Inclusive SUSY searches at CMS

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(on behalf of the CMS Collaboration)

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Supersymmetry (SUSY)

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A symmetry of the space-time

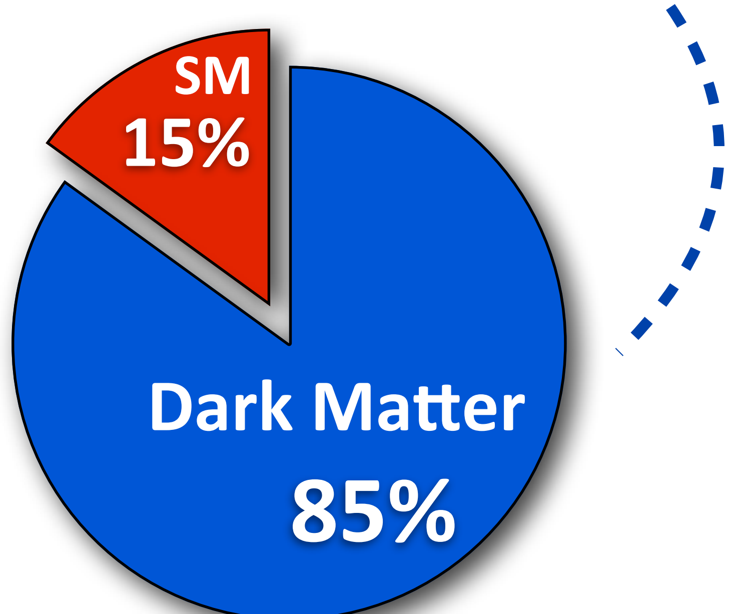
- For each *boson* there is a *fermion* and vice versa

- Solves a big problem: fixes the m_H divergences
- MSSM favors a light $m_H < 135$ GeV
- **Higgs boson discovery, paves the way for SUSY ?**

SUSY as a BSM Model

✓ Solves hierarchy problem
✓ Predicts unification of all forces
✓ Needed for incorporating gravity
✓ Provides a DM candidate

} theoretical motivations



} experimental motivation

Biggest Problems for SUSY

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- Not yet discovered, can't be an exact symmetry (if it was we would have seen **selectrons** and **smuons** of 511 keV/105 MeV)
  - Higher is the SUSY breaking scale, **hierarchy problem is kind of reintroduced ...**
  - Don't have a golden SUSY model to instruct us, **not easy to optimize the SUSY search analyses**
- The last point, is a common problem for BSM searches

Biggest Problems for SUSY

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- Not yet discovered, can't be an exact symm… ry (if it was we would have seen **selectrons** … **ns** of 511 keV/105 MeV)
  - Higher is the SUS… **blem is kind of** …
- … struct us, **not** … **rch analyses**
- … mon problem for BSM searches

SUSY is still the best BSM model
in the market, if to be found in
Run II will rocket fuel HEP

Reality can be complicated

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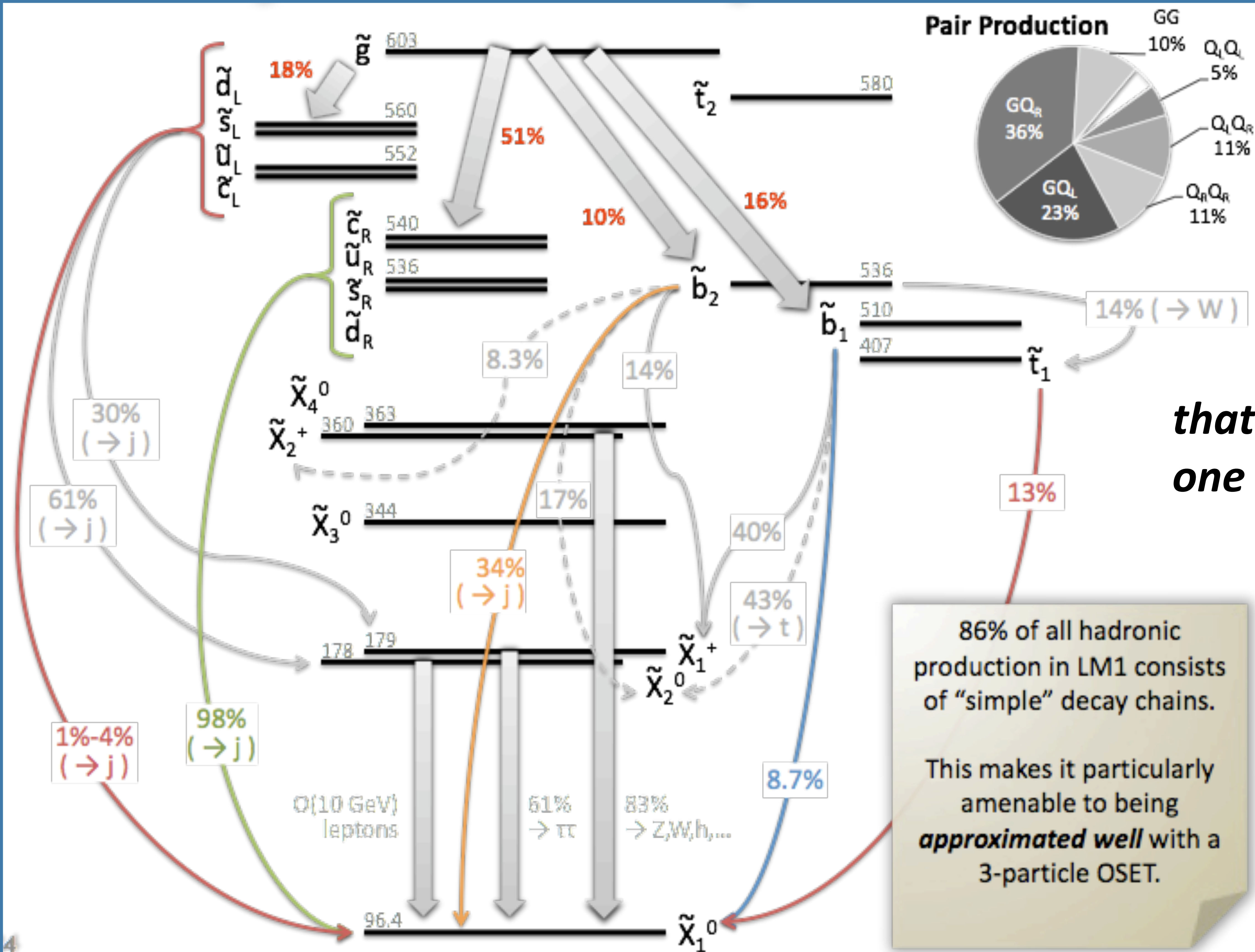


86% of all hadronic production in LM1 consists of "simple" decay chains.

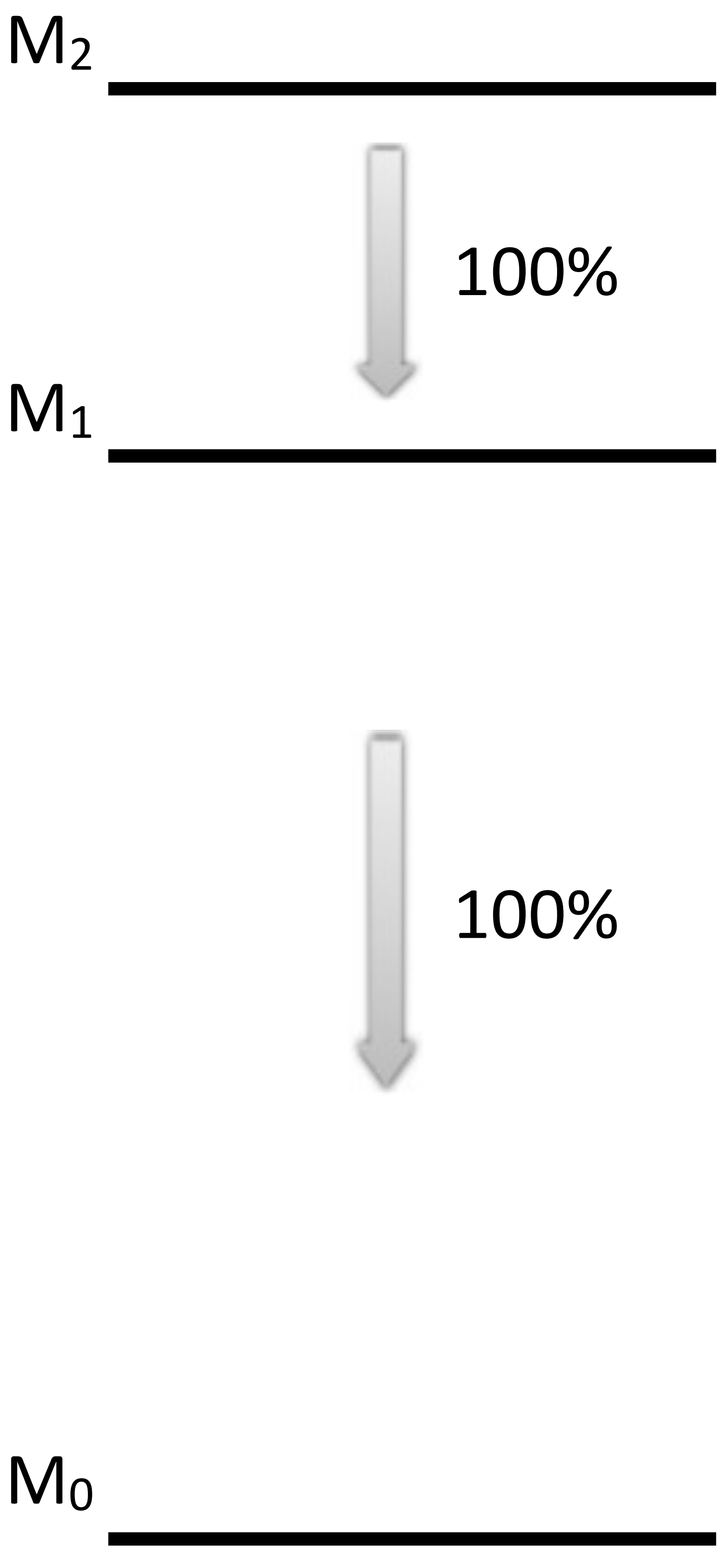
This makes it particularly amenable to being ***approximated well*** with a 3-particle OSET.

