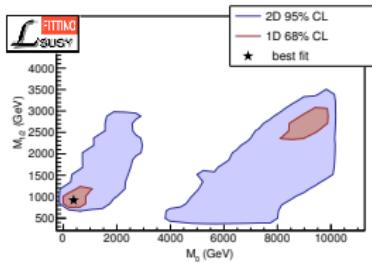


Towards a phenomenological MSSM fit with Fittino

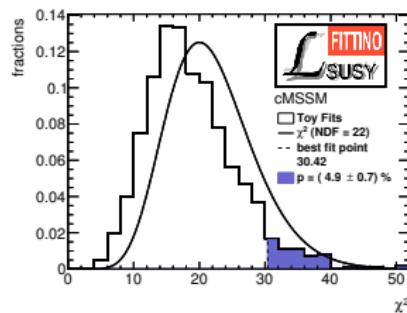
Jory Sonneveld
for the Fittino collaboration



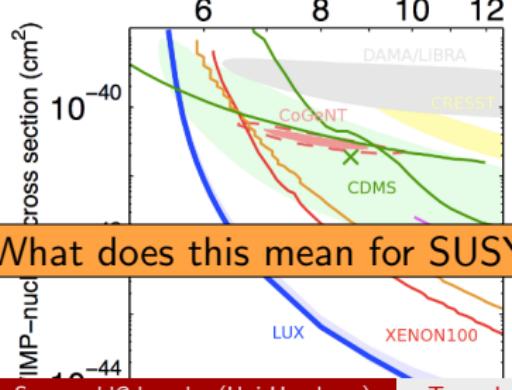
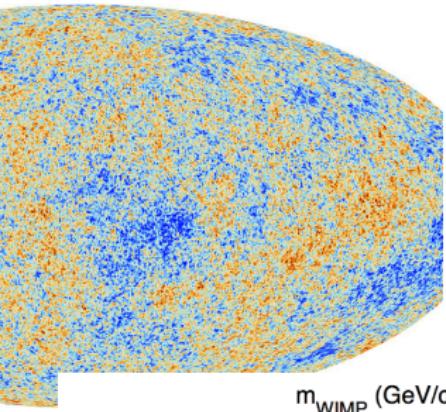
SUSY 2016, Melbourne

Bechtle, Camargo-Molina, Desch,
Dreiner, Hamer, Johnston, Keller, Krämer,
Porod, Sarrazin, Schmeier, Schütte-Engel,
Stefaniak, Tattersall, Uhlenbrock, Wienemann

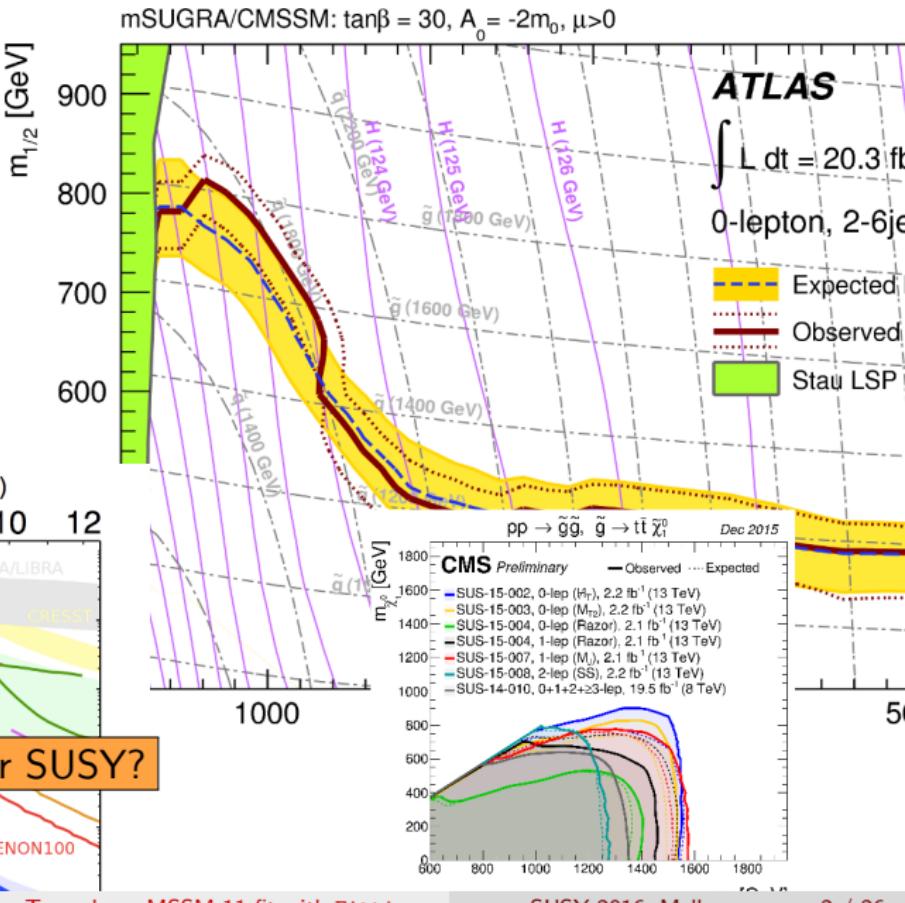
arXiv:1508.05951



Observables

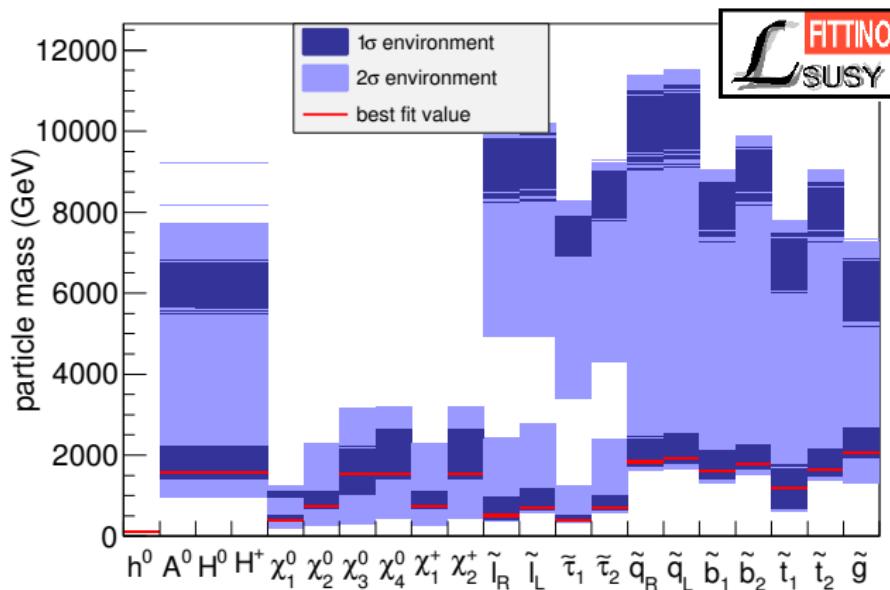


What does this mean for SUSY?



cMSSM Fit with Fittino

Fittino 5-param. cMSSM fit



Inputs:

- $\text{br}(B_s \rightarrow \mu^+ \mu^-)$
- $\text{br}(B^\pm \rightarrow \tau^\pm \nu)$
- $\text{br}(b \rightarrow s\gamma)$
- Δm_s
- $a_\mu - a_\mu^{\text{SM}}$
- m_t
- m_W
- $\sin^2 \theta_{\text{eff}}$
- $\Omega_{\text{CDM}} h^2$
- LUX results
- Higgs results
- LEP m_{χ^\pm} limit

ATLAS-SUSY-2013-02

[Bechtle, Camargo-Molina, Desch, Dreiner, Hamer, Krämer, O'Leary, Porod, Sarrazin, Stefaniak, Uhlenbrock, Wienemann [arXiv:1508.05951](https://arxiv.org/abs/1508.05951)]

Fittino cMSSM results

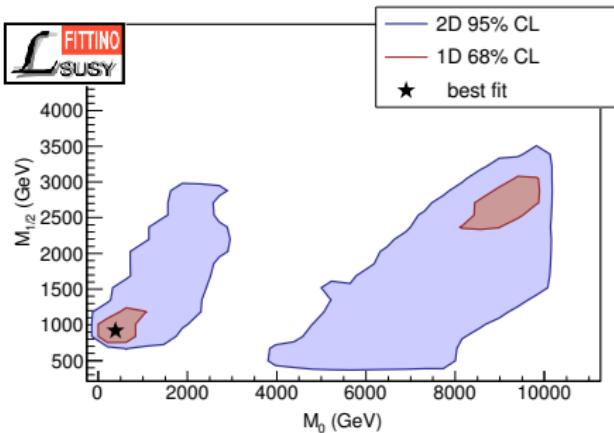
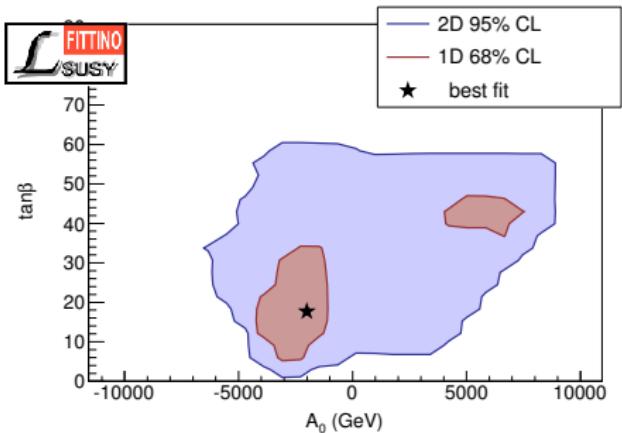


Table 7 Central values and 1σ uncertainties of the free model parameters at the global and secondary minimum when using the Medium Observable Set

Parameter	global minimum	secondary minimum
M_0 (GeV)	$387.4^{+481.7}_{-151.2}$	$8983.4^{+990.6}_{-1039.6}$
$M_{1/2}$ (GeV)	$918.2^{+297.7}_{-59.3}$	$2701.1^{+582.6}_{-560.5}$
A_0 (GeV)	$-2002.8^{+541.5}_{-1992.9}$	$5319.0^{+2339.8}_{-1357.9}$
$\tan\beta$	$17.7^{+16.8}_{-10.8}$	$43.2^{+5.5}_{-6.6}$
m_t (GeV)	$174.3^{+1.1}_{-1.1}$	$172.1^{+0.6}_{-0.6}$

