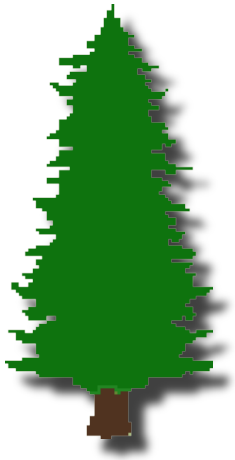
LHC Experiments: Searches for Physics Beyond the Standard Model

Jason Nielsen

Santa Cruz Institute for Particle Physics

University of California, Santa Cruz



Theoretical Advanced Studies Institute

Boulder, Colorado

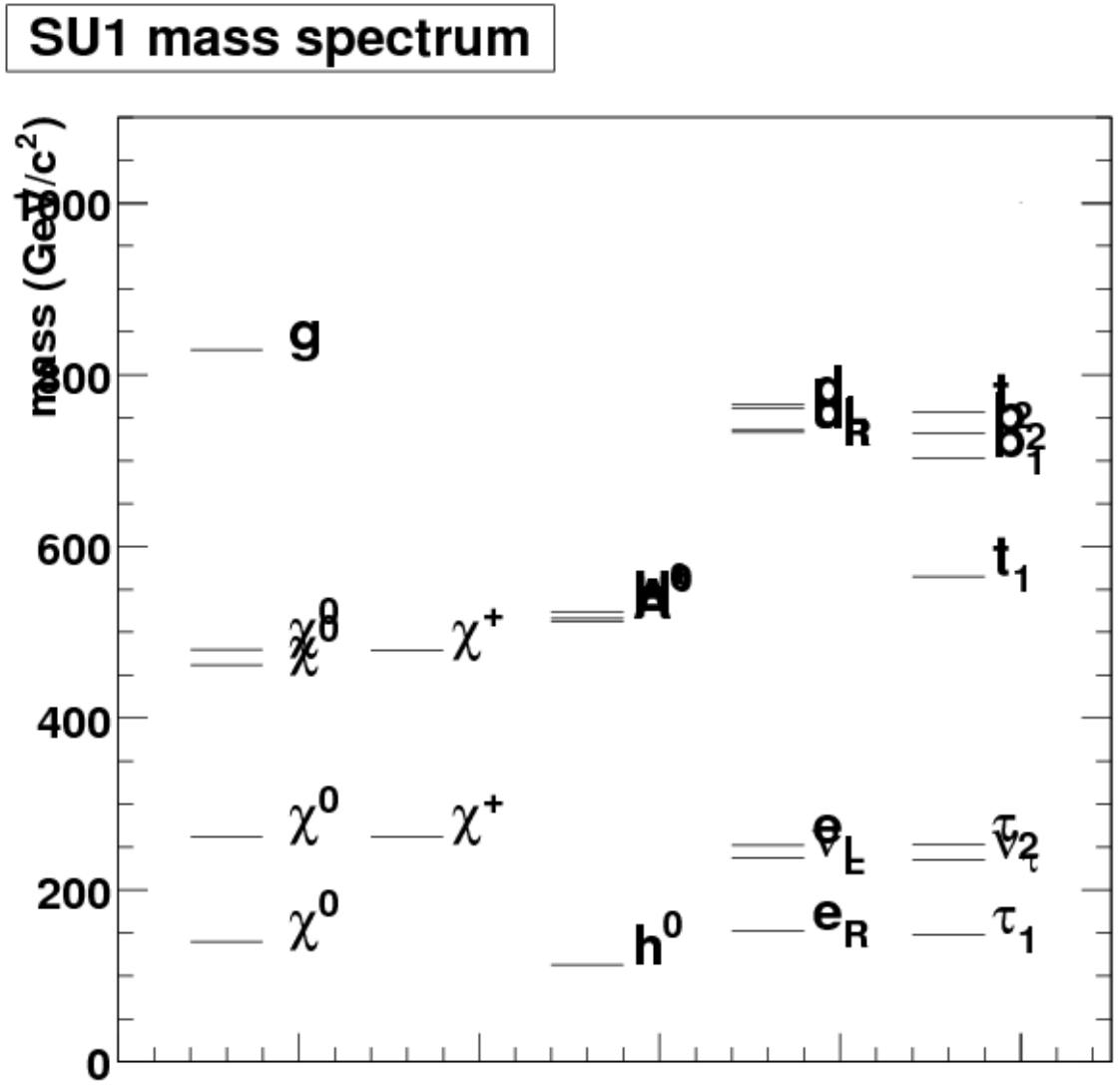
June 2010

Signature-Based Searches

- If we are looking for SM Higgs bosons or have a particular model in mind, we benefit from developing a tailored event selection, but do we have to start from a model?
  - 1 physicist per model (parameter set) is not feasible
- Experimental focus includes hunting "features" in data that may correspond to a wide range of models
- This is a short tour of some well-motivated features that will be sought in early data

- In general, these searches are not quite as powerful as a dedicated search if parameters are known or constrained

