Part 4/2: SUSY parameter measurements

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Summary of argument

Assume an excess seen in inclusive analyses: how does one verify wheteher it is actually SUSY? Need to demonstrate that:

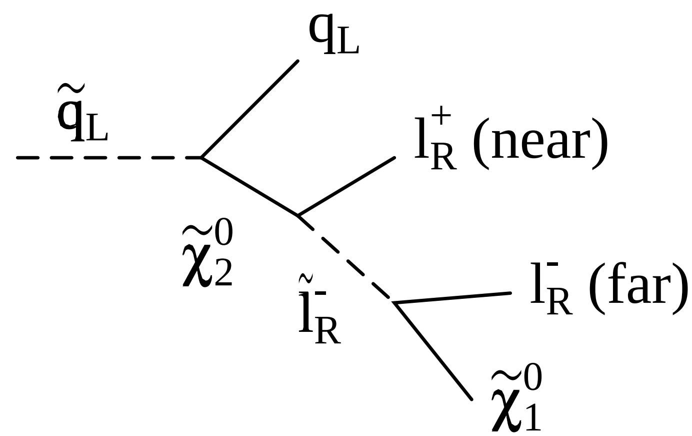
- Every particle has a superpartner
- Their spin differ by $1/2$
- Their gauge quantum numbers are the same
- Their couplings are identical
- Mass relations predicted by SUSY hold

Yesterday's lecture:

Shown for specific SUSY model that:

- Long sequences of two-body decay chains can be isolated
- The masses of the involved particles can be measured, even in the case of the LSP at bottom of chain undetected

Complete results for $\tilde{q}_L \to \tilde{\ell}\ell$ decay chain: (Allanach et al. hep-ph/0007009)



l^+l^- edge $\quad (m_{ll}^{\text{max}})^2 = (\tilde{\xi} - \tilde{l})(\tilde{l} - \tilde{\chi})/\tilde{l}$

l^+l^-q edge $\quad (m_{llq}^{\text{max}})^2 = (\tilde{q} - \tilde{\xi})(\tilde{\xi} - \tilde{\chi})/\tilde{\xi}$

l^+l^-q thresh

$$(m_{llq}^{\text{min}})^2 = \begin{cases} [\ \ 2\tilde{l}(\tilde{q} - \tilde{\xi})(\tilde{\xi} - \tilde{\chi}) \\ +(\tilde{q} + \tilde{\xi})(\tilde{\xi} - \tilde{l})(\tilde{l} - \tilde{\chi}) \\ \ \ -(\tilde{q} - \tilde{\xi})\sqrt{(\tilde{\xi} + \tilde{l})^2(\tilde{l} + \tilde{\chi})^2 - 16\tilde{\xi}\tilde{l}^2\tilde{\chi}}\ \ ] \\ /(4\tilde{l}\tilde{\xi}) \end{cases}$$

$l^{\pm}_{\text{near}}q$ edge $\quad (m_{l_{\text{near}}q}^{\text{max}})^2 = (\tilde{q} - \tilde{\xi})(\tilde{\xi} - \tilde{l})/\tilde{\xi}$

$l^{\pm}_{\text{far}}q$ edge $\quad (m_{l_{\text{far}}q}^{\text{max}})^2 = (\tilde{q} - \tilde{\xi})(\tilde{l} - \tilde{\chi})/\tilde{l}$

With $\quad \tilde{\chi} = m^2_{\tilde{\chi}^0_1}, \quad \tilde{l} = m^2_{\tilde{l}_R}, \quad \tilde{\xi} = m^2_{\tilde{\chi}^0_2}, \quad \tilde{q} = m^2_{\tilde{q}}$

We end up with a set of kinematic measurements for model SPS1a (300 fb^{-1}):

		Errors		
Variable	Value (GeV)	Stat. (GeV)	Scale (GeV)	Total
$m_{\ell\ell}^{max}$	77.07	0.03	0.08	0.08
$m_{\ell\ell q}^{max}$	428.5	1.4	4.3	4.5
$m_{\ell q}^{low}$	300.3	0.9	3.0	3.1
$m_{\ell q}^{high}$	378.0	1.0	3.8	3.9
$m_{\ell\ell q}^{min}$	201.9	1.6	2.0	2.6
$m_{\ell\ell b}^{min}$	183.1	3.6	1.8	4.1
$m(\ell_L) - m(\tilde{\chi}_1^0)$	106.1	1.6	0.1	1.6
$m_{\ell\ell}^{max}(\tilde{\chi}_4^0)$	280.9	2.3	0.3	2.3
$m_{\tau\tau}^{max}$	80.6	5.0	0.8	5.1
$m(\tilde{g}) - 0.99 \times m(\tilde{\chi}_1^0)$	500.0	2.3	6.0	6.4
$m(\tilde{q}_R) - m(\tilde{\chi}_1^0)$	424.2	10.0	4.2	10.9
$m(\tilde{g}) - m(\tilde{b}_1)$	103.3	1.5	1.0	1.8
$m(\tilde{g}) - m(\tilde{b}_2)$	70.6	2.5	0.7	2.6

Interpretation of results

The measurements do not depend a priori on a special choice of the model

For instance, we can state that in the data appear the decays:

$$
\begin{array}{llll}
a \to b & q & & \\
& \hookrightarrow c & \ell^{\mp} & \\
& & \hookrightarrow d & \ell^{\pm}
\end{array}
$$

$$
\begin{array}{llll}
a \to b & q & & \\
& \hookrightarrow e & \tau^{\mp} & \\
& & \hookrightarrow d & \tau^{\pm}
\end{array}
$$

Where we know the masses of a, b, c, d, e, and we might conjecture that a, b, d appearing in both decays are the same having the same masses

So we have a mass hierarchy, some of the decays related these particles and, perhaps, the relative rates

Having decay chains help restricting the possibilities, if one imposes some conservations, e.g. charges or quantum numbers

Model dependence enters when we try to give a name to the particles, and match them to a template decay chain

Among the models proposed to solve the hierarchy problem, various options providing a full spectrum of new particles, with cascade decays:

- Universal extra-dimensions: first KK excitation of each of the SM fields (tomorrow)
- Little Higgs with T parity

