Constraining SUSY models beyond “vanilla” supersymmetry at the LHC

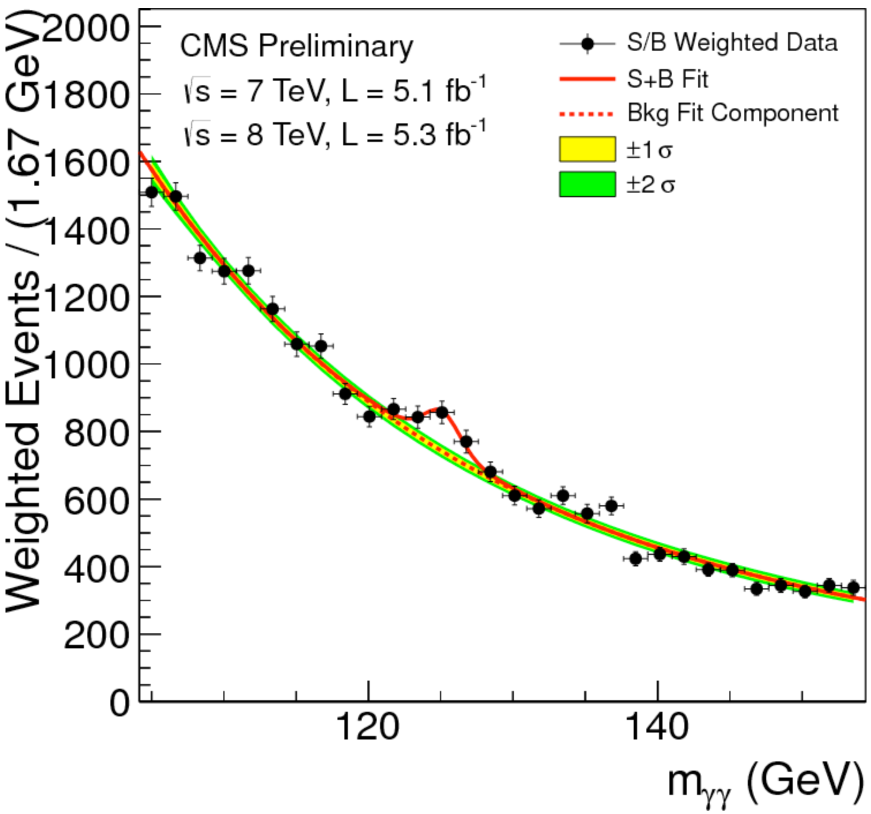
Kazuki Sakurai

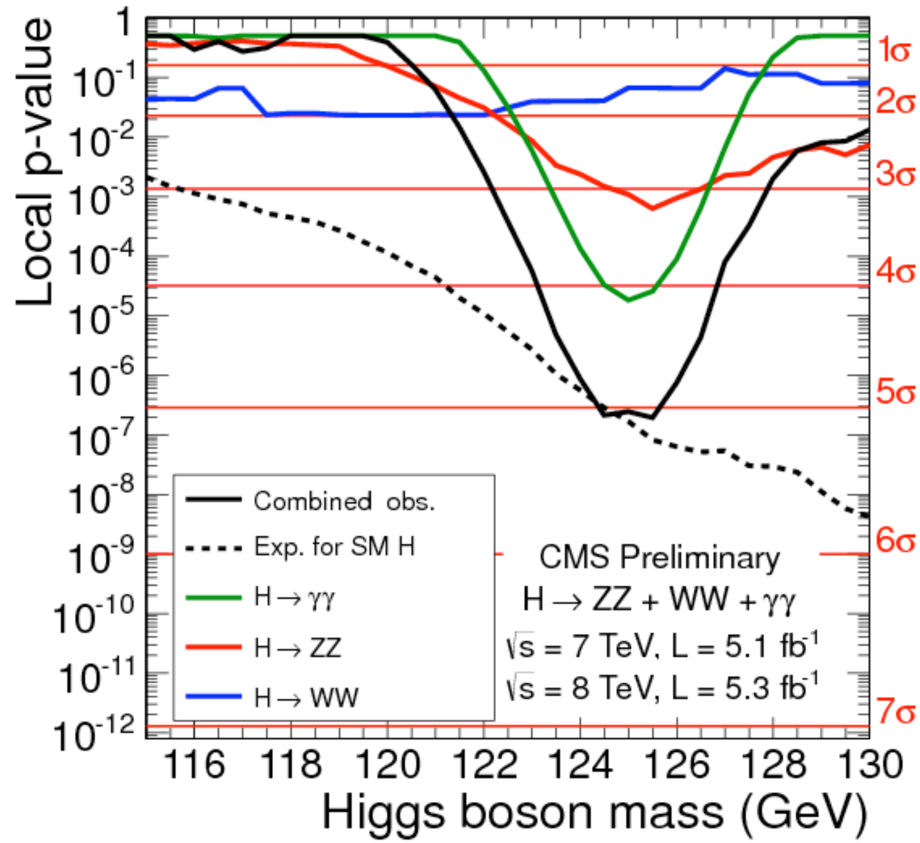
In collaboration with
Masaki Asano (Hamburg Univ.), Krzysztof Rolbiecki (DESY)

Based on
arXiv:1206.6767, arXiv:1209.5778

Lessons from the first phase of the LHC
27/9/2012, DESY, Hamburg

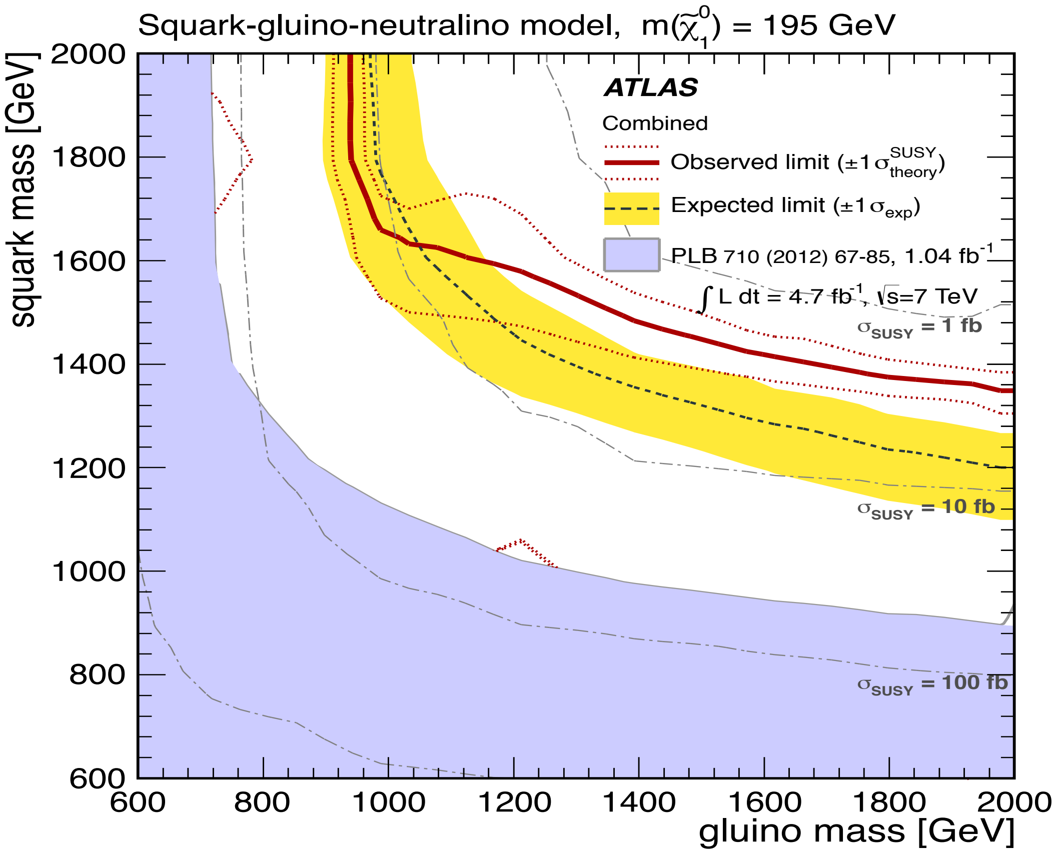
The “Higgs” discovery

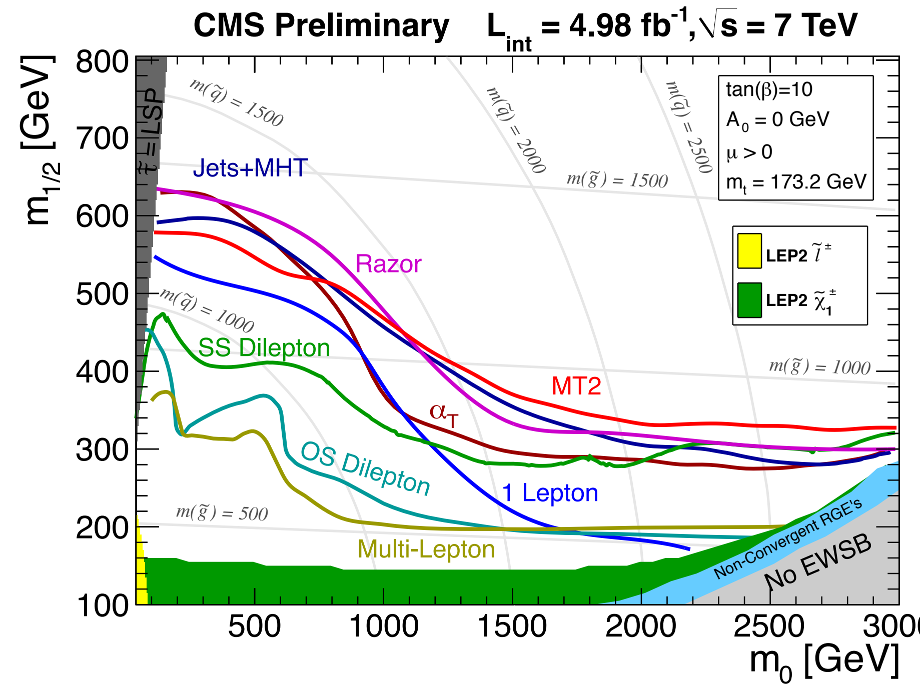




The discovery of a Higgs-like particle at 126GeV is a big scientific achievement of the LHC.

SUSY searches and constraints





- Squark/gluino mass below 1~1.4 TeV is excluded in the simplified model

- The constraints applies to "vanilla" type supersymmetry, which involves R-parity conservation, a gaugino GUT relation, flavour universality for squarks

"Vanilla" supersymmetry below 1 - 1.4 TeV is ruled out !!

What's next ?

- Continuing the similar searches and pushing up the squark/gluino mass bound?

What’s next ?

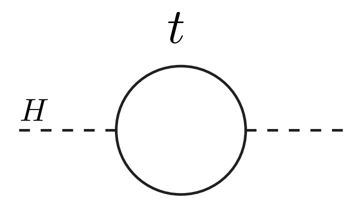
• Continuing the similar searches and pushing up the squark/gluino mass bound?

• Searching for SUSY particles below 1 TeV in a general MSSM framework, going beyond the “vanilla” SUSY assumption (R-parity, a gaugino GUT relation, flovour universality for squarks)

naturalness of EWSB

Standard Model:

$$m_H^2 = m_{H0}^2(\Lambda) + \Delta m_H^2$$



cancel

$$m_H^2 \simeq (126\,\mathrm{GeV})^2$$

$$\Delta m_H^2 \simeq -\frac{Y_t^2}{8\pi^2}\Lambda^2 \sim (10^{17}\,\mathrm{GeV})^2$$

Supersymmetry:

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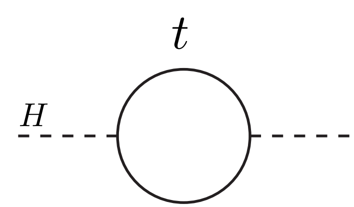

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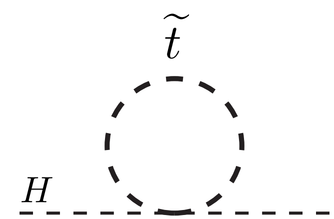

$$m_{H0}^2(\Lambda) \simeq \mu^2 + (m_H^{\cancel{\text{SUSY}}})^2$$

$$\Delta m_H^2 \simeq \frac{Y_t^2}{8\pi^2} m_{\tilde{t}}^2 \ln\left(\frac{\Lambda_{\text{medi}}}{m_{\tilde{t}}}\right)$$

$$\Delta m_{\tilde{t}}^2 \sim \frac{\alpha_s}{4\pi} m_{\tilde{g}}^2 \ln\left(\frac{\Lambda_{\text{medi}}}{m_{\tilde{t}}}\right)$$

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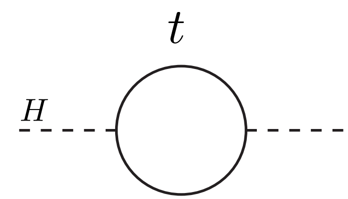

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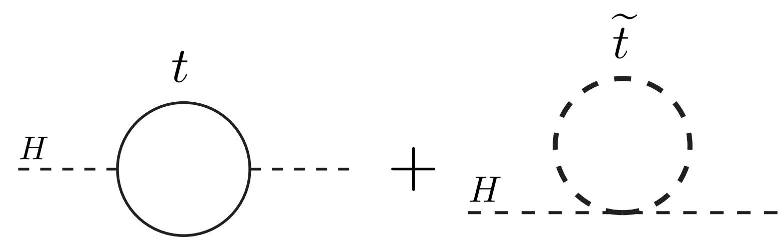

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higgsino, stops, gluino masses should be below 1 TeV

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• Searching for SUSY particles below 1 TeV in a general MSSM framework, going beyond the "vanilla" SUSY assumption (R-parity, a gaugino GUT relation, flovour universality for squarks)

• If we discover such particles,

we can measure the properties of those particles and obtain the information of the underlying theory.

• If we exclude such particles,

this would be an indication that naturalness is not a good guide for supersymmetric model building. The argument of the natural EWSB should be reconsidered.

Where can SUSY be hidden?

$$\sigma_{\rm vis}^{\rm bound} > \sigma_{\rm vis}^{\rm SUSY} = \sigma_{\rm SUSY} \cdot \epsilon_{\rm SUSY}$$

experimental upper bound — cross section — efficiency

❖ two ways to hide supersymmetry

✦ small cross section ($\sigma_{\rm SUSY} \ll 1$)

✦ small efficiency ($\epsilon_{\rm SUSY} \ll 1$)

- **split generation SUSY**
- **compressed SUSY**
- **R-parity violation**

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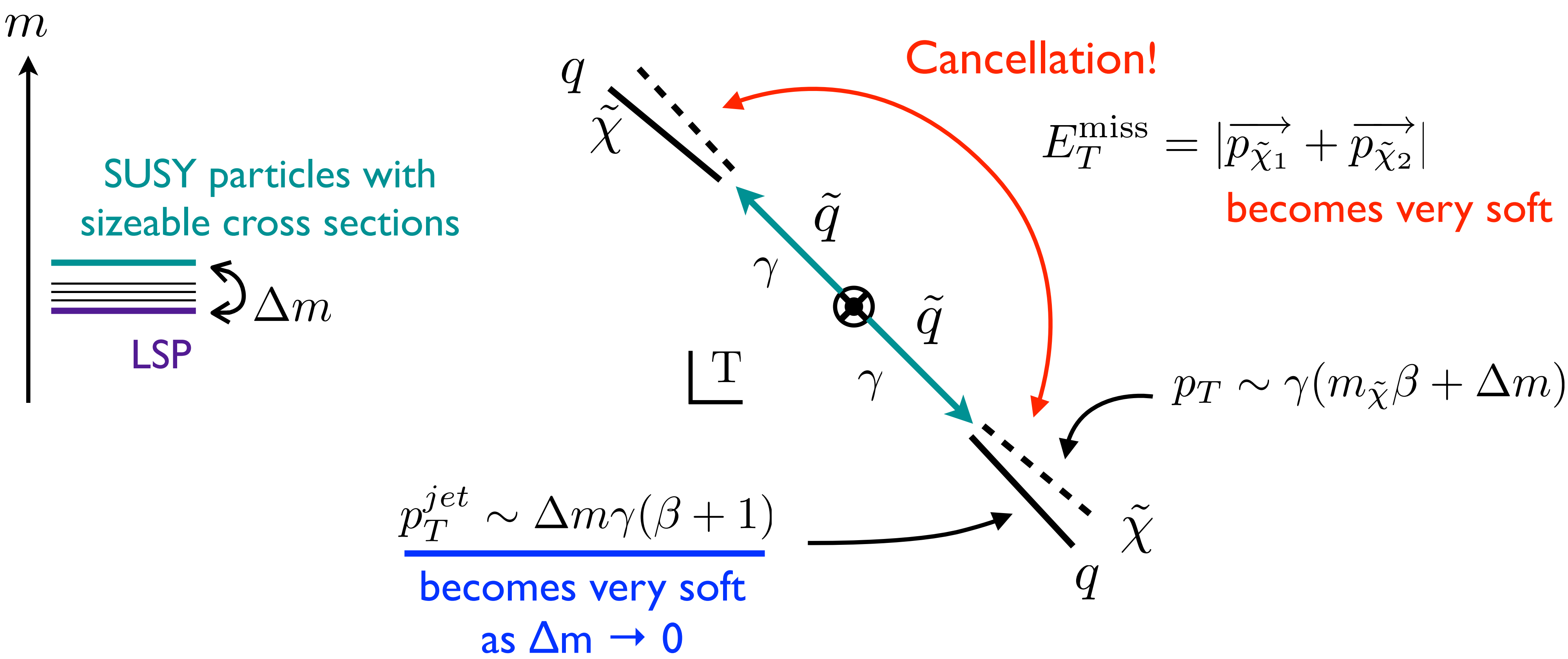
Compressed SUSY

Compressed SUSY

- If produced SUSY particles are mass degenerate with the LSP, pT of visible particles and ETmiss will become very soft as decreasing the mass splitting, which results in very small efficiency for the high pT cut.

