A tool for consistent combination of indirect constraints on the MSSM

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- Introduction
- A common framework for MSSM calculations
- Applications:
  - Fit in the CMSSM
  - Influence of indirect constraints
- Conclusions and Outlook

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Introduction

- How can we best exploit the available experimental data to constrain New Physics models?
  - Combine as much experimental information as possible
  - Famous example:
    - Standard Model fit to electroweak precision data
- Extend it to include New Physics models
  - Here: Minimal SuperSymmetic Standard Model (MSSM)

- Necessary tools:
  - calculations for experimental observables in that model

  and

  - a common framework that interfaces between the different calculations and combines the obtained information

- Objectives/Outcome:
  - Fit model parameters in some MSSM scenarios
  - Explore sensitivity of different observables to parameter space

General Idea

- What observables can be used to constrain the model?
  - Low energy (precision) data
    - Flavour physics (many constraints from B physics)
    - Other low energy observables, e.g. g-2
  - High energy (precision) data
    - Precision electroweak observables, e.g. M_W, m_{top}, asymmetries
  - Cosmology and Astroparticle data
    - e.g. relic density

- How to exploit this information?
  - State of the art theoretical predictions (tools)
  - Development of a framework for combination of these tools

- Collaboration between experiment and theory

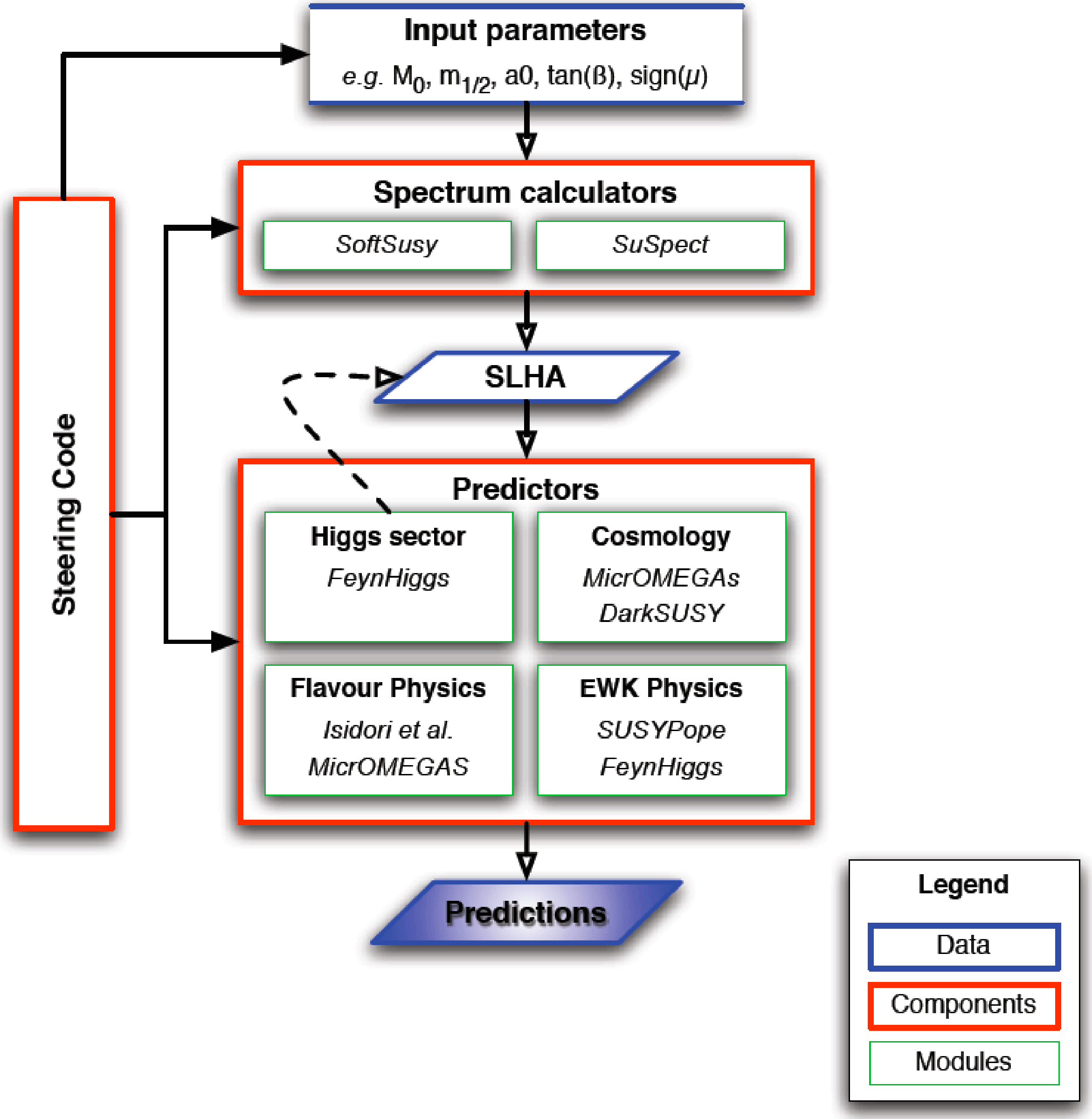
Buchmüller, Oliver (CERN) – Exp.
De Roeck, Albert (CERN & Uni. Antwerpen) – Exp.
Flächer, Henning (CERN) – Exp.
Isidori, Gino (INFN Frascati) – Theo.
Olive, Keith (Uni. of Minnesota) – Theo.
Ronga, Frédéric (CERN) – Exp.
Weiglein, Georg (Durham) – Theo.
Cavanaugh, Richard (Uni. of Florida) – Exp.
Ellis, John (CERN) – Theo.
Heinemeyer, Sven (Santander) – Theo.
Mahmoudi, Farvah N. (Uppsala) – Theo.
Paradisi, Paride (Uni. of Valencia) – Theo.
Weber, Arne (Max Planck Inst. (Munich)) – Theo.