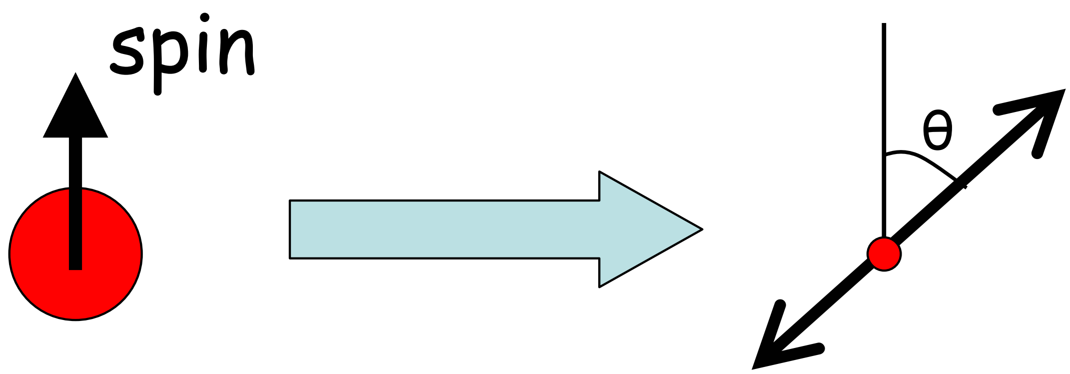
Special feature of SUSY: if one identifies the heavy partners through their quantum numbers, the spins of all of them are wrong by $1/2$

Worth investigating if exploiting the identified chains one can obtain information on the sparticle spins

Spin measurement in squark decay (A. Barr)

Basic recipe:

- Produce polarised particle
- Look at angular distributions



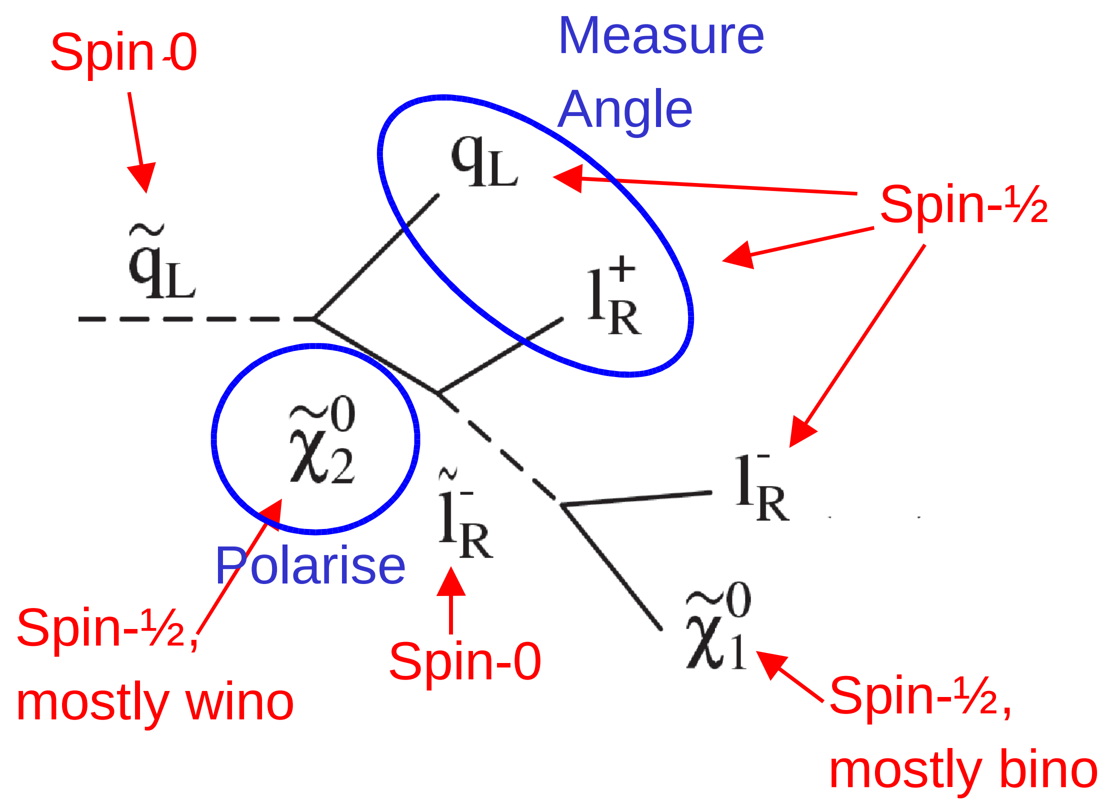
Sparticle spins in squark decay chain

Consider usual squark decay chain in SPA point

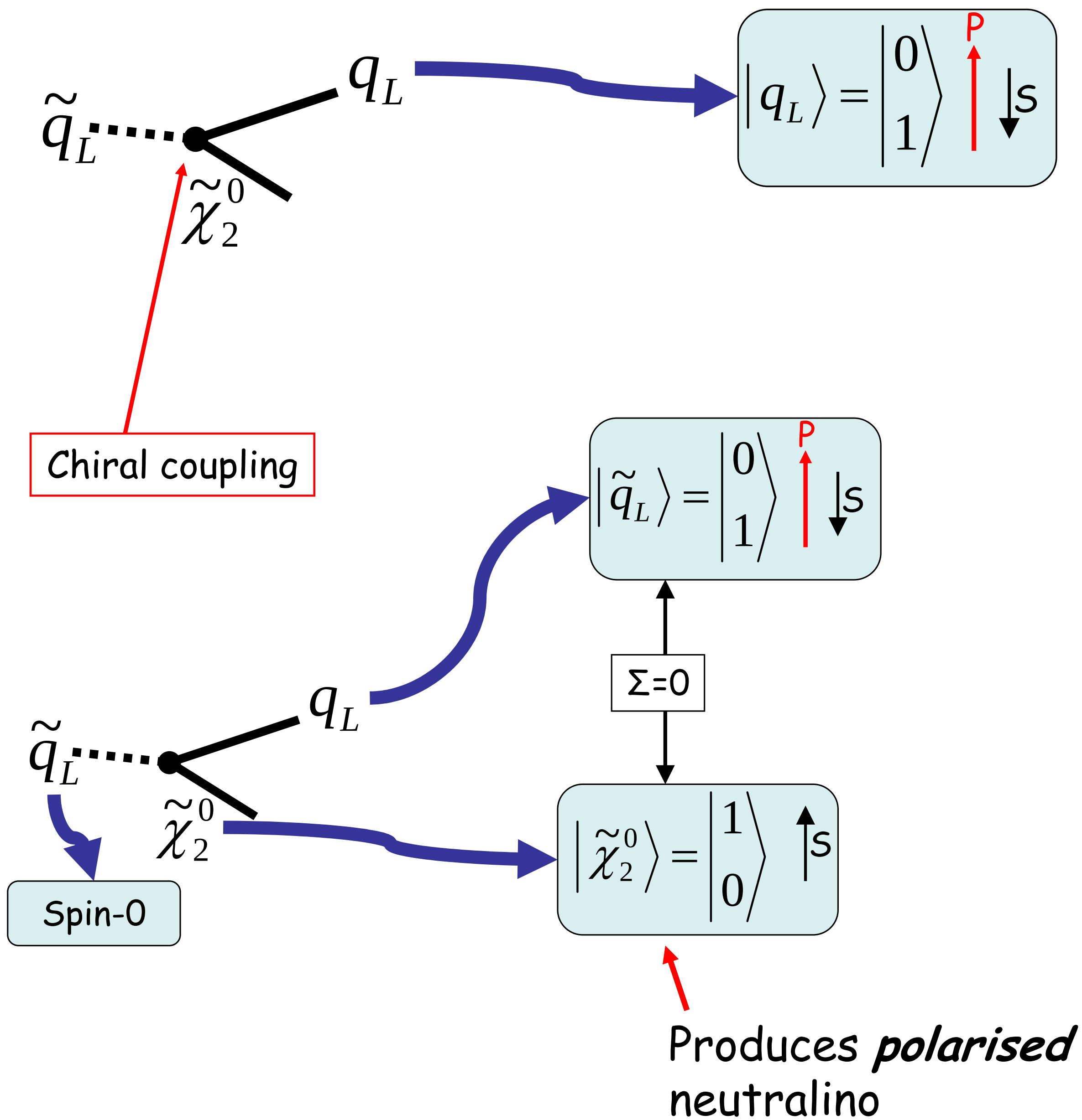
Three visible particles in final state: 1 jet, two leptons

