Light-flavored Squark Production at CLIC

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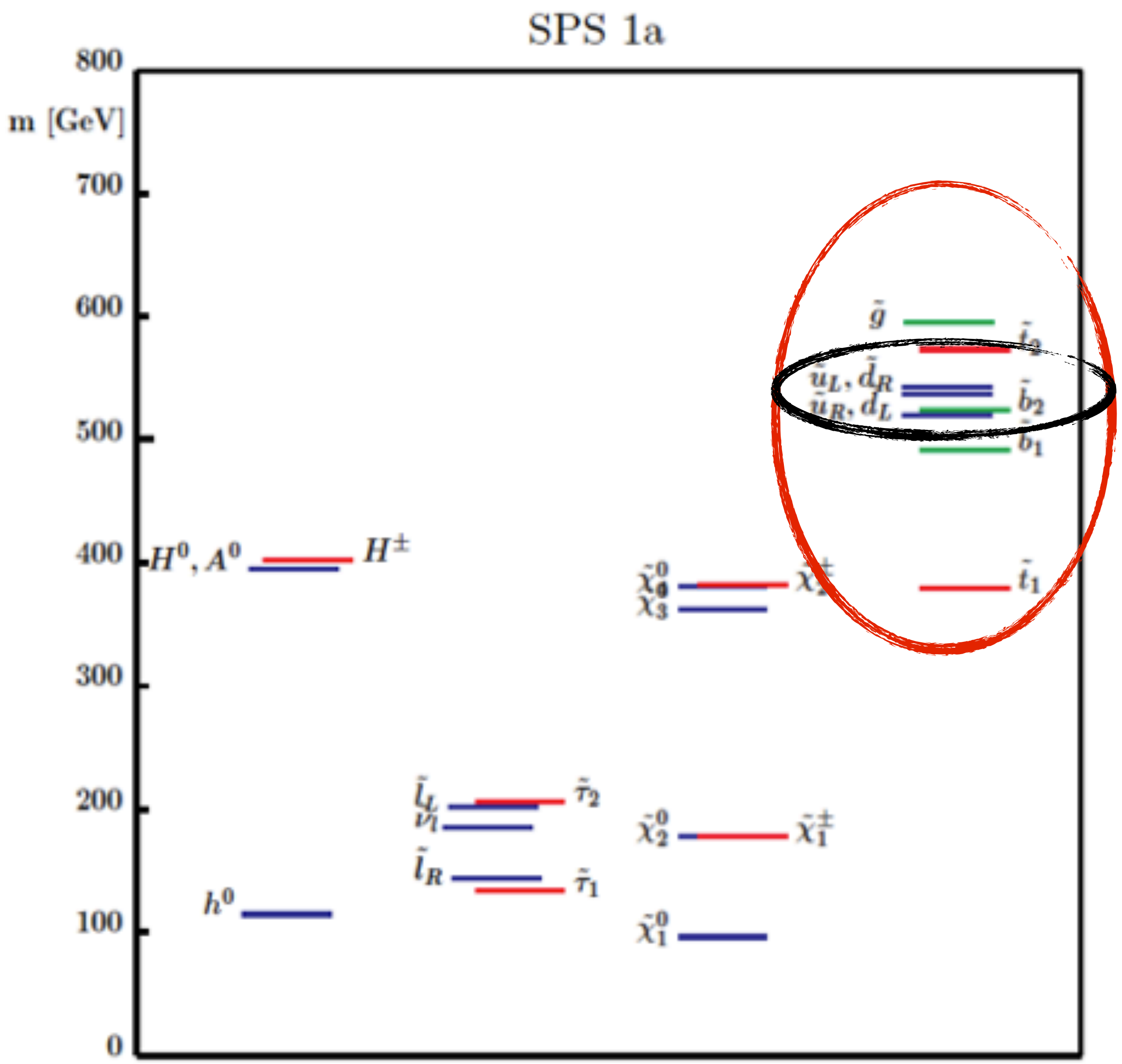
Outline

- Squark production and decay at CLIC
- Techniques for mass measurements
- Experimental challenges
  - SM background suppression
  - $\gamma\gamma \rightarrow$ hadrons background
- 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

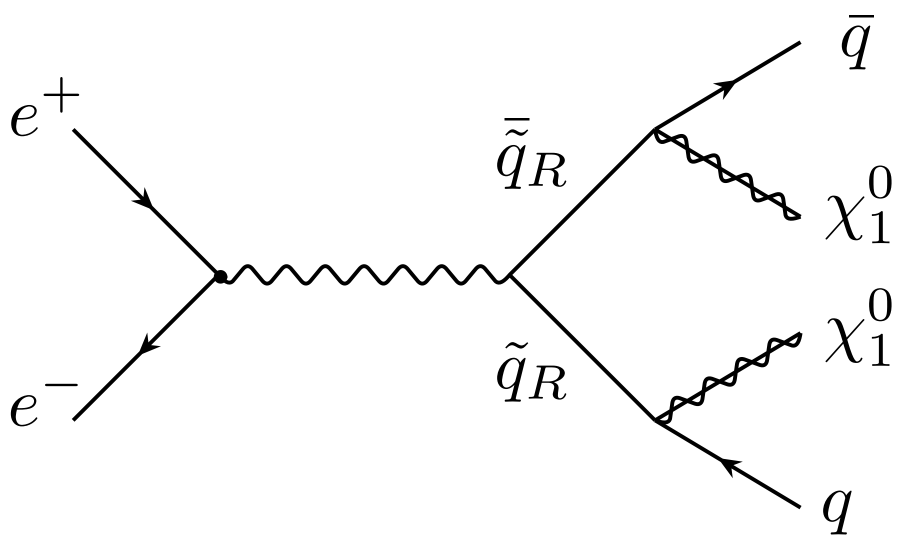


- typically no distinction between first and second generation:
  - up, charm squarks and down, strange squarks have equal masses
  - small mass difference between up-type and down-type
  - mass difference between left- and right squarks

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

Light-flavored Squark Production & Decay

- The CLIC benchmark scenario:
  - Light-flavored (u, d, s, c) Right-Squark mass ~ 1.12 TeV
  - Neutralino mass 328 GeV
- Right-Squarks as benchmark scenario:
  - 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!

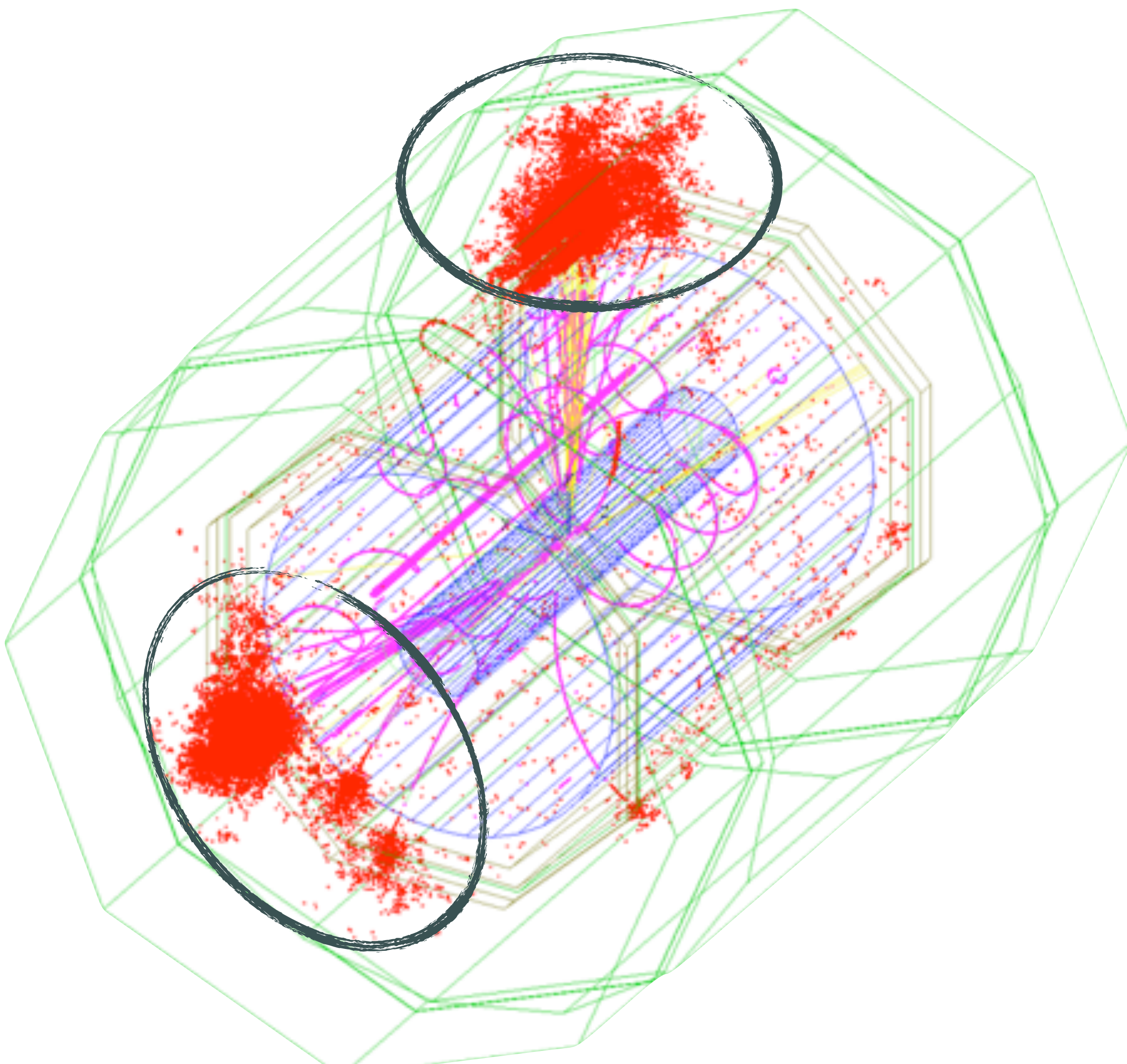


3 TeV CLIC cross section (u, d, s, c): ~ 1.45 fb

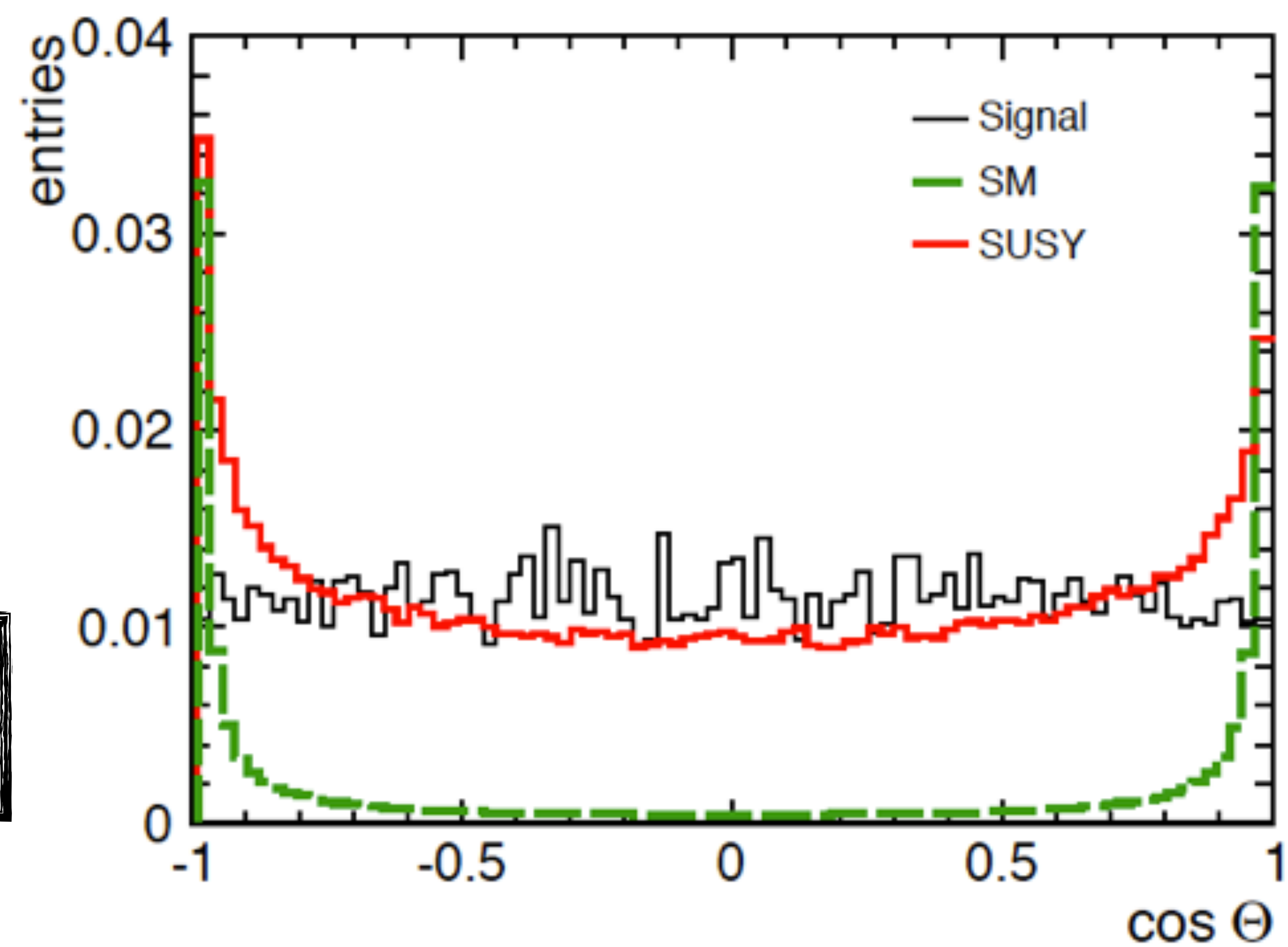
(almost) exclusive decay $\tilde{q}_R \rightarrow q\chi_1^0$

Production ratio up / down type: 4:1

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



➪ Particular emphasis on barrel calorimetry, tracking and particle flow

Mass Measurement Techniques

Mass Measurement Techniques

- Parameters of the used SUSY scenario:

$$m(\tilde{u}_R, \tilde{c}_R) = 1126\,\mathrm{GeV} \quad m(\tilde{d}_R, \tilde{s}_R) = 1116\,\mathrm{GeV} \quad m(\chi_1^0) = 328\,\mathrm{GeV}$$

- Also used for illustration purposes: SPS1b:

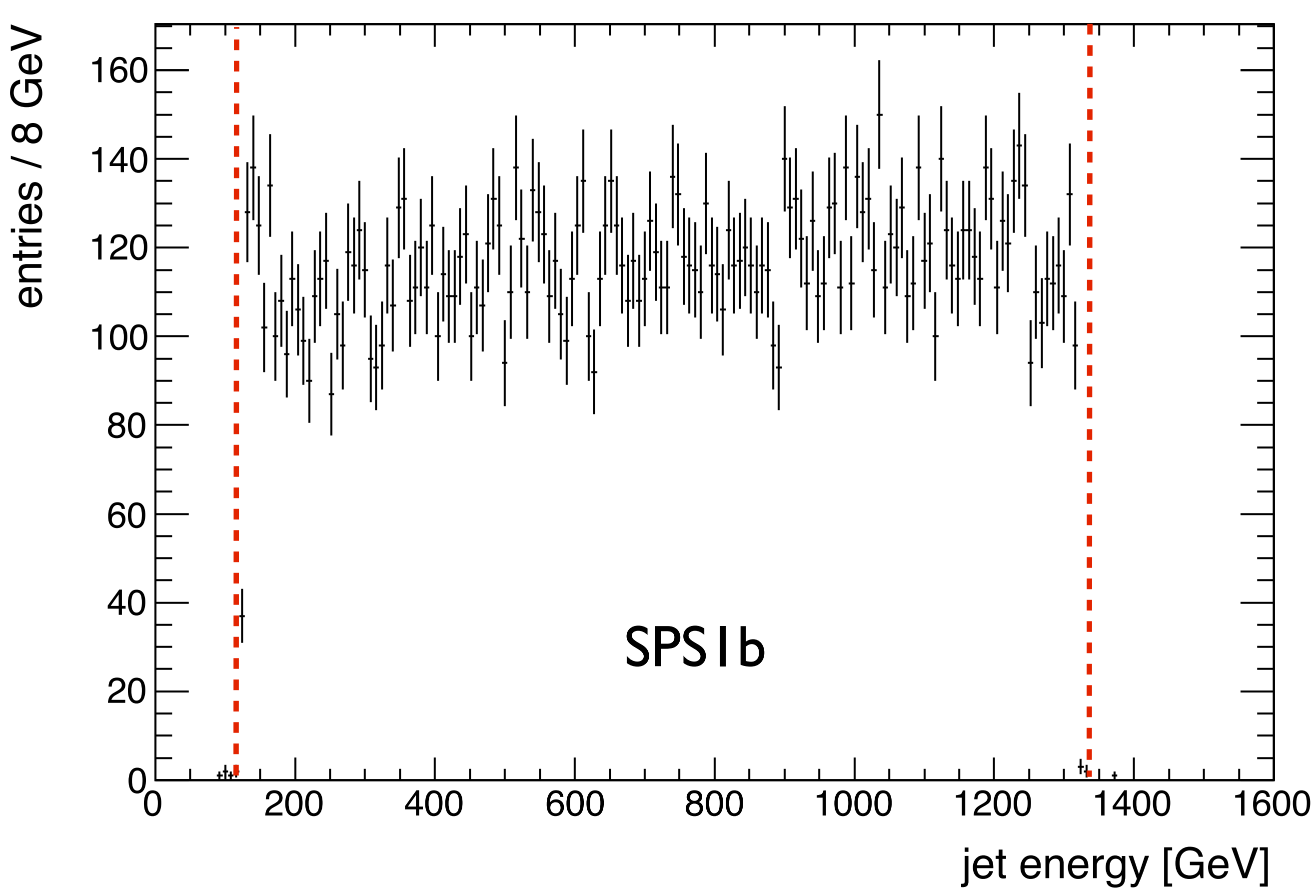
$$m(\tilde{u}_R, \tilde{c}_R) = 846\,\mathrm{GeV} \quad m(\tilde{d}_R, \tilde{s}_R) = 843\,\mathrm{GeV} \quad m(\chi_1^0) = 162\,\mathrm{GeV}$$

