SUSY Mass Determination using Kinematic Fits

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Outline

- Motivation
- Kinematic Constraints in SUSY Events
- Mass Determination Method
- Application to Leptonic Decays
  - Event Selection
  - Initial LSP Momenta
  - Fit Performance
  - Mass Determination
- Summary

Introduction

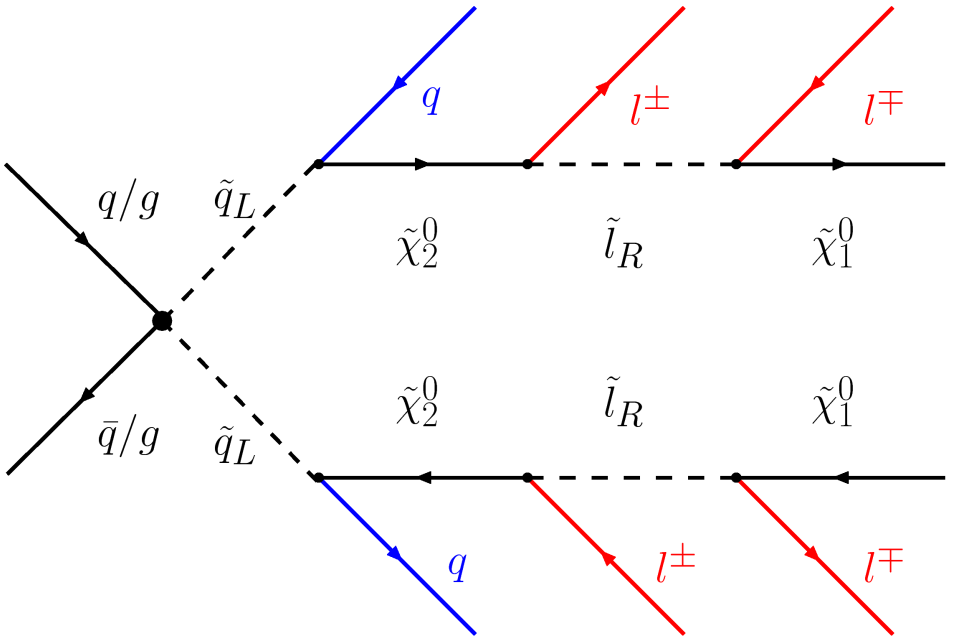
- First goal: Discover Supersymmetry at the LHC
- Second step: Determine model parameters
  - Necessary inputs to fitting codes: **Masses** or mass differences, spins, couplings ...

R-parity conserving model

- Pair production
- Cascade decay, stable LSP
  - Missing transverse energy
  - Many jets & leptons

Access to masses

- Established methods, e.g. mass edges
- Here: Full reconstruction of event kinematics

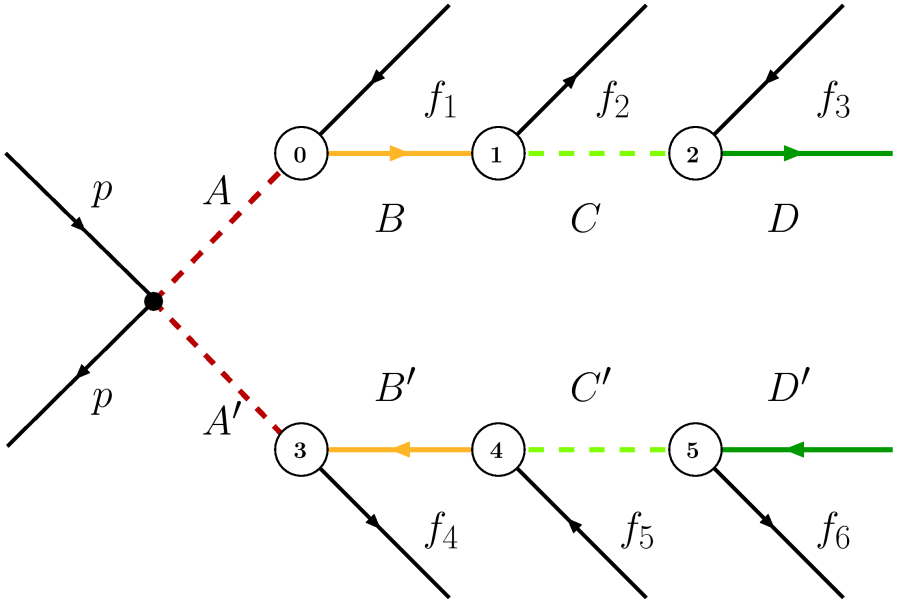


mSUGRA example event

Kinematic Constraints

One Event

- Parameters
  - Measured f_i momenta 6x3=18
  - Unmeasured LSP momenta 2x3=6
  - Unknown masses (A,B,C,D,A',B',C',D') 4
- Constraints
  - Masses (A,B,C,A',B',C') 6
  - pT – balance 2
- Problem over-constrained if masses are known/assumed
- Able to determine LSP momenta → constrained kinematic fit



