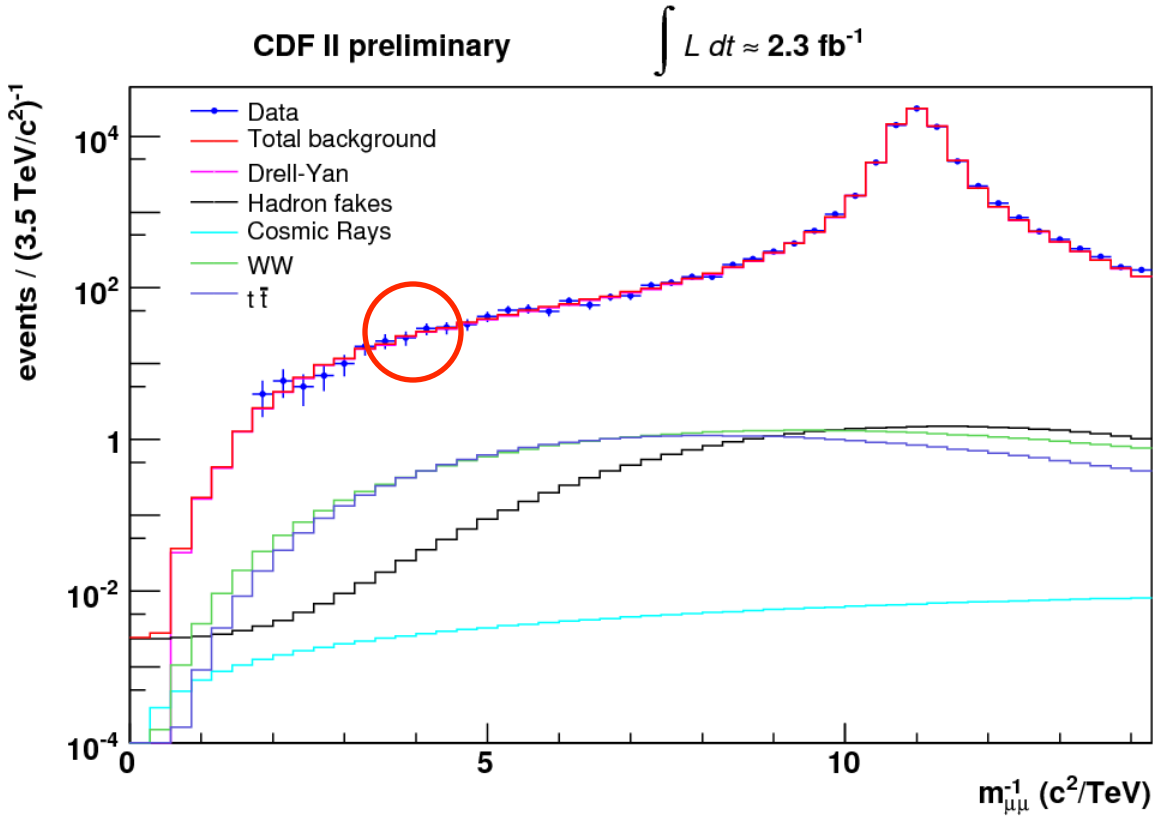
Dimuon Resonances

Two muons with $p_T > 30$ GeV

Resolution is roughly constant in 1/m

$\delta m^{-1} \approx 0.17\ \text{TeV}^{-1}$,
about three bins

$1/(250\ \text{GeV}) = 4\ \text{TeV}^{-1}$



DY : PYTHIA with NNLO k-factor, normalized in Z window
QED radiation effects simulated with WGRAD

WW, tt : PYTHIA normalized to NLO cross section

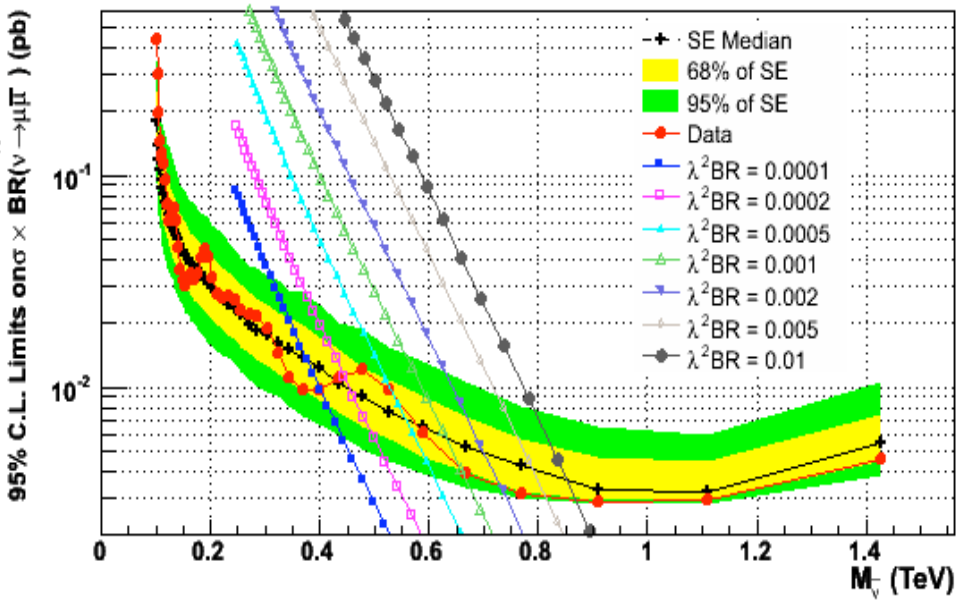
Others : data-driven

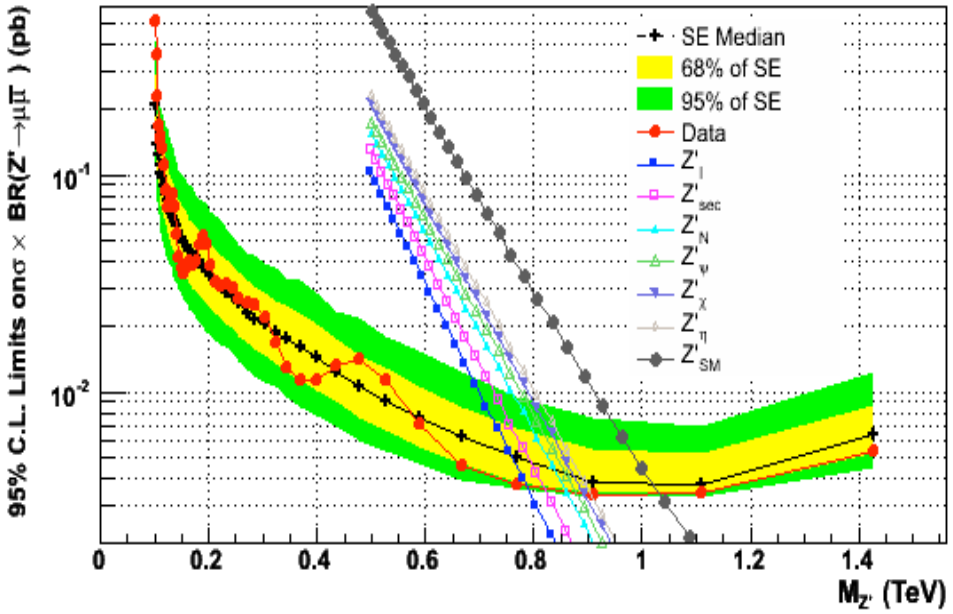
Dimuon Mass Limits

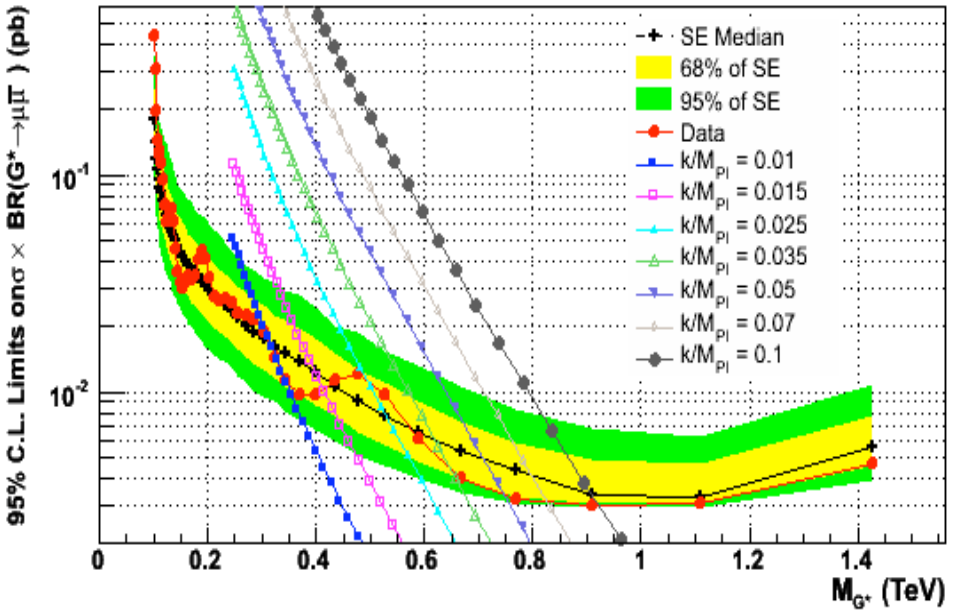
Mass limits for a variety of signal models

- RPV sneutrino : M > 866 GeV
- SM-like Z' : M > 1030 GeV
- RS graviton ($k/M_{pl} = 0.1$) : M > 921 GeV

Signal templates generated with PYTHIA
Cross sections: PYTHIA+NNLO k-factor (Z', G*) or NLO calculation (sneutrino)







Dijet Resonances

Common final state for a variety of new heavy particles

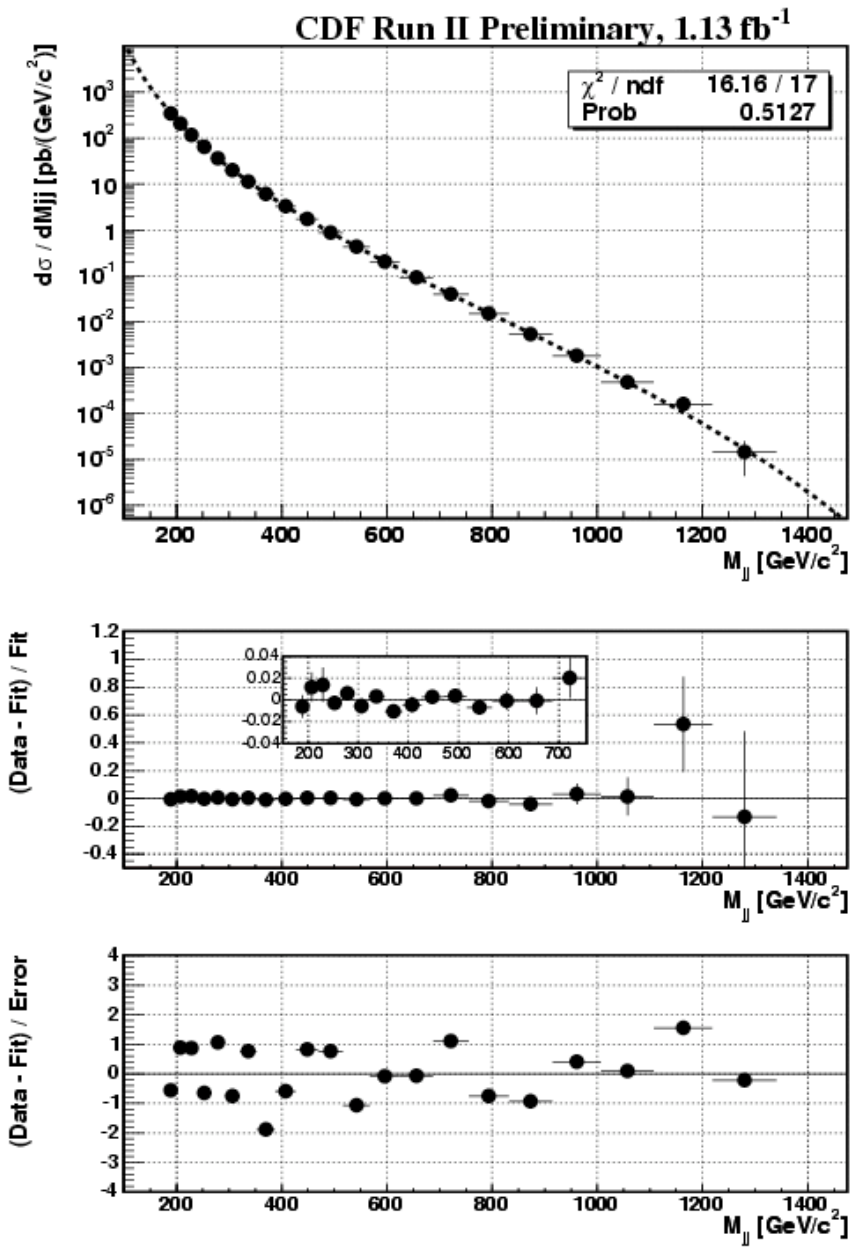
Two central jets ($|\eta|<1$) with $m_{jj} > 180$ GeV

