LECTURE 2 B

SUSY

MSSM (briefly)

from the MSSM to more difficult scenarios

Updates: a few examples

Split supersymmetry hep-ph/0507137 squarks and sleptons made heavy *

Splitting split supersymmetry hep-ph/0501265

Supersplit supersymmetry hep-th/0503249: raise also gaugino and higgsino masses

Folded supersymmetry hep-ph/0609152 *

Inert doublet arXiv:0712.4206

Twin SUSY hep-ph/0604066

Mirage Mediation hep-ph/0604192 arXiv:0804.0592

Gaugino mediation hep-ph/9911323 hep-ph/0001172

Bosonic supersymmetry? Getting fooled at the LHC hep-ph/0205314 *

SUSY

great merits from the theoretical side

in MSSM, relatively abundantly produced via squarks and gluinos

mostly mSUGRA has been studied

- $m_h > 114$ GeV $\rightarrow$ "tension", O(1%) fine tuning

  ways to escape:

  ? we missed a non SM-like light Higgs: e.g. h (97) $\rightarrow$ aa $\rightarrow$ 4 τ

  ? NMSSM would also solve the μ problem

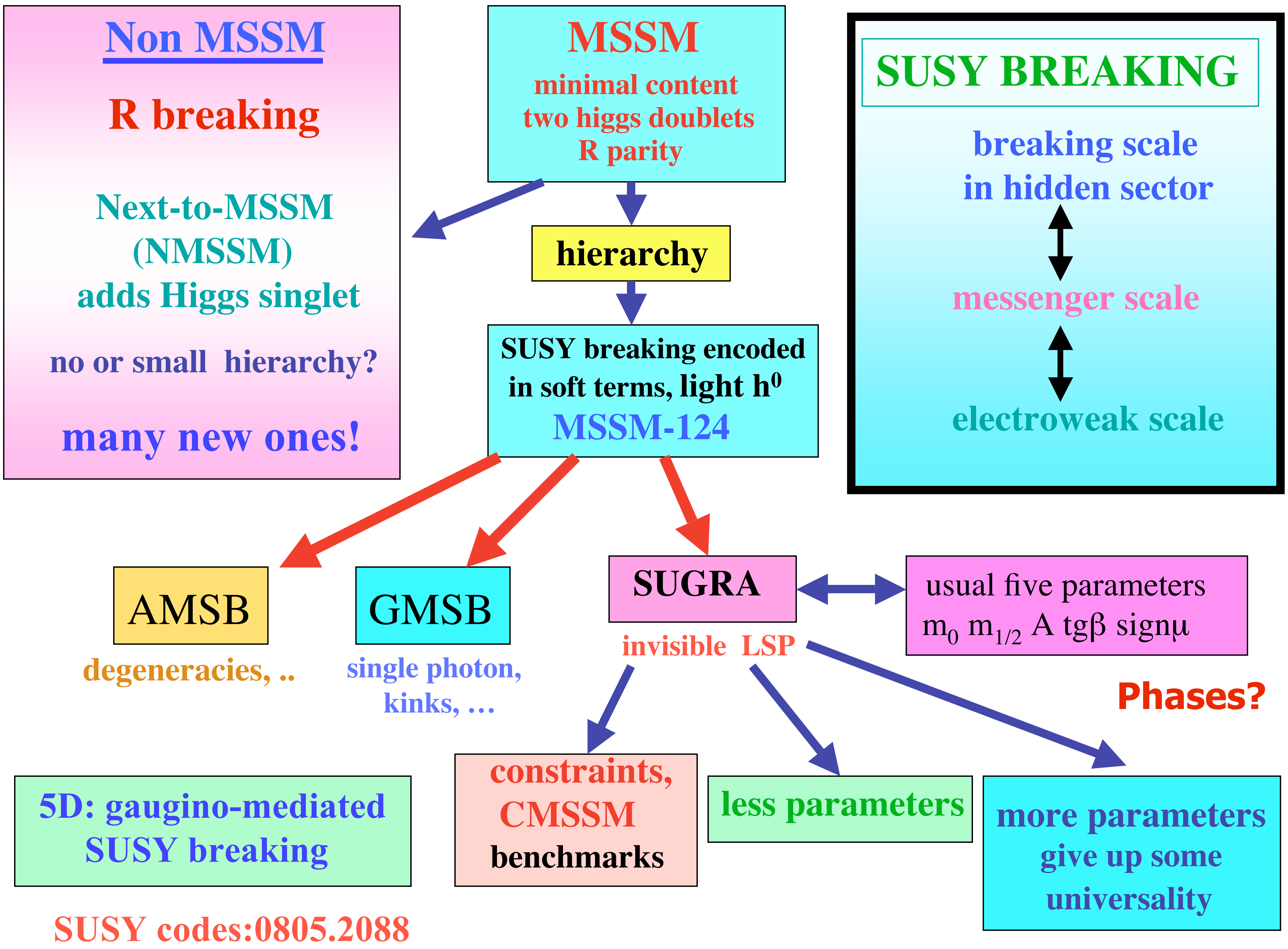
  ? ignore the tension: e.g. Split SUSY

- R-parity? to ensure proton stability

offers LSP dark matter, missing E_T but is it wishful thinking?

- missing E_T + ... as a privileged handle for mSUGRA

  can we do without it? try also "positive" identification



Non MSSM
R breaking
Next-to-MSSM
(NMSSM)
adds Higgs singlet
no or small hierarchy?
many new ones!
MSSM
minimal content
two higgs doublets
R parity
hierarchy
SUSY breaking encoded
in soft terms, light h^0
MSSM-124
SUSY BREAKING
breaking scale
in hidden sector
messenger scale
electroweak scale
AMSB
degeneracies, ..
GMSB
single photon,
kinks, …
SUGRA
invisible LSP
usual five parameters
m_0 $m_{1/2}$ A tgβ signμ
Phases?
5D: gaugino-mediated
SUSY breaking
constraints,
CMSSM
benchmarks
less parameters
more parameters
give up some
universality
SUSY codes:0805.2088

doubling the number of elementary particles
fermion $\leftrightarrow$ boson

but same couplings as SM

in unbroken SUSY, one parameter less than the SM!

Higgs potential quartic term fixed by the gauge couplings

the problem of hierarchy is solved provided the masses of super-partners are not too high

❑ Gauge / Gaugino Sector

Standard Bosons	Supersymmetric Partners
$W^{\pm}$ $H^{\pm}$	Charginos $\chi_1^{\pm}$ $\chi_2^{\pm}$
g Z h H A	Neutralinos χ_1^0 χ_2^0 χ_3^0 χ_4^0
g_i	Gluinos $\tilde{g}_i$

[Two Higgs doublets] [All fermions]

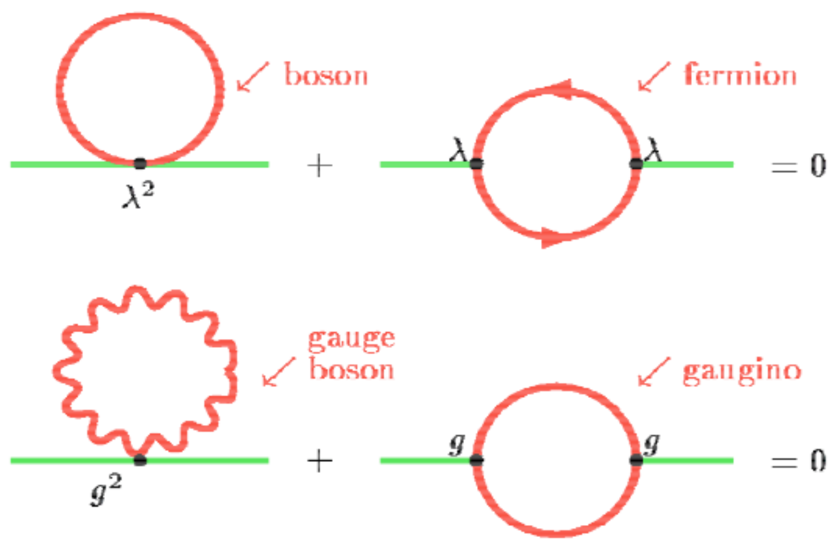
And also …

Graviton G	Gravitino $\tilde{G}$

❑ Particle / Sparticle Sector

Standard Particles	Supersymmetric Partners
Leptons ℓ	Sleptons $\tilde{\ell}_{R,L}$
Neutrinos ν_ℓ	Sneutrinos $\tilde{\nu}_\ell$
Quarks q	Squarks $\tilde{q}_{R,L}$

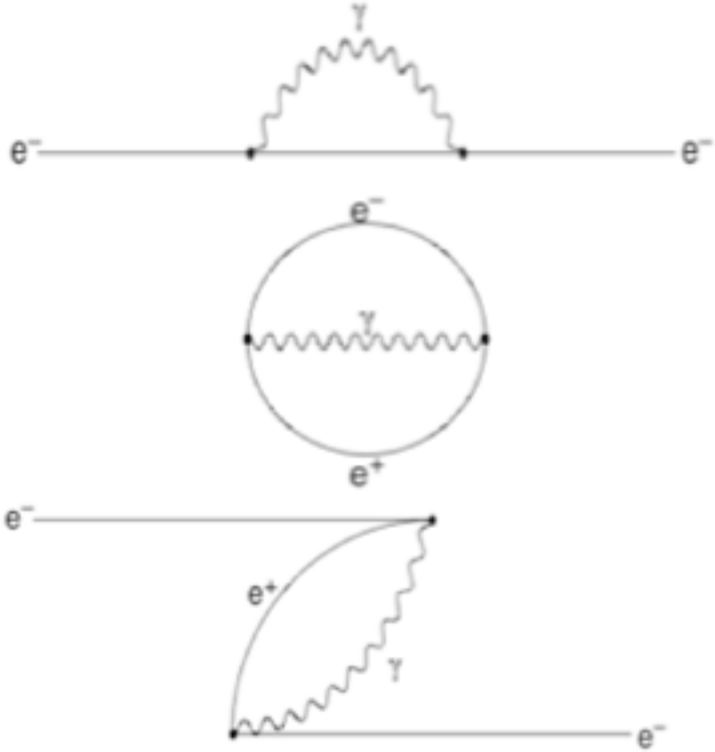
[All scalars]



$$\Delta m_H^2 \sim (M_{SUSY}^2 - M_{SM}^2)\frac{\lambda_f^2}{16\pi^2}\ln\left(\frac{\Lambda}{M_{SUSY}}\right)$$

This happened already with antimatter

Murayama



.. to keep the charge within r_e

$$\Delta E_{\text{Coulomb}} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r_e}$$

$$(m_e c^2)_{obs} = (m_e c^2)_{bare} + \Delta E_{\text{Coulomb}}$$

$$0.511 = -9999.489 + 10000.000\text{MeV}$$

Dirac, plus Weisskopf

$$\Delta E_{\text{pair}} = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r_e}$$

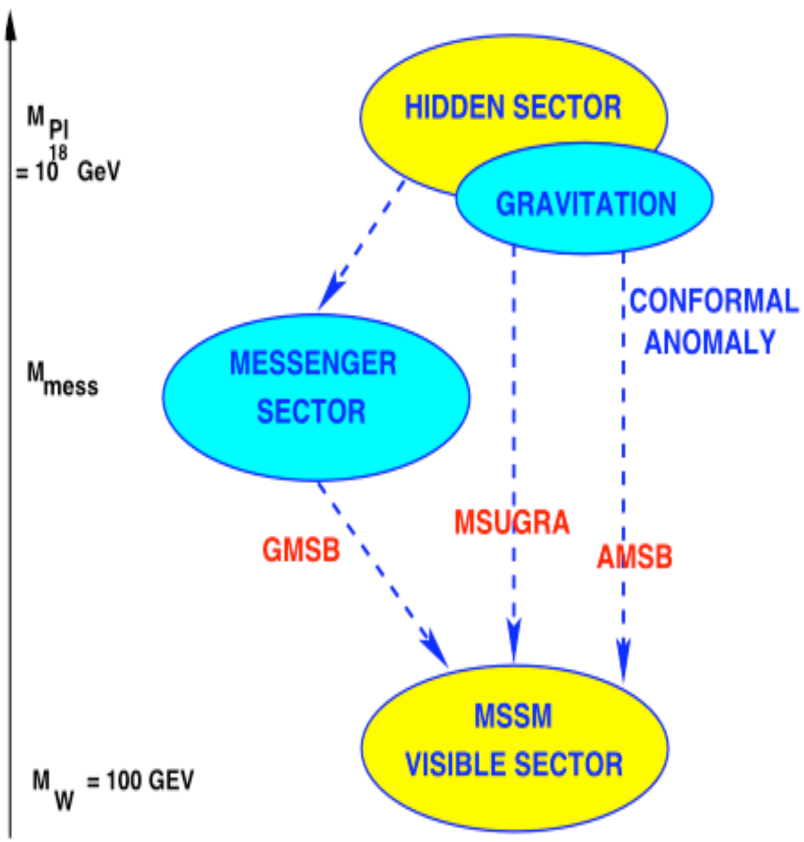
$$\Delta E = \Delta E_{\text{Coulomb}} + \Delta E_{\text{pair}} = \frac{3\alpha}{4\pi} m_e c^2 \log\frac{\hbar}{m_e c r_e}$$

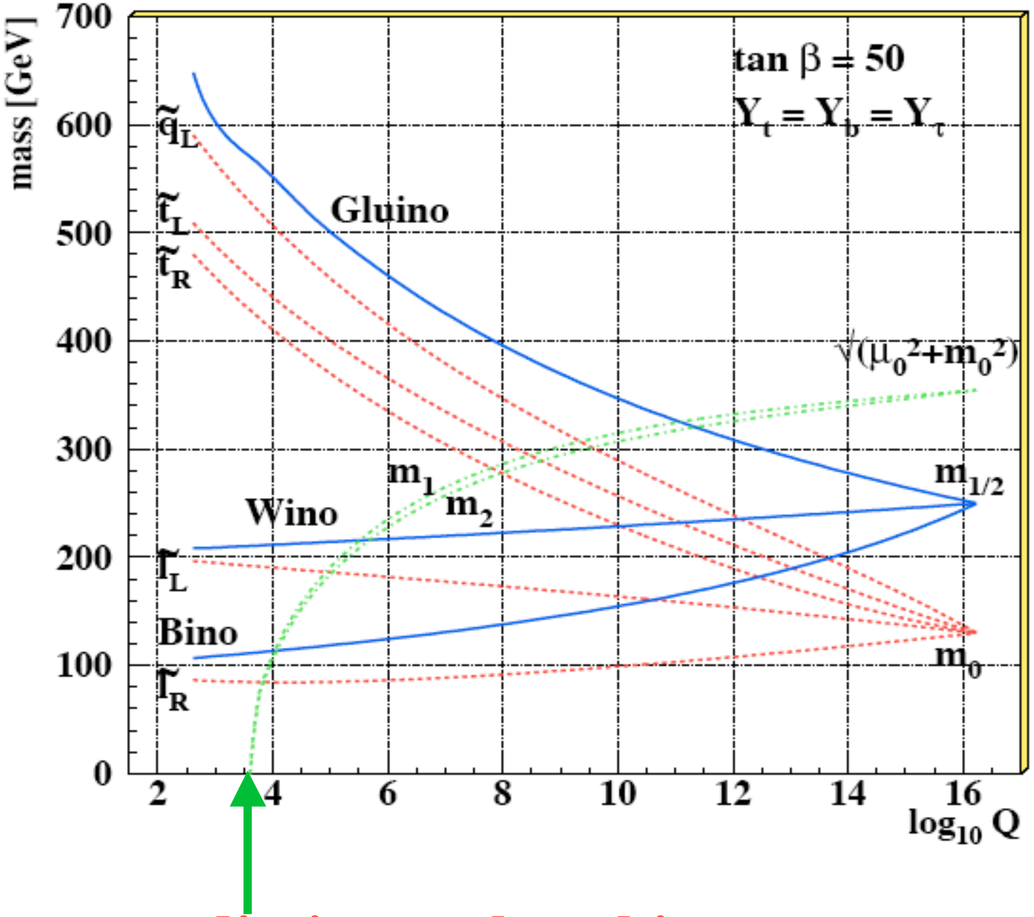
$$(m_e c^2)_{obs} = (m_e c^2)_{bare}\left[1 + \frac{3\alpha}{4\pi}\log\frac{\hbar}{m_e c r_e}\right]$$

The problems come when one breaks SUSY

“Soft” breaking, not to re-introduce quadratic divergences

Several scenarios, a jungle of parameters

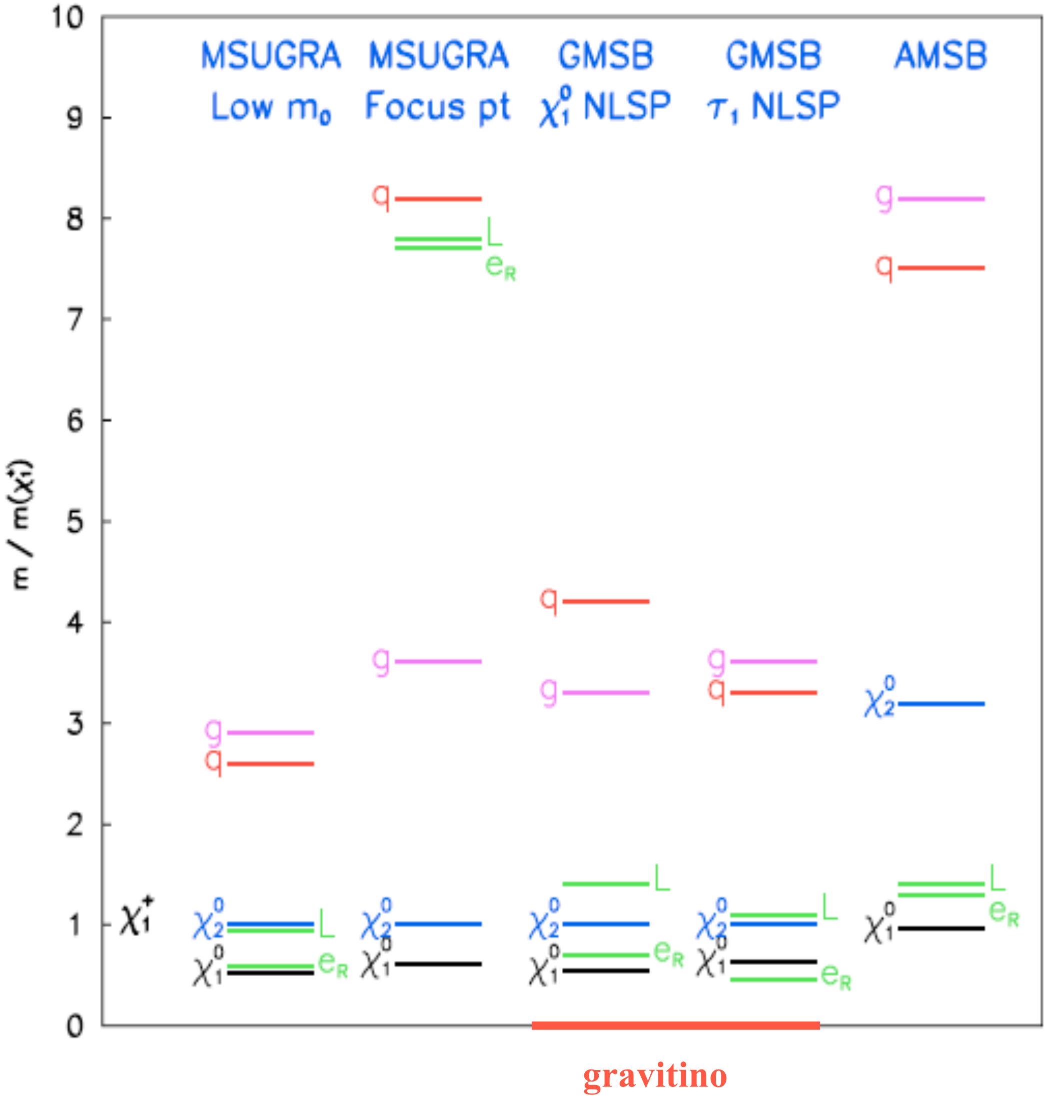




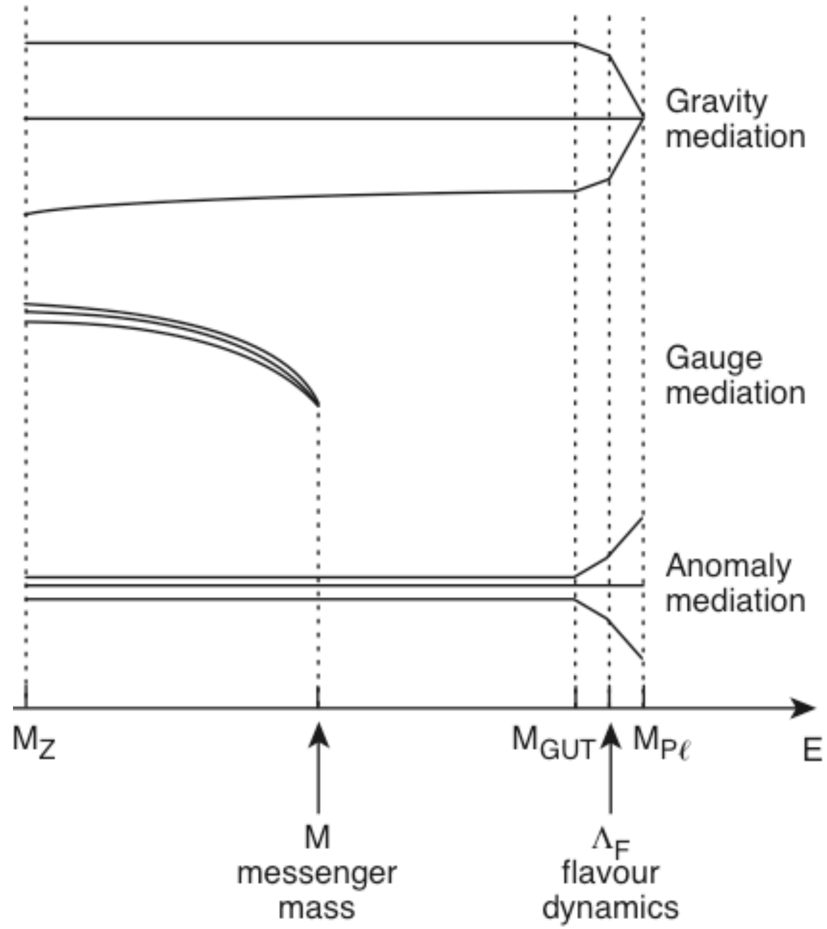
radiative ew breaking
tells "why" EWSB happens

don't we overlook
some problems?

hep-ph/0612100



hep-ph/9912279



Main features:

SUGRA: missing energy from neutralino LSP

AMSB: mass degeneracies

GMSB: gravitino LSP, phenomenology depends of which is the NLSP, $\tilde{\chi}^0$ or $\tilde{\tau}$

quite different treatments of the flavour problem

MSUGRA

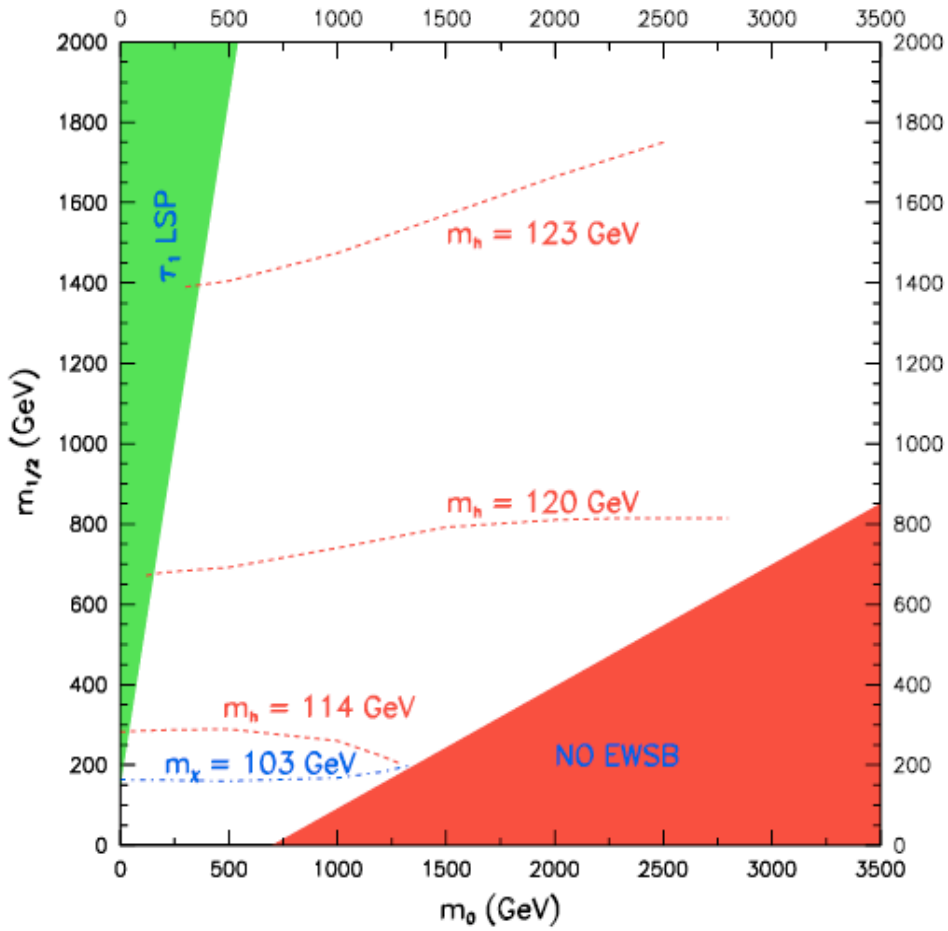
parameters $m_{1/2},\ m_0,\ \tan\beta$ and $sgn(\mu)$ $\quad A_0 = 0$

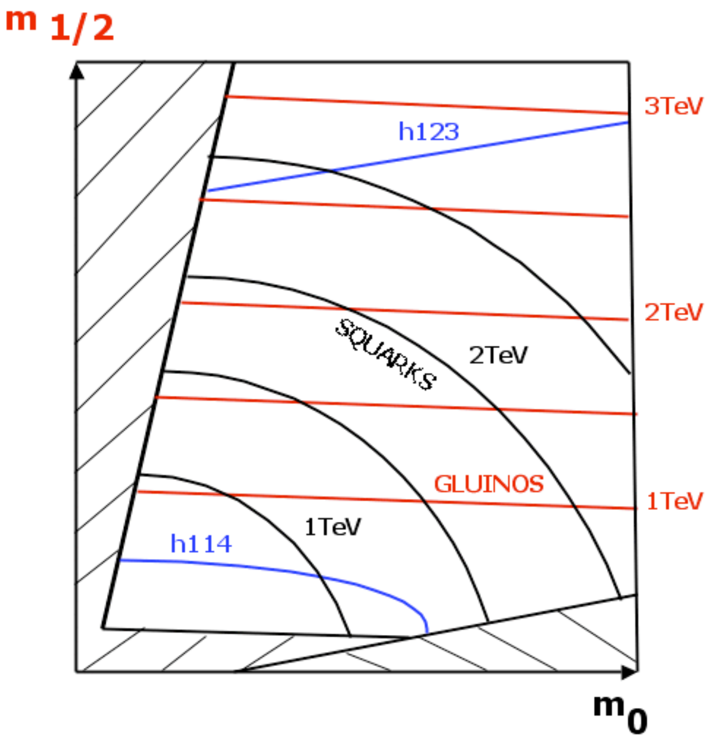
focus on m_0–$m_{1/2}$ plane

E_T^{miss} as a main handle

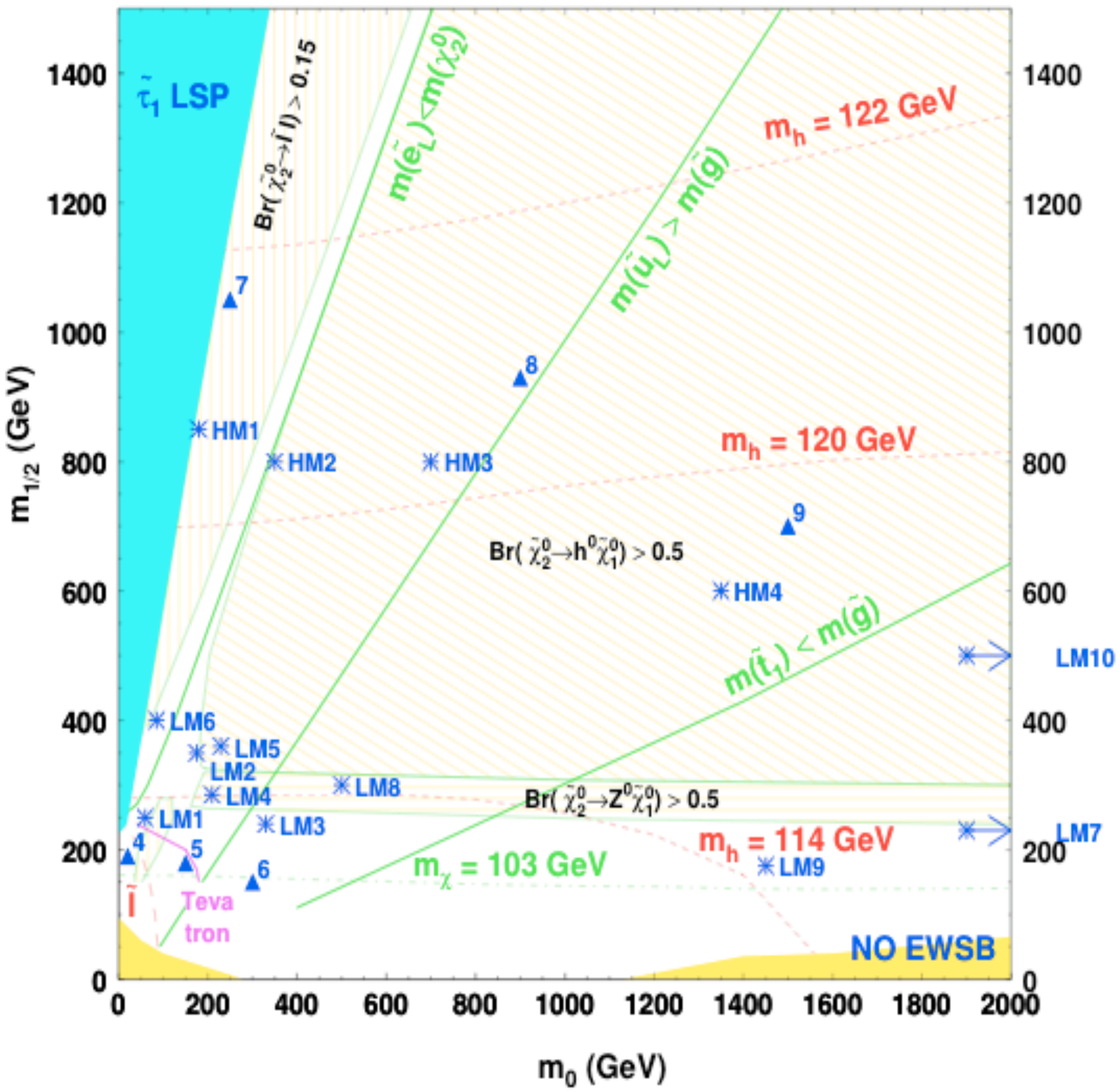
can one do another way?

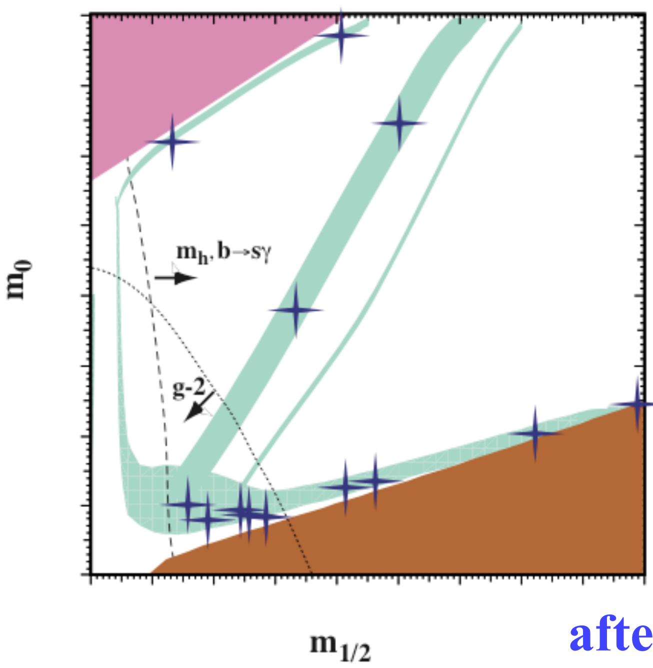
for later: can one distinguish mSUGRA from UED, etc?





at LHC pair production of squarks and gluinos, which cascade down



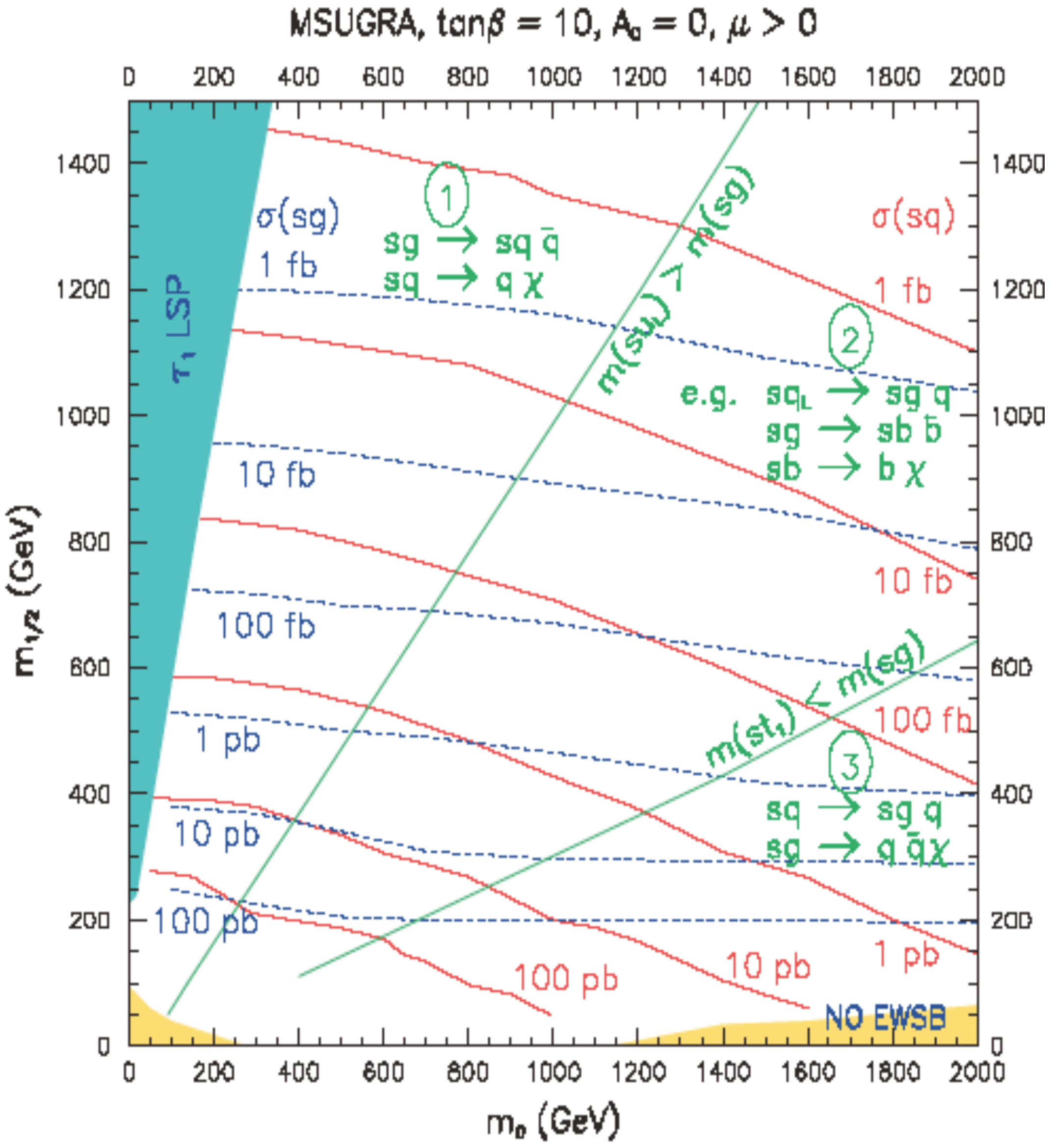


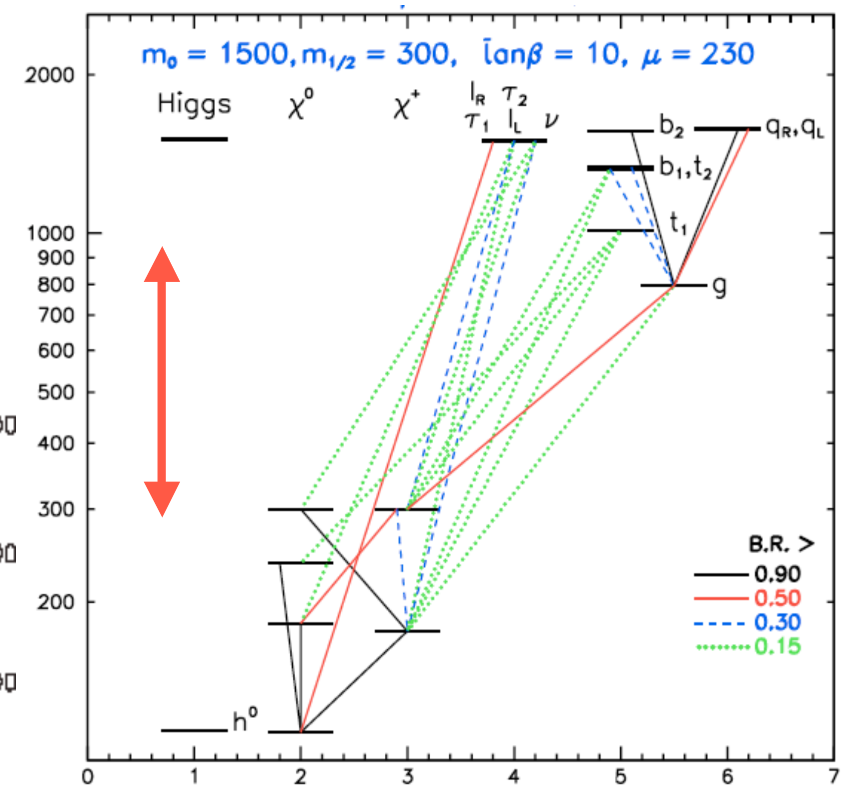
after WMAP

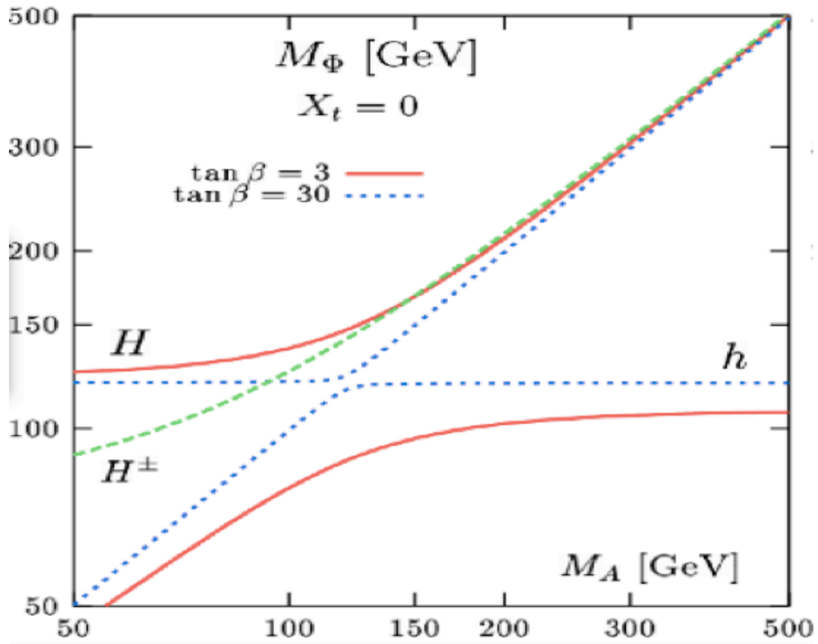
benchmark points

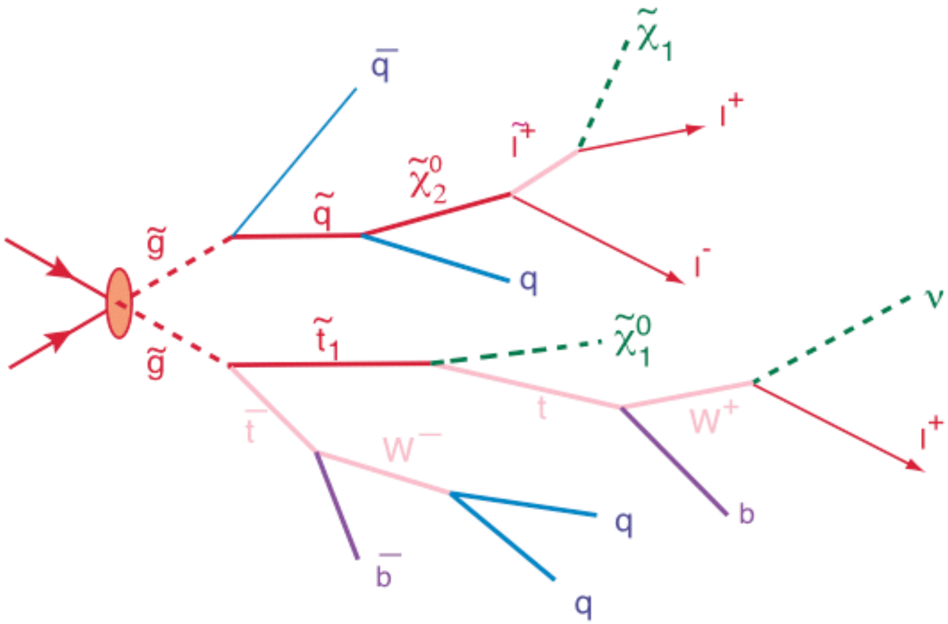
many different spectra are possible

only one firm prediction in MSSM: a very light Higgs boson h^0, likely to be SM-like

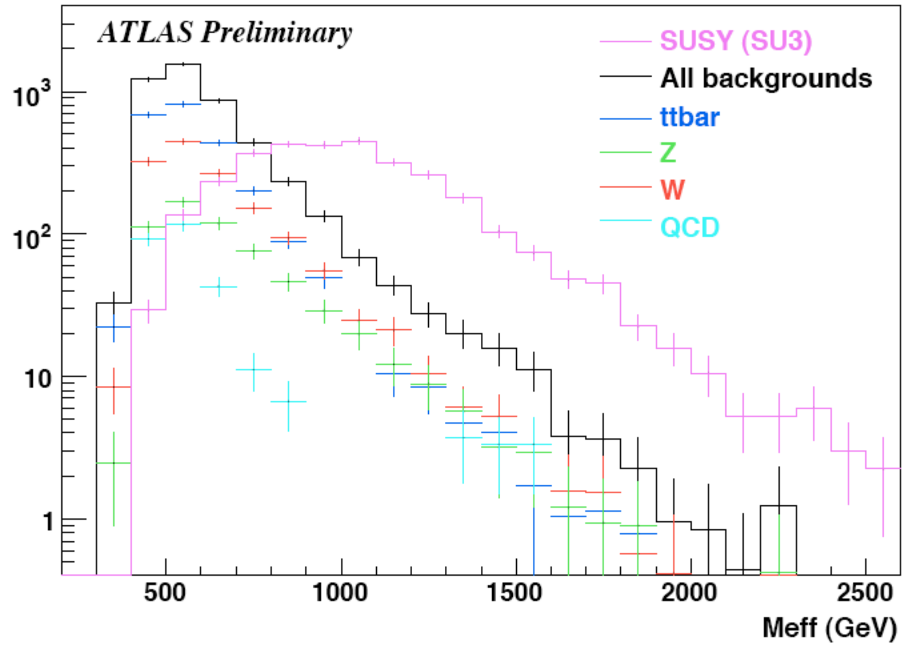




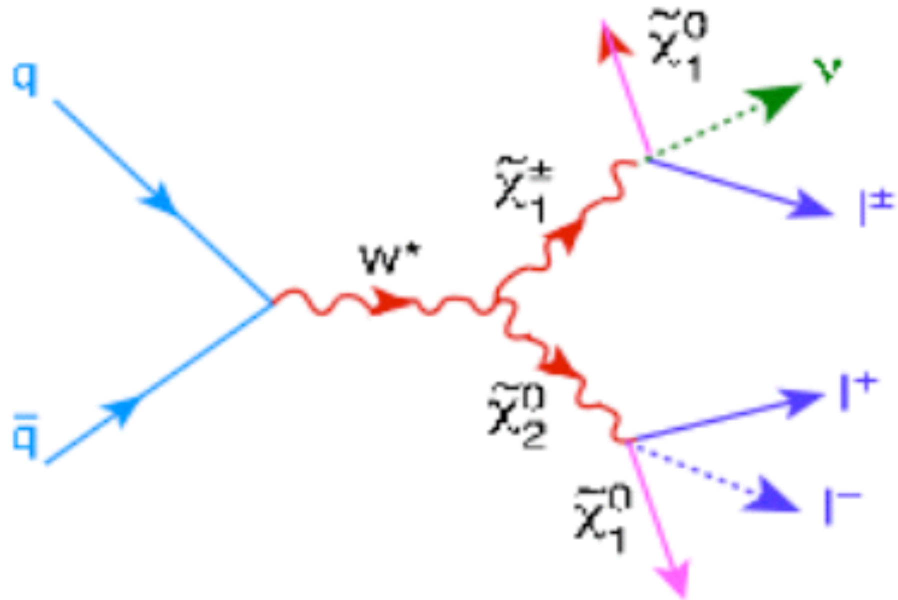




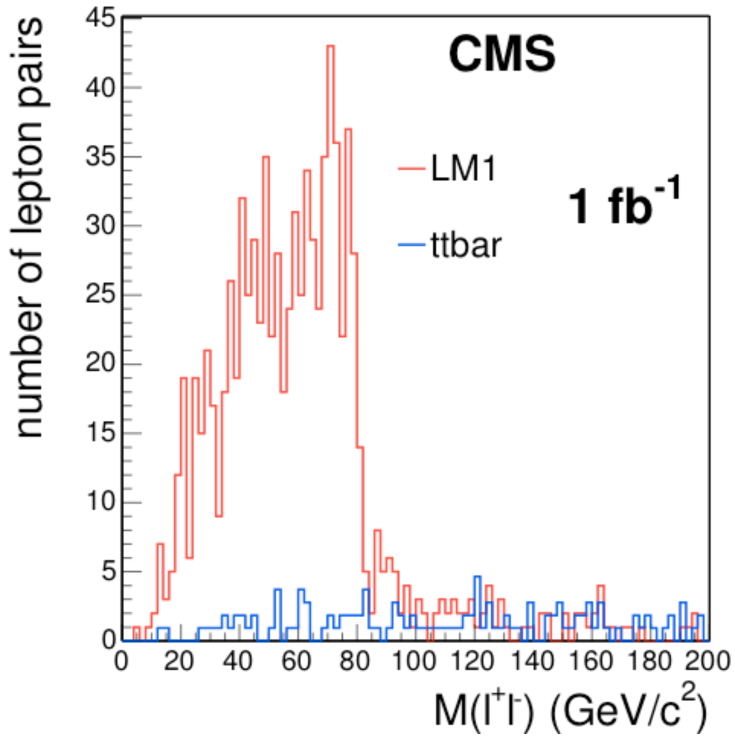
$\tilde{g}$
$\tilde{g}$
$\bar{q}$
$\tilde{q}$
q
$\tilde{\chi}_2^0$
$\tilde{l}^{\mp}$
$\tilde{\chi}_1$
l^+
l^-
$\tilde{t}_1$
$\tilde{\chi}_1^0$
ν
$\bar{t}$
t
W^-
W^+
l^+
b
q
q
$\bar{b}$



