Kinematic Fitting of Supersymmetric Events

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Supersymmetry

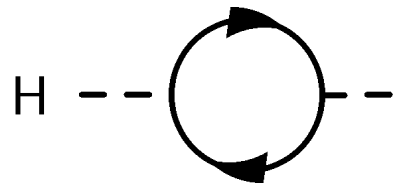
- Supersymmetry is the symmetry between fermions and bosons.
- All quantum numbers of a particle and its superpartner are equal except the spin which differs by 1/2.
- Obviously within the Standard Model particles there is no such symmetry, therefore at least one new particle as superpartner has to be introduced for each particle of the Standard Model.
- Since no Susy particle has been discovered yet, the symmetry must be broken. The masses of the supersymmetric particles have to be larger than the Standard Model particles.

Problems of the Standard Model and solutions by Supersymmetry

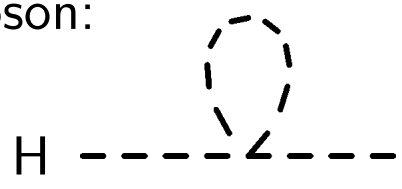
Fine tuning / hierarchy problem.

The bosonic superpartners of the fermions cancel the loop corrections to Higgs mass.

fermion:



boson:

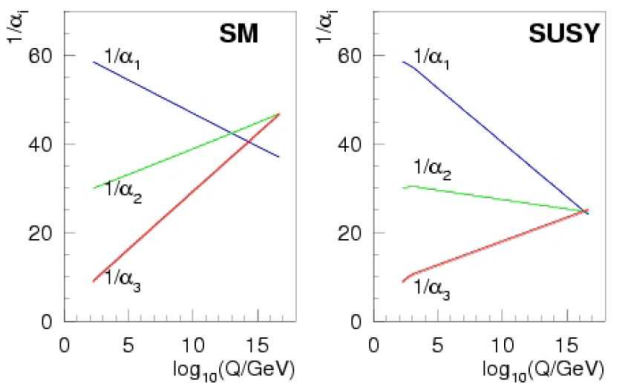


No Dark Matter candidate.

In most Susy models where R-parity is conserved there exists a stable, massive and only weakly interacting particle (LSP).

No unification of the three coupling constants.

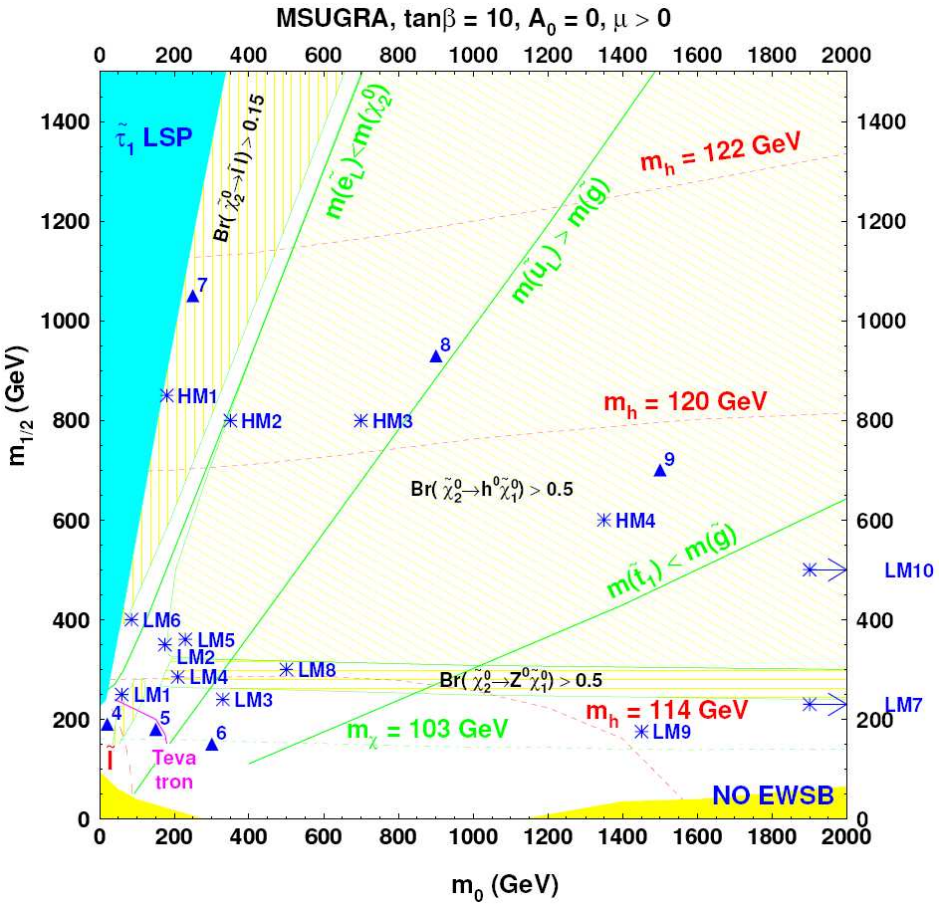
The new Susy particles contribute to the coupling constants and give their running a kink.