~120 unknown model parameters

that's just one example

from P.Sphicas talk in Latsis 2013

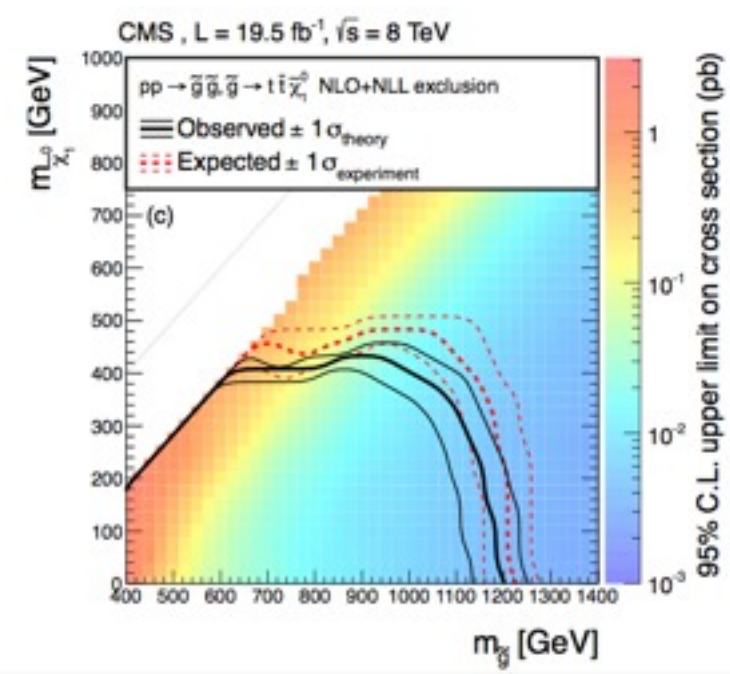
Simplified Models Spectra



Assume a 2 step cascade decay, with 3 unknown masses

- A parent particle M_2 is generated (squark/gluino/ewkino) with σ_{SUSY}
- M_0 is the LSP, and M_1 is an intermediate

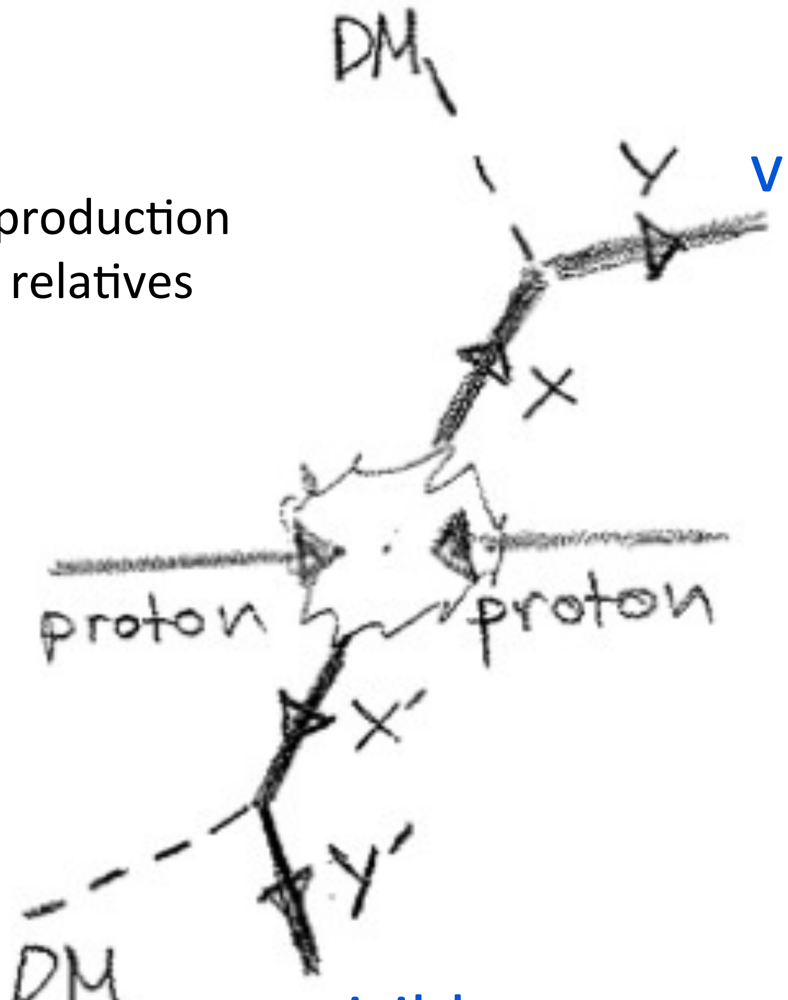
SMS allow for a simple way to interpret data; produce crisp results; (*sometimes* tempting to be over-interpreted)



Generic Search Signature

unseen

example production
via heavy relatives



visible

unseen

visible

- Stability of the **DM** in the universe is likely enforced by a new conservation law* (symmetry) ➞ implies pair production of new particles
- Strategy: search for events with some **MET, models without stable LSP is another story ...**

**e.g. R-parity in SUSY*

Jets + MET inclusive search

References

SUS-13-012 (19 fb-1 @ 8 TeV)

arXiv:1402.4770

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

0 Leptons Inclusive Search

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arXiv:1402.4770 / SUS13012

Phase space selected:

$N_{Lep} = 0$, $N_{jets} \geq 3$,

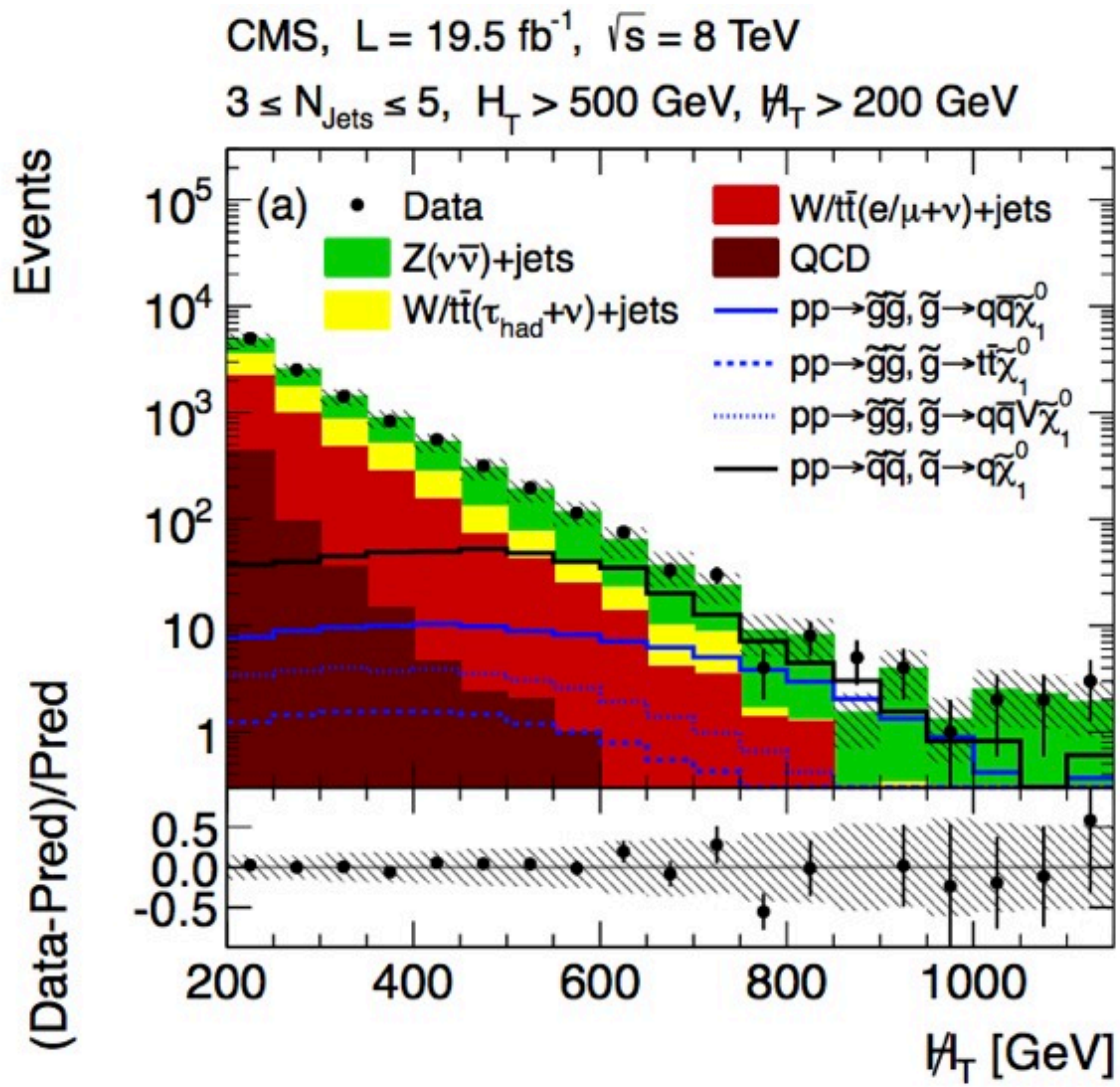
$H_T > 500$ GeV,

$MH_T > 200$ GeV*

$\Delta\phi(J_1, MH_T) > 0.5$,

$\Delta\phi(J_2, MH_T) > 0.5$,

$\Delta\phi(J_3, MH_T) > 0.3$



MH_T = like MET, but built with jets of p_T, η restricted acceptance

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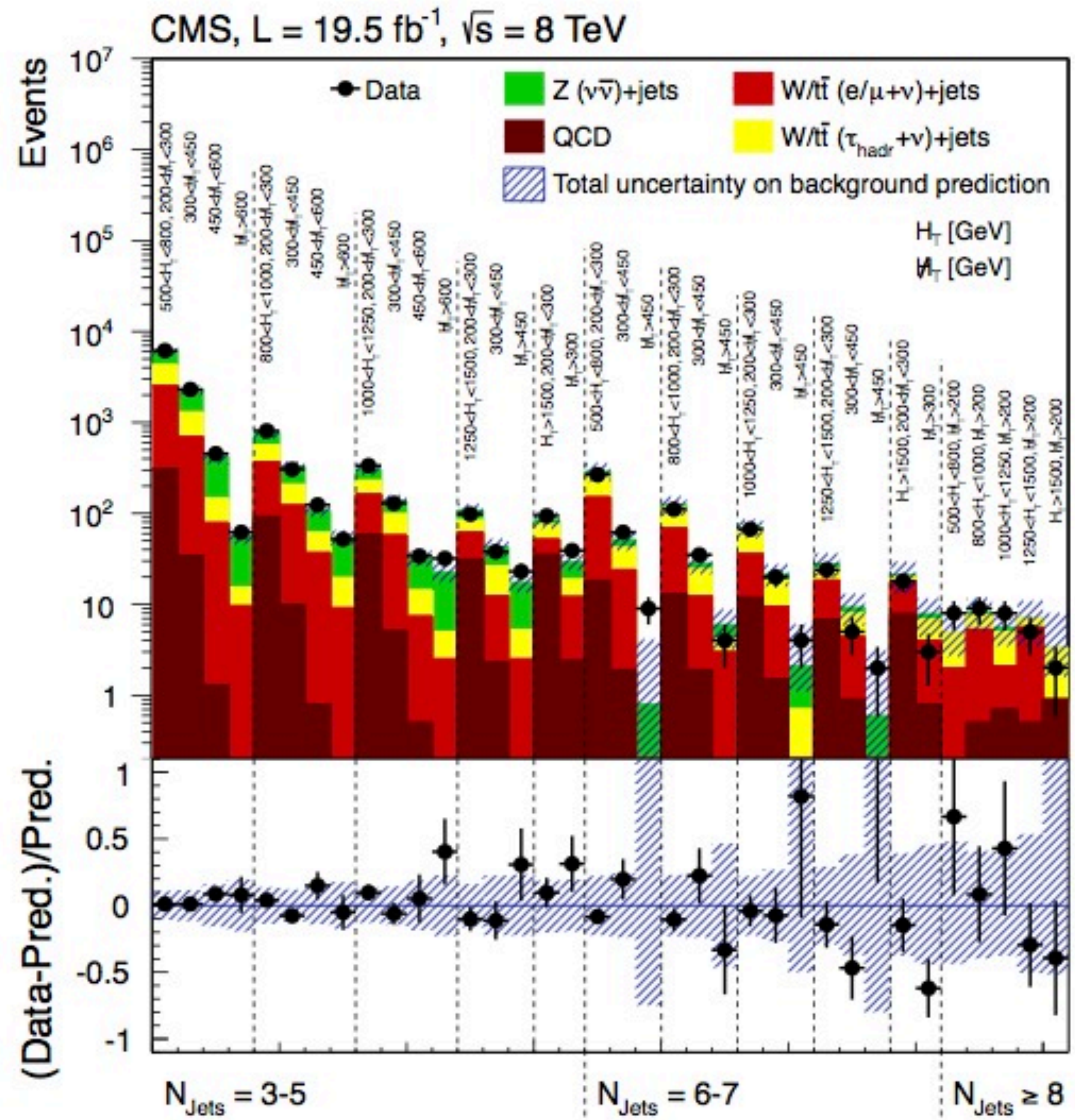
arXiv:1402.4770 / SUS13012