For *N* events with identical branches:

- (*N*x18 measurements (6 final-states))
- 4 common unknowns (SUSY masses)
- *N*×6 local unknowns (2 LSPs)
- *N*×8 constraints

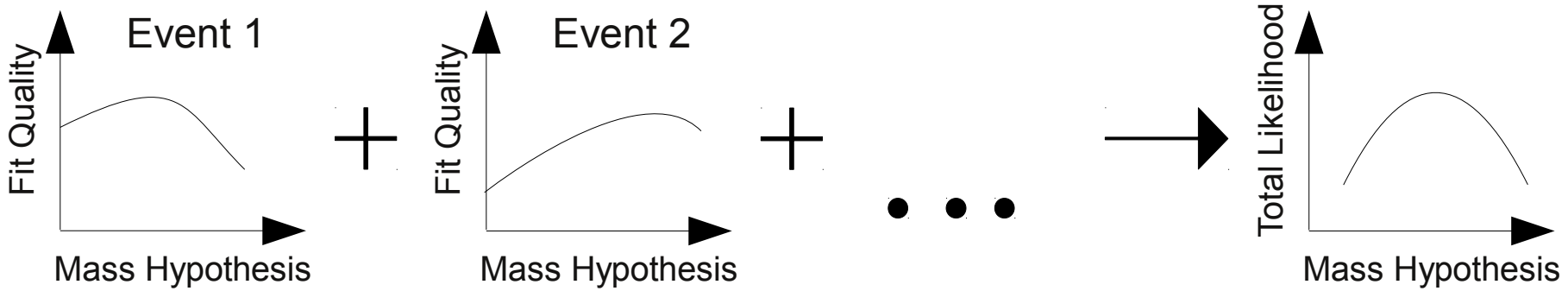
Over-constrained for *N* > 2

Set of events with same topology:

- Unknown masses are common parameters: problem can be over-constrained

Mass Determination Method

- Hypothesis for unknown masses → over-constrained event
- Constrained kinematic fit to reconstruct LSP momenta
  - Including detector resolutions
  - Full combinatorics
- Quality of fit indicates compatibility of hypothesis with the event
- Combine events into a single likelihood
  - Including SUSY backgrounds
- Scan mass space to determine best fitting regions

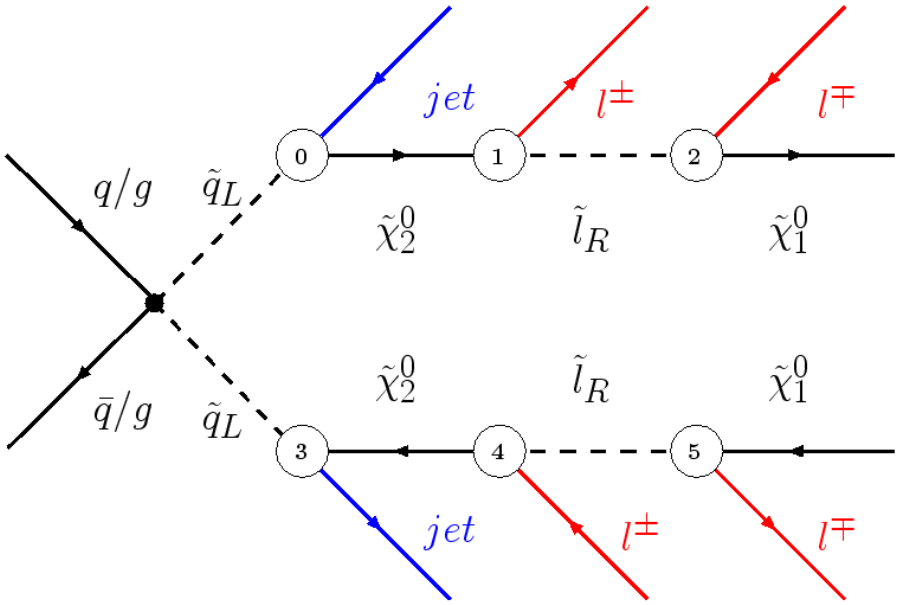


Scenario with Leptonic Decays

- mSUGRA benchmark point SPS1a

SPS1a Parameter	
m_0	100 GeV
$m_{1/2}$	250 GeV
A_0	-100 GeV
tan β	10
sign μ	+

Particle	Mass [GeV]
$\tilde{q}_L$	562
$\tilde{\chi}_2^0$	180
$\tilde{l}_R$	143
$\tilde{\chi}_1^0$	97



