phenomenological MSSM interpretation of the 7 and 8 TeV CMS SUSY results

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on behalf of the CMS Collaoration

BSM Fitting Workshop
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CMS pMSSM documentation

- Public 7 TeV results: CMS-SUS-12-030
  twiki: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12030
  PAS: http://cds.cern.ch/record/1552402
- Public 7 + 8 TeV results: CMS-SUS-13-020
  twiki: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS13020
  PAS: http://cds.cern.ch/record/1693148

Many thanks to S. Bein, J. F. Gunion, S. Kraml, H. B. Prosper, L. Vanelderen and W. Waltenberger.

The model definition

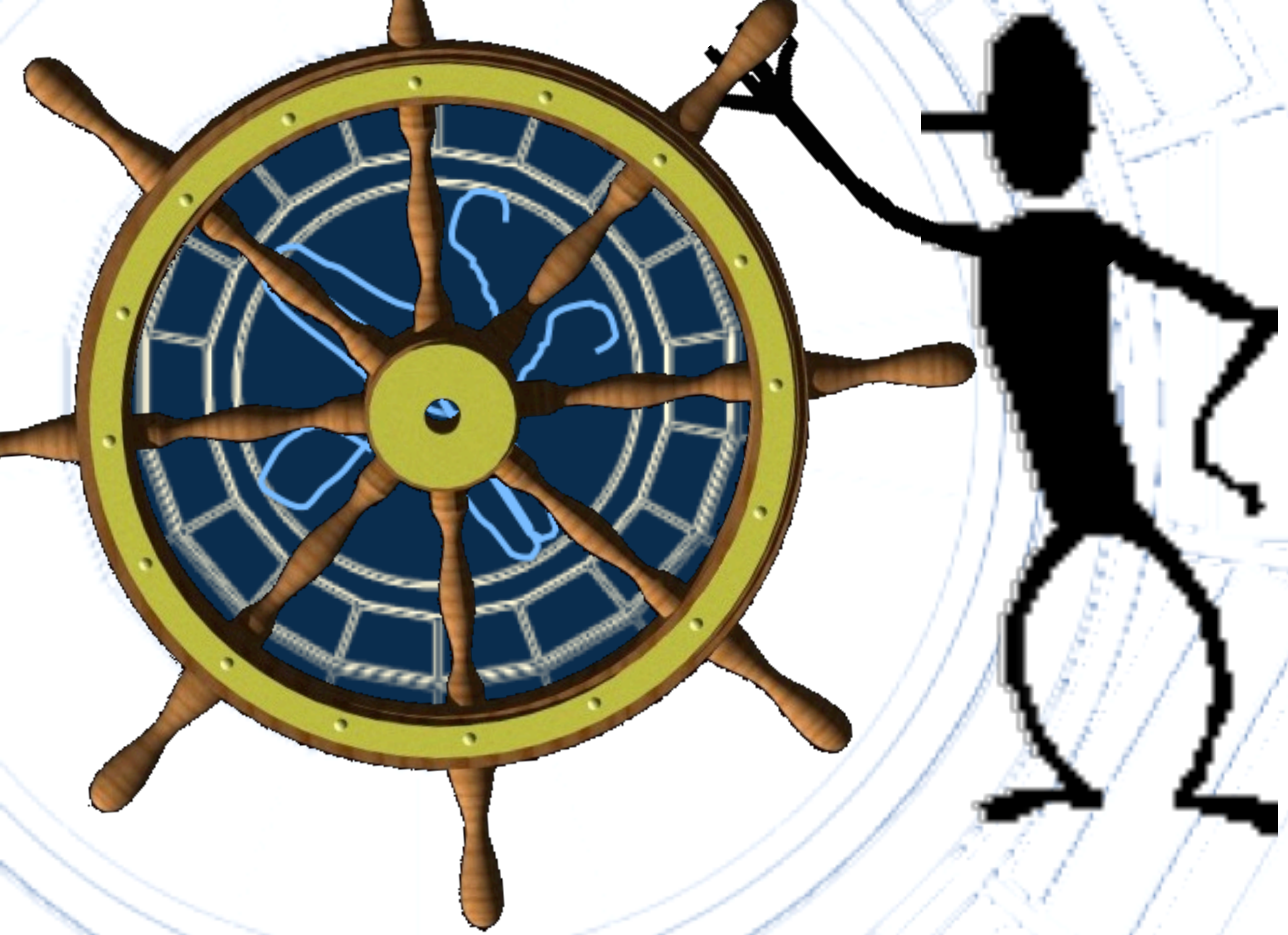
p(henomenological)MSSM is a 19-dimensional parameterization of the 124-parameter MSSM at the SUSY scale $M_{\rm SUSY} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$.

- the gaugino mass parameters M_1, M_2, and M_3;
- the ratio of the Higgs VEVs $\tan\beta = v_2/v_1$;
- the higgsino mass parameter μ and the pseudo-scalar Higgs mass m_A;
- 10 sfermion mass parameters $m_{\tilde{F}}$, where $\tilde{F} = \tilde{Q}_1, \tilde{U}_1, \tilde{D}_1, \tilde{L}_1, \tilde{E}_1, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3$ (imposing $m_{\tilde{Q}_1} \equiv m_{\tilde{Q}_2}$, $m_{\tilde{L}_1} \equiv m_{\tilde{L}_2}$, etc.), and
- 3 trilinear couplings A_t, A_b and A_τ ,

Minimal assumptions: R parity conserved; no new CP phases; flavor-diagonal sfermion mass matrices and trilinear couplings; 1st/2nd generation degenerate; A-terms negligible; lightest neutralino is the LSP.

Motivation

- A well-founded theory: Sufficiently generic 19-dimensional realization of the MSSM at the SUSY scale, which captures most of MSSM's phenomenological features
- No assumptions on the nature of SUSY breaking mechanism
- No correlations between the sparticle masses. Has a very rich phenomenology that covers diverse (and surprising) LHC signatures.
- Allows to make very generic statements on sparticle masses.
- Can make diverse predictions, on electroweak observables, branching ratios of rare decays, dark matter-related observables, etc.



Analysis

We perform a global Bayesian analysis and obtain posterior probability distributions of model parameters, masses and predicted observables.

Input parameters

pMSSM input parameters and parameter ranges:

$$
\begin{gathered}
-3\,\mathrm{TeV} \le M_1, M_2 \le 3\,\mathrm{TeV} \\
0 \le M_3 \le 3\,\mathrm{TeV} \\
-3\,\mathrm{TeV} \le \mu \le 3\,\mathrm{TeV} \\
0 \le m_A \le 3\,\mathrm{TeV} \\
2 \le \tan\beta \le 60 \\
0 \le \tilde{Q}_{1,2}, \tilde{U}_{1,2}, \tilde{D}_{1,2}, \tilde{L}_{1,2}, \tilde{E}_{1,2}, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3 \le 3\,\mathrm{TeV} \\
-7\,\mathrm{TeV} \le A_t, A_b, A_\tau \le 7\,\mathrm{TeV},
\end{gathered}
$$

SM input parameters:

$$m_t,\ m_b(m_b) \text{ and } \alpha_s(M_Z)$$

(allowed to vary in an unlimited range, but constrained by a likelihood)

Building the non-DCS (direct CMS search) prior distribution

We obtain a discrete representation of this prior by sampling 20 000 000 points from the pMSSM space using MCMC.

We implement a prompt chargino requirement (since simulation of long-lived particle decays is not available in FastSim) afterwards.

non-DCS prior

$$p^{\text{non-DCS}}(\theta) = L(D^{\text{non-DCS}}|\theta) \cdot p(\text{prompt } \tilde{\chi}_1^{\pm}|\theta) \cdot p(\text{theory}|\theta) \cdot p_0(\theta)$$

- $L(D^{\text{non-DCS}}|\theta)$: non-DCS likelihood
- $p(\text{prompt } \tilde{\chi}_1^{\pm}|\theta)$: prompt chargino
- $p(\text{theory}|\theta)$: theoretical constraints
- $p_0(\theta)$: initial flat prior

non-DCS likelihood and measurements

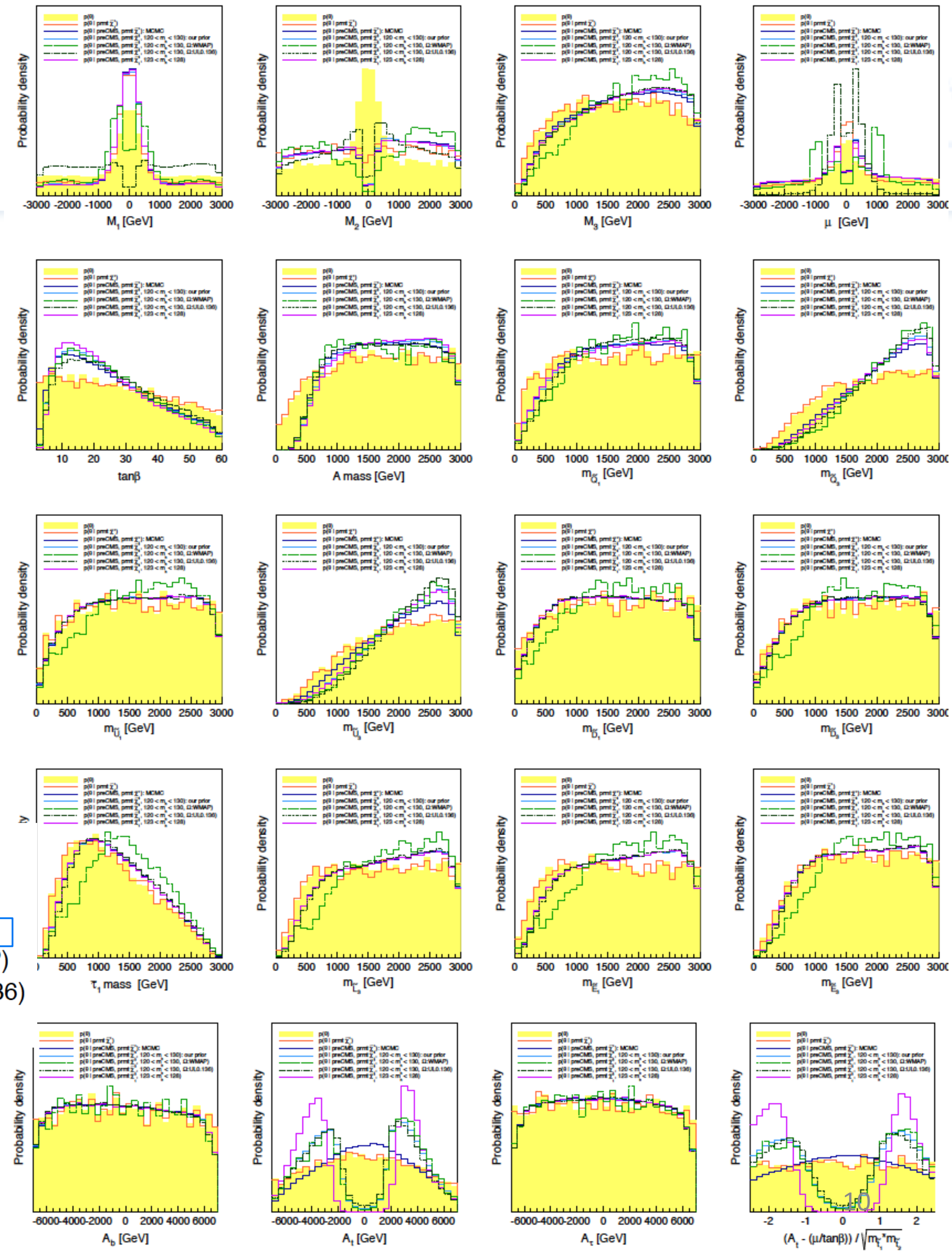
$$L(D^{\text{non-DCS}}|\theta) = \left\{ \prod_i L(D_i^{\text{non-DCS}}|\mu_i(\theta)) \right\}$$