Spin analyser is the angle between the quark and the lepton from $\tilde{\chi}_2^0$ decay

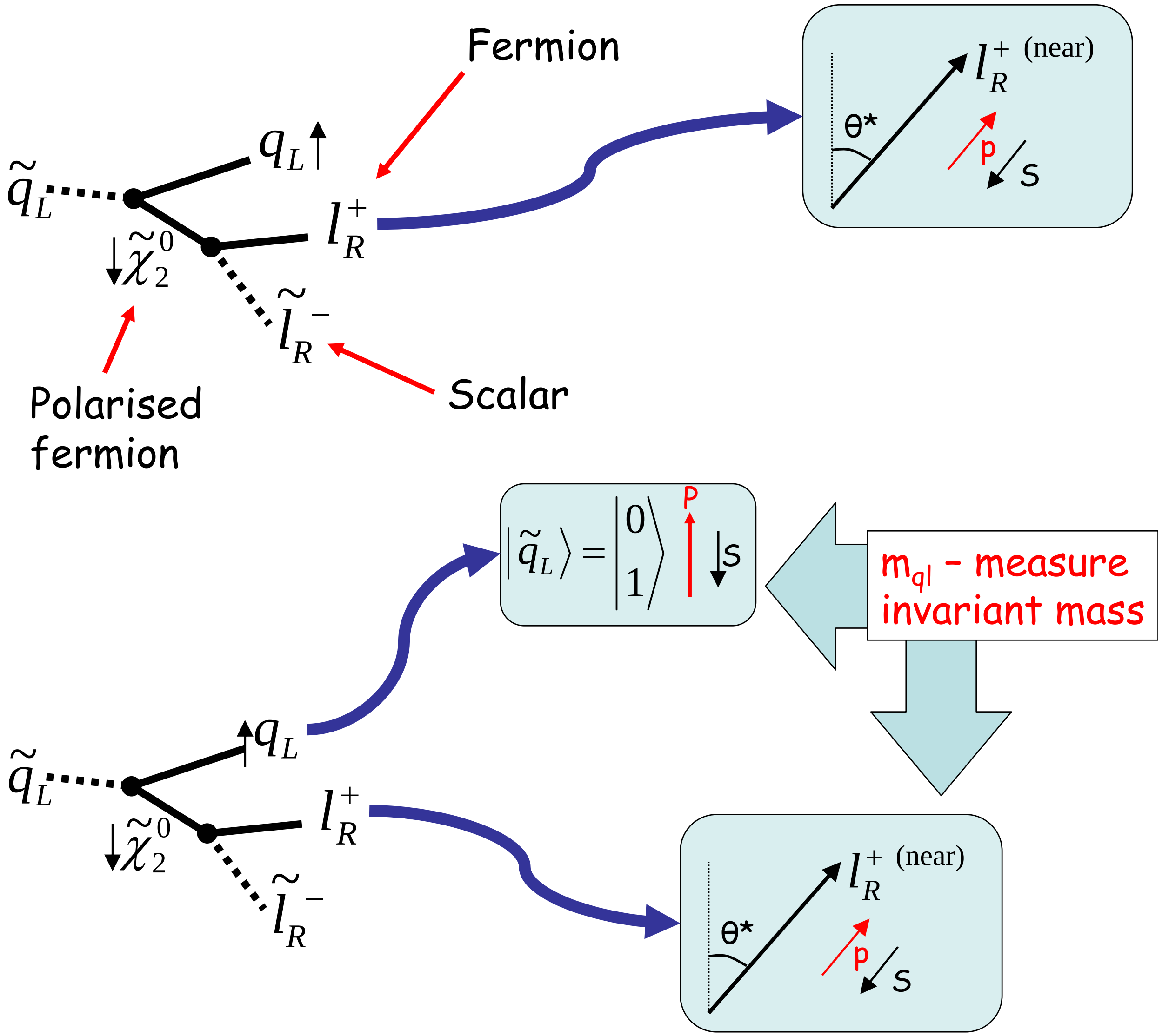
No dynamic information from angle between two leptons, as $\tilde{\ell}_R$ is spin zero



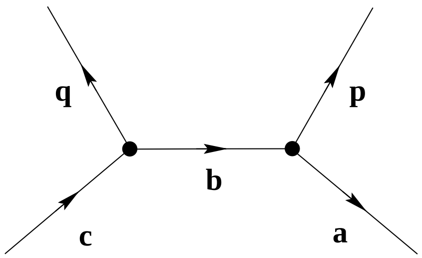
Spin projection factors (1)