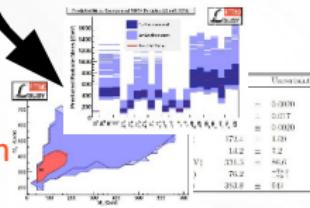
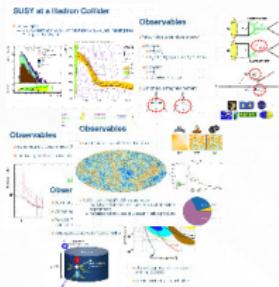
arXiv:1508.05951

The Fittino Framework & Outline

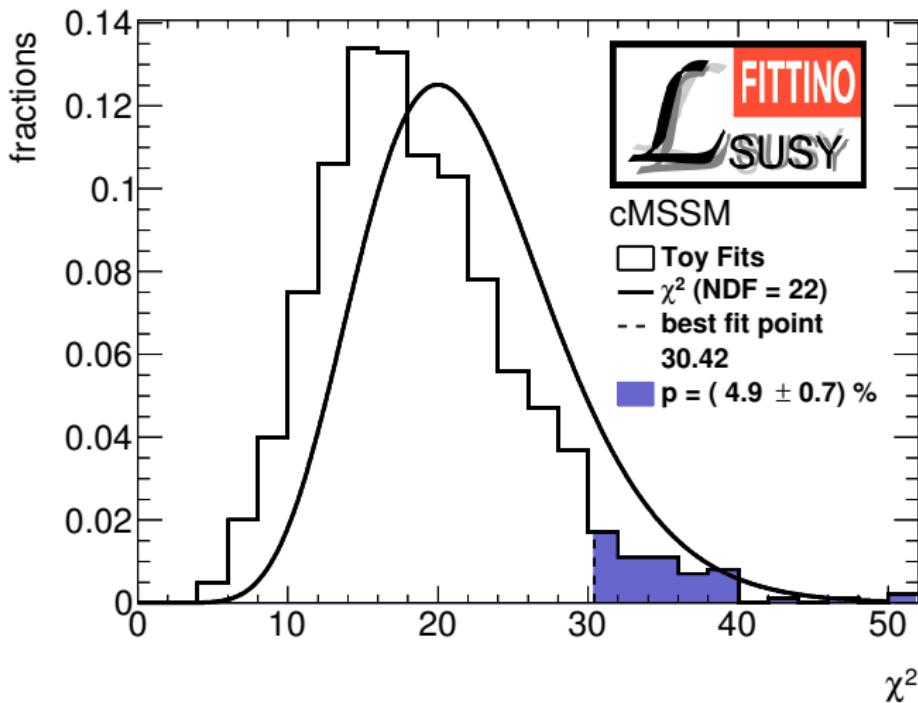
- ★ select sensitive observables
 - ★ low energy observables
 - ★ Higgs boson properties
 - ★ collider searches for sparticle production
 - ★ direct/indirect dark matter detection

- ★ scan the parameter space
 - ★ public codes for calculation of model predictions
 - ★ χ^2 as a measure for level of agreement
 - ★ Markov Chain Monte Carlo for smart sampling

- ★ statistical analysis
 - ★ frequentist interpretation
 - ★ preferred parameter regions and mass spectrum
 - ★ calculation of p-value with pseudo experiments



First true p-value for cMSSM



arXiv:1508.05951

More p-values

Observable Set	$\chi^2 / \text{n.d.f}$	naive p-value	toy p-value	stat. uncert.
Combined	17.5/13	17.7%	8.3%	0.8%
Small	27.1/16	4.0%	1.9%	0.4%
Medium	30.4/22	10.8%	4.9%	0.7%
Large	101.1/92	24.3%	41.6%	4.4%
Medium / g-2	18.1/21	64.1%	51%	3%

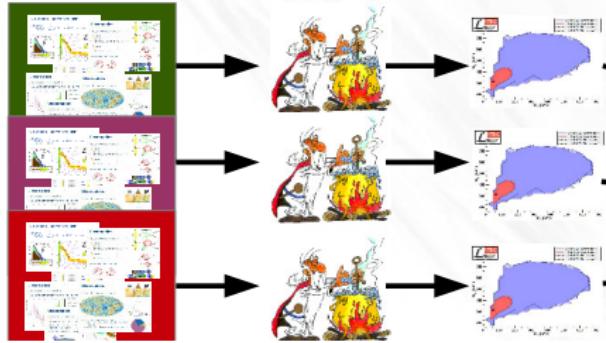
- **naive p-value**: p-value according to gaussian χ^2 -distribution
- **toy p-value**: p-value extracted from pseudo experiments
- **stat.uncertainty**: estimated uncertainty on p-value

$$\Delta p = \sqrt{\frac{p \cdot (1-p)}{n_{\text{Toy}}}}$$

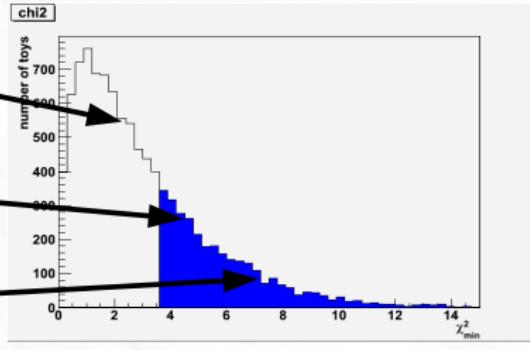
What is this p-value?

- ★ non-gaussian observable set
 - 1-sided and hard **limits**
 - **non-gaussian** uncertainties
 - **relative** uncertainties
 - highly **non-linear** model

- ★ gaussian χ^2 -distribution accurate?
 - get **true χ^2 -distribution** from pseudo measurements
 - **~1000** pseudo datasets per obs set



$$P_n(\chi^2) = \frac{(\chi^2)^{\frac{n}{2}} \cdot e^{\frac{-\chi^2}{2}}}{2^{\frac{n}{2}} \Gamma(\frac{n}{2})}$$



So many (Higgs) results!

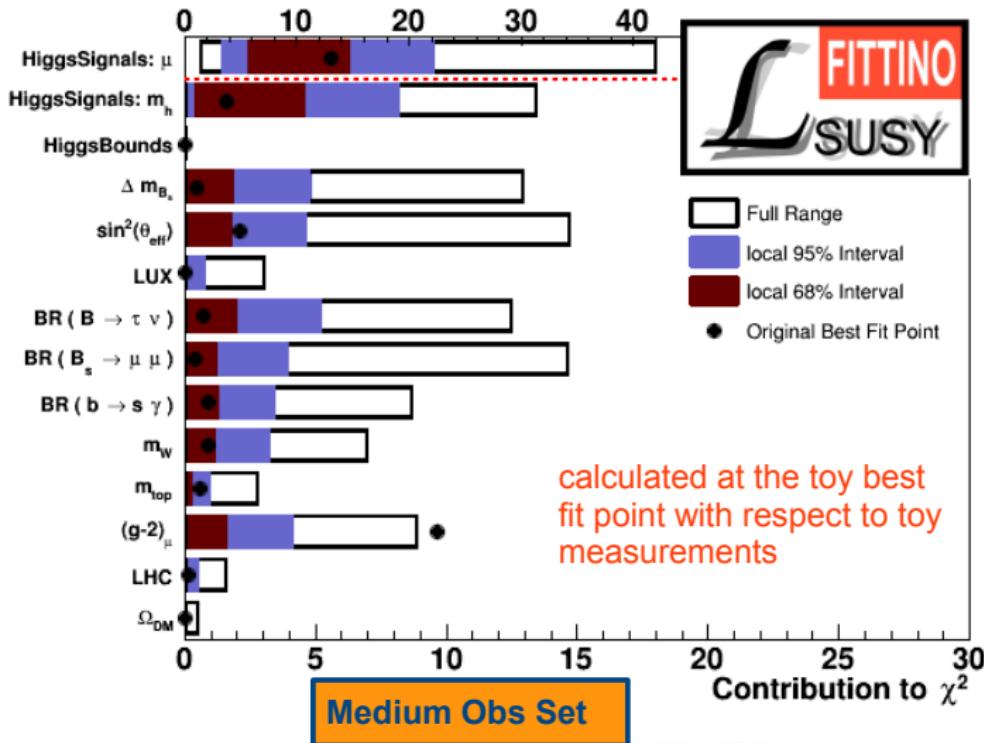
- ★ Large Obs Set: 84 different measurements in Higgs sector
→ CMSSM makes the same prediction for several subsets
- ★ in terms of the p-value, the model can be
 - punished for bad agreement within the data
 - rewarded for good agreement within the data
- ★ p-value should reflect the quality of the model
 - combine measurements with same prediction
 - use combination in global fit

