

Hunt for supersymmetry

--- hints and constraints ---

Kazuki Sakurai



In collaboration with:

Masaki Asano (Hamburg Univ), Krzysztof Rolbiecki (IFT)

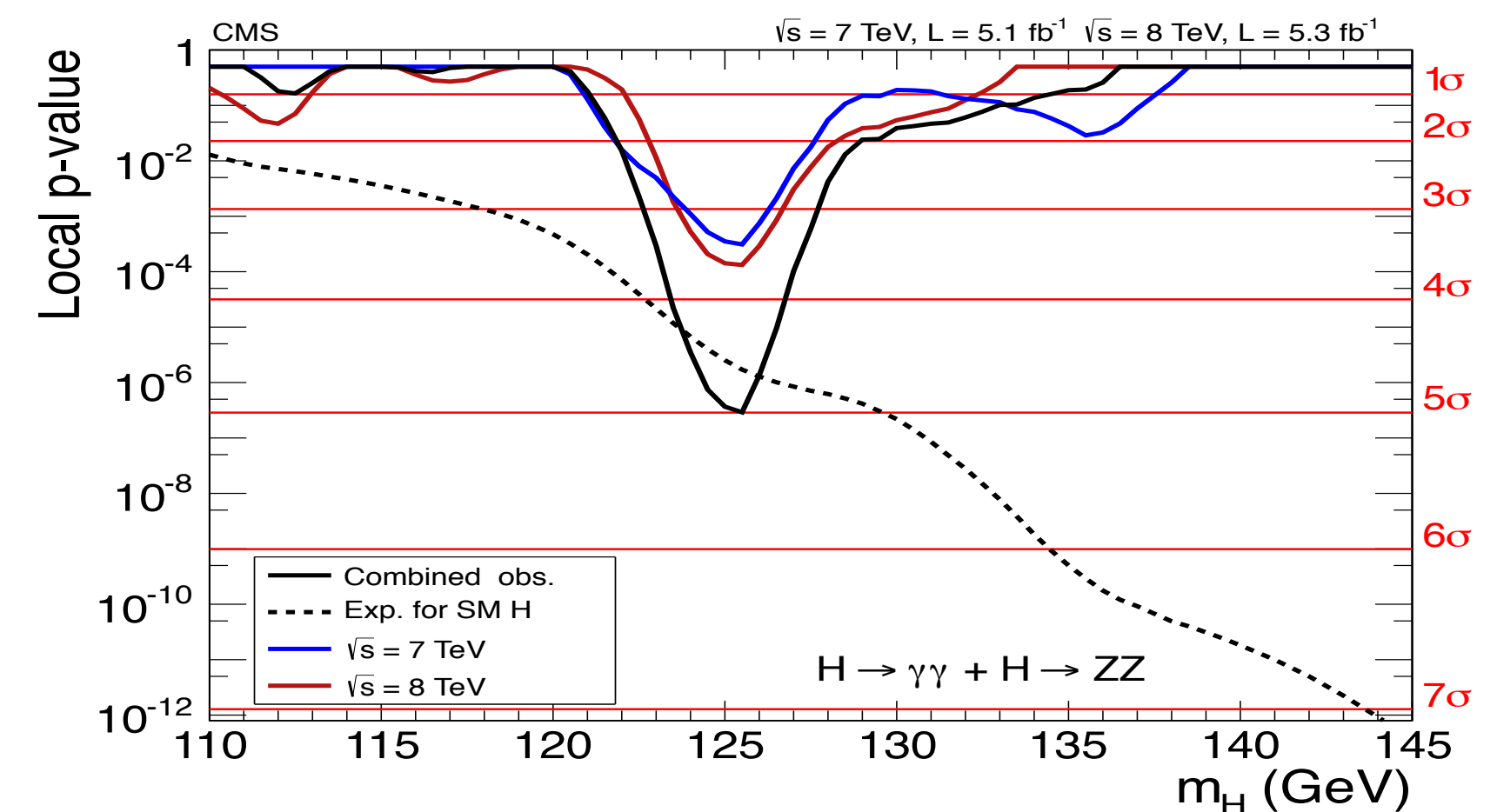
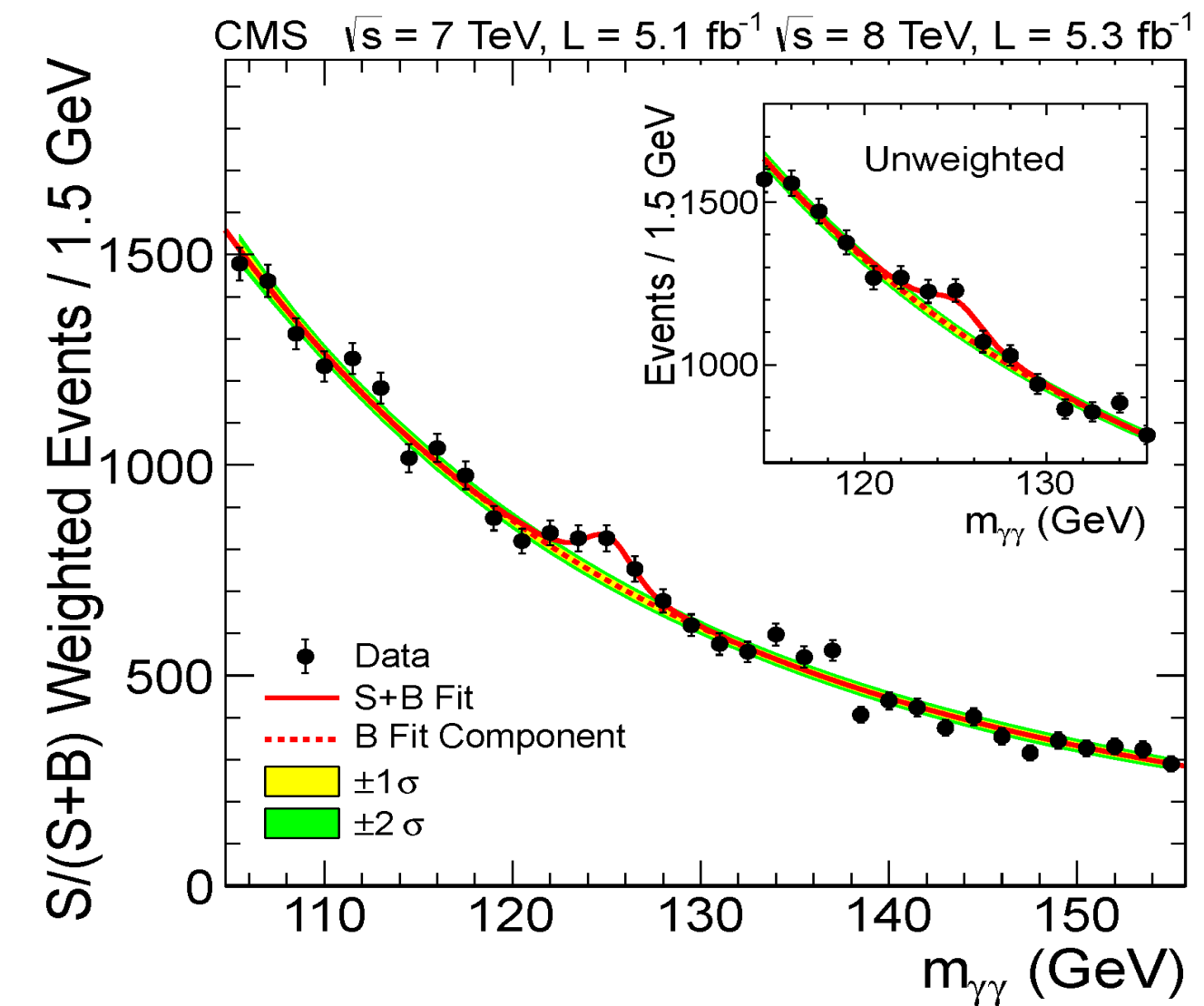
3/6/2013 bctp Seminar @ Bonn

Outline

- Introduction
- Beyond vanilla SUSY and constraints
 - Compressed SUSY
 - R-parity violation
- SUSY and excess in the WW xsec. measurements
- Summary

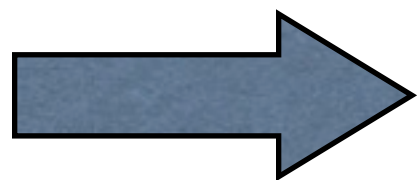
Discovery of a Higgs-like boson: 4th july 2012

last piece of the Standard Model



Beyond the Standard Model

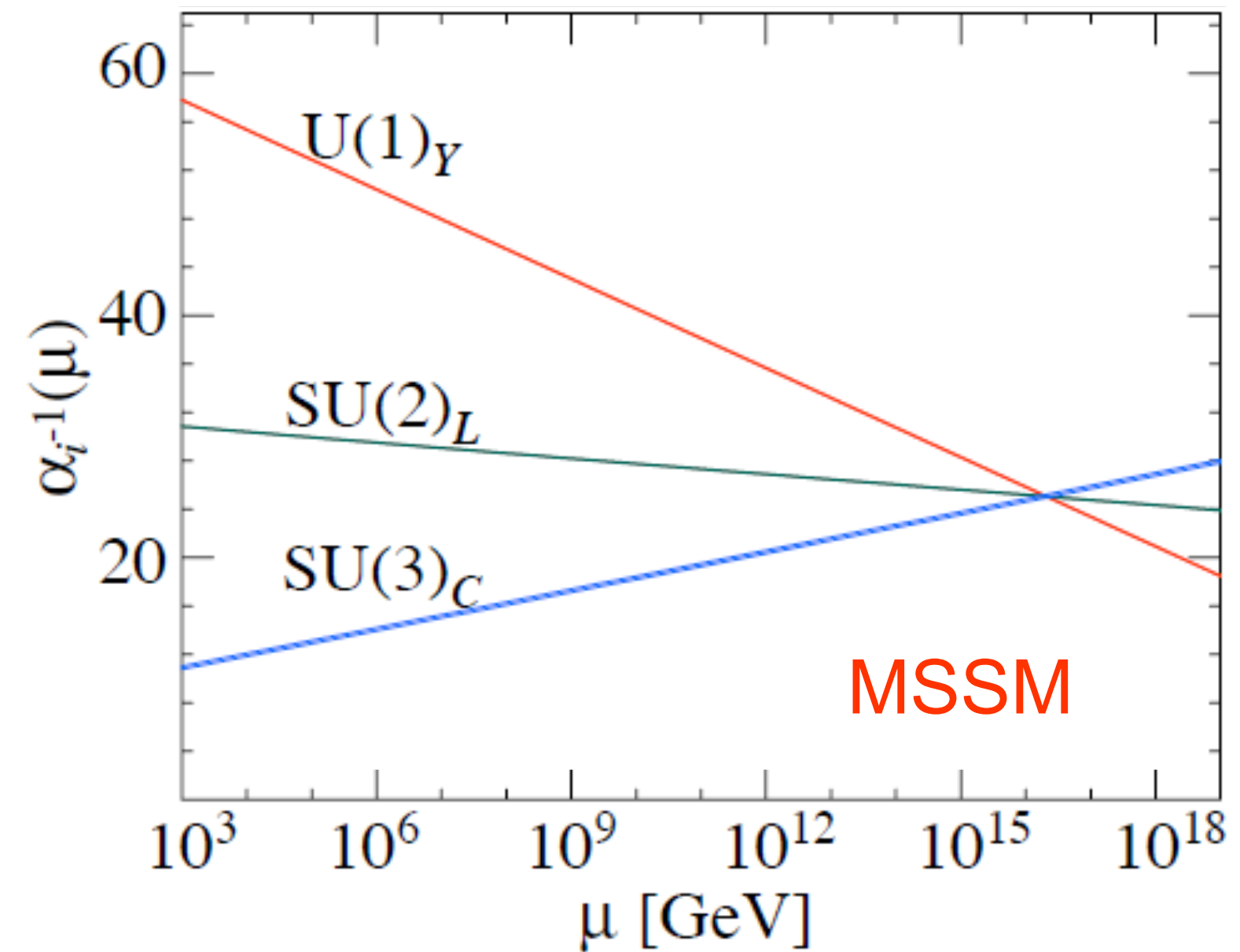
- SM is very successful but...
 - gravity is not included
 - cannot explain baryon asymmetry in the Universe
 - absence of Dark Matter particles
 - hierarchy problem
 - ...



beyond the Standard Model

Supersymmetry

- Supersymmetry is one of the most promising candidates of BSM
 - gauge coupling unification
 - has Dark Matter candidates
 - ameliorates hierarchy problem

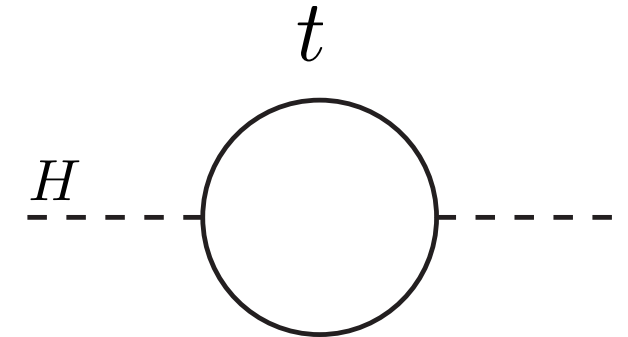


Naturalness of EWSB

Standard Model:

$$\begin{array}{ccc}
 m_H^2 & = & m_{H0}^2(\Lambda) + \Delta m_H^2 \\
 \wr & & \wr \\
 (126 \text{ GeV})^2 & & -\frac{Y_t^2}{8\pi^2} \Lambda^2 \sim (10^{17} \text{ GeV})^2
 \end{array}$$

cancel



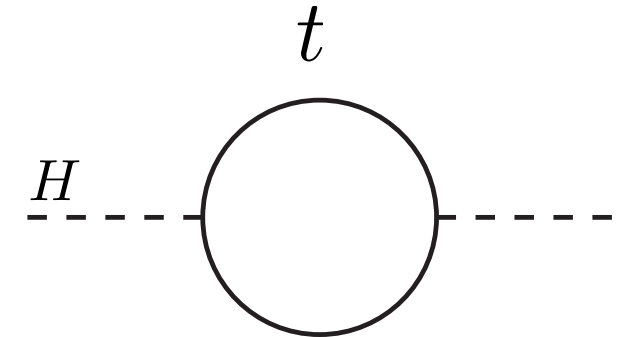
The Feynman diagram shows a circle representing a top quark loop. A dashed line labeled 'H' enters from the left and a dashed line labeled 'H' exits to the right. A solid line labeled 't' enters from the top of the circle.

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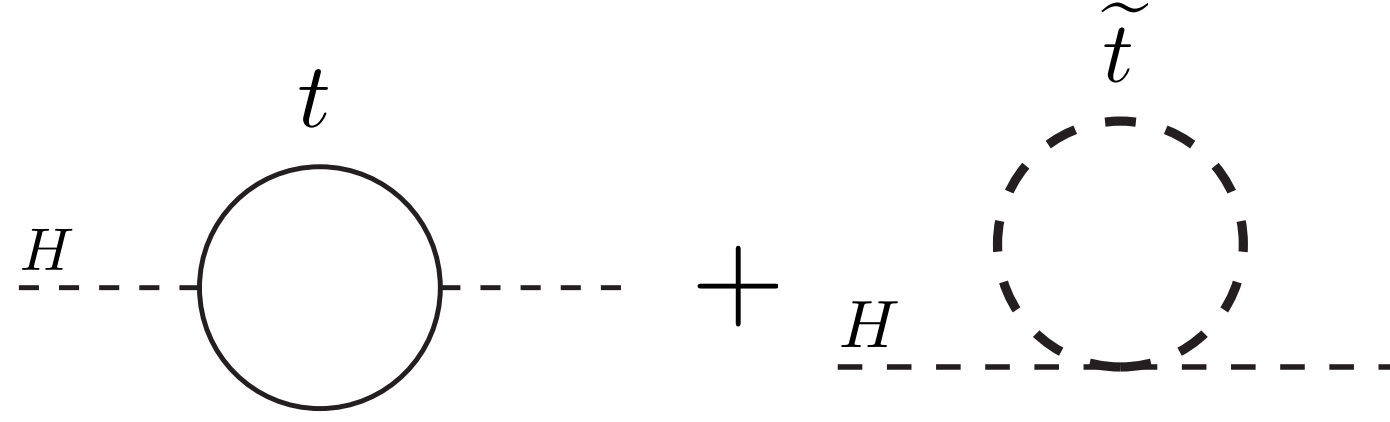
$\underbrace{\hspace{10em}}_{\substack{|\lambda \\ (126 \text{ GeV})^2}} \quad \xrightarrow{\text{cancel}} \quad \underbrace{\hspace{10em}}_{\substack{|\lambda \\ -\frac{Y_t^2}{8\pi^2} \Lambda^2 \sim (10^{17} \text{ GeV})^2}}$



Supersymmetry:

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

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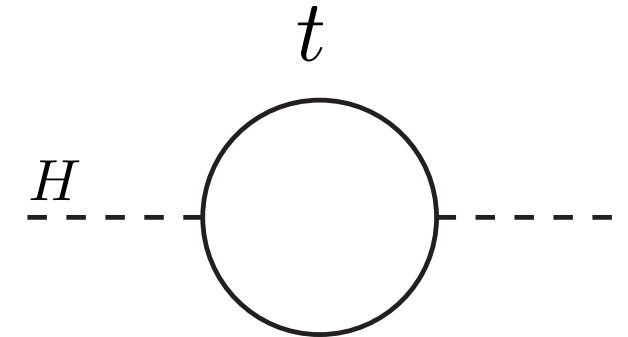
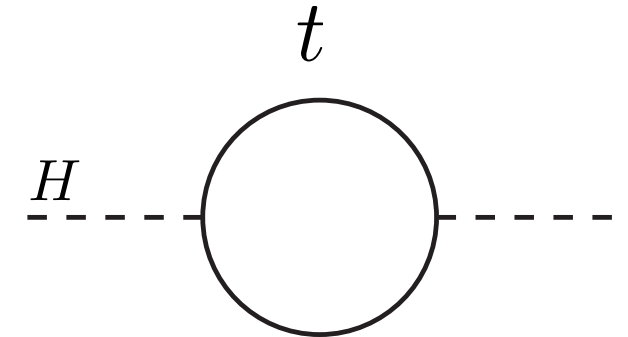


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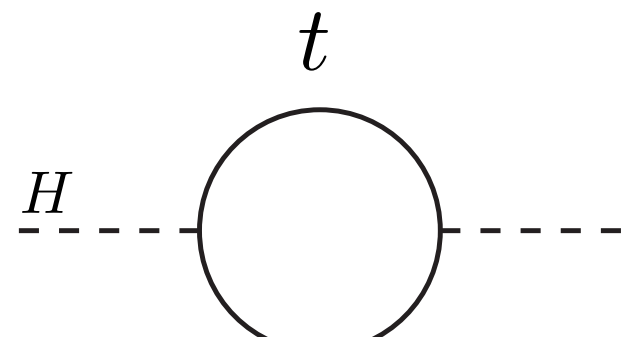
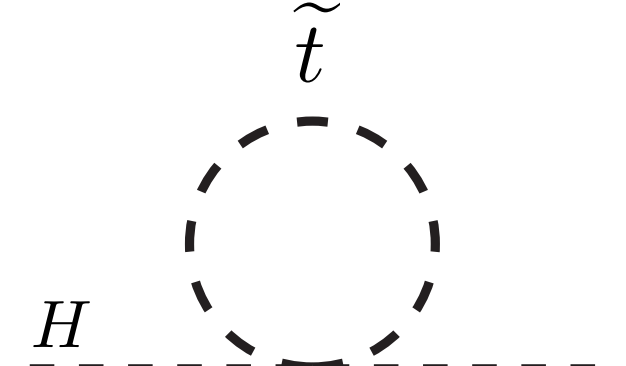
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$$\Delta m_{\tilde{t}}^2 \sim \frac{\alpha_s}{4\pi} m_{\tilde{g}}^2 \ln \left(\frac{\Lambda_{\text{medi}}}{m_{\tilde{t}}} \right)$$

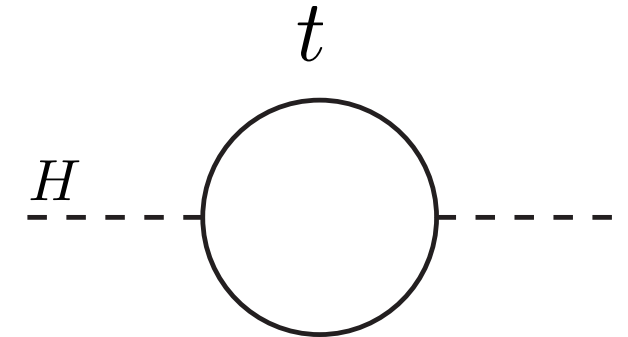
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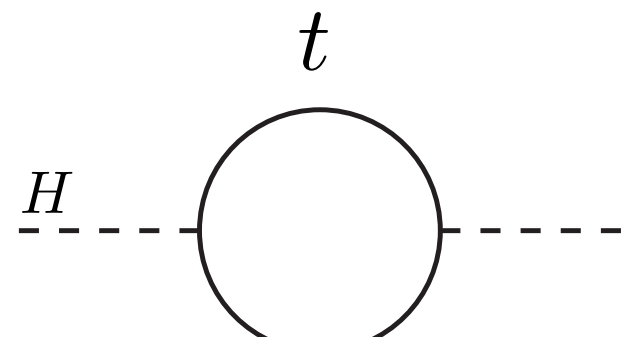
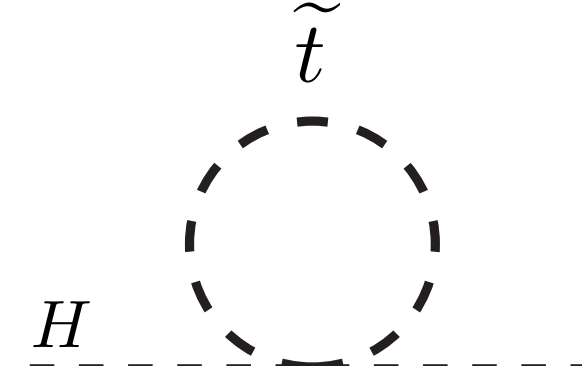


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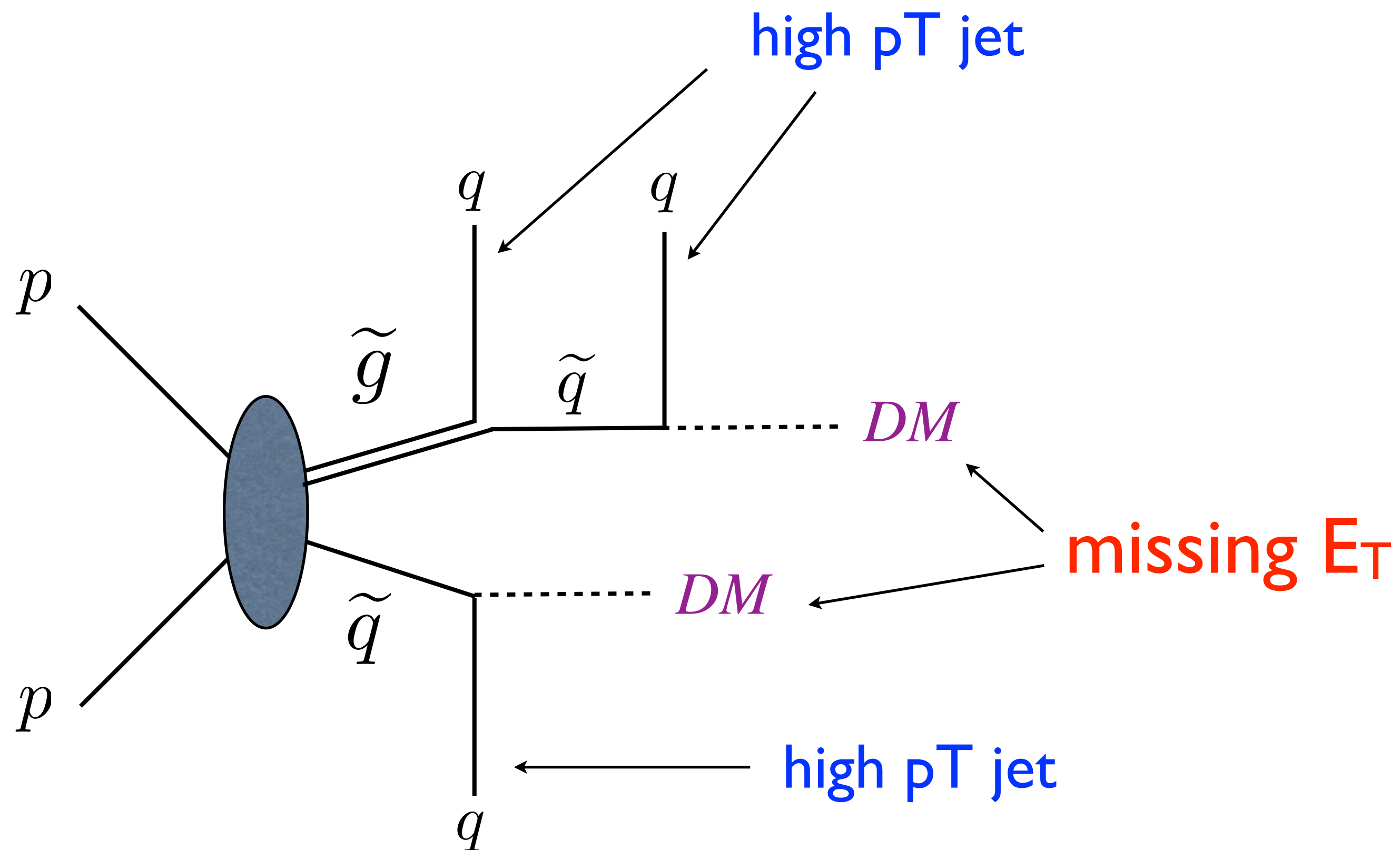
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higgsinos, stops, gluino masses should not be too far from the EW scale $\Rightarrow$ ***should be seen at the LHC***

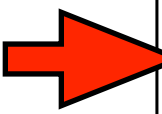
Typical SUSY signature at the LHC

- coloured SUSY particles ($\tilde{g}$, $\tilde{q}$) have sizeable cross section
- R-parity $\left\{ \begin{array}{l} - \text{pair production} \\ - \text{SUSY} \rightarrow \text{SM} + \text{neutral LSP} \end{array} \right.$

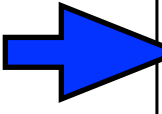
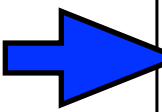


General procedure of BSM searches

large missing E_T



high p_T jets

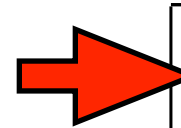


Requirement	A 2-jets	B 3-jets
$E_T^{\text{miss}} [\text{GeV}] >$	160	
$p_T(j_1) [\text{GeV}] >$	130	
$p_T(j_2) [\text{GeV}] >$	60	
$p_T(j_3) [\text{GeV}] >$	–	60
$p_T(j_4) [\text{GeV}] >$	–	–
$\Delta\phi(\text{jet}, \mathbf{E}_T^{\text{miss}})_{\min} [\text{rad}] >$	0.4 ($i = \{1, 2, (3)\}$)	
$E_T^{\text{miss}}/m_{\text{eff}}(Nj) >$	0.3/0.4/0.4 (2j)	0.25/0.3/– (3j)
$m_{\text{eff}}(\text{incl.}) [\text{GeV}] >$	1900/1300/1000	1900/1300/1000

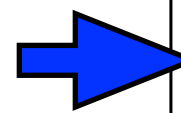
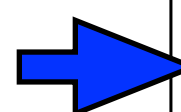
Signal Region	A-tight	B-tight
Total bkg	14 ± 5	8.7 ± 3.4
Observed	10	7
p_0	0.499	0.500
UL on N_{BSM}	8.9	7.3

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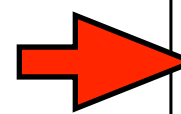
SM prediction

observed

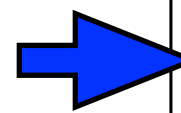
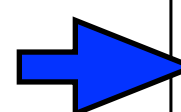
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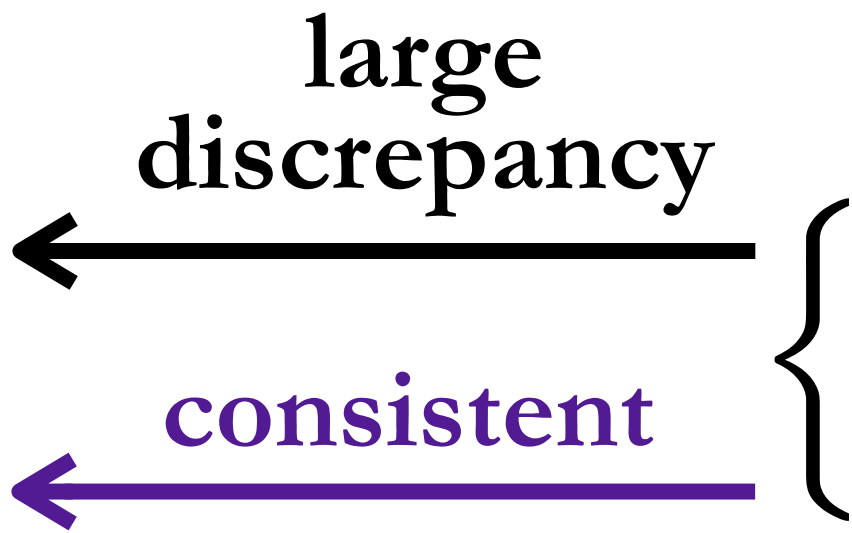
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discovery of new physics

can set limits on models

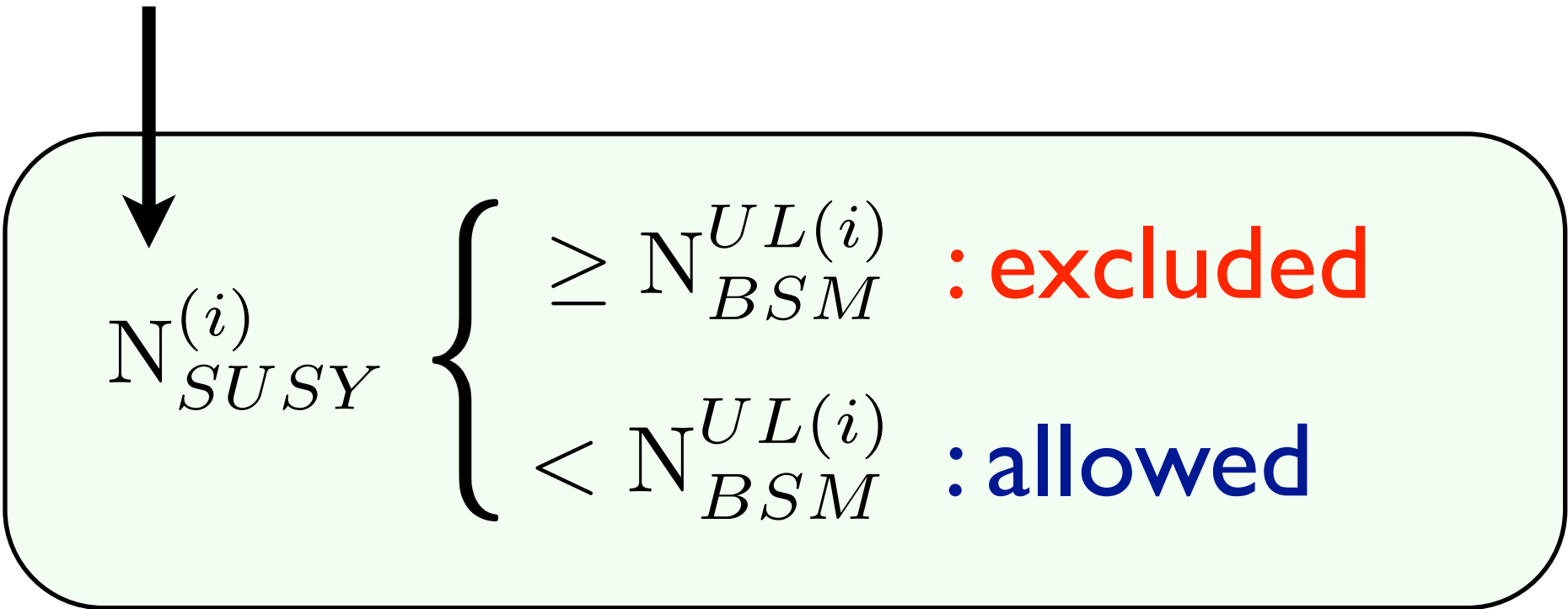


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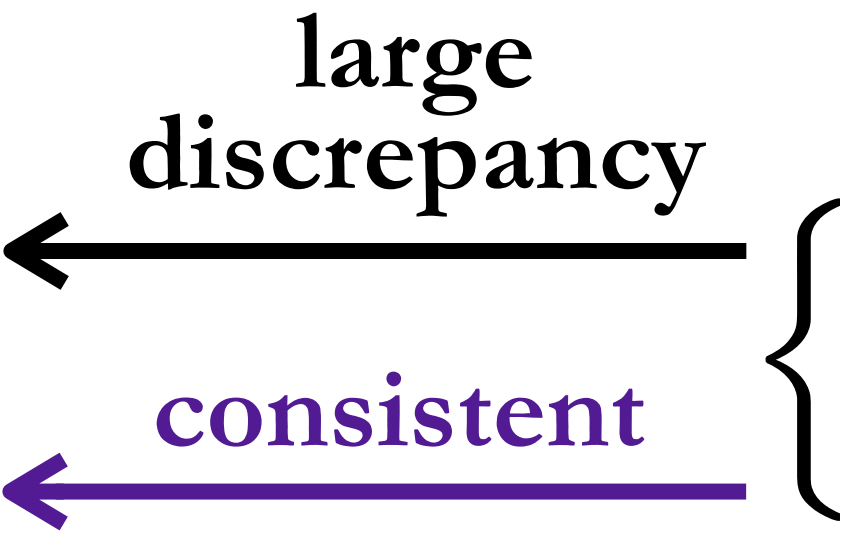
General procedure of BSM searches

SUSY contribution to the signal region i



discovery of new physics

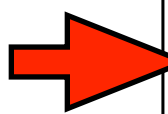
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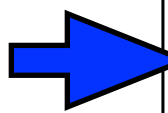
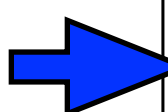
SM prediction
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UL on BSM contribution

large missing E_T



high p_T jets



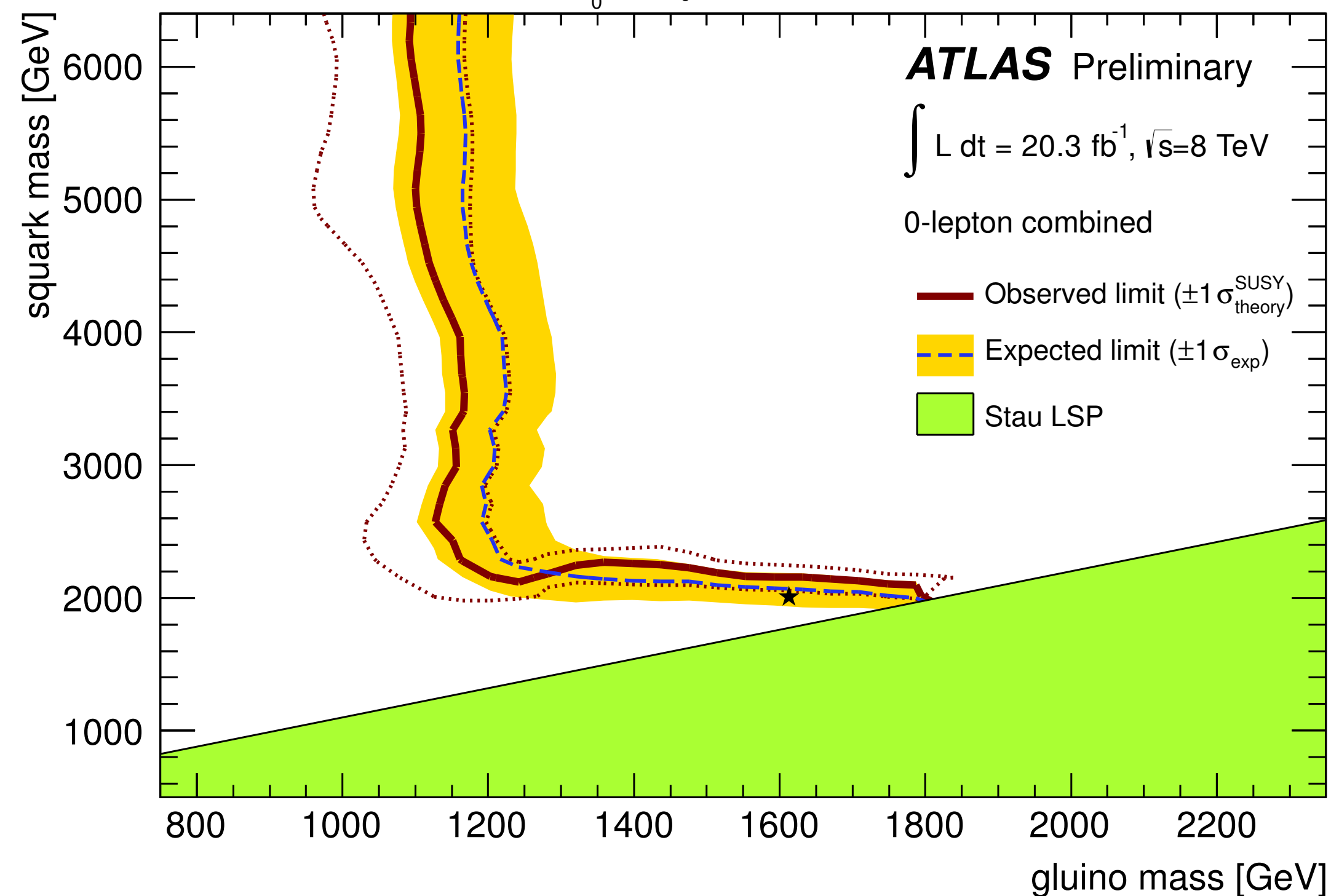
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Recent results