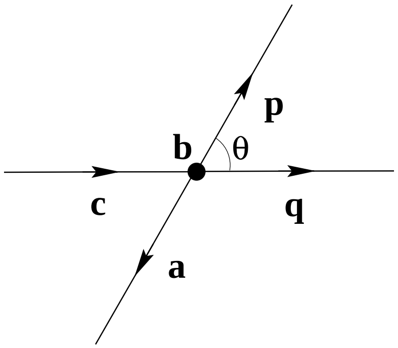


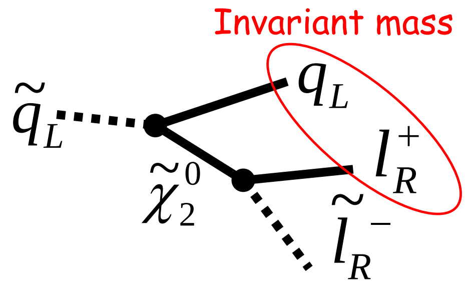
Spin projection factors (2)



Invariant mass distribution for visible particles







The angle θ between the two visible particles in rest frame of b related to m_{pq} as:

$$m_{pq}^2 = 2|\vec{p_p}||\vec{p_q}|(1-\cos\theta) \quad \text{and} \quad (m_{pq}^{max})^2 = 4|\vec{p_p}||\vec{p_q}|$$

for p, q massless

We can thus define the dimensionless variable:

$$\hat{m}^2 = \frac{m_{pq}^2}{(m_{pq}^{max})^2} = \frac{1}{2}(1-\cos\theta) = \sin^2\frac{\theta}{2}$$

For intermediate particle with spin zero:

$$\frac{dP}{d\cos\theta} = \frac{1}{2} \quad \Rightarrow \frac{dP}{d\hat{m}} = 2\hat{m}$$

Spin 1/2: two cases:

- Lepton same helicity as quark:

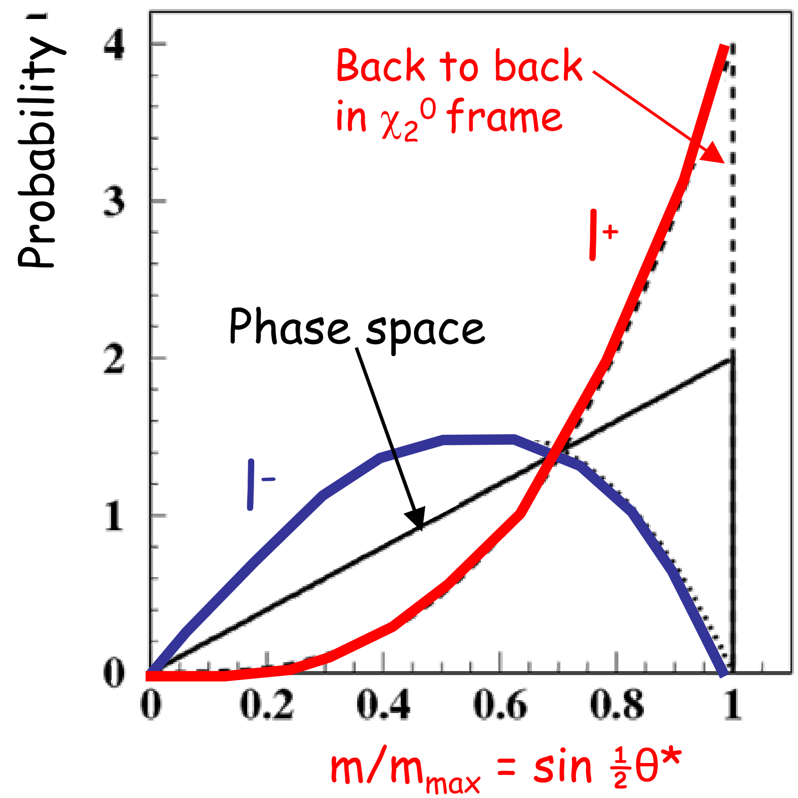
  l^+q, $l^-\bar{q}$ for $\tilde{q}_L$, $\tilde{\ell}_R$

  $$\frac{dP}{d\cos\theta} = \frac{1}{2}(1-\cos\theta) \quad \Rightarrow \frac{dP}{d\hat{m}} = 4\hat{m}^3$$

- Lepton opposite helicity to quark:

  l^-q, $l^+\bar{q}$ for $\tilde{q}_L$, $\tilde{\ell}_R$

  $$\frac{dP}{d\cos\theta} = \frac{1}{2}(1+\cos\theta) \quad \Rightarrow \frac{dP}{d\hat{m}} = 4\hat{m}(1-\hat{m}^2)$$



Difference in shape of m_{ℓ^+q} and m_{ℓ^-q}: indication for $\tilde{\chi}_2^0$ spin $1/2$

Experimental measurement

$\ell^{near}q$ shows nice charge asymmetry:

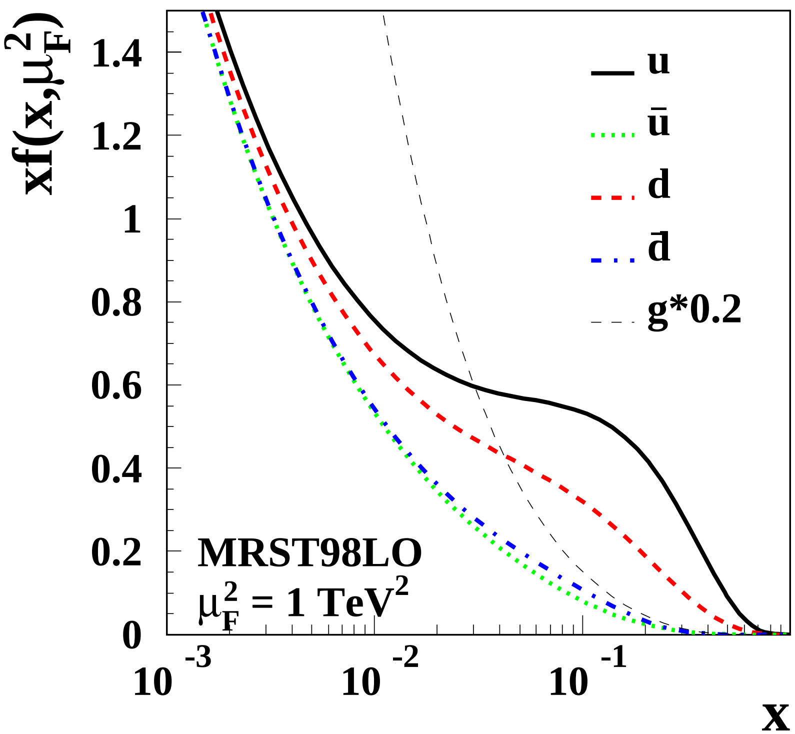
$\Rightarrow$ Excellent probe of $\tilde{\chi}_2^0$ spin

