Discriminating SUSY and UED at LHC

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Motivation and outline

- What is the difference between SUSY and UED ?

	SUSY	UED
Spin of new particles	$\pm\frac{1}{2}$	same
Couplings of new particles	same as SM	same^* as SM
Masses	SUSY breaking ?	boundary terms ?
How many new particles	1^{**}	KK tower
Generic signature***	$\not{E}_T$	$\not{E}_T$

- Discriminating method :
  - Finding KK tower
  - Spin measurements

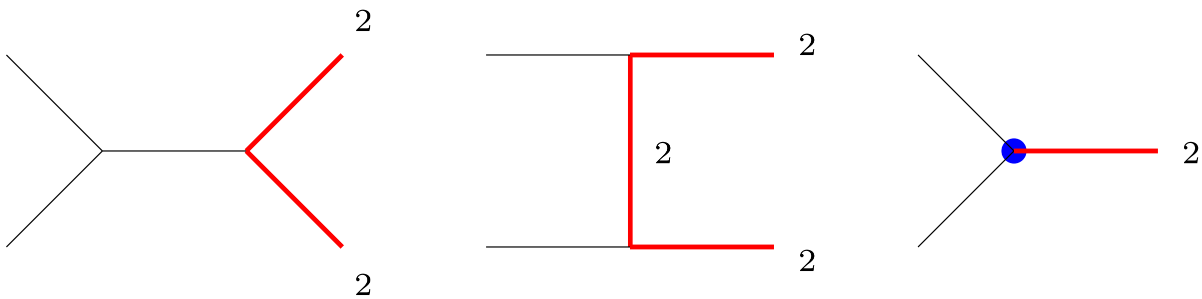
* Couplings among some KK particles may have factors of $\sqrt{2}$, $\sqrt{3}$, $\cdots$

** $N = 1$ SUSY

*** with dark matter candidates

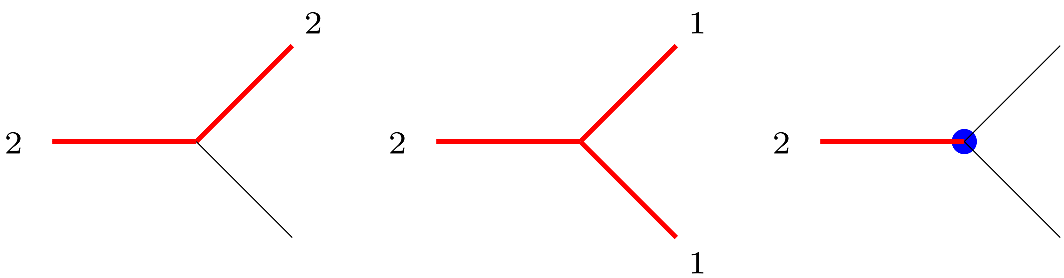
Looking for level 2 KK partners

- $n = 1$ is like MSSM and can be discovered
  (Cheng, Matchev, Schmaltz, hep-ph/0205314)
- Look for $n = 2$
- Production



(a) (b) (c)

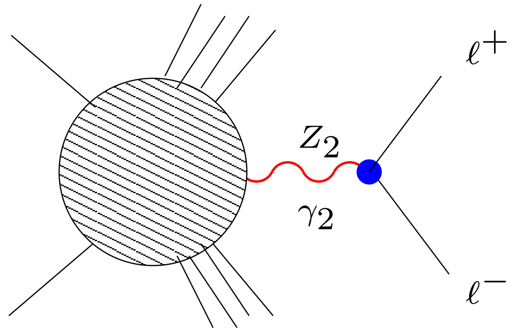
  - a, b : kinematically suppressed
  - c : suppressed couplings
  - only V_2 have KK number violating couplings to SM
  - Q_2 and L_2 : either forbidden or higher dimensional operator
- Decay



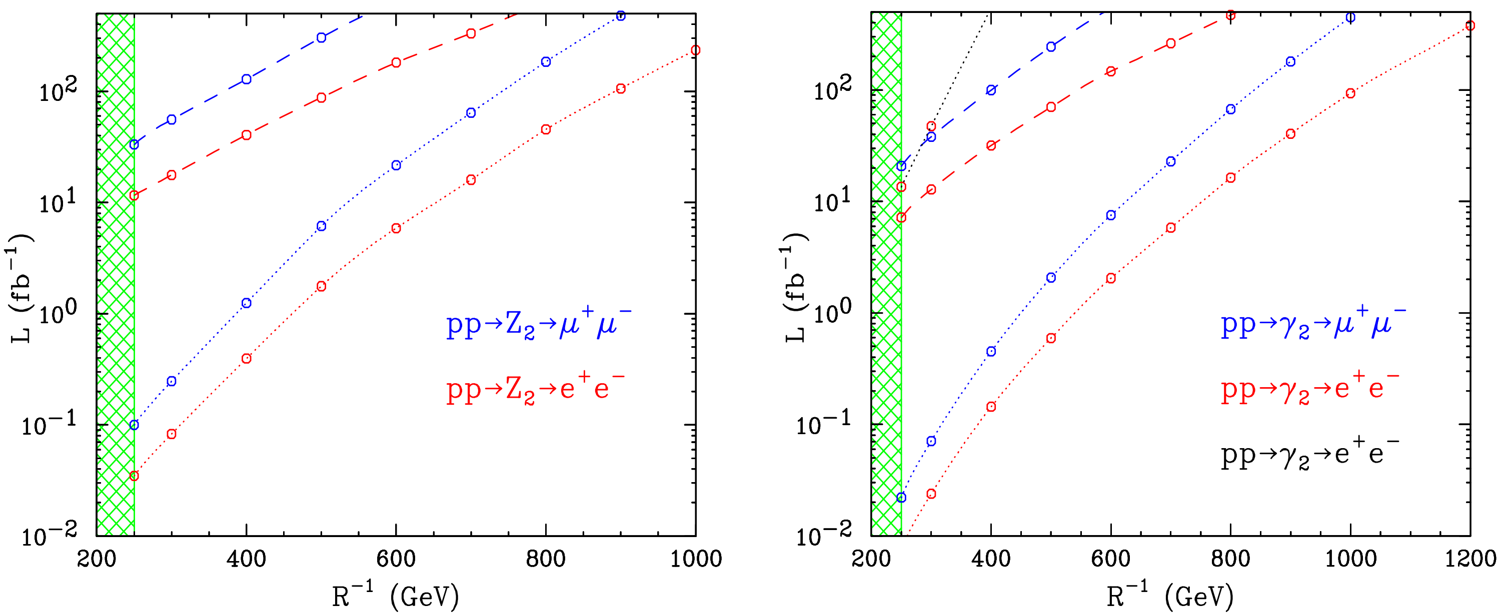
(a) (b) (c)

