Vacuum Stability Bounds on Lepton Flavor Violating Tri-linear Soft-terms in the General MSSM

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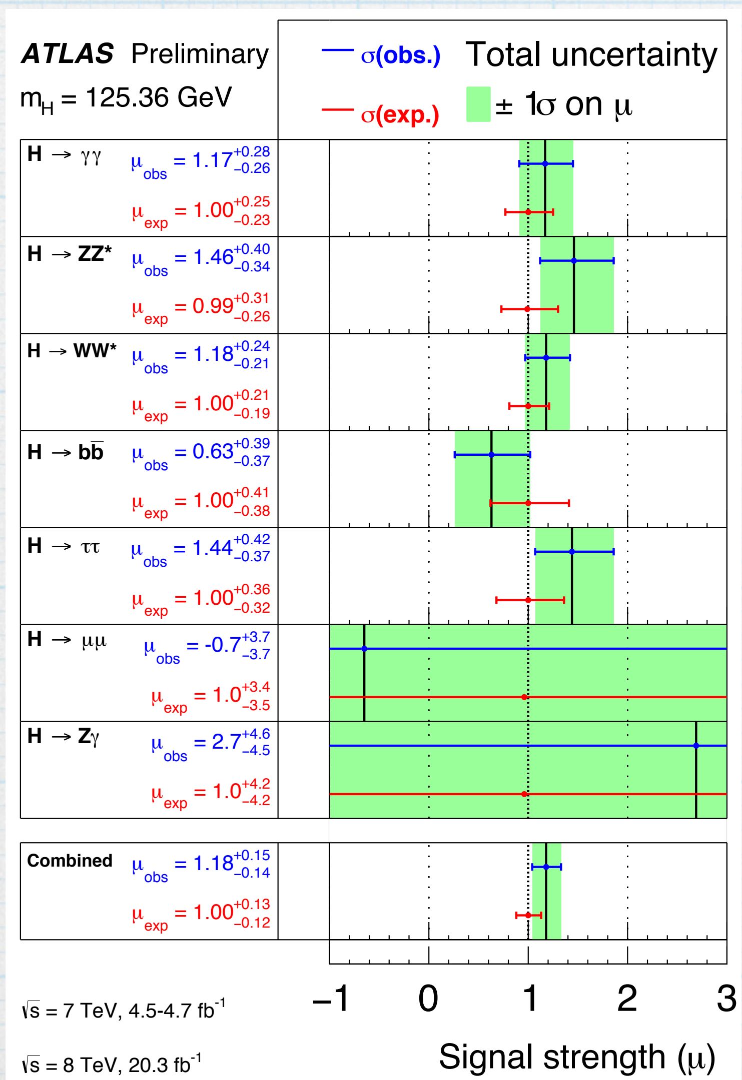
INFN, Rome

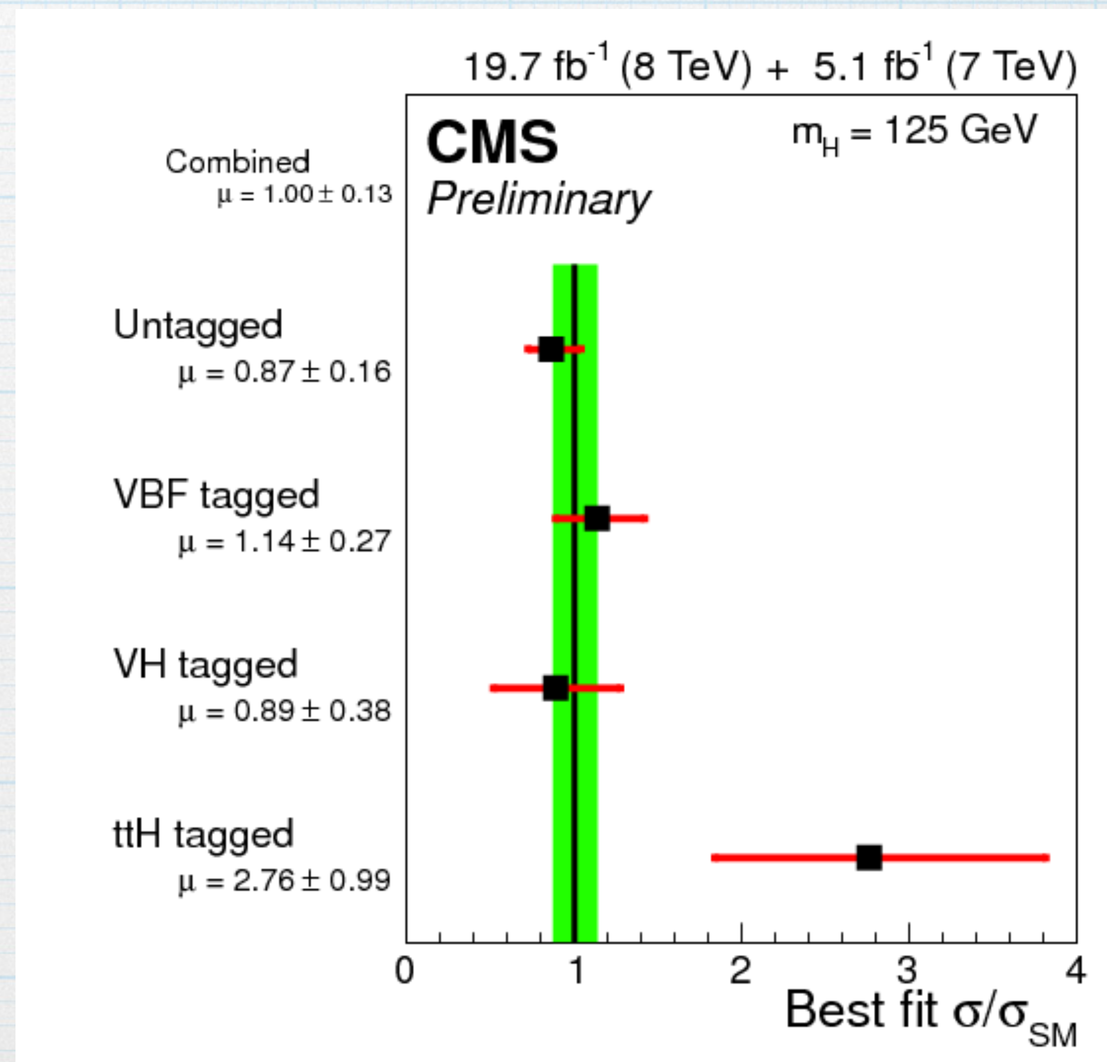
in collaboration w/ O. Eberhardt, A. Paul, and L. Silvestrini
[arXiv:1607.0XXXX]

SUSY 2016
Melbourne, Australia
July 4, 2016

Higgs Discovery at LHC

- Mass of the Higgs is around 125 GeV
- Higgs is parity even and spin-0
- Higgs properties in Run-1 look “SM-like”





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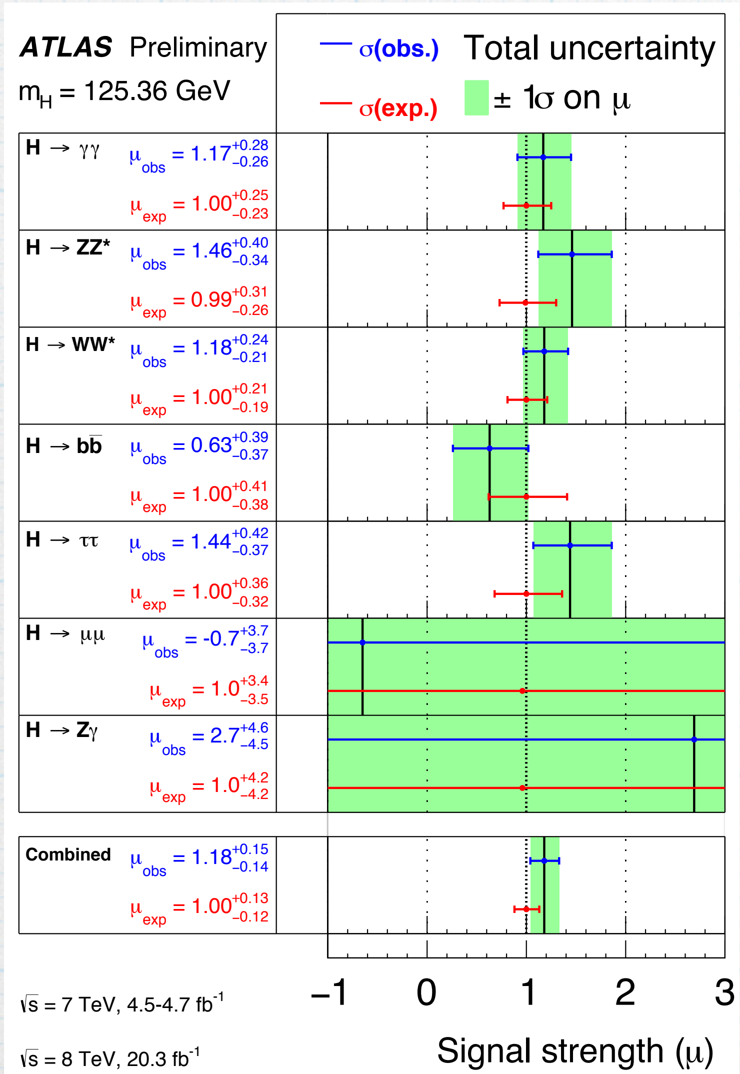
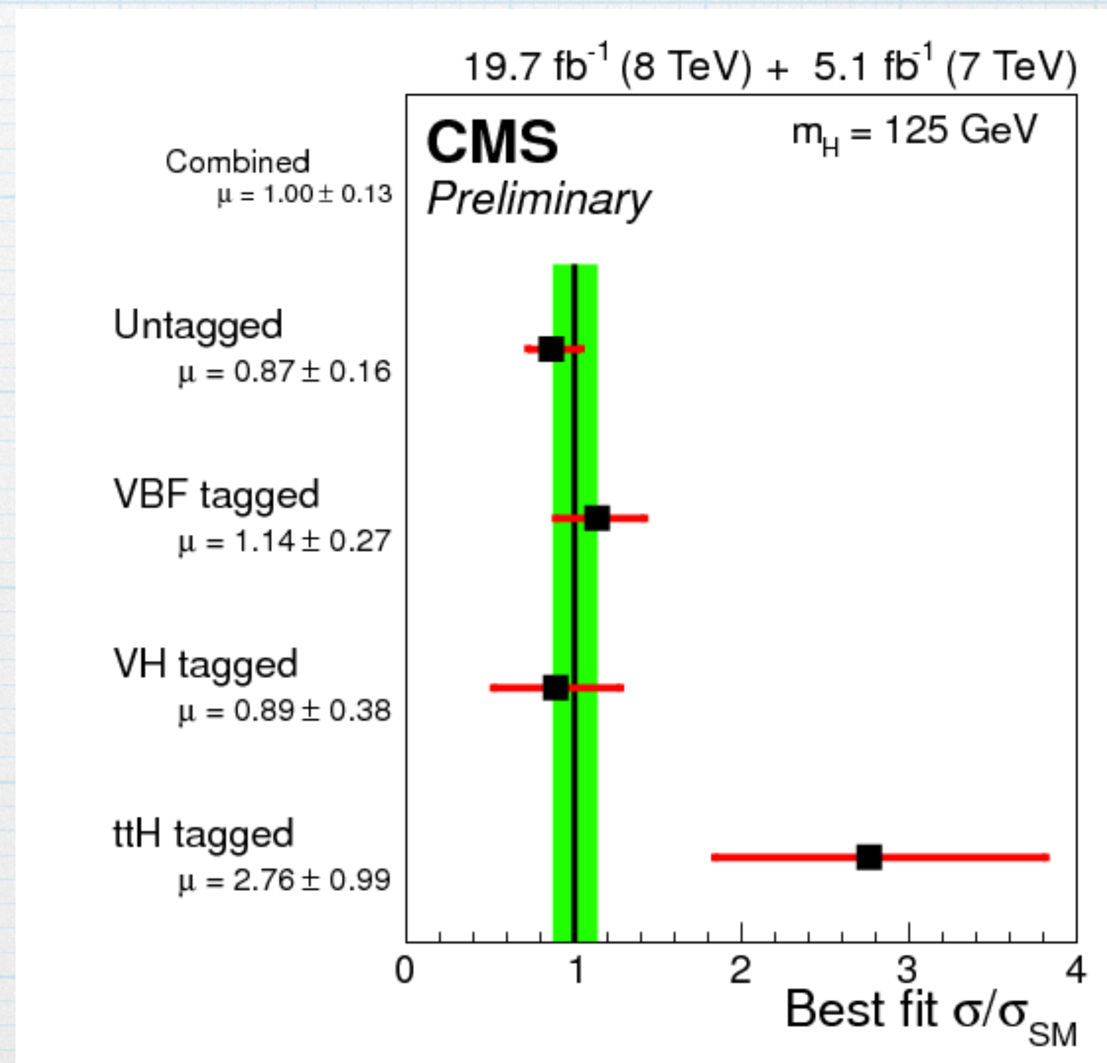
Discovery of 125 GeV Higgs at LHC puts constraints on the MSSM parameters.