See O. Buchmüller et al., PLB 657/1-3 pp.87-94

Common framework development

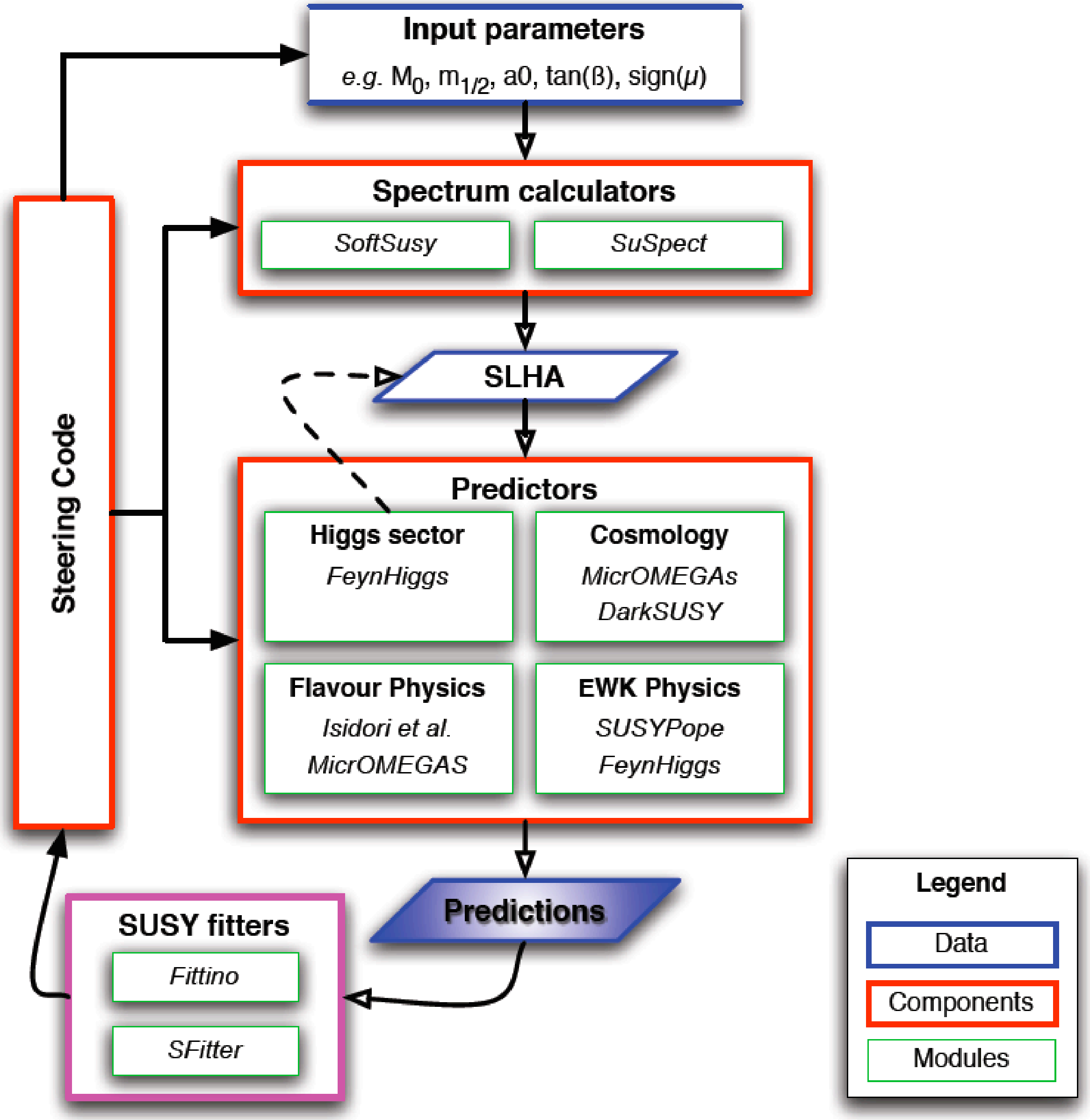
- General overview:

- Consistency
  - Relies on SLHA interface
- Modularity
  - Compare calculations
  - Add/remove predictions
- State-of-the-art calculations
  - Direct use of code from experts



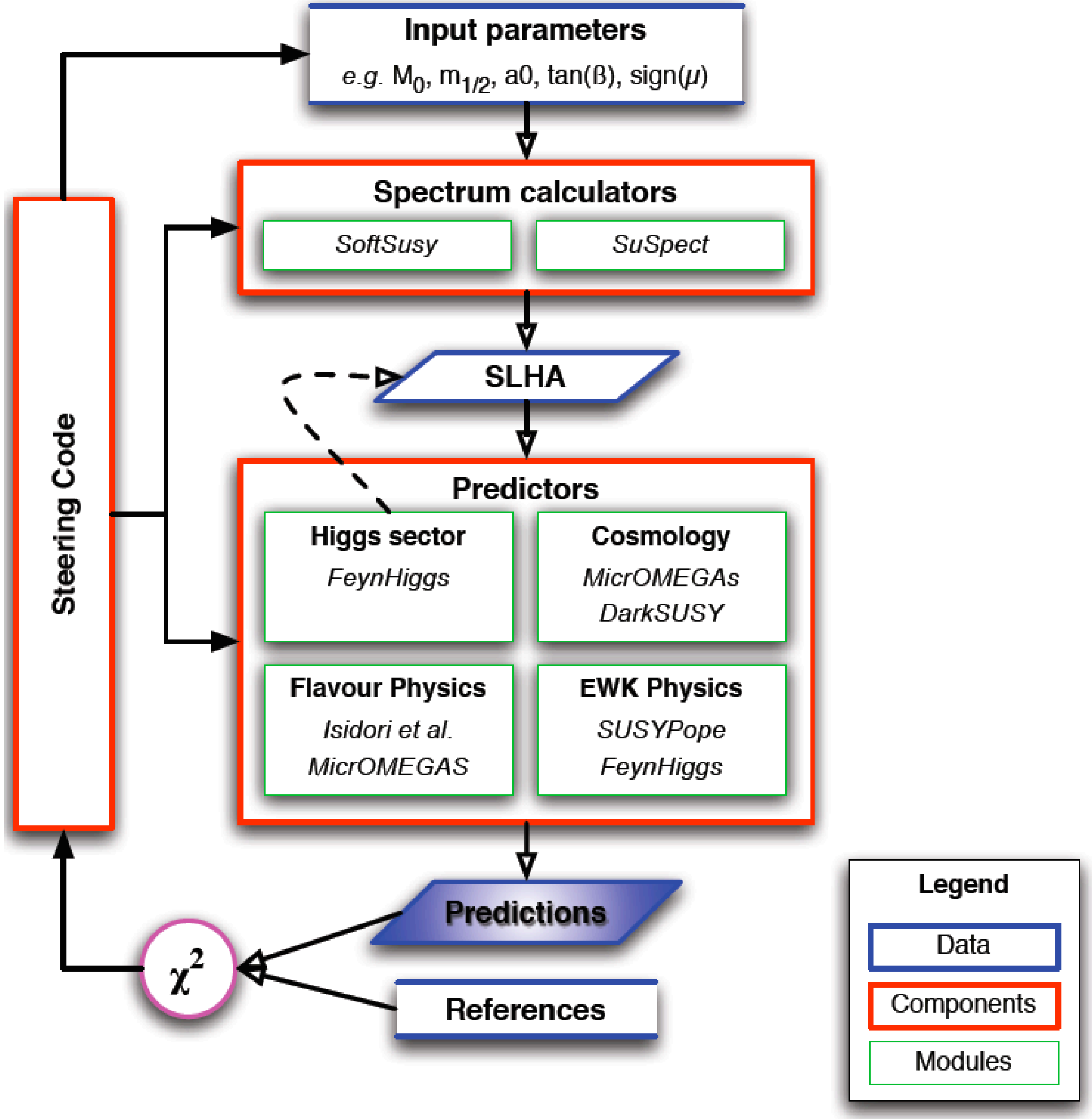
Common framework applications (I)

