



Spin Determination @ LHC

Itay Yavin

Princeton University

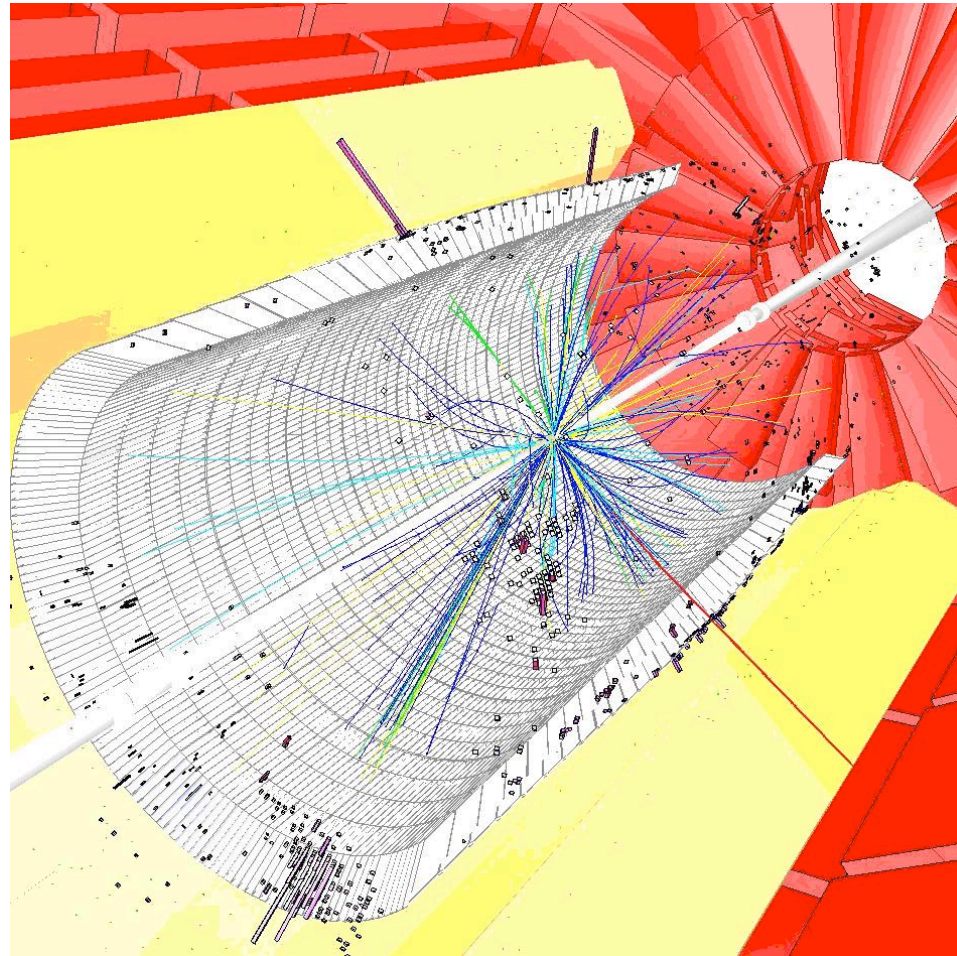
L. Wang and I.Y. hep-ph/0605296

C. Kilic, L. Wang and I.Y. hep-ph/0703085

L. Wang and I.Y. hep-ph/0802.2726

A. Hook, L. Wang and I.Y. To be published

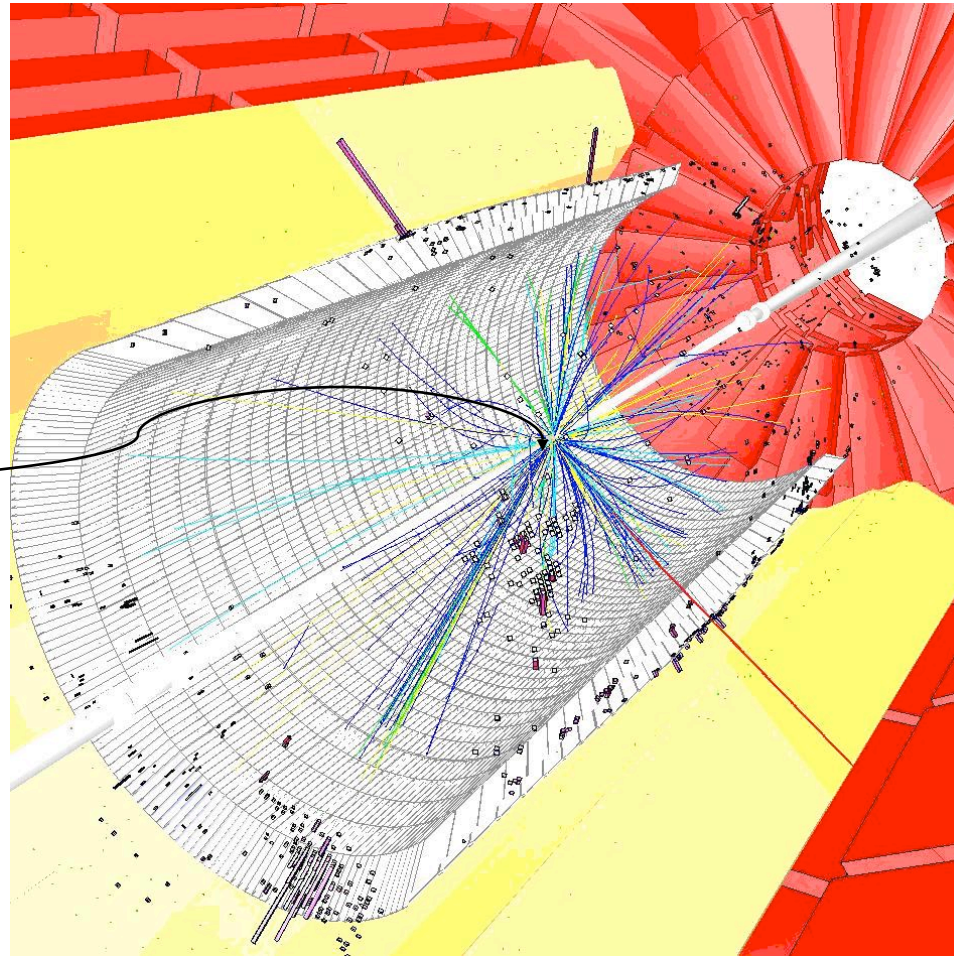




Simulation of a SUSY event at CMS. Taken from Iguana CMS.



Spin ???



Simulation of a SUSY event at CMS. Taken from Iguana CMS.



The Question:



Spin determination

UC Davis

Itay Yavin

The Question:

Can spin be determined @ LHC ? ?



The Question:

Is there any spin information to begin with?

Can spin be determined @ LHC ? ?



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What are the conditions for spin effects to manifest themselves?

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Can spin be determined @ LHC ? ?



The road ahead



Spin determination

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The road ahead

- Rules for the existence of spin information in cascade decays.

(Using these rules you can simply look at any Feynman diagram and tell whether or not spin correlations exist!!!)



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- Gauge-boson partners' spin.



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- Matter partners' spin.



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- Rules for the existence of spin information in cascade decays.

(Using these rules you can simply look at any Feynman diagram and tell whether or not spin correlations exist!!!)

- Gauge-boson partners' spin.
- Matter partners' spin.
- Future directions and unresolved issues.

(The experimental challenges are numerous, but they are at least well-defined and finite).



Assumptions



Spin determination

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Assumptions

We can isolate a subset of events containing new physics.



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We have a rough idea of the event topology.

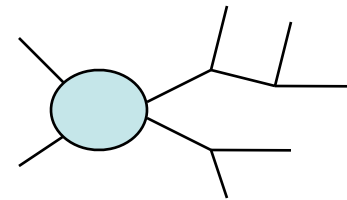


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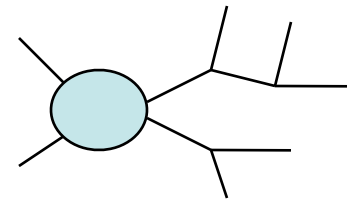


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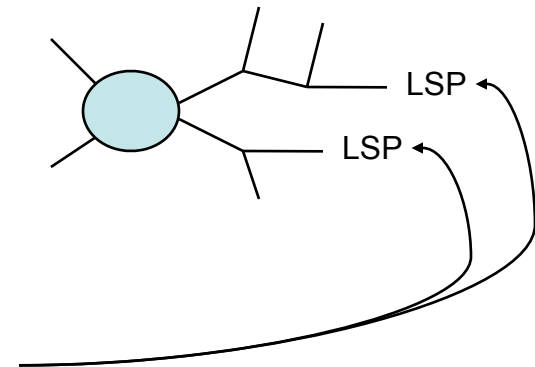


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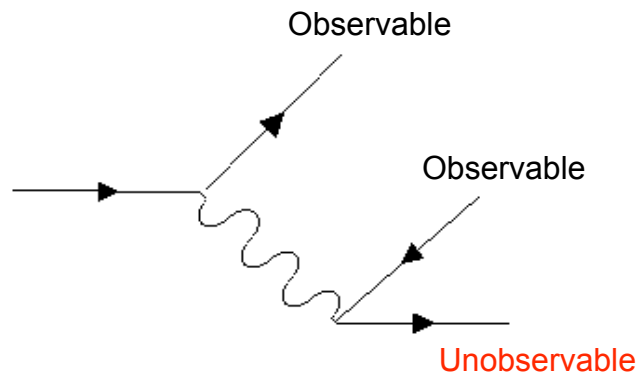
Cascade decays

In this talk I will concentrate on measuring the spin through cascade decays.



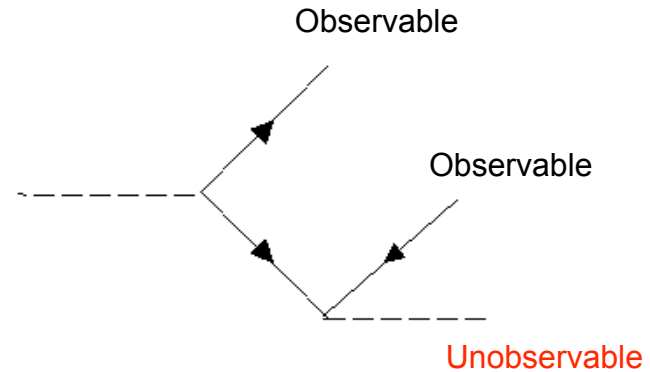
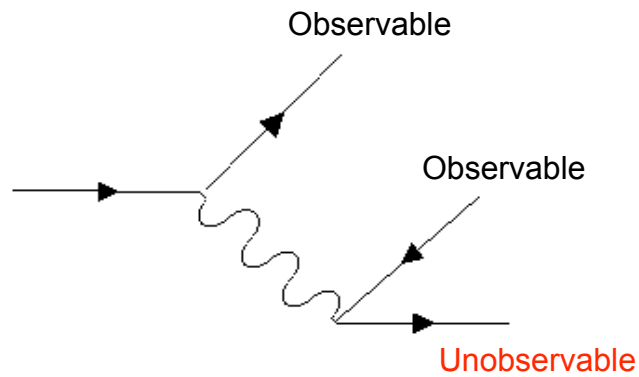
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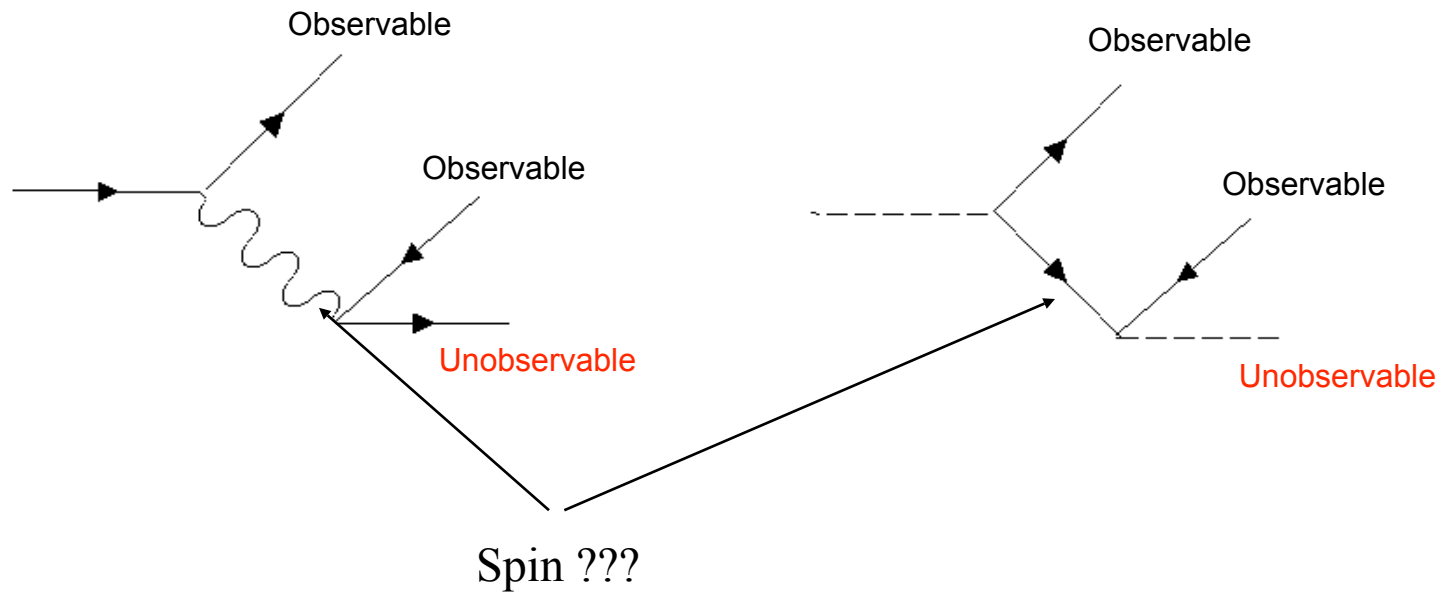
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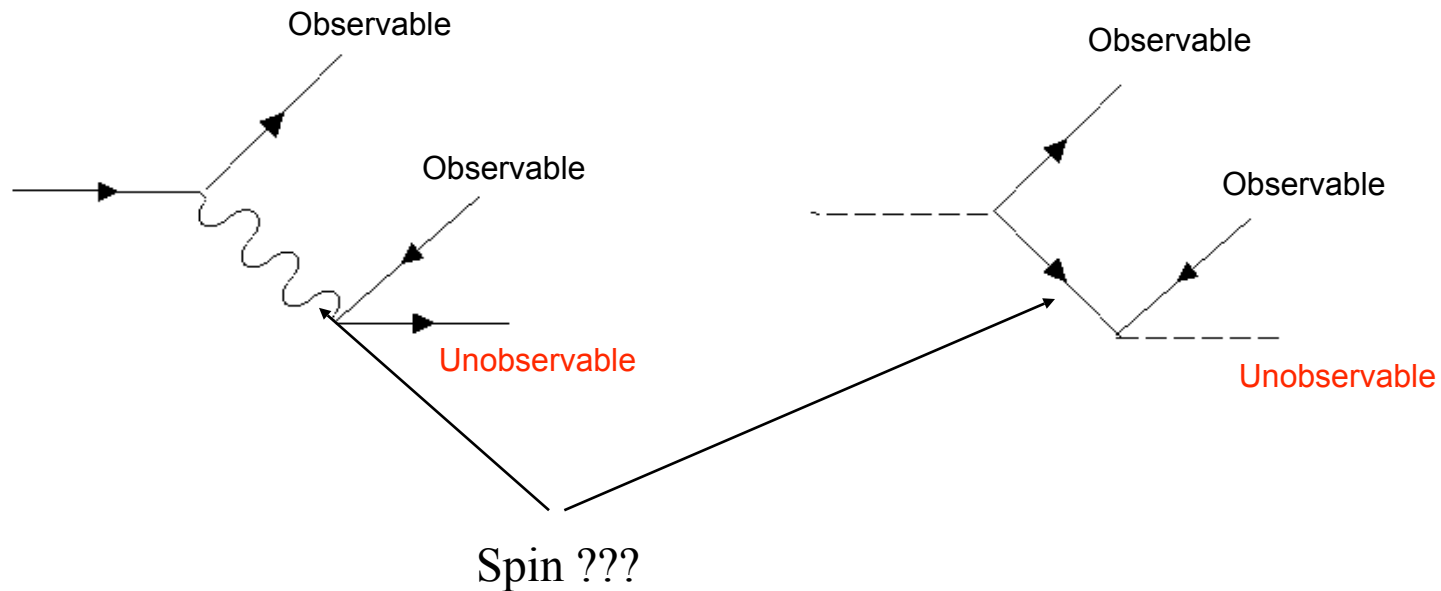
Cascade decays