The mSUGRA model

- One breaking scenario of Supersymmetry is mSUGRA: the minimal Supergravity model.
- Not only the coupling constants unify at GUT-scale but also the sparticle masses:
  - All Superfermions unify to the GUT-mass $m_{1/2}$
  - All Superbosons unify to the GUT-mass m_0
  - So there are only two free "mass parameters"!
- The other parameters of the model are:
  - the ratio of the vacuum expectation values of the two Higgs doublets $\tan\beta = \frac{\text{VEV } H_u}{\text{VEV } H_d}$
  - the unified trilinear coupling A_0
  - the sign of the higgs mass parameter sgn μ

The mSUGRA model



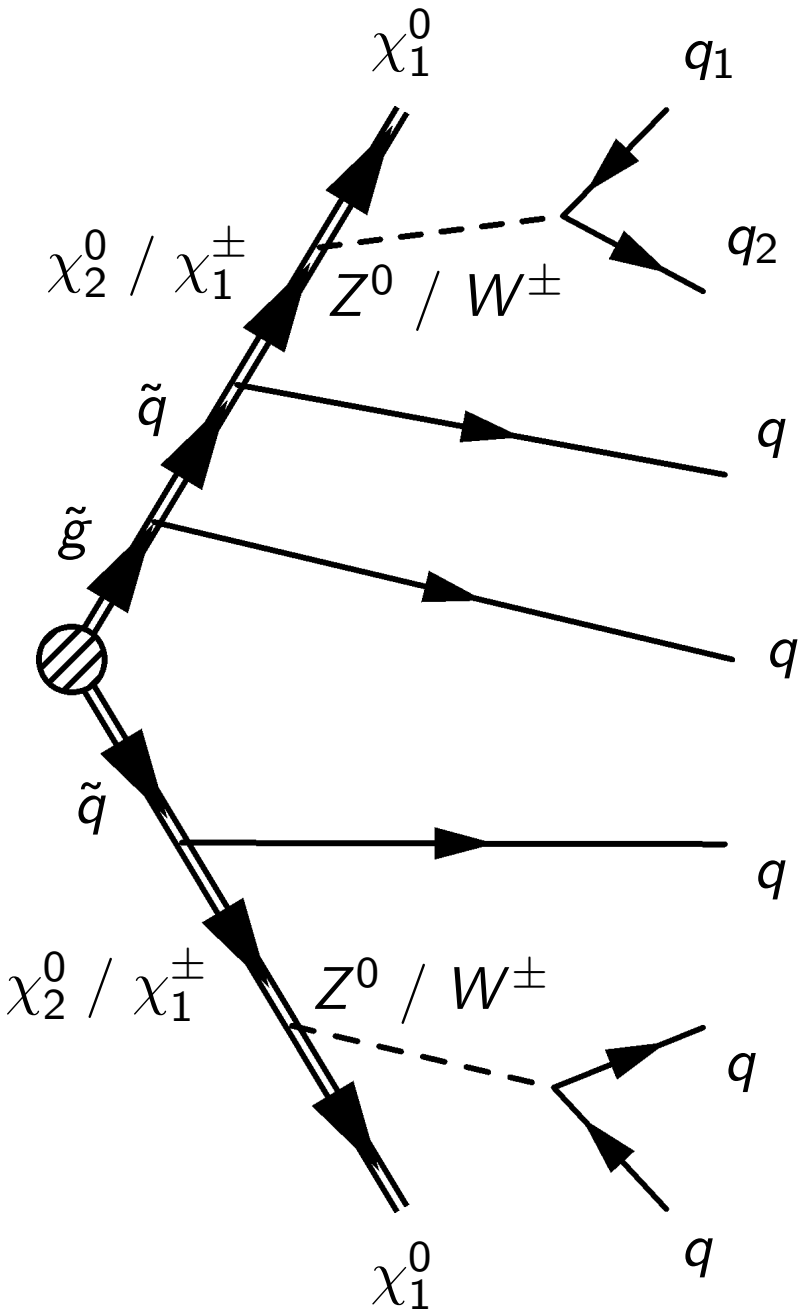
mSUGRA test point LM4:

- $m_0 = 210\,\text{GeV}$, $m_{1/2} = 385\,\text{GeV}$
- $\tan\beta = 10$, $A_0 = 0$, $\text{sgn}\,\mu = +$

Masses at the electroweak scale:

- Gluino: $M(\tilde{g}) \approx 695\,\text{GeV}$
- Squark ($\tilde{u}_L$, $\tilde{d}_L$, $\tilde{s}_L$, $\tilde{c}_L$): $M(\tilde{q}) = 655 \cdots 660\,\text{GeV}$
- Neutralino and Chargino: $M(\chi_2^0) \approx M(\chi_1^\pm) \approx 208\,\text{GeV}$
- LSP: $M(\chi_1^0) \approx 110\,\text{GeV}$

A supersymmetric event



Kinematics of this event:

- Undetermined variables
  - $2 \times 3 = 6$ momentum components of the LSPs cannot be measured.
- Invariant masses
  - 5 Susy masses

    example: $M^2_{\chi_1^\pm} = \left(P_{\chi_1^0} + P_1 + P_2\right)^2$
  - 2 Z^0 / $W^\pm$ masses
- p_T balance
  - 2 p_T equations since the summed p_T of the event should be zero.

    $\sum p_x = 0$ and $\sum p_y = 0$
- The system is overconstrained.

If Supersymmetry is discovered, for example with missing E_T studies, one challange it will be to determine the mass parameters.

Principles of kinematic constrained least square fitting

- Suitable to compare measured values with the prediction of some model and to determine unmeasurable values.
- The weighted sum of the squared deviations has to be minimized:

$$\chi^2 = \Delta\mathbf{y}^T \mathbf{V}^{-1} \Delta\mathbf{y}$$

- If there are constraints from a model the method of the Lagrangian Multipliers λ_k can be used:

$$L = \chi^2(\mathbf{y}) + 2\sum_k \lambda_k f_k(\mathbf{y}, \mathbf{a})$$

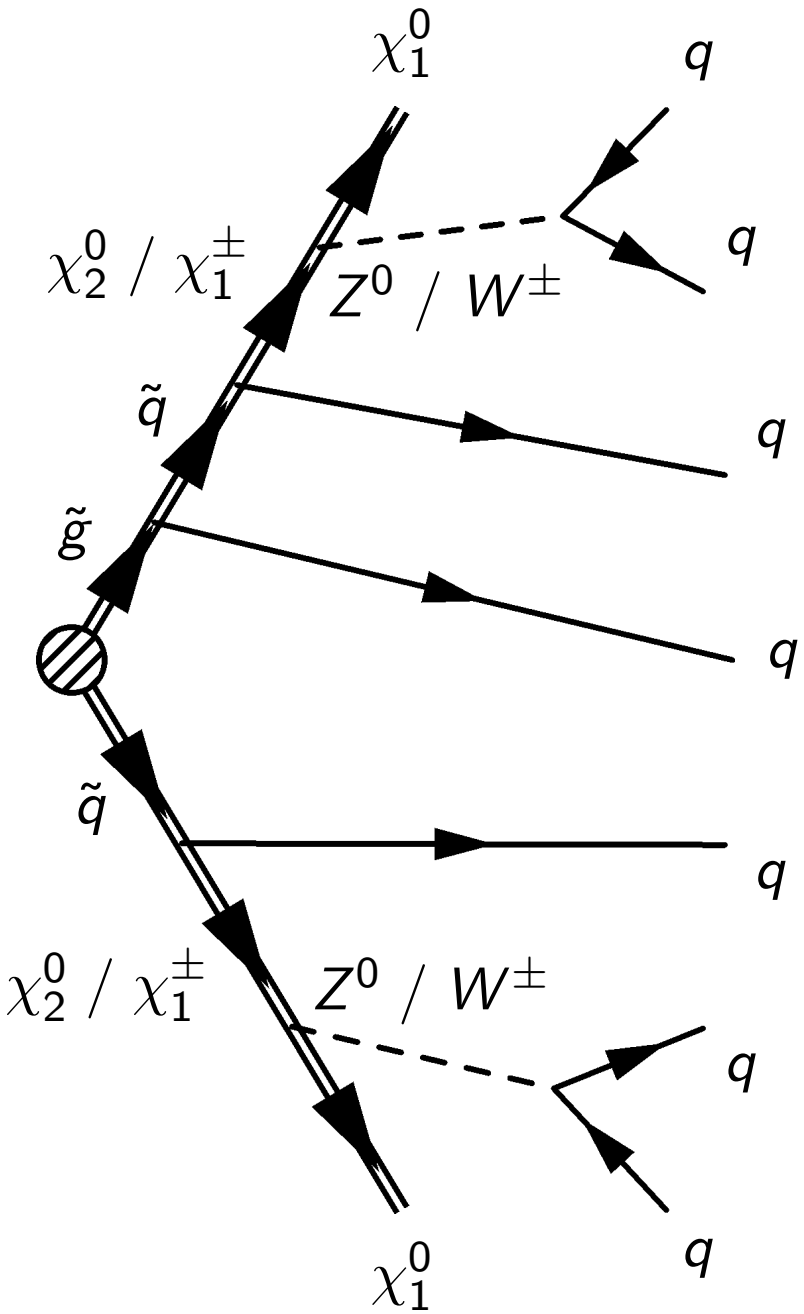
where $\Delta\mathbf{y}$ are the diviations, $\mathbf{V}$ is the covariance matrix, f_k are the constraint functions and $\mathbf{a}$ are the unmeasurable values.

