

Three Reasons to Still Study Supersymmetry

Tilman Plehn

Universität Heidelberg

CERN, October 2017

Where we stand

Status

Future

Parameters

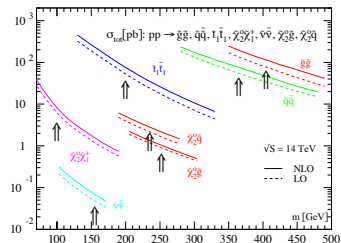
WIMP model

Precision

Experimental status

- squarks and gluinos at best heavy
- stops not much lighter
- no unexplained missing energy
- $(g - 2)_\mu$ begin checked [only relevant anomaly]

⇒ 'Why, you are telling me it's not dead?'



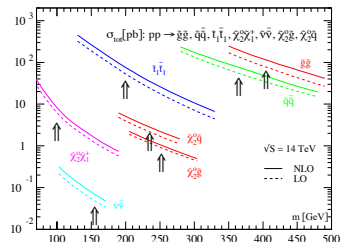
Where we stand

Experimental status

- squarks and gluinos at best heavy
 - stops not much lighter
 - no unexplained missing energy
 - $(g - 2)_\mu$ begin checked [only relevant anomaly]
- ⇒ 'Why, you are telling me it's not dead?'

Theoretical status

- light Higgs, no sign of compositeness
hierarchy problem ... all but solved ...
- stop mass not slight
little hierarchy problem ... whatever ...



Where we stand

Experimental status

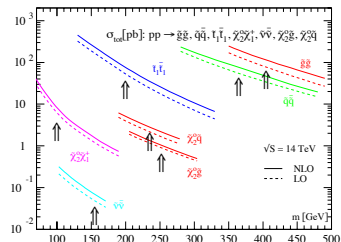
- squarks and gluinos at best heavy
 - stops not much lighter
 - no unexplained missing energy
 - $(g - 2)_\mu$ begin checked [only relevant anomaly]
- ⇒ 'Why, you are telling me it's not dead?'

Theoretical status

- light Higgs, no sign of compositeness
hierarchy problem ... all but solved ...
- stop mass not slight
little hierarchy problem ... whatever ...

Bottom line

- LHC model building practically dead
- dark matter still attractive
- new, data driven approaches to BSM physics?



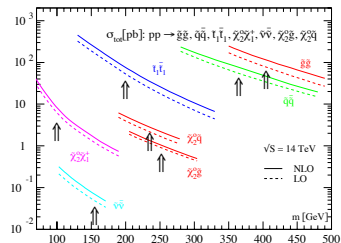
Experimental status

- squarks and gluinos at best heavy
 - stops not much lighter
 - no unexplained missing energy
 - $(g - 2)_\mu$ begin checked [only relevant anomaly]
- ⇒ 'Why, you are telling me it's not dead?'

- light Higgs, no sign of compositeness
hierarchy problem ... all but solved ...
- stop mass not slight
little hierarchy problem ... whatever ...

- LHC model building practically dead
- dark matter still attractive
- new, data driven approaches to BSM physics?

⇒ At least I am not interested in SM precision measurements!



Driven by LHC achievements

Physics

- perturbative QFT appropriate framework
- Higgs physics now window to BSM physics
- case for (WIMP) dark matter not weakened [watch out for DD]
- resonance searches mostly good for flukes [local vs global CL]

Simulation

- jets and QCD no longer scare us
- precision predictions automatized
- detector simulation etc standard
- simple signal-background studies no longer worth a paper

Analysis

- communication with experimentalists working
 - jets being deconstructed for 10 years
 - everything multi-variate, big data everywhere
- ⇒ LHC being turned into a flexible precision machine ...

Driven by LHC achievements

Physics

- perturbative QFT appropriate framework
- Higgs physics now window to BSM physics
- case for (WIMP) dark matter not weakened [watch out for DD]
- resonance searches mostly good for flukes [local vs global CL]

Simulation

- jets and QCD no longer scare us
- precision predictions automatized
- detector simulation etc standard
- simple signal-background studies no longer worth a paper

Analysis

- communication with experimentalists working
 - jets being deconstructed for 10 years
 - everything multi-variate, big data everywhere
- ⇒ LHC being turned into a flexible precision machine ...
... and we have no idea what to do with it?

Future plans

Personal, depressed take on the future of particle physics

- HL-LHC the path to eternal boredom [all systematics and theory limited]
- ILC/FCCee really intensity frontier [measure bunch of Higgs couplings for 20 years?]
- 3 TeV CLIC not even conclusive on WIMPS [what's the case??]

⇒ but FCChh report was great fun!

Future plans

Personal, depressed take on the future of particle physics

- HL-LHC the path to eternal boredom [all systematics and theory limited]
- ILC/FCCee really intensity frontier [measure bunch of Higgs couplings for 20 years?]
- 3 TeV CLIC not even conclusive on WIMPS [what's the case??]

⇒ but FCChh report was great fun!

