

SUSY TOOLS FOR THE LHC

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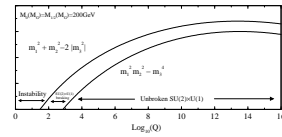
CERN

- Supersymmetry at the LHC
- Discoveries
- Measurements
- Parameter Studies

SUPERSYMMETRY AT TEV SCALE

Bright side

- ★ light Higgs – consistent with data
- ★ radiative symmetric breaking — 2 Higgs doublets
- ★ R parity — stable proton yields dark matter
- ★ unification — 3 running couplings meet
- ★ local supersymmetry – unified theory including gravity?
- ★ **rich LHC phenomenology** — no nasty surprises



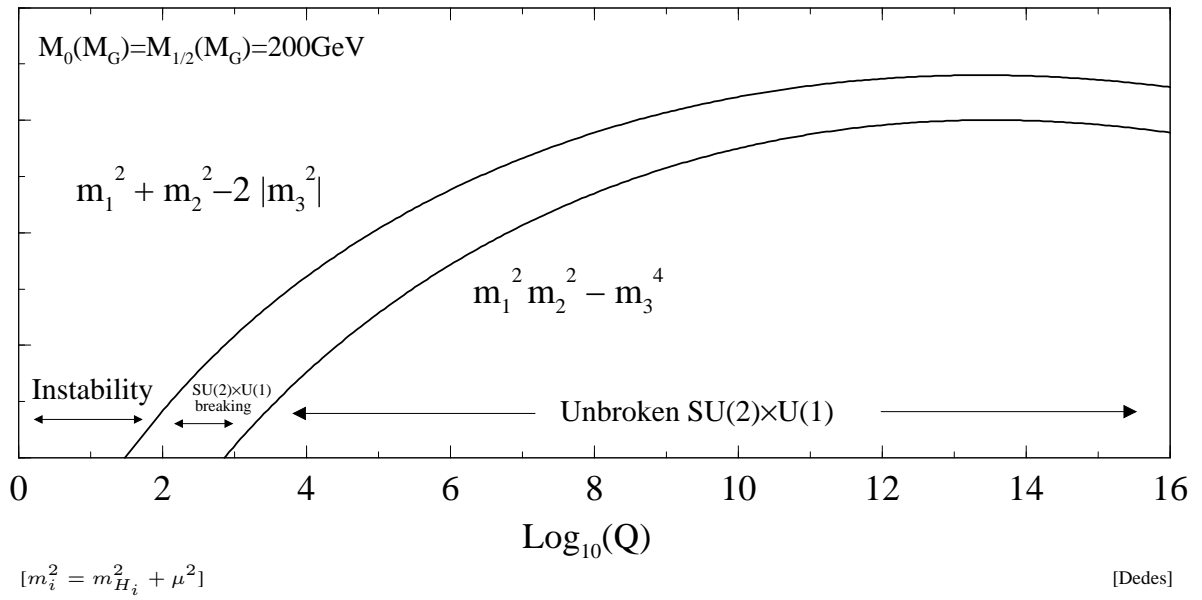
Dark side

- ★ unknown SUSY breaking
 - soft breaking without quadratic divergences
 - 100+ parameters: masses, scalar couplings, phases...
- ★ flavor physics — CKM and lepton flavor through SUSY breaking?
2HDM — μ parameter through SUSY breaking? [Giudice, Masiero]

★ MSSM spectrum

		spin	charge	d.o.f.	
quark	q_L, q_R	1/2	2/3, -1/3	1+1	6 flavors
→ squark	\tilde{q}_L, \tilde{q}_R	0	2/3, -1/3	1+1	
gluon	G_μ	1	0	$n - 2$	Majorana
→ gluino	\tilde{g}	1/2	0	2	
gauge bosons	γ, Z	1	0	2+3	Majorana
Higgs bosons	h^0, H^0, A^0	0	0	3	
→ neutralinos	$\tilde{\chi}_i^0$	1/2	0	4 · 2	
gauge bosons	W^\pm	1	± 1	2 · 3	Dirac
Higgs bosons	H^\pm	0	± 1	2	
→ charginos	$\tilde{\chi}_i^\pm$	1/2	± 1	2 · 4	