  - a : SM particle is soft
  - b is like direct $n = 1$ production
  - c is the best : resonances

Discovery reach for MUEDS at LHC in inclusive dilepton channel



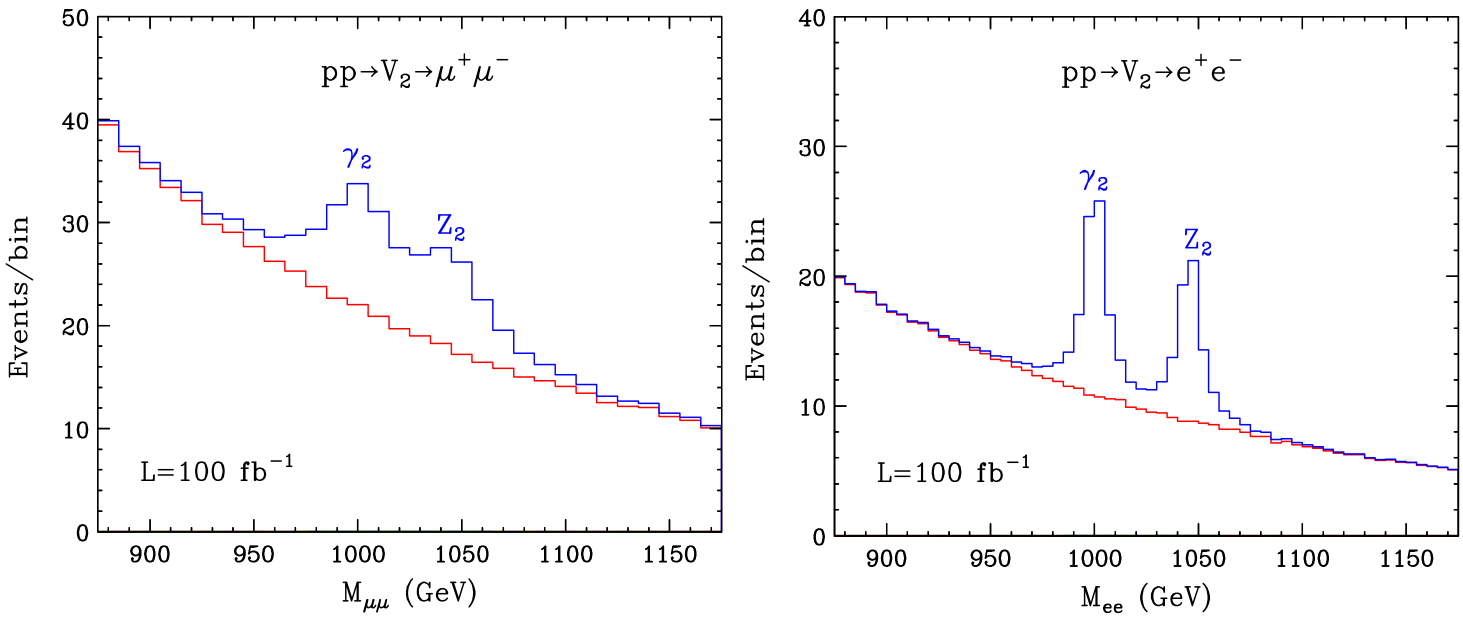
(Datta, Kong, Matchev, hep-ph/0509246)



- $|p_t| > 20$ GeV, $|\eta| < 2.4$
- $|M_{\ell^+\ell^-} - M_{V_2}| < 2\Delta M_{\ell^+\ell^-}$
- $\Delta M_{\ell^+\ell^-} = \sqrt{(\Gamma(V_2 \to \ell^+\ell^-))^2 + (\delta m)^2} \approx \delta m$
- δm = mass resolution
  - $\delta m = 0.01 M_{V_2}$ for e^+e^-
  - $\delta m = 0.0215 M_{V_2} + 0.0128 \left(\frac{M_{V_2}^2}{1TeV}\right)$ for $\mu^+\mu^-$
- Background with Pythia

How many resonances

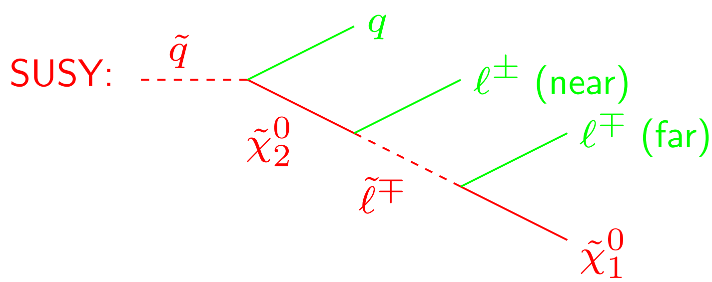
(Datta, Kong, Matchev, hep-ph/0509246)



- Narrow peaks are smeared due to the mass resolution
- Two resonances can be better resolved in e^+e^- channel
- Is this a proof of UED ?
  - Not quite : resonances could still be interpreted as Z's
  - Smoking guns :
    - Their close degeneracy
    - $M_{V_2} \approx 2M_{V_1}$
    - Mass measurement of $W_2^{\pm}$ KK mode
- However in nonminimal UED models, degenerate spectrum is not required
  $\longrightarrow$ just like SUSY with a bunch of Z's
  $\longrightarrow$ need spins to discriminate

