A Study of Light-flavored SQuark Production at CLIC

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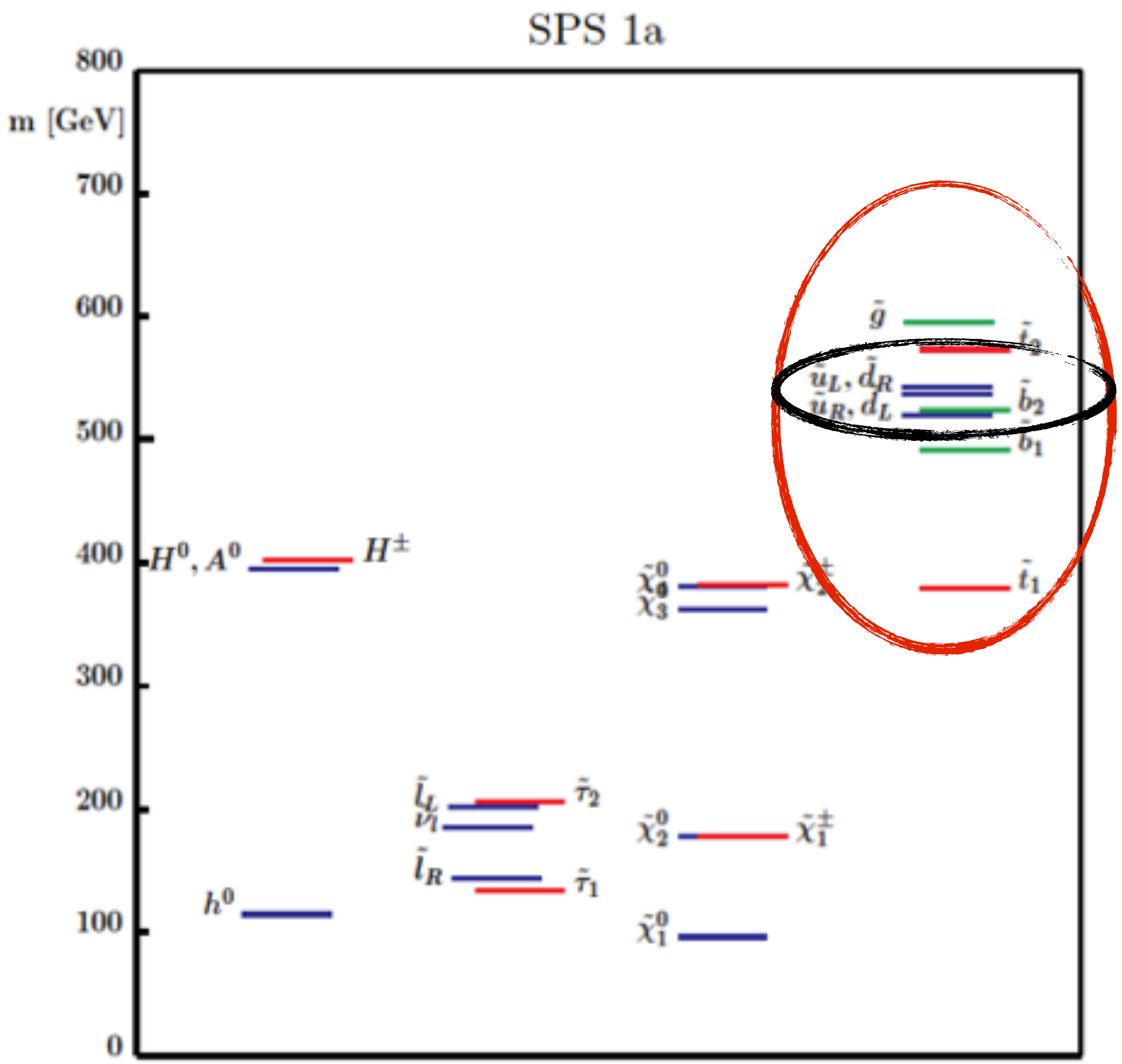
Excellence Cluster Universe

Outline

- Squark production and decay at CLIC
- Techniques for mass measurements
- First generator level study
- Summary/Outlook

SQuarks: The Domain of Multi-TeV Colliders

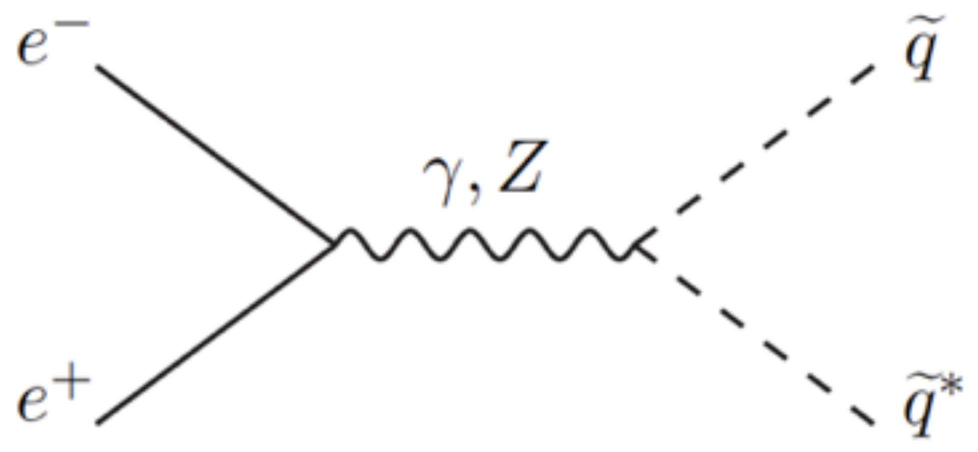
- In many mSUGRA models the squarks are among the heaviest sparticles
  - Requires collision energies beyond 1 TeV for pair production
  - The light-flavored quarks are special: Left and right squarks don't mix to form two mass states



- typically no distinction between first and second generation:
  - up, charm squarks and down, strange squarks have equal masses
  - small mass difference between up-type and down-type
  - mass difference between left- and right squarks

Precise squark mass measurements are an important ingredient for SUSY spectroscopy!

Squark Production and Decay



- Pair production via Z/γ exchange
  - Right squarks do not carry weak isospin: here only em coupling
  - cross section ratio for up/down type: 4:1

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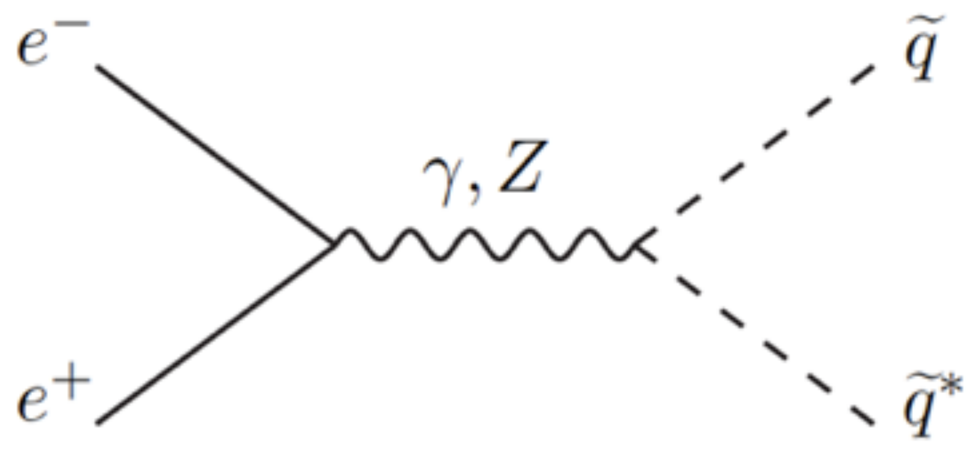

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$$\tilde{q} \to \tilde{g} q$$

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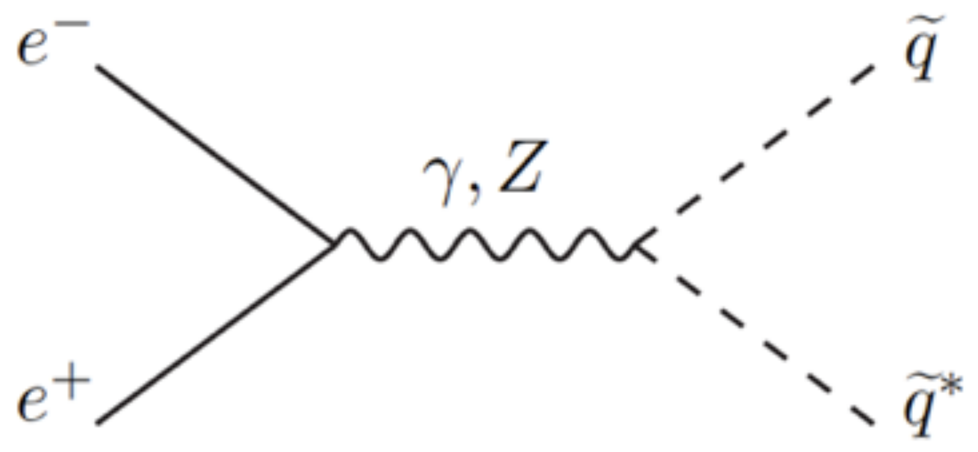

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  - If the M(gluino) > M(squark), the decay occurs via weak interaction:

$$\tilde{q} \to \chi_n^0 q \qquad \tilde{q} \to \chi_n^{\pm} q'$$

For right-squarks:

- only decay to neutralinos occur, since they do not couple to winos
- decay $\tilde{q} \to \chi_1^0 q$ dominates if lightest neutralino is mostly bino