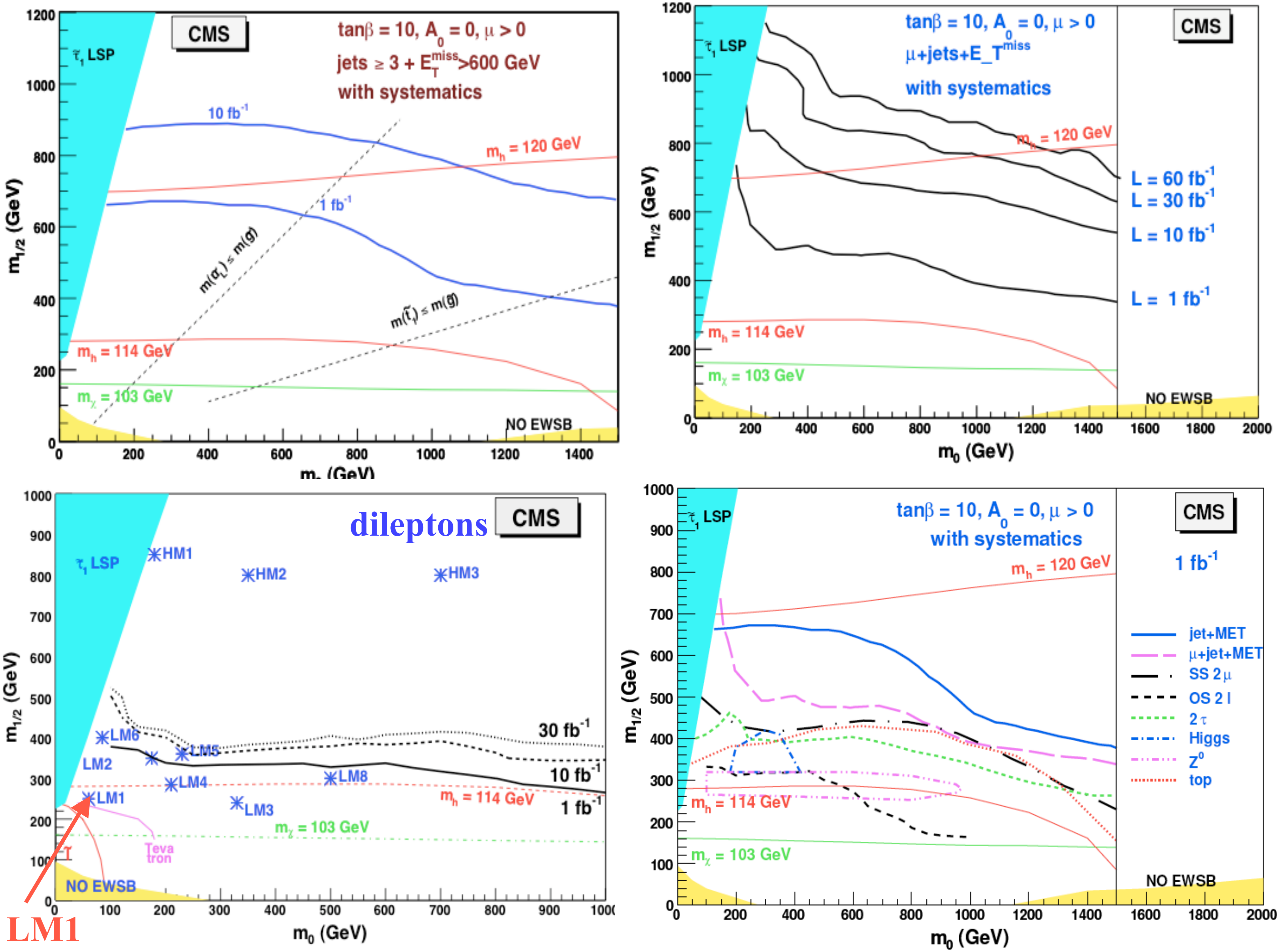
ATLAS Preliminary
SUSY (SU3)
All backgrounds
ttbar
Z
W
QCD
10^3
10^2
10
1
500
1000
1500
2000
2500
Meff (GeV)



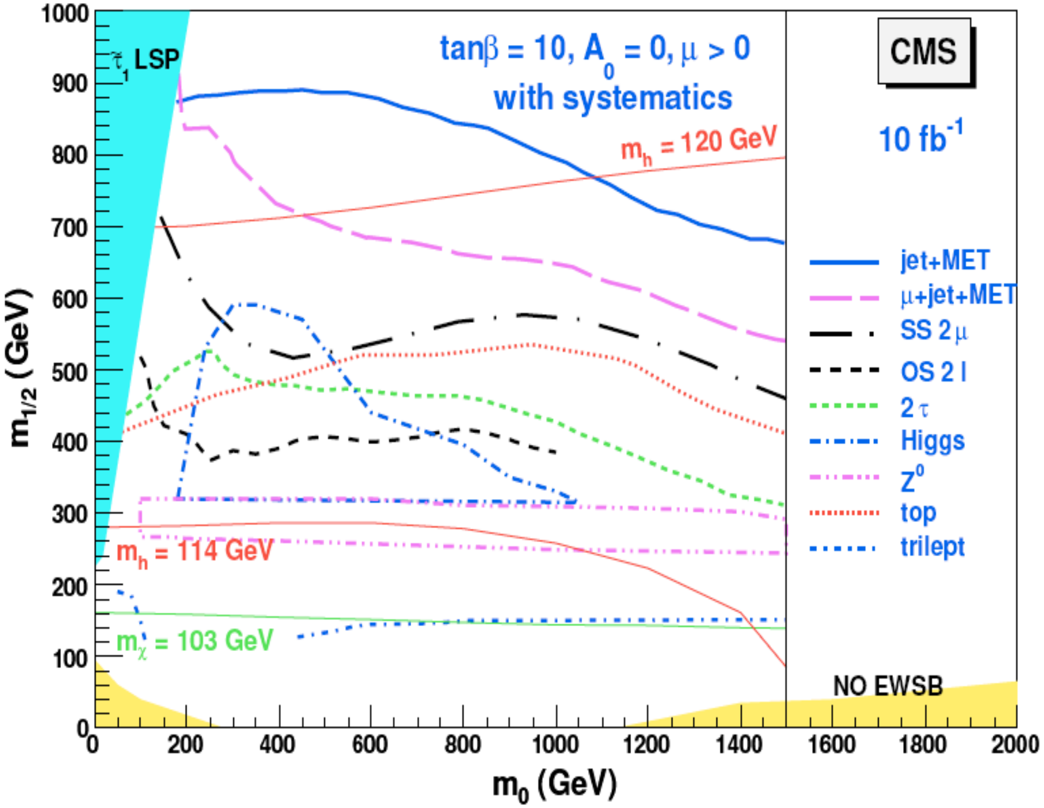
q
$\bar{q}$
W^*
$\tilde{\chi}_1^{\pm}$
$\tilde{\chi}_1^0$
ν
$l^{\pm}$
$\tilde{\chi}_2^0$
l^+
l^-
$\tilde{\chi}_1^0$



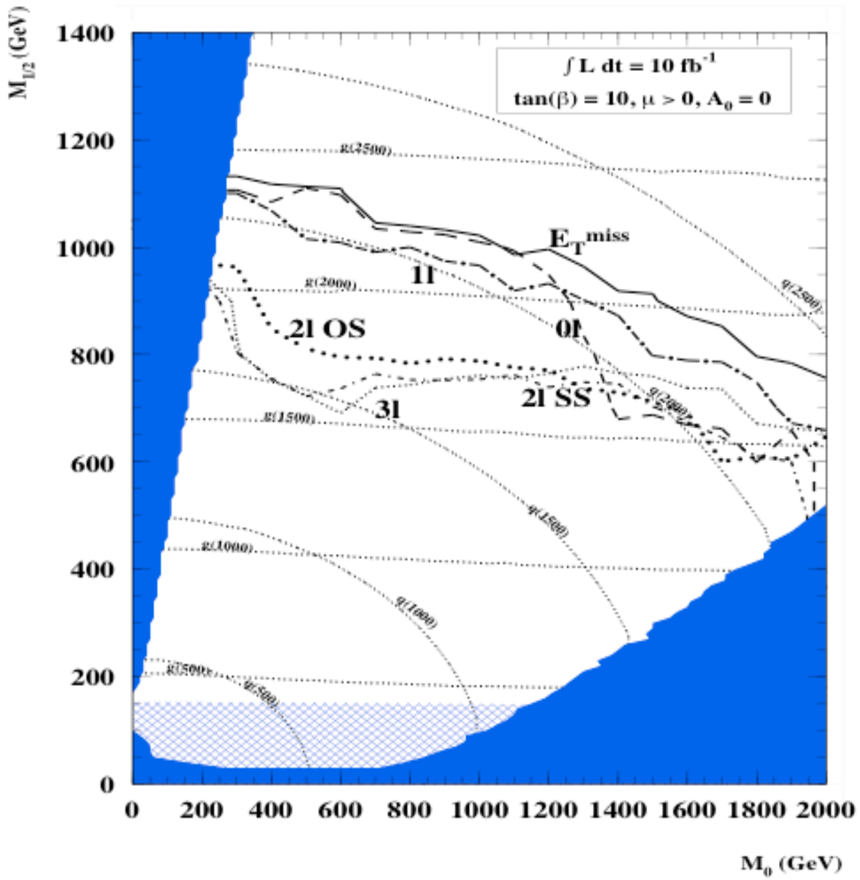
CMS
LM1
ttbar
1 fb^{-1}
number of lepton pairs
0
5
10
15
20
25
30
35
40
45
0
20
40
60
80
100
120
140
160
180
200
$M(l^+l^-)$ (GeV/c^2)


CMS
tanβ = 10, A0 = 0, μ > 0
jets ≥ 3 + ETmiss>600 GeV
with systematics
τ̃1 LSP
10 fb-1
1 fb-1
mh = 120 GeV
mh = 114 GeV
mχ = 103 GeV
m(q̃L) ≤ m(g̃)
m(t̃1) ≤ m(g̃)
NO EWSB
m1/2 (GeV)
m0 (GeV)
CMS
tanβ = 10, A0 = 0, μ > 0
μ+jets+E_Tmiss
with systematics
τ̃1 LSP
mh = 120 GeV
L = 60 fb-1
L = 30 fb-1
L = 10 fb-1
L = 1 fb-1
mh = 114 GeV
mχ = 103 GeV
NO EWSB
m1/2 (GeV)
m0 (GeV)
dileptons
CMS
τ̃1 LSP
HM1
HM2
HM3
LM6
LM5
LM2
LM4
LM8
LM1
LM3
30 fb-1
10 fb-1
1 fb-1
mh = 114 GeV
mχ = 103 GeV
Teva tron
NO EWSB
m1/2 (GeV)
m0 (GeV)
LM1
CMS
tanβ = 10, A0 = 0, μ > 0
with systematics
τ̃1 LSP
1 fb-1
mh = 120 GeV
jet+MET
μ+jet+MET
SS 2μ
OS 2 l
2 τ
Higgs
Z0
top
mh = 114 GeV
mχ = 103 GeV
NO EWSB
m1/2 (GeV)
m0 (GeV)

$10fb^{-1}$



CMS
tanβ = 10, A0 = 0, μ > 0
with systematics
10 fb-1
m_h = 120 GeV
m_h = 114 GeV
m_χ = 103 GeV
τ1 LSP
NO EWSB
jet+MET
μ+jet+MET
SS 2μ
OS 2 l
2 τ
Higgs
Z0
top
trilept
m1/2 (GeV)
m0 (GeV)



∫L dt = 10 fb-1
tan(β) = 10, μ > 0, A0 = 0
ET miss
1l
0l
2l OS
2l SS
3l
M1/2 (GeV)
M0 (GeV)

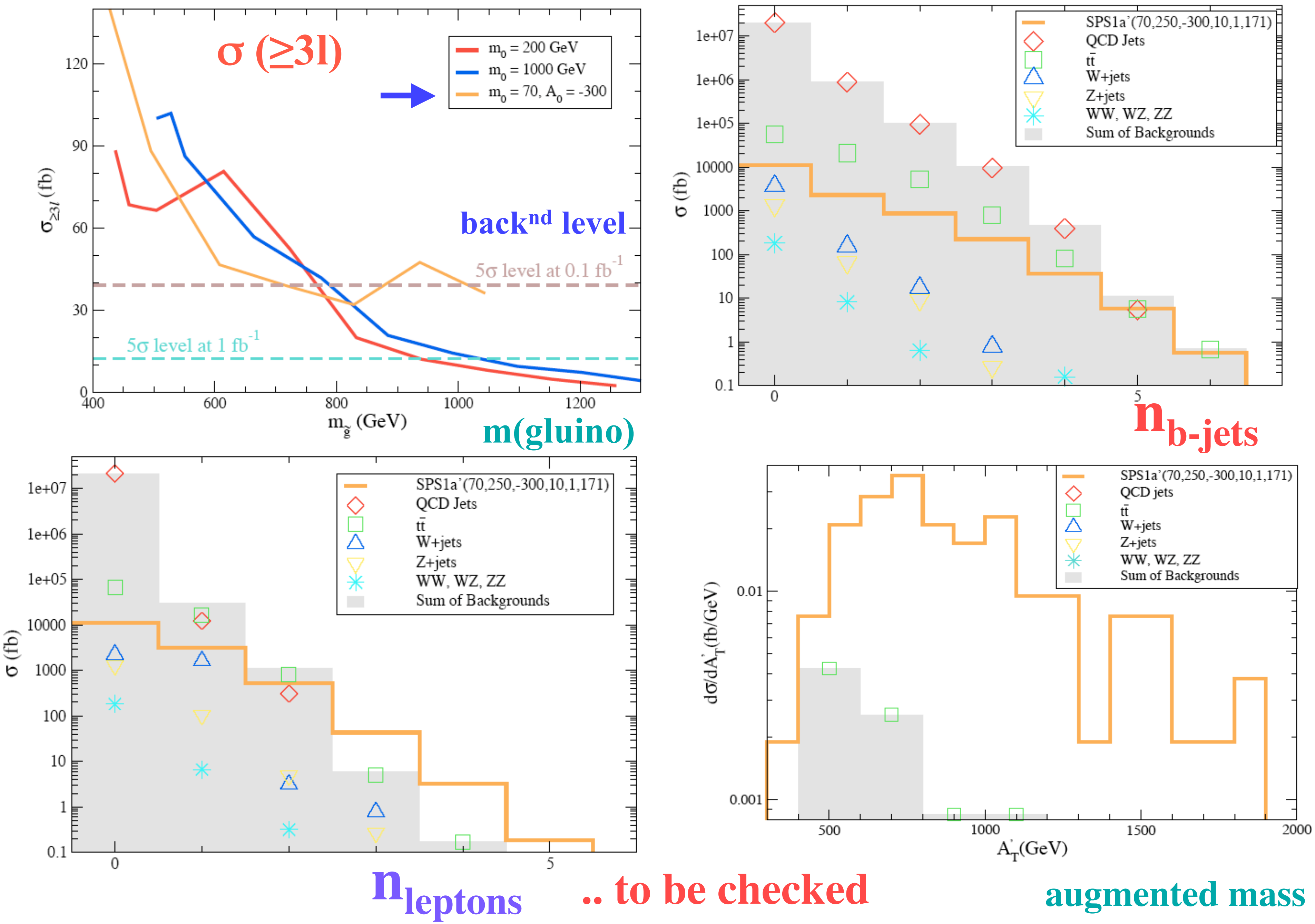
Can one do first without E_t^{miss} ?

theorist's analyses

Can one distinguish SUSY from UED?

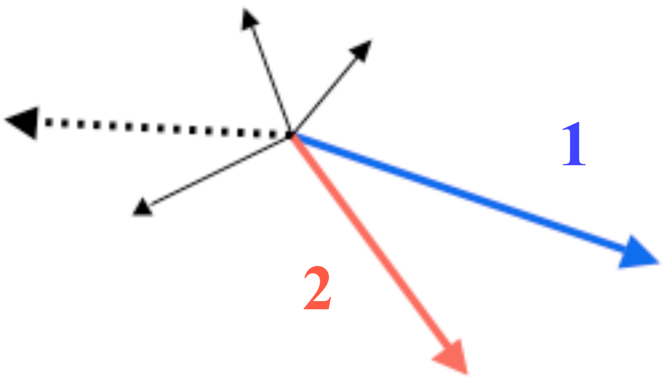
see later

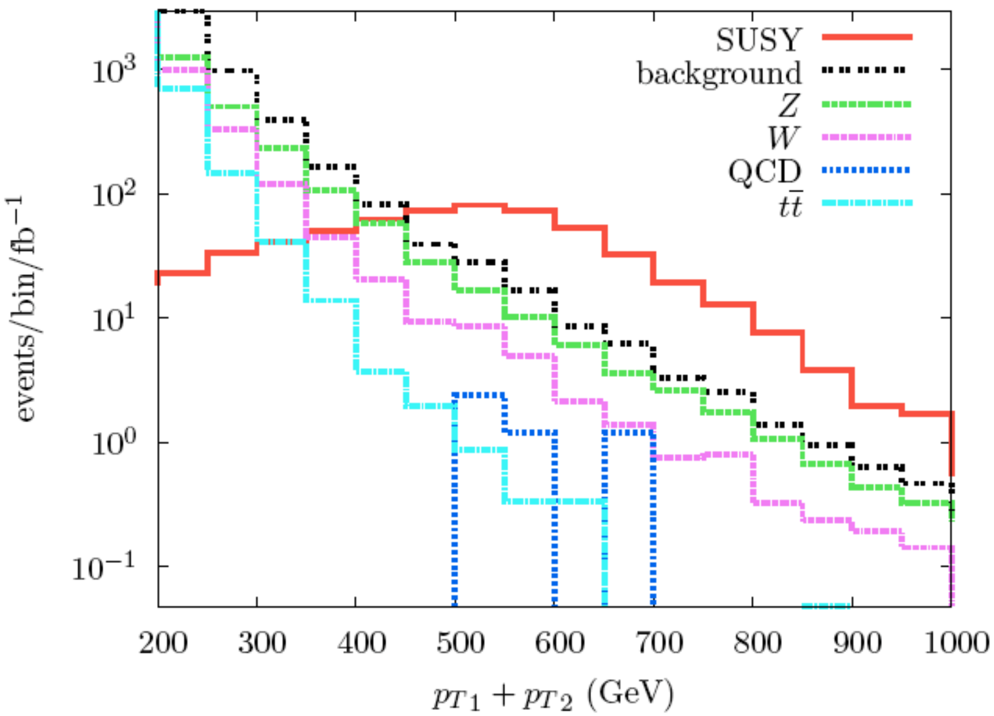
0801.3799 early SUSY discovery at LHC without E_T^{miss}: role of multi-leptons

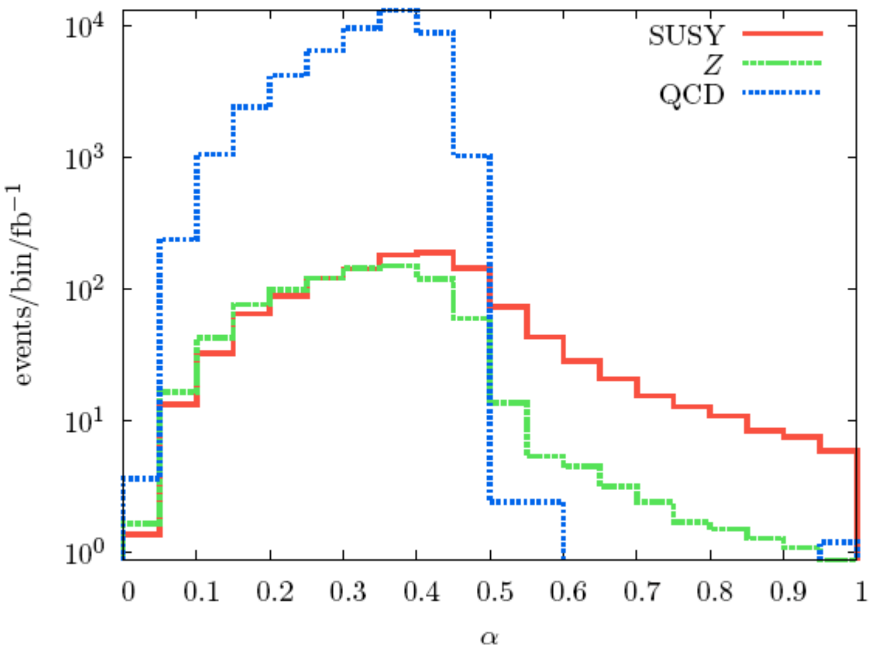


Two leading jets only?