Simulate W', Z', RS graviton, and excited quarks using PYTHIA

Background derived from a smooth fit function

$$\frac{d\sigma}{dm} = p_0(1-x)^{p1} / x^{p2+p3\log(x)}, \quad x = m/\sqrt{s}$$

Validity of fit function verified using PYTHIA and HERWIG jet samples

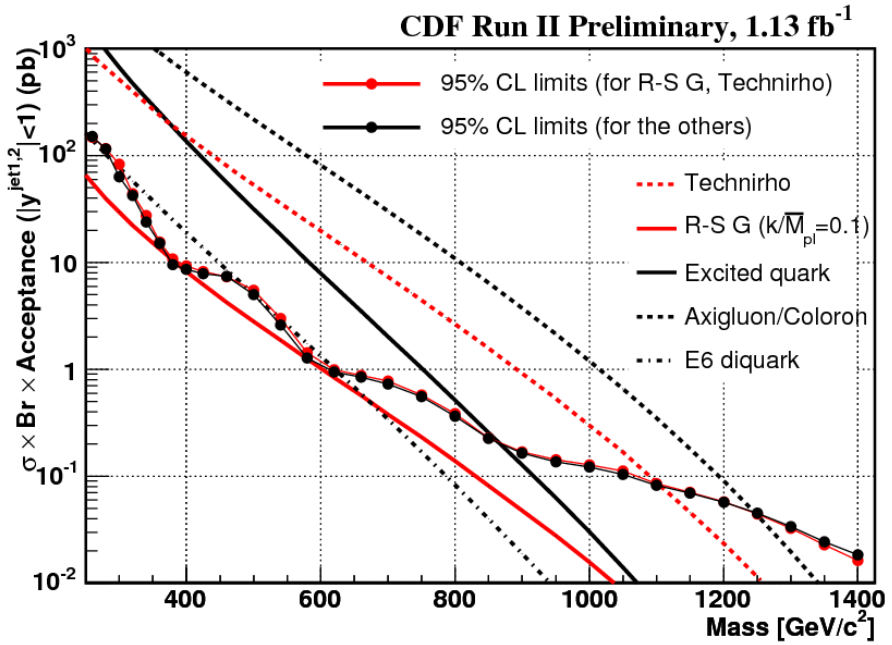


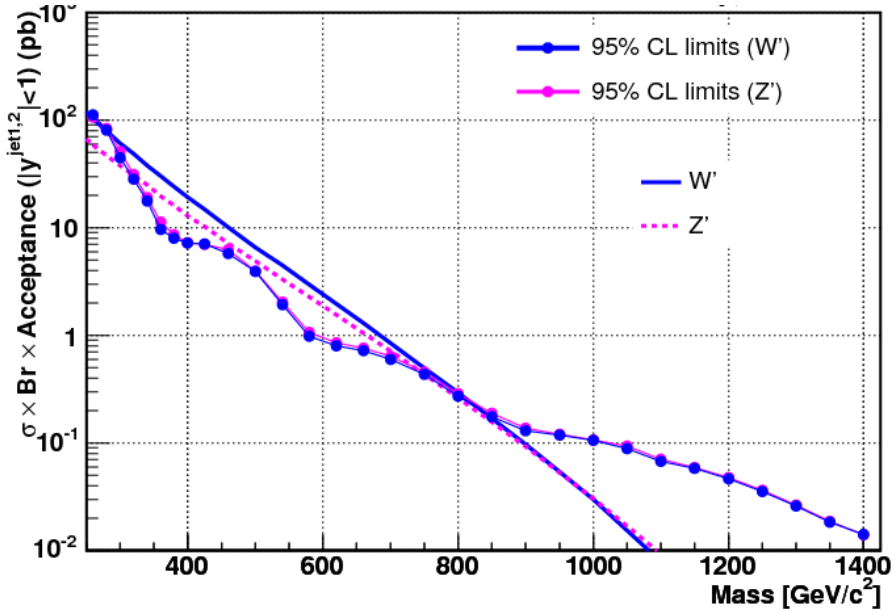
Dijet Mass Limits

Mass limits in a variety of models

W', Z', RS graviton : PYTHIA x k-factor 1.3
Excited quarks : PYTHIA LO
others : parton-level LO predictions

Model	Observed exclusion
Excited quark	260-870 GeV
Color-octet technirho	260-1110 GeV
Axigluon & coloron	260-1250 GeV
E6 diquark	260-630 GeV
SM-like W'	260-840 GeV
SM-like Z'	260-740 GeV

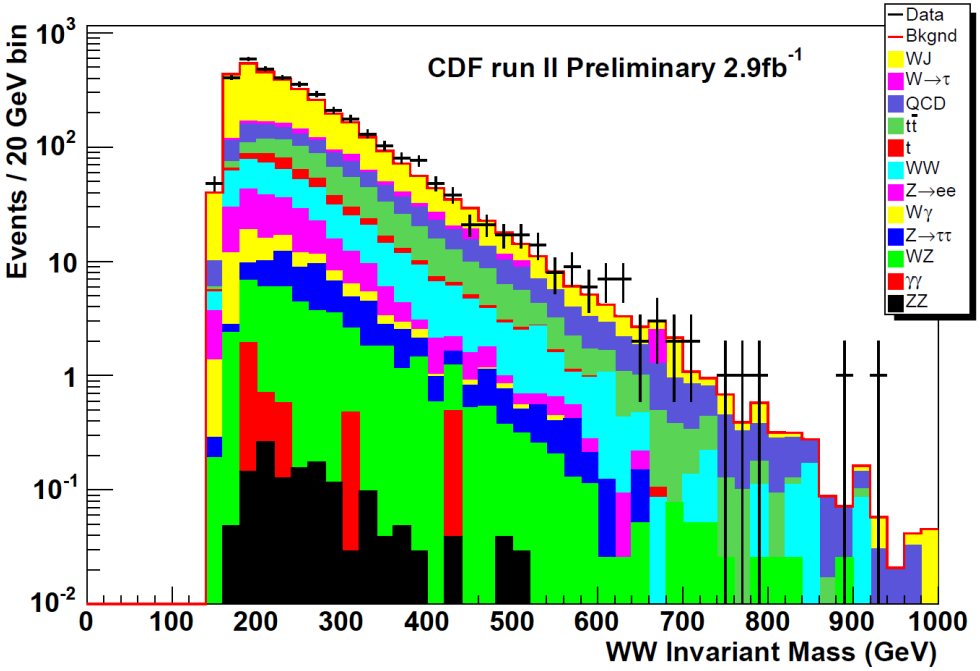


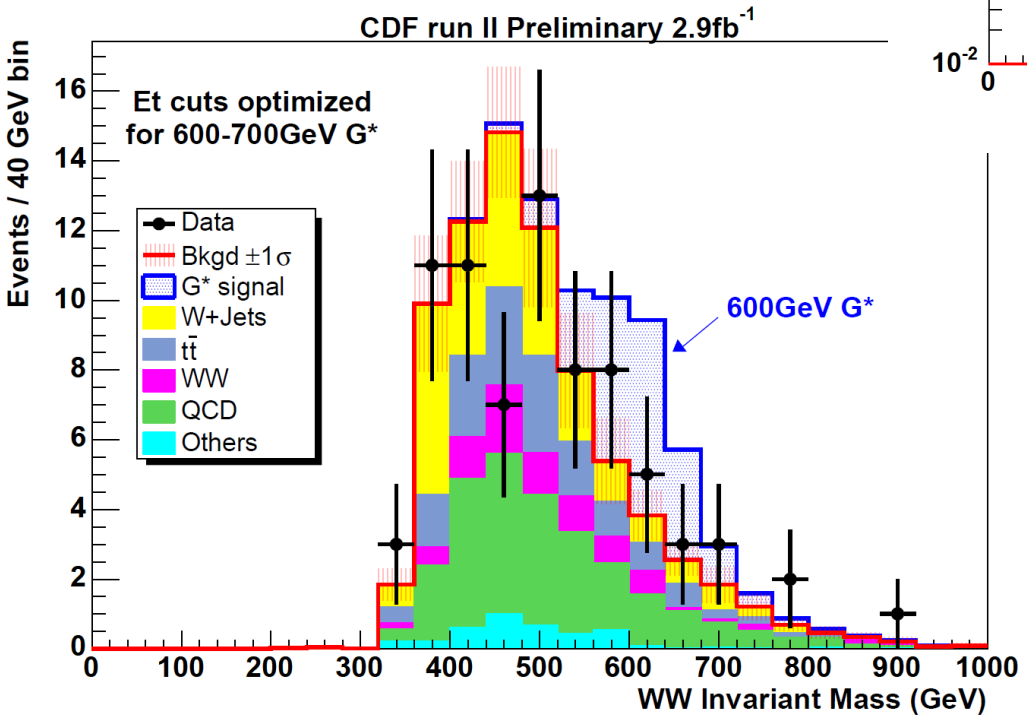


WW/WZ Resonances

Electron with E_T > 30 GeV
MET > 30 GeV
Two or three jets, at least one pair consistent with W or Z mass

Further WW/WZ mass-specific E_T cut optimization





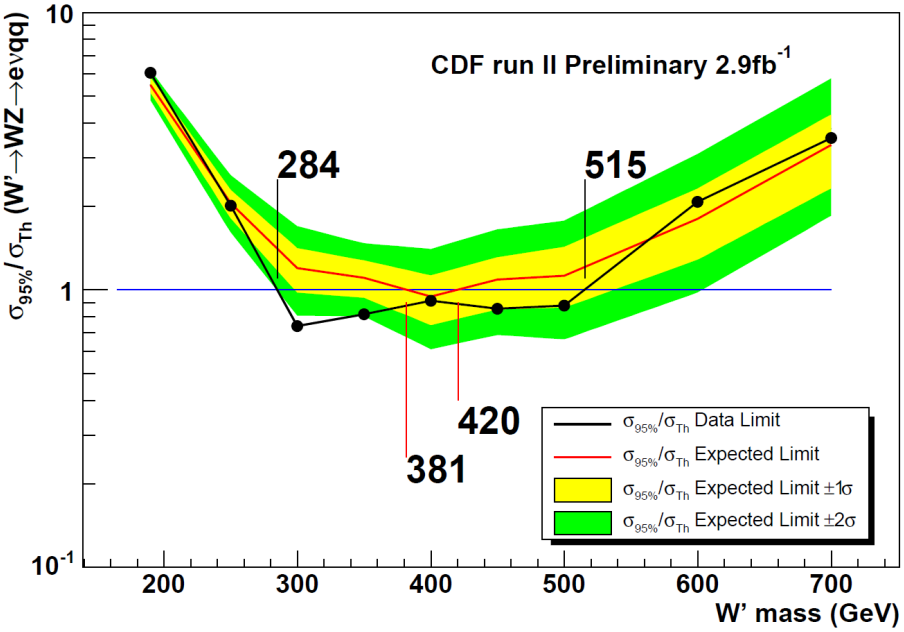
diboson, tt : PYTHIA normalized to NLO cross sections

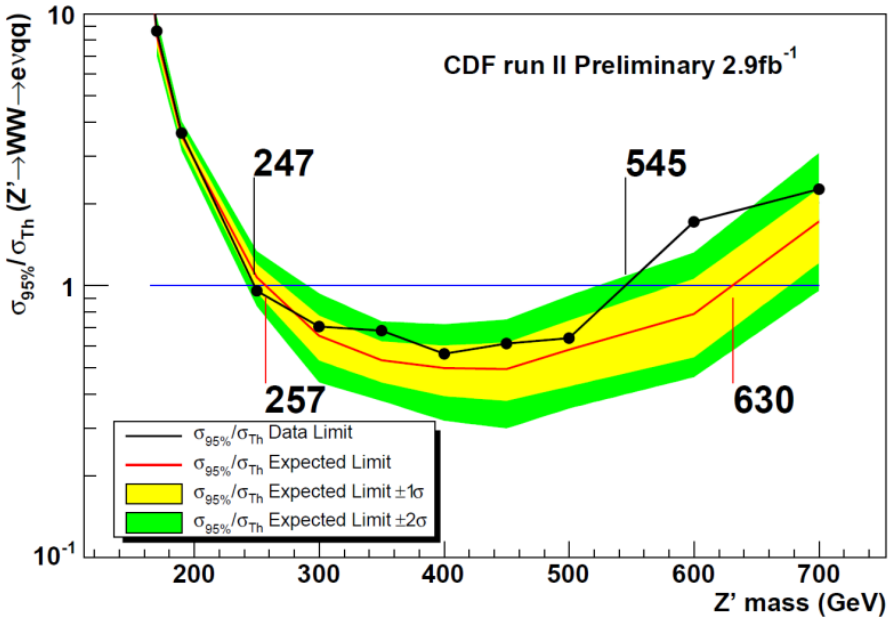
W+jet : ALPGEN+PYTHIA, MLM-matched, k-factor 1.3

QCD : data-driven

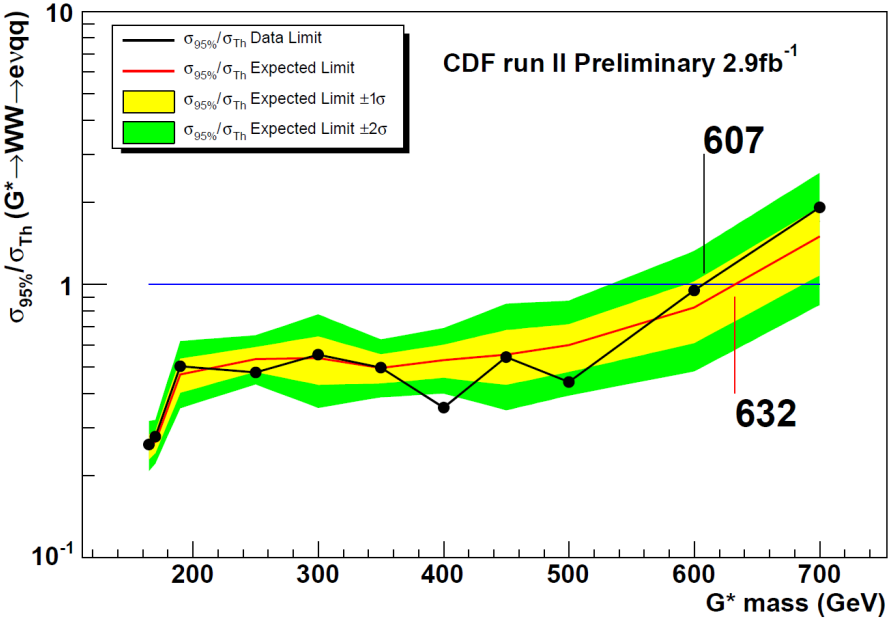
Signal templates : PYTHIA

WW/WZ Mass Limits





Z', G* : PYTHIA x k-factor 1.3
W' : PYTHIA template scaled to NLO calculation



	G*	Z'	W'
Expected exclusion	< 632 GeV	257 – 630 GeV	381 – 420 GeV
Data exclusion	< 607 GeV	247 – 545 GeV	284 – 515 GeV

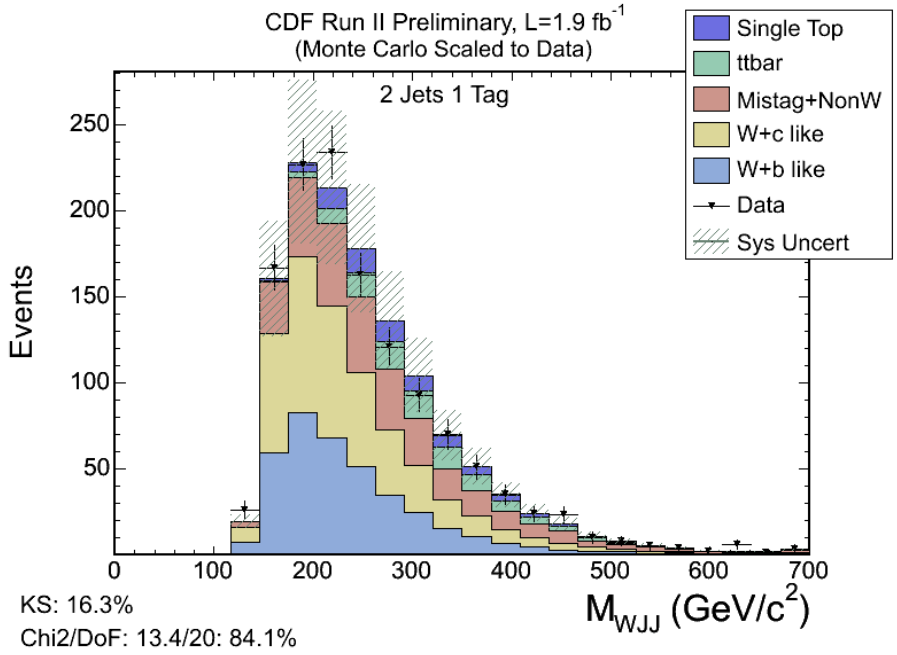
CDF Run II Preliminary. $\int L\,dt = 2.9\ fb^{-1}$

