Characterizing New Physics at the LHC

Scott Thomas

Sourabh Dube, Yuri Gershtein, Eric Glatzer, Richard Gray, Eva Halkiadakis, Amit Lath, Michael Park, Josh Ruderman, David Shih, Sunil Somalwar, Alex Sood, Yue Zhao

Rutgers University

September 24, 2010

- **Working Group:**

  Signatures → Data

- **Characterizing New Physics**

  Factorized Mapping: Data ←→ Theory

- **Early Searches (Now) for Compressed Spectra**

  Leptons or Photons (+ Jets + MET)

Characterization of New Physics -

(Lessons from Tevatron Run II Workshops)

Workshop Priorities for Theorists (Pre-Discovery):

- Signatures

  Enumerate Possibilities, Inspired by Models, …

- Triggers

  Prompt, High p_T, Isolated
  Prompt, High p_T, Non-Isolated
  Non-Prompt, High p_T, Isolated
  Out of Time, …

- **Analysis**

  Optimize Cuts for Existing Analyses
  New Analysis or Measurement Techniques

- **Presentation of Results**

  σ . Br in Individual Channels
  Expected + Observed Backgrounds

- **Interpretation of Results**

  Model Spaces
  Test Hypothesis for Production + Decay Topology
  Factorized Mapping Method: Data ←→ Theory

- Analysis

    Optimize Cuts for Existing Analyses
    New Analysis or Measurement Techniques

- Presentation of Results

    σ . Br in Individual Channels
    Expected + Observed Backgrounds

    Not Always Done This Way !
    Please Always Include This Info

- Interpretation of Results

    Model Spaces
    Test Hypothesis for Production + Decay Topology
    Factorized Mapping Method: Data ←→ Theory

    Probably Least Important Aspect of Workshop

Probably Most Important Aspect of this Workshop -
And if Successful Theorists Can Interpret Within Any Model Space

Low Scale SUSY Run II Workshop:

NLSP	Prompt Decay	Macroscopic Decay Length	Long-lived
Bino-$\widetilde{\chi}_1^0$	$\gamma\gamma\ X\ \not{E}_T$	(Displaced γ) $X\ \not{E}_T$ TOF	$X\ \not{E}_T$
Higgsino-$\widetilde{\chi}_1^0$	$(\gamma,h,Z)(\gamma,h,Z)\ X\ \not{E}_T$ $[\gamma b\ X\ \not{E}_T,\quad \gamma bj X \not{E}_T,$ $\gamma jj\ X\ \not{E}_T,\quad \gamma X \not{E}_T,$ $b\bar{b}\ X\ \not{E}_T,\quad bbb\ X\ \not{E}_T,$ $\gamma\ell\ell\ X\ \not{E}_T,\quad \ell\ell\ell\ell\ X\ \not{E}_T]$	(Displaced γ , Displaced Z , LNIP b-jets) $X\ \not{E}_T$ TOF	$X\ \not{E}_T$
$\widetilde{\tau}_1$	$\tau^\pm\tau^\pm\ X\ \not{E}_T$ $\ell^\pm\ell^\pm\ X\ \not{E}_T$ $\tau\tau\tau\ X\ \not{E}_T$ $\tau\tau\ell\ X\ \not{E}_T$ $\tau\ell\ell\ X\ \not{E}_T$ $\ell\ell\ell\ X\ \not{E}_T$ $\tau\tau\ell\ell\ X\ \not{E}_T$ $\tau\ell\ell\ell\ X\ \not{E}_T$	HIT $\rightarrow \tau$ kinks HIT $\rightarrow e,\mu$ kinks	HITs Same-Charge HITs Same-Charge MITs $\ell\ell X \not{E}_T$ $\ell\ell\ell X \not{E}_T$ CC-HITs TOF
$\widetilde{\ell}$ co-NLSP	(as for Stau NLSP, but with different profiles, lepton democracy) $\ell\ell\ell\ell\ X\ \not{E}_T$	HIT $\rightarrow e,\mu,\tau$ kinks	HITs $\ell\ell X \not{E}_T$ $\ell\ell\ell X \not{E}_T$ TOF
$\widetilde{Q}$	$jj\ X$ $cc\ X\ \not{E}_T$ $bb\ X\ \not{E}_T$ $tt\ X\ \not{E}_T$ Same-Charge $tt\ X\ \not{E}_T$	Displaced jets H-HIT $\rightarrow$ jet kinks LNIPs Mesino Oscillations	CE-HITs H-HITs $\not{E}_T$ TOF
$\widetilde{g}$	$jj\ X\ \not{E}_T$	Displaced jets LNIPs	CE-HITs H-HITs $\not{E}_T$ TOF

