Update on Kinematic Fits

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Kinematic Fits and Parameter Determination

- If some masses are (almost) degenerated (e.g. squark masses or χ^0 and $\chi^\pm$ in mSUGRA scenarios) it might be possible to select events with a rather similar cascade topology
- In these cascades the masses of the SUSY particles at a particular position in the decay chain can be assumed equal for each event

Global unknowns: SUSY masses

Local unknowns: momenta of two LSPs

Constraints 1: right combinations of the final state particles should have invariant masses of corresponding SUSY particle

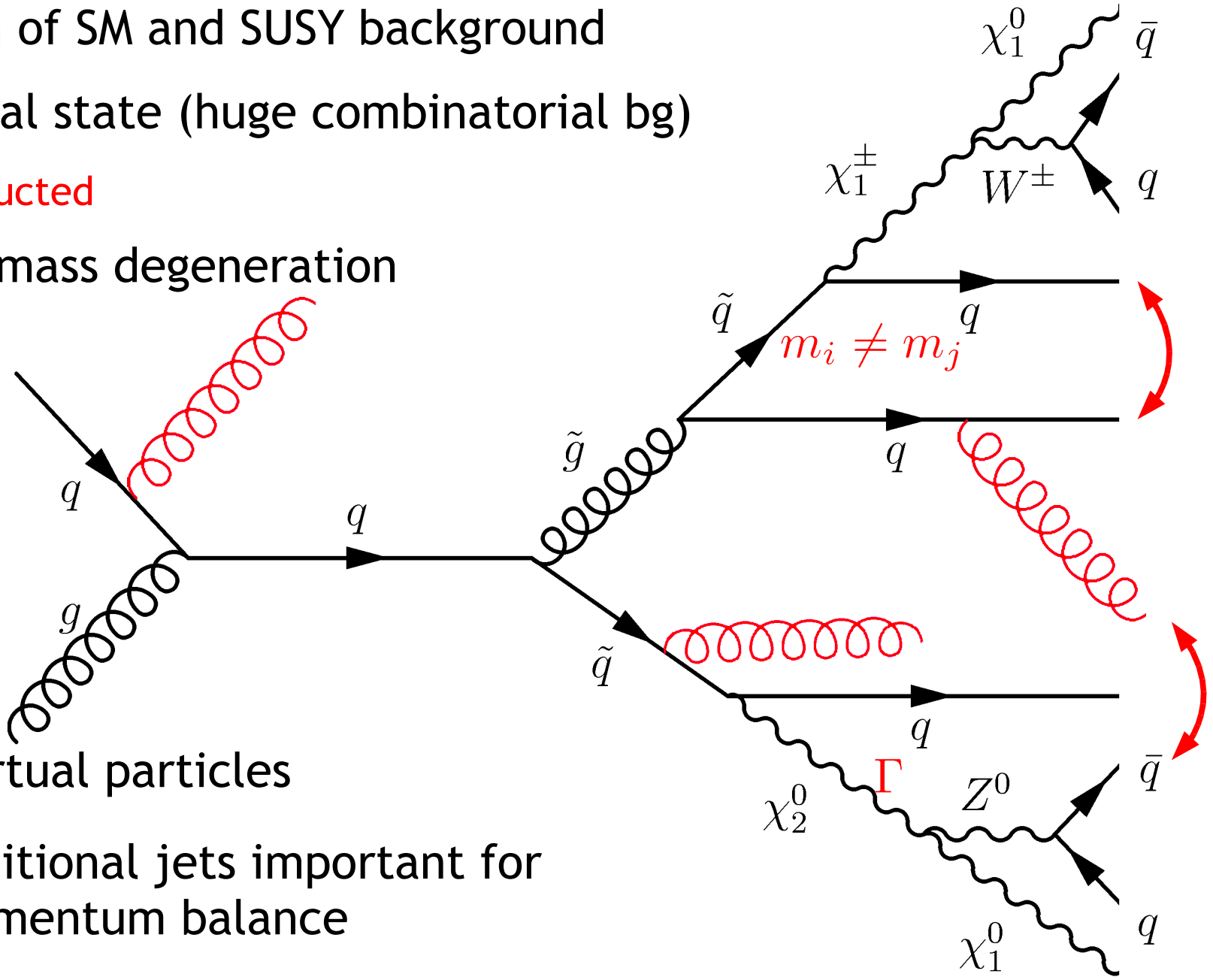
Constraints 2: Momentum balance in transverse plane

→ **If there are more constraints than local unknowns, the problem is overconstrained for a large number of events**

- Analogy: Tracker alignment (global unknowns: alignment parameters, local unknowns: track parameters, constraints: vertex ...)

Potential Problems

- Suppression of SM and SUSY background
- 7 jets in final state (huge combinatorial bg)
  - all reconstructed
- No perfect mass degeneration



- Width of virtual particles
- +FSR
- +ISR

} additional jets important for momentum balance

Commonly Used Approach

- Constrained fitting via Lagrangian Multiplier

$$\sum_{i=1}^{N_m} \left(\frac{m_i - t_i}{\sigma_i} \right)^2 + 2 \cdot \sum_{i=1}^{N_c} \lambda_i \cdot f_i$$

- Find extremum where all derivatives vanish
- If constraints are linear find perfect solution within one Gauss-Newton step
- Invariant mass constraints are (highly) non-linear → linearization and iterative approach
- **General problem:** Fit can converge at local (and not global) minimum

