Supersymmetry at the LHC

M. Margarete Mühlleitner
ITP (Karlsruhe)

Seminar

Freiburg
8 July 2015

$\mathcal{O}$utline

- ◇ Introduction

- ◇ SUSY Particle Production

- ◇ Light Stop Search

- ◇ NMSSM Higgs Bosons

- ◇ Conclusions

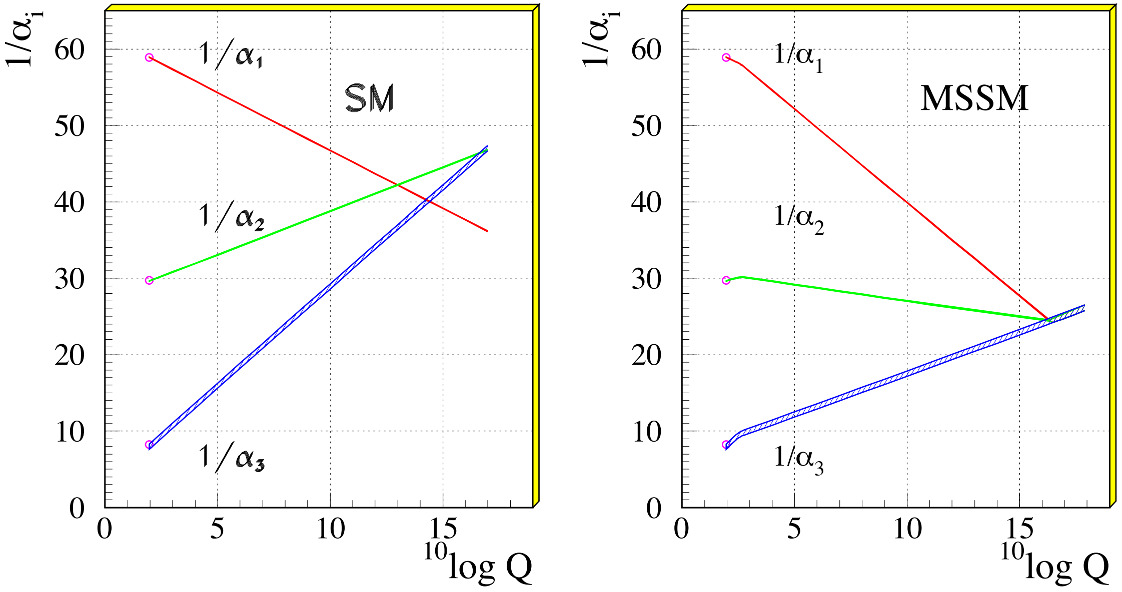
$\mathcal{I}$ntroduction

$\mathcal{W}$hy $\mathcal{B}$eyond $\mathcal{S}$tandard $\mathcal{M}$odel ($\mathcal{BSM}$) $\mathcal{P}$hysics?

Standard Model: incomplete picture of the universe

- How explain the values of the free parameters of the Standard Model (SM)?
- Common origin of all three forces of the SM?
- How to incorporte gravity?
- Candidate for Dark Matter (DM)?
- ...

Unification of the Coupling Constants
in the SM and the minimal MSSM



Why Beyond Standard Model (BSM) Physics?

Standard Model: incomplete picture of the universe

- How explain the values of the free parameters of the Standard Model (SM)?
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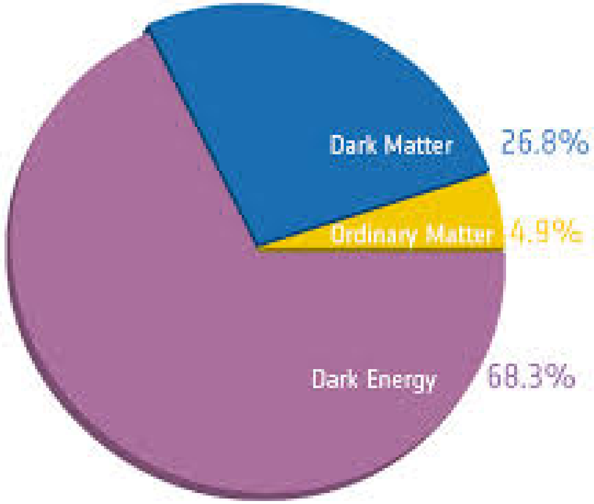
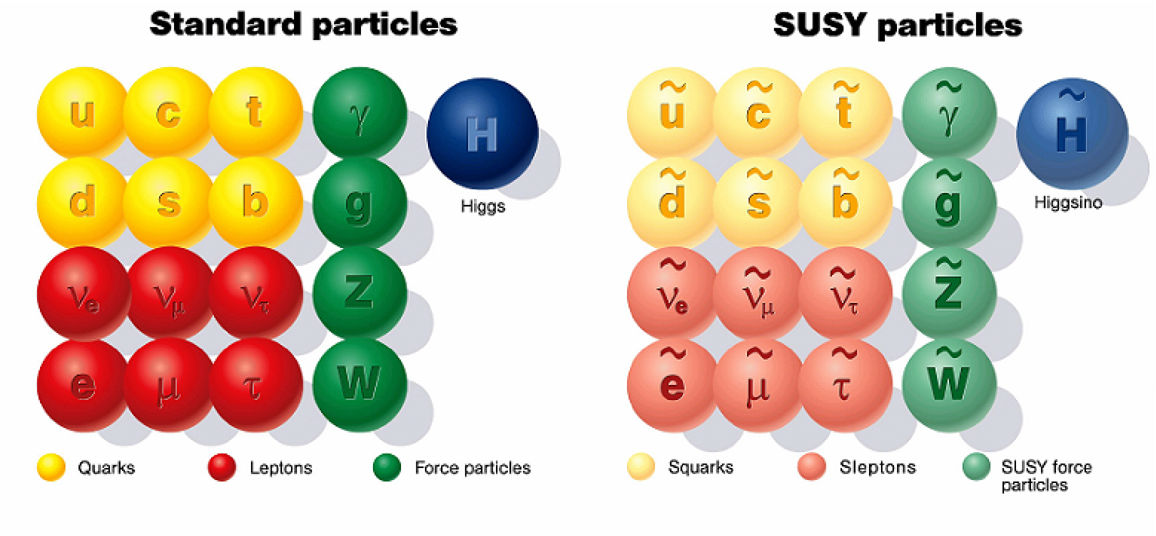


Supersymmetry

Possible answers from: Supersymmetry

Fermions ↔ Bosons

Price: doubling of the particle spectrum



$\mathcal{S}$upersymmetry - $\mathcal{M}$otivation

(i) Relates bosons ↔ fermions:

$$\left.\begin{array}{l} Q|F>=|B> \\ Q|B>=|F> \end{array}\right\} \text{1 multiplet}$$

(ii) Maximal symmetry of the $\mathcal{S}$-matrix:

Coleman-Mandula theorem:	Bosonic operators cannot extend the Poincaré algebra.
Fermionic operators:	$Q \sim$ spin $\frac{1}{2} \Rightarrow$ graded Lie-algebra

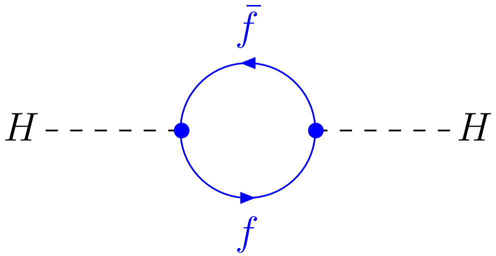
(iii) Hierarchy problem:

assume Standard Model validity:

ELW scale $v \sim 10^2$ GeV – GUT scale $M_{GUT} \sim 10^{16}$ GeV

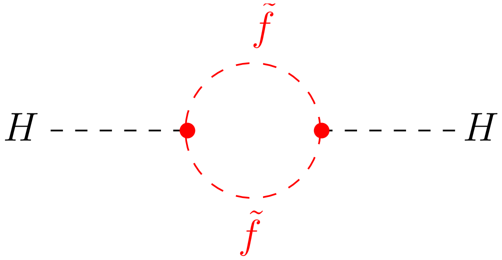
$\mathcal{R}$adiative $\mathcal{C}$orrections $\mathcal{T}$o $\mathcal{H}$iggs $\mathcal{B}$oson $\mathcal{M}$ass

- **Corrections from fermions loops**



$$\delta M^2_{H,f} = -\frac{\lambda_f^2}{8\pi^2}[\Lambda^2 - m_f^2 \ln \frac{\Lambda^2}{m_f^2}] + \ldots$$

- **Corrections from scalar fermion superpartner**



$$\delta M^2_{H,\tilde{f}} = +\frac{\lambda_{\tilde{f}}^2}{8\pi^2}[\Lambda^2 - m_{\tilde{f}}^2 \ln \frac{\Lambda^2}{m_{\tilde{f}}^2}] + \ldots$$

$\mathcal{C}$ancellation of $\mathcal{Q}$uadratic $\mathcal{D}$ivergences

- **Quadratic divergences are cancelled if**

  # d.o.f SUSY particles = # d.o.f. SM particles

  $\lambda_f = \lambda_{\tilde{f}}$

- **Corrections completely cancelled if**

  $m_f = m_{\tilde{f}}$

- **Soft SUSY breaking:** so far no SUSY particles have been discovered $\rightsquigarrow$ SUSY particles are heavier than SM particles $\rightsquigarrow$ soft SUSY breaking: $m_f \neq m_{\tilde{f}}$ and $\lambda_f = \lambda_{\tilde{f}}$

  $\Rightarrow$ Higgs mass corrections logarithmically divergent

  $\Rightarrow$ For SUSY mass scale $M_{SUSY} \lesssim \mathcal{O}(\text{TeV})$ no new finetuning

  $\Rightarrow$ TeV scale SUSY solution to hierarchy problem

$\mathcal{S}$upersymmetry - $\mathcal{M}$otivation

(iv) Higgs mechanism generated via radiative corrections (for $m_t \sim 100...200$ GeV)

(v) Unification of ELM + weak + strong couplings

(vi) Cold Dark Matter (CDM) If SUSY particles assigned conserved multiplicative quantum number,

