How alive is constrained SUSY really ?

SUSY 2014, Manchester

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Outline

Sorry?
CMSSM?

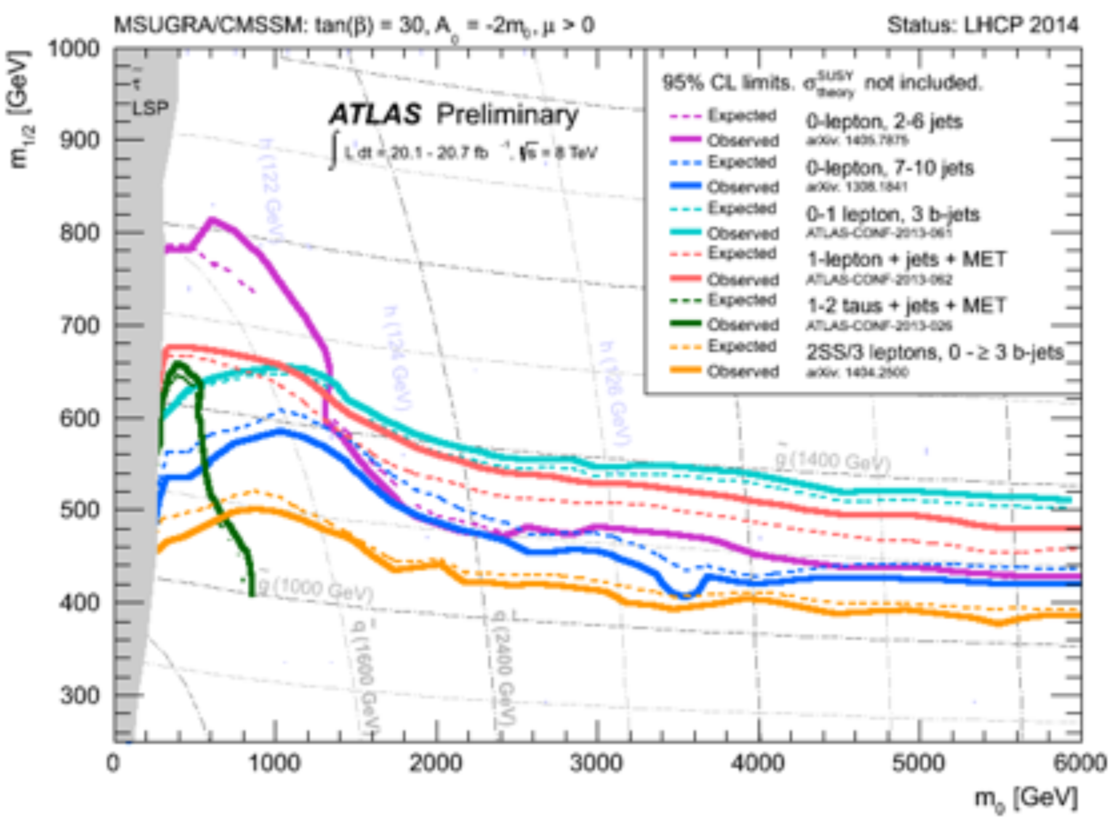
This is so 2010!

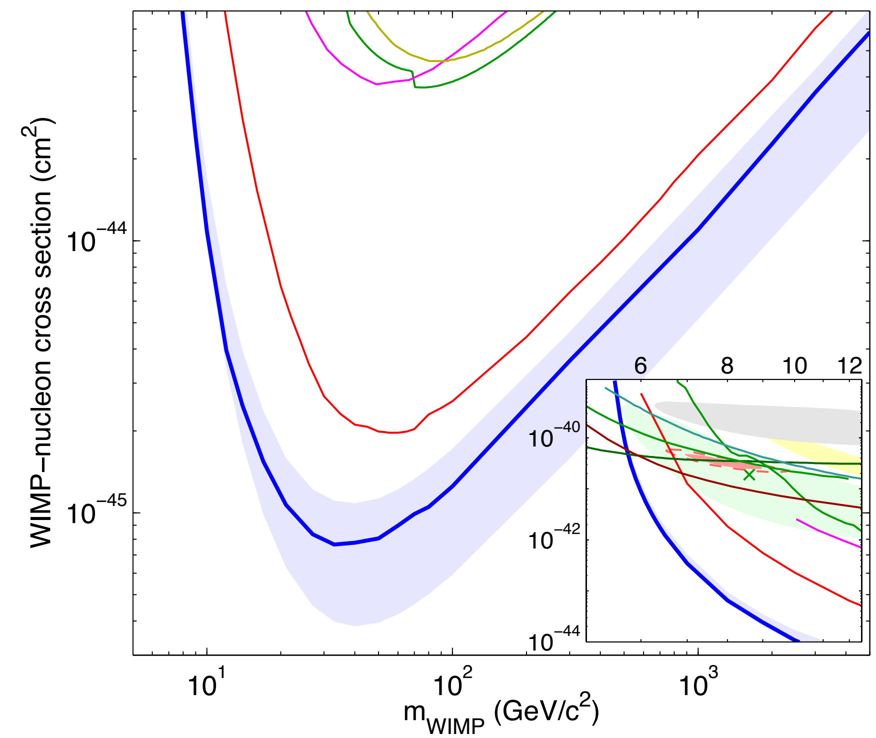
Yeah, I think it's time to move to another model.

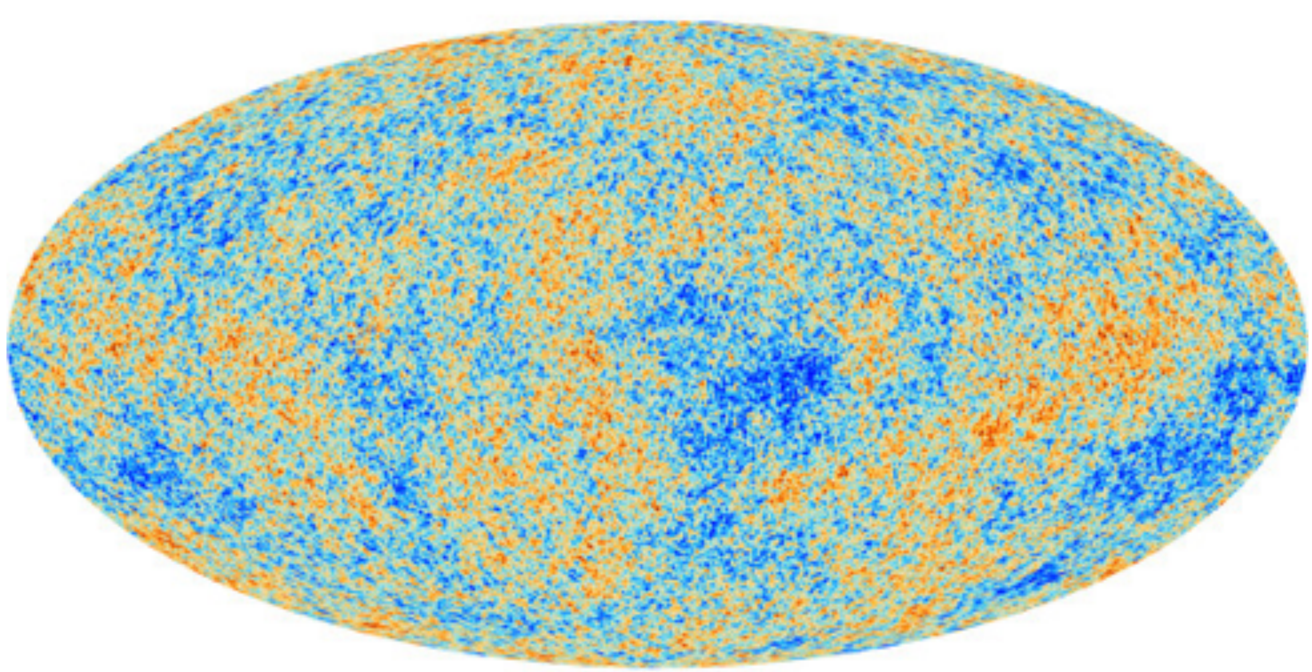
I. How the CMSSM came into such troubles

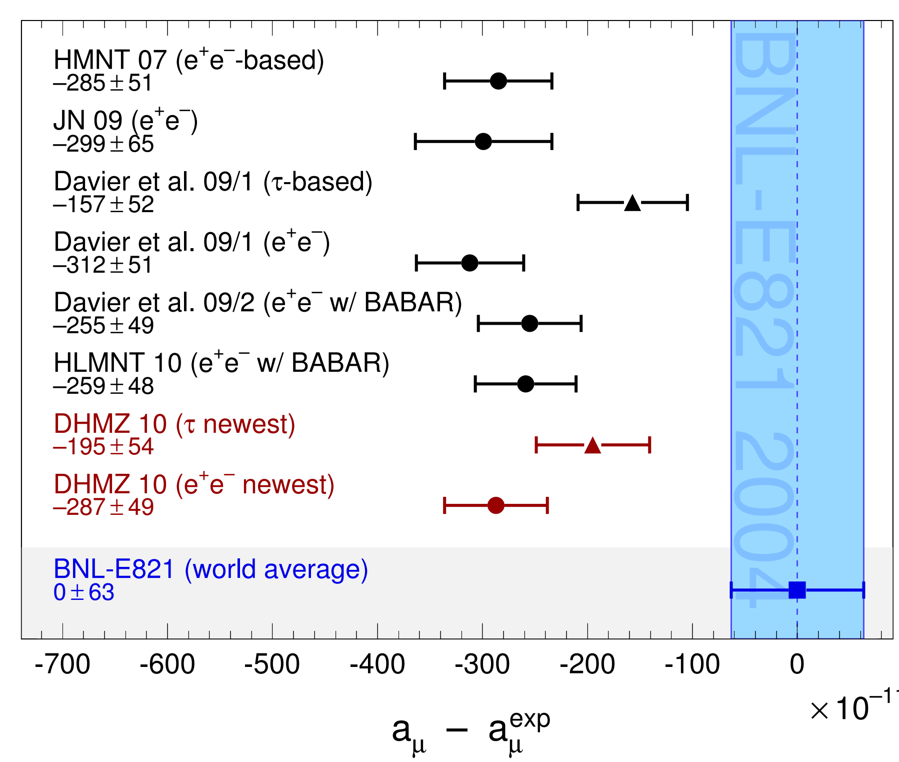
II. The *one more thing* which still has to be done

