LHC signals from R-parity violating chargino decays

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In collaboration with: Bomark, Lola, Osland, Raklev

JHEP 1412 (2014) 121 (arXiv: 1410.0921)
JHEP 1405 (2014) 007 (arXiV: 1310.2788)

SUSY 2015

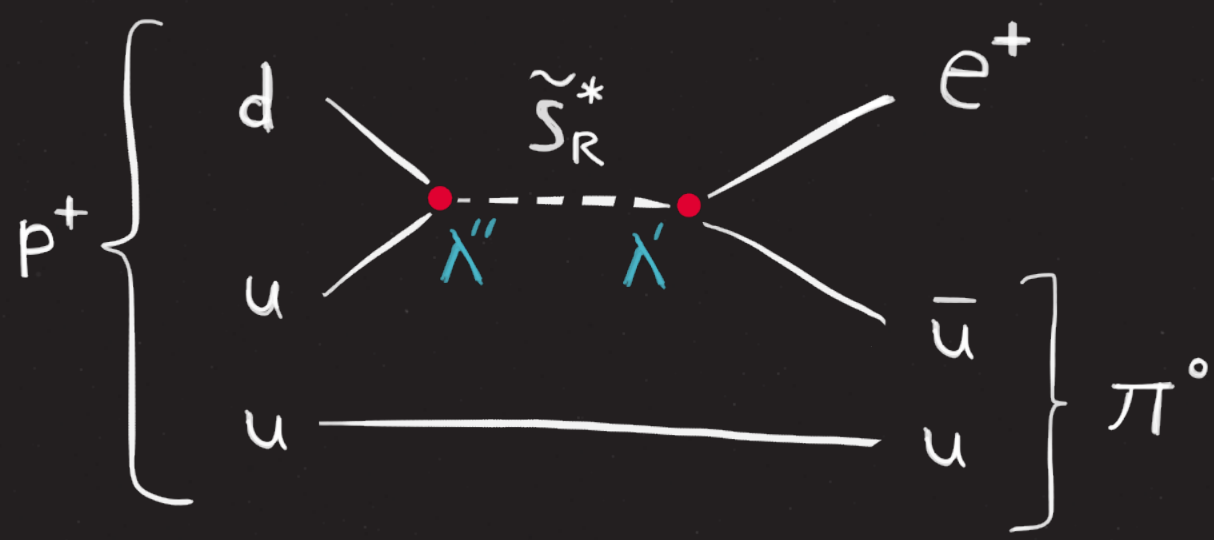
Basic scenario:
almost degenerate chargino/neutralino in the MSSM

- Neutralino mass parameters: M_1, M_2, mu
- Chargino mass parameters: M_2, mu
- Smallest parameter dominates mass & mixing of lightest states
- Degeneracy expected in wino (M_2) and higgsino (mu) scenarios

Extend MSSM by trilinear RPV operators

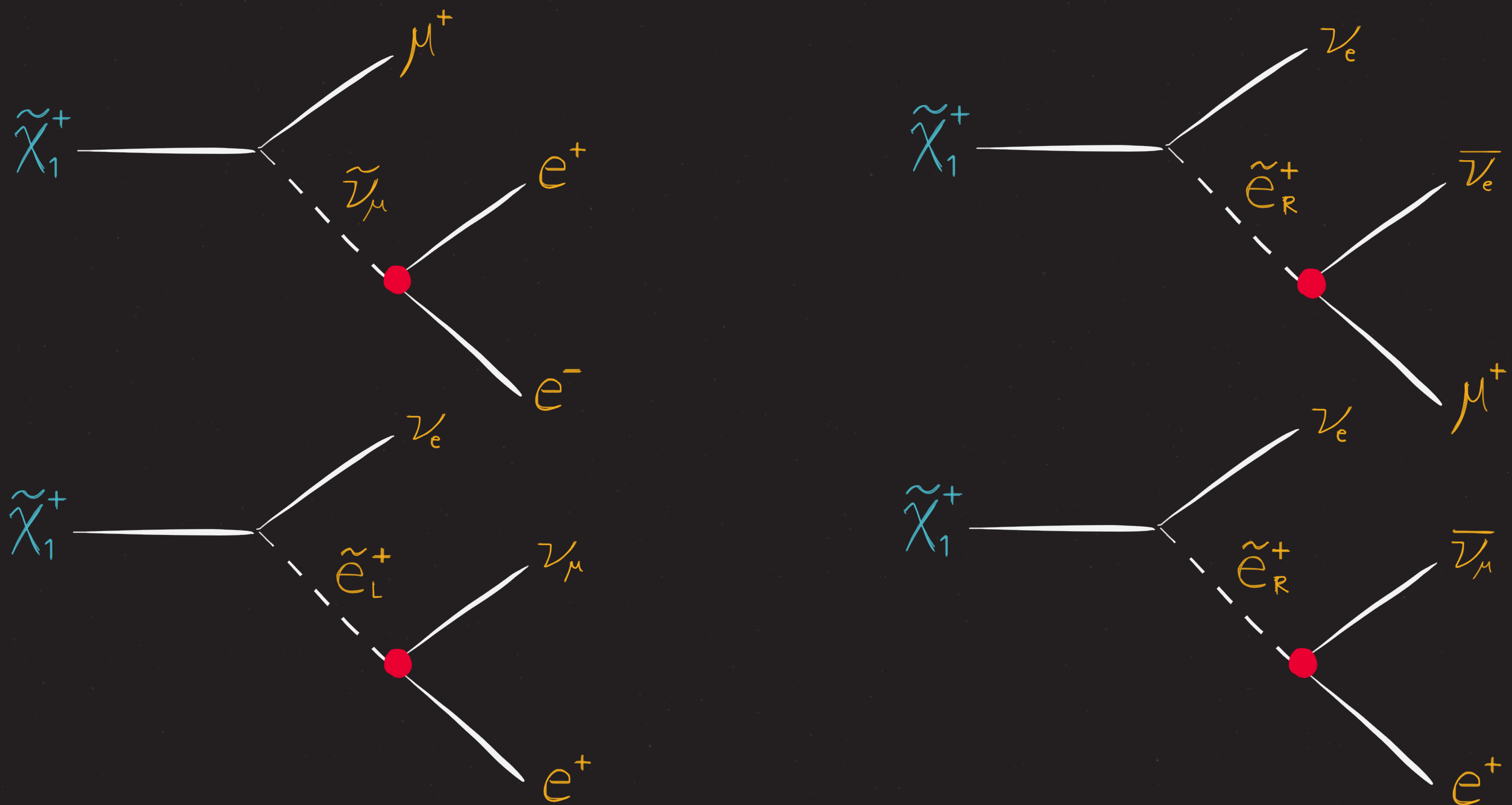
$$W \supset \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

- Baryon and lepton number violation
- Several couplings strongly constrained, especially products of couplings



Examples of chargino decay modes

$L_1 L_2 \bar{E}_1$



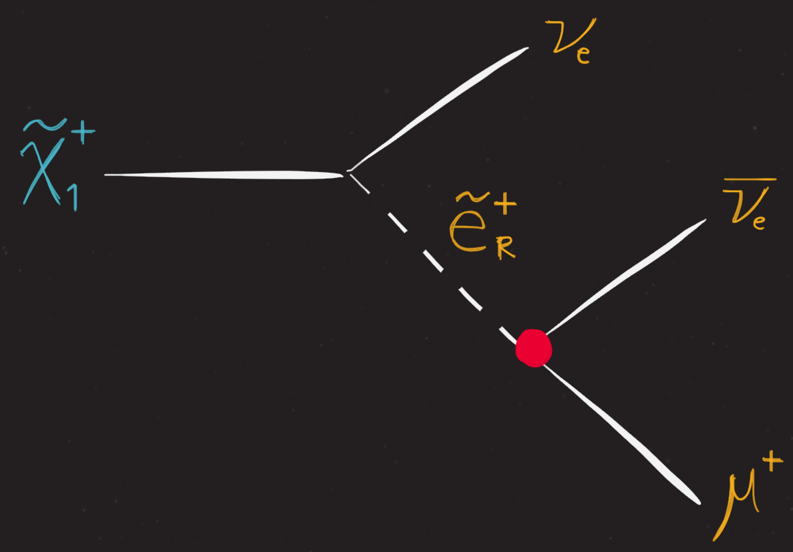
- Decay rate scaling: $$\Gamma_{RPV} \propto \frac{\lambda^2 \, m_{\tilde{\chi}_1^+}^5}{m_{\tilde{e}/\tilde{\nu}}^4}$$

