SPA

SUPERSYMMETRY PARAMETER ANALYSIS

$\mathcal{SPA}$

SUPERSYMMETRY PARAMETER ANALYSIS

$*$ $\mathcal{SPA}$ Collaboration $*$

ILC + LHC

Authors from America, Asia, Europe

B.Allanach, A.Bartl, P.Bechtle, G.Bélanger, G.Blair, E. Boos, K.Desch, A.Djouadi, A.Freitas, T.Fritzsche, J.Guasch, S.Heinemeyer, W.Hollik, C.Hugonie, H.Eberl, U.Ellwanger, I.Jack, D.R.T.Jones, J.Kalinowski*, W.Kilian*, S.Kraml, R.Lafaye, W.Majerotto, U.Martyn*, D.J.Miller, G.Moortgat-Pick, M.M.Mühlleitner, W.Öller, T.Plehn, G.Polesello, W.Porod*, P.Skands, P.Slavich, M.Spira, D.Stöckinger, G.Weiglein, P.Wienemann, D.Zerwas, PMZ, $\mathcal{NN}$[Am,As,Eu]

SUPERSYMMETRY: stabilizing bridge [qu. fluctuations] between elw and GUT/PL scales ⇒ connection gravity

⇒ root of particle phys

extrapolation over 14 orders of magnitude:
successful for gauge couplings

$\mathcal{SPA}$ Target : experimental: precision analyses of masses, mixings, couplings incldg higher orders

theoretical: $N = 1, 2, 3, ..$ loops between Lagrangian params and observables

$N = 1, 2, 3, ..$ RGE's for extrapolations to high scales

Reconstruction of fundamental SUSY theory and micro breaking mechanism

$\mathcal{SPA}$ PROJECT

1.) $\mathcal{SPA}$ Convention

renormalization schemes / LE parameters / decay widths, cross sections

2.) Programme Base

theor + exp analyses / ILC+LHC / Susy Les Houches Accord (SLHA)

3.) Theoretical and Experimental Tasks

short-term and long-term sub-projects

4.) Reference Point SPS1a′

derivative of SPS1a [$\Leftarrow$ LE + cosm data]

5.) Future Extensions

MSSM-CP, NMSSM, superstring eff theories, ..

1. SPA CONVENTION

- The masses of the SUSY particles and Higgs bosons are defined as pole masses.
- All SUSY Lagrangian parameters, mass parameters and couplings, including $\tan\beta$, are given in the $\overline{DR}$ scheme and defined at the scale $\tilde{M} = 1$ TeV.
- Gaugino/higgsino and scalar mass matrices, rotation matrices and the corresponding angles are defined in the $\overline{DR}$ scheme at $\tilde{M}$, except for the Higgs system in which the mixing matrix is defined in the on-shell scheme, the scale parameter chosen as the light Higgs mass.
- The Standard Model input parameters of the gauge sector are chosen as G_F, α, M_Z and $\alpha_s^{\overline{MS}}(M_Z)$. All lepton masses are defined on-shell. The t quark mass is defined on-shell; the b, c quark masses are introduced in $\overline{MS}$ at the scale of the masses themselves while taken at a renormalization scale of 2 GeV for the light u, d, s quarks.
- Decay widths / branching ratios and production cross sections are calculated for the set of parameters specified above.

2. PROGRAMME BASE

	EXAMPLES:
– Scheme translation tools: $\overline{DR} \leftrightarrow \overline{MS} \leftrightarrow pole$	
– Spectrum calculators: Lagrangian $\leftrightarrow$ masses	`FeynHiggs, IsaSusy, Spheno, SOFTSUSY, SuSpect ..`

– Other observables: decays, cross sections
LE params $b \to s\gamma, g_\mu - 2, ..$
cosmology, astrophysics
	`MPI,Vienna,DESY/FNAL`
	`HDecay, SDecay, NMHDecay, prospino's ..`
	`micrOMEGAs, DarkSusy`

– Event generators	`Pythia, Whizard ..`
– Analysis programmes	`Fittino, SFitter`
– RGE programmes: $\tilde{M} \leftrightarrow M_{GUT/PL}$ mSUGRA .. string eff th.	*see above*

web-address: `http://spa.desy.de/spa/`

3. PROJECT TASKS

(a) SUSY calculations: $LO, NLO, N^2LO, ..$

match experimental precision:

shift $\tilde{M} = 1$ TeV *to* 100 GeV $\Rightarrow$ next loop!

Particle	Mass	δ_{scale}	Particle	Mass	δ_{scale}
h^0	115.4	1.3	$\tilde{u}_R$	547.7	9.4
$\tilde{\chi}_1^0$	97.75	0.4	$\tilde{t}_1$	368.9	5.4
$\tilde{\chi}_2^0$	184.4	1.2	$\tilde{g}$	607.6	1.4
$\tilde{e}_R$	125.2	1.2			

(b) New channels, observables: $\tan\beta$,..

(c) Combining LHC+LC: many of the fundamental parameters cannot be determined [well] in only one of the colliders

ex: gaugino masses $M_1, M_2, M_3 \Rightarrow$ Weiglein Report

(d) Extensions: MSSM-CP, R_p violation,..,NMSSM, superstring,..

