Supersymmetric Spins in Cascade Decays

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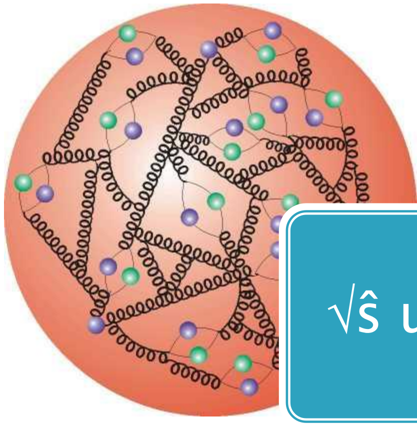
In collaboration with Per Osland and Are Raklev

Introduction

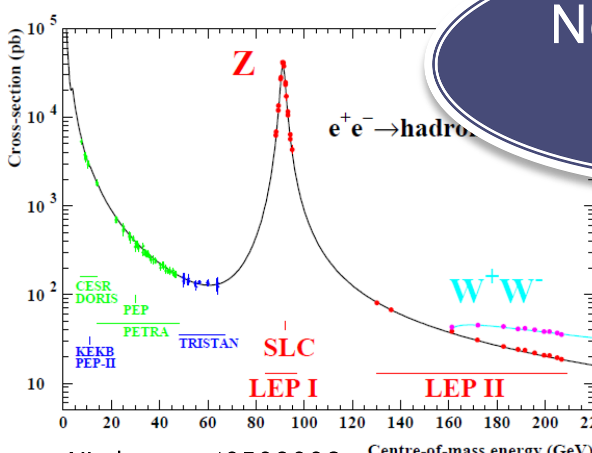
Measuring the spins of susy partners is not easy at the LHC.



$\sqrt{\hat{s}}$ unknown

LSP lost

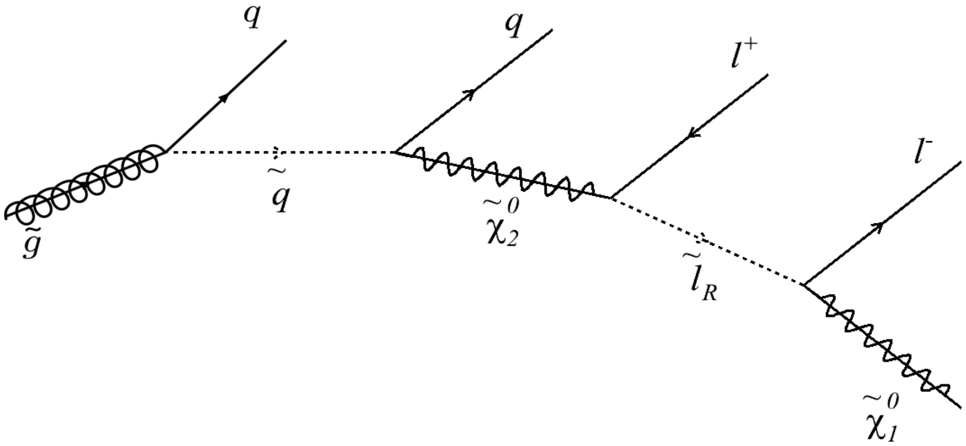
No nice mass peaks



arXiv:hep-ex/0509008

The Cascade

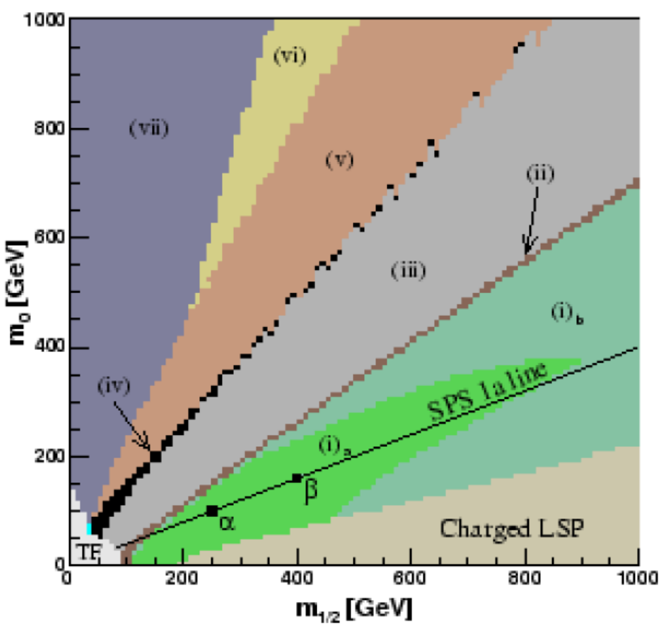
Most analyses of sparticle spins to date have investigated some part of this susy cascade:



This decay is not always open, but is there for a large part of the cMSSM parameter space, including SPS 1a.

