SUSY Simplified Models at the SppC

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(SLAC)

Third Workshop on Future High Energy Circular Colliders
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Workshop on Physics
at a 100 TeV Collider
April 23-25, 2014, SLAC
Workshop Topics
PDFs and Generators
Detector Challenges
SM at 100 TeV
Physics Reach
BSM Spectroscopy
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www.slac.stanford.edu/th/100TeV.html

Acknowledgements

Gluino-Neutralino Simplified Model:

TC, Tobias Golling, Anna Henrichs, Kiel Howe, Joshua Loyal, Sanjay Padhi, Jay Wacker

arXiv:1311.6480

Stop-Neutralino Simplified Model:

TC, Raffaele D'Agnolo, Mike Hance, Hou Keong Lou, Jay Wacker

In progress

Snowmass Backgrounds:

Aram Avetisyan, John Campbell, TC, Nitish Dhingra, James Hirschauer, Kiel Howe, Subir Malik,Meenakshi Narain, Sanjay Padhi, Michael Peskin, John Stupak, Jay Wacker

arXiv:1308.1636

Answering big questions

Is the electroweak scale tuned?

What is the dark matter?

Is there supersymmetry (at any scale)?

Do the gauge couplings unify?

Is the Higgs elementary or composite?

What surprises await us at higher energies?

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What surprises await us at higher energies?

Requires big investments

300 fb^{-1} 13-14 TeV LHC

3000 fb^{-1} 13-14 TeV LHC

33 TeV circular proton-proton collider

100 TeV circular proton-proton collider

Complimentary machine: $e^+ \, e^-$ Higgs factory.

Outline

- Motivation
- SM Background generation
- Gluino-neutralino Simplified Model
- Stop-neutralino Simplified Model
- Conclusions

Motivation

No Stone Unturned

Lack on new physics has inspired wave of "hide-and-seek" model building.

Maybe the electroweak scale is natural, and mechanism will be hard to find.

Might require high luminosity.

High energy should help too.

Motivation

If we see new physics at the LHC, the future program is obvious!

If the LHC does not see new physics, are there motivated lampposts to look under?

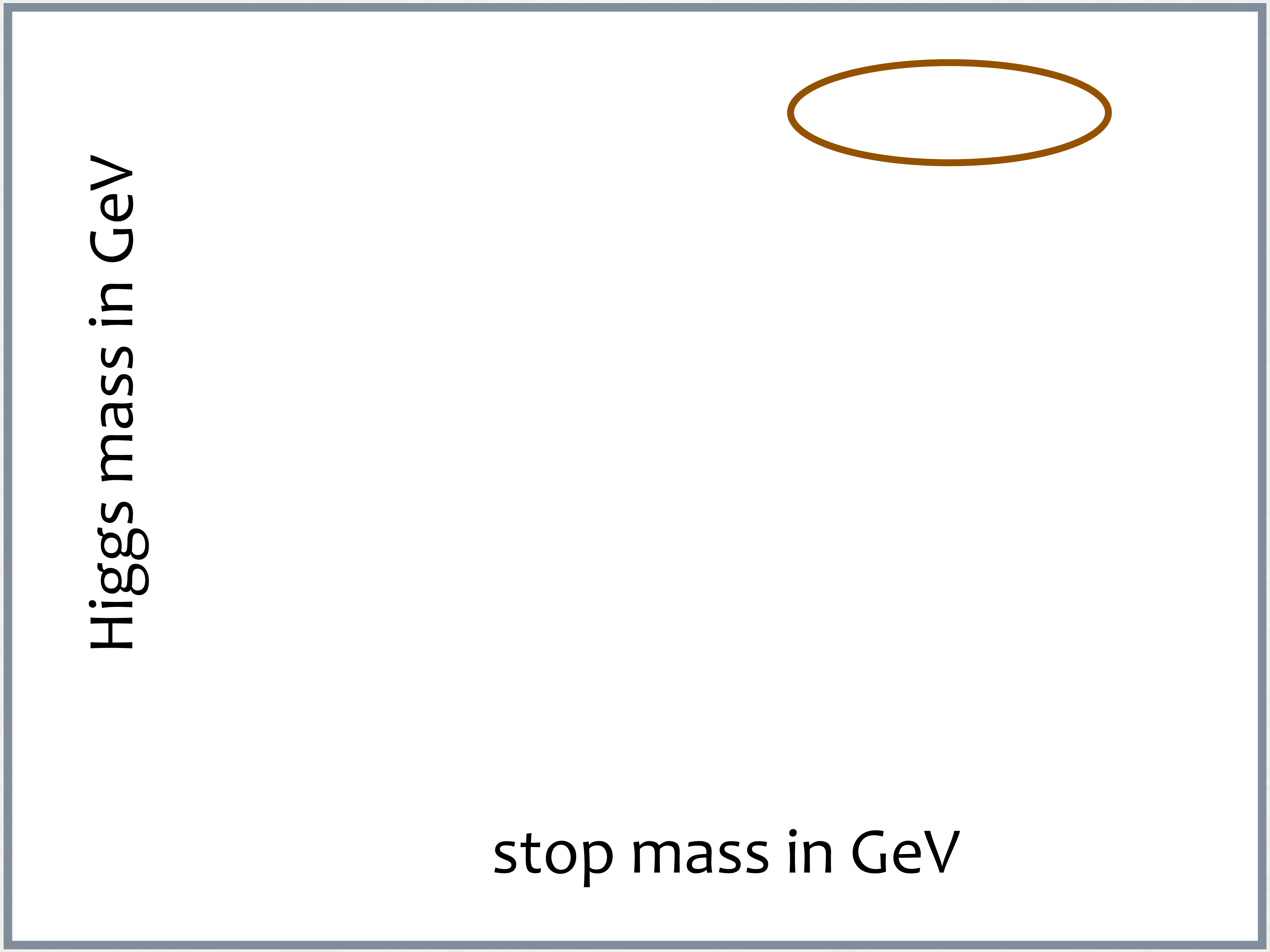
YES! There are many!

Unification,dark matter, and 125 GeV SM-like Higgs accommodated by Mini-Split SUSY.

Arvaniaki, Craig, Dimopoulos, Villladoro [arXiv:1210.0555];
Arkani-Hamed, Gupta, Kaplan, Weiner, Zorawski [arXiv:1212.6971];
Hall, Nomura, Shirai [arXiv:1210.2395];
Kane, Kumar, Lu, Zheng [arXiv:1112.1059];
Ibe, Yanagida [arXiv:1112.2462]

The MSSM Higgs boson

Giudice and Strumia [arXiv:1108.6077]



The MSSM Higgs boson

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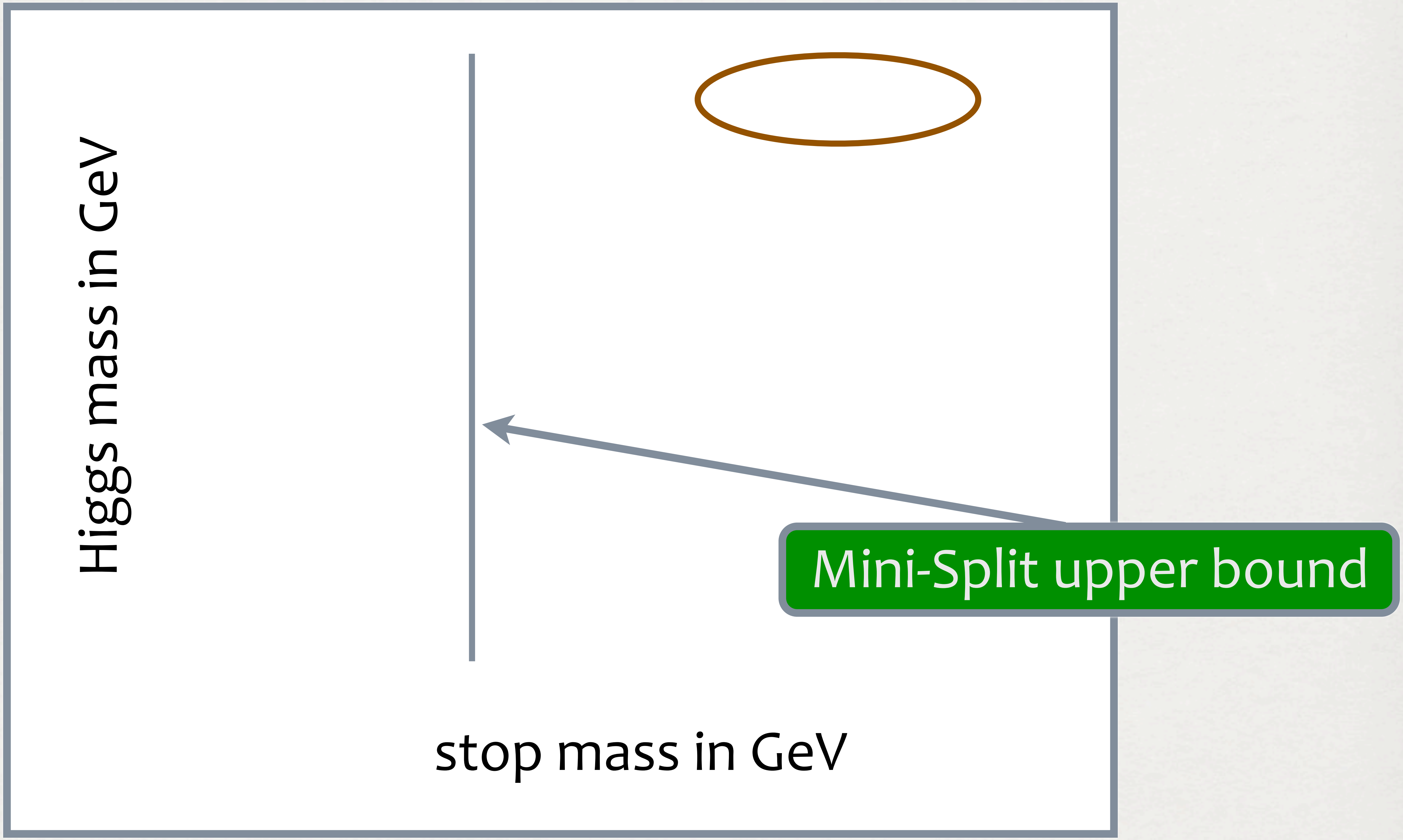


Want to motivate future circular colliders.

One important question:

What is the mass reach of human-buildable colliders?

SM Backgrounds: A Monte-Carlo Challenge

Generating 3 ab^{-1}

$$\sigma_{\rm NLO}(p\,p \to t\,\bar{t}) = 0.8\ \rm nb$$

$$\mathcal{L} = 3\ \rm ab^{-1}$$

Want factor of 10 more MC than expected events

$$10 \times \sigma \times \mathcal{L} = 2.4 \times 10^{10}$$

If each event is 1 kilobyte:

24 Terabytes for tops (per pileup setting)

Is there a solution?

1-1 event generation is not feasible.

Step one:

kinematically weighted event generation.

Weighted Events

As an example

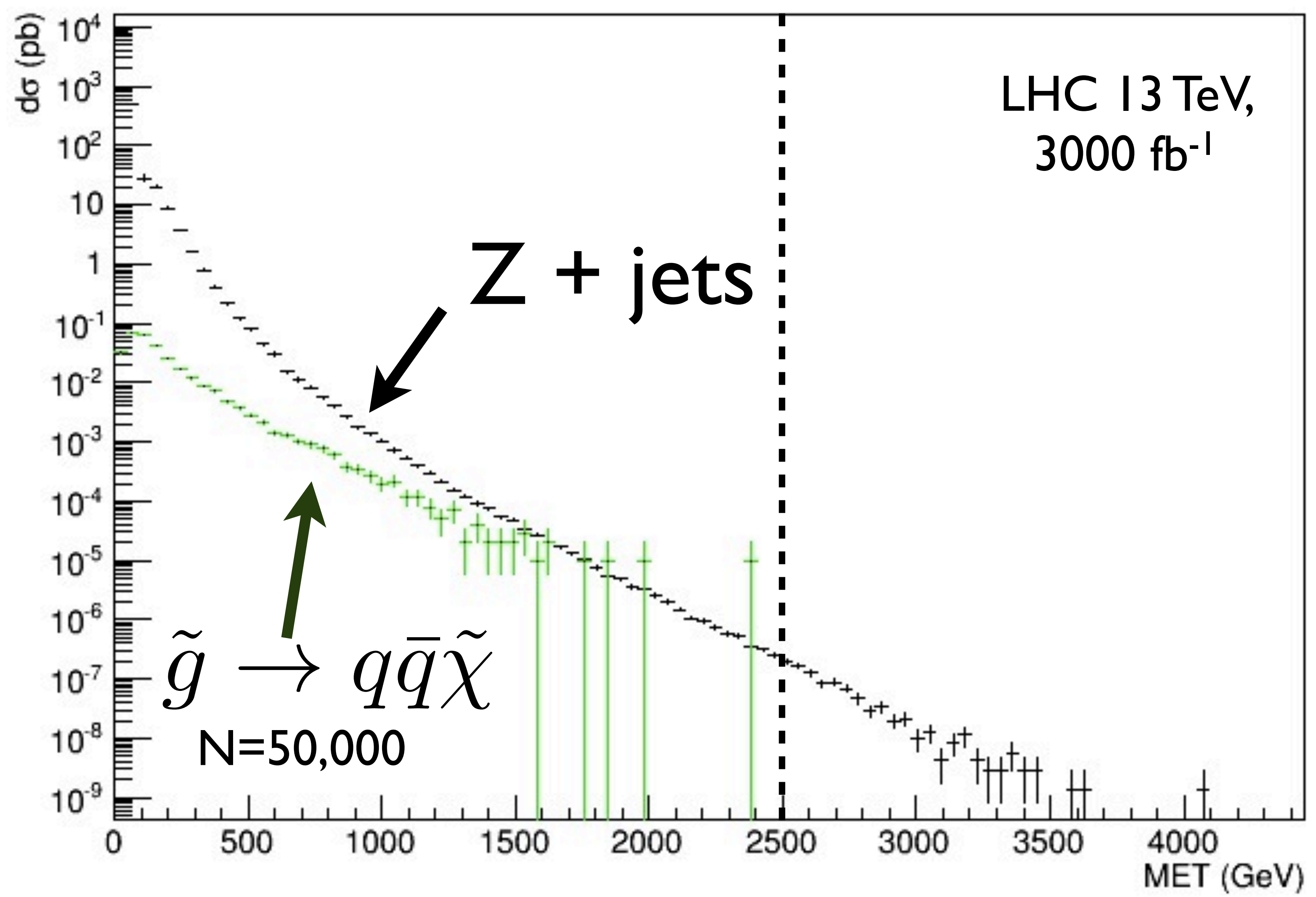
Take the gluino-neutralino simplified model:

$$p\,p \to \widetilde{g}\,\widetilde{g} \to \left(q\,\overline{q}\,\chi\right)\left(q\,\overline{q}\,\chi\right)$$

Compressed region is difficult to simulate.
Modeling tails of distributions is crucial for searches.