medium obs set comes closest to what we need

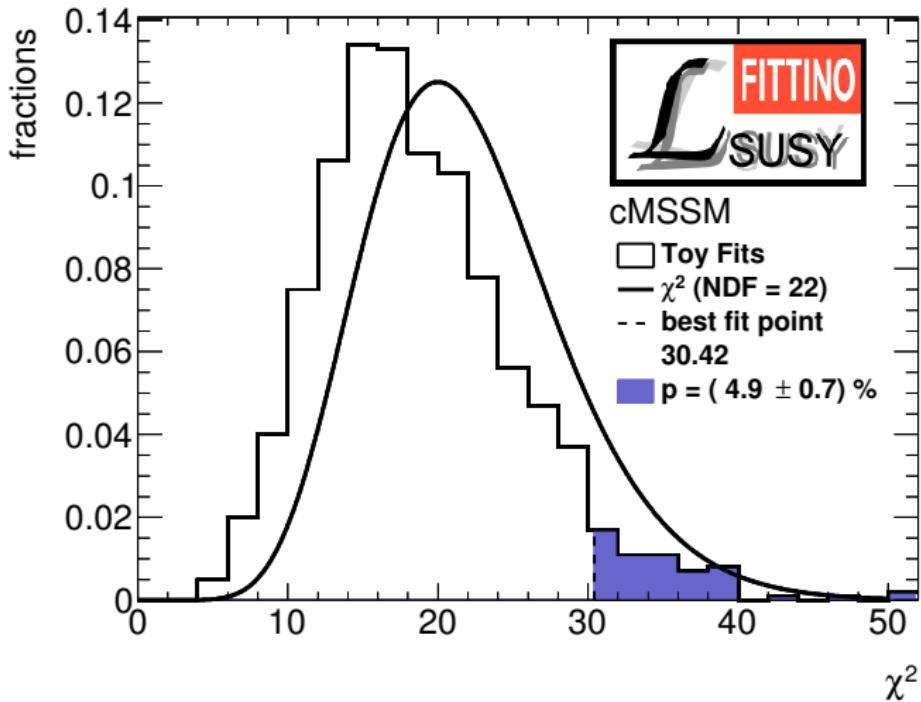
Experiment, Channel	observed μ	observed m_h
ATLAS, $h \rightarrow WW \rightarrow \ell\nu\ell\nu$ [80]	$0.99^{+0.31}_{-0.28}$	-
ATLAS, $h \rightarrow ZZ \rightarrow 4\ell$ [80]	$1.43^{+0.40}_{-0.35}$	(124.3 ± 1.1) GeV
ATLAS, $h \rightarrow \gamma\gamma$ [80]	$1.55^{+0.33}_{-0.28}$	(126.8 ± 0.9) GeV
ATLAS, $h \rightarrow \tau\tau$ [81]	$1.44^{+0.51}_{-0.43}$	-
ATLAS, $Vh \rightarrow V(bb)$ [82]	$0.17^{+0.67}_{-0.63}$	-
CMS, $h \rightarrow WW \rightarrow \ell\nu\ell\nu$ [83]	$0.72^{+0.29}_{-0.18}$	-
CMS, $h \rightarrow ZZ \rightarrow 4\ell$ [84]	$0.93^{+0.29}_{-0.25}$	(125.6 ± 0.6) GeV
CMS, $h \rightarrow \gamma\gamma$ [85]	$0.77^{+0.30}_{-0.27}$	(125.4 ± 1.1) GeV
CMS, $h \rightarrow \tau\tau$ [86]	$0.78^{+0.27}_{-0.27}$	-
CMS, $Vh \rightarrow V(bb)$ [86]	$1.00^{+0.50}_{-0.50}$	-

Medium observable set: 10 Higgs observables

Effects of individual measurements



The p-value found for the cMSSM



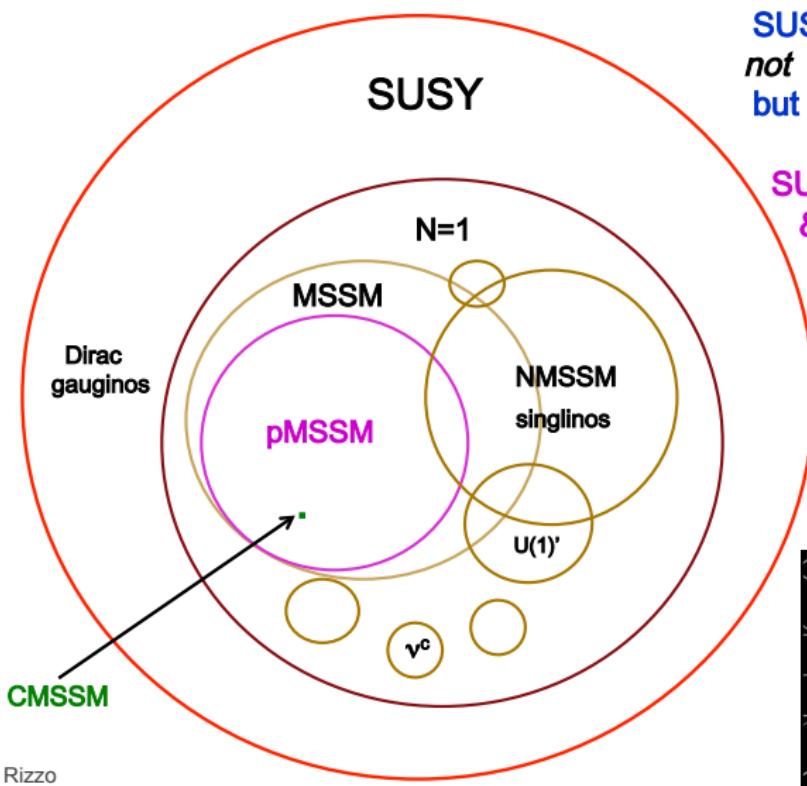
Medium obs set

arXiv:1508.05951

Calculating model predictions

- Fittino uses
 - **SPheno** for the mass Spectrum
 - **SuperIso** for the B-meson branching fractions
 - **FeynHiggs** for Higgs properties, m_W , $\sin \theta_{\text{eff}}$, $(g - 2)_\mu$
 - **micrOMEGAs** for Ωh^2
 - **DarkSUSY via AstroFit** for direct detection cross section
 - **MadGraph/Pythia/Delphes/NLLFast/Prospino/CheckMATE** for the emulation of LHC searches.

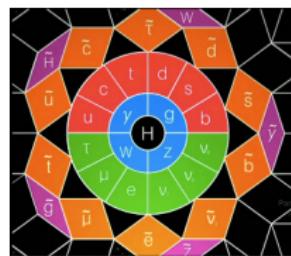
Beyond cMSSM: phenomenological MSSM



SUSY is complex:
not a single model
but a large framework

SUSY can be hiding
& may only appear
at 13 TeV

SUSY is too big
to explore without
SOME assumptions



Joanne Hewett

Beyond cMSSM: phenomenological MSSM

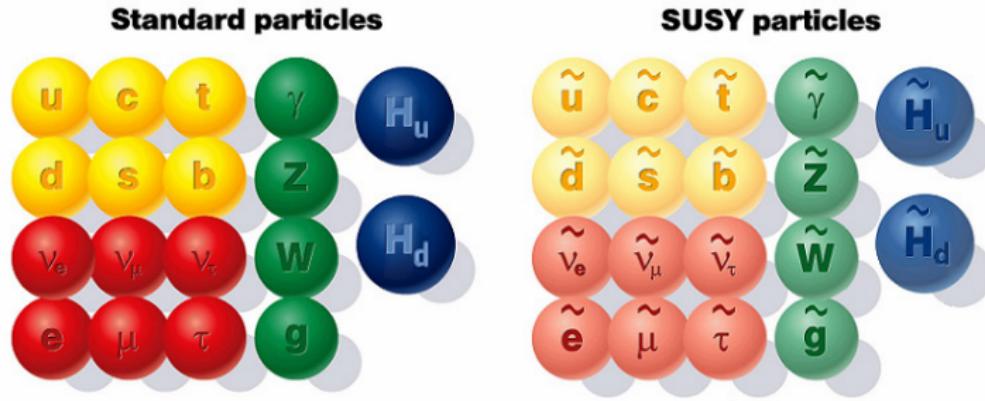


Figure courtesy of Jan Heisig

R-parity conserving Minimal Supersymmetric Standard Model

Reduce 119 free parameters to 19 by assuming:

[Djouadi et. al. 1998]

- ① *No new source of CP violation*
- ② *No flavor-changing neutral currents*
- ③ *First and second generation universality*

interpretations: e.g. [Cahill-Rowley et al. (2012)], [Fittino (2009)], [ATLAS (2015)], [CMS (2016)], [Barr, Liu (2016)]

Parameter space considered in the pMSSM

pMSSM-11

- $1 \leq \tan \beta \leq 60$
- $100 \text{ GeV} \leq M_A \leq 2 \text{ TeV}$
- $-5 \text{ TeV} \leq \mu \leq 5 \text{ TeV}, \mu \notin [-0.1, 0.1] \text{ TeV}$
- $-4 \text{ TeV} \leq M_1 \leq 4 \text{ TeV}$
- $0.1 \text{ TeV} \leq M_2 \leq 4 \text{ TeV}$
- $-4 \text{ TeV} \leq M_3 \leq 4 \text{ TeV}, M_3 \notin [-0.4, 0.4] \text{ TeV}$
- $0.1 \text{ TeV} \leq M_{\tilde{l}_{1,2}} \leq 3 \text{ TeV}$
- $0.1 \text{ TeV} \leq M_{\tilde{l}_3} \leq 4 \text{ TeV}$
- $0.3 \text{ TeV} \leq M_{\tilde{q}_{1,2}} \leq 5 \text{ TeV}$
- $0.1 \text{ TeV} \leq M_{\tilde{q}_3} \leq 5 \text{ TeV}$
- $-5 \text{ TeV} \leq A_0 \leq 5 \text{ TeV}$
- still under discussion*

Prior constraints

- $m_h \geq 110 \text{ GeV};$
- $m_W, \Delta m_s,$
 $\text{Br}(B_s \rightarrow \mu\mu),$
 $\text{Br}(b \rightarrow s\gamma),$
 $\text{Br}(B \rightarrow \tau\nu)$
within 5σ of
experimental
value.

used only for LHC
searches preparation

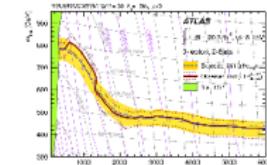
Theoretical assumptions

- χ_1^0 is the Lightest (stable) Supersymmetric Particle (LSP);
- no tachyons.