Testing SUSY

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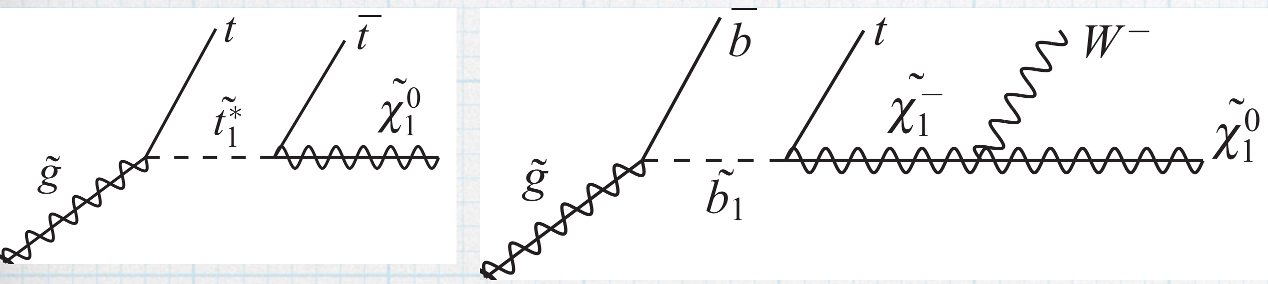
Direct Search

producing sparticles
at the colliders like LHC, ILC



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sparticle masses like

- gluinos are ruled out up to masses 1–1.25 TeV
- stops, sbottoms are > 600 GeV
- first two generations of squarks are > 0.9 TeV

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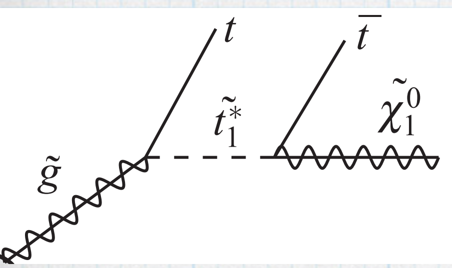

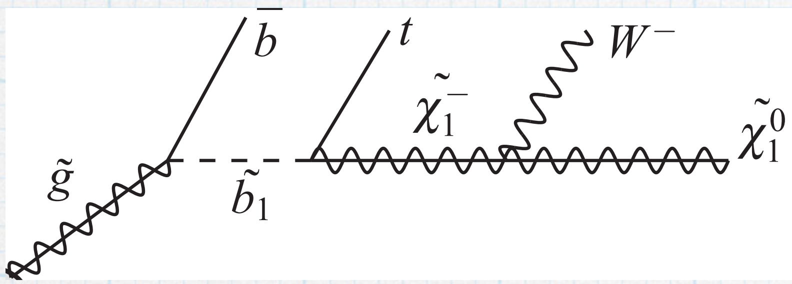

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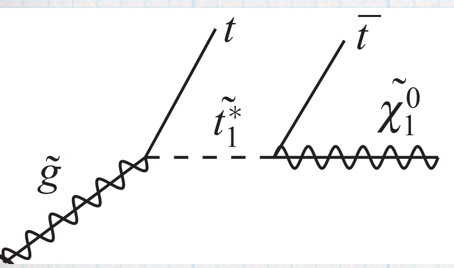

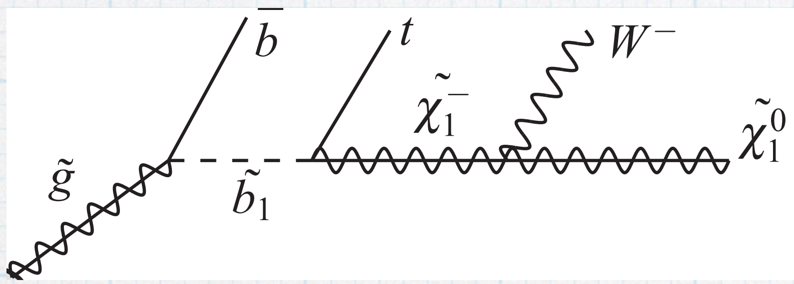

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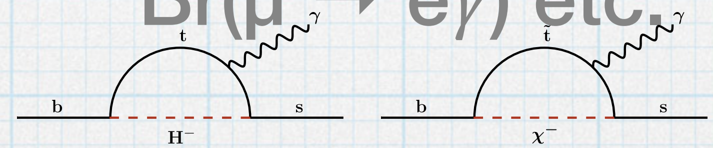
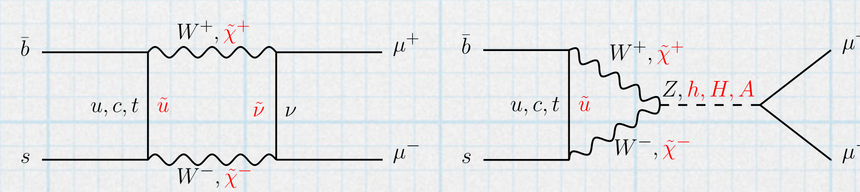
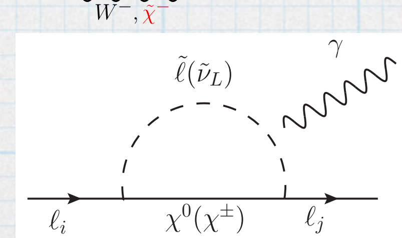
Flavor

sparticles in the loops
of the SM flavor processes
like, Br(b → sγ),
Br(B_s → μμ),
Br(μ → eγ) etc.







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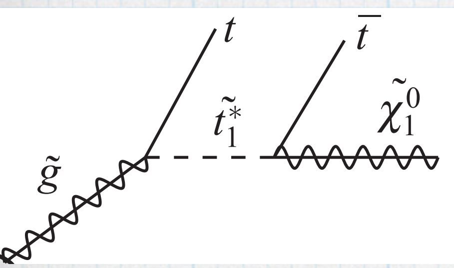

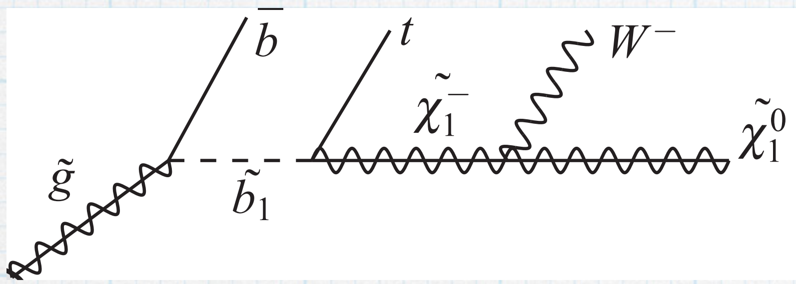

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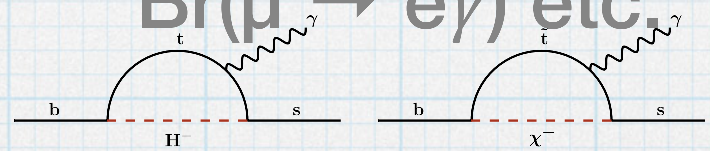
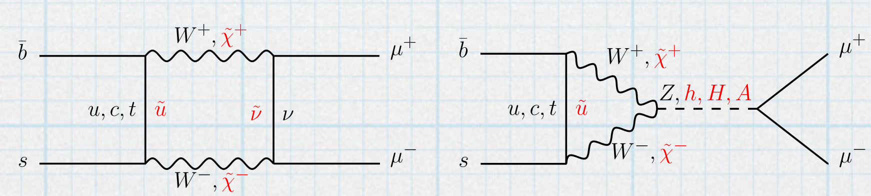
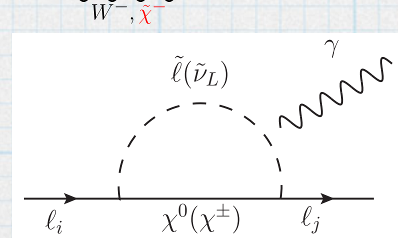
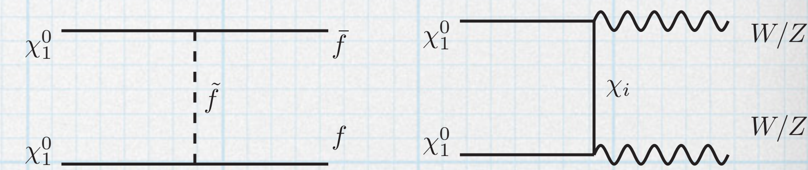


