Recent SUSY Results From CDF in multilepton Final States.

10/11/11

Rob Forrest, UC Davis
For the CDF collaboration

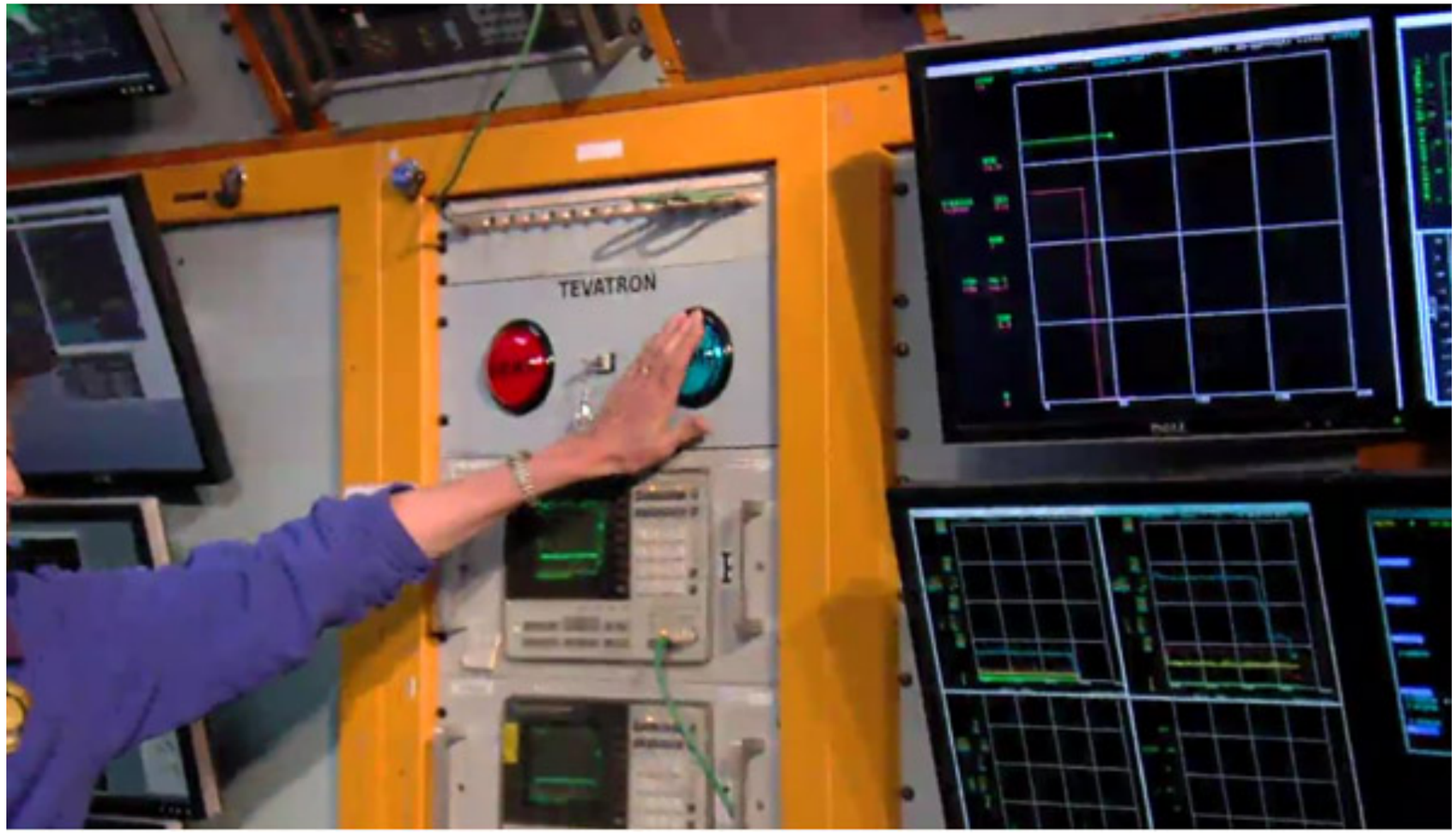
Outline

- Overview of electroweak production of SUSY
- Dilepton SUSY searches
- Trilepton SUSY searches

The Tevatron

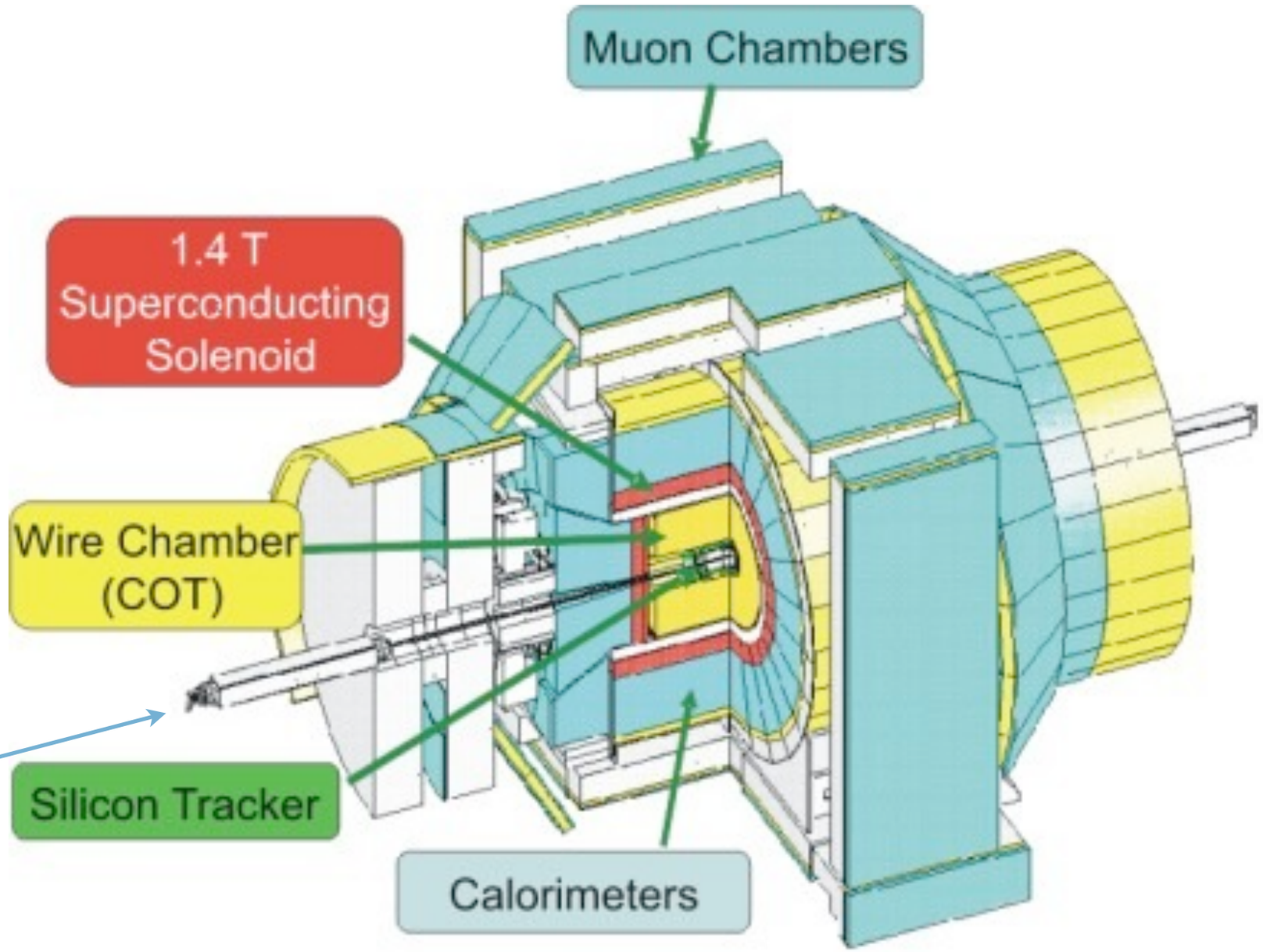
- ppbar collider at $\sqrt{s}$ = 1.96 TeV

The Tevatron



- 1983- Oct 5, 2011
- 12 fb^{-1} delivered to CDF and D0

Collider Detector at Fermilab (CDF)

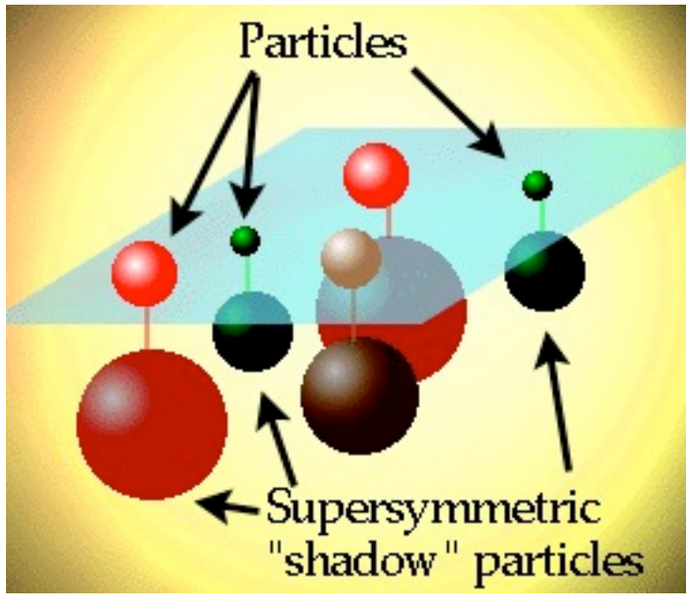


CDF

- 1985(first collision)- Oct 5, 2011

Supersymmetry

- Postulates a new symmetry that creates a superpartner for every known SM particle.



- Charginos $\tilde{\chi}^{\pm}_{1,2}$ and neutralinos $\tilde{\chi}^{0}_{1,2,3,4}$ emerge as mixtures of SUSY higgsinos and gauginos.
- Provides a dark matter candidate; protects ewk scale from divergences.

mSUGRA

- mSUGRA is the most phenomenologically studied of SUSY breaking theories.
- Experimentalists use it to compare sensitivity between analysis.
- Involves 5 parameters:

m_0 Universal Scalar Mass

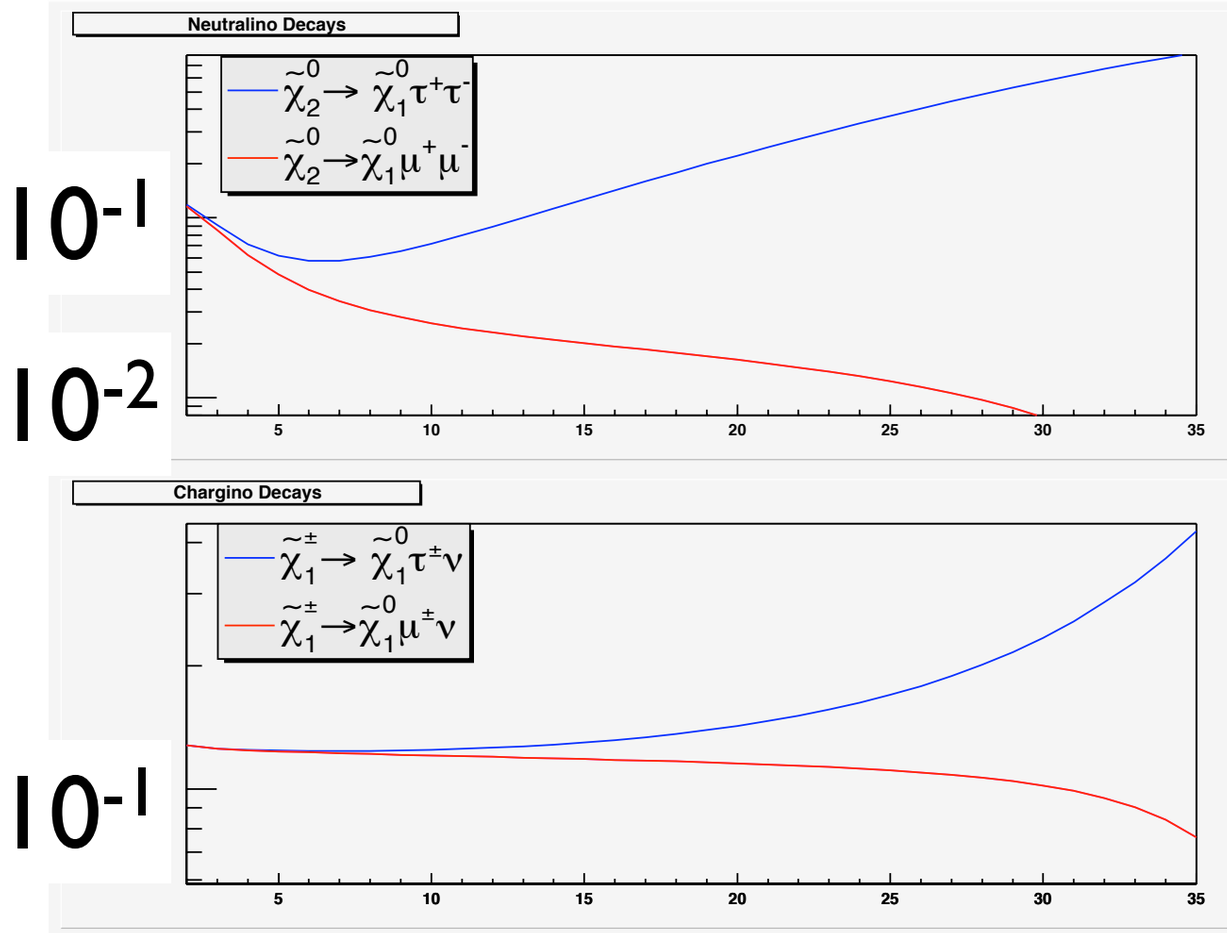
$m_{1/2}$ Universal Gaugino Mass

A_0 Trilinear Coupling

$sign(\mu)$ Sign of SUSY Higgs Mass

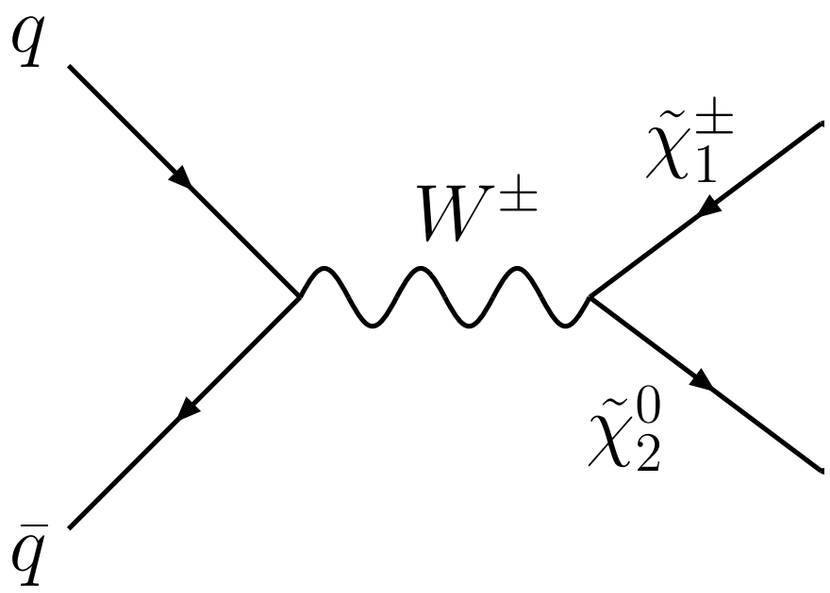
$\tan(\beta) = \langle H_1 \rangle / \langle H_2 \rangle$ Ratio of Higgs VEVs

High tan(β):
Lightest stau becomes lighter than the charginos and neutralinos. BR to τ increases.



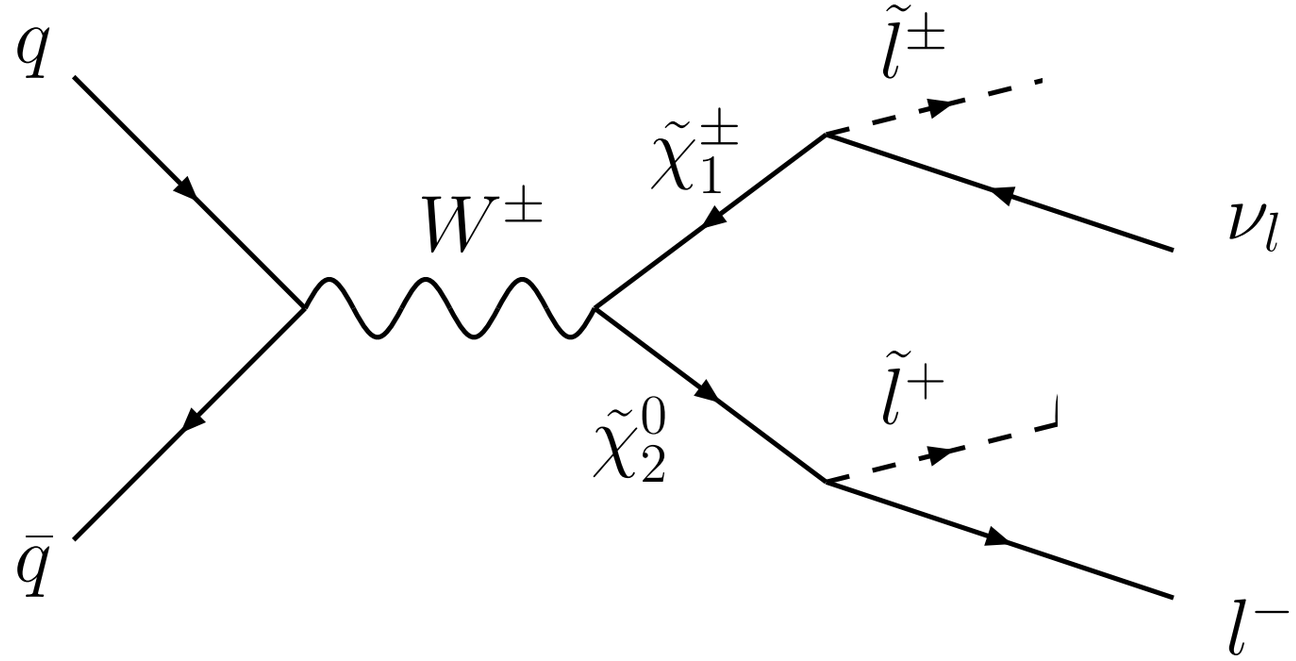
$$m_{\tilde{\tau}_1} - m_{\tilde{\tau}_2} \propto \tan\beta$$

Electroweak SUSY Production



- Chargino $\tilde{\chi}_1^{\pm}$, Neutralino $\tilde{\chi}_2^0$ directly produced and subsequently decay to leptons and MET.
- Neutralino/Chargino associated production can have appreciable cross sections.
- Other production diagrams exist, but have small σ.
- Direct production allows avoidance of strong sector squarks and gluinos.

Electroweak SUSY Production



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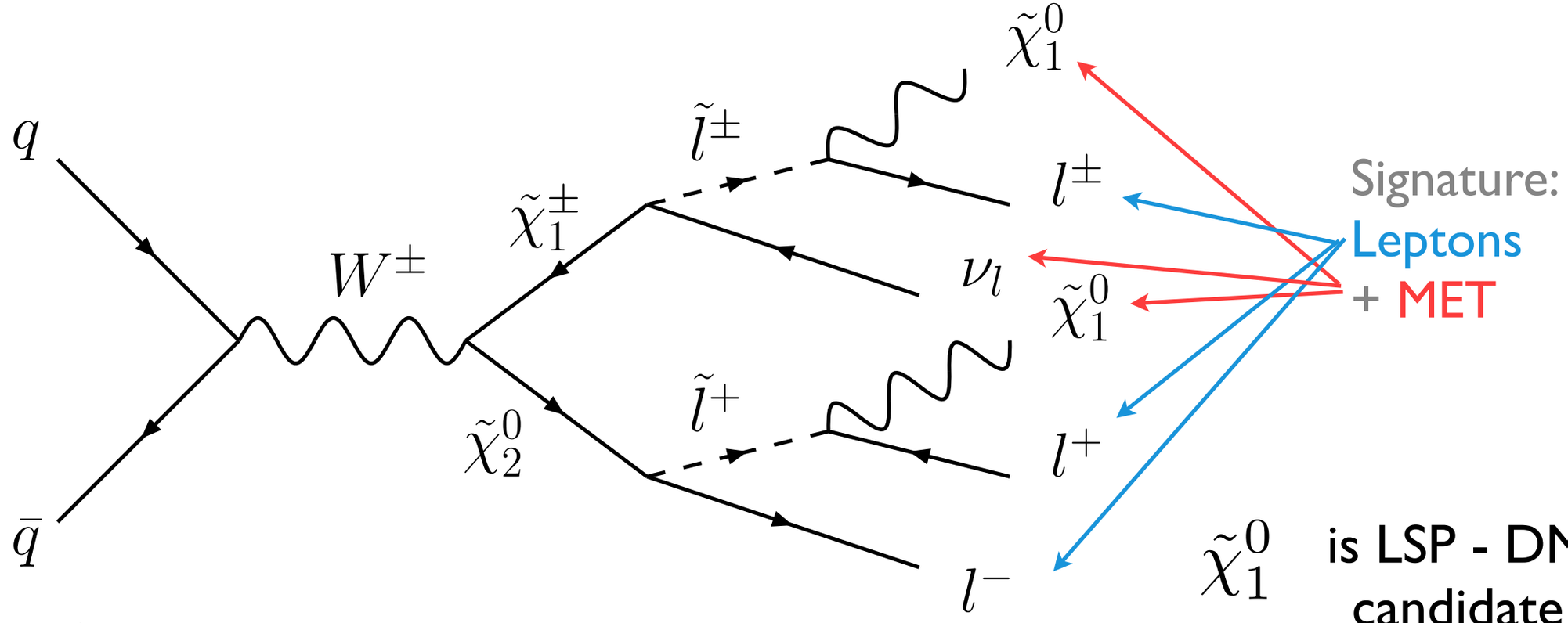
Electroweak SUSY Production



$\tilde{\chi}_1^0$ is LSP - DM candidate

- Chargino $\tilde{\chi}_1^{\pm}$, Neutralino $\tilde{\chi}_2^0$ directly produced and subsequently decay to leptons and MET.
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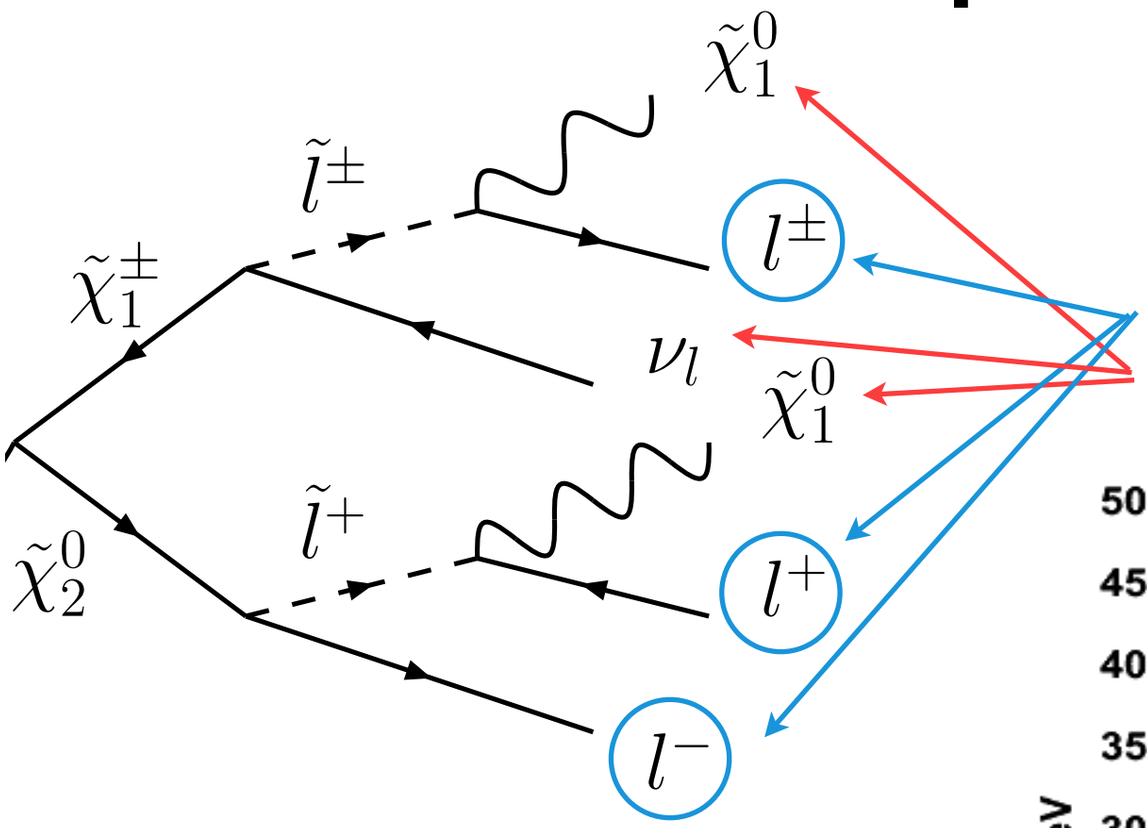
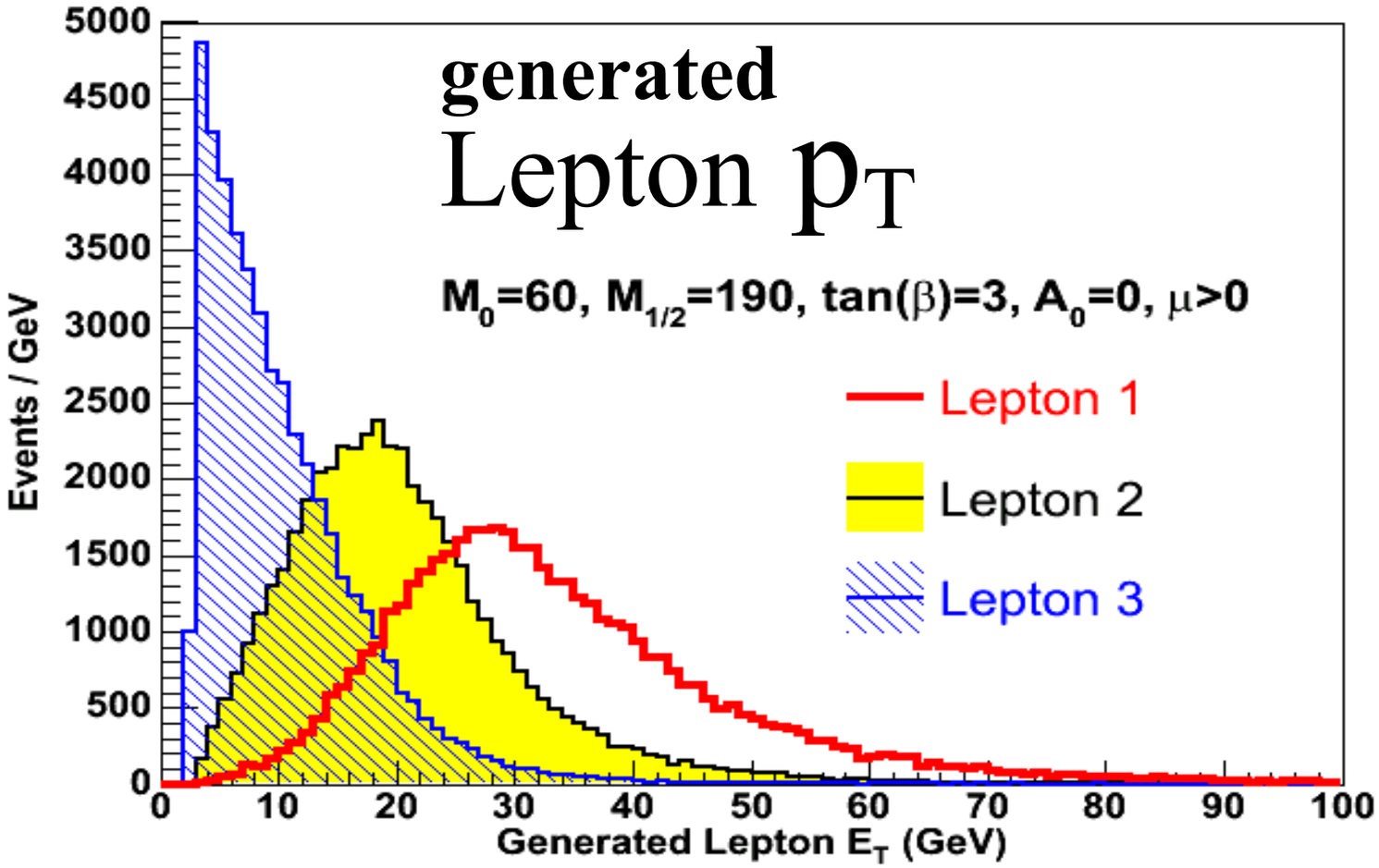
Trilepton Searches



Signature:

3 Leptons

+ MET



- Very low SM backgrounds.
- Cascade decay results in characteristic low Pt leptons; requiring 3 leptons presents acceptance challenges.

