Phenomenological MSSM interpretation of CMS results

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[1] Vardan Khachatryan et al. Phenomenological MSSM interpretation of CMS searches in pp collisions at sqrt(s) = 7 and 8 TeV. 2016. arXiv:1606.03577

Submitted to JHEP

Road map

- Definition of the pMSSM
- CMS analyses considered
- Posterior density
- Interpretation of CMS 7 and 8 TeV results
- pMSSM points that evaded run 1 analyses

pMSSM

Non-prejudiced submodel of the MSSM that captures most of the phenomenological features of the MSSM

19 Parameters:

Gaugino mass parameters M_1, M_2, and M_3
Higgs sector parameters $\tan(\beta)$, μ, and m_A
10 sfermion mass parameters m_i
Trilinear couplings A_t, A_b, and A_τ

MCMC scan (20 million points) Simulated events for 7200 points

Probability density

Bayes' theorem

$$\boxed{p(\theta|Data^{CMS})} \propto L(Data^{CMS}|\theta)\Pi(\theta)$$

Probability density

pre-CMS results

$\mathcal{B}(\mathrm{b} \to \mathrm{s}\gamma)$ α_s $\mathrm{B}_s \to \mu\mu$

m_t μ_h

[2][3][4][5][6][7][8][9][10][11][12]

Bayes' theorem

$$p(\theta|Data^{CMS}) \propto L(Data^{CMS}|\theta)\Pi(\theta)$$

Probability density

pre-CMS results

$\mathcal{B}(\mathrm{b} \to \mathrm{s}\gamma)$ α_s $\mathrm{B}_s \to \mu\mu$

m_t μ_h

[2][3][4][5][6][7][8][9][10][11][12]

Bayes' theorem

$$p(\theta|Data^{CMS}) \propto L(Data^{CMS}|\theta)\Pi(\theta)$$

H_T m_T2 n_ℓ n_jets

$E_\mathrm{T}^\mathrm{miss}$ b-jets $\tilde{\mathrm{t}}$ Monojet

CMS searches [13][14][15][16][17][18][19][20][21][22][23]

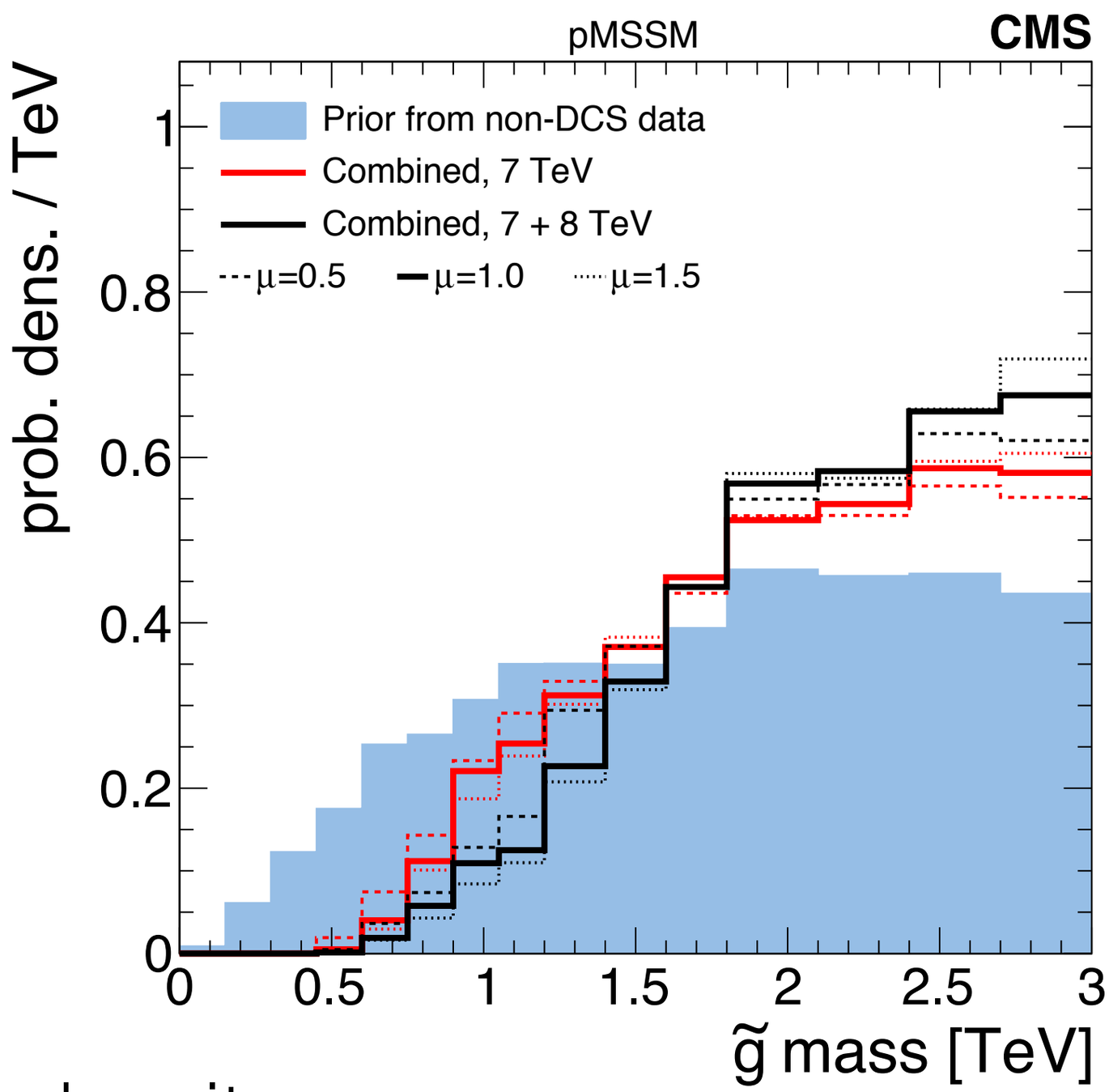
Why this procedure?

Two reasons for Bayesian approach:

1. Result can be interpreted as a probability density for hypotheses of mass patterns

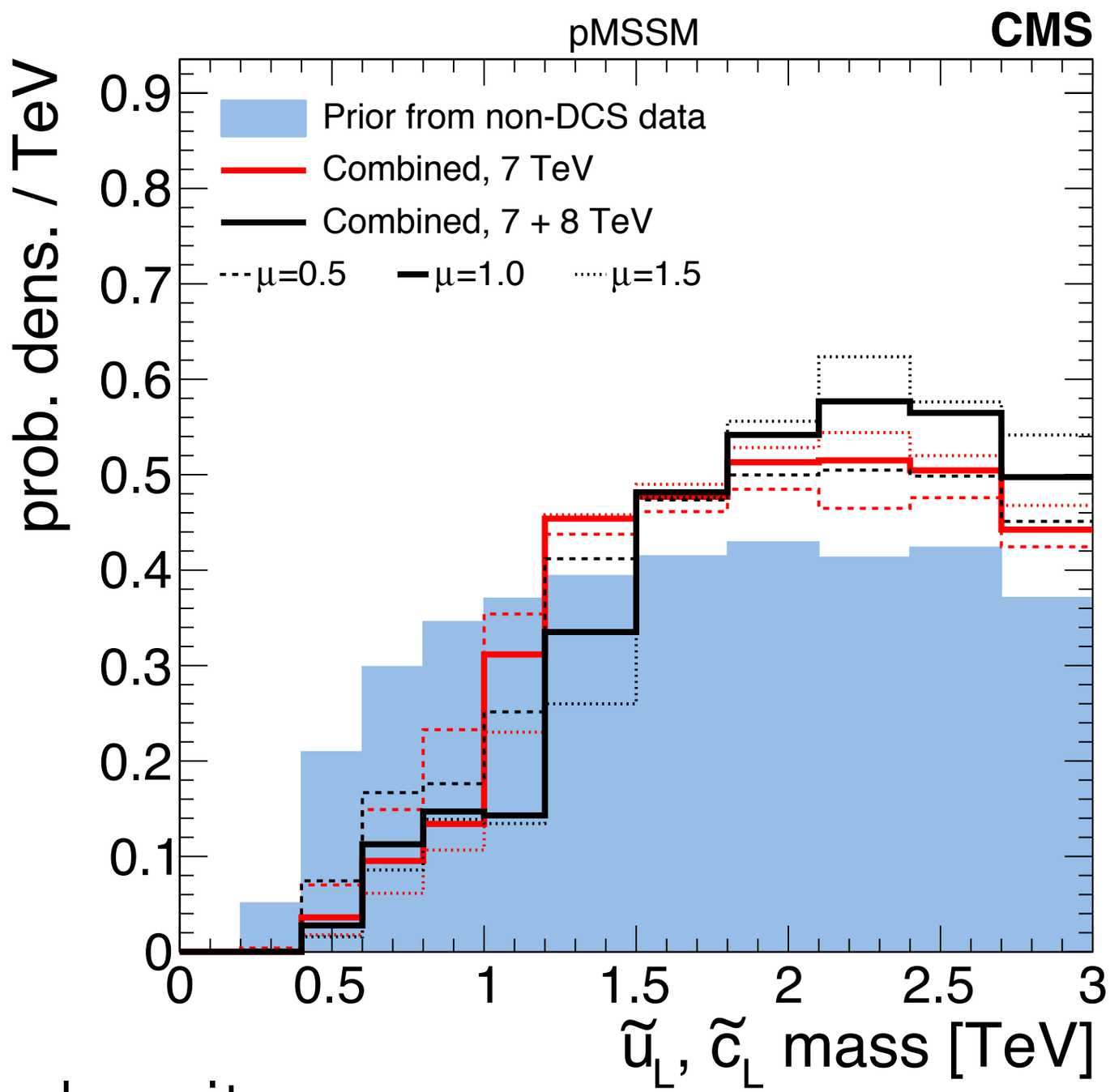
2. We sample interesting regions of the pMSSM subspace with a higher density

