Searches for Physics Beyond the Standard Model at CDF

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On behalf of the CDF collaborations

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Beyond SM: the unknown

Good reasons to believe there is unknown physics beyond the Standard Model

- Many possible new particles and theories
  - Supersymmetry
  - Extra Dimension
  - New Gauge groups (Z', W')
  - New fermions (e*, t', b' …)
  - …

Can show up in direct searches or as subtle deviations in precision measurements

→ **Model-inspired searches**
- Theory driven
- Model-dependent optimization of event selection
- Set limits on model parameters

→ **Signature-based searches**
- Signature driven
- Optimize selection to reduce backgrounds
- Event count; event kinematics

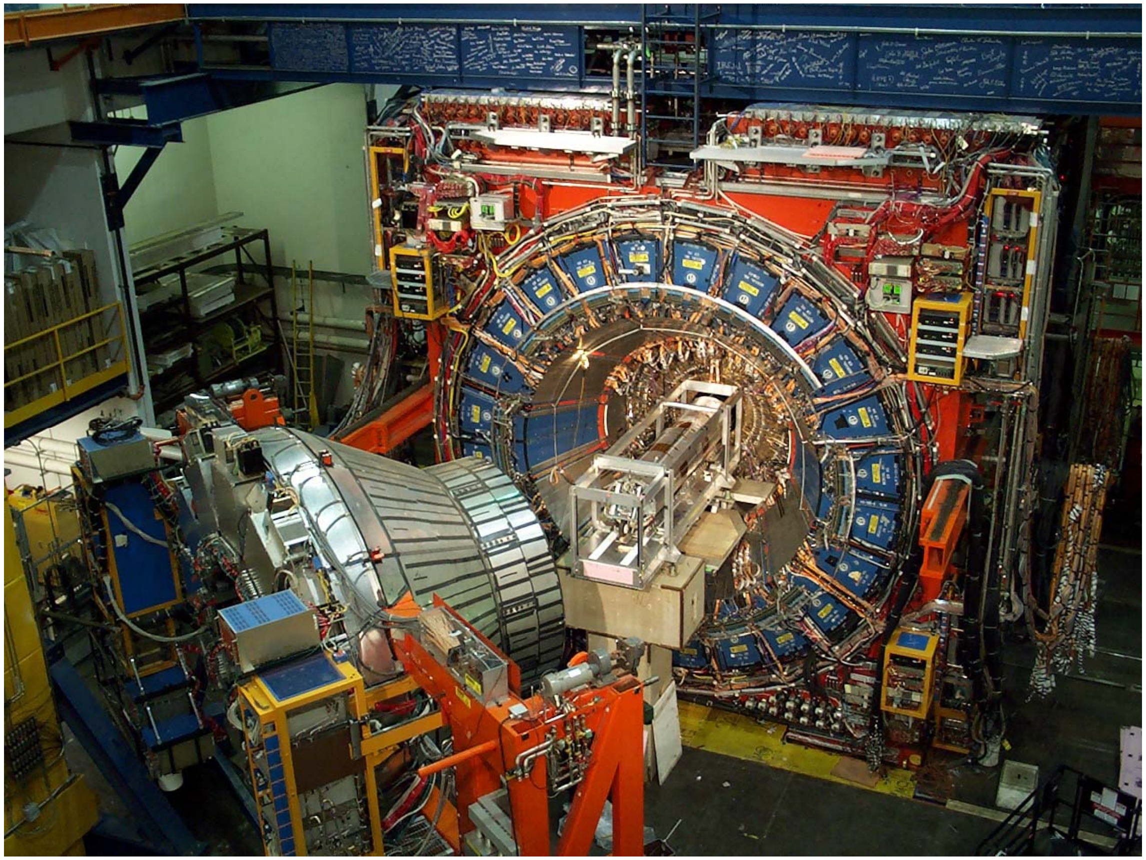
Outline

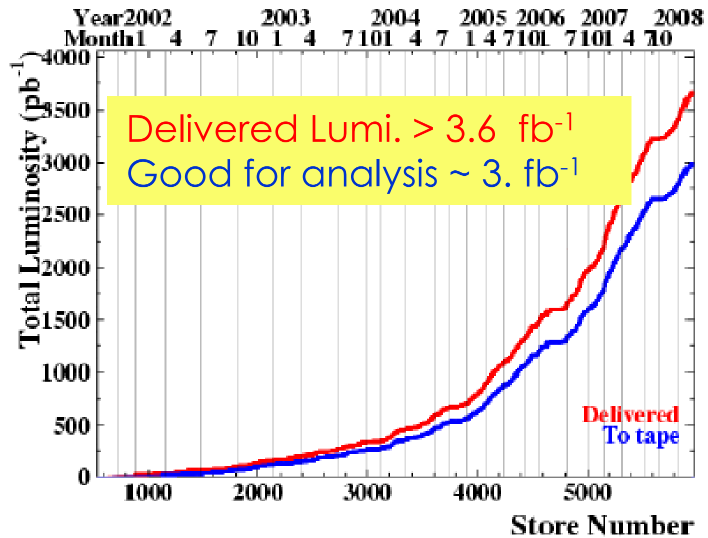
- Overview of the CDF experiment
- Model-inspired searches:
  - mSUGRA:
    - Chargino/neutralino
    - Squark/gluino
    - Stop/Sbottom
  - W' → $t\bar{b}$
  - Flavor Changing Neutral Current: $t \rightarrow Zq$
  - MSSM Higgs
- Signature-based searches
  - High Mass resonances: Dielectron, dijet
  - $\gamma + \not{E}_T$, $\gamma\gamma + \not{E}_T$, $\gamma\gamma + \tau$
- Emphasize new results based on $\int L \geq 1$ fb^{-1} of data
- Underlying problems and issues in terms of MC tools

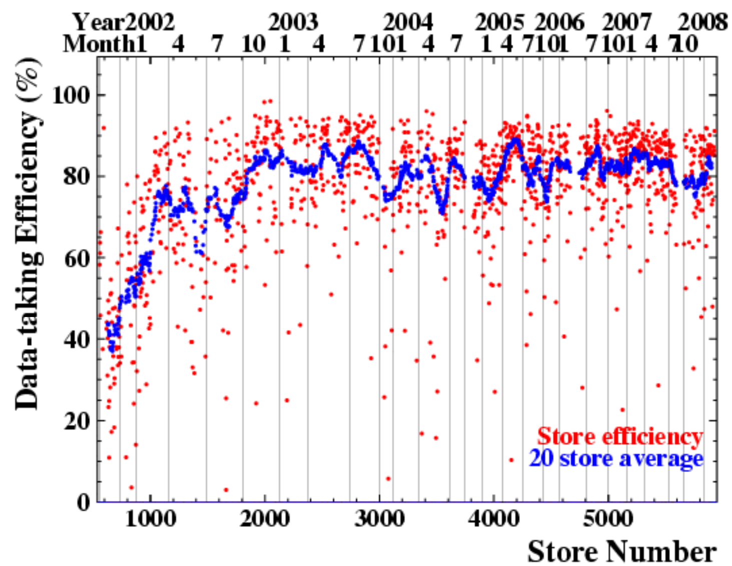
CDF results

http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-cdf.fnal.gov/physics/new/hdg/hdg.html
http://www-cdf.fnal.gov/physics/new/top/top.html

The CDF experiment







- Multipurpose detector
- Recording data with high **efficiency (~85%)** and making full use of detector capabilities.

Model-inspired searches

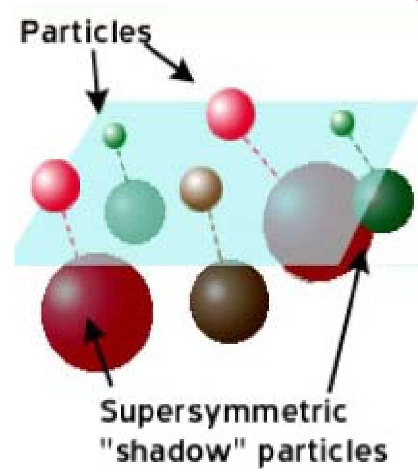
Supersymmetry

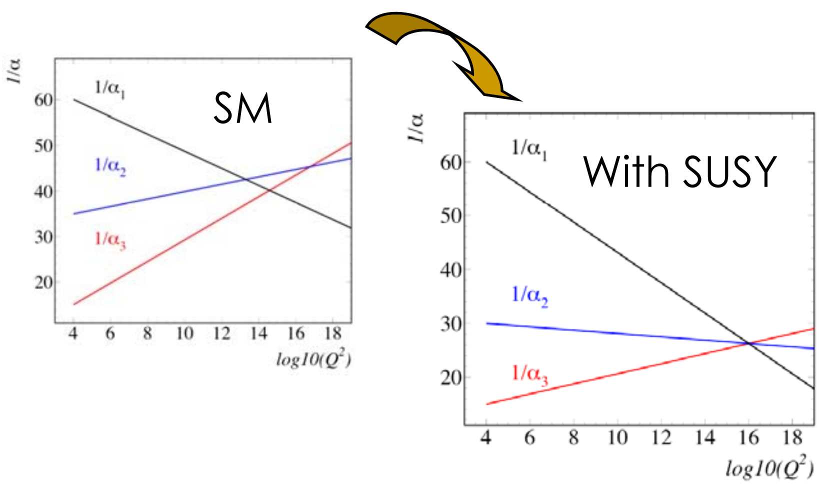
- New symmetry relating fermions and bosons to cancel out contributions to Δm^2_H : **Supersymmetry**

Q|Boson> = Fermion **Q|Fermion> = Boson**

- Minimal SuperSymmetric SM (MSSM):
  - Mirror spectrum of particles
  - Enlarged Higgs sector (two doublets with 5 physical states)
- Define R-parity = $(-1)^{3(B-L)+2s}$
  - R = 1 for SM particles, R = -1 for MSSM partners

→ if R-parity conserved, sparticles produced in pair, LSP stable





- Unifications of forces possible
- Provide a suitable candidate for Dark matter:
  - LSP stable if R-parity is conserved
  - Typically LSP is the lightest neutralino
  - Current mass limit > 43 GeV
  - Abundance of neutralino matches Dark Matter density in the Universe

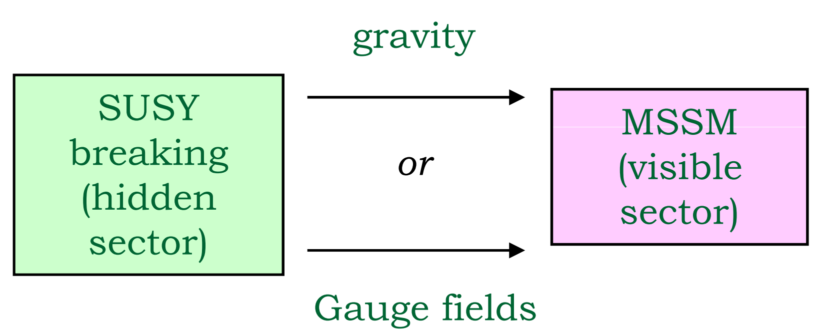
Symmetry breaking

No SUSY particles found as yet:

- SUSY must be broken: breaking mechanism determines phenomenology and search strategy at colliders
- More than 100 parameters even in minimal (MSSM) models!

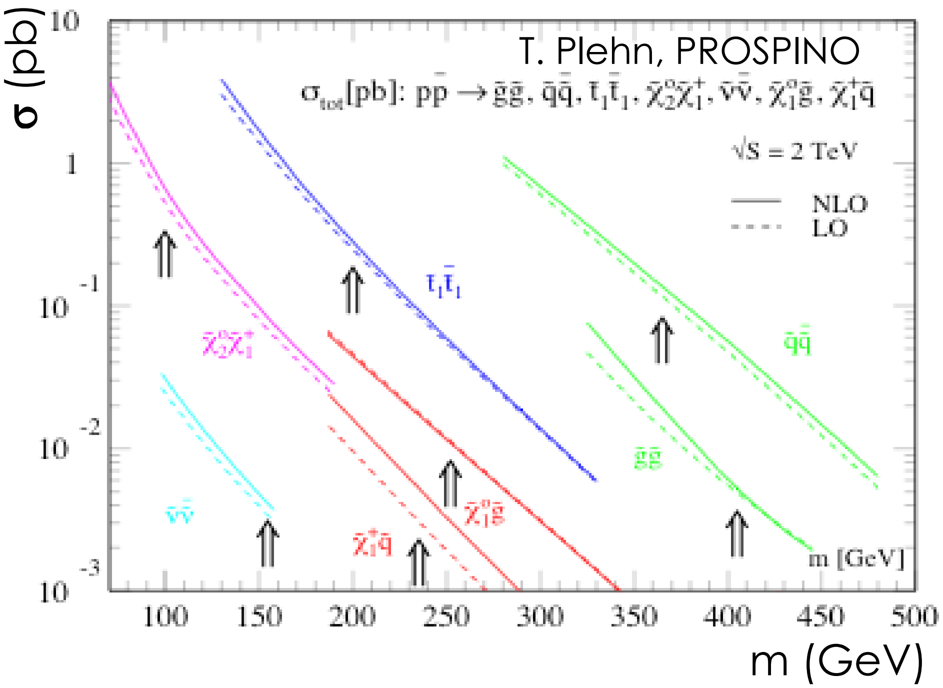
choose a model

- **mSUGRA** (gravity-mediated susy breaking)
  - Neutralino is the LSP
  - Common scalar and gaugino masses (5 parameters at GUT scale)
  - Many possible final states
- **GMSB** (gauge-mediated susy breaking)
  - Gravitino is the LSP
  - Photons from $\chi \rightarrow G\gamma$ in the final states
- **AMSB** (anomaly-mediated susy breaking)
- **Split SUSY**

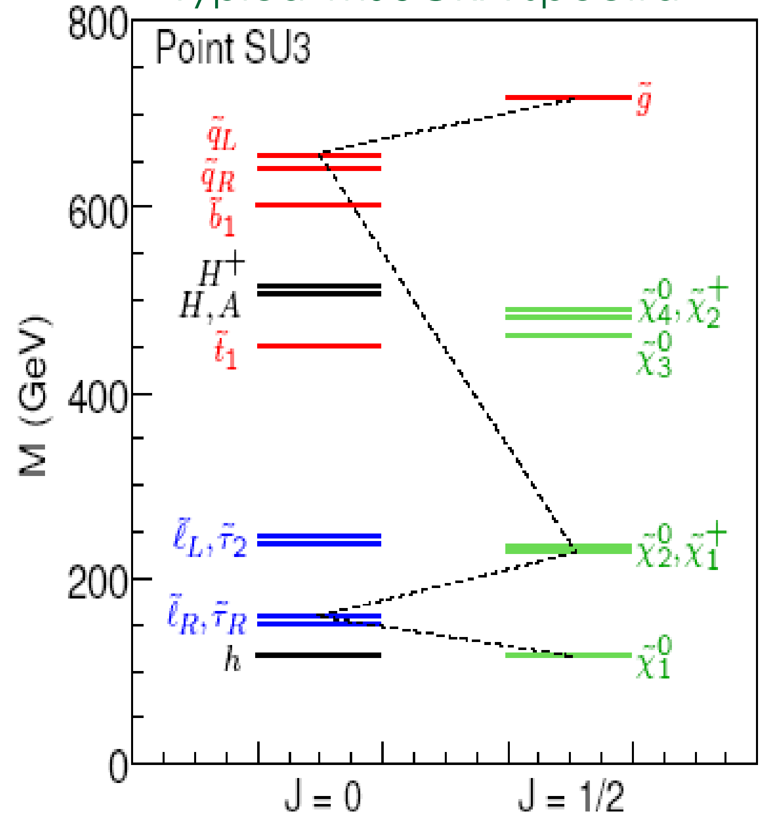


R-parity
- conserved: sparticles produced in pairs
- Not-conserved: single sparticle production, constrained by proton decay

mSUGRA: Sparticles cross sections and spectrum



Typical mSUGRA spectra



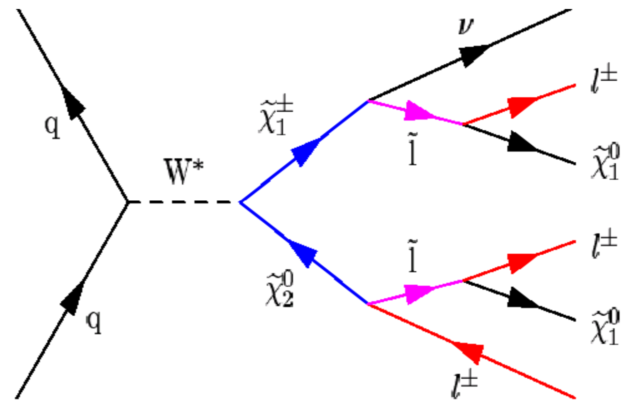
- Squarks and gluinos are heavy
- Chargino/neutralino cross sections are sizeable
- mixing of third generation leads to light stop/sbottom and stau
- One higgs is very light (< 135 GeV)

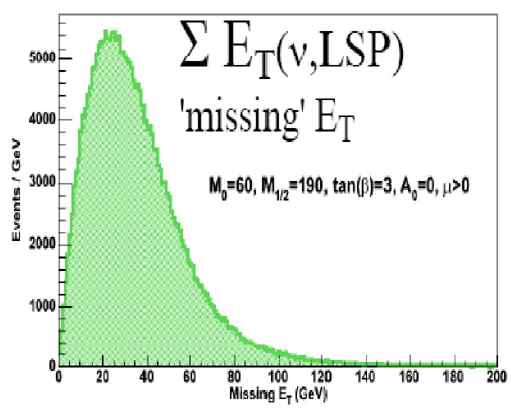
Typical signature at colliders: large transverse energies and large missing E_T.