Trilepton Searches

Two Recent CDF Searches

1. ‘Catchall’ trilepton exclusive channel ordered search.

Defines generic lepton ‘tight’ and ‘loose’ categories.

Assigns events to exclusive signal bins based on purity.

2. Trileptons with increased acceptance.

Increases sensitivity by including more detector objects.

1.

Strategy:

- Leptons (e, μ) categorized as 'Tight' (t) or 'Loose' (l).
- Also define an isolated track (T) object. Recoups acceptance from detector gaps, leptons failing cuts, 1-pronged taus.
- This is a unified analysis, with predefined **exclusive** trilepton channels ordered by sensitivity.
- Final combination of trilepton channels is straightforward.

1.

Exclusive Channels (ordered):

More Sensitive

Less Sensitive

3 Tight Leptons	(ttt)	Trilepton Channels
2 Tight + 1 Loose	(ttl)	
1 Tight + 2 Loose	(tll)	
2 Tight + Track	(ttT)	Dilepton+Track Channels
1 Tight + 1 Loose + Track	(tlT)	

An event can only qualify for **one** of these channels.

1.

SM Backgrounds

Drell-Yan, WW } 2 real leptons + conversion

WZ, ZZ, ttbar } 3 real leptons

SM Dilepton + Fake Lepton } Lepton fakes

SM Dilepton + Fake Track } Track Fakes

1.

Data

- 3.23 fb^{-1}

Triggers Used:

- High Pt inclusive lepton triggers. (Pt > 18 GeV/c)
- Lower Pt dilepton triggers. (Pt > 4, 4 GeV/c)

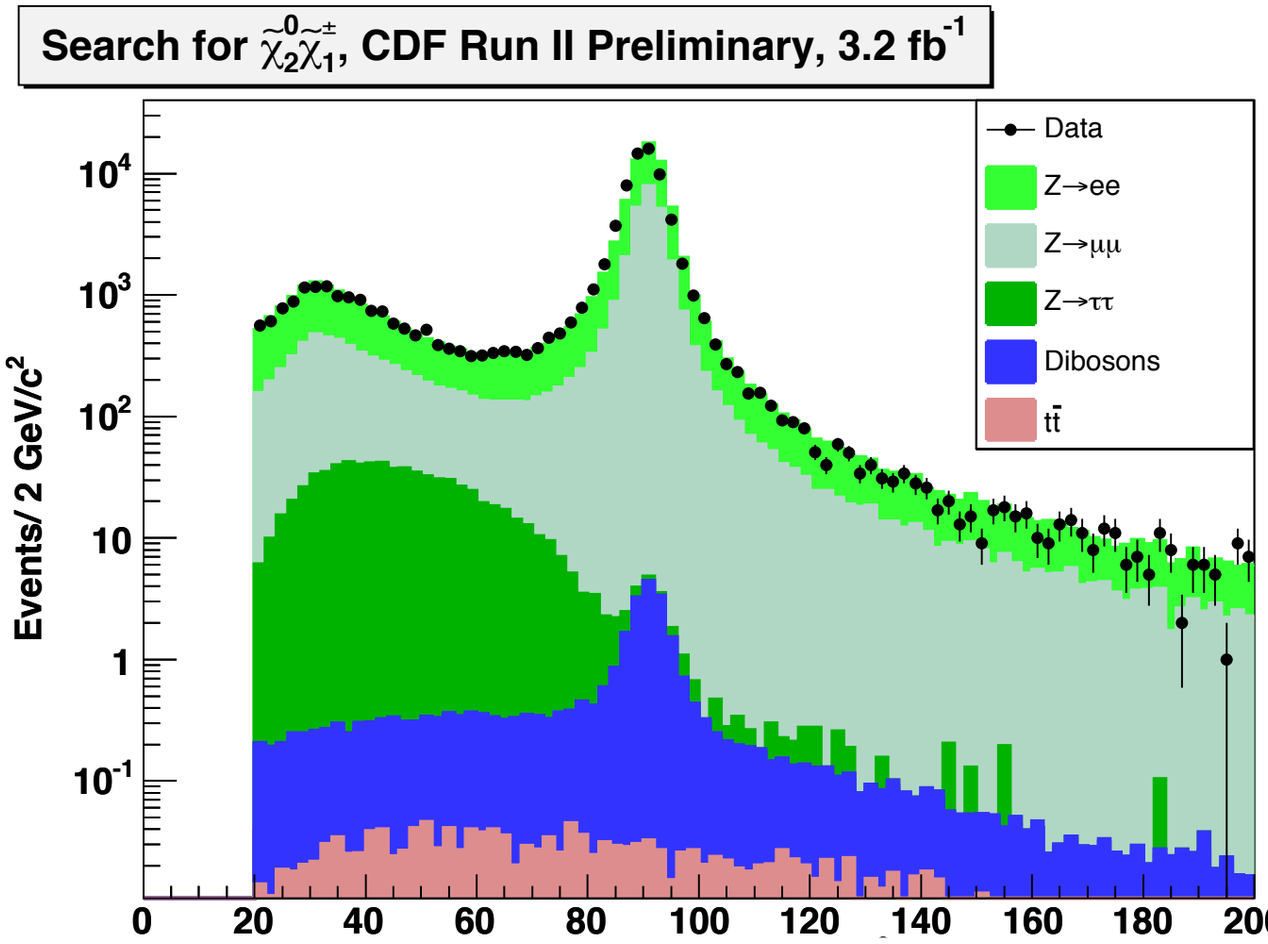
Dilepton Selection

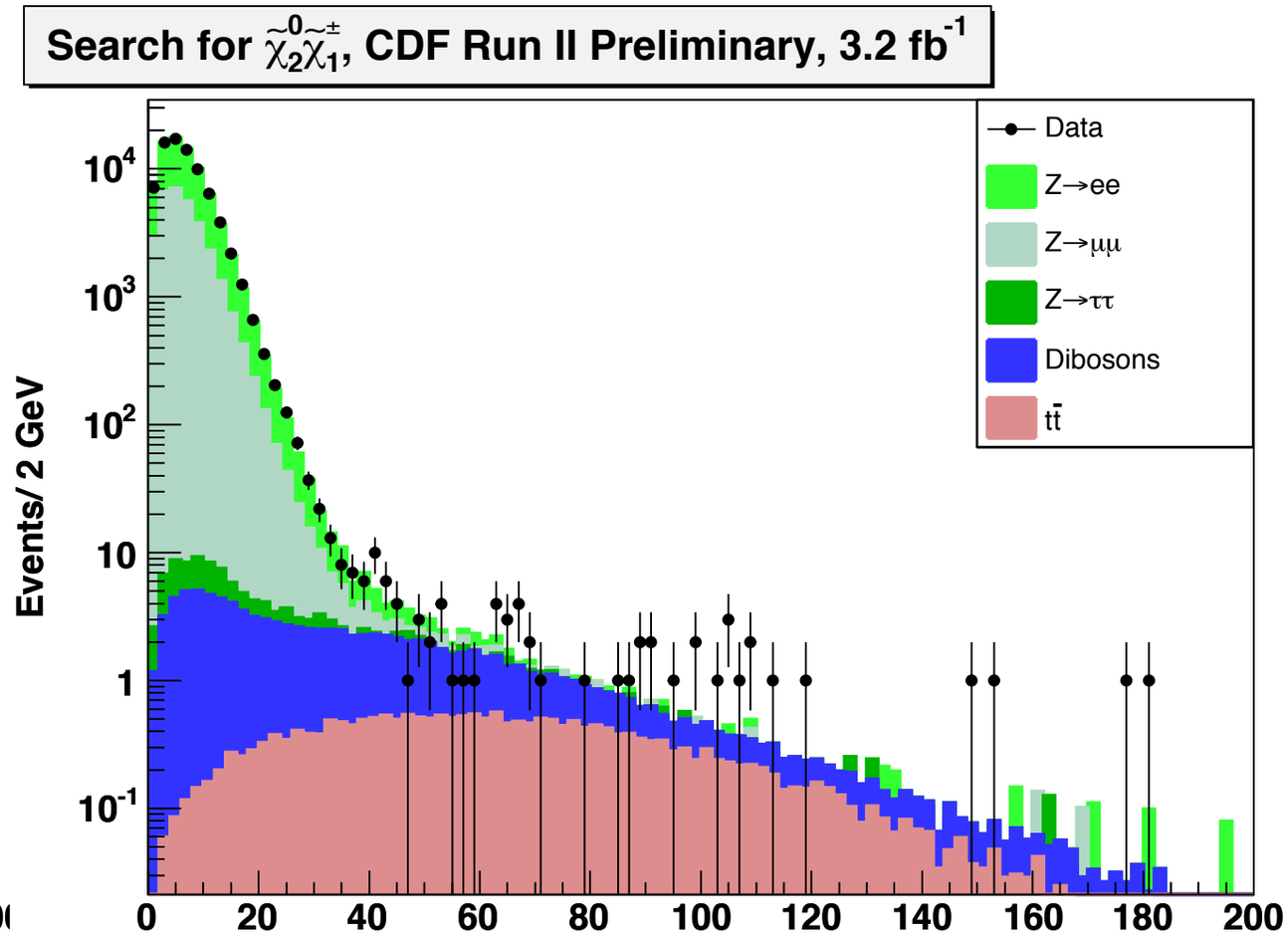
Category	Lepton Pt Cuts (GeV/c)
tight-tight (tt)	15, 5
tight-loose (tl)	20, 8

1. Sanity Check: First 2 Tight Leptons

Low MET region.
$\not\!\!E_T$ < 10 GeV

Z Window
76 GeV/c < M(ll) < 106 GeV/c





1.

Trilepton Selection

Select the third lepton

Category	Object Pt Cuts (GeV/c)
ttt	15, 5, 5
ttl	15, 5, 10
tll	20, 8, 5
ttT	15, 5, 5
tlT	20, 8, 5

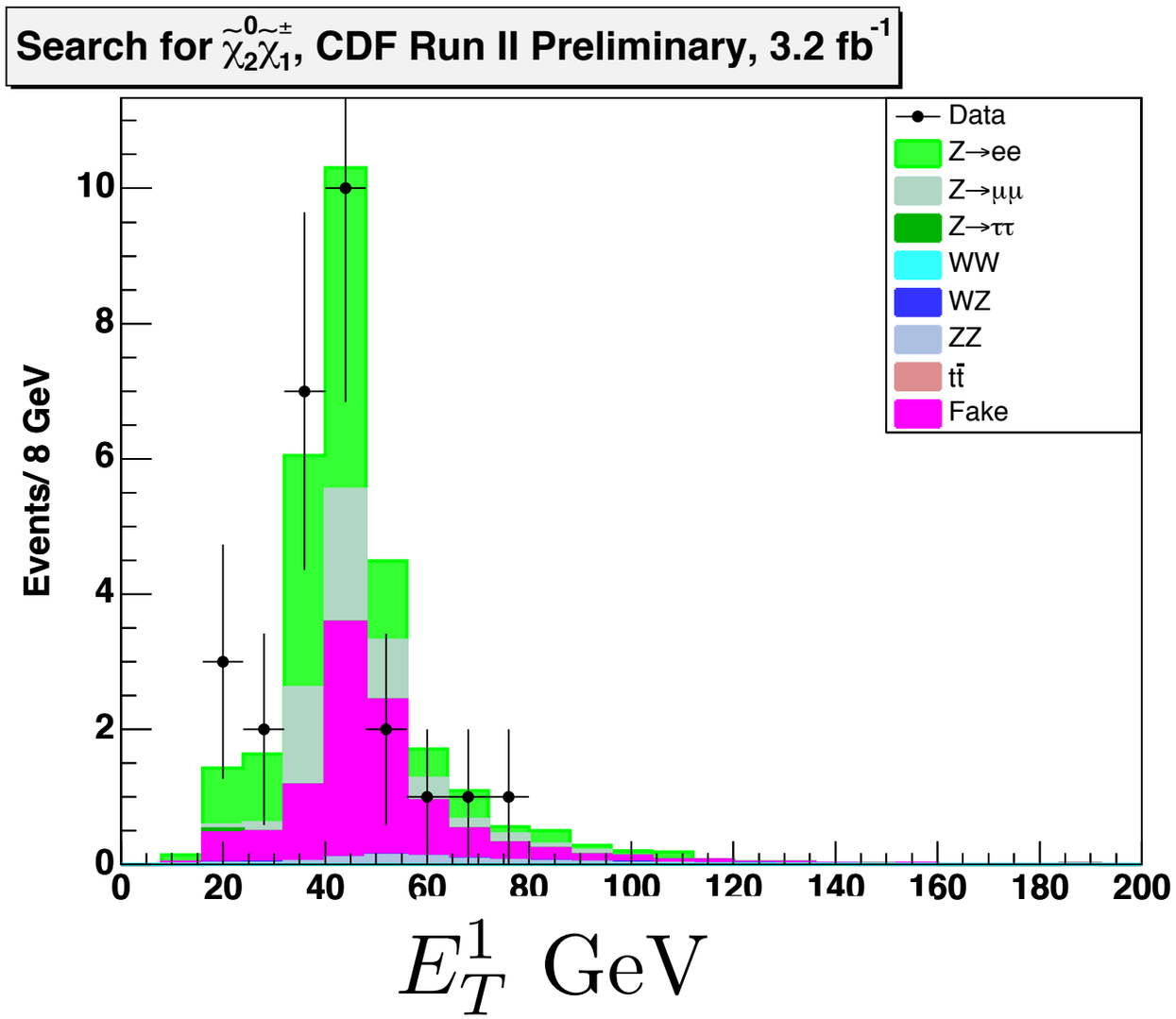
Other event objects: Jets with $E_T > 15$ GeV

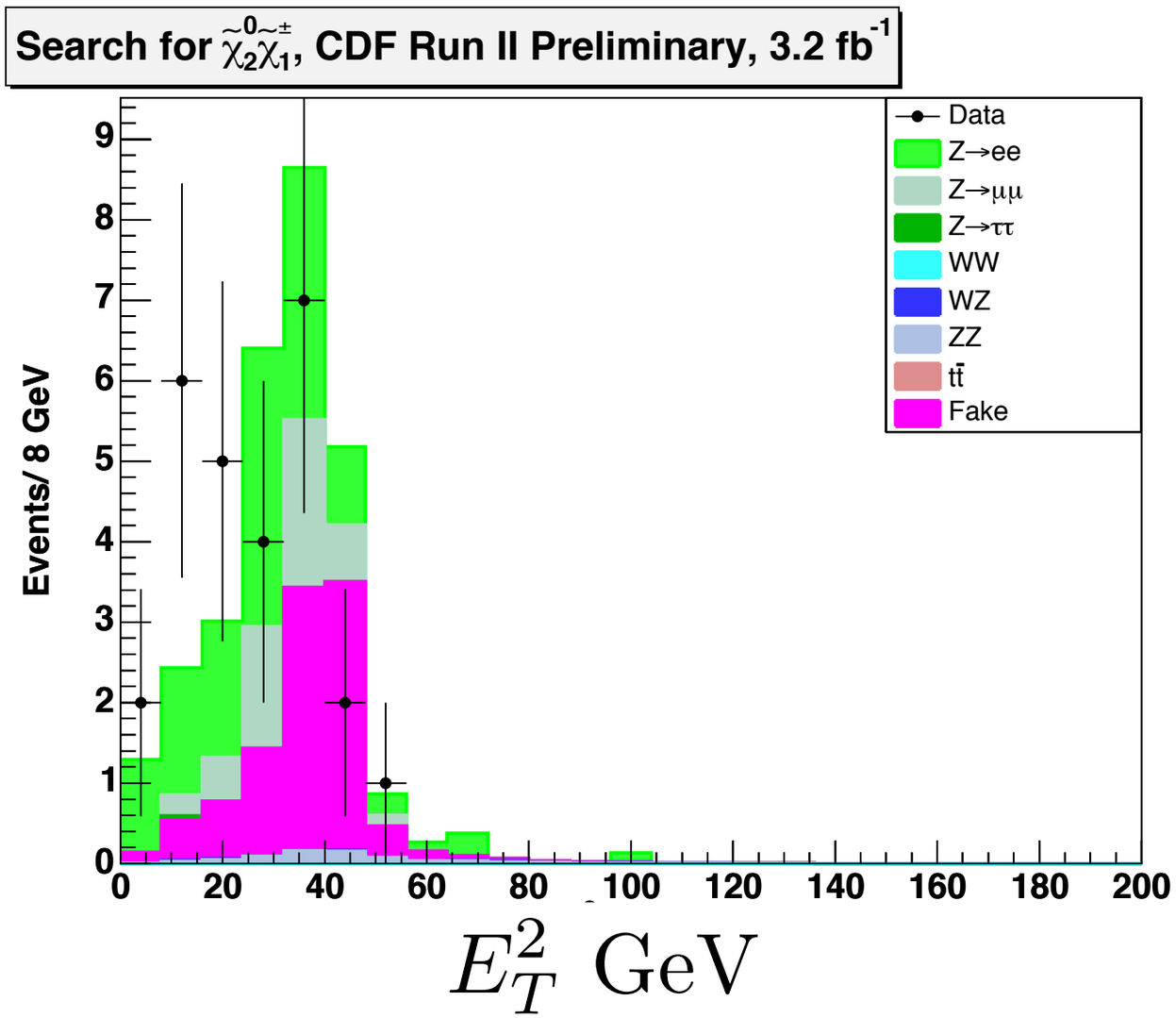
Missing energy, $\not\!\!E_T$

1.

Trilepton Plots - 3 Tight

Low MET region.
$\not\!\!E_T$ < 10 GeV

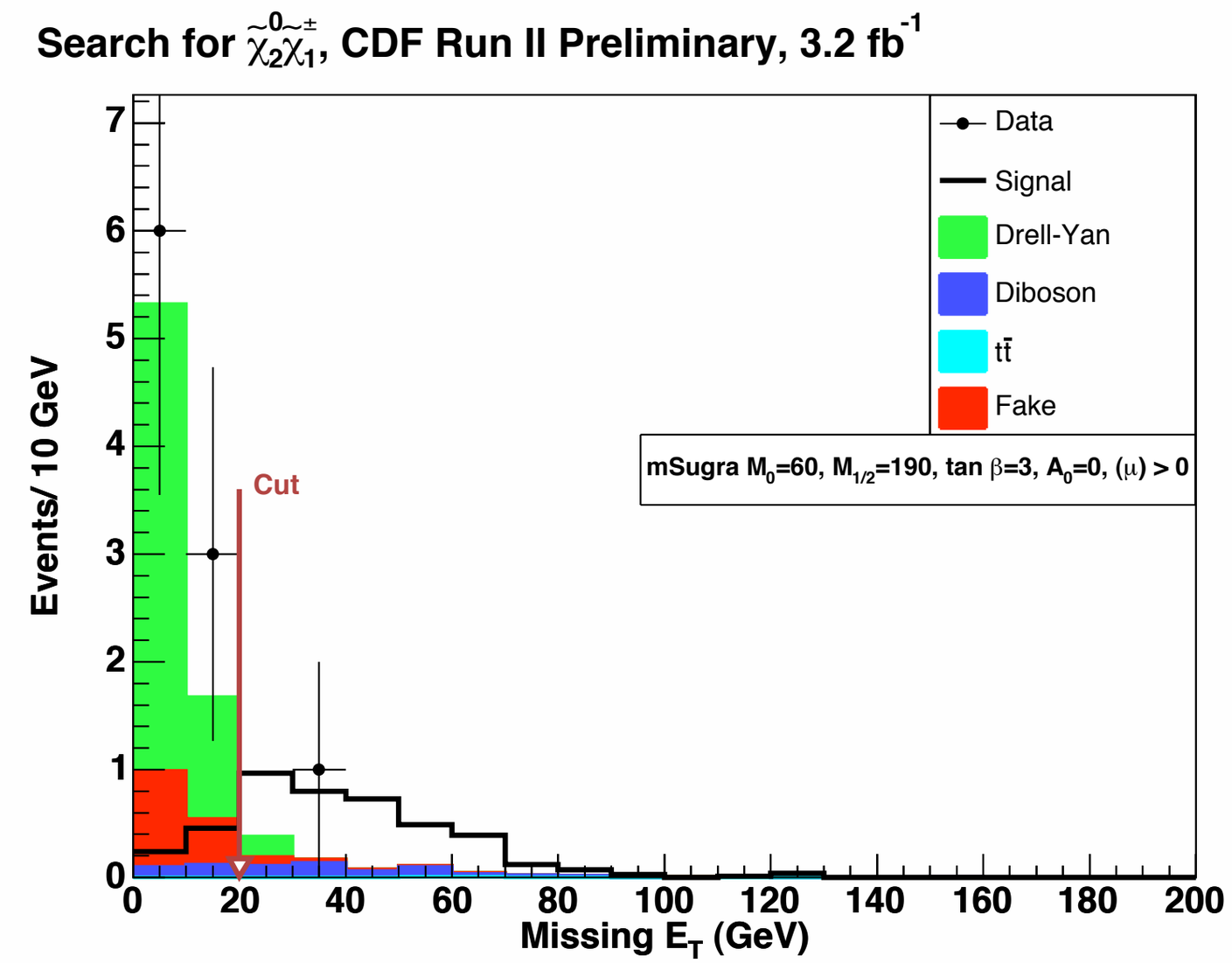




1. Event Selection - SUSY Cuts

Reduce DY:

$$\not\!\!E_T \geq 20\mathrm{GeV}$$



ttt Category N-1 Plot

Additional cuts applied to reduce Drell-Yan and $t\bar{t}$
Limit jet activity.

1.

