Extending LHC reach in the Focus Point region

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Minimal Supergravity Model (mSUGRA)

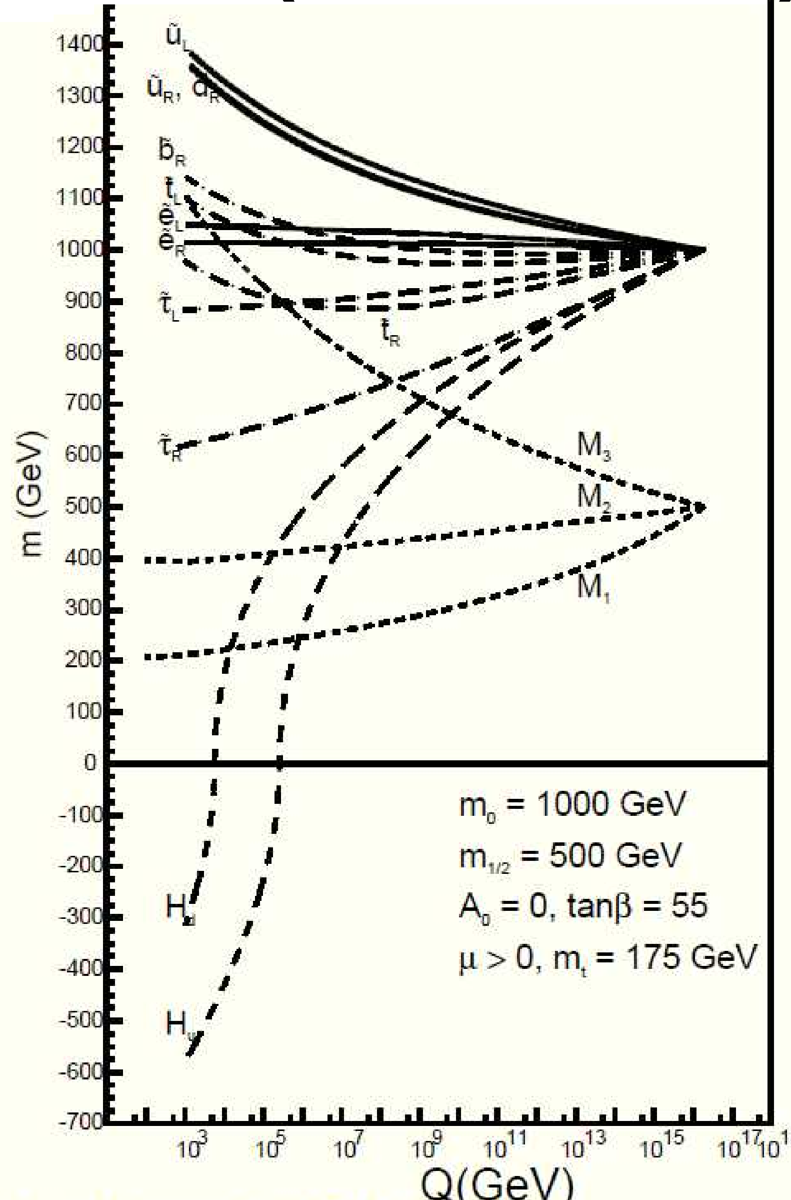
- *Visible-Hidden sectors interact with each other via gravity*
- *Weak scale model constructed via RGE evolution, assuming:*
  - *Universality of the soft breaking parameters at GUT ($\sim 10^{16}$ GeV)*
  - *diagonal form of Yukawa matrices and trilinear parameters*
  - *gauge couplings unification*
- *Independent parameters left:*

  $m_0, m_{1/2}$ – *universal scalar and gaugino masses*

  $sign(\mu)$, μ^2 *value is fixed by the minimization condition for Higgs potential*

  A - *the initial value of trilinear soft parameter*

  B - *parameter – usually expressed via* $\tan\beta$

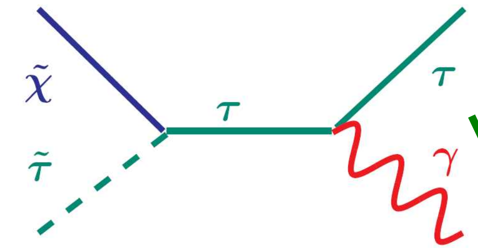


- *Flavor and CP problem can be addressed, Lightest neutralino is the perfect DM candidate*
- *Is it too simple to be true?*

Neutralino relic density in mSUGRA

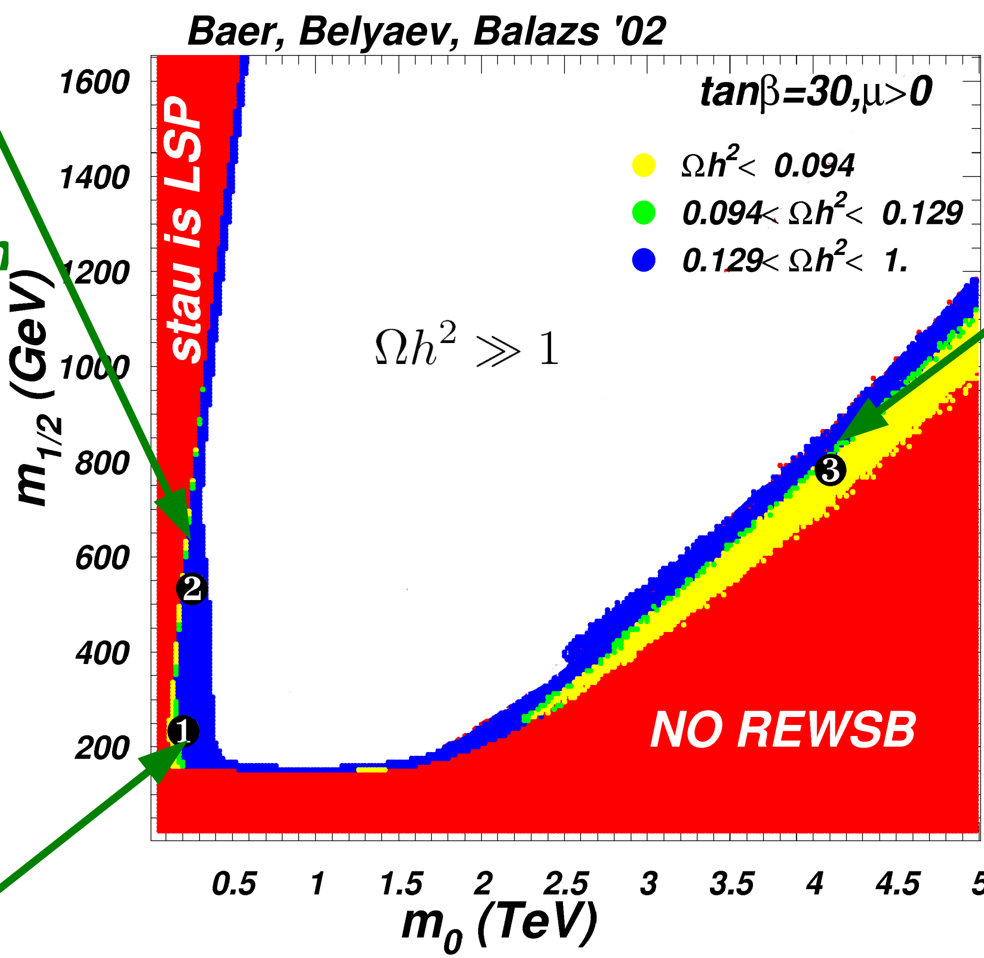
- *most of the parameter space is ruled out!* $\Omega h^2 \gg 1$

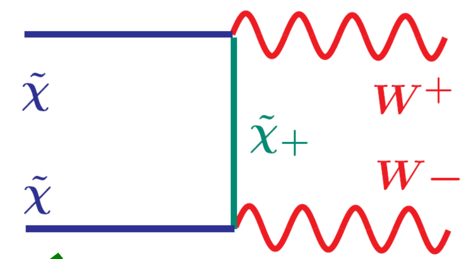
special regions with high σ_A *are required to get* $0.094 < \Omega h^2 < 0.129$



2. stau coannihilation

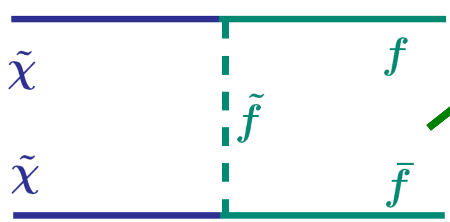
degenerate χ *and stau*





3. focus point:

mixed neutralino, low μ*, importance of higgsino-wino component*



1. bulk region: *light sfermions*

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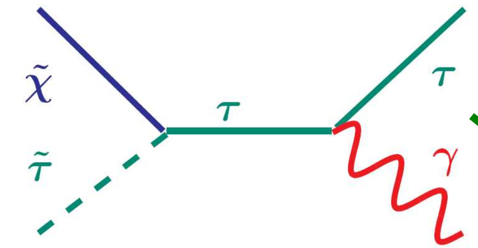

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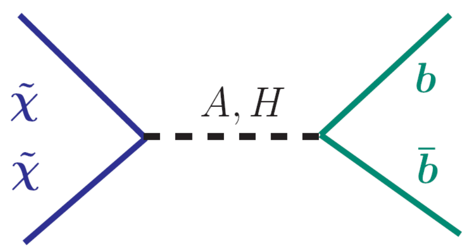
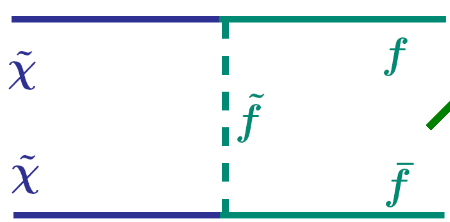
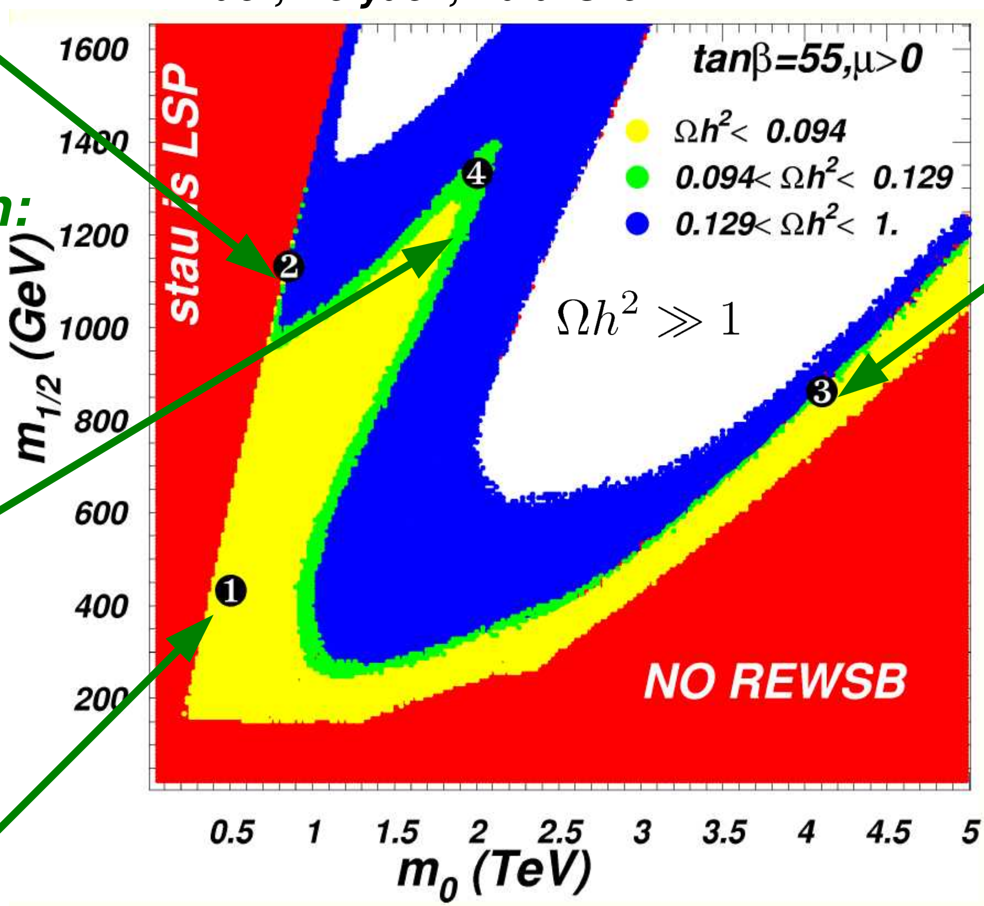


4. funnel: *(large tanβ)*

annihilation via A, H



Baer, Belyaev, Balazs '02



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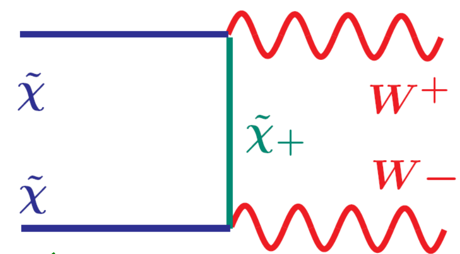


3. focus point:

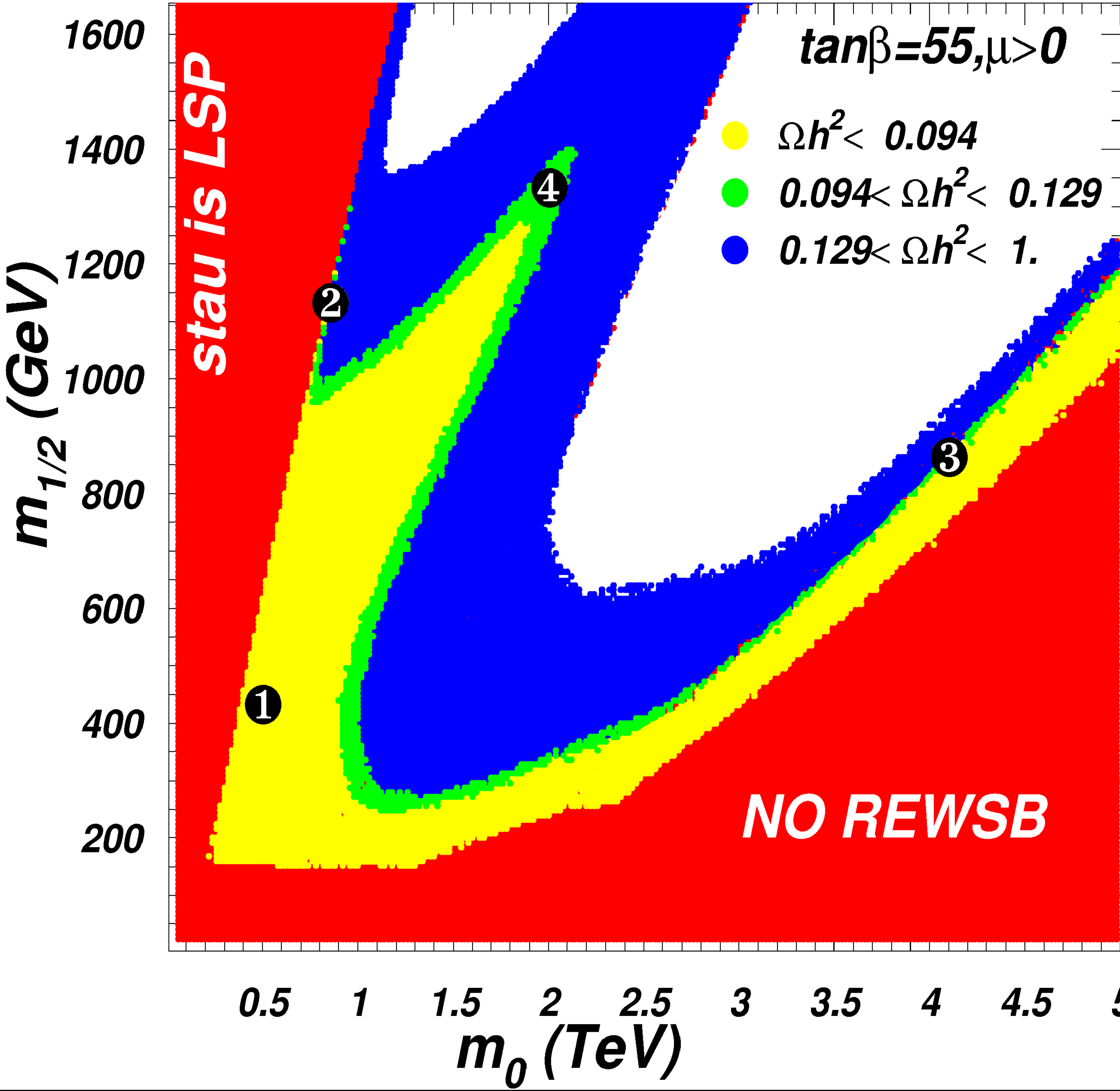
mixed neutralino, low μ, importance of higgsino-wino component

additional regions:

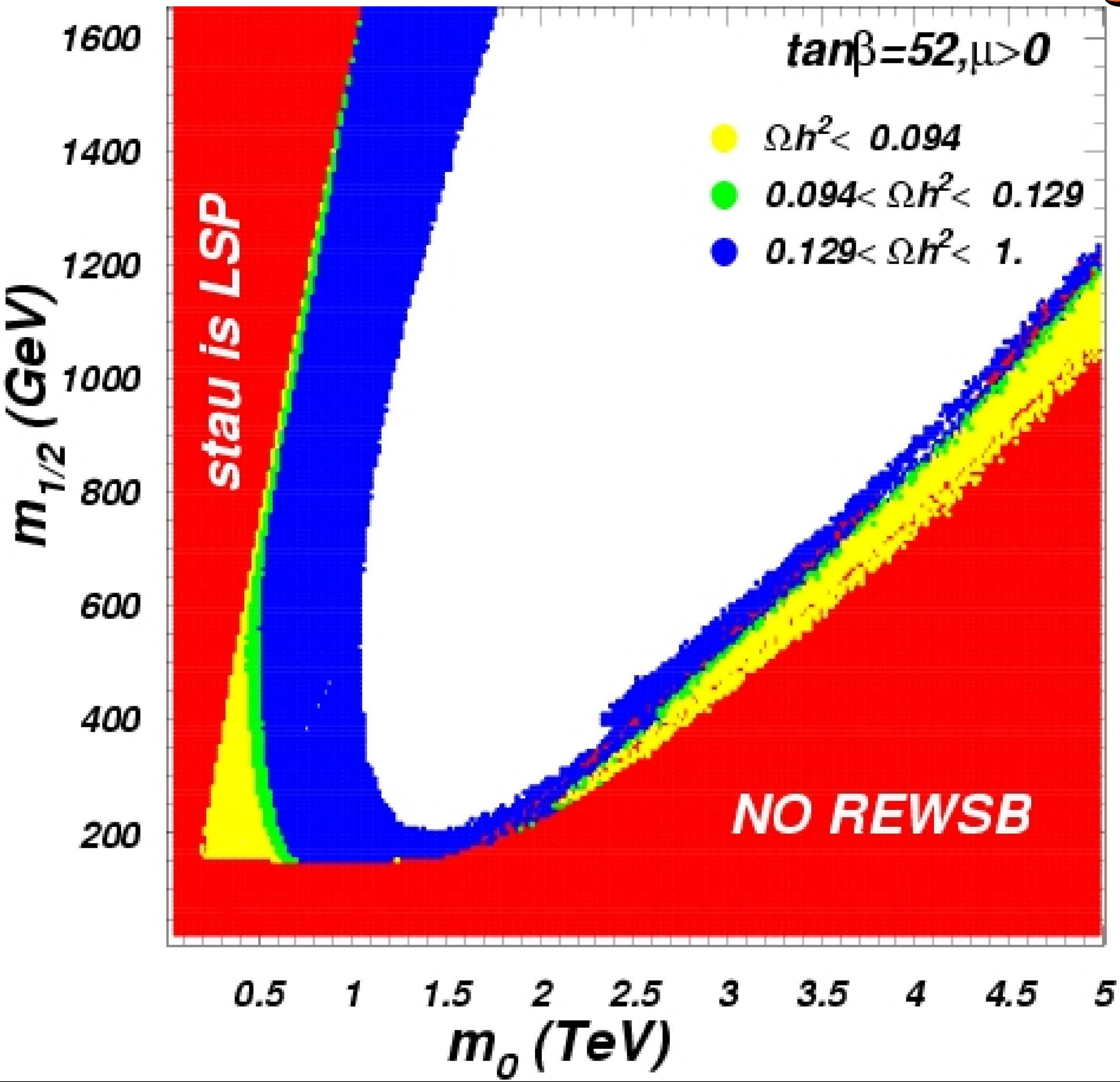
Z/h annihilation

stop coannihilation

mSUGRA: dark matter favored regions



mSUGRA: dark matter favored regions



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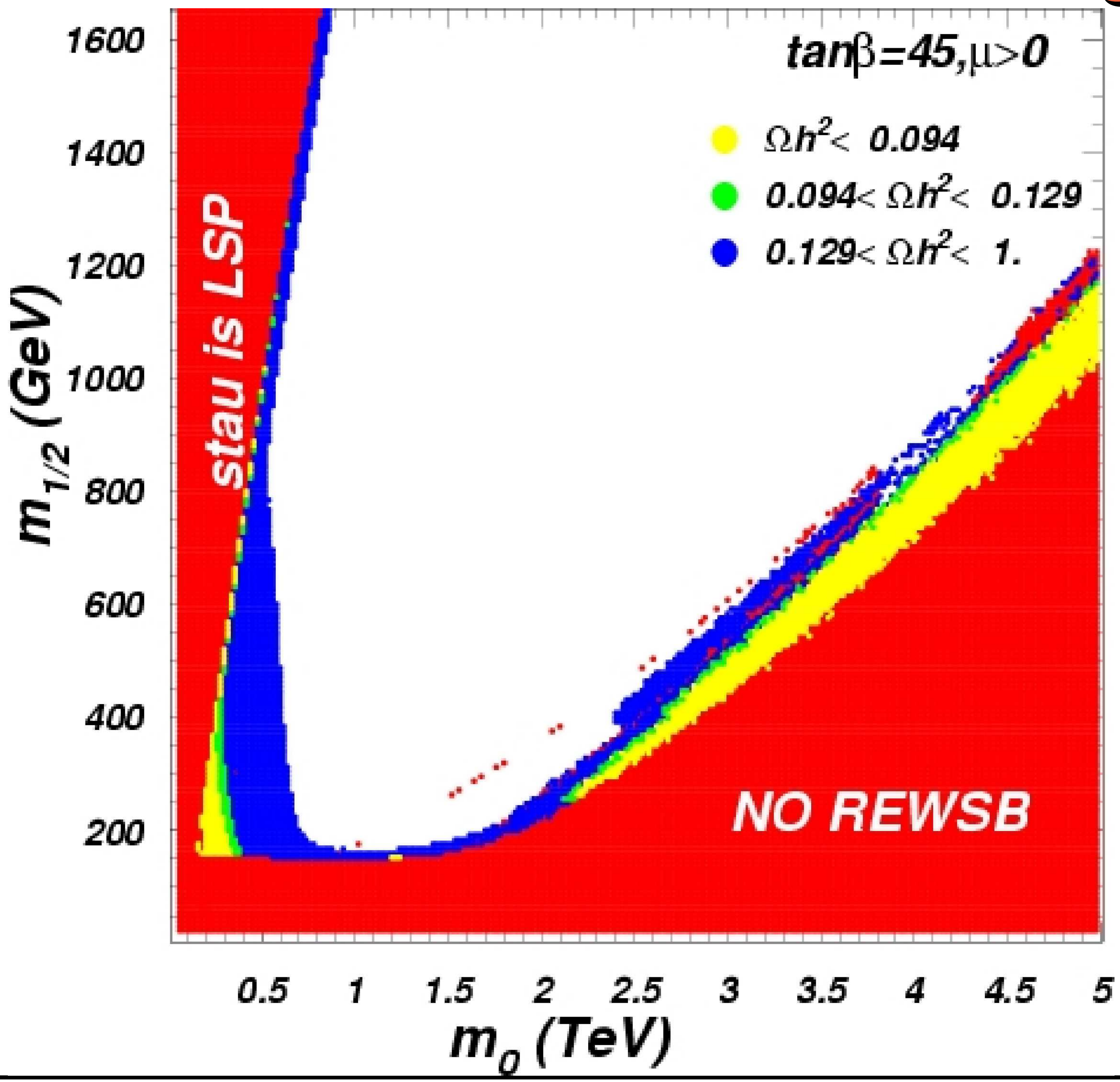

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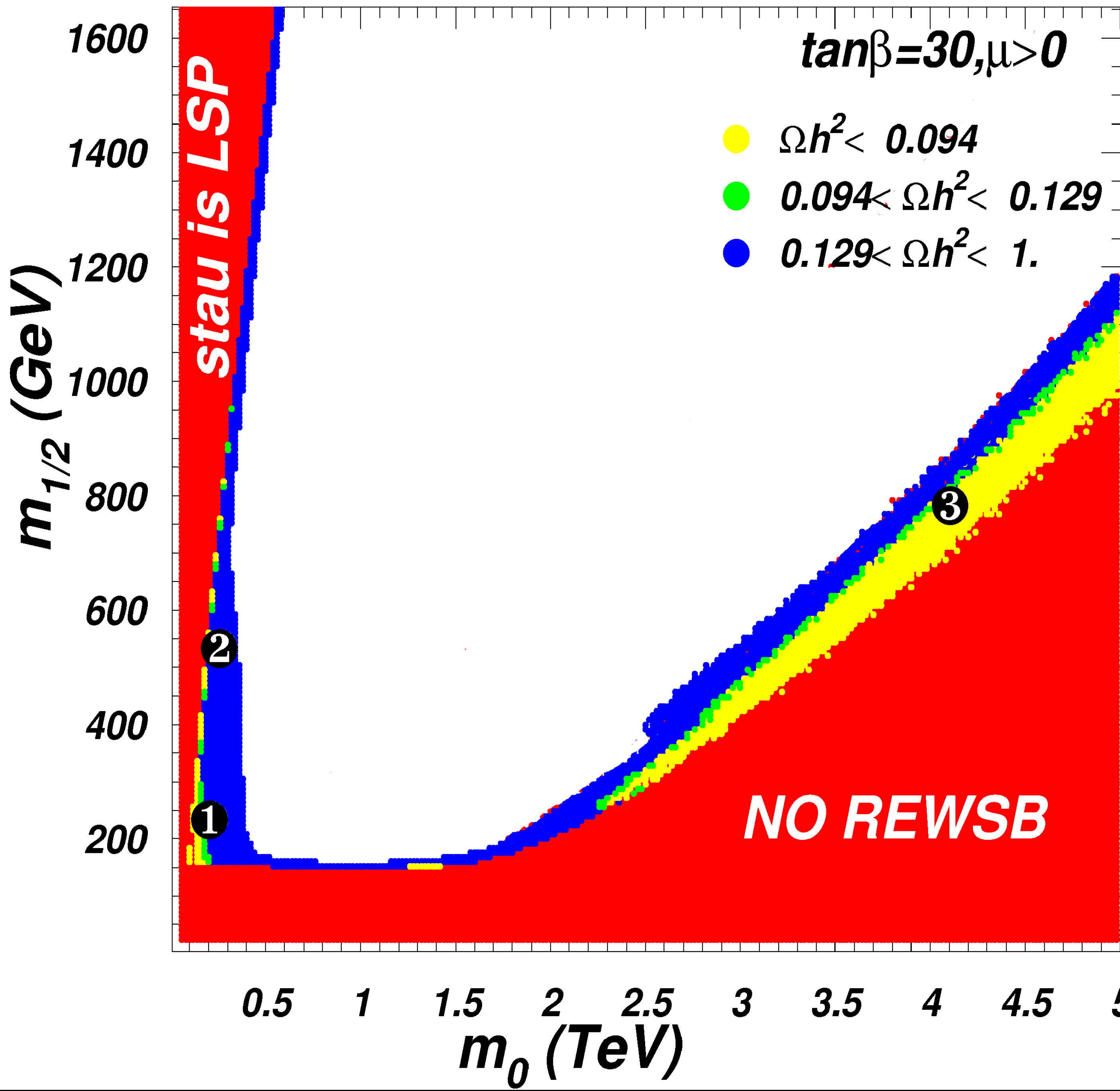

