SUSY vs UED Spins at the LHC

Bryan Webber, Cambridge
Dresden MC Workshop, Jan 2006

- Spin correlations in SUSY and UED models
- Event and detector simulation
- Conclusions

A Barr, hep-ph/0405052, hep-ph/0511115; T Goto et al, hep-ph/0406317;
G Bhattacharya et al, hep-ph/0502031; M Battaglia et al, hep-ph/0502041;
J Smillie & BW, hep-ph/0507170

Spin Correlations in SUSY & UED

- SUSY: new particles are superpartners

  $$q \leftrightarrow \tilde{q}\,,\;\; g \leftrightarrow \tilde{g}\,,\;\; l \leftrightarrow \tilde{l}\,,\;\; (\gamma, Z, \ldots) \leftrightarrow (\tilde{\chi}^0_1, \tilde{\chi}^0_2, \ldots)$$

  ➜ spins differ by one-half

- UED: new particles are KK excitations

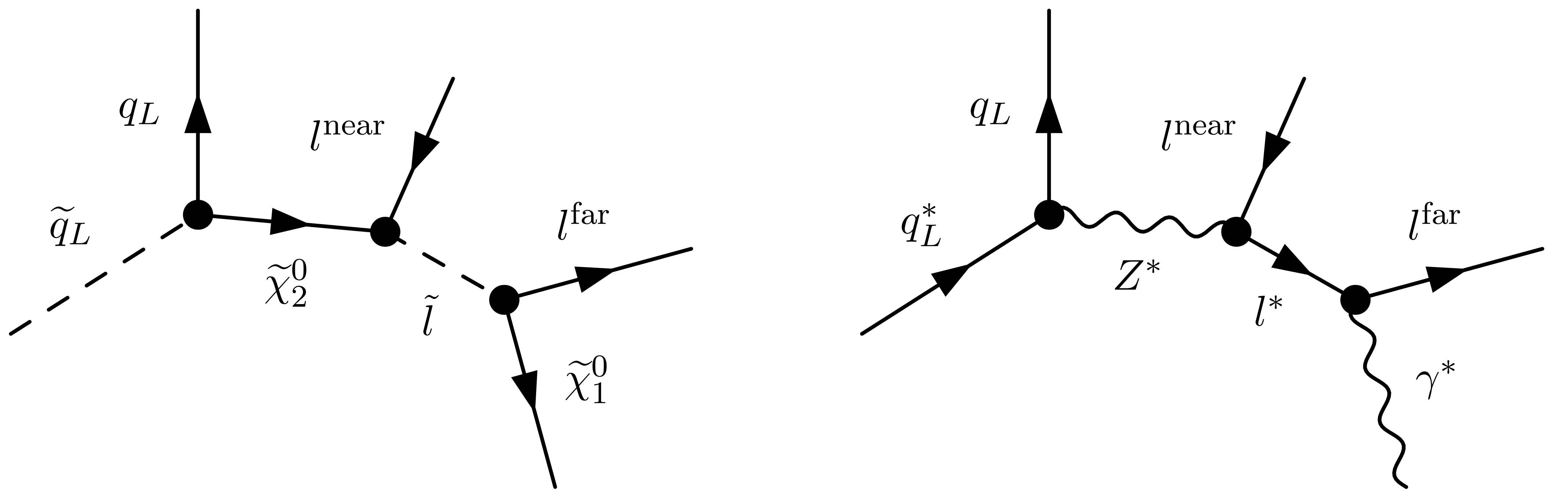
  $$q \leftrightarrow q^*\,,\;\; g \leftrightarrow g^*\,,\;\; l \leftrightarrow l^*\,,\;\; (\gamma, Z, \ldots) \leftrightarrow (\gamma^*, Z^*, \ldots)$$

  ➜ spins are the same!

- Suppose masses have been measured: how could we distinguish?

  ➜ need evidence on spins to be sure

SUSY and UED decay chains



➡ Two distinct helicity structures, with different spin correlations:

- Process 1: $\{q, l^{\rm near}, l^{\rm far}\} = \{q_L, l_L^-, l_L^+\}$ or $\{\bar{q}_L, l_L^+, l_L^-\}$ or $\{q_L, l_R^+, l_R^-\}$ or $\{\bar{q}_L, l_R^-, l_R^+\}$;
- Process 2: $\{q, l^{\rm near}, l^{\rm far}\} = \{q_L, l_L^+, l_L^-\}$ or $\{\bar{q}_L, l_L^-, l_L^+\}$ or $\{q_L, l_R^-, l_R^+\}$ or $\{\bar{q}_L, l_R^+, l_R^-\}$.

Distinguishing Spins in Supersymmetric and Universal Extra Dimension Models at the Large Hadron Collider*

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hep-ph/0507170 = JHEP 10(2005)069

UED and SUSY mass spectra

- UED models tend to have quasi-degenerate spectra

γ^*	Z^*	q_L^*	l_R^*	l_L^*
501	536	598	505	515

Table 1: UED masses in GeV, for $R^{-1} = 500\text{GeV}$, $\Lambda R = 20$, $m_h = 120\text{GeV}$, $\overline{m}_h^2 = 0$ and vanishing boundary terms at cut-off scale Λ.

($M_n \sim n/R$ broken by boundary terms and loops, with low cutoff)

- SUSY spectra typically more hierarchical

$\widetilde{\chi}_1^0$	$\widetilde{\chi}_2^0$	$\widetilde{u}_L$	$\widetilde{e}_R$	$\widetilde{e}_L$
96	177	537	143	202

Table 2: SUSY masses in GeV, for SPS point 1a.

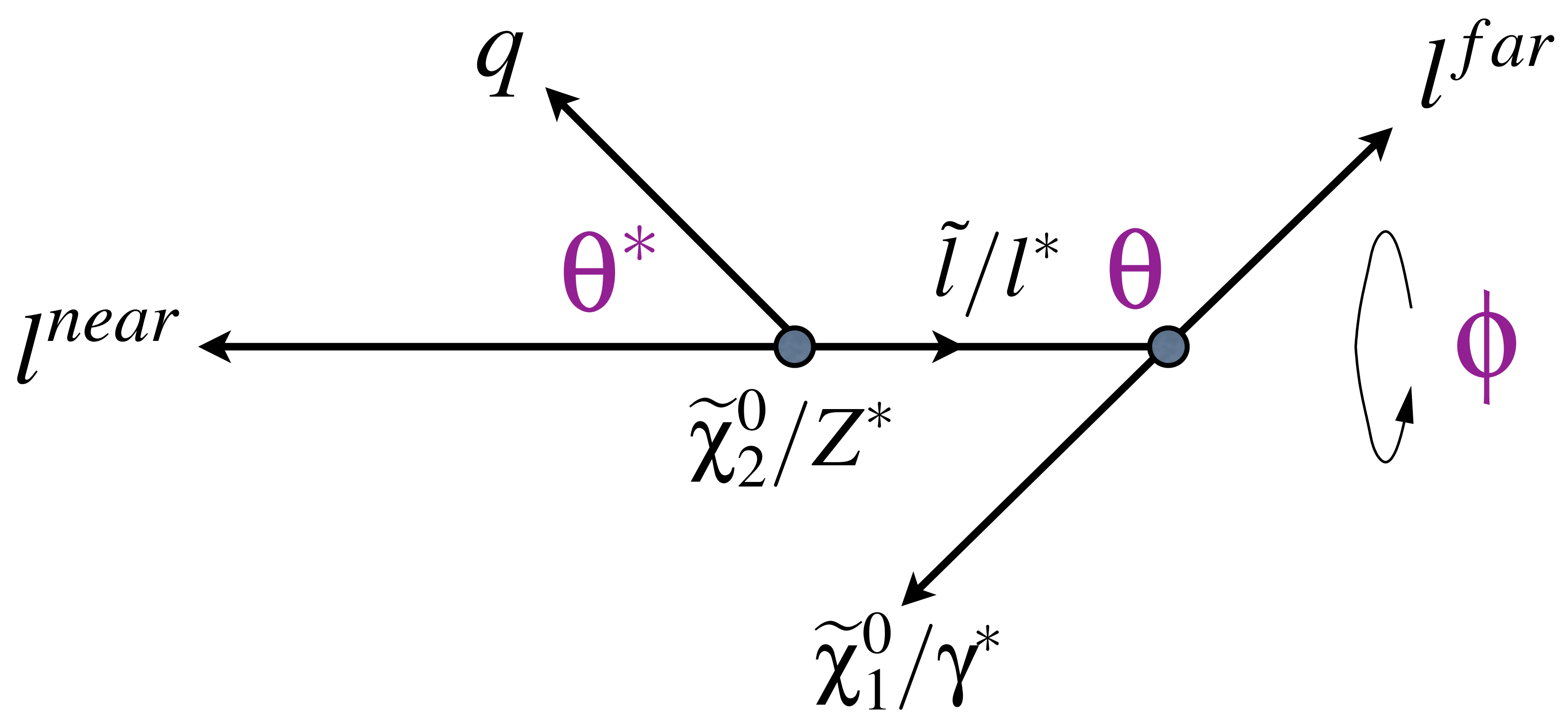
(high-scale universality)