CMSSM

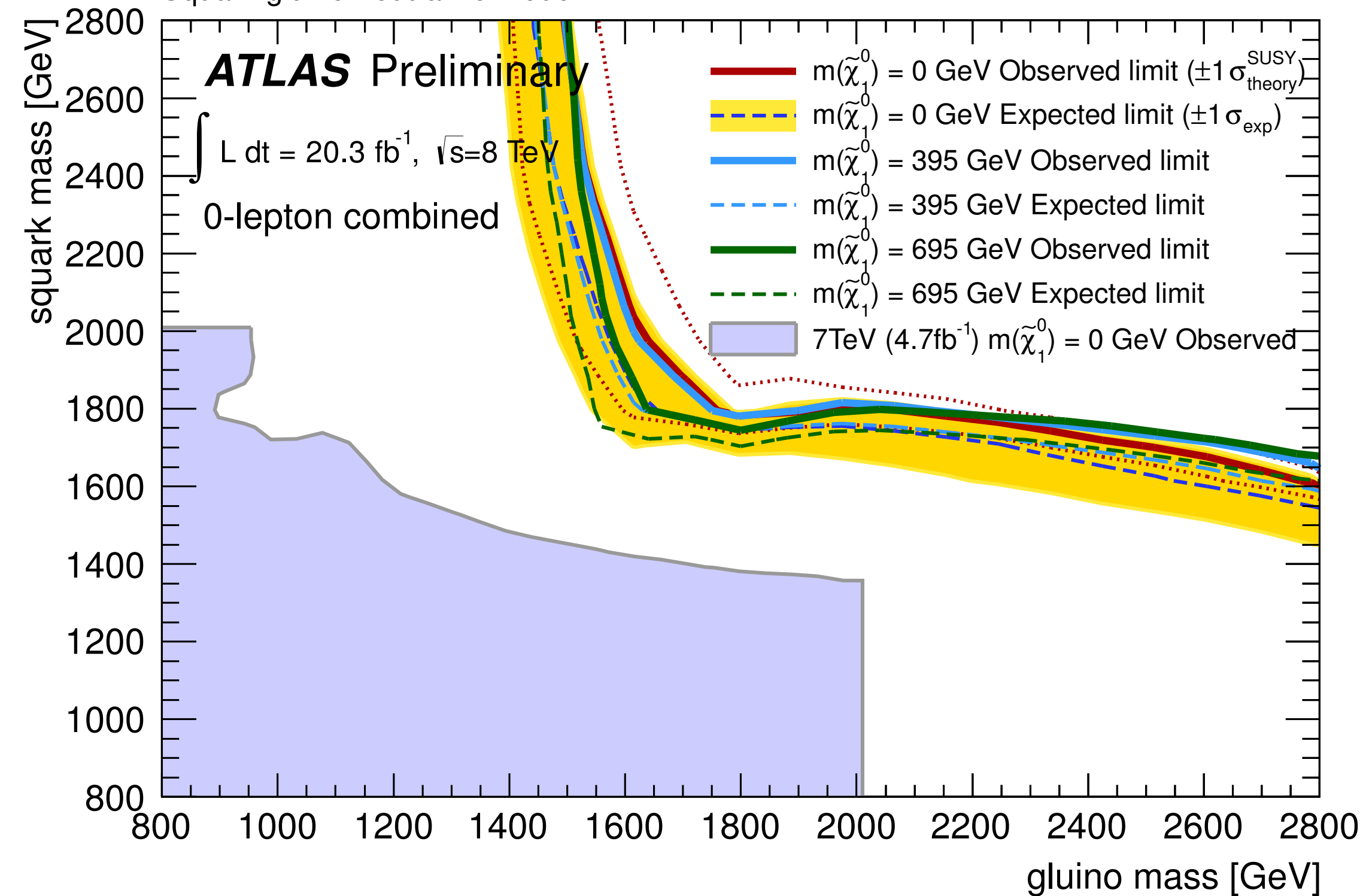
MSUGRA/CMSSM: $\tan\beta = 30$, $A_0 = -2m_0$, $\mu > 0$



- $M_{\text{gluino}} \gtrsim 1.1 \text{ TeV}$
- $M_{\text{squark}} \gtrsim 2.0 \text{ TeV}$

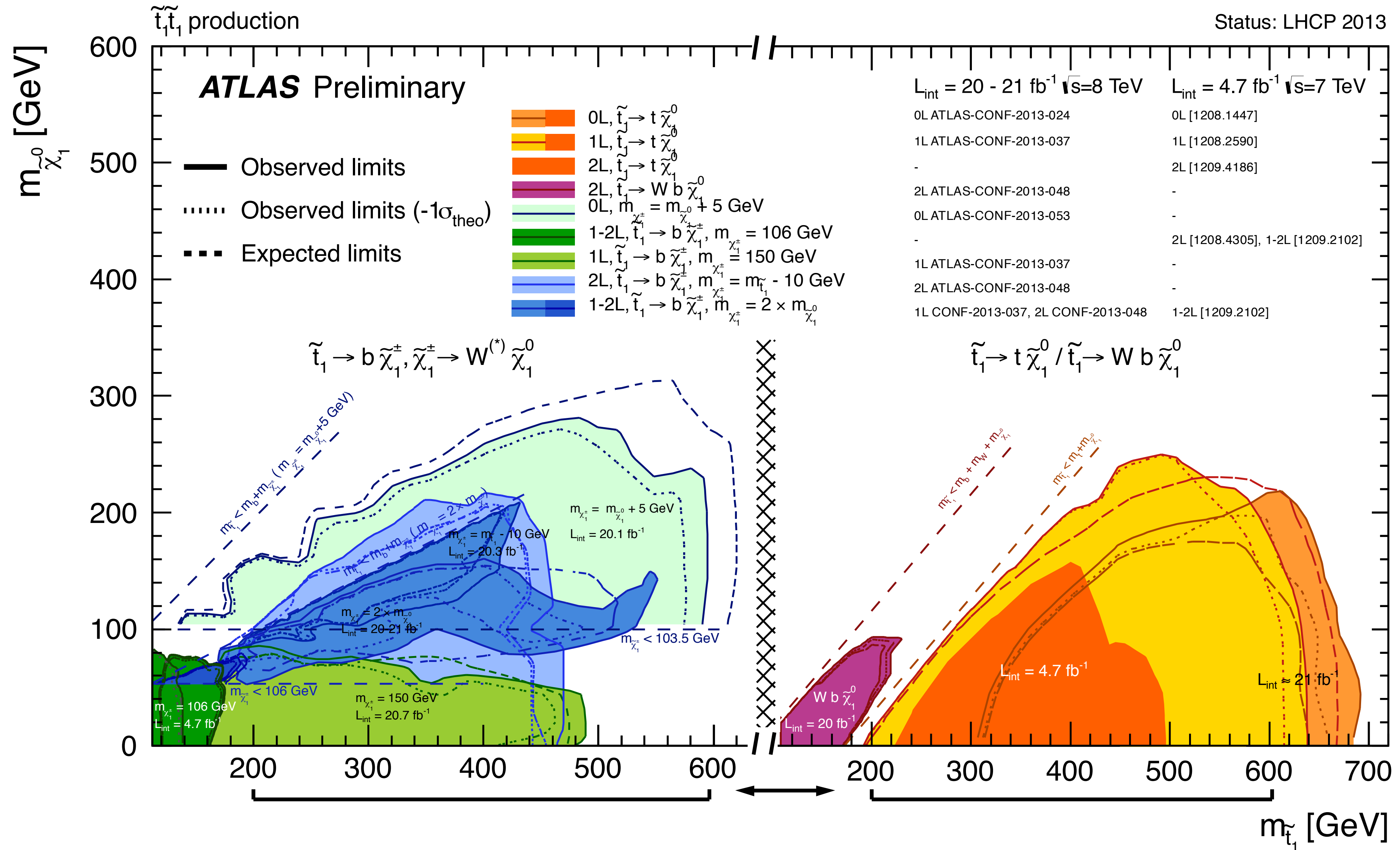
Squark-gluino-neutralino model

Squark-gluino-neutralino model



- $M_{\text{gluino}} \gtrsim 1.5 \text{ TeV}$
- $M_{\text{squark}} \gtrsim 1.6 \text{ TeV}$

Direct stop searches



Beyond vanilla SUSY

- In 7 and 8 TeV runs, ATLAS and CMS have put various constraints on the SUSY parameter space. So far most searches rely on high p_T jets (b-jets) or large E_T^{miss} signatures.
- What if SUSY *does not* produce high p_T jets and large E_T^{miss} ? E.g. in

Compress SUSY, R-parity violation

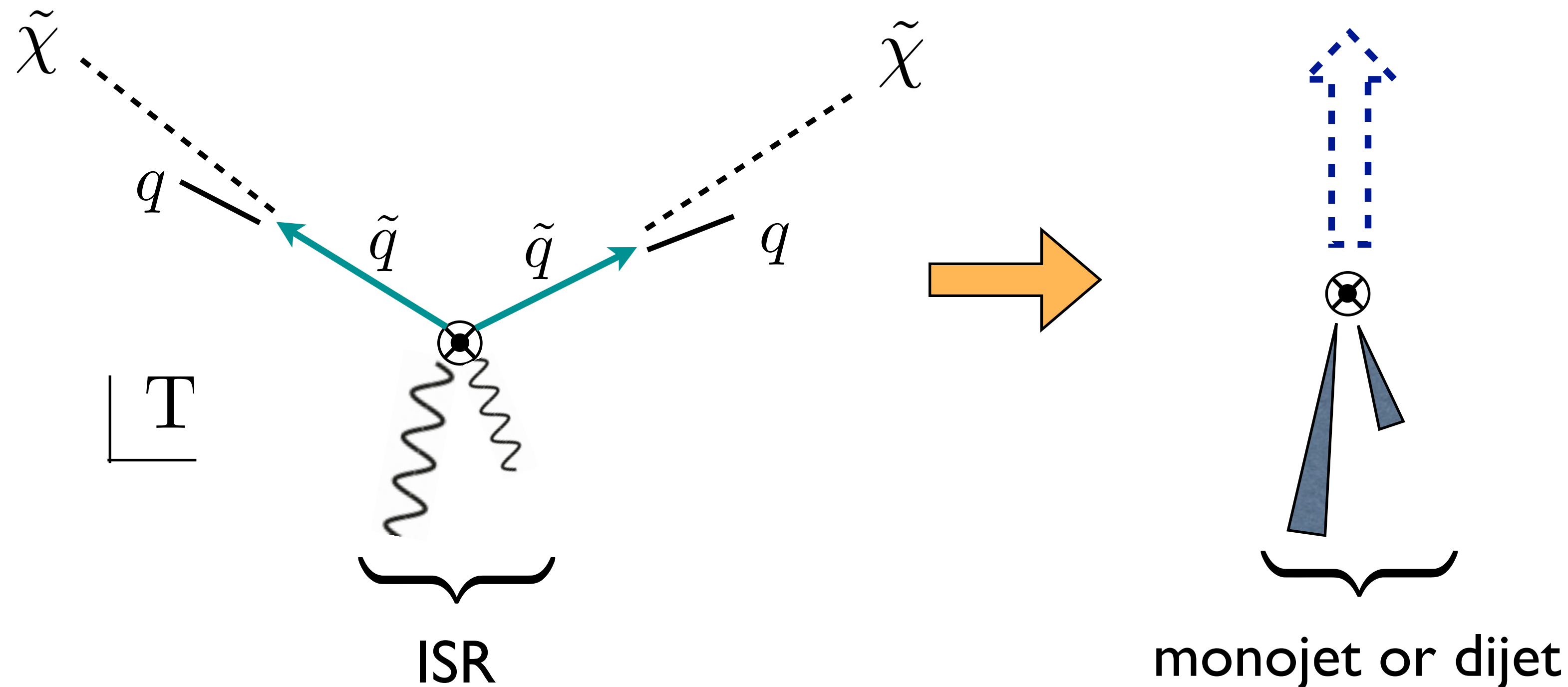
- **Multi-lepton** and **very large jet multiplicity channels** have a good handle on controlling SM backgrounds without requiring high p_T jets or large E_T^{miss} and can place stringent limits on the above models.

Initial State Radiation

- If there are hard initial state radiations, the squark system is kicked recoiling against the ISR jets. Then the two neutralinos are no longer back-to-back in the transverse plane and the cancelation does not occur in the net E_T^{miss} .

Alwall, de Visscher, Maltoni (0810.5350), Alwall, Le, Li santi, Wacker (0809.3264)

- The events look like mono or dijet plus moderate E_T^{miss} .



Monojet and dijet constraint

$$p_{j1}^T > 120 \text{ GeV}$$

$$\Delta\phi(\vec{p}_T^{\text{miss}}, \vec{p}_{j2}^T) > 0.5$$

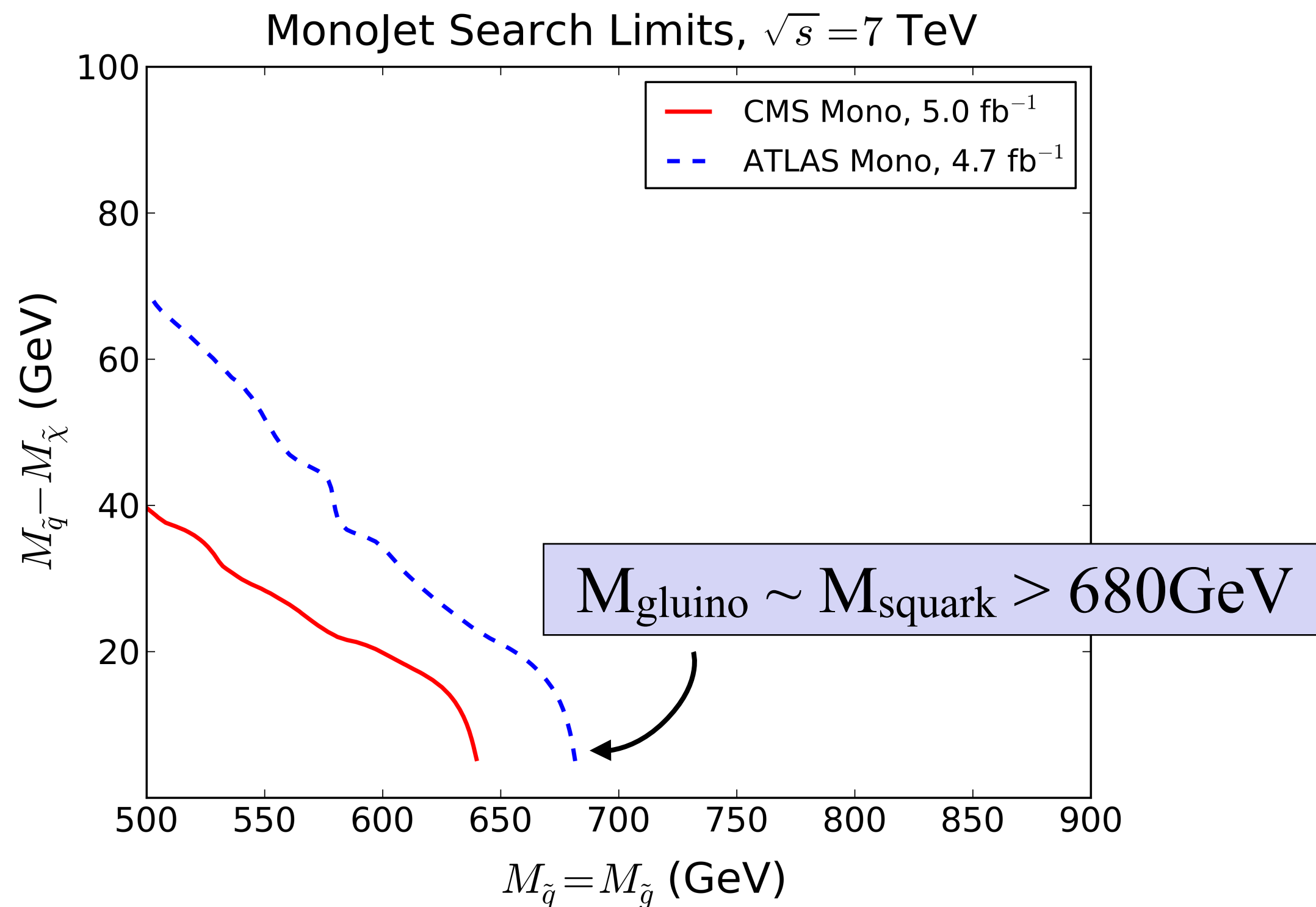
no 3rd jet with $p_T > 30 \text{ GeV}$

$$E_T^{\text{miss}} > 160 \text{ GeV} \quad E_T^{\text{miss}}/m_{\text{eff}}(2j) > 0.4$$

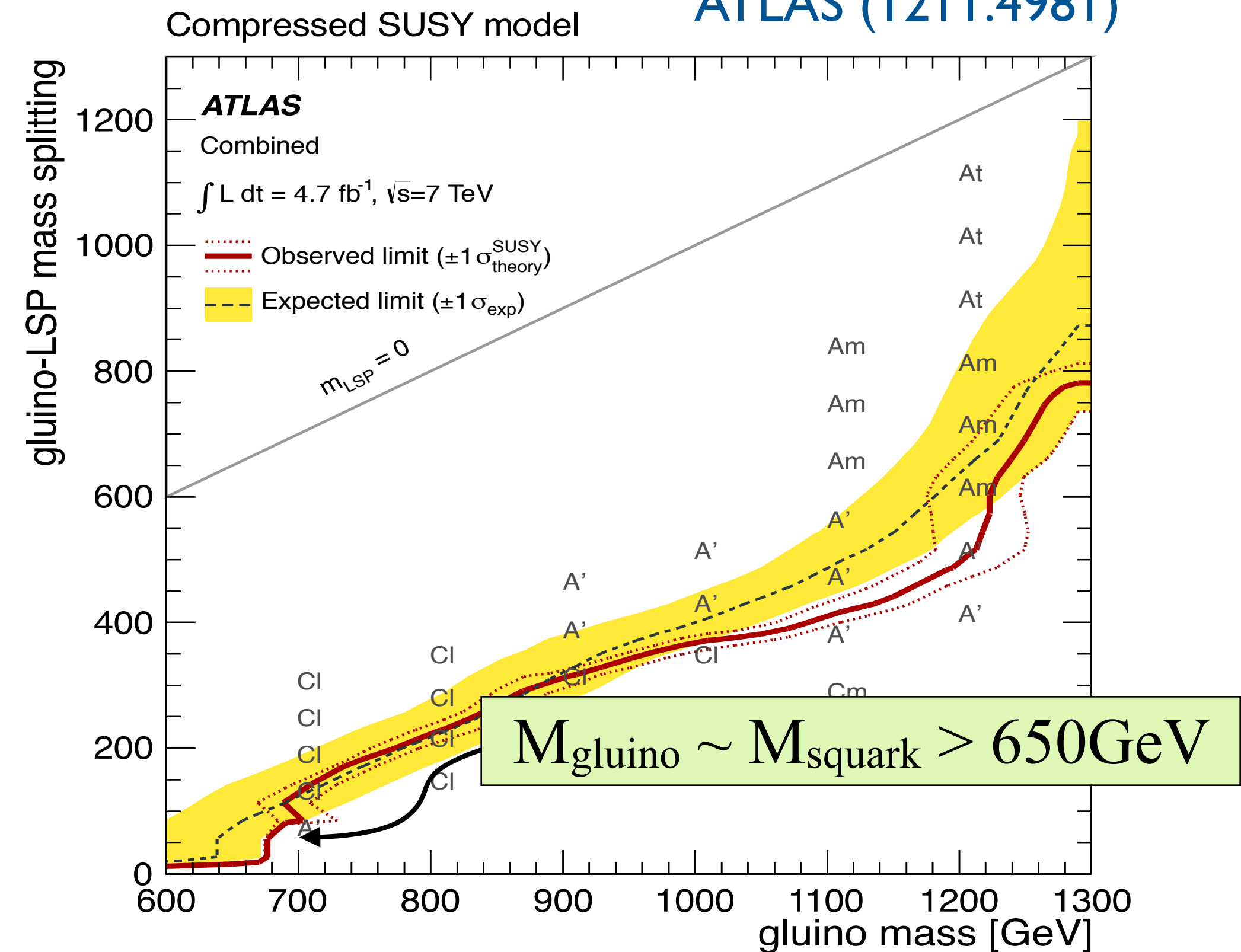
$$p_{j1}^T > 130 \text{ GeV} \quad p_{j2}^T > 60 \text{ GeV}$$

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

Dreiner, Kramer, Tattersall (1211.4981)



ATLAS (1211.4981)



Looking at leptonic signatures

- We reinterpret three ATLAS (7TeV) analyses: 1110.6189, 1204.5638, ATLAS-CONF-2012-001

Signal Region	2OS	2SS	3LEP	4LEP
# of leptons	= 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

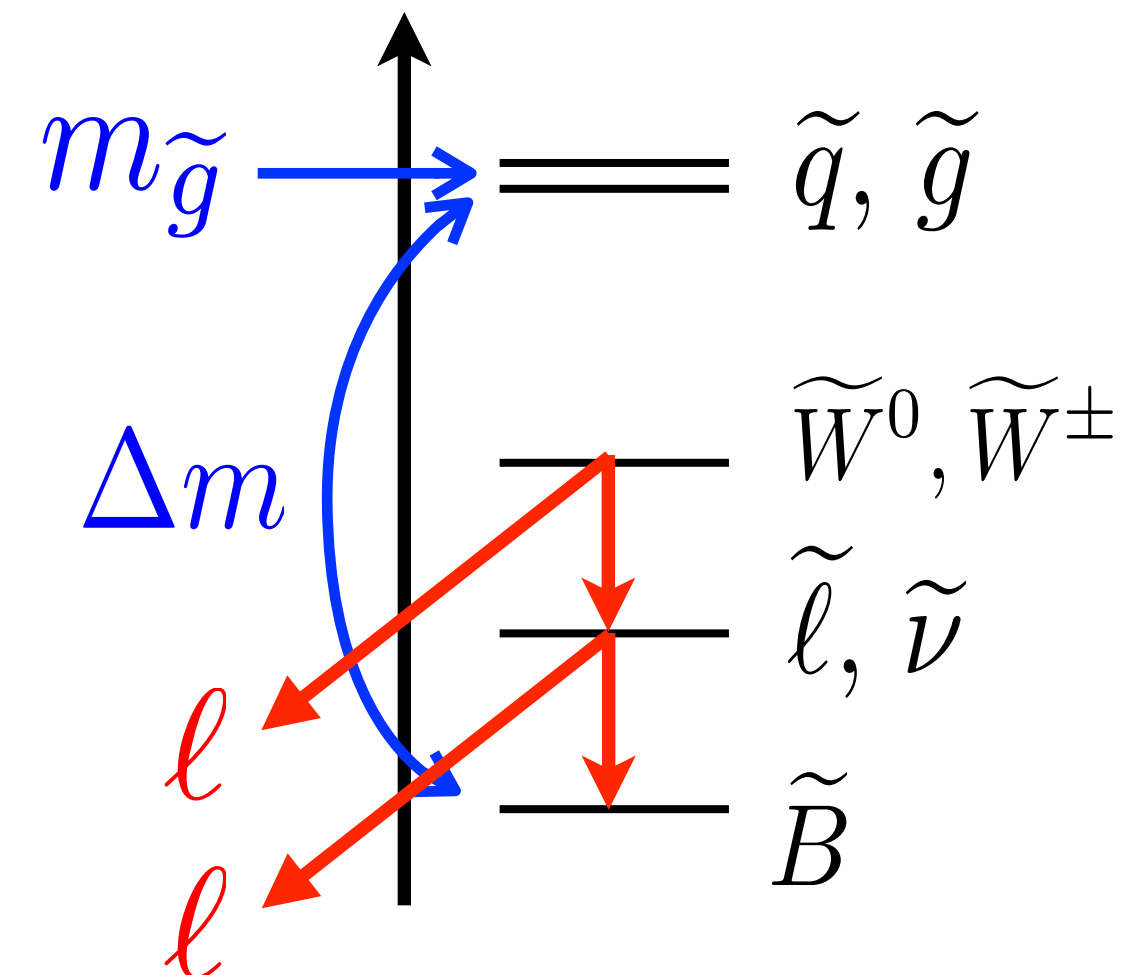
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- We use a simplified model defined as follows

- $m_{\tilde{q}} \simeq m_{\tilde{g}}$
- $m_{\tilde{W}} = \frac{m_{\tilde{g}} + m_{\tilde{\chi}_1^0}}{2}, m_{\tilde{\ell}} = \frac{m_{\tilde{W}} + m_{\tilde{\chi}_1^0}}{2}$



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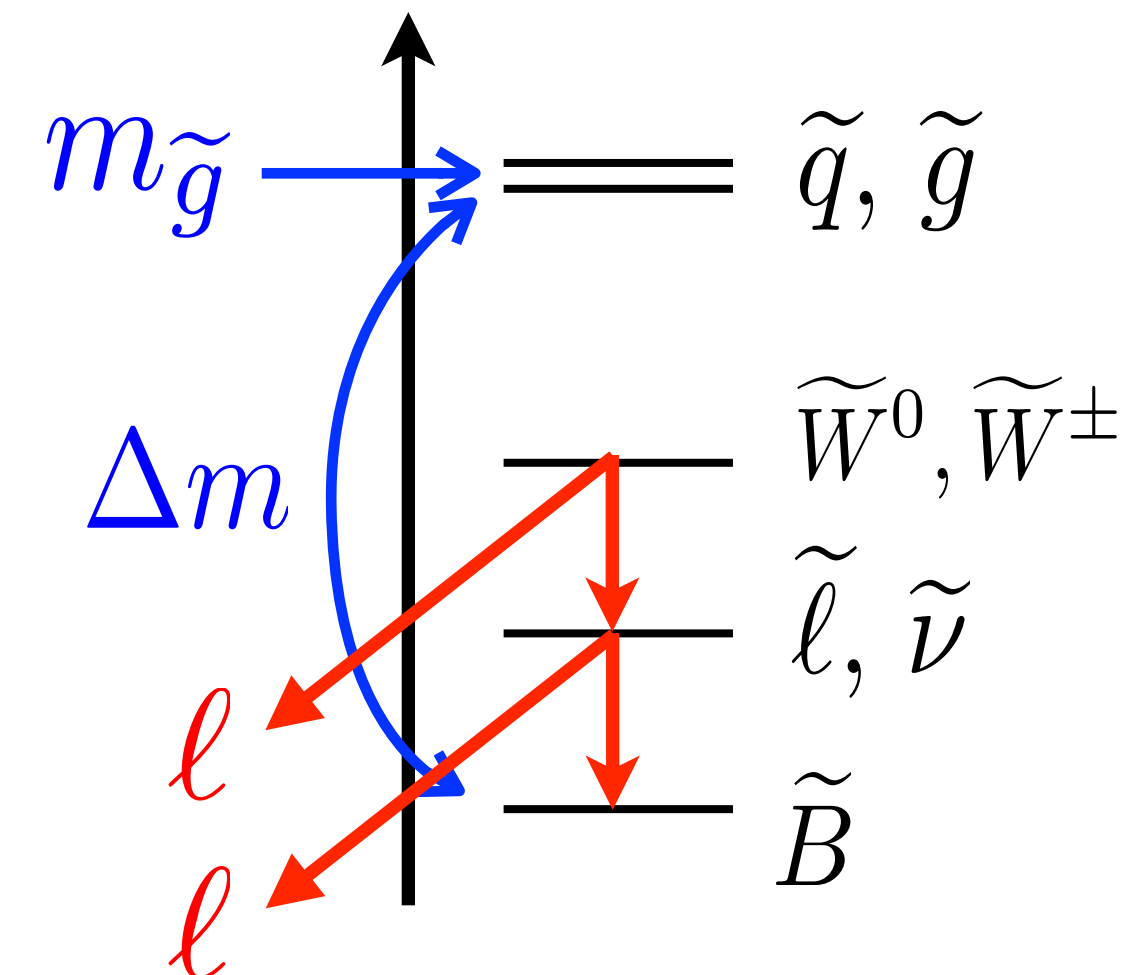
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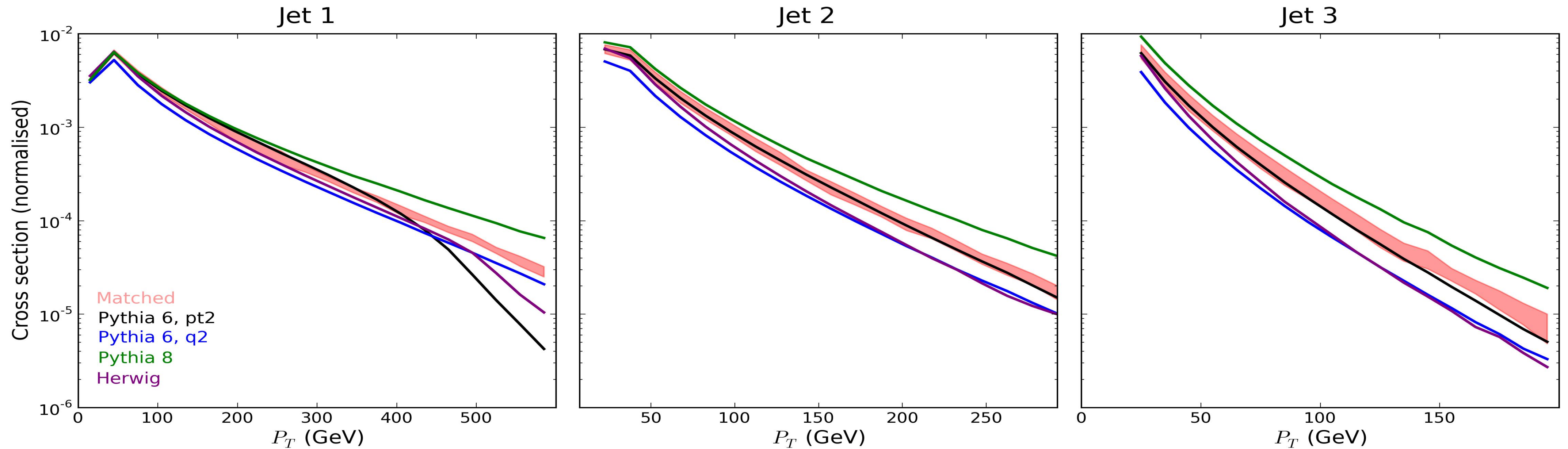
- MC simulation and cross section calc. using

Hersig++, Delphes, Prospino2.1



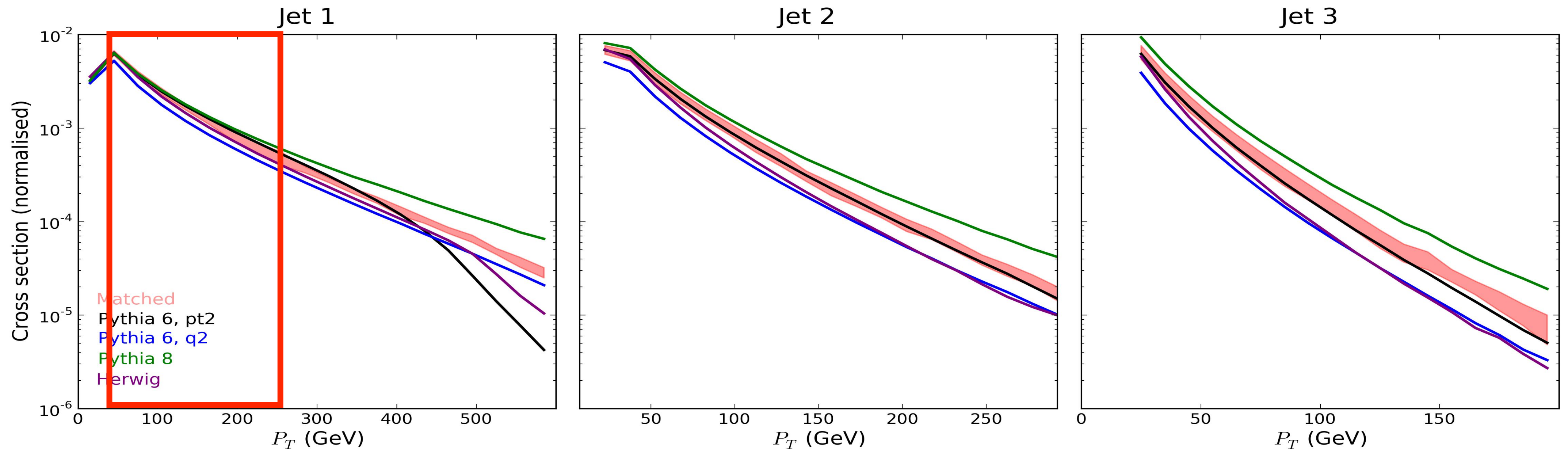
Validity of parton shower approx.

- The uncertainty of the parton shower-based event simulation have been discussed in detail in [Dreiner, Kramer, Tattersall \(1211.4981\)](#).



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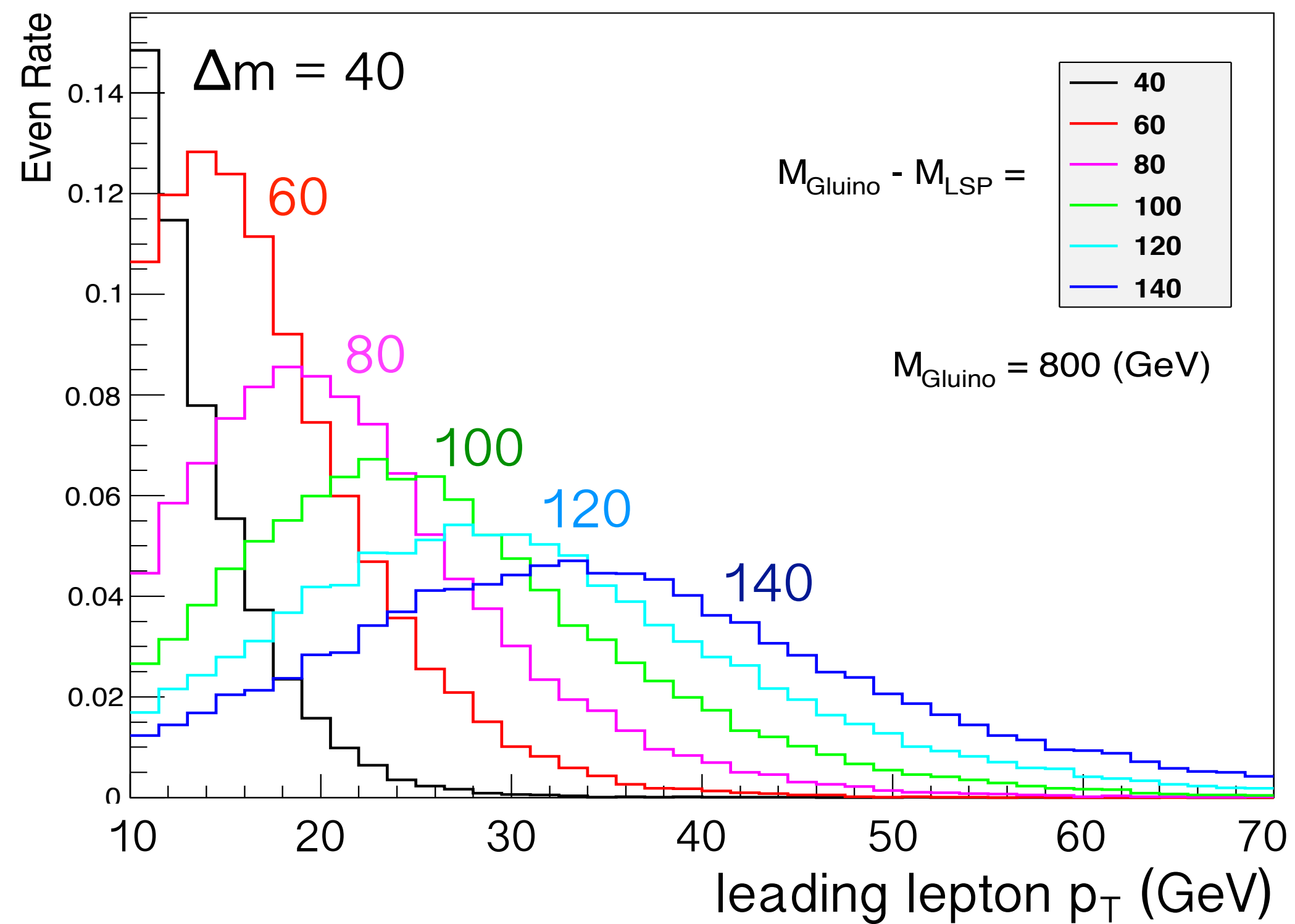
- Discrepancy between Herwig and matched ISR is not large in small p_T region

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leading lepton p_T

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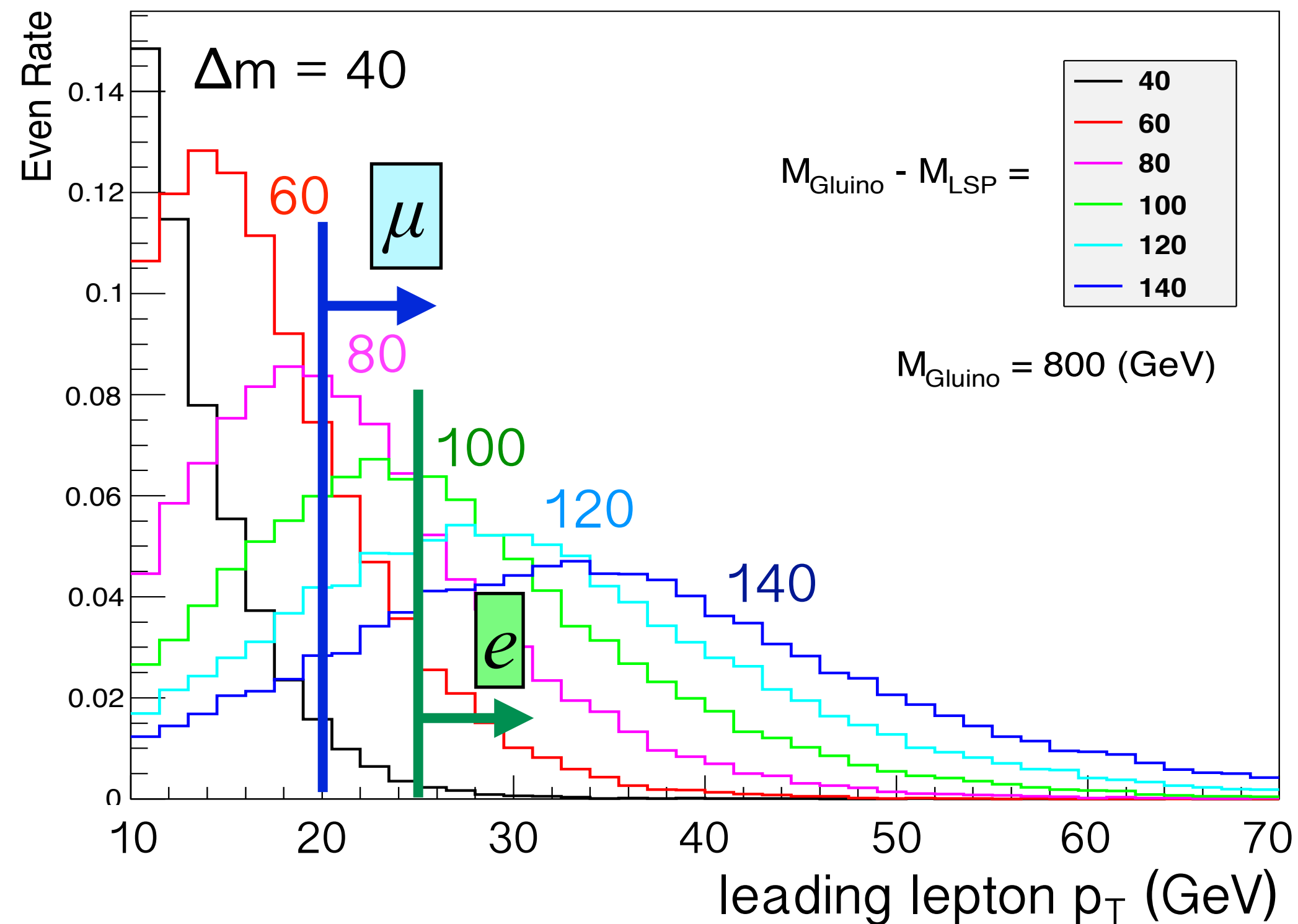
signal