L.Randall, D.Tucker-Smith, 0806.1049







$$\alpha \equiv \frac{p_{T\,2}}{m_{jj}}$$

FOCUS POINT

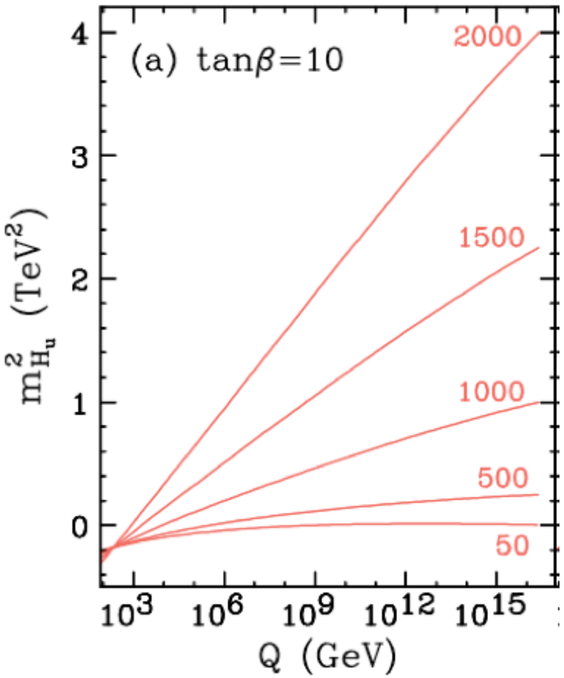
a difficult MSSM scenario

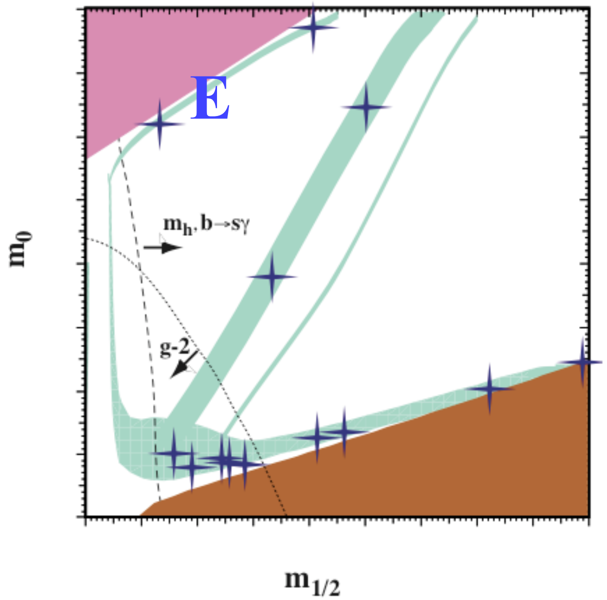
large m_0: very heavy squarks

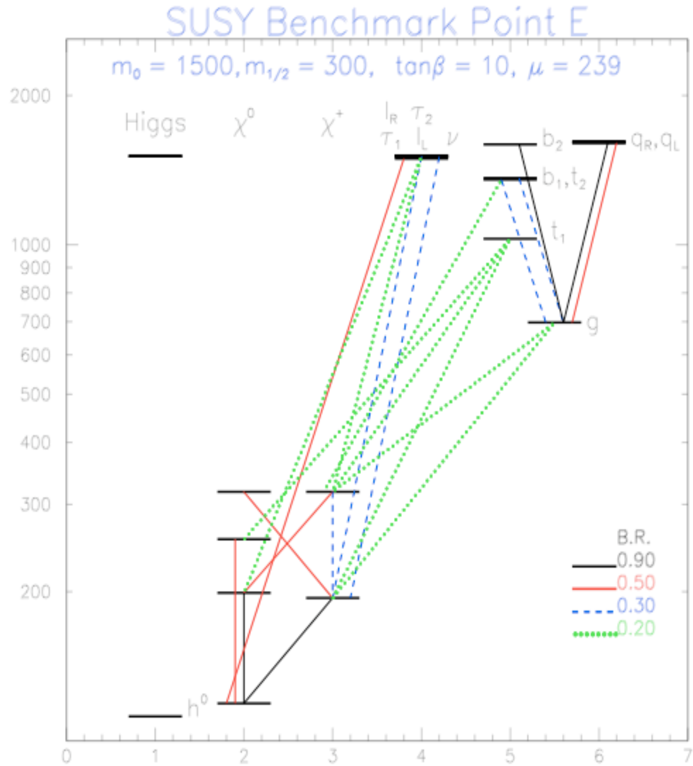
left with gauginos only

Focus point

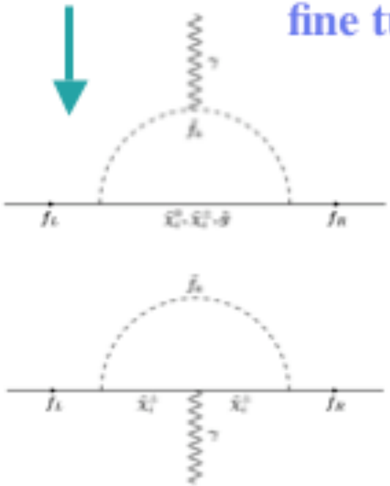
What it means

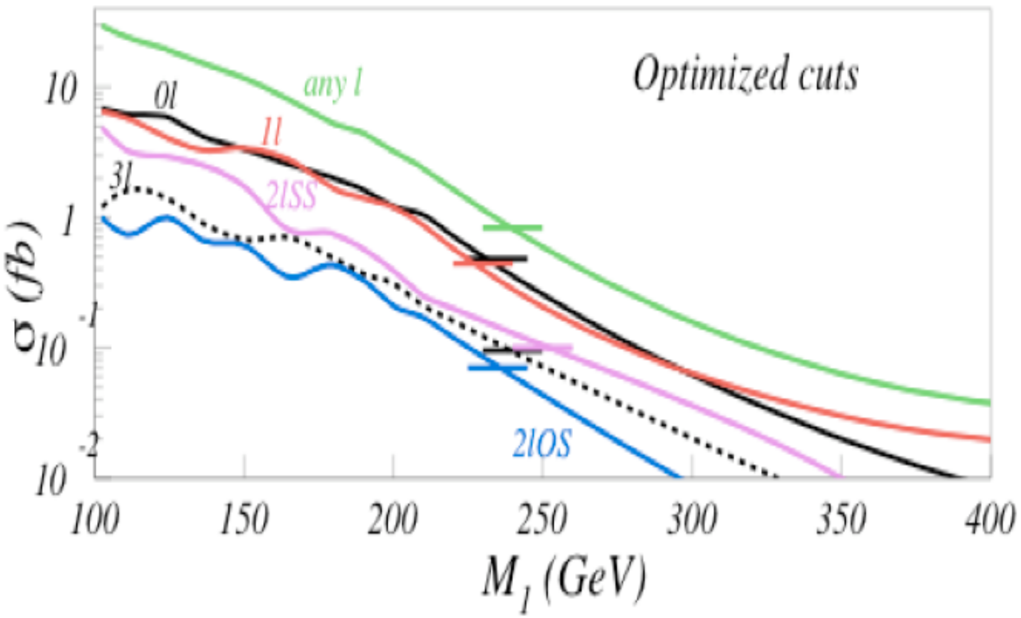






interest → less or no fine tuning





5pb (HERWIG)

$\chi^0\chi^0$ $\chi^0\chi^\pm$ $\chi^\pm\chi^\pm$

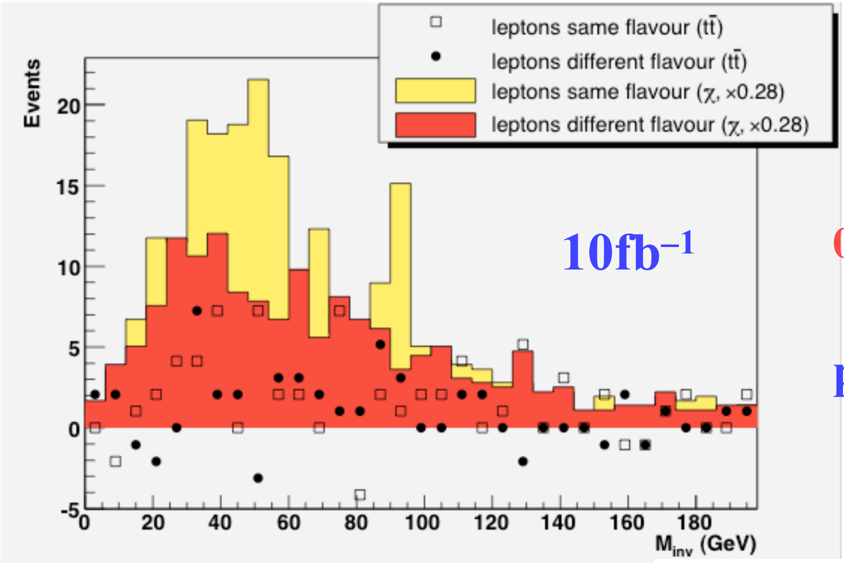
0.22pb 3.06pb 1.14pb

$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+ l^-$

$\tilde{\chi}_3^0 \to \tilde{\chi}_1^0 l^+ l^-$

gluino pairs: 0.58pb, goes to χg, $\chi q\bar{q}$

Particle	Mass (GeV)	Particle	Mass (GeV)	Particle	Mass (GeV)
χ_1^0	103.35	$\tilde{b}_1$	2924.8	$\tilde{\nu}_\tau$	3532.3
χ_2^0	160.37	$\tilde{b}_2$	3500.6	h	119.01
χ_3^0	179.76	$\tilde{t}_1$	2131.1	H^0	3529.7
χ_4^0	294.90	$\tilde{t}_2$	2935.4	A^0	3506.6
$\chi_1^\pm$	149.42	$\tilde{e}_L$	3547.5	$H^\pm$	3530.6
$\chi_2^\pm$	286.81	$\tilde{e}_R$	3547.5		
$\tilde{g}$	856.59	$\tilde{\nu}_e$	3546.3		
$\tilde{u}_L$	3563.2	$\tilde{\tau}_1$	3519.6		
$\tilde{u}_R$	3574.2	$\tilde{\tau}_2$	3533.7		



0704.2515

lepton pairs with opposite charge

hep-ph/0507282

0712.3151

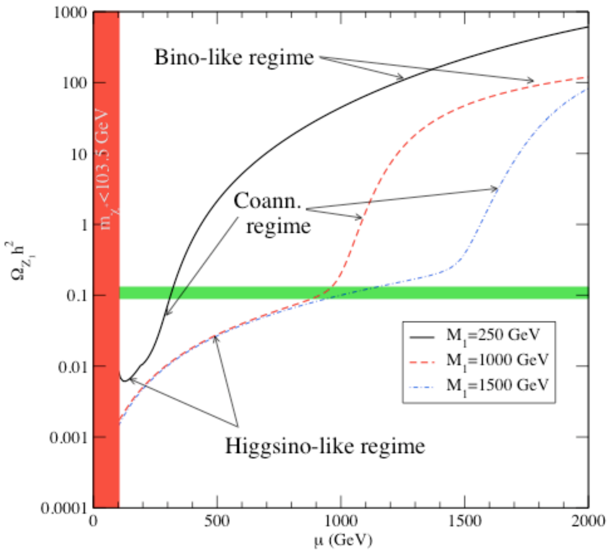
● competition with astroparticles

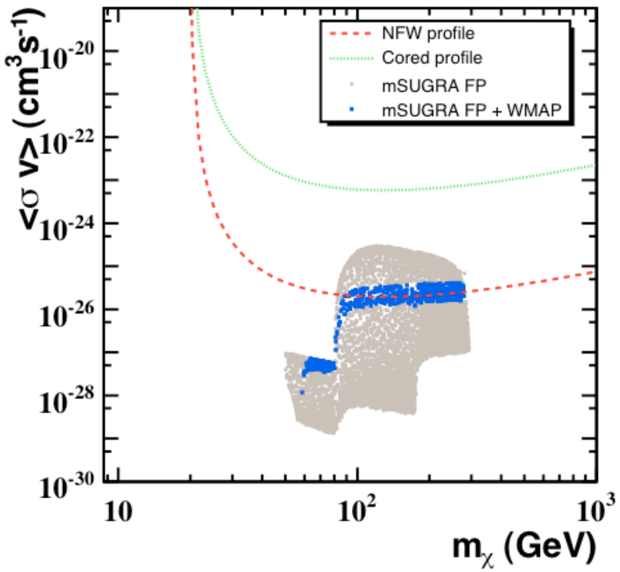
mixed bino-higgsino LSP

$\chi\chi \to \gamma\gamma$

$\chi\chi \to \gamma Z$

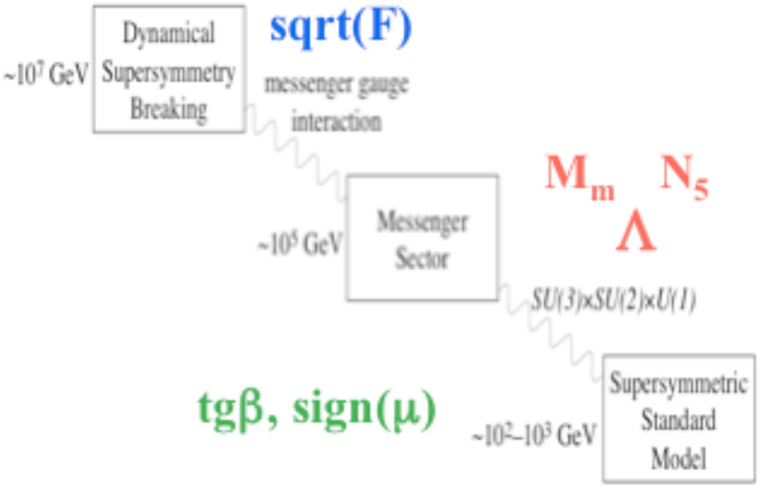
$\chi\chi \to \gamma h$



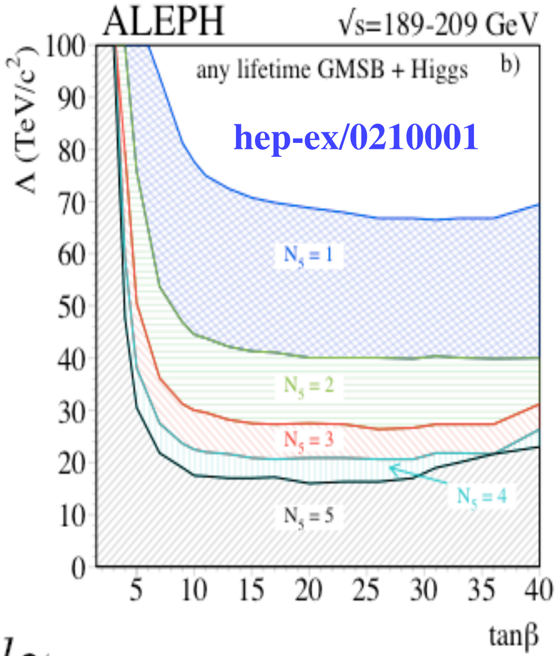


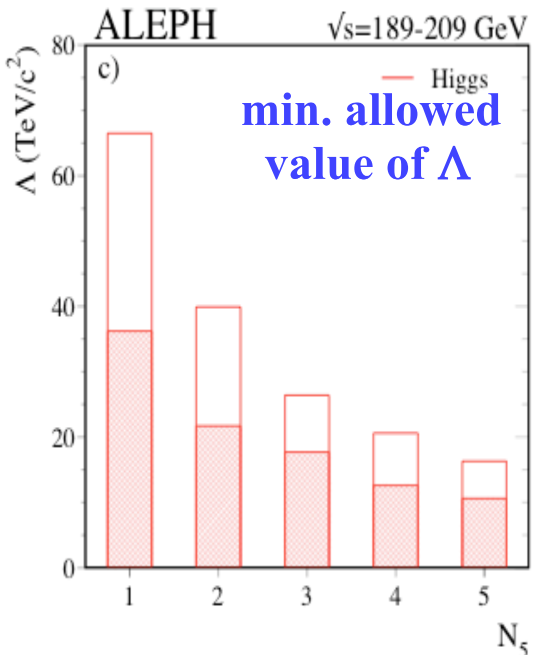
Non SUGRA breaking

GMSB*
AMSB
Gaugino-mediated (5D)



Λ : mass scale parameter responsible for the MSSM masses at M_m



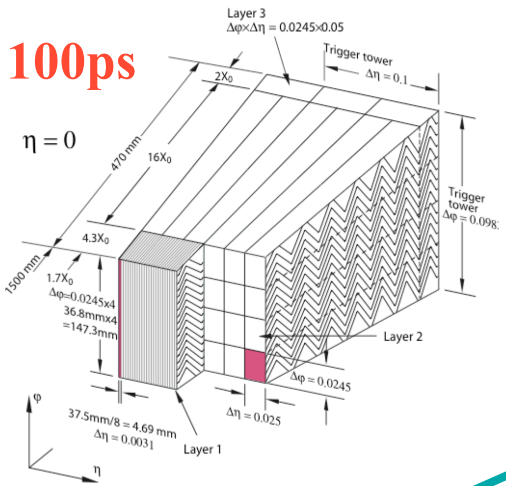


ATLAS 0507083 $\quad \tilde{l} \to \tilde{\chi}_1^0 l \to \tilde{G} l \gamma$

Point	Λ (TeV)	M_{mess} (TeV)	N_5	$tan\beta$	$sgn(\mu)$	C_{grav}
G1	90	500	1	5.0	+	-

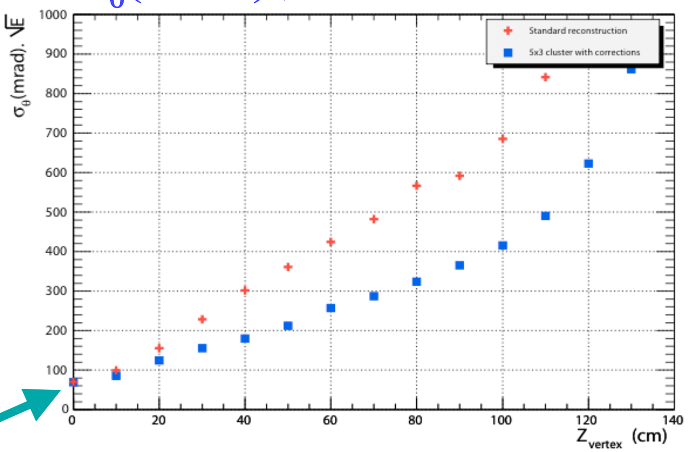
$$c\tau = \frac{1}{k_\gamma}\left(\frac{100\ GeV}{m_{NLSP}}\right)^5 \left(\frac{\sqrt{F_0}}{100\ TeV}\right)^4 \times 10^{-2}\ cm$$

100ps



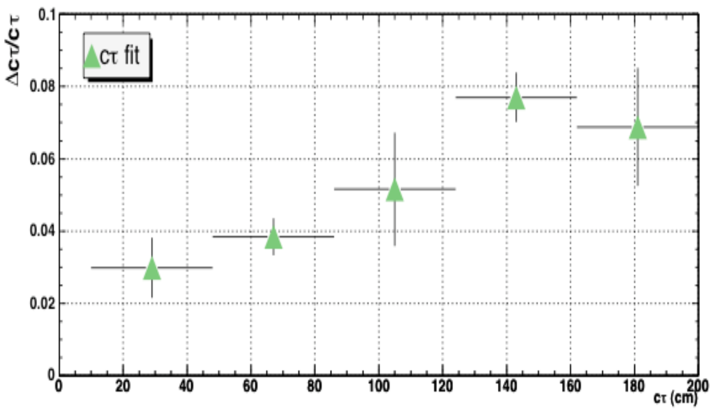
100 GeV: 6mrad

σ_θ(mrad)$\sqrt{E}$



polar angular resolution **Z**

$\Delta c\tau/c\tau$



sensitivity on the measure of the χ^0_1 lifetime

$c\tau$

Next-to-MSSM

NMSSM

- Add one singlet superfield. It solves the μ-problem.
  No mass term in Superpotential. PQ symmetry, to be broken.

$$W = \lambda S H_1 H_2 + \frac{\kappa}{3} S^3$$

- Richer phenomenology in Higgs and neutralino sectors
  Less fine tuning than in MSSM, but still some.

$$m_h^2 \leq M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \log \frac{m_{\tilde{t}}^2}{m_t^2} \qquad m_{hNMSSM}^2 \leq M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \log \frac{m_{\tilde{t}}^2}{m_t^2}$$

- But more parameters, unfeasible to perform multi-dimensional scans. How to proceed?