➩ These masses determine location of kinematic edges in distributions

The "classic" observable:

Distribution of jet energies

- Simultaneous measurement of squark and neutralino masses



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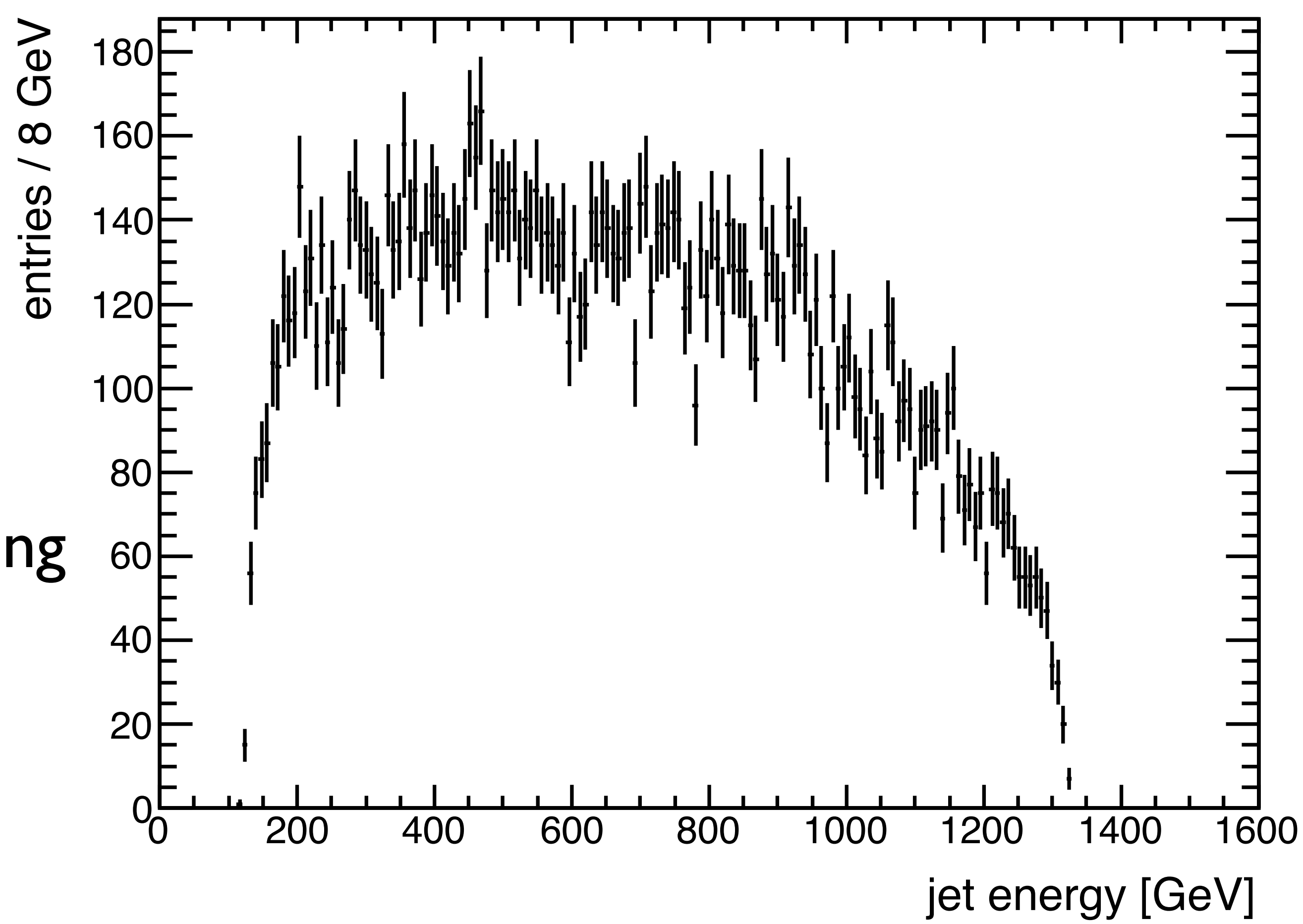
The "classic" observable:

Distribution of jet energies

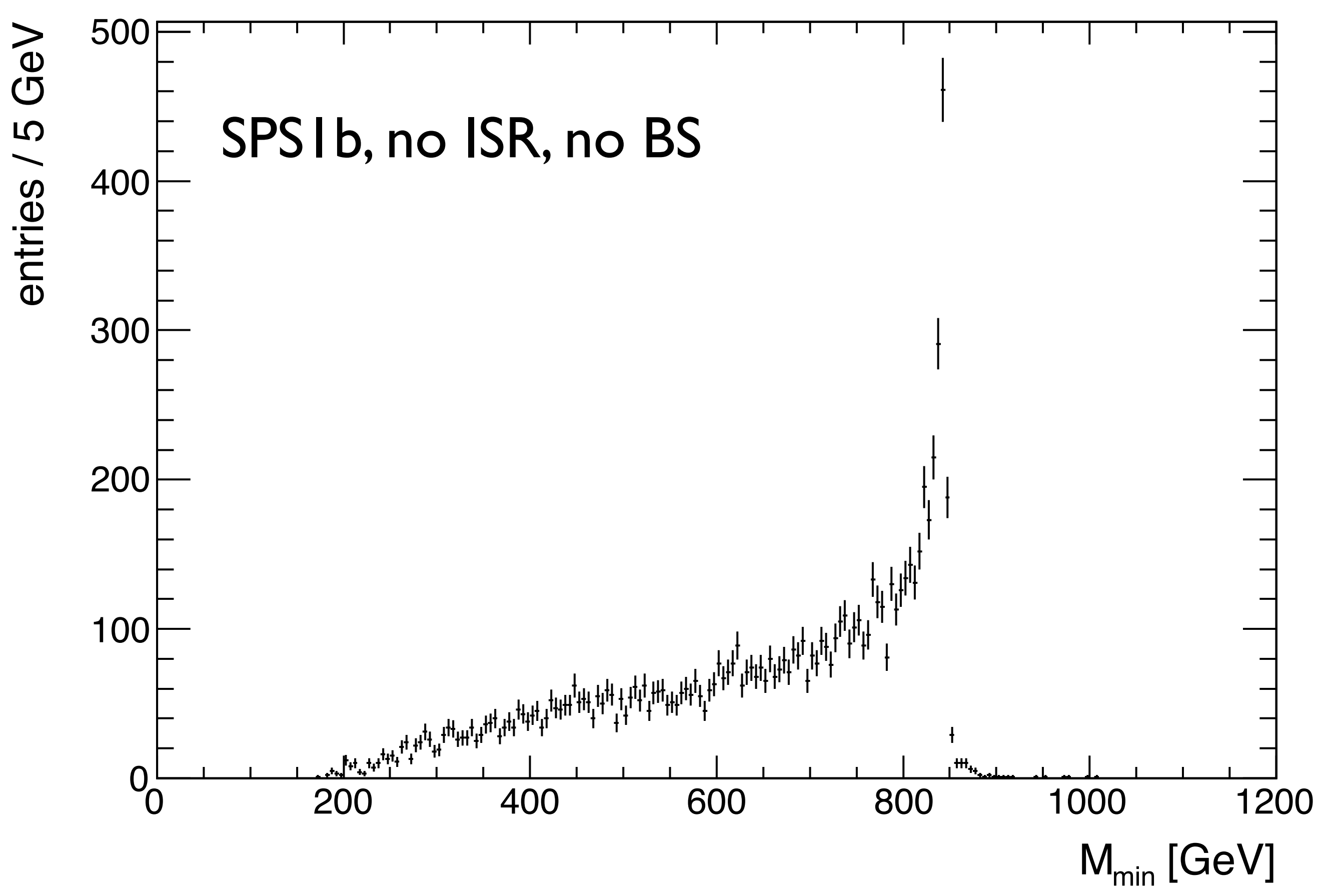
- Simultaneous measurement of squark and neutralino masses
- Strong distortions of upper edge from beam energy smearing due to beamstrahlung
- both edges suffer from SM background, γγ → hadrons background strongly affects single jet observables



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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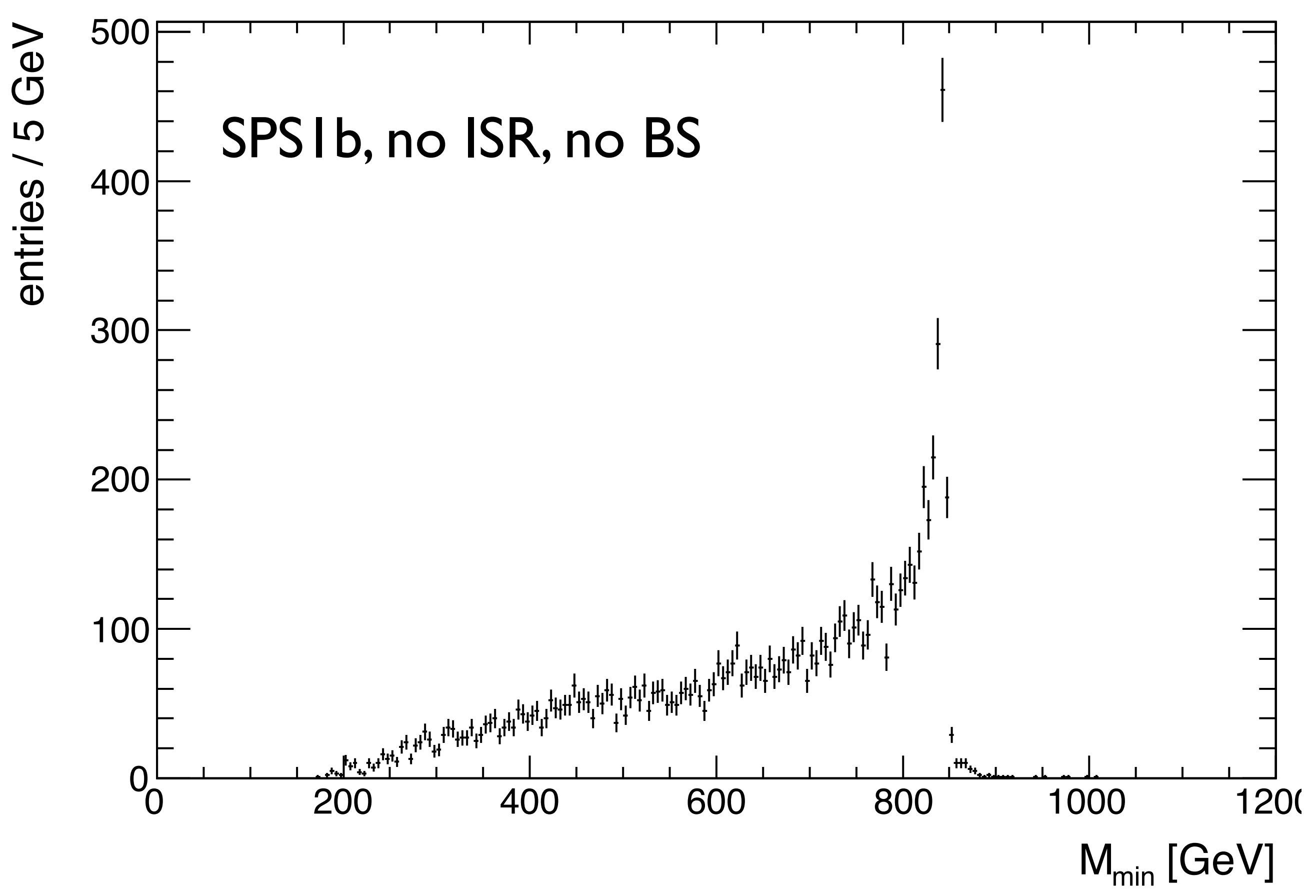
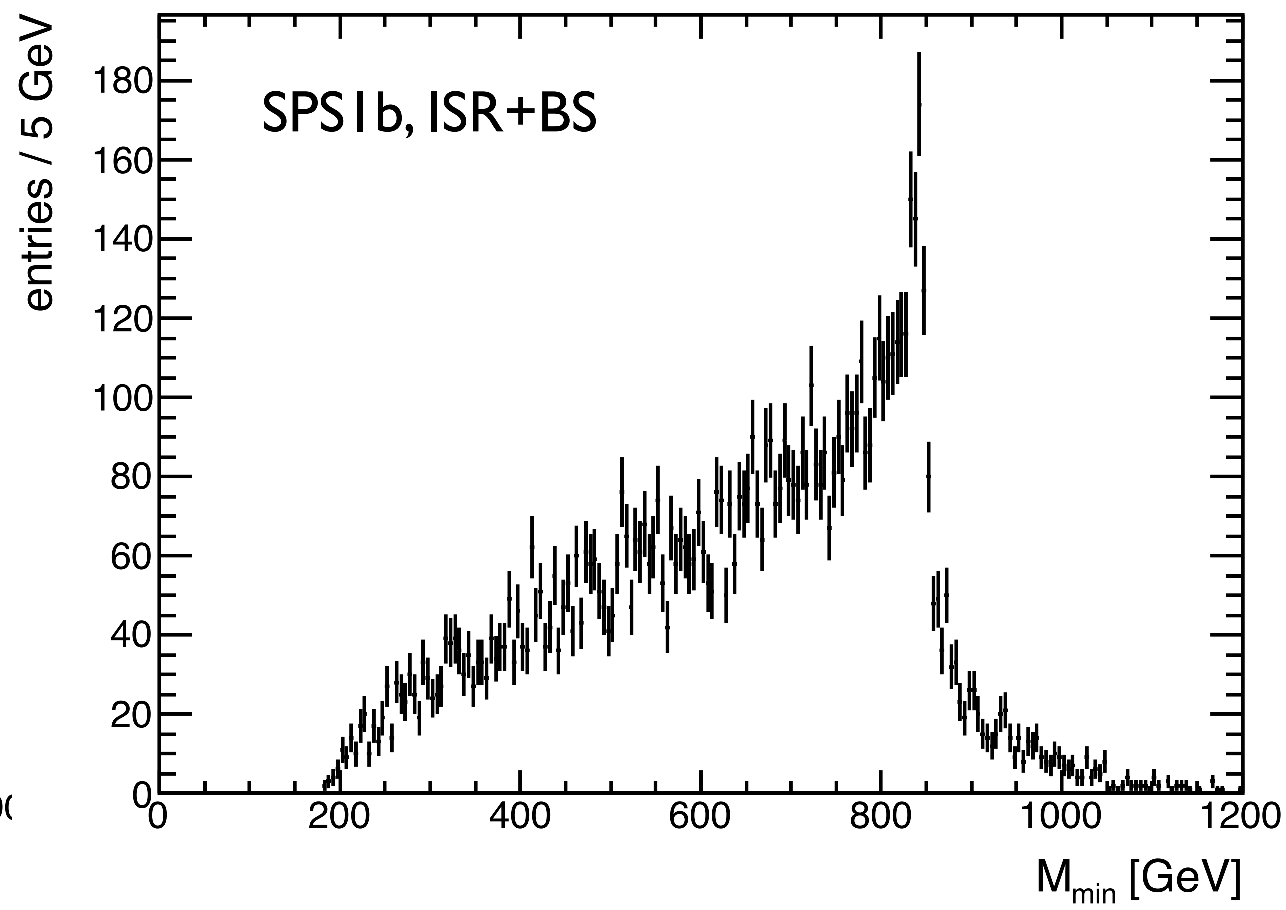




➯ peaks at true squark mass: good for low statistics

➯ 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

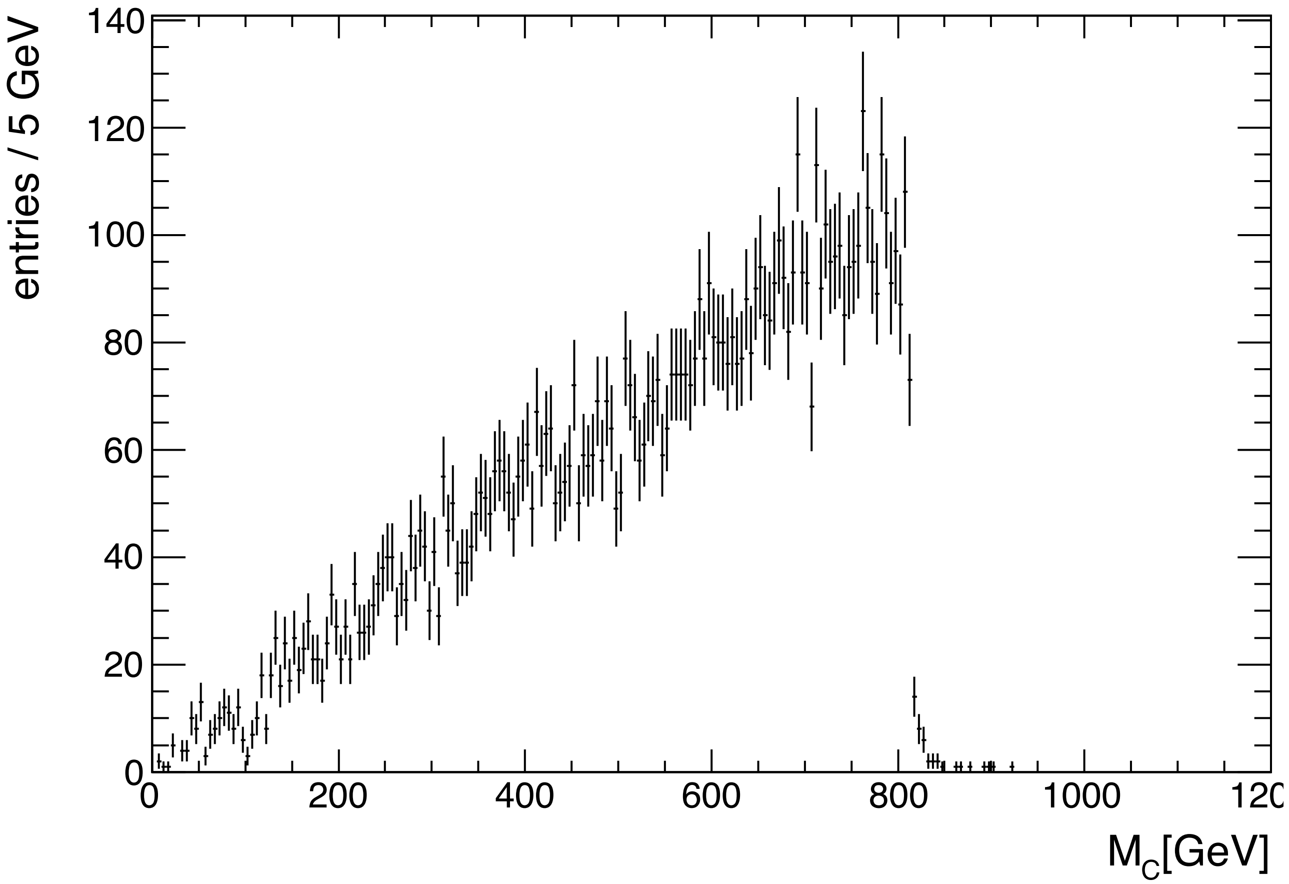
D.R. Tovey, JHEP 04, 34 (2008)