Sample mSUGRA Sparticle Spectrum



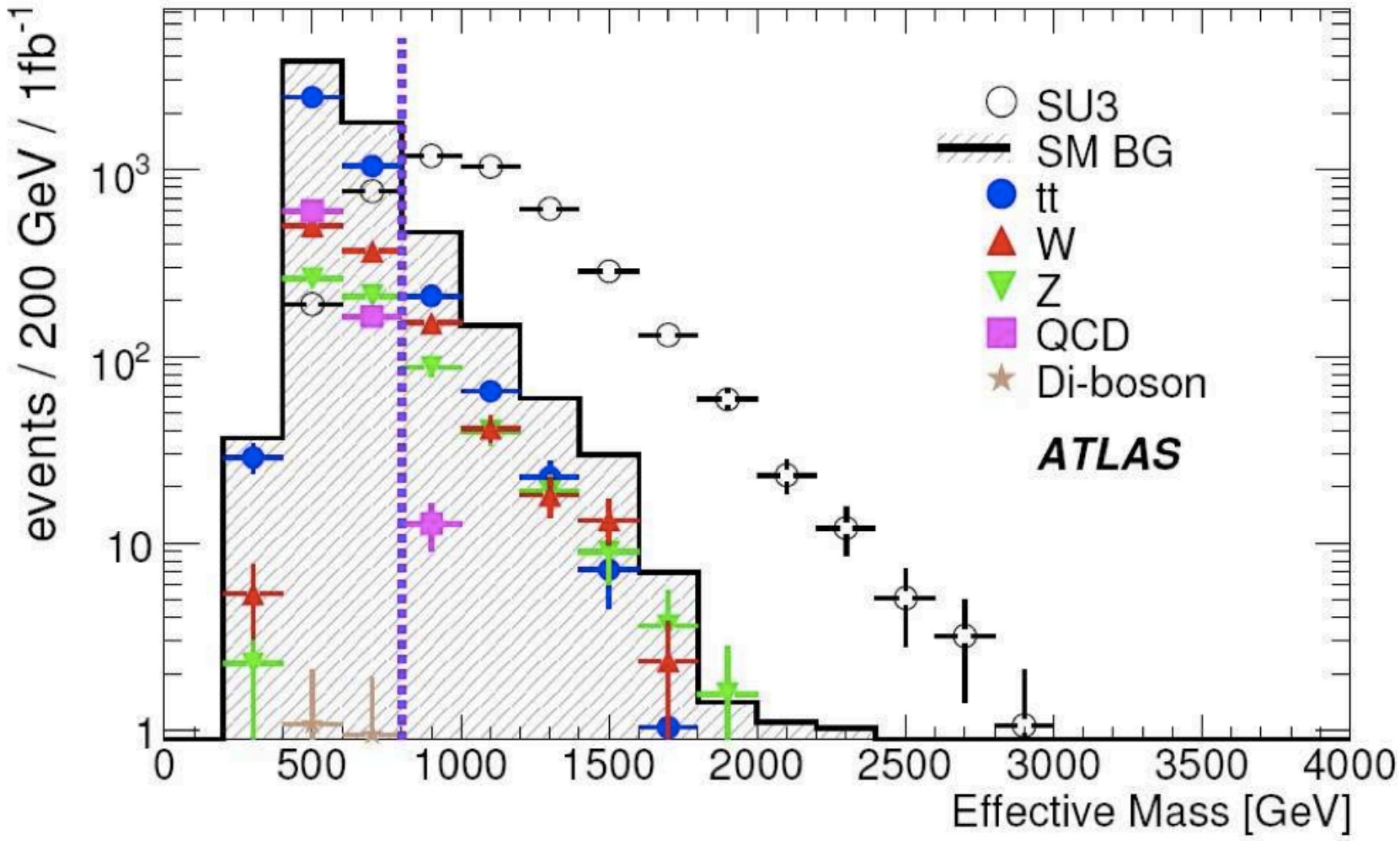
Total Event Energy

- Outgoing particles in hard scatter set the event scale, which is near the mass of the particles
  - Whatever the outgoing particles in hard scatter, the subsequent decays preserve this rough event scale
- The total observed energy in the event is a good handle for pair-production of high-mass new particles O(TeV)

- Focus on robust definition of event energy
  - M_{eff} uses physics objects