Spin measurement

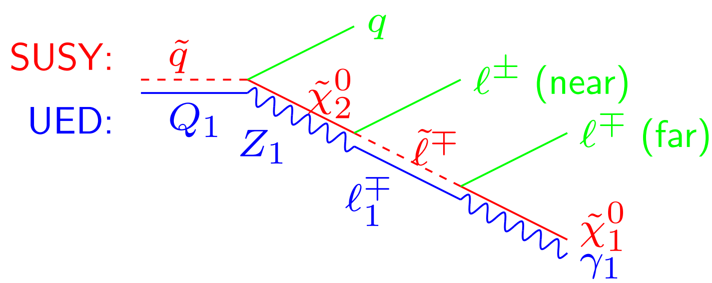
- To prove SUSY, must measure spins but it's difficult
  - LSP is neutral $\longrightarrow$ missing energy
  - There are two LSPs $\Rightarrow$ cannot find CM frame
  - Decay chains are complicated $\longrightarrow$ cannot uniquely identify subchains
  - Look for something easy : look for 2 SFOS leptons
    $\tilde{\chi}_2^0 \longrightarrow \tilde{\ell}^{\pm}\ell^{\mp} \longrightarrow \ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0$
    (subtract 2OFOS leptons (see Craig's talk))
  - Dominant source of $\tilde{\chi}_2^0$: squark decay
    $\tilde{q} \longrightarrow q\tilde{\chi}_2^0 \longrightarrow q\tilde{\ell}^{\pm}\ell^{\mp} \longrightarrow q\ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0$:



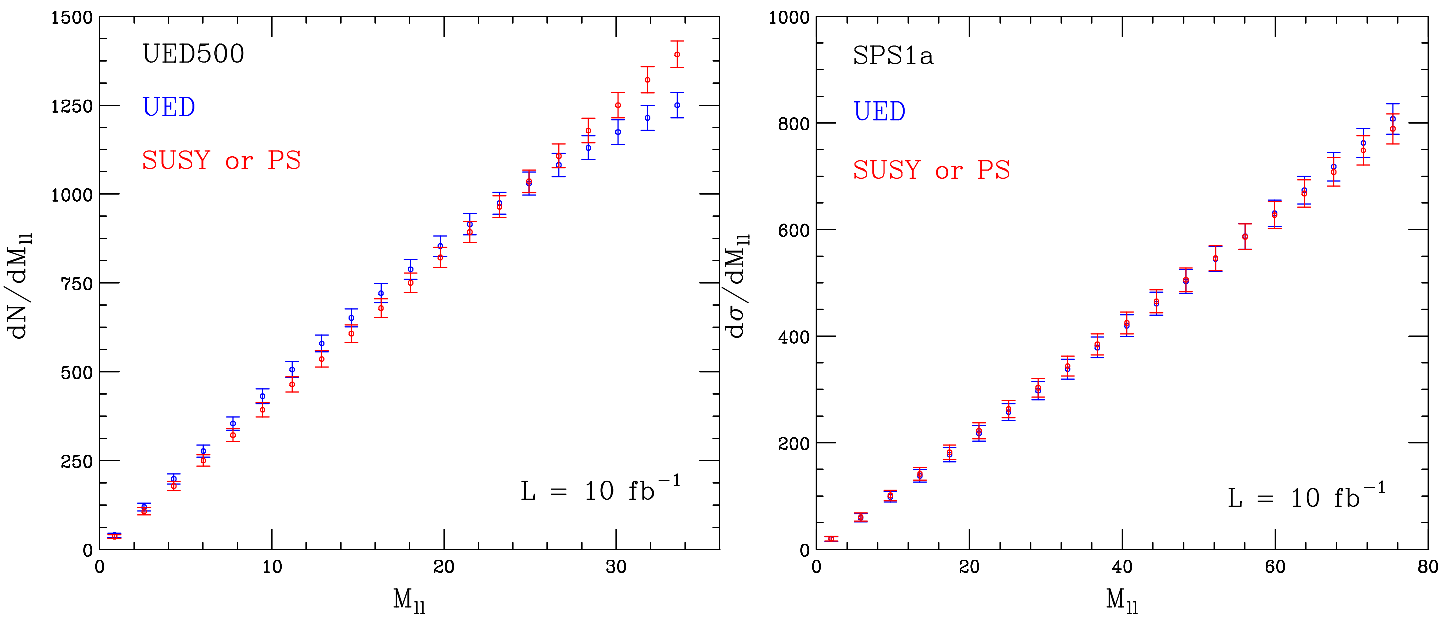
- Study this chain
  - Observable objects : q and $\ell^{\pm}$

Dilepton distribution

- Look for spin correlations in $M_{\ell^+\ell^-}$
- Choose a study point in one model and fake mass spectrum in the other model



(Kong, Matchev Preliminary and Smillie, Webber hep-ph/0507170)



- Why are they the same ?

Dilepton distribution

- How do we fake the two ?

(Smillie, Webber hep-ph/0507170)

$$\text{Phase Space} : \frac{dN}{d\hat{m}} = 2\hat{m}$$

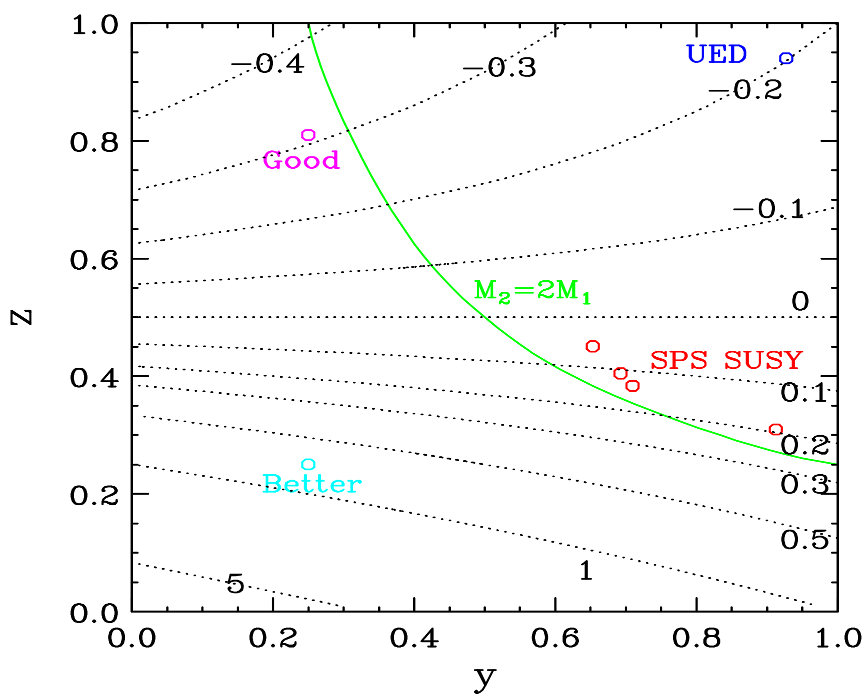
$$\text{SUSY} : \frac{dN}{d\hat{m}} = 2\hat{m}$$