Gluino mass



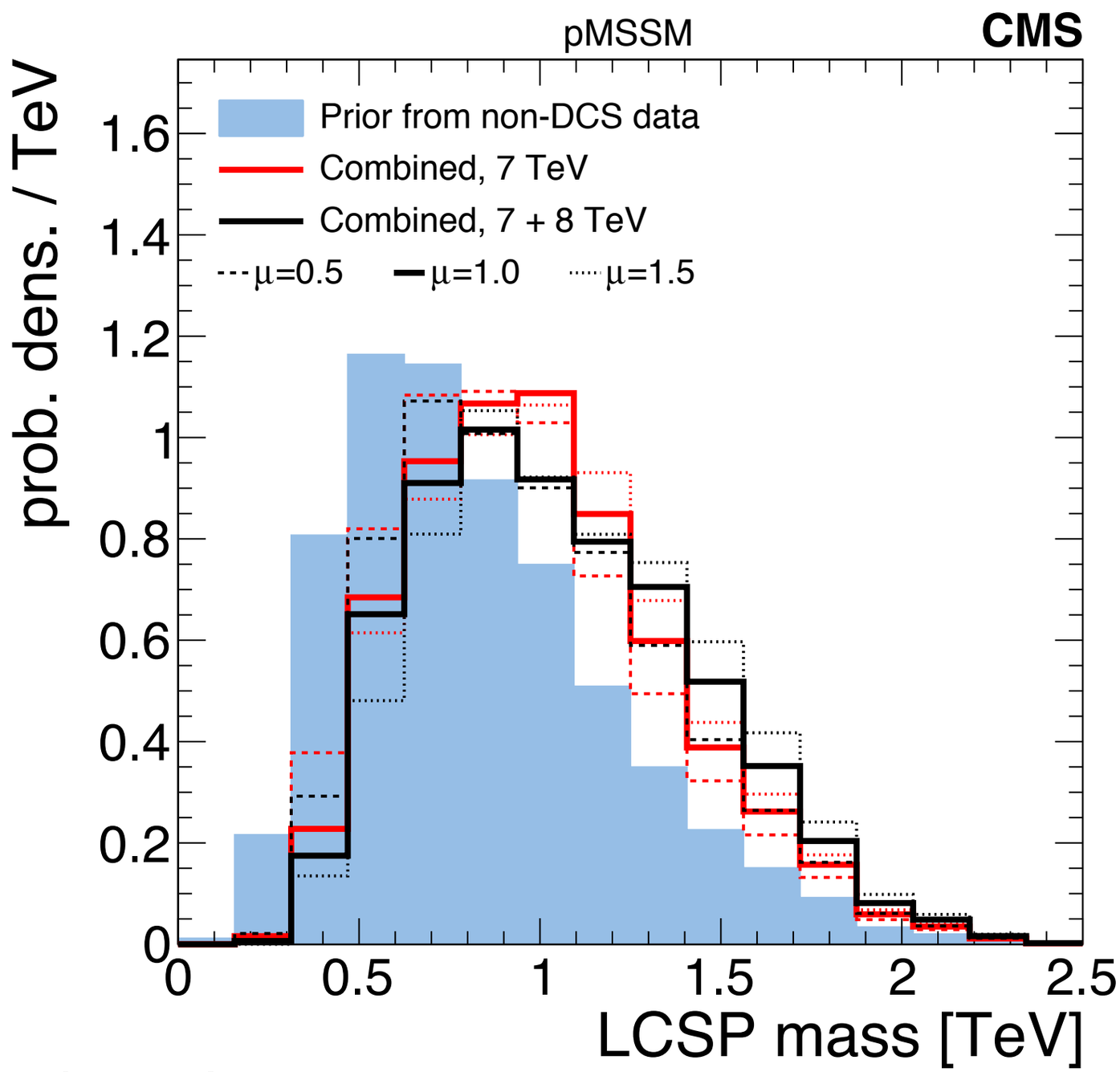
Probability density

Squark Mass



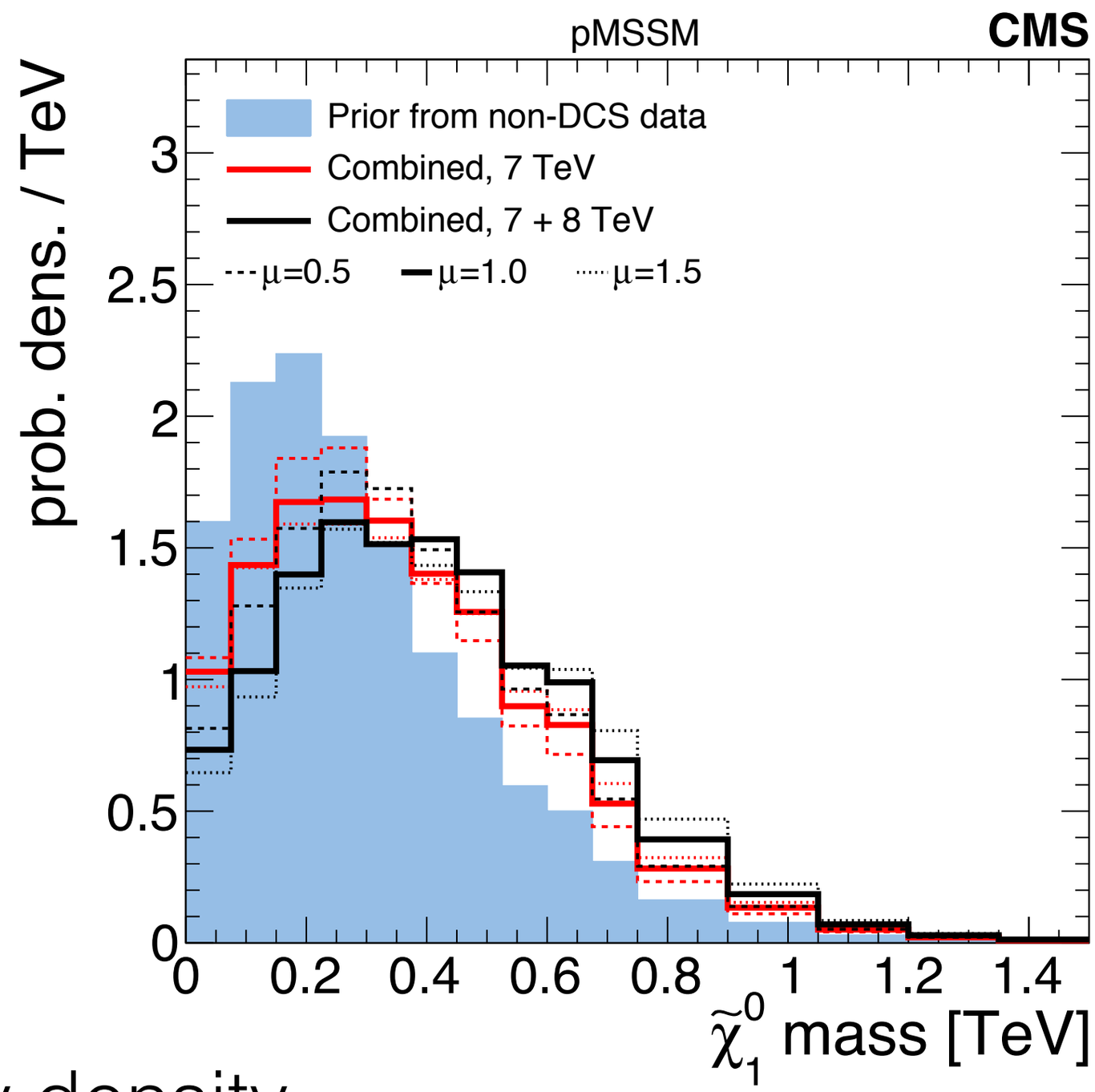
Probability density

Lightest colored particle



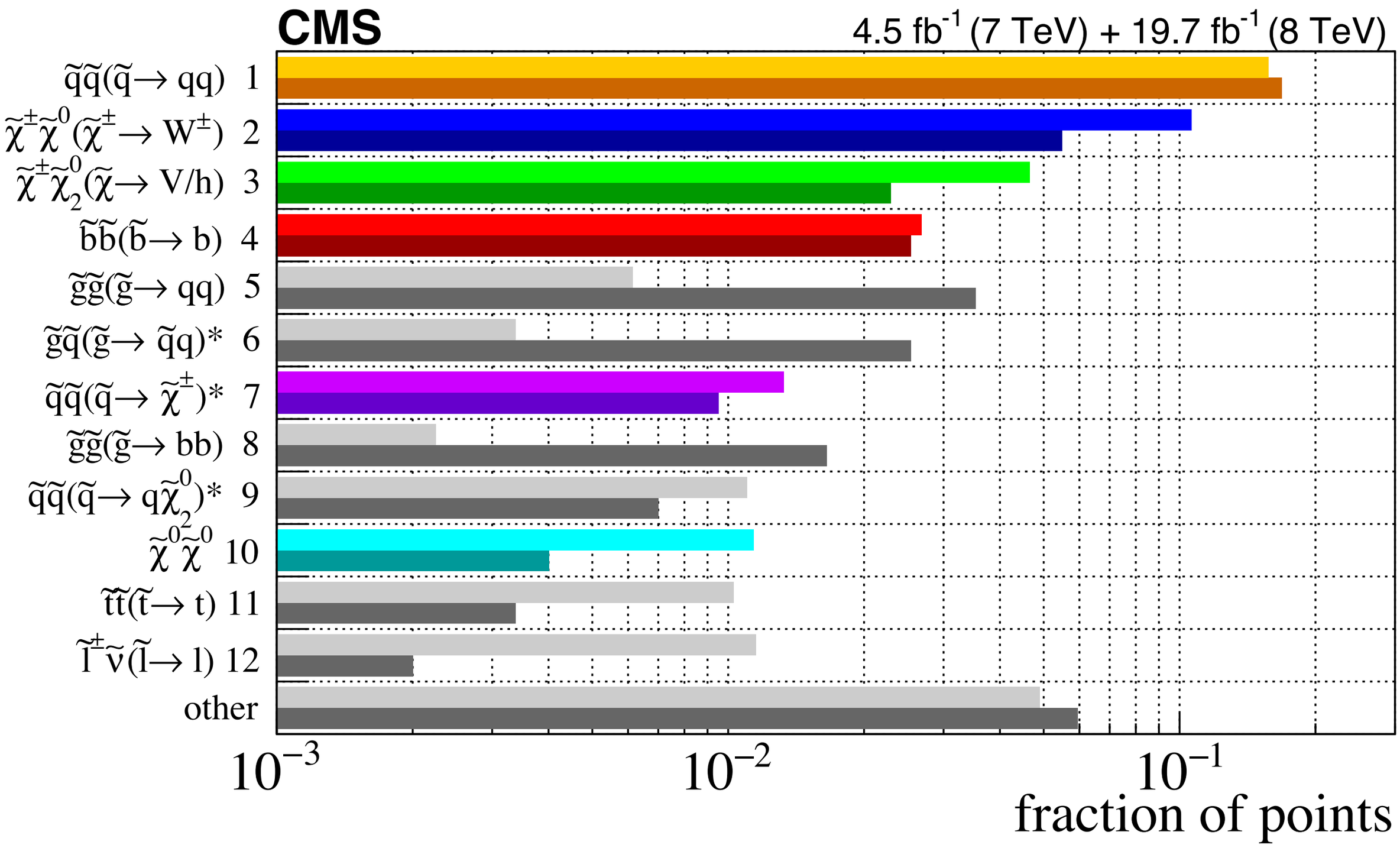
Probability density

LSP mass

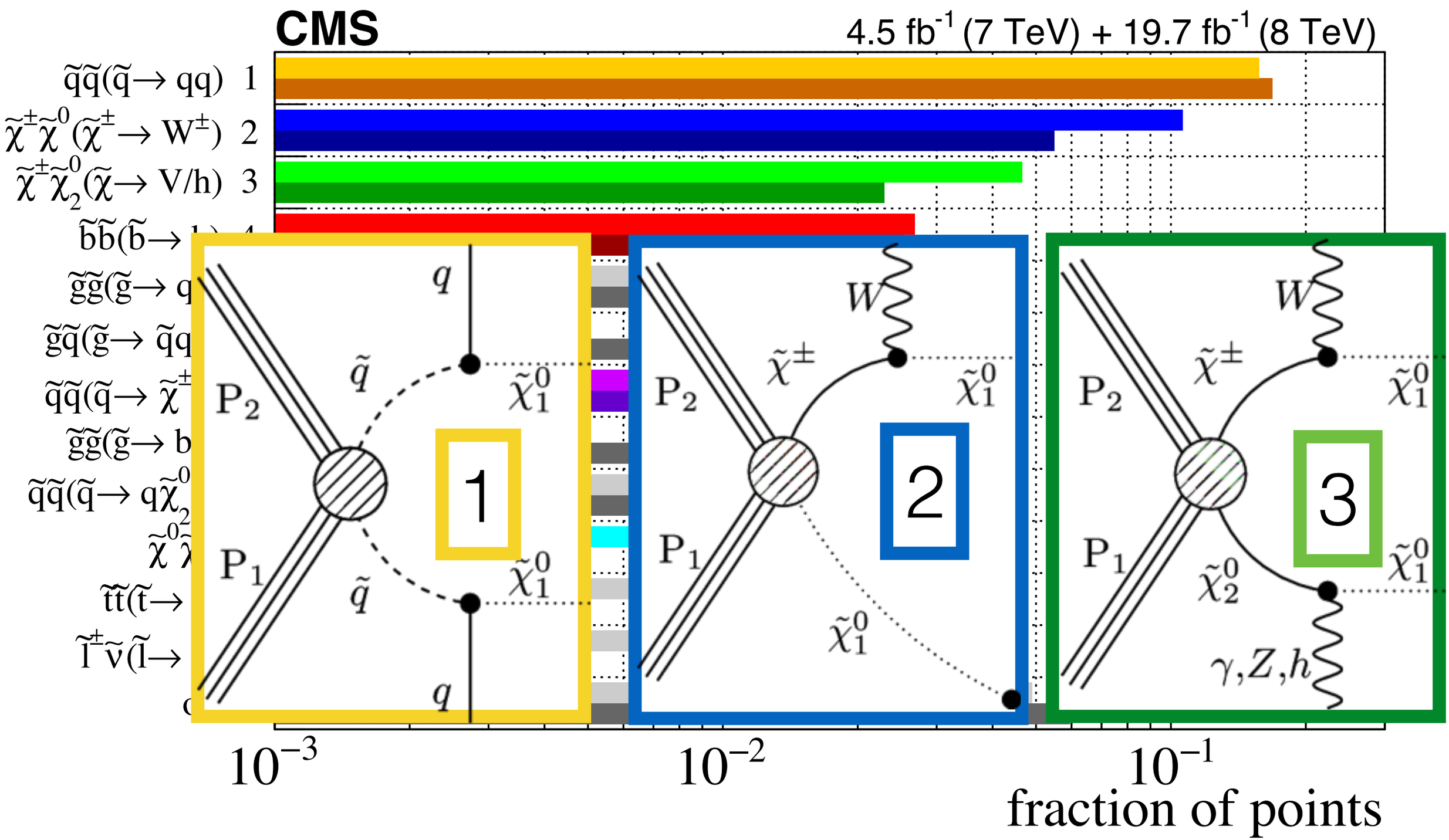


Probability density

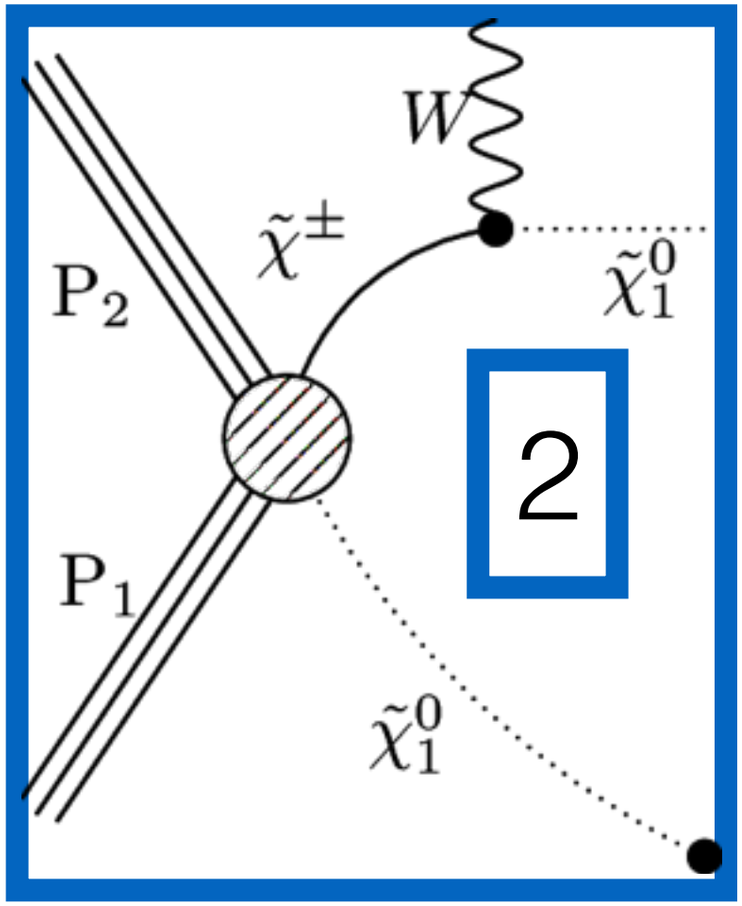
Processes


CMS
4.5 fb^{-1} (7 TeV) + 19.7 fb^{-1} (8 TeV)
$\tilde{q}\tilde{q}(\tilde{q}\to qq)$ 1
$\tilde{\chi}^{\pm}\tilde{\chi}^{0}(\tilde{\chi}^{\pm}\to W^{\pm})$ 2
$\tilde{\chi}^{\pm}\tilde{\chi}_2^{0}(\tilde{\chi}\to V/h)$ 3
$\tilde{b}\tilde{b}(\tilde{b}\to b)$ 4
$\tilde{g}\tilde{g}(\tilde{g}\to qq)$ 5
$\tilde{g}\tilde{q}(\tilde{g}\to \tilde{q}q)^*$ 6
$\tilde{q}\tilde{q}(\tilde{q}\to \tilde{\chi}^{\pm})^*$ 7
$\tilde{g}\tilde{g}(\tilde{g}\to bb)$ 8
$\tilde{q}\tilde{q}(\tilde{q}\to q\tilde{\chi}_2^{0})^*$ 9
$\tilde{\chi}^{0}\tilde{\chi}^{0}$ 10