Local kinematic fitting

Testing a mass hypothesis for all involved Susy particles:

- The mass hypothesis leads to mass constraints.
- Event by event all measured variables (i.e. jet 4-vectors) are varied within their errors to fulfill the constraints as good as possible.
- Each event delivers a χ^2, which quantifies the agreement of the data with the hypothesis.

The cascade



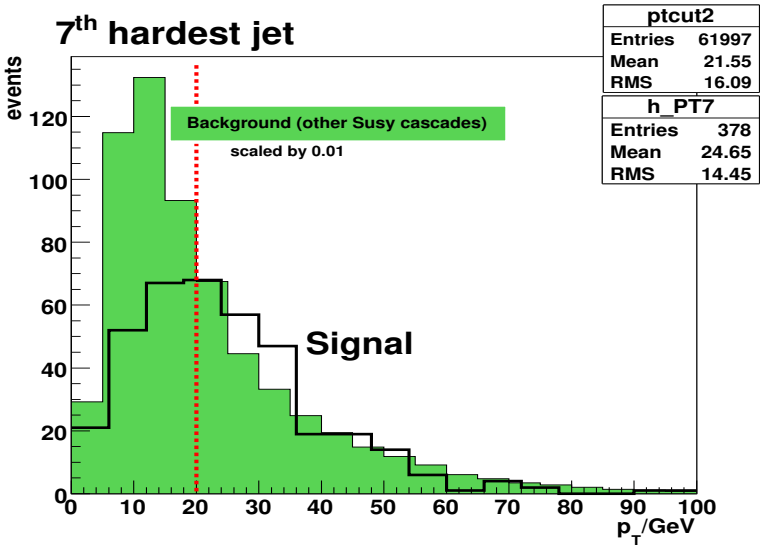
The total cross section of LM4 is 25 pb. The cross section of $\tilde{g}$ $\tilde{q_L}$ production is 6.5 pb (NLO). About 10% of these decay according to this cascade.

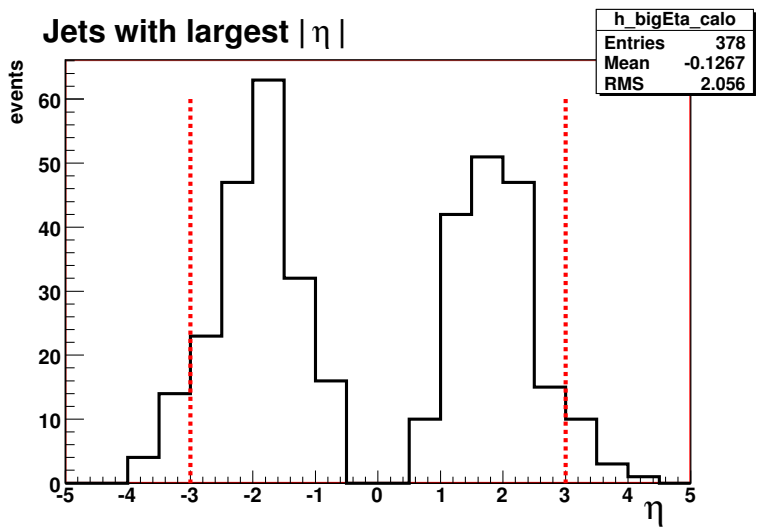
The constituants of the cascade are:

- 7 Susy particles:
  - 1 gluino $\tilde{g}$
  - 2 squarks $\tilde{q}$: $\tilde{u}_L$, $\tilde{d}_L$, $\tilde{s}_L$, $\tilde{c}_L$
  - 2 neutralinos χ_2^0 or charginos $\chi_1^\pm$
  - 2 neutralinos χ_1^0 (LSPs)
- 2 bosons: Z^0 or $W^\pm$
- 7 jets
- Large missing E_T caused by the stable and not detectable LSPs

Signal selection

- In a LM4 sample of about 90,000 events, the cascade is found 1,700 times.
- In 378 events detector jets can be matched to cascade partons on generator level (ΔR-matching).
- All 7 jets are required to have transverse momentum p_T larger than 20 GeV and a pseudo-rapidity η smaller than 3.
  202 of the matched events survive these cuts.
- In addition one initial state radiation jet per event is accepted. This is needed for the p_T balance.