Light-flavored Right Squarks at CLIC

- Light-flavored right-squarks are an excellent benchmark process:

$$e^+e^- \rightarrow \tilde{q}\tilde{q} \rightarrow qq\chi_1^0\chi_1^0$$

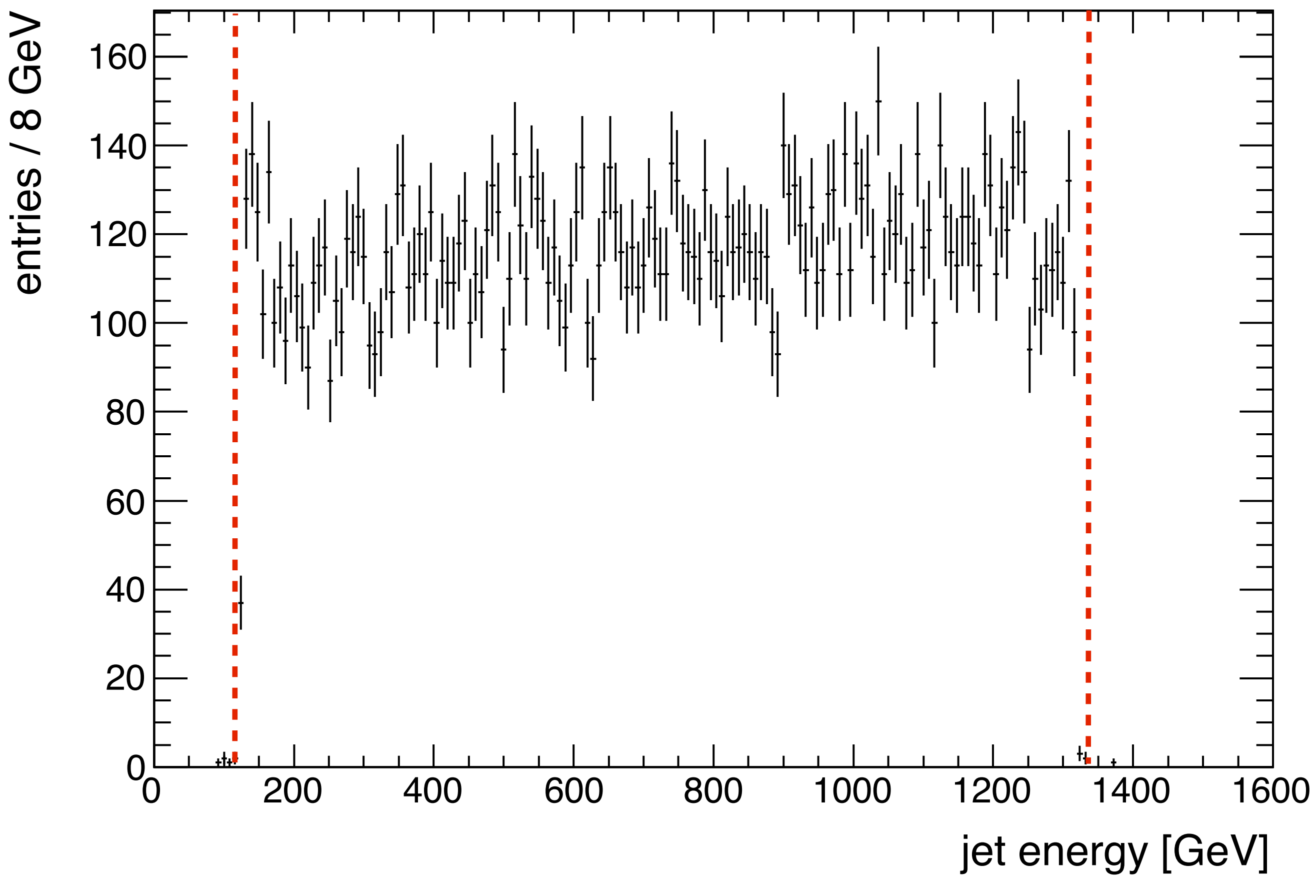
  characterized by two high-energy jets and missing energy.

- The goal: Measure the squark mass and the production cross section

- Here: study different mass measurement techniques, first investigations of possible backgrounds
  - Two SUSY scenarios, both with almost degenerate light right-squark masses (u,d,s,c):
    - The CLIC benchmark: $m(\tilde{u}_R, \tilde{c}_R) = 1126\,\mathrm{GeV}$ $\quad m(\tilde{d}_R, \tilde{s}_R) = 1116\,\mathrm{GeV}$ $\quad m(\chi_1^0) = 328\,\mathrm{GeV}$
    - SPS1b (typical mSUGRA): $m(\tilde{u}_R, \tilde{c}_R) = 846\,\mathrm{GeV}$ $\quad m(\tilde{d}_R, \tilde{s}_R) = 843\,\mathrm{GeV}$ $\quad m(\chi_1^0) = 162\,\mathrm{GeV}$

Mass Measurement Techniques: Jet Energy

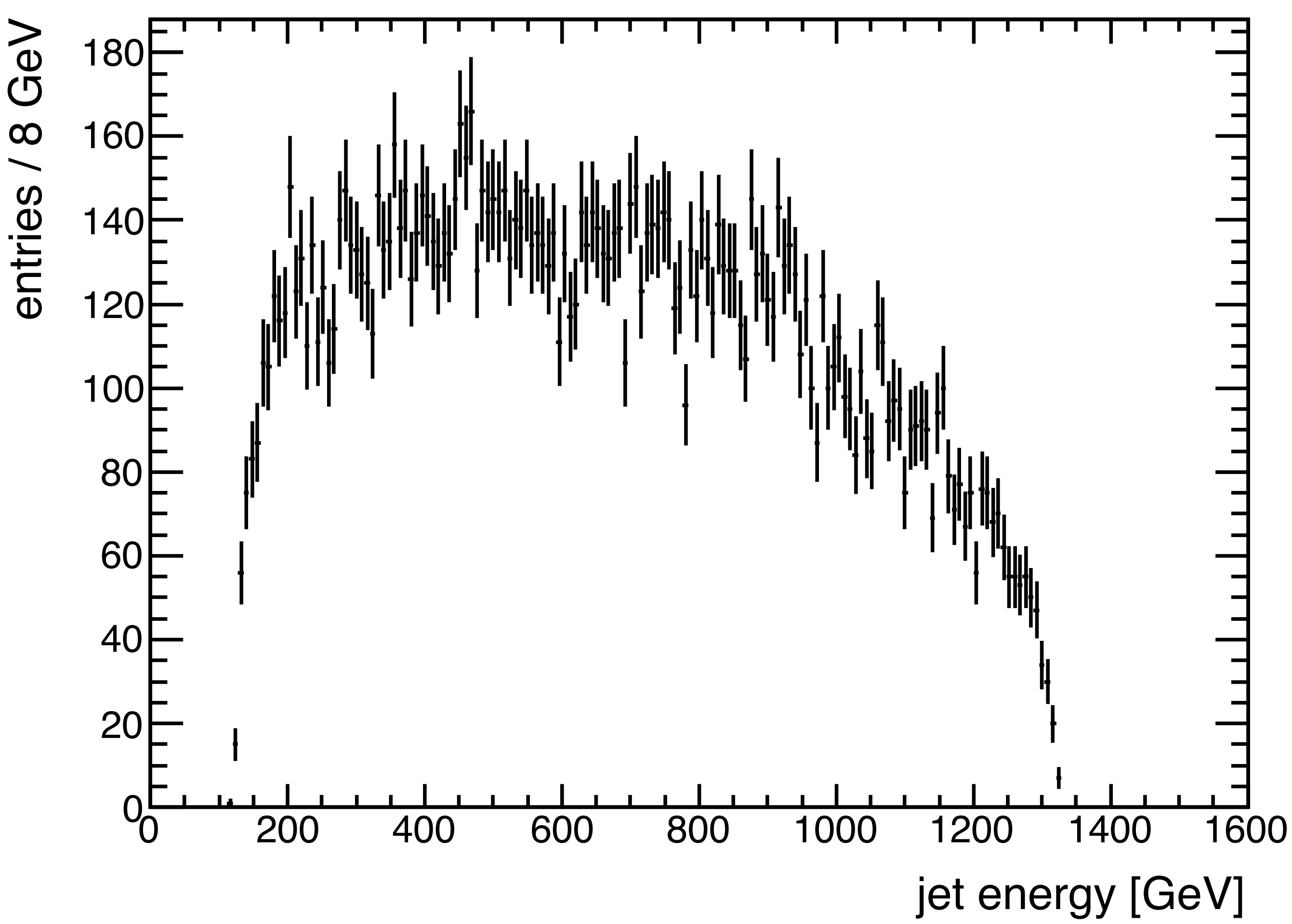
- The "Classic": Use the distribution of the jet energy
  - Upper and lower edge of the distribution is given by s, m(squark), m(neutralino)
  - ▸ Allows the simultaneous measurement of neutralino and squark mass



SPS1b, generator level (quark energies)
10k events, WHIZARD 1.95
no ISR, no BS, no detector effects

Jet Energy: Impact of ISR and Beamstrahlung

- Beamstrahlung in particular has a strong impact on the luminosity spectrum at CLIC, and thus on the observables themselves:
  - observables using *s* explicitly get distorted
  - asymmetric collision energies and the corresponding boost of the cm frame lead to distortions when measured in the detector frame