$\tilde{t}\tilde{t}(\tilde{t}\to t)$ 11
$\tilde{l}^{\pm}\tilde{\nu}(\tilde{l}\to l)$ 12
other
10^{-3}
10^{-2}
10^{-1}
fraction of points

Processes

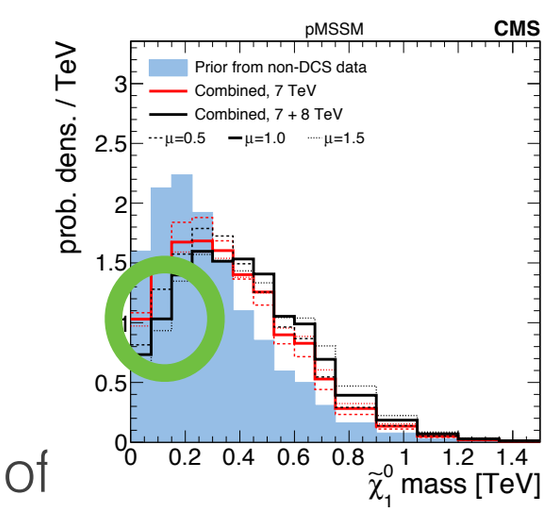

CMS
4.5 fb^{-1} (7 TeV) + 19.7 fb^{-1} (8 TeV)
$\tilde{q}\tilde{q}(\tilde{q}\to qq)$ 1
$\tilde{\chi}^{\pm}\tilde{\chi}^{0}(\tilde{\chi}^{\pm}\to W^{\pm})$ 2
$\tilde{\chi}^{\pm}\tilde{\chi}_2^{0}(\tilde{\chi}\to V/h)$ 3
$\tilde{b}\tilde{b}(\tilde{b}\to$
$\tilde{g}\tilde{g}(\tilde{g}\to q$
$\tilde{g}\tilde{q}(\tilde{g}\to \tilde{q}q$
$\tilde{q}\tilde{q}(\tilde{q}\to \tilde{\chi}^{\pm}$
$\tilde{g}\tilde{g}(\tilde{g}\to b$
$\tilde{q}\tilde{q}(\tilde{q}\to q\tilde{\chi}_2^{0}$
$\tilde{\chi}^{0}\tilde{\chi}$
$\tilde{t}\tilde{t}(\tilde{t}\to$
$\tilde{l}^{\pm}\tilde{\nu}(\tilde{l}\to$
P_1
P_2
q
$\tilde{q}$
$\tilde{\chi}_1^0$
$\tilde{\chi}^{\pm}$
W
$\tilde{\chi}_2^0$
γ, Z, h
1
2
3
10^{-3}
10^{-2}
10^{-1}
fraction of points