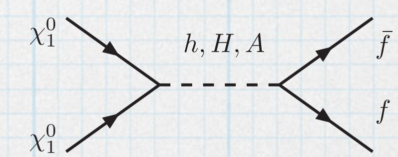


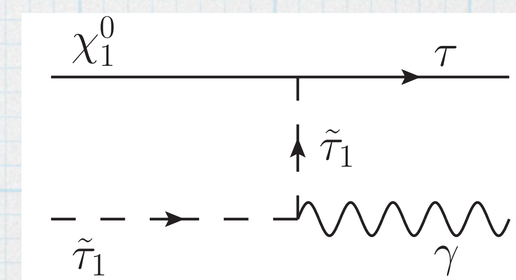


Dark Matter

presence of new vertices ➜ efficient annihilation







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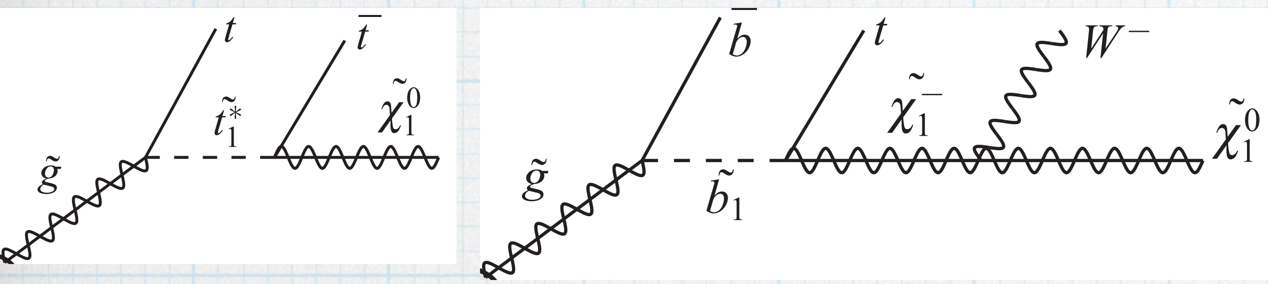

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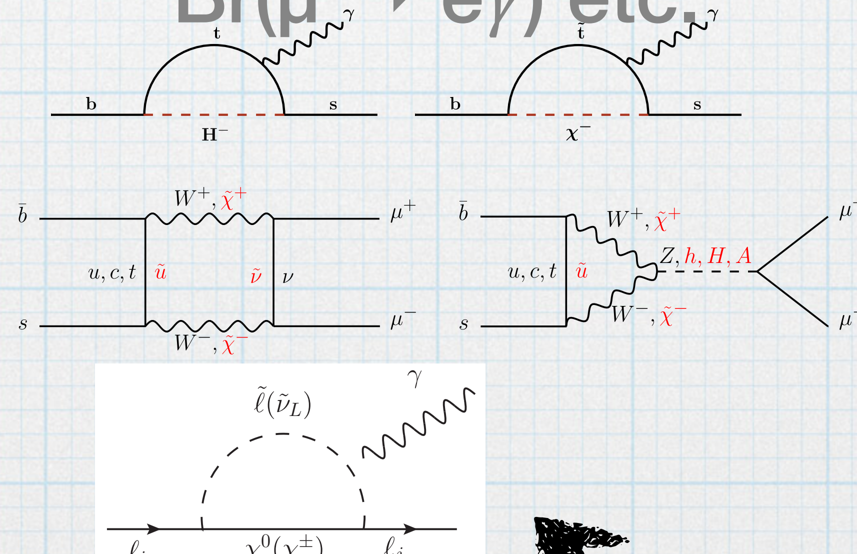

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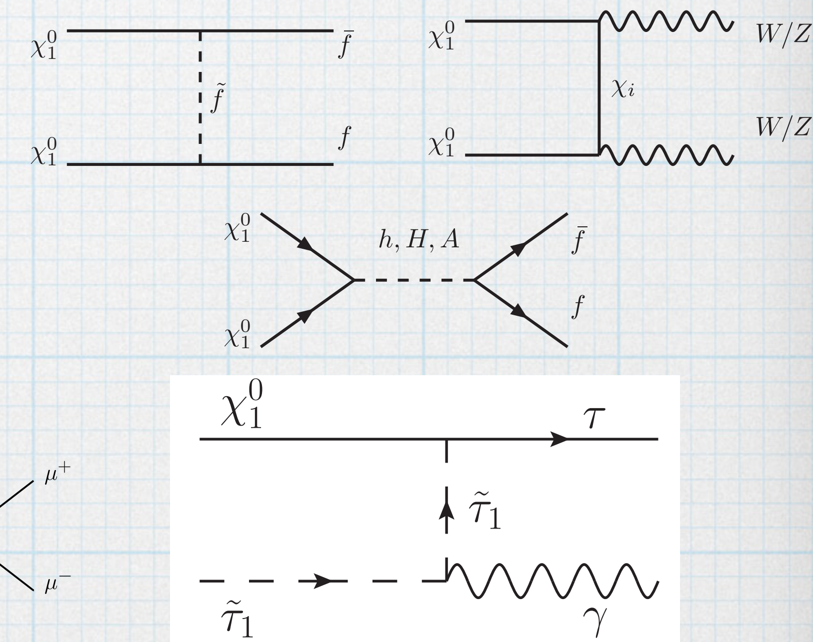


puts constraints on
masses and couplings

SUSY Flavor Violation

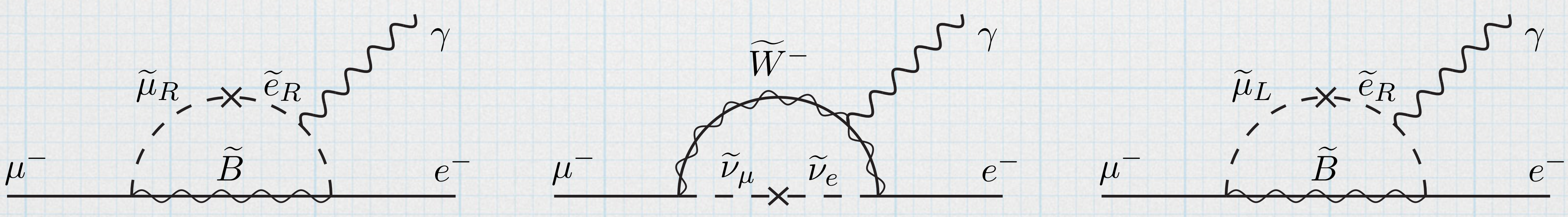
- In exact SUSY, equal masses for particles and its super-partners.

$$\mathcal{L}_{\rm soft}^{\rm MSSM} = -\frac{1}{2}\left(M_3\widetilde{g}\widetilde{g} + M_2\widetilde{W}\widetilde{W} + M_1\widetilde{B}\widetilde{B} + {\rm c.c.}\right) -(\tilde{\bar{u}}\mathbf{a}^u\tilde{Q}H_u - \tilde{\bar{d}}\mathbf{a}^d\tilde{Q}H_d - \tilde{\bar{e}}\mathbf{a}^l\tilde{L}H_d + {\rm c.c.}) -\widetilde{Q}^\dagger\,\mathbf{m_Q^2}\,\widetilde{Q} - \widetilde{L}^\dagger\,\mathbf{m_L^2}\,\widetilde{L} - \widetilde{\bar{u}}\,\mathbf{m_{\bar{u}}^2}\,\widetilde{\bar{u}}^\dagger - \widetilde{\bar{d}}\,\mathbf{m_{\bar{d}}^2}\,\widetilde{\bar{d}}^\dagger - \widetilde{\bar{e}}\,\mathbf{m_{\bar{e}}^2}\,\widetilde{\bar{e}}^\dagger - m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - (bH_uH_d + {\rm c.c.})\,.$$

- To realize in nature, SUSY must be broken.

- 3 kinds of soft-breaking terms introduced in the Lagrangian.

- soft-masses and tri-linear couplings => New sources of flavor violation. Flavor-changing neutral currents **(e.g. b → sγ, μ → eγ)**



Charge breaking constraint

Soft-breaking tri-linear term in the Lagrangian

$$\mathcal{L}_{\rm soft} = -\bar{\tilde{\mathsf{e}}}\mathbf{a}^{l}\tilde{L}H_{d} + \text{c.c.}$$

In the presence of $H_d, \tilde{\tau}_L$ and $\tilde{\mu}_R$

$$\begin{aligned}\mathcal{V} = (m_{H_d}^2 + \mu^2)|H_d|^2 + m_{\mu_R}^2|\tilde{\mu}_R|^2 + m_{\tau_L}^2|\tilde{\tau}_L|^2 \\ - (A_{23}^l H_d \tilde{\mu}_R^* \tilde{\tau}_L + \text{c.c.}) + Y_\tau^2|H_d\tilde{\tau}_L|^2 + Y_\mu^2|H_d\tilde{\mu}_R|^2 \\ + \frac{g_1^2}{8}\left(2|\tilde{\mu}_R|^2 - |\tilde{\tau}_L|^2 - |H_d|^2\right)^2 + \frac{g_2^2}{8}\left(|\tilde{\tau}_L|^2 - |H_d|^2\right)^2\end{aligned}$$

the CCB minima of the potential around the D-flat direction

$$|H_d| = |\tilde{\tau}_L| = |\tilde{\mu}_R| \equiv a$$

$$\mathcal{V} = (m_{H_d}^2 + \mu^2 + m_{\mu_R}^2 + m_{\tau_L}^2)\, a^2 - 2|A_{23}^l|\, a^3 + (Y_\mu^2 + Y_\tau^2)\, a^4$$

