Constraining SUSY using the relic density and the Higgs boson

Outline:
- Constraining SUSY: Assumptions
- Illustration in mSUGRA
- TeV-Scale MSSM
- Conclusion

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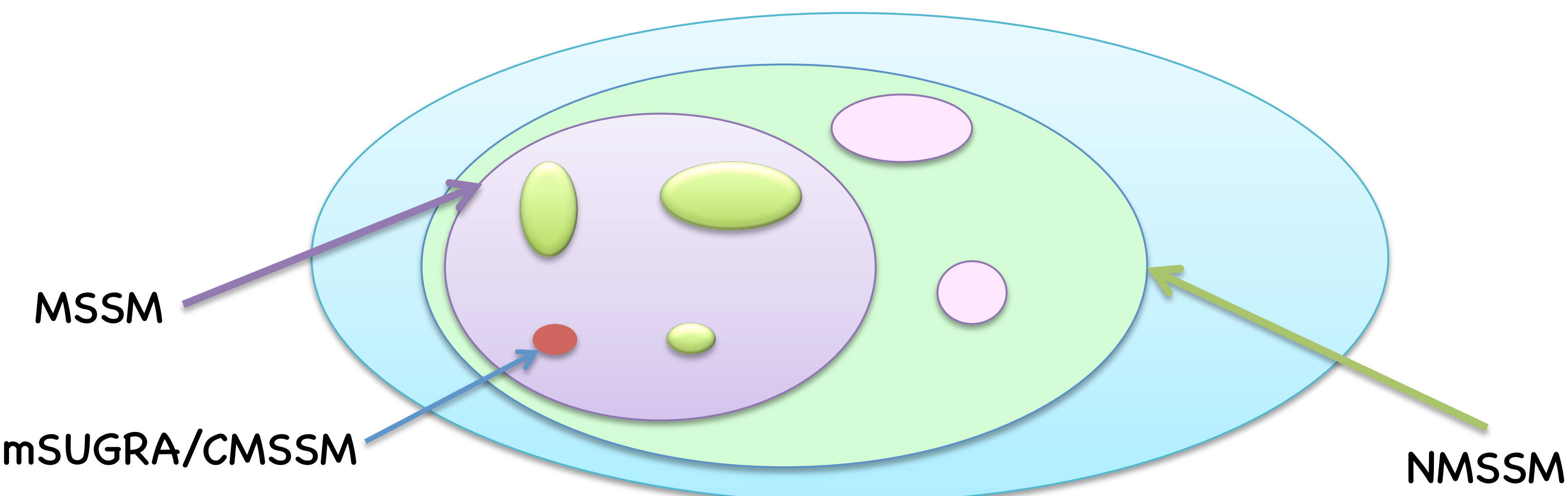
ATLAS EXPERIMENT

Constraining SUSY

Assuming a specific SUSY model, the fundamental parameters (driving the mass spectrum) can be constrained:

- either by direct searches @the LHC
- Or/and via Standard Model -Higgs/rare decays- &Dark Matter… :

… But there is a wide variety of them



Adapted from Rizzo

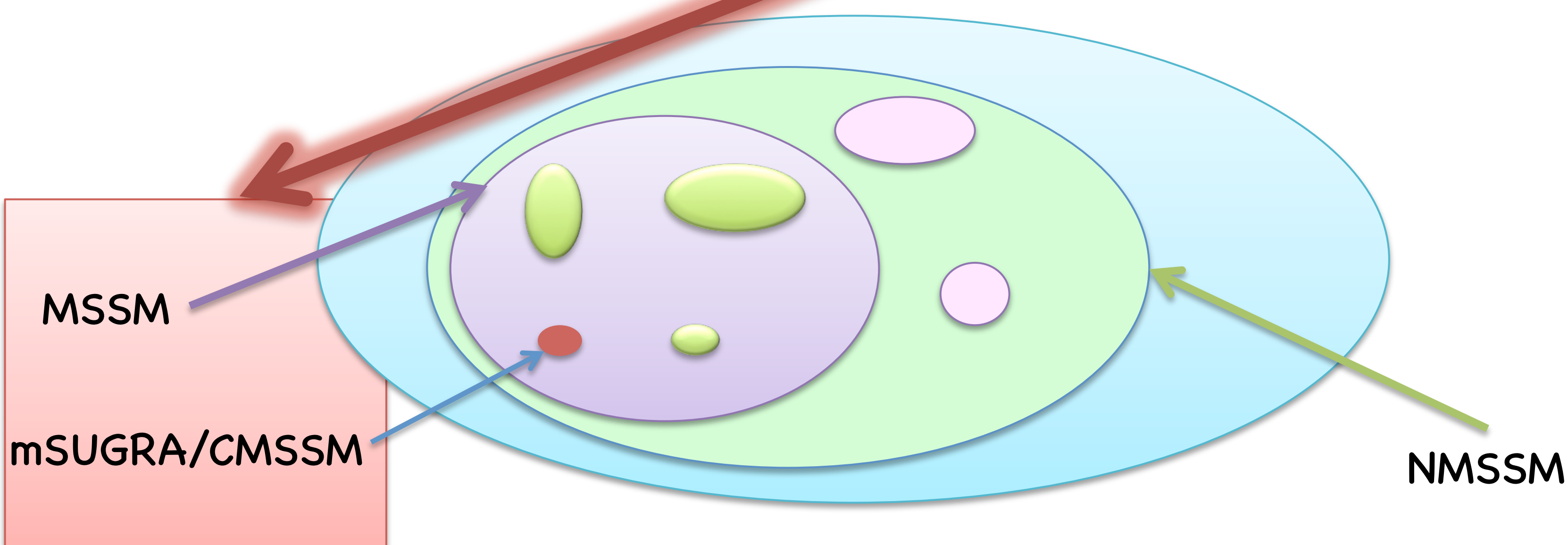
Constraining SUSY

Assuming a specific SUSY model, the fundamental parameters (driving the mass spectrum) can be constrained:

- either by direct searches @the LHC
- Or/and via Standard Model -Higgs/rare decays- &Dark Matter :

Points that will be considered/ illustrated in this talk

… But there is a wide variety of the[…]



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Assumptions/Constraints ?

The input measurements

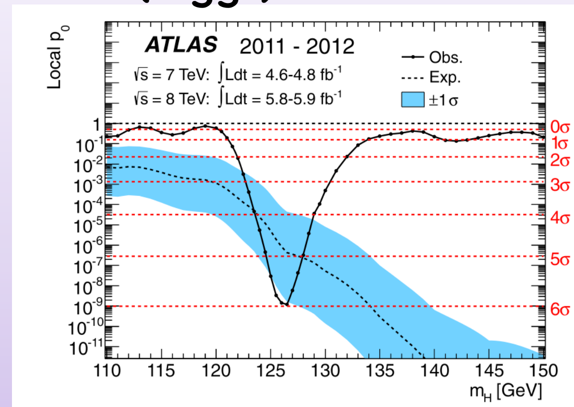
=> m(Higgs), and Ωcdm are the most constraining

TABLE I. Some of the key measurements used in our analysis, including the error. The last number is the theoretical uncertainty on the supersymmetric prediction, except for the BR($b \to X_s \gamma$) and m_t for which no theoretical uncertainty is considered.