Process with the highest significance

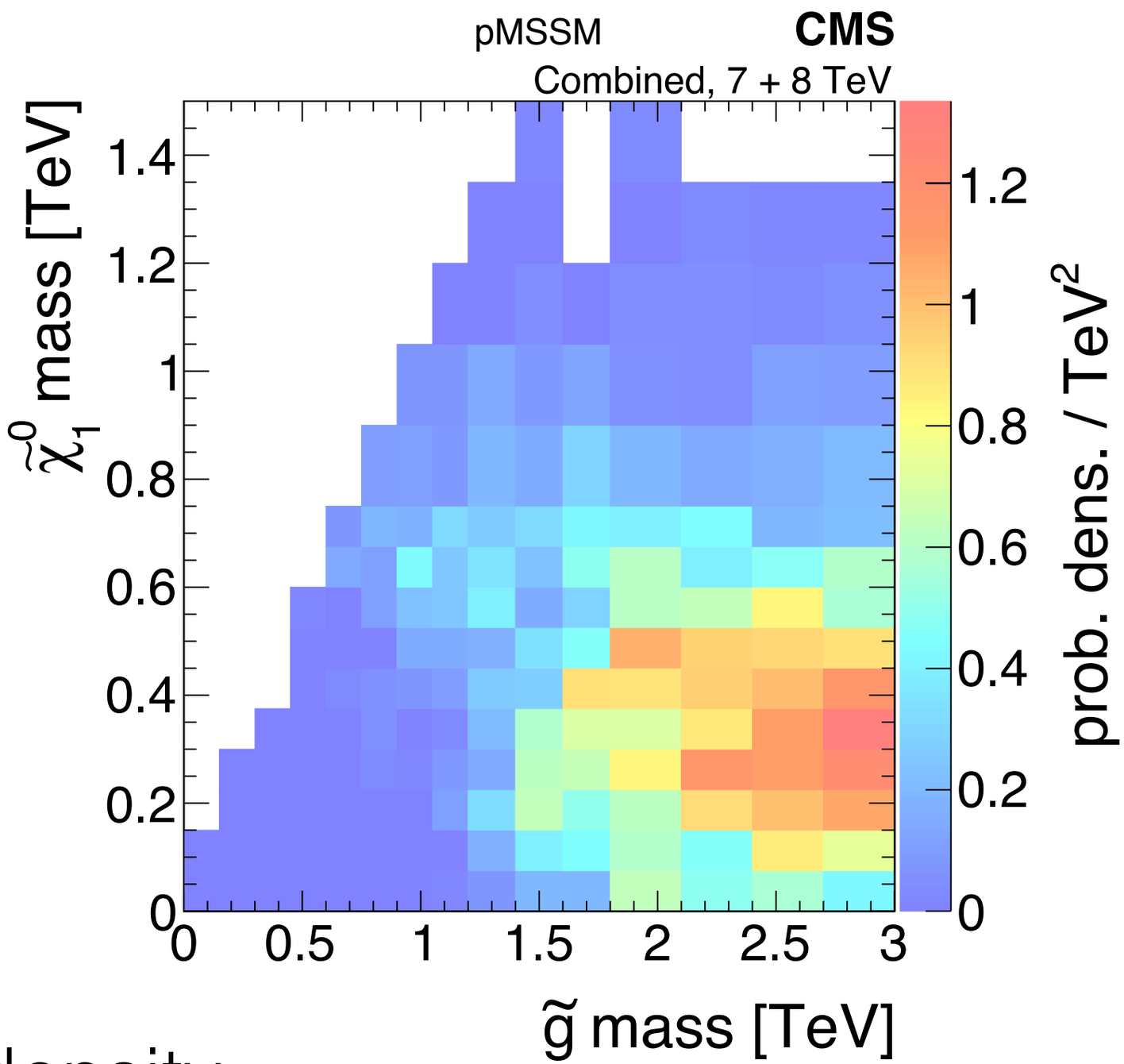


$$\Delta m(\tilde{\chi}_1^0, \tilde{\chi}_1^{\pm}) \sim 3 \text{ GeV}$$
$$m_{\tilde{\chi}_1^0} \sim 200 \text{ GeV}$$

