Global fits
à la frequentist

F. Ronga (ETH Zurich)

Joint HEP-APP IOP meeting on SUSY

March 24 2010

Global fits à la frequentist?

ETH Institute for Particle Physics

- Confronting a model to data
  - **combine measurements**
  - **compare with predictions**
  - **constrain the parameters**
    - or exclude the model...
- Key ingredients
  - **consistent set of measurements**
    - and their errors
  - **state-of-the-art predictions**
    - and their errors
  - **and a combination of the two**

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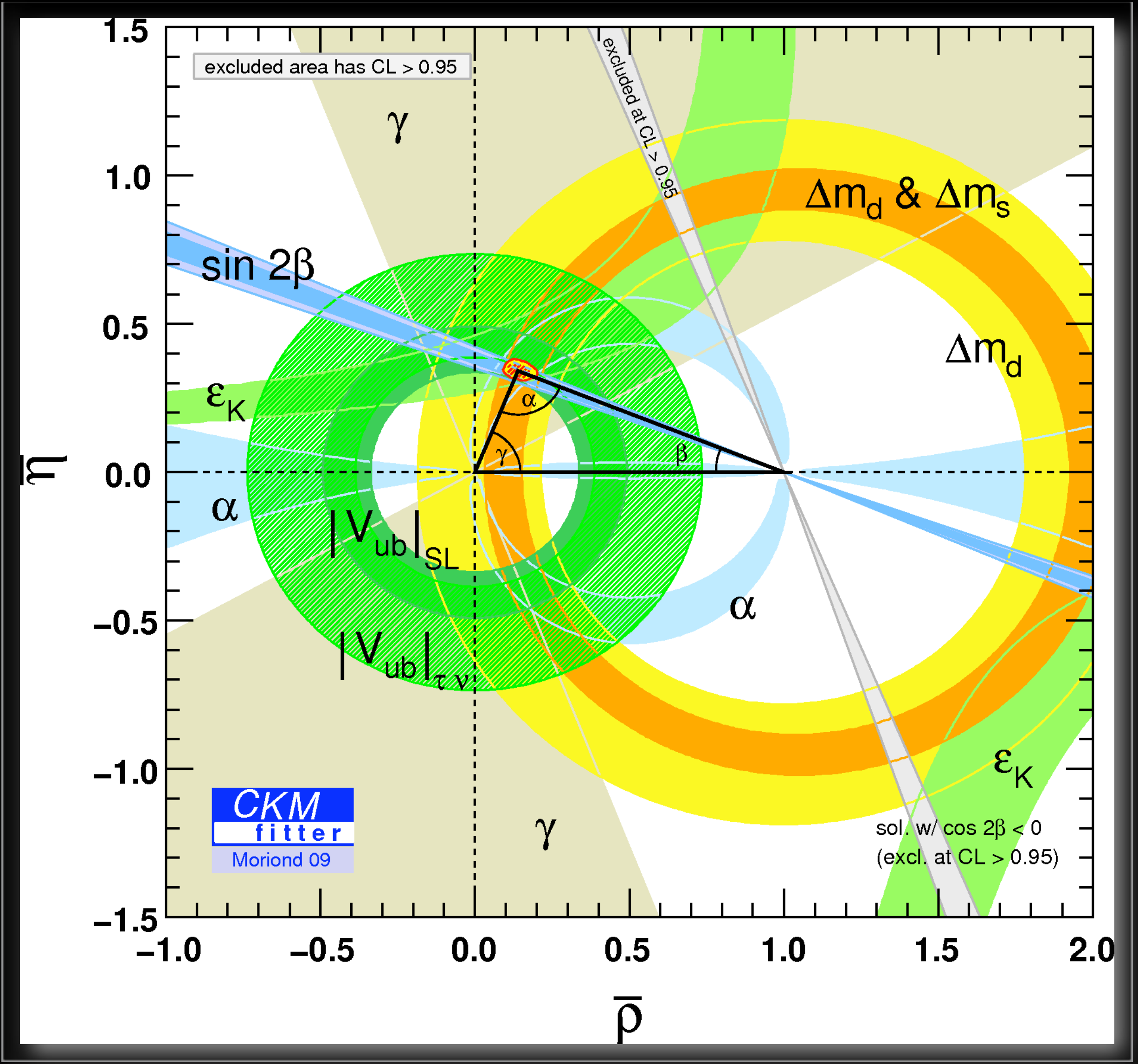

Famous examples of global fits

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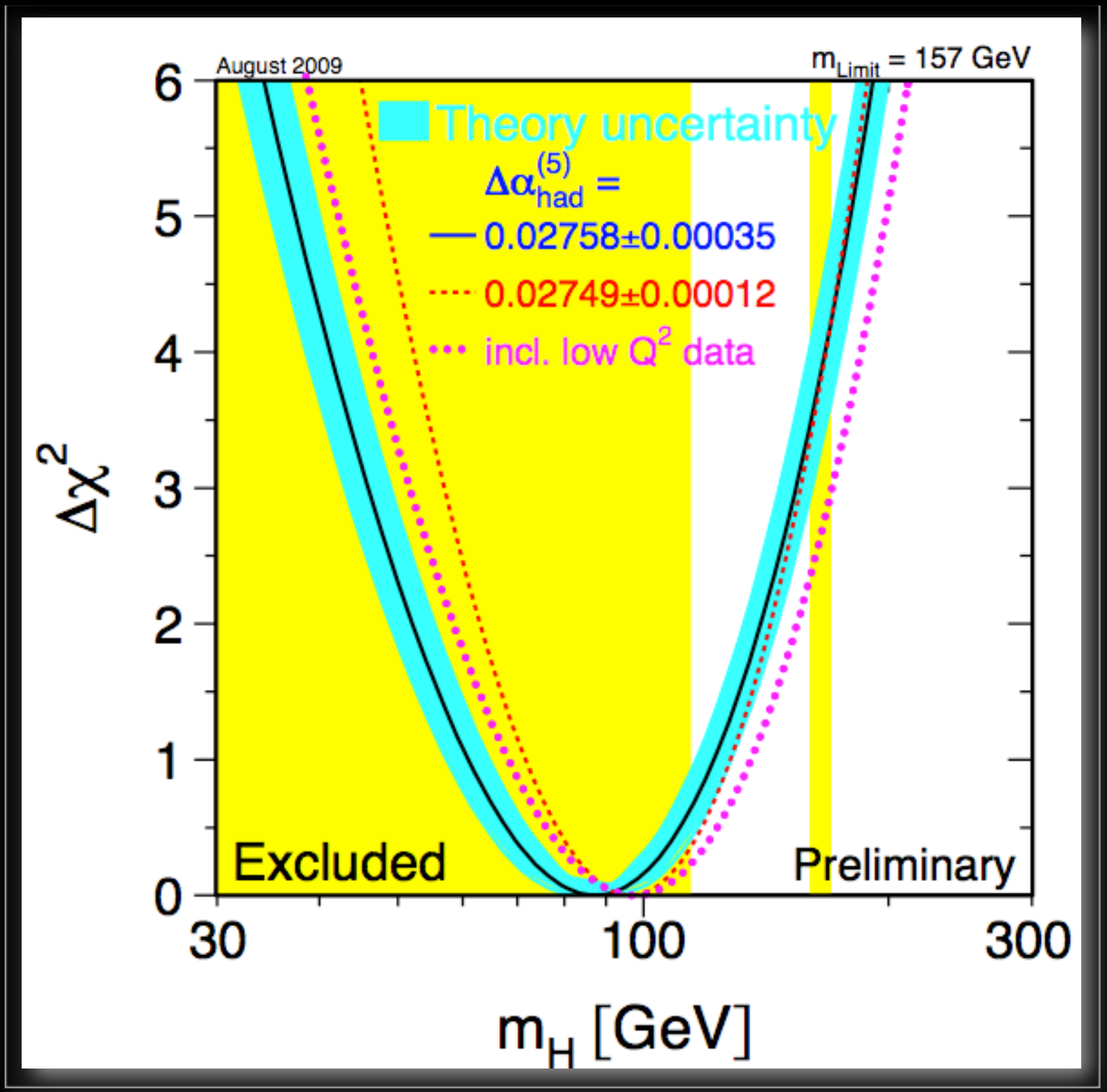

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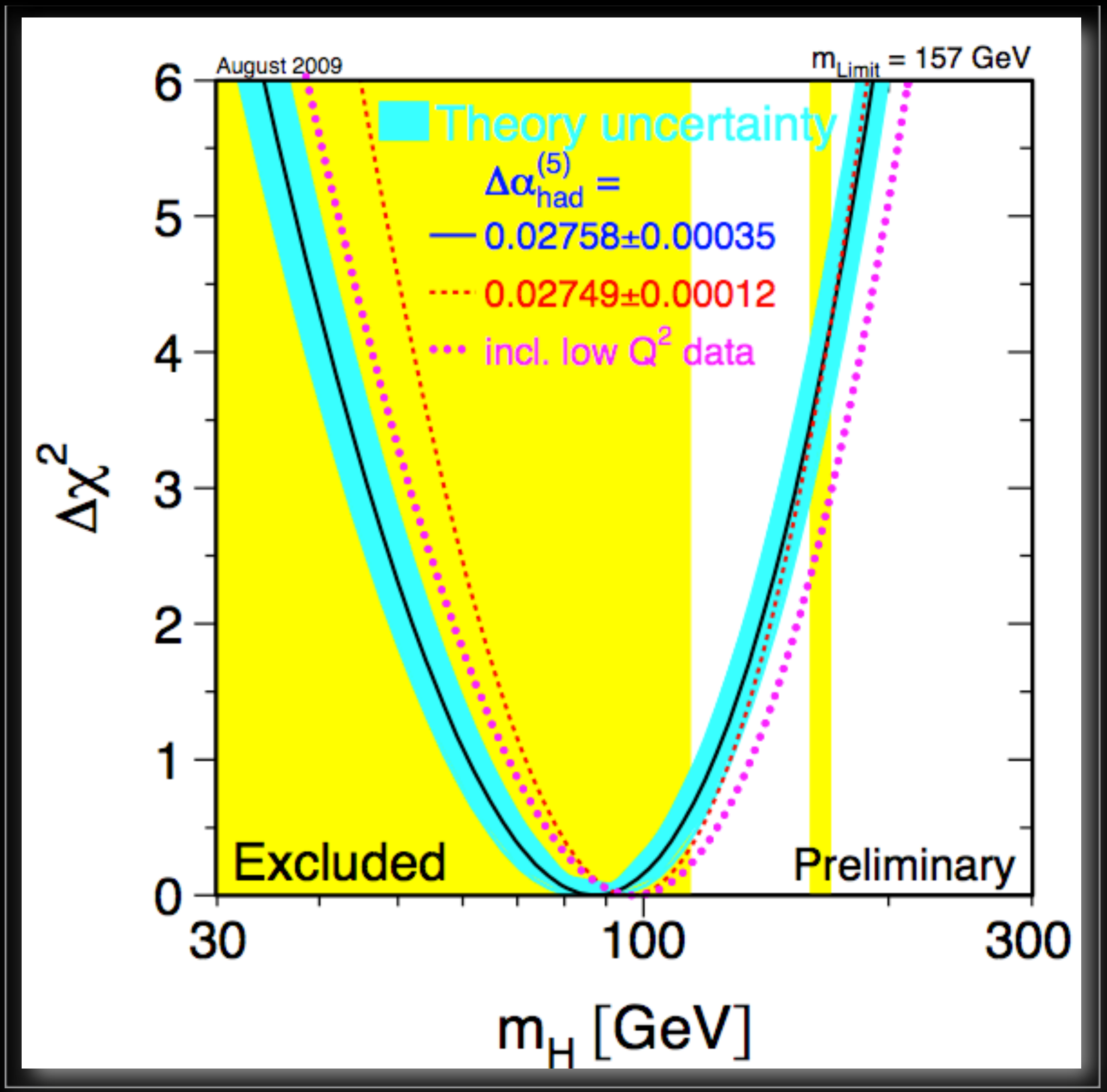

Famous examples of global fits

à la frequentist

Global fits à la...: framework

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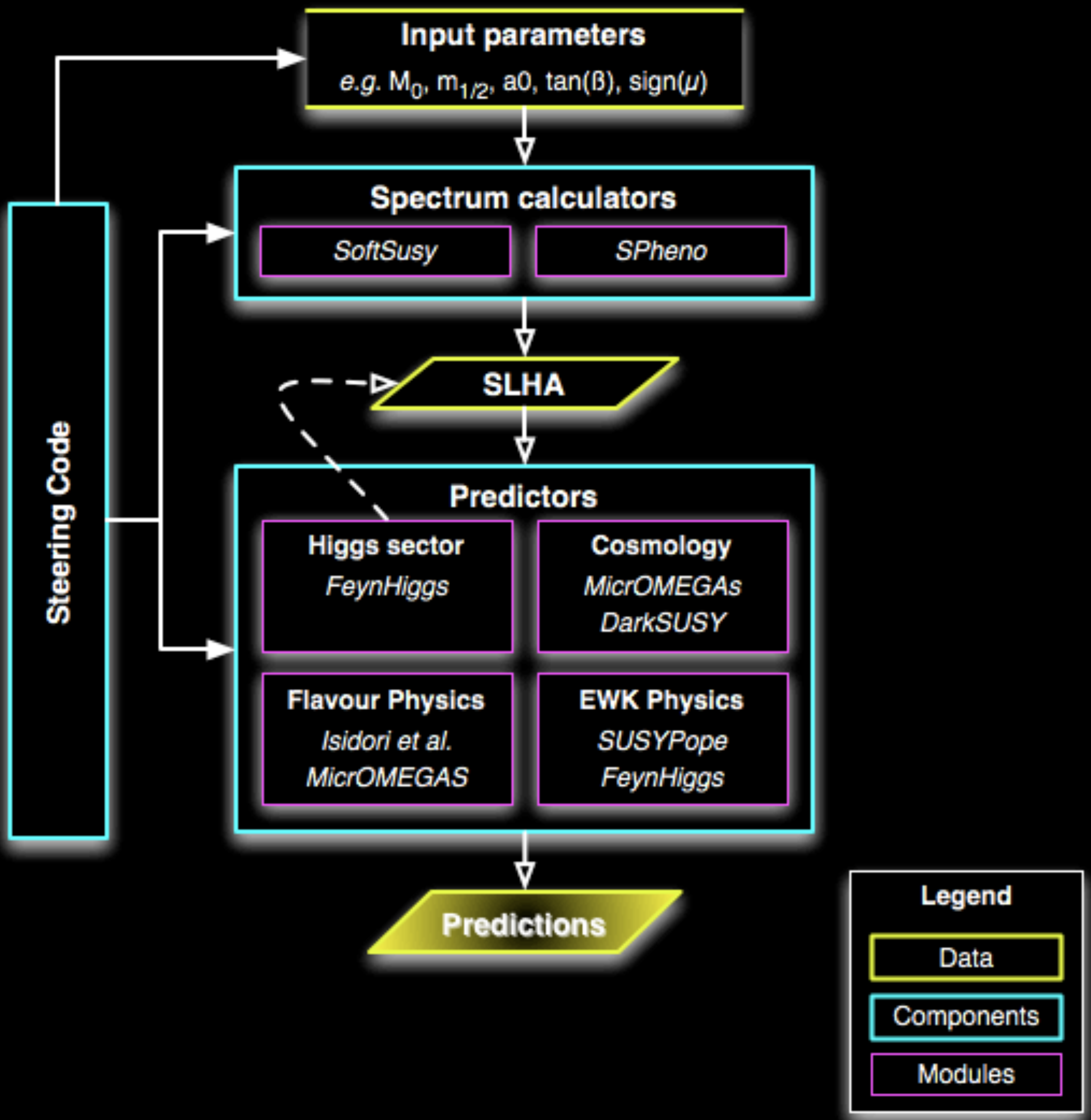
- Consistency
  - **SLHA interface**
- Modularity
  - **Compare calculations**
  - **Add/remove predictions**
- State-of-the-art "tools"
  - **Directly from experts**
- Flexibility
  - **Several uses**



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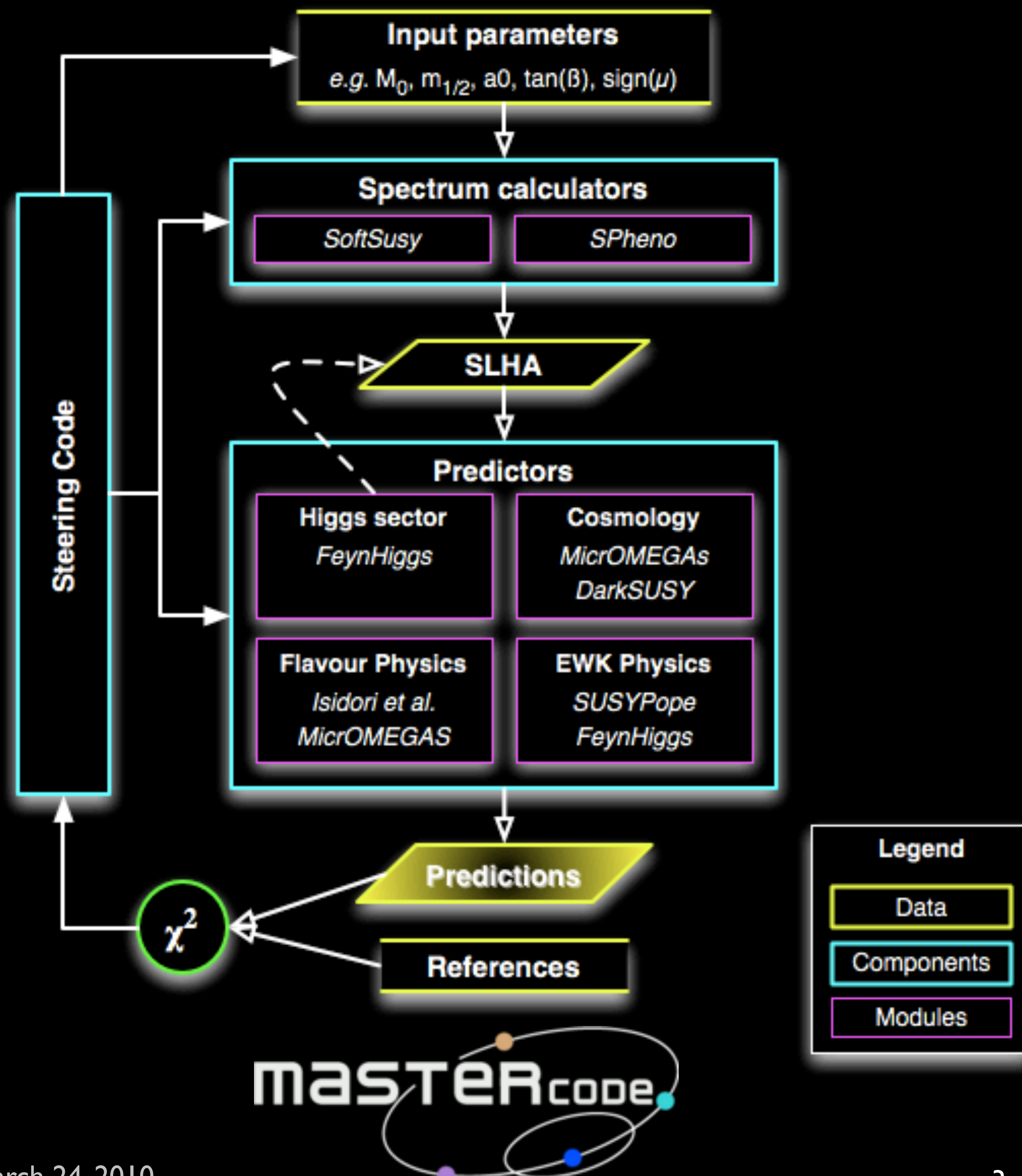
    - $\chi^2 \Rightarrow$ `Minuit` fit, MCMC



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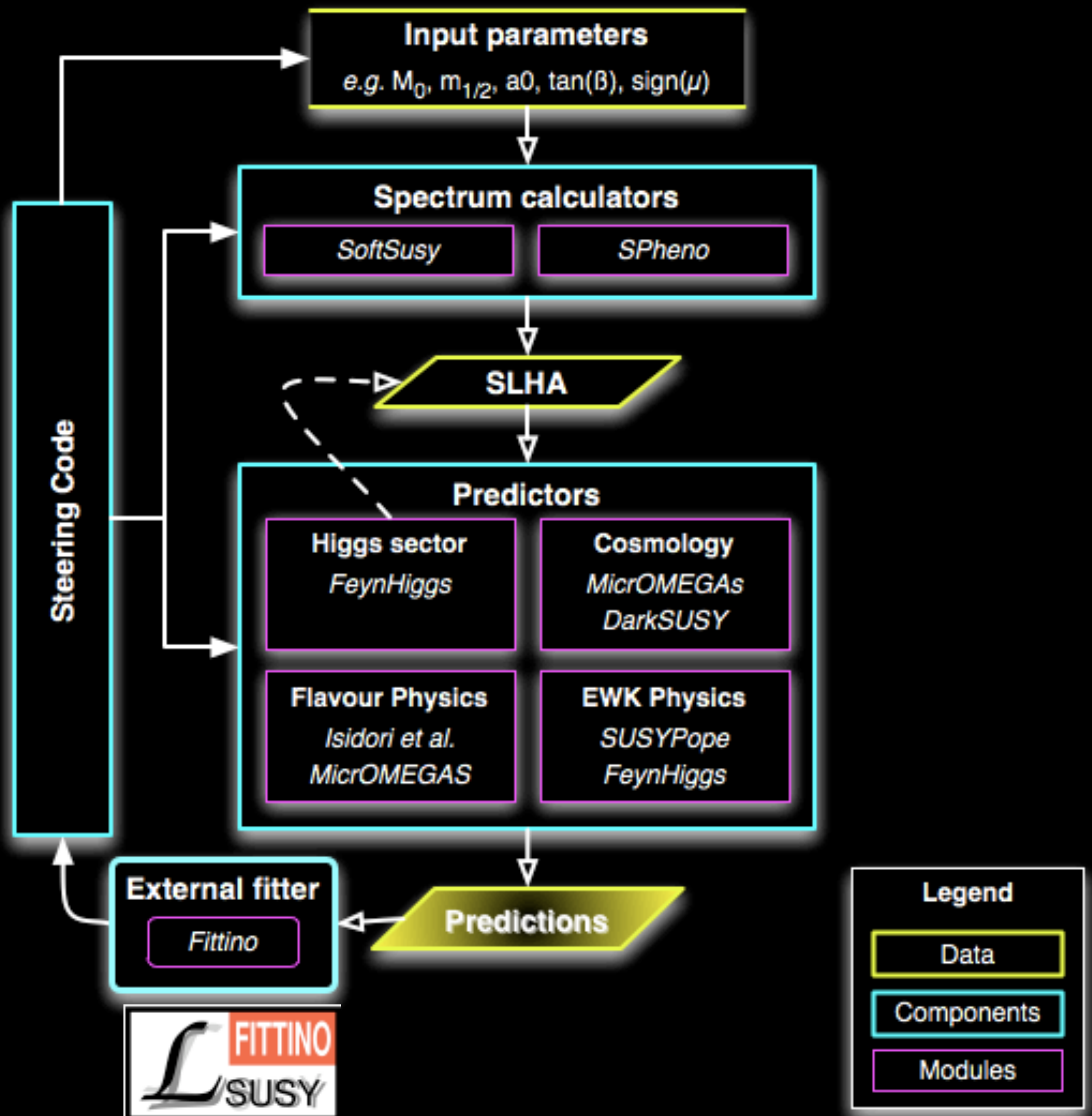
  - **Several uses**
    - $\chi^2 \Rightarrow$ `Minuit` fit, MCMC
    - input to external tool