Production cross sections (pb)

Masses	Model	$\sigma_{\rm all}$	σ_{q^*}	$\sigma_{\bar{q}^*}$	f_q
UED	UED	253	163	84	0.66
UED	SUSY	28	18	9	0.65
SPS 1a	UED	433	224	80	0.74
SPS 1a	SUSY	55	26	11	0.70

- $\sigma_{\rm UED} \gg \sigma_{\rm SUSY}$ for same masses (100 pb = 1/sec)
  - $q^*/\bar{q}^* \sim 2 \;\Rightarrow$ charge asymmetry

Angular variables



- θ^* defined in $\tilde{\chi}_2^0/Z^*$ rest frame
- θ, ϕ defined in $\tilde{l}/l^*$ rest frame

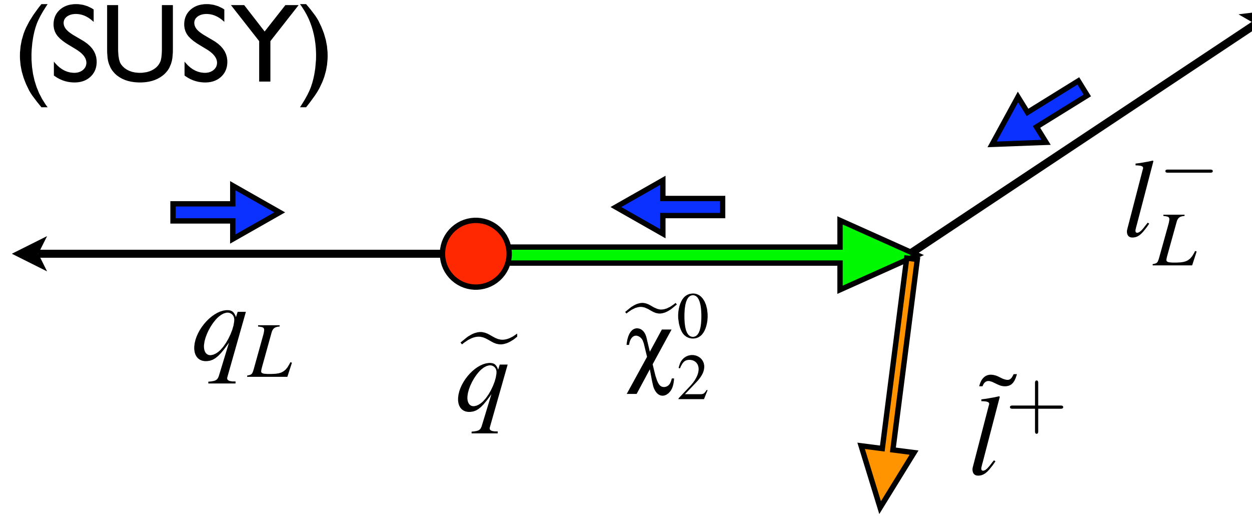
Invariant masses

- ql^{near}: $m_{ql}/(m_{ql})_{max} = \sin(\theta^*/2)$
- $l^{near}l^{far}$: $m_{ll}/(m_{ll})_{max} = \sin(\theta/2)$
- ql^{far}: $m_{ql}/(m_{ql})_{max} = \frac{1}{2}\Big[(1-y)(1-\cos\theta^*\cos\theta)+ +(1-y)(\cos\theta^*-\cos\theta)-2\sqrt{y}\sin\theta^*\sin\theta\cos\phi\Big]^{\frac{1}{2}}$

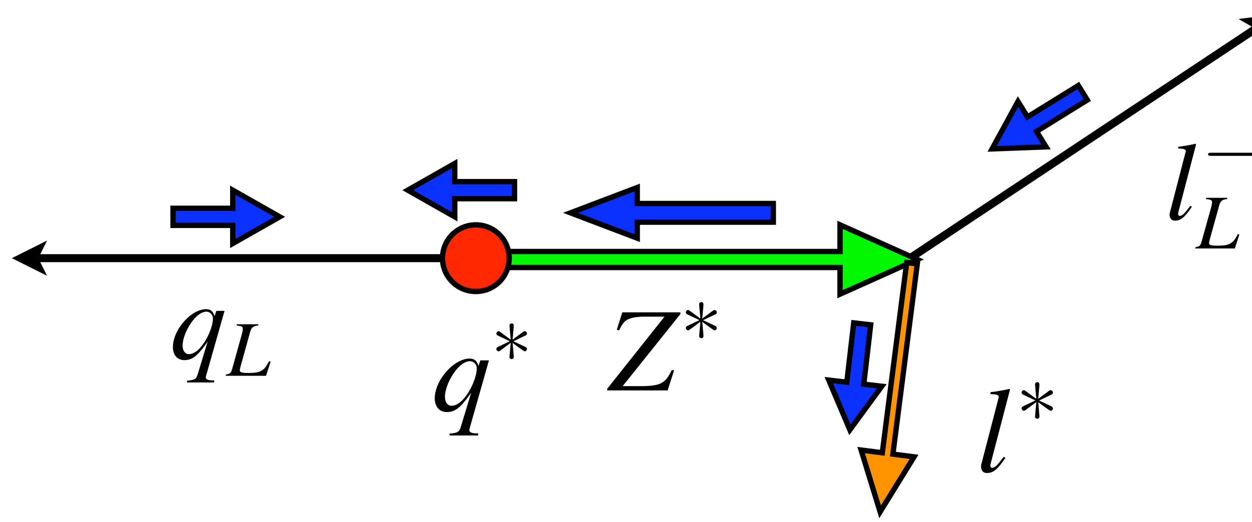
where $x = m_{Z^*}^2/m_{q^*}^2,\ y = m_{l^*}^2/m_{Z^*}^2,\ z = m_{\gamma^*}^2/m_{l^*}^2$

Helicity dependence

- Process 1 (SUSY)



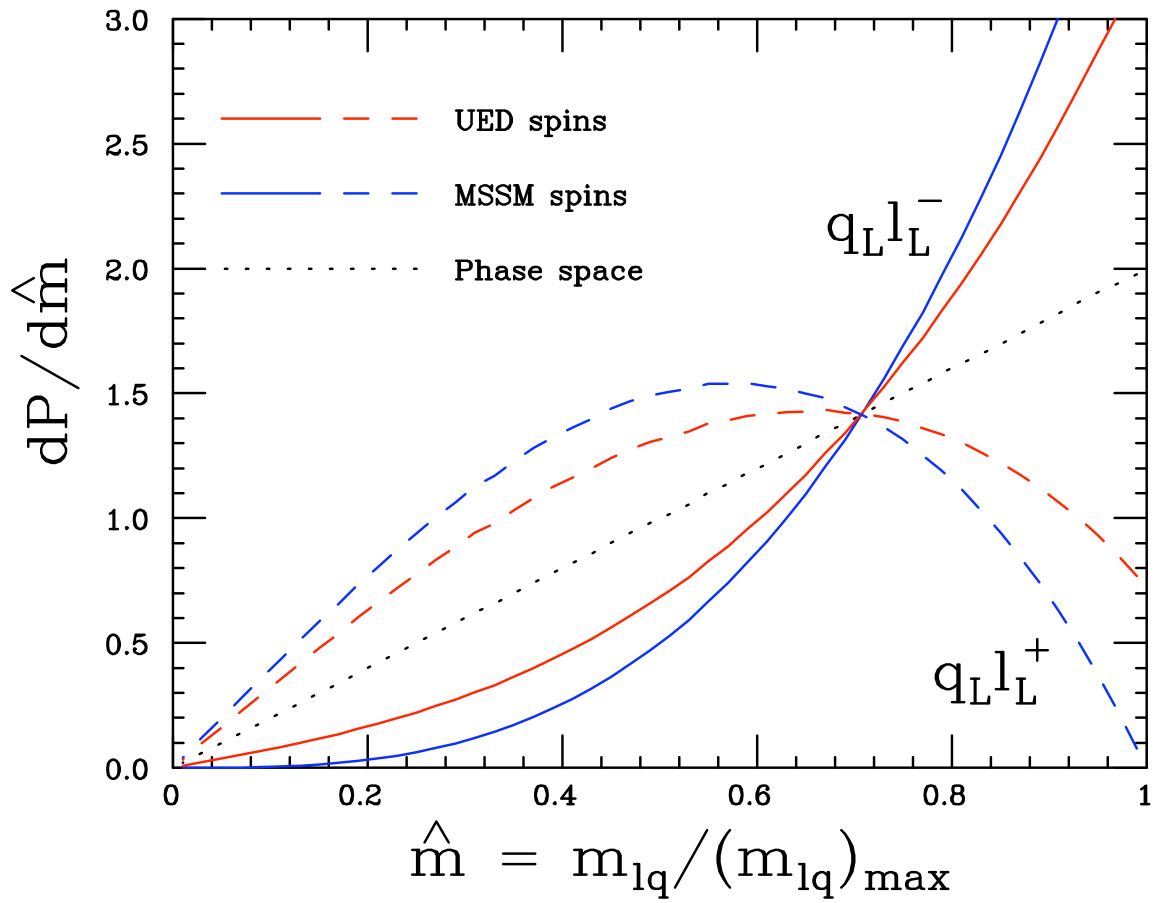
- Process 1 (UED, transverse Z*: $P_T/P_L = 2x$)



