Correlations in Supersymmetric Cascade Decays

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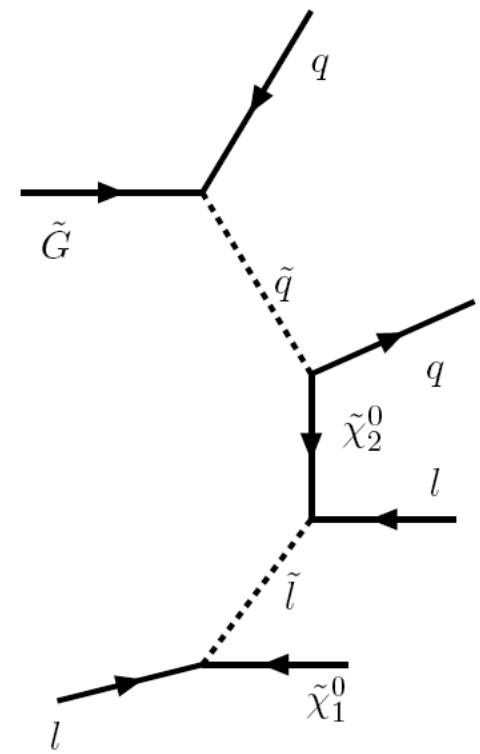
Cascade Decays

If sleptons are lighter than the squarks then they may be produced in the decays of squarks. Sleptons then produce leptons.

$$\tilde{g} \rightarrow \tilde{q} + q$$
$$\tilde{q} \rightarrow \tilde{\chi}_2^0 + q$$
$$\tilde{\chi}_2^0 \rightarrow \tilde{l} + l$$
$$\tilde{l} \rightarrow \tilde{\chi}_1^0 + l$$



Suppose there is a “discovery” of events containing leptons (and convincing missing energy).

What are some tests of this decay chain, or of other topologies?

Topology model dependent, but within a given topology can hypothesis-test various scenarios for particle identities, interactions

After discovery, would like to measure masses and determine spins of new particles and their interactions

Invariant mass distributions useful tool to discriminate between models

Previous references focused on final states such as

- jet-l
- jet-l-l
- jet-W or jet-Z

See for instance:

A.Barr; C.Athansiou,C.Lester & J.Smillie,B.Webber;Wang&Yavin;Killic,Wang and Yavin;Burns, Kong, Matchev & Park

More generally, what can be learned from final states containing leptons, b-quarks or tau leptons?

- b-l from stop or sbottom decay
- tau-lepton
- tau-tau Tau Polarization

For dileptons, b-l, tau-l,tau-tau, can get both OS and SS

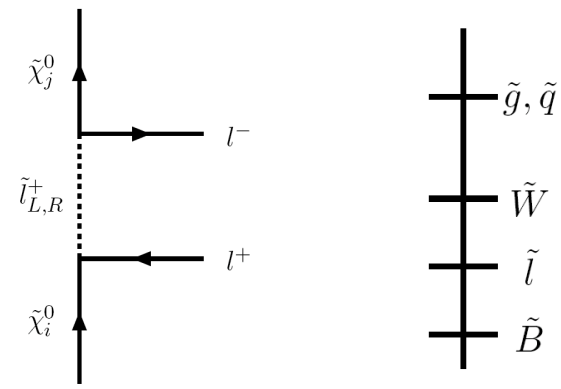
Correlations between OS and SS provide important cross-checks on underlying hypothesis

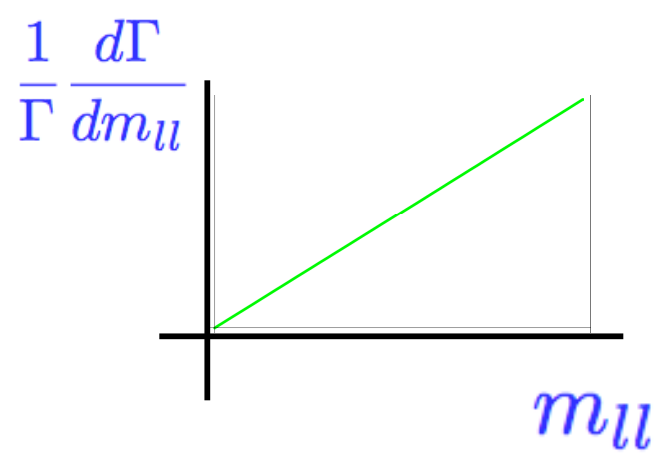
Challenge and caveat: Combinatorial confusion not addressed here !

Decays from intermediate on-shell scalar only give well-known opposite-sign, same flavor "triangle" distributions. "Triangles" well-measured soon after discovery.

