Title: Sneutrino NLSP at the LHC

Date: Feb 12, 2010 02:30 PM

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Abstract: The sneutrino is a viable NLSP candidate in SUSY with gravitino LSP. In my talk I will focus on this possibility, in particular concentrating on the question of whether the LHC can distinguish spectra with a sneutrino NLSP from alternatives, e.g. ones with neutralino LSP. I will show that there are at least two different families of experimentally allowed spectra with sneutrino NLSP which exhibit distinctive multilepton signals. These spectra are not easy to fake within the MSSM. I will discuss these signals in detail and illustrate our analysis approach on simulations.

$\tilde{\nu}$ NLSP at the LHC

A.K. and Brock Tweedie; arXiv: 0911.4132

A.K. and Brock Tweedie; to appear

Andrey Katz

University of Maryland

Outline

1. Motivation and the main goal of the project.
2. Generic features of the spectrum, types of spectra.
3. Cascades and signatures in the “ideal world":
    - Counting of the leptonic events.
    - Structure in the 2l and 3l channels.
    - Jet-lepton invariant mass
4. Real signatures and main worries: backgrounds, check of the tools on realistic spectra.
5. Spectra with “active" RH selectron.
6. Conclusions and outlook.

$\tilde{\nu}$ at the bottom of SUSY-spectrum

How $\tilde{\nu}$ can be at the bottom of the SUSY spectrum?

Can it be LSP, DM candidate?

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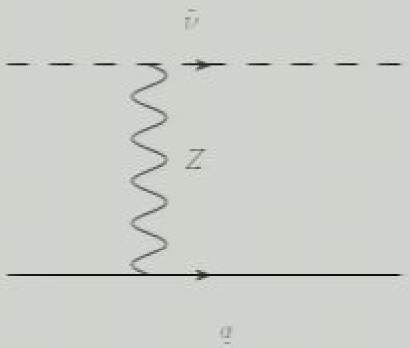

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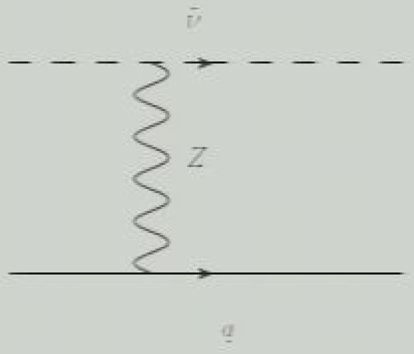
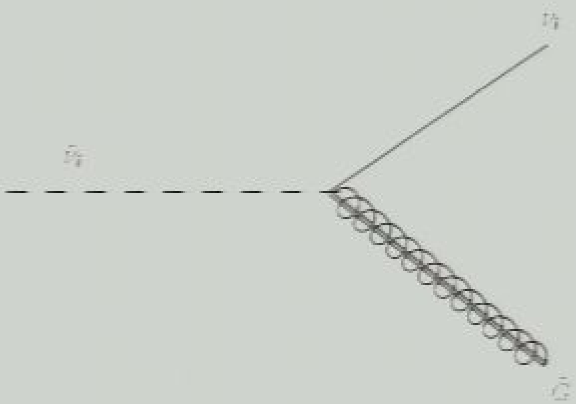


The cross-section for the direct detection is too big! If it had been a DM, we would have already had signals in the direct detection experiments!

$\tilde{\nu}$ NLSP

Two possible giveaways:

- Give up on R-parity, allow $\tilde{\nu}$ to decay into the SM particles
- Consider gravitino LSP, allow “invisible sneutrino decay"



Top down motivation

$\tilde{\nu}$ at the bottom of the spectrum is not easy to get, but nevertheless it is possible:

- we find $\tilde{\nu}$ NLSP in a big portion of GGM parameter space (nonetheless it is very hard to get $\tilde{\nu}$ NLSP in minimal gauge mediation).
- There were some works, pointing out that $\tilde{\nu}$ can be at the bottom of the spectrum in high-scale mediation models (e.g. gaugino mediation). In these models $\tilde{G}$ LSP is less natural, but not impossible.

Motivation and main questions

If $\tilde{\nu}$ is an NLSP, the last step in the cascade is completely invisible.
From the point of view of collider behavior looks very similar (too similar) to the neutralino LSP (or long lived NLSP).

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Is it possible practically distinguish between two these possibilities, at least in some cases?

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Neglecting the left-right mixing, all the splitting comes from the D-terms

$$m_{\tilde{l}} - m_{\tilde{\nu}} = -\frac{m_W^2 \cos(2\beta)}{m_{\tilde{l}} + m_{\tilde{\nu}}} > 0 \ .$$

Example: $m_{\tilde{l}} = 150 \text{ GeV}$, $\tan\beta = 10$.

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If a charged LH slepton is produced (either directly or in cascade), how does it decay?

Assume:

the whole LH doublet sits at the bottom of the SUSY spectrum.

Decays via W^*

Remarks about LH slepton decay

- most of the time ($\gtrsim 2/3$) decays into jets
- 20 % of time can decay emitting lepton
- flavor correlation of the lepton with the parent slepton is lost.
- decay products may often be quite soft (splitting of several dozens GeV)
- soft jets - useless
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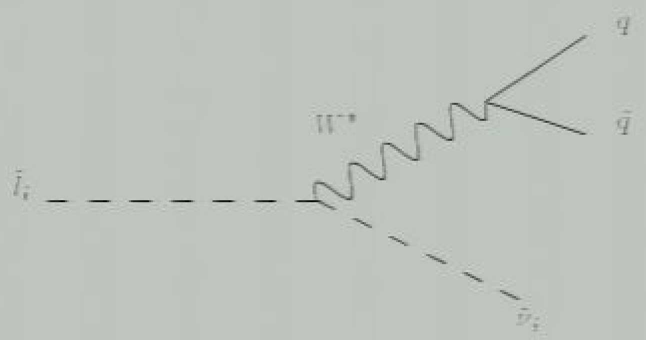