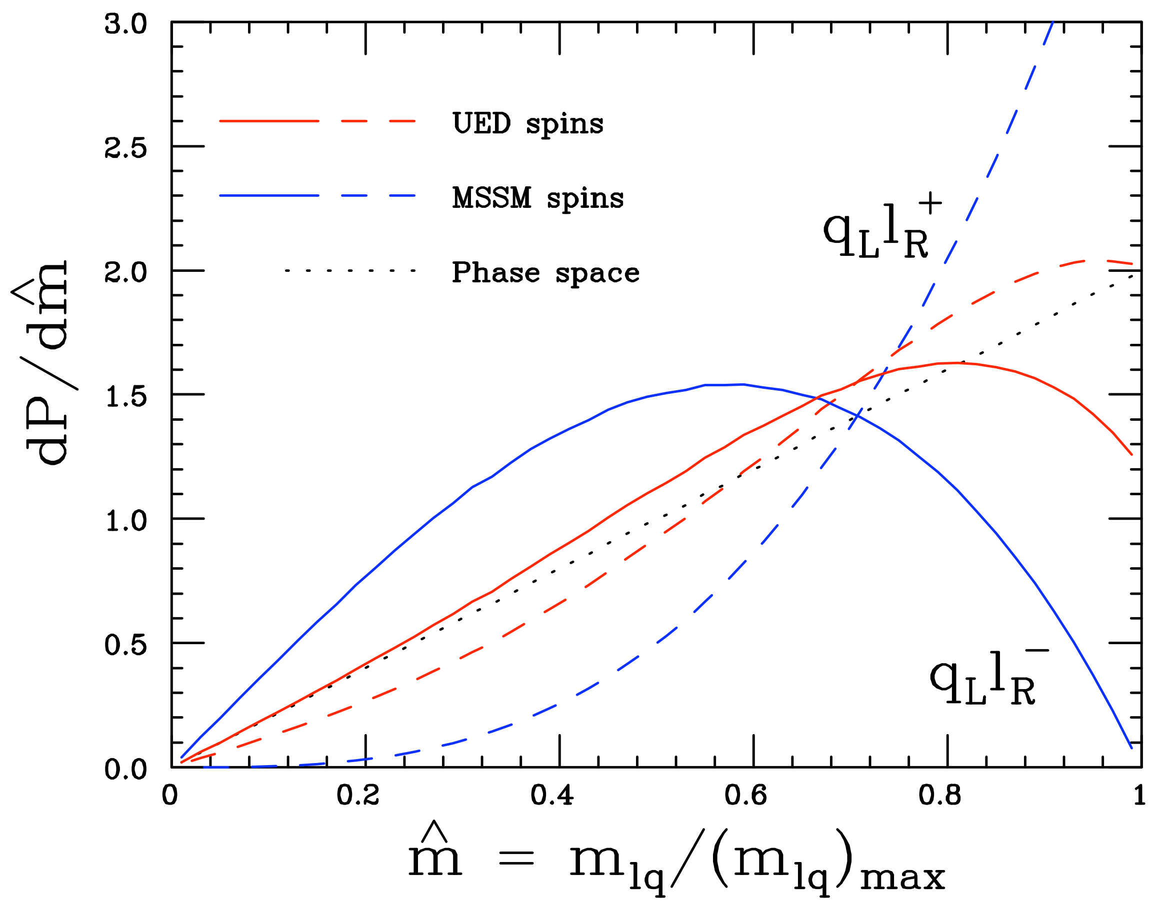
⇒ Both prefer high $(ql^-)^{near}$ invariant mass