  - ΣE_T uses total energy in calorimeter (incl. pileup, etc.)

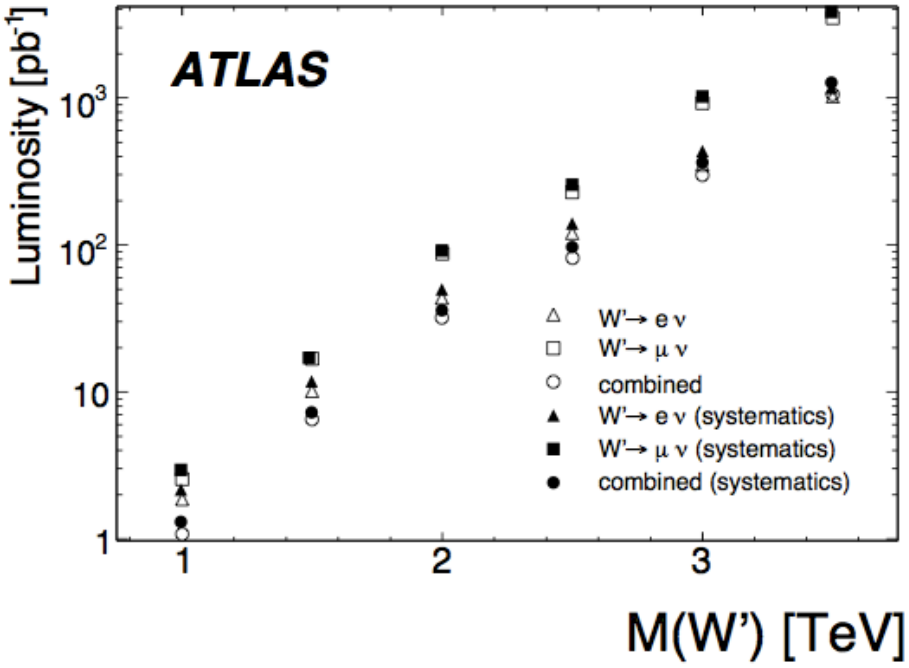
Example of Meff in SUSY Searches

After simple pre-selection, requiring 4 high-pT jets and large missing ET



Resonances in Leptons, Photons, Jets

- We heard arguments for higher-mass versions of SM particles: some of these correspond to resonances (invariant mass peaks) of simple objects
- Reconstruction of resonances is straightforward, if we have 4-vectors for all particles involved