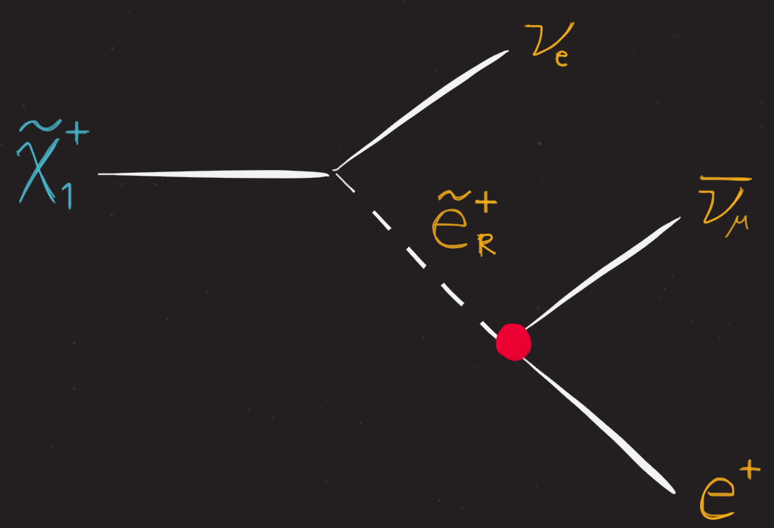
Can RPV chargino decays be important?

- Compete with RPC decays to neutralino + pion(s) or l nu
- RPC decay modes depend on chargino-neutralino mass difference

$$\Delta m = m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0}$$

- Wino/higgsino scenarios give small Δm - can RPV decays dominate?
- Some RPV decays suppressed by R-chirality (wino chargino)