ql^{near} mass distribution

UED masses



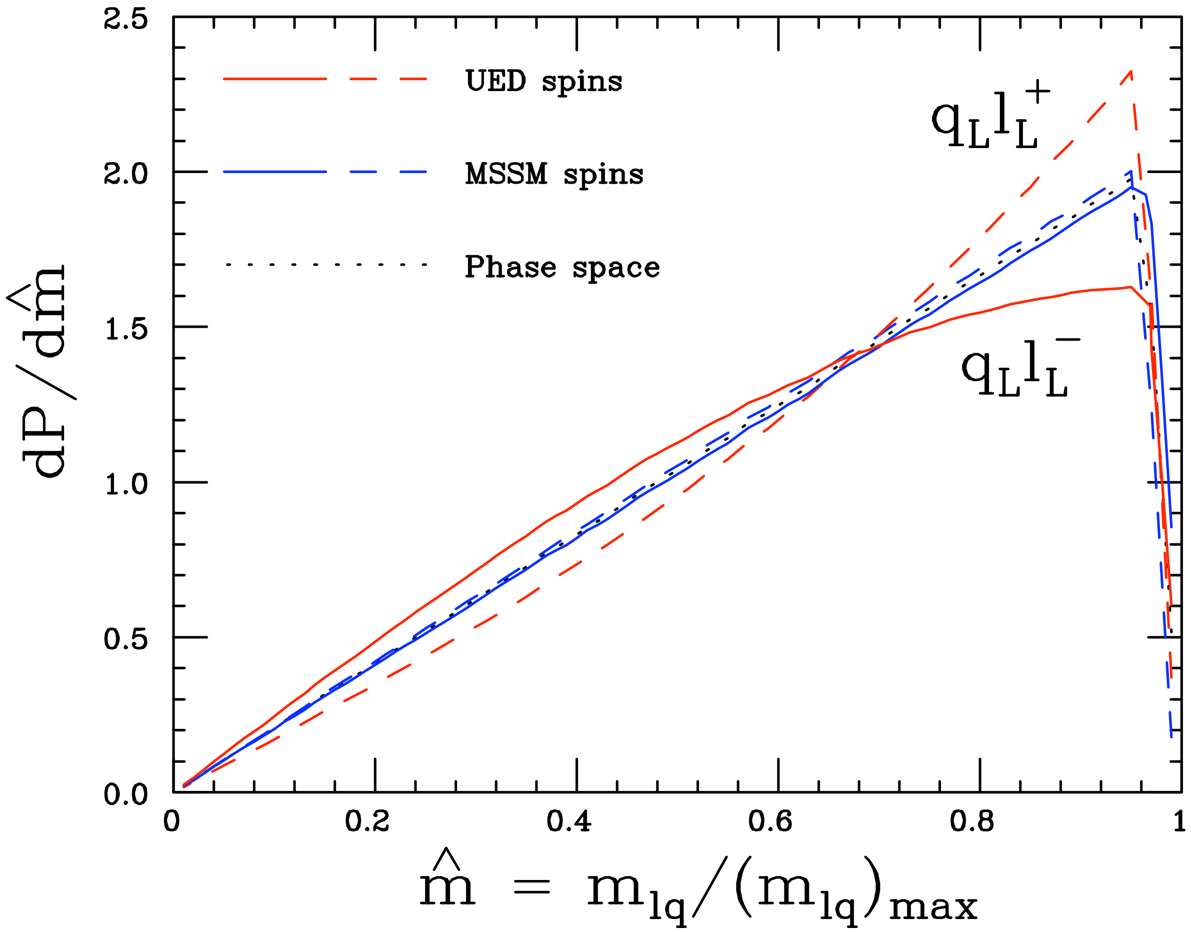
SPS 1a masses



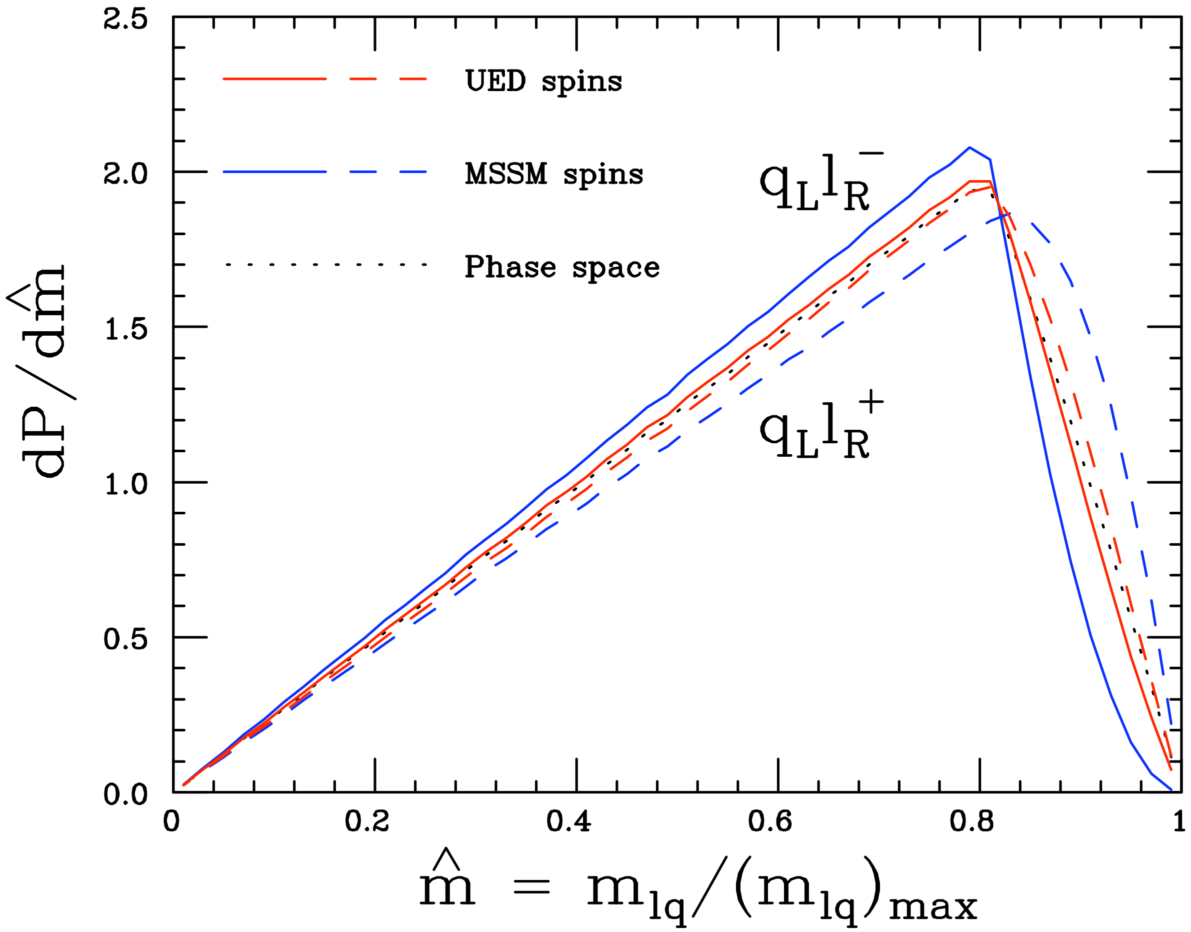
UED and SUSY not distinguishable for UED masses