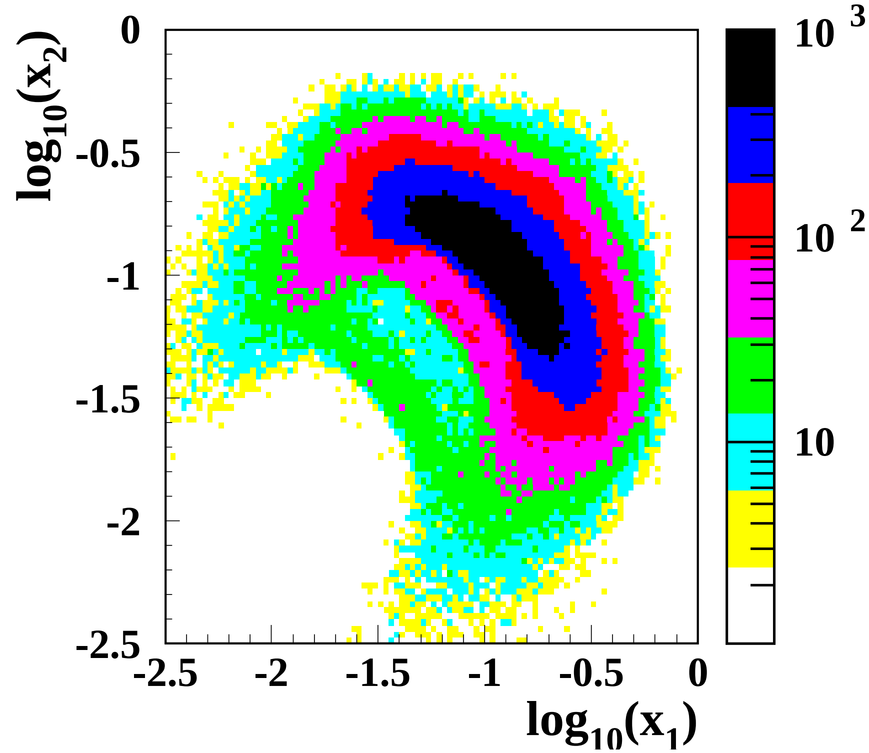
Experimental problems in measurement:

- Can't tell quark jet from anti-quark
  - Both q and $\bar{q}$ appear in decay chain
  - pp Collider $\rightarrow$ PDF favour production of squarks over anti-squarks
- Two leptons in the event
  - We are only interested in the first lepton (from neutralino decay)
  - Plot ℓ^+q and ℓ^-q, minimal distorsion of asymmetry from ℓ^{far}

Production asymmetry

For squark production in considered model ($m_{\tilde{q}} \sim 600$ GeV), dominant contribution of $x \sim 0.1$

