Mass and Cross Section Measurements of light-flavored Squarks at CLIC

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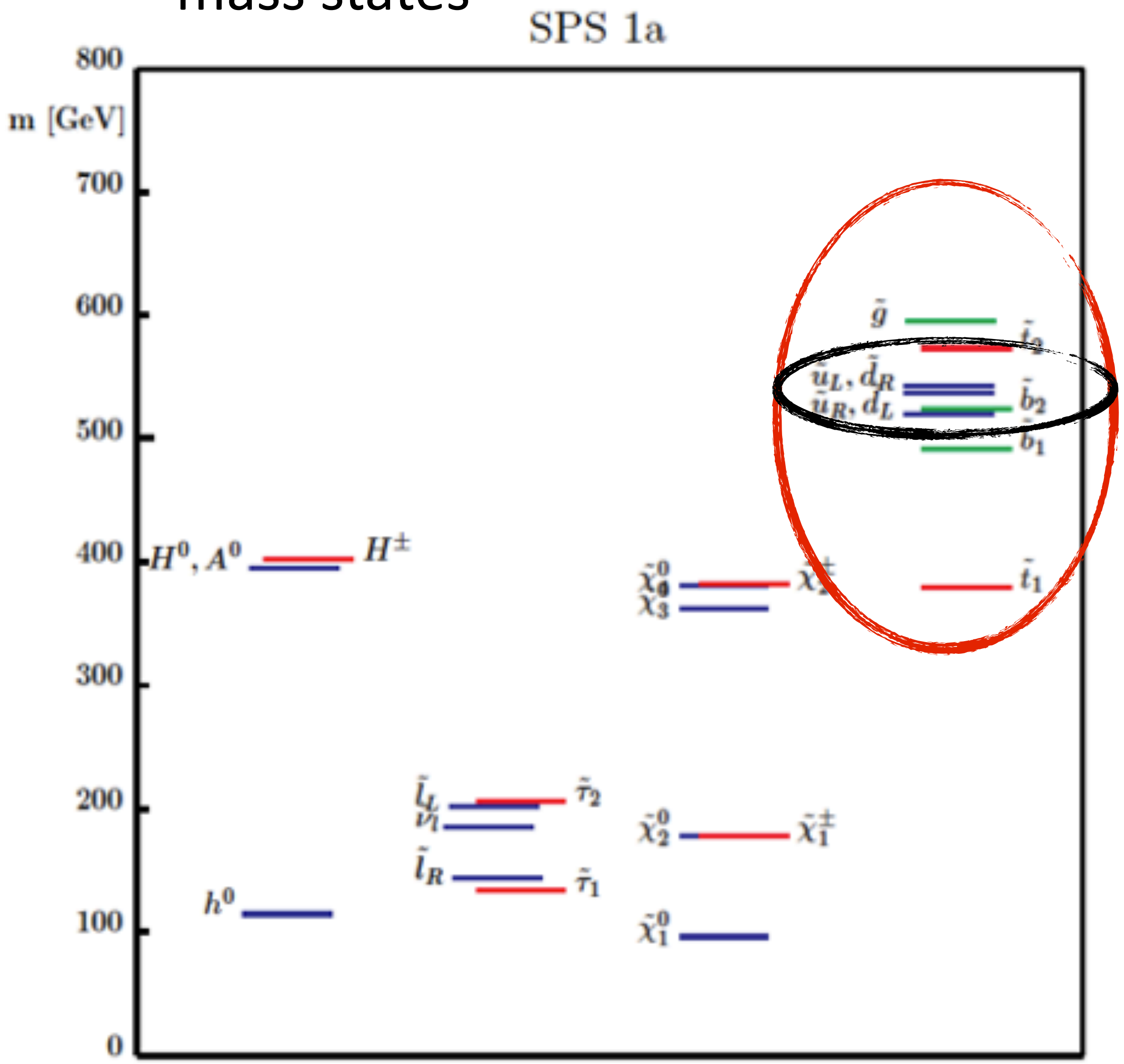
Overview

- Squark production at e^+e^- colliders
- Measuring squarks at CLIC
  - Experimental conditions
  - Pile-up from $\gamma\gamma \rightarrow$ hadrons processes
  - Controlling Standard Model backgrounds
- Mass & cross section extraction

Squarks: The Domain of Multi-TeV Colliders

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

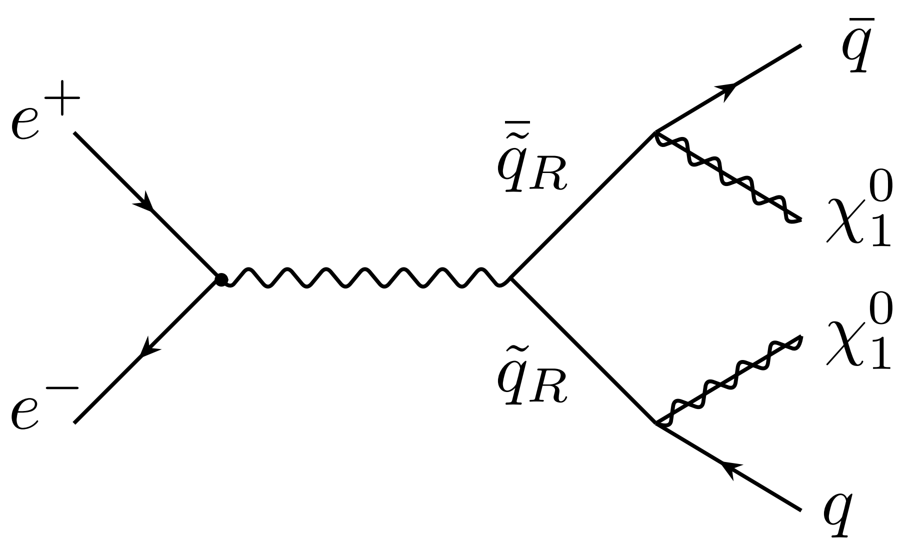


- typically no distinction between first and second generation:
  - up, charm squarks and down, strange squarks have equal masses
  - small mass difference between up-type and down-type
  - mass difference between left- and right squarks

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

Light-flavored Squark Production & Decay

- The CLIC benchmark scenario for the CDR:
  - Light-flavored (u, d, s, c) Right-Squark mass ~ 1.12 TeV
    (LHC is getting close to that mass value...)
  - Neutralino mass 328 GeV
- Right-Squarks as benchmark process:
  - Decay exclusively into neutralinos: right-squarks don't carry weak isospin - No coupling to Winos
  - Simple event signature: Two highly energetic jets, missing energy
    - SM-Background can be a challenge!