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

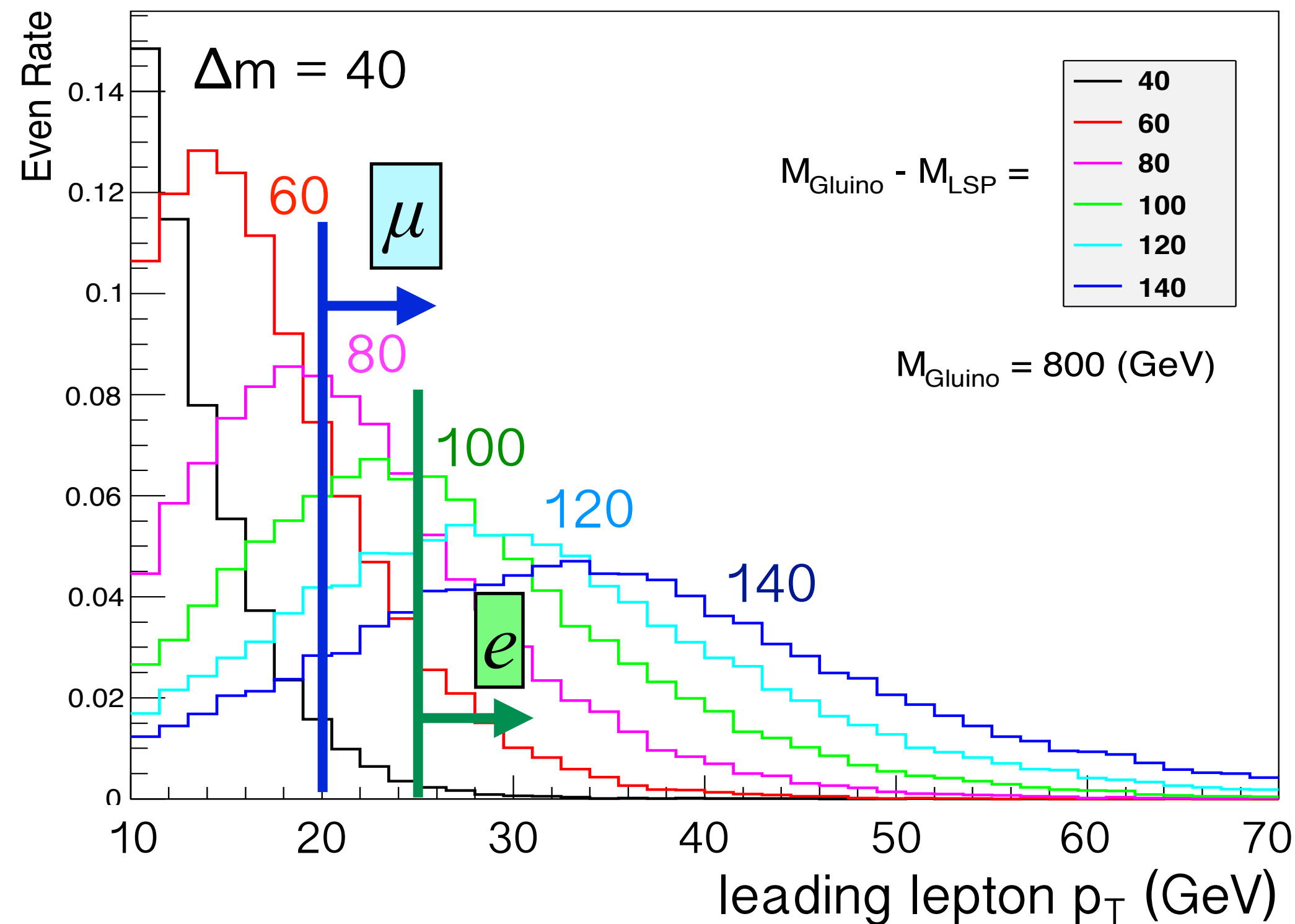
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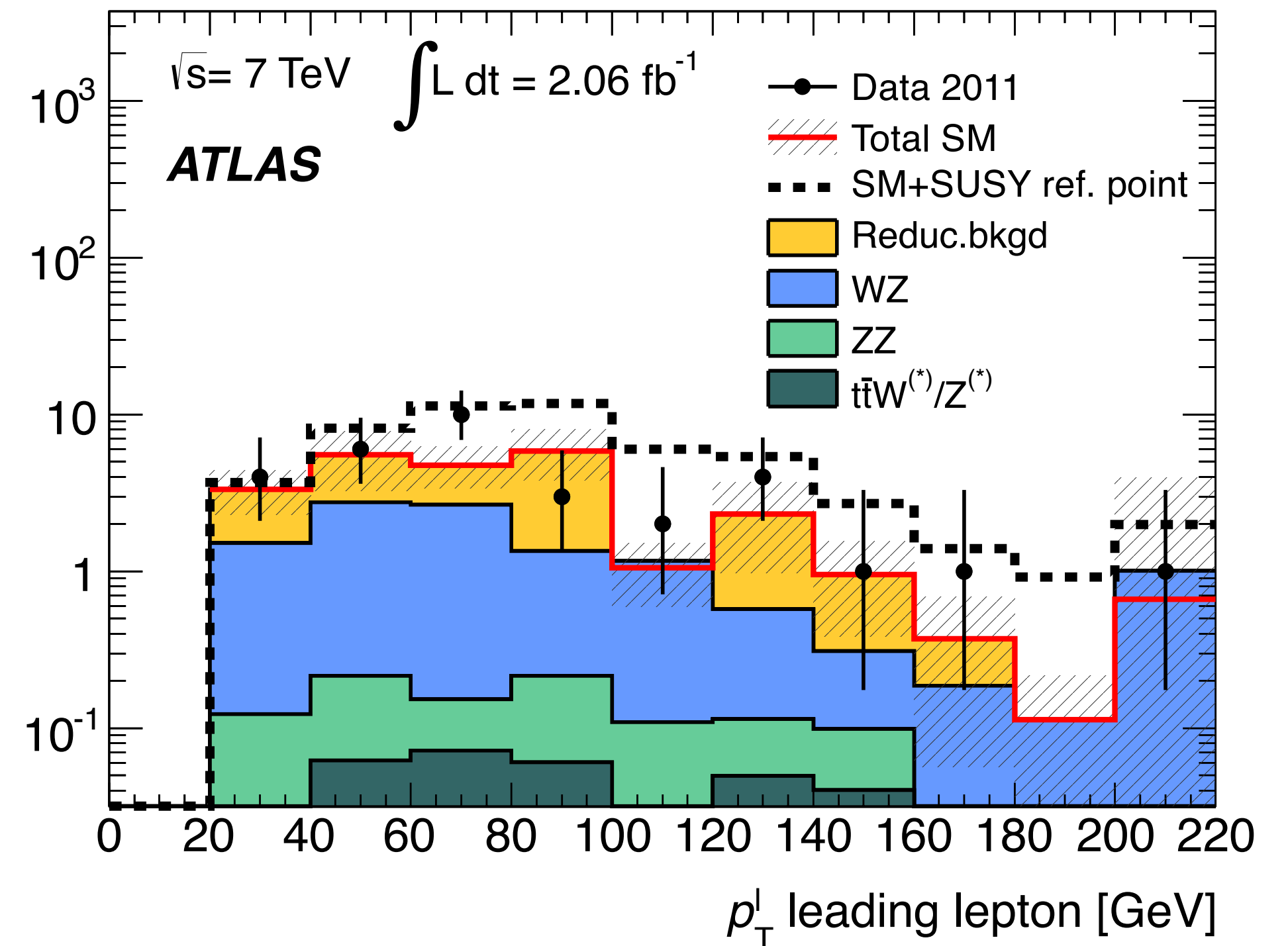
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- p_T^{lep} distributions peak around $\Delta m/4$, and quickly fall towards the high p_T region.
- The p_T cut of 20(25) GeV for μ (e) is the limiting factor of the analysis in the small Δm .

signal



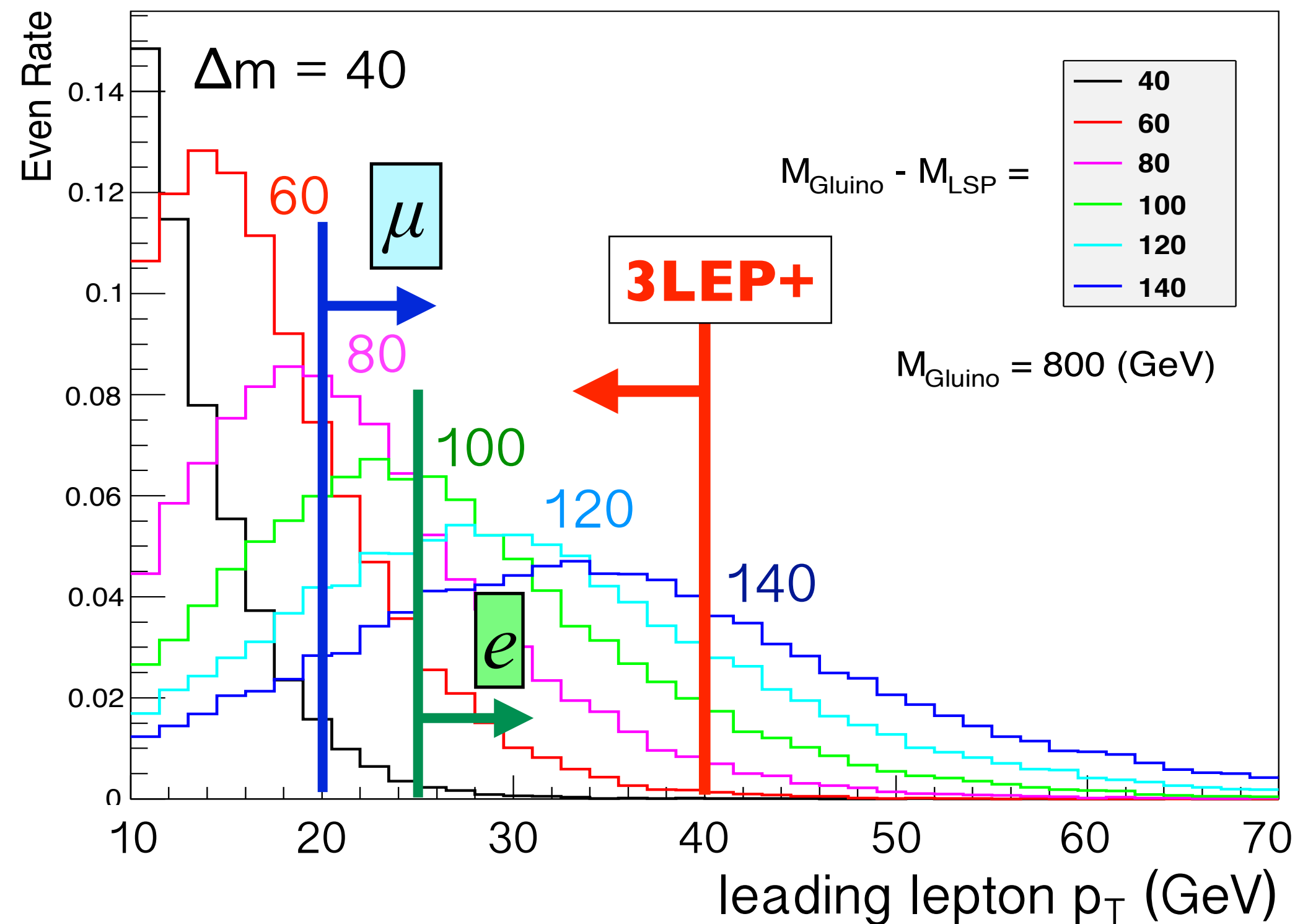
3LEP (background)



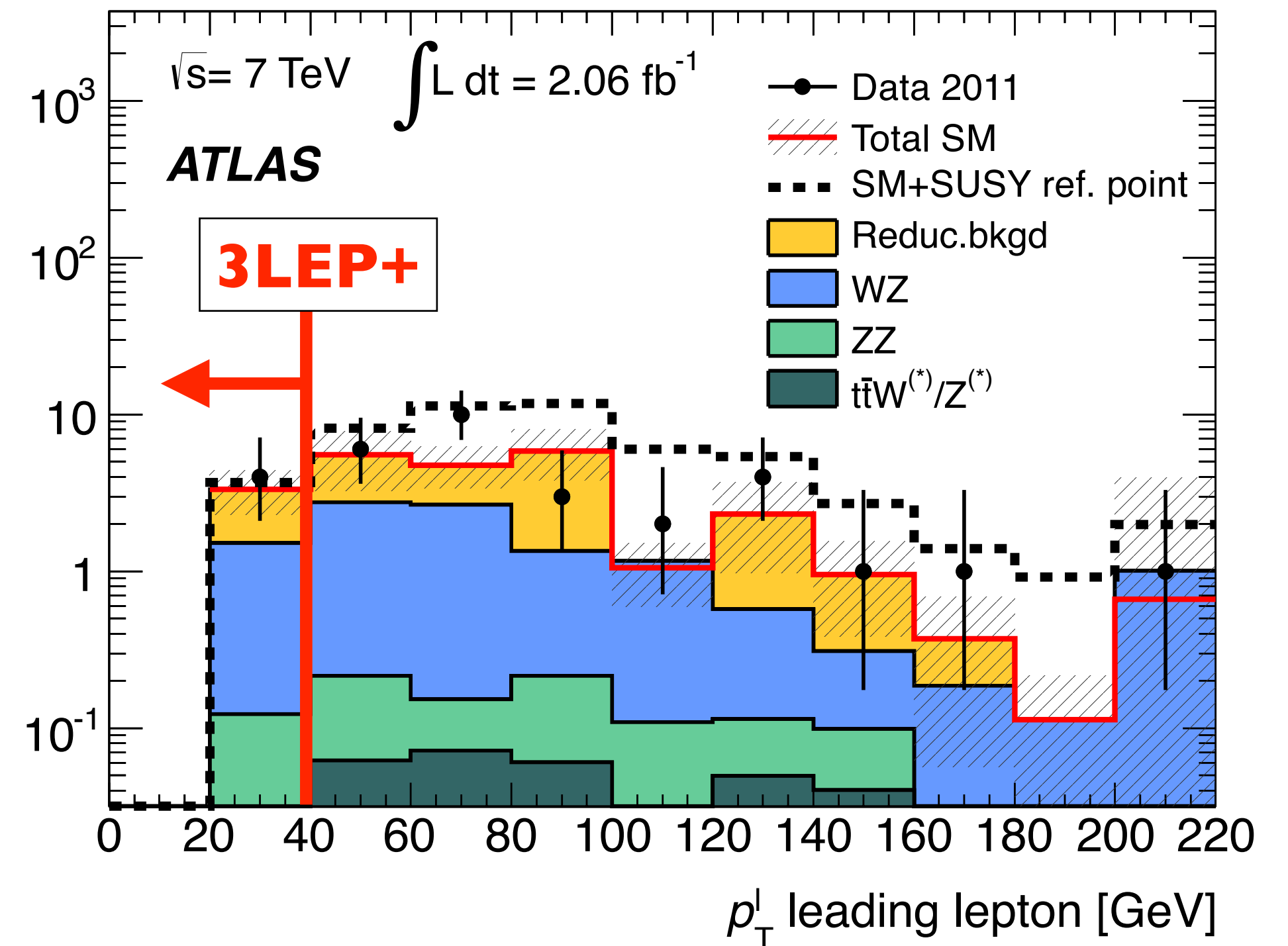
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- If a low p_T cut of 40 GeV is added in 3LEP, 90% of the BG is removed, but the reduction is only 10% in the signal (for $\Delta m \sim 80$ GeV).

signal



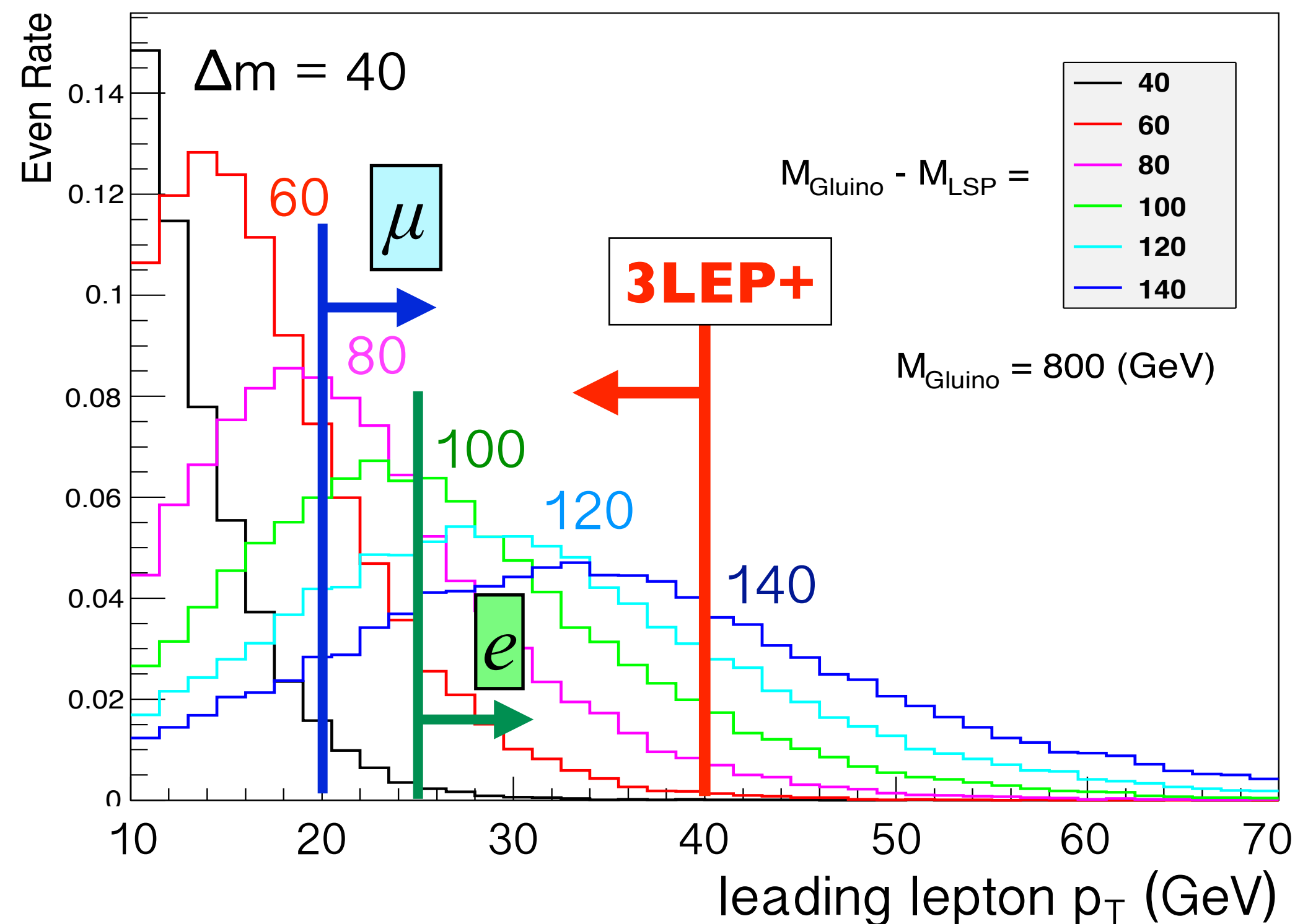
3LEP (background)



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signal



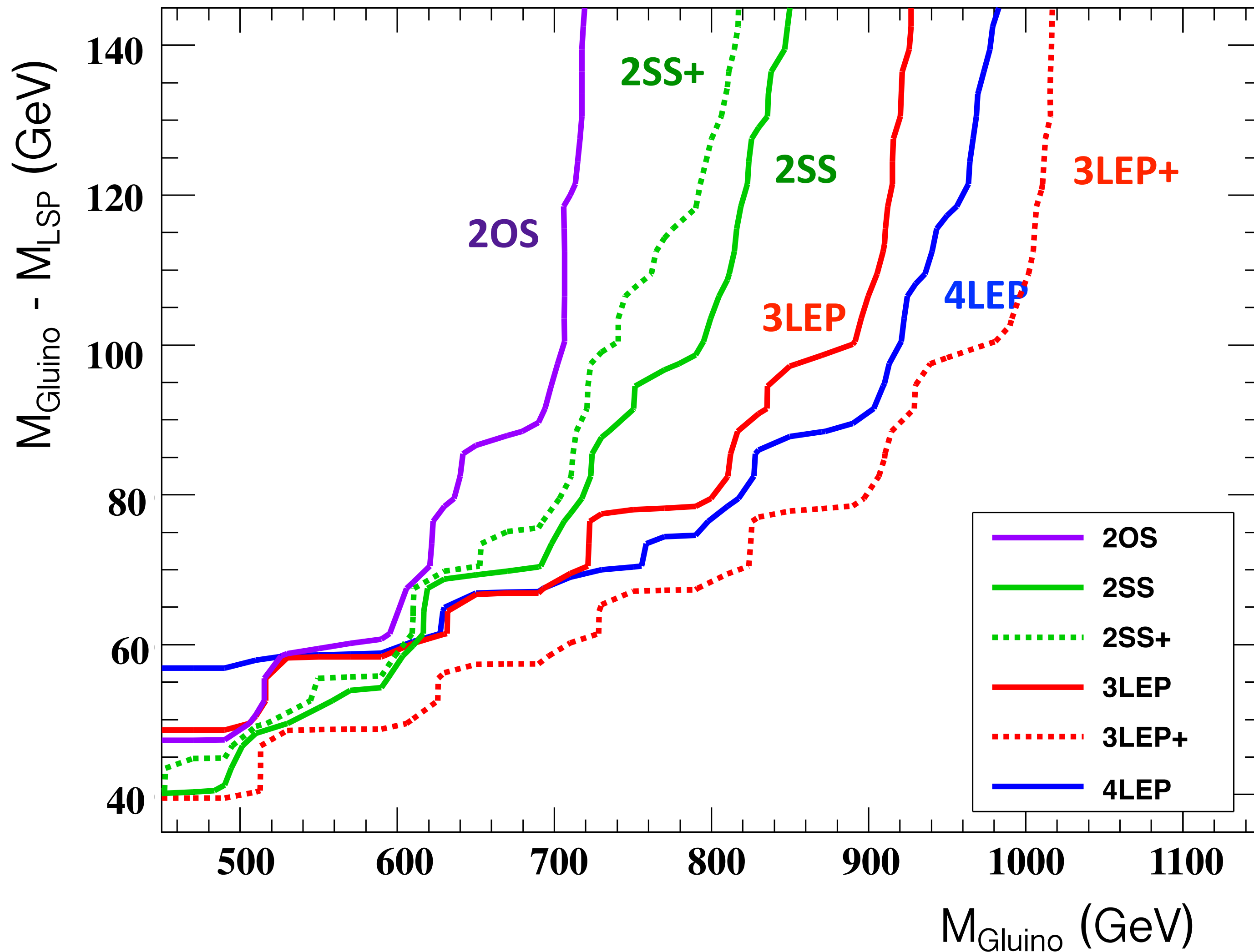
► We define a new signal region **3LEP+**

Signal Region	3LEP	3LEP+
# of leptons	= 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
$\sigma_{\text{vis}}^{\text{bound}} (95\%)$	10.0 fb	3.3 fb

Constraints

Observed 95% exclusion

K.Rolbiecki, KS (1206.6767)

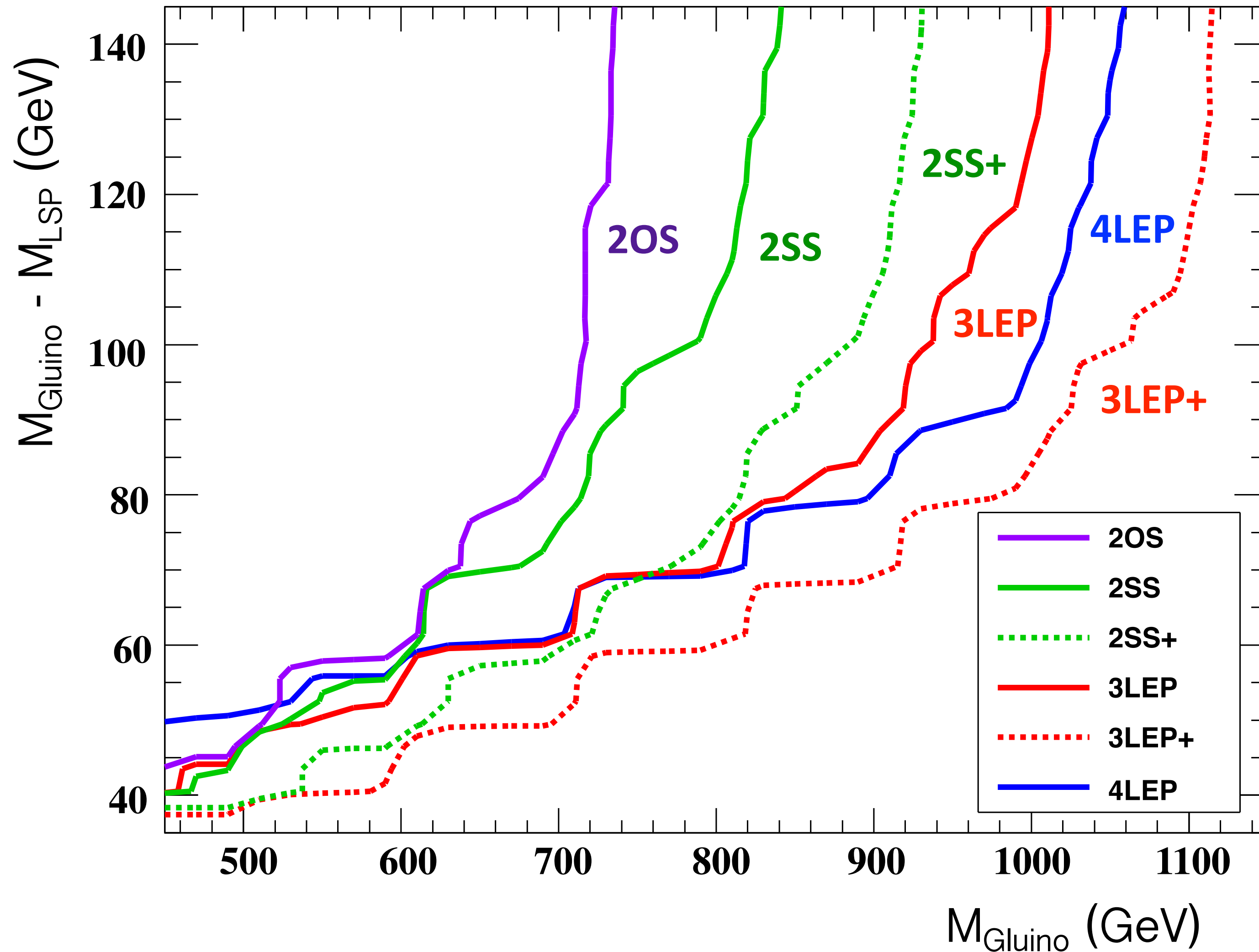


- $m_{\text{Gluino}} > 900\text{GeV}$ if $\Delta m \sim 100\text{GeV}$
- **3LEP+** significantly extends the exclusion limit

Constraints

Expected 95% exclusion at 5.25 fb⁻¹

K.Rolbiecki, KS (1206.6767)

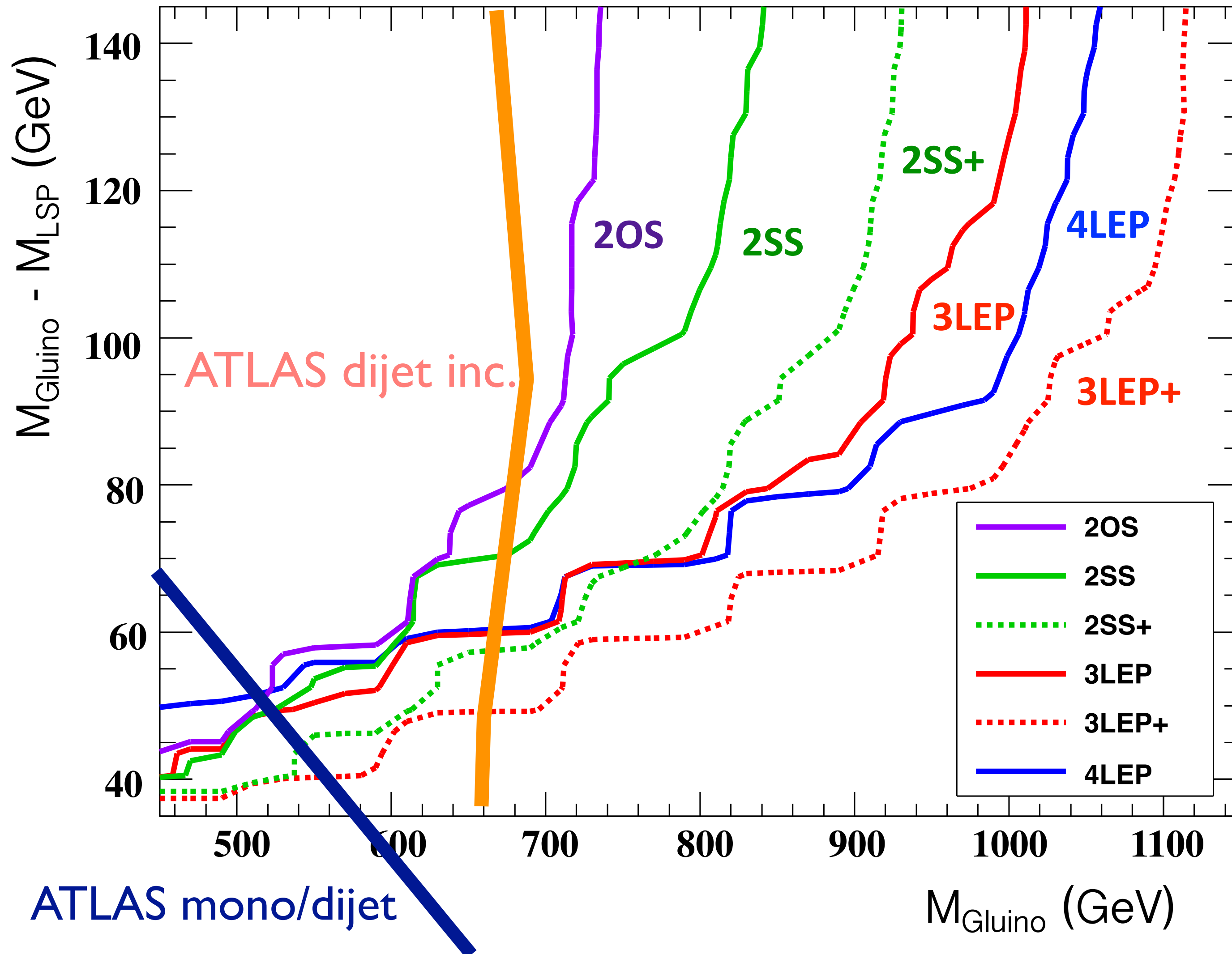


- $m_{\text{Gluino}} > 900\text{GeV}$ if $\Delta m \sim 100\text{GeV}$
- **3LEP+** significantly extends the exclusion limit
- at 5 fb⁻¹,
 $m_{\text{Gluino}} > 1\text{ TeV}$ if $\Delta m \sim 100\text{GeV}$

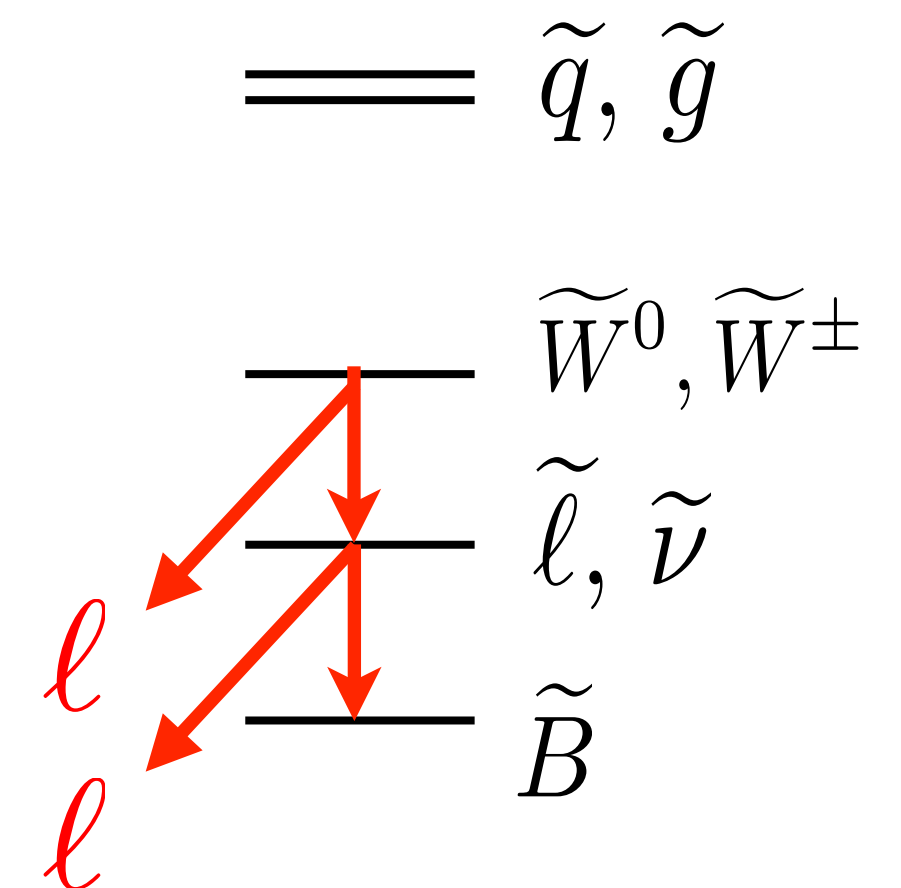
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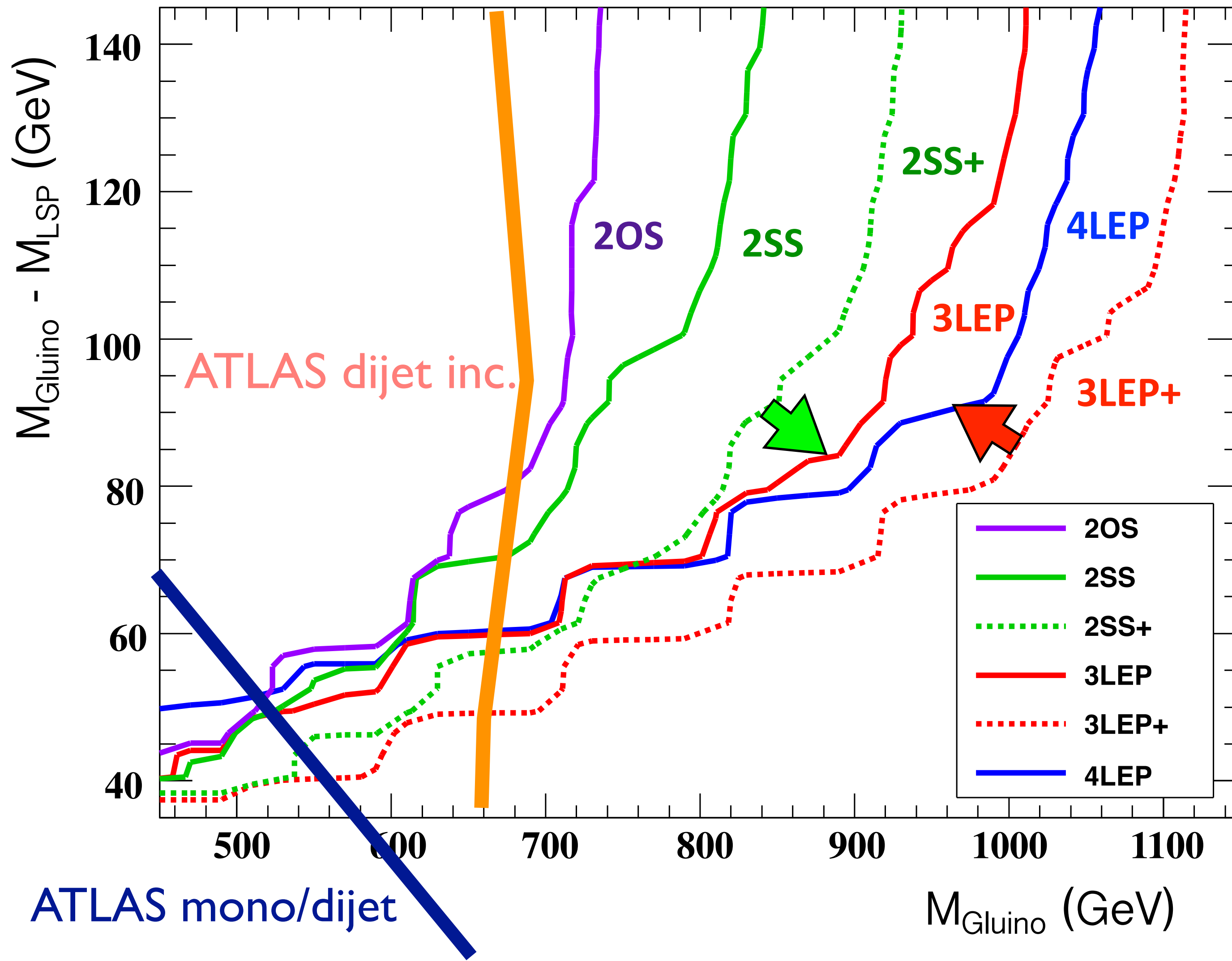
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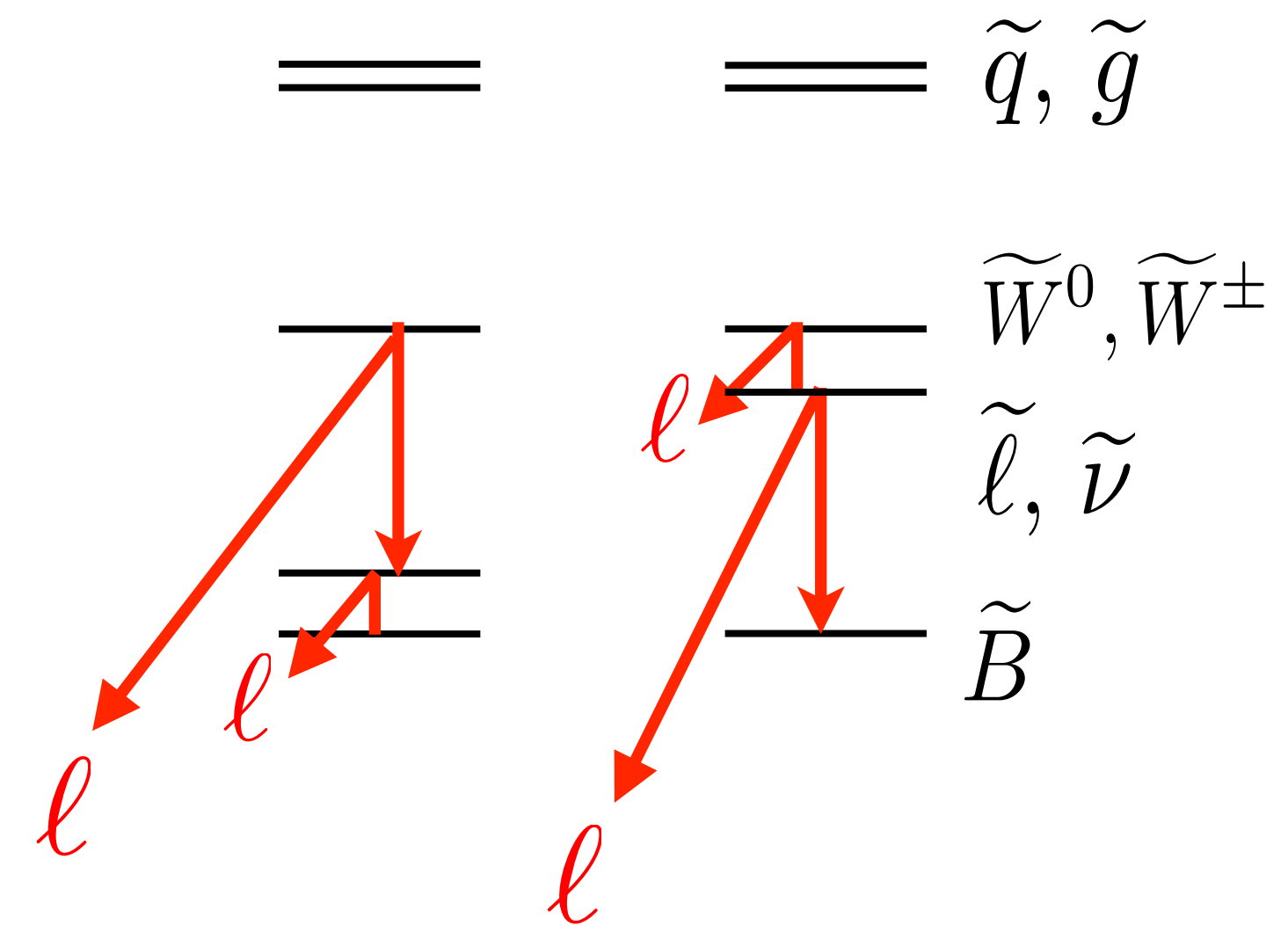
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R-parity violation