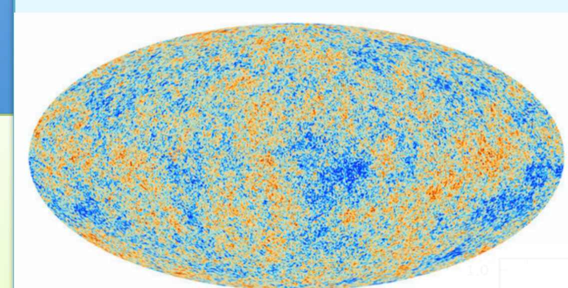
Measurement	Value and error	
m_h	$(126 \pm 0.4 \pm 0.4 \pm 3)$ GeV	[39]
$\Omega_{\rm cdm} h^2$ Planck	$0.1187 \pm 0.0017 \pm 0.012$	[4]
$\Omega_{\rm cdm} h^2$ WMAP-9year	$0.1157 \pm 0.0023 \pm 0.012$	[16]
BR($B_s \to \mu^+ \mu^-$)	$(3.2^{+1.5}_{-1.2} \pm 0.2) \times 10^{-9}$	[44]
BR($b \to X_s \gamma$)	$(3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$	[45]
$\Delta\mu$	$(287 \pm 63 \pm 49 \pm 20) \times 10^{-11}$	[46]
m_t	$(173.5 \pm 0.6 \pm 0.8)$ GeV	[47]

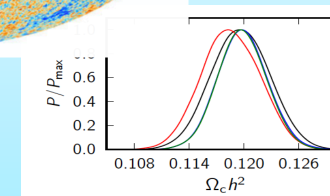
+Xenon100 + Higgs Couplings +EW precision

m(higgs)



Ωcdm [Planck vs. Wmap]





Which tool for which computation:

Light Higgs mass : SuSpect2

Higgs BR : Susy-Hit HDecay

Cold DM density : MicrOMegas

Electroweak precision : SusyPope

B decay & $(g-2)_\mu$: SuSpect2+MicrOMegas

Context

In this talk: illustration in mSUGRA & a TeV-scale 13 parameters MSSM

What was in the litterature (@ the time of this paper) ??

FITTINO: LHC data + WMAP-7year on MSUGRA and NUHM
[J. High Energy Phys. 06 (2012) 098.]

MASTERCODE: same mSUGRA and nonuniversal Higgs models including Xenon100
[Eur. Phys. J. C 72, 2243 (2012).].

C. BOEHM et al.: Light neutralino DM with Planck + Higgs + Xenon100
in the TeV-scale MSSM [J. High Energy Phys. 06 (2013) 113.].

BayesFITS: MSUGRA + 9 parameters MSSM
[J.HighEnergyPhys.09(2013)061.][Phys. Rev. D 88, 055012 (2013).]

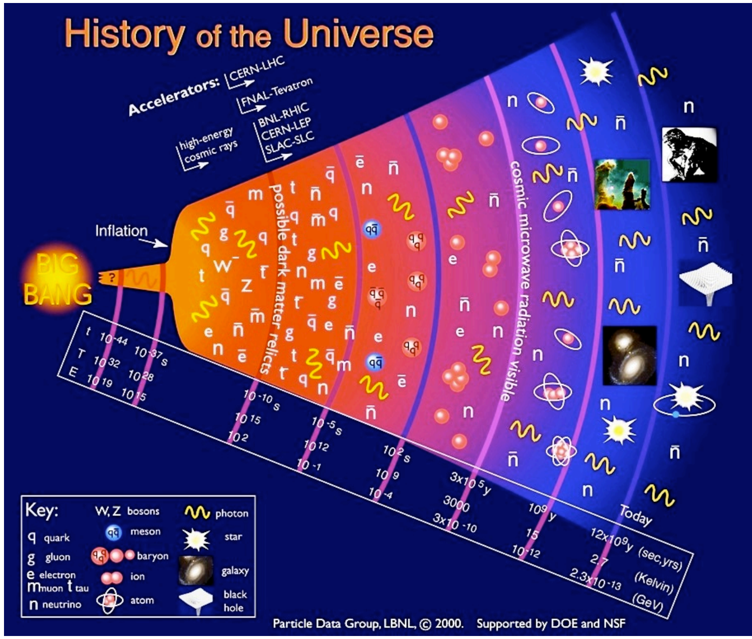
+ ..a lot more

Why this analysis ??

$\Rightarrow$ Up to date measurements

$\Rightarrow$ Wider explored SUSY parameters space

Dark Matter (DM)



* Early Universe: all particules are in thermal equilibrium.

* The Universe cools down and expands: interaction rate too small for equilibrium

* As the density decreases the annihilation rate becomes small compared to the expansion: this is the LSP freeze out.

The number density of DM particle is given by:

$$\frac{dn}{dt} = -3Hn - \langle \sigma_A v \rangle (n^2 - n_{eq}^2),$$

H: the Hubble expansion rate

thermally averaged annihilation cross-section

number density in thermal equilibrium

Dilution from expansion

Annihilation processes

production processes

$$\Omega_{cdm} h^2 \approx 1./\langle \sigma v \rangle$$

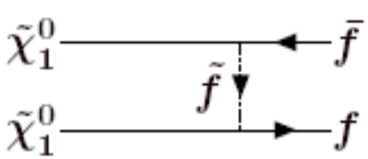
The neutralino as LSP

In the following we will assume the lightest neutralino to be the LSP.
With R parity conservation: the LSP is stable.

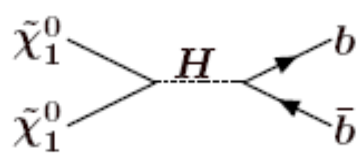
The neutralinos are linear combinations of the neutral Higgsinos and EW gauginos.
The neutralino mass matrix in the gauge eigenstates basis ($\tilde{B}$, $\tilde{W}^0$, $\tilde{H}_1$, $\tilde{H}_2$):

$$\mathcal{M}_N = \begin{pmatrix} M_1 & 0 & -M_Z c_\beta s_W & M_Z s_\beta s_W \\ 0 & M_2 & M_Z c_\beta c_W & -M_Z s_\beta c_W \\ -M_Z c_\beta s_W & M_Z c_\beta c_W & 0 & -\mu \\ M_Z s_\beta s_W & -M_Z s_\beta c_W & -\mu & 0 \end{pmatrix} \Rightarrow \tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W} + N_{13}\tilde{H}_1 + N_{14}\tilde{H}_2$$

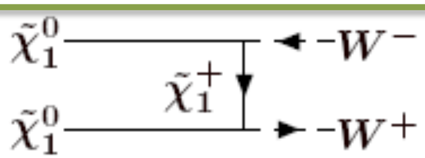
Some contributions to the annihilation/co-annihilation cross section:



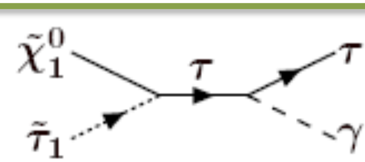
Bino LSP
Light $\tilde{\chi}^0{}_1$



Higgs funnel
mH≈2m($\tilde{\chi}^0{}_1$)



LSP with strong Higgsino component



Co-annihilation
m($\tilde{\tau}$)≈m(LSP)

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General Philosophy:

1/ We build the likelihood function (measurements vs. predictions),

2/ We use Monte Carlo Markov Chains to explore the parameter space

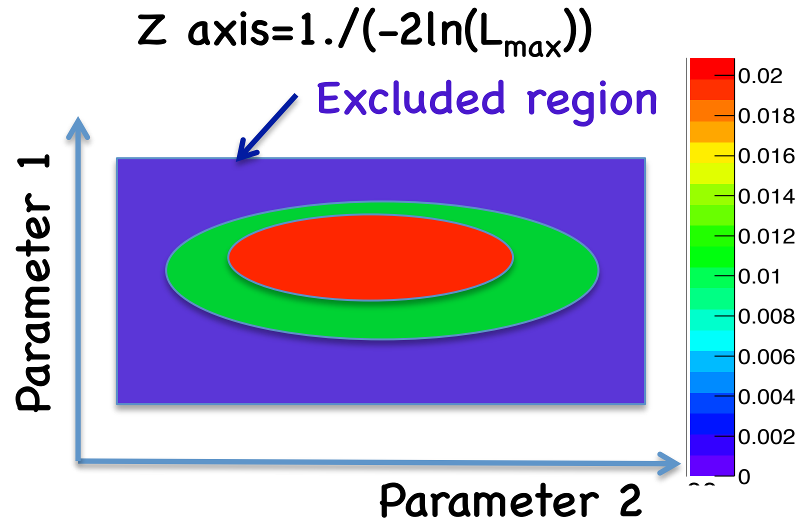
mSUGRA: 49 chains of 200k points each

MSSM: 100 chains of 200k points each

3/ We build profile likelihoods

Profile Likelihoods

2D profiles are obtained after maximization of the likelihood function on all the other dimensions (except for parameter 1 and 2 that are fixed) of the parameter space