	Triangle	Hump	Half-Cusp
Opposite-Sign Same-Flavor	$\tilde{\chi}_i^0 \to \tilde{l}_{L,R}^{\mp} l^{\pm}$ $\to \tilde{\chi}_j^0 l^{\mp} l^{\pm}$		
Opposite-Sign Opposite-Flavor			
Same-Sign Same-Flavor			
Same-Sign Opposite-Flavor			

Spectrum:



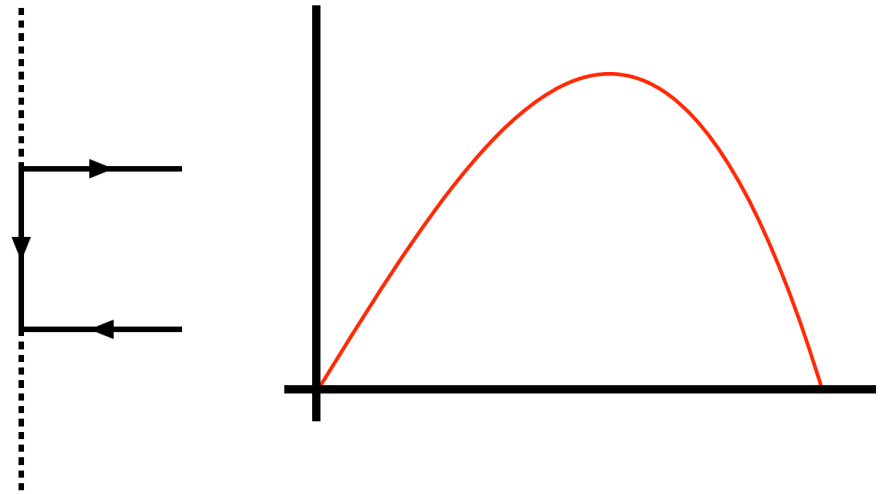


Susy di-leptons. 1st and 2nd generation. No Yukawa couplings or L-R mixing or flavor violation or flavor non-universality.

Decays through intermediate on-shell neutralino(s) occurring with an interlaced spectrum:

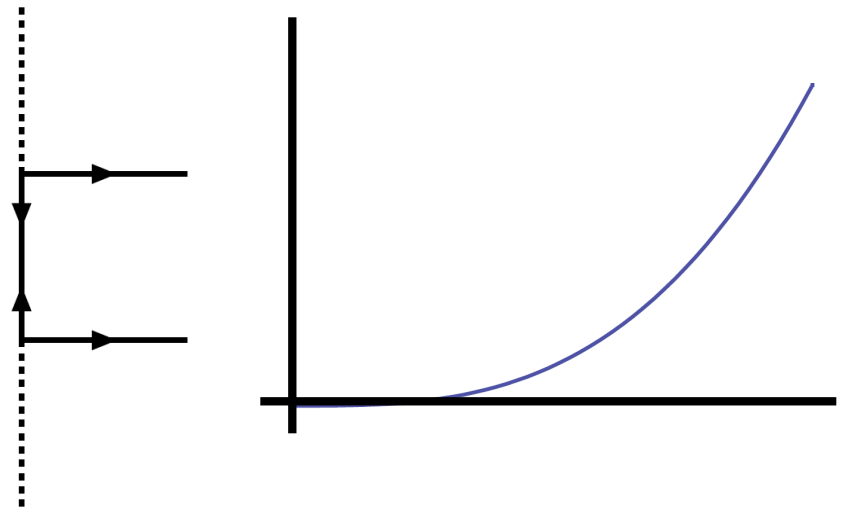
"hump":

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx} = 4x(1-x^2)$$



"half-cusp'':

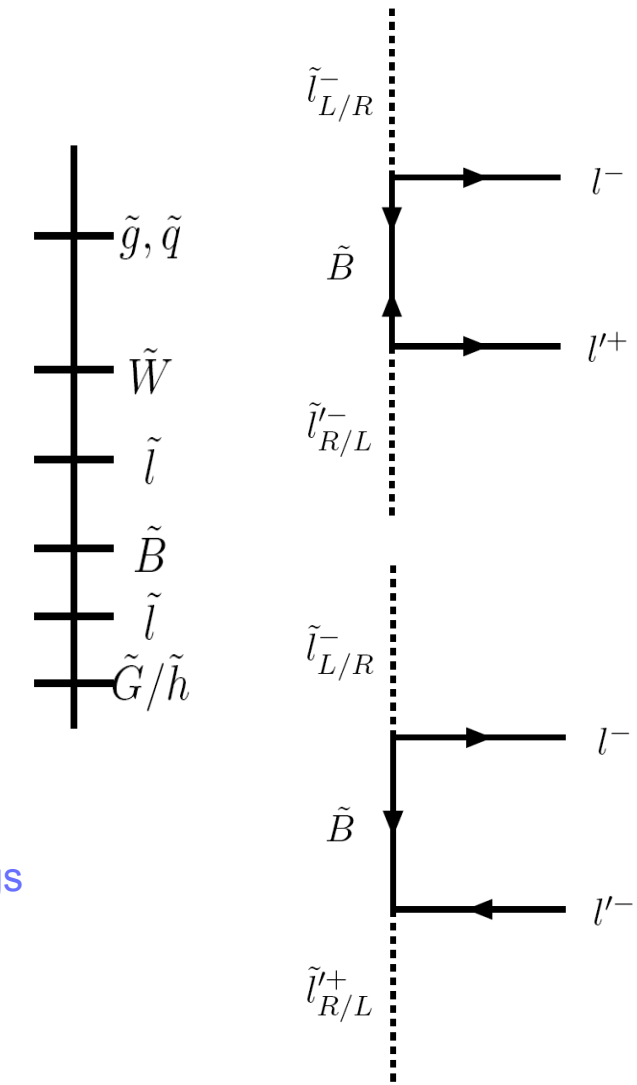
$$\frac{1}{\Gamma}\frac{d\Gamma}{dx} = 4x^3$$