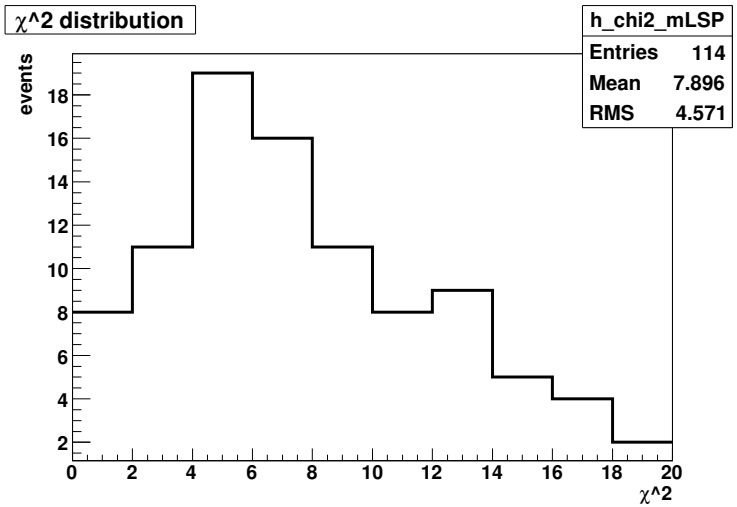


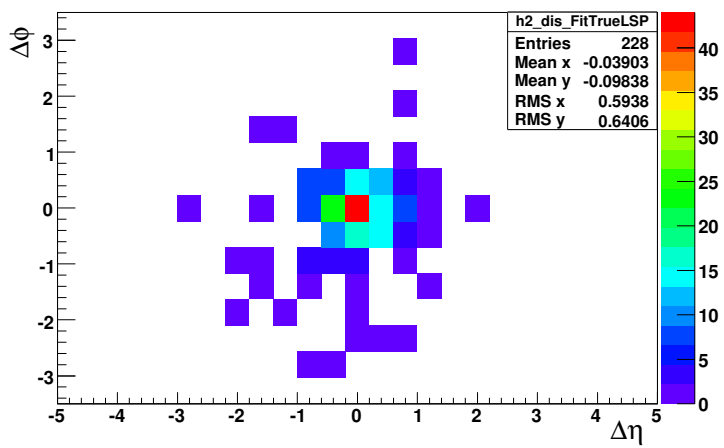
The "truth" scenario

Some results of the fitting in a "truth" scenario are presented. The "truth" scenario is characterized by the following:

- Only "signal" events are used, selected like on the previous slide shown.
- The cuts on p_T and η make sure that all jets are in a region where the detector is very precise.
- All 7 jets are matched to the cascade so there is no combinatorial background.
- One additional jet is taken if a initial state radiation parton can be matched to it.
- In the first step the true masses of the Susy particles are taken as the mass hypothesis.

Results of the "truth" scenario fitting





χ^2 distribution and the corresponding probability has to be handled with care since the constraints are correlated.

χ_1^0 momentum: deviation from the truth. The maximum of the distribution agrees with the true momenta but the width is quite large.

Variation of the masses in the "truth" scenario

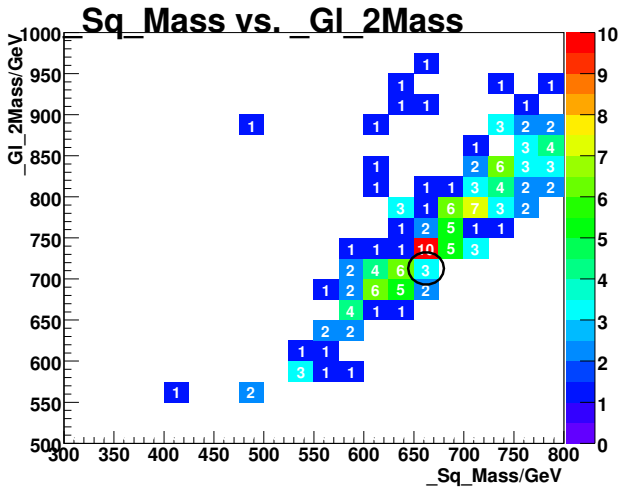
The masses that are not varied are fixed on the true values.

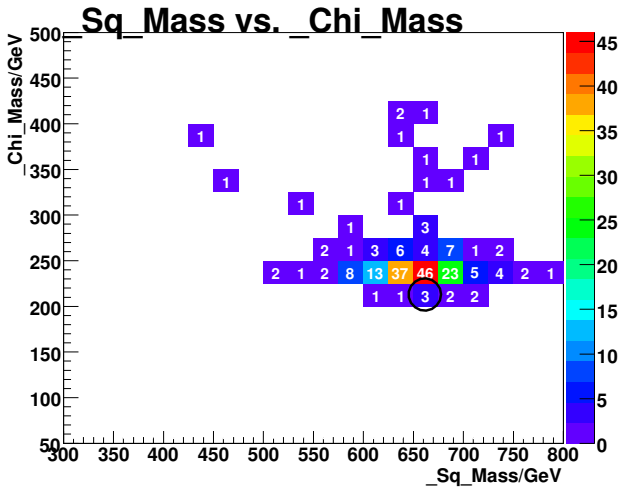
upper plots:

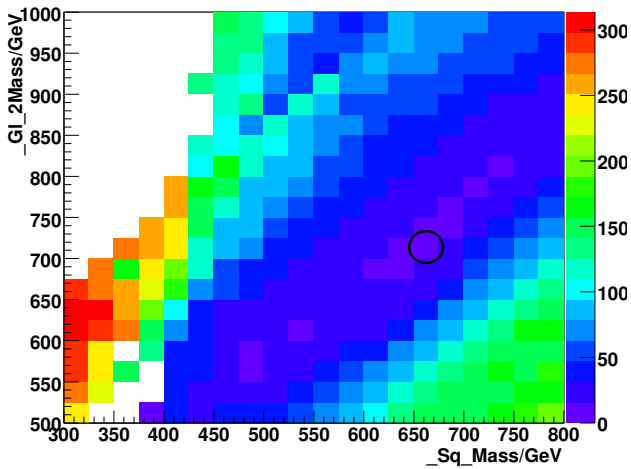
histogram of the mass pair which leads to smallest χ^2 per event.

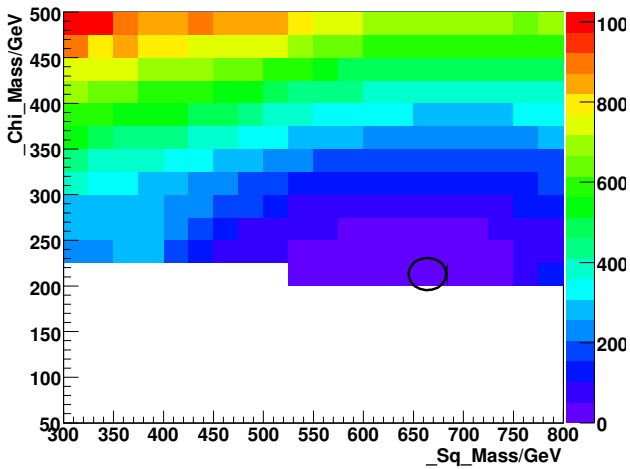
lower plots:

mean χ^2 per mass pair.