Inclusive analysis of **36 search regions**, binned in N_{jets}, H_T, MH_T

Upper limits using the framework of Simplified Models are set



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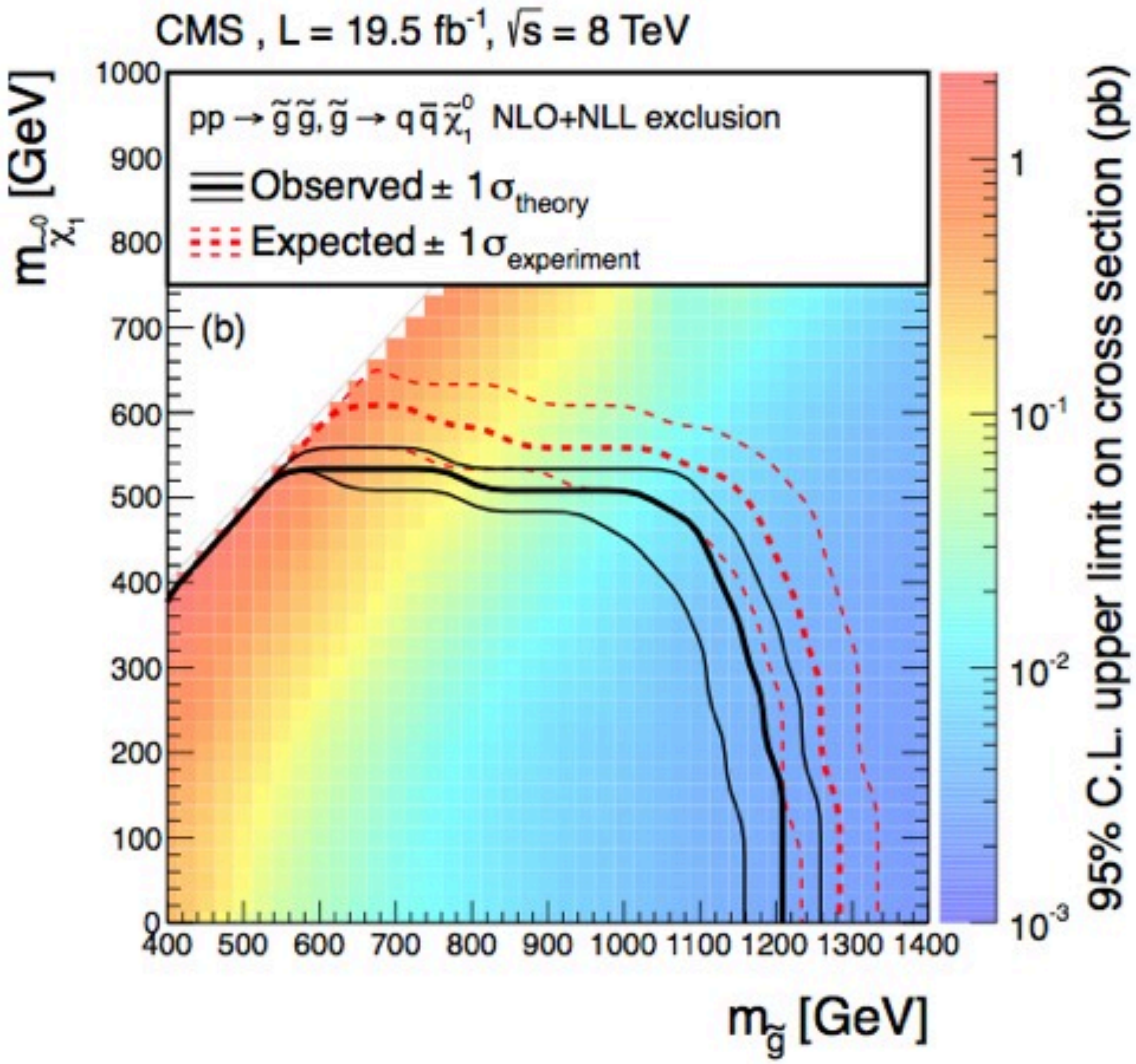

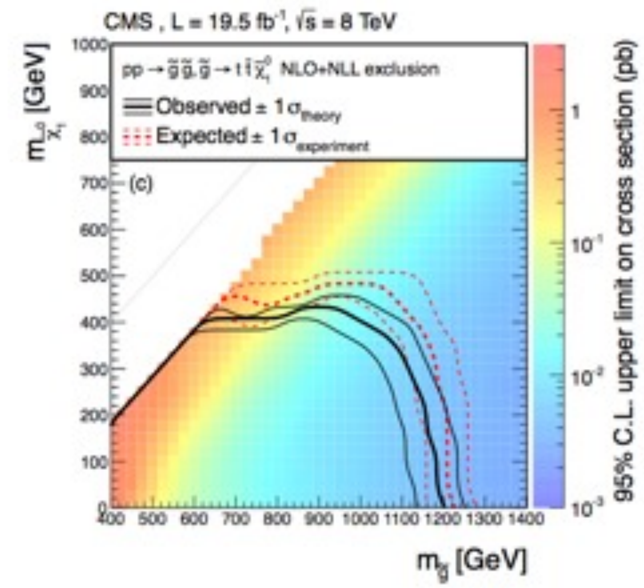

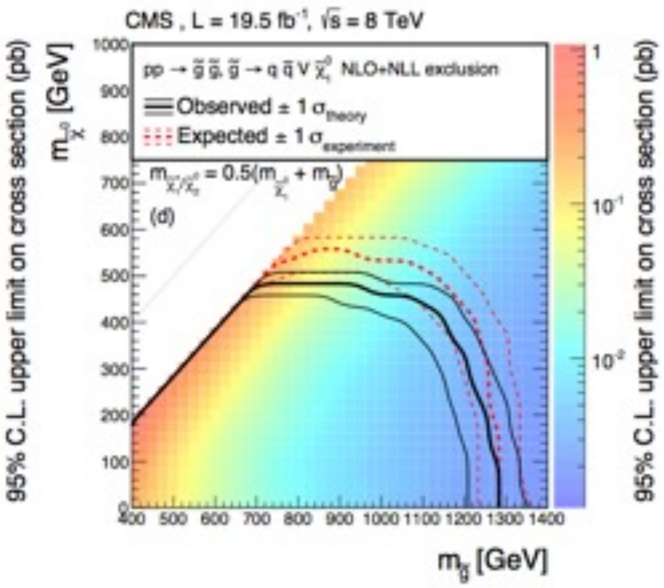

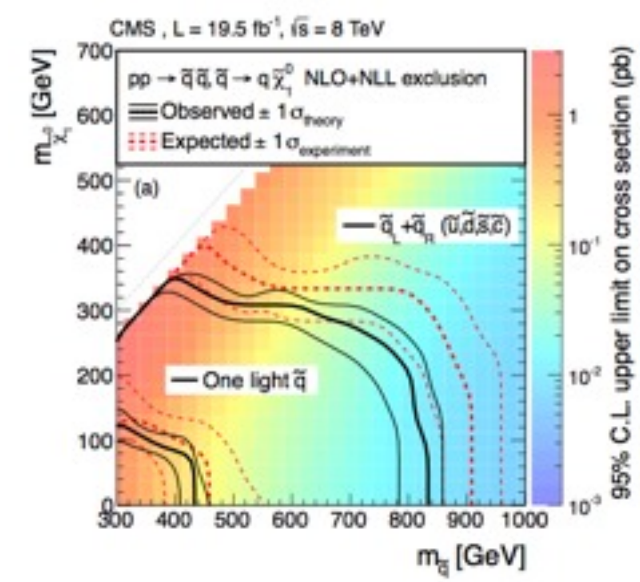

Squark (gluino) masses below 0.8 (1.2) TeV are not favored in the studied simplified models

0 Leptons Inclusive Search

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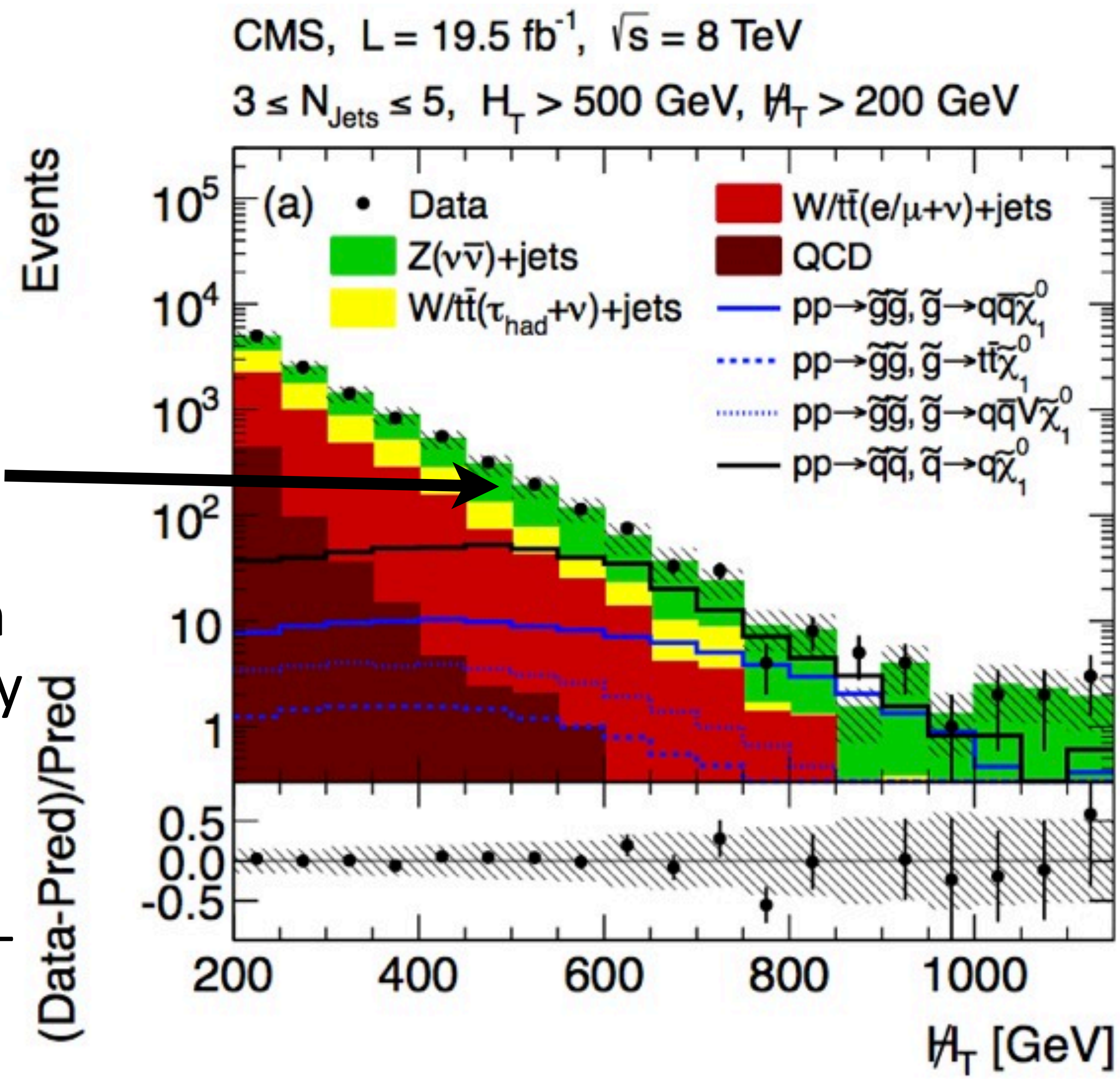
arXiv:1402.4770 / SUS13012

Most of the analysis novelty goes in the background estimation

Think about it: How Zvv + jets can be estimated for $N_{jets} \geq 5$ when the best NLO estimation is at parton level and goes only up to $N_{jets} = 4$?