Observable $\mu_j(\theta)$	Constraint $D_j^{\text{non-DCS}}$	Likelihood function $L(D_j^{\text{non-DCS}}\|\mu_j(\theta))$	MCMC / post-MCMC
$BR(b \to s\gamma)$ [37, 38]	$(3.55 \pm 0.23^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.09^{\text{sys}}) \times 10^{-4}$	Gaussian	MCMC
$BR(b \to s\gamma)$ [39]	$(3.43 \pm 0.21^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.07^{\text{sys}}) \times 10^{-4}$	Gaussian	reweight
$BR(B_s \to \mu\mu)$ [40]	observed CLs curve from [40]	$d(1-CLs)/d(BR(B_s \to \mu\mu))$	MCMC
$BR(B_s \to \mu\mu)$ [41]	$(2.9 \pm 0.7 \pm 0.29^{th}) \times 10^{-9}$	Gaussian	reweight
$R(B_u \to \tau\nu)$[42]	1.63 ± 0.54	Gaussian	MCMC
$R(B_u \to \tau\nu)$[39]	1.04 ± 0.34	Gaussian	reweight
Δa_μ [43]	$(26.1 \pm 6.3^{\text{exp}} \pm 4.9^{\text{SM}} \pm 10.0^{\text{SUSY}}) \times 10^{-10}$	Gaussian	MCMC
m_t [44]	$173.3 \pm 0.5^{\text{stat}} \pm 1.3^{\text{sys}}$ GeV	Gaussian	MCMC
m_t [45]	$173.20 \pm 0.87^{\text{stat}} \pm 1.3^{\text{sys}}$ GeV	Gaussian	reweight
$m_b(m_b)$ [42]	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian	MCMC
$\alpha_s(M_Z)$ [42]	0.1184 ± 0.0007	Gaussian	MCMC
m_h	pre-LHC: $m_h^{low} = 112$	1 if $m_h \geq m_h^{low}$ 0 if $m_h < m_h^{low}$	MCMC
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 $m_h > m_h^{up}$	reweight
sparticle masses	LEP [46] (via micrOMEGAs [31–33])	1 if allowed 0 if excluded	MCMC

Tools

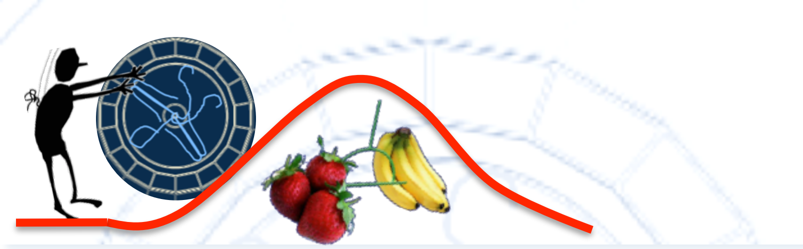
- SUSY spectrum calculation: SOFTSUSY 3.3.1
- EW and B-physics observables: SuperIso 3.3
- Dark matter relic density, DD cross section: micrOMEGAs 2.4.5
- SUSY mass limits: micrOMEGAs 2.4.5
- SUSY decays: SUSYHIT SUSYHIT (SDECAY1.3b, HDECAY3.4)
- SUSY event generation: PYTHIA 6
- Interfaces: SUSY Les Houches Accord
- Detector simulation: CMSSW, FASTSIM

1D preCMS posterior probability distributions for the pMSSM input parameters. Effects of the light Higgs mass and DM relic density constraints are shown.

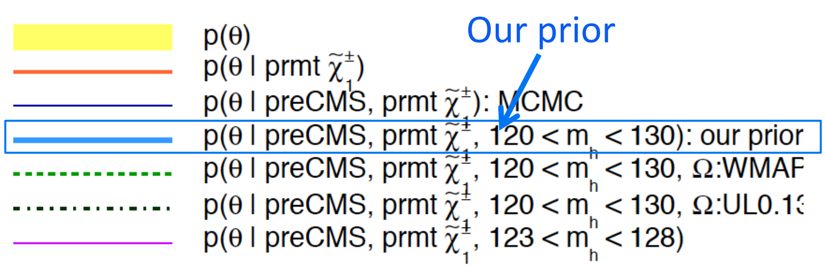


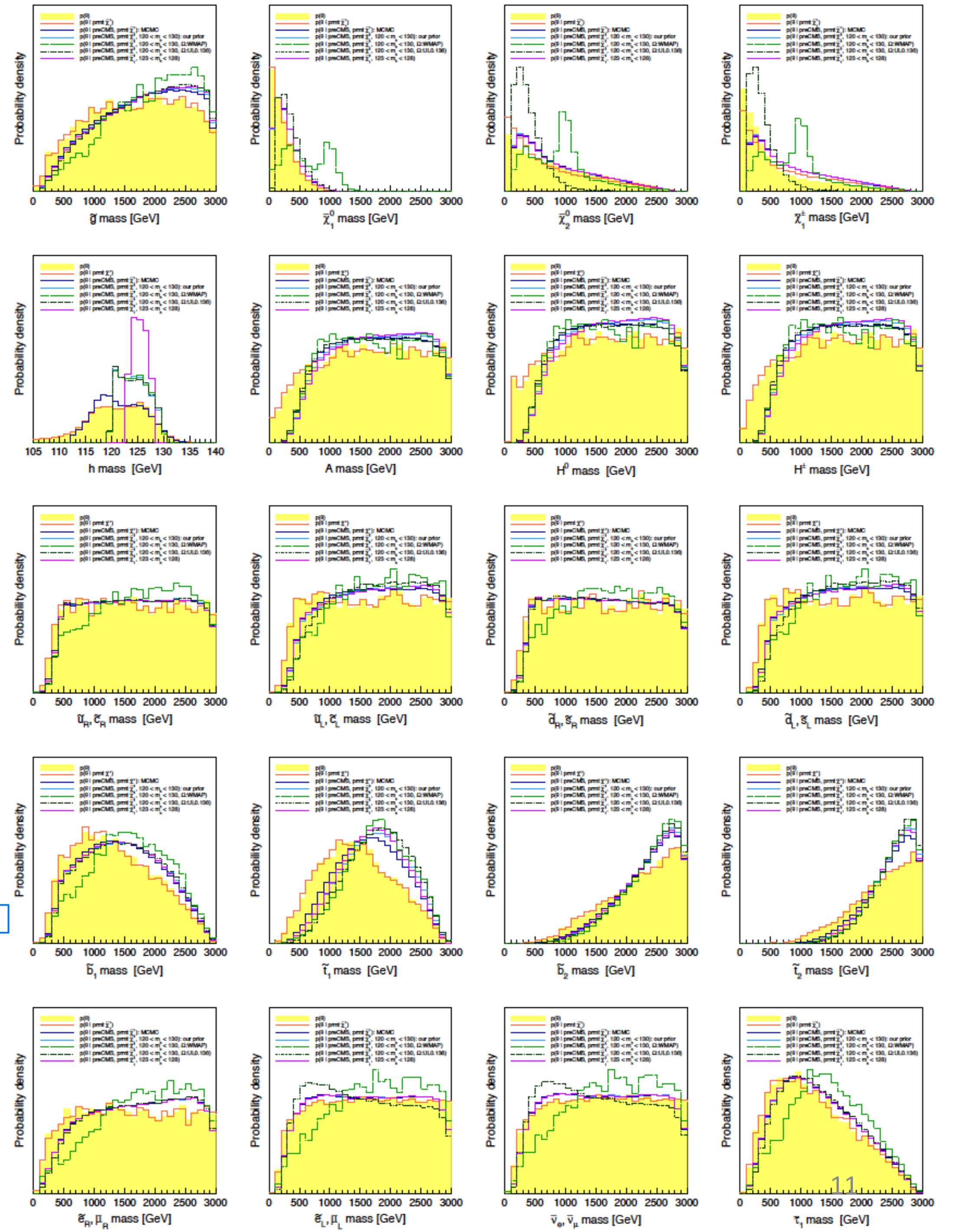
(yellow fill)	$p(\theta)$
(orange line)	$p(\theta \mid \text{prmt } \tilde{\chi}_1^{\pm})$
(dark blue line)	$p(\theta \mid \text{preCMS, prmt } \tilde{\chi}_1^{\pm})$: MCMC
(light blue line)	$p(\theta \mid \text{preCMS, prmt } \tilde{\chi}_1^{\pm}, 120 < m_h < 130)$: our prior
(green dashed)	$p(\theta \mid \text{preCMS, prmt } \tilde{\chi}_1^{\pm}, 120 < m_h < 130, \Omega\text{:WMAP})$
(black dash-dot)	$p(\theta \mid \text{preCMS, prmt } \tilde{\chi}_1^{\pm}, 120 < m_h < 130, \Omega\text{:UL0.136})$
(magenta line)	$p(\theta \mid \text{preCMS, prmt } \tilde{\chi}_1^{\pm}, 123 < m_h < 128)$

Our prior



1D preCMS posterior probability distributions for selected sparticle masses. Effects of the light Higgs mass and DM relic density constraints are shown.





Building the CMS posterior distribution - I

CMS posterior distribution

$$p(\theta|D^{\mathrm{CMS}}) = L(D^{\mathrm{CMS}}|\theta)\; p^{\text{non-DCS}}(\theta)$$

CMS likelihood

based on simulation of signal events:
per point 10000 events, `PYTHIA` + `FastSim`

analysis groups provide necessary (simple) input to calculate an approximate likelihood

We select 7300 points out of the non-DCS point set with a prompt chargino and weight each by $L(D^{\mathrm{CMS}}|\theta)$.

Building the CMS posterior distribution - II

$$p(\theta|D^{\text{CMS}}) = L(D^{\text{CMS}}|\theta)\; p^{\text{non-DCS}}(\theta)$$

likelihood method 1:
for pure count experiments
full treatment of statistical uncertainties bkg prediction, correlation between systematic uncertainties ignored

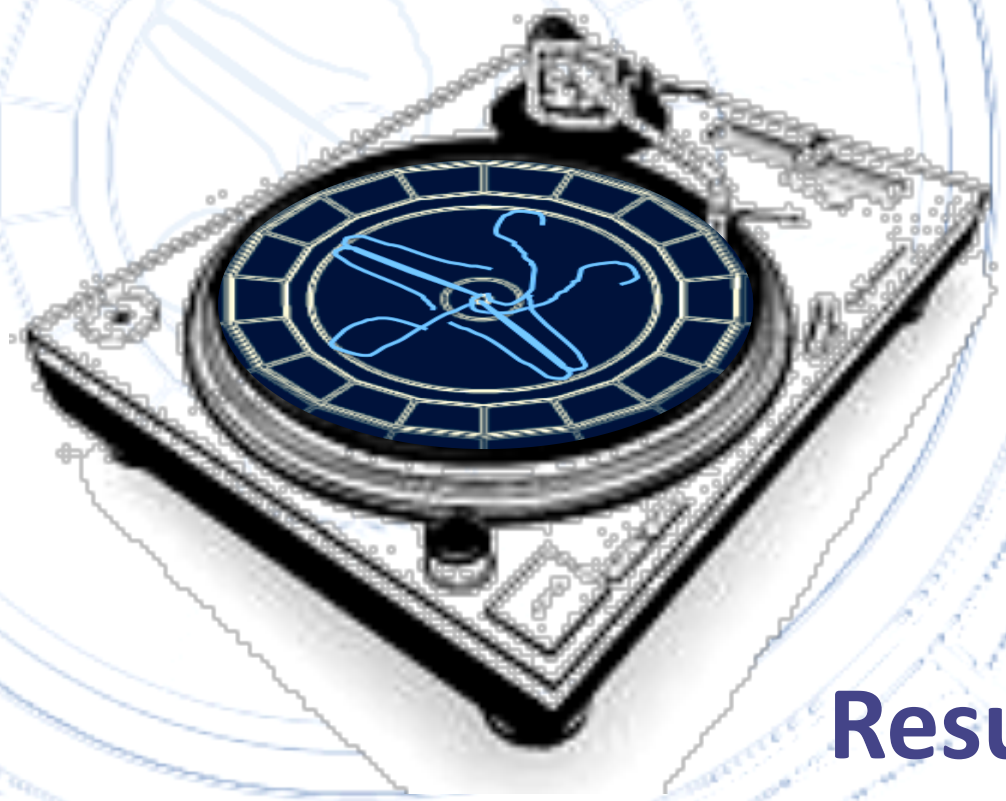
likelihood method 2:
for likelihood based experiments
full treatment of systematic uncertainties bkg prediction, statistical uncertainties treated in asymptotic limit