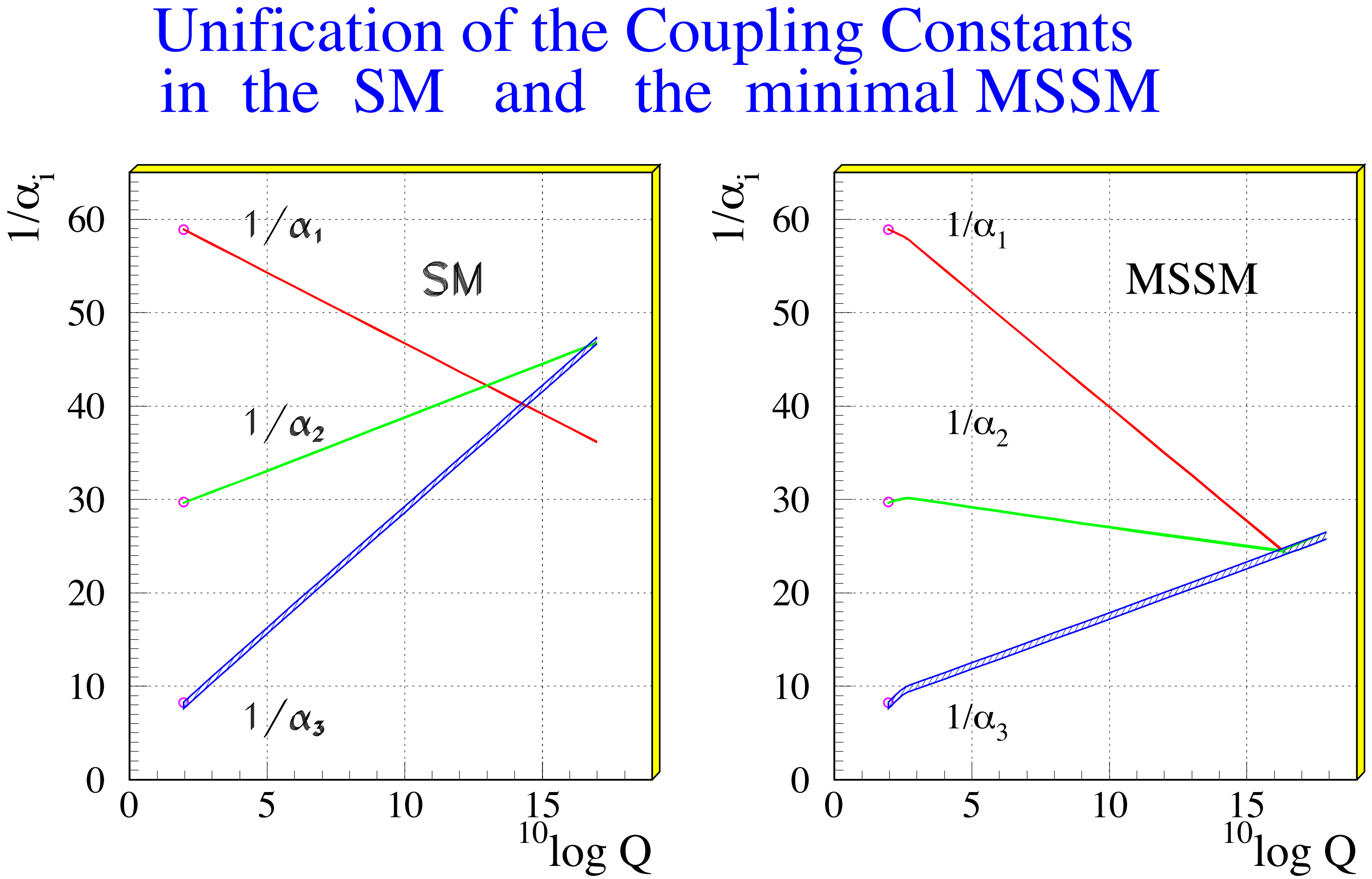
R-parity $= +1$ SM, $= -1$ SUSY, then

SUSY particles prod. pairwise in SM collisions   lightest SUSY particle stable: CDM candidate

(vii) Local SUSY: enforces gravity

$\mathcal{S}$upersymmetry - $\mathcal{M}$otivation

Amaldi,de Boer,Fürstenau



$\mathcal{M}$inimal $\mathcal{S}$upersymmetric $\mathcal{S}$tandard $\mathcal{M}$odel ($\mathcal{MSSM}$)

Low-energy Supersymmetry:

1.) Doubling of the particle spectrum

2.) Equal coupling constants in the fermionic $\sim$ bosonic couplings

3.) $m_{SM} \sim \mathcal{O}(100$ GeV$) \Rightarrow m_\phi \equiv \tilde{m} \lesssim \mathcal{O}(1$ TeV$)$???

The SM alone cannot be formulated as SUSY theory $\Rightarrow$

$$\boxed{\text{SUSY-Standard Model} = SM \otimes SUSY(N=1)}$$

minimal particle content

$\rightarrow$ Doubling of the particle spectrum: SM+SUSY partner

- **Minimal Supersymmetric Standard Model (MSSM)**

  most economic supersymmetric extension

  based on $SU(3) \times SU(2)_L \times U(1)_Y$

$\mathcal{T}$he $\mathcal{MSSM}$ $\mathcal{H}$iggs $\mathcal{S}$ector

MSSM Higgs sector – supersymmetry & anomaly free theory ⇒ 2 complex Higgs doublets

$\overset{\text{EWSB}}{\longrightarrow}$ neutral, CP-even h, H neutral, CP-odd A charged H^+, H^-

The MSSM Higgs Sector

MSSM Higgs sector – supersymmetry & anomaly free theory ⇒ 2 complex Higgs doublets

$\xrightarrow{\text{EWSB}}$ neutral, CP-even h, H neutral, CP-odd A charged H^+, H^-

Higgs masses

$$M_h \lesssim 140 \text{ GeV}$$
$$M_{A,H,H^\pm} \sim \mathcal{O}(v)...1 \text{ TeV}$$

Ellis et al;Okada et al;Haber,Hempfling;
Hoang et al;Carena et al;Heinemeyer et al;
Zhang et al;Brignole et al;...

The MSSM Higgs Sector

MSSM Higgs sector – supersymmetry & anomaly free theory ⇒ 2 complex Higgs doublets

$\overset{\text{EWSB}}{\longrightarrow}$ $\boxed{\text{neutral, CP-even } h, H \qquad \text{neutral, CP-odd } A \qquad \text{charged } H^+, H^-}$

Higgs masses

$$\begin{array}{lcl} M_h & \lesssim & 140 \text{ GeV} \\ M_{A,H,H^\pm} & \sim & \mathcal{O}(v) ... 1 \text{ TeV} \end{array}$$

Ellis et al;Okada et al;Haber,Hempfling;
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Decoupling limit:

$M_A \sim M_H \sim M_{H^\pm} \gtrsim v$

$M_h \rightarrow$ max. value, $\tan\beta$ fixed; h becomes SM-like

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Modified couplings with respect to the SM: (decoupling limit Gunion,Haber)

Φ	$g_{\Phi u\bar{u}}$	$g_{\phi d\bar{d}}$	$g_{\Phi VV}$
h	$c_\alpha/s_\beta \rightarrow 1$	$-s_\alpha/c_\beta \rightarrow 1$	$s_{\beta-\alpha} \rightarrow 1$
H	$s_\alpha/s_\beta \rightarrow 1/\text{tg}\beta$	$c_\alpha/c_\beta \rightarrow \text{tg}\beta$	$c_{\beta-\alpha} \rightarrow 0$
A	$1/\text{tg}\beta$	$\text{tg}\beta$	0

$\tan\beta \uparrow \quad \Rightarrow g_{\Phi uu} \downarrow$

$g_{\Phi dd} \uparrow$

$g^{MSSM}_{\Phi VV} \lesssim g^{SM}_{\Phi VV}$

MSSM Particle Content

Names	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	$H_d = \begin{pmatrix} H_d^{0*} \\ -H_d^- \end{pmatrix}, \; H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$	$h, H, A, H^\pm$
Squarks	$\tilde{u}_L, \tilde{u}_R, \tilde{d}_L, \tilde{d}_R$	same
	$\tilde{c}_L, \tilde{c}_R, \tilde{s}_L, \tilde{s}_R$	same
	$\tilde{t}_L, \tilde{t}_R, \tilde{b}_L, \tilde{b}_R$	$\tilde{t}_1, \tilde{t}_2, \tilde{b}_1, \tilde{b}_2$
Sleptons	$\tilde{e}_L, \tilde{e}_R, \tilde{\nu}_e$	same
	$\tilde{\mu}_L, \tilde{\mu}_R, \tilde{\nu}_\mu$	same
	$\tilde{\tau}_L, \tilde{\tau}_R, \tilde{\nu}_\tau$	$\tilde{\tau}_1, \tilde{\tau}_2, \tilde{\nu}_\tau$
Neutralinos	$\tilde{B}^0, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0$	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$
Charginos	$\tilde{W}^\pm, \tilde{H}_u^+, \tilde{H}_d^-$	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$
Gluino	$\tilde{g}$	same

$\mathcal{S}$USY $\mathcal{P}$article $\mathcal{P}$roduction

$\mathcal{SUSY}$ $\mathcal{P}$article $\mathcal{P}$roduction

R-Parity: multiplicative quantum numbers (prevents proton decay)

$$R = (-1)^{3B+L+2S} = \begin{cases} +1 & \text{SM particle} \\ -1 & \text{SUSY partner} \end{cases}$$

$$\begin{aligned} R-\text{parity} &= +1 \quad \text{for SM particles} \\ &= -1 \quad \text{for SUSY partners} \end{aligned} \quad \Rightarrow$$

- SUSY particle production in pairs
- lightest SUSY particle LSP stable

Assume R-parity conservation in the following

$\mathcal{SUSY}$ $\mathcal{P}$article $\mathcal{P}$roduction

- **Hadron Collider:**

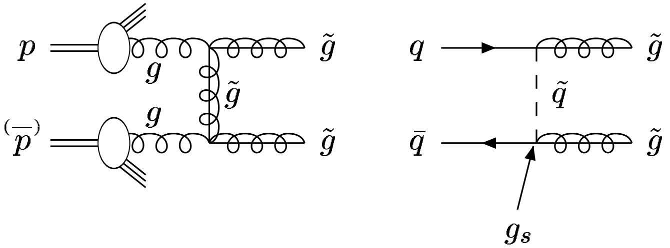
  Large production cross sections for moderate squark/gluino masses through strong interactions in $pp/p\bar{p}$ collisions

  Through cascade decays + 3 classes of SUSY pair production processes:

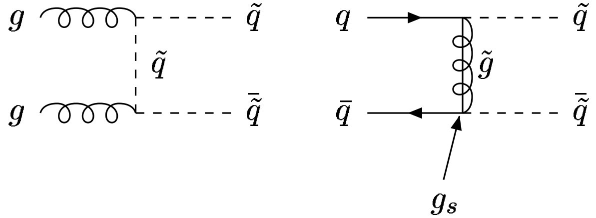
$\mathcal{SUSY}$ $\mathcal{P}$article $\mathcal{P}$roduction

(i) Strongly interacting particle pairs

$p\overset{(-)}{p} \longrightarrow \tilde{g}\tilde{g}$



$p\overset{(-)}{p} \longrightarrow \tilde{q}\bar{\tilde{q}}$



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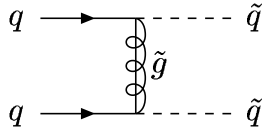

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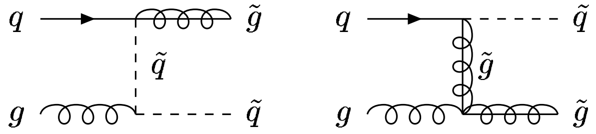

Higher Order Corrections

- **Status**
  - NLO QCD [Beenakker eal; Berger eal]; included in `PROSPINO` [Beenakker eal]
  - NLO EW [Bornhauser eal; Hollik eal; Beccaria eal; Mirabella; Arhrib eal; Germer eal]
  - NLL, NNLL [Kulesza, Motyka; Langenfeld, Moch+Pfoh; Beneke,Falgari,Schwinn; Beenakker eal;] [Kauth eal; Falgari,Schwinn,Wever; Pfoh; Broggio eal]
  - NLO+NLL implemented in `NLL-Fast` [Kulesza,Motyka; Beenakker eal]

- **NLO QCD implementation in `PROSPINO`**
  - squark masses assumed to be degenerate
  - various subchannels not treated individually
  - (differential) K-factors assumed to be flat