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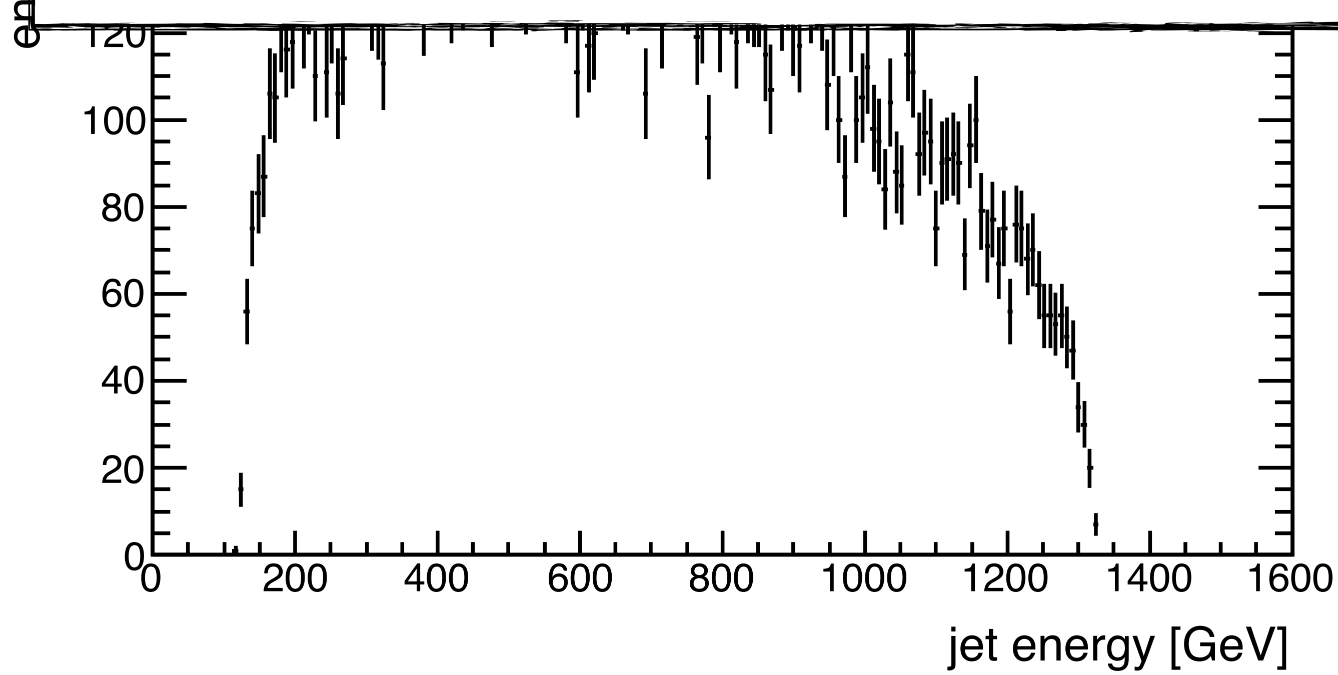
Measurement based on jet energy challenging in the presence of distortions introduced by beamstrahlung

-

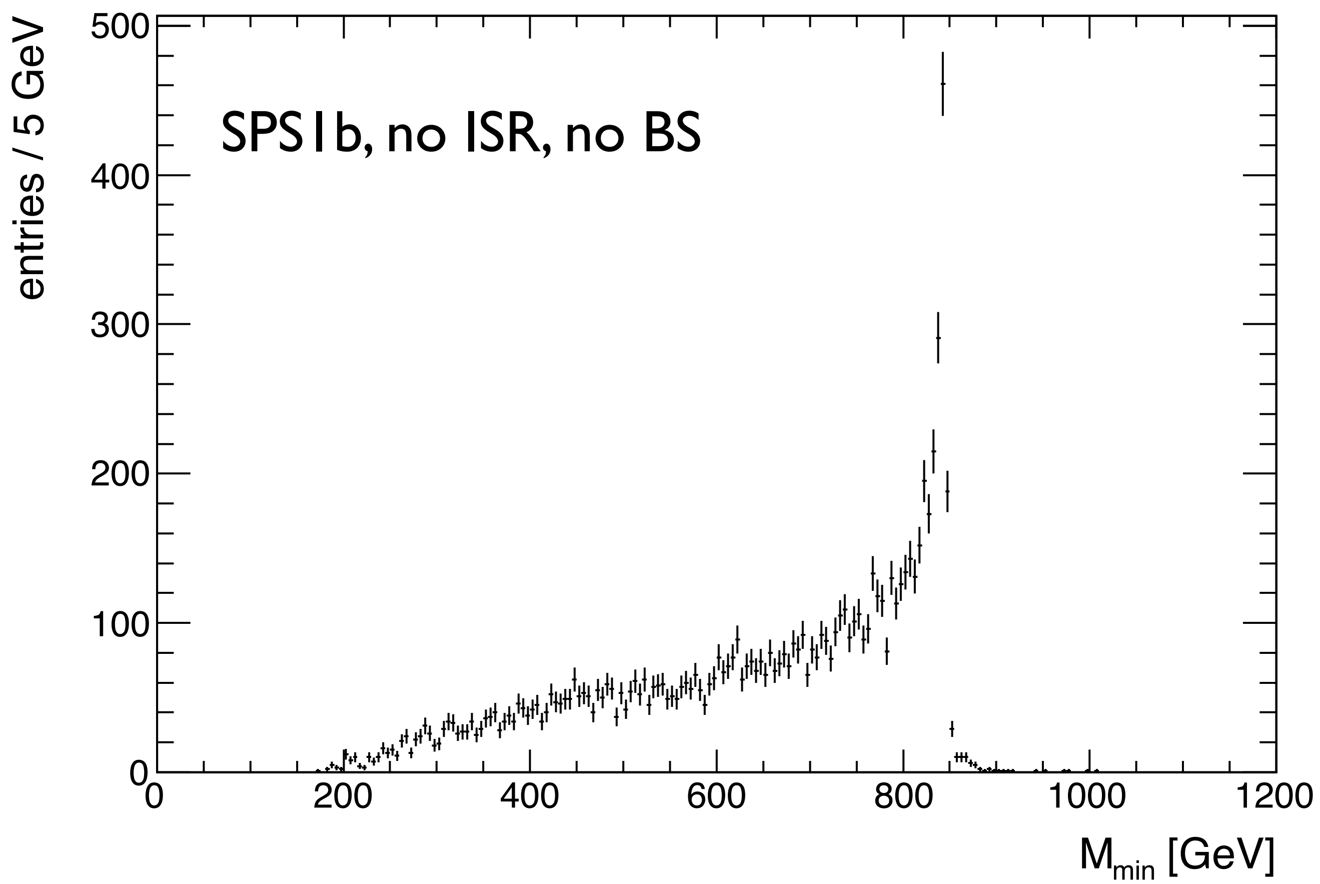
Are there alternatives?



Mass Measurement Techniques: Minimum Squark Mass

- Calculate the minimum squark mass allowed in an event, using
  - the measured jet three momenta (assuming massless quarks)
  - the neutralino mass (assuming it is known from other measurements)
  - the collision energy *s*

J.L Feng, D.E. Finnell, PRD 49, 2369 (1994)