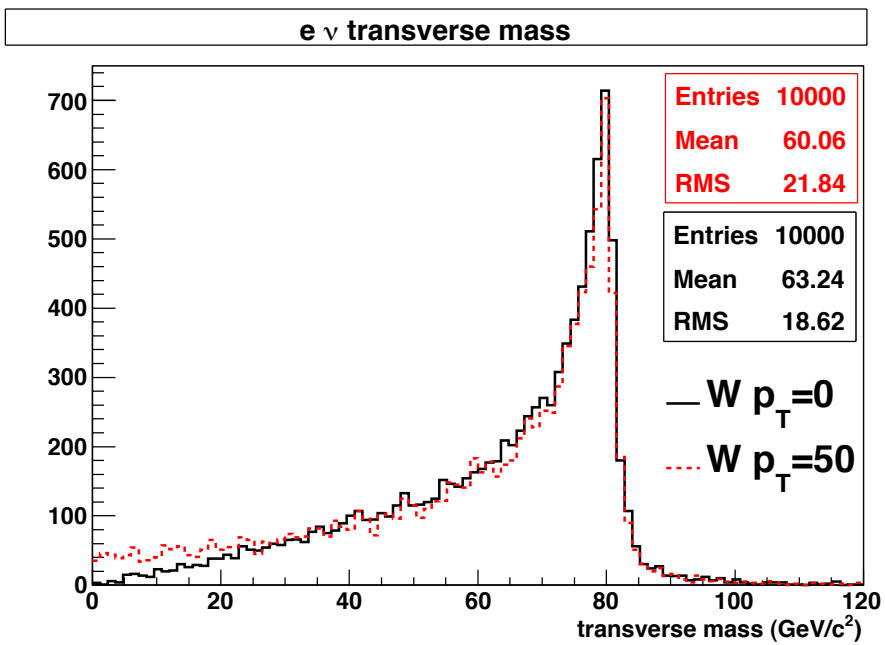
Origin of Resonances in BSM Models

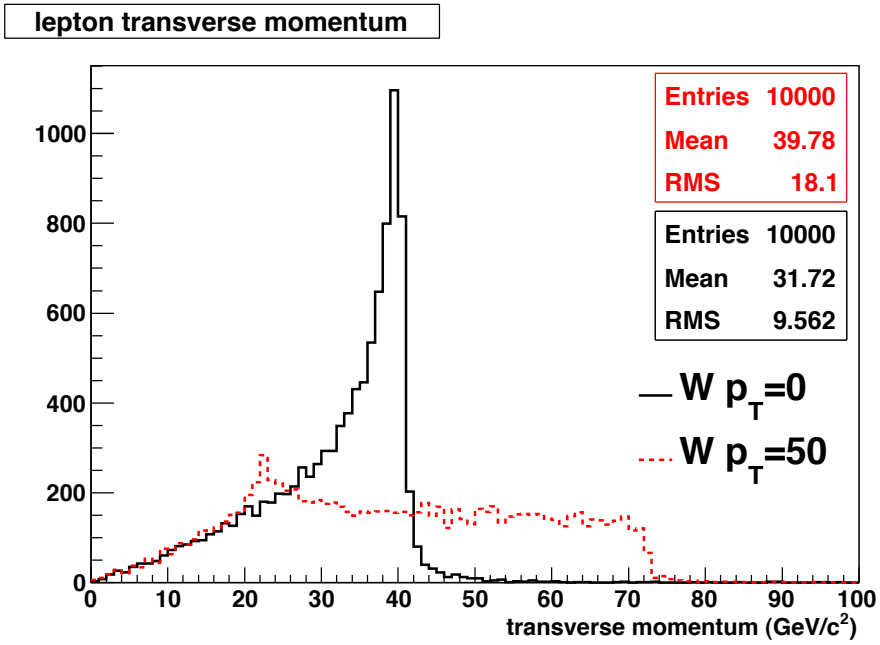
- Myriad possibilities as suggested earlier: higher-mass partners of SM particles needed for loop cancellation
  - Z', W', t', KK towers confined in extra dimensions
- But what if the decay products are invisible? This is the natural case if a quantum number is conserved and the lightest particle with a non-zero value interacts weakly
  - SUSY: $pp \to X + \tilde{\ell}^+_R \tilde{\ell}^-_R \to X + \ell^+\ell^- \tilde{\chi}^0_1 \tilde{\chi}^0_1$
  - 4th-gen lepton: $X + \ell^+_4 \ell^-_4 \to X + \overline{\nu}_{\ell_4} W^+ \nu_{\ell_4} W^-$
- In this case the simple invariant mass will not work because we do not have a 4-vector for the invisible particle