Alternative Approach

- Formulation of constraints as additional χ^2 term → "cost function"
- To interpret cost function as χ^2 all correlations have to be taken into account

$$\left(\frac{M_{\mathrm{inv}}(j_1, j_2, j_3) - M}{\sigma} \right)^2$$

with

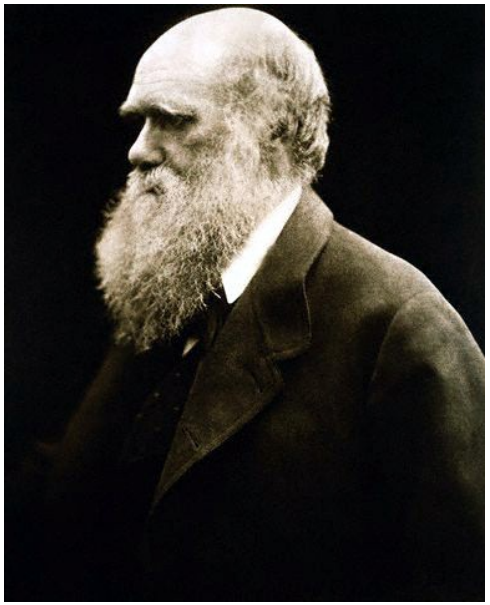
$$\sigma^2 = \sum_{i=1}^{N_m} \left(\frac{\partial M_{\mathrm{inv}}}{\partial i} \right)^2 \cdot \sigma_i^2 + \Gamma_m^2$$

- Minimize cost function: many possible algorithms (gradient, simplex, LBFGS, simulated annealing ... genetic algorithm)

Genetic Algorithm

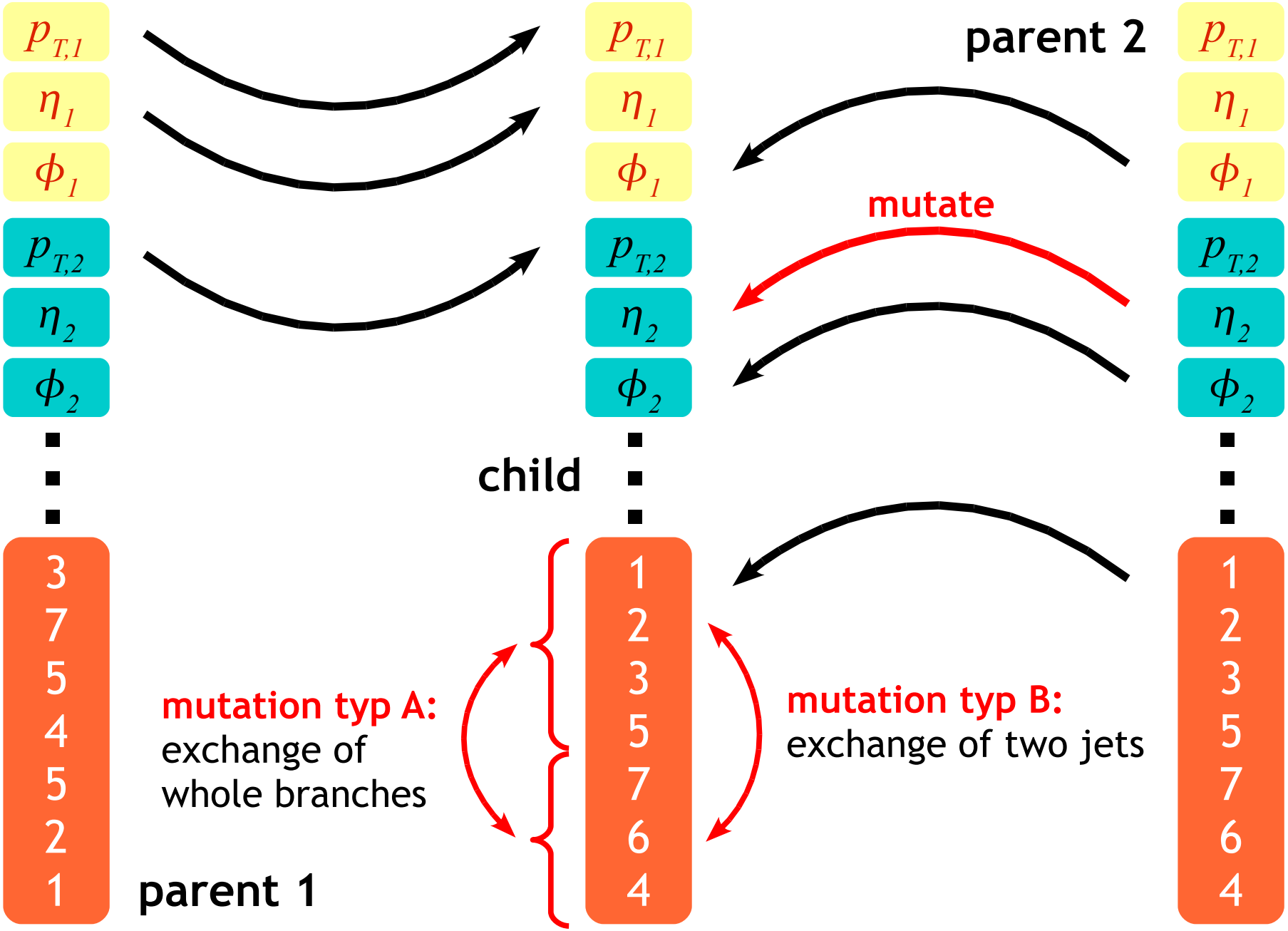
- Final state 4-momenta are properties (*genes*) of *individuum*; jet combination is one additional *gene*
- A fitness function (here χ^2) defines if a *individuum* is *fittest*

1) Starting from starting values create a first *generation* of *individua* (starting *population*): use all possible jet combinations (1260 for 7 jets)
2) Select N best fitting *individua* (here 30)
3) Create M (here 1000) new *individua* by selecting randomly two *parents* and take randomly the *genes* from either one or the other *parent*
4) *Mutate* (variation within the measurement errors) each *gene* (except jet combination) with a given probability (here 10 %)
5) Back to step 2) until convergence is reached (here: no change within 3 *generations*) or fixed iteration number is reached (here 200)