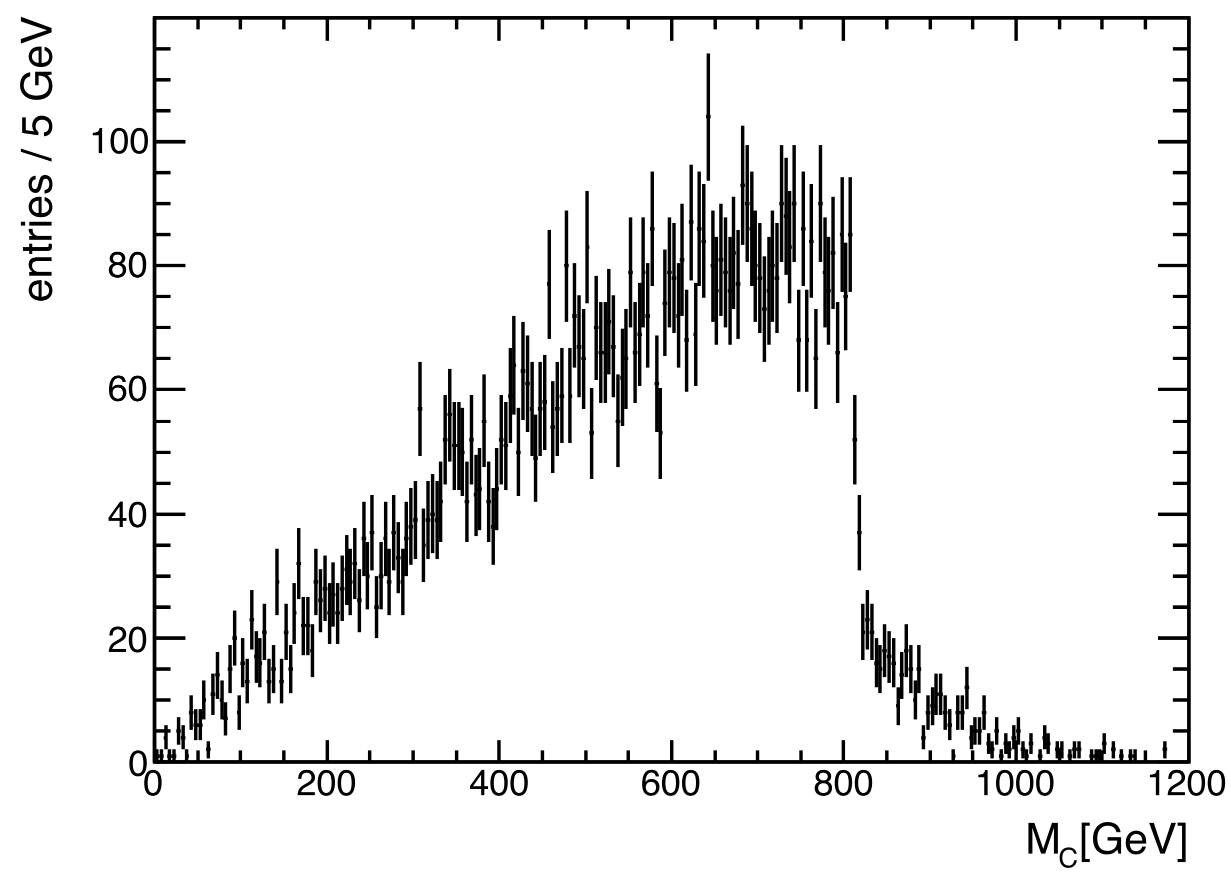
  - invariant under contra-linear boosts: works for back-to-back pair production of particles
    - at LHC, use a transverse form, use full 3D for lepton colliders
  - requires quark momenta and neutralino mass as input

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





Signal & Background

Signal, Background & Events

	Final State	σ (with ISR + BS)
Signal	qqχχ (u,d,s,c)	~ 1.5 fb
SM Background	qq	~ 3000 fb
	qqνν	~ 1500 fb
	qqee	~ 3300 fb
	qqeν	~ 5300 fb
	ττνν	~ 130 fb
SUSY	qqννχχ	~ 1.0 fb
	qqlνχχ	~ 8.5 fb
	qqllχχ	~ 0.6 fb

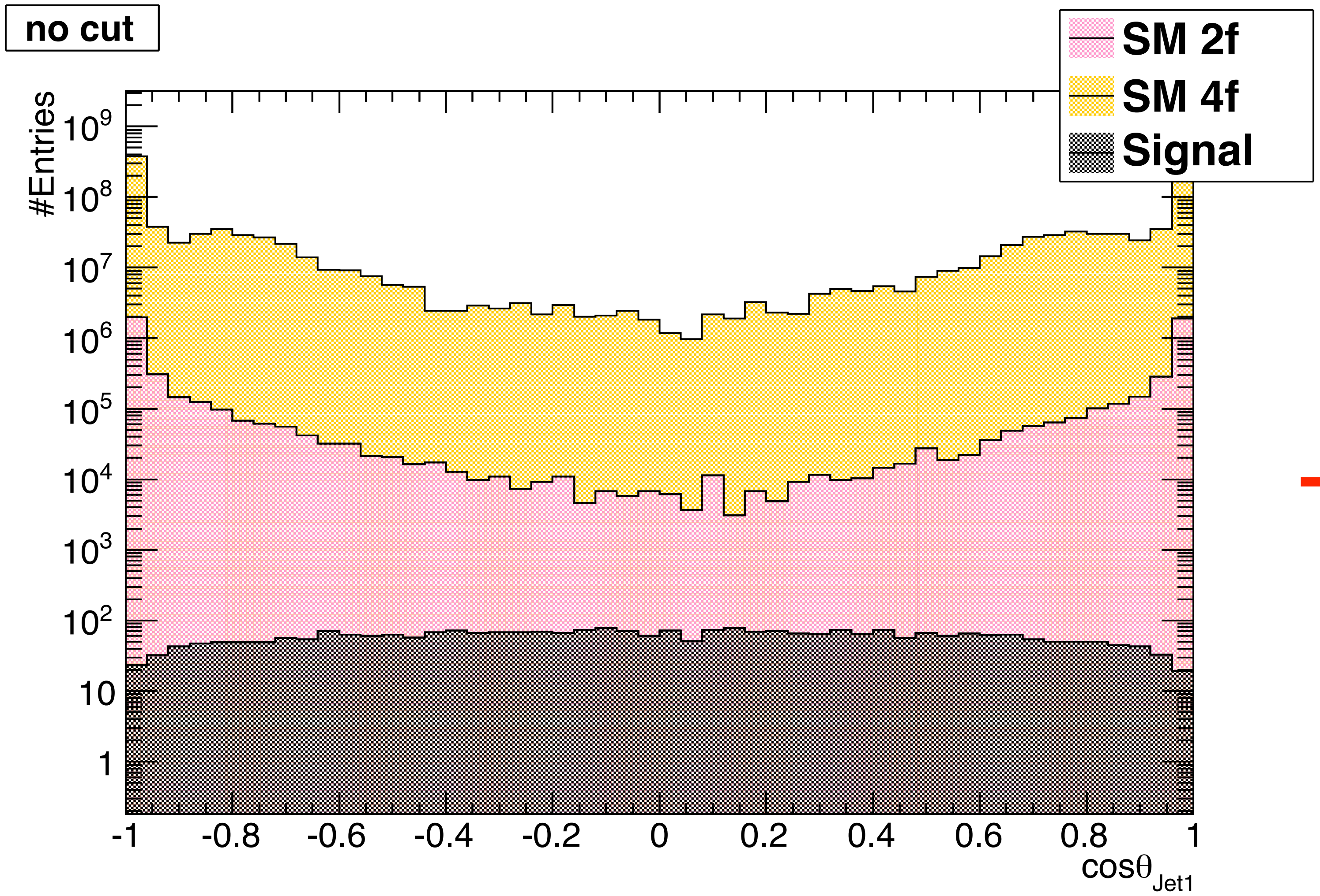
still under study:

qqll, qqνl for l = μ, τ

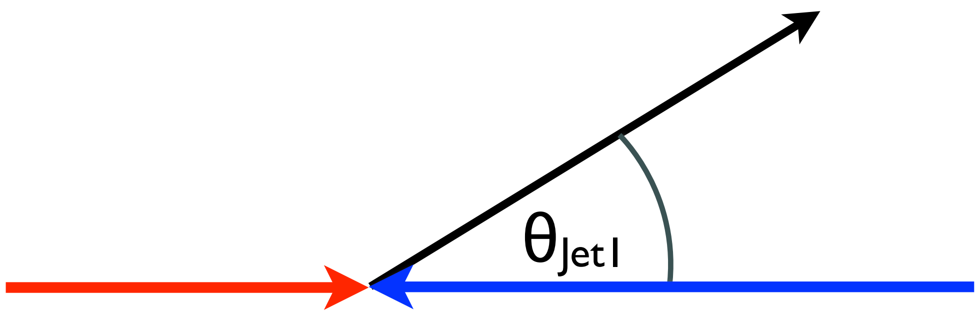
} dominating contributions

- Present status:
    - First round of production of extensive samples of signal and background - Generator only, minor issues make regeneration necessary
    - Study with γγ → hadrons background possible on generator level!
    - Second round of production ongoing - including full detector simulation and reconstruction with overlaid γγ → hadrons background
        - Full signal sample available, background statistically limited

Variables to Cut On - Event Properties



- Background peaks forward and backward



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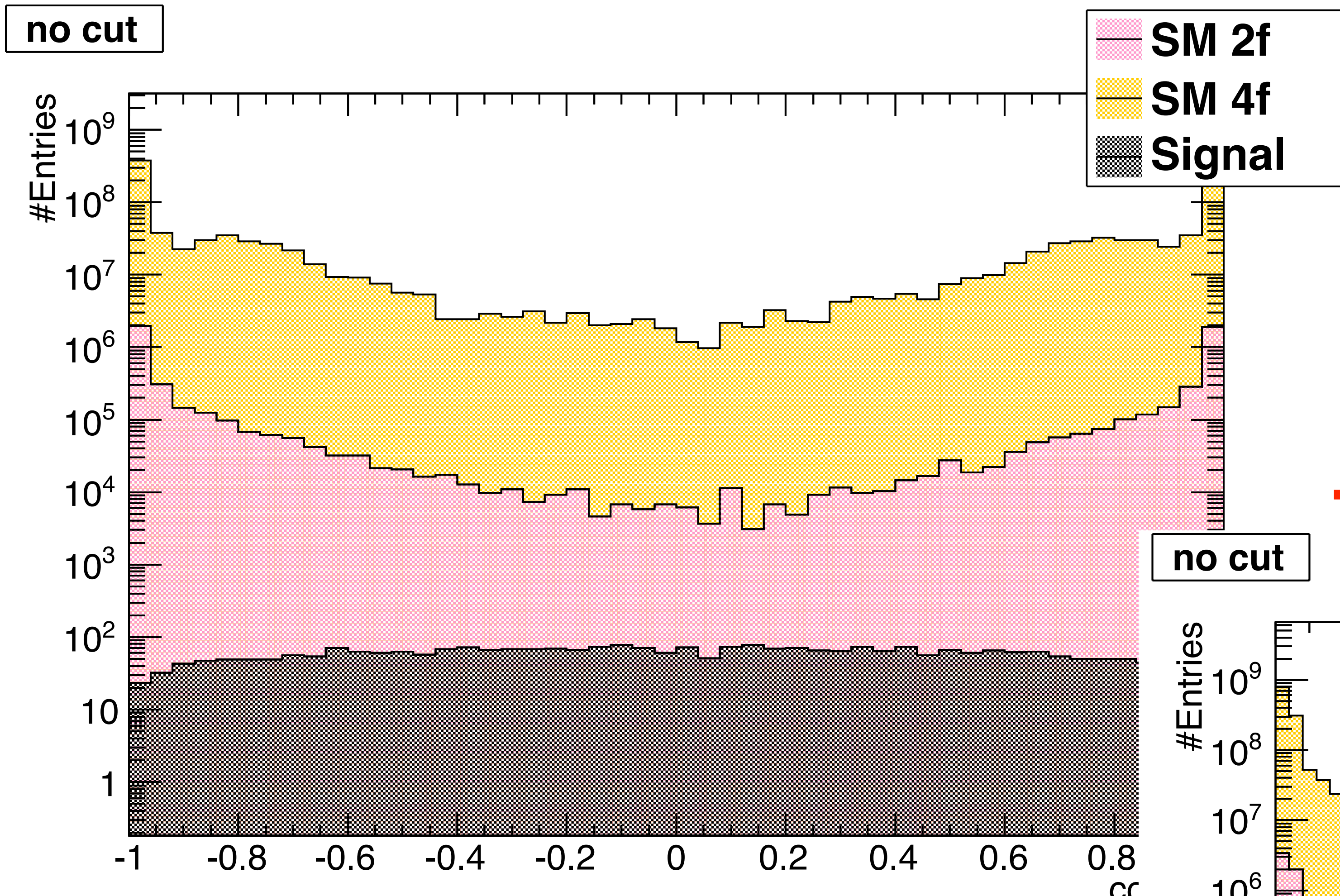