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$$a \sim 2\frac{|A^l_{23}|}{Y_\tau^2}$$

absolute stability

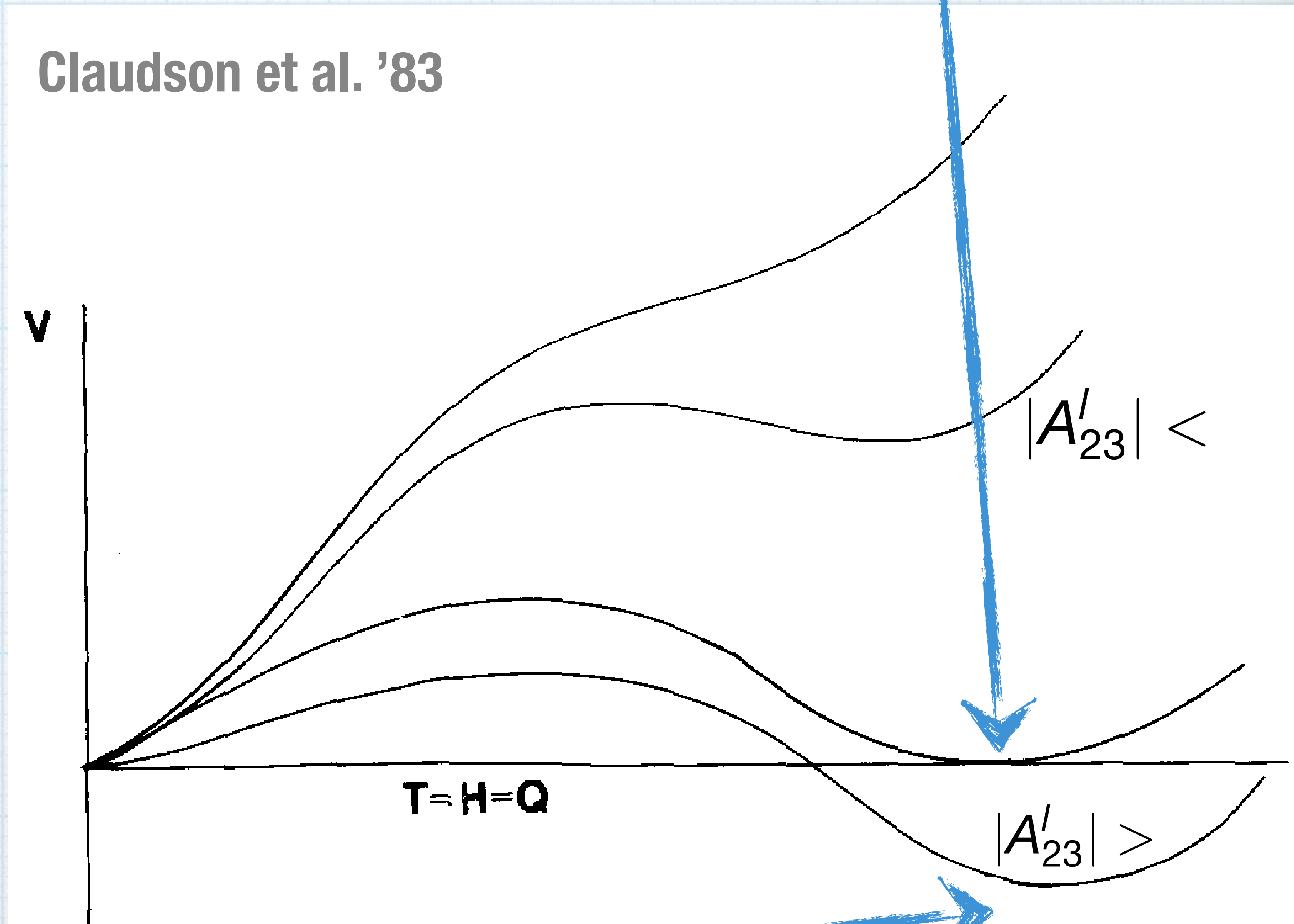
$$|A^l_{23}|^2 \leq Y_\tau^2(m^2_{H_d} + \mu^2 + m^2_{\mu_R} + m^2_{\tau_L})$$

$$\frac{\Gamma}{V} = A\, e^{-S[\bar{\phi}]}$$

meta-stability: $\Gamma/V \sim H_0^4$

$$S[\bar{\phi}] \gtrsim 400$$

Coleman et al. '77

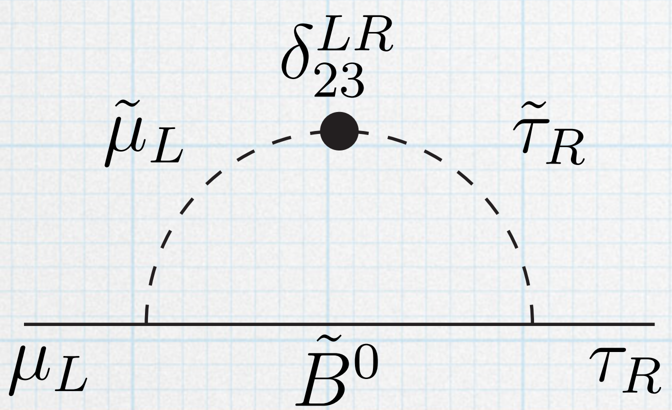


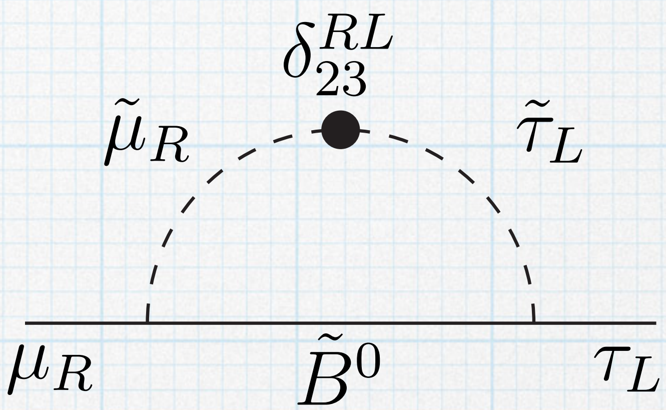
meta-stability

Quiros '94, Kusenko et al. '96, Carena et al. '96

BR($\tau \to \mu\gamma$)

In the presence of A^l_{23} and A^l_{32} the branching fraction is





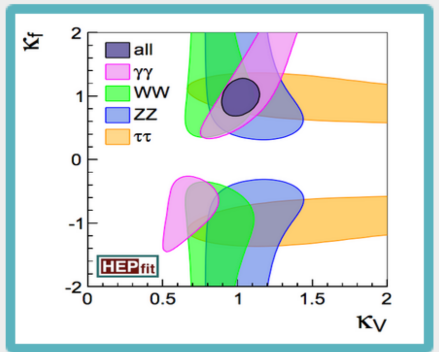
$$\mathrm{BR}(\tau \to \mu\gamma) \propto \frac{M_1^2 \tan\beta^2}{|\mu|^2} \left[\left(\delta_{23}^{LR}\right)^2 \left| \frac{m_R m_L}{m_\tau \mu \tan\beta} I_B \right|^2 + \left(\delta_{23}^{RL}\right)^2 \left| \frac{m_R m_L}{m_\tau \mu^* \tan\beta} I_B \right|^2 \right]$$

$$\delta_{23}^{RL} \equiv \frac{A^l_{23}\langle H_d^0 \rangle}{m_{\tilde{l}}^2} \qquad m_{\tilde{l}} \equiv \sqrt{m_R^2 m_L^2}$$

HEPfit

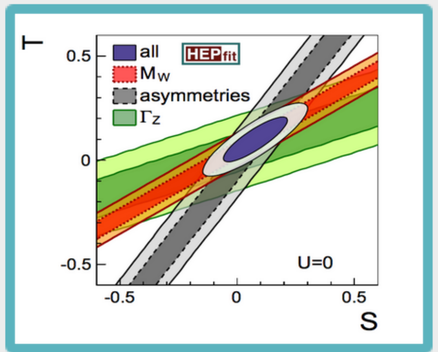
home developers samples documentation

HEPfit: a Code for the Combination of Indirect and Direct Constraints on High Energy Physics Models.



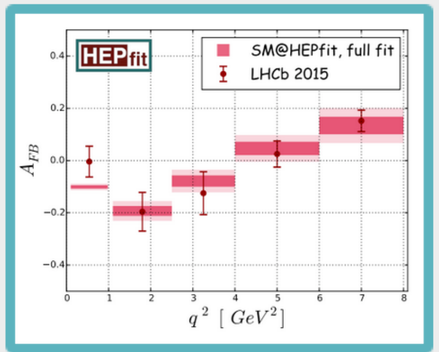
Higgs Physics

HEPfit can be used to study Higgs couplings and analyze data on signal strengths.



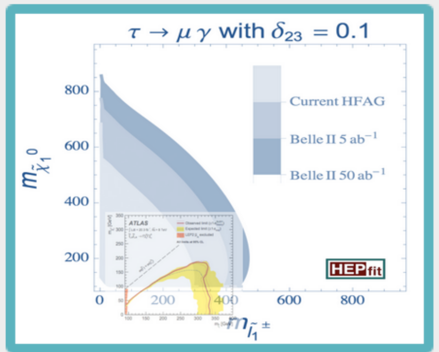
Precision Electroweak

Electroweak precision observables are included in HEPfit



Flavour Physics

The Flavour Physics menu in HEPfit includes both quark and lepton flavour dynamics.