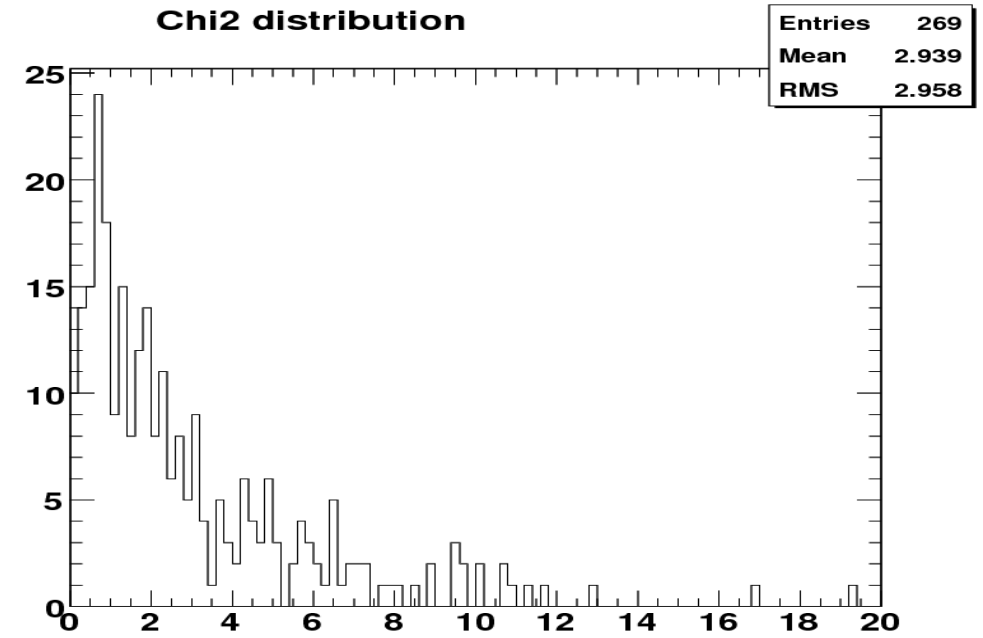


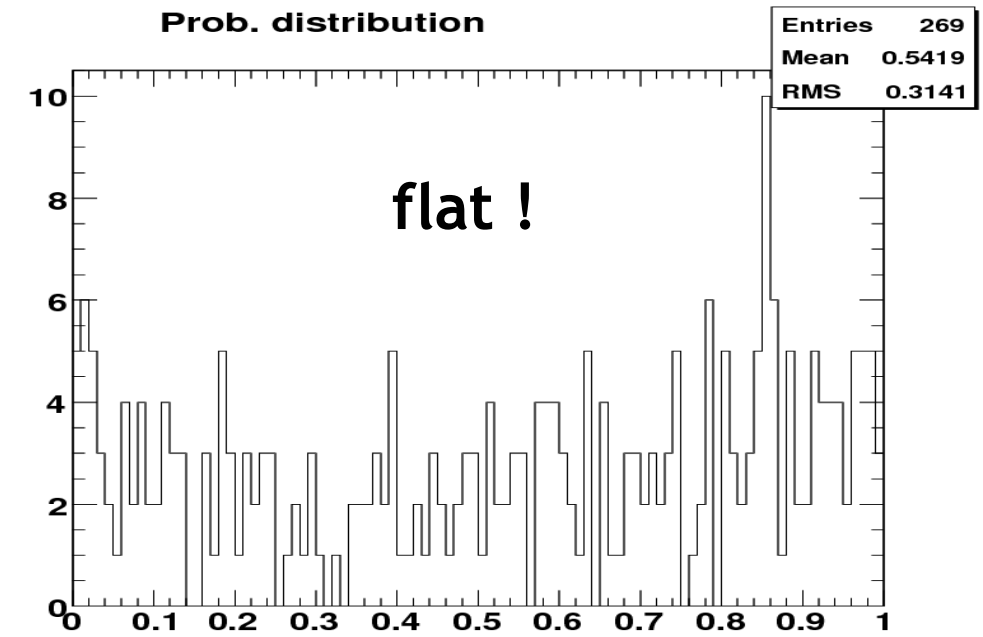
Charles Darwin
(**1809** – 1882)
On the origin of species (**1859**)