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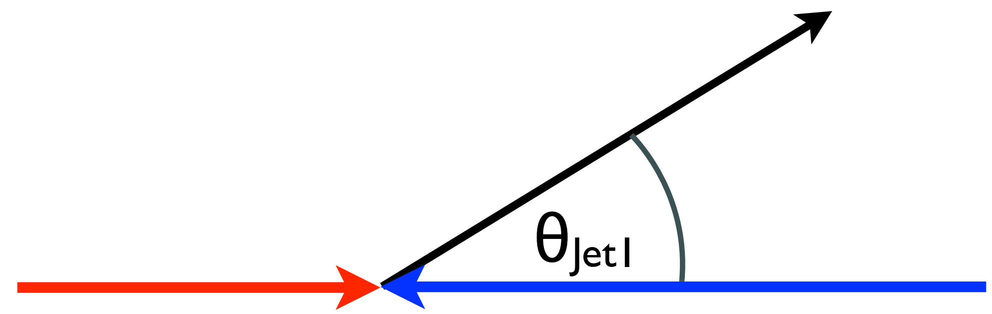
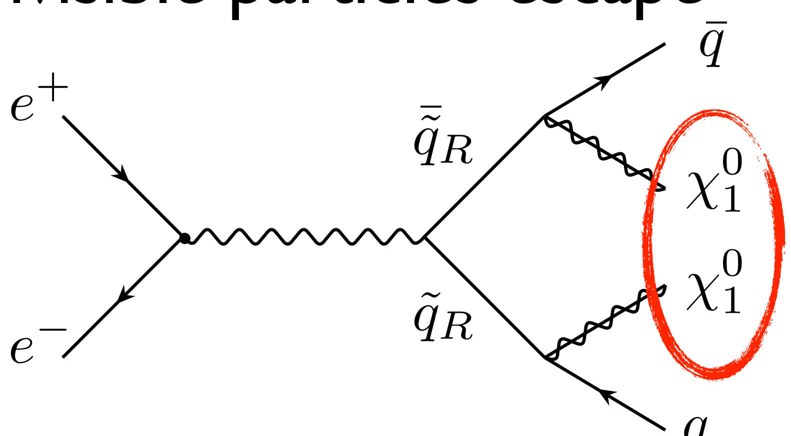
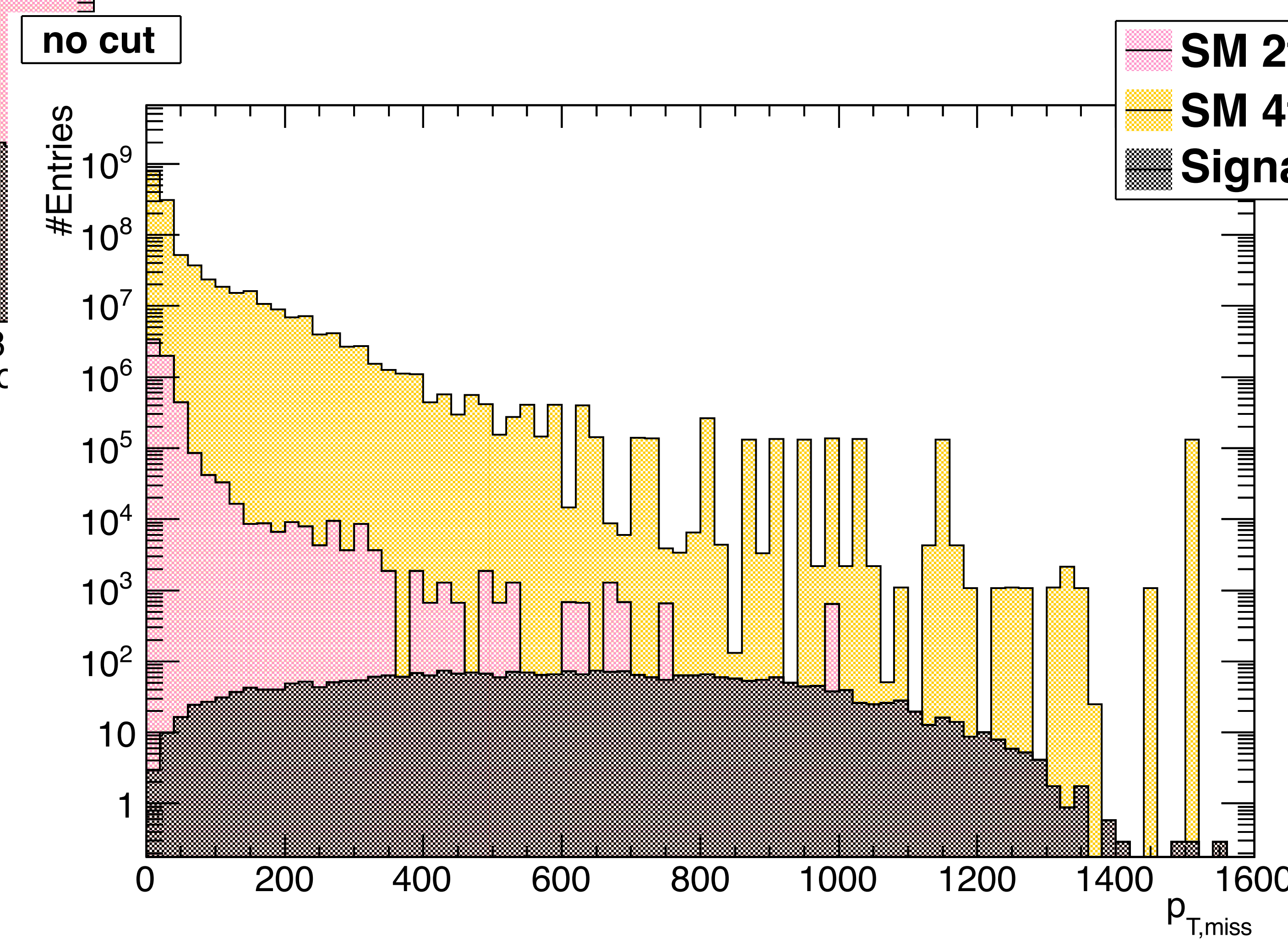
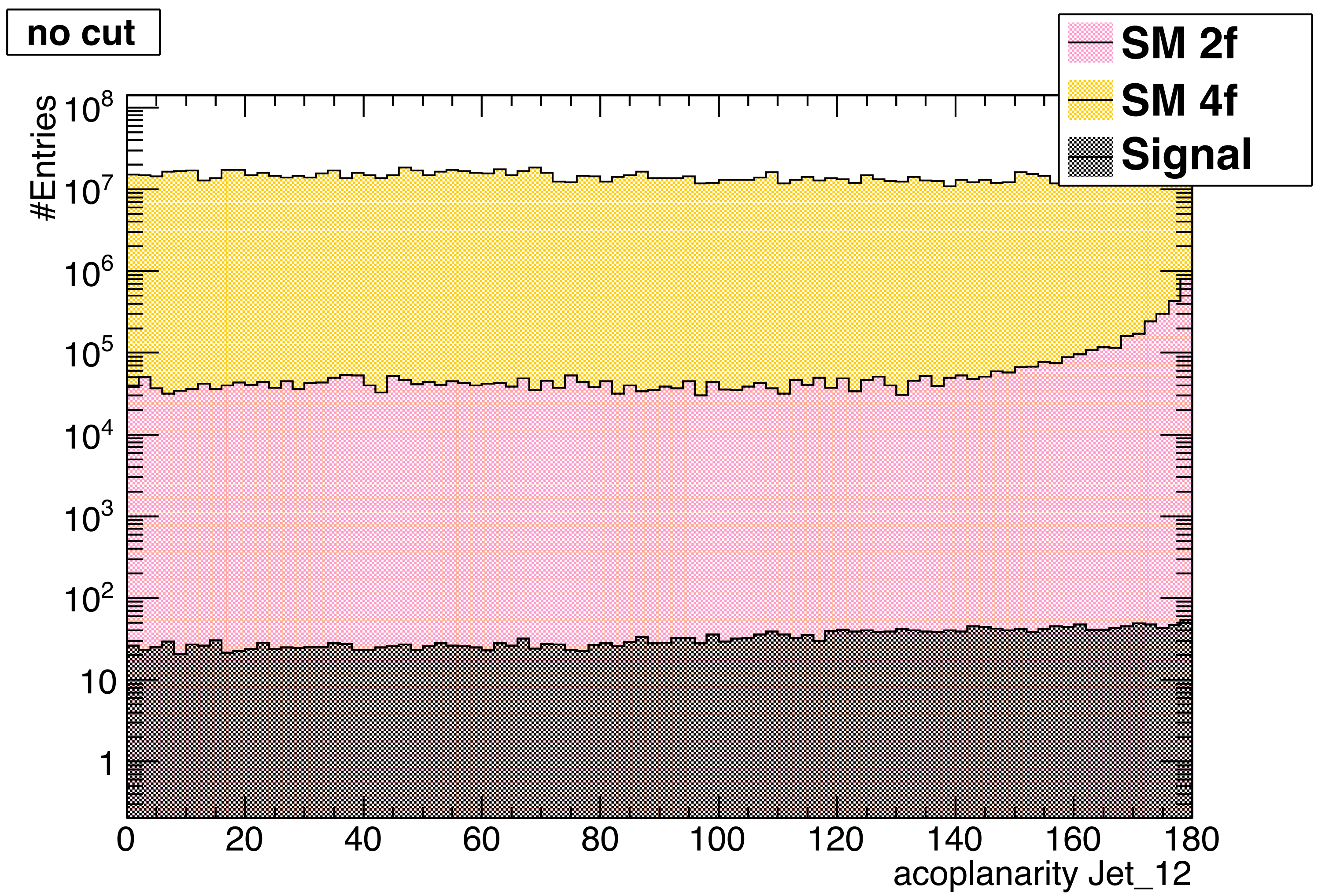


- Missing p_T: High for signal - two heavy invisible particles escape

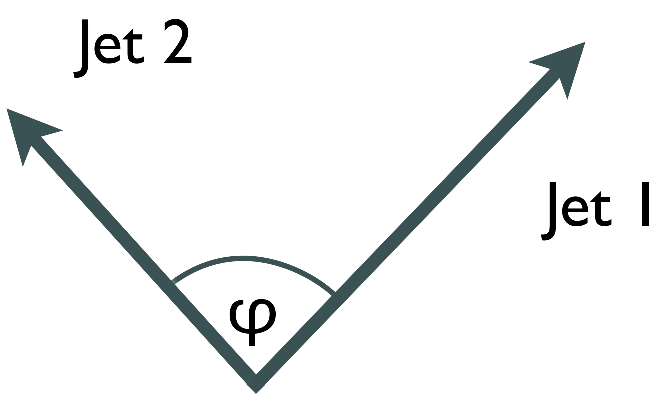




Variables to Cut On - Event Geometry



- Accoplanarity: Two fermion SM background tends to be back to back, Signal (and four fermion background) is more smoothly distributed



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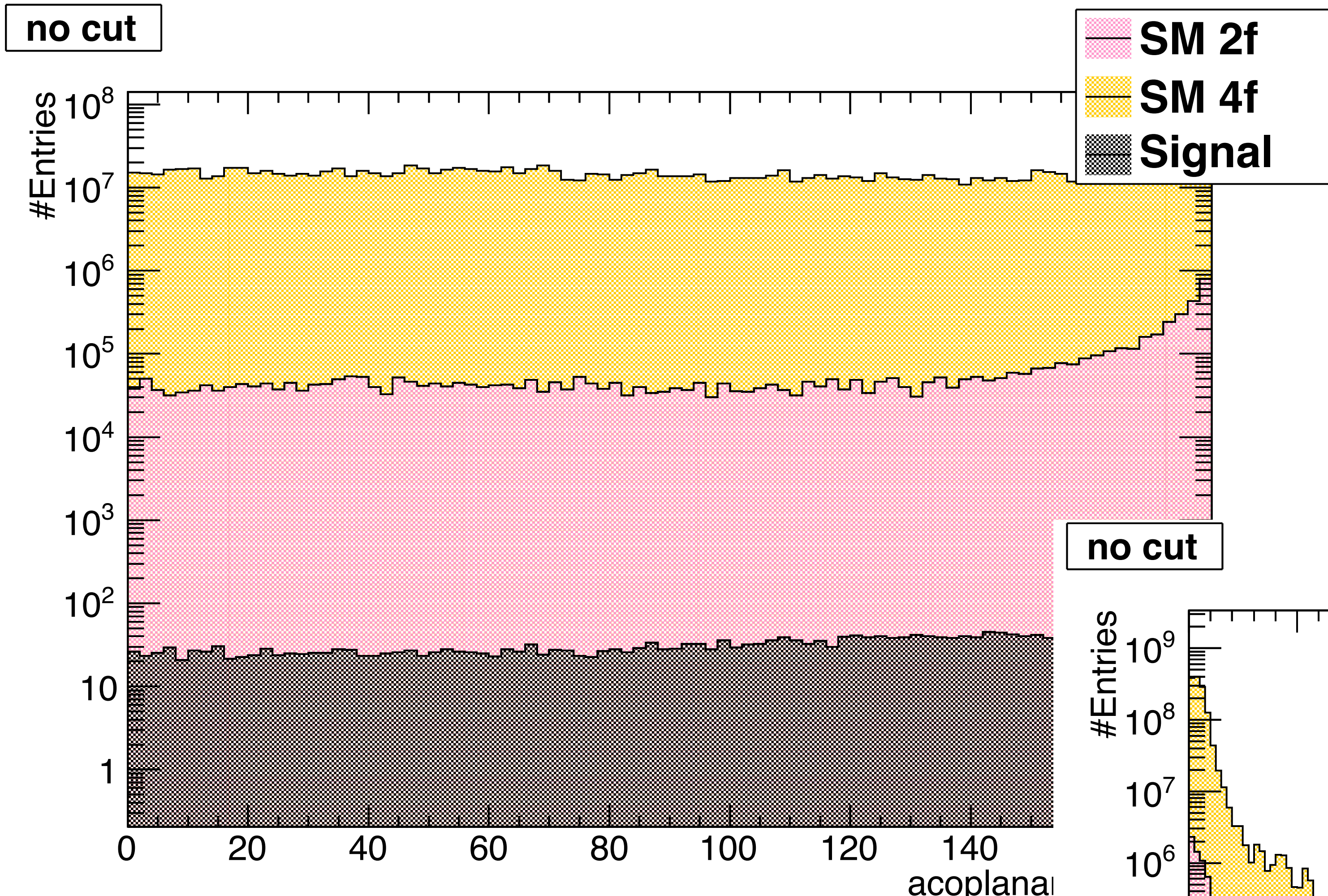

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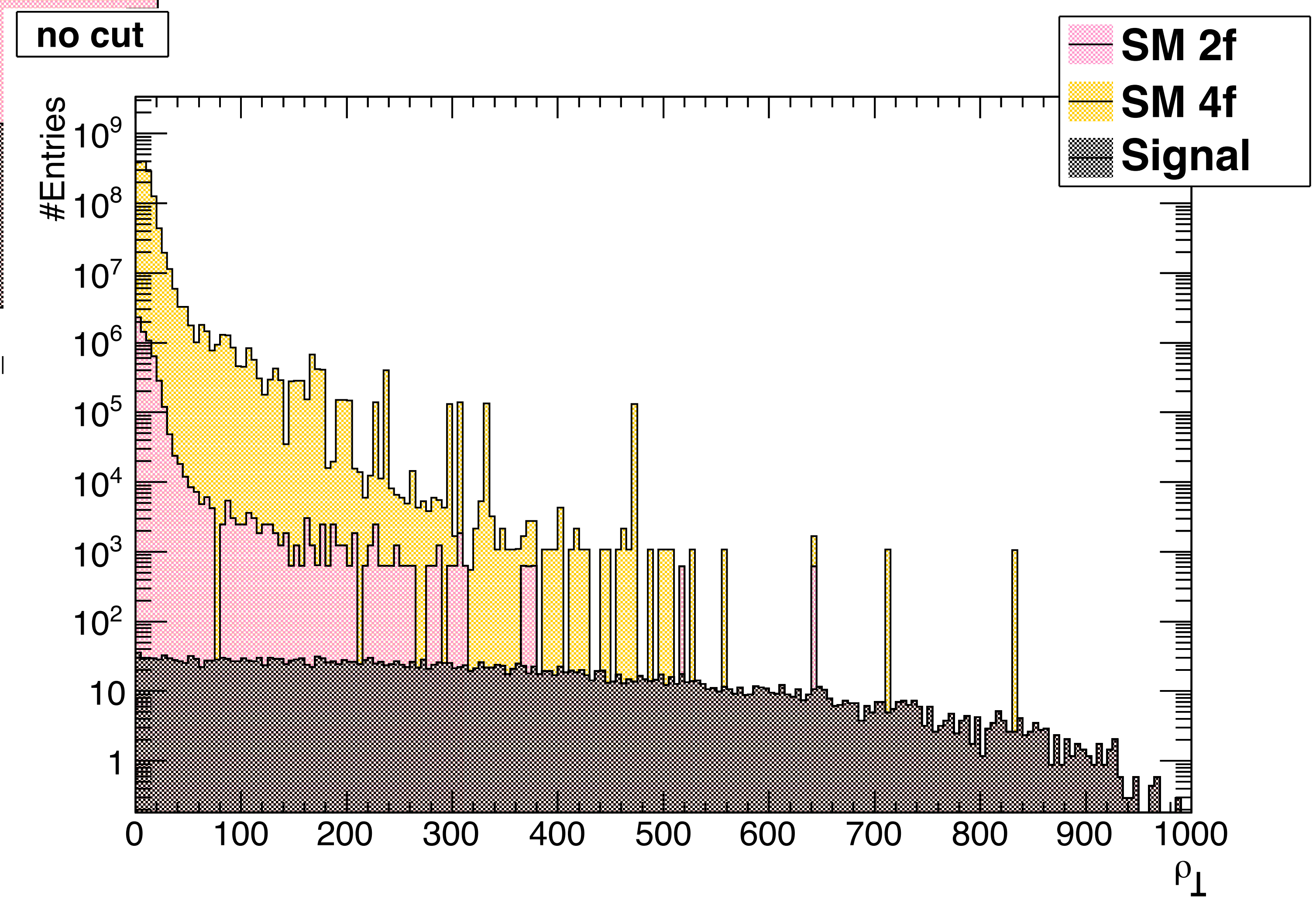
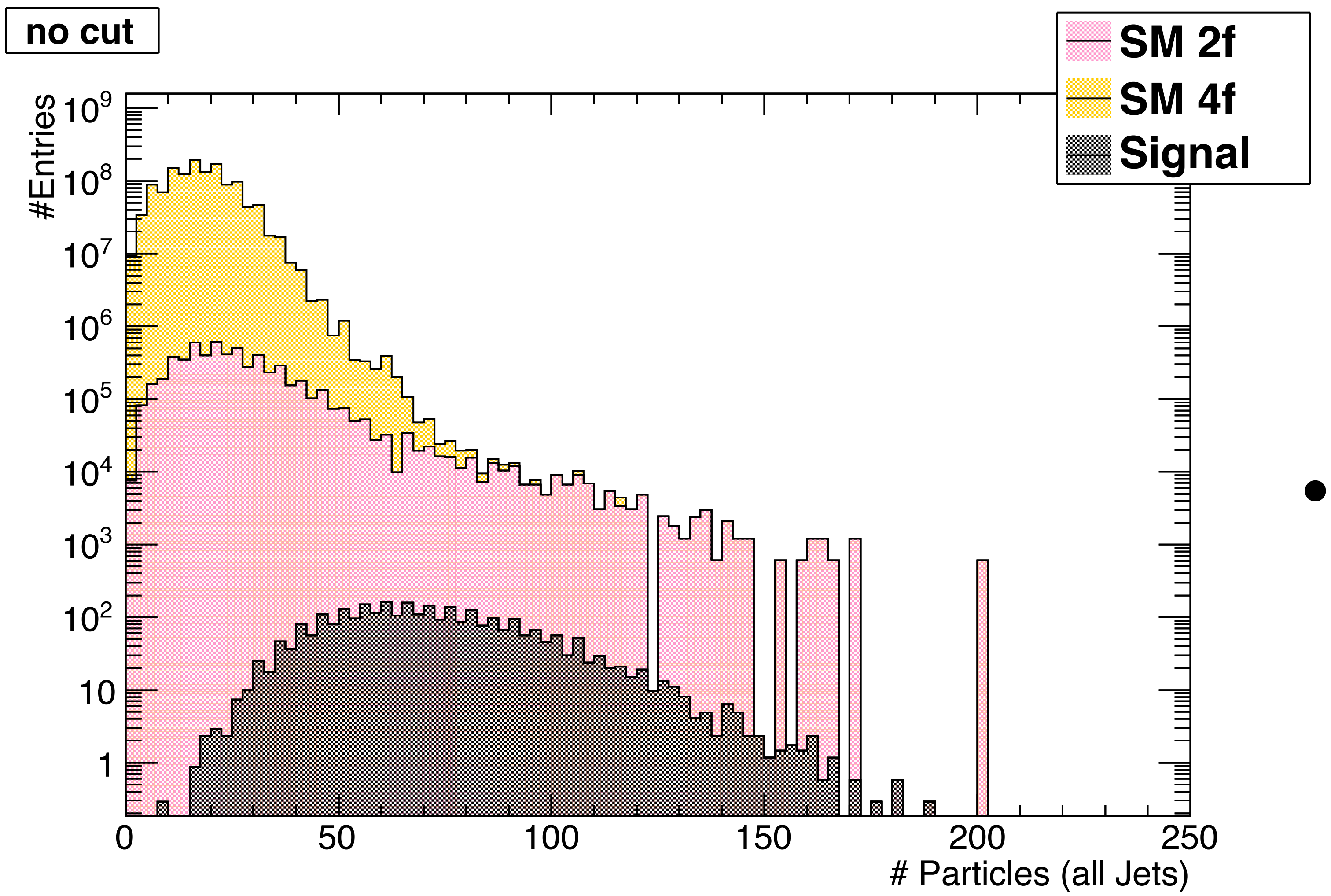
$$\rho_t = \frac{2\left|\vec{j}_{t,1} \times \vec{j}_{t,2}\right|}{\left|\vec{j}_{t,1} \pm \vec{j}_{t,2}\right|}$$

