Using Spin to Distinguish Models at the LHC

Jennifer Smillie
Cambridge

UK BSM 07, Liverpool 29 March, 2007

Spin

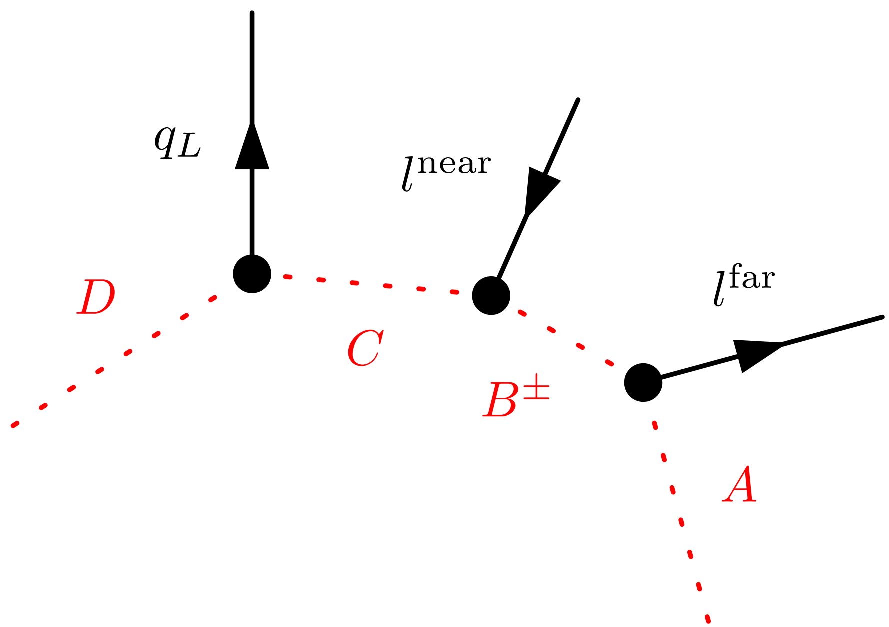
- If a signal of new physics is confirmed at the LHC, it is vital to be able to distinguish different models.

- Spin studies have become important due to the popularity of SUSY extensions to the Standard Model.
  - Need evidence that observed potential SUSY partners have the correct spin.

- Other models can have experimental signatures which could be mistaken for SUSY.
  - E.g. Universal Extra Dimensions (UED) and Little Higgs with T-parity (LHT)

Cascade Decay

Consider the following cascade decay of a quark partner:



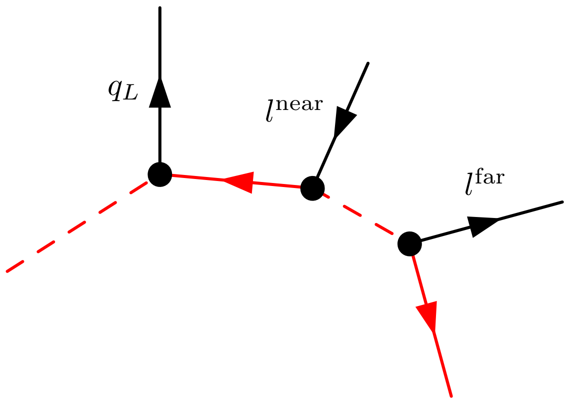
A, $B^{\pm}$, C and D are new massive particles.

Final state is $q\ \ell^+\ \ell^-$ and 'A'.

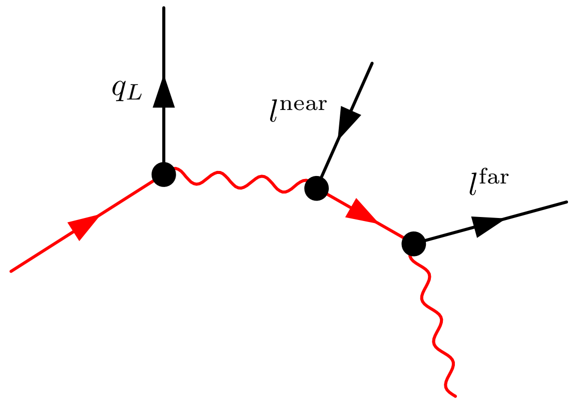
E. g. $\tilde{q}_L \to q\tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \to \tilde{l}_R l$, $\tilde{l}_R l \to l\tilde{\chi}_1^0$ in the MSSM.