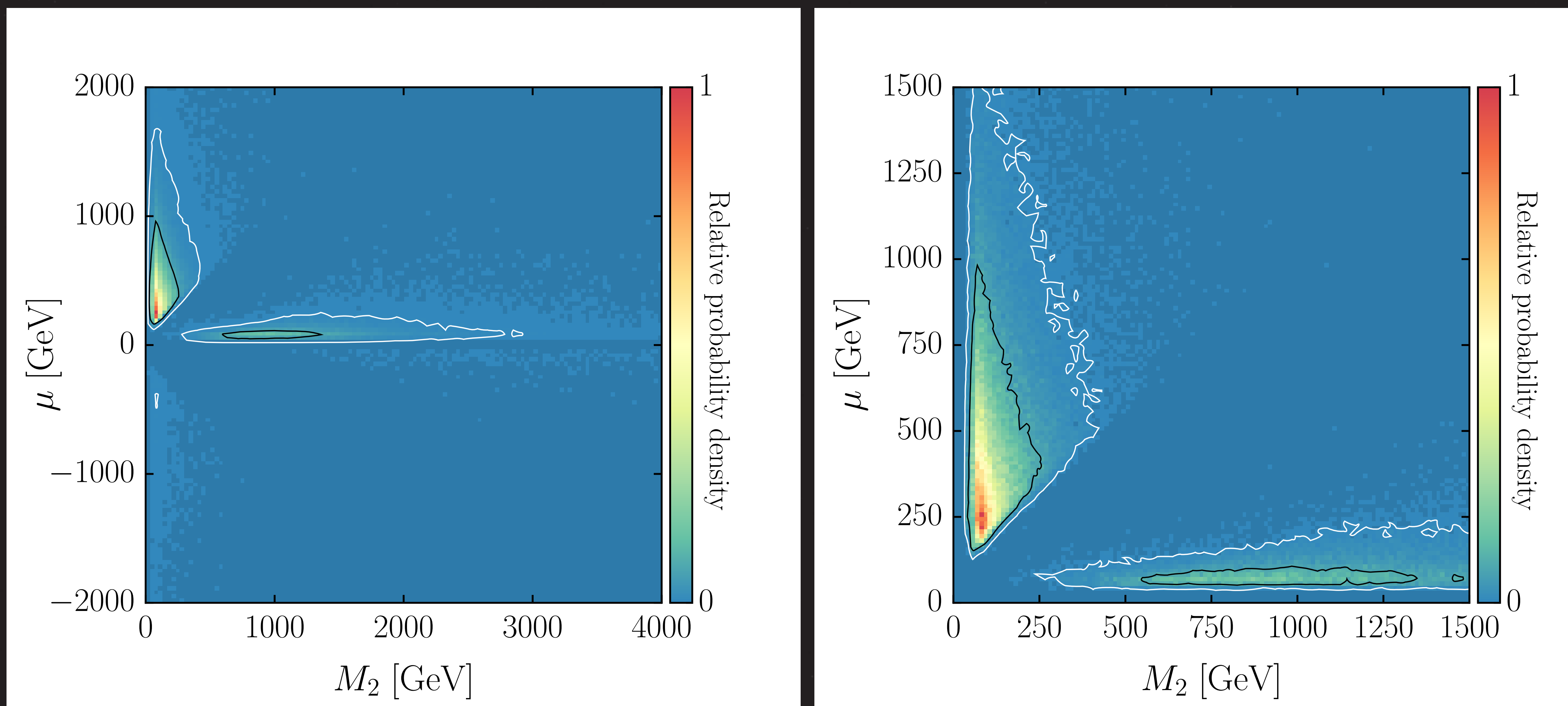




Investigate using a Bayesian parameter scan

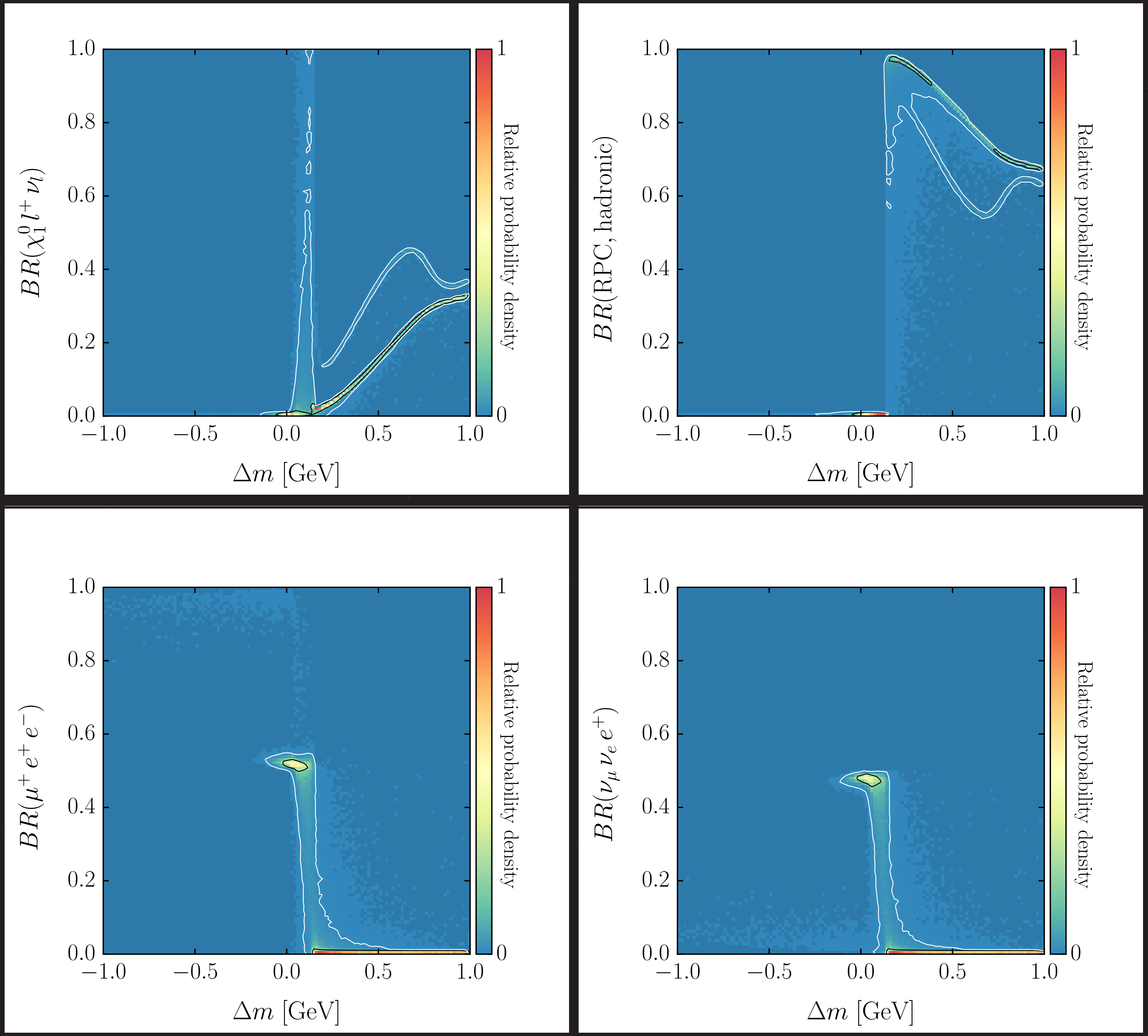
- Likelihood function from M_W, g-2, B-physics, m_{higgs}, LEP limit
- Additional requirement: $\Delta m < 1$ GeV (equivalent to prior req. on M_1, M_2, mu)
- Log priors for dimensionful parameters
  (prior dependece checked using flat priors)
- RPV couplings not included in scan - way too many parameters!
- After scan: introduce a single RPV operator and recalculate decay rates for all points in posterior sample
- For each point, use the maximum allowed coupling value
  (Allanach et al., hep-ph/9906209)

Posterior distributions



Posterior distributions

$L_1 L_2 \bar{E}_1$



Posterior distributions

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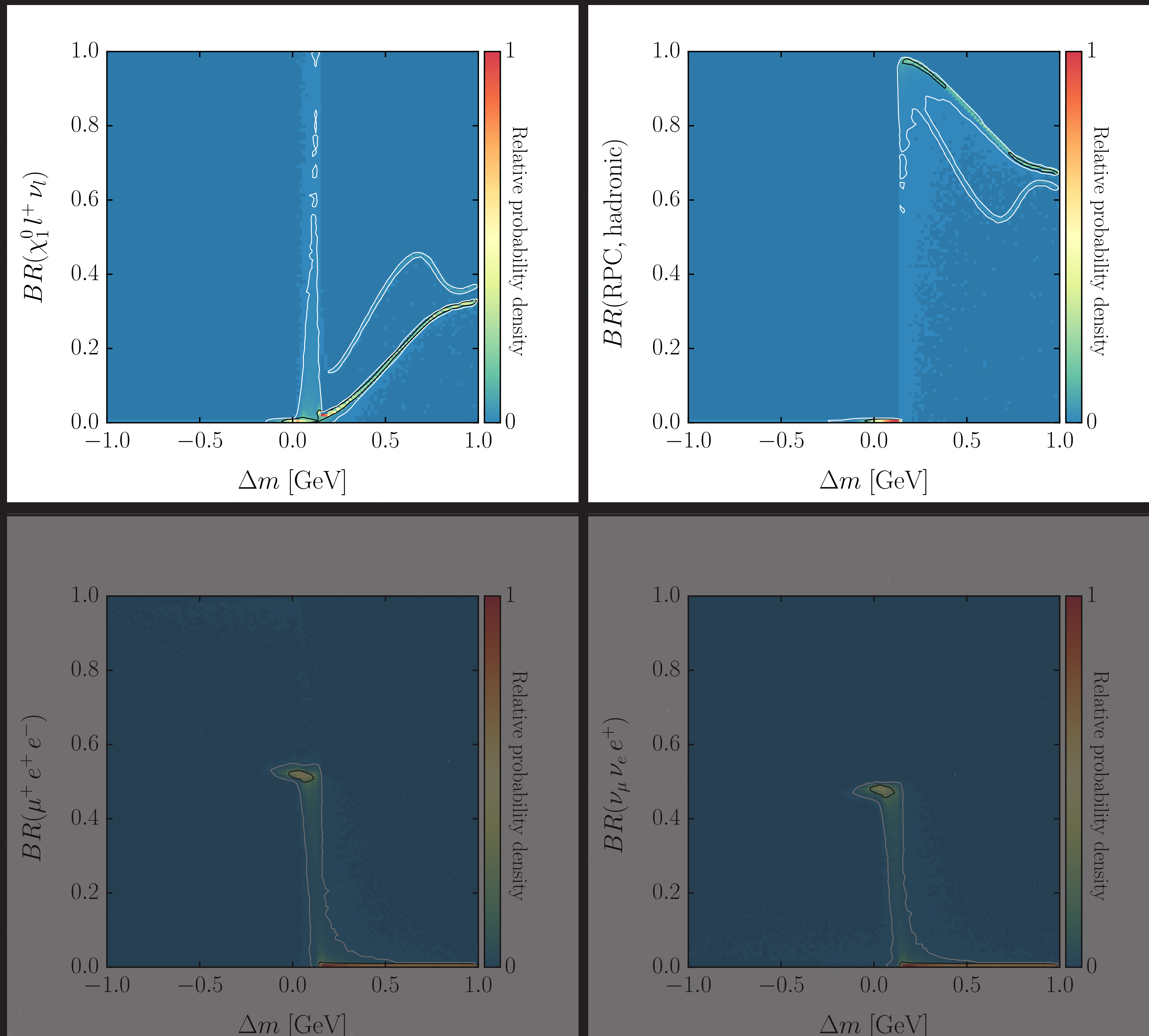

