Addressing the Multi-Channel Inverse Problem: A Model Independent Approach to Trilepton Searches

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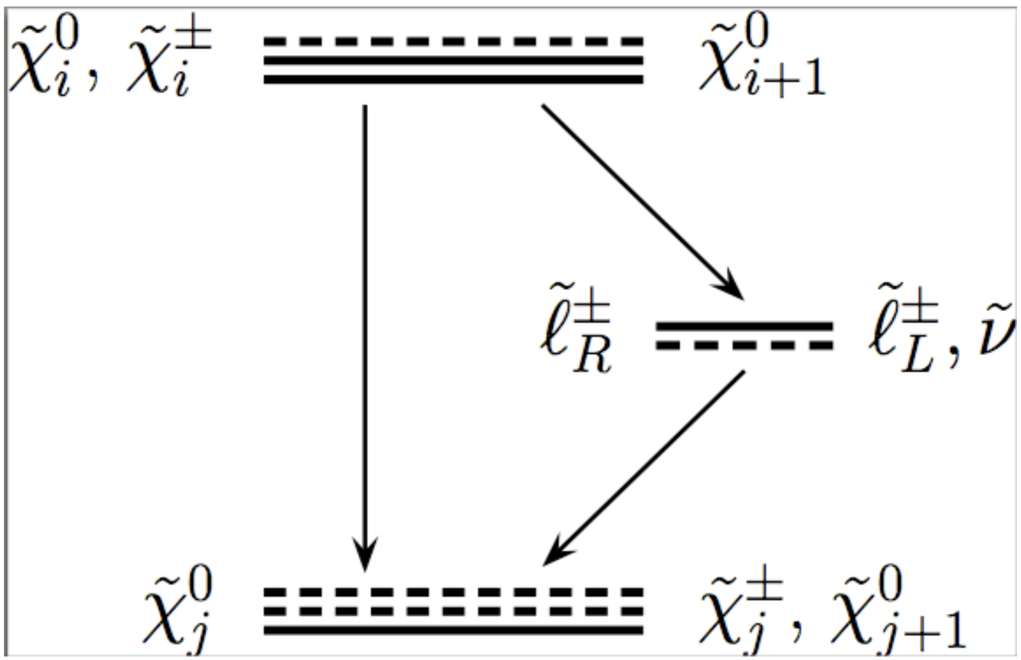
Outline

- **Review of Trilepton Searches at Tevatron**
- **Problem of Model Dependence**
- **Recipe for Model Independent Results**
- **Apply to Tevatron Trilepton Searches**
- **Recover CDF 2 fb^{-1} mSUGRA Result**

Our paper is being submitted to PRD and can currently be found at arXiv:0808:1605