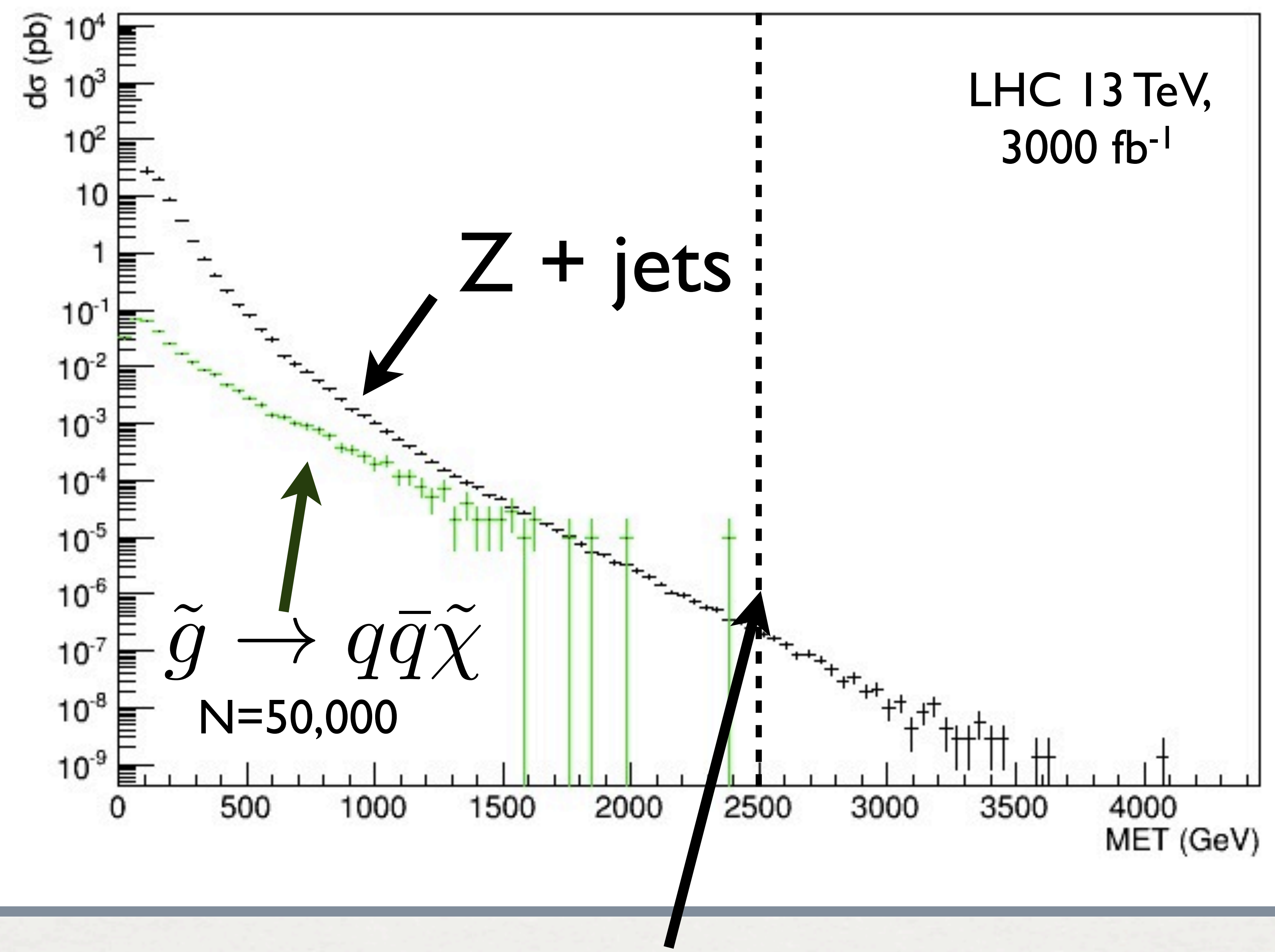
Un-weighted Events

$$\tilde{m}_g = 1000 \text{ GeV}, \tilde{m}_\chi = 900 \text{ GeV} \quad (\sigma = 0.3 \text{ pb})$$



Un-weighted Events

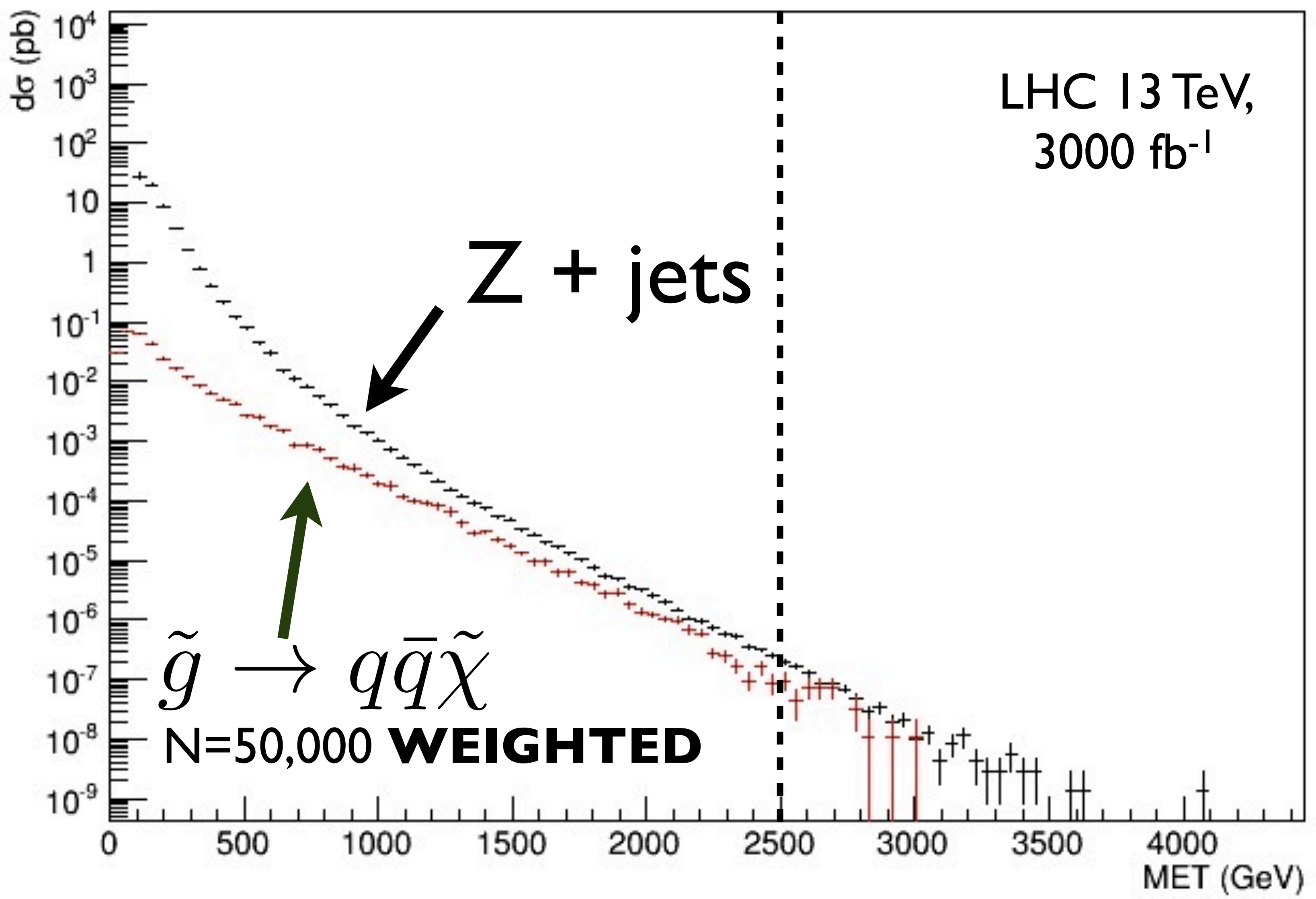
$$\tilde{m}_g = 1000\ \mathrm{GeV}, \tilde{m}_\chi = 900\ \mathrm{GeV} \quad (\sigma = 0.3\ \mathrm{pb})$$



Cut design thrown off by single event

Kinematic Weighting

$\tilde{m}_g = 1000 \text{ GeV}, \tilde{m}_\chi = 900 \text{ GeV} \quad (\sigma = 0.3 \text{ pb})$



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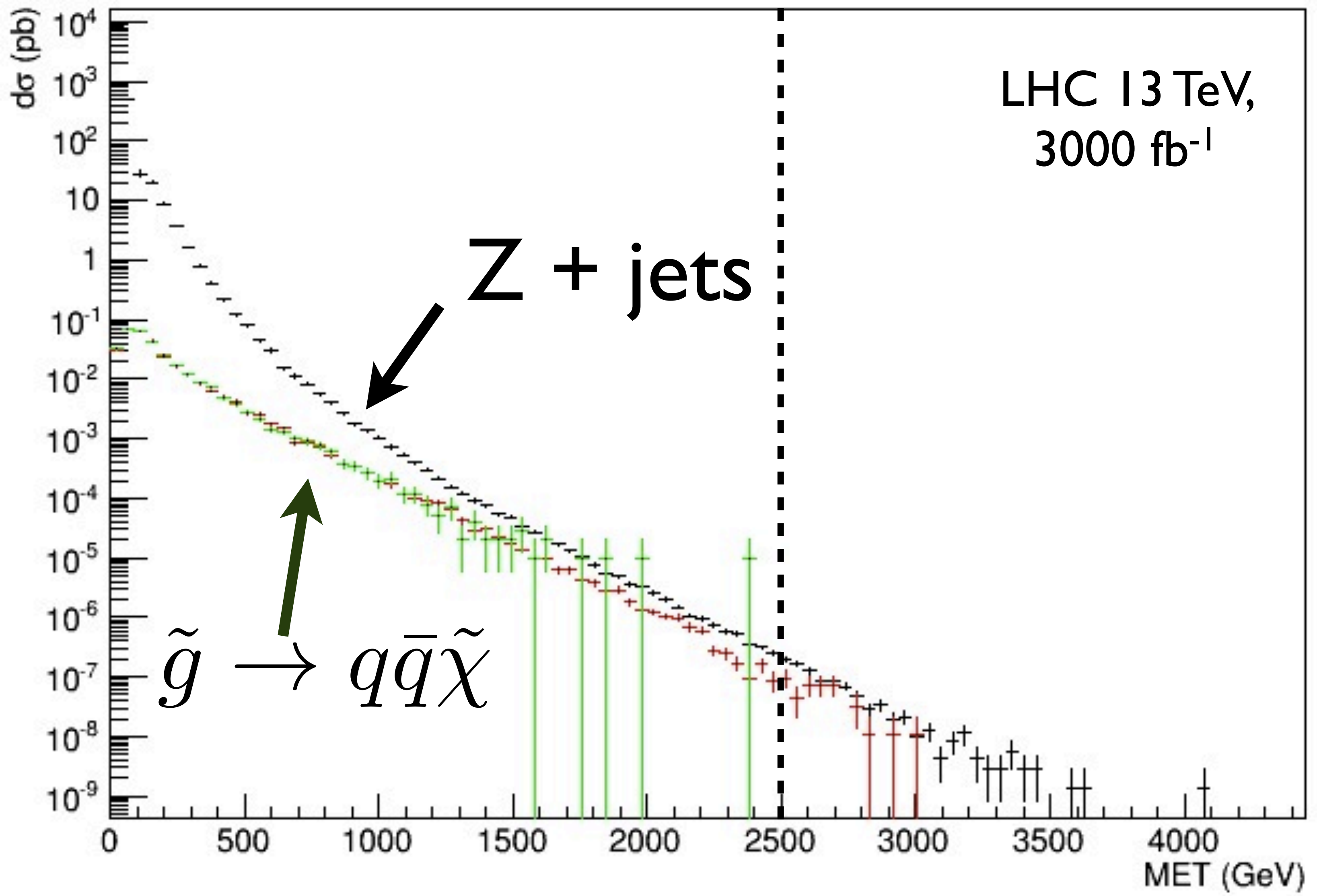