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Cascade decays

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A complementary approach, which I will not discuss, is using total rate information. For interesting ideas in this direction,

Datta et al [hep-ph/0510204](https://arxiv.org/abs/hep-ph/0510204), *Meade and Reece*, [hep-ph/0601124](https://arxiv.org/abs/hep-ph/0601124), and Kane et al. [hep-ph/0805.1397](https://arxiv.org/abs/hep-ph/0805.1397)



Standard Model Analogue



Spin determination

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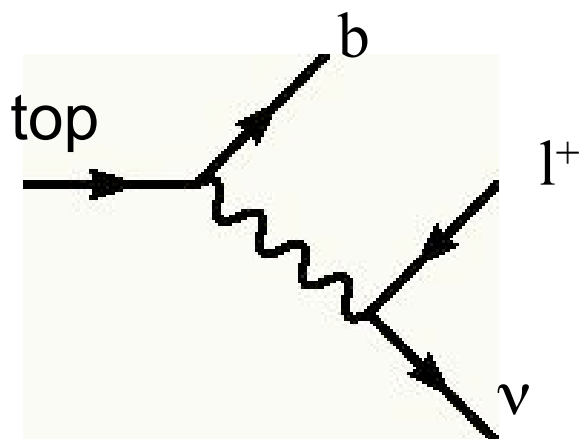
Standard Model Analogue

Determining the W-boson's spin in top decays



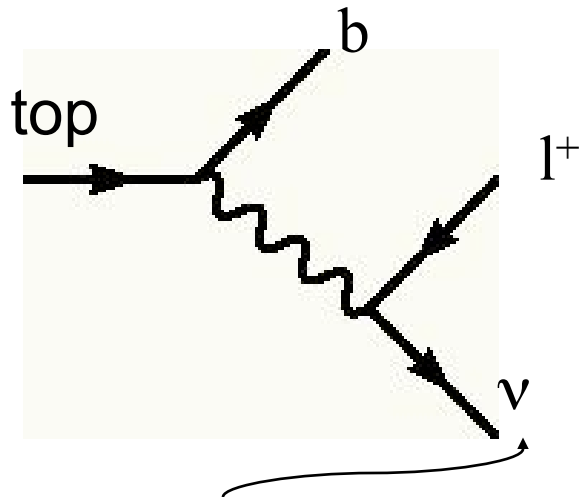
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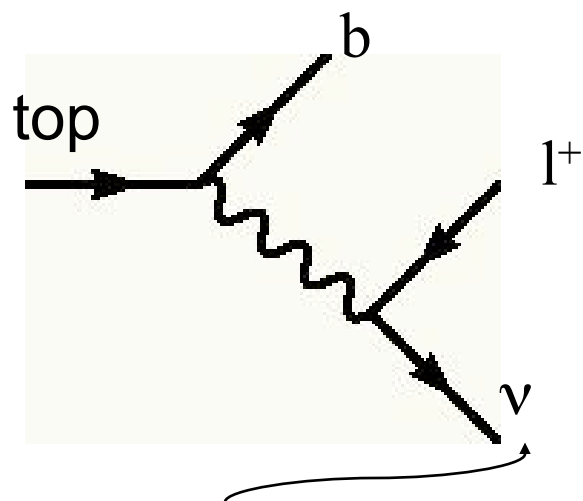
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cannot reconstruct W's
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Standard Model Analogue

Determining the W-boson's spin in top decays



Define a Lorentz invariant,

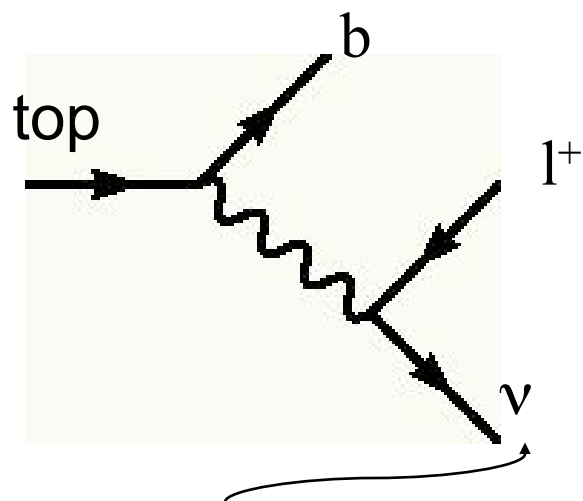
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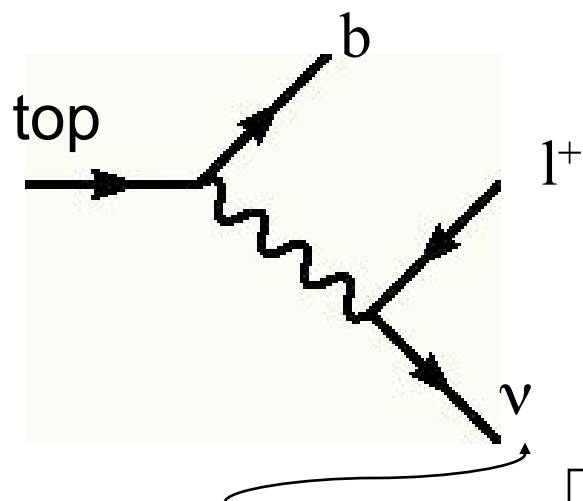
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$$d\Gamma/dt_{bl} = c_2 t_{bl}^2 + c_1 t_{bl} + c_0$$



Angular correlations in fermions decay



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Under a rotation a fermion transforms as,



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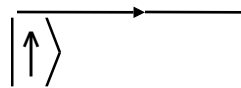
$$|\uparrow\rangle \xrightarrow{\theta} \cos(\theta/2)|\uparrow\rangle + \sin(\theta/2)|\downarrow\rangle$$



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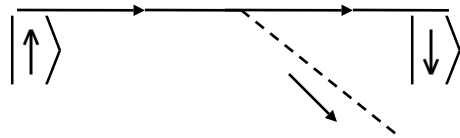
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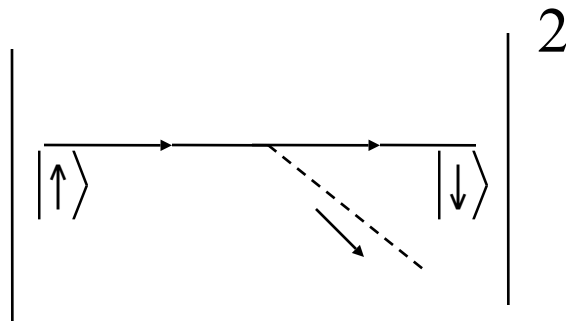
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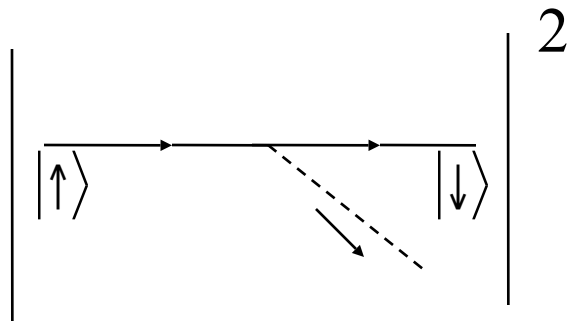
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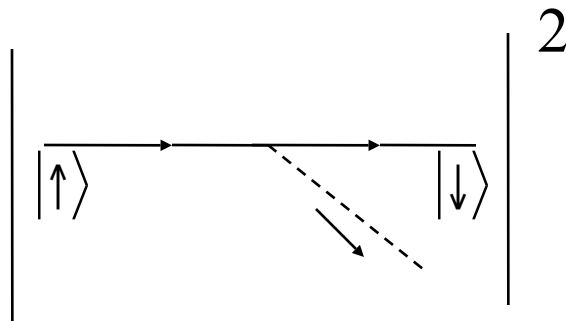
$$\propto 1 - \cos(\theta)$$



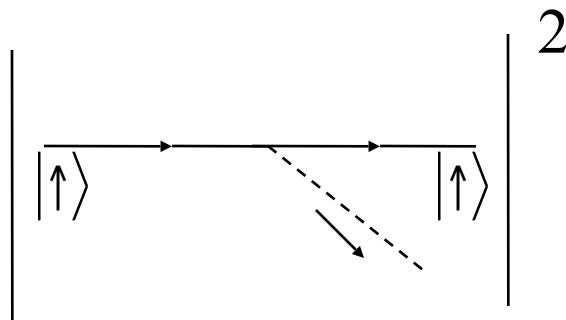
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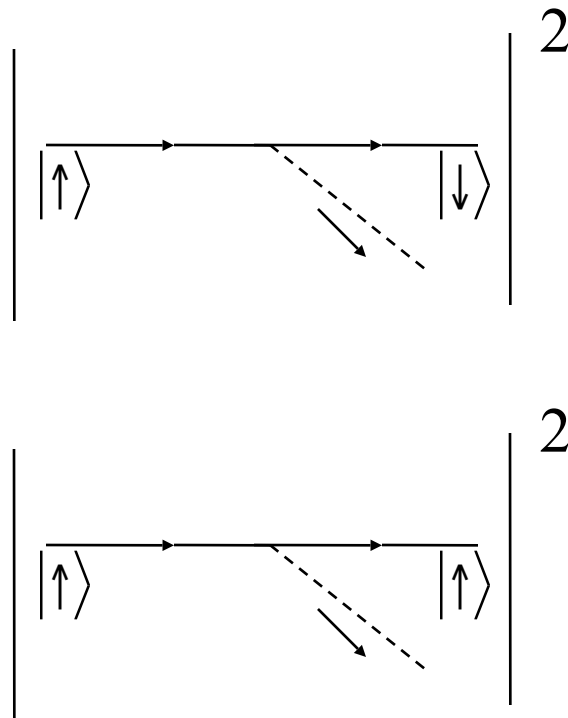
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Angular correlations in fermions decay

Under a rotation a fermion transforms as,

$$|\uparrow\rangle \xrightarrow{\theta} \cos(\theta/2)|\uparrow\rangle + \sin(\theta/2)|\downarrow\rangle$$



$$\propto 1 - \cos(\theta)$$

The interaction must be chiral otherwise the angular correlations are washed out!

$$\propto 1 + \cos(\theta)$$

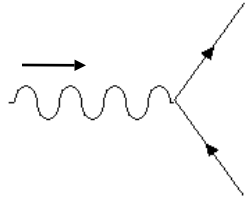
In addition, the decaying fermion must be polarized as well!



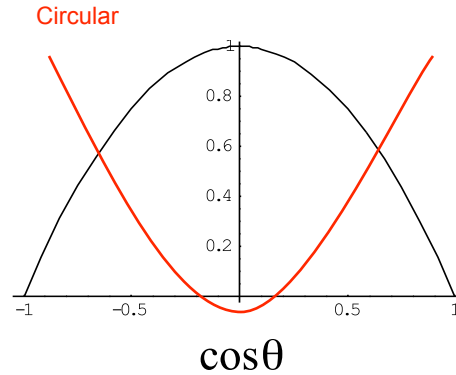
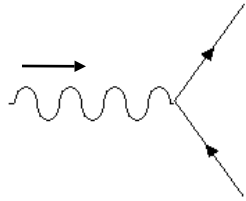
Angular correlations in vector-boson decay



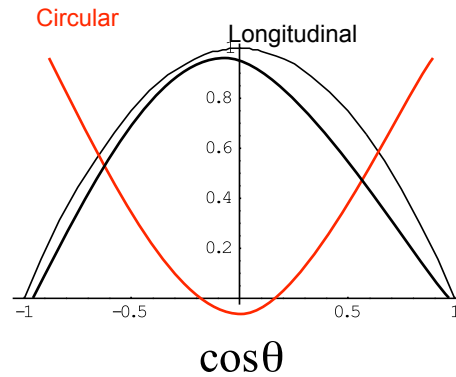
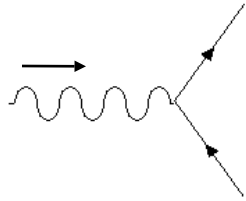
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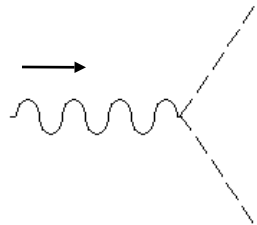
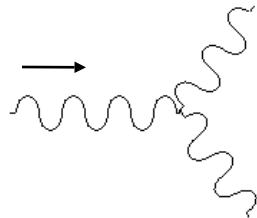
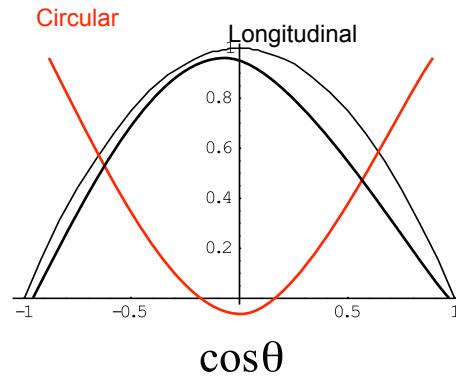
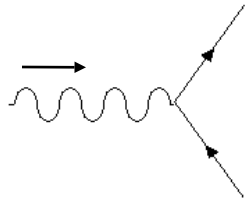
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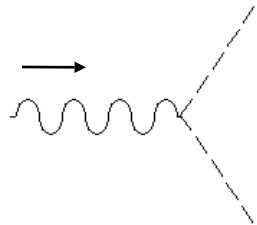
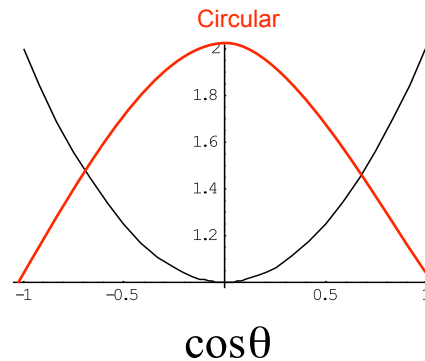
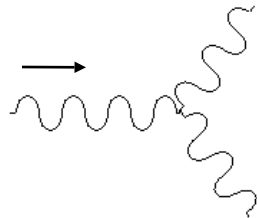
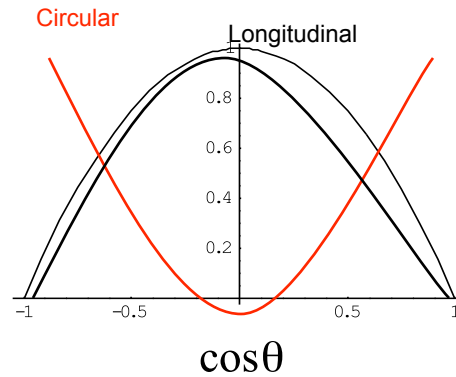
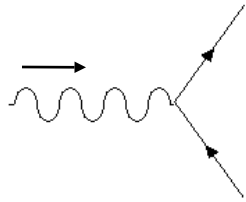
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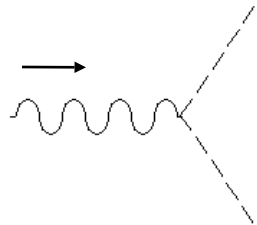
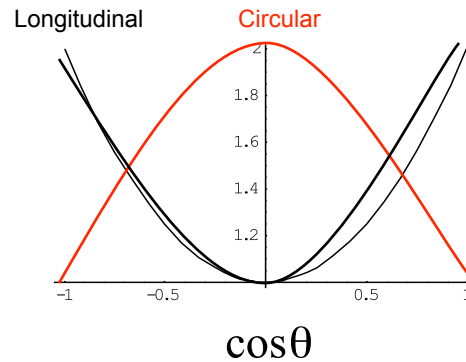
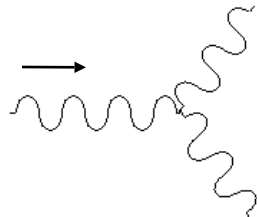
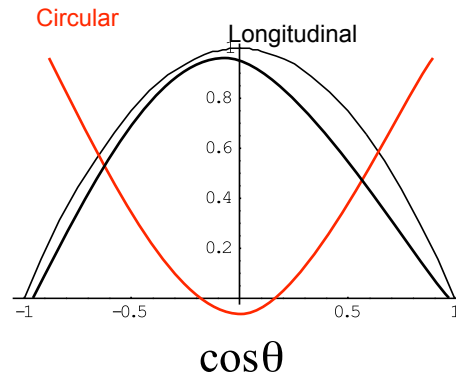
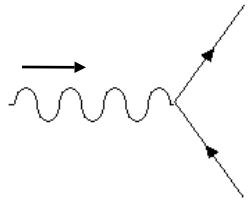
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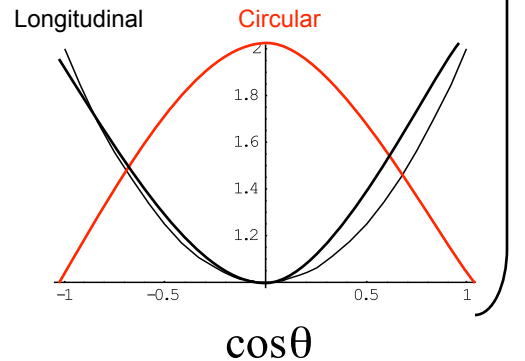
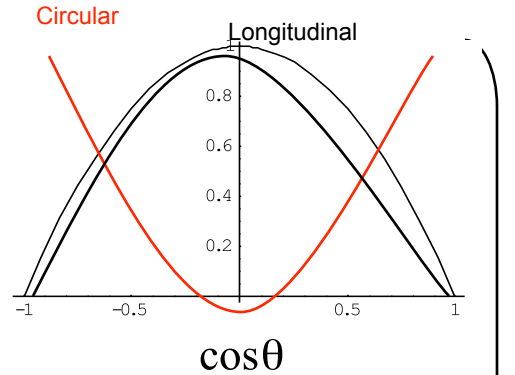
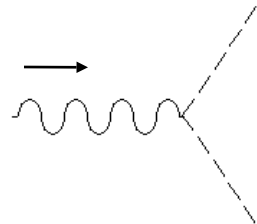
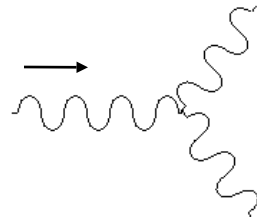
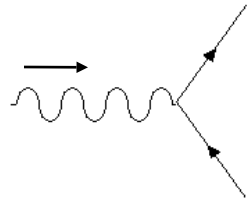
Angular correlations in vector-boson decay