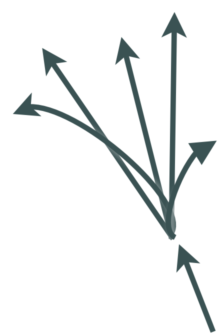
- Energy - weighted jet geometry: Even more powerful - Non-back to back, high energy



Variables to Cut On - Jet Substructure

- Exploiting Particle Flow to the extreme: Using the number of identified particles within the jets



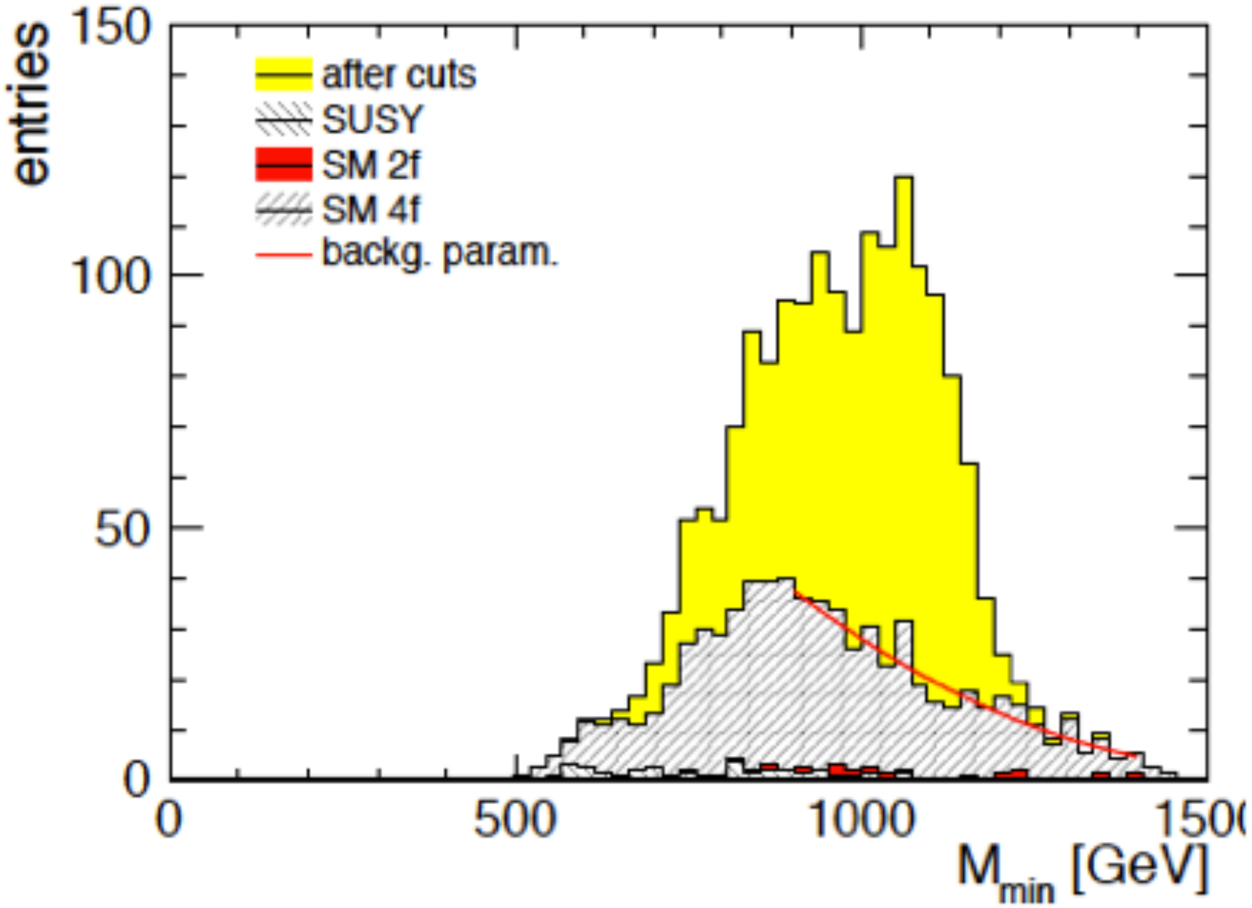


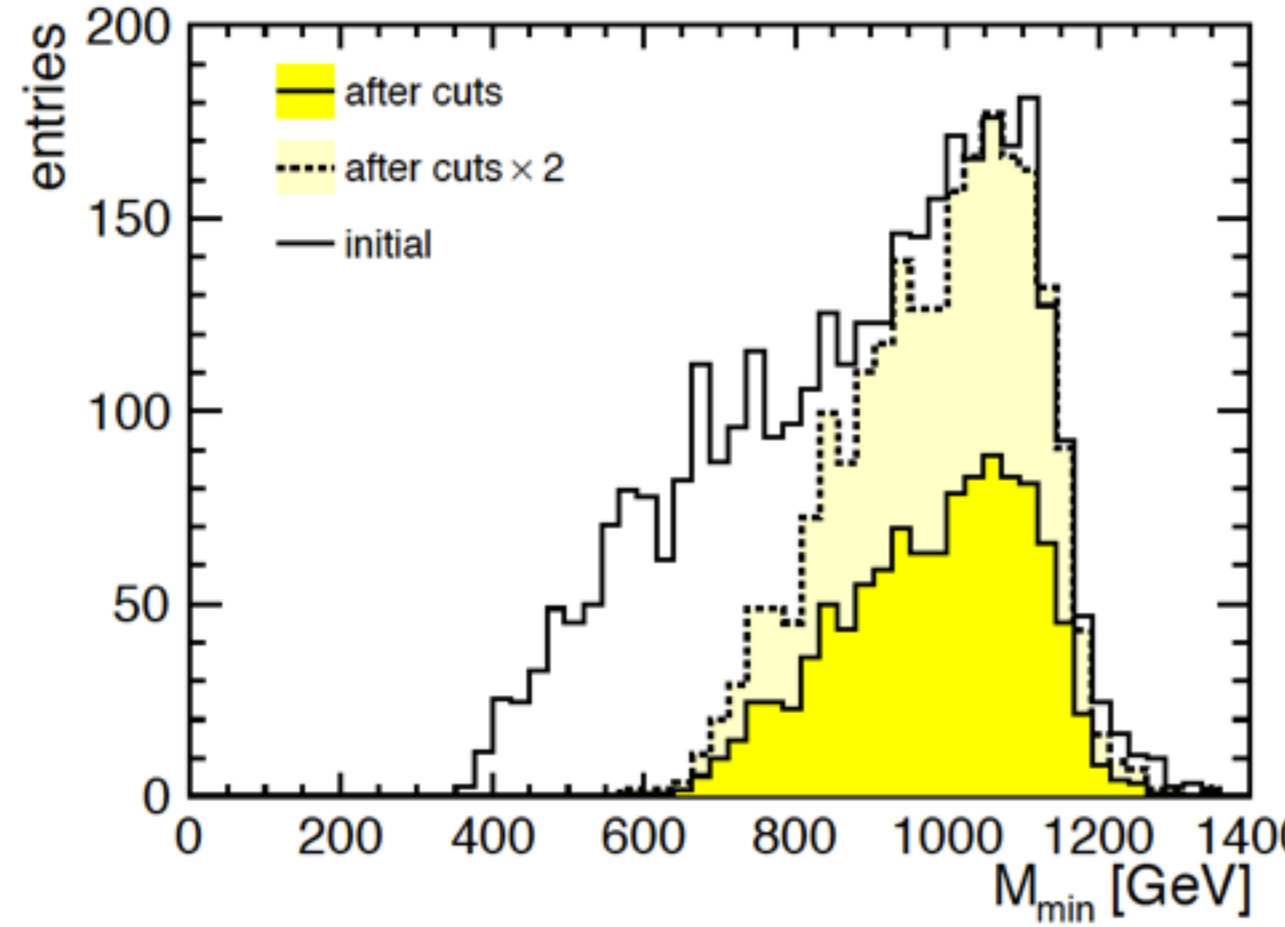
$N_{reco} = \Sigma_{Jet}\, \Sigma_{Particles}$

- Signal jets tend to have higher particle multiplicity than background jets
  - Reasonable agreement between generator level and full simulations observed in initial studies, further investigations ongoing

Rejection of Physics Background

- First study of cuts on generator level (including jet energy smearing)
  - Cuts optimized to keep upper edge of minimum squark mass distribution for signal events intact





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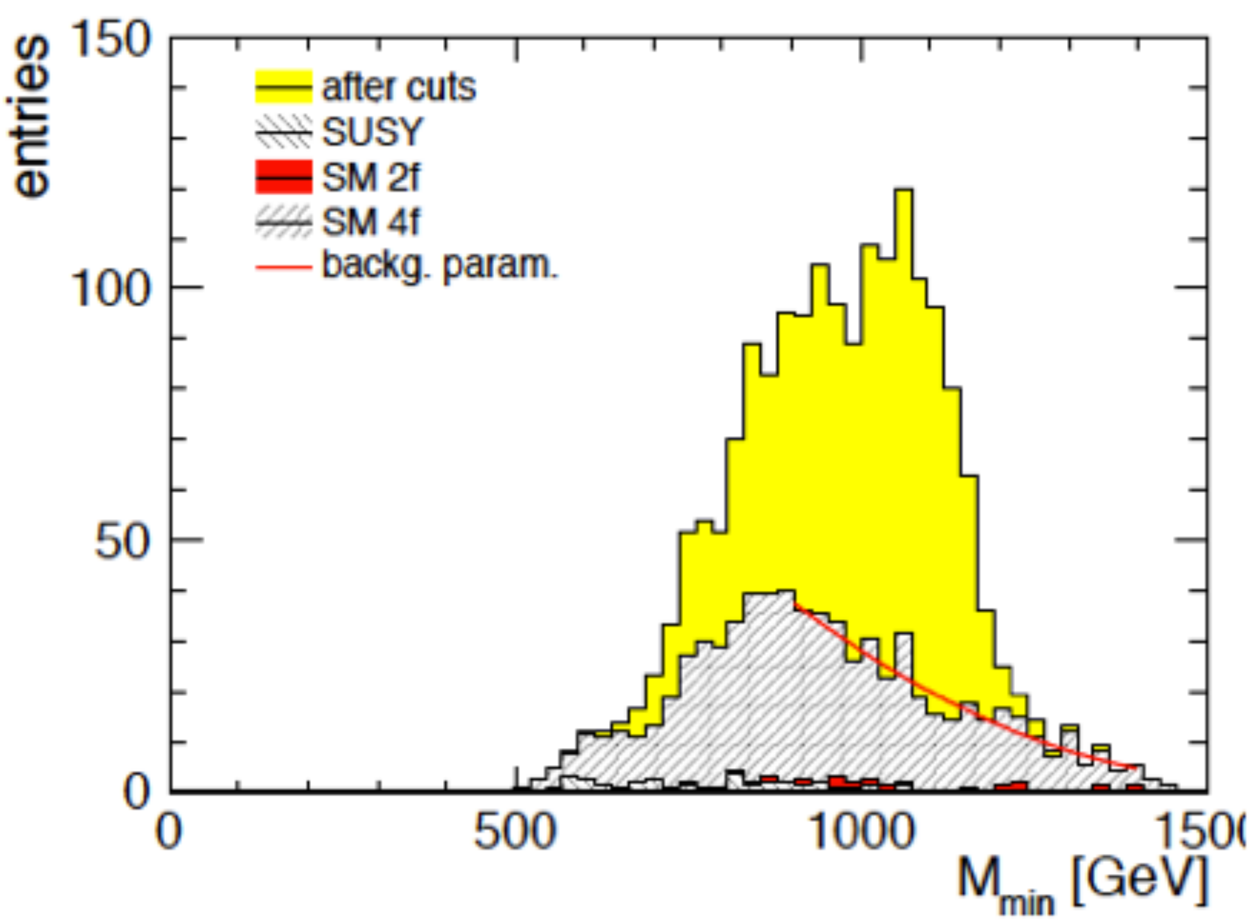
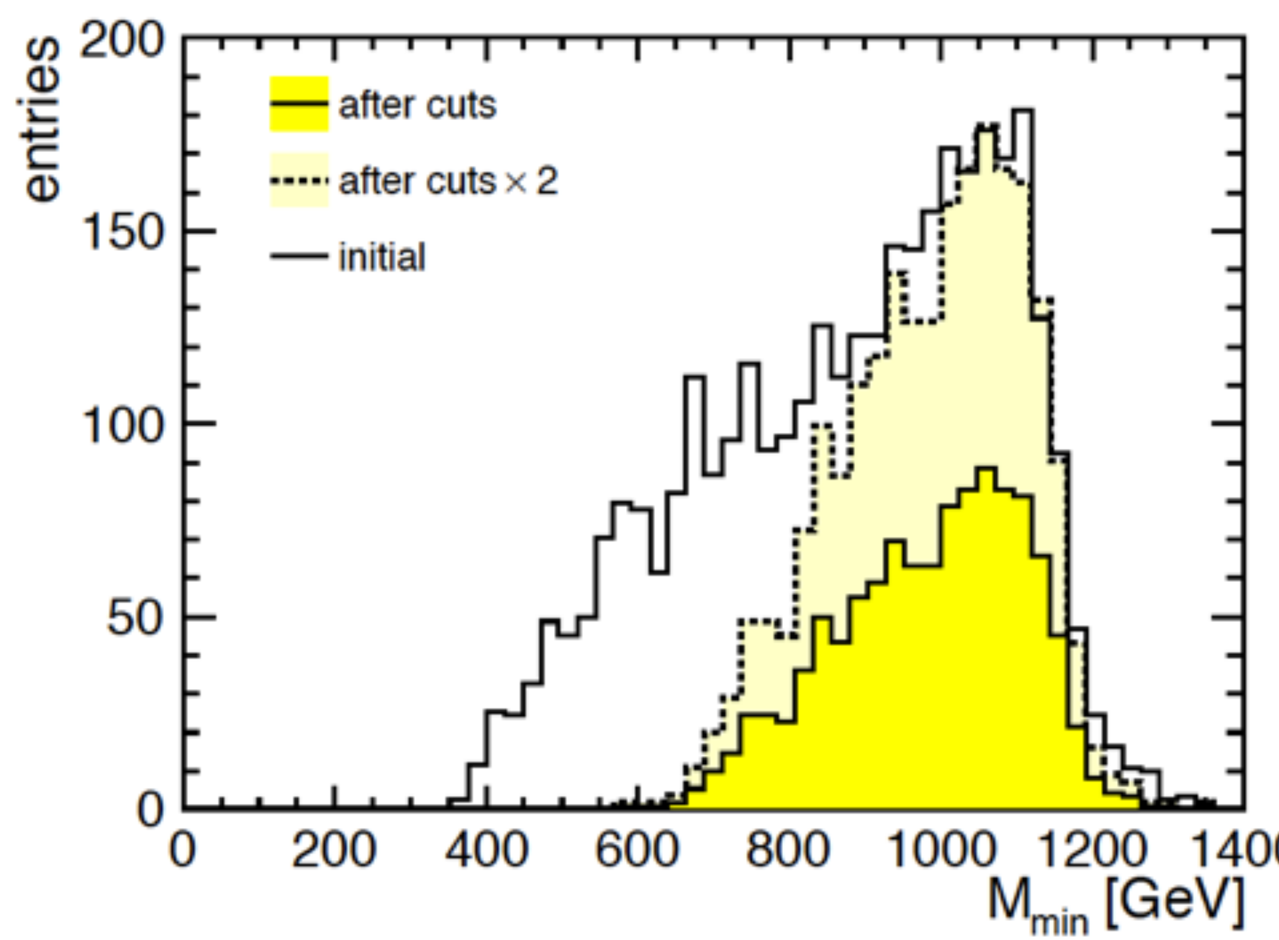