Cascade Decay Chains

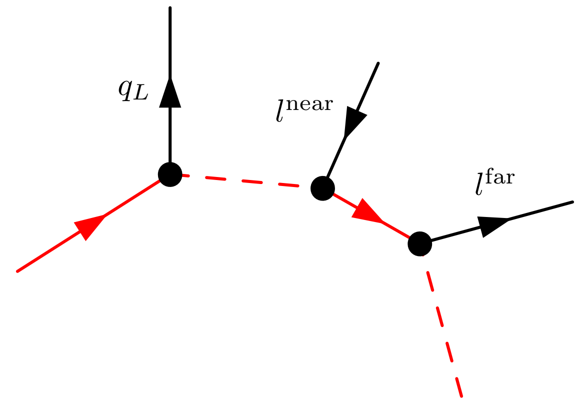
There are 6 possible spin assignments:



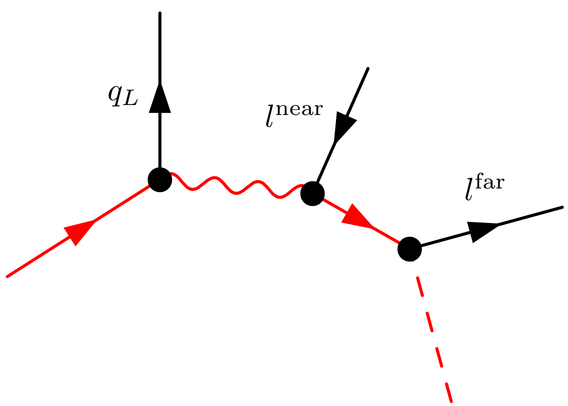
SFSF



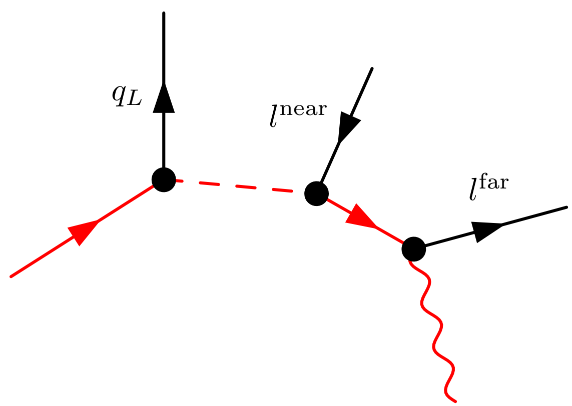
FVFV



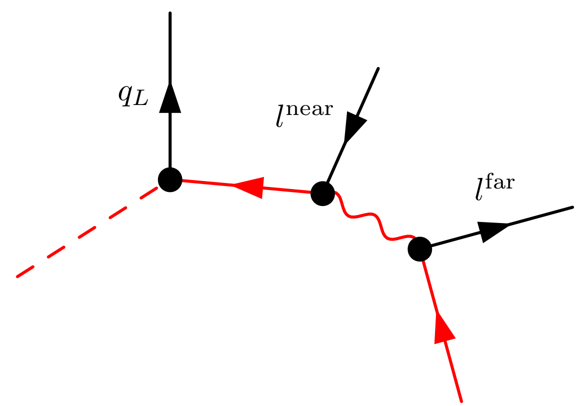
FSFS



FVFS



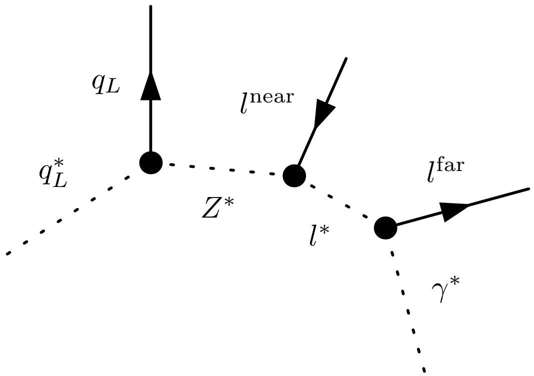
FSFV



SFVF

S = scalar F = fermion V = Vector

m^2_{ab}



In this chain, the observable particles are the quark the leptons.

Their invariant mass-squared is $m^2_{ab} = (p_a + p_b)^2$.

Plot

$$\frac{\mathrm{d}P}{\mathrm{d}m} = \frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}m}$$

where Γ is the total decay rate for the chain.