$$\text{UED} : \frac{dN}{d\hat{m}} = \frac{4(y+4z)}{(1+2z)(2+y)}\left(\hat{m} + r\,\hat{m}^3\right)$$

$$r = \frac{(2-y)(1-2z)}{y+4z}$$

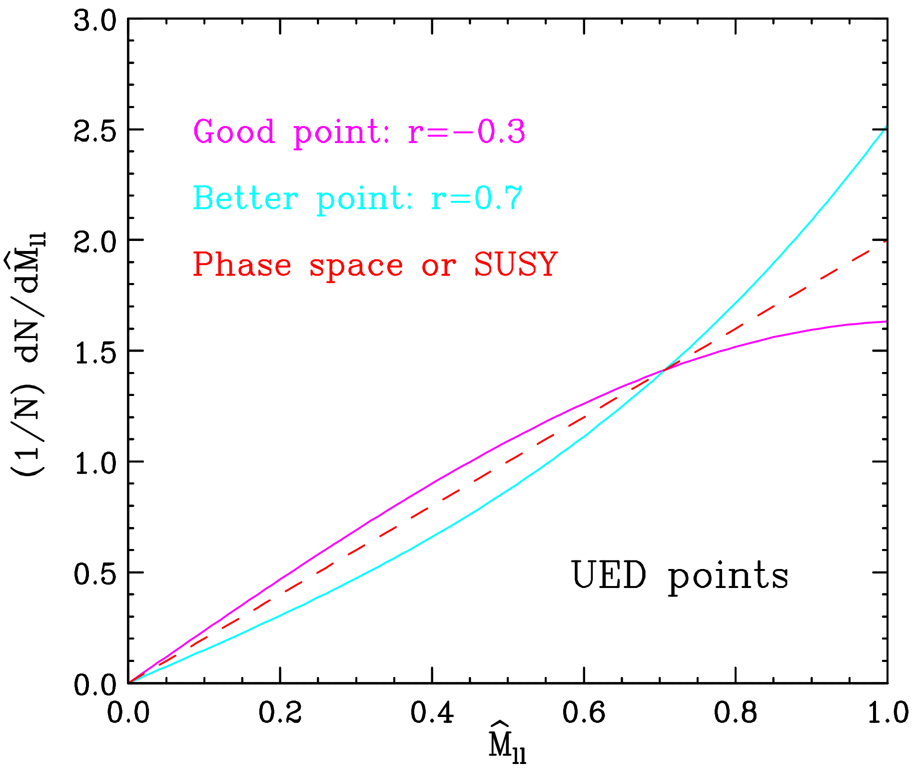
where $\hat{m} = \frac{m_{\ell\ell}}{m_{\ell\ell}^{max}}$, $y = \left(\frac{m_{\tilde{\ell}}}{m_{\tilde{\chi}_2^0}}\right)^2$ and $z = \left(\frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{\ell}}}\right)^2$

(Kong, Matchev Preliminary)



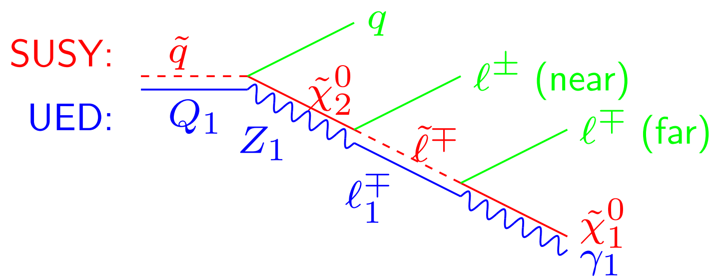
Dilepton distribution

(Kong, Matchev Preliminary)



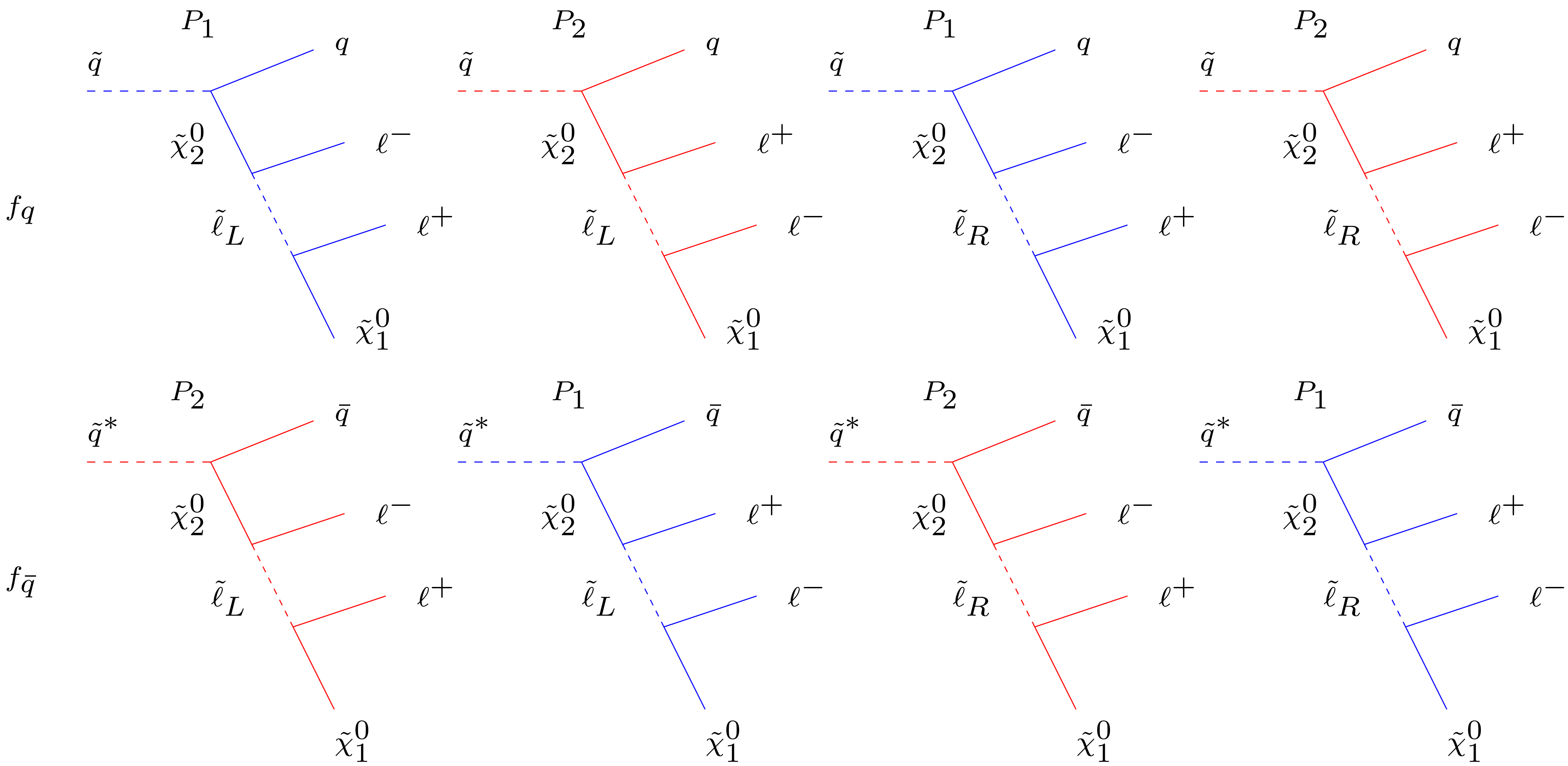
- Good point : $m_{\tilde{\chi}_1^0} : m_{\tilde{\ell}} : m_{\tilde{\chi}_2^0} = 9 : 10 : 20$
- Better point : $m_{\tilde{\chi}_1^0} : m_{\tilde{\ell}} : m_{\tilde{\chi}_2^0} = 1 : 2 : 4$
- If r is big (not in mSUGRA or MUED), can distinguish