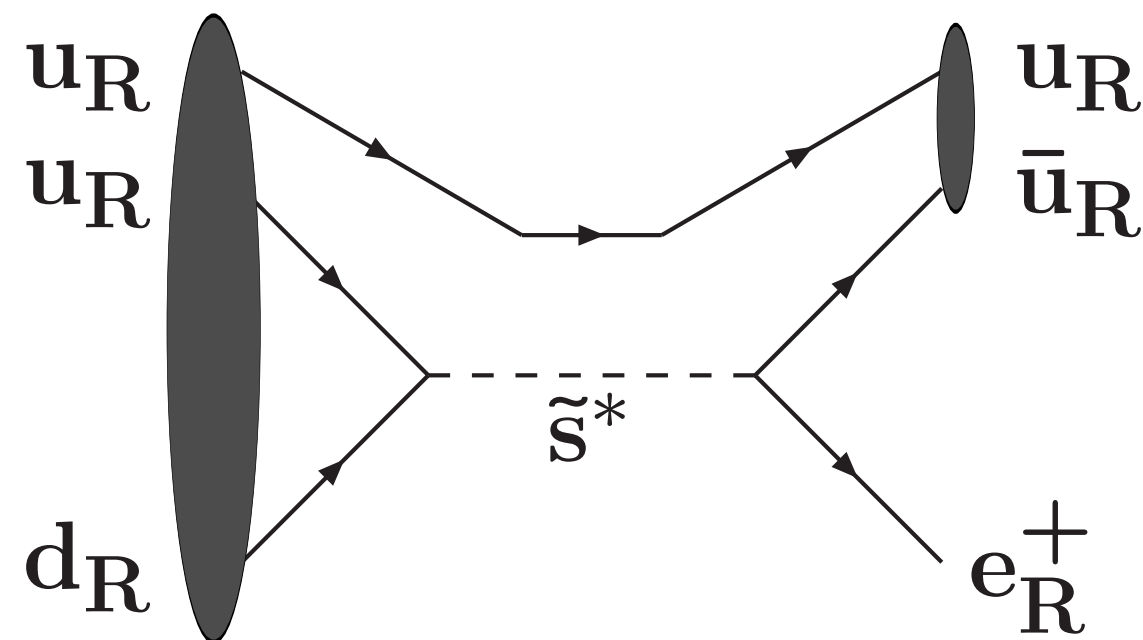
R-parity

- The following terms are allowed by gauge symmetry:

$$W_{\text{RPV}} = \underbrace{\lambda''_{ijk} U_i^c D_j^c D_k^c}_{\cancel{B}} + \underbrace{\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \kappa_i L_i H_u}_{\cancel{L}}$$

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

needs a symmetry to explain the smallness of the couplings



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

R-parity

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

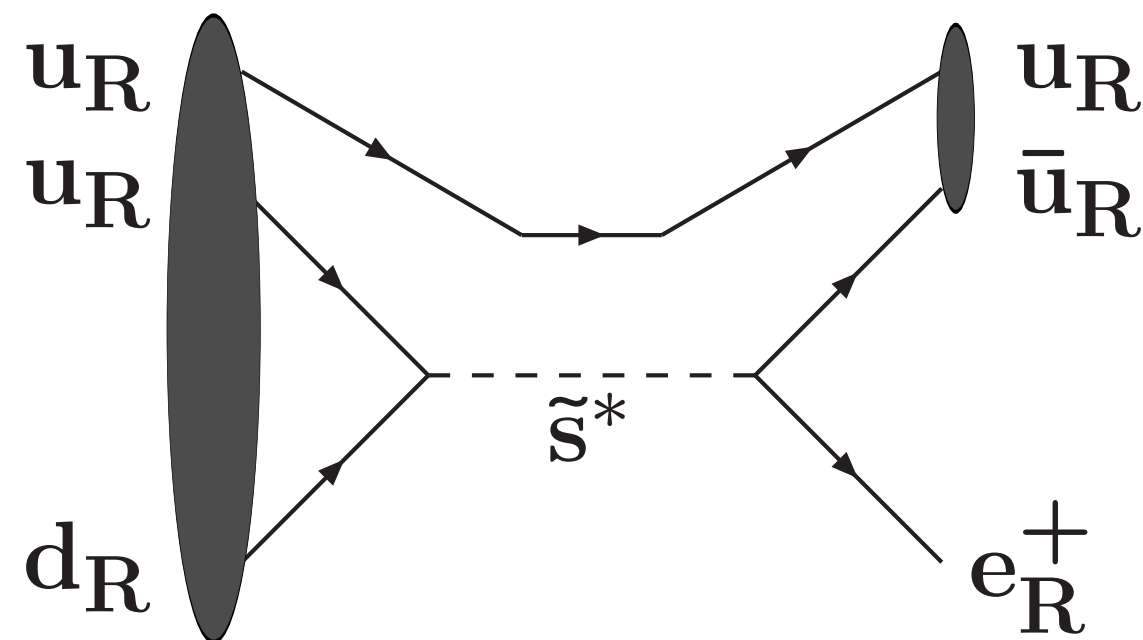
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forbidden
by R-parity

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R-parity violation

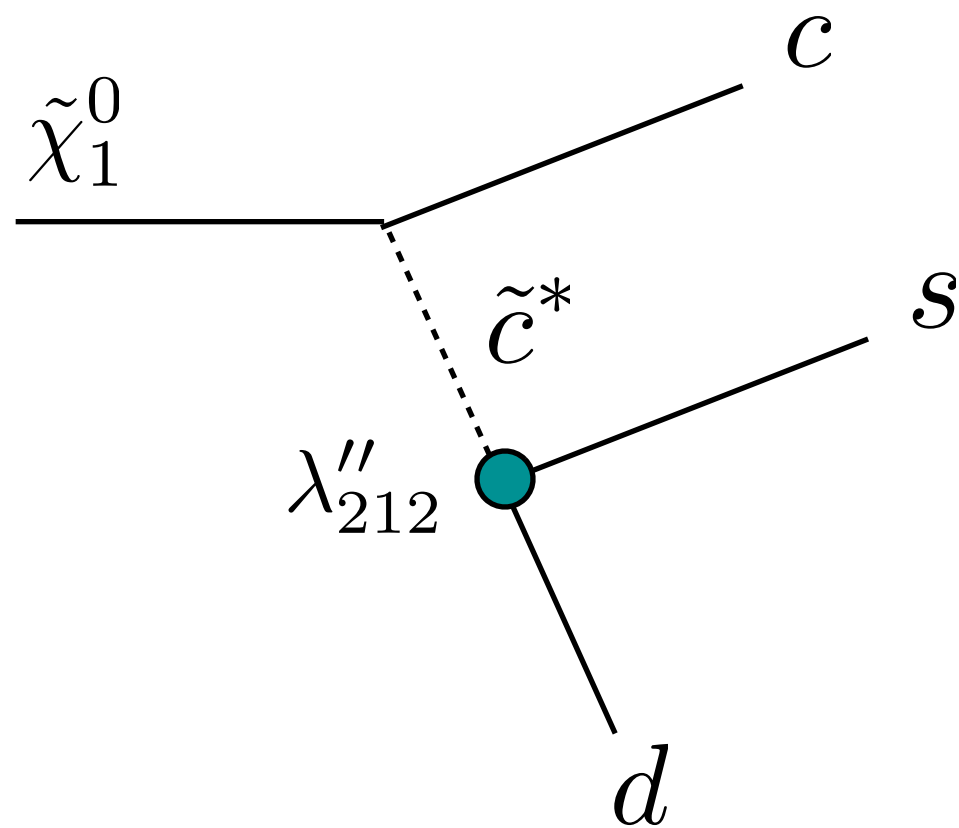
- Other symmetries are also possible to suppress proton decay.

[Other discrete symmetries are also possible. H.K.Dreiner, M.Hanussek (1206.6305)]

- Then, the LSP is no longer stable.

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

$$W_{RPV} = \lambda''_{ijk} U_i^c D_j^c D_k^c$$

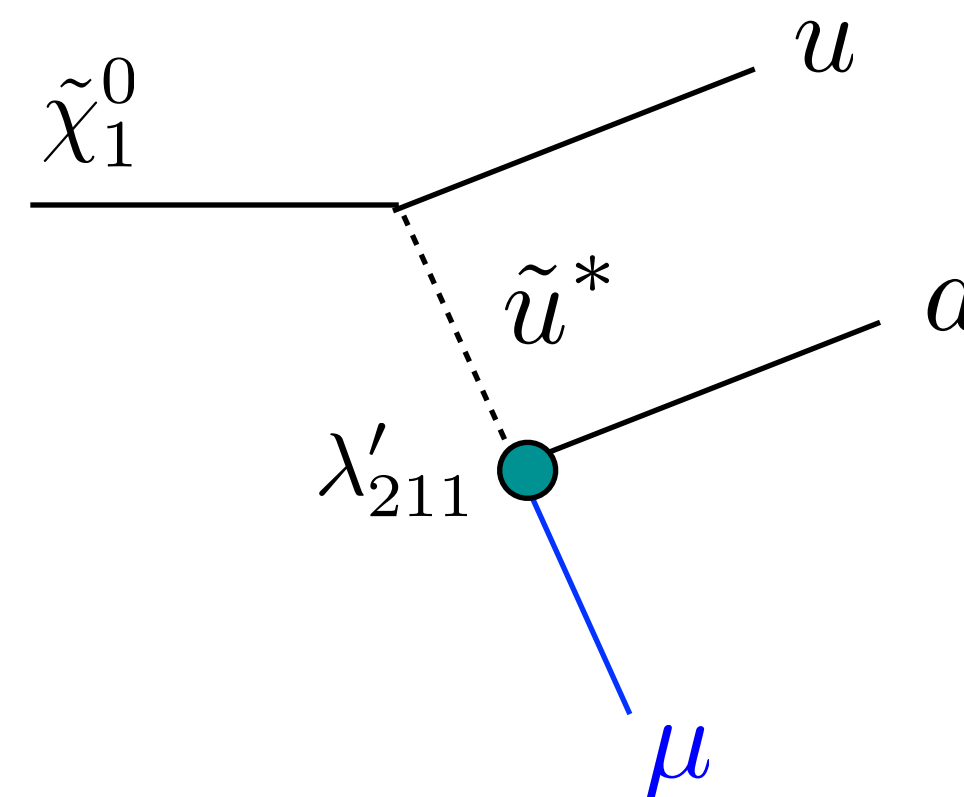


absence of leptons

→ more challenging in SUSY searches

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

$$W_{RPV} = \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \kappa_i L_i H_u$$



Missing energy signal is removed

R-parity violation

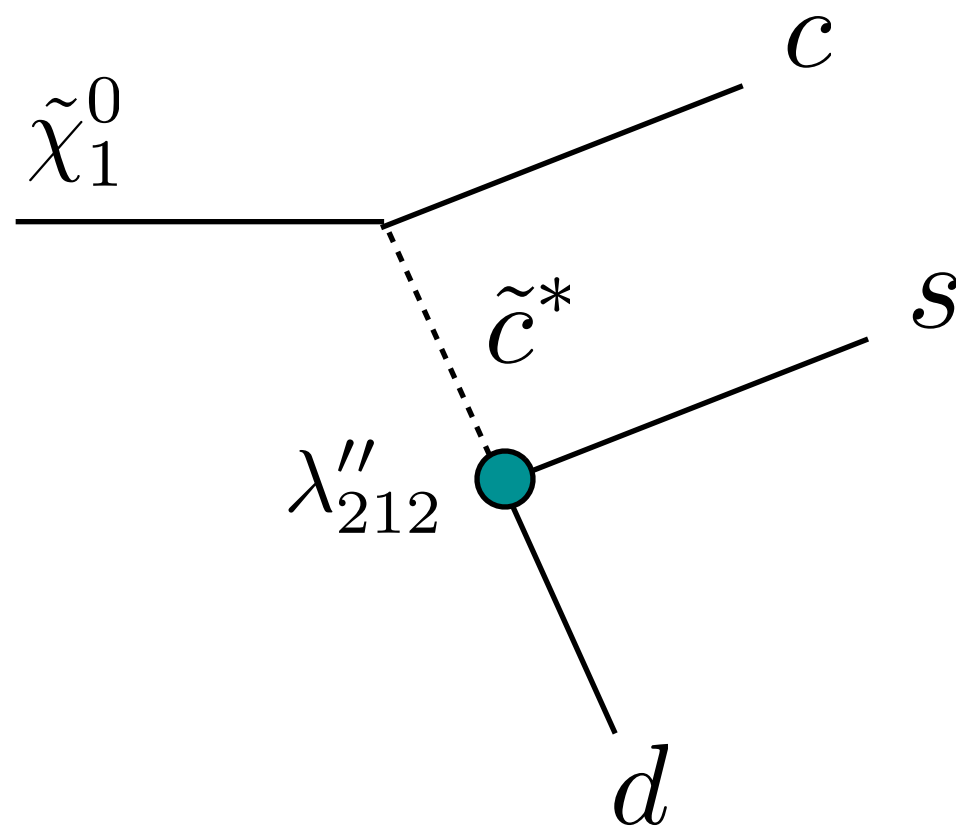
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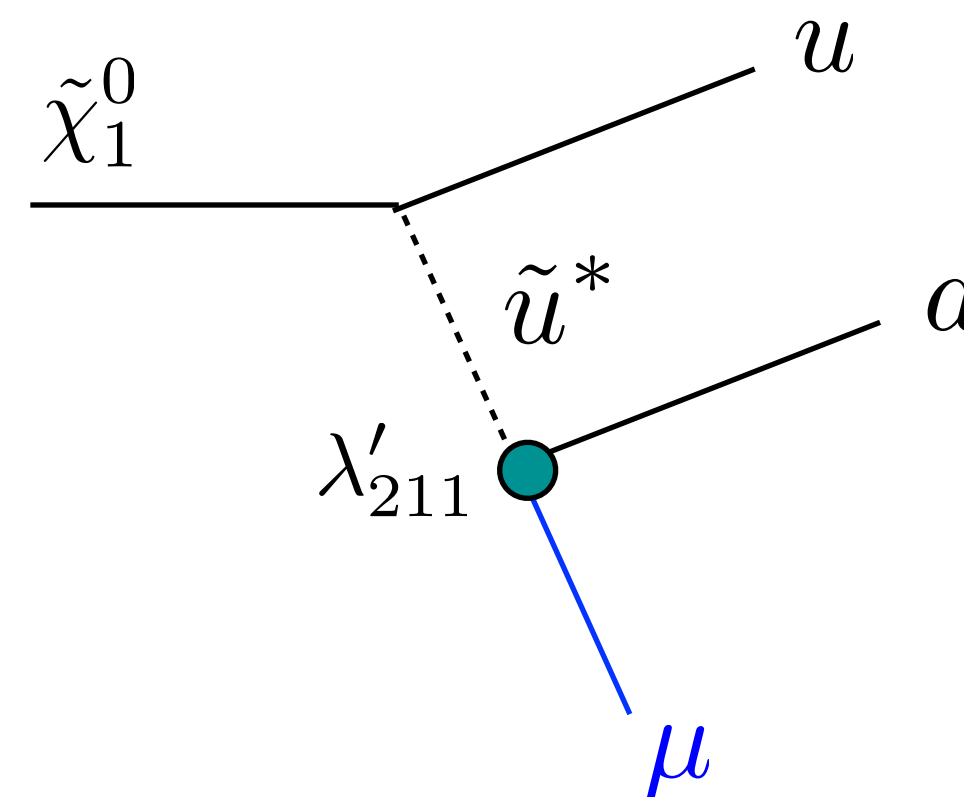


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Missing energy signal is removed

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 $\rightarrow$ 3jet (resonance)	CMS, 1107.3084
UDD or LLE	$\tilde{q} \rightarrow \tilde{\chi}_1^0 j \rightarrow \tilde{\ell} \ell j \rightarrow \ell \ell j \tilde{G} (\tilde{G} \rightarrow \text{RPV decay})$	CMS, 1204.5341
LLE	$\geq 4\text{lep} + E_T^{\text{miss}}$	ATLAS, 1210.445
LLE	exactly 4lep	CMS PAS SUS-13-010
LLE and QLD	$d\bar{d} \rightarrow \tilde{\nu}_\tau \rightarrow e\mu$	ATLAS, 1109.3089
LLE, QLD	4-3 lepton + 0-1 tau	CMS PAS SUS-13-003
LLE, QLD	dijet/like-sign dimuon from slepton decays	H.K.Dreiner, T.Stefaniak, 1201.5014
QLD	$pp \rightarrow e\mu$	ATLAS, 1205.0725
QLD	μ + displaced vertex	ATLAS CONF 2012-108
QLD	same-sign dimuon	CMS PAS SUS-13-005
...	...	...

UDD w/o 3rd gen.
is not studied
intensively

Model setup

RPV coupling:

- **most challenging case** → **UDD-type RPV**
- $\lambda''_{212} = 10^{-3}$ $\left\{ \begin{array}{l} \text{no experimental constraint} \\ \text{prompt decay of neutralino} \\ \text{no b-jet} \end{array} \right.$ (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 with UDD**
 - ▶ Only light flavour squarks and gauginos are present at low energy.
 - ▶ approximate GUT relation: $M_3 : M_2 : M_1 = 6 : 2 : 1$
 - ▶ free parameters: **gluino mass, squark mass**

Reinterpretation

- **ATLAS large jet multiplicities plus missing energy search** (I206.I760) [7TeV, 5/fb]

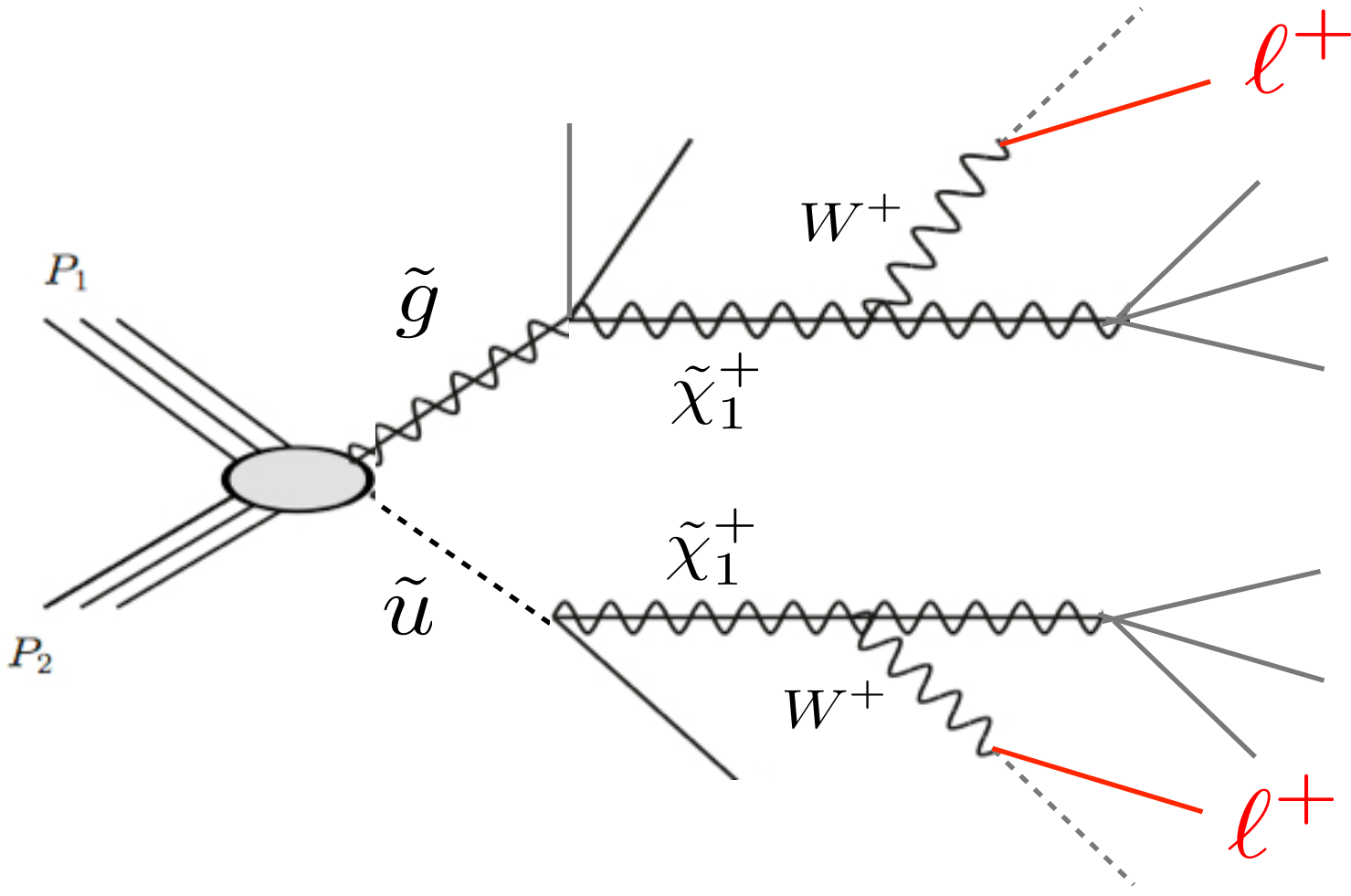
signal region	7j55	8j55	9j55
$N_{\text{lepton}}(p_T^{e,\mu} > 20, 10 \text{ GeV})$	$= 0$		
$E_T^{\text{miss}} / \sqrt{H_T}$	$> 4 \sqrt{\text{GeV}}$		
$N_{\text{jet}}(p_T > 55 \text{ GeV})$	≥ 7	≥ 8	≥ 9

- ▶ three additional jets via $\tilde{\chi}_1^0 \rightarrow udd$
- ▶ missing energy via $\tilde{q} \rightarrow q\tilde{\chi}_1^\pm \rightarrow W^{(*)}q\tilde{\chi}_1^0 \rightarrow \nu_\tau \tau q\tilde{\chi}_1^0$

- **CMS SS dilepton with jets plus missing energy search** (I205.6615) [7TeV, 5/fb]

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

- ▶ same-sign dilepton signatures

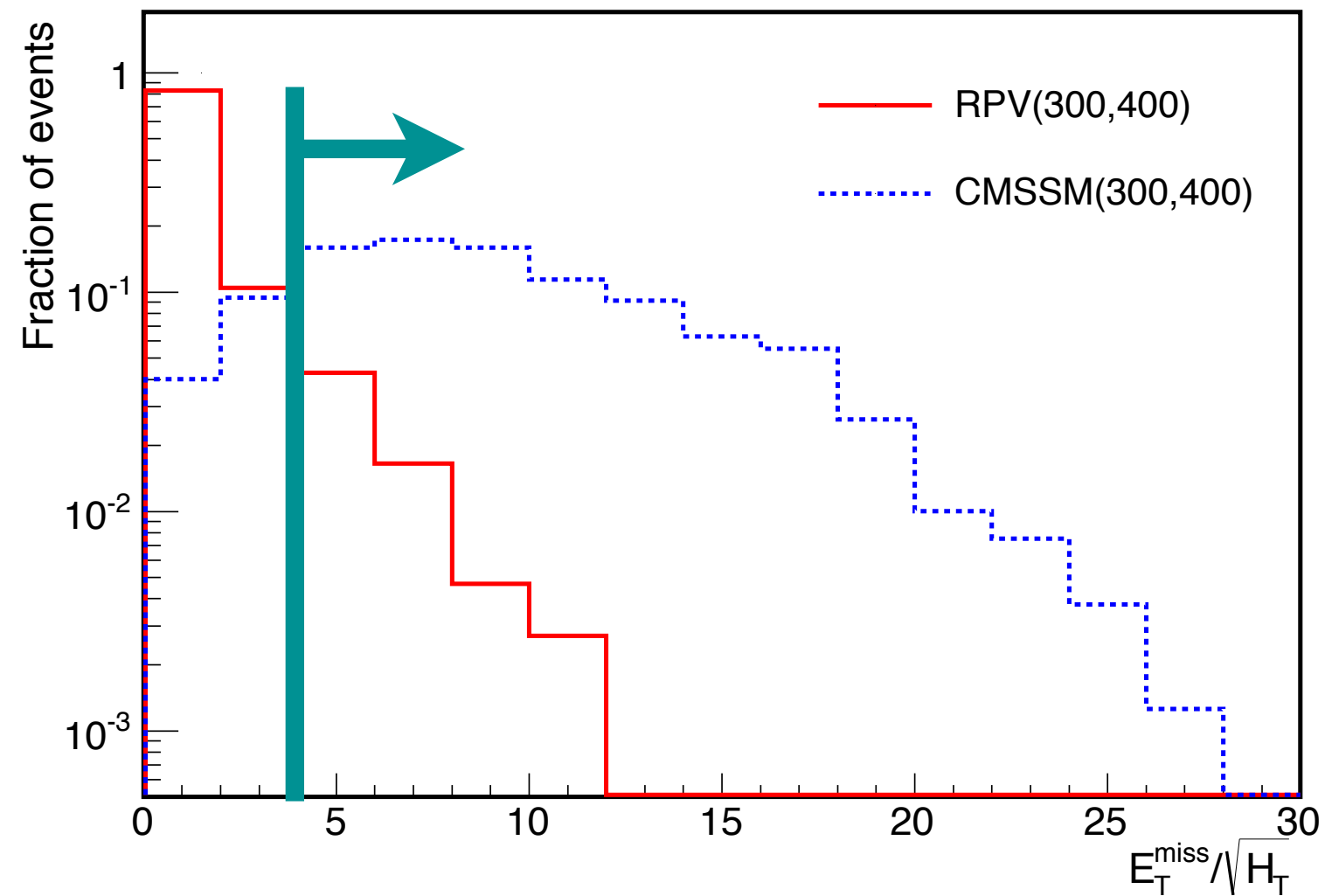


For both analyses, leptonic W decay is crucial

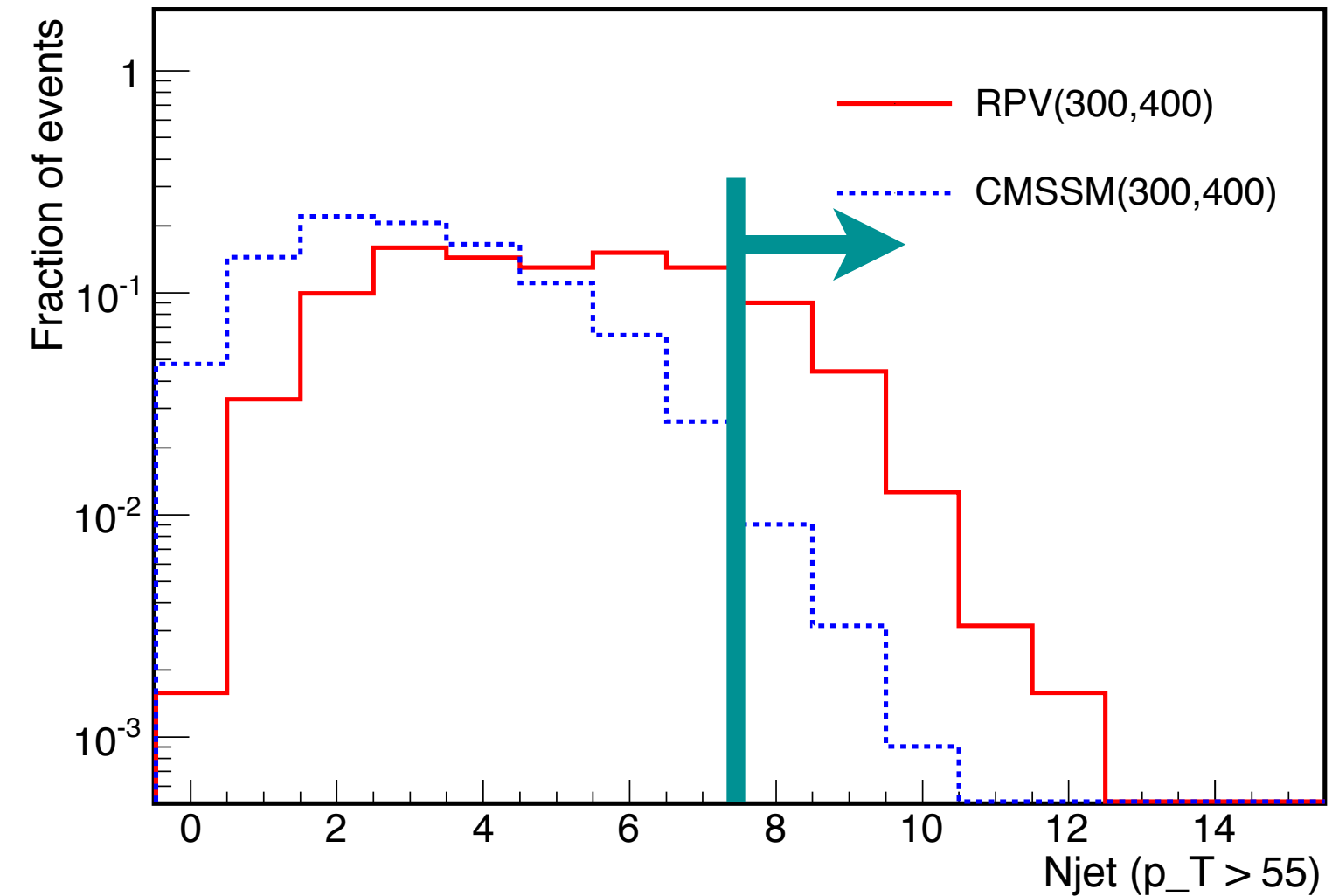
E_T^{miss} , H_T , Njets distributions

M.Asano, K. Rolbiecki, KS I209.5778

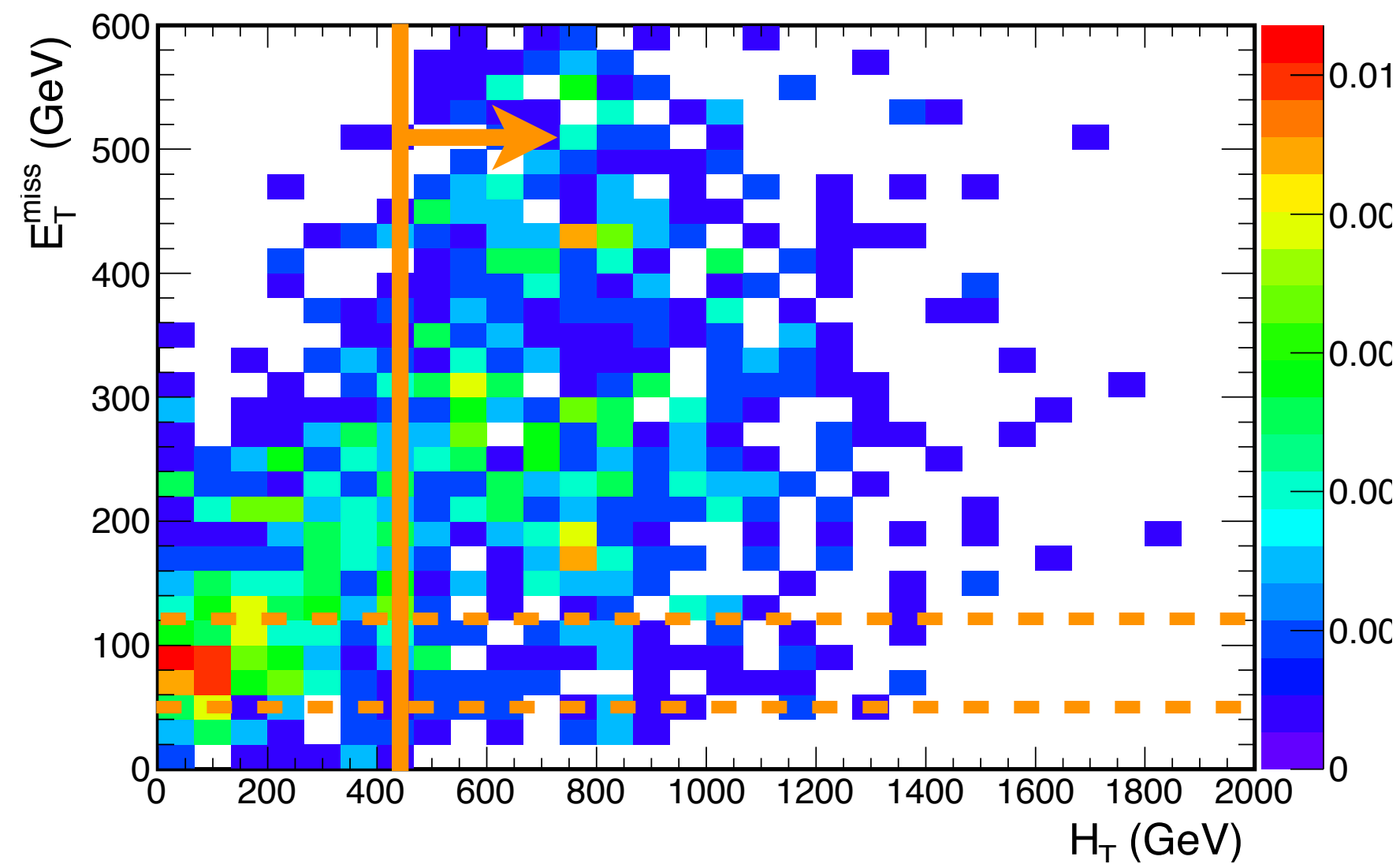
cut: (no lepton, Njet($p_T > 55$) > 5)



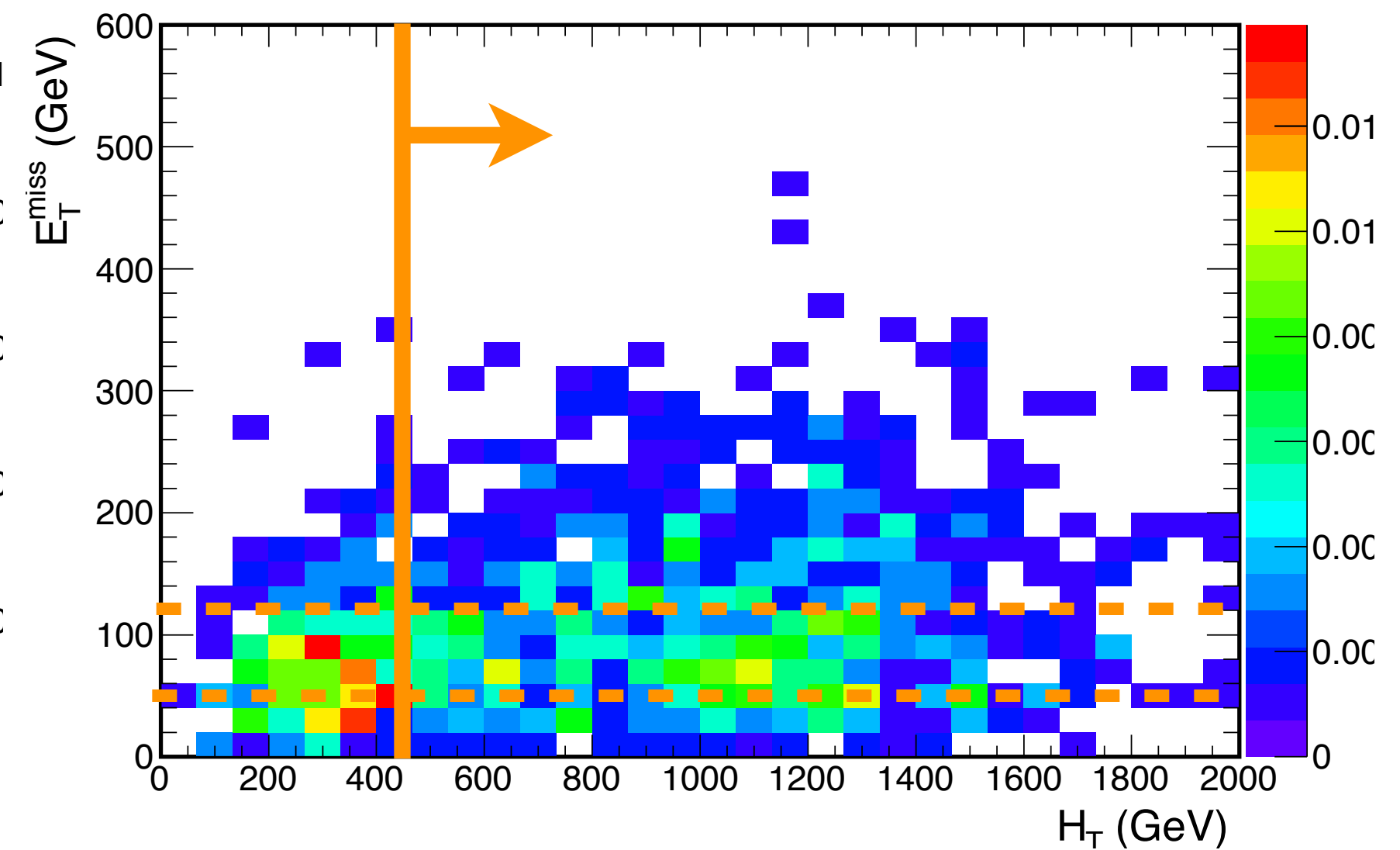
cut: (no lepton, $E_T^{\text{miss}} / \sqrt{H_T} > 4$)



CMSSM(300,400)



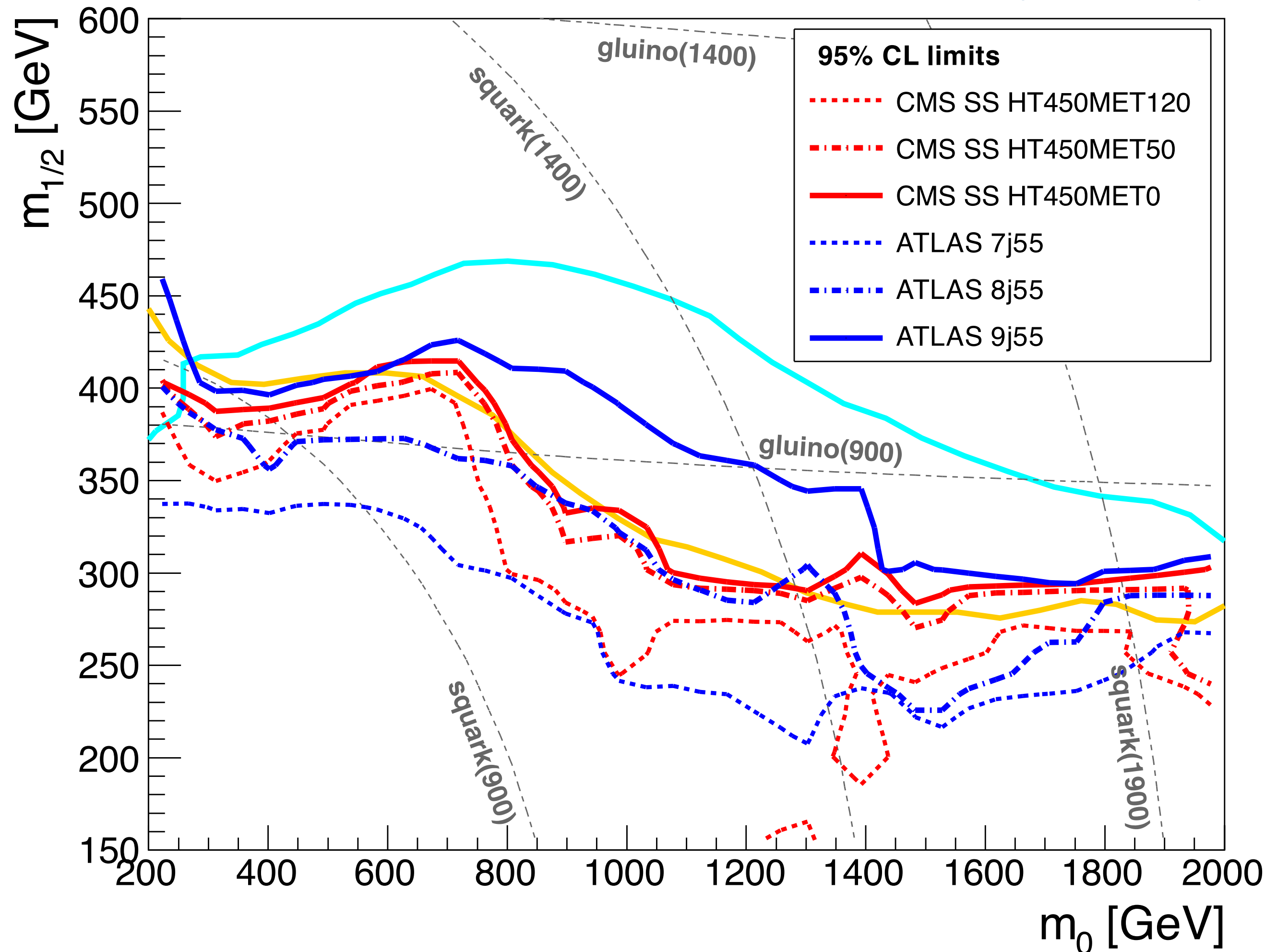
RPV(300,400)



Result (CMSSM+UDD)

CMSSM + UDD

M.Asano, K. Rolbiecki, KS (1209.5778)

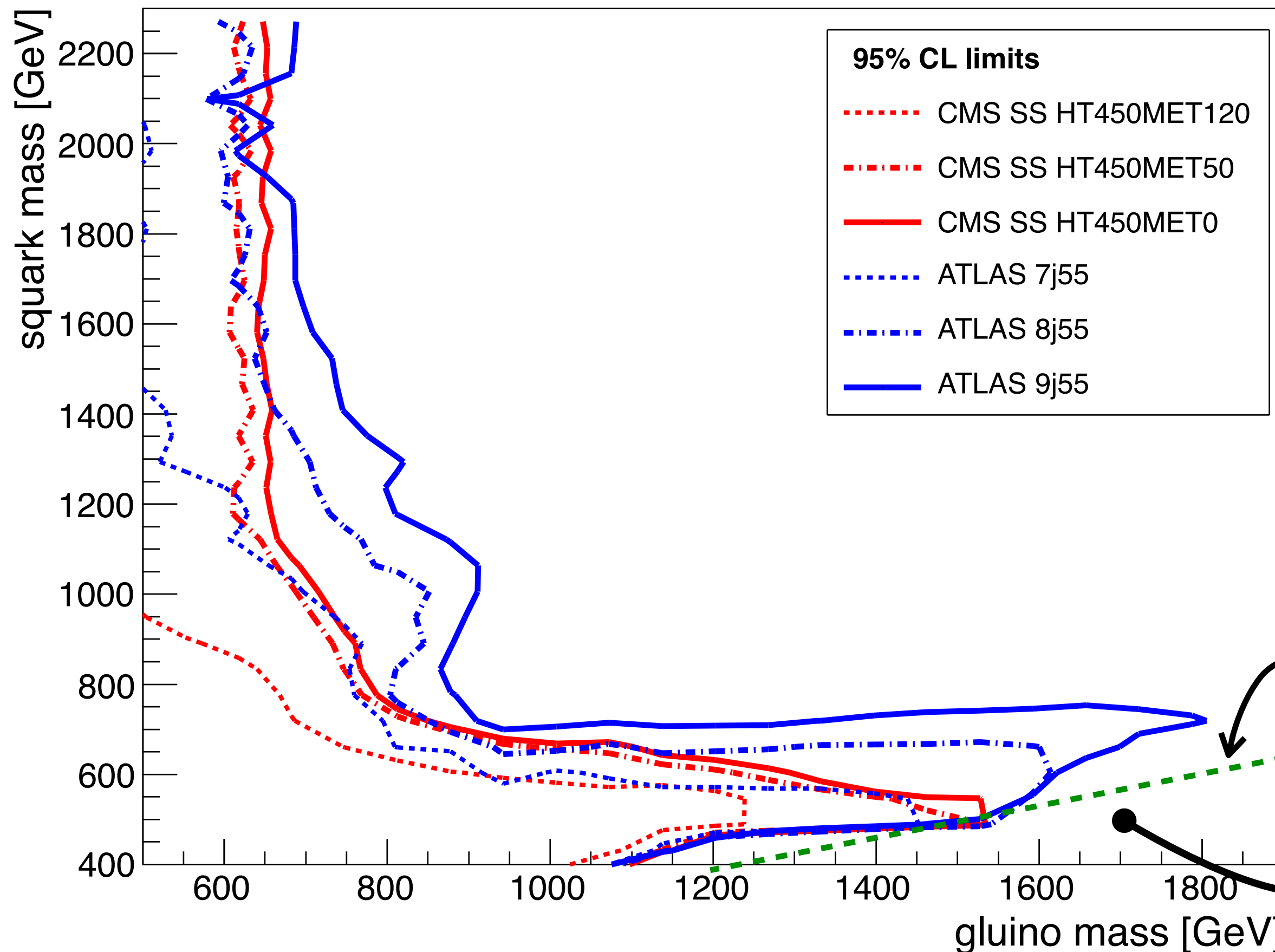


- For the equal squark/gluino mass, **squark/gluino mass up to 900GeV is excluded**

Result (simplified model+UDD)

simplified model + UDD

M.Asano, K. Rolbiecki, KS (1209.5778)



- leptons and moderate E_T^{miss} solely come from chargino decays

$$M_3:M_2:M_1 = 6:2:1, \quad M_3 = M_{\text{squark}}$$

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

Hint of SUSY?