ql^{far} mass distribution

UED masses

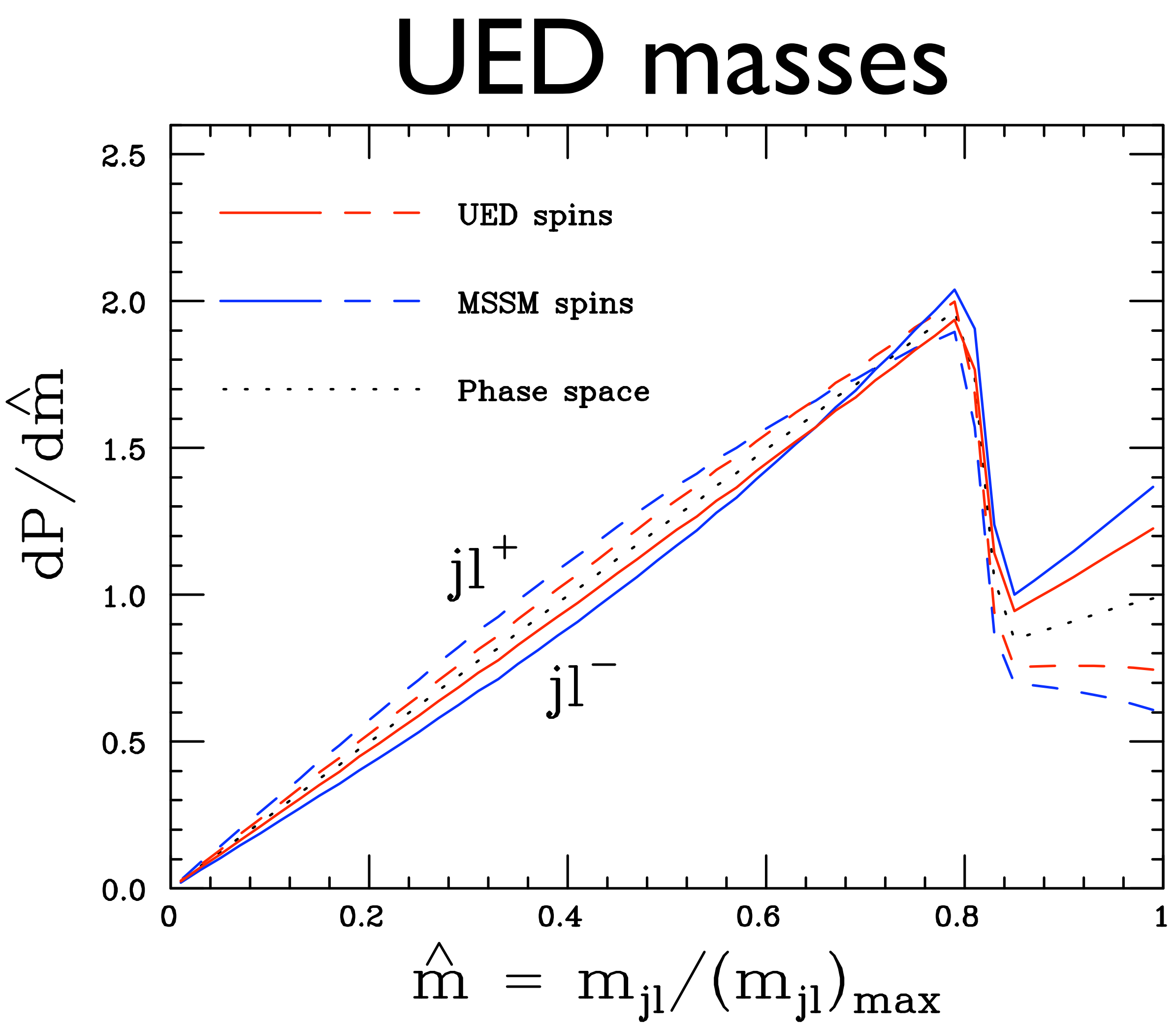


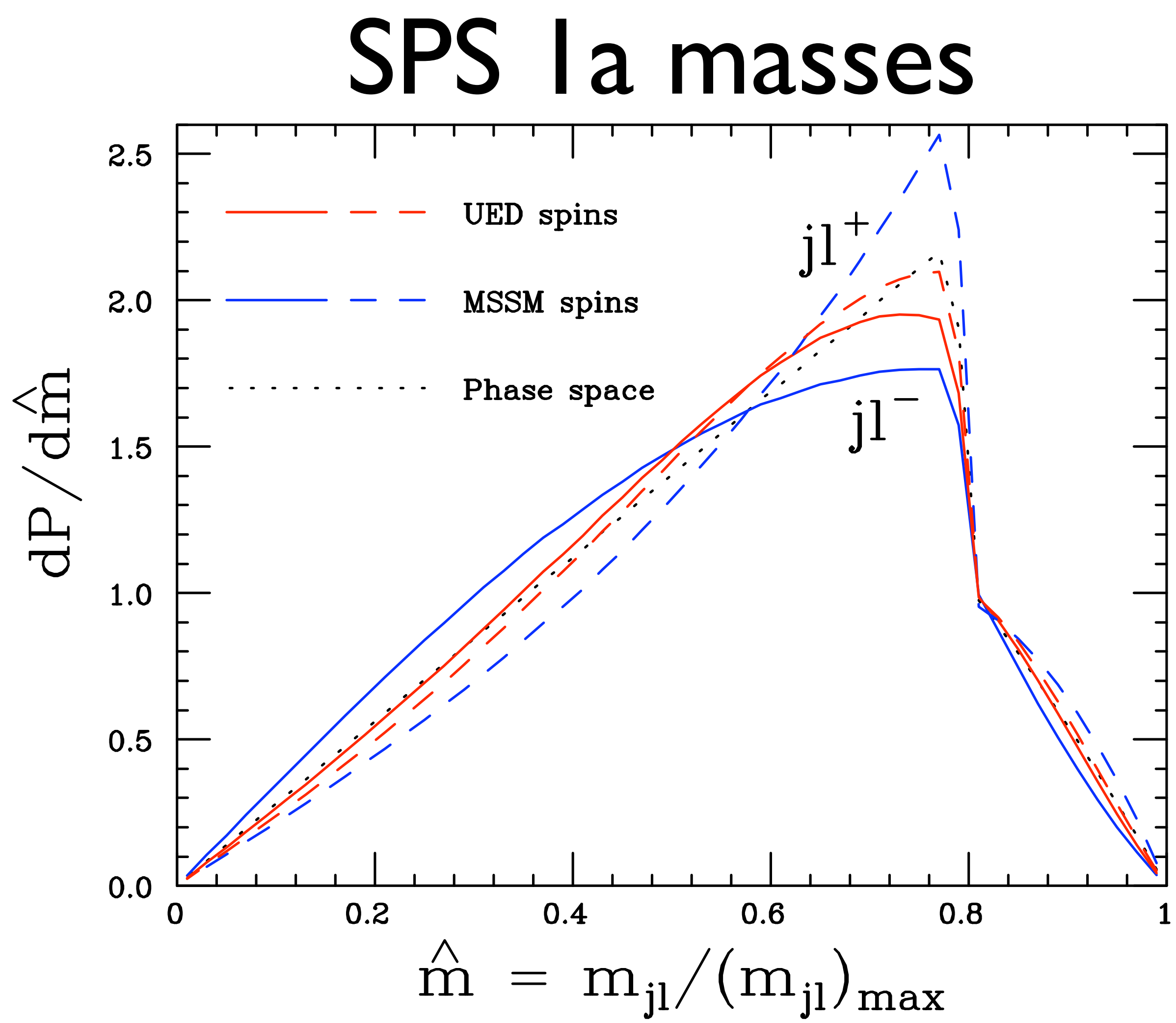
SPS 1a masses



➡ Correlation weak but slightly enhances UED-SUSY difference

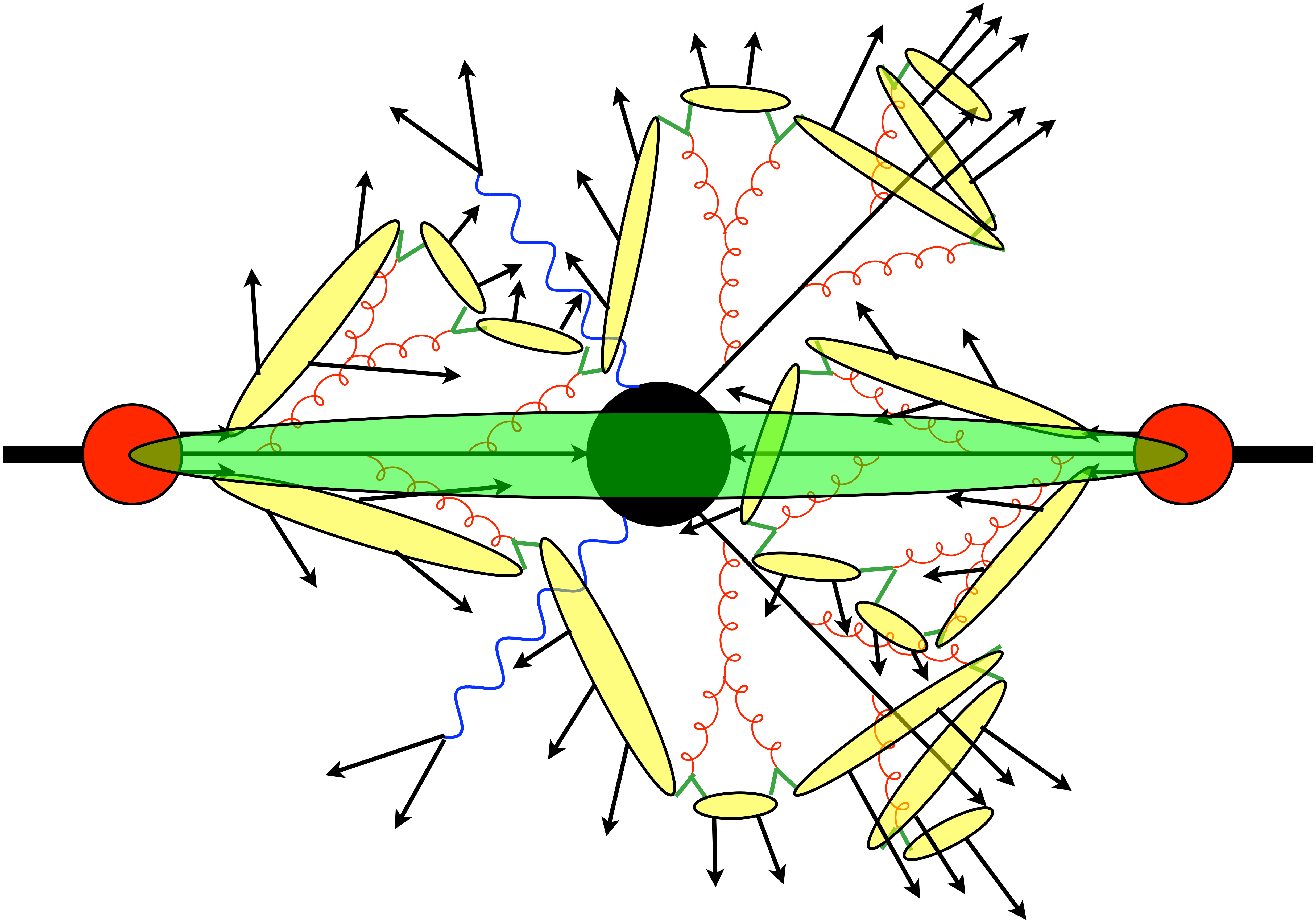
Jet + lepton mass distribution





- Not resolvable for UED masses, maybe for SUSY masses
- Charge asymmetry due to quark vs antiquark excess