Observed

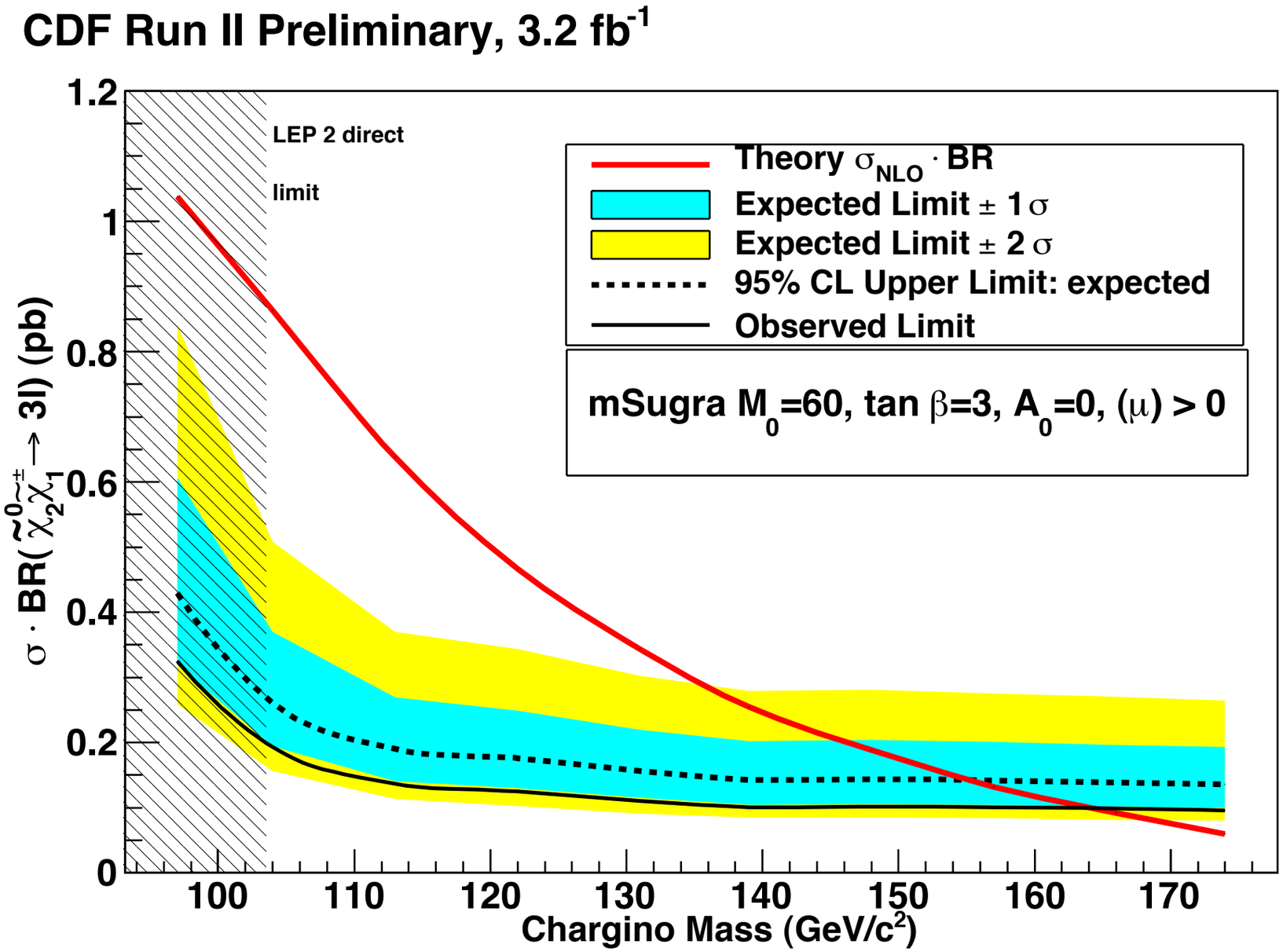
Totals:

	Background	Signal	Observed
Trilepton	1.5 ± 0.2	7.4 ± 0.7	1
Dilepton+Track	9.4 ± 1.4	11.2 ± 1.1	6

Data consistent with background, moderate deficit in dilepton+track channels.

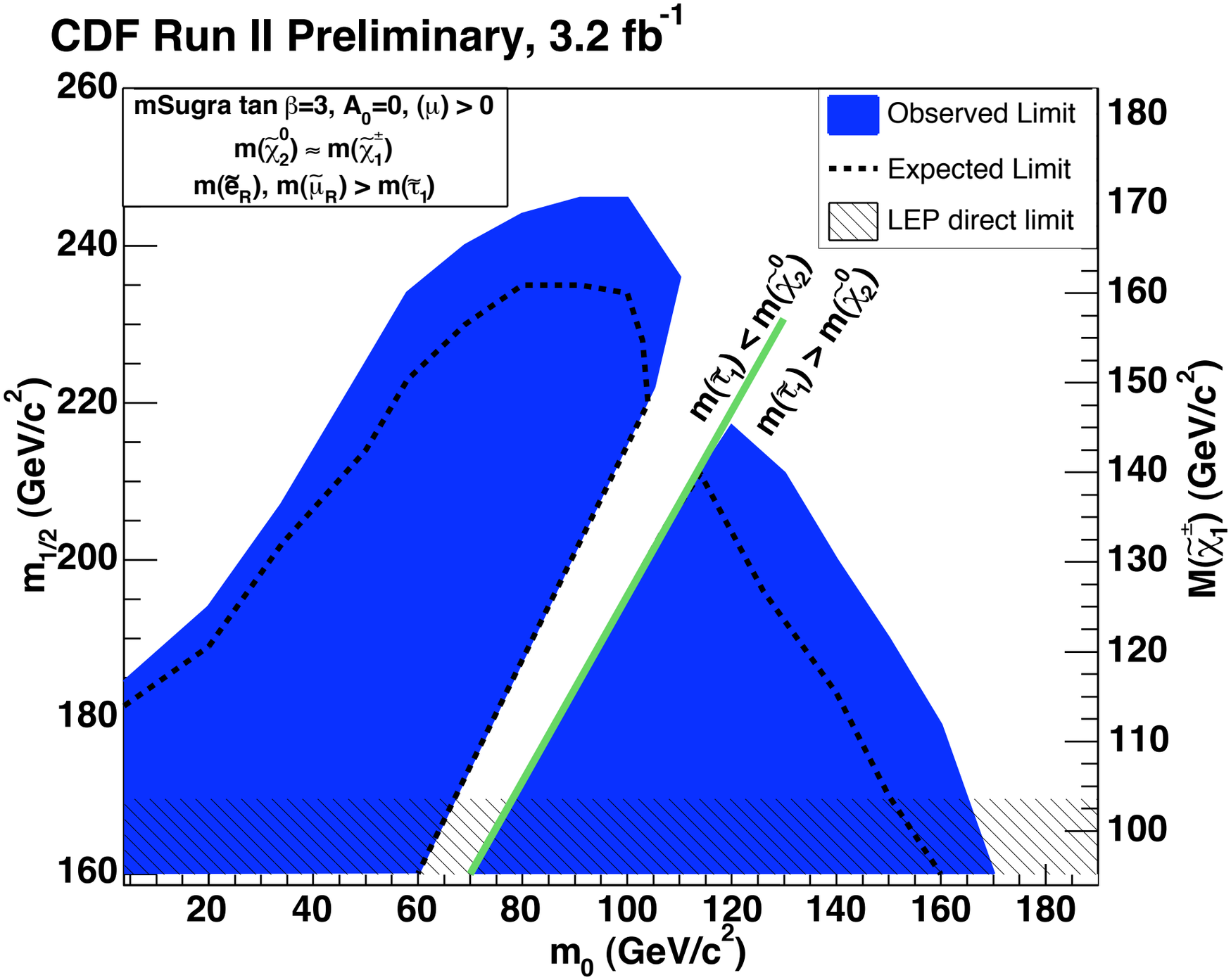
No evidence of SUSY.

1. Cross Section times BR upper limit



- We exclude Chargino masses of up to $164\ \mathrm{GeV}/c^2$ at this reference SUSY point.
- Previous CDF limit was $145\ \mathrm{GeV}/c^2$ with 2.0 fb^{-1}: Phys.Rev.Lett. 101, 251801 (2008)

2-D Limit



- Generate ~50 million signal events at almost 100 points, get limit at each point.

2. Trileptons with Increased Acceptance

- Channels:

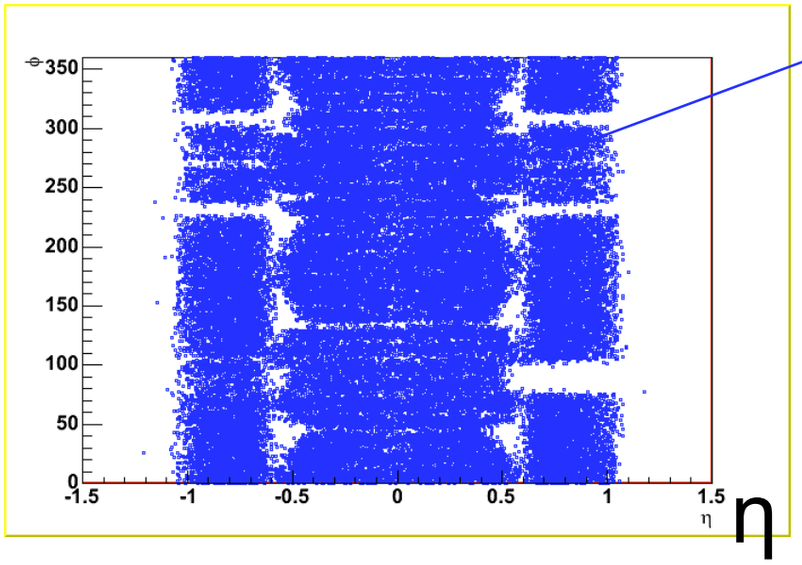
  ee+lepton
  ee+isoTrack
  μμ+lepton
  μμ+isoTrack
  (Lepton is e, μ, or hadronic τ)

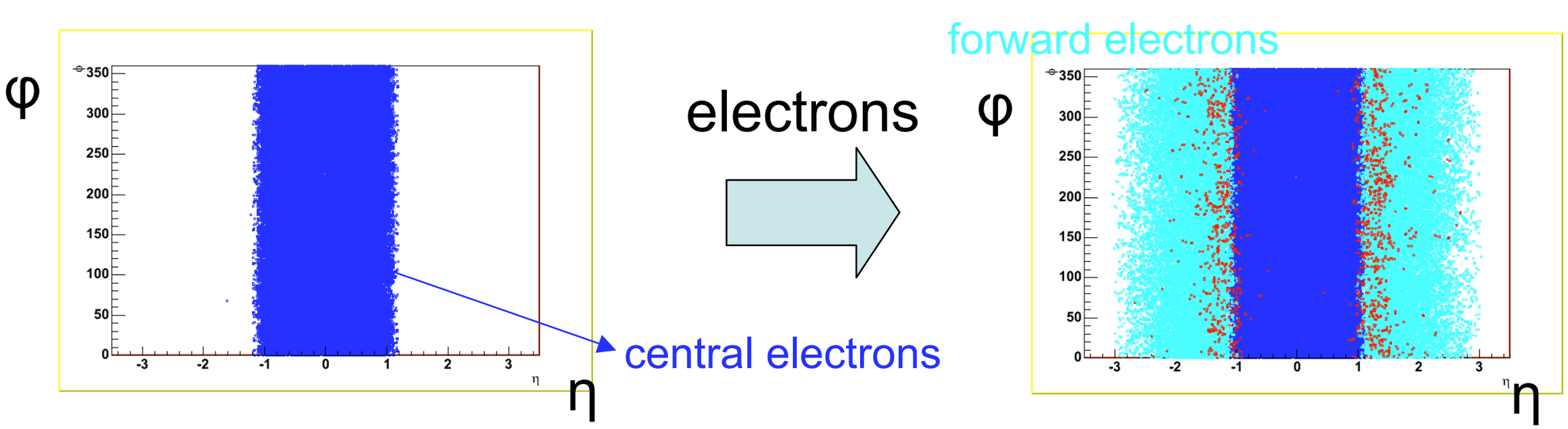
- Improvements over standard CDF object selection:

  Expand geometrically ($|\eta| > 1$), looser μ objects.
  Expand kinematically Low-Pt objects.
  New objects. Hadronic τ, isoTracks.

2.

Increased Coverage



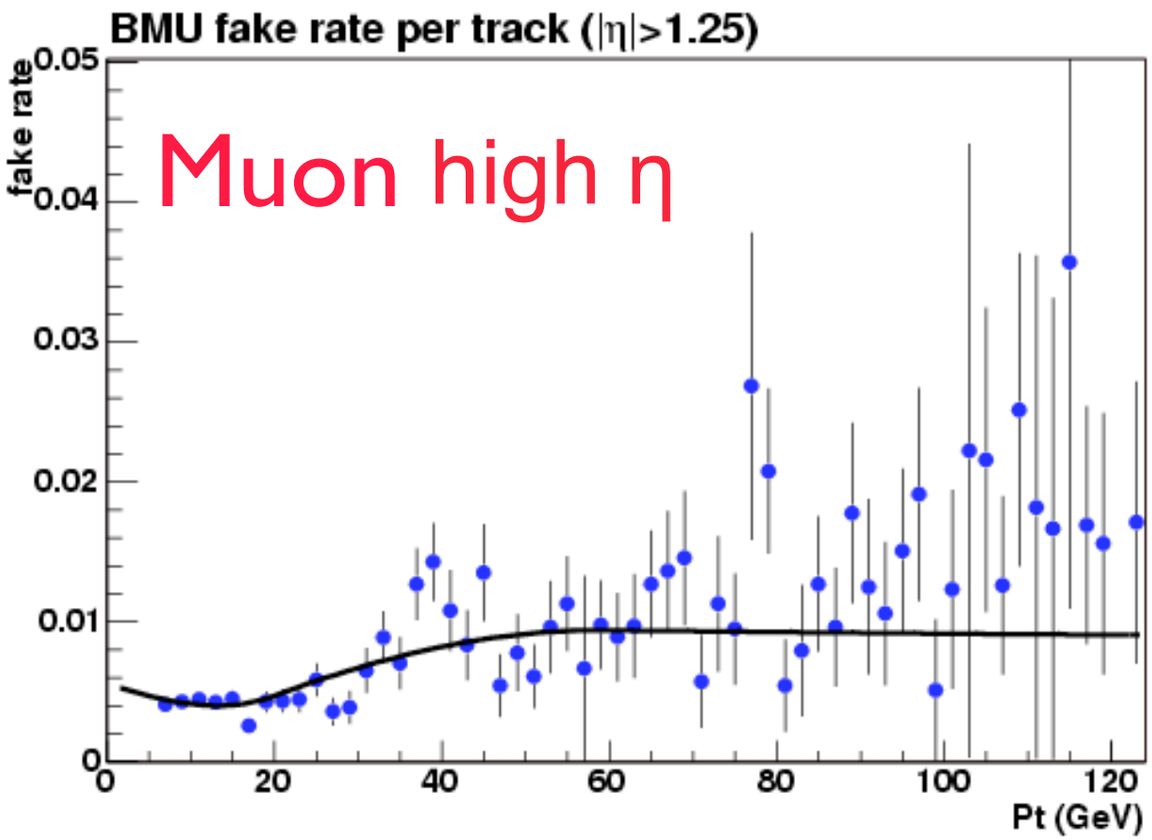


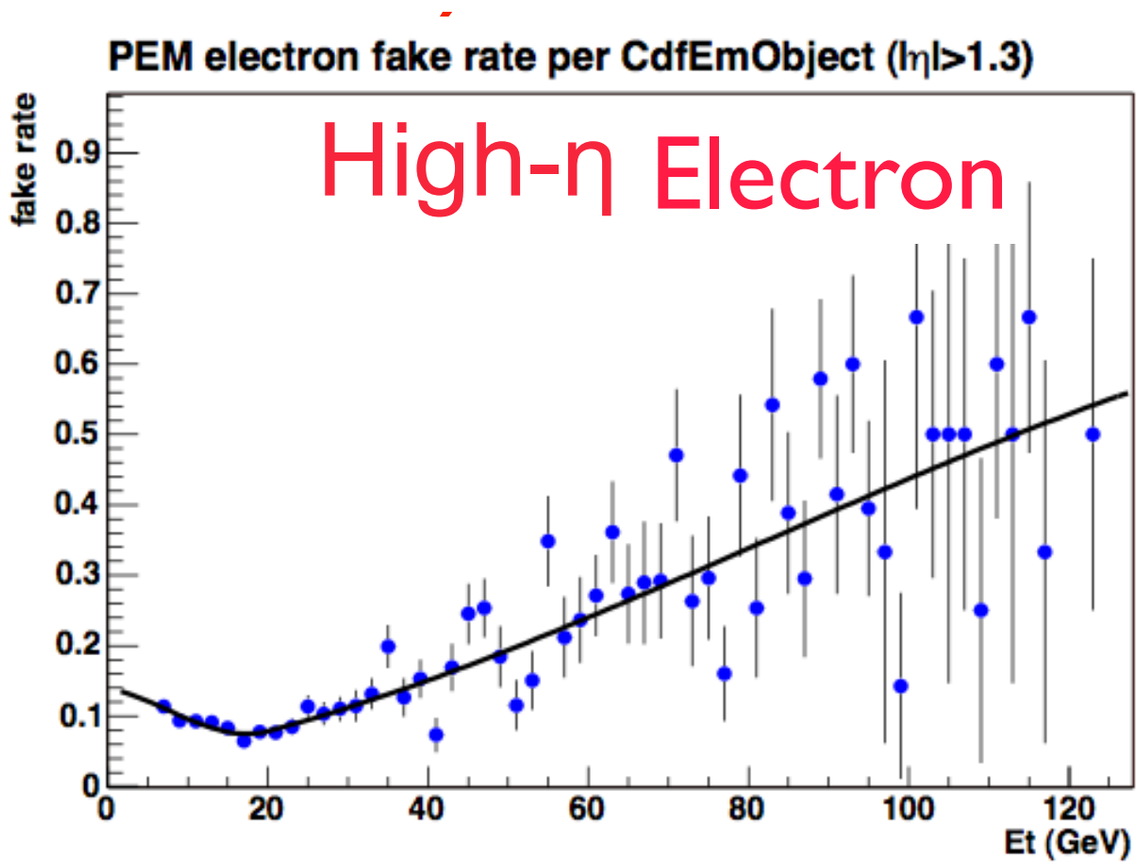
Using whole detector (plug) ~triples overall trilepton acceptance

2.

Fake Rates

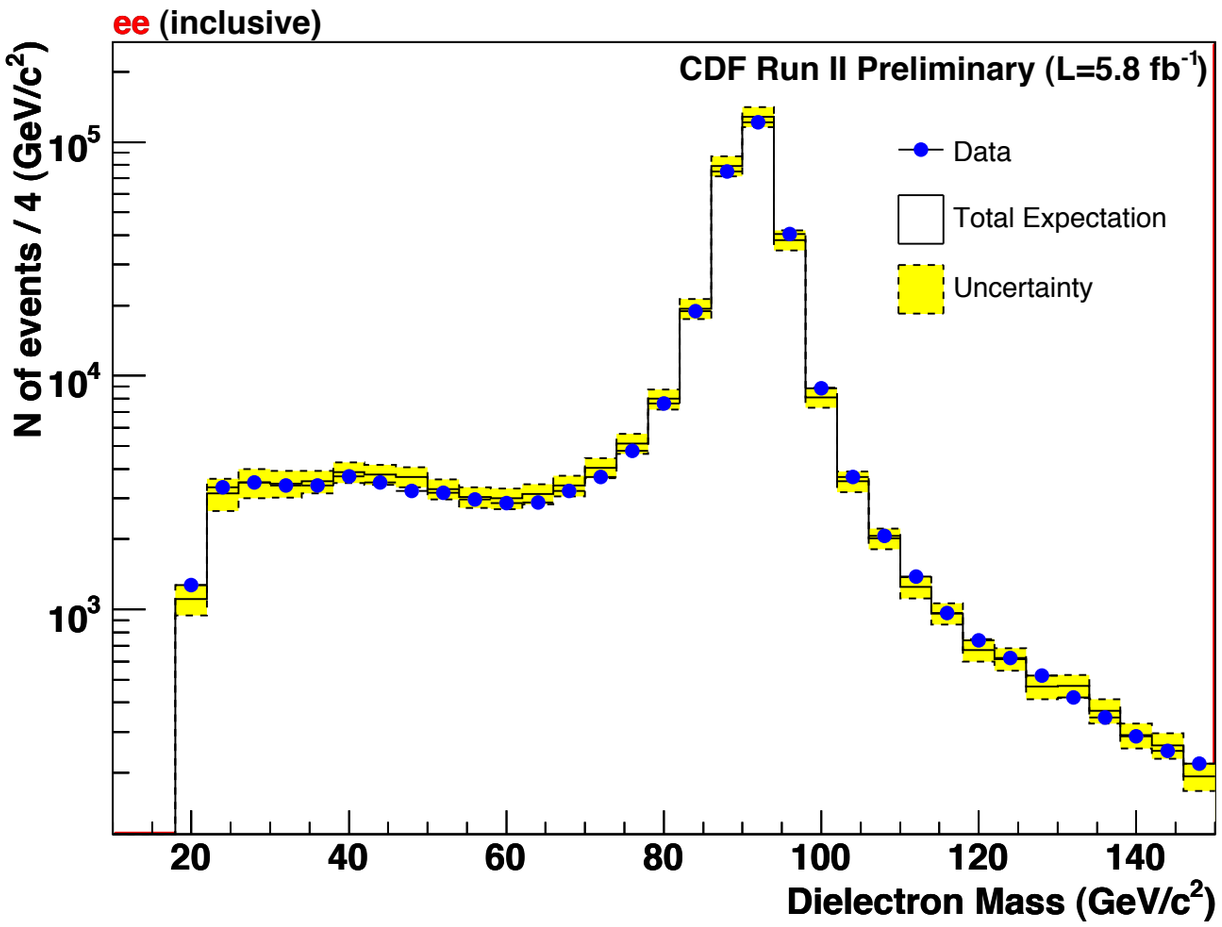
- Large effort for measurement of new object fake rate (often why these objects are rare in analysis).
- Rate of track faking a μ, or loose EM cluster faking an e

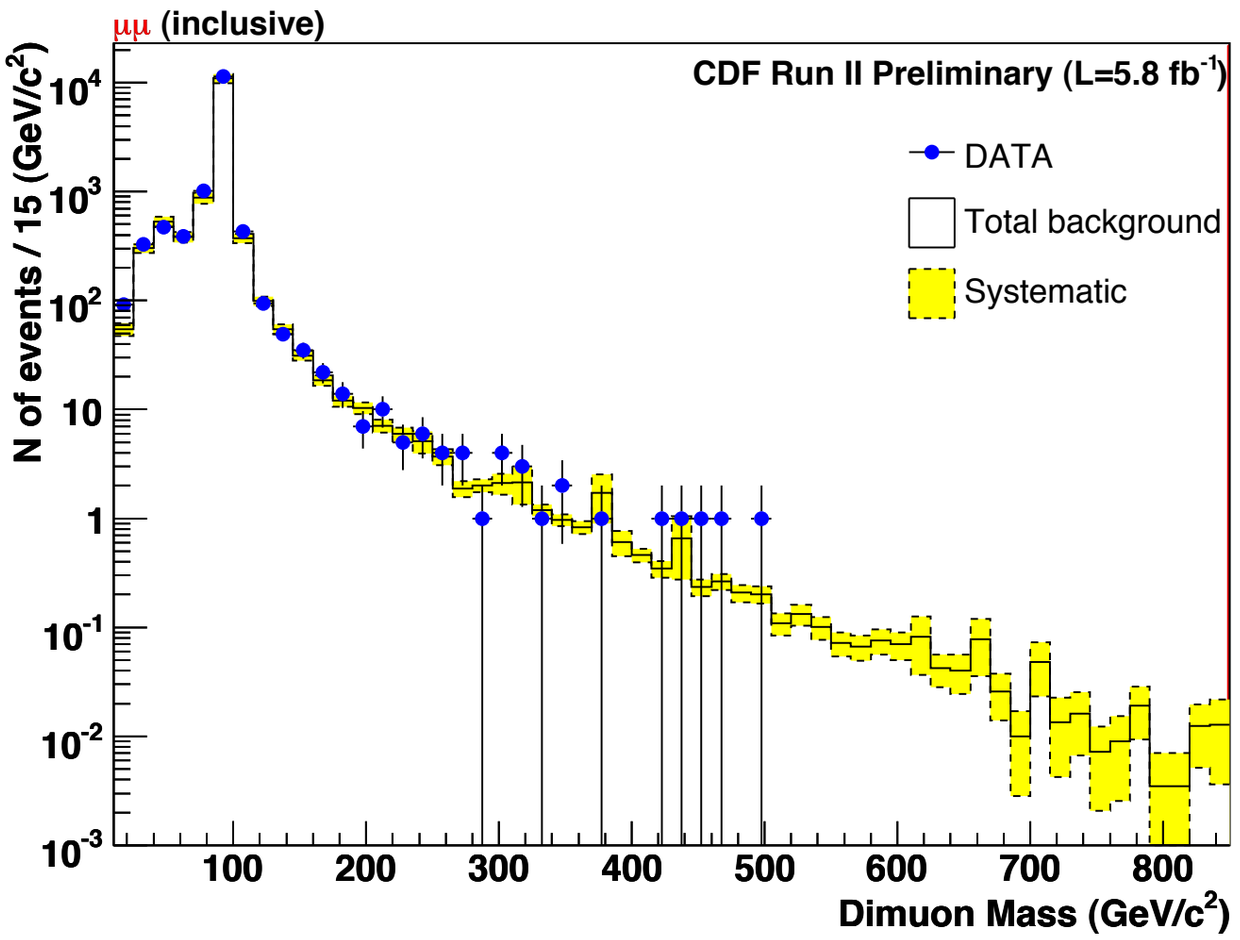




2.