Posterior distributions

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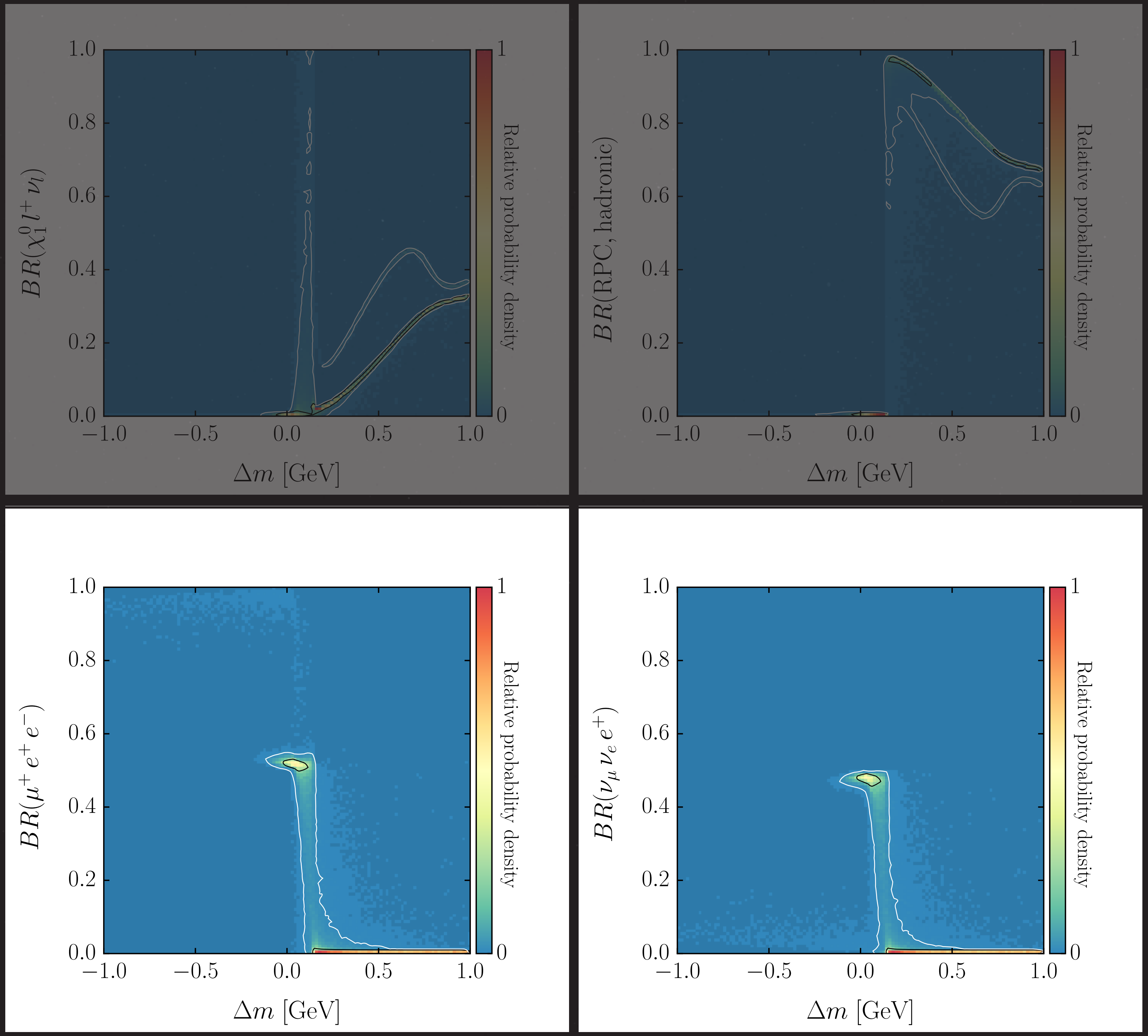
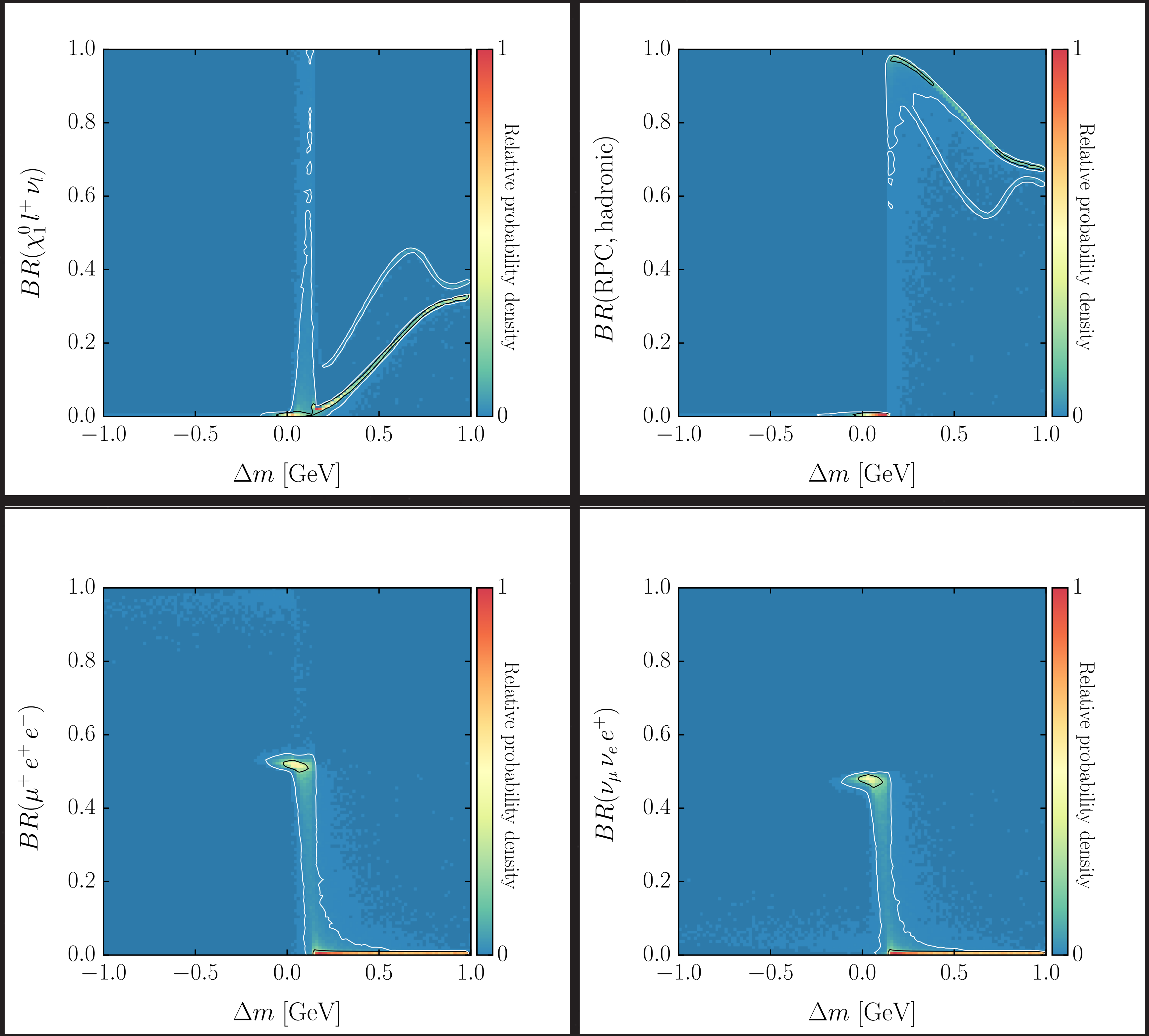


Posterior distributions

$L_1 L_2 \bar{E}_1$



What about LQD and UDD?

- Similar results for LQD, RPV decays to (l d d) and (nu u d)
- UDD processes suppressed by heavy squark propagators preferred by scan
- When RPC decays dominate, small Δm leads to long chargino lifetime
- LHC searches for kinked tracks important, $\tau > 10^{-11}$ s (arXiv: 1310.3675)

Benchmark collider study

- Focus on LLE
- Benchmark point from posterior sample

Point	RPV_C1	RPV_C2	RPV_C3
$m_{\tilde{\chi}_1^\pm}$	252.1	327.7	526.4
Δm	0.119	0.108	0.182
Wino	0.990	0.986	0.989
Higgsino	0.142	0.166	0.148

Point/Coupling	λ_{121}	λ_{122}	λ_{123}	λ_{131}	λ_{132}	λ_{133}	λ_{231}	λ_{232}	λ_{233}
RPV_C1	0.244	0.244	0.260	0.309	0.309	0.013	0.349	0.349	0.372
RPV_C2	0.215	0.215	0.221	0.272	0.272	0.011	0.307	0.308	0.316
RPV_C3	0.369	0.369	0.388	0.467	0.467	0.016	0.527	0.528	0.554

- EW production cross section (NLO): 49.9 fb
- Generate 10^6 events (smooth distributions), normalize yield to 1 fb^{-1}
- Simulation includes both chargino and neutralino RPV decays