- **NLO QCD for generic MSSM spectra**

  [Hollik eal; Goncalves-Netto eal; Gavin,Hangst,Krämer,MMM,Pellen,Popenda,Spira '13,'14]

$\mathcal{H}$igher $\mathcal{O}$rder $\mathcal{C}$orrections

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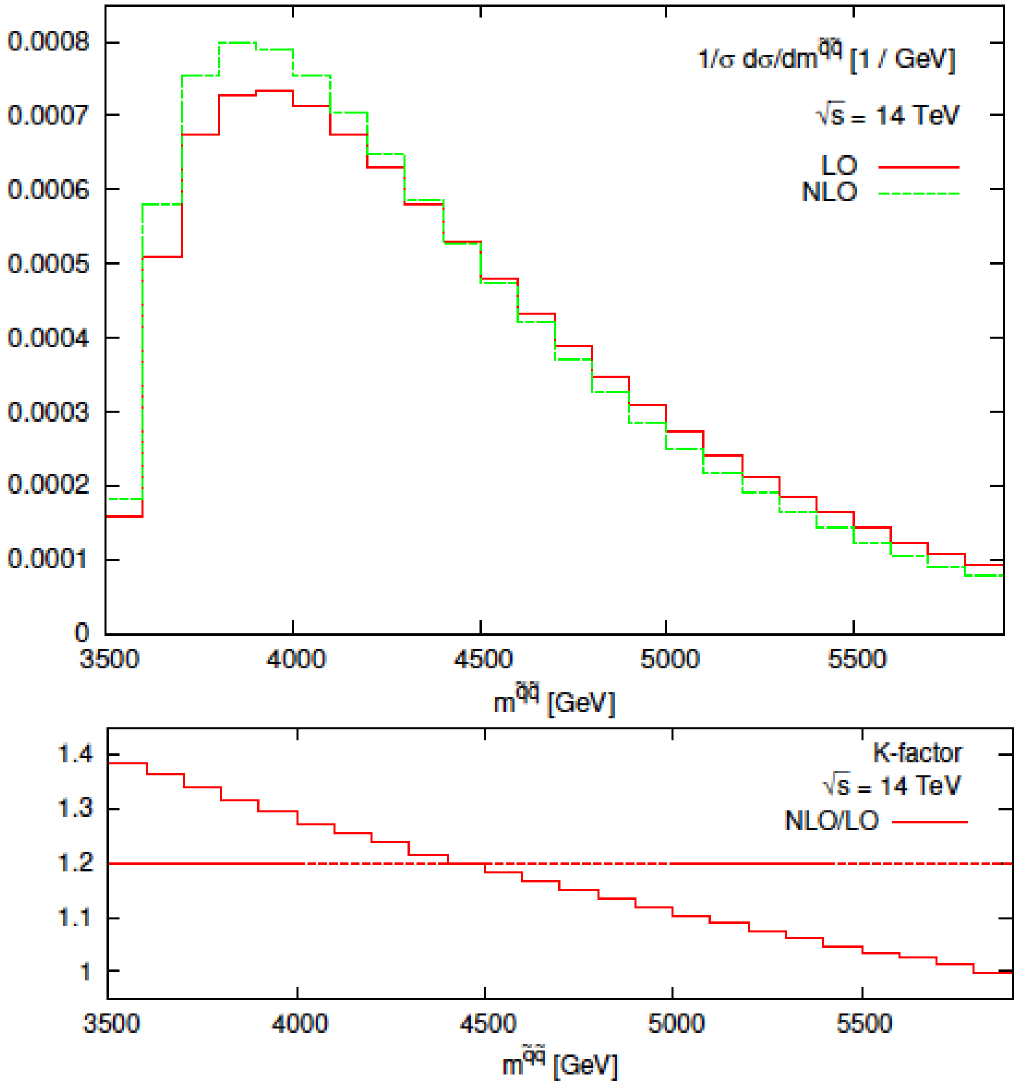
- **NLO QCD for generic MSSM spectra - $\tilde{q}\tilde{q}^{(*)}$ production**

  [Gavin,Hangst,Krämer,MMM,Pellen,Popenda,Spira '13,'14]

  - w/o any assumptions on mass spectra
  - decay $\tilde{q} \rightarrow q + \tilde{\chi}_1^0$ added
  - matched with parton showers in the `POWHEG-BOX`

Differential K-Factors on the Production Level

Gavin,Hangst,Krämer,MMM,Pellen,Popenda,Spira



- $m_{\tilde{q}} \approx 1.8$ TeV, $m_{\tilde{g}} = 1.6$ TeV, $\sqrt{s} = 14$ TeV
- differential K-factor varies in a range of 40%
- NLO corrections can change shape of distributions
- full NLO distributions should be taken into account

- implemented in POWHEG Box
  Frixione,Nason,Oleari

Impact on Total Rates

- **SUSY searches in 2-jet events by ATLAS ('A-loose'):** [ATLAS-CONF-2013-047]

$$p_T^{j_1} > 130\text{ GeV}\,,\quad p_T^{j2} > 60\text{ GeV}\,,\quad \not{E}_T > 160\text{ GeV}\,,\quad \frac{\not{E}_T}{m_{\text{eff}}} > 0.2$$

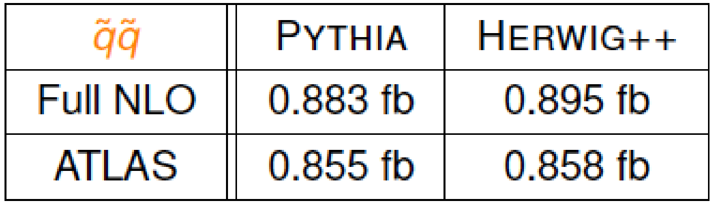
$$m_{\text{eff}}^{\text{incl}} > 1\text{ TeV}\,,\quad \Delta\phi(j_{1/2},\vec{\not{E}}_T) > 0.4\,,\quad \Delta\phi(j_3,\vec{\not{E}}_T) > 0.4\quad\text{if}\quad p_T^{j_3} > 40\text{ GeV}$$

- **Method for theoretical predictions used by ATLAS:**

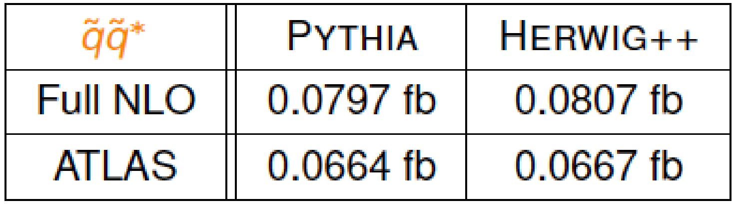
∗ production at LO (CTEQ6L1) rescaled with K-factor from `PROSPINO`

∗ multiplied with NLO branching ratios calculated by `SDECAY`

∗ decays + showering performed by `HERWIG++` and `PYTHIA`



$\tilde{q}\tilde{q}$	PYTHIA	HERWIG++
Full NLO	0.883 fb	0.895 fb
ATLAS	0.855 fb	0.858 fb



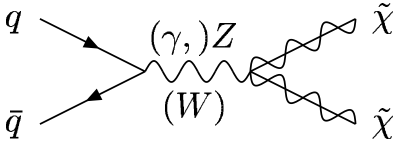
$\tilde{q}\tilde{q}^*$	PYTHIA	HERWIG++
Full NLO	0.0797 fb	0.0807 fb
ATLAS	0.0664 fb	0.0667 fb

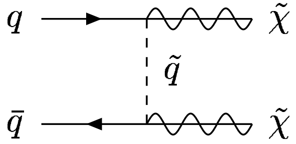
⇝ not in all cases sufficient to use approximate approach applied by ATLAS

Weakly Interacting Particles

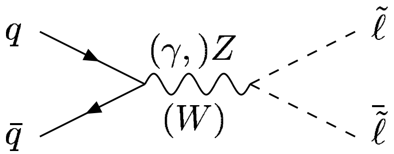
(ii) Weakly interacting particle pairs

$$p\overset{(-)}{p}\to\tilde{\chi}\tilde{\chi}$$





$$p\overset{(-)}{p}\to\tilde{l}\bar{\tilde{l}}$$

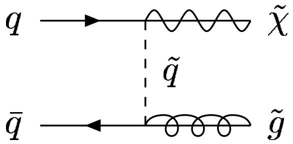


Signatures:

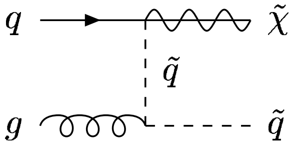
$$\begin{array}{lcll} \tilde{l} & \to & l\tilde{\chi}_1^0 \ : & pp\to l^+l^- + E_T^{miss} \\ \tilde{\chi}_2^0 & \to & l^+l^-\tilde{\chi}_1^0 \ \text{etc.} \ : & pp\to l^+l^+l^-l^- + E_T^{miss} \quad \text{etc.} \end{array}$$

