Using Spins to Distinguish Models at the LHC

Jennifer Smillie, Cambridge

Planck 06

UED versus CMSSM

Each Standard Model (SM) particle has

- a tower of excited Kaluza-Klein (KK) modes

  $q_L \leftrightarrow q^*_{L_n},\ l \leftrightarrow l^*_n$

- ⋆ one supersymmetric partner

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Model has a $\mathbb{Z}_2$ symmetry:

• KK-parity	⋆ R-parity

UED versus SUSY

Level 1 UED modes and R-parity conserving SUSY have common key experimental signatures:

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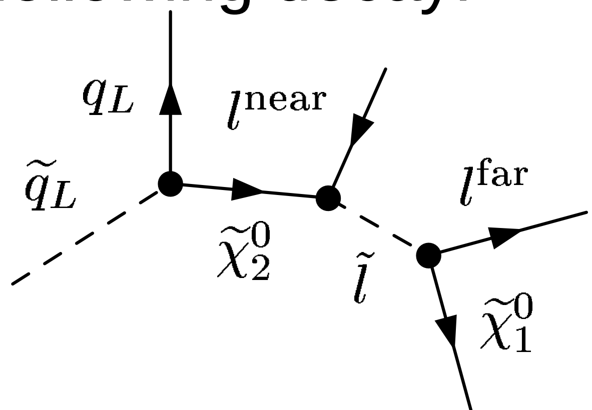
SPIN

We will try to extract information about the spin of the particles produced at the Large Hadron Collider (LHC).

JS & Bryan Webber [JHEP 10 (2005) 069]

Spin

Alan Barr showed that there was an observable difference in the invariant mass distributions of SUSY and the case with no spins in the following decay:



[Phys. Lett. B 596 (2004) 205]

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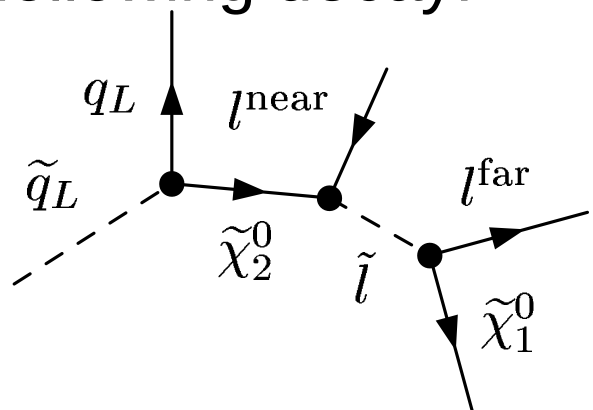
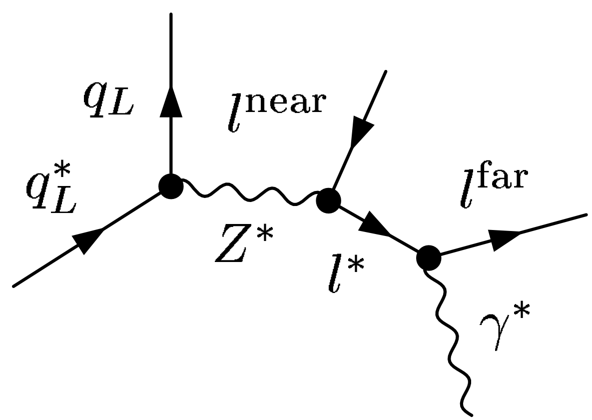


[Phys. Lett. B 596 (2004) 205]

We compare these with the same distributions for the UED decay:



$q\ l^{\rm near}$

We define the $q\ l^{\rm near}$ invariant mass as

$$(\widehat{m}_{ql}^{\rm near})^2 \propto (p_q + p_l^{\rm near})^2 \simeq 2p_q.p_l^{\rm near}$$

neglecting SM particle masses. It is normalised to take values between 0 and 1.

The invariant mass distribution is $\frac{1}{\Gamma}\frac{{\rm d}\Gamma}{{\rm d}\widehat{m}} = \frac{{\rm d}P}{{\rm d}\widehat{m}}$.