⇒ Equivalent $-2\ln(L_{max})$ regions are found and will be illustrated with dedicated points

⇒ $-2\ln(L_{max}) \approx 46$ (d.o.f=75) in mSUGRA: constant offset due to Δa_μ

NB: m_{top} is also let free within the error bars for all the fits

mSUGRA illustration

Parameters:

m_0 the common scalar mass parameter
$m_{1/2}$ the common gaugino mass parameter
A_0 the common trilinear mass parameter
$\tan\beta$ the ratio of the vacuum expectation values of the two Higgs doublets
sign(μ) the sign of the Higgsino mass parameter
=> both cases have been investigated: only $\mu>0$ is shown below
+ the top mass

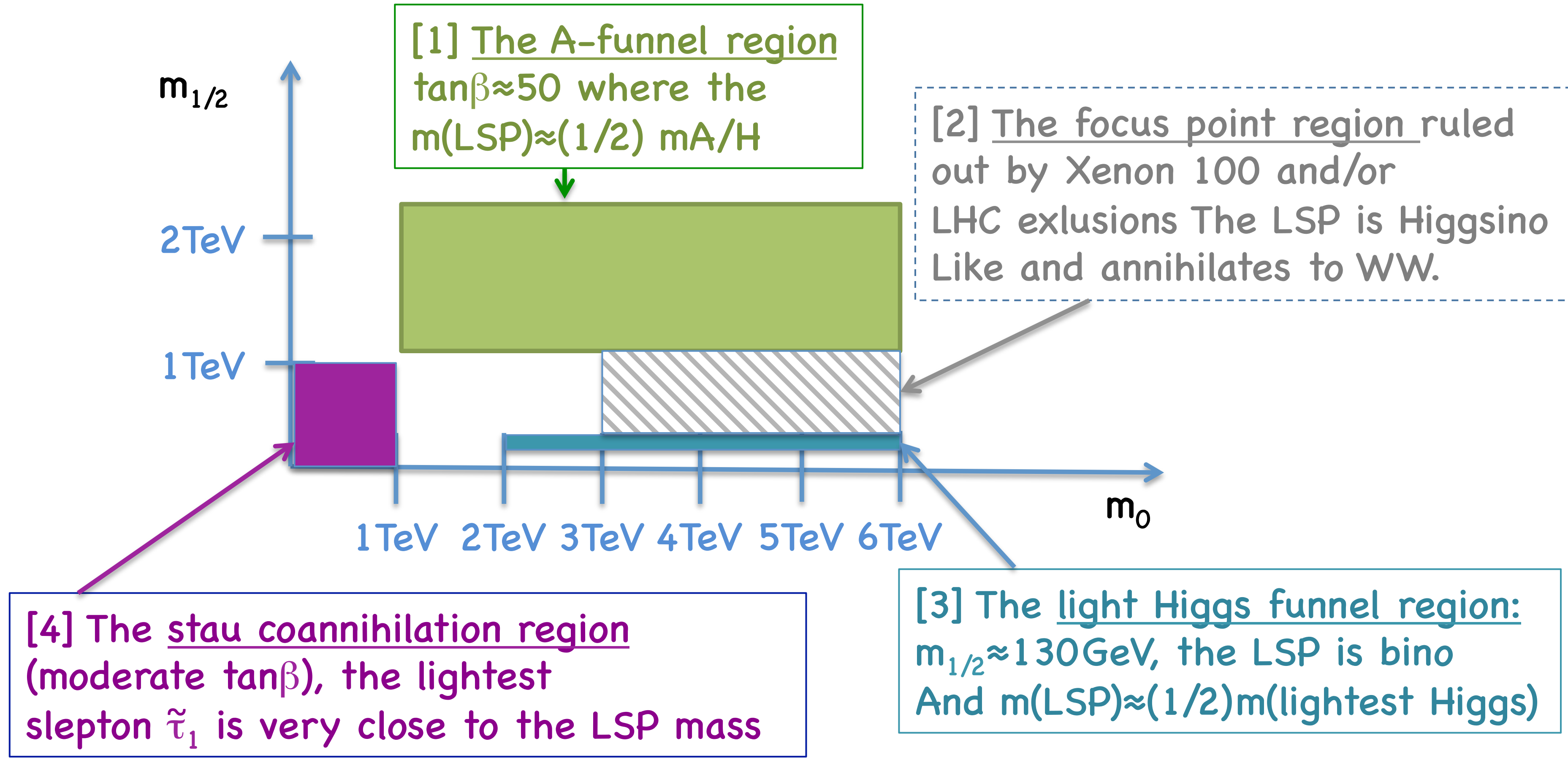
Assumed Bounds:

$m_0<5$TeV
$m_{1/2}<5$TeV
$|A_0|<4$TeV
$\tan\beta<=60$

⇒ Small number of parameters
⇒ Highly correlated
The light higgs mass measurement constrains the parameter space through the top squark sector

The parameters are set at mGUT
We evolve the soft SUSY-Breaking parameters to the TeV scale [using SUSPECT2], and compute the corresponding mass spectra.

Annihilation channels: Illustration with mSUGRA



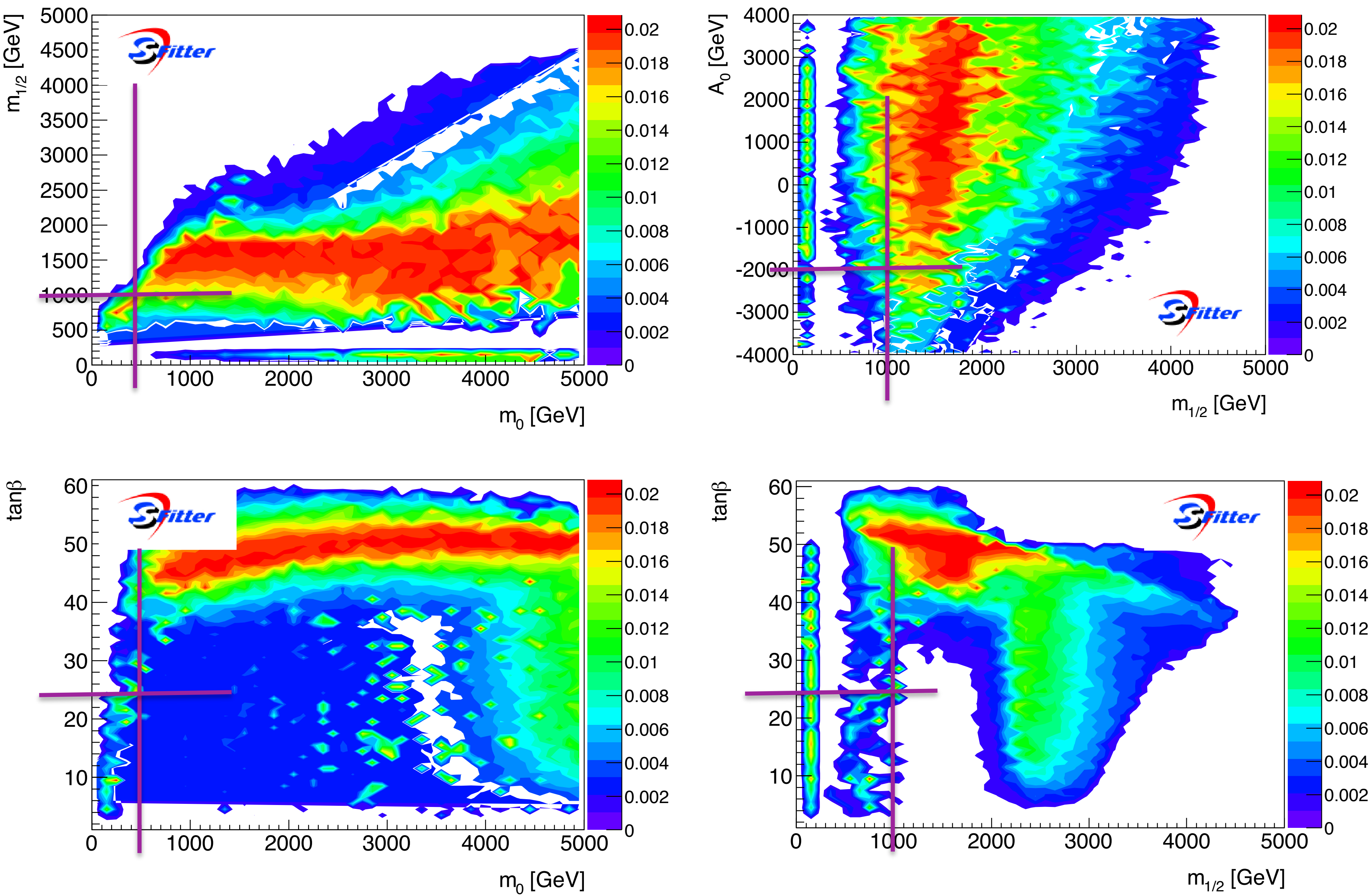
[5] The region of coannihilation in the neutralino-chargino sector. The LSP is mainly bino or Higgsino (not in mSUGRA)