SUSY-related topics at 100 TeV

- supersymmetry:
squarks, gluinos
electroweakinos
long-lived particles
- dark matter:
WIMP with SM mediators
WIMP with BSM mediators
non-minimal models and co-annihilation
super-WIMPS and gravitinos
- Higgs pairs, naturalness,...

⇒ in absence of better ideas: which of those need 100 TeV?

CERN-TH-2016-111

Physics at a 100 TeV *pp* collider: beyond the Standard Model phenomena

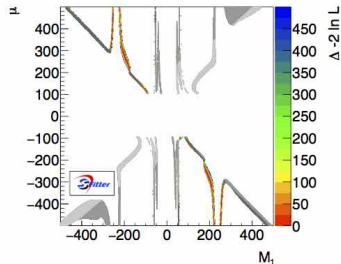
Editors:
T. Golling¹, M. Hance², P. Harris³, M.L. Mangano⁴, M. McCullough⁴, F. Moortgat³, P. Schwallier⁵, R. Torre⁶.

Contributors:
P. Agrawal¹, D.S.M. Alves^{6,9}, S. Antusch^{10,11}, A. Arbey^{4,12}, B. Auerbach¹³, G. Bambhaniya¹⁴, M. Battaglia¹⁵, M. Bauer¹⁵, P.S. Bhupal Dev^{16,17}, A. Boveia³, J. Bramante¹⁸, O. Buchmueller¹⁹, M. Buschmann²⁰, J. Chakraborty²¹, M. Chala¹, S. Chekanov¹³, C.-Y. Chen^{22,23}, H.-C. Cheng²⁴, M. Cirelli²⁵, M. Citron¹⁹, T. Cohen²⁶, N. Craig²⁷, D. Curtin²⁸, R.T.D'Agnolo²⁹, C. Doglioni³⁰, J.A. Dror³¹, T. du Pree¹, D. Dylevsky³², J. Ellis^{33,4}, S.A.R. Ellis³⁴, R. Essig³⁵, J.J. Fan³⁶, M. Farina³⁷, J.L. Feng³⁸, F.J. Fox³⁹, J. Galloway⁴⁰, G. Giudice⁴¹, J. Gluza⁴², S. Gori^{23,41}, S. Gaha⁴³, K. Hahn⁴⁴, T. Han^{45,46}, C. Helsens², A. Henriques², S. Ivanoa⁴⁷, T. Jelinski⁴⁸, S. Jung^{49,50}, F. Kahlhoefer⁵¹, V.V. Khoze⁵², D. Kim⁵³, J. Kopp⁵⁴, A. Kotwal⁵⁵, M. Krämer⁵⁶, J.M. Lindert⁵⁷, J. Liu⁵⁸, H.K. Lou⁵, J. Love¹³, M. Low⁵⁹, P.A.N. Machado⁵⁴, F. Mahmoudi^{4,12}, J. Marrouche¹⁹, A. Martin¹⁸, K. Mohan¹⁵, R.N. Mohapatra²⁸, G. Nardin⁶⁰, K.A. Olive²⁷, B. Ostdiek²⁶, G. Panico⁵⁸, T. Plehn¹⁵, J. Proudfoot¹³, Z. Qian⁶¹, M. Reece¹, T. Rizzo⁵⁷, C. Roska⁶², J. Ruderman³, R. Ruiz⁶³, F. Sala²³, E. Salvioni²⁴, P. Sarasua^{29,61}, T. Schell¹⁵, K. Schmidt-Hoberg¹, J. Serra⁴, Y. Shadmi⁶⁴, J. Shelton⁶¹, C. Solans¹, M. Spannowsky⁴⁸, T. Srivastava²¹, D. Stolarski⁶⁵, R. Szafron⁶¹, M. Taoso⁶⁴, S. Tarem⁶⁶, A. Thalaitiri⁶⁷, A. Thanu⁶⁸, Y. Tsai⁶⁹, C. Verhaaren⁶⁴, N. Vignaroli^{65,63}, J.R. Walsh^{63,69}, L.T. Wang^{67,68}, C. Weiland⁴⁸, J. Wells³⁴, C. Williams²⁹, A. Walzer³, W. Xue⁷⁰, F. Yu²⁰, B. Zheng³⁴, J. Zheng⁶³

1– Parameter-space-related patterns

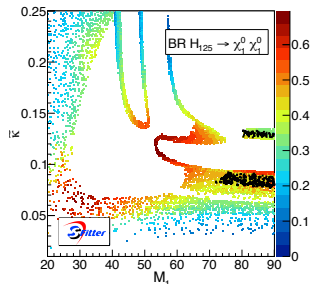
Inspiration from parameter studies (sic!)

- observables $m_h, \Omega_\chi h^2$
add Hooperon for fun
decouple strongly interacting particles
 - analysis of parameter volumes pointless(?)
 - check DM-related MSSM patterns
 - annihilation $\tilde{\chi}\tilde{\chi} \rightarrow b\bar{b}, WW, t\bar{t}$ possible
- ⇒ are XENON1T/LZ really MSSM killers?