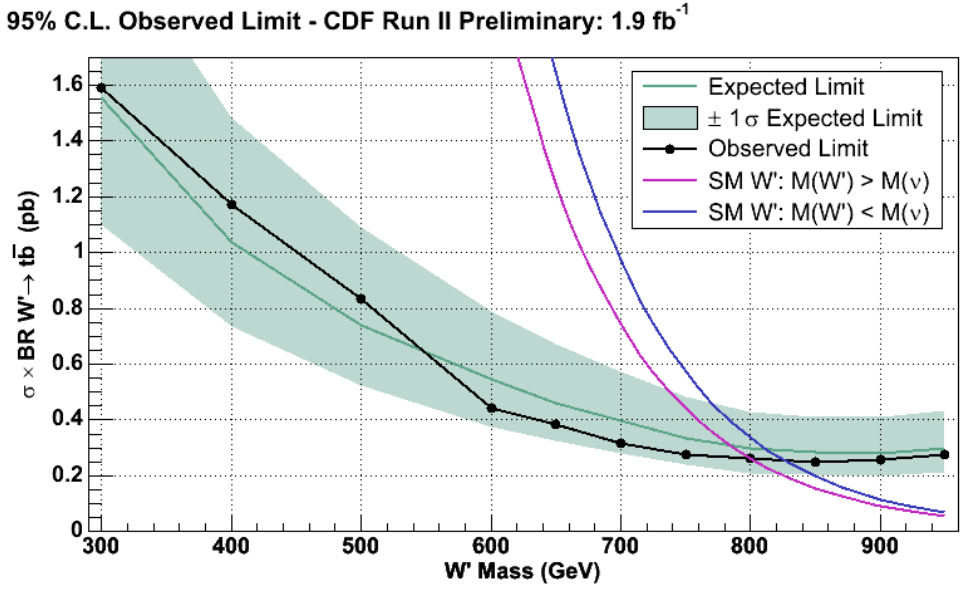
W' → tb

Electron or muon with p_T>20 GeV
MET > 25 GeV
Two or three jets with E_T > 20 GeV
At least one b-tagged jet

Search in combined W+jets mass

Signal model : PYTHIA templates, NLO cross section





top : PYTHIA + NLO cross sections

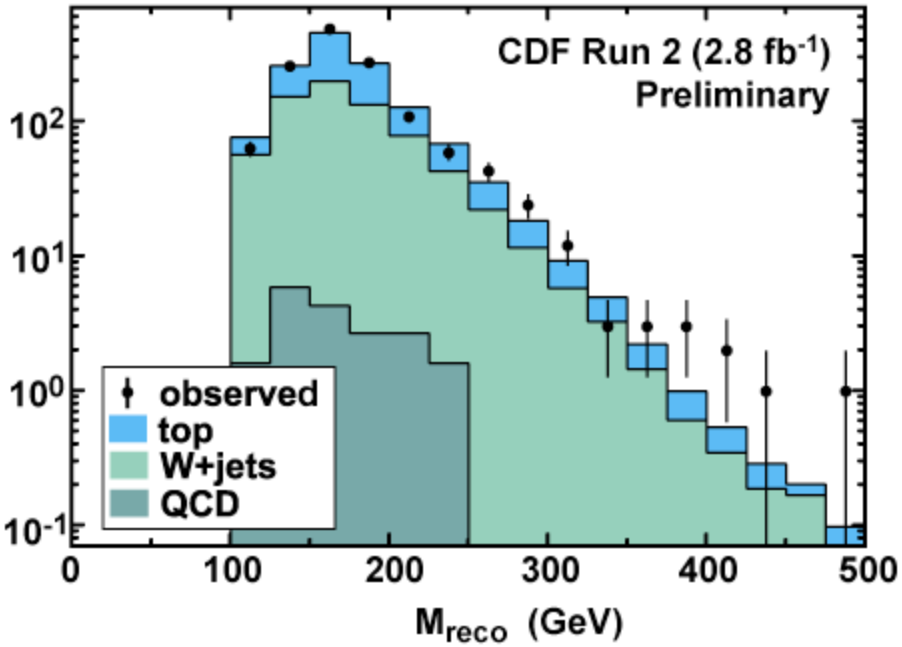
Mistag+QCD : data-driven

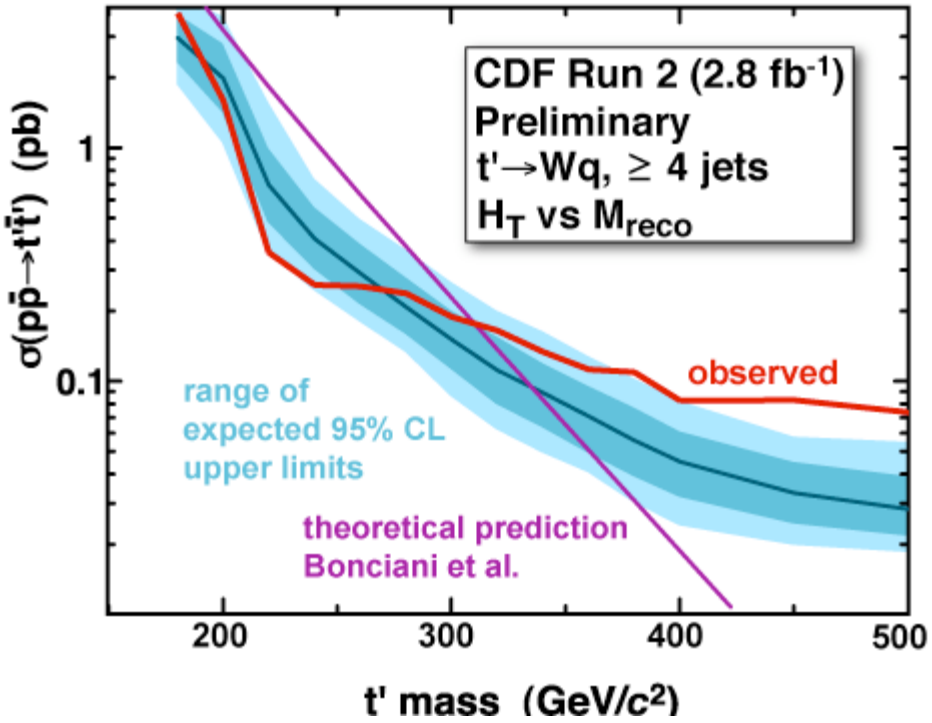
W+b/W+c : ALPGEN+PYTHIA, MLM-matched, “method II” with HF calibration from 1-jet bin

t' Search

- Electron or muon with p_T > 20 GeV
- MET > 20 GeV
- at least four jets E_T > 20 GeV
- no b-tagging requirement

Search in H_T vs m_{reco} from kinematic fitter





tt : Pythia + NLO cross section
W+jets : ALPGEN+PYTHIA, float in fit
QCD : data-driven

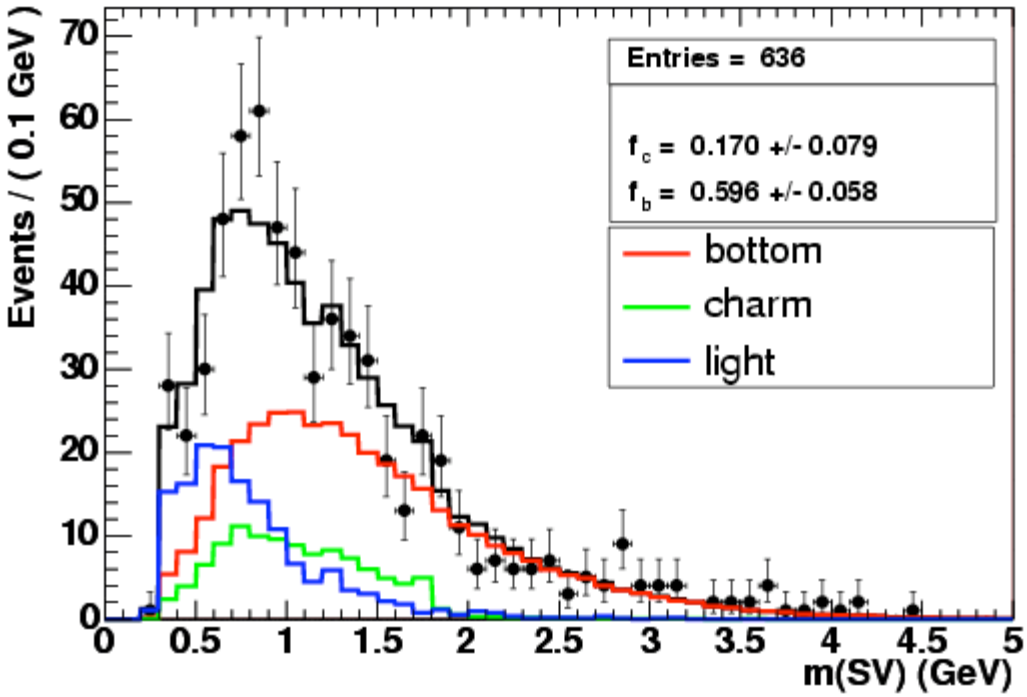
Most discrepant tail region
m_{reco} > 250, H_T > 550 : 1.05% prob

γ + b-jet + jet + MET

Potential GMSB signature
Also technicolor (without MET)
Small SM contributions

Photon E_T > 25 GeV
MET > 25 GeV
Two jets E_T > 15 GeV
At least one b-tagged

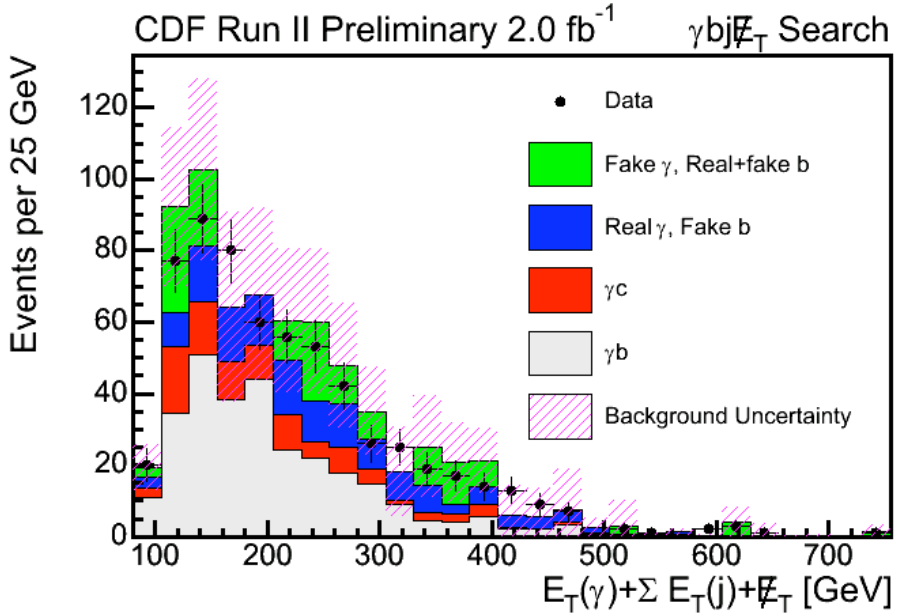
$$\tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow (\gamma \tilde{\chi}_1^0)(\tilde{t}\bar{b}) \rightarrow (\gamma \tilde{\chi}_1^0)(\bar{b} c \tilde{\chi}_1^0) \rightarrow (\gamma \bar{b} c \not{E}_T)$$

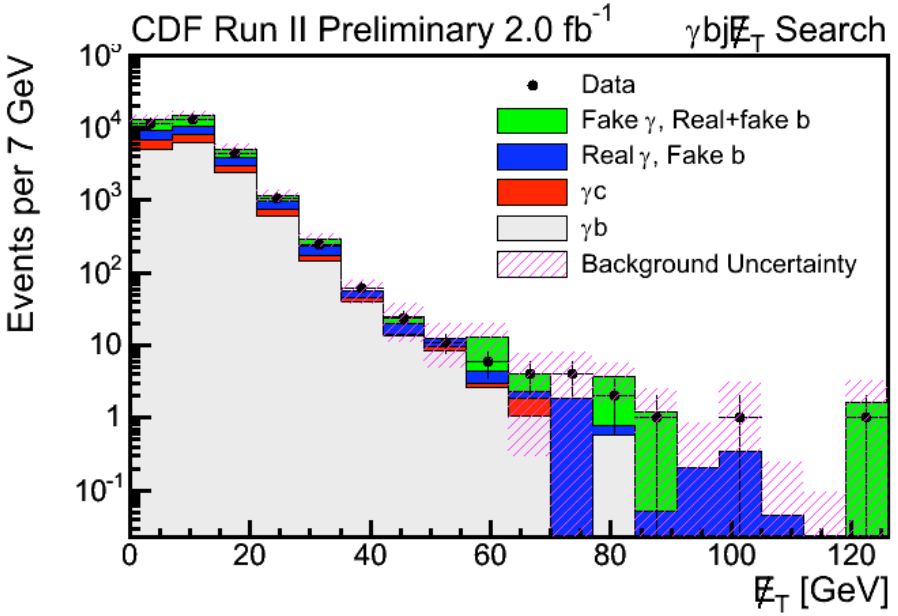


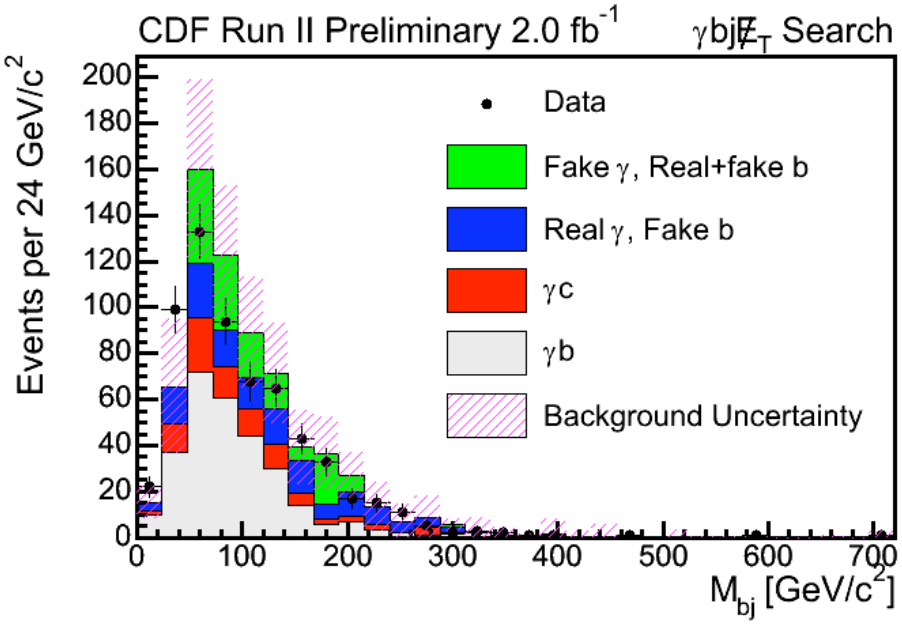
Fakes (γ, b-tag) : data-driven
γb, γc : MadGraph + Pythia, CKKW-matched