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Behaves like,

$$\sim \cos^2(\theta)$$

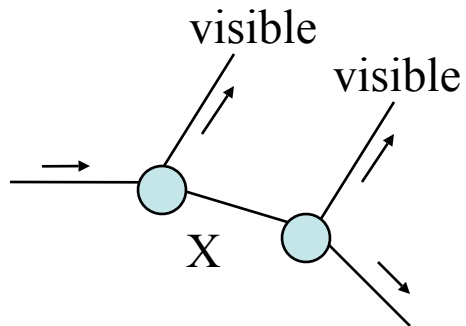
No requirements on the vertex, but the vector-boson must be polarized.



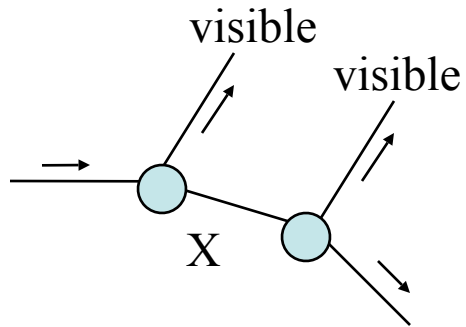
Conditions for spin effects



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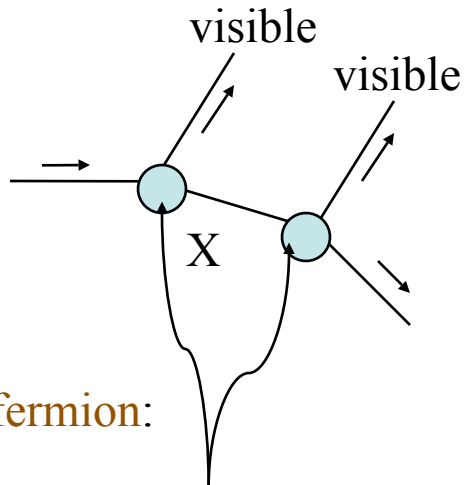
Conditions for spin effects



If X is a **fermion**:



Conditions for spin effects



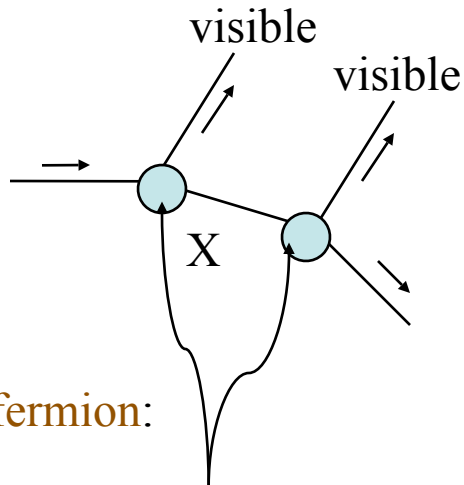
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Dirac: Both vertices must be at least partially chiral.

Majoranna: also need charge determination



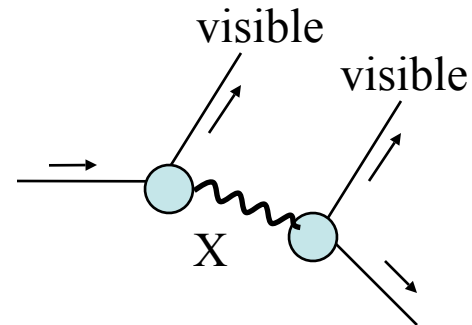
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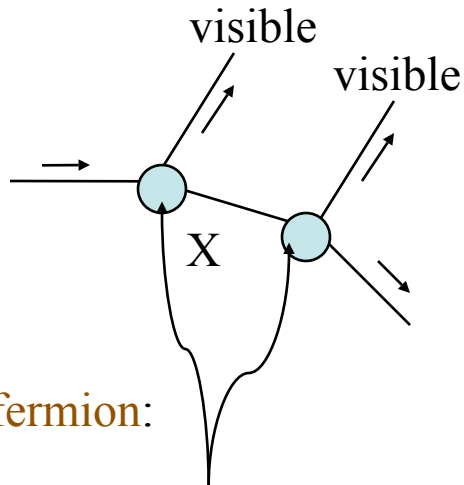
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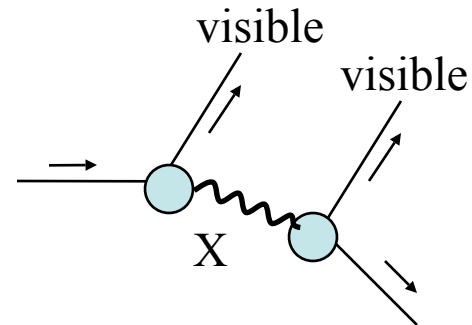
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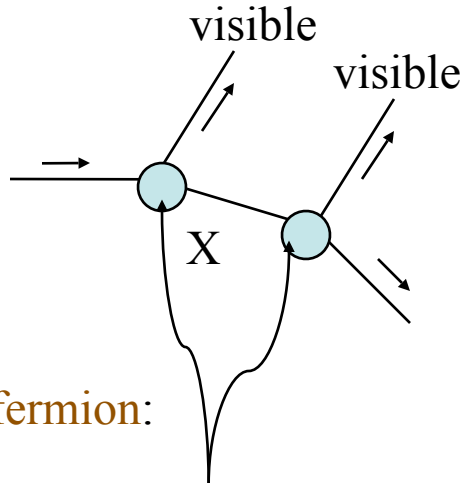


If X is a **gauge-boson**:

X should be boosted so it is longitudinally enhanced.



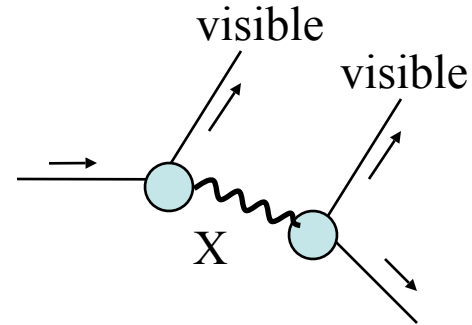
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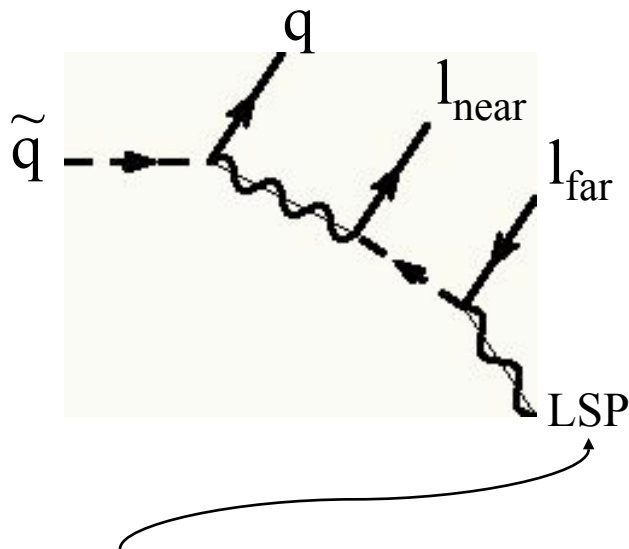
Otherwise, spin effects are washed out!!!



SUSY cascade decays



SUSY cascade decays

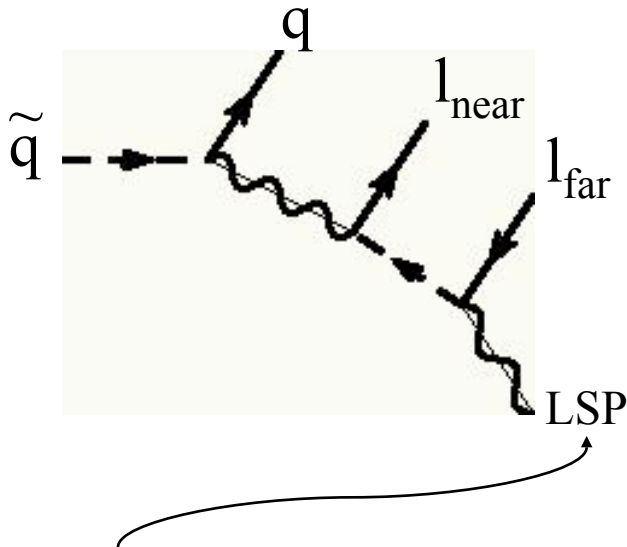


Invisible.

cannot reconstruct rest
frame of neutralino.



SUSY cascade decays



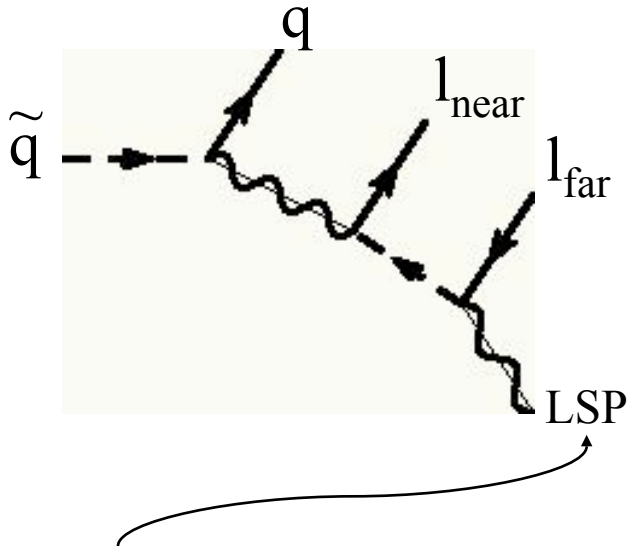
Barr,
Datta, Kong & Matchev
Smillie & Webber
Alves, Eboli & Plehn

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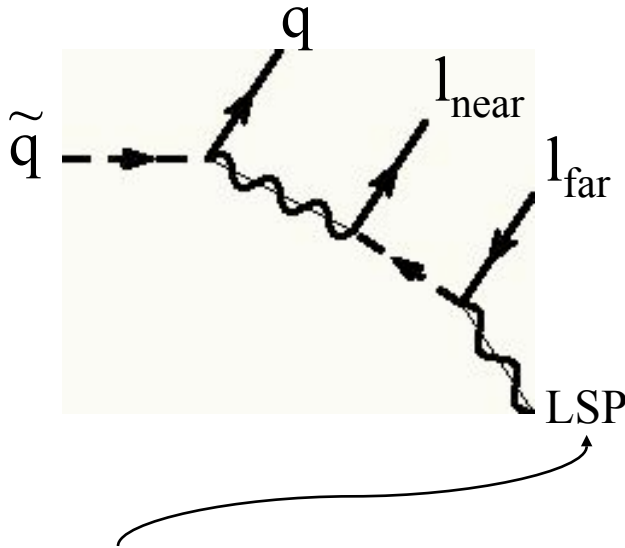
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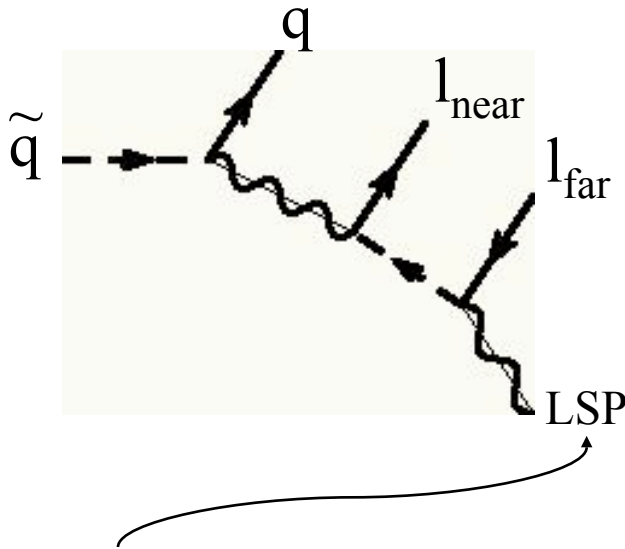
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Define an asymmetry
var.



SUSY cascade decays



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$$t_{ql^\pm} = (p_q + p_{l^\pm})^2$$

Define an asymmetry
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$$A = \frac{s_+ - s_-}{s_+ + s_-} \quad s_\pm = \frac{d\Gamma}{dt_{ql^\pm}}$$



Gauge-boson Partner's Spin

(fermions vs. vector-bosons)



W-boson partners



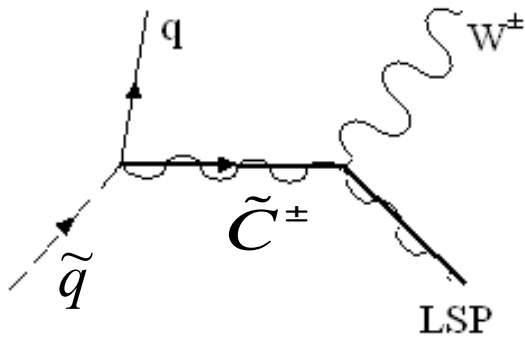
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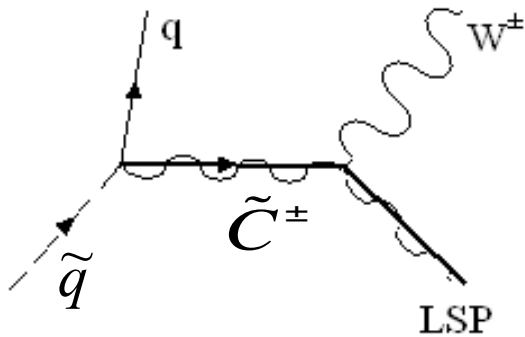
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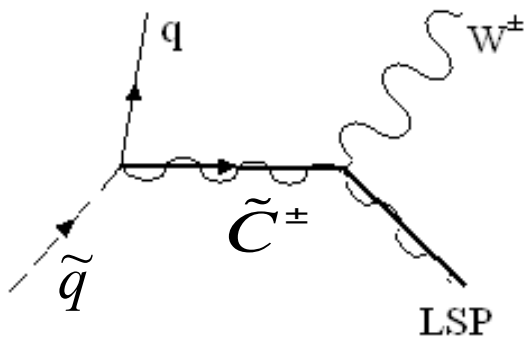


$$d\Gamma/dt_{qW} = c_1 t_{qW} + c_0$$

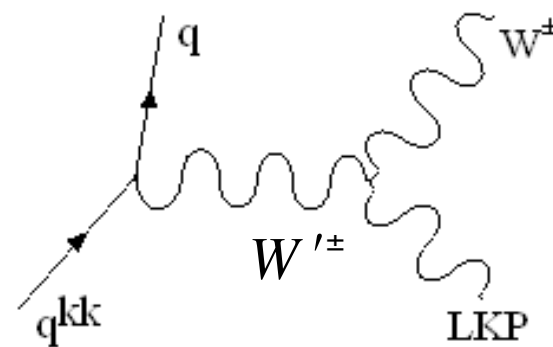


W-boson partners

e.g. SUSY



e.g. Little Higgs, UED, etc.