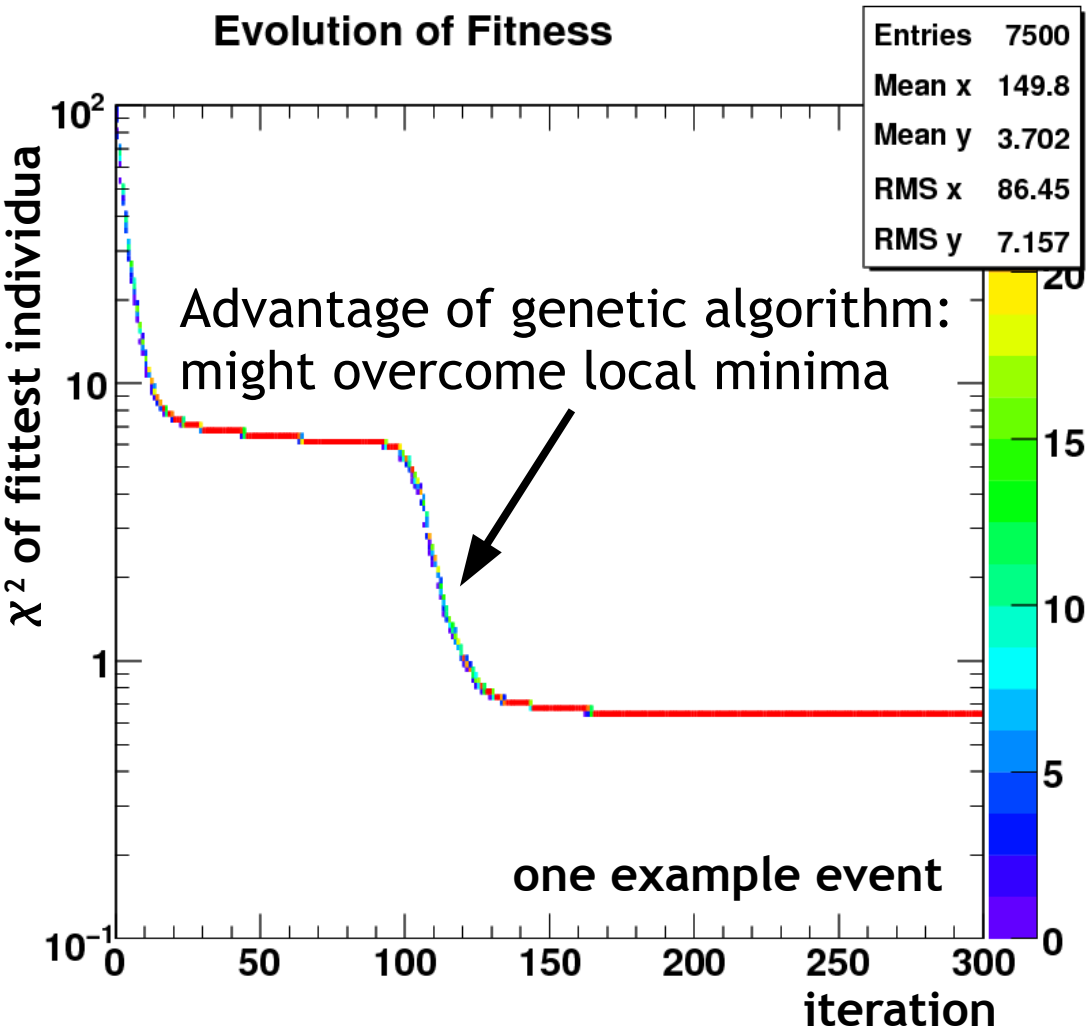
Genetic Algorithm (cont.)



Fundamental Behaviour



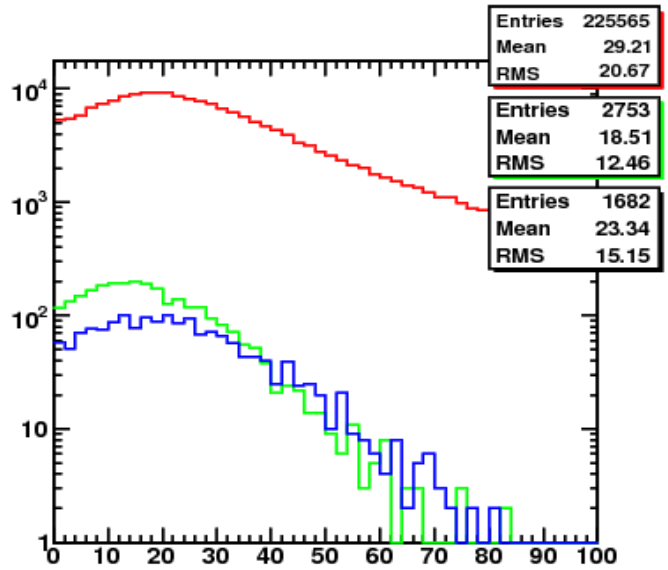




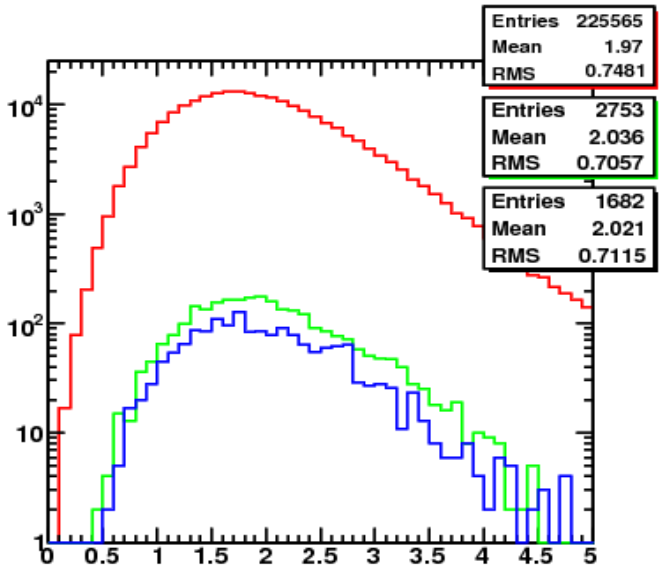
Input:
no combinatorial bg
no SUSY bg
ISR for momentum balance from MC

Preselection

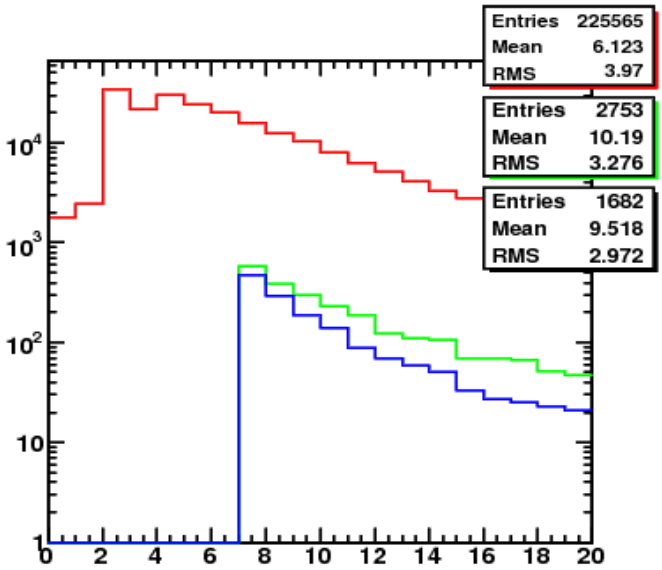
- Demand exactly 7 jets with:
  - $p_T > 20\ \mathrm{GeV}$
  - $|\eta| < 3.0$
- This will reject many signal events with hard ISR or FSR, but combinatorics is reduced