Today, we will consider this cascade, starting from the squark.

hep-ph/0410303



$A_0 = -m_0$ and $\tan\beta = 10$

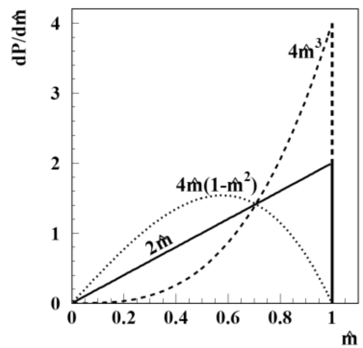
Some previous studies

(Not a complete set!)

Barr

$$A = \frac{s^+ - s^-}{s^+ + s^-}$$

with $s^\pm = \dfrac{d\sigma}{dm_{l^\pm q}}$

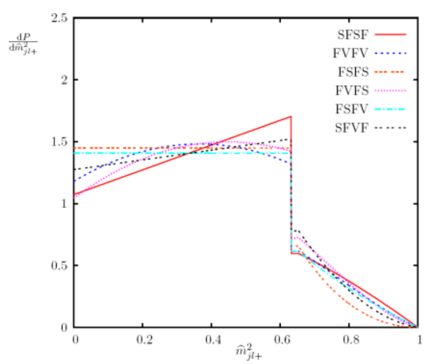


hep-ph/0405052

Athanasiou, Lester, Smillie, Webber

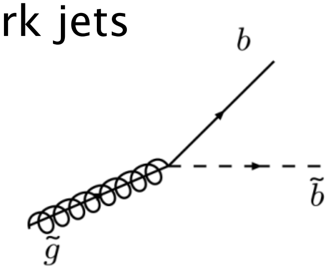
Compare shapes of distributions

hep-ph/0507170
hep-ph/0605286



Alves, Eboli, Plehn

Use a b-tag to distinguish quark from antiquark jets



Used this to measure gluino spin

hep-ph/0605067

Wang, Yavin

via charginos,

e.g. $\tilde{u} \to \chi_1^+ d \to W^+ \chi_1^0 d$

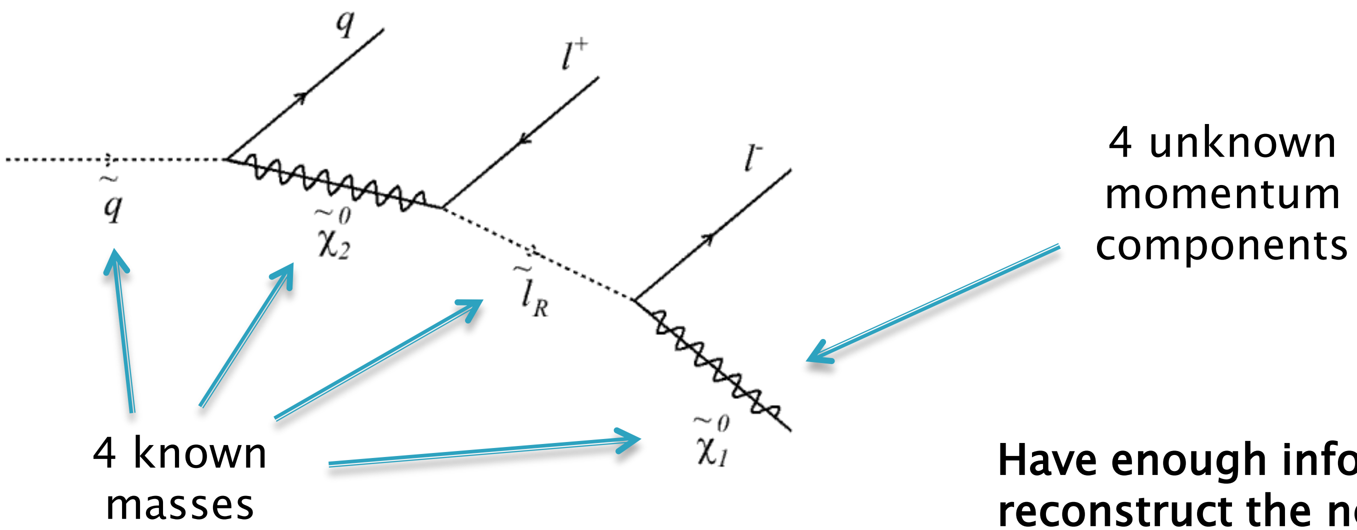
hep-ph/0605296

Reconstructing the LSP

We adopt a different approach and use the (previously measured) sparticle masses to reconstruct the neutralino momentum.