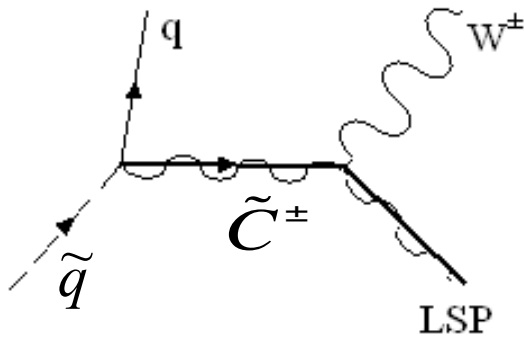


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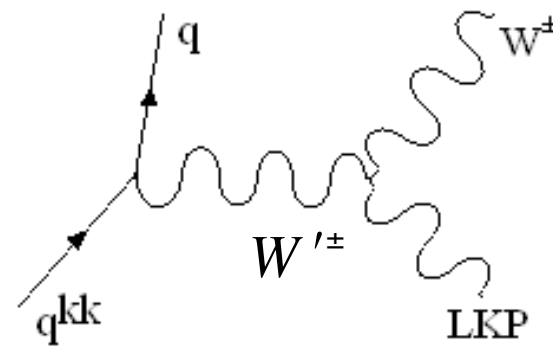
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Different order polynomials!



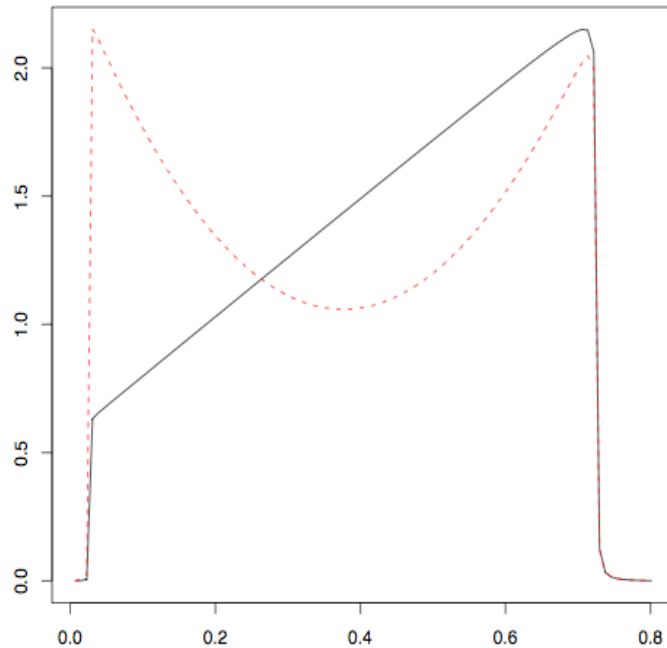
Implementation in HERWIG

We have modified HERWIG to include spin effects for massive spin-1 particles



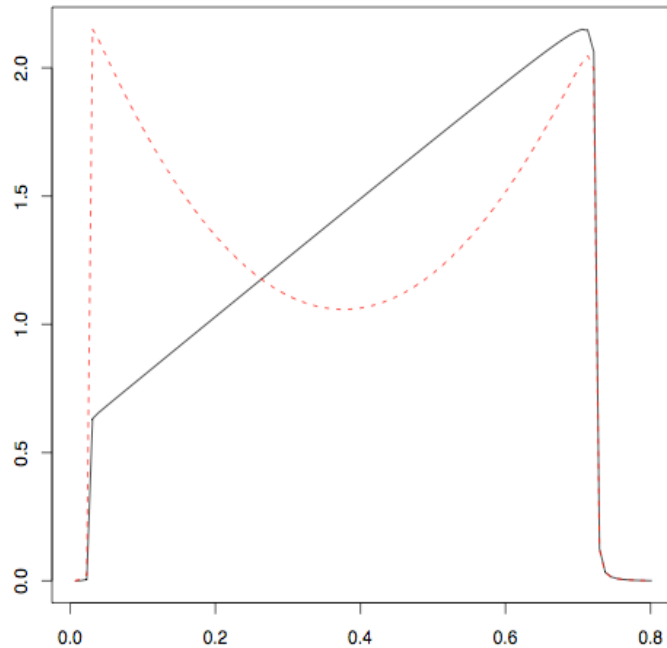
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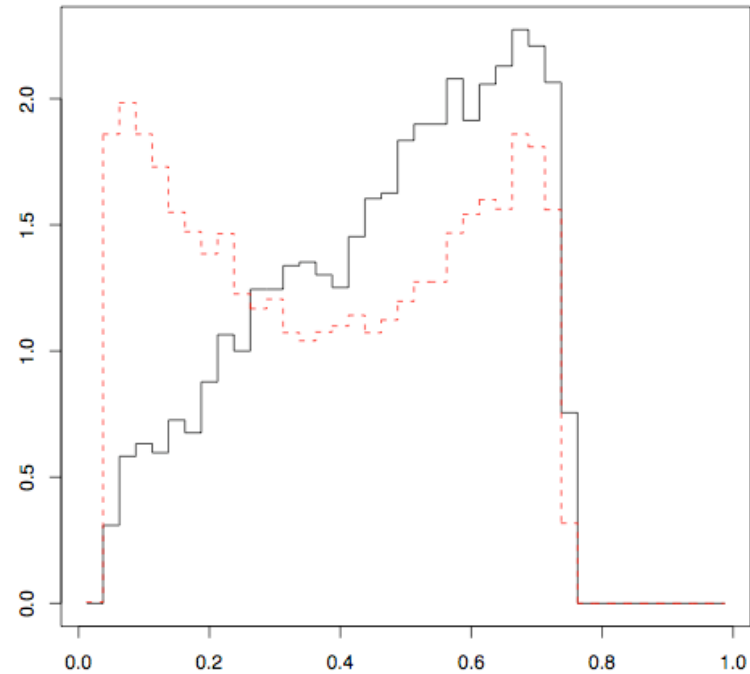
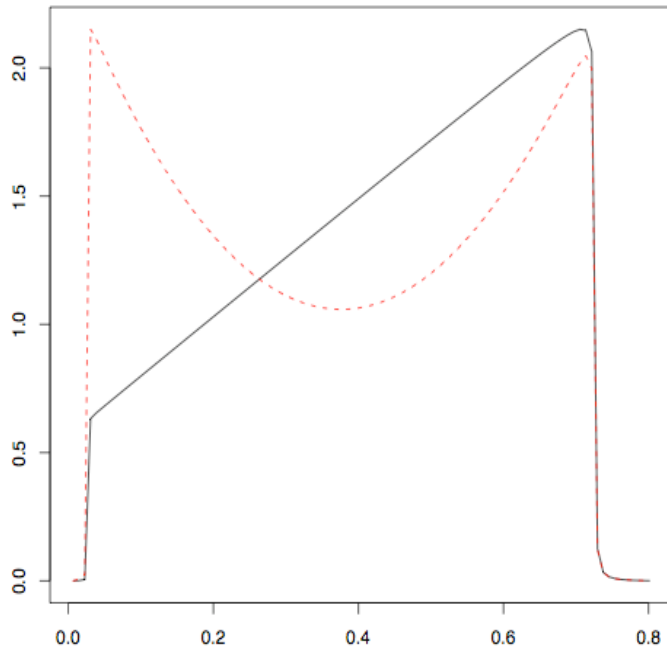


$$t_{qW} = (p_q + p_w)^2$$



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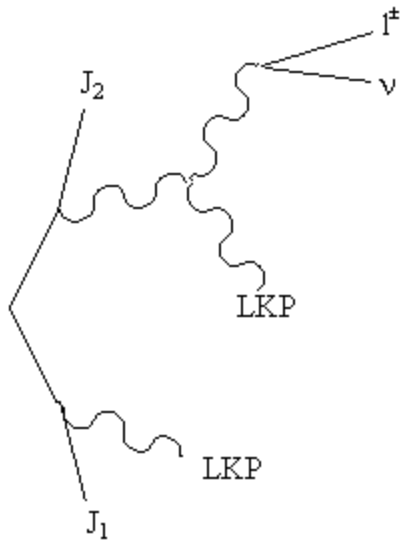
Jet-lepton correlations

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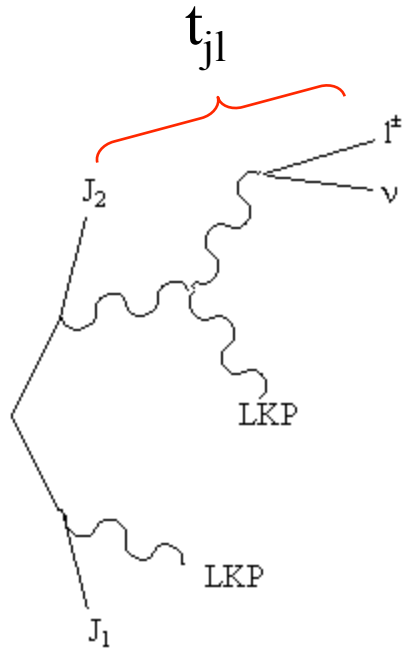
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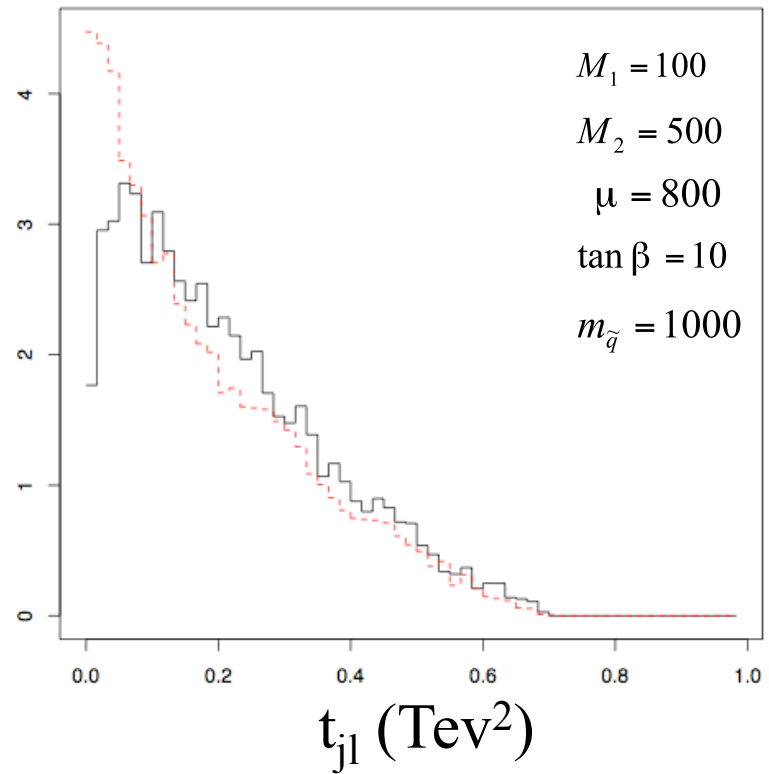
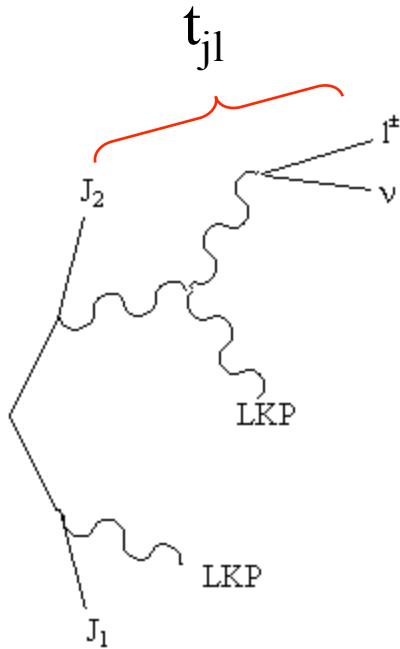
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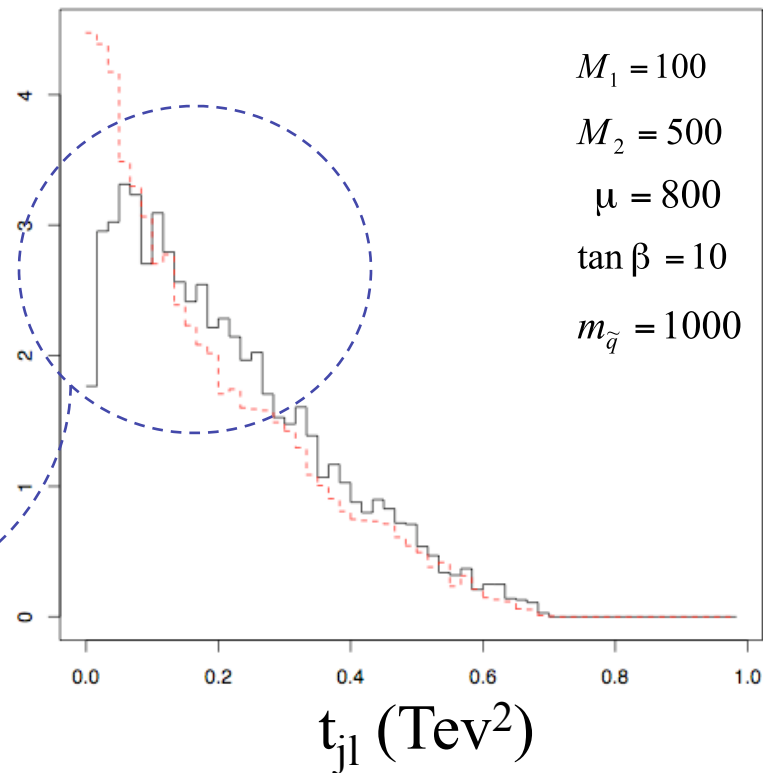
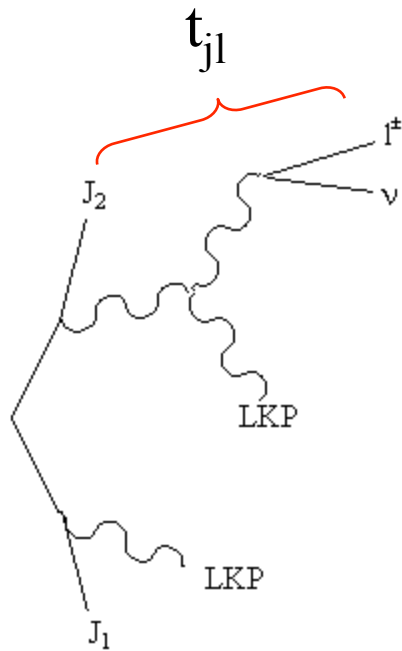
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Further study required



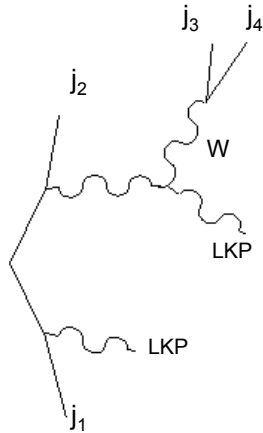
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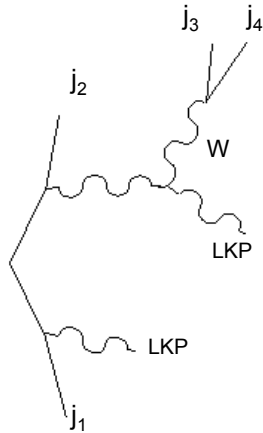
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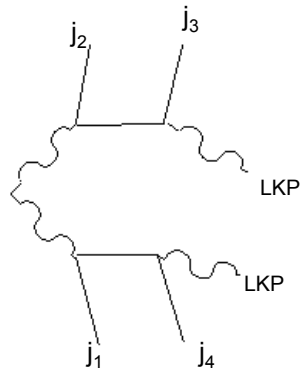