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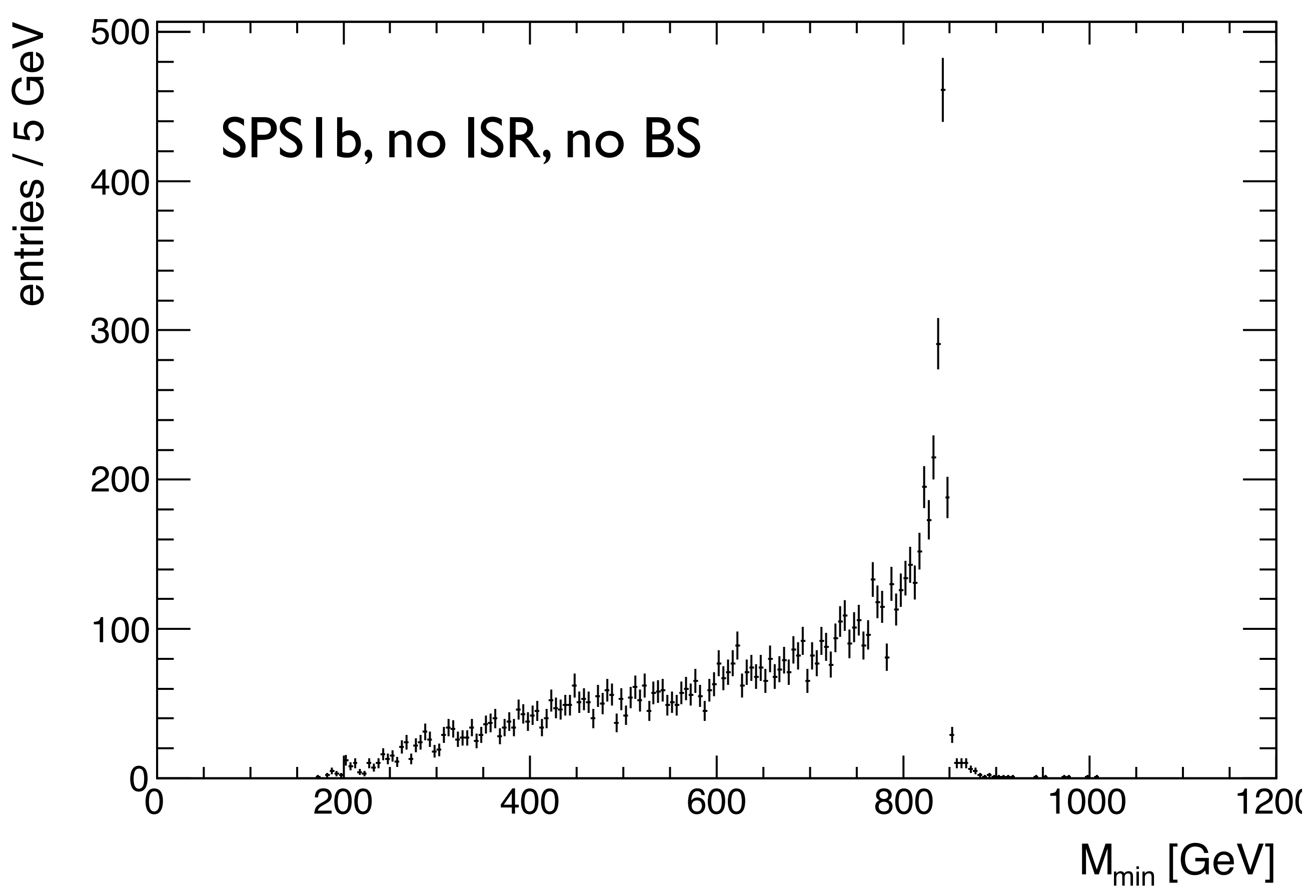
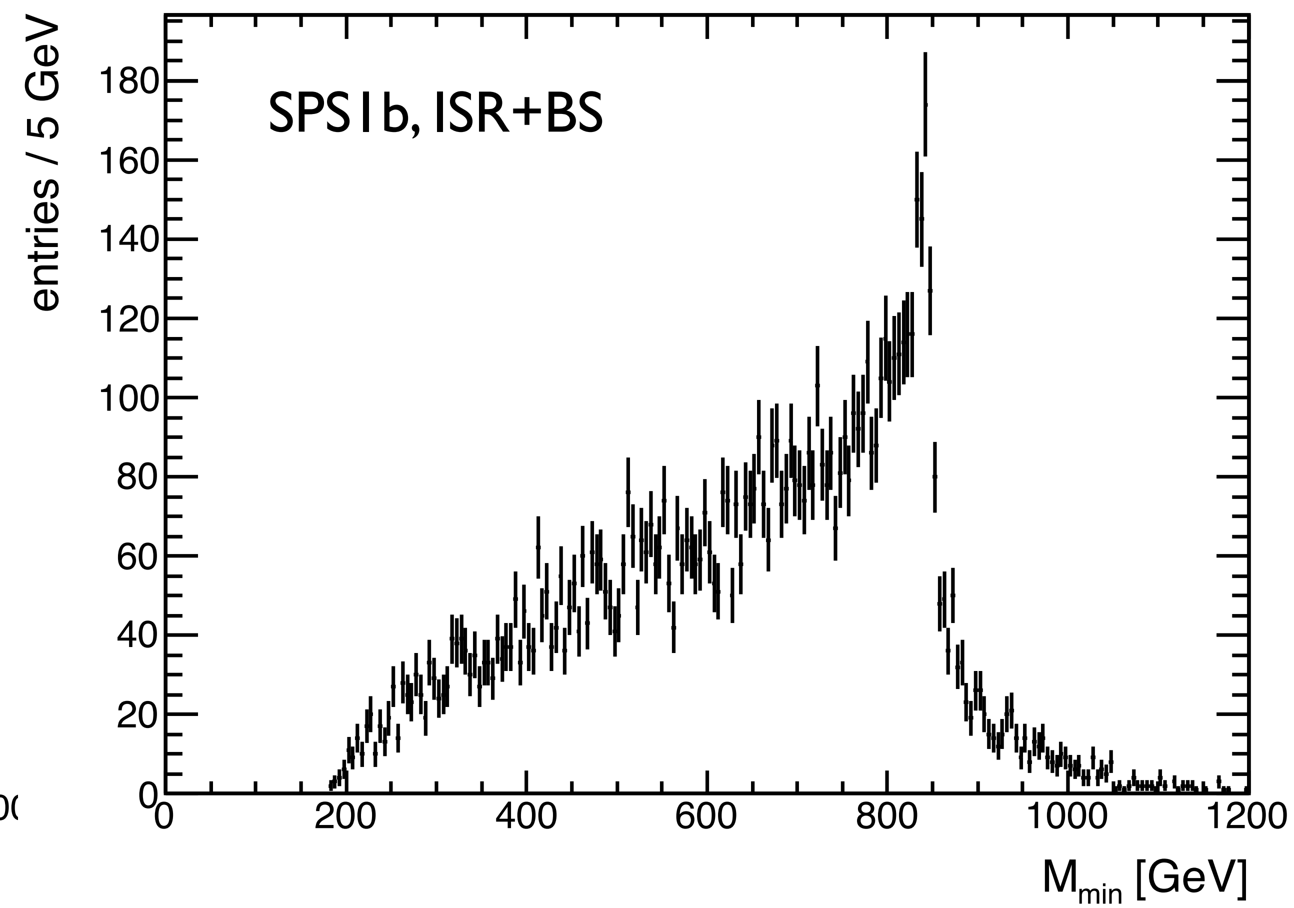




➯ peaks at true squark mass: good for low statistics

➯ reduced distortions from beamstrahlung

Mass Measurement Techniques: M_C

- Several new techniques studied for LHC: Need independence from collision energy, typically use only transverse observables
- Interesting technique: A modified invariant mass, calculated from the four momentum of one quark and the parity-transformed four momentum of the other quark

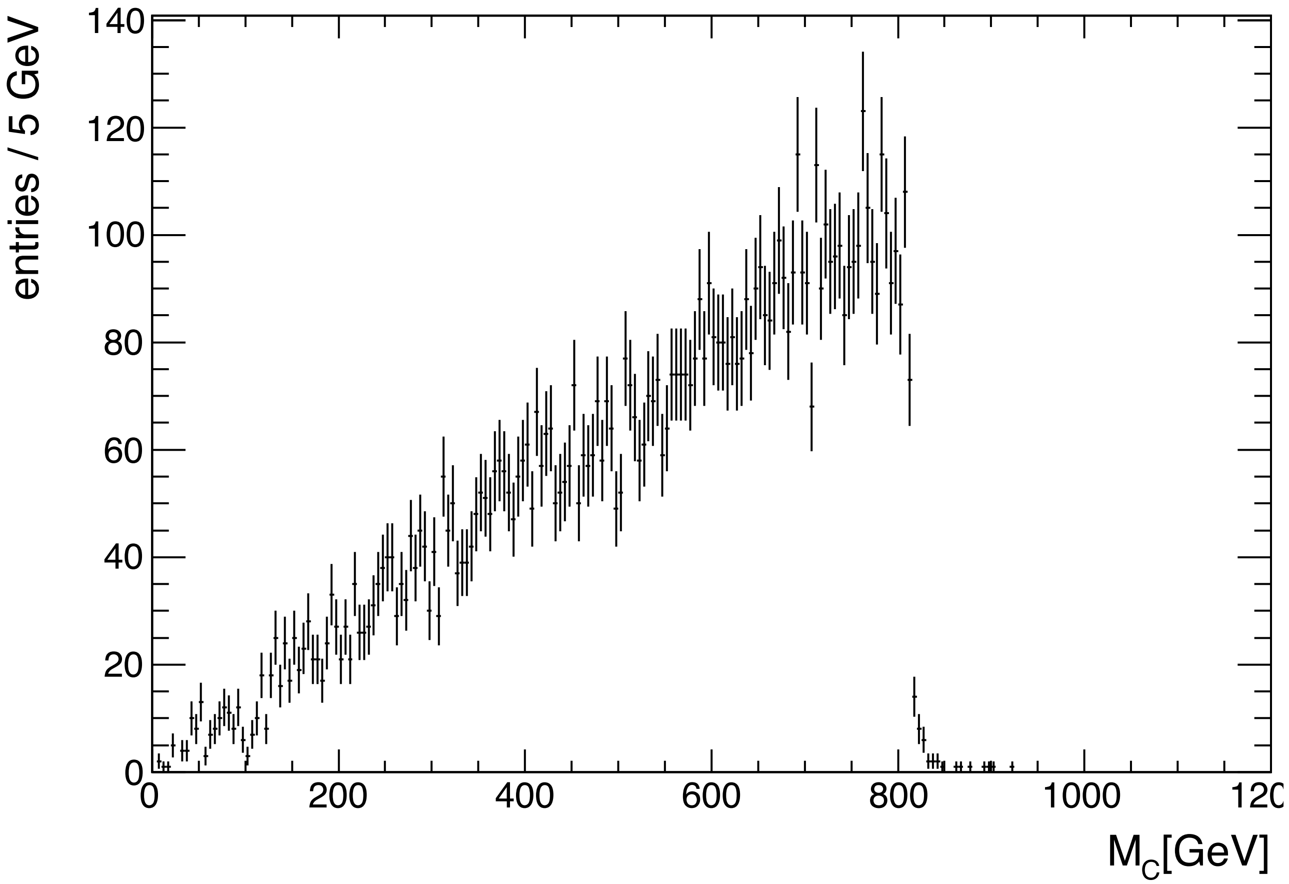
D.R. Tovey, JHEP 04, 34 (2008)