Other interpretations: [Mastercode (2015)]

pMSSM-11 challenges in LHC searches

Beyond



SLHA
pMSSM-11

event generation
@8TeV

event generation
@13TeV

CHECKMATE
ATLAS
and
CMS
analyses

χ^2

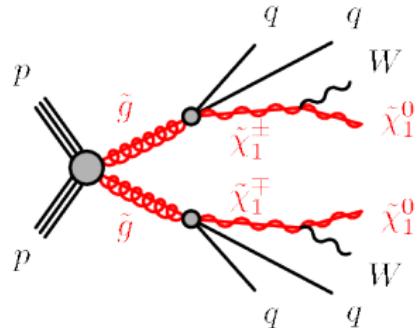
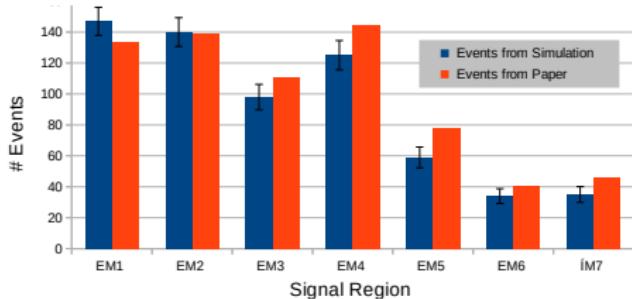
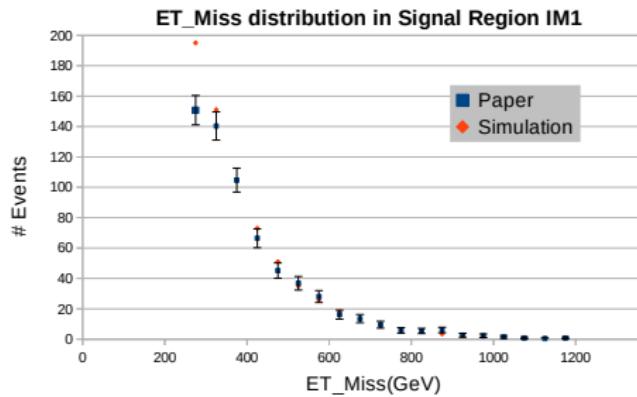
- ✗ Event generation takes $\mathcal{O}(\text{hours})$.
- ✗ Scan 10 points in each parameter direction: 10^{11} points \rightarrow scan runs 10^6 years!
- ✓ \rightarrow neural net

Analyses at 8TeV: arXiv:1402.7029, arXiv:1403.5294, ATLAS-CONF-2013-036, arXiv:1308.2631, arXiv:1403.4853, arXiv:1404.2500, arXiv:1405.7875, arXiv:1407.0583, arXiv:1407.0608, arXiv:1502.01518, arXiv:1503.03290

Analyses at 13TeV: ATLAS-CONF-2015-076, arXiv:1602.09058, ATLAS-CONF-2015-062, ATLAS-CONF-2015-082, ATLAS-CONF-2015-076, arXiv:1604.07773, CMS-PAS-SUS-15-011, ATLAS-CONF-2016-013, ATLAS-CONF-2015-067

Validation of an LHC search in CheckMATE

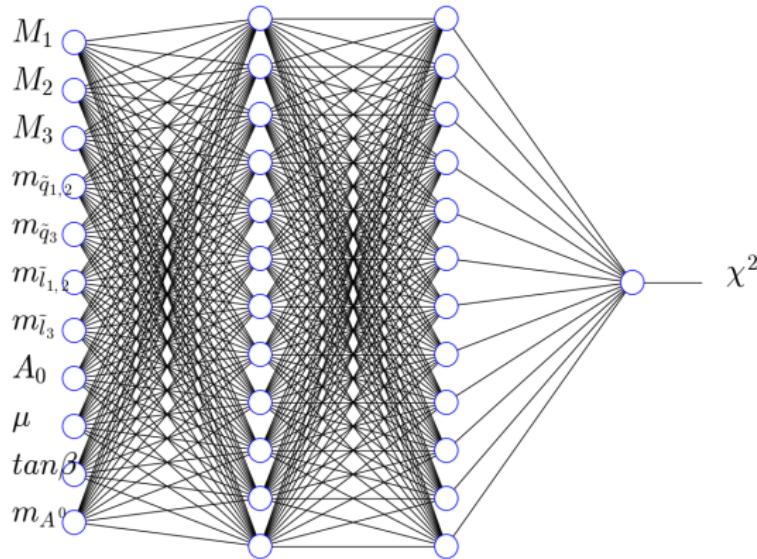
Validation of ATLAS EXOT-2015-03 search:



Validation of arXiv:1604.07773

Preparation for LHC searches: neural net with 11 inputs

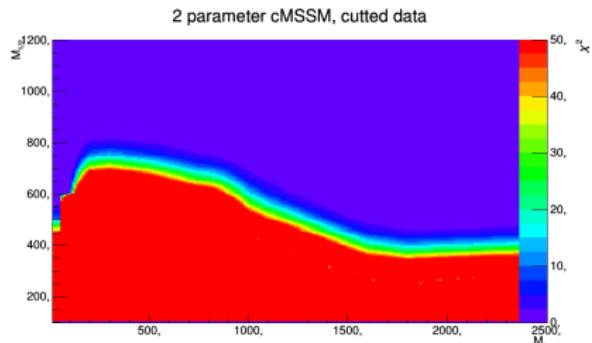
Example



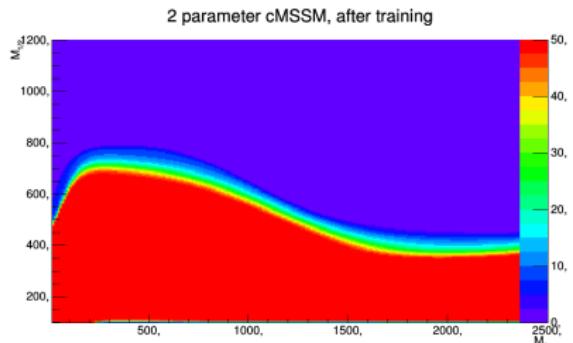
Train a neural net to predict a χ^2 for a pMSSM-11 parameter point

Example: cMSSM-2

Preliminary



Actual χ^2



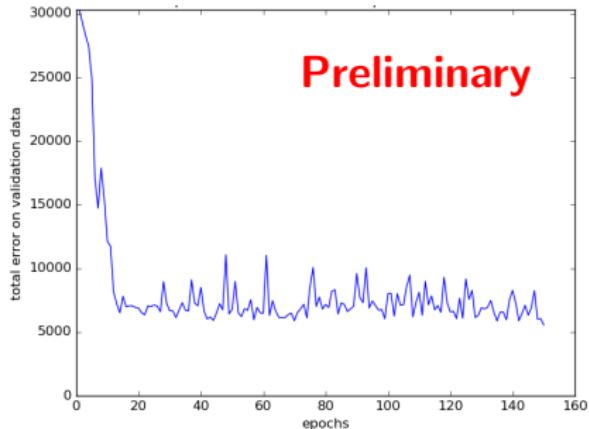
Predicted χ^2

'Cut': any $\chi^2 \geq 50$ is set to 50.

Fixed cMSSM parameters: $\tan \beta = 10$, $A_0 = 0$, $\mu = +1$

Jan Schütte-Engel

Performance for cMSSM-2

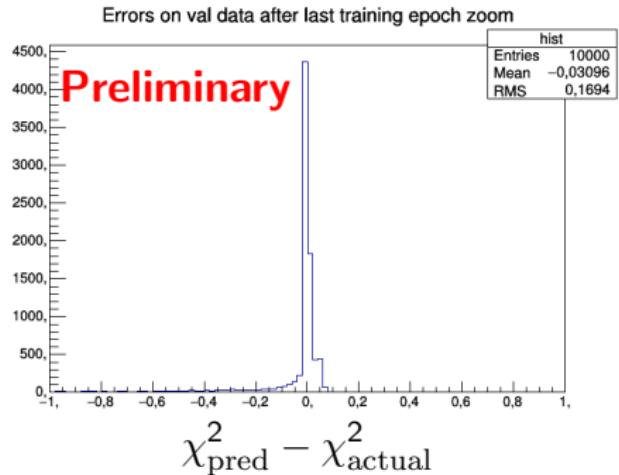


Training the neural net:

$$\text{total} = \sum_i^{n_{\text{validation}}} |\chi^2_{i,\text{pred}} - \chi^2_{i,\text{actual}}|$$

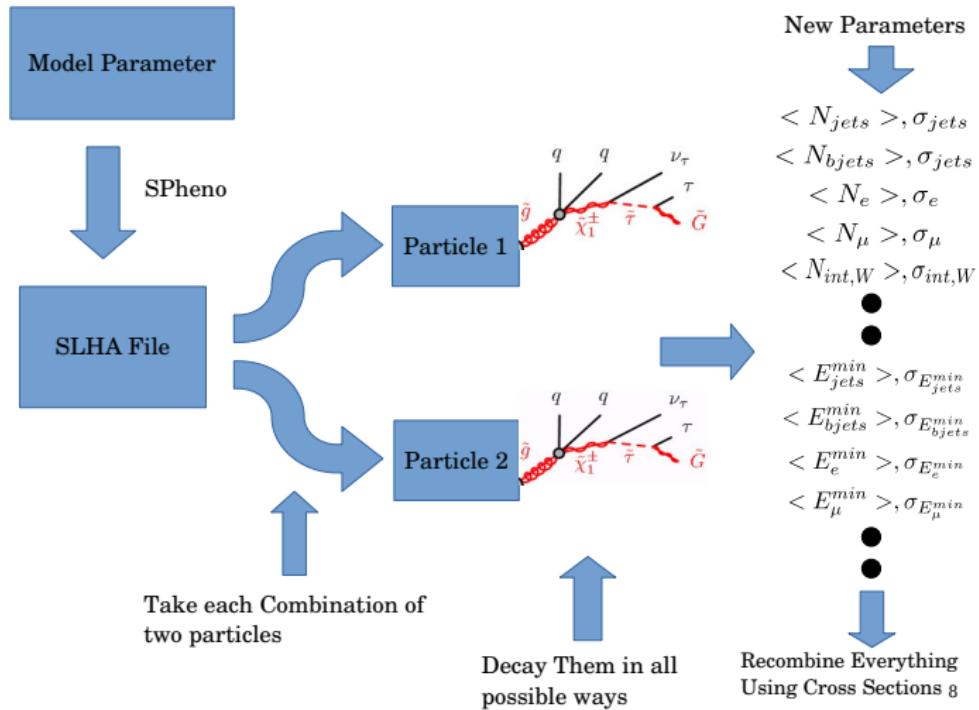
after each training iteration.