Signatures

- Classification Useful

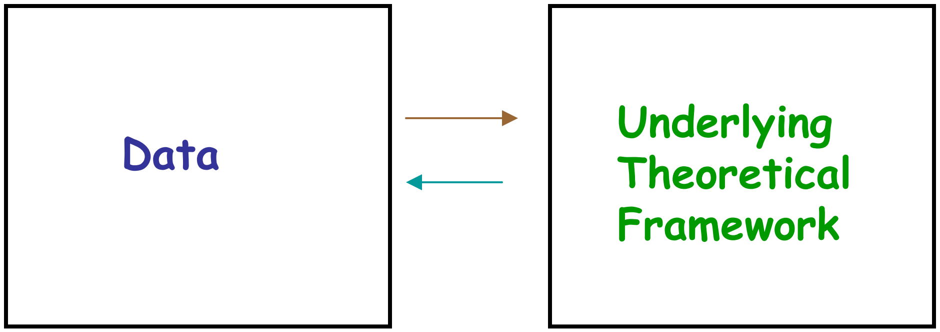
Triggers+Analysis

- Non-Prompt Photon, Z, Higgs
- HIT, CE-HIT, Stopped Gluino
- Kinks, LNIPS, …

Presentation of Results

- Same-Sign Dilepton,
- Trilepton, Multilepton, …

Physics Interpretation of Results



The Experimental Problem

Theoretical (Inverse) Problem

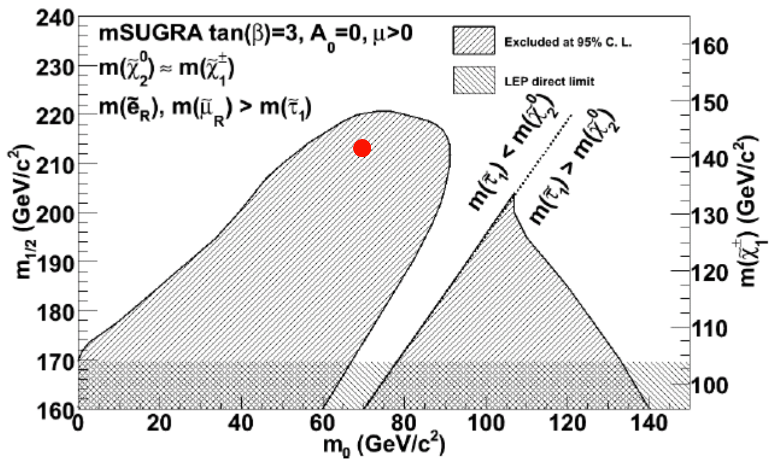
- **Benchmark Model Points, Lines, Manifolds, …**

  Can be Useful for Presenting Null Results –
  Quantify How Well Probe Specific Models
  But Then Presentation of Results – Can Be Very Model Specific

  Unlikely to be as Useful if Postive Results -
  Probably Won't Capture All Features of Signal

Physics Interpretation of Results

- Example – Tevatron Tri-Lepton Searches



mSUGRA parameter space

(see backup Slides for comments)

Search Results Presented in this form:

Mapping from σ.Br Results in Multiple Channels Onto Model Space n =0,1,2,3 τ

Information Lost !