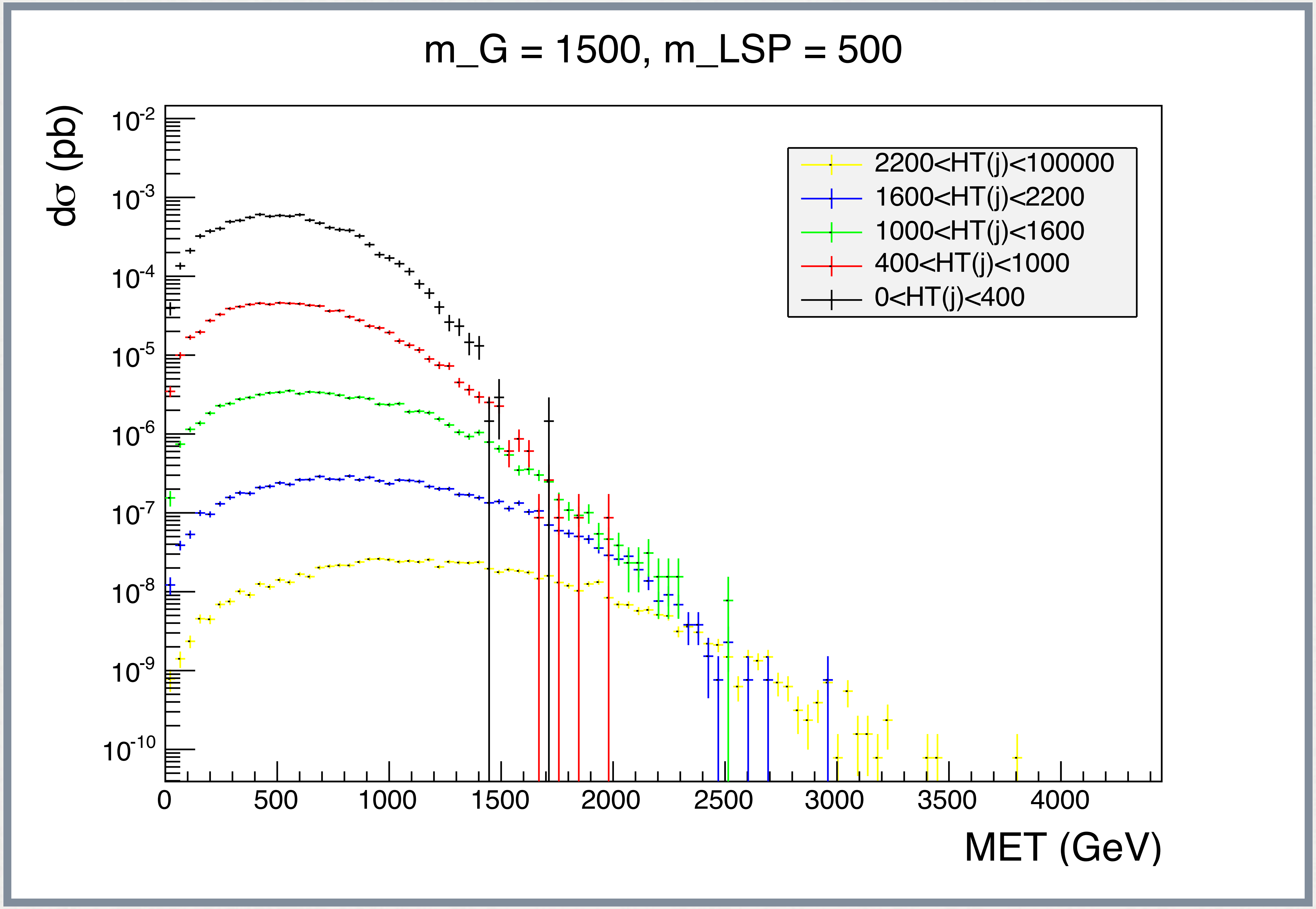
ALGORITHM

1) Choose an appropriate generator level variable, x
   - Background: x = H_T for all states [ihtmin/ihtmax]*
   - Signal: x = H_T of ISR jets [htjmin/htjmax]
2) Compute the cross section as a function of x
3) Define bins:
   - First bin: $\sigma(\mathrm{bin}_1) \geq 0.9 \times \sigma_{\mathrm{tot}}$
   - Subsequent bins: $\sigma(\mathrm{bin}_k) \geq 0.9 \times \sigma_{\mathrm{remaining}}$
   - Final bin is inclusive: $\sigma(\mathrm{bin}_{\mathrm{final}}) < 10/\mathcal{L}$
4) Generate events (n_k events in bin *k* after matching)
   - Event weight: $w_k = \dfrac{\sigma(\mathrm{bin}_k)}{n_k}$

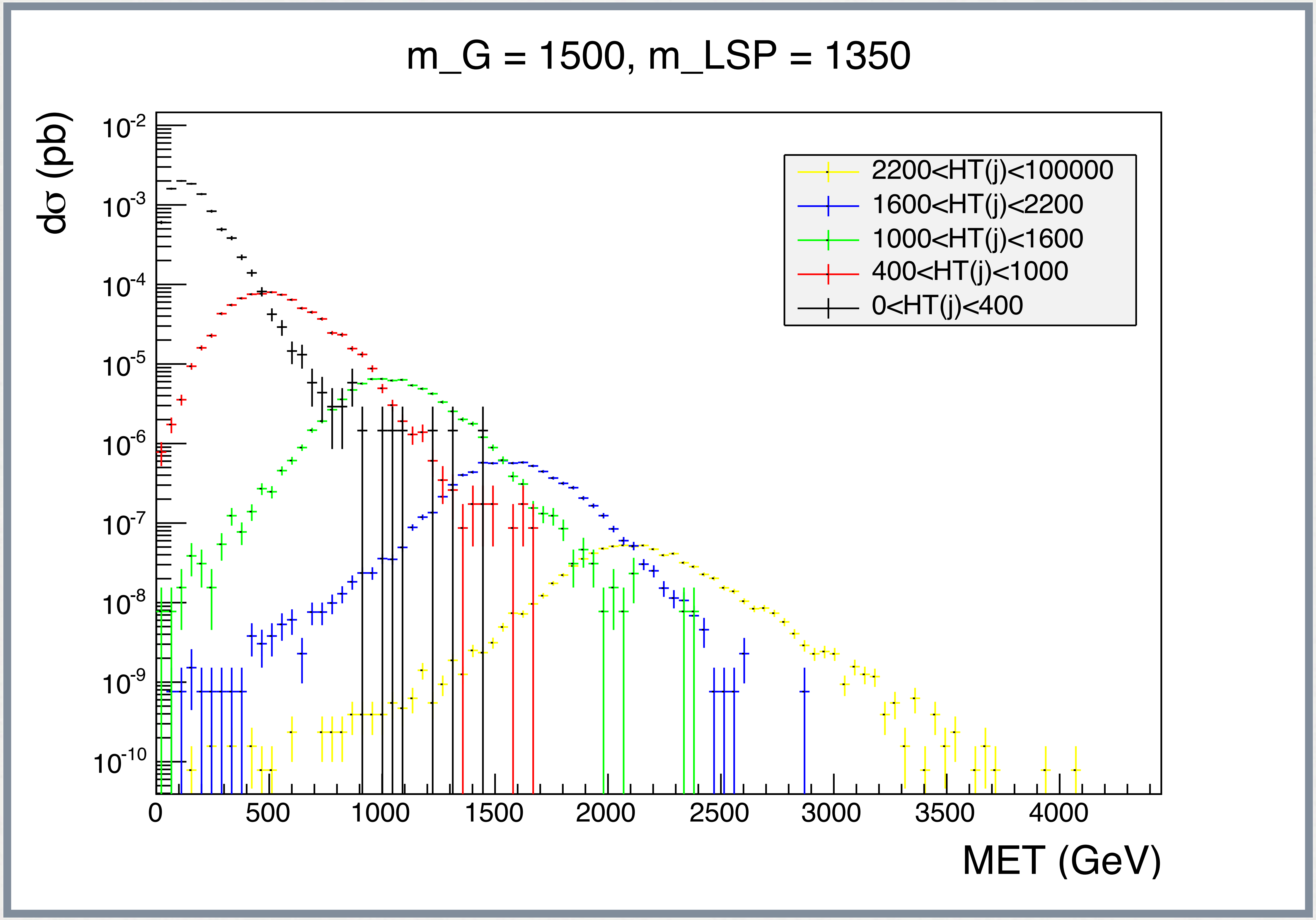
* requires a modification to include states besides partons

For details, see Avetisyan, Campbell, TC, Dhingra, Hirschauer, Howe, et al [arXiv:1308.16365]

Uncompressed



Compressed


m_G = 1500, m_LSP = 1350
dσ (pb)
MET (GeV)
2200<HT(j)<100000
1600<HT(j)<2200
1000<HT(j)<1600
400<HT(j)<1000
0<HT(j)<400
0
500
1000
1500
2000
2500
3000
3500
4000

Kinematic Weighting

It works!

Can we do more?

Any other tricks?

Due to color factor, particles tend to decay hadronically.

Want fully inclusive samples.

No reason to desire better Monte Carlo statistics in any given channel.

What if we enforce that all branching ratios are equal?

Then BR is included as part of the event weight.

Flatten BR's

Decay particles to all available decay modes with equal probability.

$W \to$	Weight	In Sample	Change
$e^+ \nu_e$	11%	20%	1.8
$\mu^+ \nu_\mu$	11%	20%	1.8
$\tau^+ \nu_\tau$	11%	20%	1.8
$u \bar{d}$	33%	20%	0.6
$c \bar{s}$	33%	20%	0.6

Even more substantial gains for Z.

Flatten BR's

$t\bar{t} \rightarrow$	Weight	In Sample	Change
hadronic	44%	25%	0.56
semileptonic	44%	50%	1.13
dileptonic	11%	25%	2.25

Saves factor 2.25 for dileptons,
no loss for semileptonic

Takes 5M events/H_T bin to 2.5M

Update weights

All decay modes of particle X treated equally.

There is an effective BR = $1/N^X_{\text{modes}}$.

Need to updated the event weight by

$$f_i = \prod_j N^{X_j}_{\text{modes}} \times \text{BR}^{X_j}_{d_j}$$

Flatten BR's

Flattening BR's save many computing cycles!

Implementation for Snowmass backgrounds relies on BRIDGE (modified by SLAC team to flatten BR's).

Meade and Reece [arXiv:hep-ph/0703031]

In future: implement flat BR's including spin correlation.

K-FACTORS

Define *K*-factor:

$$K = \frac{\sigma_{\mathrm{NLO}}}{\sigma_{\mathrm{MadGraph}}}$$

Use MCFM to compute σ_{NLO} .

http://mcfm.fnal.gov/

$\sigma_{\mathrm{MadGraph}}$ is the matched + showered cross section.

For Snowmass: *K*-factors are included in event weights.

Event weights

- Events are available for download.
- Each file corresponds to an H_T bin.
- σ_{MadGraph} is provided for each bin.
- Each event contains $w_i^* = K_i \times f_i$.