Probing the CMSSM









Fittino

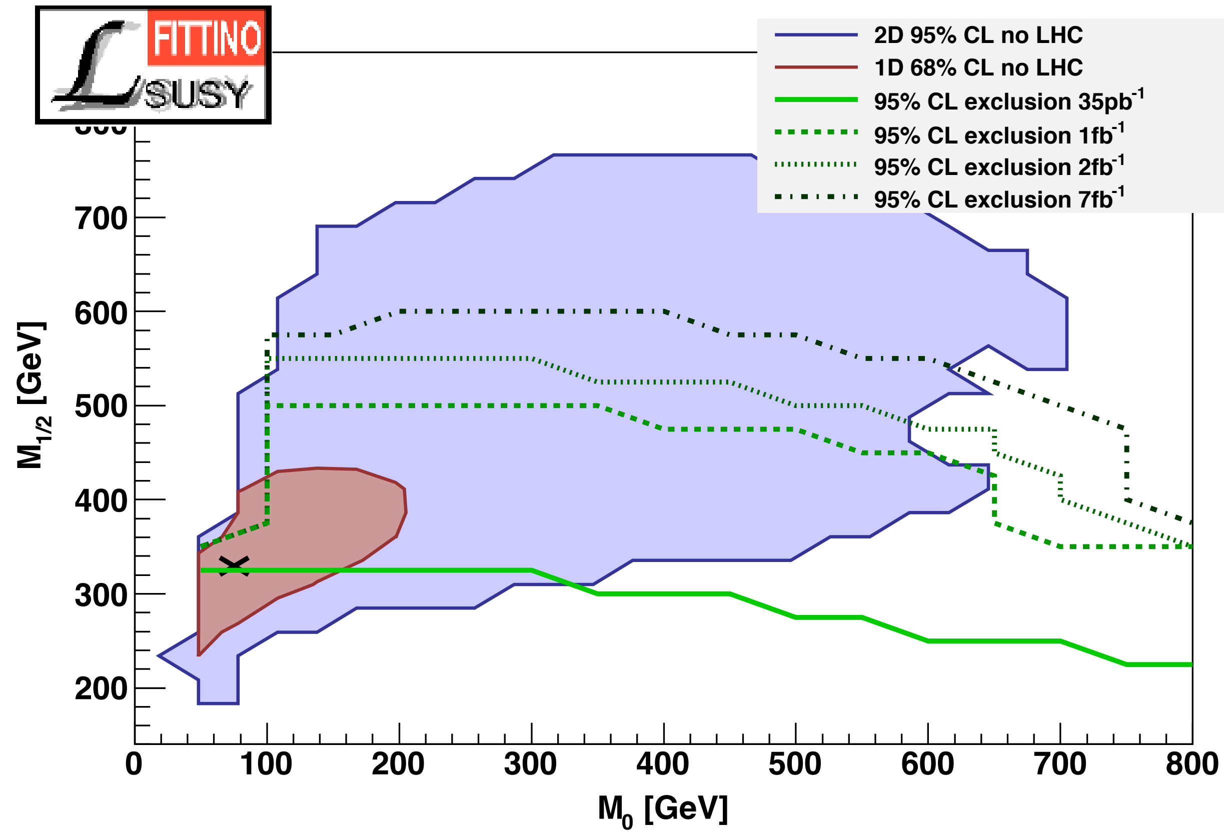
- Using the C++ program Fittino we combine a wide range of measurements sensitive to supersymmetry:
  - indirect constraints from low energy measurements
  - Higgs boson properties
  - direct searches for sparticles and BSM Higgs bosons
  - astrophysical observations

- Fittino uses
  - public codes to calculate model predictions
  - a χ^2 function to compare measurements and predictions
  - an auto-adaptive Markov Chain to sample the parameter space
  - frequentist interpretation

Fittino Timeline

arXiv:1102.4693

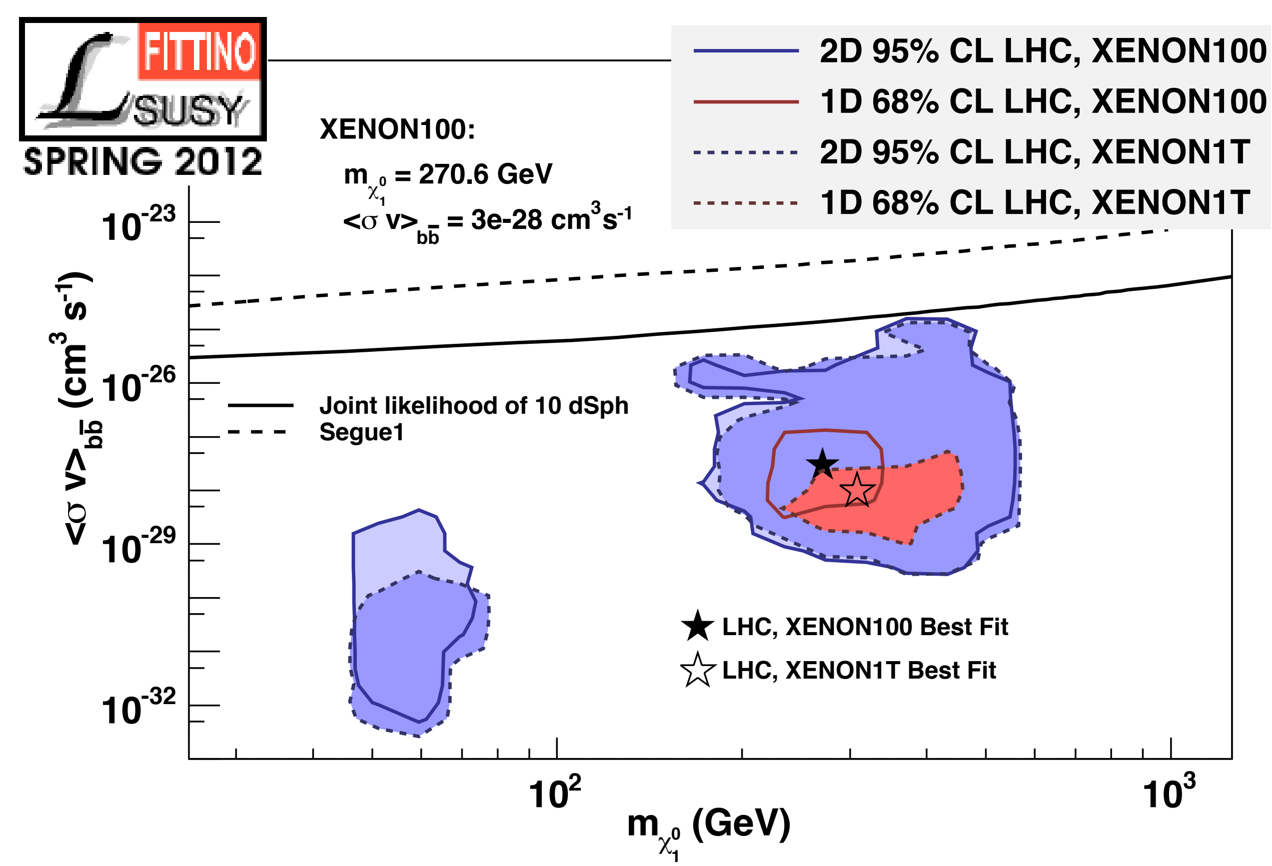
some tension building up between low energy observables and LHC