Any Point in Model Space - Model Dependent Correlation Among Spectrum, σ, and Br's

Physics Interpretation of Results

(Dube, Glatzer, Somalwar, Sood, Thomas arXiv:0808.1605)

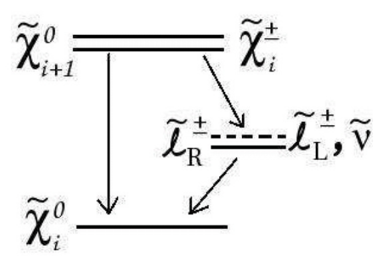
- **Model Independent Method for Presenting and Interpreting Multi-Channel Results**

Factorized Mapping Method:

Data ←→ Multiple Topologies or Directly into Model Space

1. Hypothesis for Production and Decay Tree Topologies

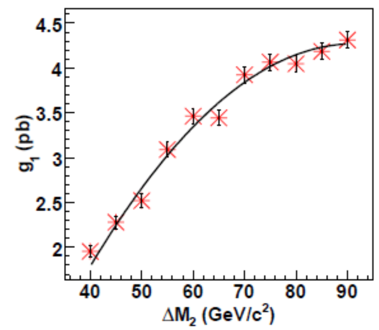
   Can Include
   Multiple Topologies and
   Multiple Final State Channels



Physics Interpretation of Results

(Dube, Glatzer, Somalwar, Sood, Thomas arXiv:0808.1605)

2. Parameterize Experimental Signal Efficiency times Acceptance for Each Topology in Each Final State Channel in terms of Masses Only
(Br's=1 and Independent of Signal σ)



Convert to σ.Br Sensitivity for Each Topology in Each Channel as function of Masses Only (Br's=1)

Using Background + Systematic Error Determination for Each Channel

Hard Work – Done by Experimentalists Anyway

Physics Interpretation of Results

(Dube, Glatzer, Somalwar, Sood, Thomas arXiv:0808.1605)

3. Map Results Onto Any Hypothesis for Any Combination of Production and Decay Tree Topologies with Given Br's

or Map Directly onto Any Model Space

$$\frac{1}{\sigma_{\mathrm{Model,Exp}}} = \sum_f \frac{\mathrm{Br}(pp \to X \to f)|_{\mathrm{Model}}}{[\sigma \cdot \mathrm{Br}(pp \to X \to f)]_{\mathrm{Exp}}}$$

- Exclusive Channels

(Inclusive with Hierarchy of Backgrounds OK)

Applicable to …

- Null Results: Exclusion Contours in Spectrum + Br Space or Directly in Model Space
- Positive Results: Likelihood Function in Spectrum + Br Space or Directly in Model Space

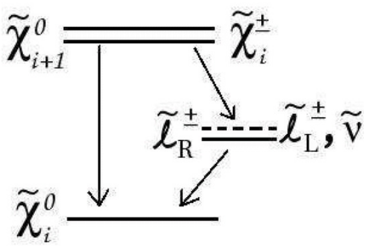
Physics Interpretation of Results

(Dube, Glatzer, Somalwar, Sood, Thomas arXiv:0808.1605)

Factorized Mapping Method Example: Tevatron Trileptons

1. Topology Hypothesis

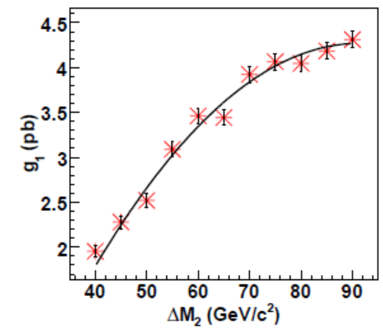
SU(2) Triplet Fermion
Charged Scalars
Singlet Fermion



Final State Channels

eee, eemu, eet, … , …

2. Parameterize Sensitivity of Each Production and Cascade Topology in Each Channel as Function of Masses Only
(Private Simulation Tools)



Physics Interpretation of Results

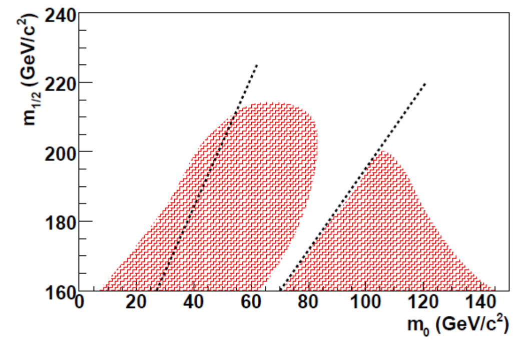
(Dube, Glatzer, Somalwar, Sood, Thomas arXiv:0808.1605)