--- WW cross section measurements ---

WW cross section measurements

- The WW cross section have been measured by ATLAS 7TeV and CMS 7 and 8TeV data sets and all observed 1-2 sigma level excesses.

7 TeV

SM prediction: $\sigma = 46 \pm 2$ pb

ATLAS: $\sigma = 51.9 \pm 2.0$ (stat) ± 3.9 (syst) ± 2.0 (lumi) pb [ATL-2012-242](#)

CMS: $\sigma = 52.4 \pm 2.0$ (stat) ± 4.5 (syst) ± 1.2 (lumi) pb [CMS-12-005](#)

8 TeV

SM prediction: $\sigma = 57.3 \pm 2$ pb

CMS: $\sigma = 69.9 \pm 2.8$ (stat) ± 5.6 (syst) ± 3.1 (lumi) pb [CMS-12-005](#)

Can we explain these excesses as a contribution of new physics?

Need 10(5) pb @ 8(7) TeV

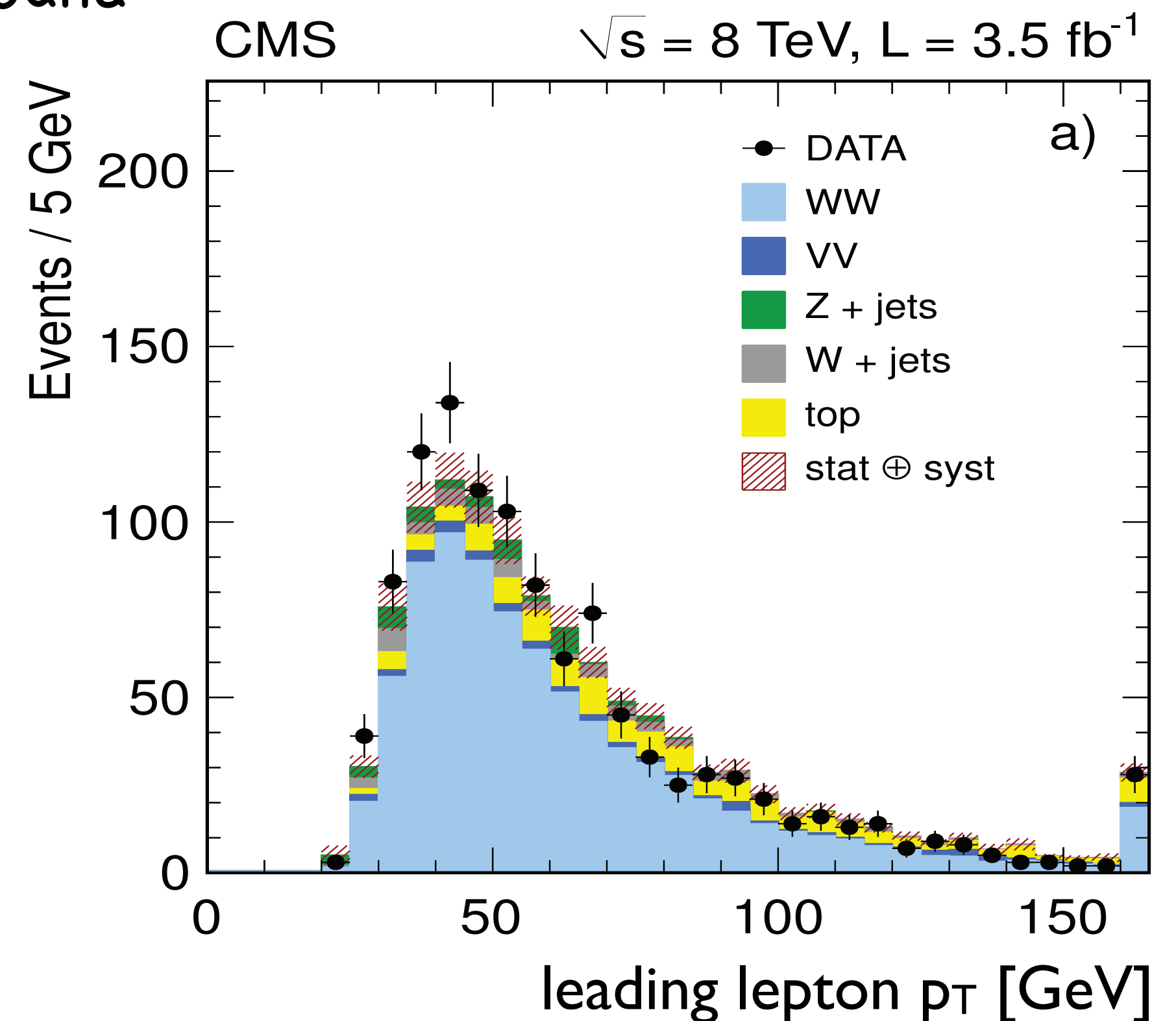
WW cross section measurements

- Looking for $pp \rightarrow W^+W^- \rightarrow \ell^+ \nu \ell^- \bar{\nu}$
- Event selection (details are depending on the analyses):
 - ▶ Opposite sign dilepton ($p_T > 20\text{GeV}$)
 - ▶ Jet veto ($p_T > 25\text{GeV}$) to suppress $t\bar{t}$ background
 - ▶ Z veto for same flavour dilepton
 - ▶ relative $E_T^{\text{miss}} > 40\text{GeV}$

$$E_{T,\text{rel}}^{\text{miss}} = \begin{cases} E_T^{\text{miss}} \times \sin \Delta\phi_{\ell,j} & \text{if } \Delta\phi_{\ell,j} < \pi/2 \\ E_T^{\text{miss}} & \text{if } \Delta\phi_{\ell,j} \geq \pi/2 \end{cases}$$

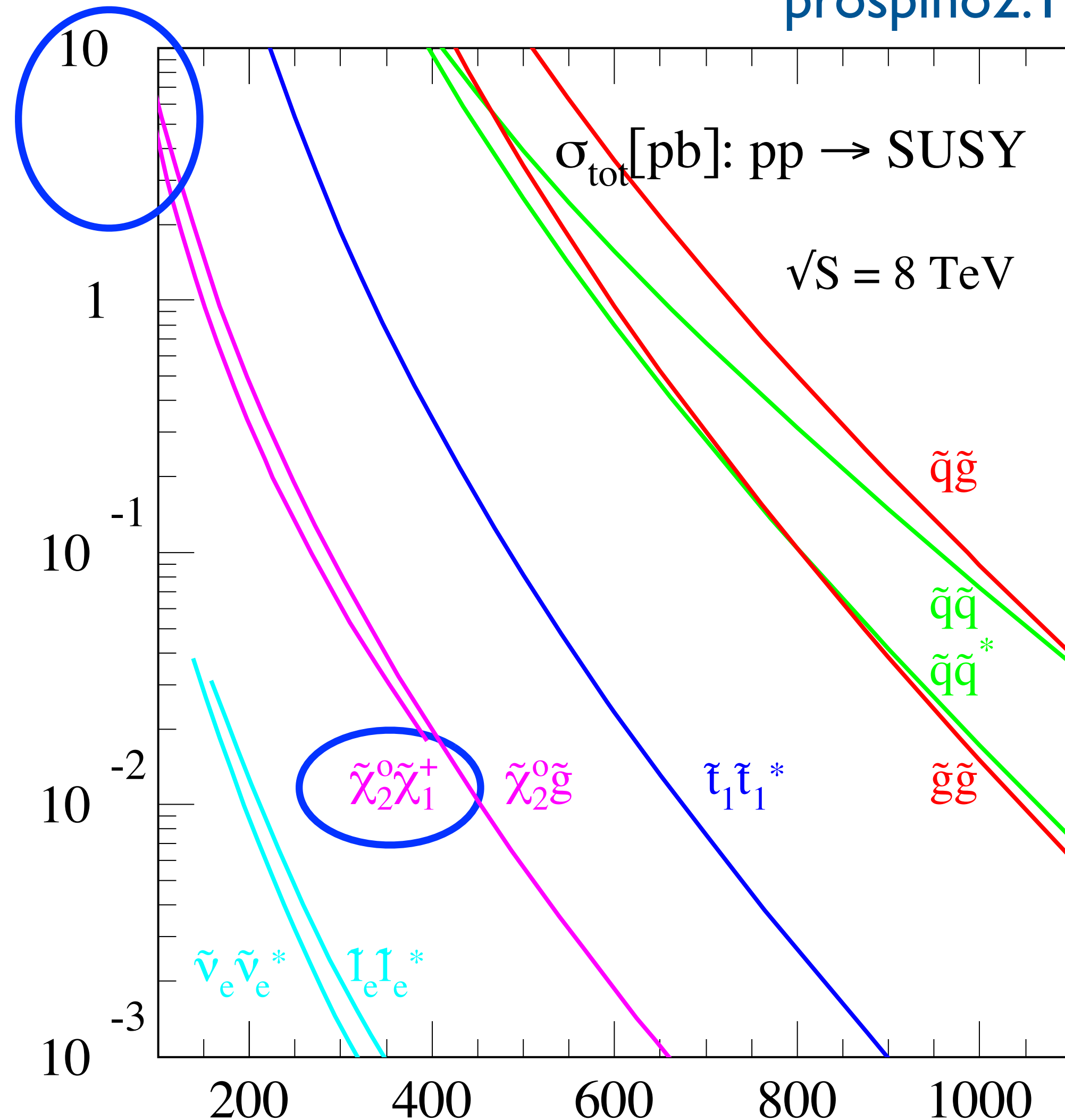
➡ Needs almost on-shell Ws without jets

$$\tilde{\chi}^+ \tilde{\chi}^- \rightarrow W^+ W^- \tilde{\chi}_1^0 \tilde{\chi}_1^0 \quad ??$$



Charginos from Stops

prospino2.l



- To obtain **10pb** cross section, **M(chargino)** should be **$\sim O(100)\text{GeV}$** is needed (just above the LEP limit).

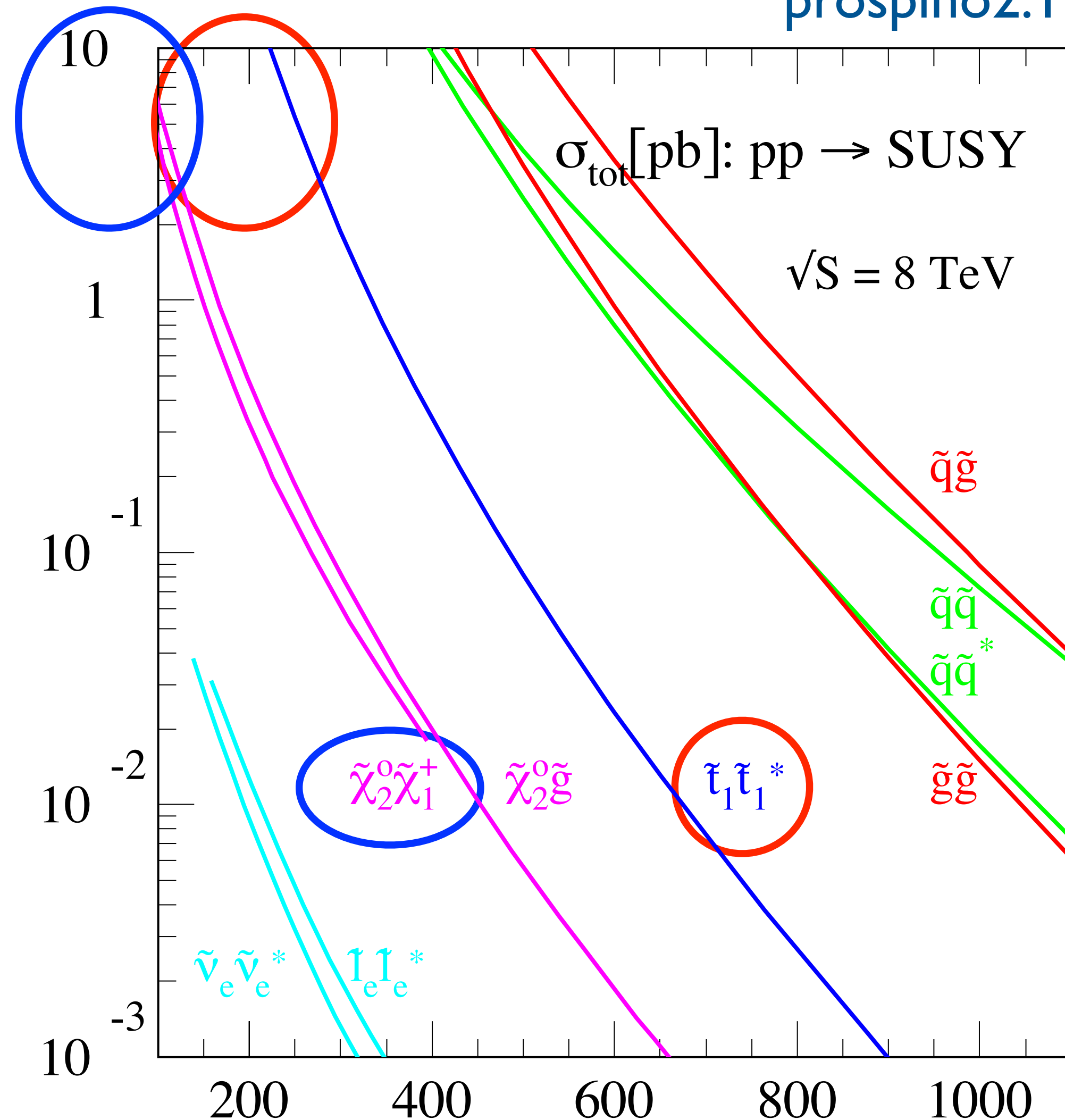
- In order to obtain on-shell Ws from the $\chi^\pm \rightarrow W^\pm \chi^0$, $M(\chi^0)$ has to be **$\sim 20\text{GeV}$** , which is severely constrained by LEP.

- If gravitino is LSP and chargino is NLSP, the chargino explanation is possible but not easy to obtain a large enough contribution.

D.Curtin, P.Jaiswal, P.Meade (1206.6888)

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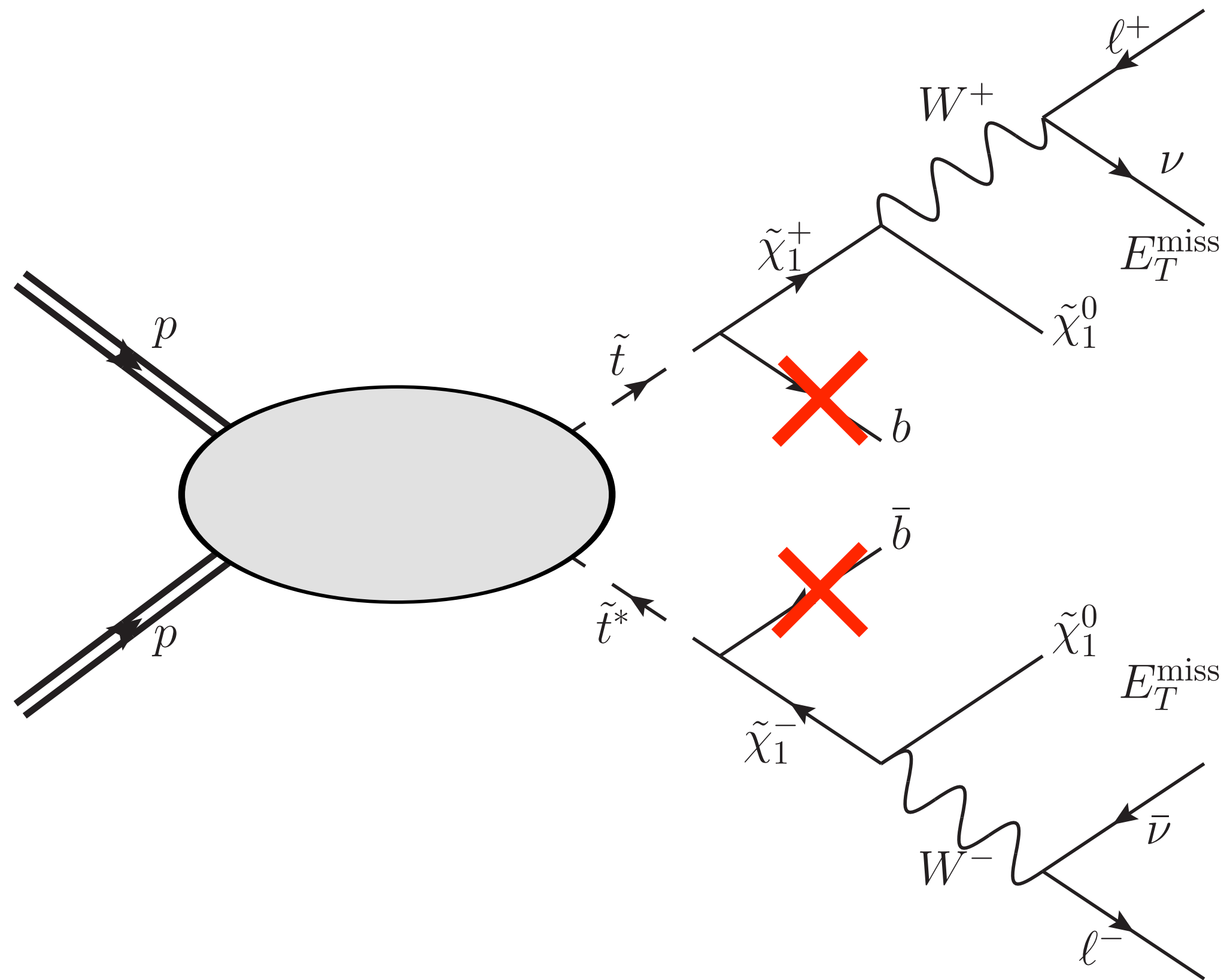
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D.Curtin, P.Jaiswal, P.Meade (1206.6888)

- **Charginos can appear in the stop decays** (**stop $\rightarrow b \chi^\pm$**). 10pb cross section is easily obtained with $M(\text{stop}) \sim 200\text{GeV}$

Stop explanation



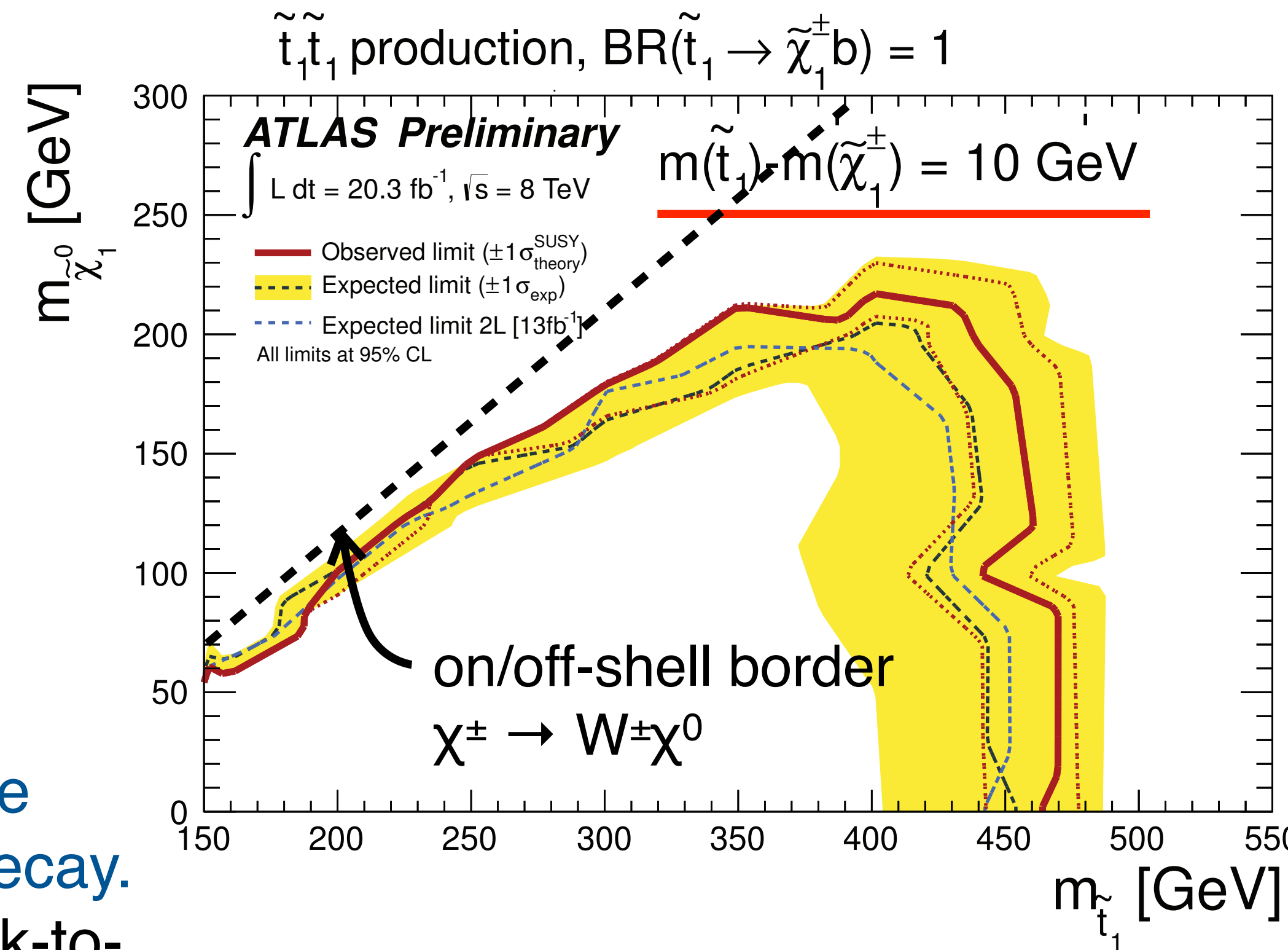
- Large QCD production can easily provide $O(10)\text{pb}$ cross section with $M(\text{stop}) \sim 200\text{GeV}$.
- b-jets should evade the jet veto cut (20GeV). If chargino mass is close enough to the stop mass, the b-jets will be too soft to be reconstructed.
We assume $M(\chi^\pm) = M(\text{stop}) - 10\text{GeV}$
- To obtain on-shell Ws, the neutralino mass can be $M(\chi^0) \sim (M(\chi^\pm) - 80\text{GeV}) \sim O(100)\text{GeV}$.
→ No LEP bound

Direct search constraints

- ATLAS-CONF-2013-048 studies exactly the same scenario:

$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^\pm} = 10 \text{ GeV}, \quad Br(\tilde{t}_1 \rightarrow \tilde{\chi}_1^\pm b) = 1$$

- The search strategy is to look for an extra missing energy in addition to the neutrinos by using the leptonic M_{T2} .
- The limit disappears when $m(\chi^0)$ approaches the kinematical threshold for the 2 body $\chi^\pm \rightarrow W^\pm \chi^0$ decay. (Note in this region the two neutralinos travel back-to-back and their p_T are cancelled out.)
- No relevant chargino constraints if $Br(\chi_2^0 \rightarrow h \chi_1^0)$ is large.



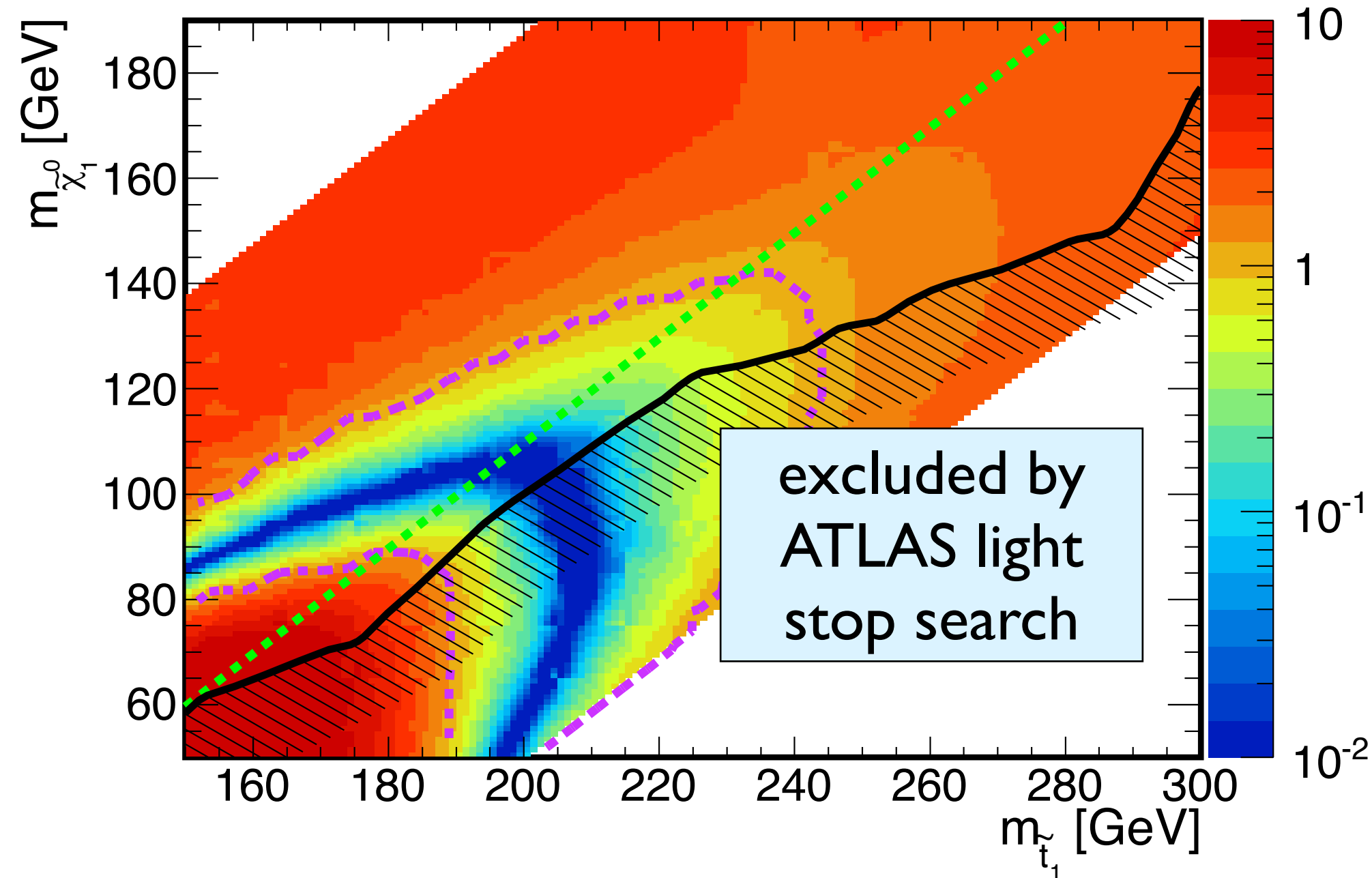
Preferred parameter region

- To identify the preferred parameter region, we scan over the $[m(\text{stop}), m(\chi^0)]$ parameter plane and calculate the chi-square.

$$\chi_i^2(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = \frac{\left[N_{\text{obs}}^{(i)} - N_{\text{SM}}^{(i)} - N_{\text{SUSY}}^{(i)}(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) \right]^2}{\sigma_i^2}$$

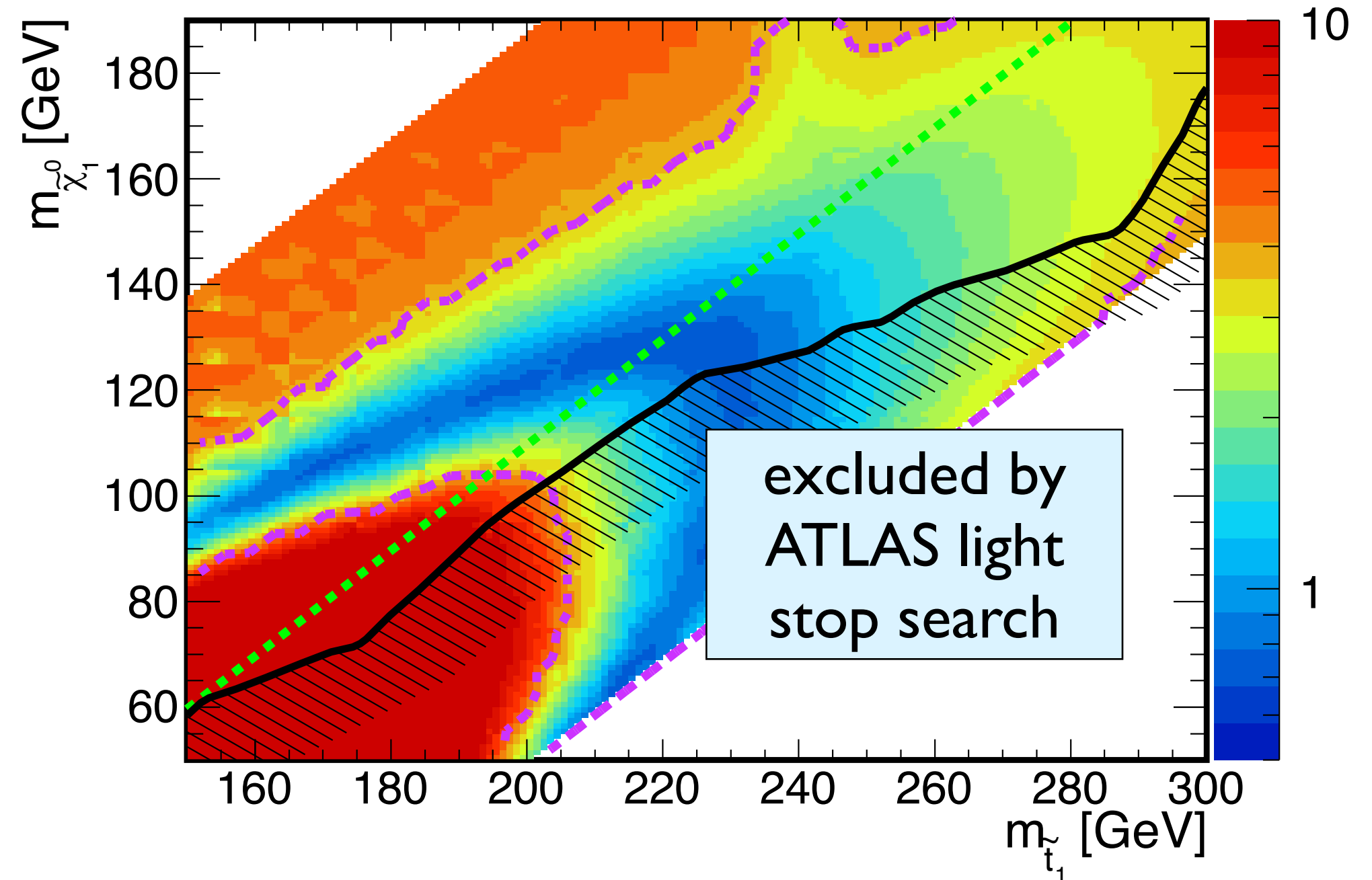
Scan Results

χ^2 : CMS 8TeV



χ^2 : [ATLAS7, CMS7, CMS8]

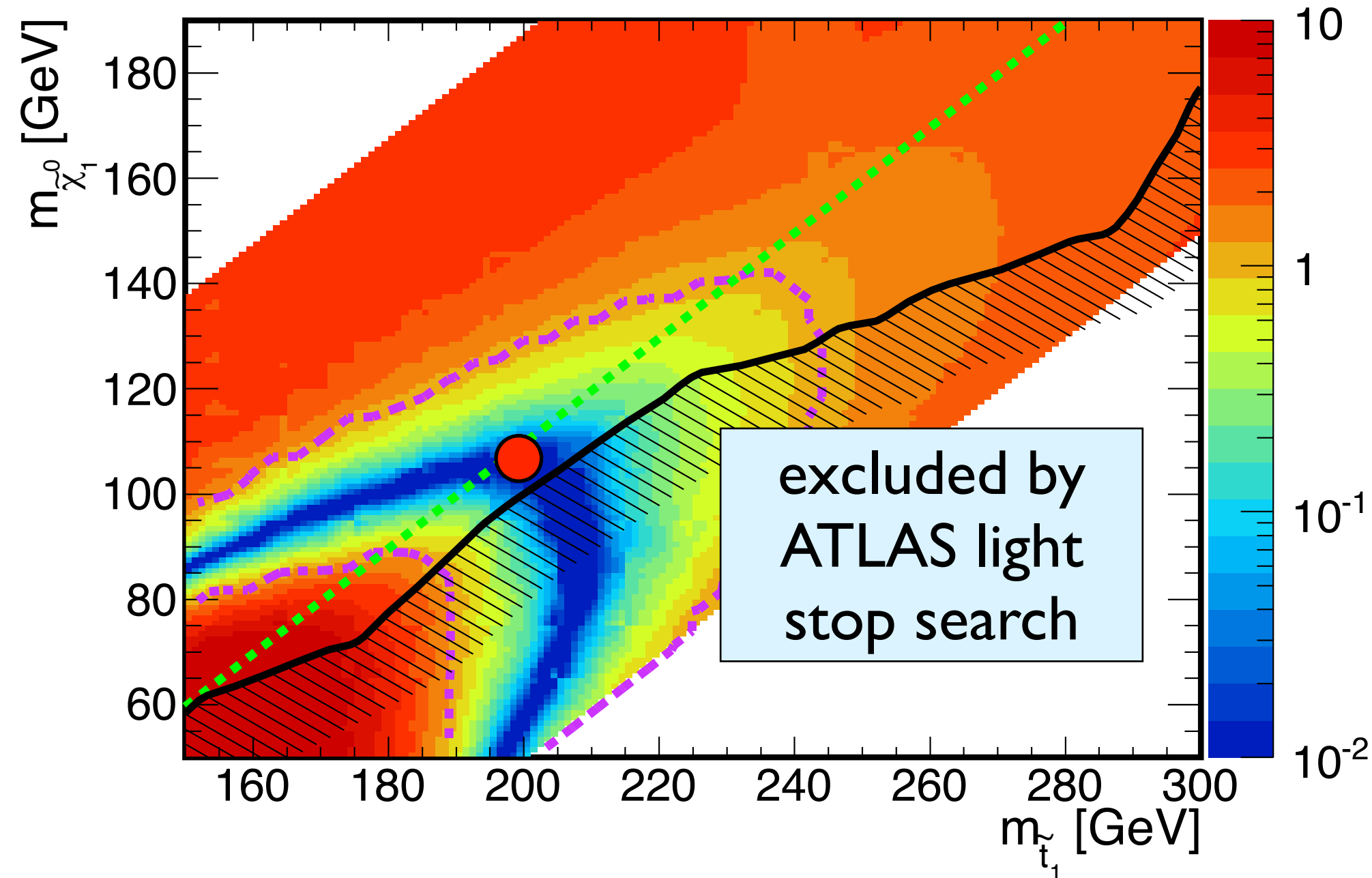
M.Asano, K. Rolbiecki, KS (1209.5778)



- The excess in CMS 8TeV is well explained with $150\text{GeV} < m(\text{stop}) < 240\text{GeV}$, $80\text{GeV} < m(\chi^0) < 130\text{GeV}$.
- The preferred region of the combined chi-square spreads rather broadly.
- Stop is strongly disfavoured in the lower left red regions. ==> The analysis used for WW cross section measurements can be also used as light stop searches.