$\prod_j N_{\text{modes}}^{X_j} \times \text{BR}_{d_j}^{X_j}$

event number

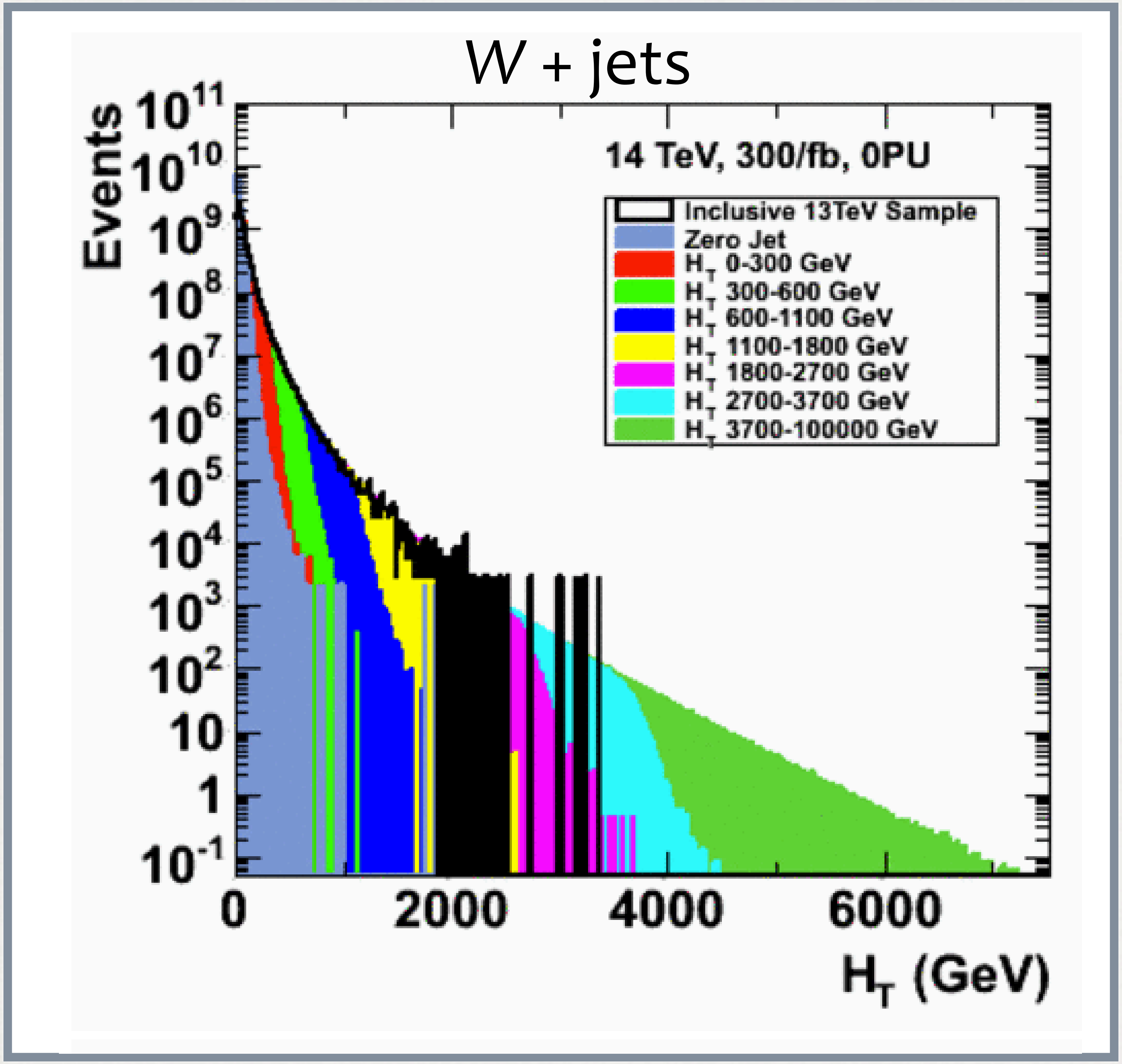
H_T bin

- User implements $w_i = \sigma_{\text{MadGraph},\alpha}\, w_i^*$.
- Each event contributes $\frac{w_i}{N_\alpha}$ to a histogram.

num events in H_T bin

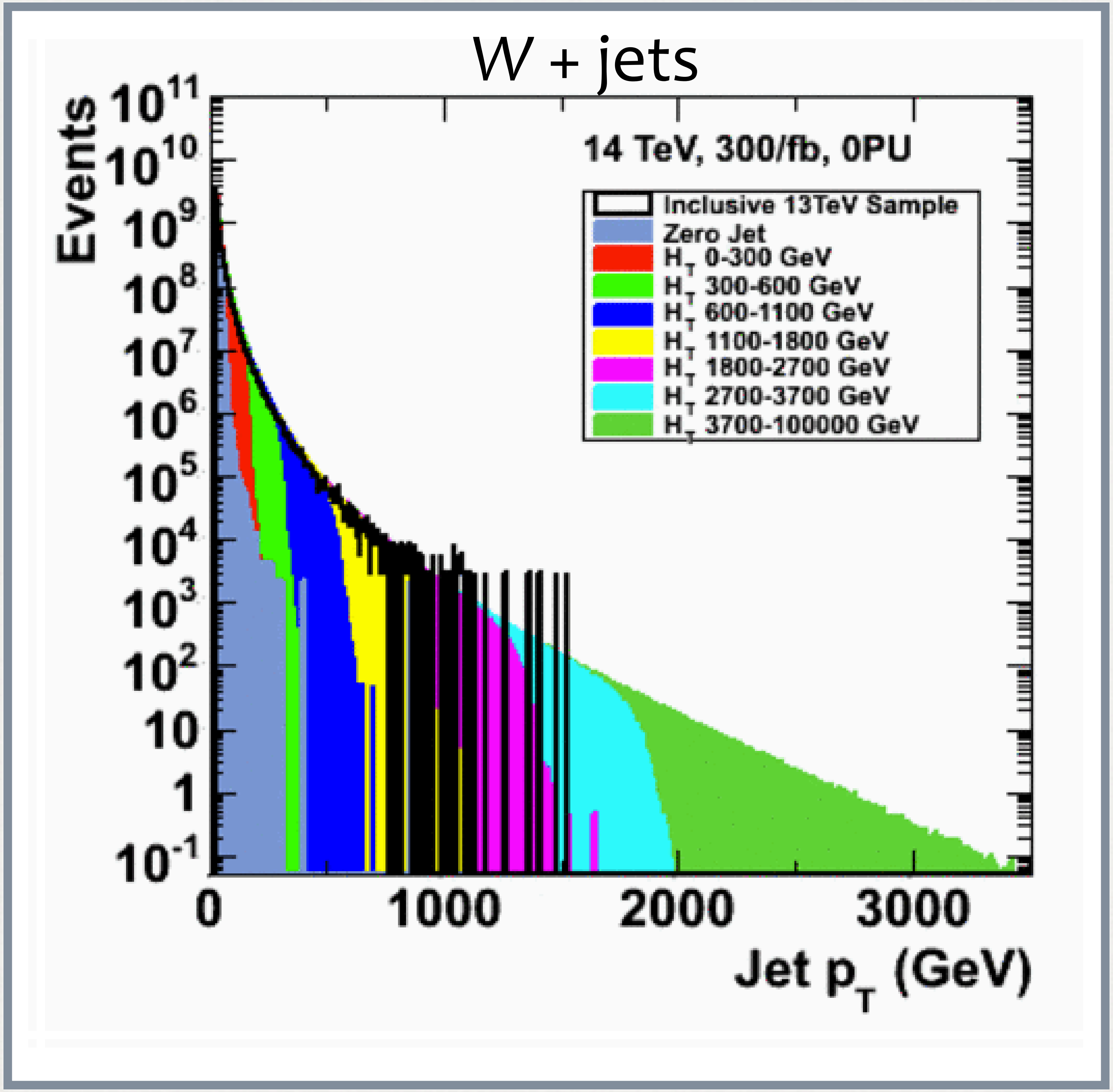
- Enforces $\sum_i^{N_\alpha} \frac{w_i}{N_\alpha} = \sigma_{\text{NLO},\alpha} \times \text{BR}$.

Results



W + jets
Events
14 TeV, 300/fb, 0PU
Inclusive 13TeV Sample
Zero Jet
H_T 0-300 GeV
H_T 300-600 GeV
H_T 600-1100 GeV
H_T 1100-1800 GeV
H_T 1800-2700 GeV
H_T 2700-3700 GeV
H_T 3700-100000 GeV
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
0
2000
4000
6000
H_T (GeV)

Results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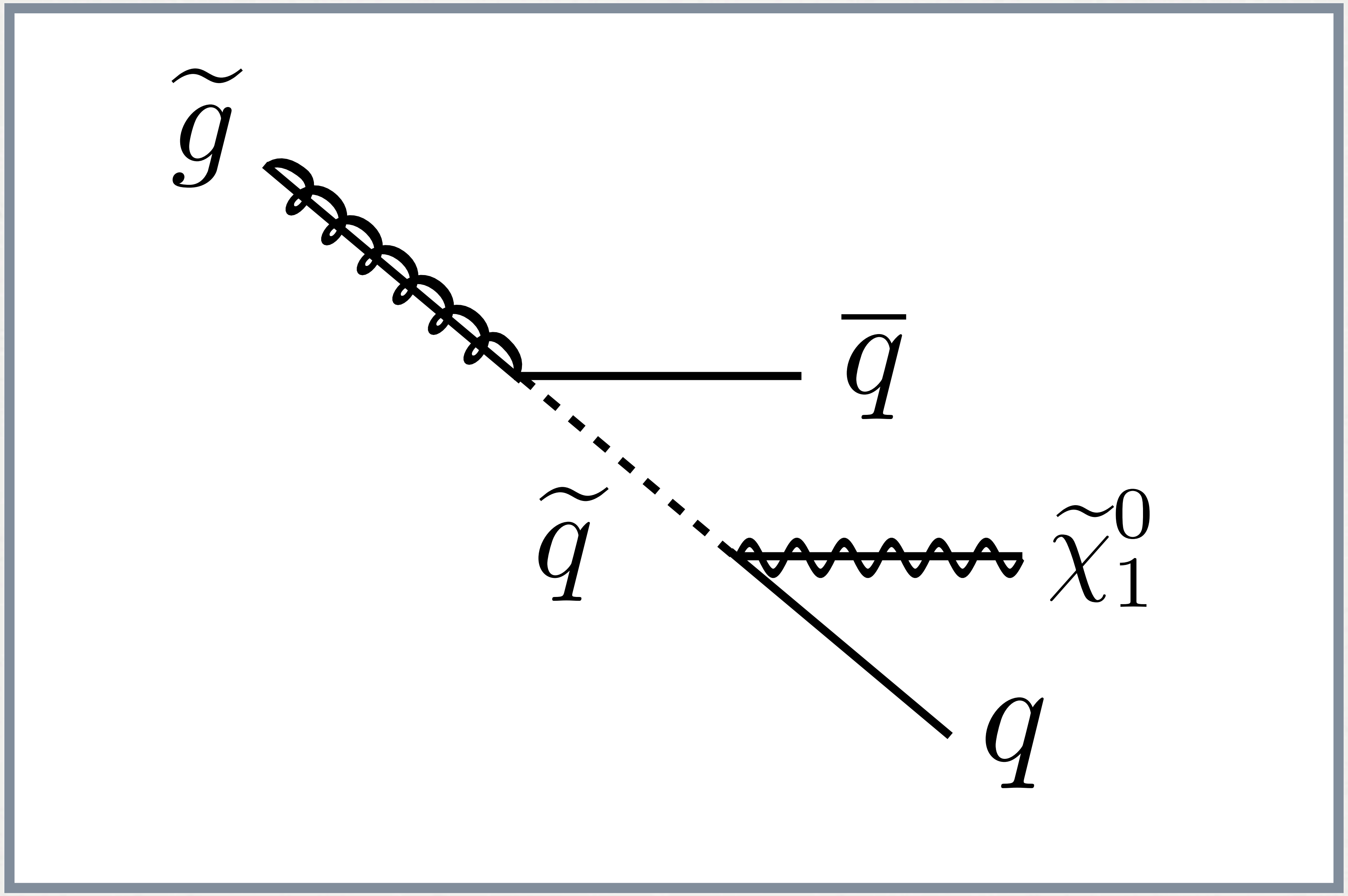
H_T 2700-3700 GeV
H_T 3700-100000 GeV
Jet p_T (GeV)

Searching for Gluinos

Gluino-Neutralino



$$p\,p \to \tilde{g}\,\tilde{g} \to q\,\bar{q}\,q\,\bar{q}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

Jets + MET

Preselection

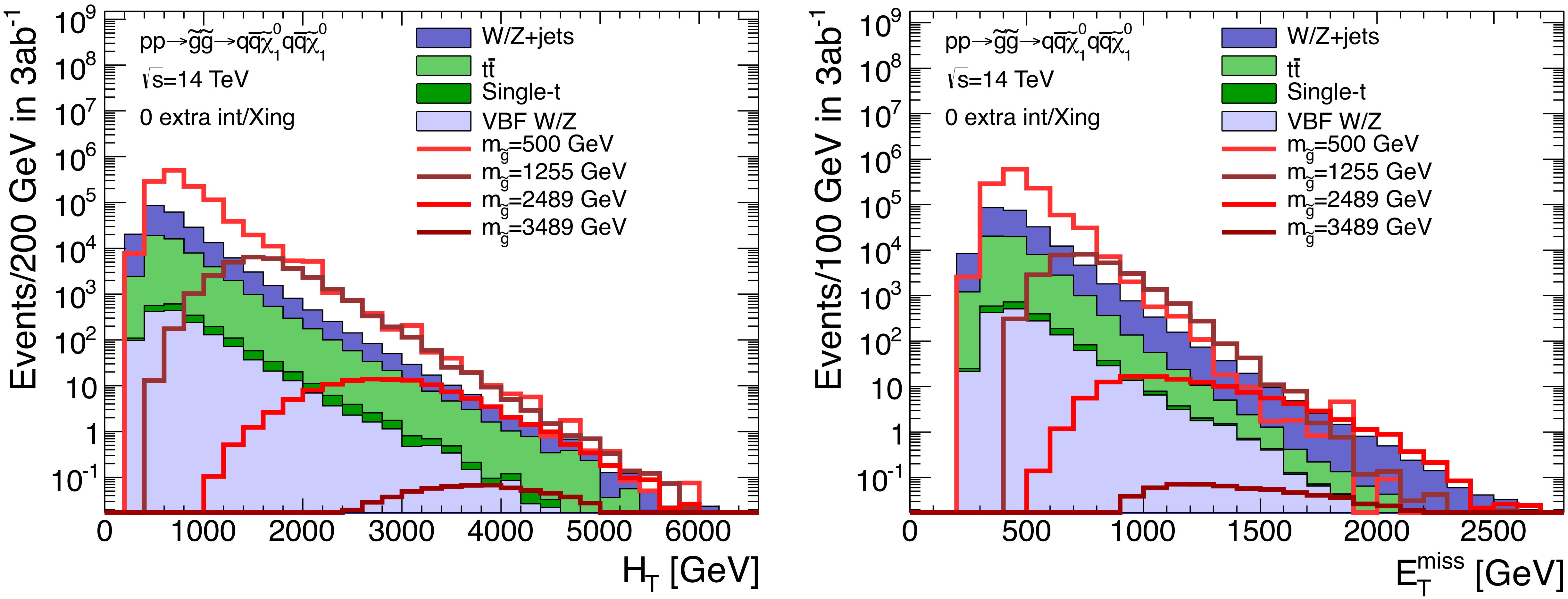
- zero selected electrons or muons
- $E_T^{\text{miss}} > 100$ GeV
- at least 4 jets with $p_T > 60$ GeV