Factorized Mapping Method Example: Tevatron Trileptons

3. Test - Map Results Onto mSUGRA Parameter Space

(Full Simulation Results Implicitly Included in CDF Publication)

$$\frac{1}{\sigma_{\mathrm{Model,Exp}}} = \sum_f \frac{\mathrm{Br}(pp \to X \to f)|_{\mathrm{Model}}}{[\sigma \cdot \mathrm{Br}(pp \to X \to f)]_{\mathrm{Exp}}}$$



Spectrum Parameterization of Sensitivities Available at
http://www.physics.rutgers.edu/pub-archive/0901/

Physics Interpretation of Results

(Dube, Glatzer, Somalwar, Sood, Thomas arXiv:0808.1605)

Factorized Mapping Method Features:

- Production σ's Factor Out of Problem
- Cascade Br's Factor Out of Problem
- Multiple Topologies + Multiple Channels Easily Combined

(c.f. Question at CERN Workshop)

- Only Requires Parameterizing Efficiency times Acceptance in Spectrum Space + Organizing Exclusive Channels

Experimentalist:

Exclusive Organization of Channels
Few Wisely Chosen Points for Full Simulation

Requires a Little Coordination

Theorist:

Fill in Finer Grid in Spectrum Space with Fast Theory Detector Simulator (TDS) (PGS Not Well Suited)

[Rutgers Simulation Tool Beta-Version]

. Hope to Release and Will Support Topologies Used in Rutgers Analysis

Searches at the LHC

- Renormalization Group Evolution of Expectations …

  14 TeV → 10 TeV → 7 TeV

  1 fb^{-1} → 100 pb^{-1} → 10 pb^{-1} → 1 pb^{-1} → …

- Search First for What You Can Discover First

  Cautionary Tale:

  In the search for extra-solar planets one collaboration missed first discovery because they didn't extend FFT to low enough periods (even though they had the data !)

  Another collaboration specifically searched for low period planets and made first discovery (with less data)

  Benchmark = Jupiter mass Planet with O(10) yr Orbit

  Discovery = Jupiter mass Planet with O(few) day Orbit

SUSY Signatures

Cross Section + Cascade Decay Patterns → Final States Depend on SUSY Spectrum

Most Benchmarks of This Type- Relatively Low Cross Section

Gauge Ordered Spectra

$\alpha_s >> \alpha_W > \alpha_Y$

Renormalization Group Evolution Stretches Spectrum

$m_{\text{Gluino, Squarks}} >> m_{\text{Wino, Sleptons-L}} > m_{\text{Bino,Slepton-R}}$