SuperSymmetric Trilepton Production

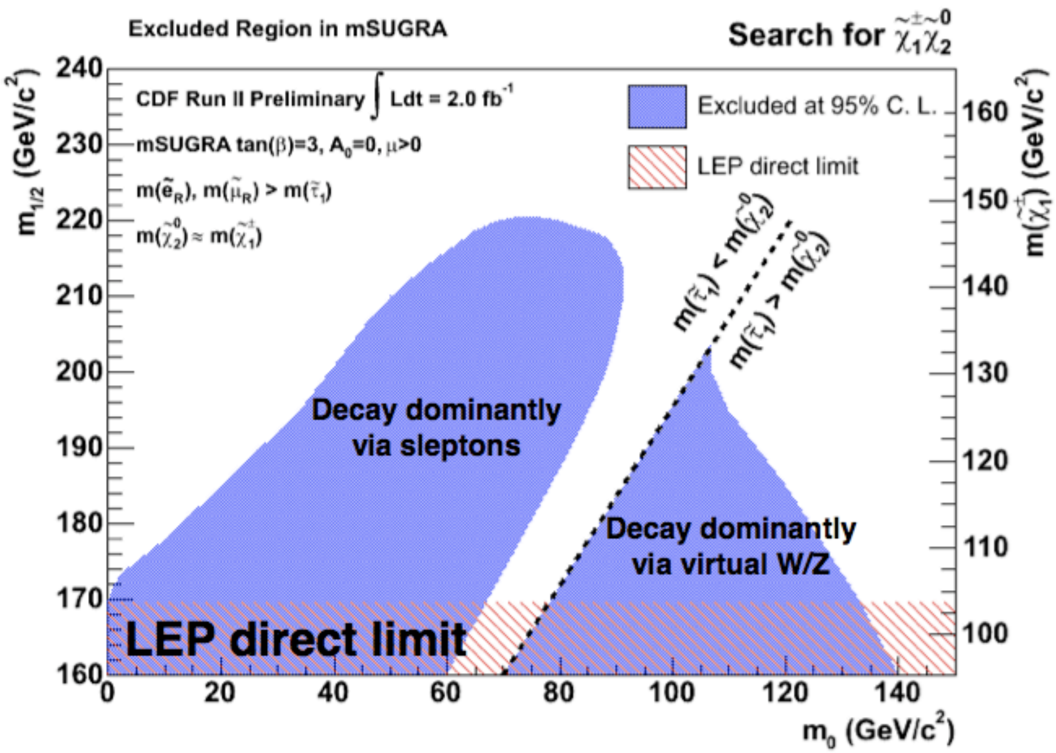


Chargino and neutralino decay to lighter neutralino (LSP), producing 3 leptons and a neutrino

Process may involve intermediate slepton and/or sneutrino.

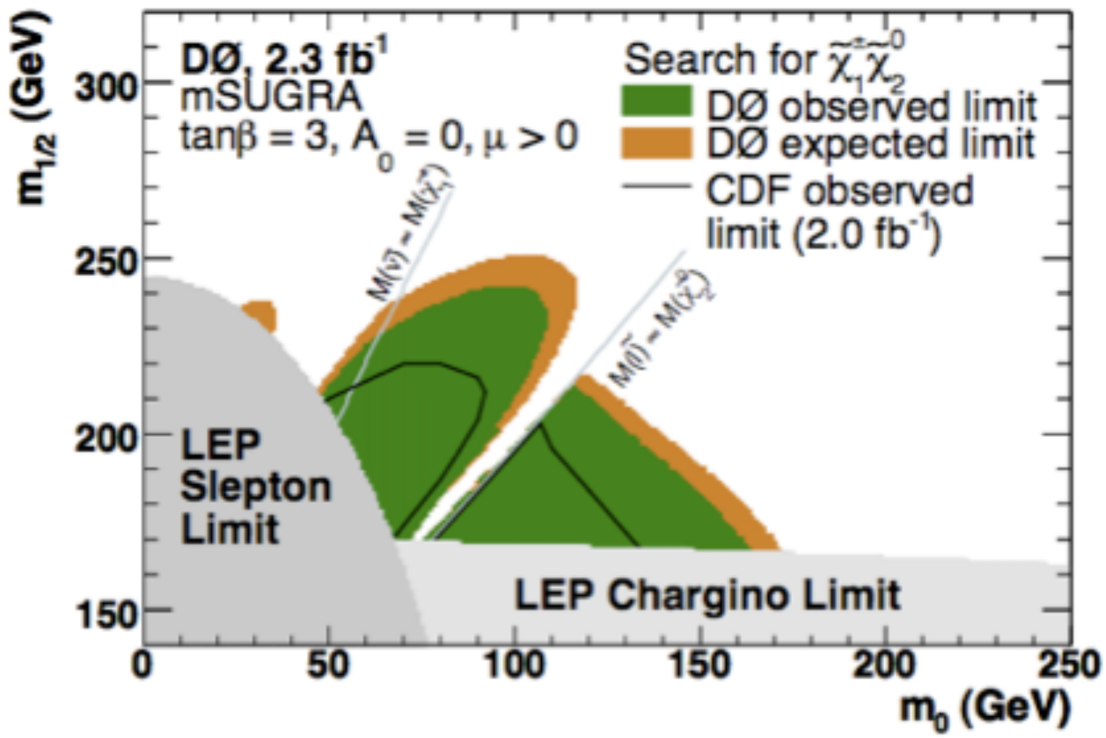
Review of Trilepton Searches at the Tevatron

- CDF
  - Exclusive channels based on expected signal purity
  - Consist of 3 e's/μ's or 2 e's/μ's and isolated track
  - Results interpreted in mSUGRA context and shown as function of m_0 and $m_{1/2}$



Review of Trilepton Searches at the Tevatron

- DØ
  - Channels based on lepton flavor
  - Contain 2 e's/μ's or 1 μ and 1 τ
  - Third object always isolated track
  - Results shown as function of m_0 and $m_{1/2}$



Problem

- What about when A_0 = 100 or tan(β) = 15?
- What about other SUSY models?
- Other extensions to SM?