Building the χ^2

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$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_j^M \frac{(f^{\rm obs}_{{\rm SM}_j} - f^{\rm fit}_{{\rm SM}_j})^2}{\sigma(f_{{\rm SM}_j})^2}$$

- *Multi-parameter χ^2 variable*
  - **C_i – experimental constraints**
  - ***P_i – predicted value for a given CMSSM parameter set***
- *Fitting for all model parameters, e.g., CMSSM*
  - ***M_0, $M_{1/2}$, A_0, $\tan\beta$ (sign(μ)=1)***
- *including relevant SM uncertainties*
  - ***m_{top}, m_Z, Γ_Z, $\Delta\alpha_{had}$***

List of observables

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Low energy observables

$R(b \to s\gamma)$	SuFla*	micrOMEGAs
$R(B \to \tau\nu)$	SuFla	
$BR(K \to \tau\nu)$	SuFla	
$R(B \to X_s \ell\ell)$	SuFla	
$R(K \to \pi\nu\bar{\nu})$	SuFla	
$BR(B_s \to \ell\ell)$	SuFla	micrOMEGAs
$BR(B_d \to \ell\ell)$	SuFla	
$R(\Delta m_s)$	SuFla	
$R(\Delta m_s)/R(\Delta m_d)$	SuFla	
$R(\Delta m_K)$	SuFla	
$R(\Delta_0(K^*\gamma))$	SuperIso	
$\Delta(g-2)$	FeynHiggs	

Higgs sector observables

m_h^{light}	FeynHiggs	

Cosmology observables

Ωh^2	DarkSUSY	micrOMEGAs
σ_p^{SI}	DarkSUSY	micrOMEGAs

Electroweak observables

$\Delta\alpha_{\text{had}}^{(5)}(m_Z^2)$	FeynWZ
m_Z	FeynWZ
σ_{had}^0	FeynWZ
R_l	FeynWZ
$A_{\text{fb}}(\ell)$	FeynWZ
$A_\ell(P_\tau)$	FeynWZ
R_b	FeynWZ
R_c	FeynWZ
$A_{\text{fb}}(b)$	FeynWZ
$A_{\text{fb}}(c)$	FeynWZ
A_b	FeynWZ
A_c	FeynWZ
$A_\ell(\text{SLD})$	FeynWZ
$\sin^2\theta_w^\ell(Q_{\text{fb}})$	FeynWZ
m_W	FeynWZ
m_t	FeynWZ

* G. Isidori, P. Paradisi

List of observables

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$R(b \to s\gamma)$	SuFla*	micrOMEGAs
$R(B \to \tau\nu)$	SuFla	
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$R(B \to X_s \ell\ell)$	SuFla	
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$BR(B_s \to \ell\ell)$	SuFla	micrOMEGAs
$BR(B_d \to \ell\ell)$		
$R(\Delta m_s)$		
$R(\Delta m_s)/R(\Delta m_d)$	SuFla	
$R(\Delta m_K)$	SuFla	
$R(\Delta_0(K^*\gamma))$	SuperIso	
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Compare calculations

Electroweak observables

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R	FeynWZ
	FeynWZ
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$A_{fb}(c)$	FeynWZ
A_b	FeynWZ
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$A_\ell(SLD)$	FeynWZ
$\sin^2\theta_w^\ell(Q_{fb})$	FeynWZ
m_W	FeynWZ
m_t	FeynWZ

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Fit methods & “data” samples

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- Fit methods
  - **Markov Chain Monte Carlo (MCMC)**
    - actually used as a mere *sampling* method (sampling density not used)
      - success and failure of the steps are defined by the χ^2
  - **χ^2 fit: `Minuit` minimisation**
    - used for “scans” or in conjunction with MCMCs to get the overall best minimum
- Data samples for MCMCs
  - **MasterCode**
    - about 25 million points for each model (CMSSM & NUHM1)
  - **Fittino**
    - about 20 million points (x2 different starting points)
    - “toy” fits (uncertainty on fit parameters, model disambiguation)

Probing the parameter space

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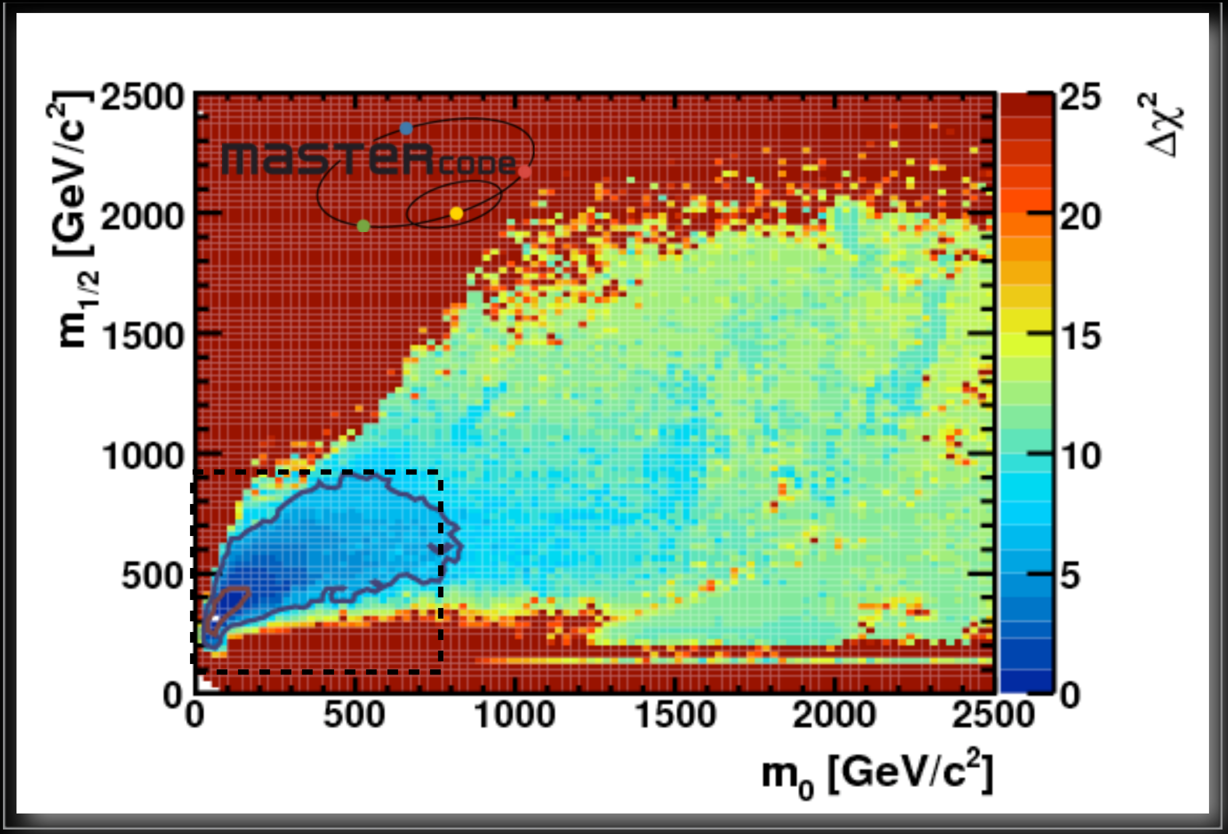
arXiv:0907.5568 [hep-ph]



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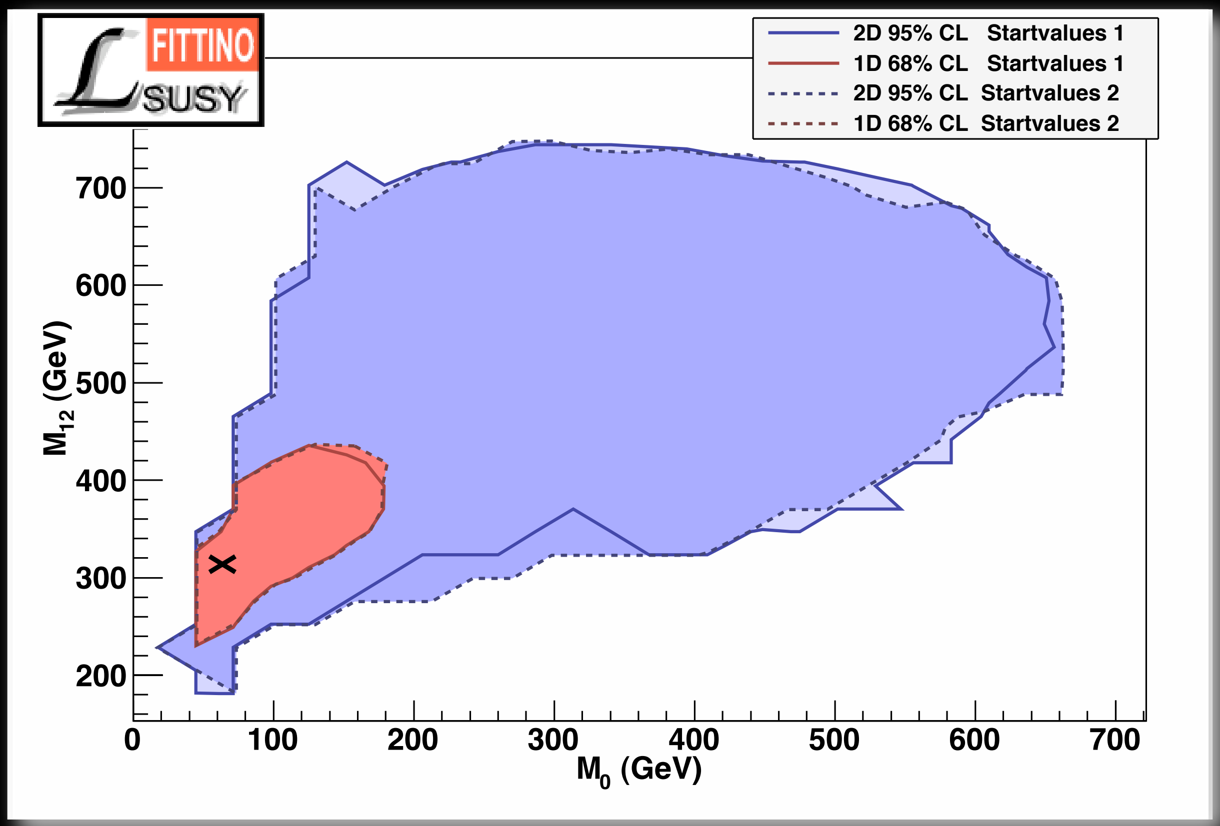

MasterCode

Best fit point:

$M_0=60$, $M_{1/2}=310$, $A_0=130$, $\tan\beta=11$

Fittino

Best fit point:

$M_0=76$, $M_{1/2}=332$, $A_0=383$, $\tan\beta=13$

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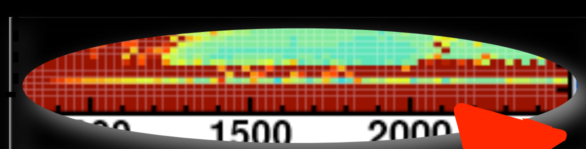

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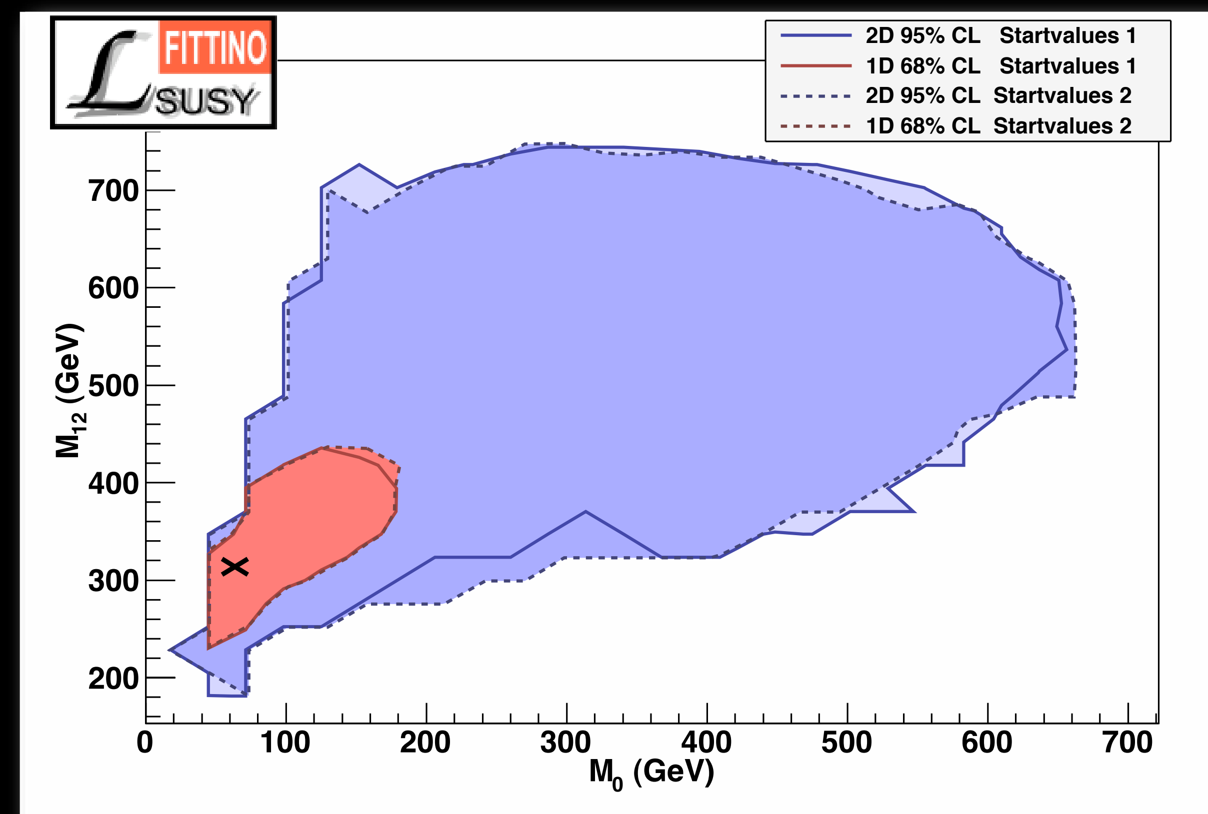

Higgs funnel!

$$2 \times m_{\tilde{\chi}^0} \lesssim M_h$$

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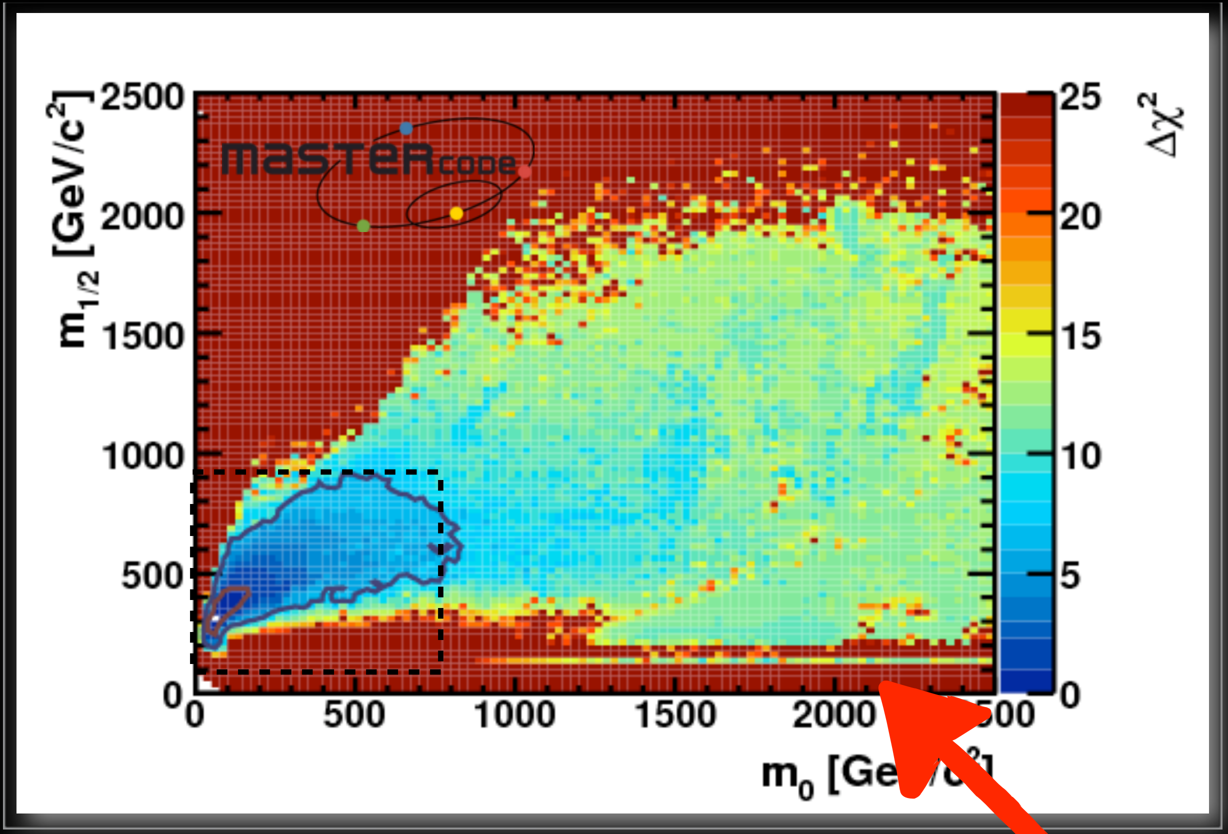

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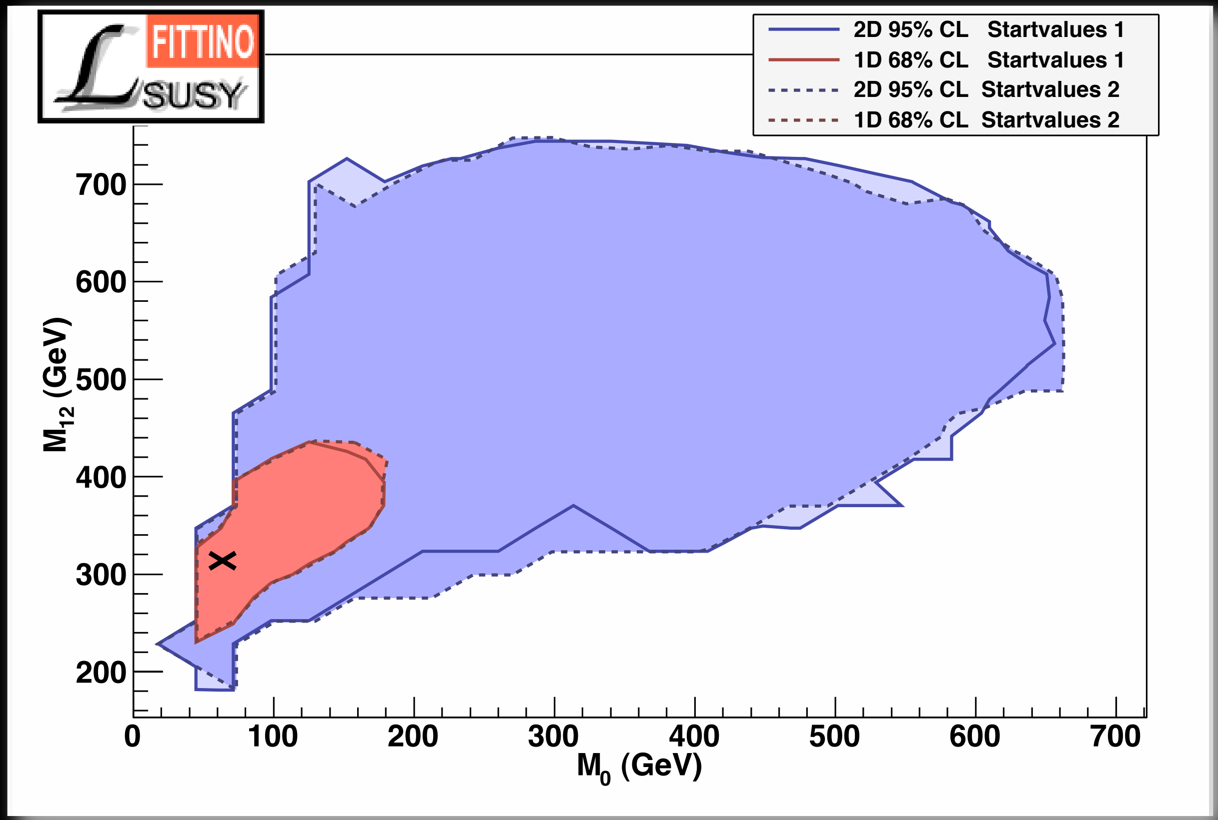

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The predicted spectrum

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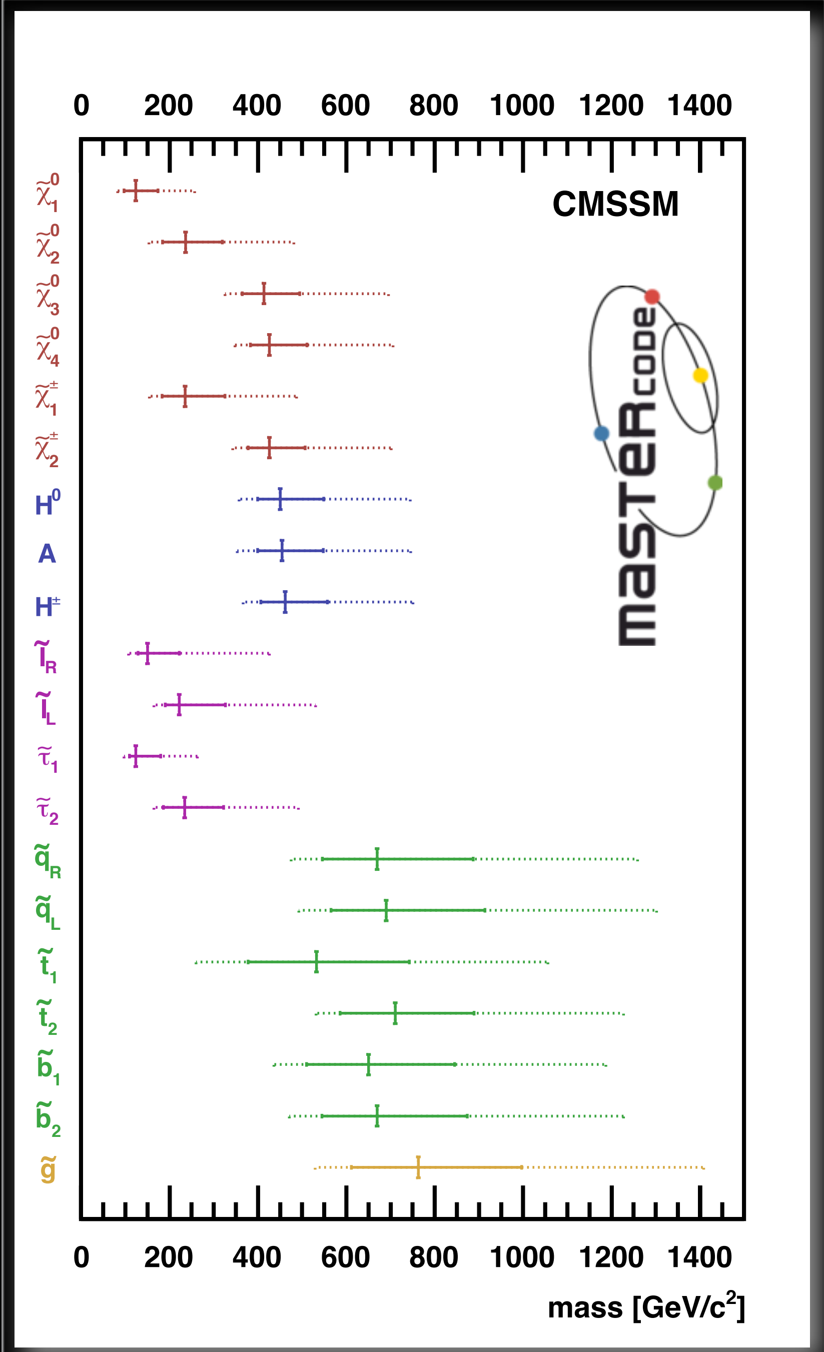