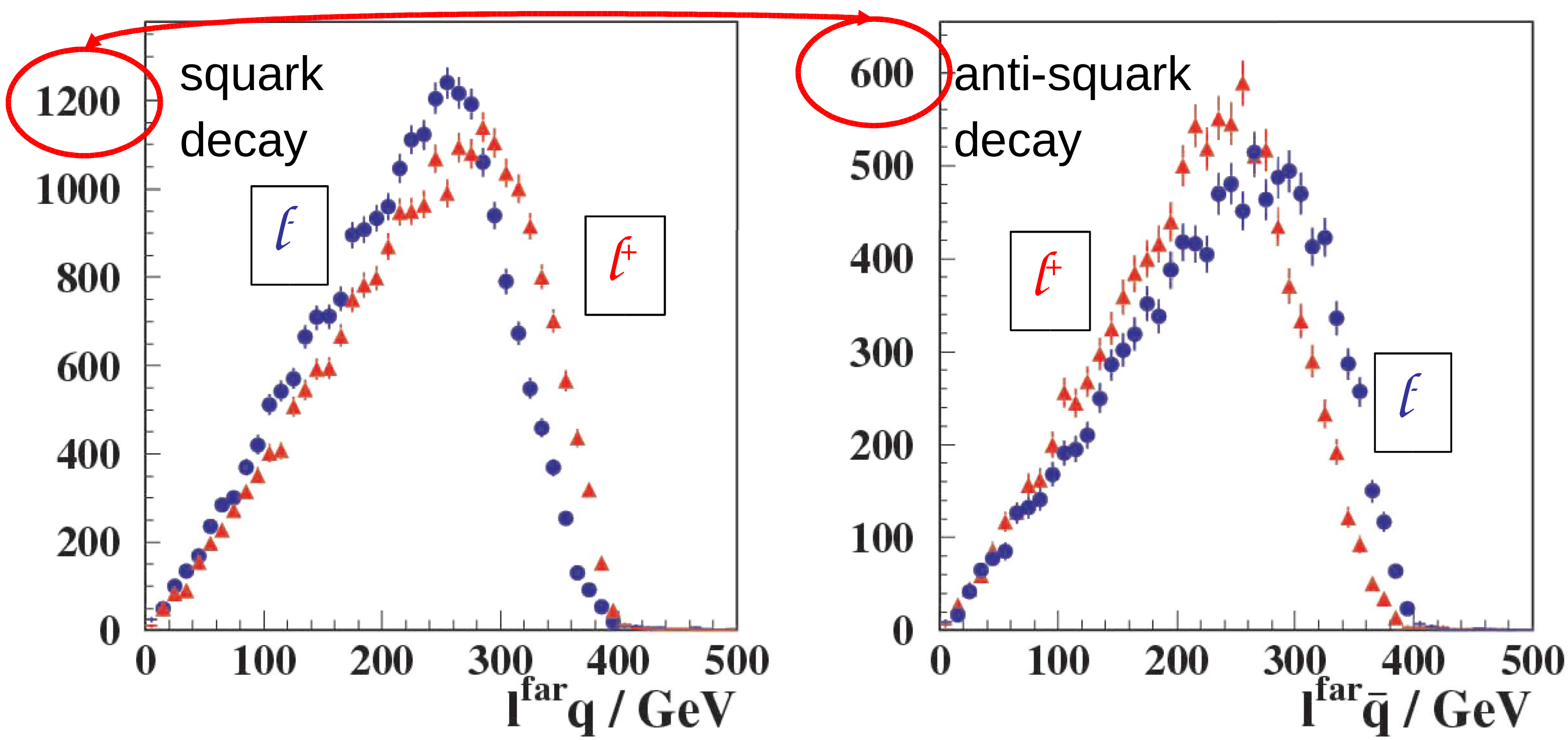




At $x \sim 0.1$ dominant contribution of valence quarks

$\ell^{far} q$ invariant mass

Lepton from slepton decay only: not directly measurable

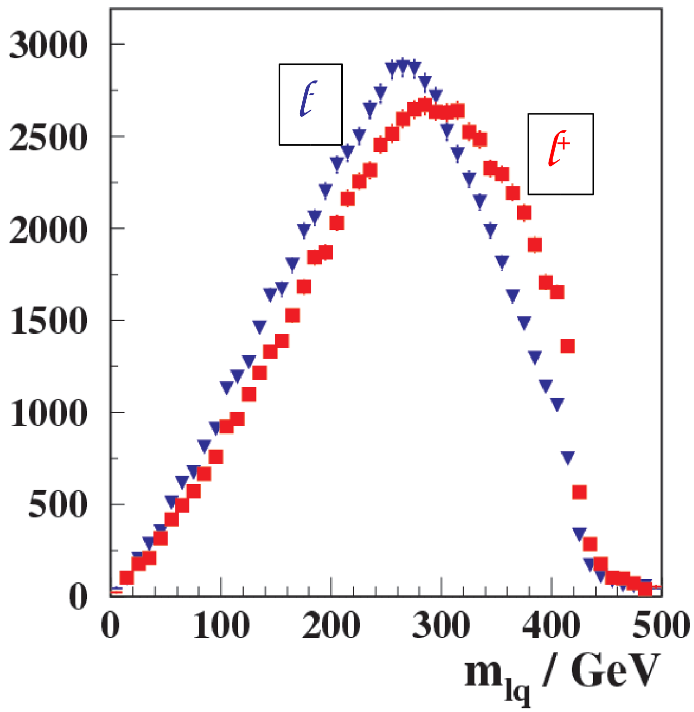


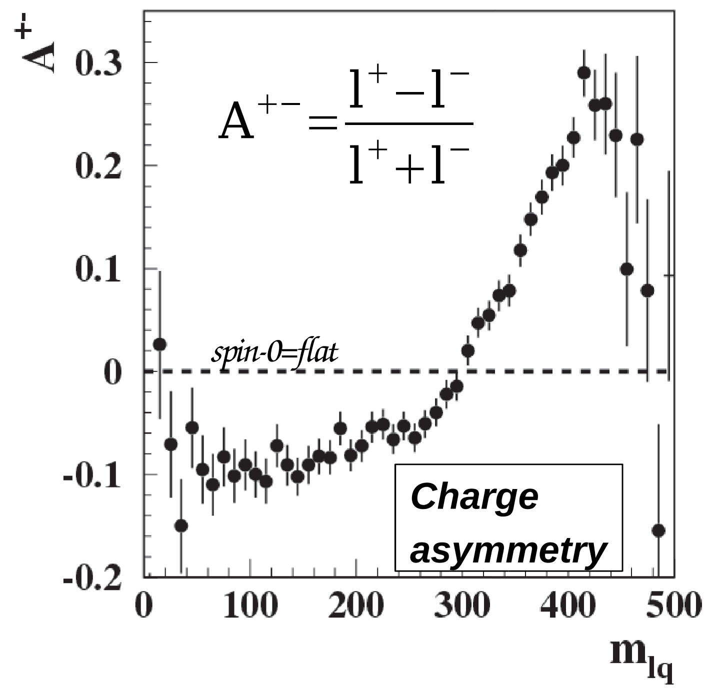
Small residual asymmetry from boost of slepton in $\tilde{\chi}_2^0$ rest frame

Parton level

We now build at parton level on simulated events the lepton-jet invariant mass, and take the bin-by-bin asymmetry of ℓ^+ and ℓ^- distributions

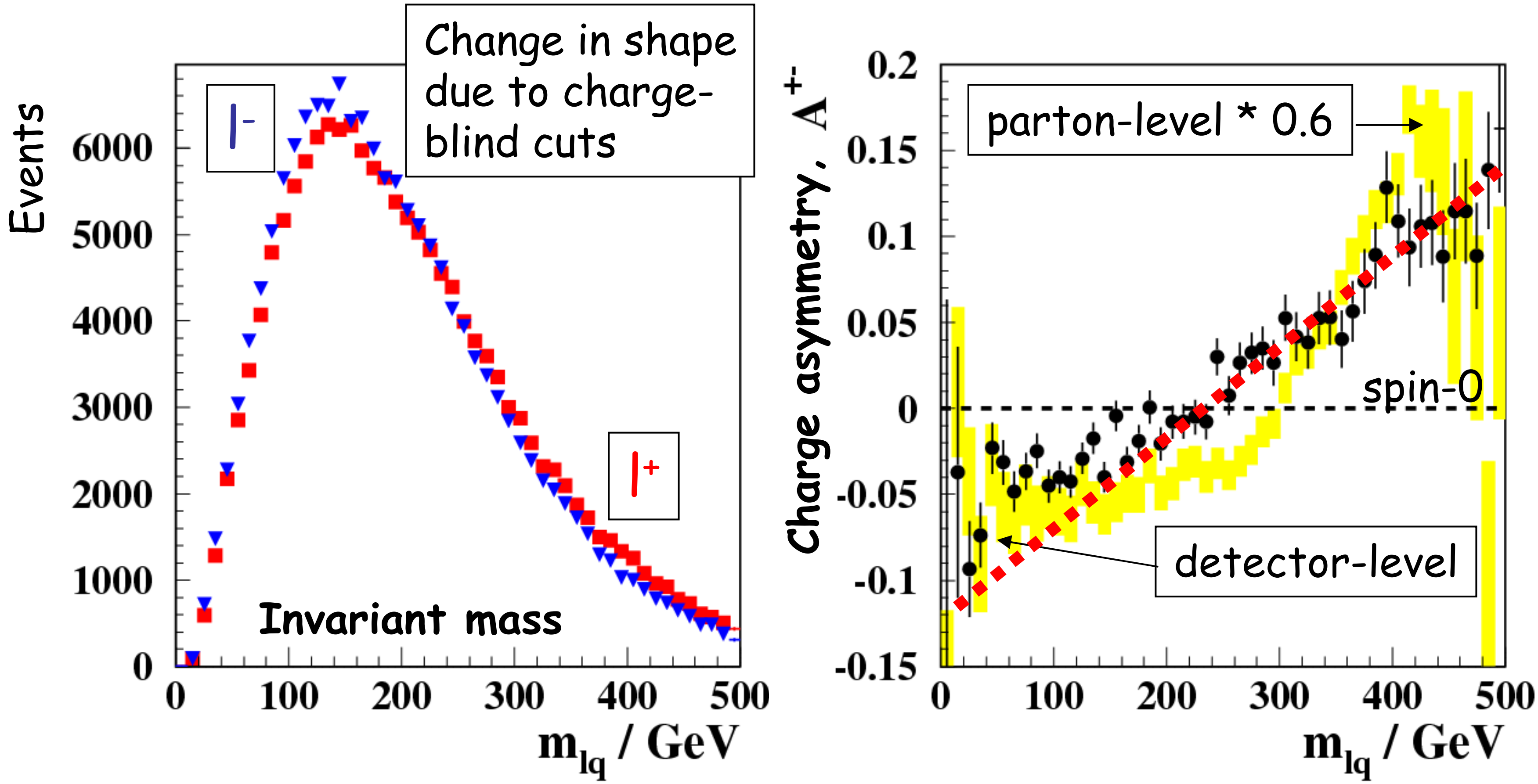
Experimentally measurable: both q and $\bar{q}$ in plot, both near and far lepton





