Measuring sparticles with the Matrix Element

- Status report -

Johan Alwall, SLAC

with Olivier Mattelaer (Louvain)
and Ayres Freitas (Pittsburgh)

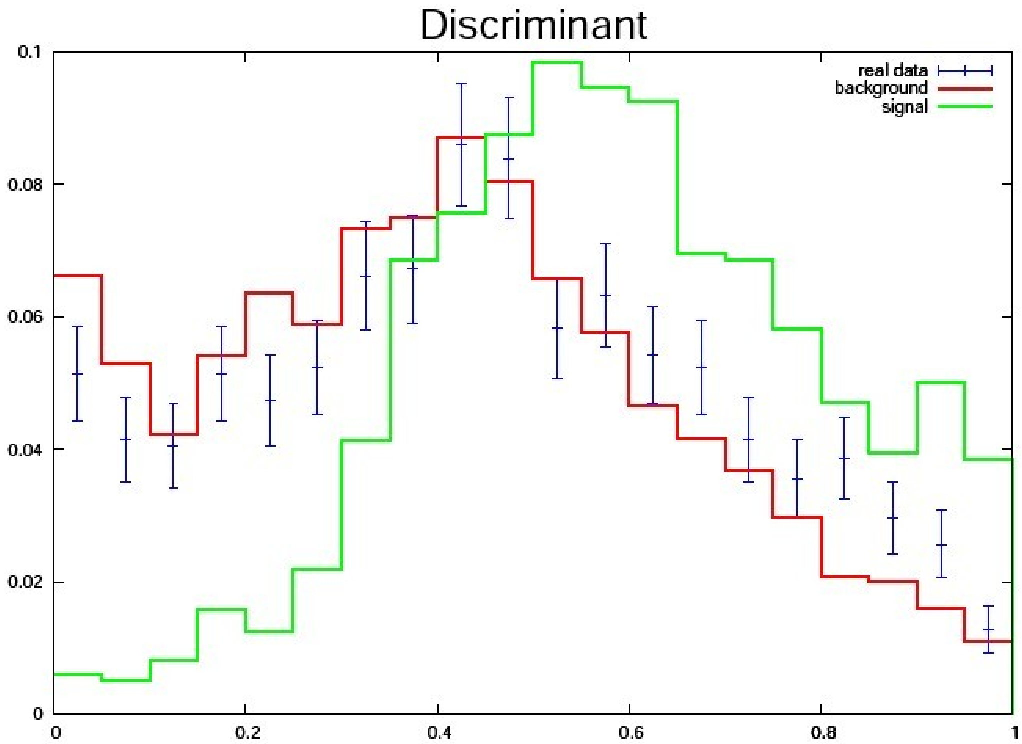
IPMU Focus Week, March 18, 2009

New Physics at the LHC

- Main difficulty: Events with jets and missing energy
  - No way to fully reconstruct event
  - Pair production with missing energy on both side of event → No resonance peaks
- How to distinguish between different models, and determine parameters of the model
  - Compare distributions (effective masses, edges/endpoints, angular distributions)
  - Find discriminating variables/functions

Discriminator functions

- Challenge: Construct discriminator function which uses kinematical information to distinguish between processes



Discriminator functions

- Challenge: Construct discriminator function which uses kinematical information to distinguish between processes
  - Give a weight to each experimental event based on its probability to come from a particular process
  - Use maximum amount of information in the event

Discriminator functions

- Challenge: Construct discriminator function which uses kinematical information to distinguish between processes
  - Give a weight to each experimental event based on its probability to come from a particular process
  - Use maximum amount of information in the event
- Optimal function: The matrix element $|M_\alpha|^2(\boldsymbol{x})$
  - Contains all information about the process
  - Encodes dependence on all relevant parameters
  - Automatically reproduces any kinematical distribution

Difficulties

- Correspondance parton level objects – detector level objects
  - Hadronization, detector resolution, detector mismeasurement
- Extra activity due to QCD radiation
  - ISR boosts central production process w.r.t. ME
  - Extra jets in event – difficult distinguish decay jets and ISR jets

Detector-ME object matching

- Event selection
  - Must pick events with identical degrees of freedom as the matrix element considered

$$P(\boldsymbol{x},\alpha) = \qquad |M_\alpha|^2(\boldsymbol{x})$$

Prob for event *x* given *α*

Squared matrix element

Detector-ME object matching

- Event selection
  - Must pick events with identical degrees of freedom as the matrix element considered
- Transfer functions from objects to particles

$$P(\boldsymbol{x}, \alpha) = \qquad |M_\alpha|^2(\boldsymbol{y}) W(\boldsymbol{x}, \boldsymbol{y})$$

Prob for event *x* given *α*	Squared matrix element	Transfer function

Transfer functions

- New peaks in energy and angle variables
  - Here modeled by Gaussian, fit to detector simulation

resolution

$$W(\boldsymbol{x},\boldsymbol{y}) \approx \prod_i \frac{1}{\sqrt{2\pi}\sigma_{E,i}} e^{-\frac{(E_i^{rec}-E_i^{gen})^2}{2\sigma_{E,i}^2}}$$

in energy

$$\times \frac{1}{\sqrt{2\pi}\sigma_{\phi,i}} e^{-\frac{(\phi_i^{rec}-\phi_i^{gen})^2}{2\sigma_{\phi,i}^2}}$$

in azimuthal angle

$$\times \frac{1}{\sqrt{2\pi}\sigma_{\eta,i}} e^{-\frac{(\eta_i^{rec}-\eta_i^{gen})^2}{2\sigma_{\eta,i}^2}}$$

in pseudo-rapidity

Detector-ME object matching

- Event selection
  - Must pick events with identical degrees of freedom as the matrix element considered
- Transfer functions from objects to particles

$$P(\boldsymbol{x},\alpha) = \frac{1}{\sigma}\int d\phi(\boldsymbol{y})|M_\alpha|^2(\boldsymbol{y})W(\boldsymbol{x},\boldsymbol{y})$$

Prob for event *x* given *α*	Norm	Phase space integral	Squared matrix element	Transfer function