Transverse Mass and Friends

- How can we reconstruct two-body decay, where one particle escapes undetected? (W→en or $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$)
  - Define transverse mass for massless decay products

$$m_T^2 = 2E_{T1}E_{T2}[1 - \cos(\Delta\phi)]$$





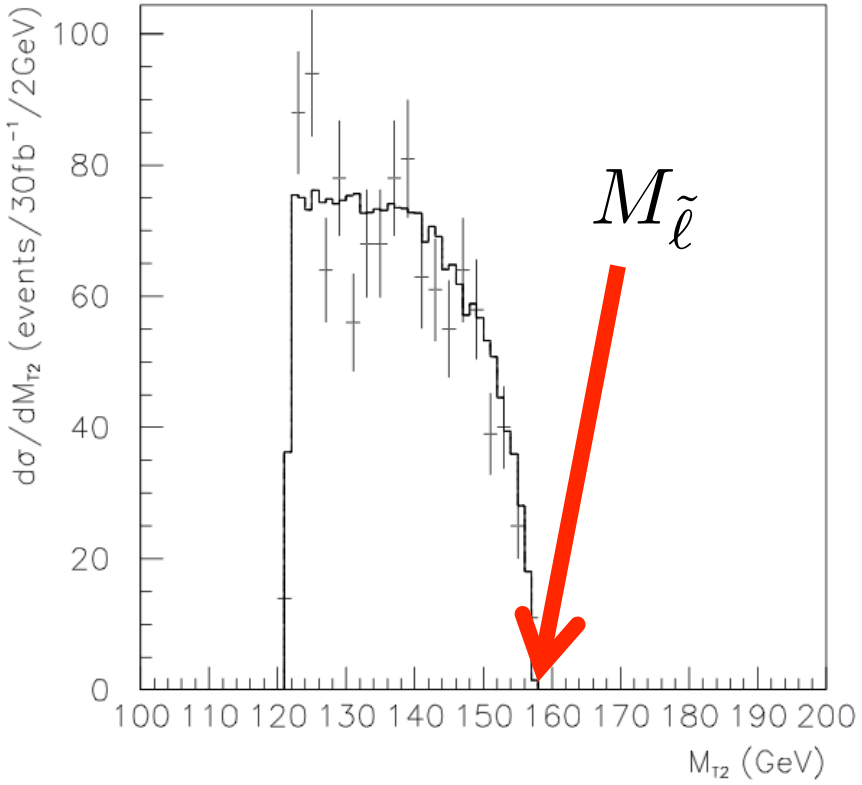
Modified Transverse Mass

- If two particles decay to invisible daughters, how to assign the correct missing energy to each side?
- Consider again $pp \to X + \tilde{l}_R^+ \tilde{l}_R^- \to X + l^+ l^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$

$$m_{\tilde{l}}^2 \geq M_{T2}^2 \equiv \min_{\not{p}_1 + \not{p}_2 = \not{p}_T} \left[\max \left\{ m_T^2(\mathbf{p}_{Tl^-}, \not{p}_1), m_T^2(\mathbf{p}_{Tl^+}, \not{p}_2) \right\} \right]$$