$$n_{\text{validation}} = 10000, n_{\text{training}} = 45000$$



Jan Schütte-Engel

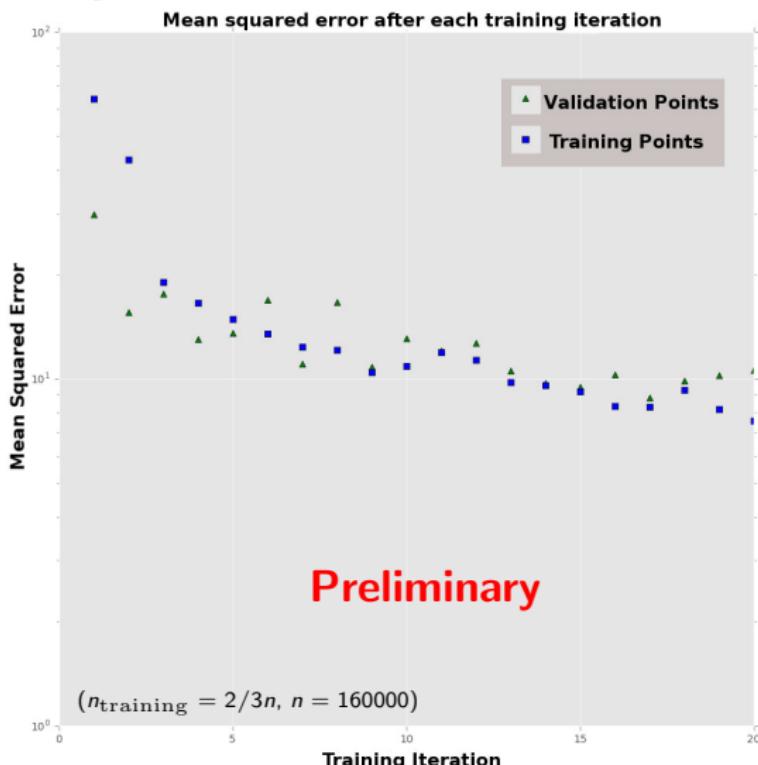
Reparametrization: physical parameters



$$\langle O \rangle = \frac{\sum_i (\sigma \text{Br})_i O_i}{\sum_i (\sigma \text{Br})_i}$$

Performance in the pMSSM-11 at 8TeV

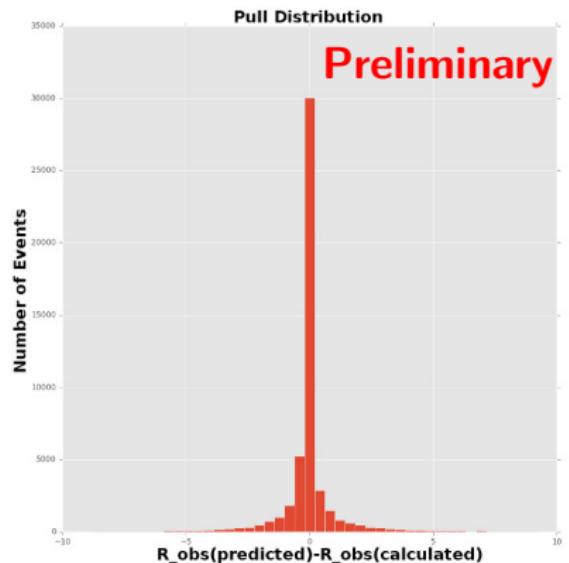
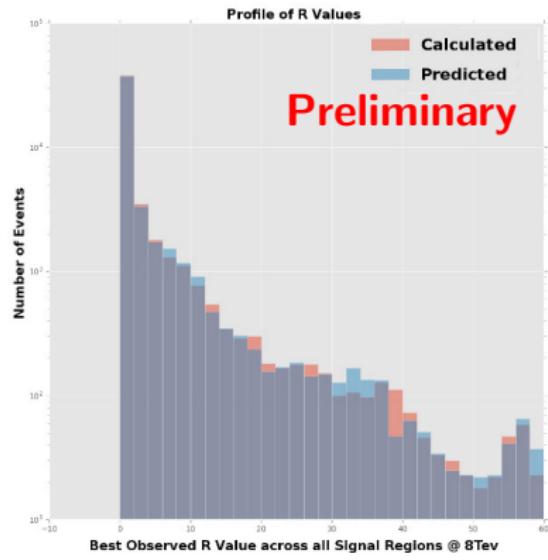
$\sum_i^{n_{\text{training}}} (\chi^2_{i,\text{pred}} - \chi^2_{i,\text{actual}})^2$ after each training iteration



Tim Keller

Predicted exclusions from physical parameters at 8 TeV

Preliminary



$$\text{Best } R_{\text{obs}} \equiv (s_{\text{pred}}^{\text{theo}} - 1.96\Delta s_{\text{pred}}^{\text{theo}})/s_{\text{obs}}^{\text{UL,95\%}}$$

$$R_{\text{obs,pred}} - R_{\text{obs,actual}}$$

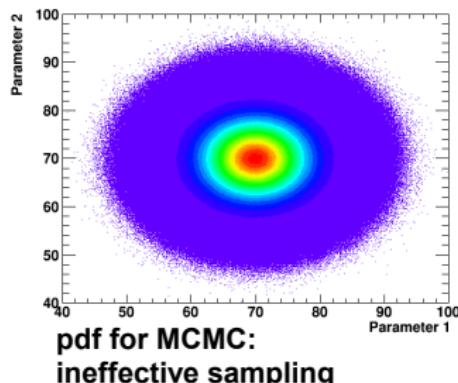
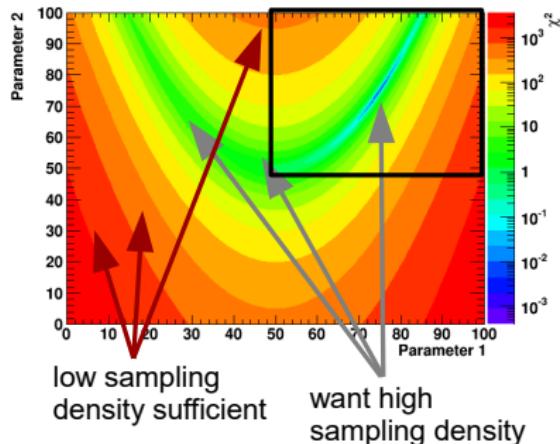
We currently achieve an allow/exclude classification accuracy of 95%

Tim Keller

(Higher Order) Markov Chain Monte Carlo

- ★ high dimensional, complex parameter space
- ★ non-trivial χ^2 landscape with local minima
- ★ preferred regions likely to be highly correlated

- ★ calculation of a complete point takes ~30s
- ★ high sampling density required in regions with small χ^2
- ★ regions with a high χ^2 don't have to be sampled as highly
- ★ use of a Markov Chain Monte Carlo requires intelligent steering mechanism



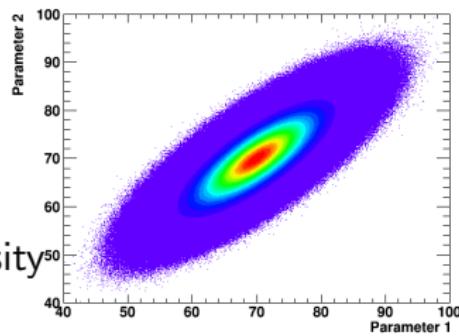
Jory.Sonneveld@desy.de (Uni Hamburg)

Towards a pMSSM-11 fit with Fittino

SUSY 2016, Melbourne

24 / 26

Proposal density

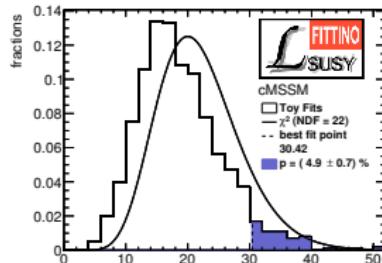


pdf for HOMCMC:
effective sampling

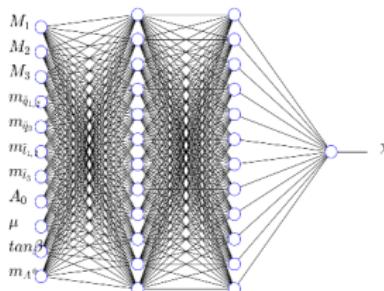
Summary

arXiv:1508.05951

- Fittino **combines low and high energy observables**
 - B branching ratios
 - direct searches
 - Higgs observables
 - cosmology and astrophysics results
- World's first true p-value for the cMSSM:
 - combined identical measurements for smaller χ^2 dependence on # of measurements
 - with optimal observable set excluded cMSSM at 95% CL
 - cMSSM pushed to a region where it cannot accomodate $(g - 2)_\mu$



Outlook



pMSSM-11

- CheckMATE for **more LHC results**
- **Neural nets** for fast interpolation of pMSSM-11
- **Model independent parametrization** in terms of physical final state parameters
- **Higher order MCMC** for smarter sampling

and: SModelS for missing LHC simplified model results.