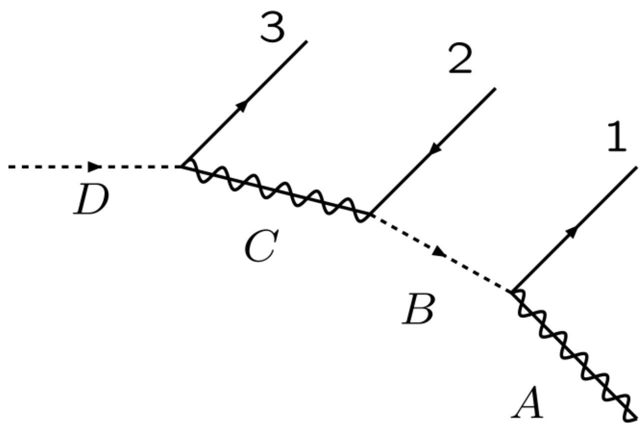
This is an idea originating from

M.M. Nojiri, G. Polesello and D.R. Tovey, arXiv:hep-ph/0312317
K. Kawagoe, M.M. Nojiri and G. Polesello, Phys.Rev. D**71** (2005) 035008



Have enough information to reconstruct the neutralino!

See also Cheng, Han, Kim, Wang, arXiv:1008.0405



Writing

$$\begin{aligned} N_1 &= (m_B^2 - m_A^2)/2 \\ N_2 &= (m_C^2 - m_B^2 - m_{12}^2)/2 \\ N_3 &= (m_D^2 - m_C^2 - m_{123}^2 + m_{12}^2)/2 \end{aligned}$$

the mass-shell conditions give $p_A \cdot p_i = N_i$

With $M_{ij} = \vec{p}_i \cdot \vec{p}_j$ the reconstructed neutralino momentum is $\vec{p}_A = \alpha_i \vec{p}_i$

where $\alpha_i = (E_A E_j - N_j) M_{ji}^{-1}$ and

$$E_A = \frac{1}{1 - E_i E_j M_{ij}^{-1}} \left[-E_i N_j M_{ij}^{-1} \pm \sqrt{(E_i N_j M_{ij}^{-1})^2 + (1 - E_i E_j M_{ij}^{-1})(N_i N_j M_{ij}^{-1} + m_A^2)} \right]$$

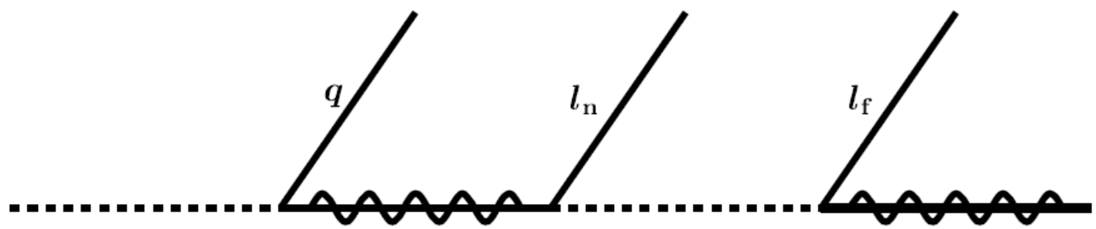
Reconstruction of LSP $\Rightarrow$ reconstruction of all momenta in the chain

» use traditional methods of determining spin via angular distributions

An event sample

Generate 10,000 events via HERWIG (not SPS 1a).

For comparison, SPS 1a would have 1669 events per fb^{-1} but this is before cuts to remove background. Obviously we would need a very clean sample.



$\sigma = 32.8$ pb	$\tilde{q}_L$ 31.4%						1245 fb
$\sigma = 7.7$ pb	$\tilde{b}_1$ 35.5%	$\tilde{\chi}_2^0$	12.1%	$\tilde{l}_R$	100%	$\tilde{\chi}_1^0$	329 fb
$\sigma = 4.3$ pb	$\tilde{b}_2$ 18.0%						94 fb
							1669 fb

- We require our events to have two cascades.
- Also, there are many different susy processes with the same pattern of quark and leptons contributing to the cascade (see later).

Initial problems

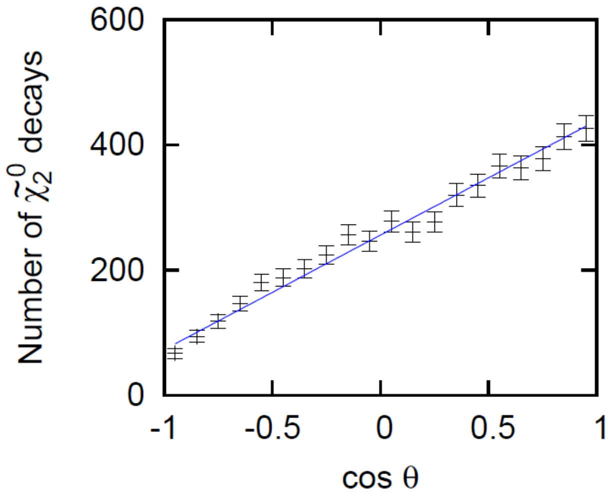
- We have 2 solutions to the reconstruction
- Which lepton is "near" and which is "far"?
- Which leptons and quarks belong to each chain?