4. REFERENCE POINT SPS1a′

SPS1a′ deriv. of Snowmass Point SPS1a: conform with Ω_{cdm}, LE data

mSUGRA values:

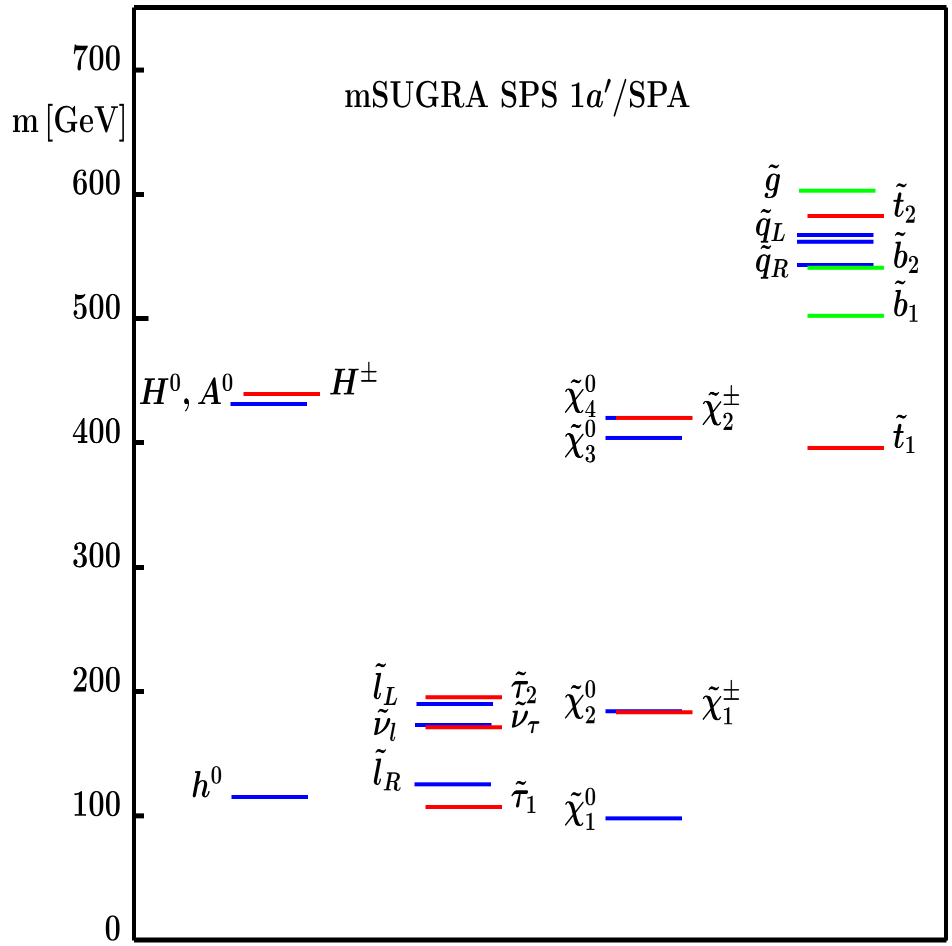
$M_{1/2}$	=	250 GeV	sign(μ)	=	+1
M_0	=	70 GeV	$\tan\beta$	=	10
A_0	=	−300 GeV			

LE/cosmic parameters:

$BR(b \to s\gamma) = 3.0 \times 10^{-4}$	micrOMEGAs
$\Delta[g_\mu - 2]/2 = 34 \times 10^{-10}$	FeynHiggs
$\Omega_{cdm} h^2 = 0.10$	micrOMEGAs

POLE MASSES:

	m [GeV]		m [GeV]
h^0	115.4	$\tilde{e}_R$	125.2
H^0	431.1	$\tilde{e}_L$	190.1
A^0	431.0	$\tilde{\nu}_e$	172.8
H^+	438.6	$\tilde{\tau}_1$	107.4
$\tilde{\chi}_1^0$	97.75	$\tilde{\tau}_2$	195.3
$\tilde{\chi}_2^0$	184.4	$\tilde{\nu}_\tau$	170.7
$\tilde{\chi}_3^0$	406.8	$\tilde{u}_R$	547.7
$\tilde{\chi}_4^0$	419.6	$\tilde{u}_L$	565.7
$\tilde{\chi}_1^+$	184.2	$\tilde{t}_1$	368.9
$\tilde{\chi}_2^+$	421.1	$\tilde{t}_2$	584.9
$\tilde{g}$	607.6	$\tilde{b}_1$	506.3