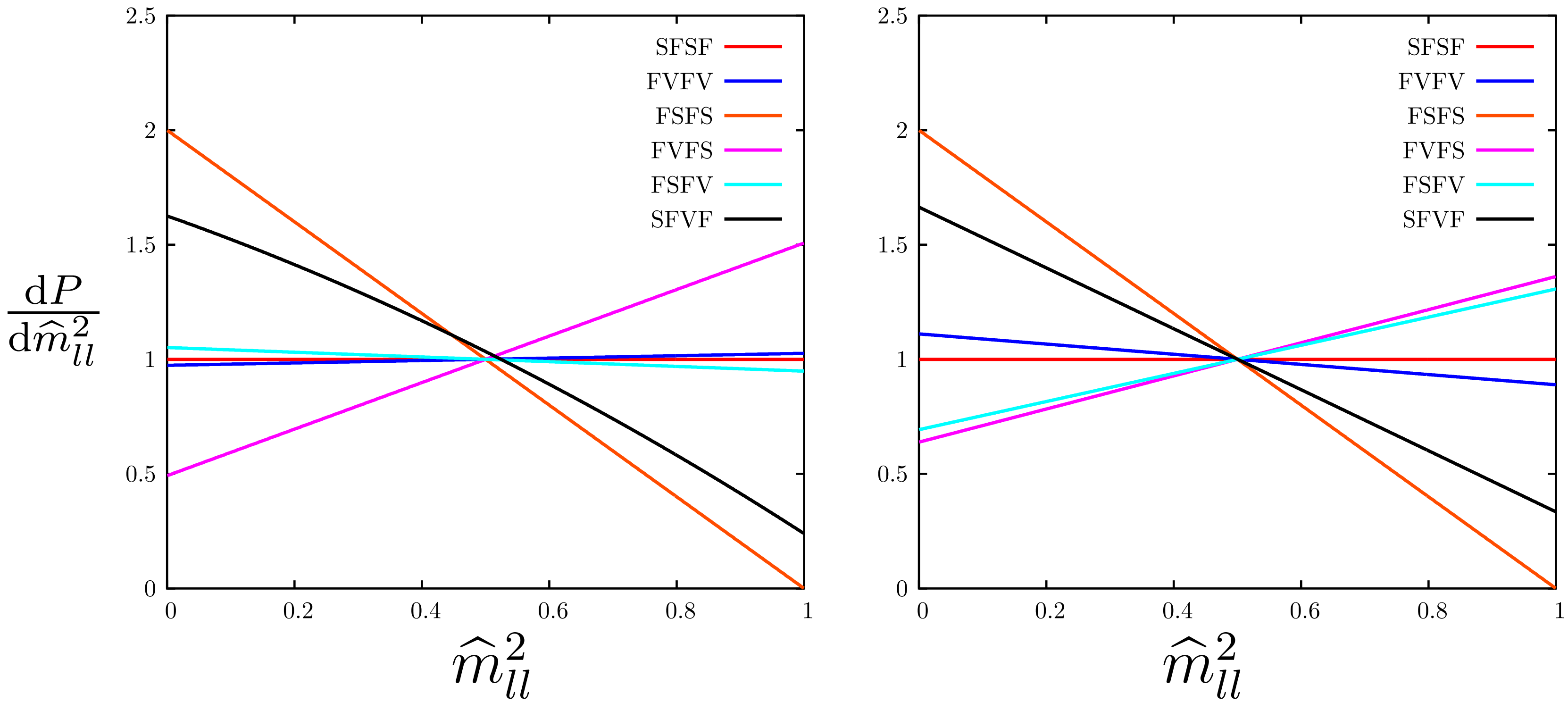
Observable distributions are:

$$\frac{\mathrm{d}P}{\mathrm{d}\widehat{m}_{l^+l^-}}, \quad \frac{\mathrm{d}P}{\mathrm{d}\widehat{m}_{j\ell^+}}, \quad \frac{\mathrm{d}P}{\mathrm{d}\widehat{m}_{j\ell^-}} \quad \text{and} \quad \frac{\mathrm{d}P}{\mathrm{d}\widehat{m}_{j\ell^-\ell^+}}.$$

Only 3 are independent.