Usually, using the wrong solution or mixing up the particles will give an unphysical reconstruction.

If not, we look at the P_T of the event, and choose the one with lowest p_T.

To check this, our analysis is blind – we throw away any information as to which particle is which.

This seems to work well.

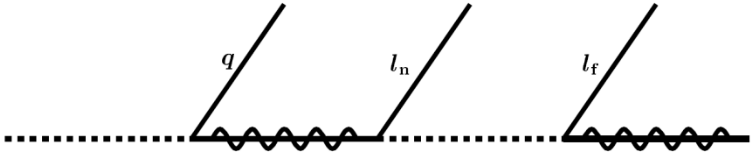


For a scalar decay, this would be flat.

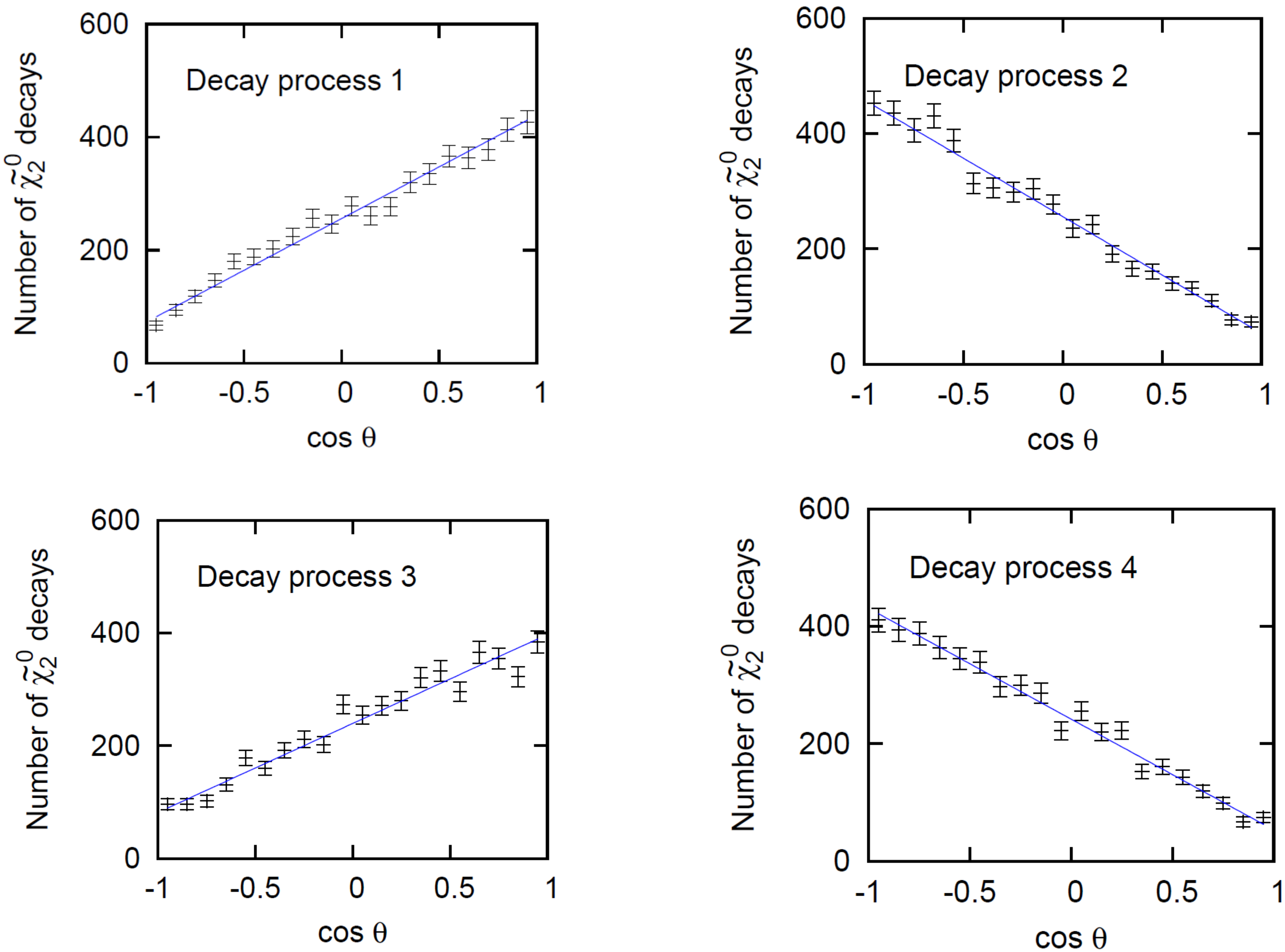
However, we really have 16 processes contributing to the cascade chain, which potentially have different slopes!