arXiv:1204.4199

increasing tension

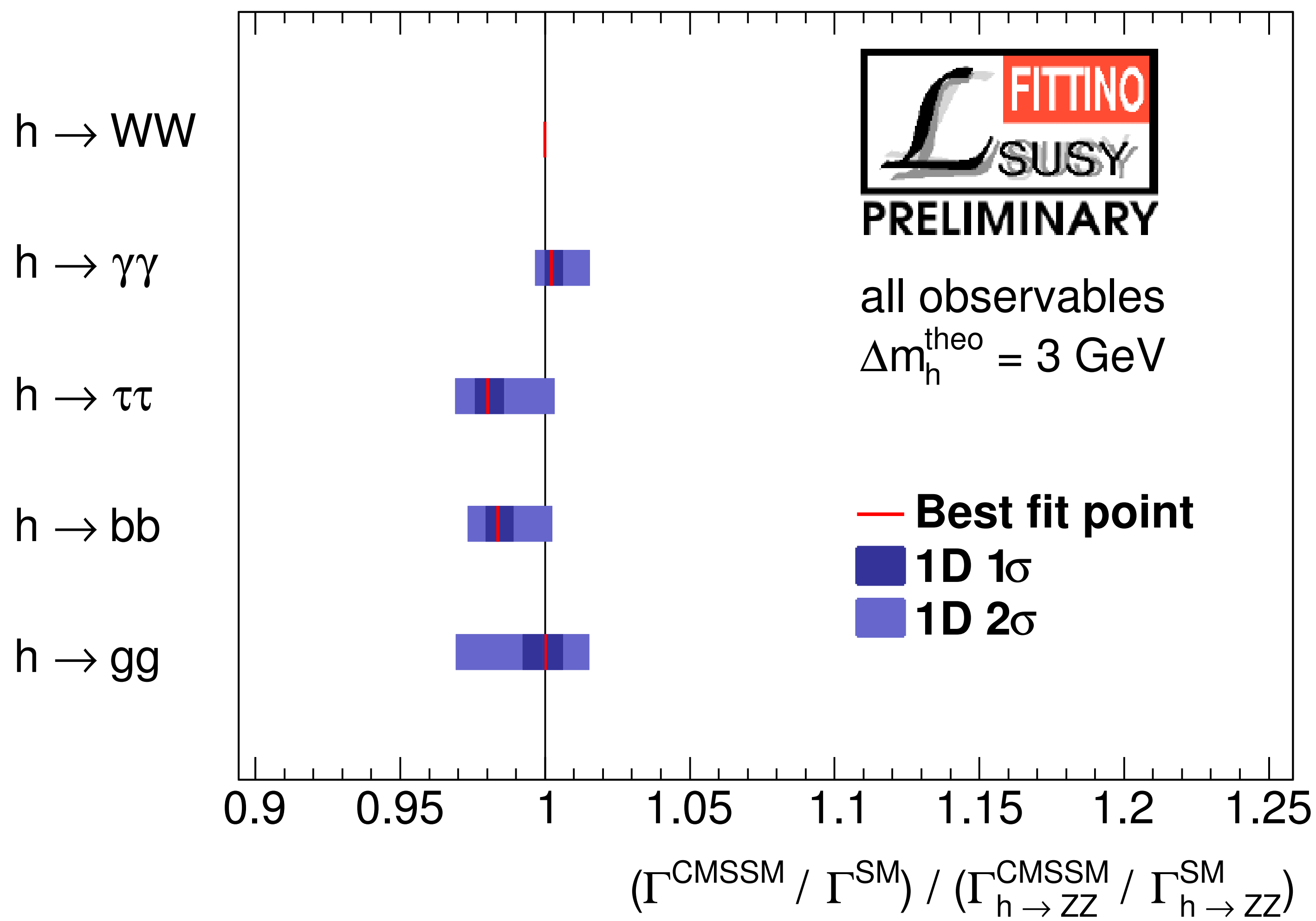
direct and indirect astrophysical detection experiments
not yet sensitive to 2 sigma region



arXiv:1310.3045

SM like Higgs well described by CMSSM

χ^2/ndf decreases when the numerous Higgs measurements are taken into account



Updated measurements

Low energy observables

BR($B_s \longrightarrow \mu^+\mu^-$)	(2.90 ± 0.70 ± 0.76_{theo}) x 10^{-9}	CMS + LHCb '13
BR($B^\pm \longrightarrow \tau^\pm \nu$)	(1.14 ± 0.22 ± 0.07_{theo}) x 10^{-4}	PDG '13
BR($b \longrightarrow s\gamma$)	(3.43 ±0.21± 0.07± 0.48_{theo}) x 10^{-4}	HFAG
Δm_s	(17.719 ±0.036 ± 0.023 ± 4.200_{theo}) ps^{-1}	PDG '13
$a_\mu - a_\mu^{SM}$	(28.7 ± 8.0 ± 2.0_{theo}) x 10^{-10}	Muon g-2, Davier et al
m_t	(173.34 ± 0.27 ± 0.71) GeV	world average '14
m_W	(80.385 ± 0.015 ± 0.010_{theo}) GeV	CDF + D0 '12
$\sin^2 \theta_{eff}$	0.2311 ± 0.00021 ± 0.00012t$_{heo}$	LEP + SLD '06

Higgs boson properties and searches

- Higgs limits via HiggsBounds
- Higgs signals via HiggsSignals

Direct sparticle searches

- LEP chargino mass limit
- ATLAS MET + jets + 0 lepton search ($20fb^{-1}$)

Astrophysical observables

- We require χ_1^0 to be the LSP
- $\Omega_{CDM}h^2 = 0.1187 \pm 0.0017 \pm 0.0119_{theo}$ (Planck '13)
- Direct detection limit from LUX