Event selection

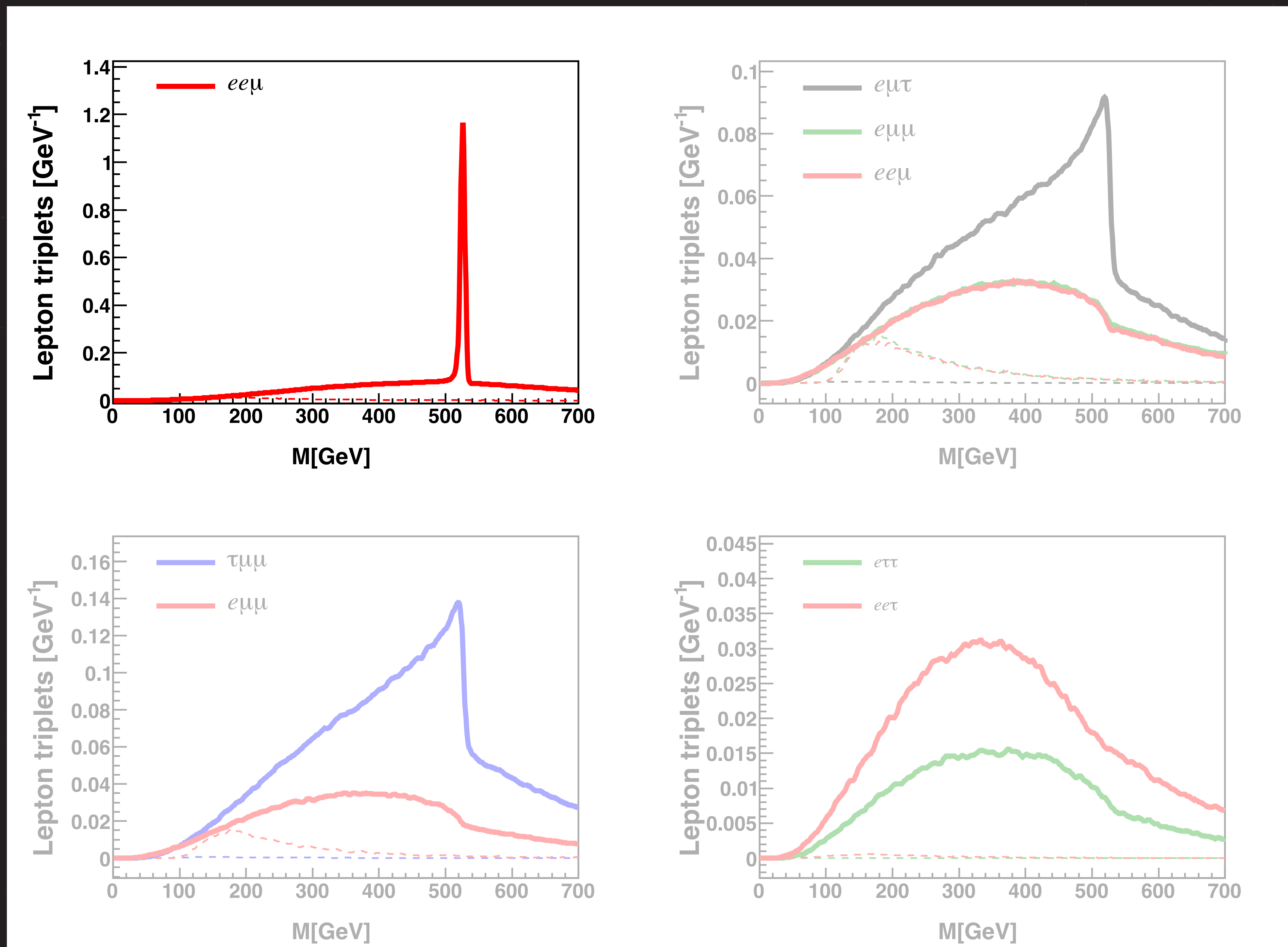
- At least three isolated leptons
- pT > 70, 20, 20 GeV
- ETmiss > 100 GeV (neutrinos)

Dominant SM backgrounds

- Diboson production (if no Z veto)
- ttbar production (if Z veto)