We need to invent smart data-driven methods



Estimating Z(νν) + jets

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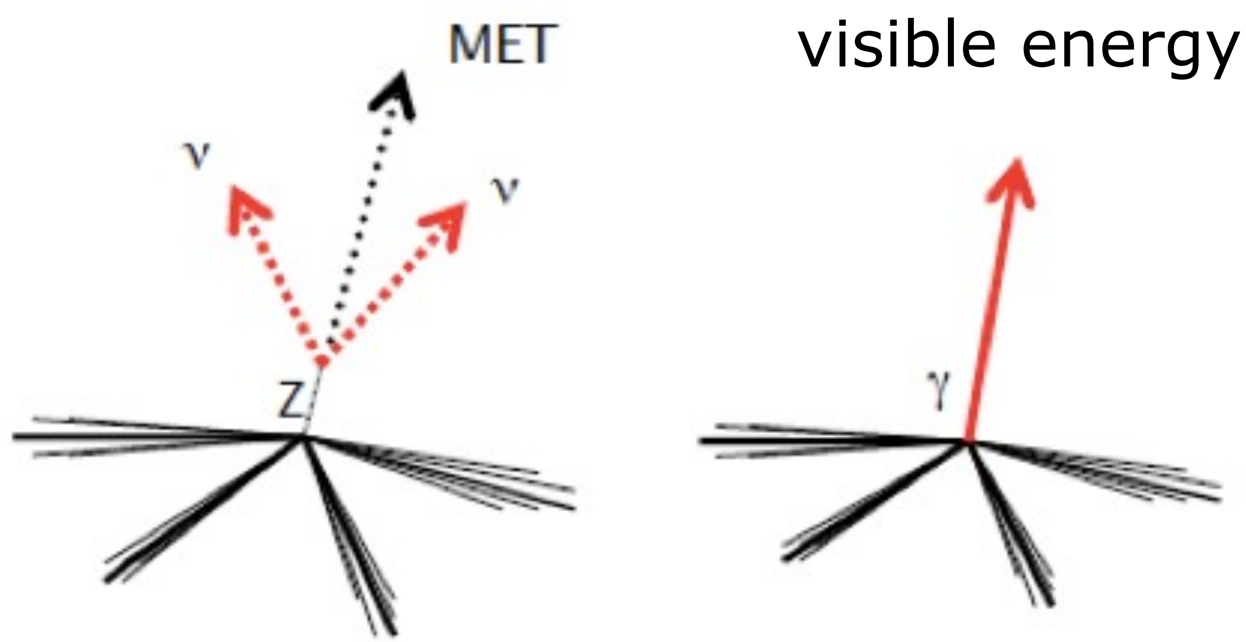
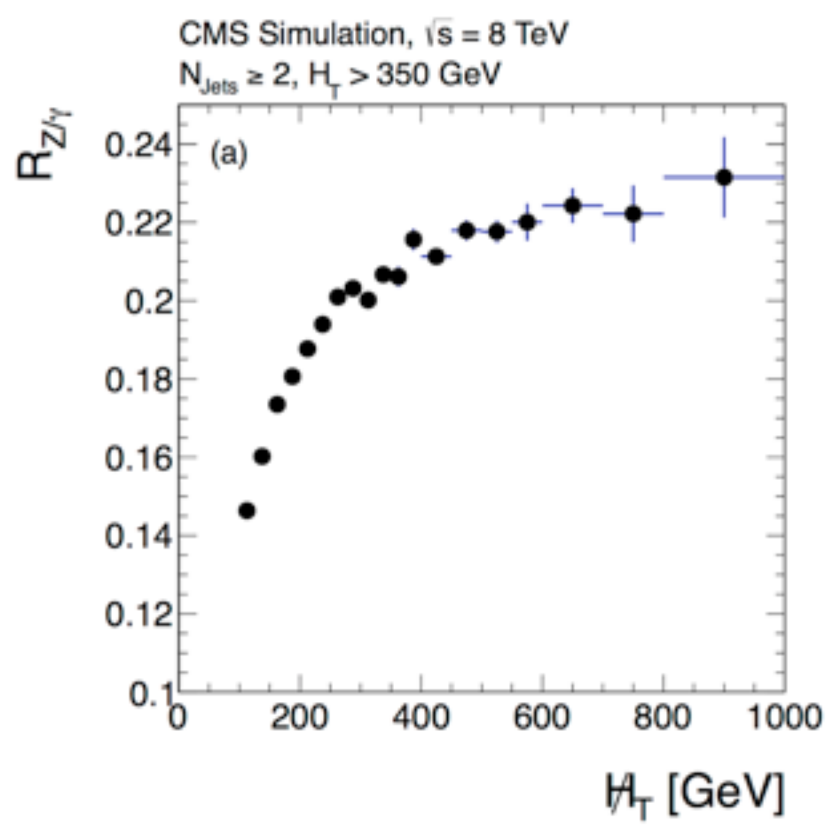


Z+jets vs γ + jets

- Different couplings & mass but similar QCD radiation (jets)
- Production cross section ratio R(Z+jets/γ+jets) known within 20%
- Method: Use the R(Z+jets/γ+jets) from theory and the photon's p_T spectrum to predict the MET of Z(νν)+jets



That's just one example among the many data-driven methods that have been developed for the major SM backgrounds

Searching for SUSY using M_{T2}

References

SUS-13-019 (19 fb-1 @ 8 TeV)

JHEP 1210 (2012) 018 (4.7 fb-1 @ 7 TeV)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

M_{T2} = A Mass Variable

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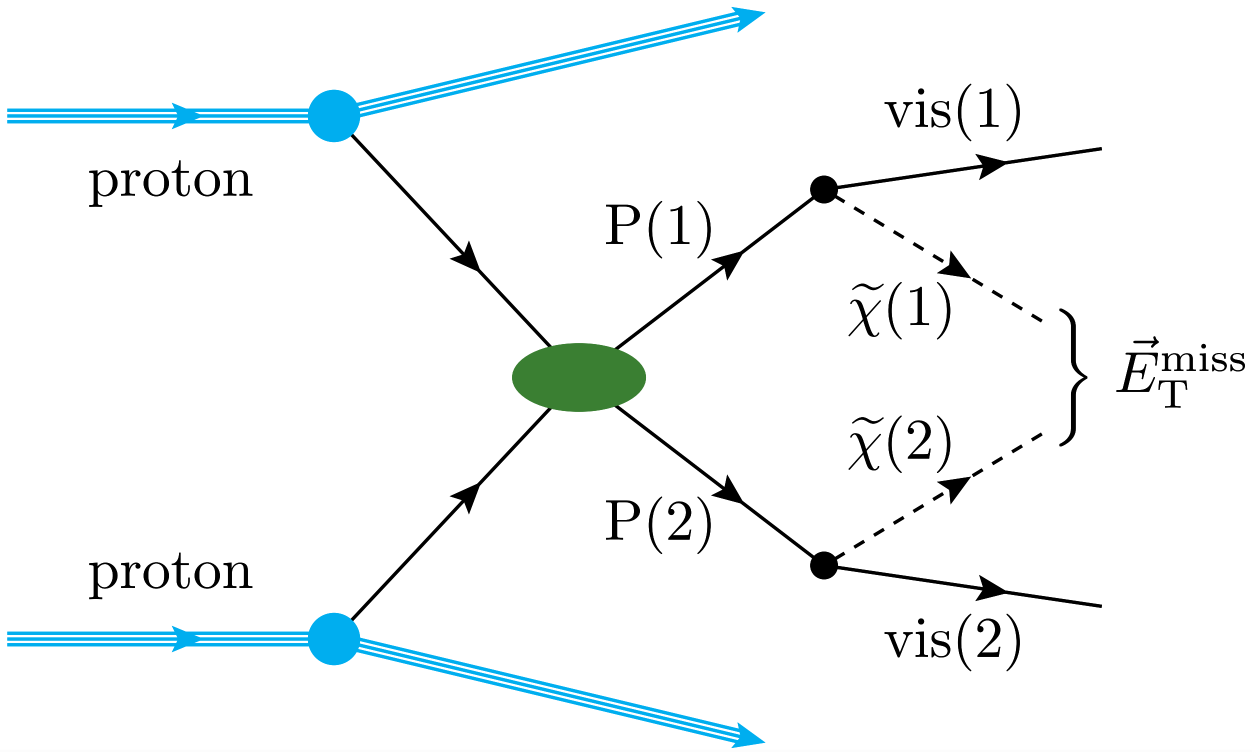
M_{T2} **is a generalization of the transverse mass M_T** for the case of 2 decay chains with 2 unobserved particles

$$M_{T2}(m_c) = \min_{\vec{p}_T^{c(1)}+\vec{p}_T^{c(2)}=\vec{p}_T^{\text{miss}}} \left[\max\left(M_T^{(1)}, M_T^{(2)}\right)\right]$$

- If the visible systems (grouped in pseudojets) are correctly chosen and LSP mass m_c is known, MT2 has an endpoint at parent mass



$$(M_T)^2 = M_{vis}^2 + M_{LSP}^2 + 2\left(E_T^{vis}E_T^{LSP} - \vec{p}_T^{vis}\cdot\vec{p}_T^{LSP}\right)$$

M_{T2} vs MET

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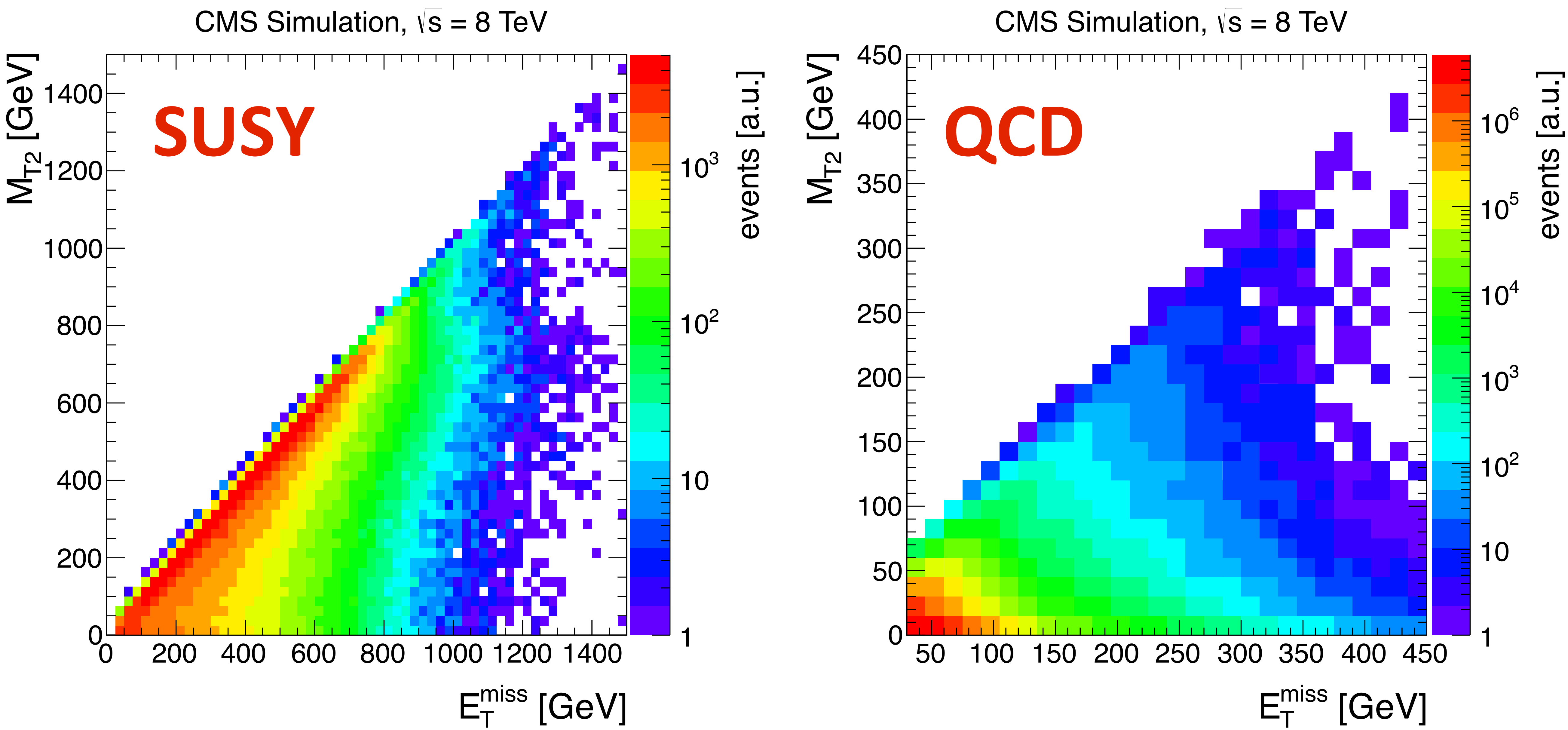