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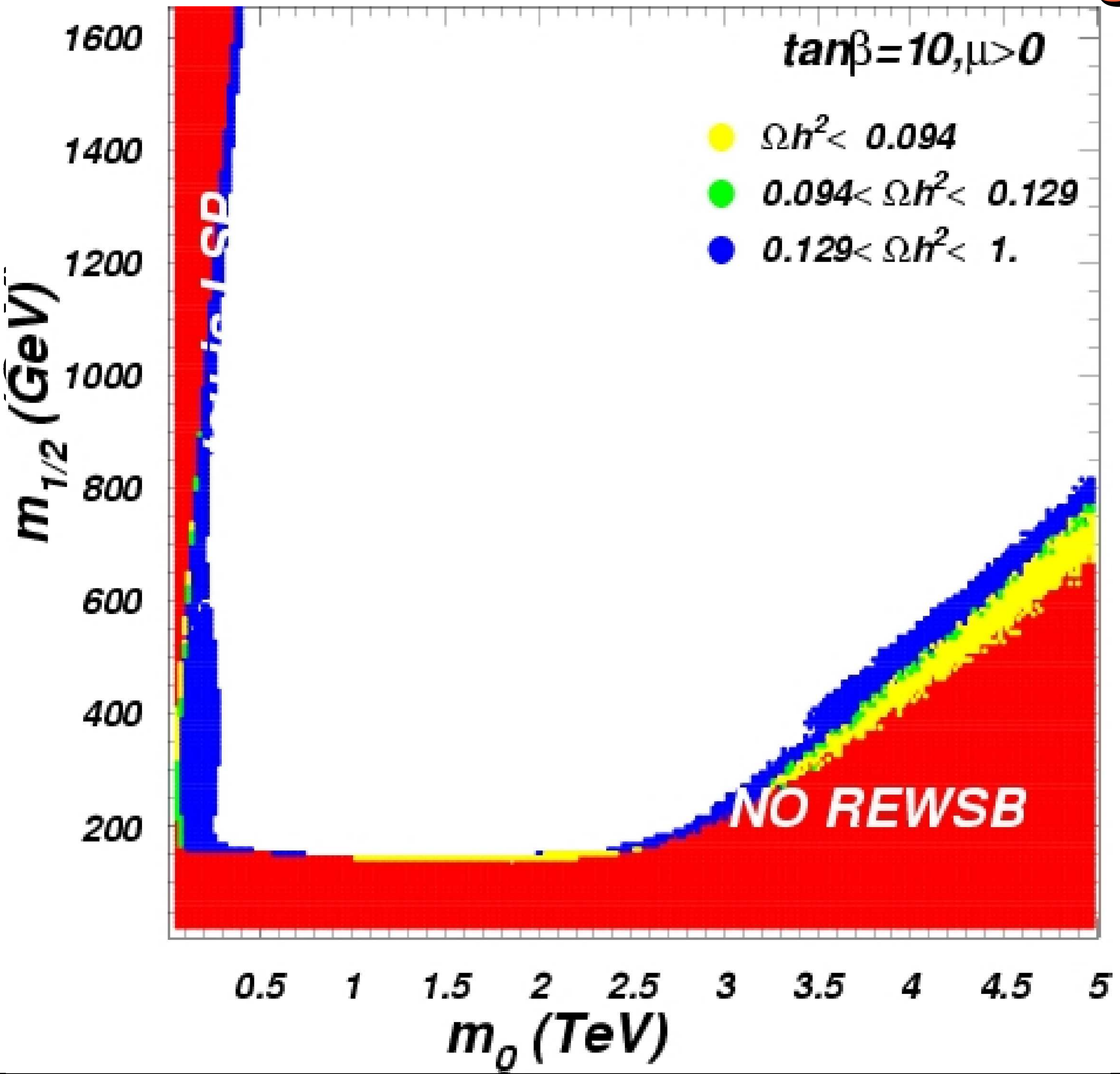
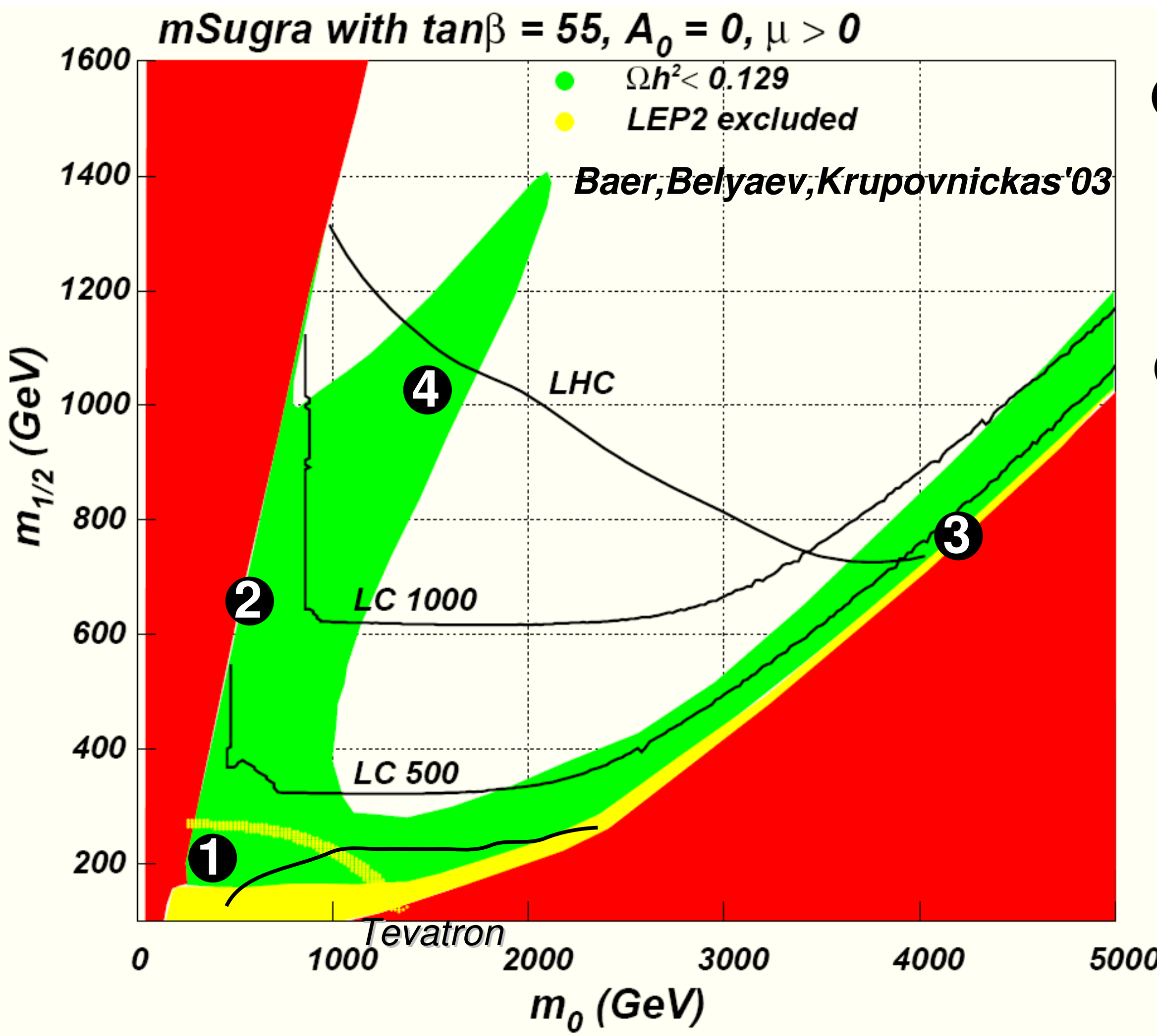
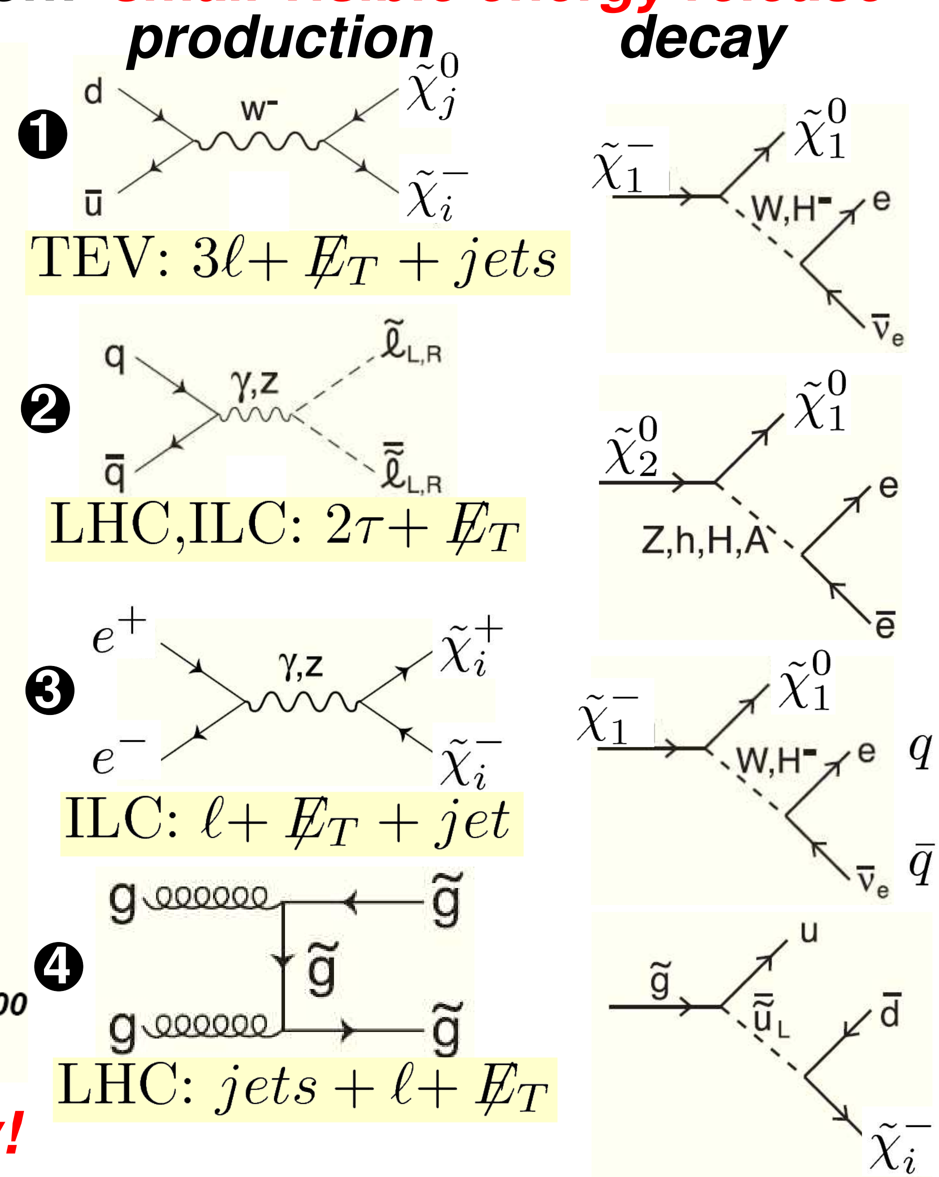


Collider signatures in DM allowed regions

- ***DM allowed regions are difficult for the observation at the colliders:***

stau(stop) co-annihilation , FP region: ***small visible energy release***



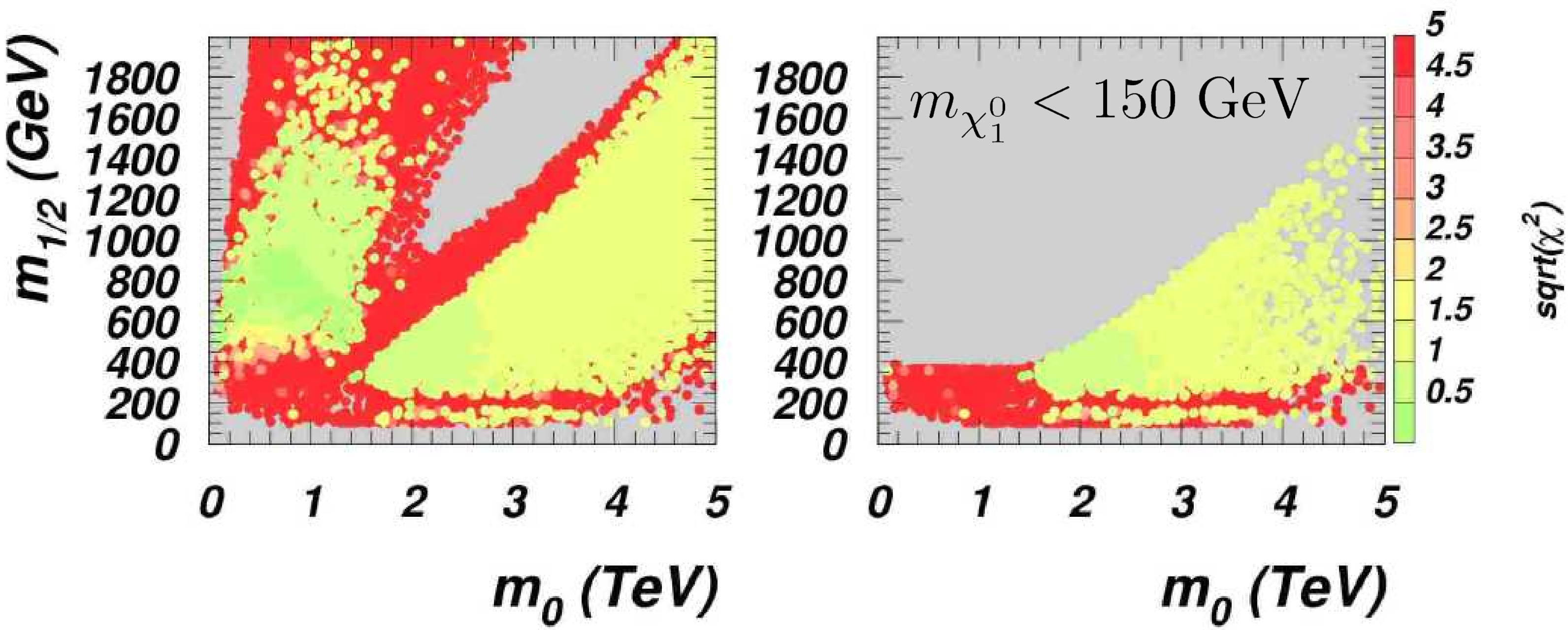


LHC and ILC are highly complementary!

