SUPERSYMMETRY – AN INTRODUCTION

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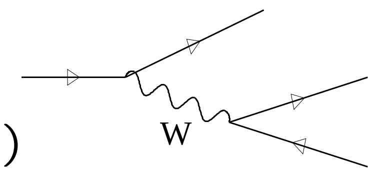
– Fine tuning in the Standard Model
– Supersymmetry as one solution
– The MSSM
– Supersymmetry at the Tevatron and the LHC
– Supersymmetry at the Linear Collider
– and lots of little side remarks...

WHAT IS WRONG WITH THE STANDARD MODEL: 1

A brief history of the mess we are in...

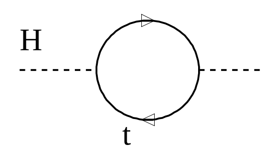
– Fermi 1934: theory of weak interactions [$n \to p e^- \bar{\nu}_e$ and $\mu \to e^- \bar{\nu}_e \nu_\mu$]
$\to$ divergent four fermion reaction amplitude: $\mathcal{A} \propto G_F E^2$
$\to$ unitarity violation [transition probability $\propto |\mathcal{A}|^2$]
$\to$ 'effective theory' valid for $E < 600$ GeV

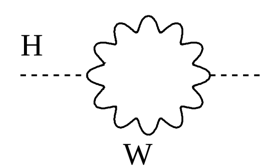
– Yukawa 1935: massive virtual particle exchange
$\to$ Fermi's theory for $E \ll M$
$\to$ four fermions unitary for large energies: $\mathcal{A} \propto g^2 E^2/(E^2 - M^2)$
$\to$ unitarity violation in $WW \to WW$ [$\mathcal{A} \propto G_F E^2$]



– Higgs & Kibble 1967: spontaneous symmetry breaking
$\to$ unitary gauge theory with massive W, Z [discovered 1983]
$\to$ fermion masses linked to Yukawa couplings [top quark discoverd 1995]
$\to$ fundamental Higgs scalar below TeV scale [mass unknown]
$\to$ Higgs couplings fixed $g_{HXX} \propto g m_X$

– desaster strikes: scalar mass perturbatively unstable
quadratic divergences $\delta m_H^2 \propto g^2 \Lambda^2$ [Λ loop cutoff]
all–orders Higgs mass driven to cutoff $m_H \to \Lambda$





$\Rightarrow$ new approach needed to solve hierarchy problem

What is wrong with the Standard Model: 2

Starting from data...

– ...which seem to indicate a light Higgs

– problem of light Higgs: mass driven to cutoff of theory [remember pain to get that up]

$$\delta m_H^2 \propto g^2 (2m_W^2 + m_Z^2 + m_H^2 - 4m_t^2)\ \Lambda^2$$

Veltman's condition $(\cdots) = 0$ would be fun

problem preferably solved to arbitrary loop order

$\Rightarrow$ solution: counter term for exact cancellation $\Rightarrow$ artificial, unmotivated, ugly

$\Rightarrow$ or new physics at TeV scale:
- supersymmetry
- extra dimensions
- little Higgs (pseudo–Goldstone Higgs)
- Higgsless/composite Higgs
- YourFavoriteNewPhysics...

$\Rightarrow$ typically either cancellation with new particles or discussing away high scale

$\Rightarrow$ all really beautiful concepts and symmetries

$\Rightarrow$ in general problematic to realize at TeV scale [data seriously in the way]

Idea of supersymmetry: cancellation of divergences through statistics factor (-1)

[scalars vs. SM fermions; fermions vs. SM gauge bosons; fermions vs. SM scalars]

TeV Scale Supersymmetry: 1

Great idea: solve hierarchy problem by only doubling particle number?!

- stops (scalar) cancel top loop [couplings also protected]
- gauginos (neutral or charged) cancel W, Z loop
- higgsinos cancel Higgs loop [mix with neutralinos]
- since we are at it, let's postulate gluino
- top not special, so postulate sleptons and squarks

$\Rightarrow$ hierarchy problem gone

$\Rightarrow$ rich collider and non-collider phenomenology guaranteed

Slight problem with Higgs sector

- adjoint Higgs field not allowed in $\mathcal{L}$
  $\longrightarrow$ how to give mass to t and b?
  $\longrightarrow$ two doublets

$\Rightarrow$ SUSY Higgs sector interesting by itself

[no SUSY knowledge needed]

		spin	d.o.f.	
fermion	f_L, f_R	1/2	1+1	
$\longrightarrow$ sfermion	$\tilde{f}_L$, $\tilde{f}_R$	0	1+1	
gluon	G_μ	1	n-2	
$\longrightarrow$ gluino	$\tilde{g}$	1/2	2	Majorana
gauge bosons	γ, Z	1	2+3	
Higgs bosons	h^0, H^0, A^0	0	3	
$\longrightarrow$ neutralinos	$\tilde{\chi}^0_i$	1/2	$4 \cdot 2$	Majorana
gauge bosons	$W^\pm$	1	$2 \cdot 3$	
Higgs bosons	$H^\pm$	0	2	
$\longrightarrow$ charginos	$\tilde{\chi}^\pm_i$	1/2	$2 \cdot 4$	Dirac
graviton	G	2	5	
$\longrightarrow$ gravitino	$\tilde{G}$	3/2	5	hard to catch

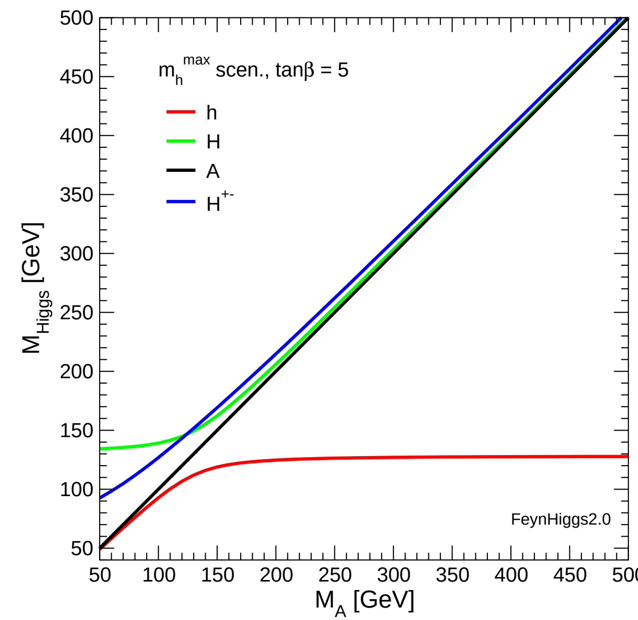
SUPERSYMMETRIC HIGGS SECTOR: 1

Required by supersymmetry: two Higgs doublet model

– one (complex) Higgs doublet: 4 degrees of freedom
  $\longrightarrow$ three for longitudinal W, Z, one for scalar Higgs

– two Higgs doublets: 8 degrees of freedom
  $\longrightarrow$ three for longitudinal W, Z, five for Higgs particles
  $\longrightarrow$ scalars h^0, H^0, pseudoscalar A^0, charged $H^\pm$

– free parameters
  (1) still only one free mass scale: m_A
  (2) two vacuum expectation values: $\tan\beta = v_t/v_b$



Plateau structure

– only plateau Higgs coupling to W, Z

– heavy Higgs with $\tan\beta$-enhanced coupling to b, τ

– light Higgs mass limited from above

$$2m_h^2 \simeq m_{AZ}^2 - \sqrt{m_{AZ}^4 - 4m_A^2 m_Z^2 c_{2\beta}^2 - 4\,\frac{3G_F}{\sqrt{2}\pi^2}\,\frac{m_t^4}{s_\beta^2}\,\log\frac{m_{\tilde{t}}^2}{m_t^2}\,(m_A^2 s_\beta^2 + m_Z^2 c_\beta^2)} \lesssim 2\cdot 135\ \text{GeV}$$

$\Rightarrow$ Little hierarchy problem $m_{\tilde{t}} \gg m_t$ because $m_h > 114$ GeV a la LEP2

SUPERSYMMETRIC HIGGS SECTOR: 2

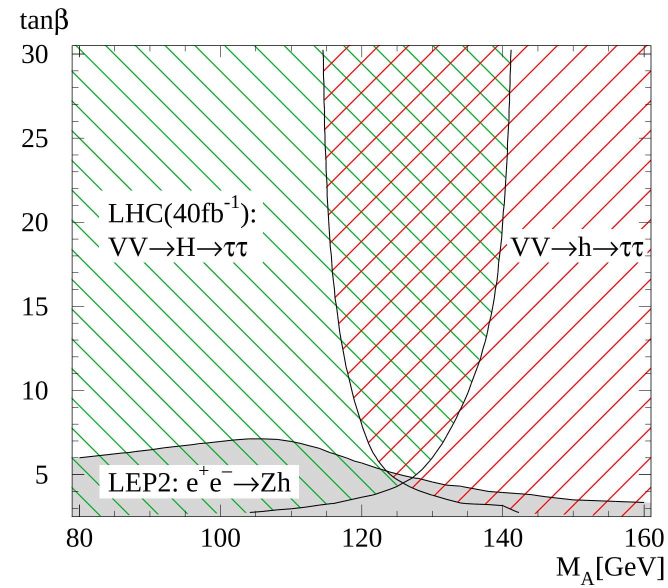
Challenge: find one Higgs at the LHC [very diffi cult at Tevatron]