- within each analysis signal regions are combined if they are statistically independent by multiplying the per signal region likelihoods
- for combinations of overlapping signal regions and analyses: see further

detailed description in PAS

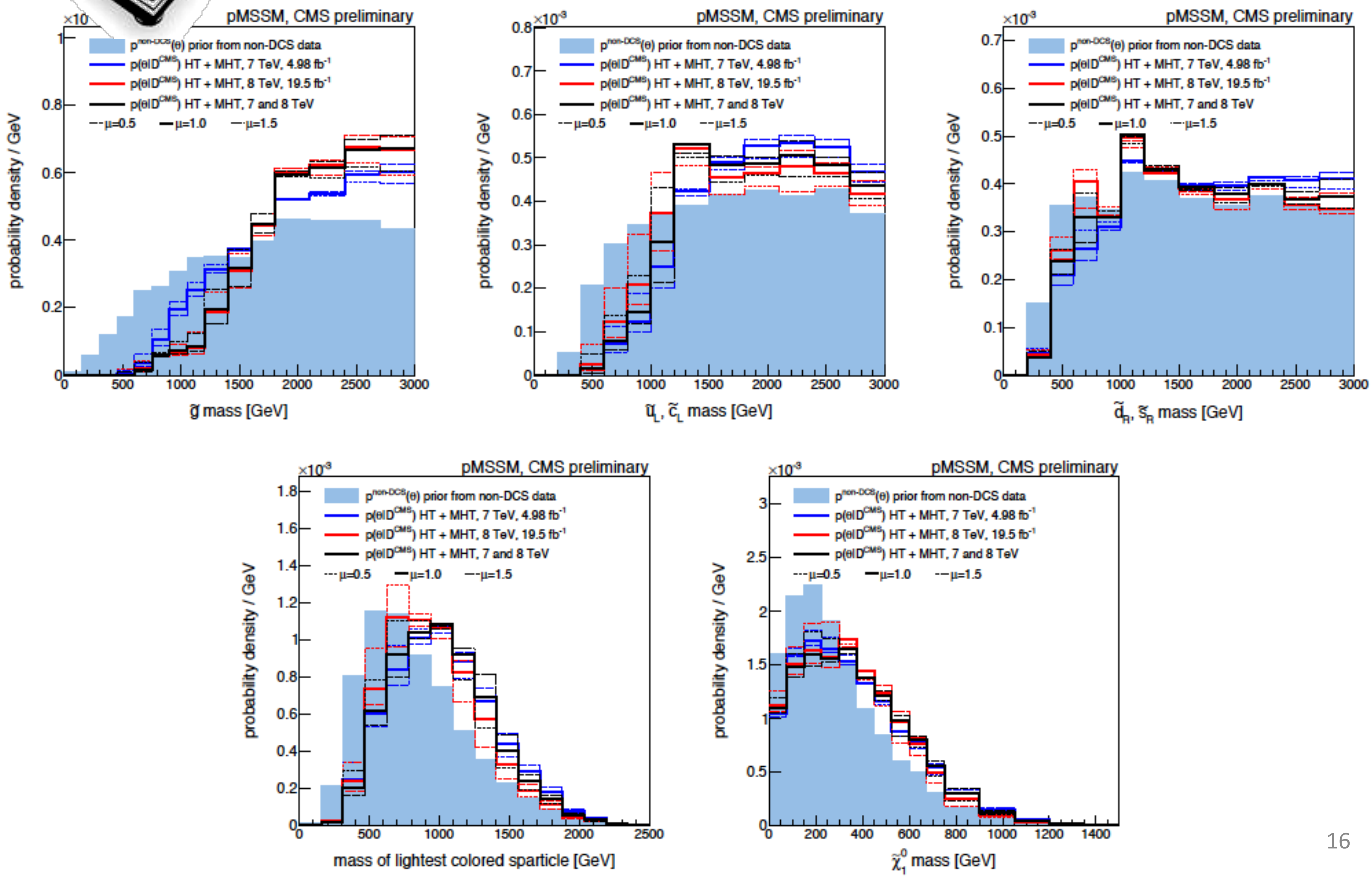
CMS analyses

Analysis	$\sqrt{s}$	$\int dL$	CERN doc.
in the PAS			
$H_T + H_T^{miss}$ search	7 TeV	4.98 fb^{-1}	SUS-12-011
$H_T + E_T^{miss} + b$-jets search	7 TeV	4.98 fb^{-1}	SUS-12-003
EW prod of $\tilde{\chi}^{\pm}$, $\tilde{\chi}^{0}$, $\tilde{l}$	7 TeV	4.98 fb^{-1}	SUS-12-006
$H_T + H_T^{miss}$ search	8 TeV	19.5 fb^{-1}	SUS-13-012
$H_T + E_T^{miss} + b$-jets search	8 TeV	19.4 fb^{-1}	SUS-12-024
EW prod of $\tilde{\chi}^{\pm}$, $\tilde{\chi}^{0}$, $\tilde{l}$	8 TeV	19.5 fb^{-1}	SUS-12-006