⇒ **analyses independent of SUSY breaking?**



SUSY SIGNALS AT LHC: 1

Appearance of supersymmetry

- 1 **discovery** — signals for new physics, possibly SUSY?
 - 2 **measurements** — masses, cross sections, decays?
 - 3 **parameter studies** — MSSM Lagrangean, SUSY breaking?
- ⇒ well founded doubts always expected

Challenge: find fool proof SUSY signals at LHC

- ★ jets und \cancel{E}_T : $pp \rightarrow \tilde{q}\tilde{q}^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$ [$\tilde{q} \rightarrow q\tilde{\chi}_1^0$; $\tilde{g} \rightarrow \tilde{q}\tilde{q} \rightarrow q\tilde{q}\tilde{\chi}_1^0$]
 - ★ bottoms und \cancel{E}_T : $pp \rightarrow \tilde{b}_1\tilde{b}_1^*$ [$\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$]
 - ★ like sign dileptons: $pp \rightarrow \tilde{g}\tilde{g}$ [$\tilde{g} \rightarrow \tilde{u}\tilde{u} \rightarrow \tilde{\chi}_1^+ d\tilde{u}$ oder c.c.]
 - ★ tri-leptons, no Z -Pol: $pp \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^-$ [$\tilde{\chi}_2^0 \rightarrow \tilde{\ell}\tilde{\ell} \rightarrow \tilde{\chi}_1^0\tilde{\ell}\tilde{\ell}$; $\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\ell}\tilde{\nu}$]
 - ★ funny tops: $pp \rightarrow \tilde{t}_1\tilde{t}_1^*$ [$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^+ \rightarrow b\tilde{\ell}\nu\tilde{\chi}_1^0$]
 - ★ [more ideas your job...]
- ⇒ **experience from Tevatron searches**

Precise NLO prediction of production cross sections [Prospino]

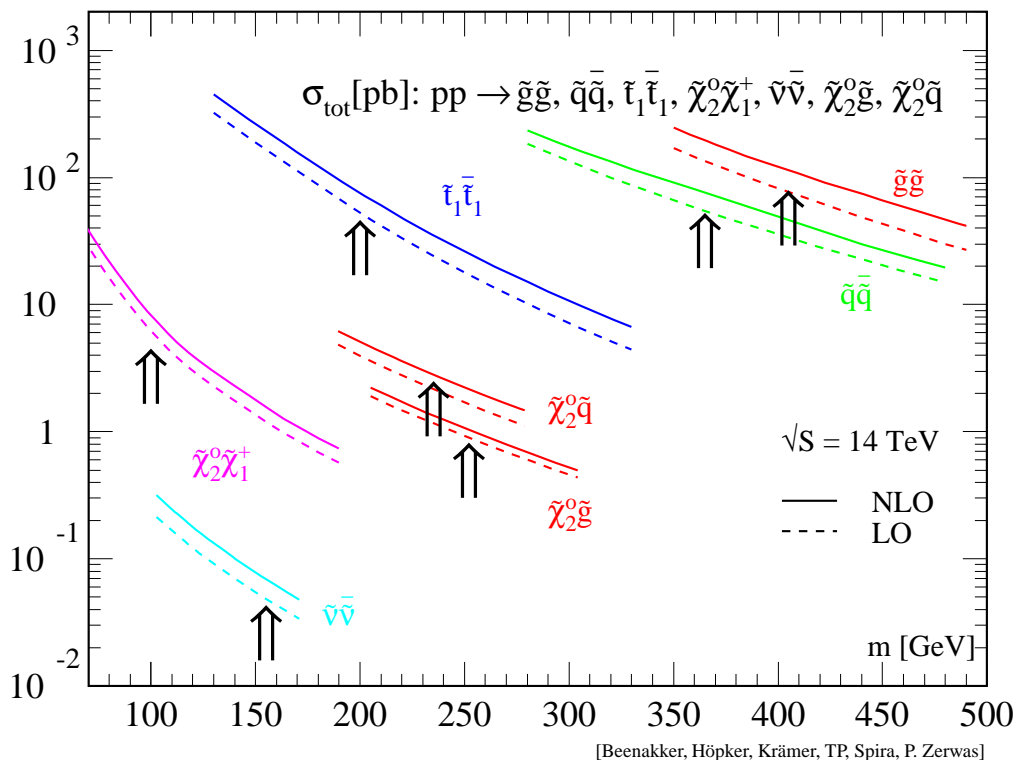
- ★ masses from inclusive analyses
- ★ branching fractions from cascade analyses [Sdecay: Mühlleitner]
- ★ until now: exclusion limits for SUSY particles