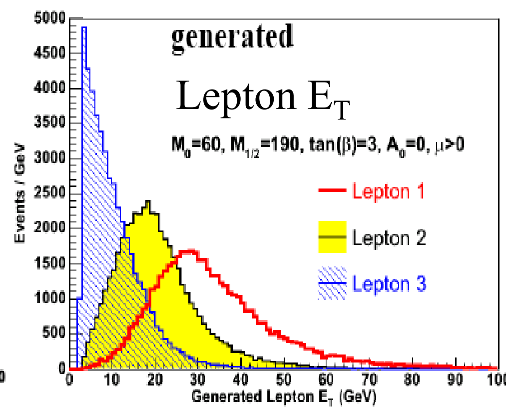
Search for chargino/neutralino

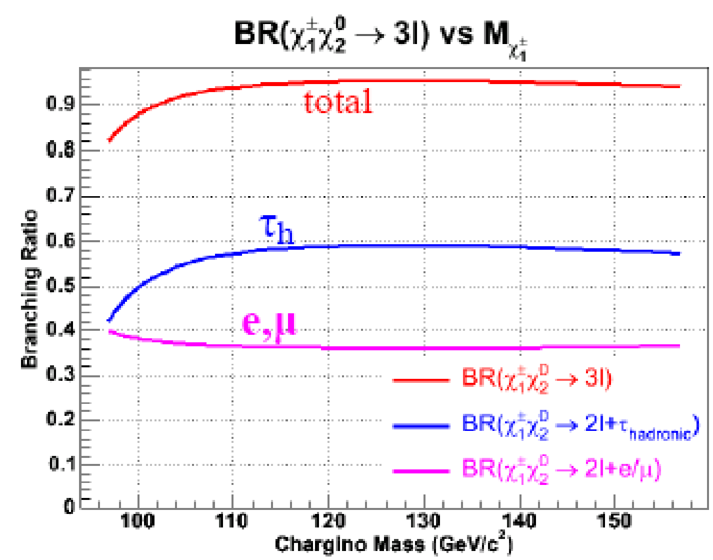
2 fb^{-1}

- mSUGRA $\chi^0_2 \chi^\pm_1$ pair production
  - Signal generated with PYTHIA Tune A (Isasugra v7.51), rescaled to NLO PROSPINO cross section
- Signature: three leptons and significant missing transverse energy ($\not{E}_T$)
  - **Small cross sections (~0.1-0.5 pb)**
  - **Very low background**



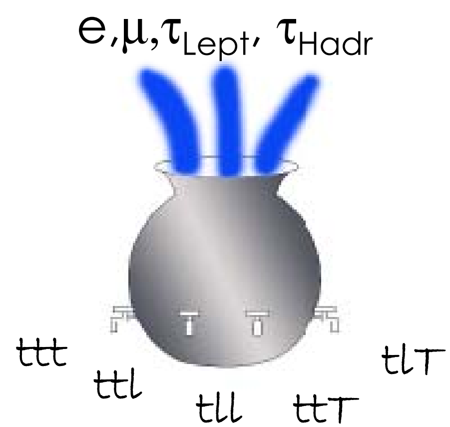






- Data collected via high p_T single lepton (18 GeV) and low p_T dilepton (4 GeV) trigger paths
- Hadronic decaying τ as "isolated tracks" (T_τ)

The analysis



- **5 exclusive channels** with optimized energy lepton thresholds
- various combinations of "tight" (t) and "loose" (l) lepton categories
  - 3-leptons (e,μ,τ_{Lept})
  - 2-leptons (e,μ,τ_{Lept}) + iso-track T (τ_{Hadr})
- Ordered in terms of **S/B**

Signal region: Missing E_T > 20 GeV + topological cuts, N_{jet}=0,1 and E_T^{jet} < 80 GeV

SM Background

MC-driven estimate

- Drell-Yan
- Diboson (*WW*, *WZ*/γ*, *ZZ*/γ*, *W*γ)
- top pair production *t-tbar*

→ **PYTHIA 6.216** **(Tune A, P_T^Z correction)**

NNLO/NLO theoretical cross sections used for absolute renormalization

Data-driven estimate

Misidentified tight/loose leptons or Iso-tracks (fakes)

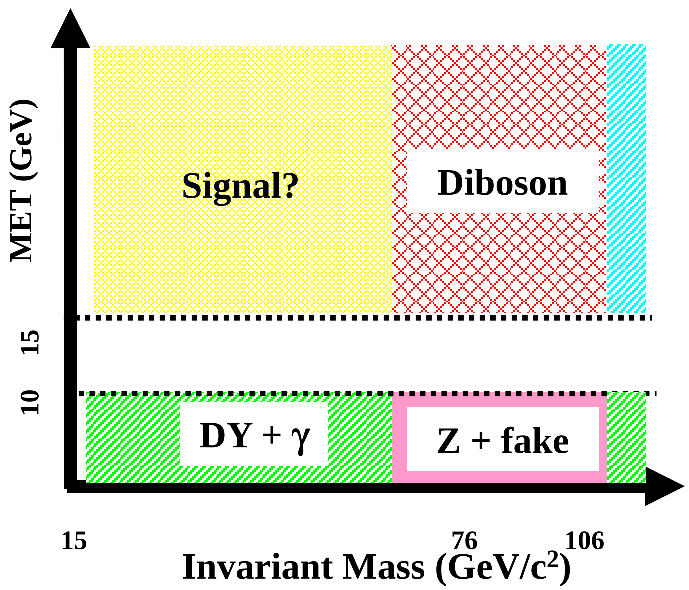
(W+jets, QCD)

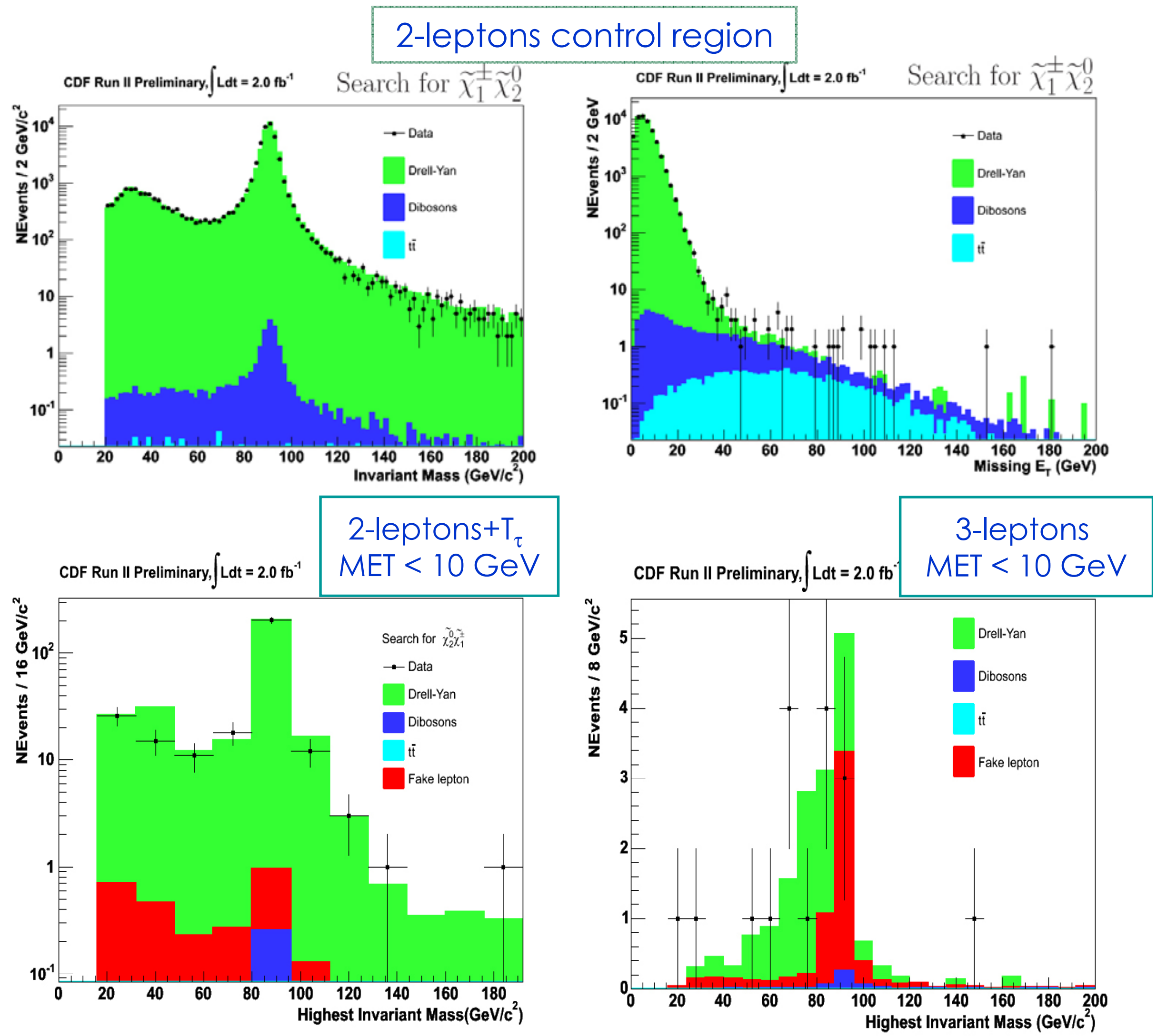
Large number of control regions defined to test SM predictions

Control regions

Dilepton and trilepton control regions defined in terms of $\not{E}_T$ and the invariant mass of the 2 leading leptons

→ **47 in total!**



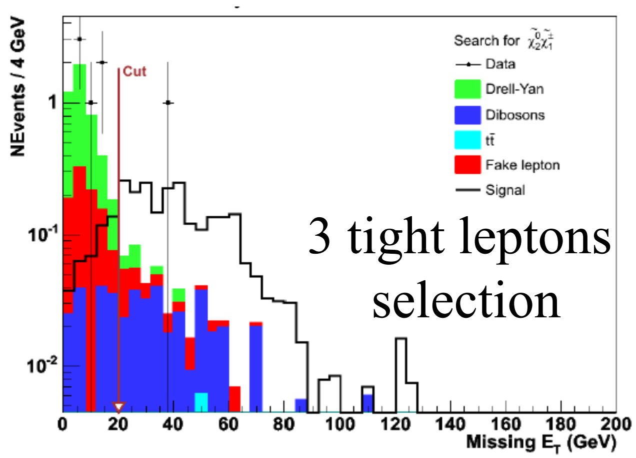


Results and exclusion limit

channel	mSUGRA Signal	SM Expected	DATA
Trilepton (3 channels)	$4.5 \pm 0.2 \pm 0.4$	$0.88 \pm 0.05 \pm 0.13$	**1**
dilepton + track (2 channels)	$6.9 \pm 0.2 \pm 0.7$	$5.5 \pm 0.7 \pm 0.9$	**6**

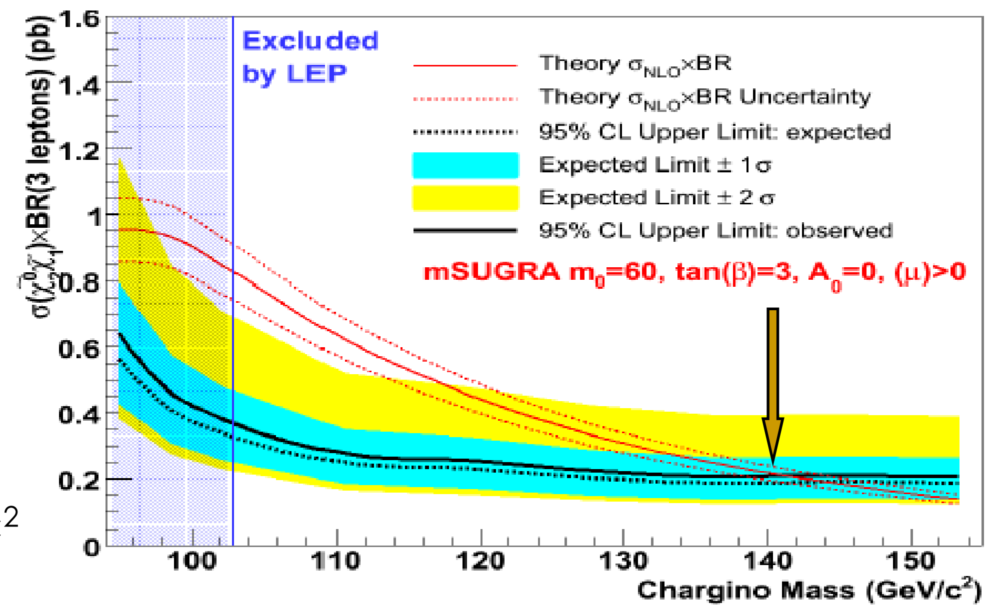
mSUGRA Benchmark:
m_0=60 GeV/c^2,
$m_{1/2}$=190 GeV/c^2,
$\tan\beta$=3, A_0=0, μ>0

Good agreement between data and SM prediction → set limit



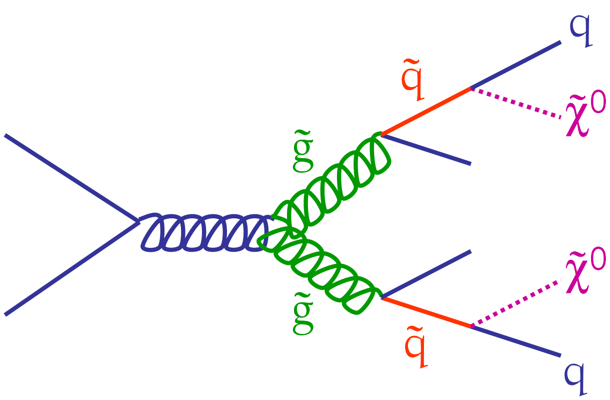
- Use Bayesian approach
- Sensitive up to 145 GeV/c^2
- Mass($\chi^{\pm}_1$) excluded up to 140 GeV/c^2

First chargino mass limit in mSUGRA scenario at the Tevatron!