Search strategy

- $E_T^{\text{miss}}/\sqrt{H_T} > 15\ \text{GeV}^{1/2}$
- The leading jet p_T must satisfy $p_T^{\text{leading}} < 0.4\, H_T$
- $E_T^{\text{miss}} > (E_T^{\text{miss}})_{\text{optimal}}$
- $H_T > (H_T)_{\text{optimal}}$

Discriminating Variables

$$\sqrt{s} = 14\ \text{TeV} \qquad p\,p \to \tilde{g}\,\tilde{g} \to \left(q\,\bar{q}\,\tilde{\chi}_1^0\right)\left(q\,\bar{q}\,\tilde{\chi}_1^0\right)$$

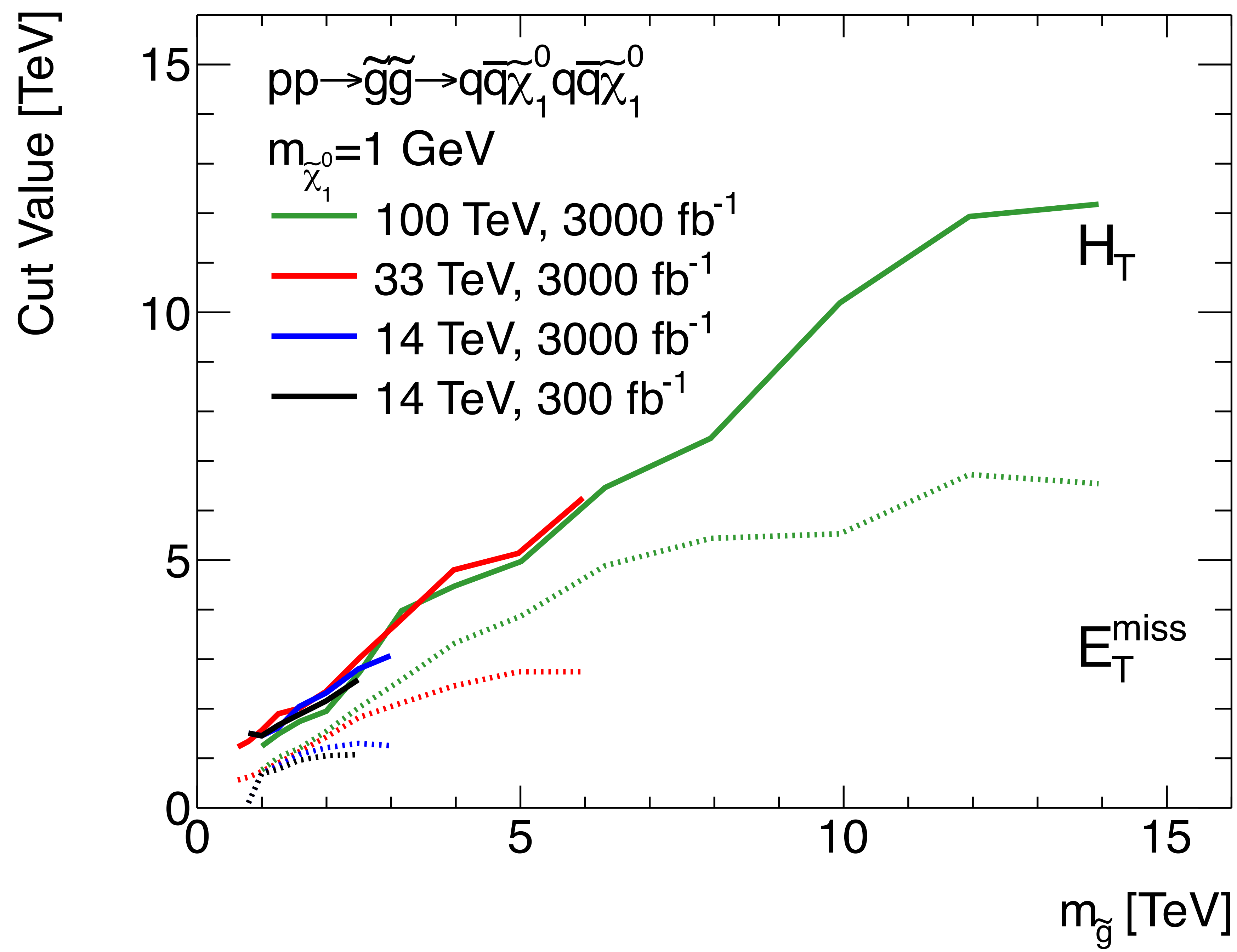


Dominant background:

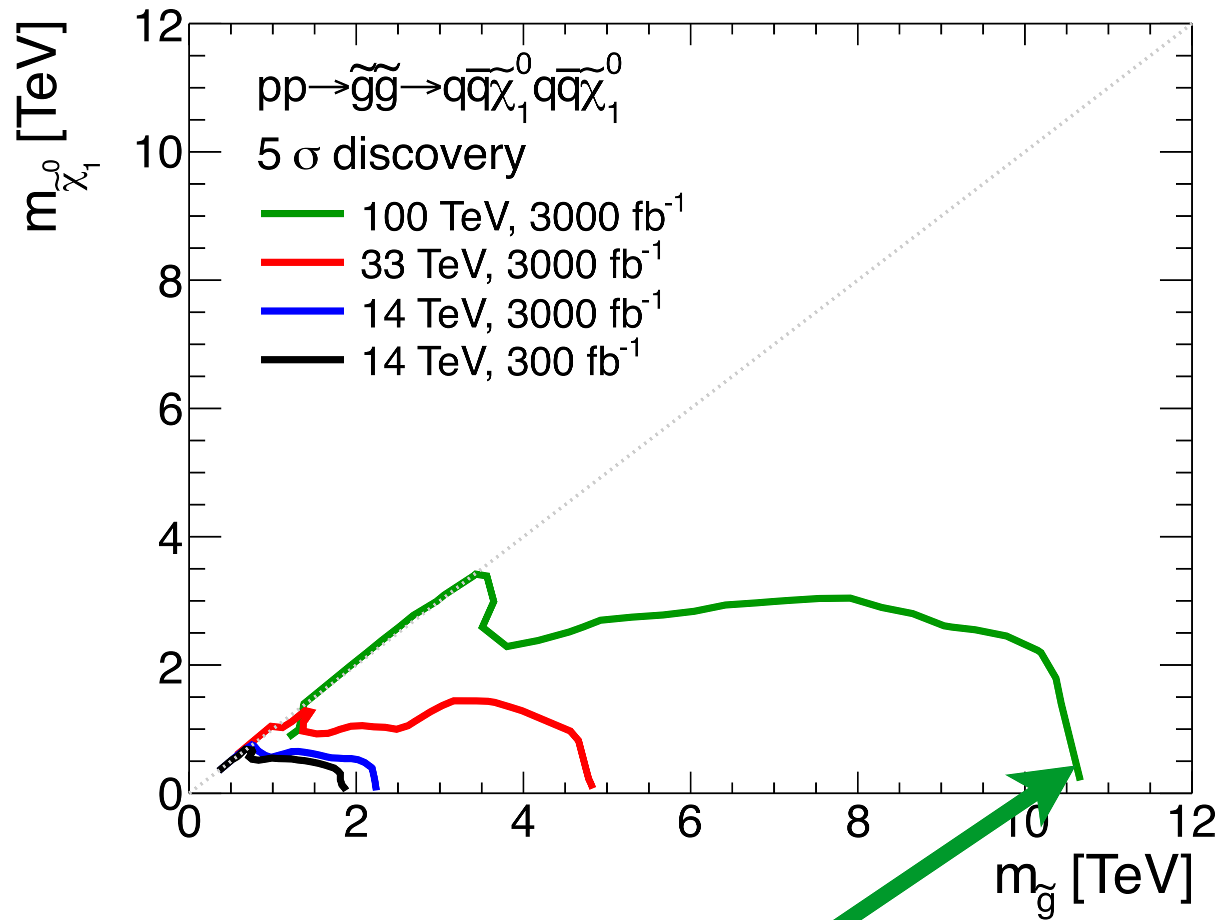
W/Z + jets @ 14 TeV

$t\,\bar{t}$ @ 100 TeV

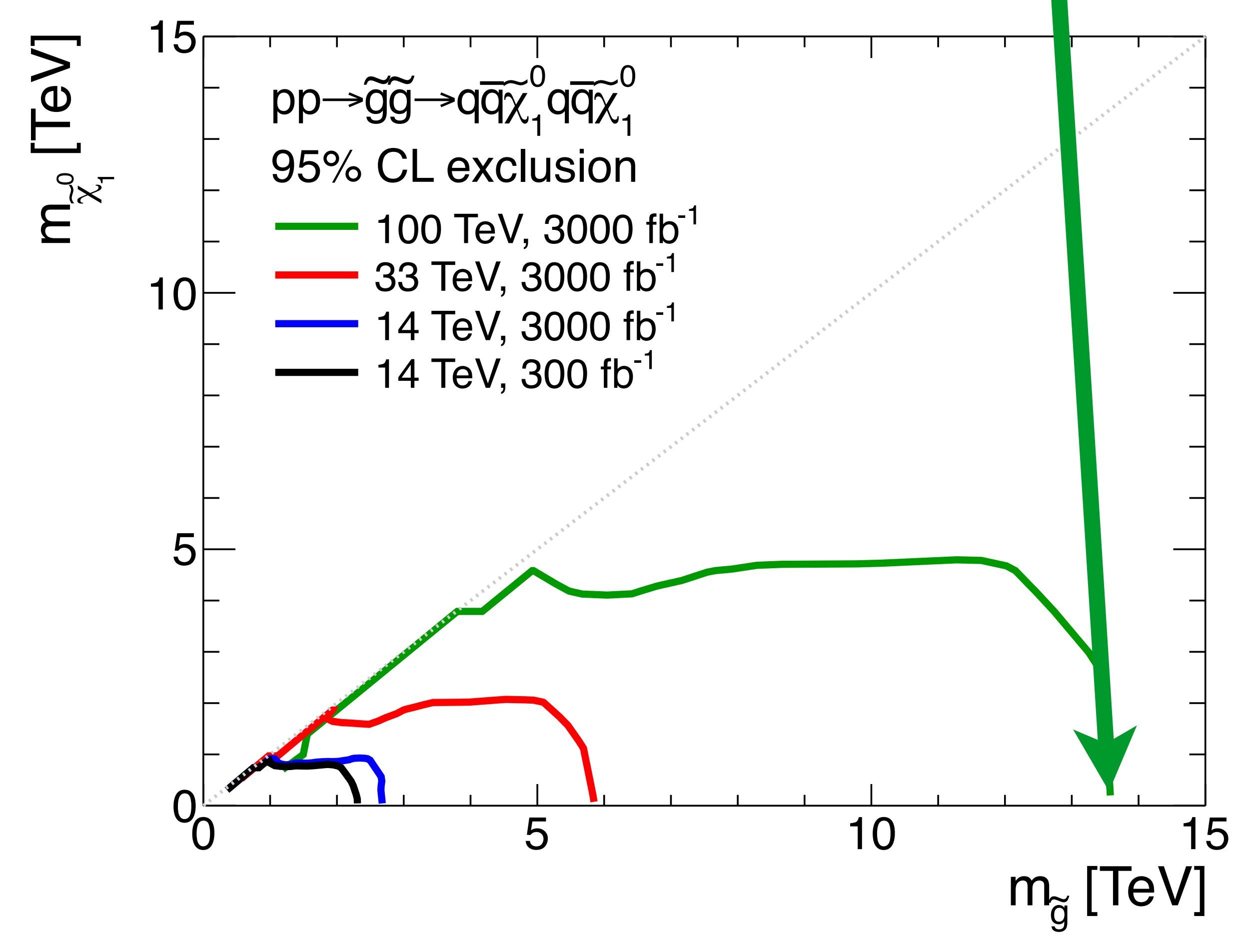
Optimal Cuts



Results



Exclude 13.5 TeV gluino!
(with 60 events)



Discover 11 TeV gluino!