When m_{LSP} is set to 0, QCD with high MET is mapped to low M_{T2} values, while the SUSY signal is retained in the M_{T2} (MET) tails

M_{T2} Event Selection

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Phase space selected:

NLep = 0,

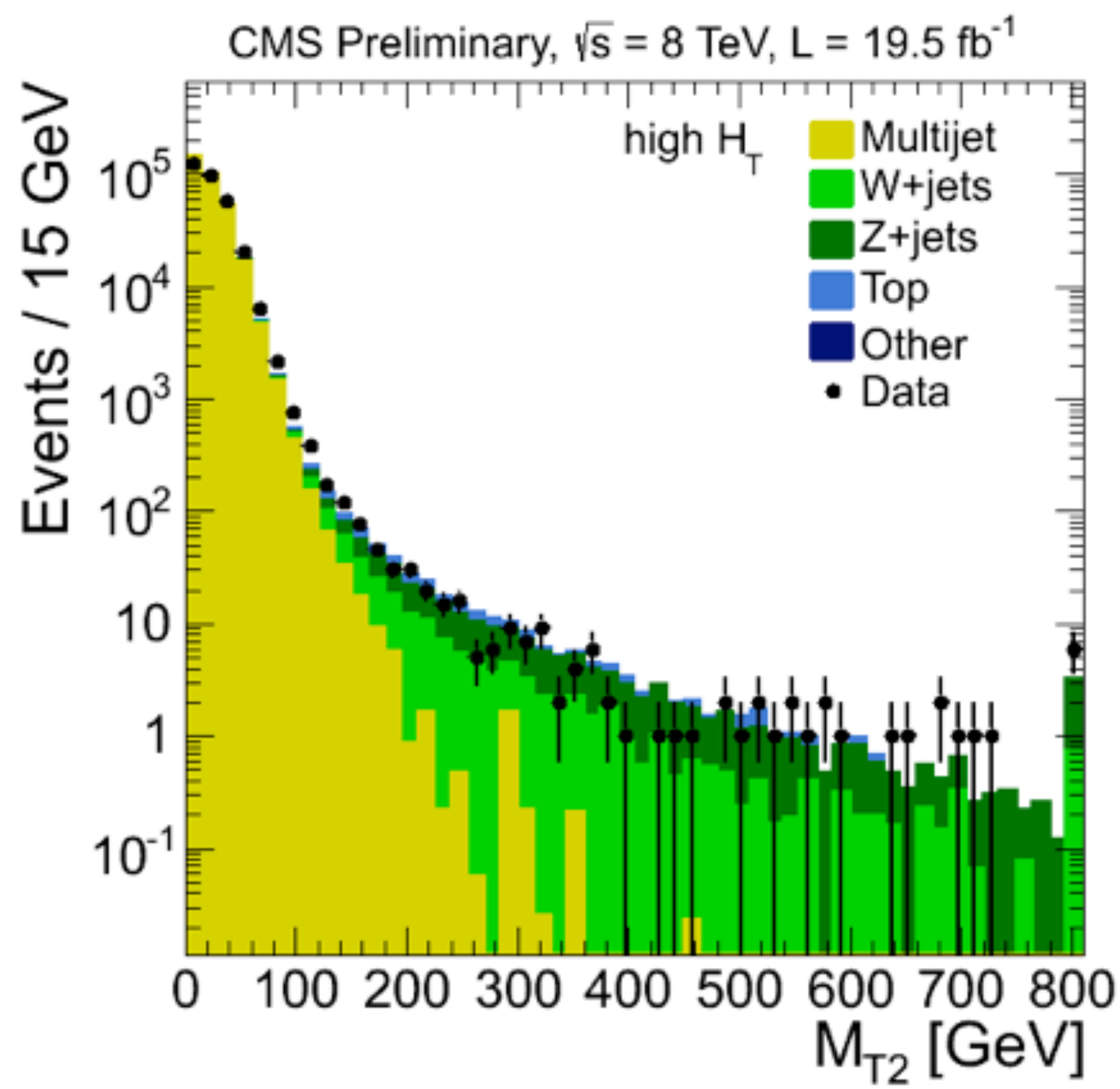
$H_T > 750$ || ($H_T > 450$ && MET > 200)

$N_{jets} \geq 2$ with pT>100 GeV and |η| <2.4

$\Delta\phi(Ji, MHT) > 0.3$ for i = 1,2,3 and 4

Events are further binned in terms of MET, H_T, N_{bjets} N_{jets}

Data-driven background estimation of all major processes



Multi Bin Analysis

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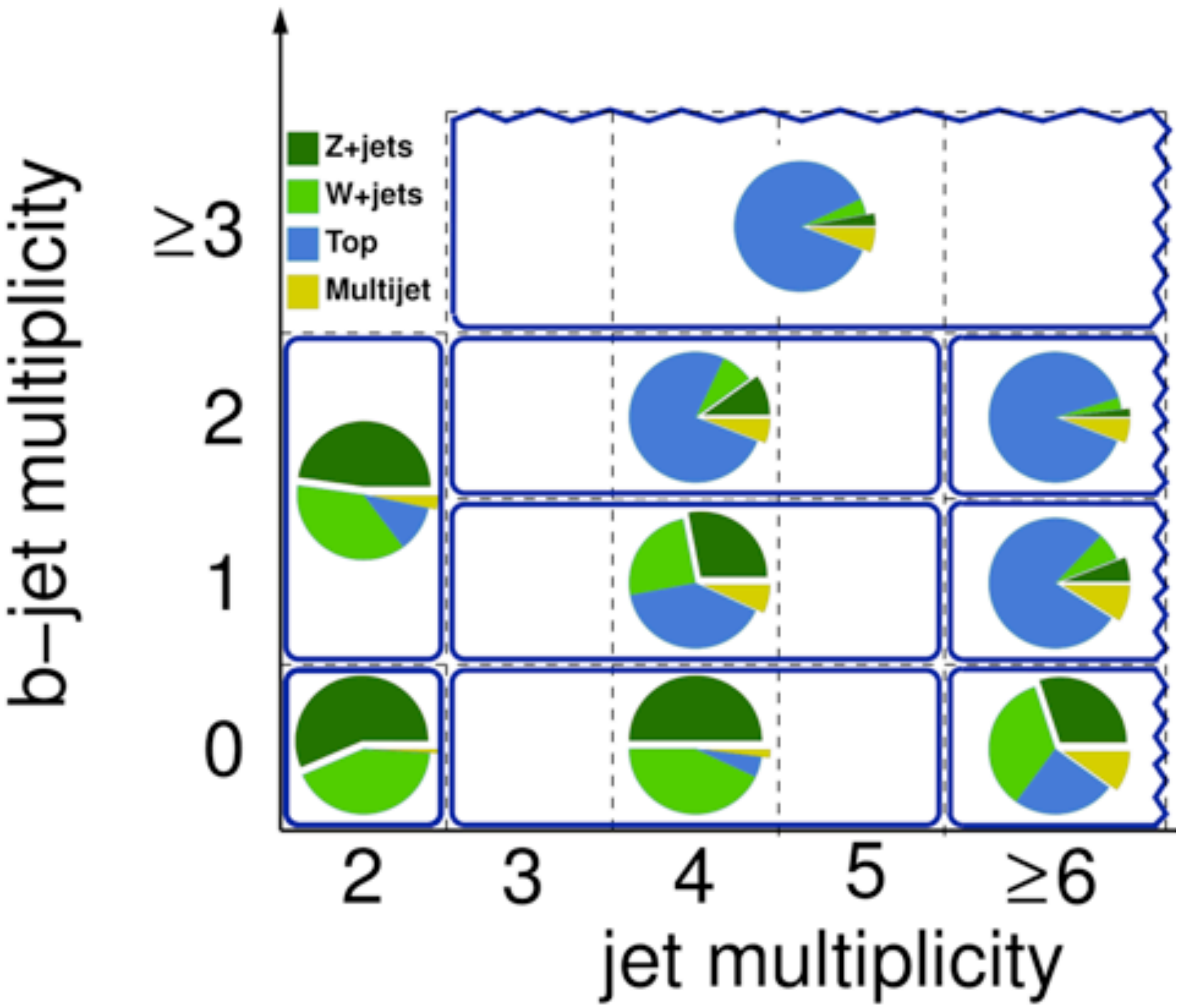