Phase space integration

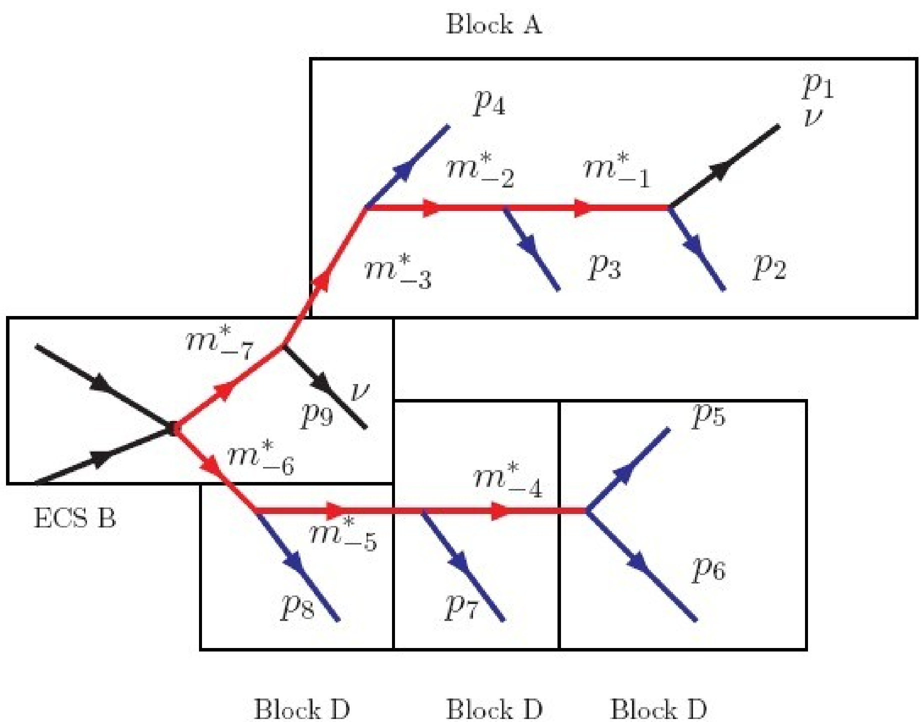
- Need full phase space integral for every event and every parameter choice
  - Very time consuming
  - Need optimized phase space integration!
- Is it possible to optimize for any process topology?

YES!

MadWeight

Artoisenet, Mattelaer, Lemaitre, Maltoni

- Automatic analytic alignment of integration variables with peaks in cross section and TFs

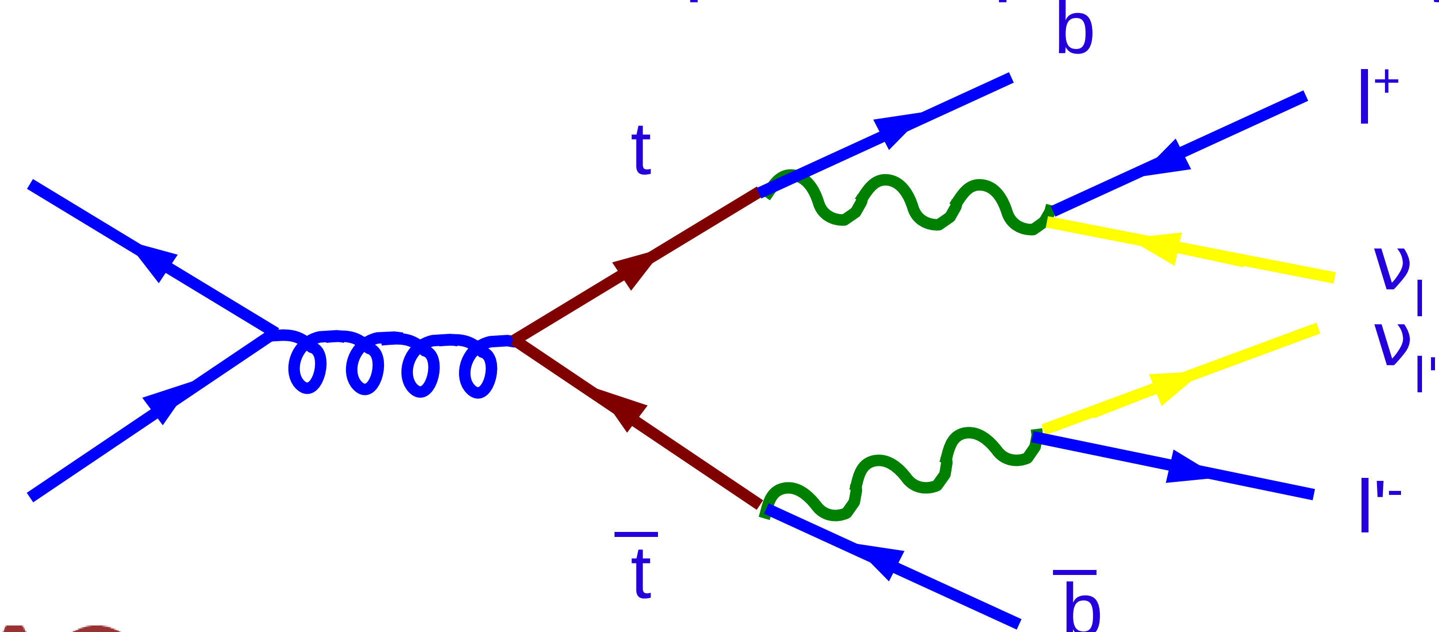


Final parameterization (for this example):

$$d\phi = d|\boldsymbol{p}_2|d|\boldsymbol{p}_3|d|\boldsymbol{p}_4|d|\boldsymbol{p}_6| \prod_{i=2}^{8} d\theta_i d\phi_i \prod_{j=1}^{7} dm^{*2}_{-j} \times J$$