3 TeV CLIC cross section (u, d, s, c): ~ 1.45 fb

(almost) exclusive decay $\tilde{q}_R \to q\chi_1^0$

Production ratio up / down type: 4:1

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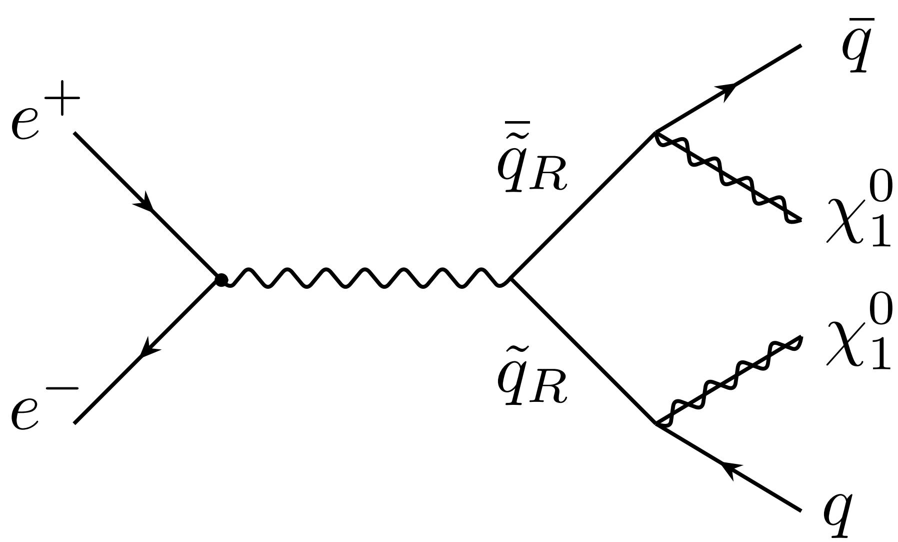
General observation:
The CLIC performance for this benchmark process is also relevant for other new particles decaying into one quark and an invisible particle!



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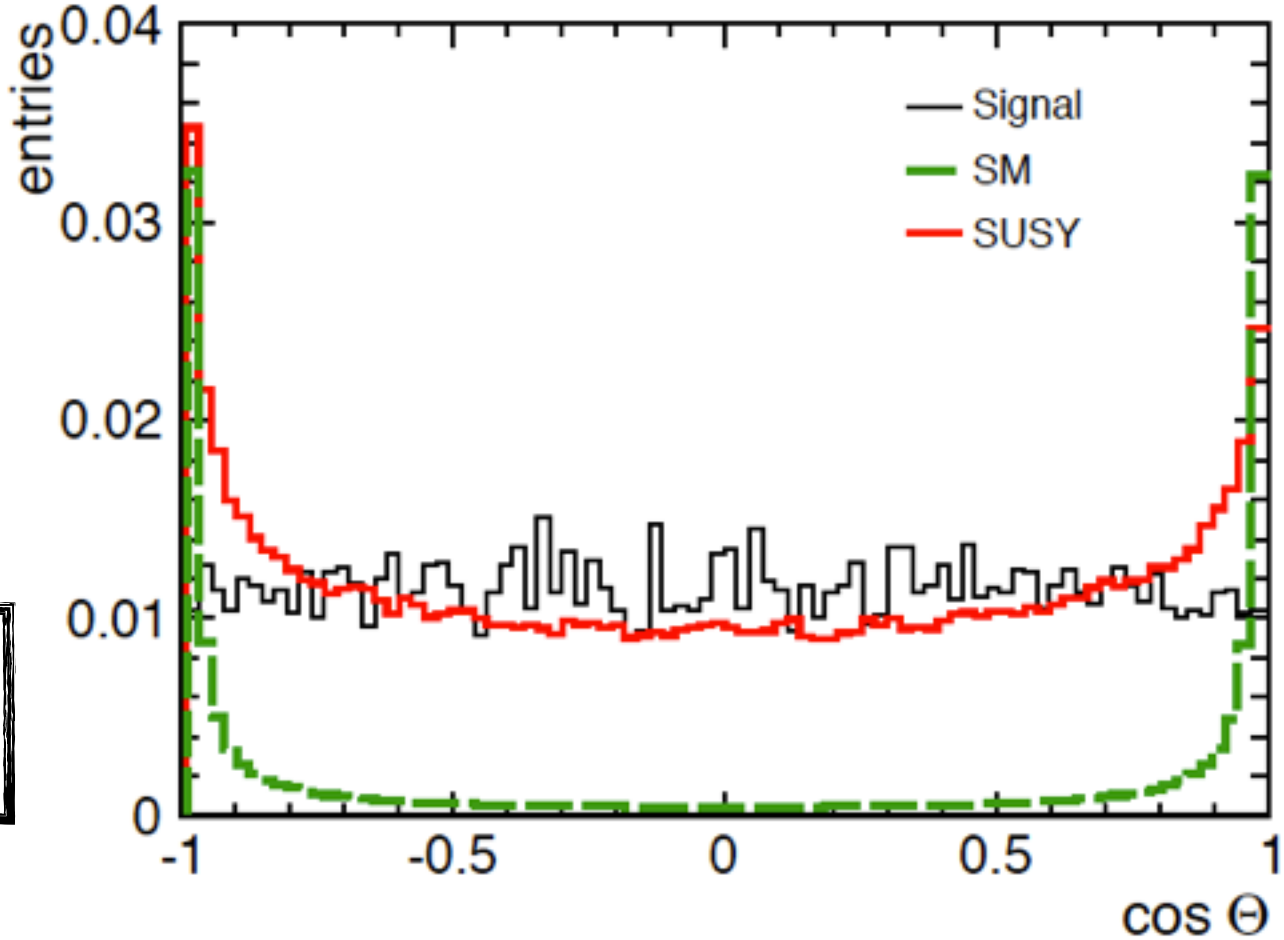
Light-flavored Squark Production - Signal & Background

- Signal flat in cosθ
- Backgrounds peak forward and backward
  - Dominating background SM 4 fermion final states - xsect ~ 10 pb - almost 4 orders of magnitude above signal



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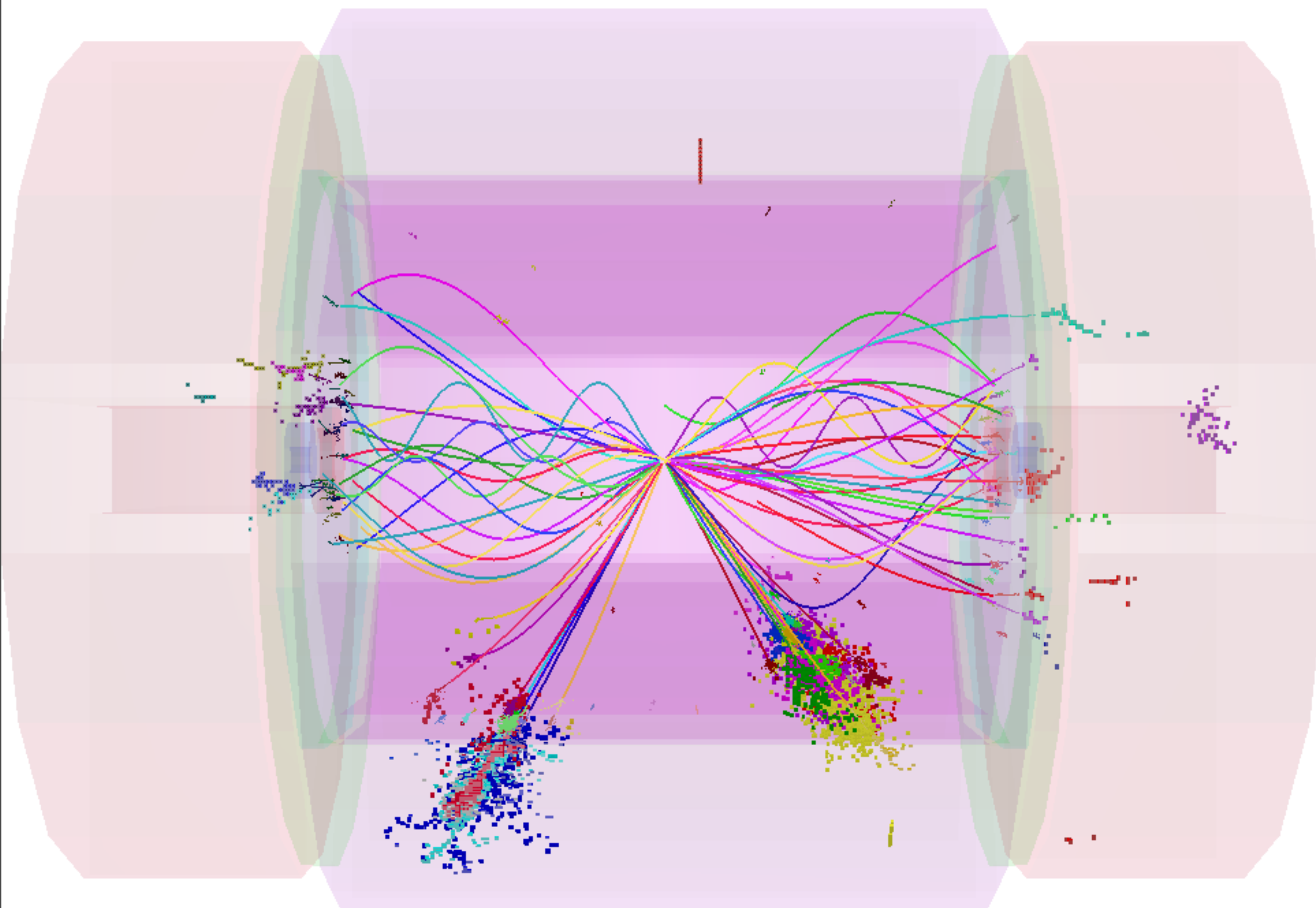