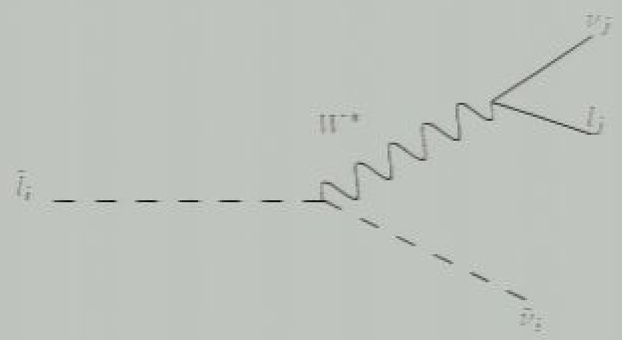

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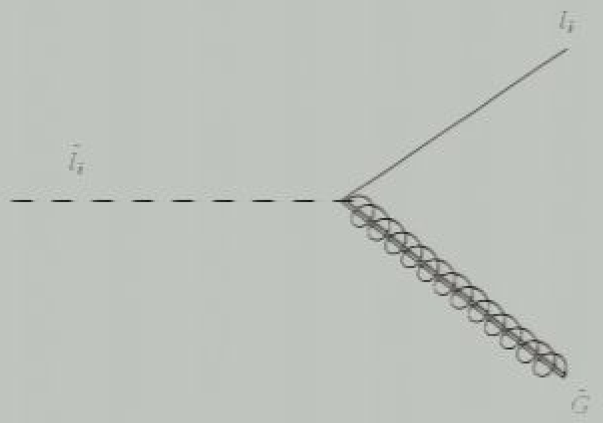

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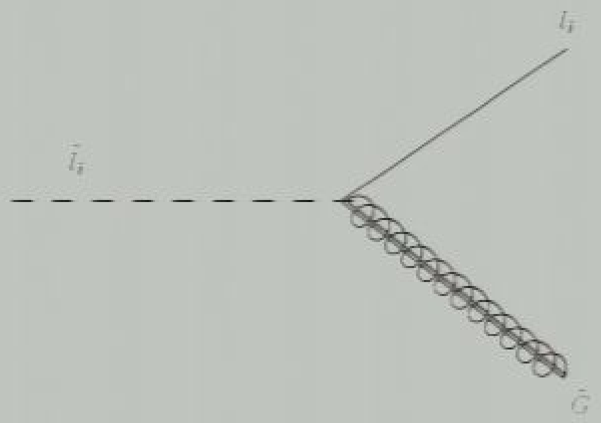

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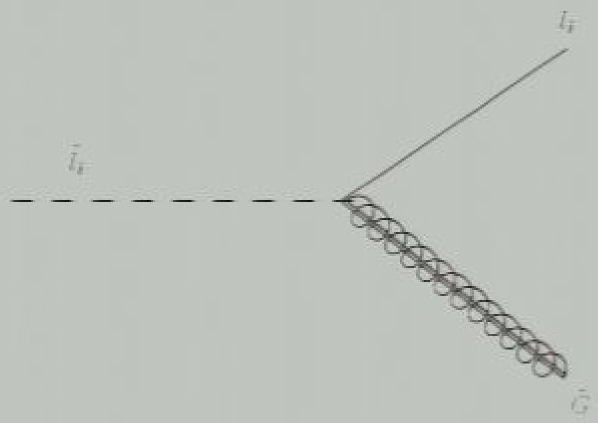

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- Direct EW production - either very hard to trigger or very hard to reduce backgrounds (or both).
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We will further concentrate on :

- QCD production
- Leptonic channel – see if it is different from neutralino LSP

“Active'' vs. “inactive'' spectra

Usually the mixing in the gaugino-Higgsino sector is not big. It is not difficult to distinguish bino-like neutralino vs. Higgsino vs. wino. Consider a spectrum with

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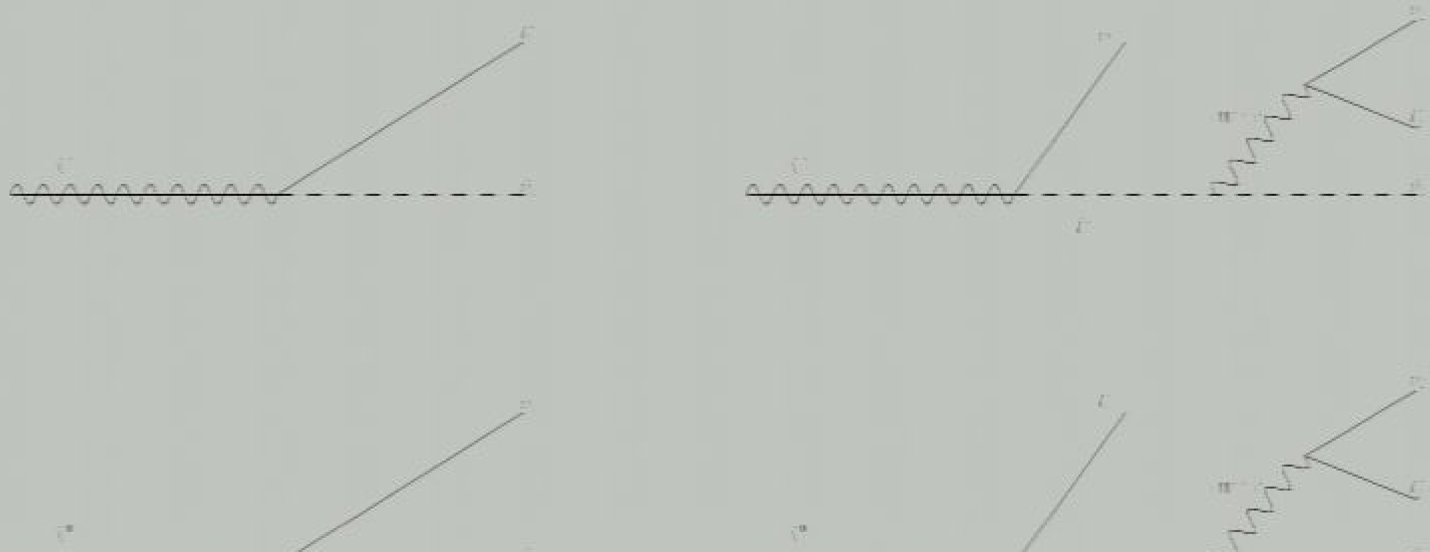
If the ordering is different, the spectrum becomes active, phenomenology similar to leptogenic SUSY w/o CHAMP.

Counting hard leptons.