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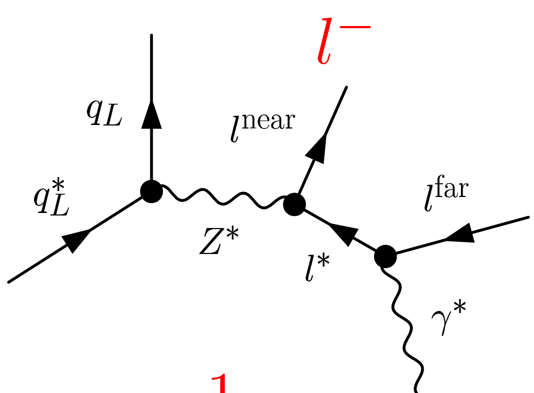
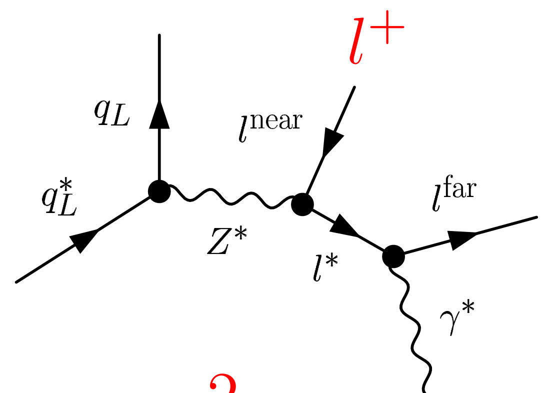
We must consider $l^{\text{near}} = l^-$ and $l^{\text{near}} = l^+$ separately.