Shape shows clear deviation from what expected for spin-zero $\tilde{\chi}_2^0$

After parametrised detector simulation

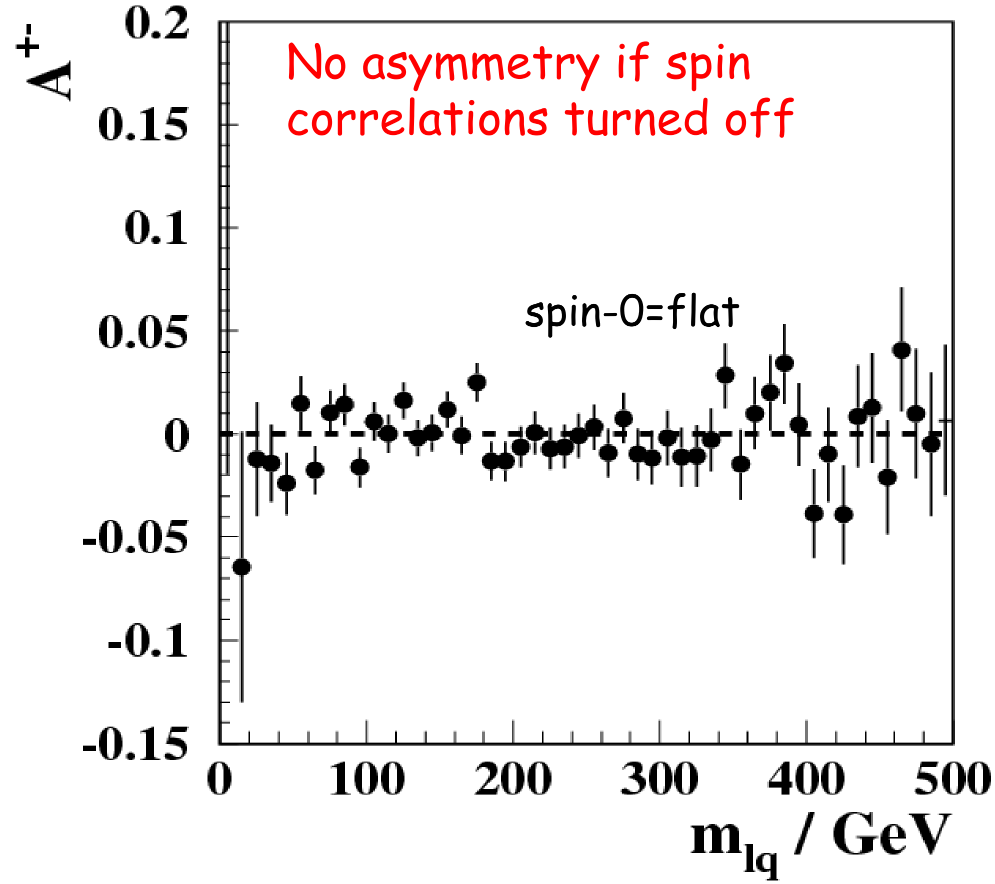


Charge asymmetry survives detector simulation

Similar shape for asymmetry as at parton level, but with BG and smearing

Cross-check

- Use HERWIG Monte Carlo
- Can switch off spin correlations
  - Distribution for scalar $\tilde{\chi}_2^0$
  - Consistent with flat
  - Not consistent with spin-1/2 $\tilde{\chi}_2^0$ of previous page