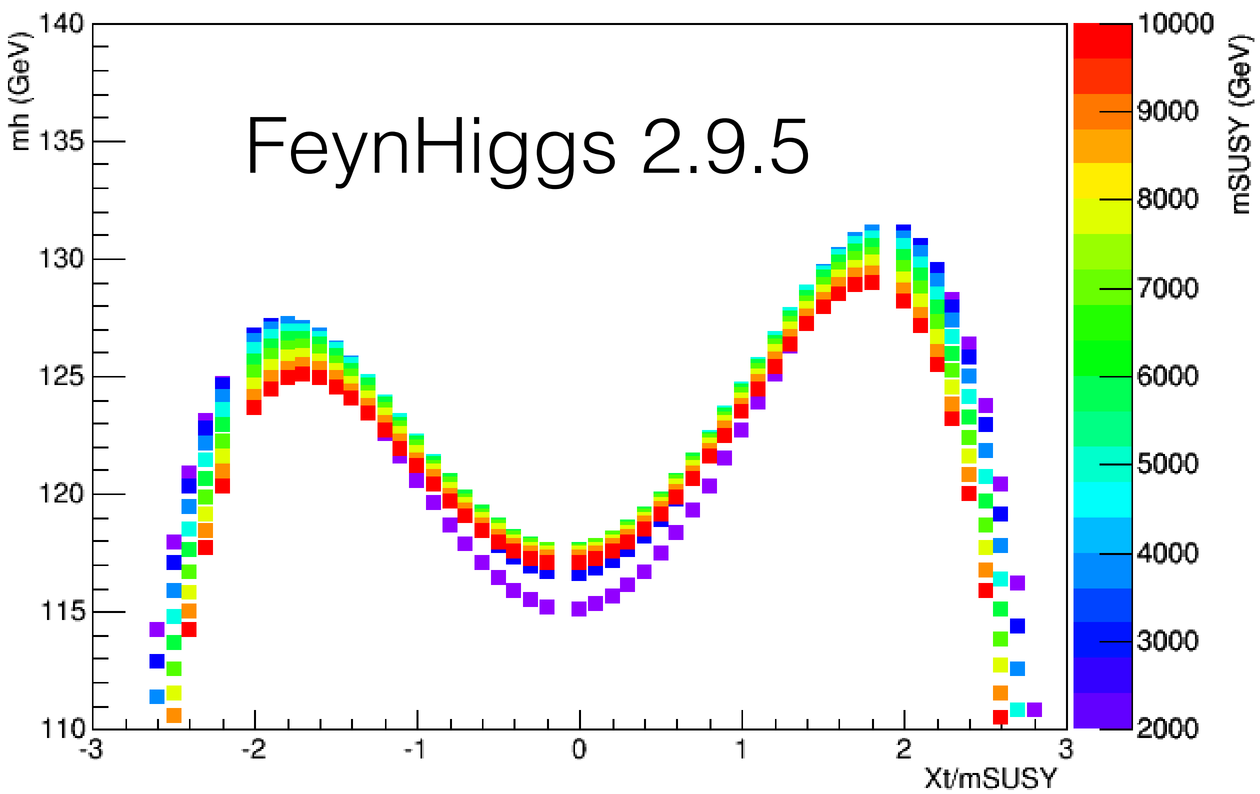
Model Predictions

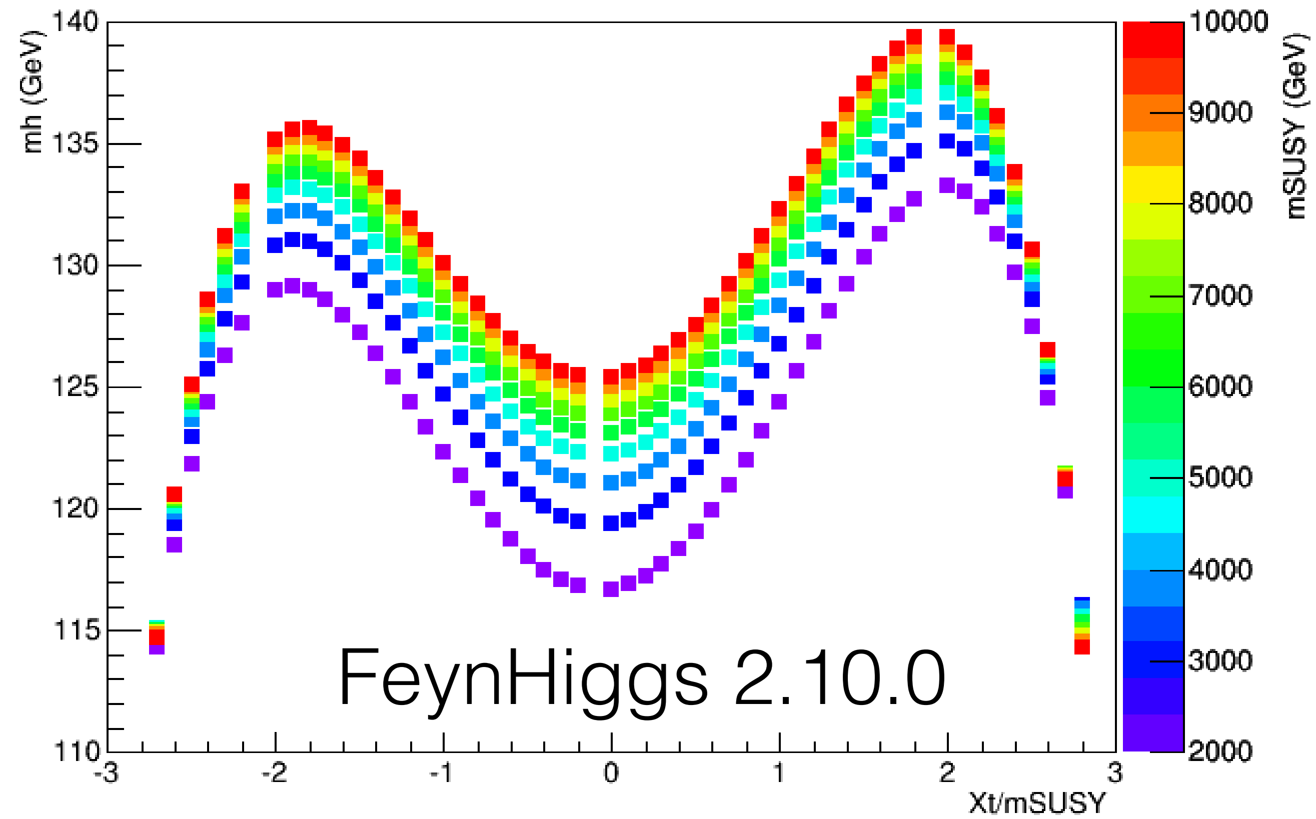
To evaluate the corresponding model predictions we use:

- SPheno for spectrum calculation
- FeynHiggs for Higgs properties, $a_\mu - a_\mu^{SM}$, $\sin^2\theta_{eff}$, m_W
- SuperIso for BR($B_s \to \mu^+\mu^-$),BR($B^\pm \to \tau^\pm\nu$),BR($b \to s\gamma$)
- Prospino, Herwig++, Delphes for direct sparticle searches
- micrOMEGAs for dark matter relic density
- DarkSUSY via AstroFit for direct detection cross section

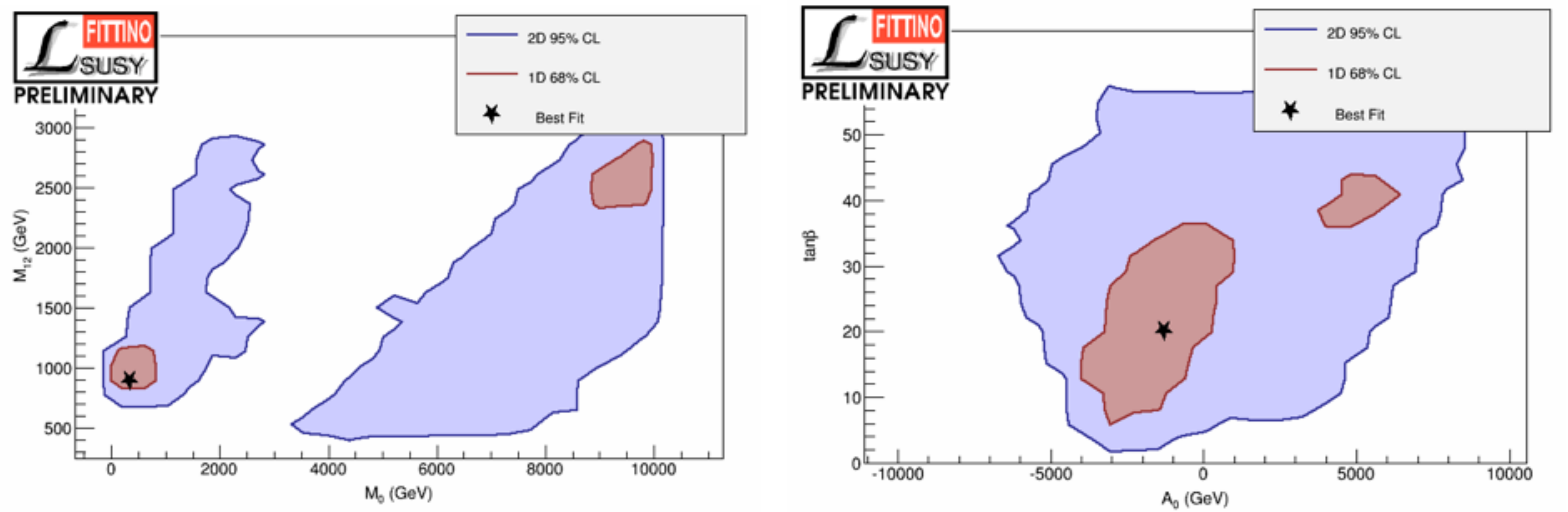
Impact of new Higgs mass calculation

- Of course there are also improvements on the theory side
- The new Higgs mass calculation contained in FeynHiggs 2.10.0 makes it significantly easier to reach high Higgs masses



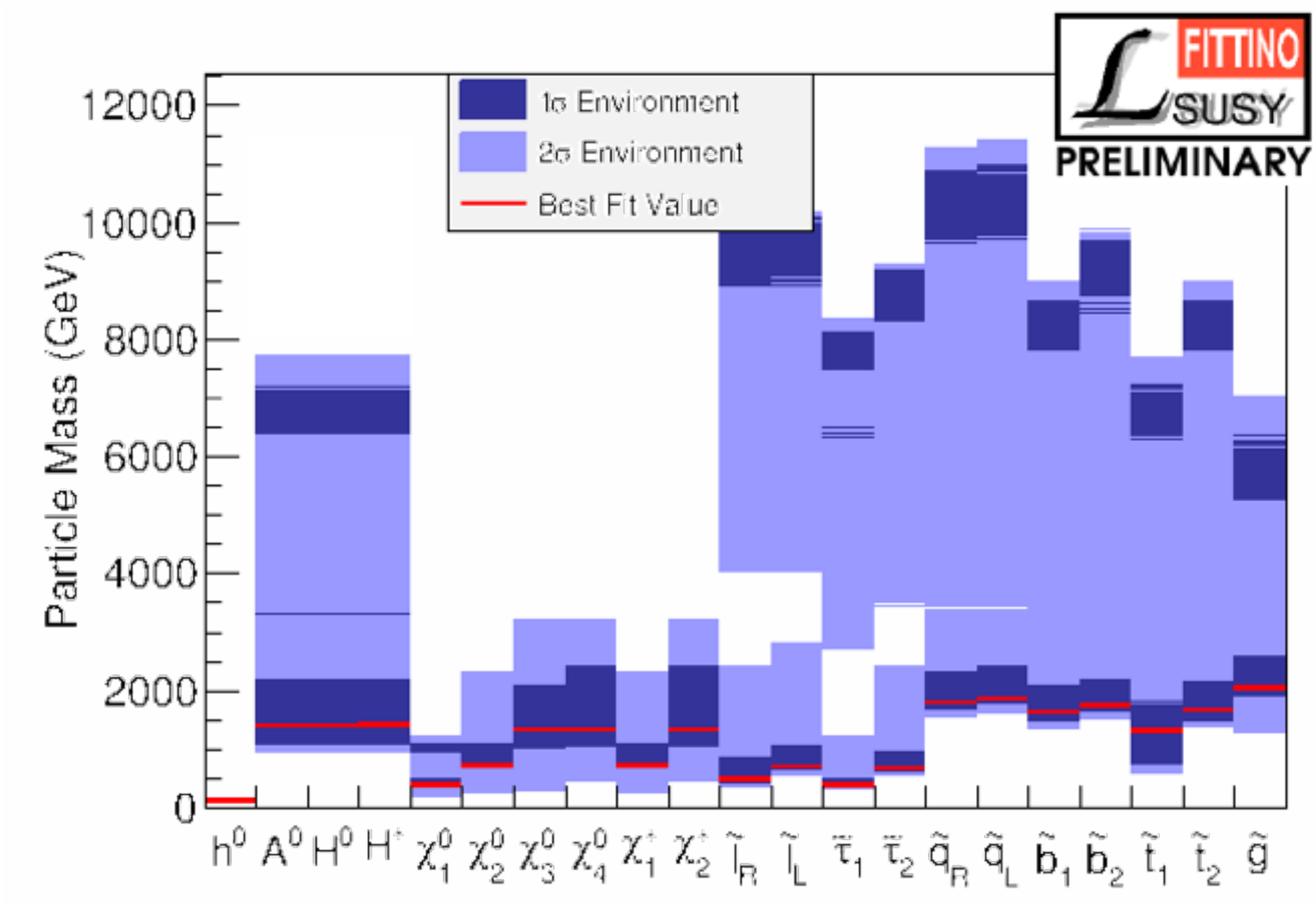


Preferred parameter region



- χ^2/ndf = 26.5/15
- High mass region allowed at 1D 1sigma due to new Higgs mass calculation

Predicted mass spectrum



- squark and gluino masses at best fit point about 2 TeV
- But now also masses of 10 TeV allowed at 1 sigma

Summary of part I

- In the CMSSM there is some tension between low energy observables and exclusions from LHC

- The CMSSM is in agreement with astrophysical measurements but on the other hand no convincing direct or indirect detection hints are found

- A SM like Higgs is well described by the CMSSM with large particle masses but no BSM Higgs sector is found

What do we do with the CMSSM now?