This exhausts all the difermion possibilities in susy from on-shell decays (A. Barr)

Di-leptons from on-shell neutralino exchange can occur

	Triangle	Hump	Half-Cusp
Opposite-Sign Same-Flavor	$\tilde{\chi}_i^0 \to \tilde{l}_{L,R}^{\mp} l^{\pm}$ $\to \tilde{\chi}_j^0 l^{\mp} l^{\pm}$		$\tilde{l}_{L,R}^{\pm} \to \chi_i^0 l^{\pm}$ $\to \tilde{l}_{R,L}^{\pm} l^{\mp} l^{\pm}$
Opposite-Sign Opposite-Flavor			$\tilde{l}_{L,R}^{\pm} \to \chi_i^0 l^{\pm}$ $\to \tilde{l}'^{\pm}_{R,L} l'^{\mp} l^{\pm}$
Same-Sign Same-Flavor		$\tilde{l}_{L,R}^{\pm} \to \chi_i^0 l^{\pm}$ $\to \tilde{l}_{R,L}^{\mp} l^{\pm} l^{\pm}$	
Same-Sign Opposite-Flavor		$\tilde{l}_{L,R}^{\pm} \to \chi_i^0 l^{\pm}$ $\to \tilde{l}'^{\mp}_{R,L} l^{\pm} l'^{\pm}$	

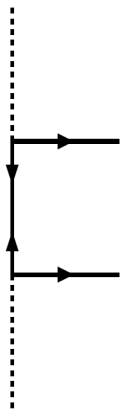


Susy di-leptons. 1st and 2nd generation. No Yukawa couplings or L-R mixing or flavor violation or flavor non-universality.

Symmetry of Dark Matter, or R-charged superpartners

Suppose a convincing missing energy signal is discovered. Is the symmetry stabilizing the dark matter particle a Z_2 parity or a larger symmetry?

- In U(1)_R or Z_N (N>2) symmetric limit gauginos acquire Dirac masses by marrying new chiral adjoints that don't couple to SM fields. Consequences:
  lose all U(1)_R (or Z_{N>2}) violating decays



no ``half-cusp'' distributions with U(1)_R conservation.

Lose, e.g.:

$$\tilde{q}_L \to q_L \tilde{l}^*_L l_L$$
$$\tilde{l}_L \to \tilde{l}_R l_L \bar{l}_R$$