mSUGRA

Coannihilation

⇒ Mtop(fitted value)=174. GeV

⇒ $M(\tilde{\chi}_1^0)$=429GeV, $M(\tilde{q})$≈2TeV, $M(\tilde{g})$≈2TeV



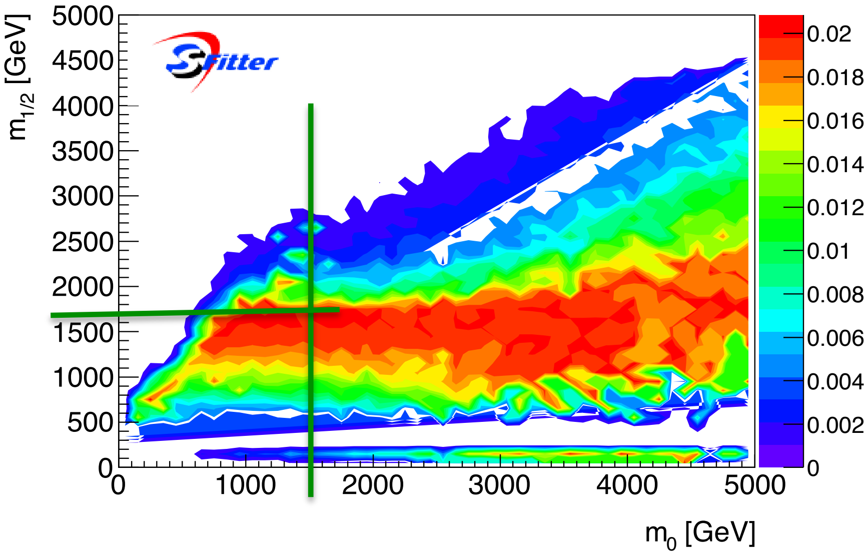
mSUGRA

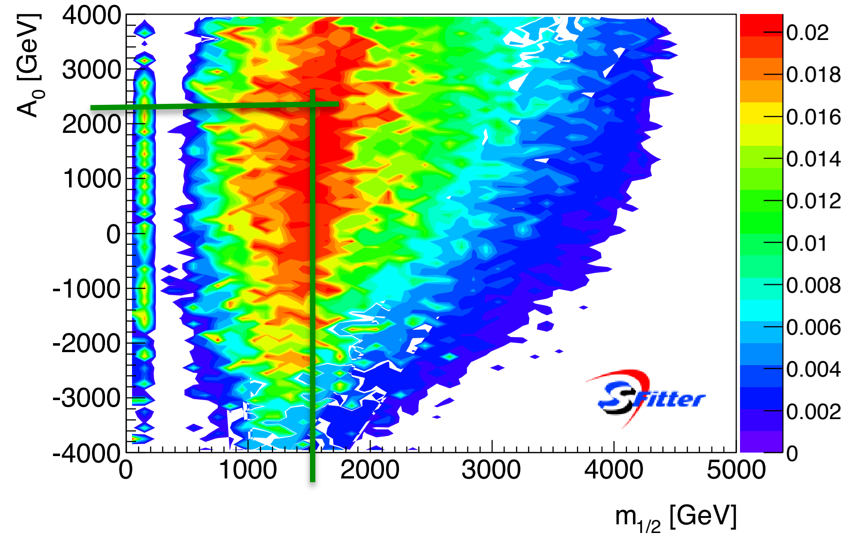
A funnel

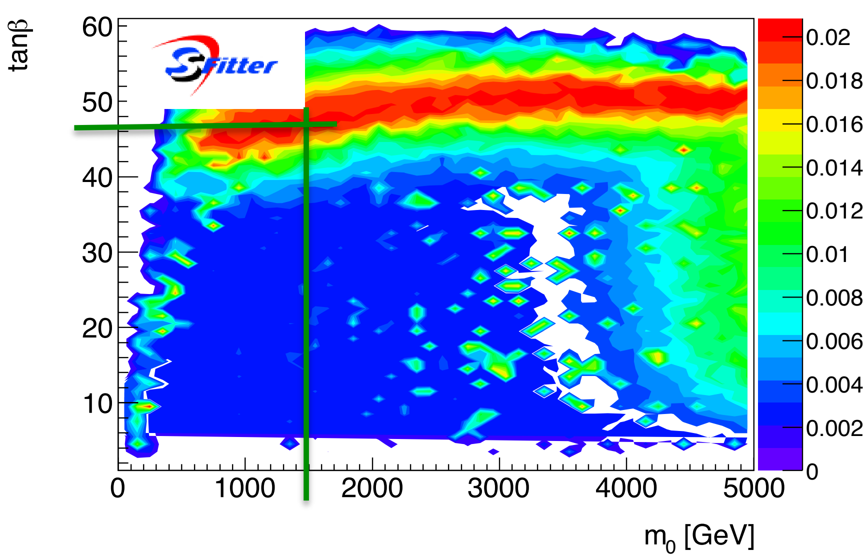
⇒ the LSP is mostly bino

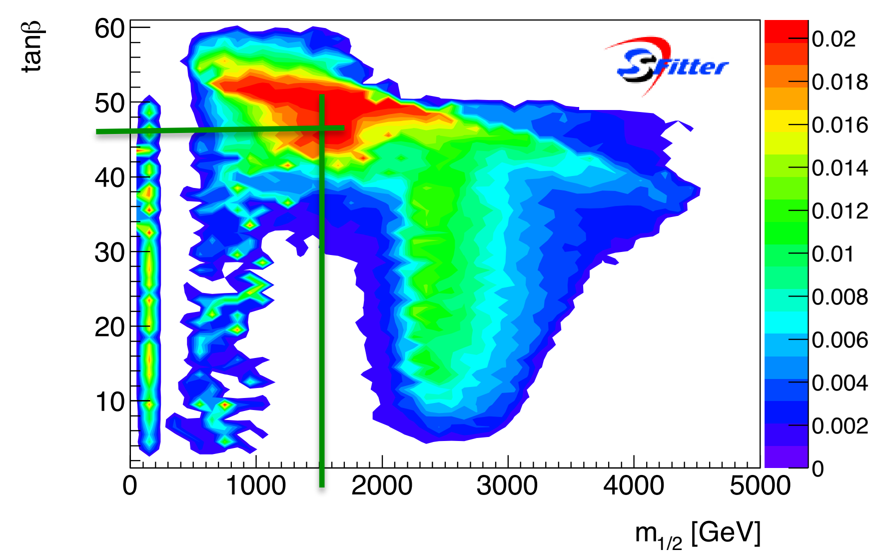
⇒ Mtop(fitted value)=173.9GeV

⇒ $M(\tilde{\chi}_1{}^0)$=745GeV, $M(\tilde{q})\approx$3.4TeV, $M(\tilde{g})\approx$3.6TeV