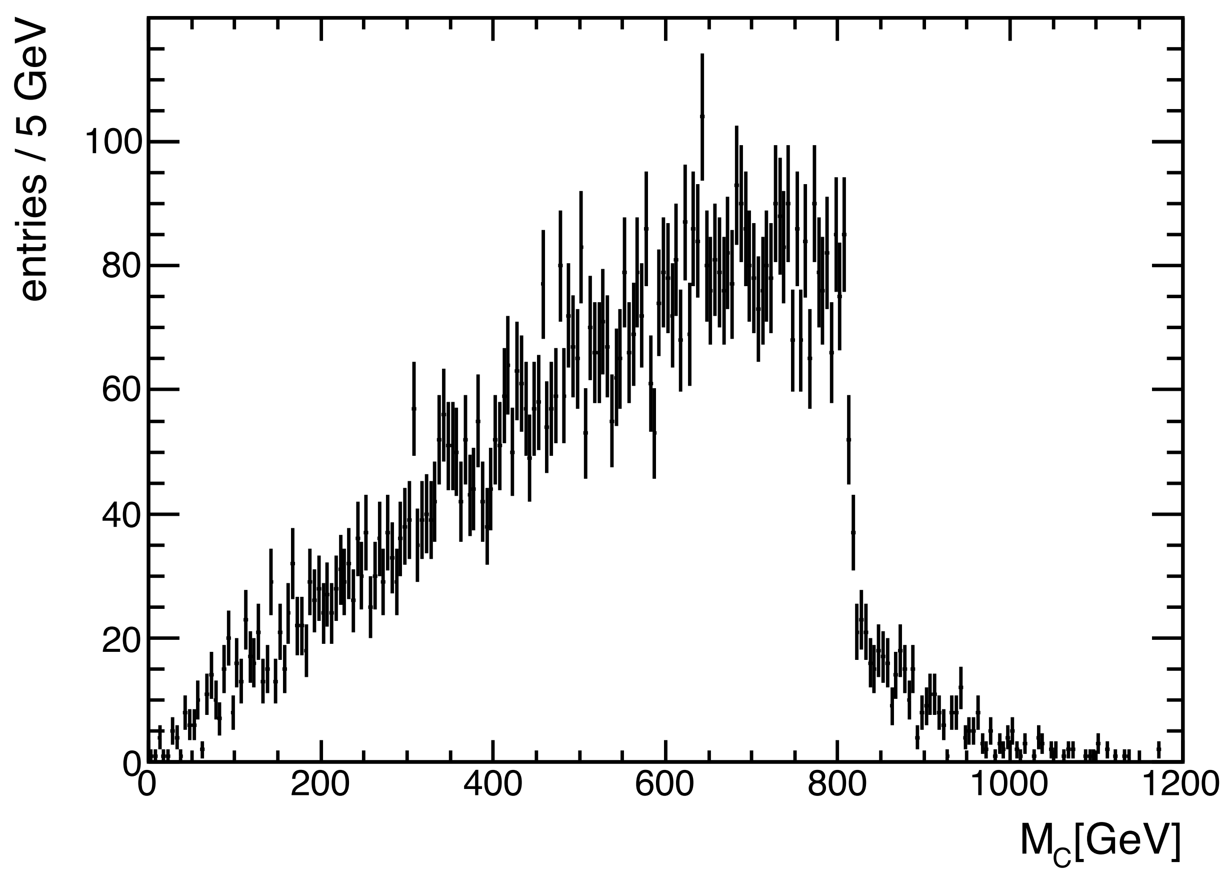
  - invariant under contra-linear boosts: works for back-to-back pair production of particles
    - at LHC, use a transverse form, use full 3D for lepton colliders
  - requires quark momenta and neutralino mass as input

upper edge of distribution given by: $$M_C^{max} = \frac{m_{\tilde{q}}^2 - m_\chi^2}{m_{\tilde{q}}}$$

Mass Measurement Techniques: M_C

- Collision energy does not enter: Reduced sensitivity to collider energy spectrum (beamstrahlung enters due to boost along beam axis)
- Maximum at upper edge: Advantageous in environments with low statistics
- Simple tri-angular shape (without cuts and distortions): Potentially easy to fit





First Look at the CLIC Benchmark Scenario

- Studies within the CLIC benchmark scenario
  - cross section at 3 TeV: $\sigma(\tilde{u}_R) = 1.14\,\mathrm{fb}$ $\sigma(\tilde{d}_R) = 0.29\,\mathrm{fb}$
    - total: $\sigma(\tilde{u}_R, \tilde{d}_R, \tilde{s}_R, \tilde{c}_R) = 2.9\,\mathrm{fb}$
      (without ISR and beamstrahlung, reduced for realistic collider energy distribution
    - compare to SPS1b: total cross section $\sigma(\tilde{u}_R, \tilde{d}_R, \tilde{s}_R, \tilde{c}_R) = 5.0\,\mathrm{fb}$

- Generator-level studies including hadronization
  - WHIZARD 1.95, unpolarized beams
  - Simple jet finding, detector resolution parametrized using expected PFA performance
  - Acceptance: $|\cos\theta| < 0.99$, $p_T > 0.25$ GeVs

Signal, Background and Cuts

	Final State	σ (with ISR + BS)
Signal	qqχχ (u,d,s,c)	~ 1.8 fb
SM Background	qq	~ 2300 fb
	qqνν	~ 950 fb
	qqee	~ 3300 fb
	qqeν	~ 5300 fb
SUSY	qqννχχ	~ 1.0 fb
	qqlνχχ	~ 8.5 fb
	qqllχχ	~ 0.6 fb

still under study:

qqll, qqνl for l = μ, τ

- First cut-based study: Cuts optimized for a signal efficiency of 20% with TMVA
  - cuts on N_{reco}, accoplanarity of jets, cosθ, jet invariant mass,
    invariant mass of two reconstructed jets
    transverse momentum relative to event thrust axis
    missing p_T, maximum lepton momentum in event
- General selection cuts - based on event characteristics (missing E, di-jet final state)
  - E_{vis} < 2.3 TeV, E_{Jet} < 1.4 TeV, no lepton with more than 400 GeV

Cuts: Signal and Background Distributions

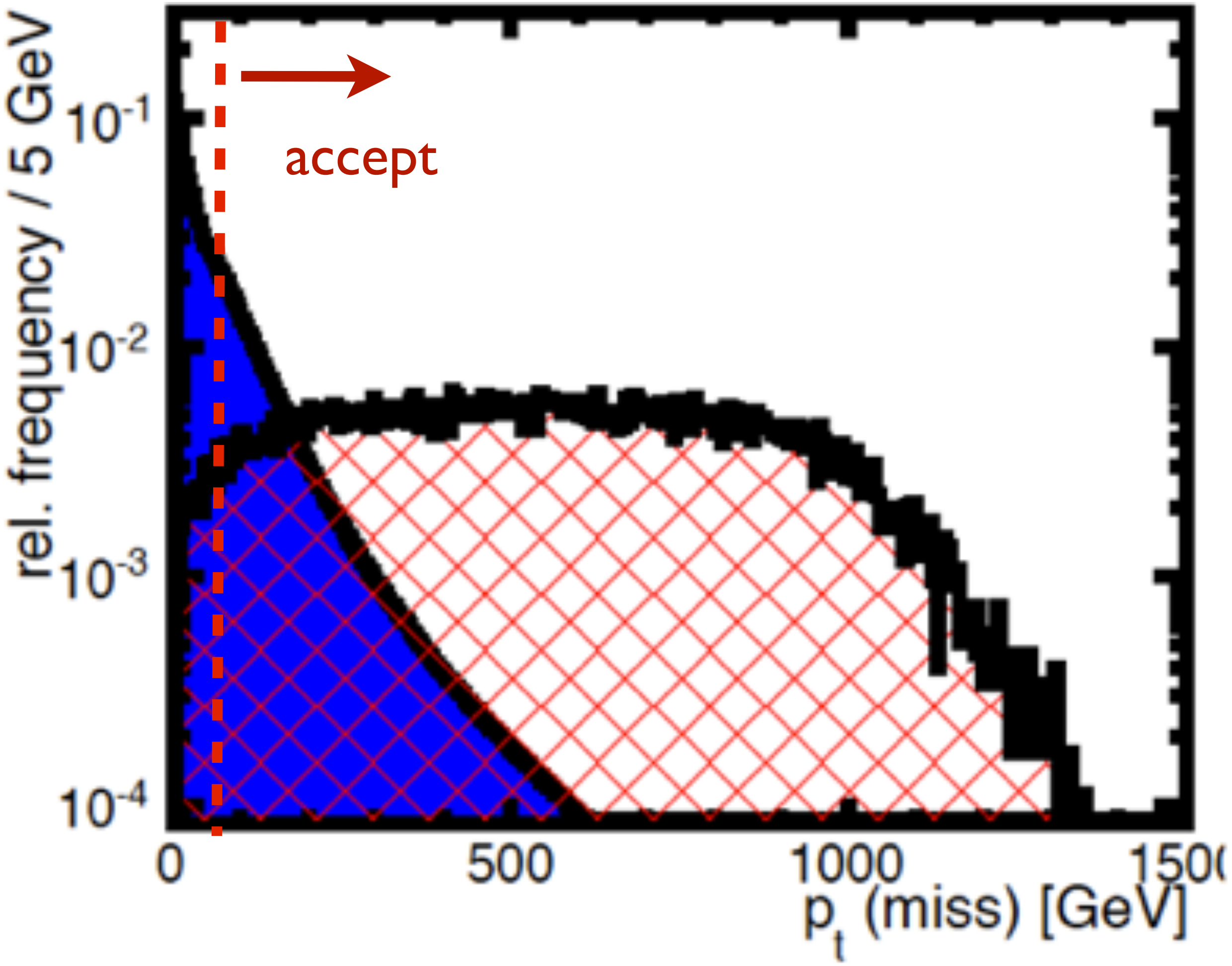
For 2000 fb^{-1} (~4 years of CLIC running):