- Use case 1:
- Input to external SUSY fitters
  - Provide consistent predictions (low-energy, EW, etc.) to LHC/ILC-oriented fitters
  - Work started in this direction with the Fittino collaboration



Common framework applications (II)

- Use case 2:
- Fit today's data (χ^2-minimisation)
  - Constrain SUSY parameter space
  - Will become even more interesting when combined with discoveries
  - Various modes:
    - Overall best minimum (MINUIT)
    - χ^2 scans
    - Markov-Chain Monte Carlo



List of implemented Observables

Low energy observables

R($b \to s\gamma$)	Isidori & Paradisi	`micrOMEGAs`
R($B \to \tau\nu$)	Isidori & Paradisi	
BR($K \to \mu\ \nu$)	Isidori & Paradisi	
R($B \to X_s \ell\ell$)	Isidori & Paradisi	
R($K \to \pi\nu\bar{\nu}$)	Isidori & Paradisi	
BR($B_s \to \ell\ell$)	Isidori & Paradisi	`micrOMEGAs`
BR($B_d \to \ell\ell$)	Isidori & Paradisi	
R(Δm_s)	Isidori & Paradisi	
R(Δm_s)/R(Δm_d)	Isidori & Paradisi	
R(Δm_K)	Isidori & Paradisi	
R($\Delta_0(K^*\gamma)$)	`SuperIso`	
$\Delta(g-2)$	`FeynHiggs`	

Higgs sector observables

m_h^{light}	`FeynHiggs`

Cosmology observables

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

Electroweak observables

$\Delta\alpha_{\mathrm{had}}^{(5)}(m_Z^2)$	SUSY-Pope
m_Z	SUSY-Pope
Γ_Z	SUSY-Pope
σ_{had}^0	SUSY-Pope
R_l	SUSY-Pope
$A_{\mathrm{fb}}(\ell)$	SUSY-Pope
$A_\ell(P_\tau)$	SUSY-Pope
R_{b}	SUSY-Pope
R_{c}	SUSY-Pope
$A_{\mathrm{fb}}(\mathrm{b})$	SUSY-Pope
$A_{\mathrm{fb}}(\mathrm{c})$	SUSY-Pope
A_{b}	SUSY-Pope
A_{c}	SUSY-Pope
$A_\ell(\mathrm{SLD})$	SUSY-Pope
$\sin^2\theta_{\mathrm{w}}^\ell(Q_{\mathrm{fb}})$	SUSY-Pope
m_{W}	SUSY-Pope
m_{t}	SUSY-Pope

Example Application

- Constraining the parameter space of the CMSSM
  - multi-parameter χ^2 fit

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

C_i: experimental constraint
P_i: predicted value for a given CMSSM parameter set

- fitting for all CMSSM (aka mSUGRA) parameters:
  - M_0 – common scalar mass (at GUT scale)
  - $M_{1/2}$ – common gaugino mass (at GUT scale)
  - A_0 – tri-linear mass parameter (at GUT scale)
  - $\tan\beta$ – ratio of Higgs vacuum expectation values
  - sign(μ) – sign of Higgs mixing parameter (fixed)

- including relevant SM uncertainties (m_{top}, m_Z, $\Delta\alpha_{\mathrm{had}}^{(5)}$)

See O. Buchmüller et al., PLB 657/1-3 pp.87-94

Observables used in the CMSSM fit

Low energy observables

$R(b \to s\gamma)$	`micrOMEGAs`
$\mathrm{BR}(B_s \to \ell\ell)$	`micrOMEGAs`
$\Delta(g-2)$	`FeynHiggs`