Summary

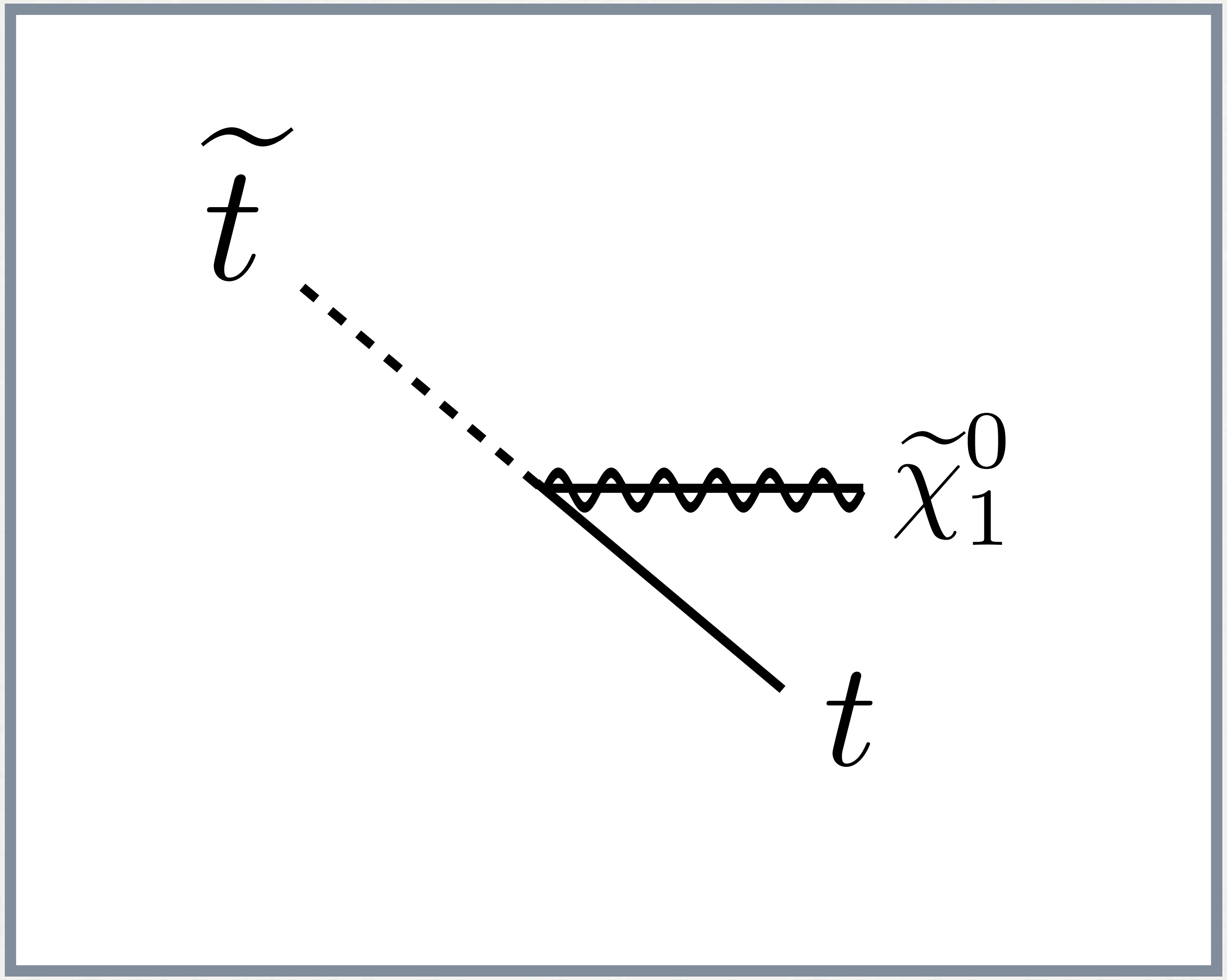
Can probe gluinos up to 13.5 TeV!

Moving from LHC to SppC:
Dominant background changes.

Jets + MET strategy still effective.

Searching For Stops

Stop-Neutralino



$$p\,p \to \widetilde{t}\,\widetilde{t}^* \to t\,\bar{t}\,\widetilde{\chi}_1^0\,\widetilde{\chi}_1^0$$

8 TeV Strategy

Preselection

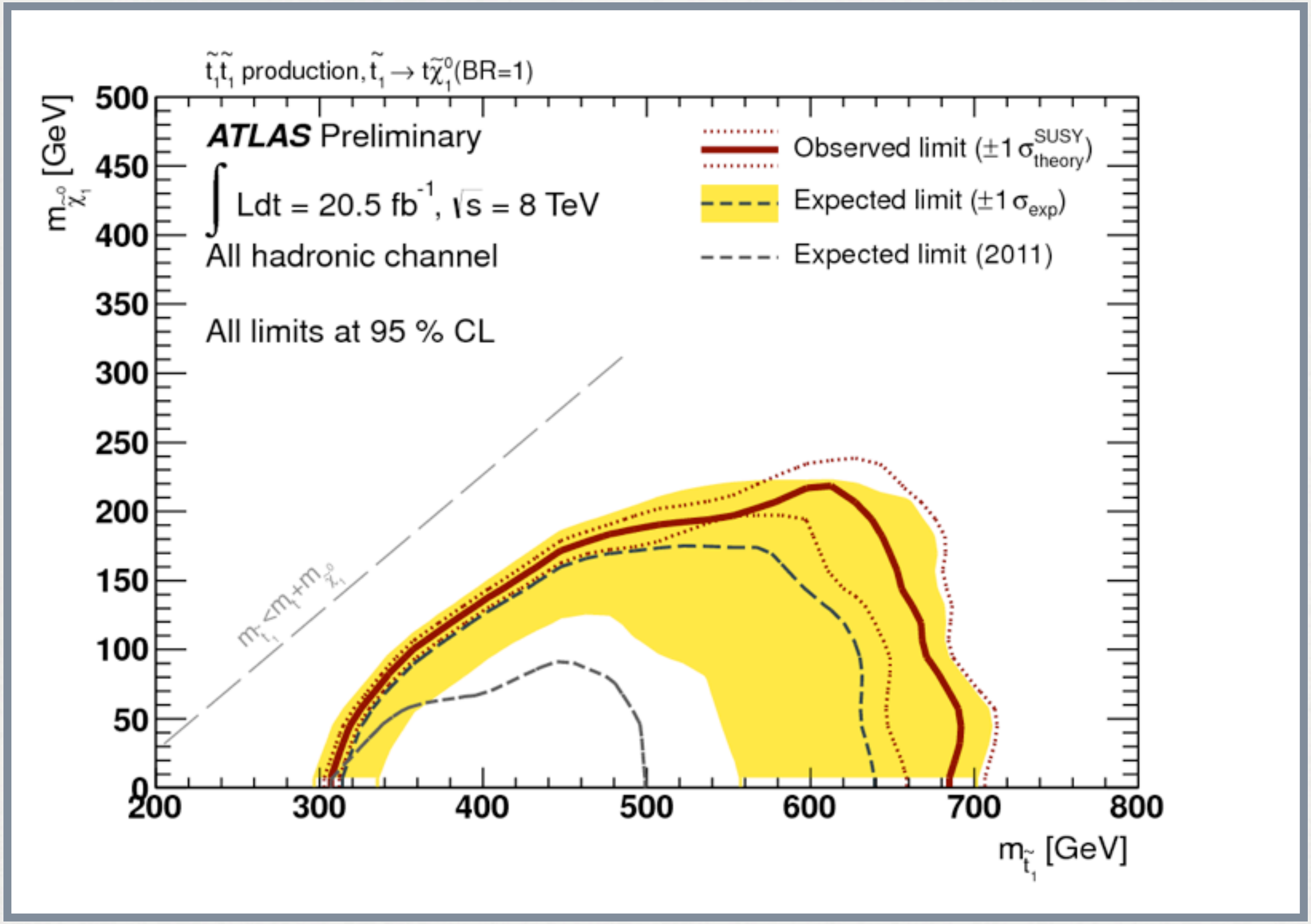
- 0 leptons
- 6 or more jets
- 2 or more *b*-jets
- Tau veto

Search Strategy

- Cut on MET
- Cut on transverse mass between *b*-jet and MET
- Cut on $\Delta\phi$ between jet and MET.

ATLAS Collaboration [ATLAS-CONF-2013-024]

Results



ATLAS Collaboration [ATLAS-CONF-2013-024]

Going to 100 TeV

Can probe stops with much larger mass:

$$m_{\tilde{t}} \gg m_t$$

final state top quarks will be highly boosted!

(Assuming light neutralino.)

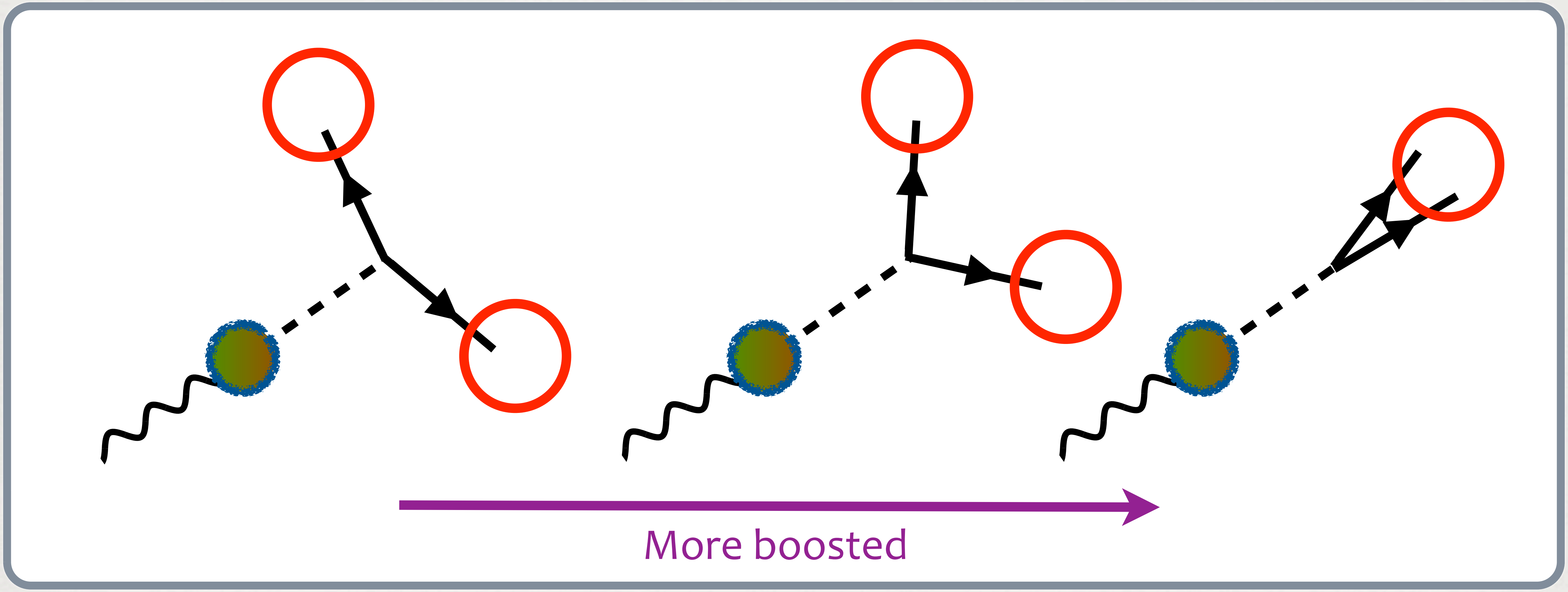
Need new search strategy.

Boosted Objects

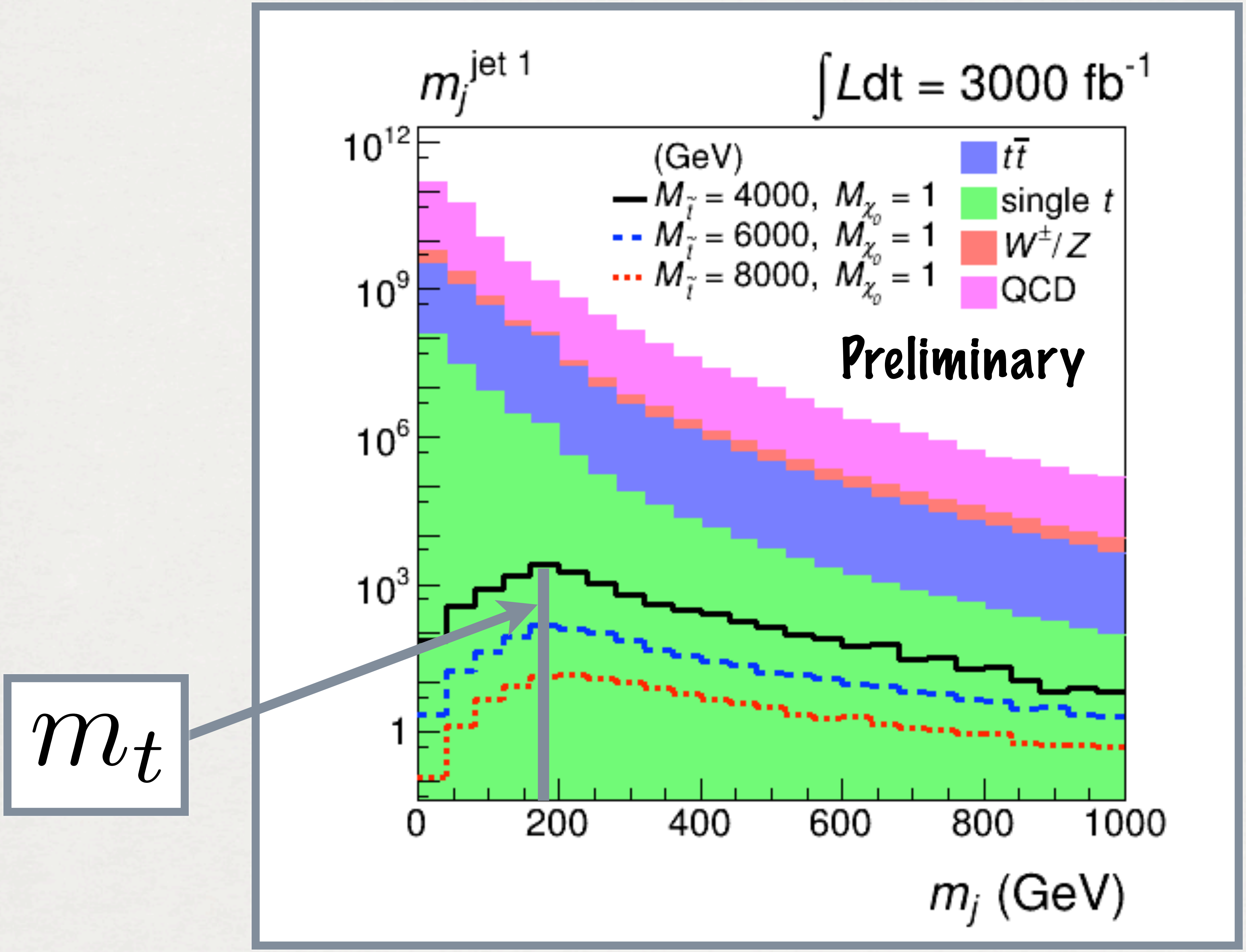
Boosted objects $\Rightarrow$ entire final state within the jet.