	Process	chirality of q	chirality of l_{n}	chirality of l_{f}	Slope
1	$\tilde{q}_L \to q {l_{\mathrm{n}}}^- {l_{\mathrm{f}}}^+ \tilde{\chi}_1^0$	L	L	L	$+$
2	$\tilde{q}_L \to q {l_{\mathrm{n}}}^+ {l_{\mathrm{f}}}^- \tilde{\chi}_1^0$	L	L	L	$-$
3	$\tilde{\bar{q}}_L \to \bar{q} {l_{\mathrm{n}}}^+ {l_{\mathrm{f}}}^- \tilde{\chi}_1^0$	L	L	L	$+$
4	$\tilde{\bar{q}}_L \to \bar{q} {l_{\mathrm{n}}}^- {l_{\mathrm{f}}}^+ \tilde{\chi}_1^0$	L	L	L	$-$
5	$\tilde{q}_L \to q {l_{\mathrm{n}}}^- {l_{\mathrm{f}}}^+ \tilde{\chi}_1^0$	L	R	R	$-$
6	$\tilde{q}_L \to q {l_{\mathrm{n}}}^+ {l_{\mathrm{f}}}^- \tilde{\chi}_1^0$	L	R	R	$+$
7	$\tilde{\bar{q}}_L \to \bar{q} {l_{\mathrm{n}}}^+ {l_{\mathrm{f}}}^- \tilde{\chi}_1^0$	L	R	R	$-$
8	$\tilde{\bar{q}}_L \to \bar{q} {l_{\mathrm{n}}}^- {l_{\mathrm{f}}}^+ \tilde{\chi}_1^0$	L	R	R	$+$
9	$\tilde{q}_R \to q {l_{\mathrm{n}}}^- {l_{\mathrm{f}}}^+ \tilde{\chi}_1^0$	R	L	L	$-$
10	$\tilde{q}_R \to q {l_{\mathrm{n}}}^+ {l_{\mathrm{f}}}^- \tilde{\chi}_1^0$	R	L	L	$+$
11	$\tilde{\bar{q}}_R \to \bar{q} {l_{\mathrm{n}}}^+ {l_{\mathrm{f}}}^- \tilde{\chi}_1^0$	R	L	L	$-$
12	$\tilde{\bar{q}}_R \to \bar{q} {l_{\mathrm{n}}}^- {l_{\mathrm{f}}}^+ \tilde{\chi}_1^0$	R	L	L	$+$
13	$\tilde{q}_R \to q {l_{\mathrm{n}}}^- {l_{\mathrm{f}}}^+ \tilde{\chi}_1^0$	R	R	R	$+$
14	$\tilde{q}_R \to q {l_{\mathrm{n}}}^+ {l_{\mathrm{f}}}^- \tilde{\chi}_1^0$	R	R	R	$-$
15	$\tilde{\bar{q}}_R \to \bar{q} {l_{\mathrm{n}}}^+ {l_{\mathrm{f}}}^- \tilde{\chi}_1^0$	R	R	R	$+$
16	$\tilde{\bar{q}}_R \to \bar{q} {l_{\mathrm{n}}}^- {l_{\mathrm{f}}}^+ \tilde{\chi}_1^0$	R	R	R	$-$

our 10,000 events



Neutralino decays

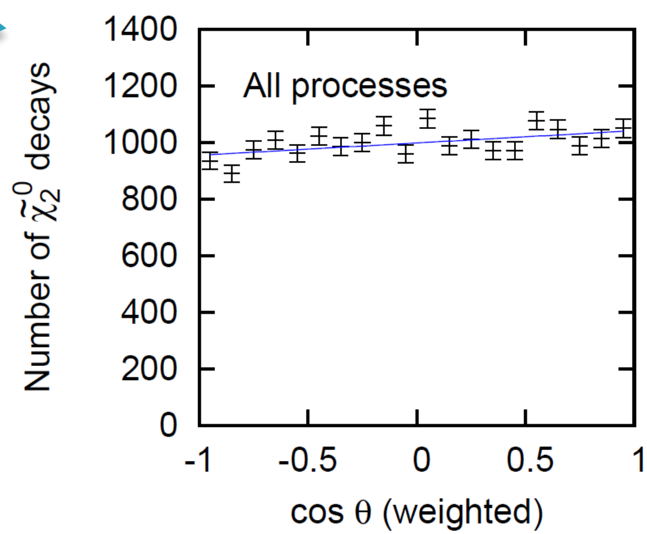


These processes cannot all be separated unless we know

- the lepton charge
- whether the "quark" is really a quark or antiquark.