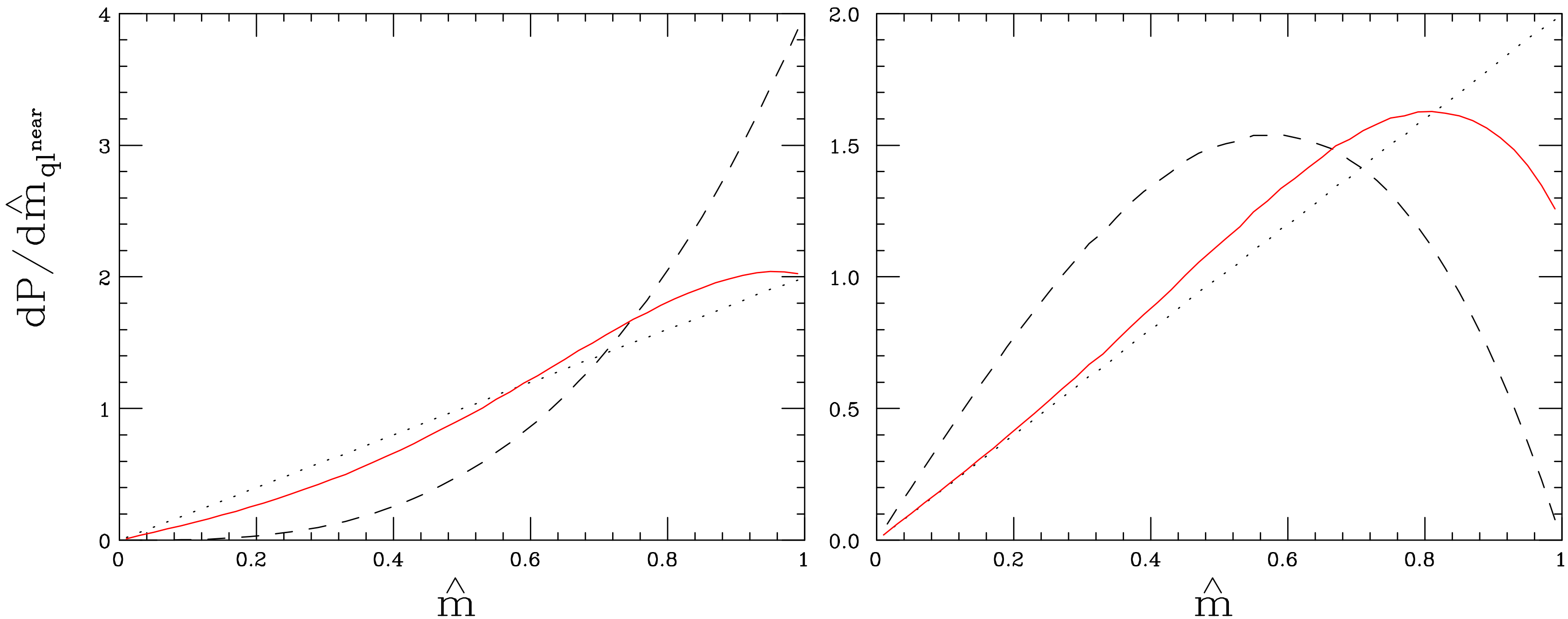
1



2

$q\ l^{\text{near}}$

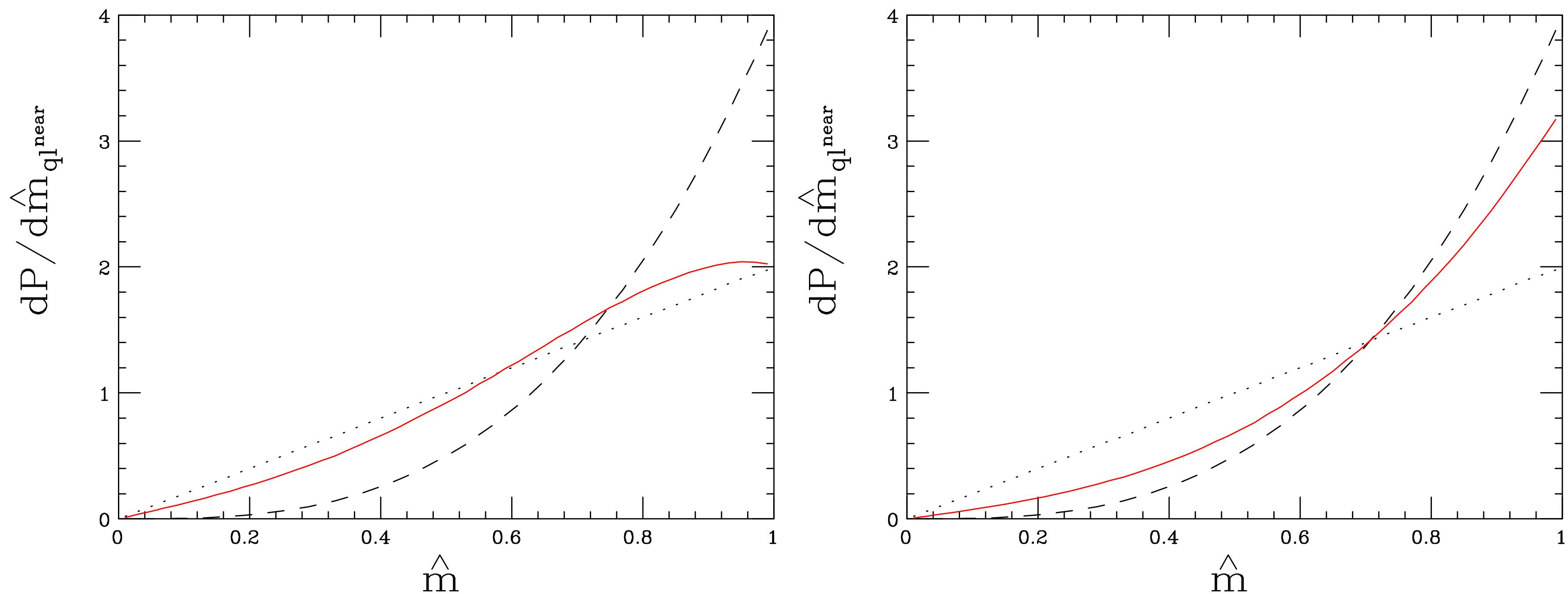
For the SPS1_a SUSY mass spectrum we find the following invariant mass distributions for case 1 and 2 respectively.



solid = UED spins dashed = SUSY spins

$q\ l^{\rm near}$

However, the UED curves are mass-dependent. Here are the distributions for case 1 with a SUSY mass spectrum again, and a UED mass spectrum.



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$jl^{\pm}$

In reality, we can only hope to measure jet and lepton combinations.

These are given by:

$$\frac{\mathrm{d}P}{\mathrm{d}m_{jl^+}} = f_q \left(\frac{\mathrm{d}P_2}{\mathrm{d}m_{ql}^{\mathrm{near}}} + \frac{\mathrm{d}P_1}{\mathrm{d}m_{ql}^{\mathrm{far}}} \right) + f_{\bar{q}} \left(\frac{\mathrm{d}P_1}{\mathrm{d}m_{ql}^{\mathrm{near}}} + \frac{\mathrm{d}P_2}{\mathrm{d}m_{ql}^{\mathrm{far}}} \right)$$