LHC Event Simulation



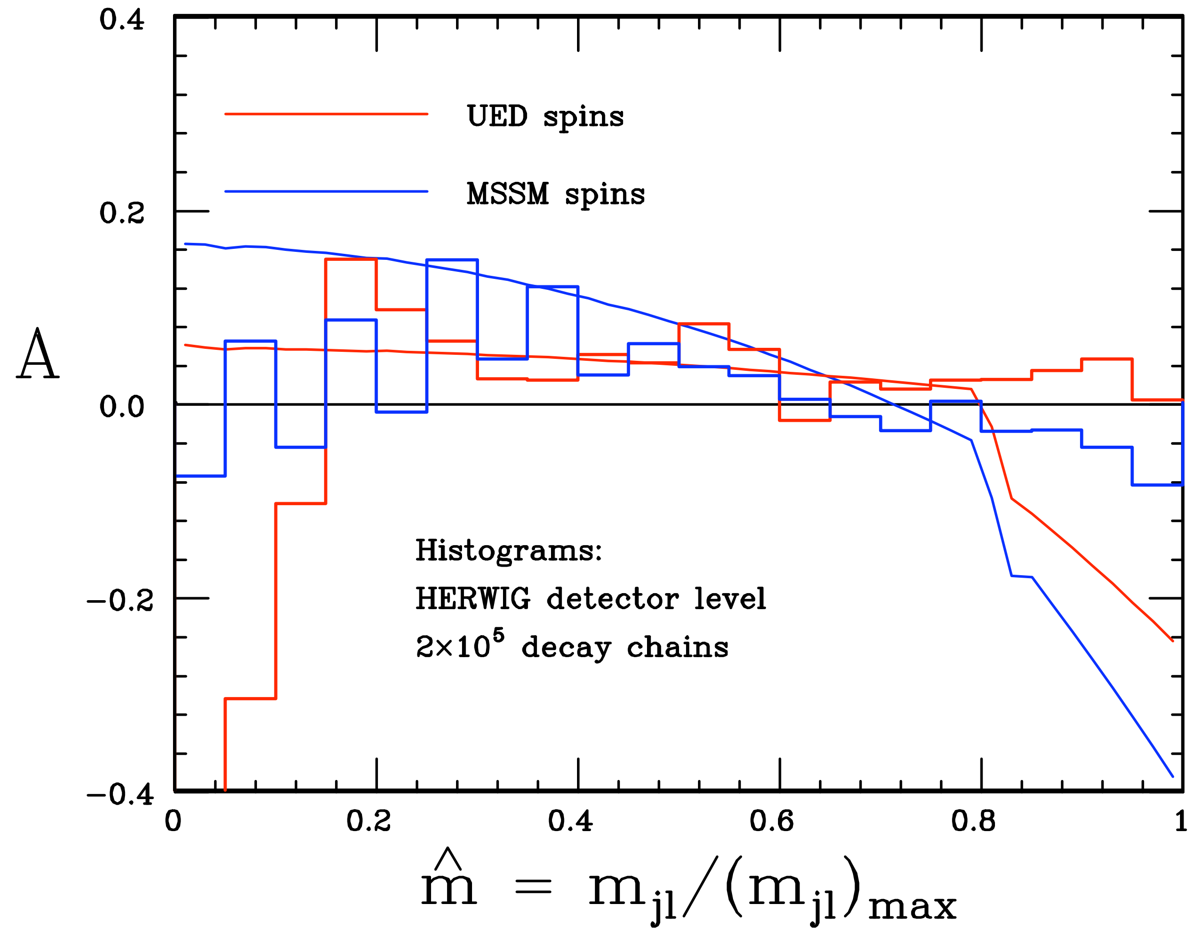
HERWIG Event Generator

- Most important SM & MSSM processes at LO
  - ➜ spin correlations included
  - ➜ parton showers at leading log (LL)
  - ➜ no showering from SUSY particles
- MC@NLO provides some SM processes at NLO
  - ➜ see S Frixione & BW, hep-ph/0506182 & refs therein
- UED model put in ‘by hand’ at present
- Interface to CHARYBDIS black hole generator

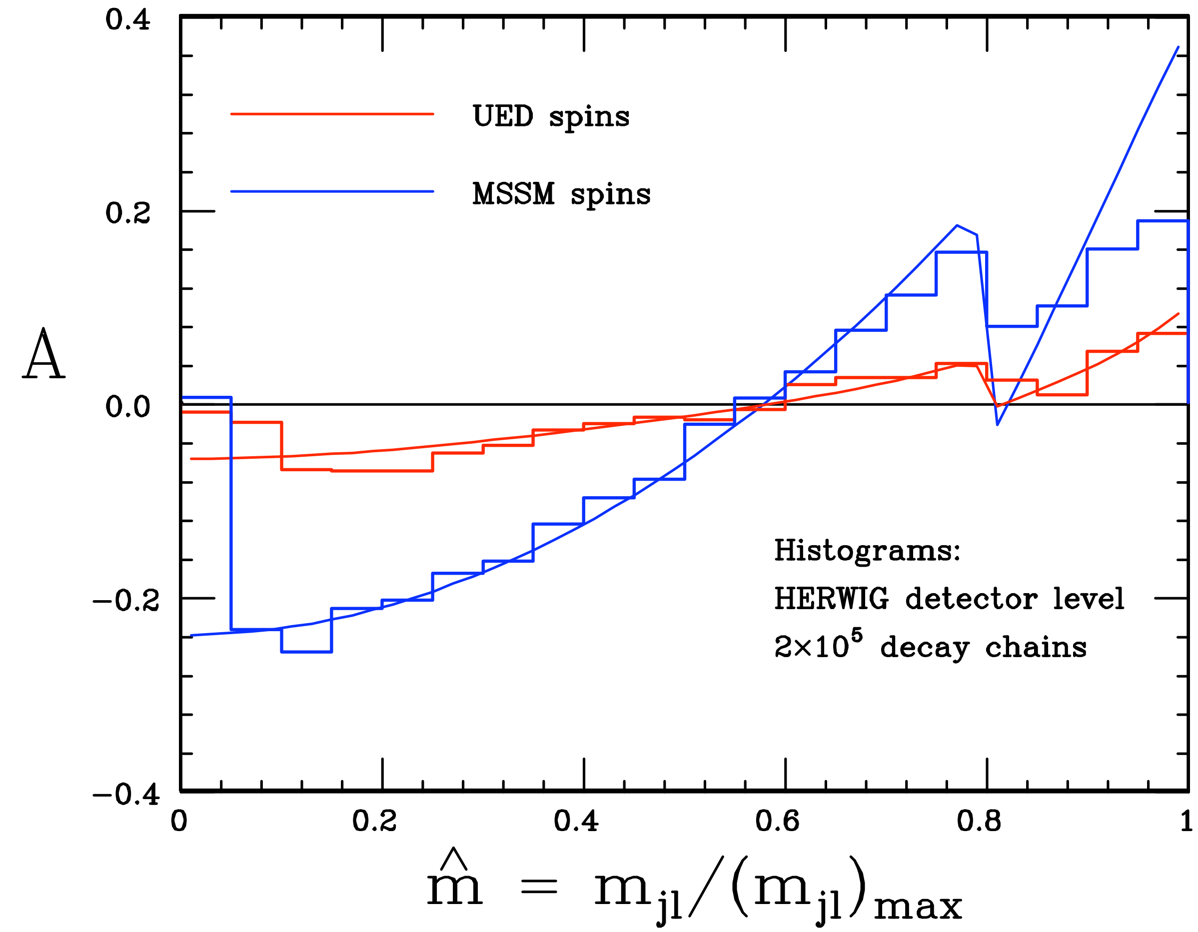
Charge Asymmetry

$$A = \frac{(jl^+) - (jl^-)}{(jl^+) + (jl^-)}$$

UED masses



SPS 1a masses



- Similar form, different magnitude
- Not detectable for UED masses

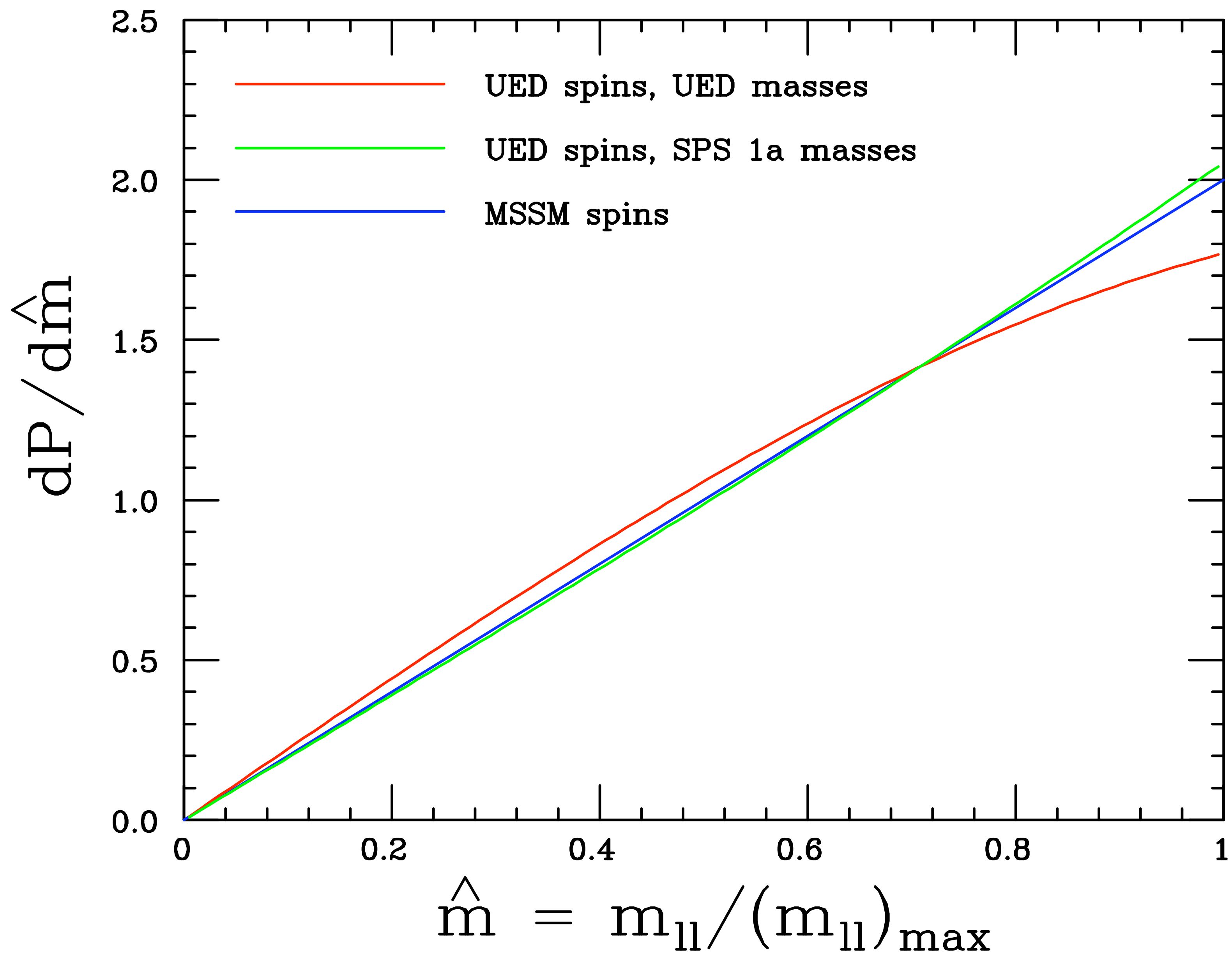
Dilepton mass distribution

$$\frac{dP^{UED}}{d\widehat{m}_{ll}} = \frac{4\widehat{m}_{ll}}{(2+y)(1+2z)}\left[y + 4z + (2-y)(1-2z)\widehat{m}_{ll}^2\right]$$