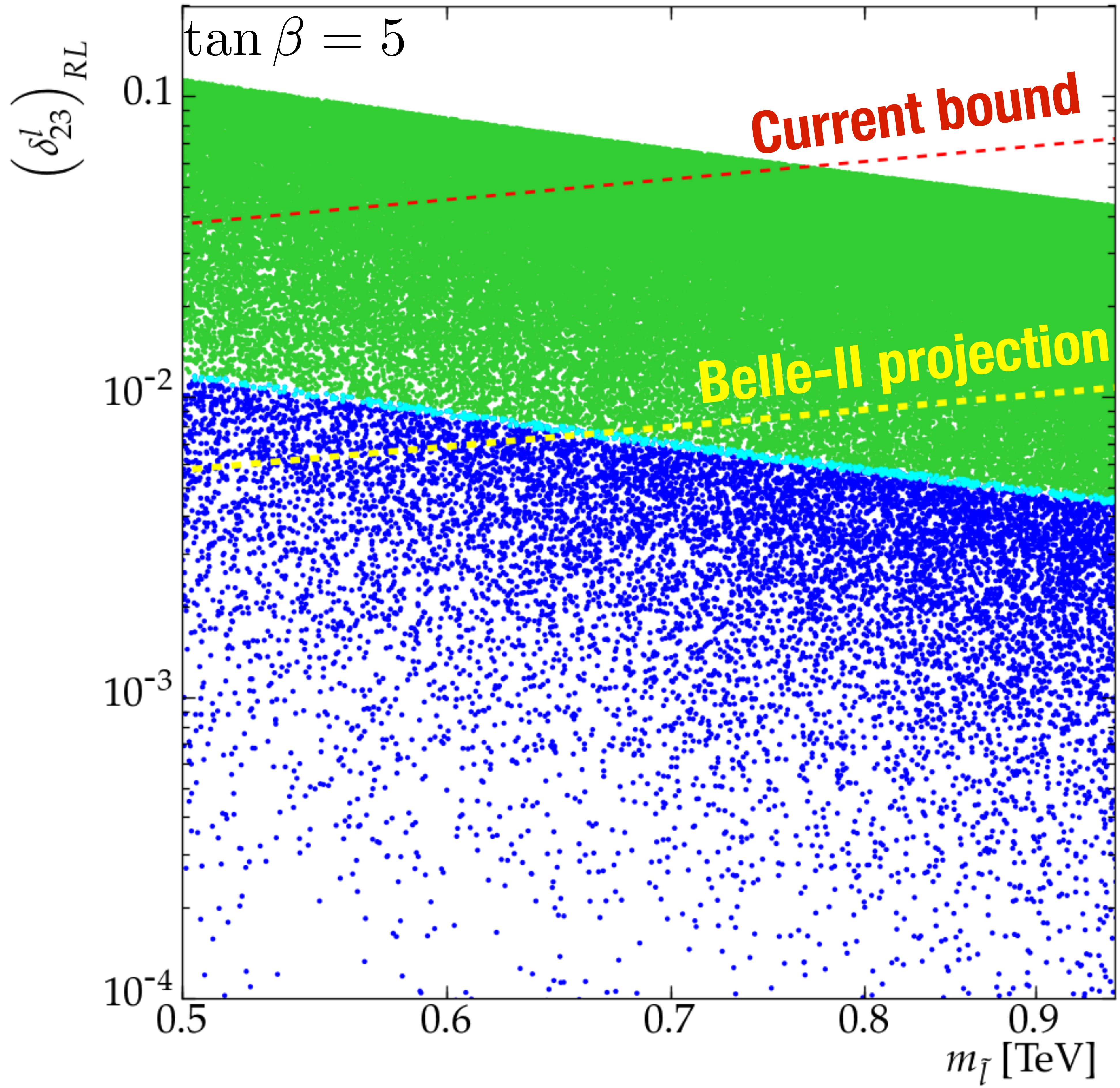


BSM Physics

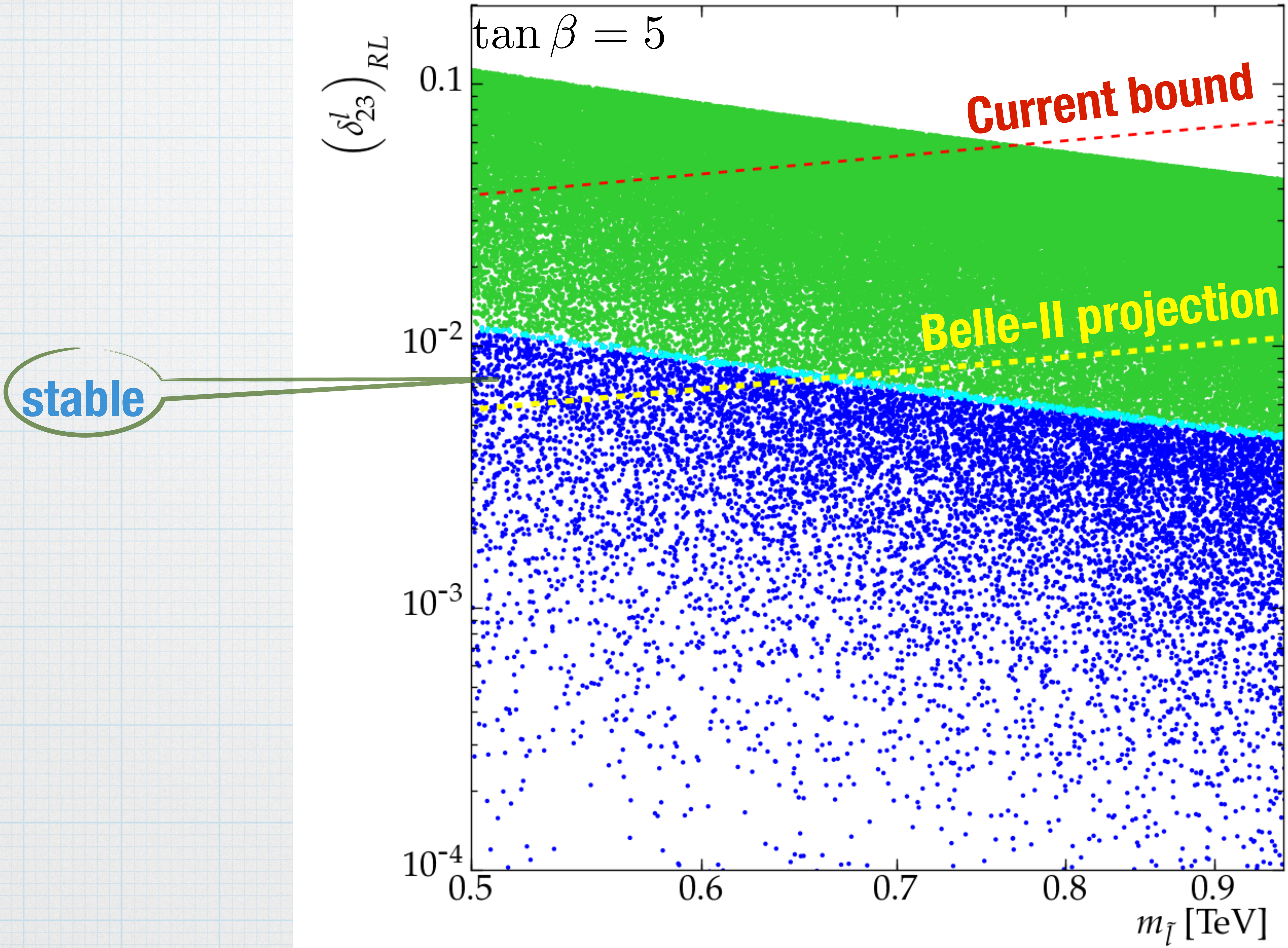
Dynamics beyond the Standard Model can be studied by adding models in HEPfit.

- Flexible open-source C++ code to do calculations with various observables in the SM and beyond:
  - Simple user-defined models and/or observables
  - Stand-alone or library modes to compute single observables.
  - Optional Bayesian fitting framework to do global statistical analyses (run-time optimized, parallelized; can be replaced by a different one)

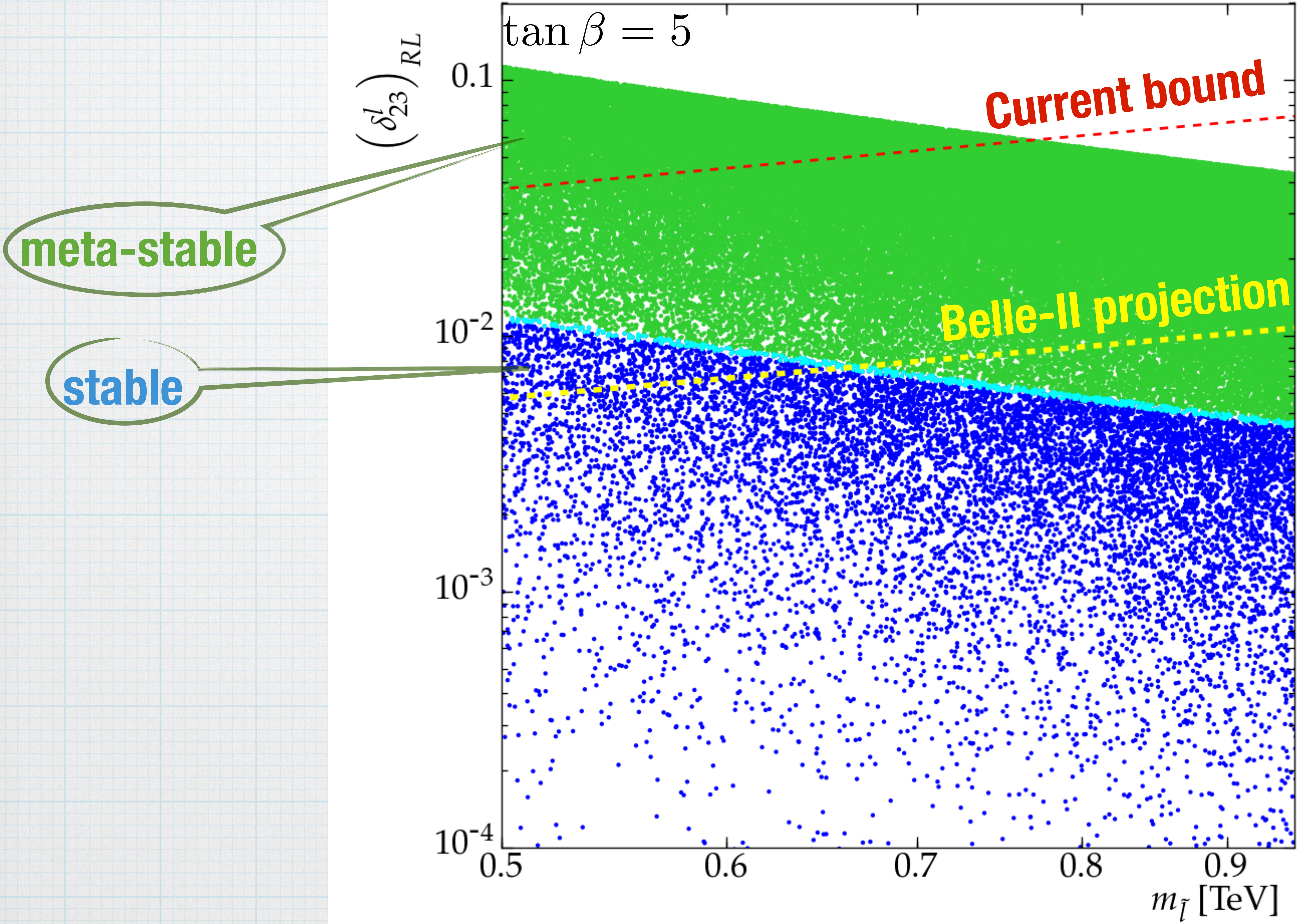
For more details, look at the talk by J. de Blas this afternoon