Higgs sector observables

m_h^{light}	`FeynHiggs`

Cosmology observables

Ωh^2	`micrOMEGAs`

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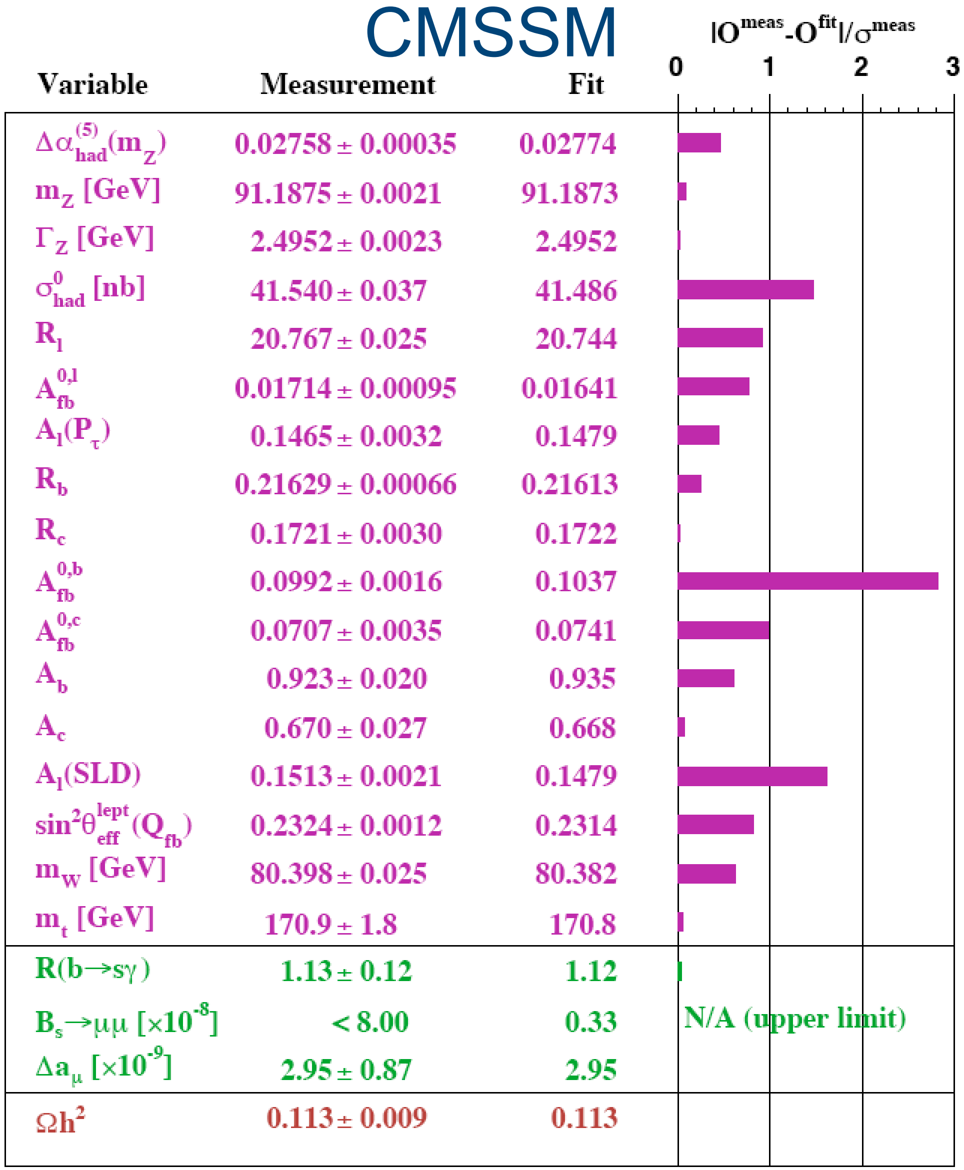
$A_\ell(\mathrm{SLD})$	SUSY-Pope
$\sin^2\theta_{\mathrm{w}}^{\ell}(Q_{\mathrm{fb}})$	SUSY-Pope
m_{W}	SUSY-Pope
m_{t}	SUSY-Pope

“Electroweak fit” in the CMSSM

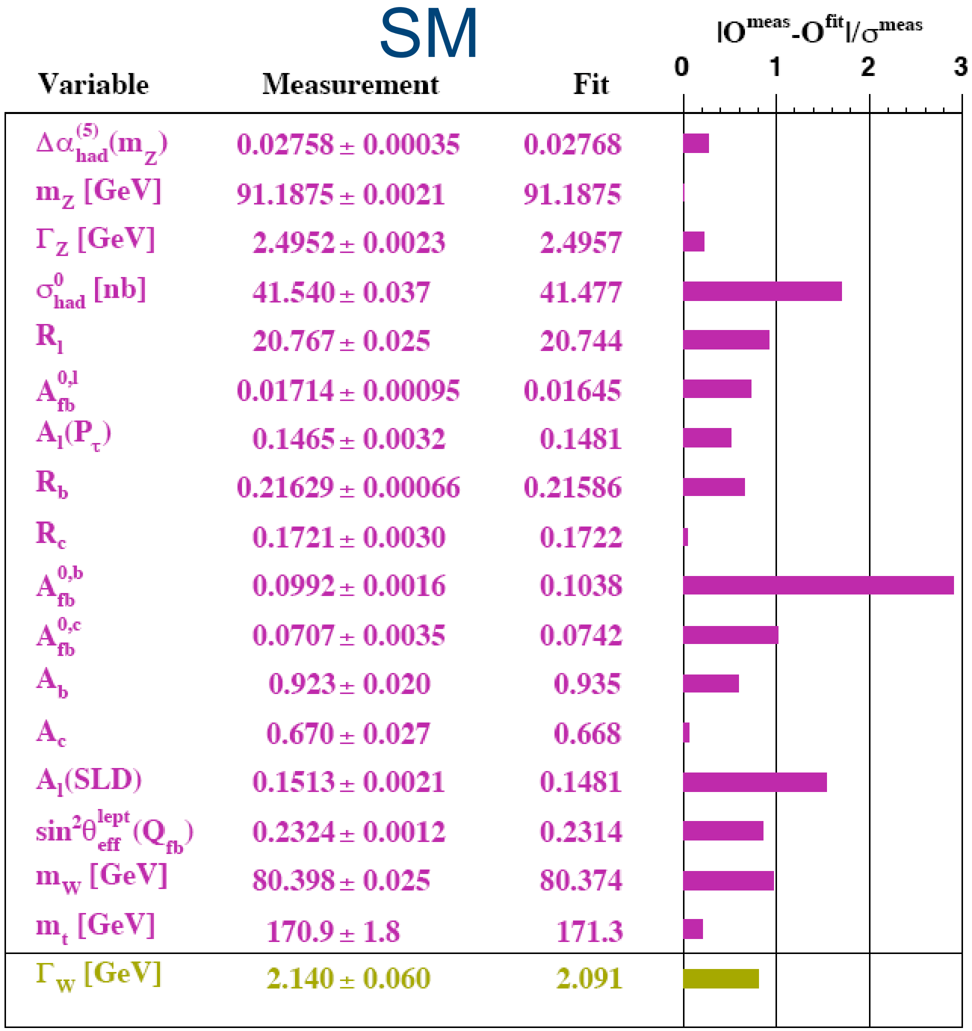
CMSSM



Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	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
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95
Ωh^2	0.113 ± 0.009	0.113

χ^2/N_{dof} = 17.0/13 (20% prob.)