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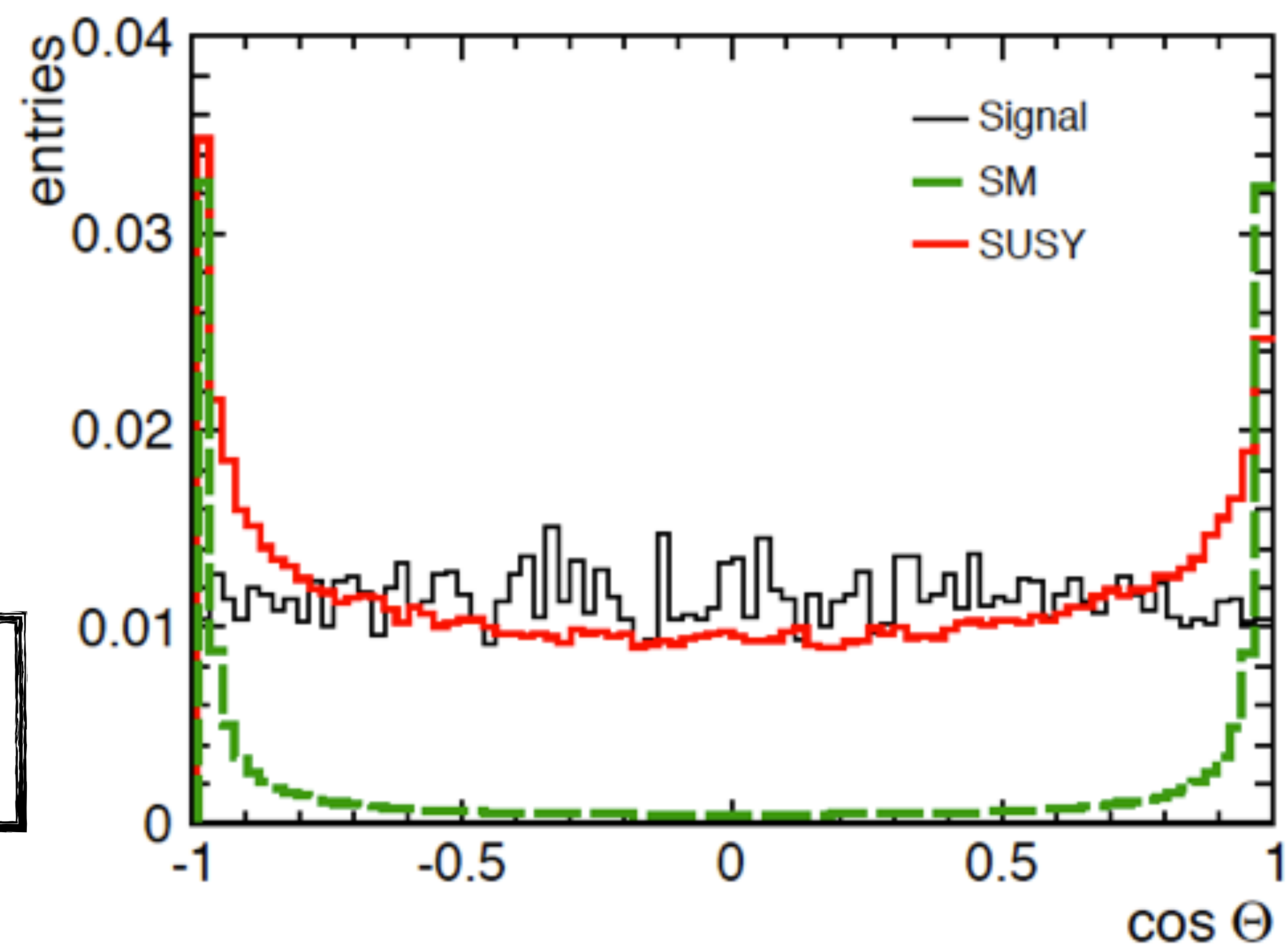

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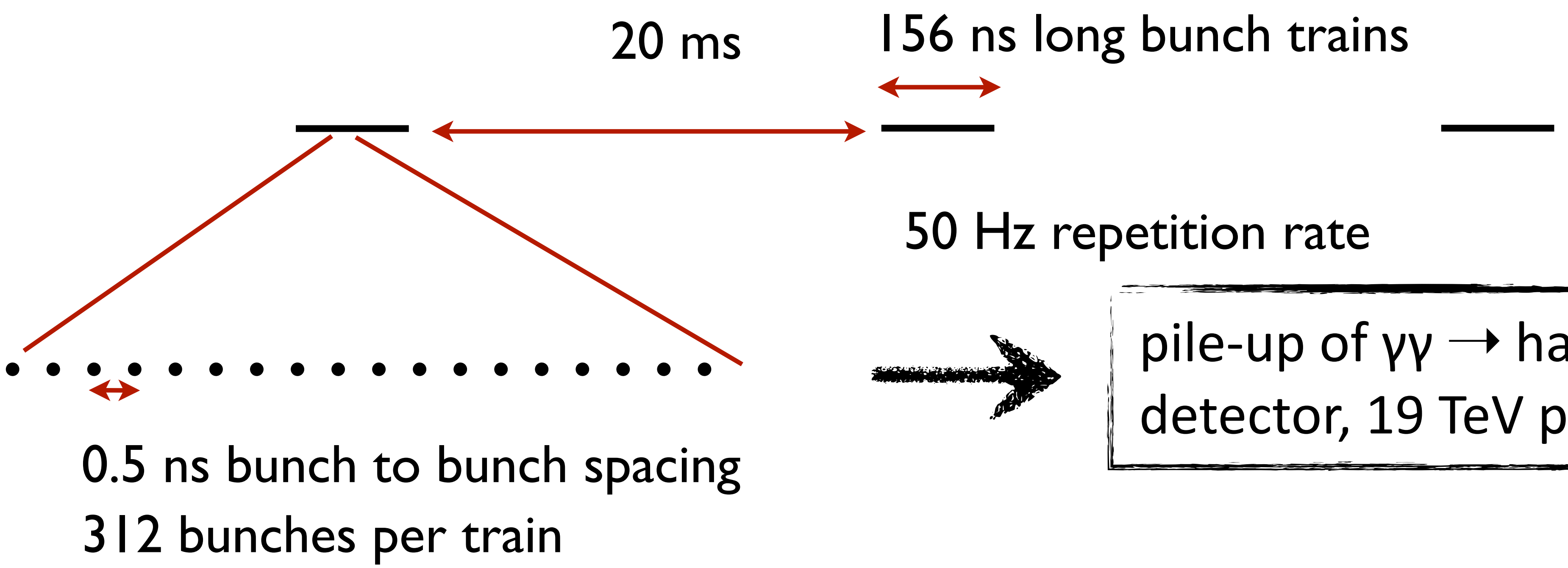
The Conditions at CLIC