(iii) Associated production

$$p\overset{(-)}{p}\to\tilde{g}\tilde{\chi}$$



$$p\overset{(-)}{p}\to\tilde{q}\tilde{\chi}$$

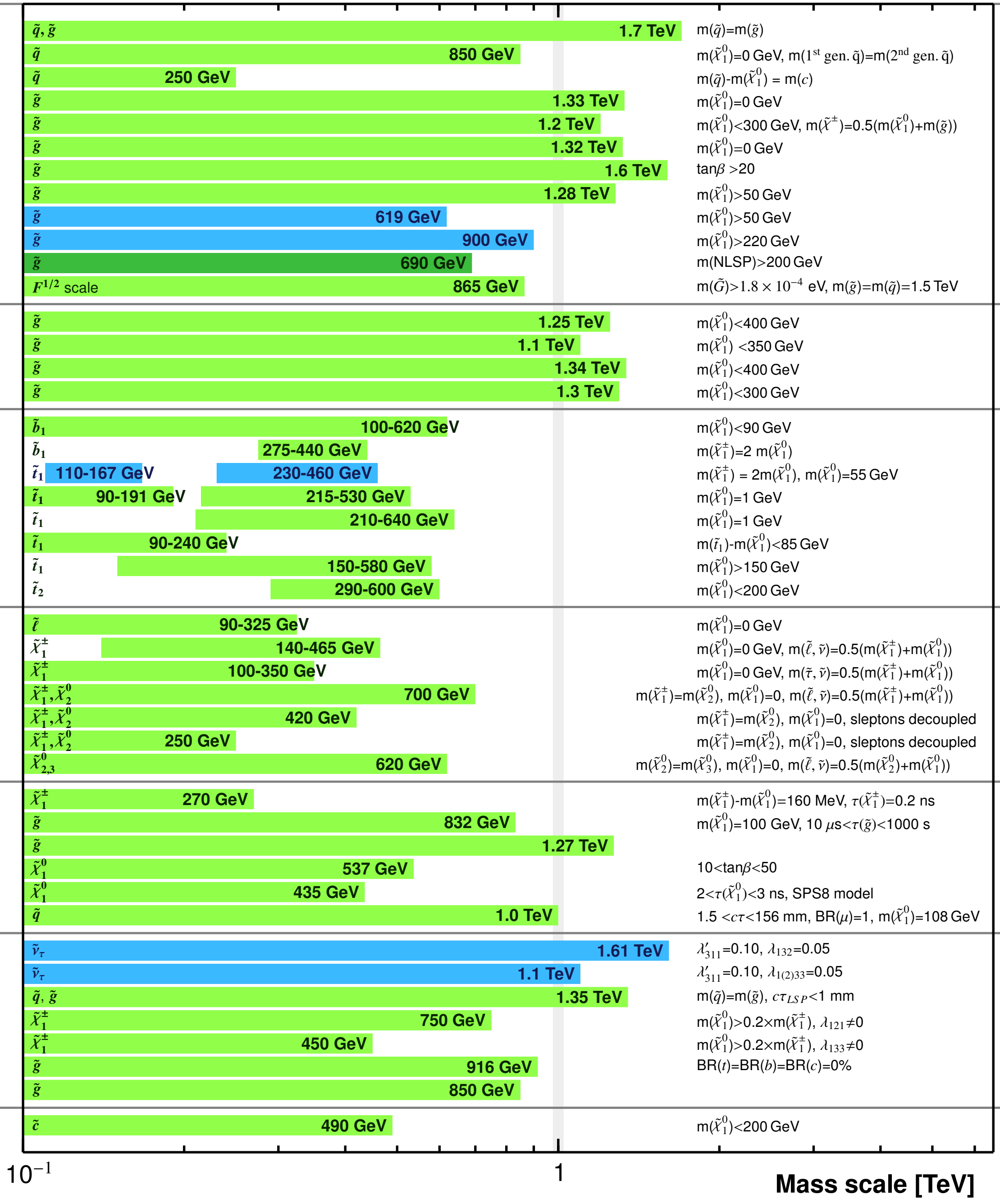


ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV



	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q},\tilde{g}$ 1.7 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1405.7875
	$\tilde{q}\tilde{q}$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m(1^{st} gen. $\tilde{q}$)=m(2^{nd} gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}\gamma$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$ (compressed)	1 γ	0-1 jet	Yes	20.3	$\tilde{q}$ 250 GeV	m($\tilde{q}$)-m($\tilde{\chi}_1^0$) = m(c)	1411.1559
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1405.7875
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	1 e,μ	3-6 jets	Yes	20	$\tilde{g}$ 1.2 TeV	m($\tilde{\chi}_1^0$)<300 GeV, m($\tilde{\chi}^{\pm}$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	1501.03555
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.32 TeV	m($\tilde{\chi}_1^0$)=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 e,μ + γ	-	Yes	4.8	$\tilde{g}$ 619 GeV	m($\tilde{\chi}_1^0$)>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	m($\tilde{\chi}_1^0$)>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	m($\tilde{G}$)>1.8×10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	m($\tilde{\chi}_1^0$) <350 GeV	1308.1841
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	m($\tilde{\chi}_1^0$)<400 GeV	1407.0600
	$\tilde{g}\rightarrow b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	m($\tilde{\chi}_1^0$)<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\rightarrow t\tilde{\chi}_1^{\pm}$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	m($\tilde{\chi}_1^{\pm}$)=2 m($\tilde{\chi}_1^0$)	1404.2500
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV 230-460 GeV	m($\tilde{\chi}_1^{\pm}$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 90-191 GeV 215-530 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1403.4853, 1412.4742
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	0-1 e,μ	1-2 b	Yes	20	$\tilde{t}_1$ 210-640 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1407.0583,1406.1122
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\rightarrow\tilde{t}_1 + Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\rightarrow\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	m($\tilde{\chi}_1^0$)=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 140-465 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 100-350 GeV	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{\tau},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1407.0350
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 700 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^{\pm}$)+m($\tilde{\chi}_1^0$))	1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 420 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$, $h\rightarrow b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 250 GeV	m($\tilde{\chi}_1^{\pm}$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\rightarrow\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 270 GeV	m($\tilde{\chi}_1^{\pm}$)-m($\tilde{\chi}_1^0$)=160 MeV, $\tau(\tilde{\chi}_1^{\pm})$=0.2 ns	1310.3675
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$ 1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\rightarrow\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 435 GeV	2<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde{q}\tilde{q}$, $\tilde{\chi}_1^0\rightarrow qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, m($\tilde{\chi}_1^0$)=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\rightarrow\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\rightarrow e + \mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\rightarrow\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\rightarrow e(\mu) + \tau$	1 e,μ + τ	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.35 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 750 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\rightarrow qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\rightarrow\tilde{t}_1 t$, $\tilde{t}_1\rightarrow bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
Other	Scalar charm, $\tilde{c}\rightarrow c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 490 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

$\sqrt{s}$ = 7 TeV full data

$\sqrt{s}$ = 8 TeV partial data

$\sqrt{s}$ = 8 TeV full data

**Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.*

$\mathcal{L}$ight $\mathcal{S}$top $\mathcal{S}$earch

$\mathcal{S}$tops at the $\mathcal{LHC}$

- **Stops $\tilde{t}_{1,2}$**

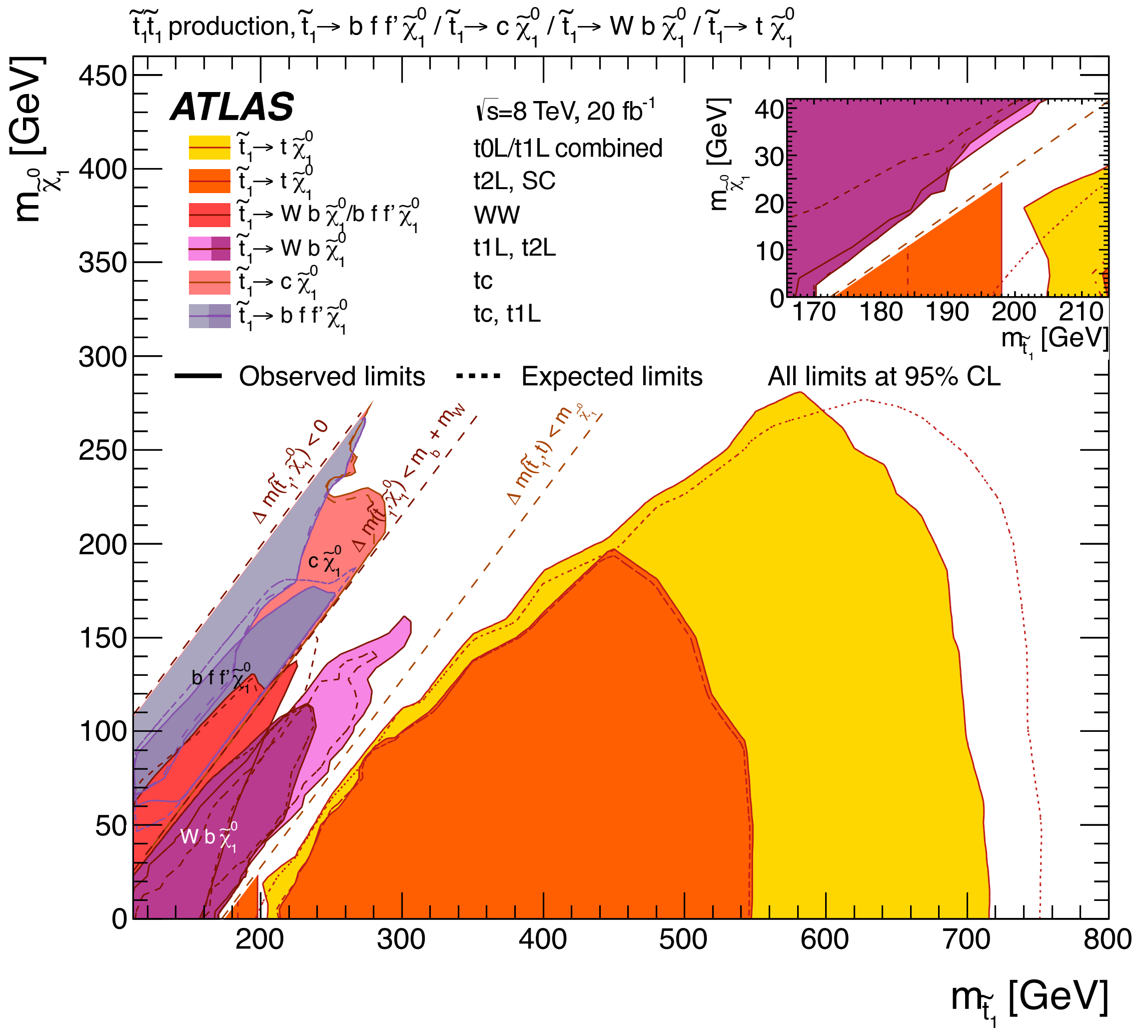
$*$ mass of light CP-even Higgs boson depends sensitively on stop sector $(m_{\tilde{t}_{1,2}}, A_t)$

$*$ large top Yukawa couplings $\rightsquigarrow$ large mass splitting $\rightsquigarrow$ light $\tilde{t}_1$

$*$ light stop arises naturally from renormalization group running

$*$ light stop favoured by baryogenesis

$\mathcal{S}$tops at the $\mathcal{LHC}$



- This talk:

  light stop decays with
  $m_{\tilde t_1} - m_{\tilde\chi_1^0} < m_t$

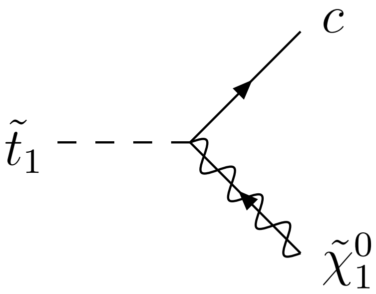
- Possible decays:

  if $m_{\tilde t_1} < m_W + m_b + m_{\tilde\chi_1^0}$:
  - $\ast\ \tilde t_1 \to (c/u)\tilde\chi_1^0$
  - $\ast\ \tilde t_1 \to b\tilde\chi_1^0 f\bar f'$

  if $m_{\tilde t_1} > m_W + m_b + m_{\tilde\chi_1^0}$:
  - $\ast\ \tilde t_1 \to (c/u)\tilde\chi_1^0$
  - $\ast\ \tilde t_1 \to b\tilde\chi_1^0 W$

$\mathcal{F}$lavour $\mathcal{C}$hanging $\mathcal{L}$ight $\mathcal{S}$top $\mathcal{D}$ecay

- **FCNC decay $\tilde{t}_1 \to c + \tilde{\chi}_1^0$**



$\mathcal{F}$lavour $\mathcal{P}$roblem

- **Precision measurements in flavour physics**
  - ∗ in agreement with predictions of the Standard Model (SM)
  - ∗ observed flavour violation can be described by SM Cabibbo-Kobayashi-Maskawa (CKM) matrix

  ⇒ New Physics (NP) contributions to Flavour Violation strongly constrained

- **Minimal Supersymmetric Extension of the SM (MSSM)**

  in principle many new flavour violating sources
  ⇒ New Physics Flavour Problem

- **Minimal Flavour Violation (MFV)** provides solution, agrees with precision measurements
  - ∗ sources of flavour and CP violation given by SM structure of the Yukawa couplings ⇒
  - ∗ flavour mixing in NP models governed by CKM matrix ⇒
  - ∗ no flavour changing neutral currents (FCNC) at tree level at $\mu = \mu_{MFV}$

$\mathcal{F}$lavour $\mathcal{C}$hanging $\mathcal{L}$ight $\mathcal{S}$top $\mathcal{D}$ecay