8 TeV signed significance: +3.6

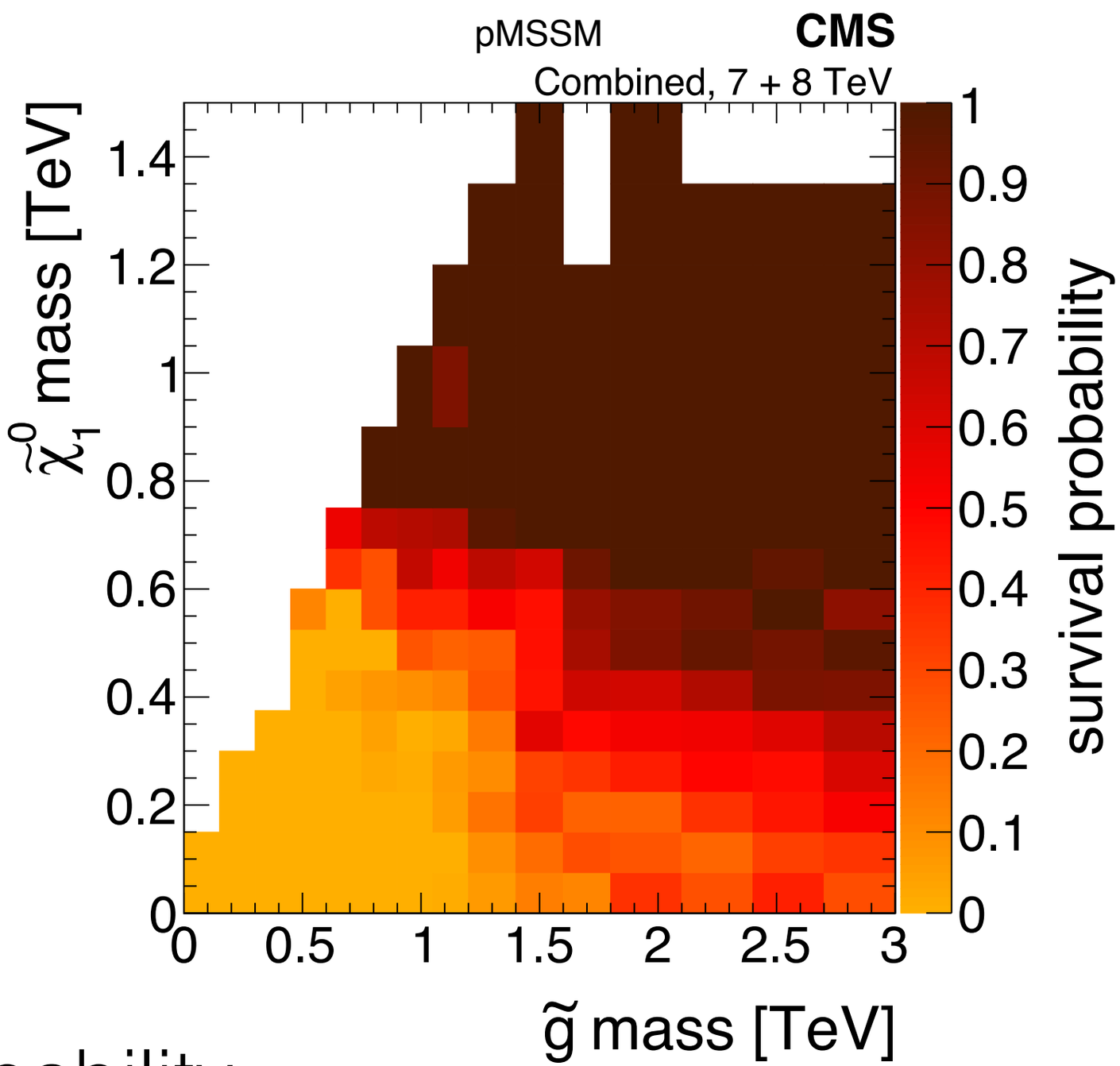


Gluino vs LSP mass



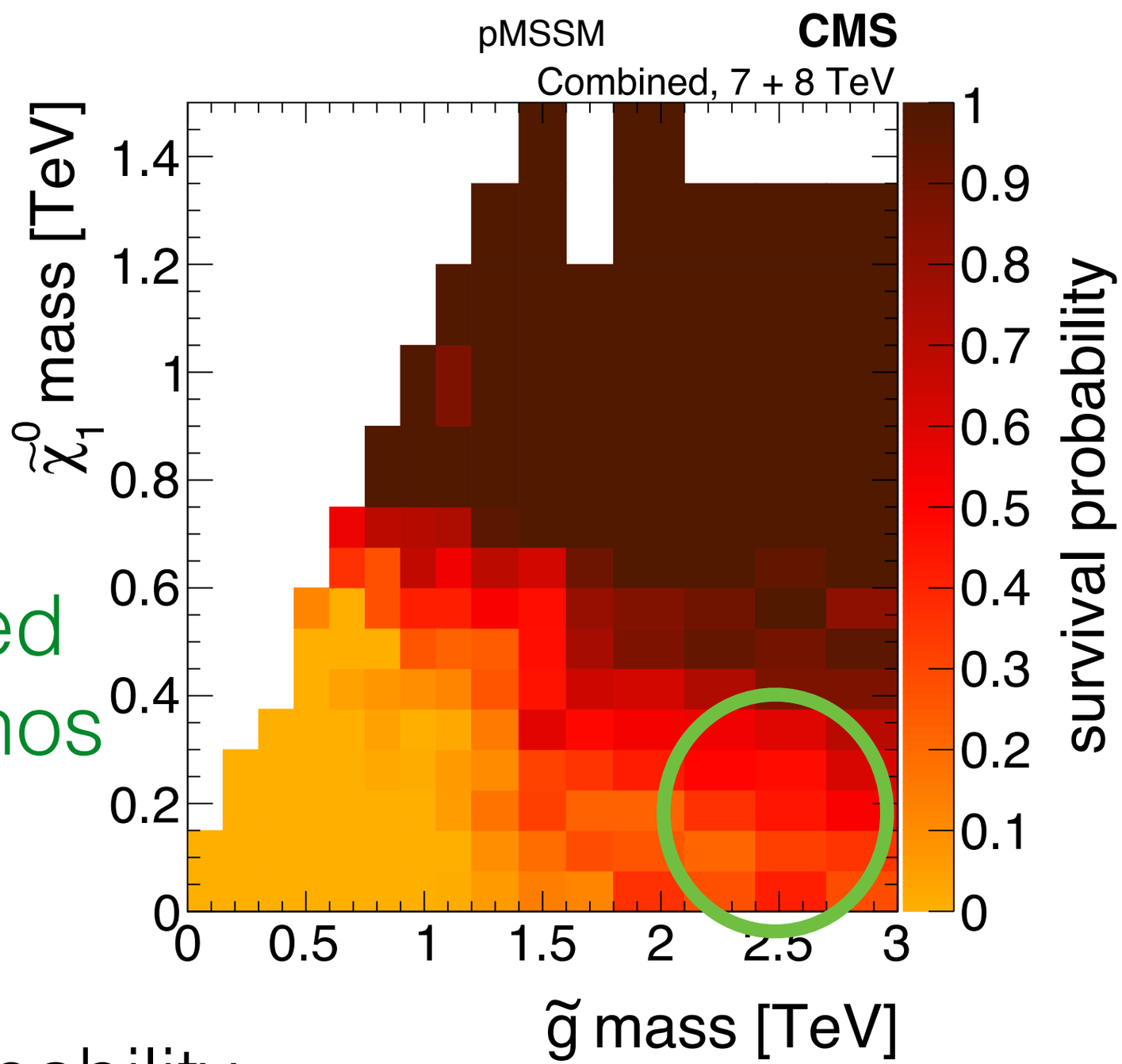
Probability density

Gluino vs LSP mass



Survival probability

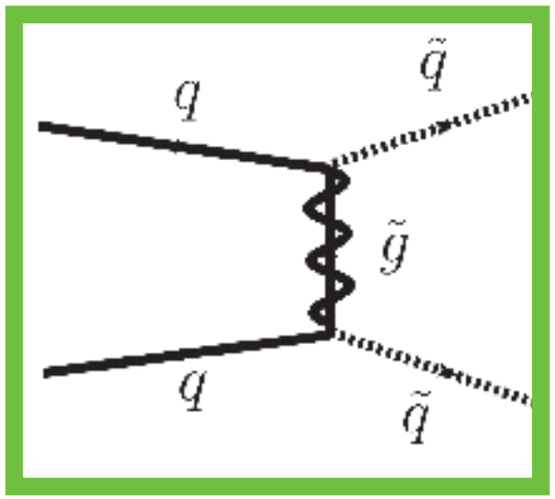
Gluino vs LSP mass

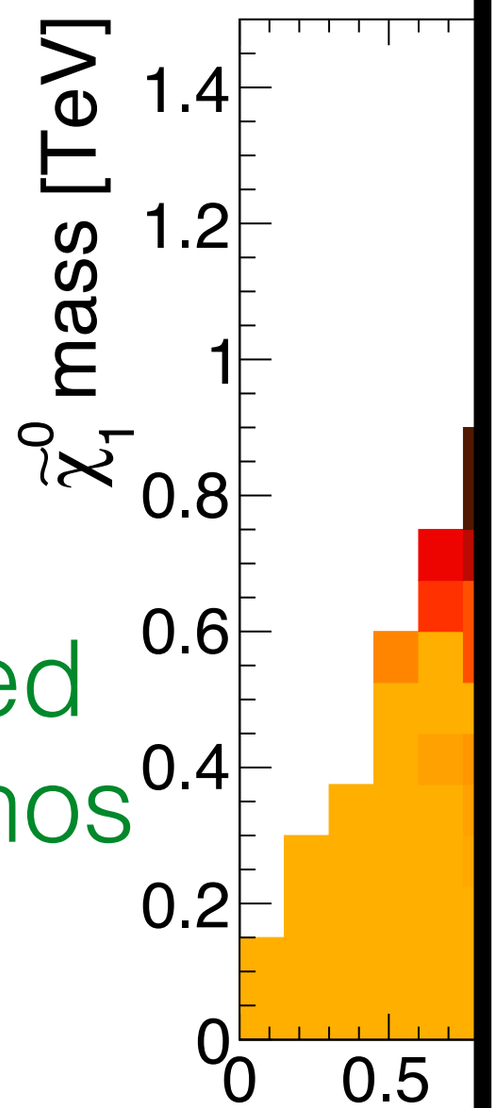


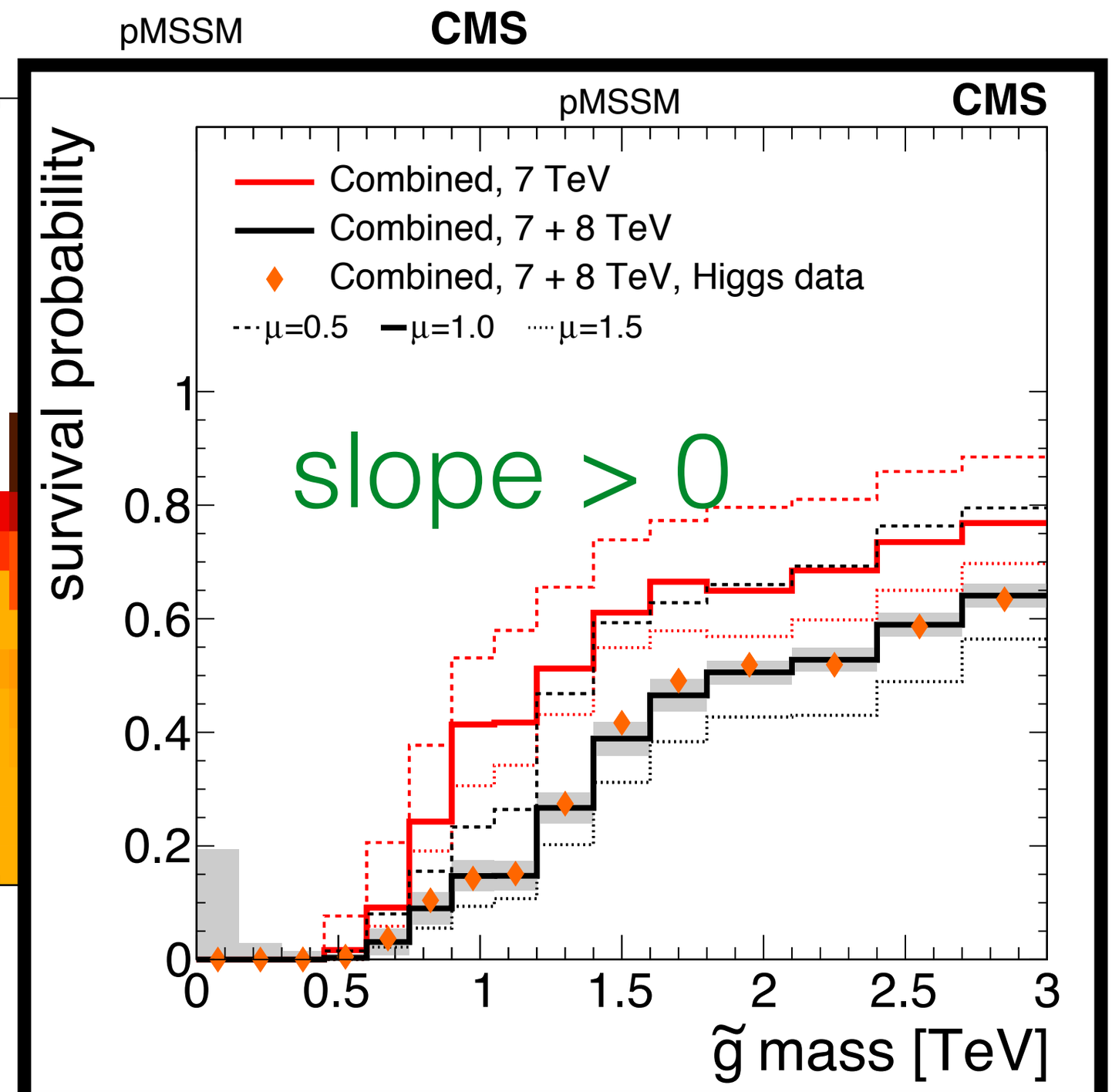
CMS probed heavy gluinos

Survival probability

Gluino vs LSP mass







CMS probed heavy gluinos

Survival probability

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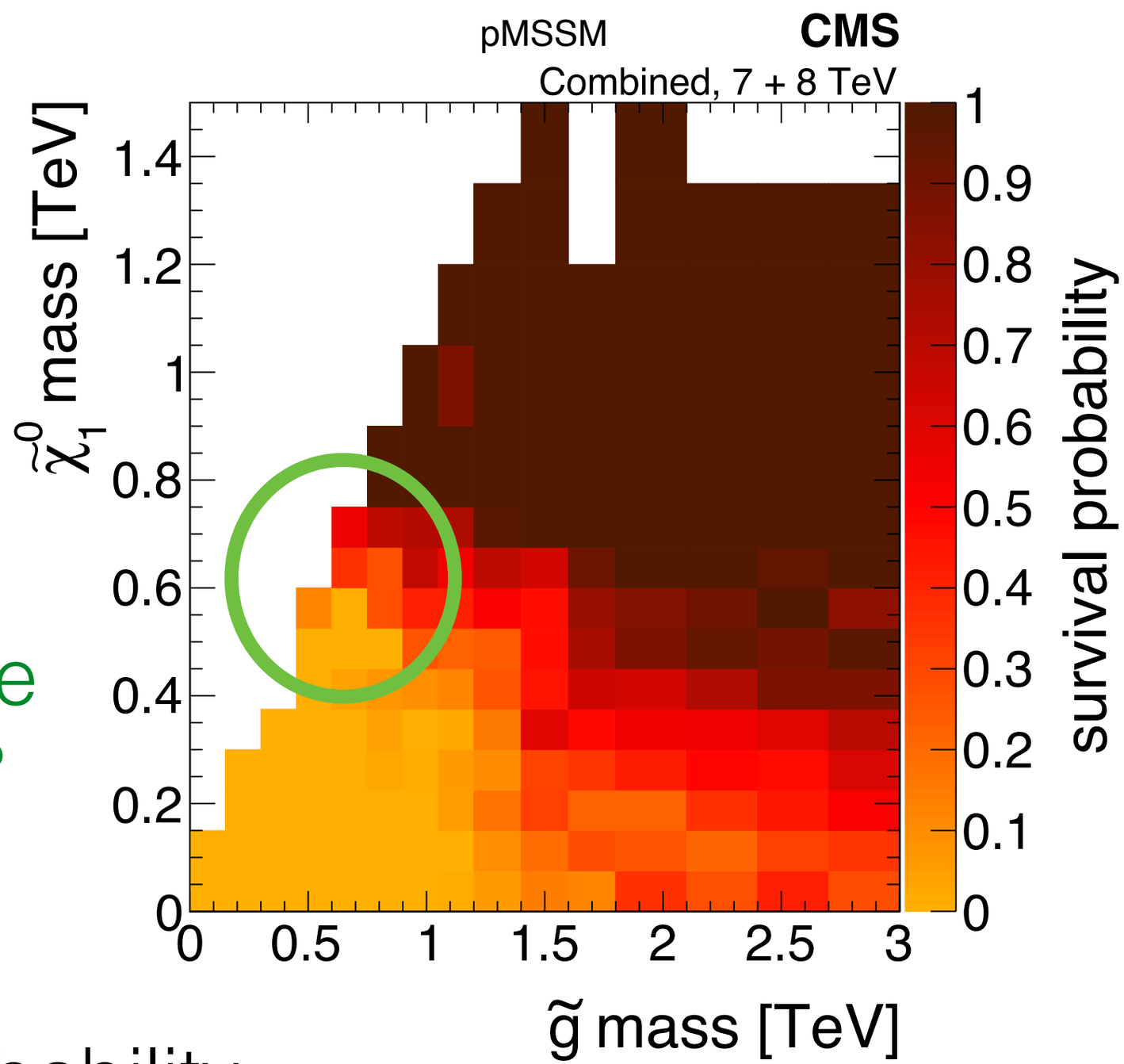
pMSSM interpretation of CMS searches