SM



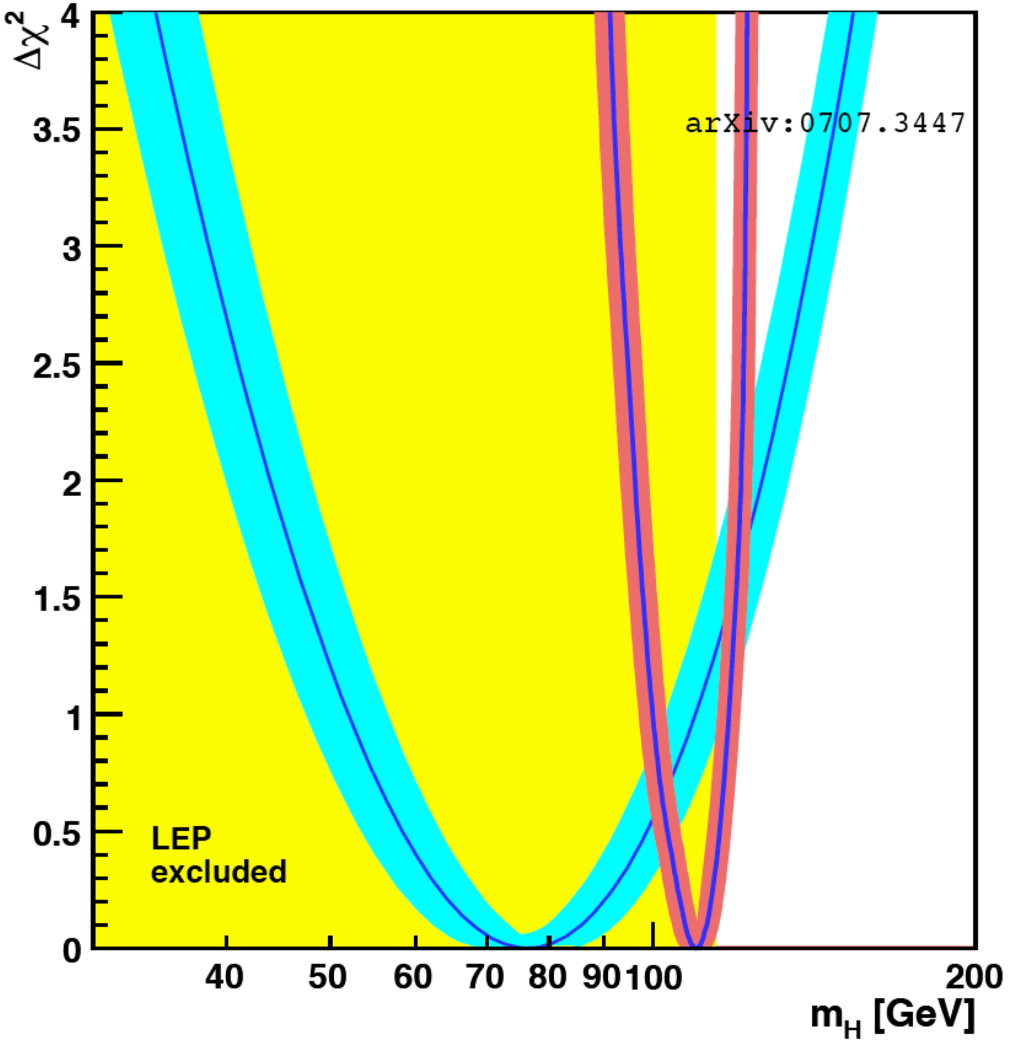
Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 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

χ^2/N_{dof} = 18.2/13 (15% prob.)

See O. Buchmüller et al., PLB 657/1-3 pp.87-94

M_H in the CMSSM

SM vs CMSSM



Direct dependence on M_H in CMSSM as compared to indirect dependence in SM

- Scan of the Higgs mass
  - fix M_H to scan value
  - minimize all model parameters in each point
  - determine uncertainty in M_H prediction
- SM fit:
  - $M_H = 78\ ^{+33}_{-22}$ GeV
  - 12% probability at LEP exclusion limit (including theoretical uncertainty)
    - LEPEWWG: arXiv:0712.0929
- CMSSM fit:
  - $M_H = 110\ ^{+8}_{-10} \pm 3$ GeV
  - 20% probability at LEP exclusion limit (including theoretical uncertainty)