- **Status $\tilde{t}_1 \to c + \tilde{\chi}_1^0$**

$*$ One-loop decay assuming **vanishing** $c/u - \tilde{\chi}_1^0 - \tilde{t}_1$ tree-level coupling

- leading log contributions [Hikasa,Kobayashi]
- non-logarithmic contributions [MMM,Popenda]

$*$ One-loop SUSY-QCD correction to $\tilde{t}_1 \to (c/u)\tilde{\chi}_1^0$ with **non-vanishing** $c/u - \tilde{\chi}_1^0 - \tilde{t}_1$ tree-level coupling [Grober,MMM,Popenda,Wlotzka]

$$K = \frac{\Gamma_{\text{NLO}}}{\Gamma_{\text{LO}}} \approx 1.07...1.26$$

$\mathcal{F}$our-$\mathcal{B}$ody $\mathcal{D}$ecay $\tilde{u}_1 \to \tilde{\chi}_1^0 d_i f \bar{f}'$

- **Status $\tilde{u}_1 \to \tilde{\chi}_1^0 d_i f \bar{f}'$** ($\tilde{u}_1$ dominantly top-like)

$*$ Four-body decays with **vanishing** FCNC tree-level couplings [Boehm,Djouadi,Mambrini]

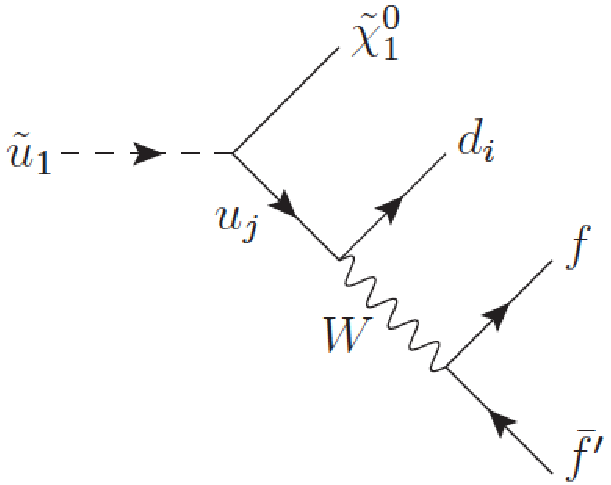
$*$ Computation of $\tilde{u}_1 \to \tilde{\chi}_1^0 d_i f \bar{f}'$ [Grober,MMM,Popenda,Wlotzka]

with $d_i = b, s, d$ and

$f, f' = b, s, d, c, u, \tau, \mu, e, \nu_\tau, \nu_\mu, \nu_e$

with **non-vanishing** FCNC tree-level couplings

  - full dependence on masses of third generation fermions
  - implemented in `SUSY-HIT` [Djouadi,MMM,Spira]



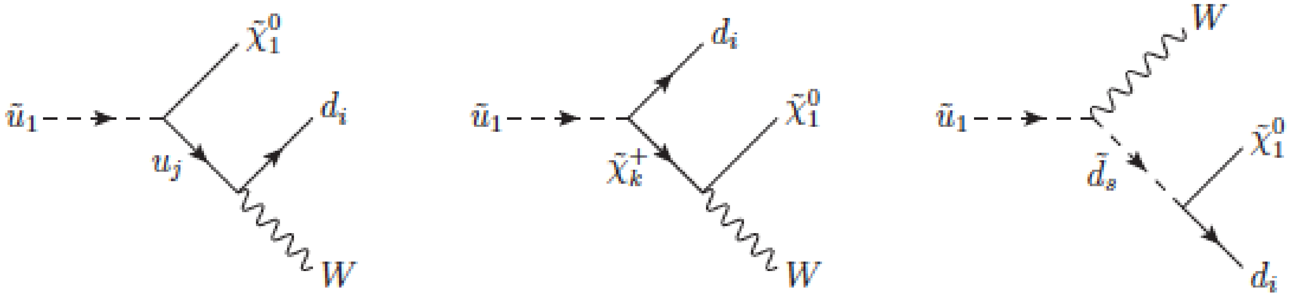
$\mathcal{T}$hree-$\mathcal{B}$ody $\mathcal{D}$ecay $\tilde{u}_1 \to d_i W \tilde{\chi}_1^0$

- **Relevant above W-boson threshold**

- **Status $\tilde{u}_1 \to d_i W \tilde{\chi}_1^0$:** ($\tilde{u}_1$ dominantly top-like)

$\ast$ On-shell production with **vanishing** FCNC tree-level couplings [Porod,Wohrmann;Djouadi,Mambrini]

Three-Body Decay $\tilde{u}_1 \to d_i W \tilde{\chi}_1^0$



[Grober,MMM,Popenda,Wlotzka]

$*$ Extension by including also **non-vanishing** FCNC tree-level couplings

$*$ Transition region between 3- and 4-body decays:

- W boson width included in 4-body decay: overall-factor scheme (gauge-independent)

$$\Pi_W\text{-propagators } \frac{p_W^2 - m_W^2}{p_W^2 - m_W^2 + i m_W \Gamma_W}$$

- in `SUSY-HIT`: $\tilde{u}_1 \to d_i W \tilde{\chi}_1^0$ w/ full flavour structure

for $m_{\tilde{u}_1} - m_{\tilde{\chi}_1^0} < m_W + 30$ GeV 4-body decays are calculated

$\mathcal{S}$can over $\mathcal{P}$arameter $\mathcal{S}$pace

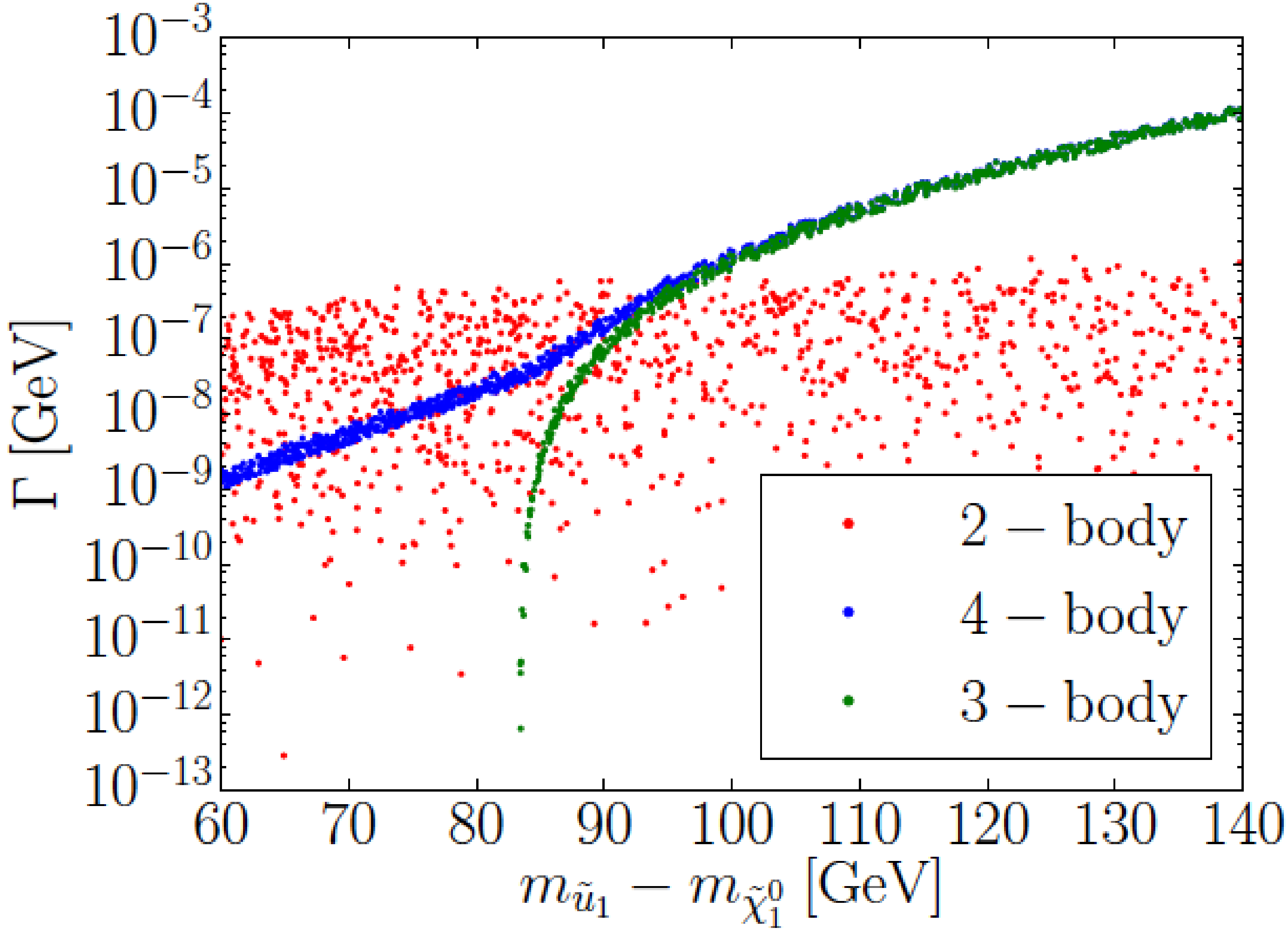
- Spectrum generated with `SPHENO` [Porod,Staub]
- Light stop decays implemented in `SUSY-HIT`

Check of compatibility:

- Higgs results: checked with `HiggsBounds` and `HiggsSignals` [Bechtle eal]
  for Higgs branching ratios `HDECAY` [Djouadi,Kalinowski,MMM,Spira]
- Relic density $\Omega_c h^2 < 0.12$ [Planck] with `SuperIsoRelic` [Arbey,Mahmoudi]
- Some B flavour observables with `SuperIsoRelic`
- Masses of sparticles chosen to evade LHC exclusion limits