Just adding these together will give a flat distribution.

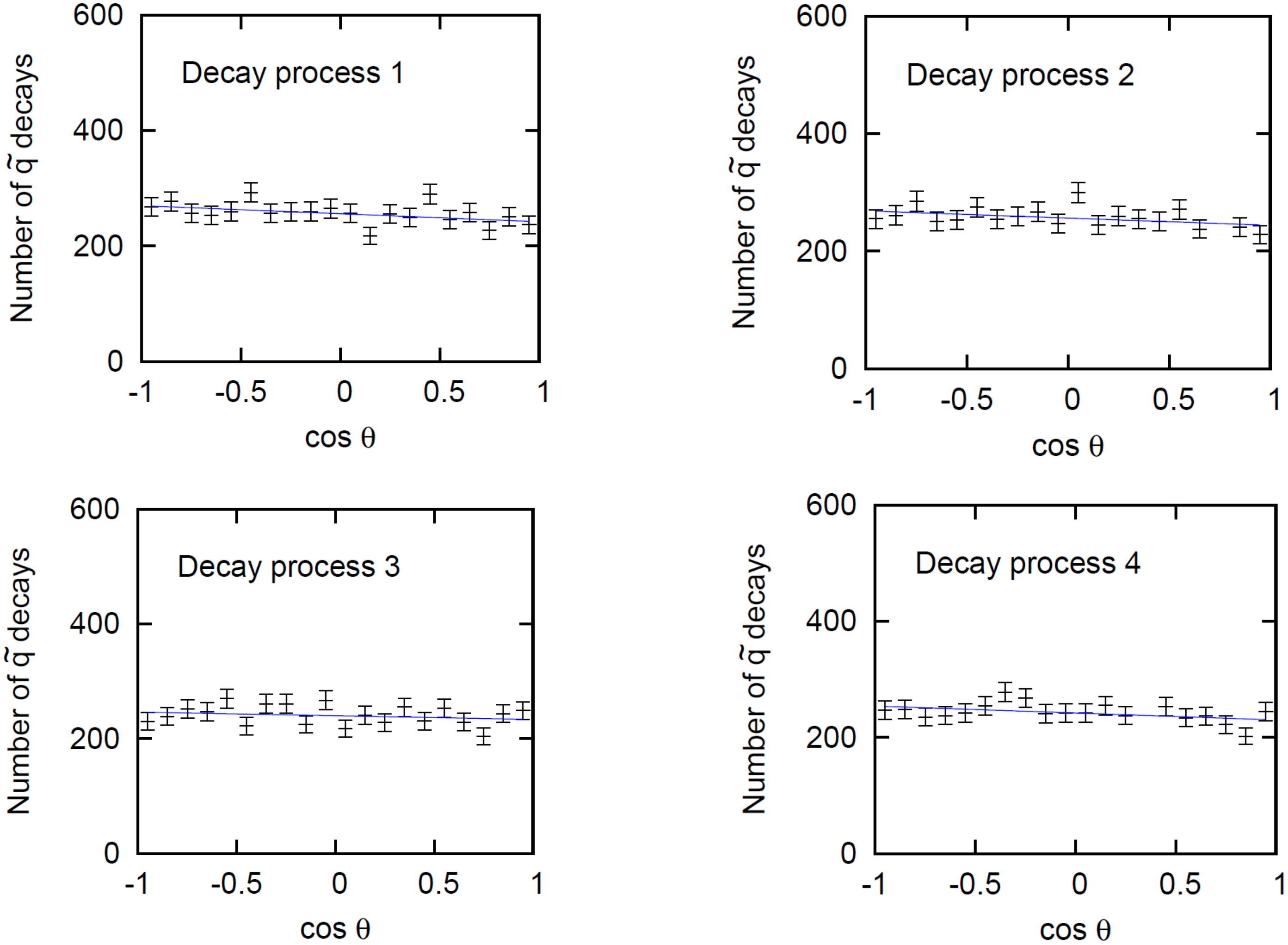
Using the lepton charge gives



The slope is non-zero because we have more squarks than antisquarks, since the proton contains more quarks than antiquarks.
(This is the same trick Barr used.)

But this is not statistically significant (~2.8 sigma)

Squark decays give flat distributions



Tagging the quark

For this to work, we really need to separate the processes.