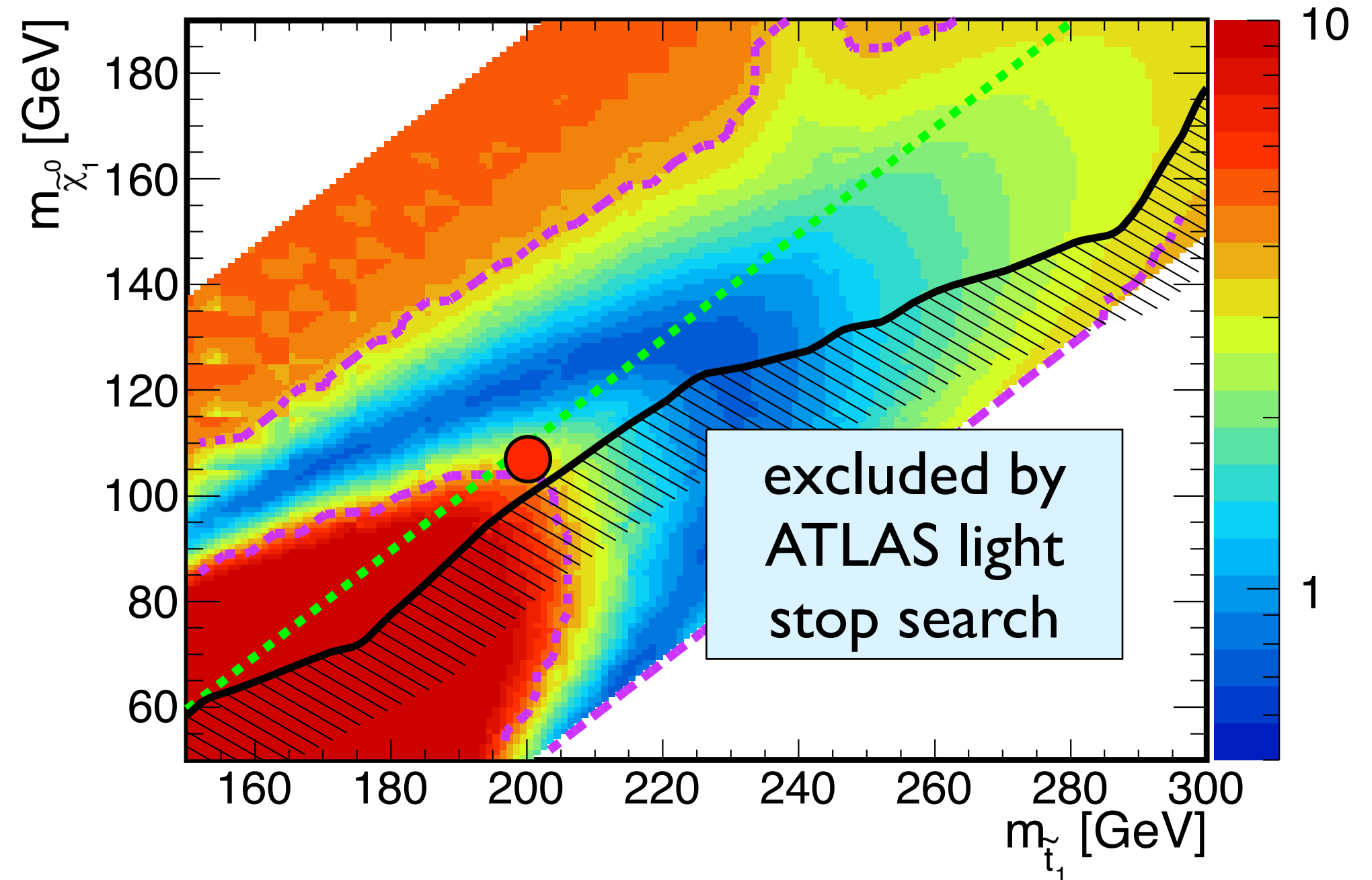
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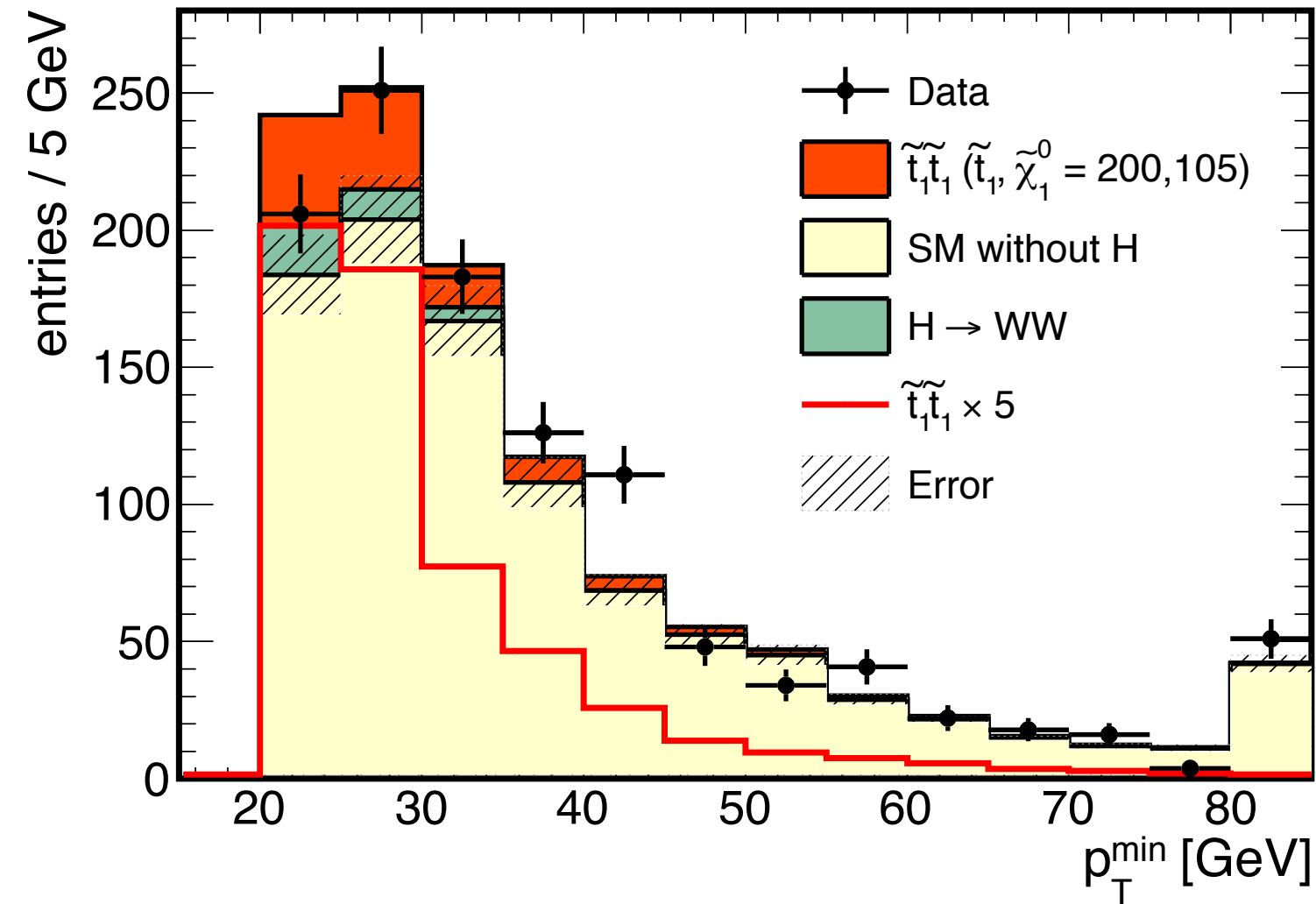
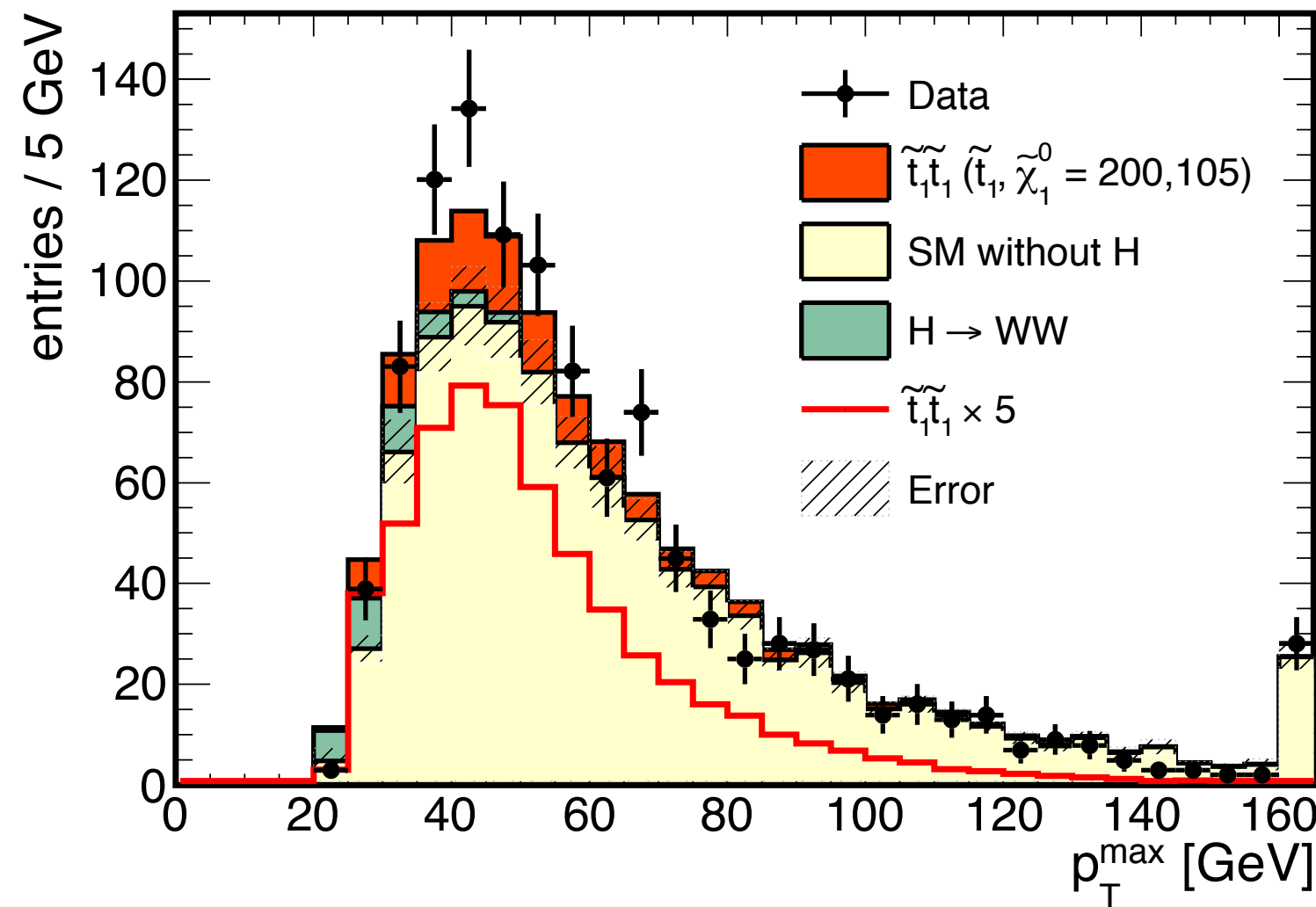
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M. Asano, K. Rolbiecki, KS (1209.5778)



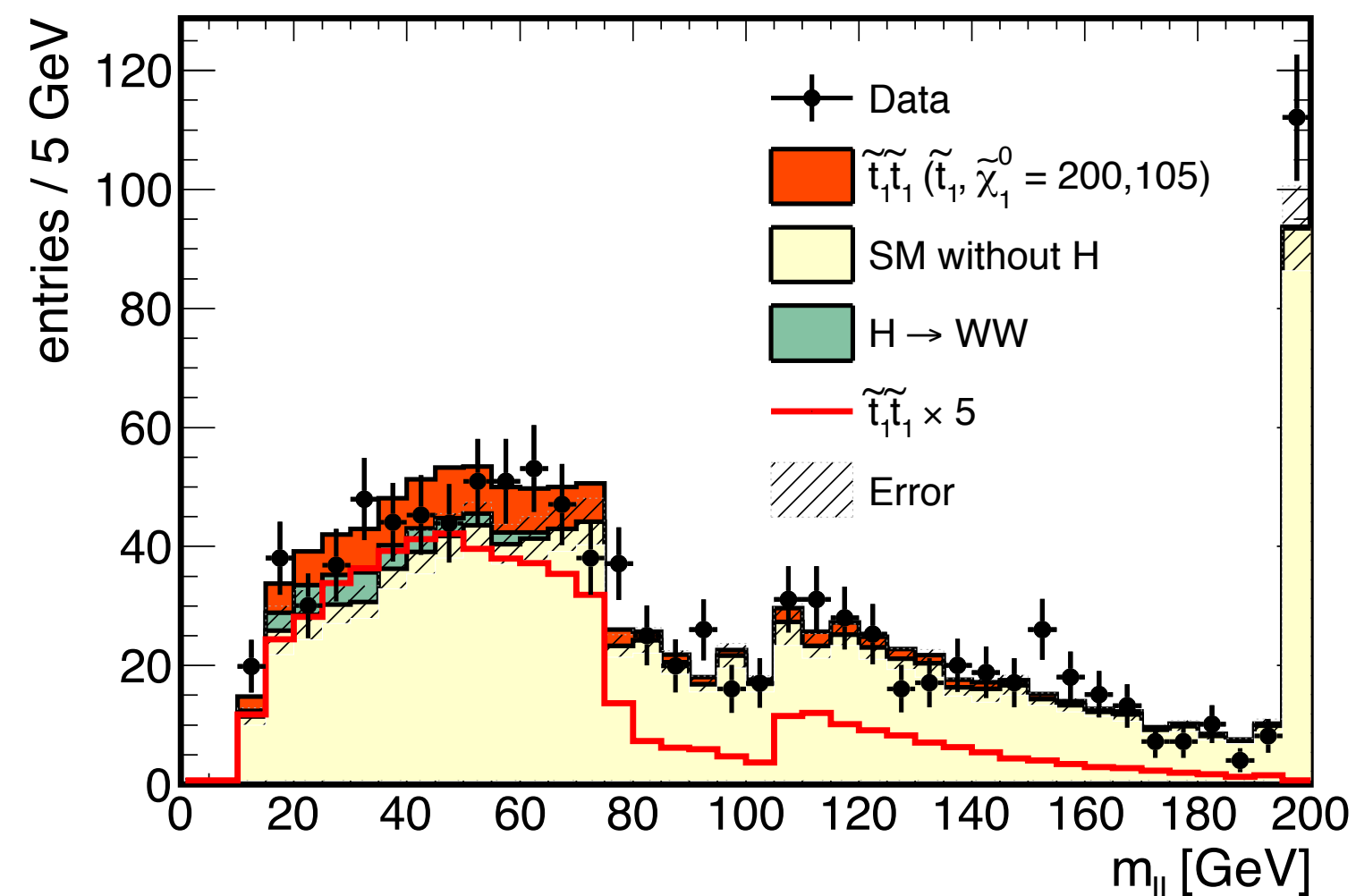
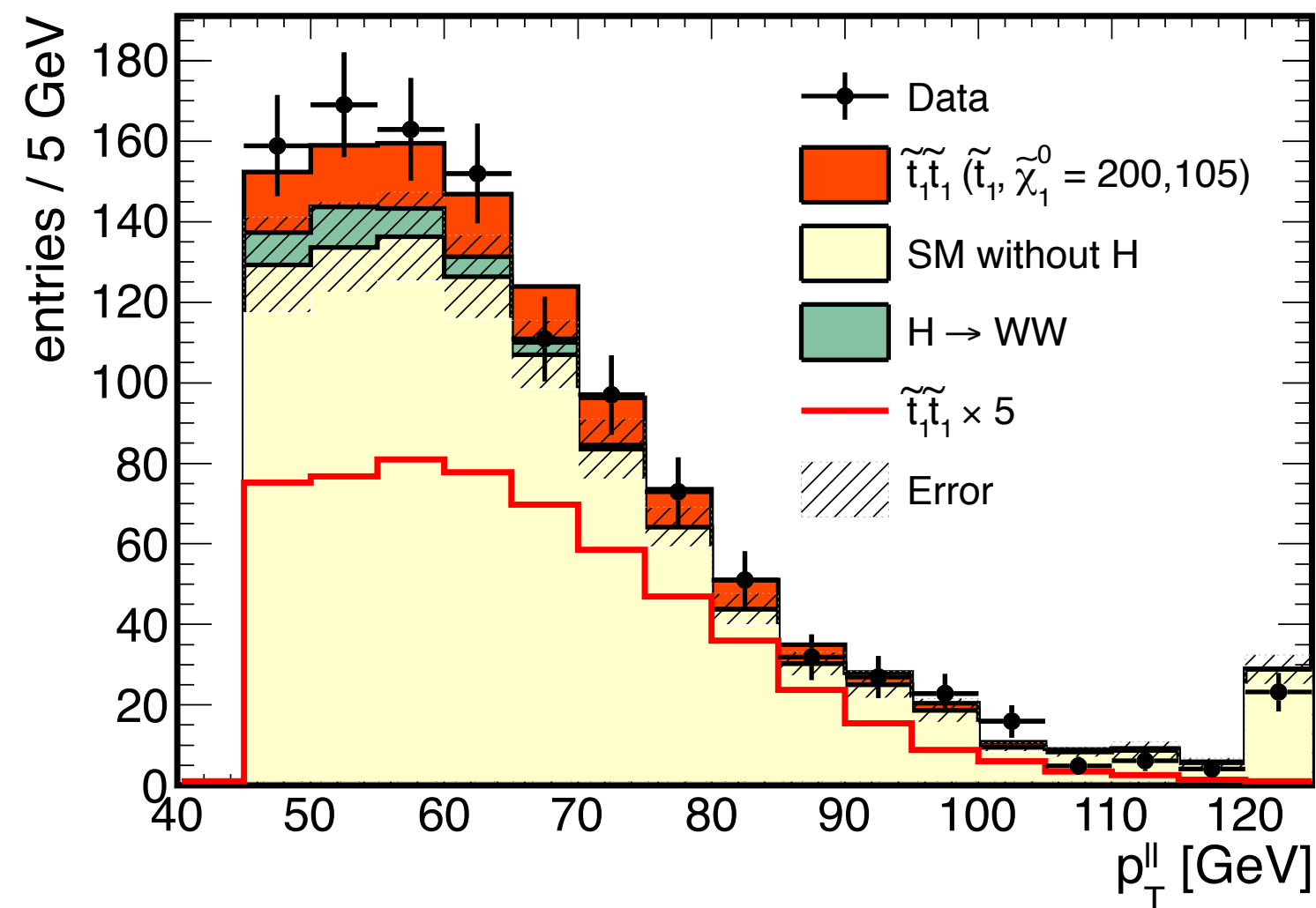
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p_T and $m(l\bar{l})$ distributions



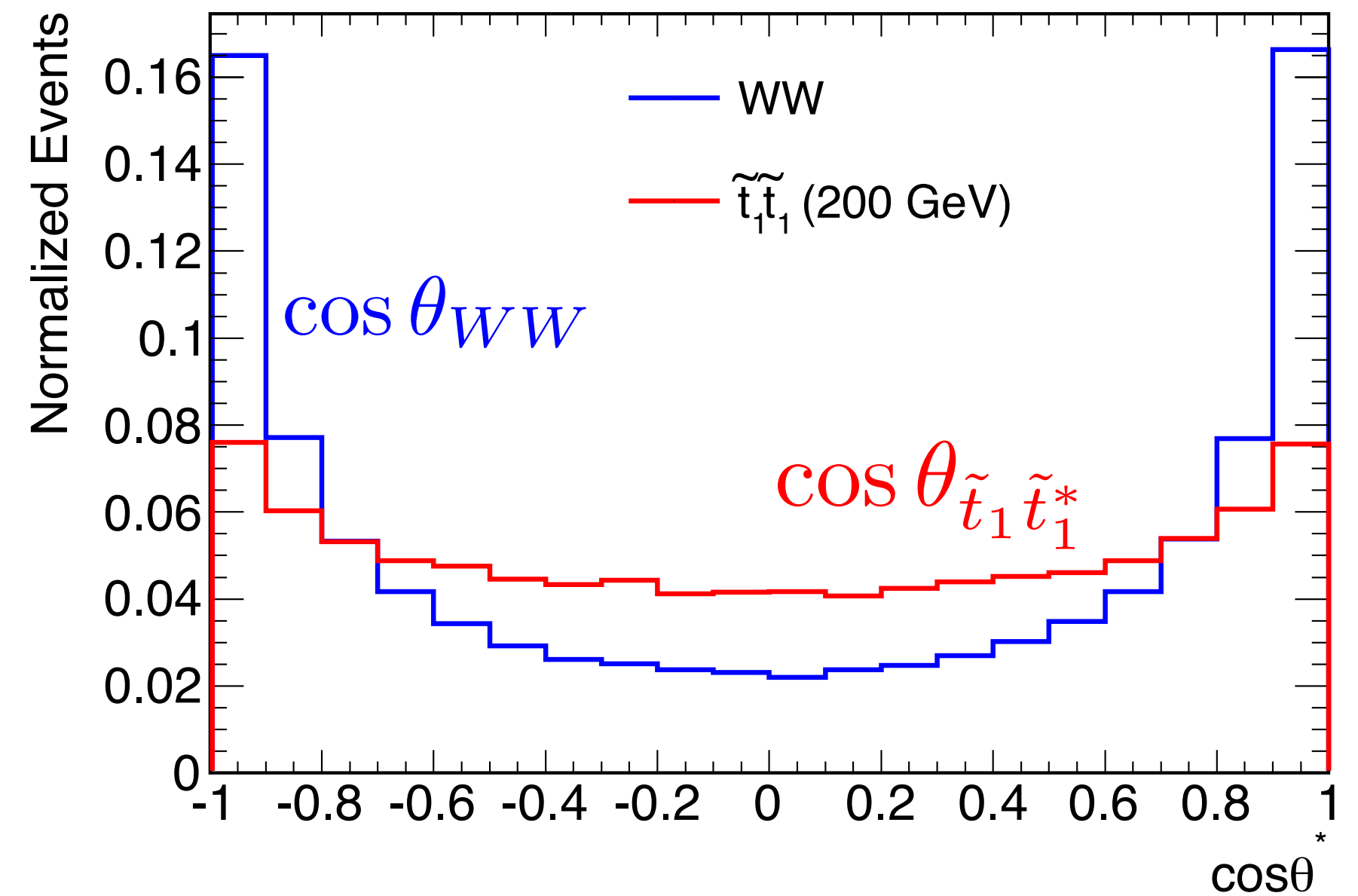
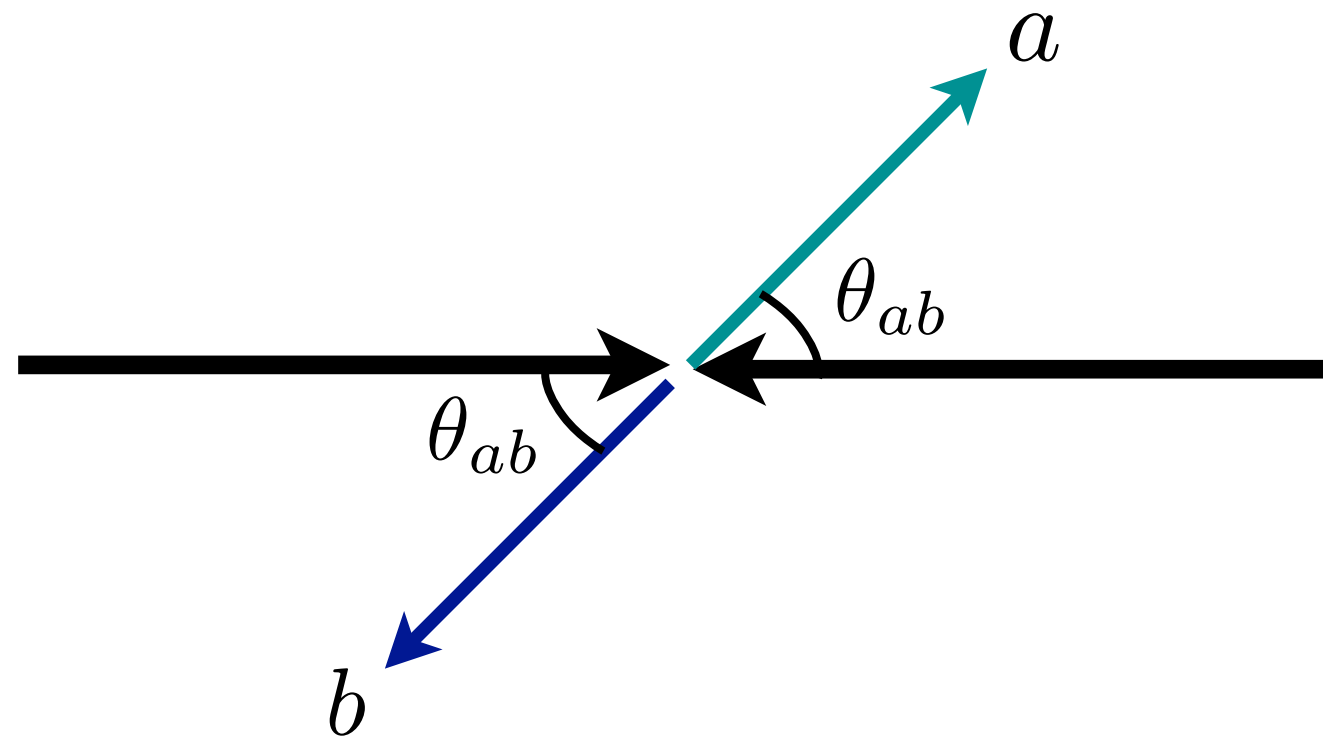
• stop contribution looks very similar to the genuine WW events in the p_T distributions.

==> How can we distinguish between stop and WW events?



Polar angle distribution

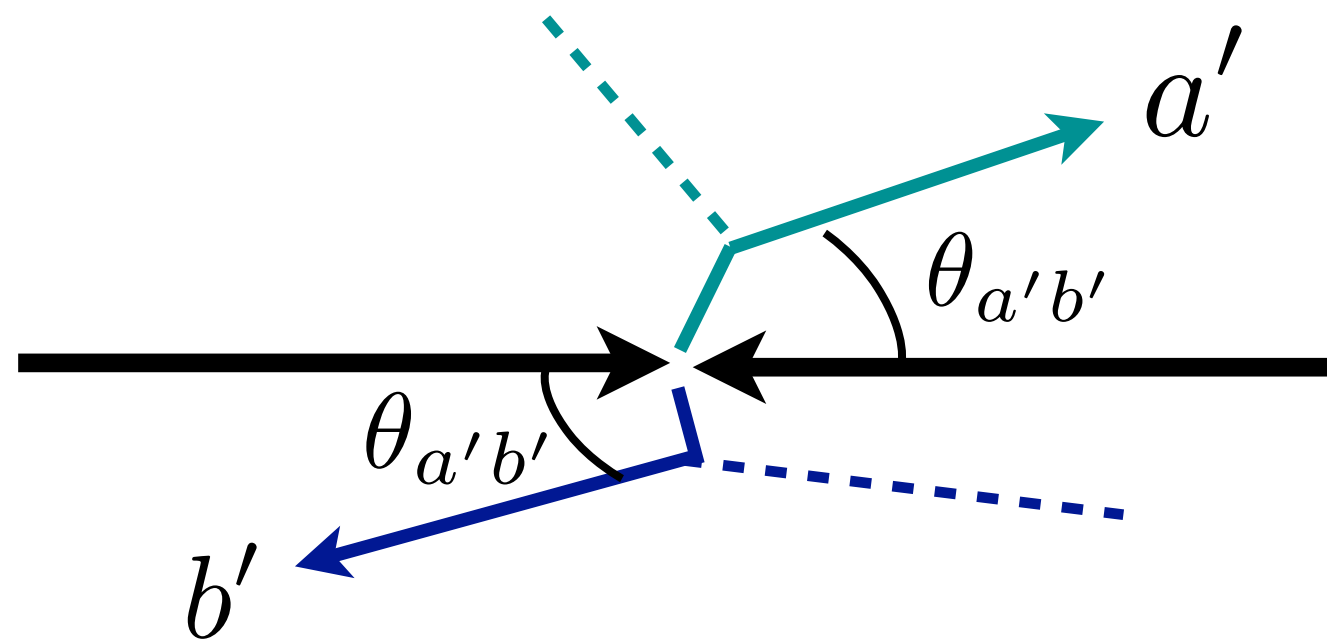
- The angle between the beam and particle a(b) in the frame where the two angles are equal.



- Ws are strongly prefer the forward region whereas the distribution is more or less flat for the stop events.

Polar angle distribution

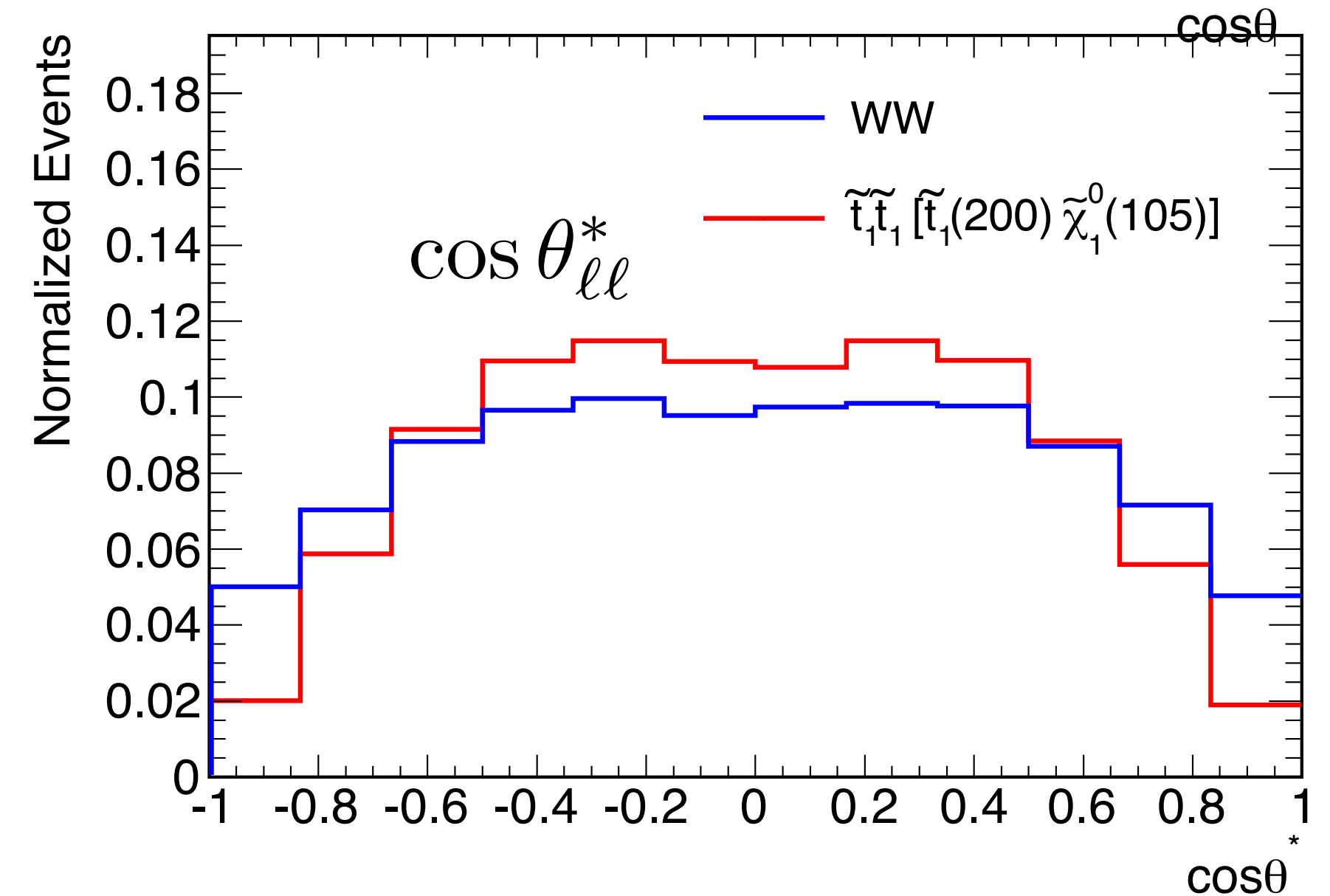
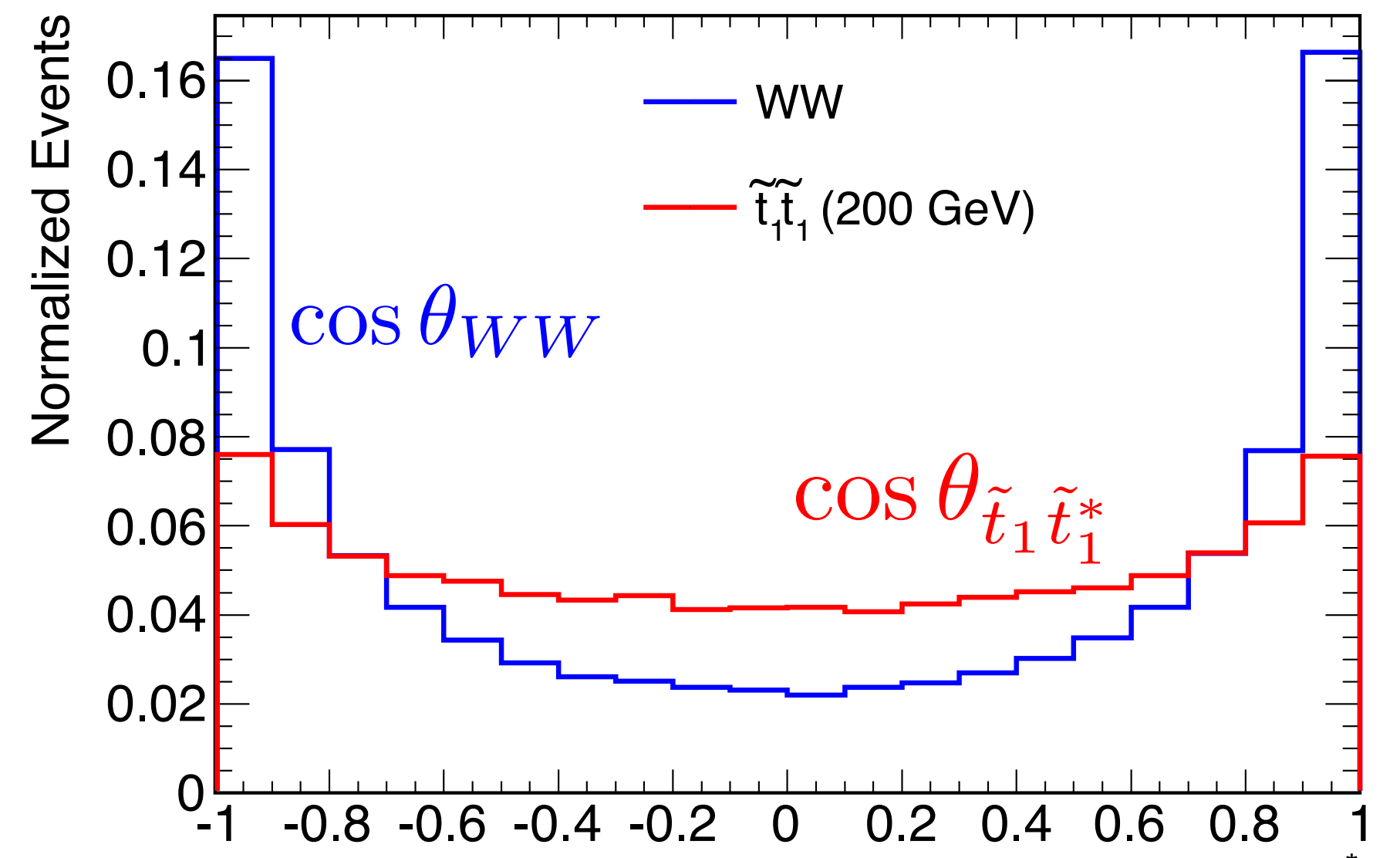
- The angle between the beam and particle a(b) in the frame where the two angles are equal.



- For the massless decay products, we can use

$$\cos \theta_{\ell\ell}^* = \tanh \left(\frac{\Delta\eta_{\ell\ell}}{2} \right) \text{ with } \Delta\eta_{\ell\ell} = \eta_{\ell_1} - \eta_{\ell_2}$$

- The difference between W and stop events is now very weak because the directions of decay products are poorly correlated to the direction of initially produced particles in the threshold region.