Backup

Higher order MCMC

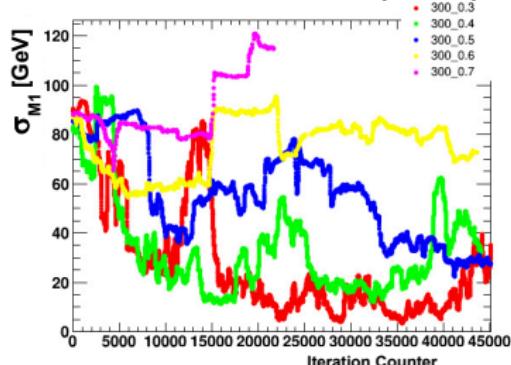
- ★ Higher Order Markov Chain Monte Carlo
 - ★ run standard MCMC until it contains n accepted points
 - ★ then use parameter covariance matrix to propose new points
 - ★ downscale proposal widths with a common factor

- ★ adjust memory size and scaling factor to achieve
 - ★ somewhat stable behaviour of Markov Chain
 - ★ reasonable acceptance rate
 - ★ good coverage of the full parameter space
 - ★ high sampling density in the preferred region

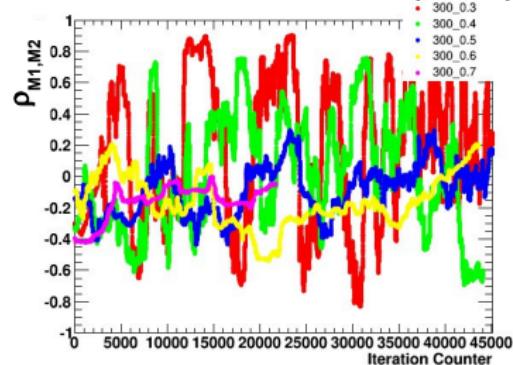
prefit indicates a memory size of 200-300 and a scaling factor of 0.3-0.5 are preferable

consider only correlation factors between -0.9 and 0.9

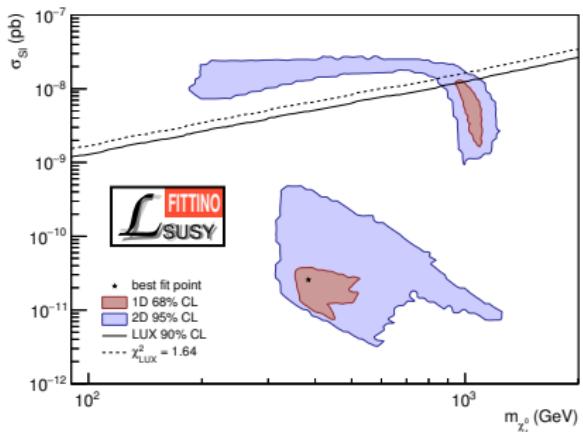
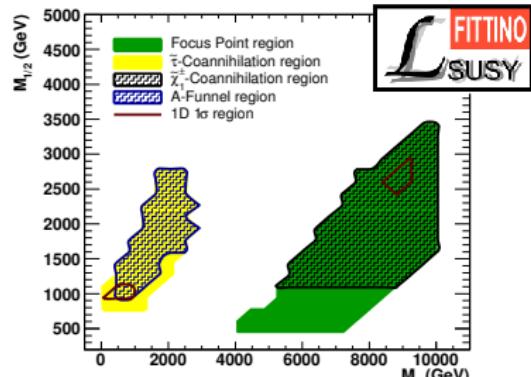
standard dev. of last n accepted points



correlation of last n accepted points



Fittino cMSSM results



- $\tilde{\tau}_1$ coannihilation: $m_{\tilde{\tau}_1}/m_{\tilde{\chi}_1^0} - 1 < 0.15$
- \tilde{t}_1 coannihilation: $m_{\tilde{t}_1}/m_{\tilde{\chi}_1^0} - 1 < 0.2$
- $\tilde{\chi}_1^\pm$ coannihilation: $m_{\tilde{\chi}_1^\pm}/m_{\tilde{\chi}_1^0} - 1 < 0.1$
- A/H funnel: $|m_A/2m_{\tilde{\chi}_1^0} - 1| < 0.2$
- focus point region: $|\mu/m_{\tilde{\chi}_1^0} - 1| < 0.4$

arXiv:1508.05951

Fittino inputs

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
- $\Omega_{\text{CDM}} h^2 = 0.1187 \pm 0.0017 \pm 0.0119_{\text{theo}}$ (Planck '13)
- Direct detection limit from LUX

From Björn Sarrazin: [ICHEP, SUSY14](#); [arXiv:1508.05951](#)

Updated measurements

Low energy observables

$\text{BR}(B_s \rightarrow \mu^+ \mu^-)$	$(2.90 \pm 0.70 \pm 0.76_{\text{theo}}) \times 10^{-9}$	CMS + LHCb '13
$\text{BR}(B^\pm \rightarrow \tau^\pm \nu)$	$(1.14 \pm 0.22 \pm 0.07_{\text{theo}}) \times 10^{-4}$	PDG '13
$\text{BR}(b \rightarrow s \gamma \gamma)$	$(3.43 \pm 0.21 \pm 0.07 \pm 0.48_{\text{theo}}) \times 10^{-4}$	HFAG
Δm_s	$(17.719 \pm 0.036 \pm 0.023 \pm 4.200_{\text{theo}}) \text{ ps}^{-1}$	PDG '13
$a_\mu - a_\mu^{\text{SM}}$	$(28.7 \pm 8.0 \pm 2.0_{\text{theo}}) \times 10^{-10}$	Muon g-2, Davier et al
m_t	$(173.34 \pm 0.27 \pm 0.71) \text{ GeV}$	world average '14
m_w	$(80.385 \pm 0.015 \pm 0.010_{\text{theo}}) \text{ GeV}$	CDF + D0 '12
$\sin^2 \theta_{\text{eff}}$	$0.2311 \pm 0.00021 \pm 0.00012 t_{\text{theo}}$	LEP + SLD '06

From Björn Sarrazin: ICHEP, SUSY14; [Bechtle et al. arXiv:1508.05951]

Fittino inputs

Table 1 Precision observables used in the fit.

$a_\mu - a_\mu^{\text{SM}}$	$(28.7 \pm 8.0) \times 10^{-10}$	[82, 83]
$\sin^2 \theta_{\text{eff}}$	0.23113 ± 0.00021	[84]
m_t	$(173.34 \pm 0.27 \pm 0.71) \text{ GeV}$	[85]
m_W	$(80.385 \pm 0.015) \text{ GeV}$	[86]
Δm_s	$(17.719 \pm 0.036 \pm 0.023) \text{ ps}^{-1}$	[87]
$\mathcal{B}(B_s \rightarrow \mu\mu)$	$(2.90 \pm 0.70) \times 10^{-9}$	[88]
$\mathcal{B}(b \rightarrow s\gamma)$	$(3.43 \pm 0.21 \pm 0.07) \times 10^{-4}$	[89]
$\mathcal{B}(B \rightarrow \tau\nu)$	$(1.05 \pm 0.25) \times 10^{-4}$	[87]

Table 2 Standard Model parameters that have been fixed. Please note that m_b and m_c are $\overline{\text{MS}}$ masses at their respective mass scale, while for all other particles on-shell masses are used.

$1/\alpha_{\text{em}}$	128.952	[83]
G_F	$(1.1663787 \times 10^{-5}) \text{ GeV}^{-2}$	[87]
α_s	0.1184	[87]
m_Z	91.1876 GeV	[87]
m_b	4.18 GeV	[87]
m_τ	1.77682 GeV	[87]
m_c	1.275 GeV	[87]

Table 6 Theoretical uncertainties of the precision observables used in the fit.

$a_\mu - a_\mu^{\text{SM}}$	7%
$\sin^2 \theta_{\text{eff}}$	0.05%
m_t	1 GeV
m_W	0.01%
Δm_s	24%
$\mathcal{B}(B_s \rightarrow \mu\mu)$	26%
$\mathcal{B}(b \rightarrow s\gamma)$	14%
$\mathcal{B}(B \rightarrow \tau\nu)$	20%

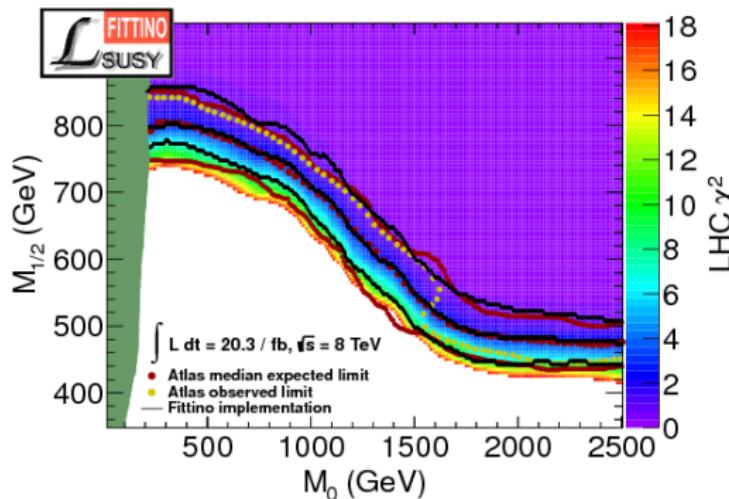
arXiv:1508.05951

χ^2 contributions

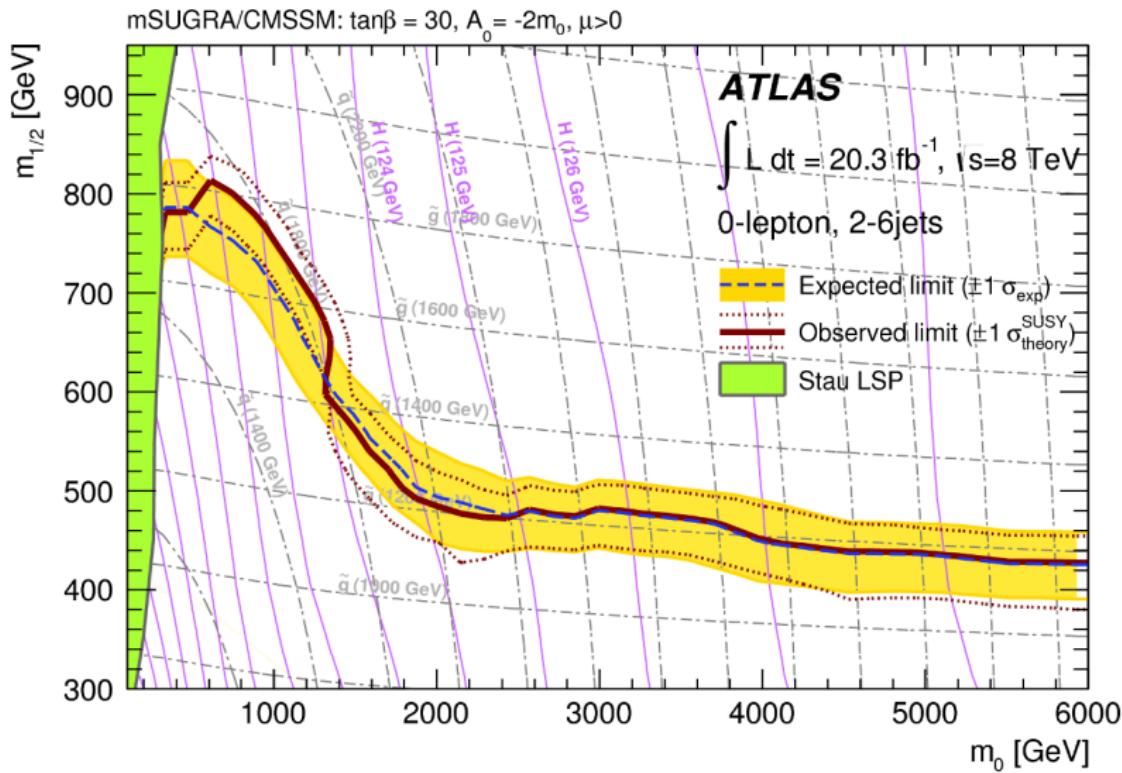
At each parameter point \vec{P} calculate:

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

- An example for a limit: The ATLAS 0-lepton generic SUSY search



ATLAS-SUSY-2013-02 cMSSM exclusion



First true p-value for cMSSM

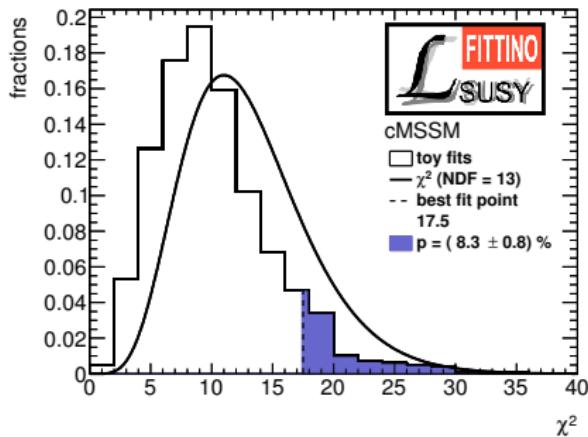
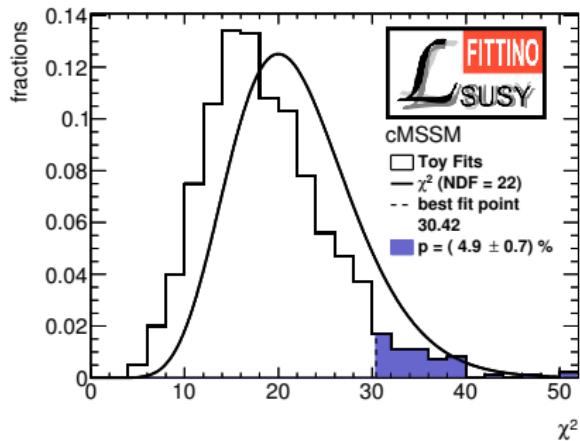


Table 3 Higgs boson mass and rate observables of *Set 2* (Medium Observable Set).

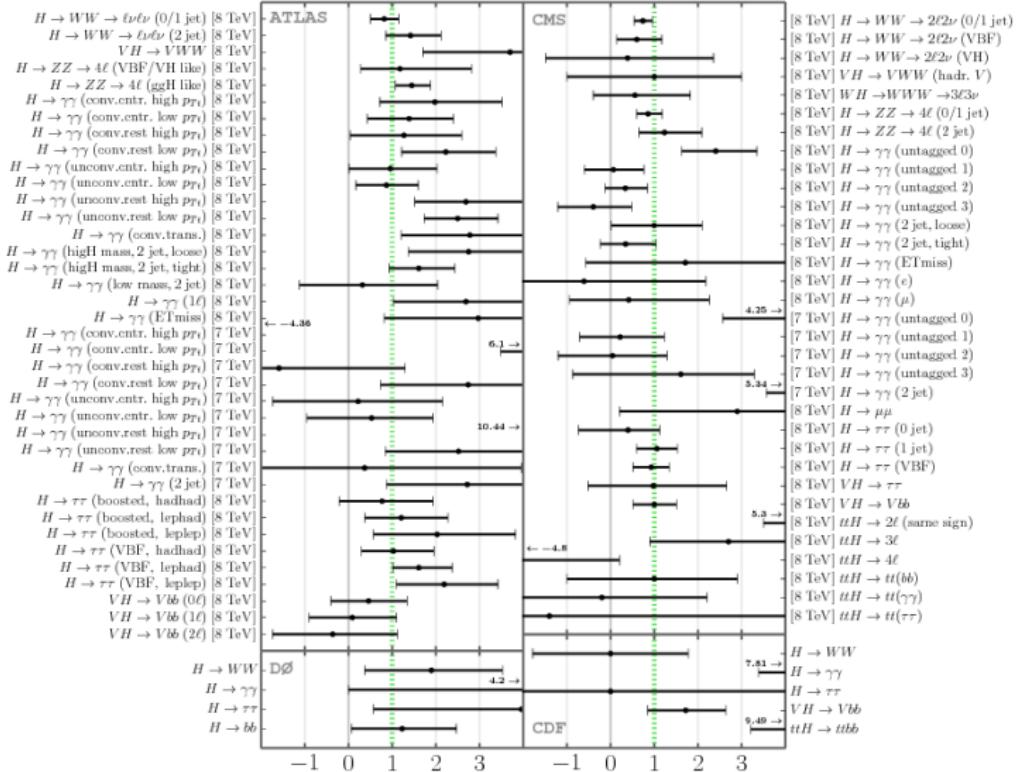
Experiment, Channel	observed μ	observed m_h
ATLAS, $h \rightarrow WW \rightarrow \ell\nu\ell\nu$ [100]	$0.99^{+0.31}_{-0.28}$	-
ATLAS, $h \rightarrow ZZ \rightarrow 4\ell$ [100]	$1.43^{+0.40}_{-0.35}$	$(124.3 \pm 1.1)\text{ GeV}$
ATLAS, $h \rightarrow \gamma\gamma$ [100]	$1.55^{+0.33}_{-0.28}$	$(126.8 \pm 0.9)\text{ GeV}$
ATLAS, $h \rightarrow \tau\tau$ [103]	$1.44^{+0.51}_{-0.43}$	-
ATLAS, $Vh \rightarrow V(bb)$ [104]	$0.17^{+0.67}_{-0.63}$	-
CMS, $h \rightarrow WW \rightarrow \ell\nu\ell\nu$ [105]	$0.72^{+0.20}_{-0.18}$	-
CMS, $h \rightarrow ZZ \rightarrow 4\ell$ [101]	$0.93^{+0.29}_{-0.25}$	$(125.6 \pm 0.6)\text{ GeV}$
CMS, $h \rightarrow \gamma\gamma$ [102]	$0.77^{+0.30}_{-0.27}$	$(125.4 \pm 1.1)\text{ GeV}$
CMS, $h \rightarrow \tau\tau$ [106]	$0.78^{+0.27}_{-0.27}$	-
CMS, $Vh \rightarrow V(bb)$ [106]	$1.00^{+0.50}_{-0.50}$	-

Table 5 Higgs boson mass and rate observables of *Set 4* (Combined Observable Set).

Experiment, Channel	observed μ	observed m_h
ATLAS+CMS, $h \rightarrow WW, ZZ$	$0.94^{+0.17}_{-0.16}$	$(125.7 \pm 0.45)\text{ GeV}$
ATLAS+CMS, $h \rightarrow \gamma\gamma$	$1.16^{+0.22}_{-0.20}$	-
ATLAS+CMS, $h \rightarrow \tau\tau$	$1.11^{+0.24}_{-0.23}$	-
ATLAS+CMS, $Vh, tth \rightarrow bb$	$0.69^{+0.37}_{-0.37}$	-

arXiv:1508.05951

Large Higgs observable set



Higgs Observables Set

- ★ CMSSM can't distinguish between all measurements
- ★ use 3 additional combinations

Experiment, Channel	observed μ	observed m_h
ATLAS, $h \rightarrow WW \rightarrow \ell\nu\ell\nu$ [80]	$0.99^{+0.31}_{-0.28}$	-
ATLAS, $h \rightarrow ZZ \rightarrow 4\ell$ [80]	$1.43^{+0.40}_{-0.35}$	$(124.3 \pm 1.1) \text{ GeV}$
ATLAS, $h \rightarrow \gamma\gamma$ [80]	$1.55^{+0.33}_{-0.28}$	$(126.8 \pm 0.9) \text{ GeV}$
ATLAS, $h \rightarrow \tau\tau$ [81]	$1.44^{+0.51}_{-0.43}$	-
ATLAS, $Vh \rightarrow V(bb)$ [82]	$0.17^{+0.67}_{-0.63}$	-
CMS, $h \rightarrow WW \rightarrow \ell\nu\ell\nu$ [83]	$0.72^{+0.20}_{-0.18}$	-
CMS, $h \rightarrow ZZ \rightarrow 4\ell$ [84]	$0.93^{+0.29}_{-0.25}$	$(125.6 \pm 0.6) \text{ GeV}$
CMS, $h \rightarrow \gamma\gamma$ [85]	$0.77^{+0.30}_{-0.27}$	$(125.4 \pm 1.1) \text{ GeV}$
CMS, $h \rightarrow \tau\tau$ [86]	$0.78^{+0.27}_{-0.27}$	-
CMS, $Vh \rightarrow V(bb)$ [86]	$1.00^{+0.50}_{-0.50}$	-