Search for Squarks and gluinos

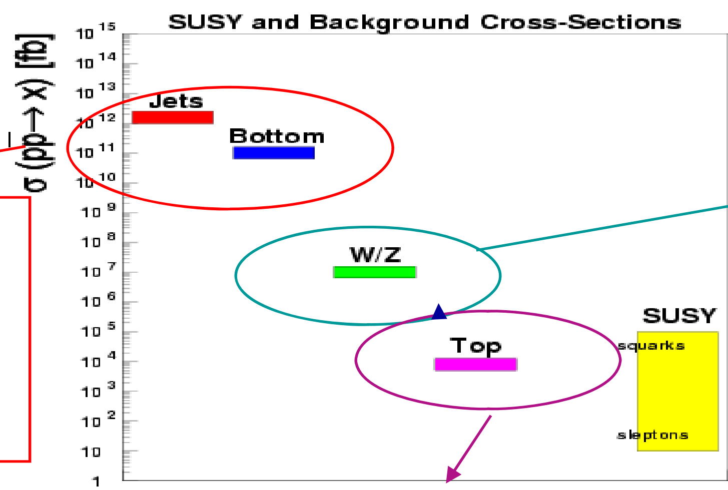
2 fb^{-1}



- ✓ pair production of gluinos and squarks
- ✓ scan across gluino/squark plane
  - ✓ PYTHIA Tune A, input masses, mixing and couplings using ISASUSY 7.74
  - ✓ Normalized to PROSPINO v2 NLO s

$\tan\beta = 5$, $A_0 = 0$, $\mu<0$
$M_0 \in [0,500$ GeV/c$^2]$
$m_{1/2} \in [50,200$ GeV/c$^2]$

✓mSUGRA signature with energetic jets of hadrons and large missing E_T (χ^0)



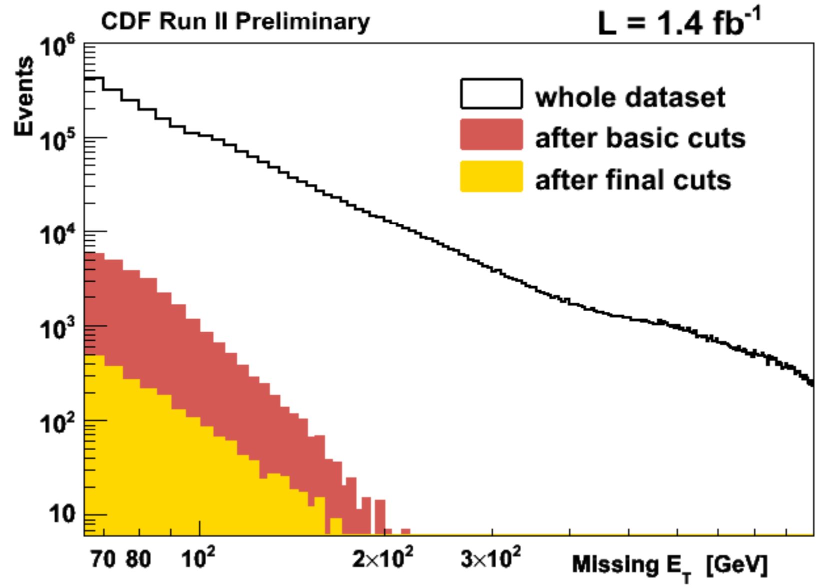
QCD multijets:
→ Missing E_T due to jet energy mismeasurements
→ use **Pythia Tune A MC** normalized to data in low-missing ET region

W→lν+jets, Z→ll+jets and Z→νν+jets:
- Use ALPGEN v2.1+PYTHIA 6.325 (MLM matching), normalized to the inclusive measured DY cross section

DiBoson
- use MC normalized to MCFM NLO cross section

- Top: use Pythia MC samples mt = 172 GeV/c^2 normalized to NLO cross section σ_{ttbar}= 7.3 pb

Background rejection



Cleanup Cuts

- at least one central jet with $|\eta|<1.1$
- minimum missing E_T of 70 GeV
- **beam-related backgrounds** and **cosmics**. Removed using vertex information, calorimeter activity with correspondent tracking activity...

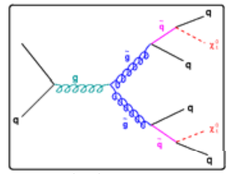
QCD rejection

- $|\Delta\phi$ (missingE_T-jets)$| > 0.7$ to avoid events where the missing E_T is due to jet enregy mismeasurement.

W/Z+jets and diboson rejection

- Electromagnetic fraction of the jets less than 90% to reject electrons mis-identified as jets
- $|\Delta\phi$ (missingE_T-isolated track)$| > 0.7$ to reject events with MET due to undetected muons
- Z veto applied

Optimization

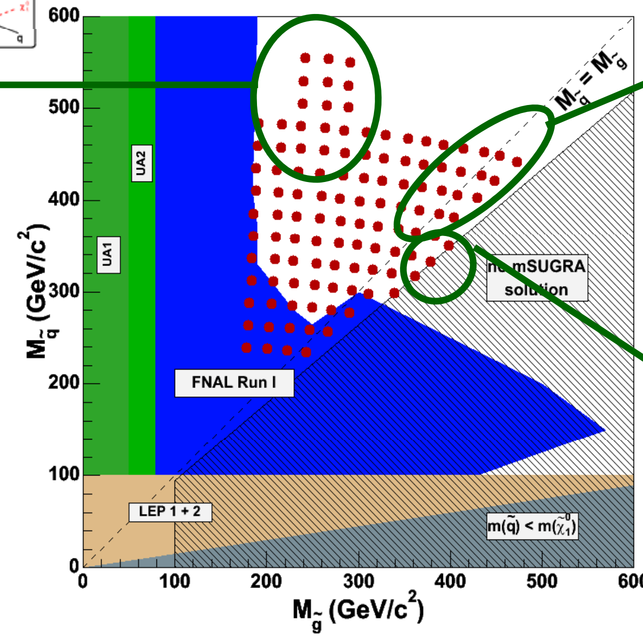


$M_{\tilde{q}} > M_{\tilde{g}}$

$\tilde{g}\tilde{g}$ prod. dominates

≥ 4 jets expected

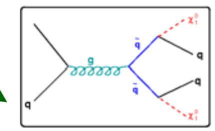
- $\not{E}_T$, $H_T = \Sigma Etj_{(j=1..4)}$, E_T of the leading jets considered to further discriminate signal from background
- Different topologies expected throughout the squark-gluino plane



$M_{\tilde{q}} \sim M_{\tilde{g}}$

$\tilde{q}\tilde{g}$ prod. dominates

≥ 3 jets expected



$M_{\tilde{q}} < M_{\tilde{g}}$

$\tilde{q}\tilde{q}$ prod. dominates

≥ 2 jets expected

[GeV]	**4 jets**	**3 jets**	**2 jets**
HT	280	330	330
missing E_T	90	120	180
Et(jet1)	95	140	165
Et(jet2)	55	100	100
Et(jet3)	55	25	--
Et(jet4)	25	--	--

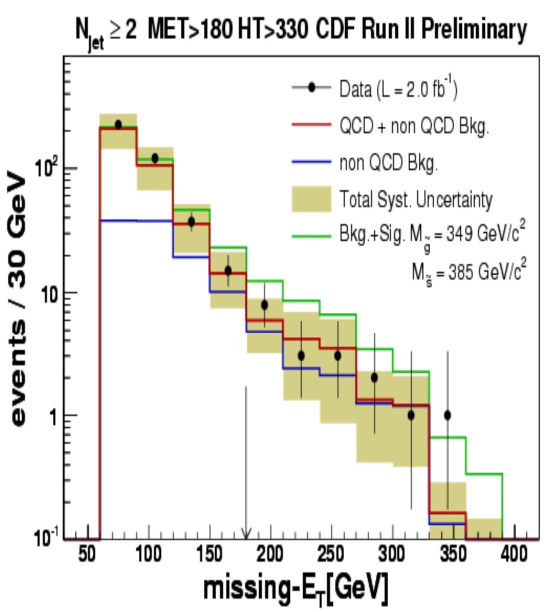
- Use jet multiplicity topologies to maximize signal efficiencies and enhance $S/\sqrt{B}$

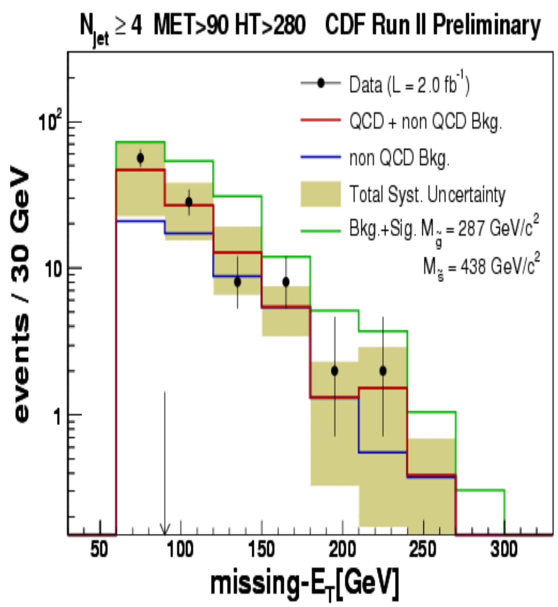
→ Define 3 signal regions

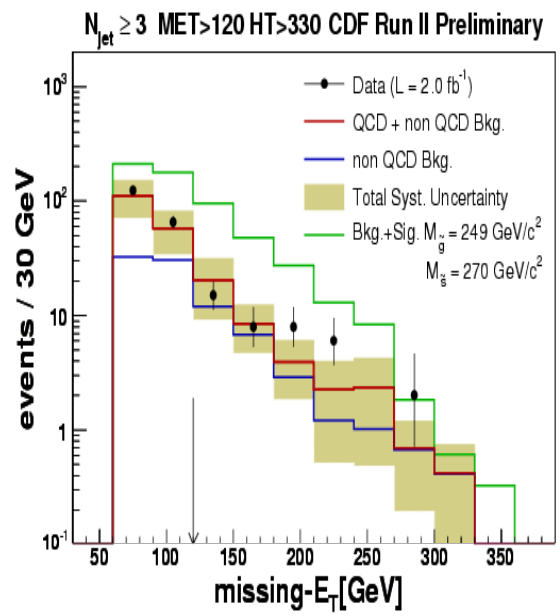
DATA vs SM predictions

events in 2.0 fb^{-1}	DATA	SM Expected
$\geq$ 4 jets	45	48 ± 17 (syst ± stat)
$\geq$ 3 jets	38	37 ± 12 (syst ± stat)
$\geq$ 2 jets	18	16 ± 5 (syst ± stat)

Good agreement between Observed and Expected events





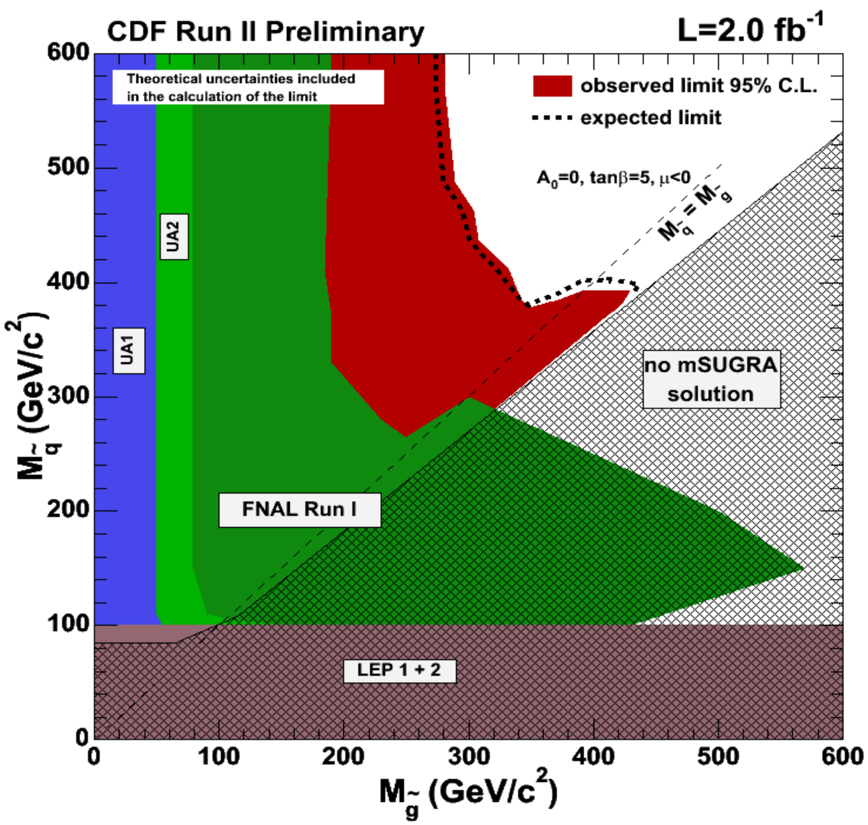


Exclusion limits

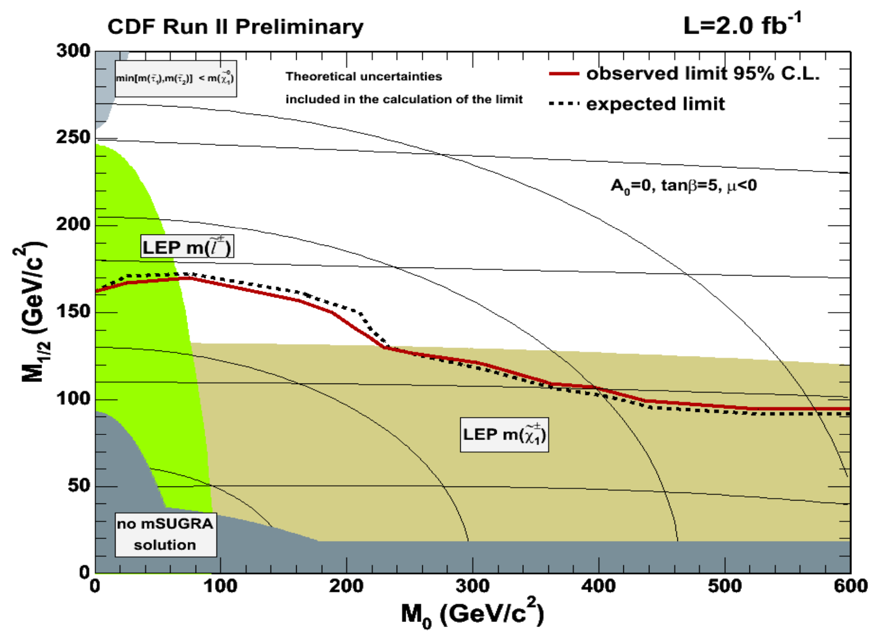
Use Bayesian approach

95% C.L. Exclusion limit on $M_{\tilde{g}}M_{\tilde{q}}$ and $M_0M_{1/2}$ planes

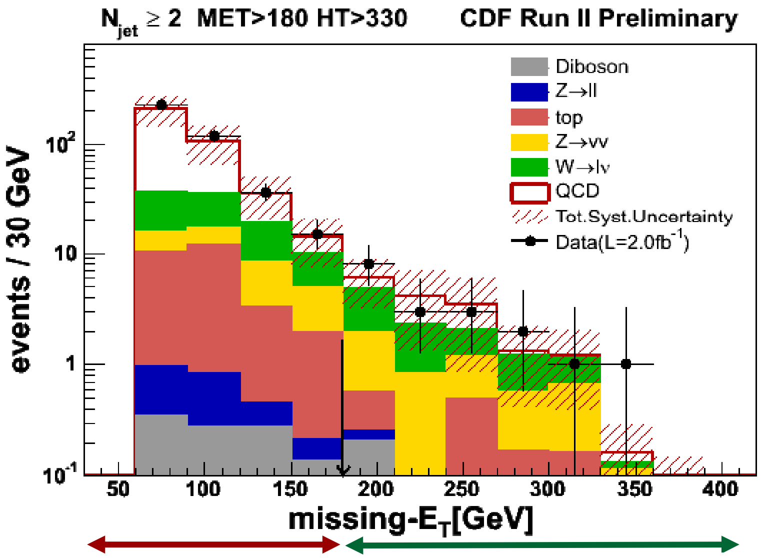
- When $M_{\tilde{g}}=M_{\tilde{q}} \rightarrow$ **M > 392** GeV/c^2
- **$M_{\tilde{g}}$ < 280** GeV/c^2 excluded in any case



- LEP limit improved in the region where **75<M_0<250** and **130<$M_{1/2}$<170 GeV/c^2**