Link to invisible Higgs decays

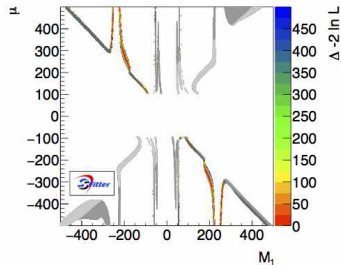
- possible in the MSSM
- linked to Hooperon in NMSSM
- probably ruled out by DD



1– Parameter-space-related patterns

Inspiration from parameter studies (sic!)

- observables $m_h, \Omega_\chi h^2$
add Hooperon for fun
decouple strongly interacting particles
 - analysis of parameter volumes pointless(?)
 - check DM-related MSSM patterns
 - annihilation $\tilde{\chi}\tilde{\chi} \rightarrow b\bar{b}, WW, t\bar{t}$ possible
- ⇒ are XENON1T/LZ really MSSM killers?



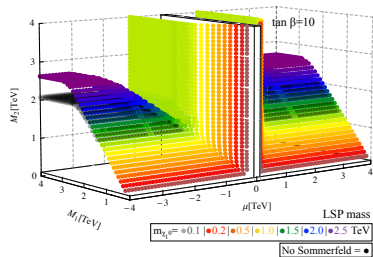
Direct/indirect BSM searches

- BSM and Higgs and flavor all mixed
 - minimal vs non-minimal SUSY realizations
 - ‘generic’ is not the question
 - ??? [insert your best idea here]
 - ??? [insert your friend’s idea here]
 - ??? [insert some mediocre ideas here]
- ⇒ extrapolation to high scales still the theme

2– Just a WIMP model

Electroweakinos only

- define DM through $SU(2)_L$ representation singlet, doublet, triplet
 - allow for general mixing
 - add co-annihilation partners, if needed
 - ignore squarks, gluinos
- ⇒ **relic neutralino surface**



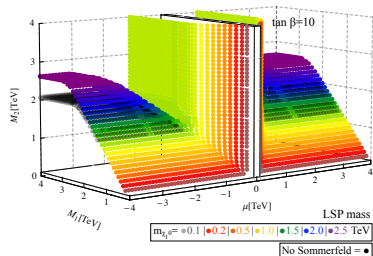
Majorana neutralino, different mediators

- SM Z -boson $\chi\chi \rightarrow Z \rightarrow \text{jets}$
 - SM-like Higgs $\chi\chi \rightarrow h \rightarrow b\bar{b}$
 - heavy Higgs $H, A \rightarrow b\bar{b}, t\bar{t}$
 - t -channel chargino $\chi\chi \rightarrow WW \rightarrow \text{jets}$
 - chargino co-annihilation $\chi^0\chi^\pm \rightarrow W$
 - stau co-annihilation $\tilde{\tau}\chi \rightarrow \tau + X$
- ⇒ giving upper limit on neutralino mass
- ⇒ better than set of simplified models?

2– Just a WIMP model

Electroweakinos only

- define DM through $SU(2)_L$ representation singlet, doublet, triplet
 - allow for general mixing
 - add co-annihilation partners, if needed
 - ignore squarks, gluinos
- ⇒ relic neutralino surface



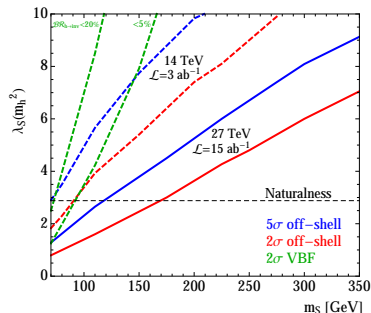
Inspiring signatures

- charged tracks
 - low-momentum photons/leptons
 - combination of very soft and very hard objects
 - ????
 - ????
- ⇒ targeting signatures and analyses

3– Benchmark for precision BSM physics

When signatures get tough

- SUSY in low rates
- SUSY in tails or rotten phase space
- SUSY in loops [fig: Goncalves, Han, Mukhopadhyay]
- ...or at least something SUSY-related



New approach to BSM Physics

- it's not going to be easy
 - it might not be tree-level
 - it might be hidden in the backgrounds
 - it might not show up in resonance searches
 - it might not show up in generic signatures
- ⇒ theory framework crucial
- ⇒ LHC physics will be hard, but once the pain goes...

What's next?

Supersymmetry serving as...

- ...not only classic and best but also only BSM model still standing
- ...an inspiration for BSM searches (1)
- ...a WIMP dark matter model (2)
- ...a benchmark for an era of precision BSM physics (3)
- ...whatever we can use it for (4-99)

Everyone under 40...

- ...this is your task!
- ...stop listen to old guys like me!
- ...stop re-writing your advisors' theses!
- ...get up-to-date on experimental techniques!
- ...embrace whatever you find, and be convincing!

Three Reasons

Tilman Plehn

Status

Future

Parameters

WIMP model

Precision