Gluino vs LSP mass

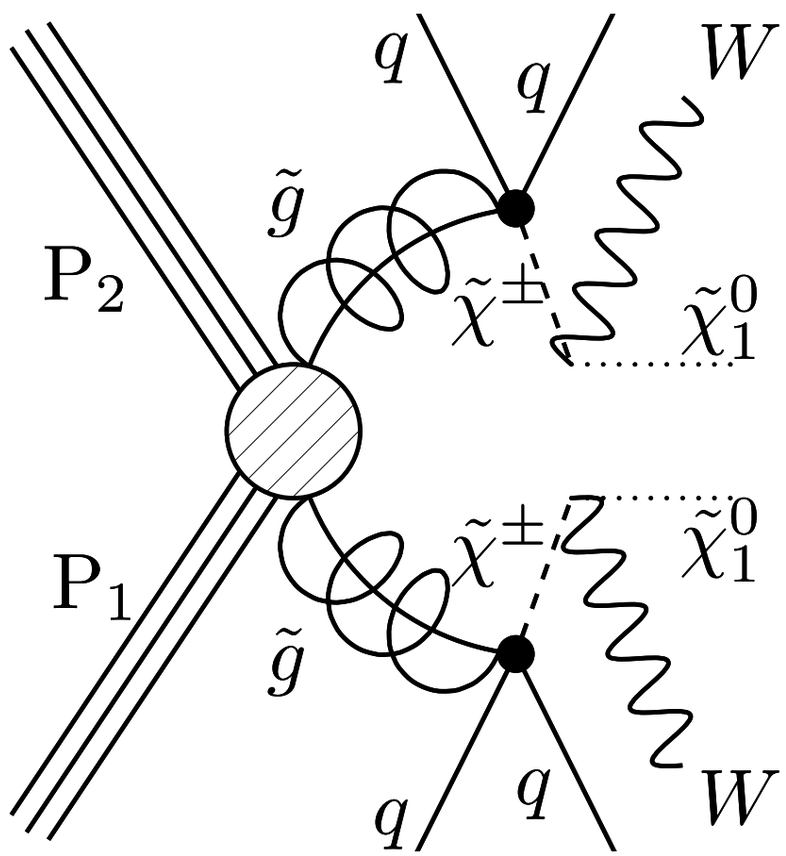


Can we characterize this region?

Survival probability

2nd lightest surviving gluino

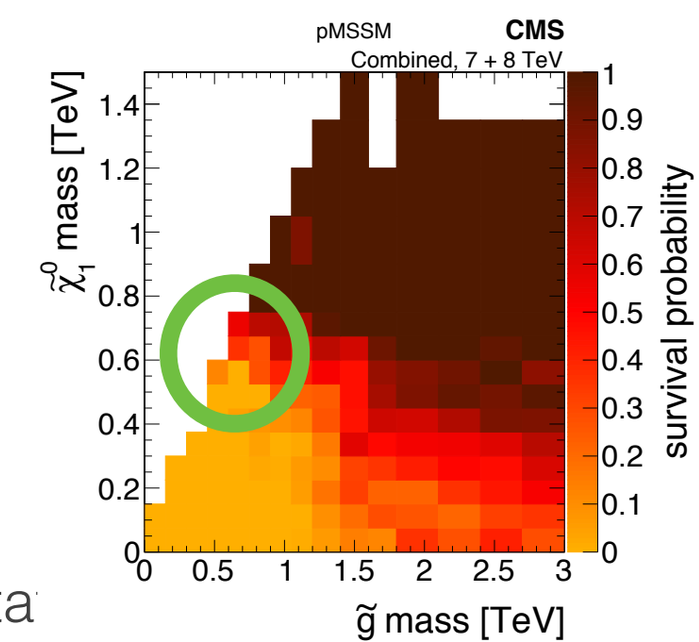
Scenario 1



$$m_{\tilde{g}} = 644 \text{ GeV}$$

$$m_{\tilde{\chi}_2^{\pm}} = 400.8 \text{ GeV}$$

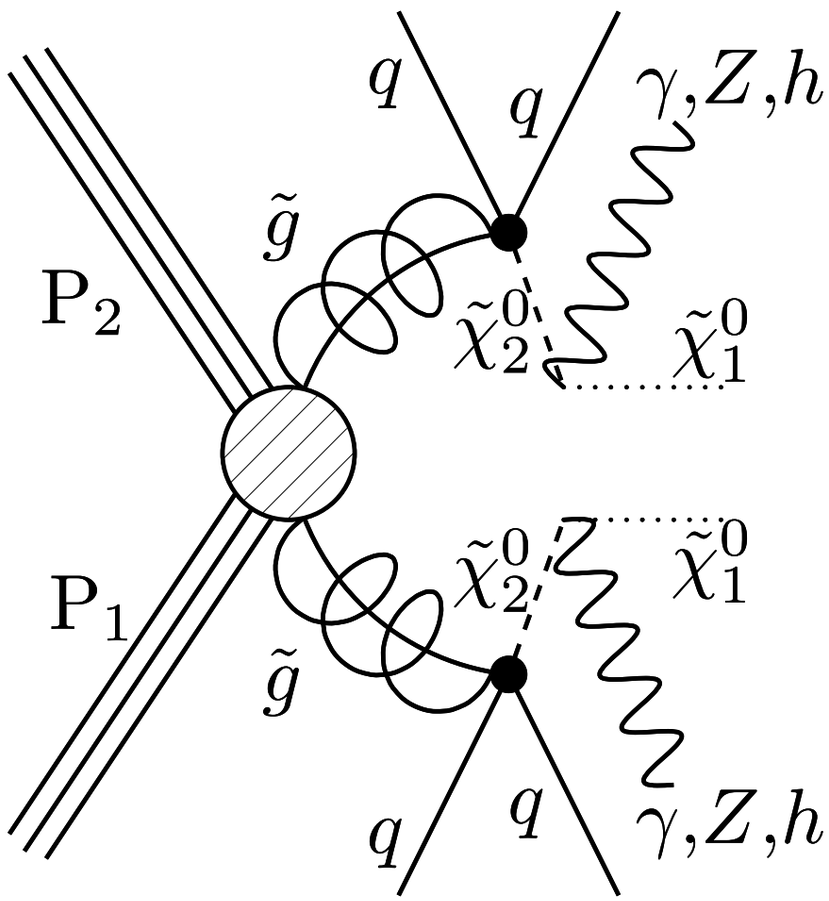
$$m_{\tilde{\chi}_1^0} = 400.4 \text{ GeV}$$



8 TeV signed significance: +1.8

Lightest surviving gluino

Scenario 2

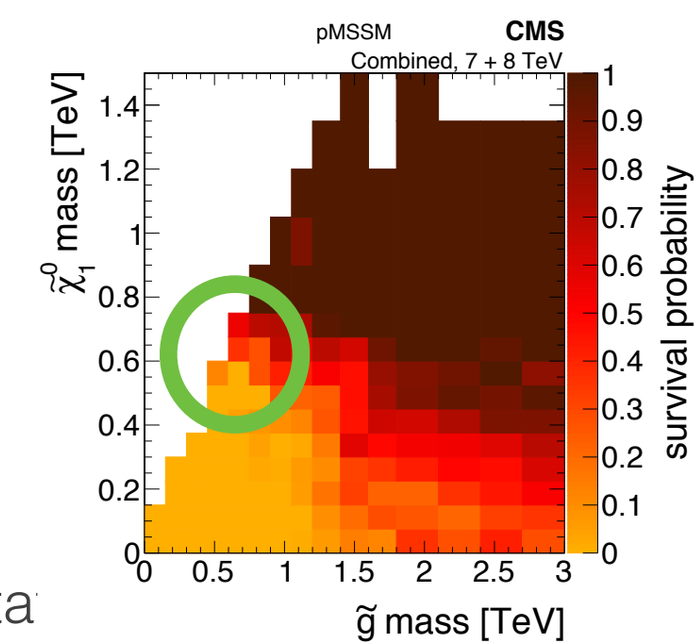


$$m_{\tilde{g}} = 581 \text{ GeV}$$

$$m_{\tilde{\chi}_2^0} = 533 \text{ GeV}$$

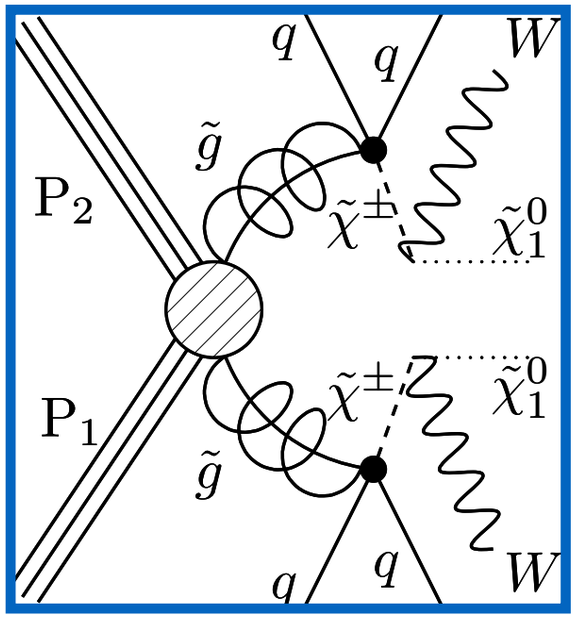
$$m_{\tilde{\chi}_1^0} = 528 \text{ GeV}$$