Example: Boosted $h \to b\,\bar{b}$.

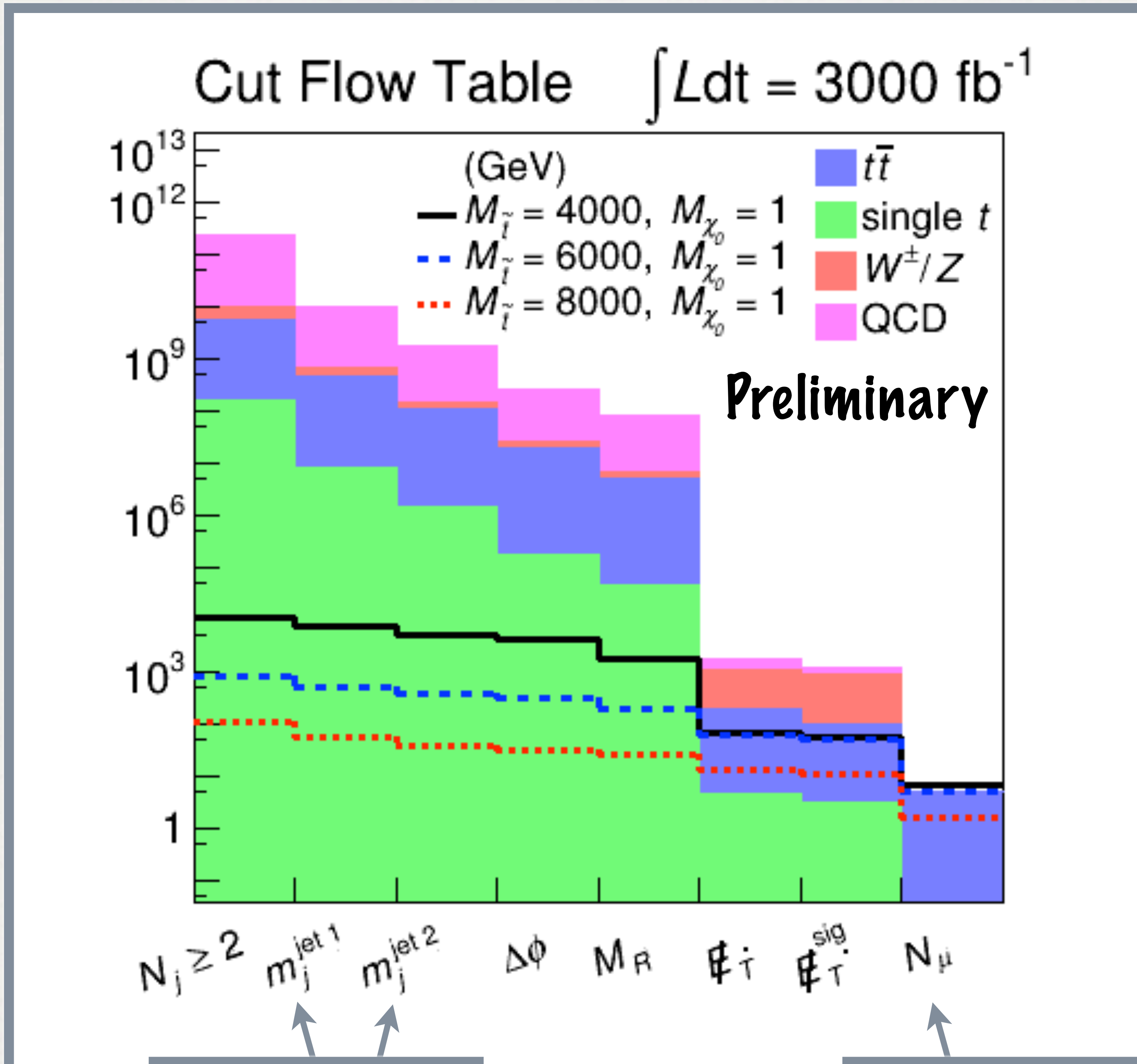
Butterworth, Davidson, Rubin, Salam [arXiv:0802.2470]



Boosted Stops



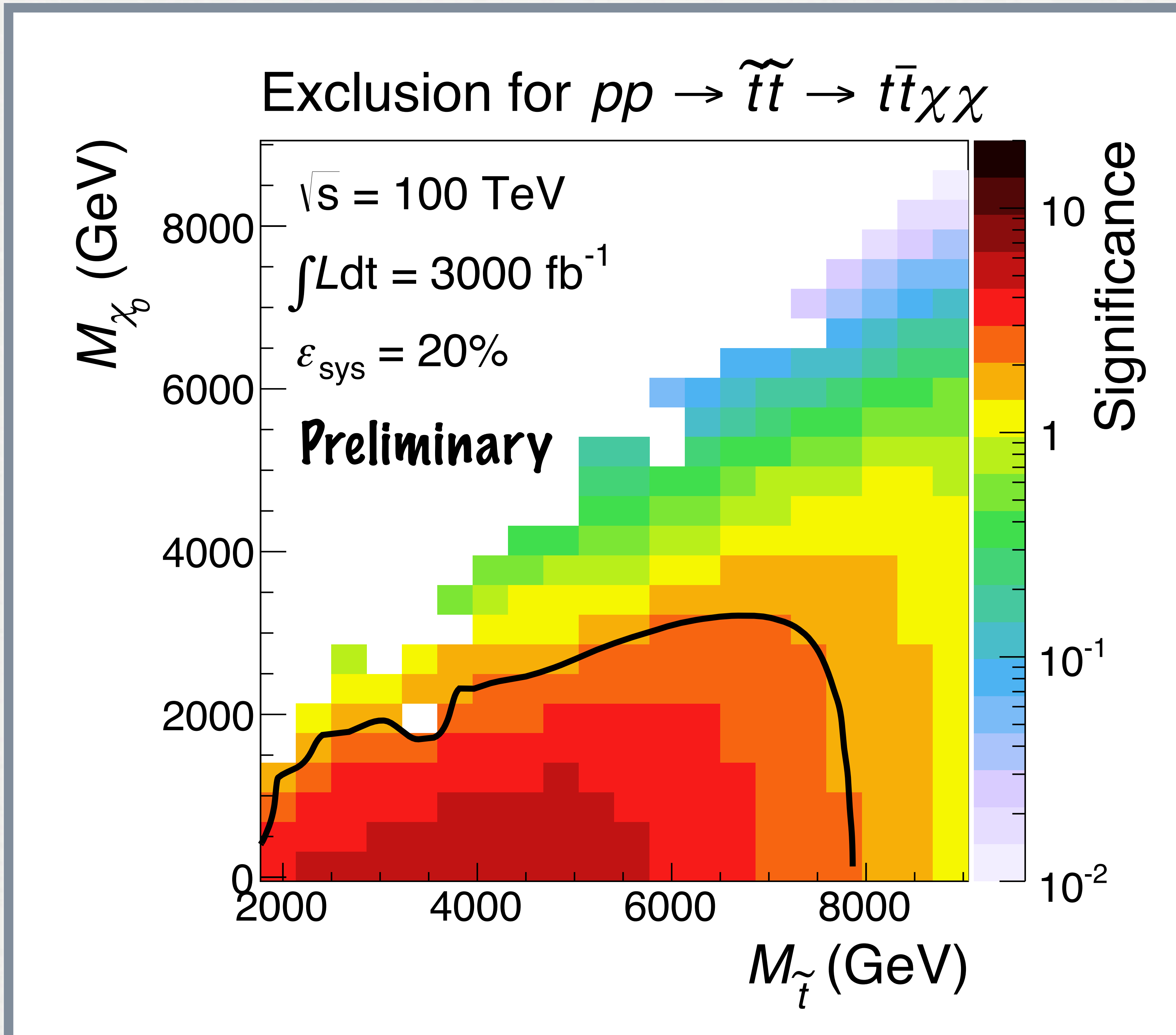
100 TeV Strategy



Jet mass near m_t

At least one muon within a jet

Results



Sensitive to stops with mass of 8 TeV!

Summary

Sensitive to stops up to 8 TeV!

Translates to fine-tuning of roughly 1 part in 10^{-4}

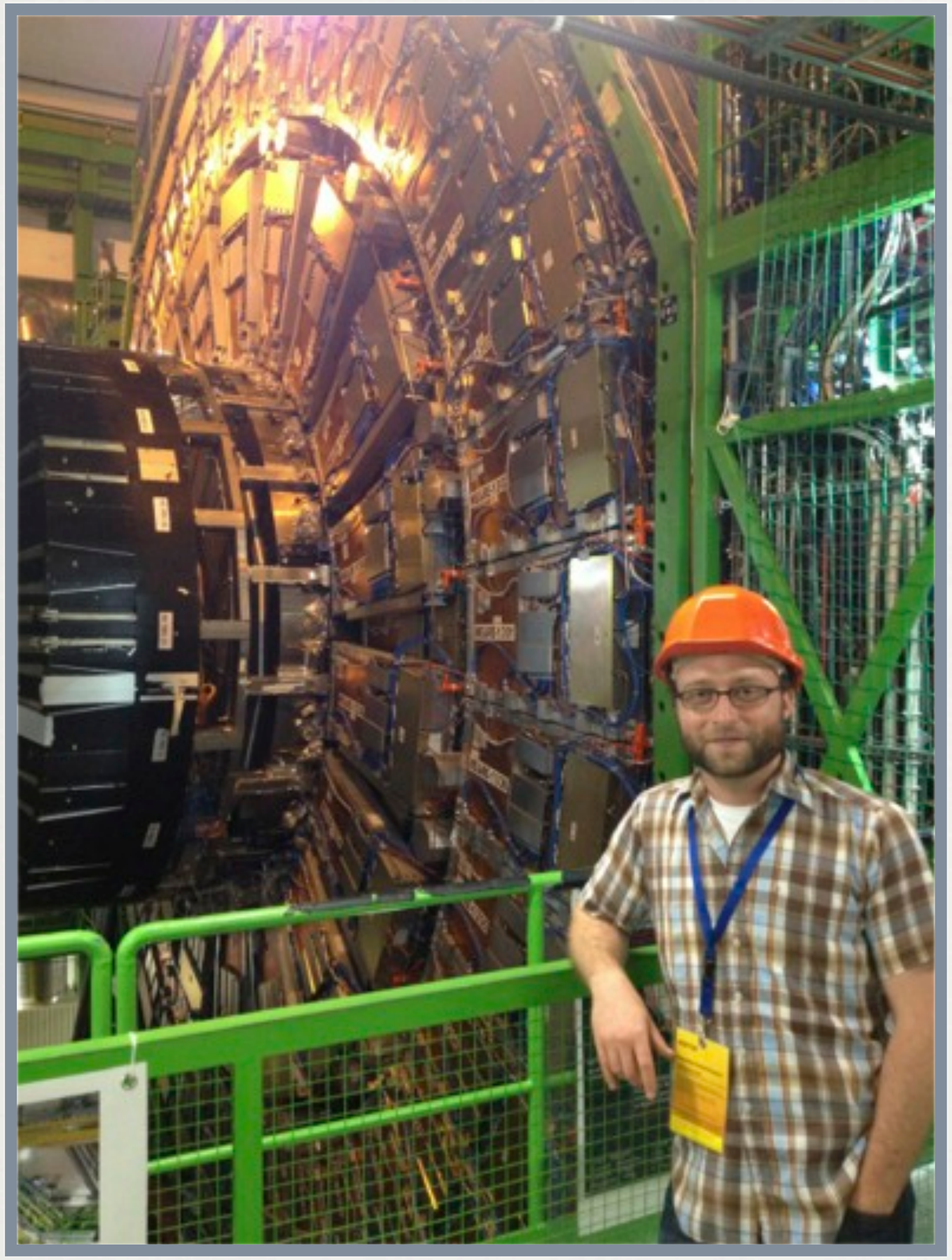
Moving from LHC to SPPC:

New search strategy required.