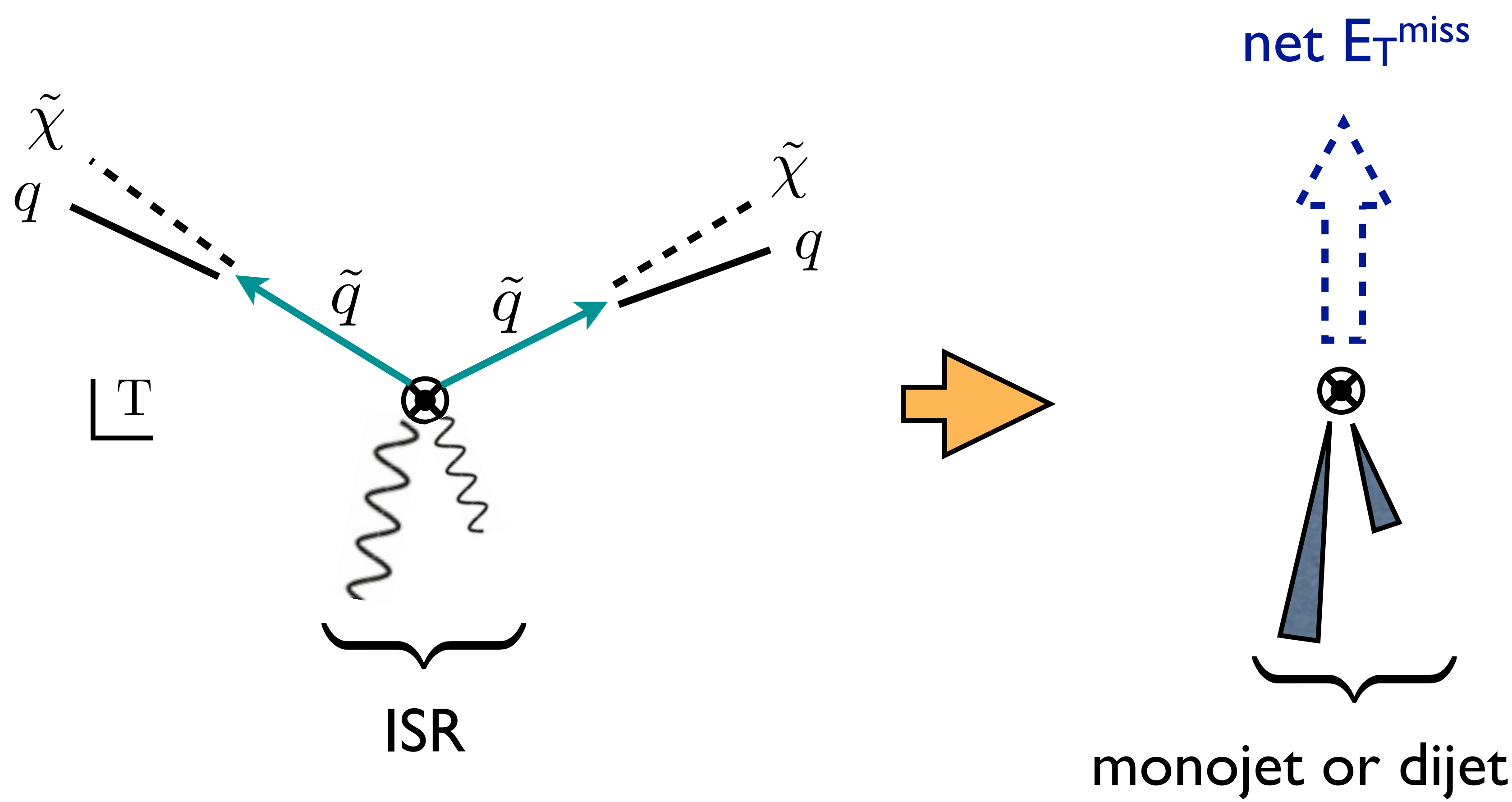


$$\epsilon_{\mathrm{SUSY}} \ll 1$$

- A concrete model: H.Murayama, Y.Nomura, S.Shirai, K.Tobioka (1206.4993)

Initial State Radiation

- Initial state radiation can kick the two squark system. The two neutralinos are no longer back-to-back and momentum cancellation in the ETmiss can be avoided.



Monojet and dijet constraint

$$p_{j1}^T > 110\,\mathrm{GeV} \qquad p_{j3}^T < 30\,\mathrm{GeV}$$

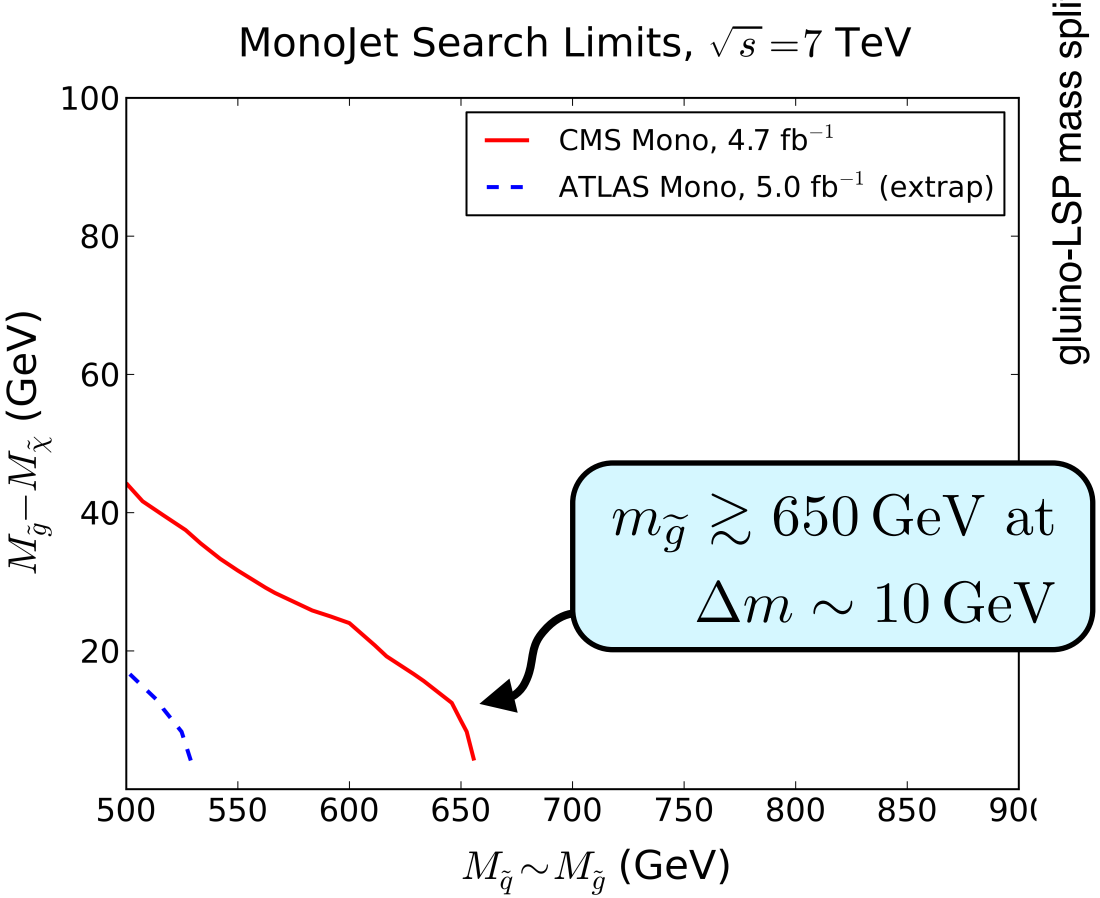
$$E_T^{\mathrm{miss}} > 200\,\mathrm{GeV} \qquad \Delta\phi(j_1, j_2) < 2.5$$

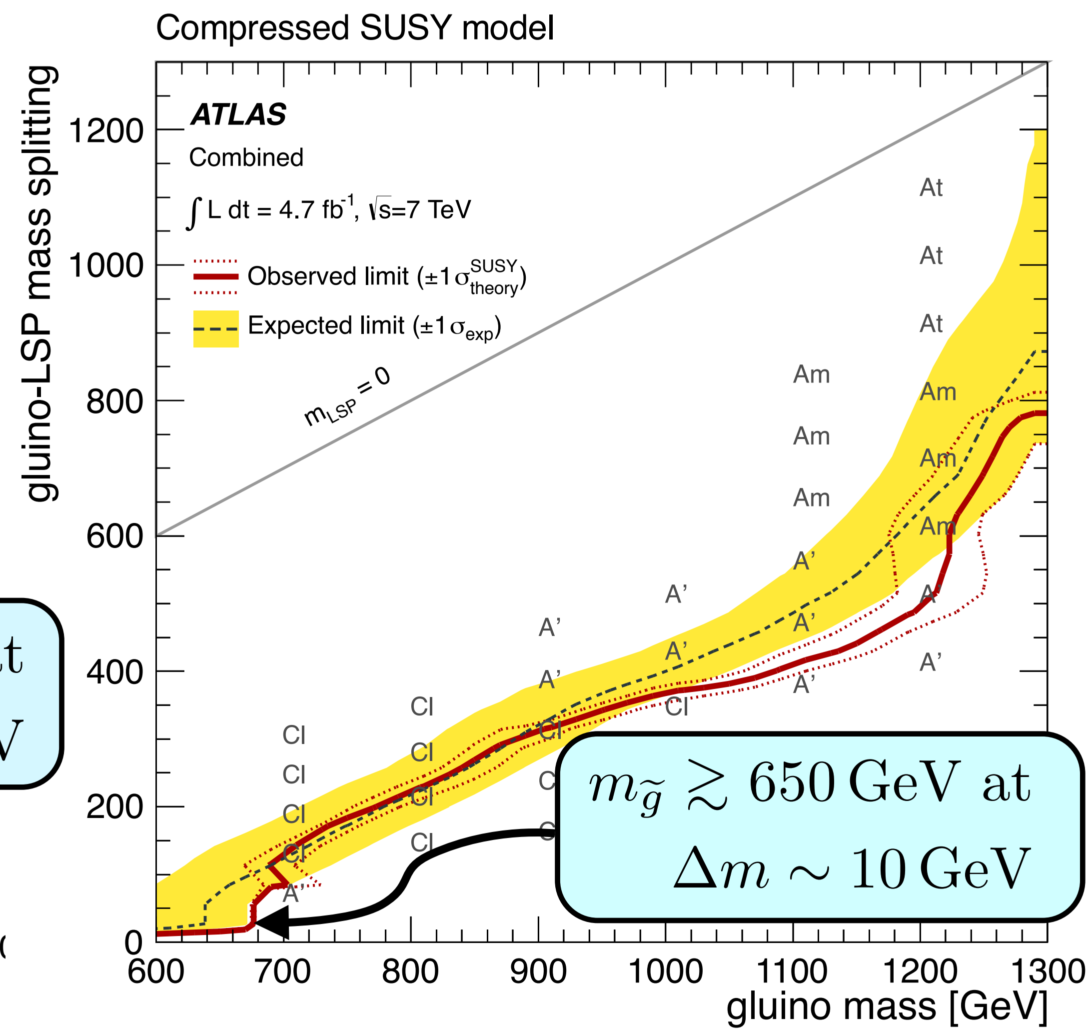
$$E_T^{\mathrm{miss}} > 160\,\mathrm{GeV} \qquad E_T^{\mathrm{miss}}/m_{\mathrm{eff}}(2j) > 0.4$$

$$p_{j1}^T > 130\,\mathrm{GeV} \qquad p_{j2}^T > 60\,\mathrm{GeV}$$

$$m_{\mathrm{eff}}(\mathrm{incl.}) > 1200\,\mathrm{GeV}$$

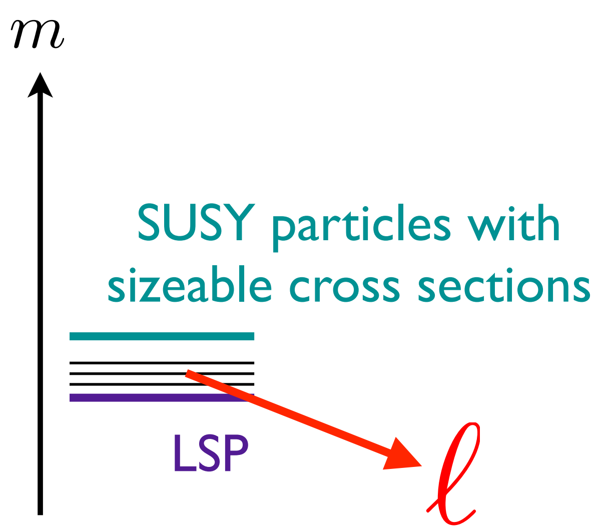
Dreiner, Kramer, Tattersall (1207.1613)





Using leptonic signature

K. Rolbiecki, KS
arXiv:1206.6767



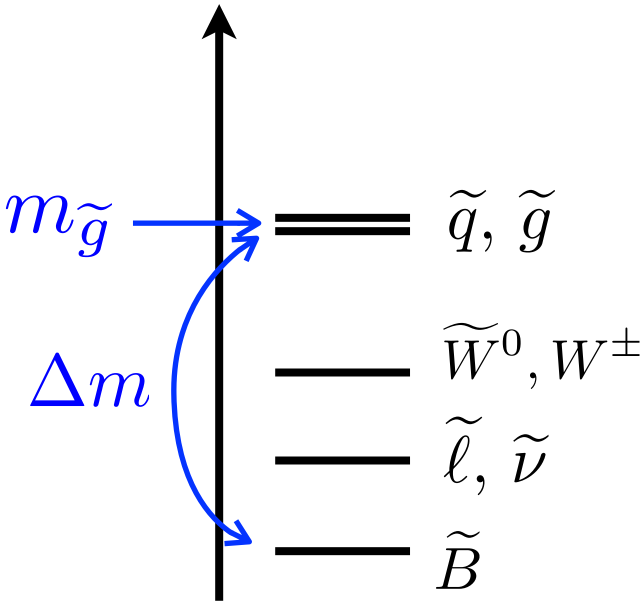
- The leptonic signature is rare in the Standard Model. By requiring isolated leptons, QCD background is drastically suppressed, without demanding a hard E_T^{miss} cut.

- If compressed SUSY models produce leptons in the final state, we can constrain such models using leptonic signature.

ATLAS multi−lepton searches: arXiv:1110.6189, arXiv:1204.5638, ATLAS-CONF-2012-001

signal region	2OS	2SS	3LEP	4LEP
N(lep)	= 2 (OS)	= 2 (SS)	= 3	>= 4
leading μ (e) p_T (GeV)	> 20 (25)	> 20 (25)	> 20 (25)	> 20 (25)
E_T^{miss} (GeV)	> 250	> 100	> 50	> 50
dilpton mass (GeV)	> 12	> 12	> 20	> 20
luminosity (fb^{-1})	1.04	1.04	2.06	2.06

Simplified model



- The model considers only gluino, 1st-2nd squarks, wino, sleptons, bino at the low energy spectrum
- $m_{\widetilde{q}} \simeq m_{\widetilde{g}}$
- $m_{\widetilde{W}} = \dfrac{m_{\widetilde{g}} + m_{\widetilde{\chi}_1^0}}{2}, \; m_{\widetilde{\ell}} = \dfrac{m_{\widetilde{W}} + m_{\widetilde{\chi}_1^0}}{2}$

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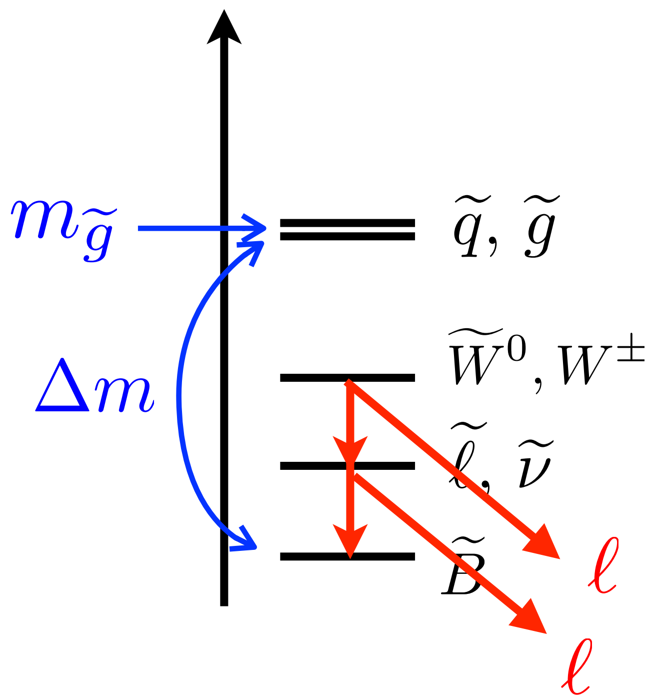

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- $m_{\tilde{q}} \simeq m_{\tilde{g}}$

- $m_{\widetilde{W}} = \dfrac{m_{\tilde{g}} + m_{\tilde{\chi}_1^0}}{2}, \quad m_{\tilde{\ell}} = \dfrac{m_{\widetilde{W}} + m_{\tilde{\chi}_1^0}}{2}$

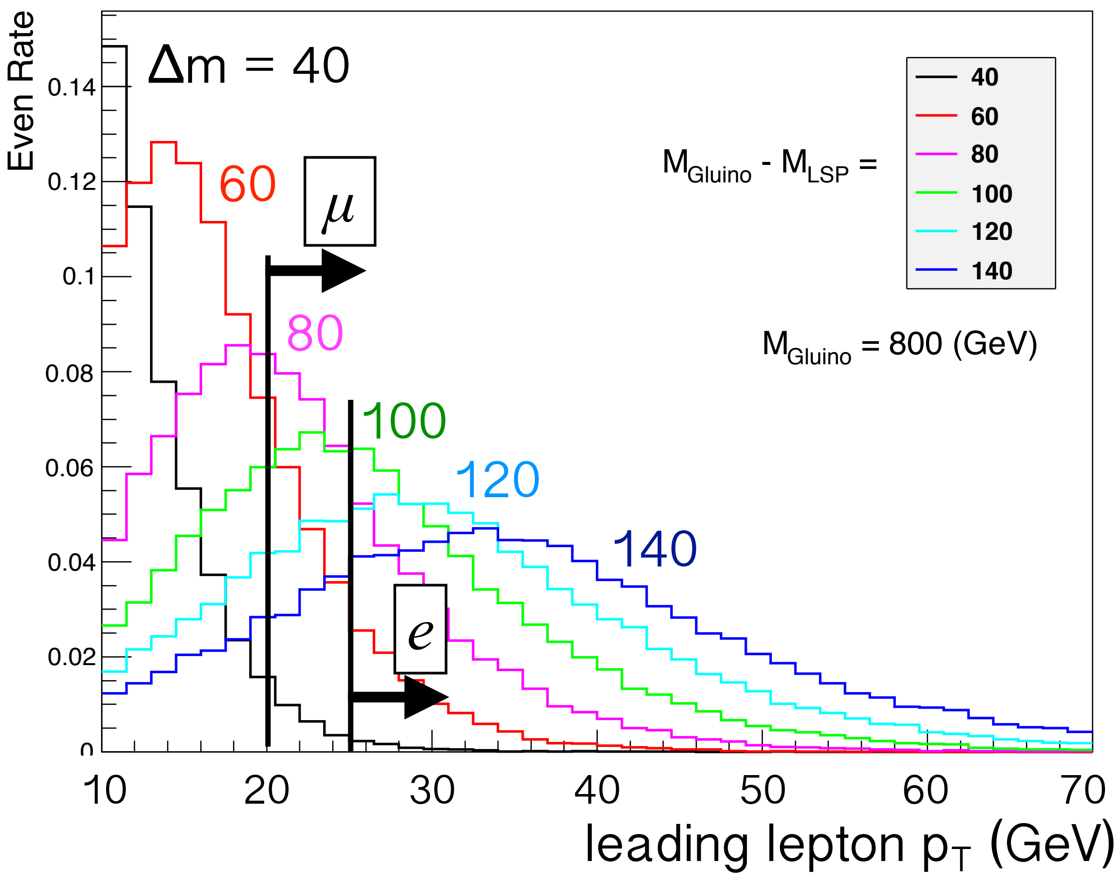
$\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{\ell}^\pm \ell^\mp q \to \ell^\pm \ell^\mp q \tilde{\chi}_1^0$	$BR = 33\%$
$\tilde{q}_L \to \tilde{\chi}_1^\pm q \to \tilde{\ell}^\pm \nu_\ell q (\tilde{\nu}_\ell \ell^\pm q) \to \ell^\pm \nu_\ell q \tilde{\chi}_1^0$	$BR = 67\%$
$\tilde{g} \to \tilde{\chi}_2^0 qq \to \tilde{\ell}^\pm \ell^\mp qq \to \ell^\pm \ell^\mp qq \tilde{\chi}_1^0$	$BR \simeq 16\%$
$\tilde{g} \to \tilde{\chi}_1^\pm qq \to \tilde{\ell}^\pm \nu_\ell qq (\tilde{\nu}_\ell \ell^\pm qq) \to \ell^\pm \nu_\ell qq \tilde{\chi}_1^0$	$BR \simeq 33\%$