mSUGRA

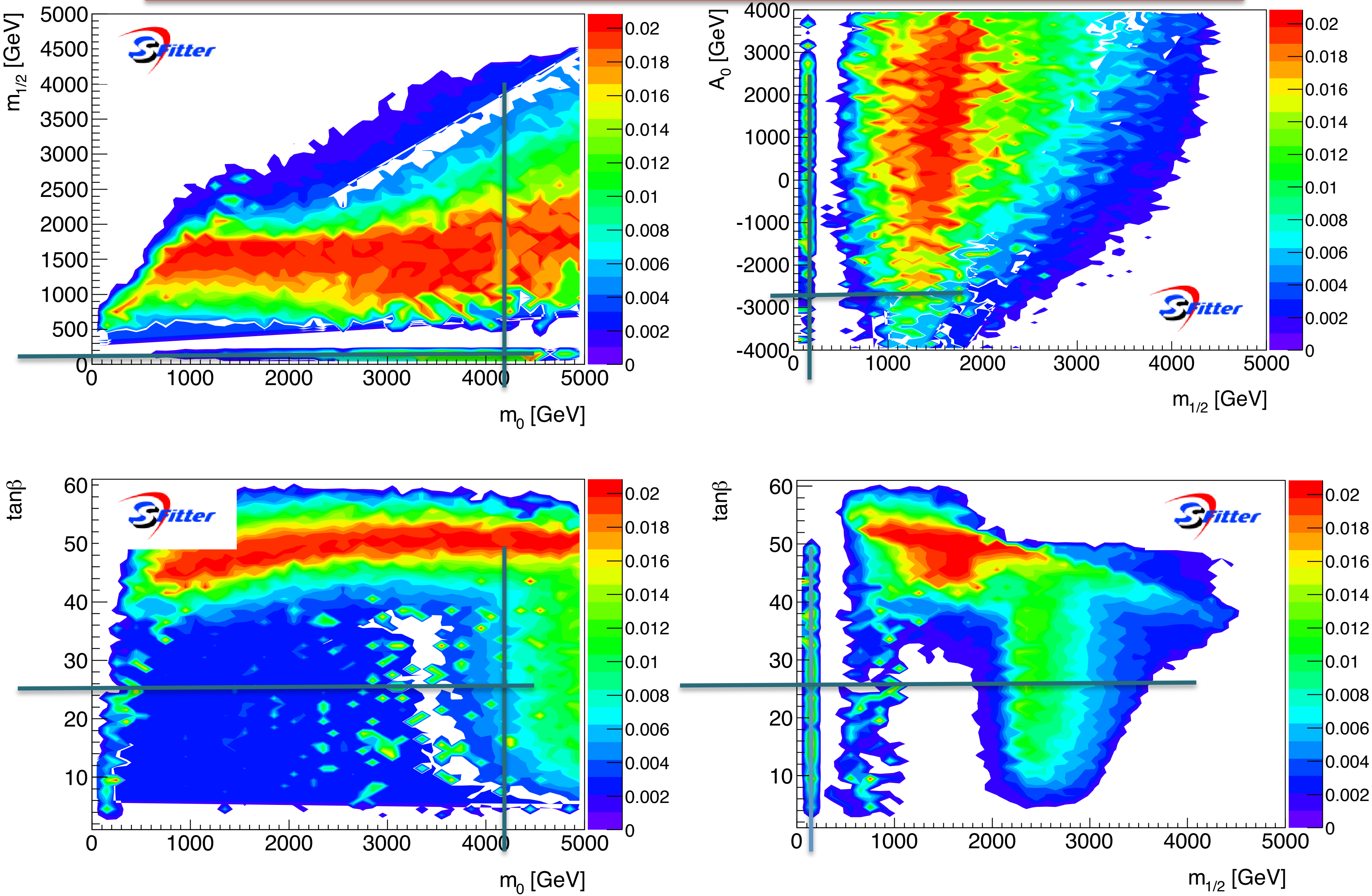
h funnel

⇒ the LSP is mostly bino

⇒ Mtop(fitted value)=174.2GeV

⇒ $M(\tilde{\chi}_1^0)$=59GeV, $M(\tilde{g})$=476GeV

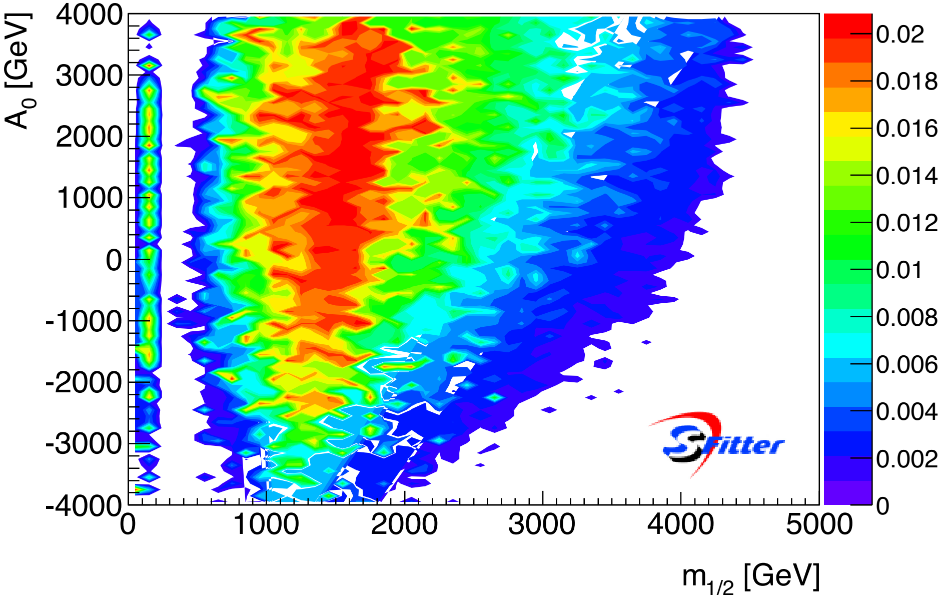
Excluded by ATLAS/CMS Inclusive squark and gluinos searches



mSUGRA Planck vs. WMAP

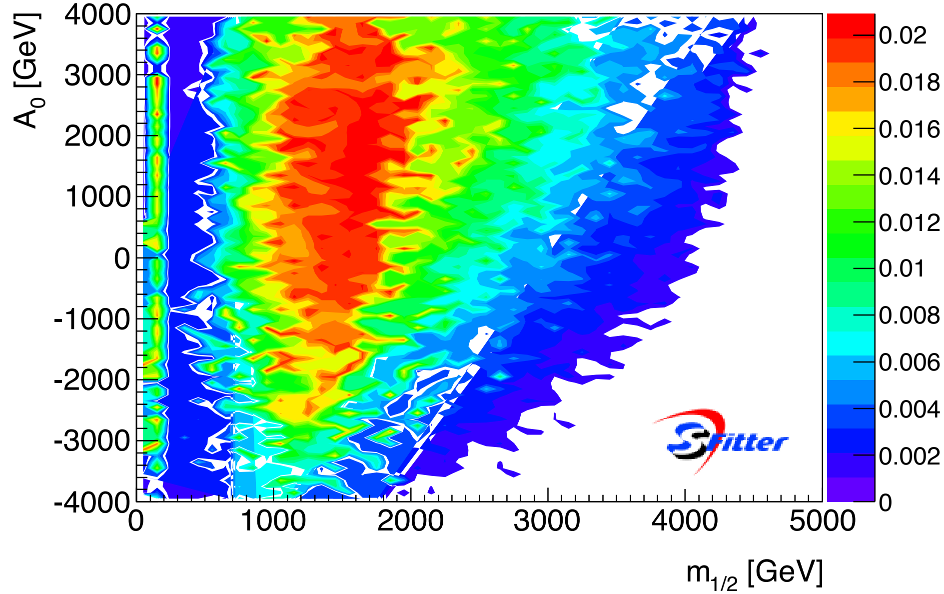
Planck

($\Omega_{cdm}h^2$=0.1187±0.0017±0.012)