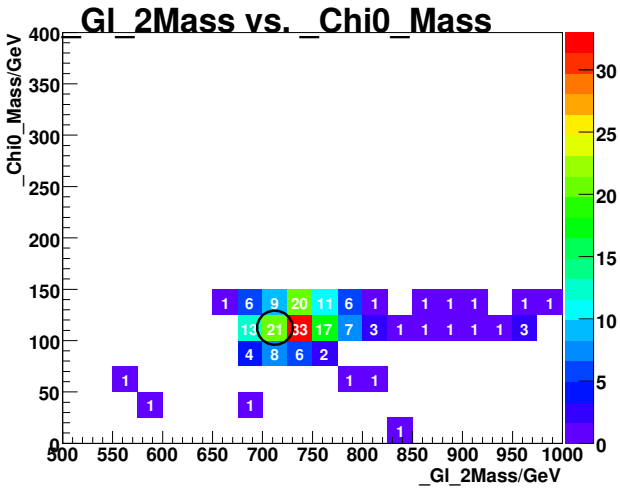


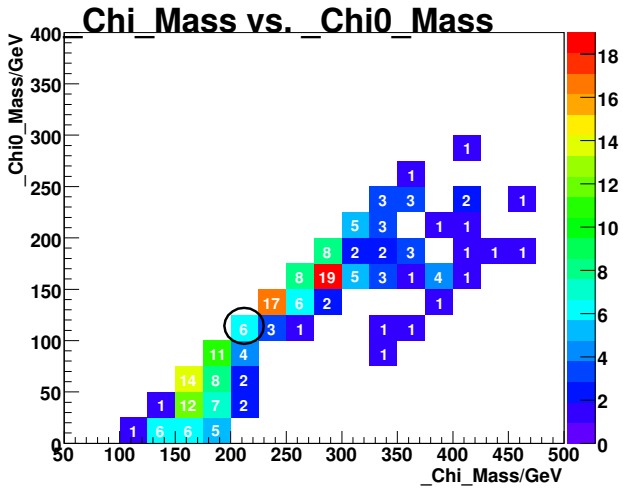


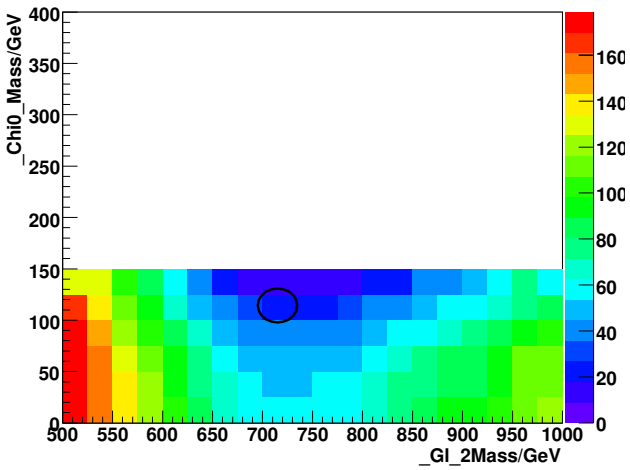


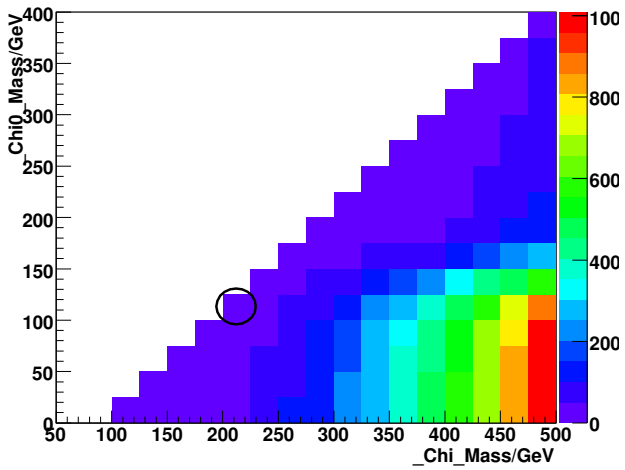


Variation of the masses in the “truth” scenario





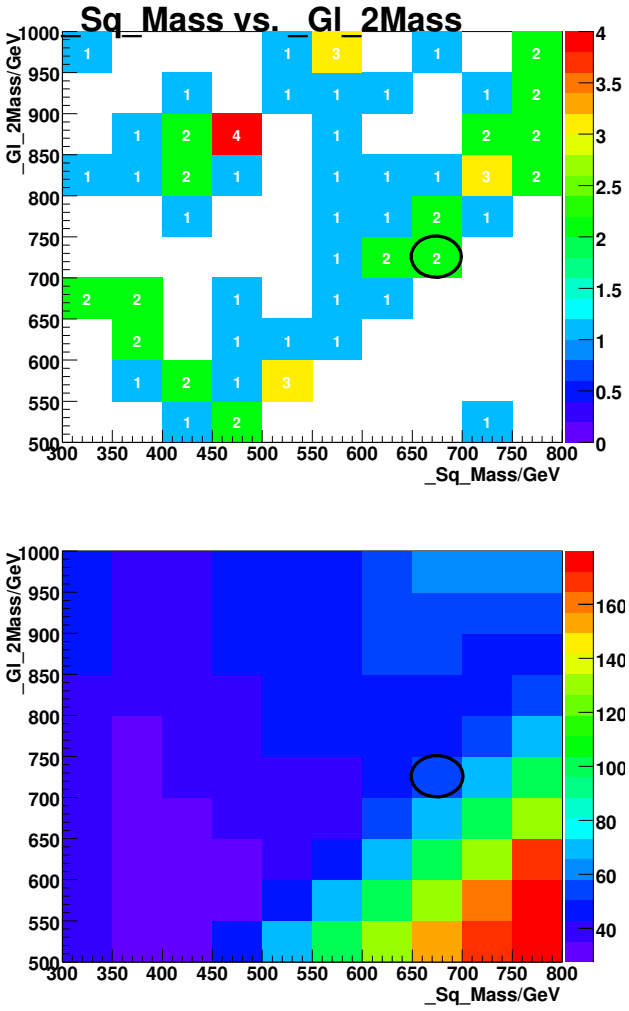




As expected the masses are correlated. The dependencies differ for different mass pairs.

Variation of the masses in a more realistic scenario

- Instead of matched jets the seven (eight) hardest jets are taken.
- Huge combinatorial background since there is no matching between the cascade partons and the jets any more. Any combination has been tried and the one with the smallest χ^2 is taken for the upper plot. The lower plot shows the χ^2-means of all events and all combinations.