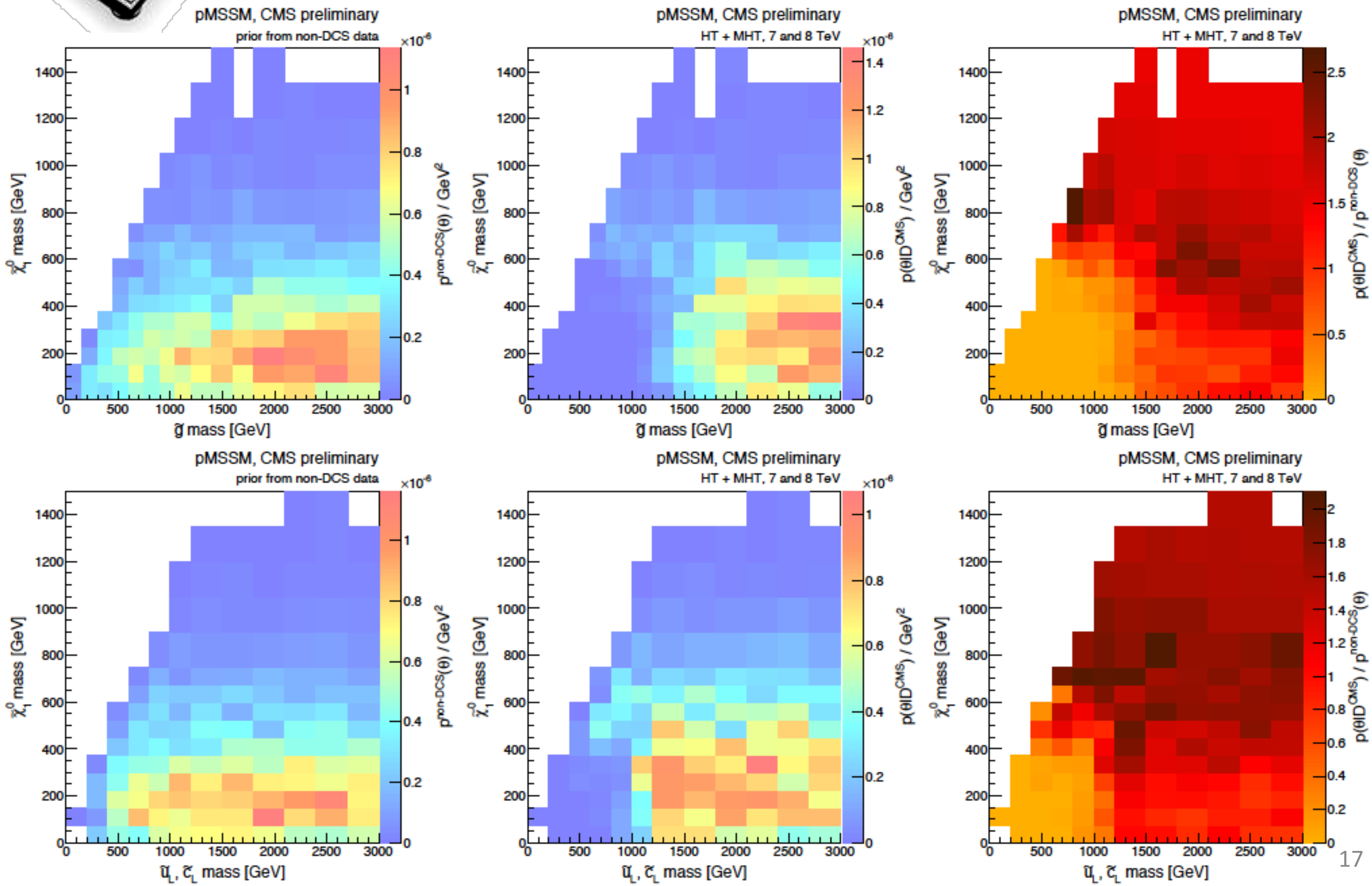


Results

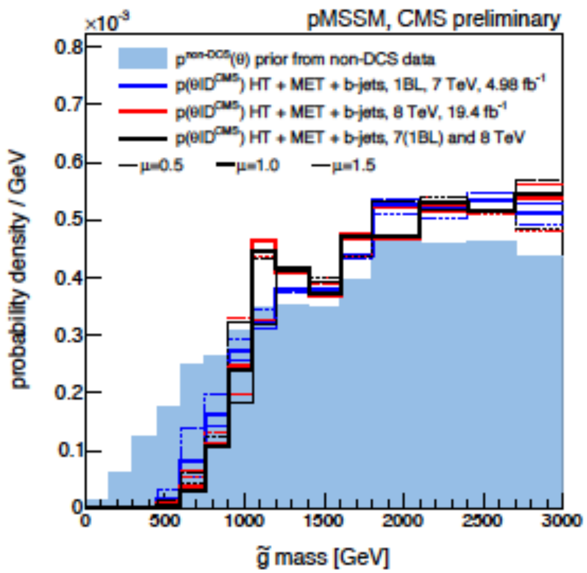
Impact of the HT + MHT search - I

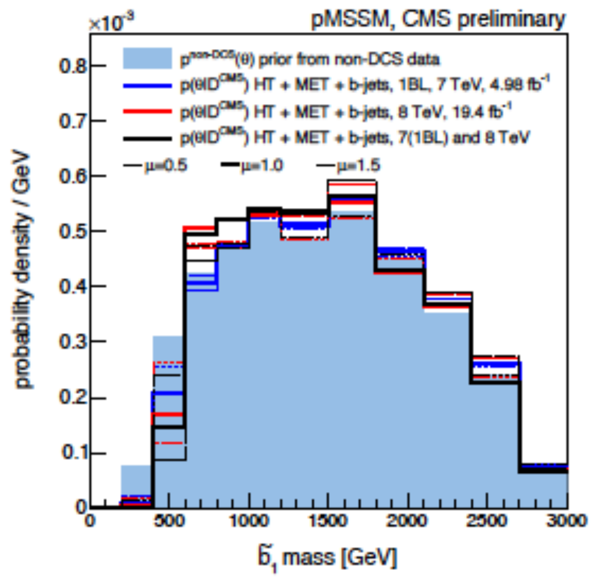


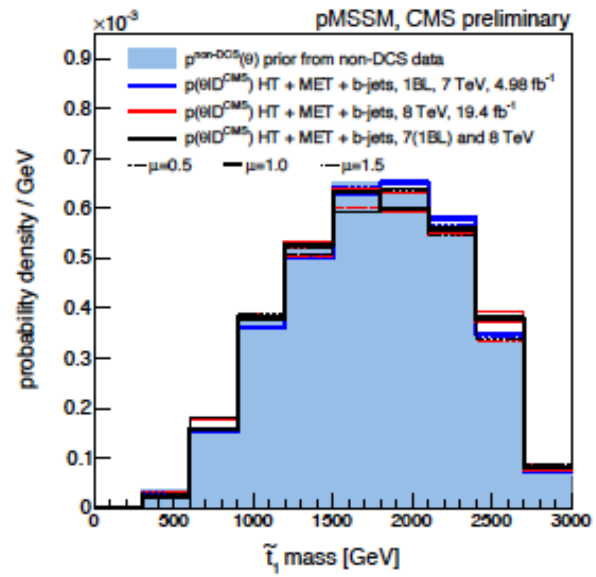
Impact of the HT + MHT search - II



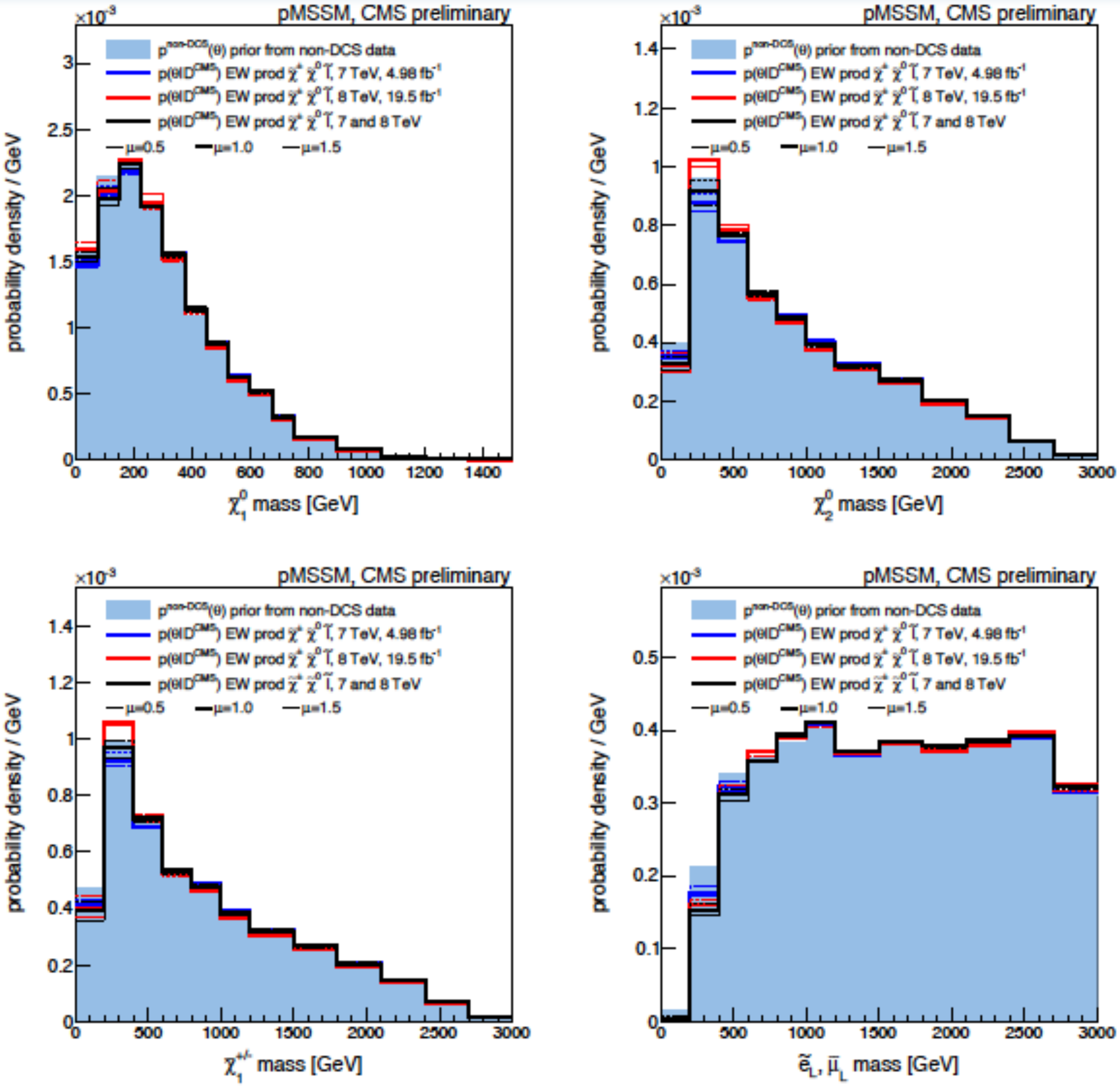
Impact of the HT + MET + jets search







Impact of the EW search



The Z significance

Bayesian analog of frequentist "*n*-sigma'

$$Z(\theta) = \mathrm{sign}(\ln \mathrm{B}_{10}(\theta))\sqrt{2|\ln \mathrm{B}_{10}(\theta)|}$$

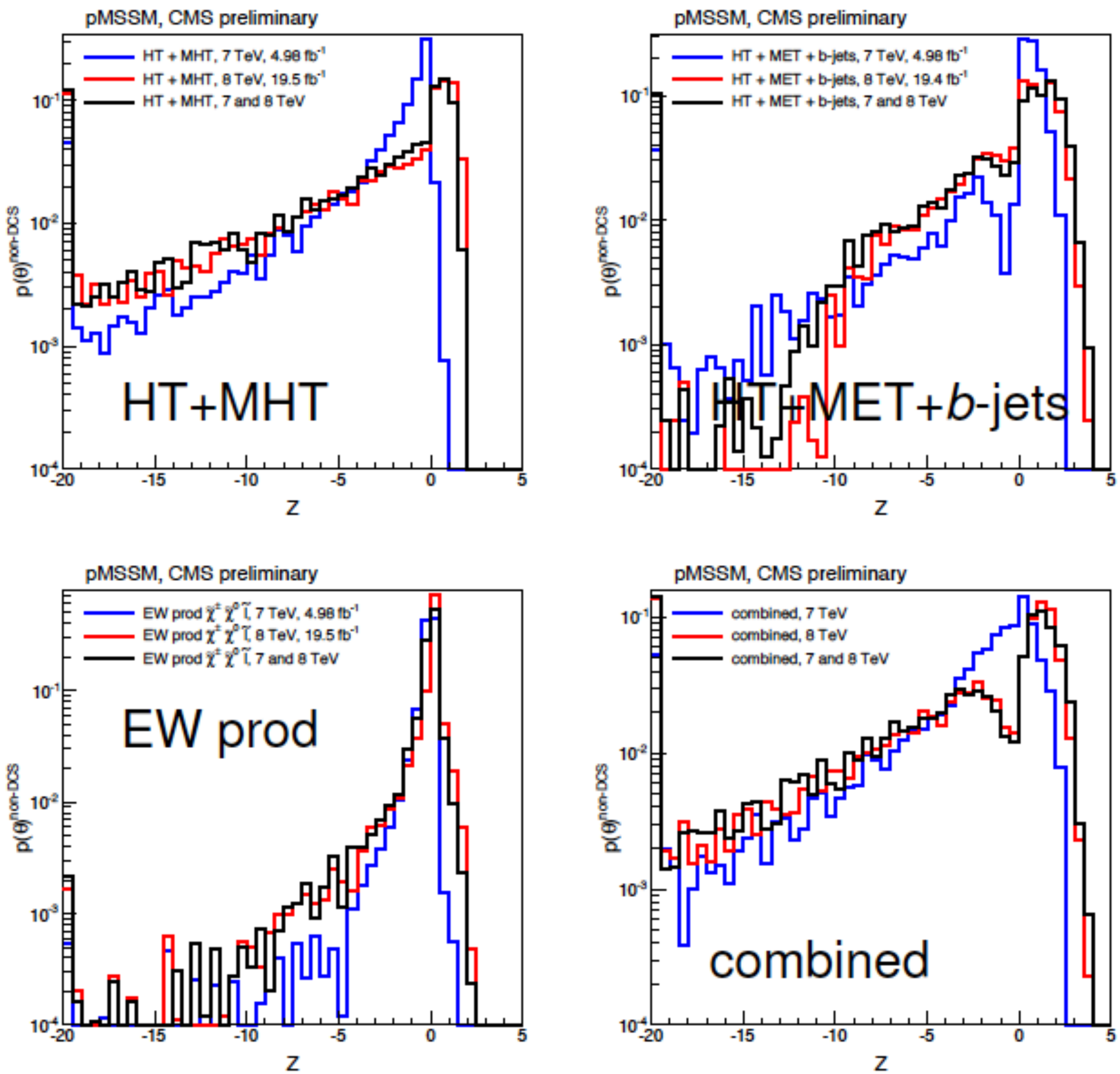
$$B_{10}(\theta) = L(D^{\mathrm{CMS}}|\theta, H_1)/L(D^{\mathrm{CMS}}|H_0)$$

$\mathbf{Z(\theta) < -1.64}$	$\approx$	**signal θ excluded, 95% CL**
$Z(\theta) > 5$	$\approx$	5-σ discovery

Combination:

Z: Z_l with max $|Z_l|$

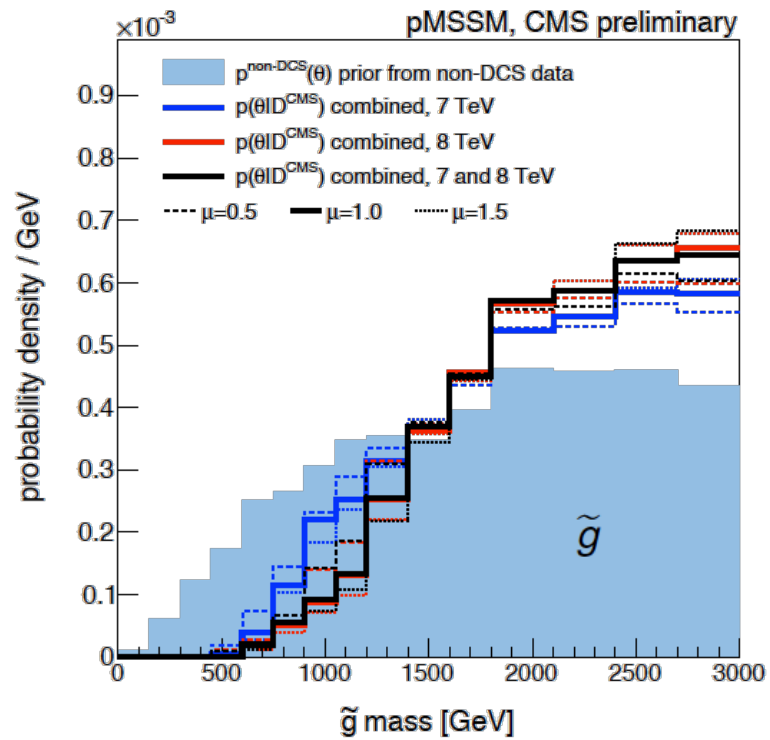
Z distributions

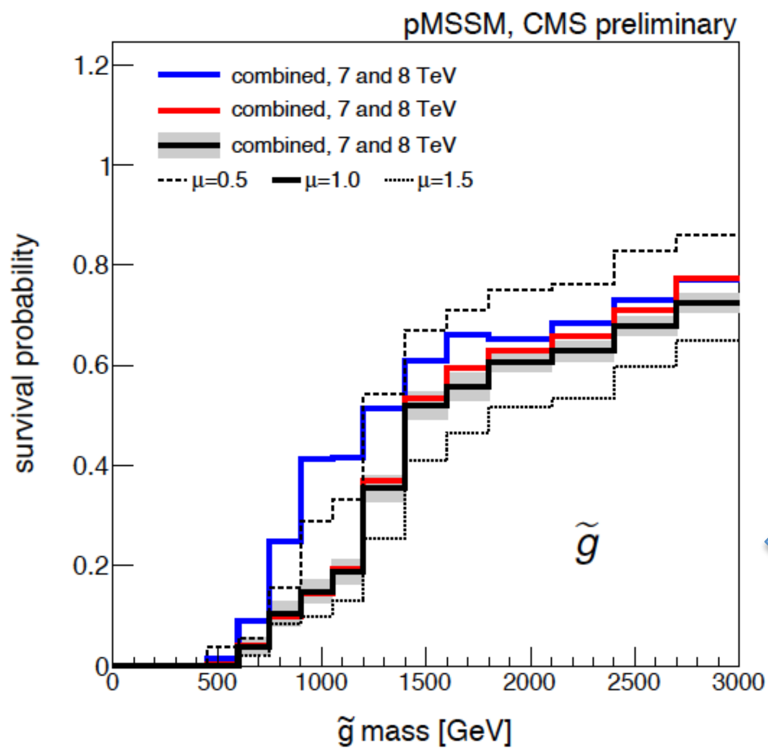


Z likelihood and survival probability

Z likelihood:

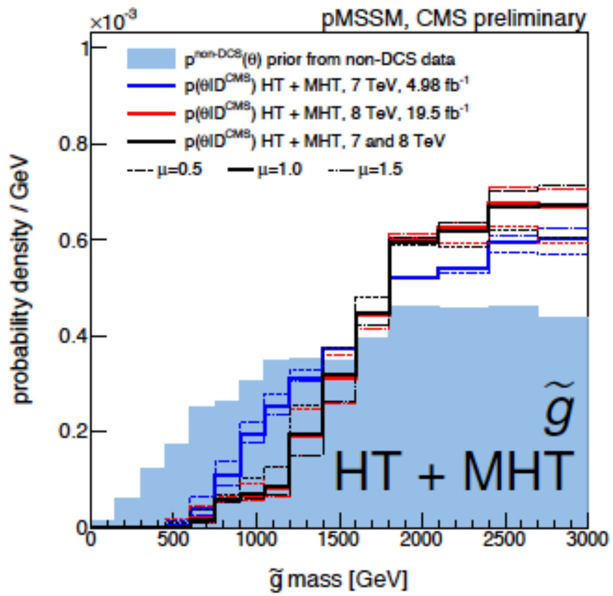
$$L(D^{\mathrm{CMS}}|\theta) = \begin{cases} 0 \text{ if } Z_{\mathrm{best}} < -1.64 \\ 1 \text{ if } Z_{\mathrm{best}} \geq -1.64 \end{cases}$$

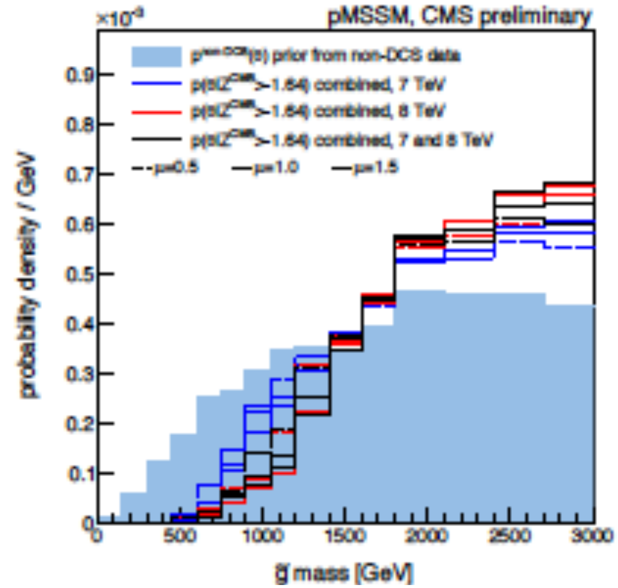


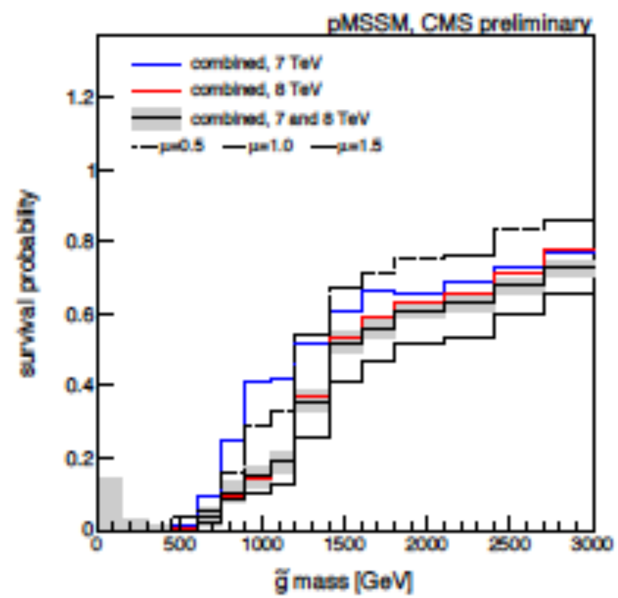


Survival probability is defined as the fraction of points per bin surviving the cut Z > -1.64.

Combined impact: gluinos

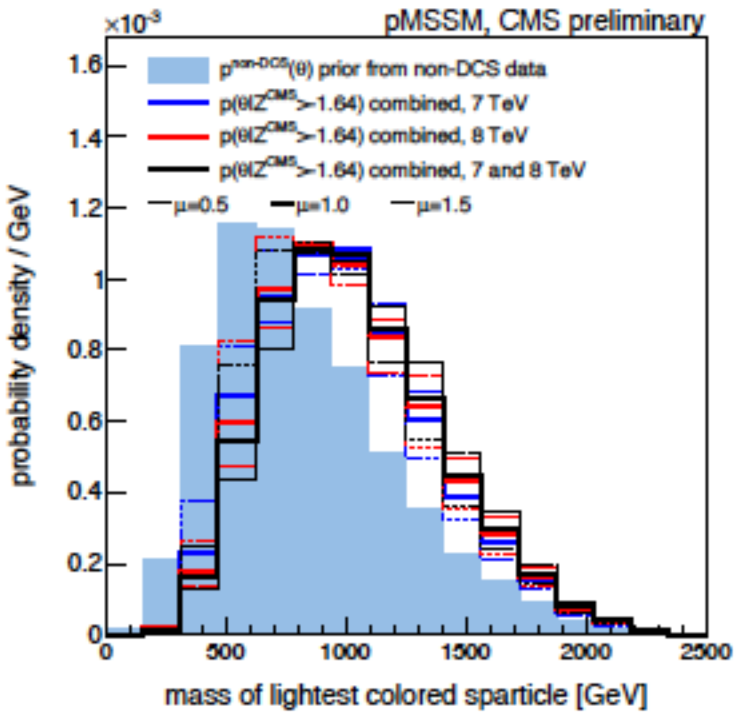


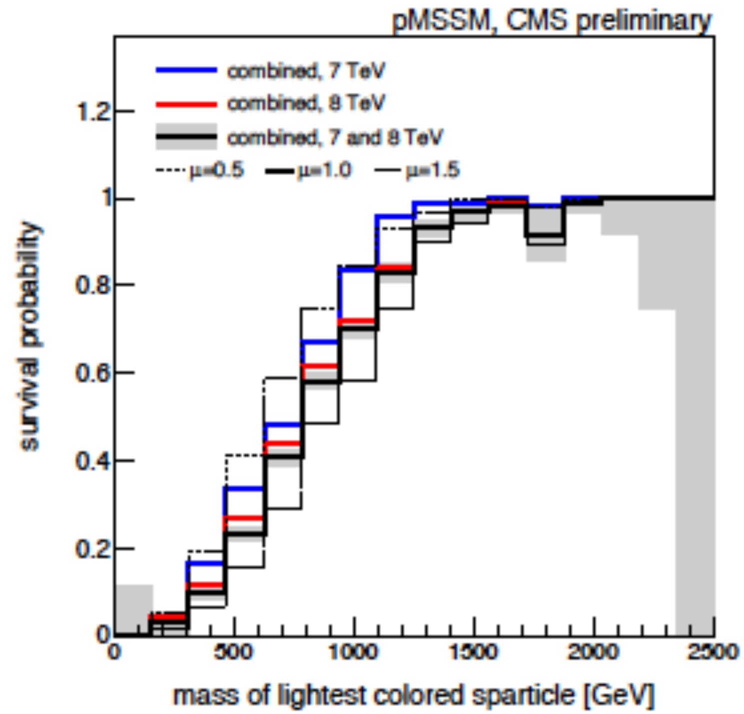




- HT + MHT search drives sensitivity in the colored sector.
- Gluino mass is strongly disfavored below 1200 GeV.