There's at least *one more thing* to do!

How well does the CMSSM describe the data quantitatively?

P-Value

If the best fit
point is realised in nature

doing a global fit to the
measurement

how probable is it to get

a minimal chi2 at least as
bad as the one observed?

Difficulties

- If our χ2 - function would be χ2 - distributed we could just look up the integral

$$\int_{\chi^2_{\min}}^{\infty} P_{\chi^2_{\mathrm{ndf}}}(x)\, dx$$

- Unfortunately this is not necessarily true because of:
  - Non - linear dependence of observables on parameters
  - Non - gaussian uncertainties
- Thus also χ^2/ndf isn't the appropriate goodness-of-fit measure

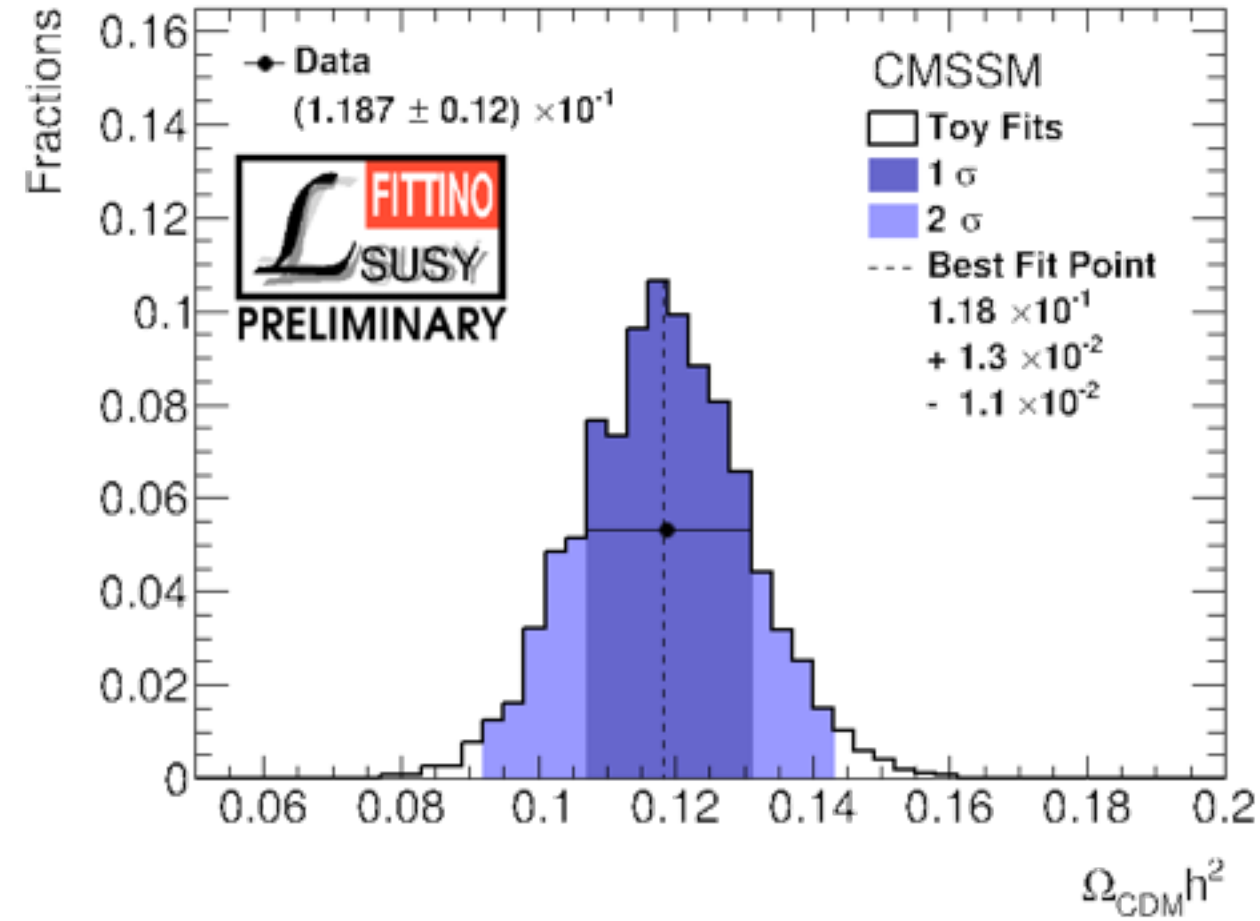
How well does the CMSSM describe the data quantitatively?

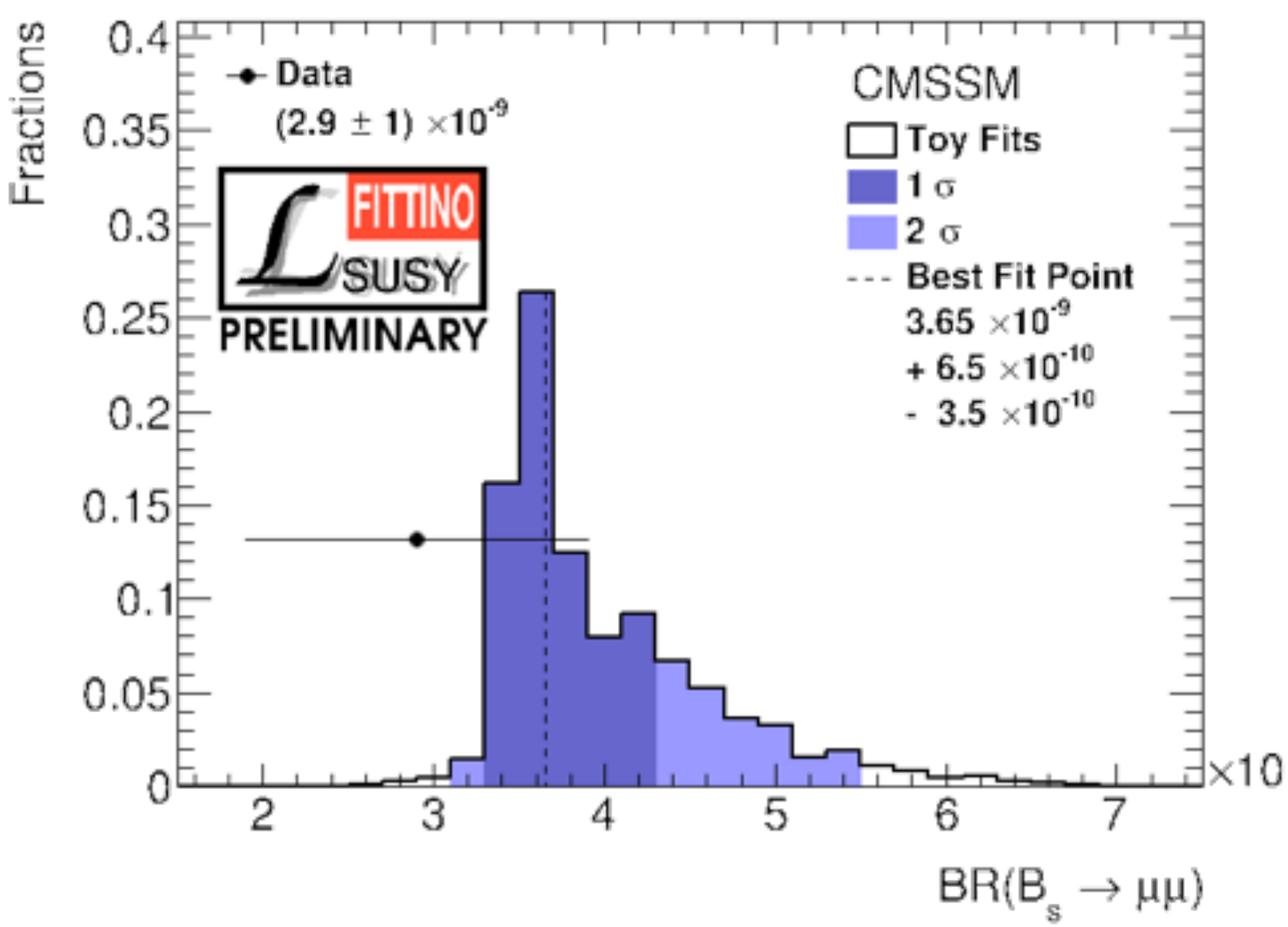
P-Value	Toy fits
If the best fit point is realised in nature	Smearing observables around the best fit prediction
fitting the model to the measurements	and fitting the model to each of these toy measurements
how probable is it to get	how often do you get