- $y = m_{l^*}^2 / m_{Z^*}^2$ and $z = m_{\gamma^*}^2 / m_{l^*}^2$
- UED: $y = 0.92 \quad z = 0.95$
- SPS 1a: $y = 0.65 \quad z = 0.45$

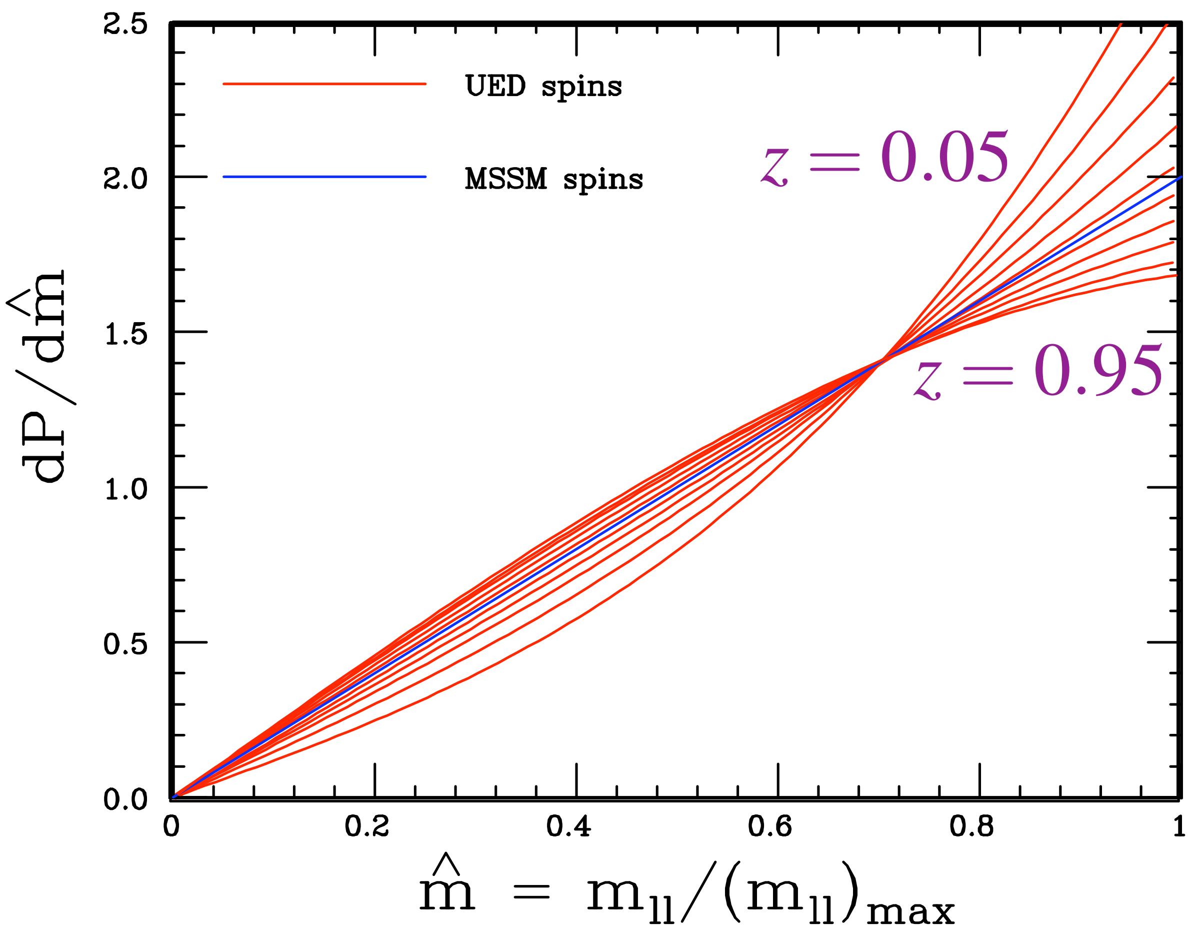
➡ Sensitivity greatest at small y and z

Dilepton mass distribution (2)



➡ No sensitivity for these masses!

Dilepton mass distribution (3)



$$y = m_{l^*}^2/m_{Z^*}^2 = 0.65, \; z = m_{\gamma^*}^2/m_{l^*}^2 = 0.95 - 0.05$$

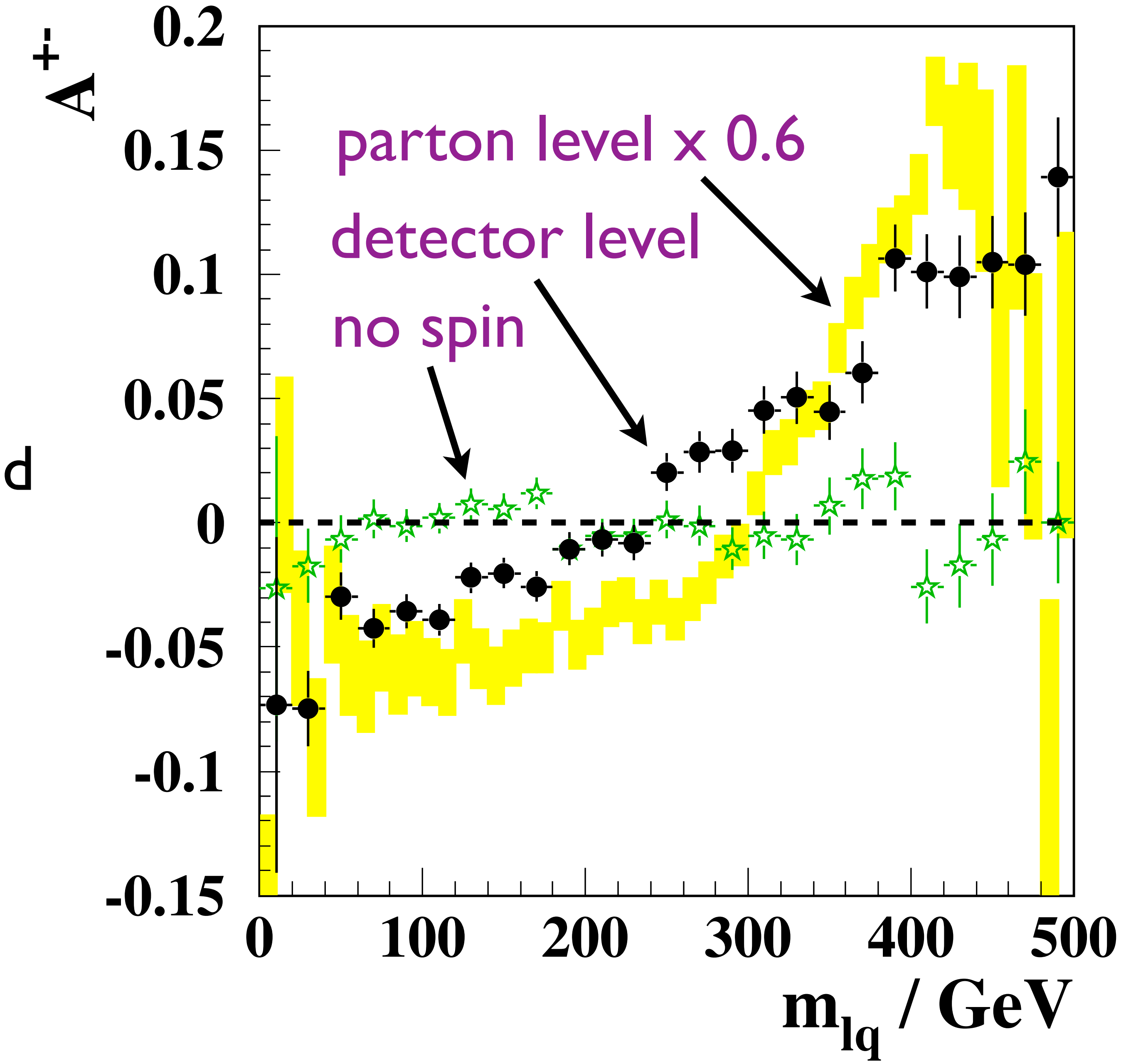
➡ Independent of masses and spins at $\widehat{m} = 1/\sqrt{2}$ $(\theta = \pi/2)$