- Event generation: **Herwig++**, Detector simulation: **Delphes**

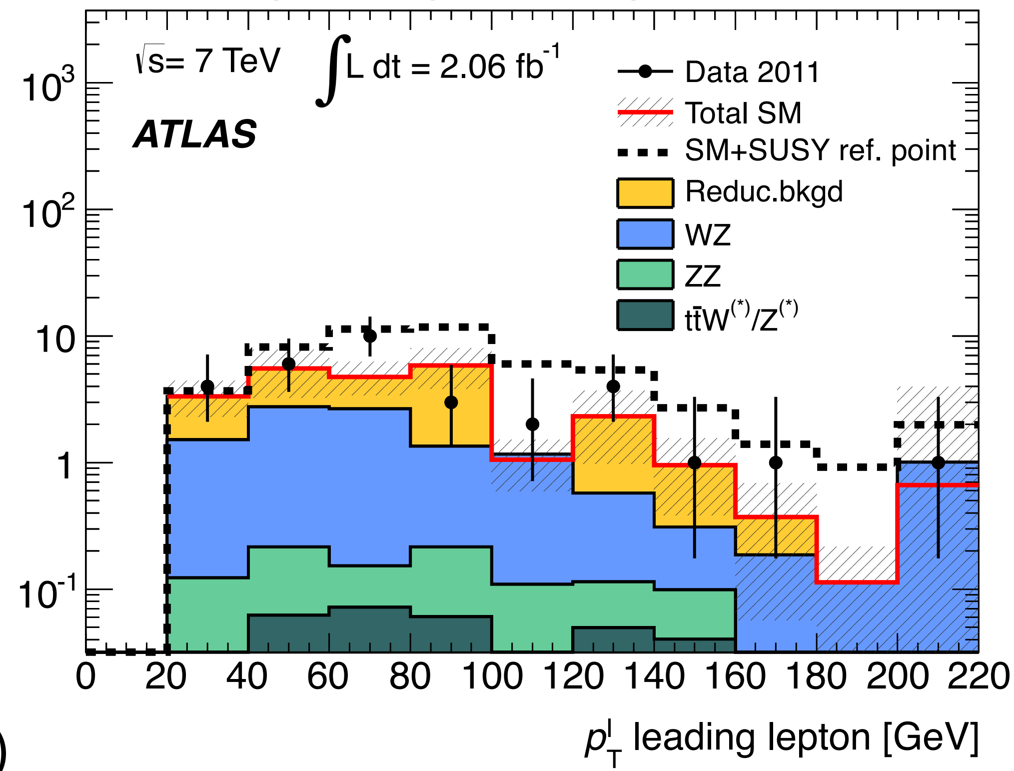
leading lepton p_T

- The p_T^{lep} distributions peak around Δm/4, and fall off towards the higher region.

signal



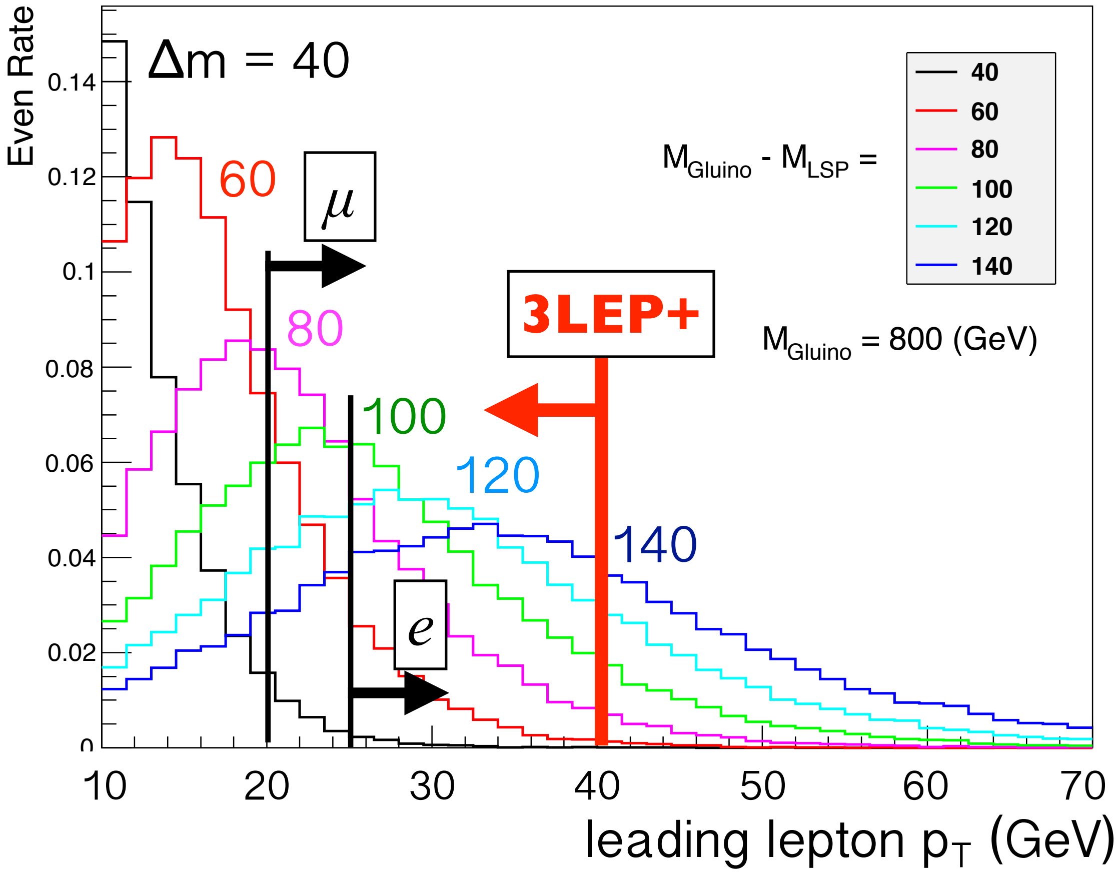
3LEP (background)



leading lepton p_T

- The p_T^{lep} distributions peak around Δm/4, and fall off towards the higher region.
- If a low pT cut of 40GeV is added in 3LEP, 90% of the BG is removed, but the signal reduction is only 10% (Δm ~ 60GeV).

signal



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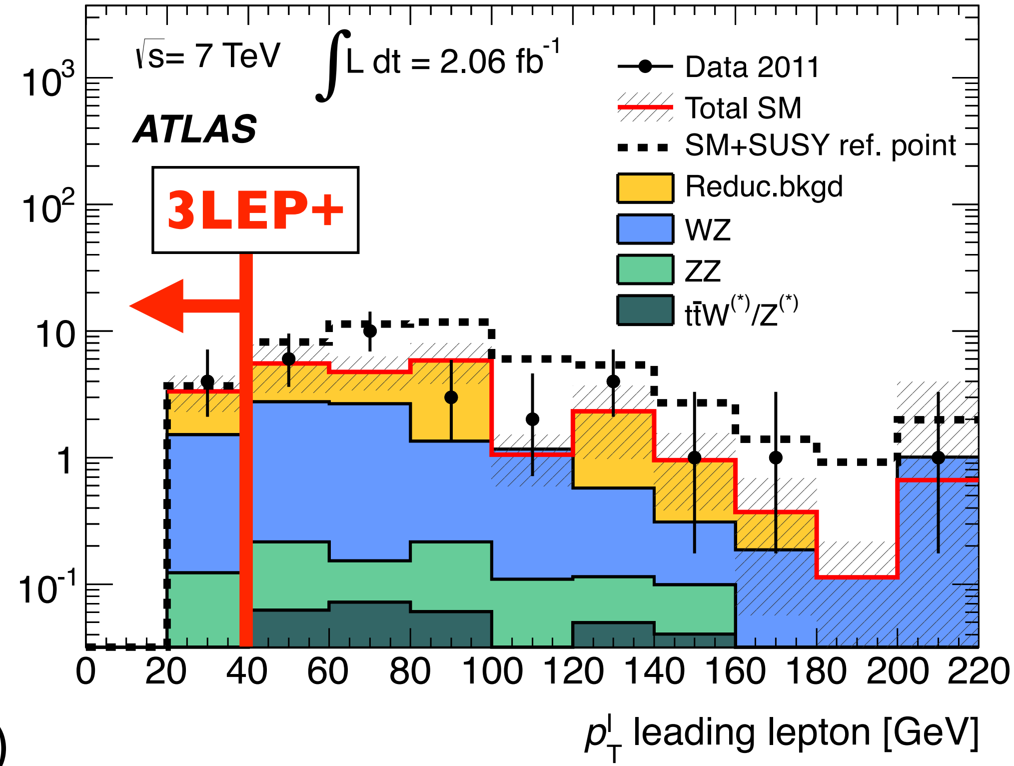

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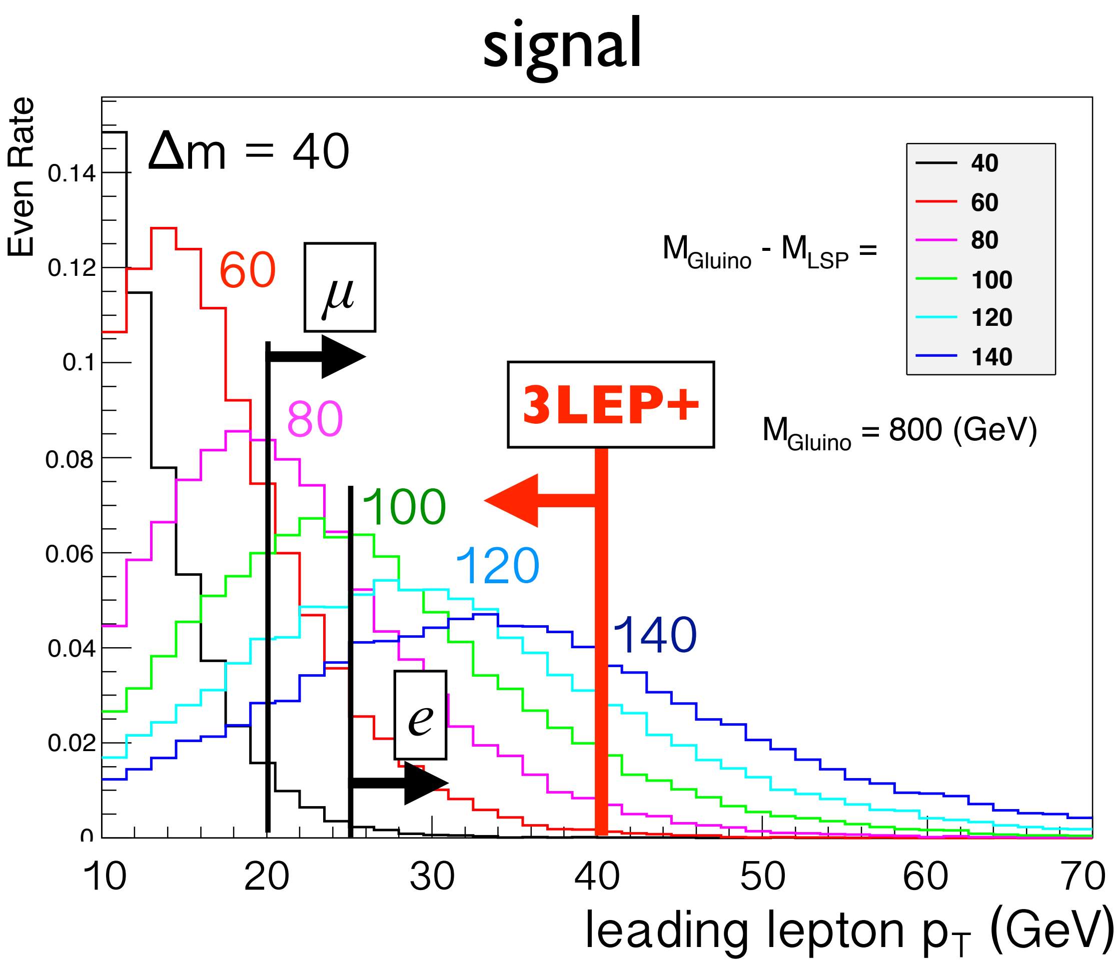
- If a low pT cut of 40GeV is added in 3LEP, 90% of the BG is removed, but the signal reduction is only 10% (Δm ~ 60GeV).
- We define a new signal region 3LEP+.

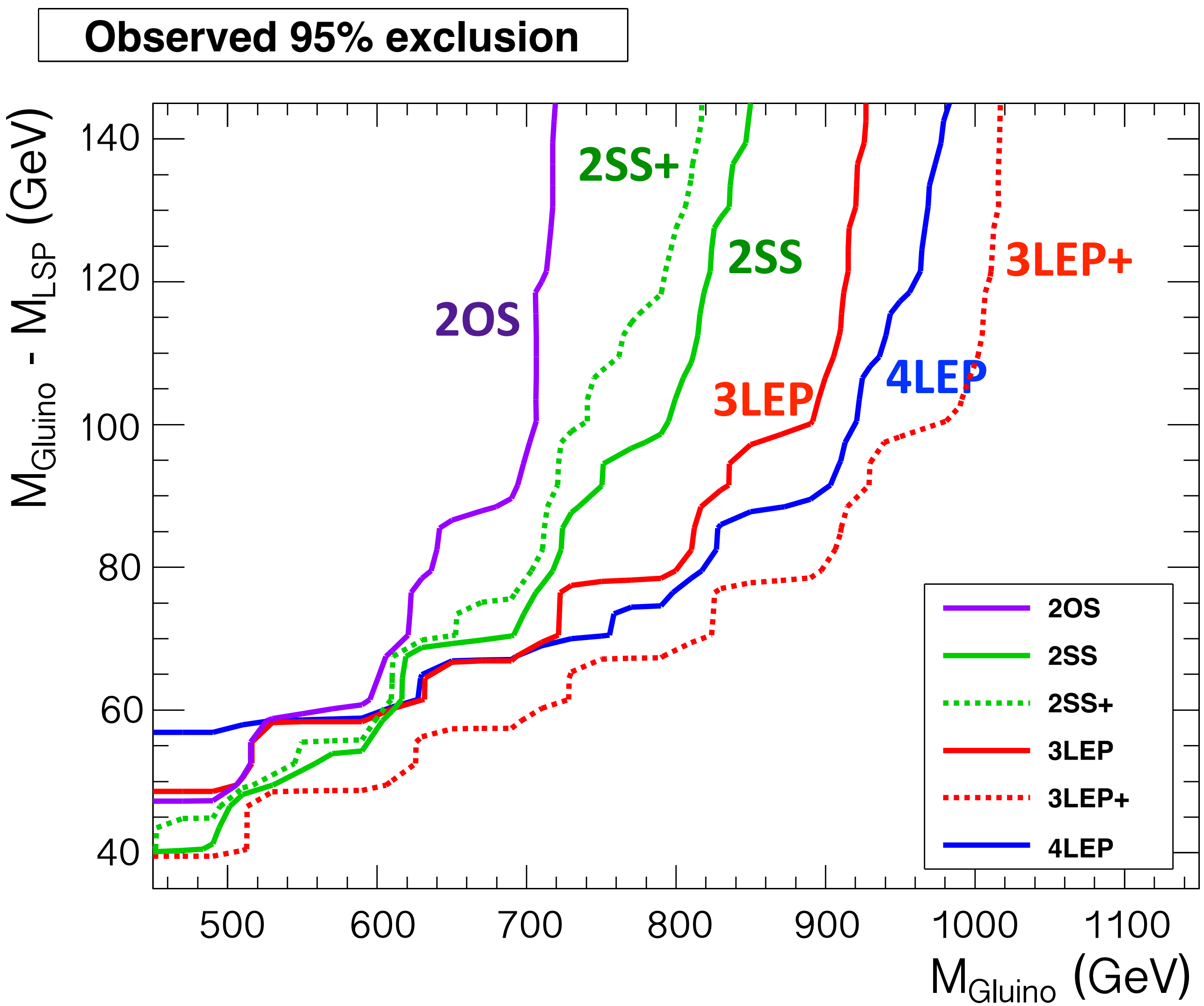


signal region	3LEP	3LEP+
N(lep)	= 3	= 3
leading μ (e) p_T	> 20 (25)	> 20 (25), <40
E_T^{miss} (GeV)	> 50	> 50
dilpton mass	> 20	> 20
luminosity (fb^{-1})	2.06	2.06
expected BG	26 ± 5	3.3 ± 0.6
observed	32	4
σ_{vis}^{bound} (95%)	10.0 fb	3.3 fb

Results

K. Rolbiecki, KS
arXiv:1206.6767

- m_{Gluino} > 900GeV if Δm ~ 100GeV.
- New 3LEP+ significantly extends the exclusion limit.



