Karlsruher Institut für Technologie

An efficient scanning technique of the NMSSM parameter space

arXiv:1712.02531
arXiv:1703.01255

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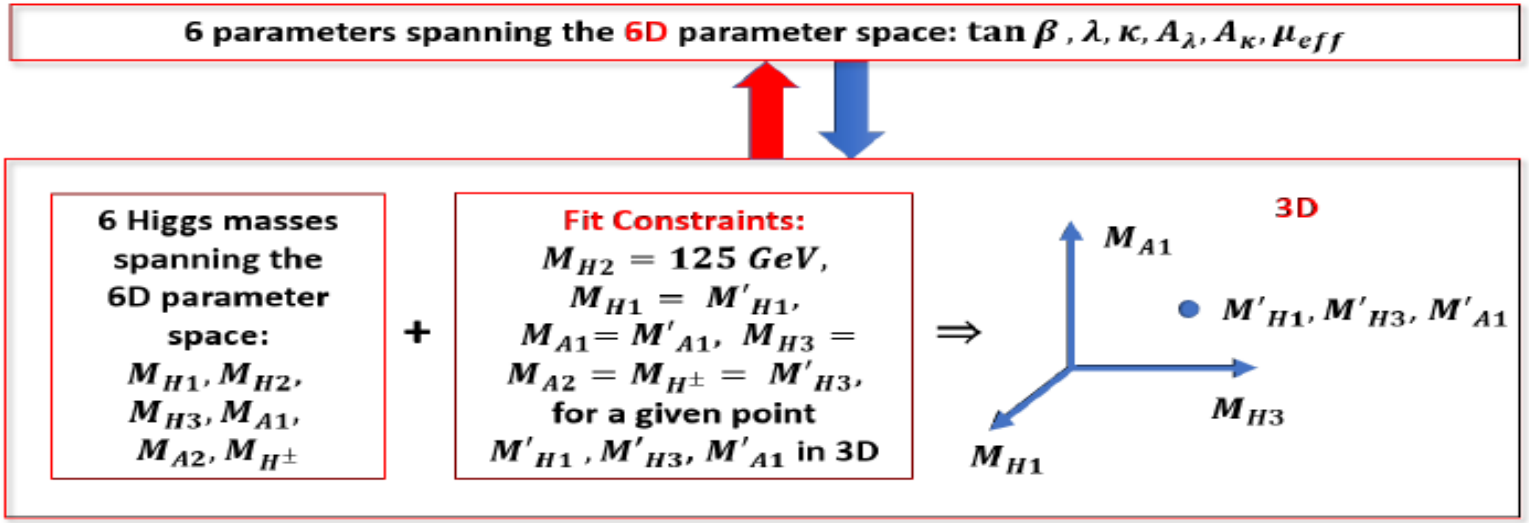


Problem with scanning NMSSM parameter space

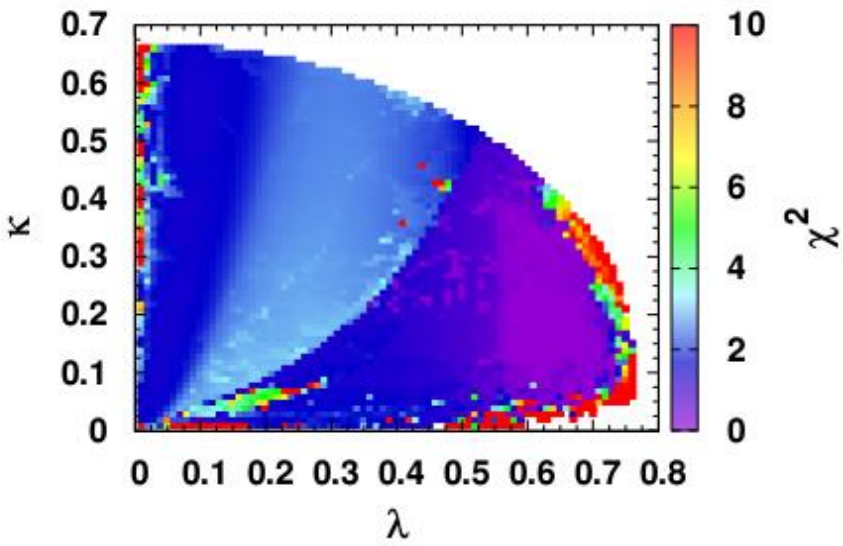
- **Bad:** large parameter space
- **Bad:** highly correlated, so random scan of parameter space very inefficient without correlation matrix, telling if parameter x moves in one direction, parameters y and z should move in a well-defined (but not random) direction.
- **Bad:** we do not know the correlation matrix
- **How to solve?**
- **Idea:** if we would have measured all the Higgs masses, would we be able to determine the couplings?
- **Result: yes**, but not necessarily a unique solution. Two preferred solutions in parameter space, called Region I and Region II.