– 'decoupling regime' $m_A \gtrsim 160$ GeV
  $\rightarrow h^0$ looks like SM Higgs [of corresponding mass]

– opposite case $m_A \lesssim 120$ GeV
  $\rightarrow qq \rightarrow qqH^0 \rightarrow qq\tau\tau$ as in SM

– in between: maybe even two bumbs

$\Rightarrow$ No-lose theorem: $qq \rightarrow qq\{h^0, H^0\} \rightarrow qq\tau\tau$



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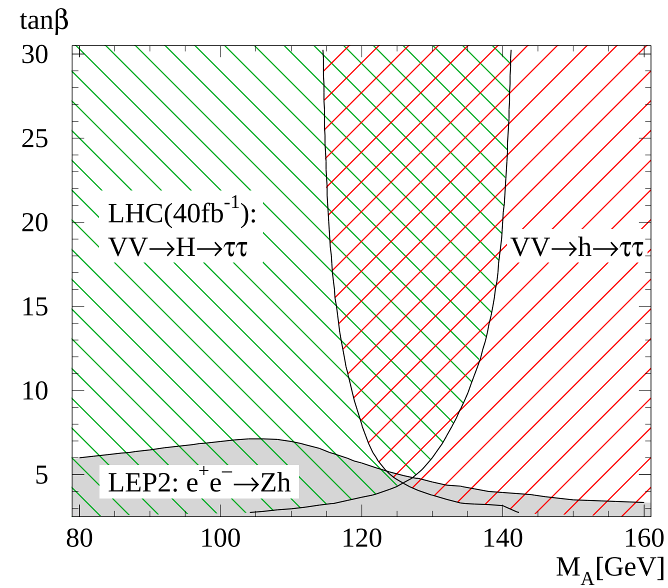
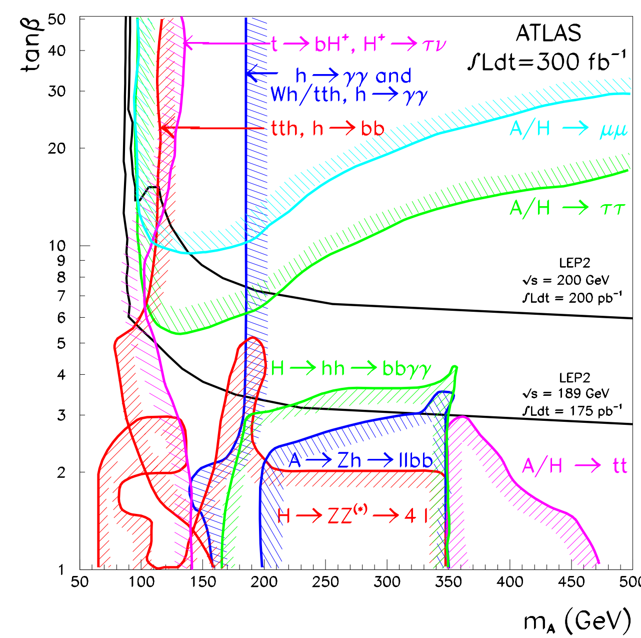


Nightmare: confirm SUSY Higgs sector

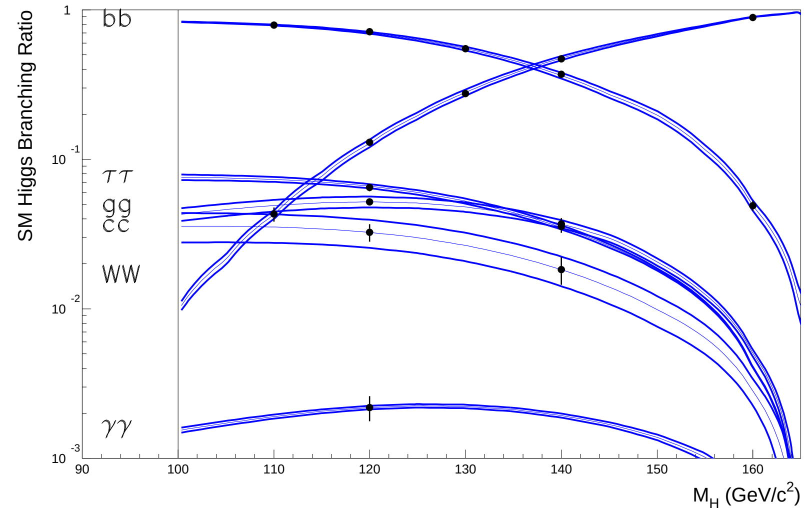
– decoupling regime $m_A \gtrsim 160$ GeV
  $\rightarrow$ Yukawa coupling for $H^0, A^0, H^\pm$: $m_b \tan\beta$
  $\rightarrow$ production e.g. $b\bar{b} \rightarrow H^0$ or $gb \rightarrow tH^-$
  $\rightarrow$ decays e.g. $H^0 \rightarrow \tau\tau, \mu\mu$ or $H^- \rightarrow \tau\bar{\nu}$

– intermediate $m_A \sim 120$ GeV:
  $\rightarrow$ lots of Higgs bosons h^0, H^0, A^0 observable
  $\rightarrow$ problem distinguishing them: $H^0 \rightarrow \mu\mu$
  $\rightarrow$ top quark decays $t \rightarrow bH^+$? [Tevatron sample small]



Higgs searches at the ILC

- production rate the challenge (energy), backgrounds under control
- Higgs-strahlung $e^+e^- \to Zh^0$ for SM-like Higgs
  pair production $H^+H^-, A^0h^0, ...$
  single production $WW \to h^0, \gamma\gamma \to h^0, H^0$,...
- precision the key



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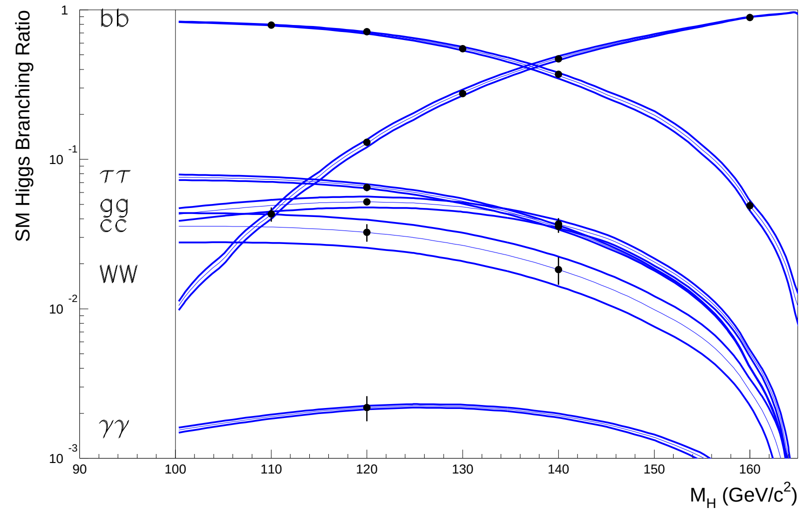
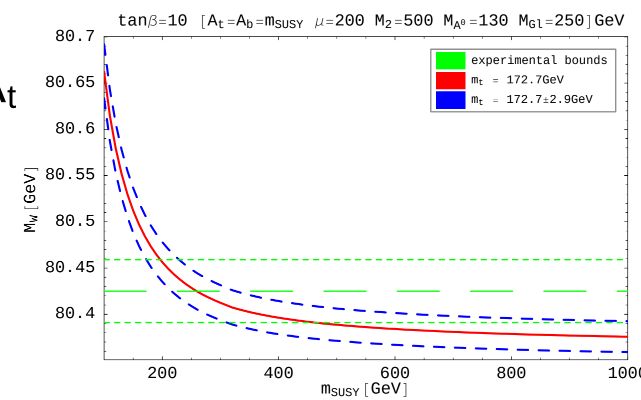


Electroweak analyses at the ILC [Wolfgang Hollik's talk]

- similar to LEP–electroweak fit
- input SUSY-Higgs, electroweak sector with SUSY loops
- logarithmic dependence on SUSY masses

$\Rightarrow$ measure W mass and some SUSY masses, derive A_t
measure SUSY masses and tell people m_W is wrong



SUSY particle masses

– mechanism of mass generation unknown [soft breaking leaves quadratic divergences alone]

– link to flavor physics and baryongenesis/leptogenesis unknown

– assume SUSY breaking in hidden sector
+ mediation to visible sector [gravitationally coupled, branes in extra dimensions]

– maximally blind mediation at high scale: mSUGRA
scalars: m_0, fermions: $m_{1/2}$, tri-scalar term: A_0
plus sign(μ) and $\tan\beta$ from Higgs sector [Higgs masses let free: NUHM]

