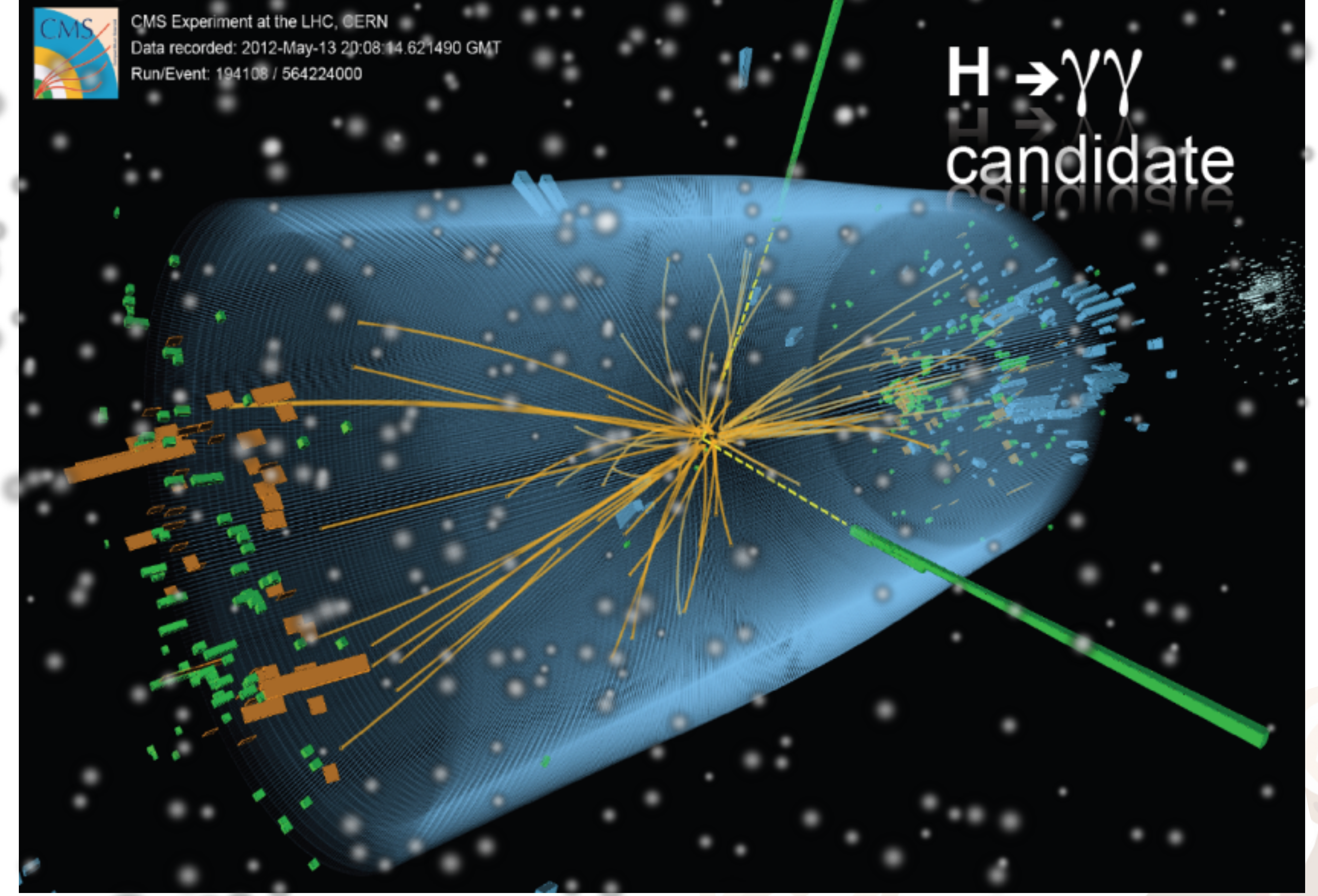
Sensitivity to NMSSM Signatures with Low Missing Transverse Energy at the LHC

Alexander Titterton

NMSSM meeting, 12th December 2018



Sensitivity to NMSSM Signatures with Low Missing Transverse Energy at the LHC

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NMSSM meeting, 12th December 2018

University of BRISTOL
UNIVERSITY OF Southampton
Science & Technology Facilities Council
Rutherford Appleton Laboratory
NExT

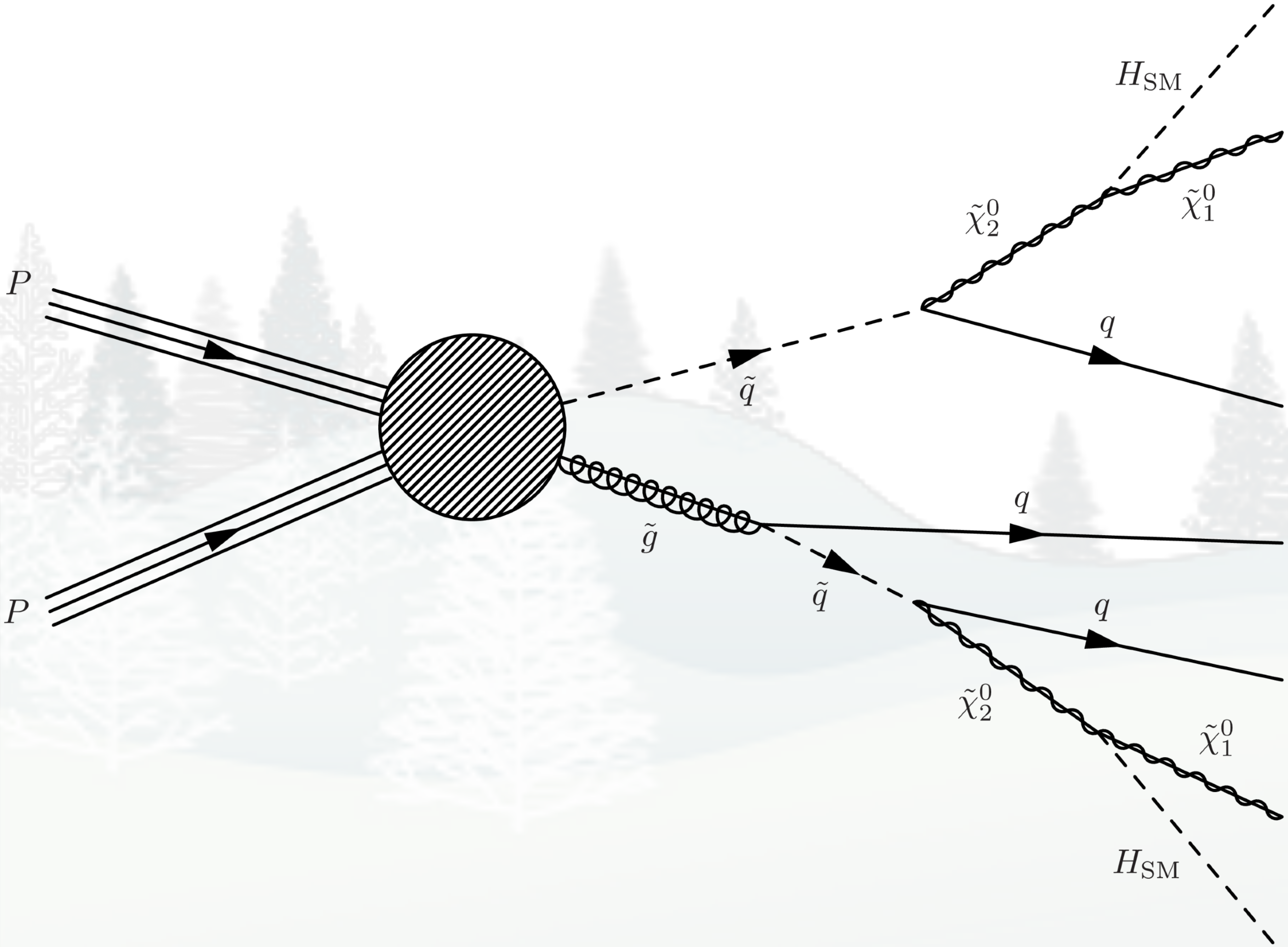
Motivation

- Large Missing Transverse Energy (MET) searches have ruled out many areas of parameter space.
- How about scenario for Lightest Supersymmetric Particle (LSP) production with low MET.
- Consider if LSP were a Singlino in the NMSSM:

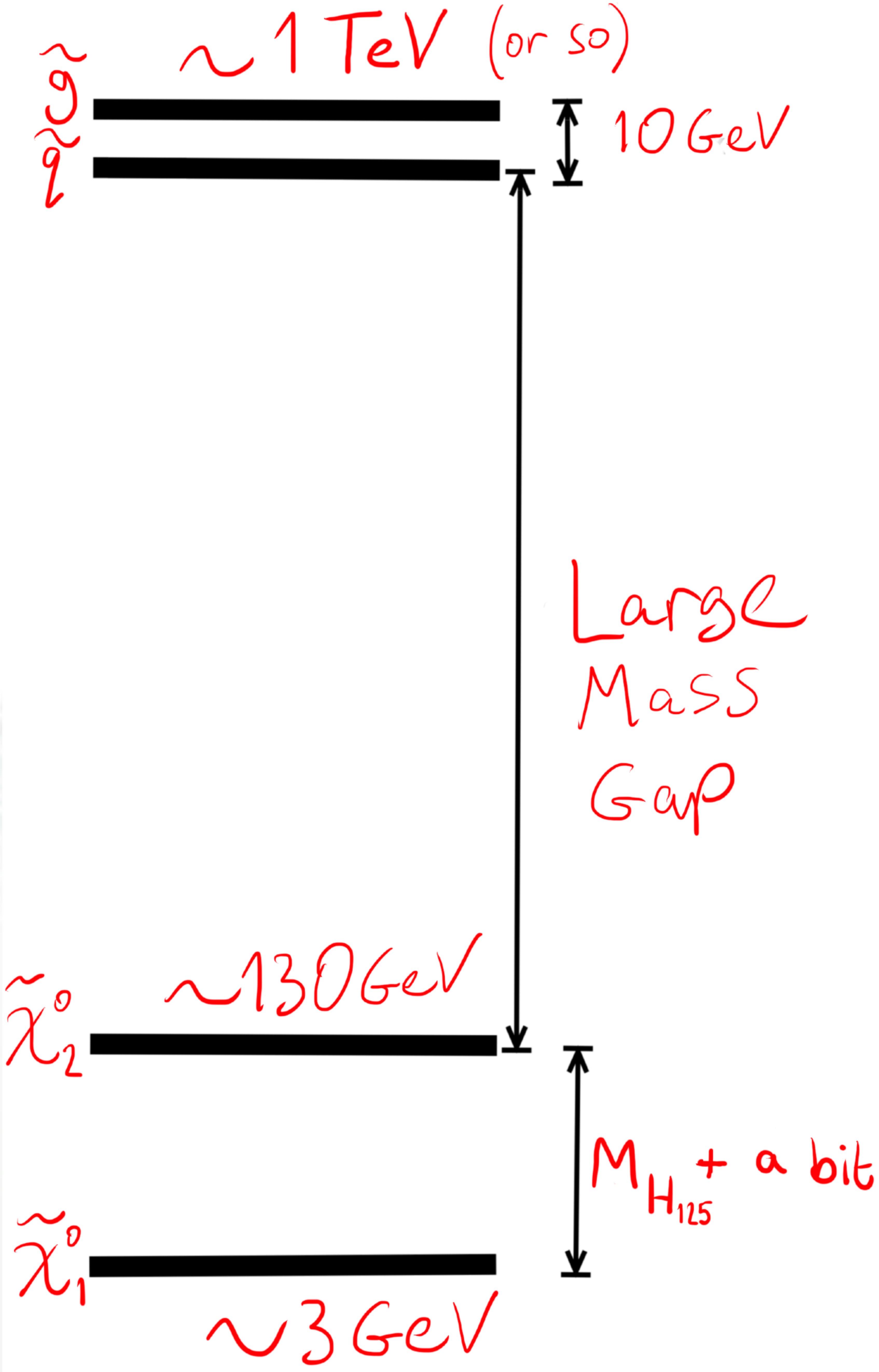
S

Motivation

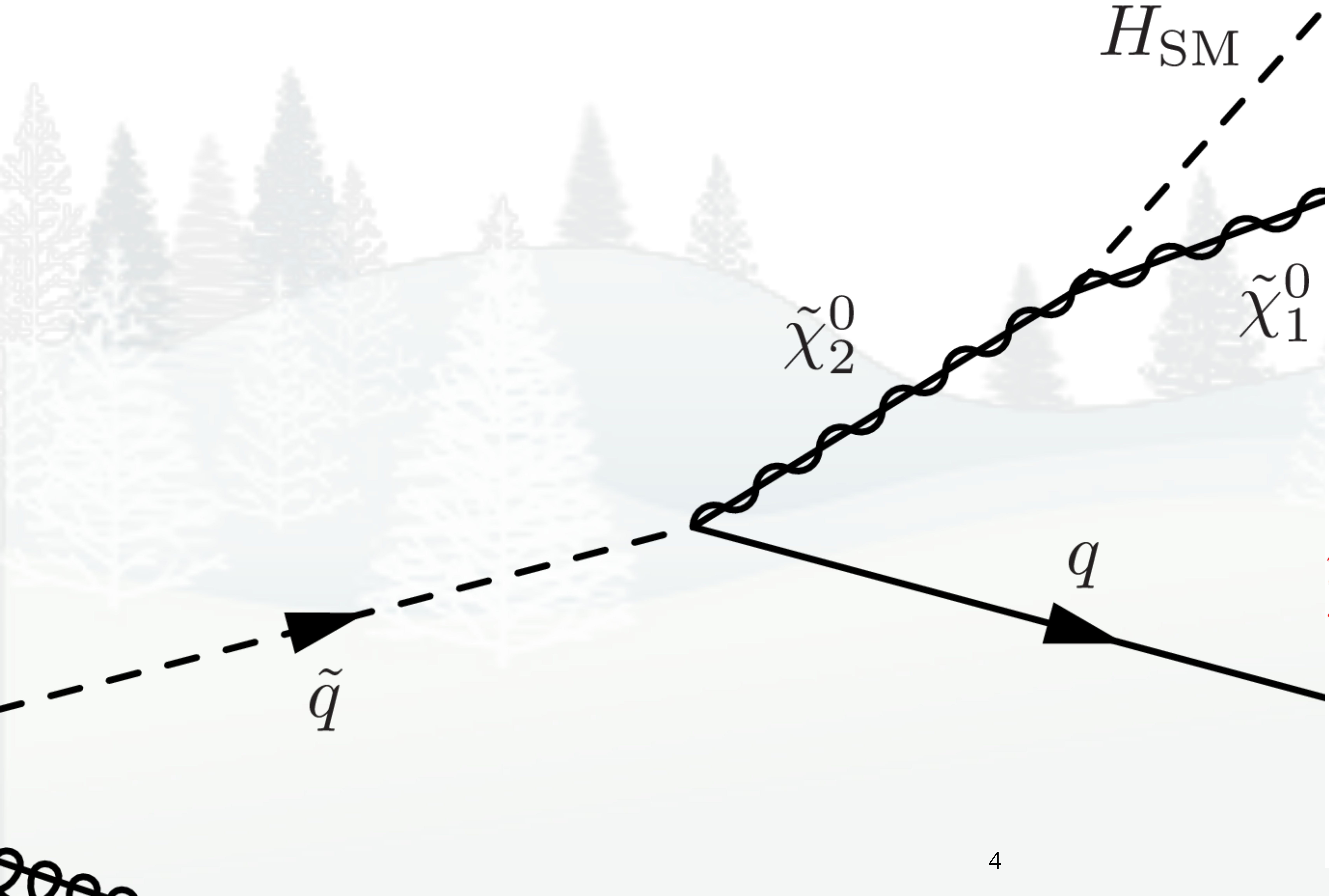
- Initial squark/gluino production — decays to NLSP ($X^0{}_2$) plus hadronic jets
- <u>Decay</u>: NLSP ($X^0{}_2$) —> LSP ($X^0{}_1$) + Higgs (H_{125})
- If Lightest SUSY particle very light and mass gap small, we get small MET!
- Singlino LSP allows this decay route to be enforced — in MSSM we could skip the NLSP part of the cascade entirely, giving larger MET
- Final states depend on Higgs decay — we are interested in H —>bb