For Example, l^+l^-

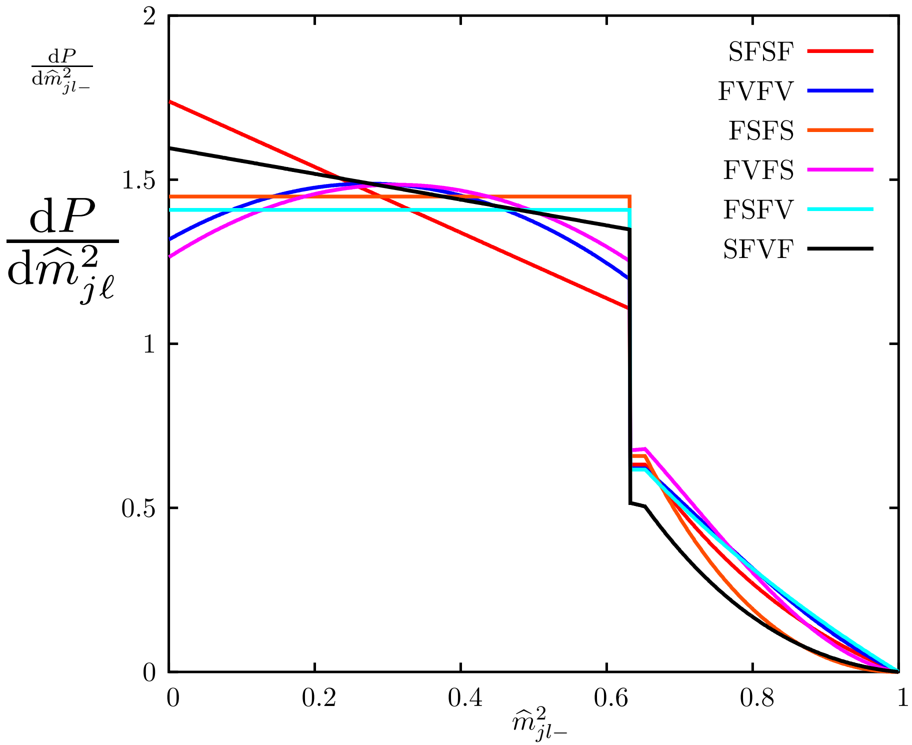
The m_{ll}^2 distributions for SPS 1a masses and UED masses ($R^{-1} = 800\mathrm{GeV}, \Lambda R = 20$) are:



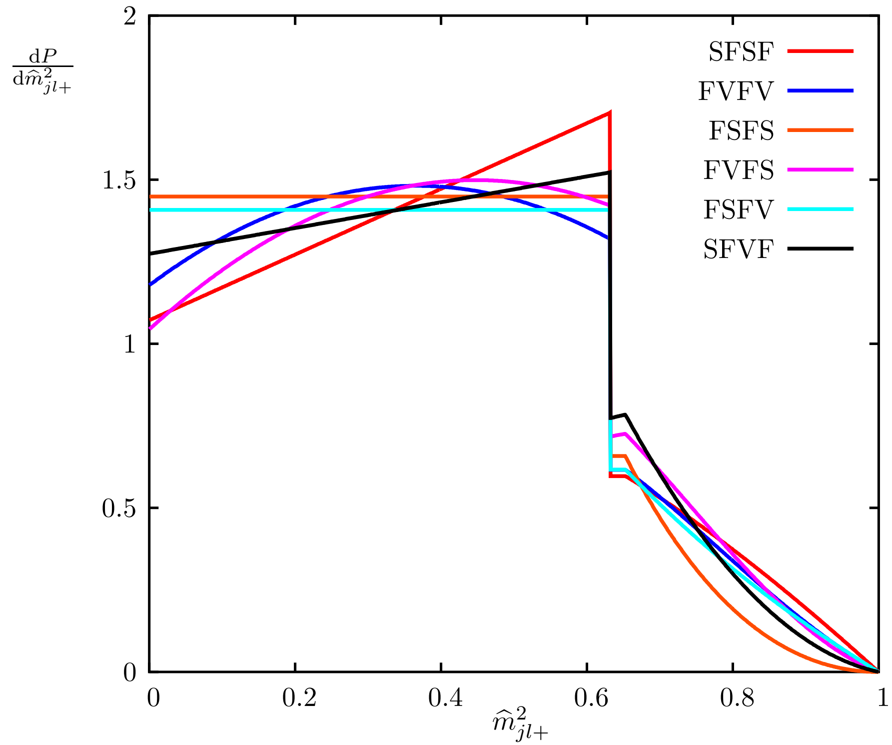
Athanasiou, Lester, JS & Webber
hep-ph/0605286

jet + $l^{\pm}$

At SPS 1a:

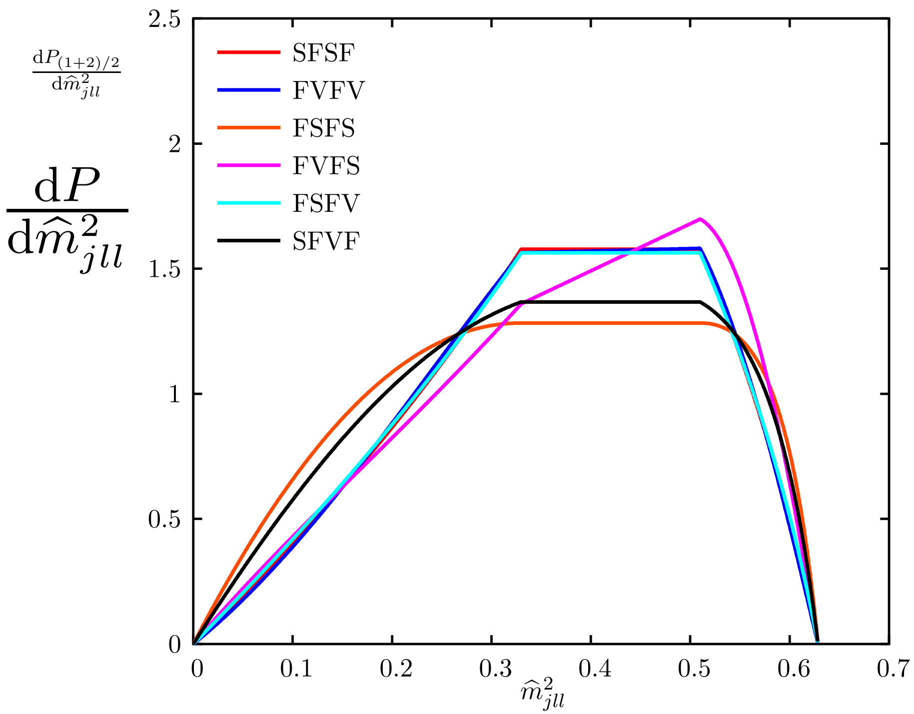


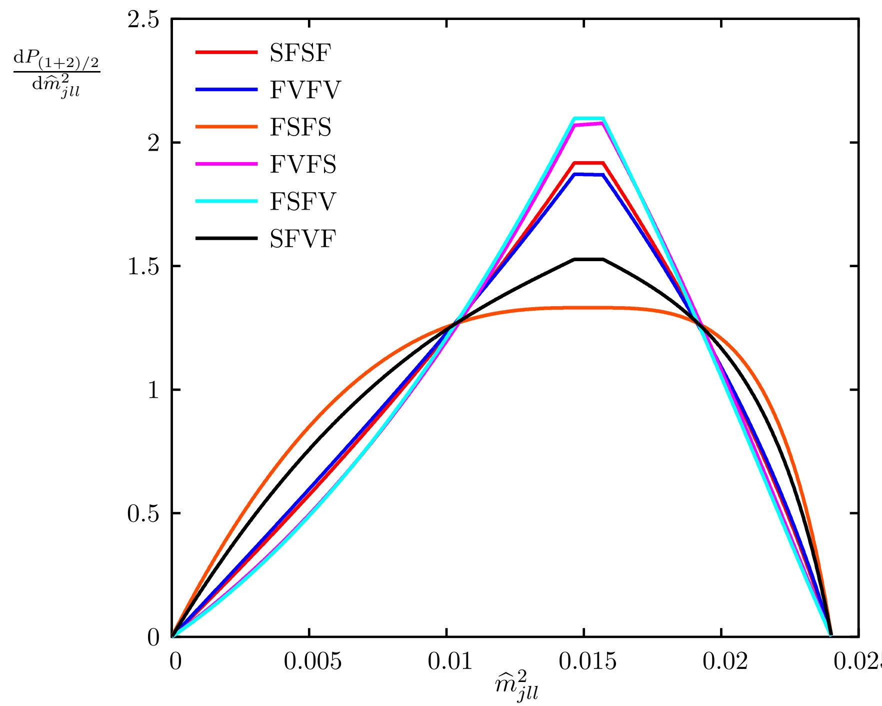
jet + ℓ^-



jet + ℓ^+

jet $\ell^+ \ell^-$





$\widehat{m}^2_{jll}$ $\widehat{m}^2_{jll}$

SPS 1a UED-type

Discrimination

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

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

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

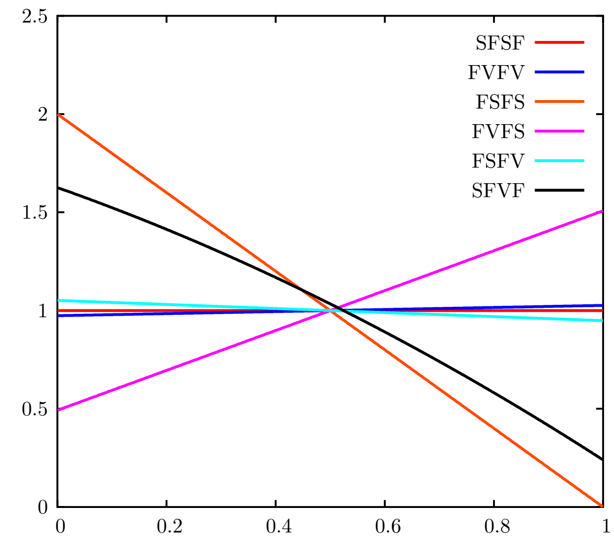
We use this to give a quantitative measure of how different these distributions are:

T$\downarrow$ S$\rightarrow$	SFSF	FVFV	FSFS	FVFS	FSFV	SFVF
SFSF						
FVFV	$\Longleftarrow$ Assuming model on the left,					
FSFS	calculate the minimum number of events					
FVFS	needed for the left model to be R times					
FSFV	more likely than the top model					
SFVF						

Discrimination

T↓ S→	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	∞

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



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

3D Kullback-Leibler

However, we can also combine information of all 3 distributions by changing