8 TeV signed significance: +2.3

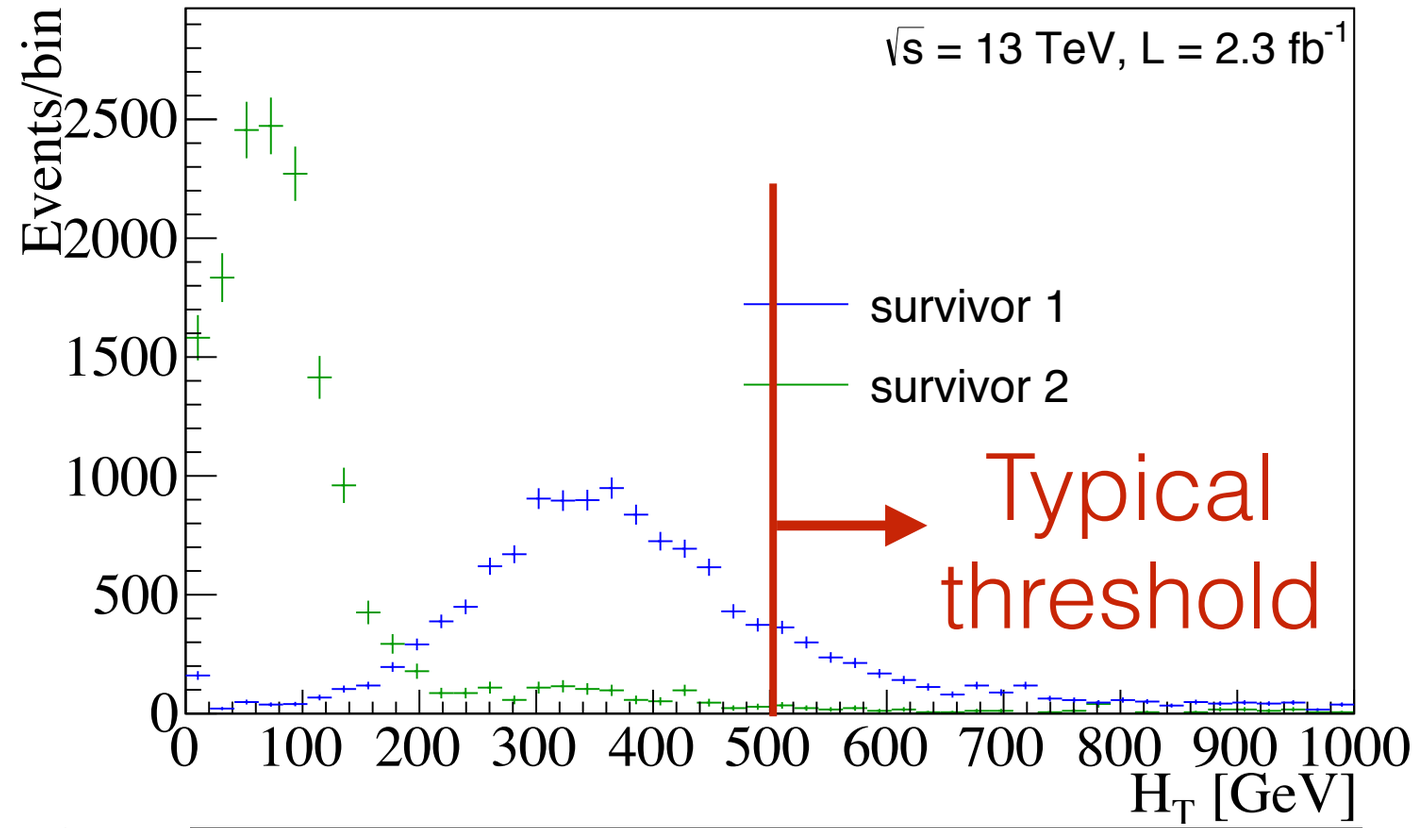


Observables

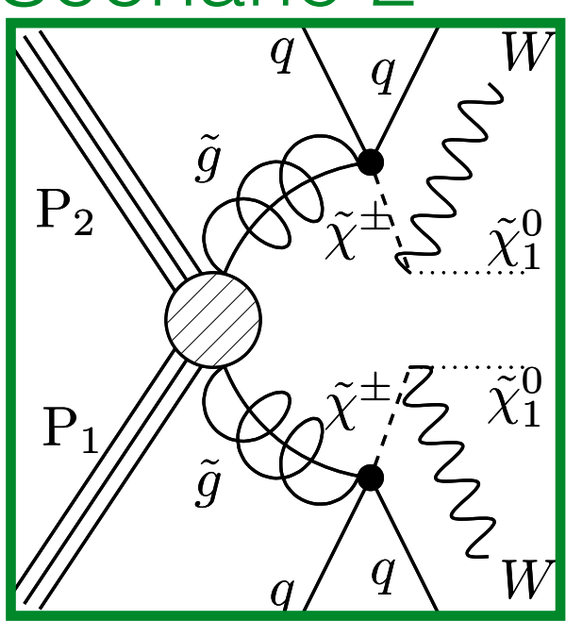
Scenario 1



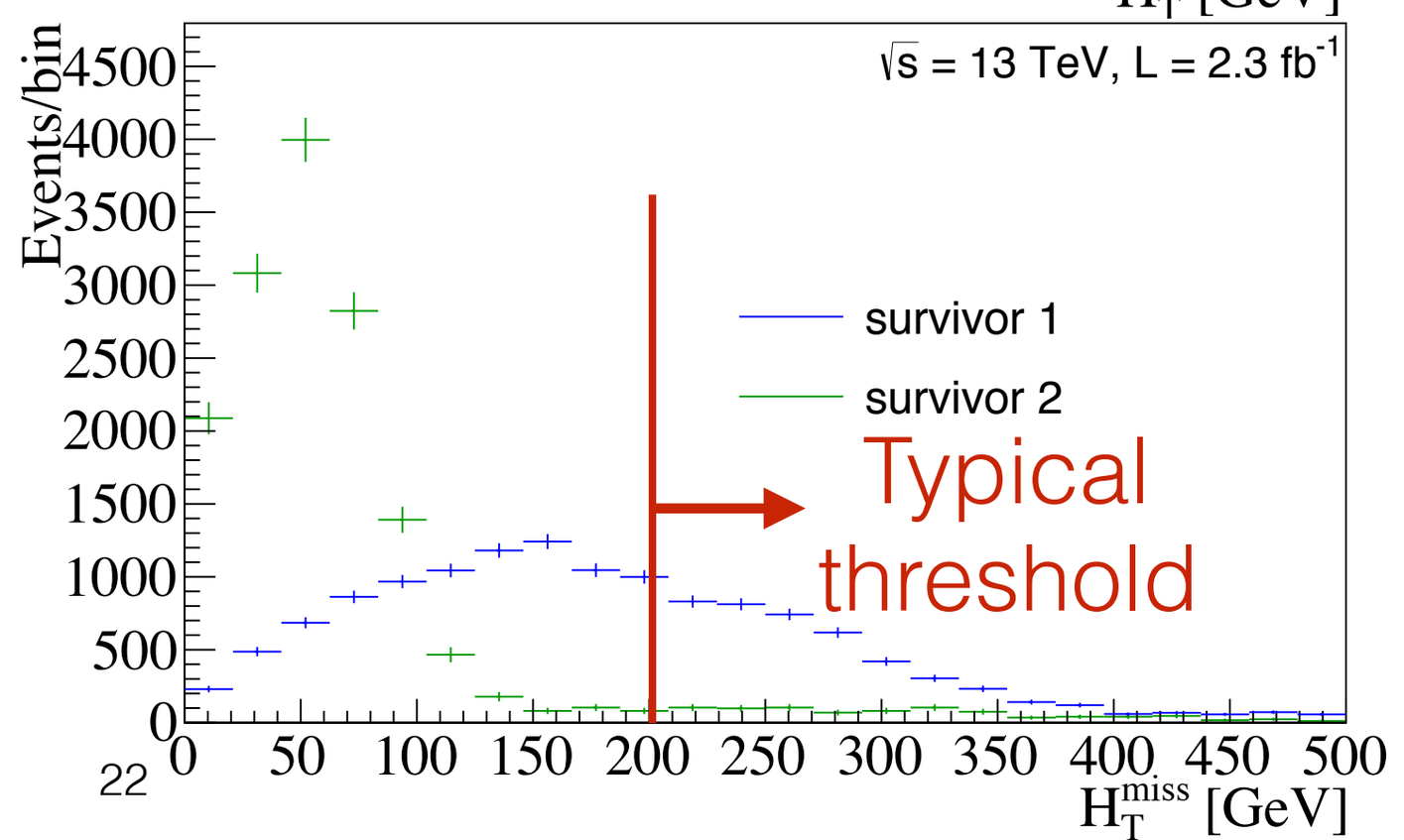
H_T



Scenario 2



E_T^{miss}



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Summary

- Much knowledge has been gained about the possible masses of gluinos, light-flavor squarks
- Gluinos as light as 600 GeV survived Run 1 due to compressed spectra, intermediate sparticle decays
- Second-most prevalent diagram predicts events that fail typical supersymmetry triggers
- Low-HT, monojet+X event signatures describe many surviving scenarios

[1] Vardan Khachatryan et al. Phenomenological MSSM interpretation of CMS searches in pp collisions at sqrt(s) = 7 and 8 TeV. 2016.

References

[1] Vardan Khachatryan et al. Phenomenological MSSM interpretation of CMS searches in pp collisions at sqrt(s) = 7 and 8 TeV. 2016.

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[14] Serguei Chatrchyan et al. Search for supersymmetry in events with b-quark jets and missing transverse energy in pp collisions at 7 TeV. *Phys. Rev. D*, 86:072010, 2012.

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[16] Serguei Chatrchyan et al. Search for new physics in the multijet and missing transverse momentum final state in proton-proton collisions at $\sqrt{s} = 8$ TeV. *JHEP*, 06:055, 2014.

[17] Serguei Chatrchyan et al. Search for supersymmetry in hadronic final states using MT2 in pp collisions at $\sqrt{s} = 7$ TeV. *JHEP*, 10:018, 2012.

[18] Serguei Chatrchyan et al. Search for gluino mediated bottom- and top-squark production in multijet final states in pp collisions at 8 TeV. *Phys. Lett. B*, 725:243, 2013.

[19] Vardan Khachatryan et al. Search for dark matter, extra dimensions, and unparticles in monojet events in proton-proton collisions at $\sqrt{s} = 8$ TeV. *Eur. Phys. J. C*, 75:235, 2015.

References

[20] Vardan Khachatryan et al. Searches for third-generation squark production in fully hadronic final states in proton-proton collisions at $\sqrt{s} = 8$ TeV. *JHEP*, 06:116, 2015.