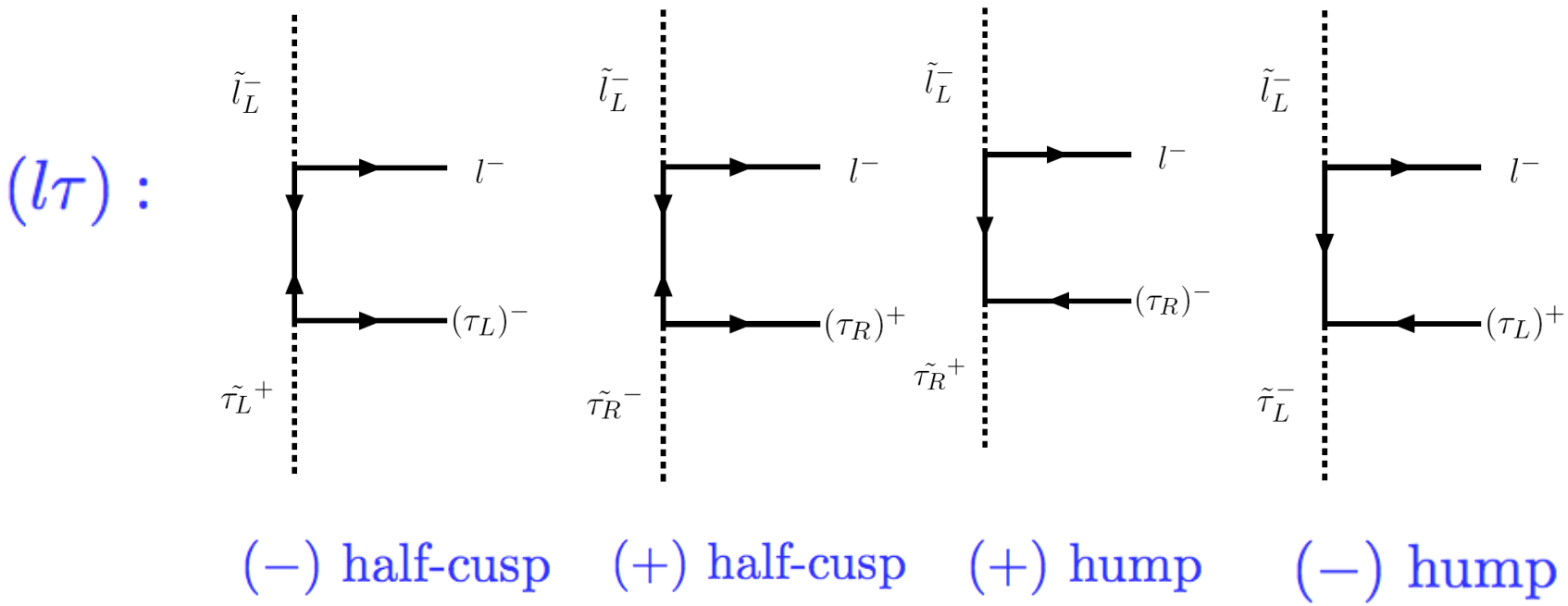
(unsigned jet)-lepton distributions are now "humps'', not "triangles''.

	Triangle	Hump	Half-Cusp
Opposite-Sign Same-Flavor	$\tilde{\chi}^0_i \to \tilde{l}^{\mp}_{L,R} l^{\pm}$ $\to \tilde{\chi}^0_j l^{\mp} l^{\pm}$		
Opposite-Sign Opposite-Flavor			
Same-Sign Same-Flavor		$\tilde{l}^{\pm}_{L,R} \to \chi^0_i l^{\pm}$ $\to \tilde{l}^{\mp}_{R,L} l^{\pm} l^{\pm}$	
Same-Sign Opposite-Flavor		$\tilde{l}^{\pm}_{L,R} \to \chi^0_i l^{\pm}$ $\to \tilde{l}'^{\mp}_{R,L} l^{\pm} l'^{\pm}$	

Same assumptions as before for dileptons, but here additional U(1)_R conservation assumed.

Invariant mass distributions involving τ's: "Precision Measurements"

If dilepton events are found, would also like to find l τ and τ τ events



- Tau decays produce missing energy, so invariant mass distributions distorted
- Invariant mass distributions depend on handedness of parent tau
- L/R stau mixing, tau Yukawa coupling effects potentially important

Tau polarization as a probe of new physics (Y-S Tsai (1971), Hagiwara, Martin, Zeppenfeld (1990) Bullock,Hagiwara,Martin (1991), CMS Note 2006/096,S-Y Choi, Hagiwara, Kim, Mawatari, Zerwas (2007))

Energy distribution of tau decay products provides a statistical handle on the handedness of the initial (boosted) tau in the collinear approximation

-angular distribution of tau decay products in tau rest frame depends on direction of the spin of the tau relative to the boost axis (e.g. $\tau \to \pi\nu$, angular distribution of the pion is 1+/- cos)

Application to boosted taus produced from decay of heavy particle:

-charged Higgs decay to $\tau\nu$, τ is "right-handed"

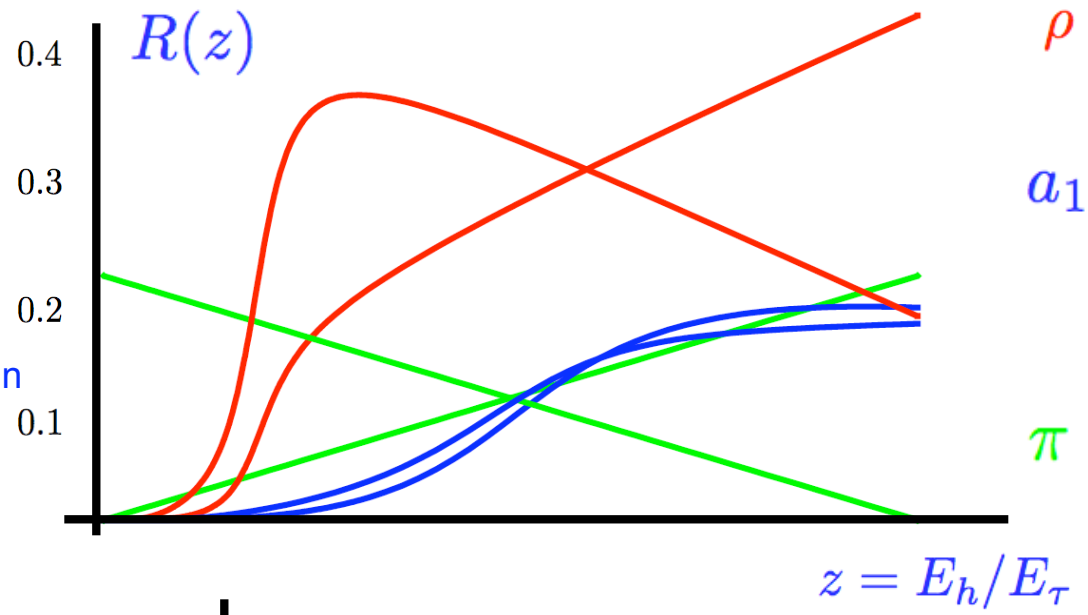
-susy decays:

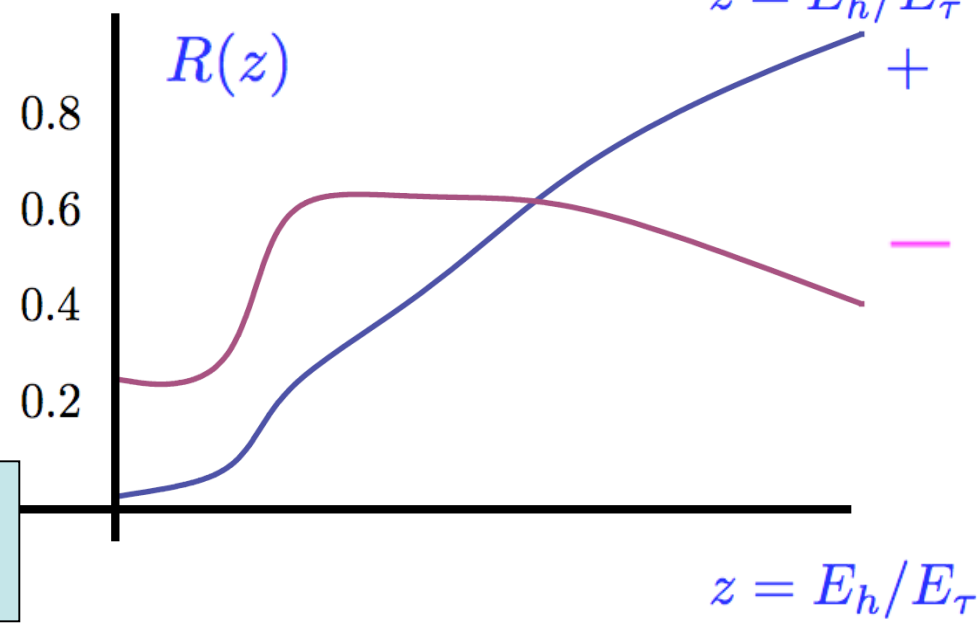
lepton-tau final states

tau-tau final states

Tau decays: (focus on 1-prong)