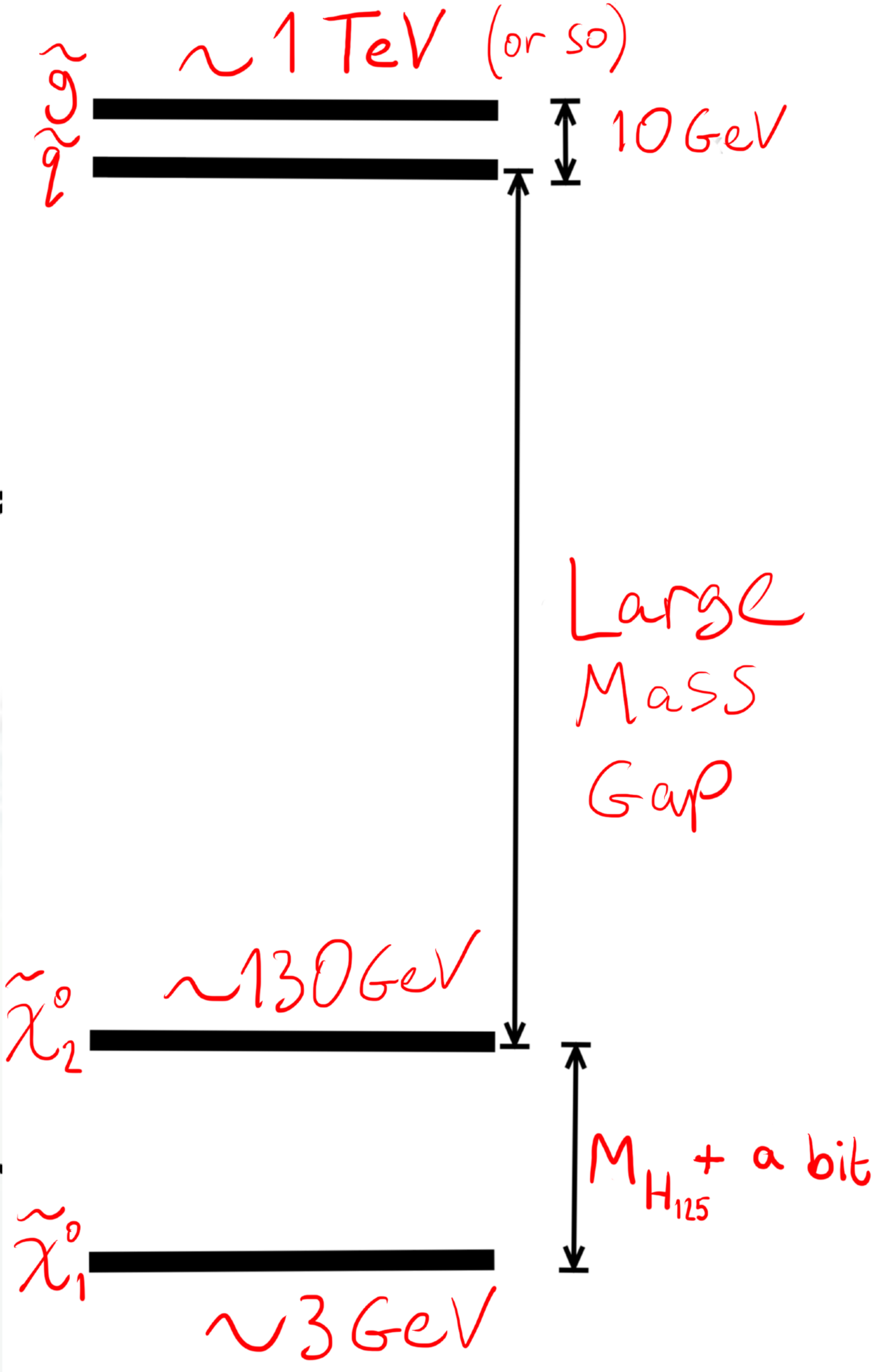


P
P
$\tilde{q}$
$\tilde{g}$
$\tilde{q}$
q
q
q
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^0$
H_{SM}
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^0$
H_{SM}



$\tilde{g}$
$\tilde{q}$
~ 1 TeV (or so)
10 GeV
Large Mass Gap
$\tilde{\chi}_2^0$
~ 130 GeV
$M_{H_{125}}$ + a bit
$\tilde{\chi}_1^0$
~ 3 GeV


H_{SM}
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^0$
q
$\tilde{q}$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Large Mass Gap
~ 130 GeV
$\tilde{\chi}_2^0$
$M_{H_{125}}$ + a bit
$\tilde{\chi}_1^0$
~ 3 GeV

Original benchmark points

- Eight benchmark points which characterise this low-MET light-LSP scenario [1]
- LSP mass 3GeV in all cases
- BP1-2: Gluino heavier than squark
- BP3-4: Gluino lighter than squark
- BP5: BP1/2 but with stop in decay
- BP6: “ “ sbottom in decay
- BP7: BP3/4 but with stop in decay
- BP8: “ “ sbottom in decay

Point	$M_{\tilde{q}}$ [GeV/c^2]	$M_{\tilde{g}}$ [GeV/c^2]	$M_{\tilde{t},\tilde{b}}$ [GeV/c^2]
BP1	1000	1010	decoupled
BP2	1400	1410	decoupled
BP3	1100	900	decoupled
BP4	1500	1300	decoupled
BP5	1400	1410	$M_{\tilde{t}} = 750$
BP6	1100	1110	$M_{\tilde{b}} = 750$
BP7	1500	1300	$M_{\tilde{t}} = 750$
BP8	1400	1200	$M_{\tilde{b}} = 750$

[1] U. Ellwanger and A.M. Teixeira, “Excessive Higgs pair production with little MET from squarks and gluinos in the NMSSM” JHEP 1504, 172 (2015)

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BP1	1000	1010	decoupled
~~BP2~~	~~1400~~	~~1410~~	~~decoupled~~
BP3	1100	900	decoupled
~~BP4~~	~~1500~~	~~1300~~	~~decoupled~~
BP5	1400	1410	$M_{\tilde{t}} = 750$
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Mass scans

- Eight benchmark points become six scans since BP1/2 the same except for M_{SUSY}, and same for BP3/4
- Vary Msquark and Mgluino (& M_{stop}, $M_{sbottom}$) together, keeping mass gap(s) fixed
- Vary M_{NLSP} and M_{LSP} together, keeping mass gap fixed at (125 + 2) GeV

	$M_{\tilde{q}}$ [GeV/c^2]	$M_{\tilde{g}}$ [GeV/c^2]	$M_{\tilde{\chi}_1^0}$ [GeV/c^2]	$M_{\tilde{\chi}_2^0}$ [GeV/c^2]	$M_{\tilde{t},\tilde{b}}$ [GeV/c^2]
BP1/BP2	$1200 \rightarrow 3000$	$M_{\tilde{q}} + 10$	$3 \rightarrow \{M_{\tilde{q}} - 20\}$	$M_{\tilde{\chi}_1^0} + 127$	decoupled
BP3/BP4	$1200 \rightarrow 3000$	$M_{\tilde{q}} - 200$	$3 \rightarrow \{M_{\tilde{g}} - 20\}$	$M_{\tilde{\chi}_1^0} + 127$	decoupled
BP5	$1200 \rightarrow 3000$	$M_{\tilde{q}} + 10$	$3 \rightarrow \{M_{\tilde{t}} - 200\}$	$M_{\tilde{\chi}_1^0} + 127$	$M_{\tilde{t}} = M_{\tilde{q}} - 250$
BP6	$1200 \rightarrow 3000$	$M_{\tilde{q}} + 10$	$3 \rightarrow \{M_{\tilde{b}} - 20\}$	$M_{\tilde{\chi}_1^0} + 127$	$M_{\tilde{b}} = M_{\tilde{q}} - 250$
BP7	$1200 \rightarrow 3000$	$M_{\tilde{q}} - 200$	$3 \rightarrow \{M_{\tilde{t}} - 200\}$	$M_{\tilde{\chi}_1^0} + 127$	$M_{\tilde{t}} = M_{\tilde{g}} - 250$
BP8	$1200 \rightarrow 3000$	$M_{\tilde{q}} - 200$	$3 \rightarrow \{M_{\tilde{b}} - 20\}$	$M_{\tilde{\chi}_1^0} + 127$	$M_{\tilde{b}} = M_{\tilde{g}} - 250$

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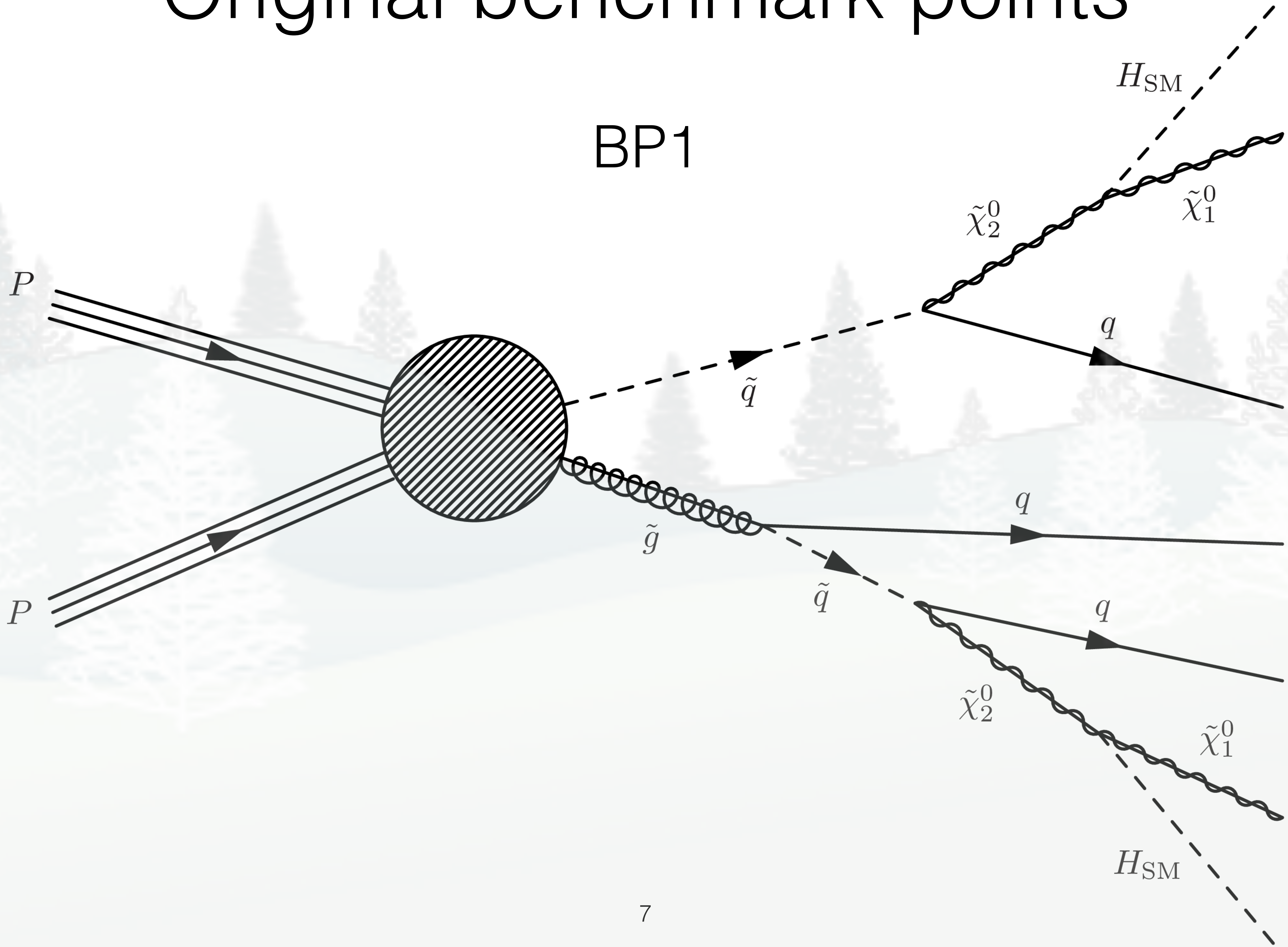
Original benchmark points