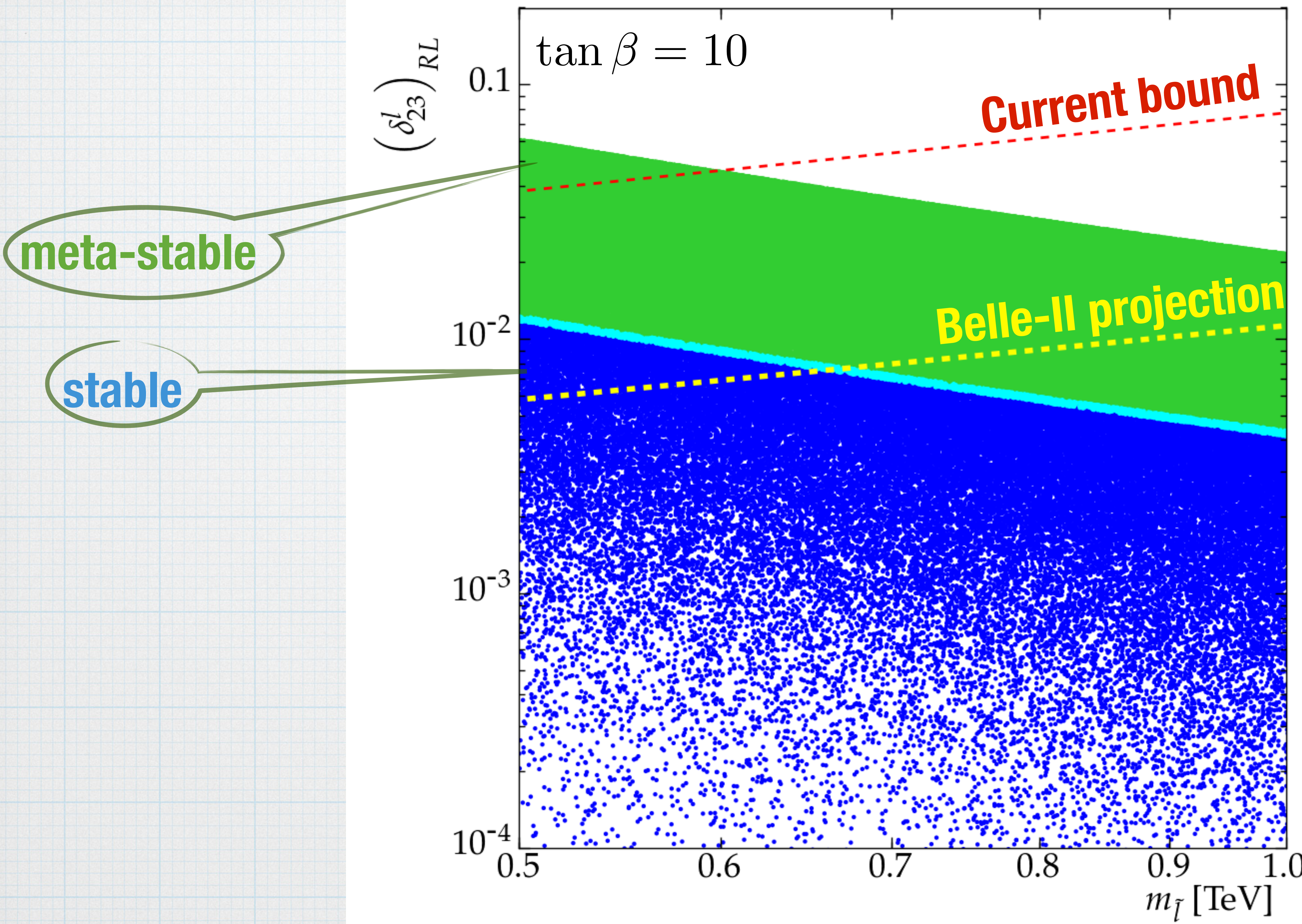
$\tan\beta = 5$
Current bound
Belle-II projection
$\left(\delta^l_{23}\right)_{RL}$
0.1
10^{-2}
10^{-3}
10^{-4}
0.5
0.6
0.7
0.8
0.9
$m_{\tilde{l}}$ [TeV]



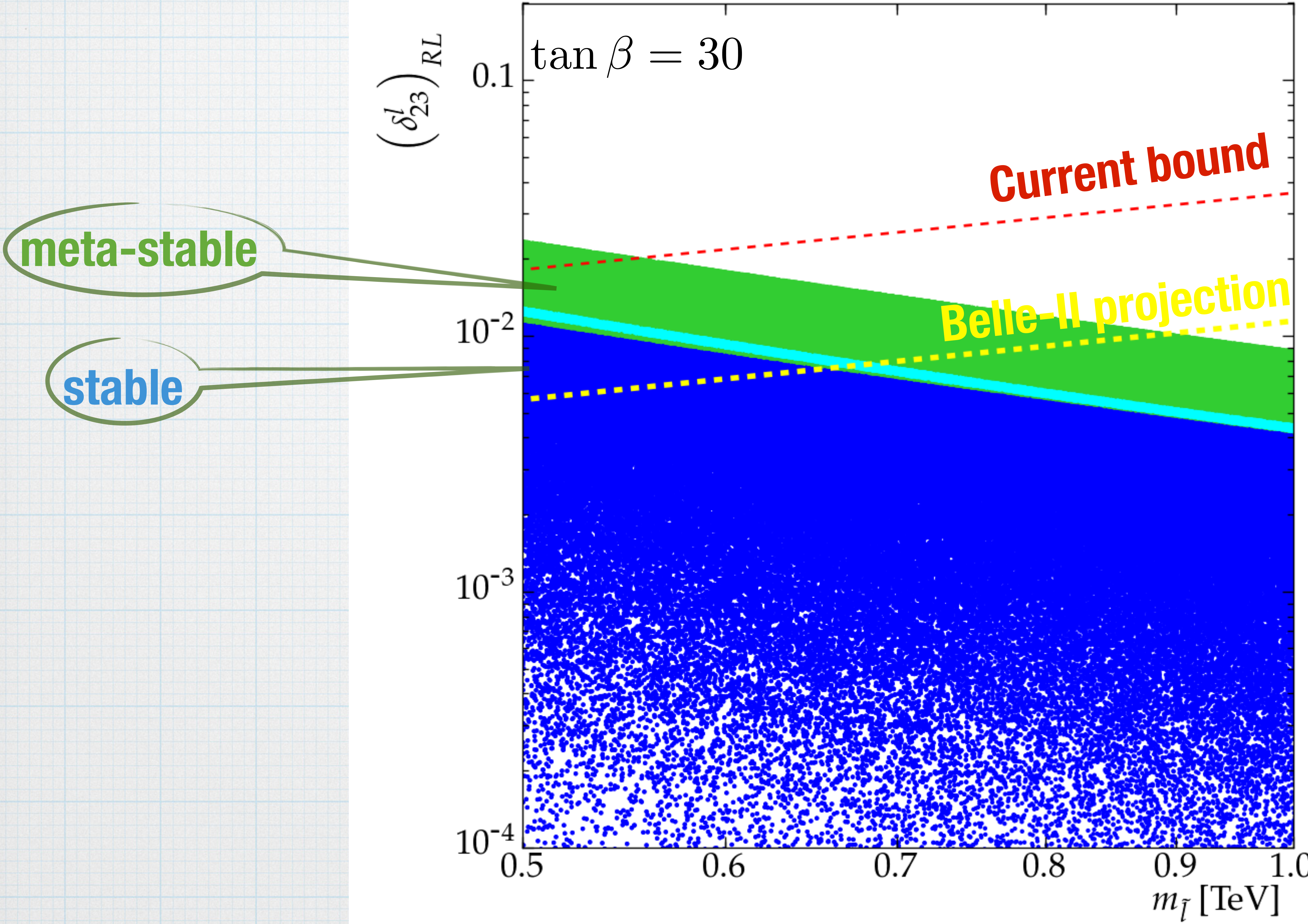
$\tan\beta = 5$
Current bound
Belle-II projection
stable
$(\delta^l_{23})_{RL}$
0.1
10^{-2}
10^{-3}
10^{-4}
0.5
0.6
0.7
0.8
0.9
$m_{\tilde{l}}$ [TeV]



meta-stable
stable
$\tan\beta = 5$
$(\delta^l_{23})_{RL}$
0.1
10^{-2}
10^{-3}
10^{-4}
Current bound
Belle-II projection
0.5
0.6
0.7
0.8
0.9
$m_{\tilde{l}}$ [TeV]



meta-stable
stable
$\tan\beta = 10$
Current bound
Belle-II projection
$\left(\delta^{l}_{23}\right)_{RL}$
0.1
10^{-2}
10^{-3}
10^{-4}
0.5
0.6
0.7
0.8
0.9
1.0
$m_{\tilde{l}}$ [TeV]



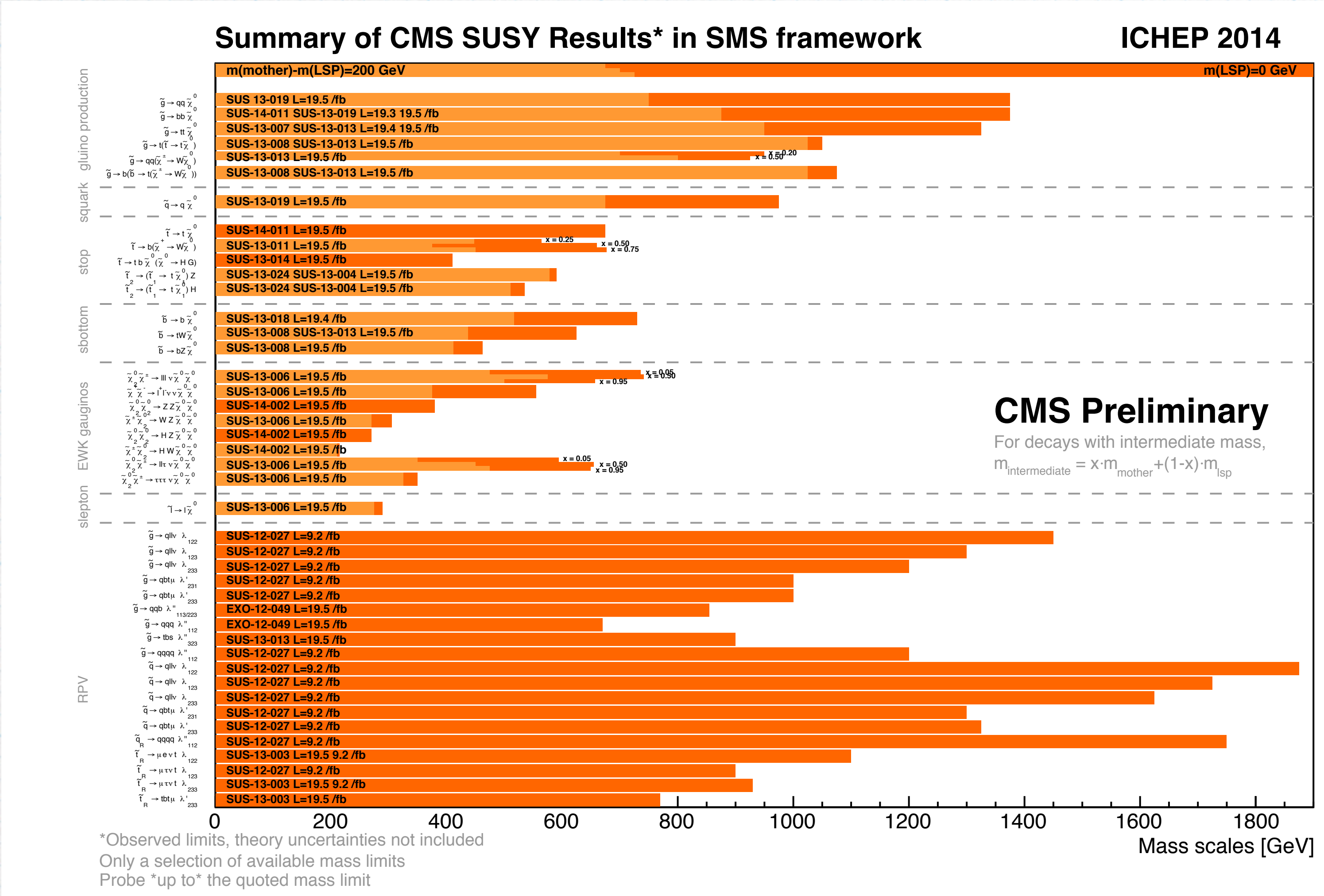
meta-stable
stable
$\tan\beta = 30$
Current bound
Belle-II projection
$(\delta^l_{23})_{RL}$
0.1
10^{-2}
10^{-3}
10^{-4}
0.5
0.6
0.7
0.8
0.9
$m_{\tilde{l}}$ [TeV]

Conclusion

* Unlike the FCNC bounds, the strength of the CCB and UFB bounds does not decrease as the scale of supersymmetry breaking increases.
* meta-stability relaxes the bounds on the flavor violating tri-linear couplings.
* Future flavor factories, e.g. Belle-II will be able to probe large factions of the meta-stable region for A^l_{23}.