Dilepton Checks

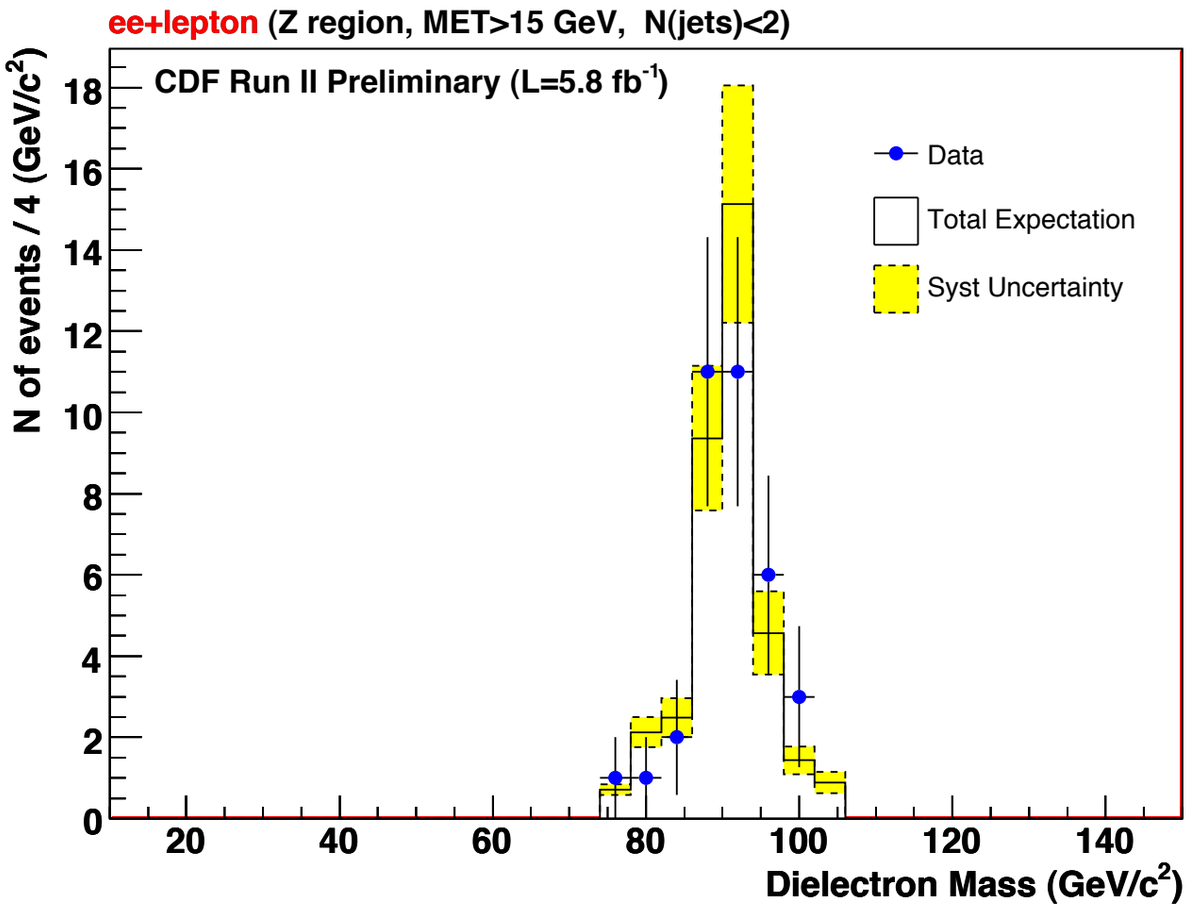


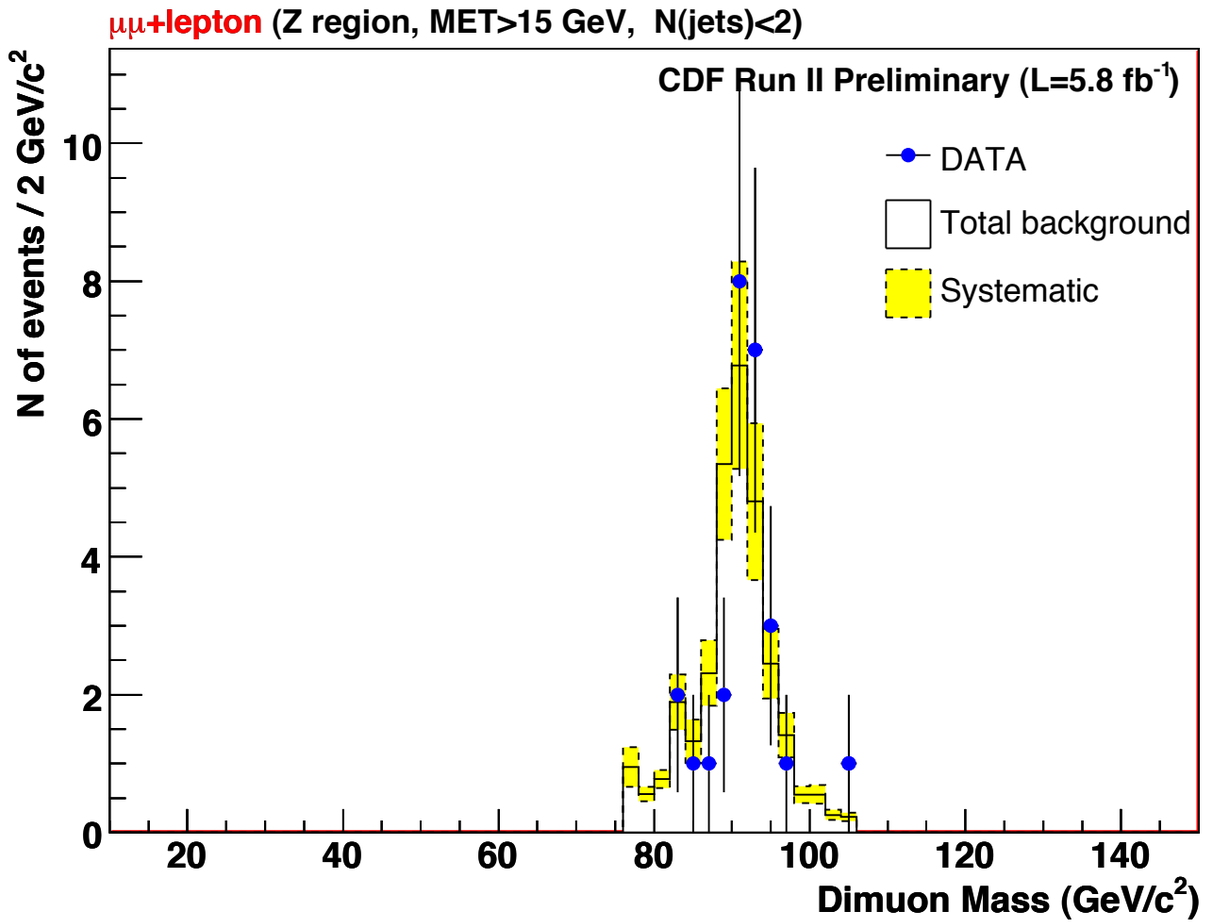


Several dozen more checks done.

2.

Trilepton Checks

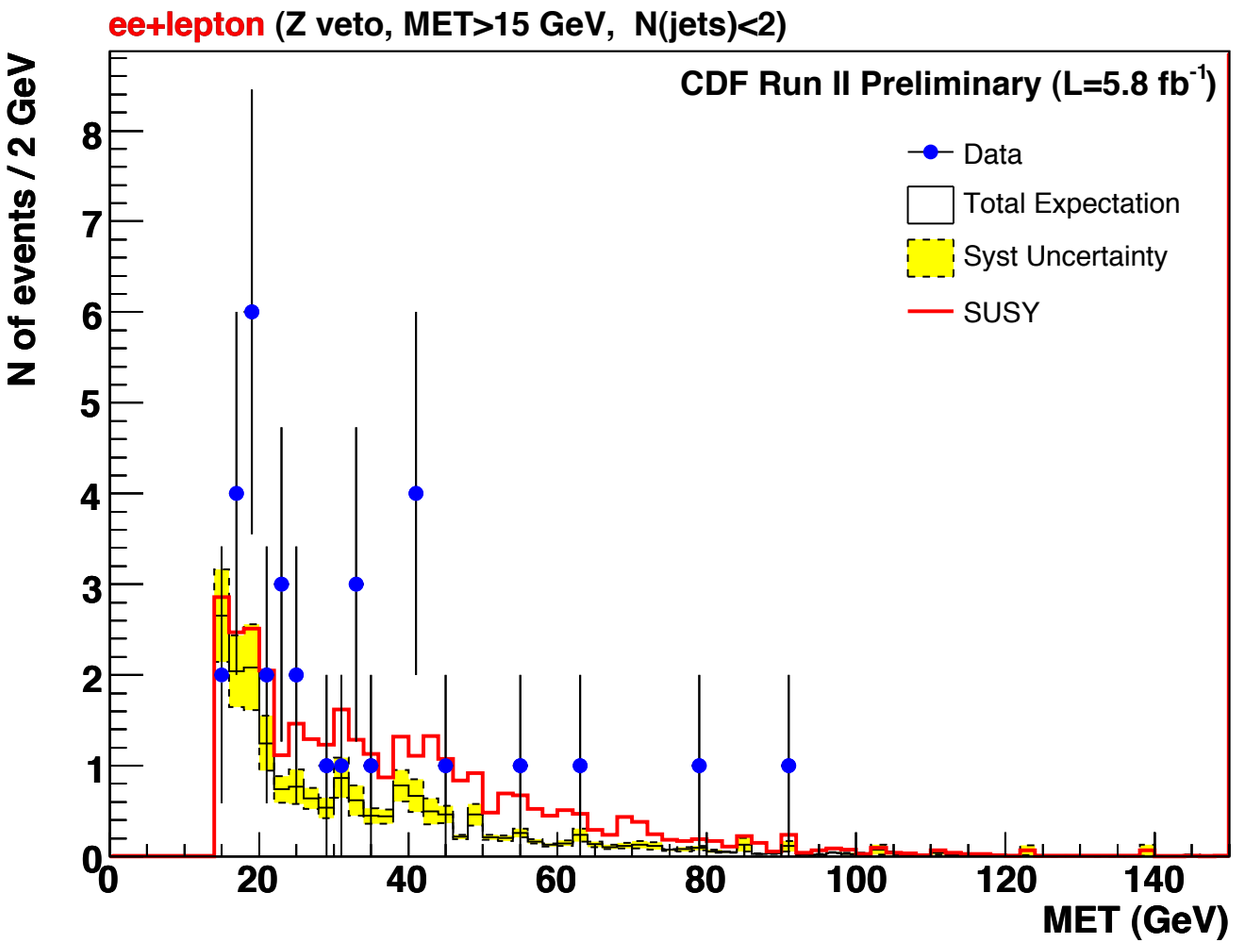


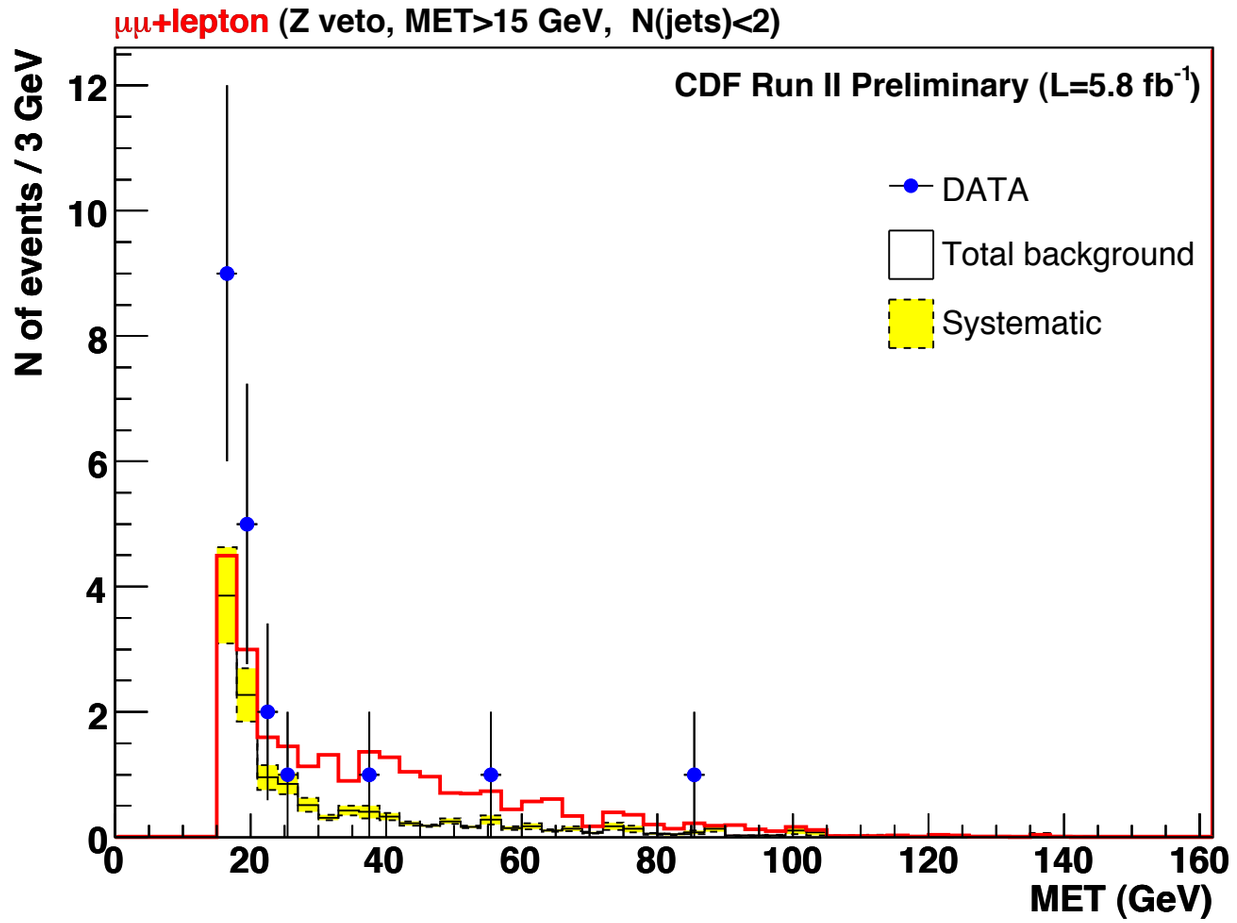


- Trilepton control region Z window, High MET
- Large drop in acceptance from third object.
- Two additional channels with isolated track.

2.

Signal Region - MET Plots

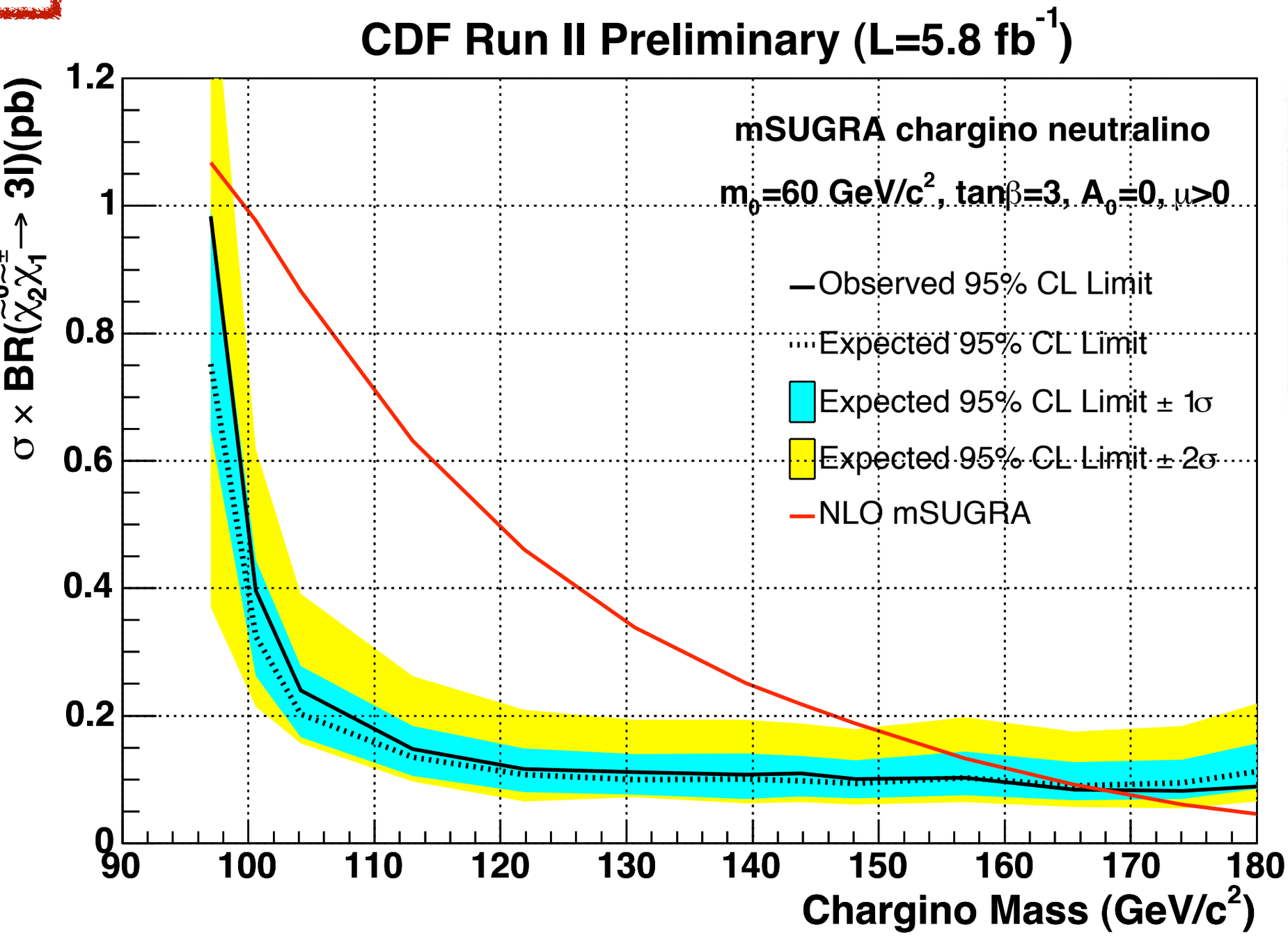




- MET > 15 GeV, N(jets) < 2, Z Veto
- Signal point stacked on backgrounds here.

2.

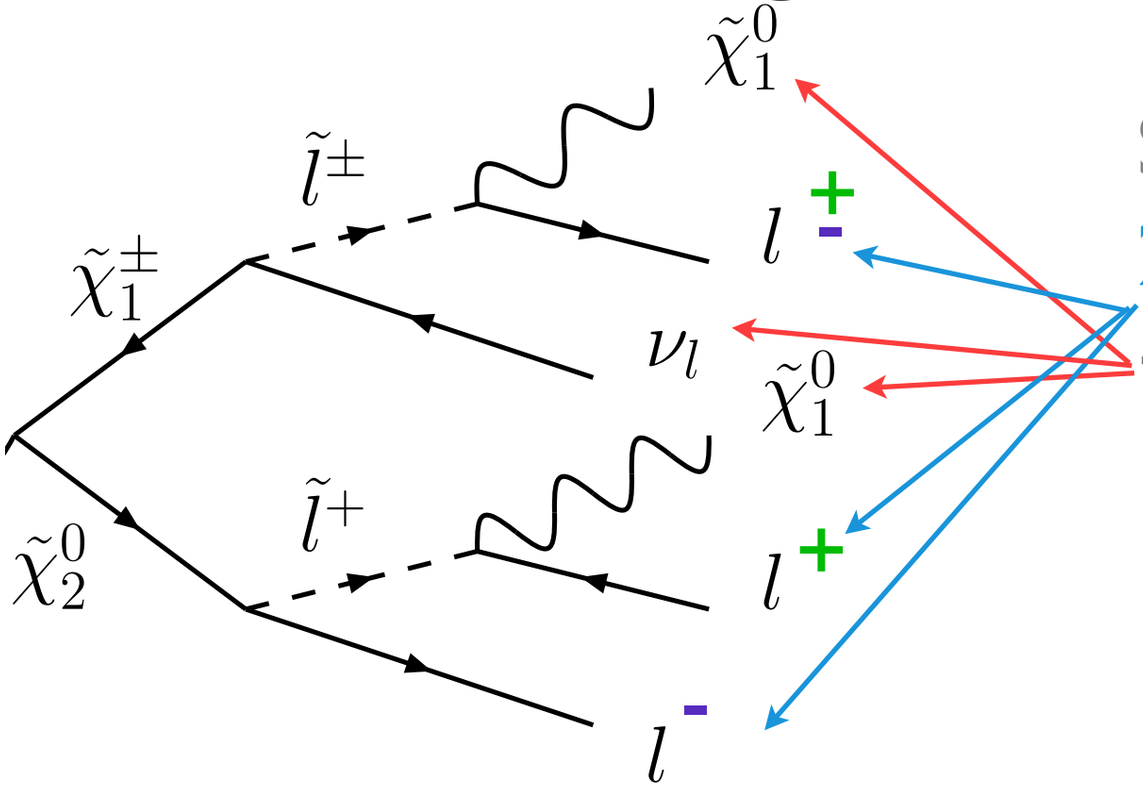
New Limits



Optimization cuts	
$M_{\ell_1\ell_2}$	$> M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0}$
$M_{\ell_1\ell_3}$	< 75 GeV/c^2
$M_{\ell_2\ell_3}$	< 75 GeV/c^2
$\not\!\!E_T$	> 25 GeV
$p_{T,2}$	$(> 8$ and $< 36 - 65)$ GeV/c
$p_{T,3}$	> 8 GeV/c

- New result released in August at SUSY '11
- New limit increased to 168 GeV/c^2

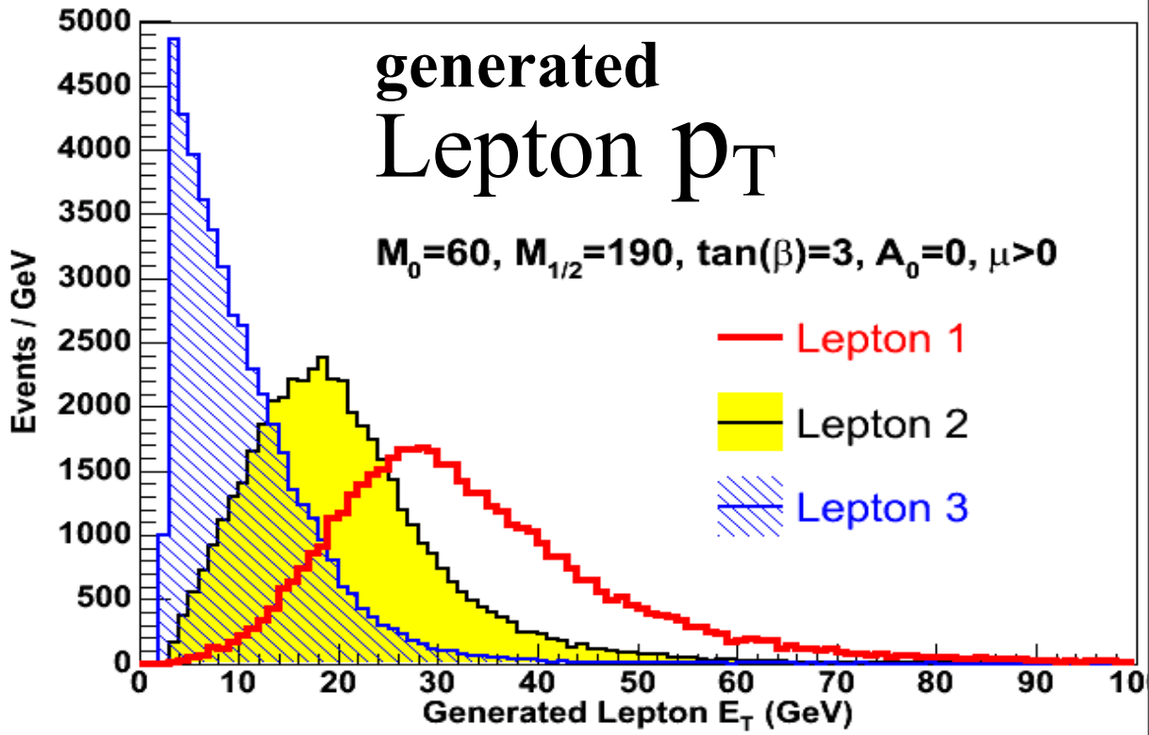
Same Signed Dilepton Searches



Signature:

2 SS Leptons

+ MET



- Ignoring the third lepton increases acceptance.
- Low SM background in for SS leptons.
- Increased acceptance allows searches for less efficient objects (hadronic τs)

SS Dilepton Searches

Two Recent CDF Searches

3. SS Dileptons with inclusive high Pt sample

Standard CDF objects e, μ

Generic search can be used to look for more than SUSY

4. SS Dileptons with Taus

Including Taus extends reach to high Tan(β) SUSY space.

Orthogonal and complimentary to analysis 3.

3. SS Dileptons with inclusive high Pt sample

- Standard CDF leptons e, μ
- eeeμ, μμ Channels
- 6.1 fb^{-1} of inclusive high Pt leptons (20,10) GeV.
- $|\eta| < 1.1$, M(ll) > 25 GeV and Z veto.