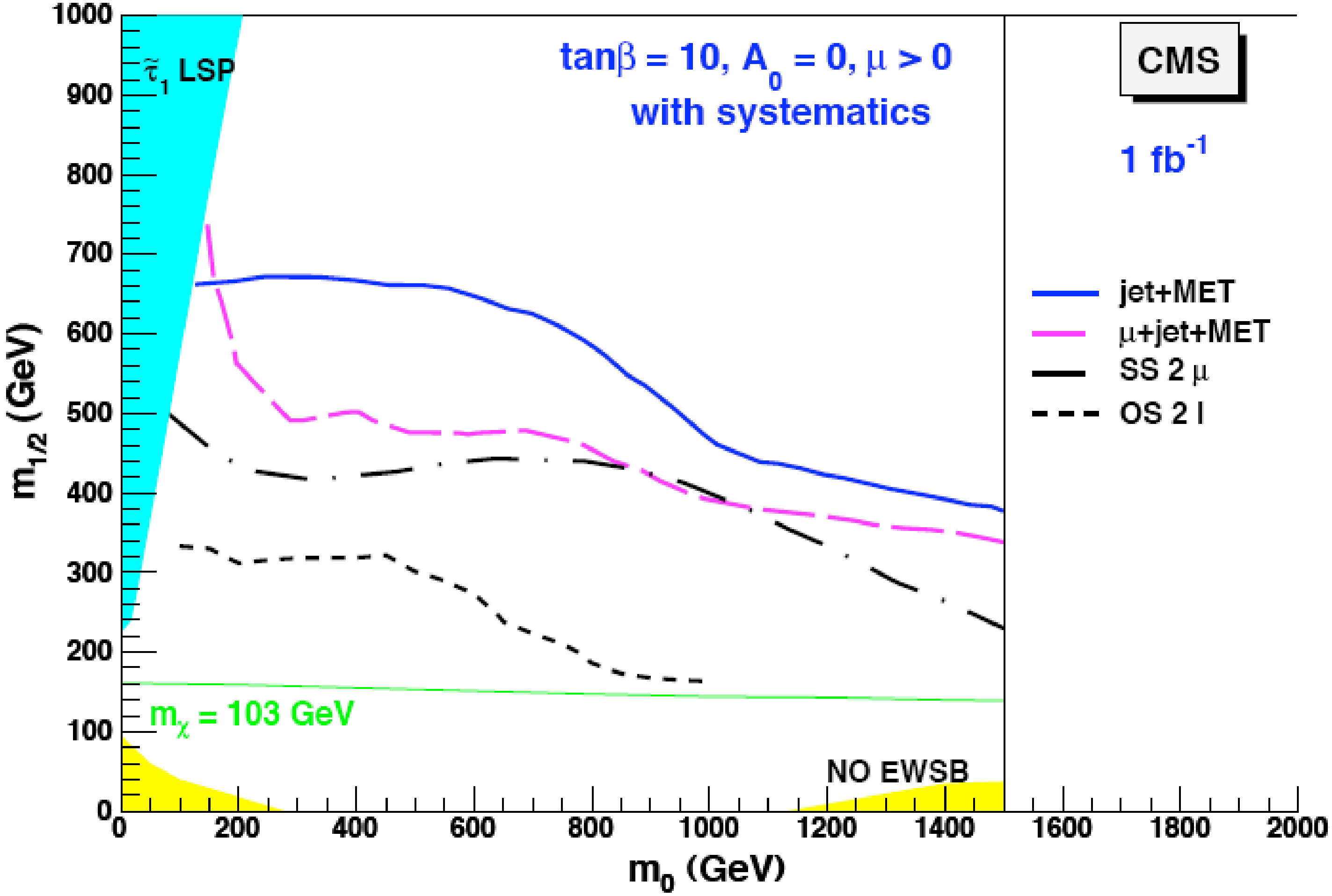
Next steps

- Use the developed framework to obtain predictions for EW and low-energy observables
  - study parameter space of CMSSM as an example
  - other scenarios within MSSM possible

- What information can we obtain?
  - Study not only effect on M_H but also on the other model parameters
  - Study the importance of the individual constraints
    - EW and B Observables, g-2, WMAP
  - Use Markov-Chain type Monte Carlo to intelligently sample 4-dim parameter space
    - Not only to find minimum but also to map CL regions
  - Minima determined through MINUIT fits