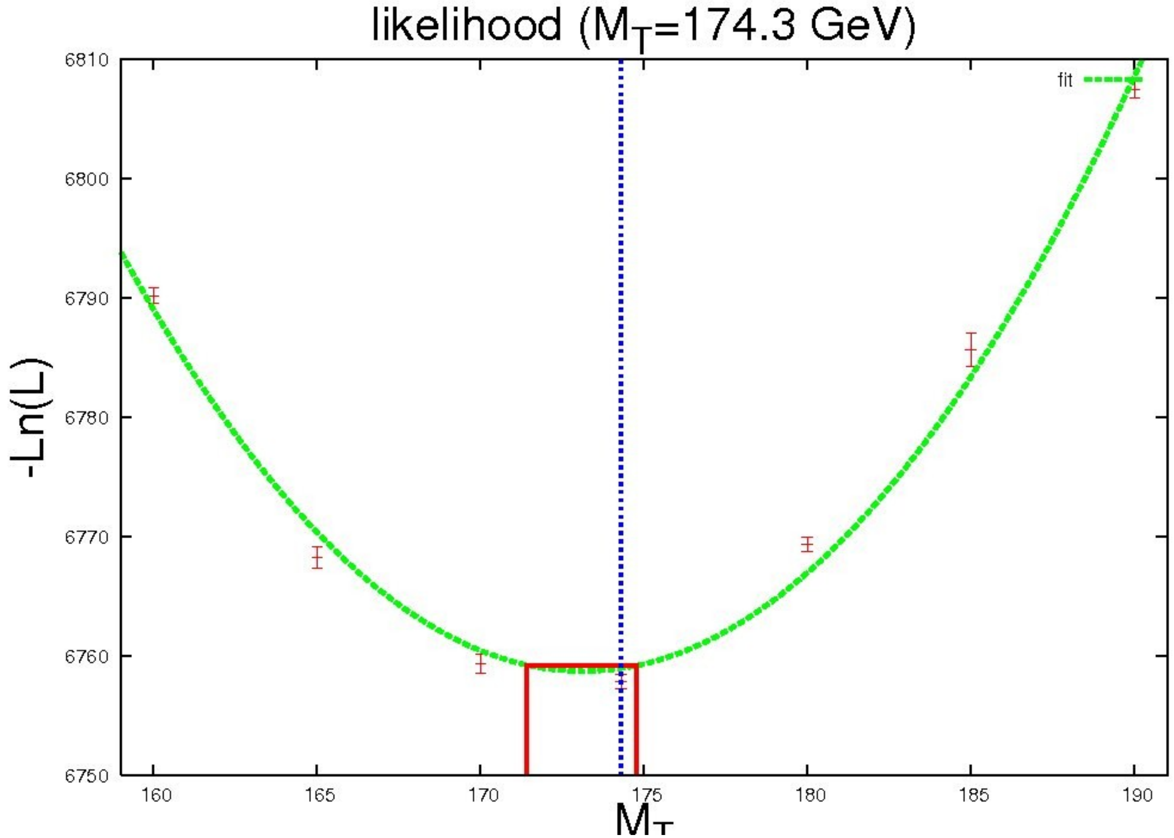
Example 1: Top mass

- Classical example
- ME method used (to great success) at the Tevatron
- Only one parameter: m_T
- Perfect test example: Dileptonic decay



Example 1: Top mass

- 192 dileptonic top events (generated with MadEvent/Pythia/PGS)
- Input: 174.3 GeV Output: 173.1 ± 1.7 GeV

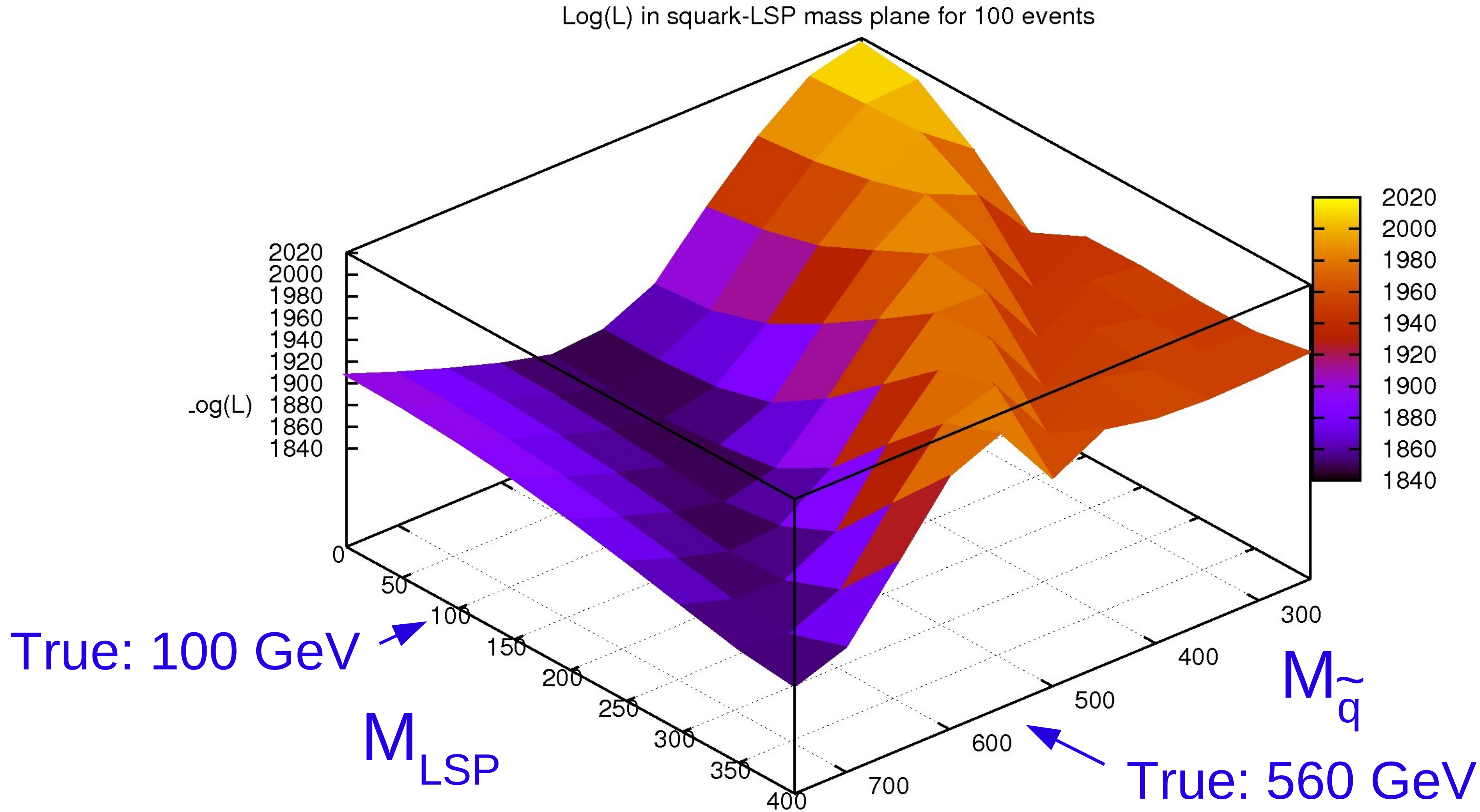


Example 2: Squark_R pairs

- Imagine (crazy?) scenario with **only** 2j+MET events visible in the early data (i.e. events compatible with pair produced squarks decaying directly to dark matter)
- How simultaneously measure masses of squark and LSP?
- Matrix element extract maximum information!