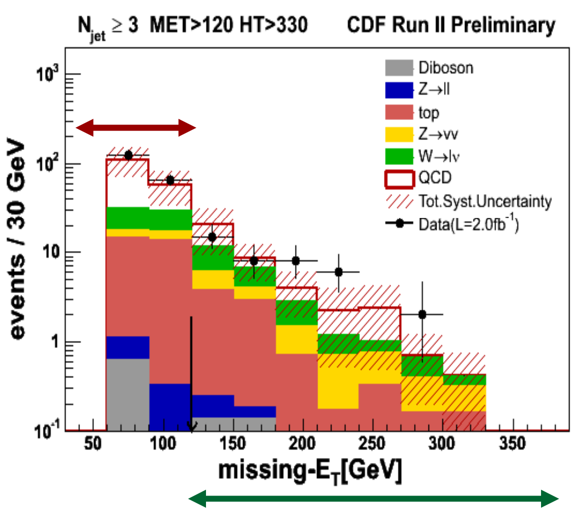


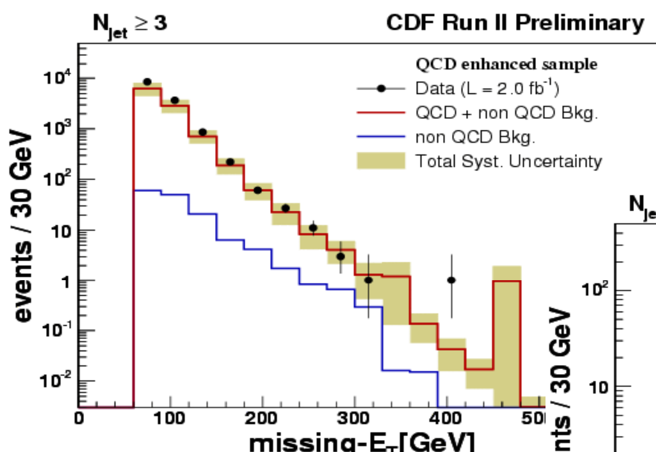
Knowledge of SM Backgrounds



Control region **Signal region**

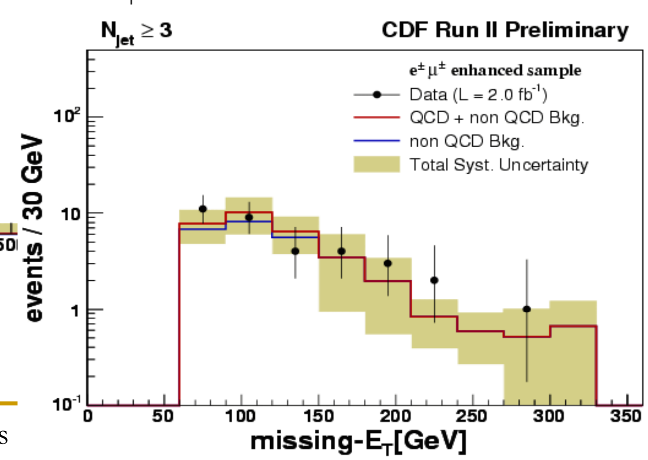
- **Understanding SM backgrounds is fundamental**
  - Tested away from signal region
  - In $\tilde{q}/\tilde{g}$ analysis control regions done reversing selection requirements
- → PYTHIA Tune A does a good job for QCD-multijets and top production
- → Boson+jets well reproduced with ME+PS (ALPGEN + PYTHIA in this case) once normalized to measured DY cross section





$\Delta\phi$(MET-jets) cut reversed for at least one of the considered leading jets

isolated tracks reversed cuts



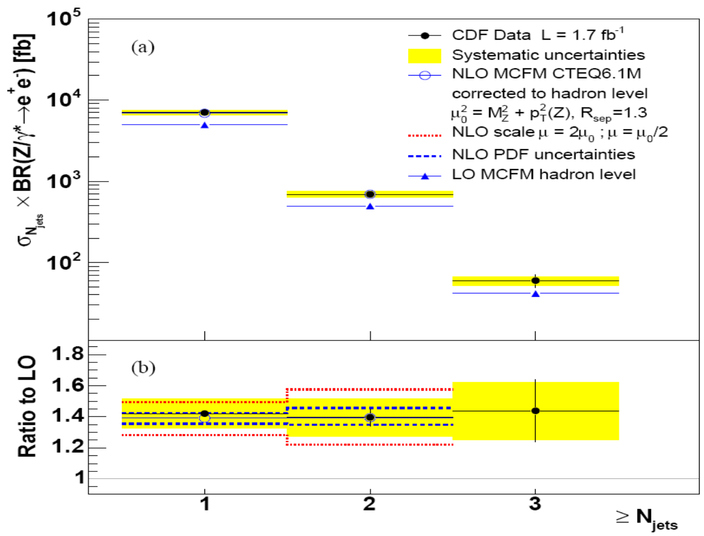
W/Z + inclusive jets

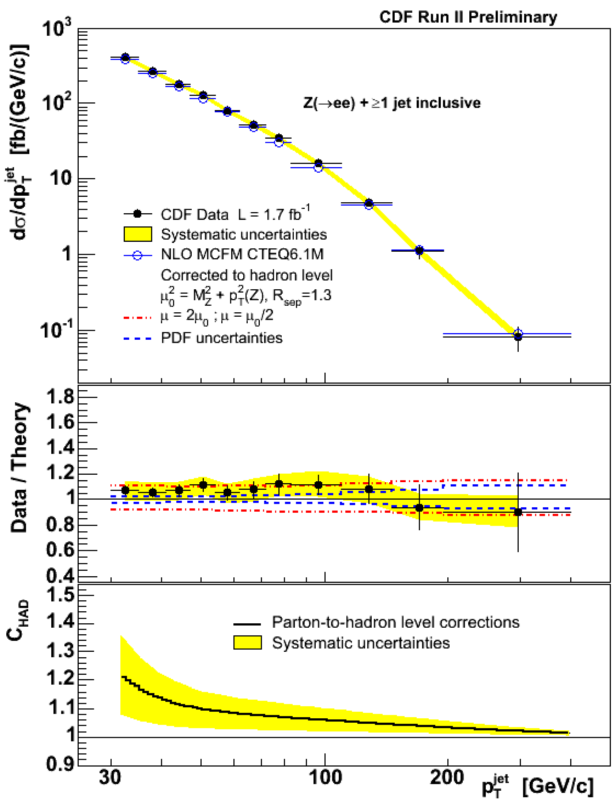
Dedicated measurements performed for boson+jets cross sections

$Z(\rightarrow e^+e^-)$+jets:

- clean signature, low background
- Does not constitute background for BSM physics involving MET

MCFM: NLO, no showering + CTEQ6.1M, hadron-to-parton corrections from PYTHIA TUNE A

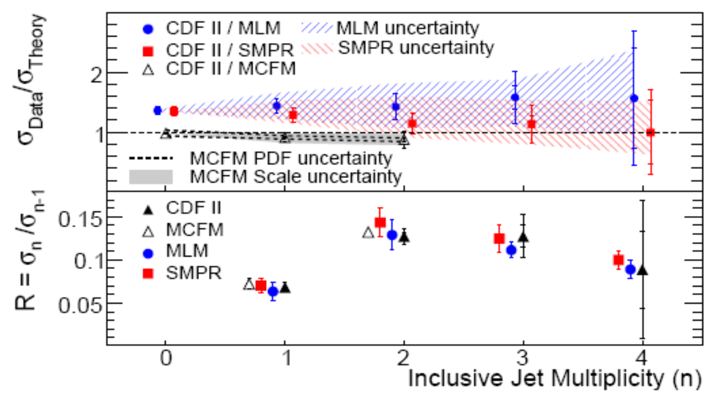




- Data in good agreement with MCFM NLO predictions
- Can define a common scale factor for all jet multiplicity

W+jets

- Statistics for high jet multiplicity
- Real MET, signature similar BSM signals



MLM : ALPGEN v2.12 (LO) + Herwig v6.5 + MLM + CTEQ5L
SMPR: MadGraph v4 (LO) + Pythia v6.3 + CKKW + CTEQ6L1
MCFM: NLO, no showering + CTEQ6.1M

Model-inspired searches: heavy flavor in the final state

Sbottom/stop searches

0.4 fb^{-1}

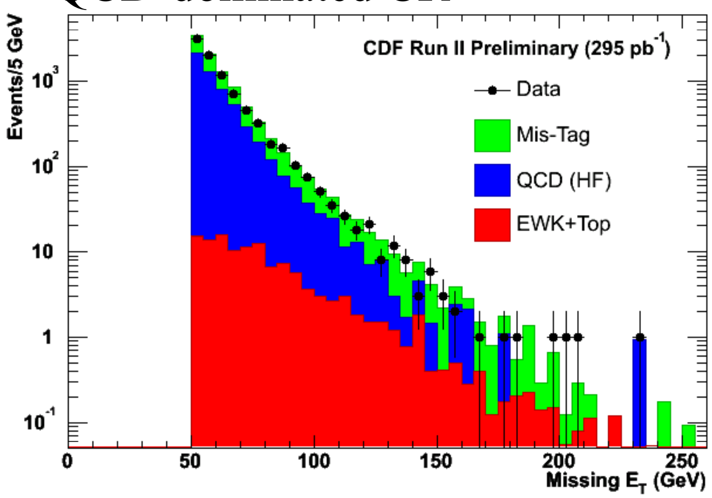
- In mSUGRA framework, dedicated searches for $\tilde{b}/\tilde{t}$ pair production
  - assume masses are light and sbottom/stop decay in b/c + neutralino (LSP)
- Final state: missing E_T + HF jets, identified via tagging algorithms

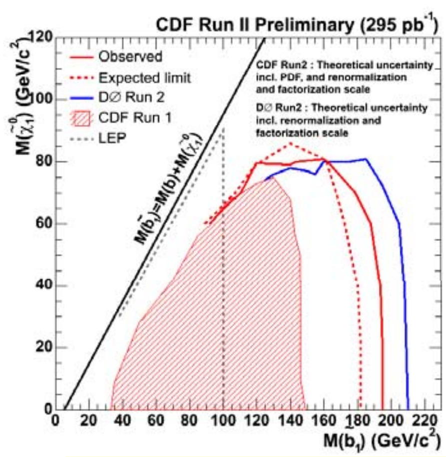
Main background:

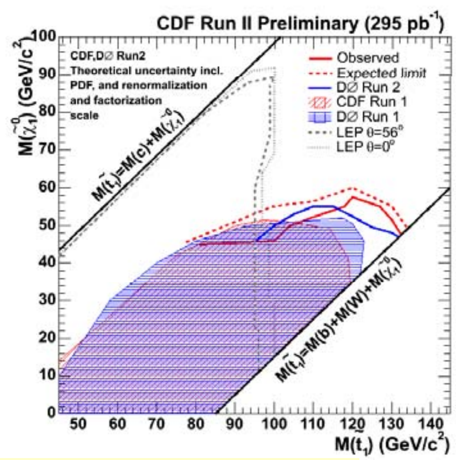
- top, W/Z+jets, QCD multi-jet
- Tests MC predictions in control regions

- Light Flavor contributions (mis-tags) → from data
- HF contributions → **from MC samples**
  - ALPGEN v1.3+HERWIG 6.5: W/Z+jets(b,c)
  - PYTHIA 6.216 Tune A: di-boson, top, QCD(bb,cc))
- QCD Multi-jet normalization → extracted from data

QCD-dominated CR





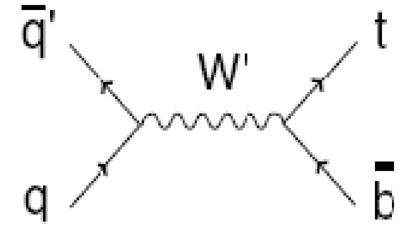


On-going searches updates with more data and new MC tools (ALPGEN v2)

$W' \rightarrow t\bar{b}$

1.9 fb^{-1}

- Search for resonant $t\bar{b}$(+cc) pair production
- In W+2 jets and +3 jets channels (semileptonic W), look for unexpected structure in M(Wjj)

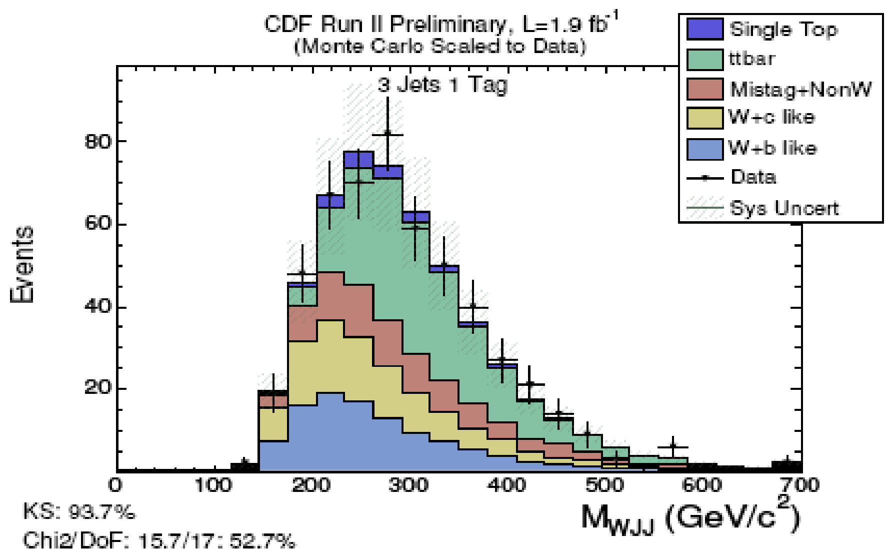


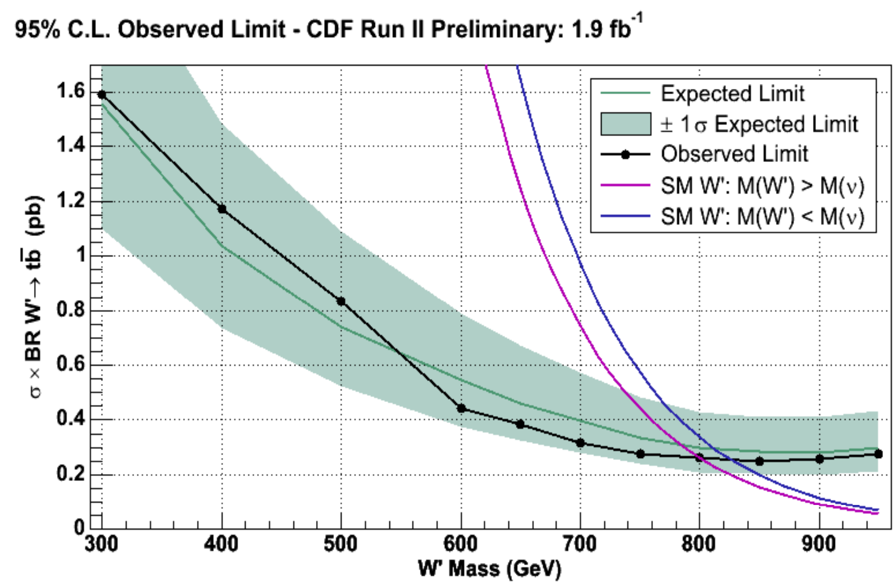
W' with SM-like fermions coupling

Event selection
- -1 high p_T lepton (p_T>20 GeV)
- -MET>25 GeV, 2 or 3 jets
- -At least 1 tagged jets
- -Z and QCD veto applied

Background estimate:

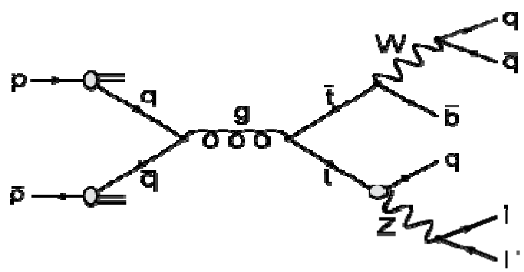
- DiBoson and tt: Pythia MC, normalized to NLO cross sections
- **W+bb/+cc/+c/+mistagged light quark jets:**
  - Normalization taken from data
  - Determine HF fraction from MC samples (ALPGEN v2+PYTHIA)
  - HF fraction calibrated in W+1 jet data sample using distributions sensitive to HF content (shape informations)
  - Remove overlap W+inclusive jets / W+HF jets MC samples