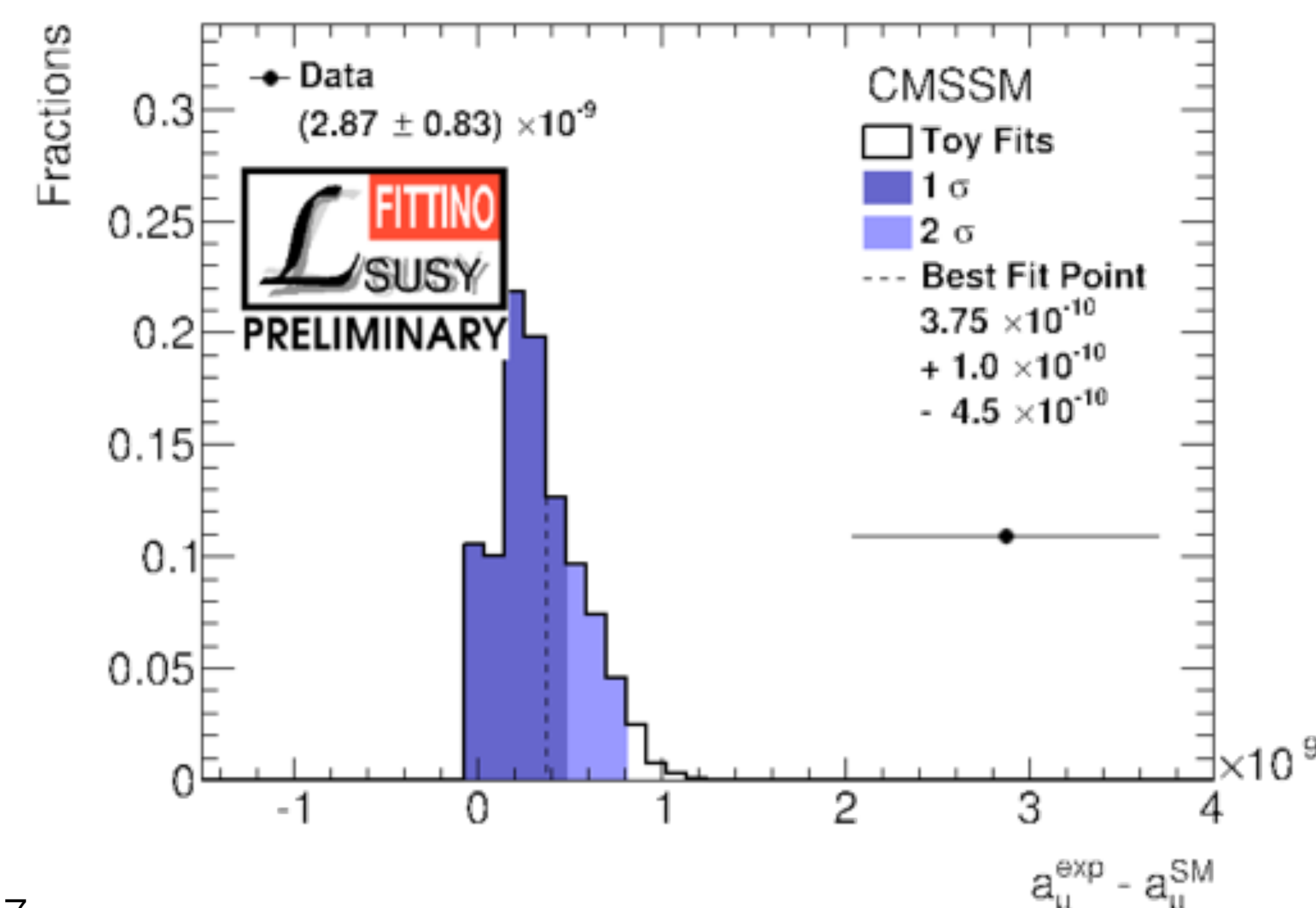
a minimal chi2 at least as bad as the one observed?

- Very common in HEP
- Hasn't been done in global SUSY fits (extremely CPU intensive)

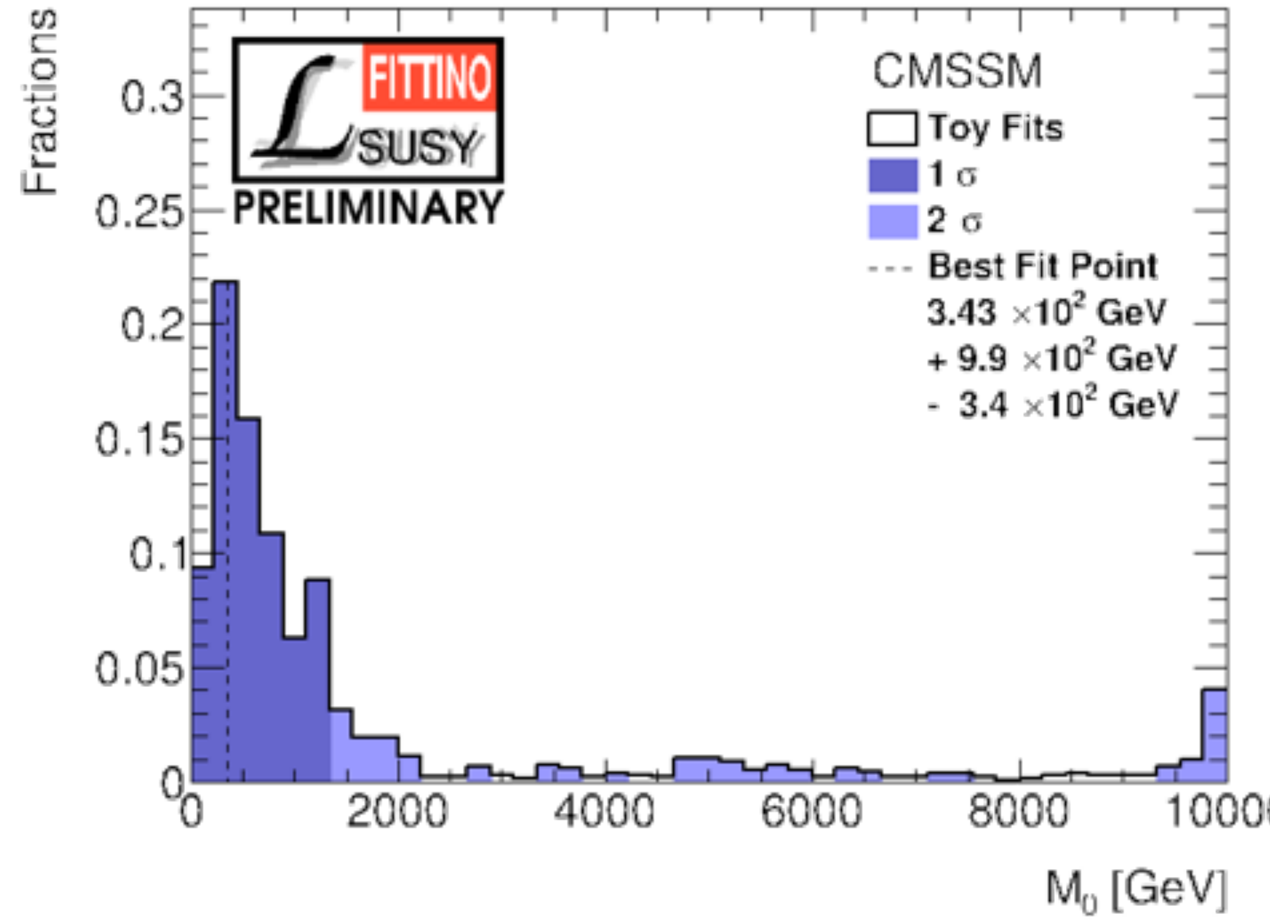
We repeat the fit described above **1600** times with smeared observables and get these predicted observable values at the best fit points.