BP1

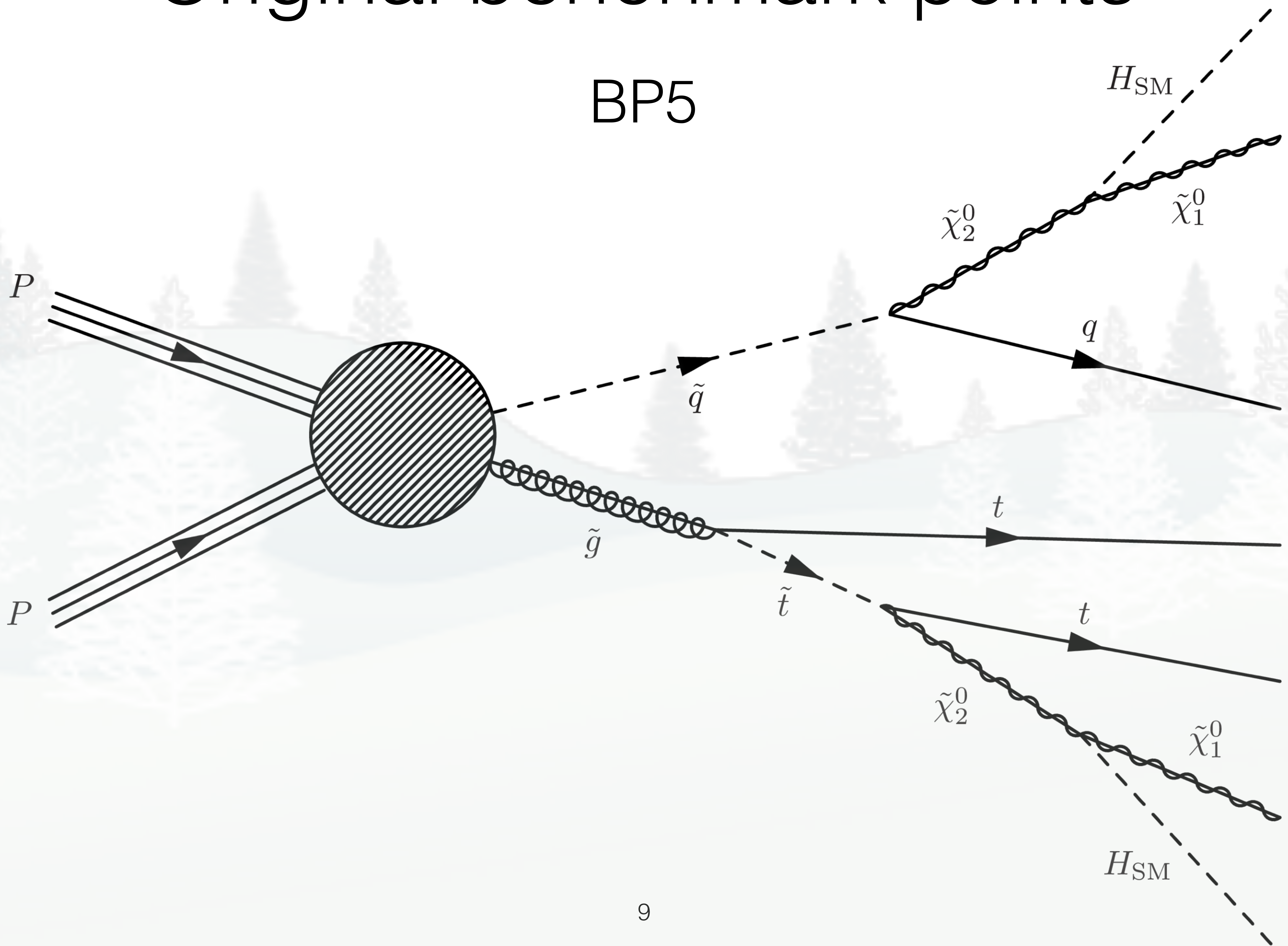


Original benchmark points

BP3

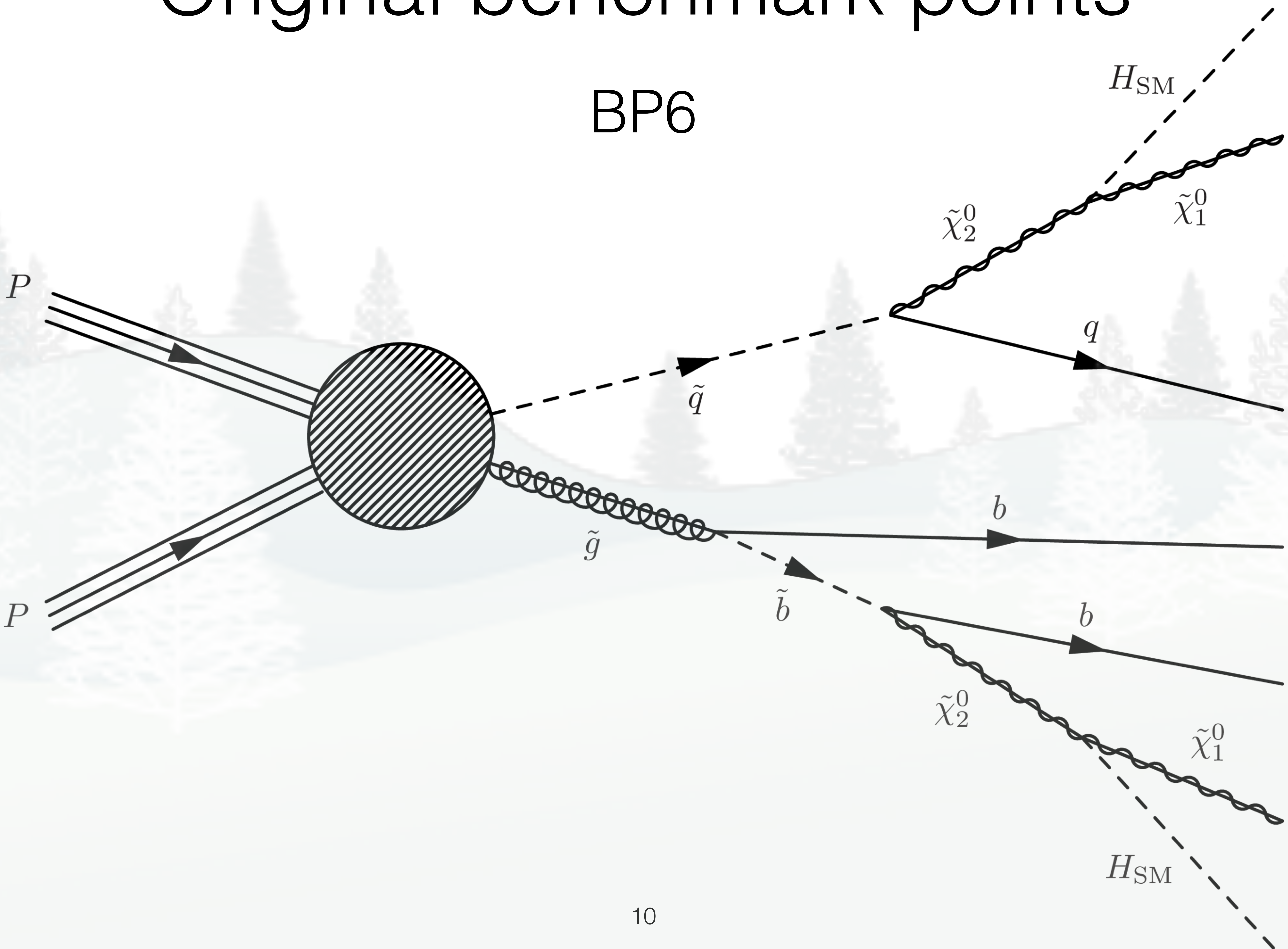
Original benchmark points

BP5



Original benchmark points

BP6

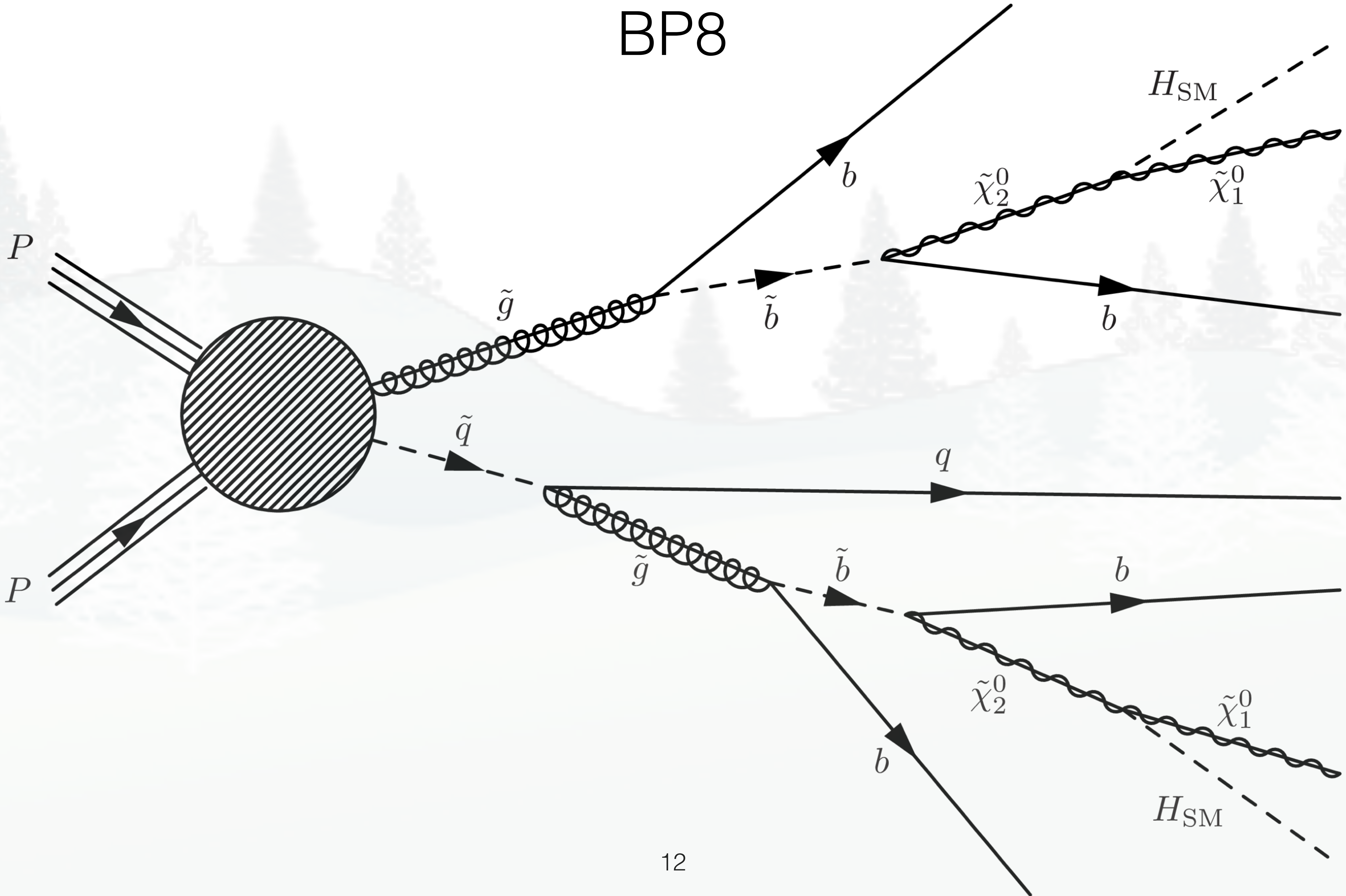


Original benchmark points

BP7

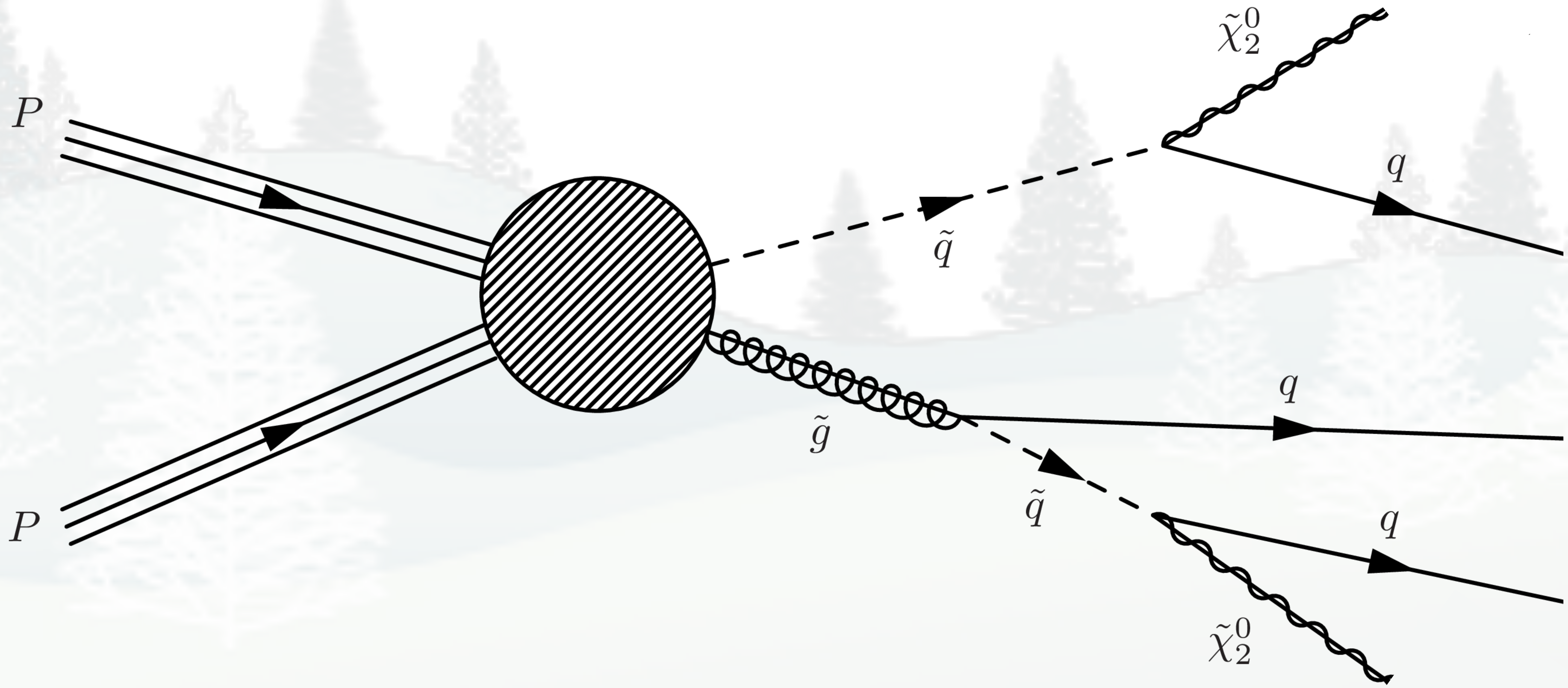
Original benchmark points

BP8

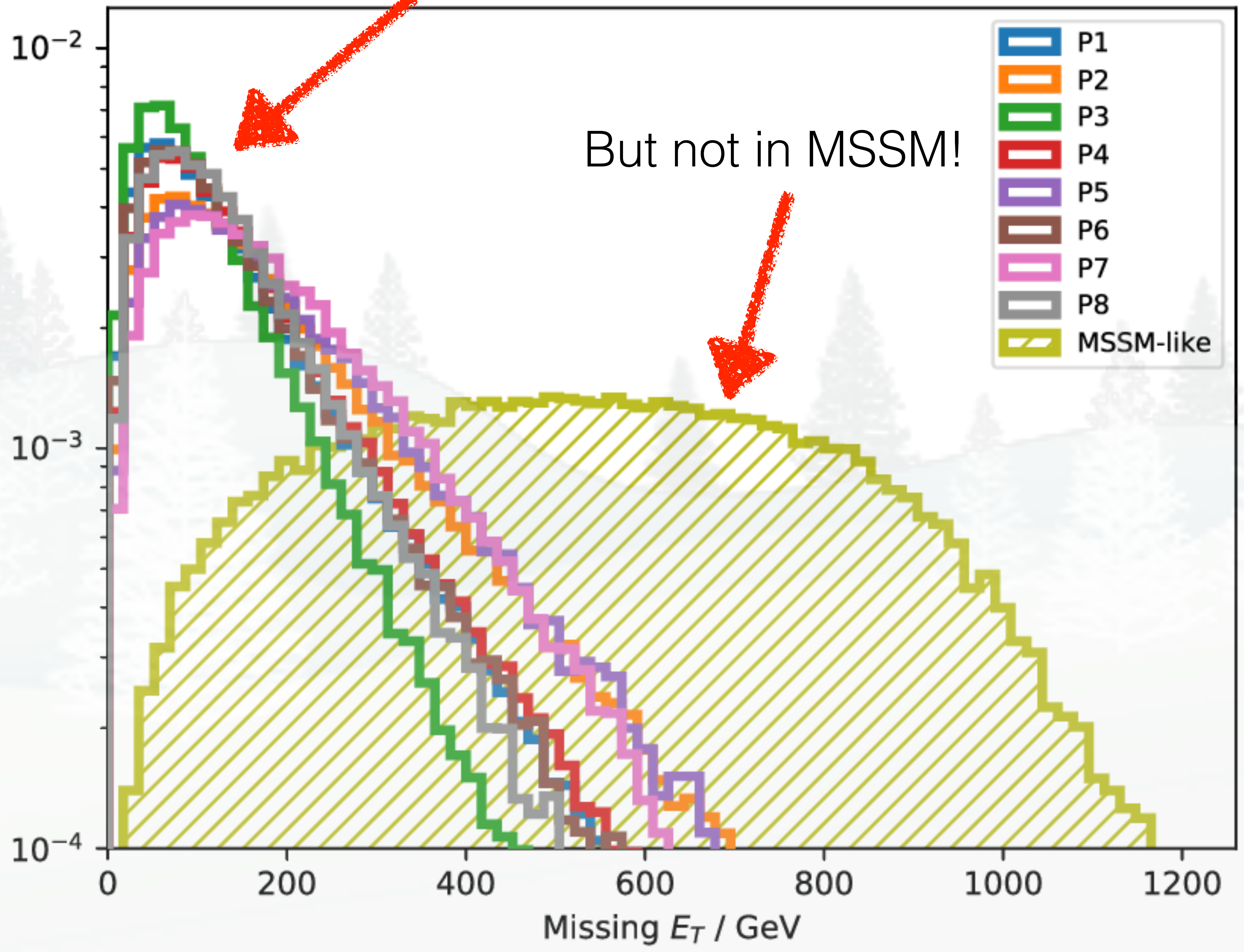


Compare: MSSM-like simplified model

BP1-like without X^0_2 decay (becomes new "LSP")



Can have this low-MET scenario in NMSSM…



Simulation

- Compute diagrams and matrix elements using MADGraph at Leading Order, cross-sections at Next-to-Leading Order using Prospino.
- Decay/shower particles using Pythia 8.
- Simulate the detector measurements using Delphes (for phenomenology work), later within CMSSW, CMS' detector response simulation framework.
- Read output ROOT files into dataframes (pandas/dask)
- Compare the number of events in our signal process with the Standard Model background prediction and observed yields, after applying some selections/cuts.