Example 2: Squark_R pairs

-Log(L) for 100 events – still parton level



Example 2: $Squark_R$ pairs

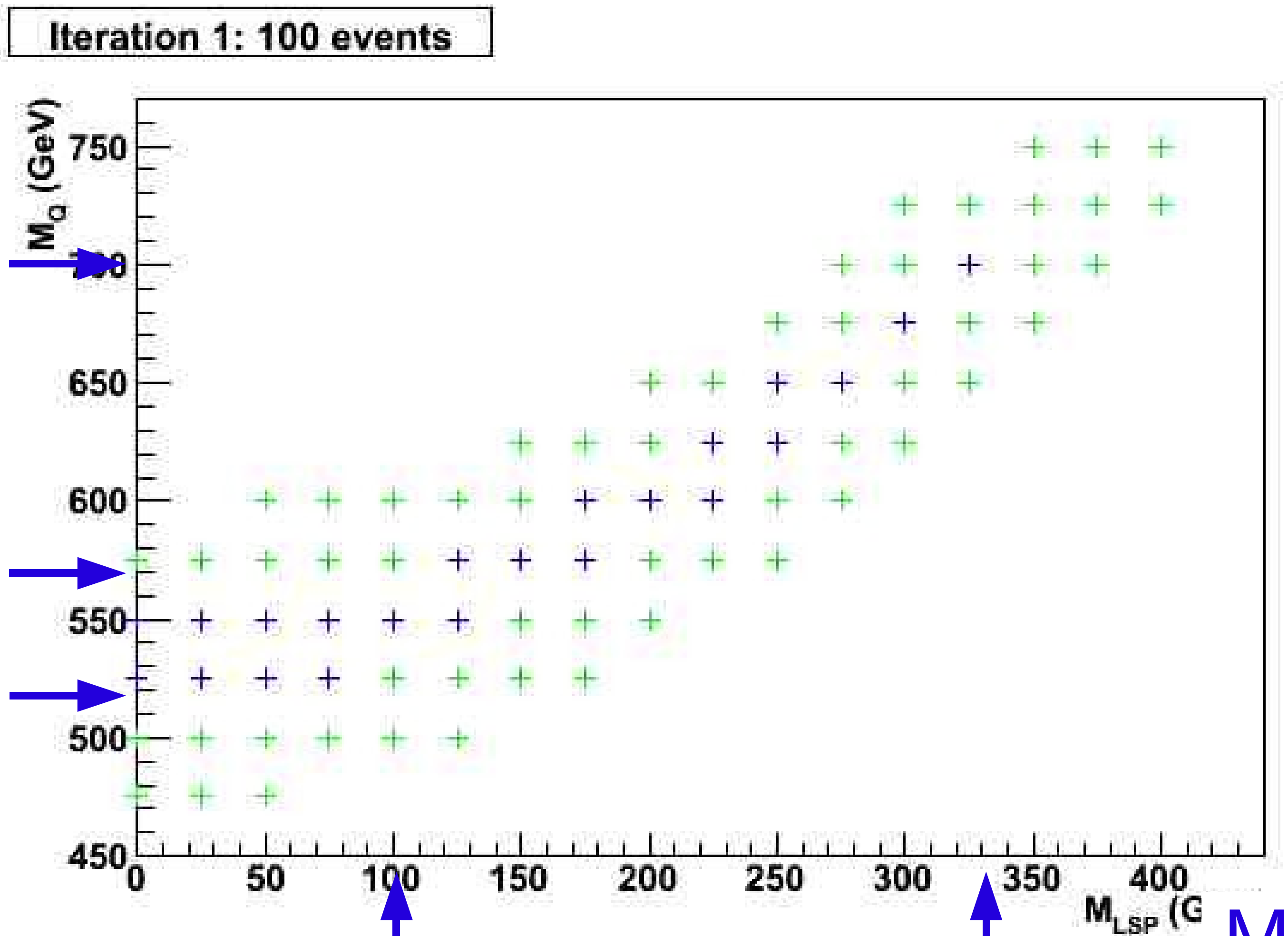
-Log(L) for 100 events – blue below min+4

$M_{\tilde{q}}$

Max: 700 GeV

True: 560 GeV

Min: 525 GeV



True: 100 GeV

Max: 330 GeV

M_{LSP}

Example 2: $Squark_R$ pairs

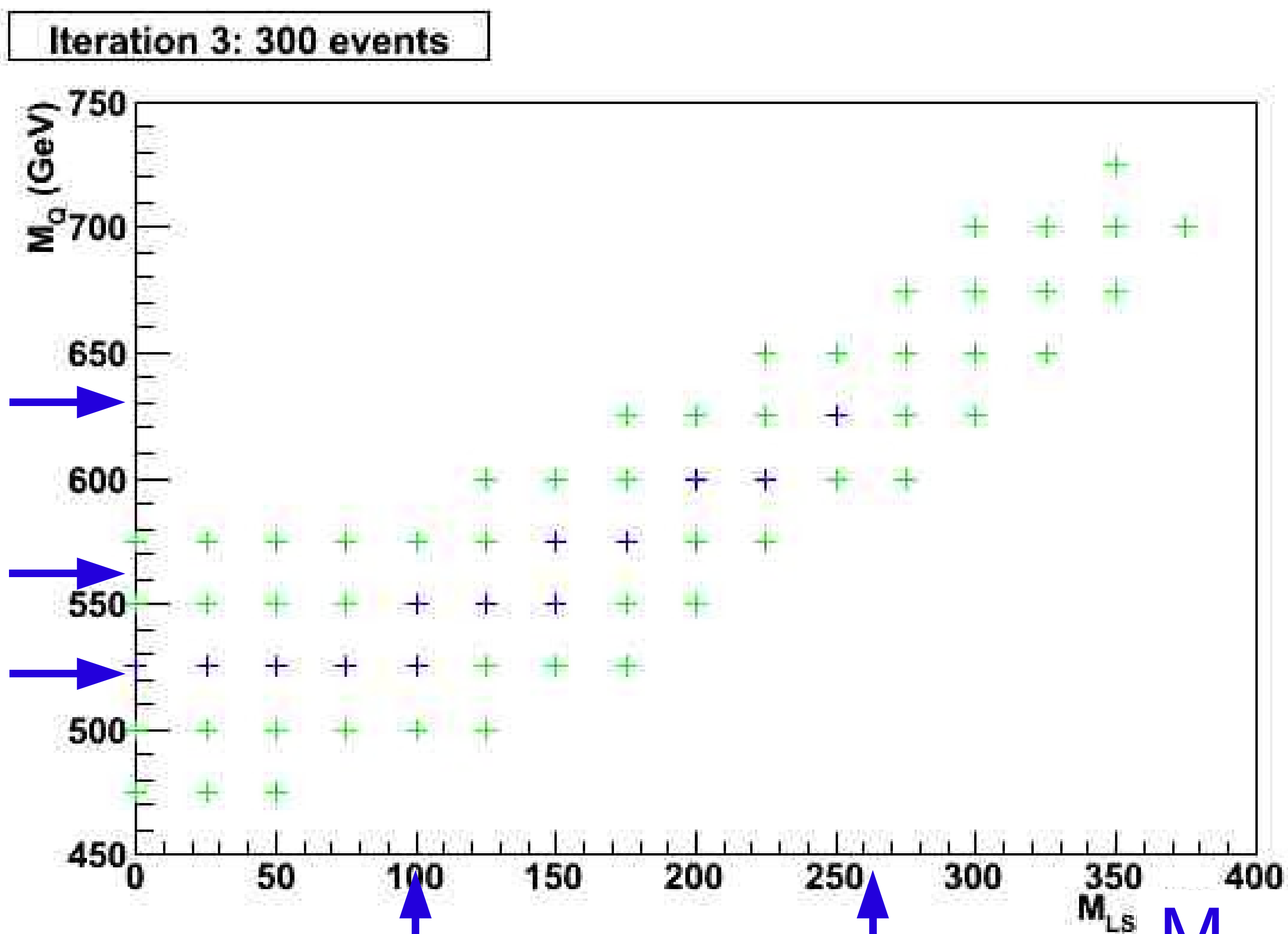
-Log(L) for 300 events – blue below min+4