Why FP region is attractive?

- ***small value of $|\mu|$-parameter: mixed higgsino-bino LSP***
- ***Light mass spectum of chargino and neutralinos***
- ***low value of $|\mu|$-parameter was advocated as "fine-tuning" measure***

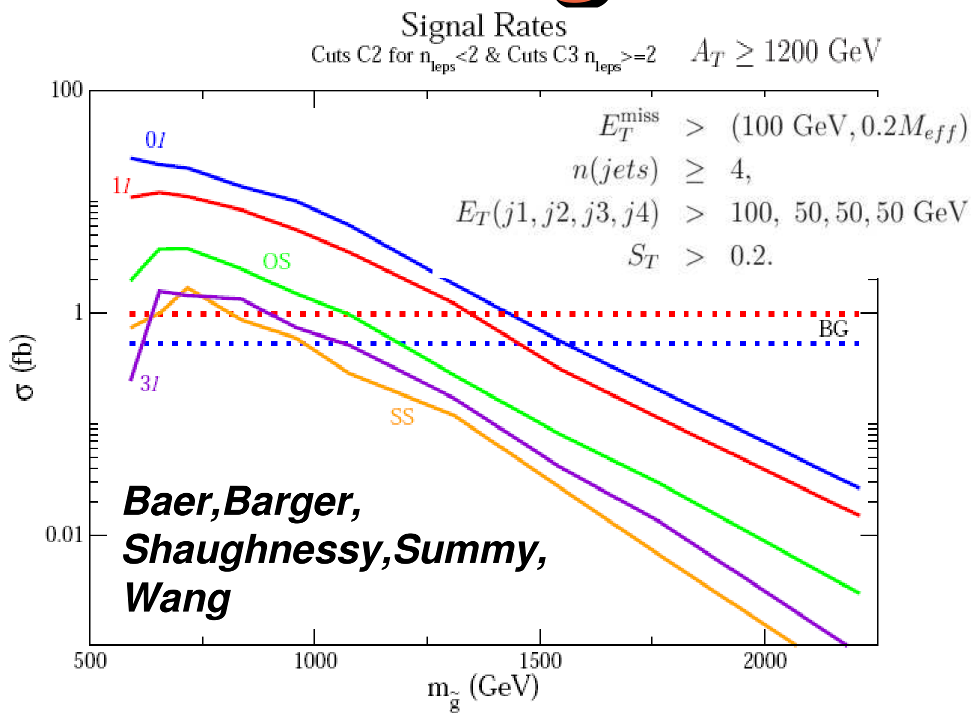
  Chan, Chattopadhyay,Nath '97; Feng, Matchev, Moroi '99; Baer, Chen,Paige,Tata '95
- ***DM motivated mSUGRA region with 'natural' neutralino mass ~100 GeV !***
- ***ILC connection: the signal observation at the LHC is crucial for the fate of ILC***



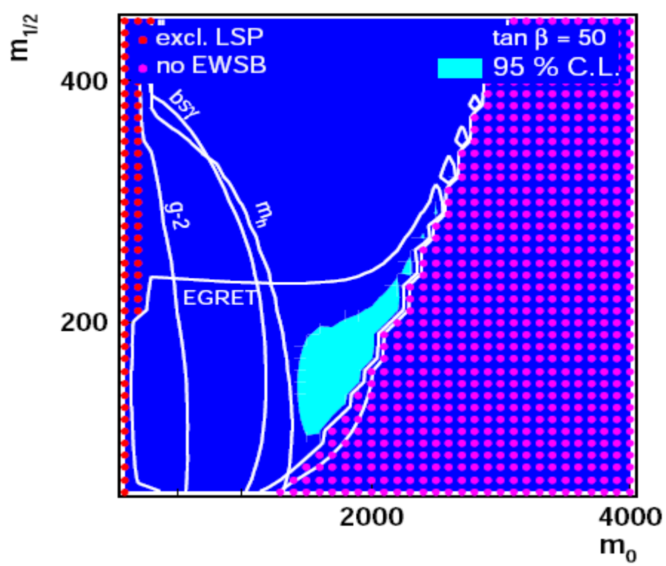
$$0.1 \text{ TeV} < m_0 < 5 \text{ TeV}$$
$$0.1 \text{ TeV} < m_{1/2} < 2 \text{ TeV}$$
$$1.1 < \tan\beta < 60$$
$$-3 \text{ TeV} < A_0 < 3 \text{ TeV}$$
$$\text{with } \ m_{top} = 171.4 \ \text{ GeV}, \quad \mu > 0$$

Recent Studies in FP region

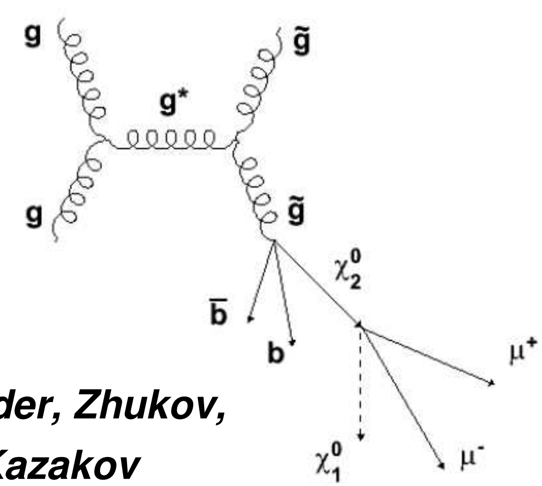
Point	m_0	$m_{1/2}$	$M_{\tilde{g}}$	$\delta M_{\tilde{g}}/M_{\tilde{g}}$	$\Gamma_{\tilde{g}}$
FP0	2300	200	591	LEP2 excl.	0.2
FP1	2450	225	655	LEP2 excl.	0.4
FP2	2550	250	717	$\pm 10\%$	0.6
FP3	2700	300	838	$\pm 8\%$	1.1
FP4	2910	350	959	$\pm 7\%$	1.8
FP5	3050	400	1076	$\pm 8\%$	2.7
FP6	3410	500	1310	$\pm 8\%$	5.1
FP7	3755	600	1540	—	8.1
FP8	4100	700	1766	—	11.8
FP9	4716	900	2211	—	20.7



Baer, Barger, Shaughnessy, Summy, Wang



DeBoer, Sander, Zhukov, Gladyshev, Kazakov

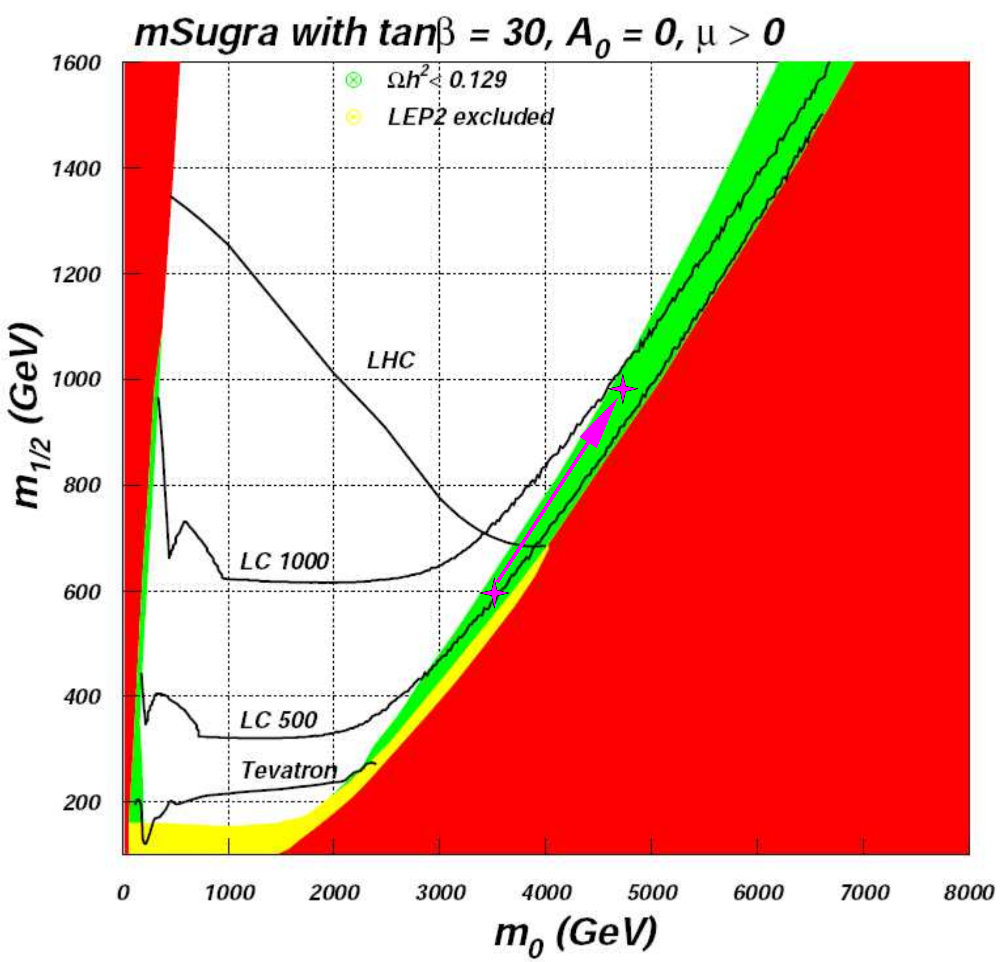


Bednyakov, Budagov, Gladyshev, Kazakov, Khoriauli, Khubua, Khramov

Motivations for these FP analysis

- *to study the LHC reach in the 'far' FP region dominated by EW chargino-neutralino production - requires special cuts/analysis*
- *the signal observation in the 'far' FP region could be crucial for the fate of ILC*

Particle	[3500,600] GeV Mass(GeV)	[4670,975] GeV Mass(GeV)
$\tilde{Z}_1$	239.12	403.54
$\tilde{Z}_2$	317.22	485.37
$\tilde{Z}_3$	324.92	486.23
$\tilde{Z}_4$	528.59	841.62
$\tilde{W}_1^{\pm}$	315.53	488.41
$\tilde{W}_2^{\pm}$	517.21	832.74
$\tilde{g}$	1531.37	2365.94
$\tilde{u}_L$	3653.71	4976.93
h	120.80	122.14
H^0	3033.45	4085.70
A^0	3013.62	4058.99
$H^{\pm}$	3034.72	4086.65



Relative contributions of SUSY subprocesses (before cuts)

Produced sparticles	[3500,600] GeV Fraction of SUSY events(%)	[4670,975] GeV Fraction of SUSY events(%)
$\tilde{W}_1 + \tilde{W}_1$	16.42	15.78
$\tilde{W}_2 + \tilde{W}_2$	5.88	4.46
$\tilde{W}_1 + \tilde{W}_2$	0.68	0.22
$\tilde{Z}_1 + \tilde{W}_1$	8.48	8.66
$\tilde{Z}_1 + \tilde{W}_2$	0.02	0.04
$\tilde{Z}_2 + \tilde{W}_1$	21.36	25.88
$\tilde{Z}_2 + \tilde{W}_2$	0.56	0.20
$\tilde{Z}_3 + \tilde{W}_1$	20.10	22.48
$\tilde{Z}_3 + \tilde{W}_2$	0.56	0.16
$\tilde{Z}_4 + \tilde{W}_2$	10.34	6.98
$\tilde{Z}_4 + \tilde{W}_1$	0.46	0.26
$\tilde{Z}_1 + \tilde{Z}_1$	0.02	0.02
$\tilde{Z}_1 + \tilde{Z}_2$	<0.02	4.46
$\tilde{Z}_1 + \tilde{Z}_3$	3.72	<0.02
$\tilde{Z}_2 + \tilde{Z}_3$	8.72	10.20
$\tilde{Z}_2 + \tilde{Z}_4$	<0.02	0.04
$\tilde{Z}_3 + \tilde{Z}_4$	0.34	0.02
$\tilde{g} + \tilde{g}$	2.12	0.06

Simulations

- **ATLFAST**

$$\Delta\eta \times \Delta\phi = 0.025 \times 0.025$$

- **Leptons**

$$-2.5 < \eta < 2.5$$

$$0.1/\sqrt{E}(GeV) \bigoplus 0.007 \qquad E_T > 5 \text{ GeV}$$

$$\Delta\eta \times \Delta\phi = 0.1 \times 0.1$$

$$-2.5 < \eta < 2.5,$$

- **Jets**

$$0.5/\sqrt{E(GeV)} \oplus 0.03 \qquad E_T > 20 \text{ GeV}$$

$$\Delta R = 0.4$$

Signal and Backgrounds

- signature $1\ell + jets + \not{E}_T$
- signal $[m_0, m_{1/2}] = [3500, 600]$ → ~ 240 fb
- $t\bar{t}$ background → 20.7 pb
- W+jets background 366 pb