p_T of softest signal jet



signal jet with largest $|\eta|$



pos. of softest signal jet

Starting Values for Neutralinos

- In typical Susy scenarios: $m_{\chi_1^\pm} - m_{\chi_1^0} \gtrsim m_W$

→ small relative momentum of W and χ^0

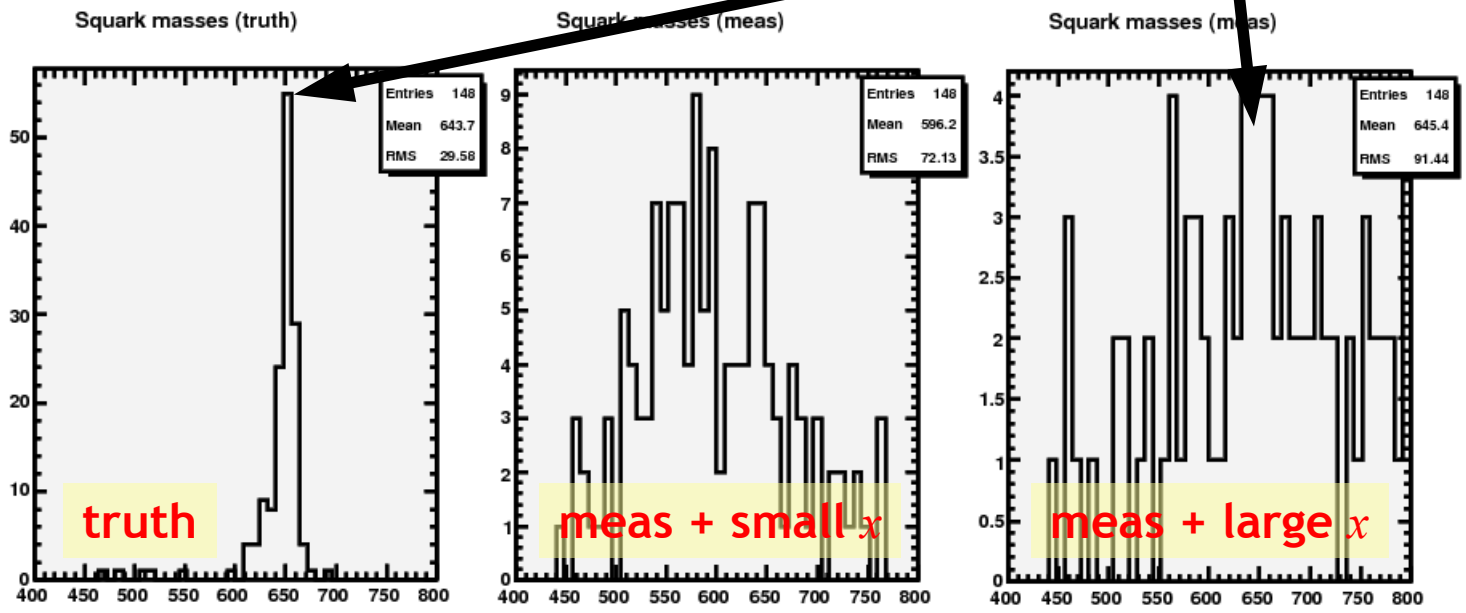
- Assume same direction of W and χ^0 and adjust χ^0 momentum to fulfill mass constraint

$$0 \stackrel{!}{=} f(x) = m_{\chi_1^\pm}^2 - \left(\left(E_W + \sqrt{m_{\chi_0}^2 + (x \cdot p_W)^2} \right)^2 - (1+x)^2 p_W^2 \right)$$

- In general there are 0, 1 or two solutions for x
  - 0: take x with smallest $|f(x)|$ (set derivative df/dx to 0)
  - 1: ok ... but in practice this never happens
  - 2: choose larger solution!

mean at right position

invariant squark masses:



Counting of Cascades

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**************************************************
Total number of events: 50000
Number of right cascades (selected): 149
          right cascades (present): 74
          right cascades (not selected): 473
          similar cascades (selected): 101
          similar cascades (present): 65
          similar cascades (not selected): 272
          false cascades (selected): 3754
          false cascades (not selected): 45352
          one branch (selected): 64
          one branch (present): 49
          one similar branch (selected): 750
          one similar branch (present): 537
Best is right: 17 from 74
**************************************************
```

Fit Results Including Bg (without comb.)

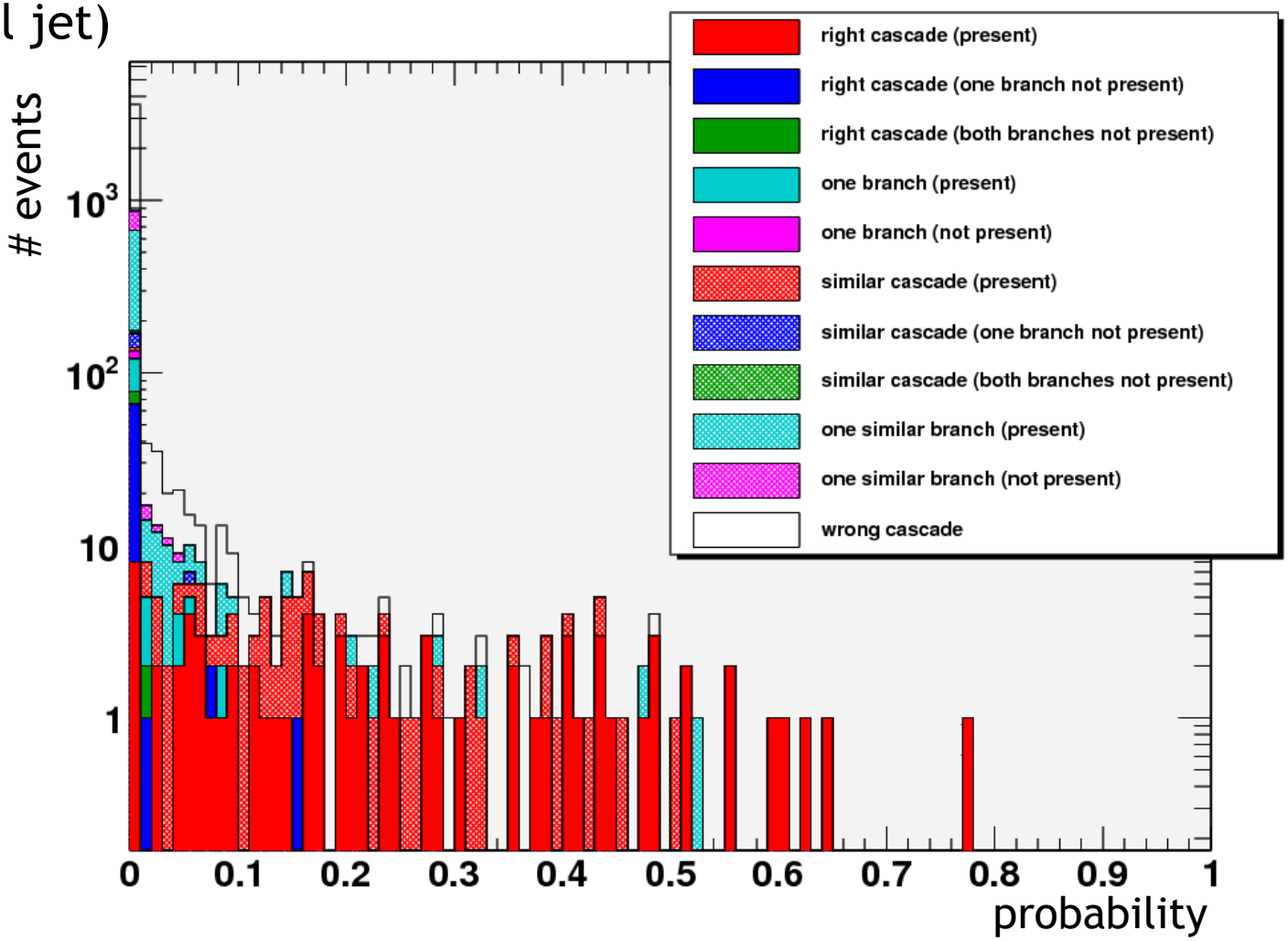
- Included backgrounds:
  - SUSY
  - signal cascades but not all signal jets selected (at least one ISR or FSR jet is harder than one signal jet)