Natural Expectation – Not a Theorem

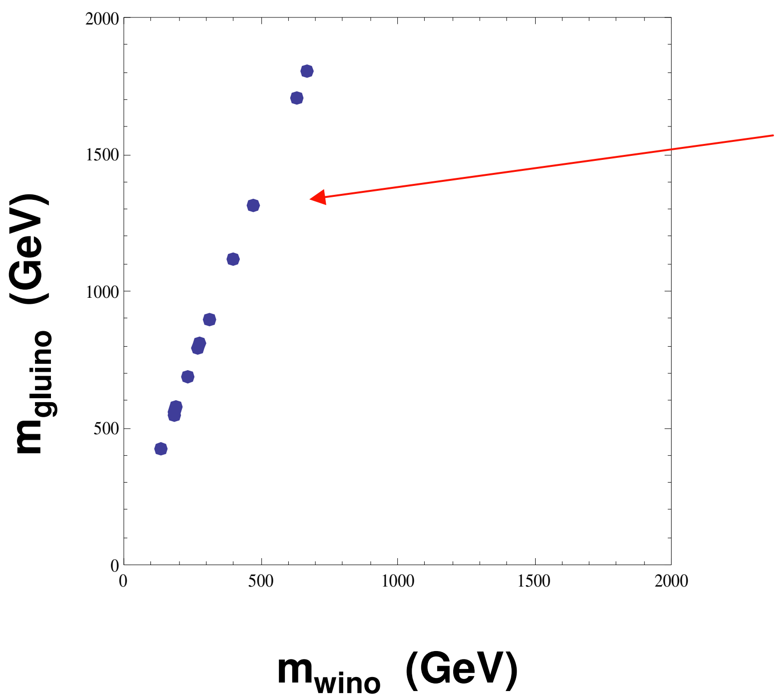
Gauge Ordered Signatures

Strong Production of Heavy Gluino + Squark →
Cascade Decay to Wino-like Gauginos emitting Jets →
Cascade Decay (through Sleptons) to Bino-like Neutralino emitting Leptons, W, Z, or Higgs → Neutralino = MET

Jets + Leptons + MET

SUSY Signatures

CMS (Public) SUSY Benchmarks (Atlas Similar)