Alternatives to mSUGRA

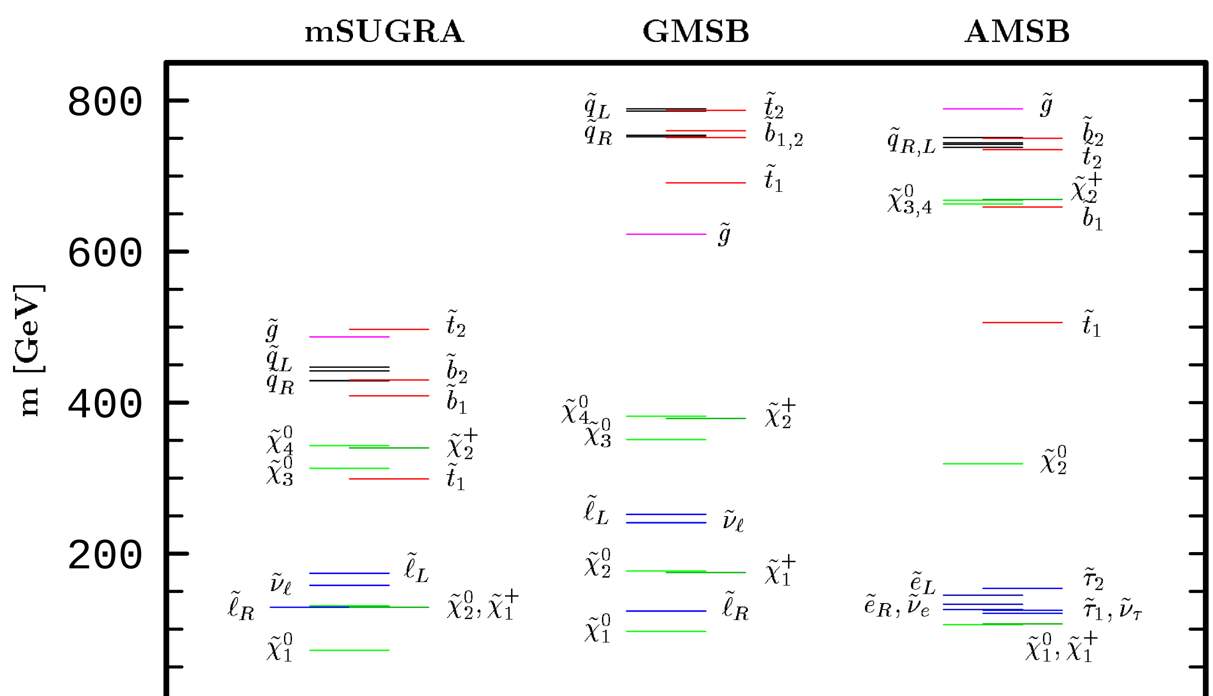
– gauge mediation

– anomaly mediation

– gaugino mediation

⇒ none of them convincing

⇒ mesasure spectrum



Structures in the SUSY spectrum

– gauginos–higgsinos mixing: $m_{\tilde{\chi}_2^0} \sim m_{\tilde{\chi}_1^+}$ or $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^+}$ in MSSM

$$\begin{pmatrix} m_{\tilde{B}} & 0 & -m_Z s_w c_\beta & m_Z s_w s_\beta \\ 0 & m_{\tilde{W}} & m_Z c_w c_\beta & -m_Z c_w s_\beta \\ -m_Z s_w c_\beta & m_Z c_w c_\beta & 0 & -\mu \\ m_Z s_w s_\beta & -m_Z c_w s_\beta & -\mu & 0 \end{pmatrix} \quad \begin{pmatrix} m_{\tilde{W}} & \sqrt{2} m_W s_\beta \\ \sqrt{2} m_W c_\beta & -\mu \end{pmatrix}$$

– stop and sbottom mixing in MSSM

$$\begin{pmatrix} m_Q^2 + m_t^2 + \left(\frac{1}{2} - \frac{2}{3} s_w^2\right) m_Z^2 c_{2\beta} & -m_t \left(A_t + \mu \cot \beta\right) \\ -m_t \left(A_t + \mu \cot \beta\right) & m_U^2 + m_t^2 + \frac{2}{3} s_w^2 m_Z^2 c_{2\beta} \end{pmatrix}$$

– heavy gluinos and squarks through unification: $m_{\tilde{B},\tilde{W},\tilde{g}}/m_{1/2} \sim 0.4, 0.8, 2.6$

$m_{\tilde{\ell},\tilde{q}}/m_{1/2} \sim 0.7, 2.5$ [$m_0 \ll m_{1/2}$]

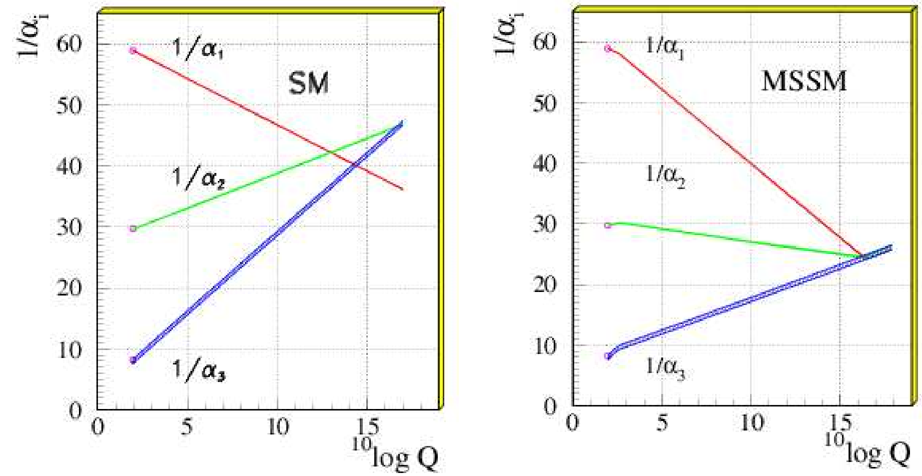
[mass and coupling unification independent]

– lightest SUSY partner $\tilde{\chi}_1^0, \tilde{\nu}$ $\Rightarrow$ after dark matter data $\tilde{\chi}_1^0 \sim \tilde{B}, \tilde{W}$ [gravitinos?]

Unification of couplings

- gauge couplings run: $g_{U(1)}, g_{SU(2)}, g_{SU(3)}$
- remember observed running of α_s
- running described as $\mu dg/d\mu = \beta_g$
- beta functions from particle content
- at one loop $\beta(n_H, n_s, n_f, ...)$

  $[\beta_{SQCD} = 11/3N - 2/3N - 2/3n_f - 1/3n_s]$



TeV Scale Supersymmetry: 4

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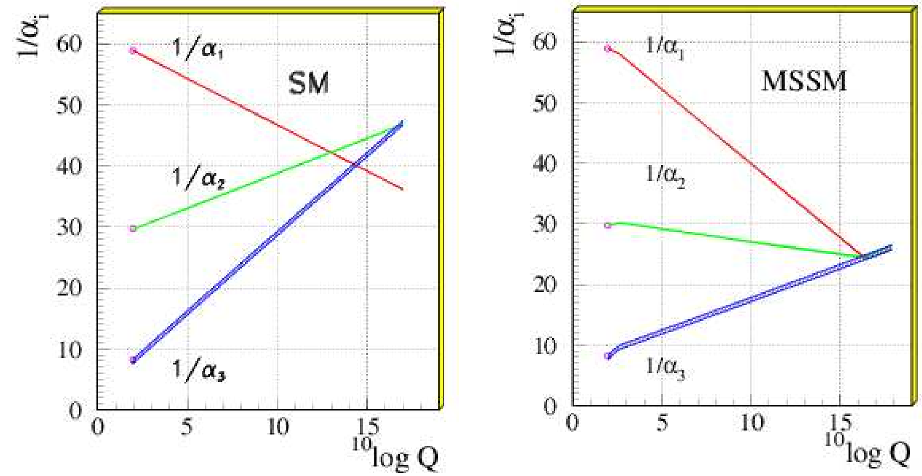


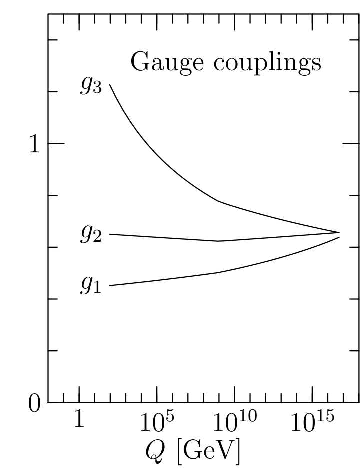
Unification of mass parameters

– parameters which gets renormalized run because of $\mu^{2\epsilon} \int dq^{4-2\epsilon}$

– Standard Model masses run: $m_b, m_t, m_{\tilde{g}}, \ldots$

– SUSY-breaking parameters run: $m_{\tilde{g}}, m_{\tilde{B}}, m_{\tilde{W}}, ..$

$\Rightarrow$ insight into SUSY breaking at some scale?