MasterCode
CMSSM spectrum at best fit point

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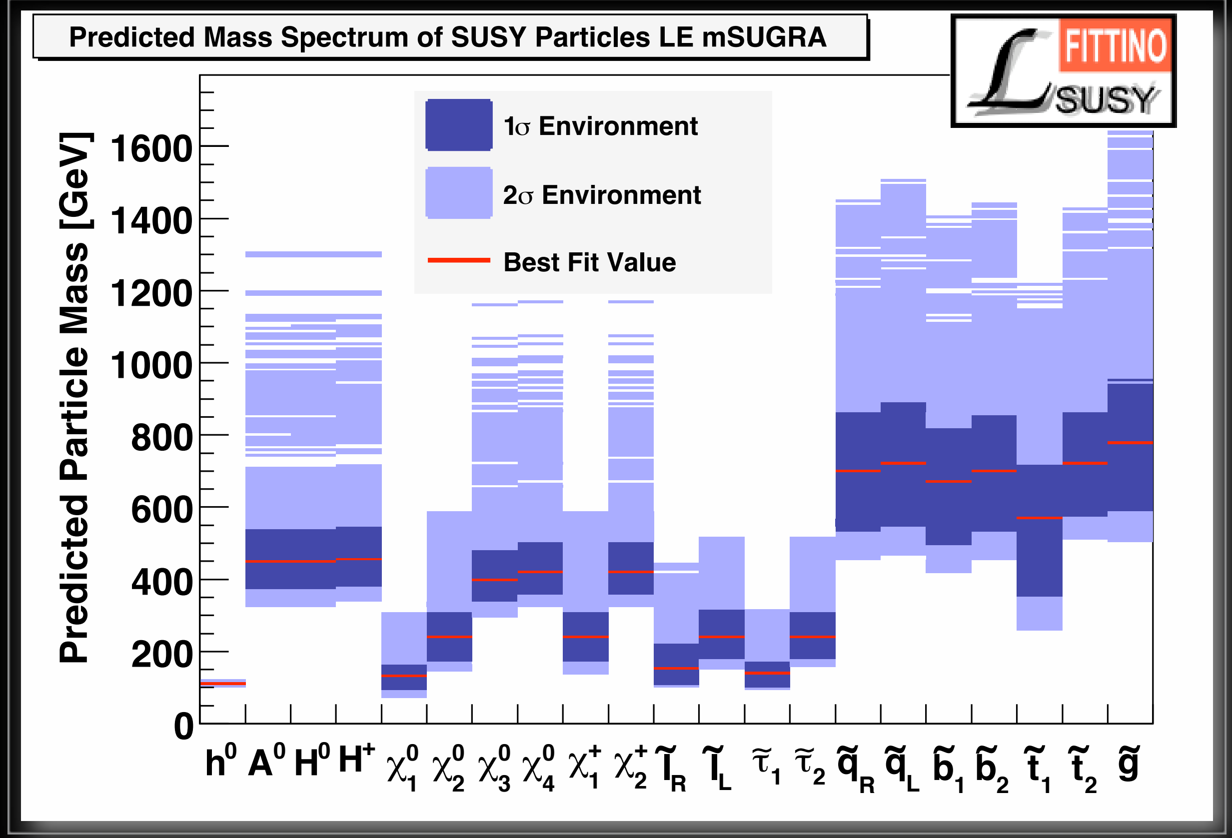

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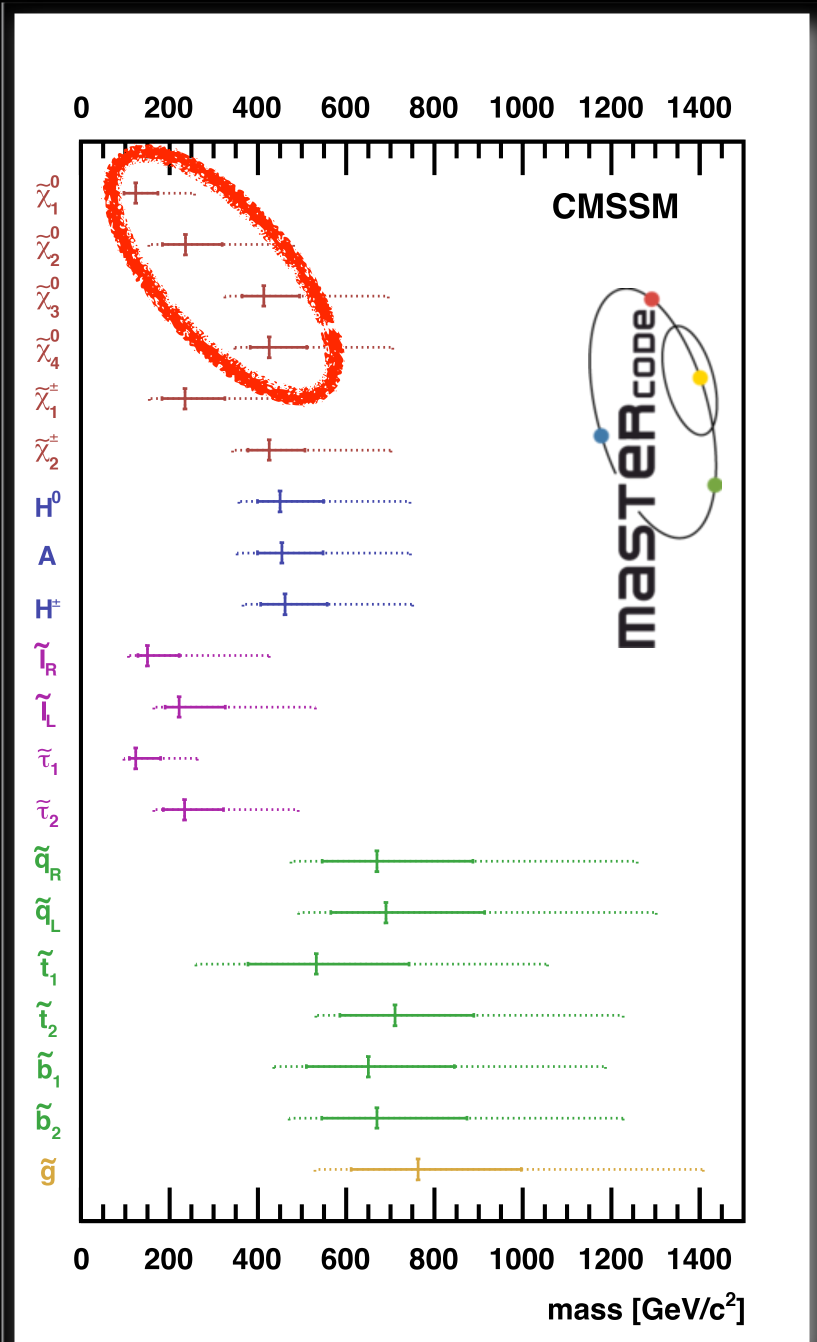

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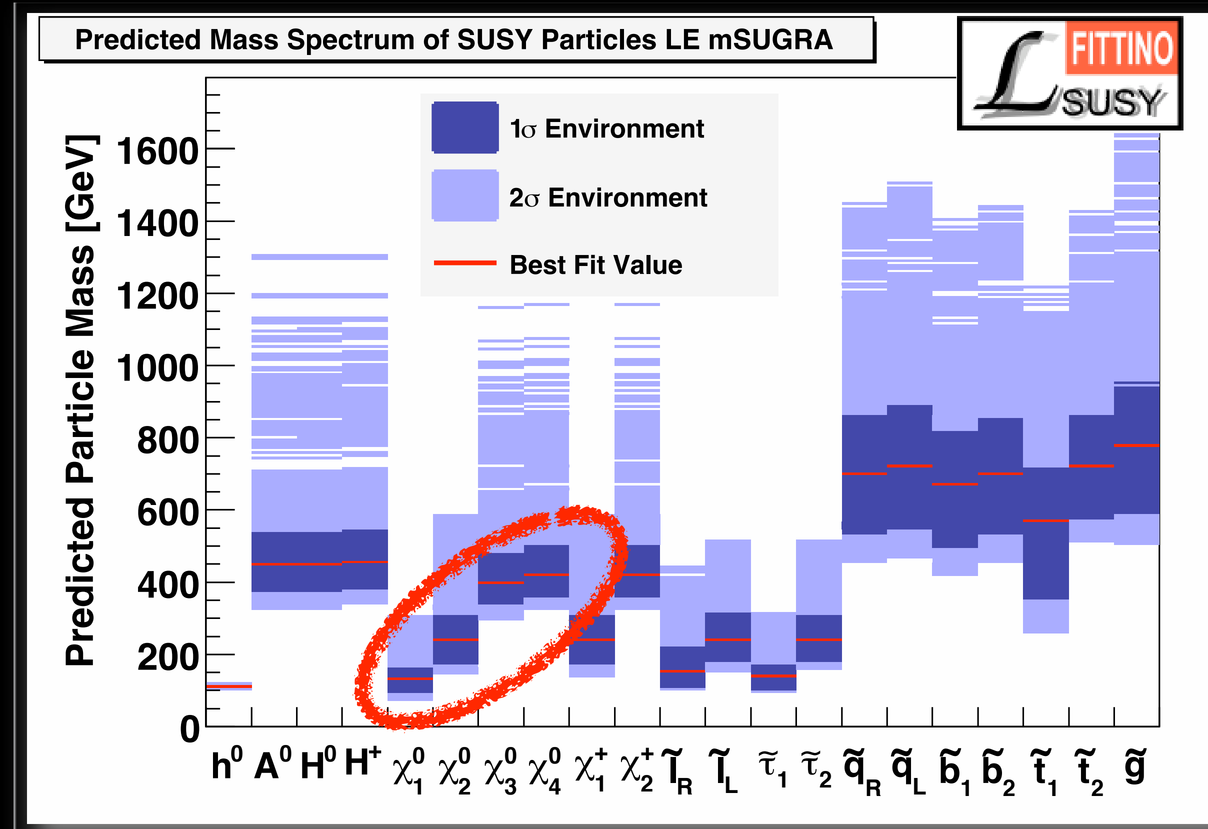

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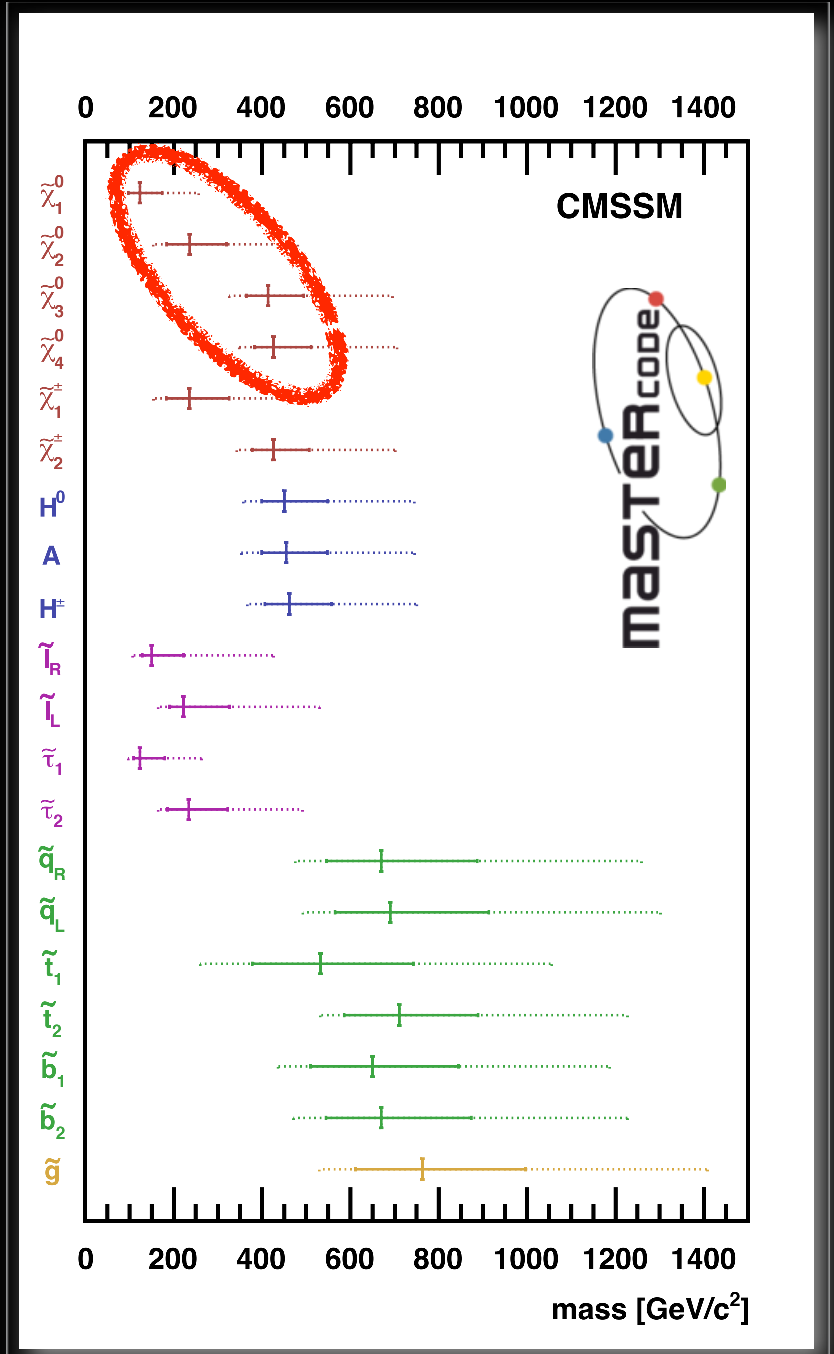

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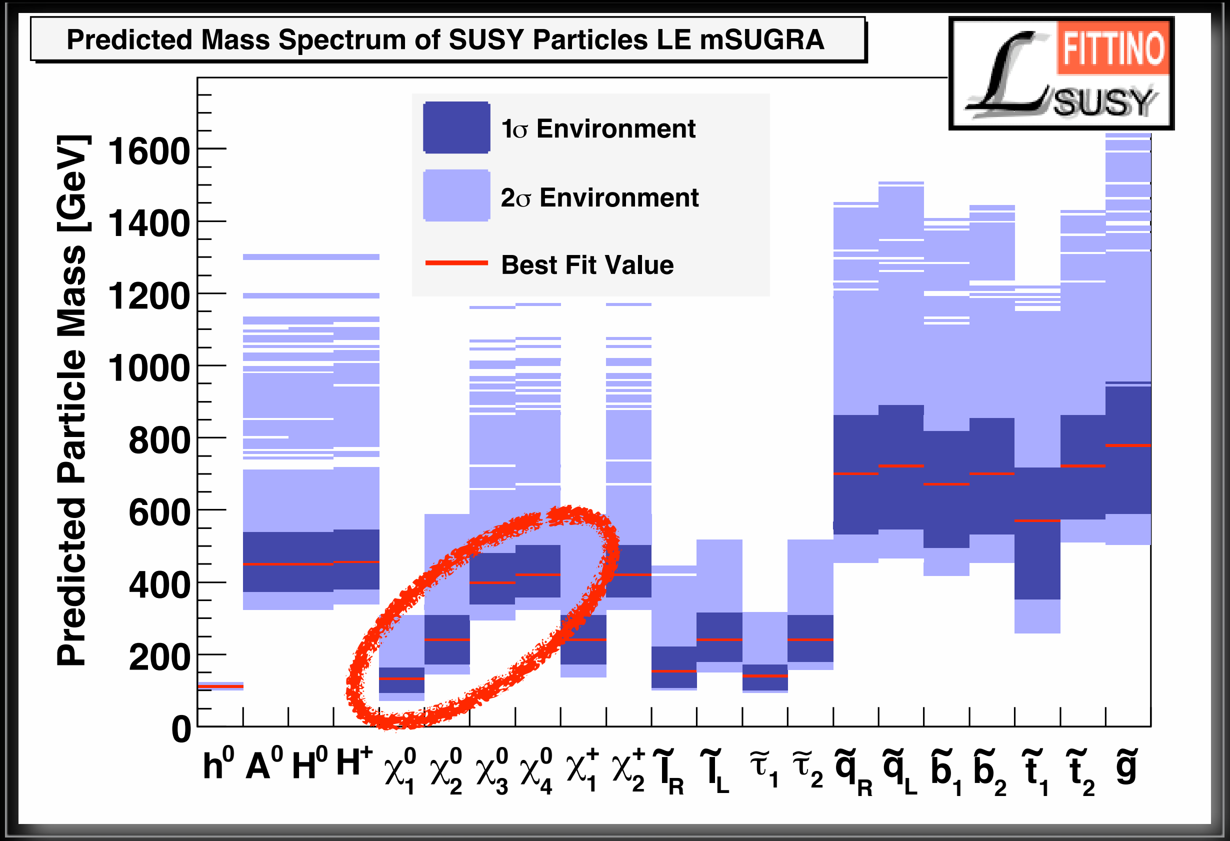

Fittino

CMSSM spectrum at best fit point

➠ Present data favours low mass SUSY

The key players

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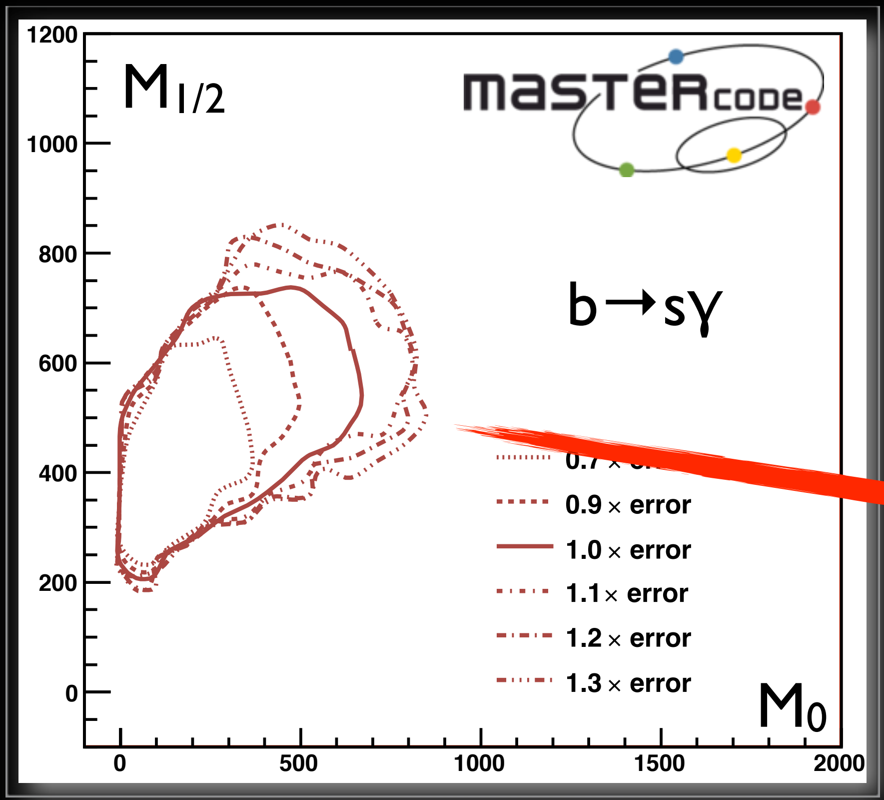
- Percent change of 95% C.L. contour area as a function of relative uncertainty
  - **in general, parameter space weakly constrained**
  - **g-2 still the strongest constraint**



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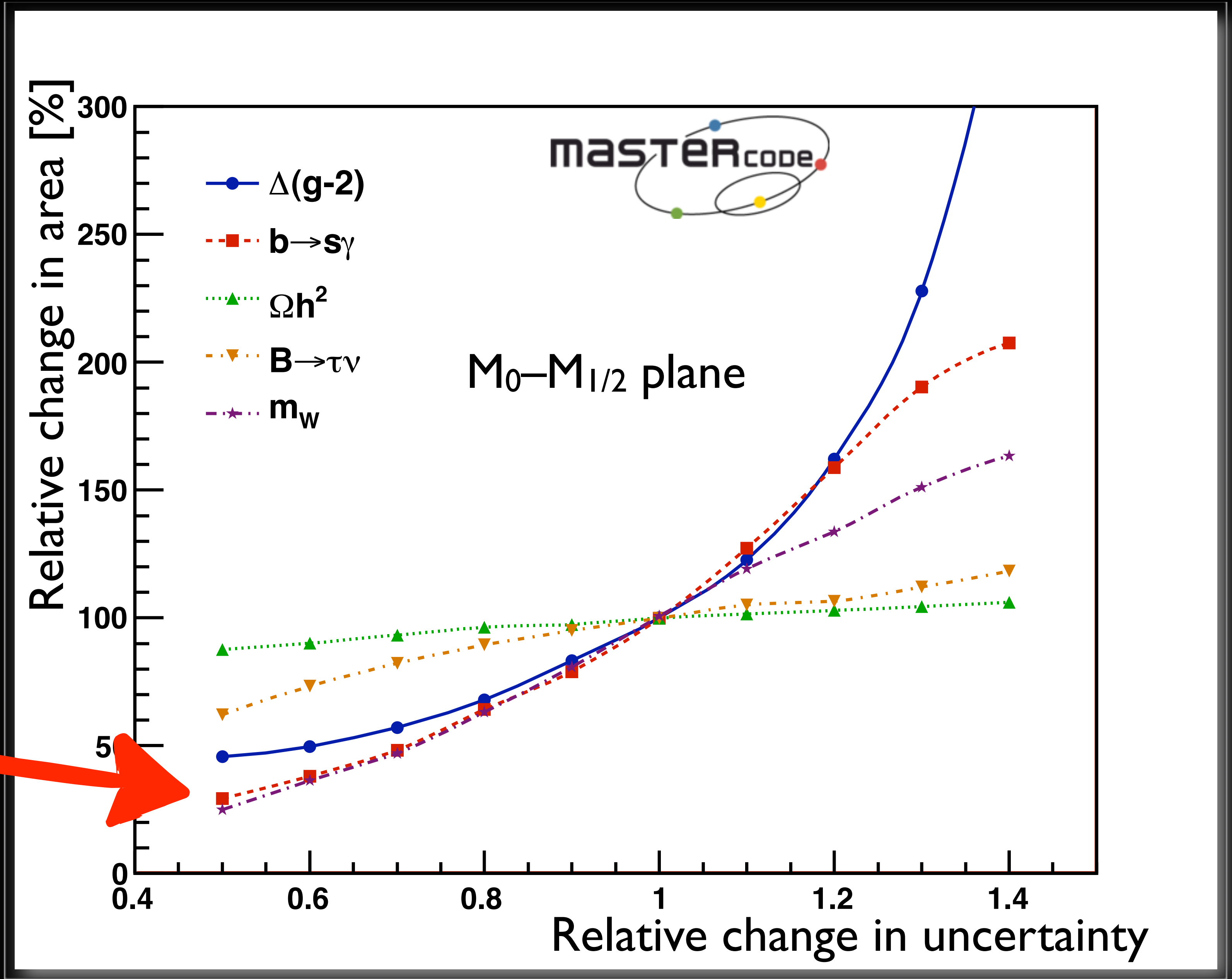