$$m_i \;\rightarrow\; \underline{m}_i \;=\; (m^{jl+}, m^{jl-}, m^{ll})$$

Each event gives us a point in 3D phase space.

SPS 1a (for example)

N_{ll}	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	∞

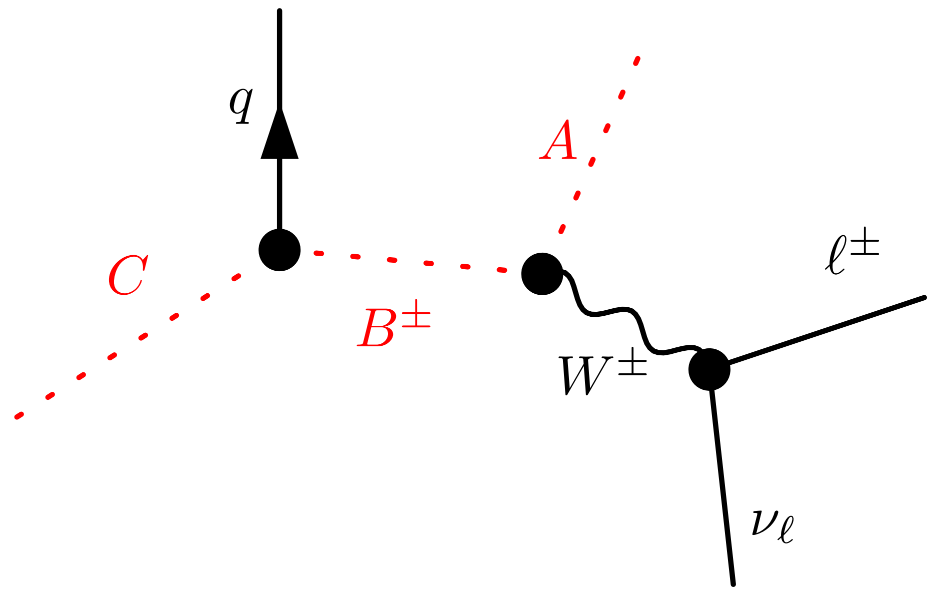
$\leftarrow m_{ll}$ distribution

m_{ll}, m_{jl+} and m_{jl-} $\rightarrow$

N_{all}	SFSF	FVFV	FSFS	FVFS	FSFV	SFVF
SFSF	∞	455	21	47	348	55
FVFV	474	∞	21	54	1387	55
FSFS	33	34	∞	13	39	188
FVFS	55	67	10	∞	54	19
FSFV	341	1339	25	45	∞	66
SFVF	62	64	143	19	79	∞

Decays via a W

Instead, consider the following decay of a new particle, C:



where B and A are also new particles.

These may occur in the MSSM, UED or LHT models.

Caveat: Depends on electroweak structure due to W.

JS hep-ph/0609296

Conclusions

- Spin studies are very important in the LHC era.
- Cascade decays of new particles can be a useful tool in spin determination.
  - Invariant mass distributions have discriminatory power
- Kullback-Leibler distance is excellent tool to determine which processes can be analysed.
- Can apply this kind of study to more than one decay chain.