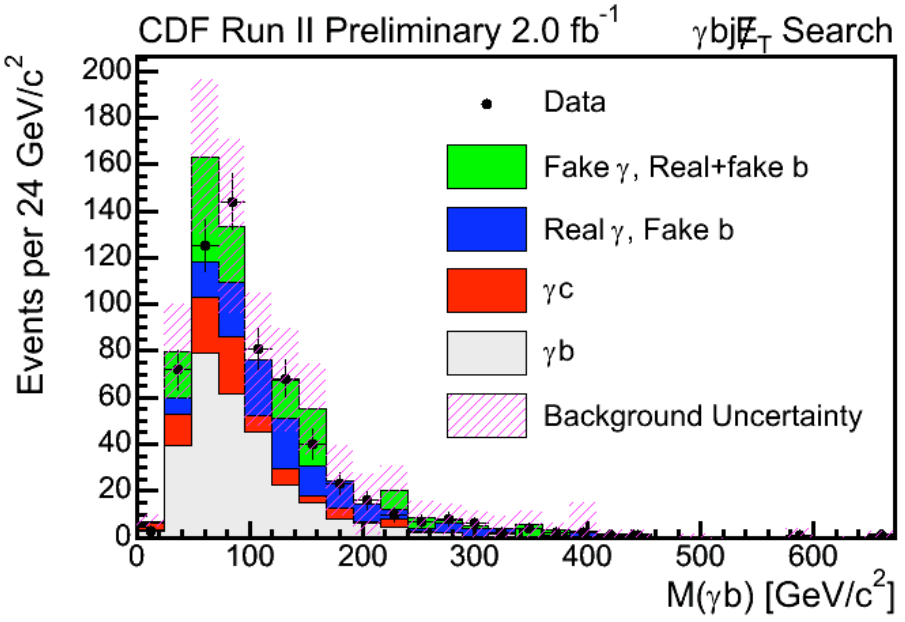
Normalization of γb, γc from γ + 1 tagged jet control region
Extrapolate to signal region using relations from CKKW-matched MC

γ + b-jet + jet + MET Results









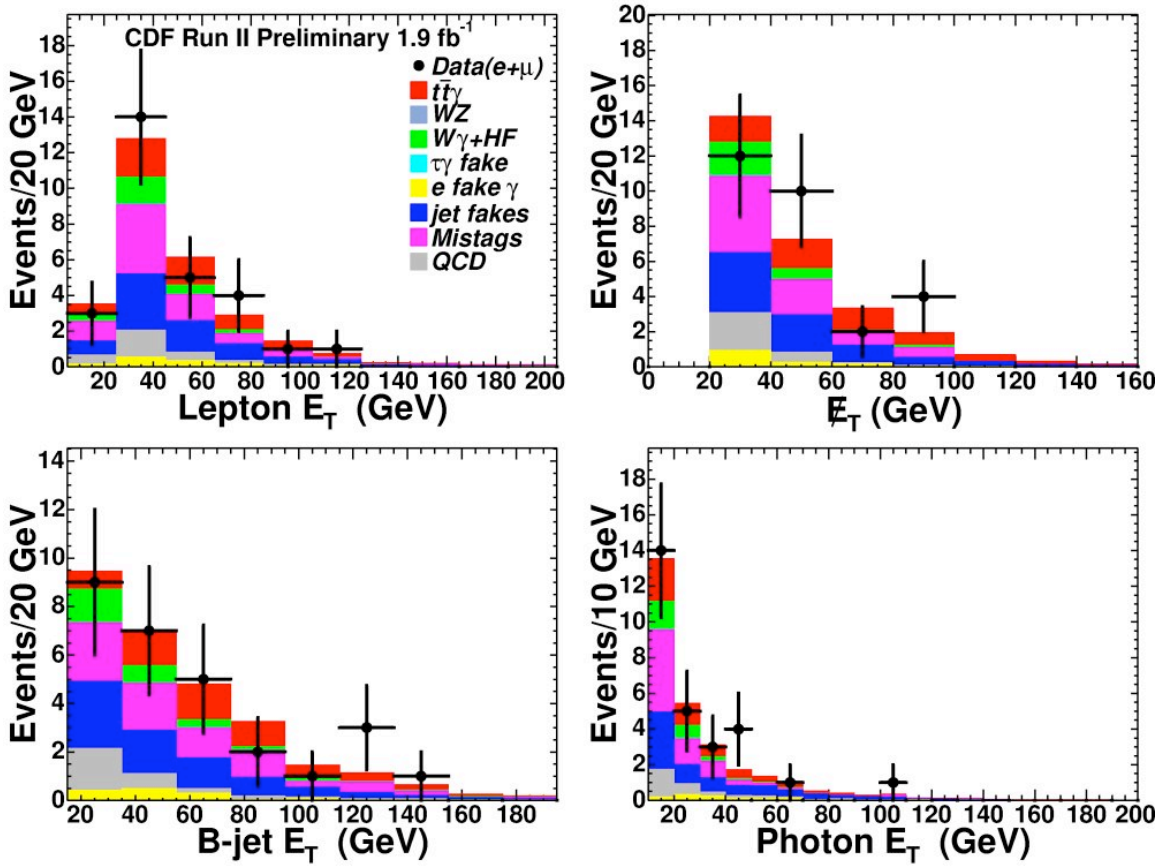
Lepton + γ + b-jet + MET

Similar to previous channel, replace jet with lepton

Electron or muon p_T > 20 GeV
Photon E_T > 10 GeV
MET > 20 GeV
At least one b-tagged jet E_T > 15 GeV

Sample is dominated by fake objects (γ, b-tag) and ttγ

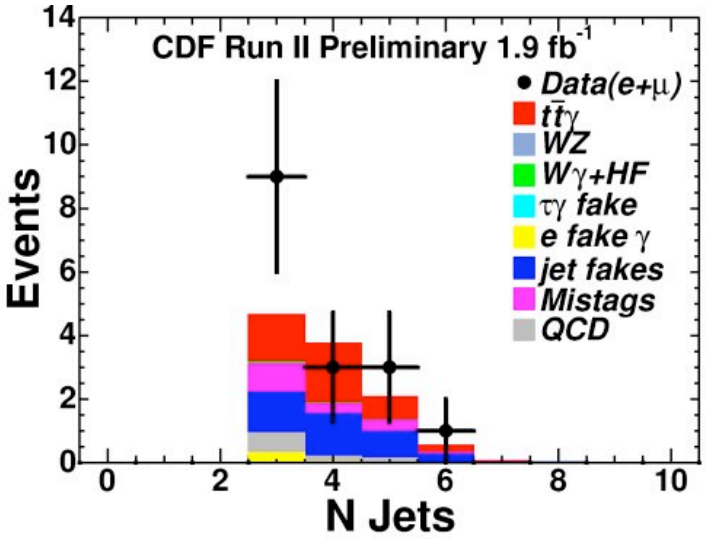
Fakes : data-driven
Wγ+HF : MadGraph
ttγ : MadGraph x k-factor 1.1

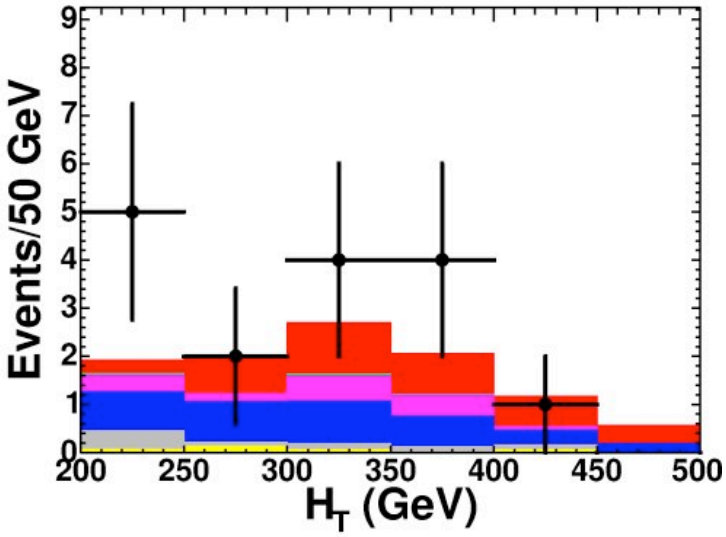


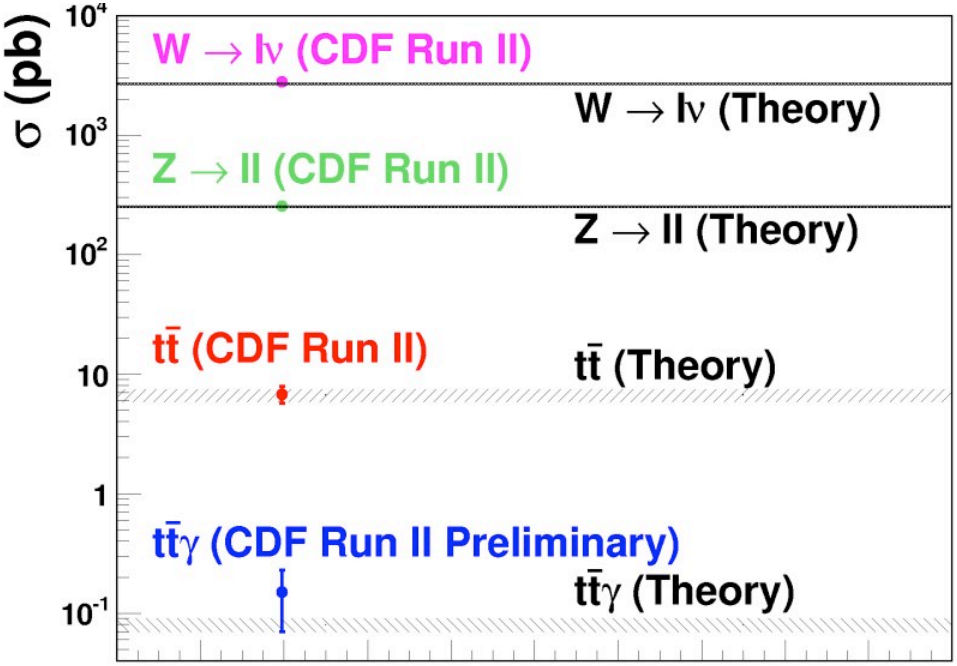
ttγ Optimized

Optimize for ttγ

$N_{jet} > 2$
$H_T > 200$ GeV







Data consistent with non-ttγ backgrounds at 1% level

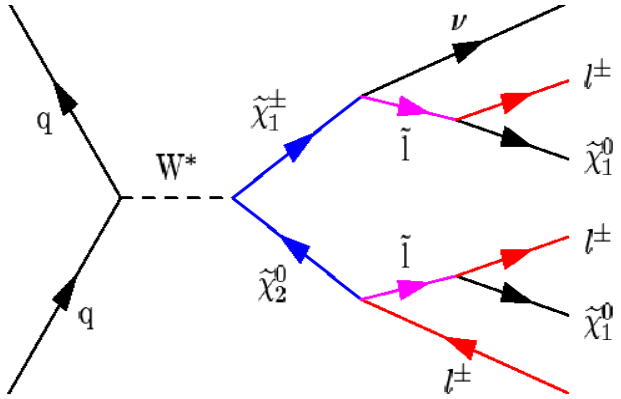
Corresponding ttγ cross section is 0.15 ± 0.08 pb
(compare to SM 0.08 ± 0.01)

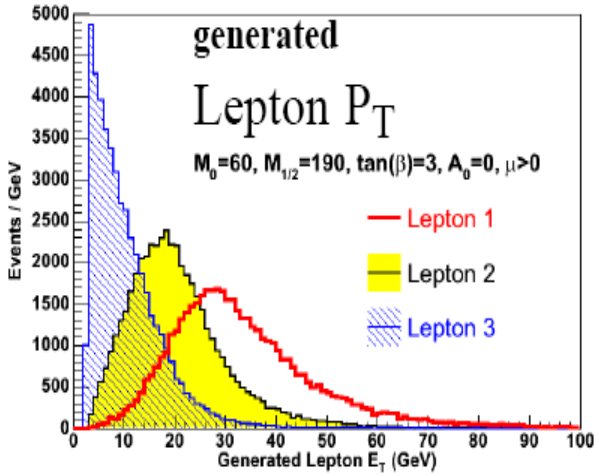
Model-Based Searches

Gaugino Pairs

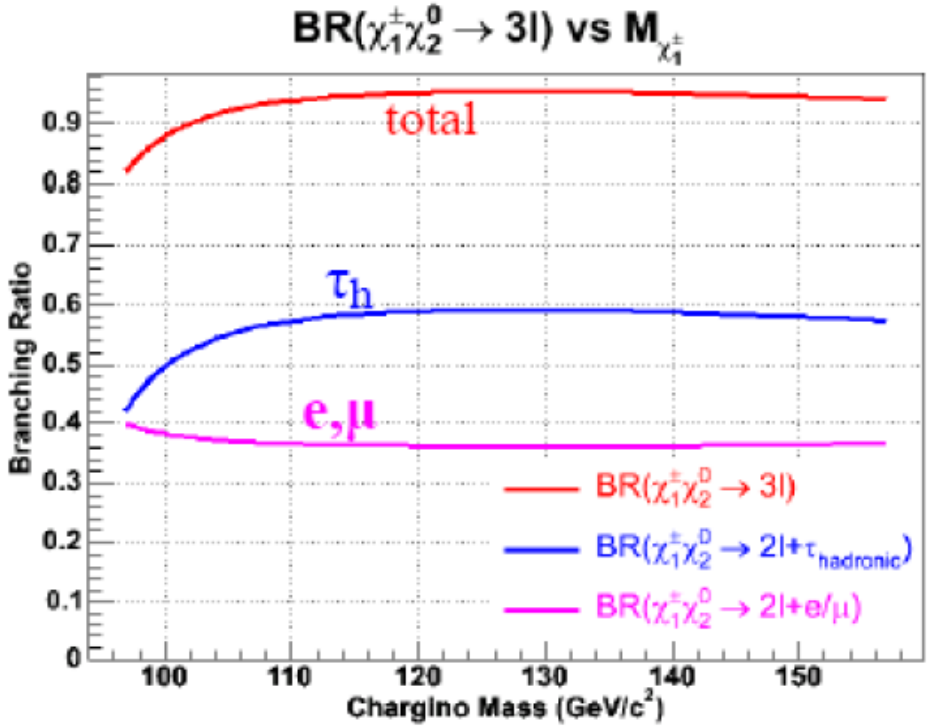
Production of $\chi_1^+\chi_2^0$ pairs
Low cross sections (0.1-0.8 pb) but BR into three leptons is high