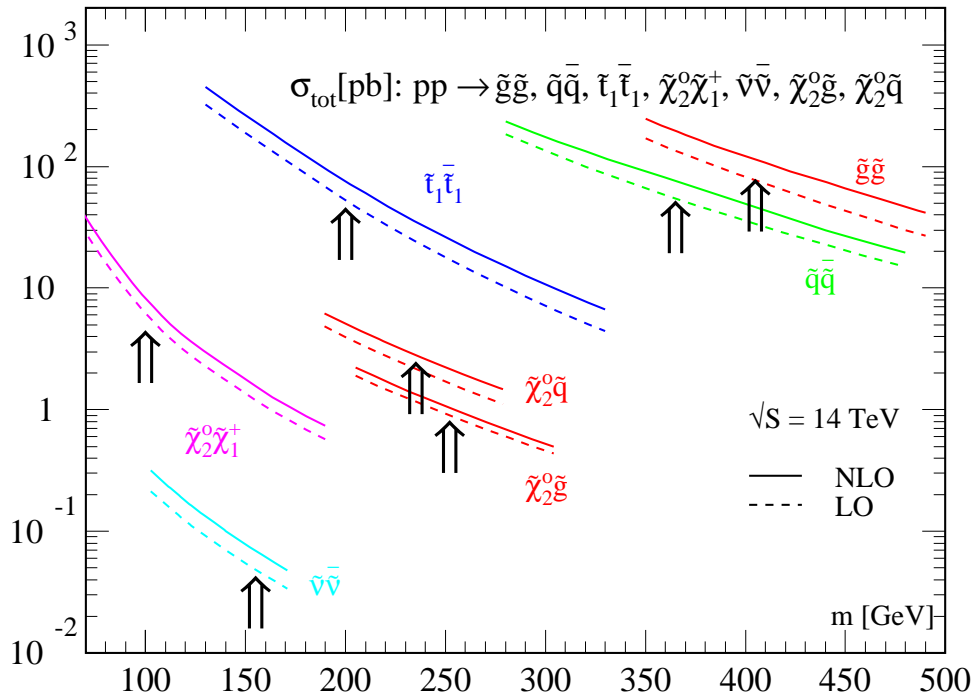
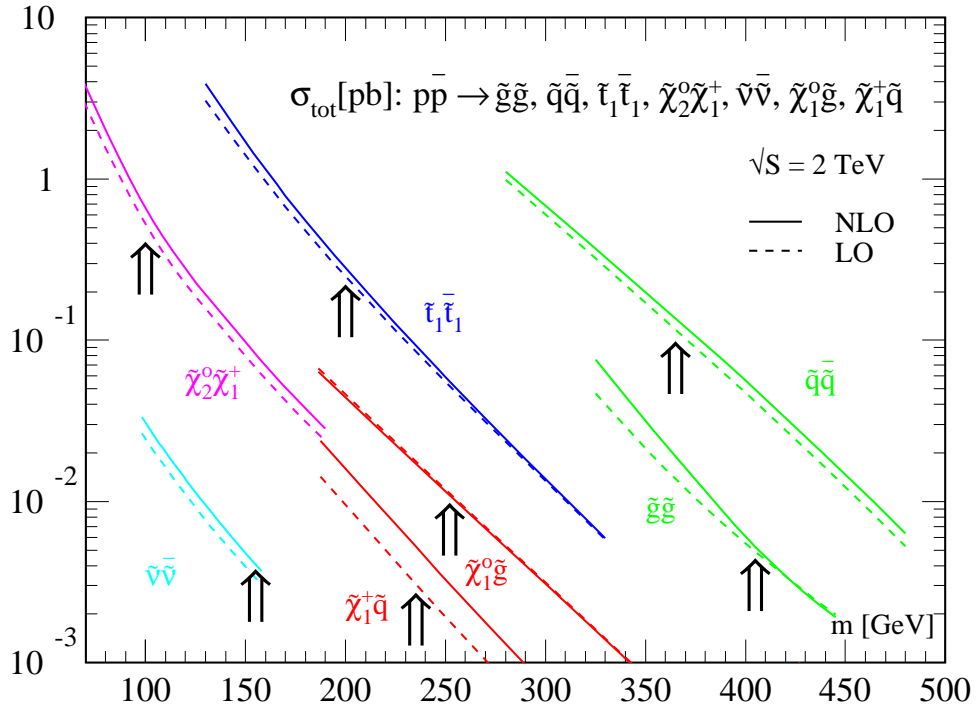
SUSY SIGNALS AT LHC: 2