Significance of Tevatron results is unclear!

Experimental Sensitivity

Experiments measure $[\sigma B]$, the product of cross section and branching ratio, as calculated below:

$$[\sigma B] = \frac{N}{LA}$$

N: Number of observed events minus expected background

L: Total integrated Luminosity

A: Detector Acceptance

Breaking Away From mSUGRA

- Why are CDF and DØ married to mSUGRA?
  - Sensitivity depends on τ's
    - Detector acceptance, and thus sensitivity, is greatly affected by the number of τ's in each trilepton event
      - (eee/μμμ vs. τττ, e.g.)
  - *Single* $[\sigma \times B]$ is model-specific!
    - Different sensitivity to models with different branching ratios to τ's
    - Reporting only one $[\sigma \times B]$ assumes model-specific branching ratios

Breaking Away From mSUGRA

- Solution
  - Split into channels based on phenomenological objects of interest
    - Since τ's dramatically affect sensitivity, split into channels based on number of τ's
  - Provide four $[\sigma B]$'s, one for each channel
  - Now sensitivity is independent of branching ratios
  - One more step to achieve model independence

Sensitivity for Each τ Channel

Sensitivity also depends on kinematics of analysis objects (leptons, missing E_T, for example)

Sparticle masses determine energy available to decay products

Therefore sensitivity can be parameterized as a function of sparticle masses

$$[\sigma B] = S(m_1, m_2, m_3, \ldots)$$

Model Independence Achieved?

- Recipe:
  - Instead of single model dependent $[\sigma B]$, provide four $[\sigma B]_i$'s
    - $[\sigma B]_{0\tau}$, $[\sigma B]_{1\tau}$, $[\sigma B]_{2\tau}$, and $[\sigma B]_{3\tau}$
    - $[\sigma B]_{0\tau} = N/LA_{0\tau}$ e.g.
  - Express each $[\sigma B]_i$ as a function of masses of relevant sparticles
- Now we claim model independence
  - Must be able to confront arbitrary model

Combine Four Channels to Measure Cross Section

But how?

For signal spread across several channels, we know that

$$N = \sum_{i=1}^{n} L \sigma B_i A_i$$

A more suggestive rearrangement is

$$\frac{1}{\sigma} = \sum_{i=1}^{n} \left(\frac{L A_i}{N}\right) B_i$$

But N/LA_i is just the $[\sigma B]$ of the i^{th} channel!

Combine Channels to Measure Cross Section

Now take a model with branching ratios B_i and plug in the four $[\sigma B]_i$'s to obtain the eXperimentally determined cross section for that Model.

$$\frac{1}{\sigma_{XM}} = \sum_i \frac{B_i}{[\sigma B]_i}$$

If $\sigma_{XM} < \sigma_{Model}$, model is ruled out.

Method extends beyond trileptons!

Making Tevatron Trilepton Searches Model Independent

- Three mass parameters
  - M: mass of LSP
  - ΔM_1: mass of chargino – mass of intermediate particle
  - ΔM_2: mass of chargino – mass of LSP
- Two assumptions for simplicity
  - Equal chargino/neutralino mass
  - Allow at most one intermediate particle

Parameterization of Sensitivity

$$([\sigma B]_i)^{-1} = S_i(M, \Delta M_1, \Delta M_2)$$

Dependence on M factors out

$$([\sigma B]_i)^{-1} = f_i(M) * S_i(\Delta M_1, \Delta M_2)$$

Two Cases

No intermediate particle:

No ΔM_1 dependence

$$([\sigma B]_i)^{-1} = f_i(M) * g_i(\Delta M_2)$$

One intermediate particle:

Depends on ΔM_1 and ΔM_2

$$([\sigma B]_i)^{-1} = f_i(M)*h_i(\Delta M_1, \Delta M_2)$$

Parameterization of Sensitivity

Functions f,g,h written as Taylor expansions

$$f_i(M) = 1 + a_1(M) + a_2(M)^2$$

$$g_i(\Delta M_2) = b_0 + b_1(\Delta M_2) + b_2(\Delta M_2)^2$$

$$h_i(\Delta M_1,\Delta M_2) = c_0 + c_1(\Delta M_2) + d_1(\Delta M_1) + c_2(\Delta M_2)^2 + d_2(\Delta M_1)^2 + e_2(\Delta M_1 * \Delta M_2)$$

Coefficients determined using experimental data

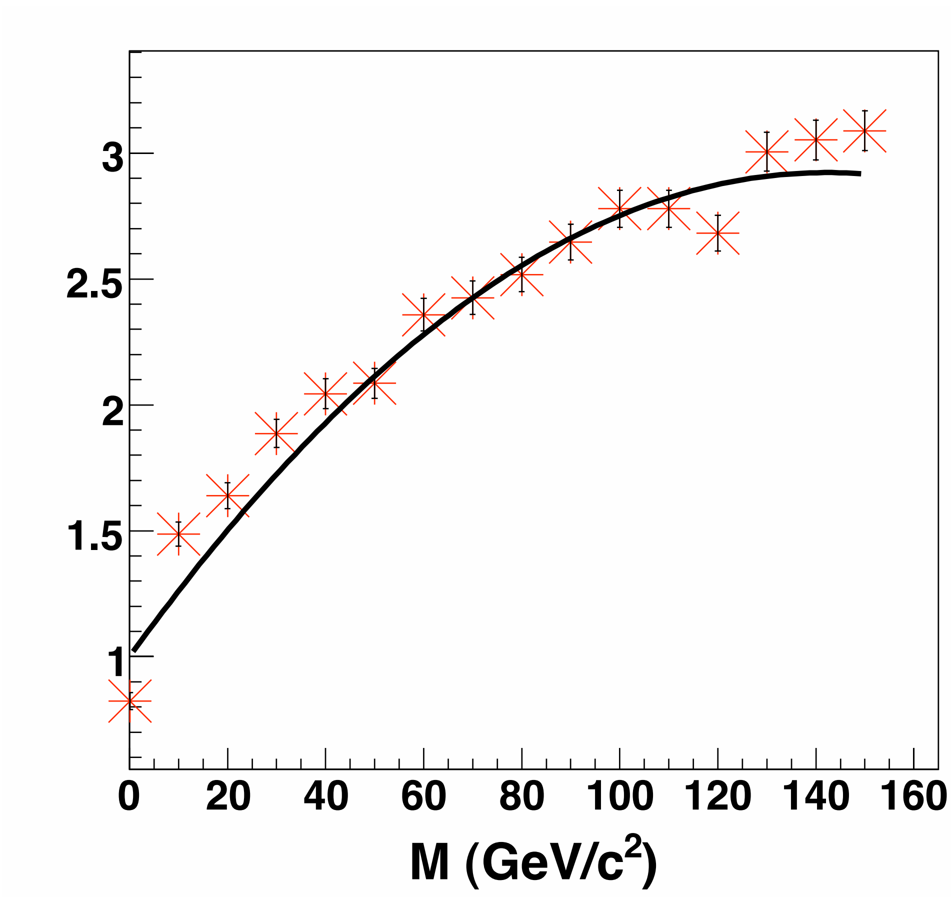
Determination of Coefficients Using CDF Results

- Generate trilepton events using PYTHIA for different values of mass parameters
- Select events with 3 e's/μ's or 2 e's/μ's and isolated charged particle

Variable	Selection
$p_{\mathrm{T}}^{1,2,3}$	$> 15, 5, 5$ GeV/c
$\lvert\eta^{1,2,3}\rvert$	< 1.1
$\not{E}_T$	> 20 GeV
max OS Mass	> 20 GeV/c^2, $\notin [76, 106]$ GeV/c^2
next OS Mass	> 13 GeV/c^2, $\notin [76, 106]$ GeV/c^2