Require three leptons or two leptons plus isolated track (τ_{had})
  * 5 categories (# loose leptons)
MET > 20 GeV and $N_{jet} < 2$





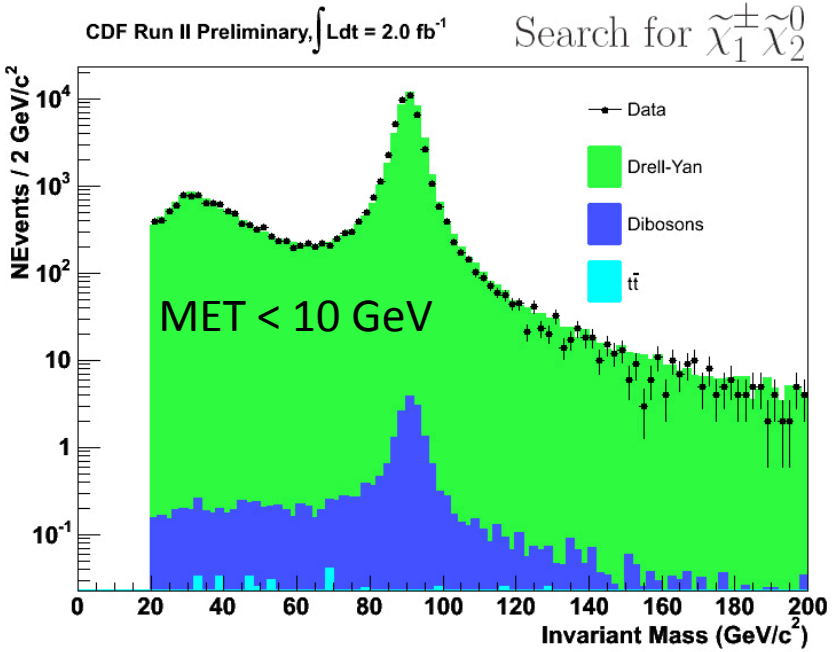
mSUGRA mass spectrum
PYTHIA + ISASUGRA 7.51 samples for acceptance



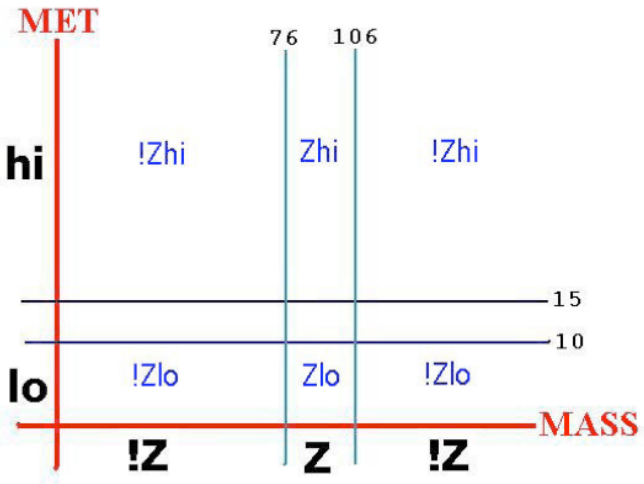
Dilepton Control Regions

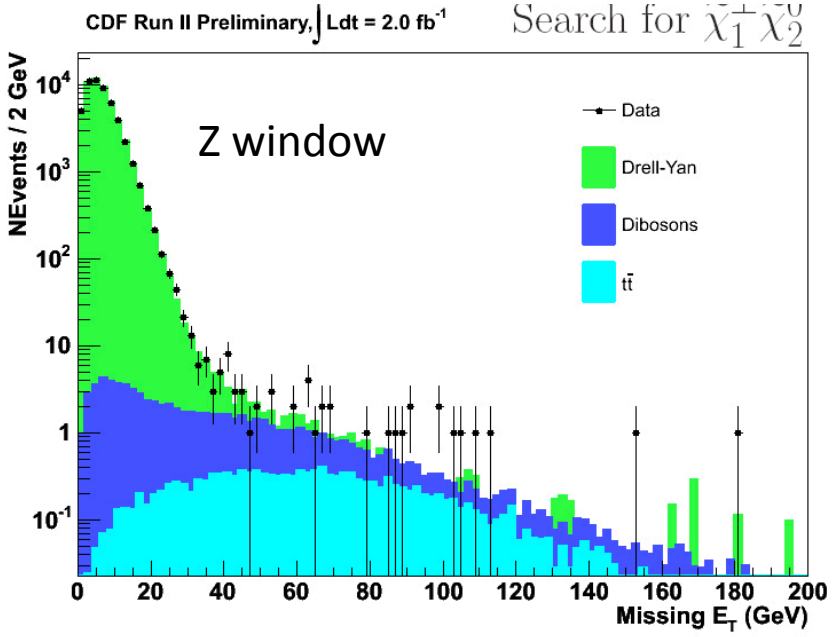
Test background modeling in high-statistics dilepton control regions

DY, tt, WW, ZZ : PYTHIA
WZ : MadEvent



CDF RUN II Preliminary $\int \mathcal{L}dt = 2.0$ fb^{-1} : Search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$





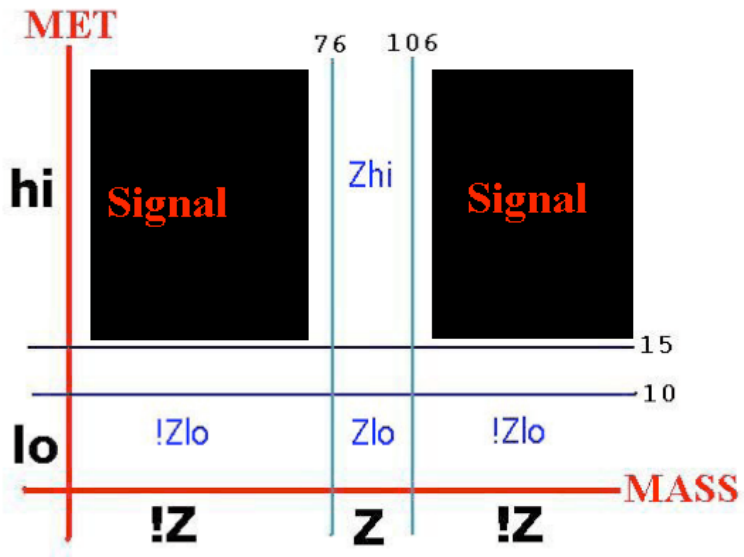
Trilepton Control Regions

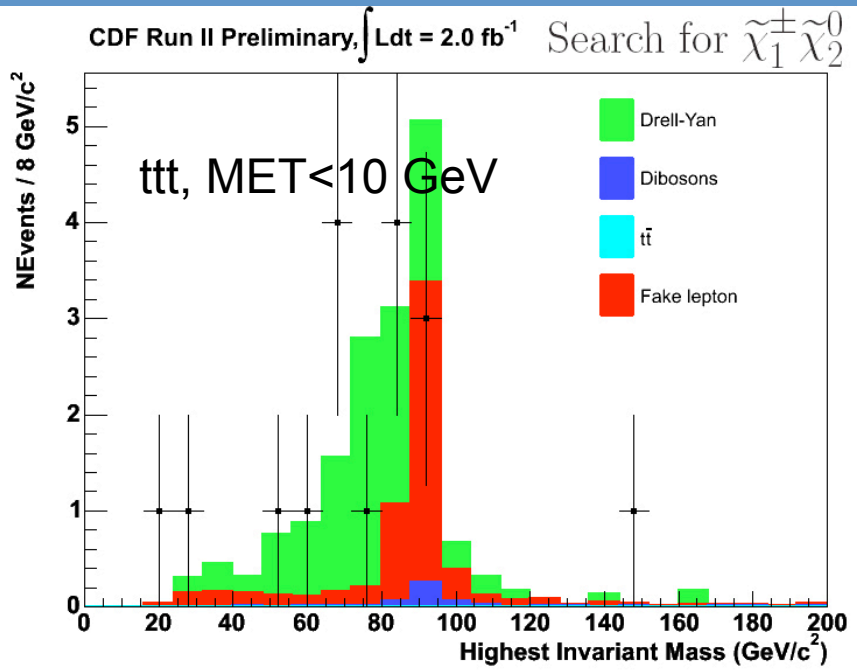
Further test backgrounds in trilepton control regions

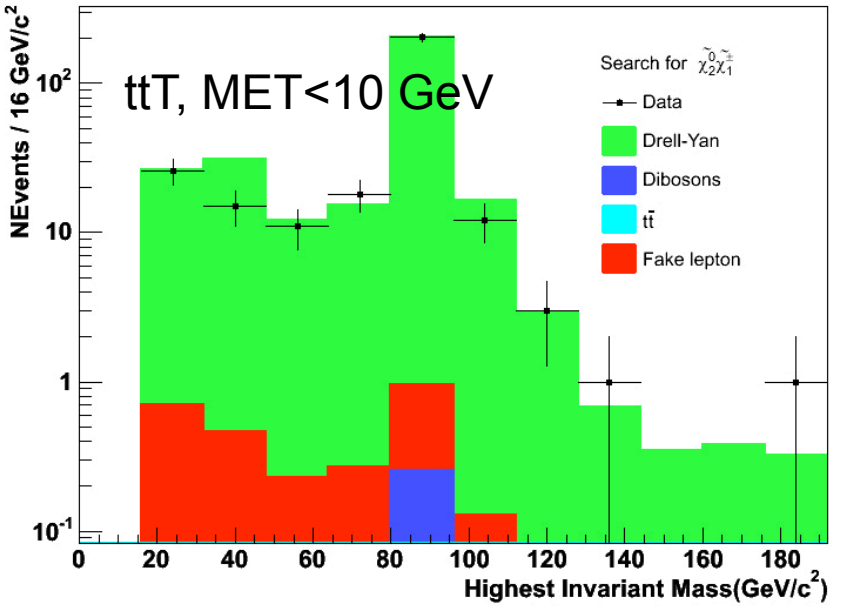
In three-lepton channels, PYTHIA DY background is really DY + FSR photon (ISR photons are 'fakes')

In dilepton+track, PYTHIA DY weighted by data-driven isolated track rate

CDF RUN II Preliminary $\int \mathcal{L}dt = 2.0$ fb^{-1} : Search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$



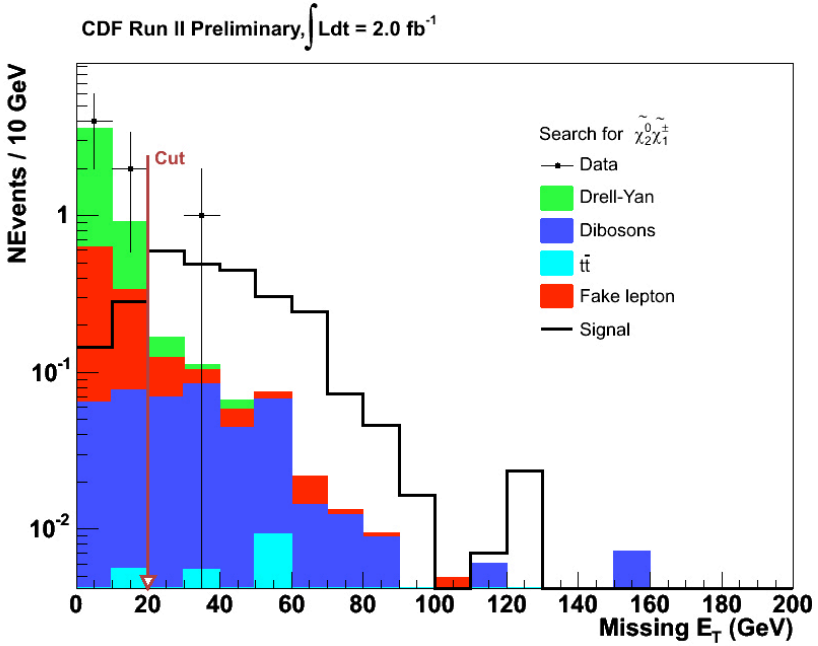


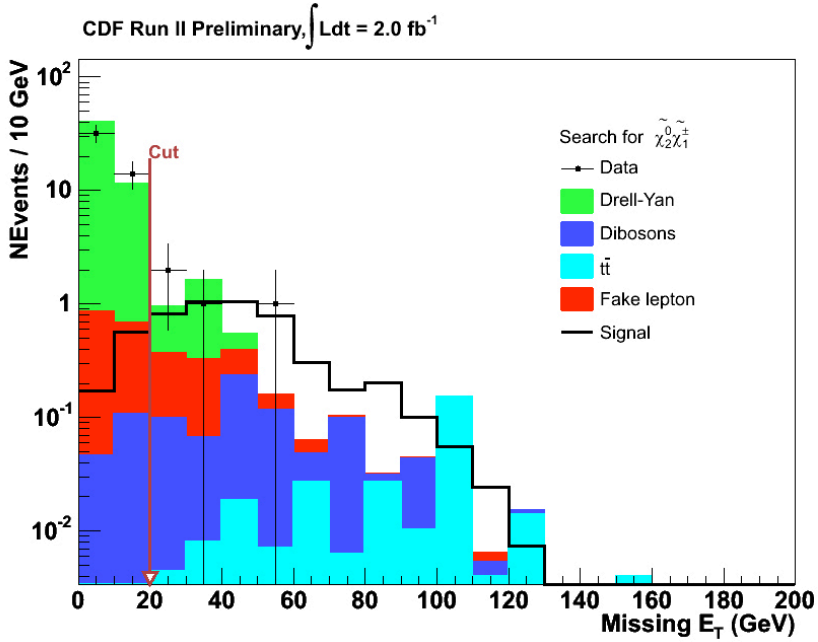


Trilepton Results

CDF RUN II Preliminary $\int \mathcal{L}dt = 2.0$ fb^{-1} : Search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$