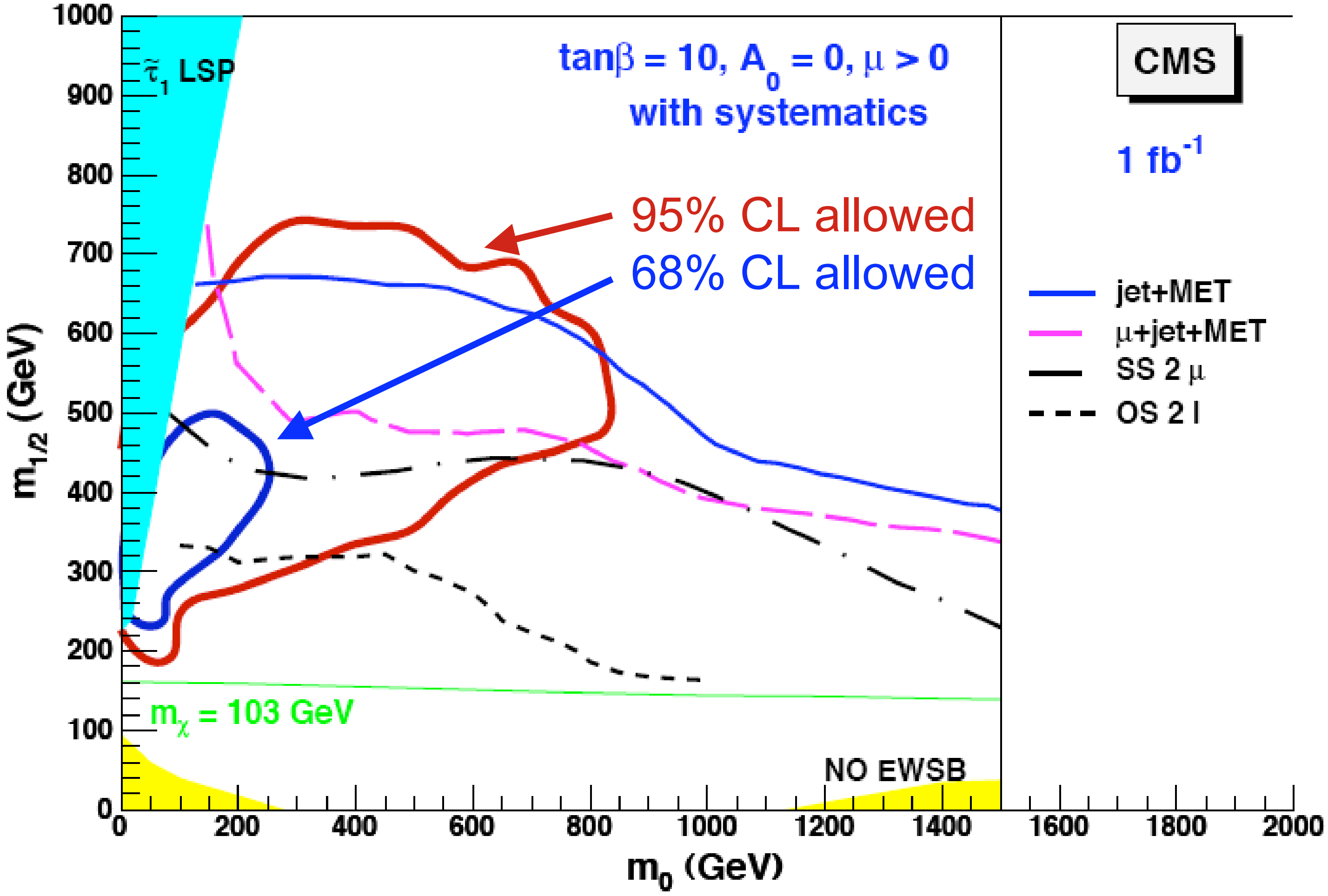
LHC discovery reach

- 5 σ discovery reach for 1fb^{-1}
  - Very similar for ATLAS and CMS



LHC discovery reach

- 5 σ discovery reach for 1fb^{-1}
  - Very similar for ATLAS and CMS

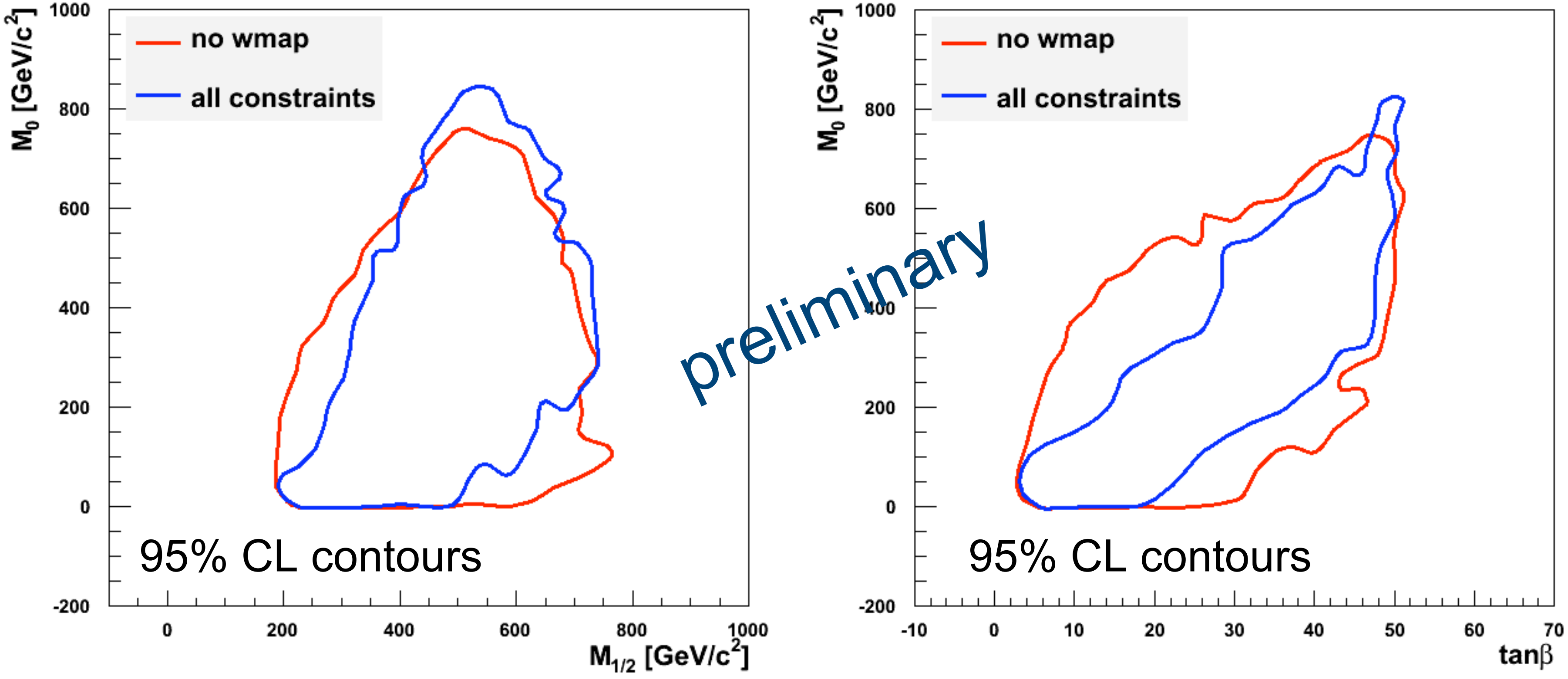


If CMSSM is realised in Nature a signal will be seen fairly early

Otherwise, exclusion will be possible

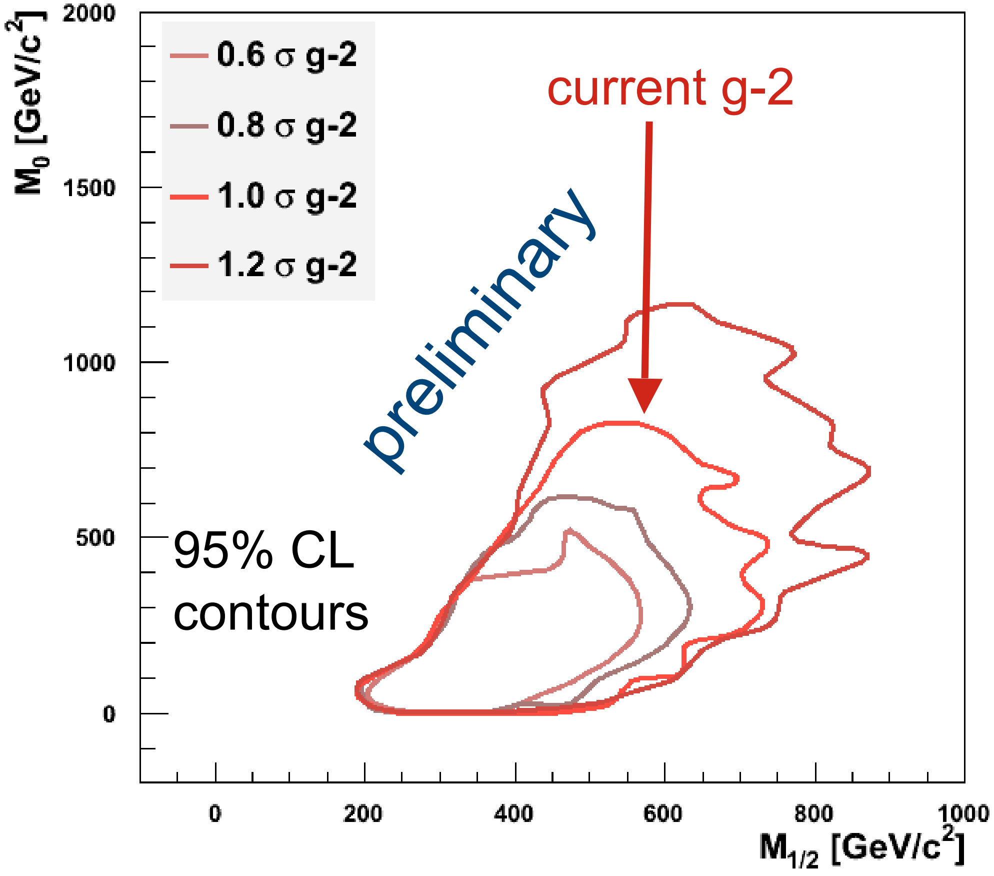
Sensitivity to individual observables (I)

- WMAP
  - How big is the influence of the cosmological data?
  - Compare 95% CL contours with/without the WMAP constraint
    - Note: minimum is different for the two scenarios



Sensitivity to individual observables (II)