Spin measurement : Barr method



- Look at correlation between q and ℓ (Barr, hep-ph/0405052)
- Complications:
  - Which (quark) jet is the right one ?
    (Webber, hep-ph/0507170 "cheated", picked the right one)
    One never knows for sure. There can be clever cuts to increase the probability that we picked right one
    (work in progress)
  - Which lepton ? : "near" and "far" cannot be distinguished
    $\longrightarrow$ must add both contributions. Improvement on selection
    (work in progress)
  - Don't know q or $\bar{q}$
- Can distinguish charges of leptons : look at $q\ell^+$ and $q\ell^-$ separately and compare

Barr method

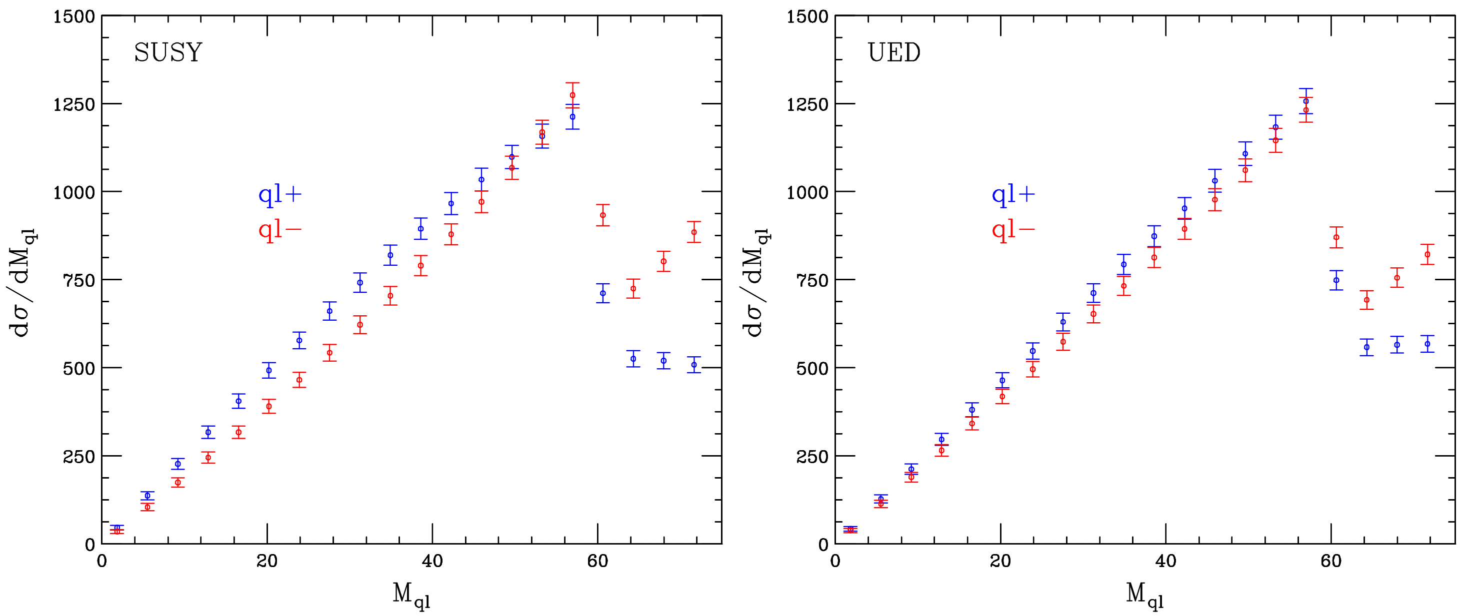


- $f_q + f_{\bar{q}} = 1$

Barr method

(Datta, Kong, Matchev, hep-ph/0509246 and Smillie, Webber, hep-ph/0507170)

- Choose a study point : UED500 ($\mathcal{L} = 10 fb^{-1}$)



- Each $M_{q\ell}$ distribution contains 4 contributions

$$\left(\frac{d\sigma}{dm}\right)_{q\ell+} = f_q\left(\frac{dP_2}{dm^n}+\frac{dP_1}{dm^f}\right)+f_{\bar{q}}\left(\frac{dP_1}{dm^n}+\frac{dP_2}{dm^f}\right)$$

$$\left(\frac{d\sigma}{dm}\right)_{q\ell-} = f_q\left(\frac{dP_1}{dm^n}+\frac{dP_2}{dm^f}\right)+f_{\bar{q}}\left(\frac{dP_2}{dm^n}+\frac{dP_1}{dm^f}\right)$$