- There is a price to pay for high energy
  - Mini-jet production in two-photon processes, γγ → hadrons, has a sizable cross section: ~ 3.2 events / bunch crossing
  - High beamstrahlung:
    wide beam energy spectrum with 35% of L in top 1% energy at 3 TeV

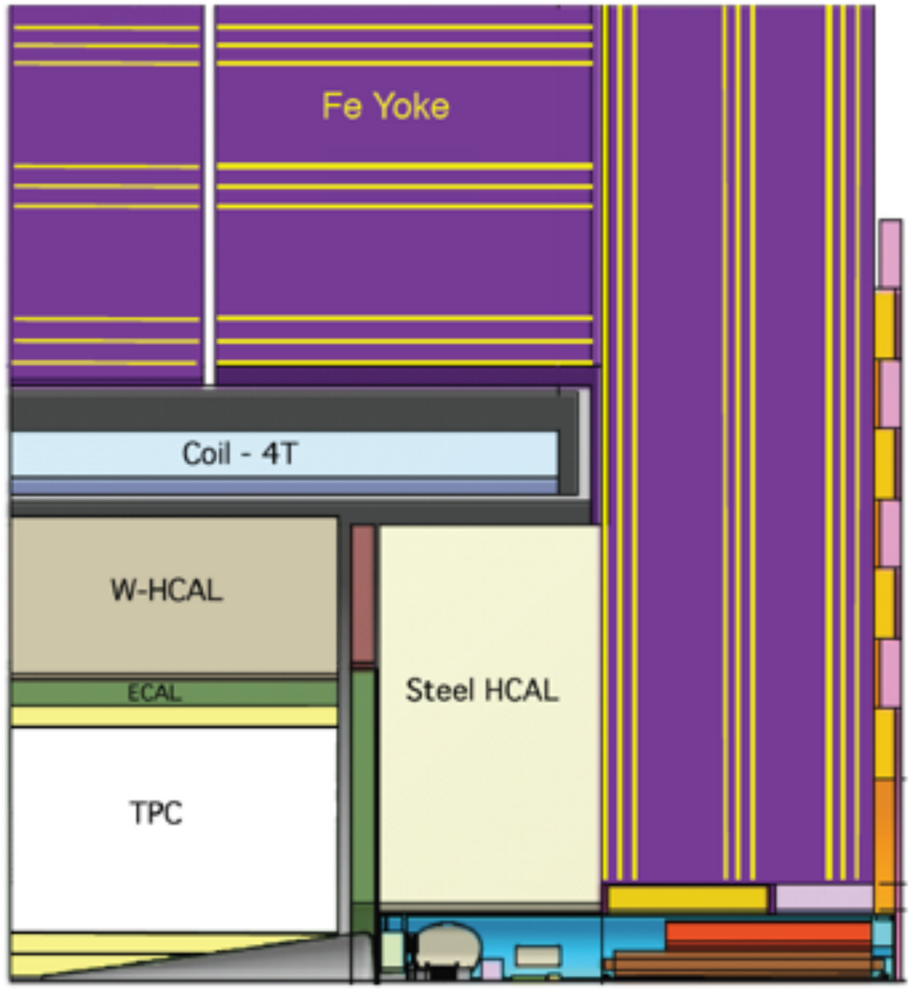
The CLIC bunch structure



pile-up of γγ → hadrons events in the detector, 19 TeV per bunch train at 3 TeV

The Study

- Performed in the CLIC_ILD detector model
  - Multi-purpose detector with large solenoid, TPC main tracking, highly granular calorimeters Tungsten HCAL in the barrel, precise time stamping



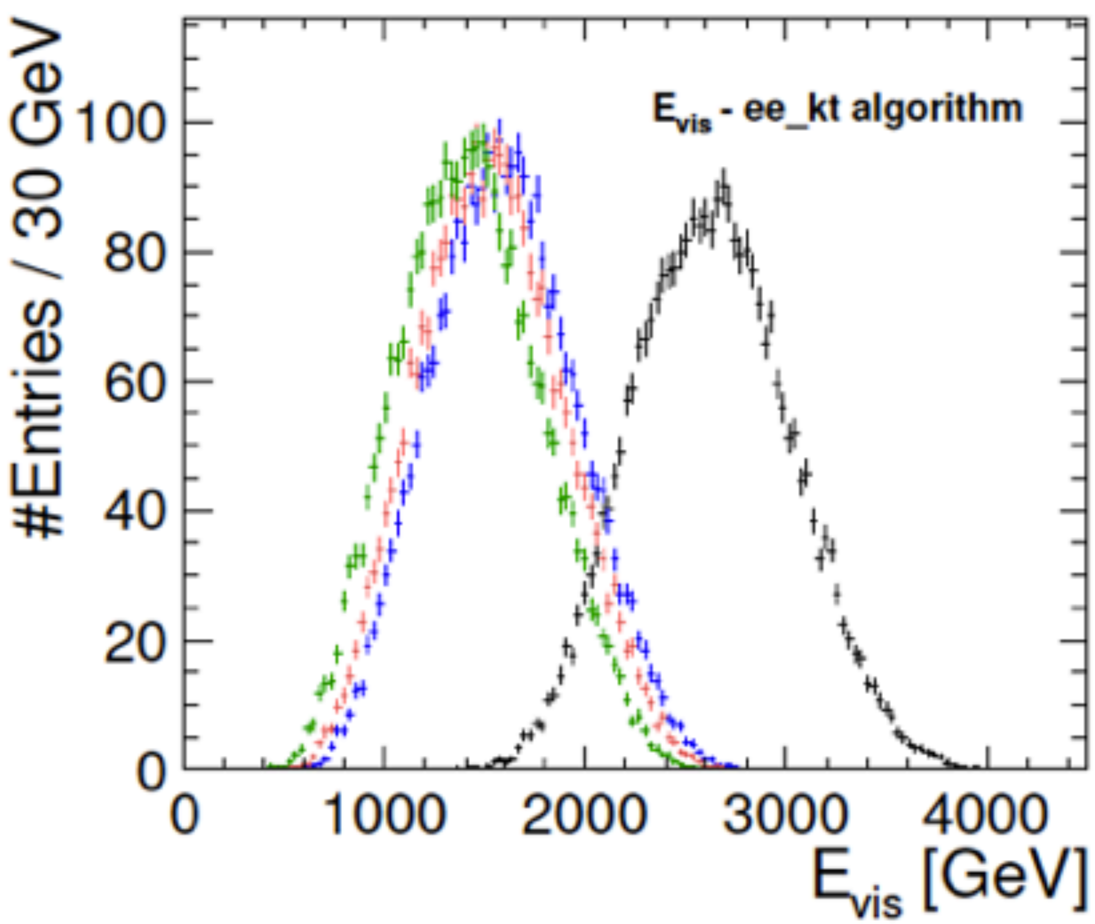
- Simulations with full GEANT4 detector model
- Overlay of γγ → hadrons (60 bunch crossings)
- Full simulation of signal and SM background, for 2 ab^{-1}