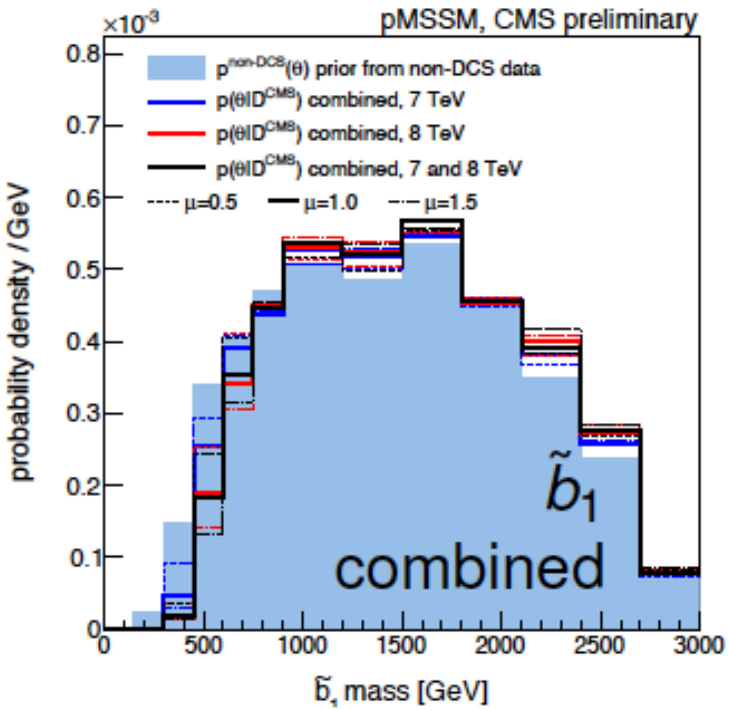
Combined impact: Colored particles

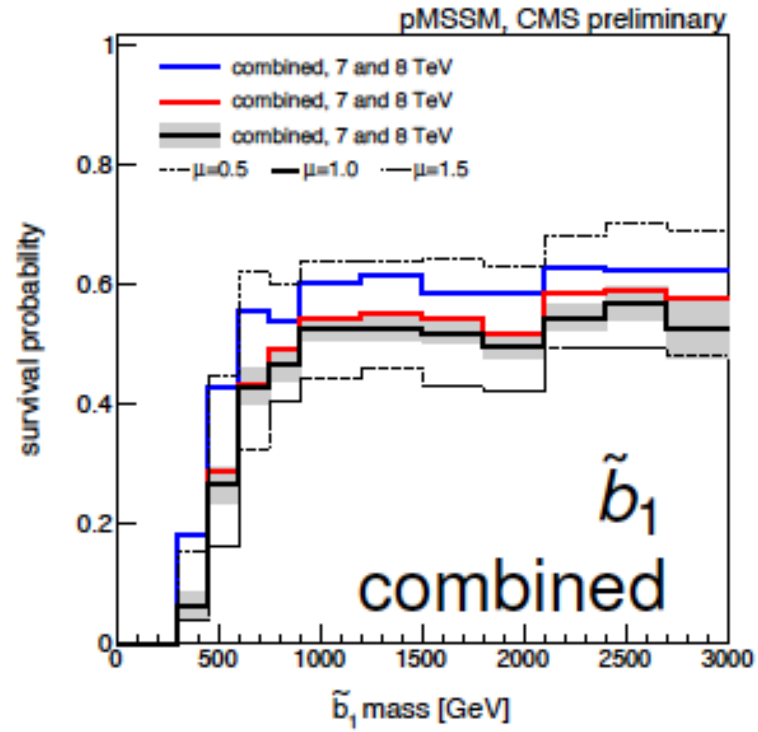




CMS sensitivity requires the model to have a colored sparticle with mass below 1300 GeV.

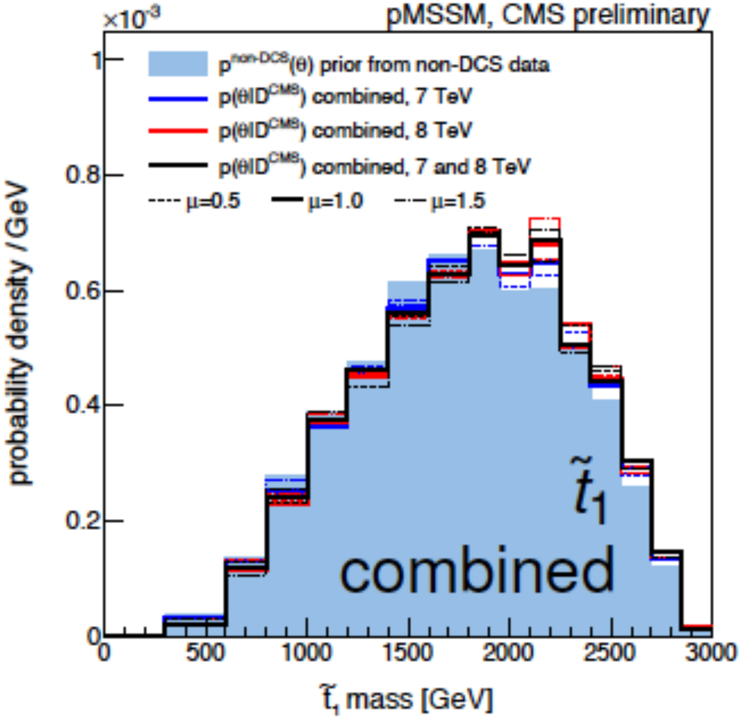
Combined impact: 3rd gen - I

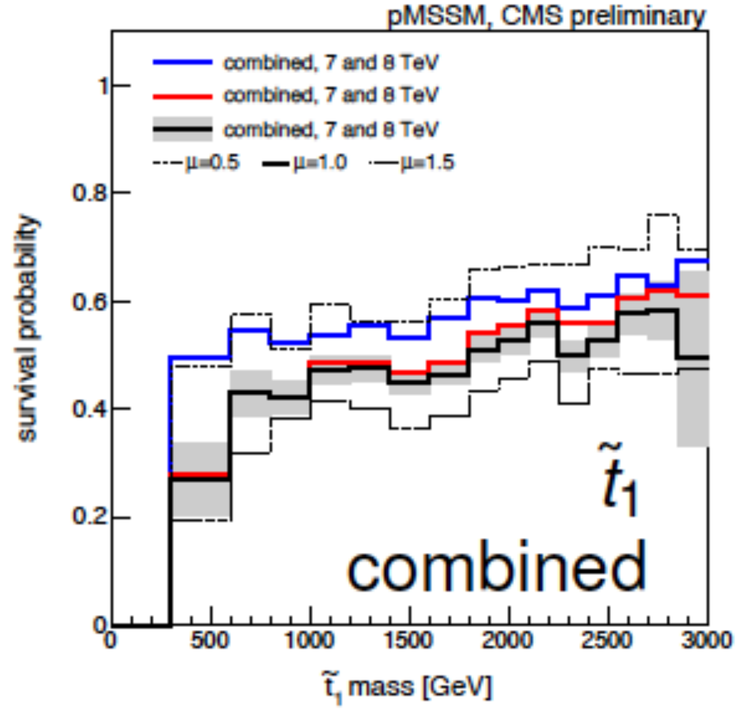




CMS sensitivity to cases with sbottom mass below 600 GeV.

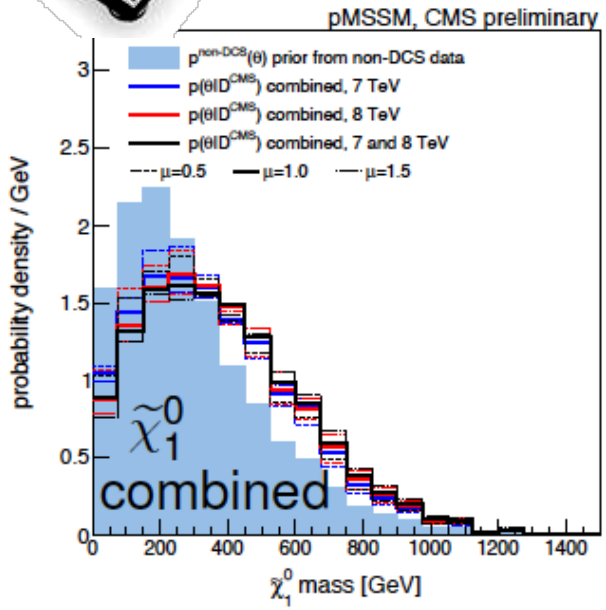
Combined impact: 3rd gen - II



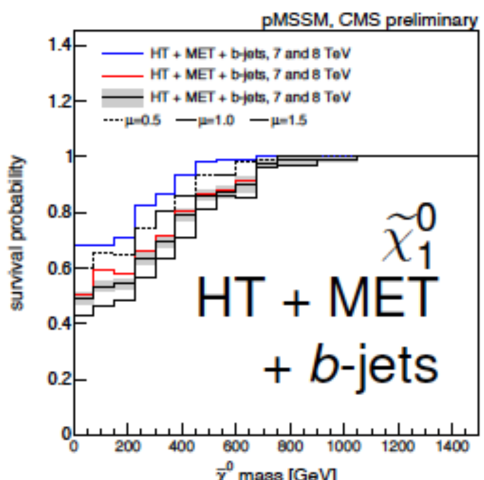


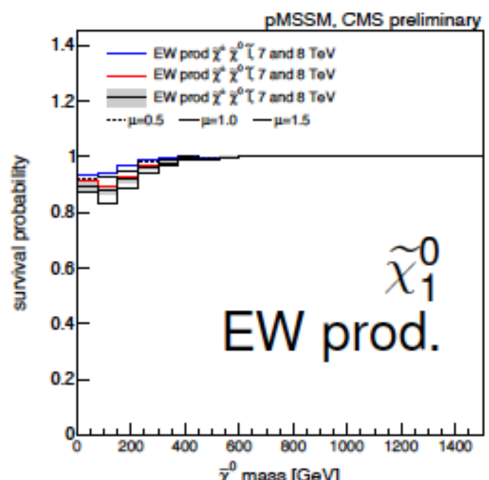
Mild CMS impact below 1 TeV

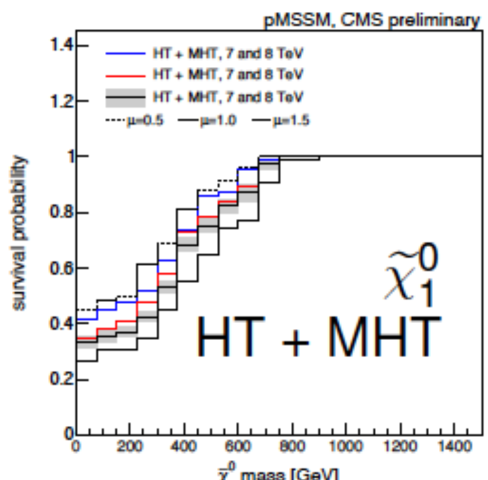
Combined impact: LSP



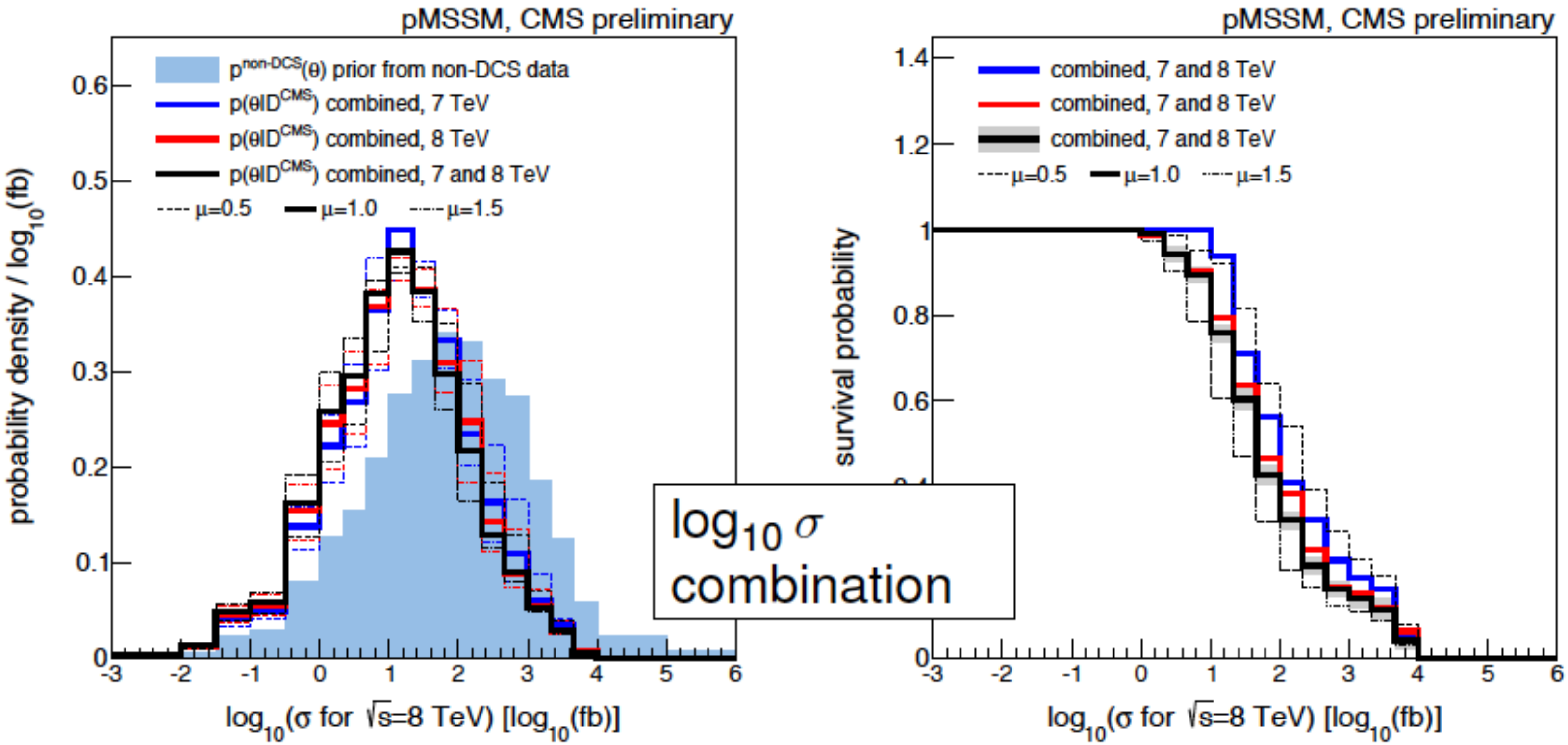
- There is CMS impact on the LSP mass.
- For the hadronic analyses, the impact arises indirectly. As colored sparticle masses are pushed up, LSPs with higher masses also become favorable.