Medium Obs Set

→ Baseline

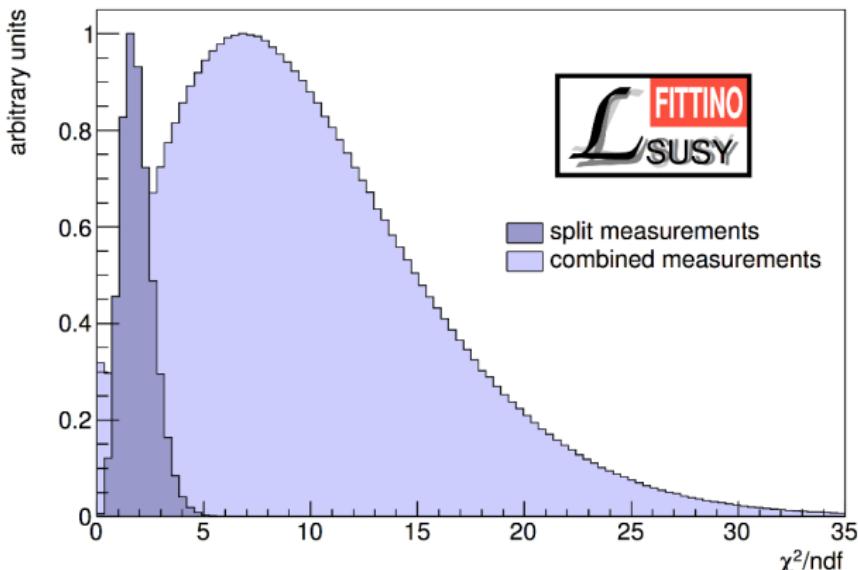
Experiment, Channel	observed μ	observed m_h
ATLAS, $h \rightarrow WW, ZZ, \gamma\gamma$ [80]	$1.33^{+0.21}_{-0.18}$	$(125.5 \pm 0.8) \text{ GeV}$
ATLAS, $h \rightarrow \tau\tau$ [81]	$1.44^{+0.51}_{-0.43}$	-
ATLAS, $Vh \rightarrow V(bb)$ [82]	$0.17^{+0.67}_{-0.63}$	-
CMS, $h \rightarrow WW, ZZ, \gamma\gamma^\dagger$	$0.80^{+0.16}_{-0.15}$	$(125.7 \pm 0.6) \text{ GeV}$
CMS, $h \rightarrow \tau\tau$ [86]	$0.78^{+0.27}_{-0.27}$	-
CMS, $Vh \rightarrow V(bb)$ [86]	$1.00^{+0.50}_{-0.50}$	-

Small Obs Set

Experiment, Channel	observed μ	observed m_h
ATLAS+CMS, $h \rightarrow WW, ZZ$	$0.94^{+0.17}_{-0.16}$	$(125.73 \pm 0.45) \text{ GeV}$
ATLAS+CMS, $h \rightarrow \gamma\gamma$	$1.16^{+0.22}_{-0.20}$	-
ATLAS+CMS, $h \rightarrow \tau\tau$	$1.11^{+0.24}_{-0.23}$	-
ATLAS+CMS, $Vh, trh \rightarrow bb$	$0.69^{+0.37}_{-0.37}$	-

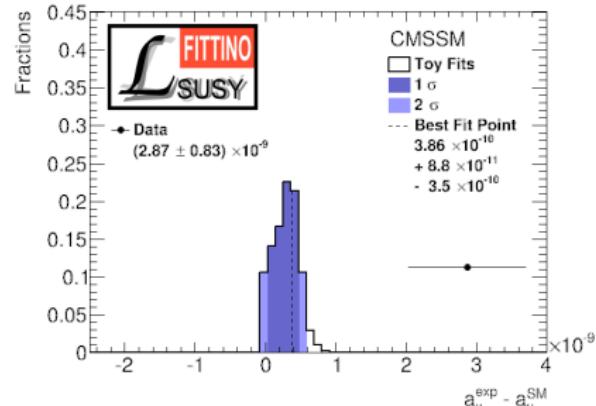
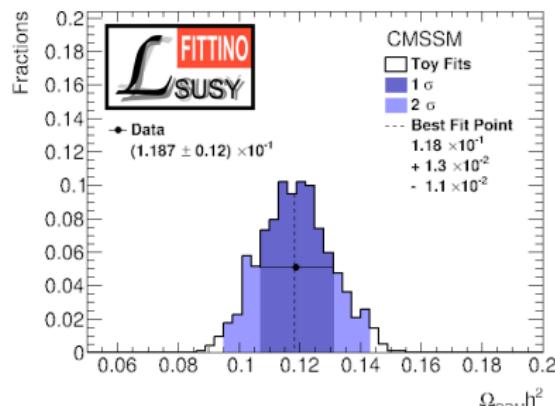
Combined Obs Set

Effect of the Combination on the \mathcal{P} -value



$n = 1, \quad N = 10, \quad 3\sigma \text{ devition}$

The Culprit

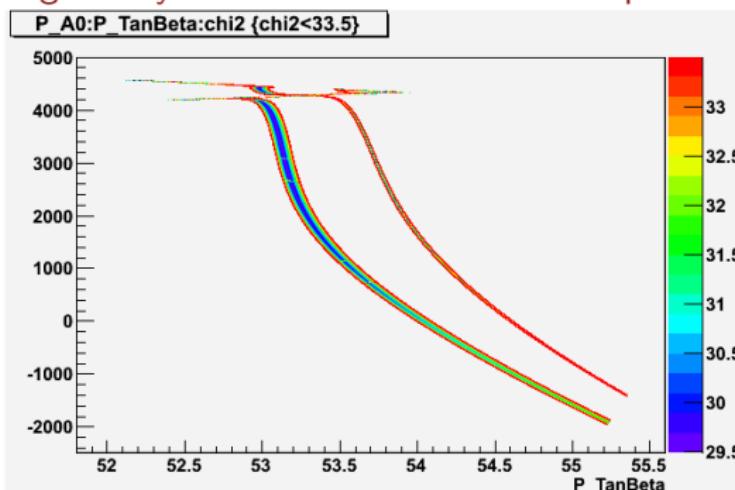


- Most observables are fitted fine in the CMSSM, but not $(g - 2)_\mu$

Why are global fits of SUSY so CPU-consuming?

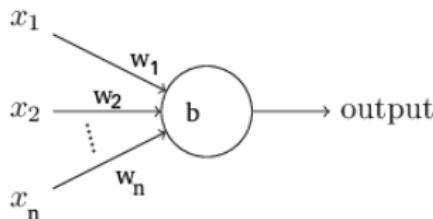
- ... and impossible with **naively** employing Minuit?
- This is an old result – just for education!

Looking at any correlations for fixed other parameters:



Looks Terrible

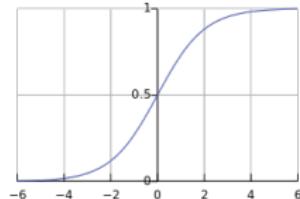
A neuron



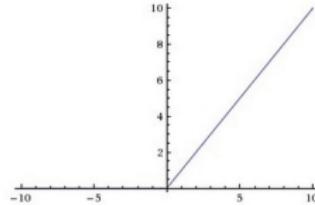
- Input to the Neuron: $\sum_{i=1}^n w_i x_i + b = z$,
- $\mathbf{w} \cdot \mathbf{x} = \sum_{i=1}^n w_i x_i$
- $w_i \in \mathbb{R}, i = 1, \dots, n, b \in \mathbb{R}$

- Output of the Neuron: $a(z)$ **Activation function**
- No general rule of choosing this function. Possibilities are:

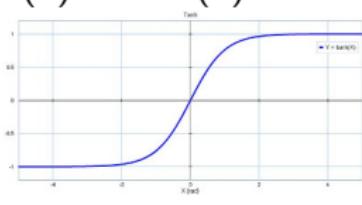
$$a = \sigma(z) := \frac{1}{1+e^{-z}}$$



$$a(z) = \max(0, z)$$

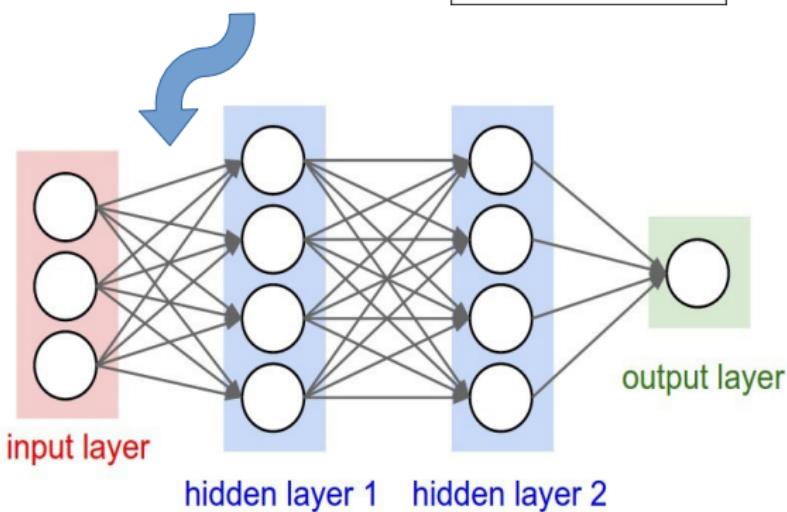
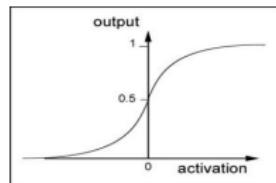


$$a(z) = \tanh(z)$$

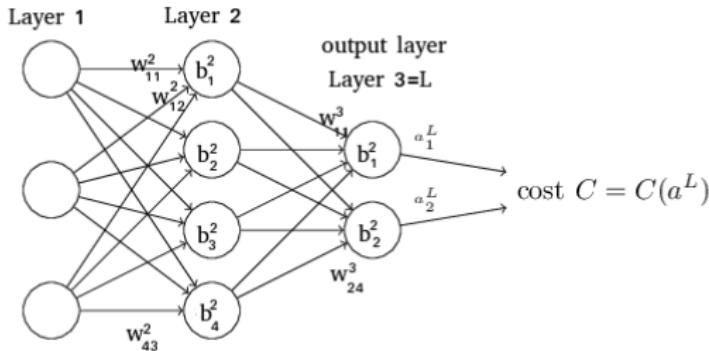


The neural network

$$\sum_i v_i \phi(\omega_i^T \cdot x + b_i)$$



The neural network



Determine network parameters by minimizing the cost function

- **Quadratic cost function** of training data:

$$C_T = \frac{1}{2N_T} \sum_{\text{training data}} ||\mathbf{a}^L(\mathbf{x}) - \mathbf{y}||^2,$$

- **Cross entropy cost function** on training data:

$$C_T = -\frac{1}{N_T} \sum_{\text{training data}} \sum_{j=1}^{n_L} y_j \ln(a_j^L) + (1 - y_j) \ln(1 - a_j^L)$$

- And many more...