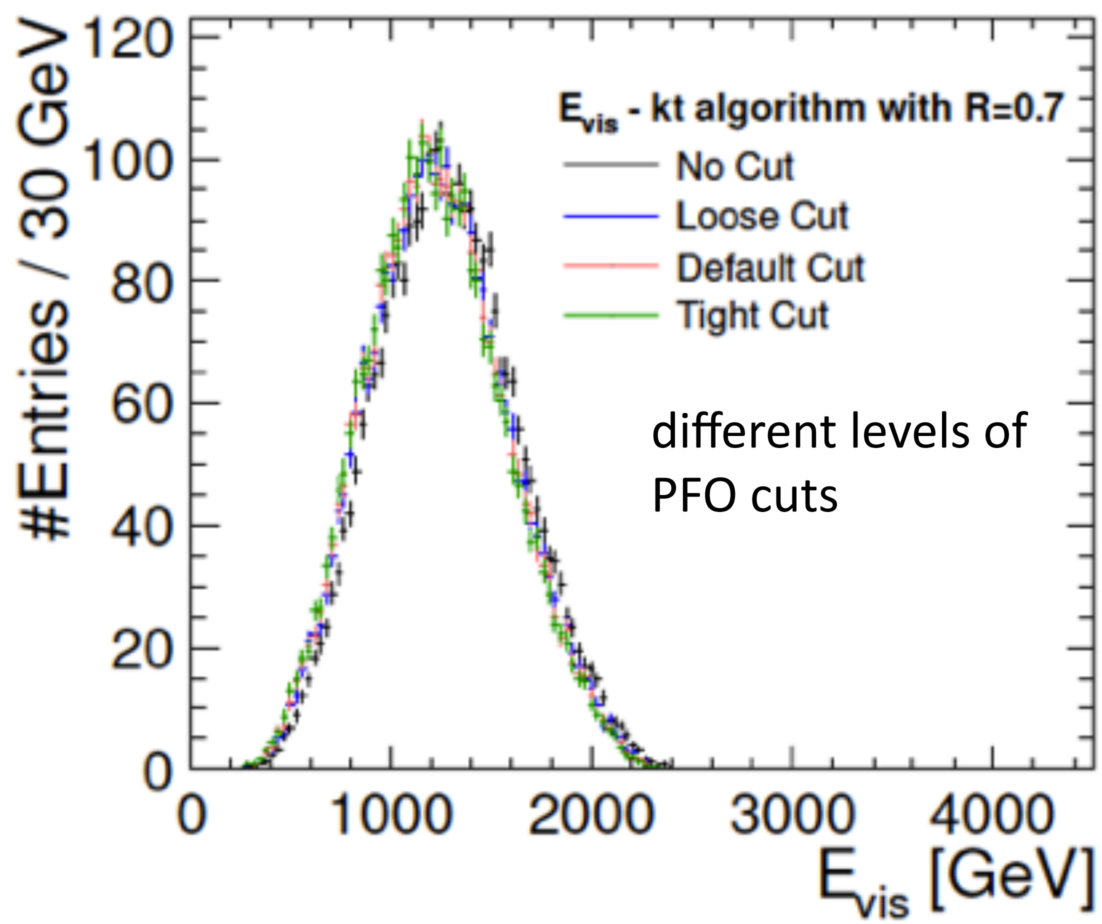
	Final State	cross section at 3 TeV
Signal	qqχχ (u,d,s,c)	~ 1.45 fb
SM Emiss	qqνν	~ 1500 fb
	qqeν	~ 5300 fb
	ττνν	~ 130 fb

... SM background without missing energy easy to reject, SUSY background has comparable cross section to signal, does not contribute substantially

Event Reconstruction & Beam Background Rejection

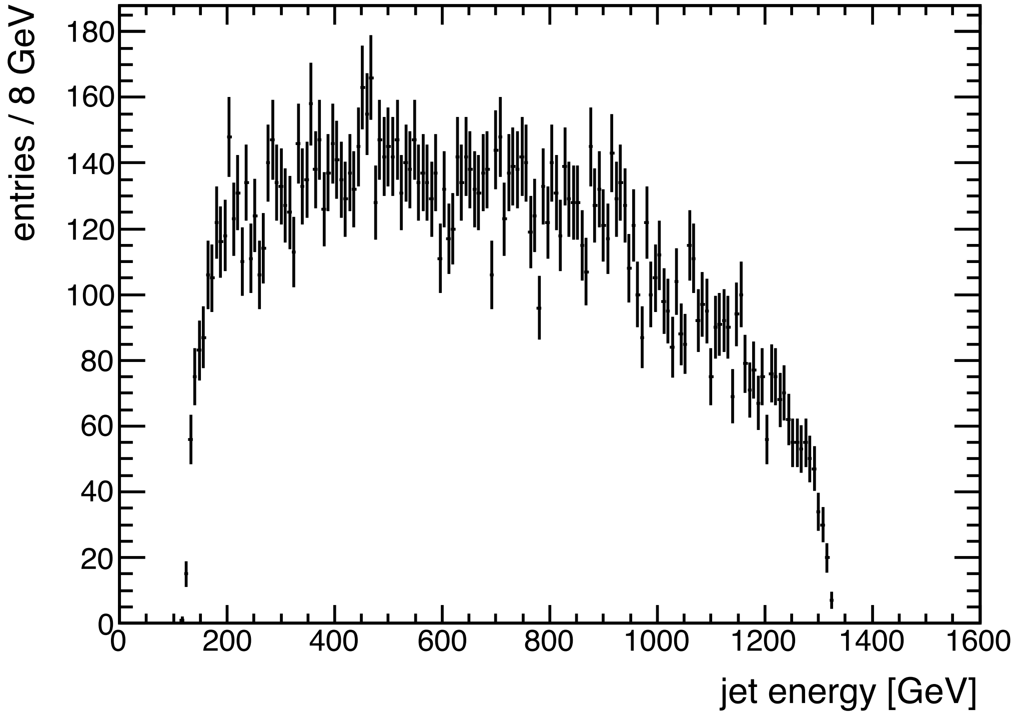
- Event reconstruction using PandoraPFA, PFO - level cuts to reduce the impact of background: Timing cuts, region-dependent p_T cuts
- The right jet finder is crucial - Signal events have two jets + missing energy
  - ee_kt: Two particle distance given by angle and k_t - susceptible to background
  - kt algorithm: Uses additional beam jets to pick up background close to beam axis, particle distance given by ΔηΔϕ - reduced background sensitivity in forward region