Signal cascade:
only left handed squarks of first two generations

Similar cascades:
other squarks

→ **Prob. distribution not flat due to missing ISR**

→ **SUSY bg peaks at small probabilities**

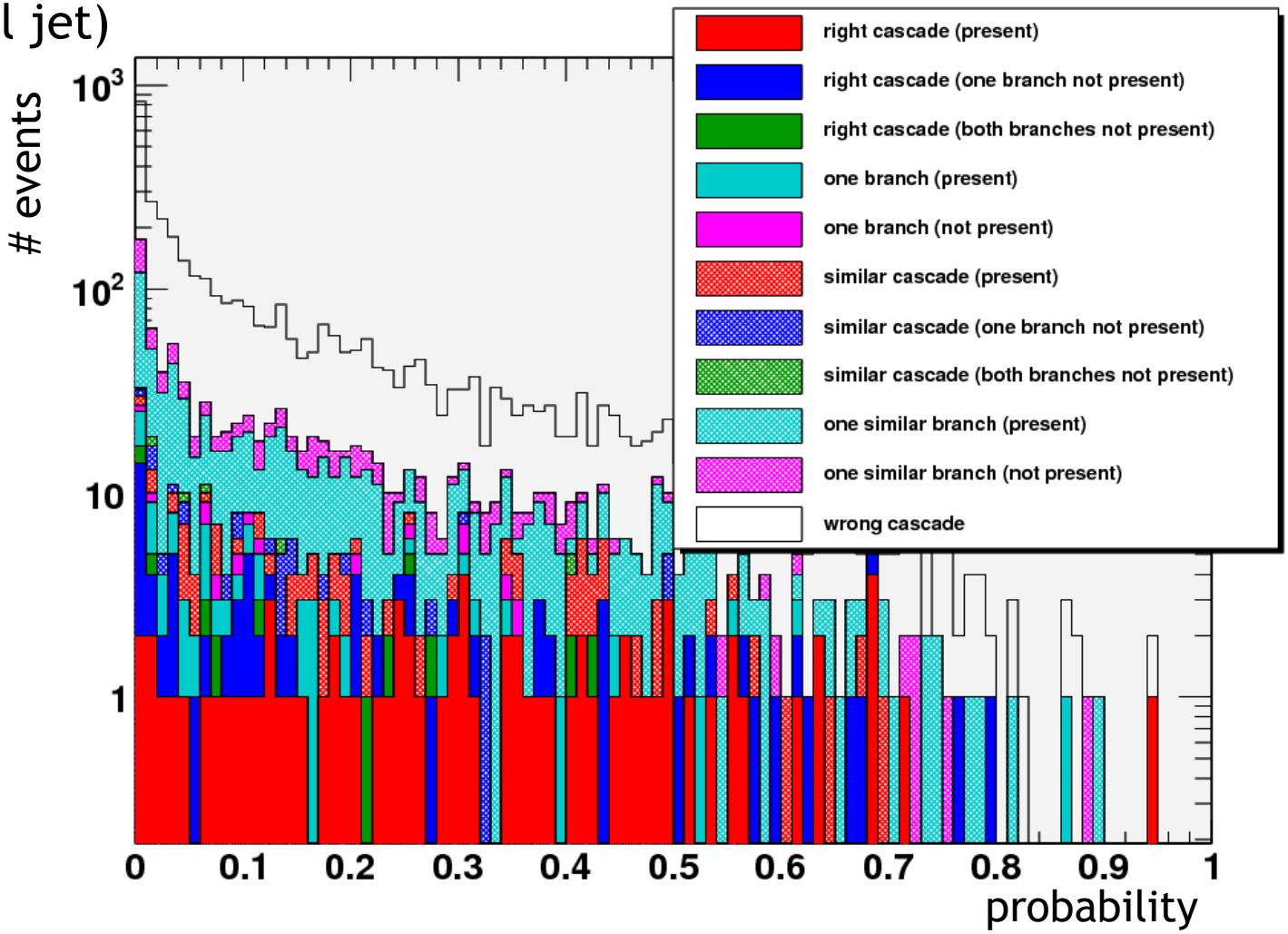


Fit Results Including Bg (with comb.)

- Included backgrounds:
  - SUSY
  - signal cascades but not all signal jets selected (at least one ISR or FSR jet is harder than one signal jet)
  - combinatroics

→ Prob. distribution not flat due to missing ISR

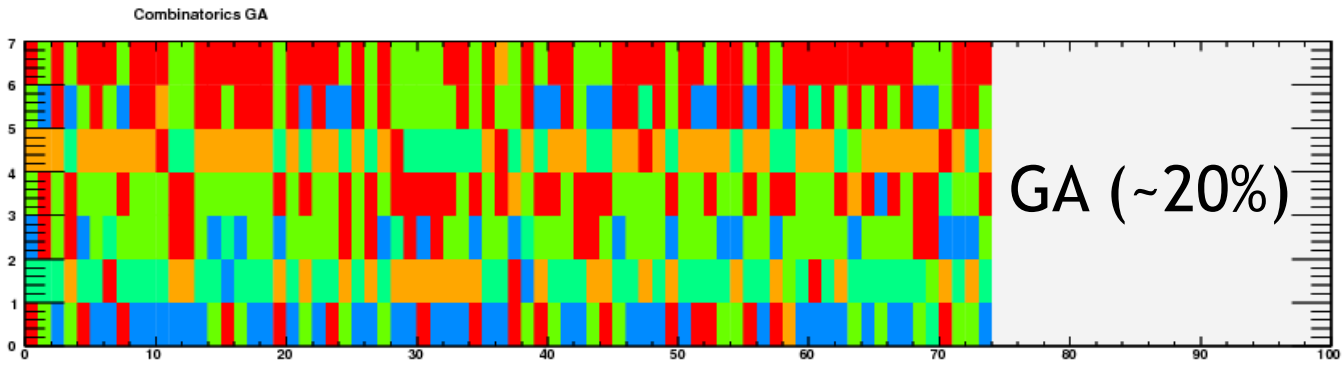
→ SUSY bg peaks at small probabilities but unfortunately at higher probabilities also dominant

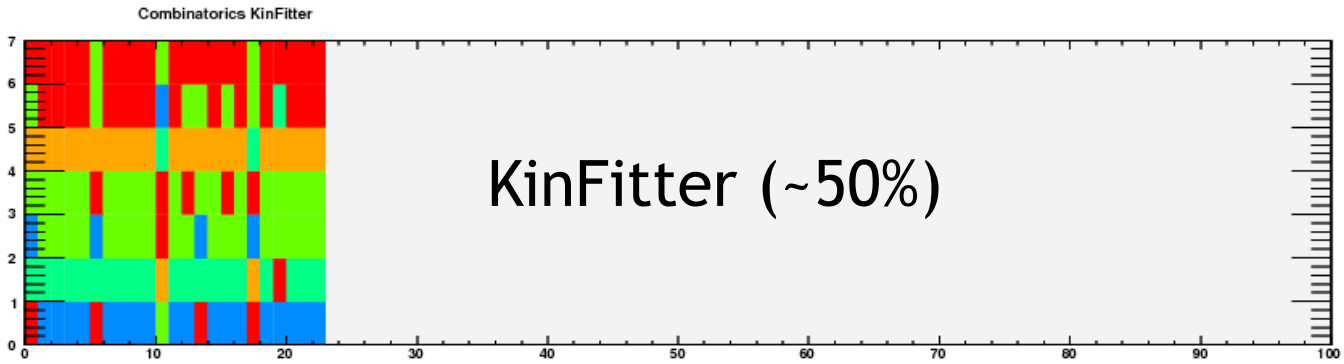


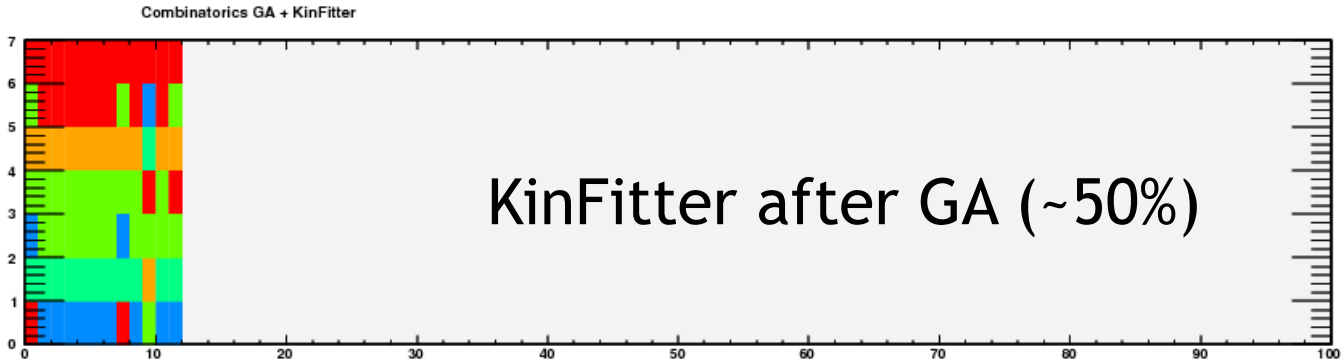
Visualization of Best Combinations

~ 20% complete right cascade
most wrong combinations are exchange of the two branches

- second W jet
- second W jet
- second squark jet
- first W jet
- first W jet
- first squark jet