Simple analysis:

- Only QCD production
- No decays into Higgsinos
- Phase space effects in decays are neglegible
- τ are never leptons



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- monoleptonic:dileptonic = 4:1
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- leptons inside the dileptonic channel are never correlated:

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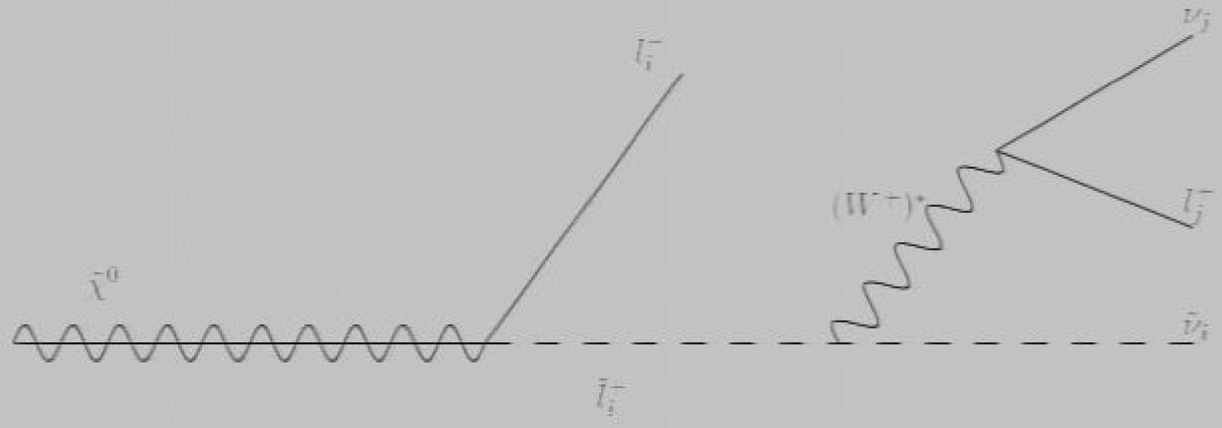

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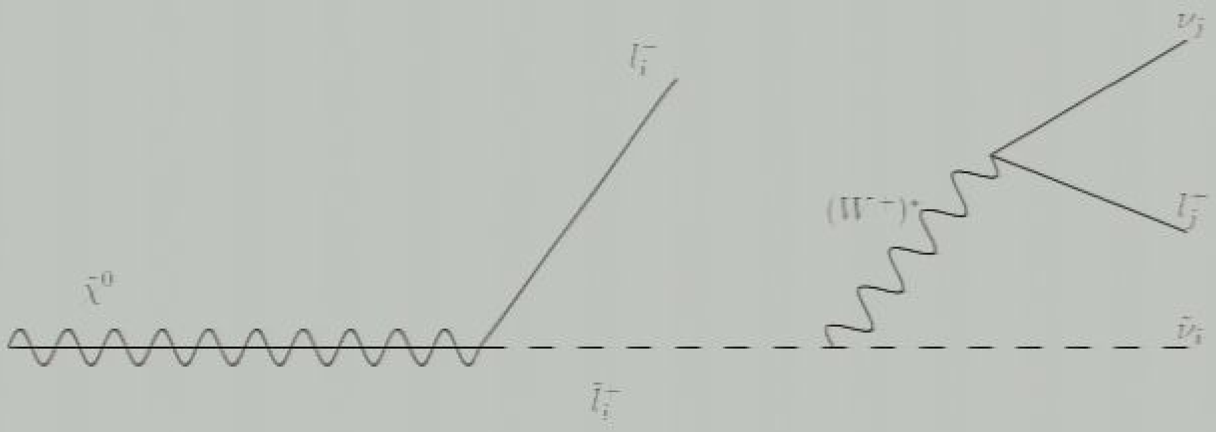
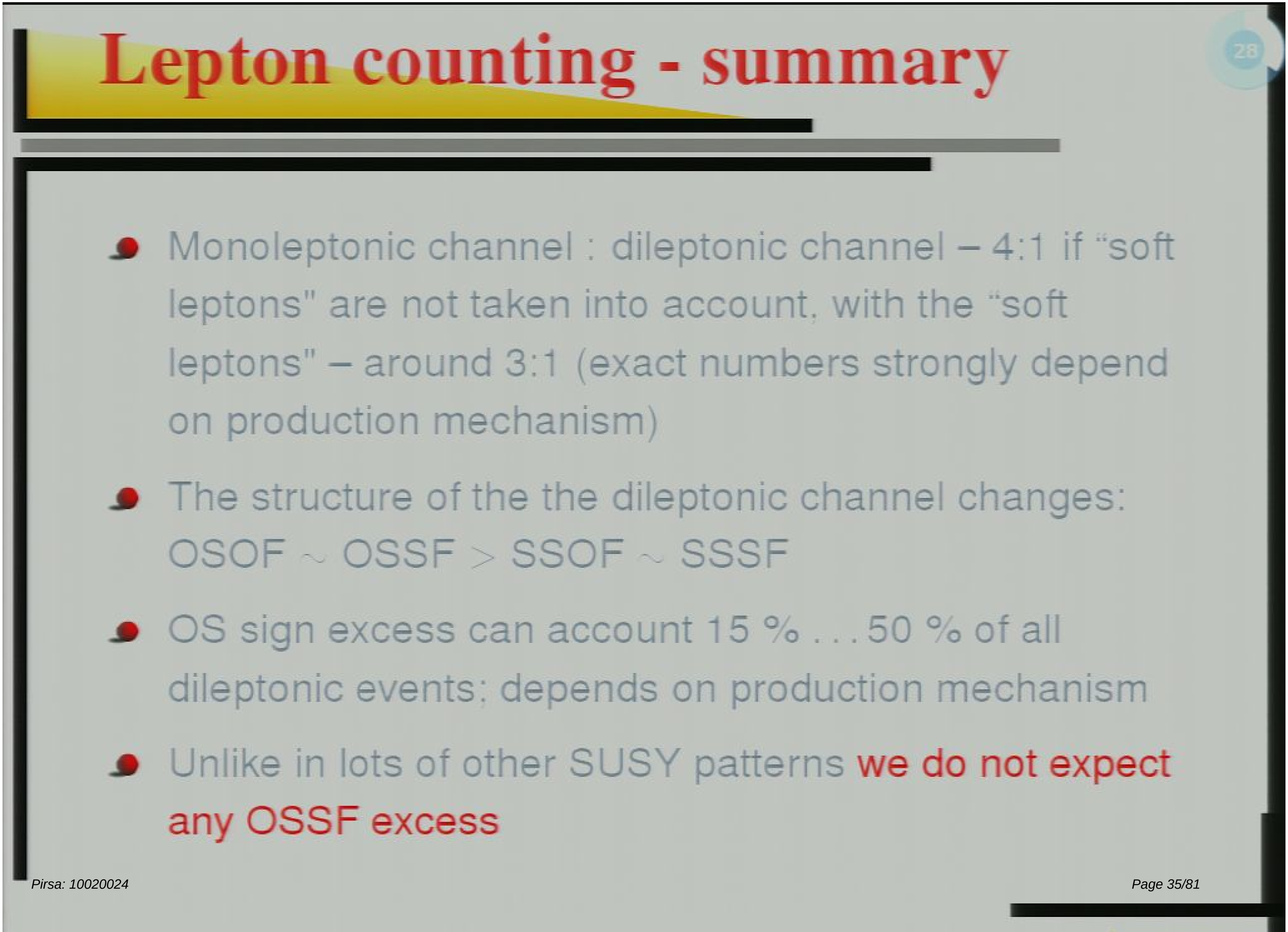