Predicting the Higgs mass

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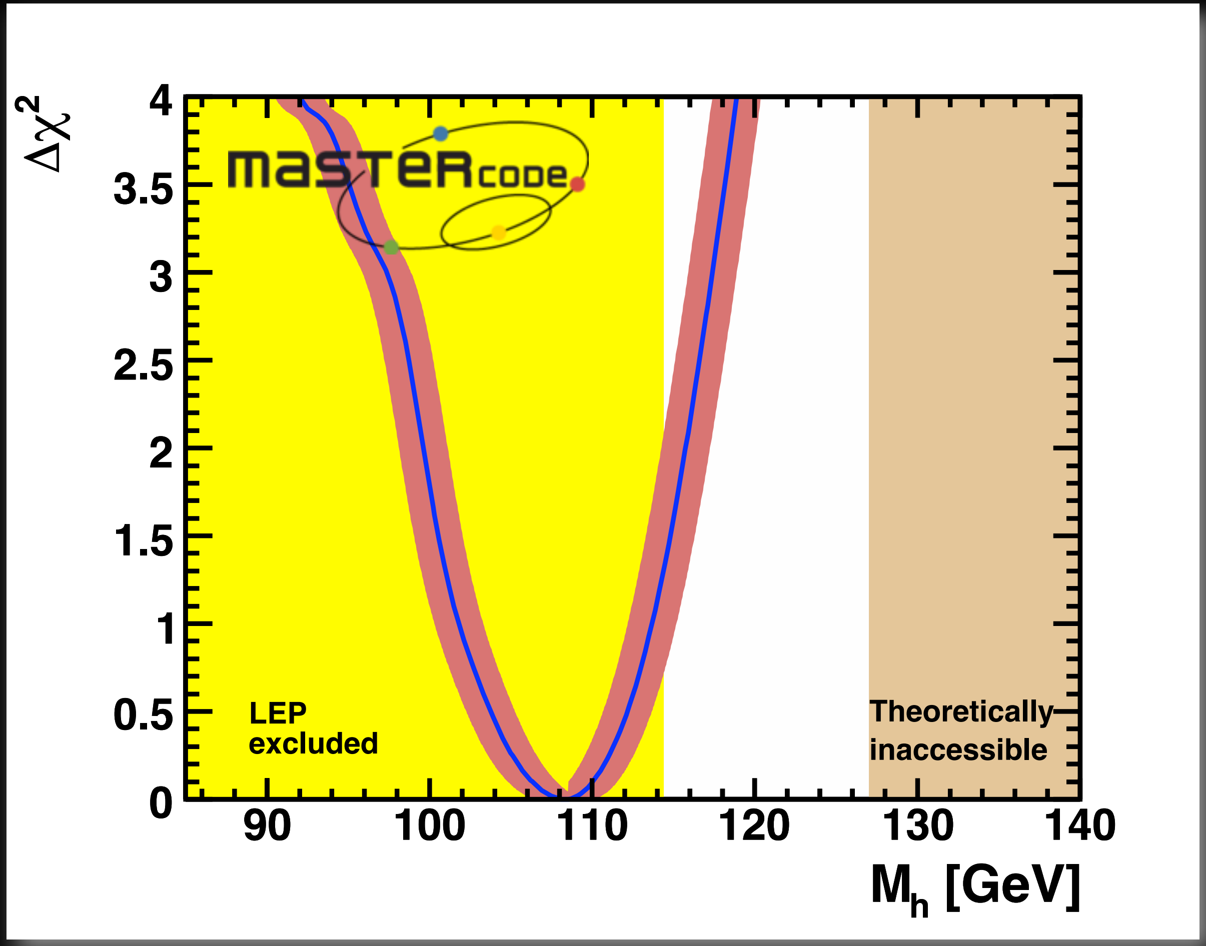
- *Not including the LEP limit*, what does the CMSSM predict with today's data?

arXiv: 0907.5568 [hep-ph]



CMSSM

Higgs mass at best fit point: 108 GeV

χ^2 value at limit: 0.7

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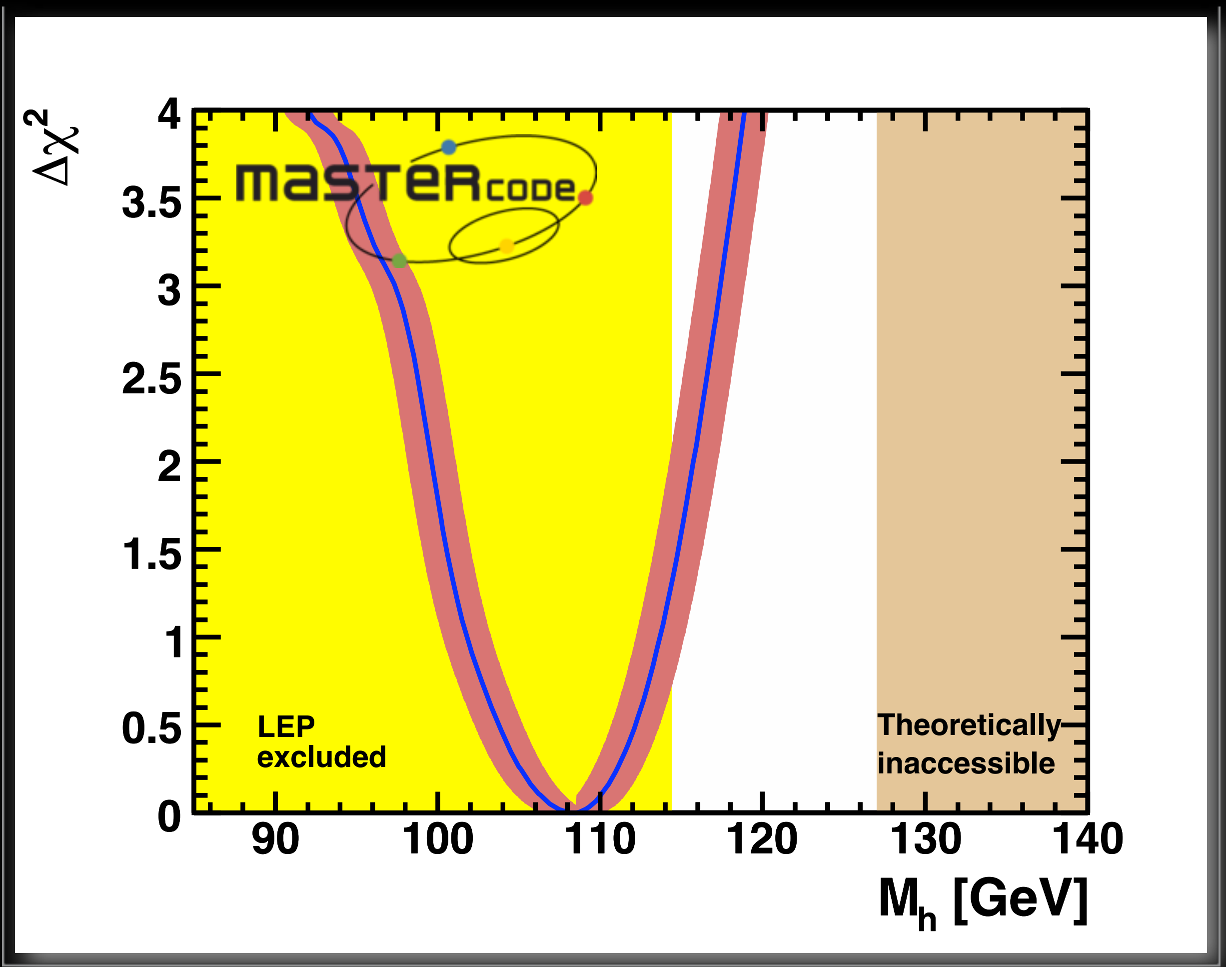

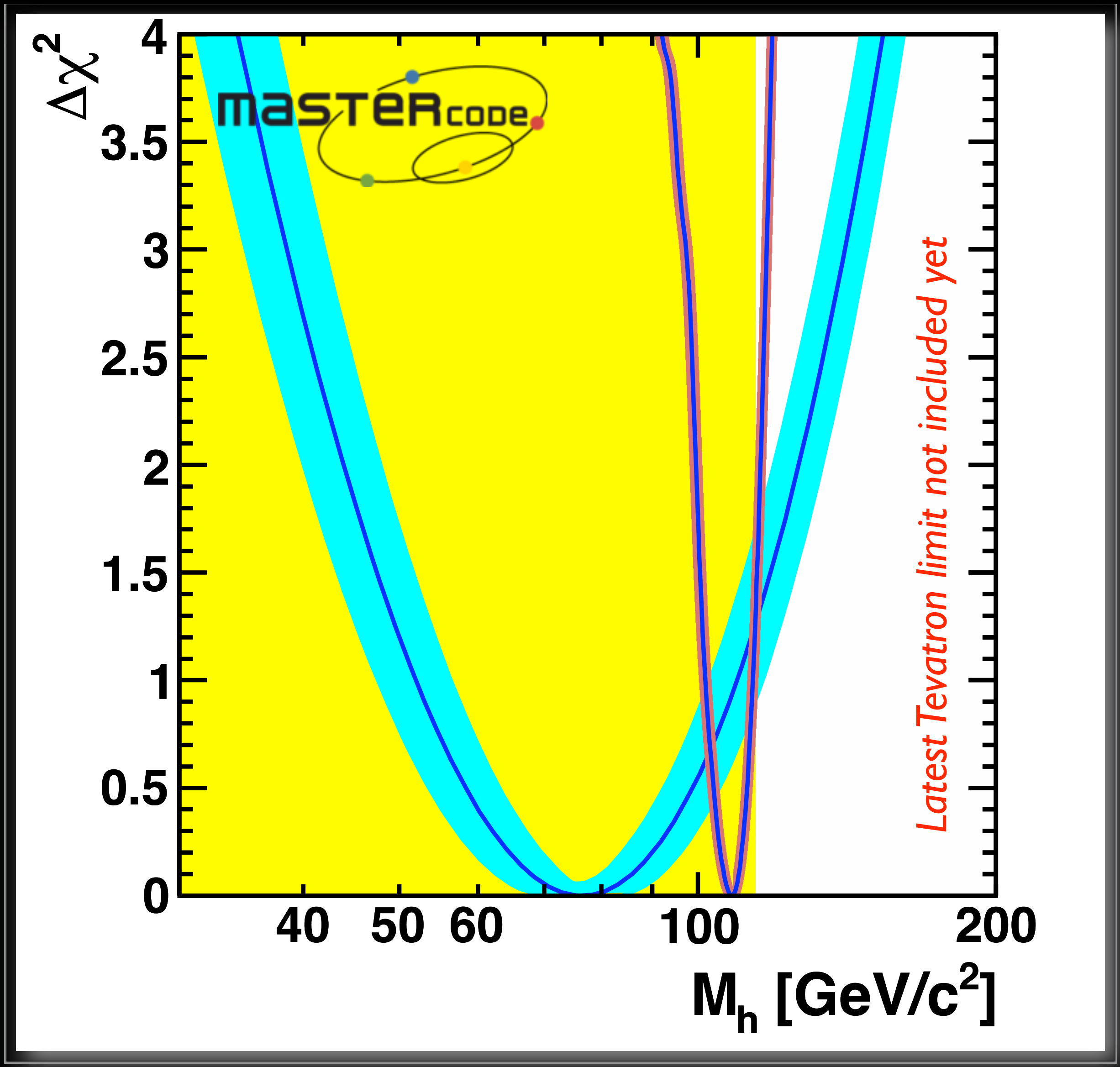

CMSSM
Higgs mass at best fit point: 108 GeV
χ^2 value at limit: 0.7

Standard Model
Higgs mass at best fit point: 87 GeV
χ^2 value at limit: 0.9

Beyond CMSSM: NUHM1

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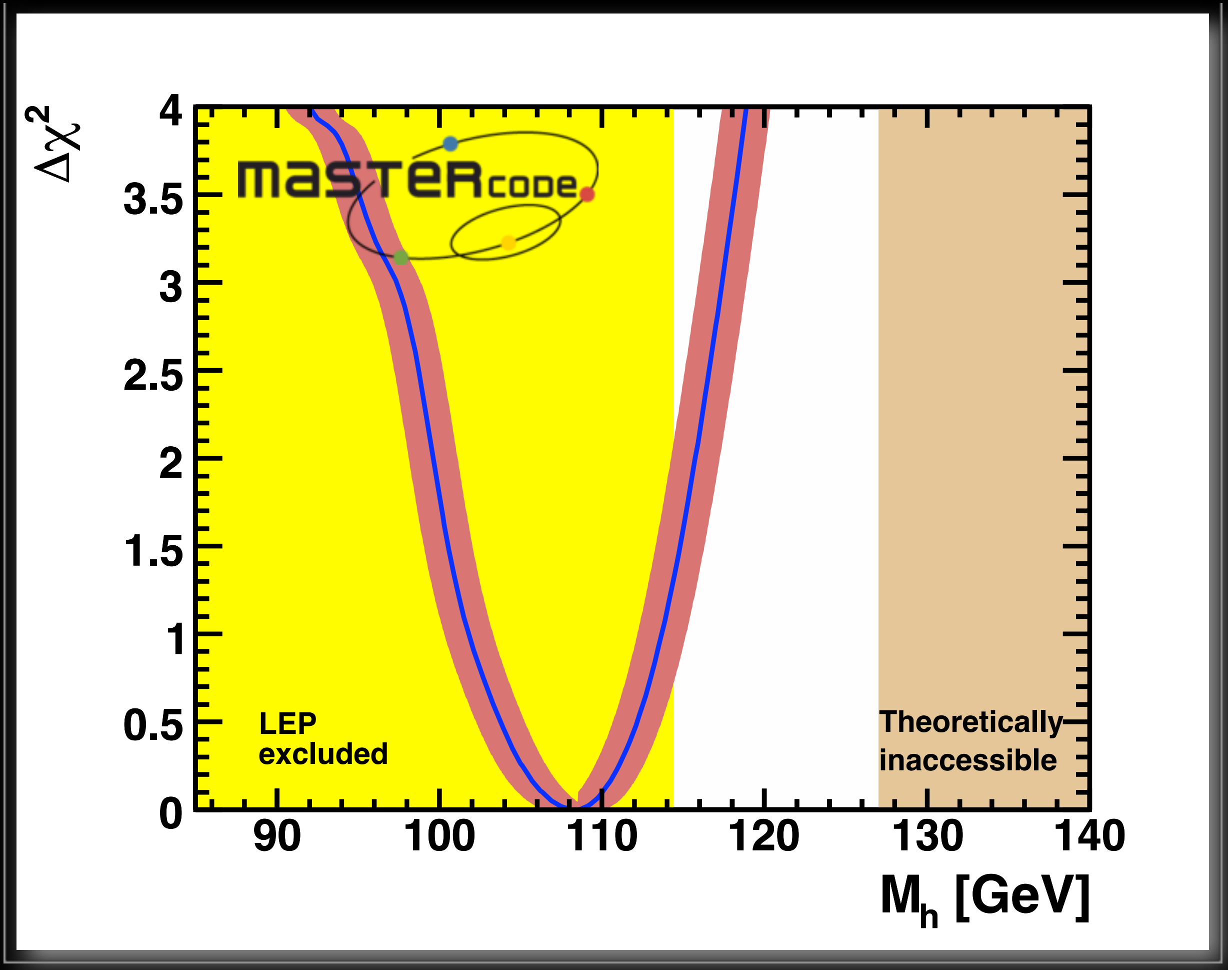
- Non-Universal Higgs Mass: adding one parameter for the Higgs sector (not bound to M_0 anymore)

arXiv: 0907.5568 [hep-ph]



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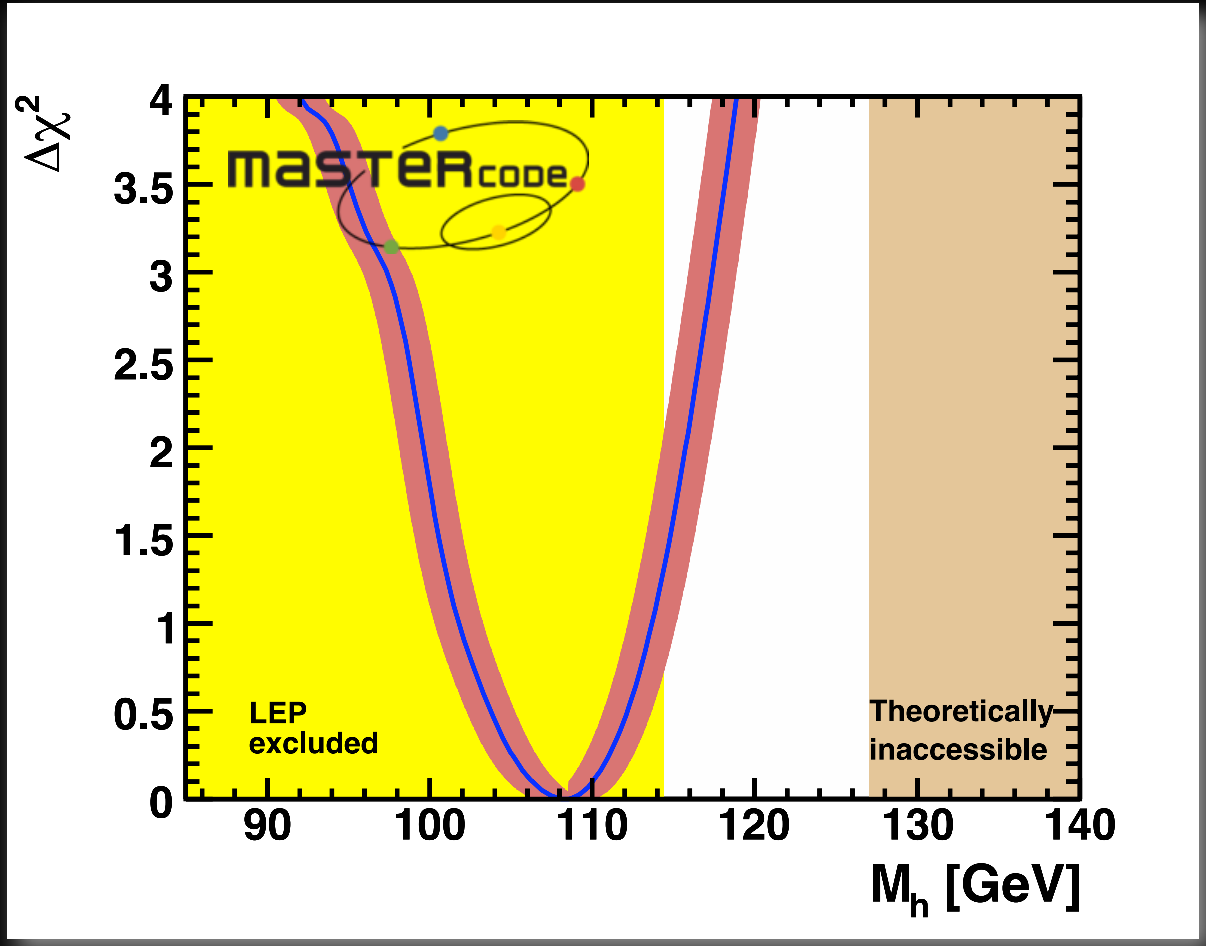

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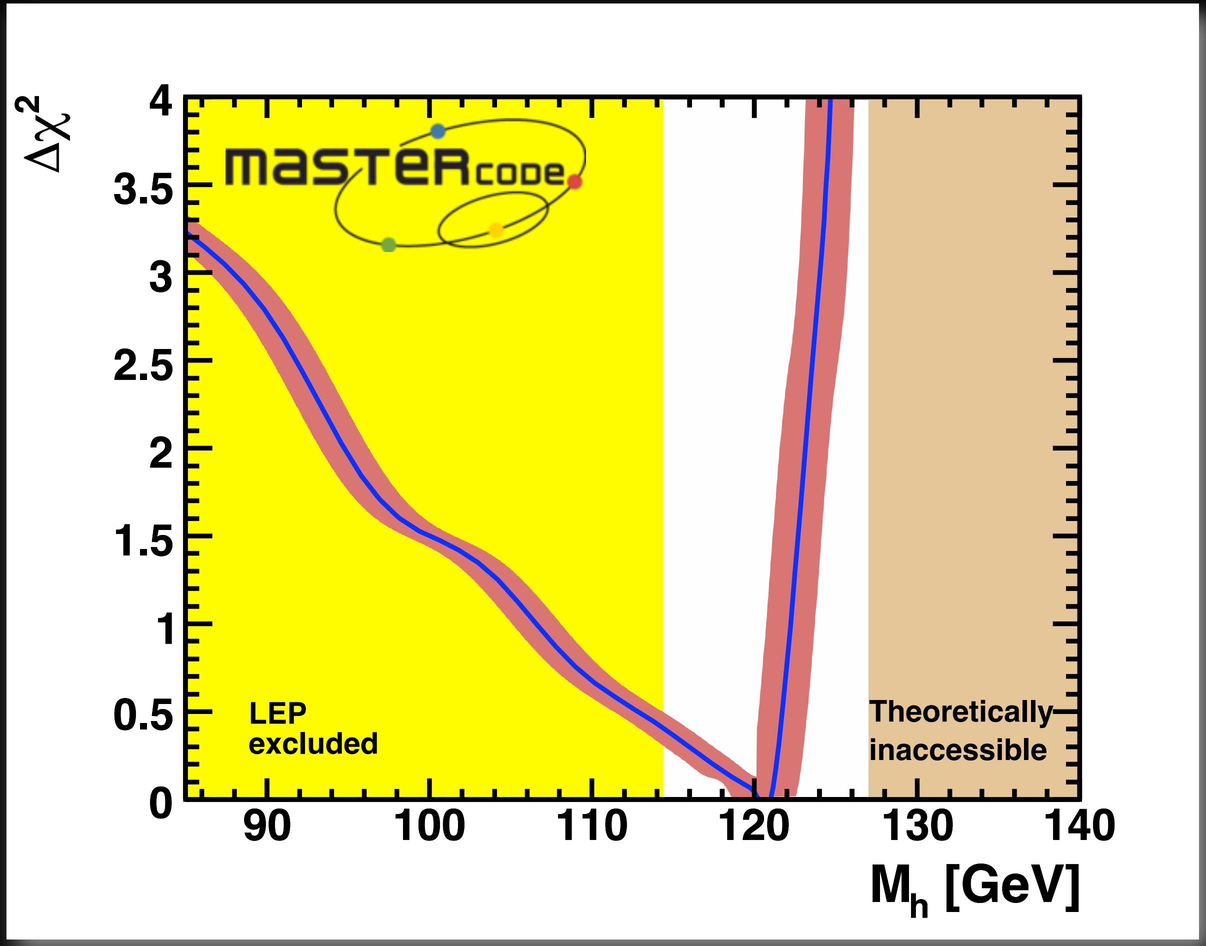