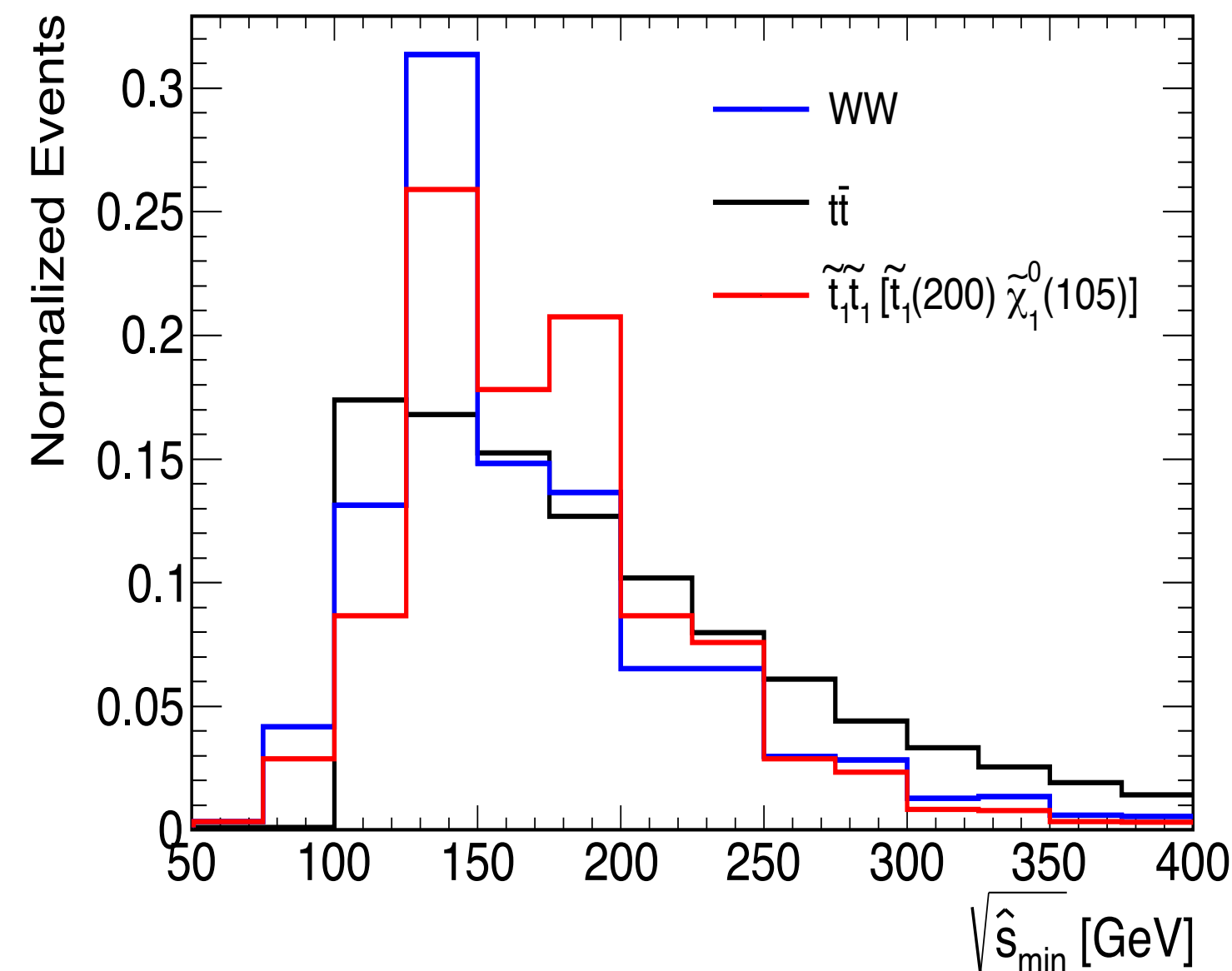


$\sqrt{\hat{s}_{\min}}$ cut

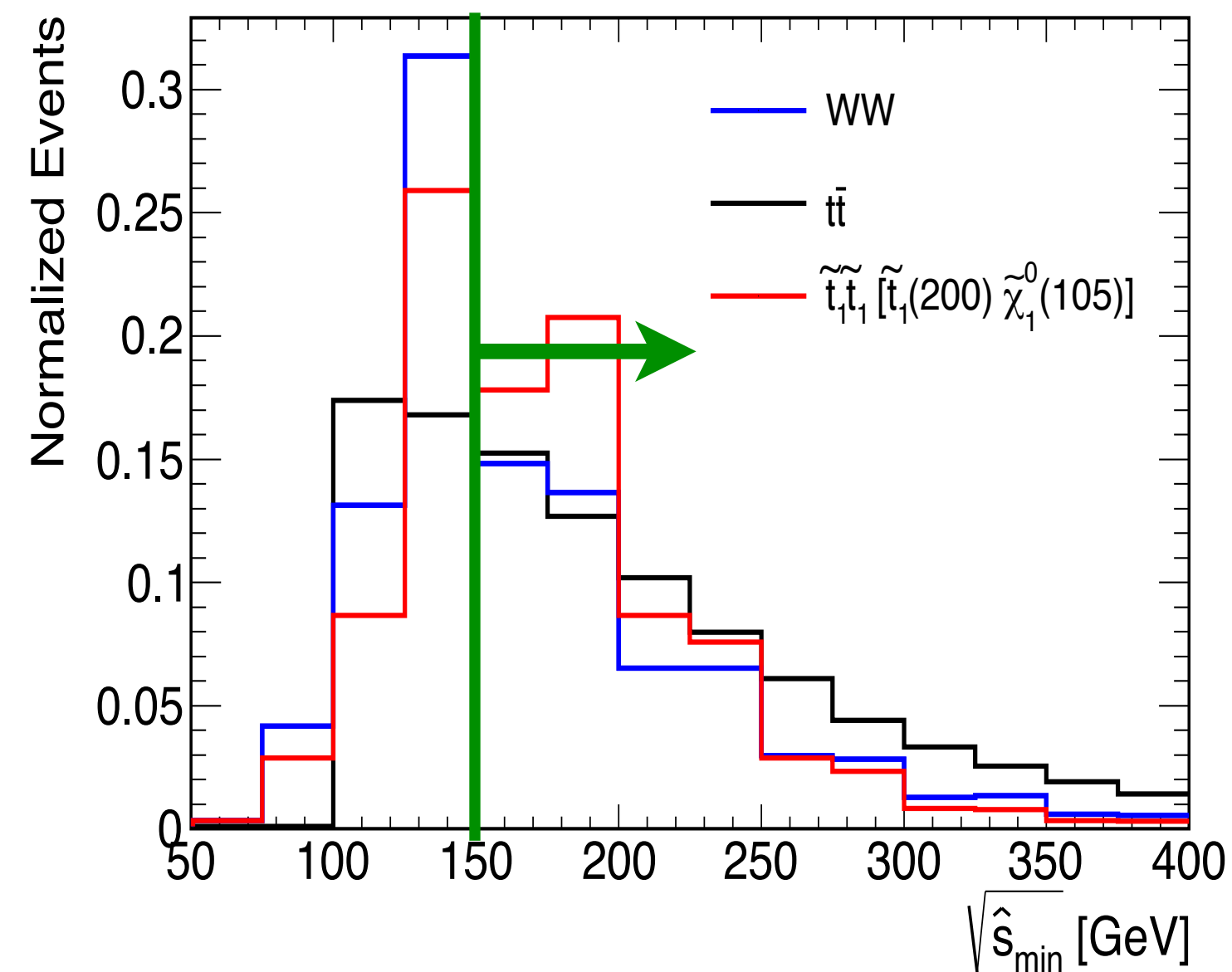
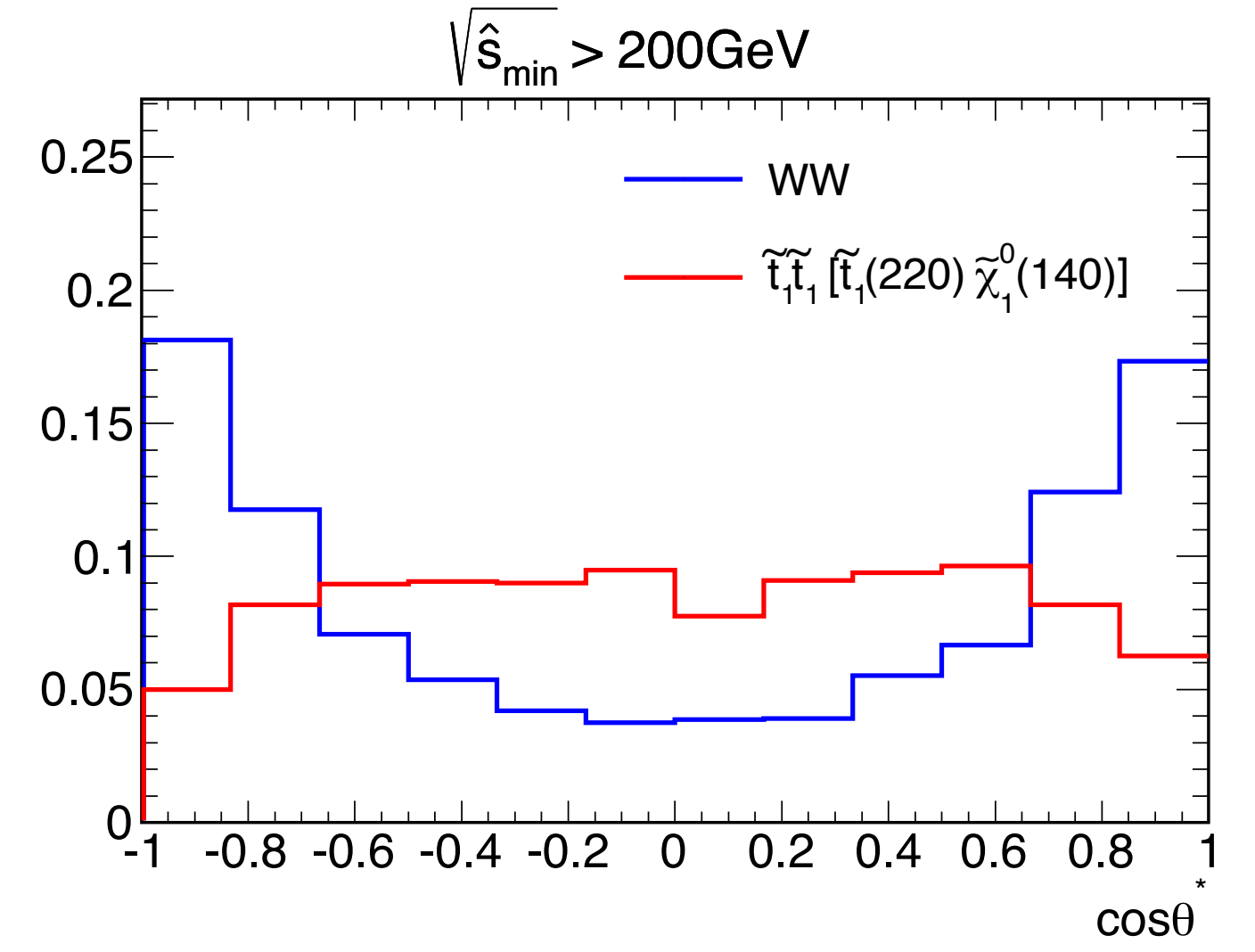
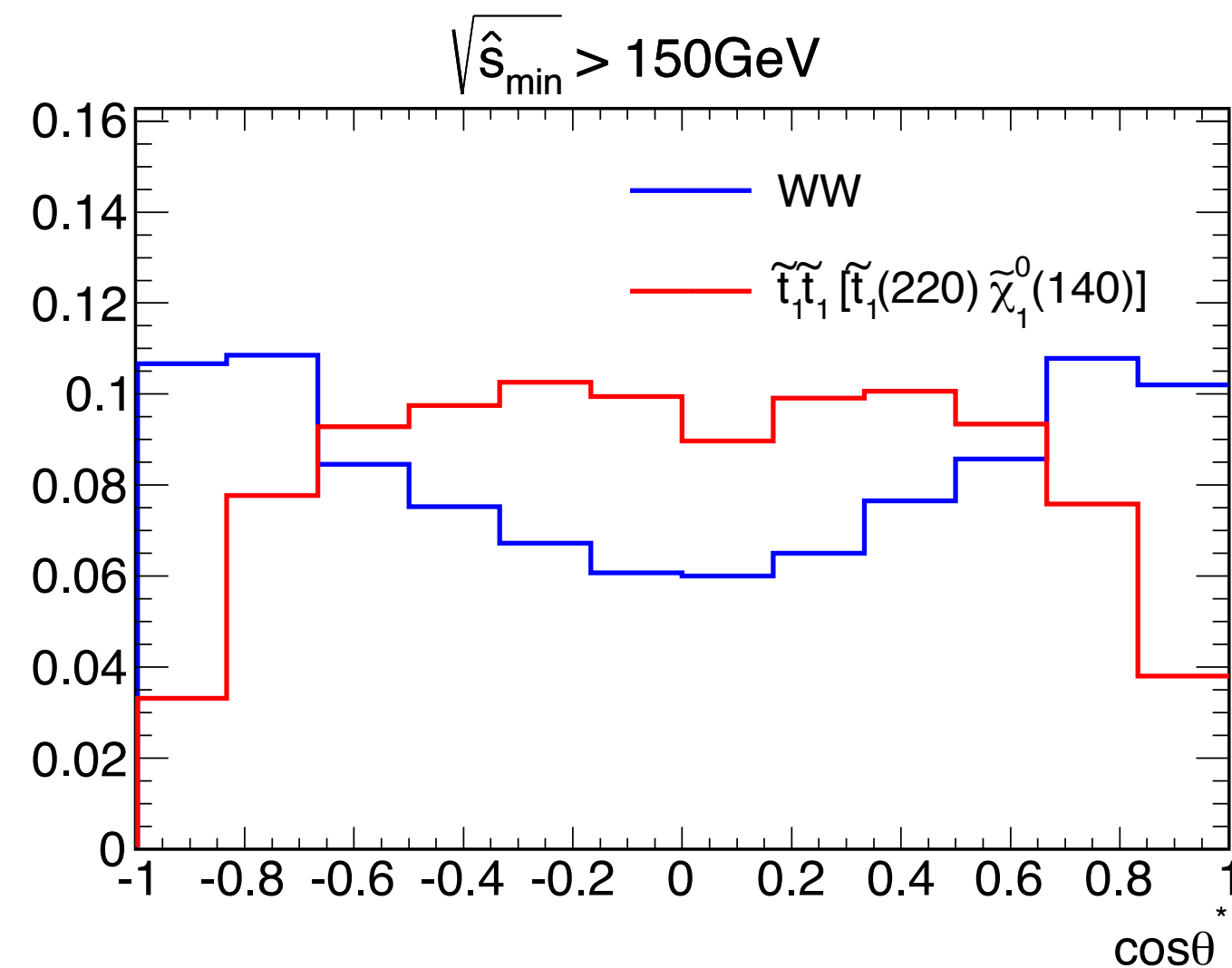
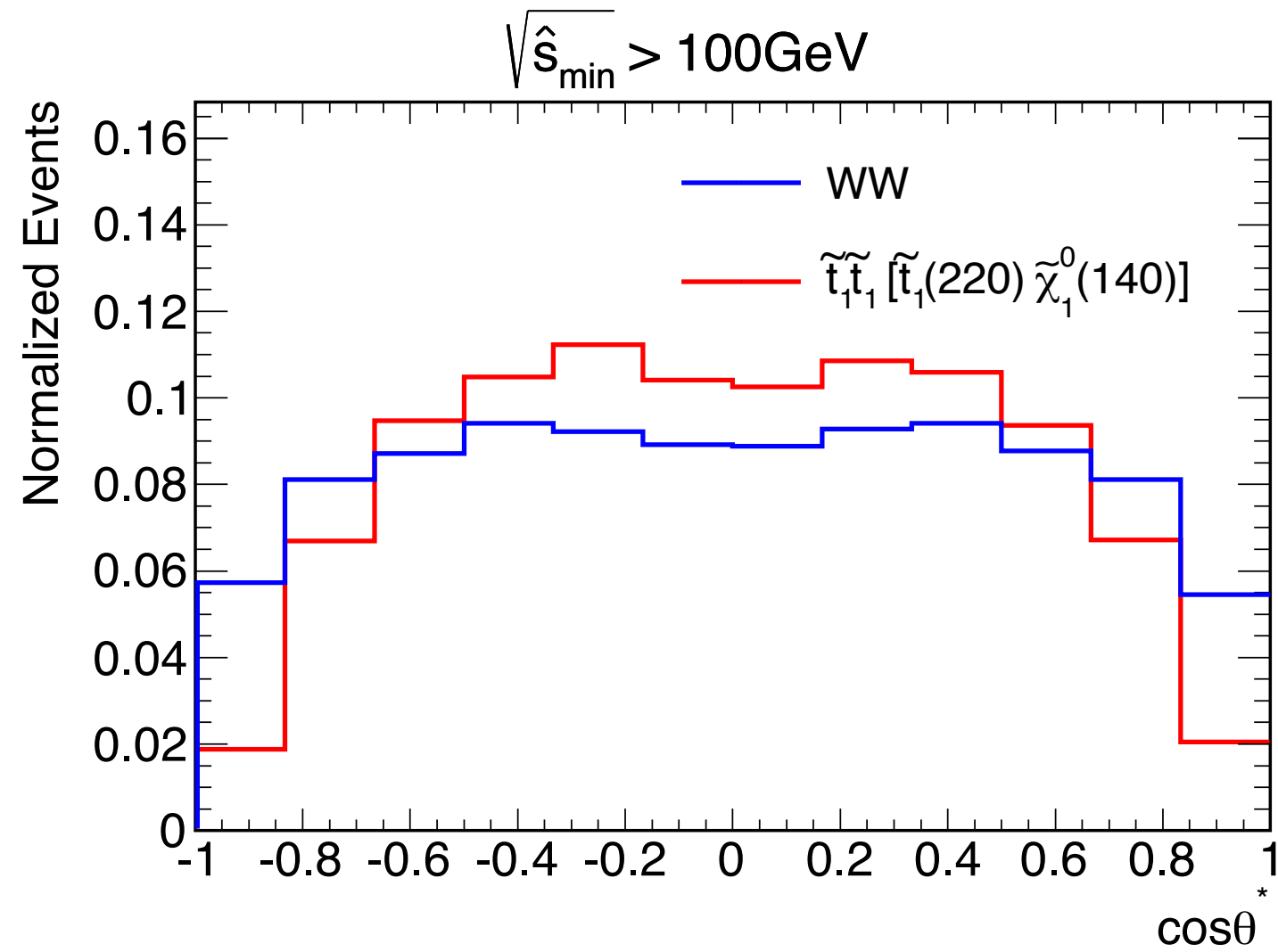
- In the events where the initial particles are highly boosted, the correlation between the initial and final particles is strong. To select such events, we impose a cut on $\sqrt{\hat{s}_{\min}}$, which is designed to estimate the minimum partonic CoM energy in the event.

P.Konar, K.Kong, K.T.Matchev (0812.1042)

$$\sqrt{\hat{s}_{\min}} = \sqrt{E_{\ell\ell}^2 - (P_{\ell\ell}^z)^2} + E_T^{\text{miss}}$$



$\sqrt{s}_{\min}$ cut



We adopt

$$\sqrt{s}_{\min} > 150 \text{ GeV}$$

for the following study

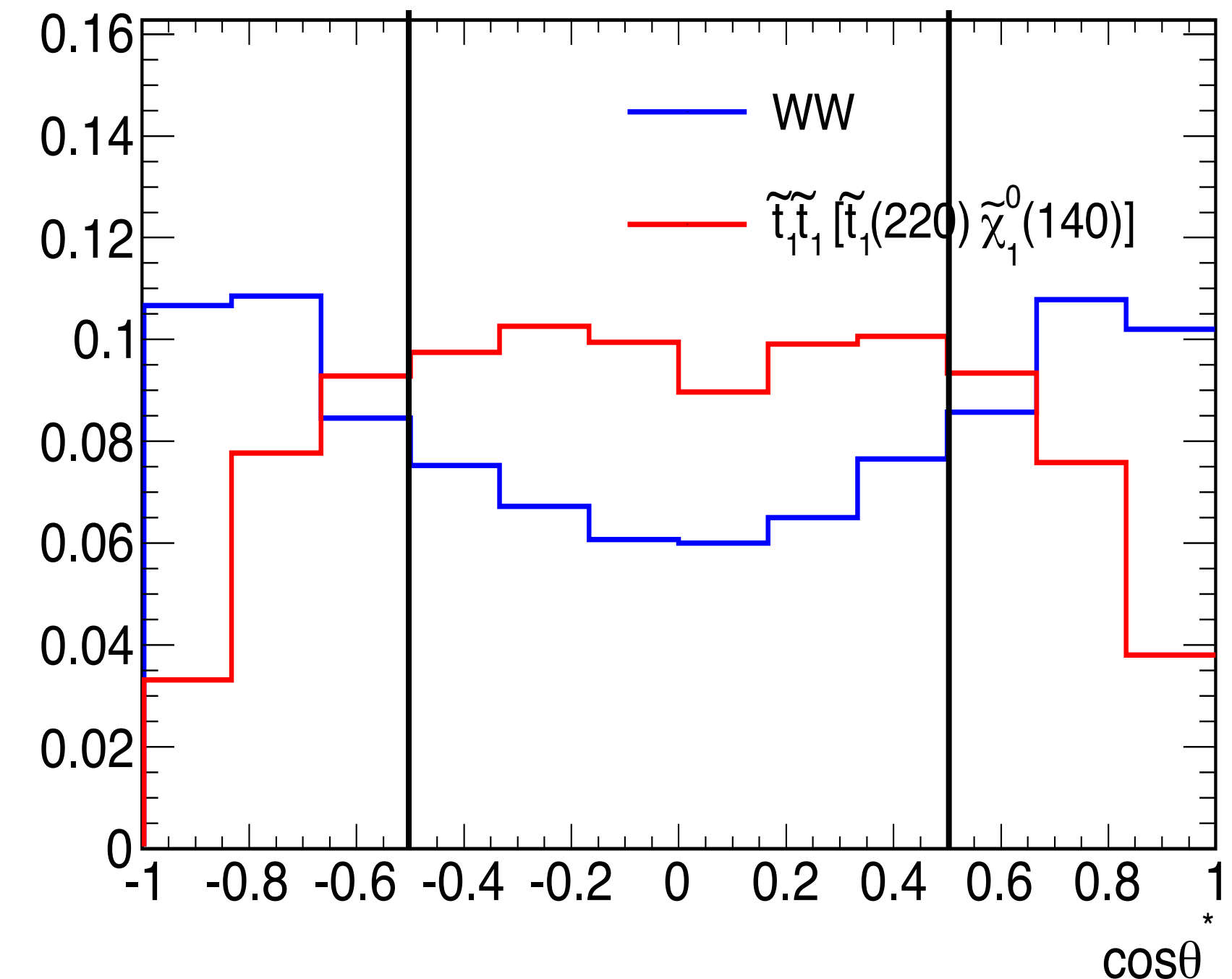
Asymmetry

- Define central vs. forward asymmetry by

$$\mathcal{A} = \frac{N(|\cos \theta_{\ell\ell}^*| > 0.5) - N(|\cos \theta_{\ell\ell}^*| < 0.5)}{N_{\text{tot}}}$$

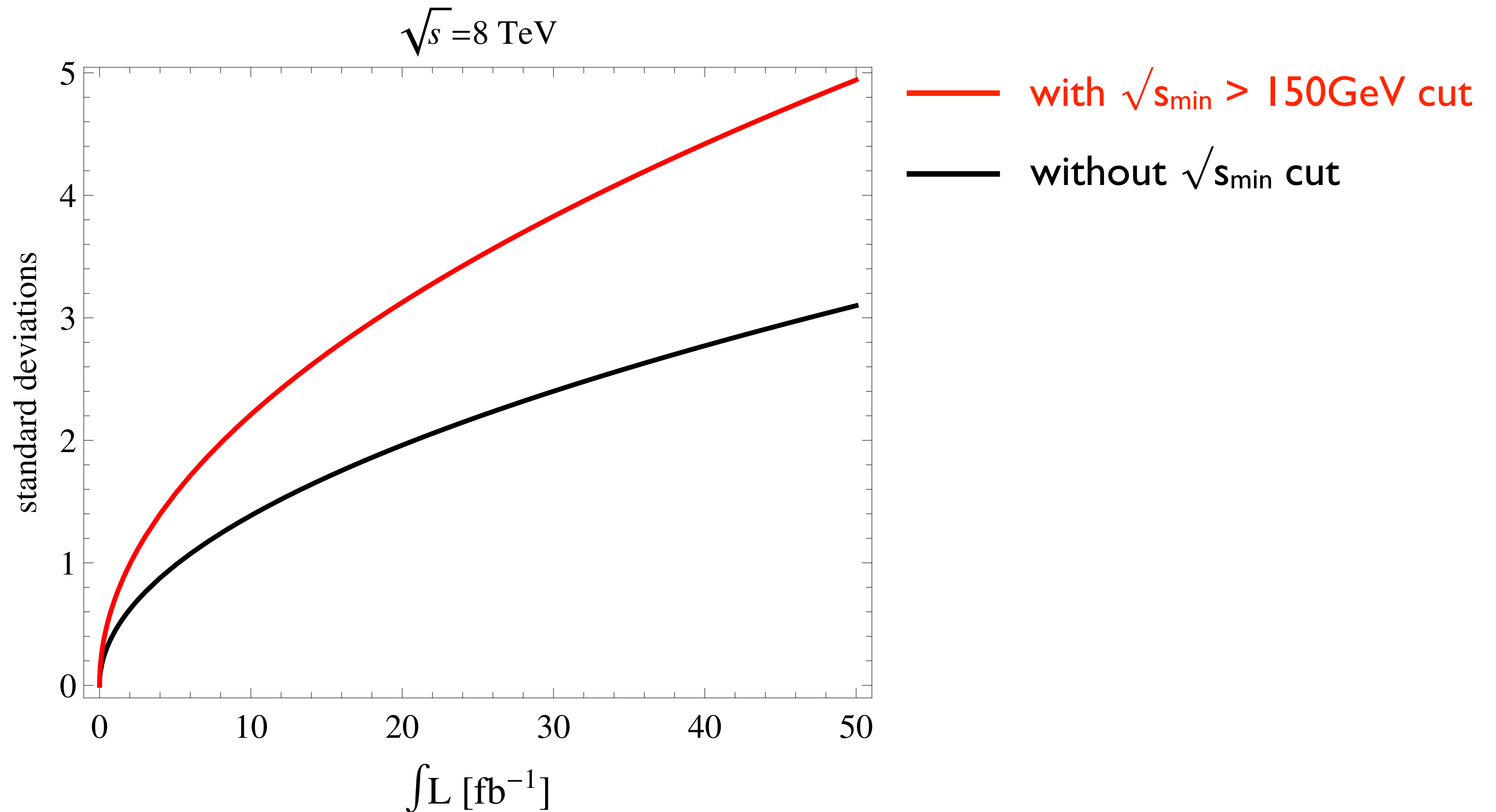
- The difference between W and stop pairs is significant after the $\sqrt{s}_{\text{min}}$ cut.

$\sqrt{\hat{s}}_{\text{min}}/\text{GeV}$	$\mathcal{A}(\sqrt{s} = 8 \text{ TeV})$	
	WW	$\tilde{t}_1\tilde{t}_1^*$
> 0	-0.170	-0.332
> 150	0.170	-0.225



- We calculate the significance of the discrepancy between $WW + \text{SMBG}$ sample and $WW + \text{SMBG} + \text{stop pair}$ sample.

Result



- if ATLAS and CMS data are combined and the $\sqrt{s}_{\min}$ cut is used, the significance can reach at **5-sigma**.

Summary

- **Multi-lepton** and **very large multiplicity jets** signatures have a good handle on controlling SM backgrounds without requiring large p_T jets or large E_T^{miss} .

- By reinterpret the existing searches, we found

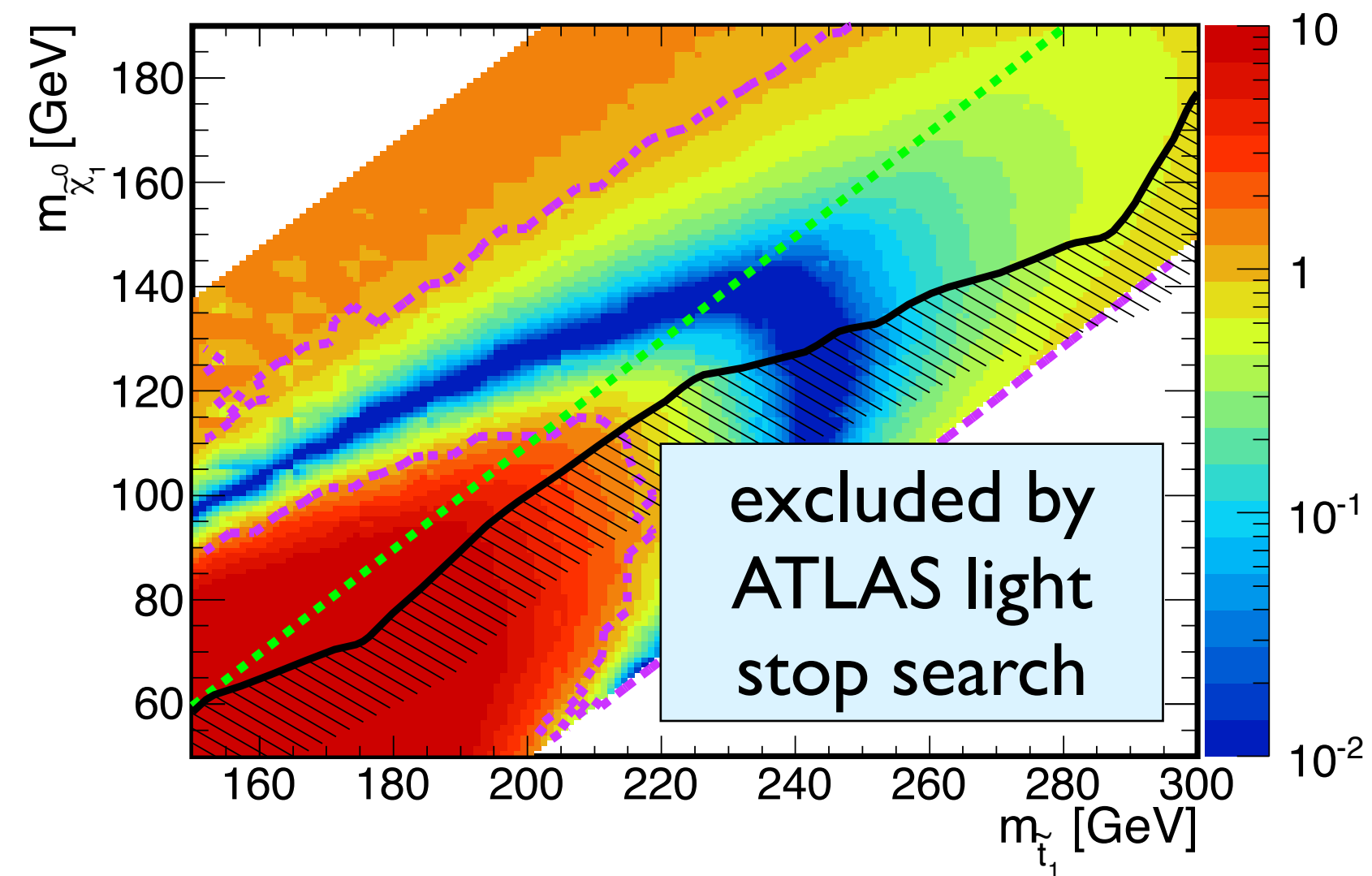
$M(\text{gluino}) \sim M(\text{squark}) > \mathbf{900\text{GeV}}$ for a **compressed SUSY simplified model**
with $\Delta m \sim 100\text{GeV}$

$M(\text{gluino}), M(\text{squark}) > \mathbf{800\text{GeV}}$ for a **RPV (UDD) simplified model**

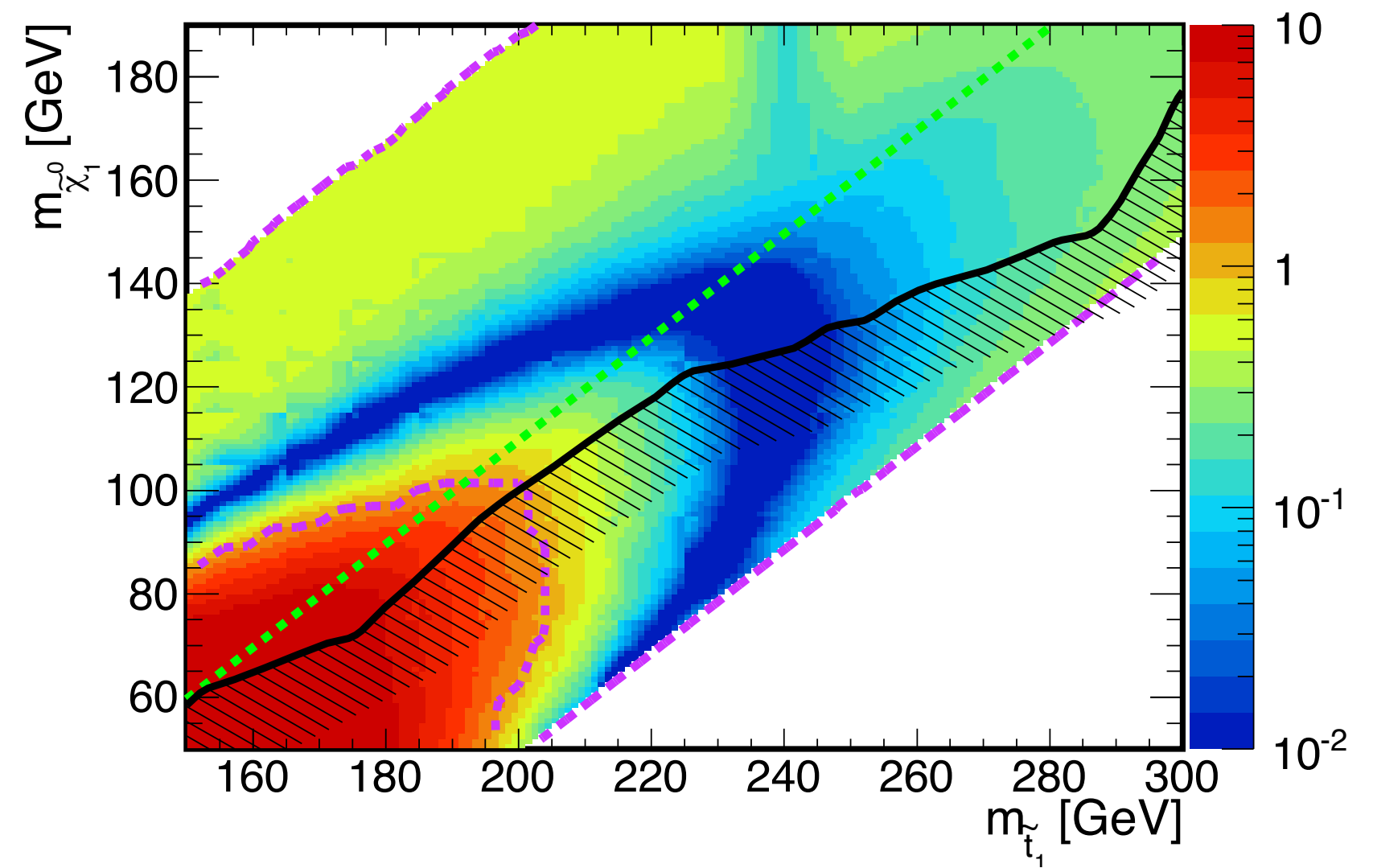
- 1-2 sigma excesses are observed in the WW cross section measurements and they can be interpreted as a contribution of stop production followed by $\tilde{t}_1 \rightarrow b \tilde{\chi}^\pm \rightarrow b W^{(*)} \tilde{\chi}^0$.
- Preferred parameter region: $\mathbf{150\text{GeV} < m(\text{stop}) < 240\text{GeV}, 80\text{GeV} < m(\chi^0) < 130\text{GeV}}$.
- The WW cross section measurements are capable to exclude the light stop region.
- The stop contribution can be distinguished from WW events by looking at the polar angle distribution imposing large $\sqrt{s}_{\text{min}}$ cut.