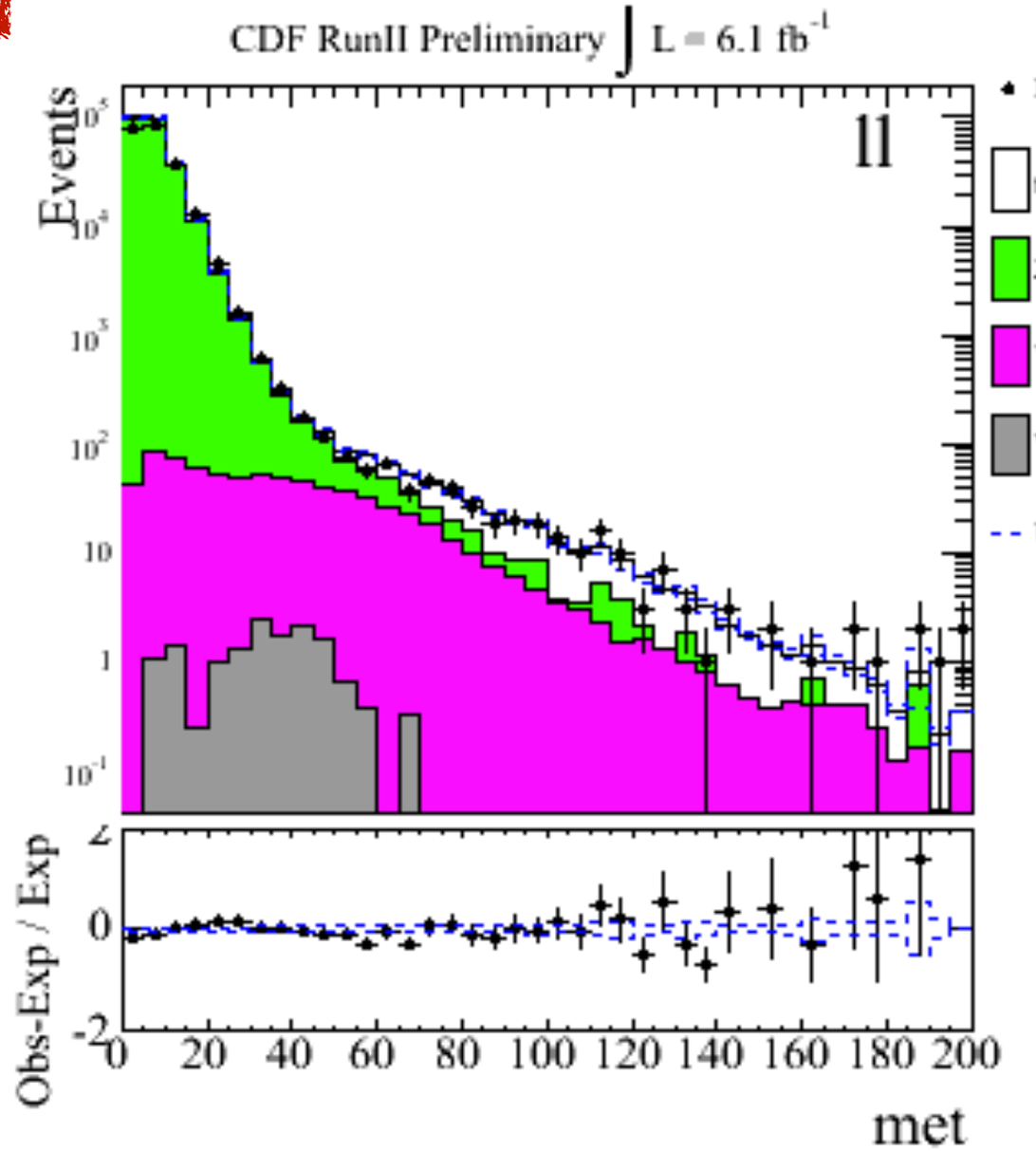
First Step: Model independent search.

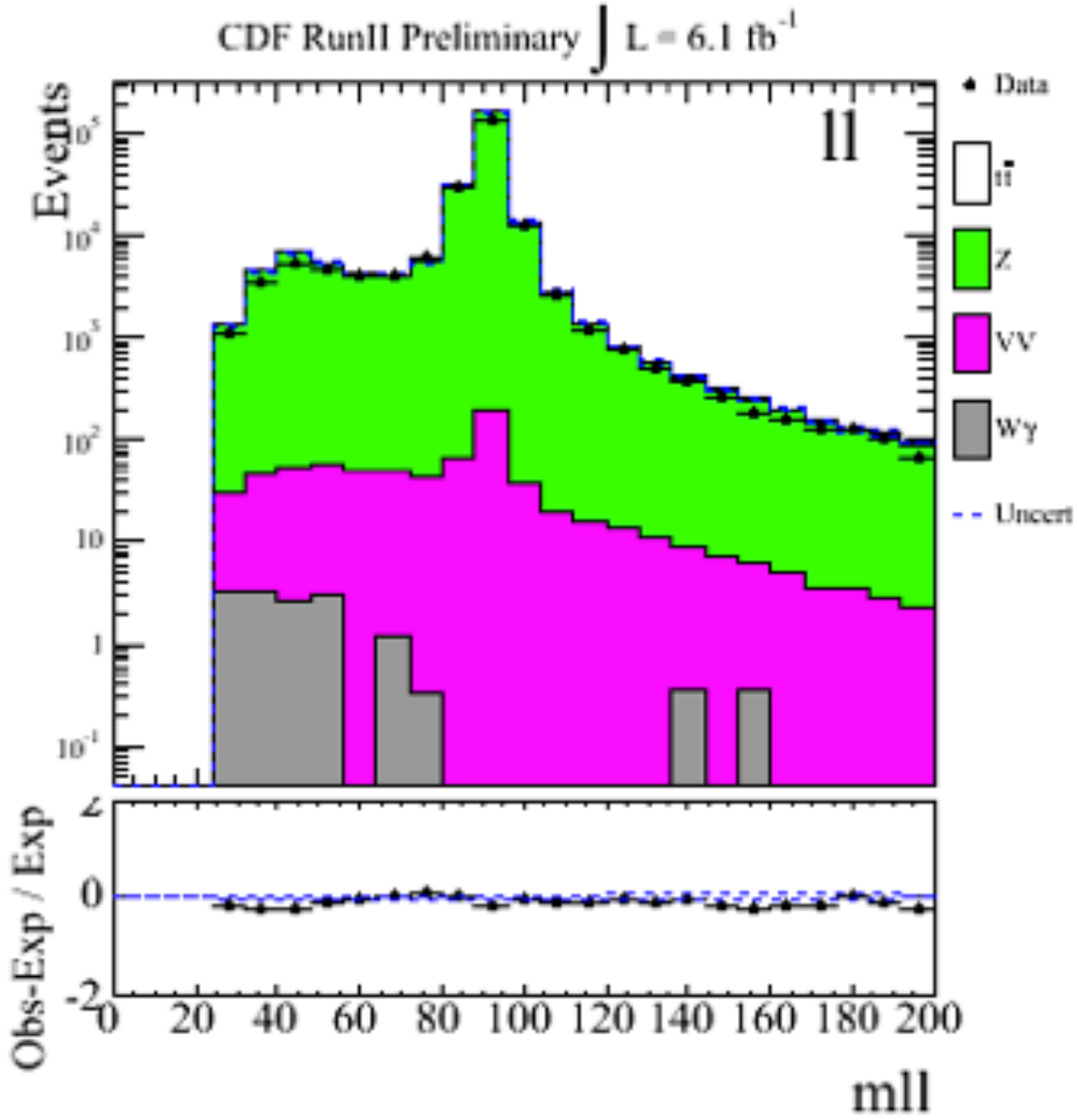
Second Step: Refine selection for many analysis, SUSY, H^{++}, SS top.

SUSY results presented in novel model-independent way.

3.

OS Validation





- Validate in OS region.

3.

SS Results

CDF RunII Preliminary $\int \mathcal{L}dt = 6.1$ fb^{-1}				
Process	Total $\ell\ell$	$\mu\mu$	ee	$e\mu$
$t\bar{t}$	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0
$Z \to ee$	15.7 ± 2.7	0.0 ± 0.0	15.7 ± 2.7	0.0 ± 0.0
$Z \to \mu\mu$	8.7 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	8.7 ± 2.0
$Z \to \tau\tau$	2.2 ± 0.9	0.0 ± 0.0	1.3 ± 0.6	1.0 ± 0.6
WZ	24.7 ± 1.3	7.0 ± 0.4	5.1 ± 0.3	12.7 ± 0.7
WW	0.2 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.0
ZZ	3.5 ± 0.2	0.9 ± 0.1	0.8 ± 0.1	1.7 ± 0.1
$W(\to e\nu)\gamma$	7.8 ± 1.7	0.0 ± 0.0	7.8 ± 1.7	0.0 ± 0.0
$W(\to \mu\nu)\gamma$	7.8 ± 1.7	0.0 ± 0.0	0.0 ± 0.0	7.8 ± 1.7
$W(\to \tau\nu)\gamma$	0.6 ± 0.4	0.0 ± 0.0	0.3 ± 0.3	0.3 ± 0.3
Fakes	51.6 ± 24.2	8.2 ± 5.3	22.1 ± 8.9	21.3 ± 10.6
Total	123.0 ± 24.6	16.1 ± 5.4	53.3 ± 9.5	53.6 ± 10.9
Data	145	14	66	65

- No excess observed in generic SS search.

3.

SS Results - Model Independence

- Previous results: assume specific model (mSUGRA) , set limits on large numbers of very model specific parameters.
- Problem: Hard to translate to arbitrary models

Think differently about limit setting.

- Choose specific production and decay modes.
- Use only minimum parameters: Masses of sparticles.
- Set limits on σ*BR as a function of sparticle mass

Limits can now be applied to any theory containing these modes.

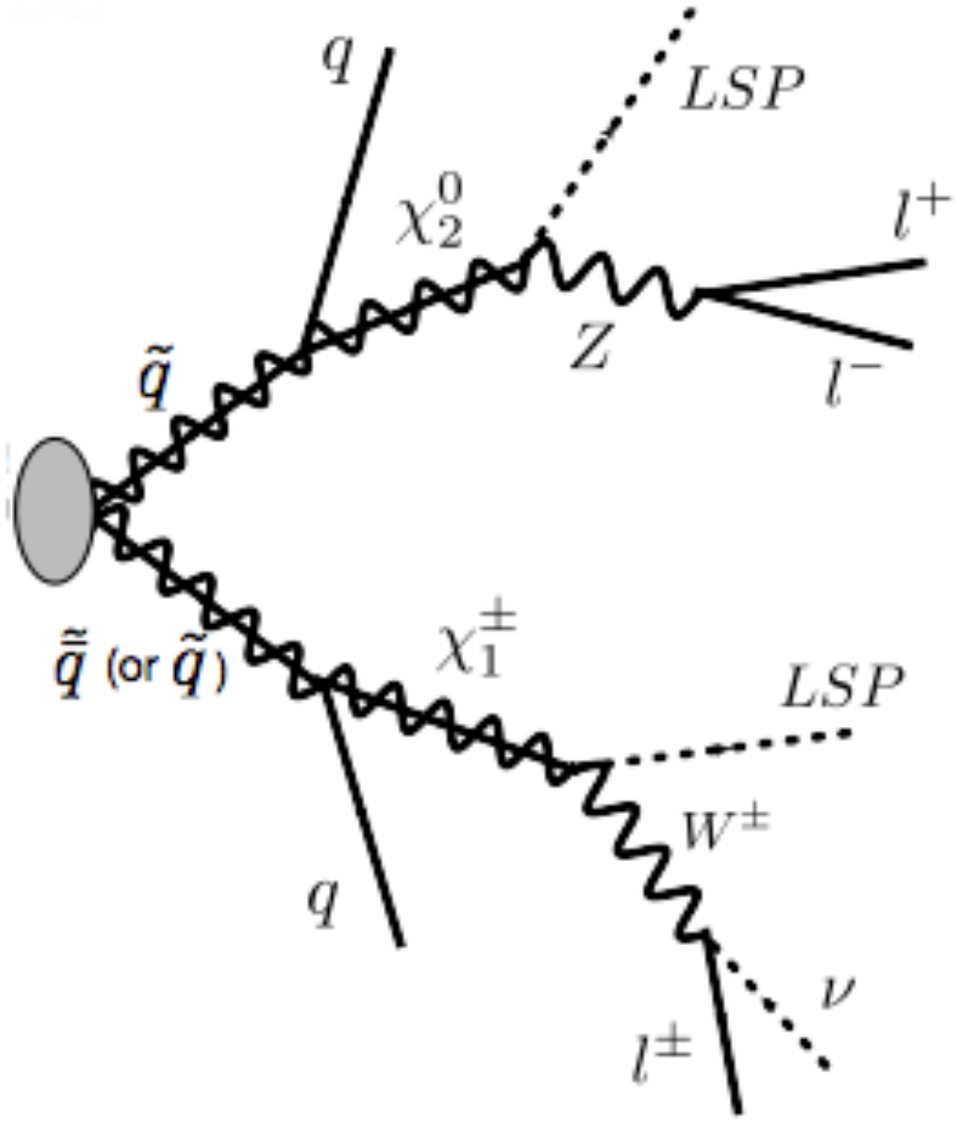
3.

SS Results - Limits

- Take generic SS results and apply to specific SS production topologies.

- This analysis looks at sQuarks and sGluon production mode.

- Similar to previous diagrams but: strong production; W,Z Bosons in decay.

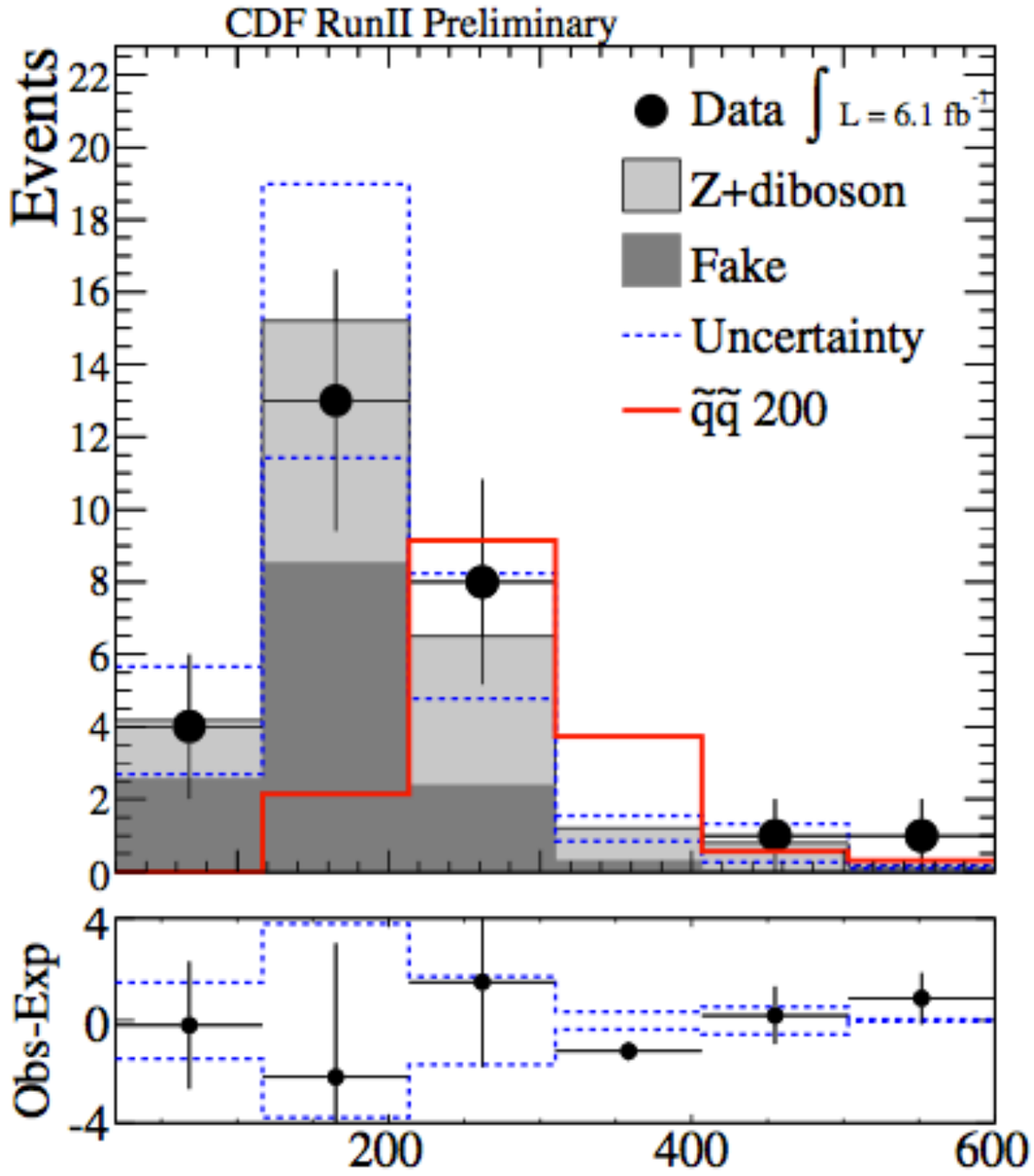


3.

SS Results - Limits

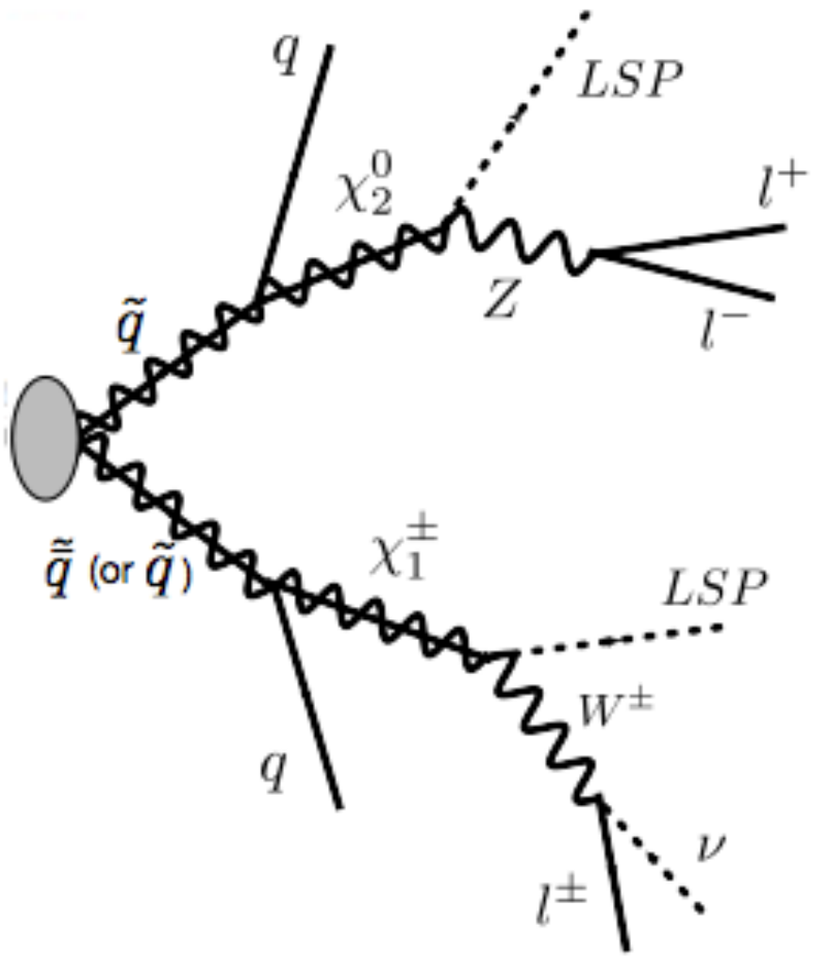
- Require at least 2 jets to optimize the generic SS search for strong production.

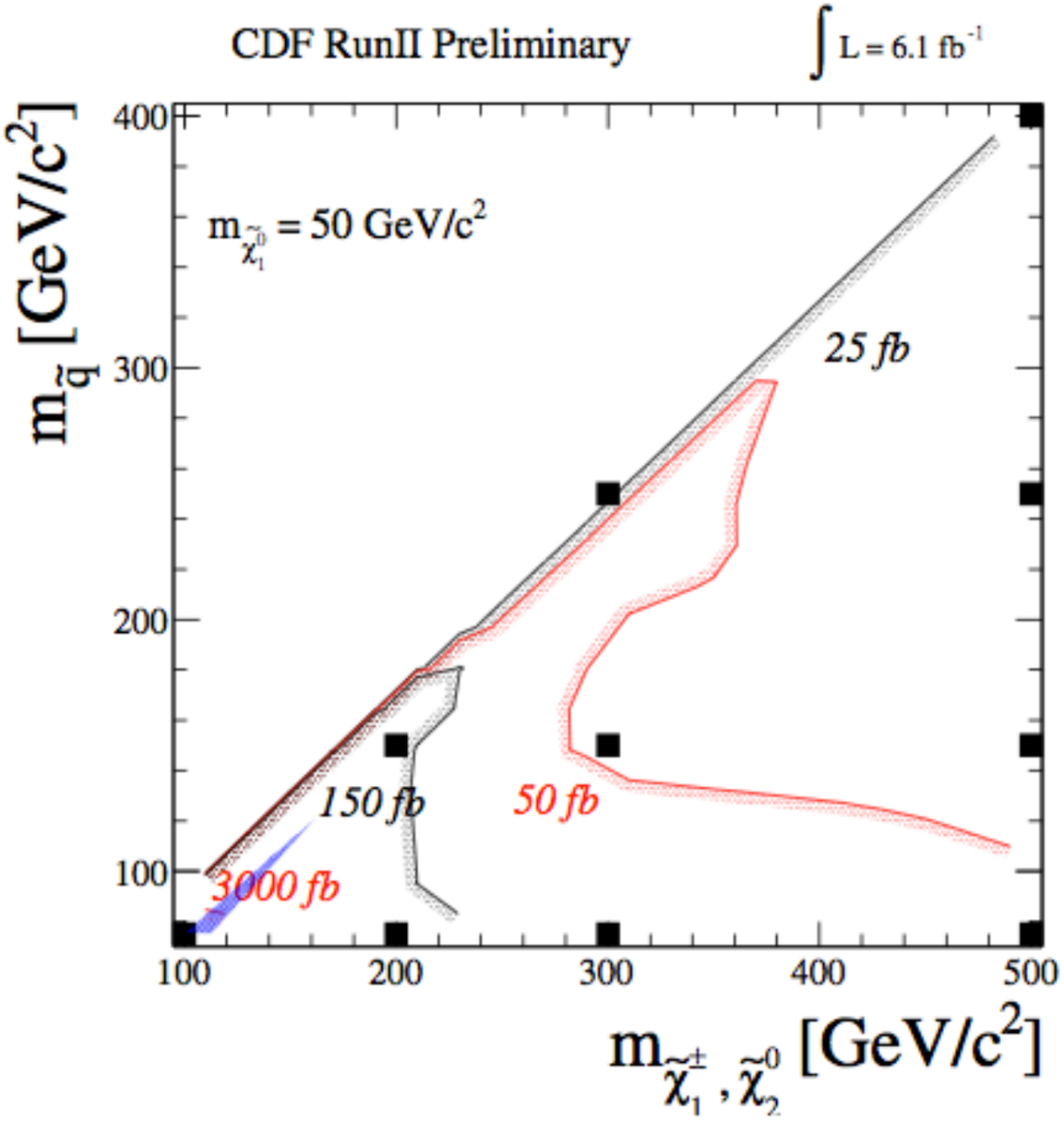
Results for squark mass of 200 GeV:



3.

SS Results - Limits

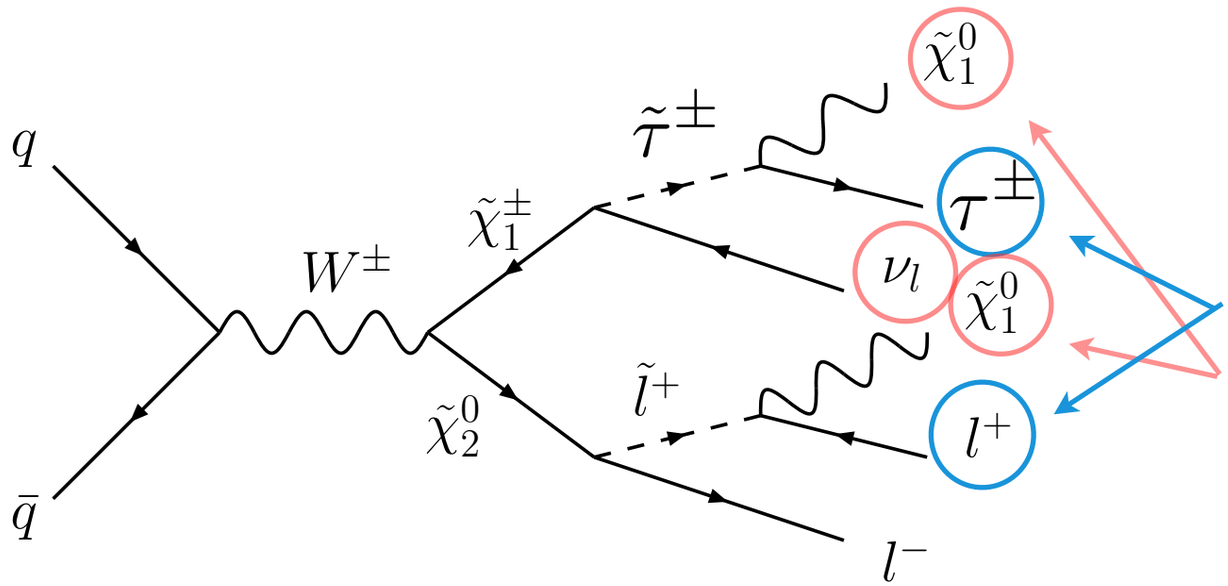




- Limits on Squark pair production for LSP mass of 50 GeV/c^2 .