for jl^+, and

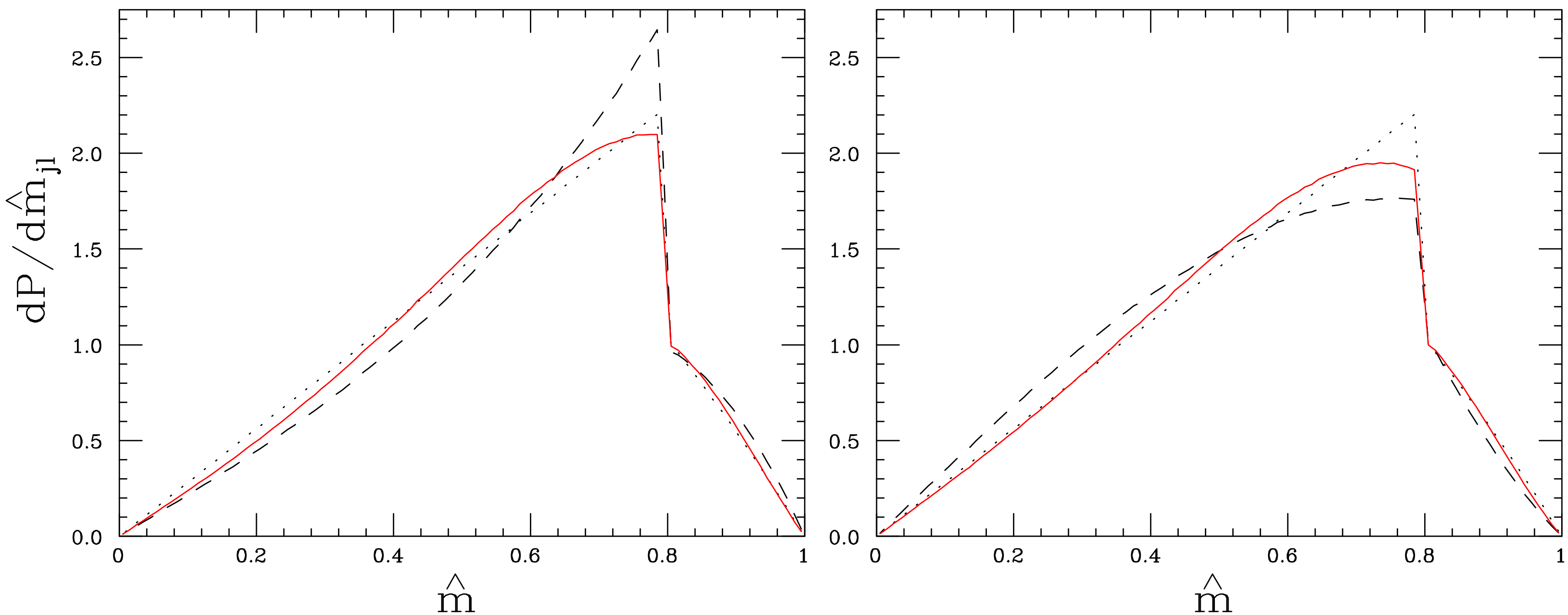
$$\frac{\mathrm{d}P}{\mathrm{d}m_{jl^-}} = f_q \left(\frac{\mathrm{d}P_1}{\mathrm{d}m_{ql}^{\mathrm{near}}} + \frac{\mathrm{d}P_2}{\mathrm{d}m_{ql}^{\mathrm{far}}} \right) + f_{\bar{q}} \left(\frac{\mathrm{d}P_2}{\mathrm{d}m_{ql}^{\mathrm{near}}} + \frac{\mathrm{d}P_1}{\mathrm{d}m_{ql}^{\mathrm{far}}} \right)$$

for jl^-.

We estimate $f_q \simeq 0.7$.