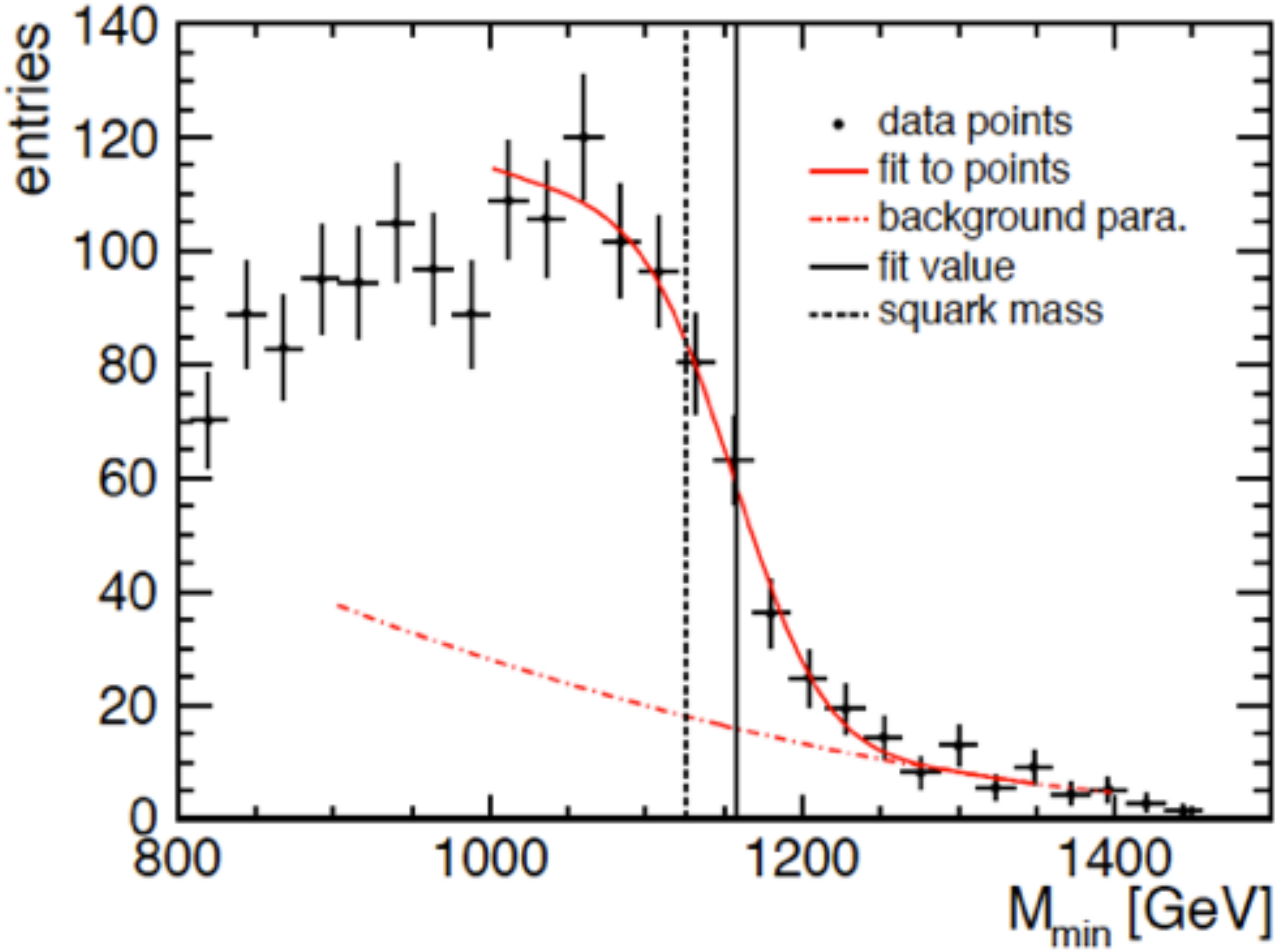


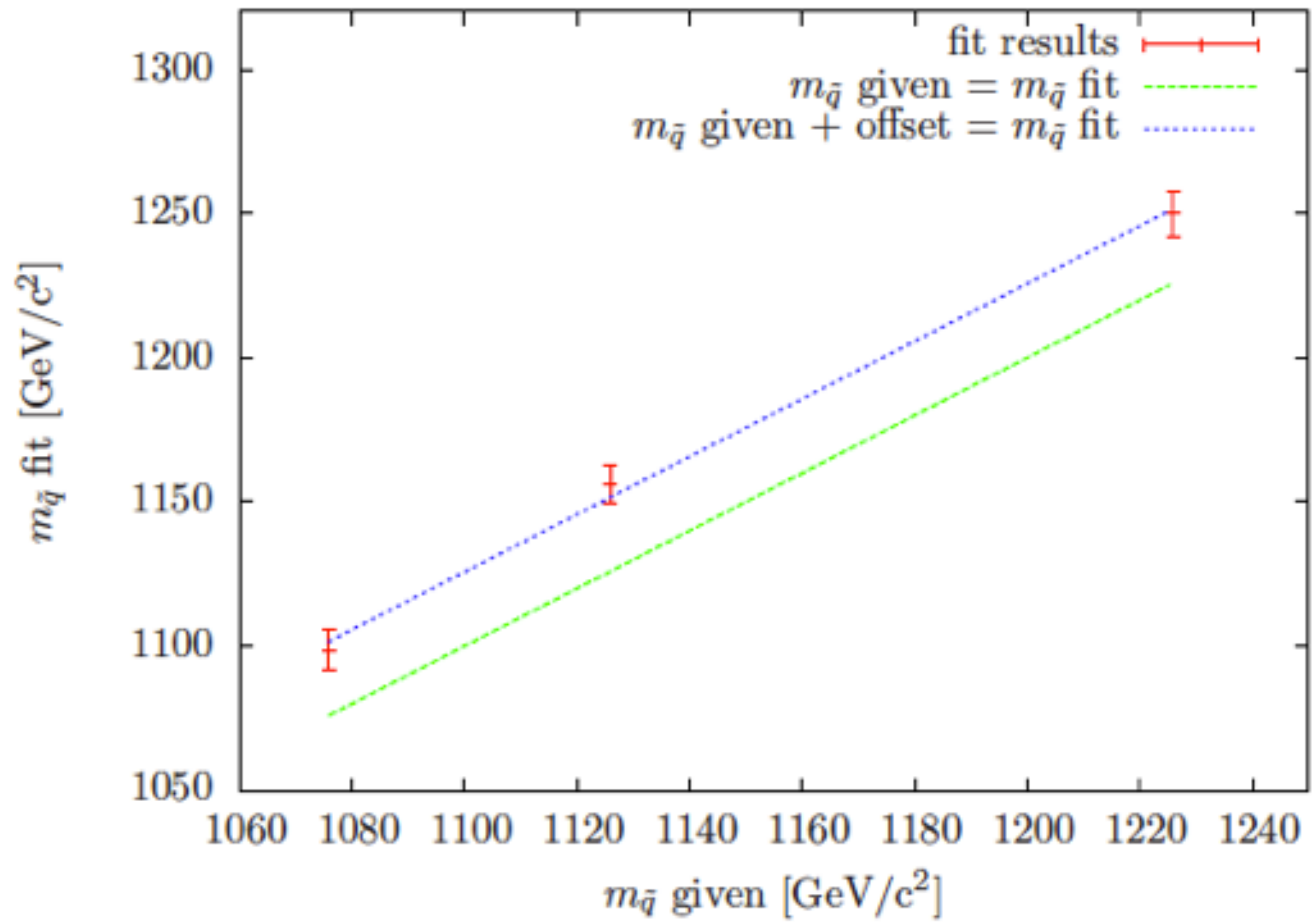
➩ Efficient rejection of physics background is possible without compromising the squark mass measurement!

Determination of Squark Mass

- Techniques for mass extraction under study - Samples with different input mass
  - Fit of edge of distribution - constant offset observed
  - Coming up: Template method: potential for higher precision, take mixture of up/down type squarks into account

Obtained resolution: ~ 10 GeV (1%) in the studied range





Event Generation - Challenging Numbers

- Study on an integrated luminosity of 2 ab^{-1}:
  - ~ 3000 signal events
  - ~ 6 M SM two fermion events
  - ~ 20 M SM four fermion events

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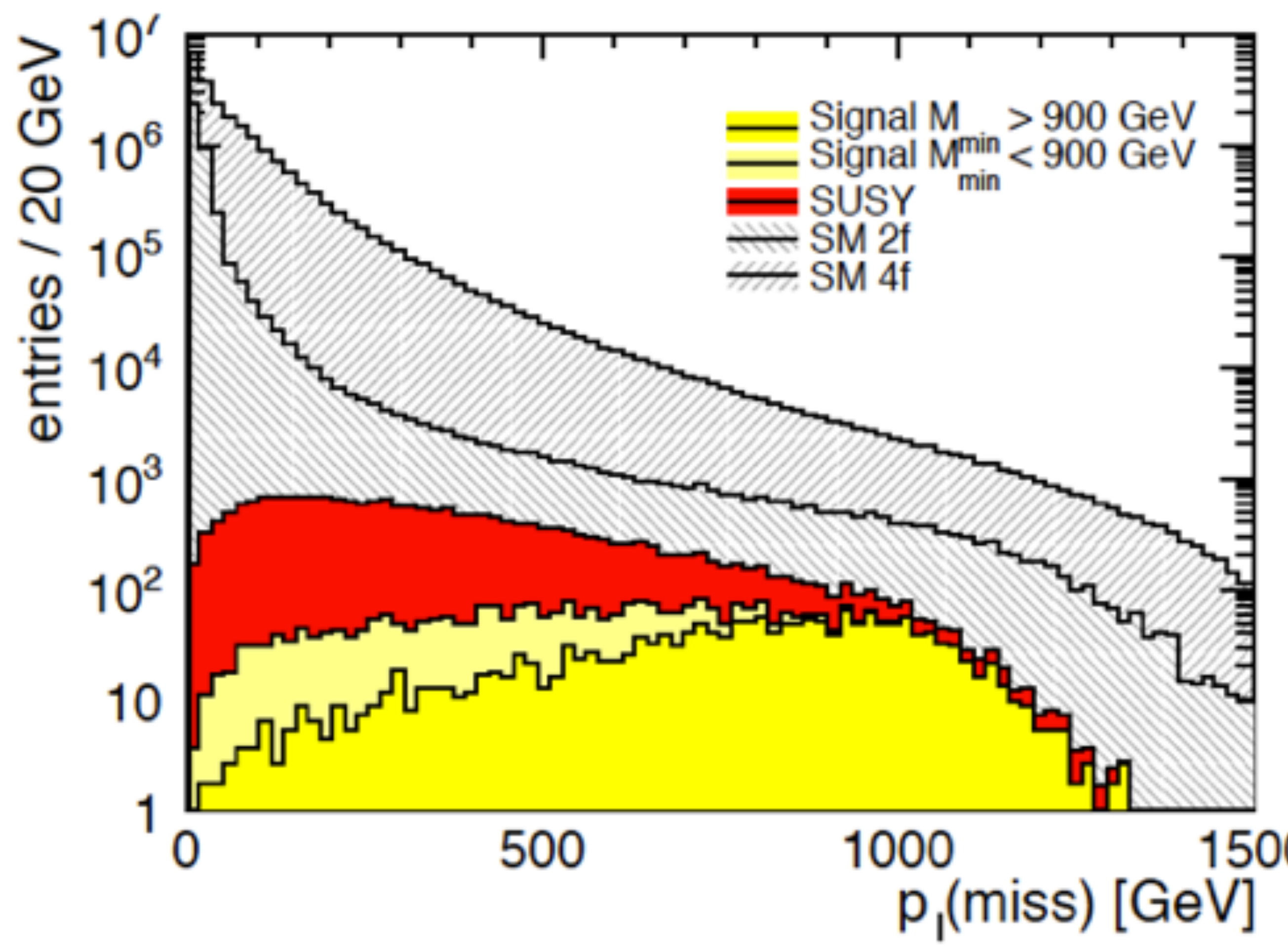
A solution:

- Generator-level cuts to reduce amount of fully simulated events
- Requirement: No impact on study!
- ▸ Cut on missing p_t (300 GeV) (higher cut will be imposed in analysis



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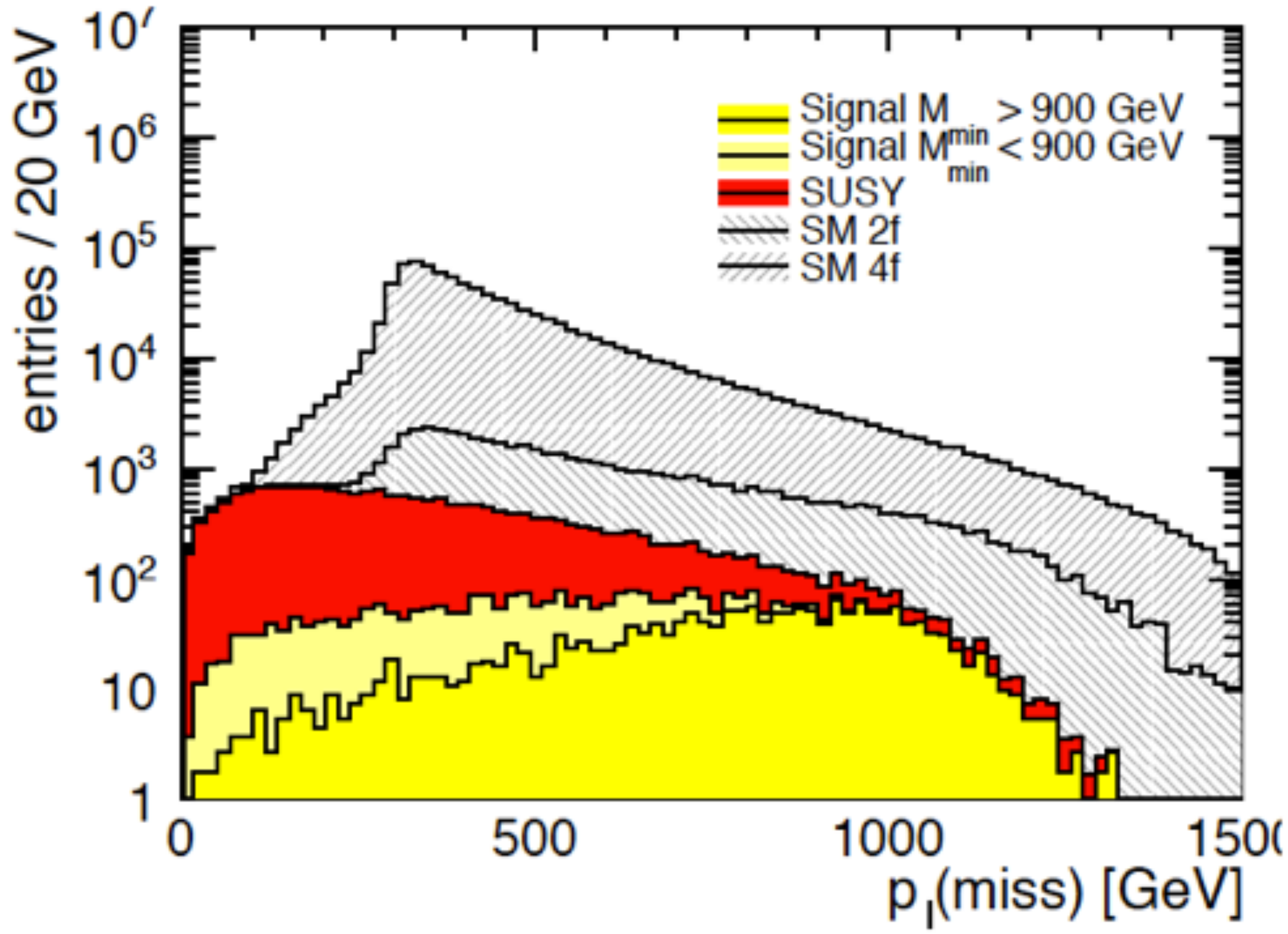
Reduction of sample by 1 order of magnitude!



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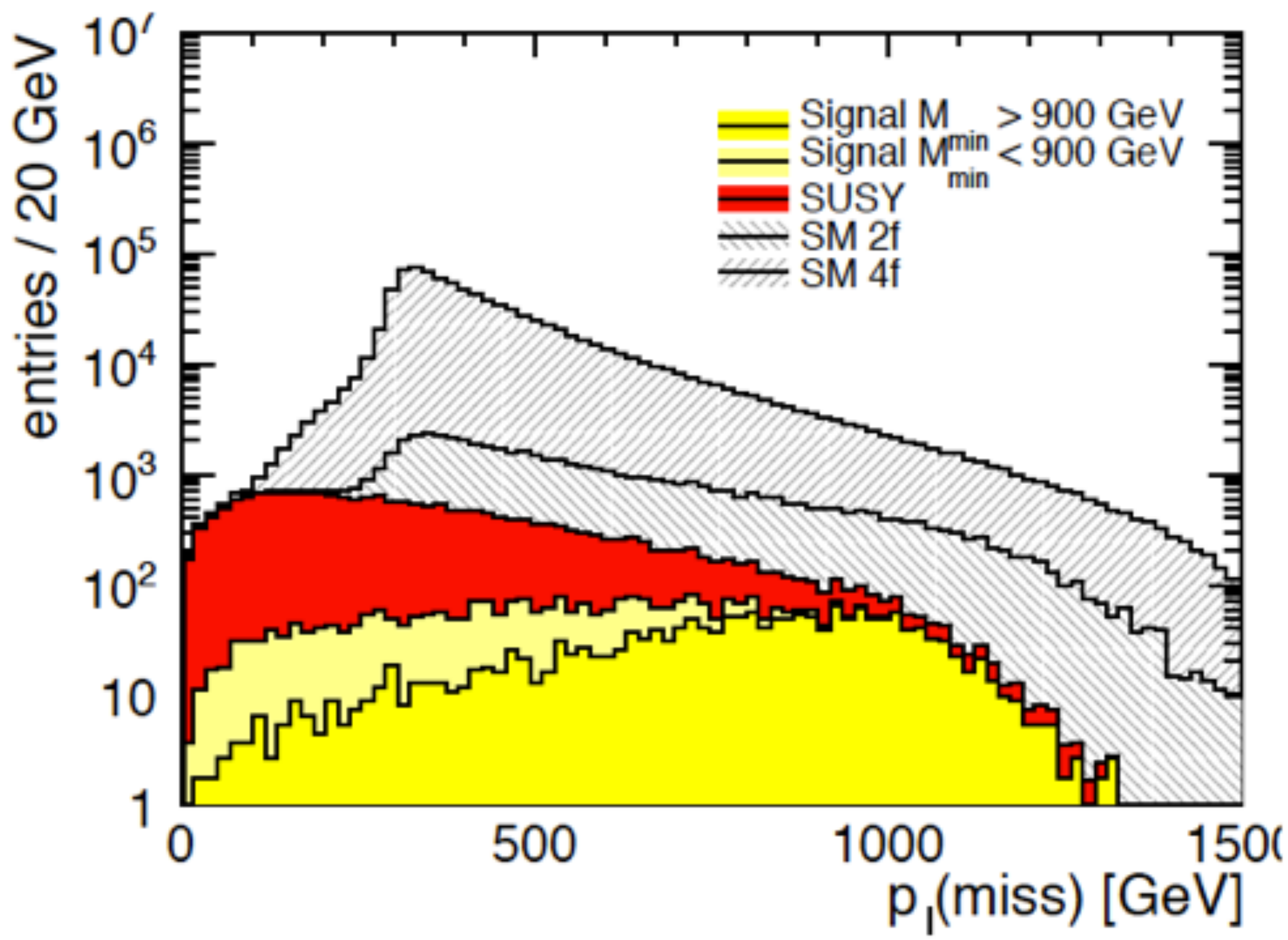