- $p_T^e > 20\ GeV,\ p_T^\mu > 10\ GeV$
- $p_T^J > 40\ GeV\ within\ |\eta| < 3.0$
- $Number\ of\ jets\ to\ be \geq 4$
- $Number\ of\ leptons\ = 1$
- $\not{E}_T \geq 400\ GeV$
- $p_T^{J_1} \geq 500\ GeV$
- $p_T^{J_2} \geq 300\ GeV$
- $\Delta\phi(p_T^{lep}, \not{E}_T) \geq 20°$

→

$[m_0, m_{1/2}]$ (GeV)	σ_{signal}' (fb)	σ_{BG}' (fb)
[3500,600]	0.44±0.03	1.7±0.3
[4000,700]	0.18±0.02	1.7±0.3

W+jets is dominant:
PYTHIA W+jets underestimates BG by factor>3
as compared to
Madgraph W+4jets which is used in our study

Improved strategy: softer preselection + new kinematical cuts

Cut Set 3 *The pre-selection cuts*

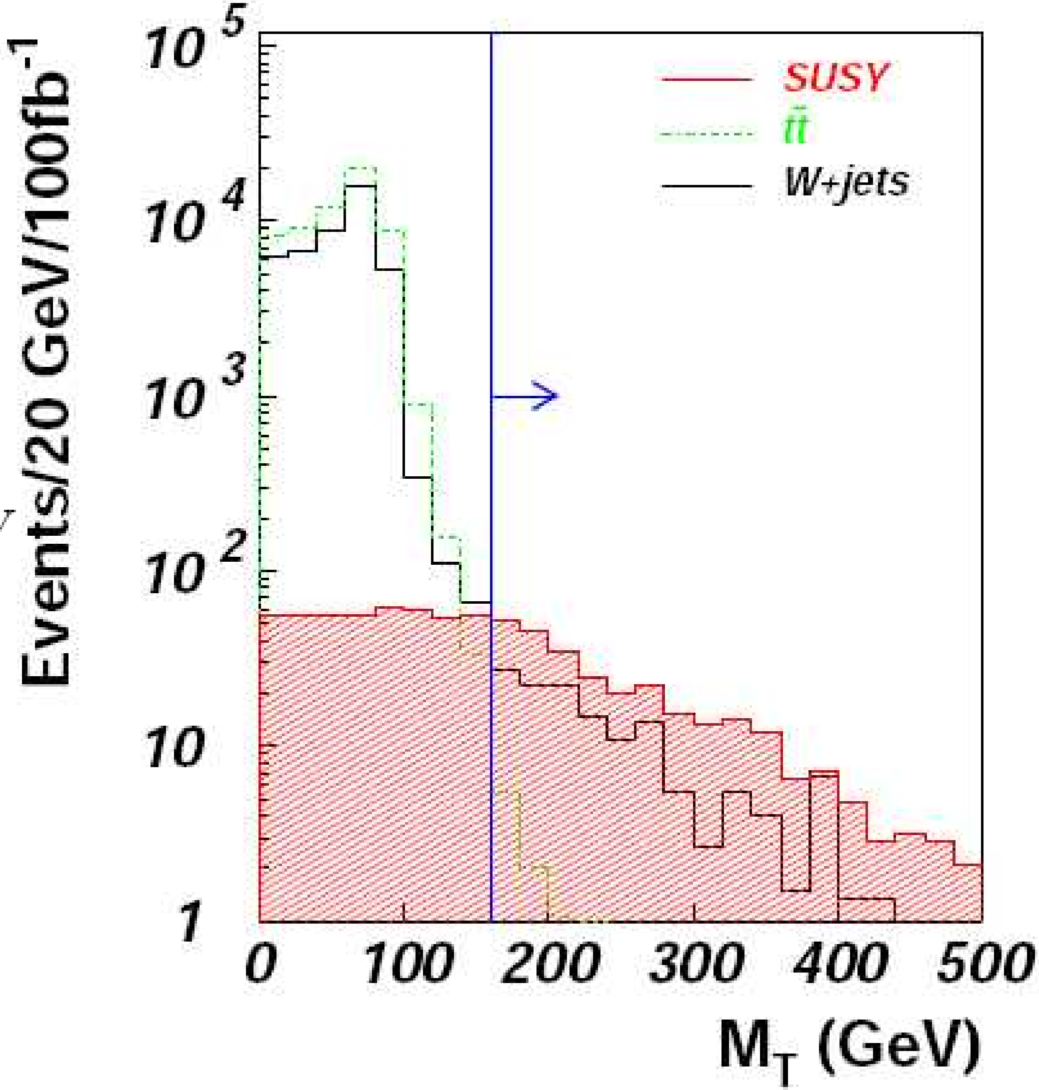
- *One lepton with* $p_T^{lep} > 20\ GeV$
- *At least four jets with* $p_T^J > 20\ GeV$
- *A leading jet with* $p_T^{J_1} \geq 40\ GeV$
- $\not{E}_T > 200\ GeV.$
- $M_{jj} = \sqrt{(}(\sum E_i)^2 - (\sum \vec{p}_i)^2) > 60\ GeV$

Cut Set 4 *The analysis cuts*

- $N_j \qquad \not{E}_T.$
- p_T^{lep} ***(max)***
- *transverse mass of the lepton and missing energy.*

$$M_T = \sqrt{2 p_T^{lep}\ \not{E}_T (1 - cos\phi(\not{E}_T, p_T^{lep})))}$$

- $R = p_T^{J_1} / \left| \sum_i \vec{p}_{T,i} \right|.$



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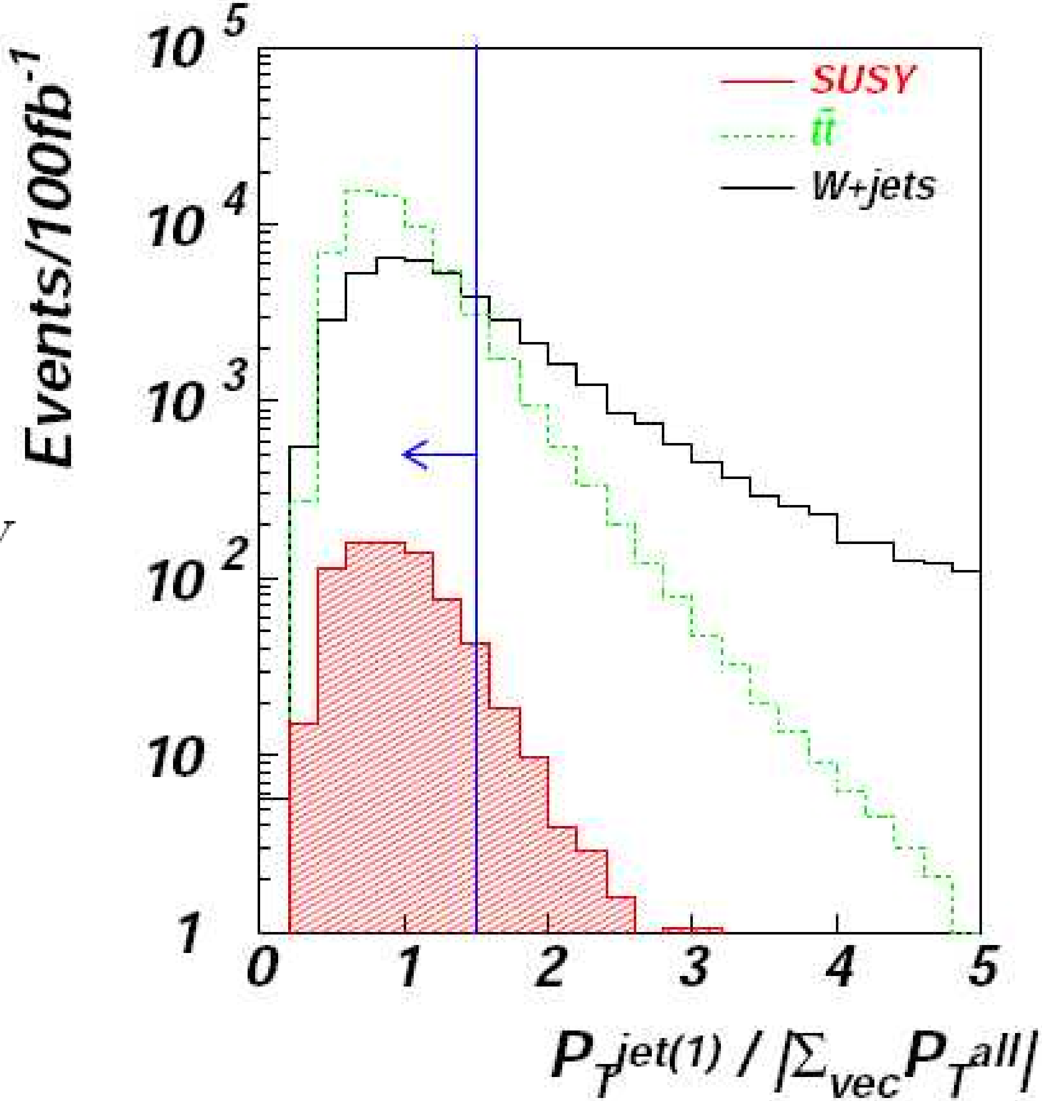
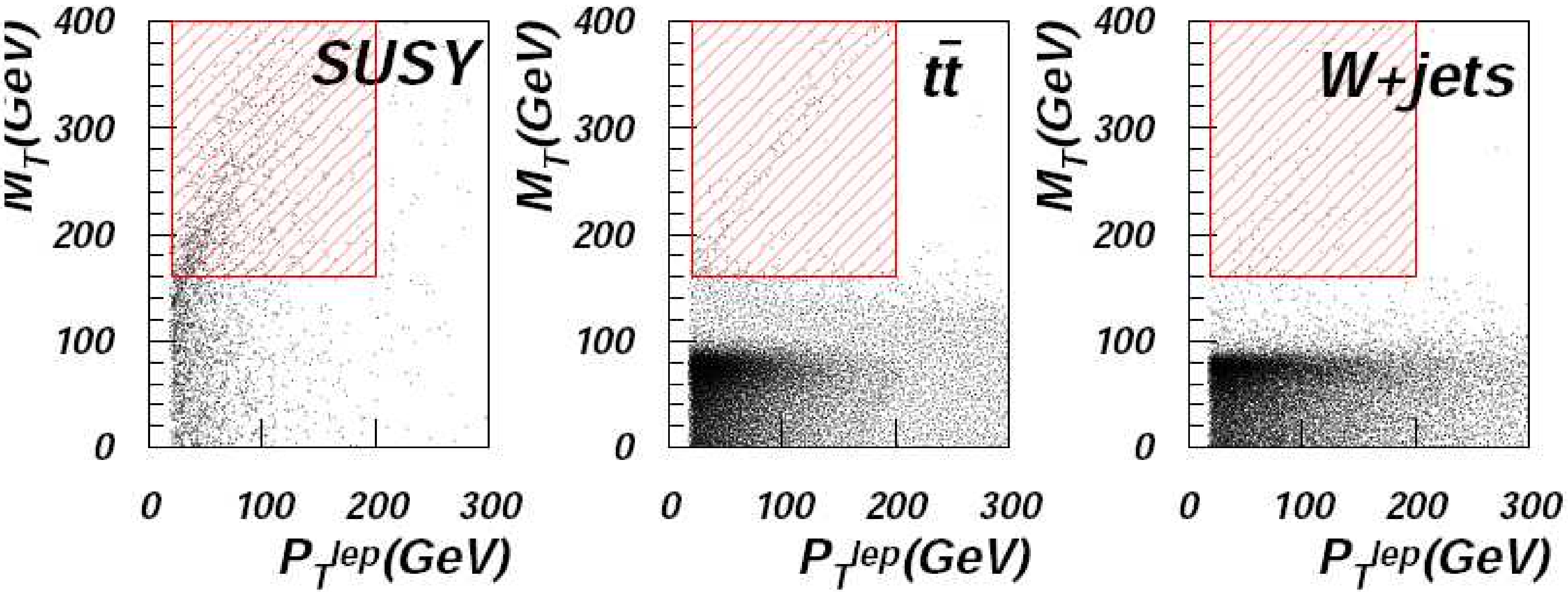