- m_{Gluino} > 900GeV at Δm〜100GeV

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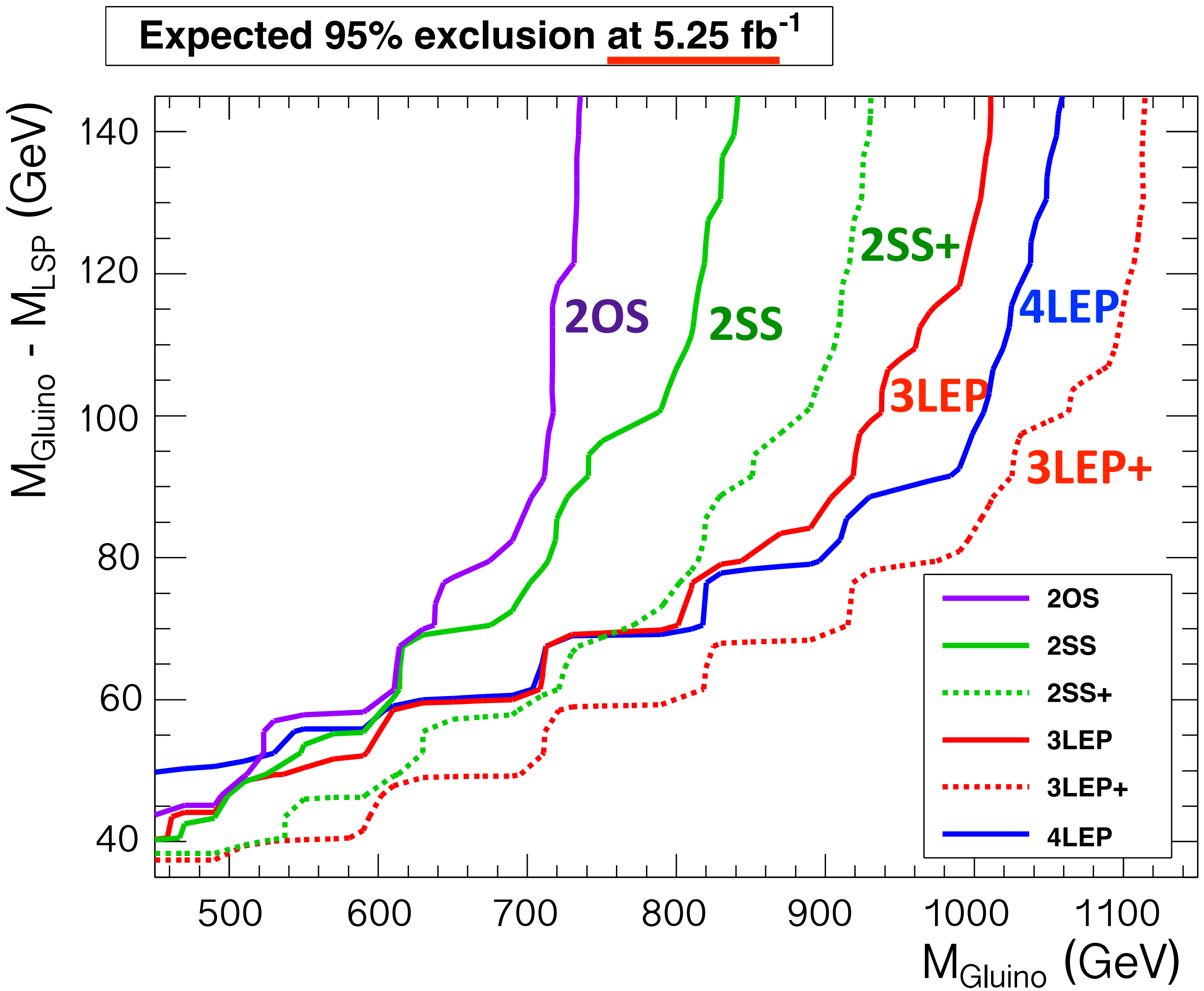
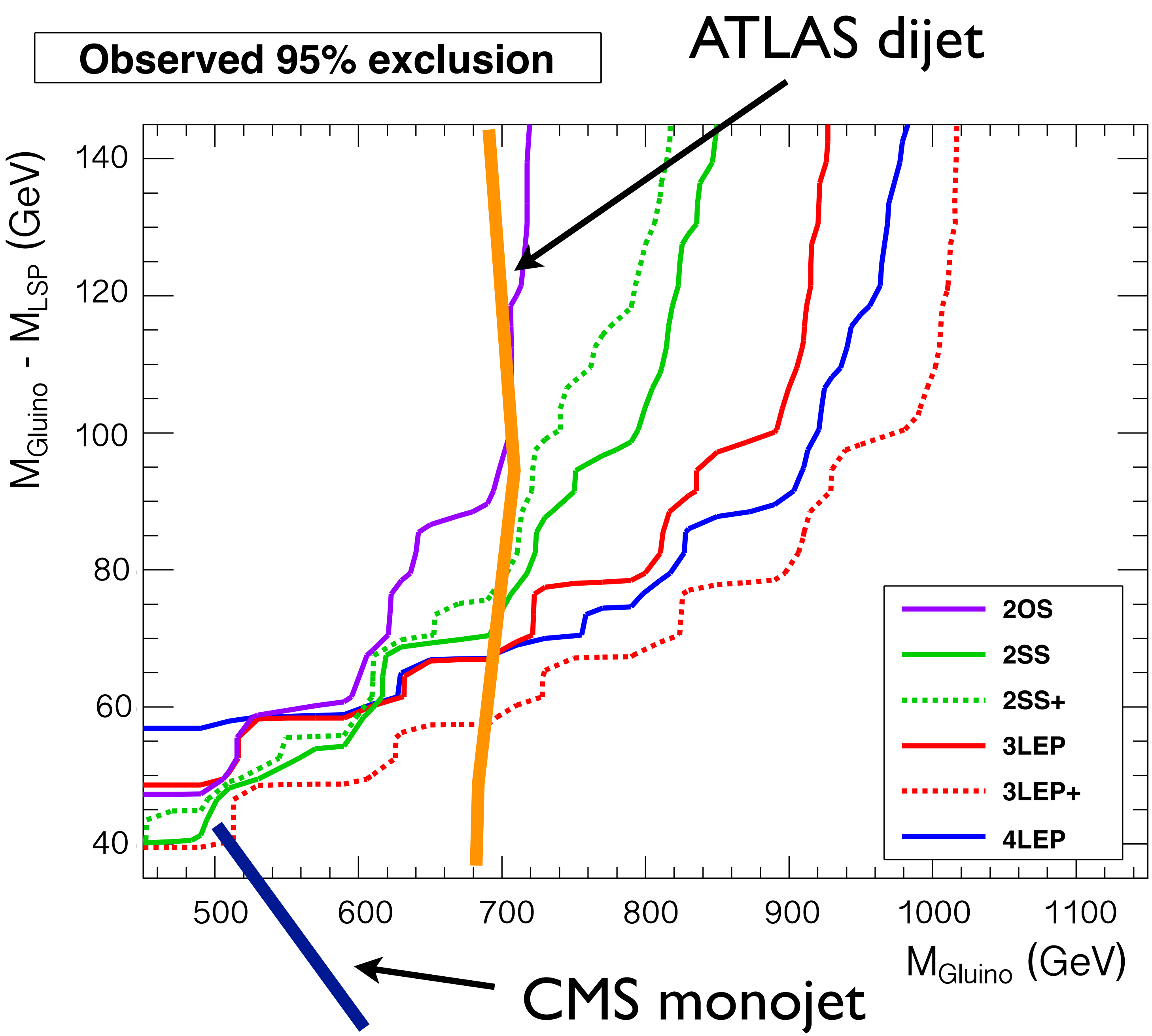


5.25/fb projection:

- m_{Gluino} > 1000GeV at Δm ~ 100GeV

Comparison



- Multi-lepton searches are sensitive to the region with moderate mass splitting: $\Delta m \gtrsim 60\,\mathrm{GeV}$

R-parity violation

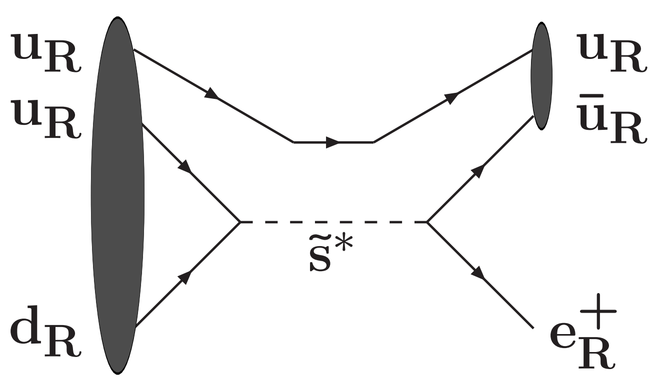
R-parity

R-parity: $(-1)^{3B+L+2s}$

- The following terms are allowed by gauge symmetry:

$$W_{\rm RPV} = \underbrace{\lambda''_{ijk} U^c_i D^c_j D^c_k}_{\not{B}} + \underbrace{\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \kappa_i L_i H_u}_{\not{L}}$$

- UDD and LQD operators lead a rapid proton decay: $p \to \pi^0 + e^+$



needs some symmetry
to explain the smallness
of the couplings

$$\lambda'_{11j} \cdot \lambda''_{11j} < 2 \cdot 10^{-27} \left(\frac{M_{\tilde{d}_j}}{100\,\text{GeV}} \right)^2, \quad i = 1, 2,\ j \neq 1,$$

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forbidden by R-parity

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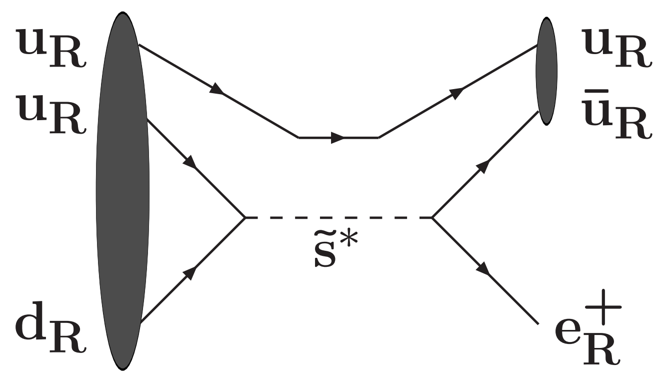

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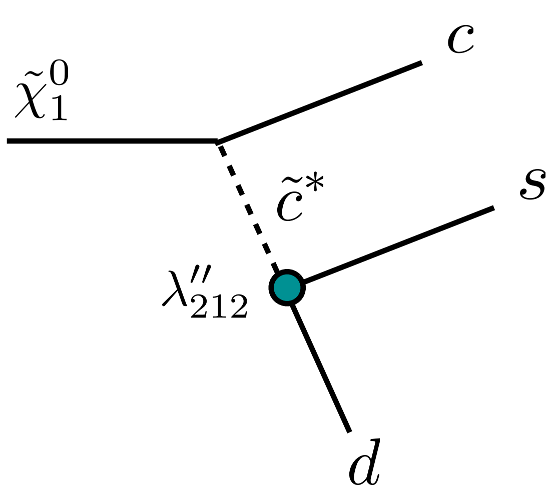
R-parity violation

- To prohibit the proton decay operator, baryon or lepton parity is sufficient.
- If one is broken, the LSP is no longer stable.

Lepton parity: $(-1)^{L+2s}$

$$W_{RPV} = \lambda''_{ijk} U^c_i D^c_j D^c_k$$

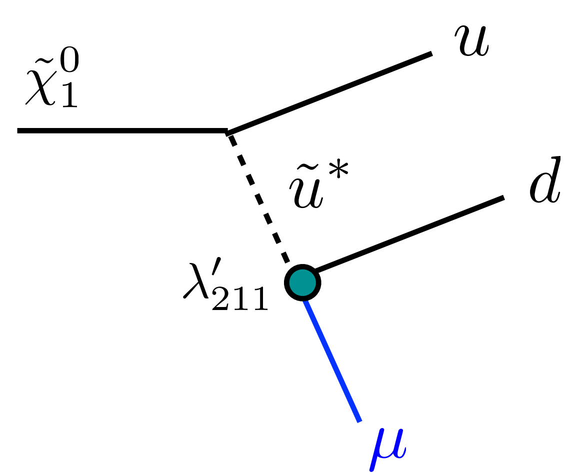


absence of lepton

→ more challenging in SUSY searches

Baryon parity: $(-1)^{3B+2s}$

$$W_{\rm RPV} = \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \kappa_i L_i H_u$$



Missing energy signal is removed

Existing studies for RPV

Operator	Remark	Reference
UDD or LQD	stop direct production	J.A. Evans, Y. Kats, 1209.0764
UDD	stop/sbottom LSP (resonance)	C.Brust, A.Katz, R.Sundrum, 1206.2353
UDD	stop/sbottom LSP (dilepton)	B.Allanach, B.Gripaios, 1202.6616
UDD	gluino → 3jet (resonance)	CMS, 1107.3084
UDD or LLE	$\tilde{q} \to \tilde{\chi}_1^0 j \to \tilde{\ell}\ell j \to \ell\ell j \tilde{G}\, (\tilde{G} \to \text{ RPV decay})$	CMS, 1204.5341
LLE	stau (N)LSP, kinky charged tracks	S.Asai1, Y.Azuma, M.Endo, K.Hamaguchi, S.Iwamoto, 1103.1881
LLE	>=4lep + E_T^{miss}	ATLAS CONF 2012-035
LLE and QLD	$d\bar{d} \to \tilde{\nu}_\tau \to e\mu$	ATLAS, 1109.3089
QLD	pp → eμ	ATLAS, 1205.0725
QLD	μ + displaced vertex	ATLAS CONF 2012-108
...	...	...

Our goal:

to see how low the gluino/squark mass can go in the "vanilla" type SUSY spectrum by letting the neutralino decay by RPV

Model setup

M. Asano, K. Rolbiecki, KS
arXiv:1209.5778

RPV:

- consider UDD-type RPV → most challenging case
- $\lambda''_{212} = 10^{-3}$ { no experimental constraint; no b-jet; prompt decay of neutralino

(washes out baryon asymmetry → baryon asymmetry should be generated after EW phase transition)

Models:

- CMSSM + UDD $(A_0 = 0, \tan\beta = 10, \mu > 0)$
  - free parameters: m_0, $m_{1/2}$
- simplified model + UDD
  - decoupled 3rd generation, sleptons, higgsinos, degenerate 1-2 gen. squarks
  - approx. GUT relation: $M_3 : M_2 : M_1 = 6 : 2 : 1$
  - free parameters: gluino mass, squark mass

Analyses

- ATLAS large jet multiplicities plus missing energy search (1206.1760) [7TeV, 5/fb]

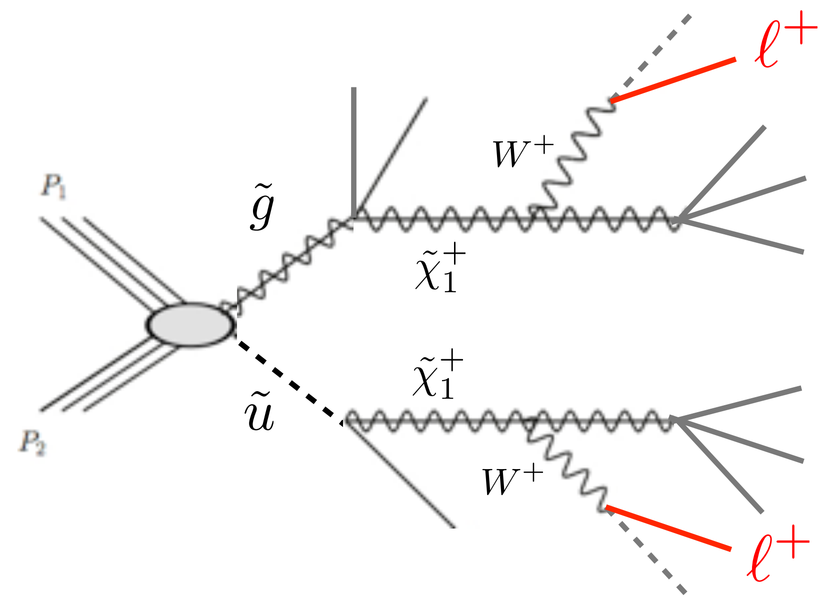
signal region	7j55	8j55	9j55
$N_{\rm lepton}(p_T^{e,\mu} > 20, 10\,{\rm GeV})$	$= 0$		
$E_T^{\rm miss}/\sqrt{H_T}$	$> 4\sqrt{\rm GeV}$		
$N_{\rm jet}(p_T > 55\,{\rm GeV})$	≥ 7	≥ 8	≥ 9

- expects up to 3 additional jets from $\tilde{\chi}_1^0 \to udd$
- expects missing energy from $\tilde{q} \to q\tilde{\chi}_1^\pm \to W^{(*)}q\tilde{\chi}_1^0 \to \nu_\tau \tau q \tilde{\chi}_1^0$

- CMS SS dilepton with jets plus missing energy search (1205.6615) [7TeV, 5/fb]

signal region	MET120	MET50	MET0
N(SS lepton pair)	≥ 1		
$N_{\rm jet}(p_T > 40\,{\rm GeV})$	≥ 2		
$p_T^{\ell 1,\ell 2}$	$> 20, 10\,{\rm GeV}$		
$m(l_i^+ l_i^-)$	$> 8\,{\rm GeV}$		
H_T	$> 450\,{\rm GeV}$		
$E_T^{\rm miss}$	$> 120\,{\rm GeV}$	$> 50\,{\rm GeV}$	$> 0\,{\rm GeV}$

- expects same-sign dilepton from



W bosons in the cascade decay chain play a crucial role for both analyses

E_T^{miss}, H_T, Njets (after cut)

M. Asano, K. Rolbiecki, KS
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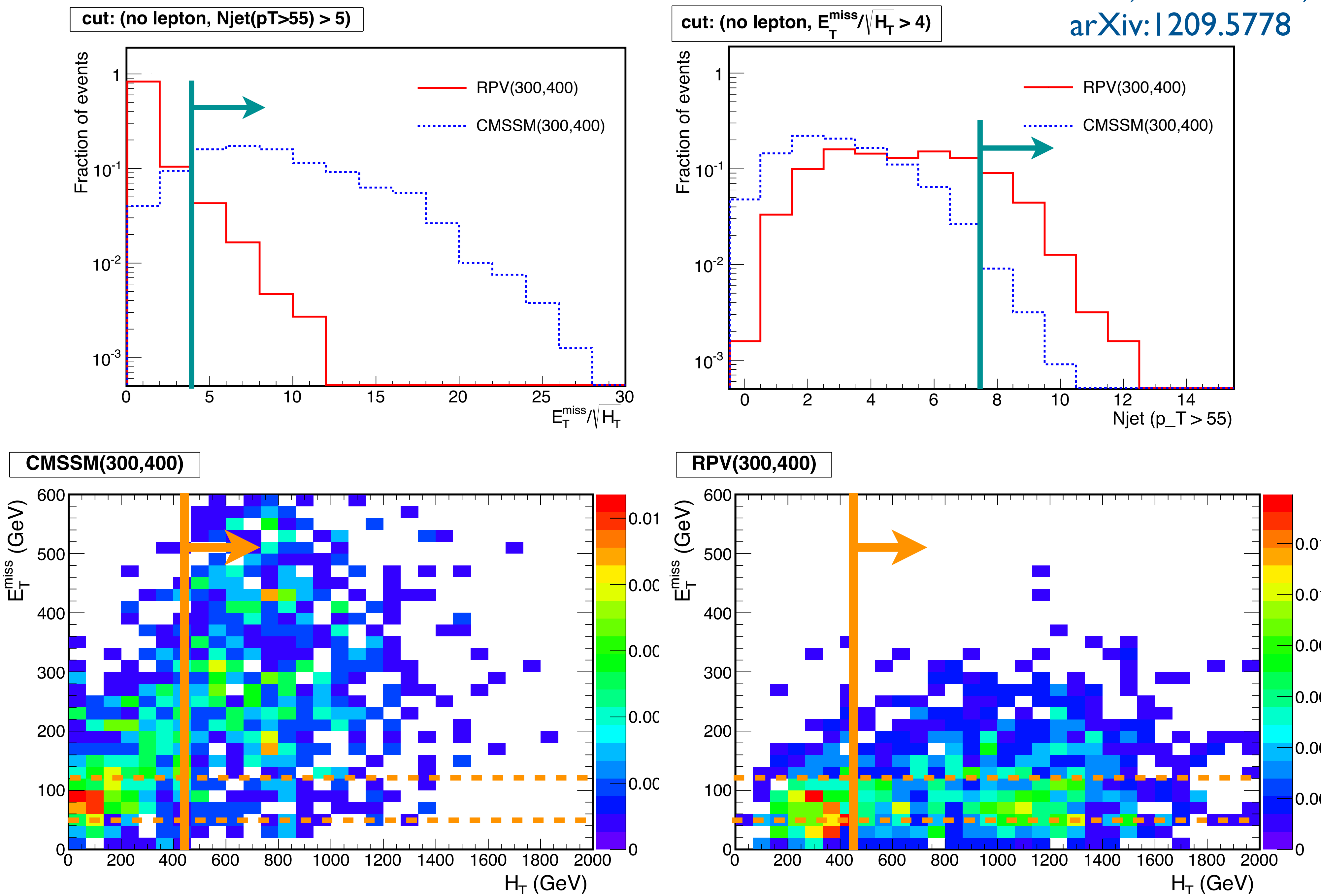

Result (CMSSM+UDD)