Current sensitivity to this type of model

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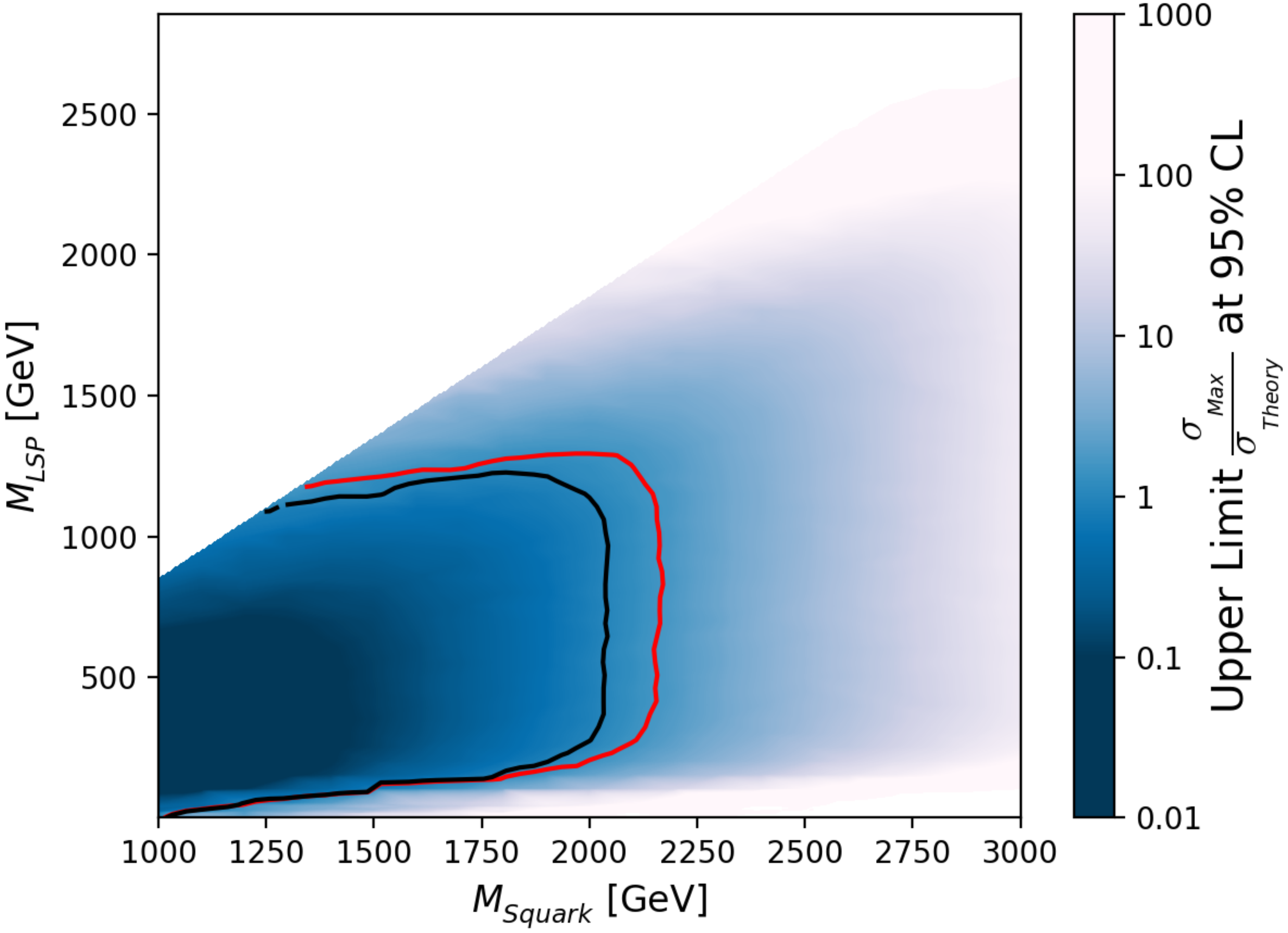
Exploring sensitivity to NMSSM signatures with low missing transverse energy at the LHC

A. Titterton,[a,b,c] **U. Ellwanger,**[d] **H.U. Flaecher,**[a] **S. Moretti**[b,c] **and C.H. Shepherd-Themistocleous**[c]

ABSTRACT: We examine scenarios in the Next-to-Minimal Supersymmetric Standard Model (NMSSM), where pair-produced squarks and gluinos decay via two cascades, each ending in a stable neutralino as Lightest Supersymmetric Particle (LSP) and a Standard Model (SM)-like Higgs boson, with mass spectra such that the missing transverse energy, E_T^{miss}, is very low. Performing two-dimensional parameter scans and focusing on the hadronic $H \to b\bar{b}$ decay giving a $b\bar{b}b\bar{b} + E_T^{miss}$ final state we explore the sensitivity of a current LHC general-purpose jets+E_T^{miss} analysis to such scenarios.

- Pheno paper recently in JHEP shows current analyses not so sensitive to this low-MET model.
- ArXiv:1807.10672

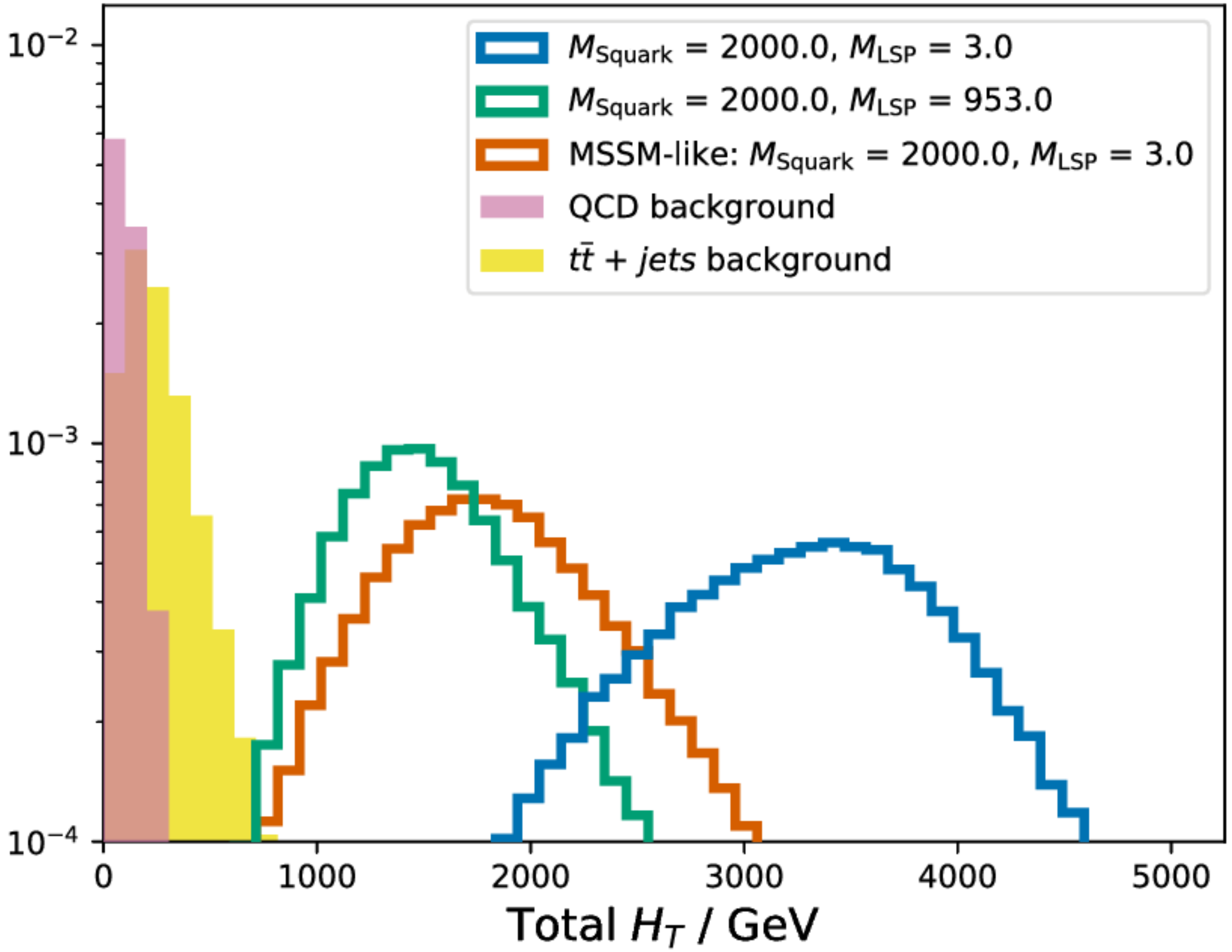
Simulation

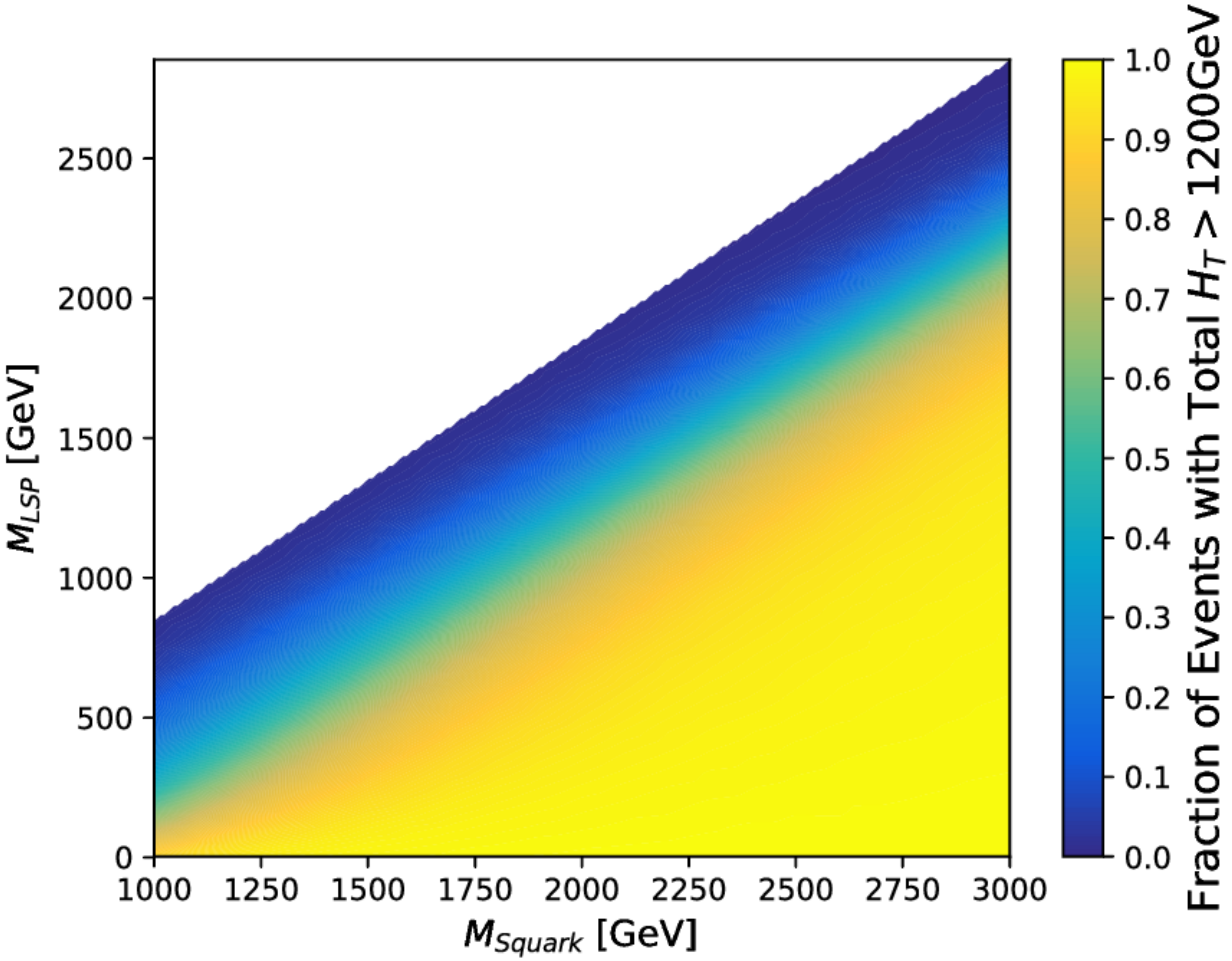


- Recast a CMS general purpose jets+MET analysis to check sensitivity of existing efforts to this model.
- Example mass scan shows lack of sensitivity for very light neutralino LSP.
- LSP mass < 200GeV or so has sharp drop in sensitivity

Signal Properties: Total H_T

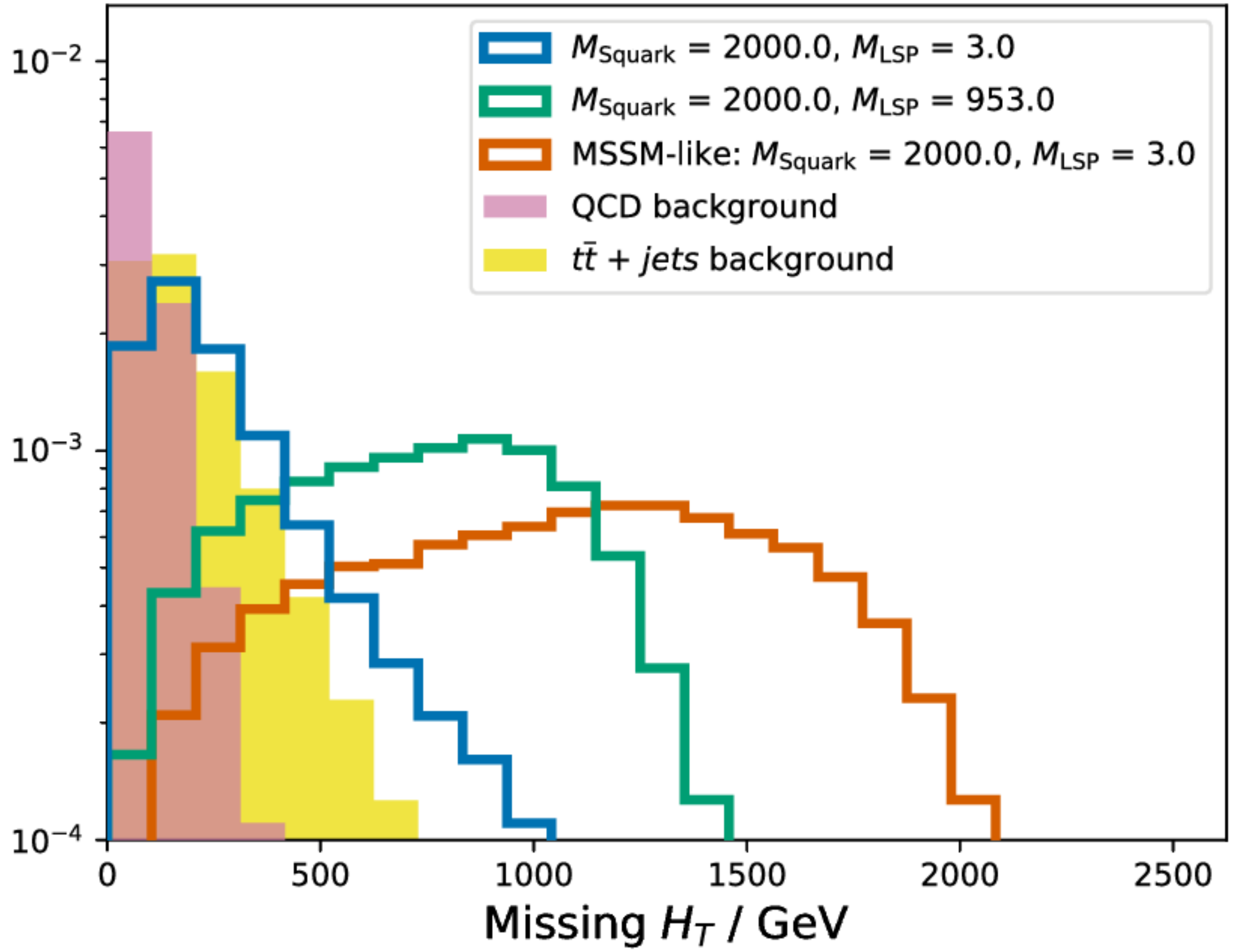
Examples with BP1 vs QCD and tt background processes