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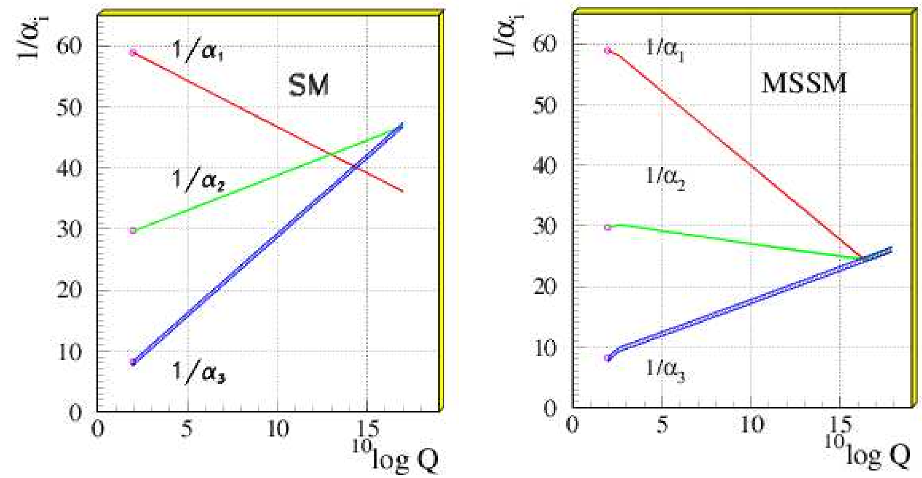

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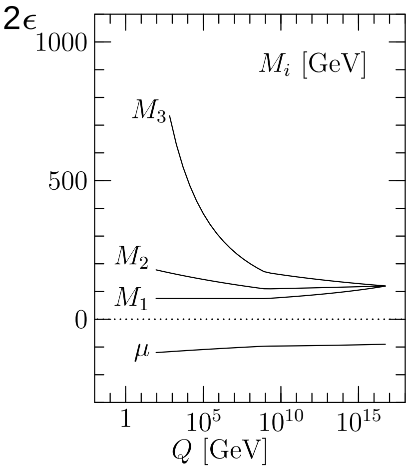

TeV Scale Supersymmetry: 4

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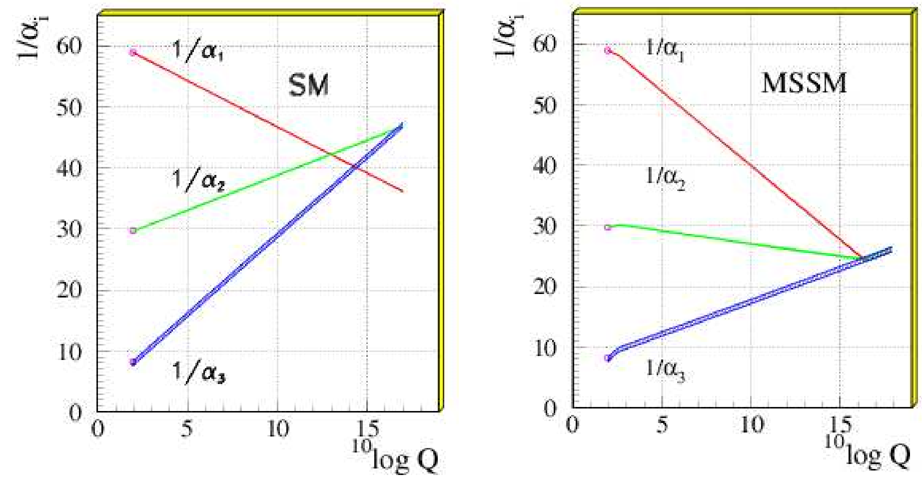

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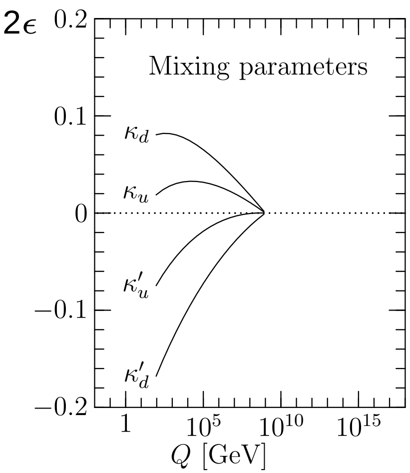


TeV Scale Supersymmetry: 5

Supersymmetric parameter conventions

– comparison of specialized codes crucial [remember: e.g. Comphep–Pythia–Isajet]

⇒ fix SUSY conventions once for all

soft breaking parameters [e.g. $\pm A_t$]
scale dependence of couplings, masses [e.g. $m(q = \text{TeV}, v, m_t)$?]
definitions of mass matrixes, mixing angles [e.g. $\tilde{t}_{L,R}$ up or down?]

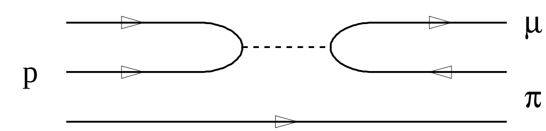
SUSY Les Houches Accord [P. Skands et al.]

– spectrum generators: SoftSusy, SPheno, FeynHiggs,...
– multi-purpose Monte Carlos: Pythia, Herwig, Sherpa
– matrix element generators: Whizard, Smadgraph
– NLO cross sections: Prospino2
– NLO decay rates: Sdecay
– SUSY parameter extraction: Fittino, Sfitter
– dark matter: Micromegas

⇒ fixed parameter convention and read-write format [list to be extended]

R PARITY

Problem with proton decay



– SUSY allows vertices like $\mathrm{q q \tilde{q}}, \mathrm{q}\ell\tilde{\mathrm{q}}, \ell\ell\tilde{\ell}$
– problem with dimension-4 proton decay
– problem with leptoquark-type constraints: atomic parity violation
– problem with $(\mathrm{e} - \mu)$ conversion
– problem with K and B decays and mixing

⇒ define ad-hoc multiplicative quantum number $\mathrm{R} = (-1)^{2\mathrm{S}-\mathrm{L}+3\mathrm{B}}$

[+1 for SM, -1 for SUSY partners, +1 for Higgses]

Impact on collider phenomenology

– every vertex involving 2 or 4 SUSY partners
– no single SUSY-partner production
– lightest SUSY partner stable (LSP)
– stable LSP at the end of each cascade

⇒ SUSY searches always for leptons+jets+missing energy [no pure QCD backgrounds]

Dark Matter in Supersymmetry

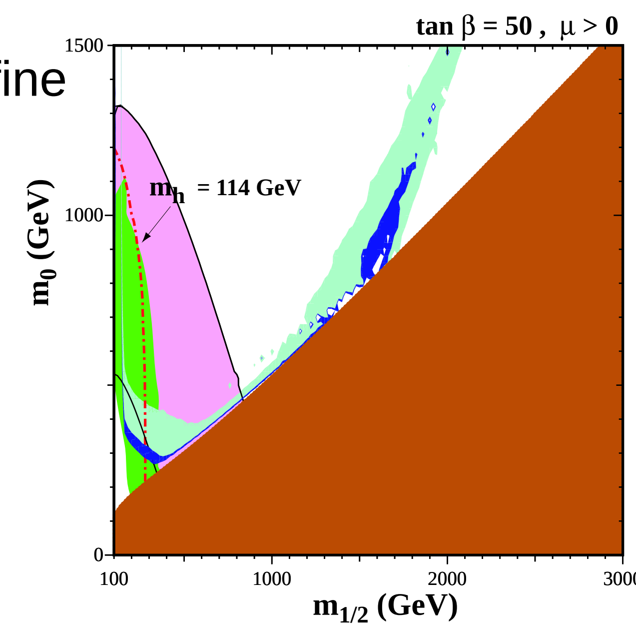
Dark matter [Georg Raffelt's talk]

- total matter density same as critial density
- observed (baryonic) matter much less
- light neutrinos too relativistic to match equation of state
- rotation of galaxies too fast (only explained by additional matter)
- cannot have charge or strong interaction, because of missing evidence

SUSY candidates with conserved R parity

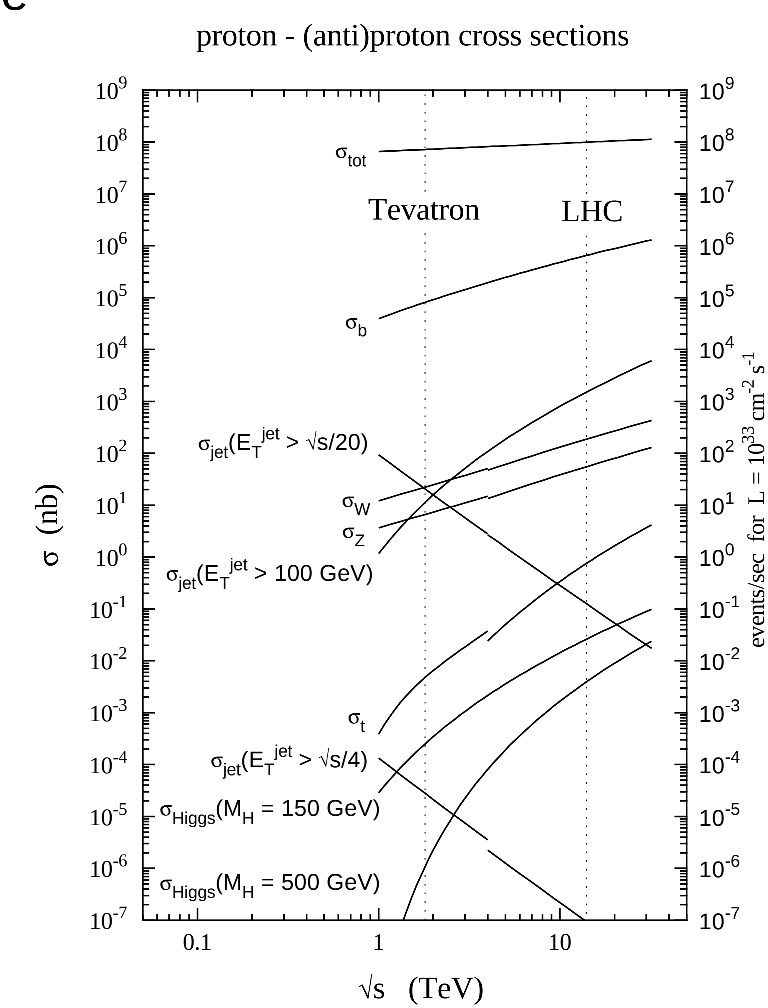
- Weakly Interacting Massive Particles at weak scale fine
- sneutrinos excluded by searches
- lightest neutralino prime candidate
- thermally produced in equilibrium, then frozen out
- annihilation $\tilde{\chi}\tilde{\chi} \to f\bar{f}$ necessary
  s-channel annihilation through A^0 at large $\tan\beta$?
  co-annihilation $\tilde{\chi}\tilde{\tau} \to Z\tau$ helpful?