  - Leading order cross-section @14 TeV: 36 pb

- Signature:
  - 2 jets (high p_T)
  - 2x2 leptons (e,μ), same flavour, opposite charge
- Branching ratio of 1.7×10^{-3}
- Max. 16 possible permutations

- Difficulties
  - Clean event selection - (SUSY) backgrounds
  - Combinatorics
  - Imperfect p_T-balance - Initial/final state radiation

Event Sample

SPS1a Monte Carlo

- Code: SuSPECT + PYTHIA
- L= 140 fb-1 for LHC, √s=14 TeV
- For demonstration:Toy MC
  - smearing of quark/lepton four-momenta with typical detector resolution
  - neglects effects from e.g.
    - Jet clustering / overlap
    - Lepton (mis-)identification
    - Fake leptons
    - ...

- Event Selection

N	pT [GeV]	|η|
Jets		
2	> 30.	< 3.5
Leptons (e, μ)		
2x2	> 10.	< 2.5
same flavour opposite charge pairs		

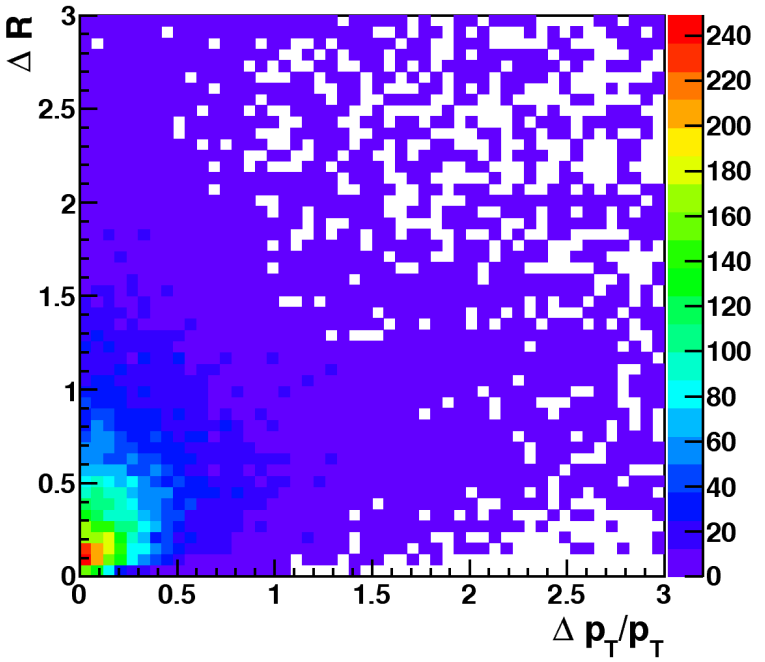
  - Efficiency: 53%
  - Background fraction: 57% (all other SUSY processes, ignored leptonic tau-decays)

- Fitting technique:
  - Constrained least-squares fit with Lagrangian Multipliers

Initial LSP Momenta for the Fit

- Approximation for starting point of unmeasured LSP
- Method of Webber
  - Use 6 out of 8 constraints
    - mass constraints except on LSP
    - p_T-balance
  - Exact solution for all 6 LSP momentum components
- True masses, correct combination:
  - Initial values already close to true LSP momenta
  - Deviation due to measurement uncertainties, mass hypothesis, imperfect p_T-balance

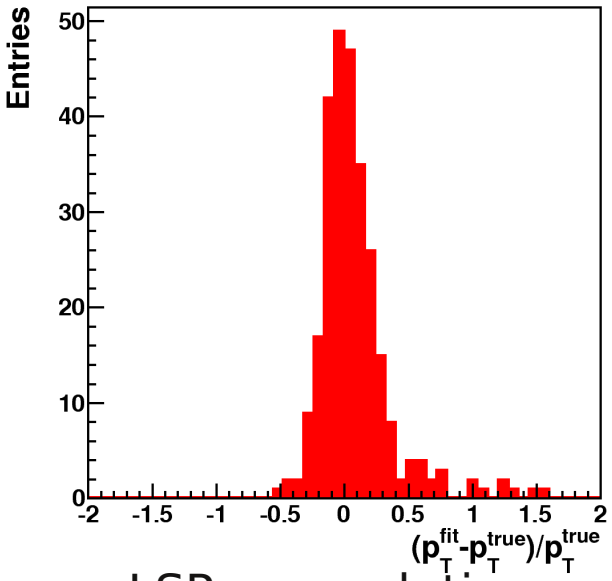
Deviation of chosen LSP momenta from true values