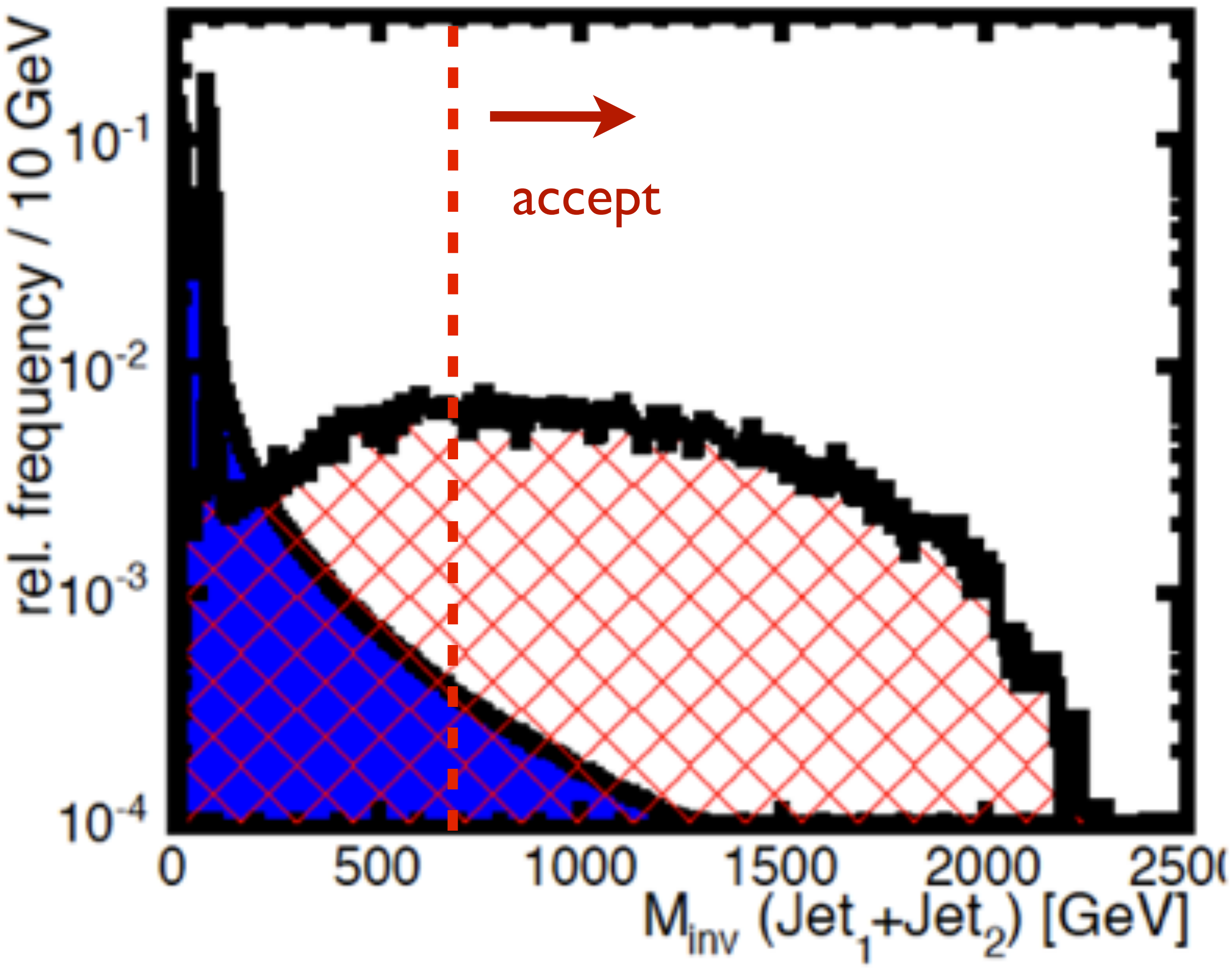
~ 650 Signal events

~ 60 SUSY background events

~ 230 SM background events

(+ contributions from μ, τ final states)



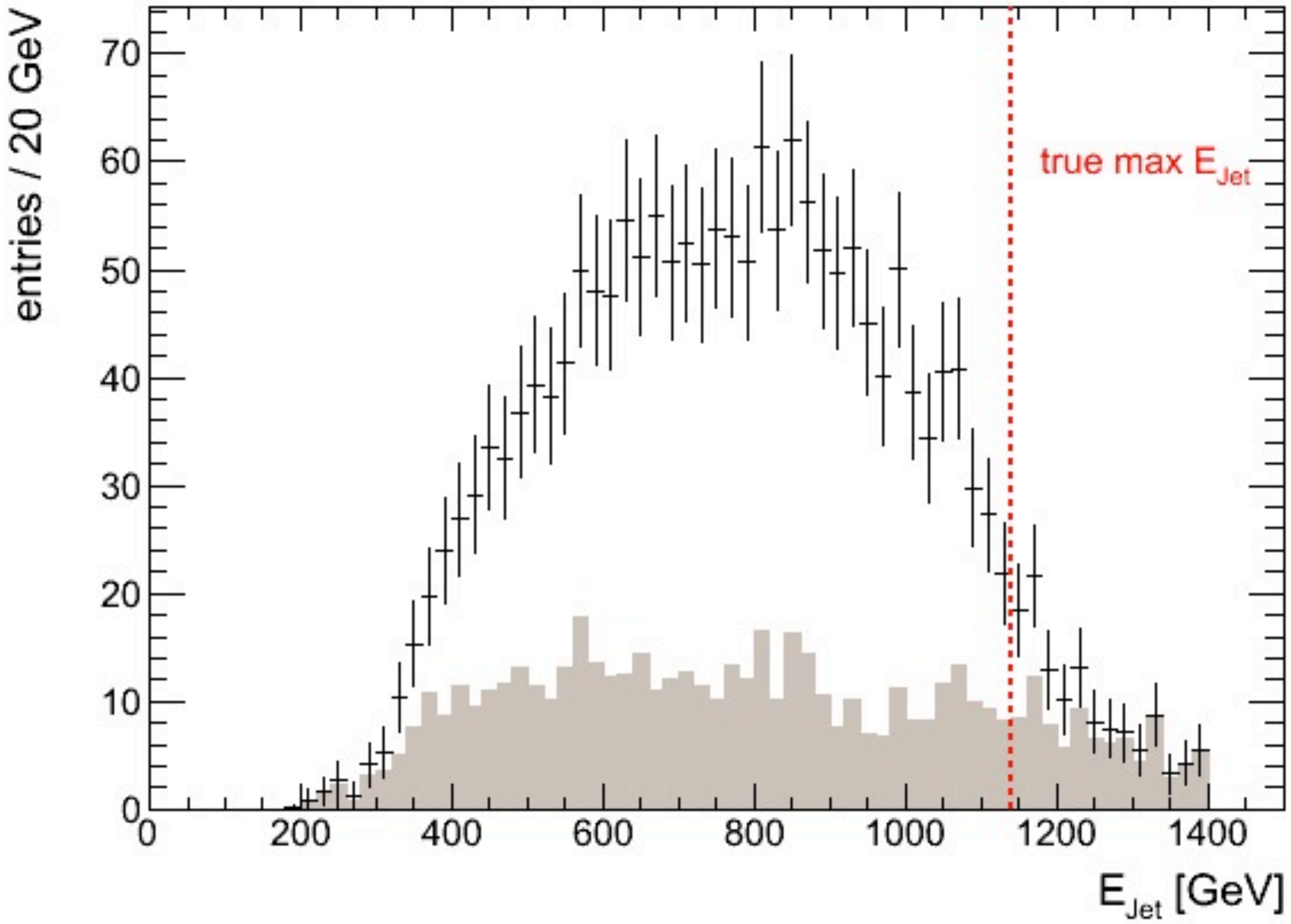


➩ efficiency for signal: 0.2

➩ efficiency for background: 1.4×10^{-4}

Jet Energy: Signal & Background

- Illustration of the effects of cuts and background (both SUSY and SM) on distributions:



In the simple jet energy distribution, both the upper and lower edges are significantly distorted:

- lower edge strongly affected by cuts
- upper edge suffers from cuts, beamstrahlung and background extending beyond the endpoint