4.

Same-Sign lepton and hadronic tau (e/μ + τ)



Signature:
2 Leptons + MET

4 Channels

$e^+ \tau^+$
$e^- \tau^-$
$\mu^+ \tau^+$
$\mu^- \tau^-$

- Adding hadronic τ decays lends sensitivity to high tan(β) SUSY models.
- Complimentary to SS dilepton analysis with all es and μs.

4.

Data

Gathered through Feb '10

- 6.0 fb^{-1}

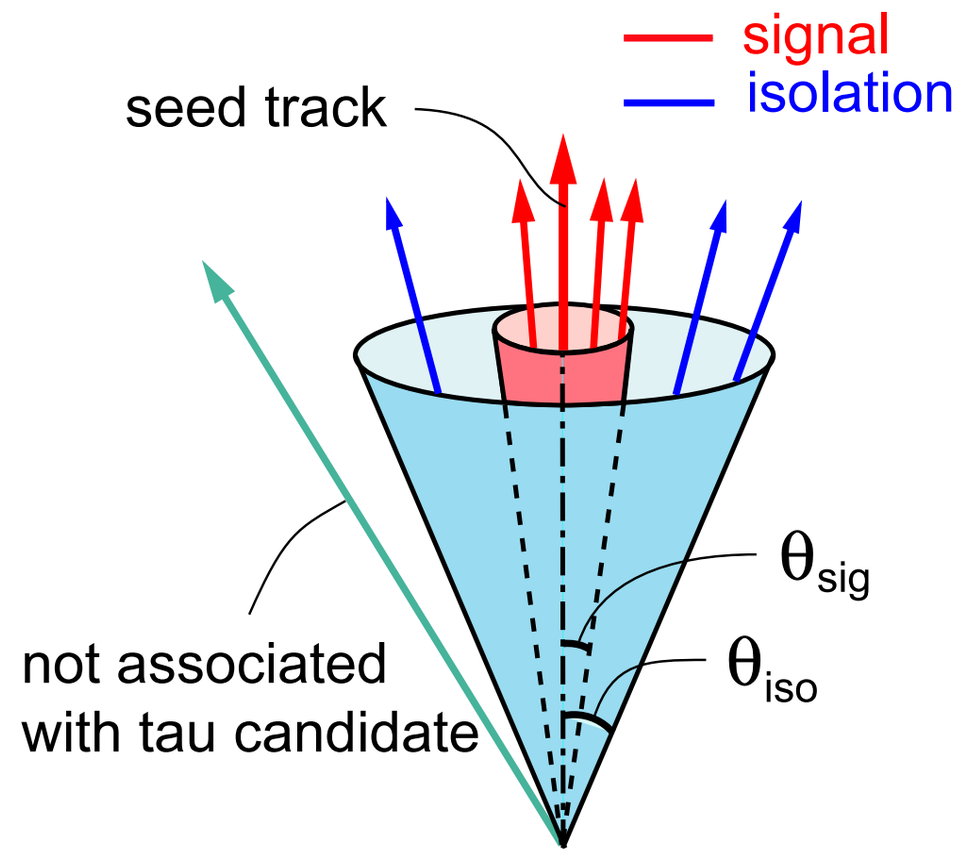


Figure 9: Tau isolation and signal cones.

- Lepton side standard e, μ
- τ side more complicated:
  - Requires τ-like signal and isolation cones
  - Jets fake τs at a rate up to 30%
  - Trigger has an isolation cone, complicating matters.

4.

Background Model

$Z \to ll,\ t\bar{t}$

Diboson

$W \to \tau\ \nu + \text{Jet}$

} From Monte Carlo.
Well-modeled, small backgrounds.

τ Fakes:

QCD

$\gamma + Jet$

$W \to l\nu + \text{Jet}$

} Jet→τ Fake Rate Method
Any event containing a fake tau.

$W \to l\nu + \text{Jet}$ will be the largest background

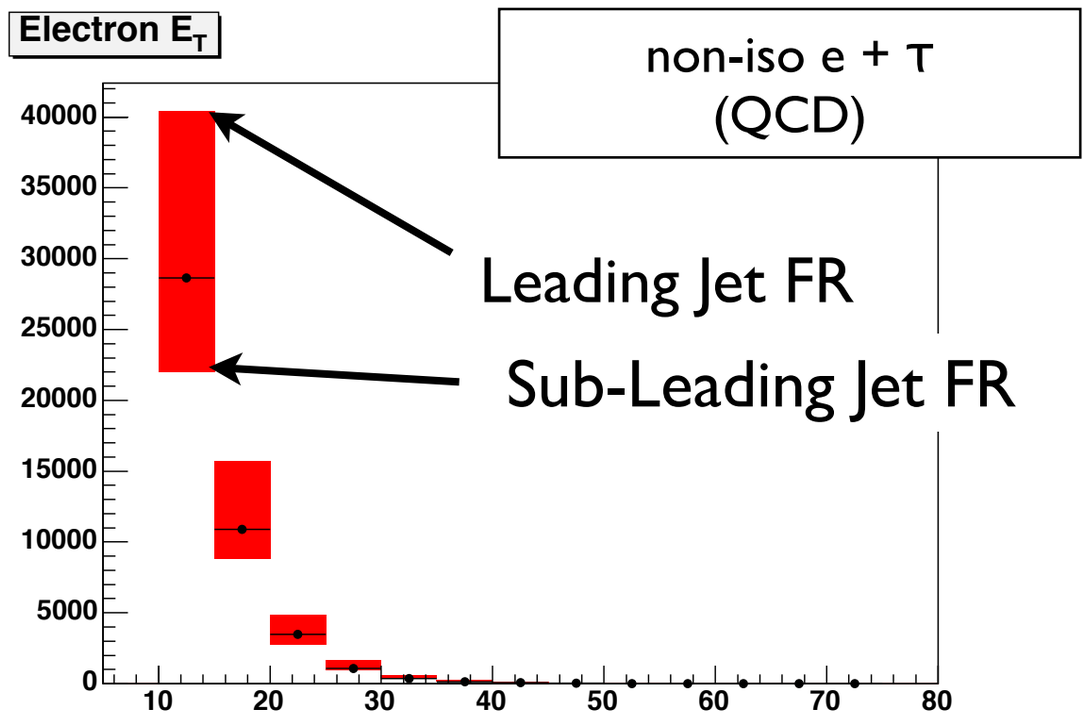
4.

Measuring jet → τ Fake Rate

Measure **relative** FR from Jet data Tight/Loose τ's.
Denominator loose τs must be tighter than the isolated trigger.
Trigger is actually quite rich in real τs.

jet → τ Fake Rate Validation

- Apply FR in orthogonal samples



Samples:
Tagged Conversions (γ + Jet)
Non-isolated e, μ (QCD)
W + Jets Enhanced region

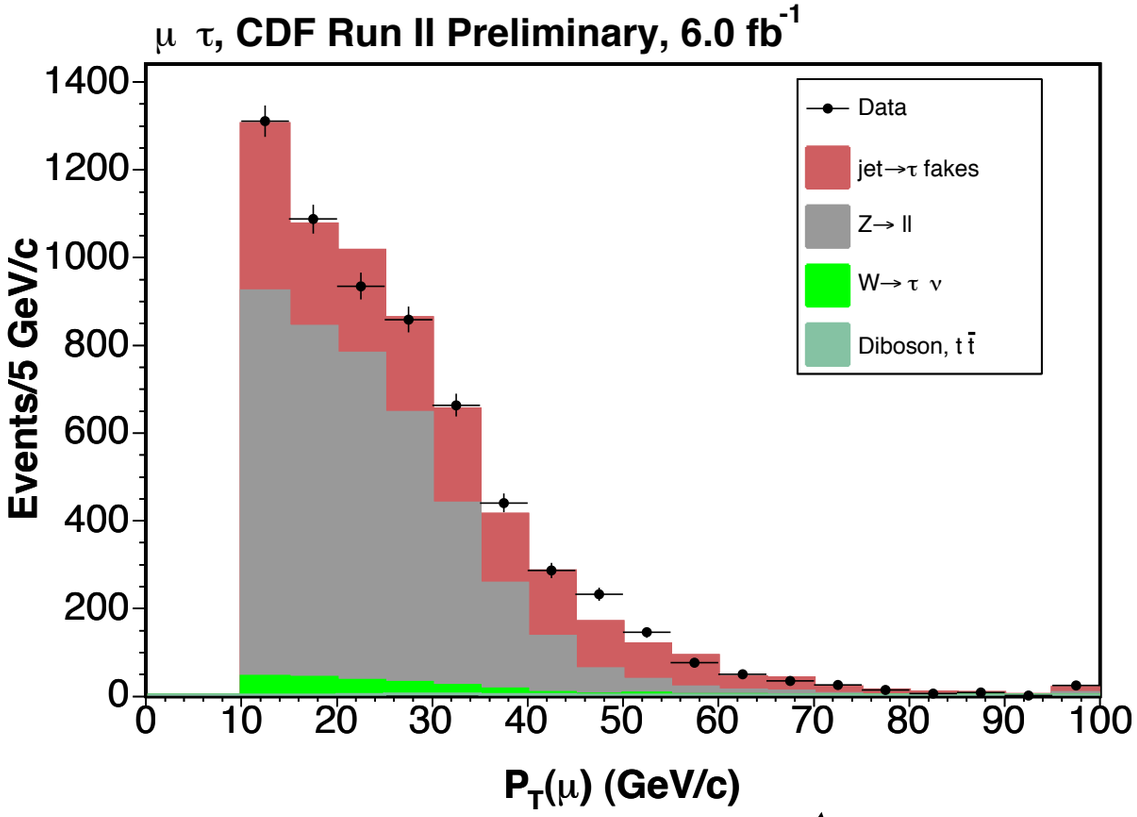
Leading Jet and sub-leading jet determine systematic.

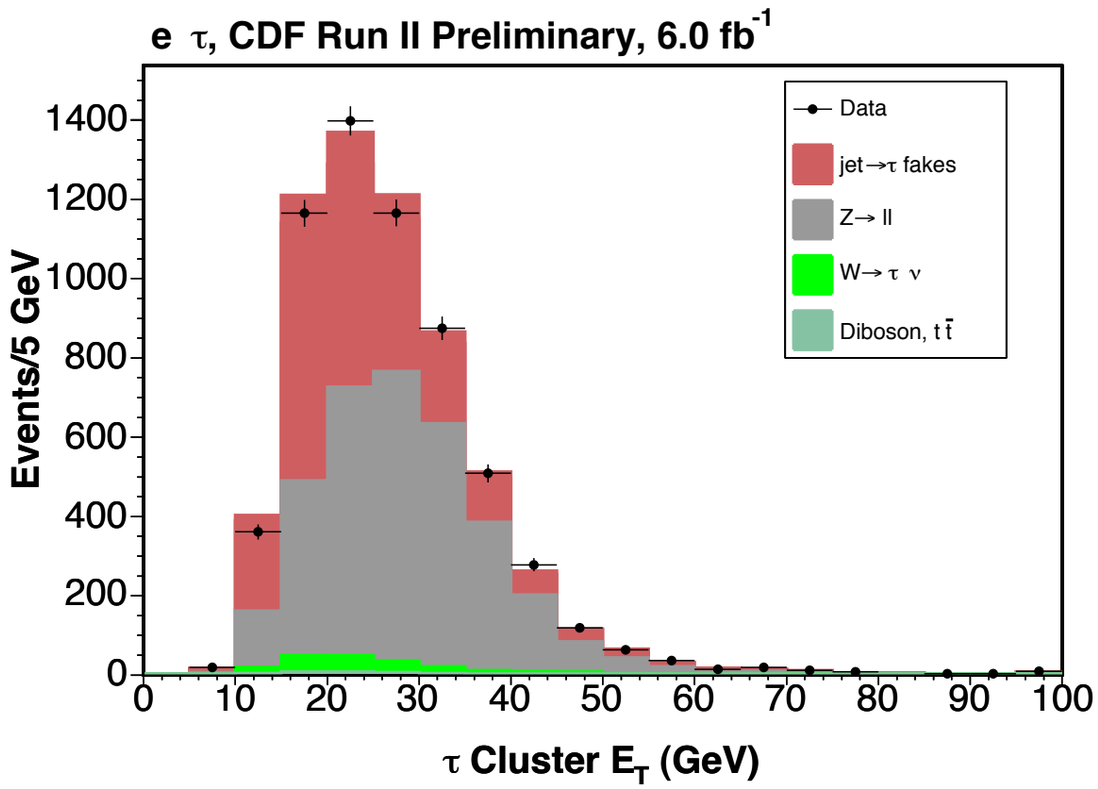
25% Systematic dominates result.

4.

OS Control Region Plots

- Basic Ht > 45 GeV cut for QCD Reduction $H_T = |P_T^l| + |P_T^\tau| + \not{E}_T$



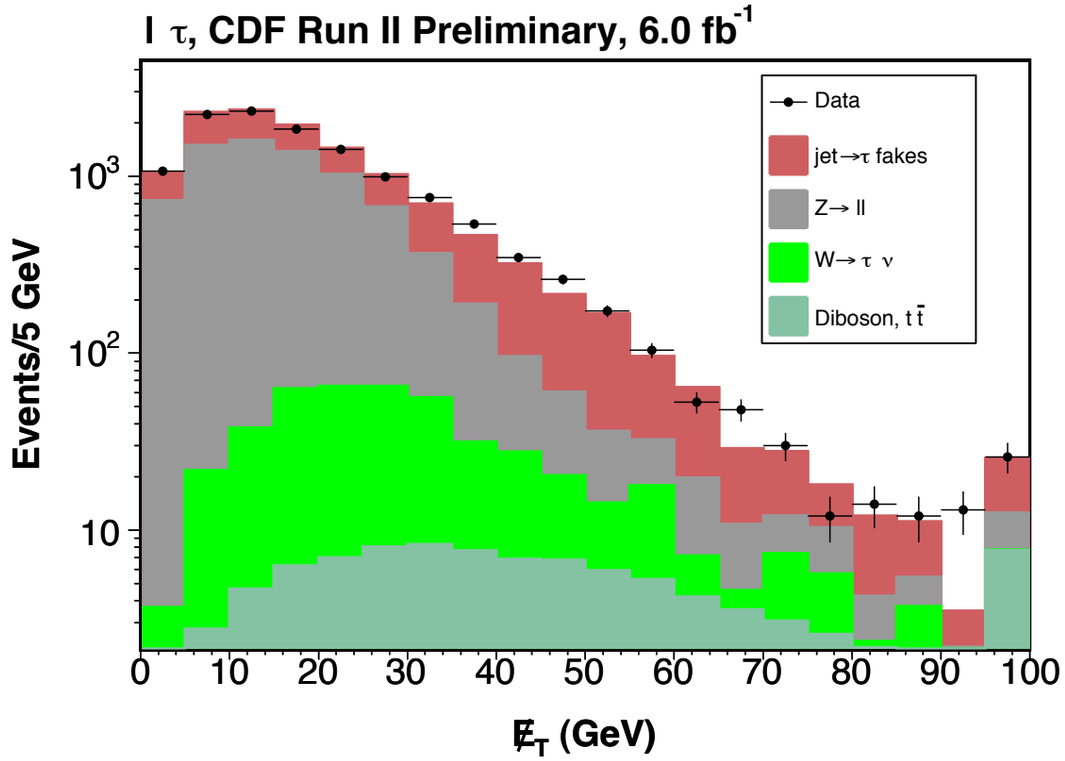


OS Plots:

μ Channel

e Channel

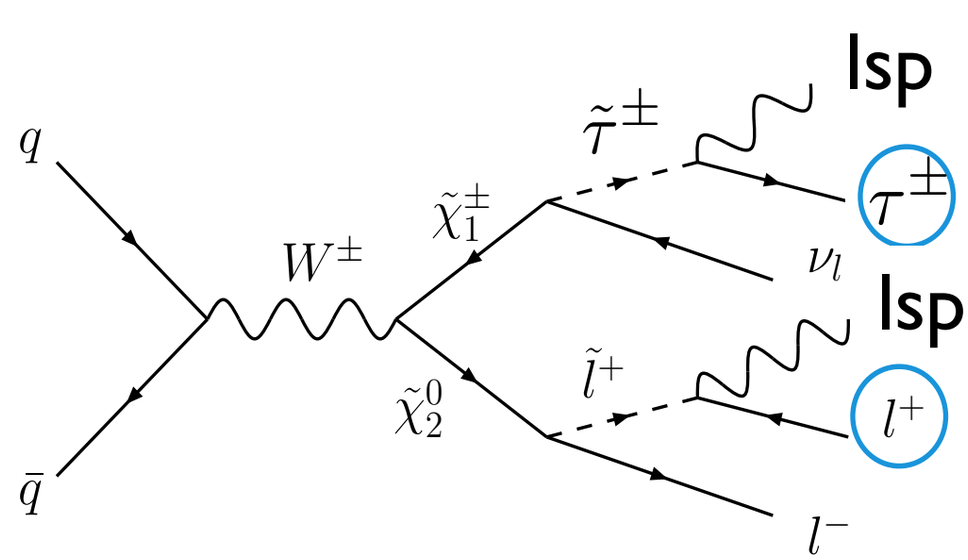
Both Channels



4.

Simplified Signal Models

- Similar concept to previous analysis.
- Simplified models enable direct manipulation of MSSM masses, independent of mSugra constraints.



- ‘Simplified Gravity’ and ‘Simplified Gauge’ Models. Set limits on SUSY σ.

4. Simplified Gravity Model

- Can vary M(Chargino), M(slepton), M(LSP).
- Also vary slepton coupling to e, μ, τ.

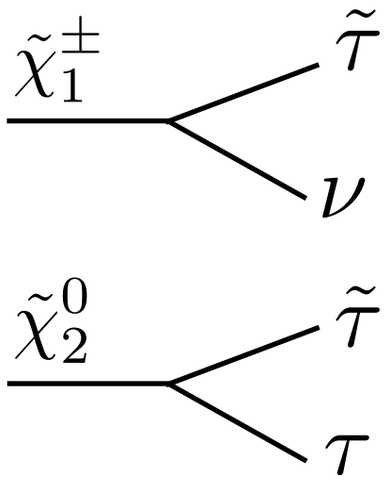
Constraints:
-M(Chargino) = M(Neutralino)
-Masses chosen so as not to decay through W,Z,H
-M(gluino, squark) is high.

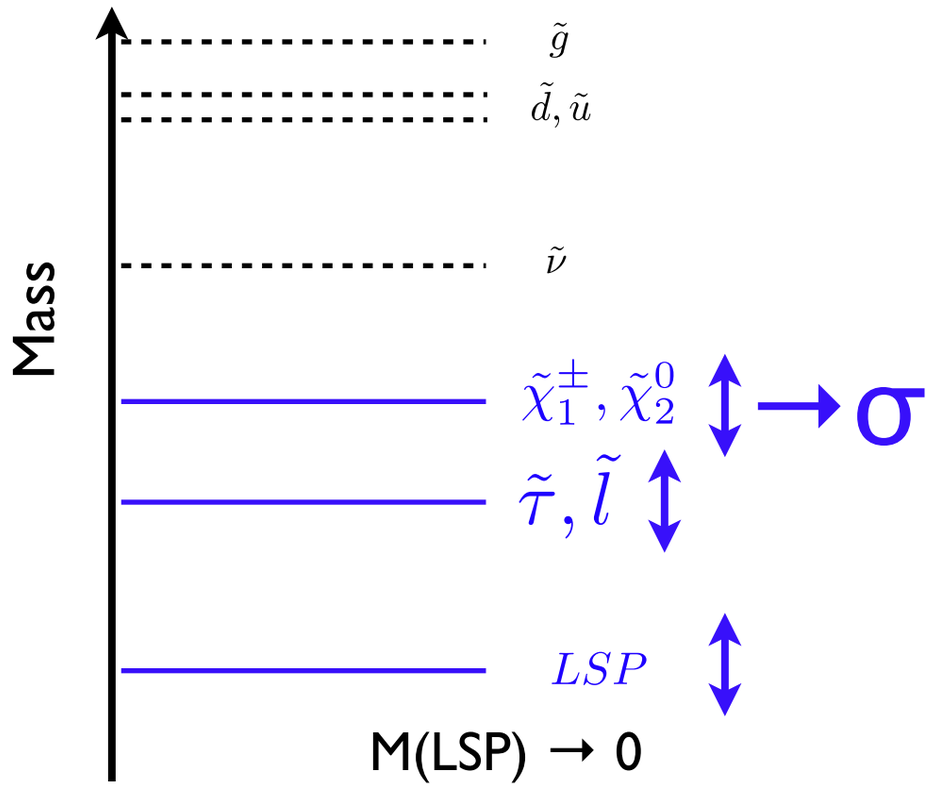
Simplified Gauge Model

- GMSB Generally predicts light (sub-KeV) gravitino (MET).
- NLSP decays to gravitino plus SM partner
- We identify simple parameter space with **slepton** NLSPs

No intermediate decays through W, Z, H

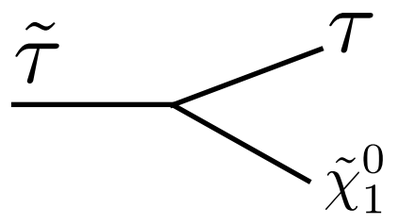
Chargino, Neutralino Decays:



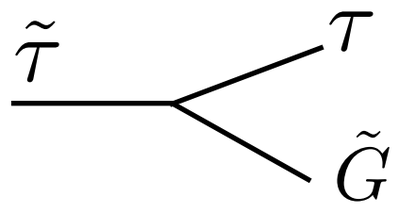


M(LSP) → 0 for Gauge

sTau Decays:



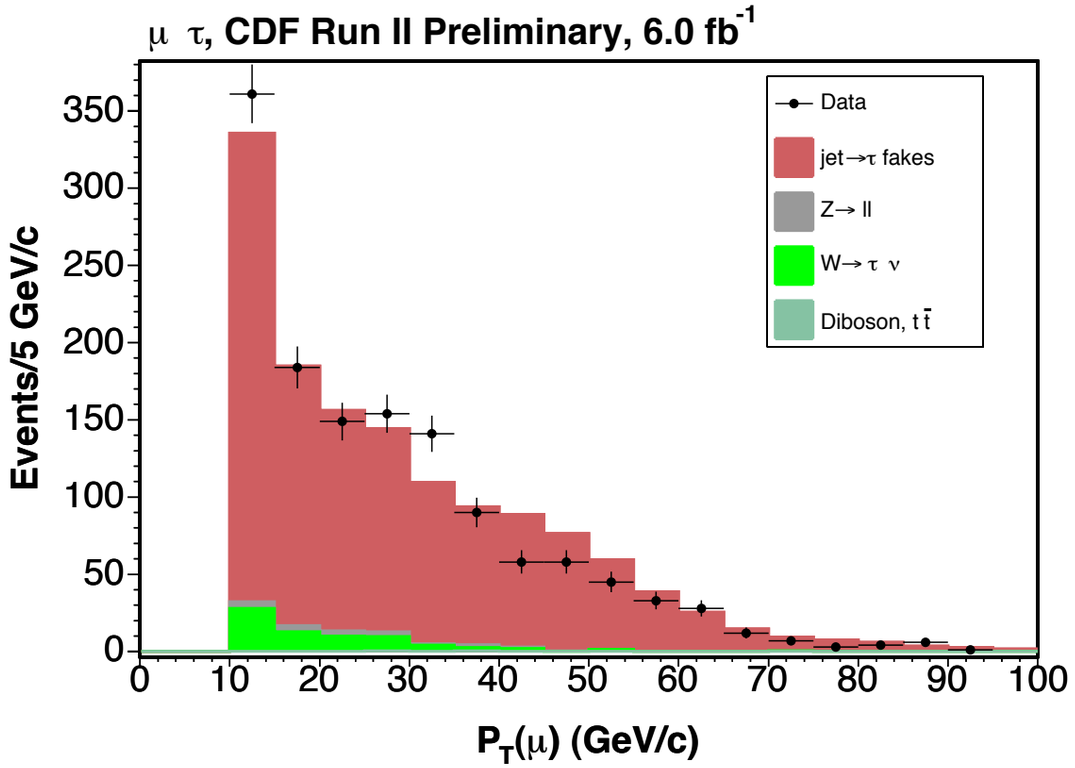
Simplified Gravity

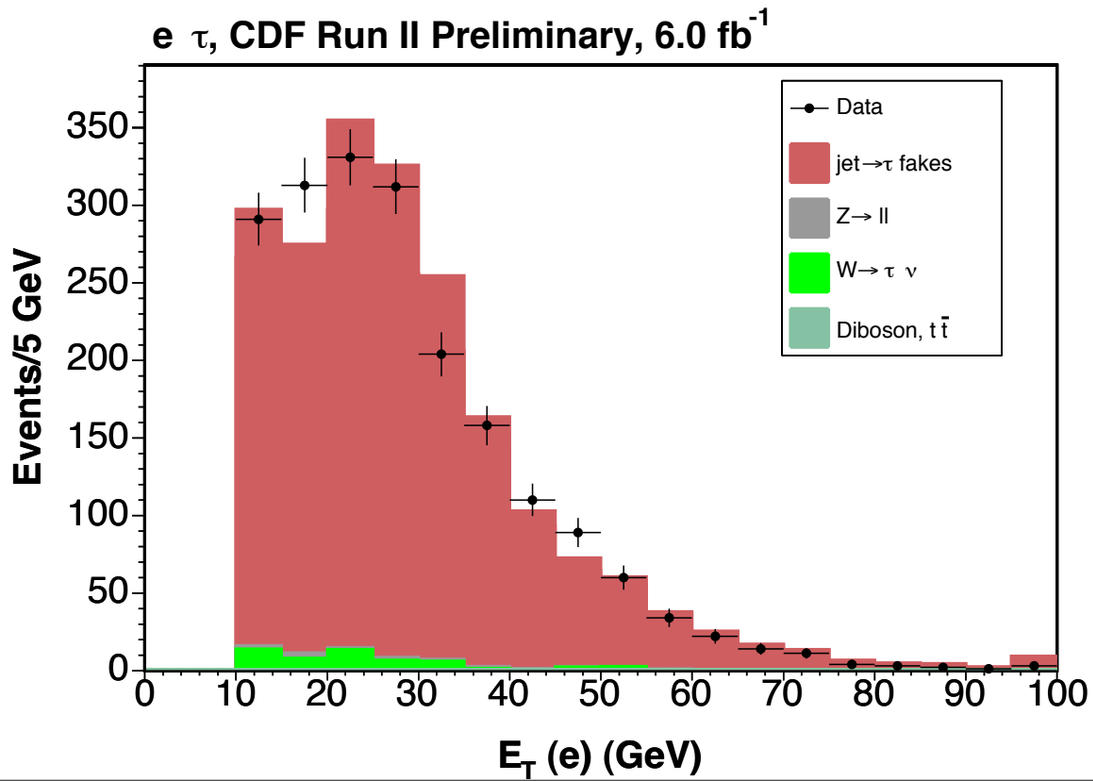


Simplified Gauge

4.