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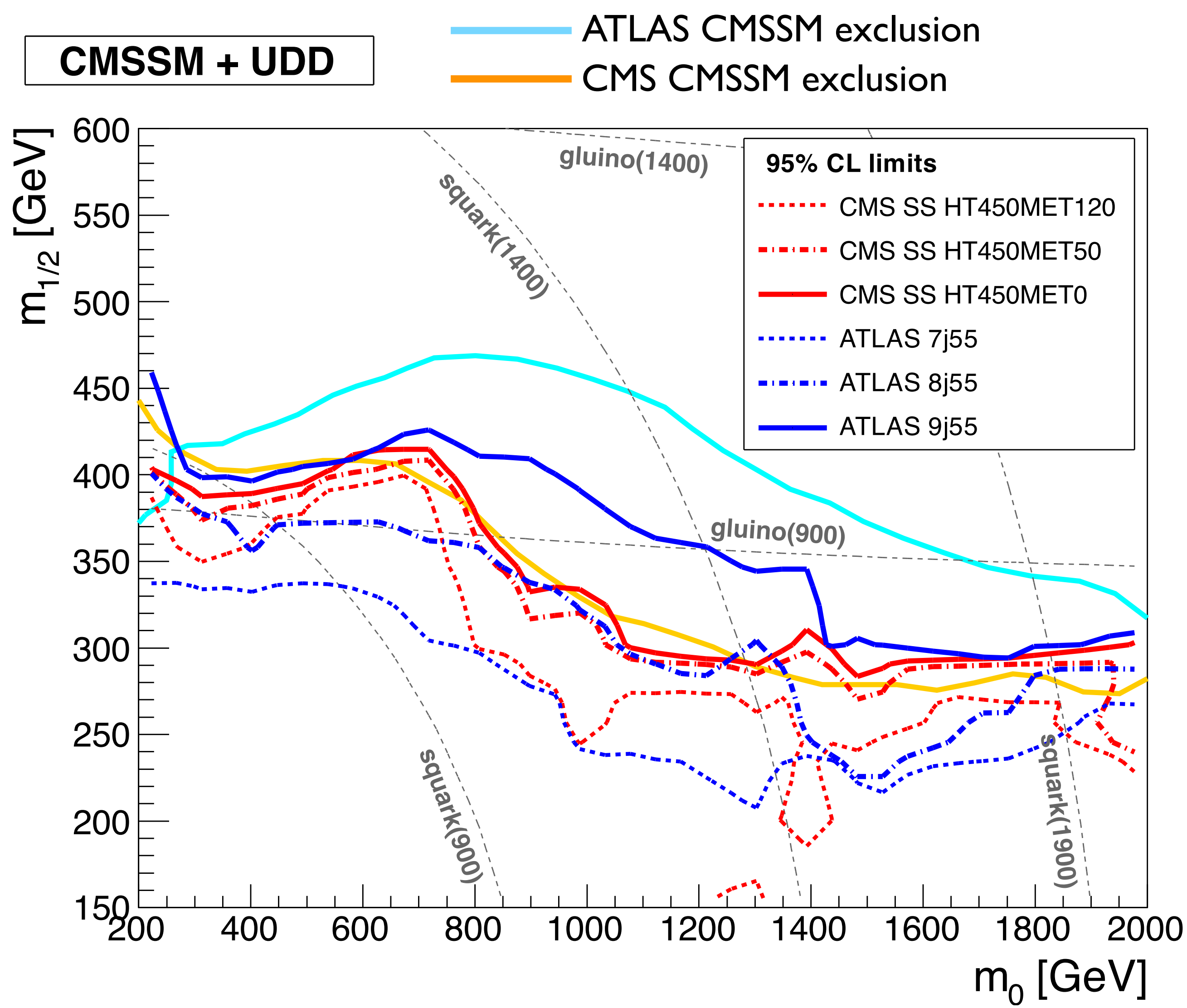
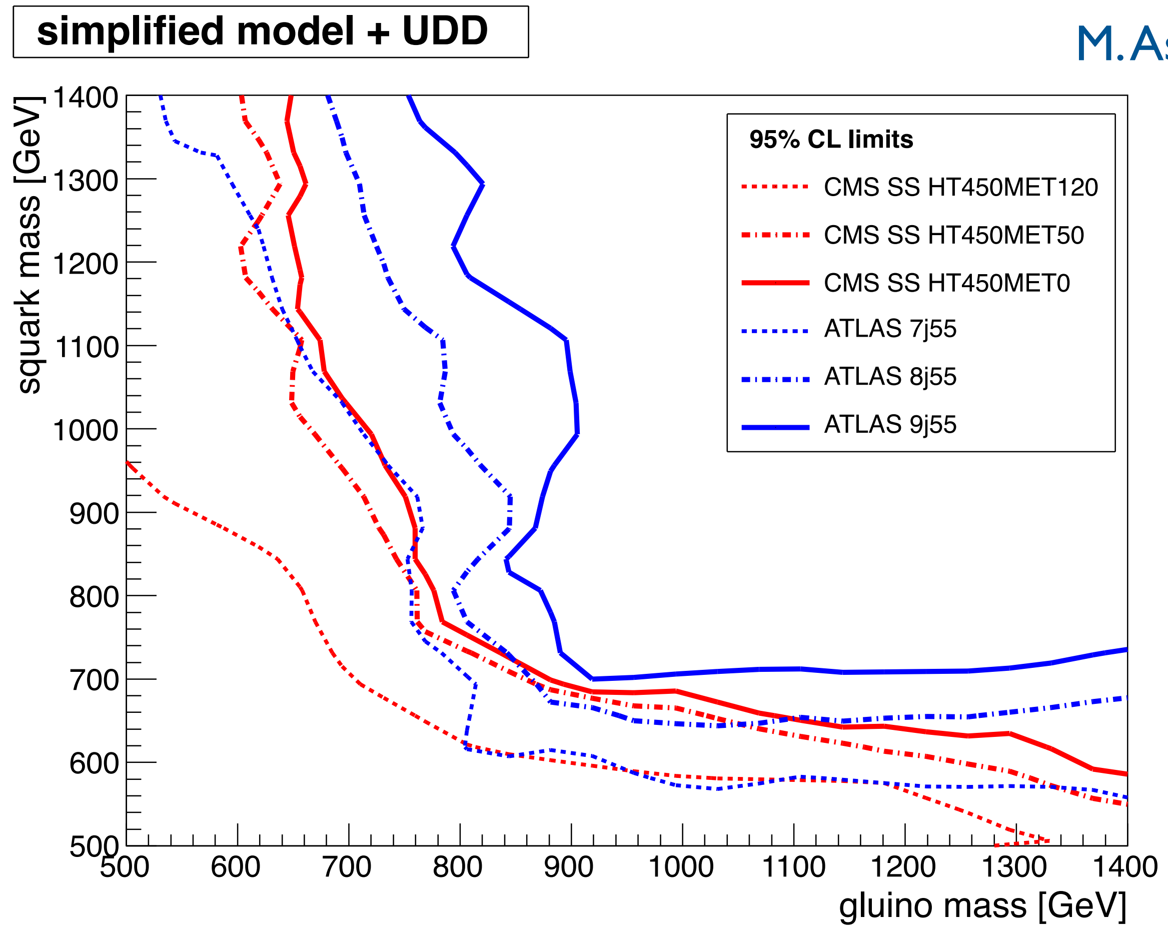


- For the equal squark/gluino mass, ***squark/gluino mass up to 900GeV is excluded !!***

Result (simplified model+UDD)

M. Asano, K. Rolbiecki, KS
arXiv:1209.5778



- For the equal squark/gluino mass, squark/gluino mass up to 800GeV is excluded

The slightly weaker bound can be explained by the absence of stops in the gluino decay chain (stop is a good source for the leptons)

Summary

- Discovering/excluding SUSY particles below 1 TeV in a general framework is particularly important in the light of the natural EWSB.

- Three main possibilities to hide SUSY (with MSSM particle contents)

split generation SUSY, compressed SUSY, R-parity violation

Compressed SUSY:

- Leptonic searches analysis can place a non-trivial constraint

$M_{gluino}(=M_{squark}) > 900$ GeV, $\Delta m \sim 100$ GeV (simplified model)

R-parity violation:

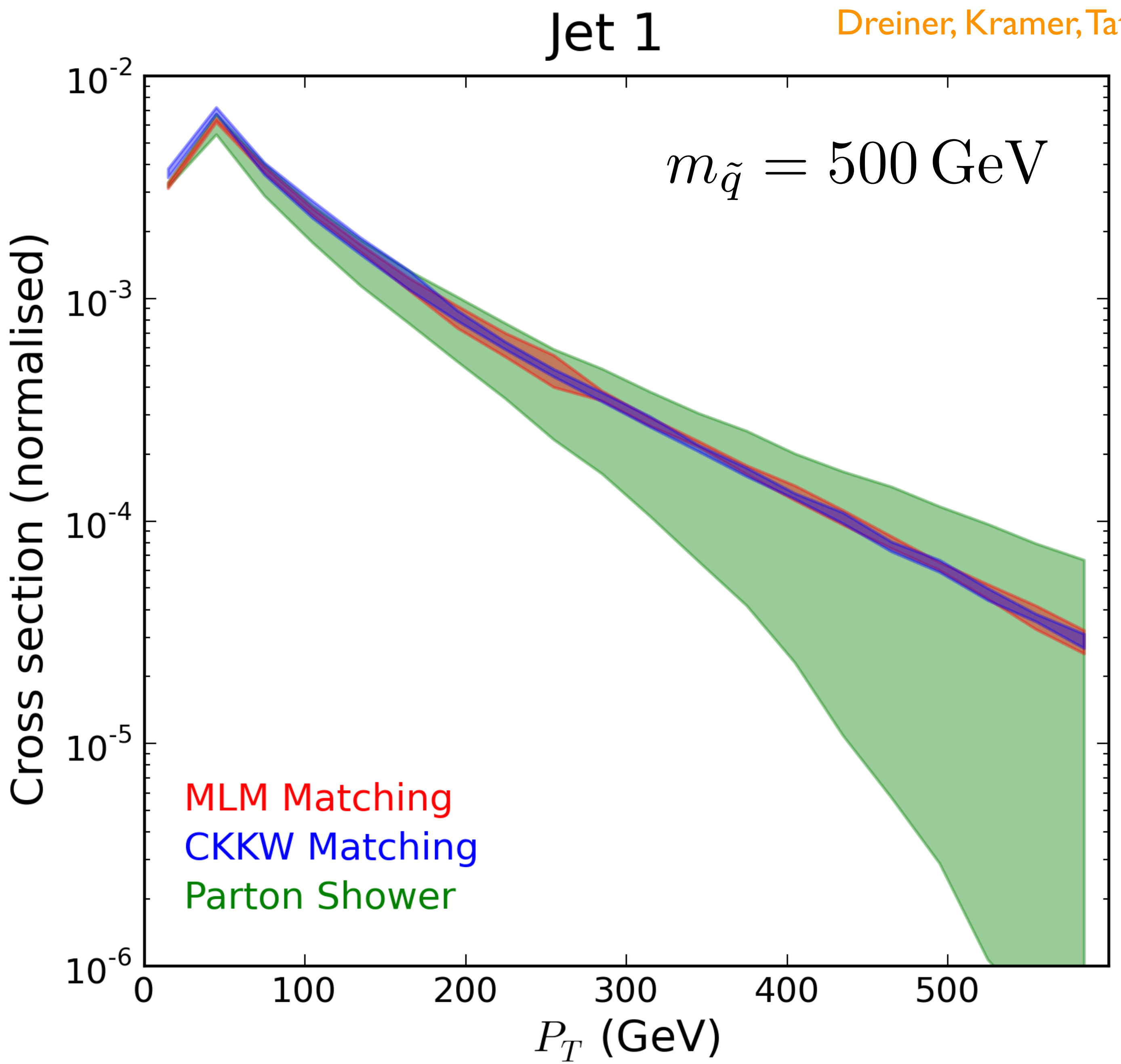
- Existing searches, large jet multiplicity (ATLAS), SS dilepton with jets (CMS), already have good sensitivity to the RPV "vanilla" SUSY.

$M_{gluino}(=M_{squark}) > 900$ GeV (CMSSM + UDD)

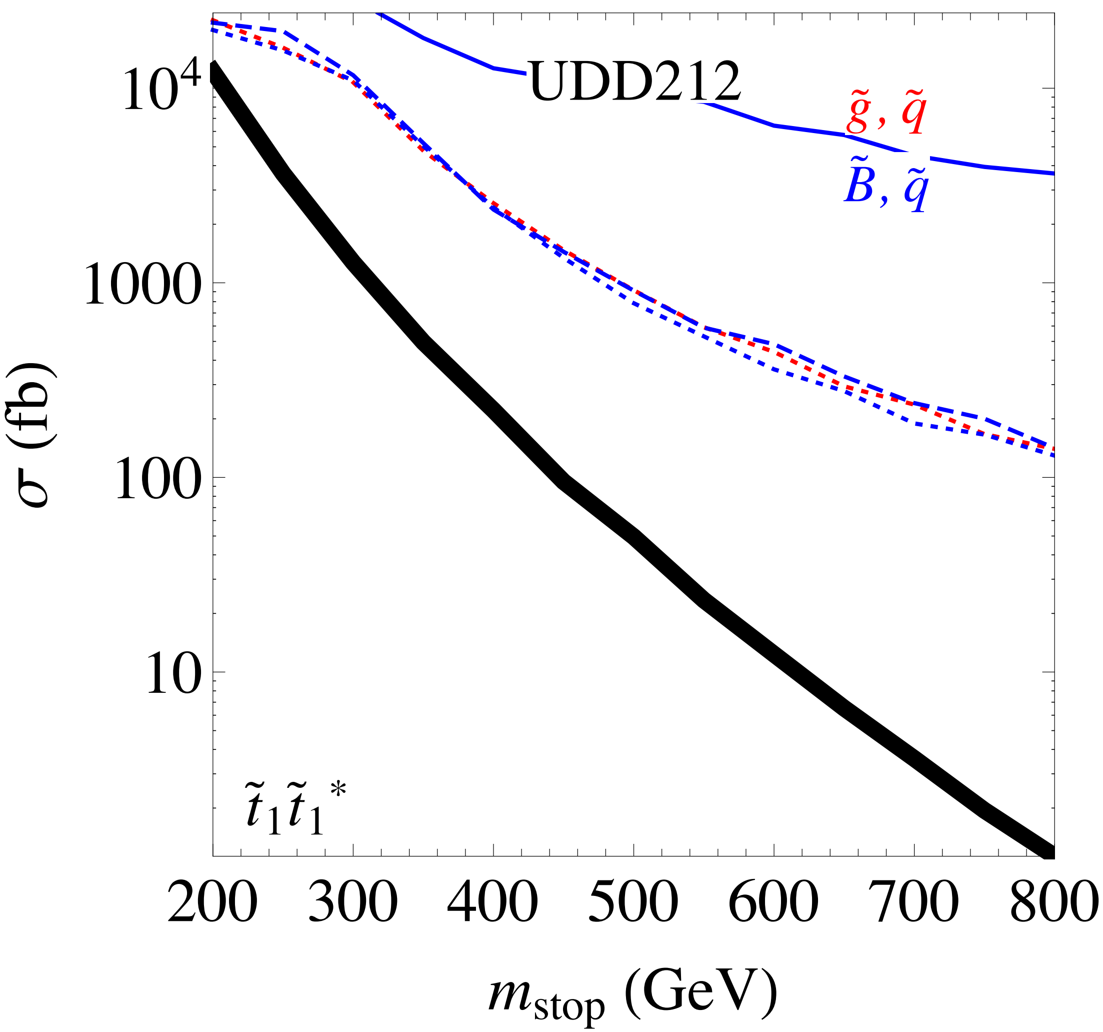
$M_{gluino}(=M_{squark}) > 800$ GeV (simplified model + UDD)

Uncertainty on ISR jet

Dreiner, Kramer, Tattersall (1207.1613)



J. A. Evans, Y. Kats 2012



Application to the other model

- The estimated mass limits are not applicable to models with different cross sections and branching ratios.

- The visible cross section may be decomposed as:

$$\sigma_{\rm vis}^{(i)} = \sum_{a \to X, b \to Y} \sigma_{ab} \cdot B_{a \to X} \cdot B_{b \to Y} \cdot \epsilon^{(i)}_{a \to X, b \to Y}$$

a, b: SUSY particles

X, Y: decay processes

σ_{ab}: cross section of a, b production

$B_{a \to X}$: branching ratio of $a \to X$.

$\epsilon^{(i)}_{a \to X, b \to Y}$: efficiency of signal region (i)

- The event simulation and detector simulation are required only to calculate the efficiencies.

Application to the other model

• The estimated mass limits are not applicable to models with different cross sections and branching ratios.

• The visible cross section may be decomposed as:

requires MC simulation

$$\sigma_{\text{vis}}^{(i)} = \sum_{a\to X, b\to Y} \sigma_{ab} \cdot B_{a\to X} \cdot B_{b\to Y} \cdot \boxed{\epsilon_{a\to X, b\to Y}^{(i)}}$$

a, b: SUSY particles

X, Y: decay processes

σ_{ab}: cross section of a, b production

$B_{a\to X}$: branching ratio of $a \to X$.

$\epsilon_{a\to X, b\to Y}^{(i)}$: efficiency of signal region (i)

• Only efficiencies require the MC simulation to be estimated.

• Visible cross section can be estimated without doing MC simulation if the efficiencies are known.

- We define three types of decay processes as:

$$(a \to X) = \begin{array}{ll} \widetilde{\chi}_2^0: & \widetilde{q}/\widetilde{g} \to \widetilde{\chi}_2^0 + \text{jets} \to \ell^+\ell^-\widetilde{\chi}_1^0 + \text{jets} \\ \widetilde{\chi}_1^\pm: & \widetilde{q}/\widetilde{g} \to \widetilde{\chi}_1^\pm + \text{jets} \to \ell\nu\widetilde{\chi}_1^0 + \text{jets} \\ \widetilde{\chi}_1^0: & \widetilde{q}/\widetilde{g} \to \widetilde{\chi}_1^0 + \text{jets} \end{array}$$

- Considering both decay chains, relevant signal regions are identified for each event process, XY:

$$XY = \begin{array}{rl} \tilde{\chi}_2^0\tilde{\chi}_1^0 & \Longrightarrow \text{2OS;} \\ \tilde{\chi}_1^\pm\tilde{\chi}_1^\pm & \Longrightarrow \text{2OS, 2SS;} \\ \tilde{\chi}_1^\pm\tilde{\chi}_2^0 & \Longrightarrow \text{3LEP (2OS, 2SS);} \\ \tilde{\chi}_2^0\tilde{\chi}_2^0 & \Longrightarrow \text{4LEP (3LEP, 2OS, 2SS);} \\ \tilde{\chi}_1^0\tilde{\chi}_1^0,\ \tilde{\chi}_1^\pm\tilde{\chi}_1^0 & \Longrightarrow \text{less than 2 leptons.} \end{array}$$

$\epsilon^{(i)}_{XY}$ in % $(m_{\tilde{q}/\tilde{g}} = 800\,\mathrm{GeV})$

Δm (GeV)		50	60	70	80	90	100
2OS	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$	0.25	0.48	0.63	1.18	1.61	1.49
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$	0.23	0.40	0.57	0.70	0.62	0.90
	$\tilde{\chi}_2^{0}\tilde{\chi}_2^{0}$	0.26	0.30	0.62	0.35	0.78	0.43
	$\tilde{\chi}_2^{0}\tilde{\chi}_1^{0}$	0.31	0.50	0.58	1.06	1.07	1.78
2SS	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$	0.94	2.03	4.52	5.85	6.65	11.0
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$	0.60	0.90	1.37	2.44	2.86	3.40
	$\tilde{\chi}_2^{0}\tilde{\chi}_2^{0}$	0.35	0.94	1.34	1.30	1.52	1.71
2SS+	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$	0.50	1.29	2.68	3.93	3.85	7.00
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$	0.36	0.52	0.73	1.27	1.60	1.76
	$\tilde{\chi}_2^{0}\tilde{\chi}_2^{0}$	0.26	0.55	0.72	0.70	0.64	0.67
3LEP	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$	0.47	1.68	3.26	6.32	9.30	11.6
	$\tilde{\chi}_2^{0}\tilde{\chi}_2^{0}$	1.00	2.58	3.72	7.33	8.10	10.4
3LEP+	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$	0.45	1.54	2.88	5.60	7.65	8.96
	$\tilde{\chi}_2^{0}\tilde{\chi}_2^{0}$	1.00	2.43	3.34	6.53	6.56	8.3
4LEP	$\tilde{\chi}_2^{0}\tilde{\chi}_2^{0}$	0.12	1.24	2.43	5.88	10.13	11.23

caveats:

- Contributions from other processes are neglected.

$$\text{e.g. } \tilde{g} \to \tilde{t}^{(*)} t^{(*)} \to \ell\ell\nu\nu bb\chi_1^0$$

- Efficiencies vary about factor of 2-5 btw $m_{g/q}$ = 400 to 1200GeV depending on Δm.