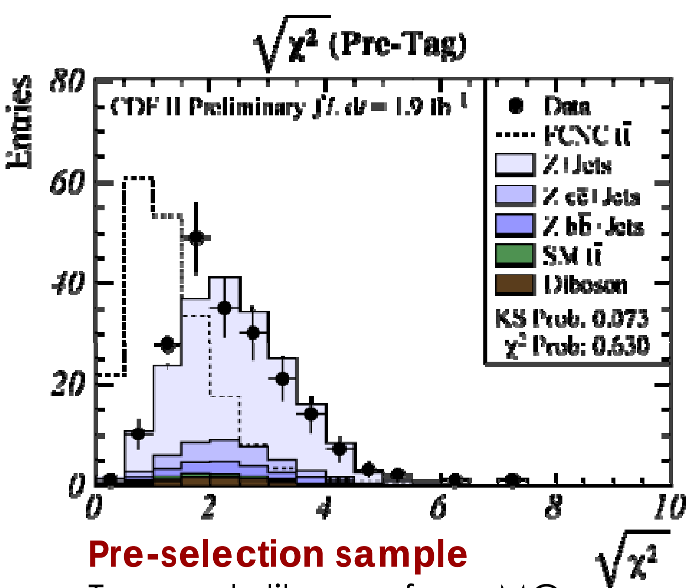




FCNC ($t \rightarrow qZ$)

1.9 fb^{-1}





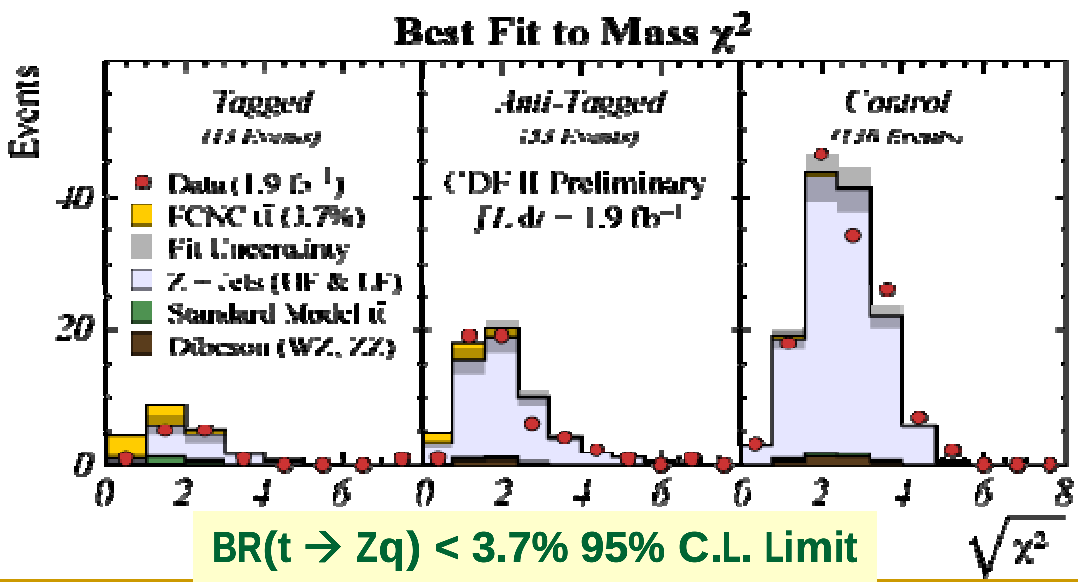
Pre-selection sample
Top and diboson from MC.
Z+jets backgrounds scaled to match the data.

➔ Free parameter in the χ^2 fit

- In SM, top FCNC decays highly suppressed (BR~10^{-14})
- Some SUSY models ➔ higher BR (up to 10^{-4})
  - FCNC signal: PYTHIA 6.216 Tune A, m_{top} = 175 GeV/c^2
- $Z(e^+e^-,\mu^+\mu^-)$+4 jets candidate events perform a template fit of mass χ^2

$$\chi^2 = \left(\frac{m_{W,\mathrm{rec}} - m_{W,\mathrm{PDG}}}{\sigma_W}\right)^2 + \left(\frac{m_{t\to Wb,\mathrm{rec}} - m_t}{\sigma_{t\to Wb}}\right)^2 + \left(\frac{m_{t\to Zq,\mathrm{rec}} - m_t}{\sigma_{t\to Zq}}\right)^2$$

- Z+jets dominant background: template from MC (ALPGEN v2+PYTHIA) ➔ **rely only on the shape**
- Two signal regions: ≥1 b-tag jets, anti-btag jet



BR($t \rightarrow Zq$) < 3.7% 95% C.L. Limit

Heavy flavor-jets SM processes

Difficult to predict heavy flavor bkg in BSM searches:

→ use MC samples for variable shapes and rescale to data

- **Boson+jets:** estimations using ME+PS or NLO calculations

→ dedicated measurements performed

  - Ambiguities due to ME and PS overlap
  - Large uncertainties (PDF, μ_R, μ_F)

Predictions underestimated

W+b (1 or 2 b-jets)

Result σxBR = 2.74 ± 0.27 (stat) ± 0.42 (syst) pb

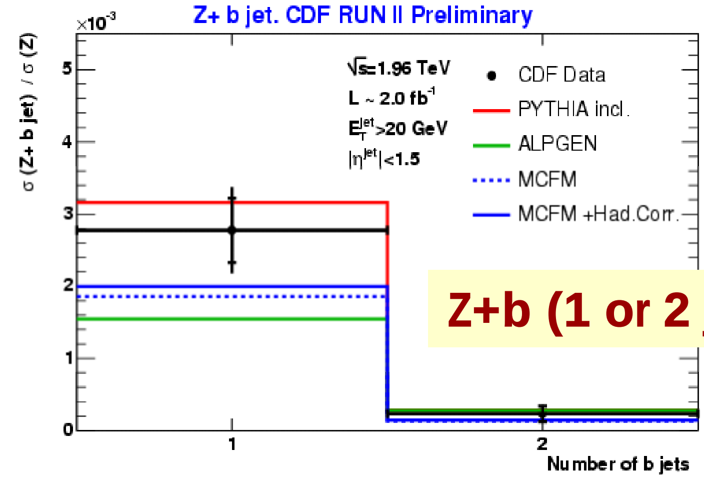
Prediction: σxBR = 0.78 pb

ALPGEN v2.10' + Pythia v6.325 + MLM + CTEQ6L

W+c (single jet)

Result:σxBR = 28.5 ± 8.2 (stat) ± 4.4 (syst) ± 1.7 (lum) pb

Prediction: σxBR = 22.2 ± 1.2 (PDF) ± 3.8 (scale) pb



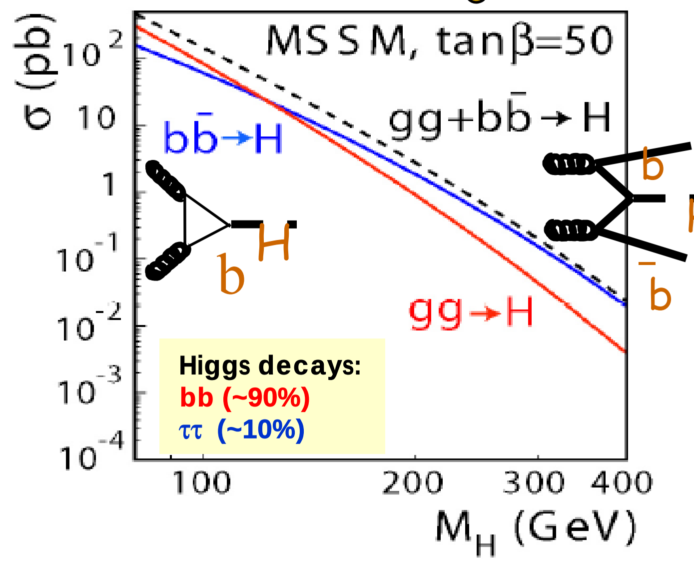
Z+b (1 or 2 jets)

	CDF Data	PYTHIA	ALPGEN	HERWIG	NLO	NLO +U.E+hadr.
$\sigma(Z+b\,\text{jet})$	$0.86 \pm 0.14 \pm 0.12$ pb	-	-	-	0.51 pb	0.53 pb
$\sigma(Z+b\,\text{jet})/\sigma(Z)$	$0.336 \pm 0.053 \pm 0.041\%$	0.35%	0.21%	0.21%	0.21%	0.23%
$\sigma(Z+b\,\text{jet})/\sigma(Z+\text{jet})$	$2.11 \pm 0.33 \pm 0.34\%$	2.18%	1.45%	1.24%	1.88%	1.77%

Neutral MSSM Higgs

1.9 fb^{-1}

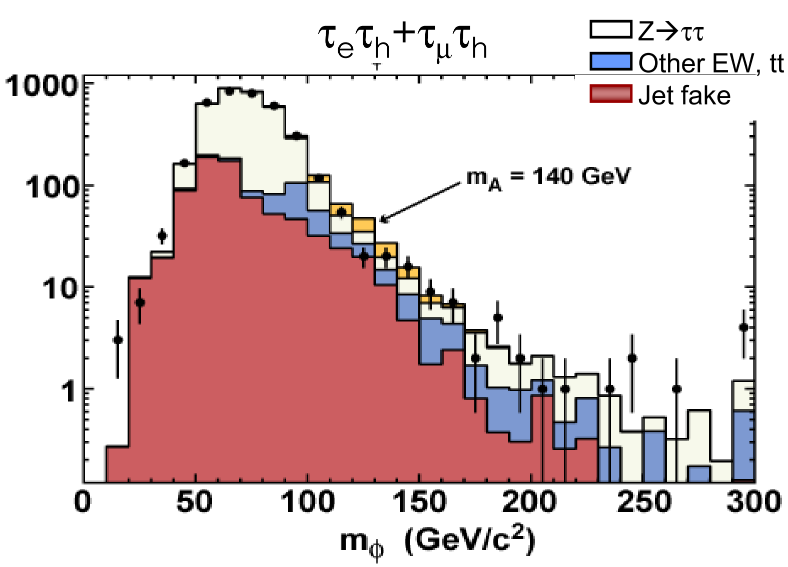
- In MSSM, two Higgs doublets
  - Three neutral (h, H, A), two charged ($H^{\pm}$)
  - Properties of the Higgs sector largely determined by m_A and tanβ
  - Higher-order effects introduce other SUSY parameters
- Large Higgs production cross section at large tanβ.



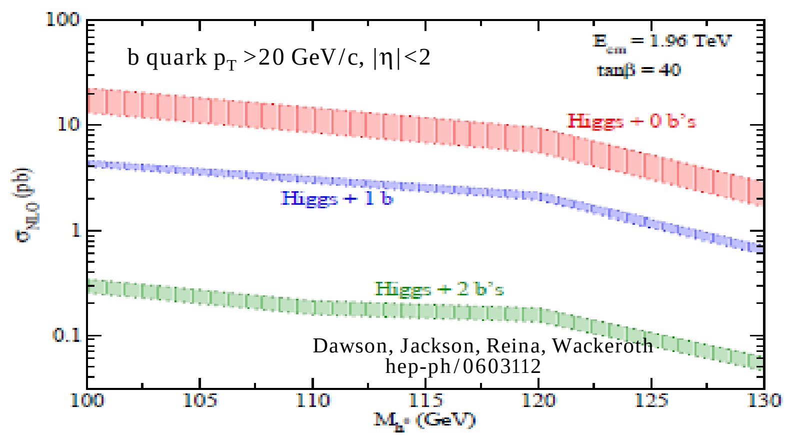
1.9 fb^{-1}

H → ττ: major background: Z→ ττ

Use partial mass τ_{lept}, τ_h, Missing E_T



- **H → bb:** "3b" channel best compromise between signal and background rates



Search in mass of two lead jets

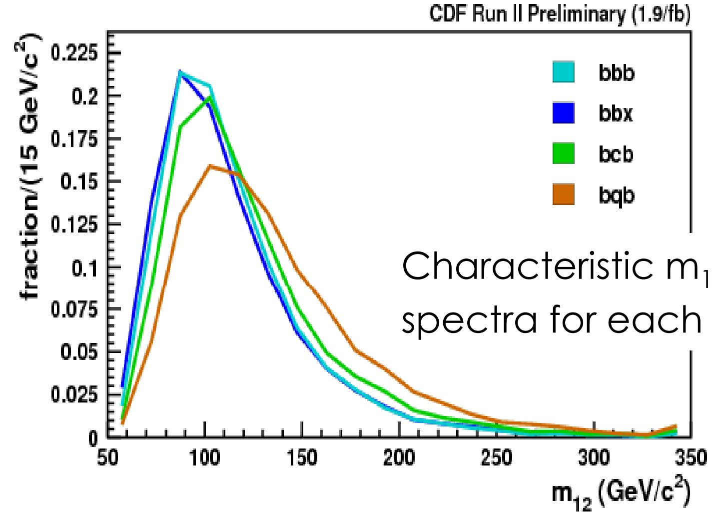
MSSM Higgs(bb)b

Backgrounds:

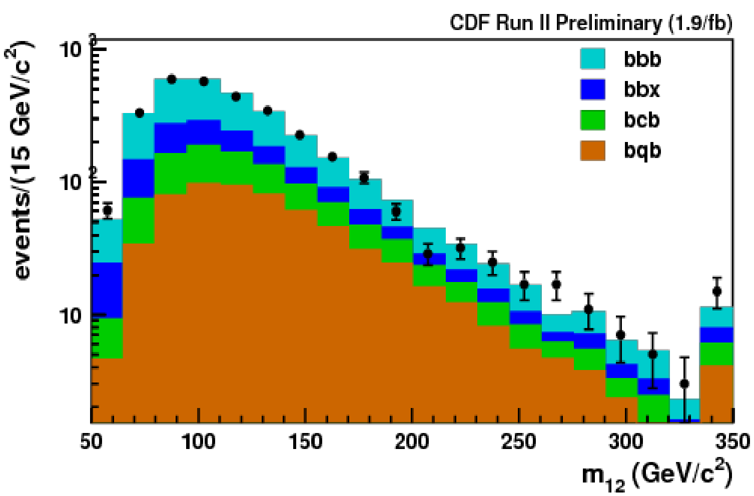
QCD-multijets (two true b-tags + b/c/fake tag)

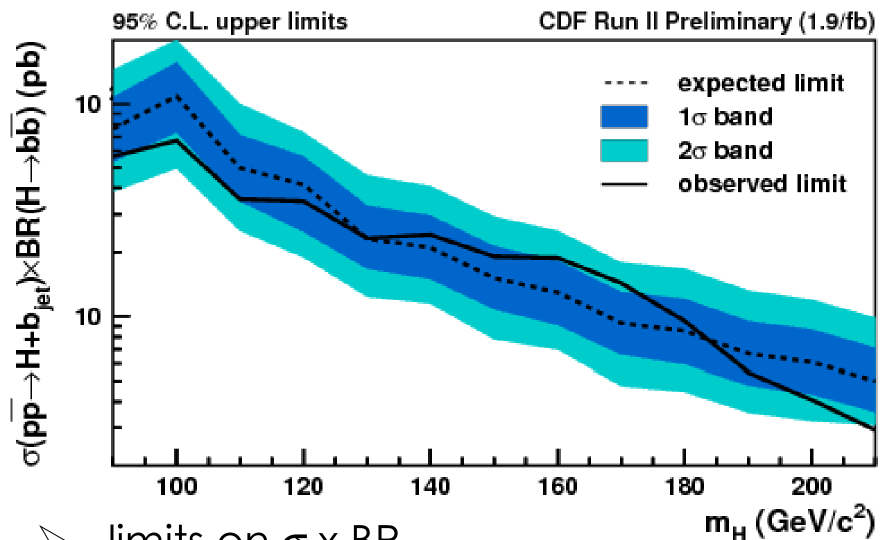
- Start from double-tagged bb sample (fake-tags subtracted), then weight events by flavor hypothesis
- Correct bbb and bcb shapes for double/triple-tag selection bias
- Fit the observed m_{12} spectrum with the backgrounds and a Higgs shape