NUHM1

Higgs mass at best fit point: 120 GeV

χ^2 value at limit: N/A

Beyond CMSSM: NUHM1

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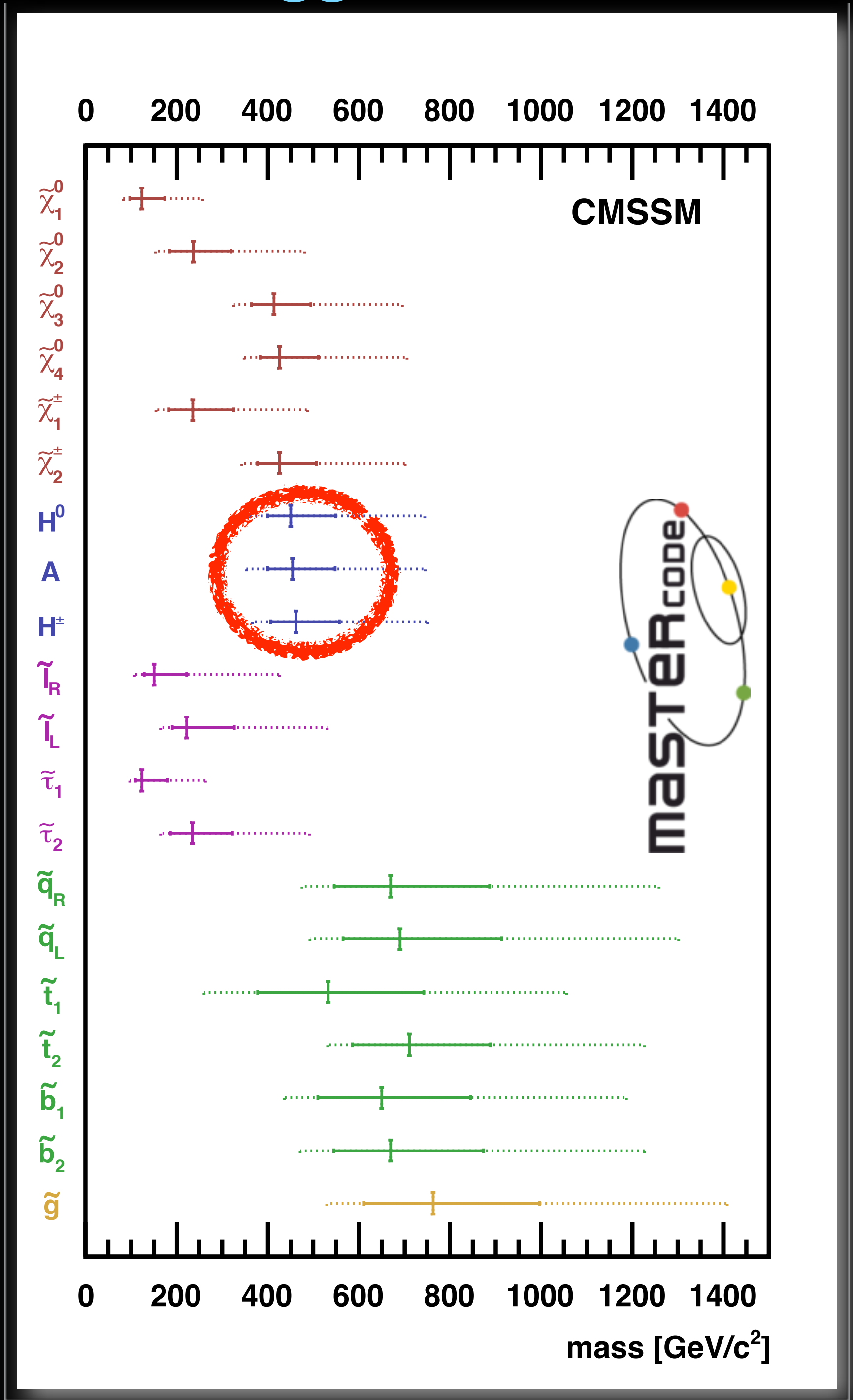
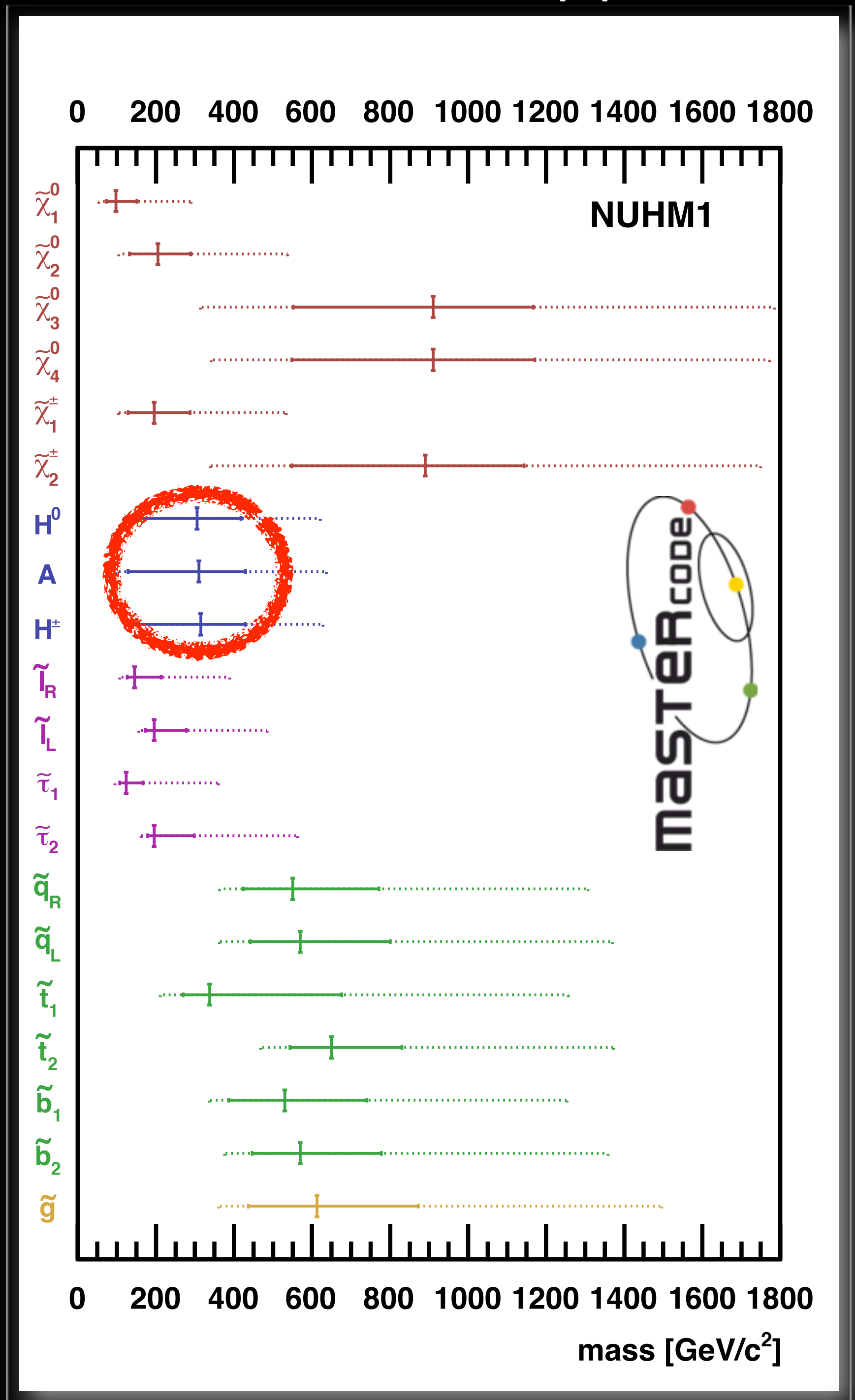
arXiv: 0907.5568 [hep-ph]





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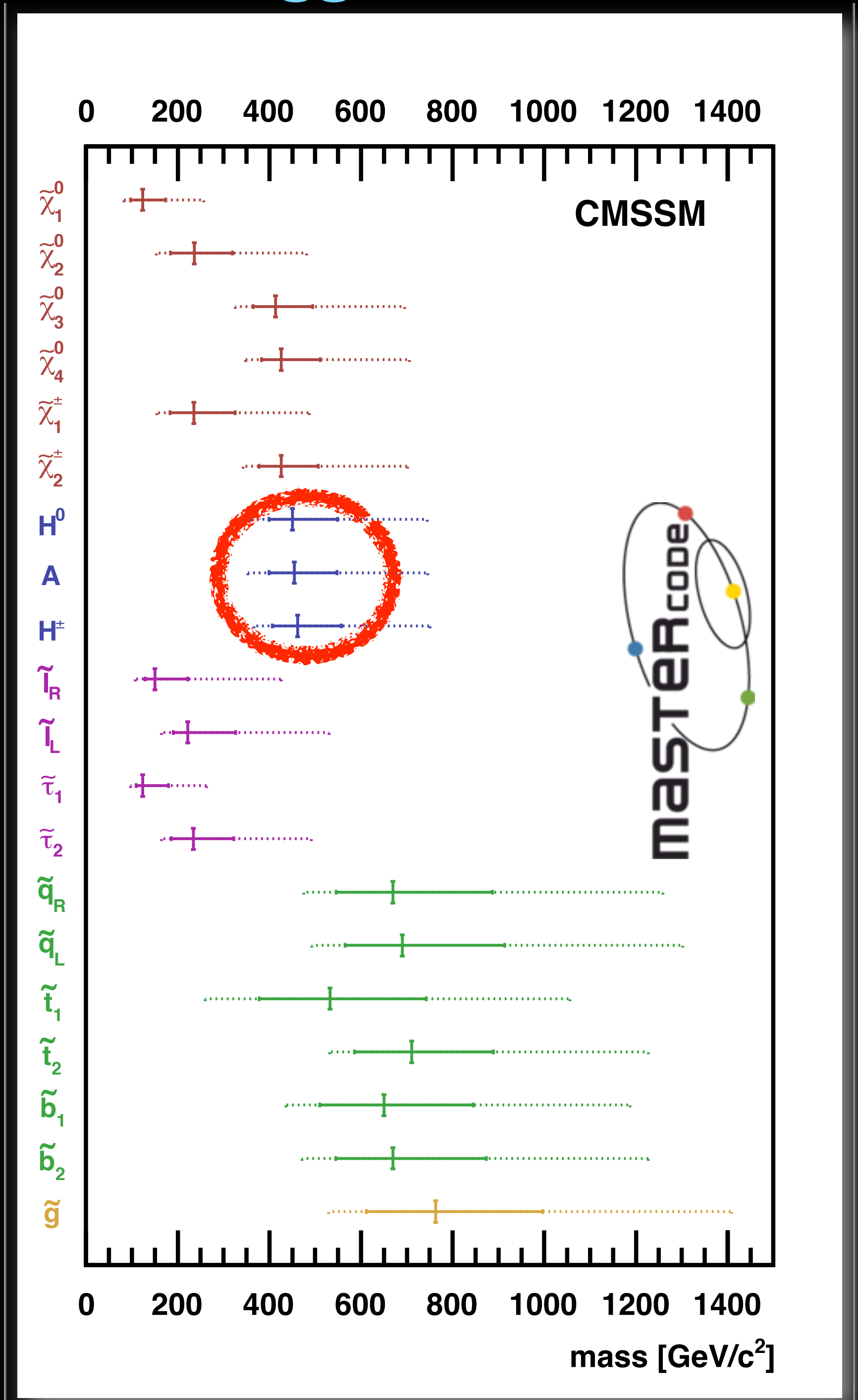

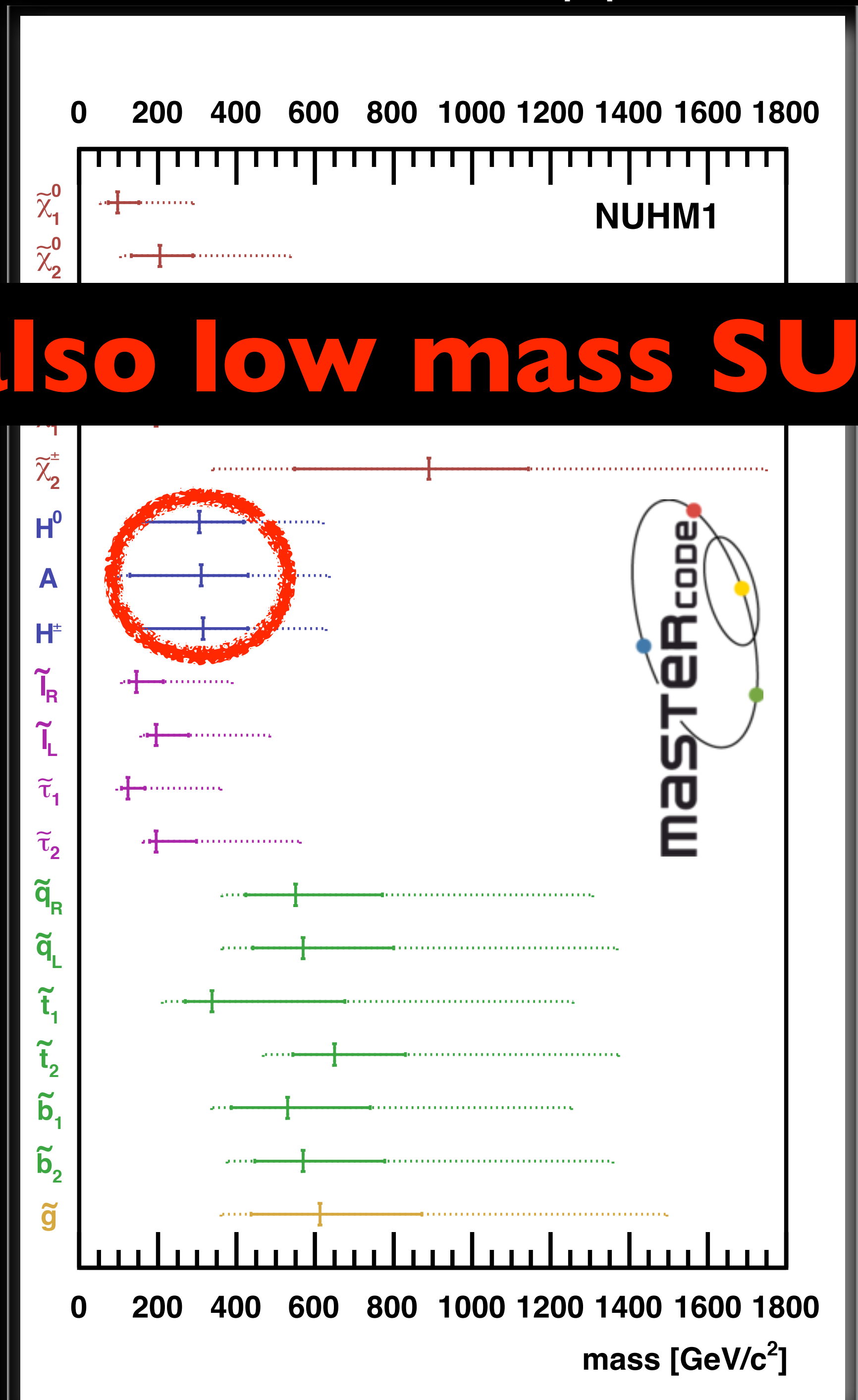

also low mass SUSY!

Beyond CMSSM: GMSB

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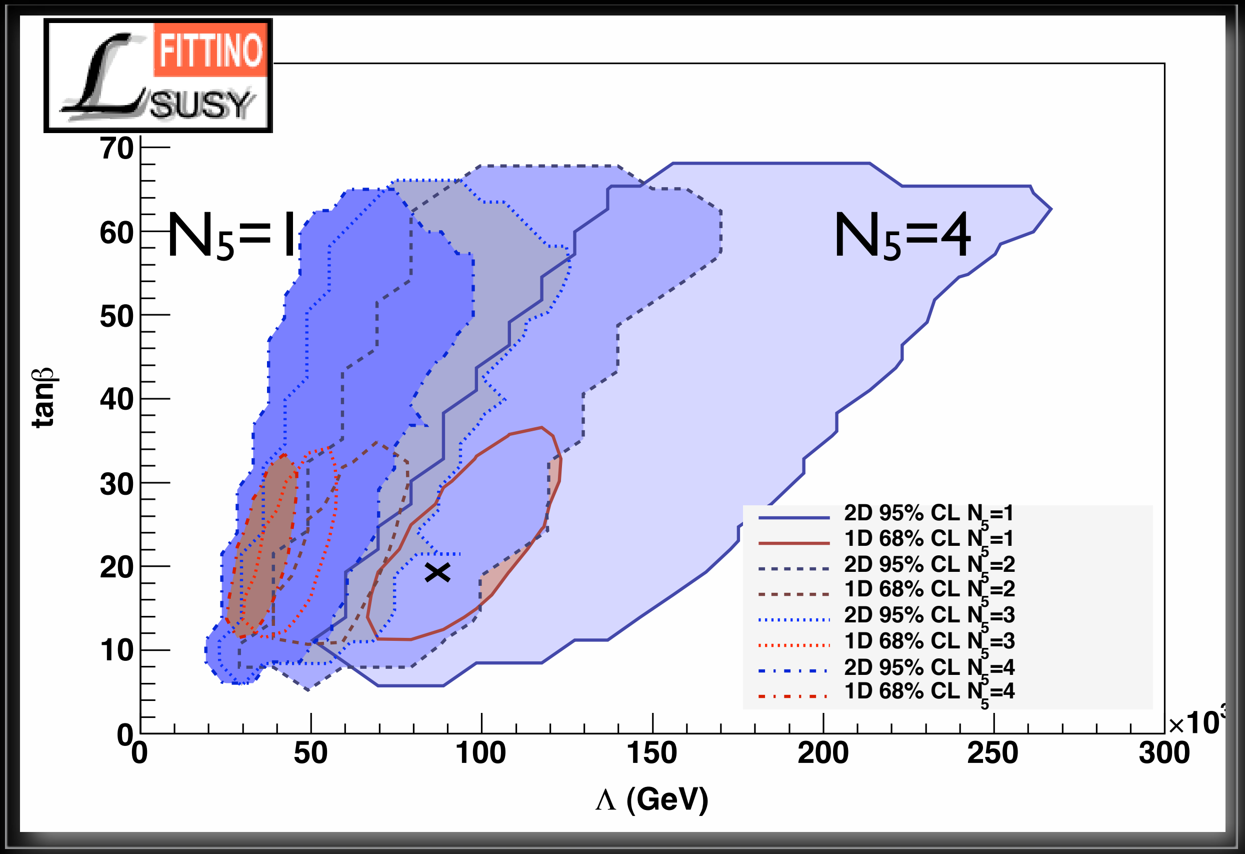
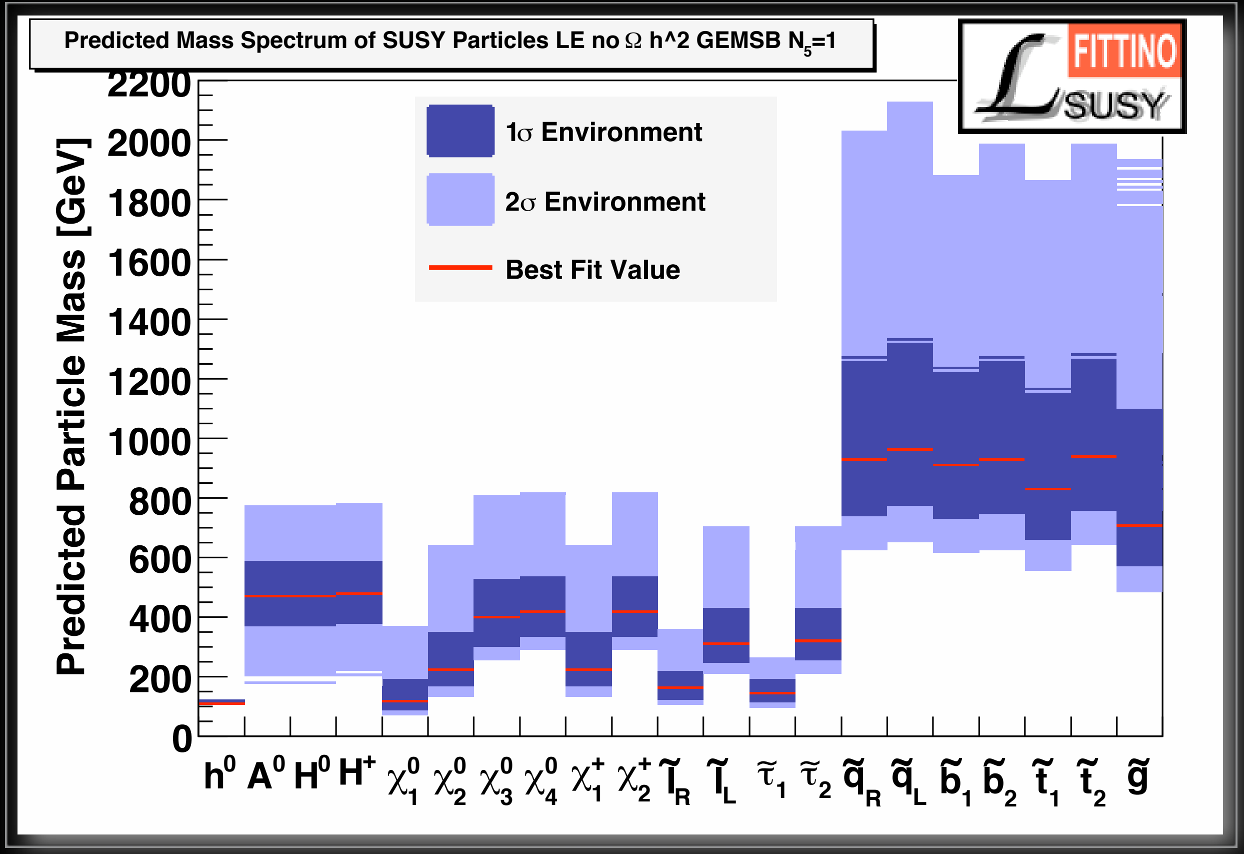
- Gauge-mediated SUSY breaking
  - **fit parameters: tanβ, Λ, M_{mess}, C_{grav}**
    - discrete parameters: sign(μ), N_5 (fixed) [no Ωh^2]

arXiv:0907.2589 [hep-ph]



tanβ vs. Λ
68% and 95% CL contours
N_5 = 1,...,4
➠ **sensitivity to N_5**



GMSB mass spectrum
N_5 = 1
similar to CMSSM

Global fits and astrophysics (I)