- Efficiencies differ if the assumption

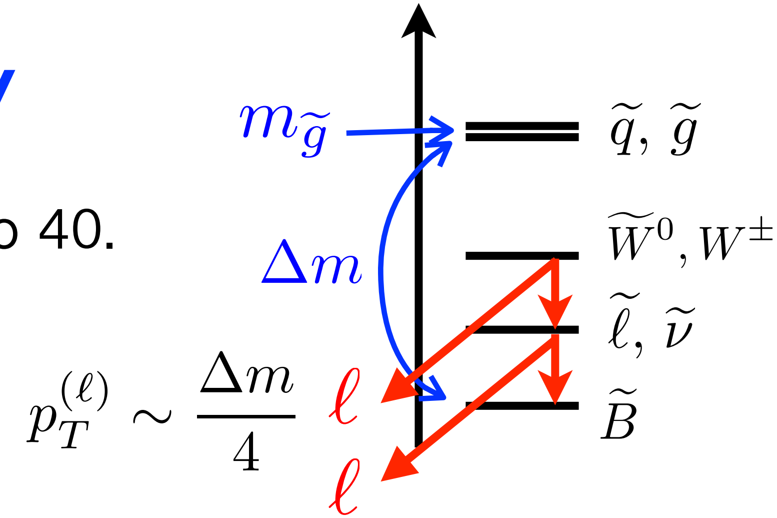
$$m_{\widetilde{W}} = \frac{m_{\tilde{g}} + m_{\tilde{\chi}_1^0}}{2}, \quad m_{\tilde{\ell}} = \frac{m_{\widetilde{W}} + m_{\tilde{\chi}_1^0}}{2}$$

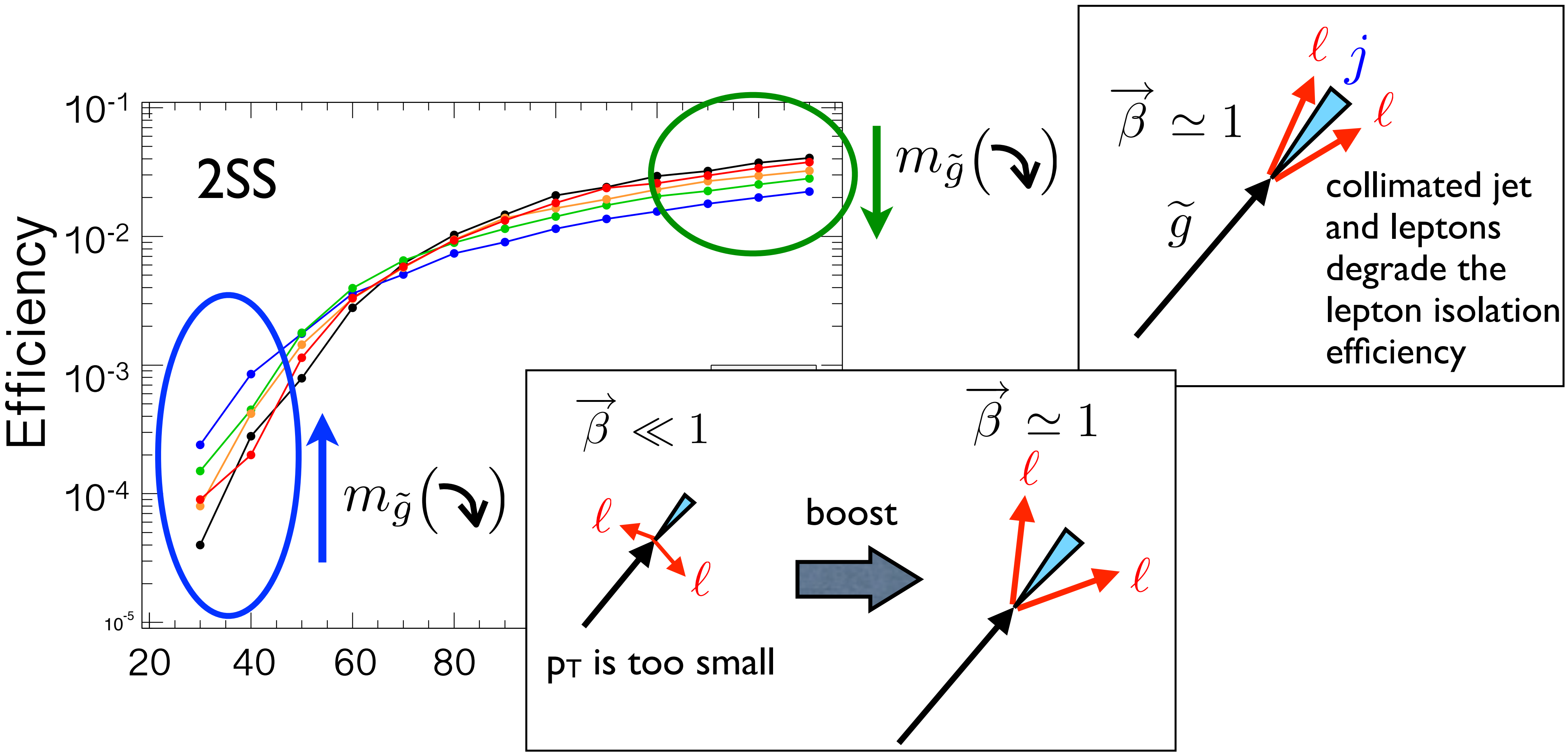
is relaxed. We have checked the efficiencies do not change much in the events with wino decaying to leptons through three body decays.

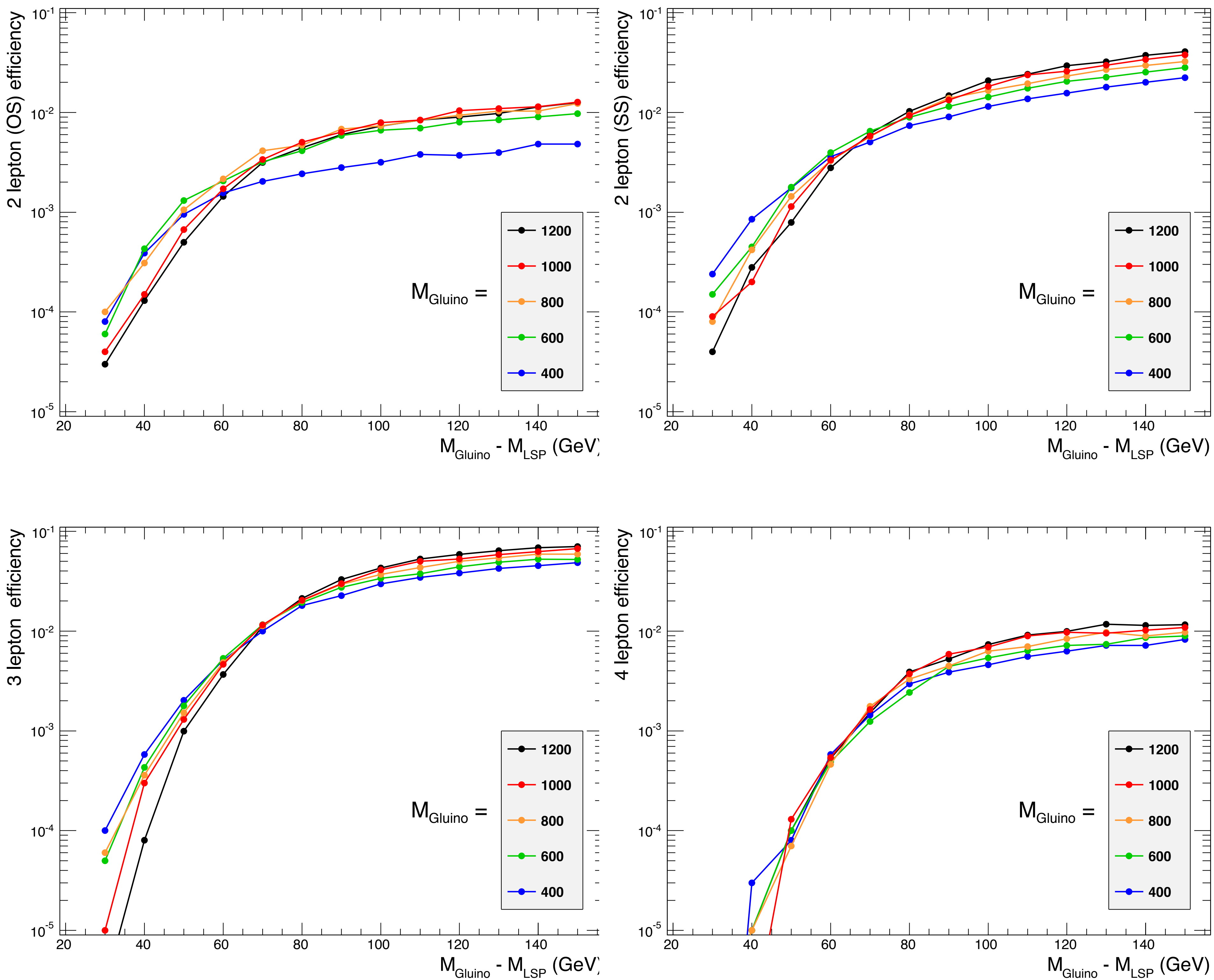
$$\sigma^{(i)}_{\mathrm{vis}} \sim \sum_{a\to X, b\to Y} \sigma_{ab} \cdot B_{a\to X} \cdot B_{b\to Y} \cdot \epsilon^{(i)}_{a\to X, b\to Y}(\Delta m)$$

Efficiency

- The efficiencies drop quickly from Δm=100 to 40.
- The efficiency hardly depends on $m_{\tilde{g}}$

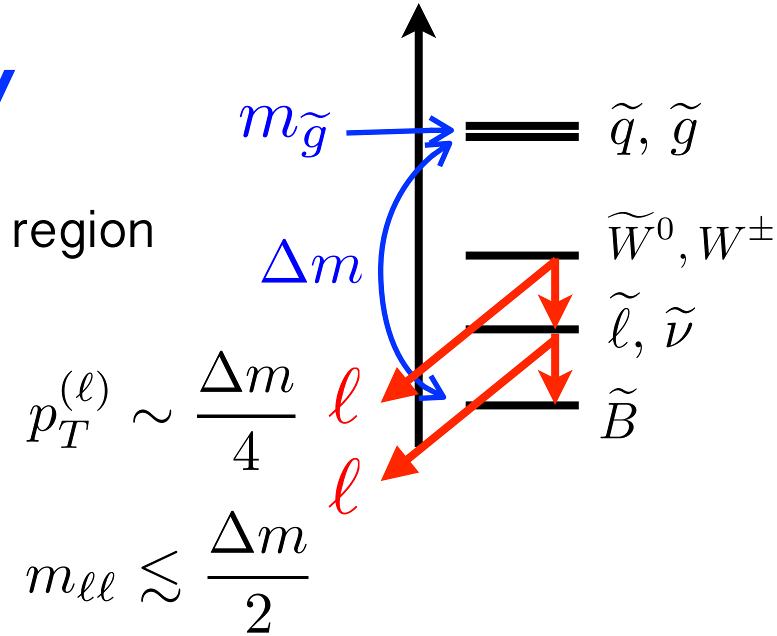





2 lepton (OS) efficiency
2 lepton (SS) efficiency
3 lepton efficiency
4 lepton efficiency
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
20
40
60
80
100
120
140
$M_{Gluino} - M_{LSP}$ (GeV)
M_{Gluino} =
1200
1000
800
600
400

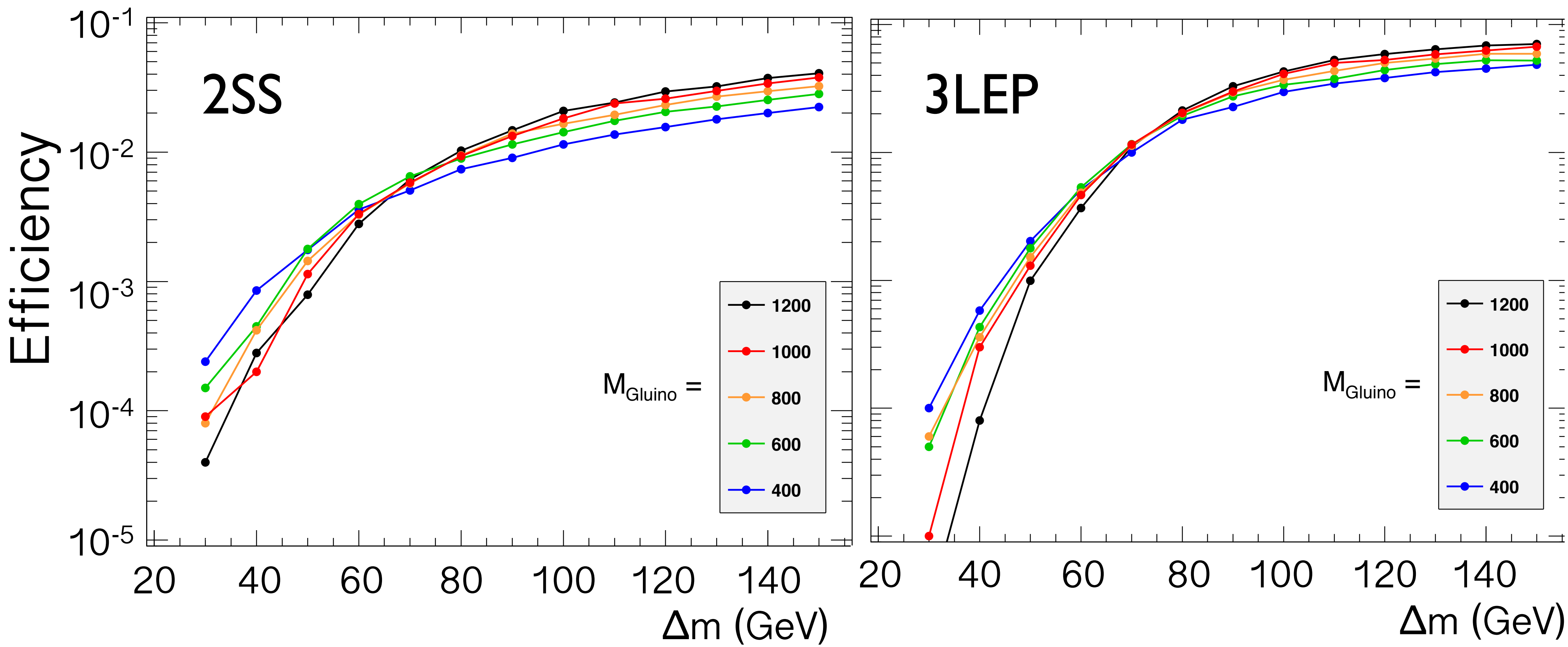
Efficiency

- The efficiencies are not small in the Δm > 80GeV region
- The efficiency hardly depends on $m_{\tilde{g}}$



Cut:

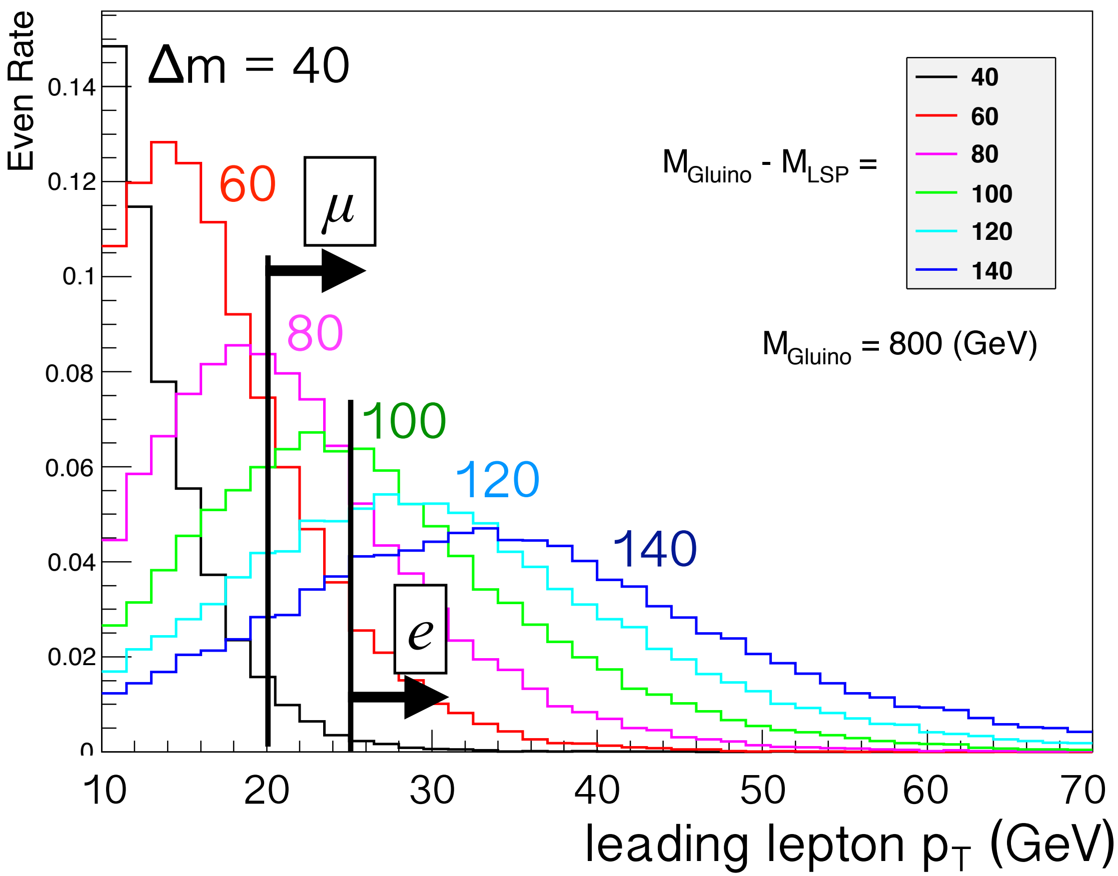
$$p^T_{\ell 1} > 20\,\mathrm{GeV},\ m_{\ell\ell} = 12(20)\,\mathrm{GeV}$$