$$R = p_T(jet(1)) / |\sum_i \vec{p}_{T,i}|$$

Further analysis of kinematical variables and correlations



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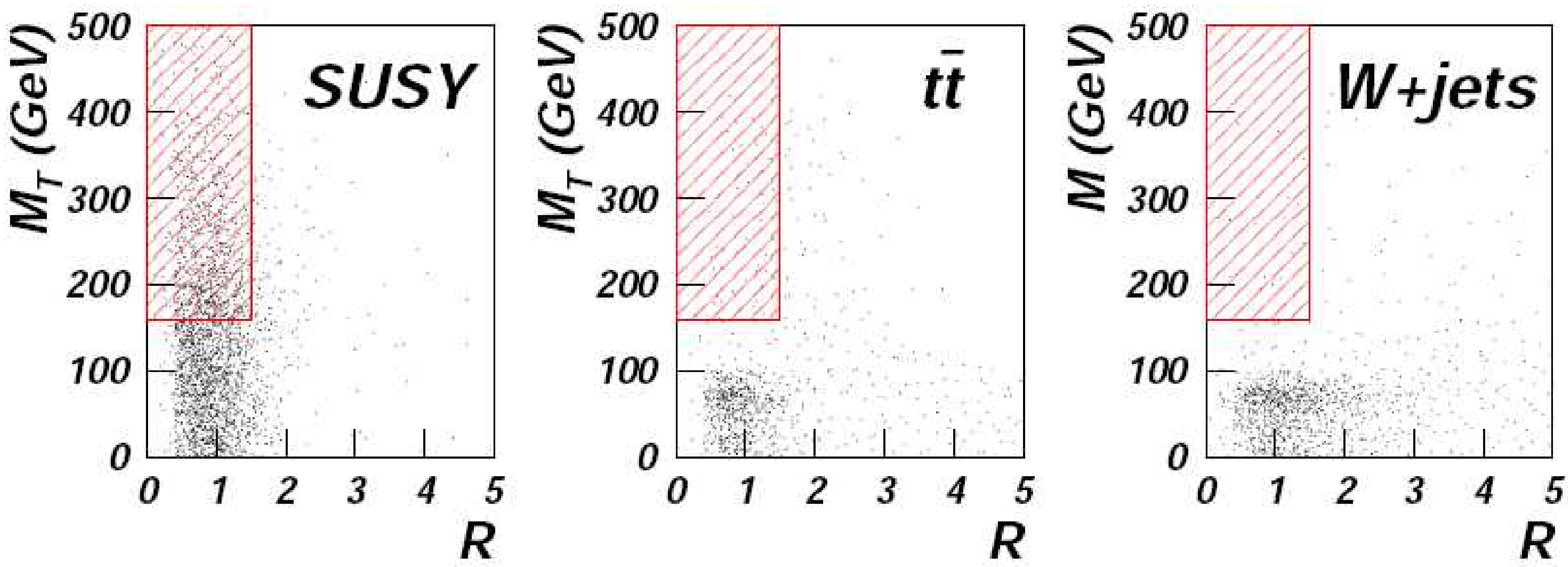
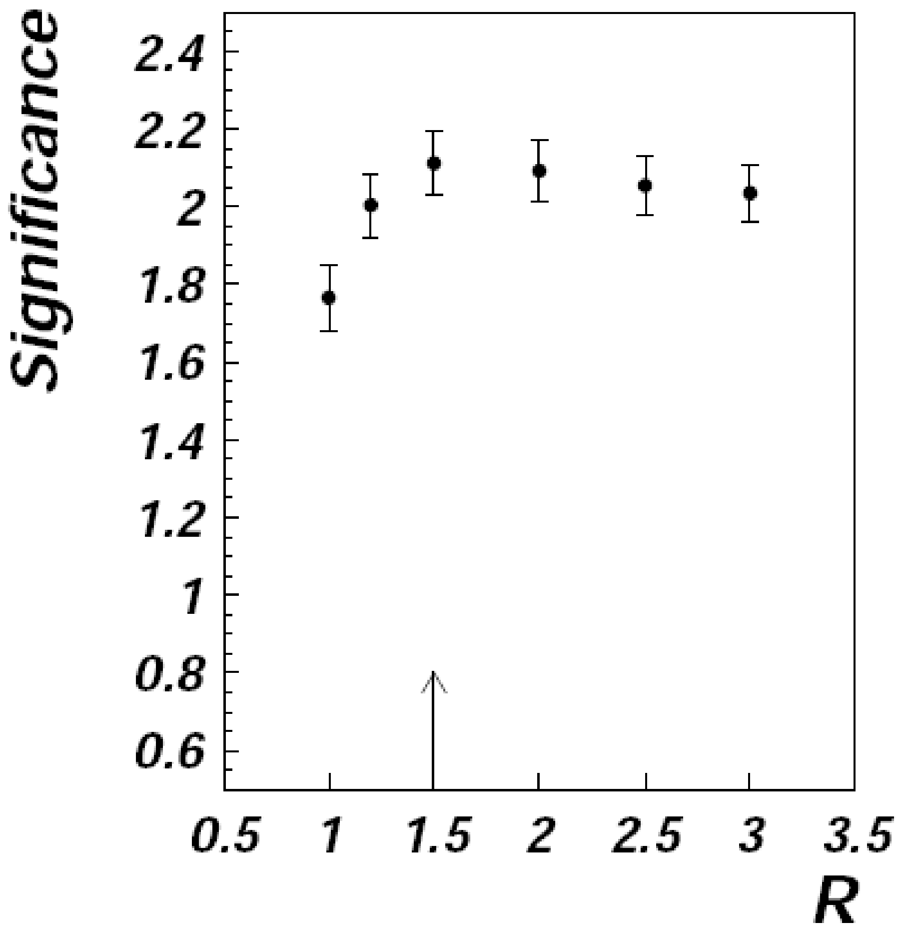
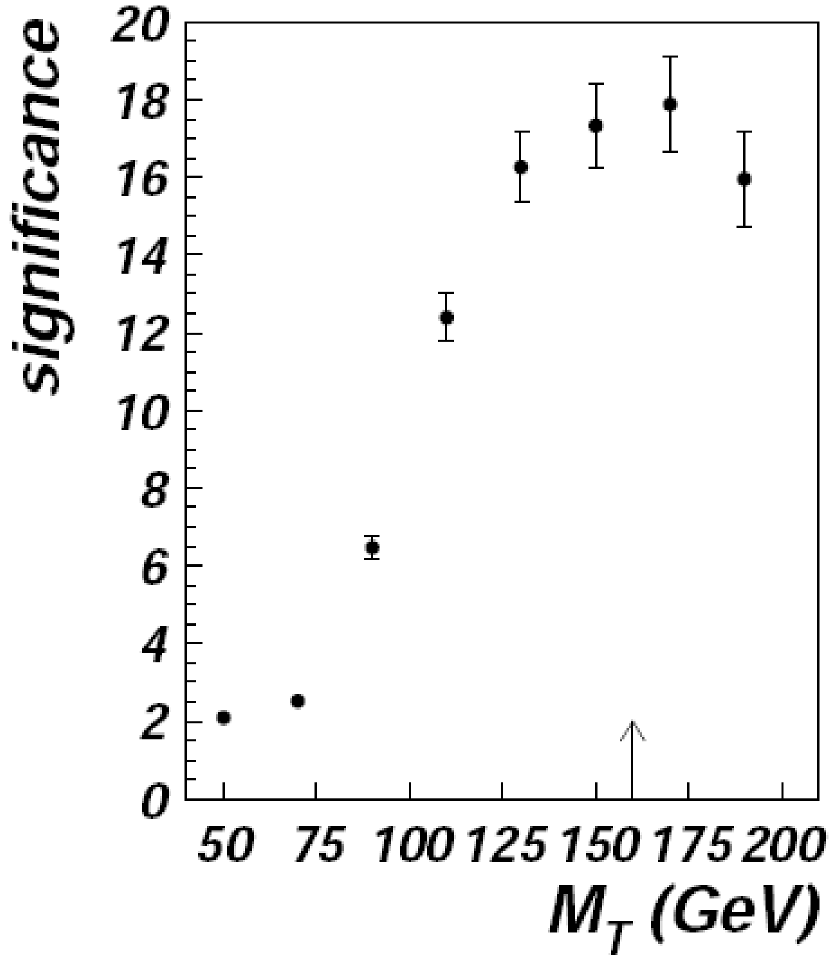


Significance optimization





For SUSY datapoint $[m_0, m_{1/2}]$=[3500,600] GeV produced in ISAJET v7.72, the statistical significance of the signal observation is shown as a function of the cut values for i) maximum R (with preselection cuts only), ii) maximum M_T (for preselection cuts only). The arrows represent the chosen cut values.

preliminary

Significance optimization

- $N_j \geq 4$
- $\not{E}_T \geq 200\ GeV$
- $p_T^{lep} \leq 200\ GeV$
- $M_T \geq 160\ GeV$
- $R_T < 1.5$

	All cuts	No cut on p_T^{lep}	No cut on M_T	No cut on R
[3500,600]	268	289	689	294
$t\bar{t}$	11	15	53905	16
W+jets	195	250	2.2×10^5	1100
$S/\sqrt{B}$	18.7	16.5	1.3	8.8

Point-dependent optimized sets of cuts

Cut Set	N_j	$\not{E}_T$	p_T^{lep}	M_T	R	W+jets	$t\bar{t}$
5	≥ 4	≥ 200 GeV	≤ 200 GeV	≥ 160 GeV	≤ 1.5	25	11
6	≥ 4	≥ 200 GeV	≤ 200 GeV	≥ 160 GeV	≤ 1.2	19	8
7	≥ 4	≥ 220 GeV	≤ 200 GeV	≥ 160 GeV	≤ 1.2	18	6
8	≥ 4	≥ 240 GeV	≤ 200 GeV	≥ 160 GeV	≤ 1.5	18	5
9	≥ 4	≥ 240 GeV	≤ 200 GeV	≥ 160 GeV	≤ 1.2	14	4
10	≥ 4	≥ 250 GeV	≤ 200 GeV	≥ 160 GeV	≤ 1.5	15	4
11	≥ 4	≥ 250 GeV	≤ 200 GeV	≥ 160 GeV	≤ 1.2	11	3

Signal and background efficiencies

preliminary

	Pre-cuts	$p_T^{lep} < 200$ GeV	$M_T \geq 160$	$R \leq 1.5$ GeV	All cuts
[3500,600] v7.72	2.65	97.01	39.21	91.14	0.92
[4000,700] v7.72	1.19	94.39	34.41	93.93	0.36
$t\bar{t}$	0.075	95.13	0.027	66.67	1.3x10^{-5}
W+jets	0.09	85.01	0.27	20.0	4.0x10^{-5}

Parameter Scan

preliminary

	m_0 (GeV)	$m_{1/2}$ (GeV)	σ (fb)	S (events)	$S/\sqrt{S+B}$
1	3500	600	292.3	268	12.3
2	3900	725	128.1	151	8.0
3	4000	700	398.2	130	7.7
4	4000	750	161.7	131	7.1
5	4060	730	297.9	101	6.4
6	4060	765	165.3	98	6.1
7	4065	720	468.3	95	6.6
8	4120	785	144.8	88	6.2
9	4130	730	456.2	96	6.2
10	4150	765	245.8	68	4.6
11	4150	800	117.0	98	6.1
12	4200	775	257.5	87	6.1
13	4200	810	118.1	97	6.1
14	4250	785	267.6	73	5.3
15	4250	825	123.4	83	5.5
16	4250	840	92.5	95	5.5
17	4325	820	158.5	67	5.0
18	4325	845	121.1	64	4.8
19	4325	870	77.0	81	5.3
20	4400	825	229.4	60	4.2
21	4400	860	134.3	59	4.1
22	4400	890	68.7	76	5.0
23	4450	875	110.9	56	3.9
24	4450	900	78.4	55	4.2

	m_0 (GeV)	$m_{1/2}$ (GeV)	σ (fb)	S (events)	$S/\sqrt{S+B}$
25	4500	860	229.0	52	3.7
26	4500	900	100.9	47	3.7
27	4500	925	68.0	61	4.1
28	4550	880	195.0	46	3.6
29	4550	925	75.4	52	4.0
30	4610	900	186.2	44	3.4
31	4610	950	65.8	46	3.6
32	4670	880	665.0	53	4.0
33	4670	930	126.1	37	3.0
34	4670	975	45.4	50	3.9
35	4750	935	211.7	34	2.5
36	4750	970	89.4	36	2.9
37	4750	1000	51.6	39	3.2
38	4830	1020	55.5	31	2.5
39	4850	935	532.7	31	2.6
40	4850	970	176.1	28	2.3
41	4850	1000	90.6	27	2.2
42	4850	1050	40.2	34	2.7
43	4950	1000	157.9	25	2.1
44	4950	1050	61.0	22	2.1
45	4975	1030	109.4	20	1.9
46	5000	1030	96.3	22	2.1
47	5000	1050	71.6	22	2.1
48	5000	1080	36.0	31	2.8

Relative contributions of SUSY subprocesses (before/after cuts)