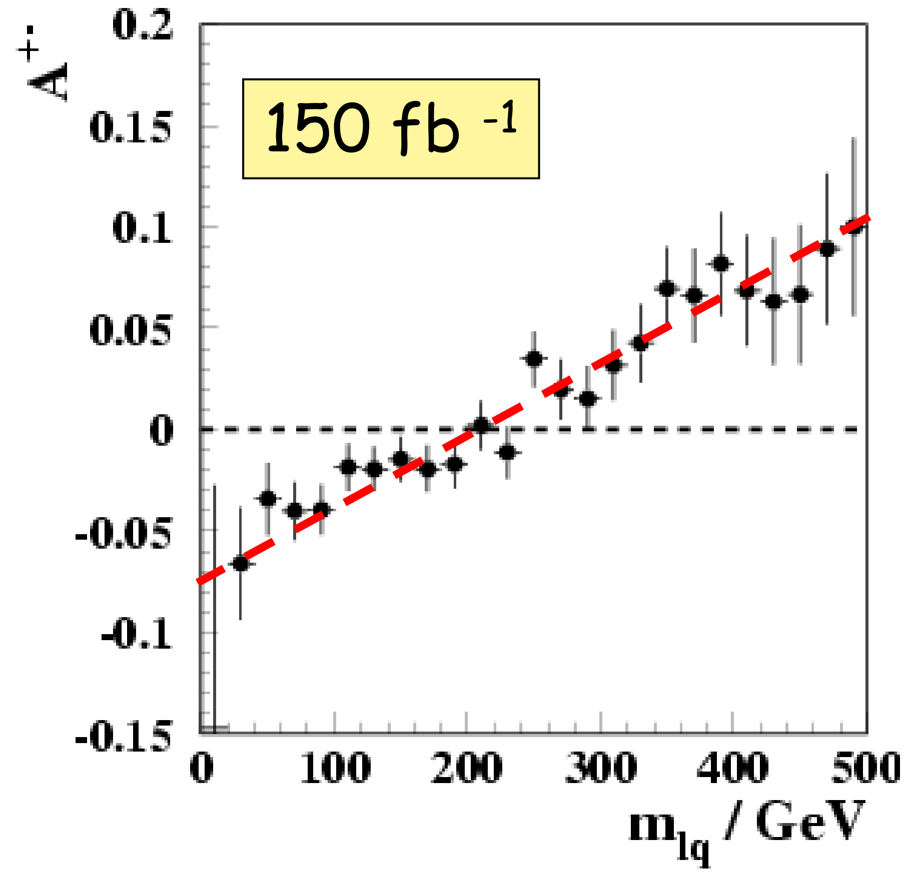


Luminosity required?

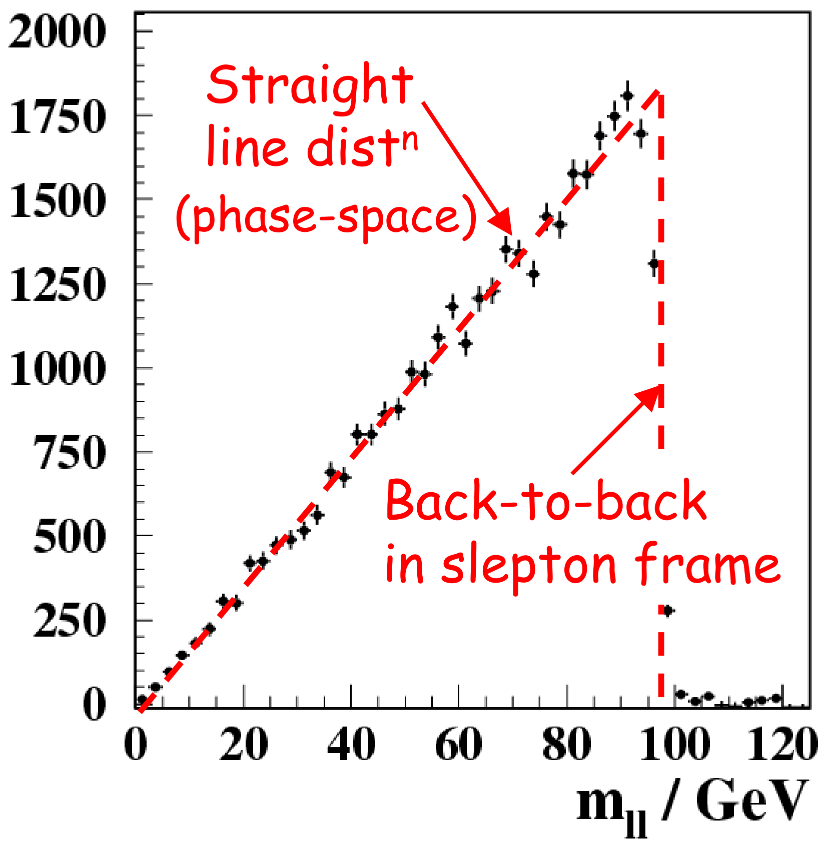
Previous plots with very high statistics

(5 years high lumiosity)

- Show shape clearly
- Necessary luminosity depends on MSSM parameters
- For considered model 150 fb^{-1} sufficient



Further evidence: slepton spin



Dilepton invariant mass

- Right-handed slepton
- ℓ^+ and ℓ^- are right-handed
- might expect pronounced spin effects
- none beacuse slepton is scalar

Scalar particle carrying lepton number

Comparison with spin 1

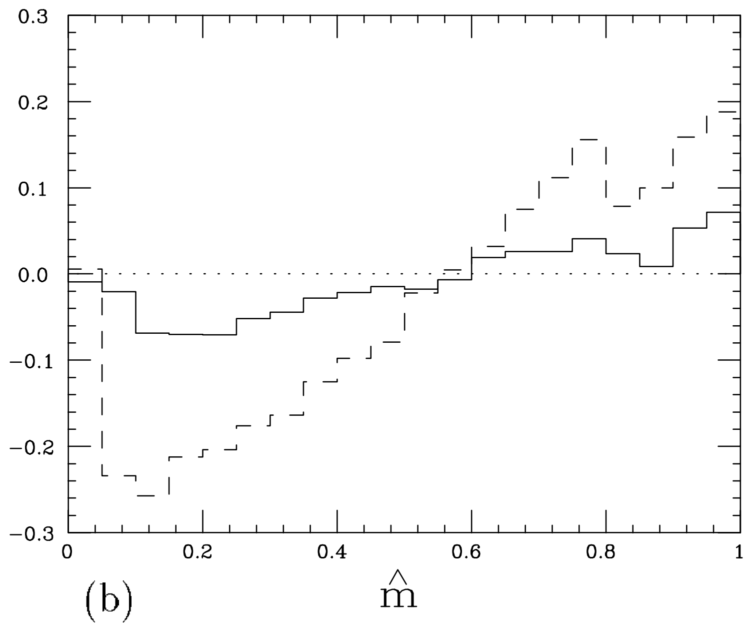
For the SPS1a SUSY model, it can be shown that $\tilde{\chi}_2^0$ is not a scalar

In competing models (UED) spin of partner of Z is 1, as in Standard Model

Not studied in previous analysis because model not available in MC generator

Comparison with spin one performed by theorists (Smillie, Webber) with very rough detector simulation

Same spectrum of sparticle masses as for SPS1a point with two spin assignments: SM-like (solid lines), SUSY (dashed lines)



Two spin assignments:

SM-like (solid lines), SUSY (dashed lines)

Excellent discrimination also against spin one case

Conclusions on spin

Methods for studying spin of particles in SUSY decays being developed

Work just at the beginning, new ideas being proposed

It seems possible, for the 'easy' SUSY model on which most studies performed to discriminate with respect e.g to UED

From this type of studies also information on helicities and Left-Right mixing of sparticles (Goto-Nojiri)

Discriminating power strong function of mass hierarchy in the model: for small mass difference among sparticles much weaker discrimination