8

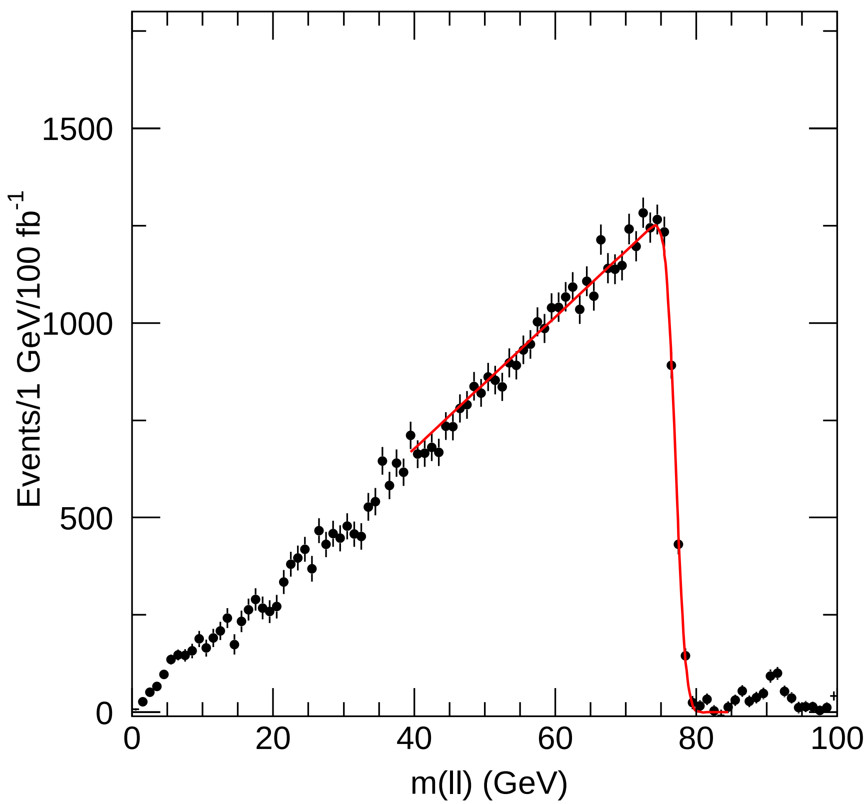
$BR(\tilde{\nu} \to \nu \chi_1^0) = 100\%$ $\Rightarrow$ $\tilde{\nu}$ invis.

MEASUREMENTS:

– edge effects at LHC

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q \rightarrow \tilde{\ell}\ell q \rightarrow \tilde{\chi}_1^0[\ell\ell]q$$

$\Rightarrow$ precise mass differences



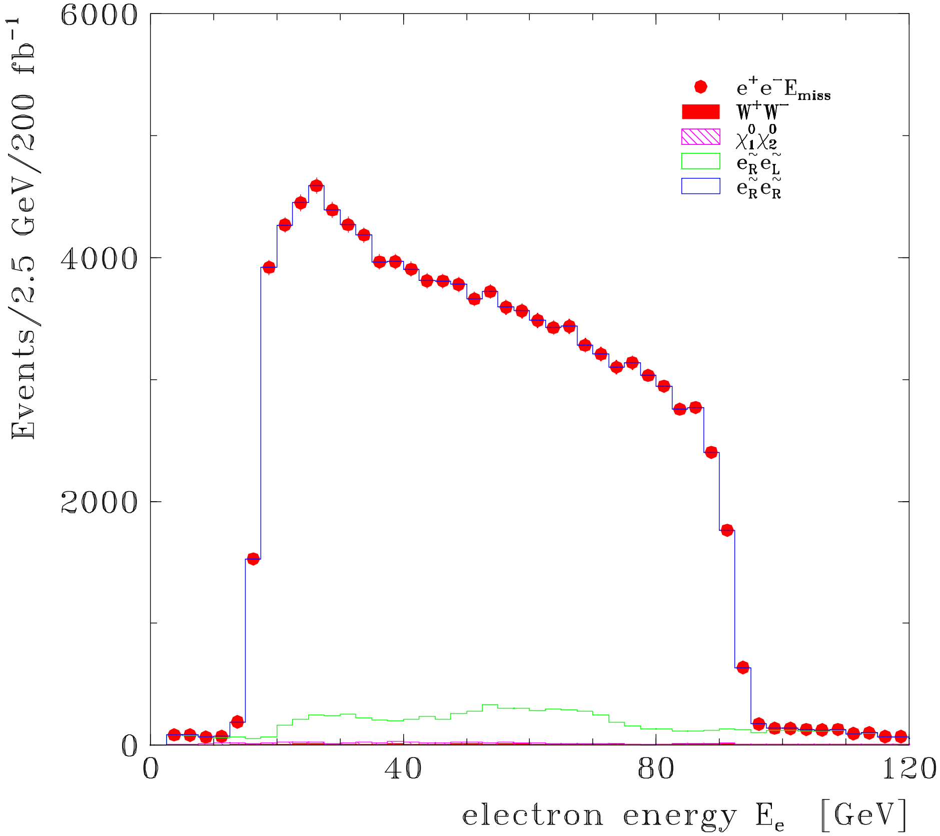
MEASUREMENTS:

– edge effects at LHC

– decay spectra at LC

$$\tilde{e}_R \to e + \tilde{\chi}_1^0$$

two edges: $\tilde{e}$ and χ_1^0 mass



MEASUREMENTS:

– edge effects at LHC

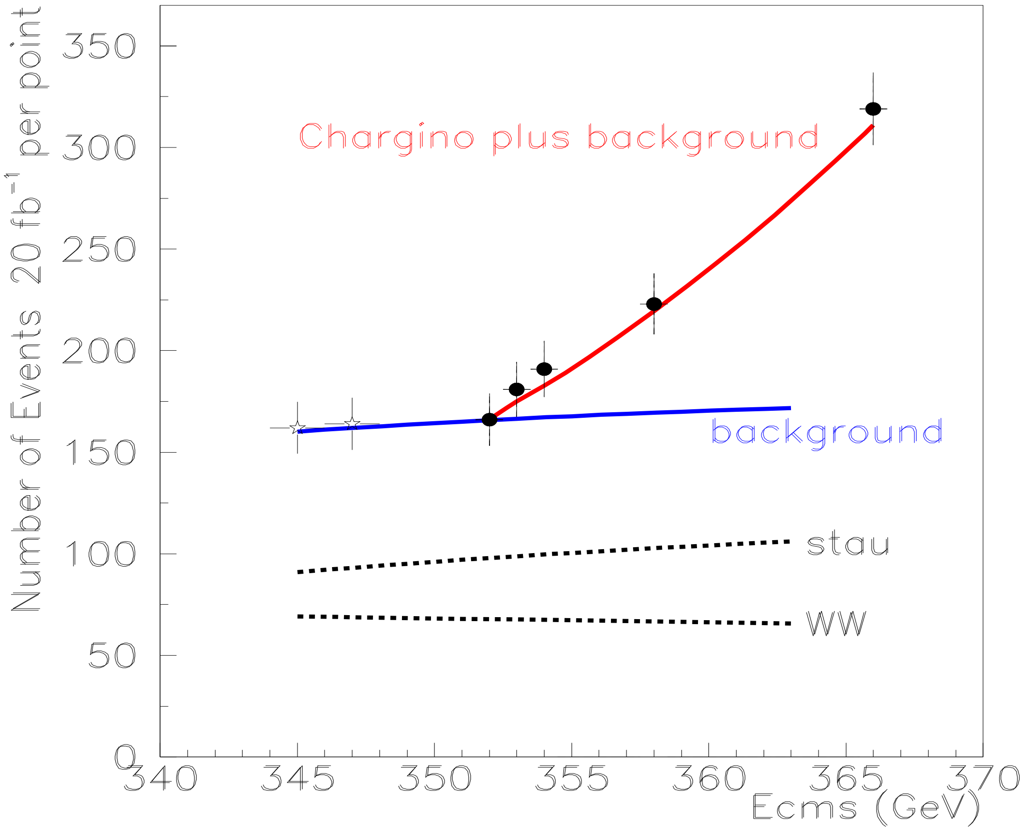
– decay spectra at LC

– threshold scan at LC

cross sections / asyms at LC

$$e^+e^- \to \chi_1^+\chi_1^-$$

steep rise of excitation curve



MEASUREMENTS:

– edge effects at LHC

– decay spectra at LC

– threshold scan at LC

– cross sections/asym LC

RESULTS `prelim SPS1a′`

– masses [LHC/LC; SFitter]*

– masses + x-sect [Fittino]

*	Mass, ideal	"LHC"	"LC"	"LHC+LC"
$\tilde{\chi}_1^\pm$	184.2		0.55	0.55
$\tilde{\chi}_2^\pm$	421.1	–	3.3	3.3
$\tilde{\chi}_1^0$	97.75	4.8	0.05	0.05
$\tilde{\chi}_2^0$	184.4	4.8	1.3	0.08
$\tilde{\chi}_4^0$	419.6	5.1	3-5	2.5
$\tilde{e}_R$	125.2	4.8	0.05	0.05
$\tilde{e}_L$	190.1	5.0	0.18	0.18
$\tilde{\tau}_1$	107.4	5-8	0.24	0.24
$\tilde{\tau}_2$	195.3	–	1.0	1.0
$\tilde{u}_R$	547.7	7-12	–	5-11
$\tilde{u}_L$	565.7	8.7	–	4.9
$\tilde{t}_1$	368.9		1.9	1.9
$\tilde{g}$	607.6	8.0	–	6.5
h^0	115.4	0.25	0.05	0.05
H^0	431.1		1.5	1.5
$H^\pm$	438.6	–	1.5	1.5

MEASUREMENTS:

– edge effects at LHC

– decay spectra at LC

– threshold scan at LC

– cross sections/asym LC

RESULTS:

– masses [LHC/LC; SFitter]