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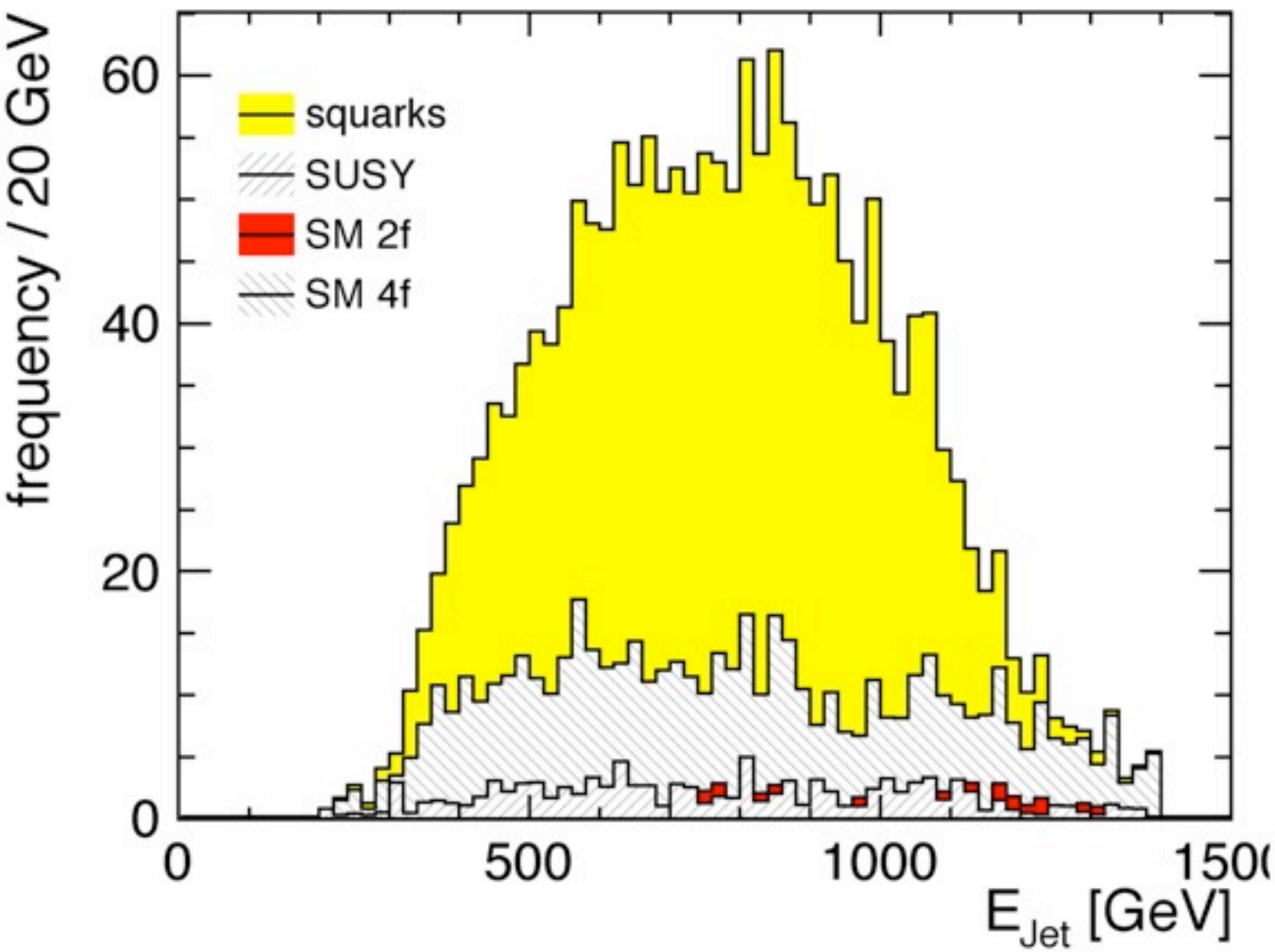

SM four fermions is the dominant background

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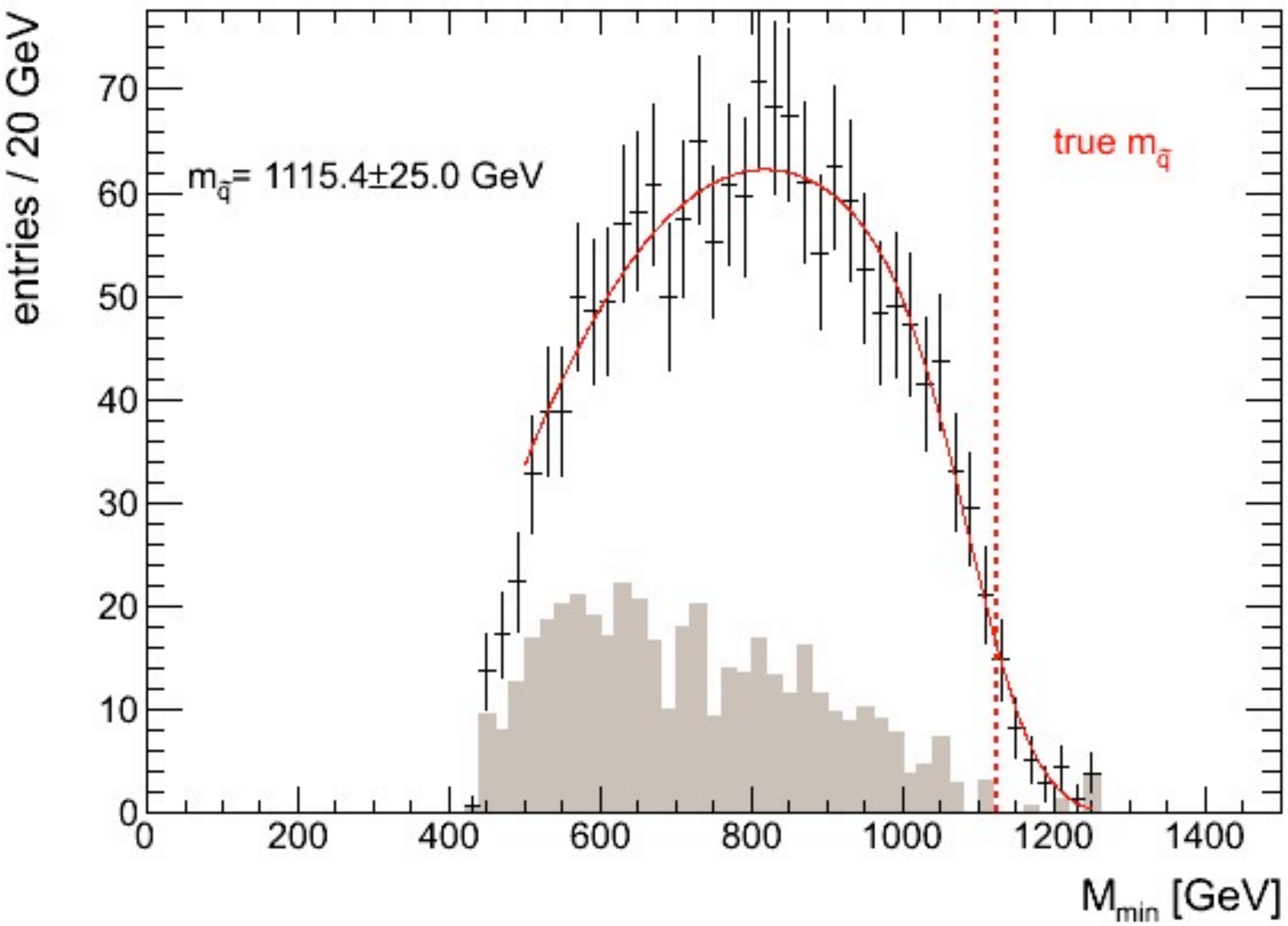
Minimum Squark Mass: Signal & Background

- Minimum squark mass:
  - cuts, beamstrahlung and detector resolution strongly affect distribution shape
  - upper edge remains, background underneath distribution endpoint completely removed: Good possibility for mass measurement (assuming M(χ) is known)



Fit of distribution with a 2nd order polynomial multiplied by an error function

Extraction of the squark mass from the fitted mean of the error function:
Obtained mass consistent with true values within errors

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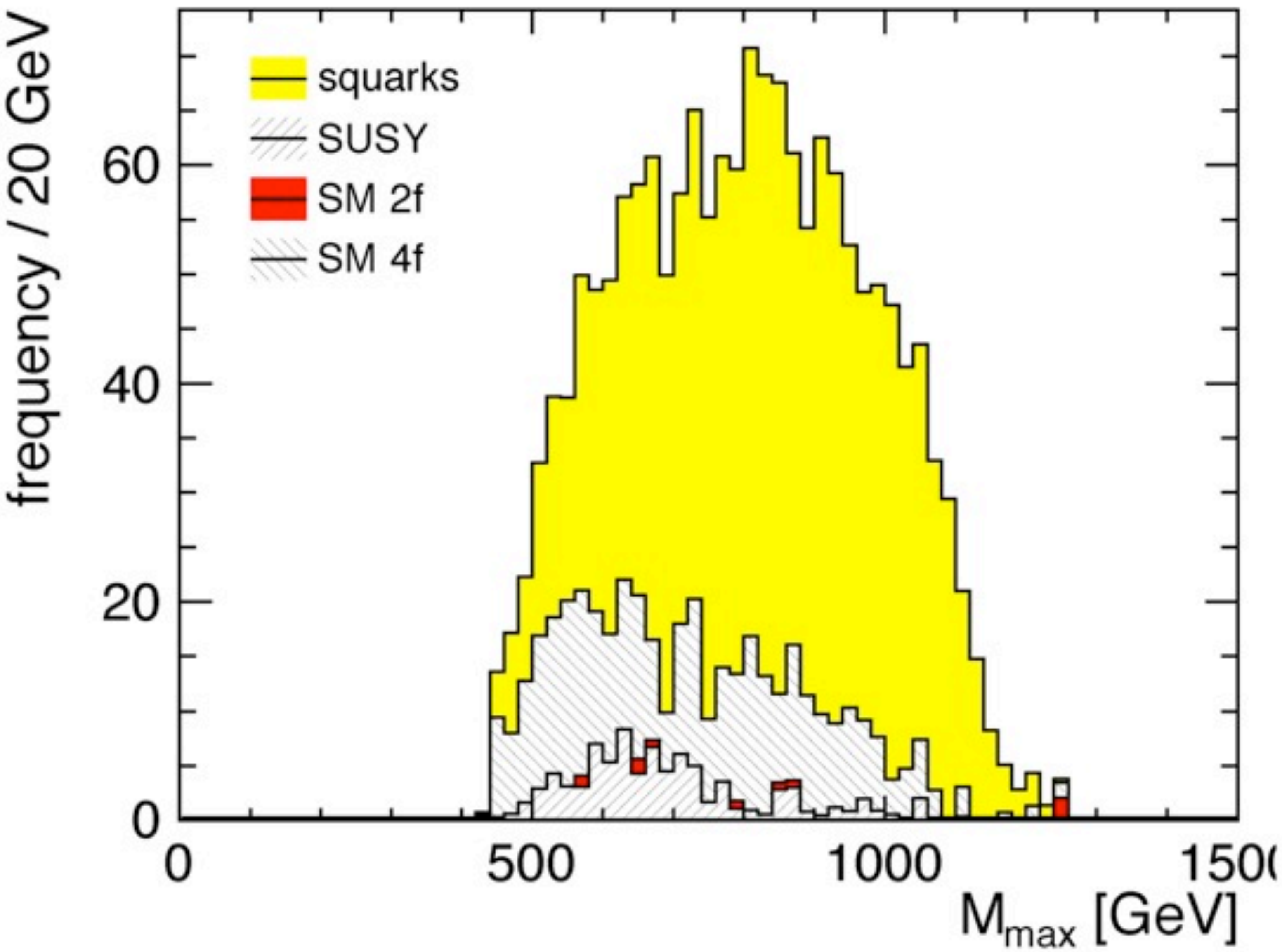