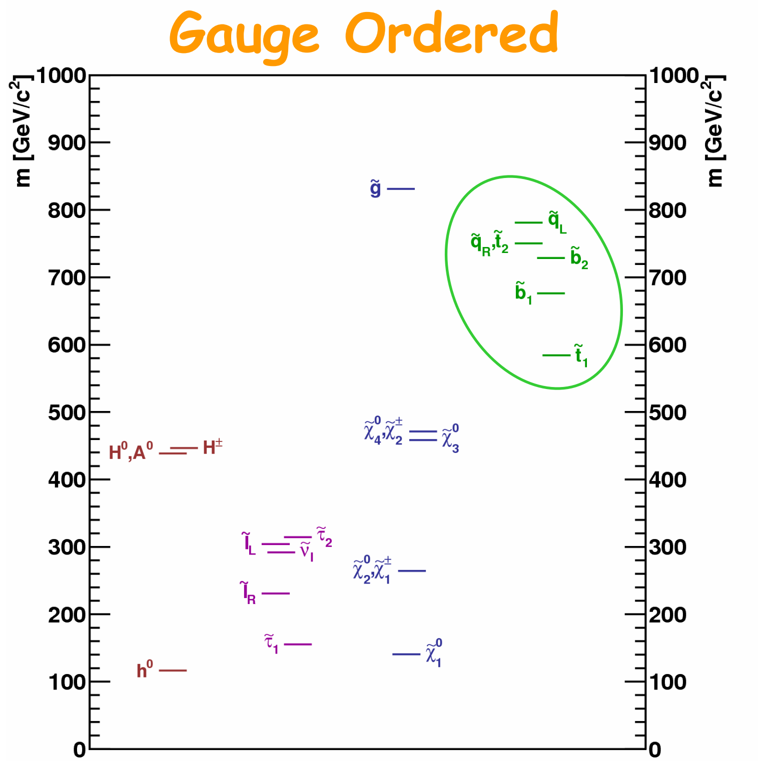
Stretched Gauge Ordered Spectra

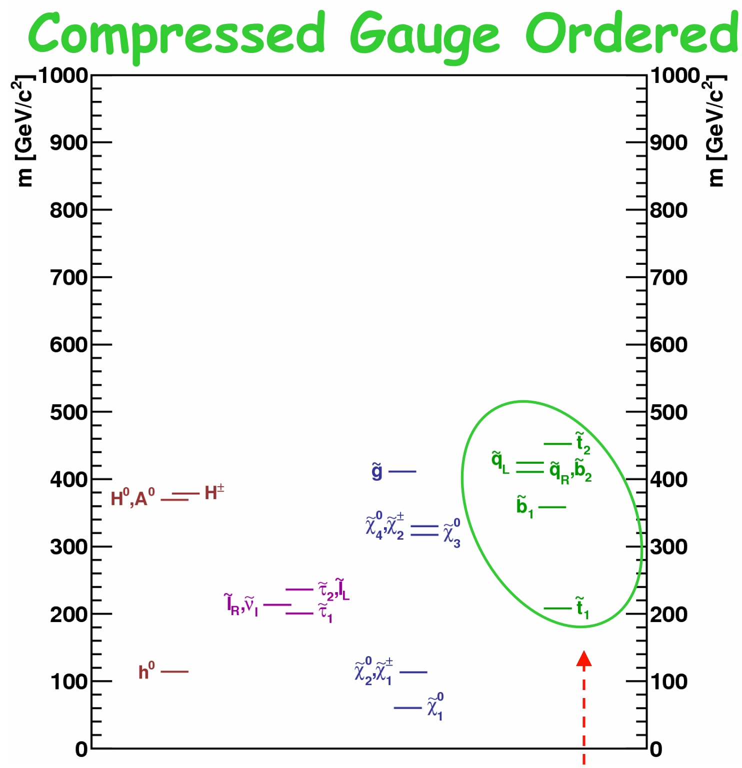
Relatively Low σ

Led to Expectation that Need O(100's) pb^-1 to go Beyond Tevatron

(Gaugino Unification)

Gauge Ordered vs Compressed SUSY Spectra

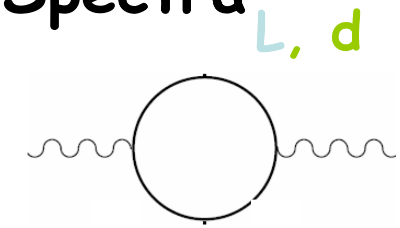




7 TeV σ_{LO} = 0.6 pb σ_{LO} = 39 pb

Strong Production of <u>Compressed</u> Spectra – Relevant for Discovery