- We need to know whether the q is a quark or antiquark.

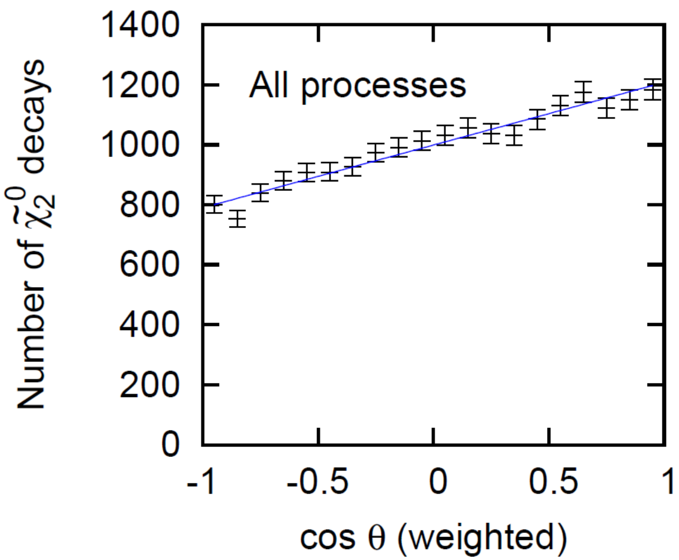
Could we take a b-quark sample and use the jet charge tagger? (This is what Alves, Eboli and Plehn did for the gluino.)

This tags b-jets with an efficiency ϵ and a dilution D related to the probability of correctly identifying quark or antiquark, P = 2D-1.

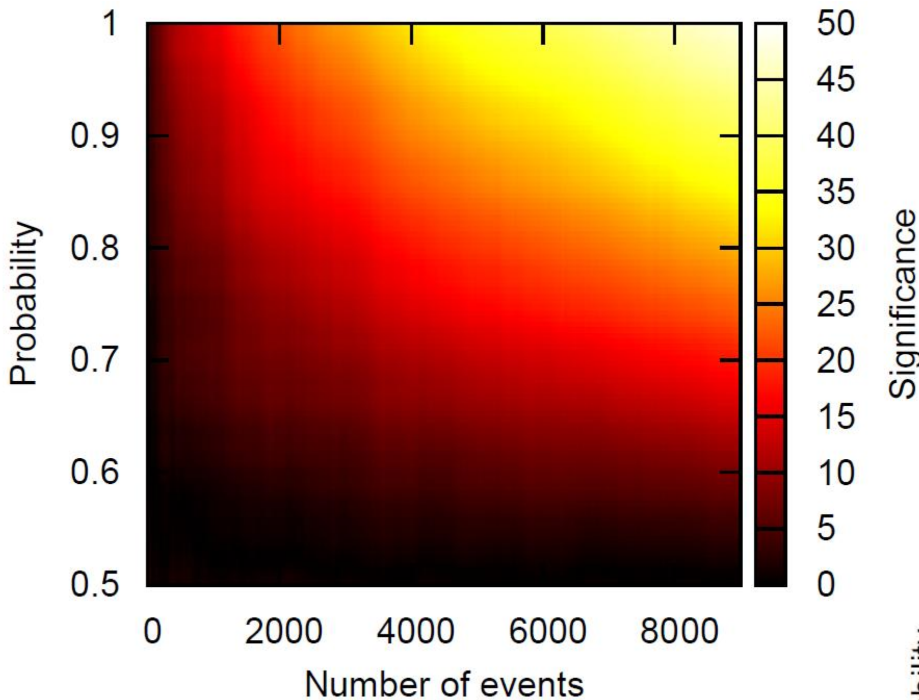
We then reweight the curve depending on the lepton charge and quark/antiquark assignment.

Taking P = 0.65 gives a clear slope.