$M_{\tilde{q}}$

Max: 630 GeV

True: 560 GeV

Min: 525 GeV

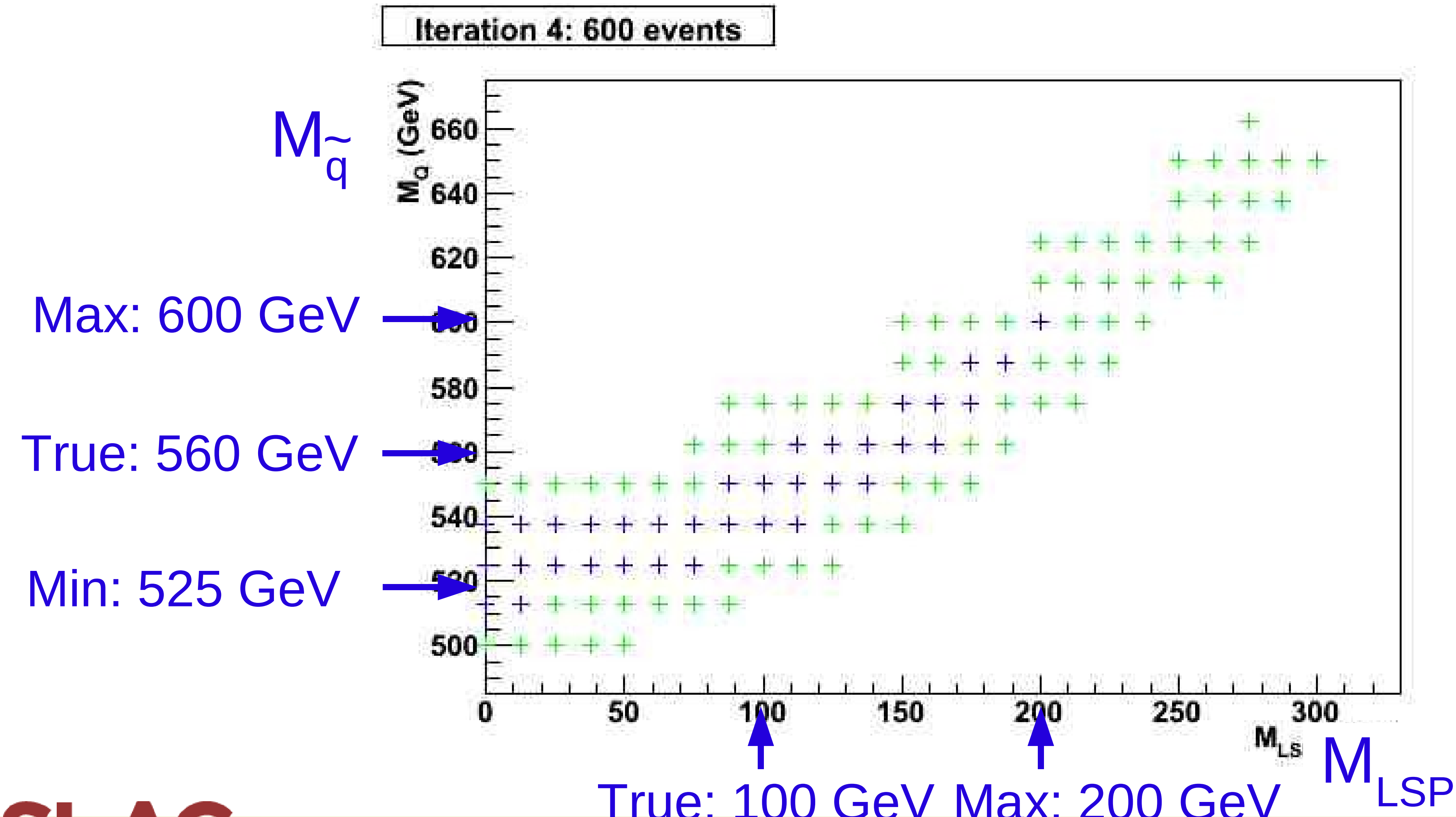


True: 100 GeV Max: 260 GeV

M_{LSP}

Example 2: Squark$_R$ pairs

-Log(L) for 600 events – blue below min+4



Example 2: Squark_R pairs

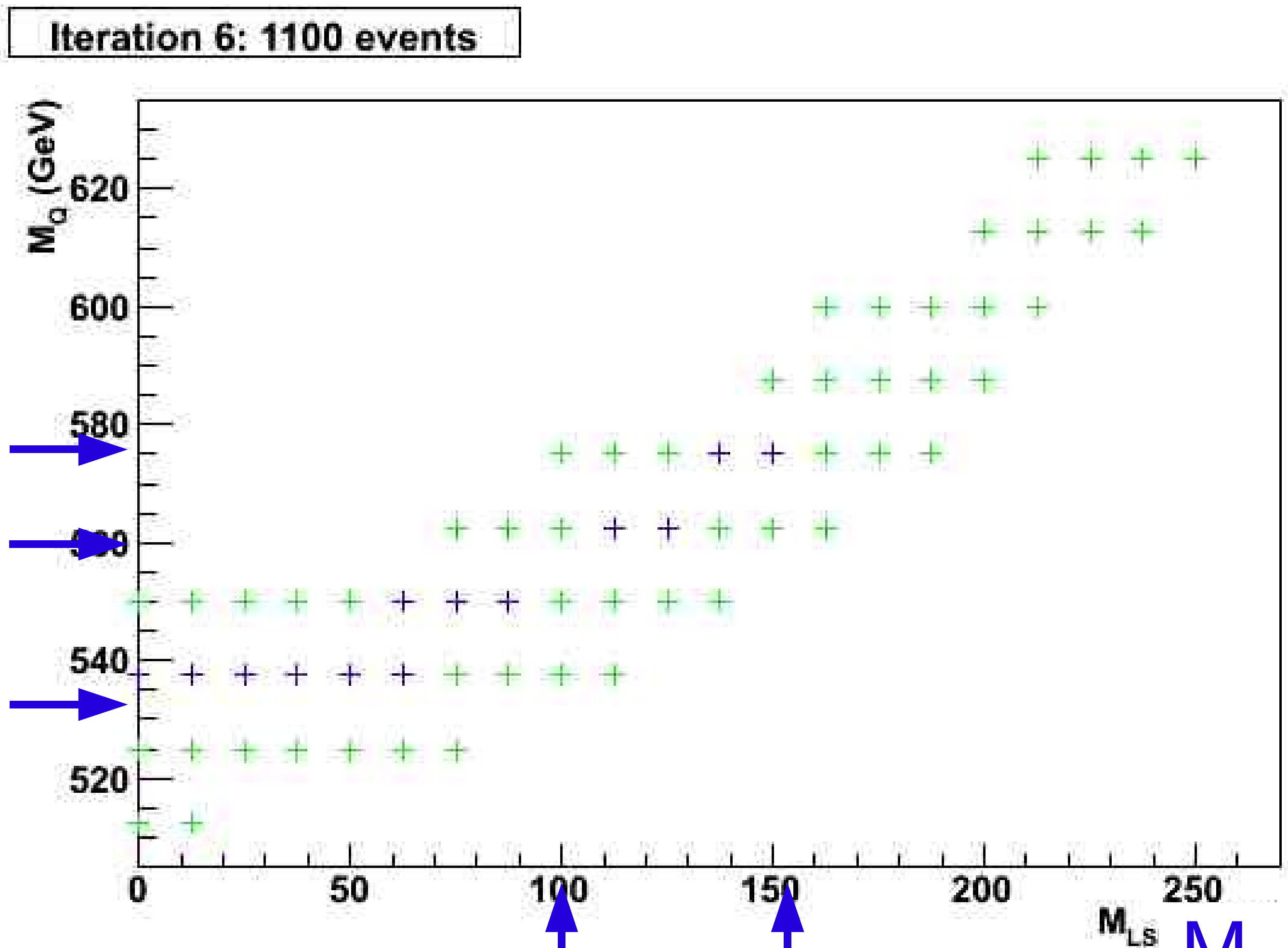
-Log(L) for 1100 events – blue below min+4