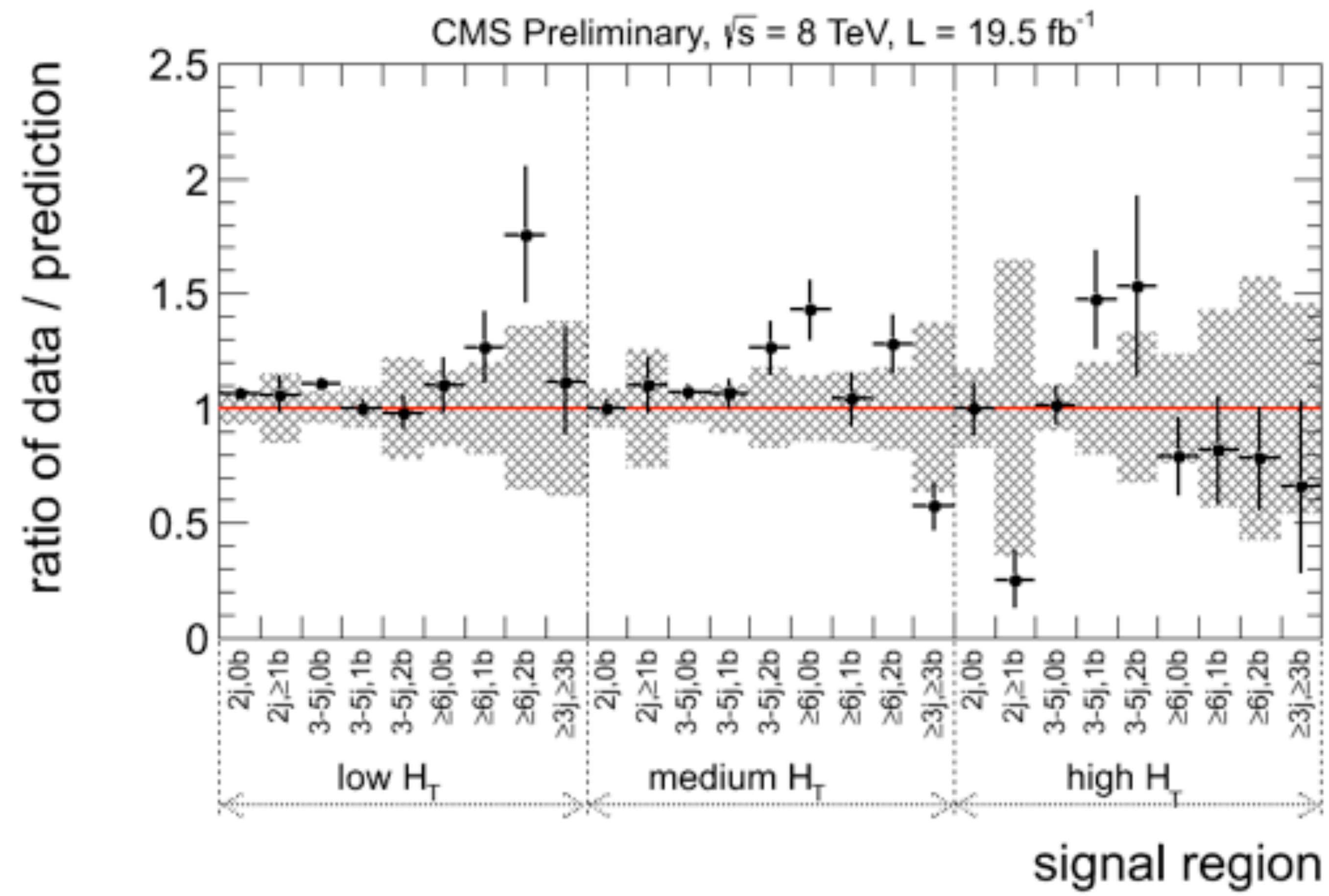

Inclusive analysis of **27 search regions**, binned in N_{jets}, N_{bjets}, H_T, M_{T2}

MT2 Results

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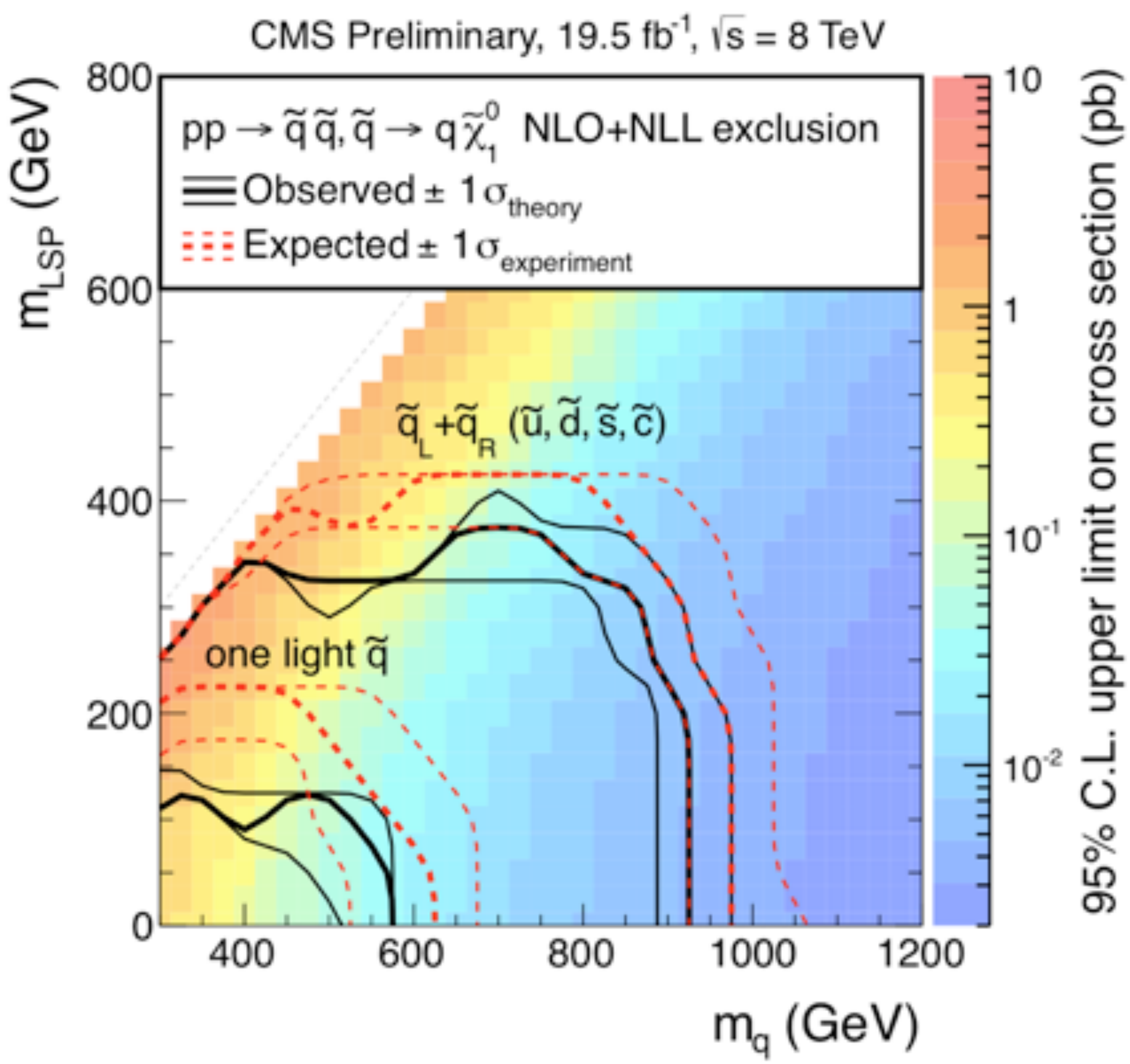

simplified model	limit on parent mass at $M_{LSP} = 0$	best limit on LSP mass	lower limit on mass splitting parent – LSP
direct squark production			
single light squark	$M_{\tilde{q}} < 520$ GeV	$M_{LSP} < 120$ GeV	$\Delta M(\tilde{q}, \tilde{\chi}_1^0) > 200$ GeV
8 degenerate light squarks	$M_{\tilde{q}} < 875$ GeV	$M_{LSP} < 325$ GeV	$\Delta M(\tilde{q}, \tilde{\chi}_1^0) > 50$ GeV
direct sbottom production	$M_{\tilde{b}} < 640$ GeV	$M_{LSP} < 275$ GeV	$\Delta M(\tilde{b}, \tilde{\chi}_1^0) > 10$ GeV
direct stop production			
$M_{stop} > M_{top} + M_{LSP}$	$300 < M_{\tilde{t}} < 450$ GeV	$M_{LSP} < 60$ GeV	$\Delta M(\tilde{t}, \tilde{\chi}_1^0) > 230$ GeV
$M_{stop} < M_{top} + M_{LSP}$	$M_{\tilde{t}} < 175$ GeV	$M_{LSP} < 60$ GeV	$\Delta M(\tilde{t}, \tilde{\chi}_1^0) > 90$ GeV
direct gluino production			
$\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$	$M_{\tilde{g}} < 1225$ GeV	$M_{LSP} < 510$ GeV	$\Delta M(\tilde{g}, \tilde{\chi}_1^0) > 25$ GeV
$\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$	$M_{\tilde{g}} < 1300$ GeV	$M_{LSP} < 740$ GeV	$\Delta M(\tilde{g}, \tilde{\chi}_1^0) > 50$ GeV
$\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$	$M_{\tilde{g}} < 1225$ GeV	$M_{LSP} < 450$ GeV	$\Delta M(\tilde{g}, \tilde{\chi}_1^0) > 225$ GeV
direct gluino production $\tilde{g}_1 \to q\bar{q}\tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \to h^0\tilde{\chi}_1^0$, $\tilde{g}_2 \to qq'\tilde{\chi}_1^{\pm}$, $\chi_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0$	$M_{\tilde{g}} < 825$ GeV	$M_{LSP} < 410$ GeV	$\Delta M(\tilde{g}, \tilde{\chi}_1^0) > 225$ GeV

Limits are set on simplified models of direct squark/gluino, sbottom/stop pair productions

Searching for SUSY with Razor

References

SUS-13-004 (19 fb-1 @ 8 TeV)

PRL 111, 081802 (2013) (4.7 fb-1 @ 7 TeV)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Razor Variables

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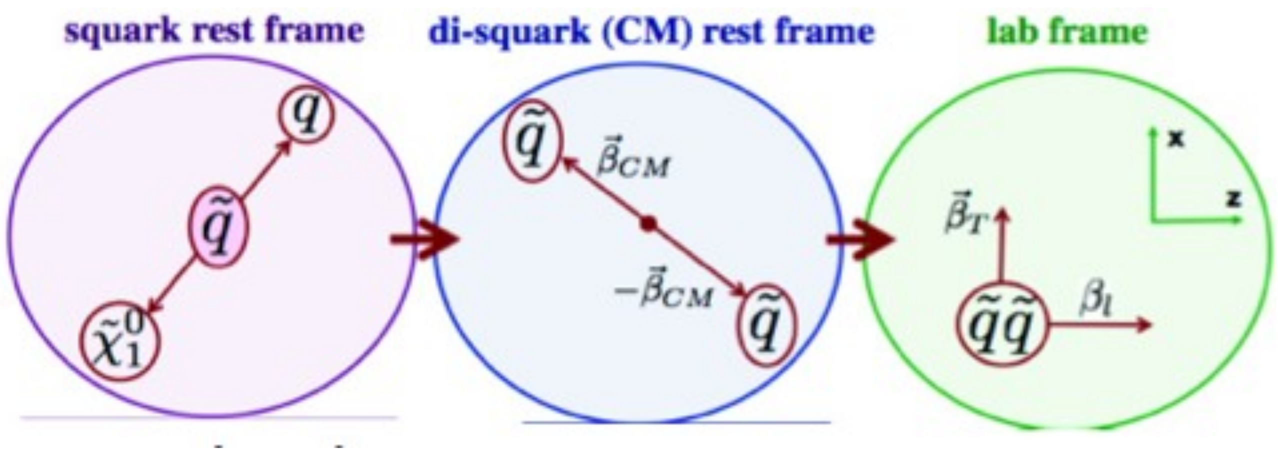
Principle idea behind: 2 equal mass sparticles are produced near threshold $\gamma_{CM} \simeq 1$, scale of the process reflected in momenta of quarks and LSPs