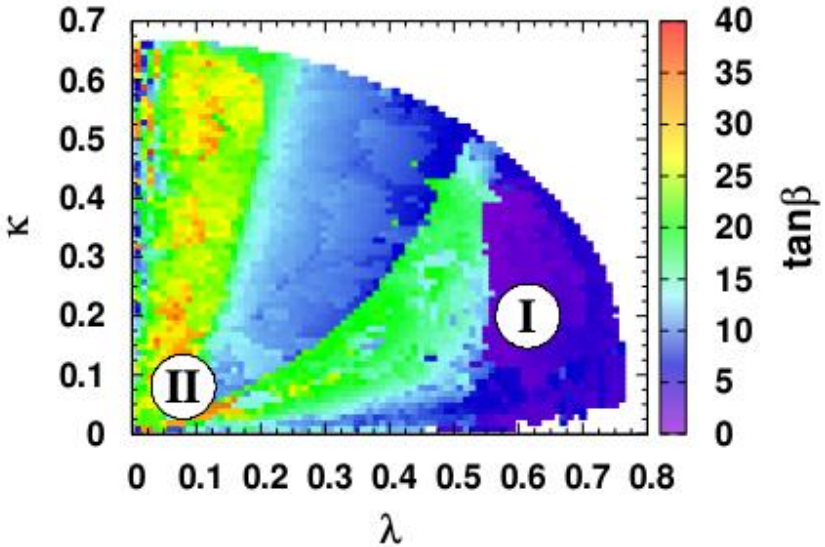
Origin of ambiguity

$$M_H^2 \approx \underbrace{M_Z^2 \cos^2 2\beta + \Delta_{\tilde{t}}}_{\text{MSSM}} + \underbrace{\lambda^2 v^2 \sin^2 2\beta - \frac{\lambda^2}{\kappa^2}(\lambda - \kappa \sin 2\beta)^2}_{\text{NMSSM}}.$$

Requiring this expression to yield the 125 GeV Higgs boson can be solved for large tanβ, as in MSSM and large stop corrections or large NMSSM corrections (last two terms), which are optimal for small tanβ.

Definition of Region I and II





Region I: large κ,λ and small tanβ (NMSSM-like)

Region II: small κ,λ and large tanβ (MSSM-like)

Region I is defined by $\lambda > 0.3$; $\tan\beta < 10$
Region II is defined by $\lambda < 0.1$; $\tan\beta < 30$

Idea: scan Higgs mass space instead of couplings

Why: **Higgs masses hardly correlated and more constraints, if we assume the decoupling limit with all heavy Higgs masses to be close to degenerate**

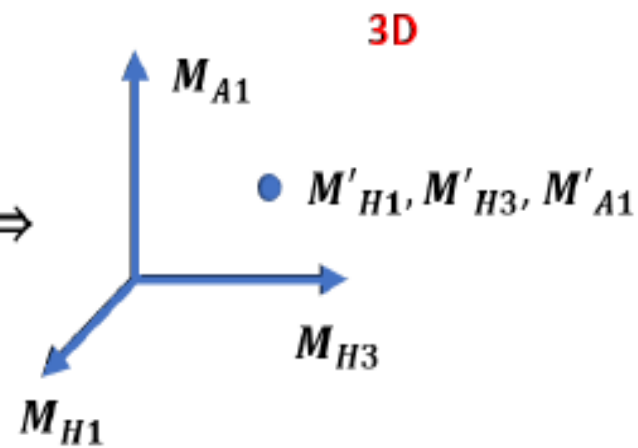
6 parameters spanning the 6D parameter space: $\tan\beta, \lambda, \kappa, A_\lambda, A_\kappa, \mu_{eff}$