Thank You!!

Extras


Summary of CMS SUSY Results* in SMS framework
ICHEP 2014
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
SUS 13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
SUS-13-007 SUS-13-013 L=19.4 19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
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SUS-14-011 L=19.5 /fb
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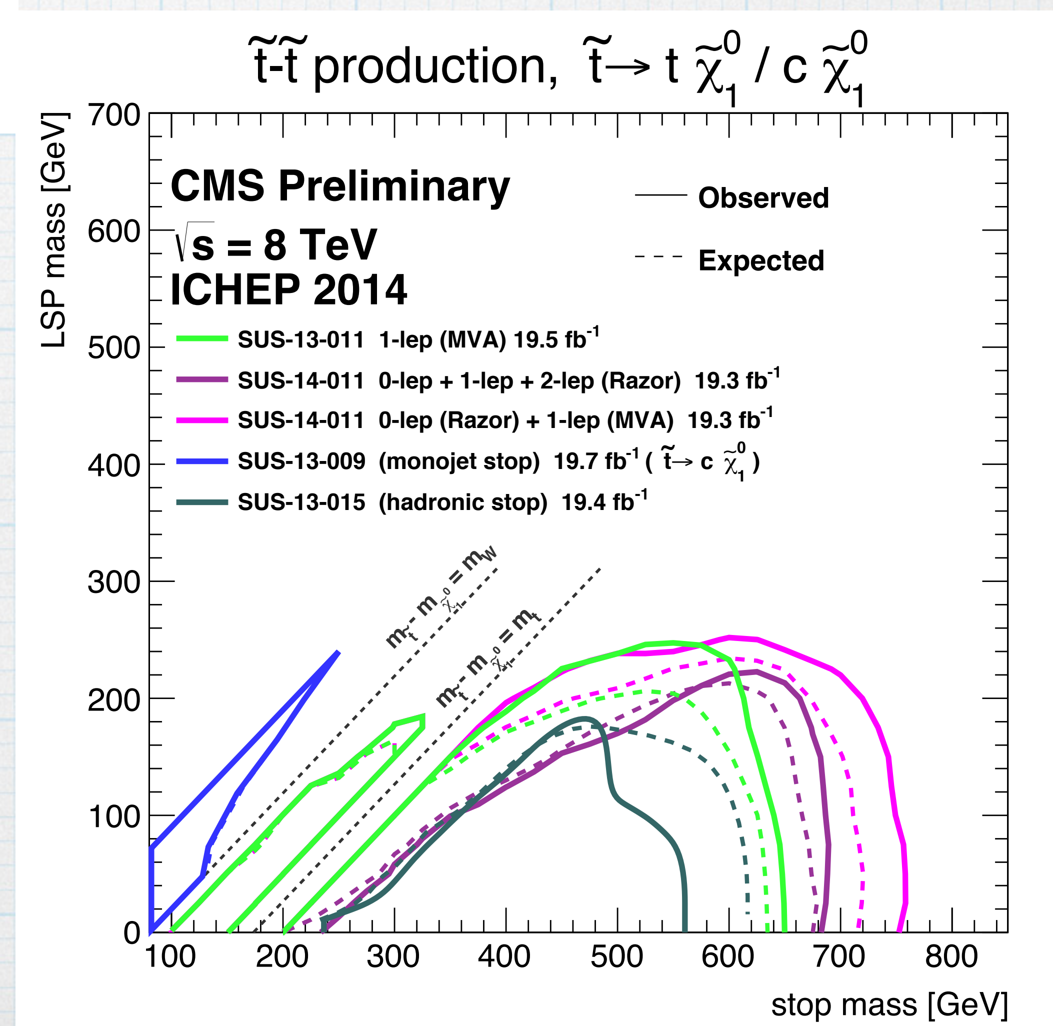
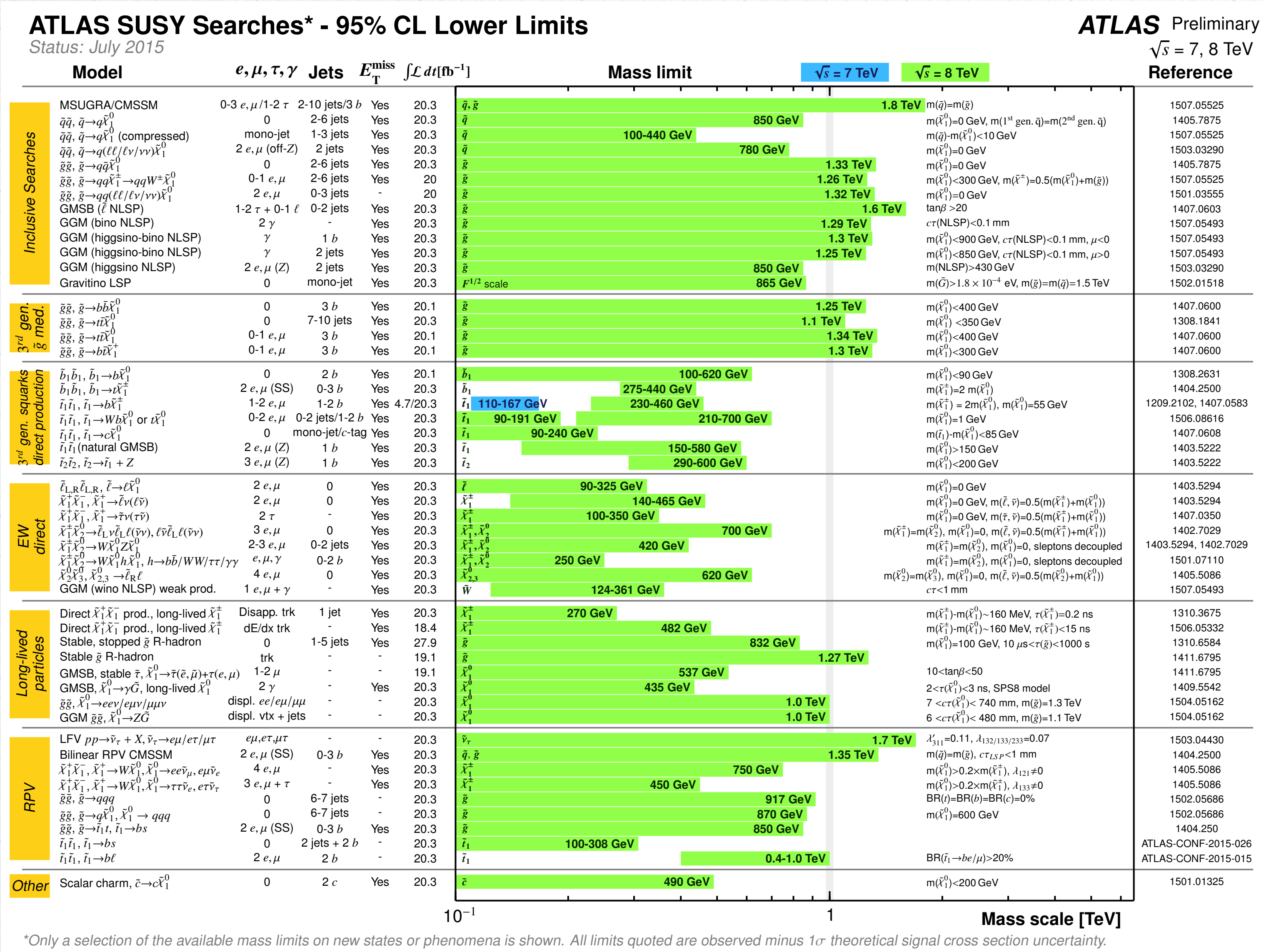
SUS-13-003 L=19.5 9.2 /fb
SUS-13-003 L=19.5 /fb
CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother + (1-x)·m_lsp
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit


t̃-t̃ production, t̃ → t χ̃₁⁰ / c χ̃₁⁰
CMS Preliminary
√s = 8 TeV
ICHEP 2014
Observed
Expected
SUS-13-011 1-lep (MVA) 19.5 fb⁻¹
SUS-14-011 0-lep + 1-lep + 2-lep (Razor) 19.3 fb⁻¹
SUS-14-011 0-lep (Razor) + 1-lep (MVA) 19.3 fb⁻¹
SUS-13-009 (monojet stop) 19.7 fb⁻¹ (t̃ → c χ̃₁⁰)
SUS-13-015 (hadronic stop) 19.4 fb⁻¹
LSP mass [GeV]
700
600
500
400
300
200
100
0
100
200
300
400
500
600
700
800
stop mass [GeV]