$\Rightarrow$ few observables in a large parameter space, though



Conversion of energy into mass [$E = mc^2$ with c=1]

- search for new particles [easier if real particle produced]
  $\rightarrow$ highest possible energies required
- electron colliders: collide two highly relativistic e
  LEP: 46 GeV each to produce Z
  LEP2: 103 GeV each for e.g. ZH
  ILC/CLIC: 1...4 TeV in the future
- hadron colliders: collide (anti)protons
  Tevatron: $p\bar{p}$ collision with 2 TeV [valence quarks]
  LHC: pp collisions with 14 TeV [gluons]
- LHC mass reach $\sim$ 3 TeV [trade luminosity for energy]



New physics with hadron colliders

- what is a jet and what is inside? [bottom tag, τ tag]
- trigger: 'no leptons — no data' [e.g. $pp \rightarrow t\bar{t} \rightarrow$jets]
- backgrounds rates $pp \rightarrow jj$ or $pp \rightarrow WZ$+jets
- statistical significance: $S/\sqrt{B} > 5$ is discovery

Promising SUSY channels at the Tevatron

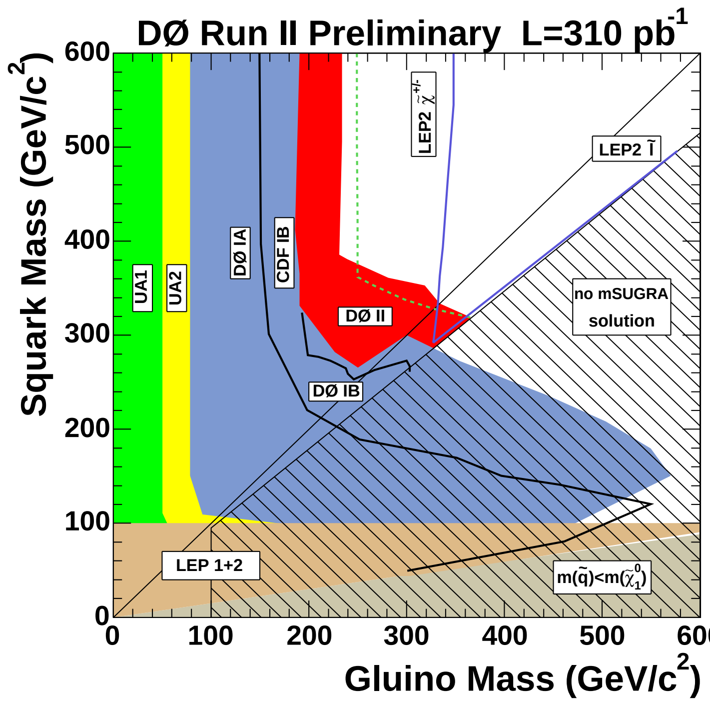
– until now: best limit $m(\tilde{\chi}^+) > 103$ GeV from LEP

[captures essentially all leptons+LSP channels]

– strongly interacting squarks and gluinos
$p\bar{p} \to \tilde{q}\tilde{q}^*, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ [best if $m(\tilde{q}) \sim m(\tilde{g})$]

– decays to jets and LSP and
$\tilde{g} \to \tilde{q}\bar{q}$, $\tilde{q}_L \to q\tilde{\chi}_2^0$, $\tilde{q}_R \to q\tilde{\chi}_1^0$
additional jets and leptons possible

$\Rightarrow$ search as inclusive as possible



Necessary model assumptions

– assume 100% branching into inclusive jets+LSP

– for detector efficiencies $m(\tilde{\chi}_2^0), \dots$

– gluino decay into squark or vice versa?

$\Rightarrow$ mSUGRA assumed, but effect moderate

More specialized: trilepton channels

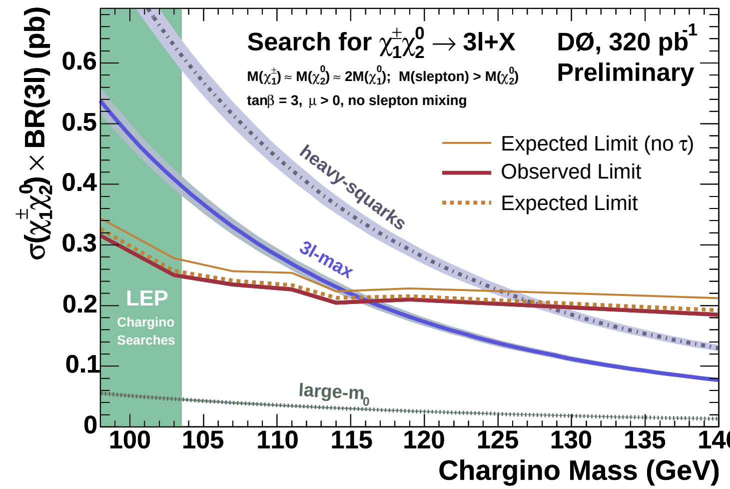
– generally assumed that charginos are lighter than gluinos

– largest cross section $p\bar{p} \to \tilde{\chi}_1^+ \tilde{\chi}_2^0$
  decays $\tilde{\chi}_1^+ \to \ell^+ \nu \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to \ell^+ \ell^- \tilde{\chi}_1^0$

– gaugino rate determined by t channel squark

– trilepton signature plagued by W, Z background

$\Rightarrow$ about to pass LEP chargino limits



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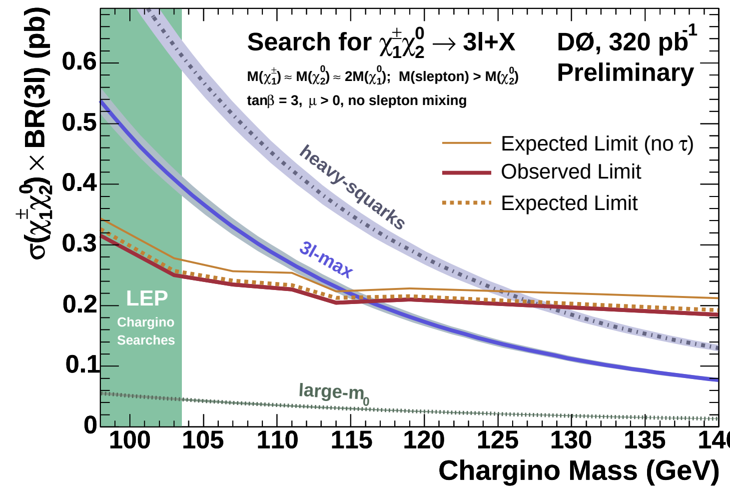
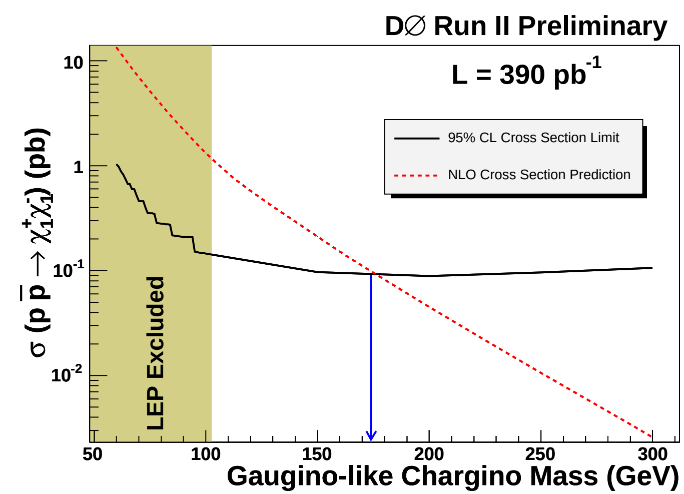


Even more specialized: long-lived gauginos

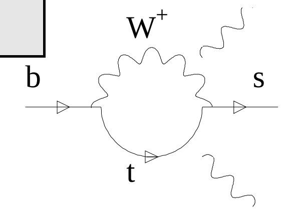
– stable on the detector time scale of ns

– like massive muons in tracker–muon chamber

– gauginos motivated by GMSB or AMSB

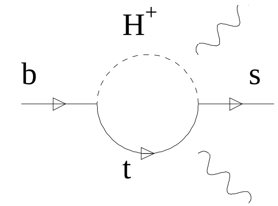


TEVATRON: B PHYSICS AND SUPERSYMMETRY

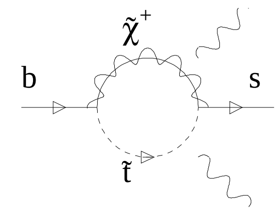


Tevatron channel: $B_s \to \mu\mu$

– s-channel exchanges dominant: H, Z, γ
  suppressed in Standard Model [$BR_{SM} \sim (2.4 \pm 0.5) \times 10^{-9}$]

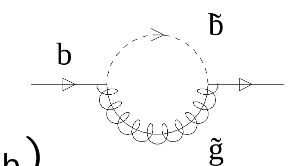


– more Higgs bosons in 2HDM
  $\tan\beta$ enhancement of s channel Higgses [$BR_{2HDM} \propto \tan^6\beta/m_A^4$]
  additional Higgs loop



– charginos in MSSM
  $\tan\beta$ enhancement for Higgsinos
  gluino loop for non-minimal flavor physics...