- Define benchmarks (0801.4321)
- Satisfy cosmological constraints and e.w. baryogenesis (0705.0431)
- Choose a model (0712.2903) : PQ MSSM

Focus on Higgs sector and/or gaugino sectors arXiv: 0801.4321

- define 4 benchmarks
- focus on lighter Higgs

CP even Higgs bosons					
$m_{h_1^0}$ (GeV)	120.2	120.2	89.9	32.3	90.7
R_1	1.00	1.00	0.998	0.034	-0.314
t_1	1.00	1.00	0.999	0.082	-0.305
b_1	1.018	1.018	0.975	-0.291	-0.644
$\mathrm{BR}(h_1^0 \to b\bar{b})$	0.072	0.056	7×10^{-4}	0.918	0.895
$\mathrm{BR}(h_1^0 \to \tau^+\tau^-)$	0.008	0.006	7×10^{-5}	0.073	0.088
$\mathrm{BR}(h_1^0 \to a_1^0 a_1^0)$	0.897	0.921	0.999	0.0	0.0
$m_{h_2^0}$ (GeV)	998	998	964	123	118
R_2	-0.0018	-0.0018	0.005	0.999	0.927
t_2	-0.102	-0.102	-0.095	0.994	0.894
b_2	10.00	10.00	9.99	1.038	2.111
$\mathrm{BR}(h_2^0 \to b\bar{b})$	0.31	0.31	0.14	0.081	0.87
$\mathrm{BR}(h_2^0 \to t\bar{t})$	0.11	0.11	0.046	0.0	0.0
$\mathrm{BR}(h_2^0 \to a_1^0 Z^0)$	0.23	0.23	0.72	0.0	0.0
$m_{h_3^0}$ (GeV)	2142	2142	1434	547	174

CP odd Higgs bosons					
$m_{a_1^0}$ (GeV)	40.5	9.1	9.1	185	99.6
t_1'	0.0053	0.0053	0.0142	0.0513	-0.00438
b_1'	0.529	0.528	1.425	0.347	-0.158
$\mathrm{BR}(a_1^0 \to b\bar{b})$	0.91	0.	0.	0.62	0.91
$\mathrm{BR}(a_1^0 \to \tau^+\tau^-)$	0.085	0.88	0.88	0.070	0.090
$m_{a_2^0}$ (GeV)	1003	1003	996	546	170
Charged Higgs boson					
$m_{h^\pm}$ (GeV)	1005	1005	987	541	188

$$gg \to h_i^0$$

$$qq \to qqW^*W^*, qqZ^{0*}Z^{0*} \to qqh_i^0$$

$$q\bar{q}' \to Wh_i^0 \text{ and } q\bar{q} \to Z^0h_i^0$$

$$q\bar{q}/gg \to Q\bar{Q}h_i^0, \text{ with } Q = t, b$$

- **ATLAS strategy for NMSSM $h_1^0 \to a_1^0 a_1^0$ searches**

  vector boson fusion $\quad h_1^0 \to a_1^0 a_1^0 \to 4\tau \to 4\mu + 4\nu_\mu + 4\nu_\tau$

- **Prospects for the CMS experiment**

  vector boson fusion

  $\mu^\pm \mu^\pm \tau^\mp_{\rm jet} \tau^\mp_{\rm jet}$ final state containing two same sign muons and two τ jets

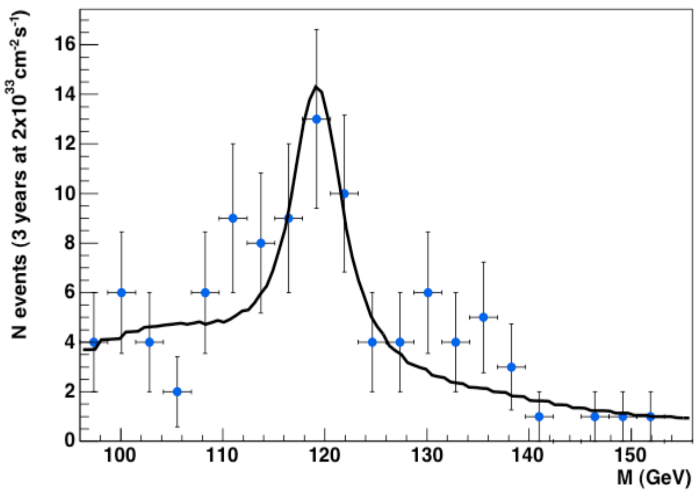
forward region, CMS 2007/039

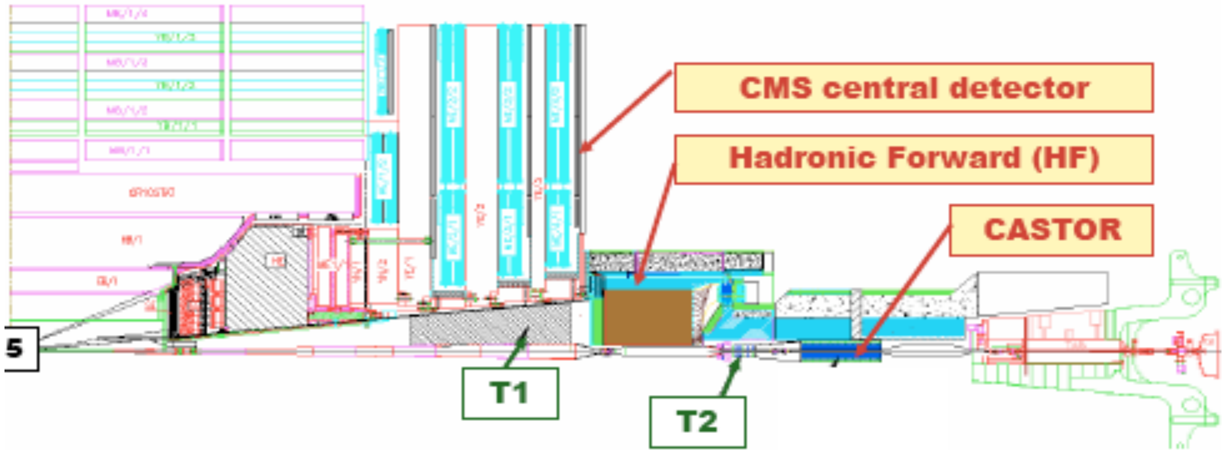
... but also

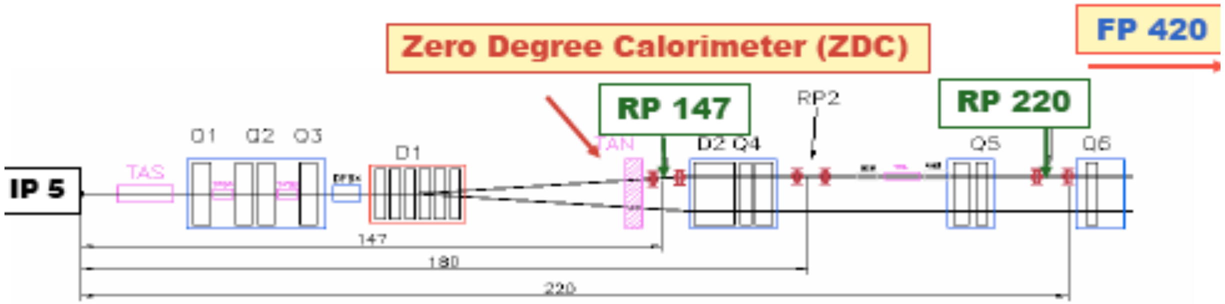
$pp \to p\, h\, p$

$h \to 4\,\tau$

5 10^{33}, 3 y, 3-4 evts, ~ 0.2 backg^d 0712.3510







CMS: red & blue

TOTEM: green

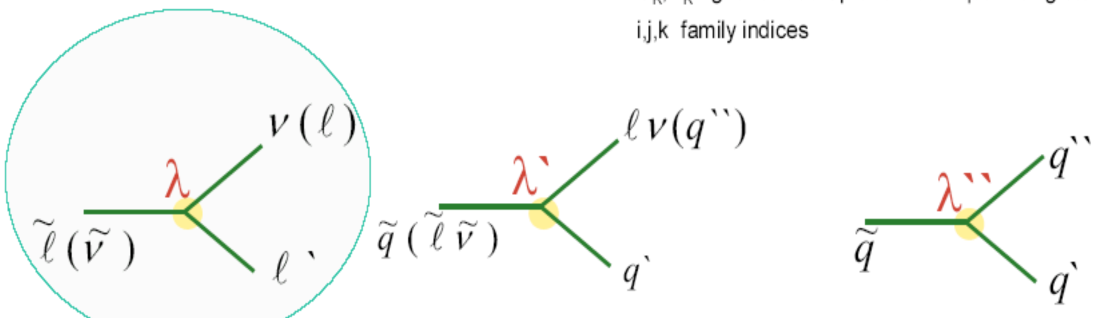
R parity breaking

Explicit RPV breaking trilinear superpotential terms:

$$\boxed{\lambda_{ijk}\, L_L^i L_L^j \overline{E}_R^k + \lambda'_{ijk}\, L_L^i Q_L^j \overline{D}_R^k + \lambda''_{ijk}\, \overline{U}_R^i \overline{D}_R^j \overline{D}_R^k}$$

$\lambda, \lambda', \lambda''$: Yukawa couplings

L_L, Q_L left-handed lepton and quark doublets
E_R right-handed lepton singlets
U_R, D_R right-handed Up and Down quark singlets
i,j,k family indices



L violation

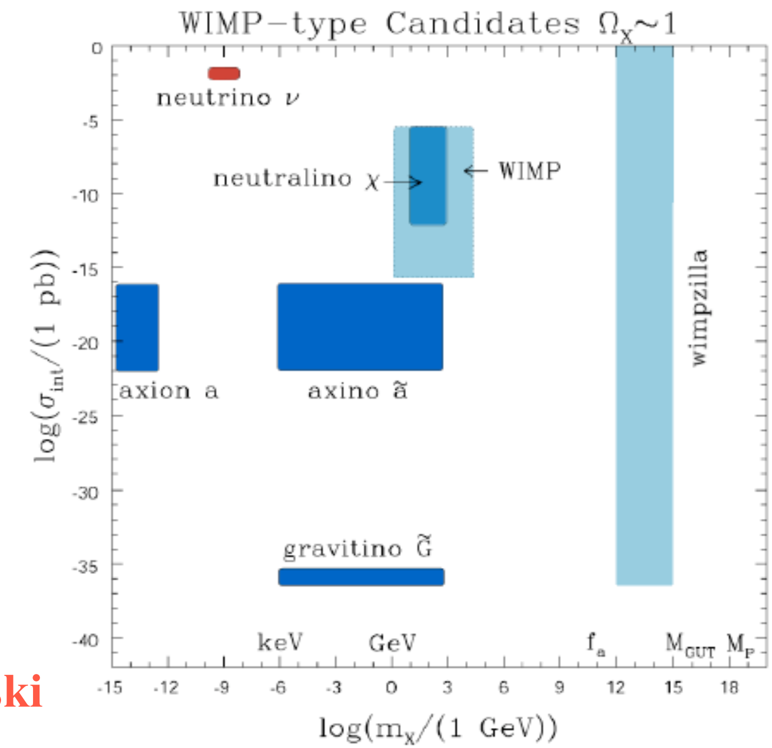
B violation

9 couplings (i≠j)

27 couplings

9 couplings (j≠k)

stable LSP is lost

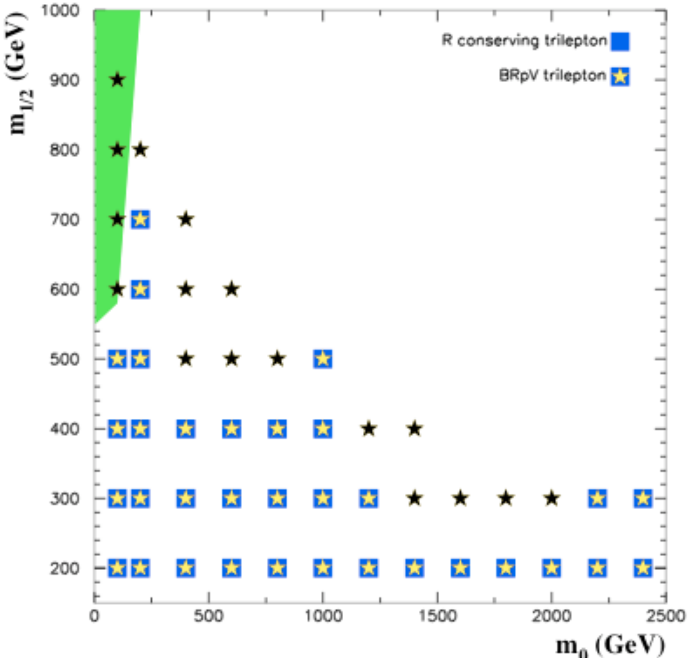


B.Clerbaux

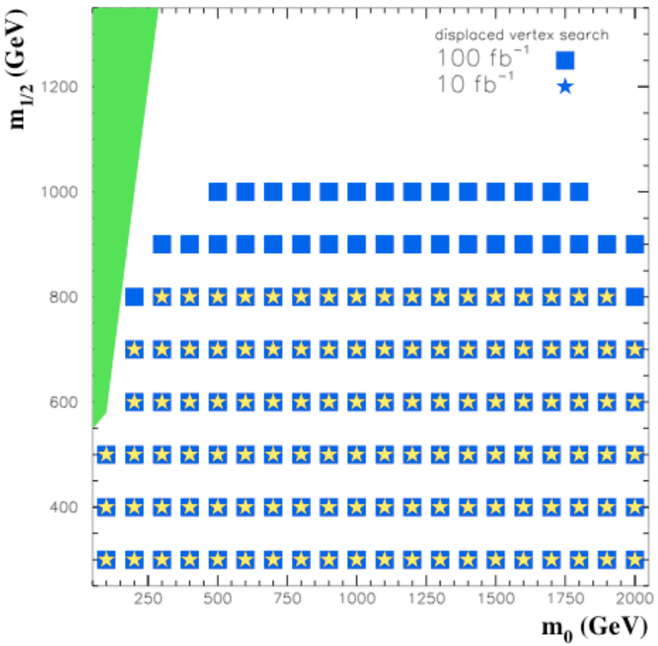
a new jungle of parameters

L.Roszkowski

R parity breaking   Dreiner hep-ph/9707435



Di- and multi-leptons,
displaced vertices
arXiv:0712.2156

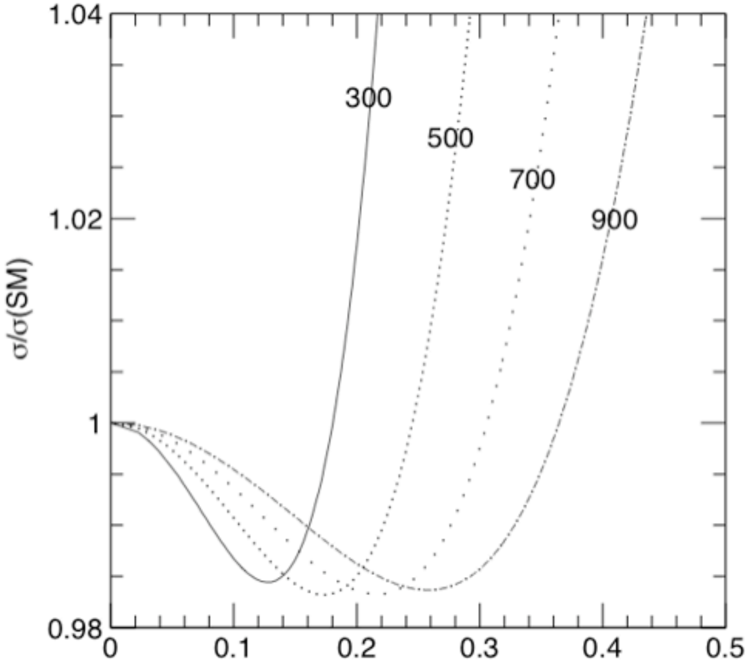


Potential effect on DY

hep-ph/0207248

Dilepton mass > 500 GeV

Squark mass: 300 to 900 GeV



λ'_{221}

$\not{R}_p$ violating minimal SUGRA

If stau decays, it can be the LSP

SUGRA + one $\not{R}_p$ coupling Λ at GUT scale

dynamically generates all of them at ew scale

if Λ small, sparticles still mostly pair-produced

and cascade down to stau

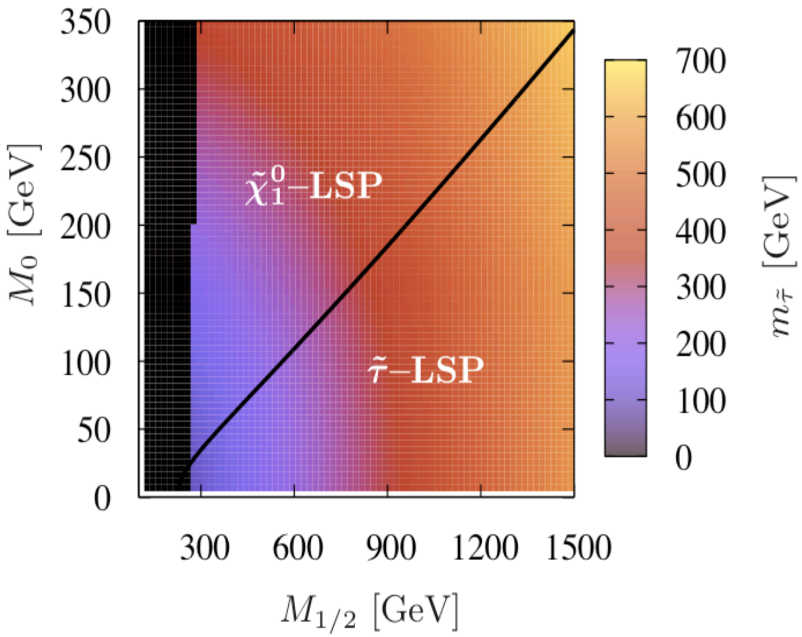
If stau directly couples to the $\not{R}_p$ operator,

2-body decay to SM particles

If not, 4-body decay

Four proposed benchmarks (035002)

arXiv:0710.2034



Scenario BC1: stau not directly coupled (e.g. λ_{121})

signal rates

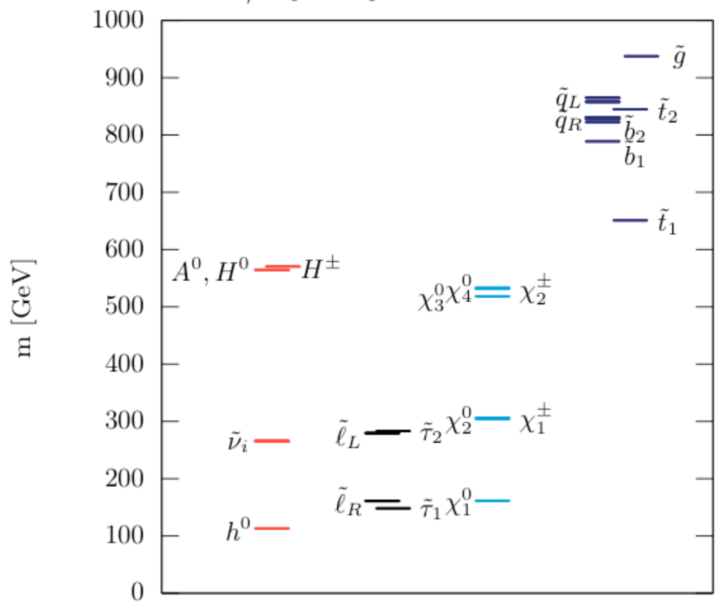
e^+ or μ^+	e^- or μ^-	τ^+	τ^-	$\not{p}_T$	event fraction
2	2	2	2	yes	35 %
3	2	2	2	yes	12 %
2	3	2	2	yes	8.3 %
3	3	2	2	yes	7.3 %
2	2	2	1	yes	4.7 %
2	2	3	2	yes	4.3 %
2	2	3	3	yes	1.4 %
4	3	2	2	yes	1.1 %

+2-4 jets

4.8 pb

dominant BR

	mass [GeV]	channel	BR	channel	BR
$\tilde\tau_1^-$	148	$\mu^+\bar\nu_e e^-\tau^-$	**32 %**	$e^+\bar\nu_\mu e^-\tau^-$	**32 %**
		$\mu^-\nu_e e^+\tau^-$	**18 %**	$e^-\nu_\mu e^+\tau^-$	**18 %**
$\tilde e_R^-$	161	$e^-\nu_\mu$	**50 %**	$\mu^-\nu_e$	**50 %**
$\tilde\mu_R^-$	161	$\tilde\tau^+\mu^-\tau^-$	51 %	$\tilde\tau^-\mu^-\tau^+$	49 %
$\tilde\chi_1^0$	162	$\tilde\tau_1^+\tau^-$	50 %	$\tilde\tau_1^-\tau^+$	50 %



detached vertices, multi-leptons
multi-taus, like-sign dileptons

Peculiar models

Peculiar signatures

Back to experimental considerations!

SPLIT SUSY

0507137, Kilian et al

to evade many of the phenomenological constraints of generic SUSY

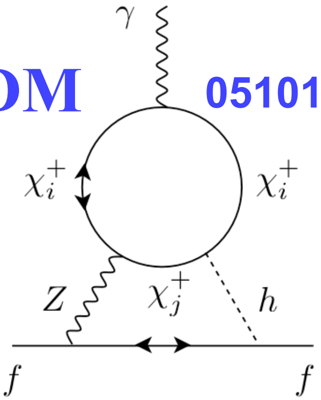
squarks and sleptons rendered heavy

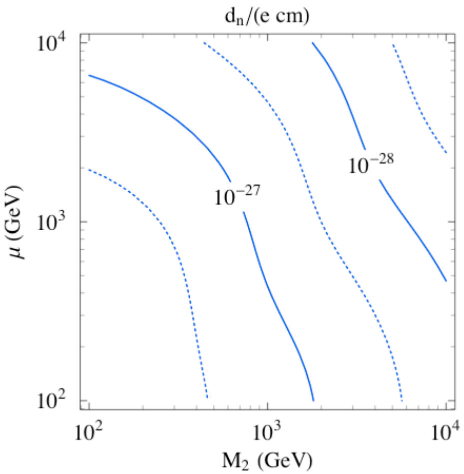
charginos and neutralinos still light: gauge unification, DM candidate OK

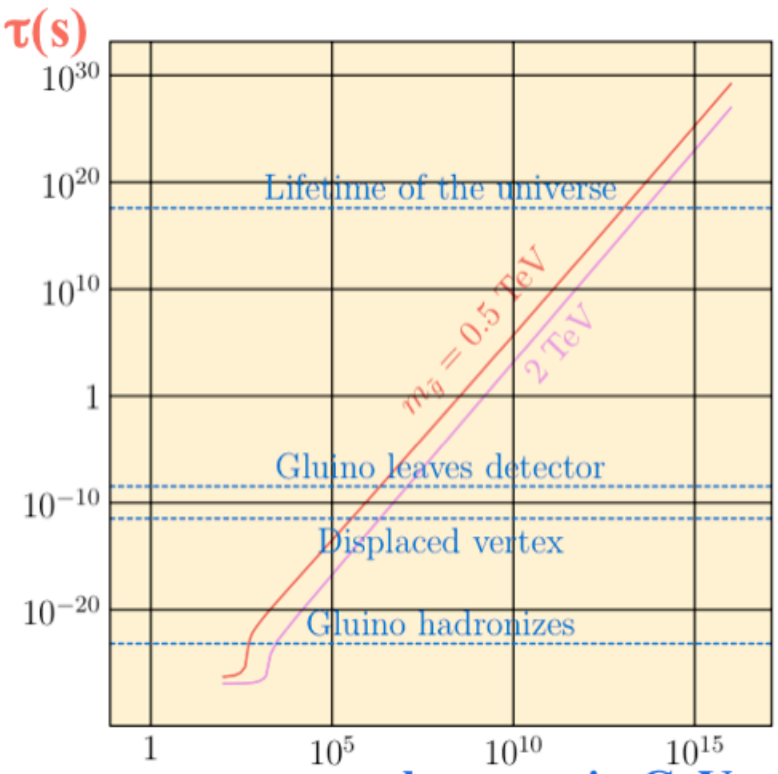
fine-tuning to pull the Higgs v.e.v. to ew scale: unnatural. Explain?