Charged trilepton resonance

$L_1 L_2 \bar{E}_1$ $L_1 L_2 \bar{E}_3$

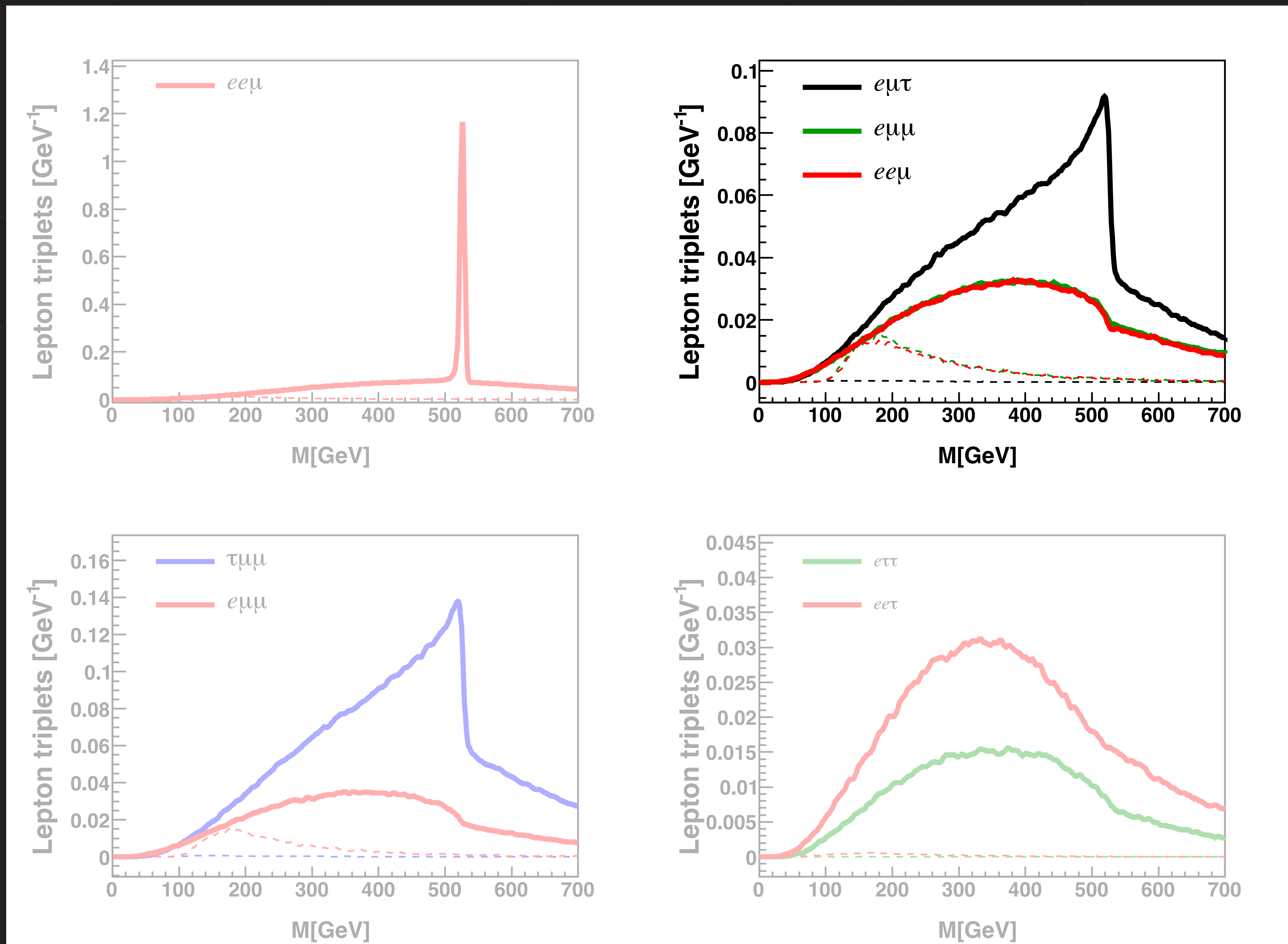


$L_2 L_3 \bar{E}_2$ $L_1 L_3 \bar{E}_3$

Identifiable features in trilepton spectra

$L_1 L_2 \bar{E}_1$ $L_1 L_2 \bar{E}_3$

$L_2 L_3 \bar{E}_2$ $L_1 L_3 \bar{E}_3$



Identifiable features in trilepton spectra

$L_1 L_2 \bar{E}_1$

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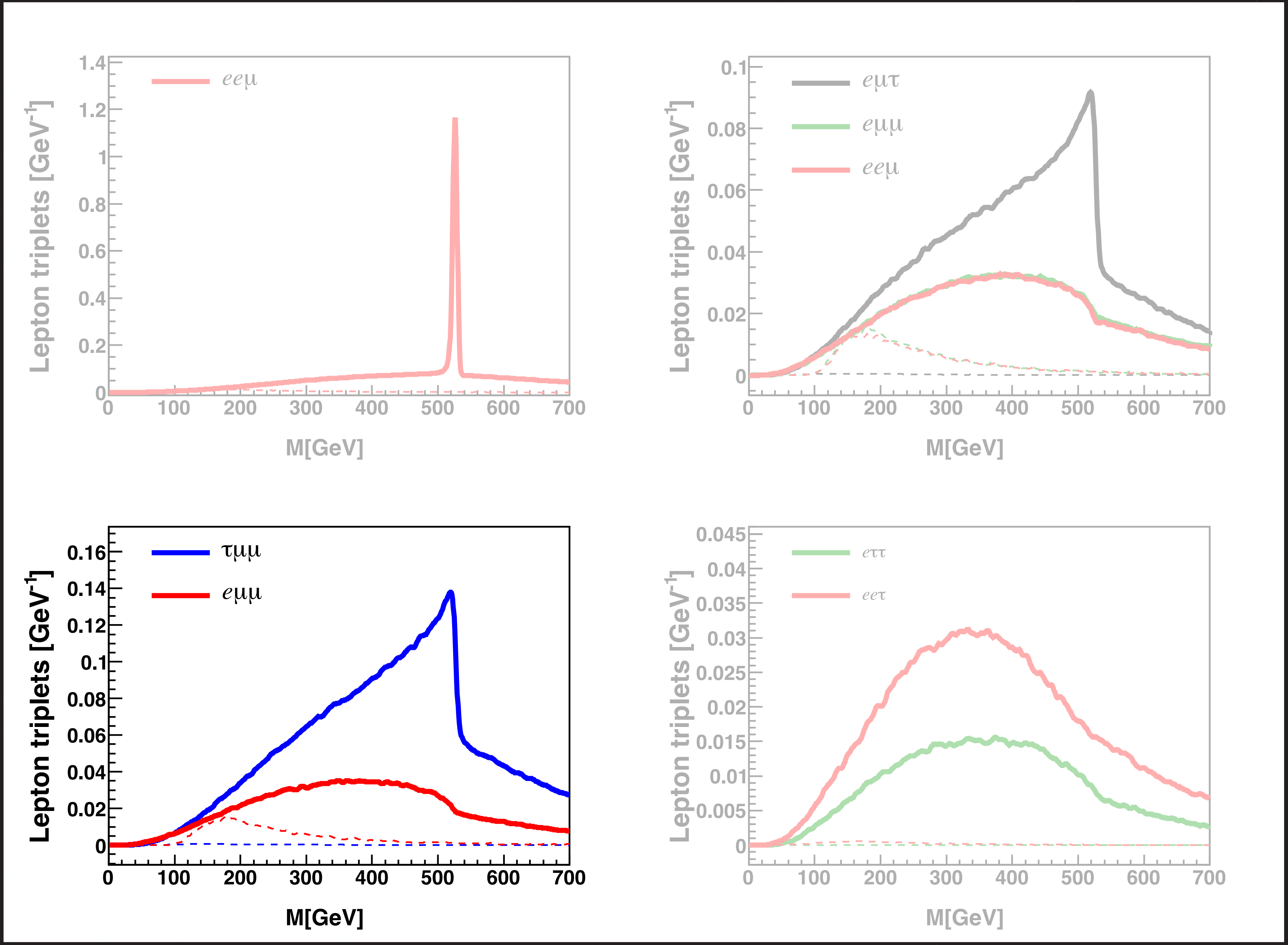
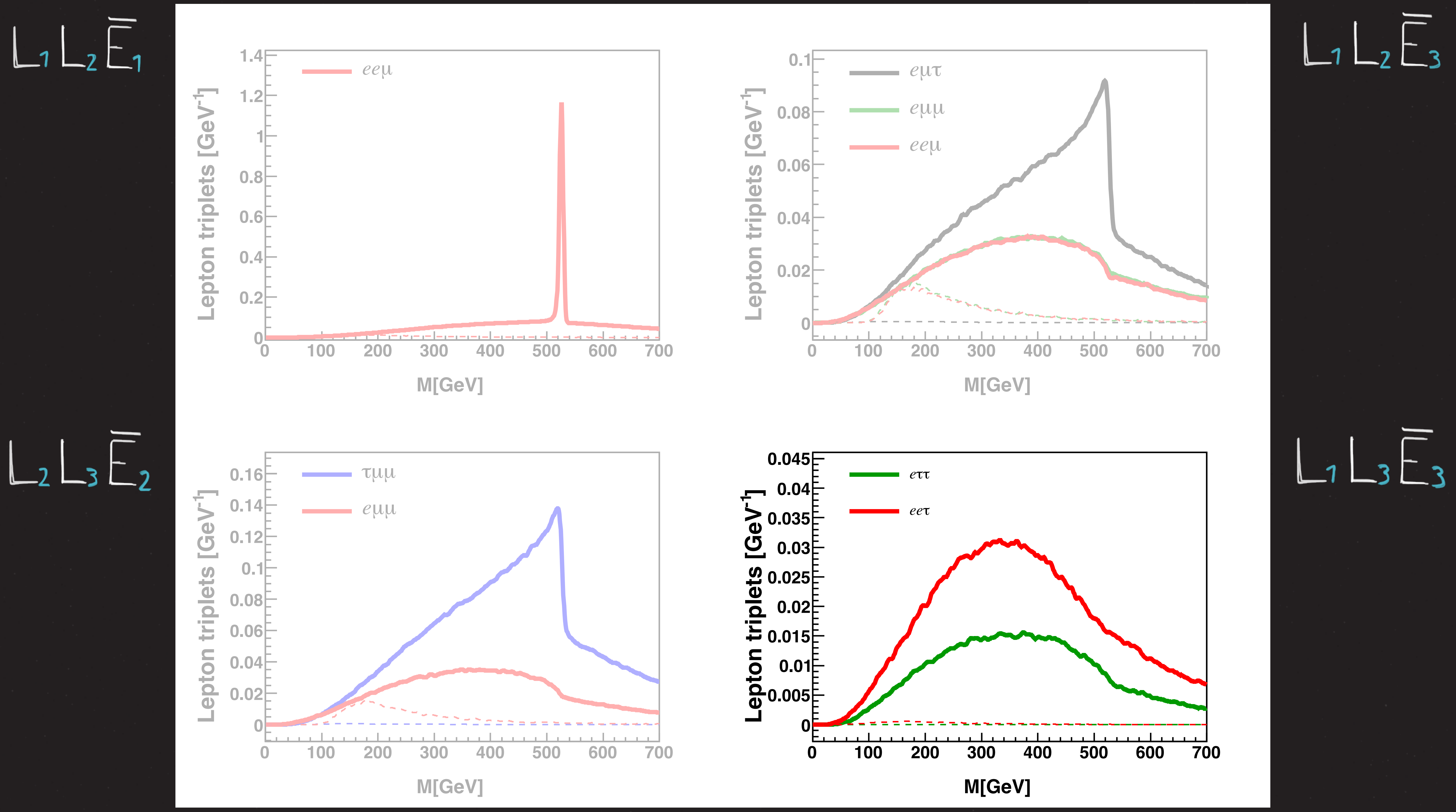