$jl^{\pm}$

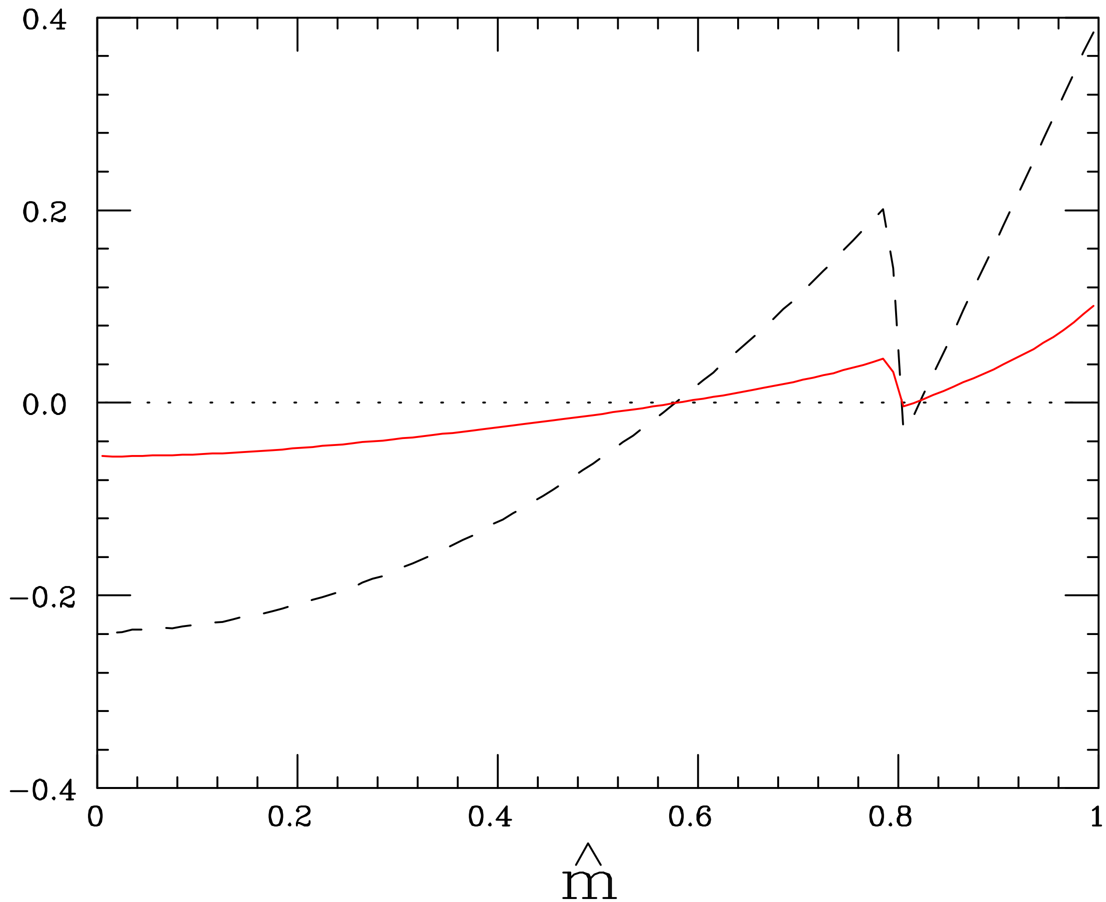
This gives the following jl^{+} and jl^{-} distributions for the SPS 1a spectrum.



solid = UED spins dashed = SUSY spins

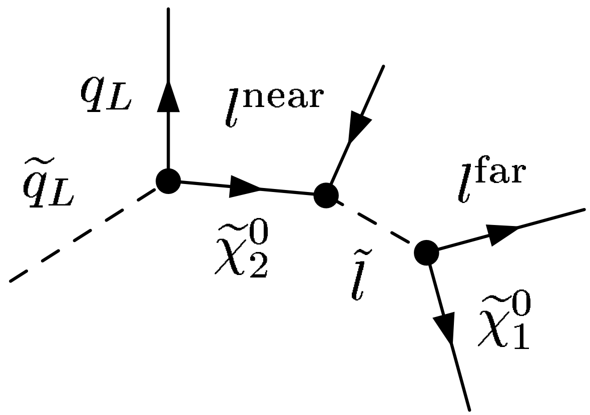
jl Asymmetry

$$A = \frac{\mathrm{d}P/\mathrm{d}m_{jl+} - \mathrm{d}P/\mathrm{d}m_{jl-}}{\mathrm{d}P/\mathrm{d}m_{jl+} - \mathrm{d}P/\mathrm{d}m_{jl-}}$$

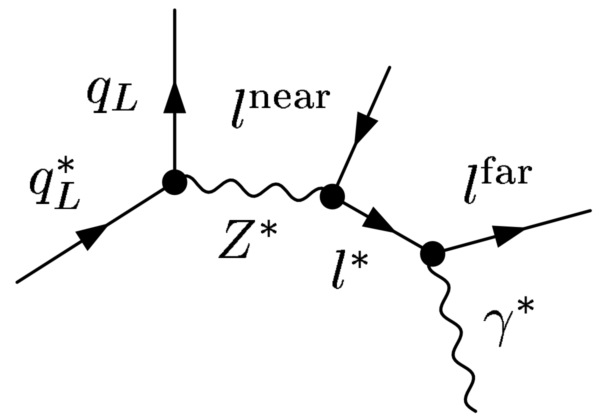


Chains

However,



and



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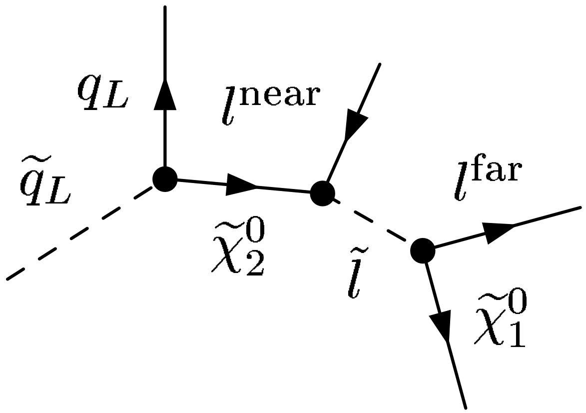