$M_{\tilde{q}}$

Max: 575 GeV

True: 560 GeV

Min: 530 GeV



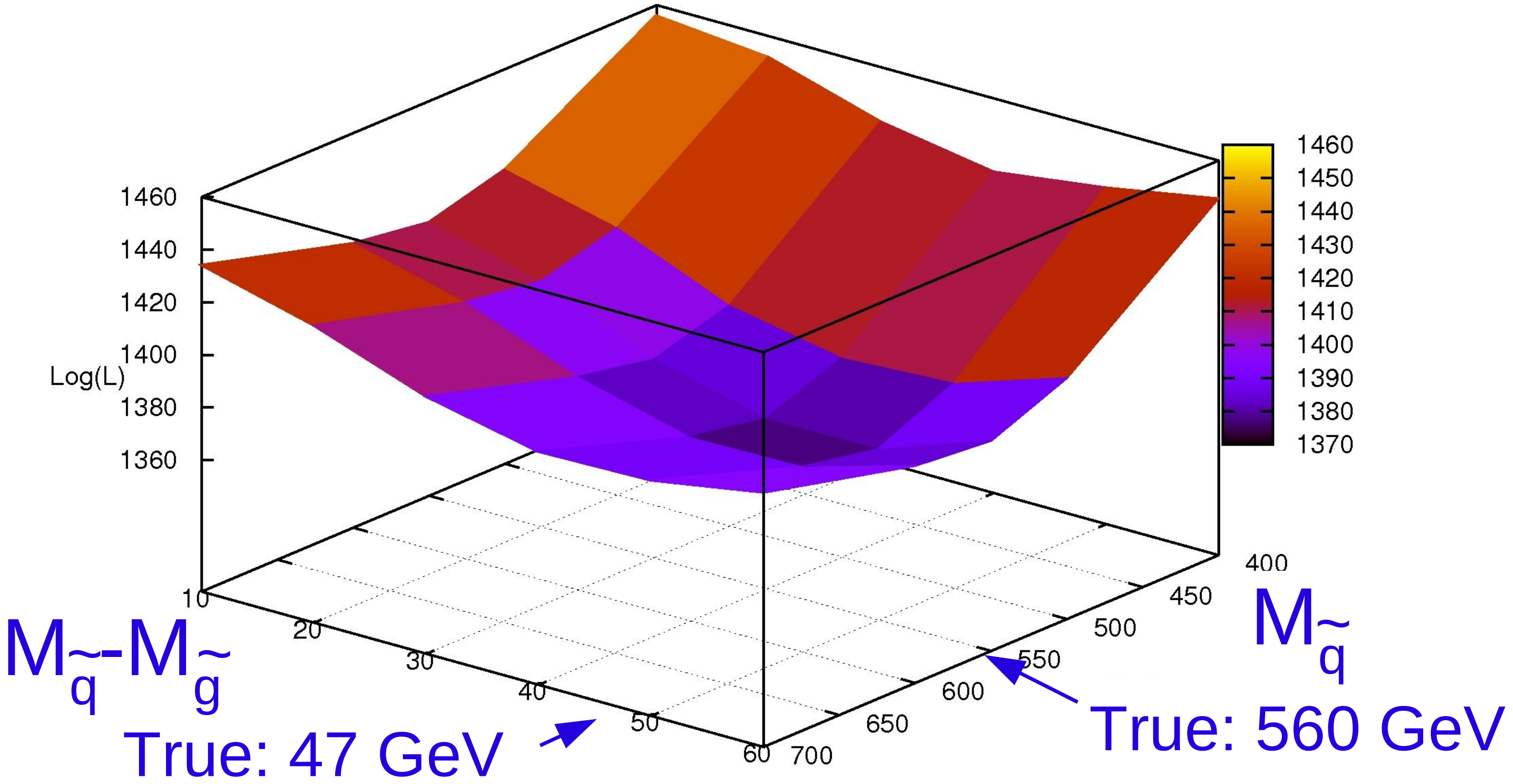
True: 100 GeV Max: 155 GeV

M_{LSP}

Example 3: Gluino-squark$_R$

607 GeV gluinos, 560 GeV squarks decaying to jets and missing energy

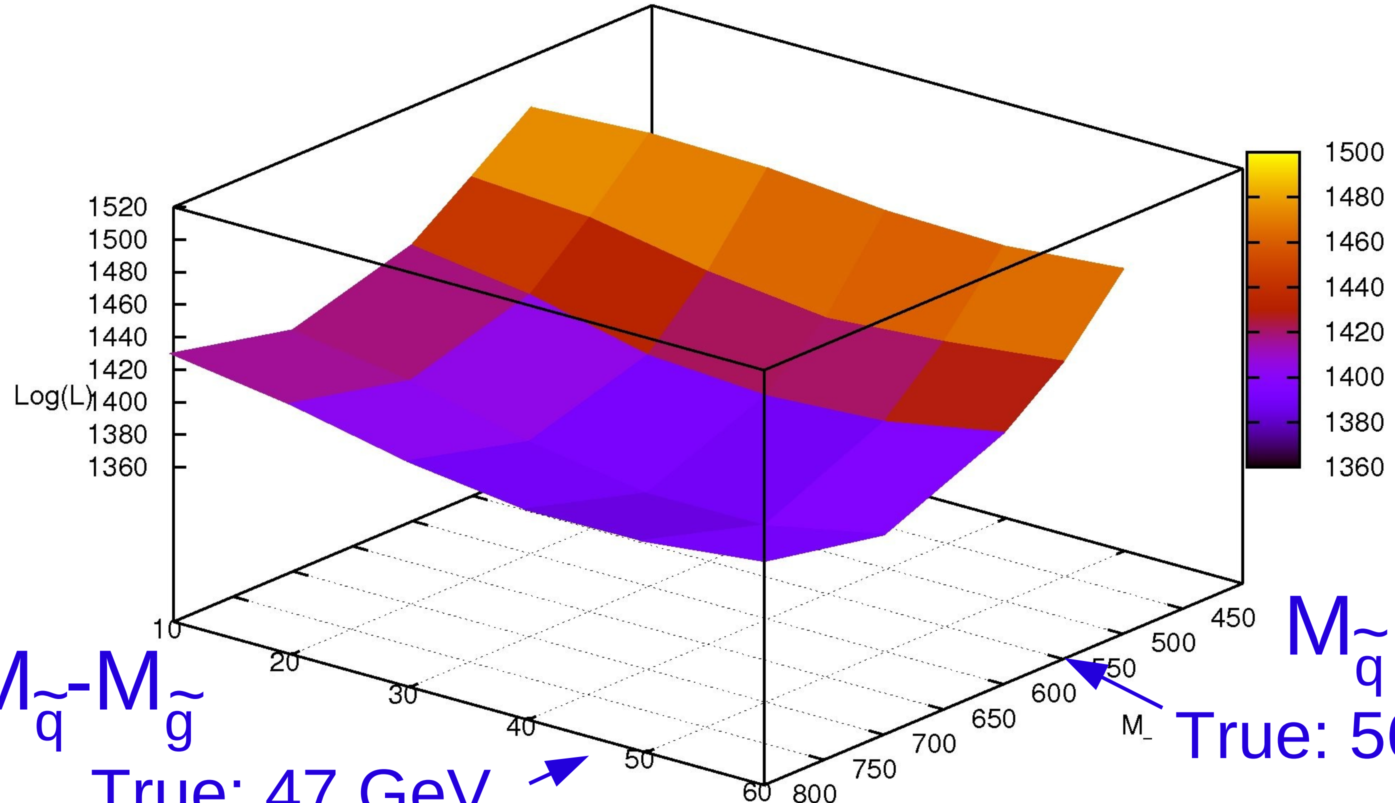
-Log(L) for M_{LSP}= 0 GeV, 50 events



Example 3: Gluino-squark$_R$

607 GeV gluinos, 560 GeV squarks decaying to jets and missing energy

-Log(L) for M_{LSP}= 300 GeV, 50 events



$M_{\tilde{q}}$-$M_{\tilde{g}}$

True: 47 GeV

$M_{\tilde{q}}$

True: 560 GeV