– masses + x-sect [Fittino]*

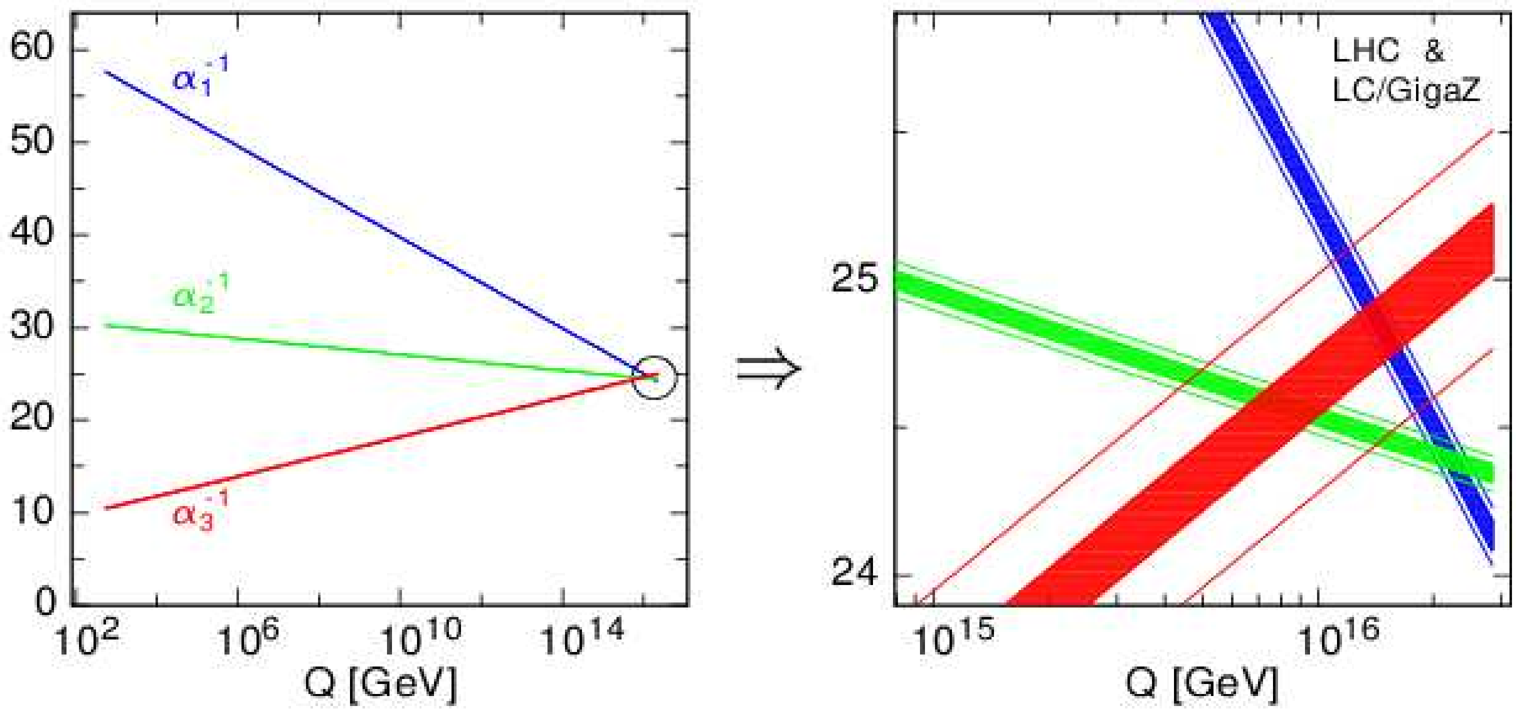
82 simulated measurements from LHC and LC

Parameter *	SPS1a′value	Fit: err [+th]
M_1	103.27 GeV	±0.066 [0.25]
M_2	193.45 GeV	±0.10 [0.14]
M_3	568.86 GeV	±7.76 GeV
μ	400.39 GeV	±1.15 [1.52]
$M_{\tilde{e}_L}$	181.30 GeV	±0.22 GeV
$M_{\tilde{e}_R}$	115.60 GeV	±0.43 GeV
$M_{\tilde{\tau}_L}$	179.54 GeV	±1.19 GeV
$M_{\tilde{u}_L}$	523.24 GeV	±5.16 [8.51]
$M_{\tilde{u}_R}$	503.87 GeV	±17.3 [24.2]
$M_{\tilde{t}_L}$	467.71 GeV	±4.93 [9.87]
m_{A}	374.95 GeV	±0.77 GeV
A_{t}	-525.61 GeV	±24.6 GeV
$\tan\beta$	10.0	±0.31 [0.38]

HIGH-SCALE EXTRAPOLATIONS:

– gauge couplings α_i^{-1}

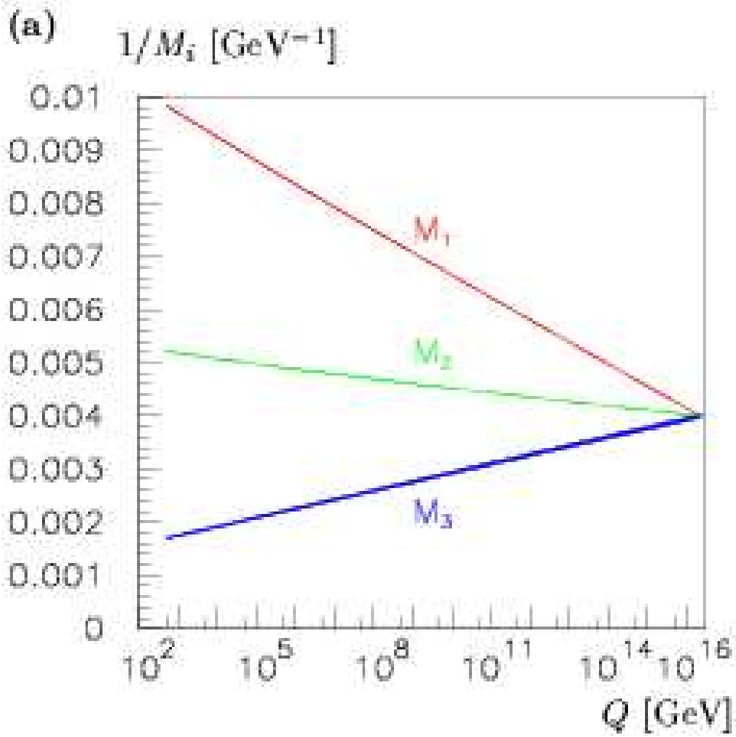
unify within 1.5% : 7σ sensitivity to GUT/PL scale physics