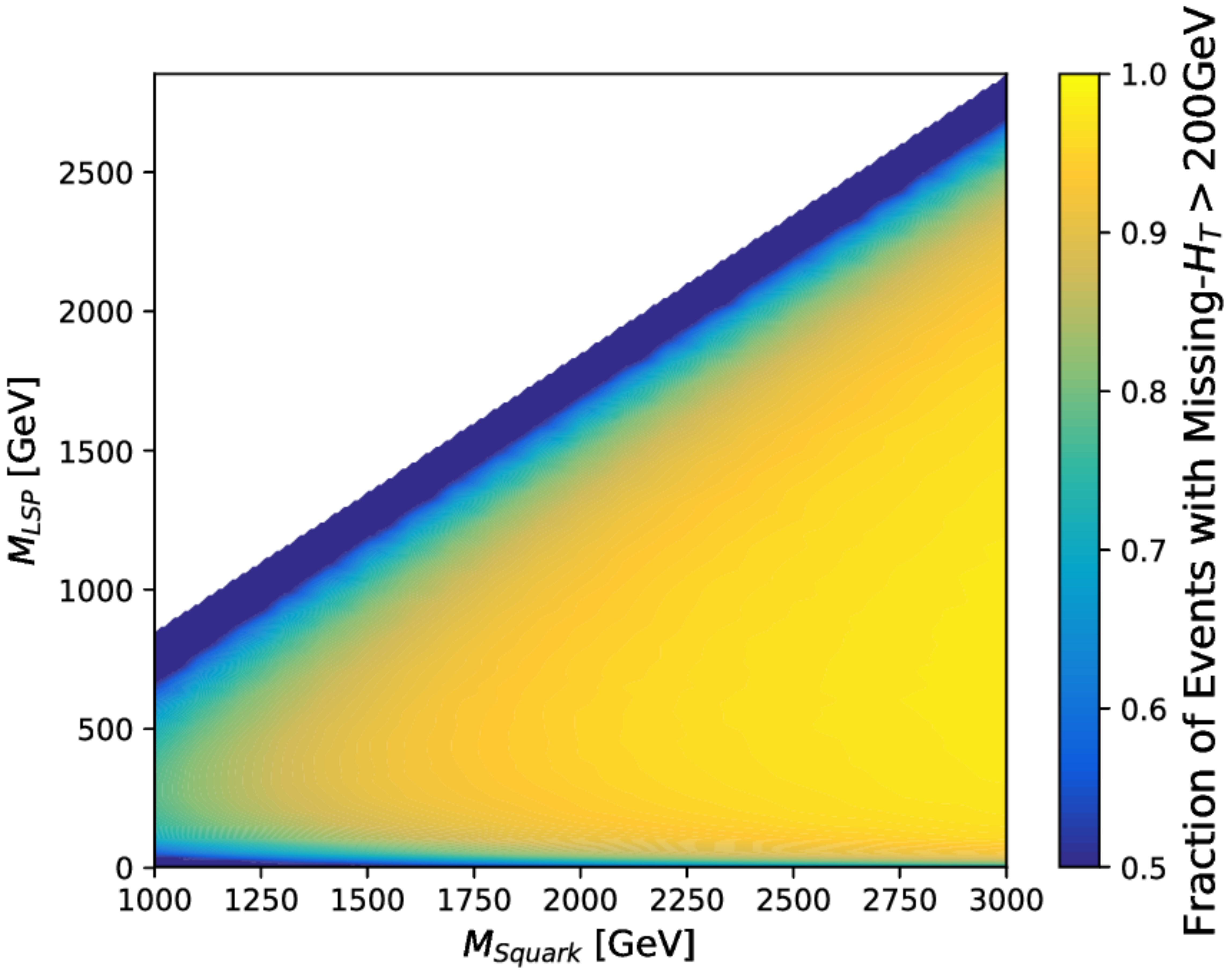




Signal Properties: Missing-H_T

Examples with BP1 vs QCD and tt background processes

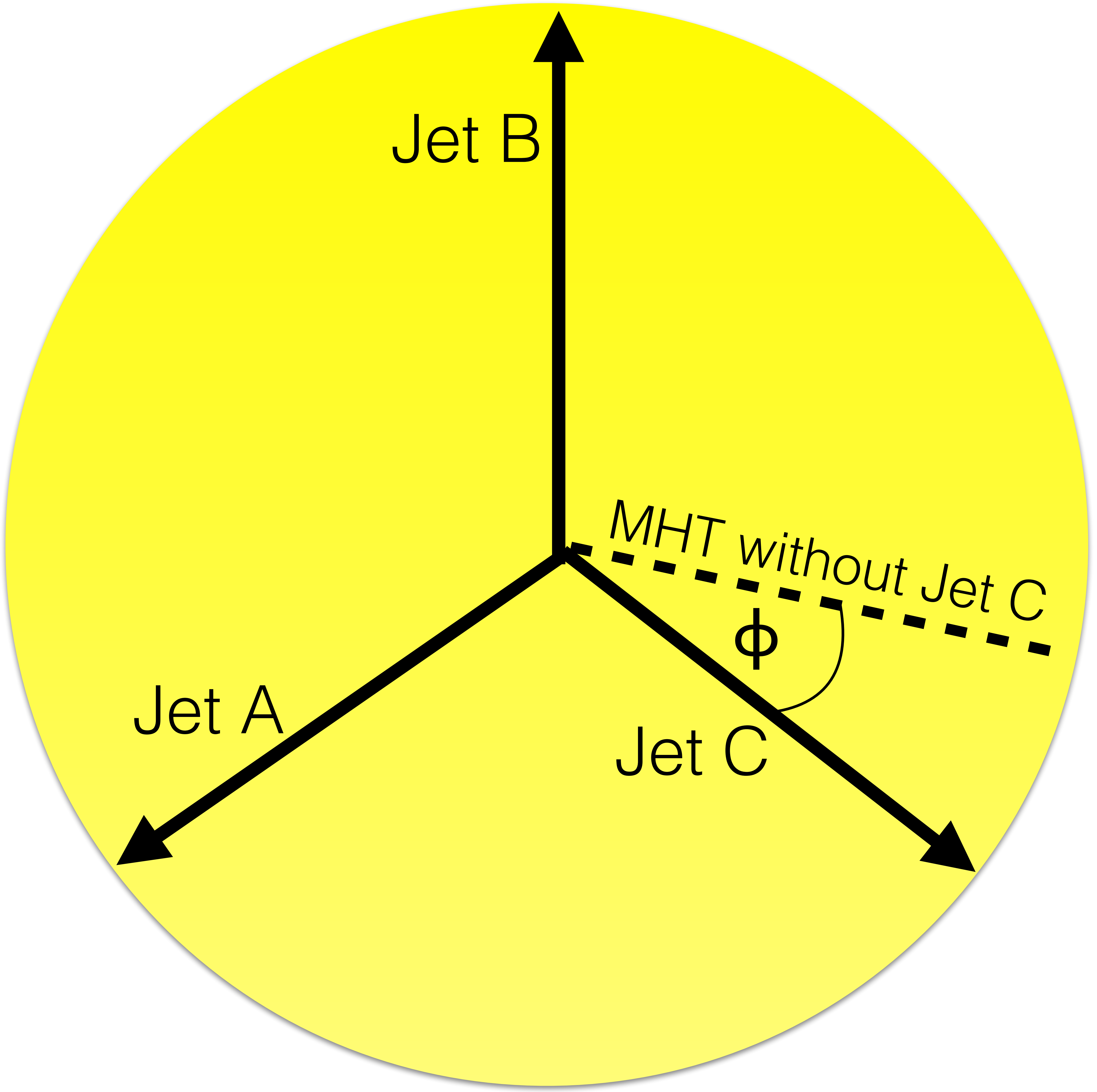




Signal Properties: min $\Delta\phi^*$

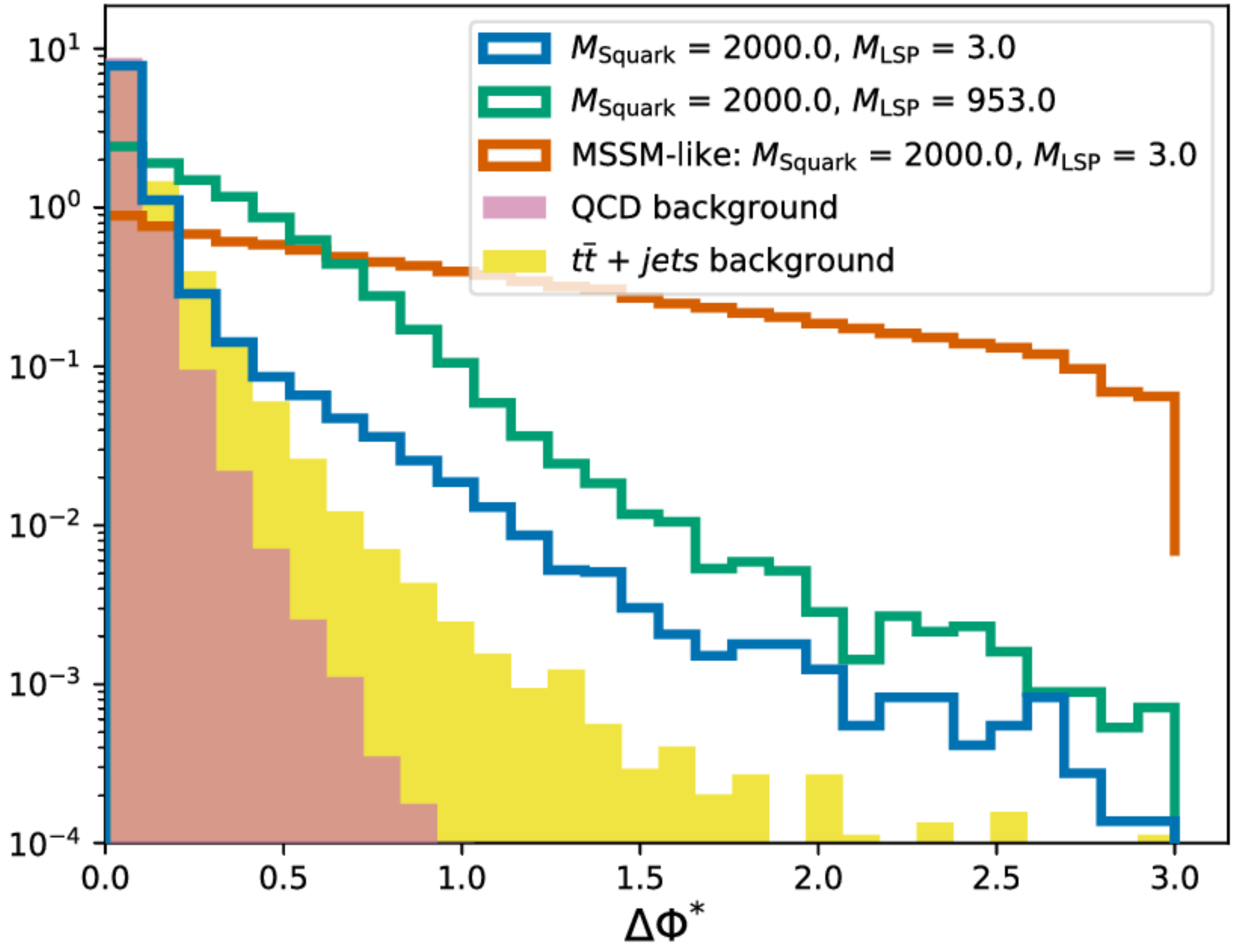
Examples with BP1 vs QCD and tt background processes

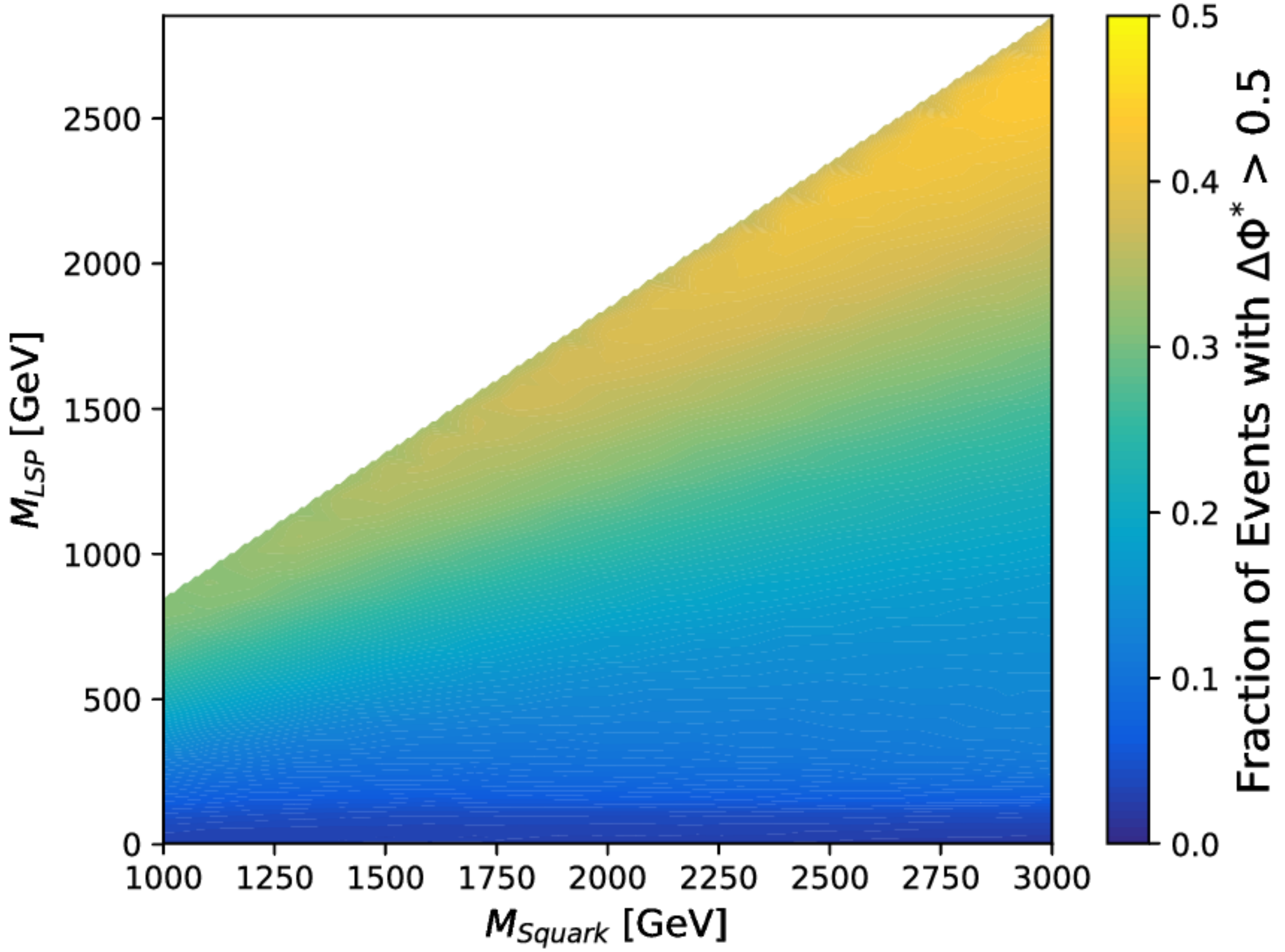
- Variable designed to reduce QCD background by identifying events with spurious MET from e.g. jet mis-measurement
- Take the difference in ϕ between a jet and the Missing-H_T without that jet
- Define "min $\Delta\phi^*$" as the minimum value over all jets in the event —> Should be the jet most likely to correspond to any mismeasurement
- Therefore if min $\Delta\phi^*$ is still large (> 0.5) then this suggests real MET