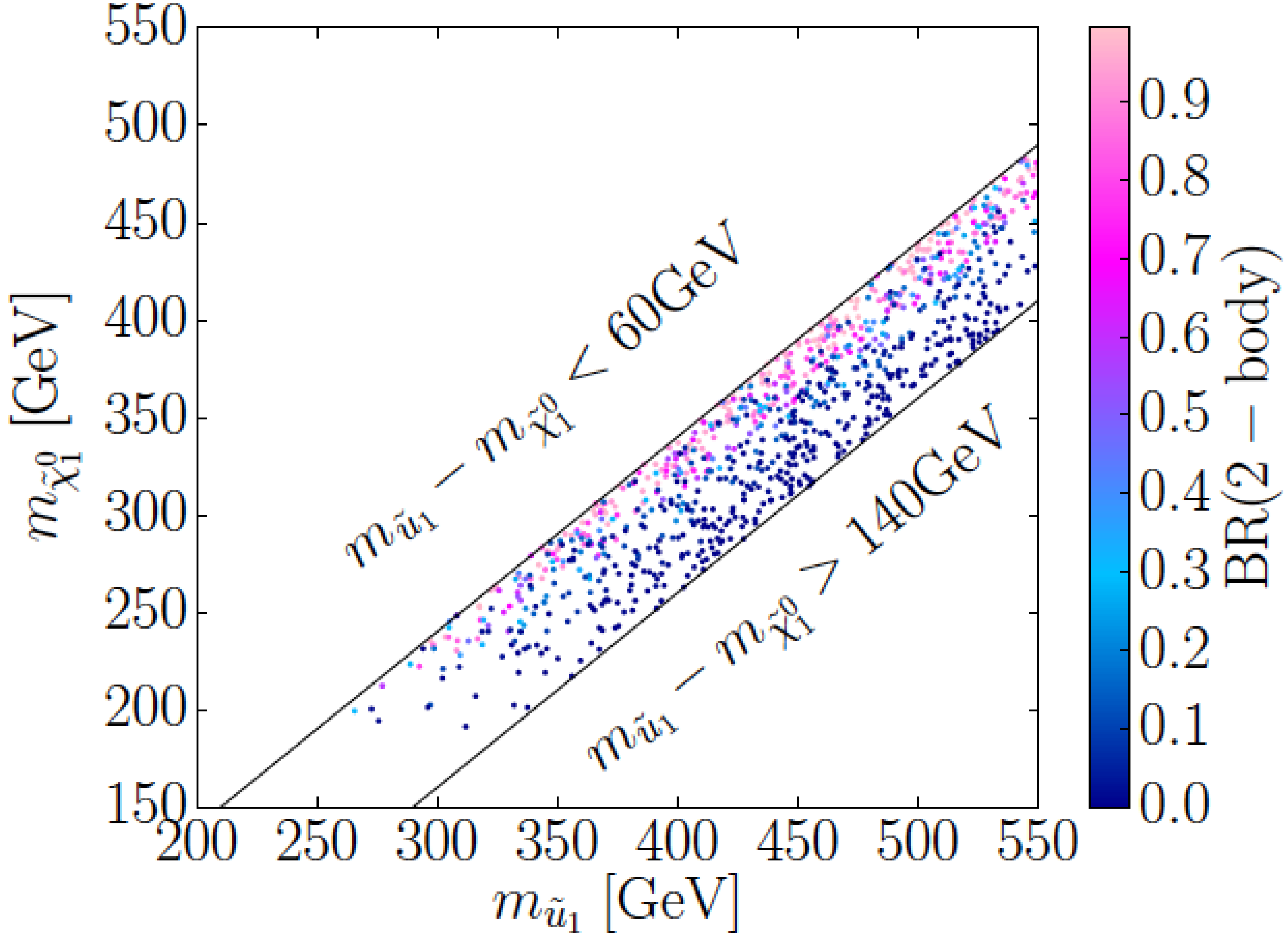
Light Stop Decay Widths

Grober,MMM,Popenda,Wlotzka



$\mathcal{T}$hreshold $\mathcal{R}$egion

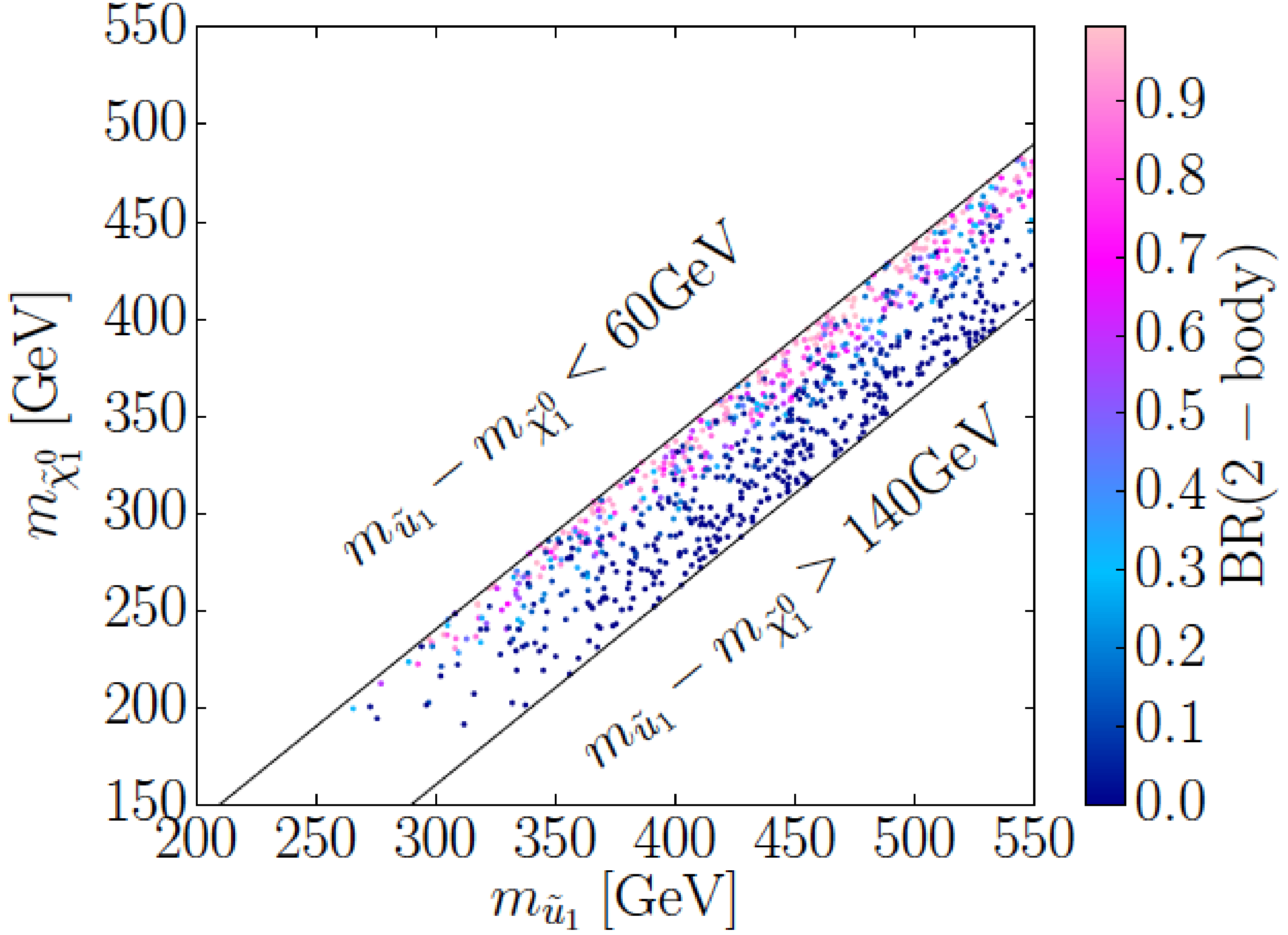
Grober,MMM,Popenda,Wlotzka



- $U(2)$ flavour model: $\tilde{u}_1 \to c\tilde{\chi}_1^0$ can still be dominant above W threshold

$\mathcal{T}$hreshold $\mathcal{R}$egion

Grober,MMM,Popenda,Wlotzka



- Assuming BRs=1 not always justified ⇝ weaker excl. limits; see also ATLAS/1506.08616

Big Questions - Big Ideas

- ◇ What is the mechanism beyond EWSB? Weak or strong dynamics?
- ◇ Huge Higgs mass corrections - finetuning?
- ◇ Do the gauge couplings unify?
- ◇ Incorporation of gravity?
- ◇ Puzzling spectrum of fermion masses and mixings
- ◇ What is the nature of Dark Matter?
- ◇ Origin of matter-antimatter asymmetry?
- ◇ New sources of CP violation?
- ◇ ...

No Observation of Physics
Beyond the SM so Far!

Supersymmetry

Compositeness

Extra Dimensions

Extended Higgs Sectors

Top Partner W'/Z'

Minimal Dark Matter

Hidden Sector ...

$\mathcal{W}$here is $\mathcal{N}$ew $\mathcal{P}$hysics?

- **Naturalness: Just around the corner!**
- **Experimental reality:** No Beyond the Standard Model Physics discovered so far!

$\mathcal{W}$here is $\mathcal{N}$ew $\mathcal{P}$hysics?

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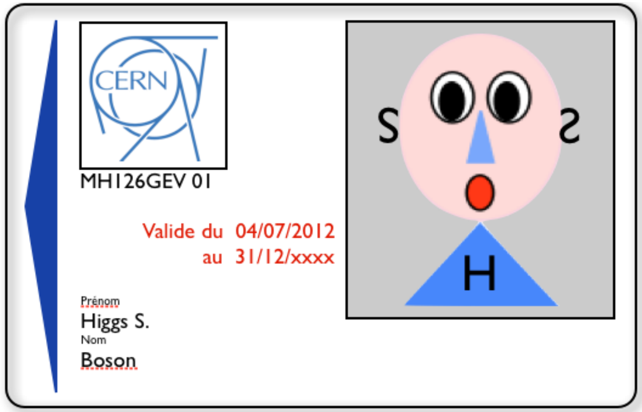
  But: Discovery of new scalar particle 4th July 2012



Valide du 04/07/2012
au 31/12/xxxx

Prénom
Higgs S.
Nom
Boson

*W*here is *N*ew *P*hysics?

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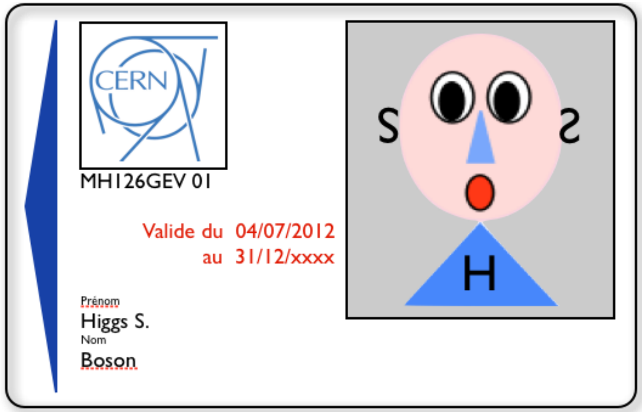


*W*hat can we learn from *H*iggs *P*hysics in the *F*uture?

What Can We Learn From Higgs Physics?

- Is it *the* Standard Model *Higgs* boson?

- Is it the harbinger of New Physics?

∗ SUSY effects on Higgs Physics

- extended Higgs sector ⇝ more Higgs bosons to be discovered with different CP properties
- SUSY particles ⇝ modification of loop induced Higgs couplings, of higher order corrections
  ⇒ change of production and decay rates
- change of Higgs couplings through mixing effects
  ⇒ change of production and decay rates
- Higgs boson decays into other lighter Higgs bosons or lighter SUSY particles
- CP violation in tree-level Higgs sector possible

$\mathcal{N}$MSSM
$\mathcal{H}$iggs
$\mathcal{S}$ector

by Clelia Anchisi

$\mathcal{I}$nterpretation within $\mathcal{SUSY}$: The $\mathcal{NMSSM}$ $\mathcal{H}$iggs $\mathcal{S}$ector

- **Supersymmetric Higgs Sector:** SUSY & anomaly-free theory $\Rightarrow$ 2 complex Higgs doublets

- **Most economic version:** Minimal Supersymmetric Extension of the SM (MSSM):

  2 complex Higgs doublets

- **Next-to-Minimal Supersymmetric Extension of the SM: NMSSM**

  Fayet; Kaul eal; Barbieri eal; Dine eal; Nilles eal; Frere eal; Derendinger eal; Ellis eal;
  Drees; Ellwanger eal; Savoy; Elliott eal; Gunion eal; Franke eal; Maniatis; Djouadi eal; Mahmoudi eal; ...