6 Higgs masses spanning the 6D parameter space: $M_{H1}, M_{H2}, M_{H3}, M_{A1}, M_{A2}, M_{H^\pm}$

+

Fit Constraints:
$M_{H2} = 125\ GeV$,
$M_{H1} = M'_{H1}$,
$M_{A1} = M'_{A1}$, $M_{H3} = M_{A2} = M_{H^\pm} = M'_{H3}$,
for a given point $M'_{H1}, M'_{H3}, M'_{A1}$ in 3D

$\Rightarrow$

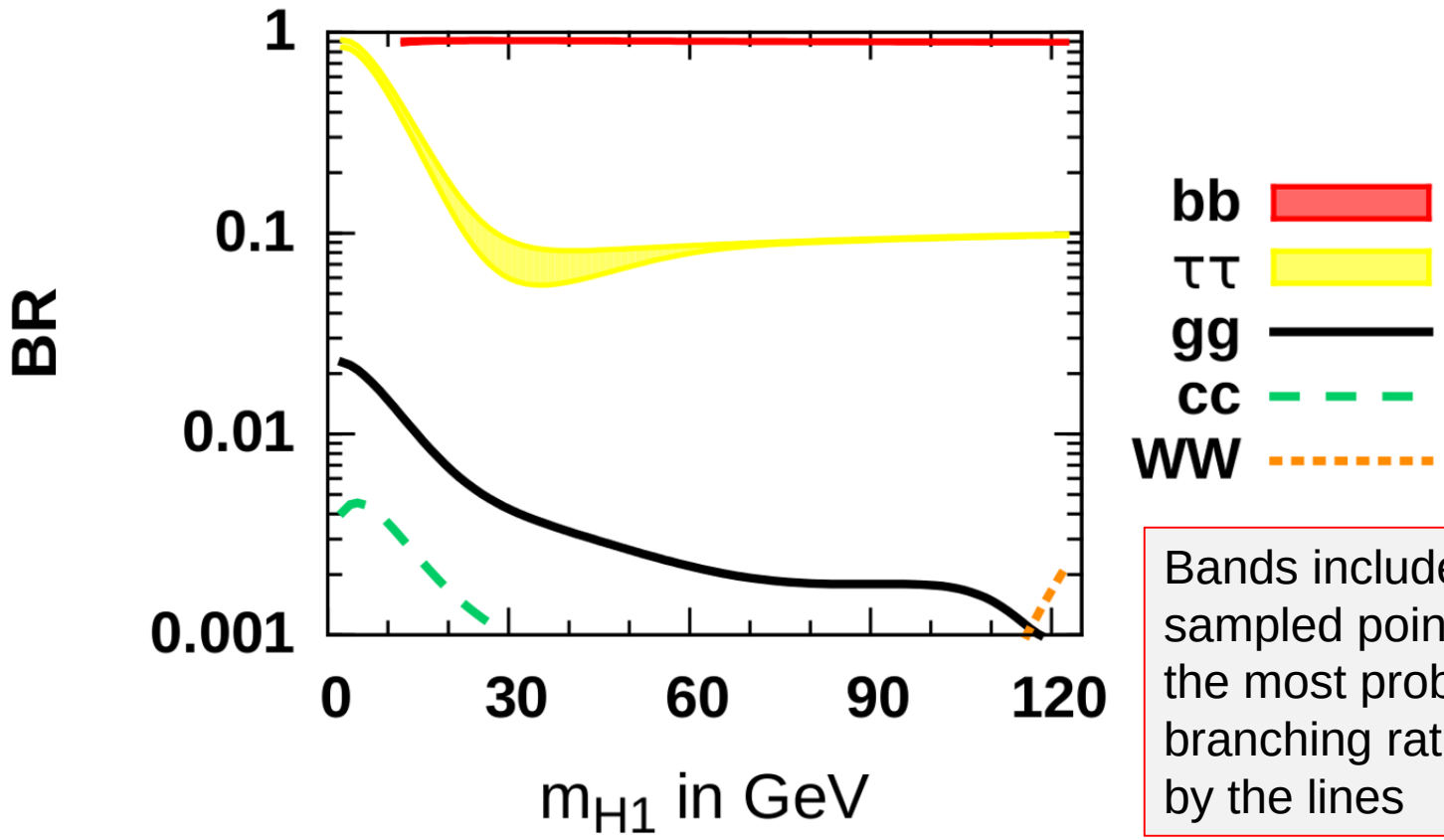


Scanning technique in practice

- Minimize chi2 function requiring all assumed Higgs and determine the corresponding couplings which are free parameters in the Minuit fit (fits separately for Region I and II)
- Use NMSSMTools to relate Higgs masses to couplings
- Use Micromegas to calculate relic density and direct scattering
- Can incorporate all other constraints from relic density, b-physics, accelerators, couplings of measured 125 GeV Higgs boson, flawlessly into chi2
- Next slides show two examples of this scanning technique from arXiv:1712.02531 and arXiv:1703.01255, respectively