WMAP

($\Omega_{cdm}h^2$=0.1157±0.0023±0.012)



=> As expected the general features are very similar

=> The light Higgs funnel is more detached in the Planck case than in the WMAP case (consequence of the smaller error bar on the DM density)

<u>What to expect @ the end of 2014:</u>

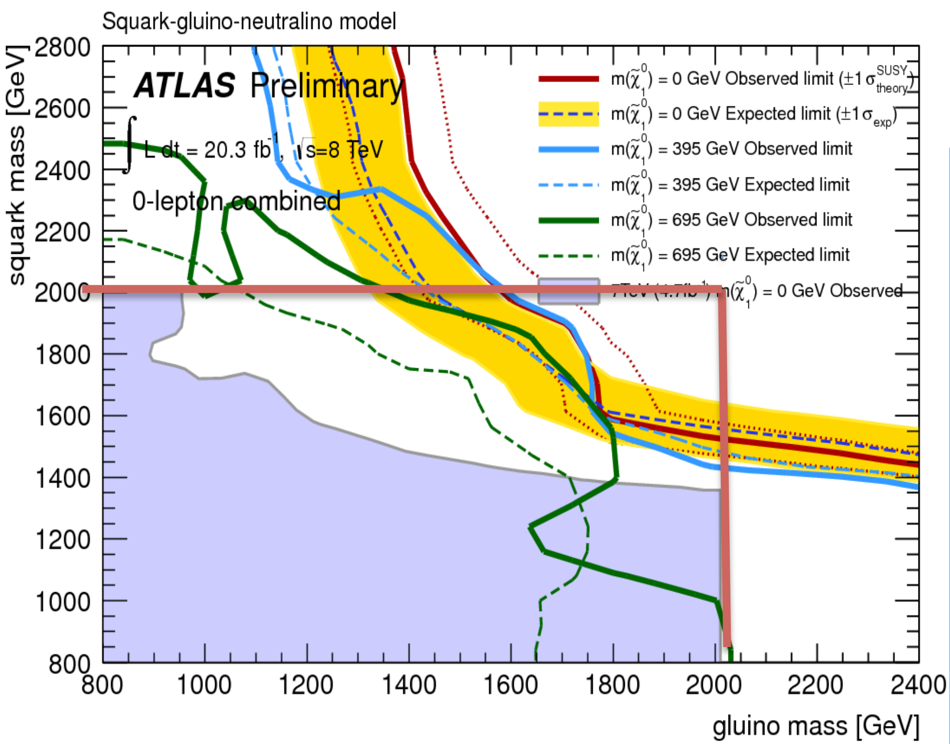
☺ Planck will release the polarisation data and a more accurate Ω_{cdm} measurement

☹ The theoretical error is already dominant...statistical improvement will not help

MSSM

Assumptions:

- all squark masses above LHC actual limits ≈2TeV (except for the stop)
- M_3 is fixed @2TeV
- A_b=0



13 parameters+the top mass:

tan β<61, M_1<4TeV, M_2<4TeV

$M_{\tilde{\mu}L/R}$, $M_{\tilde{\tau}L/R}$, $M_{\tilde{q}3L}$, $M_{\tilde{t}R}$<5TeV

$|A_t|$<4TeV, $|A_\tau|$<4TeV,

m_A<5TeV, $|\mu|$<2TeV

How parameters are related:

* M(Higgs)=f(m_A, tanβ, m_{t1}, m_{t2})
m_{t1}, m_{t2} are not related to the DM sector, nor to the light sq/gluino masses

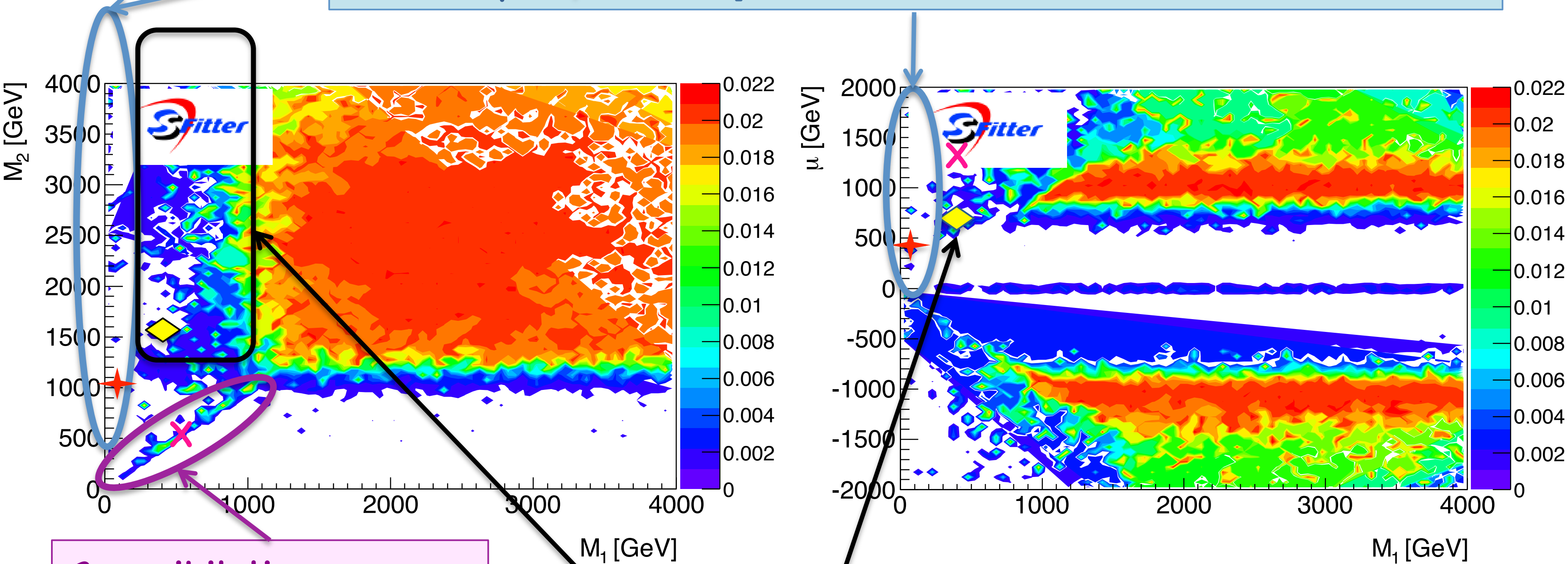
* The neutralino masses and couplings =f(M_1, M_2, tanβ, μ)

* Link between DM/Higgs=f(annihilation channels)

MSSM constraints

As expected, we recover the mSUGRA points

h funnel: for $M_1 \approx 60$GeV almost independant of M_2
An example ✦ : $m(\tilde{\chi}^0_1)$=58.5GeV, m(A/H)=3626GeV