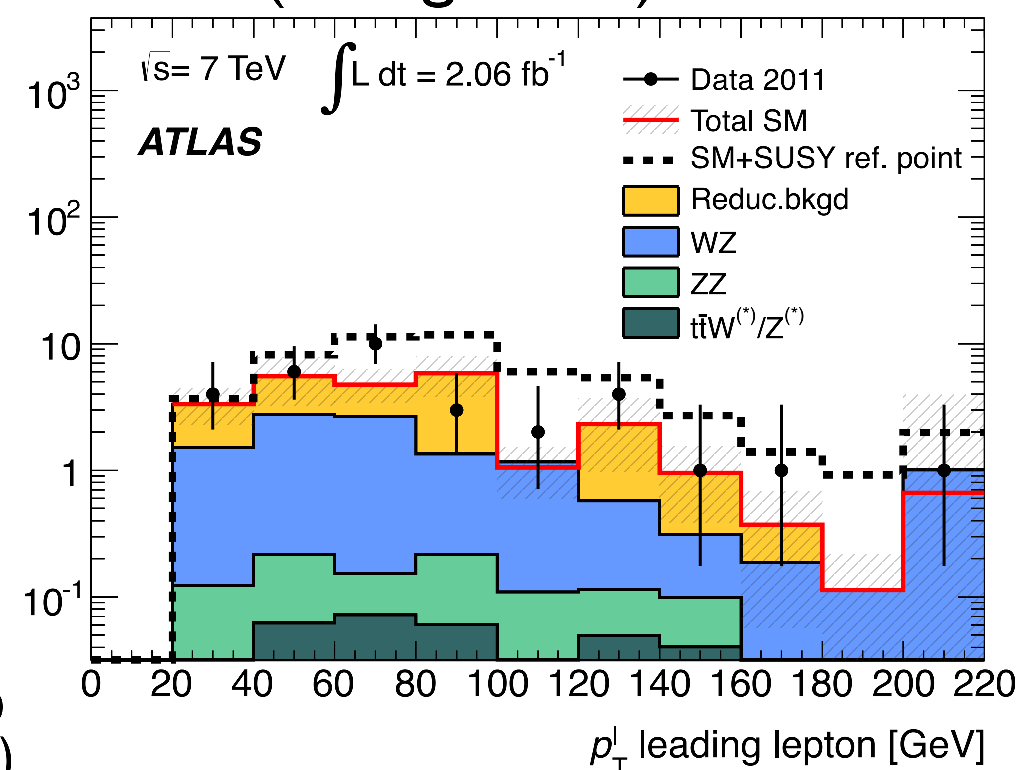
leading lepton p_T

- p_T^{lep} distributions peak around Δm/4, and quickly fall off towards the high p_T region.
- The p_T cut of 20 (25) for μ (e) is the limiting factor of the analysis for the small Δm.

signal



3LEP (background)



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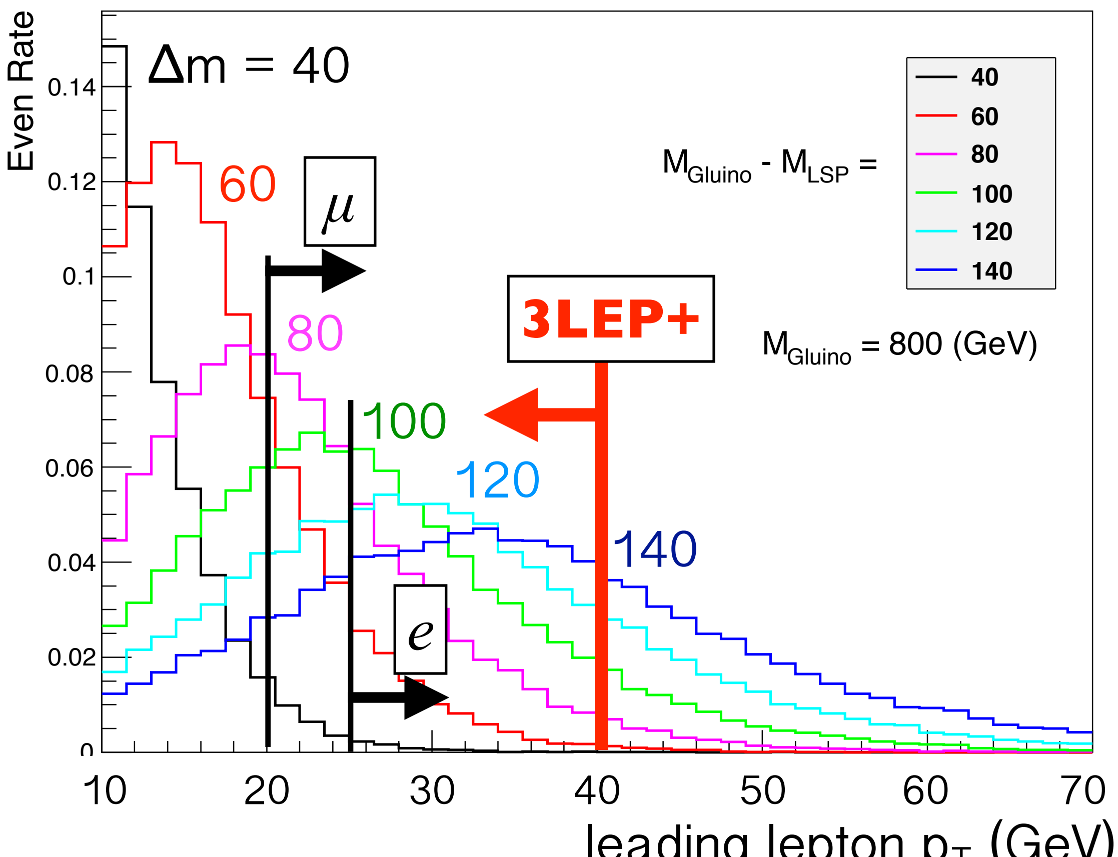
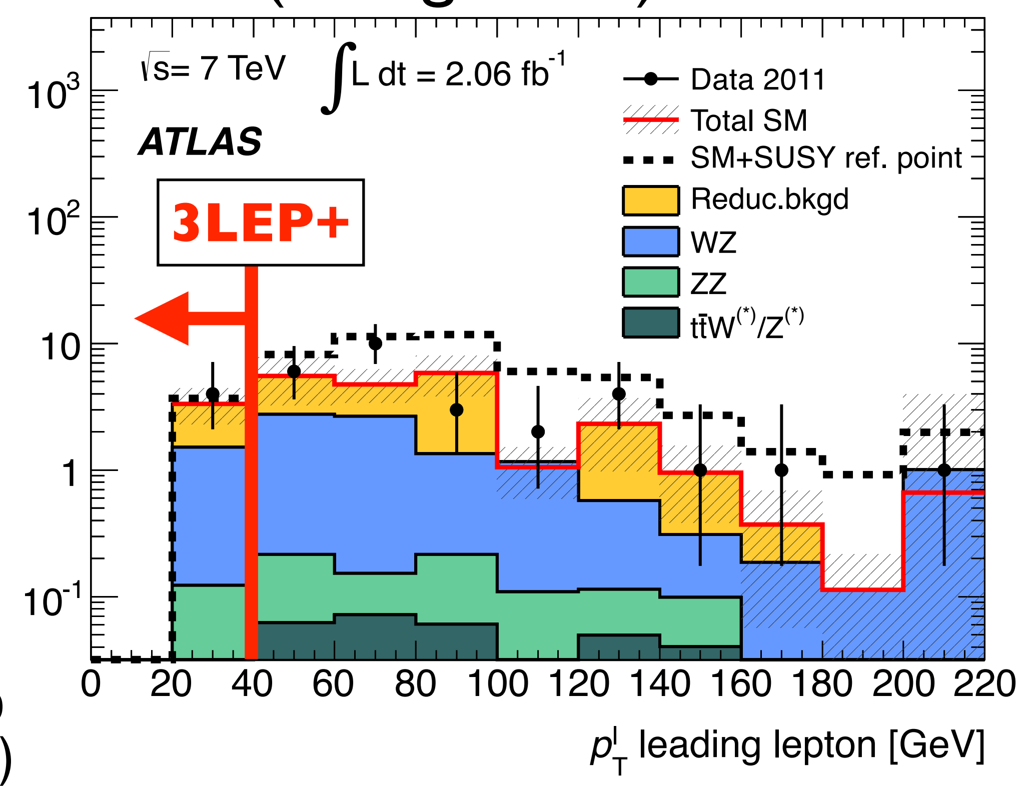
- If a low pT cut of 40GeV is added in 3LEP, 90% of the BG is removed, but reduction on signal is only 10% (Δm ~ 60GeV).

signal



3LEP (background)



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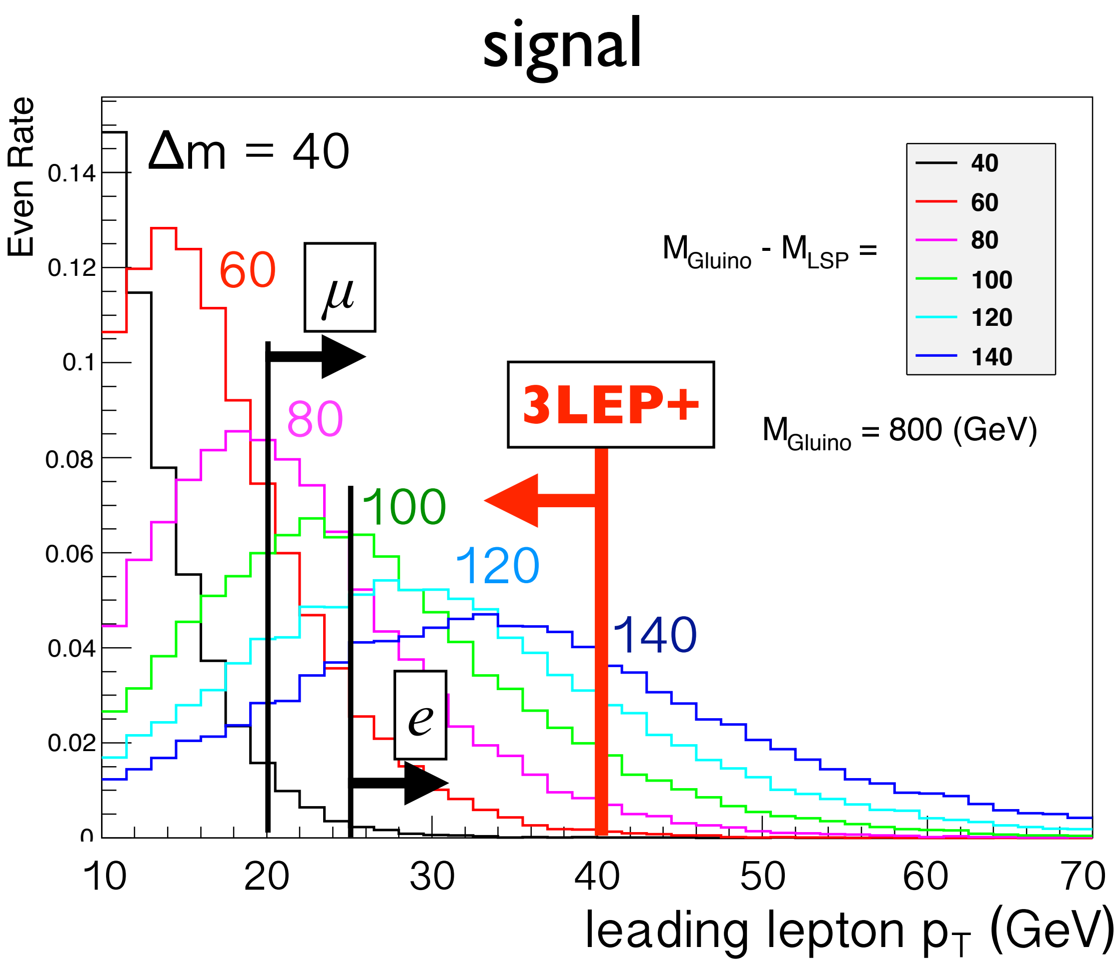
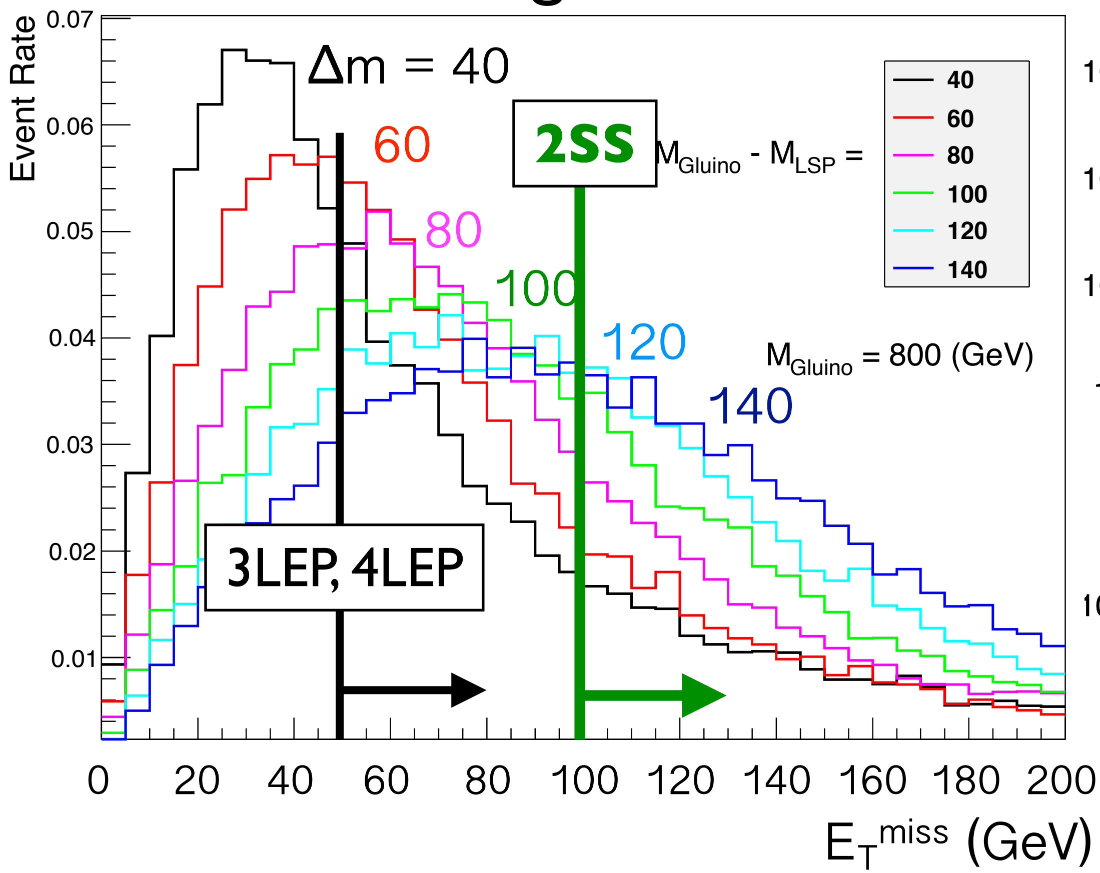


signal region	3LEP	3LEP+
N(lep)	= 3	= 3
leading μ (e) p_T	> 20 (25)	> 20 (25), <40
E_T^{miss} (GeV)	> 50	> 50
dilpton mass	> 20	> 20
luminosity (fb^{-1})	2.06	2.06
expected BG	26 ± 5	3.3 ± 0.6
observed	32	4
σ_{vis}^{bound} (95%)	10.0 fb	3.3 fb

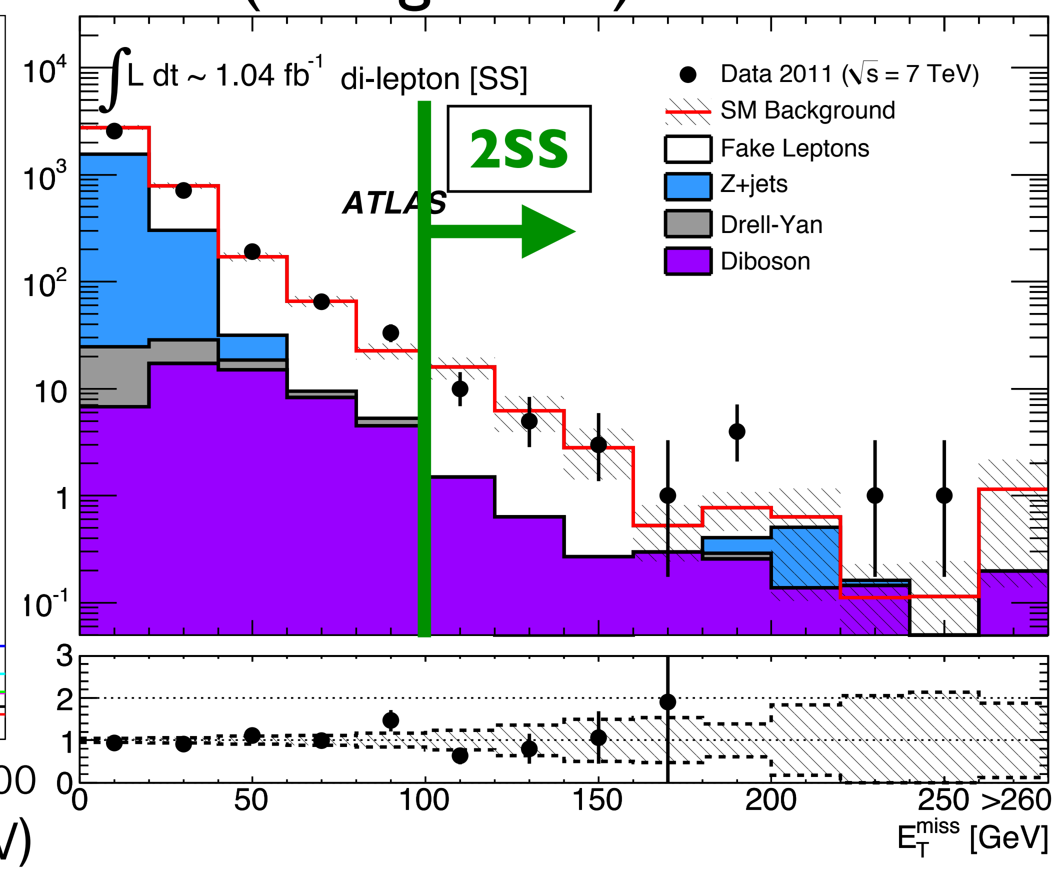
E_T^{miss}

- Neutrinos appear in the SUSY decay chains associated with charged leptons.
- E_T^{miss} distributions peak around (2/3)*Δm and have long tails.

signal



2SS (background)