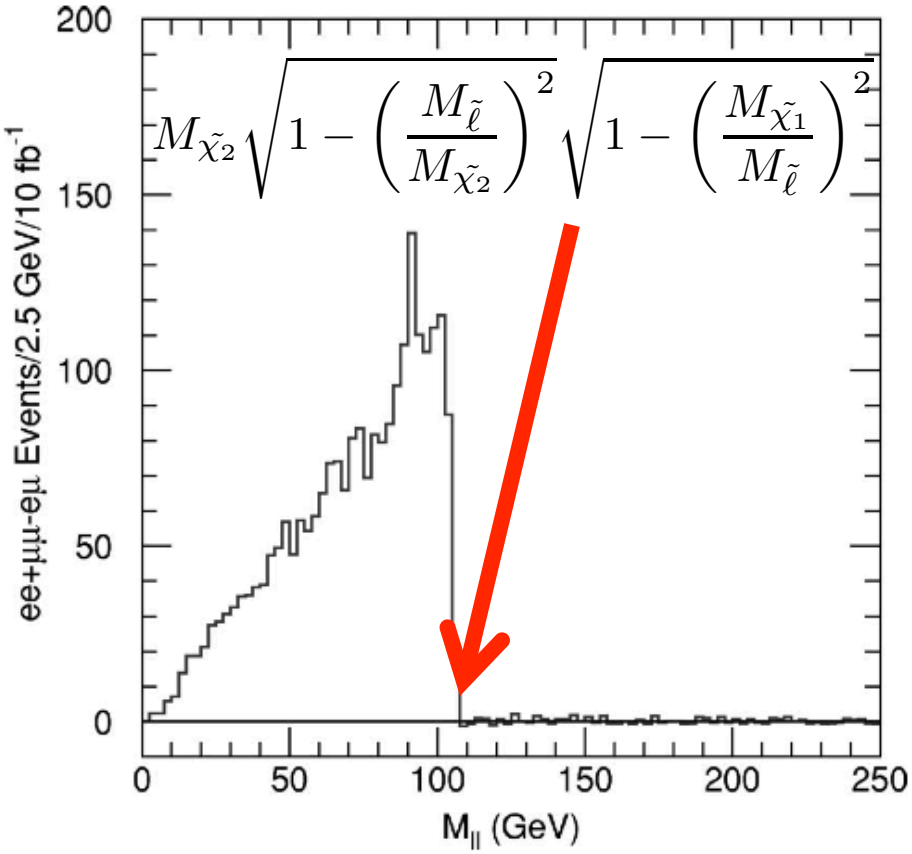
Lester & Summers, hep-ph/9906349

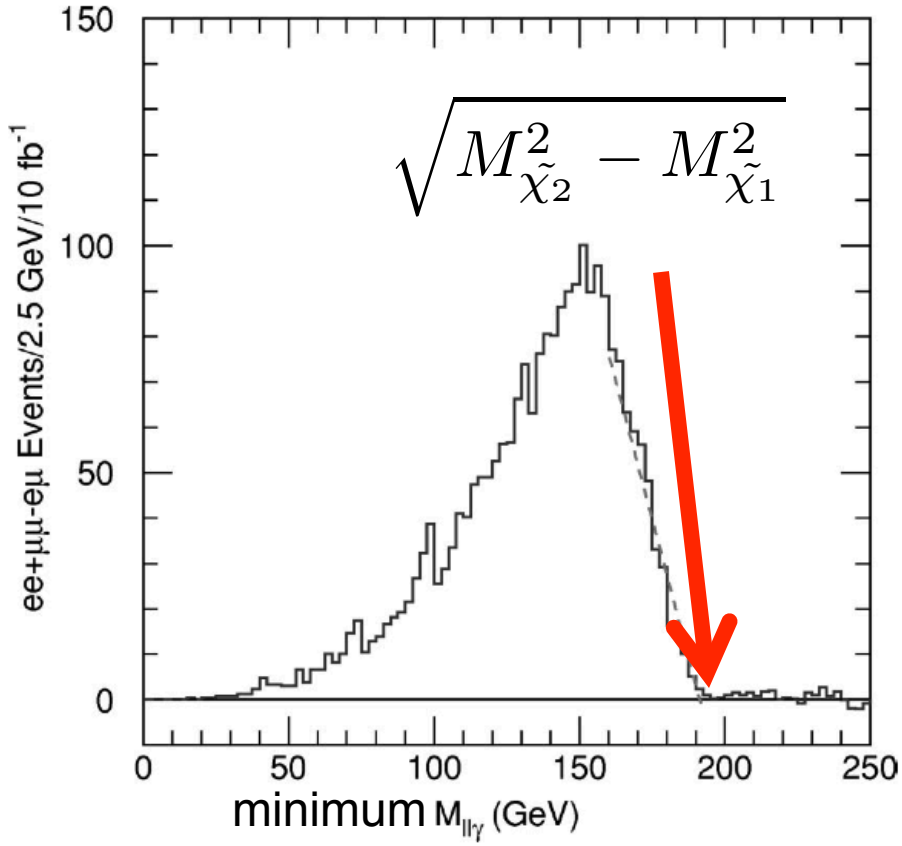
Must know m(χ) first to get an endpoint this clean!