- Asymmetry:

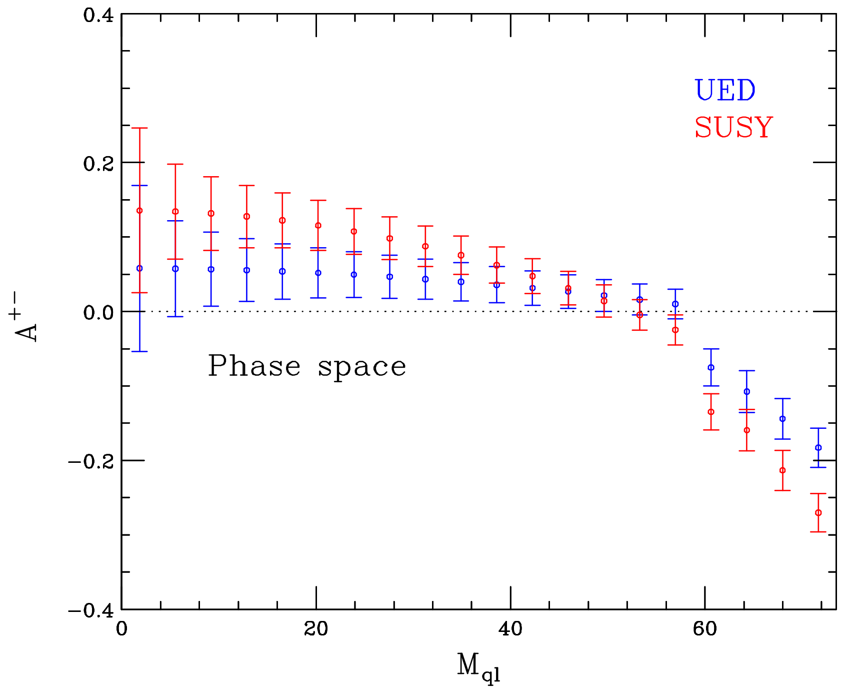
$$A^{+-} = \frac{\left(\frac{d\sigma}{dm}\right)_{q\ell+} - \left(\frac{d\sigma}{dm}\right)_{q\ell-}}{\left(\frac{d\sigma}{dm}\right)_{q\ell+} + \left(\frac{d\sigma}{dm}\right)_{q\ell-}}$$

- $f_q + f_{\bar{q}} = 1$
- If $f_q = f_{\bar{q}} = 0.5$, $A^{+-} = 0$ (for example, in the "focus point" region)

Asymmetry : UED500

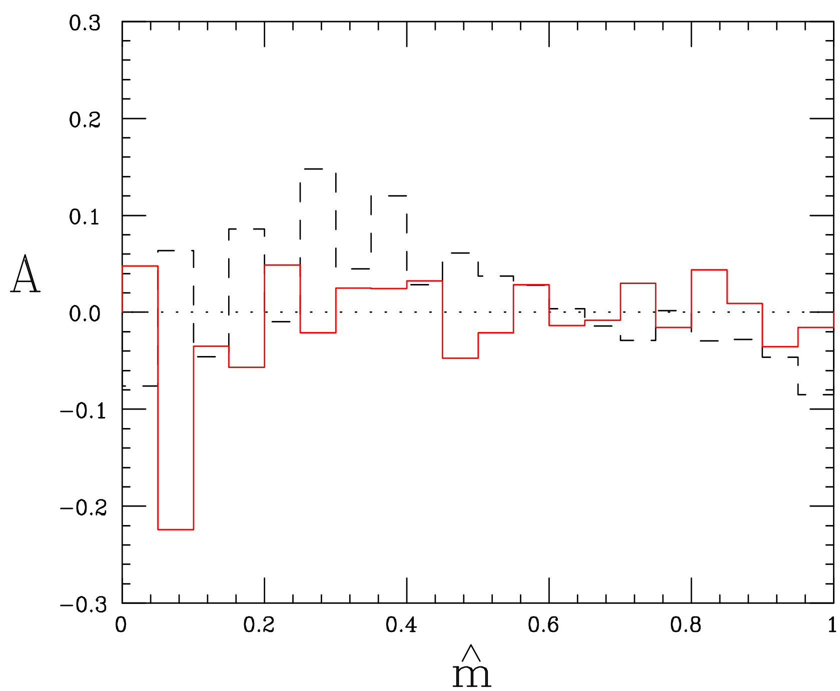
- Asymmetry with UED500 mass spectrum ($\mathcal{L} = 10\text{fb}^{-1}$)

(Datta, Kong, Matchev, hep-ph/0509246)



- "Detector level" charge asymmetry ($\mathcal{L} = 7\text{fb}^{-1}$)

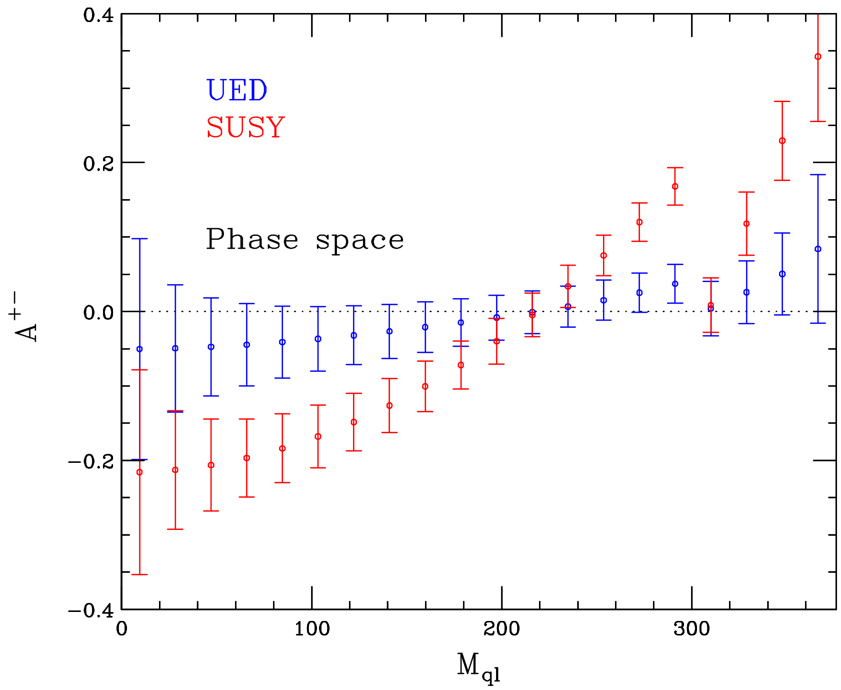
(Smillie, Webber hep-ph/0507170)