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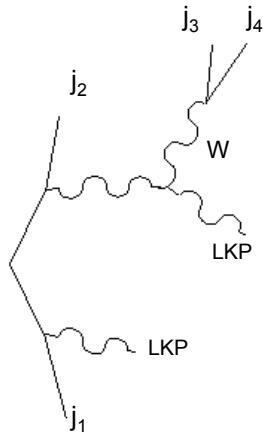
Spin determination

UC Davis

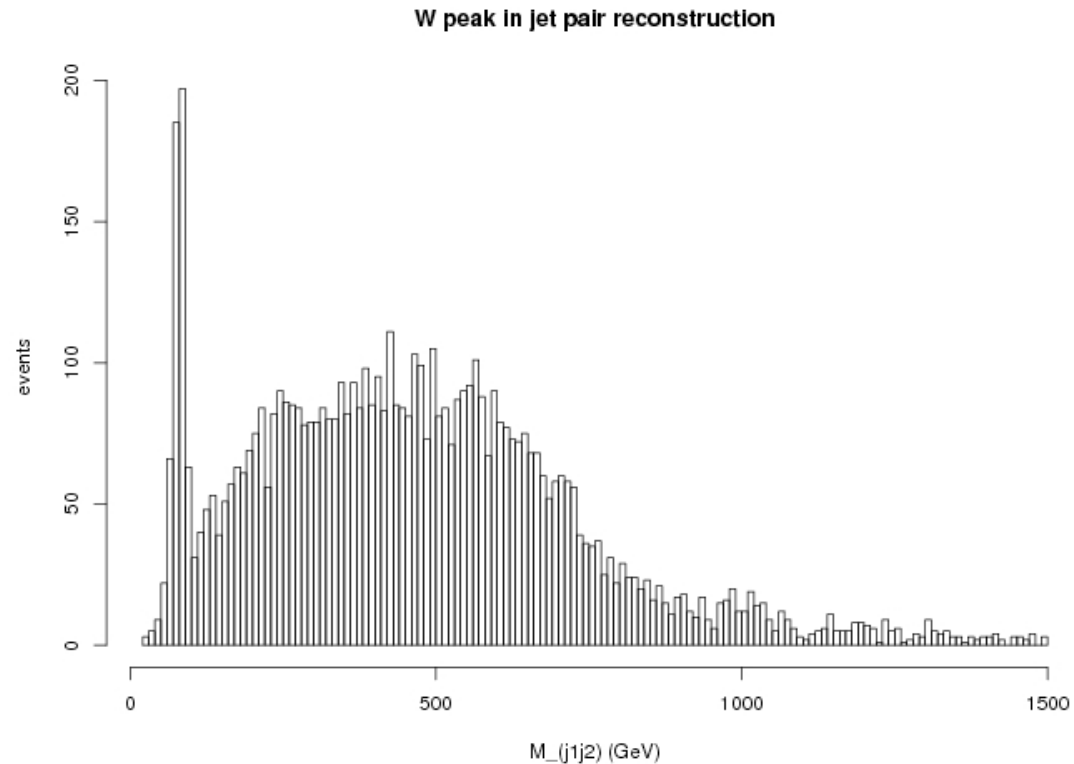
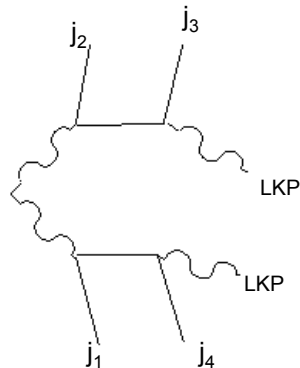
Itay Yavin

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Background:



Including ΔR and P_T cuts and smearing.



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Jet- W correlations

Even after taking combinatorics into account, the difference is very pronounced:



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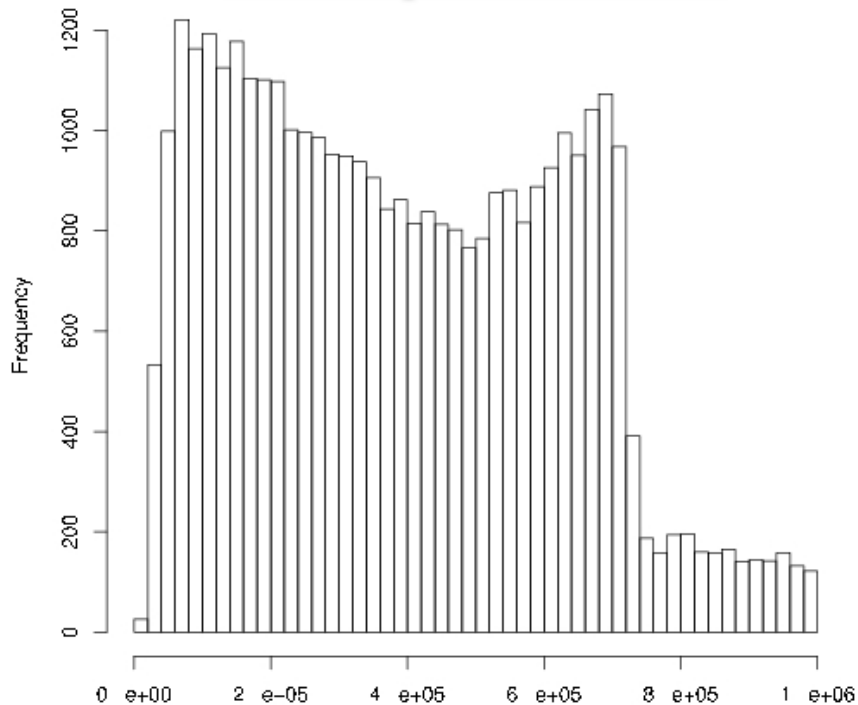
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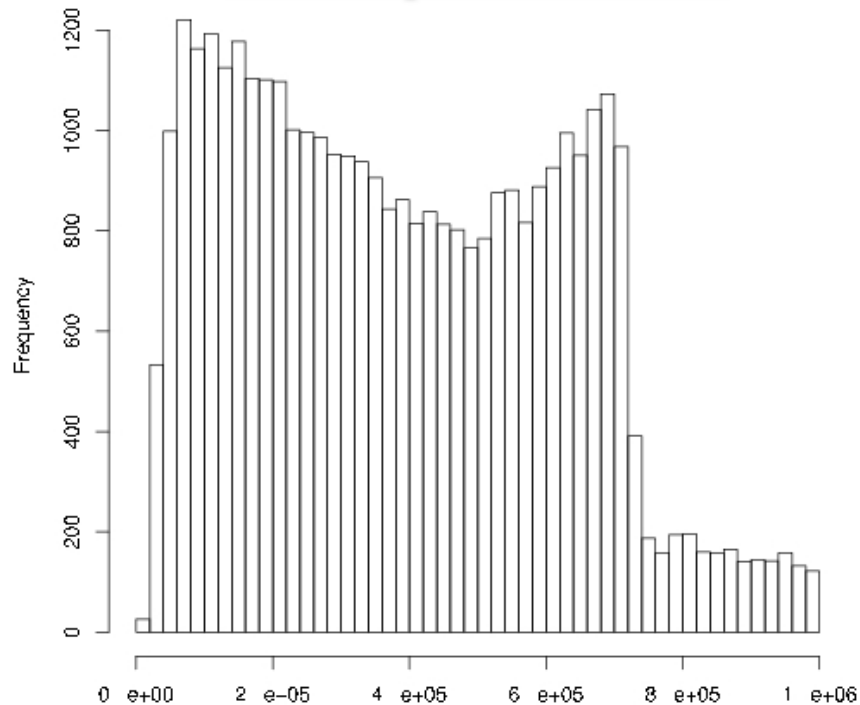


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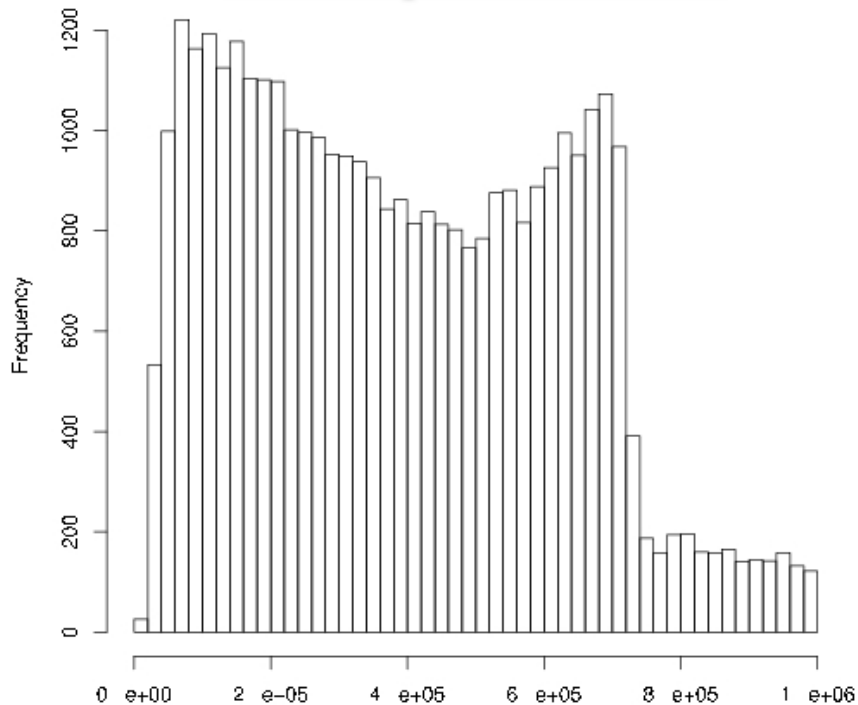
SUSY



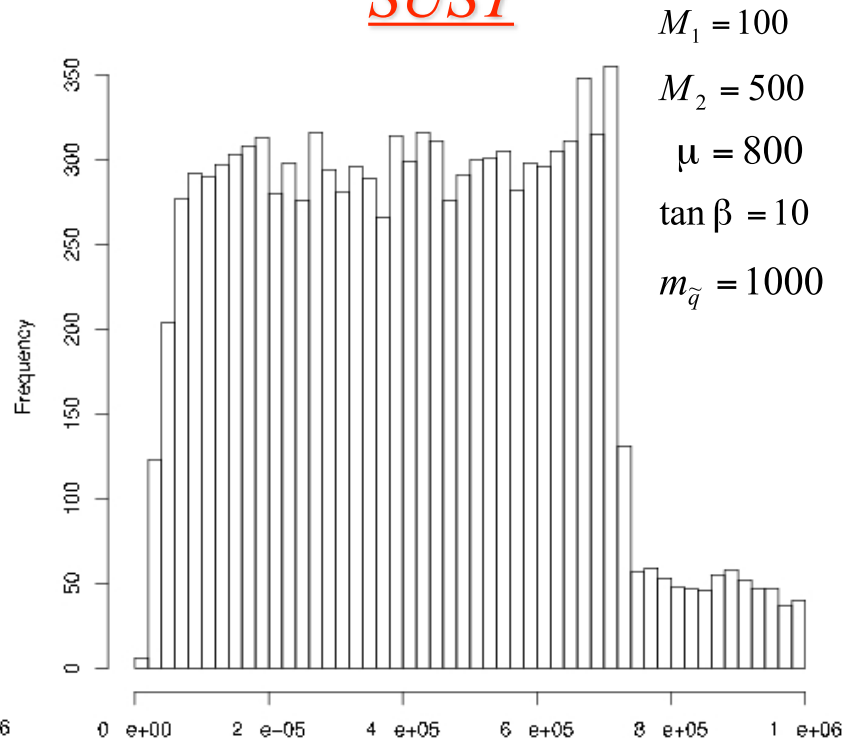
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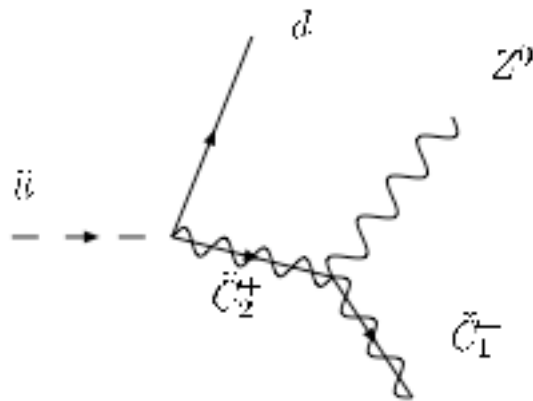


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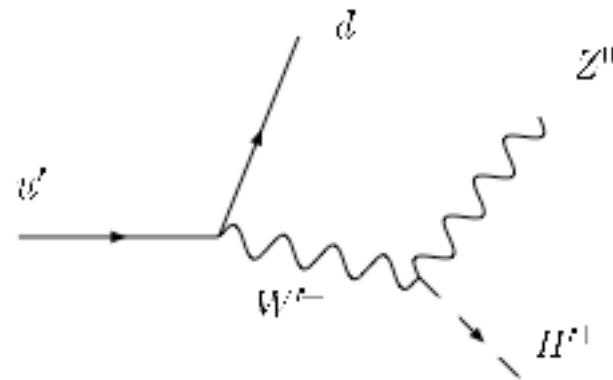
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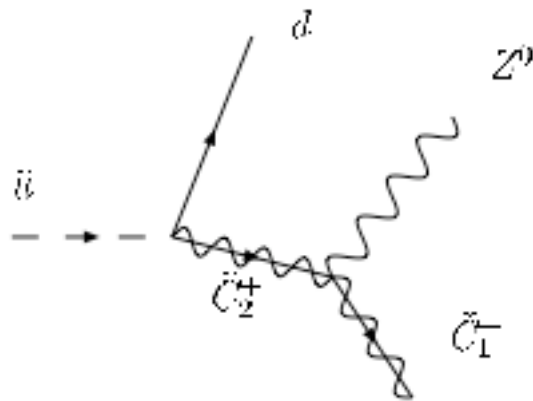


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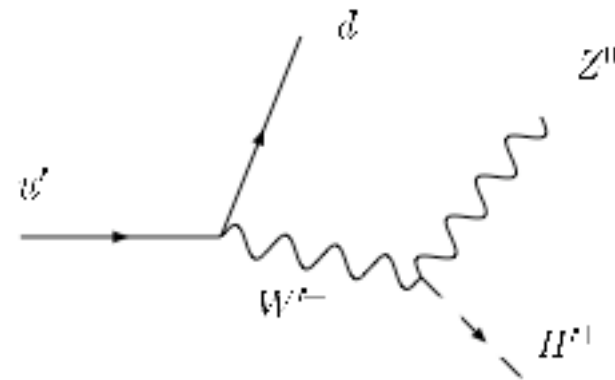
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Coming soon . . .



Backgrounds and mispairing

Demand: 3 leptons, 2 jets and MET and reconstructing a Z^0 .