BRs for light (singlet-like) Higgs boson (log scale)

Region I: NMSSM-like

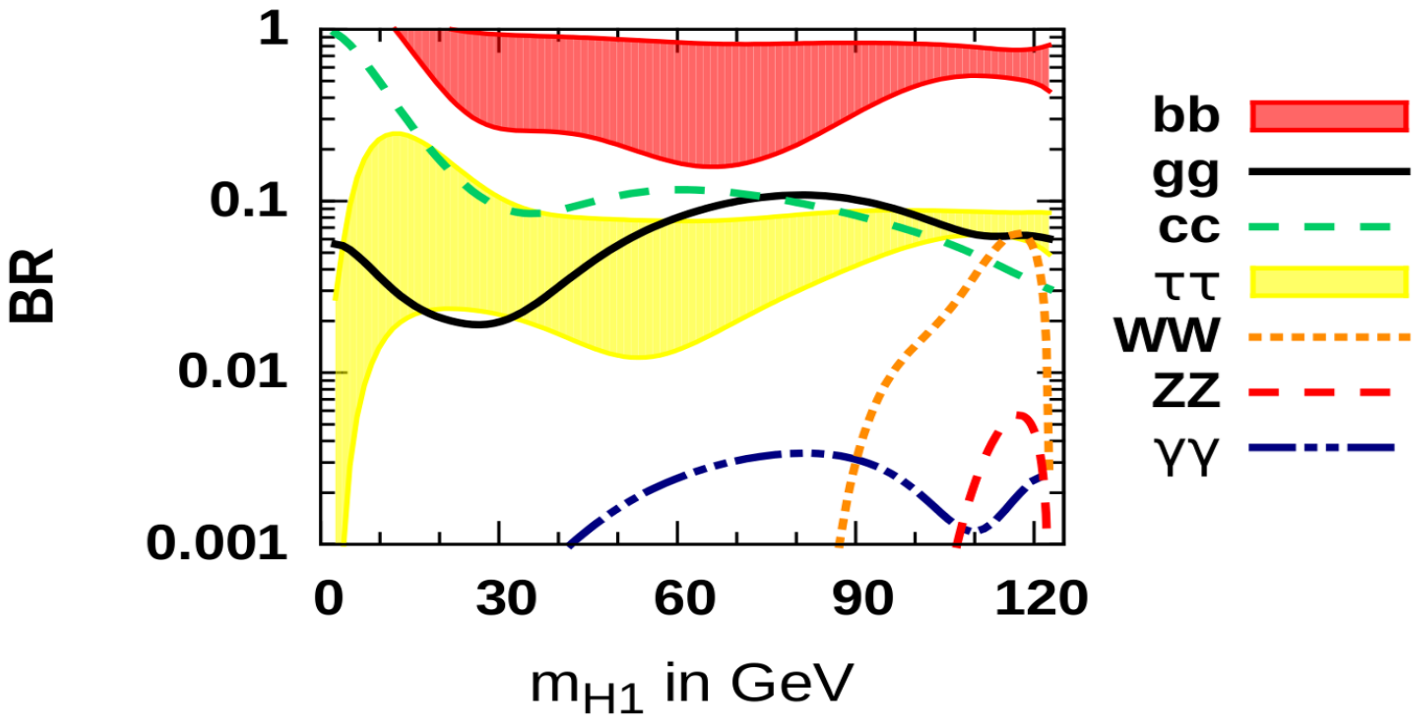


Bands include 68% of the sampled points around the most probable branching ratio indicated by the lines

Large coupling to down-type fermions → dominant decay into b quarks

BRs for light (singlet-like) Higgs boson

Region II: MSSM-like



Broad allowed range for BRs because coupling to down-type fermions changes sign and can become zero. For clarity only the 68% bands for bb and tautau are shown, but the other lines have broad bands too. If A1 and chi1 are kinematically allowed, they contribute as well. The sum adds always up to 1, as can be checked from the benchmark points in 1712.02531

Why so different BR in Region I and II?