Asymmetry : SPS1a

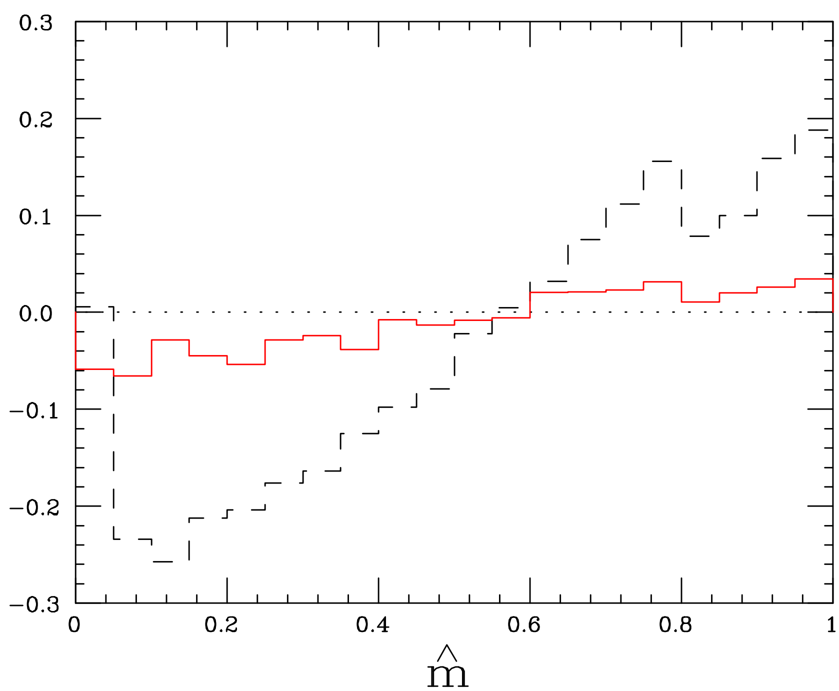
- Asymmetry with SPS1a mass spectrum ($\mathcal{L} = 10\text{fb}^{-1}$)

(Kong, Matchev Preliminary)



- Detector level charge asymmetry ($\mathcal{L} = 131\text{fb}^{-1}$)

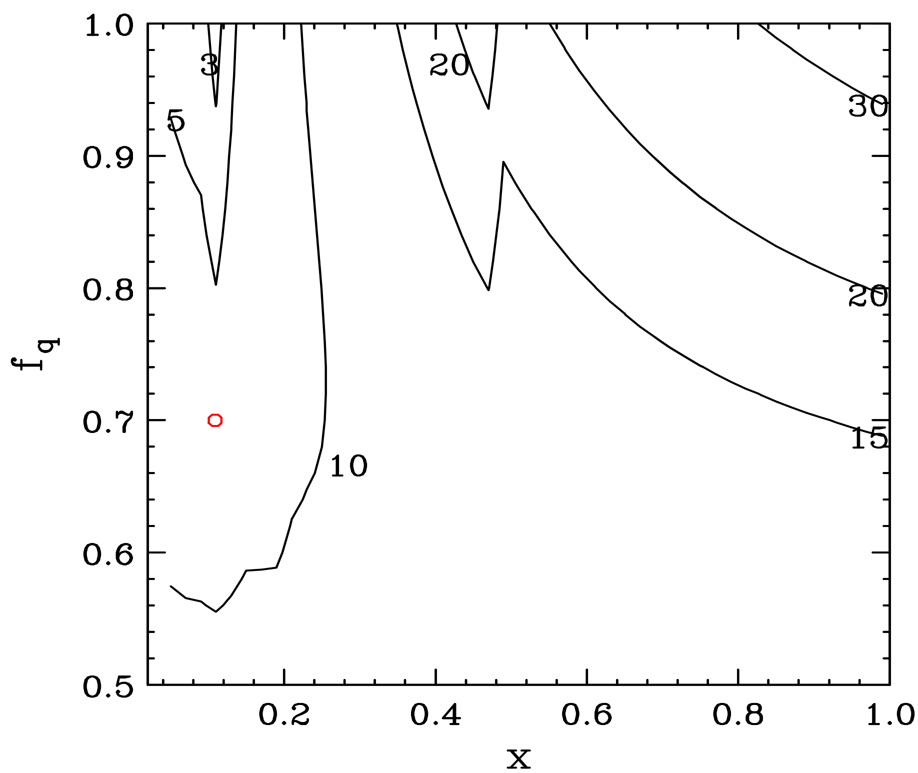
(Smillie, Webber hep-ph/0507170)



SPS1a mSUGRA point

- How to fake SPS1a asymmetry
  - five parameters in asymmetry : f_q, x, y, z, $m_{\tilde{q}}$
    - $x = \left(\frac{m_{\tilde{\chi}_2^0}}{m_{\tilde{q}}}\right)^2$, $y = \left(\frac{m_{\tilde{\ell}}}{m_{\tilde{\chi}_2^0}}\right)^2$ and $z = \left(\frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{\ell}}}\right)^2$
  - three kinematic endpoints : m_{qll}, m_{ql} and m_{ll}
    - $m_{qll} = m_{\tilde{q}}\sqrt{(1-x)(1-yz)}$
    - $m_{ql} = m_{\tilde{q}}\sqrt{(1-x)(1-z)}$
    - $m_{ll} = m_{\tilde{q}}\sqrt{x(1-y)(1-z)}$
  - two parameters left : f_q, x
  - minimize χ^2 in the (x, f_q) parameter space
  - minimum χ^2 when UED and SUSY masses are the same and $f_q \approx 1$