Bottom Yukawa in the MSSM



– gluino-sbottom loops universal: $y_b \to y_b/(1 + \Delta_b)$

– large, leading in $\tan\beta$ & resummable $\Delta_b \sim \alpha_s \tan\beta\, m_{\tilde{g}} \mu / \max^2(m_{\tilde{b},\tilde{g}})$
  $\Rightarrow$ decoupling in MSSM, but not in MSSM+μ
  [similar terms for chargino/neutralino exchange]

– easy to implement in MC, numerically great for $\tan\beta > 10$

$\Rightarrow$ enhancement good for SUSY signals, but pain in analyses

Supersymmetry at the LHC

(1) possible discovery — signals for new physics, exclusion of parameter space

(2) measurements — masses, cross sections, decays

(3) parameter studies — MSSM Lagrangean, SUSY breaking

SUSY signals included

– QCD coupling $g\tilde{q}\tilde{q}, q\tilde{g}\tilde{q}, g\tilde{g}\tilde{g}$

– jets and $\not{E}_T$: $pp \to \tilde{q}\tilde{q}^*, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$

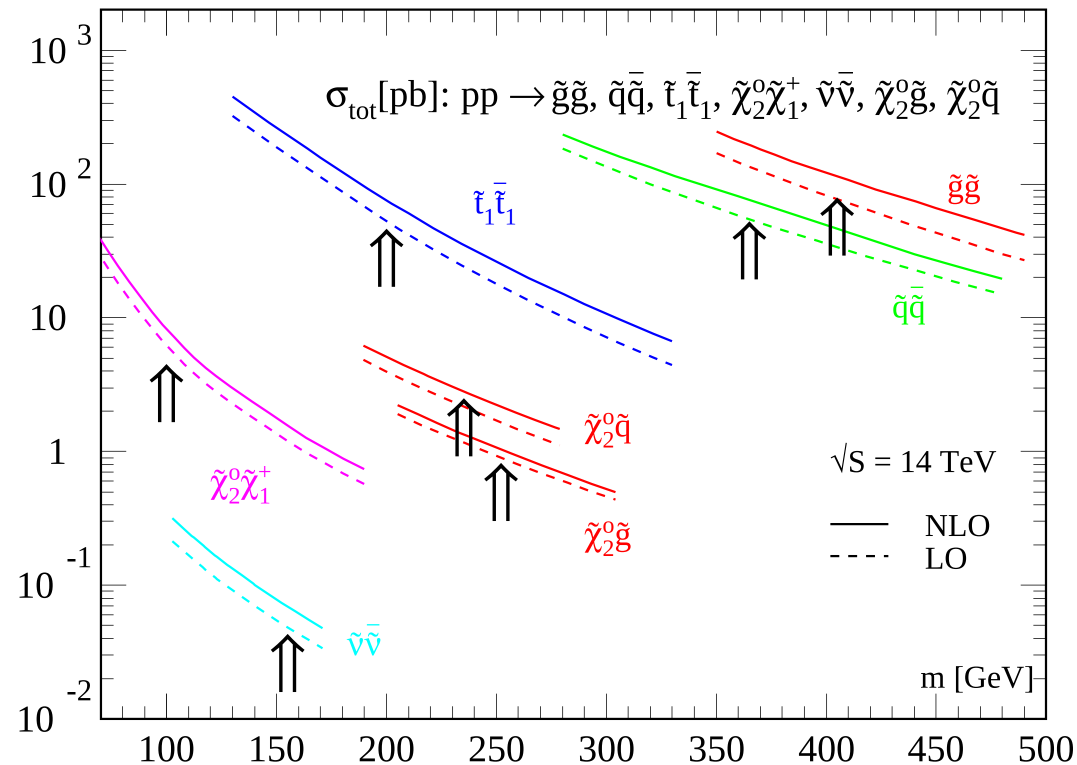
– funny tops: $pp \to \tilde{t}_1\tilde{t}_1^*$

– like sign dileptons: $pp \to \tilde{g}\tilde{g}$

[$\tilde{g} \to \tilde{u}\bar{u} \to \tilde{\chi}_1^+ d\bar{u}$ or $\tilde{g} \to \tilde{u}^* u \to \tilde{\chi}_1^- \bar{d}u$]

– tri-leptons: $pp \to \tilde{\chi}_2^0\tilde{\chi}_1^-$

[$\tilde{\chi}_2^0 \to \tilde{\ell}\ell \to \tilde{\chi}_1^0\ell\ell$; $\tilde{\chi}_1^- \to \tilde{\chi}_1^0\ell\bar{\nu}$]



SUPERSYMMETRY AT LHC: 1B

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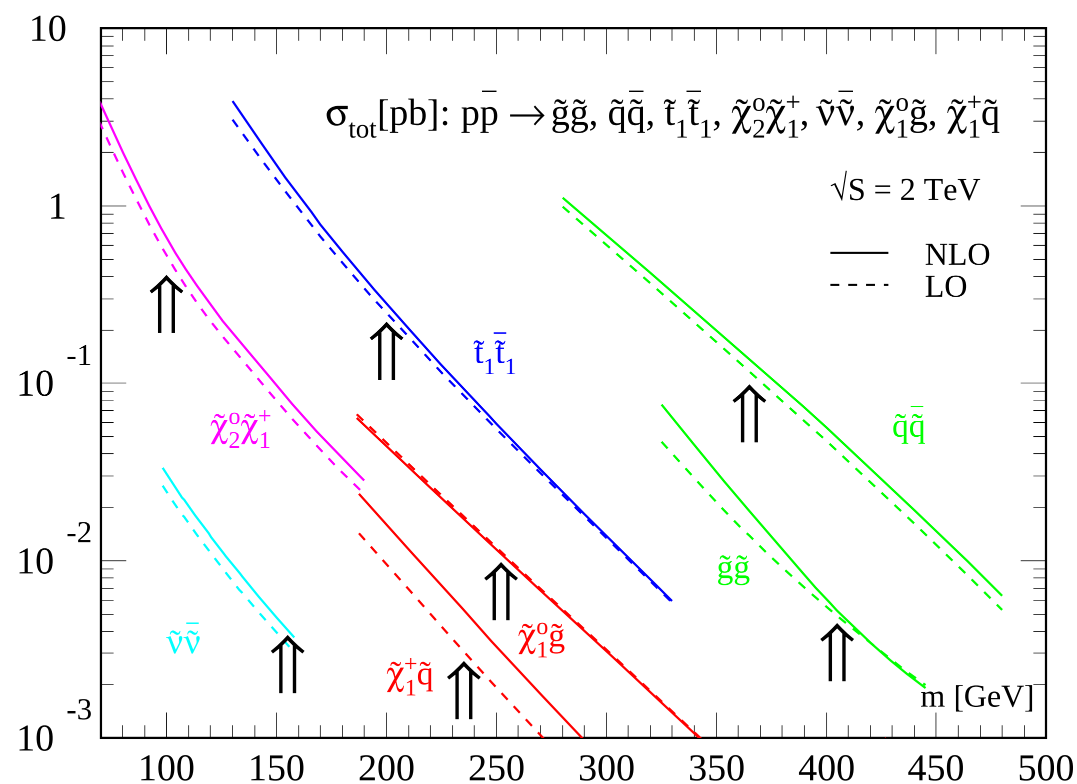


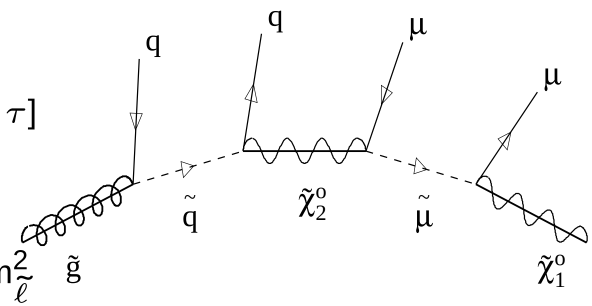
SUPERSYMMETRY AT LHC: 2

Spectra from cascade decays

– decay $\tilde{g} \to \tilde{q}\bar{q} \to \tilde{\chi}_2^0 q\bar{q} \to \mu^+\mu^- q\bar{q}\tilde{\chi}_1^0$ [better not via Z or to τ]

– cross sections some 100 pb [more than 3×10^5 events]

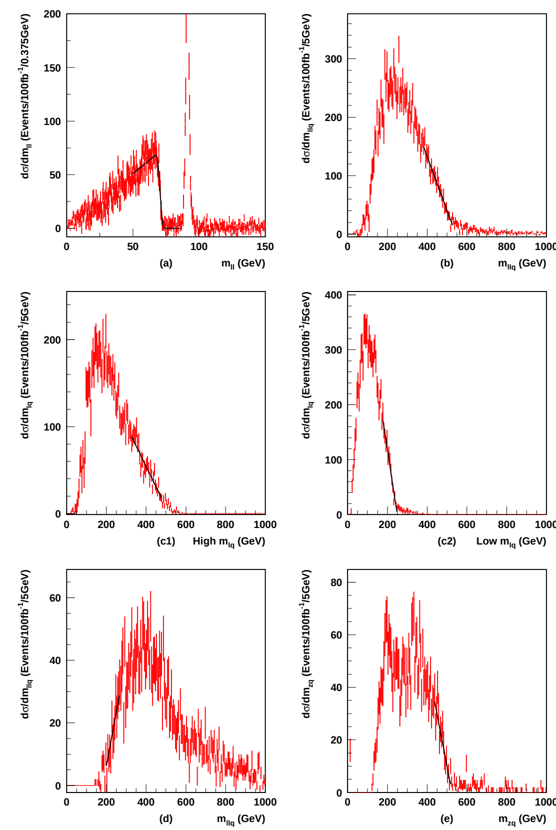
– thresholds & edges classical $m_{\ell\ell}^2 < (m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{\ell}}^2$



– detector resolution, calibration, systematic errors, shape analysis?