For more details, see arXiv:0808:1605

Determination of Coefficients Using CDF Results



To determine f:

1. Fix ΔM_1, ΔM_2
2. Allow M to vary
3. Perform χ^2 fit

Fit shown for 0 τ channel

More details available at arXiv:0808:1605

Results (Four $[\sigma B]_i$'s as function of mass parameters for CDF 2fb^{-1})

	0 τ's	1 τ's	2 τ's	3 τ's
	$f(M)$			
a_1	2.70×10^{-2}	4.48×10^{-2}	5.61×10^{-2}	4.27×10^{-2}
a_2	-9.48×10^{-5}	-1.69×10^{-4}	-2.29×10^{-4}	-1.59×10^{-4}
	$g(\Delta M_2)$			
b_0	-4.39	-3.59	-3.71×10^{-2}	2.11×10^{-1}
b_1	3.28×10^{-1}	1.72×10^{-1}	6.60×10^{-4}	-8.20×10^{-3}
b_2	-2.08×10^{-3}	-9.41×10^{-4}	1.51×10^{-4}	1.13×10^{-5}
	$h(\Delta M_1, \Delta M_2)$			
c_0	-2.84	-1.73	-2.67×10^{-1}	1.22×10^{-2}
c_1	1.92×10^{-1}	9.66×10^{-2}	8.71×10^{-3}	-9.86×10^{-4}
d_1	-3.60×10^{-2}	-3.74×10^{-2}	-4.36×10^{-3}	-1.01×10^{-3}
c_2	-1.56×10^{-3}	-7.36×10^{-4}	-7.91×10^{-5}	8.02×10^{-6}
d_2	-2.40×10^{-3}	-1.49×10^{-3}	-5.25×10^{-4}	-1.58×10^{-4}
e_2	2.72×10^{-3}	1.73×10^{-3}	5.66×10^{-4}	1.59×10^{-4}

A spreadsheet is available online at
http://www.physics.rutgers.edu/pub-archive/0901

Operating Range

$M < 150$ GeV/c^2

$\Delta M_2 < 90$ GeV/c^2

If $\Delta M_1 > 0$:

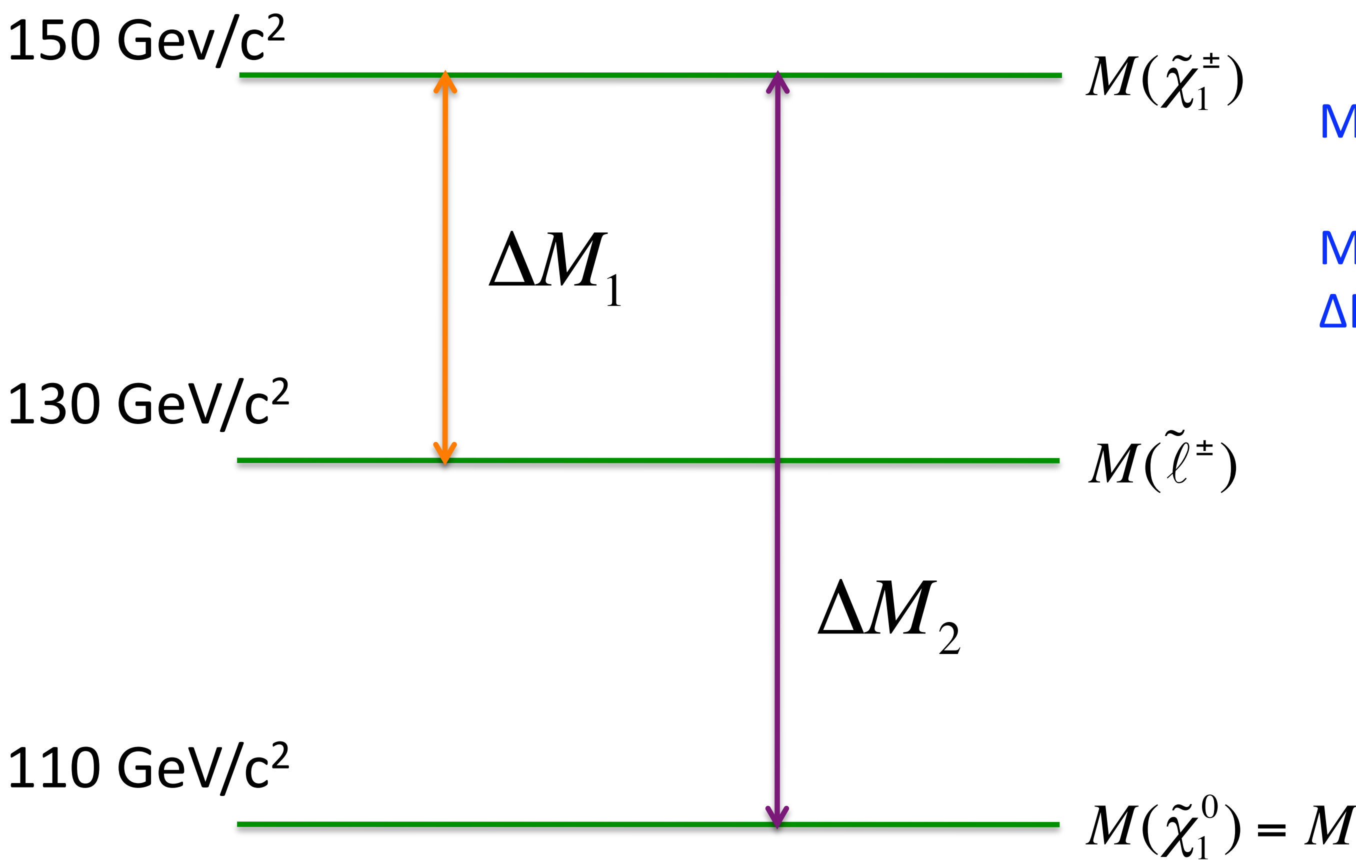
$\Delta M_1 > 5$ GeV/c^2

$\Delta M_2 - \Delta M_1 > 5$ GeV/c^2

Results accurate to within 20-30% in this range and 30-40% at edges.

Example

Suppose we have a model with the following mass spectrum



Mass parameters:

M = 110,
ΔM_1 = 20, ΔM_2 = 40

Example (continued)

Next, we use the spreadsheet to get the 4 channel sensitivities:

$([\sigma B]_{0\tau})^{-1} = 8.02\ \text{pb}^{-1}$ $([\sigma B]_{1\tau})^{-1} = 3.87\ \text{pb}^{-1}$

$([\sigma B]_{2\tau})^{-1} = 0.49\ \text{pb}^{-1}$ $([\sigma B]_{3\tau})^{-1} = 0.11\ \text{pb}^{-1}$

Now it's time to bring in the model's branching ratios

Example (continued)

Suppose your model has these branching ratios:

$B_0 = 0$, $B_1 = 0$, $B_2 = 0.6$, $B_3 = 0.3$

We plug in these B_i's and our four $[\sigma B]_i$'s

$$\frac{1}{\sigma_{XM}} = \sum_i \frac{B_i}{[\sigma B]_i}$$

And we get the experimental cross section for direct chargino/ neutralino production at Tevatron

σ_{XM} = 3.1 pb (CDF 2 fb^{-1} 95% CL upper limit)

Cross section for Wino-like production is about 0.2 pb

This model would not be ruled out

Example 2

Now suppose we have a different model with the same masses, but more favorable branching ratios:

$B_0 = 0.5$, $B_1 = 0.3$, $B_2 = 0$, $B_3 = 0$

We follow the same procedure with the new B_i's

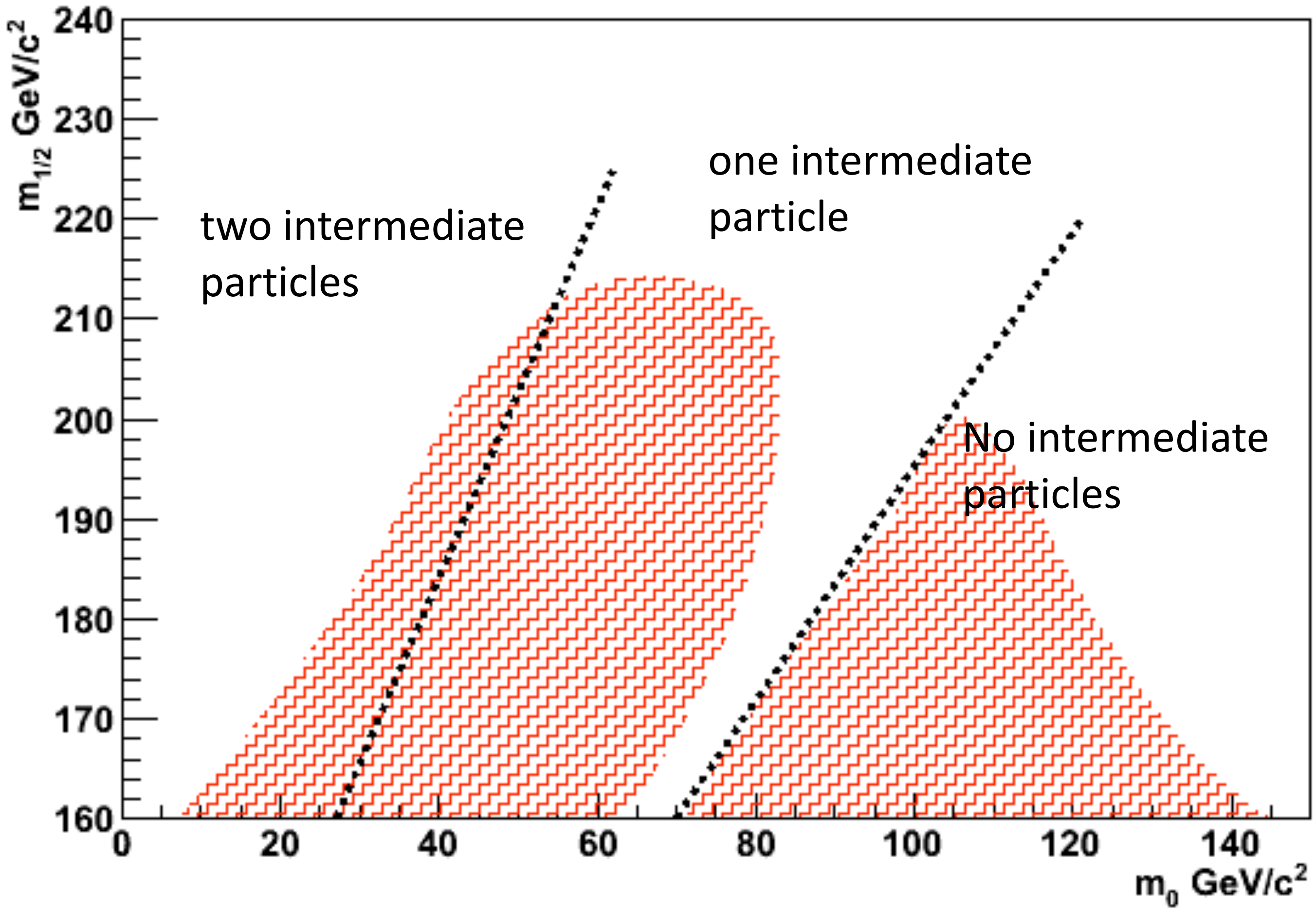
$$\frac{1}{\sigma_{XM}} = \sum_i \frac{B_i}{[\sigma B]_i}$$