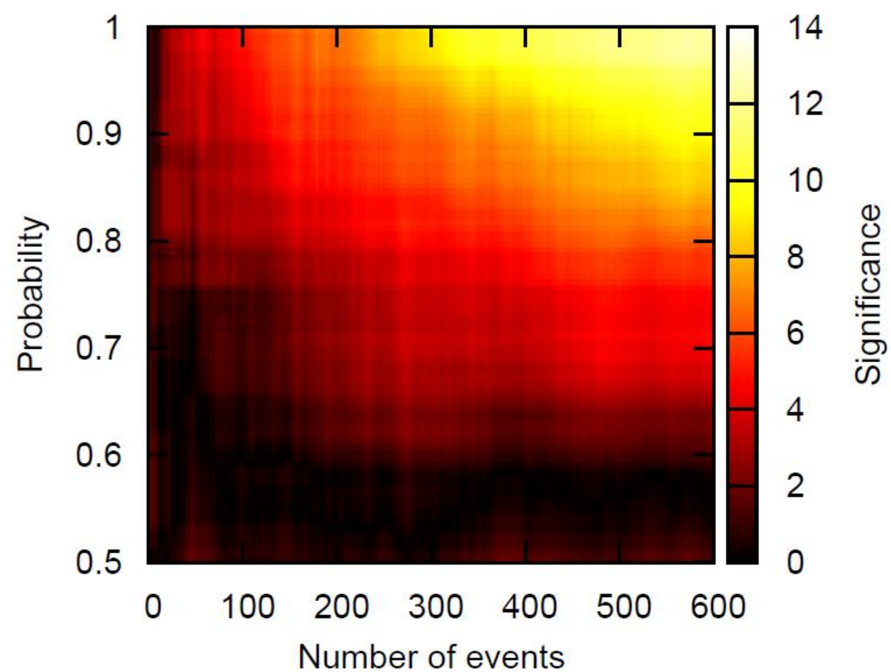
(Note this is the same sample of events as before – these are not real b events)



This method gives a good significance for quite low probabilities...

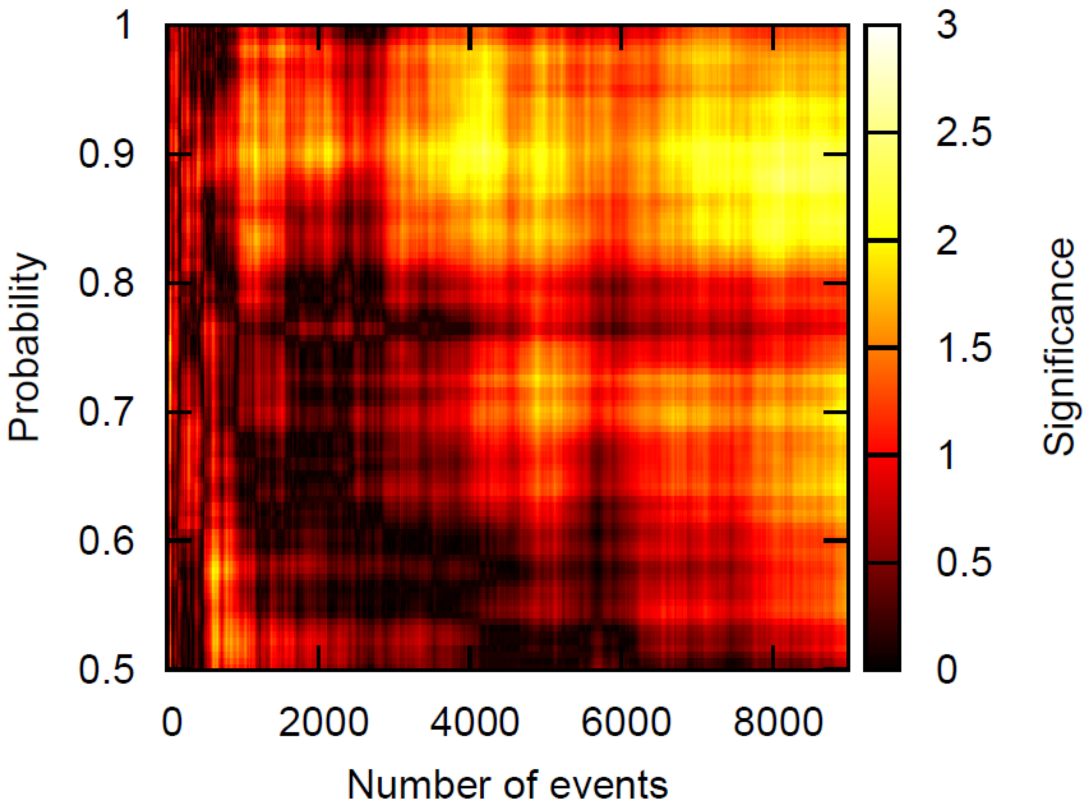


...and quite low event numbers.



stripiness is due to statistical fluctuations

With the same events (and reweighting) slepton decays stay flat



Future Work & Conclusions

This is very clearly only a first attempt. Much more work needs to be done.

- Generate a “proper” sample of b-quarks for an SPS 1a-like scenario
- Include backgrounds
- Include all the other processes
- Investigate other chain combinations, for example $\tilde{g} \rightarrow \tilde{q} \rightarrow \tilde{\chi}_1^0$ on one side with $\tilde{g} \rightarrow \tilde{q} \rightarrow \tilde{\chi}_2^0 \rightarrow \tilde{l} \rightarrow \tilde{\chi}_1^0$ on the other.

But this method looks quite hopeful for being able to disentangle the spins of supersymmetric partners in an intuitive way.