Kinematic Edges for Mass Determination

Example: $\tilde{\chi}_2^0 \rightarrow \tilde{\ell^{\pm}}\ell^{\mp} \rightarrow \tilde{\chi}_1^0\ell^{\pm}\ell^{\mp} \rightarrow \tilde{G}\gamma\ell^{\pm}\ell^{\mp}$





For full chain reconstruction, see Hinchlifffe & Paige PRD 60, 095002 (1999)

Focusing Search in Specific Subsamples

- Preselection helps reduce overwhelming SM background
  - Requiring large missing E_T helps focus on high mass
- Ideally, we could search for all of these edges and resonances in many specific regions of preselection: MET +jets, leptons+MET, leptons+jets
- Combinatorics can be overwhelming. In each sample:
  - Calculate trigger efficiency
  - Calculate background contributions
  - Select events and compare with expectations

General Searches using MUSiC Program

- Similar programs at H1, D0, CDF experiments
- Counts events in each of several high-p_T object classes (1μ1jet, 1e2jetMet, etc.) and compare to SM expectation
- Challenge is to describe completely the SM backgrounds for all signatures at once!
- Consider several distributions in each event class
  - Scalar pT sum of all high-p_T objects
  - Invariant mass (or transverse mass) of all objects
  - Missing transverse energy
- "3σ" discrepancies are "interesting" and will be followed up with a more careful study

Challenges for "Obese" Higgs

- Physical (true) width of Higgs increases substantially

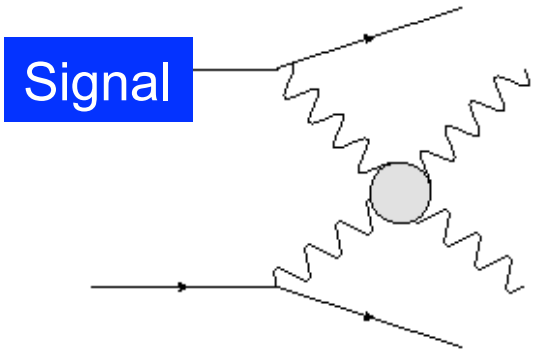
$$\Gamma_H = (0.5\,\mathrm{TeV})(m_H/1\,\mathrm{TeV})^3$$

  - With low production rate, difficult to pick it out of the signal + background distribution
- Is this still a particle, or is it a resonance in the "scattering" of its decay products?

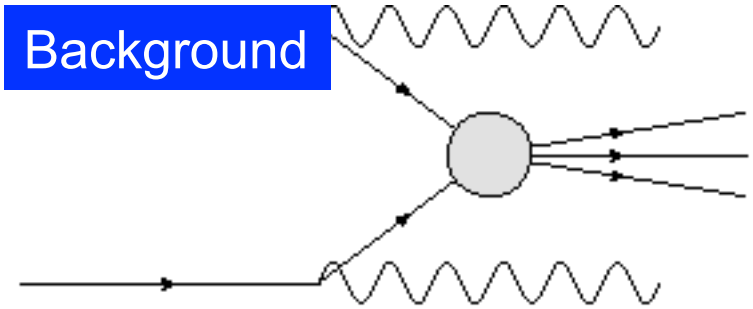
- Width is even more important than detector resolution for particles at 500 GeV: $\delta p_T/p_T$=6%(μ), 10%(e/γ)

$W^+_L W^-_L$ Scattering

- We heard the unitarity would seem to be violated in WW scattering at the 1 TeV scale, so measure this scattering
- "Unitarizing" scattering can lead to WW resonances
- How can we measure the invariant mass of the WW system if there are two neutrinos? Maybe we can select events where one W decays hadronically



High-E forward jets
No central hadronic interaction



High-E forward jets
No hadronic interaction

WW Scattering Measurements

Example of different possible resonances that may be seen in scattering (signal only shown here)