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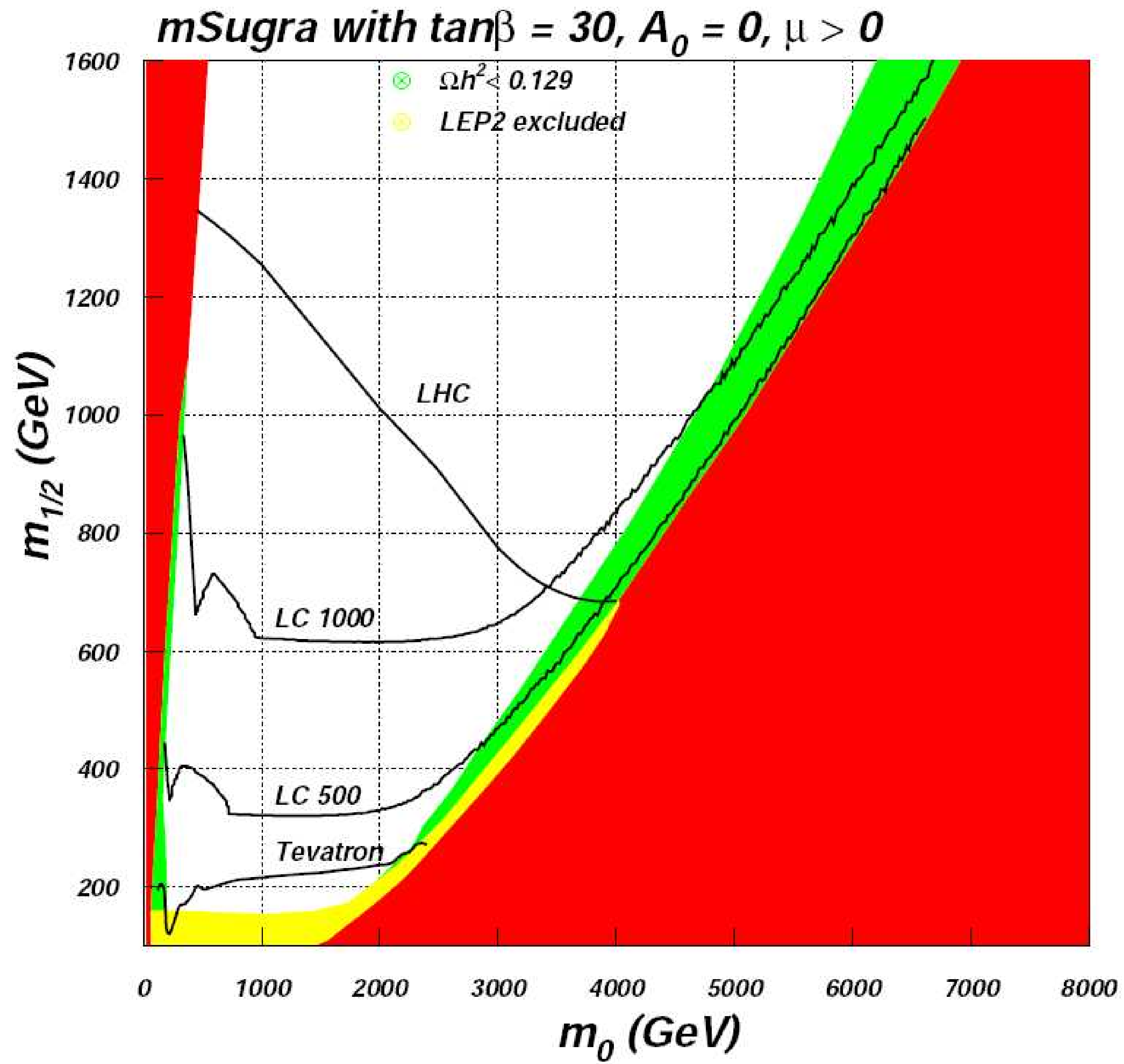
$\tilde{Z}_4 + \tilde{W}_2$	10.34	6.98
$\tilde{Z}_4 + \tilde{W}_1$	0.46	0.26
$\tilde{Z}_1 + \tilde{Z}_1$	0.02	0.02
$\tilde{Z}_1 + \tilde{Z}_2$	<0.02	4.46
$\tilde{Z}_1 + \tilde{Z}_3$	3.72	<0.02
$\tilde{Z}_2 + \tilde{Z}_3$	8.72	10.20
$\tilde{Z}_2 + \tilde{Z}_4$	<0.02	0.04
$\tilde{Z}_3 + \tilde{Z}_4$	0.34	0.02
$\tilde{g} + \tilde{g}$	2.12	0.06

Relative contributions of SUSY subprocesses (before/after cuts)

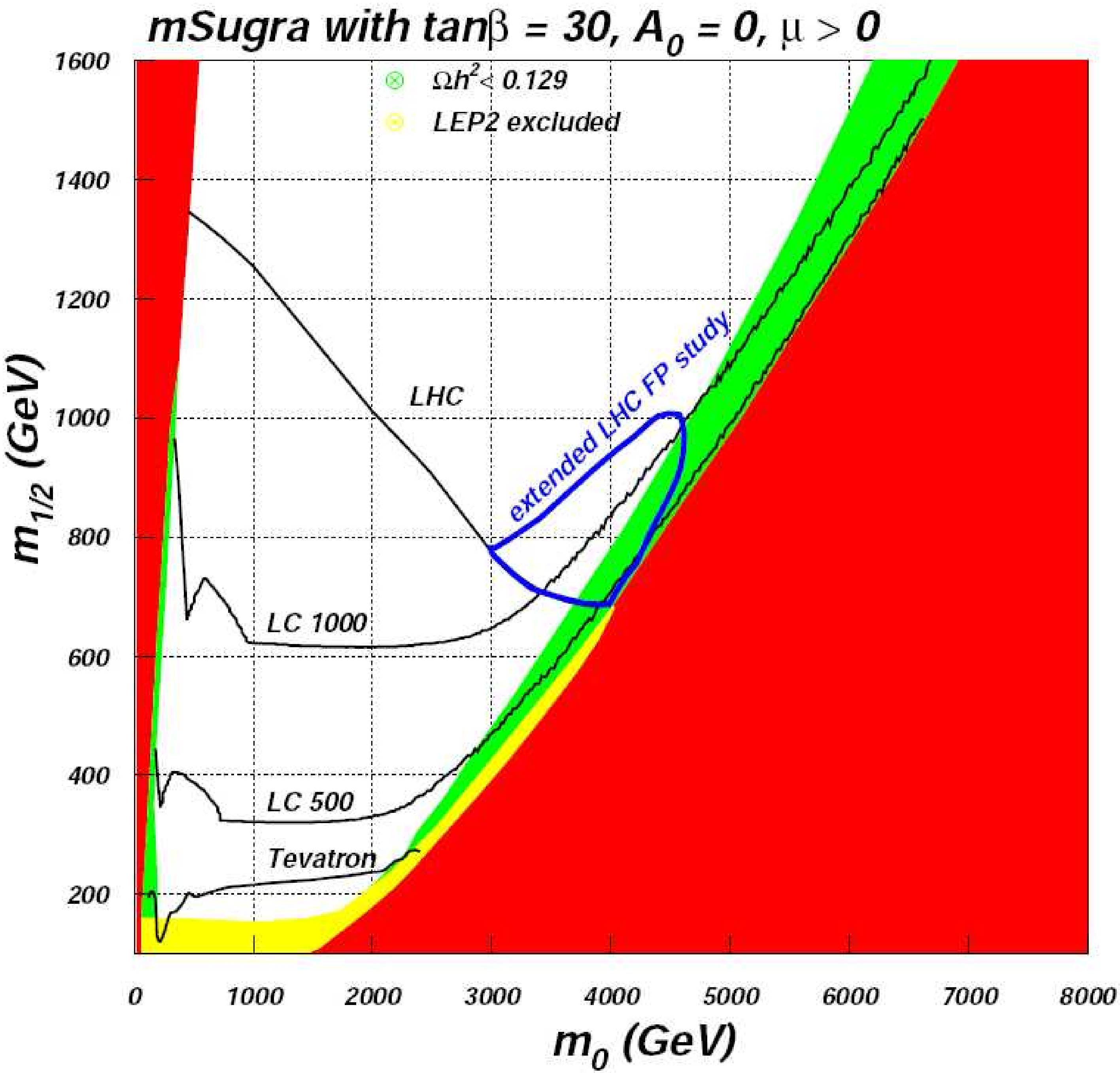
Selected sparticles	[3500,600] GeV Fraction of SUSY events(%)	[4670,975] GeV Fraction of SUSY events(%)
$\tilde{W}_1 + \tilde{W}_1$	8.25	12.60
$\tilde{W}_2 + \tilde{W}_2$	13.59	19.60
$\tilde{W}_1 + \tilde{W}_2$	< 0.49	0.35
$\tilde{Z}_1 + \tilde{W}_1$	2.43	4.90
$\tilde{Z}_1 + \tilde{W}_2$	< 0.49	< 0.35
$\tilde{Z}_2 + \tilde{W}_1$	6.31	14.00
$\tilde{Z}_2 + \tilde{W}_2$	< 0.49	0.30
$\tilde{Z}_3 + \tilde{W}_1$	7.77	12.90
$\tilde{Z}_3 + \tilde{W}_2$	0.97	0.35
$\tilde{Z}_4 + \tilde{W}_2$	26.21	31.50
$\tilde{Z}_4 + \tilde{W}_1$	1.94	0.70
$\tilde{Z}_1 + \tilde{Z}_1$	< 0.49	< 0.35
$\tilde{Z}_1 + \tilde{Z}_2$	< 0.49	< 0.35
$\tilde{Z}_1 + \tilde{Z}_3$	0.49	< 0.35
$\tilde{Z}_2 + \tilde{Z}_3$	0.49	0.70
$\tilde{Z}_2 + \tilde{Z}_4$	< 0.49	0.35
$\tilde{Z}_3 + \tilde{Z}_3$	< 0.49	< 0.35
$\tilde{g} + \tilde{g}$	29.61	1.40

Extended LHC reach



Extended LHC reach

preliminary

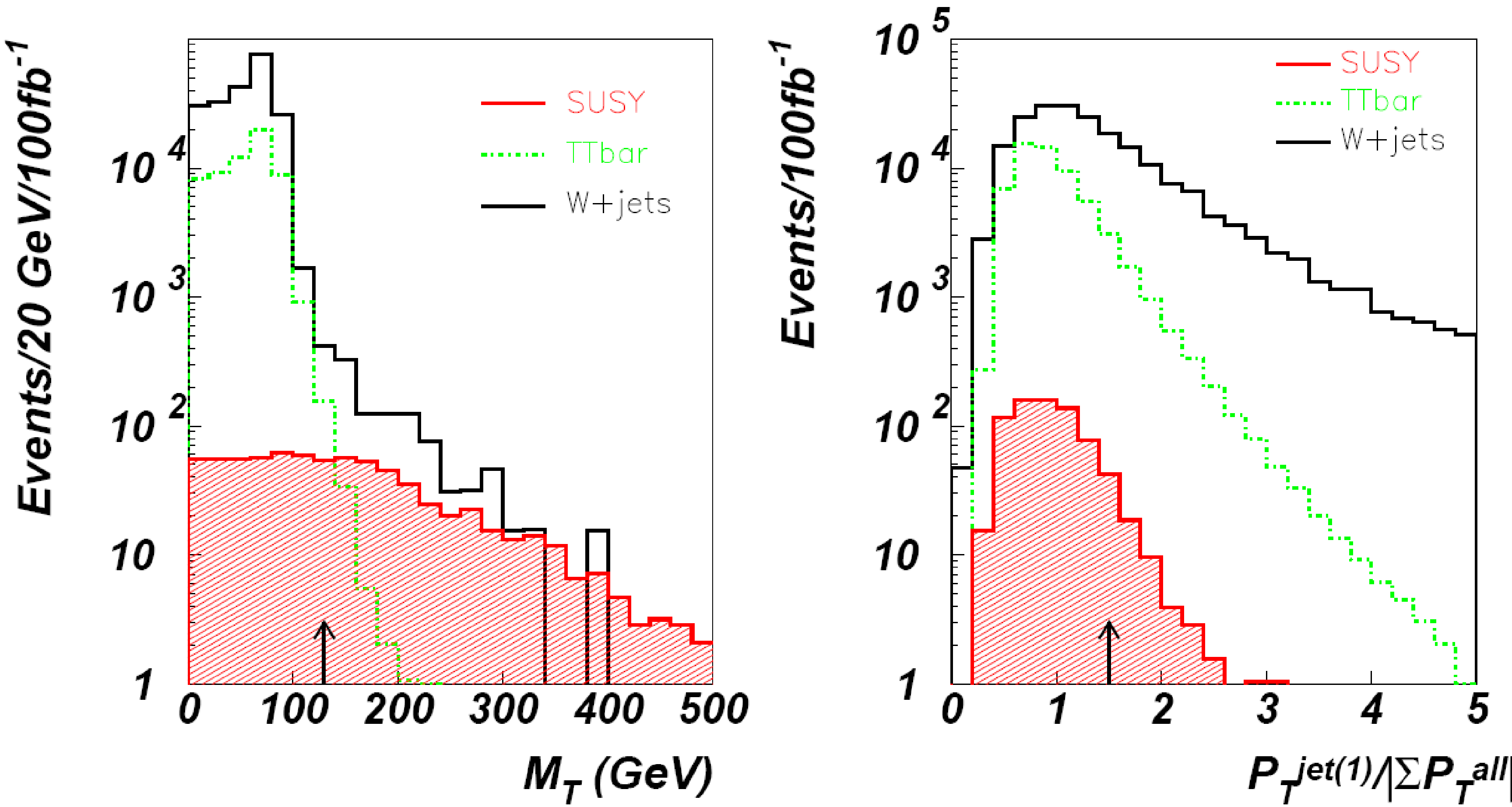


Conclusions

- *Focus Point region can be explored up to about 2.4 TeV in terms of gluino mass with new analysis!*
- *In this region signal is dominated by EW chargino-neutralino production (with the mass of ~400-500 GeV)*
- *Transverse electron-missing E_T mass cut is crucial for Wjj background suppression and extending LHC FP reach*
- *PYTHIA Wjj process considerably underestimates the Wjj background – Madgraph, Alpgen packages should be used*
- *Advanced techniques can be used (NN, decision trees, ...) to extend further LHC reach in the FP region – could be crucial for the fate of the ILC – work in progress*