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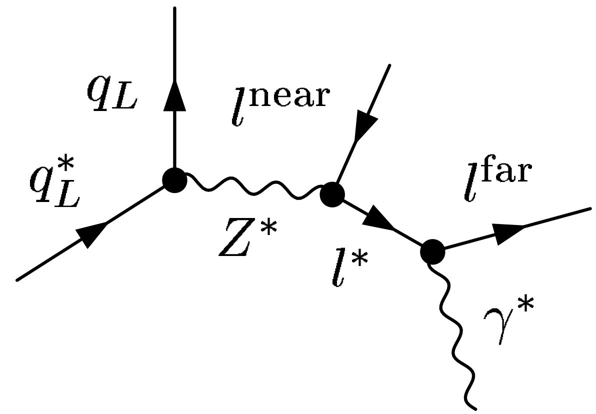
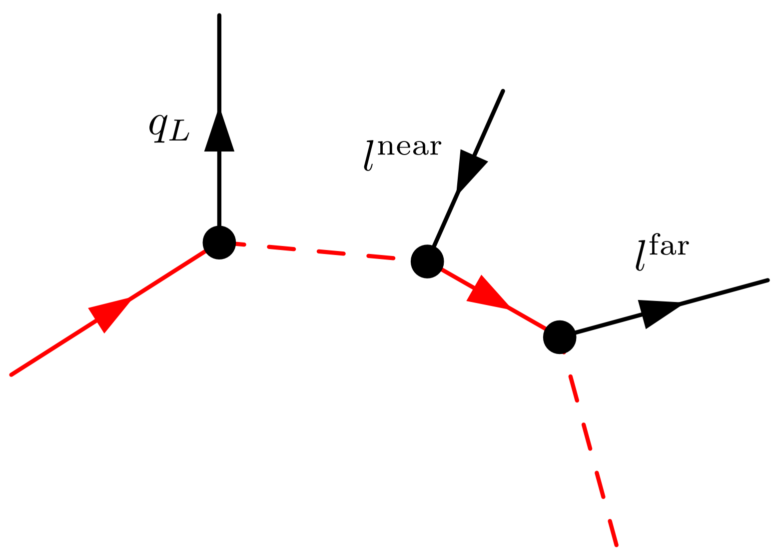
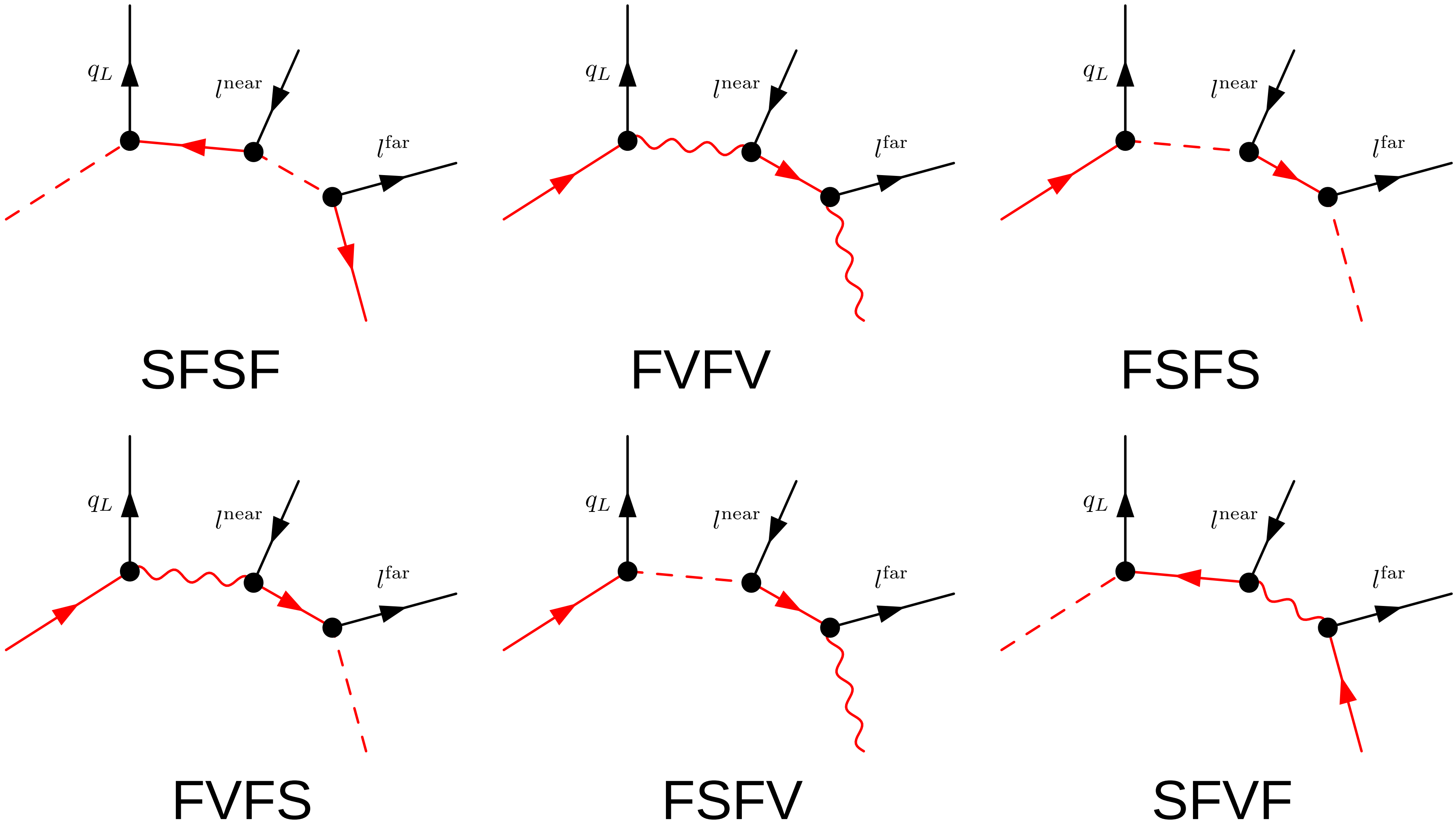