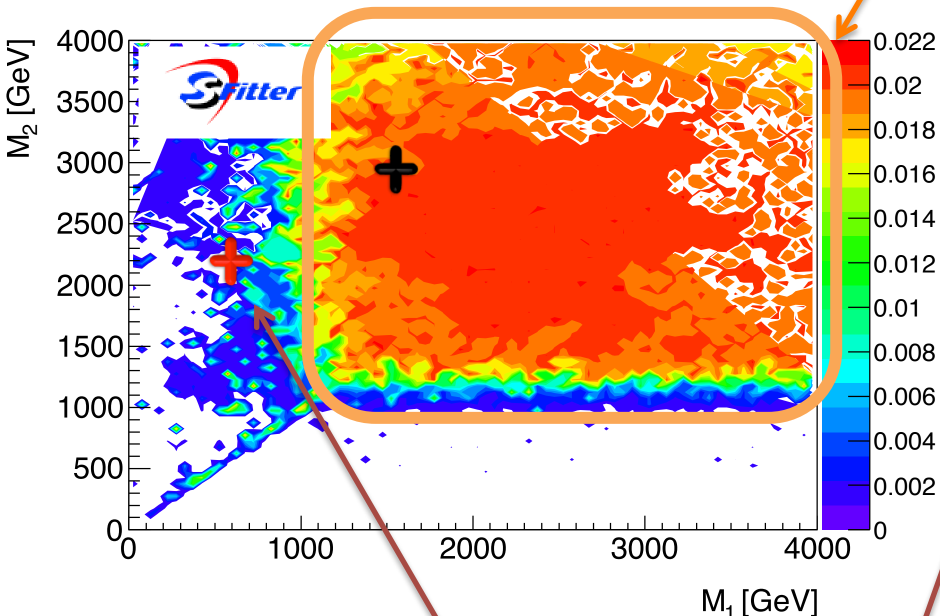
Coannihilation
For example: ✕
$m(\tilde{\chi}^0_1)$=429 GeV
$M(\tilde{\tau}_1)$=429.7GeV

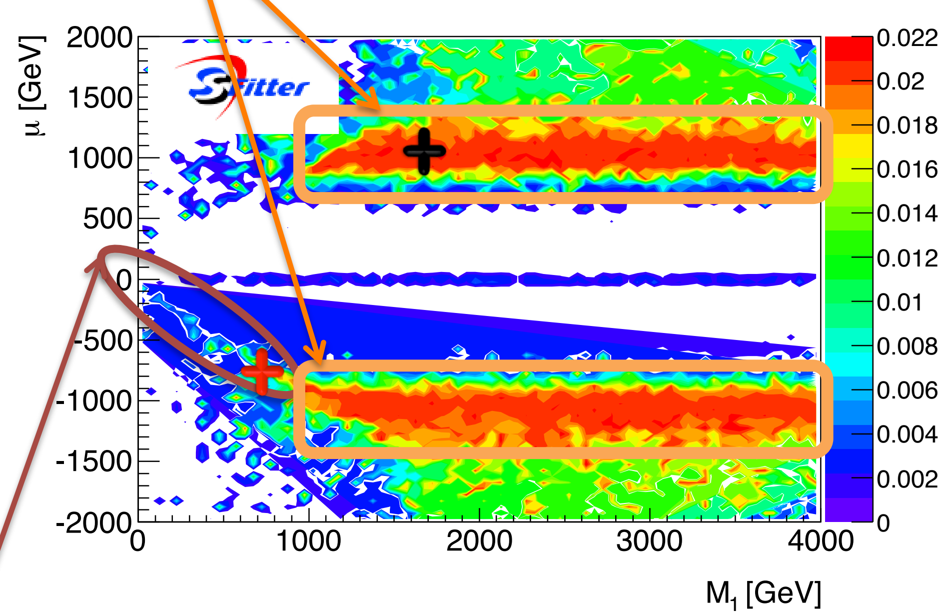
A funnel: same behaviour as for mSUGRA
An example ◆ : $m(\tilde{\chi}^0_1)$=398GeV, m(A/H)=781GeV

MSSM constraints

NEW MSSM regions

Large Higgsino Region splitted into $\mu \approx \pm 1.2$TeV
Chargino/Neutralino annihilation dominates
Example ✚: $m(\chi^0{}_1)$=1TeV





Bino-Higgsino region
for $|M1| \approx |\mu|$ and $\mu < 0$ [neutralino ≈50% Bino/50% Higgsino]
An example ✚ : $m(\tilde{\chi}^0{}_1)$=768GeV
Chargino/Neutralino co-annihilation

Summary

For mSUGRA: two main regions compatible with all measurements still remain:

- A narrow stau coannihilation at moderate $\tan\beta$
- A large A funnel region

In the TeV scale MSSM the remaining area for the parameters are:

- A narrow stau & light/A Higgs funnel regions
- A large mixed Bino-Higgsino neutralino area
- And a large Higgsino region with chargino and neutralino coannihilation.

(The stop coannihilation remains outside the scope of our model parameters)

=> The relic density and the Higgs mass measurements push SUSY toward a high new-Physics mass scale. Still, mSUGRA is far from being ruled out !

... We are waiting for the coming LHC running / DM searches /...
for new constraints !..... Or discovery !

PLANCK 2014
Ferrara Conference (*)
TODAY !!

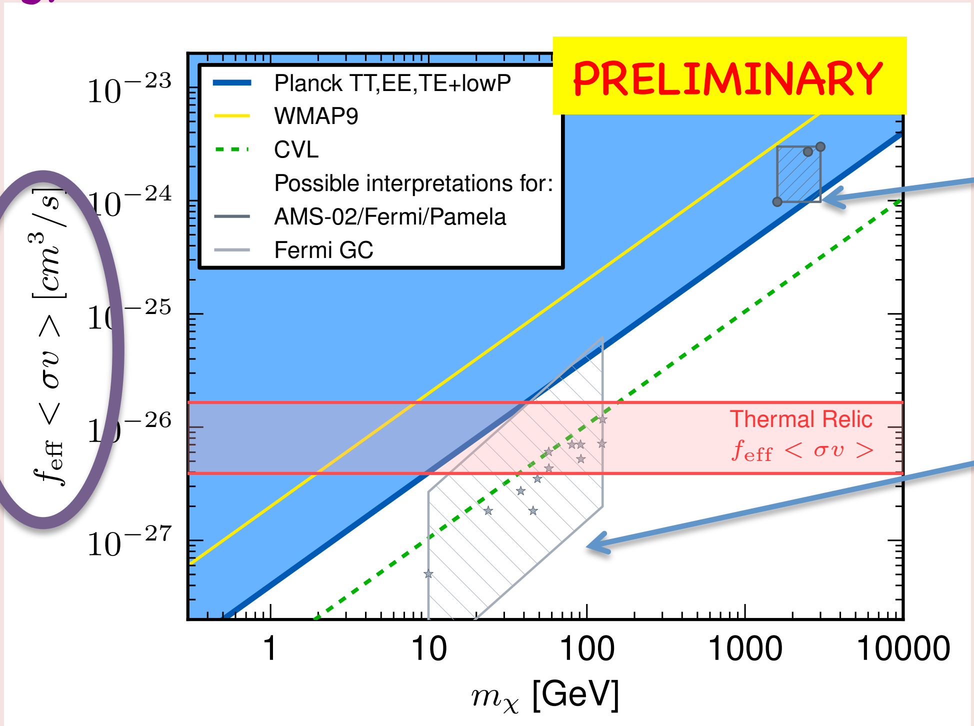
OutLook ?!

More Dark Matter Constraint ??

We constrain DM annihilation @ the epoch of recombination

Caveat: Planck and low-redshift anomalies (Pamela,Fermi etc...) can be compared ONLY under the assumption that the annihilation cross-section at the epoch of recombination was THE SAME as today

Thermally averaged annihilation cross-section x the fraction of the annihilation energy that will affect the CMB



The dark gray dots show the best fit DM models for the Pamela/AMS-02/ Fermi cosmic-ray excess as calculated by Cholis and Hooper.