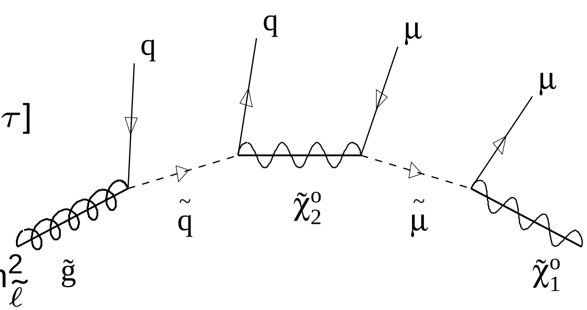
– cross sections as additional input?

⇒ $\tilde{q}_L$ cascade reconstruction great for SPS1a



Supersymmetry at LHC: 2

Spectra from cascade decays



– decay $\tilde{g} \to \tilde{q}\bar{q} \to \tilde{\chi}^0_2 q\bar{q} \to \mu^+\mu^- q\bar{q}\tilde{\chi}^0_1$ [better not via Z or to τ]

– cross sections some 100 pb [more than 3×10^5 events]

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– detector resolution, calibration, systematic errors, shape analysis?

– cross sections as additional input?

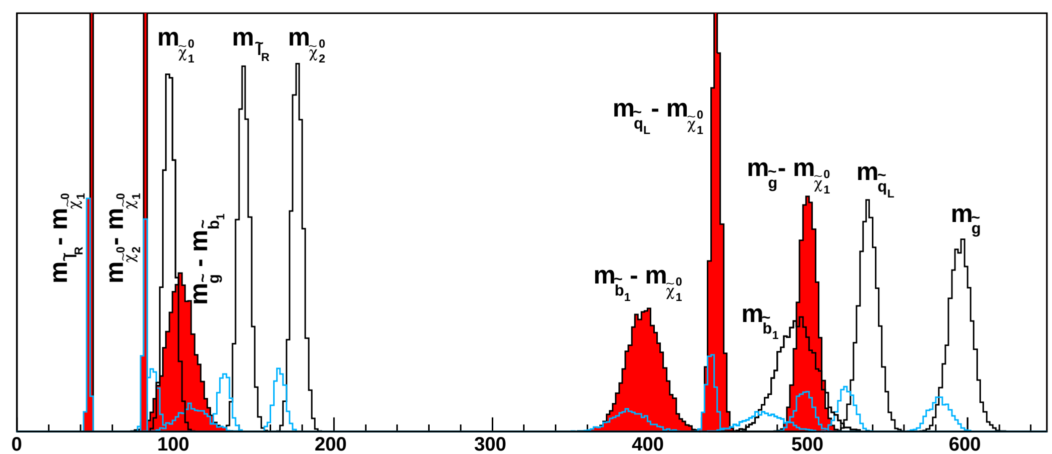
$\Rightarrow$ $\tilde{q}_L$ cascade reconstruction great for SPS1a [mass differences better]

Gluino mass

– now four jets instead of two

– $\tilde{b}_L$ instead, all jets b-tagged

$\Rightarrow$ gluino mass to $\sim$ 1%
statistical error dominant



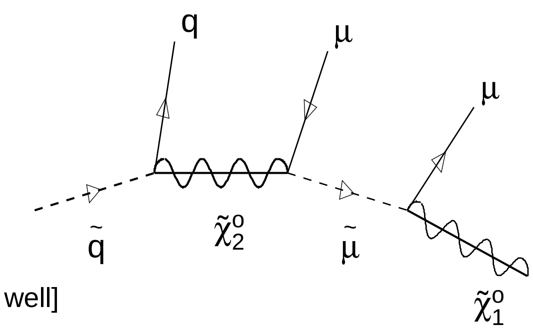
How to make sure it is SUSY

– assume neutralino is found in cascades

– compare with a model where gluino is a boson,...

$\rightarrow$ straw man: universal extra dimensions

[mass spectra degenerate —ignore this information; cross section factor 10 larger —ignore this as well]



Slepton cascade

– decay chain $\tilde{\chi}_2^0 \rightarrow \ell \tilde{\ell}^* \rightarrow \ell \bar{\ell} \tilde{\chi}_1^0$

– compare with first excited Z and ℓ

– typically largest pp $\rightarrow \tilde{q}\tilde{g}$ $[\tilde{q}/\bar{\tilde{q}} \sim 2]$

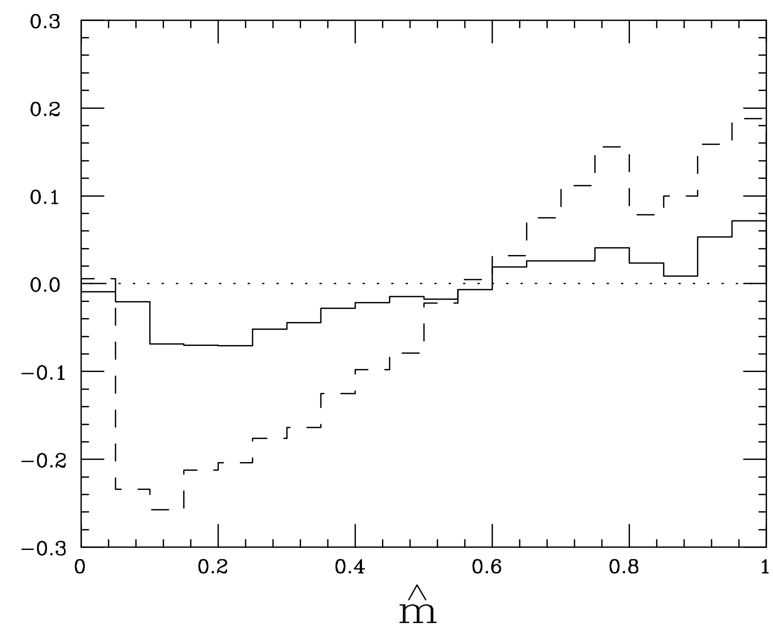
$\Rightarrow$ $\widehat{m} = m_{j\ell}/m_{j\ell}^{max}$ most promising

$\mathcal{A} = [\sigma(j\ell^+) - \sigma(j\ell^-)]/[\sigma(j\ell^+) - \sigma(j\ell^-)]$

– assume hierarchical SPS1a spectrum

[dashed SUSY, solid UED]

$\Rightarrow$ we can tell spin in cascade



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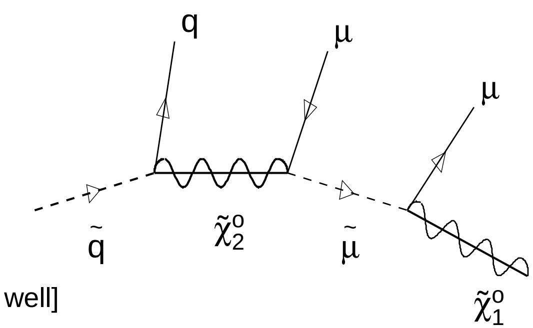

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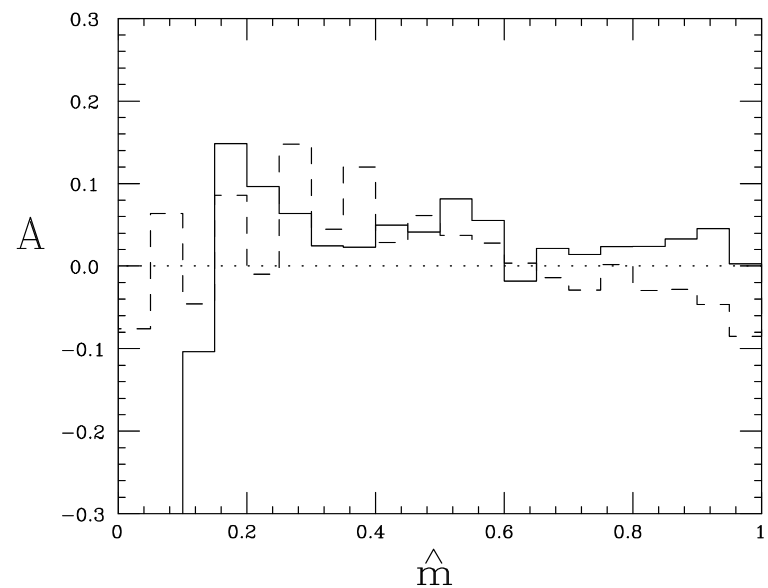
$\mathcal{A} = [\sigma(j\ell^+) - \sigma(j\ell^-)]/[\sigma(j\ell^+) - \sigma(j\ell^-)]$