SS Signal Region - Results





OS Plots:

μ Channel

e Channel

Both Channels

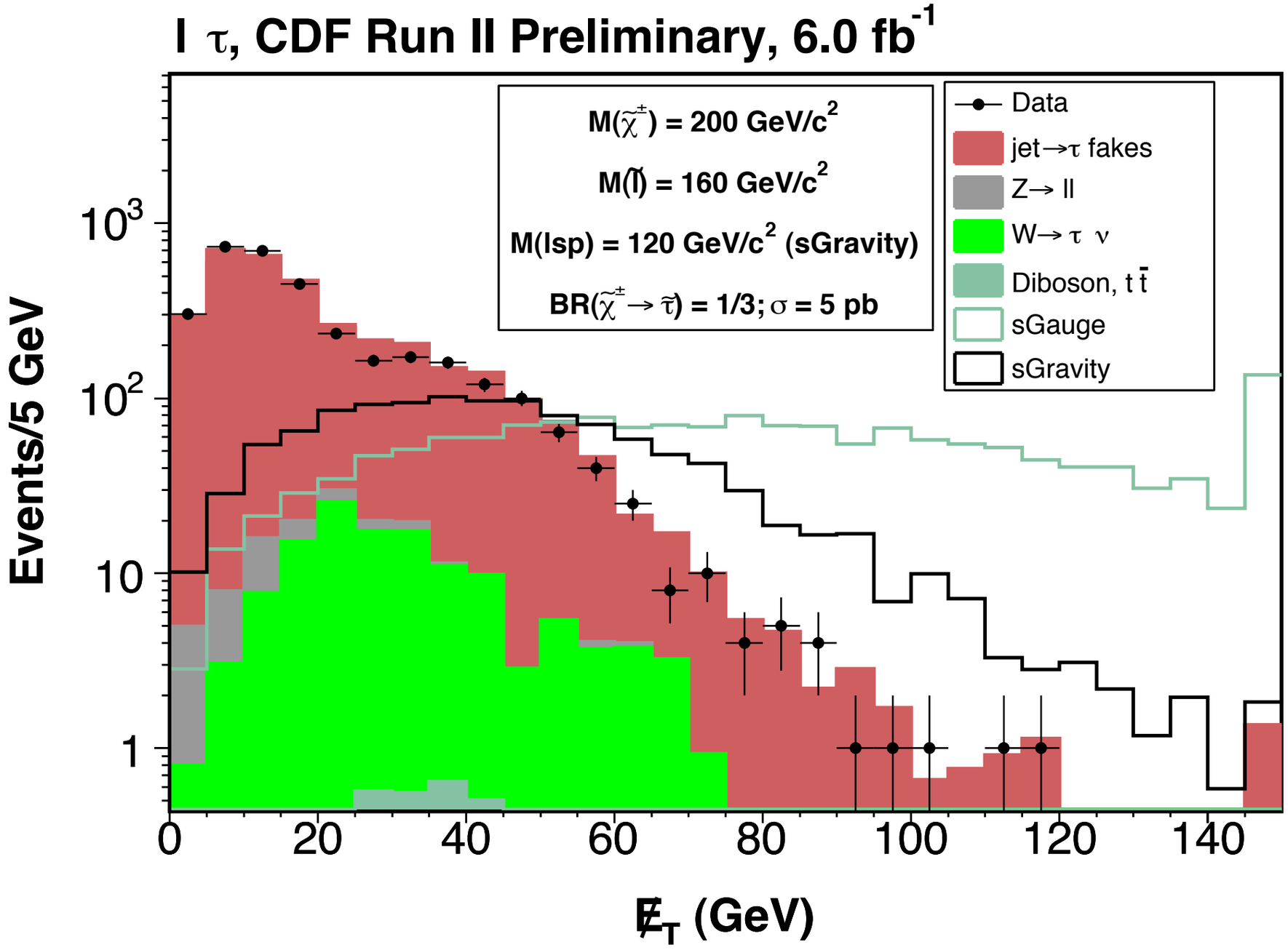
CDF Run II Preliminary 6.0 fb^{-1}
SS $\ell - \tau$

Process	Events $\pm$ stat $\pm$ syst
$Z \to \tau\tau$	$10.2 \pm 2.2 \pm 0.8$
Jet$\to \tau$	$1152.7 \pm 15.2 \pm 283.1$
$Z \to \mu\mu$	$0.0 \pm 0.0 \pm 0.0$
$Z \to ee$	$0.0 \pm 0.0 \pm 0.0$
$W \to \tau\nu$	$96.9 \pm 6.4 \pm 9.5$
$t\bar{t}$	$0.7 \pm 0.0 \pm 0.1$
Diboson	$4.3 \pm 0.2 \pm 0.4$
Total	$1264.8 \pm 16.6 \pm 283.3$
Data	1116

Backgrounds almost totally data driven.

4.

MET Both Channels



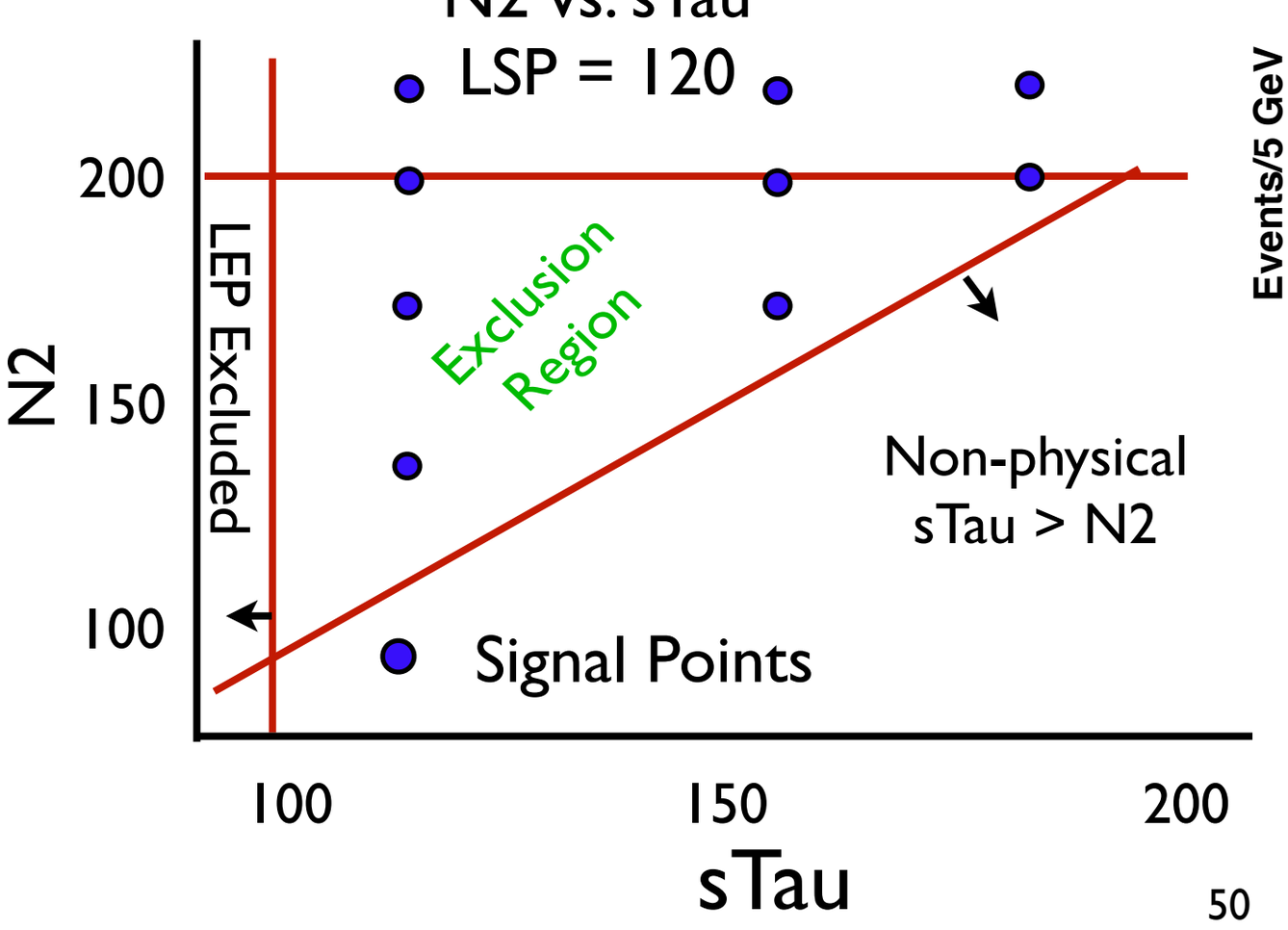
- Signal shown here for two models.
- MET > 20 GeV is our final, tuned event level cut.

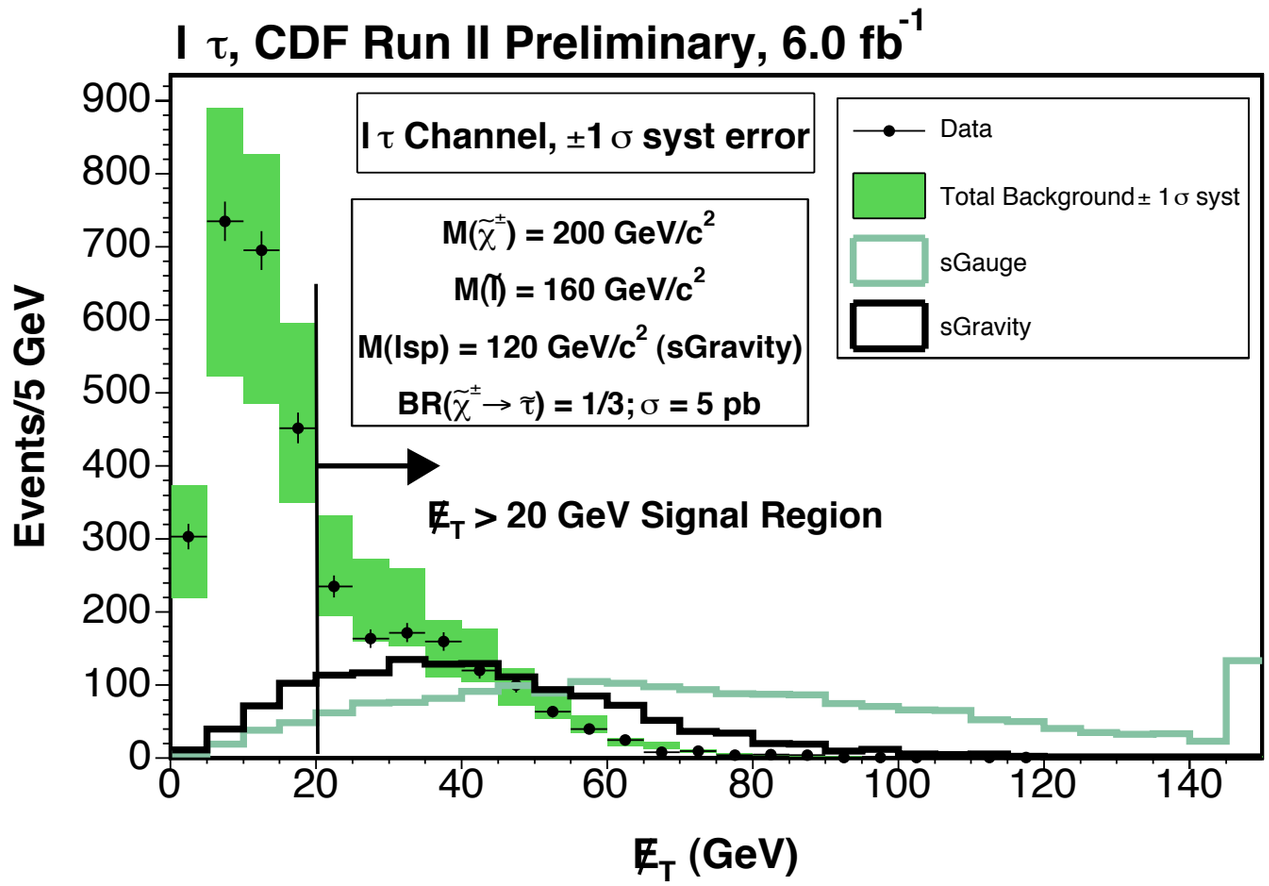
4.

2-D Exclusion Contours

- Create grid of signal points for many LSP values.
- Find best MET cut ($s/\sqrt{b}$) at each point.
- Create simple analytical expression for MET cut value.
- Interpolate limits into exclusion contours.

Grid of Points

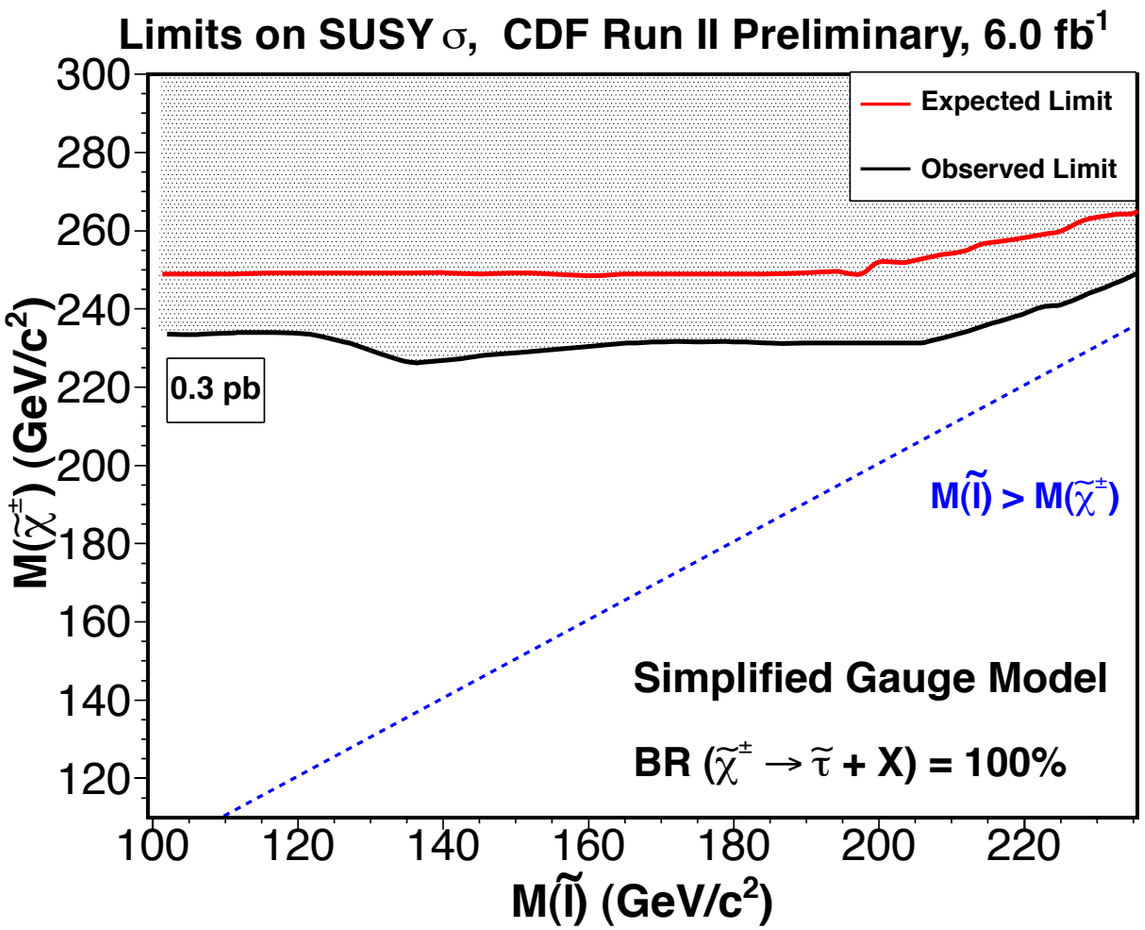


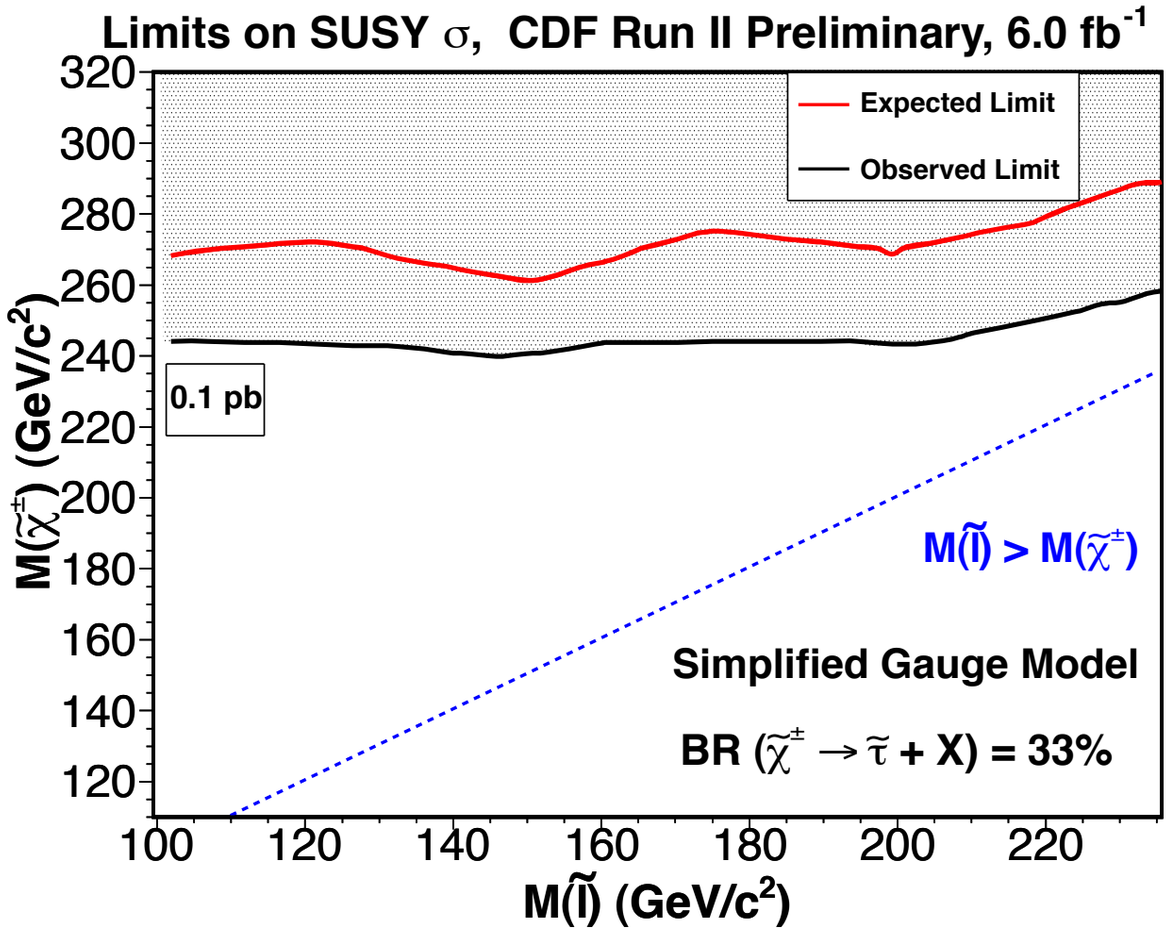


MET with Total Systematic Errors

4.

Results
Simplified Gauge Model

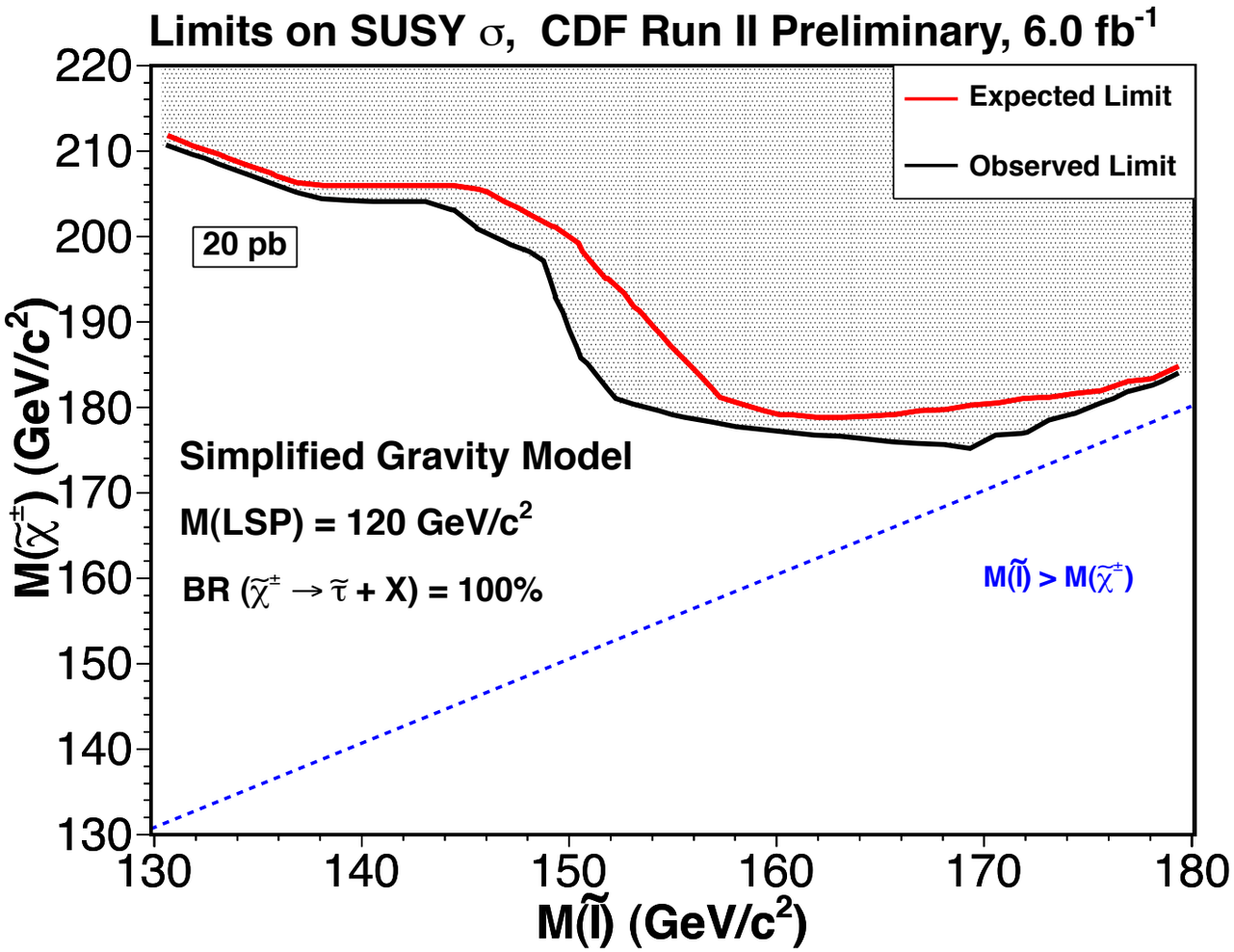




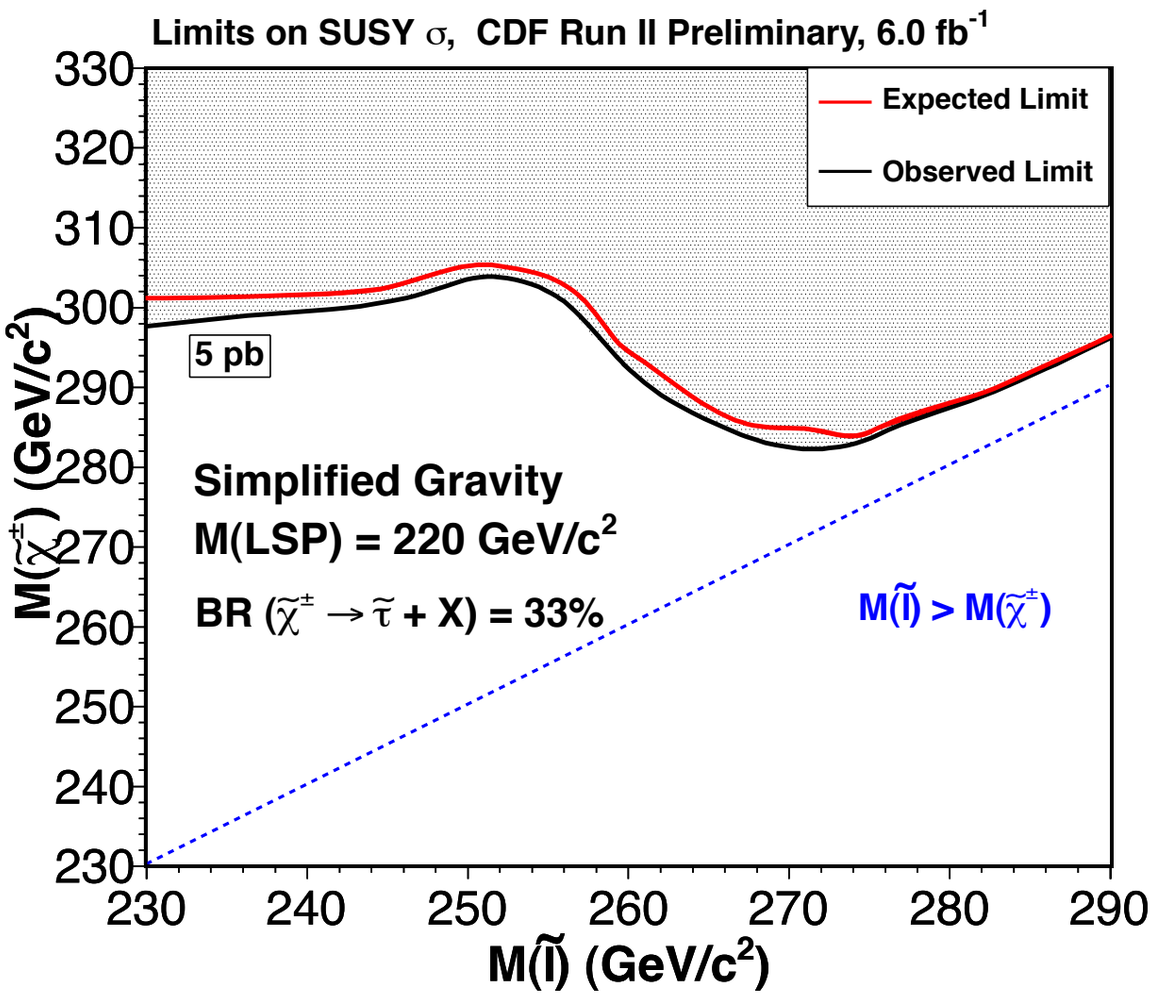
- Plot contours of iso-σ.
- Excluding SUSY process σ, lower value is better.