Identifiable features in trilepton spectra



Comments on collider study

- Cuts kept general to encompass several RPV operators
- Benchmark: early discovery at 13 TeV, but rather optimistic (chargino mass, RPV coupling)
- Cross sections decrease with chargino mass, but RPV decay rates increase
- Useful information also in dilepton invariant mass spectra

Summary

- Direct RPV chargino decays can dominate for small Δm
- BR for RPV decays increase with chargino mass
- For dominant LLE operator: resonance/features in trilepton spectra
- Signals from RPV chargino decays compliment previous RPV studies

Summary

- Direct RPV chargino decays can dominate for small Δm
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Thank you!

Backup slides

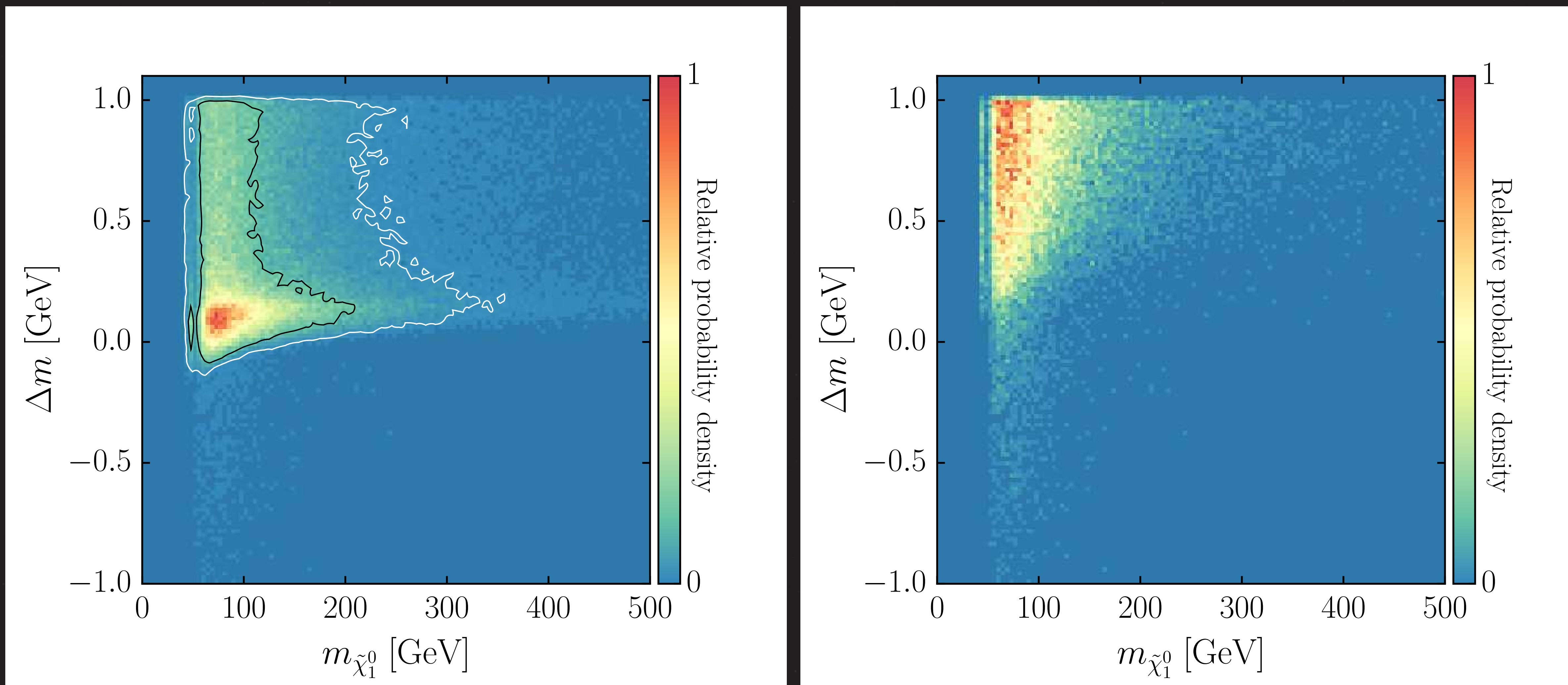
Parameter	Range	Prior	Reference
M_1	$[-4000, 4000]$	log	-
M_2	$[0, 4000]$	log	-
M_3	$[-4000, 4000]$	log	-
μ	$[-4000, 4000]$	log	-
m_{A^0}	$[0, 4000]$	log	-
$m_{\tilde{l}}$	$[0, 7000]$	log	-
$m_{\tilde{q}}$	$[0, 7000]$	log	-
$m_{\tilde{q}_3}$	$[0, 7000]$	log	-
A_0	$[-7000, 7000]$	log	-
$\tan\beta$	$[2, 60]$	linear	-
m_t	173.4 ± 1.0	gaussian	[29]
$m_b^{\overline{MS}}(m_b)$	4.18 ± 0.03	gaussian	[30]
M_Z	91.1876 ± 0.0021	gaussian	[30]
α^{-1}	127.944 ± 0.014	gaussian	[30]
α_s	0.1184 ± 0.0007	gaussian	[30]

Tools:
MultiNest 2.17
SOFTSUSY 3.3.5
FeynHiggs 2.9.4
MicrOMEGAS 2.4.5

Observable	Constraint	Likelihood
M_W	80.385 ± 0.021	gaussian
$a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}}$	$(26.1 \pm 8.0) \times 10^{-10}$	gaussian
$\mathrm{BR}(B_s \to \mu\mu)$	$2.9^{+1.1}_{-1.0} \times 10^{-9}$	from experiment
$\mathrm{BR}(b \to s\gamma)$	$(3.55 \pm 0.33) \times 10^{-4}$	gaussian
$\mathrm{R}(B \to \tau\nu)$	1.63 ± 0.54	gaussian
m_h	125.0 ± 2.0	gaussian
$m_{\tilde{\chi}_1^\pm}$	> 45	lower limit, hard cut
$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$	< 1.0	upper limit, hard cut

No LHC search constraints in scan?