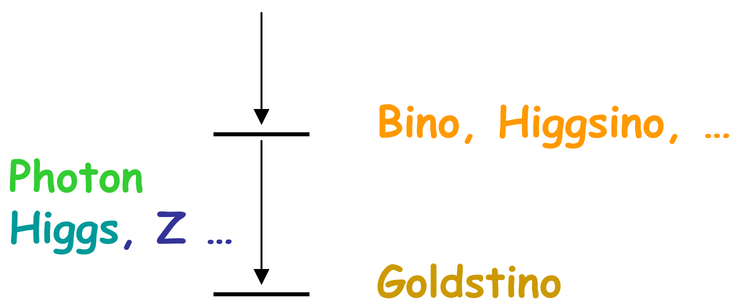
Early Searches (Now) With Compressed Spectra

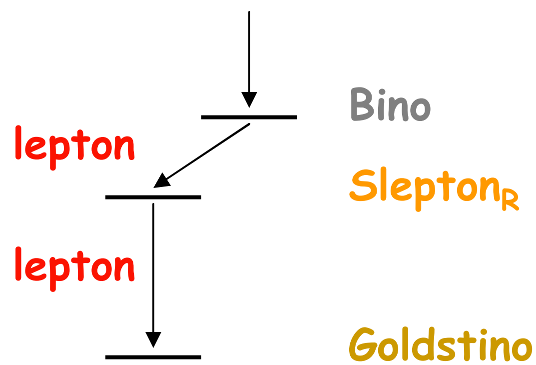


LSP = Goldstino (Essentially Massless)

NLSP = Right-Handed Slepton <u>or</u> Bino or Higgsino or …
(General Expectation)

Leptons or Photons Starting from Strong Production





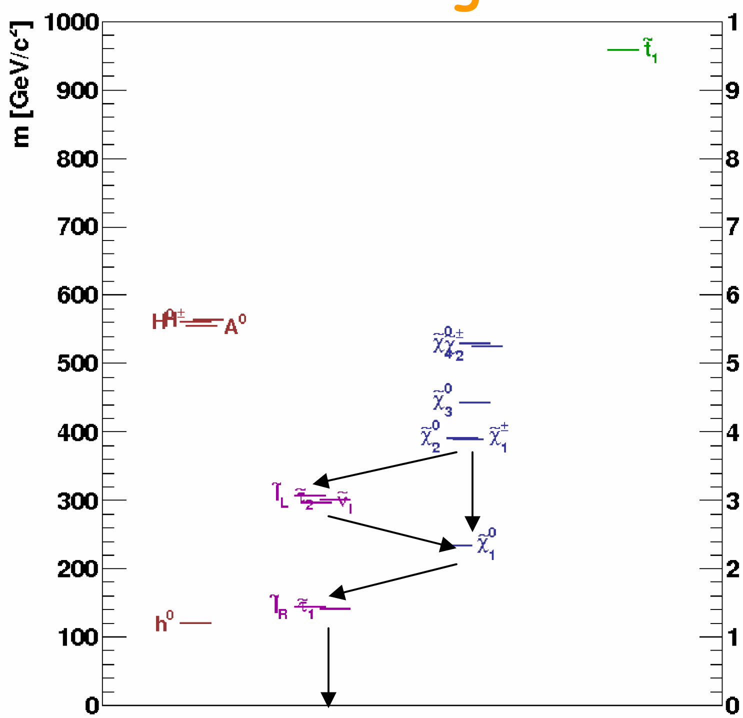
Di-Photons + MET
Di-Z + MET,
Di-Higgs + MET