Couplings to quarks given by Higgs mixing matrix elements (determined from fit):

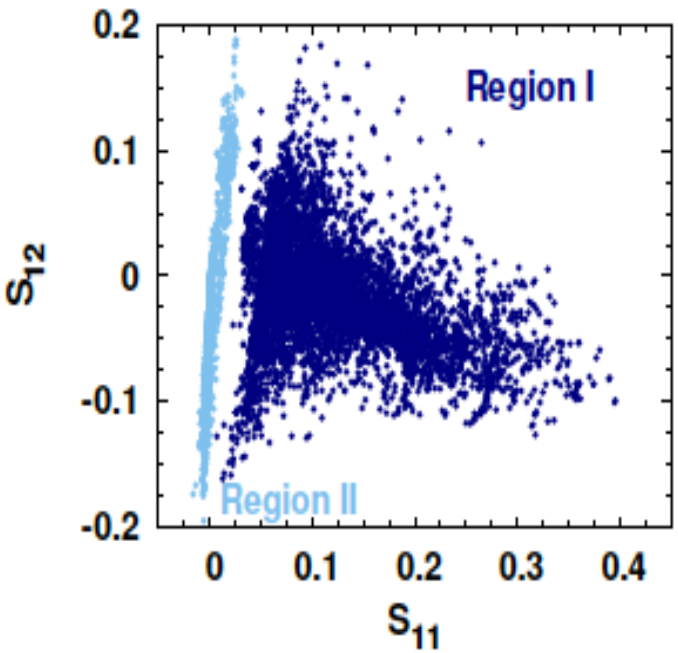
$$H_i t_L t_R^c : -\frac{h_t}{\sqrt{2}} S_{i2} \qquad h_t = \frac{m_t}{v \sin\beta},$$

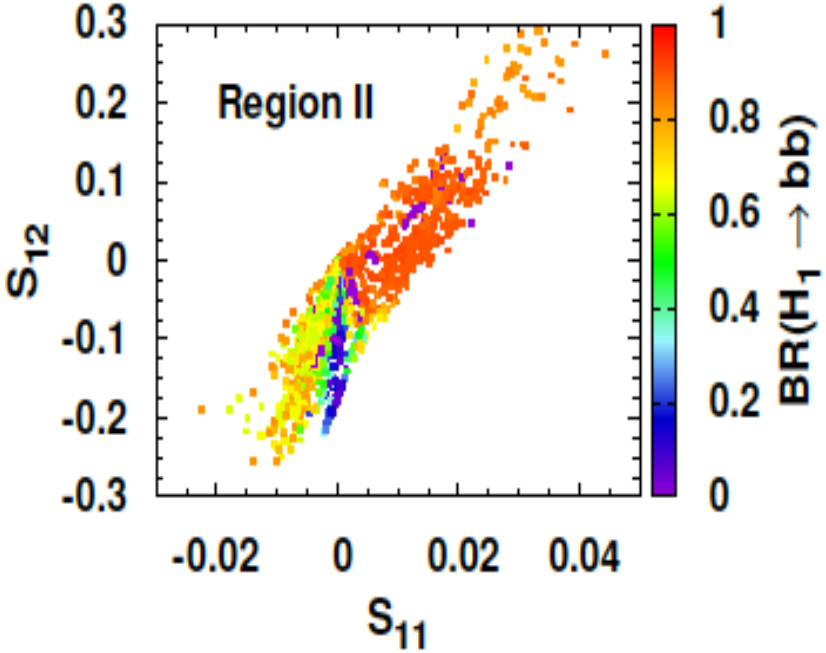
$$H_i b_L b_R^c : \frac{h_b}{\sqrt{2}} S_{i1} \qquad h_b = \frac{m_b}{v \cos\beta},$$

$$H_i \tau_L \tau_R^c : \frac{h_\tau}{\sqrt{2}} S_{i1} \qquad h_\tau = \frac{m_\tau}{v \cos\beta},$$