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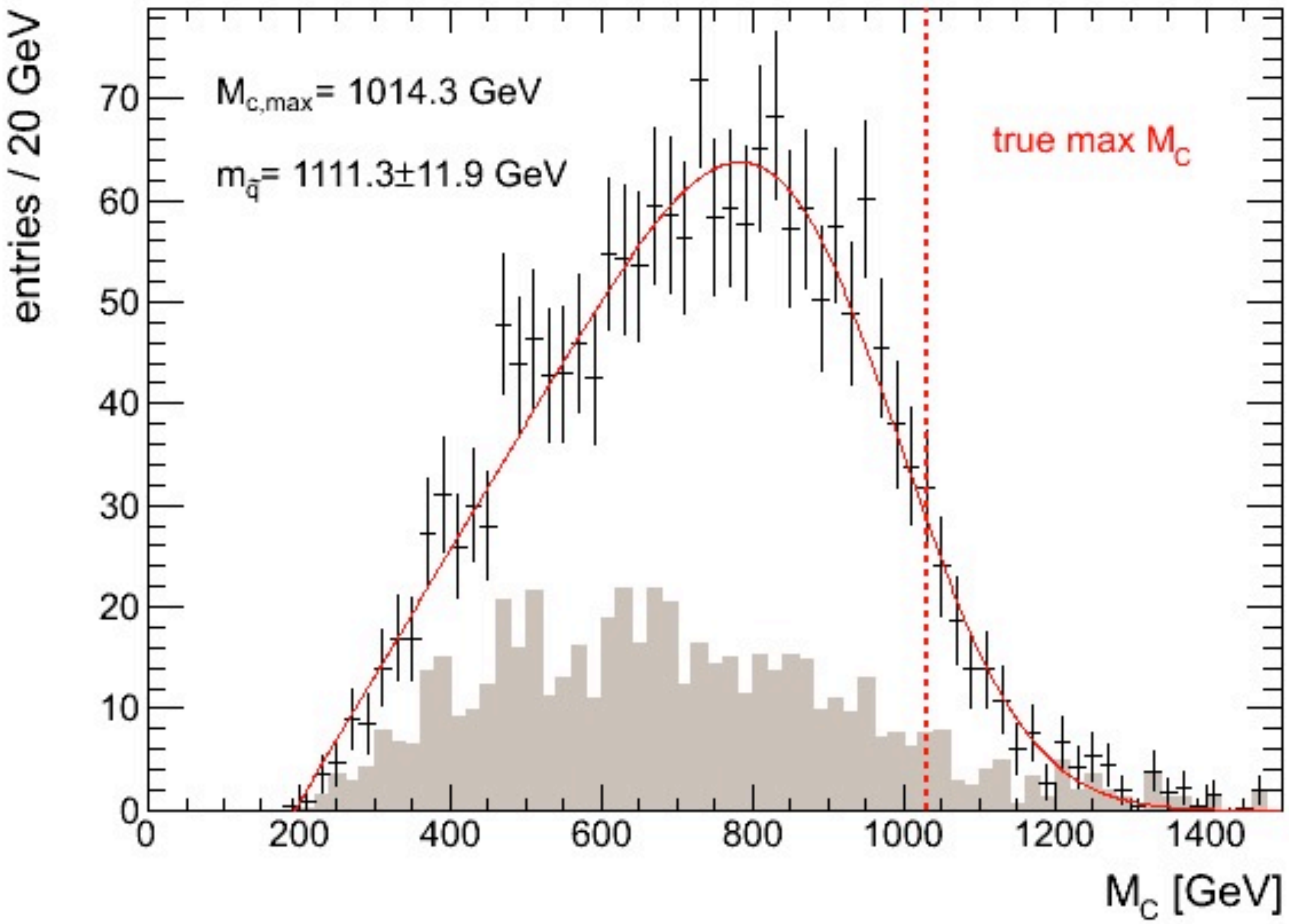
  - moderate influence of background on the upper edge of the distribution, smooth distortions by analysis effects



Fit of distribution with a 1st order polynomial multiplied by an error function

Extraction of maximum M_C from half maximum of the fitted rising edge: Offset from true value by about 10 GeV, consistent with error determined from toy MC

M_C: Signal & Background

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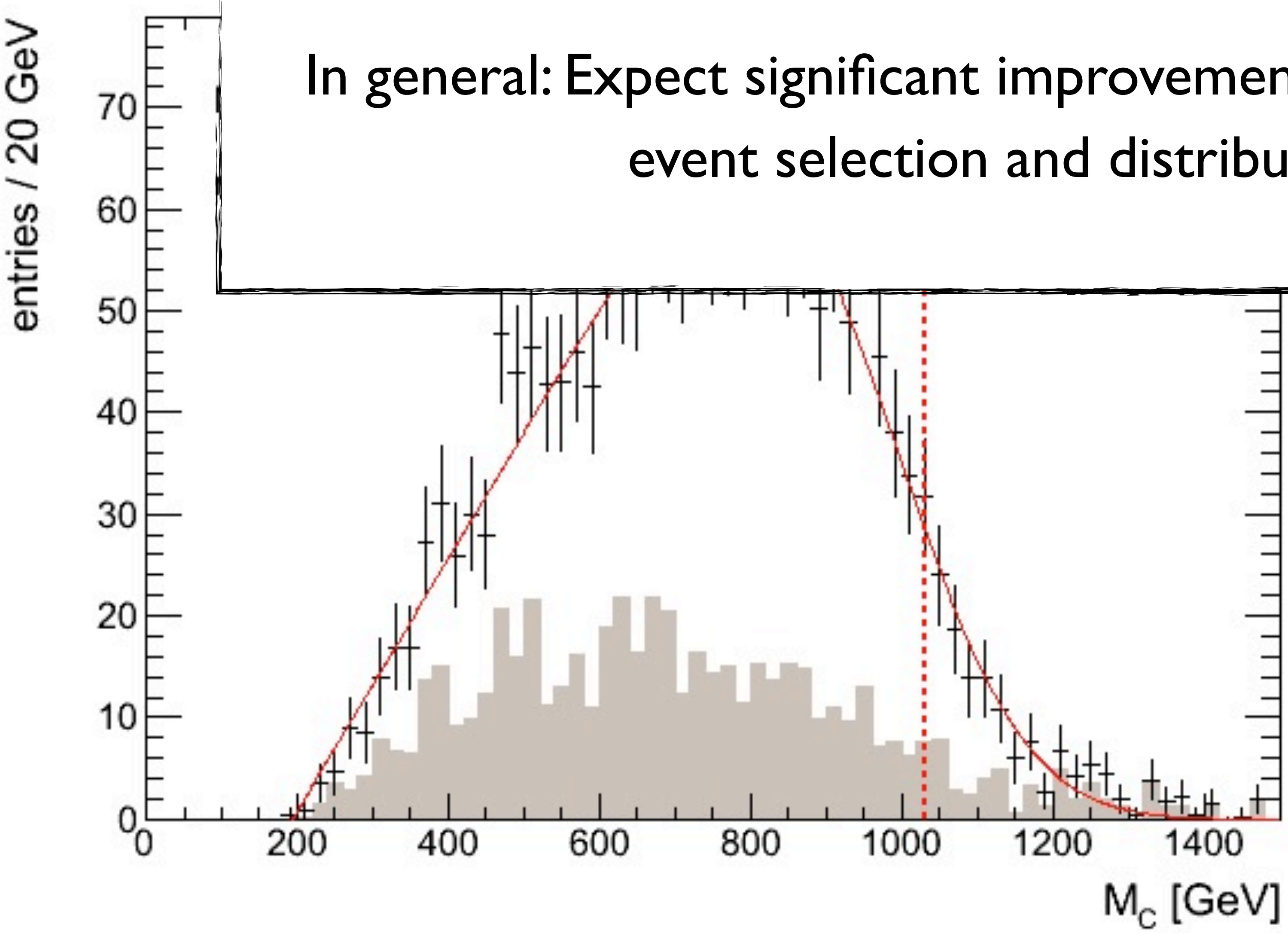
In general: Expect significant improvement expected with more sophisticated event selection and distribution fitting techniques!



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Summary / Outlook

- The study of light-flavored squarks is an integral part of SUSY spectroscopy
  - Right-squarks have potentially very simple two body decays

- Several techniques exist for the mass measurement of particles with semi-invisible two-body decays
  - Classic jet energy endpoints suffer significantly from beamstrahlung
  - More sophisticated observables using neutralino mass appear promising

- A first generator-level study including SM and SUSY backgrounds
  - Initial cut-based study shows high signal purity can be reached
  - ‣ Further optimization of analysis in progress

- Selected as one of the benchmarks for the CLIC CDR:
  - ‣ Full simulation of signal, SM and SM backgrounds coming up