are not the only possible spins in the chain.
For example,



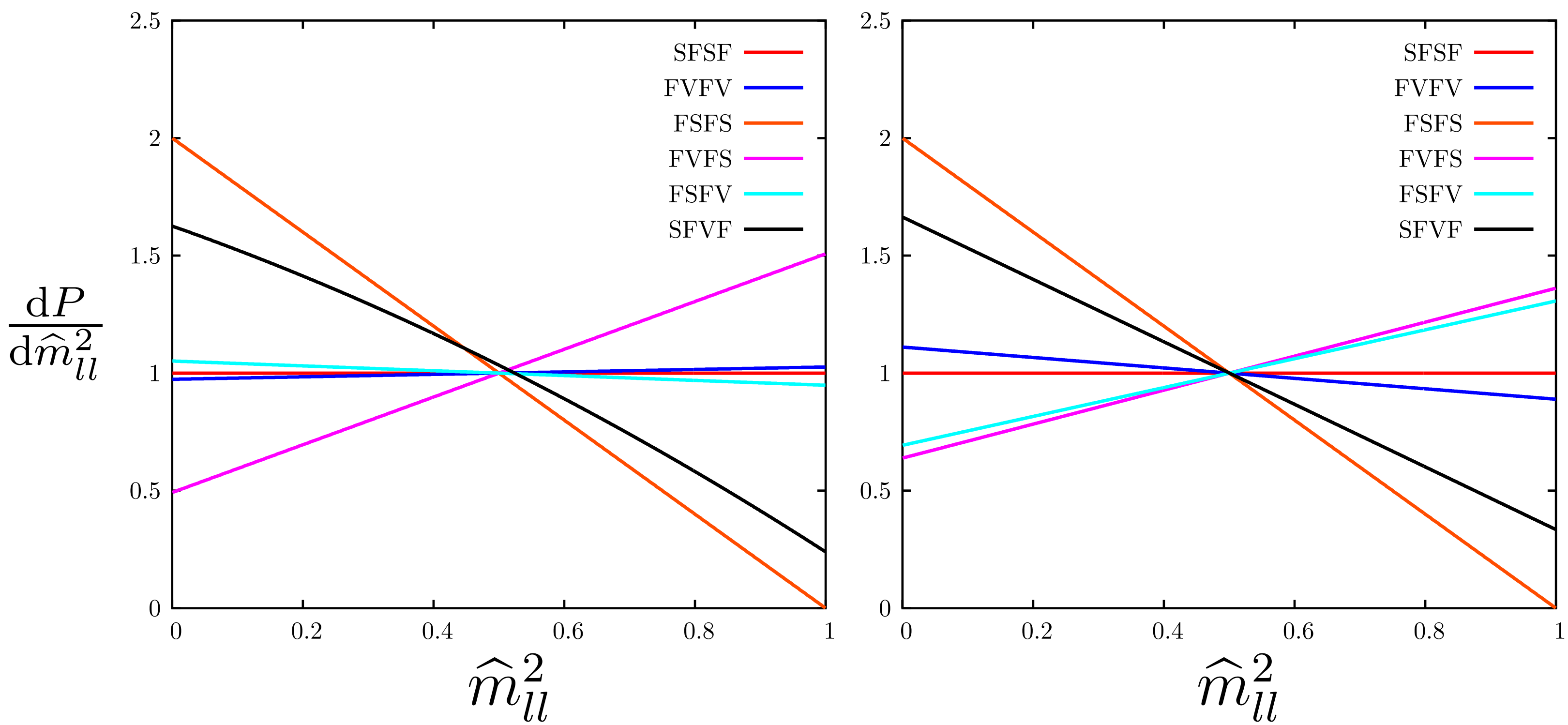
Chains

In fact there are 6 such possibilities:



For Example, $l^{\text{near}} l^{\text{far}}$

Plot invariant mass distribution as before, now for all 6 chains. The m_{ll}^2 distributions for SPS 1a masses and UED masses ($R^{-1} = 800\text{GeV}, \Lambda R = 20$) are:



[C. Athanasiou, C. G. Lester, JS & B. R. Webber: hep-ph/0605286]

Discrimination

We calculate number of events N needed to disfavour S with respect to T by a factor R:

$$\frac{1}{R} = \frac{p(S)p(N \text{ events from } T|S)}{p(T)p(N \text{ events from } T|T)}$$

This leads to, in the limit of large N,

$$N \sim \frac{\log R + \log \frac{p(S)}{p(T)}}{\mathrm{KL}(T,S)},$$

where

$$\mathrm{KL}(T,S) = \int_m \log\left(\frac{p(m|T)}{p(m|S)}\right) p(m|T)\mathrm{d}m$$

is the Kullback-Leibler distance.

Discrimination

We use this to give a quantitative measure of how different these distributions are:

<table>
<tr><th></th><th>SFSF</th><th>FVFV</th><th>FSFS</th><th>FVFS</th><th>FSFV</th><th>SFVF</th></tr>
<tr><td>SFSF</td><td rowspan="6" colspan="6">$\Longleftarrow$ Assuming model on the left,
calculate the minimum number of events
needed for the left model to be R times
more likely than the top model</td></tr>
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	SFSF	FVFV	FSFS	FVFS	FSFV	SFVF
SFSF	∞	60486	23	148	15608	66
FVFV	60622	∞	22	164	6866	62
FSFS	36	34	∞	16	39	266
FVFS	156	173	11	∞	130	24
FSFV	15600	6864	25	122	∞	76
SFVF	78	73	187	27	90	∞

$\widehat{m}^2_{ll}$ distributions at (SPS 1a)

Number of events, assuming FSFS is true, such that FSFS is 1000 times more likely than other model.

Conclusions

- We have studied decays of a q^* in a UED model and $\tilde{q}$ in the MSSM with full spin dependence, using invariant mass distributions. We found we can hope to distinguish them using $jl^{\pm}$.

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- We have studied decays of a q^* in a UED model and $\tilde{q}$ in the MSSM with full spin dependence, using invariant mass distributions. We found we can hope to distinguish them using $jl^{\pm}$.

- We have extended this to cover all possible spin assignments in the chain.

- We have calculated lower bounds on the number of events necessary to distinguish models for all the possible invariant mass combinations.

Production

We calculated production matrix elements for all UED $2 \to 2$ strong processes and added these to HERWIG to calculate (in pb):

Masses	Model	$\sigma_{\rm all}$	σ_{q^*}	$\sigma_{\bar{q}^*}$	f_q
UED	UED	252	163	83	0.66
UED	SUSY	28	18	9	0.65
SPS 1a	UED	487	239	103	0.70
SPS 1a	SUSY	55	26	11	0.70

SUSY processes from existing routines in HERWIG.