(SUSY)–QCD corrections for inclusive processes

- ★ large QCD corrections for squarks, stops, gluinos
 - ★ small SUSY effects for stops
 - ★ DY type QCD corrections for neutralinos, charginos, sleptons
 - ★ sizeable QCD corrections for neutralino+squark
 - ★ small QCD corrections for neutralino+gluino
 - ★ technically correct: divergent intermediate states, renormalization,...
 - ★ Les Houches interface to Pythia, SoftSusy, etc.
- ⇒ **Prospino2.0beta publicly available** [<http://pheno.physics.wisc.edu/~plehn>]

Prospino propaganda plot

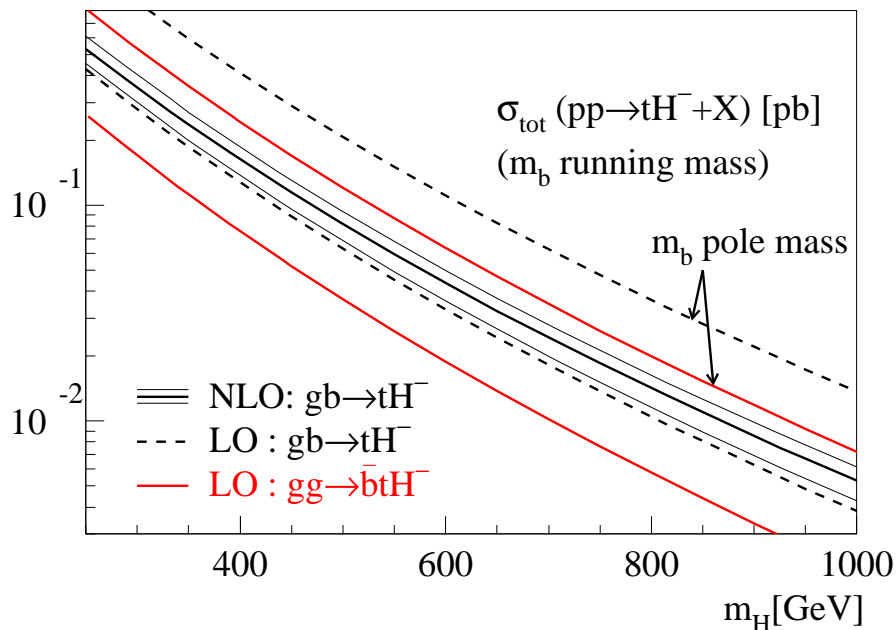
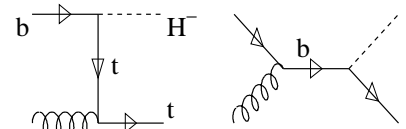




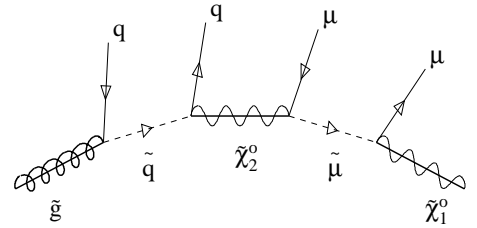
SUSY SIGNALS AT LHC: 3

Unusual SUSY signal: charged Higgs

- ★ no adjoint Higgs field in superpotential
 - 2 doublets for top und bottom mass $[\tan \beta]$
 - charged Higgs scalar $[H^- \rightarrow \tau \bar{\nu}, \bar{t} b, W^- h^0]$
- ★ production $bg \rightarrow tH^-$ [Prospino2.1, CMS: Nikitenko, ATLAS: Assamagan]
 - (a) conceptual: bottom partonen [Boos & TP]
 - (b) experimental: measurement von $\tan \beta$ [LH 2003]
- ★ proper renormalization of Yukawa coupling vital
 - NLO rate under control



SUSY MEASUREMENTS AT LHC: 1



SUSY spektra from cascade decays

- ★ decay $\tilde{g} \rightarrow \tilde{q}\bar{q} \rightarrow \tilde{\chi}_2^0 q\bar{q} \rightarrow \mu^+ \mu^- q\bar{q} \tilde{\chi}_1^0$ [hopefully not via Z]
 - ★ cross sections some 100 pb [more than 3×10^5 events]
 - ★ thresholds & edges in spectra [Allanach, Lester, Parker, Webber]
- classic $m_{\ell\ell}^2 < (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{\ell}}^2$
 critical: enough thresholds and edges available?