Channel	Signal	Background	Observed
3tight	$2.25 \pm 0.13(\text{stat}) \pm 0.29(\text{syst})$	$0.49 \pm 0.04(\text{stat}) \pm 0.08(\text{syst})$	1
2tight,1loose	$1.61 \pm 0.11(\text{stat}) \pm 0.21(\text{syst})$	$0.25 \pm 0.03(\text{stat}) \pm 0.03(\text{syst})$	0
1tight,2loose	$0.68 \pm 0.07(\text{stat}) \pm 0.09(\text{syst})$	$0.14 \pm 0.02(\text{stat}) \pm 0.02(\text{syst})$	0
Total Trilepton	$4.5 \pm 0.2(\text{stat}) \pm 0.6(\text{syst})$	$0.88 \pm 0.05(\text{stat}) \pm 0.13(\text{syst})$	1
2tight,1Track	$4.44 \pm 0.19(\text{stat}) \pm 0.58(\text{syst})$	$3.22 \pm 0.48(\text{stat}) \pm 0.53(\text{syst})$	4
1tight,1loose,1Track	$2.42 \pm 0.14(\text{stat}) \pm 0.32(\text{syst})$	$2.28 \pm 0.47(\text{stat}) \pm 0.42(\text{syst})$	2
Total Dilepton+Track	$6.9 \pm 0.2(\text{stat}) \pm 0.9(\text{syst})$	$5.5 \pm 0.7(\text{stat}) \pm 0.9(\text{syst})$	6

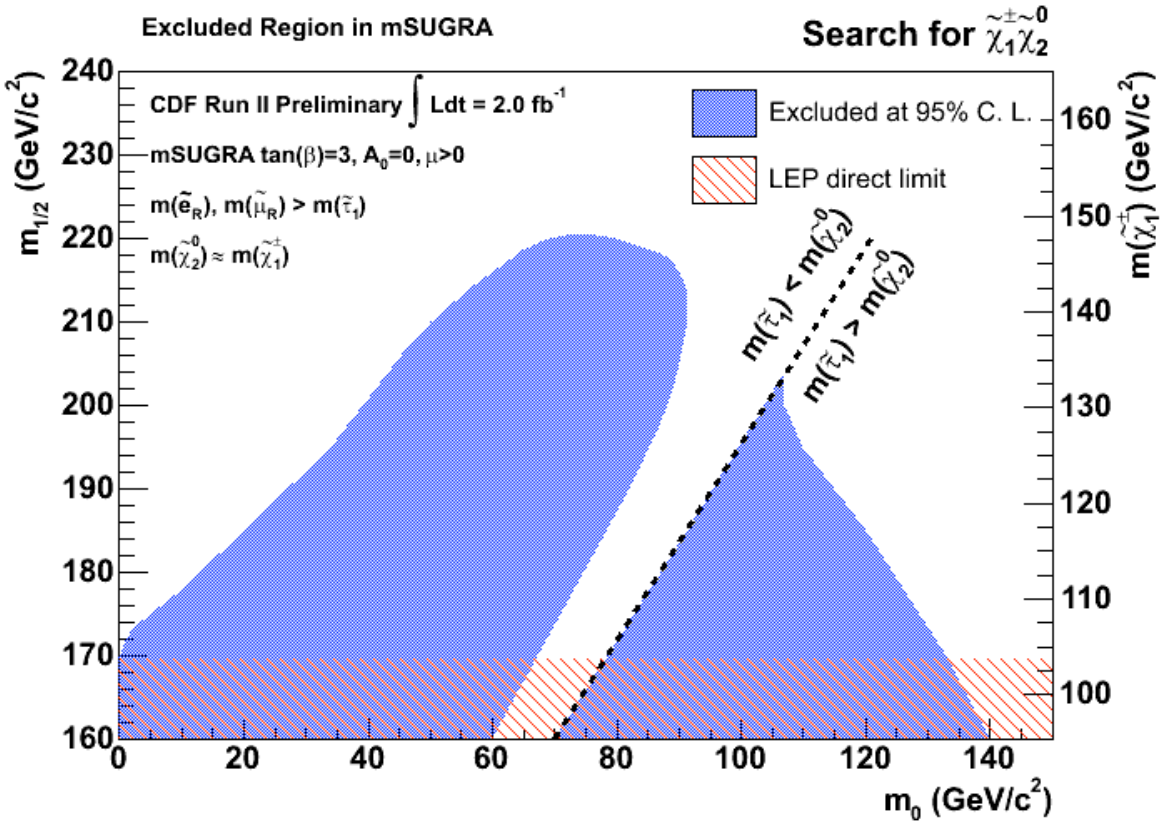


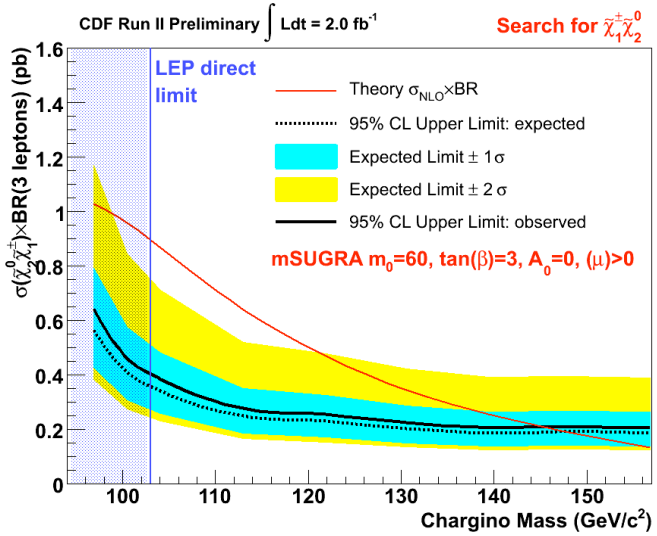


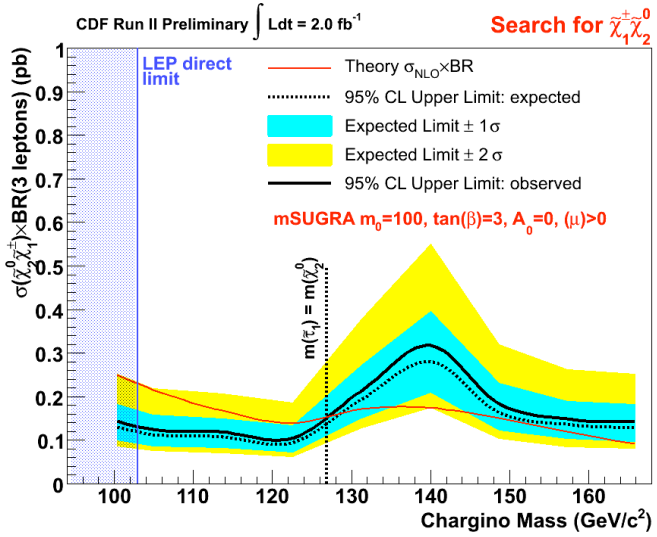
mSUGRA Interpretation

Theory cross section times BR from PROSPINO2 + ISASUGRA 7.75

Mass limits on χ_1^+ and exclusion in $m_{1/2}$ vs m_0





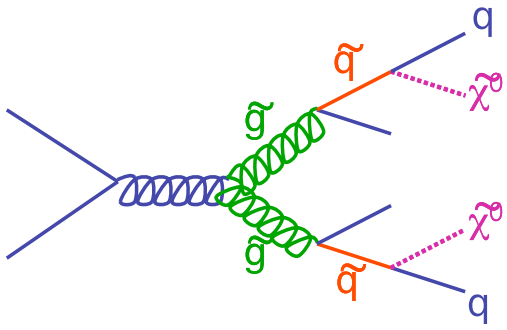


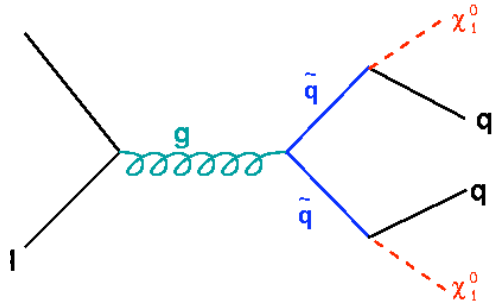
Squark/Gluino Production

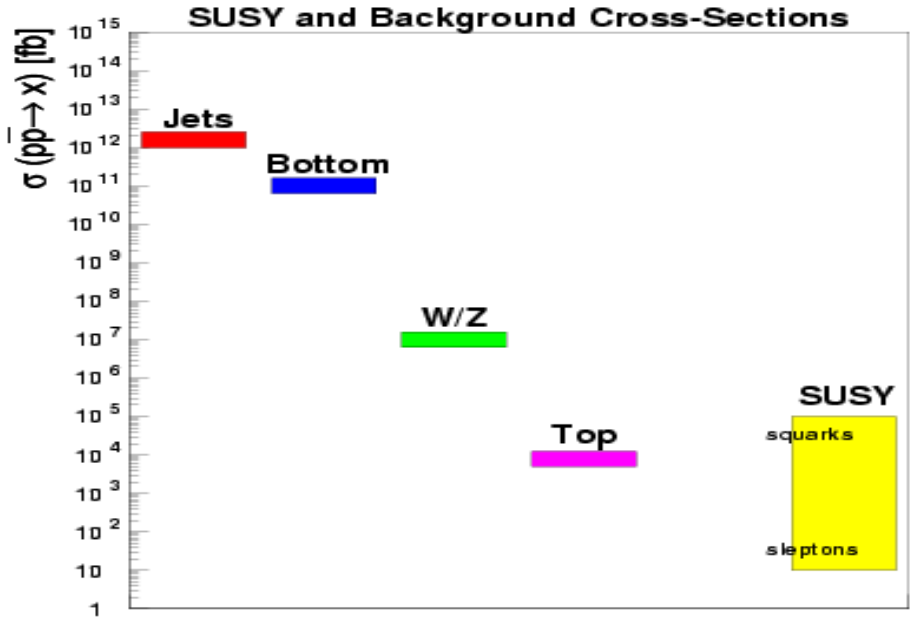
Pair production of strongly-coupled sparticles (gluinos or squarks)

Signature is multiple energetic jets and large missing energy
Three channels : at least 2, 3, or 4 jets

Cleanup cuts on jet EM and charged fraction to remove cosmics/halo







Signal : PYTHIA+ISASUGRA

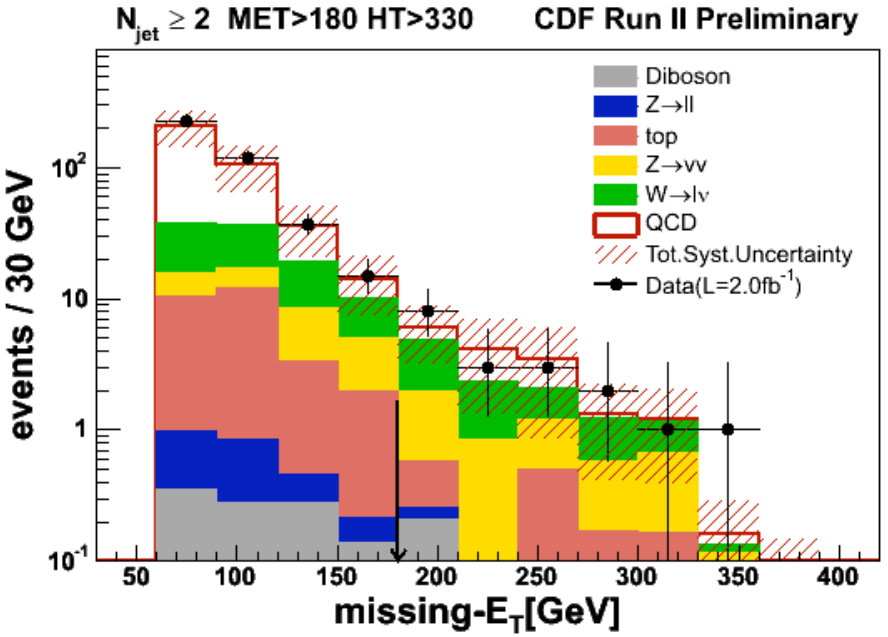
QCD (fake MET) : PYTHIA normalized in low-MET region (10's of millions of events)

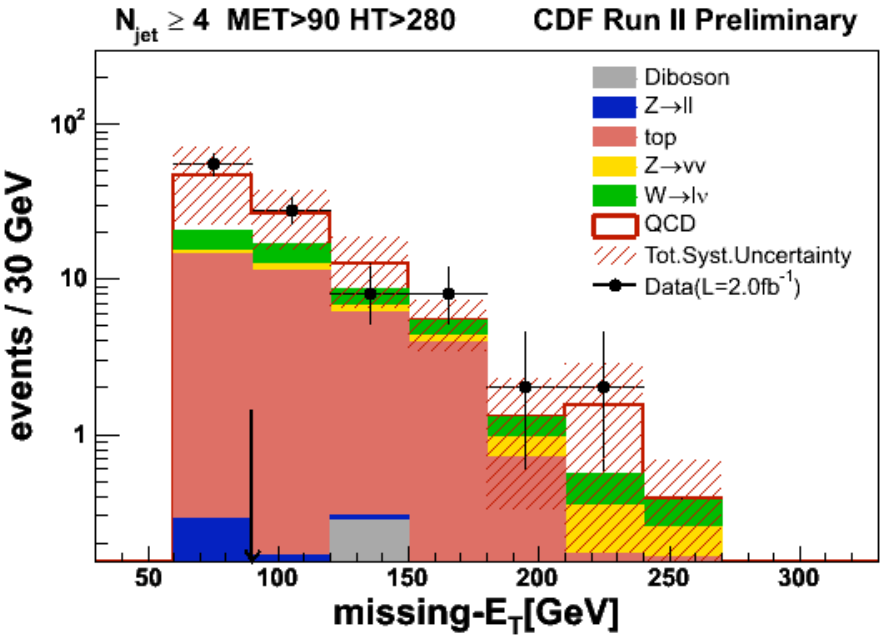
W/Z+jets : ALPGEN+PYTHIA, MLM-matched

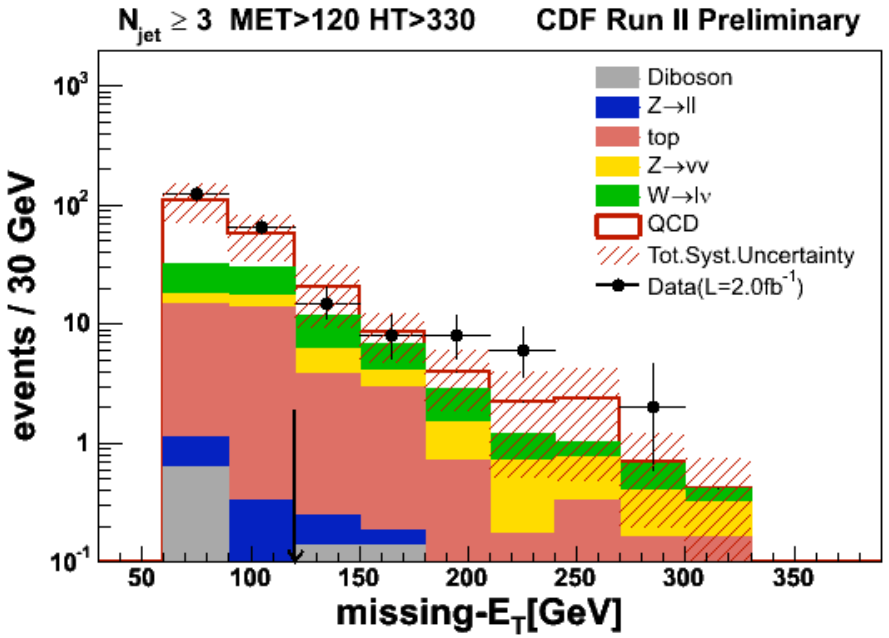
Diboson, Top : PYTHIA + NLO cross sections