Take advantage of highly boosted top quarks.

Conclusions

Conclusions



Hope to one day take picture with SppC detectors.

The SppC would have a HUGE impact on our understanding of fundamental physics.

Performing realistic studies requires new Monte Carlo techniques.

The SppC could probe gluinos below 13.5 TeV and stops below 8 TeV.

Many interesting studies to do in the future.

Backup

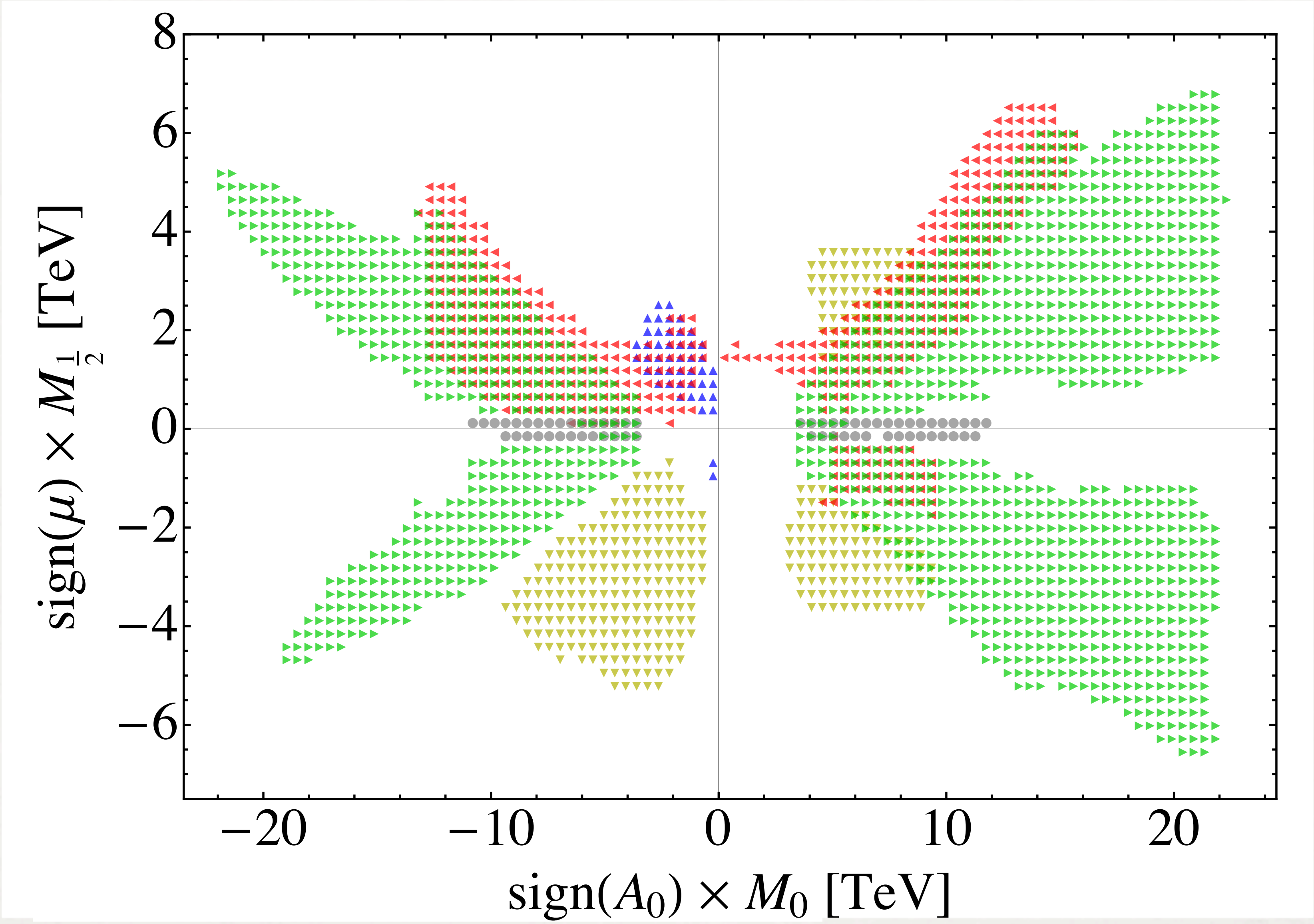
Another Motivation

If the 13-14 TeV LHC does not see anything,
do we have any other guideposts?

Want to fully explore the CMSSM ansatz.

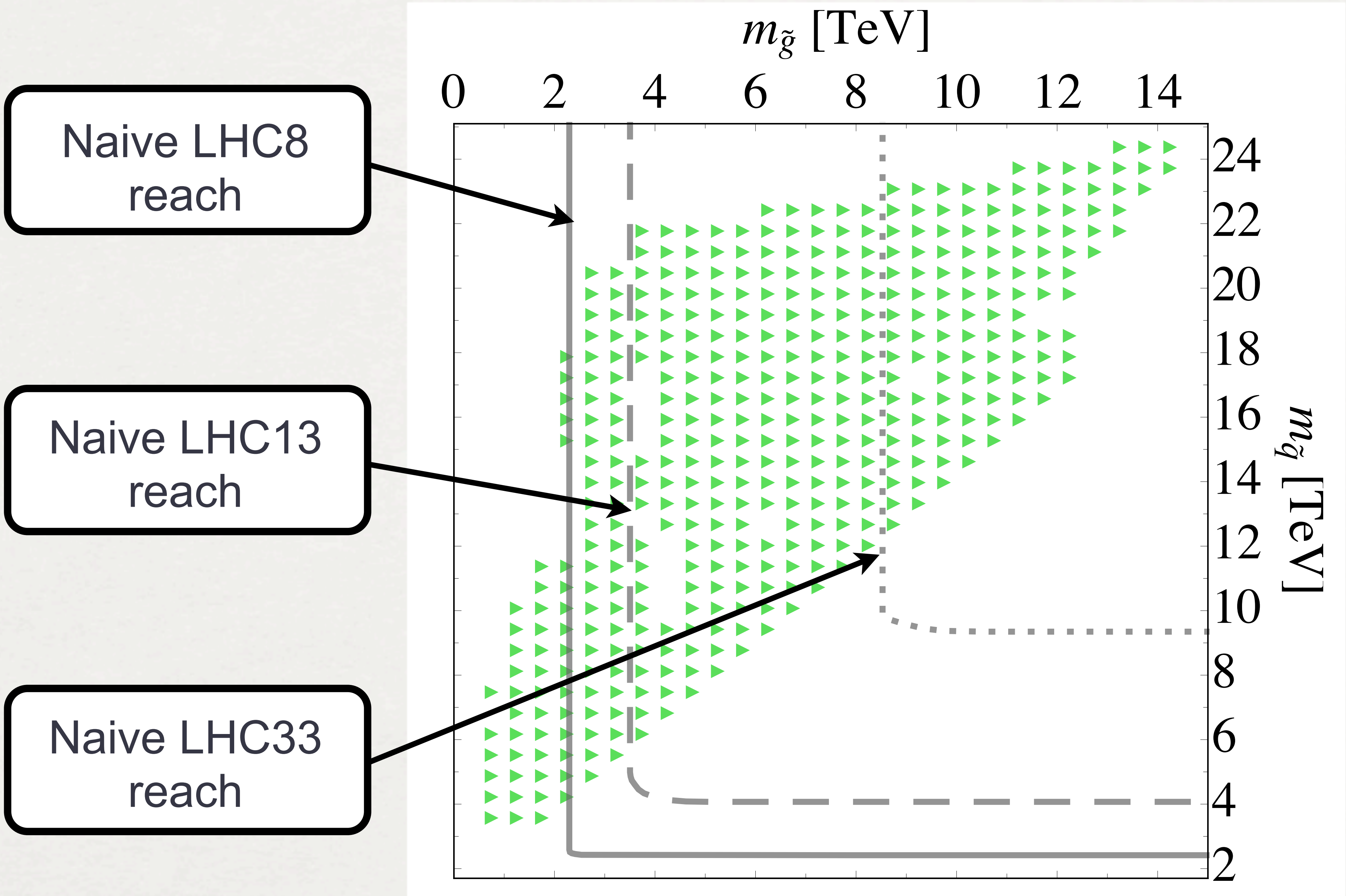
The CMSSM

TC and Wacker [arXiv:1305.2914]



CMSSM input parameters consistent with 125 GeV Higgs and neutralino dark matter.

LHC Discovery?



Naive reach means 10 events at final integrated luminosity.

Flatten BR's

$W^{\pm} Z^0 \to$	Weight	In Sample	Change
$1\,\ell$	30%	44%	1.4
$2\,\ell$	6.7%	11%	1.6
$3\,\ell$	3.3%	16%	4.8

Saves factor 5 for Trileptons

Takes 5*M* events/H_T bin to 1*M*

Flatten BR's

Also important for the Higgs:

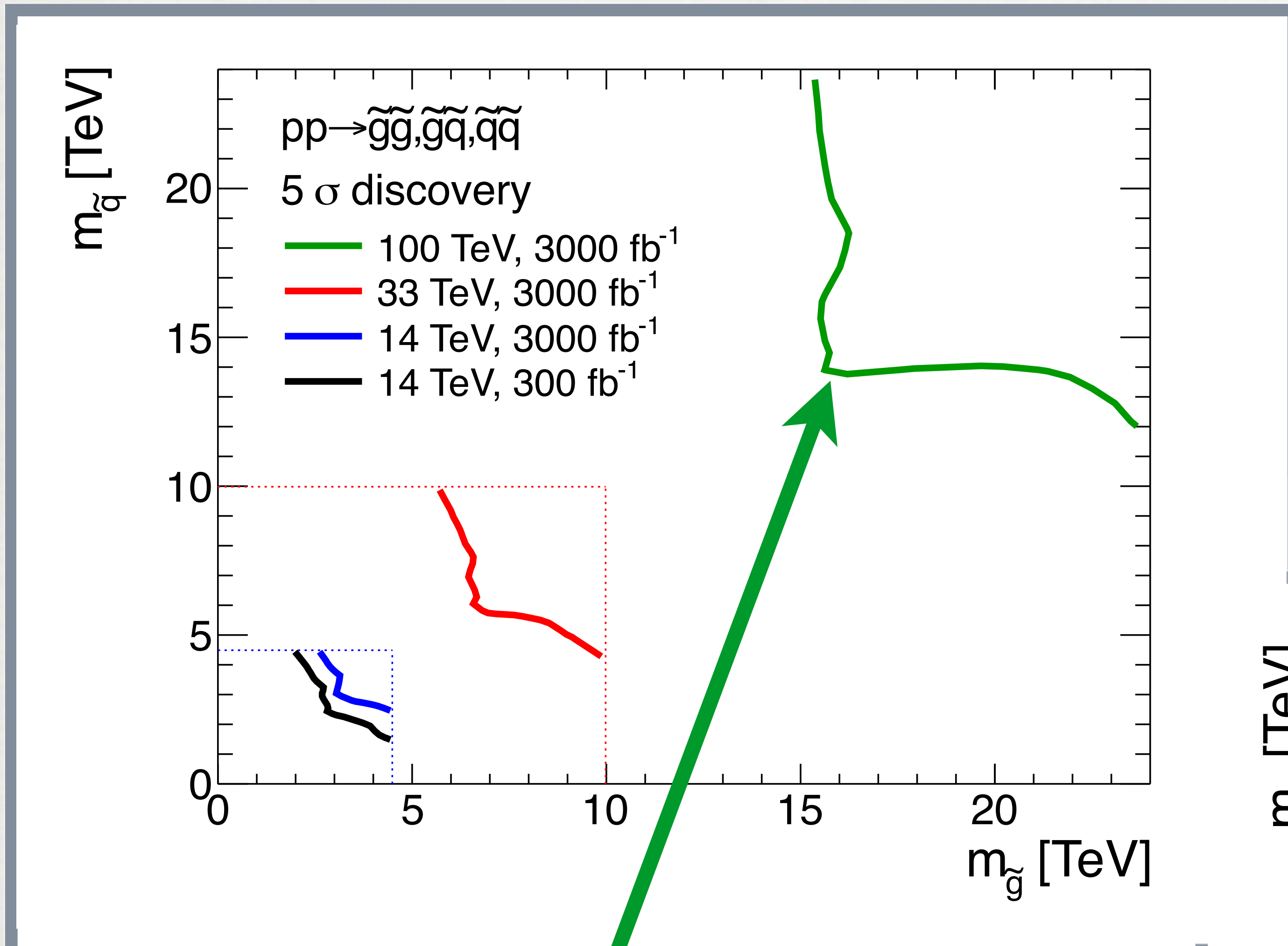
$H \rightarrow W\,W \rightarrow \ell\,\ell\,\nu\,\nu$

BR = 1.8% → 5.2% in MC

$H \rightarrow Z\,Z \rightarrow \ell\,\ell\,\ell\,\ell$

BR = 0.07% → 1.1% in MC

Gluino-Squark Results



Exclude 17 TeV gluino;
15 TeV squarks!

Discover 15 TeV gluino;
13 TeV squarks!