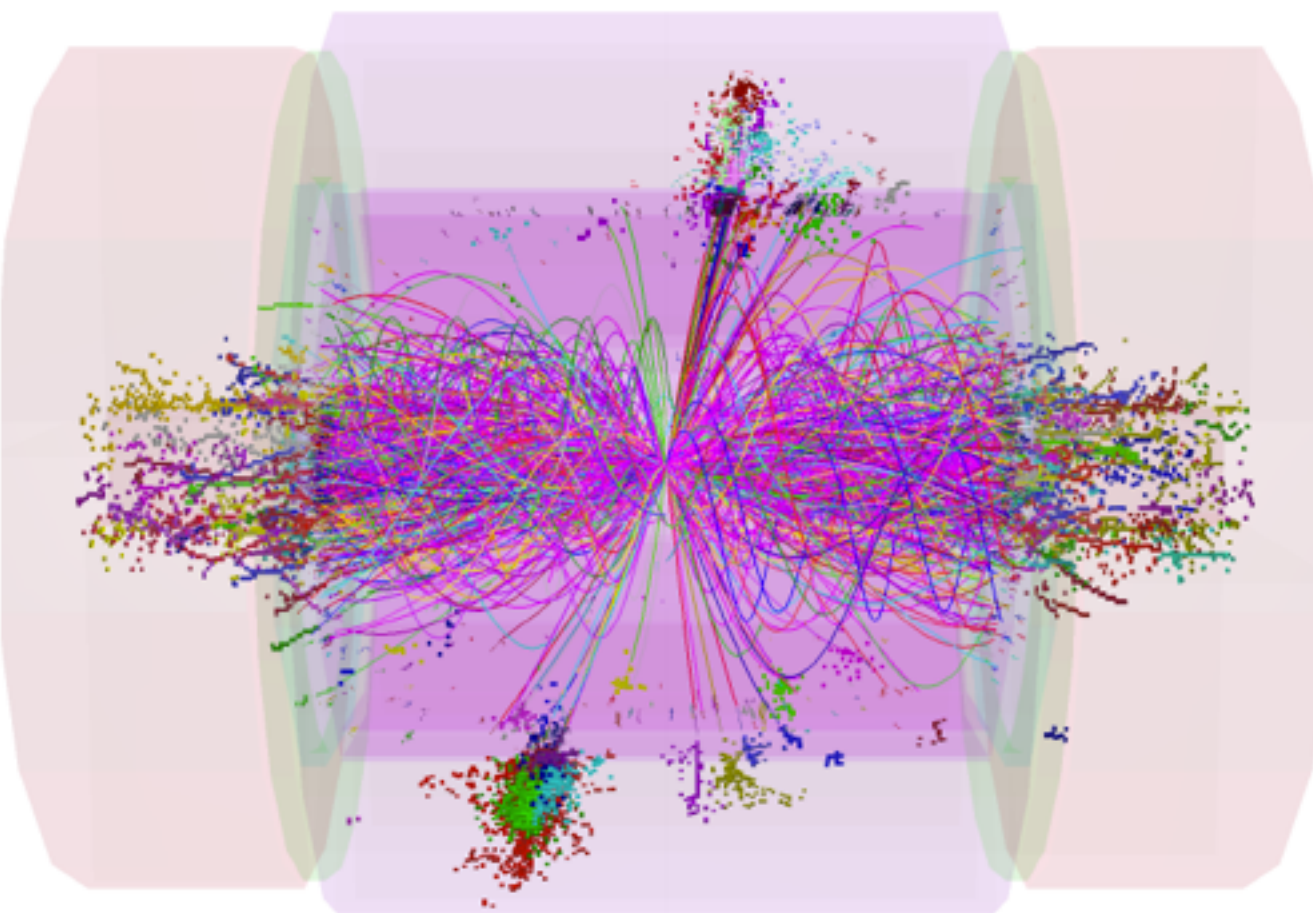
Alternative / complementary approach: No full simulation of high cross section backgrounds: Use generator level + smearing

Impact of Beam-Induced $\gamma\gamma \rightarrow$ Hadrons Background

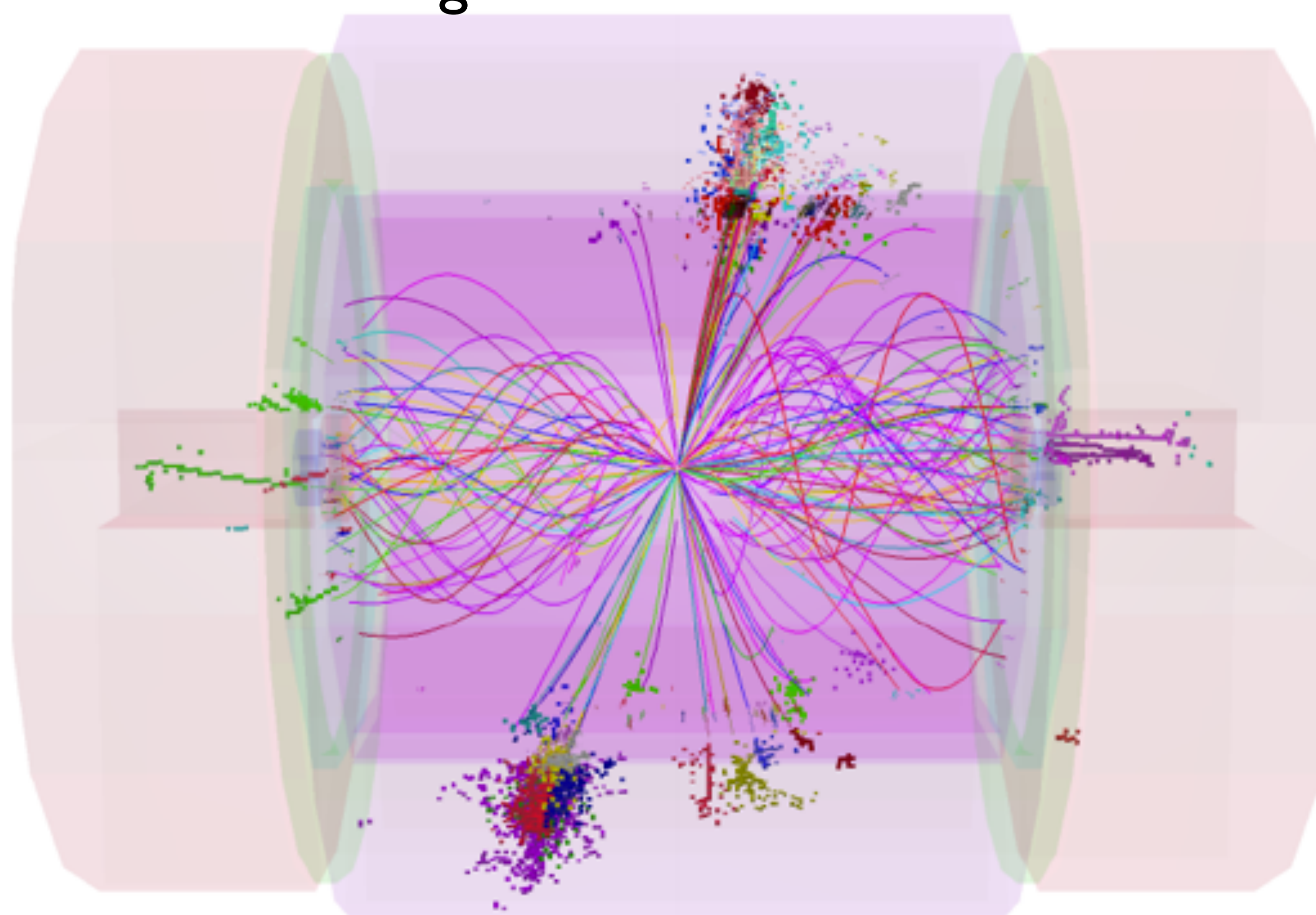
Background: Massive Impact

- Beam related background from γγ → hadrons processes adds significant energy to events, in particular in the forward region

1 TeV Z → uds + γγ → hadrons background



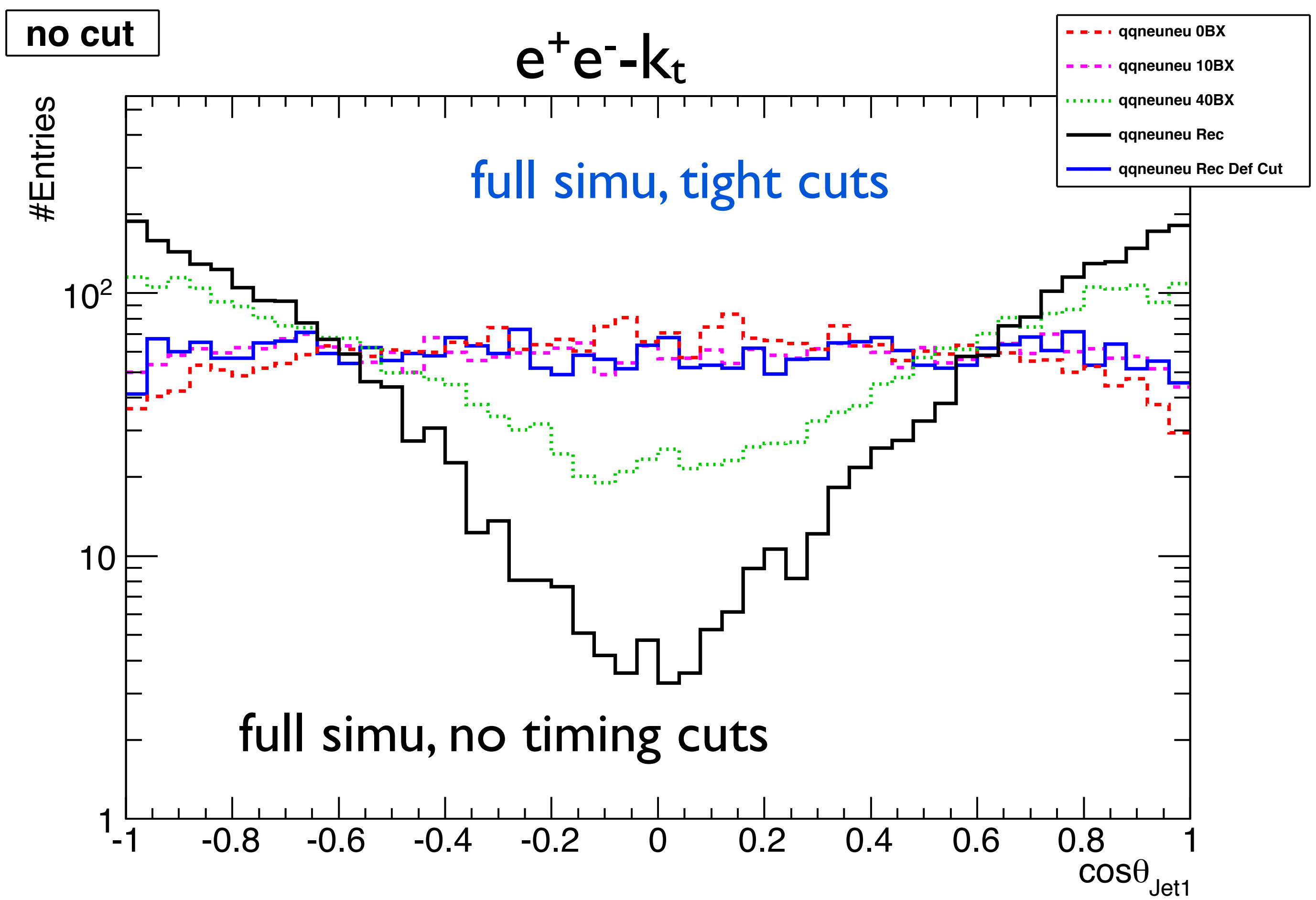
~ 60 BX, 1.4 TeV

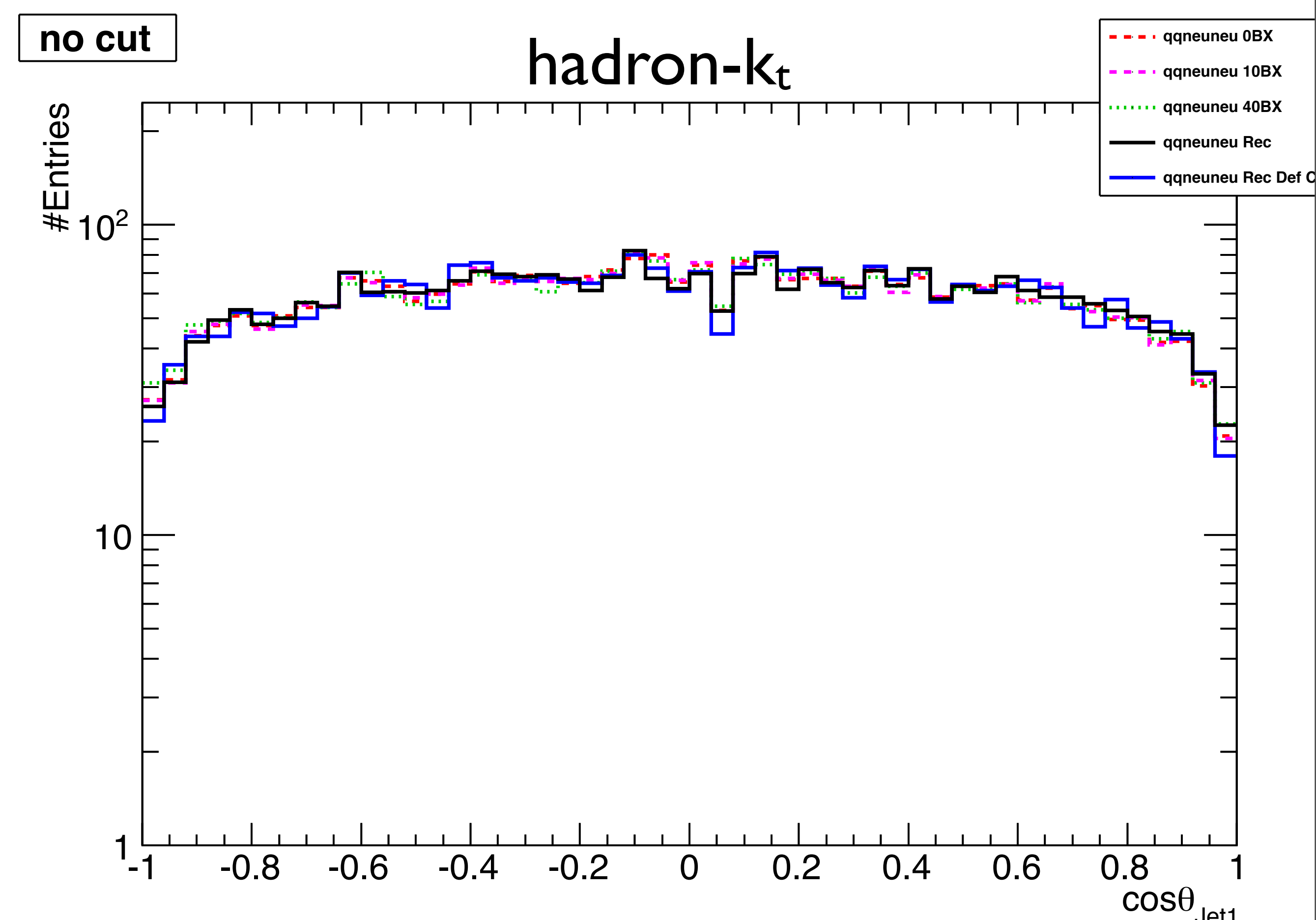


realistic timing assumptions: 200 GeV

Coping with Background: Jet Finding

- The level of background being picked up with the signal depends on the jet finder
  - Distance measure defines which particles get picked up
  - Classical k_t algorithm ("Durham", or e^+e^--k_t): $\cos\theta_{ij}$ defines distance, together with full particle energy
  - Hadron collider k_t algorithm: $\Delta\varphi$, $\Delta\eta$ defines distance, together with transverse momentum ➯ "Expansion" of distances in forward region





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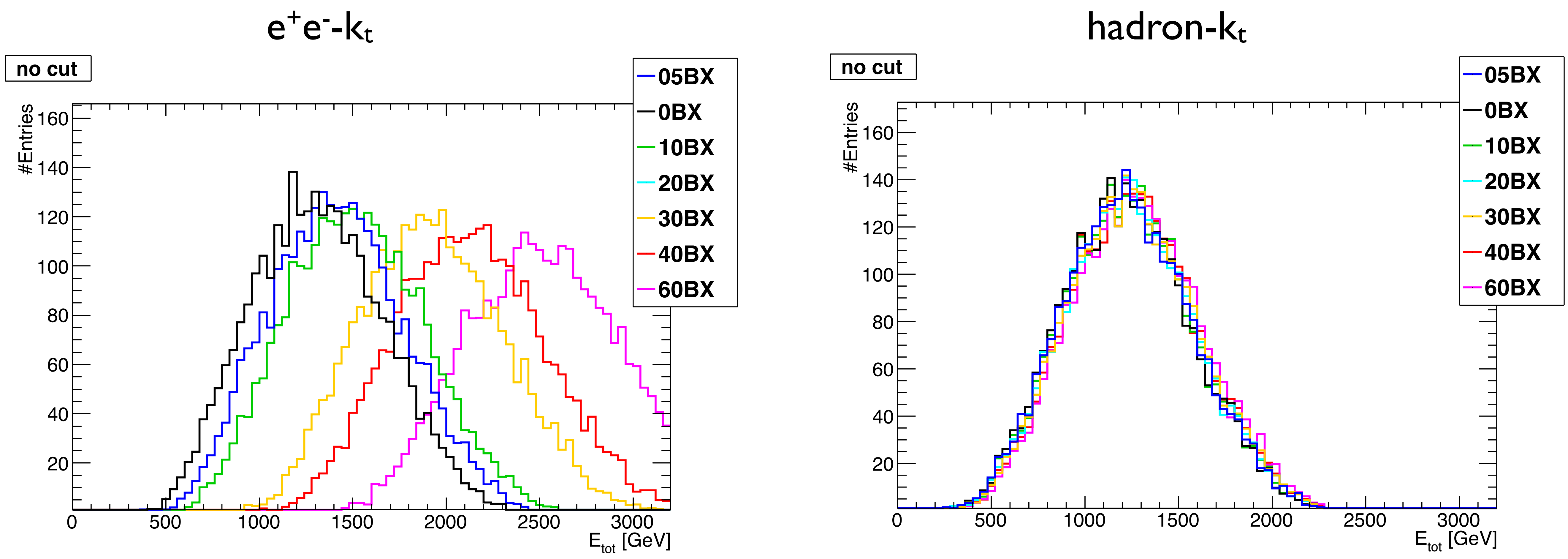
- Total reconstructed energy in both jets stable even against high background contributions for hadron-k_t
- Massive impact for e^+e^--k_t: Complete additional energy gets picked up