HIGH-SCALE EXTRAPOLATIONS:

– gauge couplings α_i^{-1}

– gaugino masses M_i^{-1} : proven to unify within mSUGRA scenario

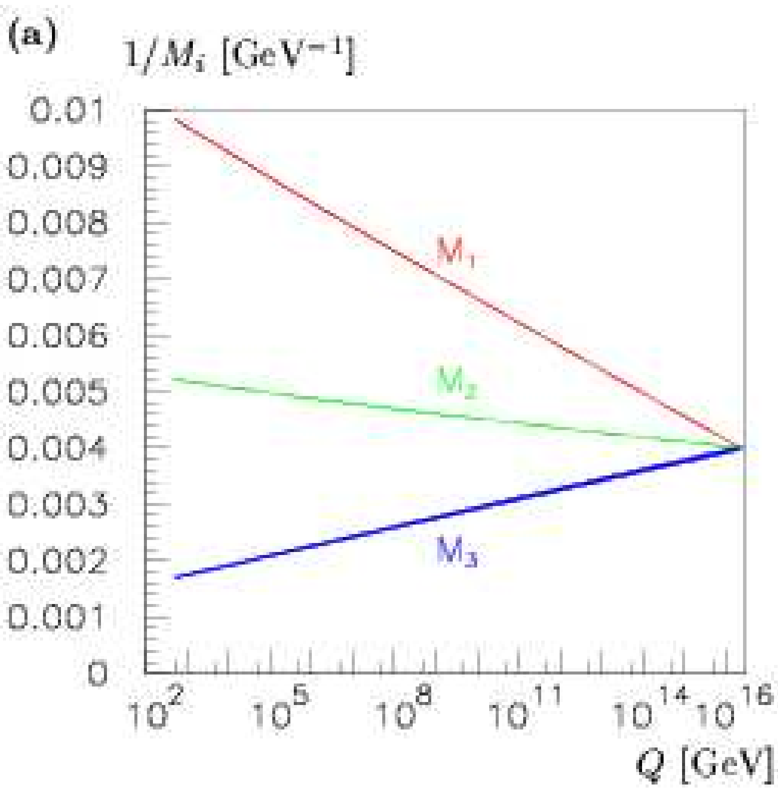


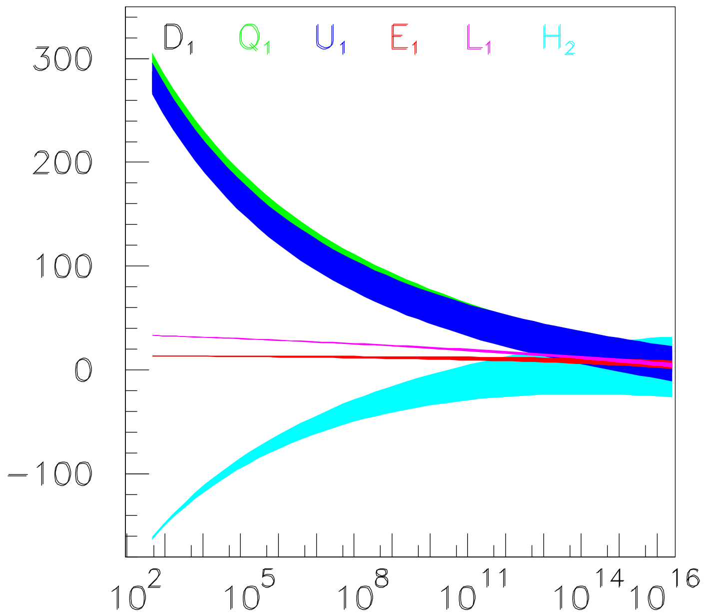
HIGH-SCALE EXTRAPOLATIONS:

– gauge couplings α_i^{-1}

– gaugino masses M_i^{-1}

– scalar masses $M_{\tilde{j}}$: unify in mSUGRA





ERRORS SPS1a′:

mSUGRA	Parameter, ideal	"LHC+LC" errors
M_1	250. GeV	0.18 GeV
M_2	*ditto*	0.26 GeV
M_3		2.8 GeV
M_{L_1}	70. GeV	4.1 GeV
M_{E_1}	*ditto*	7.9 GeV
M_{Q_1}		11. GeV
M_{U_1}		31. GeV
M_{H_1}	*ditto*	7.5 GeV
M_{H_2}		72. GeV
A_t	−300. GeV	44. GeV