  2 complex Higgs doublets plus one complex singlet field $\rightsquigarrow$

- **Solution of the μ-problem:** μ must be of $\mathcal{O}$(EWSB scale) Kim,Nilles

  μ generated dynamically through the VEV of scalar component of an additional chiral superfield field $\hat{S}$: $\mu = \lambda\langle S\rangle$ from: $\lambda\hat{S}\hat{H}_u\hat{H}_d$

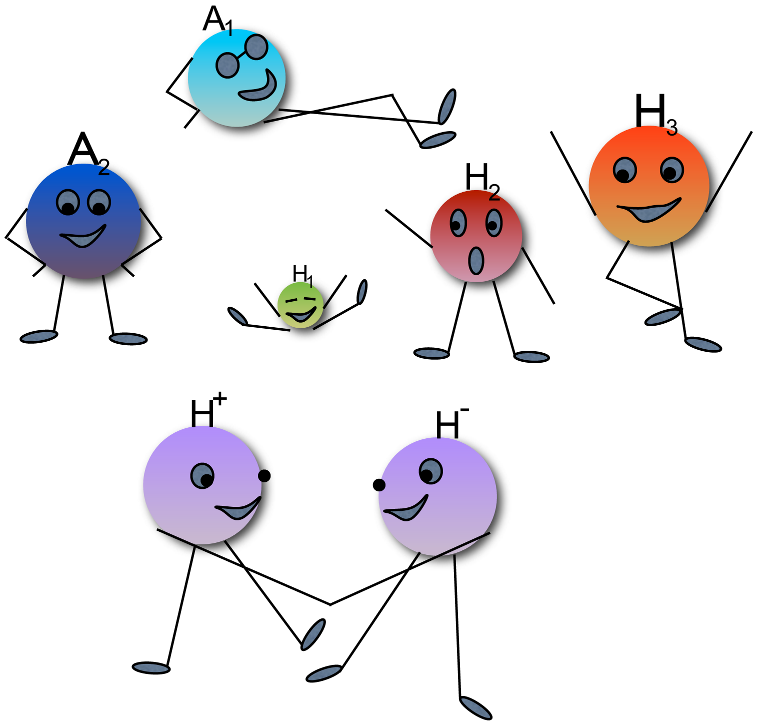
The NMSSM Higgs Sector

- **Enlarged Higgs and neutralino sector:** 2 complex Higgs doublets $\hat{H}_u, \hat{H}_d$, 1 complex singlet $\hat{S}$

7 Higgs bosons: $H_1, H_2, H_3, A_1, A_2, H^+, H^-$

5 neutralinos: $\tilde{\chi}_i^0 \; (i = 1, ..., 5)$

- **Higgs mass eigenstates:**
  superpositions of doublet and singlet components $\rightsquigarrow$
  the more singlet-like
  the smaller couplings to SM particles



- **Significant changes of Higgs boson phenomenology**
  - ∗ light Higgses not excluded, Higgs-to-Higgs decays
  - ∗ degenerate Higgs bosons around 125 GeV possible
  - ∗ very light singlino-like lightest SUSY particle (LSP)
  - ∗ $\rightsquigarrow$ invisible Higgs decays
  - ∗ tree-level CP violation ...

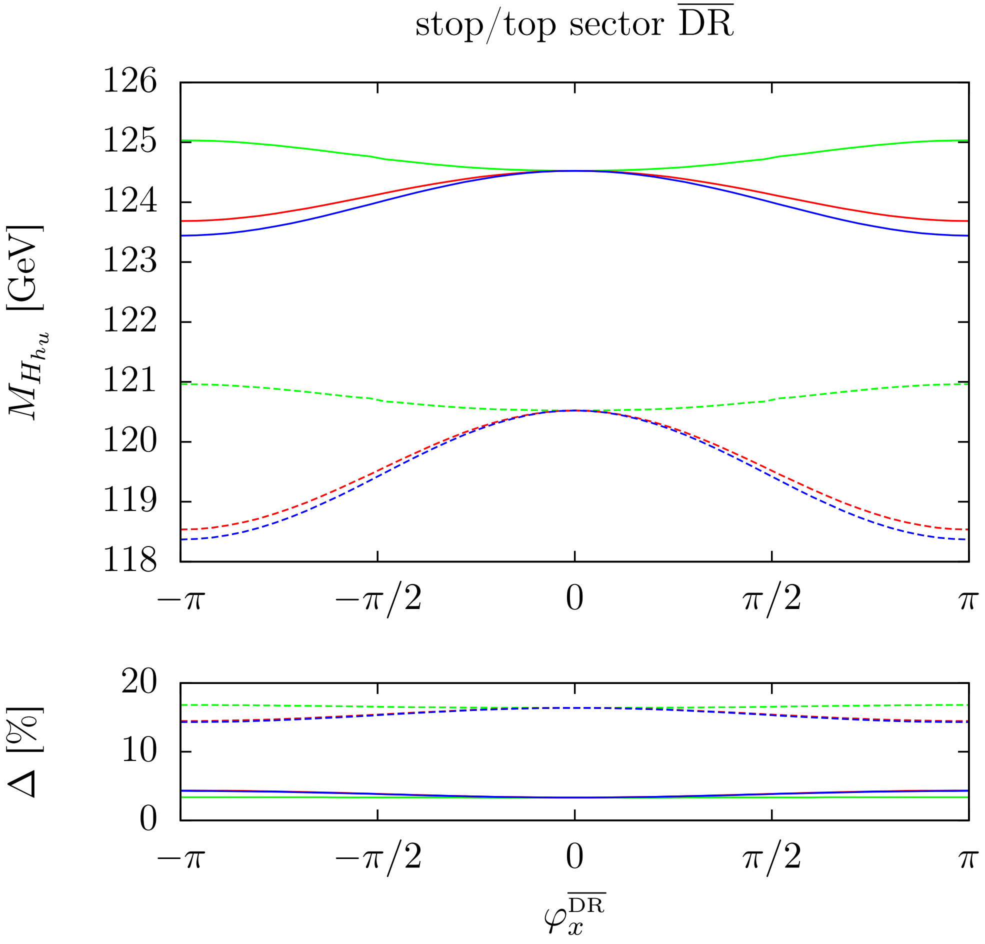
$\mathcal{NMSSM}$ $\mathcal{H}$iggs $\mathcal{B}$oson $\mathcal{M}$ass

- **NMSSM Higgs boson masses given in terms of Higgs potential parameters**
- **Higher order corrections:**
  - $*$ important to shift SM-like NMSSM Higgs boson mass to $\sim$ 125 GeV;
  - $*$ Higgs masses enter production cxns and BRs $\rightsquigarrow$
  - $*$ need to be known at highest possible accuracy for proper interpretation of exp results, for distinction of Higgs sectors of different BSM models

NMSSM Higgs Boson Mass

- **Status of higher order corrections:**
  - $*$ Real NMSSM:
    - ◇ leading one-loop [Ellwanger;Elliott eal; Pandita;Ellwanger,Huggonie]
    - ◇ full one-loop in $\overline{\text{DR}}$ scheme [Degrassi,Slavich;Staub eal]
    - ◇ full one-loop in mixed $\overline{\text{DR}}$-OS scheme [Ender(→Walz),Graf,MMM,Rzehak]
    - ◇ $\mathcal{O}(\alpha_t\alpha_s + \alpha_b\alpha_s)$ $\overline{\text{DR}}$ w/ zero external momentum [Degrassi,Slavich]
    - ◇ first results beyond this [Goodsell eal]
  - $*$ Complex NMSSM:
    - ◇ various one-loop contributions in effective potential approach [Ham,Kim,Oh,Son;Ham,Oh,Son;Ham,Jeong,Oh;Funakubo,Tao;Ham,Kim,Oh,Son]
    - ◇ full one-loop & leading two-loop in effective potential approach [Cheung,Hou,Lee,Senaha]
    - ◇ full one-loop in diagrammatic approach [Graf,Grober,MMM,Rzehak,Walz]
    - ◇ $\mathcal{O}(\alpha_t\alpha_s)$ mixed $\overline{\text{DR}}$-OS scheme w/ zero external momentum [MMM,Nhung,Rzehak,Walz]

$\mathcal{NMSSM}$ $\mathcal{H}$iggs $\mathcal{B}$oson $\mathcal{M}$ass 2-$\mathcal{L}$oop $\mathcal{C}$orrections



MMM,Nhung,Rzehak,Walz '14

dashed: one-loop, full: two-loop

variation of φ_{A_t}

variation of φ_{M_3}

variation of φ_μ

$$\Delta = |M_{H_{h_u}}^{(n)} - M_{H_{h_u}}^{(n-1)}|/M_{H_{h_u}}^{(n-1)}$$

dashed: $n = 1$, solid: $n = 2$

$m_t^{pole} = 173.5$ GeV

$m_t^{\overline{\text{DR}}} = 143.14$ GeV at $Q = 1.25$ TeV

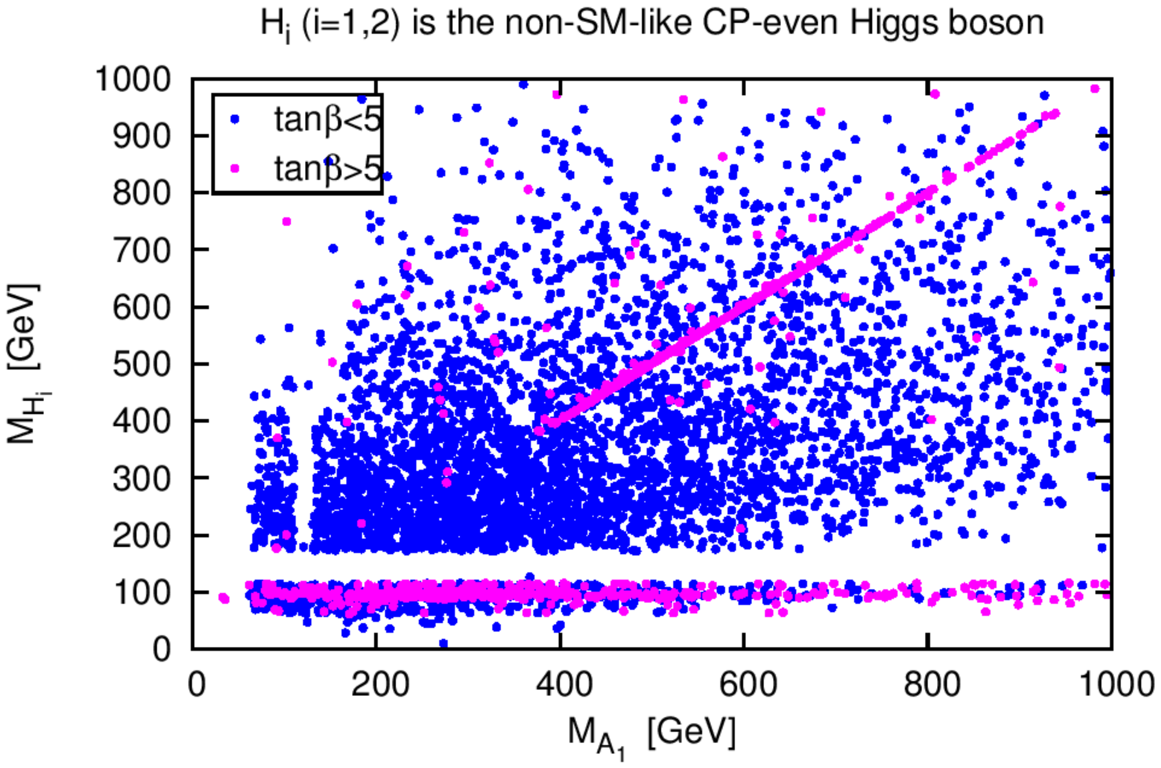
difference in $\overline{\text{DR}}$ and OS masses:

one-loop: $\mathcal{O}(15 - 25\%)$

two-loop: $\mathcal{O}(\lesssim 1.5\%)$

$\mathcal{S}$can in the $\mathcal{NMSSM}$ $\mathcal{P}$arameter $\mathcal{S}$pace - $\mathcal{M}$ass $\mathcal{D}$istributions