Squark/Gluino Results

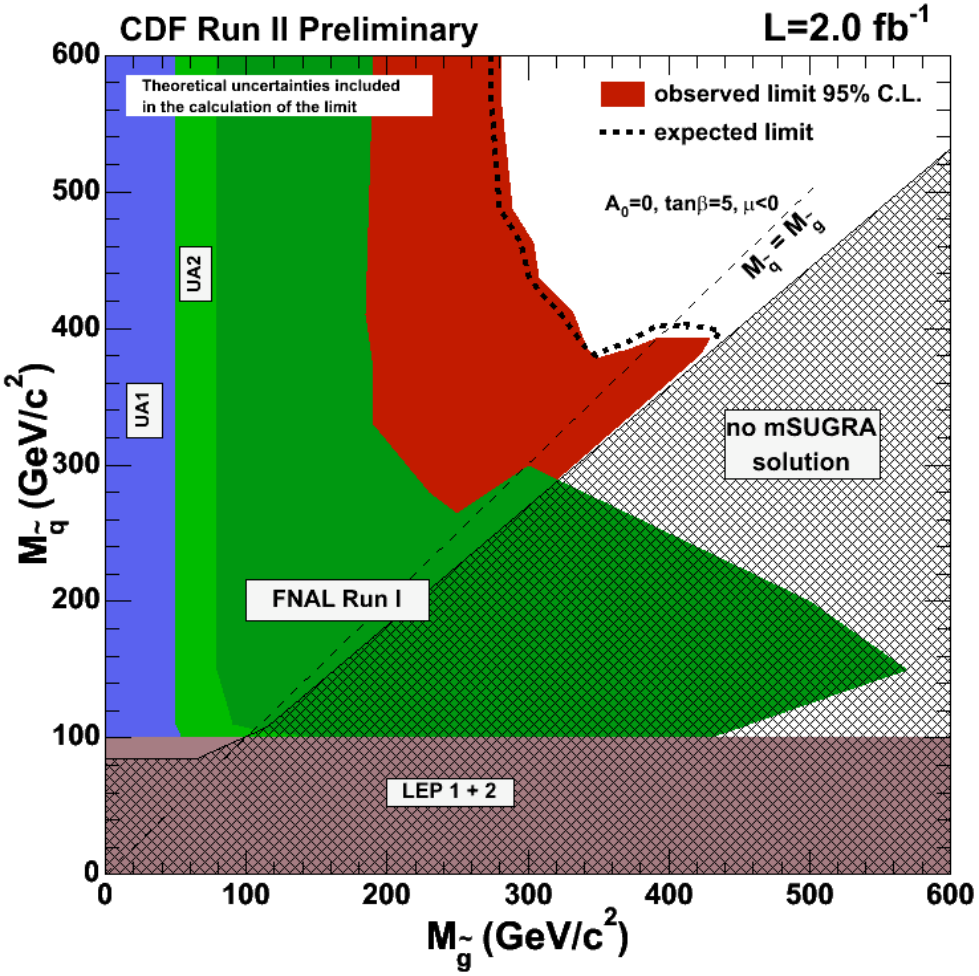
	DATA	SM Expected
≥ 4 jets	45	48 ± 17
≥ 3 jets	38	37 ± 12
≥ 2 jets	18	16 ± 5





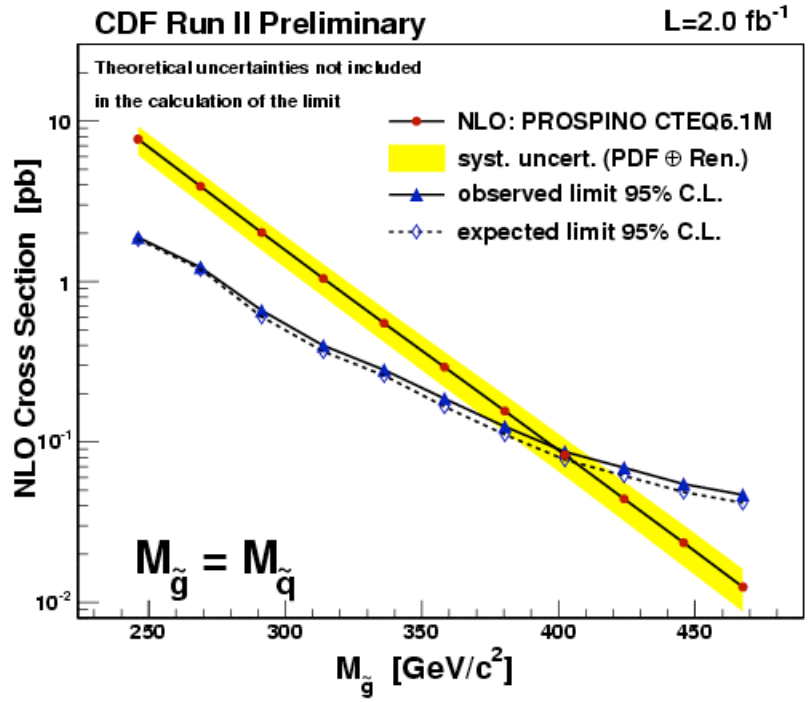


Squark/Gluino Limits



Cross sections from PROSPINO2 using ISASUGRA 7.74 mass spectrum ($A_0 = 0$, $\tan\beta = 5$, $\mu < 0$)

Use channel with best sensitivity at each test point

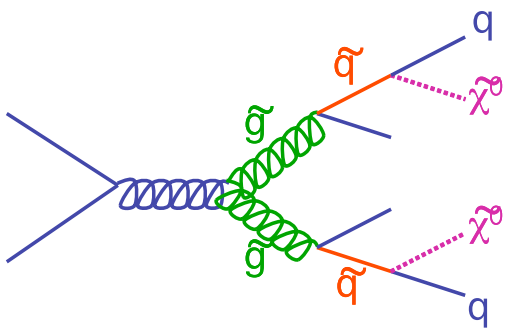


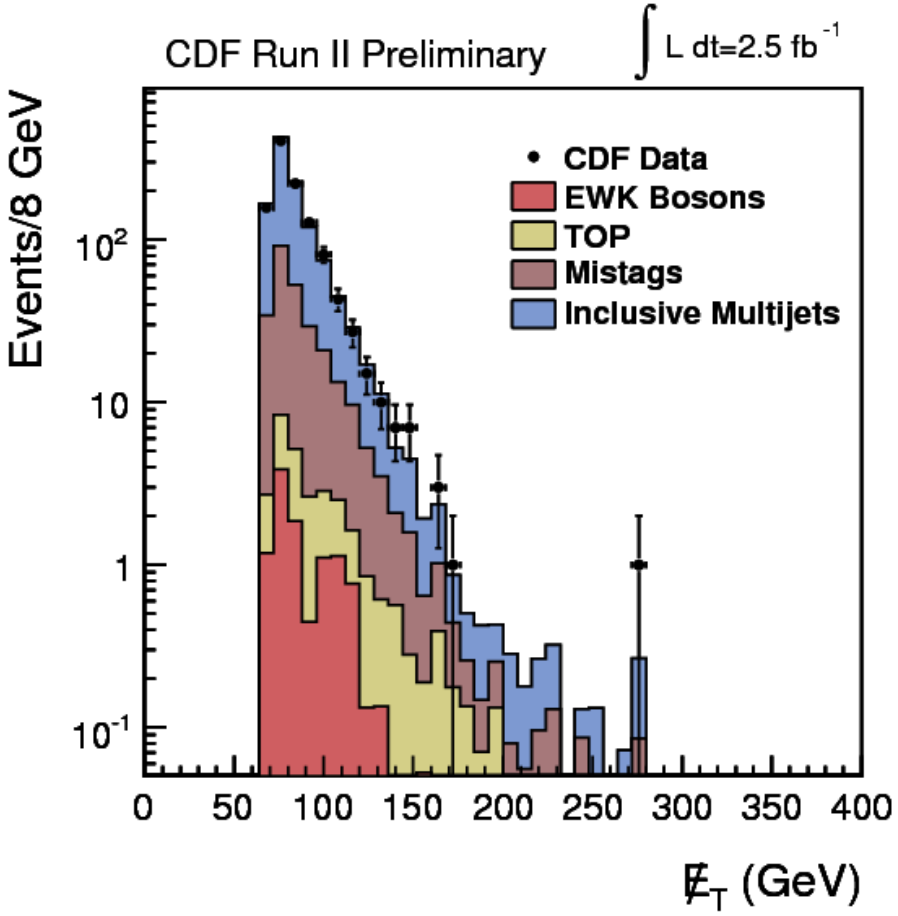
For $M_{squark} \sim M_{gluino}$, $M > 392$ GeV
Exclude $M < 280$ GeV in any scenario

Gluino-Mediated Sbottom Production

If sbottom is lightest squark, SM quarks in final state are b-quarks

Improve S/B with b-tagging



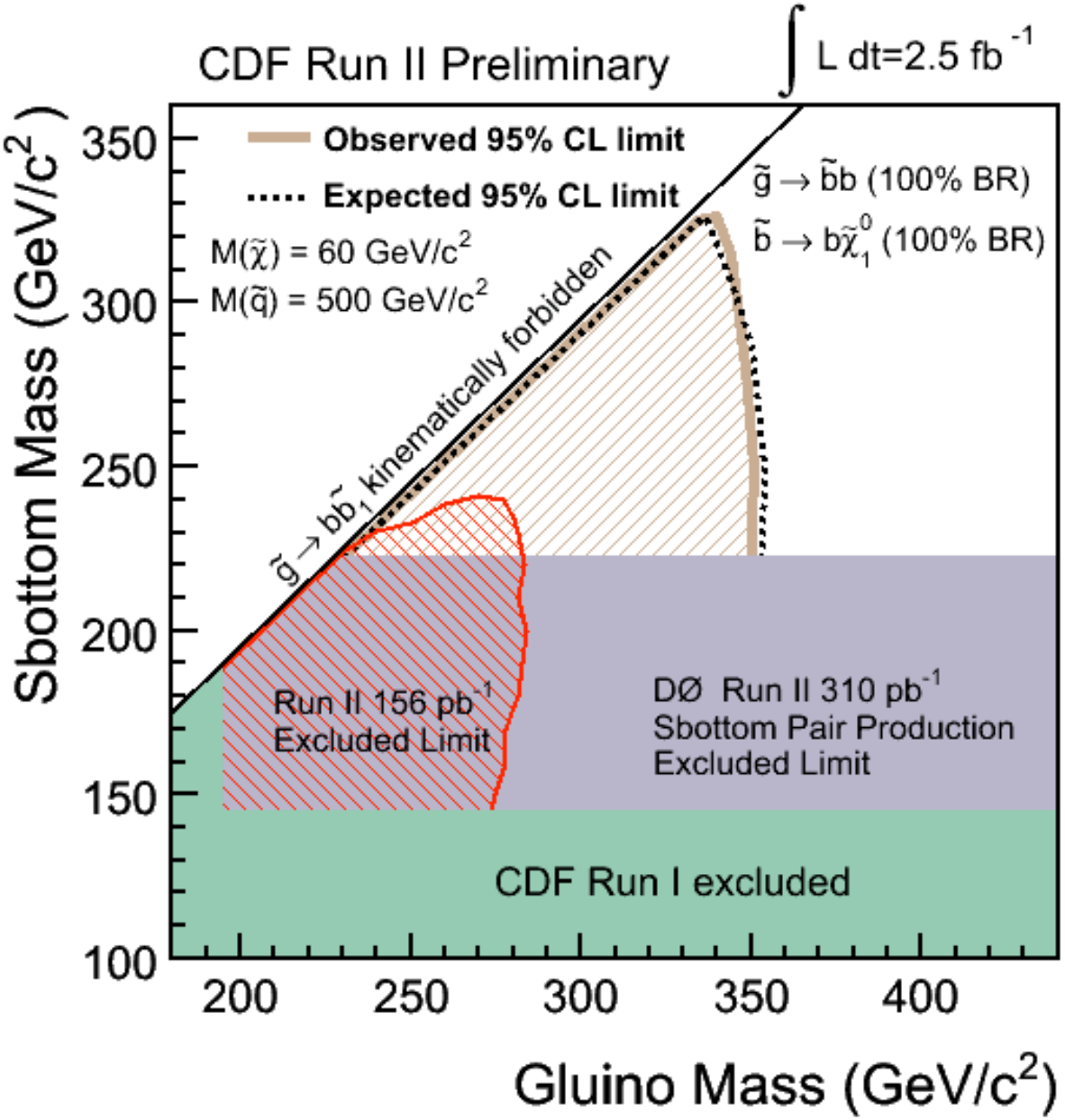


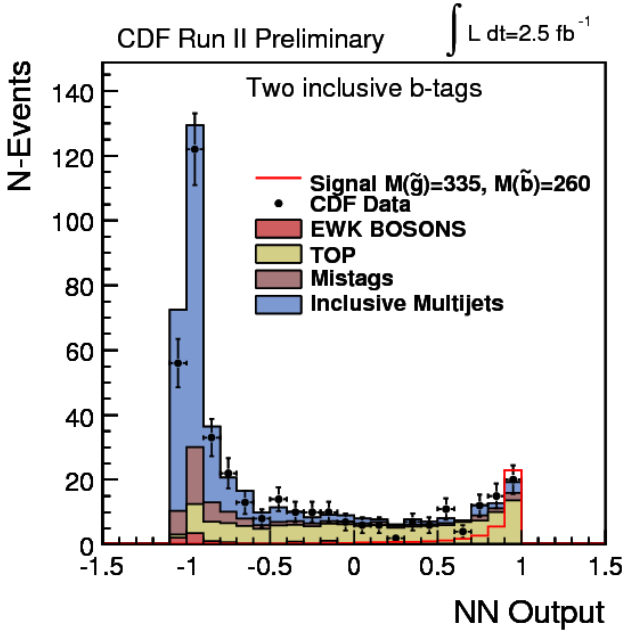
MET > 70 GeV
Two jets with E_T > (35,25) GeV
Two b-tagged jets