Opposite sign, uncorrelated flavor lepton pairs

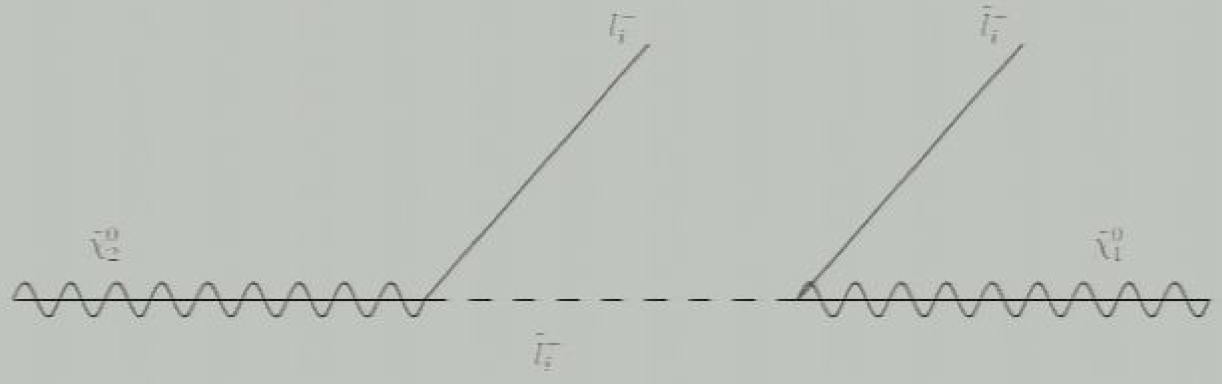


Lepton counting - summary

- Monoleptonic channel : dileptonic channel – 4:1 if "soft leptons" are not taken into account, with the "soft leptons" – around 3:1 (exact numbers strongly depend on production mechanism)
- The structure of the the dileptonic channel changes: OSOF $\sim$ OSSF $>$ SSOF $\sim$ SSSF
- OS sign excess can account 15 % . . . 50 % of all dileptonic events; depends on production mechanism
- Unlike in lots of other SUSY patterns we do not expect any OSSF excess

How do we treat 2l signal

Take one step backwards: interesting signal in dileptonic channel in neutralino-LSP SUSY: OSSF leptons, coming from



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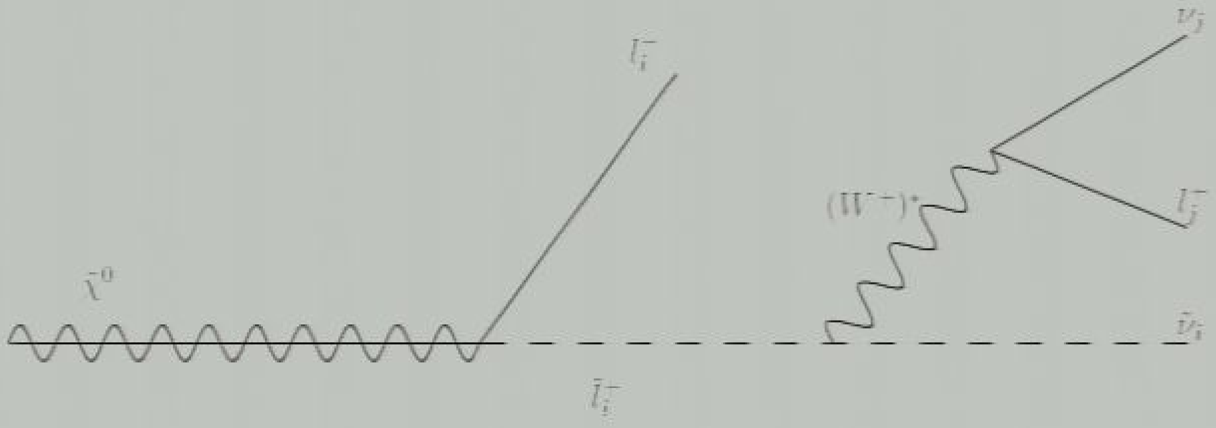

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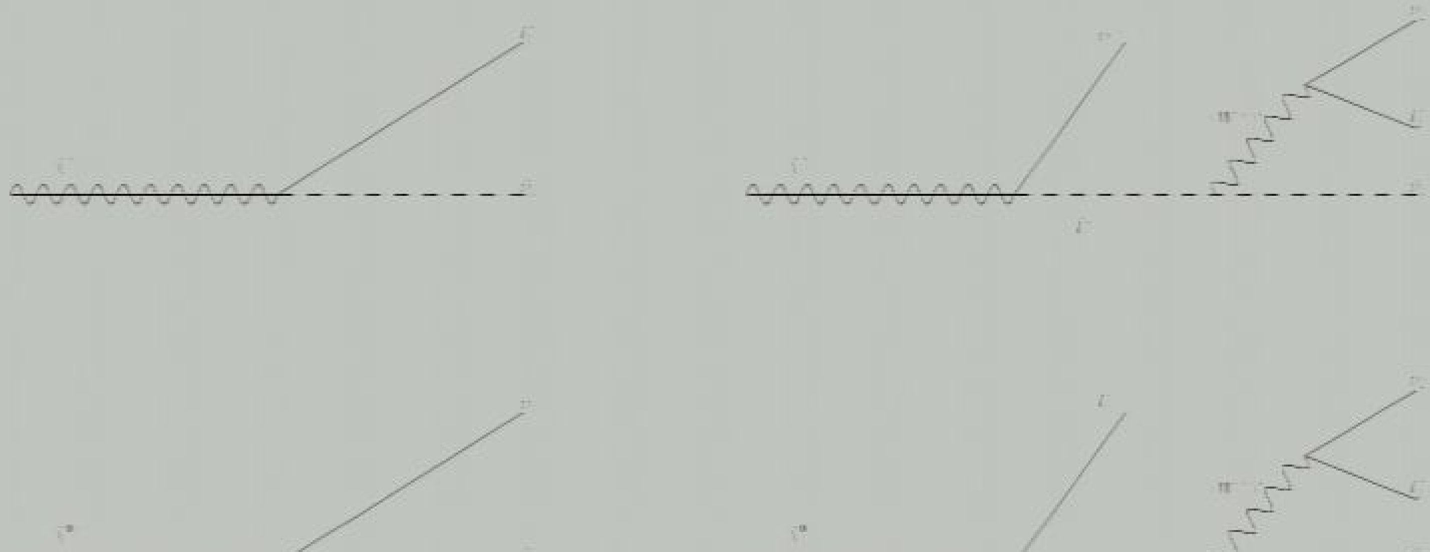