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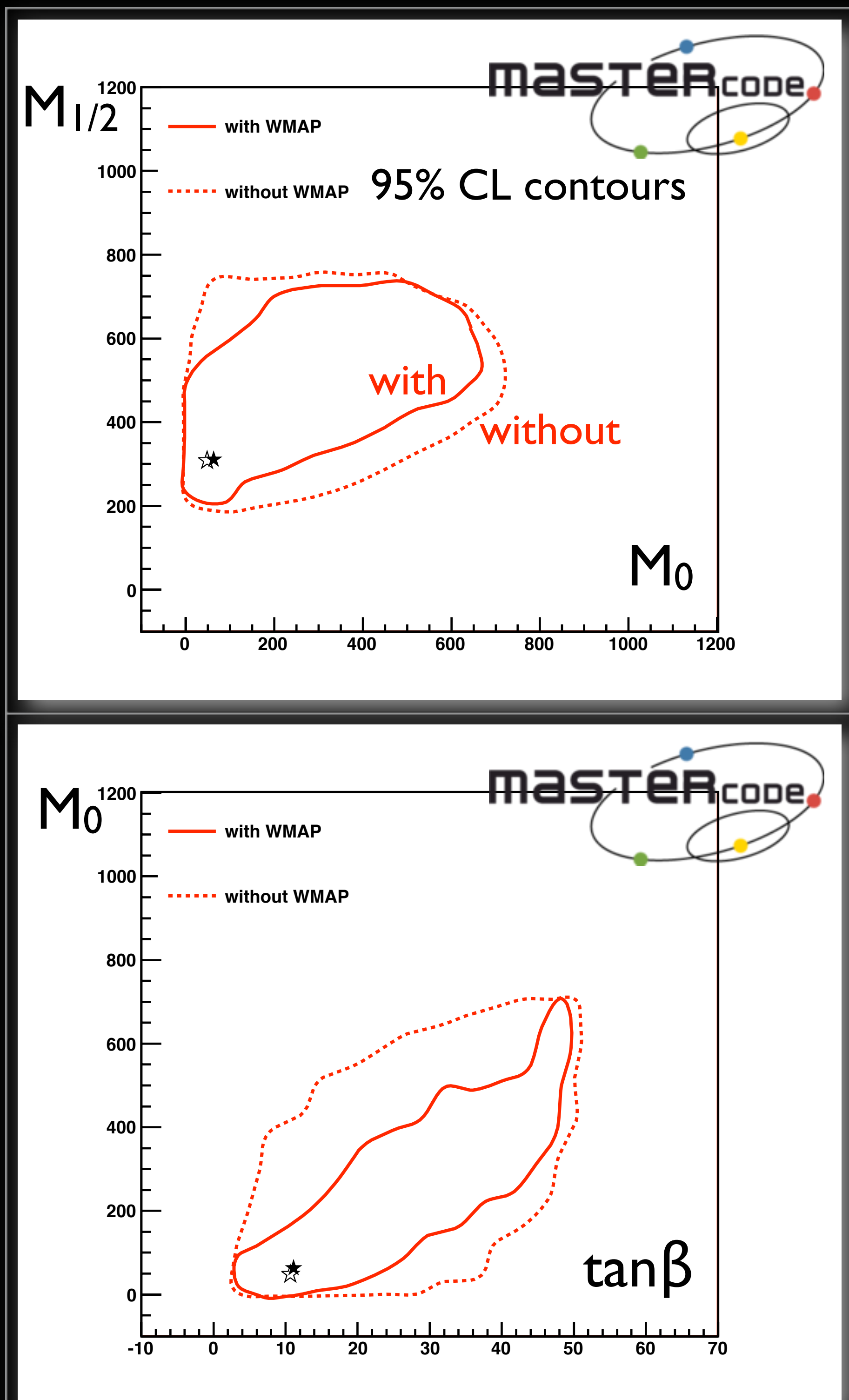
- With and without relic density

arXiv:0907.2589 [hep-ph]



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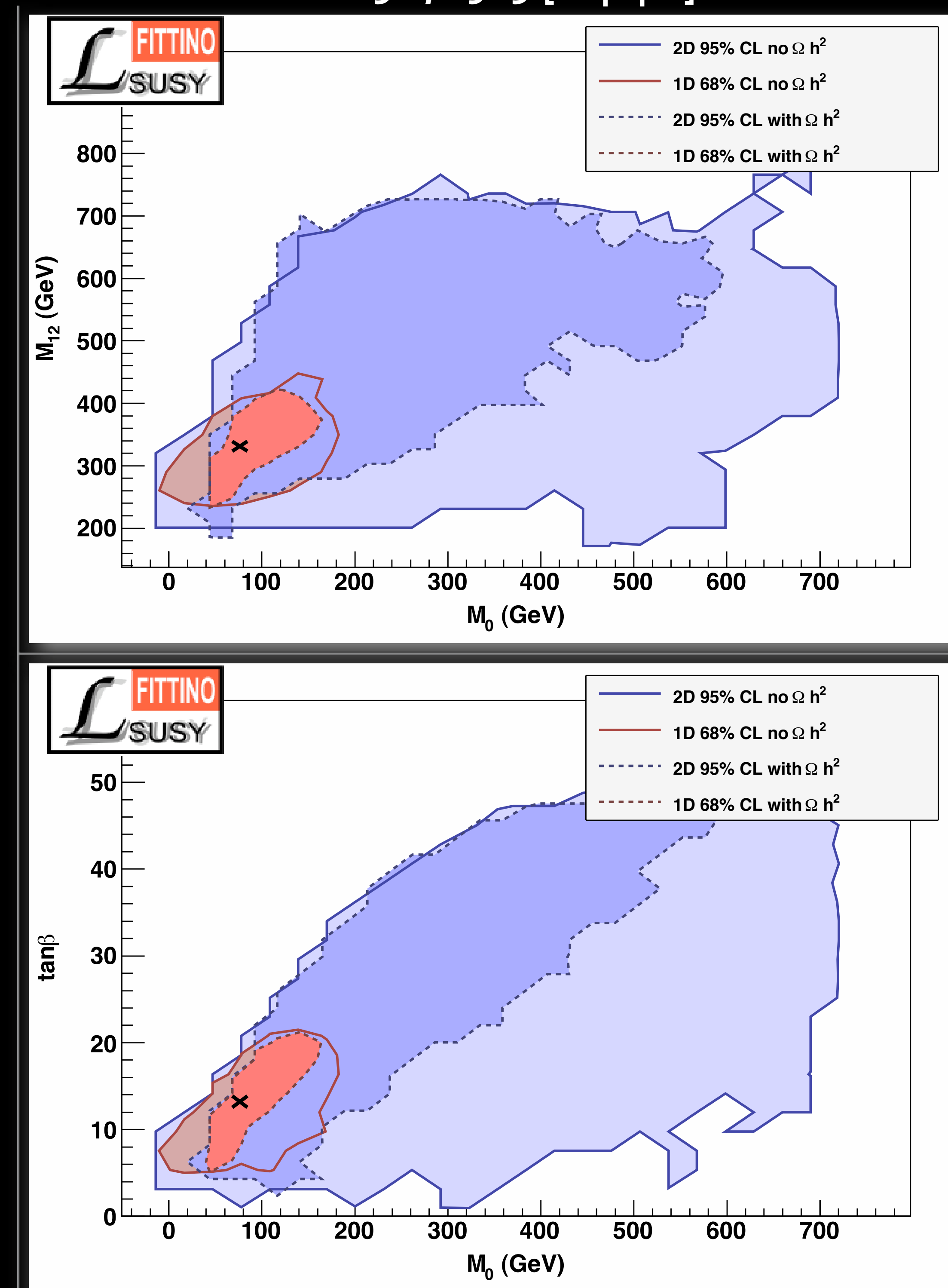

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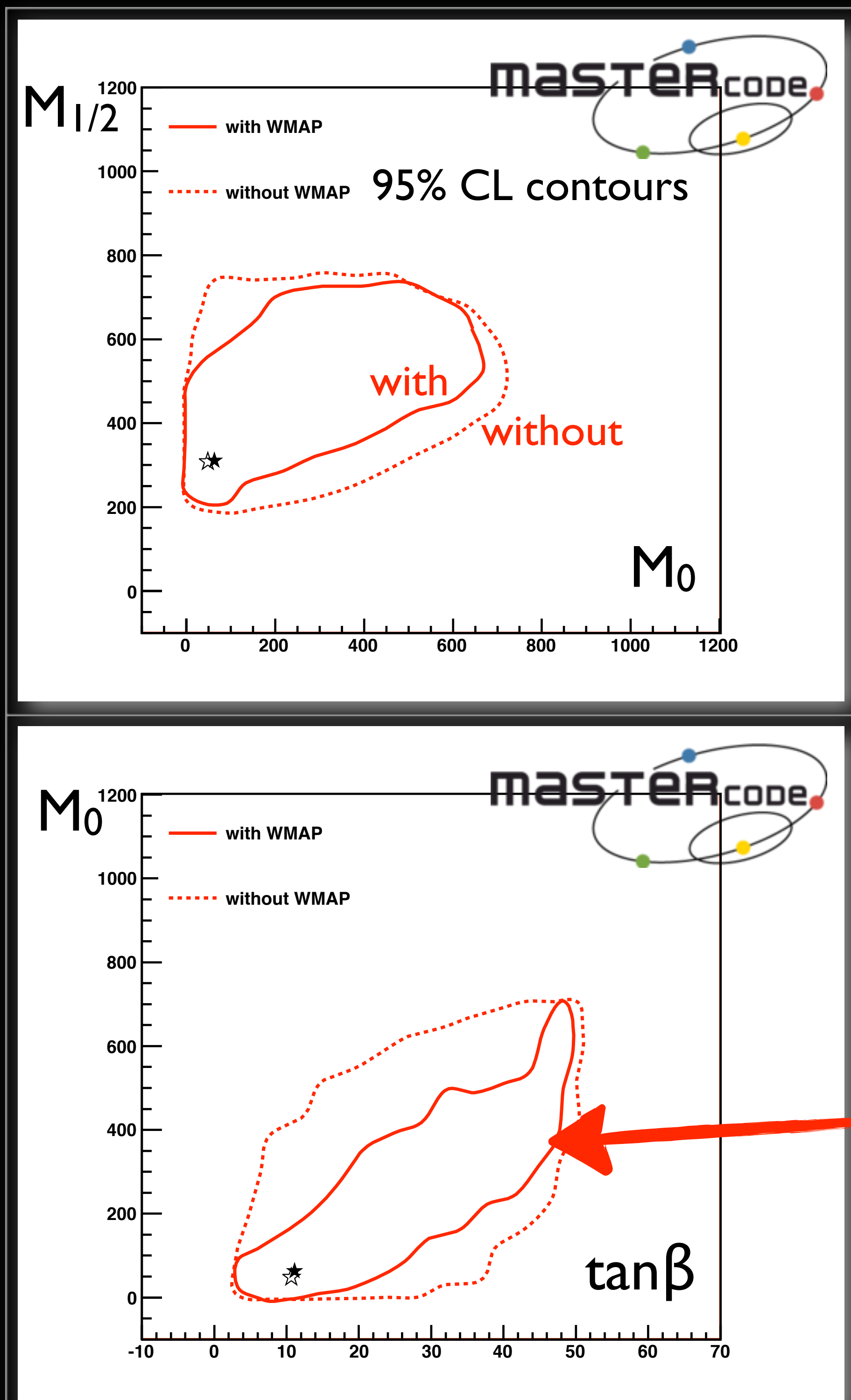
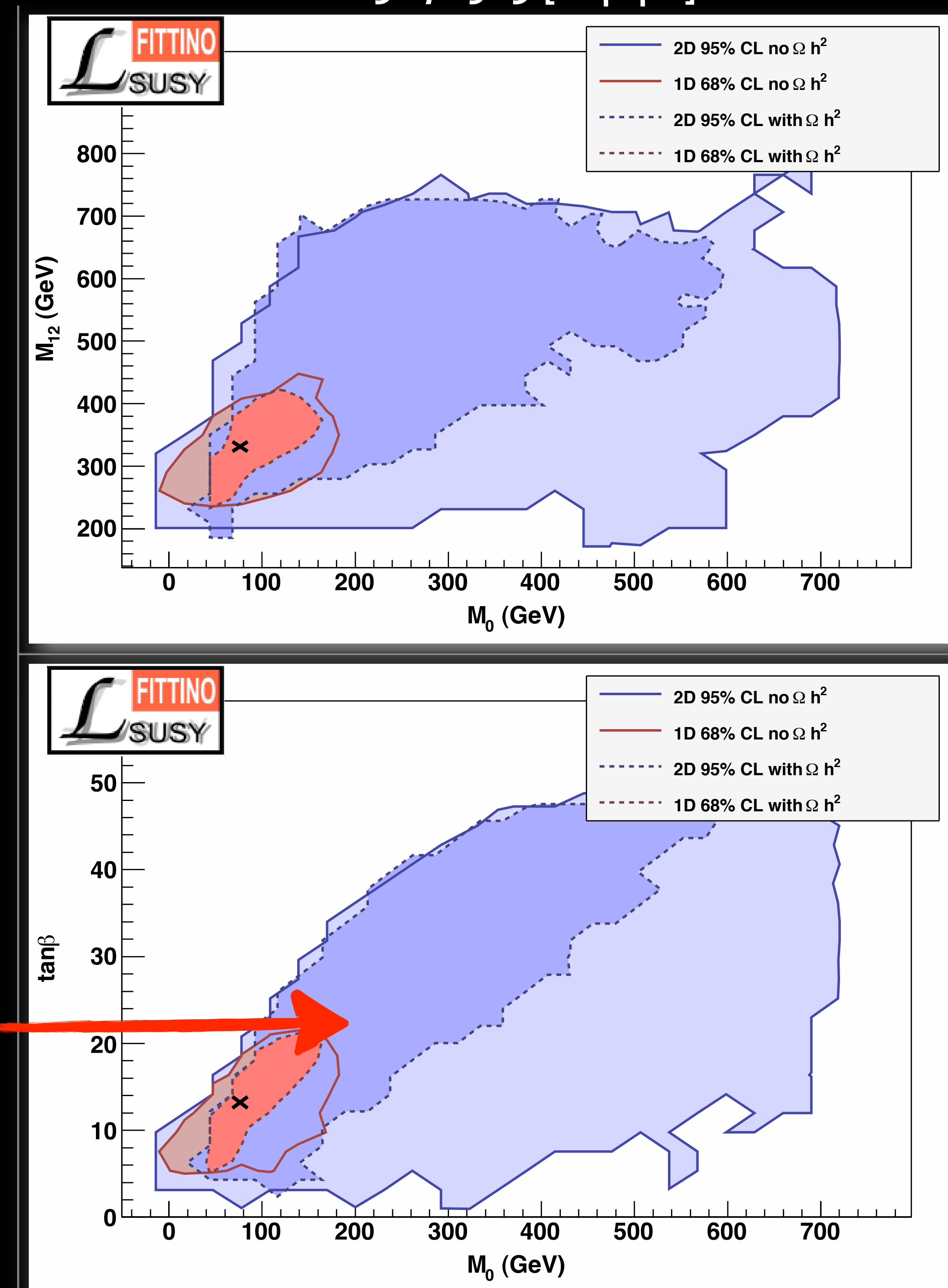


Strips?



Global fits and astrophysics (II)

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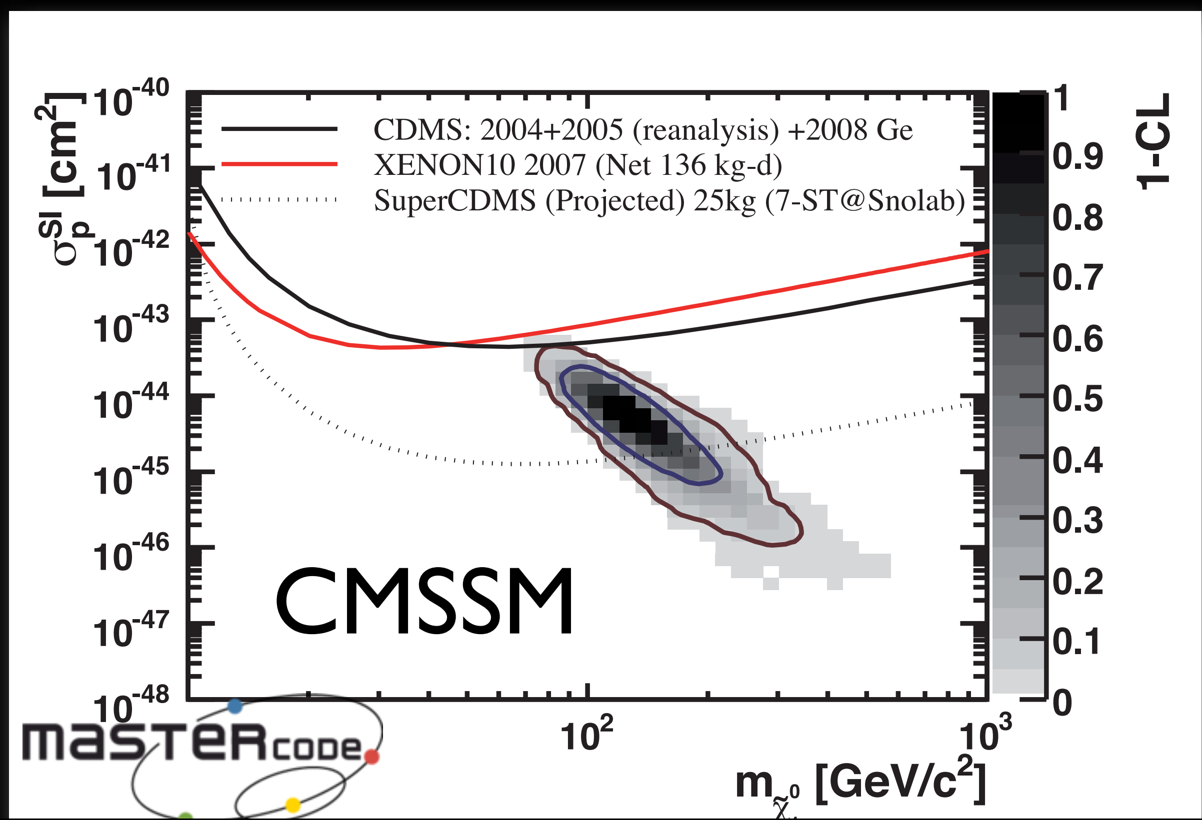
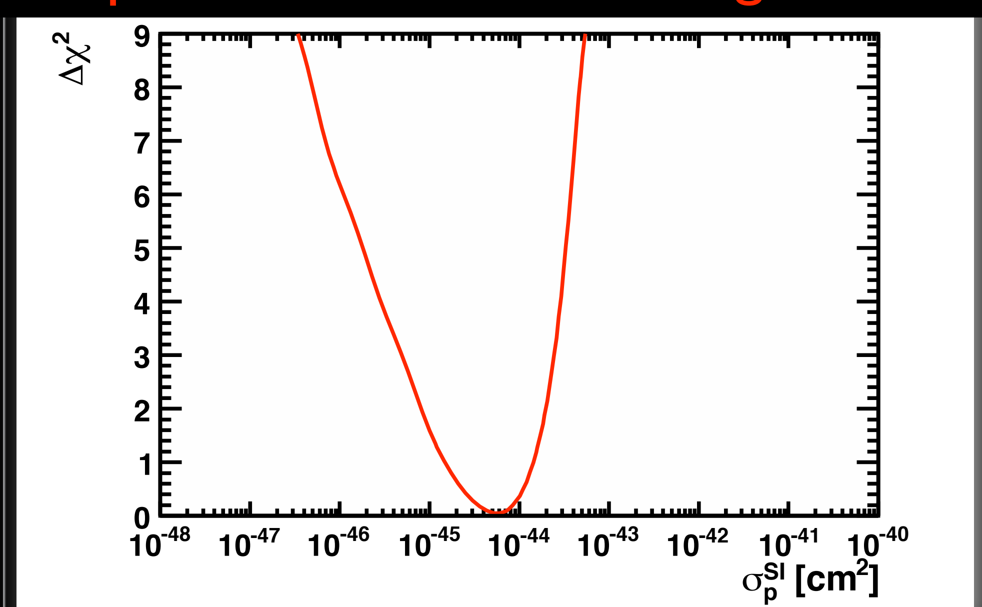
- Dark matter searches



Spin-independent WIMP scattering cross-section



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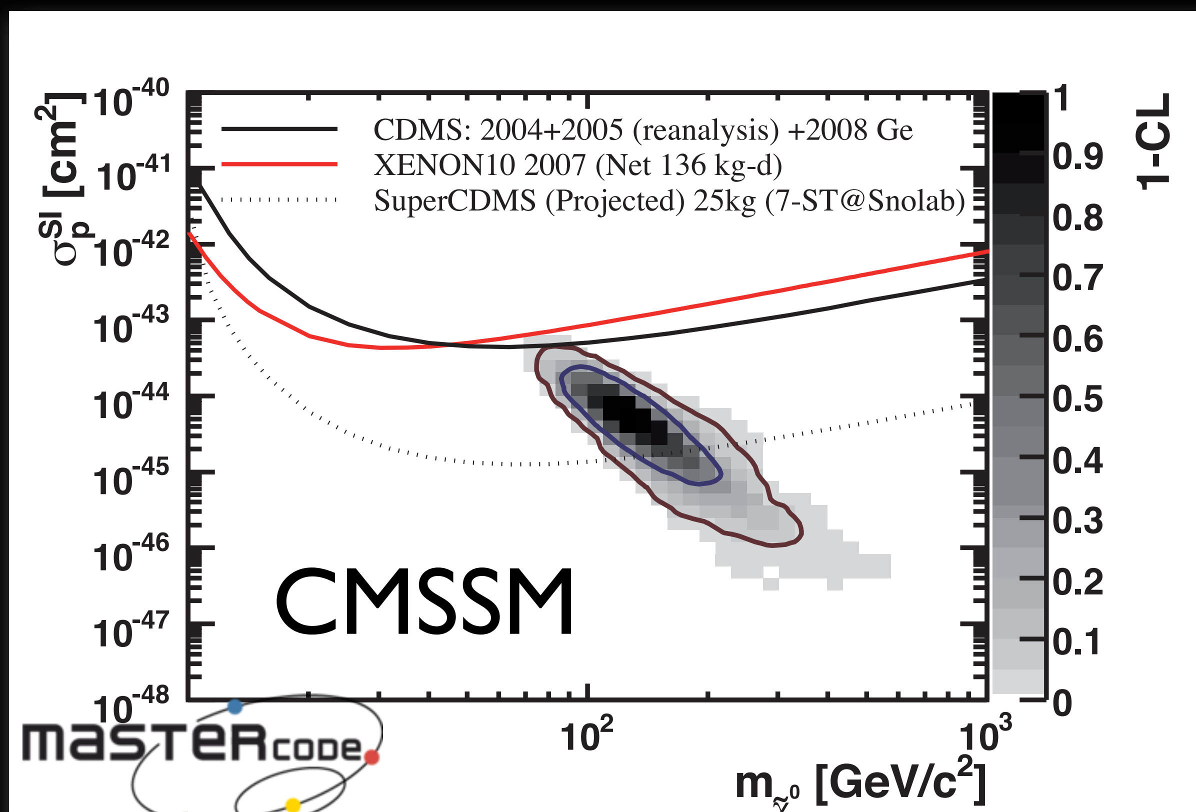