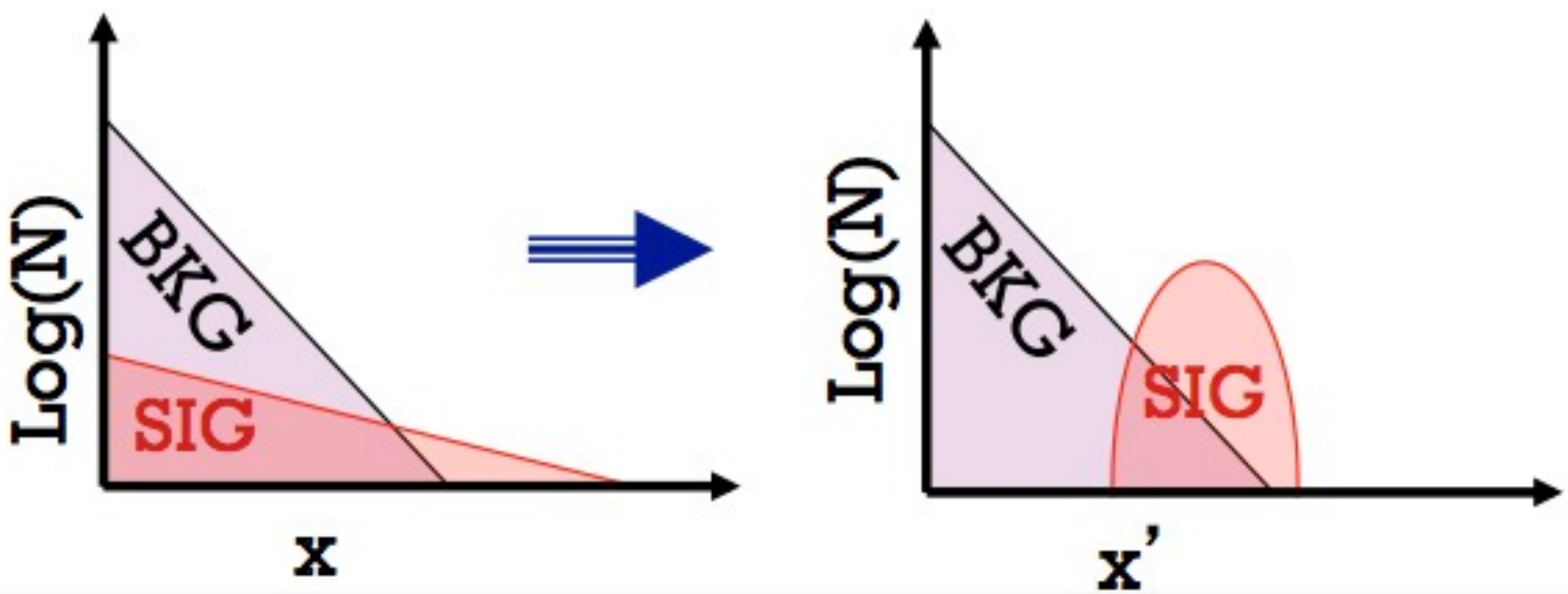


$$M_R \equiv [(|\vec{p}^{\,j_1}| + |\vec{p}^{\,j_2}|)^2 - (p_z^{j_1} + p_z^{j_2})^2]^{1/2}$$

$$M_T^R \equiv \left[\frac{1}{2}\left(E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})\right)\right]^{1/2}$$

$$R = \frac{M_T^R}{M_R}$$

Razor variables, M_R and R turn a 'tail search' into a 'bump hunt'.



Razor 2D search

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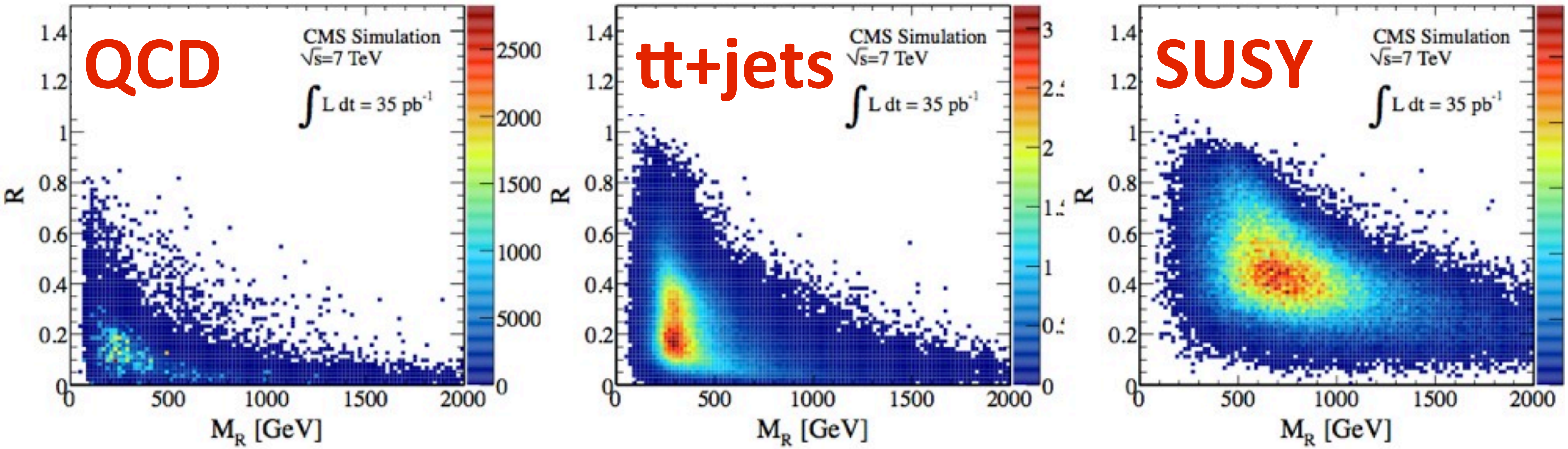

Search is binned in terms of **N_{Lep}**, N_{Jets}, N_{bjets}, M_R and R^2

treats together hadronic and leptonic final states

Razor Results

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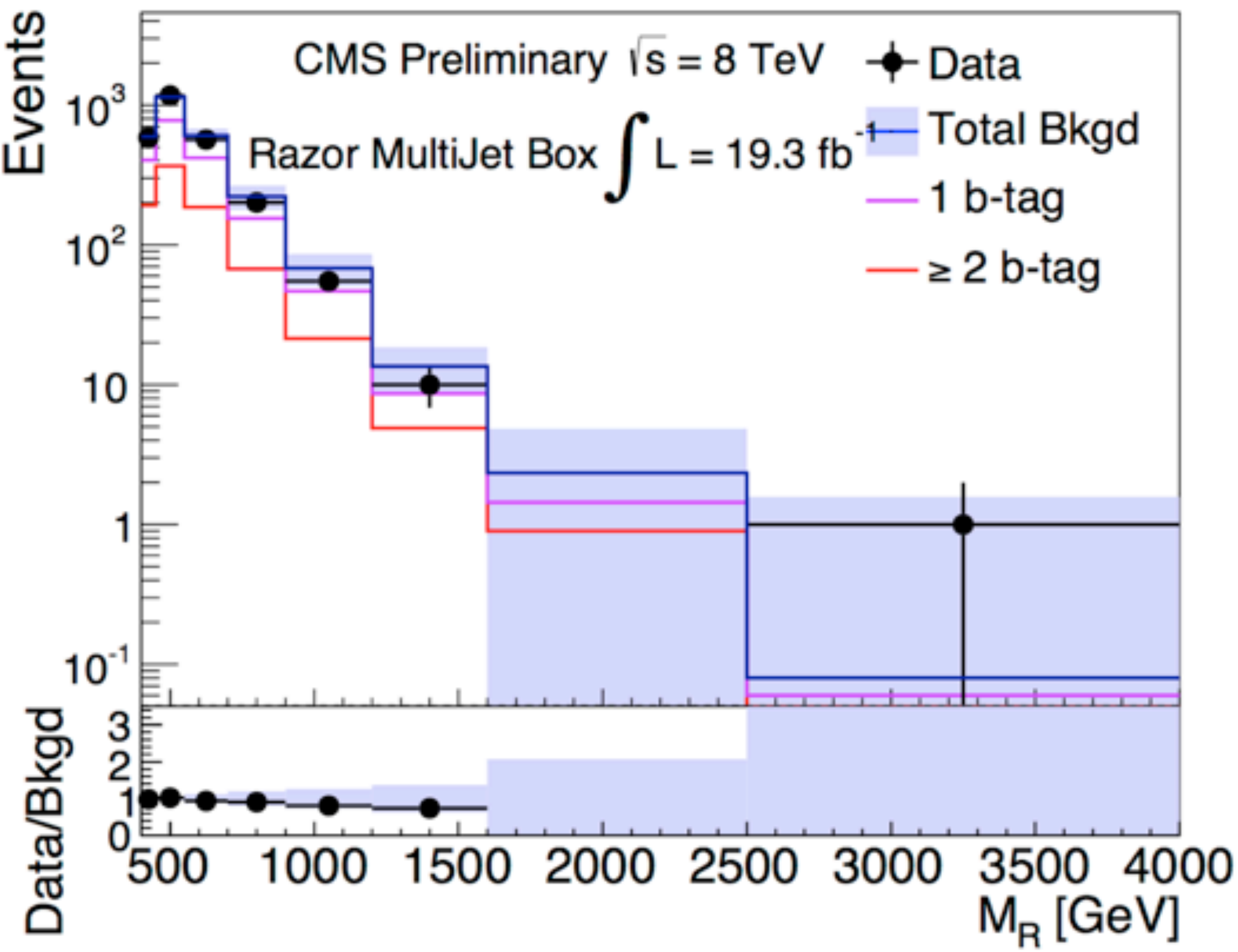

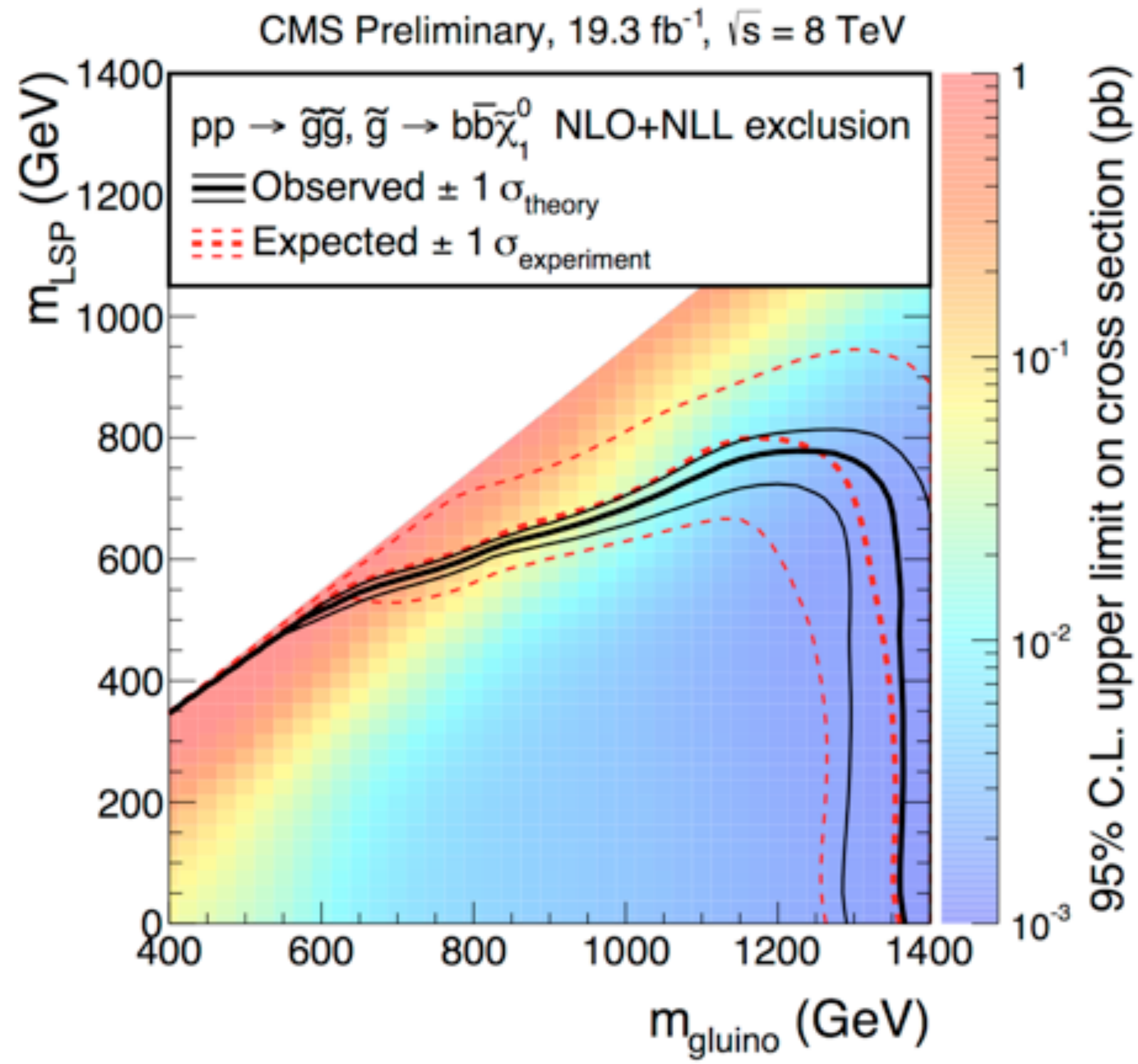

Excluding gluino (squarks) masses up to 1.3 (0.7) TeV pair produced with simplified models