Appendix

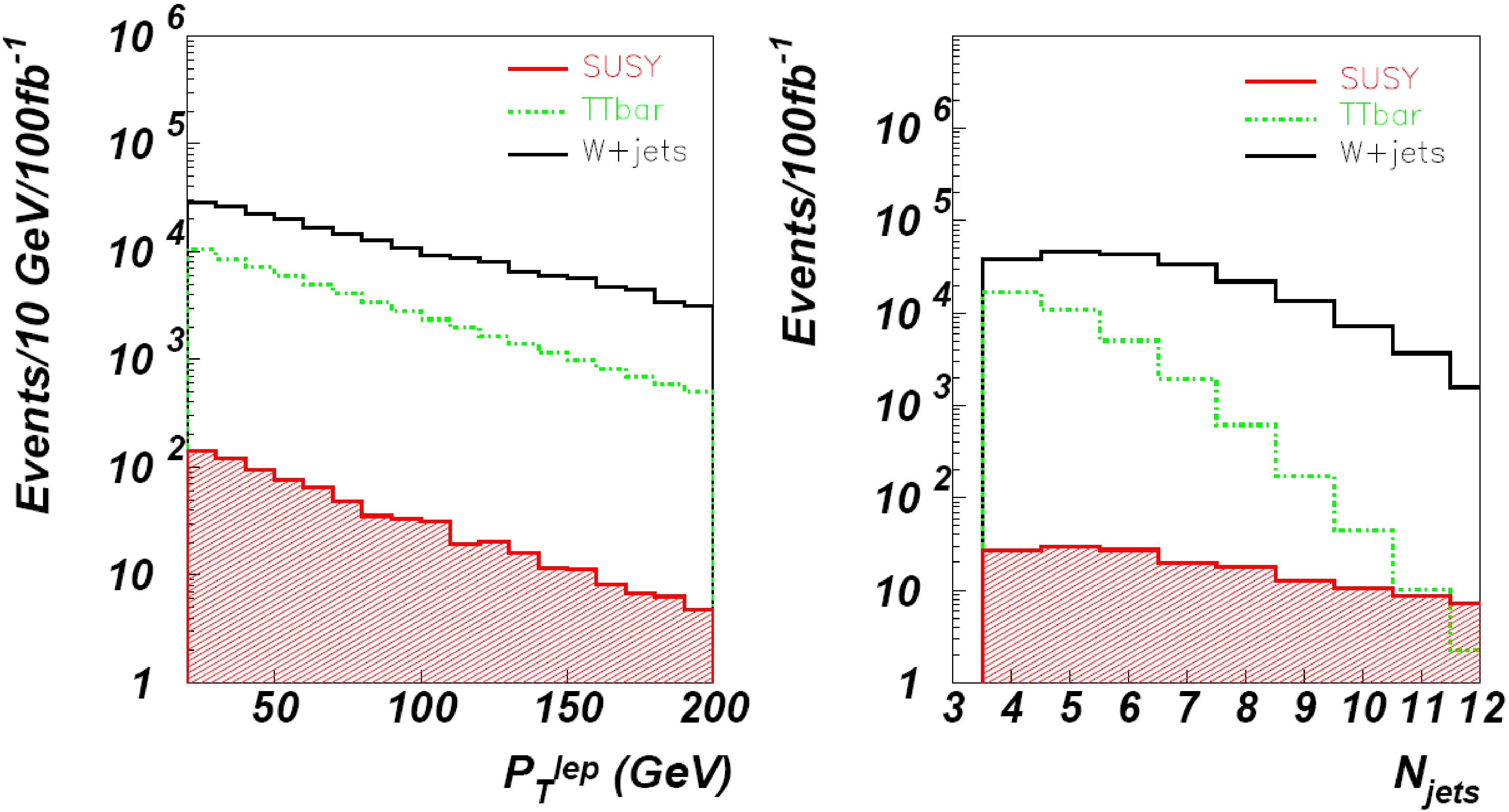
Analysis of kinematical variables and correlations



$$M_T = \sqrt{2p_T(l)\,\not{E}_T(1 - cos\phi(\not{E}_T, p_T(l))}$$

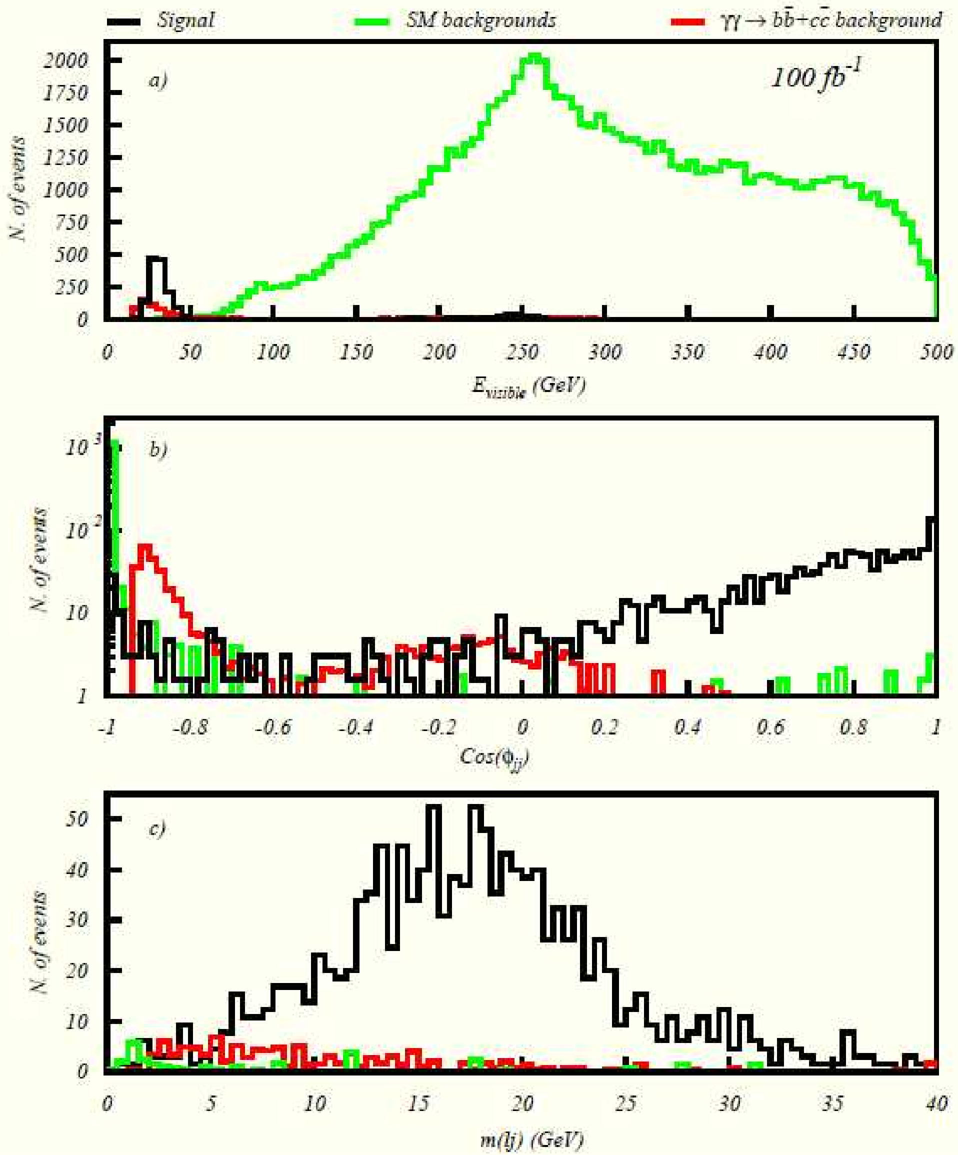
$$R = p_T(jet(1))/\left|\sum_i \vec{p}_{T,i}\right|$$

Analysis of kinematical variables and correlations



ILC FP/HB study

Baer, Belyaev, Krupovnickas, Tata



$(m_0, m_{1/2}, A_0, \tan\beta, sign(\mu))$
(4625 GeV,885 GeV,0,30,1)

parameter	value (GeV)
M_2	705.8
M_1	372.2
μ	185.9
$m_{\tilde{g}}$	2182.7
$m_{\tilde{u}_L}$	4893.9
$m_{\tilde{e}_L}$	4656.1
$m_{\widetilde{W}_1}$	195.8
$m_{\widetilde{W}_2}$	743.5
$m_{\tilde{Z}_1}$	181.6
$m_{\tilde{Z}_2}$	196.2
$m_{\tilde{Z}_3}$	377.3
$m_{\tilde{Z}_4}$	760.0
m_A	3998.3
m_h	122.0
$\Omega_{\tilde{Z}_1} h^2$	0.0104
$BF(b \to s\gamma)$	3.34×10^{-4}
Δa_μ	0.6×10^{-10}

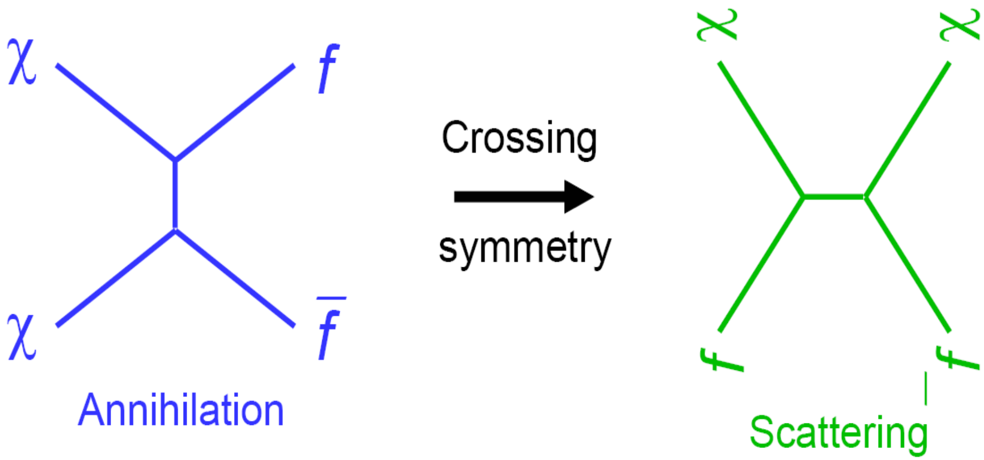
cuts	case 1	ISAJET BG	$\gamma\gamma \to c\bar{c}, b\bar{b}$	$\ell\nu q\bar{q}'$
$\eta,\ E,\ \Delta R$	16.2	897.1 (483)	9.2 (6.2)	448 (712)
$20 < E_{vis} < 100$	14.4	12.6 (3.5)	5.4 (4.9)	0.16 (0.08)
$\cos\phi(jj) > -0.6$	13.5	0.34 (0.2)	1.1 (1.1)	0.04 (0.02)
$m(\ell j) > 5$ GeV	12.9	0.17 (0.1)	0.8 (0.8)	0.04 (0.02)

A.Belyaev "Extending LHC reach in the Focus Point region", SUSY 2007

Complementarity of Direct and Indirect DM search

- ***DM direct detection:***

neutralino scattering off nuclei

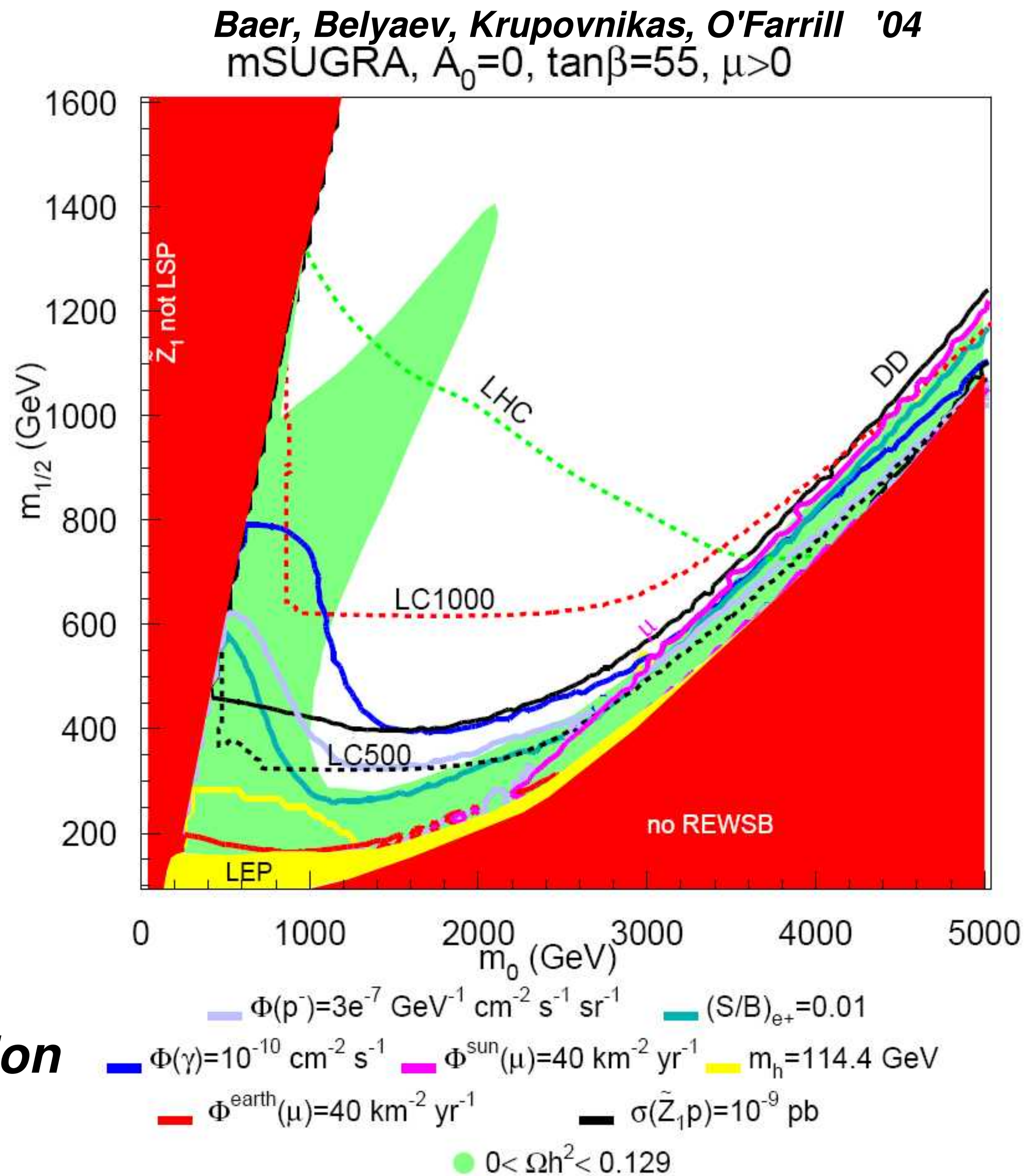


Isared code ***Isares code***

Stage 1: CDMS1, Edelweiss, Zeplin1

Stage 2: CDMS2, CRESST2, Zeplin2

Stage 3: SuperCDMS, Zeplin4, WARP



- ***DM indirect detection:***

signatures from neutralino annihilation

in halo, core of the Earth and Sun

photons, anti-protons, positrons, neutrinos

Neutrino telescopes: Amanda, Icecube, Antares

FP/HB Region

HB/FP region for $m_{1/2} = 225$ GeV, $\tan\beta = 30$, $A_0 = 0$, $\mu > 0$: $\sqrt{s} = 500$ GeV