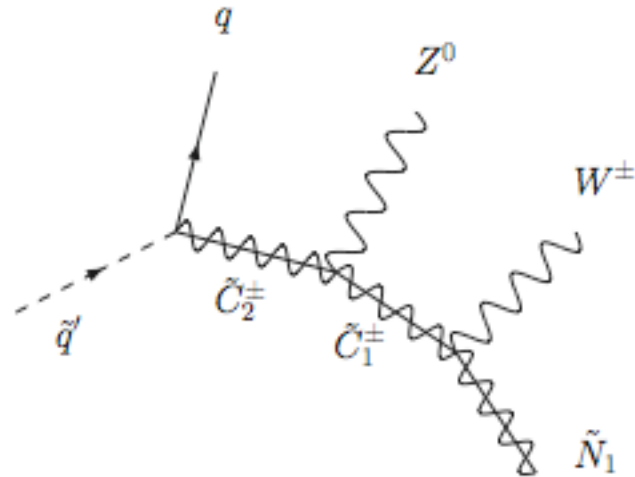
There are only two dominant processes:



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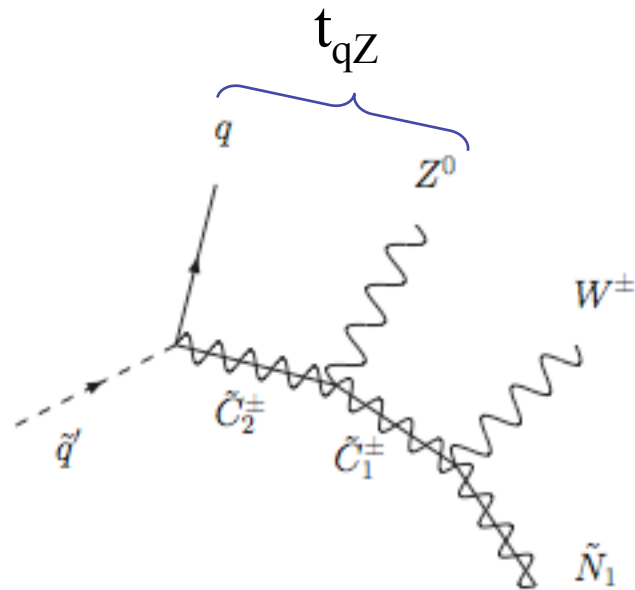
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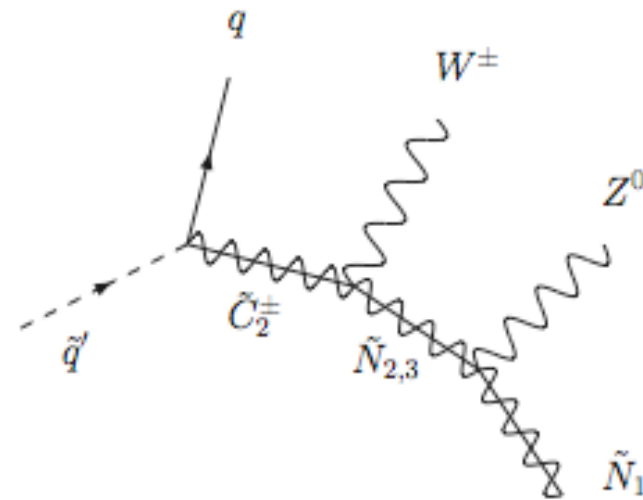
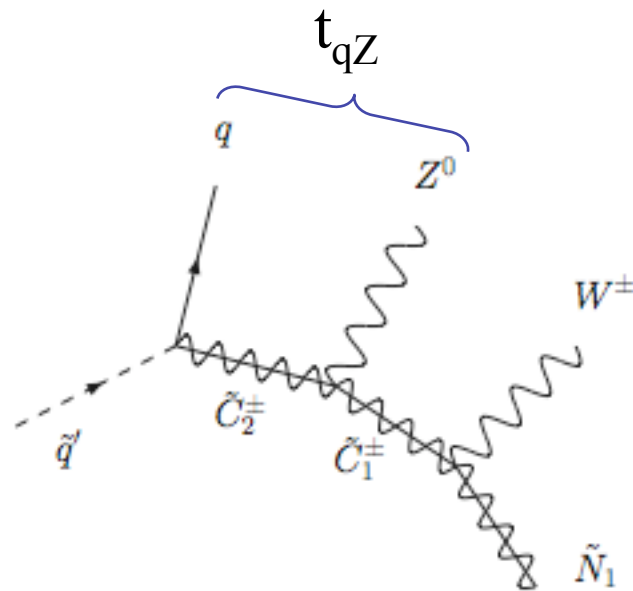
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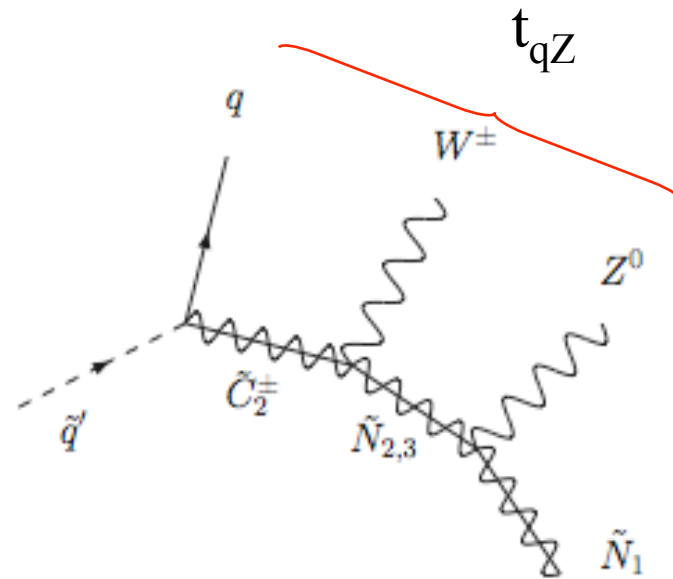
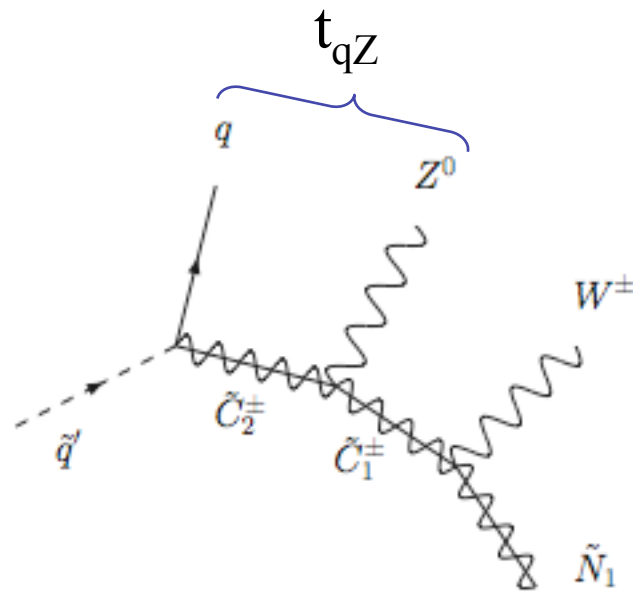
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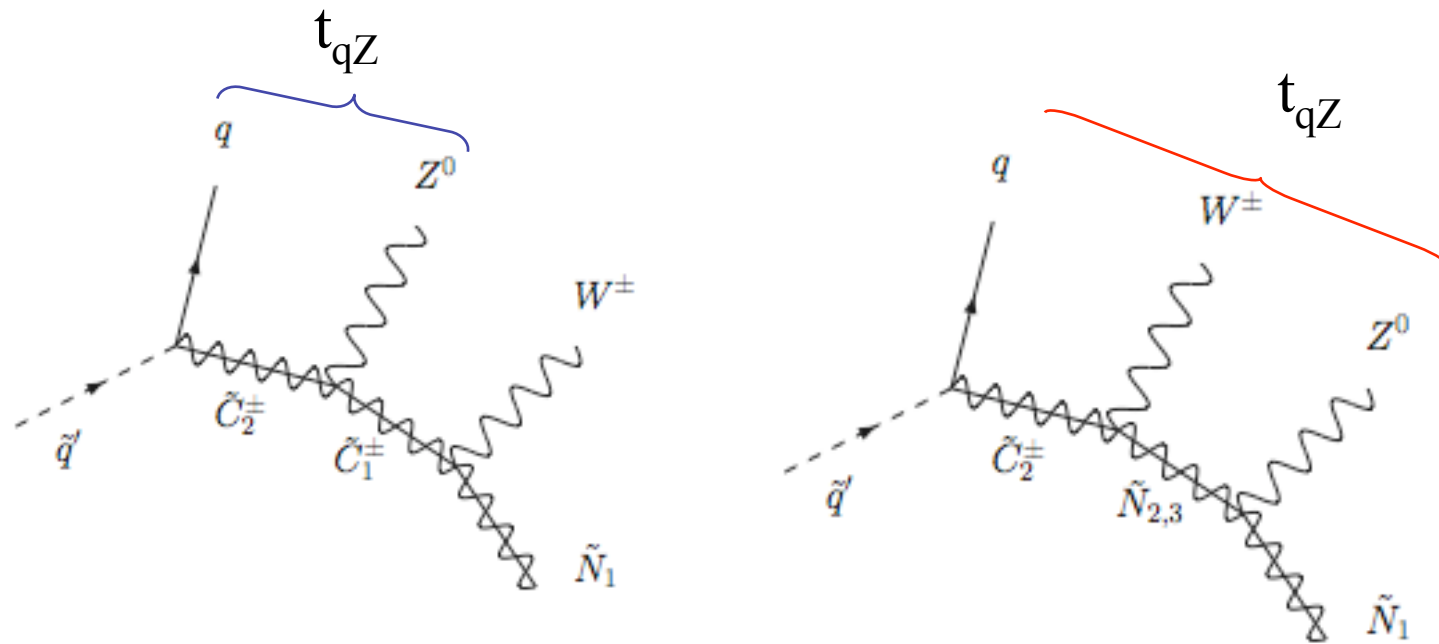
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There is also the other jet in the event and it is not clear which jet should be paired with which Z^0 .



Backgrounds and mispairing



Spin determination

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Itay Yavin

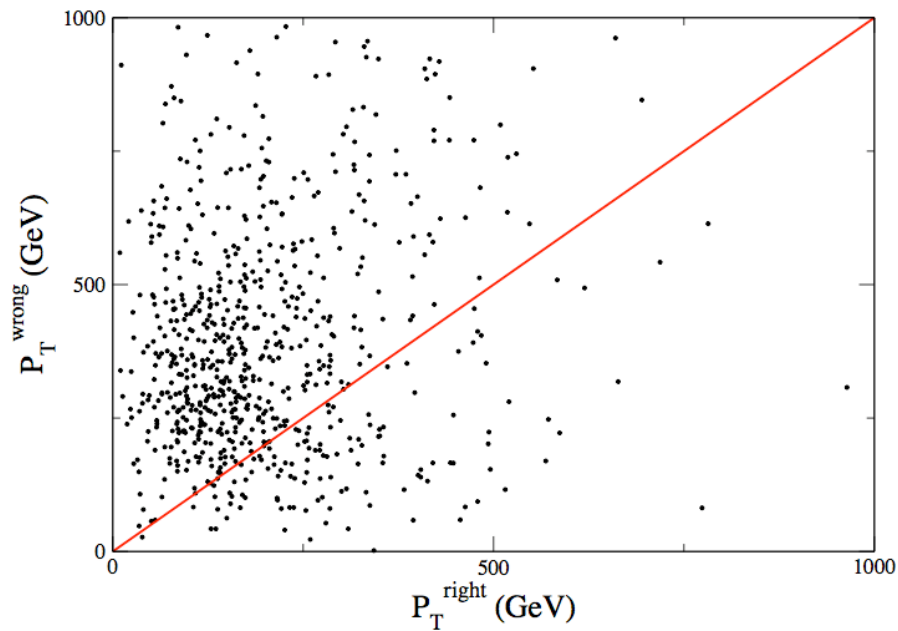
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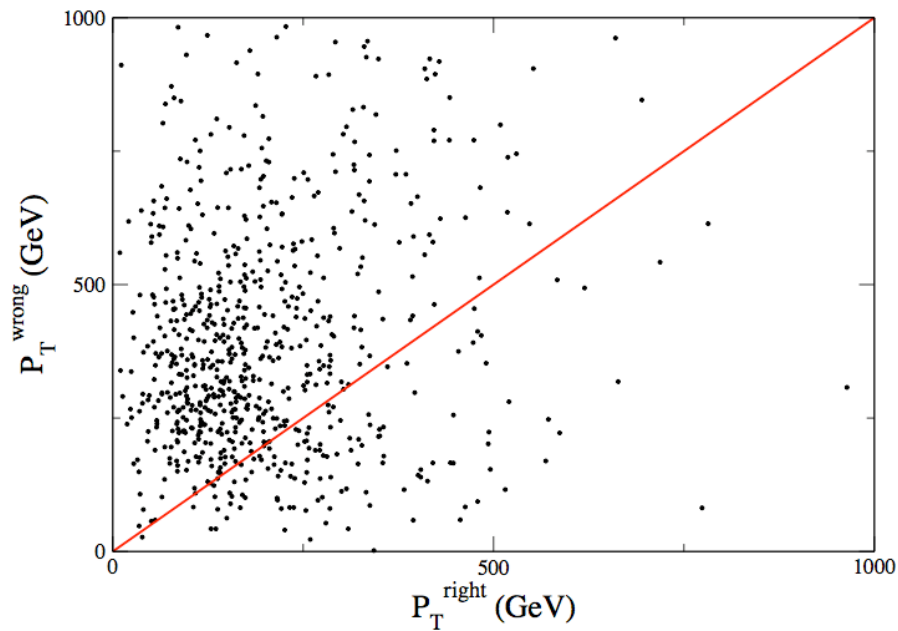
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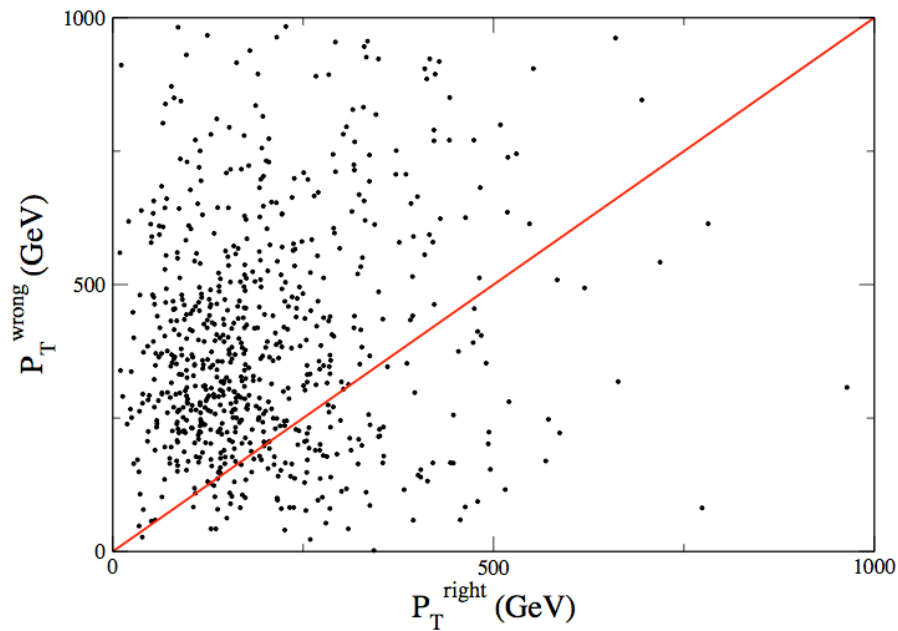
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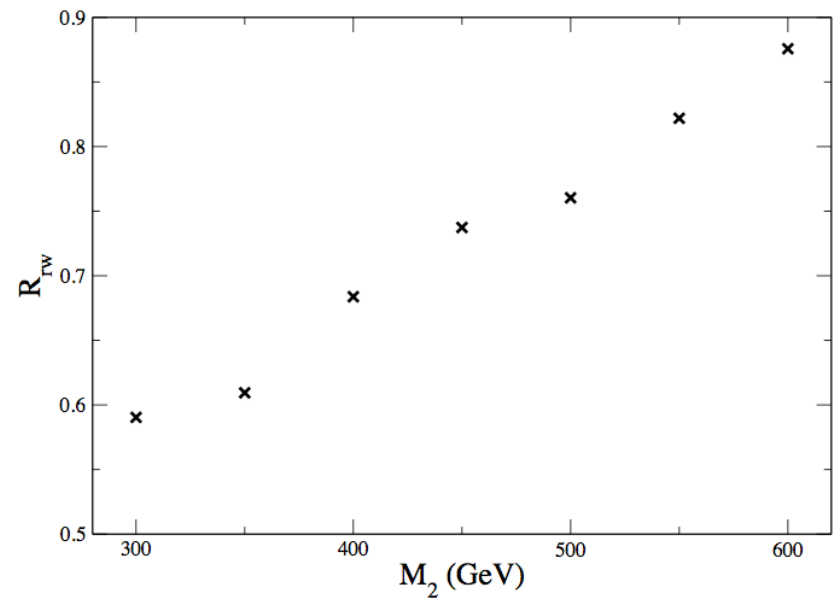