- heavy Higgs boson requires rather light stops
 - ⇒ can be overcome if the stops are split:
 - ⇒ $m_{\tilde{t}_R} = 195 \text{ GeV}$, $m_{\tilde{t}_L} = 2000 \text{ GeV}$, $A_t = 2000 \text{ GeV}$
 - ⇒ $m_h = 125.6 \text{ GeV}$, bonus: $R_{\gamma\gamma} = 1.05 \cdot R_{\gamma\gamma}^{\text{SM}}$
- gaugino parameters for correct chargino and LSP
 - ⇒ $M_1 = 105 \text{ GeV}$, $M_2 = 190 \text{ GeV}$, $\mu = 2500 \text{ GeV}$ and $\tan \beta = 15$
- light stuff having the following masses:
 - ⇒ $m_{\tilde{t}_1} = 203.7 \text{ GeV}$, $m_{\tilde{\chi}_1^0} = 104.9 \text{ GeV}$ and $m_{\tilde{\chi}_1^\pm} = 189.5 \text{ GeV}$
- low energy observables evaluated as
 - ⇒ $\text{BR}(B \rightarrow X_s \gamma) = 3.7 \times 10^{-4}$ and $\text{BR}(B_s \rightarrow \mu\mu) = 3.45 \times 10^{-9}$
 - ⇒ needs $m_{\tilde{b}_R} = 1000 \text{ GeV}$
- basic consistency can be ensured

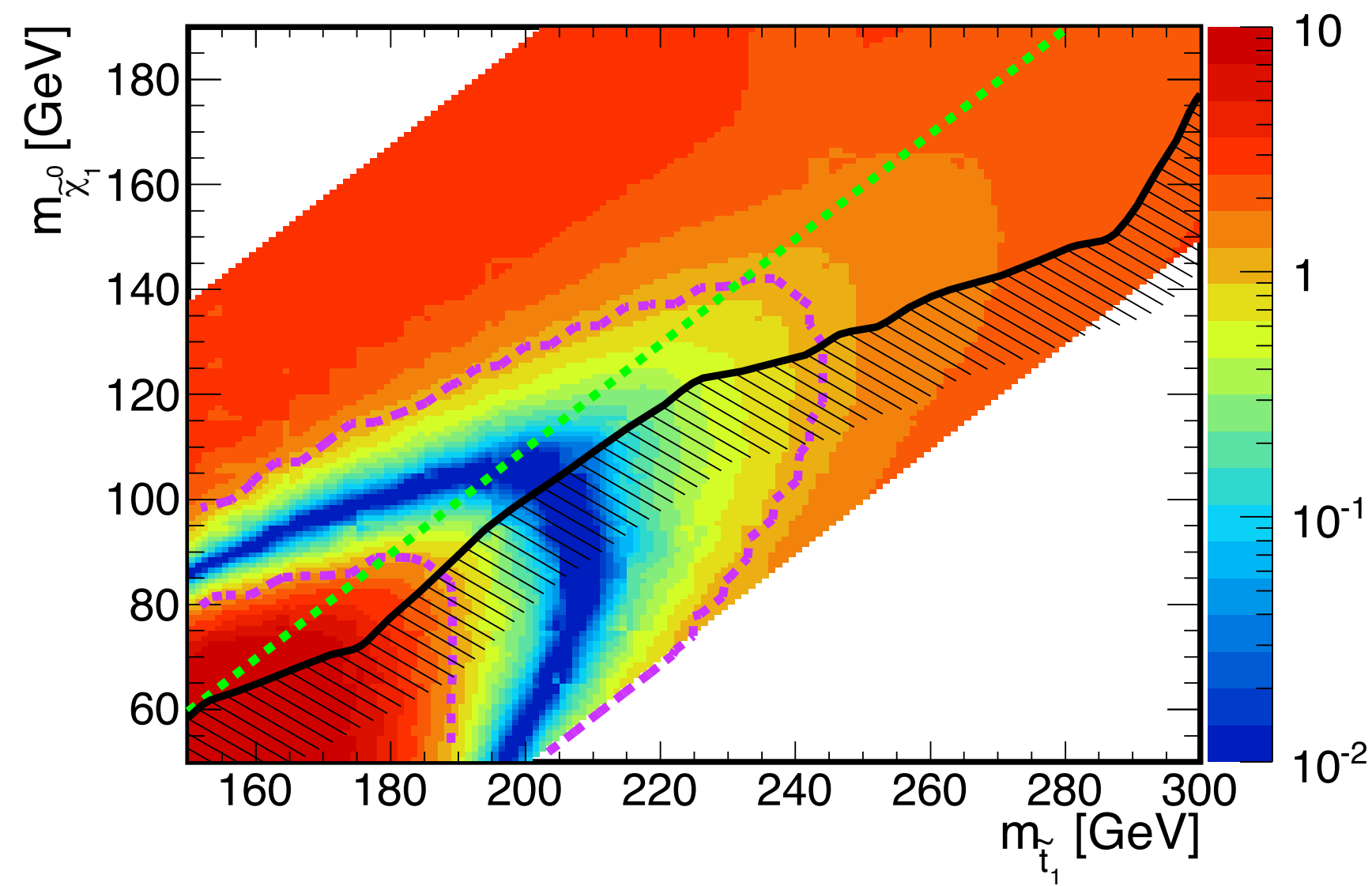
χ^2 : ATLAS 7TeV



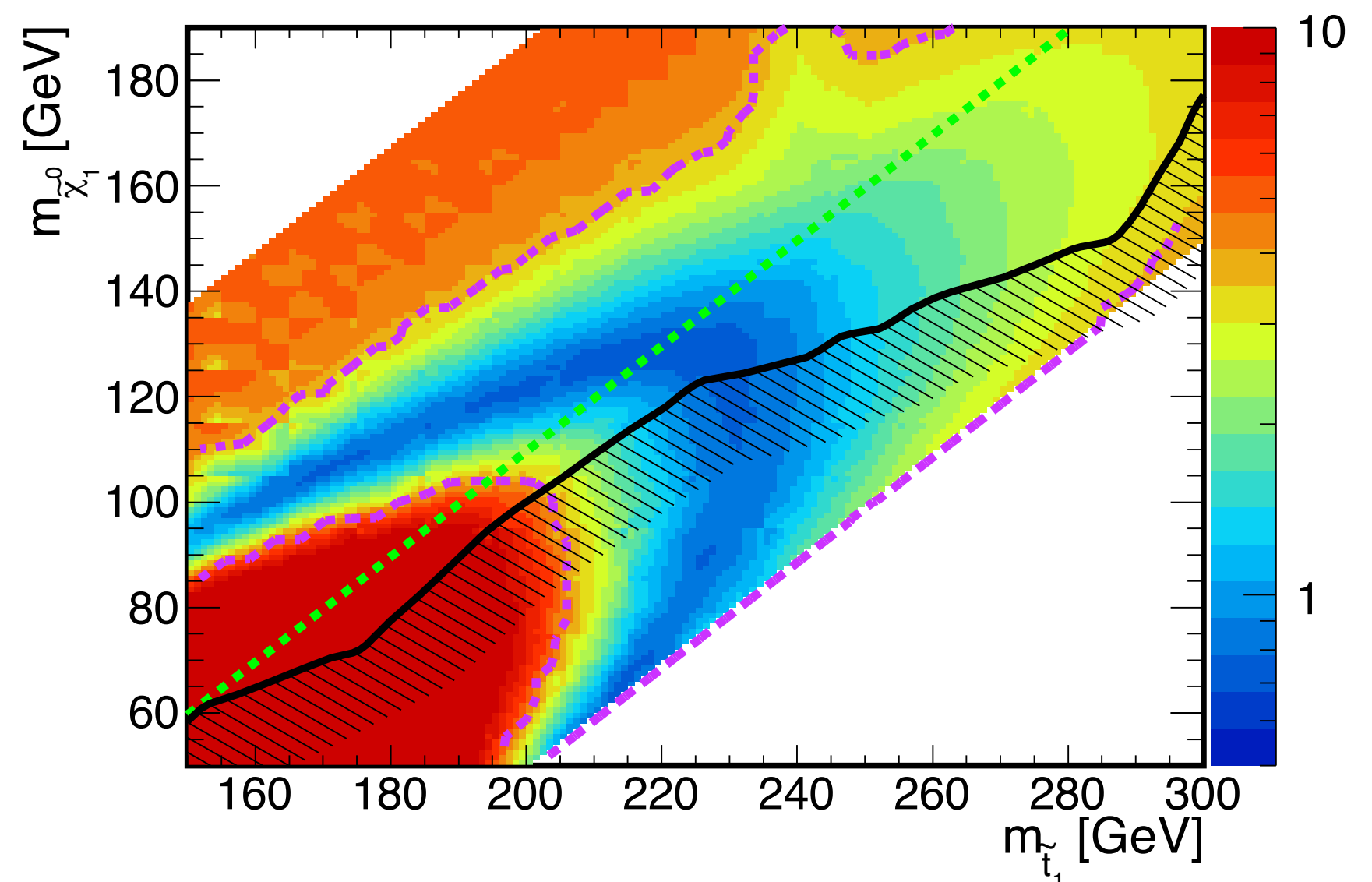
χ^2 : CMS 7TeV

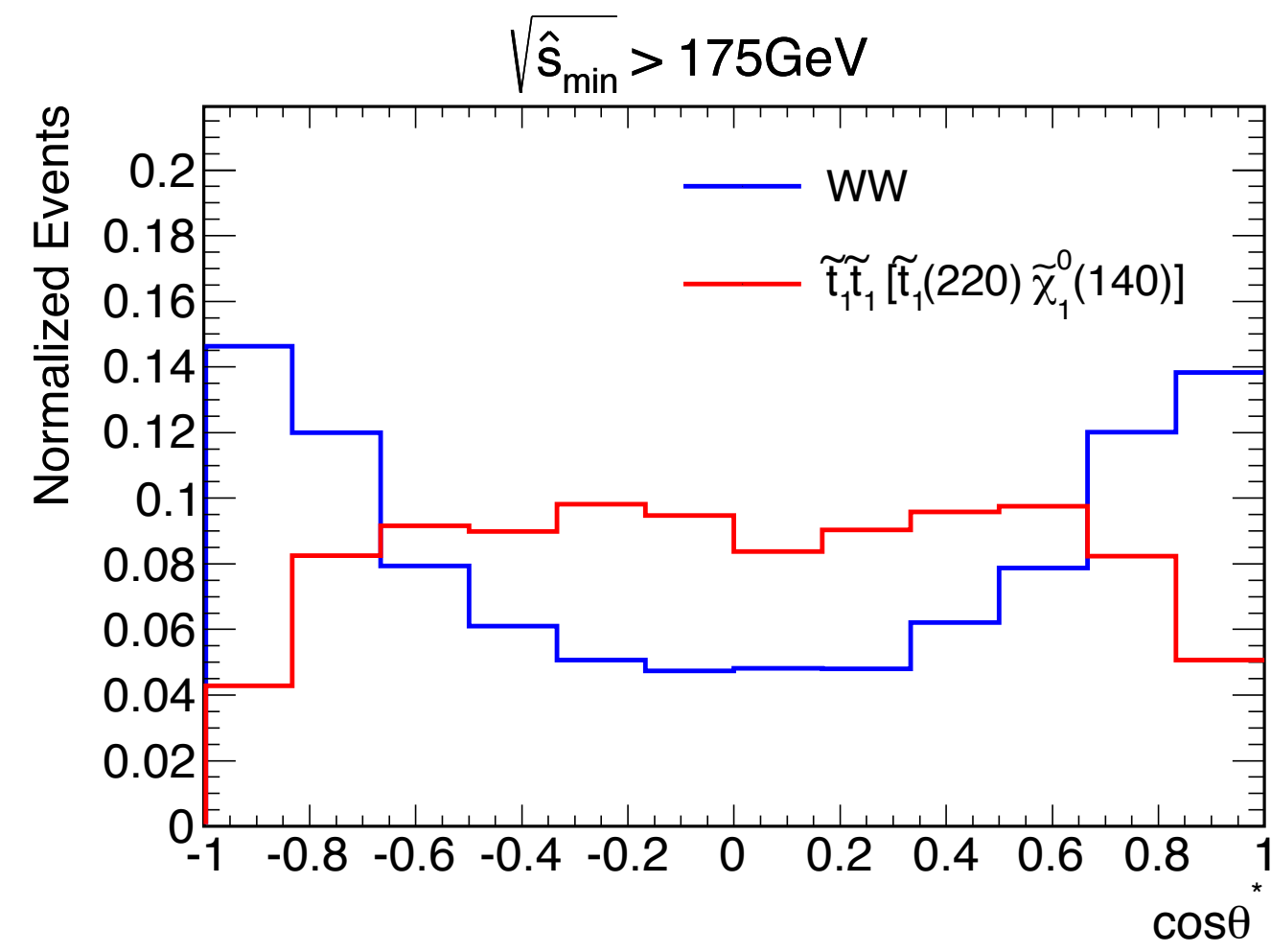
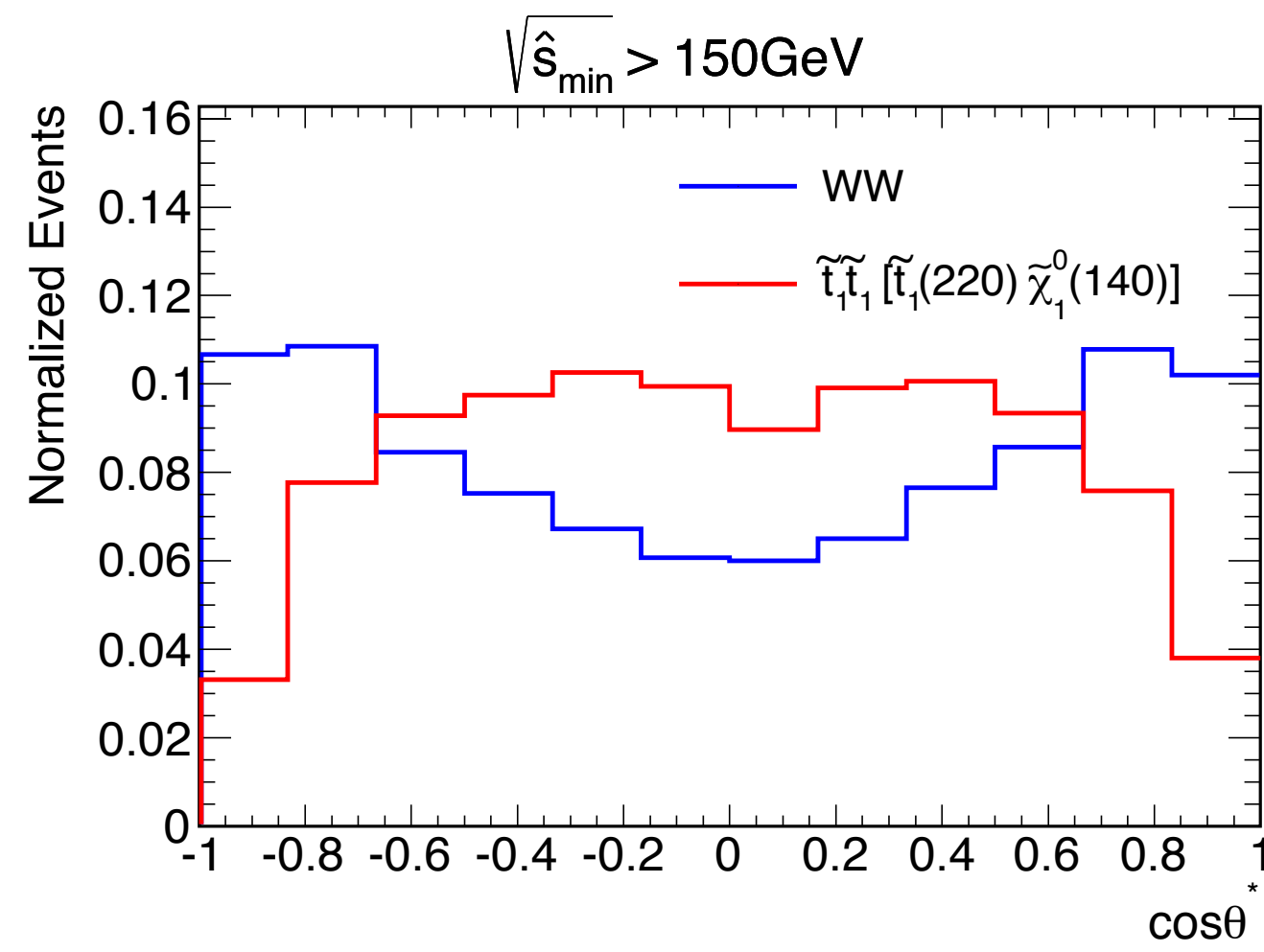
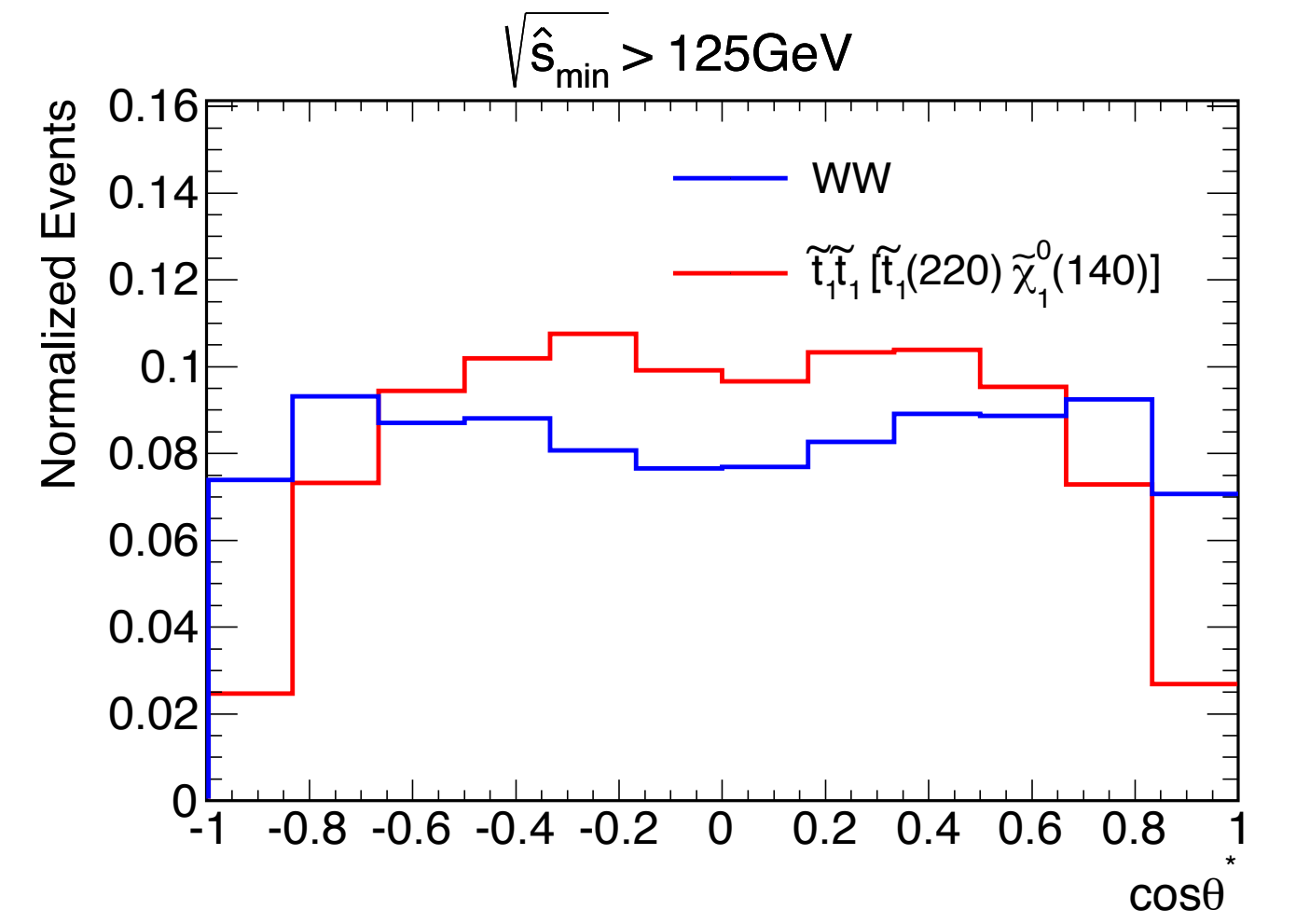
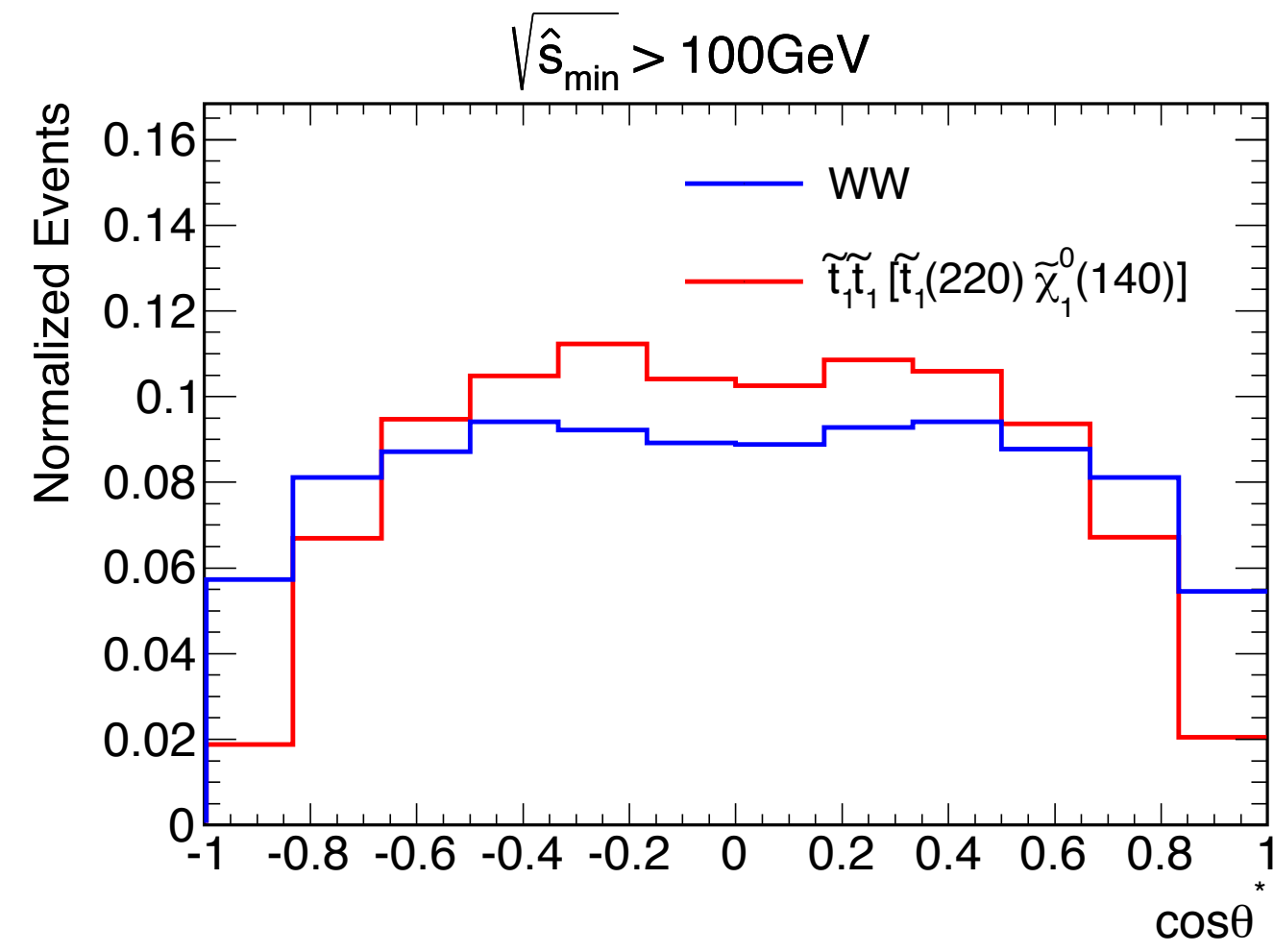
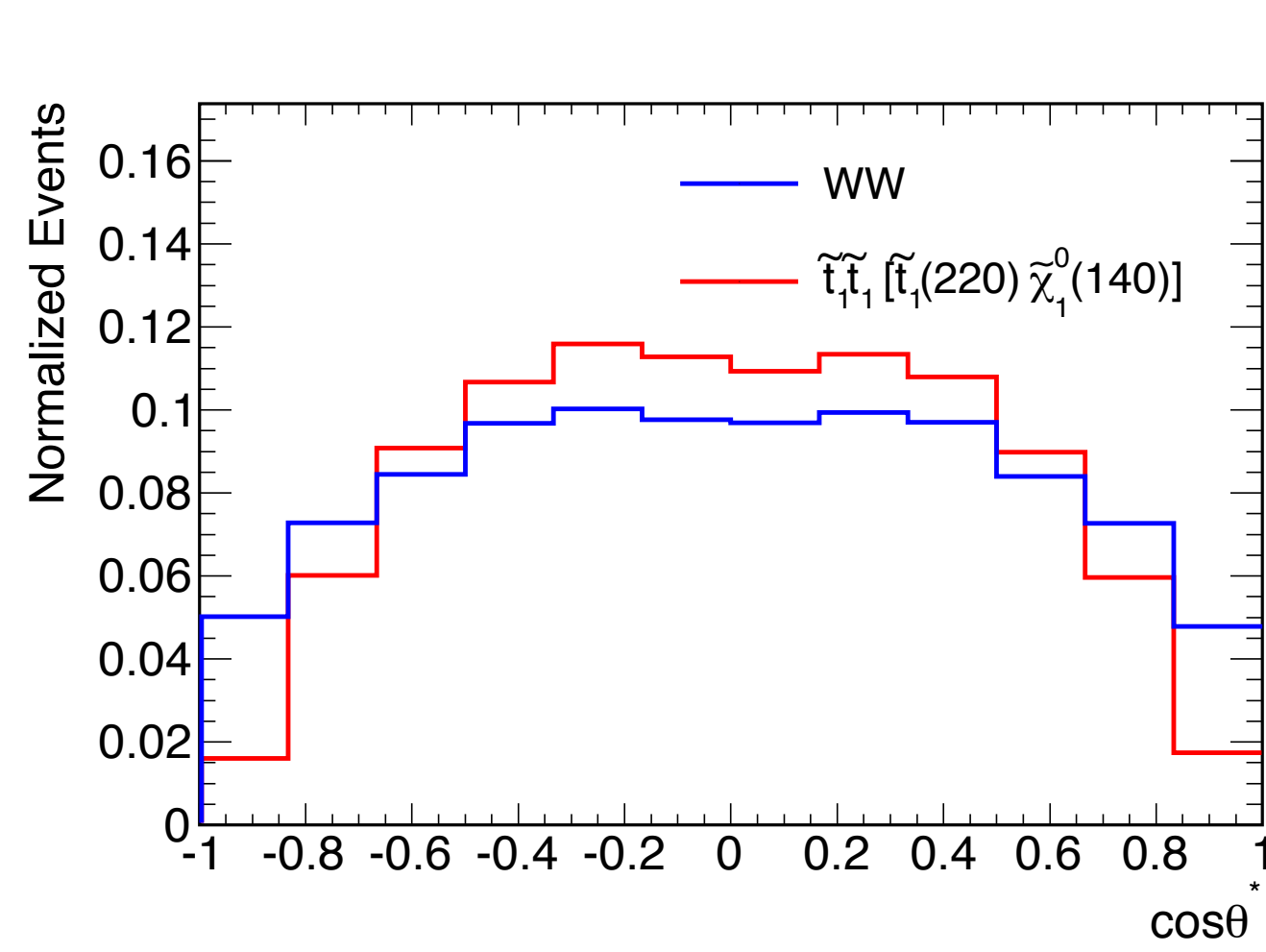


χ^2 : CMS 8TeV



χ^2 : [ATLAS7, CMS7, CMS8]



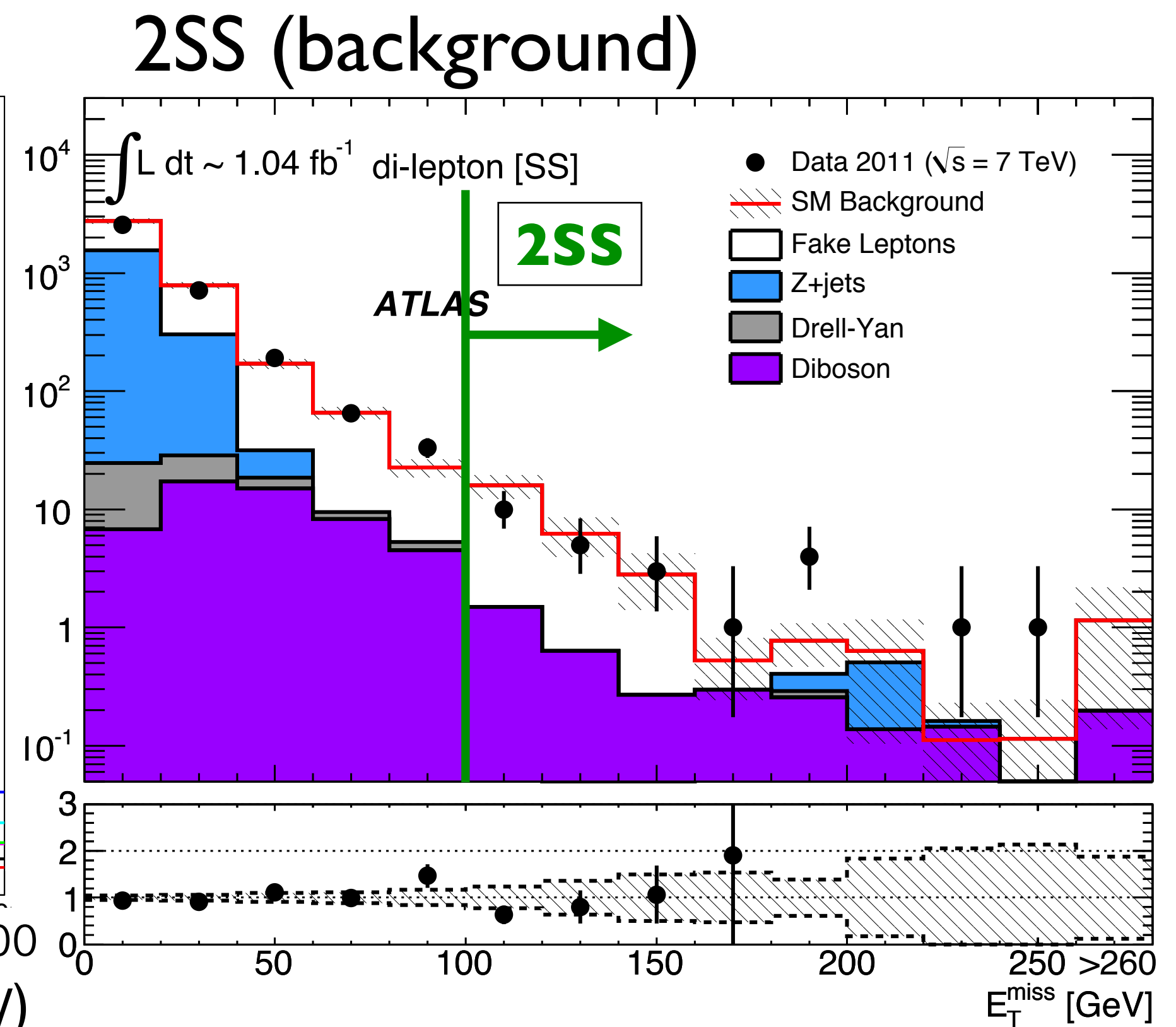
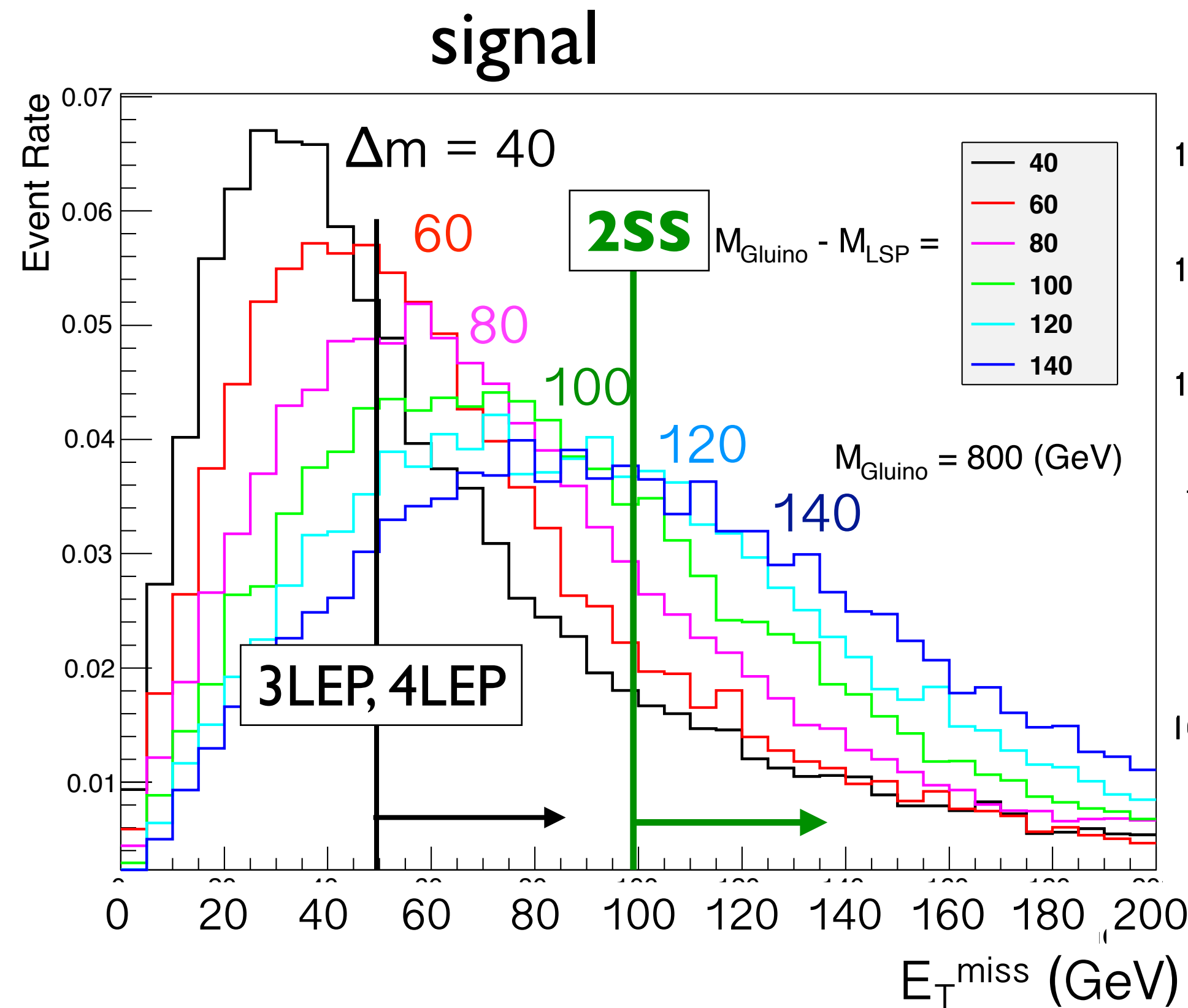


Δm (GeV)		50	60	70	80	100	120	140
2OS	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$	0.21	0.53	0.87	1.30	1.9	2.6	3.0
	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$	0.18	0.41	0.61	0.82	1.07	1.29	1.34
	$\tilde{\chi}_2^0 \tilde{\chi}_2^0$	0.18	0.27	0.37	0.42	0.52	0.53	0.48
	$\tilde{\chi}_2^0 \tilde{\chi}_1^0$	0.26	0.70	1.31	1.85	3.52	4.43	4.33
2SS	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$	0.79	2.23	4.40	7.00	12.93	18.24	22.34
	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$	0.38	0.88	1.46	2.00	3.16	4.22	5.25
	$\tilde{\chi}_2^0 \tilde{\chi}_2^0$	0.36	0.70	1.03	1.28	1.28	2.12	2.08
2SS+	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$	0.55	1.54	2.79	4.63	7.76	9.23	11.70
	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$	0.25	0.56	0.89	1.18	1.82	2.11	2.80
	$\tilde{\chi}_2^0 \tilde{\chi}_2^0$	0.25	0.46	0.63	0.78	0.63	1.03	1.00
3LEP	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$	0.16	0.73	2.16	4.41	10.39	14.75	17.33
	$\tilde{\chi}_2^0 \tilde{\chi}_2^0$	0.43	1.58	4.01	7.70	12.35	15.91	18.03
3LEP+	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$	0.15	0.71	2.05	4.07	8.57	10.17	8.83
	$\tilde{\chi}_2^0 \tilde{\chi}_2^0$	0.42	1.55	3.87	7.01	10.18	10.53	8.23
4LEP	$\tilde{\chi}_2^0 \tilde{\chi}_2^0$	0.28	1.24	3.73	8.50	15.76	18.83	23.61

Table 3. Comparison of efficiency in % for different signal regions and intermediate states as a function of mass difference, $\Delta m = m_{\tilde{g}} - m_{\text{LSP}}$. Gluino mass was set to $m_{\tilde{g}} = 800$ GeV.

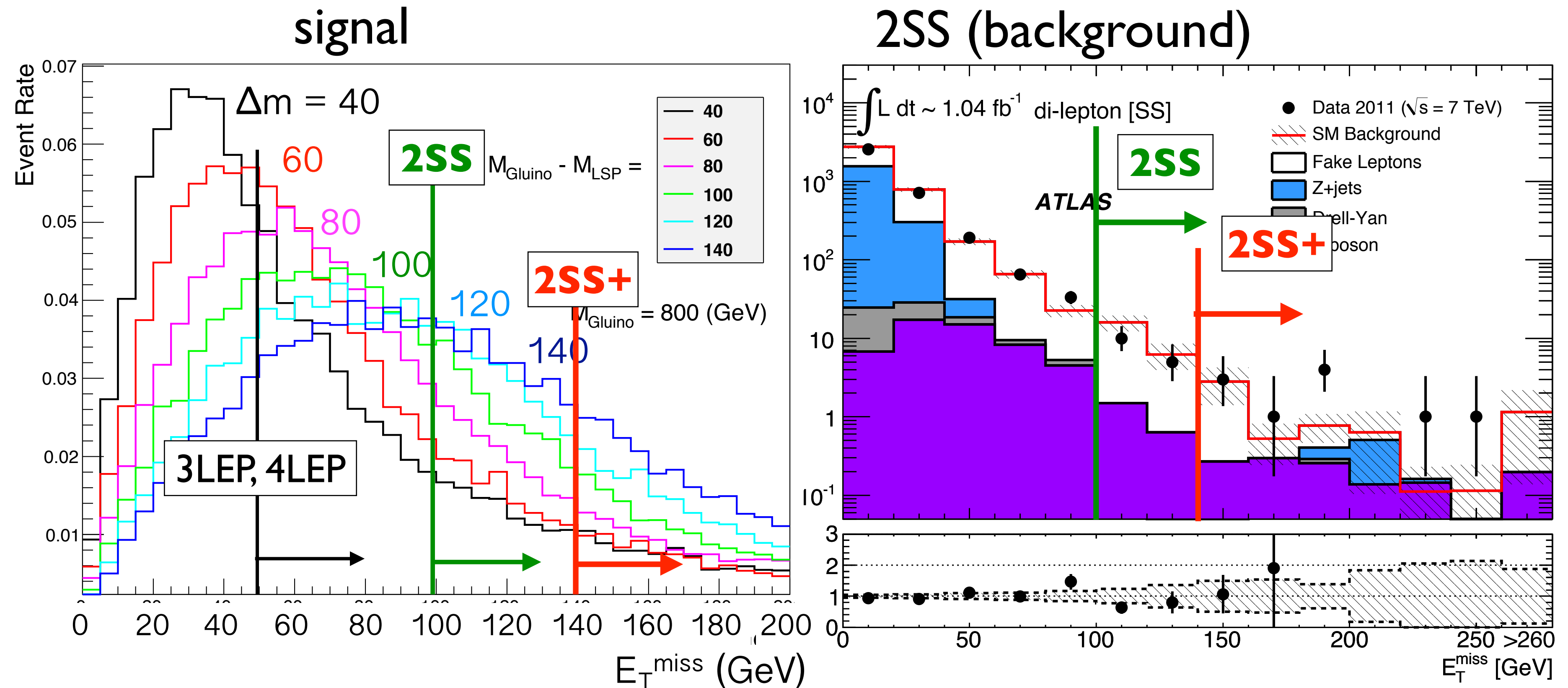
E_T^{miss}

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



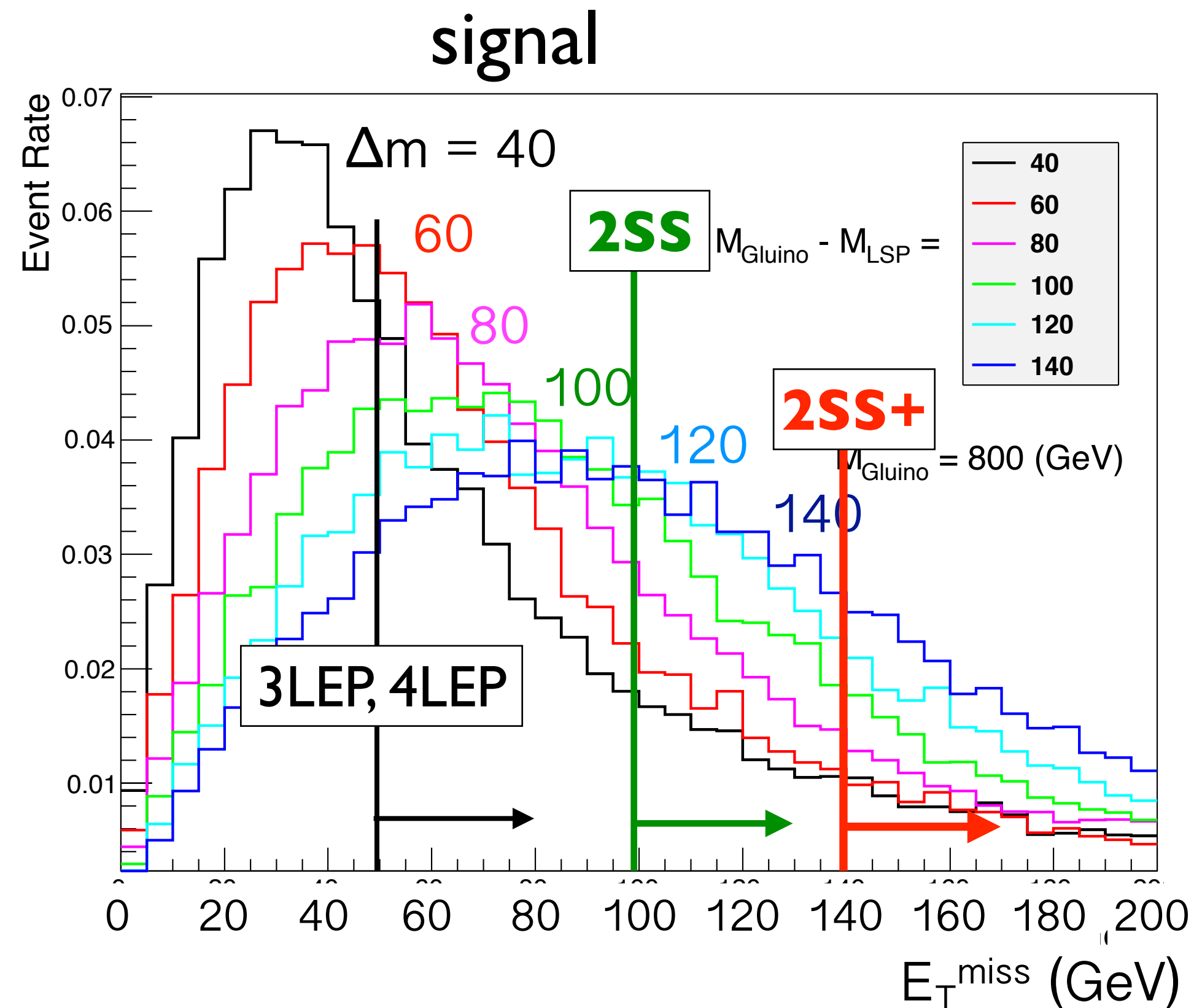
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signal region	2SS	2SS+
$N(\text{lep})$	= 2 (SS)	= 2 (SS)
leading $\mu \text{ (e)} p_T$	> 20 (25)	> 20 (25)
$E_T^{miss} \text{ (GeV)}$	> 100	> 140
dilpton mass (GeV)	> 12	> 12
luminosity (fb^{-1})	1.04	1.04
expected BG	32.6 ± 7.9	6.4 ± 1.6
observed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