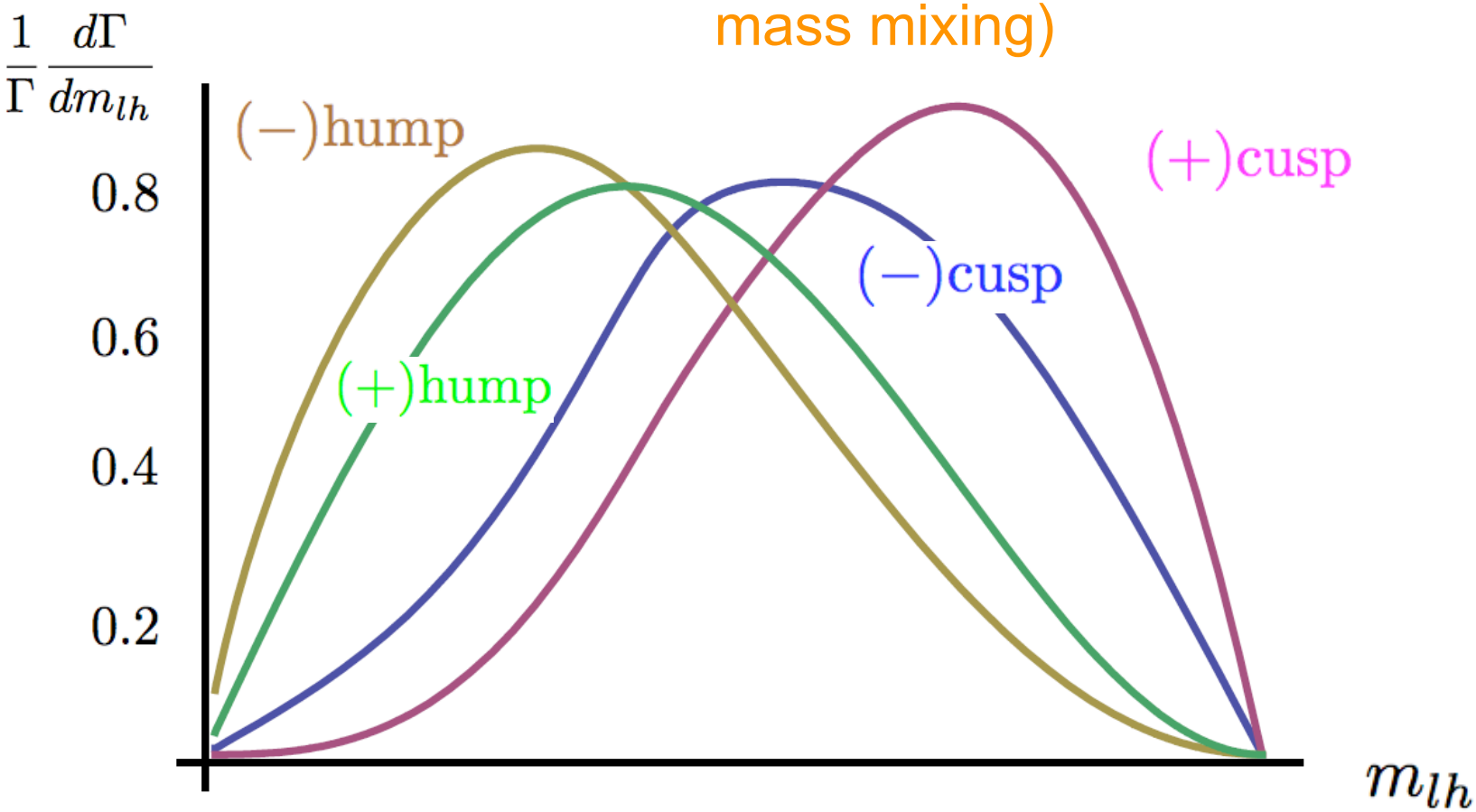
$l\nu\nu$	(0.35)	
$\pi\nu$	(0.11)	1 prong
$\rho\nu$	(0.25)	1 prong
a_1 ν	(0.18)	1 and 3 prong





$$\frac{1}{\Gamma}\frac{d\Gamma}{dm_{lh}^2} = \frac{1}{\Gamma}\int_{m_{lh}^2}^{1}\frac{dz}{z}R_h(z)\frac{d\Gamma}{dm_{l\tau}^2}\Big|_{m_{l\tau}^2 = m_{lh}^2/z}$$

Lepton-tau 1-prong distributions (no mass mixing)

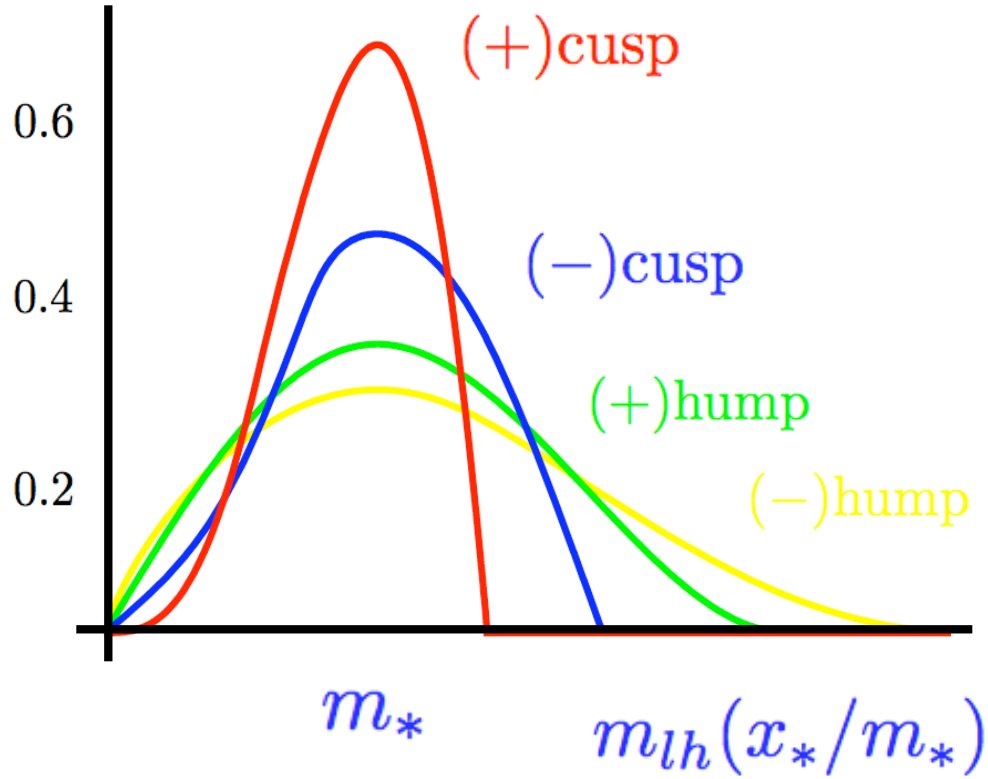


- 1-prong modified Half-cusp distributions distinguishable from modified Hump distributions
- Distributions between sign channels correlated; use to improve discrimination and determine relative ordering and handedness of slepton and stau
- However, endpoints not sharp for “hump” distributions

lepton-tau distributions (1-prong)