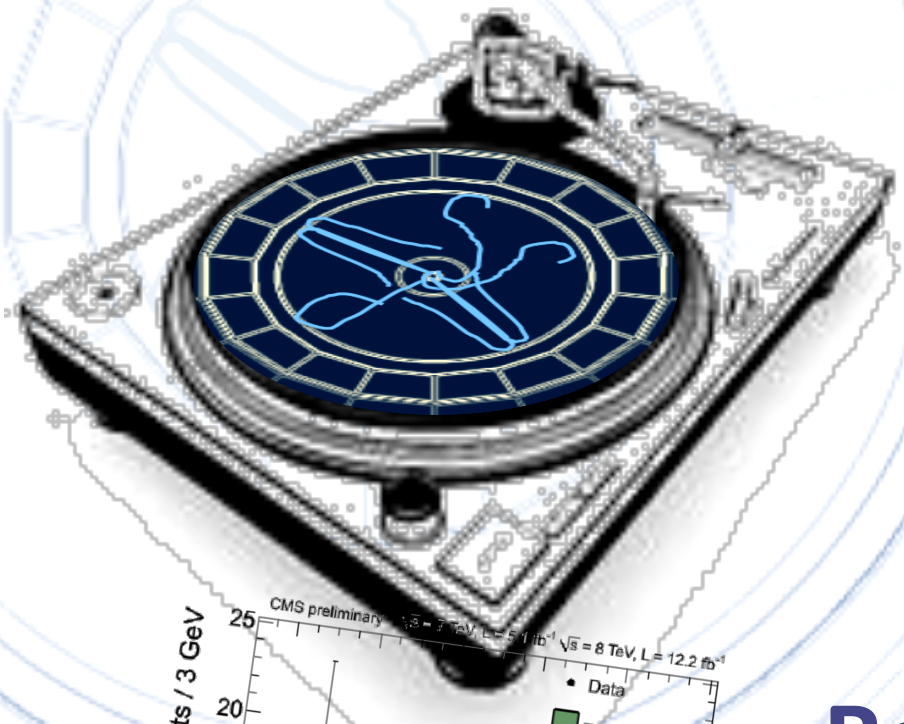


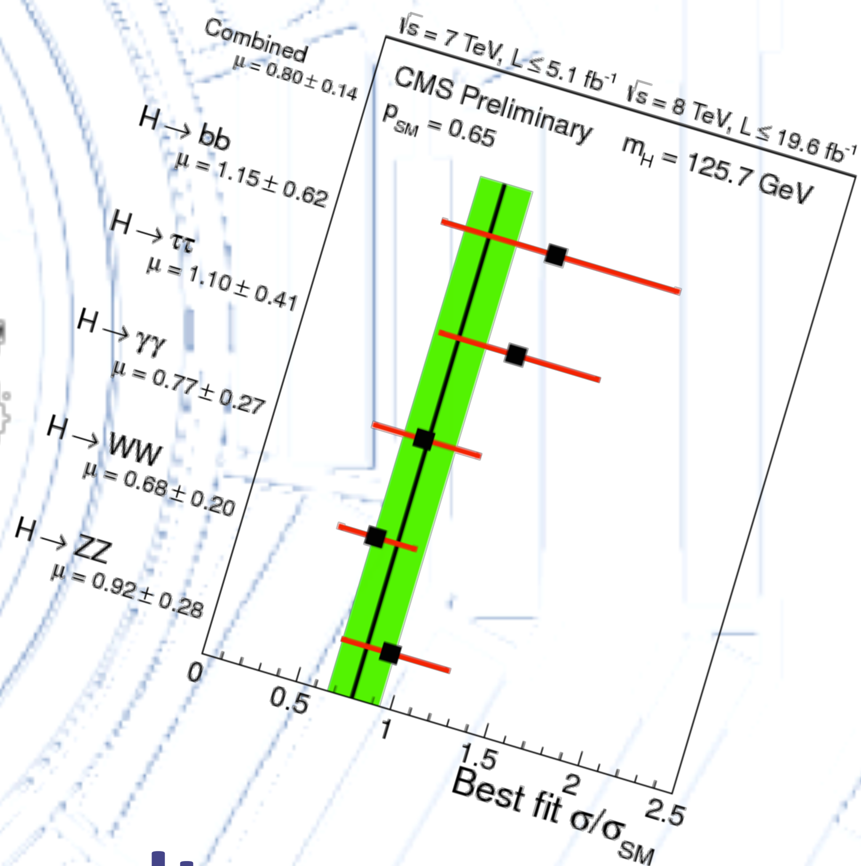


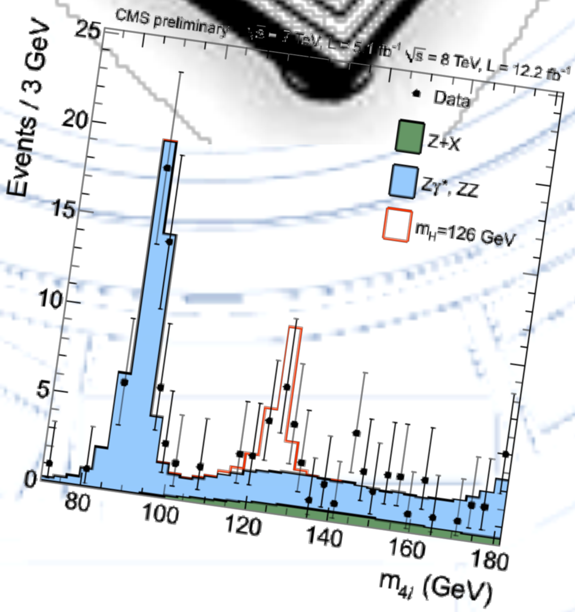
Combined impact: cross section



- Most likely cross section moved down from 100 to 10 fb.
- Scenarios with cross sections > 100 or 1000 fb are still possible.
- Probing scenarios wih cross sections < 1 fb.







Results: Consequences for the Higgs bosons

Higgs production/decay rates

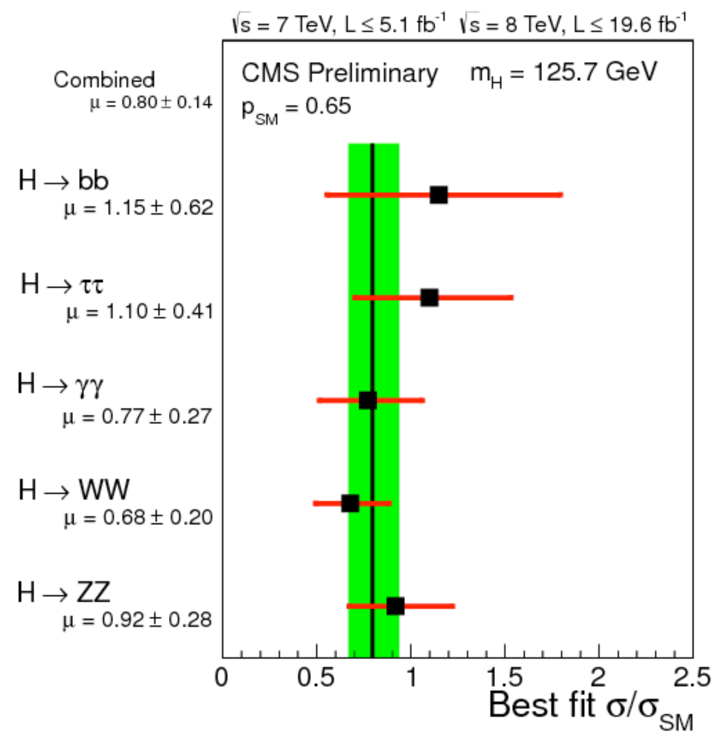
We take a closer look at the points within the $123 < m_h < 128$ window.

We examine the production/decay rates for the Higgs boson.

We use the μ ratio defined as

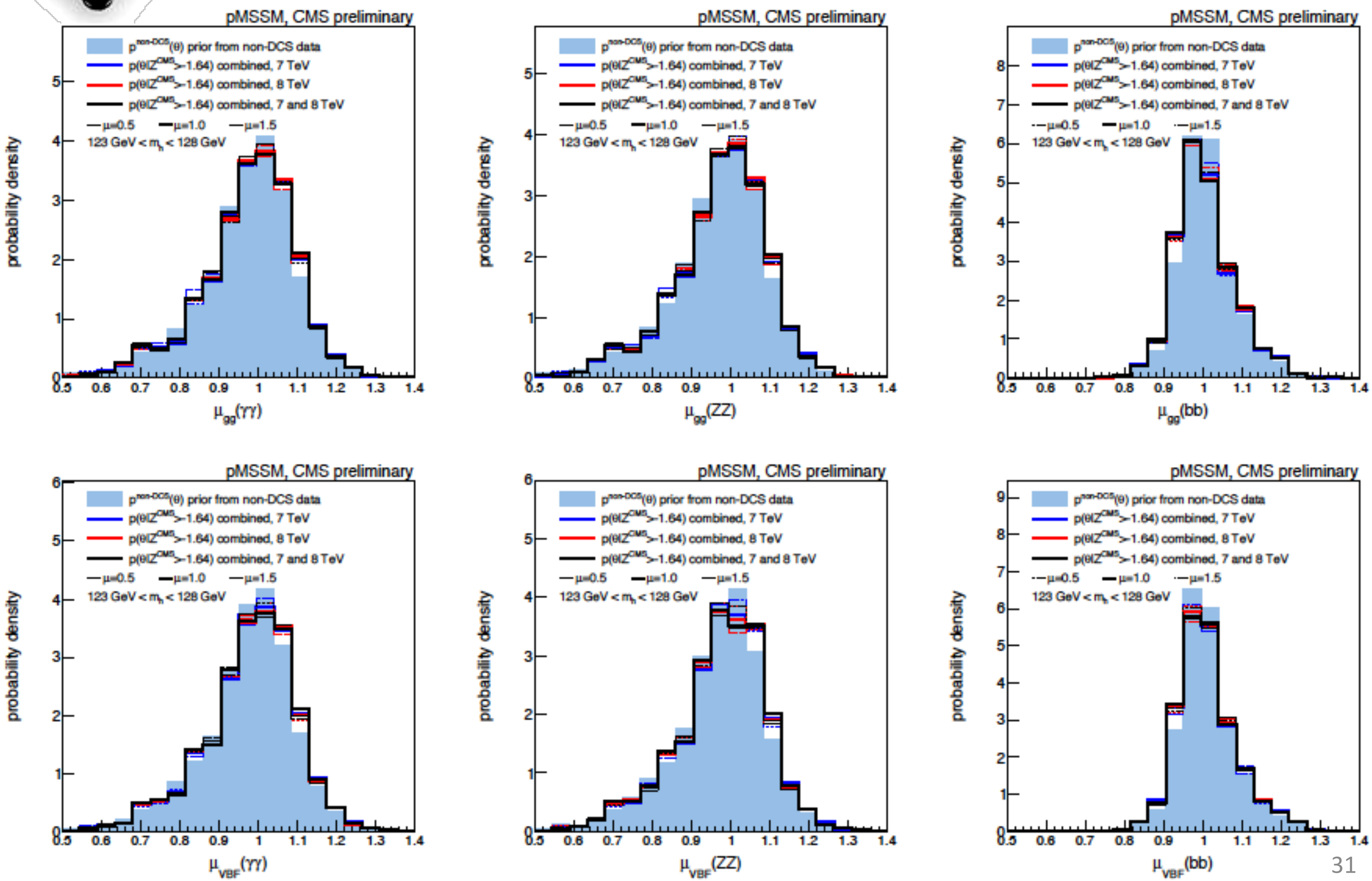
$$\mu_X(Y) = \frac{\sigma(X \to h)\mathrm{BR}(h \to Y)}{\sigma_{\mathrm{SM}}(X \to h_{\mathrm{SM}})\mathrm{BR}(h_{\mathrm{SM}} \to Y)}.$$