since all squarks heavy, gluino long-lived

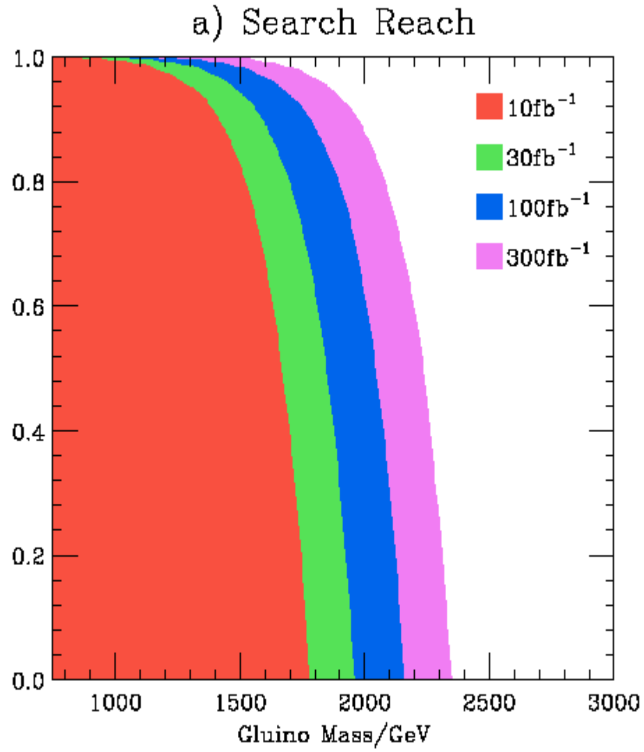
EDM 0510197







common scalar mass in GeV



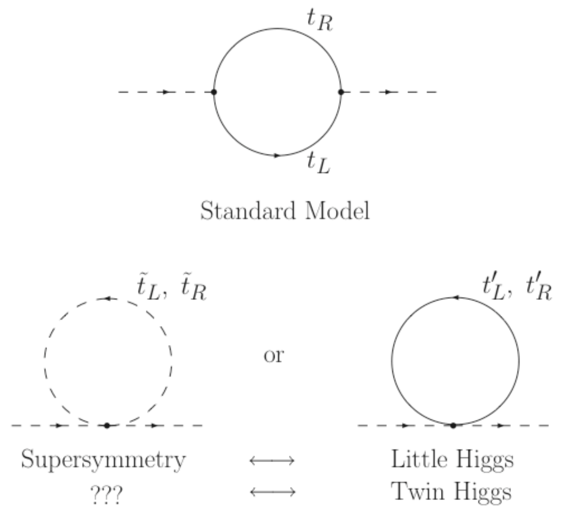
from charged R-hadrons

Other ideas

Folded SUSY

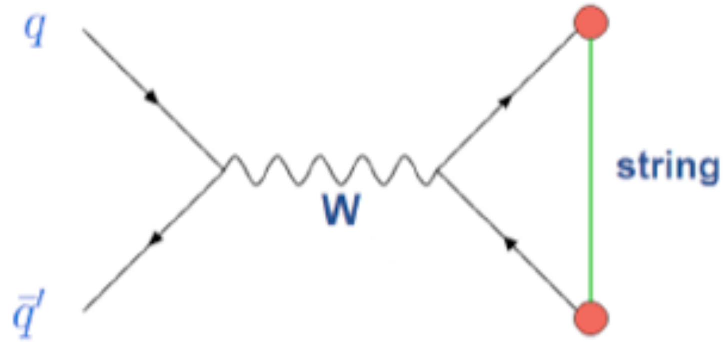
hep-ph/0609152

Harnik

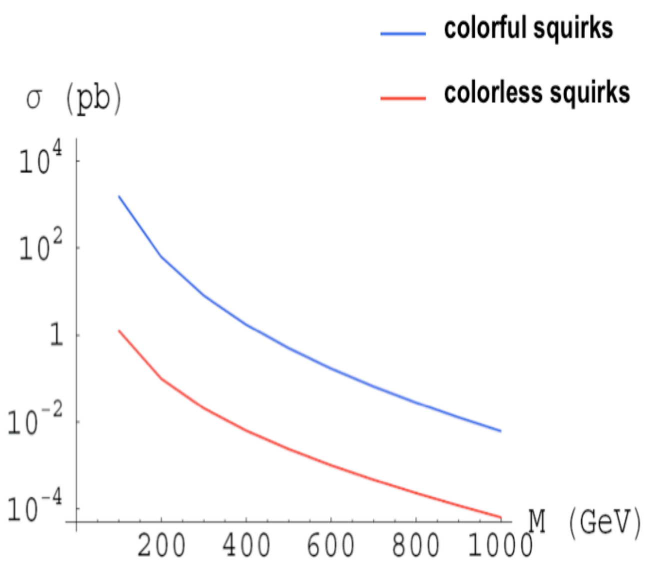


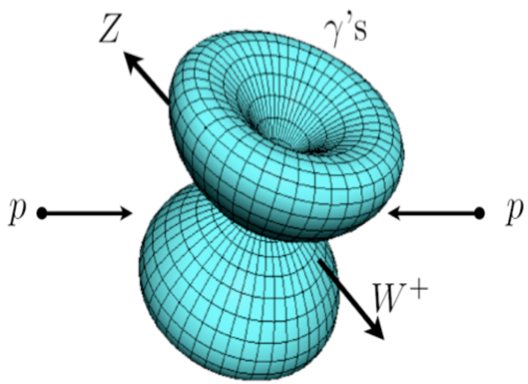
idea

opposite spin partners
but gauge quantum numbers
may be different from those
of conventional superpartners

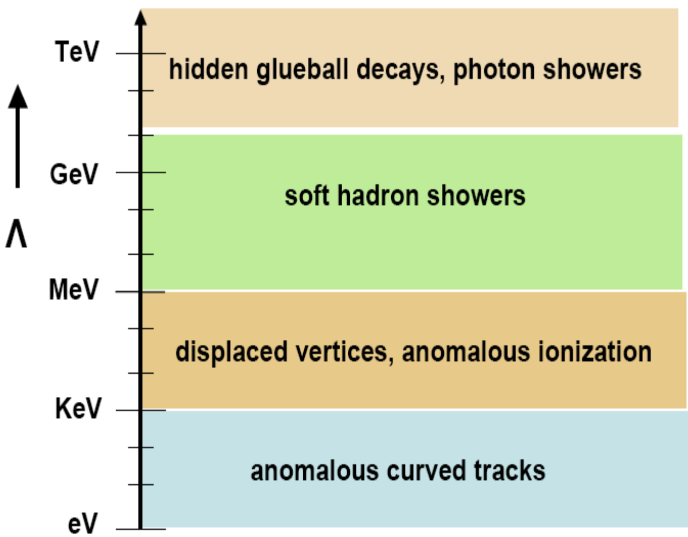


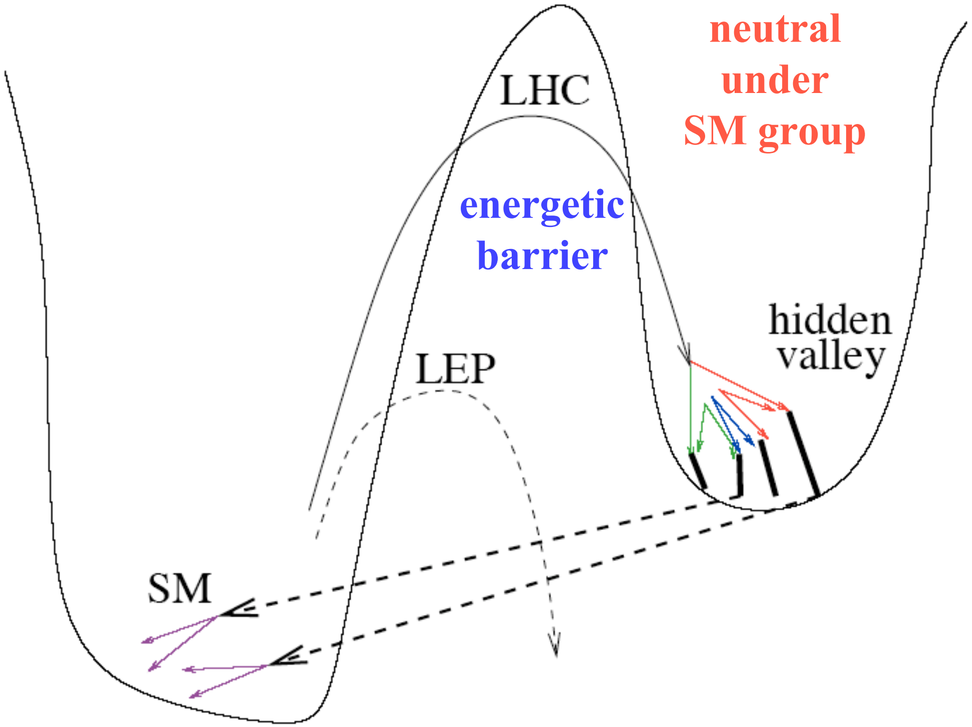
leads to the idea of quirks: exotic vector-like fermions with a hidden-confining group.
M >> Λ. Analogous to QCD with no light quarks

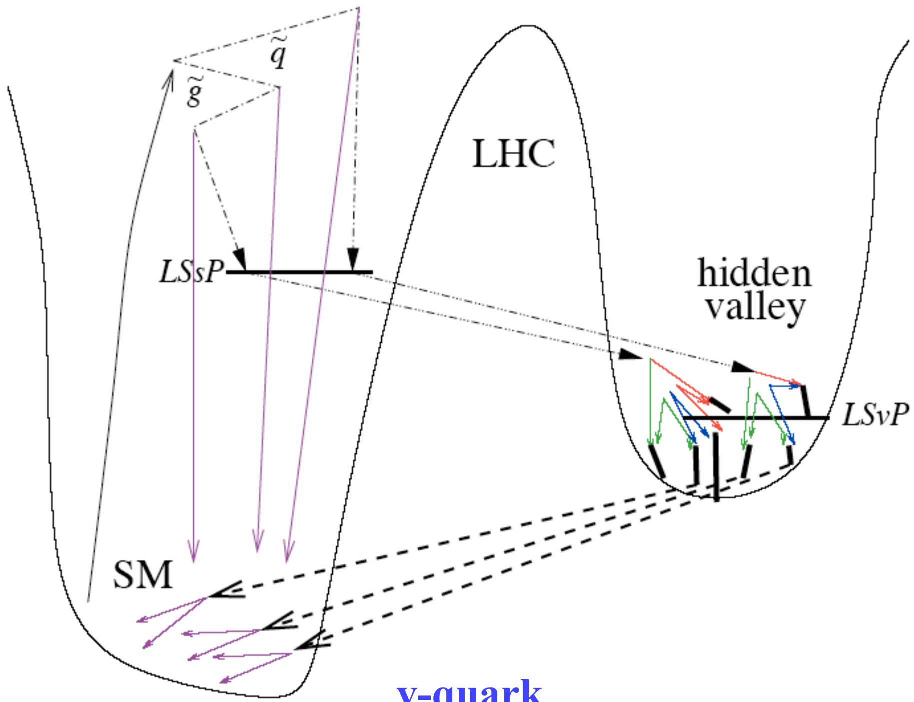




Summary of Weird Signatures



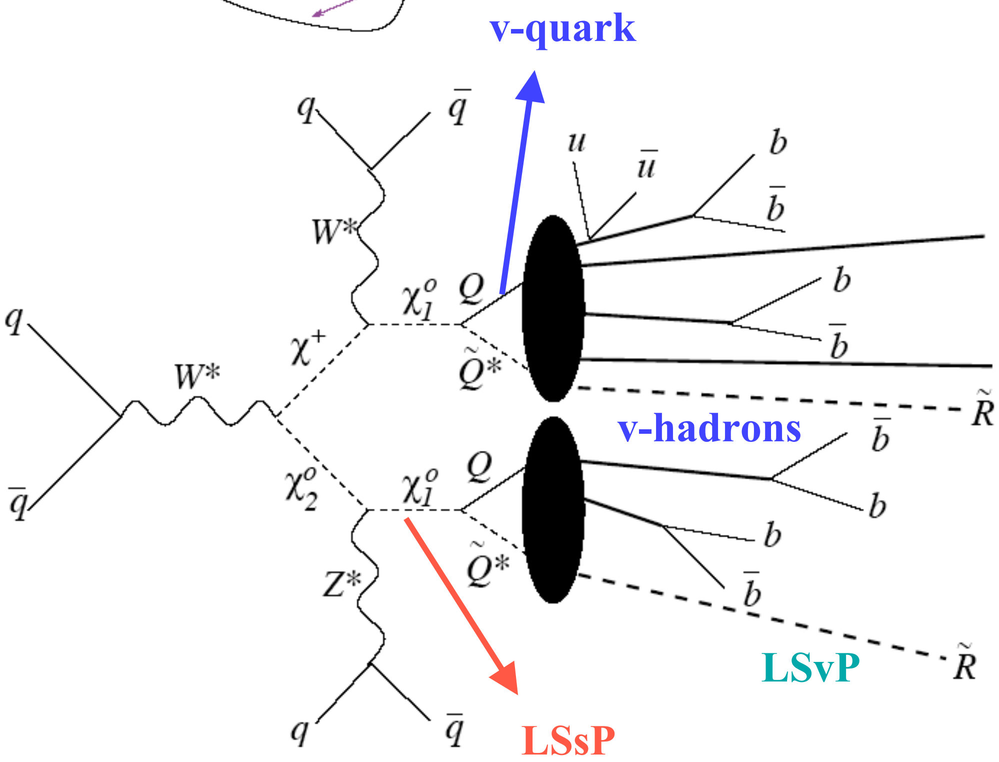




Hidden valleys

A motivation to look for highly displaced vertices or a large number of ordinary displaced vertices (b, τ)

0604261



STABLE LONG LIVED PARTICLES

many motivations

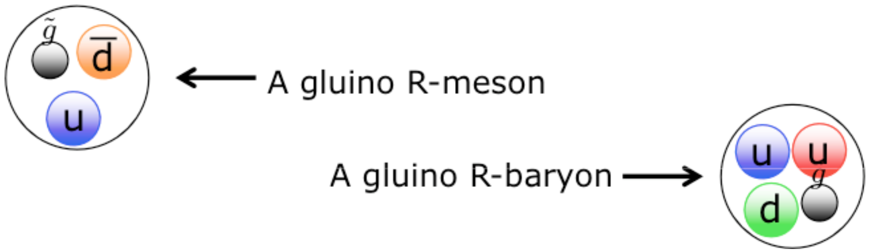
- GMSB
- Split SUSY
- SUSY breaking with boundary condition on ED
- stable KK excitations
- fourth generation fermions, etc

stable or quasi-stable
electrically charged and/or interacting strongly
SLL with strong charge hadronize and form R-hadrons

benchmarks: stable gluinos stable staus

hep-ex/0404001 hep-ex/0511014 CMS 2007-075
CMS CR 2007/021 hep-ph/0611040

if strong charge → R-hadron



nuclear interaction model assuming the heavy parton acts as a spectator

possible charge exchanges

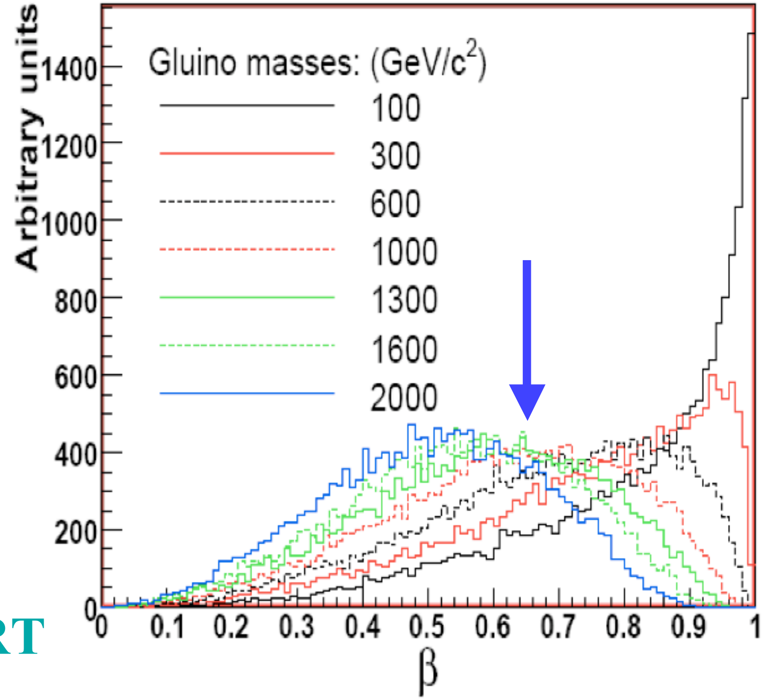
low β

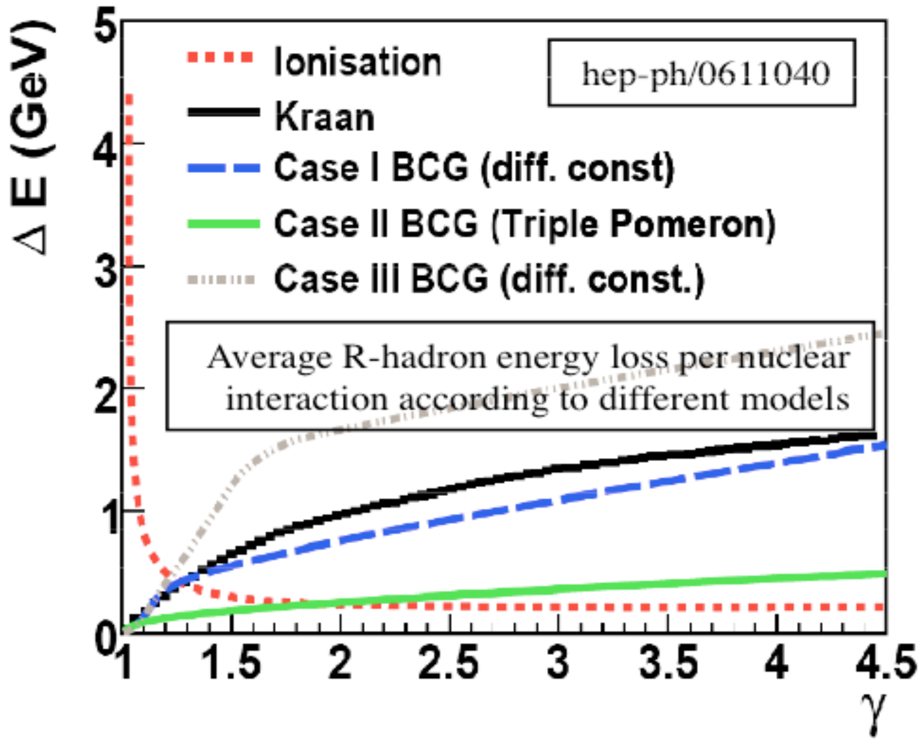
↓

time-of-flight ~ 1 ns resolution in μ det.

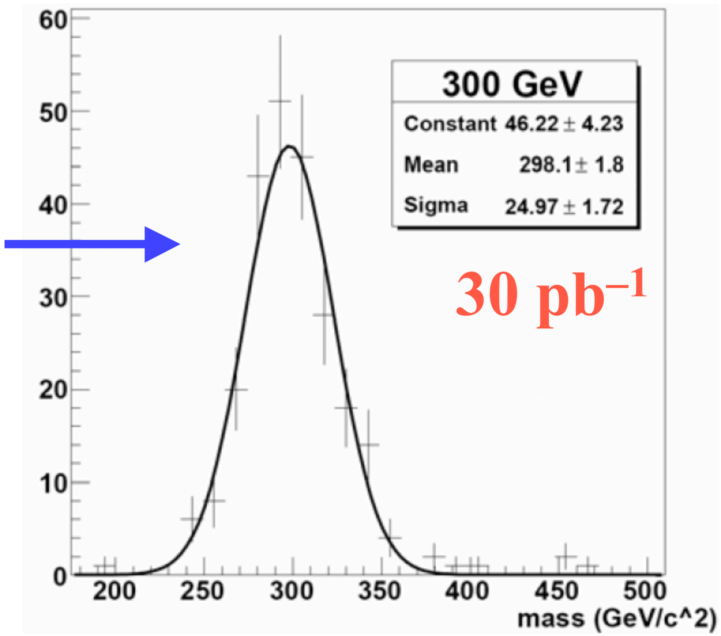
or ionisation in Si tracker

or ATLAS TRT



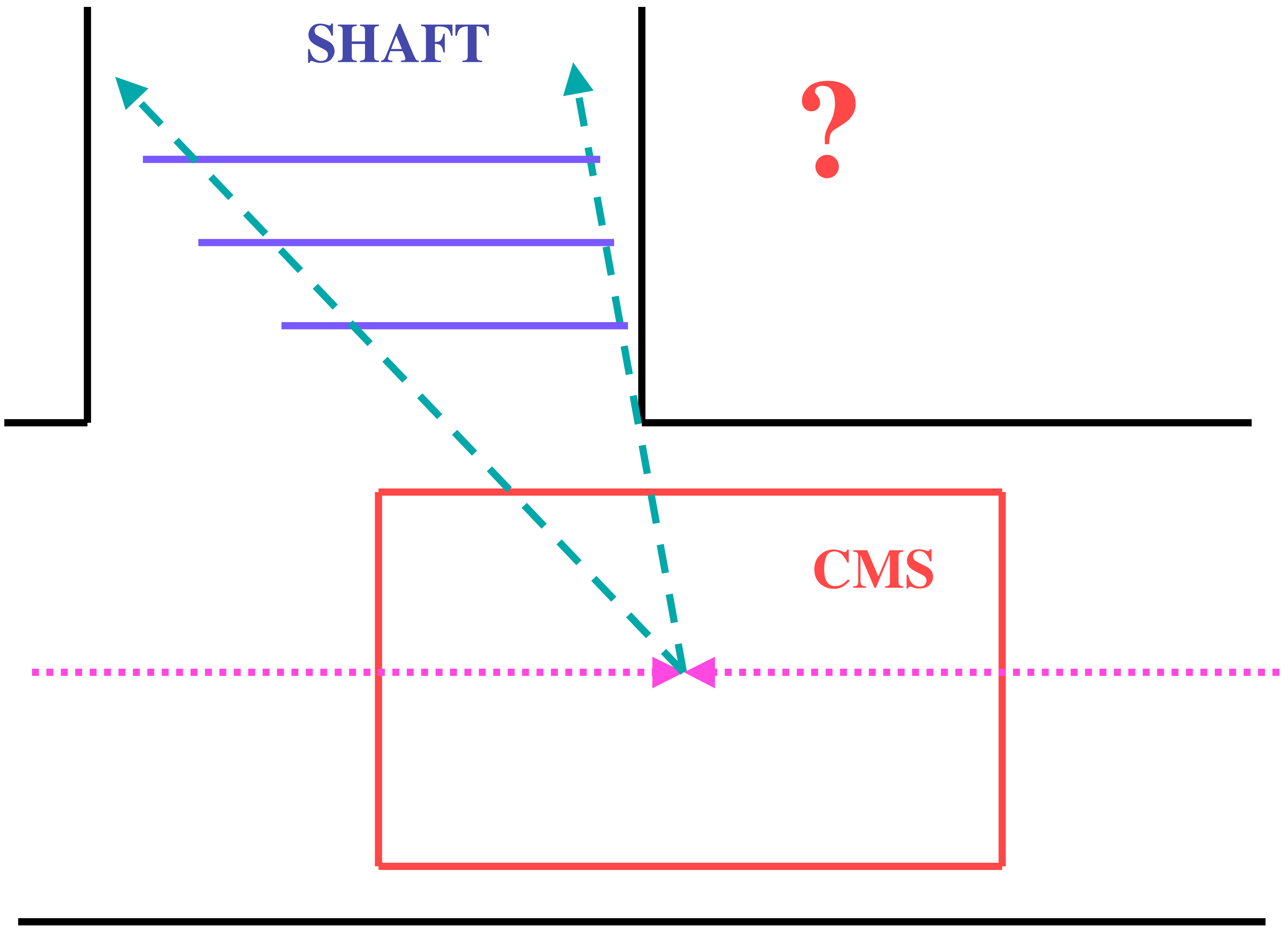


CMS: stable gluino



30 pb^{-1}

ATLAS: gluino up to 1 TeV with 100 pb^{-1}


SHAFT
?
CMS

Back up

Unparticles

why here? conjecture

dilatation generator D $\quad [D, P_\mu] = -iP_\mu$

$$\exp(+isD)P^2\exp(-isD) = \exp(2s)P^2$$

mass spectrum continuous or all masses equal to zero

scale invariance manifestly broken at tree level in SM

an operator with general non-integral scale dimension d_U in a scale invariant sector looks like d_U invisible massless particles