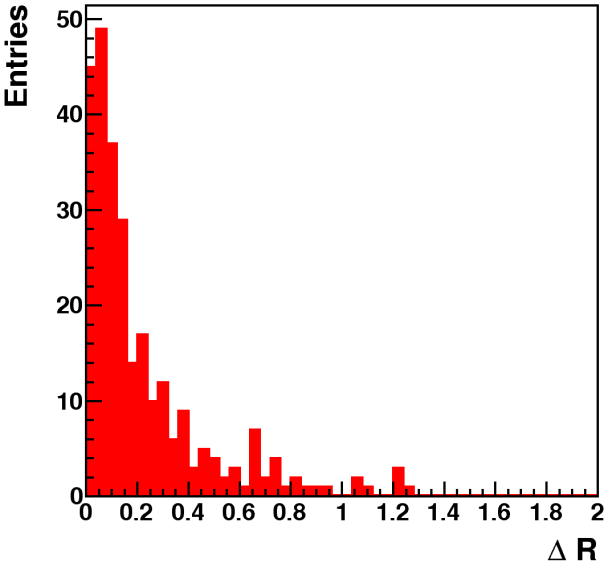
- Improve fit success rate: try several initial values per event
  - Smearing of final states and solving for LSP momenta
  - Fit finds a solution for 95% of selected signal events

Fit Performance

- Signal events only, using
  - central mass values
  - correct assignment of jets and leptons
- Good LSP momentum reconstruction
- Fit probability distribution nearly flat (natural width, selection)