The Squark Mass Measurement

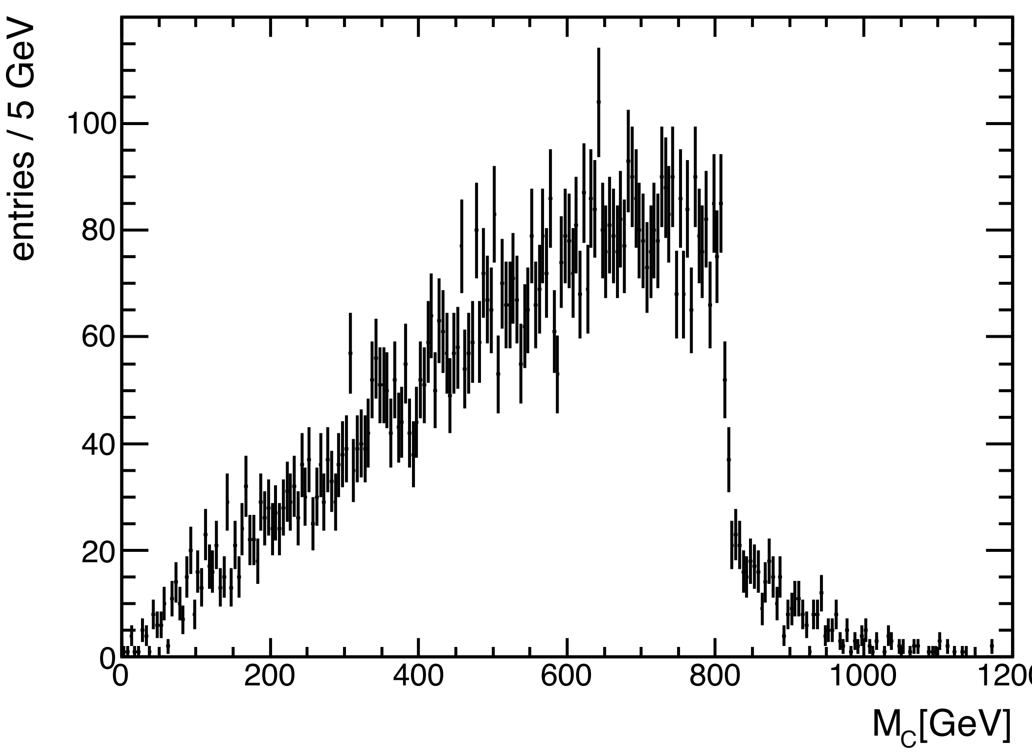
- Several techniques exist - the classic "box" given by the two jet energies



Example for SPS1b - Generator level, with CLIC beam energy spectrum

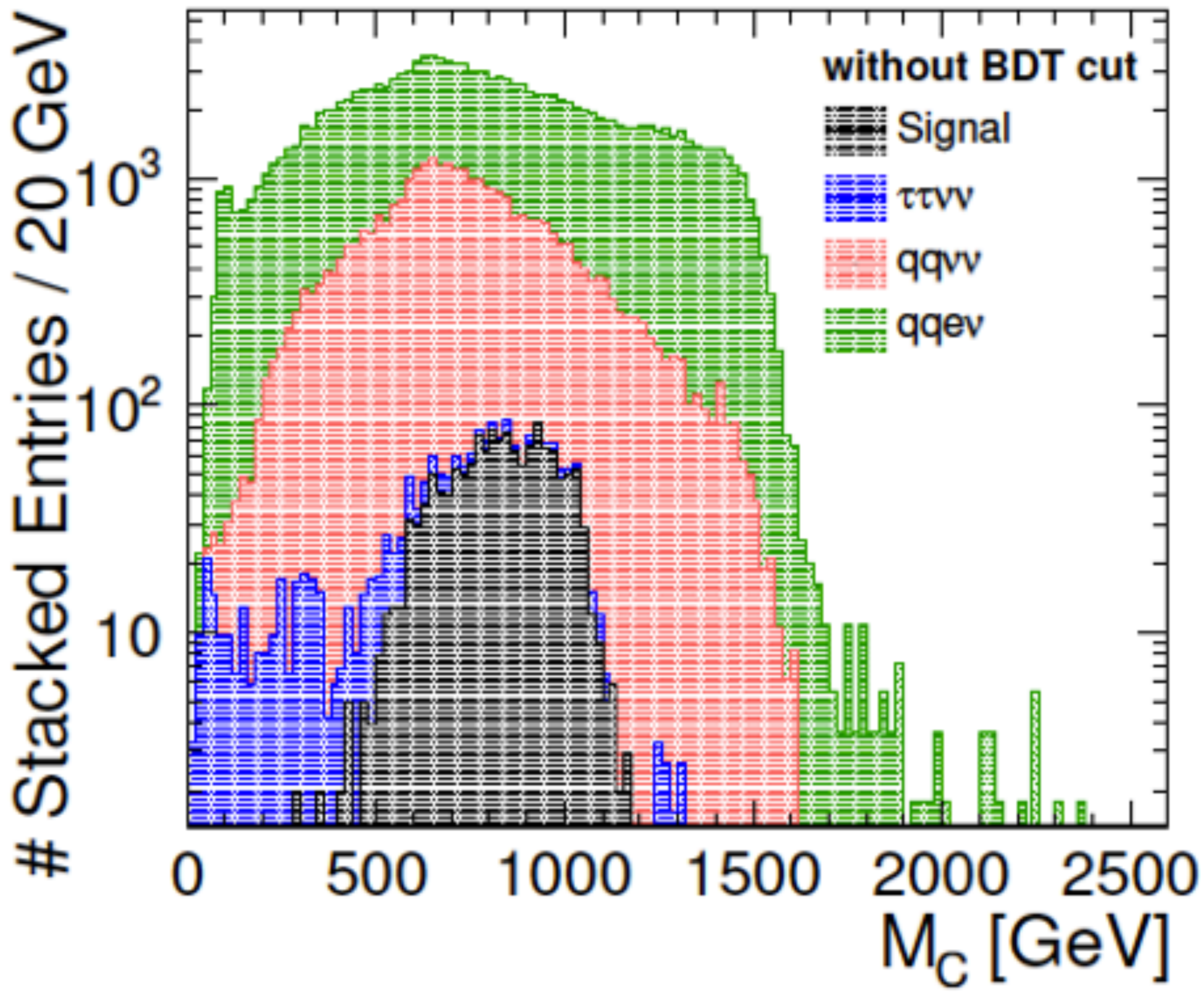
Distortion of upper edge
In addition: Edge further smeared by background, SM background extends beyond both edges

- M_C, a modified invariant mass formed out of the two jet energies, to first order independent of √s - Less impact of beam energy spectrum
  Requires knowledge of neutralino mass from other measurements (sleptons)



Coping with Standard Model Background

- SM Backgounds have almost 4 orders of magnitude higher cross section
  - Simple cut on missing transverse momentum reduces this by 2 orders of magnitude, still prohibitive