CONCLUSION:
- gauginos in excellent $\mathcal{O}$[per-mille] condition
- scalar leptons in good $\mathcal{O}$[per-cent] condition
- squarks in $\mathcal{O}$[1] condition

mSUGRA Fit:

	Param,ideal SPS1A	Experimental error
M_U	$2.36 \cdot 10^{16}$ GeV	$1.8 \cdot 10^{14}$ GeV
α_U^{-1}	24.19	0.06
$M_{\frac{1}{2}}$	250. GeV	0.2 GeV
M_0	70. GeV	0.2 GeV
A_0	-300. GeV	13. GeV
μ	357.4 GeV	0.3 GeV
$\tan\beta$	10.	0.3

General conclusion:

– universality can be tested in bottom-up approach in non-colored sector very well;

– colored sector needs improvement

– mSUGRA fit excellent

$4'$ EXTENSIONS

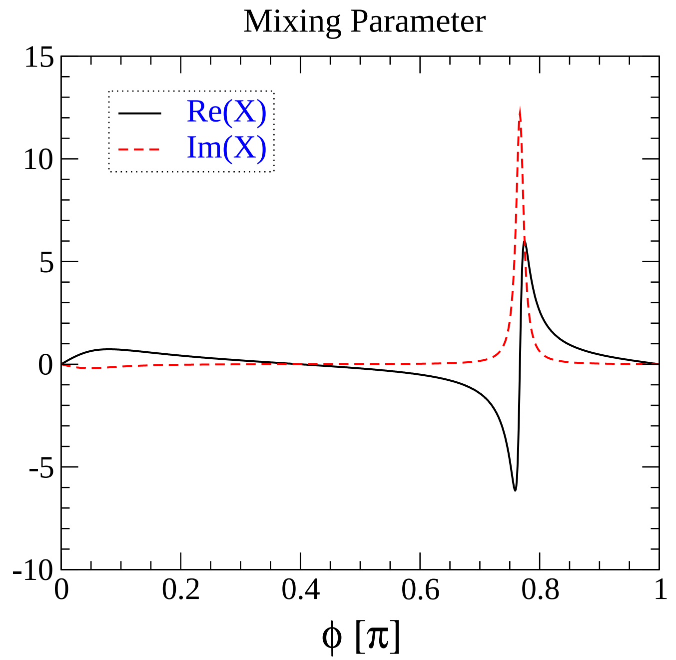
mSUGRA

path to SUSY / < complexity

MSSM-CP

wild mix eff in decouplg regime

complx mix angle: $X = \frac{1}{2}\tan 2\theta$



$4'$ EXTENSIONS

mSUGRA

path to SUSY / complexity

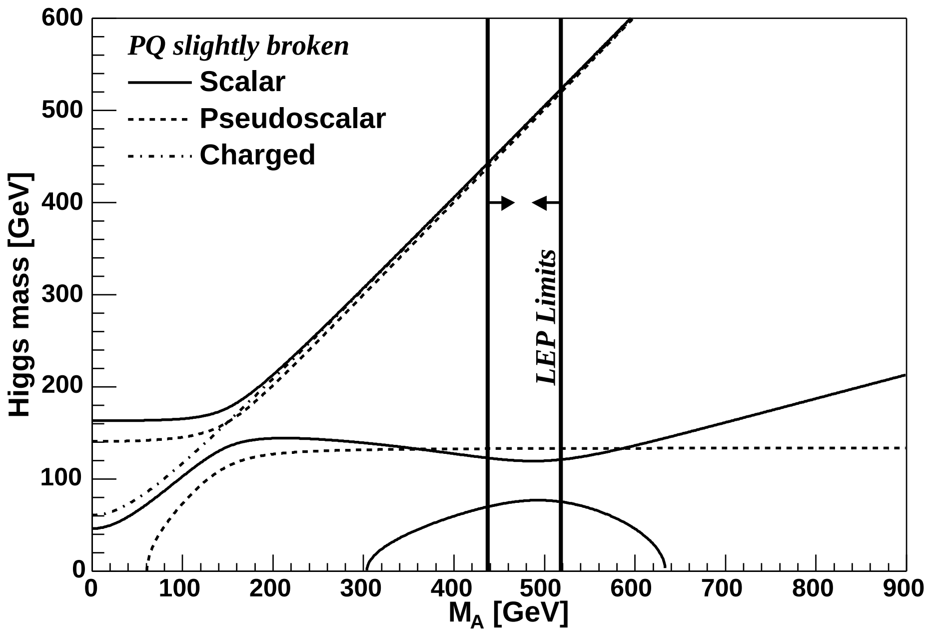
MSSM-CP

wild mix eff in decouplg regime

NMSSM

2 light $CP = \pm$ Higgs bosons

and add. higgsinos [gauginos]