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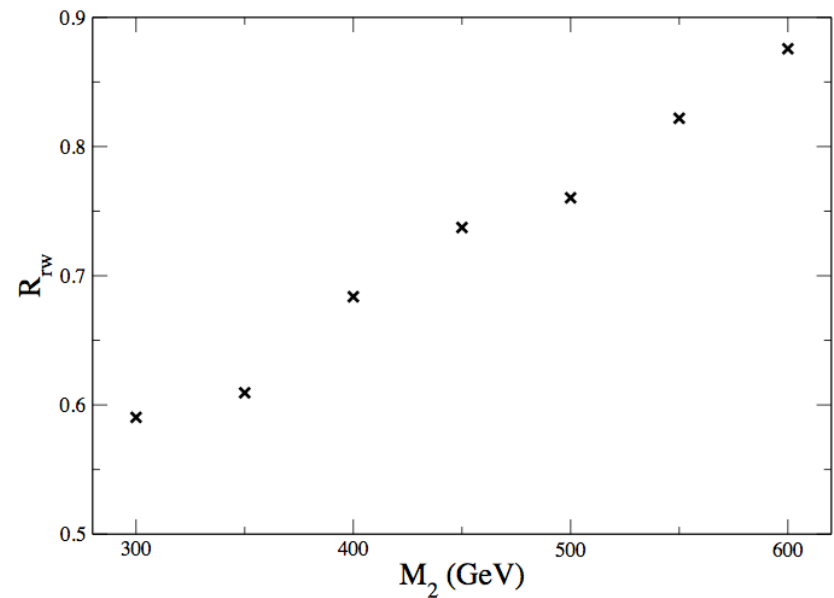
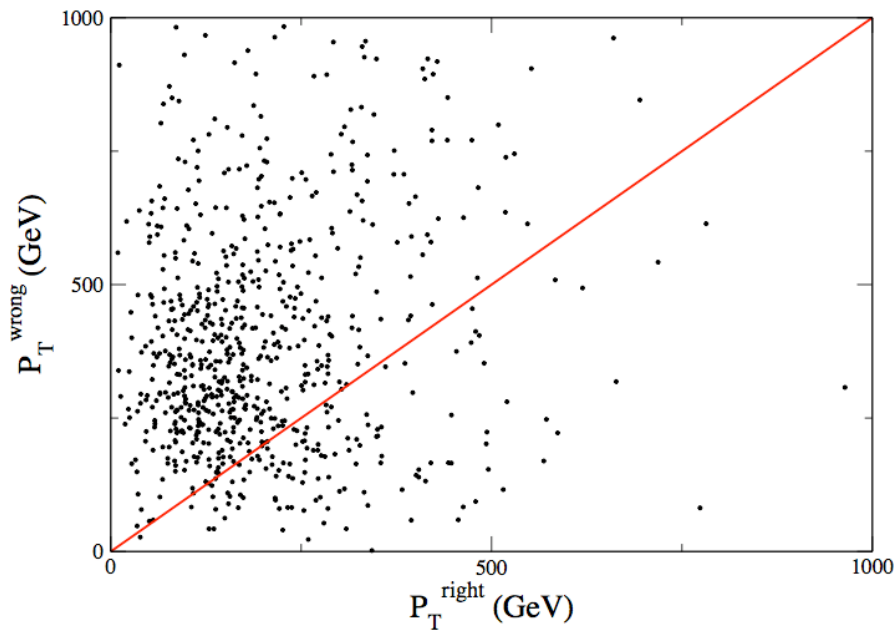
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The signal cannot be isolated entirely. Now it's a question of purity vs. statistics.



Matter Partner's Spin

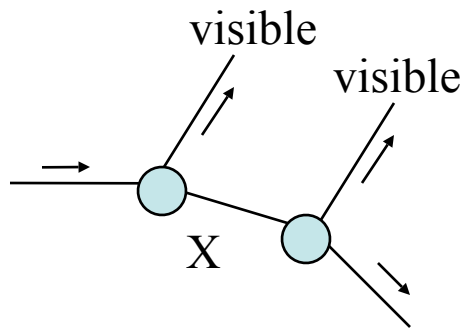
(scalars vs. fermions)



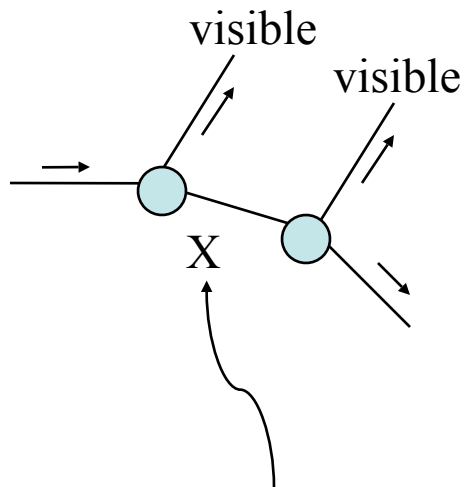
Conditions for spin effects



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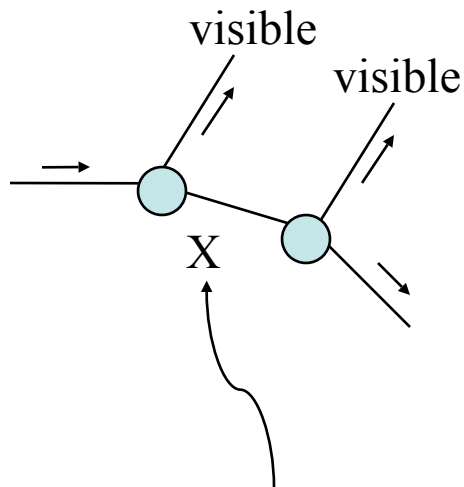
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Need both vertices to be
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Conditions for spin effects

e.g. Little Higgs, UED, etc.



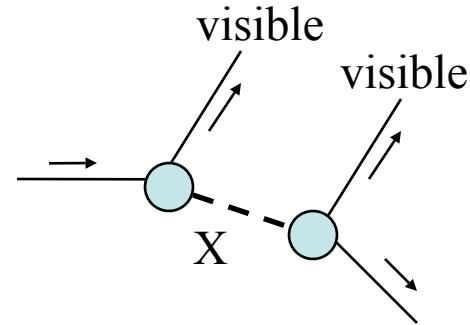
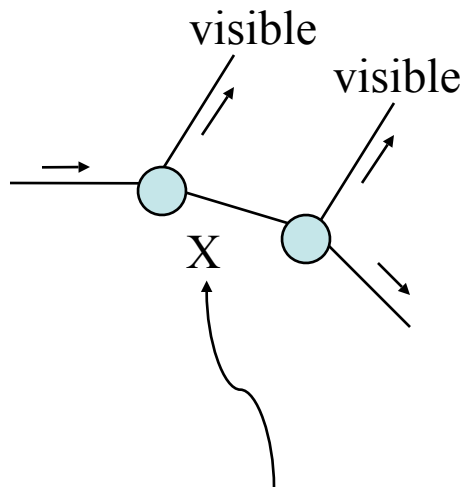
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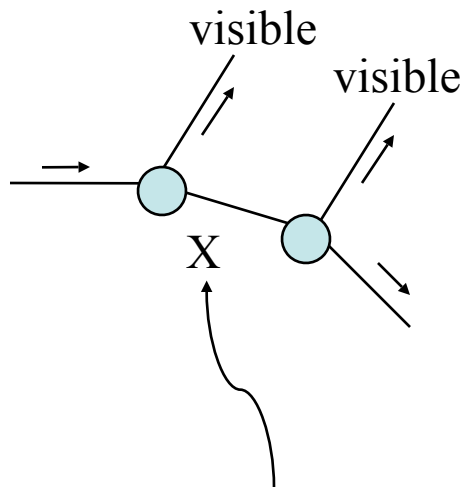
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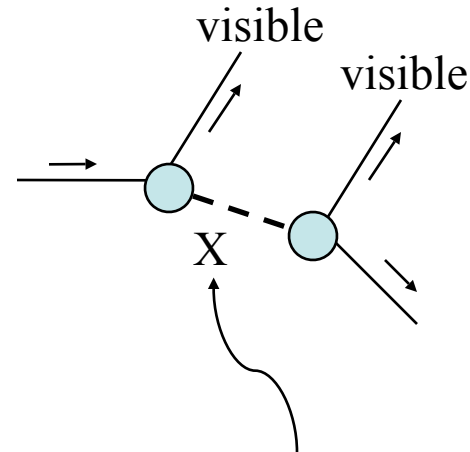
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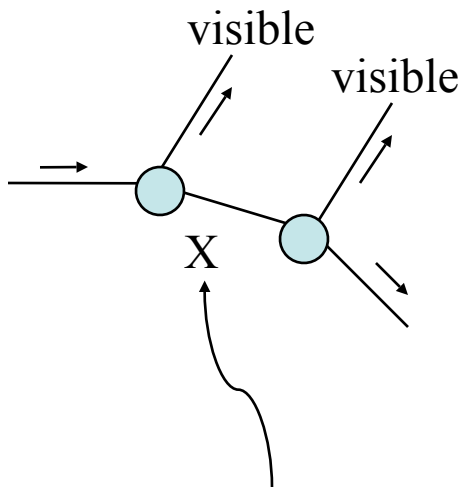
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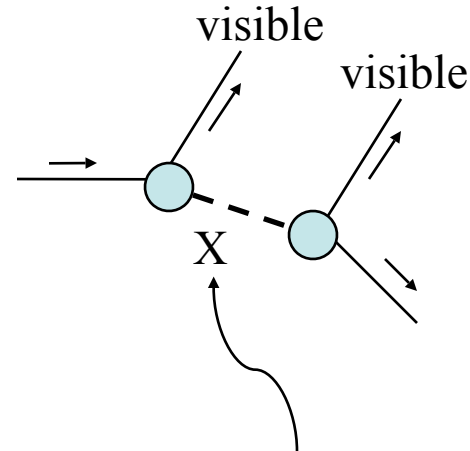
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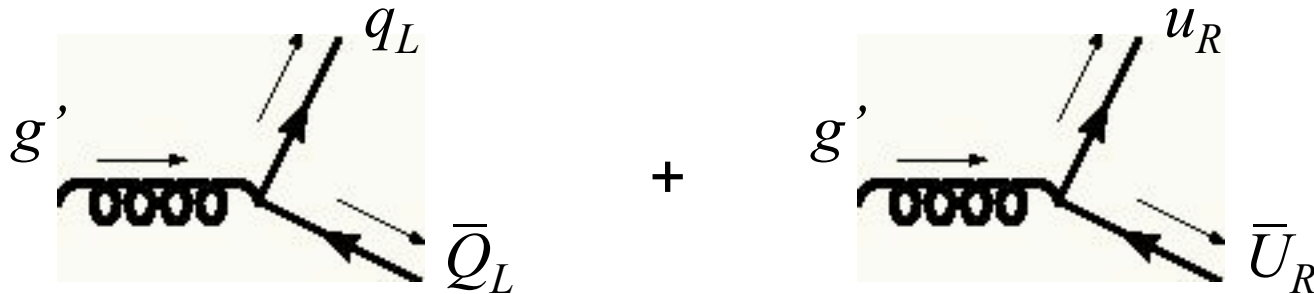


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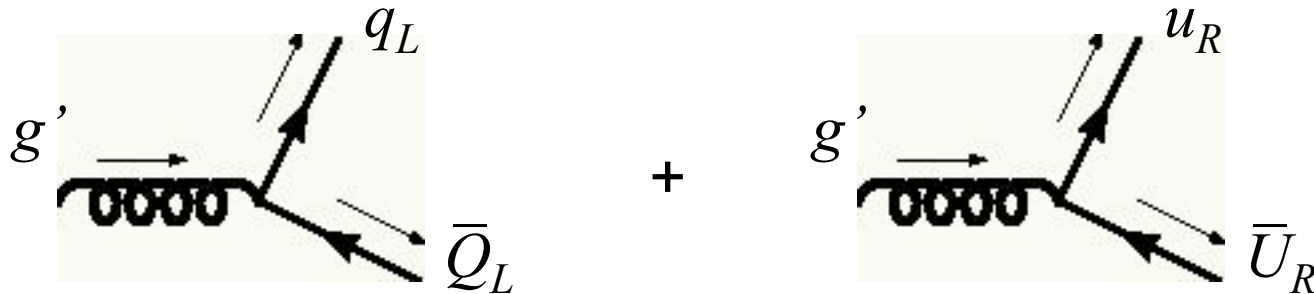


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So, are the interactions always chiral ???



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After EWSB, Q_L and U_L mix, as well as U_R and Q_R , the amount of mixing depends on the mass matrix:



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UED predicts

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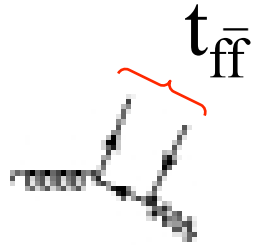
Example: dilepton correlations



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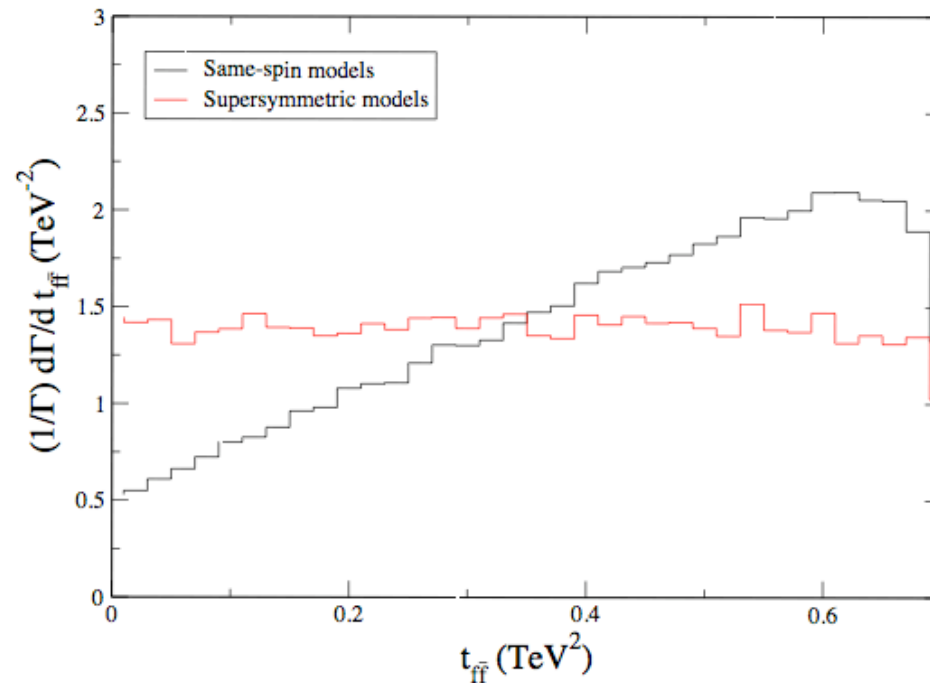
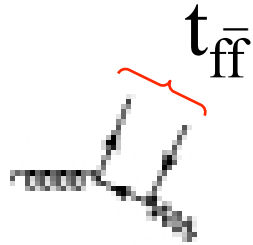


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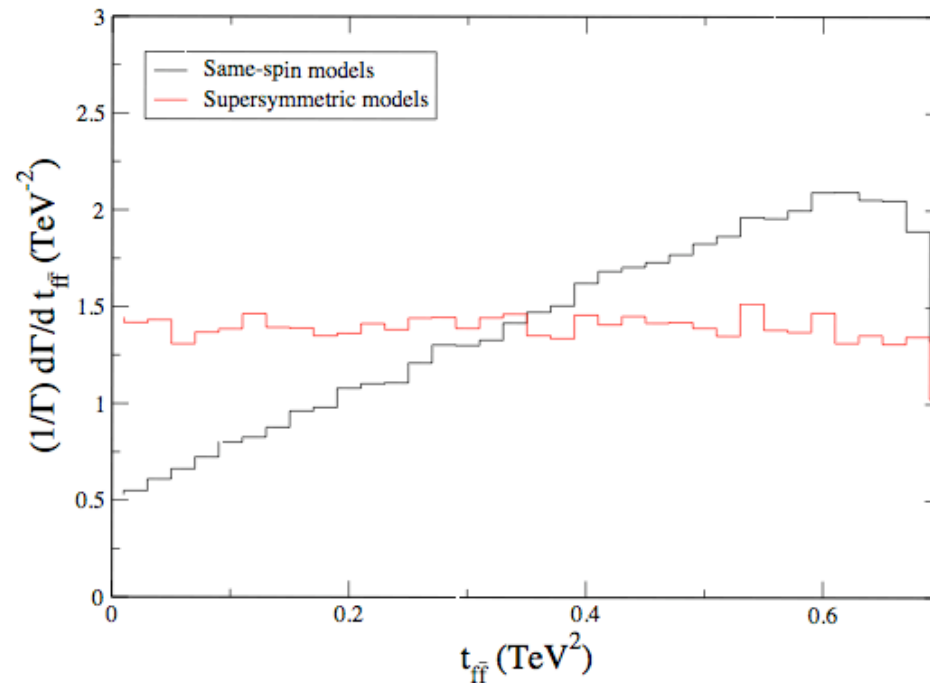
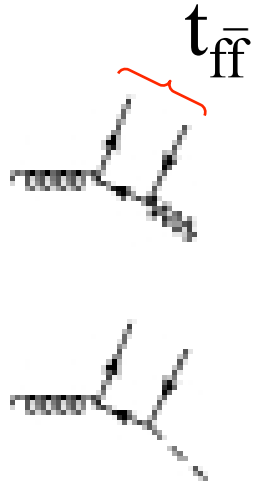
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A histogram of t_{ff} with no cuts applied