2,3,4,… Leptons + MET

Slepton Co-NLSP → Multi-Lepton Signatures

MGM

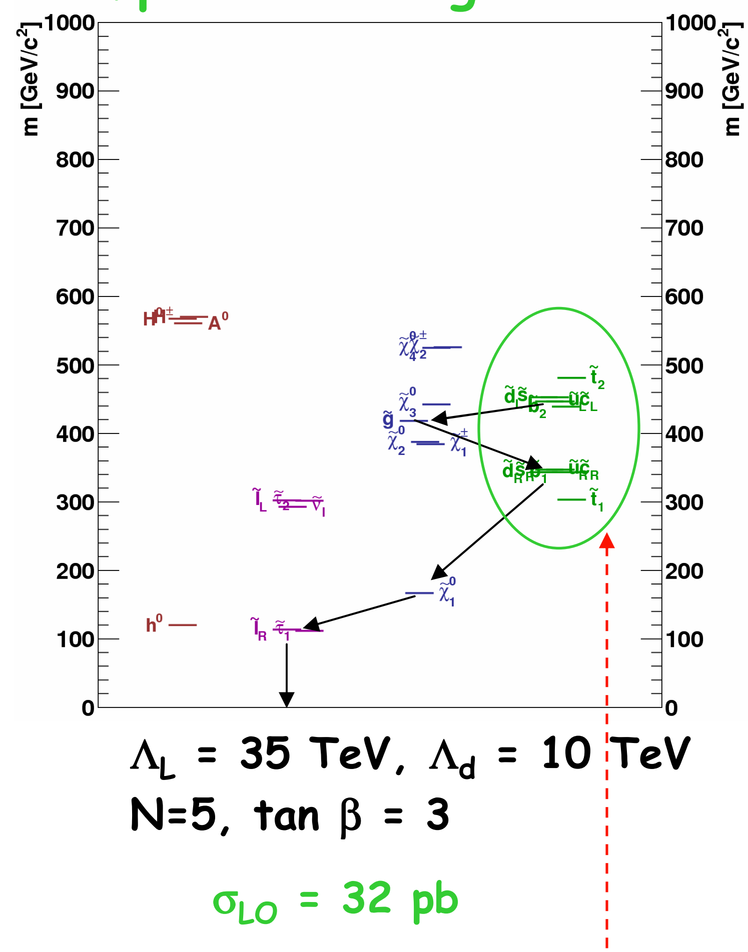
Stretched Gauge Ordered



$\Lambda_L = \Lambda_d = 35$ TeV
N=5, tan β = 3

GMSM

Compressed Gauge Ordered



$\Lambda_L = 35$ TeV, $\Lambda_d = 10$ TeV
N=5, tan β = 3

7 TeV σ_{LO} = 0.09 pb

σ_{LO} = 32 pb

Strong Production of Compressed Spectra - Relevant for Discovery

Early Searches (Now) With Compressed Spectra

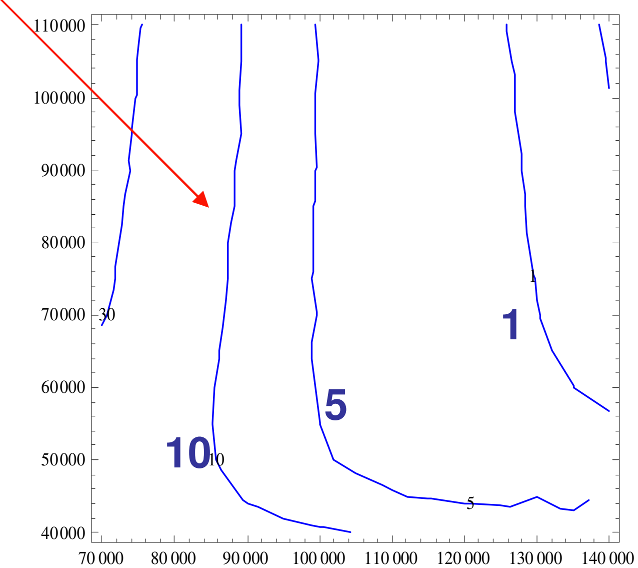
- Di-Photon + MET: Cross Section After Cuts

Complimentary Reach

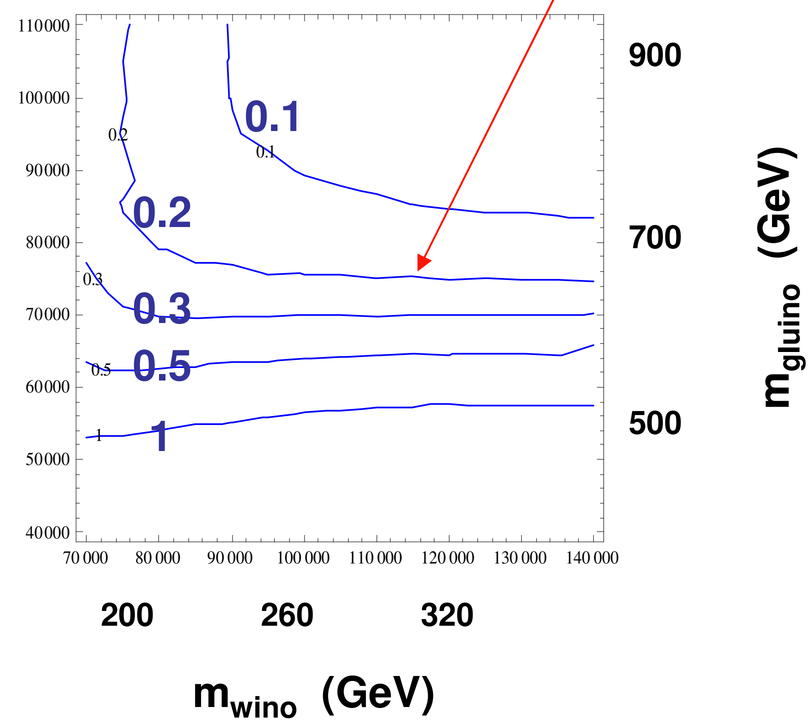
Weak Production Dominates

Strong Production Dominates

Tevatron (fb)



LHC (pb)



- Similar for Multi-Leptons

Conclusions

- **Factorized Mapping:**

  Model Independent Procedure for Presenting and
  Interpreting Multiple Topologies in Multiple Channel Results

  Rutgers Plans to Implement in Leptons+Jets+MET

  Working Group is Welcome to Adopt Procedures and Tools

- **Early Searches:**

  Compressed (SUSY) Spectra Being Probed Now

  (Collaborations Shouldn't Miss Out)

Extra Slides:

Benchmarks / Parameters Spaces

- Pre-Discovery:

  Generators for Signatures – Develop + Optimize Searches

  Every Benchmark has Particular Details –
  Easy to get too Invested

  Theory:

  Designed to Probe Underlying Theoretical Framework -
  But Actual Benchmark = Arbitrary Subspace of a
  Contrived Model with Hidden Uncontrolled Assumptions …

  Experiment:

  Possible to Over Specialize / Optimize Search Strategy
  Or Neglect Interesting Signatures Based Benchmark Details
  (e.g. Constrained SUSY Based on Higgs mass, …)

- Post-Discovery:

  Don't Try (Too Hard) to Jam Positive Results into Benchmark