$M_{\tilde{q}}$-$M_{\tilde{g}}$ already determined within 10 GeV

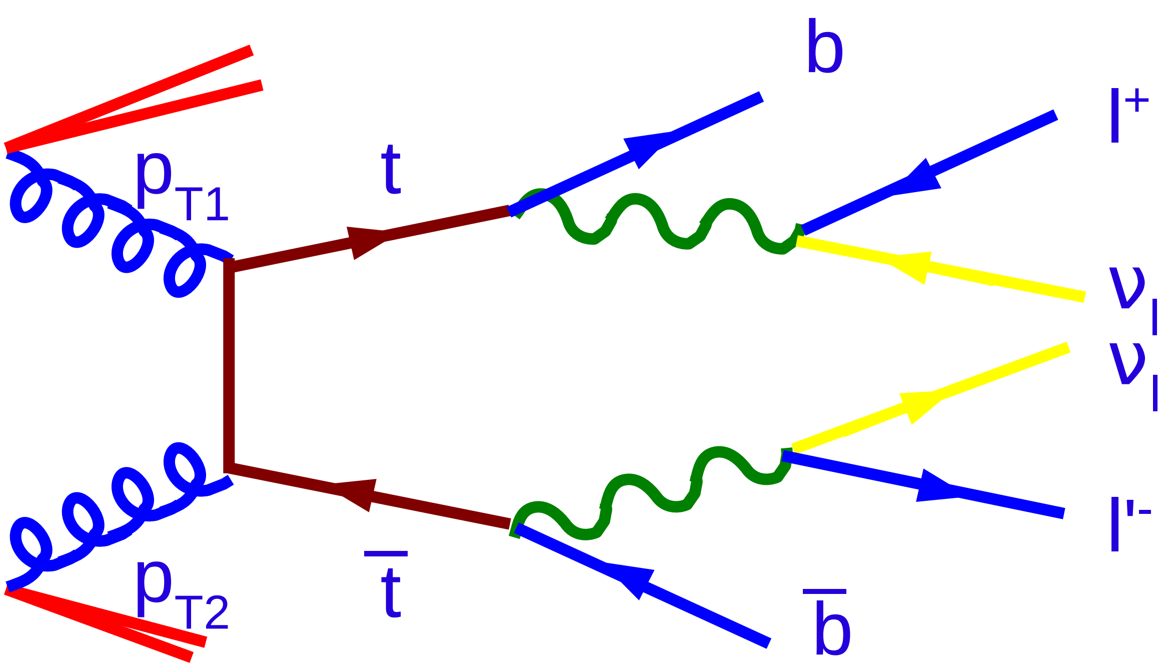
Initial state radiation

- Initial state QCD radiation results in boost of central process and extra jets
- Strong veto on extra jets
  → major reduction of statistics
- Moderate veto on extra jets
  → p_T boost affects event weight
- How to correct for the ISR radiation in events?

ME with initial state radiation

Two ways to deal with ISR corrections

1. Use the matrix element for central process + extra jet radiation (still to be done)
2. Boost and reweight event to correct for the ISR