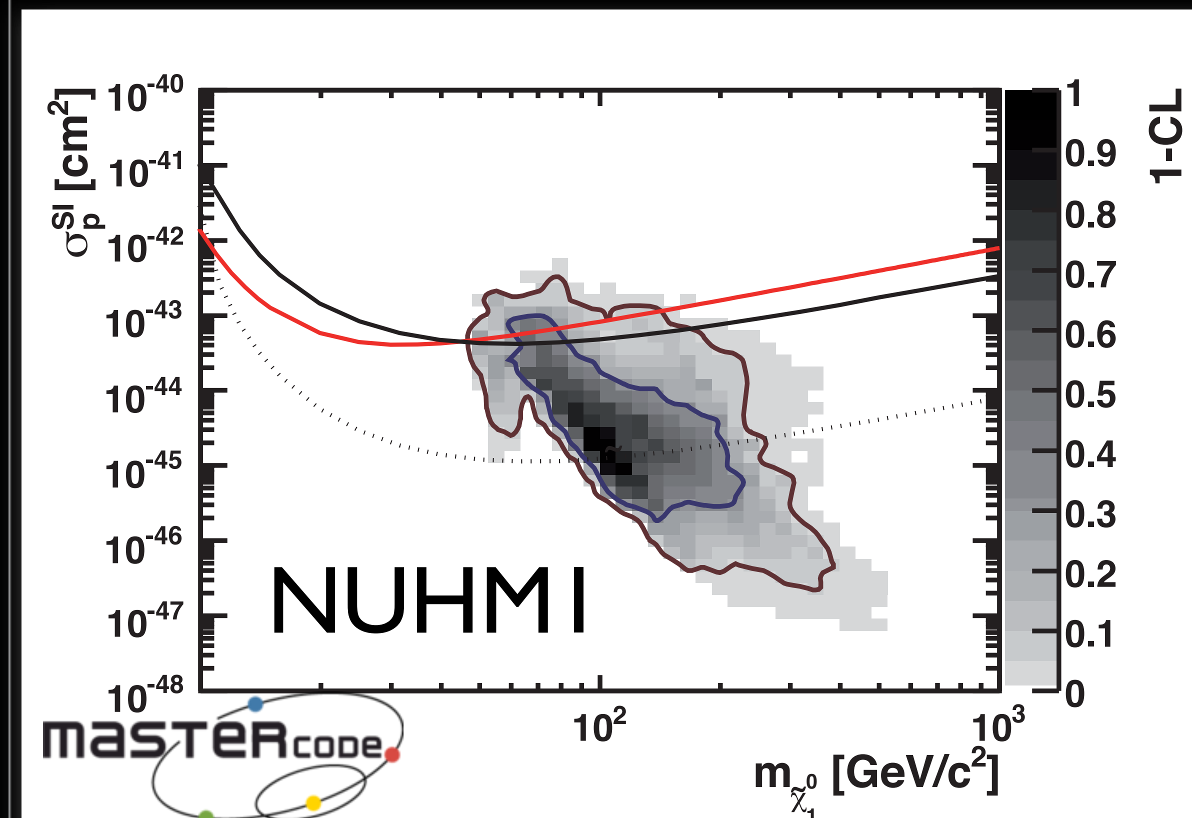

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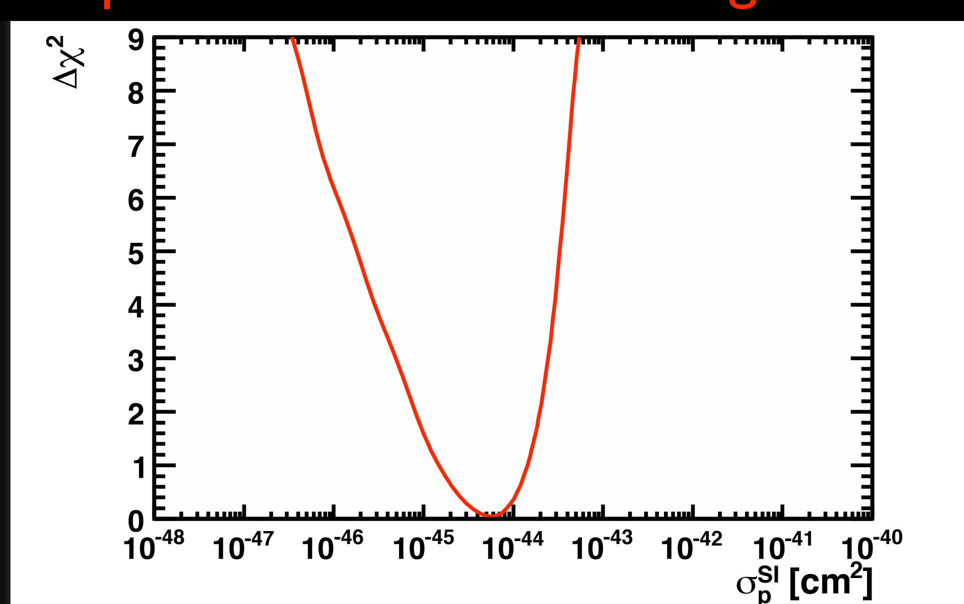
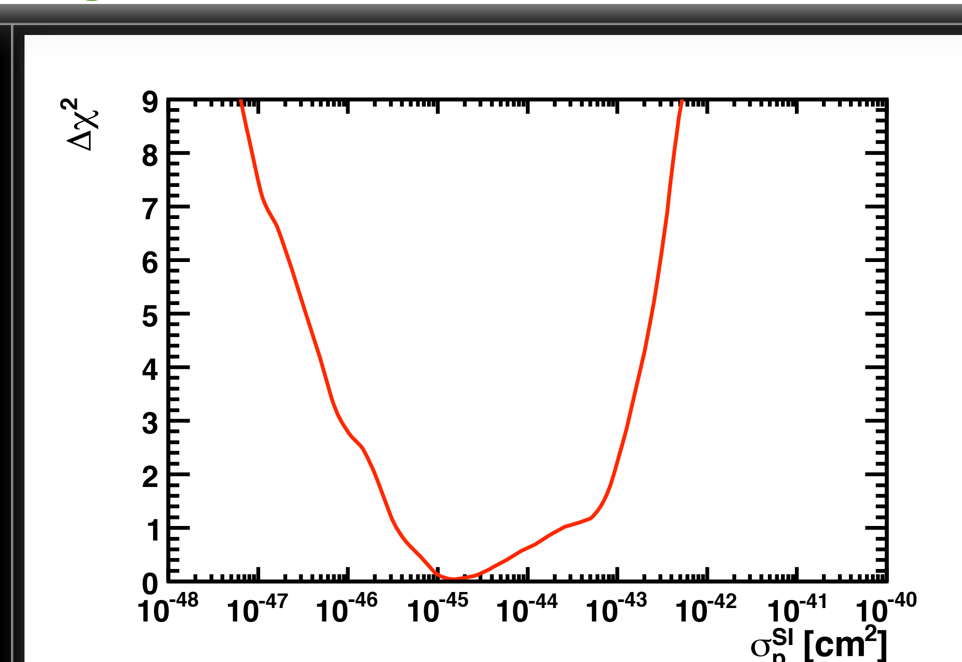
arXiv:0907.5568 [hep-ph]

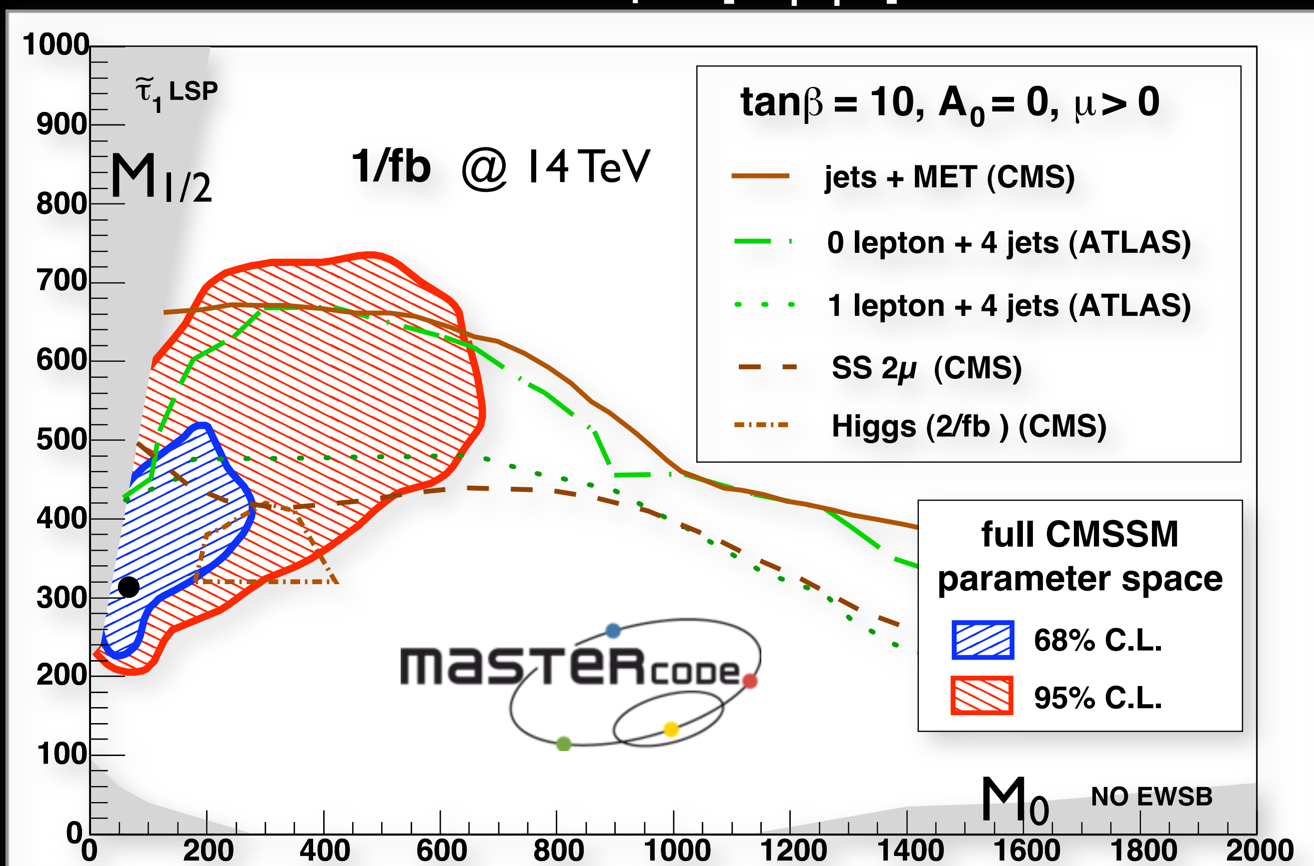




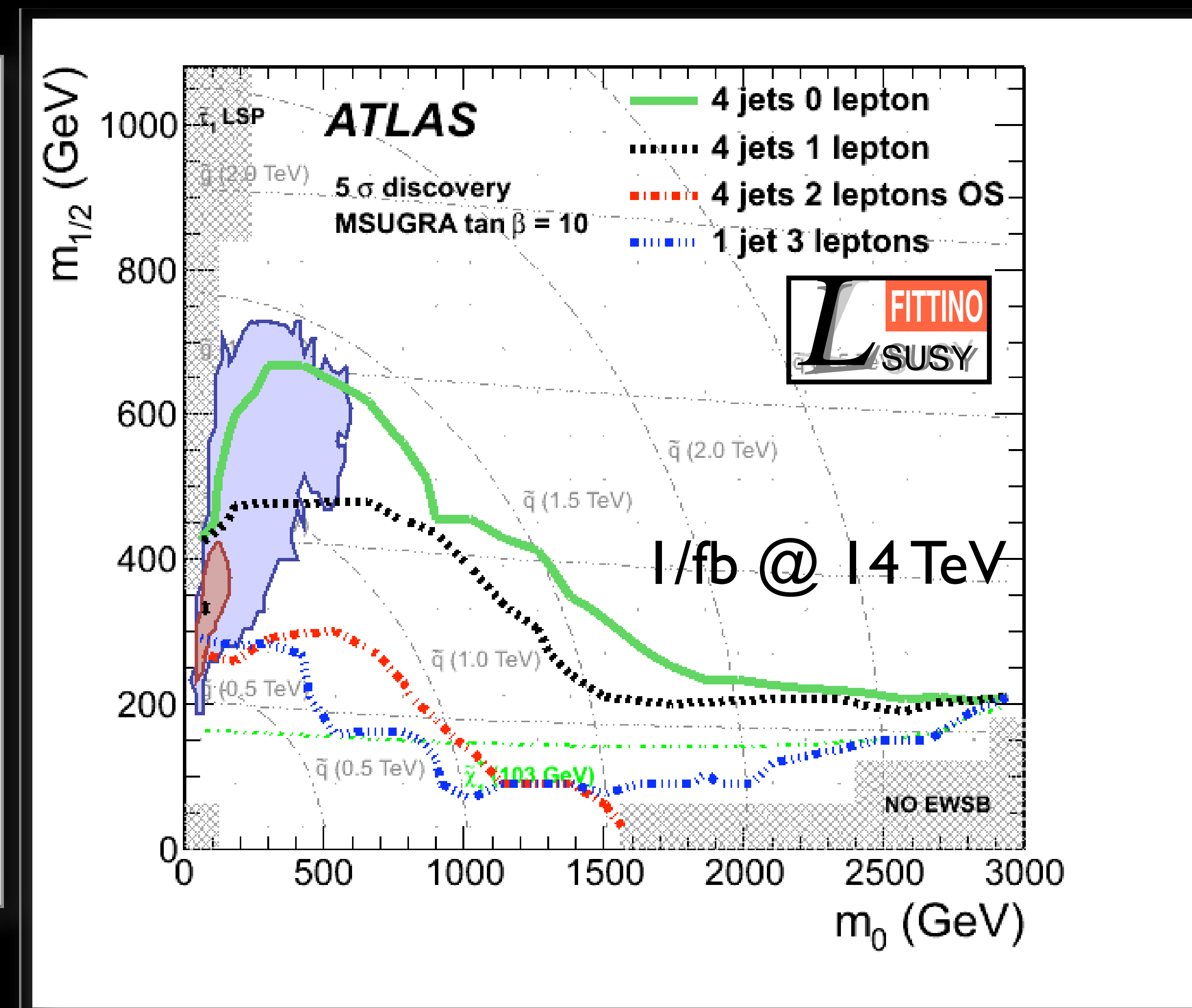
Global fits and the LHC (I)

ETH Institute for Particle Physics

arXiv:0808.4128 [hep-ph]



arXiv:0907.2589 [hep-ph]

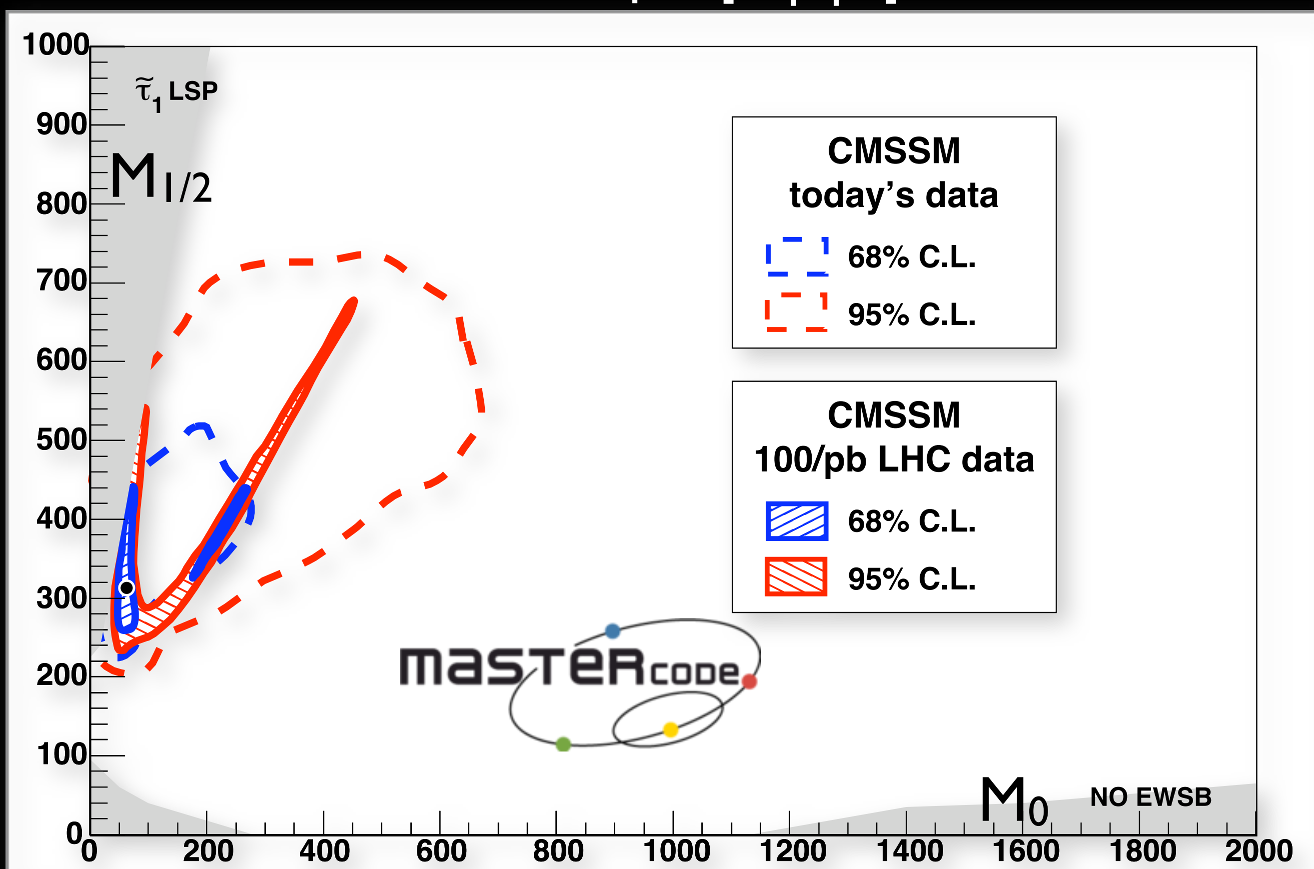


Where we stand today: CMS, ATLAS and the CMSSM

Global fits and the LHC (II)

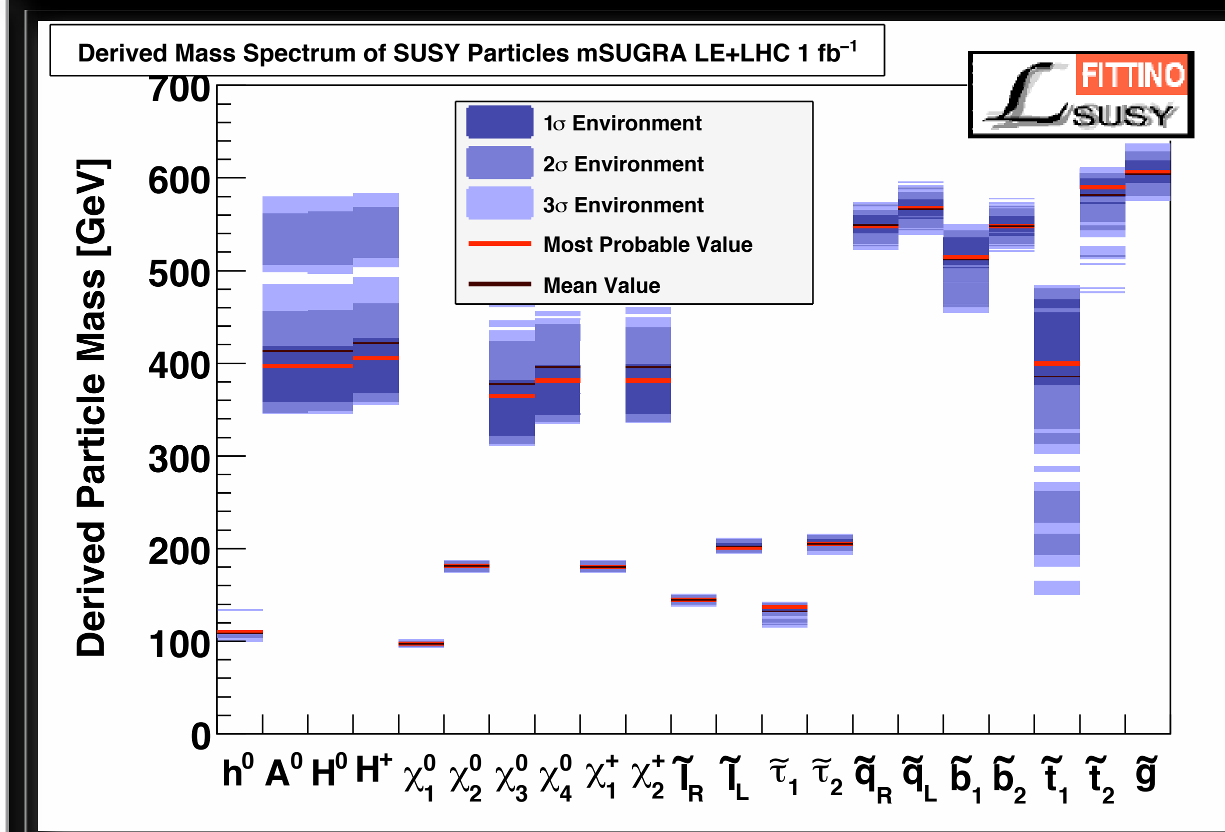
ETH Institute for Particle Physics

arXiv:0808.4128 [hep-ph]



Dilepton edge measurement at CMS
1/fb integrated luminosity @ 14 TeV

arXiv:0907.2589 [hep-ph]



Edge measurements at ATLAS
1/fb integrated luminosity @ 14 TeV

Tomorrow?
CMS, ATLAS and the CMSSM

Beyond CMSSM: pMSSM

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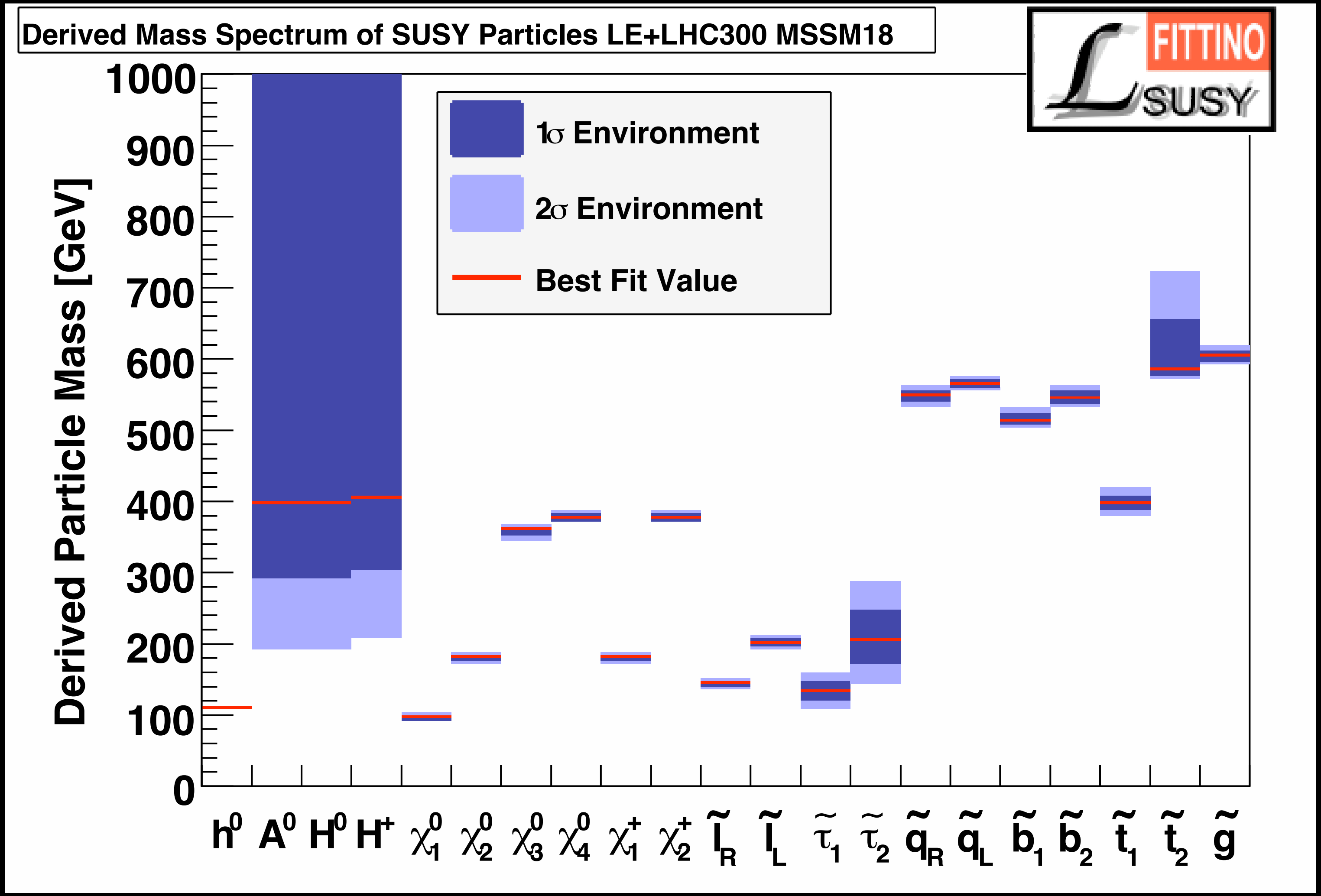
- Removing assumptions on the SUSY breaking mechanism
  - **18 parameters: today's constraints not enough**
  - **add 300/fb LHC scenario**



pMSSM mass spectrum @ SPS1a
(Higgs not directly accessible at LHC in this point)