The light gray stars show the best fit DM models for the Fermi galactic center gamma-ray excess as calculated by Calore 2014.

following S.Galli et al. Phys.Rev.D84:027302,2011

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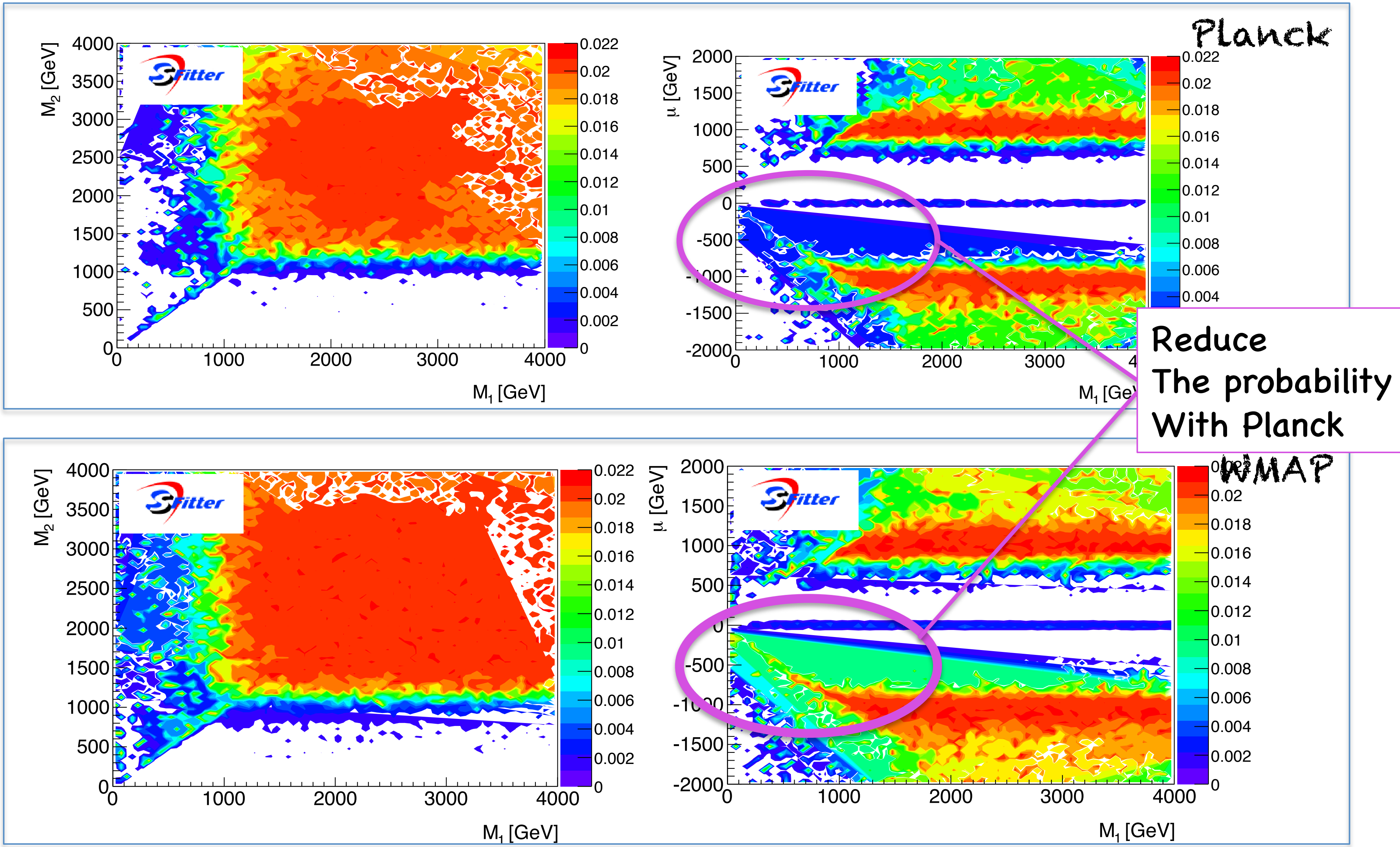
MSSM Planck vs. WMAP



pMSSM interpretation

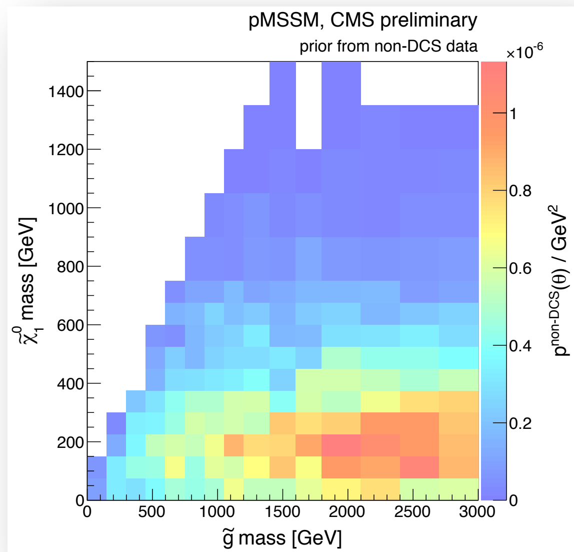
Non DCS data

1a	$BR(b \to s\gamma)$
1b	$BR(b \to s\gamma)$
2a	$BR(B_s \to \mu\mu)$
2b	$BR(B_s \to \mu\mu)$
3a	$R(B_u \to \tau\nu)$
3b	$R(B_u \to \tau\nu)$
4	Δa_μ
5a	m_t
5b	m_t
6	$m_b(m_b)$
7	$\alpha_s(M_Z)$
8a	m_h
8b	m_h
9	sparticle masses

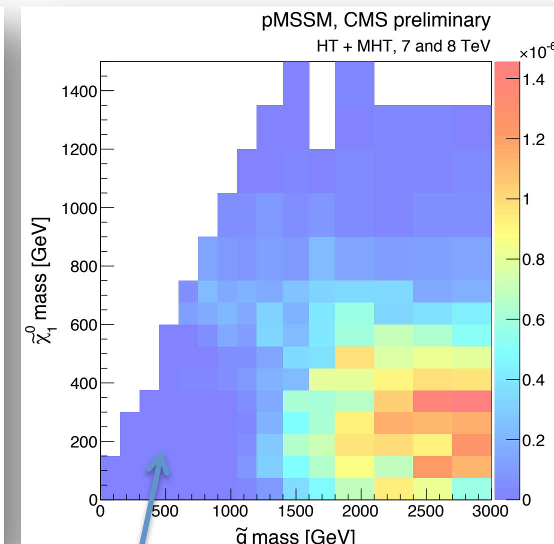
List of CMS analyses

Analysis	$\sqrt{s}$	L	Likelihood	Ref.
Hadronic HT + MHT search	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-011
Hadronic HT + MET + b-jets search	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-003
Leptonic search for EW prod. of $\tilde{\chi}^0$, $\tilde{\chi}^\pm$, $\tilde{l}$	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-006
Hadronic HT + MHT search	8 TeV	19.5 fb^{-1}	method 1	CMS-SUS-13-012
Hadronic HT + MET + b-jets search	8 TeV	19.4 fb^{-1}	method 2	CMS-SUS-12-024
Leptonic search for EW prod. of $\tilde{\chi}^0$, $\tilde{\chi}^\pm$, $\tilde{l}$ (ss, 3l and 4l channels)	8 TeV	19.5 fb^{-1}	method 1	CMS-SUS-12-006

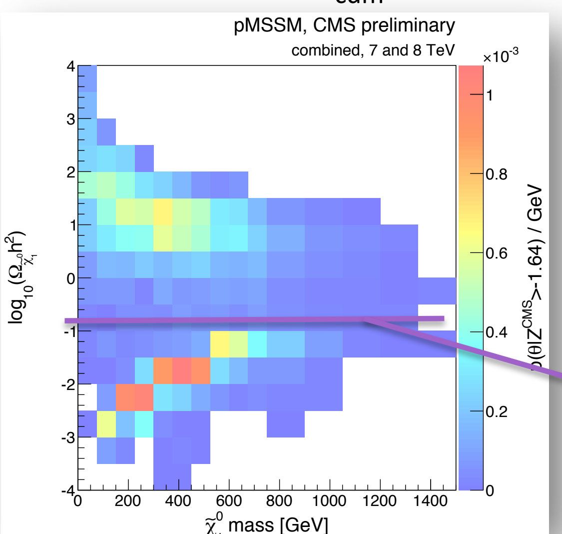
Prior from nonDCS data



Posterior for HT+MHT



Projection on $\Omega_{cdm}h^2$



Just to have a feeling: Planck $\Omega_{cdm}h^2$

The neutralino mass is shifted to higher values

CMS-PAS-SUS-13-020