And we get much different cross section limit

$\sigma_{XM} = 0.19$ pb

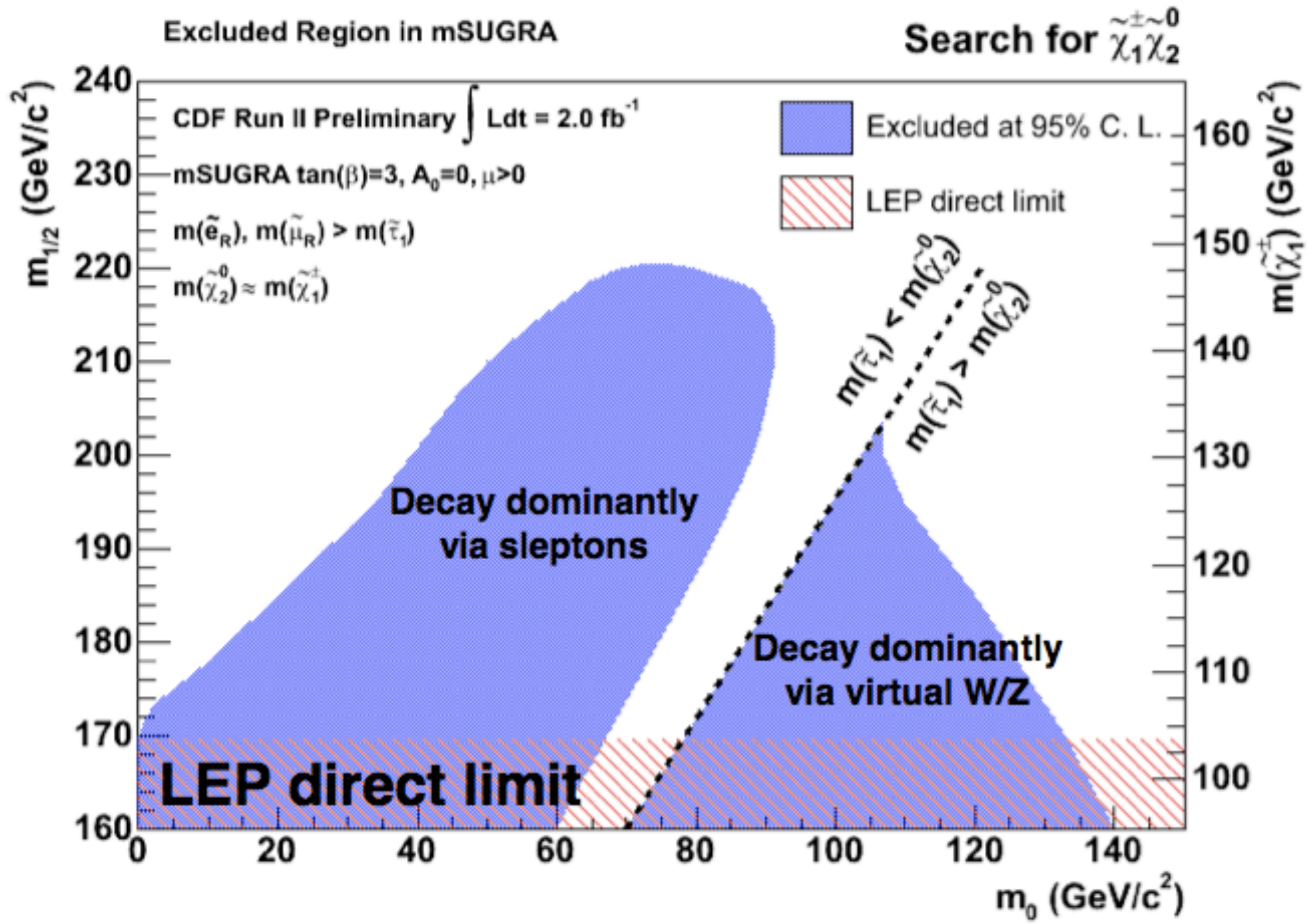
A spreadsheet utility to perform these calculations is available online at http://www.physics.rutgers.edu/pub-archive/0901

Recovering CDF's mSUGRA Result



Exclusion region obtained from model independent formula agrees well with CDF in regions with one or fewer intermediate particles.

Recovering CDF's mSUGRA Result



Actual CDF 2 fb^{-1} Result

Tackling the Inverse Problem

Inverse Problem refers to the problem of choosing between competing theories when observed signal is spread across many channels

Our method provides simple formula for combining several channels to obtain single cross section result

$$\frac{1}{\sigma_{XM}} = \sum_i \frac{B_i}{[\sigma B]_i}$$

One number makes comparisons much easier!

Conclusion

We now have a recipe for interpreting multi-channel results in a model independent fashion.

This method is quite general and can be used to combine channels with completely different signatures.

This provides an important tool for identifying new physics when the signal is spread across many channels!

Using this method, we supply model independent results for trilepton searches at the Tevatron.

Final Reminder

Further details are available in our paper, which is being submitted to PRD, and can be seen at arXiv:0808:1605