Beyond CMSSM: pMSSM

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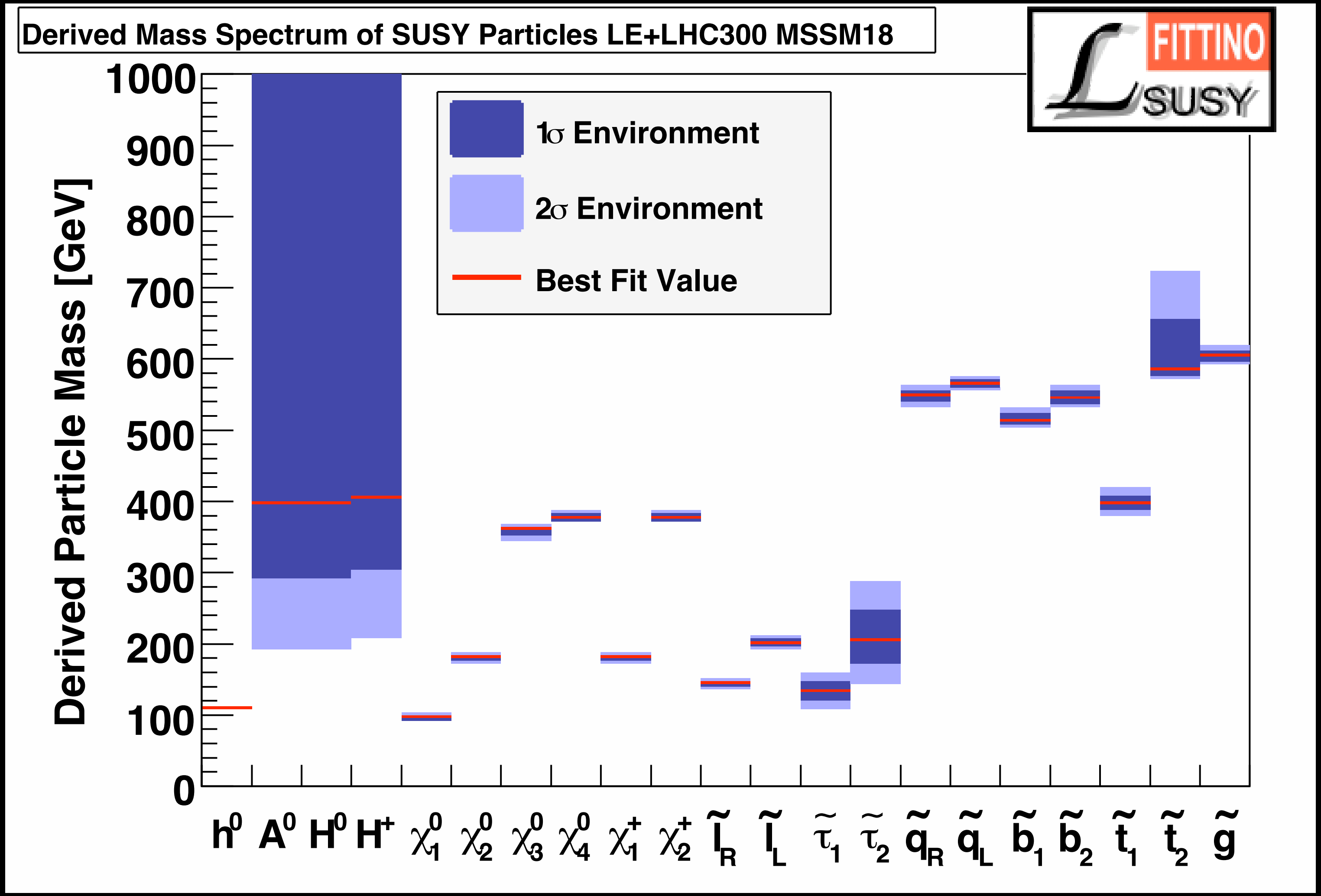
- Removing assumptions on the SUSY breaking mechanism
  - **18 parameters: today's constraints not enough**
  - **add 300/fb LHC scenario**



pMSSM mass spectrum @ SPS1a
(Higgs not directly accessible at LHC in this point)

A heroic effort!

➟ How to reduce number of parameters?

Conclusion

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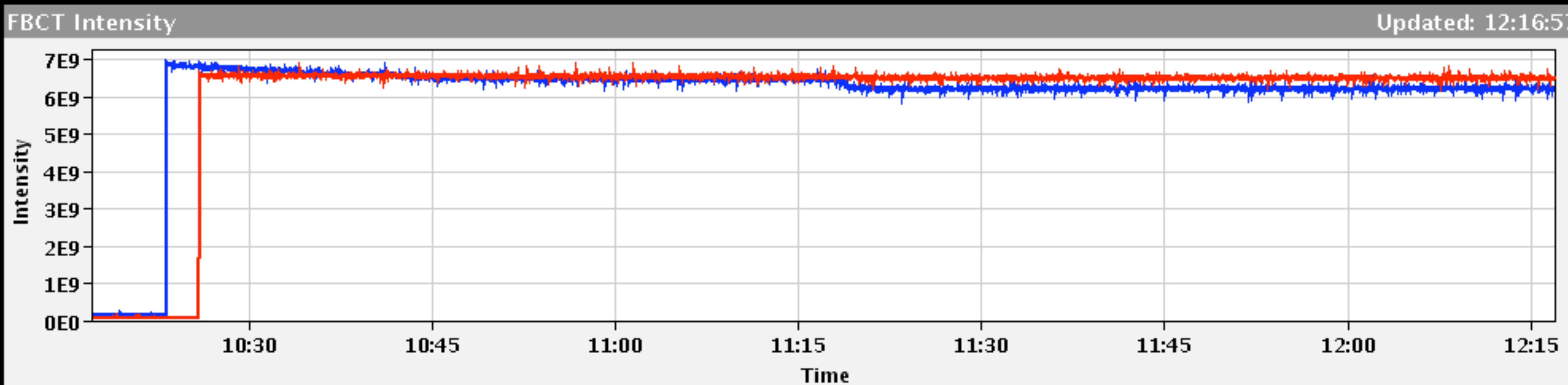
- Two independent global fits "à la frequentist"
  - **using the same substrate MasterCode and similar statistical treatment**
    - but *independent implementation*
  - **leading to identical results**
- Today's data exploited *ad nauseam*
  - **in various models (CMSSM, NUHM1, GMSB)**
  - **favour low mass SUSY**
  - **show good prospects for astrophysics and LHC**
  - **are still too weak to move away from SUSY breaking models**
- Eagerly waiting for the LHC...

LHC Page1 | Fill: 993 | E: 3500 GeV | 24-03-2010 12:16:57

BEAM SETUP: FLAT TOP

Energy:	3500 GeV	I(B1):	5.89e+09	I(B2):	4.73e+09



Comments 24-03-2010 12:07:04 :

beams circulating at 3.5Tev

B1 in bucket 1, B2 in bucket 1001

I~6e9 for both beams

Collimator studies starting at ~ 12:00

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	true	true
Setup Beam	true	true
Beam Presence	true	true
Moveable Devices Allowed In	false	false
Stable Beams	false	false

LHC Operation in CCC : 77600, 70480

PM Status B1: ENABLED | PM Status B2: ENABLED

Backup

Best fit: CMSSM vs. SM

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Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ^0_{had} [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

CMSSM

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1875	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957	
σ^0_{had} [nb]	41.540 ± 0.037	41.477	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21586	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1481	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.374	
m_t [GeV]	170.9 ± 1.8	171.3	
Γ_W [GeV]	2.140 ± 0.060	2.091	

Standard Model

Constraints (I)

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Observable	Th. Source	Ex. Source	Constraint	Add. Th. Unc.
m_t [GeV]	[68,69]	[70]	173.1 ± 1.3	–
$\Delta\alpha^{(5)}_{\rm had}(m_Z)$	[68,69]	[71]	0.02758 ± 0.00035	–
M_Z [GeV]	[68,69]	[71]	91.1875 ± 0.0021	–
Γ_Z [GeV]	[68,69]	[71]	2.4952 ± 0.0023	0.001
$\sigma^0_{\rm had}$ [nb]	[68,69]	[71]	41.540 ± 0.037	–
R_l	[68,69]	[71]	20.767 ± 0.025	–
$A_{\rm fb}(\ell)$	[68,69]	[71]	0.01714 ± 0.00095	–
$A_\ell(P_\tau)$	[68,69]	[71]	0.1465 ± 0.0032	–
$R_{\rm b}$	[68,69]	[71]	0.21629 ± 0.00066	–
$R_{\rm c}$	[68,69]	[71]	0.1721 ± 0.003	–
$A_{\rm fb}(b)$	[68,69]	[71]	0.0992 ± 0.0016	–
$A_{\rm fb}(c)$	[68,69]	[71]	0.0707 ± 0.0035	–
A_b	[68,69]	[71]	0.923 ± 0.020	–
A_c	[68,69]	[71]	0.670 ± 0.027	–
$A_\ell({\rm SLD})$	[68,69]	[71]	0.1513 ± 0.0021	–
$\sin^2\theta^\ell_{\rm w}(Q_{\rm fb})$	[68,69]	[71]	0.2324 ± 0.0012	–
M_W [GeV]	[68,69]	[72,73]	80.399 ± 0.025	0.010
${\rm BR}^{\rm exp}_{b\to s\gamma}/{\rm BR}^{\rm SM}_{b\to s\gamma}$	[74–78]	[79]	$1.117 \pm 0.076_{\rm exp} \pm 0.082_{\rm th(SM)}$	0.050
${\rm BR}(B_s \to \mu^+\mu^-)$	[80–83]	[79]	$< 4.7 \times 10^{-8}$	0.02×10^{-8}
${\rm BR}^{\rm exp}_{B\to\tau\nu}/{\rm BR}^{\rm SM}_{B\to\tau\nu}$	[82–84]	[85–87]	$1.25 \pm 0.40_{[\rm exp+th]}$	–
${\rm BR}(B_d \to \mu^+\mu^-)$	[80–83]	[79]	$< 2.3 \times 10^{-8}$	0.01×10^{-9}
${\rm BR}^{\rm exp}_{B\to X_s\ell\ell}/{\rm BR}^{\rm SM}_{B\to X_s\ell\ell}$	[88]	[79,89]	0.99 ± 0.32	–
${\rm BR}^{\rm exp}_{K\to\mu\nu}/{\rm BR}^{\rm SM}_{K\to\mu\nu}$	[82,84]	[90]	$1.008 \pm 0.014_{[\rm exp+th]}$	–
${\rm BR}^{\rm exp}_{K\to\pi\nu\bar\nu}/{\rm BR}^{\rm SM}_{K\to\pi\nu\bar\nu}$	[91]	[92]	< 4.5	–
$\Delta M^{\rm exp}_{B_s}/\Delta M^{\rm SM}_{B_s}$	[91]	[93,94]	$0.97 \pm 0.01_{\rm exp} \pm 0.27_{\rm th(SM)}$	–
$\frac{(\Delta M^{\rm exp}_{B_s}/\Delta M^{\rm SM}_{B_s})}{(\Delta M^{\rm exp}_{B_d}/\Delta M^{\rm SM}_{B_d})}$	[80–83]	[79,93,94]	$1.00 \pm 0.01_{\rm exp} \pm 0.13_{\rm th(SM)}$	–
$\Delta\epsilon^{\rm exp}_K/\Delta\epsilon^{\rm SM}_K$	[91]	[93,94]	$1.08 \pm 0.14_{[\rm exp+th]}$	–
$a^{\rm exp}_\mu - a^{\rm SM}_\mu$	[95–98]	[99–101]	$(30.2 \pm 8.8) \times 10^{-10}$	2.0×10^{-10}
M_h [GeV]	[102–105]	[106,107]	> 114.4 (see text)	1.5
$\Omega_{\rm CDM}h^2$	[108–110]	[111]	0.1099 ± 0.0062	0.012

MasterCode

Constraints (II)

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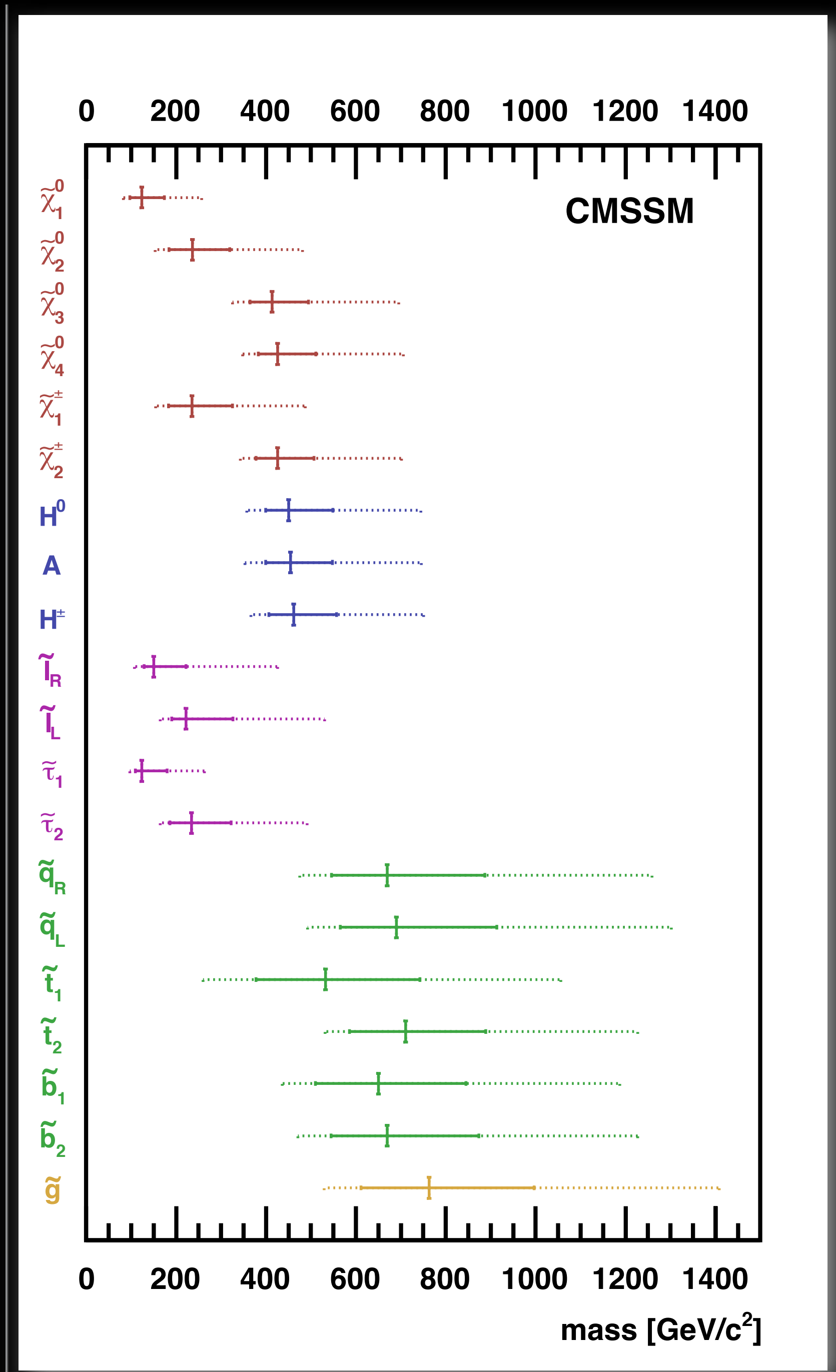
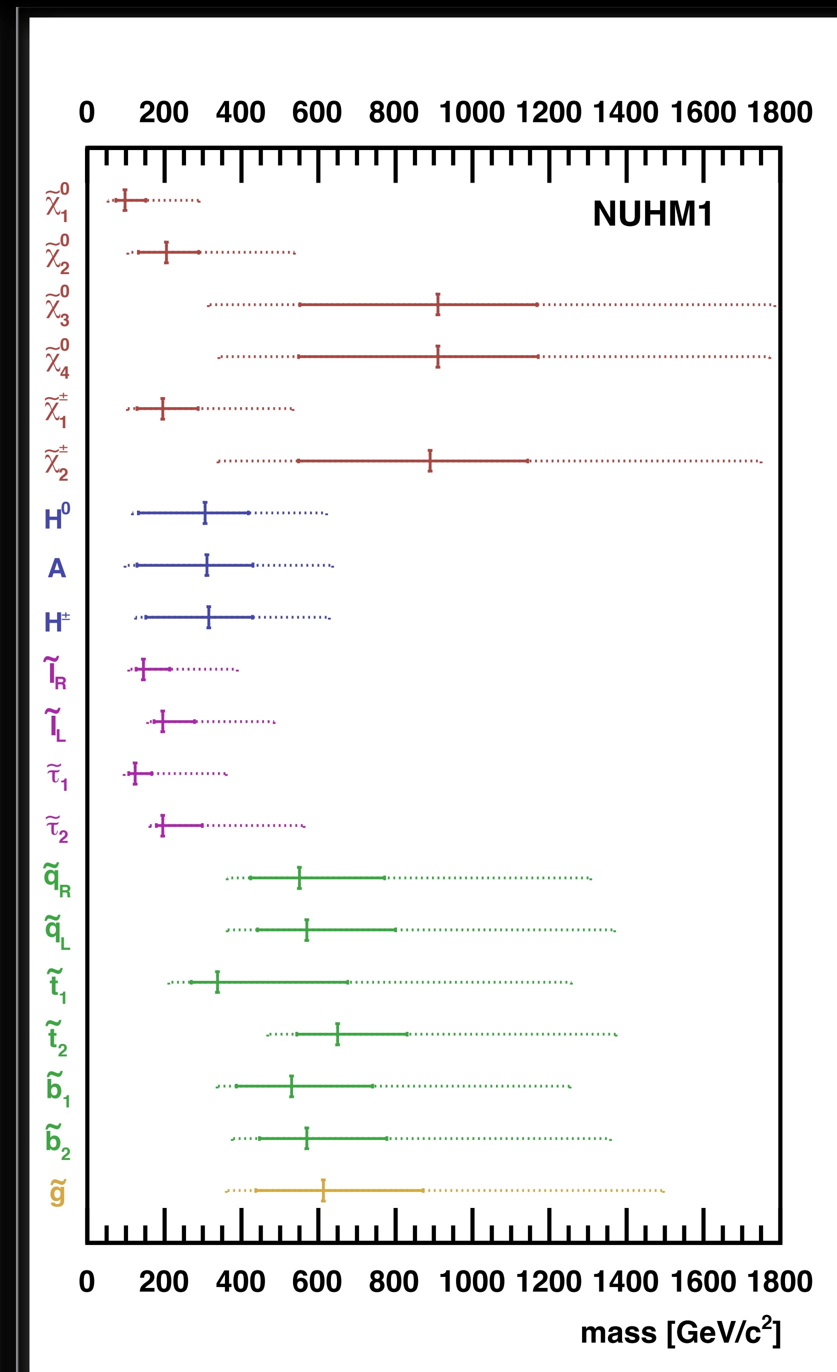
Observable	Experimental Value	Uncertainty		Exp. Reference
		stat	syst	
$\mathcal{B}(B \to s\gamma)/\mathcal{B}(B \to s\gamma)_{\rm SM}$	1.117	0.076	0.096	[47]
$\mathcal{B}(B_s \to \mu\mu)$	$< 4.7\times10^{-8}$			[47]
$\mathcal{B}(B_d \to \ell\ell)$	$< 2.3\times10^{-8}$			[47]
$\mathcal{B}(B \to \tau\nu)/\mathcal{B}(B \to \tau\nu)_{\rm SM}$	1.15	0.40		[48]
$\mathcal{B}(B_s \to X_s\ell\ell)/\mathcal{B}(B_s \to X_s\ell\ell)_{\rm SM}$	0.99	0.32		[47]
$\Delta m_{B_s}/\Delta m_{B_s}^{\rm SM}$	1.11	0.01	0.32	[49]
$\frac{\Delta m_{B_s}/\Delta m_{B_s}^{\rm SM}}{\Delta m_{B_d}/\Delta m_{B_d}^{\rm SM}}$	1.09	0.01	0.16	[47, 49]
$\Delta\epsilon_K/\Delta\epsilon_K^{\rm SM}$	0.92	0.14		[49]
$\mathcal{B}(K \to \mu\nu)/\mathcal{B}(K \to \mu\nu)_{\rm SM}$	1.008	0.014		[50]
$\mathcal{B}(K \to \pi\nu\bar{\nu})/\mathcal{B}(K \to \pi\nu\bar{\nu})_{\rm SM}$	< 4.5			[51]
$a_\mu^{\rm exp} - a_\mu^{\rm SM}$	30.2×10^{-10}	8.8×10^{-10}	2.0×10^{-10}	[52, 53]
$\sin^2\theta_{\rm eff}$	0.2324	0.0012		[46]
Γ_Z	2.4952 GeV	0.0023 GeV	0.001 GeV	[46]
R_l	20.767	0.025		[46]
R_b	0.21629	0.00066		[46]
R_c	0.1721	0.003		[46]
$A_{\rm fb}(b)$	0.0992	0.0016		[46]
$A_{\rm fb}(c)$	0.0707	0.0035		[46]
A_b	0.923	0.020		[46]
A_c	0.670	0.027		[46]
A_l	0.1513	0.0021		[46]
A_τ	0.1465	0.0032		[46]
$A_{\rm fb}(l)$	0.01714	0.00095		[46]
$\sigma_{\rm had}$	41.540 nb	0.037 nb		[46]
m_h	> 114.4 GeV		3.0 GeV	[54, 55, 56]
$\Omega_{\rm CDM}h^2$	0.1099	0.0062	0.012	[57]
$1/\alpha_{em}$	127.925	0.016		[58]
G_F	$1.16637\times10^{-5}\,\rm GeV^{-2}$	$0.00001\times10^{-5}\,\rm GeV^{-2}$		[58]
α_s	0.1176	0.0020		[58]
m_Z	91.1875 GeV	0.0021 GeV		[46]
m_W	80.399 GeV	0.025 GeV	0.010 GeV	[58]
m_b	4.20 GeV	0.17 GeV		[58]
m_t	172.4 GeV	1.2 GeV		[59]
m_τ	1.77684 GeV	0.00017 GeV		[58]
m_c	1.27 GeV	0.11 GeV		[46]

Mass spectra (I)





Mass spectra (II)

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