- Most constraints from collider searches do not apply due to combination of RPV and small Δm
- Would in general need separate scans for each coupling...
- Computationally challenging (but we are working on it...)
- Limits on couplings, chargino lifetime, etc. are taken into account when we study the effects of specific RPV operators



1.0
0.5
0.0
−0.5
−1.0
0
100
200
300
400
500
$m_{\tilde{\chi}_1^0}$ [GeV]
Δm [GeV]
1
0
Relative probability density
1.0
0.5
0.0
−0.5
−1.0
0
100
200
300
400
500
$m_{\tilde{\chi}_1^0}$ [GeV]
Δm [GeV]
1
0
Relative probability density

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Δm	0.119	0.108	0.182
Wino	0.990	0.986	0.989
Higgsino	0.142	0.166	0.148
M_1	944.1	-1082.0	-728.4
M_2	235.4	311.4	502.3
M_3	1627.6	560.6	3418.6
μ	668.0	668.5	913.2
m_{A^0}	3430.3	2775.5	3220.5
$m_{\tilde{l}}$	503.5	434.6	757.6
$m_{\tilde{q}}$	2156.2	2517.0	4742.9
$m_{\tilde{q}_3}$	6429.4	4951.8	1424.6
A_0	-25.8	2775.5	1498.1
$\tan\beta$	47.1	55.4	46.2

Point/Coupling	λ_{121}	λ_{122}	λ_{123}	λ_{131}	λ_{132}	λ_{133}	λ_{231}	λ_{232}	λ_{233}
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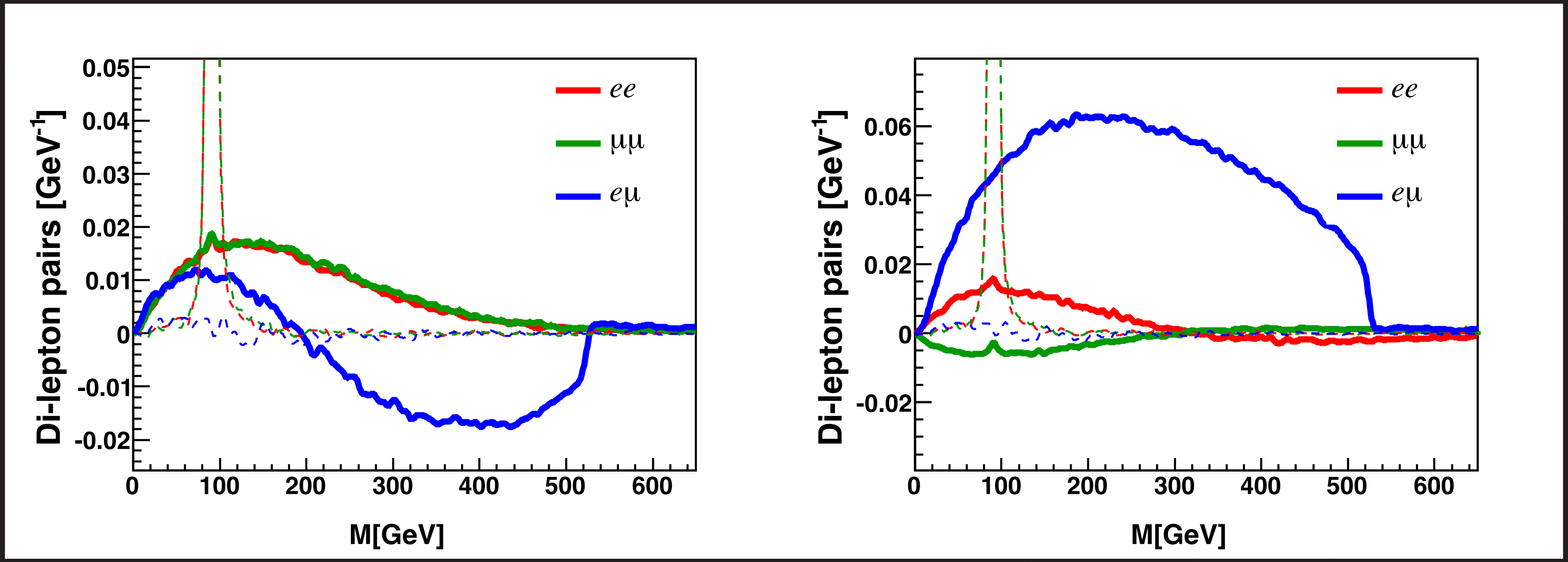
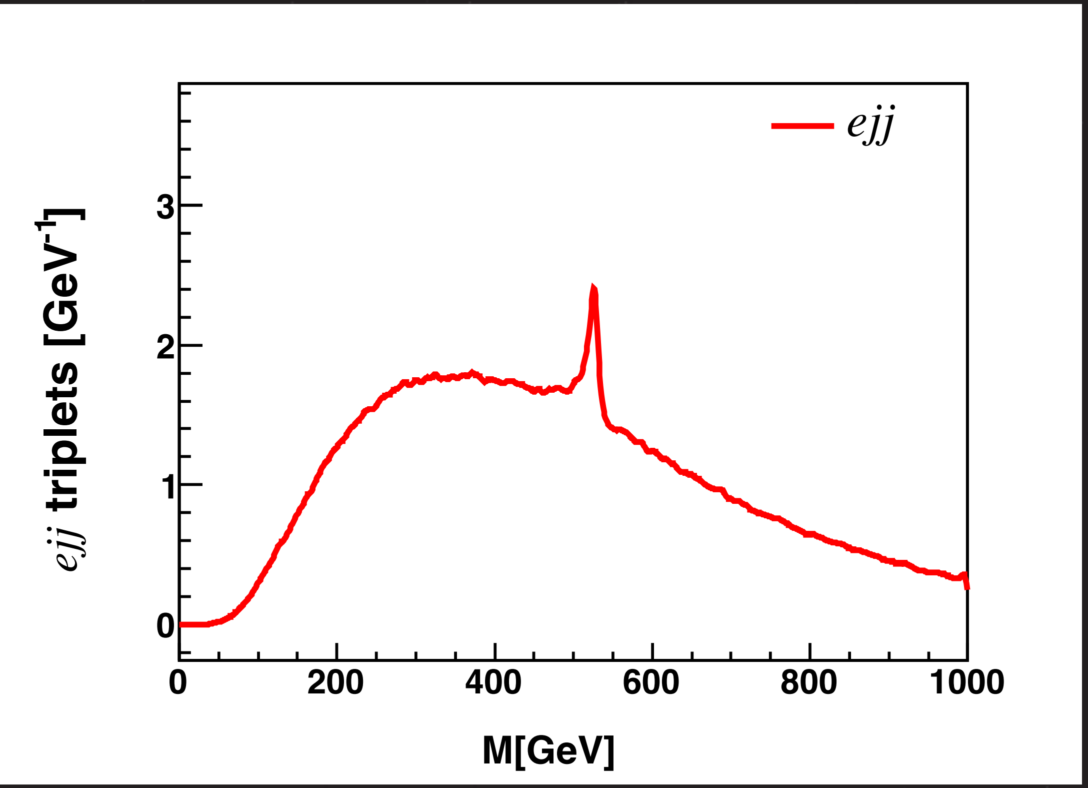
LLE123



LLE231

WZ bkg, same-sign subtraction. Plot: m(+-) - m(++) - m(--)

LQD111



For a study of the flavour structure in RPV neutralino decays, see arXiv: 1105.4022

Δm expressions

- Higgsino limit (tree-level):

$$\Delta m = \left[\frac{M_2}{M_1}\tan^2\theta_W + 1 + \text{sgn}\,\mu\left(\frac{M_2}{M_1}\tan^2\theta_W - 1\right)\sin 2\beta\right]\frac{M_W^2}{2M_2} + \mathcal{O}\left(\frac{1}{M_2^2}\right).$$

- Positive M_1 and M_2 —> Δm > 300 MeV
- Negative M_1: Can have negative Δm if M1 is small, M2 is large and tan β is small
- Main loop contributions from top-stop loops (either sign, mixing) and ɣ(Z)-higgsino loops (small unless tan β is large)

- Wino limit (tree-level):

$$\begin{aligned}\Delta m &= \frac{M_W^2}{\mu^2}\frac{M_W^2}{M_1 - M_2}\tan^2\theta_W\sin^2 2\beta + 2\frac{M_W^4 M_2\sin 2\beta}{(M_1-M_2)\mu^3}\tan^2\theta_W \\ &\quad + \frac{M_W^6\sin^3 2\beta}{(M_1-M_2)^2\mu^3}\tan^2\theta_W(\tan^2\theta_W - 1) + \mathcal{O}\left(\frac{1}{\mu^4}\right),\end{aligned}$$

- Tree-level contribution small for large tan β
- Leading loop correction from gauge bosons ~ 165 MeV (bino part of Neutralino breaks the degeneracy)
- Smaller Δm requires significant and negative tree-level contribution.