Barr's spin analyses (1)

- hep-ph/0405052 = Phys Lett B596(2004)205 considers same decay chain

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q_L \rightarrow \tilde{l}_R^{\pm} l^{\mp} q_L$$

- Different MSSM point
- Compares with no spin (phase space) only
- More careful study of background and detector effects
- Points are for 500 fb^{-1}

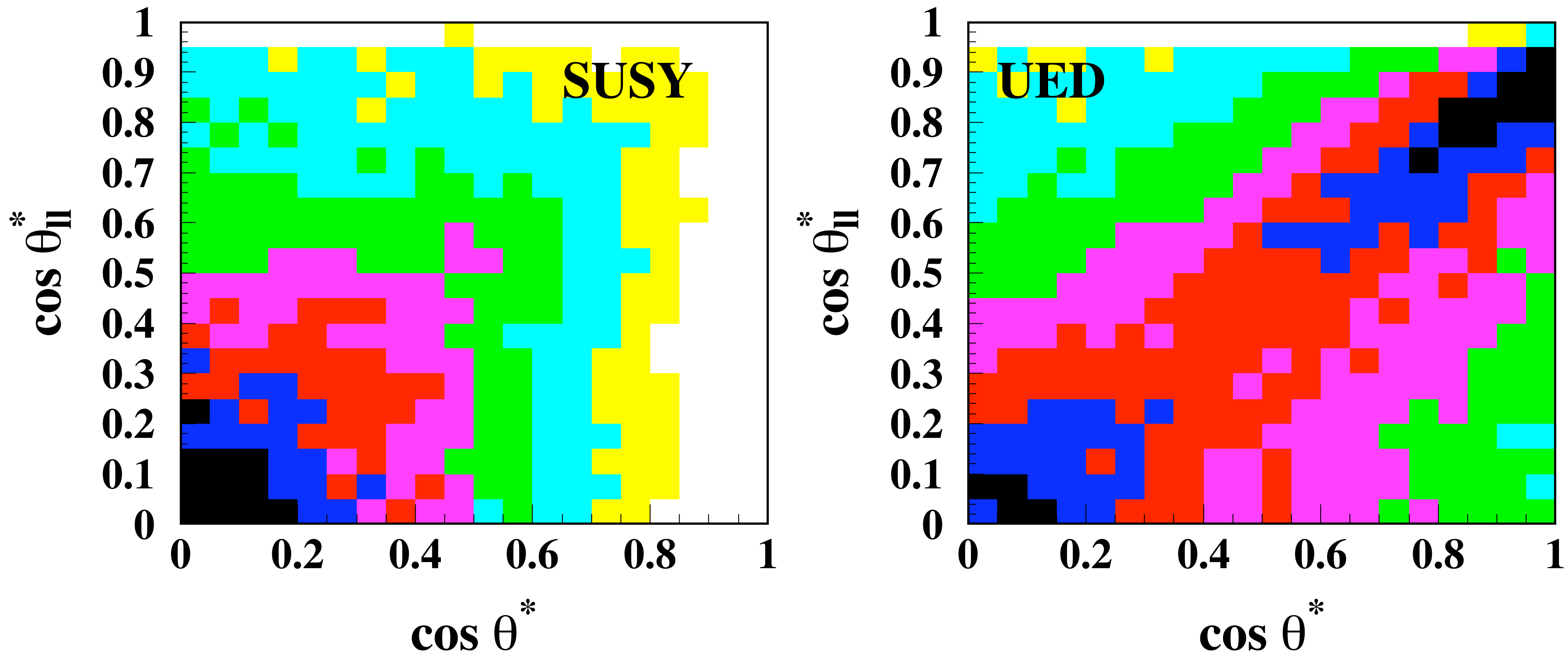


Barr's spin analyses (2)

- hep-ph/0511115 considers slepton pair production

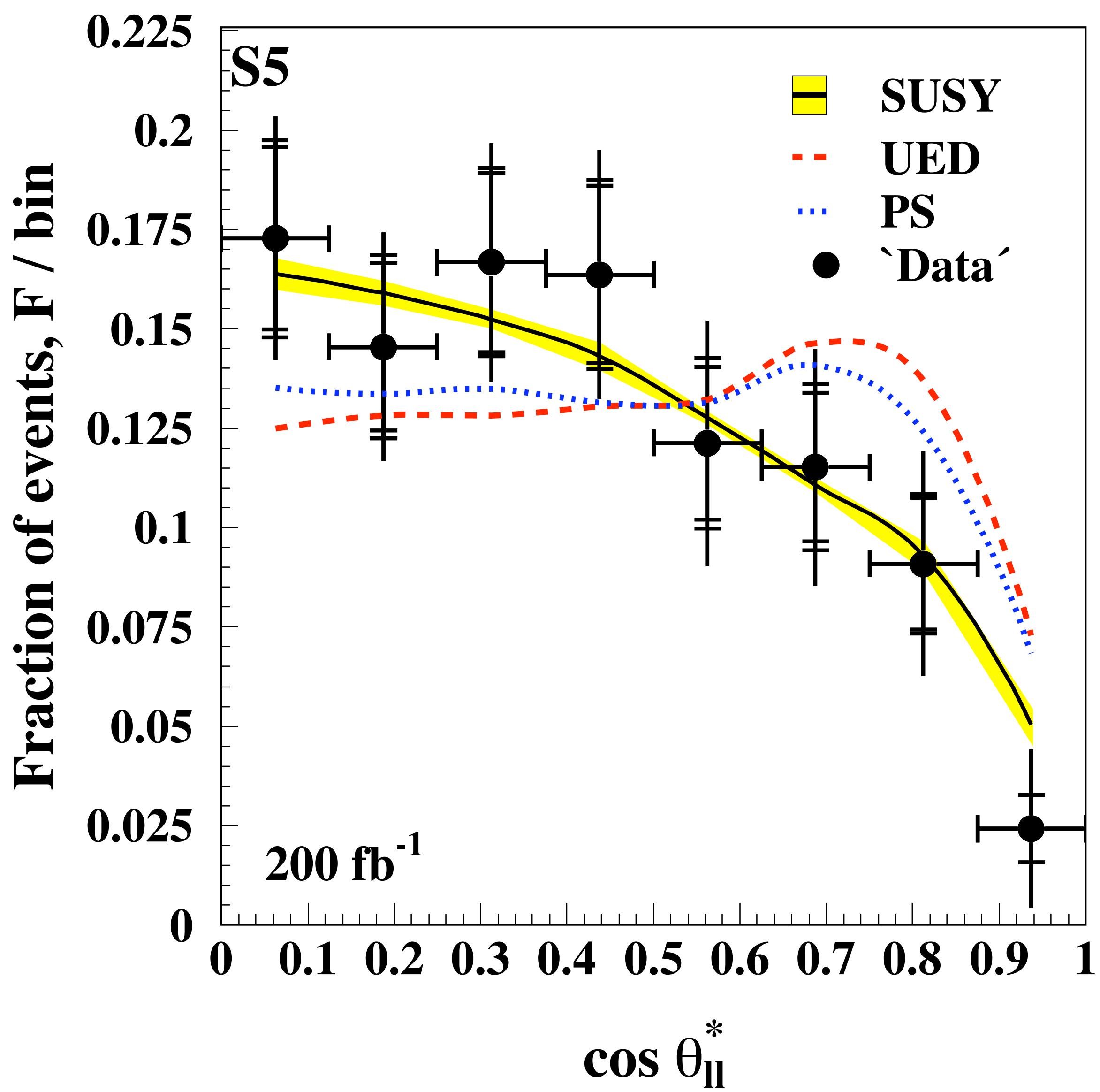
$$q\bar{q} \to Z^0/\gamma \to \tilde{\ell}^+\tilde{\ell}^- \to \tilde{\chi}_1^0\ell^+\ \tilde{\chi}_1^0\ell^-$$

- Distribution of $\cos\theta^*_{ll} \equiv \tanh(\Delta\eta_{\ell^+\ell^-}/2)$ is well correlated with Z^0/γ decay angle θ^*



(neglects KKlepton polarisation)

Barr’s spin analyses (3)



- Outer error bars: after SUSY & SM background subtraction

Conclusions

- Distinguishing SUSY from UED at LHC will be difficult
  - jet+lepton charge asymmetry similar in shape
  - dilepton distributions clean but not very sensitive
- If masses favour UED, spin confirmation very difficult
  - little sensitivity to spins
  - jets typically have low energy
  - other methods may be better (Z_2^*,...)
- If masses favour SUSY, spin sensitivity is better
  - good prospect of excluding UED spins