King,MMM,Nevzorov,Walz



$M_{H_i} \lesssim 115$ GeV $\rightsquigarrow$ H_1 non-SM-like; $M_{H_i} \gtrsim 180$ GeV $\rightsquigarrow$ H_2 non-SM-like

300 GeV $\lesssim M_{H_3}, M_{A_2} \lesssim \mathcal{O}$(TeV)

$\mathcal{B}$enchmarks for $\mathcal{H}$iggs-to-$\mathcal{H}$iggs $\mathcal{D}$ecays

- **Higgs-to-Higgs Decays**

$$\sigma(gg \to \phi_i) \times BR(\phi_i \to \phi_j \phi_k) \times BR(\phi_j \to XX) \times BR(\phi_k \to YY)$$

▷ Interesting for heavier ϕ_i discovery if σ_{prod} large enough and BR into lighter Higgs pairs dominates

▷ For lighter ϕ_j, ϕ_k interesting production if direct prod strongly suppressed due to singlet nature

- **Benchmarks for Higgs-to-Higgs Decays**

A) $H_2 = h, H_1 = H_s, \tan\beta$ small, light spectrum $\lesssim 350$ GeV

B) $H_1 = h, H_2 = H_s, \tan\beta$ small

C) $H_1 = h, H_3 = H_s, \tan\beta$ large

D) $H_2 = h$ decays into lighter Higgs pairs

$\mathcal{B}$enchmark $H_1 = h$ and $\tan\beta$ small

B.1 (Point ID Poi2a)	Scenario		
M_h, M_{H_s}, M_H	126.6 GeV	172.0 GeV	316.8 GeV
M_{A_s}, M_A	86.0 GeV	306.7 GeV	
$\tan\beta, \lambda, \kappa$	1.9	0.662	0.348
$A_\lambda, A_\kappa, \mu_{\text{eff}}$	187.9 GeV	47.0 GeV	156.9 GeV
M_1, M_2, M_3	890 GeV	576 GeV	1219 GeV
A_t, A_b, A_τ	1655 GeV	-1097 GeV	-840 GeV
$M_{Q_3}, M_{t_R}, M_{L_3} = M_{\tau_R}$, other SSB parameters	1030, 1054 GeV	530 GeV	2.5 TeV

$$\text{BR}(A_s \to \gamma\gamma) = 0.13\,, \quad \text{BR}(H_s \to A_s A_s) = 0.22\,, \quad \text{BR}(H \to h H_s) = 0.40$$

$$\text{BR}(A \to H_s A_s) = 0.17\,, \quad \text{BR}(A \to h A_s) = 0.055$$

$\mathcal{B}$enchmark $H_1 = h$ and $\tan\beta$ small

B.1 (Point ID Poi2a)	Decay Rates
$\sigma(ggA)$BR$(A \to H_sA_s \to A_s + A_sA_s \to 6\gamma)$	0.68 fb
$\sigma(ggA)$BR$(A \to H_sA_s \to A_s + A_sA_s \to bb + 4\gamma)$	13.11 fb
$\sigma(ggA)$BR$(A \to H_sA_s \to A_s + A_sA_s \to 4b + \gamma\gamma)$	85.79 fb
$\sigma(ggA)$BR$(A \to H_sA_s \to A_s + A_sA_s \to \tau\tau + 4\gamma)$	0.89 fb
$\sigma(ggA)$BR$(A \to H_sA_s \to A_s + A_sA_s \to \tau\tau + bb + \gamma\gamma)$	11.260 fb
$\sigma(ggA)$BR$(A \to H_sA_s \to A_s + A_sA_s \to 4\tau + \gamma\gamma)$	0.40 fb
$\sigma(ggA)$BR$(A \to hA_s \to \gamma\gamma + b\bar{b})$	33.60 fb
$\sigma(ggA)$BR$(A \to hA_s \to \gamma\gamma + \tau\tau)$	3.50 fb
$\sigma(ggA)$BR$(A \to hA_s \to b\bar{b} + b\bar{b})$	210 fb

involves:

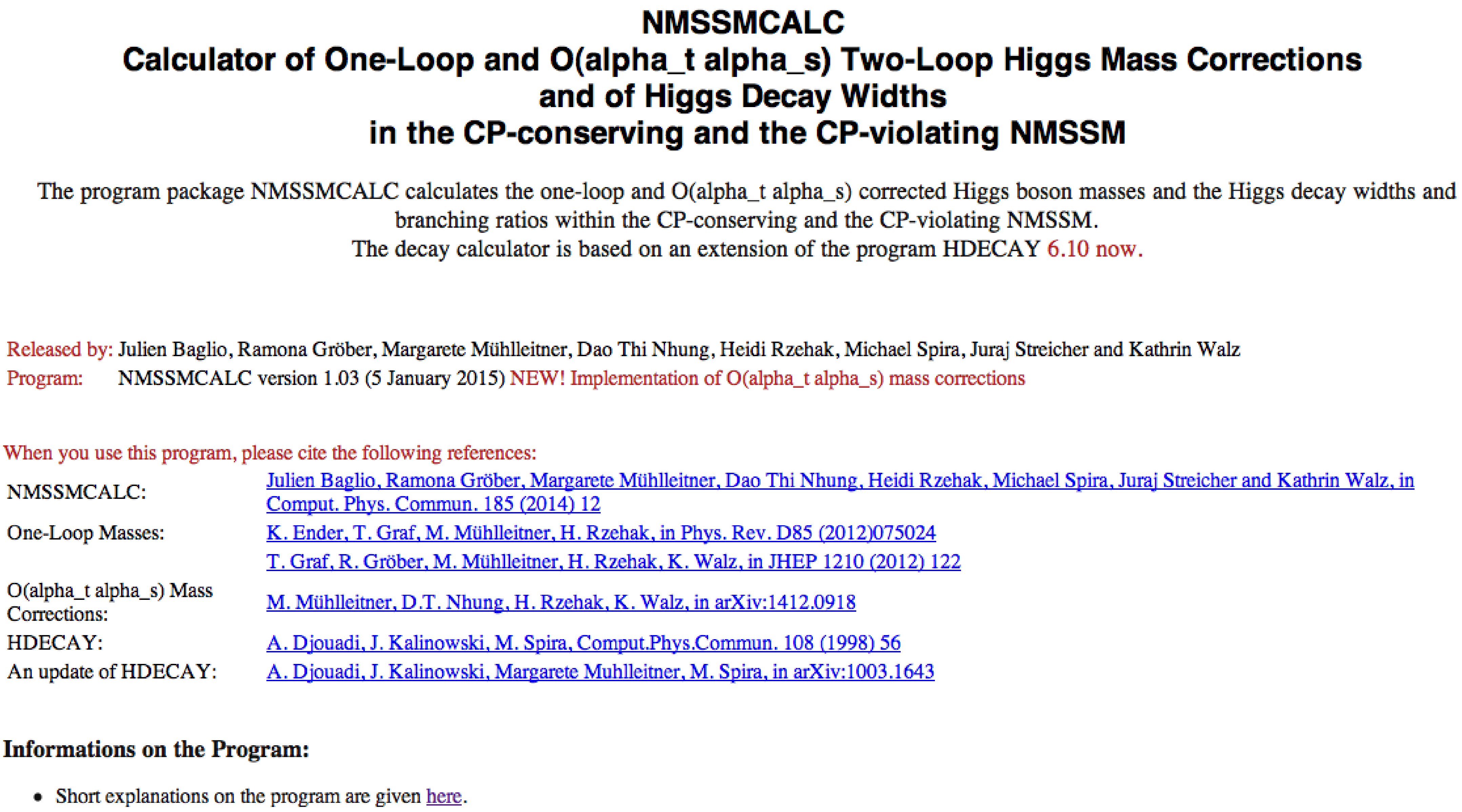
$\lambda_{H_sA_sA_s}$

λ_{HH_sh}

$\lambda_{AA_sH_s}$

λ_{AA_sh}

Not yet excluded by ATLAS search for scalar diphoton resonances [arXiv:1407.6583] http://www.itp.kit.edu/∼maggie/NMSSMCALC



NMSSMCALC
Calculator of One-Loop and O(alpha_t alpha_s) Two-Loop Higgs Mass Corrections and of Higgs Decay Widths in the CP-conserving and the CP-violating NMSSM

The program package NMSSMCALC calculates the one-loop and O(alpha_t alpha_s) corrected Higgs boson masses and the Higgs decay widths and branching ratios within the CP-conserving and the CP-violating NMSSM.
The decay calculator is based on an extension of the program HDECAY 6.10 now.

Released by: Julien Baglio, Ramona Gröber, Margarete Mühlleitner, Dao Thi Nhung, Heidi Rzehak, Michael Spira, Juraj Streicher and Kathrin Walz
Program: NMSSMCALC version 1.03 (5 January 2015) NEW! Implementation of O(alpha_t alpha_s) mass corrections

When you use this program, please cite the following references:

NMSSMCALC:	Julien Baglio, Ramona Gröber, Margarete Mühlleitner, Dao Thi Nhung, Heidi Rzehak, Michael Spira, Juraj Streicher and Kathrin Walz, in Comput. Phys. Commun. 185 (2014) 12
One-Loop Masses:	K. Ender, T. Graf, M. Mühlleitner, H. Rzehak, in Phys. Rev. D85 (2012)075024
	T. Graf, R. Gröber, M. Mühlleitner, H. Rzehak, K. Walz, in JHEP 1210 (2012) 122
O(alpha_t alpha_s) Mass Corrections:	M. Mühlleitner, D.T. Nhung, H. Rzehak, K. Walz, in arXiv:1412.0918
HDECAY:	A. Djouadi, J. Kalinowski, M. Spira, Comput.Phys.Commun. 108 (1998) 56
An update of HDECAY:	A. Djouadi, J. Kalinowski, Margarete Muhlleitner, M. Spira, in arXiv:1003.1643

Informations on the Program:

- Short explanations on the program are given here.

Conclusions

◇ Squark pair (and squark anti-squark) production and decay at NLO

- matched with parton showers in the `POWHEG` Box
- independent treatment of different subchannels important
- full NLO corrections important: distributions, total rates

◇ Light Stop Decays

- $c/u + \tilde{\chi}_1^0$ with SUSY QCD corrections
- $\tilde{\chi}_1^0 d_i f \bar{f}'$ with full dependence on masses of 3rd generation fermions
- $\tilde{\chi}_1^0 d_i W$ including off-shell effects

included in `SUSY-HIT` allowing for flavour-violating couplings

- exact BRs ⇝ weaker exclusion limits

◇ NMSSM Higgs Bosons

- Higher order corrections to masses and observables ⇝ precise predictions, distinguish models
- NMSSM Higgs sector compatible with LHC data, has a rich phenomenology
- spectacular and unique signatures possible

Thank You For Your Attention!