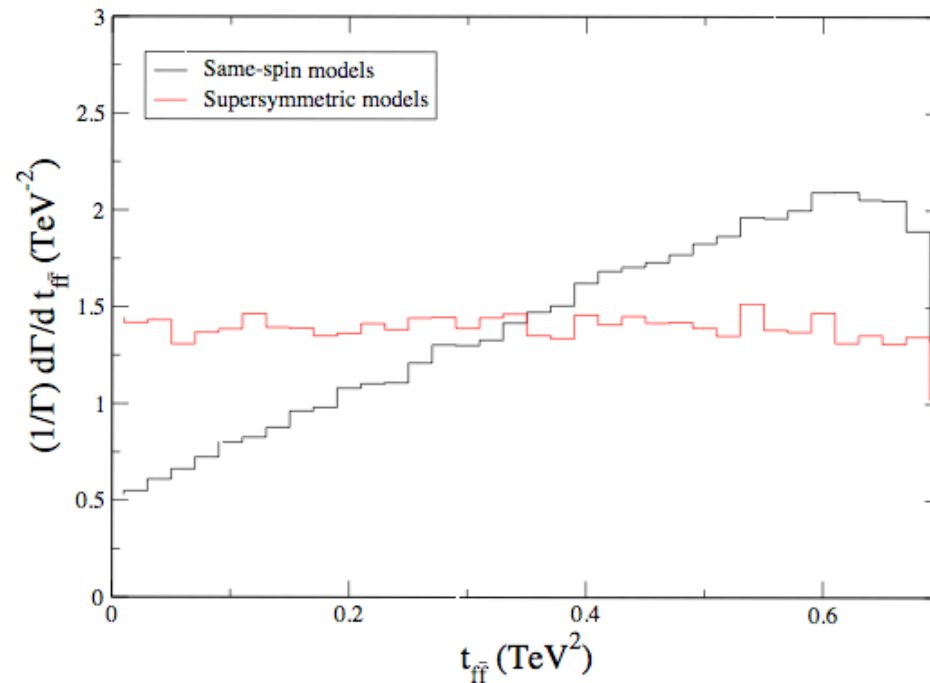
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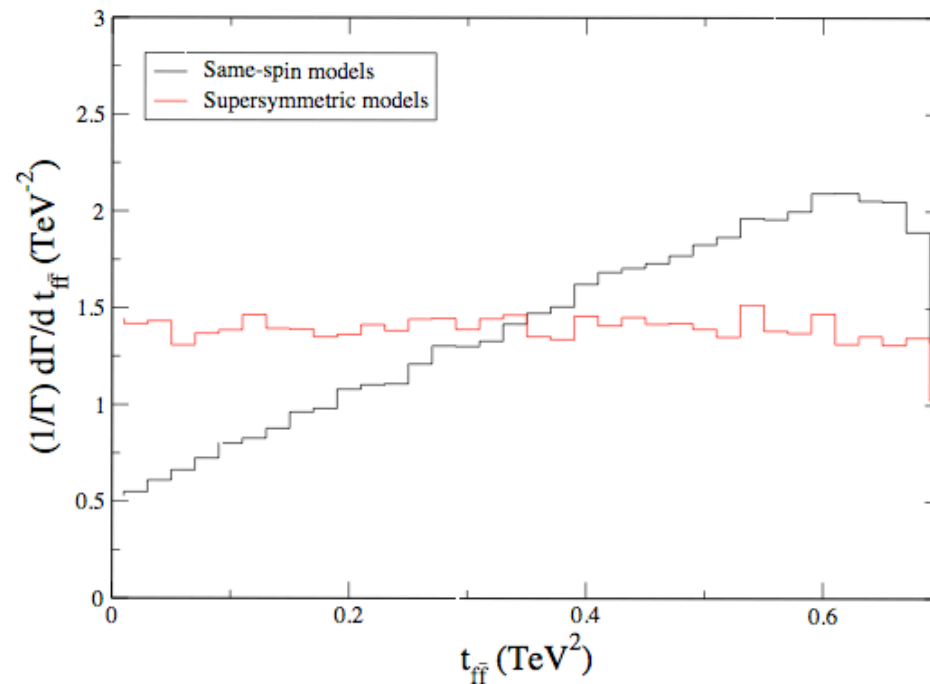
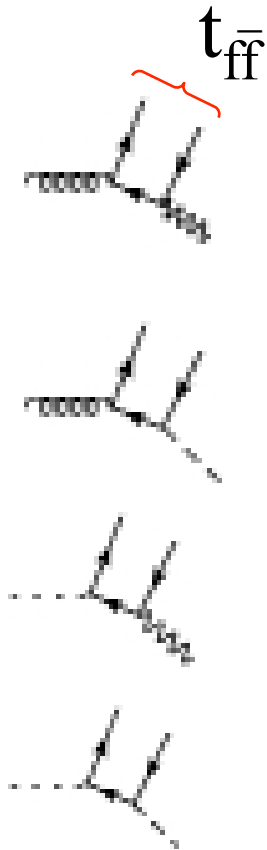
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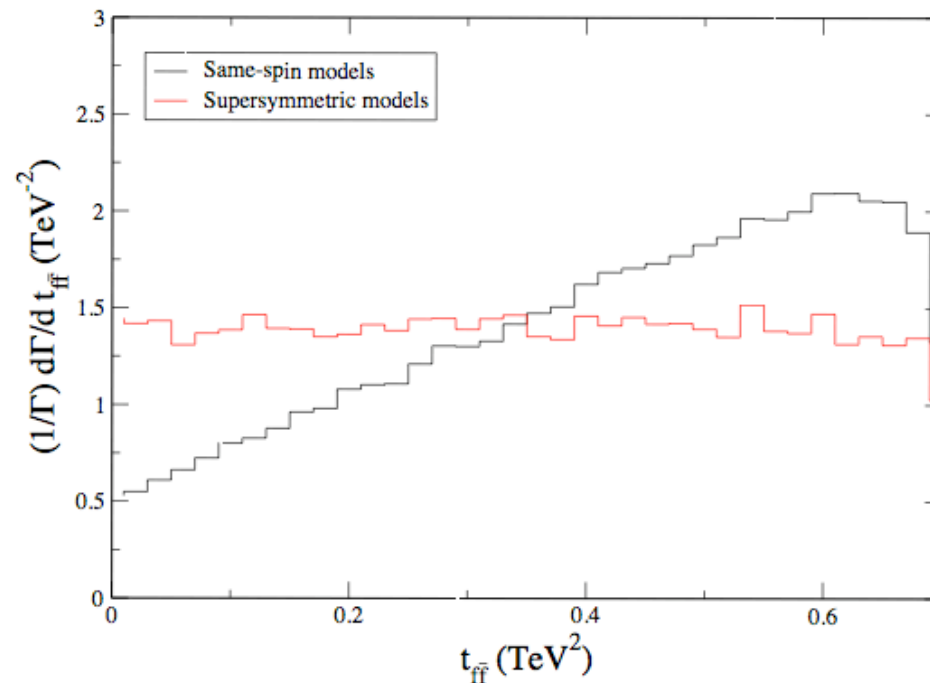
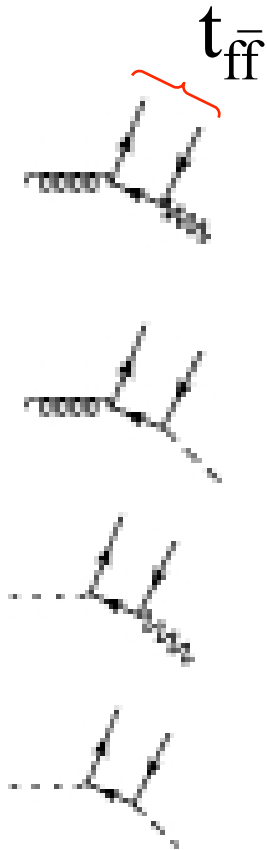
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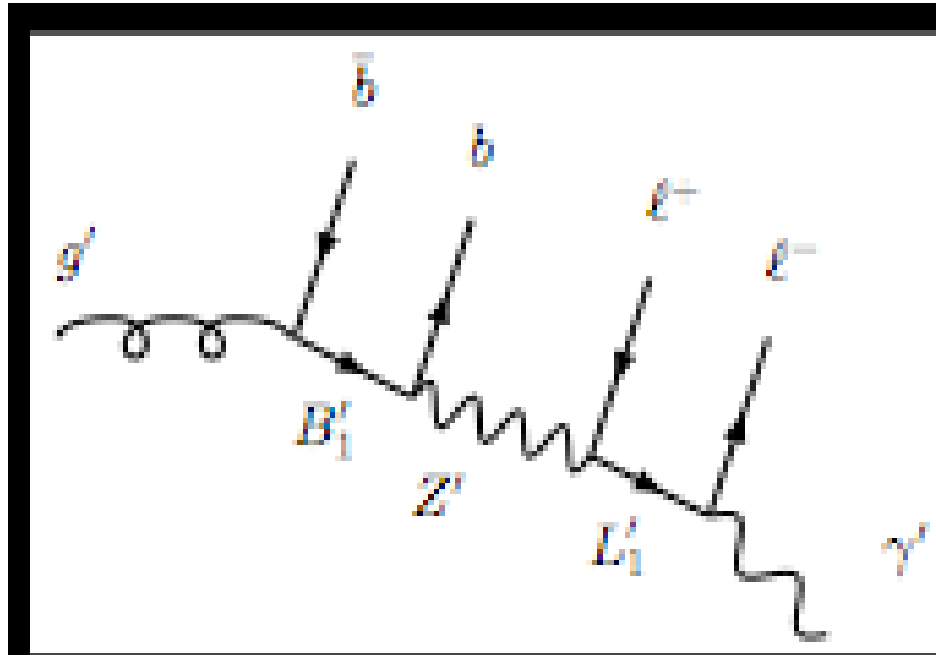
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The sign of the slope removes some of the degeneracies.



Possible to determining all the spins in a cascade



Suppose one measures the slope of the b - \bar{b} pair to be negative with $M_{B'}^2 / M_{Z'}^2 < 2$ and that of the dilepton pair to be negative with $M_{L'}^2 / M_{\gamma'}^2 < 2$ as well. Then, either all three partners, g' , Z' and γ' , are vector-bosons, or all three are scalars. Hence, with a single spin measurement of the Z' , one can determine all the spins in the event.



Off-shell decays

The requirement for chiral vertices can be formulated as the requirement that the intermediate propagator has the mass term dominating over the momentum term or vice-versa.

As was pointed out by *L. Wang* and myself and investigated in detail by *Csaki et al*, [hep-ph/0707.0014](https://arxiv.org/abs/hep-ph/0707.0014) this also happens when the intermediate fermion is off-shell.



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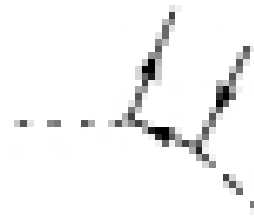


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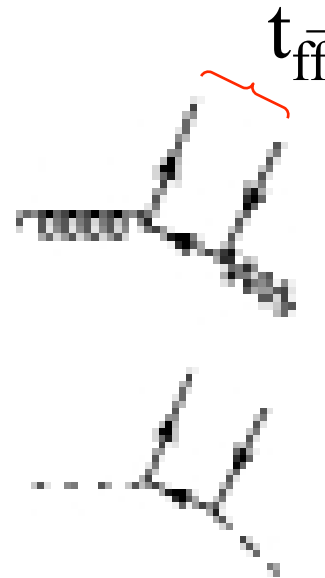


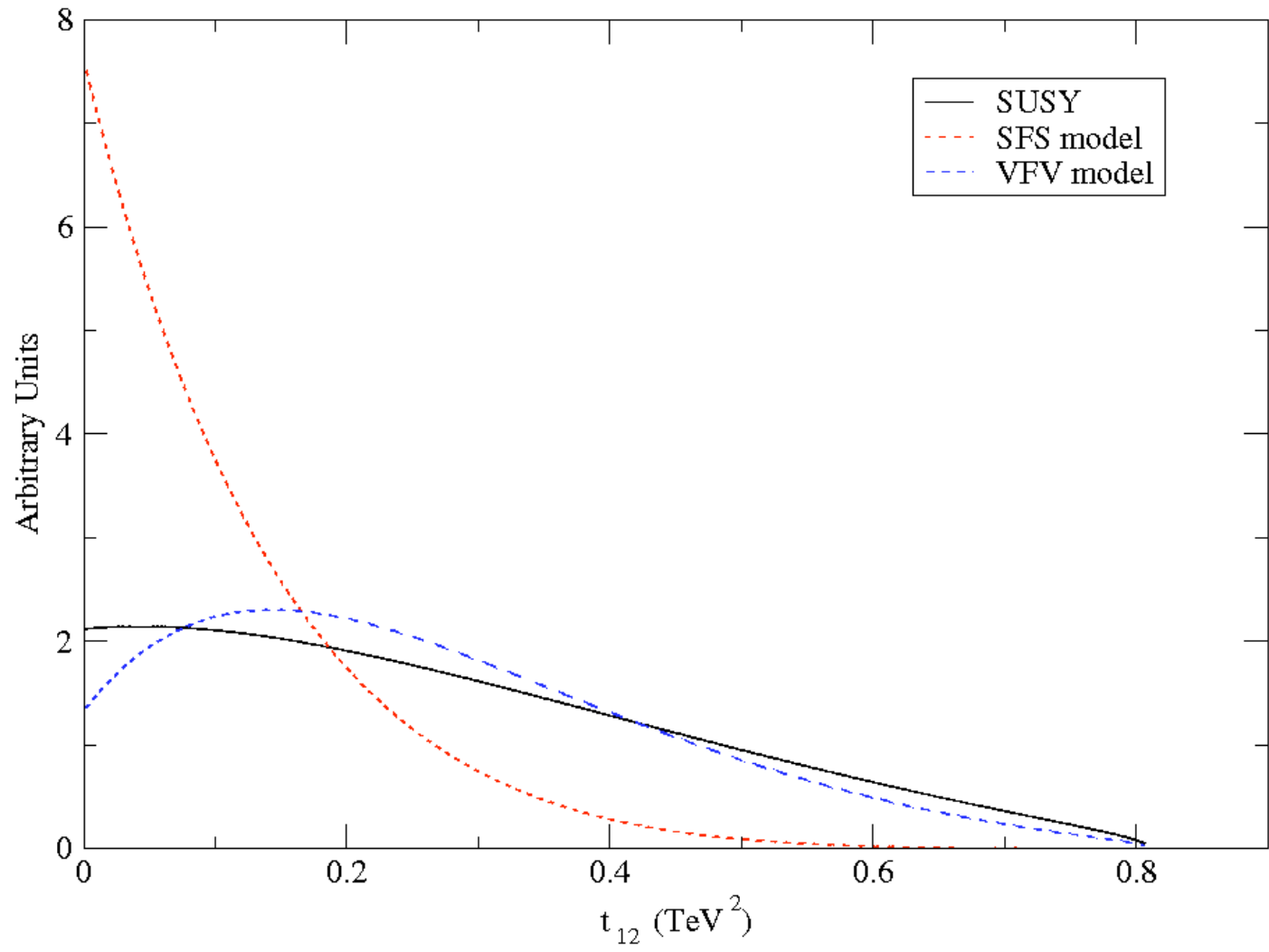
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Future directions



Spin determination

UC Davis

Itay Yavin

Future directions

- Experimental difficulties:
 - o Background
 - o Can the correct pairing be determined and combinatorics reduced?
 - o How well will b-tagging work?



Future directions

- Experimental difficulties:
 - Background
 - Can the correct pairing be determined and combinatorics reduced?
 - How well will b-tagging work?
- New methods
 - A recent interesting paper by Cheng et al, 0707.0030 [hep-ph] tries to determine all the masses in certain cascades. Can it also help in determining the spin?
 - Methods using rate information are important and should be pursued further. Are there any model independent statements one can make?



Conclusions



Spin determination

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Conclusions

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Conclusions

- The conditions for spin effects are clear.
- Several channels seem to exhibit spin effects.
- Not all fermionic matter partners can be distinguished from scalars. It depends on the spectrum!