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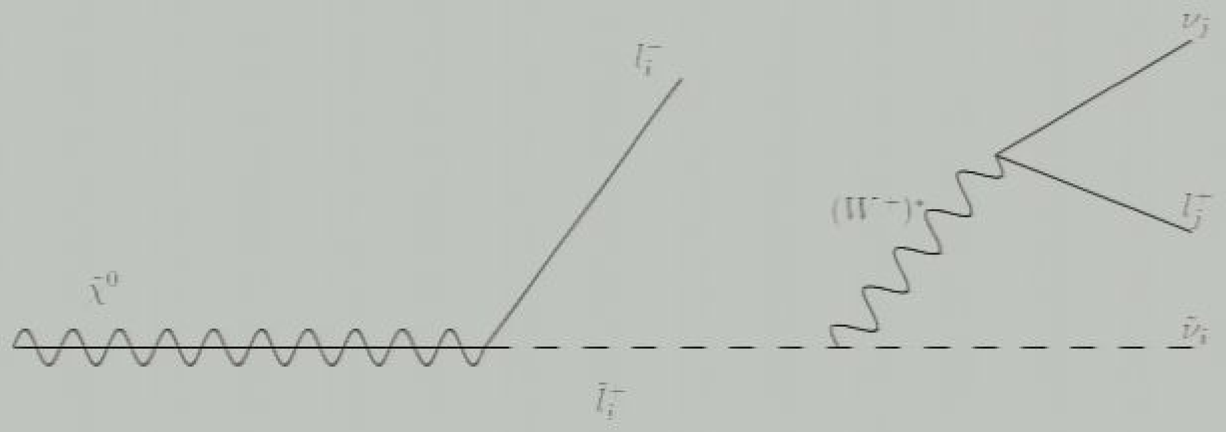

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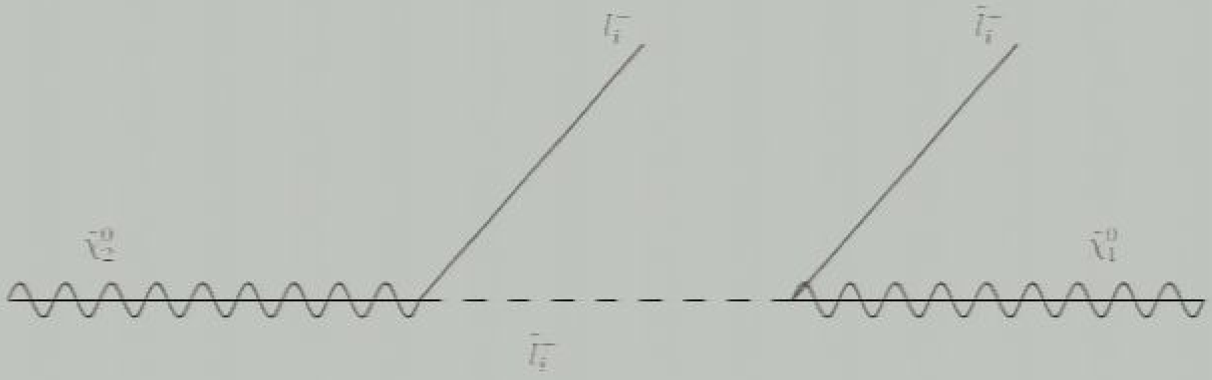

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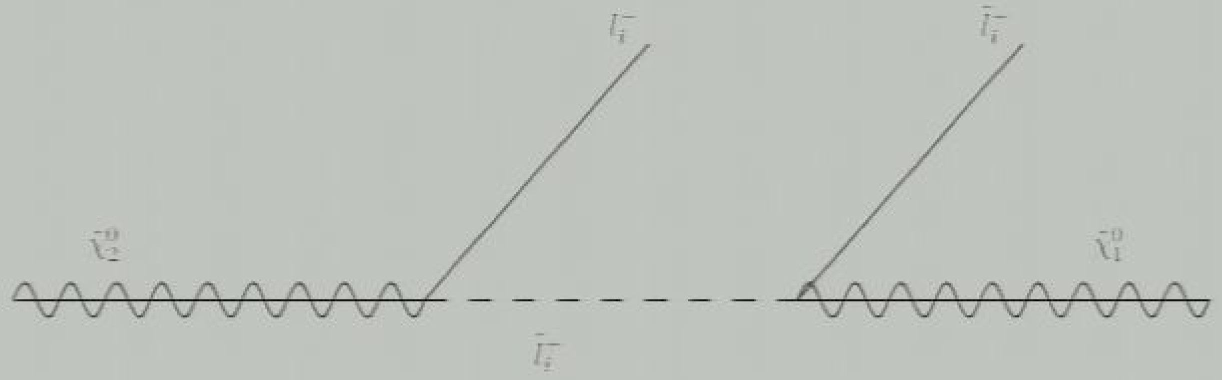
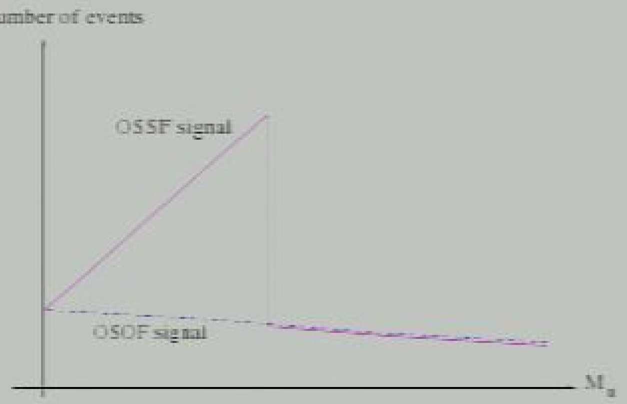


- sits on top of the SUSY background - OSSF pairs from different chains
- can be purified by OSSF-OSOF subtraction

OSSF-OSOF subtraction

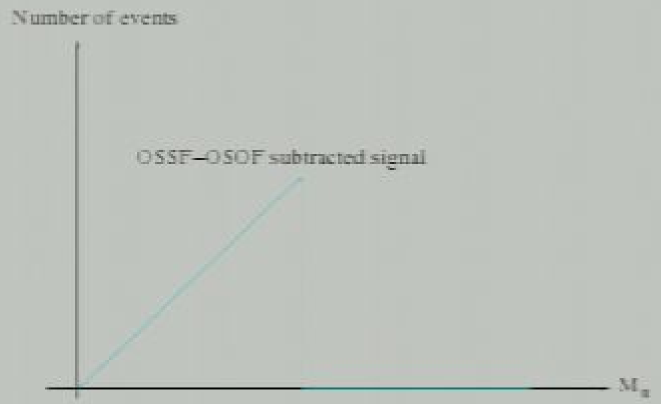
Characteristic shape of the OSSF & OSOF signal:



OSSF-OSOF subtraction

Characteristic shape of the OSSF & OSOF signal:

Subtract OSSF-OSOF



Ramp-and-edge structure is clear after subtraction

Signal in 2l channel

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Procedure: perform OS-SS subtraction to purify the signal.