No significant excess observed



Characteristic m_{12} spectra for each





- ➢ limits on σ x BR
- ➢ Background systematics limiting improvement at low m_H

Signature-based searches

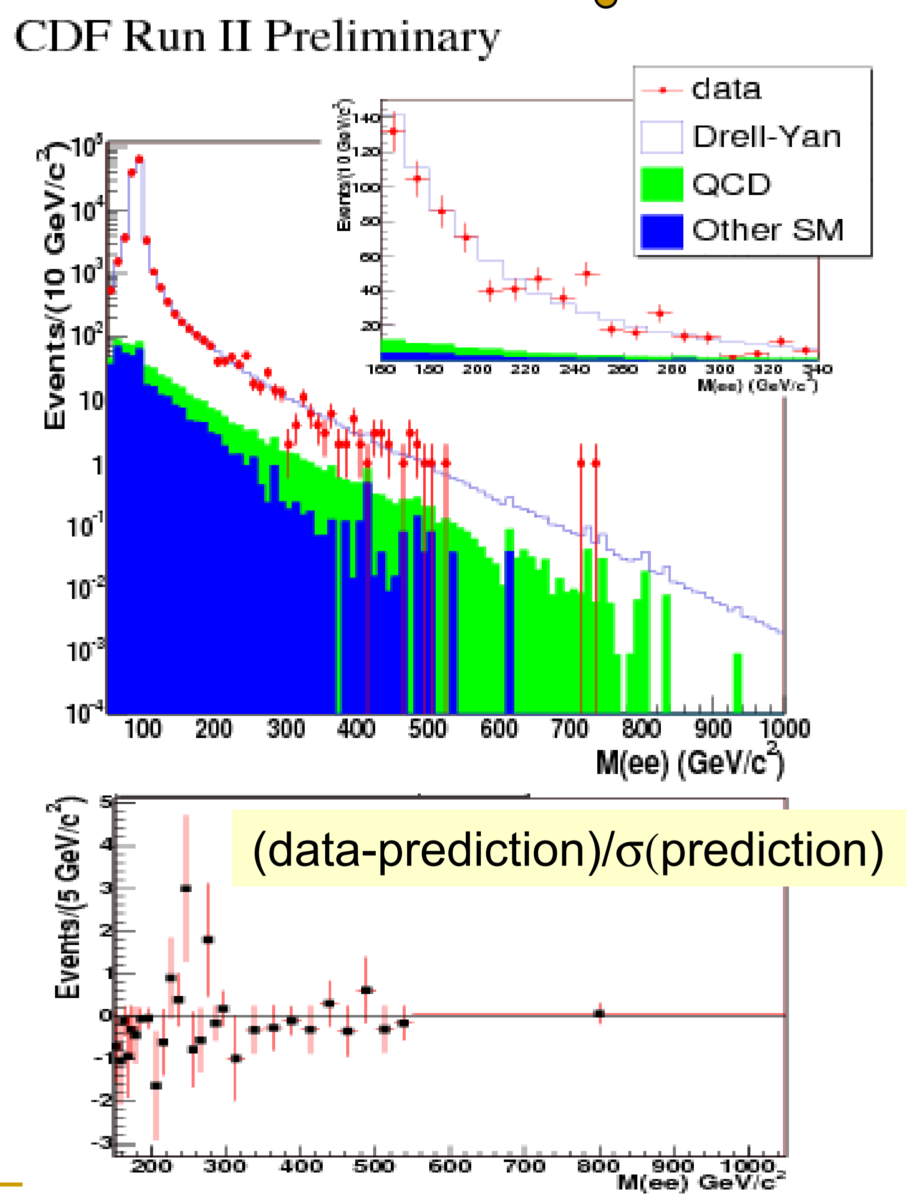
2.5 fb^{-1}

Search for High Mass e^+e^- Resonance

- Many models with di-lepton resonances
  - E_6 Z's
  - RS graviton
- Central-Central ($|\eta_{1,2}|<1$) or Central-Forward ($|\eta|<2$) e^+e^- pair with $E_T>25$ GeV

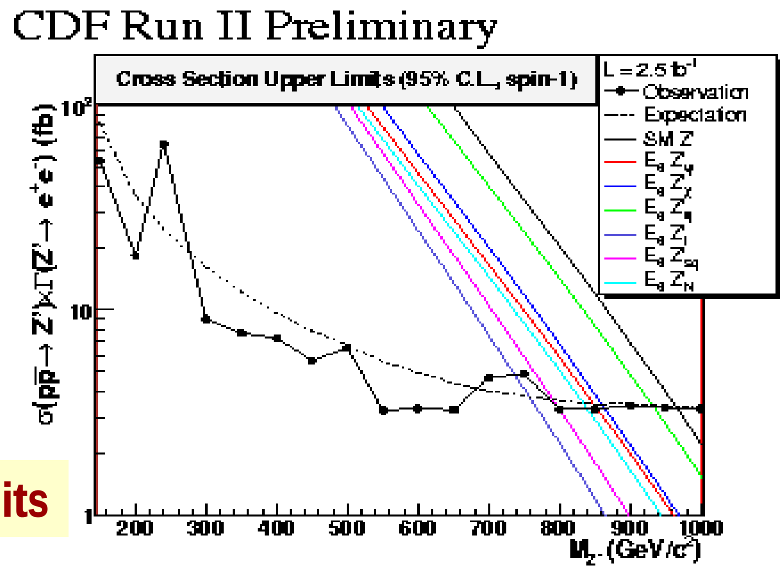
Major Backgrounds:

  - DY: PYTHIA, normalized to data in Z mass window
  - QCD (including W+jets): data-driven
- Resonance search (mass range 150-1000 GeV/c^2) performed with unbinned likelihood ratio
  - → Fluctuation ~ 240 GeV/c^2
  - → $S/\sigma B = 3.8$
  - → Probability of observing a background fluctuation: **0.6% = 2.5 σ significance** (5% if using previous analysis selection)



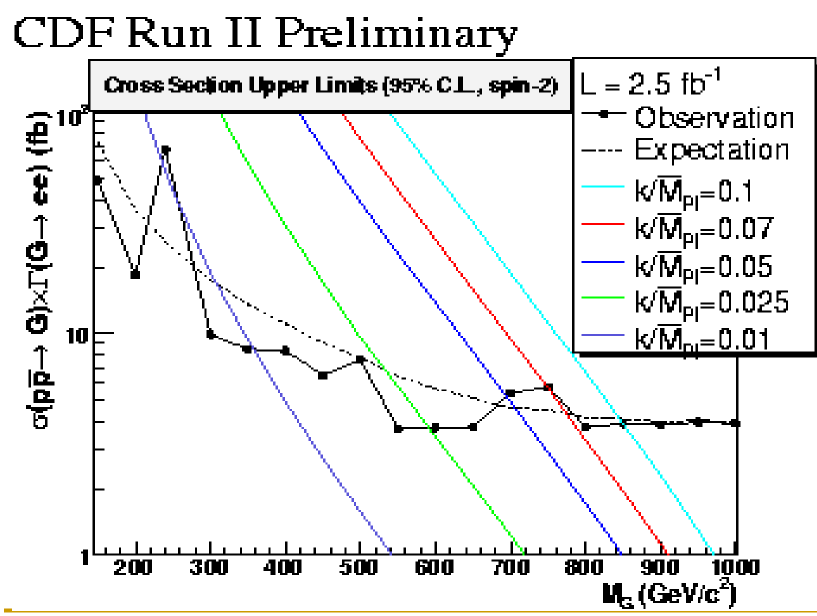
Search for High Mass e^+e^- Resonance

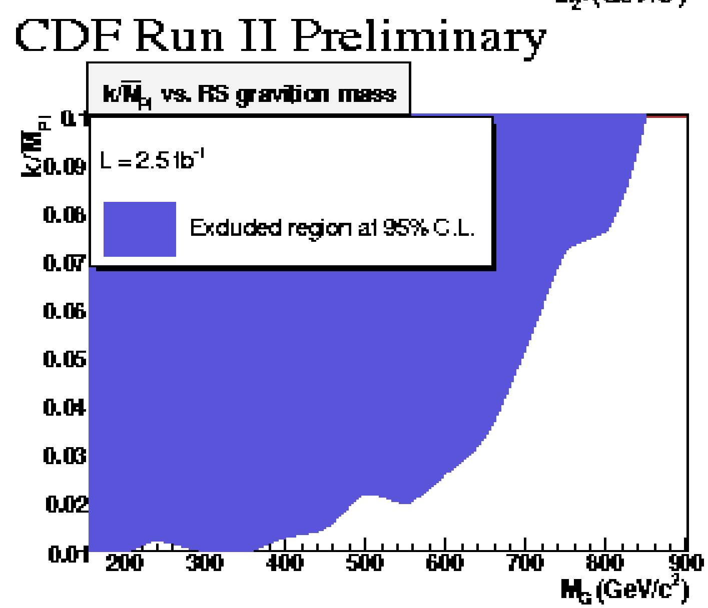
- Set mass limits on RS graviton and Z's from E_6
  - SM-like Z': 966 GeV/c^2
  - RS graviton with mass below 850 GeV/c^2 for k/MPl=0.1 is excluded



Signal samples → PYTHIA, k factor = 1.3 applied for NLO corrections

World best limits

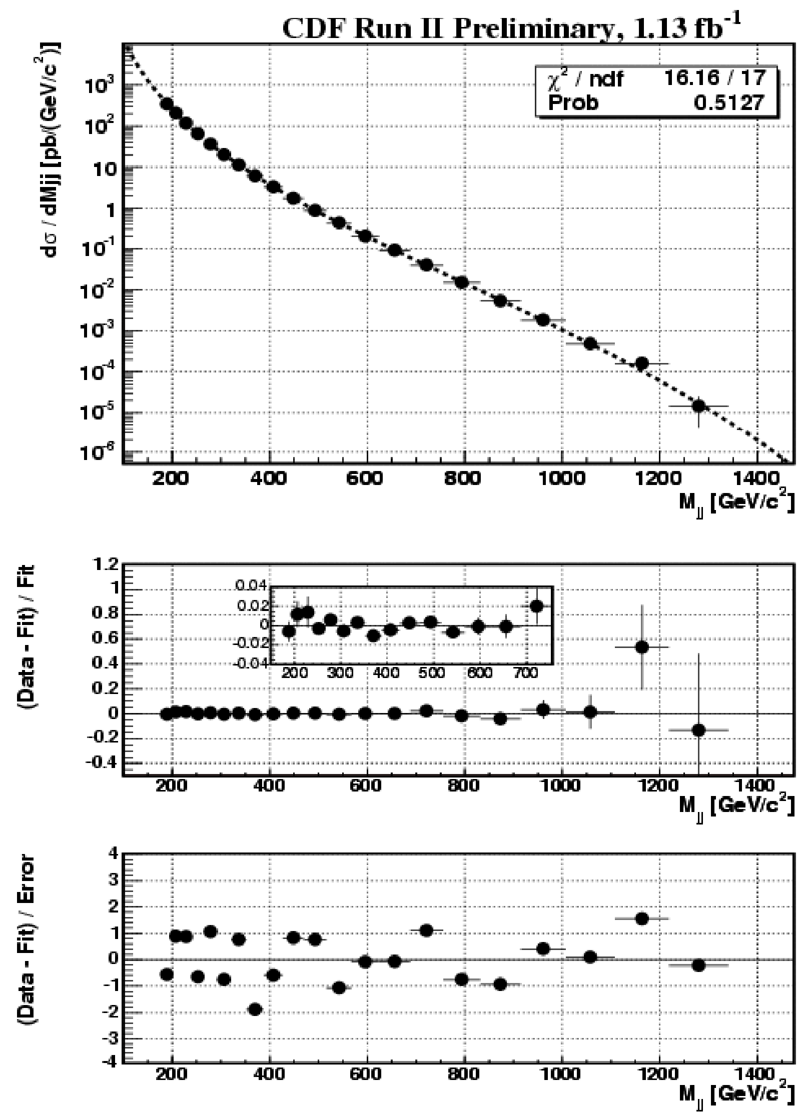




Search for High Mass Di-jet Resonances

1.1 fb^{-1}

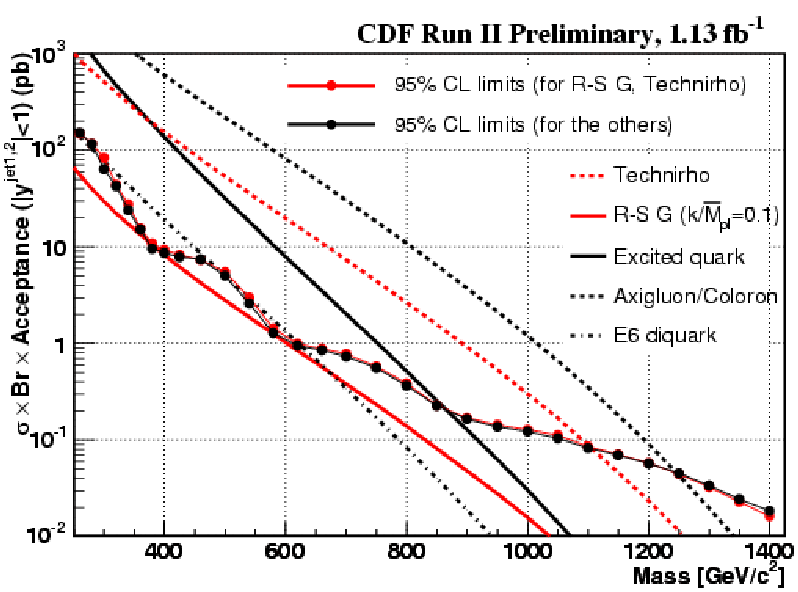
- Many Models with new particles decaying into di-jets
  - Axigluons, excited quarks, W'and Z', di-quarks in E_6, RS gravitons, etc.
  - Use PYTHIA Tune A for signal samples (k=1.3)
    - SM couplings for W'/Z'
    - k/Mpl=0.1 for R-S graviton
- Use events with $N_{jet} \geq 2$, $|y|<1.0$, $M_{jj}>180$ GeV/c^2
  - Fit mass spectrum by smooth function
    - test with Herwig, Pythia, and NLOJET++
  - look for excess over fit function

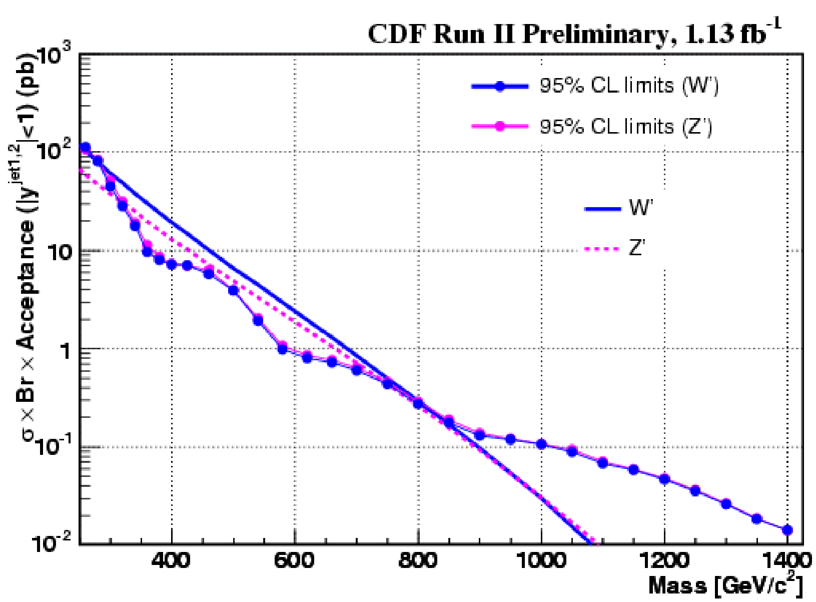


Search for High Mass Di-jet Resonances

- No excess observed
  - Set 95% CL limits
  - World best limits

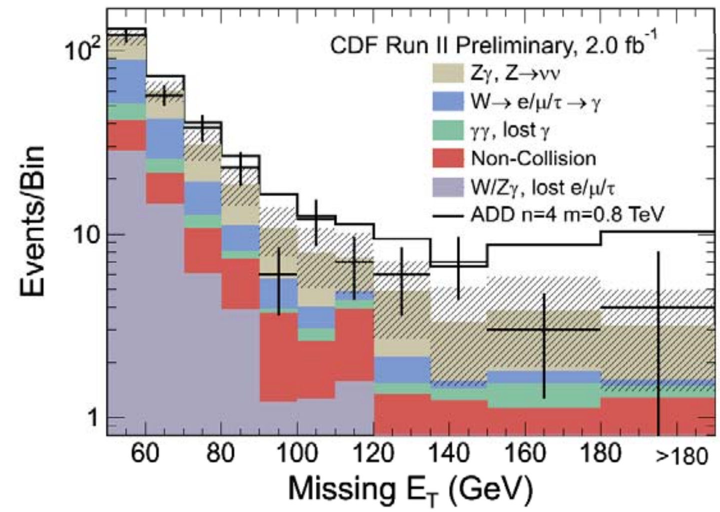
Observed mass exclusion	Model
260-870 GeV/c²	**Excited quark**
260-1110 GeV/c²	**Color-octet technirho**
260-1250 GeV/c²	**Axigluon & coloron**
260-630 GeV/c²	**E6 diquark**
260-840 GeV/c²	**W' (SM couplings)**
260-740 GeV/c²	**Z' (SM couplings)**





Single γ + Missing E_T

2 fb^{-1}



- Compactified LED models predict direct production of Gravitons:

  $qq\rightarrow\gamma G_{kk}$ (also MET+jet $qq\rightarrow gG_{kk}$, $qg\rightarrow qG_{kk}$, $gg\rightarrow gG_{kk}$)
  (signal simulated with PYTHIA 6.216)

- Event selection:
  - $|\eta_\gamma|<1.0$;
  - $E_T(\gamma)$ & MET>50 GeV;
  - no jet with E_T>15 GeV;
  - no trk with P_T>10 GeV.