Rescale to fit distributions to peak, not endpoint

Process	Same Sign	Opposite Sign
$\tilde{l}_R \to l\tau\tilde{\tau}_R$	$C(+)$	$H(+)$
$\tilde{l}_R \to l\tau\tilde{\tau}_L$	$H(-)$	$C(-)$
$\tilde{l}_L \to l\tau\tilde{\tau}_R$	$H(+)$	$C(+)$
$\tilde{l}_L \to l\tau\tilde{\tau}_L$	$C(-)$	$H(-)$



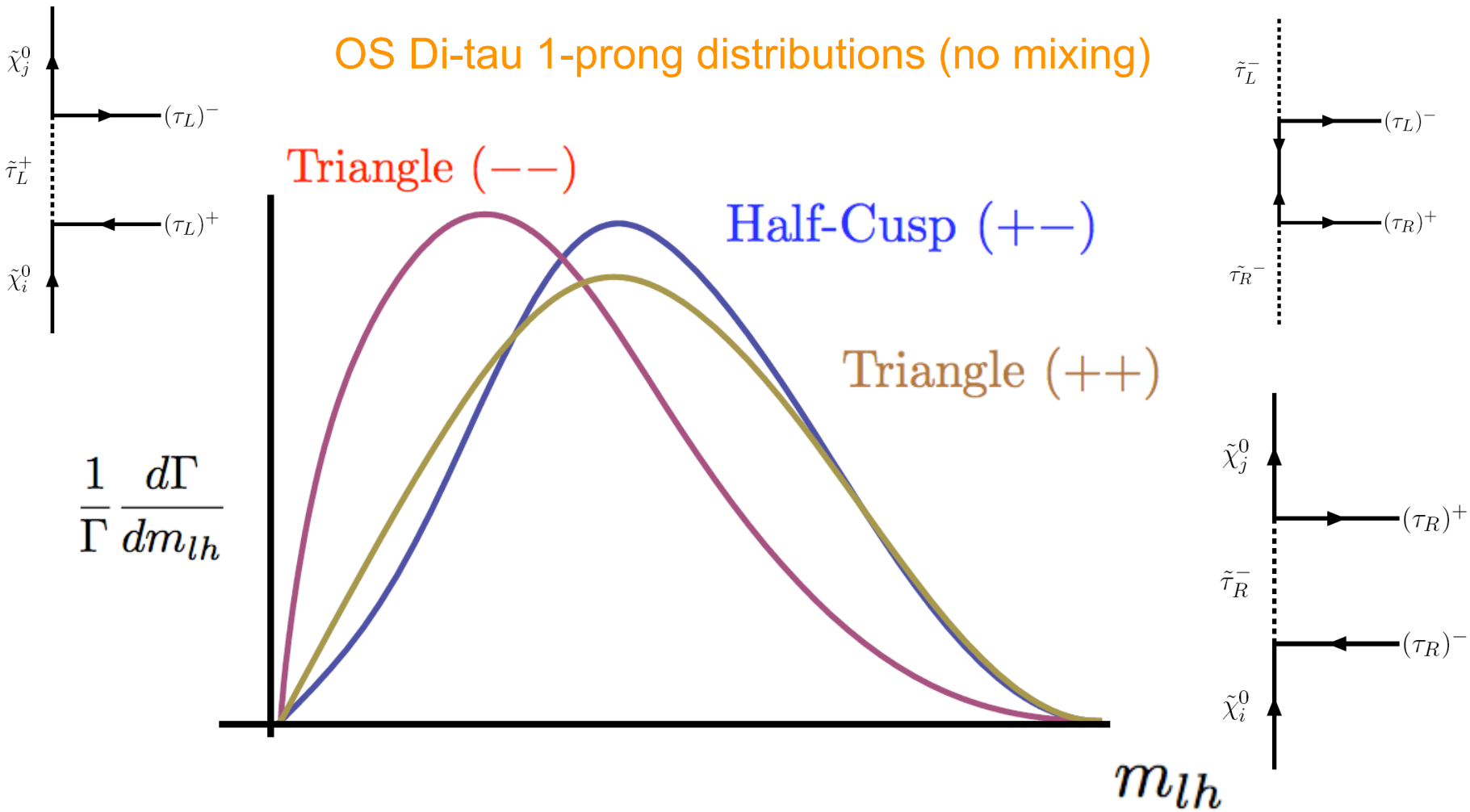
- Can include L-R stau mass mixing, tau Yukawa effects
- Can perform a similar analysis for 1-prong di-tau final states