Shape of the signal

Our decays: 2 body — 3 body.

What is the shape of the dilepton invariant mass?

Without spins – just bump (*Thomas, Tucker-Smith, Weiner 2007*).

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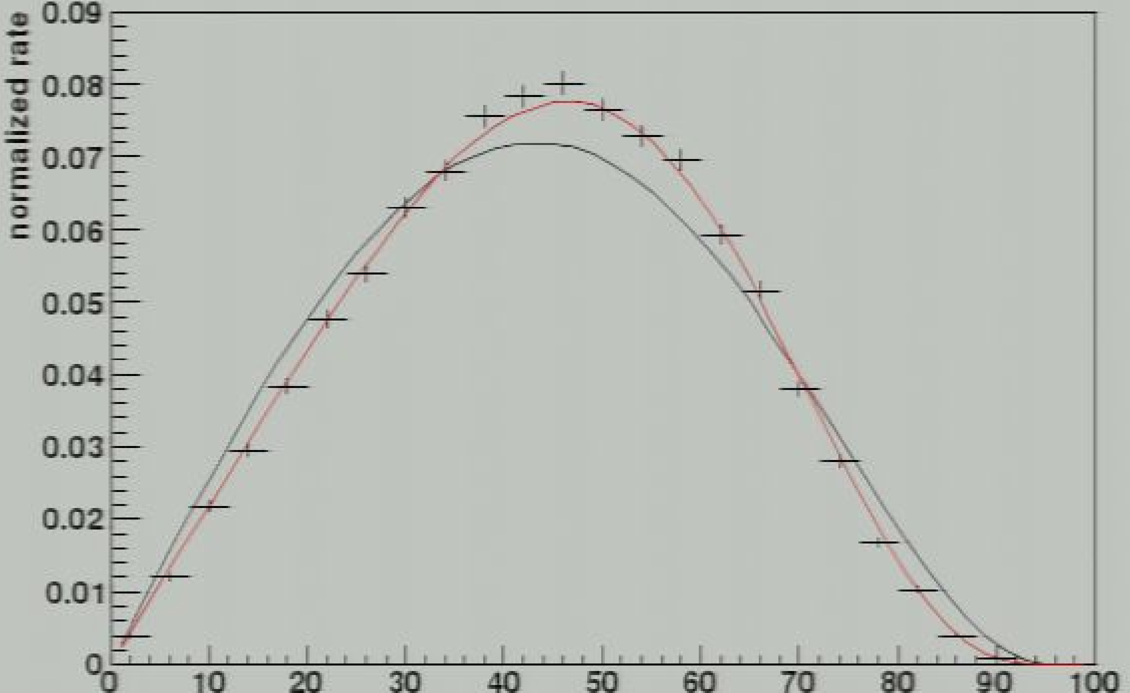

Trileptonic channel

How can we get 3l?

2l (OS, random flavor) from one side of the event, one lepton from another side of the event.

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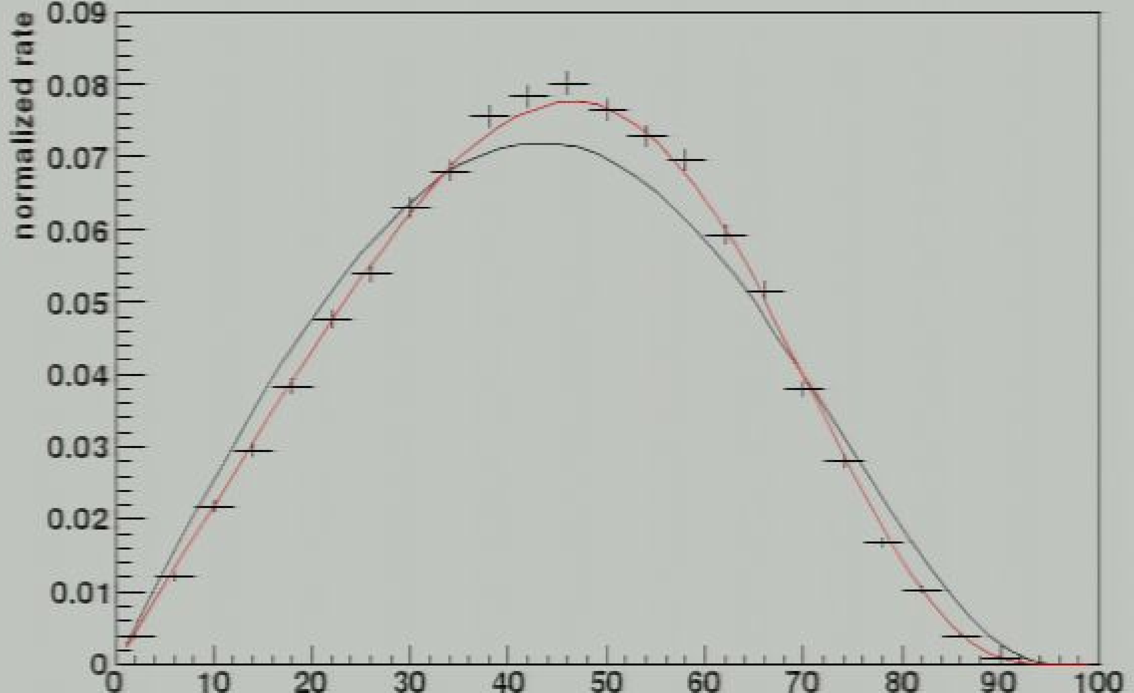