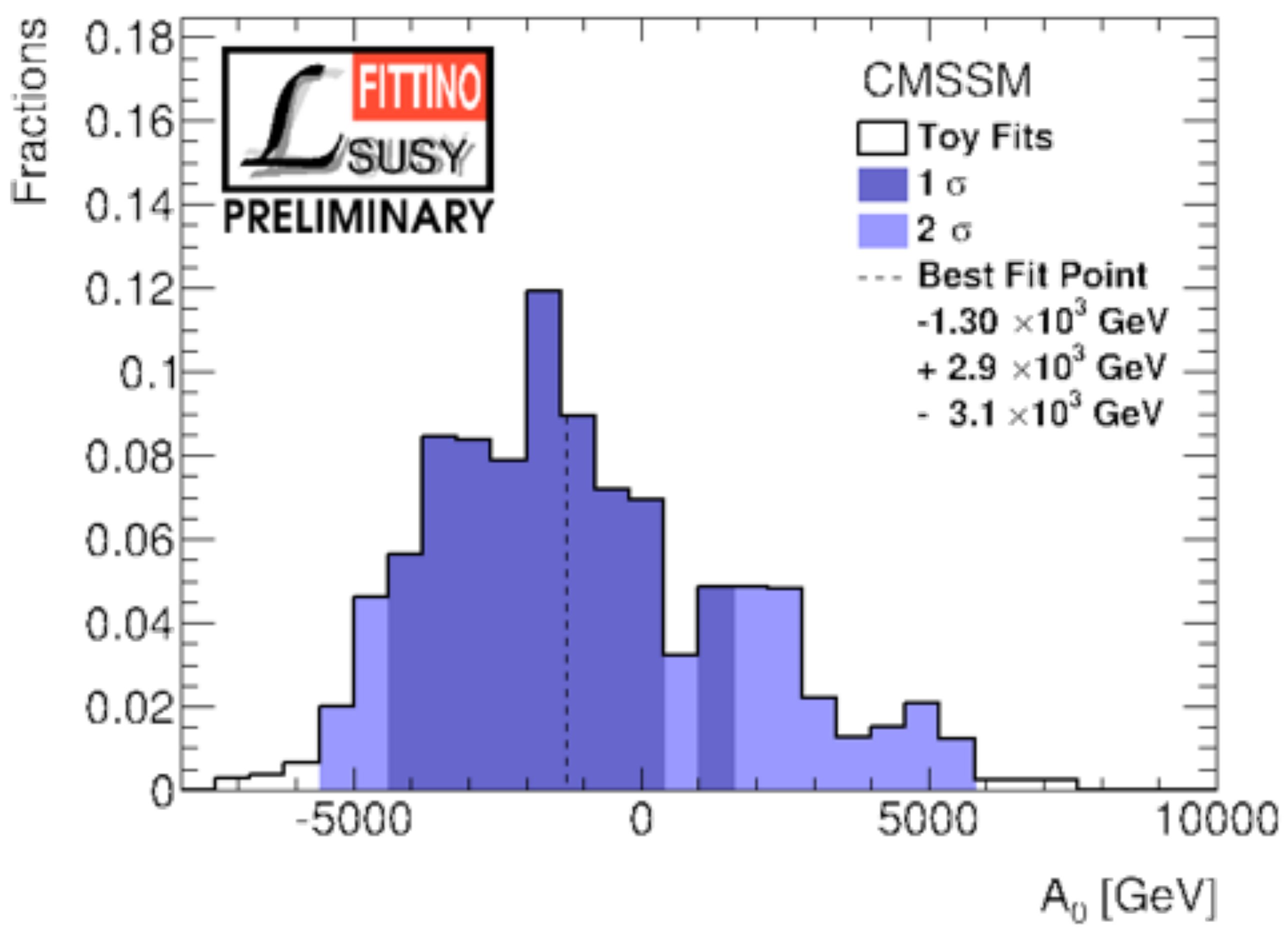


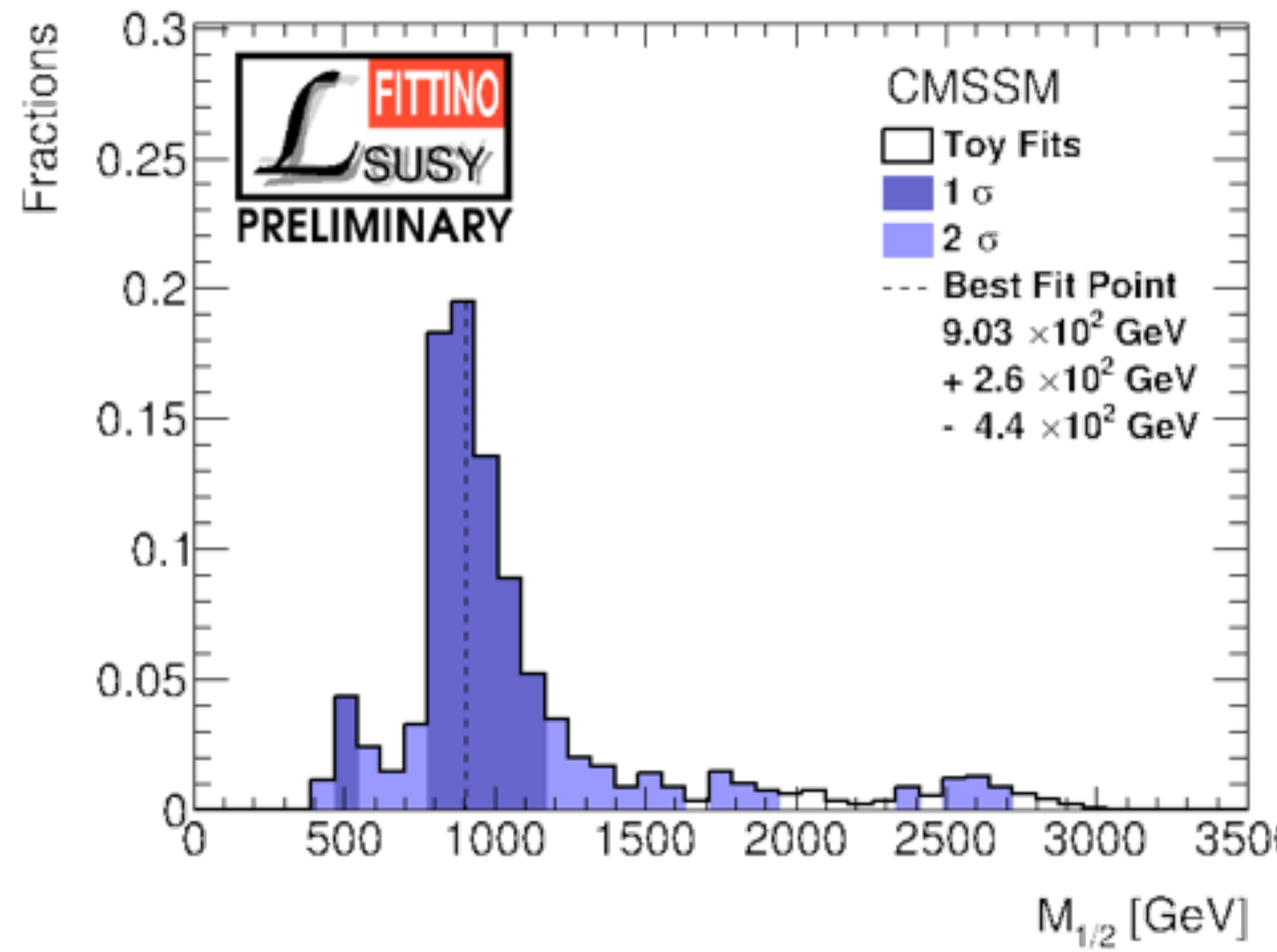




Corresponding underlying CMSSM parameter values at the best fit points

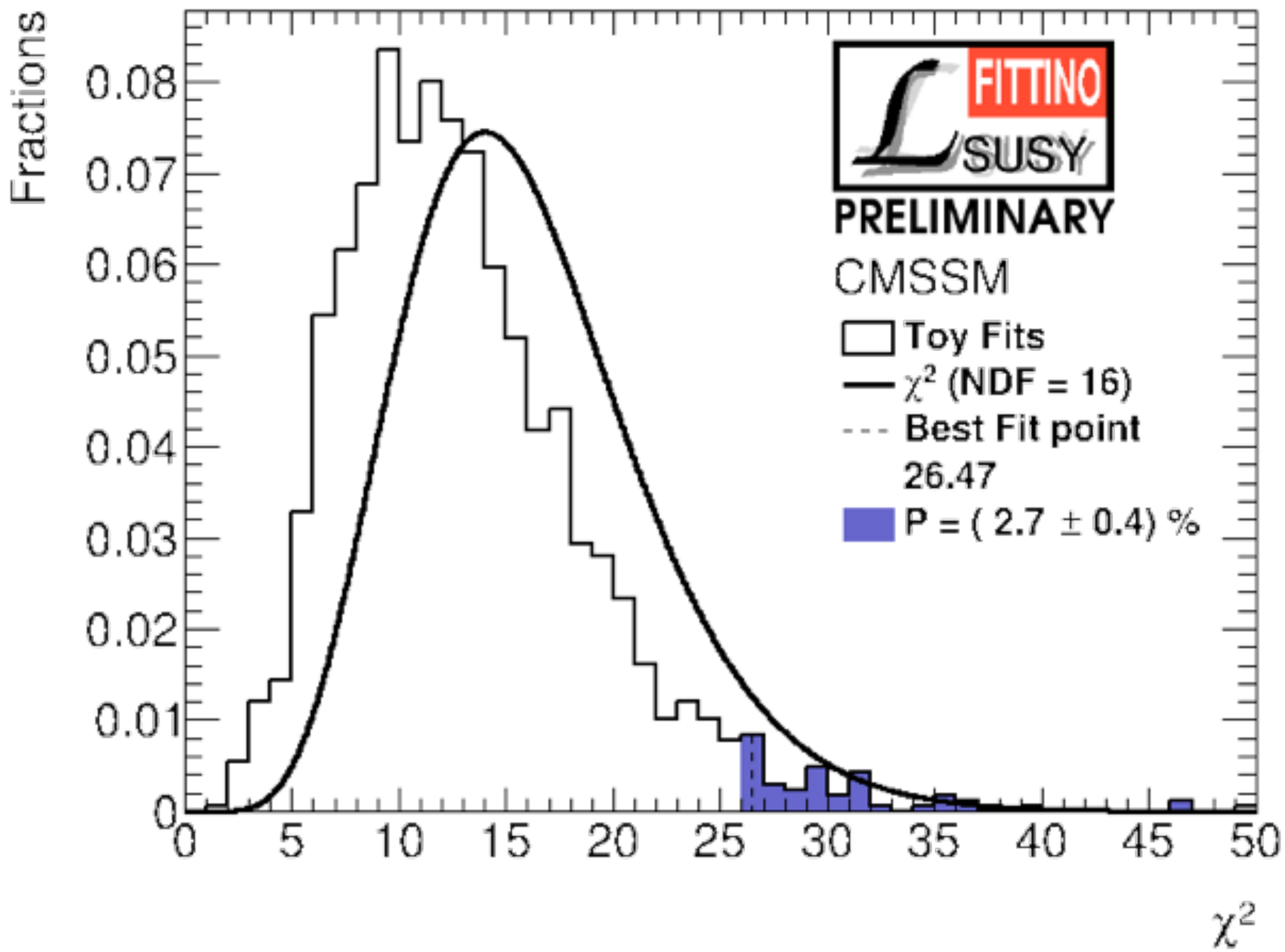






World's first p-value for the CMSSM

very preliminary!