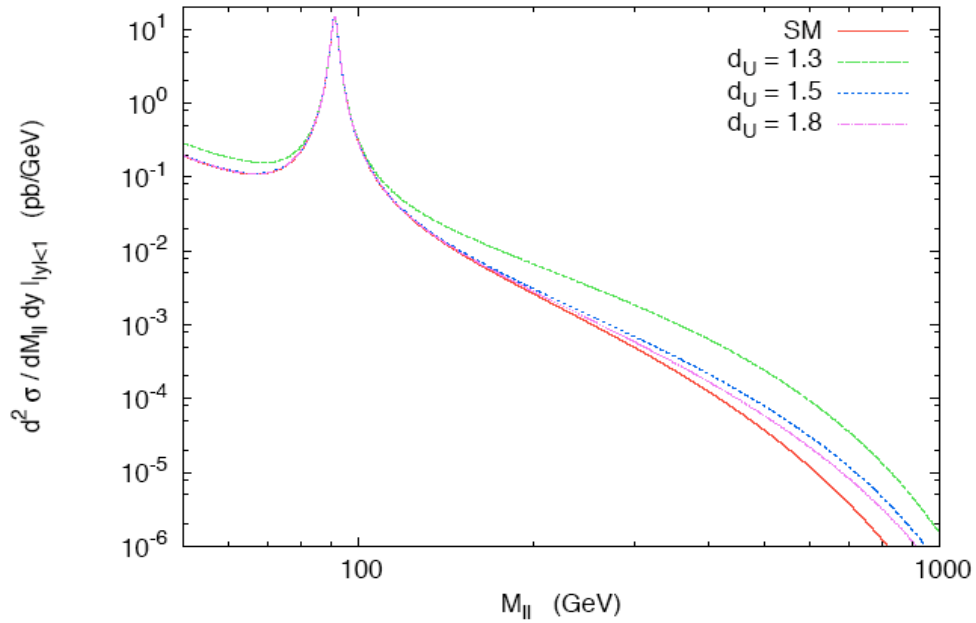
$$\frac{1}{M_{\mathcal{U}}^{d_{\mathrm{S}M}+d_{\mathcal{BZ}}-4}}\mathcal{O}_{\mathrm{S}M}\,\mathcal{O}_{\mathcal{BZ}} \qquad d_{\mathcal{U}} = \frac{n}{2}+1 \; ?$$

0706.3152

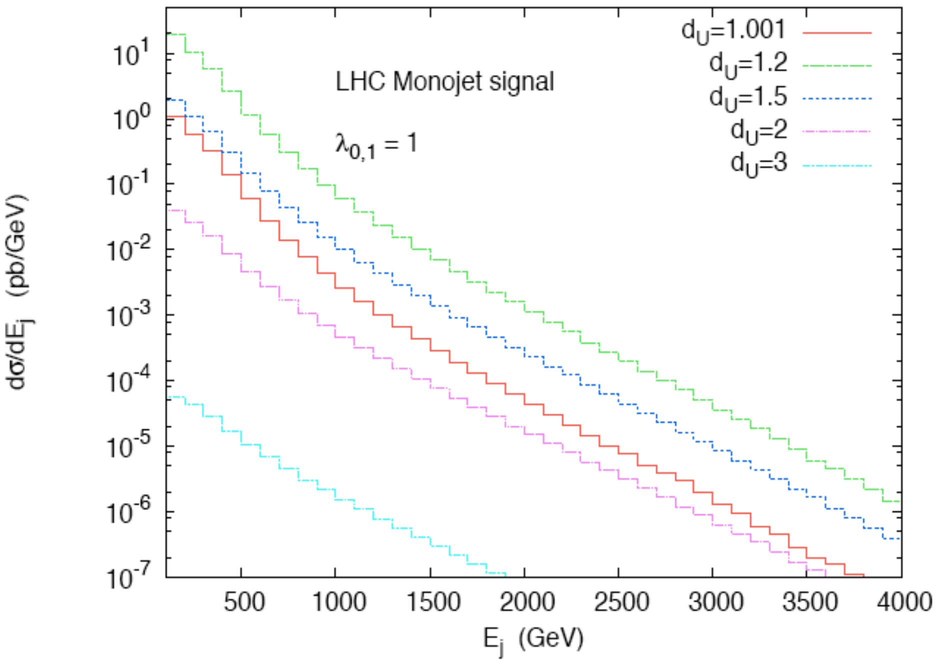
Limits from LEP

$d_{\mathcal{U}}$	$\Lambda_{\mathcal{U}}$ (TeV)
2.0	1.35
1.8	4
1.6	23
1.4	660

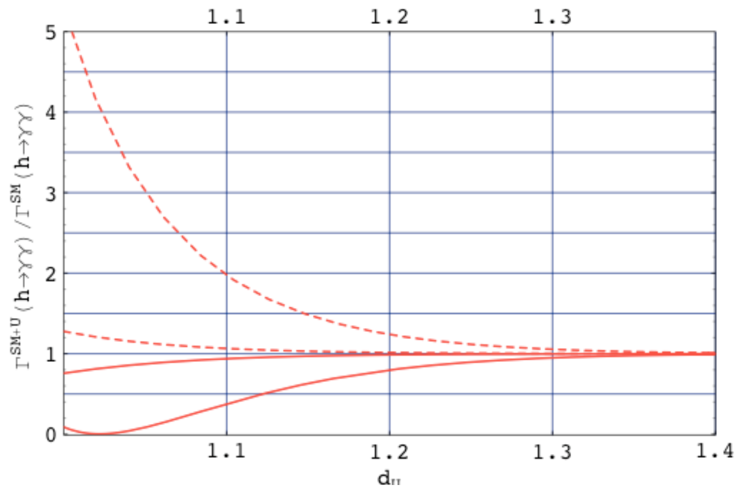
Drell-Yan at Tevatron

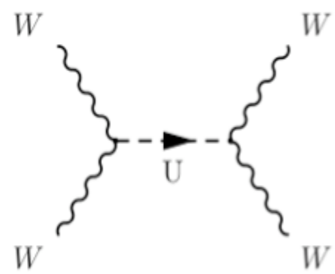


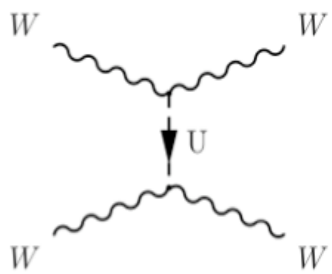
monojets at LHC



others: Higgs, WW?







MSSM

- m_A : pseudoscalar Higgs boson mass
- $\tan\beta$: ratio of vacuum expectation values of the two Higgs doublets
- μ : Higgs mixing parameter → **the μ problem**
- M_1, M_2, M_3 : Gaugino ~~SUSY~~ mass terms (χ^0, $\chi^\pm$, $\tilde{g}$)
- $m_{\tilde{\ell}_R}, m_{\tilde{\ell}_L}, m_{\tilde{\nu}_L}, m_{\tilde{q}_R}, m_{\tilde{q}_L}$: "Sfermion" ~~SUSY~~ mass terms
- $A_t, A_b, A_\tau, \ldots$: stop/sbottom/stau/... mixing parameters

the Superpotential contains a dimensionful parameter μ:

$$W = \mu H_u H_d$$

to achieve natural EWSB it must be of the order of the weak scale

C-MSSM

- Unify M_1, M_2, M_3 to a universal gaugino mass $m_{1/2}$ at the GUT scale

$$M_3 : M_2 : M_1 : m_{1/2} = \alpha_3 : \alpha_2 : \alpha_1 : \alpha_{GUT}$$

$$M_1 \approx 0.5 m_{1/2};\ M_2 \approx 0.8 m_{1/2};\ M_3 \approx 3.5 m_{1/2}.$$

χ^0 $\chi^\pm$ $\tilde{g}$ (at the EW scale)

$m_{1/2}$

- Unify all sfermion mass parameters to a universal scalar mass m_0

$$m^2_{\tilde{\ell}_R} = m_0^2 + 0.15 m^2_{1/2} + \cdots$$

$$m^2_{\tilde{\ell}_L,\tilde{\nu}} = m_0^2 + 0.5\, m^2_{1/2} + \cdots$$

$$m^2_{\tilde{q}_{R,L}} = m_0^2 + 6\, m^2_{1/2} + \cdots$$

Scalar and gaugino masses related

m_0

mSUGRA

- Unify Higgs and scalar sector at the GUT scale

$$\Rightarrow \mathrm{m}_A \ \text{fixed by}\ (m_0, \tan\beta, \ldots)$$

- Unify all trilinear couplings at the GUT scale

$$\Rightarrow \text{all } A_i\text{'s unified to } A_0$$

- Break radiatively the ElectroWeak Symmetry

$$\Rightarrow |\mu| \ \text{fixed by}\ (\mathrm{m}_0, \mathrm{m}_{1/2}, \tan\beta, \ldots)$$

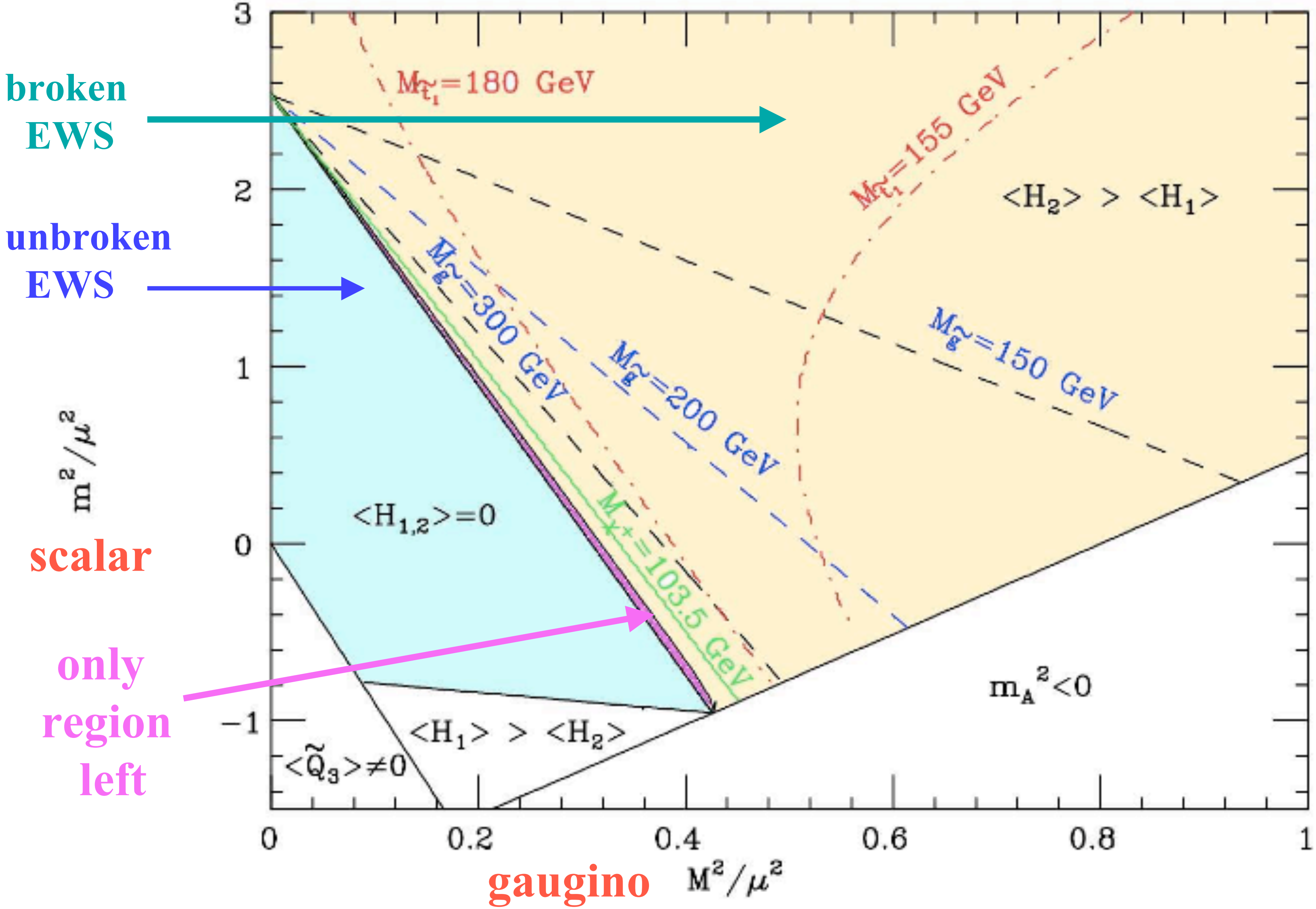
5 parameters

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

B.Clerbaux

G.Giudice 0710.3294

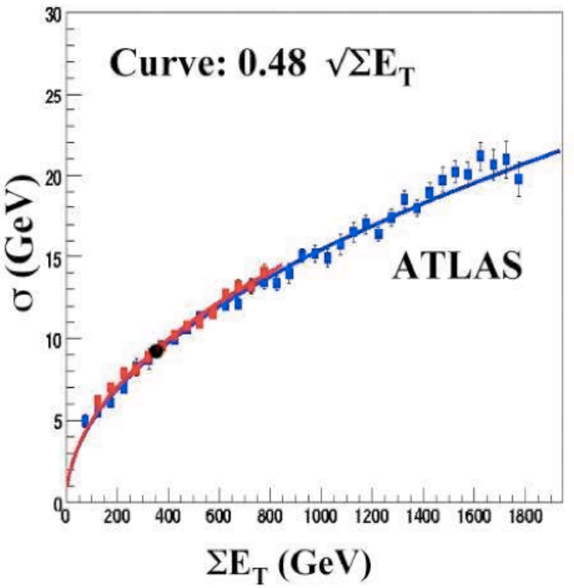
Phase diagram of MSSM

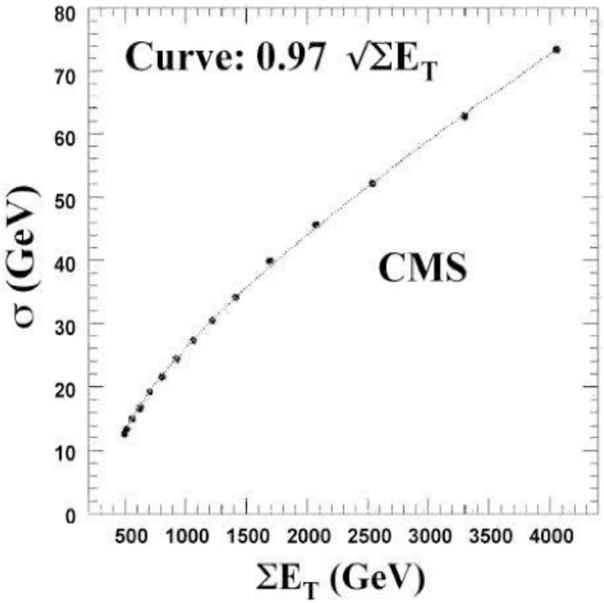


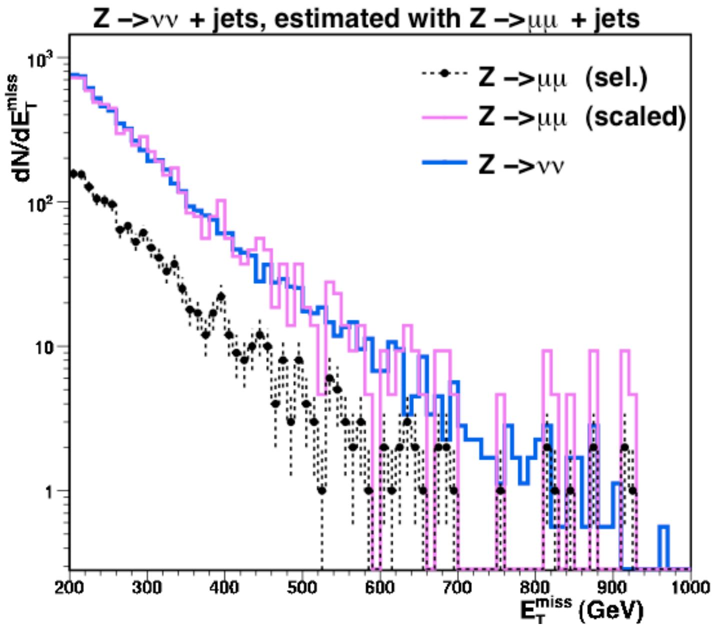
SUSY plots

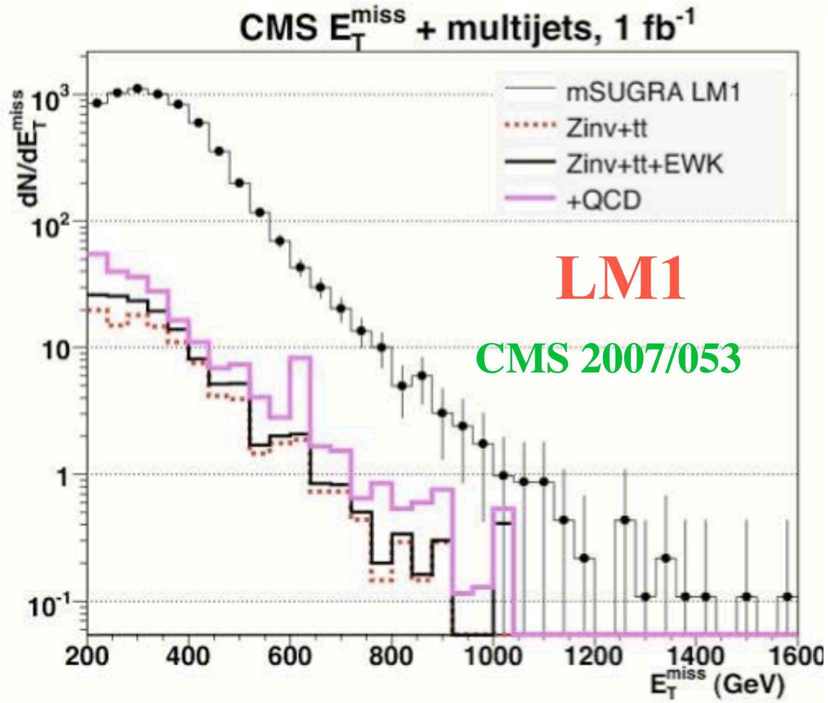
E_T^{miss} → from data

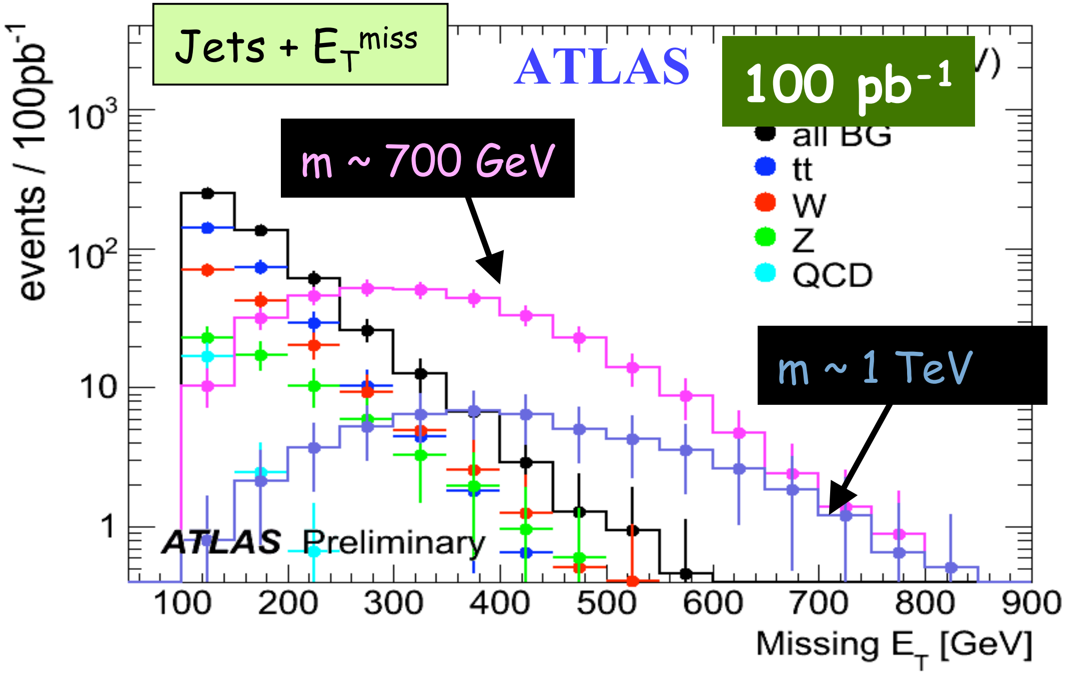
CMS 2007/053

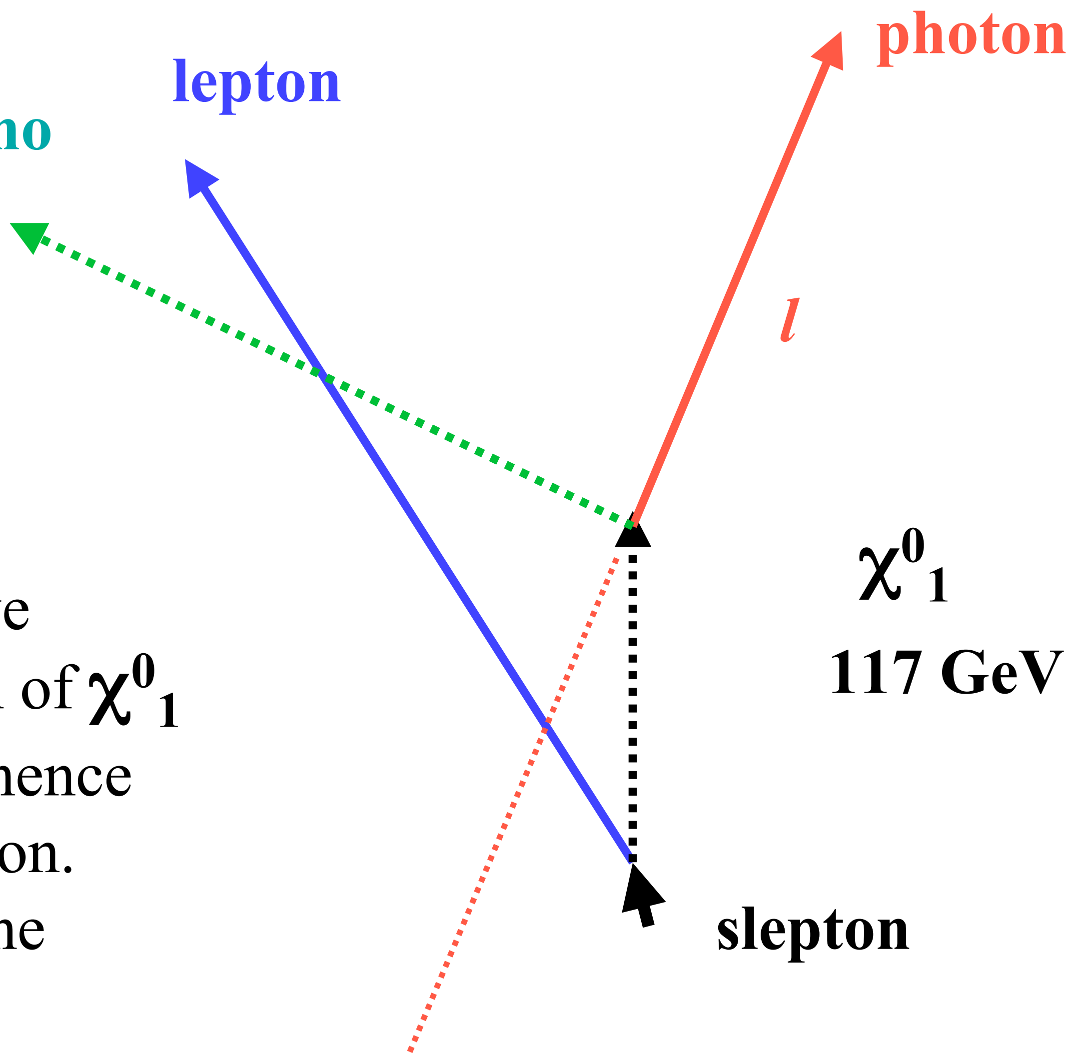










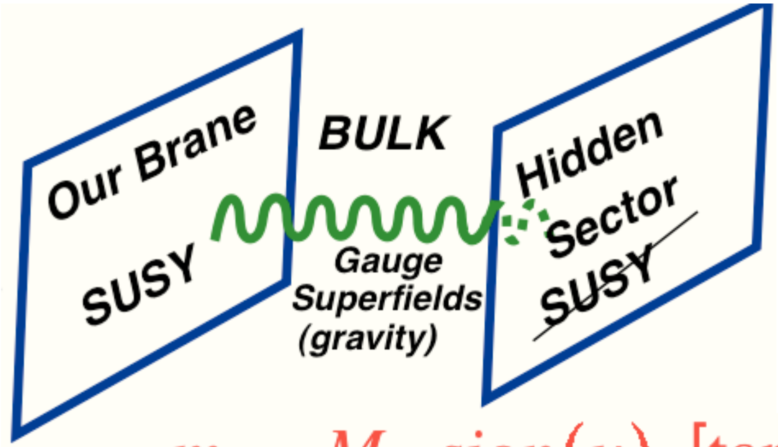


l, time give
β i.e. **p**, m of χ^0_1
hence G, hence
m of slepton.
same on the
other side

Gaugino mediated SUSY breaking

hep-ph/0410385 Belyaev

Based on two-brane scenario.
SM fields live on one brane, hidden sector on the other one.
Gravity and gauge superfields propagate in the bulk and directly couple fields on both branes.
So gauginos acquire a mass.
SSB scalar mass parameters are suppressed and may be neglected.