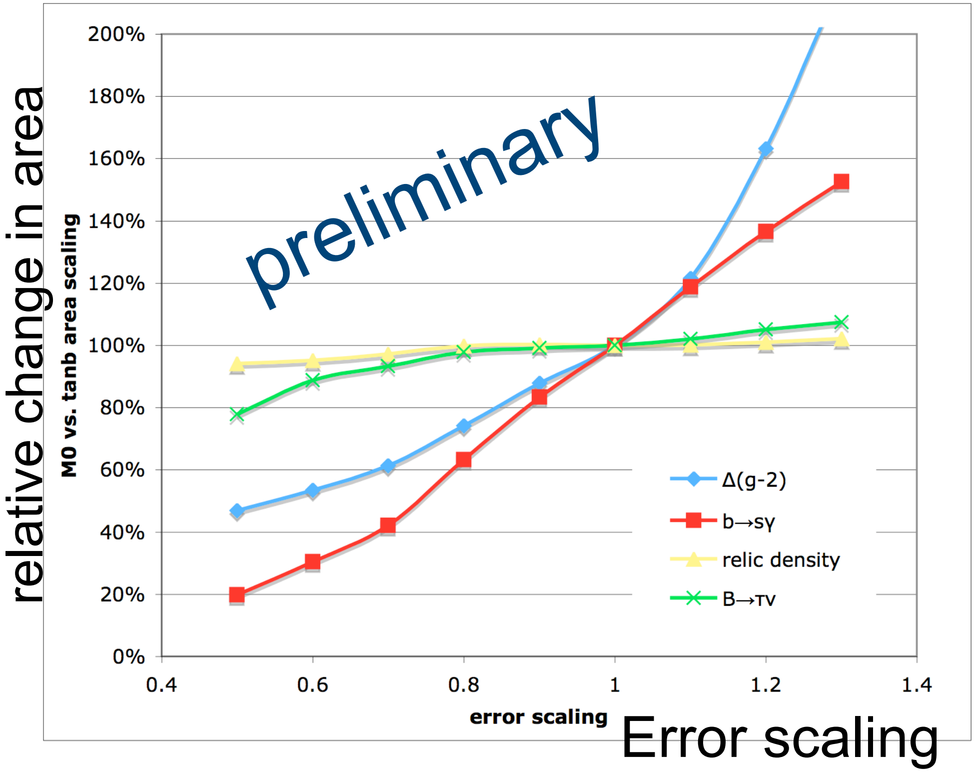
- Influence of g-2
  - Variation of uncertainty in g-2 measurement
  - How fine tuned is the current scenario (CMSSM)?
  - Use contour area in parameter space as measure
  - Determine differences in sensitivity of the various model parameters



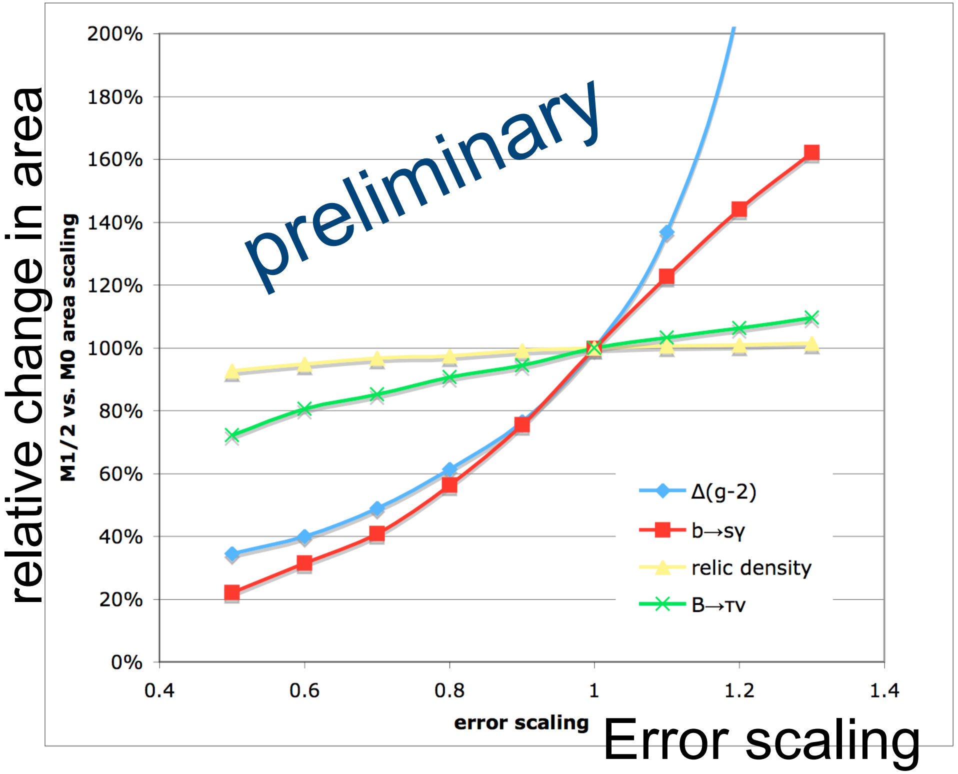
How to quantify sensitivity?

- Graphs showing percentage change in contour content as a function of observable uncertainty

M0 - tanβ projection



M0 - M12 projection



- Importance of g-2 and B→$X_s\gamma$ evident
- In these projections, WMAP not so sensitive

Future Plans

- Continue sensitivity tests
  - e.g. EW sector, M_W
  - quantify sensitivity of observables to model parameters

- Probing other models
  - Non-universal Higgs mass (NUHM I+II)
  - “phenomenological” MSSM (+additional constraints)

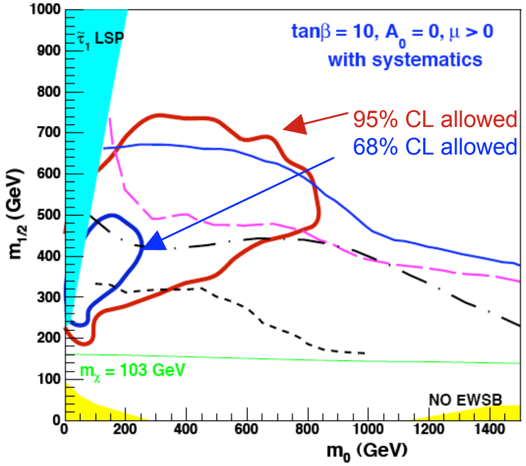
- Sharing the code
  - Still needs polishing and some documentation
  - Predictions for observables in MSSM scenarios can be provided
  - Aim is to make it public

Conclusions

- For comprehensive interpretation of LHC data it is necessary to check for consistency with all available experimental data

- Efforts to combine…
  - various sets of experimental constraints
  - in different models
  - and in different ways

…are ongoing



- CMSSM as an example:
  - provides Higgs mass compatible with LEP limit but much better constraint
  - would be discoverable at the early stages of the LHC ($1 fb^{-1}$)
  - allows to explore sensitivity of individual constraints
    - g-2, $B \rightarrow X_s\gamma$ quite “fine-tuned”

- Other models to be investigated