Signal Properties: $\Delta\phi^*$

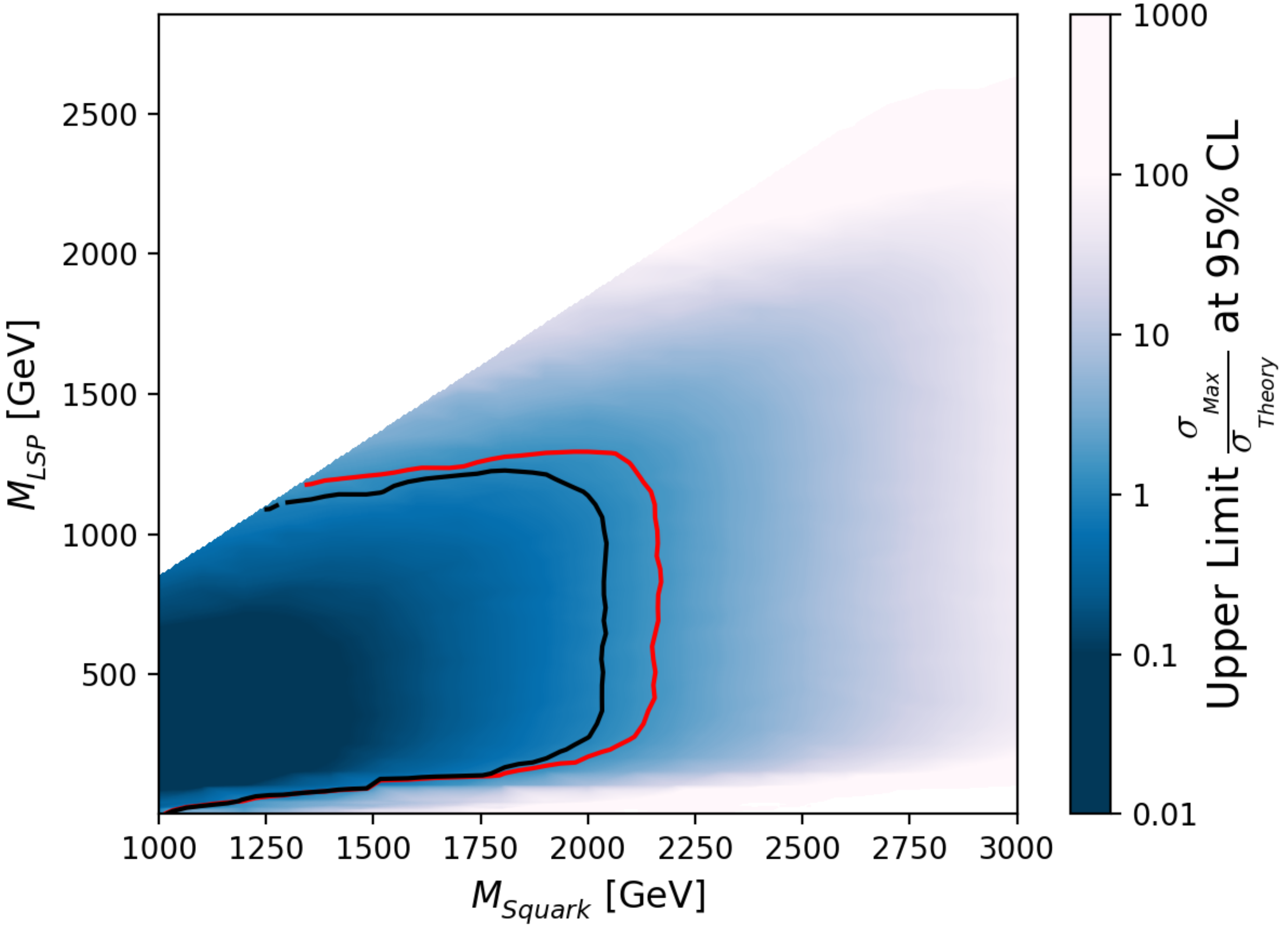
Examples with BP1 vs QCD and tt background processes