E_T^{miss}

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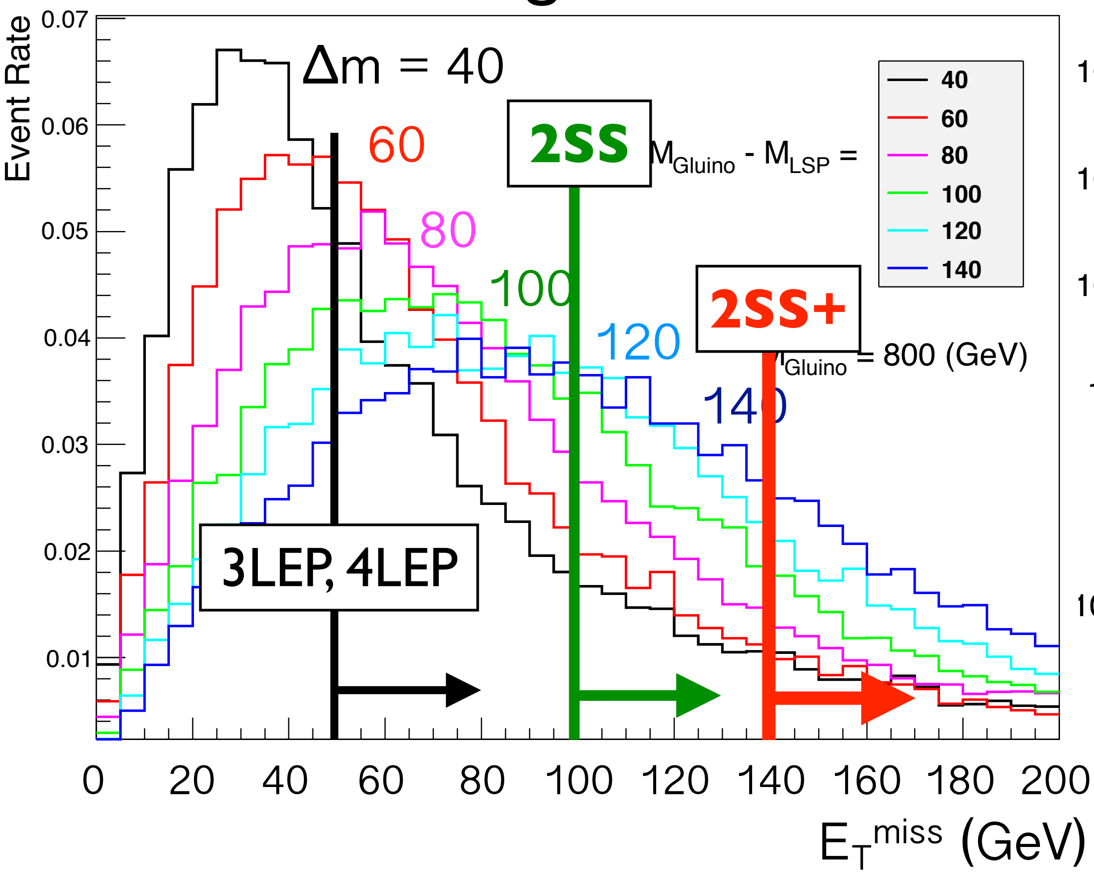
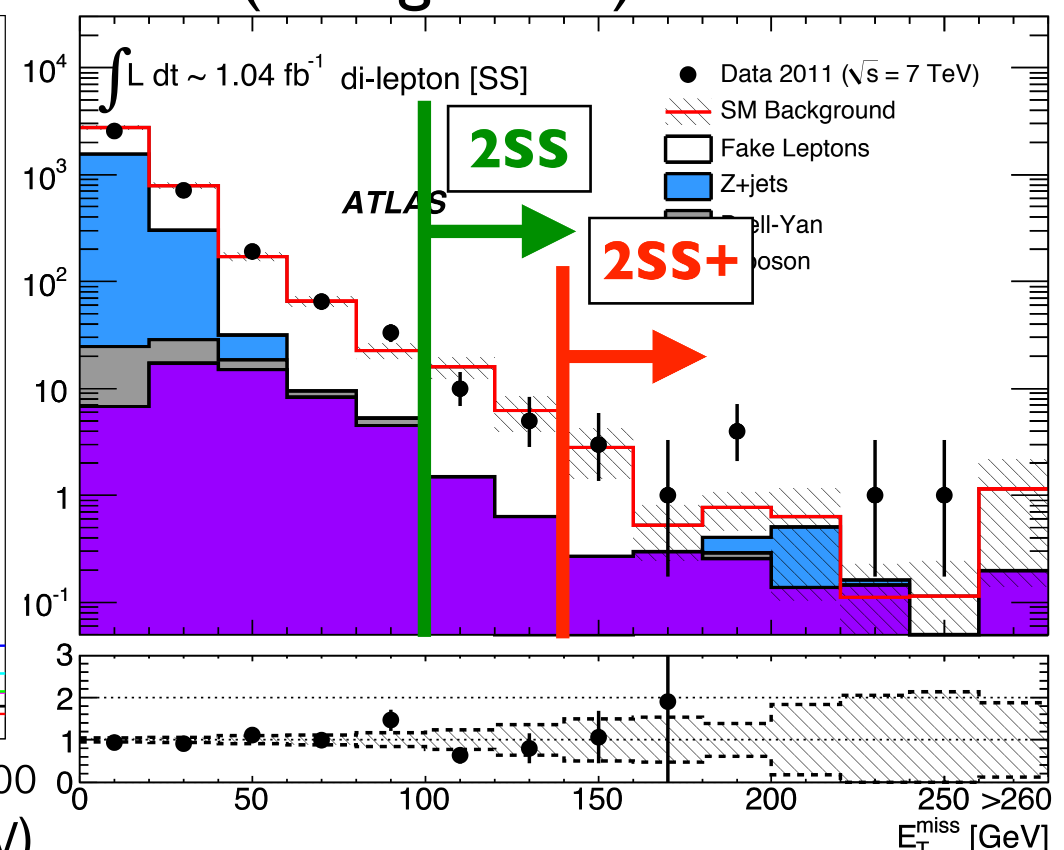
- E_T^{miss} distributions peak around (2/3)*Δm and have long tails.
- If E_T^{miss} cut is raised to 140 from 100 GeV in 2SS, 80% of the BG is removed, but reduction on the signal is only 30% (Δm ~ 70GeV).

signal



2SS (background)



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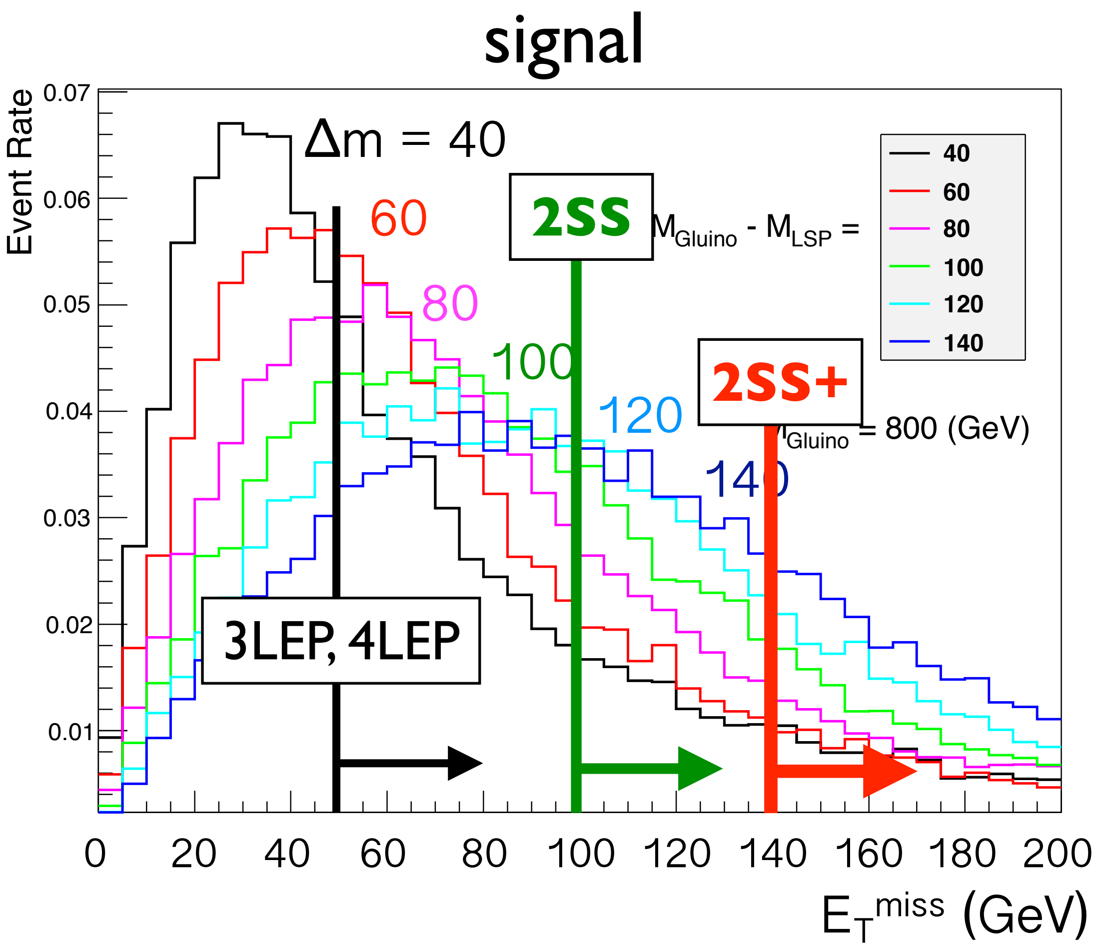
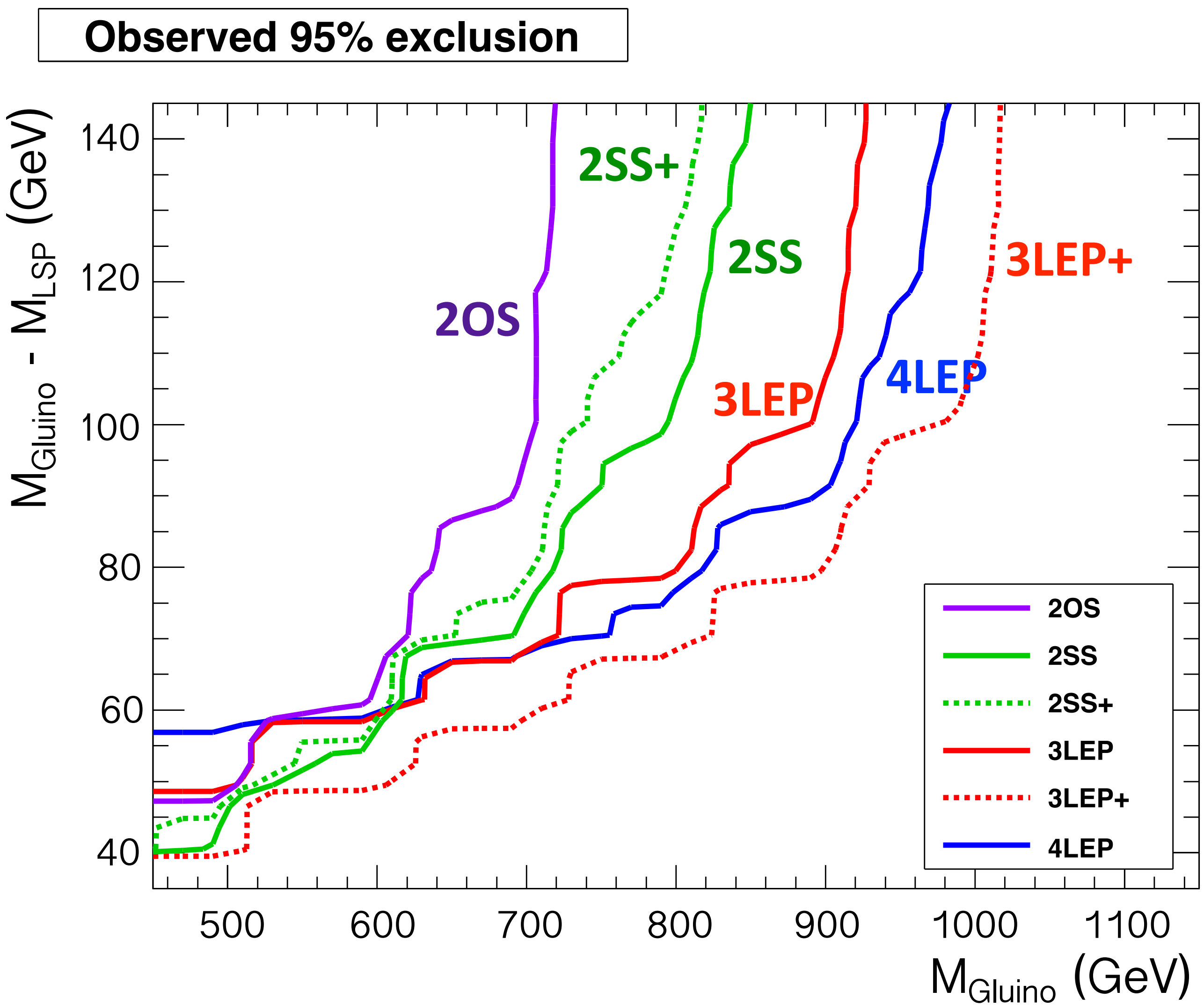


signal region	2SS	2SS+
N(lep)	= 2 (SS)	= 2 (SS)
leading μ (e) p_T	> 20 (25)	> 20 (25)
E_T^{miss} (GeV)	> 100	> 140
dilpton mass (GeV)	> 12	> 12
luminosity (fb^{-1})	1.04	1.04
expected BG	32.6 ± 7.9	6.4 ± 1.6
observed	25	10
σ_{vis}^{bound} (95% CL)	14.8 fb	10.9 fb

Exclusion

K.Rolbiecki, KS
(1206.6767)

- m_{Gluino} > 900GeV if Δm ~ 100GeV.
- New 3LEP+ significantly extends the exclusion limit.
- New 2SS+ does not extend the limit because of an excess in the signal region.



- m_{Gluino} > 900GeV at Δm～100GeV

Exclusion

K.Rolbiecki, KS
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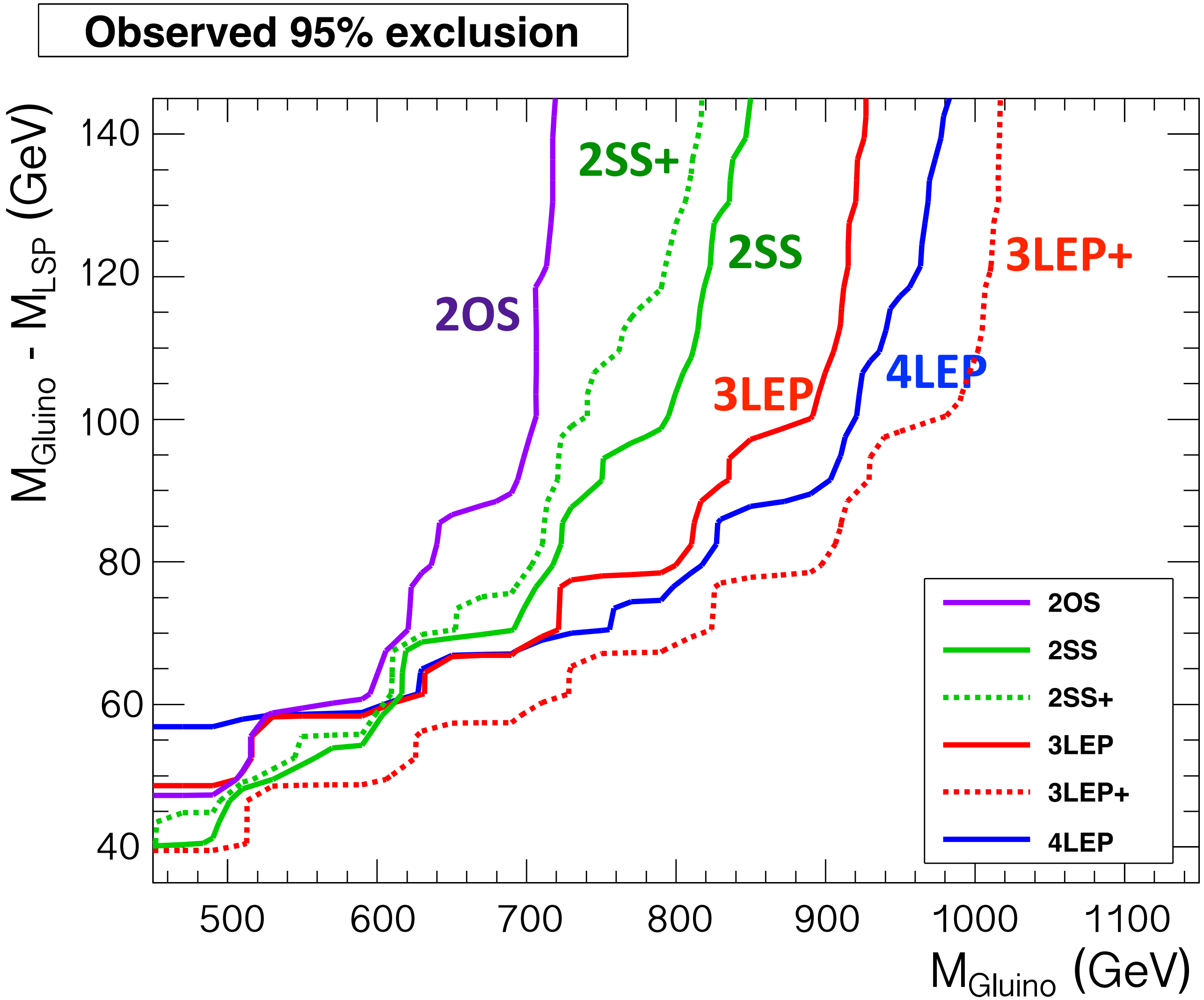
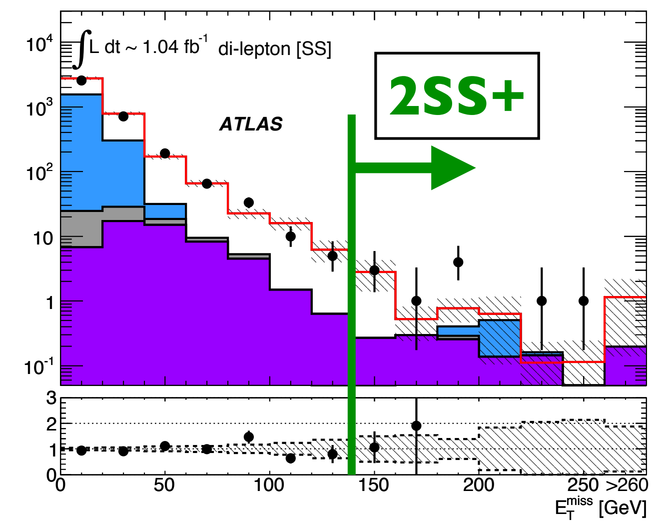
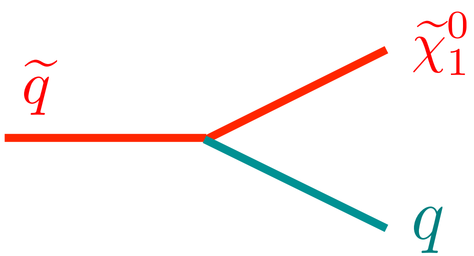




SR	2SS	2SS+
BG^{exp}	32.6±7.9	6.4±1.6
observed	25	10

R-parity

R-parity: $(-1)^{3B+L+2s}$



- Produced SUSY particles decay eventually into the lightest SUSY particle (LSP).

- The LSP is stable and should be neutral (because of cosmological constraints), and it contributes to the missing energy.

- Most SUSY searches rely on the missing energy signature.

	boson	fermion
quark, lepton	−	+
Higgs	+	−
gauge	+	−

SM particles SUSY particles