Studies on generator level, with background overlayed - 5 to 10 bx realistic with cuts

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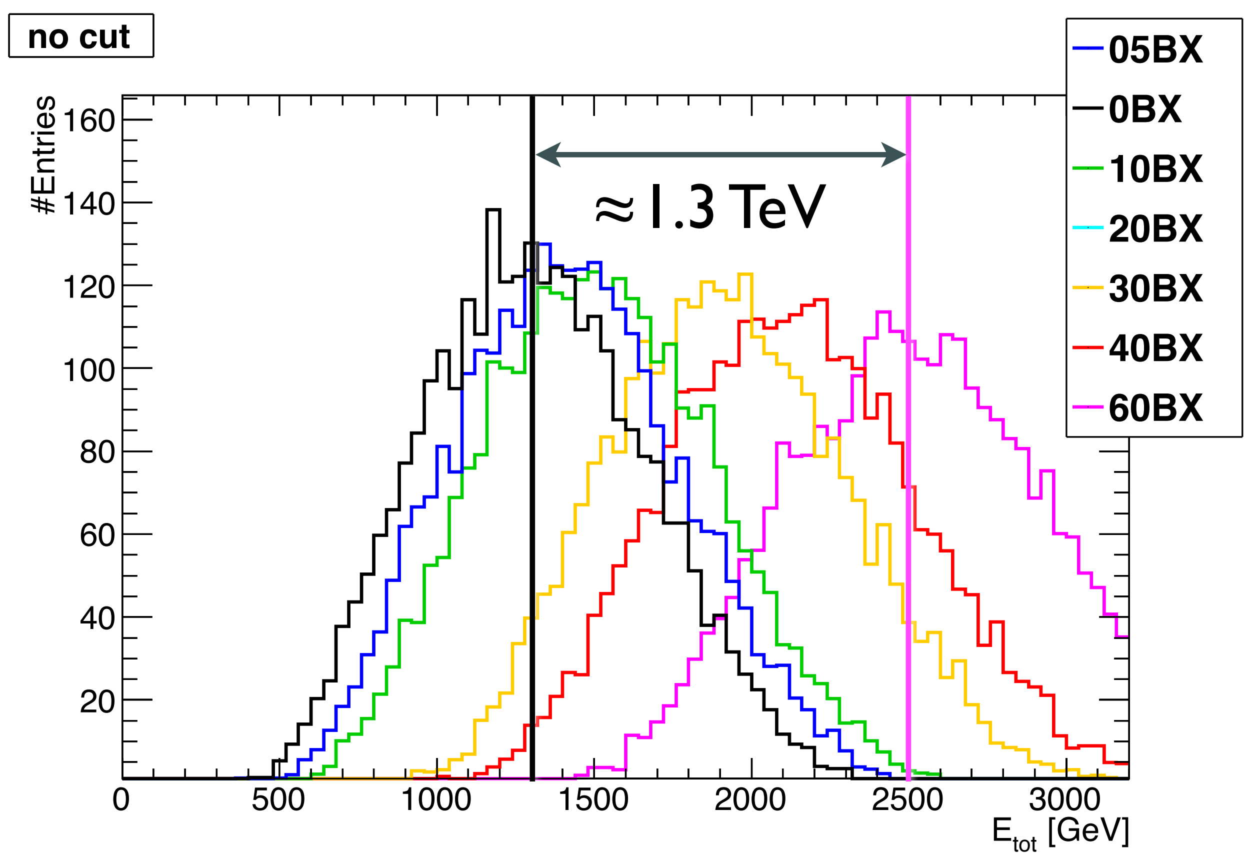
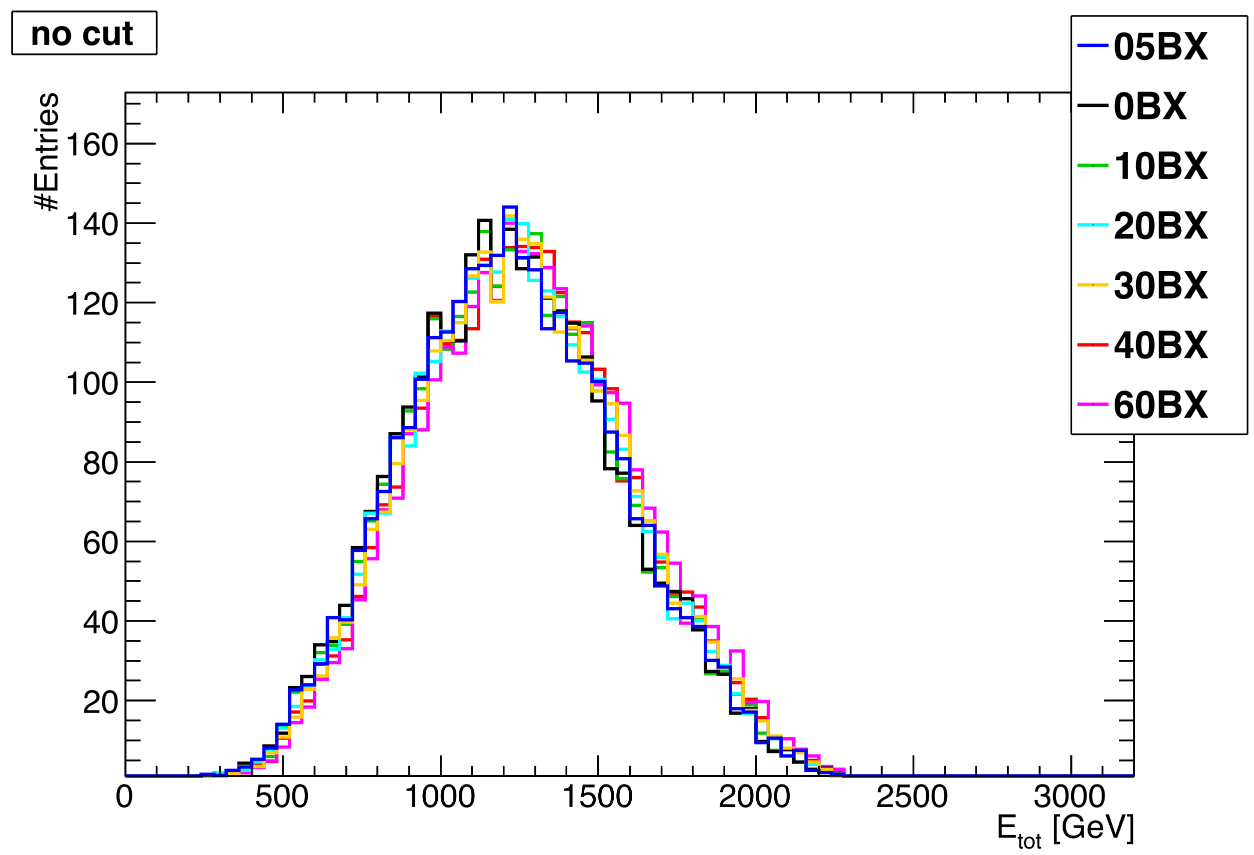


hadron-k_t



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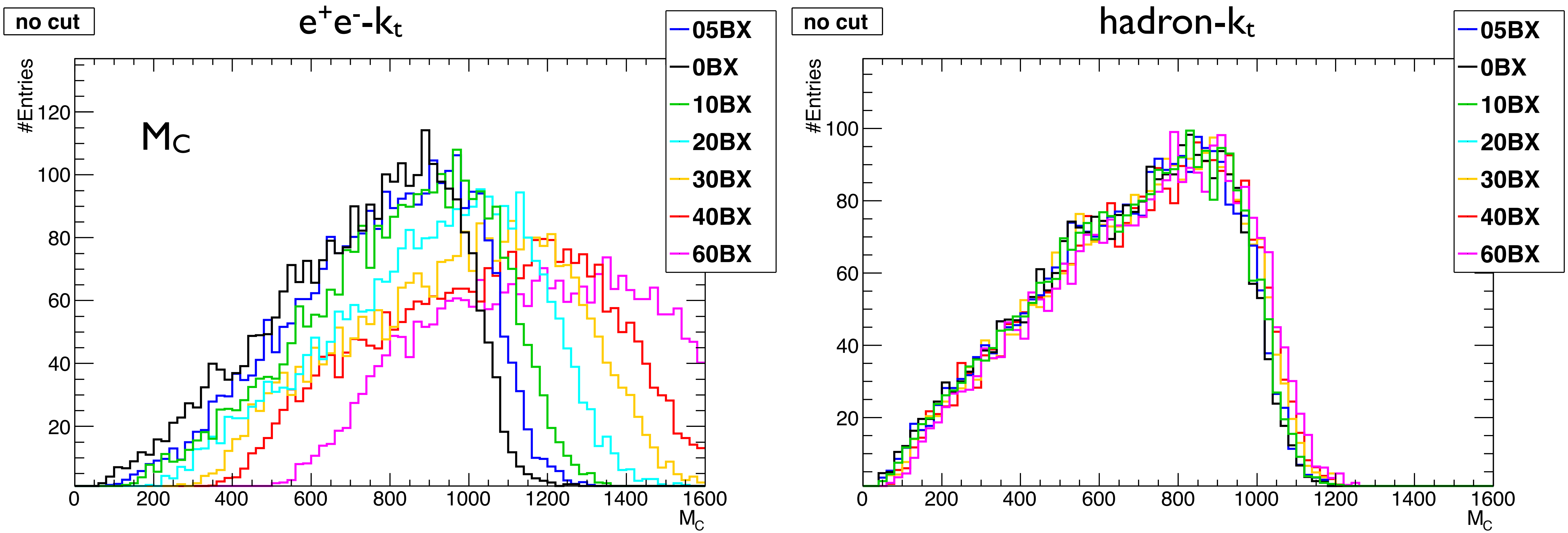
Coping with Background: Mass Measurement

- Distributions used for mass measurements suffer distortions from excessive background - Compromises mass measurement!



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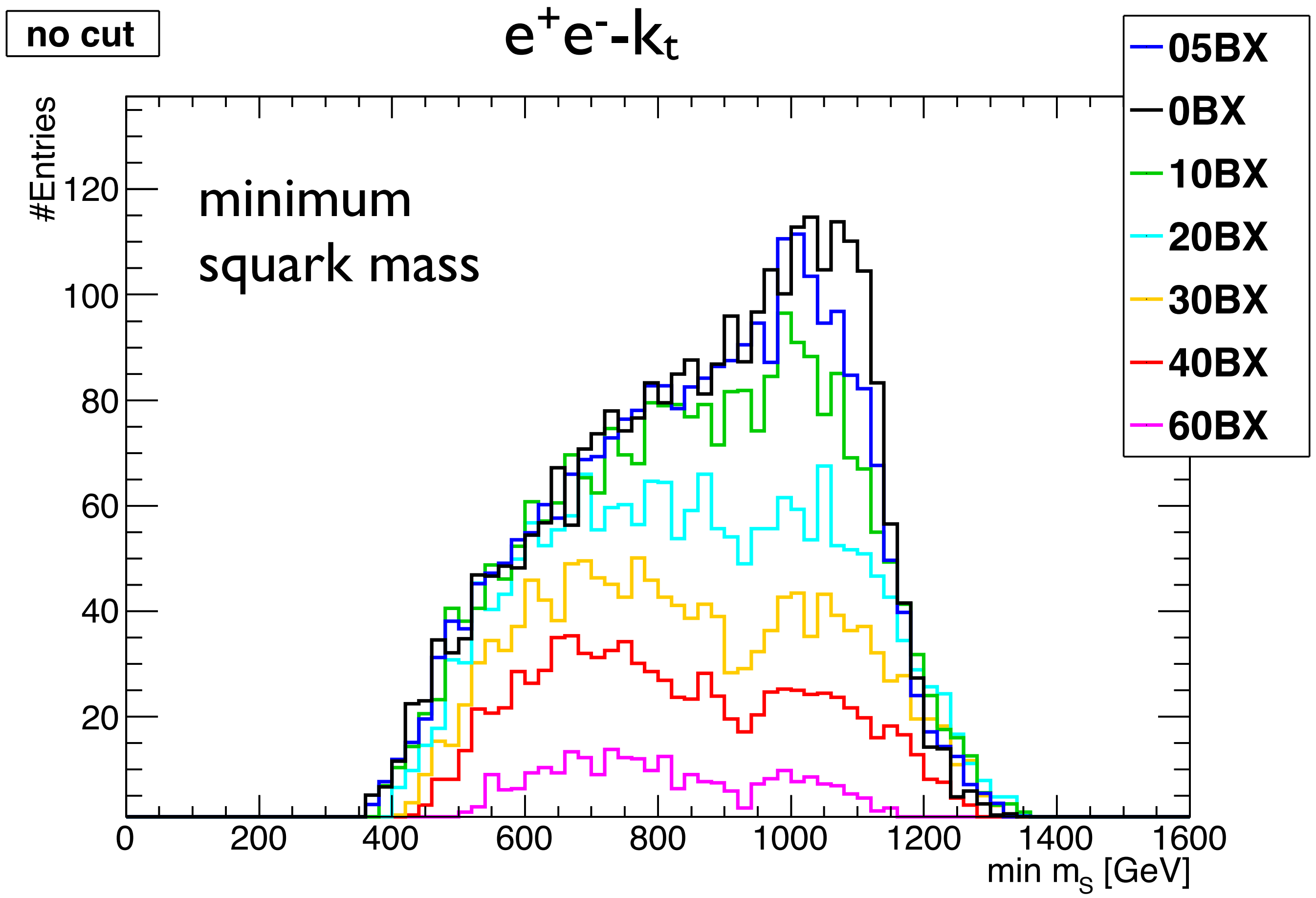

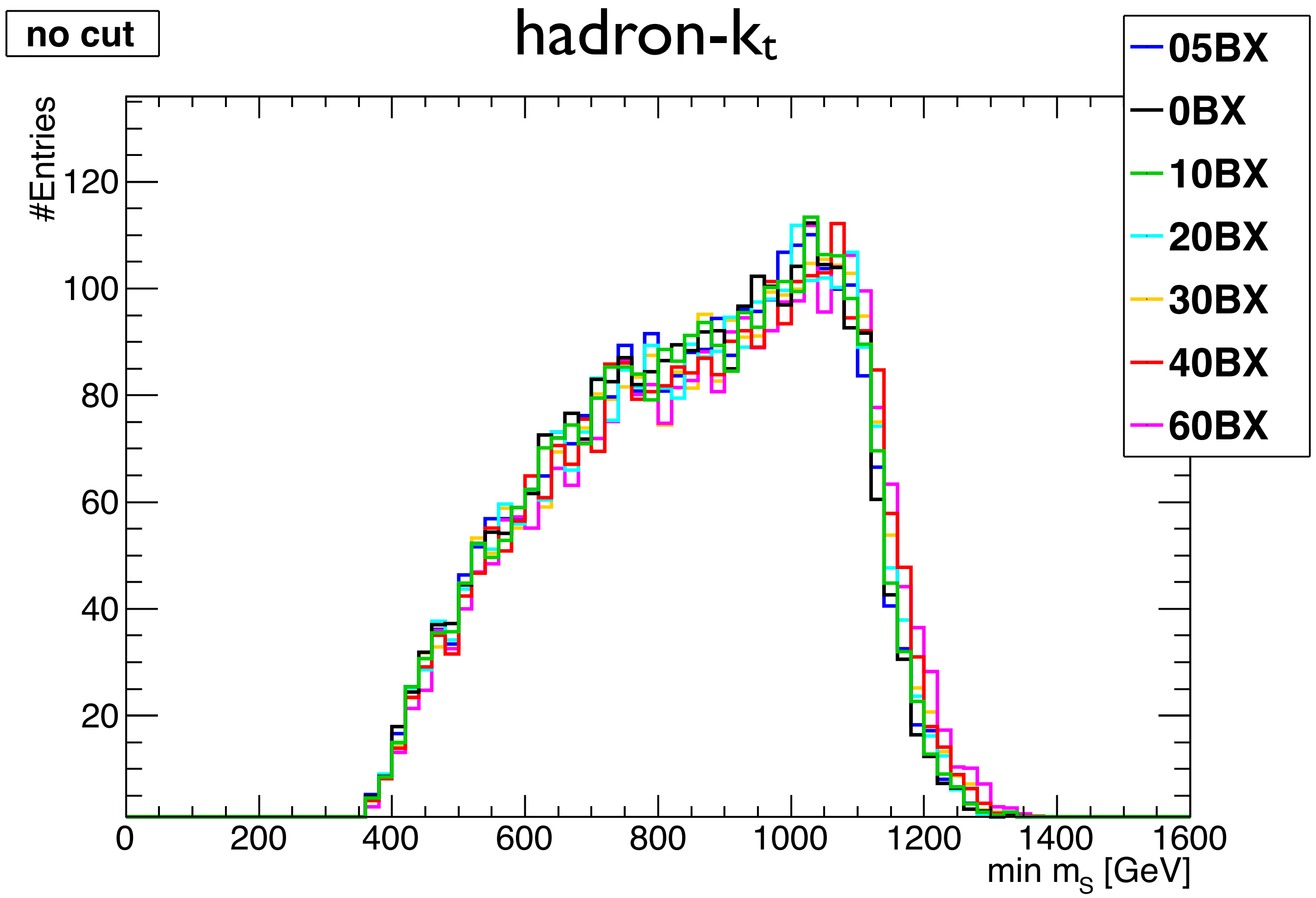

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Summary & Outlook

- 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
  - ▸ 1% mass resolution seems feasible
- Influence from high $\gamma\gamma \rightarrow$ hadrons background can be controlled by jet finding
- Full mass production in preparation - Some backgrounds potentially only on generator level