$4'$ EXTENSIONS

mSUGRA

path to SUSY / complexity

MSSM-CP

wild mix eff in decouplg regime

NMSSM

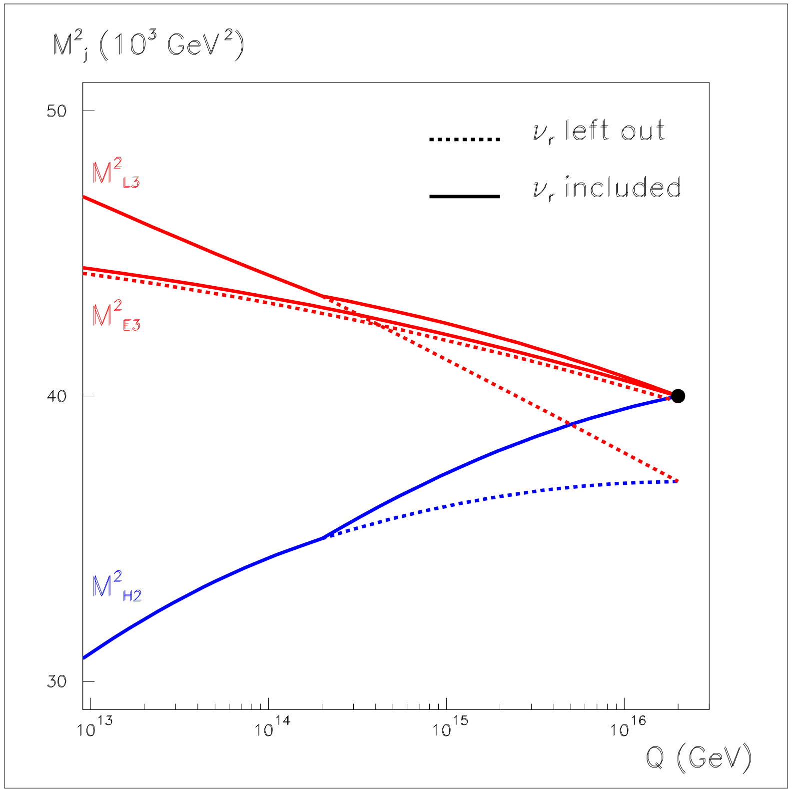
2 light $CP = \pm$ Higgs bosons

LR-SUGRA

evolution : smooth in 1/2 gen.

: ν_R kink in 3 generation

$\Rightarrow$ sensitivity to intermediate scales



4′ EXTENSIONS

mSUGRA

path to SUSY / complexity

MSSM-CP

wild mix eff in decouplg regime

NMSSM

2 light $CP = \pm$ Higgs bosons

LR-SUGRA

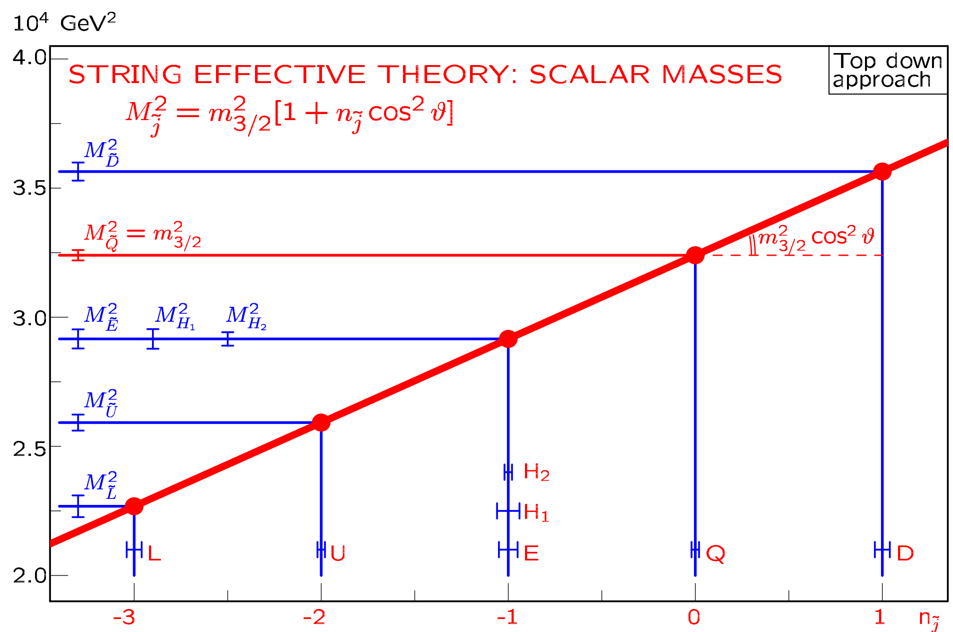
evolution smooth in 1/2 generation

ν_R kink in 3 generation

Superstring Effective Theories

measure eff params: $\langle S \rangle, \langle T \rangle$

and *integer* modular weights



5 SUMMARY AND OUTLOOK

$\mathcal{SPA}$ provides: well-defined base and frame for th+ex SUSY analyses

formulated in "$\mathcal{SPA}$ Convention"

all necessary theoretical and computational tools [$\sim$ SLHA]

well-defined testground SPS1a$'$

launch pad for future developments/extensions

ILC+LHC: TELESCOPE TO PLANCK-SCALE PHYSICS

Report: Supersymmetry Parameter Analysis: $\mathcal{SPA}$ Convention and Project

draft: $/afs/desy.de/user/z/zerwas/public/SPA.draft.ps$

You are invited to join as co-author!

Comments welcome: *zerwas@desy.de*