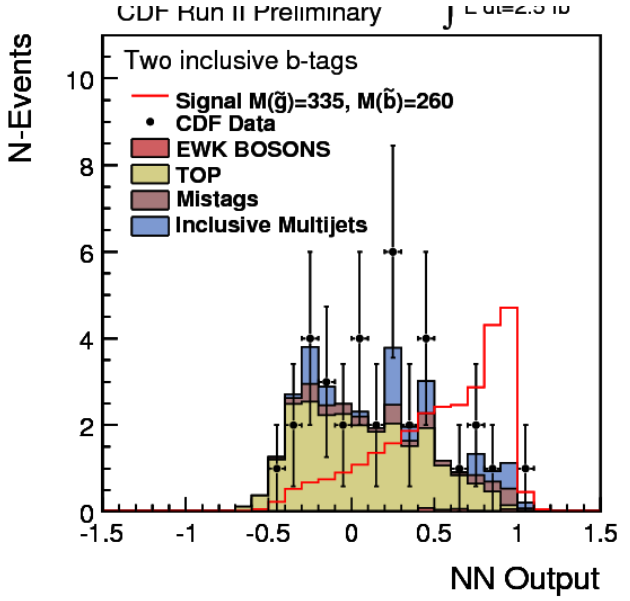
Top, EWK : PYTHIA + NLO
Mistags : data-driven
Multijets : HF-only, data-driven

Used PYTHIA in the past for 'multijets', became too computationally intensive

Sbottom Results





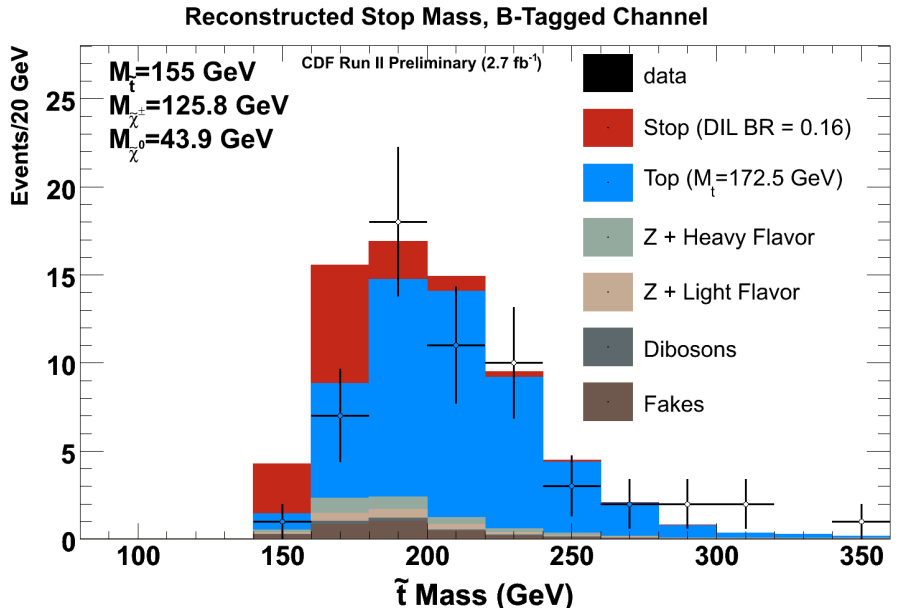


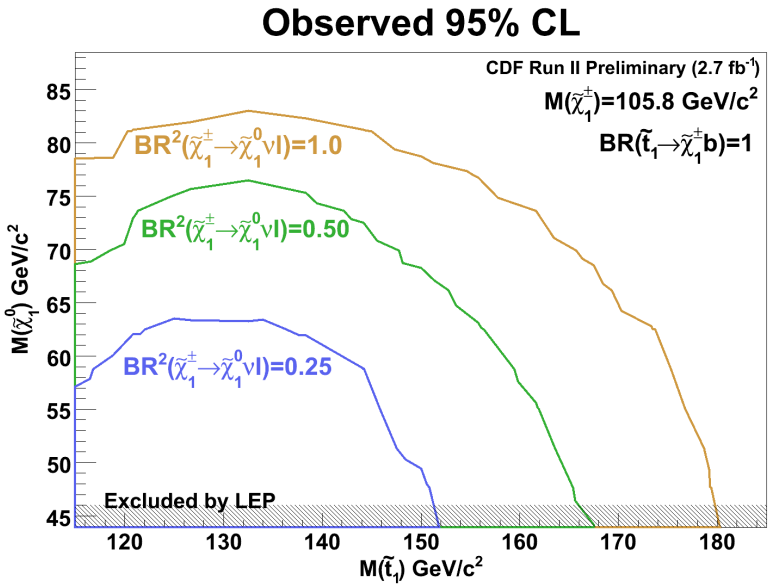
Stop Pair Production

Top dilepton sample is mixture of top/stop?

Assume BR(t~ → χ_1^+ b) = 100%
BR(χ_1^+ → l$\nu\chi_1^0$) depends on m(χ_1^+) - m(χ_1^0), other SUSY parameters

Two leptons with p_T > 20 GeV
MET > 20 GeV
Two jets, split into b-tagged /untagged
H_T < 200-300 GeV (function of $\Delta\phi$'s)





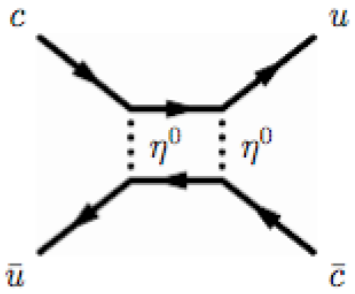
Mass reconstruction analogous to neutrino-phi technique used for m_t
m(W) → m(χ_1^+)
neutrinos → massive $\chi_1^0\nu$ system

Resulting spectrum consistent with top only

Limits in m(χ_1^0) vs m(t~) plane for fixed m(χ_1^+), varying BR's

Maximal Flavor Violation

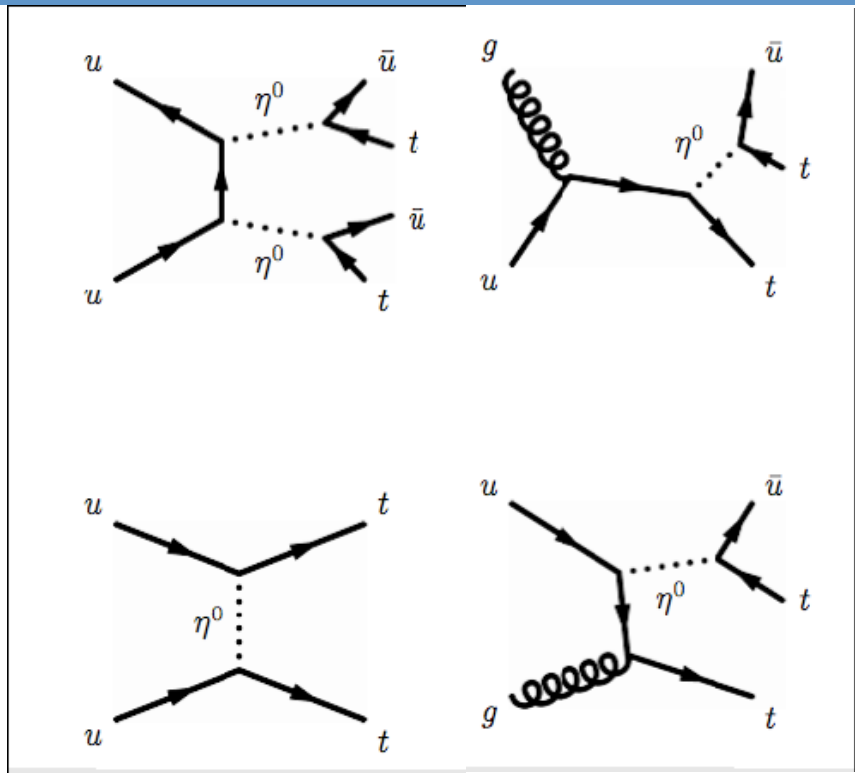
Flavor-violation limits are on products of mixing matrix elements (arXiv/0711.3193, Bar-Shalom & Rajaraman)



$$\begin{pmatrix} 0 & 0 & \xi_{13} \\ 0 & 0 & \xi_{23} \\ 0 & 0 & 0 \end{pmatrix}$$

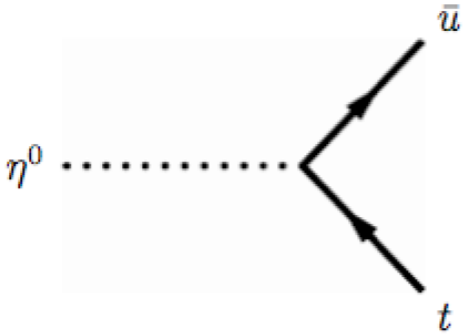
$\Phi_{FV} = (\eta^+, \eta^0)$

$$\mathcal{L}_{FV} = \xi_{ij} \bar{Q}_{iL} \tilde{\Phi}_{FV} u_{jR} + h.c.$$



No constraints on scenarios with neutral scalars if charged partner has m>600 GeV

$$\xi = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$



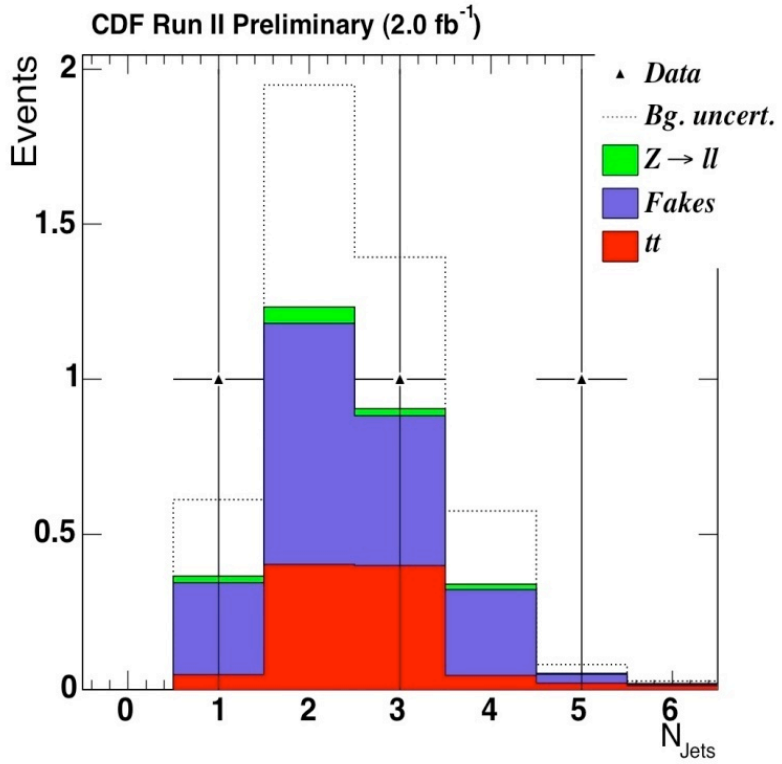
Produce same-sign top pairs (and extra jets)

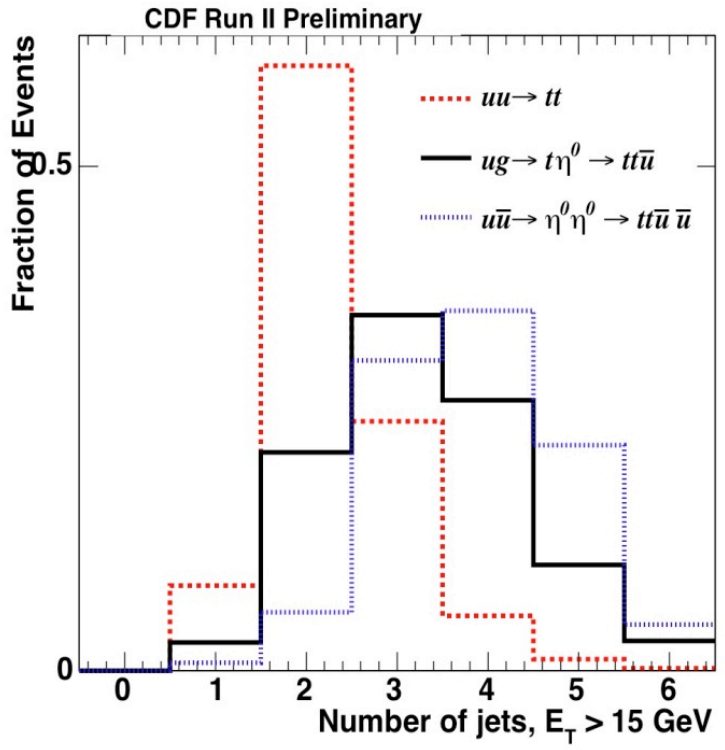
Cross sections ~0.5 pb each

MxFV Results

Event selection very like top-dilepton
Two **same-charge** leptons with p_T > 20 GeV
MET > 20 GeV
At least one b-tagged jet

Signal model : CalcHEP (LHA files) +
CDF default PYTHIA+TAUOLA+EvtGen





$Z \rightarrow \ell\ell$: ALPGEN+PYTHIA
$t\bar{t}$: PYTHIA + NLO cross section
Fakes : data-driven (primarily W+jets)

No excess observed at high Njet
Exclude ξ > 0.85 for $m_{\eta 0}$ = 200 GeV

Conclusion

- CDF is searching for new physics in many channels

- Signature-based searches in unique final states
  - High-mass region, combinations of objects, …
- Searches inspired by a particular model
  - SUSY, MxFV, technicolor, LED, leptoquarks, …

- Many more results than shown here
- No sign of new physics so far

- Monte Carlo simulations of SM backgrounds are working well
- Signature-based searches generally use PYTHIA models as benchmarks
- Capability exists to compare against any model should the need arise