- first gluino jet





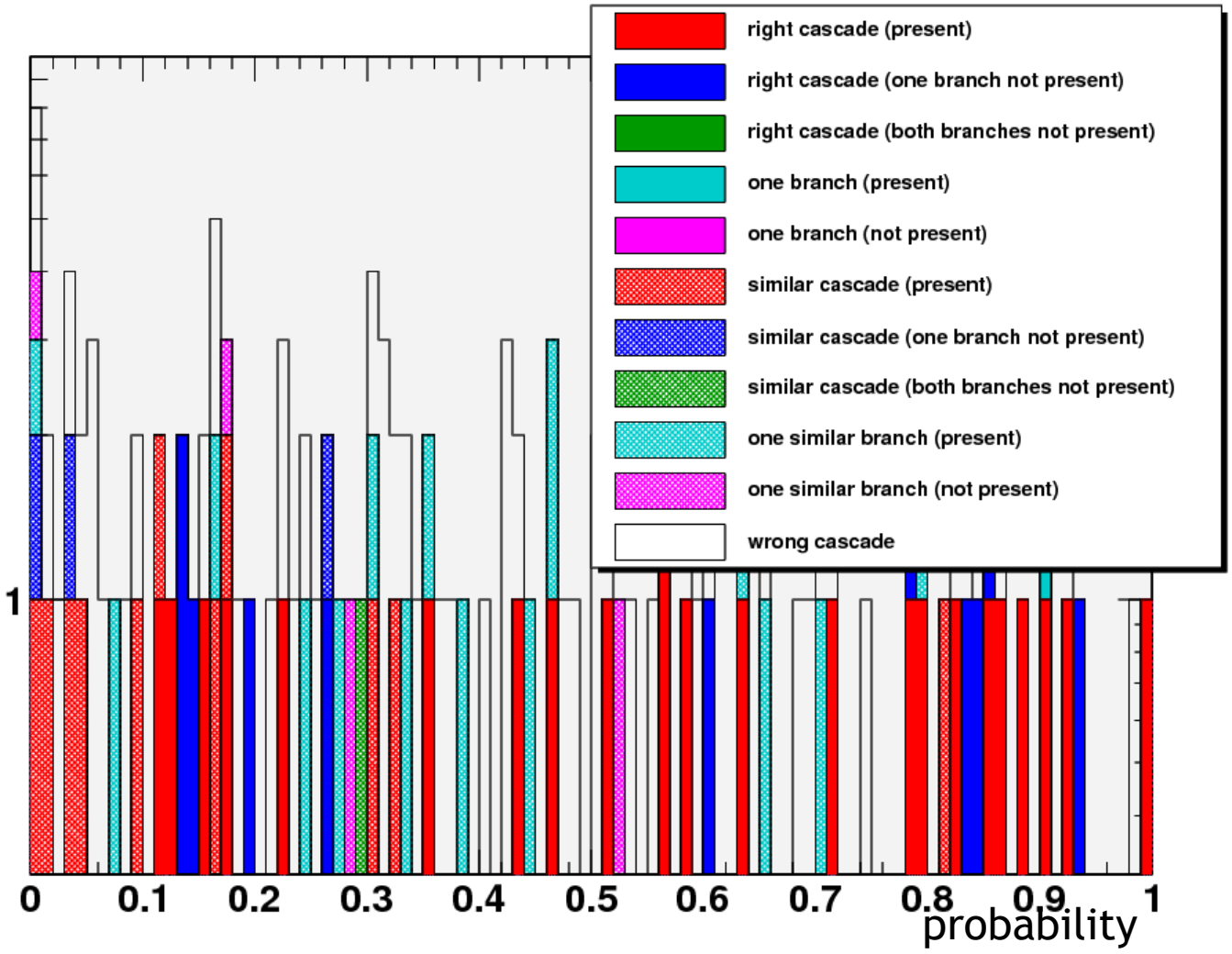


good ←χ^2→ bad

Fit Results Including Bg (with comb.)

- Included backgrounds:
  - SUSY
  - signal cascades but not all signal jets selected (at least one ISR or FSR jet is harder than one signal jet)
  - combinatroics
- KinFitter only (test only combinations with two potential W/Z candidates:

  $55\ \text{GeV} < m_{\text{inv}} < 115\ \text{GeV}$)



→ S/B improved but only a fraction of events are converging

→ strong dependence on convergence criteria

Plans and Ideas

- Scan over mass hypotheses
  - Use NAF
  - First try with: neutralino and gluino mass fixed, varying chargino and squark mass ... and other combinations?
  - In addition mSUGRA scan?
- Test different discriminating variables (e.g. averaged probability, likelihood of best N events ...)
- Include ISR jets in event selection (treat higher statistics vs. larger combinatorial bg)
- Include systematic uncertainties