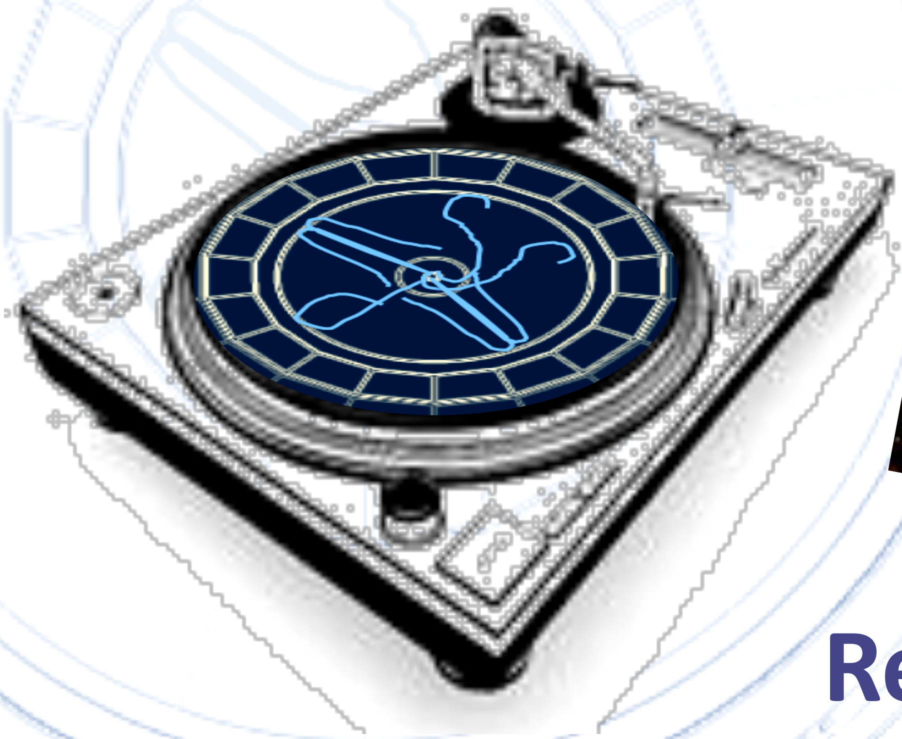
$$X = gg,\ \mathrm{VBF},\ Vh$$
$$Y = \gamma\gamma,\ ZZ,\ WW,\ \tau\tau,\ bb$$



CMS-PAS-HIG-13-005

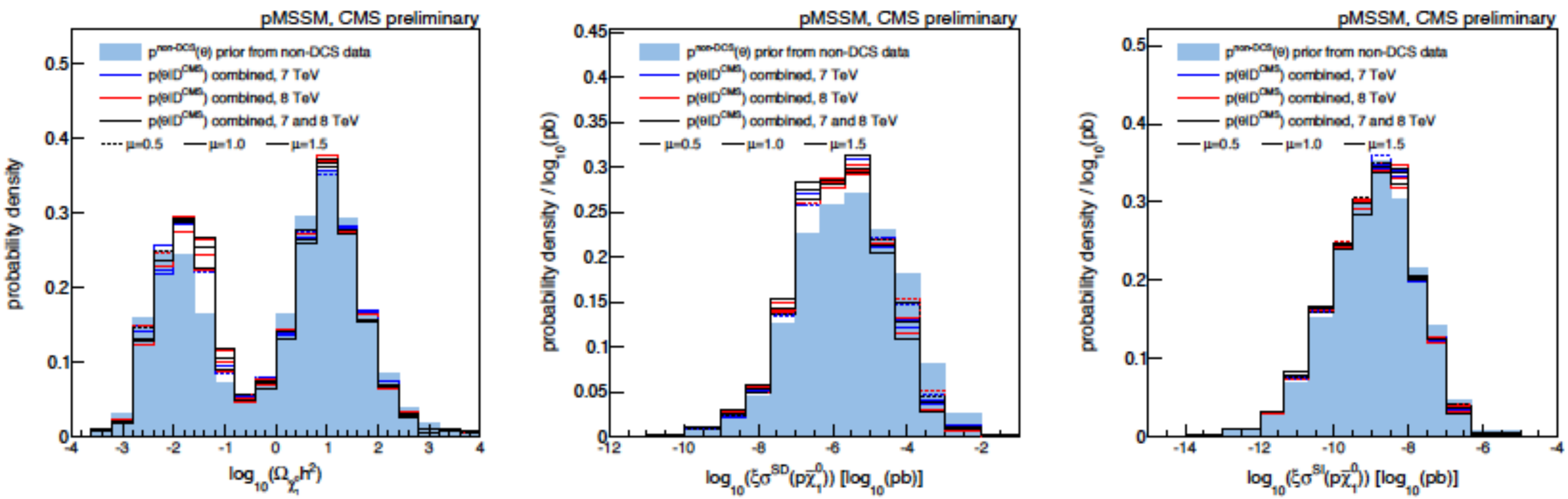
μ ratio distributions





Results: Consequences for dark matter observables

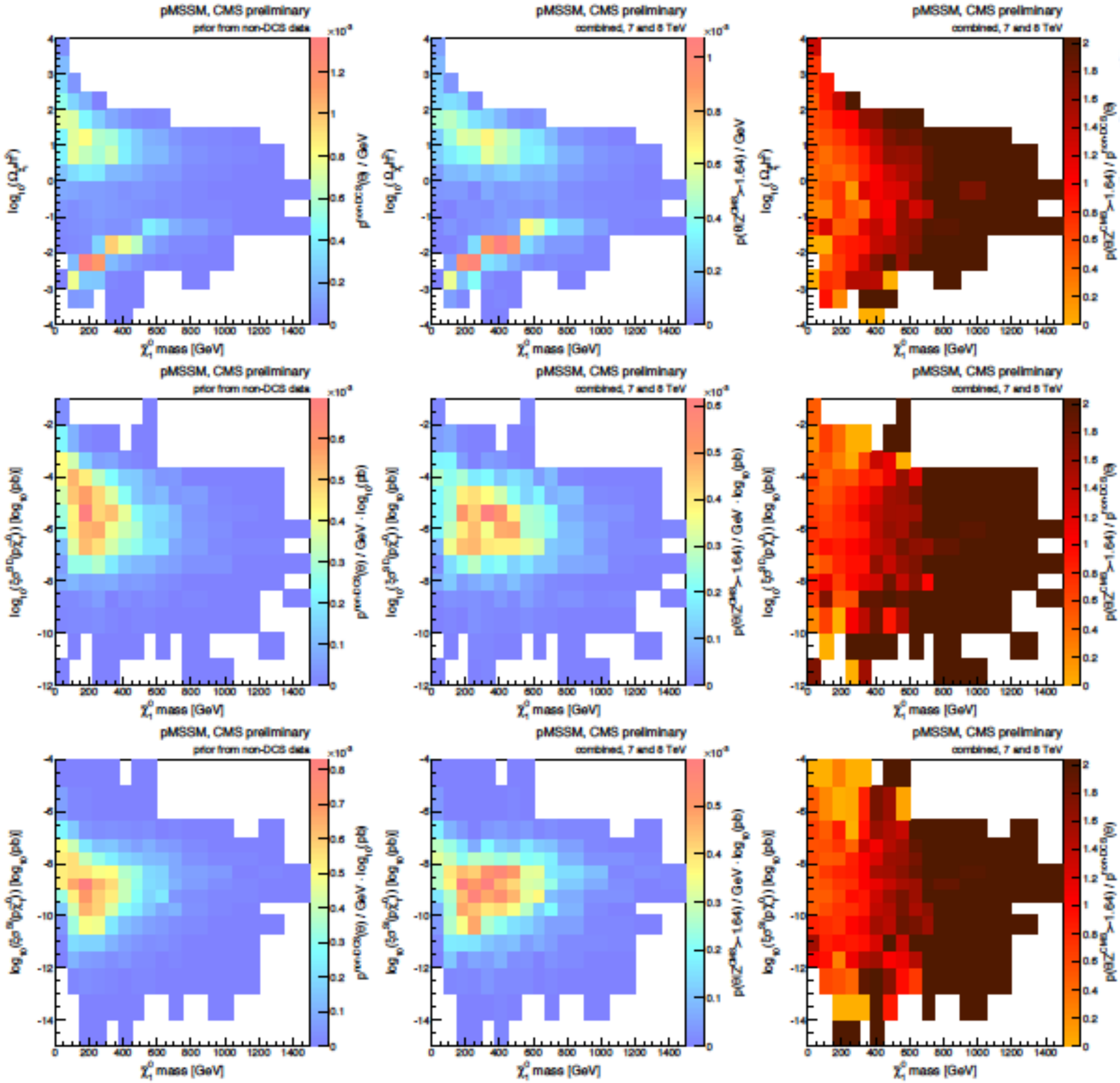
DM implications



impact on DM relic density, spin-dependent and spin-independent DM direct detection cross sections.

- The Planck relic density window is at the dip.
- CMS data favors lower relic density.
- Mild effects on nucleon-LSP cross sections.

impact on DM relic density, spin-dependent and spin-independent DM direct detection cross sections vs. LSP mass. Mid CMS impact.



Conclusions

- We have investigated the impact of a subset of the 7 and 8 TeV CMS SUSY searches on a potentially accessible sub-space of the pMSSM.
- We investigated a subspace with sparticle masses up to 3 TeV.
- We interpreted the results of 3 searches: HT + MHT, HT + MET + b jets and a dedicated EW sparticle search.
- CMS impact mostly on the colored sector (gluino reach up to 1300 GeV), but also sensitive to EW sparticles up to 600 GeV.
- Also studied the effect of the SUSY searches on Higgs and DM variables. Only very mild impact.
- Currently extending the pMSSM interpretation by adding more CMS searches (inclusive, dedicated stop and EW searches).