Optimization for Large Extra Dimension signature:
$E_T(\gamma)$>90 GeV

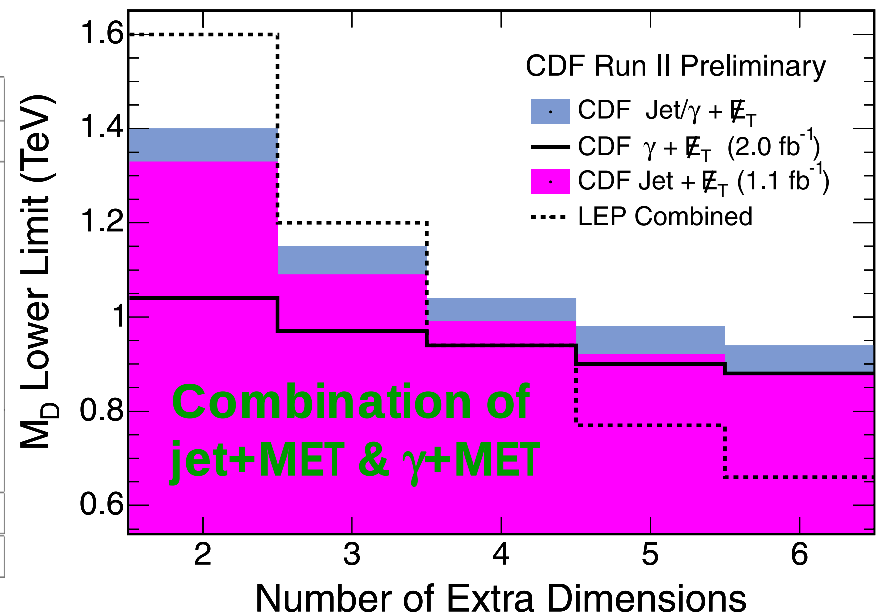
Major bkg:
- $Z\gamma\rightarrow(\nu\nu)\gamma$ (MADGRAPH)

- Non collision bkg
- Fake (l/jet → γ)

Both from Data

CDF RunII Preliminary, 2.0 fb^{-1}

Channel	$\gamma E_T > 50$ GeV	$\gamma E_T > 90$ GeV
$W \to e \to \gamma$	47.3 ± 5.1	2.6 ± 0.4
$W \to \mu/\tau \to \gamma$	19.1 ± 4.2	1.0 ± 0.2
$W\gamma \to \mu\gamma \to \gamma$	33.1 ± 10.2	1.7 ± 1.2
$W\gamma \to e\gamma \to \gamma$	8.0 ± 3.0	0.8 ± 0.7
$W\gamma \to \tau\gamma \to \gamma$	17.6 ± 1.6	2.5 ± 0.2
$\gamma\gamma \to \gamma$	18.9 ± 2.3	2.3 ± 0.6
cosmics	36.4 ± 2.5	9.8 ± 1.3
$Z\gamma \to \nu\nu\gamma$	99.7 ± 9.5	25.2 ± 2.8
Total	280.1 ± 15.7	46.7 ± 3.0
Data	280	40



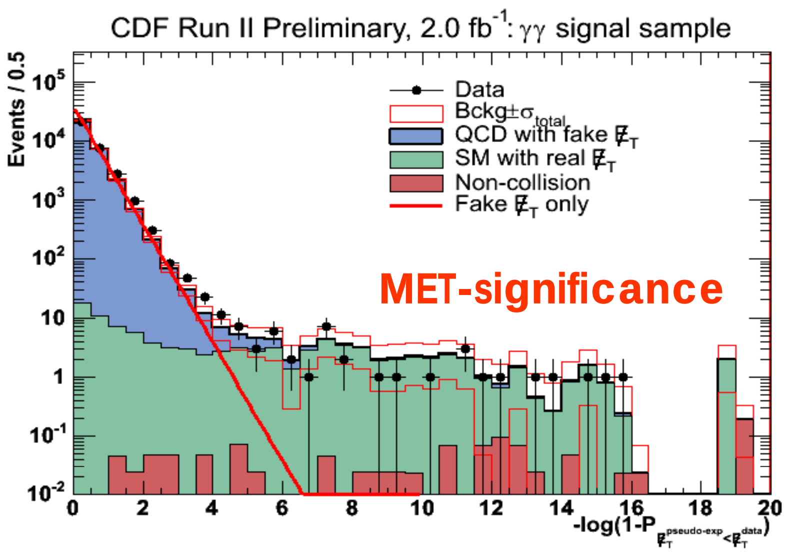
$\gamma\gamma + X$

2 fb^{-1}

- $\gamma\gamma$+X where X can be **missing E_T**, a **lepton** or a third photon

X = Missing Transverse Energy

- $|\eta_{\gamma1,2}|<1.0$; $E_T(\gamma_{1,2})>13$ GeV
- **Data driven background estimate**
  - *"MET Resolution Model"* to predict fake $\not\!\!E_T$ and select events based on ME_T-significance
  - MET-significance measurement based on jet + unclustered energy resolution
- Two control regions : $Z\rightarrow e^+e^-$; non-ISO $\gamma\gamma$



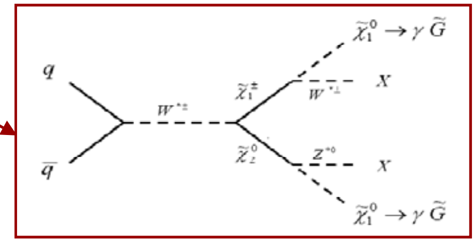
Many models to interpret results!

-Fermiophobic Higgs

-Technicolor

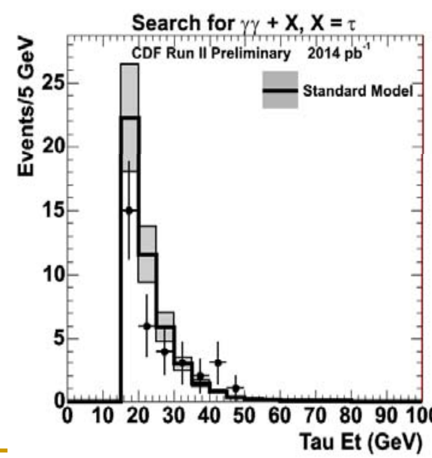
-GMSB

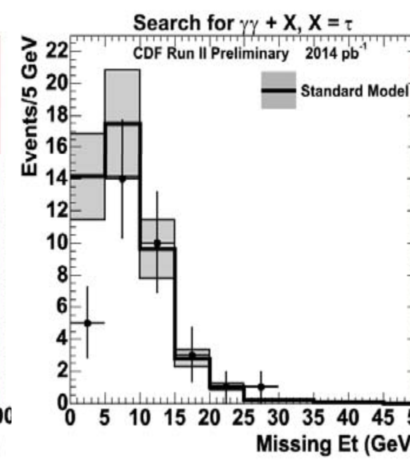
-....



X = tau lepton

- $|\eta_{\gamma1,2}|<1.0$; $E_T(\gamma_{1,2})>13$ GeV
- Tau visible mass >1.8 GeV
- 1 or 3 tracks in 10° cone
- Data driven bkg estimate (fake τ)
- Real τ from $W\gamma$ and $Z\gamma$: MadGraph





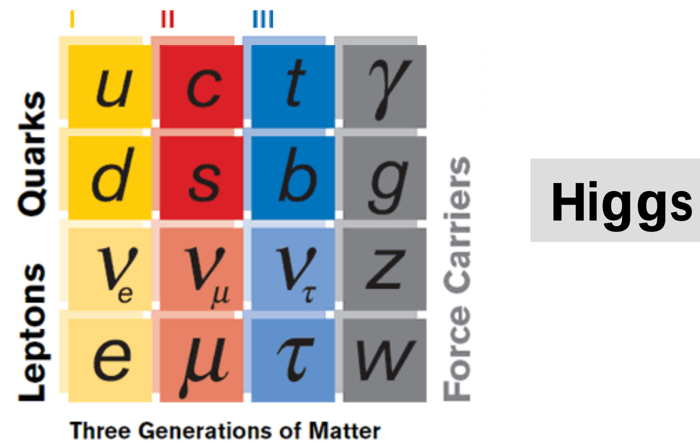
Conclusions

- CDF has a wide and rich program of searches for physics beyond the Standard Model
- Some of the most recent results (1-2 fb^{-1}) have been presented
- No evidence of new physics yet ..
- Major challenges in BSM searches:
  - understand SM background processes

Back up

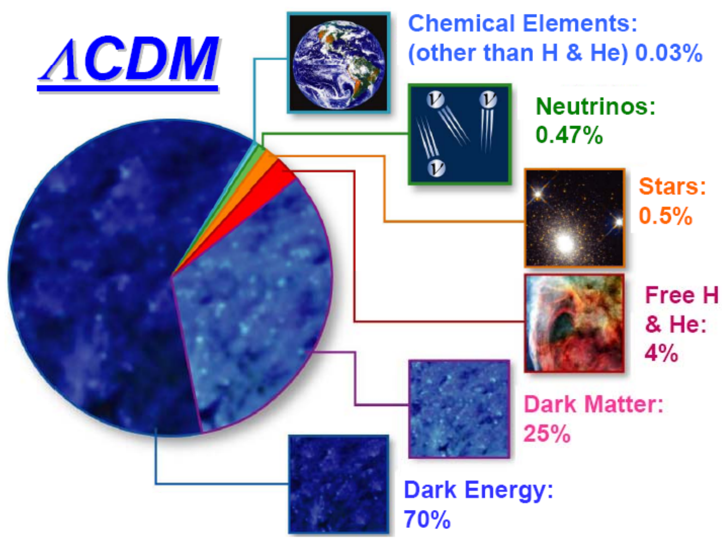
The Standard Model

- Matter is made out of fermions:
  - 3 generations of quarks and leptons
- Forces are carried by Bosons:
  - Electroweak: γ,W,Z
  - Strong: gluons
- Higgs boson:
  - Gives mass to particles → Not found yet



- Remarkably successful description of known phenomena **but** ...

The Standard Model is theoretically incomplete



- Mass hierarchy problem
- radiative correction in Higgs sector
- Unification
- Dark Matter
- Matter-antimatter asymmetry

The Hierarchy problem

The SM requires a non-vanishing VEV for the Higgs at the minimum of the potential ***V***

$$V = m_H^2|H|^2 + \lambda|H|^4$$

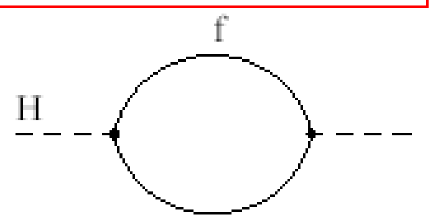
if $m^2_H < 0$, VEV results in: $\langle H \rangle = \sqrt{-m_H^2/2\lambda}$

Experimentally, <H> = 174 GeV and $m^2_H \sim -(100 \text{ GeV})^2$

+ quantum corrections from virtual effects of particles coupling to Higgs field

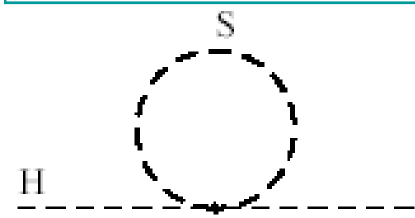
$$\Delta m_H^2 = \frac{|\lambda_f|^2}{16\pi^2}\left[-2\Lambda_{UV}^2 + 6m_f^2 \ln(\Lambda_{UV}/m_f) + \ldots\right]$$

Fermion loop



$$\Delta m_H^2 = \frac{\lambda_S}{16\pi^2}\left[\Lambda_{UV}^2 - 2m_S^2 \ln(\Lambda_{UV}/m_S) + \ldots\right]$$

loop of scalar particles



Λ_{UV} → ultraviolet cutoff

→ Mass of Higgs scalar with quantum corrections is kept small only with fine tuning of the parameters!

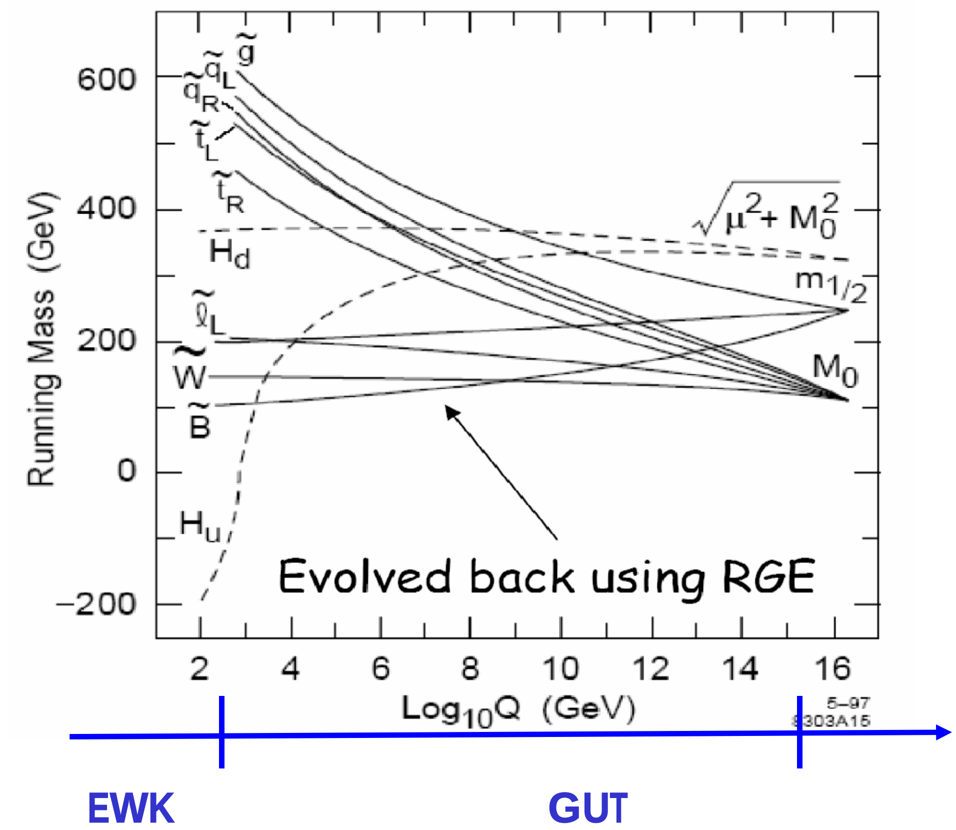
Possible solution: introduce a symmetry to cancel all dangerous contributions

mSUGRA

- New superfields in "hidden" sector
- Interact gravitationally with MSSM
- Soft SUSY breaking

5 parameters at GUT scale

1. Unified gaugino mass $m_{1/2}$
2. Unified scalar mass m_0
3. Ratio of H_1, H_2 vevs $\tan\beta$
4. Trilinear coupling A_0
5. Higgs mass term sgn(μ)