4.

Results
Simplified Gravity Model



LSP = 120 GeV

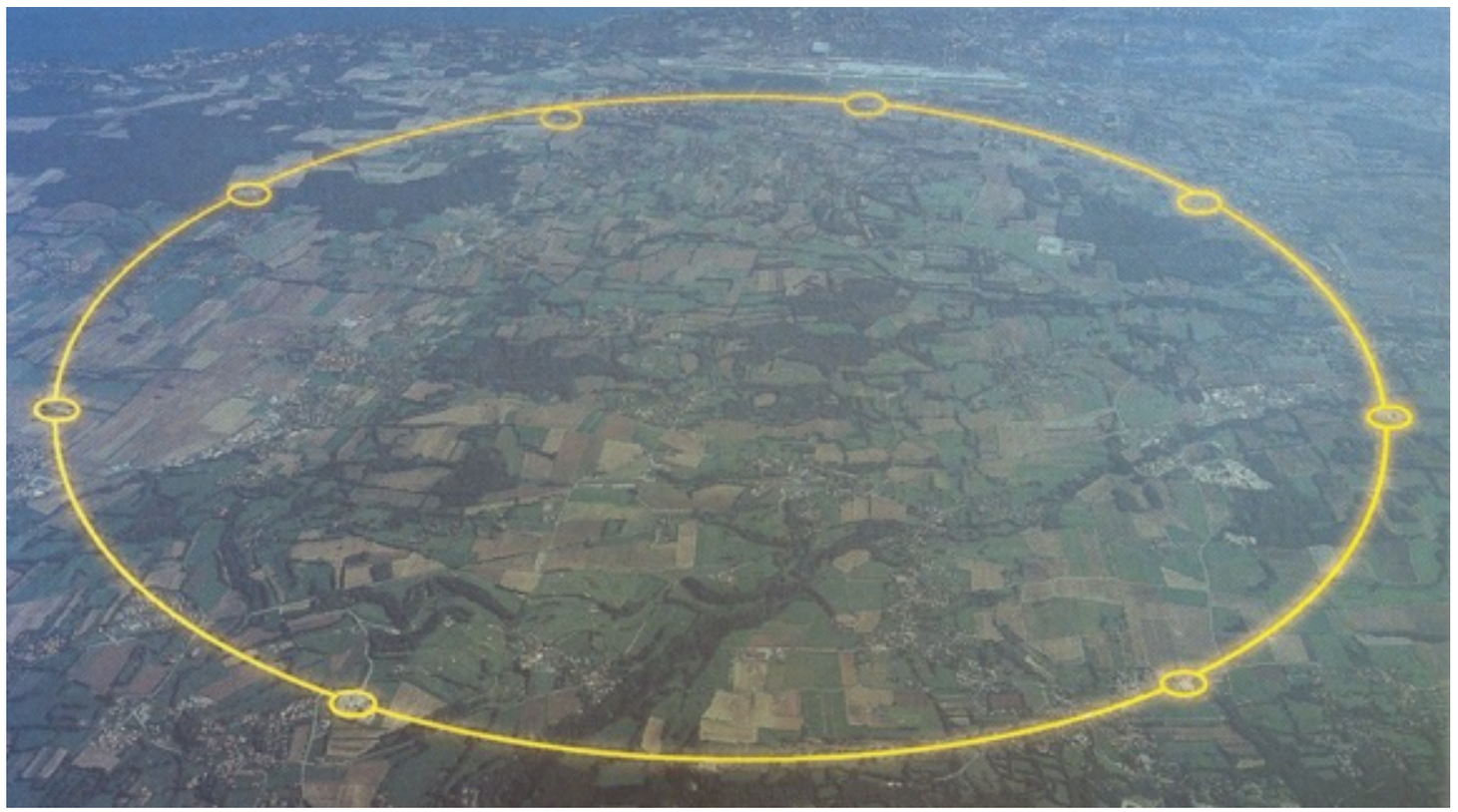


LSP = 220 GeV

- Simplified Gravity models suffer from massive LSP

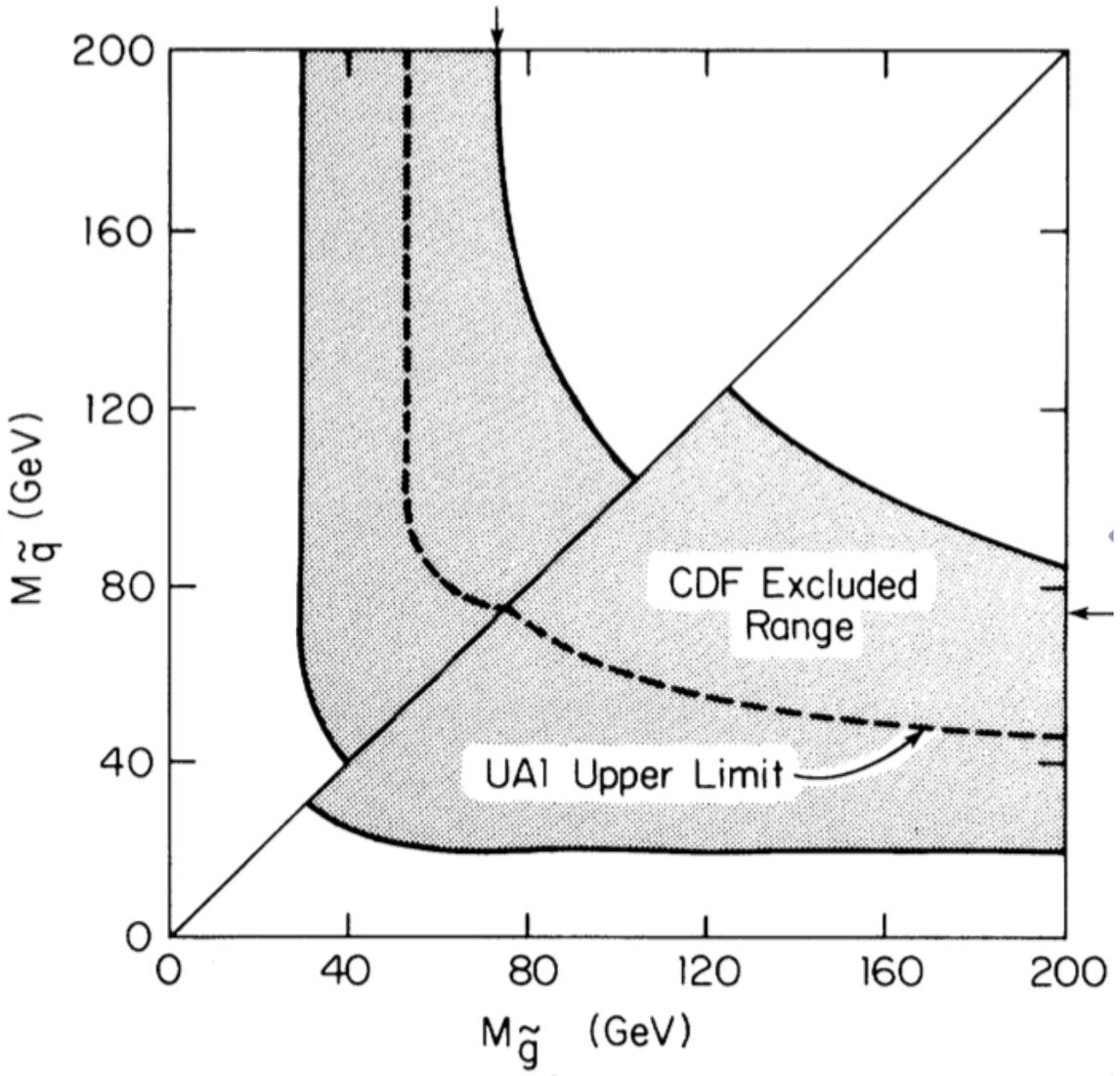
Conclusions

- A long history of lepton SUSY searches at CDF.
- These searches represent the final portfolio of CDF multi lepton searches.
- Looking forward to further results and discoveries at the LHC



Conclusions

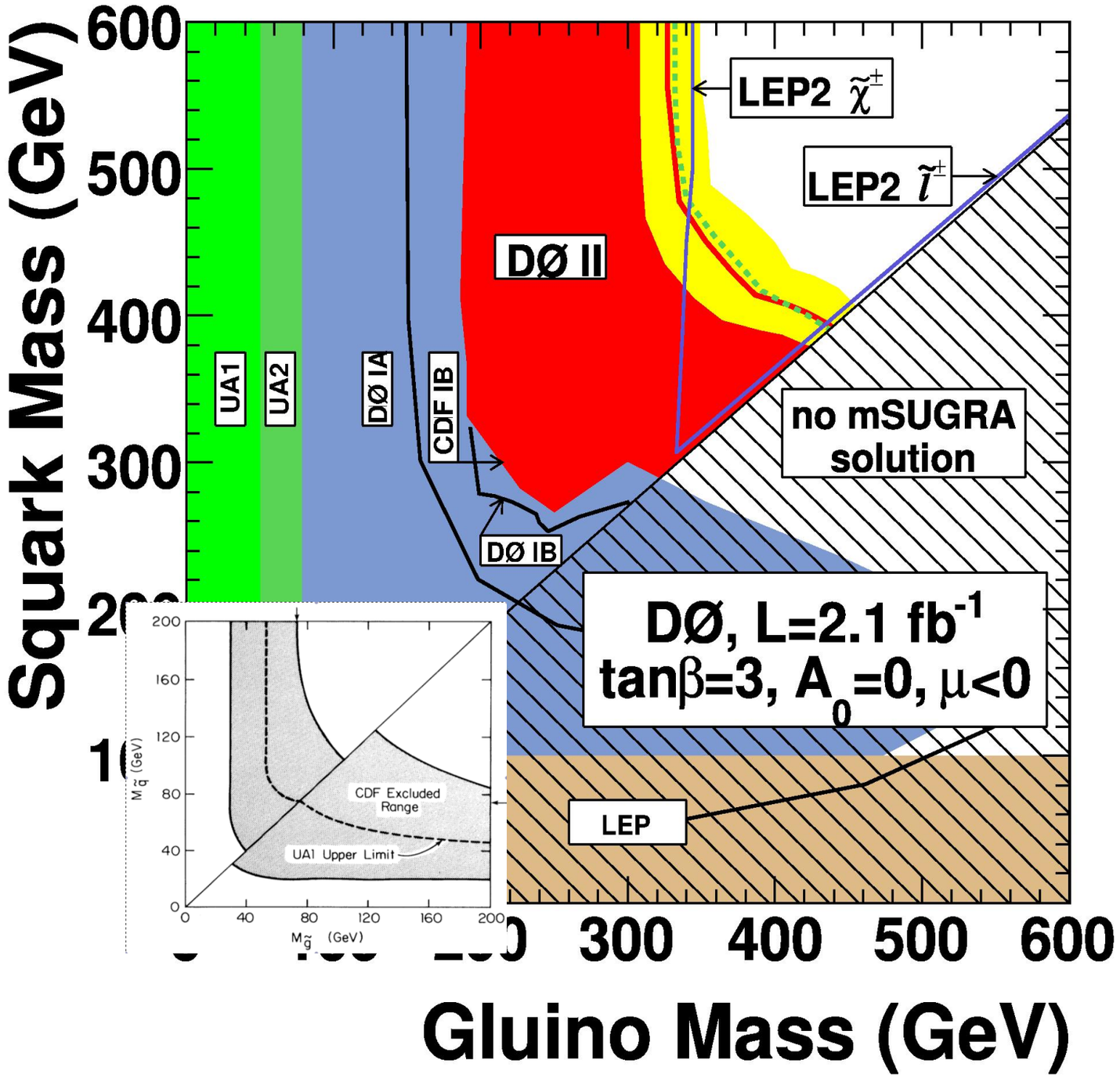
1989



L. Bellantoni (FNAL) SUSY '11

Conclusions

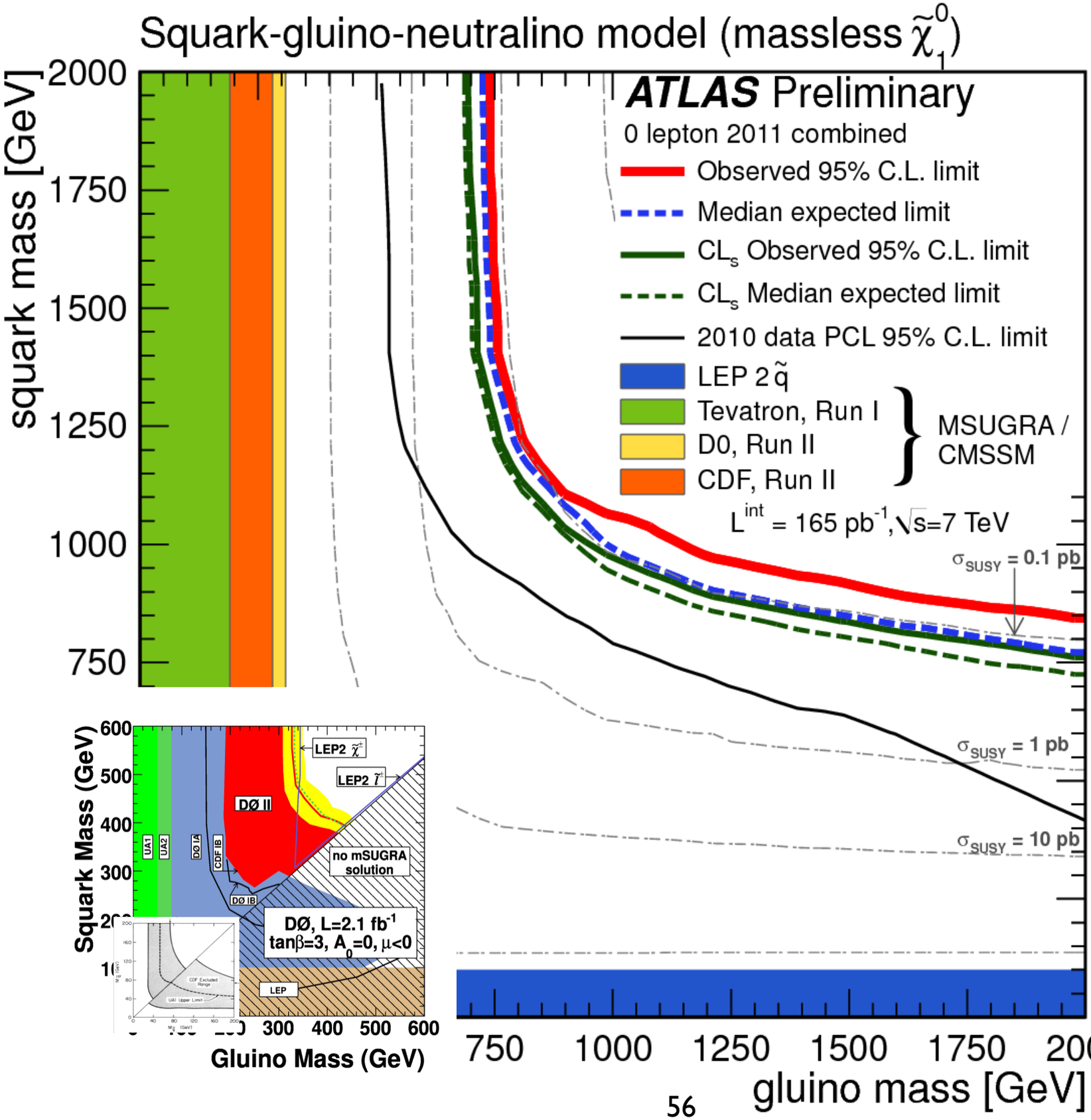
2009



L. Bellantoni (FNAL) SUSY '11

Conclusions

2011

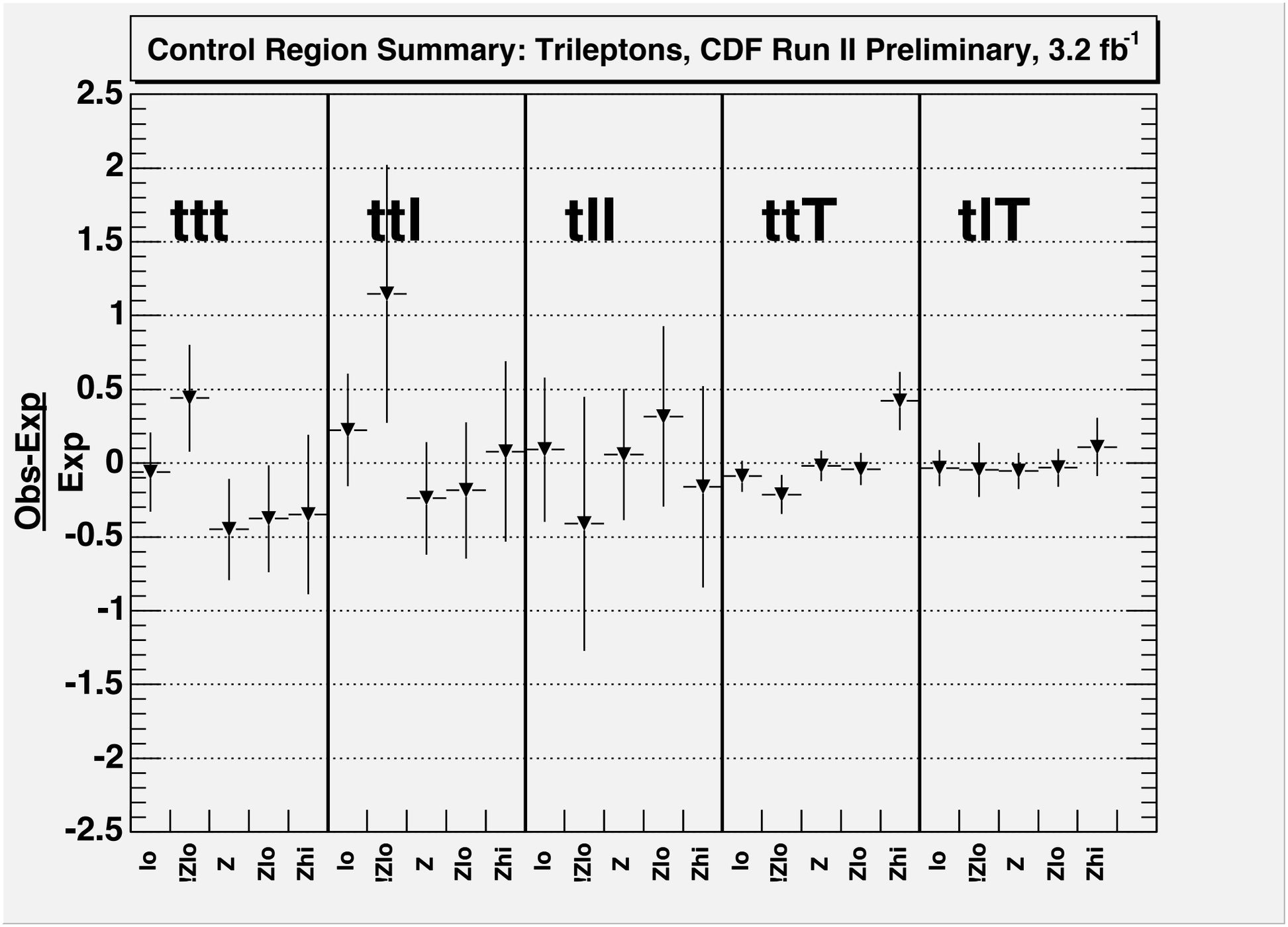


L. Bellantoni (FNAL) SUSY '11

Backup

I.

Trilepton Control Region Summary



1.

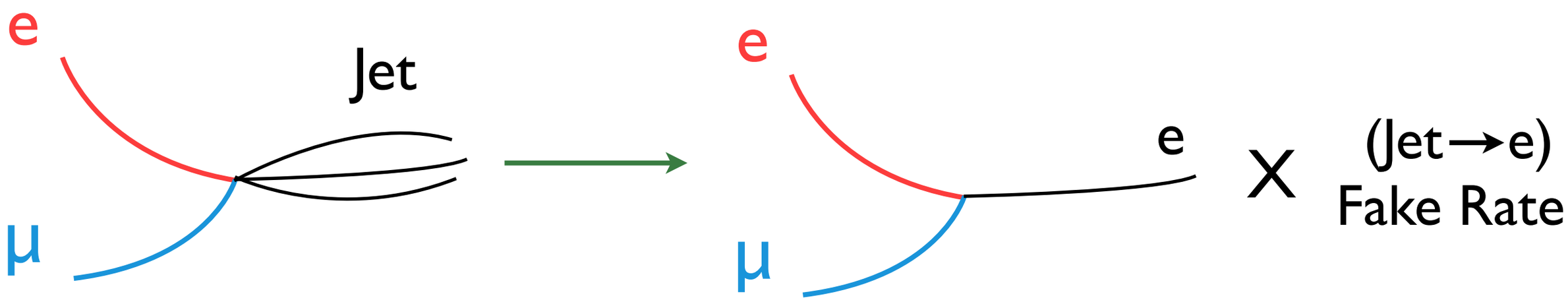
Lepton Fakes

Data-driven fake determination:

- Choose data events with 2 good leptons and fakeable object (tracks fake muons, jets fake electrons).

- Carry fake through analysis level cuts as real object.

- Fake contribution is fake rate of object:



Extra track (T) rate - Use MC for kinematics and normalize tracks to what we see in Z events.

2. UNM

Our lepton objects

- Central Electrons (**CEMtight, CEMloose**), Forward Electrons (**PEM, Phoenix**), Central Muons (**CMU, CMUP, CMX, CMIO**) and Forward muons (**BMU**)
  - Standard selection, isolated, impact parameter applied
    - Iso<2 GeV if p_T<20 GeV/c, iso/p_T<0.1 if p_T>20 GeV/c
    - D0<0.2 cm (if no silicon hits) or D0<0.02 cm (if silicon hits)
- The third objects can also be hadronic **Taus** or isolated tracks **(IsoTracks)**
- ID cuts are shown on next pages
- Central electron ID Scale factors from Perfidia for high-pt (>20 GeV/c), from CDF8479 for low-p_T electrons, and from CDF8307 for low-p_T muons
  - Forward electron ID-SF are calculated by us for all 28 periods (important for later periods due to changes in tracking)