Conclusions

- Invariant mass distributions + correlations between different charged final states (OS/SS)
  - rich dilepton possibilities in susy
  - final states containing taus
  - Tau polarization
- See forthcoming papers for:
  - Mixing effects in third generation
  - signed b quarks in (bl) distributions from stop or sbottom decays
  - top quark -lepton final states
- Future directions
  - Combinatorial confusion
  - Hadronic smearing for tau decay
  - Finite width

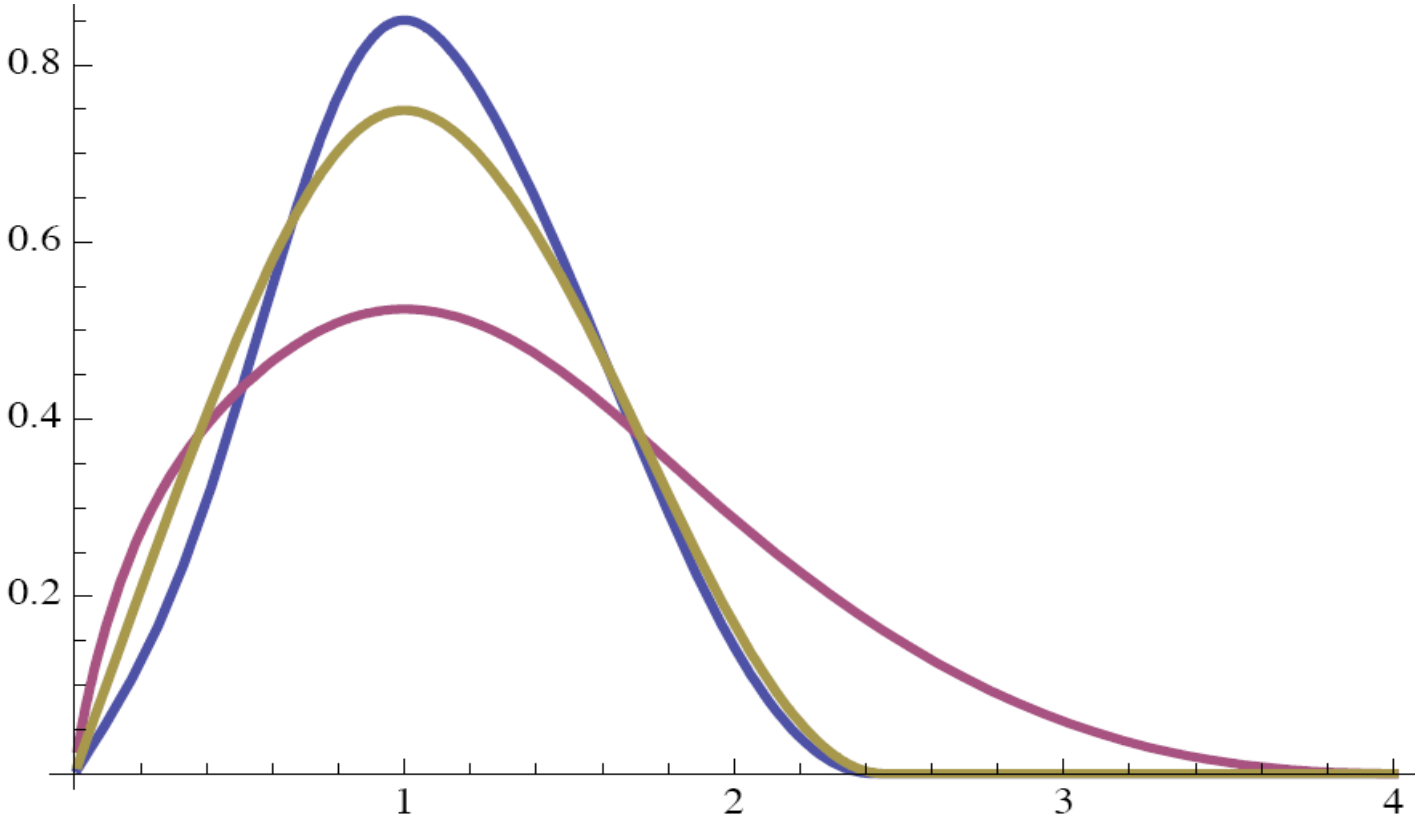
Backups

OS Di-tau 1-prong distributions (no mixing)



- use information in SS channel to lift degeneracy between (+-) half-cusp and (++) triangle
- With mass mixing and tau Yukawa couplings, 2 angles appear in di-tau “triangles”, but experimentally only sensitive to one combination of parameters

Again, rescale to fit the peak…



Di-tau triangles and half-cusp