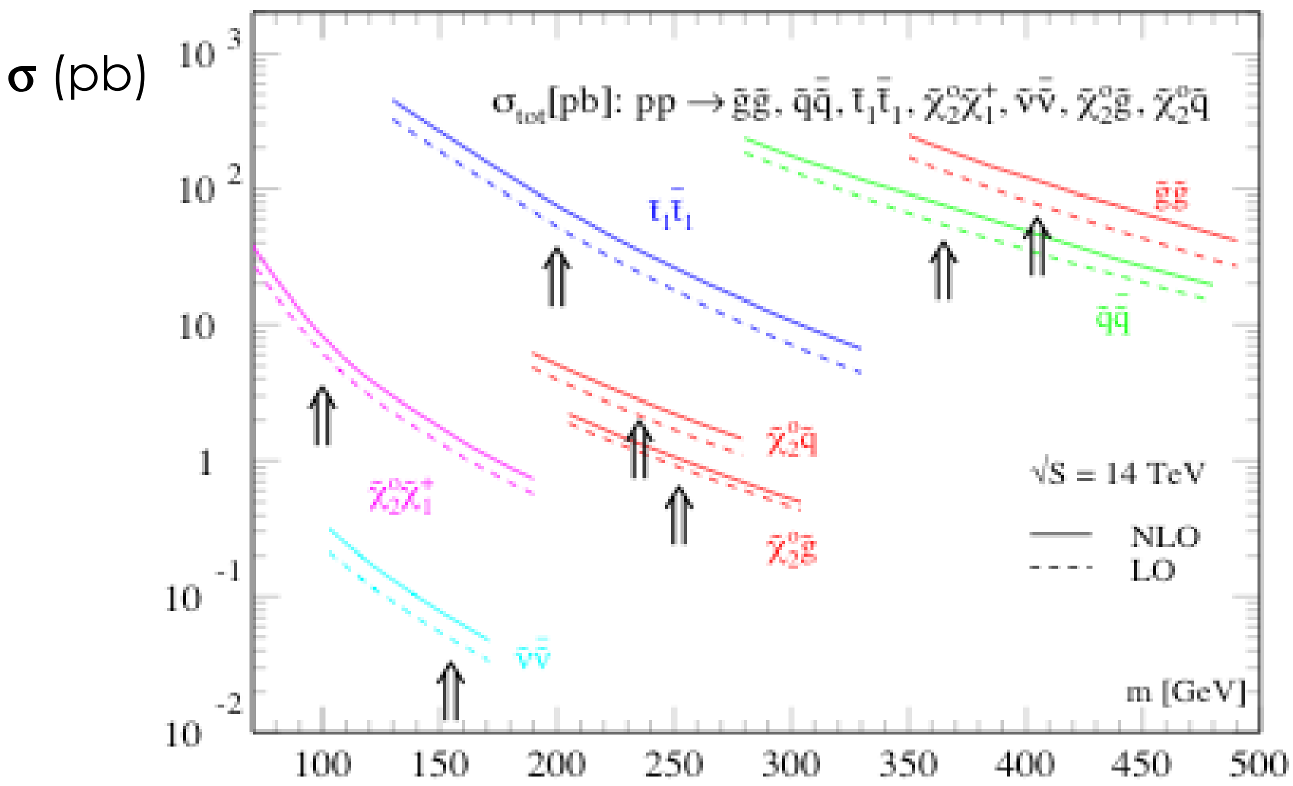
In R parity conservation scenario, the LSP is the neutralino (χ^0_1)

LHC mSUGRA cross sections

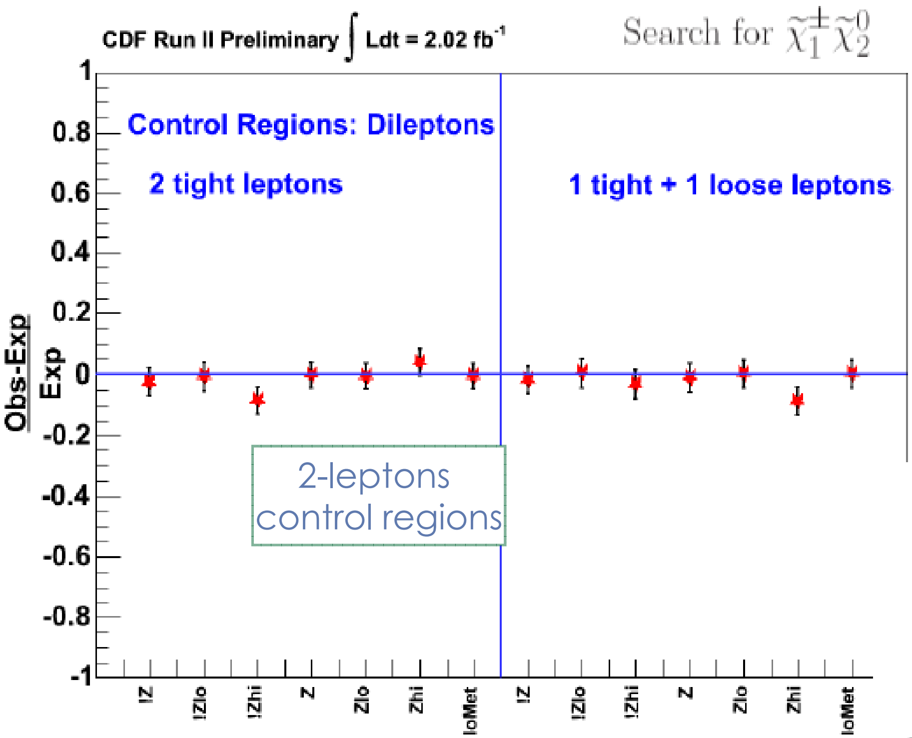
- Strongly interacting particles
- High cross sections for gluinos and squarks production

→ Golden signature!

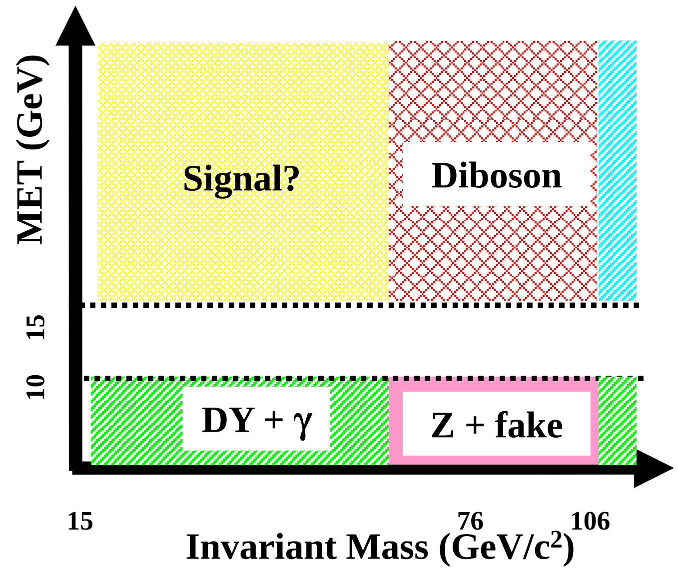
T. Plehn, PROSPINO

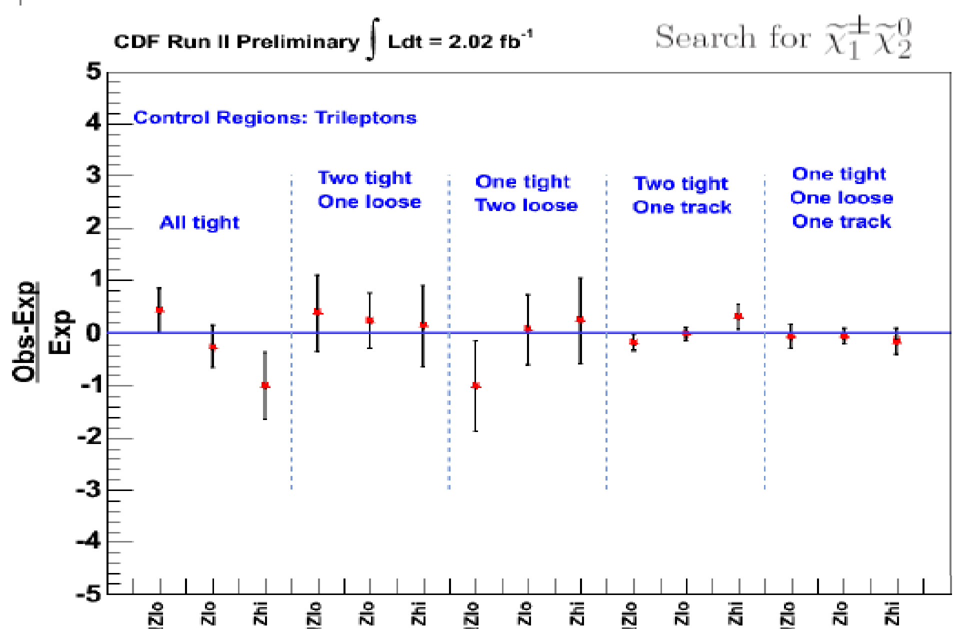


Control regions



2-leptons control regions





3-leptons control region

Fake rate estimation for trilepton analysis

- Hadrons (h) misidentified as tight/loose leptons or T_τ (fakes)
- Three lepton final state:
  - Fake rate $\mathcal{P}_l(h \rightarrow tl,ll)$ measured in data
  - Data driven estimate events with ll+h scaled by fake rate $\mathcal{P}_l$
- Dilepton + isolated track final state:
  - Fake rate $\mathcal{P}_T(h \rightarrow T_\tau)$ measured in data as a function of event track multiplicity
  - MC driven estimate events with ll+h scaled by fake rate $\mathcal{P}_T$

Systematic uncertainties for squark/gluino search

Signal & Background → 3% variation in Jet Energy Scale (JES)
→ 6% uncertainty on luminosity

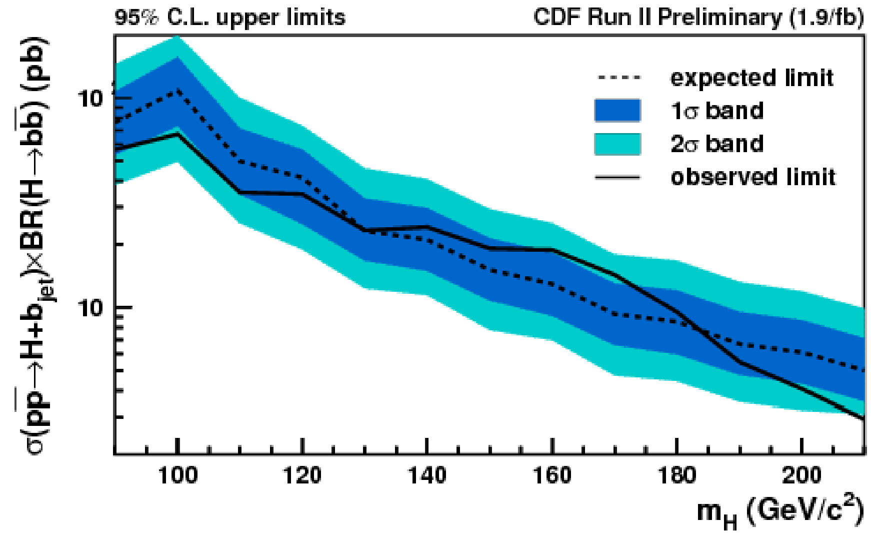
- **PDF**: CTEQ6.1M. Use Hessian method to determine systematic uncertainties.
- **Renormalization scale**:
  Default:
  - $\tilde{g}\tilde{g}$: $\mu = M_{\tilde{g}}$
  - $\tilde{s}\tilde{g}$: $\mu = 0.5[M_{\tilde{g}}+M_{\tilde{q}}]$
  - $\tilde{s}\tilde{s}$ and $\tilde{s}\tilde{b}$: $\mu = M_{\tilde{q}}$

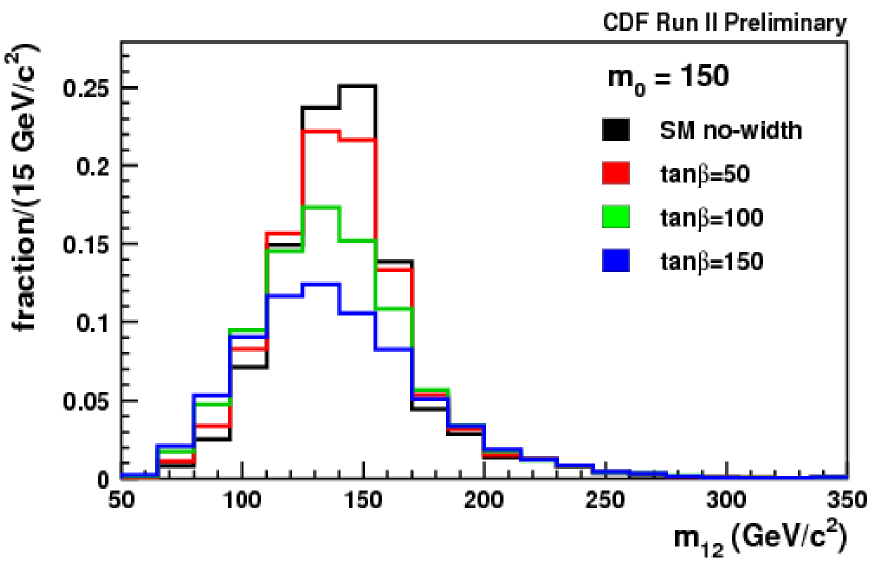
  Nominal PROSPINO scale shifted to ½ and 2 μ.
- **ISR/FSR**:
  - increased/decreased via variation of Λ_{QCD}

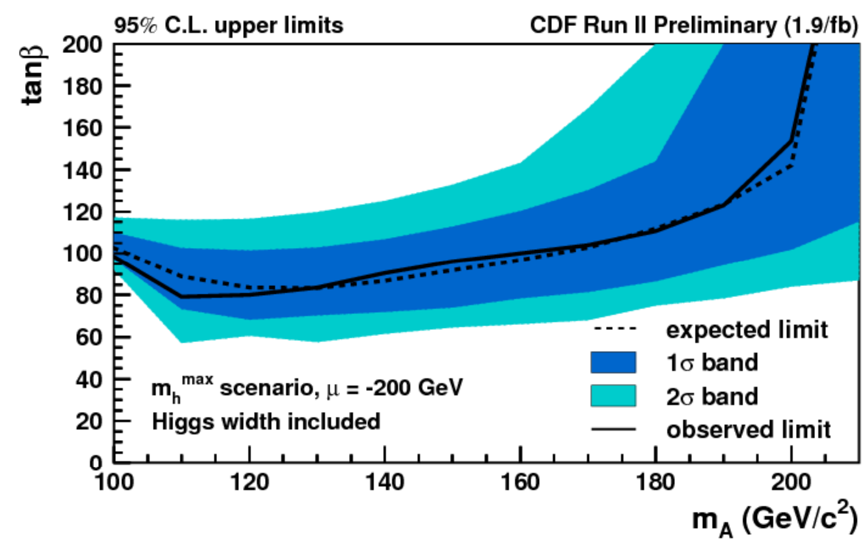
- **ISR/FSR** in top and Boson+jets production
  - Most sensitive in tails at high H_T
  - For top bkg, also consider 10% uncertainty on PDF and renormalization
- 2% global uncertainty on inclusive W/Z cross section used to normalize W/Z+jets cross section
- 10% **PDF + Renormalization** uncertainty on diboson cross section
- Uncertainty on QCD normalization negligible (< 1%)

MSSM limits for 3b-Higgs search

- From limits on σ x BR to Interpret results in MSSM scenarios:
  - Include non-negligible Higgs width (~20% for tanb = 100)
  - Lose sensitivity and yield
  - limits worsen considerably
- Best limits obtained in scenarios with μ<0 (loop enhancements)

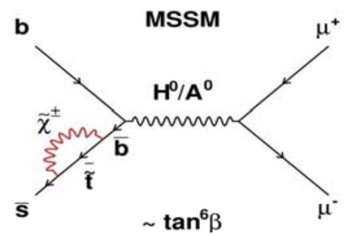






$B_s \to \mu\mu$

Sensitive to new physics: if no observation, it can strongly constraint SUSY models



SM prediction:
BR = 3.42×10^{-9}

SUSY enhancement
$\sim(\tan\beta)^6$

- Data sample dominated by random combinatorial background
- Extract signal with Neural Net based discrimina

B_s and B_d considered separately:

$B_s \to \mu\mu$ 3 observed events (3.6+/-0.3 exp.bkg.)

$B_d \to \mu\mu$ 6 observed events (4.3+/-0.3 exp.bkg.)

No significant excess → exclusion limit

$Br(B_s \to \mu\mu) < 5.8 \times 10^{-8}$ @ 95% CL
$Br(B_d \to \mu\mu) < 1.8 \times 10^{-8}$ @ 95%CL