Summary and outlook

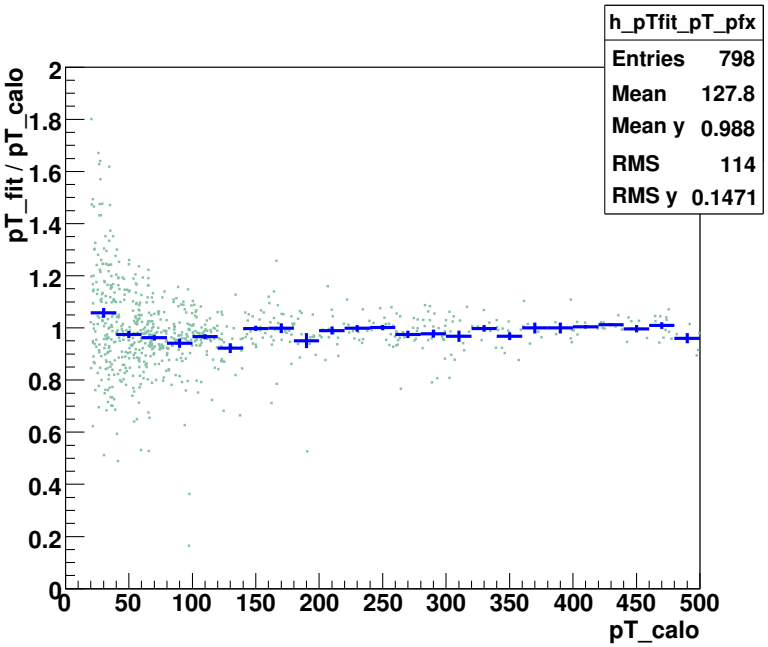
- In the "truth" scenario the fitting works.
- The scannings over two masses show clear χ^2 minima in the region of the true masses.
- The realistic scenario suffers from a lack of statistics at the moment.
- Instead of mass scannings there can be scannings over the mSURGA parameters performed.

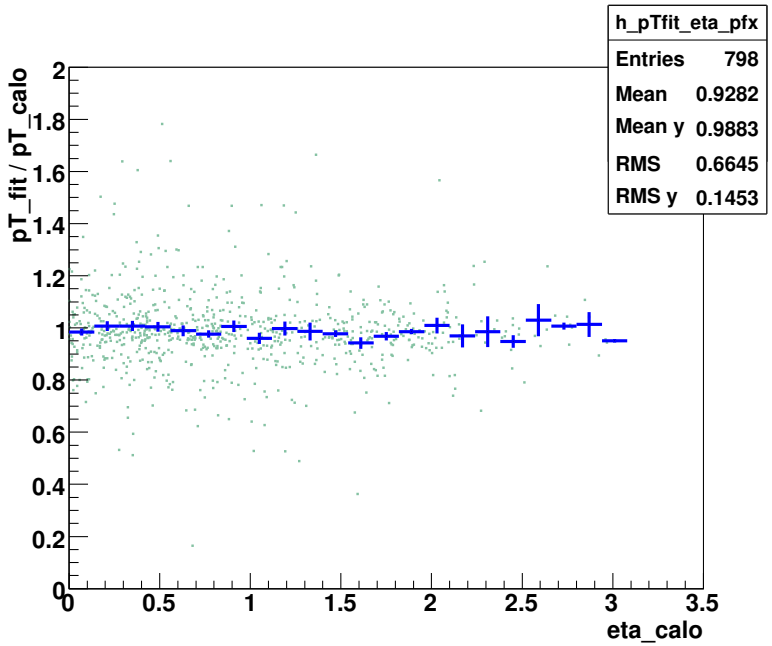
backup

Initial values

- As initial values for the measured jets, their 4-vectors are used.
- With any arbitrary initial values for the unmeasured LSP momenta the fit mostly doesn't converge.
- At LM4: $M_{\chi_2^0/\chi_1^\pm} - M_{\chi_1^0} - M_{Z^0/W^\pm} \approx 13\,\text{GeV}$.
- Small relative momentum between χ_1^0 and $Z^0/W^\pm$.
- Initial LSP:
  - Direction of $Z^0/W^\pm$
  - Magnitude chosen that the first mass constraint is fulfilled.

Results of the "truth" scenario fitting

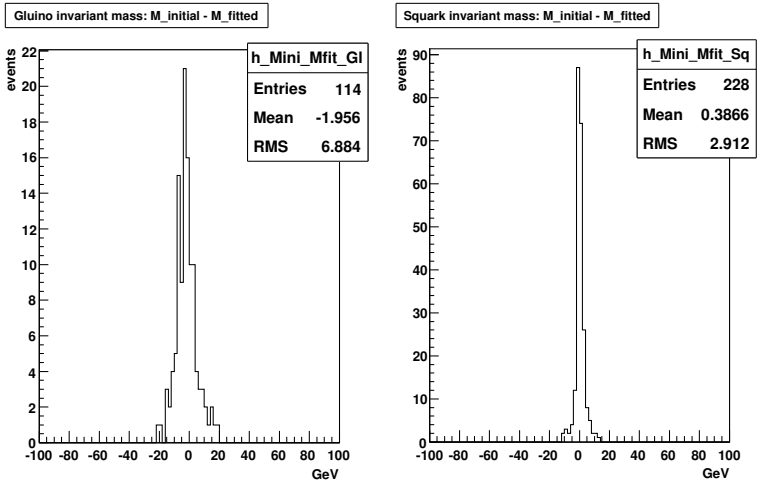




$$\frac{p_T \text{ of the fitted jets}}{p_T \text{ of the calo jets}}$$

The fitting doesn't change the energy scale of the jets.

Results of the "truth" scenario fitting



All mass constraints are fulfilled.

χ^2 probability