A brave new attempt -- interpret CMS 7 + 8 TeV results in terms of pMSSM

References

SUS-13-020 (19 fb-1 @ 8 TeV) && (4.7 fb-1 @ 7 TeV)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Phenomenological MSSM

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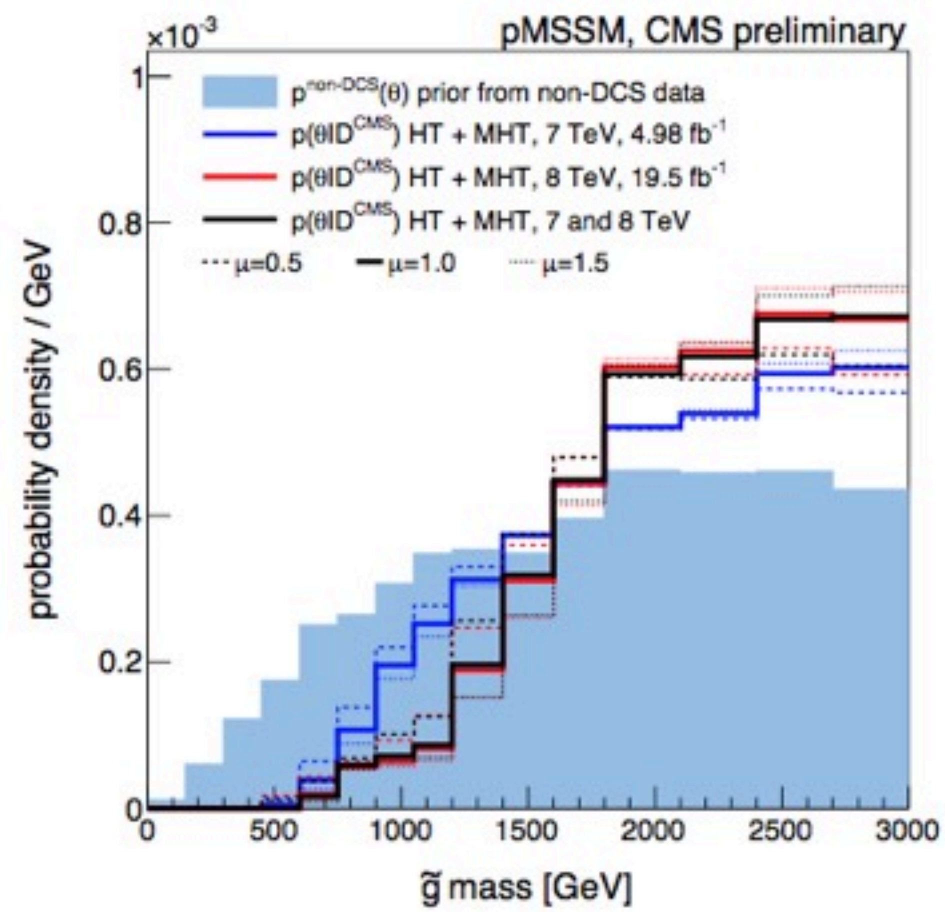
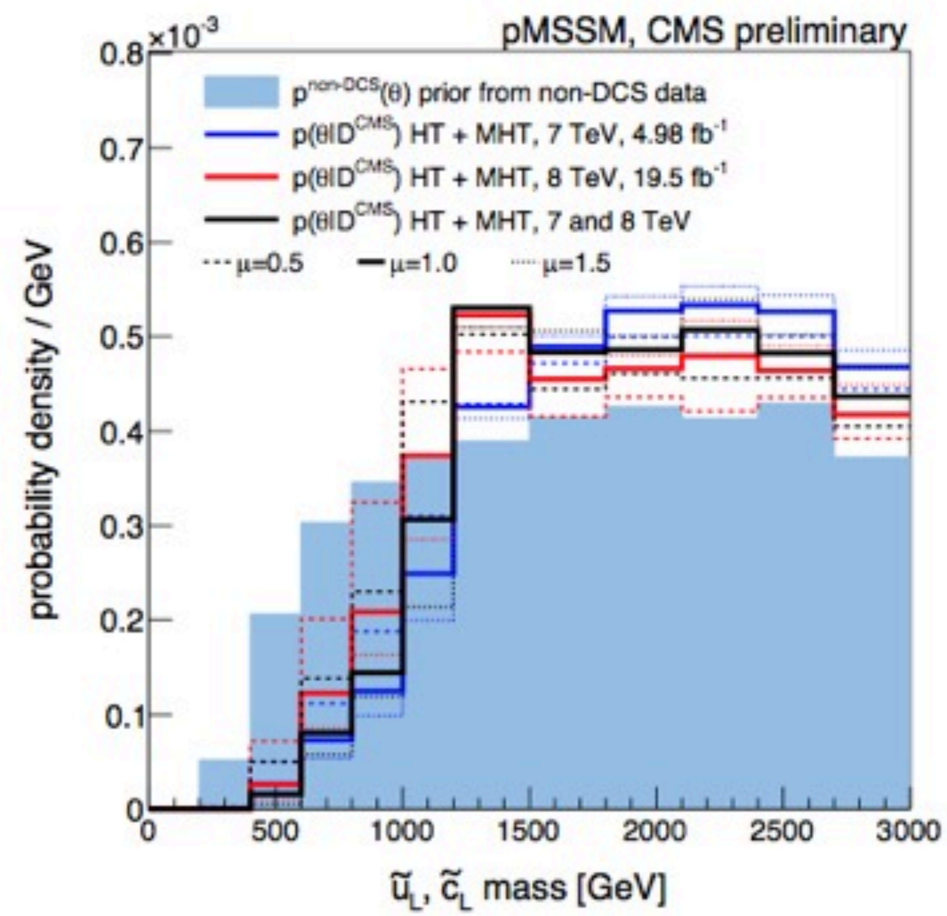
MSSM has 120 parameters, pMSSM is 19-dimension realization of MSSM with no assumption on SUSY breaking mech

- Combines b-physics, Higgs, top, EW observables (CMS, ATLAS, LHCb, Tevatron, Babar, Belle) and various CMS inclusive SUSY searches
- 20M points sample the pMSSM space, Bayesian analysis to obtain posterior probabilities densities for sparticles masses, is performed





Prospects for 2015

Expect a Boost in Sensitivity

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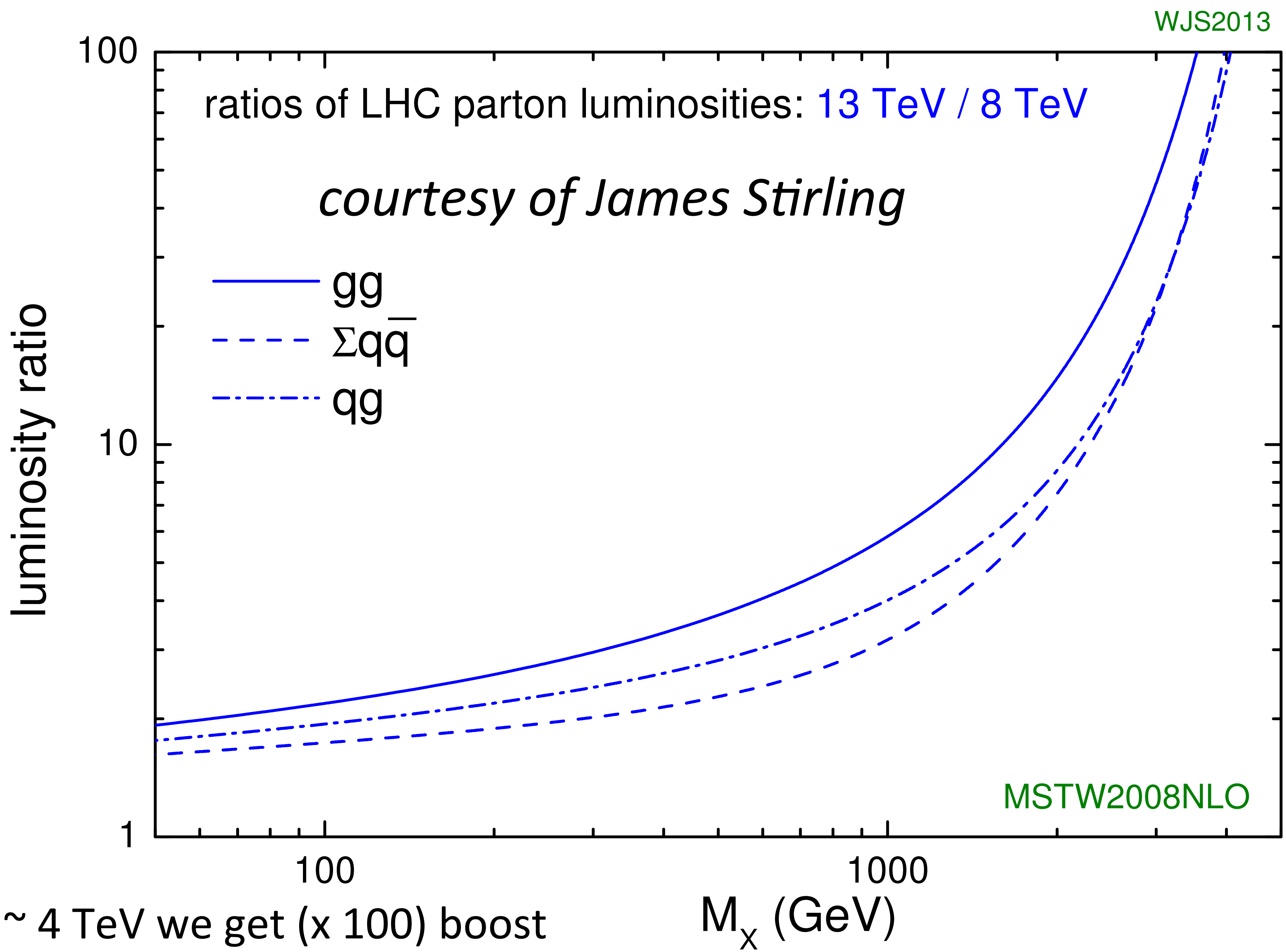

For M_x ~ 4 TeV we get (x 100) boost in sensitivity

Summary

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Searching for SUSY is not easy

- no good driving model that can be used to optimize our analyses is available on the market, *the art of searching for everything/anything*

On our way to search for SUSY we developed:

- novel methods to estimate the SM background
- novel methods to interpret the results

Absence of an evidence in Run I should not discourage the effort, still an interesting period is ahead

Backup Slides

Summary of SMS Results

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- Several more simplified models have been excluded