S11 determines coupling to b-quark

Allowed range for Higgs matrix elements

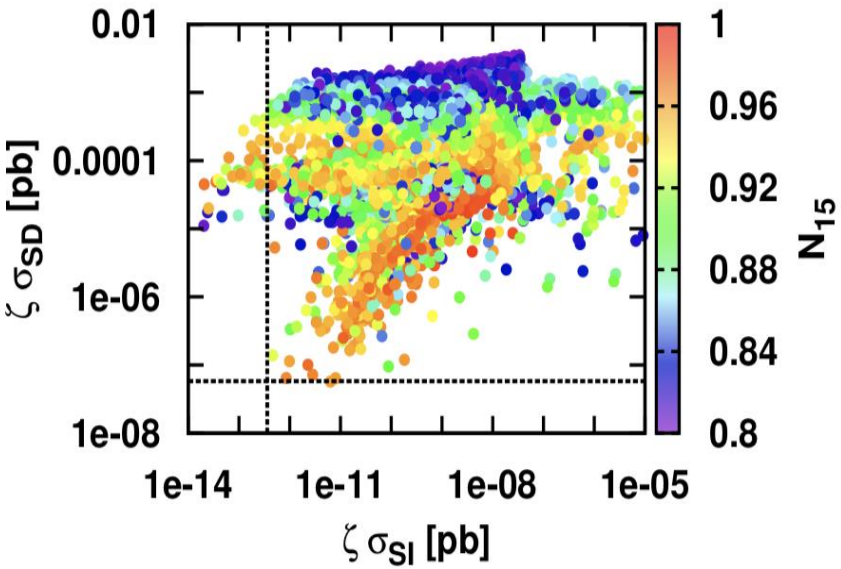




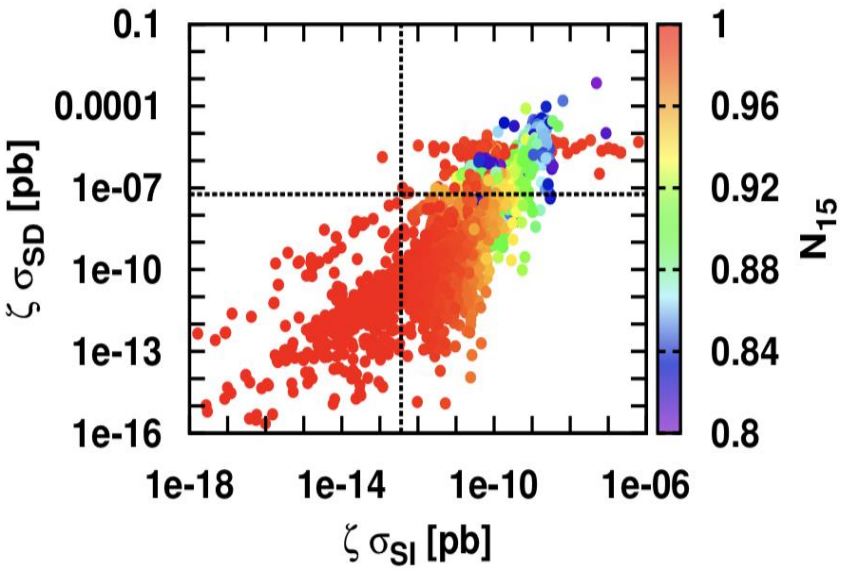
S_{11} determines the coupling to b-quarks and crosses zero in region II, so the BR to b-quarks can become zero. This is demonstrated on the right panel, which is blow-up from the left panel for S11 close to zero and has as colour coding the BR to bbar.

Direct detection in the NMSSM

Region I: NMSSM-like



Region II: MSSM-like



In 1606.02149 and 1509.00204, based on random scans, it was suggested that he whole NMSSM parameter space will be covered by the future direct DM detection experiments.

However, with our scanning technique, garanteing complete coverage, we find in Region II many points below the neutrino floor (crossed lines), which is hardly accessible with the discussed experiments

Summary

- **Scanning the 3D Higgs mass space instead of the 6D coupling parameter space allows for an efficient sampling of the complete parameter space with full coverage**

- **Two examples given:**

- **Discovery prospects at the LHC of the lightest singlet-like Higgs in the NMSSM (arXiv:1712.02531) with many benchmark points given**

- **Discovery prospects of the lightest singlino-like neutralino in direct DM searches with many points below the „neutrino floor“ in Region II (arXiv:1703.01255)**