⇒ detector resolution, calibration, systematic errors?

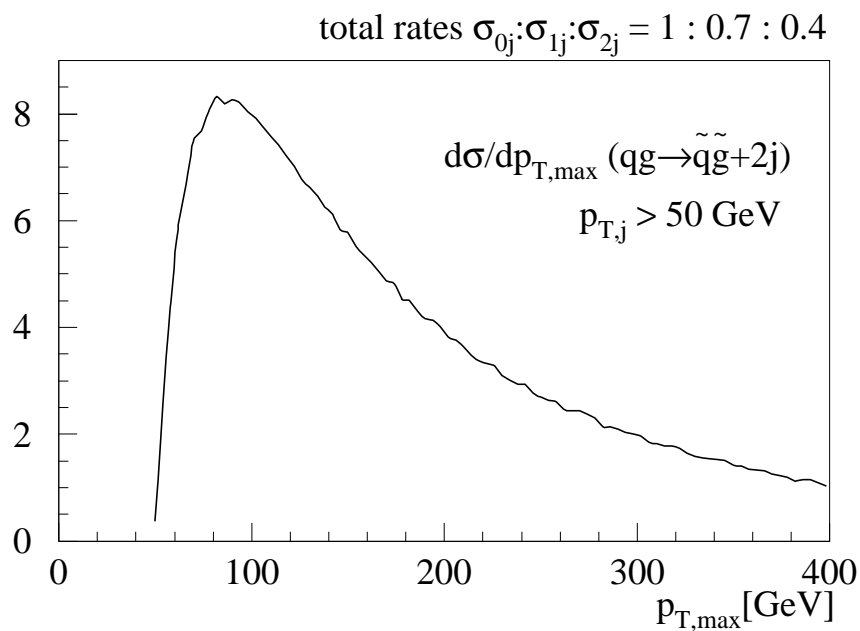
Studies for SPS points [Polesello et al.]

- ★ gluino mass in $\tilde{g} \rightarrow \tilde{b}\bar{b}$
 - ★ higgsino masses in $\tilde{q}_L \rightarrow q\tilde{\chi}_4^0, \tilde{q}_L \rightarrow \tilde{\chi}_2^\pm q$
 - ★ chargino mass in $\tilde{q} \rightarrow q\tilde{\chi}_1^\pm \rightarrow qW_{\text{had}}^\pm \tilde{\chi}_1^0$ [Nojiri, Polesello, Tovey]
 - ★ slepton mass in $\tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$
 - ★
- ⇒ generic for small $\tan \beta$
 problems with b -jets und taus for large $\tan \beta$
- ⇒ **essentiel for SUSY parameters** [SFitter results coming]

SUSY MEASUREMENTS AT LHC: 2

Problem in decay studies

- ★ typical cuts: $p_{T,j} > 150, 100, 50, 50$ GeV
courageous analyses: $p_{T,j} > 100, 100, 40, 20$ GeV
 - ★ (a) cuts on $p_{T,j}$ hierarchy?
(b) combinatorical background through jet radiation?
- ⇒ matrix elements $pp \rightarrow X_{\text{SUSY}} Y_{\text{SUSY}} + \text{hard jets}$
great success for Higgs+jets [Zeppenfeld, Rainwater; Jacobs, Mellado]
- ⇒ **SMadgraph** [Hagiwara, Kanzaki, TP, Rainwater, Stelzer]



PARAMETER DETERMINATION AT LHC: 1

Theorist's point of view

- ★ measured masses, cross sections, decays secondary
 - ★ parameters in SUSY Lagrangean from measurements
- ⇒ SUSY breaking parameters at scale M_{TeV}
- ⇒ extrapolation to M_{GUT} [Blair, Porod, P. Zerwas]

Warmup exercise: fit of mSUGRA using SFitter

- ★ fit with fixed sign of μ

	SPS1a	LHC	Δ_{LHC}	LC	Δ_{LC}	LHC+LC	$\Delta_{\text{LHC+LC}}$
m_0	100	100.03	4.0	100.03	0.09	100.04	0.08
$m_{1/2}$	250	249.95	1.8	250.02	0.13	250.01	0.11
$\tan\beta$	10	9.87	1.3	9.98	0.14	9.98	0.14
A_0	-100	-99.29	31.8	-98.26	4.43	-98.25	4.13

⇒ impact of LHC???