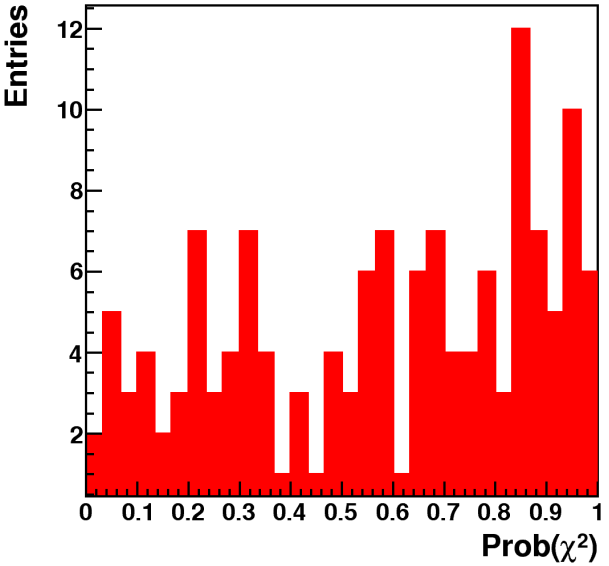


LSP p_T-resolution



LSP angular resolution

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$



Fit Probability,
only events with Prob>0.01

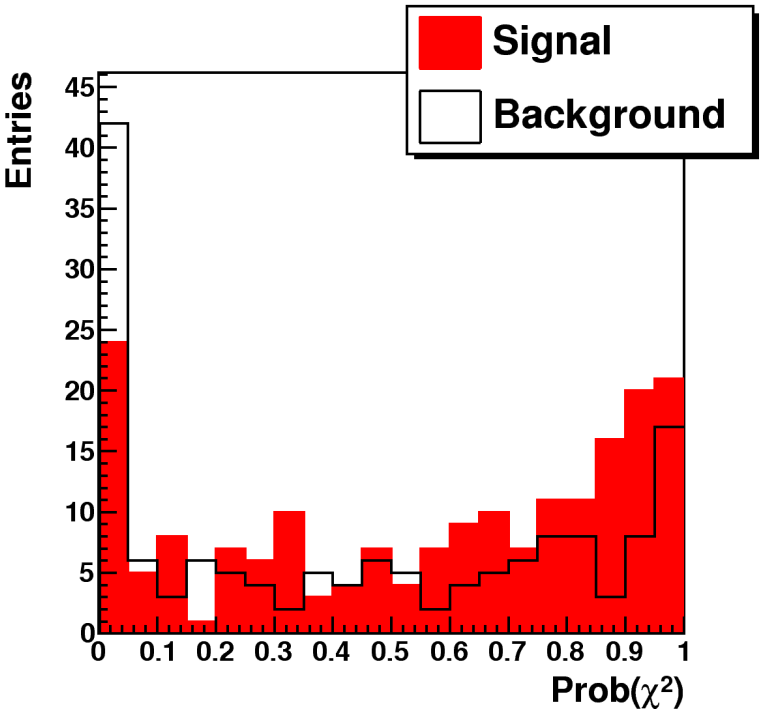
Fit Performance

- Combinatorics
  - Choose combination with largest fit probability

Correct combination	42%
Lepton switch on same branch	49%
Wrong leptons-jet combination	7%
Wrong lepton pairing	2%

  - Very good lepton pairing
  - Good assignment of lepton pairs to jets
  - Distinction of lepton position difficult at SPS1a:
    - Similar kinematics due to almost degenerate mass differences

- All SUSY processes:



- Signal: combinatorics shifts fit probability to larger values
- Background: Peak at zero
  - Signal-like events distributed over entire range

Mass Determination 2D

Likelihood for N events:

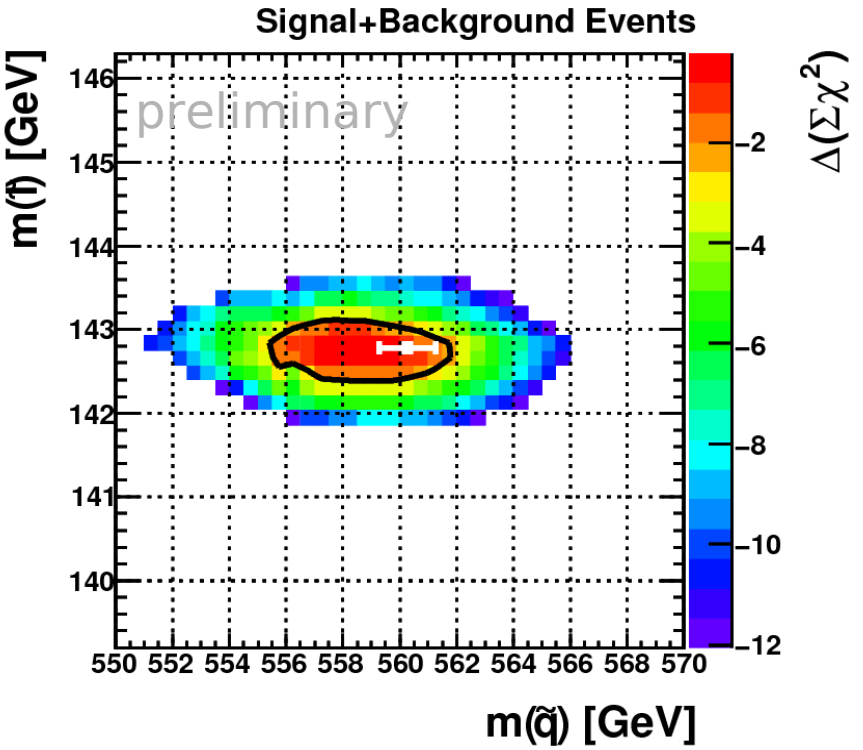
$$\log \mathbf{L} = \frac{1}{2} \cdot \sum_{i=1}^{N} \min\left(\chi_i^2, \chi_{cut}^2\right)$$

(2 dof, $\chi^2_{cut} \triangleq$ Prob(χ^2) =0.001)

Influence of cut negligible.

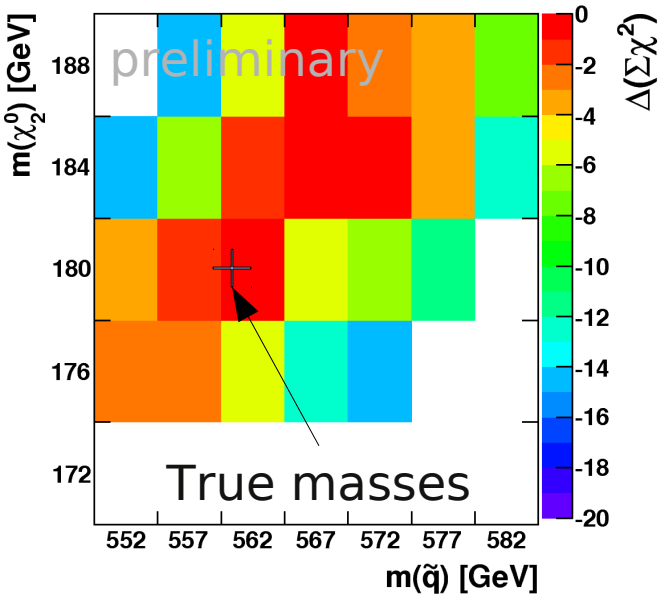
Event filtering:

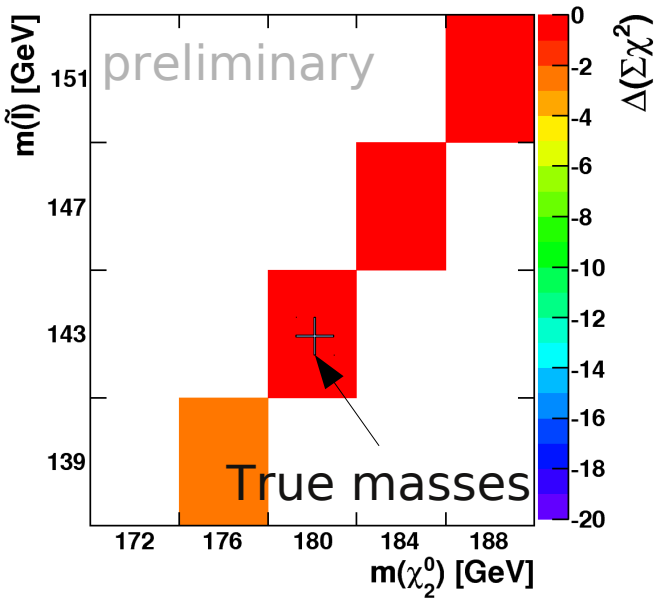
- 50 different LSP initial values per event and combination
- If only very few of them converge: likely to be a false minimum
- Select point of largest overall likelihood
- Exclude events with rate < 0.1
- Improves signal to background ratio

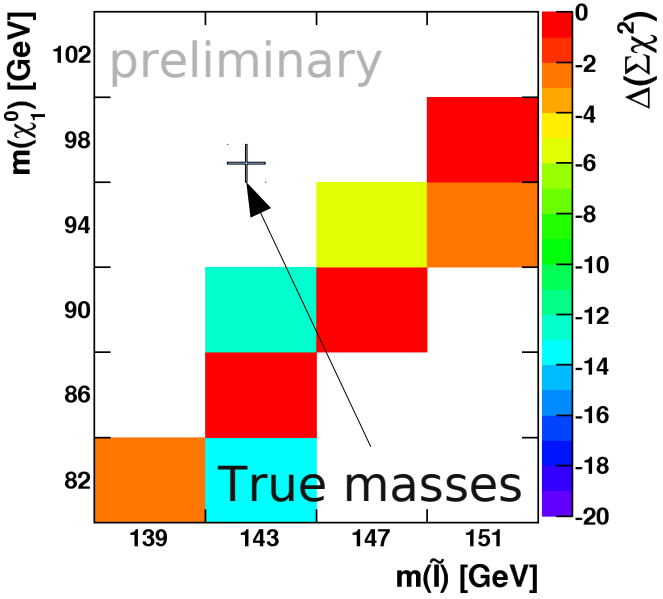


- Scan squark and slepton mass
- Fixed neutralino and LSP mass
- Good agreement of largest likelihood with true masses (white marker).

Mass Determination 4D







- 2D hyperplane: projection of largest likelihood in other mass-dimensions
- Including SUSY background
- Standard Model backgrounds negligible
- Squark mass well met

- Correlations among masses
- Neutralino-slepton mass difference well determined
- Constraining absolute mass values in the correct region
- Systematic shift in LSP mass
- Systematic uncertainties to be evaluated

Summary

- Strategy for mass determination
  - Reconstruction of cascade decay with kinematic fit
    - Using mass hypotheses
  - Scan over mass space
  - Combination of event fit results into likelihood
- Demonstration in leptonic channel
  - LSP momenta well determined if masses are known
  - Improved combinatorics using the fit probability
  - Mass determination feasible in SPS1a scenario
    - Systematic shift in LSP mass

- Similar results with detailed detector simulation (not shown)
- Also studied much more challenging hadronic decays (arxiv:0911.2607 [hep-ph])