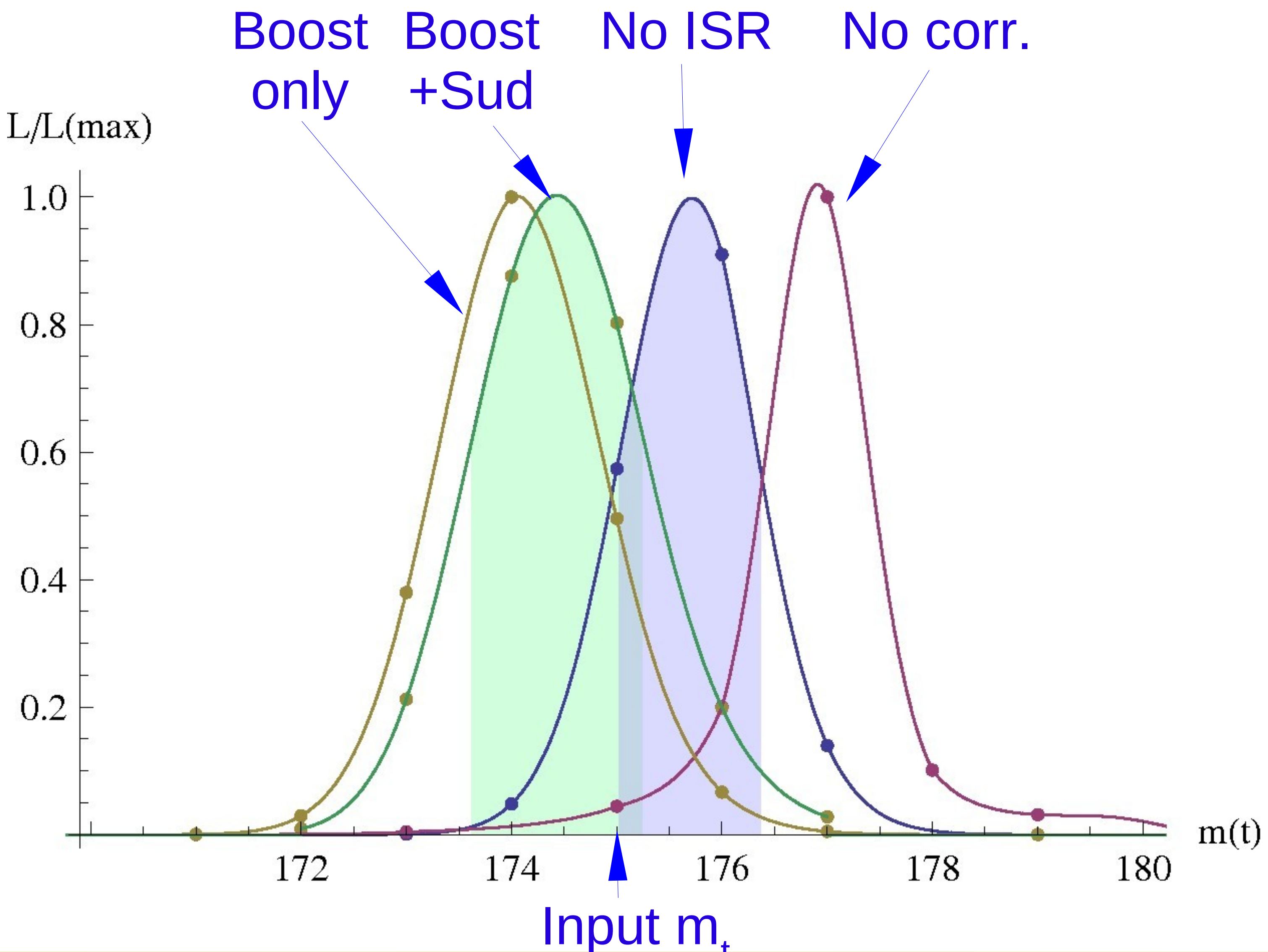
Correction factor:

$$\frac{1}{p_{\perp E}^2}\frac{\alpha_s(p_{\perp E}^2)}{2\pi}P_j(z) \text{ x}$$

$$\frac{f_j(x_i/z,p_{\perp E}^2)}{z f_i(x_i,p_{\perp E}^2)}\Delta_{\mathrm{ISR}}(p_{\perp E0}^2,p_{\perp E}^2)$$

ME with initial state radiation

L/L(max) for 100 dileptonic top events at the LHC



Conclusions

- Matrix element weighting allows to extract maximum information from experimental events
- If used with care, it can be very powerful for difficult observables such as pure jets+MET
- LSP mass challenging even for ME method
- Need better treatment of ISR for the LHC
  - Several ideas under development
- Work (very much) in progress for squark and gluino mass measurements in pure jets+MET

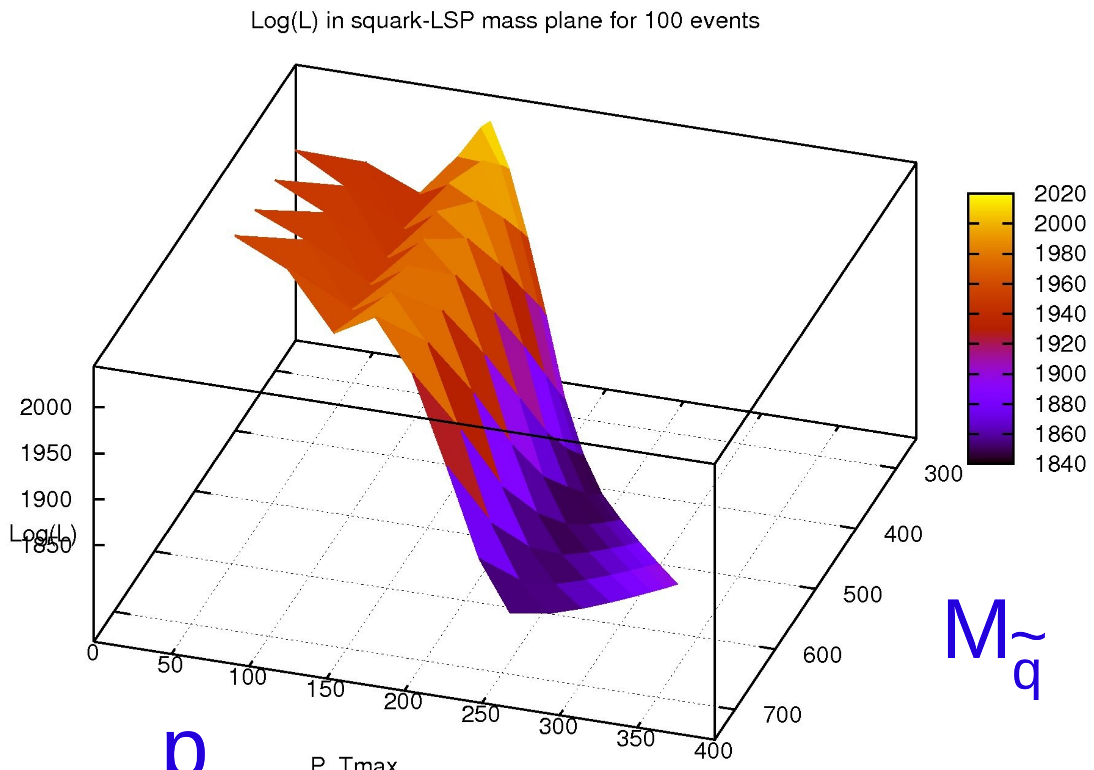
Backup slides

Shape of squark_R-LSP valley

- Energy of quark in squark decay frame:

$$E_q = (M_{\tilde{q}}^2 - M_{LSP}^2)/(2M_{\tilde{q}})$$

- This is maximum p_T of quark at threshold



$M_{\tilde{q}}$

p_{Tmax}