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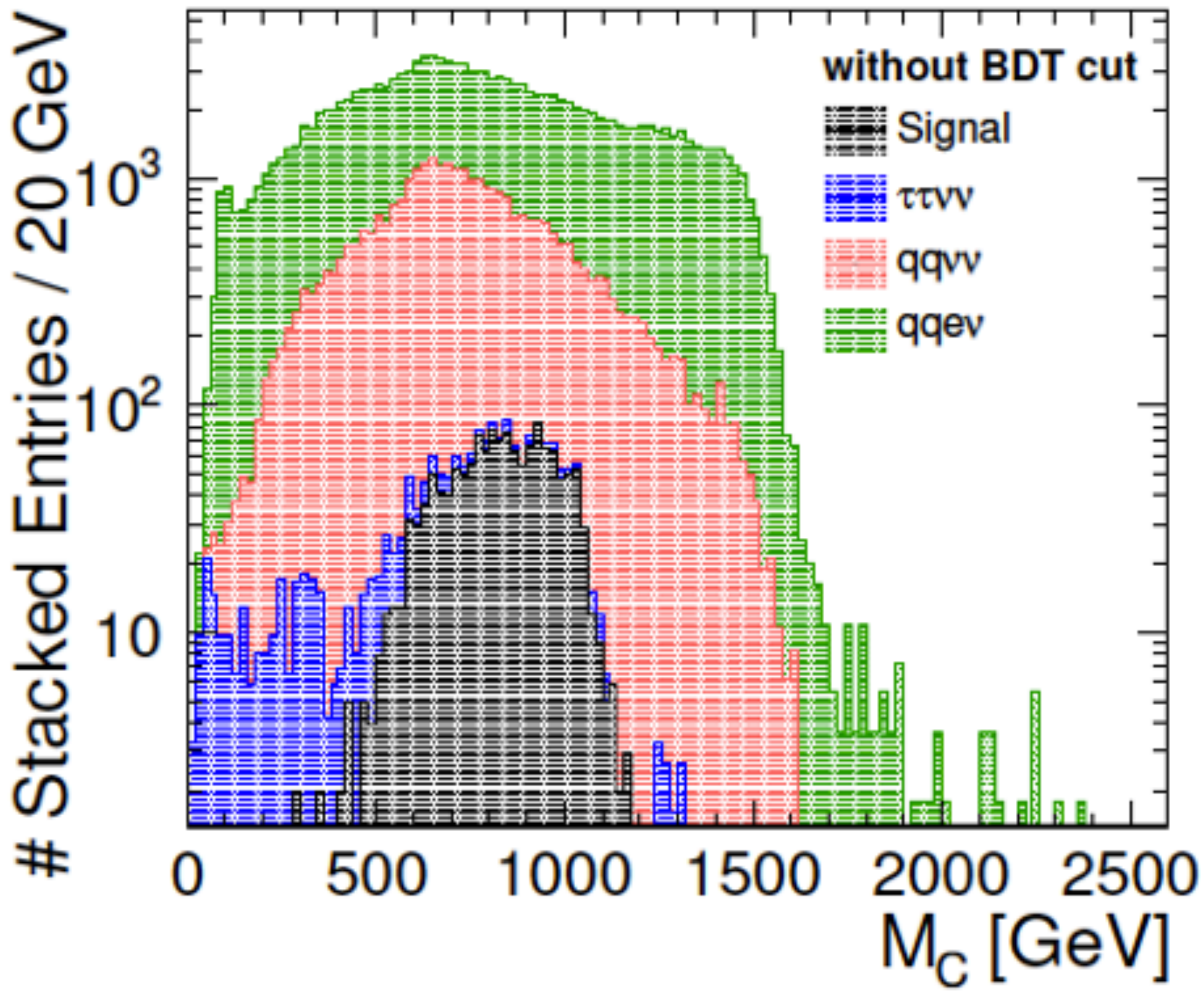
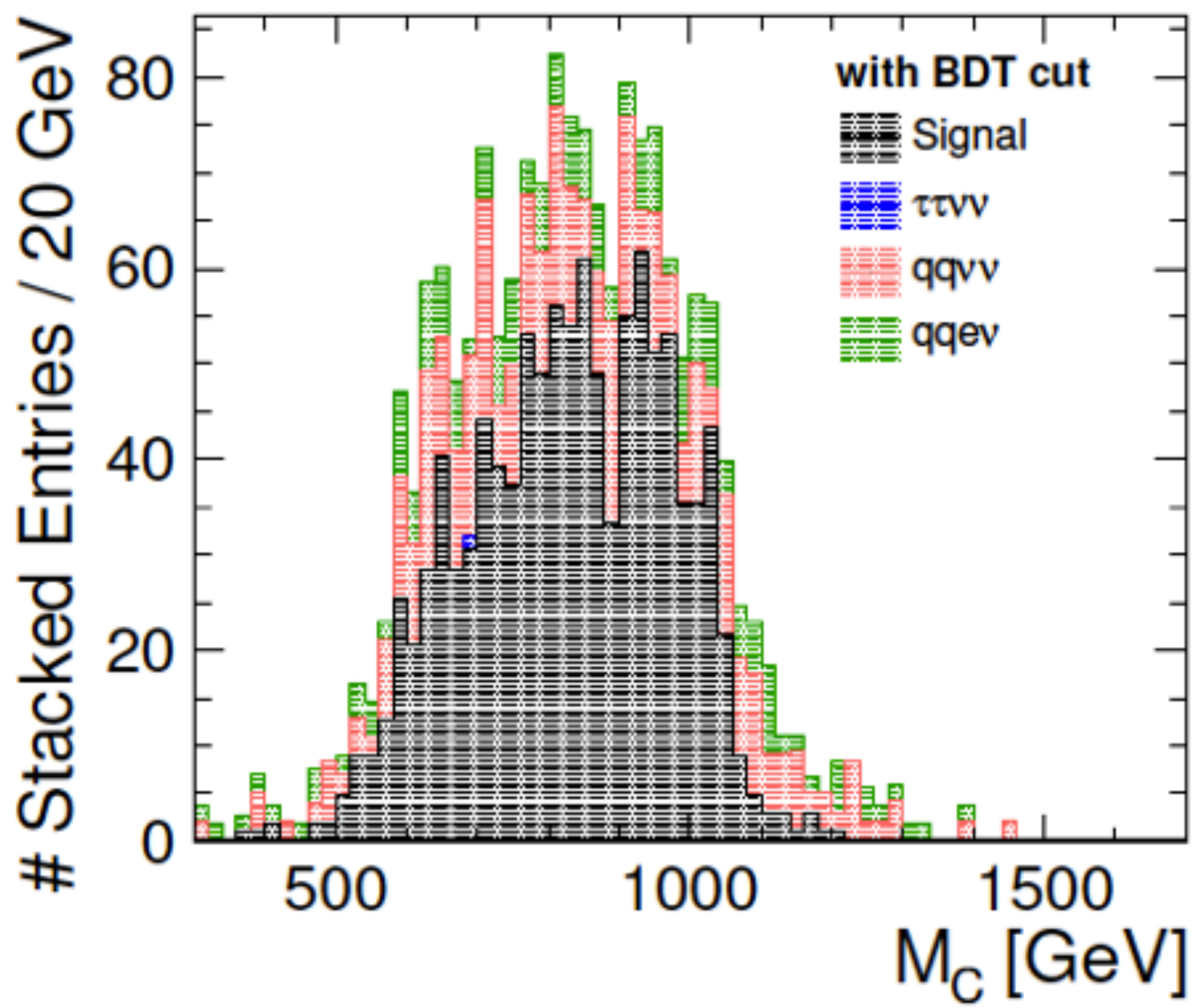
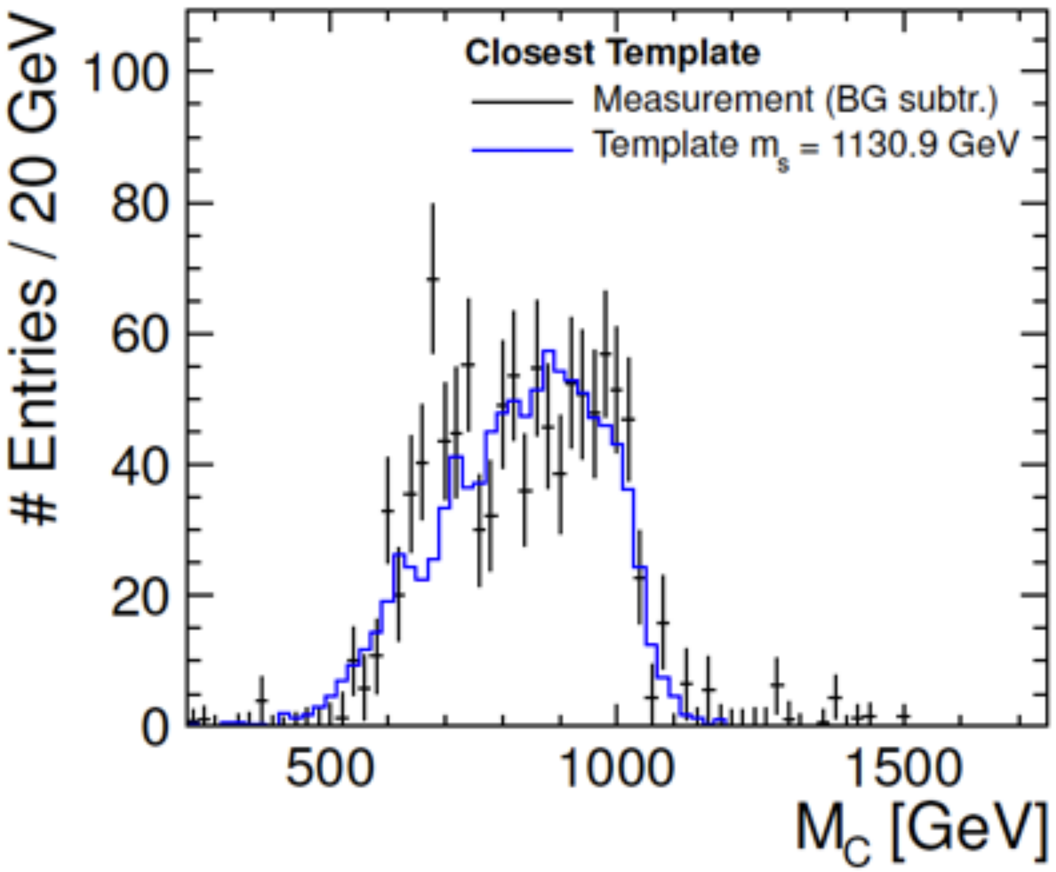