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Backup (assumptions)

A realization of the R-parity conserving MSSM with

*no new sources of CP violation

*no flavor changing neutral currents

*1st and 2nd generation squarks are degenerate

*lightest supersymmetric particle is the neutralino

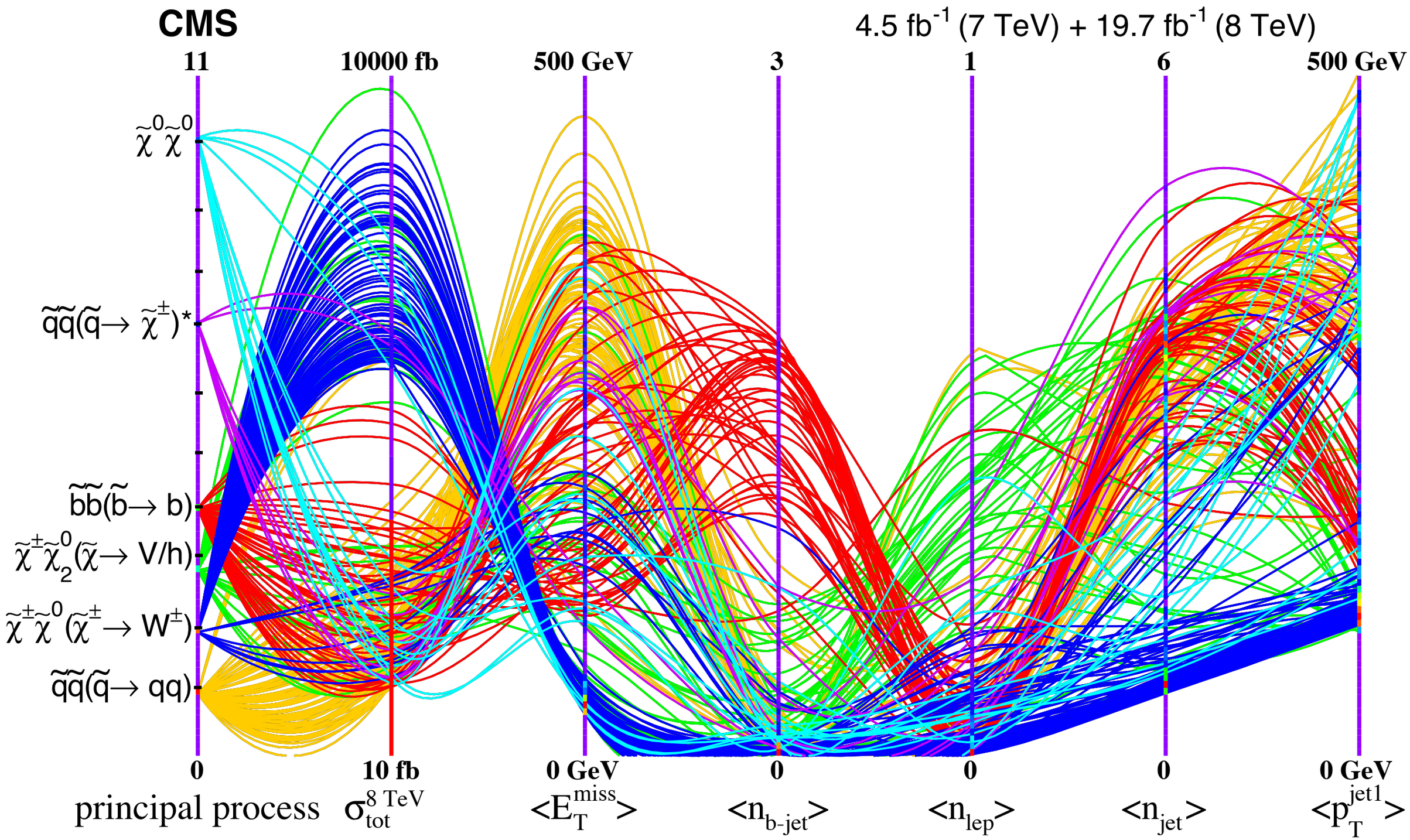
Backup

i	Observable $\mu_j(\theta)$	Constraint D_j^{preCMS}	Likelihood function $L(D_j^{\text{preCMS}}\|\mu_j(\theta))$
1	$BR(b \to s\gamma)$ [28, 29]	$(3.55 \pm 0.23^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.09^{\text{sys}}) \times 10^{-4}$	Gaussian
2a	$BR(B_s \to \mu\mu)$ [30]	observed CLs curve from [30]	$d(1 - CLs)/dx$
2b	$BR(B_s \to \mu\mu)$ [31]	$3.2^{+1.5}_{-1.2} \times 10^{-9}$	2-sided Gaussian
3	$R(B_u \to \tau\nu)$[32]	1.63 ± 0.54	Gaussian
4	Δa_μ [33]	$(26.1 \pm 8.0^{\text{exp}} \pm 10.0^{\text{th}}) \times 10^{-10}$	Gaussian
5	m_t [34]	$173.3 \pm 0.5^{\text{stat}} \pm 1.3^{\text{sys}}$(GeV	Gaussian
6	$m_b(m_b)$ [32]	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian
7	$\alpha_s(M_Z)$ [32]	0.1184 ± 0.0007	Gaussian
8a	m_h	pre-LHC: $m_h^{low} = 112$	1 if $m_h \geq m_h^{low}$ 0 if $m_h < m_h^{low}$
8b	m_h	LHC: $m_h^{low} = 120$, $m_h^{up} = 130$	1 if $m_h^{low} \leq m_h \leq m_h^{up}$ 0 if $m_h < m_h^{low}$ or $m_h > m_h^{up}$
9	sparticle masses	LEP [35] (via micrOMEGAs [24])	1 if allowed 0 if excluded
10	prompt $\tilde{\chi}_1^\pm$	$c\tau(\tilde{\chi}_1^\pm) < 10$ mm	1 if allowed 0 if excluded

Backup

Analysis	$\sqrt{s}$ [TeV]	L [fb^{-1}]
Hadronic HT + MHT search	7	4.98
Hadronic HT + MET + b-jets search	7	4.98
Leptonic search for EW prod. of $\tilde{\chi}^0, \tilde{\chi}^{\pm}, \tilde{l}$	7	4.98
Hadronic HT + MHT search	8	19.5
Hadronic M_{T2} search	8	19.5
Hadronic HT + MET + b-jets search	8	19.4
Monojet searches	8	19.7
Hadronic stop search	8	19.4
Opposite sign di-lepton (OS ll) search (count experiment only)	8	19.4
Like-sign di-leptoin (LS ll) search (only channels w/o 3rd lepton veto)	8	19.5
Leptonic search for EW prod. of $\tilde{\chi}^0, \tilde{\chi}^{\pm}, \tilde{l}$ (only ss, 3l, and 4l channels)	8	19.5

Non-excluded points, properties



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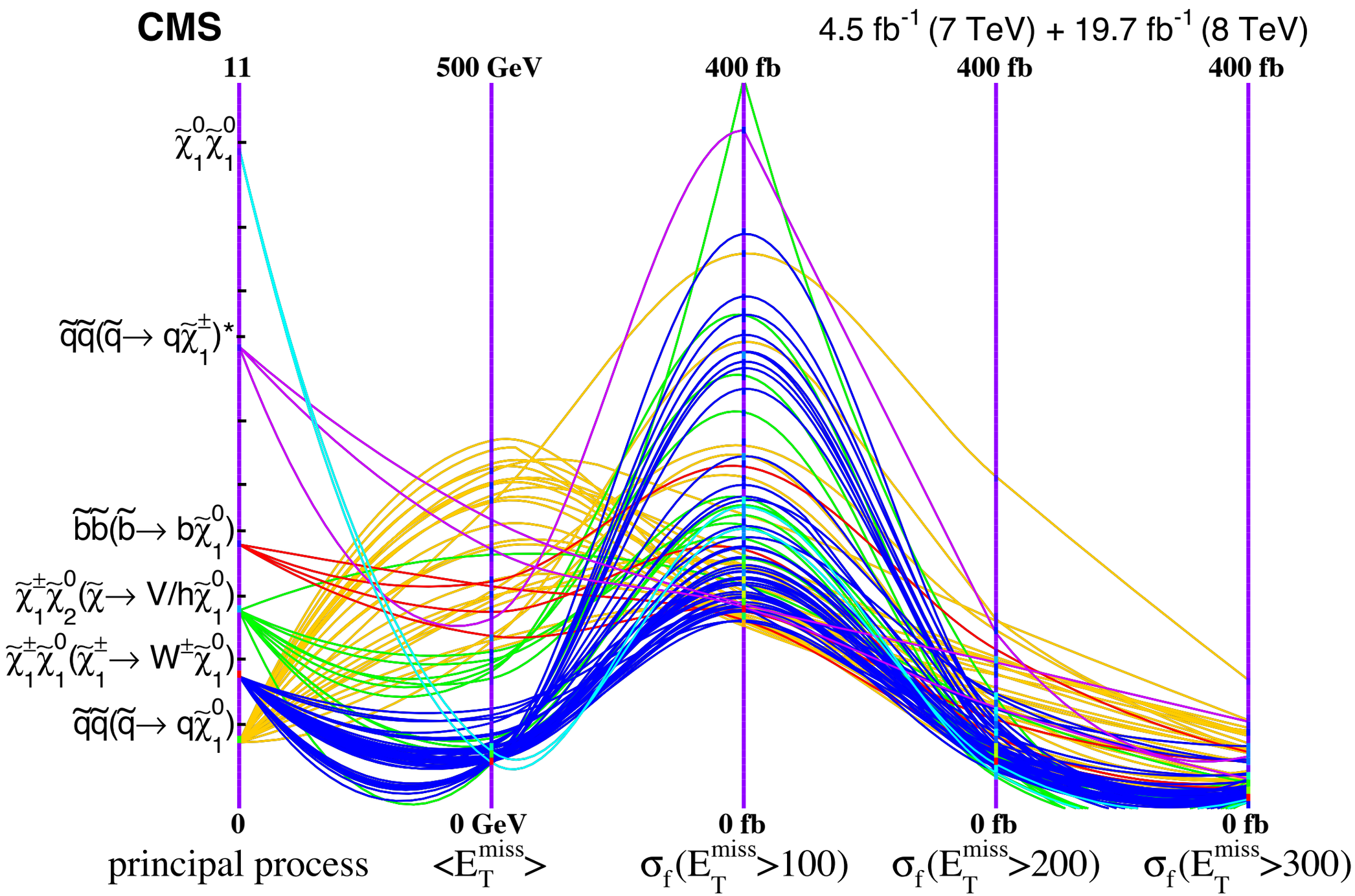

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