ATLAS SUSY Searches* - 95% CL Lower Limits

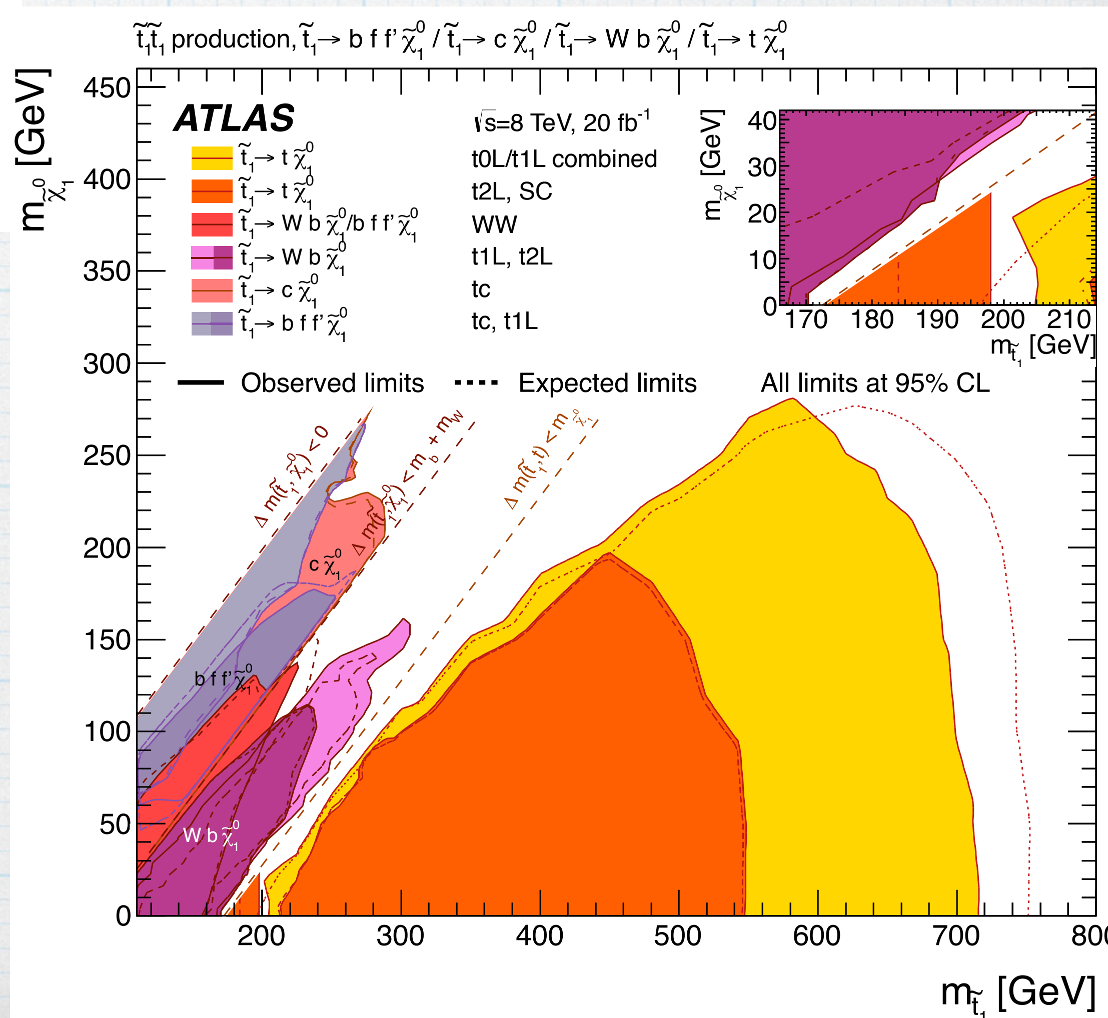
Status: July 2015

ATLAS Preliminary, $\sqrt{s}$ = 7, 8 TeV ($\sqrt{s}$ = 7 TeV; $\sqrt{s}$ = 8 TeV)

	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[fb^{-1}]$		Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$	1.8 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$	100-440 GeV	$m(\tilde{q})-m(\tilde{\chi}_1^0)$<10 GeV	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$	780 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1503.03290
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	0-1 e,μ	2-6 jets	Yes	20	$\tilde{g}$	1.26 TeV	$m(\tilde{\chi}_1^0)$<300 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1507.05525
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	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	$\tan\beta$>20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$	1.29 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<900 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}_1^0)$<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	1507.05493
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$	850 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	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
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	1-2 e,μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$	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
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$	90-191 GeV; 210-700 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1506.08616
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	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
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	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	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	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
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	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
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	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
	GGM (wino NLSP) weak prod.	1 $e,\mu+\gamma$	-	Yes	20.3	$\tilde{W}$	124-361 GeV	$c\tau$<1 mm	1507.05493
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
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^{\pm}$	482 GeV	$m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^{\pm})$<15 ns	1506.05332
	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 $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$	537 GeV	10<$\tan\beta$<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, 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
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV	7 <$c\tau(\tilde{\chi}_1^0)$< 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$	1.0 TeV	6 <$c\tau(\tilde{\chi}_1^0)$< 480 mm, $m(\tilde{g})$=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$	1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	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
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	750 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^{\pm})$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	450 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^{\pm})$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	870 GeV	$m(\tilde{\chi}_1^0)$=600 GeV	1502.05686
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$	850 GeV		1404.250
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$	100-308 GeV		ATLAS-CONF-2015-026
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$	0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$	490 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1501.01325

Mass scale [TeV] (10^{-1} – 1)

*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.

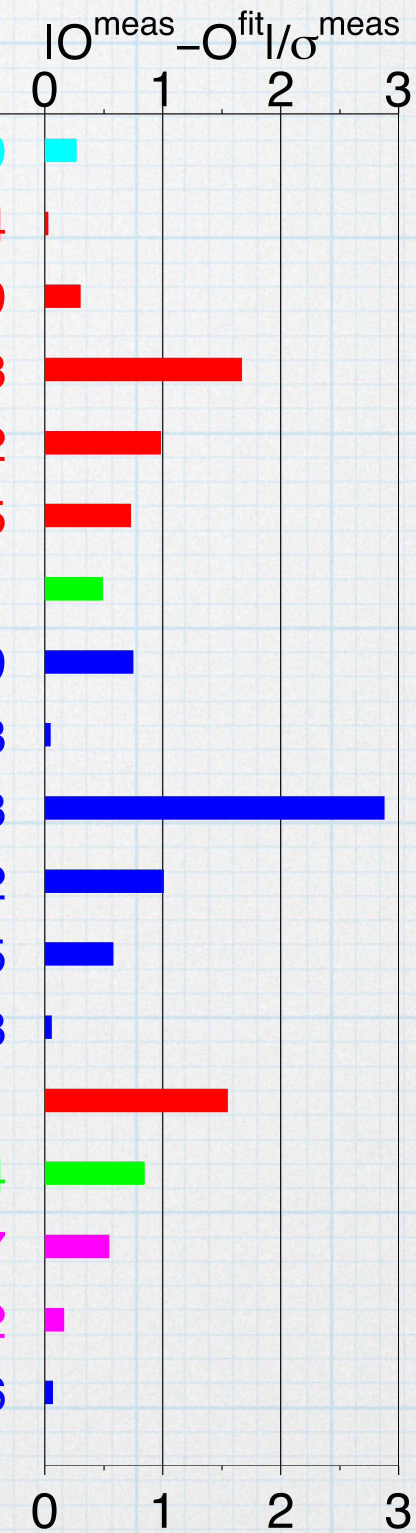


- The Standard model has passed almost all the experimental tests over decades.

- In spite of these successes SM has quite a few shortcomings, like
    - Neutrino mass
    - Dark matter
    - Baryon asymmetry of the Universe
    - Fine tuning ....

- To address these issues SM has to be extended.

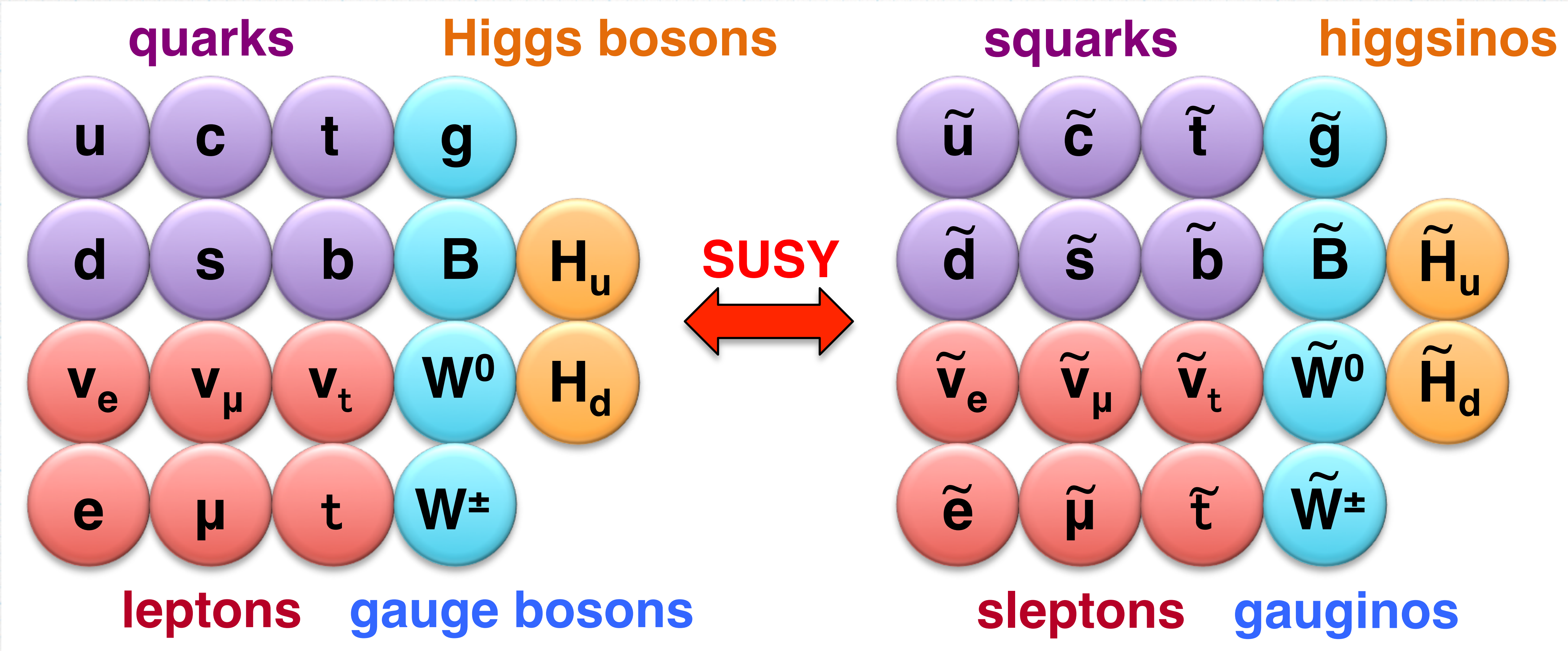
	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02750 ± 0.00033	0.02759
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ_{had}^0 [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21579
R_c	0.1721 ± 0.0030	0.1723
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.385 ± 0.015	80.377
Γ_W [GeV]	2.085 ± 0.042	2.092
m_t [GeV]	173.20 ± 0.90	173.26



March 2012

- Many possible extensions are proposed, like SUSY, Composite Higgs, Extra Dimensions ...

Supersymmetry



- Symmetry between fermions and bosons. One supersymmetric multiplet for every standard model particle.

- In conserved SUSY particles in a multiplet share the same couplings and masses.

- To realize in nature SUSY must be broken.

Advantages of SUSY

* protects the Higgs mass by introducing a new physics scale.

* calculable and thus in principle, predictable.

* provides a viable Dark Matter candidate if R-parity is conserved.

* lightest Higgs boson can be SM-like in regions of parameter space.

* unifies the SM gauge couplings.