	SPS1a	LHC	LC	LHC+LC		SPS1a	LHC	LC	LHC+LC
χ_1^0	97.03	4.8	0.05	0.05	χ_2^0	182.9	4.7	1.2	0.08
χ_3^0	349.2		4.0	4.0	χ_4^0	370.3	5.1	4.0	2.3
χ_1^\pm	182.3		0.55	0.55	χ_2^\pm	370.6		3.0	3.0
\tilde{g}	615.7	8.0		6.5					
\tilde{t}_1	411.8		2.0	2.0					
\tilde{b}_1	520.8	7.5		5.7	\tilde{b}_2	550.4	7.9		6.2
\tilde{q}_R	551.0	19.0		16.0	\tilde{q}_L	570.8	17.4		9.8
\tilde{e}_1	144.9	4.8	0.05	0.05	\tilde{e}_2	204.2	5.0	0.2	0.2
$\tilde{\mu}_1$	144.9	4.8	0.2	0.2	$\tilde{\mu}_2$	204.2	5.0	0.5	0.5
$\tilde{\tau}_1$	135.5	6.5	0.3	0.3	$\tilde{\tau}_2$	207.9		1.1	1.1
$\tilde{\nu}_e$	188.2		1.2	1.2					

⇒ what is data and what are model assumptions?

PARAMETER DETERMINATION AT LHC: 2

SUSY parameters from observables

- ★ **parameters:** MSSM Lagrangean
- ★ **measurements:** masses [SuSpect, SoftSUSY, FeynHiggs...]
 - branching fractions [MSMlib, Sdecay]
 - cross sections [Prospino, MSMlib]
 - additional measurements trivial to add
- ★ **errors:** general correlation, statistics & systematics & theory
- ★ **problem in Fit:** phase space, starting values
 - problem in Grid: huge grid, hard to completely cover

SFitter [Lafaye, TP, D. Zerwas]

- ★ 1 grid for part of measurements and parameters
- 2 fit of remaining parameters to all measurements
- 3 complete fit

	LHC	LC	LHC+LC	SPS1a
$\tan \beta$	10.22±9.1	10.26±0.3	10.06±0.2	10
M_1	102.45±5.3	102.32±0.1	102.23±0.1	102.2
M_3	578.67±15	fi x 500	588.05±11	589.4
$M_{\tilde{\tau}_L}$	fi x 500	197.68±1.2	199.25±1.1	197.8
$M_{\tilde{\tau}_R}$	129.03±6.9	135.66±0.3	133.35±0.6	135.5
$M_{\tilde{\mu}_L}$	198.7±5.1	198.7±0.5	198.7±0.5	198.7
$M_{\tilde{q}3_L}$	498.3±110	497.6±4.4	521.9±39	501.3
$M_{\tilde{t}_R}$	fi x 500	420±2.1	411.73±12	420.2
$M_{\tilde{b}_R}$	522.26±113	fi x 500	504.35±61	525.6
A_τ	fi x 0	-202.4±89.5	352.1±171	-253.5
A_t	-507.8±91	-501.95±2.7	-505.24±3.3	-504.9
A_b	-784.7±35603	fi x 0	-977±12467	-799.4

⇒ all but LHC+LC not without model assumptions [additional measurements?]

OUTLOOK

SUSY signals at LHC

- ★ measurement of rates and decays first step
- ★ NLO cross sections using **Propino2.0** [standard at Tevatron]
- ★ QCD corrections relevant
- ★ SUSY–QCD corrections not always negligible

SUSY measurements at LHC

- ★ final state with jets essential [Higgs at LHC]
- ★ hard matrix elements using **SMadgraph**
- ★ analysis of cascade decays promising strategy

SUSY parameters at LHC

- ★ SUSY observables secondary for theorists
- ★ determination of SUSY parameters using **Sfitter**
- ★ combination of experiments vital