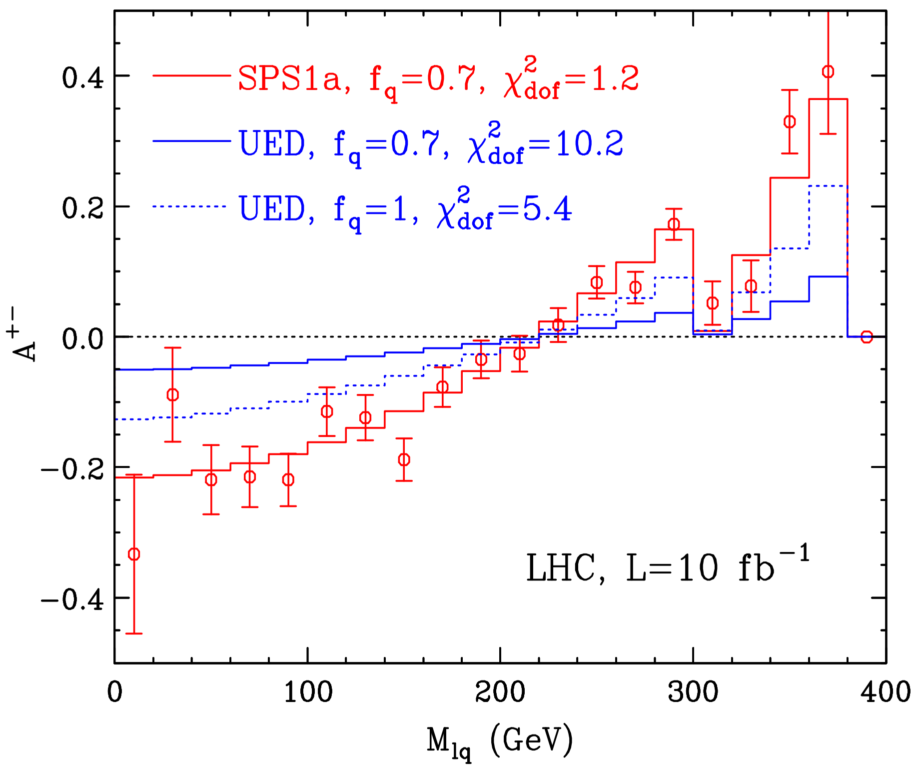
(Kong, Matchev Preliminary)



SPS1a mSUGRA point without smearing

- $f_q = 1$
  - better but still see the difference
  - difficult to fake SPS1a point

(Kong, Matchev Preliminary)

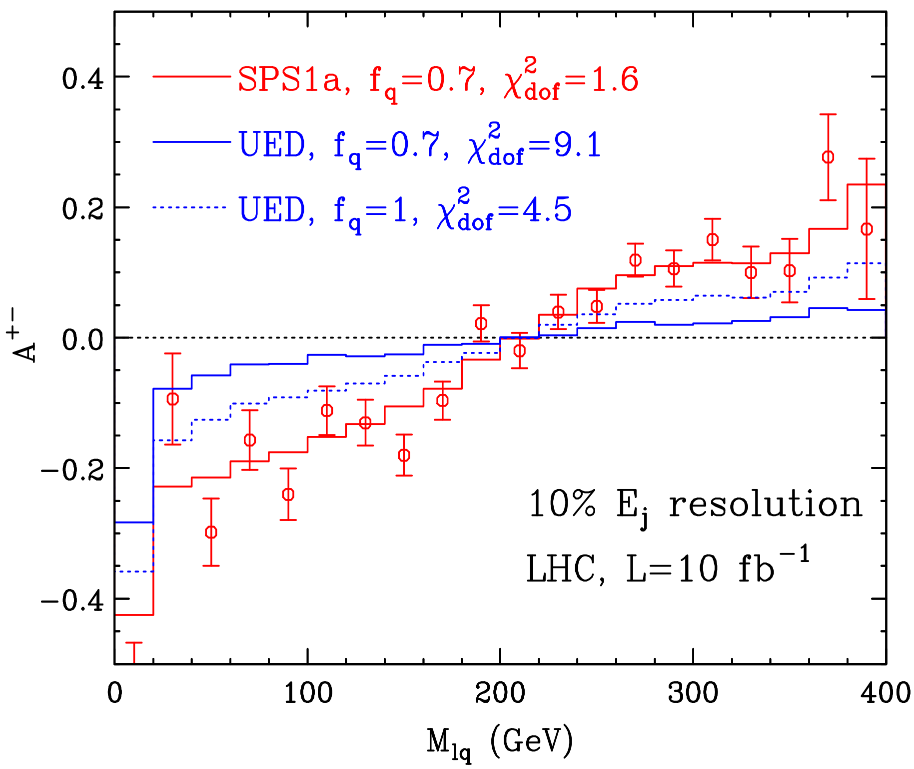


- Jet energy resolution ?
  $\longrightarrow$ histogram will be smeared
  $\longrightarrow$ can we fake once we include smearing ?

SPS1a mSUGRA point with smearing

- 10% jet energy resolution + statistical error
  $\longrightarrow \chi^2$ better but not enough
  $\longrightarrow$ SPS1a can not be faked

(Kong, Matchev Preliminary)



- effect of wrong jets $\longrightarrow$ asymmetry smaller ? (work in progress)

Summary

- $n = 2$ KK resonances :
  - easy but may not be direct proof of UED
- Spin measurements: 2 different methods
- $M_{\ell^+\ell^-}$: difficult but possible away from mSUGRA point
- $A^{+-} \neq 0$: different from phase space $\Rightarrow$ new particles with non-zero spins
- Asymmetry measures "relative" chirality
- Whether one can measure $A^{+-} \neq 0$ or not depends on the particular point in parameter space
  - "focus point" : $\tilde{g}$ production dominates, A^{+-} washed out
  - "two onshell sleptons" : two chiralities may wash out A^{+-}
  - "offshell sleptons" : less asymmetry
- If you measure asymmetry, is it SUSY/UED ?
  - SPS1a $\longrightarrow$ lucky point $\longrightarrow$ SUSY
  - degenerate case (e.g., UED) : $\longrightarrow$ can't tell
- Difficulties for optimistic case : (needs further studies)
  - jet identification : what is the right jet?
  - lepton identification :
    - leptons from $\tilde{\chi}_1^{\pm}$ or $W_1^{\pm}$
      (OF subtraction, see Craig's talk)
    - near and far
  - SM background
  - Cuts : might distort shapes (see Craig's talk)