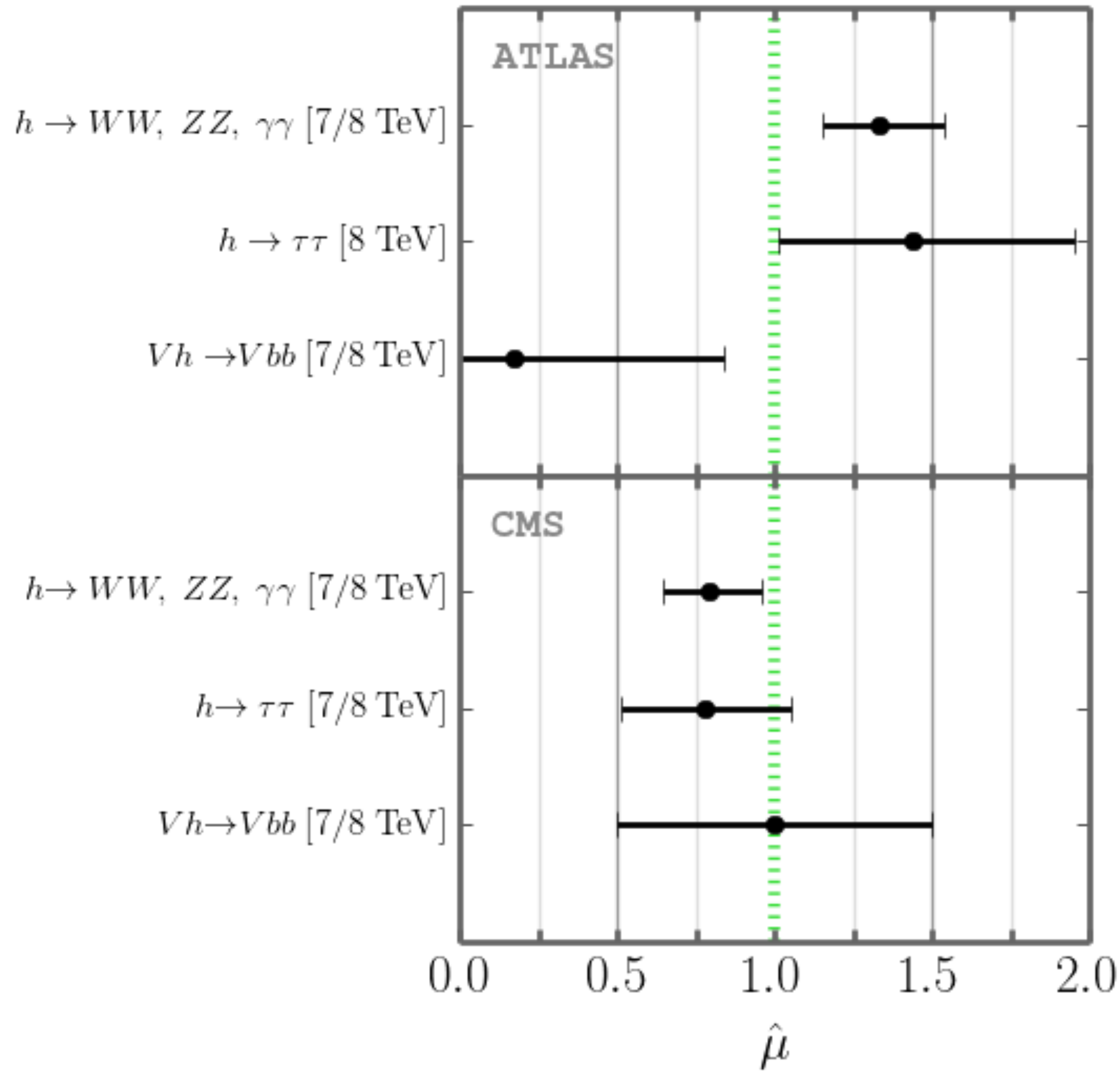


χ^2/ndf overestimates goodness of fit.

Dependence on the input and its parametrization?

p-Value describes agreement with ~~given~~ selected data

e. g. we selected these Higgs rate measurements, adding 6 ndf



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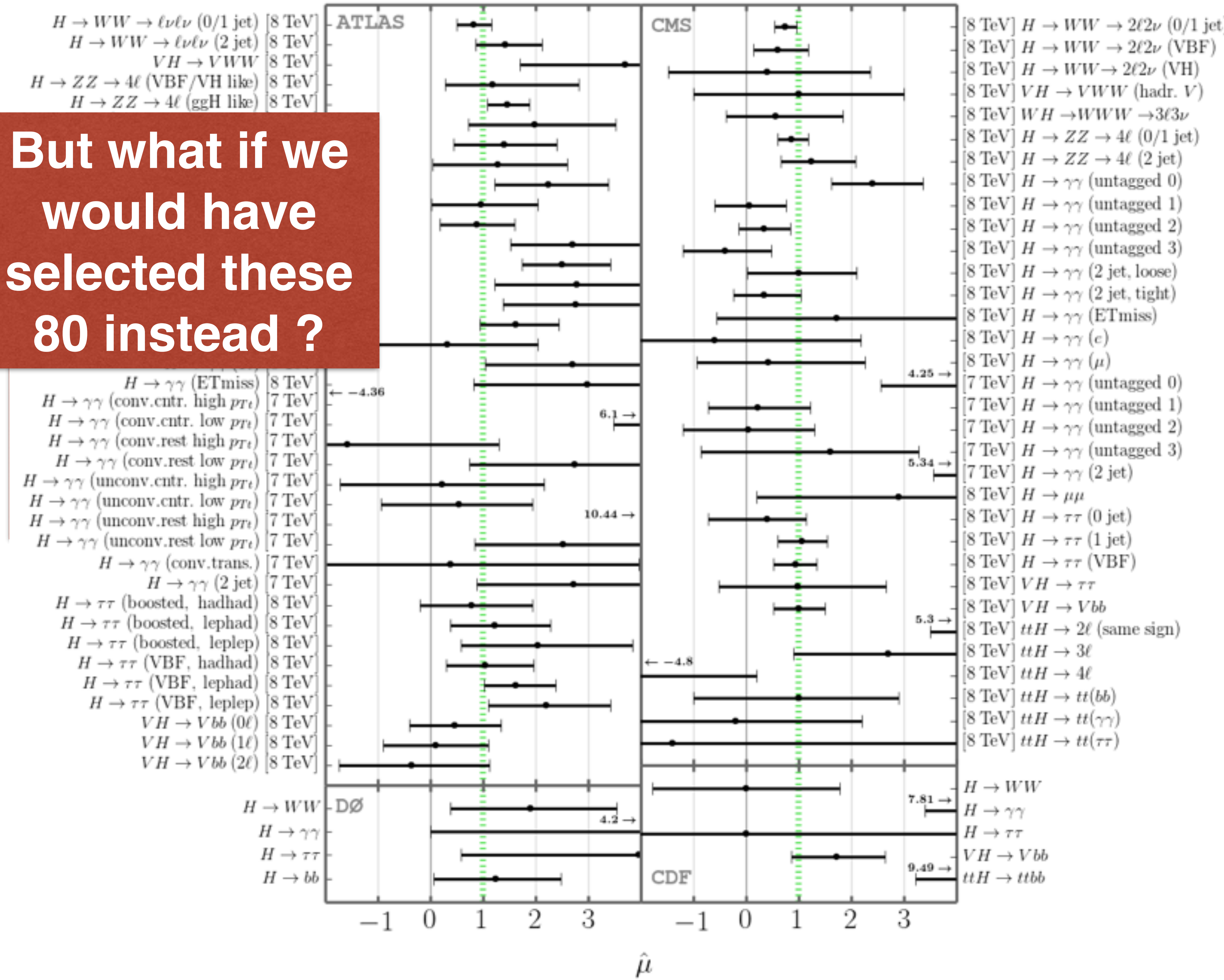

But what if we would have selected these 80 instead ?

Summary of part II and outlook

- For the first time a p-value for a SUSY model has been calculated using global toy fits

- This gives an appropriate measure for the agreement between the model and the selected data

  Possible dependance of p-value on (Higgs-) observable parametrisation will be studied

- We applied the procedure to the CMSSM

  Applying it to more general models which decouple the Higgs, electroweak and strong sector will finally quantify how much better they perform

Backup

χ^2 contributions

At each parameter point $\vec{P}$ calculate:

$$\chi^2 = \left(\vec{O}_{\text{meas}} - \vec{O}_{\text{pred}}(\vec{P})\right)^T cov^{-1} \left(\vec{O}_{\text{meas}} - \vec{O}_{\text{pred}}(\vec{P})\right) + \chi^2_{\text{limits}}$$