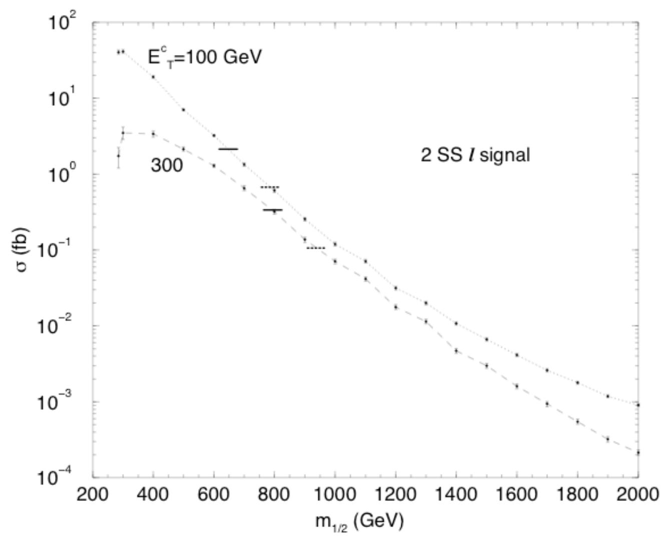


$$m_{1/2}, M_c, sign(\mu), [\tan\beta]$$

hep-ph/0110270

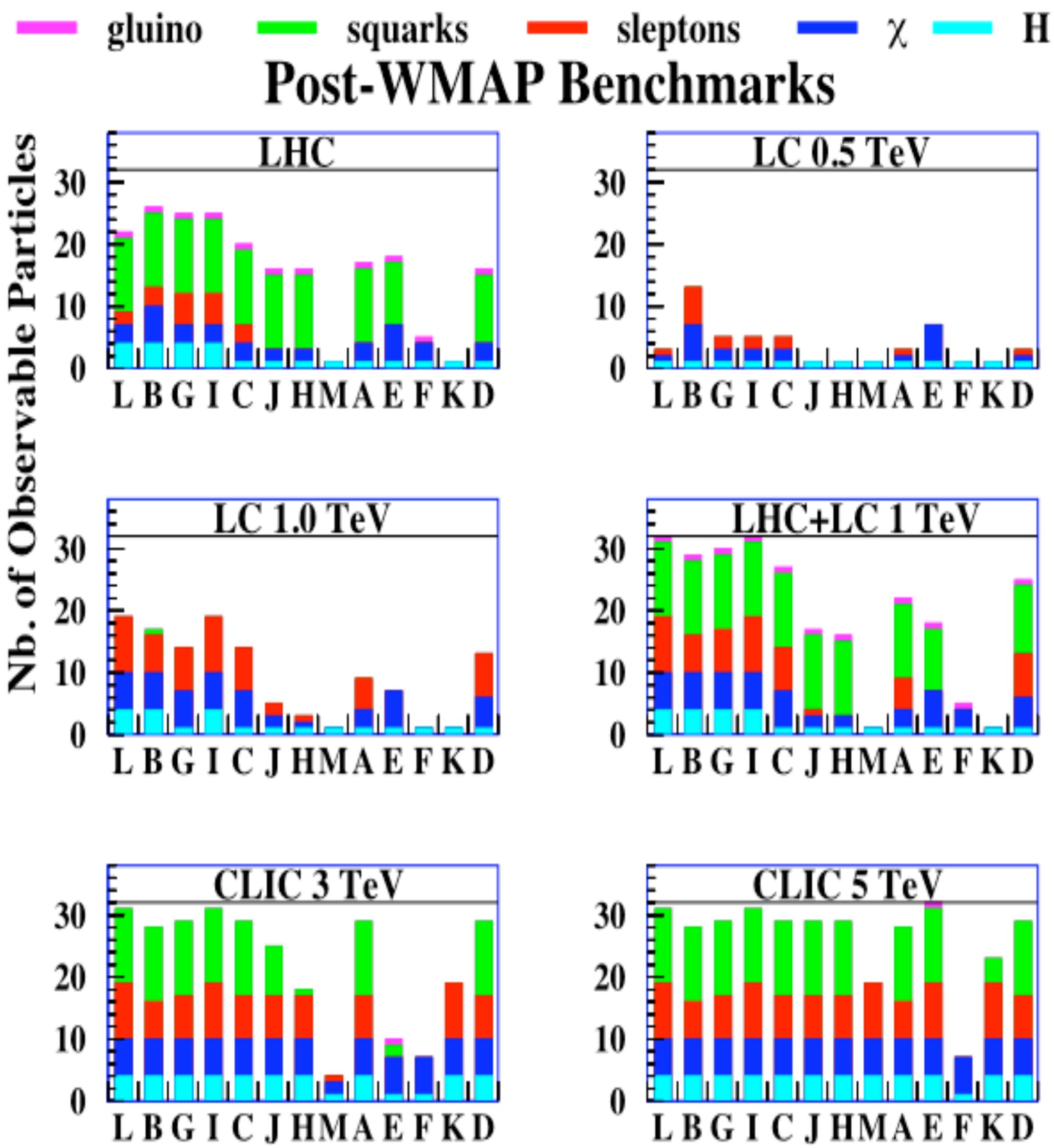
6 parameters $m_{1/2}$, $m^2_{H_u}$, $m^2_{H_d}$, μ, B, and y_t renormalized at $M_{\rm GUT}$

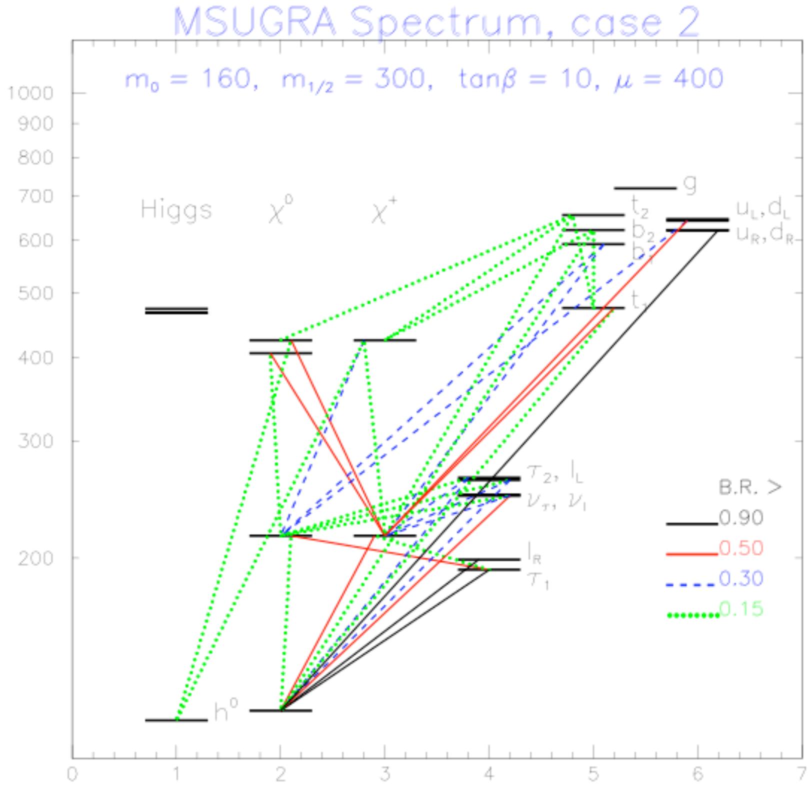
		Point 1	Point 2	Point 3
inputs:	$m_{1/2}$	200	400	400
	$m^2_{H_u}$	$(200)^2$	$(400)^2$	$(400)^2$
	$m^2_{H_d}$	$(300)^2$	$(600)^2$	$(400)^2$
	μ	370	755	725
	B	315	635	510
	y_t	0.8	0.8	0.8
neutralinos:	$m_{\chi^0_1}$	78	165	165
	$m_{\chi^0_2}$	140	315	315
	$m_{\chi^0_3}$	320	650	630
	$m_{\chi^0_4}$	360	670	650
charginos:	$m_{\chi^\pm_1}$	140	315	315
	$m_{\chi^\pm_2}$	350	670	645
Higgs:	$\tan\beta$	2.5	2.5	2.5
	m_{h^0}	90	100	100
	m_{H^0}	490	995	860
	m_A	490	1000	860
	$m_{H^\pm}$	495	1000	860
sleptons:	$m_{\tilde e_R}$	105	200	160
	$m_{\tilde e_L}$	140	275	285
	$m_{\tilde\nu_L}$	125	265	280
stops:	$m_{\tilde t_1}$	350	685	690
	$m_{\tilde t_2}$	470	875	875
other squarks:	$m_{\tilde u_L}$	470	945	945
	$m_{\tilde u_R}$	450	905	910
	$m_{\tilde d_L}$	475	950	945
	$m_{\tilde d_R}$	455	910	905
gluino:	M_3	520	1000	1050
sensitivity:	$m_{1/2}$	16	50	50
	μ	19	78	78

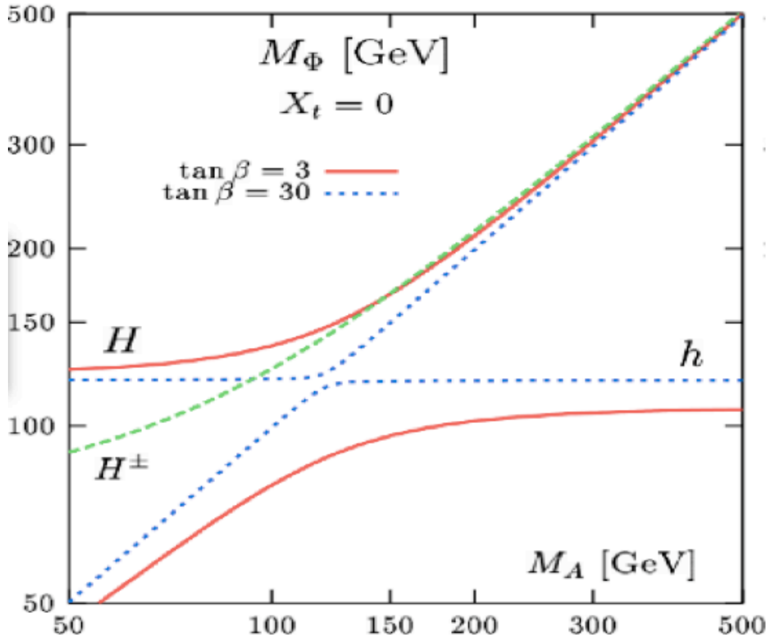


Many possible spectra

Only one firm prediction in MSSM: a very light Higgs boson h^0, likely to be SM-like







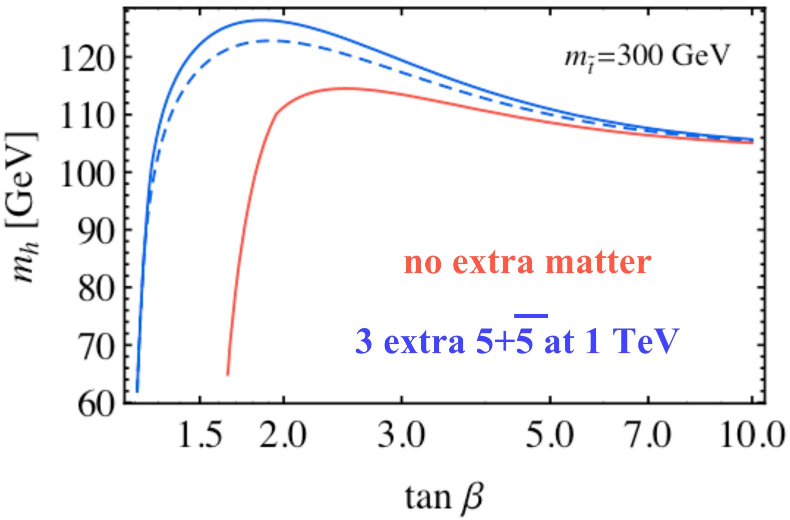
$$(m_h^0)^2 = M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta$$

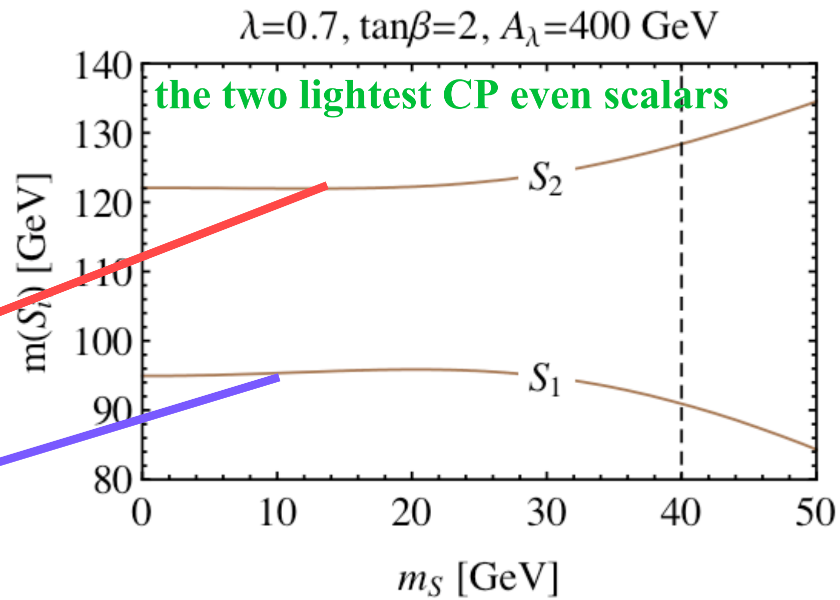
$$f = \lambda S H_1 H_2$$

Barbieri et al, 0712.2903

$$V_{\rm soft} = m_S^2|S|^2 + m_1^2|H_1|^2 + m_2^2|H_2|^2 + (A_\lambda \lambda S H_1 H_2 + \text{H.c.})$$

parameters: λ, m_S, v, tgβ, A_λ and m_G

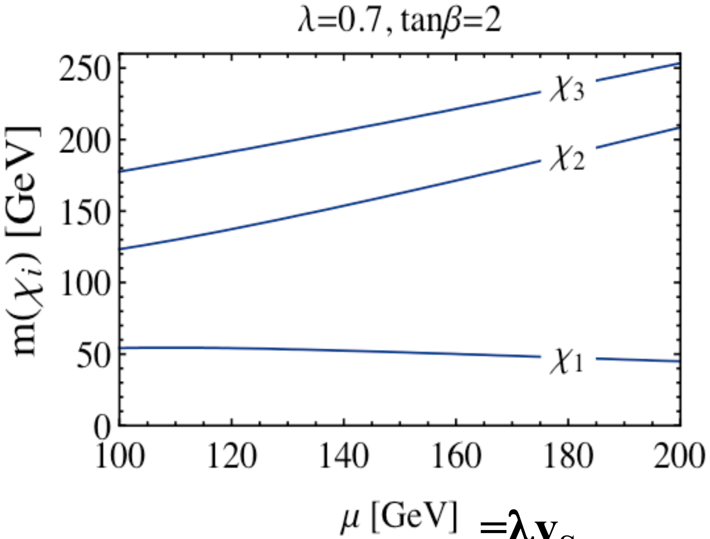




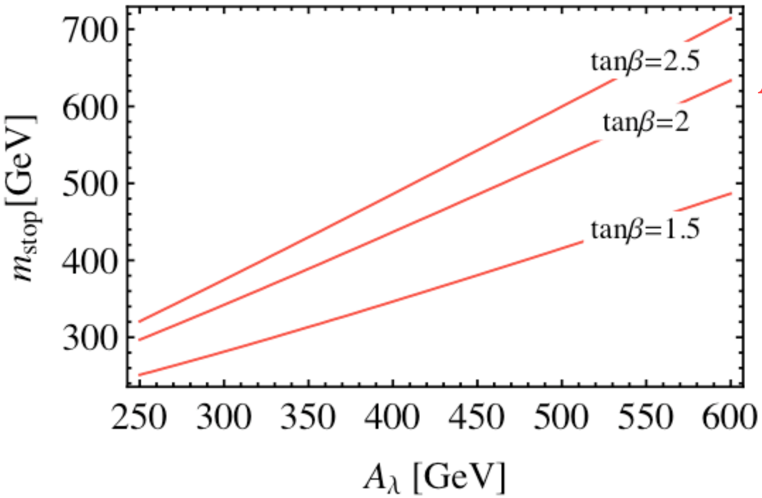
$\chi_1\chi_1 \rightarrow$ invisible or 4b + E_T^{miss}

GG$\rightarrow$4τ or 4b

light pseudoscalar G



$=\lambda v_S$



A lot to work out:
e.w. constraints,
LEP analyses,
exact LHC
phenomenology

Point	P1	P2	P3	P4	P5
GUT/input parameters					
sign(μ_{eff})	+	+	+	−	+
$\tan\beta$	10	10	10	2.6	6
m_0 (GeV)	174	174	174	775	1500
$M_{1/2}$ (GeV)	500	500	500	760	175
A_0	-1500	-1500	-1500	-2300	-2468
A_λ	-1500	-1500	-1500	-2300	-800
A_κ	-33.9	-33.4	-628.56	-1170	60
NUHM: M_{H_d} (GeV)	-	-	-	880	-311
NUHM: M_{H_u} (GeV)	-	-	-	2195	1910
Parameters at the SUSY scale					
λ (input parameter)	0.1	0.1	0.4	0.53	0.016
κ	0.11	0.11	0.31	0.12	-0.0029
A_λ (GeV)	-982	-982	-629	-510	45.8
A_κ (GeV)	-1.63	-1.14	-11.4	220	60.2
M_2 (GeV)	392	392	393	603	140
μ_{eff} (GeV)	968	968	936	-193	303
CP even Higgs bosons					
$m_{h_1^0}$ (GeV)	120.2	120.2	89.9	32.3	90.7
R_1	1.00	1.00	0.998	0.034	-0.314
t_1	1.00	1.00	0.999	0.082	-0.305
b_1	1.018	1.018	0.975	-0.291	-0.644
BR($h_1^0 \to b\bar{b}$)	0.072	0.056	7×10^{-4}	0.918	0.895
BR($h_1^0 \to \tau^+\tau^-$)	0.008	0.006	7×10^{-5}	0.073	0.088
BR($h_1^0 \to a_1^0 a_1^0$)	0.897	0.921	0.999	0.0	0.0
$m_{h_2^0}$ (GeV)	998	998	964	123	118
R_2	-0.0018	-0.0018	0.005	0.999	0.927
t_2	-0.102	-0.102	-0.095	0.994	0.894
b_2	10.00	10.00	9.99	1.038	2.111
BR($h_2^0 \to b\bar{b}$)	0.31	0.31	0.14	0.081	0.87
BR($h_2^0 \to t\bar{t}$)	0.11	0.11	0.046	0.0	0.0
BR($h_2^0 \to a_1^0 Z^0$)	0.23	0.23	0.72	0.0	0.0
$m_{h_3^0}$ (GeV)	2142	2142	1434	547	174
CP odd Higgs bosons					
$m_{a_1^0}$ (GeV)	40.5	9.1	9.1	185	99.6
t_1'	0.0053	0.0053	0.0142	0.0513	-0.00438
b_1'	0.529	0.528	1.425	0.347	-0.158
BR($a_1^0 \to b\bar{b}$)	0.91	0.	0.	0.62	0.91
BR($a_1^0 \to \tau^+\tau^-$)	0.085	0.88	0.88	0.070	0.090
$m_{a_2^0}$ (GeV)	1003	1003	996	546	170
Charged Higgs boson					
$m_{h^\pm}$ (GeV)	1005	1005	987	541	188

arXiv: 0801.4321

- **define 4 benchmarks**
- **focus on lighter Higgs**

$$gg \to h_i^0$$

$$qq \to qqW^*W^*, qqZ^{0*}Z^{0*} \to qqh_i^0$$

$$q\bar{q}' \to Wh_i^0 \text{ and } q\bar{q} \to Z^0 h_i^0$$

$$q\bar{q}/gg \to Q\bar{Q}h_i^0, \text{ with } Q = t, b$$