- Use multivariate techniques (Boosted Decision Tree) for background selection based on various event variables (event shapes, jet particle number & content, ...)

Fitting the Mass

- Mass extraction performed with a template fit
  - Templates built using high-statistic samples of generator-level (including hadronization) data, in 3 GeV steps for the squark mass, passed through BDT
  - Detector resolution taken into account by jet-energy smearing according to known PFA performance, energy shift due to machine background calibrated out



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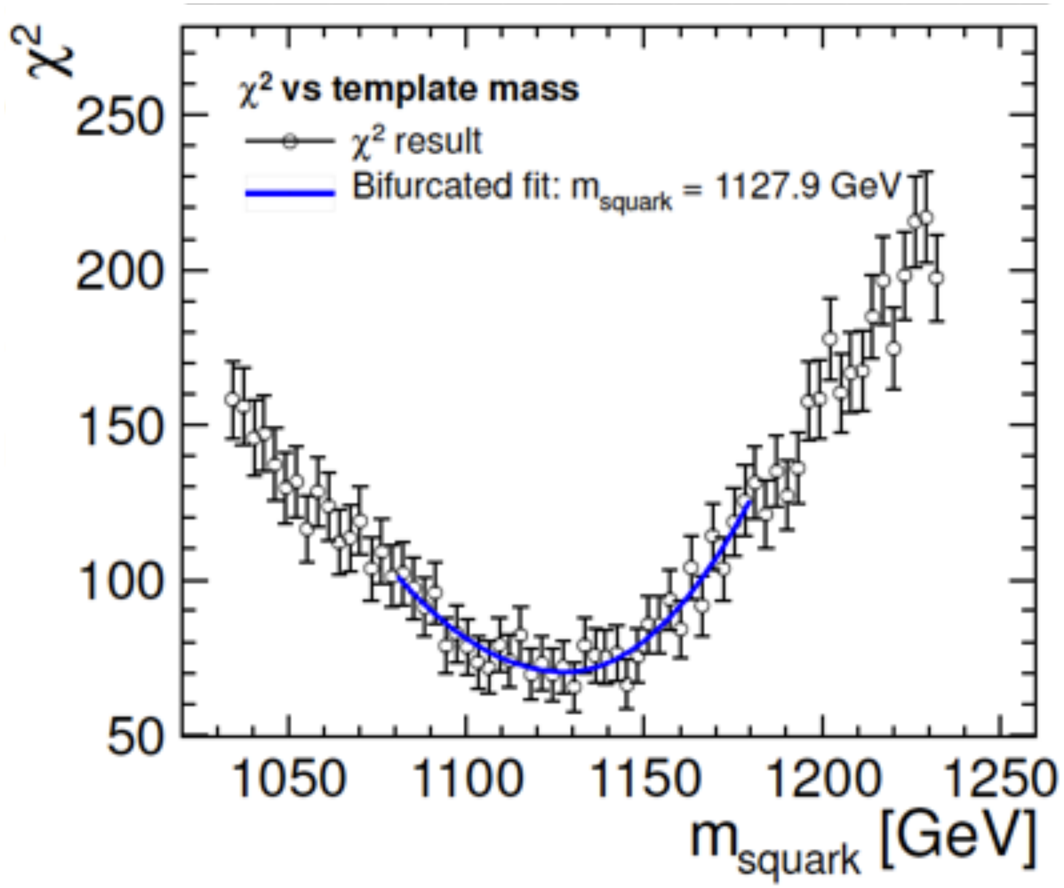

- SM background statistically subtracted using known background M_C distribution
- χ^2 for each template calculated
- Mass given by minimum of χ^2 distribution
- Statistical error determined with toy MC

$$m_{\text{squark}} = 1127.9\,\text{GeV} \pm 5.9\,\text{GeV}\,(stat)$$

0.52% statistical accuracy

input - cross section averaged - 1123.7 GeV

integrated luminosity 2 ab^{-1}

Measuring the Cross Section

- The cross section is obtained from the integral of the background-subtracted M_C distribution
- The overall efficiency of the event selection was determined to be 36.1%

$$\sigma_{\text{squark}} = \frac{N_{\text{tot}}}{\mathscr{L}} = \frac{N_{\text{cut}}}{\varepsilon \mathscr{L}} = \frac{1091.7}{0.361 \cdot 2000\,\text{fb}^{-1}}$$

$$= 1.51\,\text{fb} \pm 0.07\,\text{fb}\,(stat),$$

Input value 1.47 fb

Summary

- A 3 TeV CLIC collider is an excellent tool for the precise exploration of TeV scale physics
  - The challenging experimental conditions with high background levels due to the high collision energy and the short bunch to bunch separation can be overcome with particle-level selection cuts and jet finding
- The mass and cross section of light-flavored right squarks with masses of 1.1 TeV can be measured with 0.52% and 5% accuracy for 2 ab^{-1}, respectively
  - The high SM backgrounds can be controlled with multivariate techniques
  - Also for strongly interacting new particles, CLIC can provide competitive measurements
- This study also applies to other New Physics signatures with heavy particles decaying into quarks and massive invisible particles

Detailed analysis documentation: LCD-NOTE-2011-027

CLIC CDR Volume 2 - Physics & Detectors