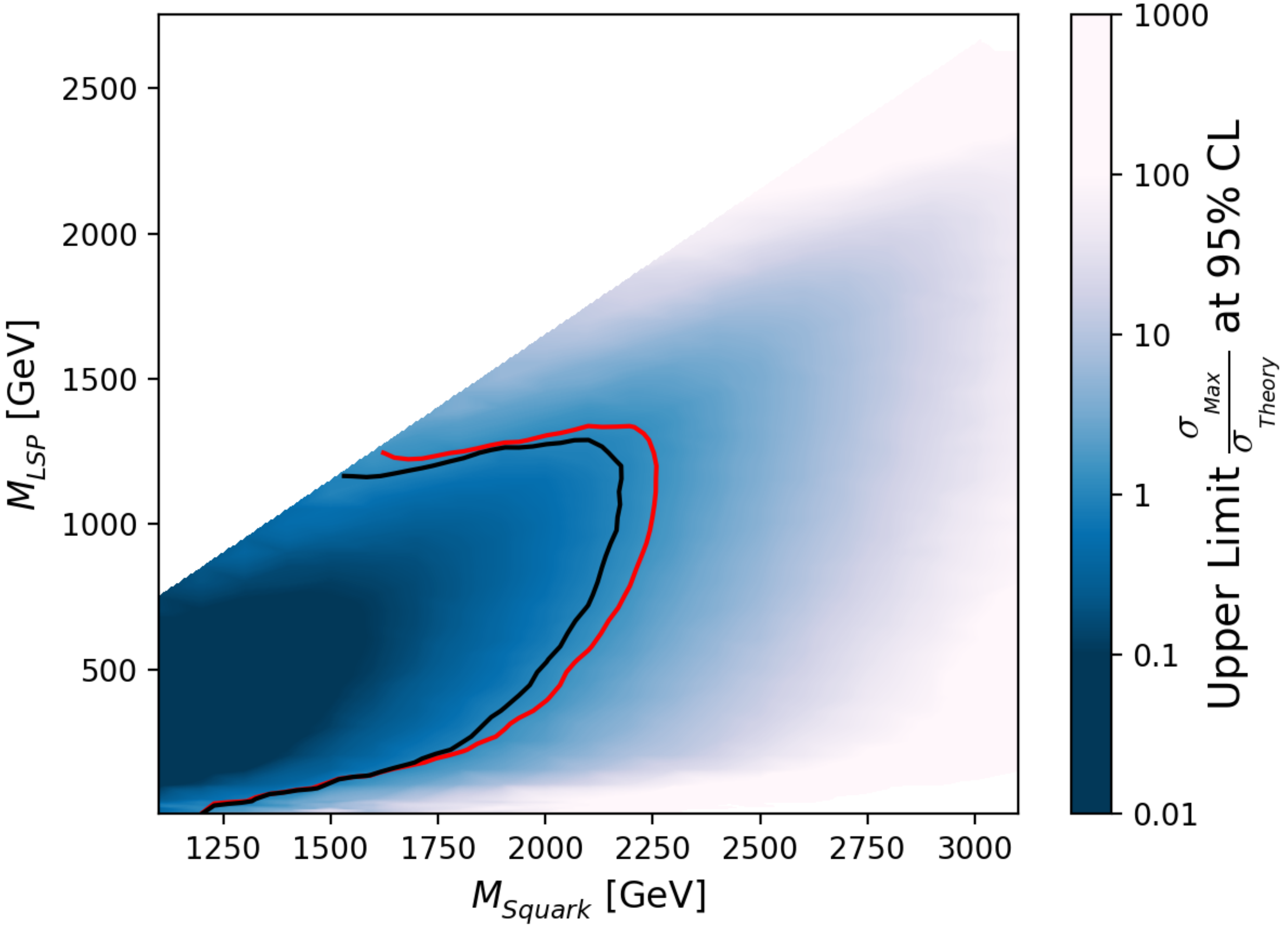


Simulation

BP1

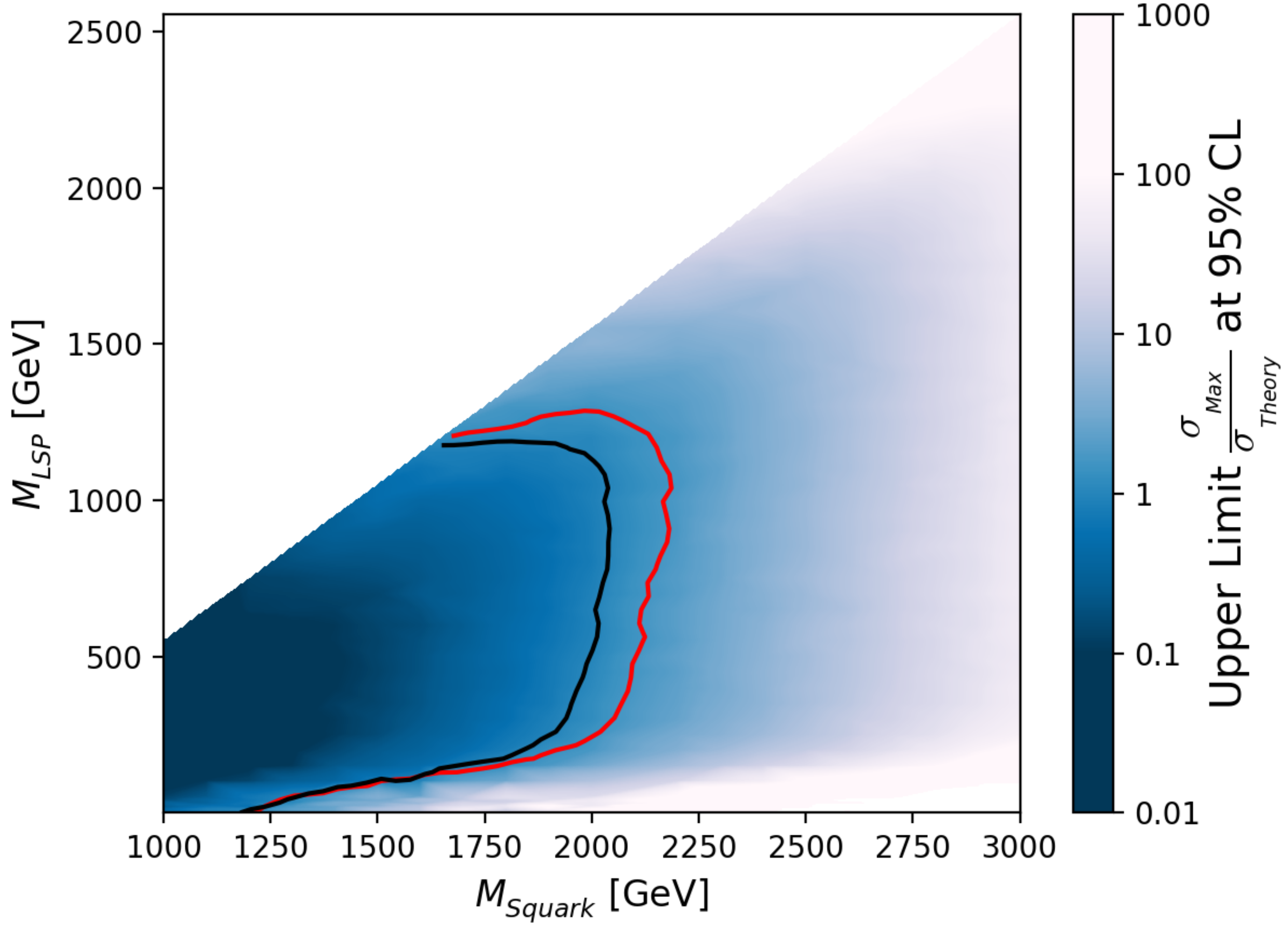


BP3

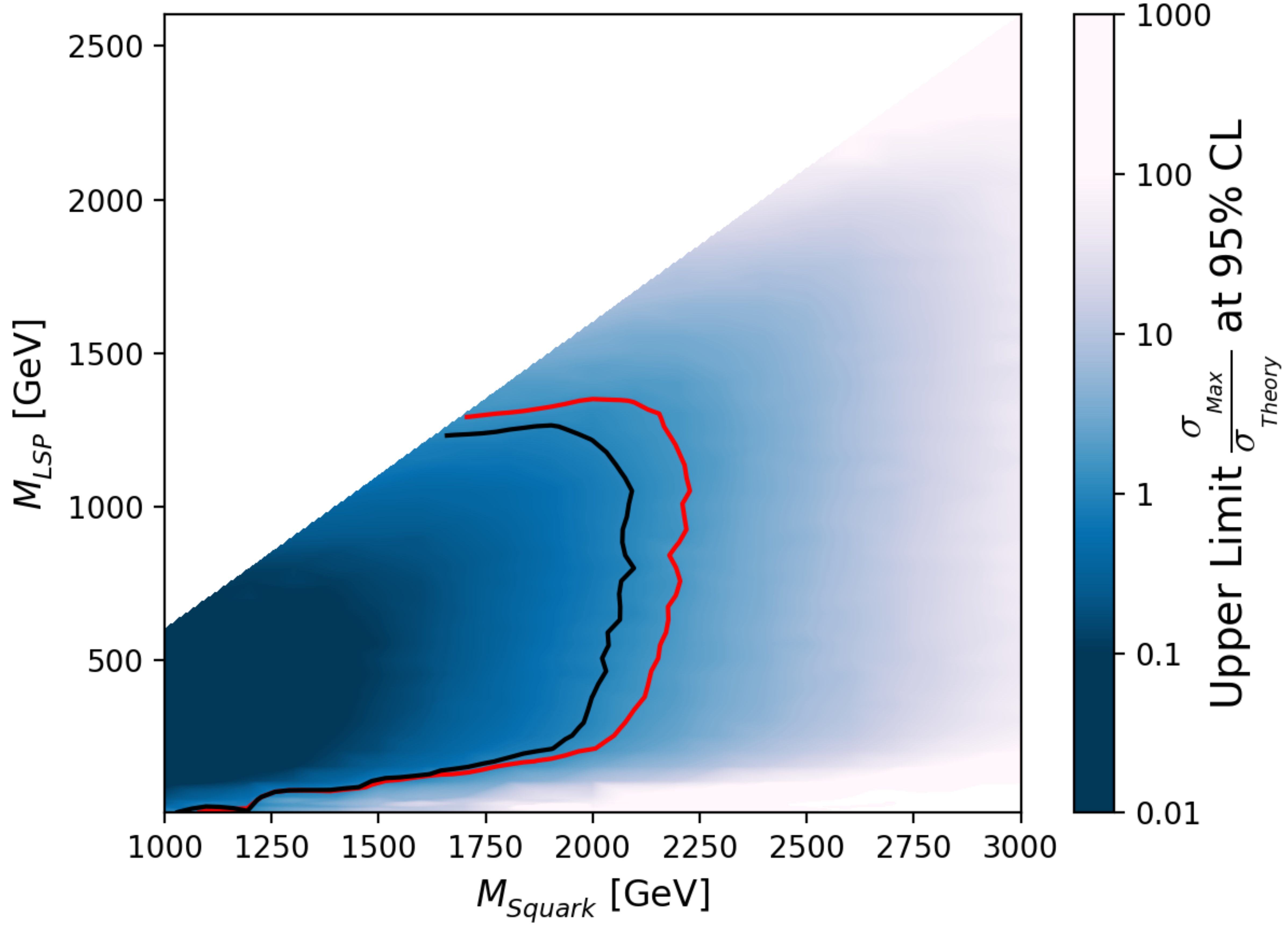


Simulation

BP5

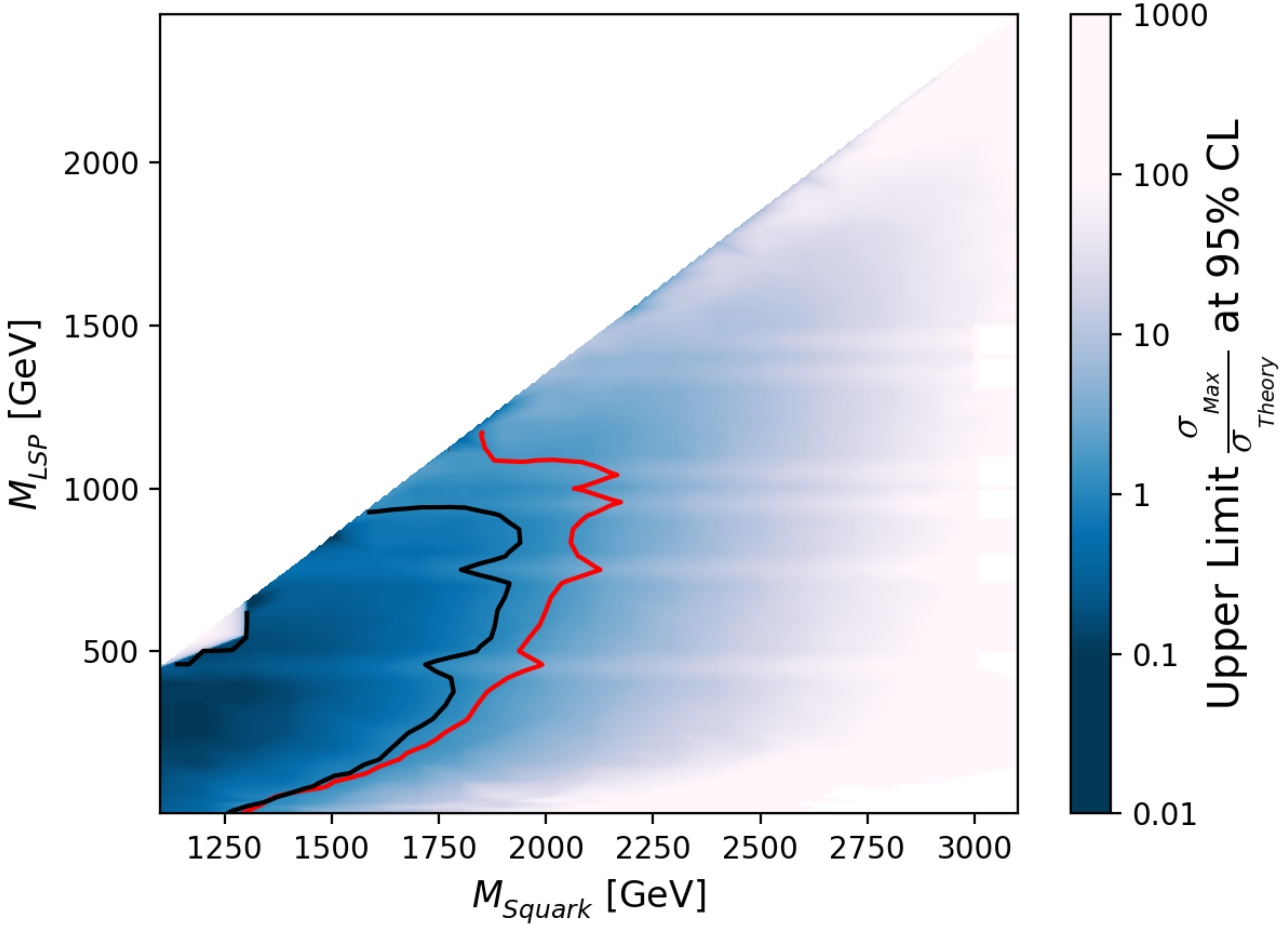


BP6

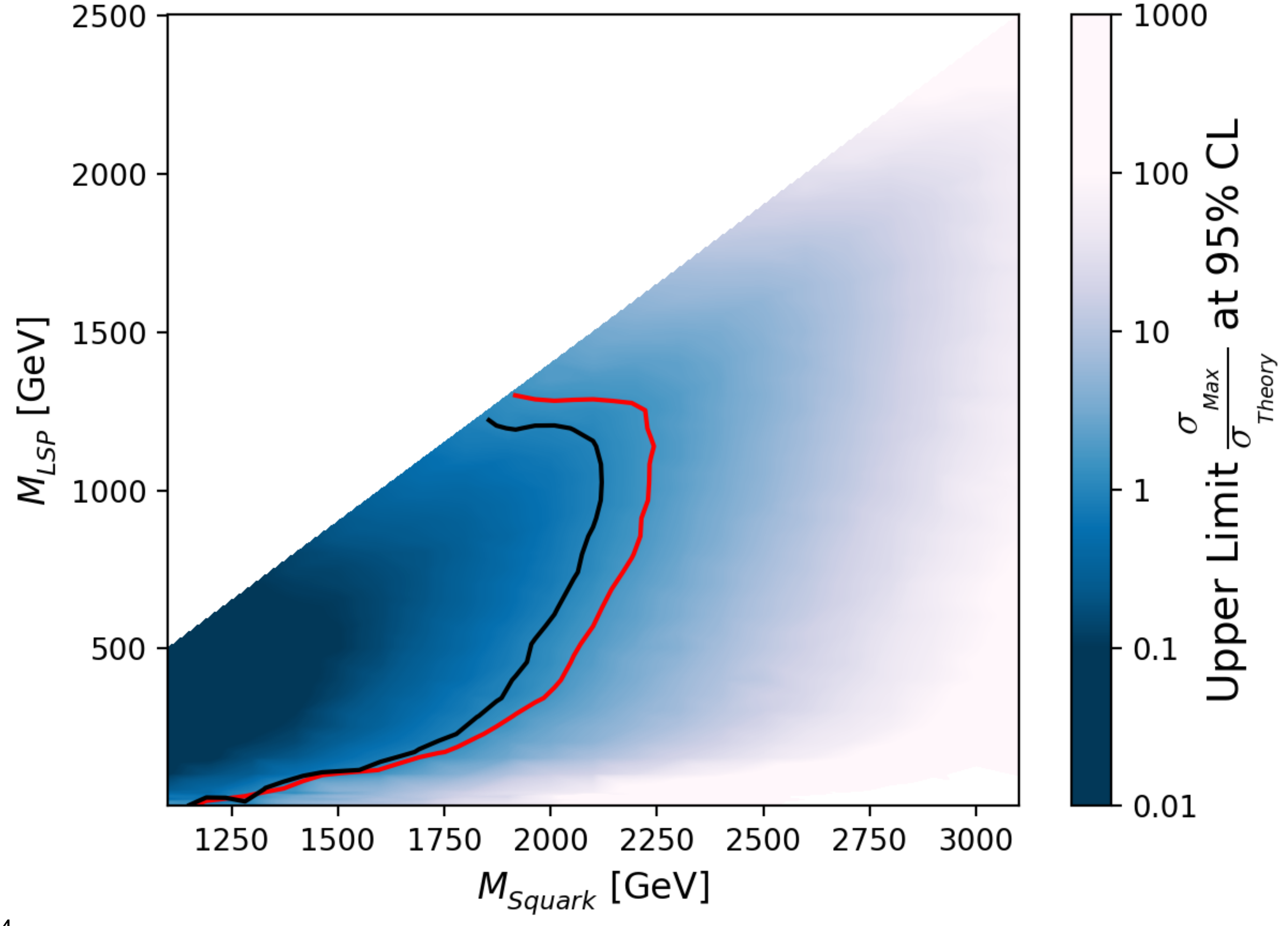


Simulation

BP7

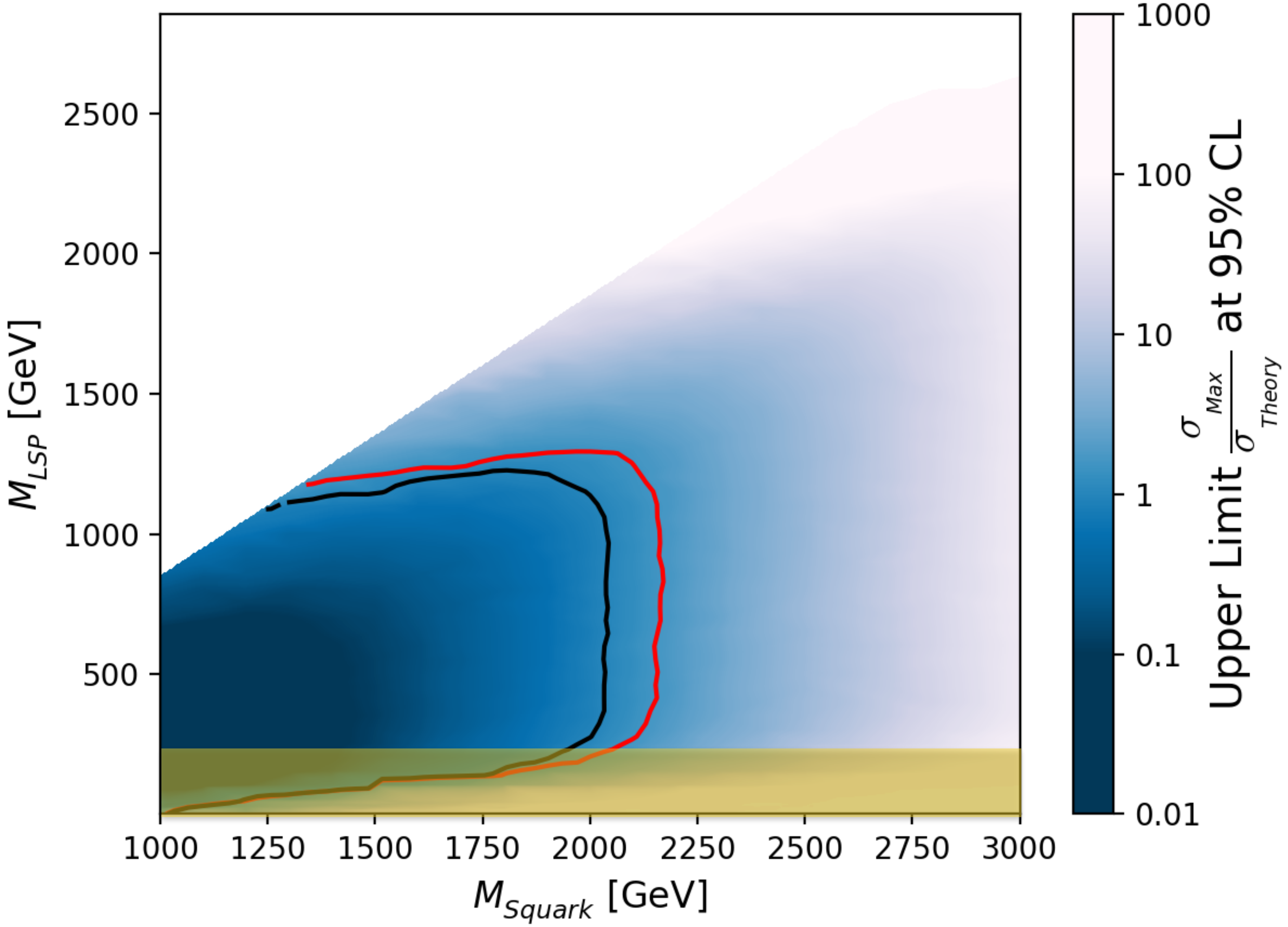


BP8



Where to go from here

- Lower bound on gluino mass very low in many cases
- Wish to access (shaded) light-LSP region, where existing jets+MET searches lack sensitivity
- In this region MET very low, Higgs highly boosted



Scan	BP1	BP3	BP5	BP6	BP7	BP8
$M_{\tilde{q},\,\mathrm{min}}$ [GeV/c^2]	1000	1200	1250	1000	1250	1200
$M_{\tilde{g},\,\mathrm{min}}$ [GeV/c^2]	1010	1000	1260	1010	1050	1000

Where to go from here:

- Heavy squarks and light LSP means very boosted topologies, can be tricky!
- Looking at two high-momentum Higgs —> bb, so rather than 4b final state might only be able to resolve 2 “fat” double-b jets
- Boosted double-b tagger: Larger radius jets formed, substructure analysed (via Boosted Decision Tree) to see whether jet contains a boosted H—>bb
- Standard model Higgs mass known, so can use jet mass measurement
- Analysis ongoing with CMS HiggsExo group

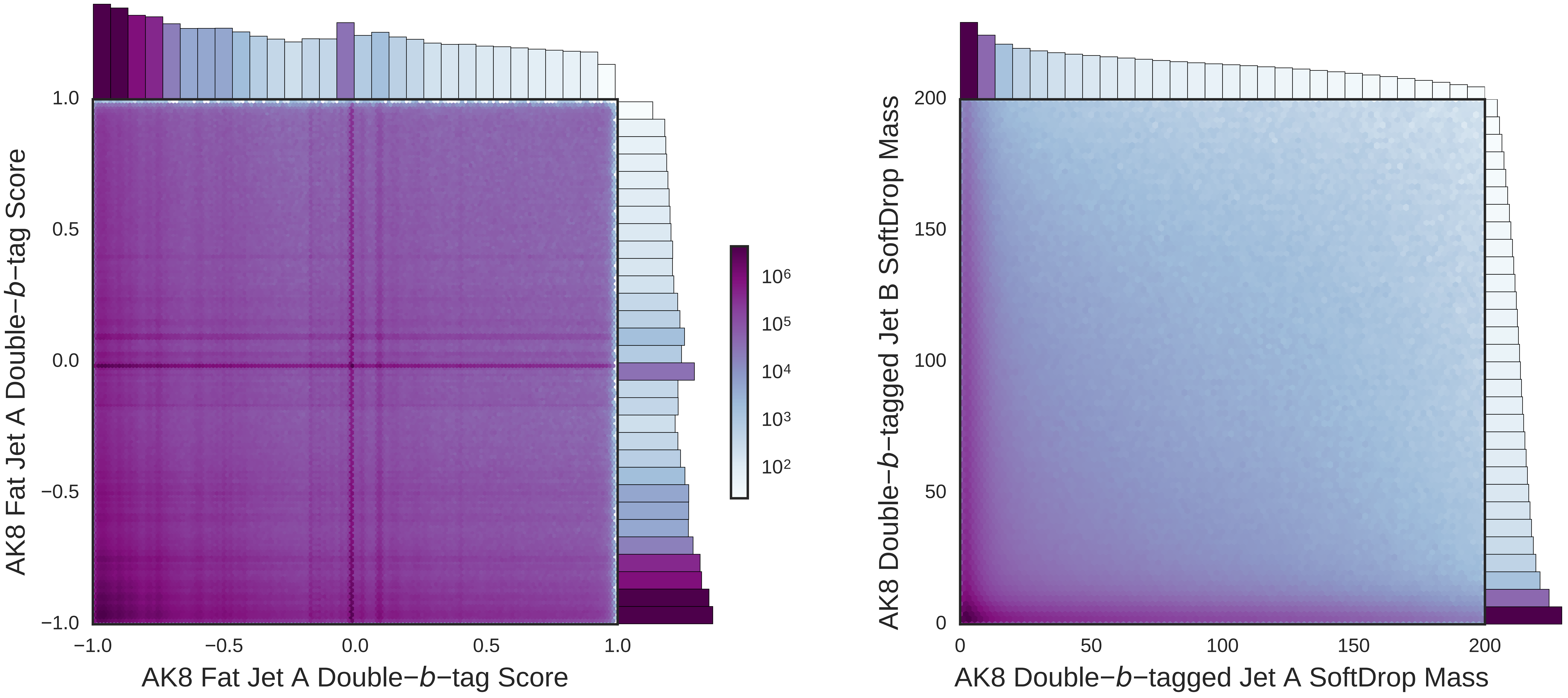
Where to go from here:

- Many background processes considered:
  - tt + jets, QCD, W/Z + jets, Single-top, WW/WZ/ZZ, ttZ, ttW etc
  - tt + jets, QCD and W/Z+jets dominant

- Control regions developed using double-b-tagged jet measurements in order to use data-driven background estimation methods

Signal: 2TeV Squarks, 3GeV LSP

QCD Background



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- Control regions developed using double-b-tagged jet measurements in order to use data-driven background estimation methods

- Talks delivered to CMS HiggsExo group in late November

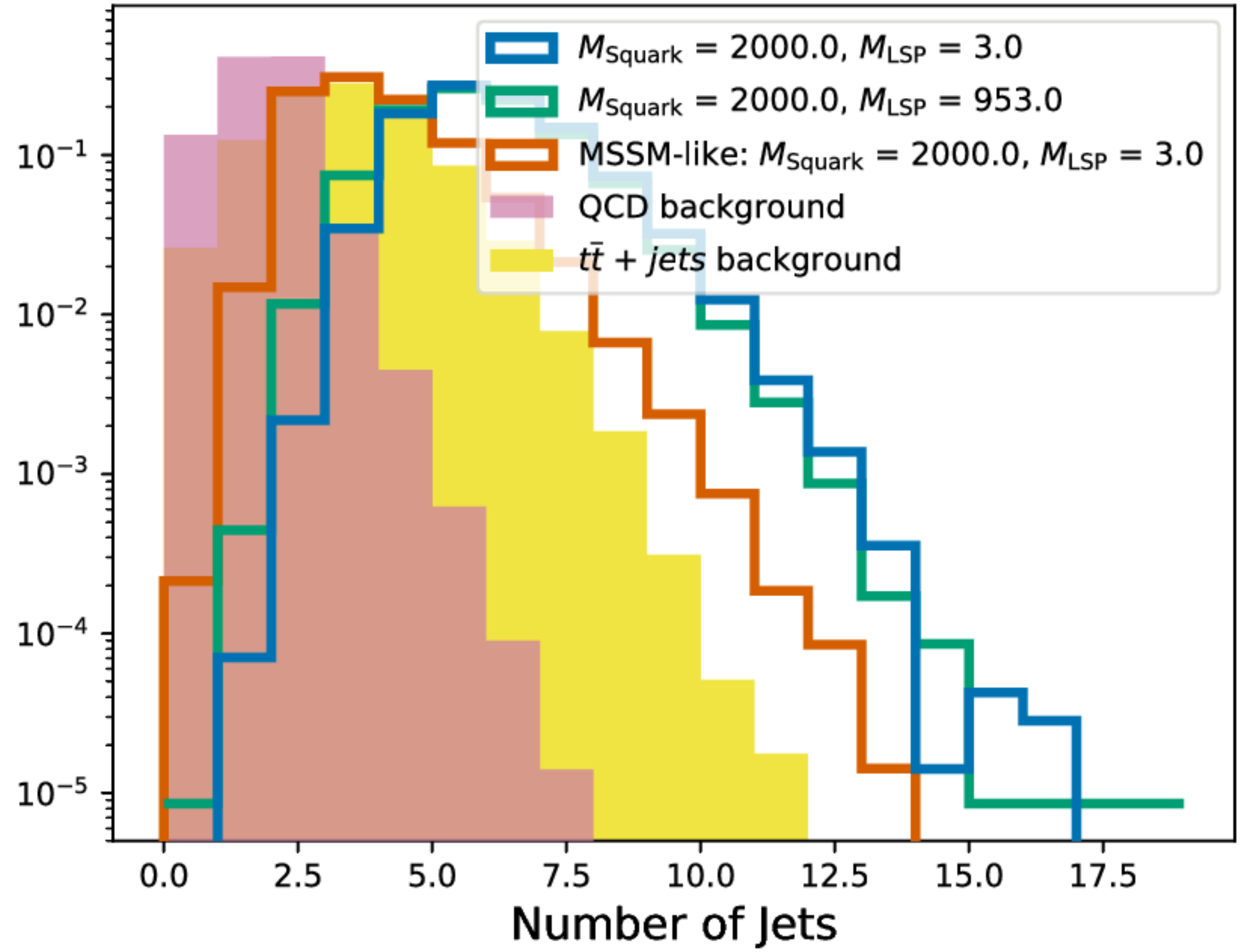
- Pre-approval to follow, then eventually unblinding

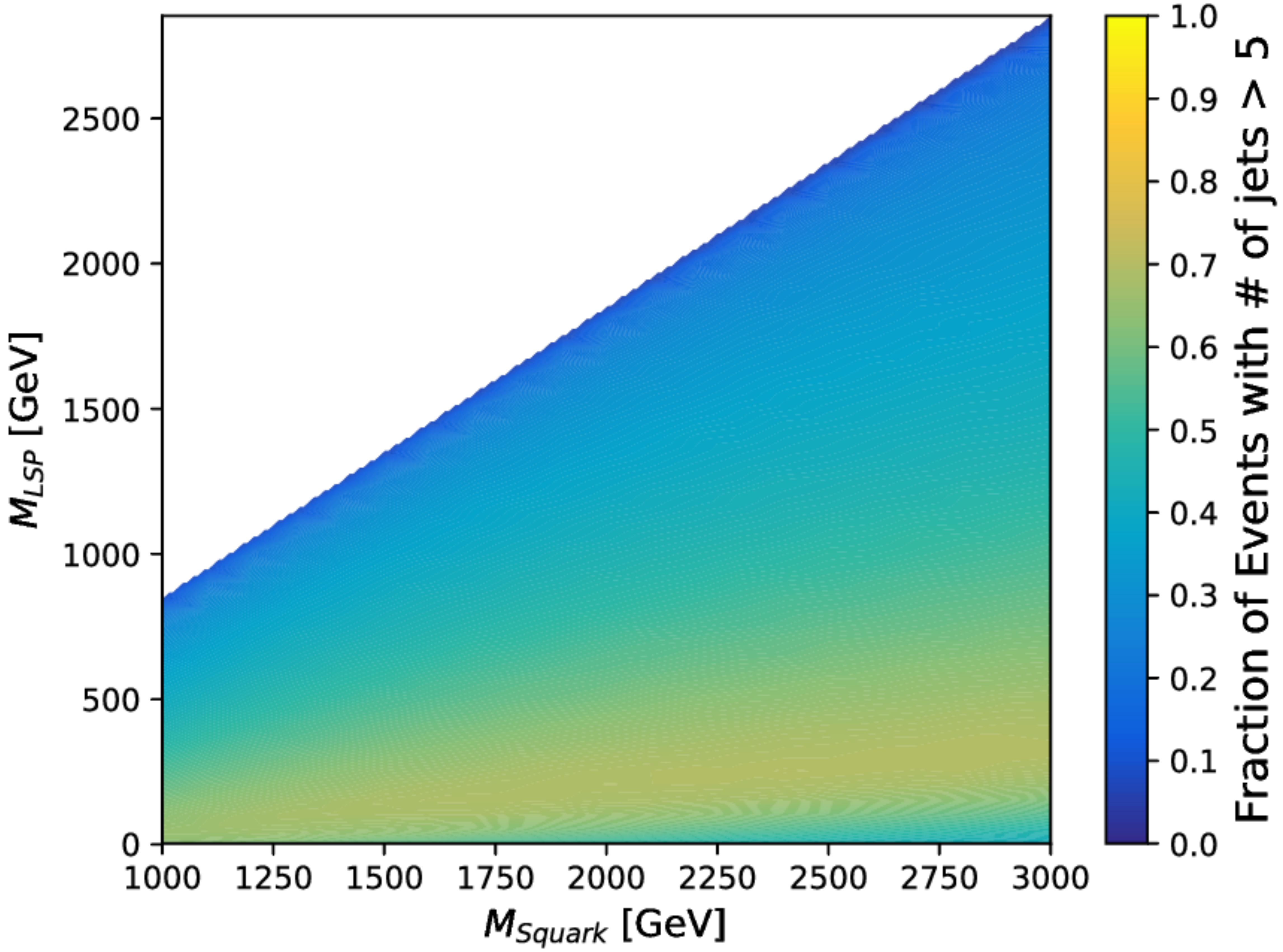
Merci et Bonnes Vacances!

Backup

Signal Properties: # of jets

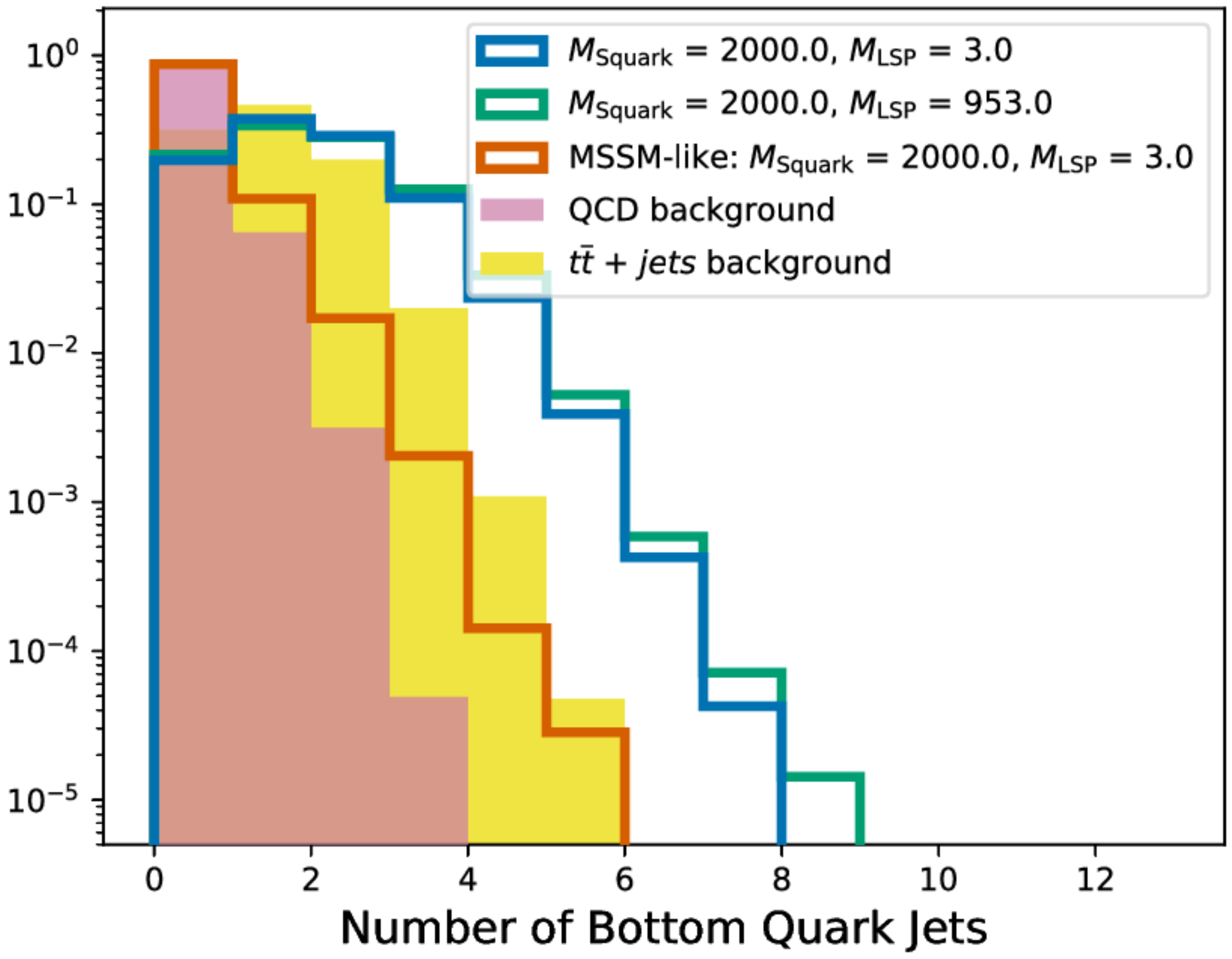
Examples with BP1 vs QCD and tt background processes

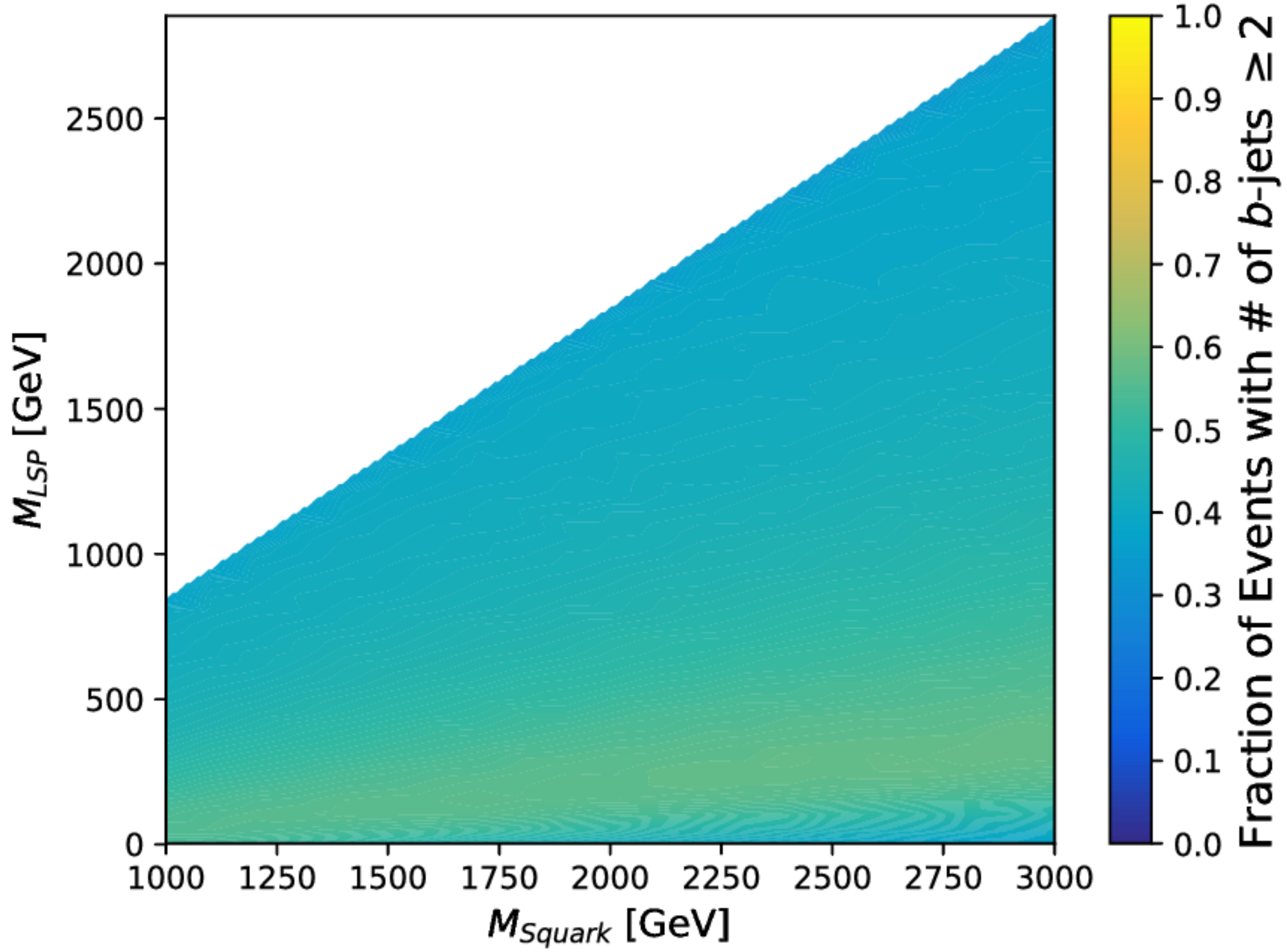




Signal Properties: # of b-tagged jets

Examples with BP1 vs QCD and tt background processes





Signal Properties: Angular separation between b-jets from Higgs decay