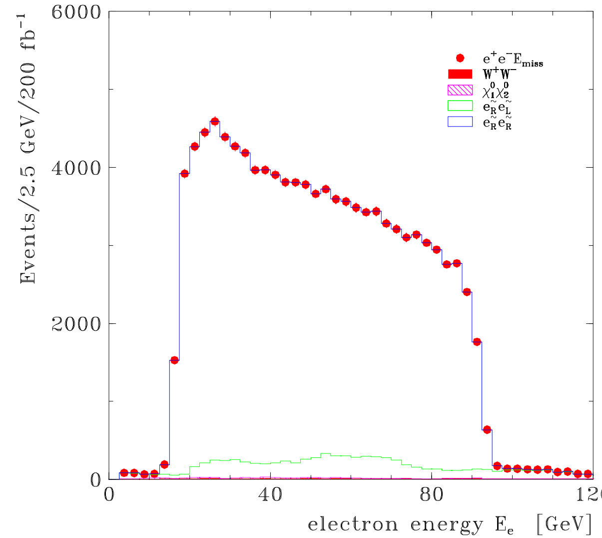
– assume non-hierarchical UED spectrum

[dashed SUSY, solid UED]

$\Rightarrow$ we can tell spin in cascade



SUPERSYMMETRY AT THE ILC: 1



All information in the kinematics

– very high luminosity: 1 ab^{-1}

– excellent mass resolution to reject backgrounds

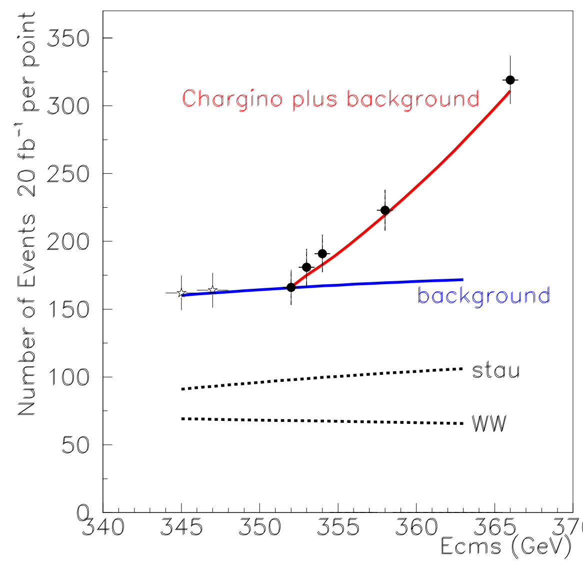
– mass determination from energy spectrum

$$m_{\tilde{\ell}} = \sqrt{s}\sqrt{E_+E_-}/(E_+ + E_-)$$

$$m_{\tilde{\chi}_1^0} = m_{\tilde{\ell}}\sqrt{1 - 2(E_+ + E_-)/\sqrt{s}}$$

– higher–order/off-shell corrections necessary

⇒ mass determination to better than 0.2%



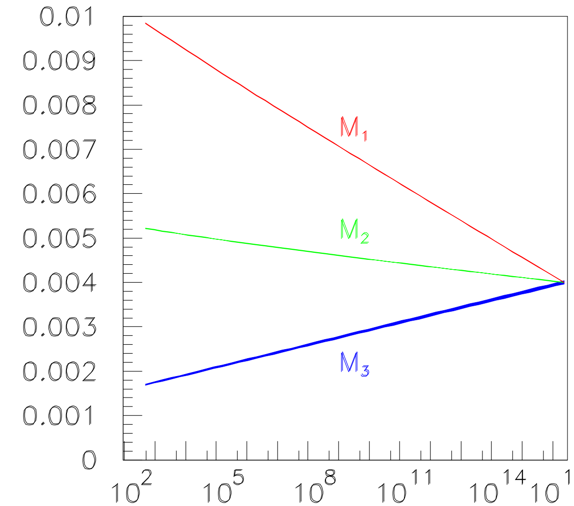
Similarly good: threshold scan

– required luminosity around 100 fb^{-1} per particle

– theoretical threshold description: what mass?

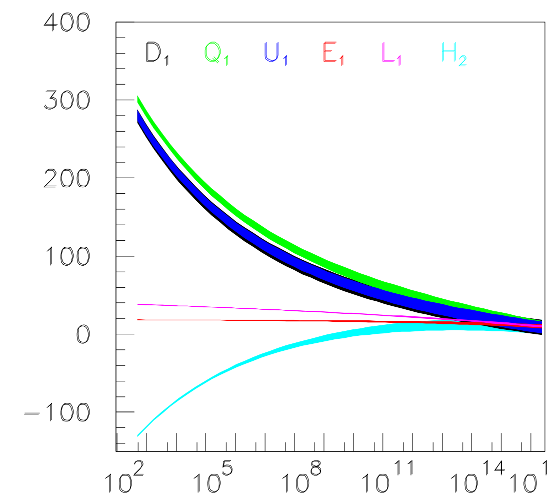
– necessary for example for $\tilde{\chi}_1^0\nu$ in decay

⇒ mass determination to better than 0.5%



Renormalization group bottom–up

- high–scale parameters without assumptions?
- all parameters in beta functions necessary
  neutralino/chargino sector from ILC (NLO)
  gluino mass from LHC
- gaugino mass unification 'SUGRA light'



Slepton masses more involved

- again test of unified masses
- quark flavor crucial input
- slepton mass running flat
  squark mass determination weak
  u-d-s-c flavor tagging in squark decays

SUPERSYMMETRIC PARAMETERS

SUSY parameters from observables

– parameters: weak-scale MSSM Lagrangean

– measurements: masses
branching fractions
cross sections

– errors: general correlation, statistics & systematics & theory

– problem in grid: huge phase space, local minimum?
problem in fit: domain walls, starting values, global minimum

Combination of methods

– (1) grid for closed subset
(2) fit of remaining parameters
(3) complete fit

– more modern alternaives:
simulated annealing
Markov Chains

$\Rightarrow$ LHC+ILC with no assumptions

	LHC	ILC	LHC+ILC	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	fix 500	588.05 ± 11	589.4
$M_{\tilde{\tau}_L}$	fix 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
$M_{\tilde{t}_R}$	fix 500	420 ± 2.1	411.73 ± 12	420.2
$M_{\tilde{b}_R}$	522.26 ± 113	fix 500	504.35 ± 61	525.6
A_τ	fix 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	fix 0	-977 ± 12467	-799.4

SUSY parameters from observables

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– measurements: masses or edges
  branching fractions
  cross sections

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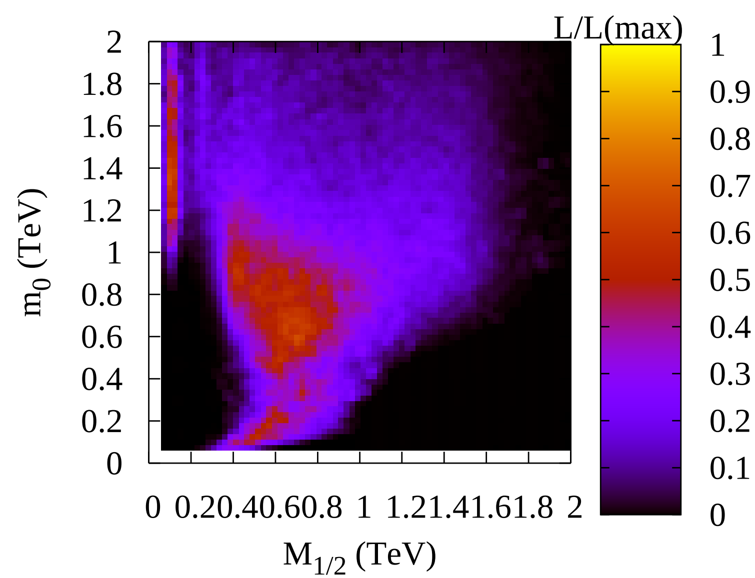
First go at problem



– ask a friend who knows how SUSY is broken

⇒ mSUGRA

– fit $m_0, m_{1/2}, A_0, \tan\beta, \mathrm{sign}(mu)$

– no problem, include indirect constraints

⇒ who would bet a month's salary on mSUGRA?

– admittedly: mSUGRA a very useful testing ground for methods

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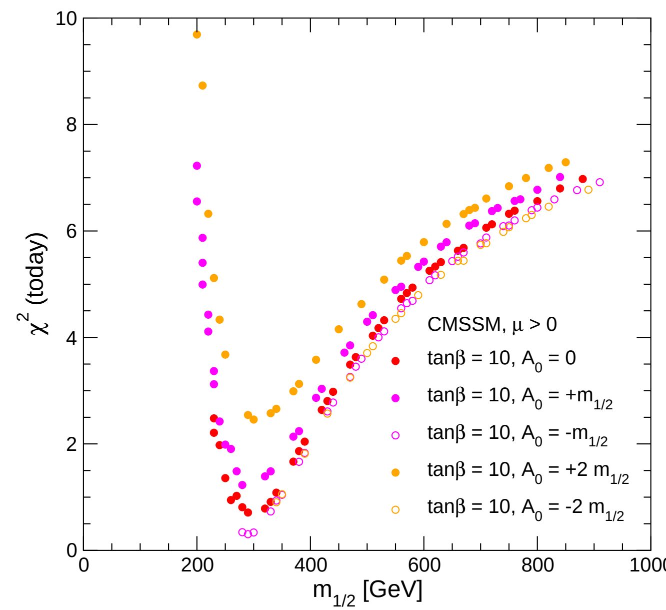

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OUTLOOK

Supersymmetry a good solution to hierarchy problem

– dark matter motivation getting stronger

– no hint of SUSY-flavor physics

– Tevatron searches promising put tough

– LHC searches much more powerful

– ILC analyses perfect tool, luminosity the issue

$\Rightarrow$ Super-cool times ahead