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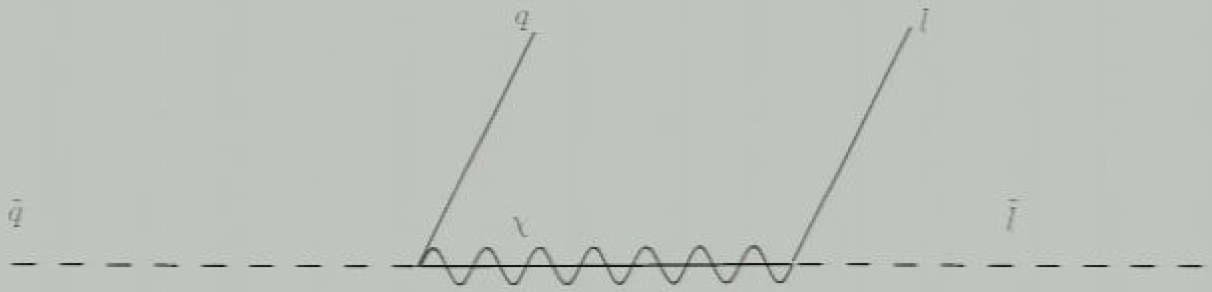
Jet-lepton invariant mass

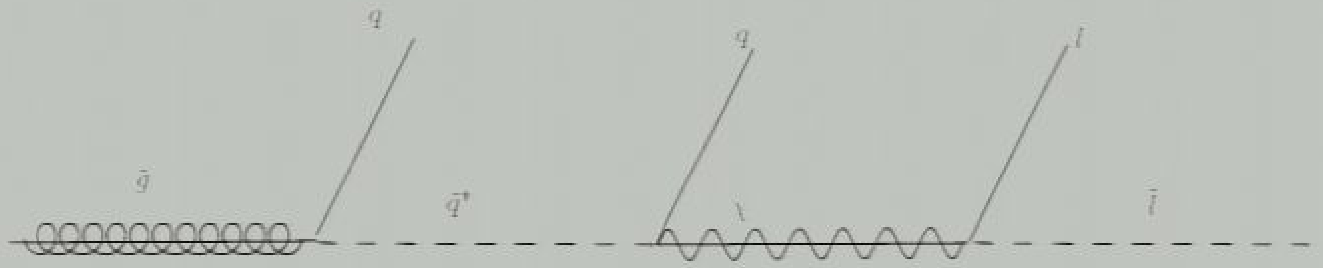
If our production is squark-anti-squark dominated:



- may carry important information about the masses of squark and gaugino
- may be an important discriminator (the most “dangerous” fakers do not have this channel)
- ideally should give a clean edge-like distribution

Why M_{jl} is not always useful?

- gluino dominated production – usually two jets in each gluino decay. The information is lost



- suffers from irreducible combinatorial background
- if squark is off-shell – we also do not expect any feature

SUSY fakers

Which supersymmetric spectrum can fake such behavior?

- spectra w/ OSSF excess are not good fakers. In our case flavor correlation is lost
- “flavorful SUSYs” – cannot be completely anarchical, at least in two first generations
- all scalars are heavy, wino and bino at the bottom of the spectrum. Heavy chargino and neutralino decay into the neutralino LSP through $W^{\pm}$, Z (on or off-shell) and Higgs.

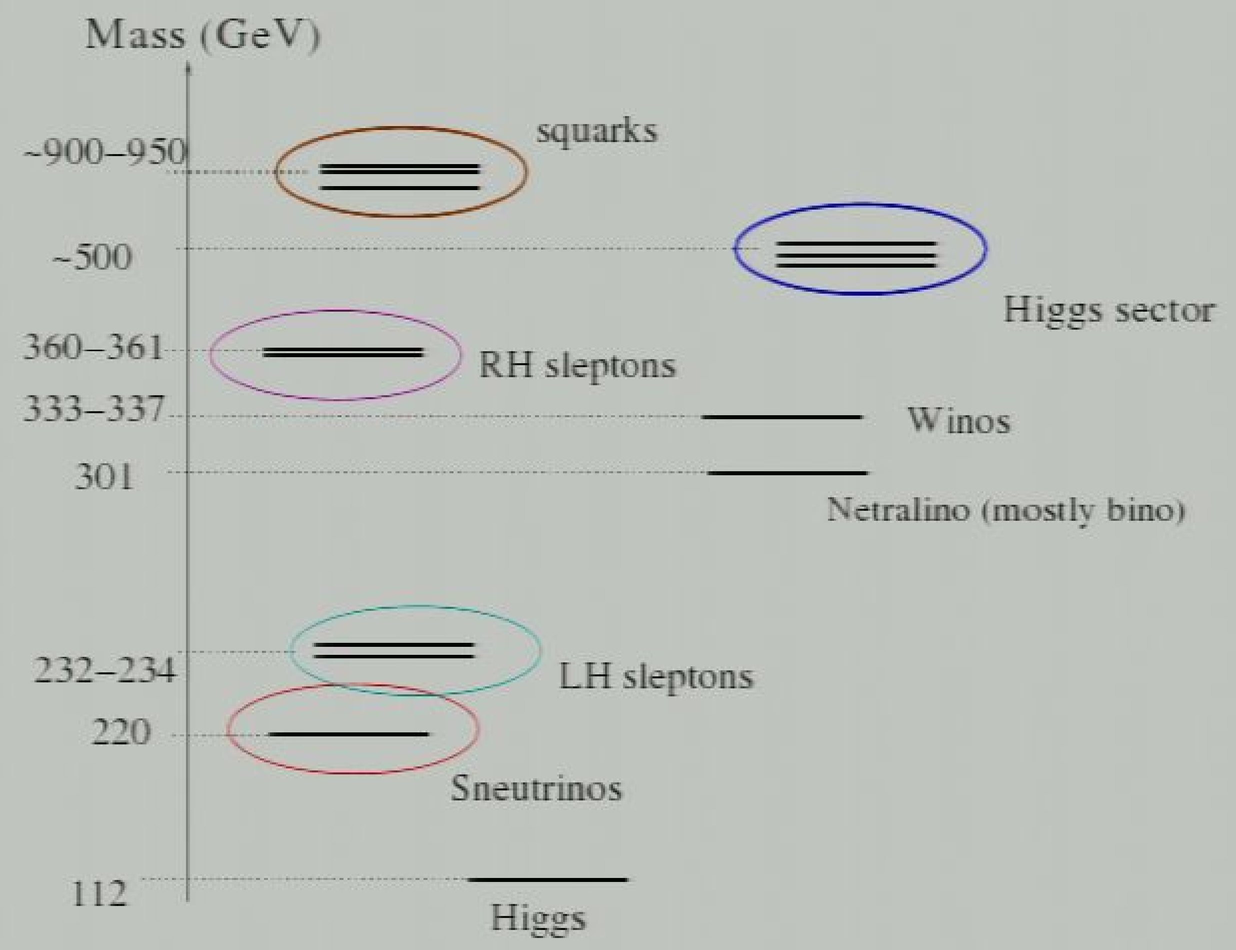
Faking $\tilde{\nu}$ NLSP by Ws

Most dangerous faker:

$$m(\tilde{l}), m(\tilde{e}_r) > m(\tilde{W}) > m(\tilde{B})$$

All leptons come from W decays

Representative spectrum



Inactive spectrum with squark production

Backgrounds

Main SM backgrounds

- $t\bar{t}$ (1l, 2l, 3l), $\sigma_{total} \approx 600 \text{ pb}$
- WW+jets (1l, 2l, 3l), $\sigma_{total} \sim \mathcal{O}(100 \text{ pb})$
- $\tau^+\tau^-+$jets (dangerous for 2l)
- W+jets (1l) (after hard cuts $\sigma \sim \mathcal{O}(1) \text{ pb}$)
- WZ^* (might impair 2l, 3l)
- might also worry about $b\bar{b}$, $c\bar{c}$ for 1l – we do not discuss these backgrounds here

Cuts

- QCD production $p_t(j1), p_t(j2) > 300$ GeV. Cut is harder than usual since OSSF-OSOF subtraction reduces $t\bar{t}$ in 2l channel, but our subtraction does not. We should just tighten the cuts.
- QCD: $E_T^{miss} > 200$ GeV.
- $M_{TW}^2 \equiv 2|\vec{l}_T||\vec{E}_T^{miss}|(1-\cos\phi) > (100 \text{ GeV})^2$ – effectively removes W+jets and monoleptonic $t\bar{t}$ (which is also effectively W+jets).

What leptons do we rely on?

- Isolation cuts for tight lepton: less than 10 % hadronic activity in $\Delta R < 0.4$ around the lepton
- Isolation cuts for the loose leptons: more than 10 % hadronic activity in $\Delta R < 0.4$ around the lepton, but the p_t of the hadronic activity in that cone does not exceed $10\ \mathrm{GeV}$
- Reconstruct leptons with $p_t > 5\ \mathrm{GeV}$. Safe for μ, probably OK for electrons with good isolation cuts.
- Never use loose leptons in 1l or 2l channel
- Multilepton channel – at least 2 tight leptons

Efficiency of lepton reconstruction

How many leptons do we lose because they are too soft/ do not pass isolation cuts?

Lepton which come from 2-body gaugino decay:

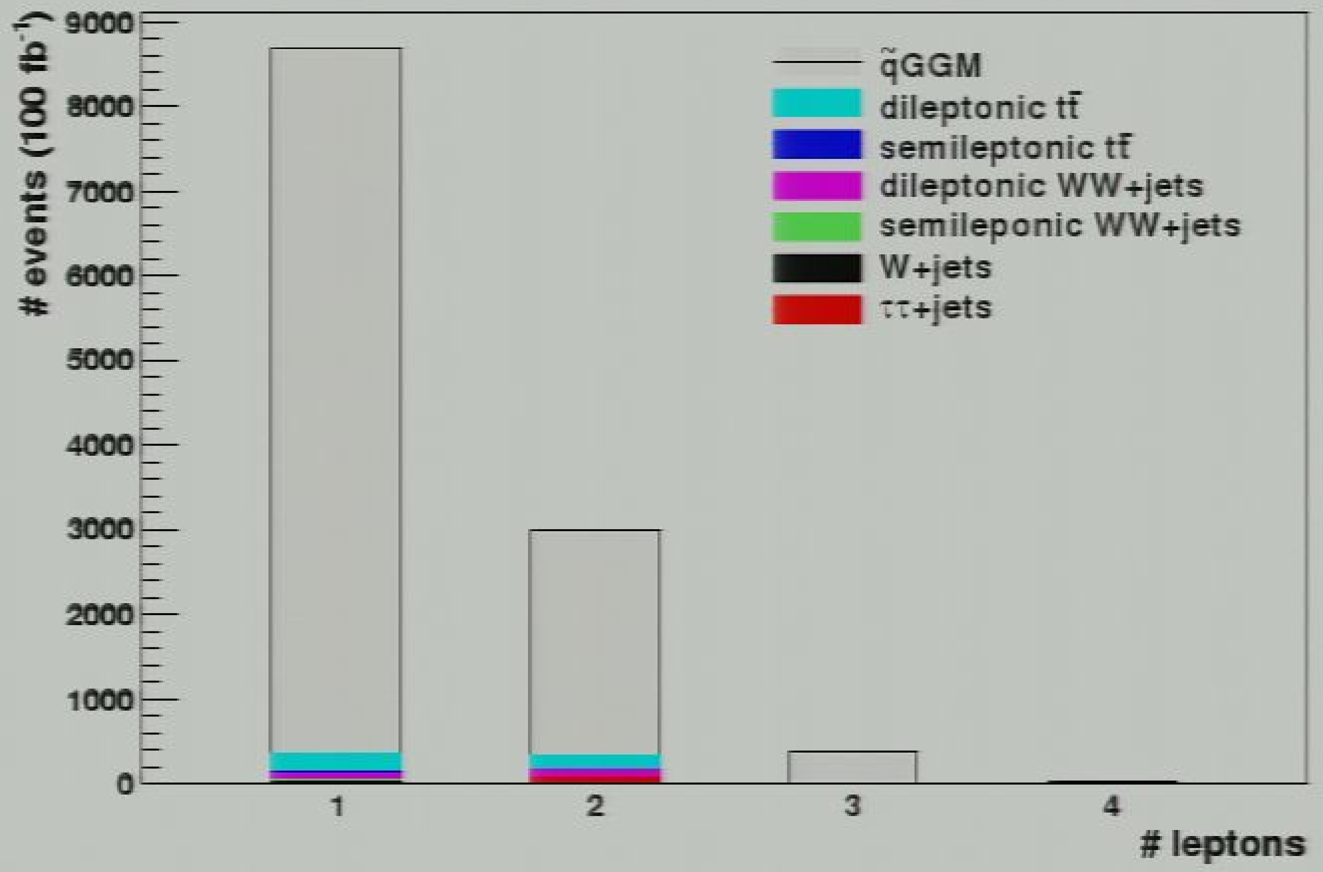
- 90 % are tight leptons, ~10 % are loose
- very few leptons are completely lost

Leptons from 3-body slepton decay:

- ~ 30 % are softer than 5 GeV – lost
- If harder than 5 GeV: $\tilde{q}\tilde{q}$ – almost all leptons are tight, $\tilde{g}\tilde{g}$ – up to 1/2 of leptons can be identified as loose.

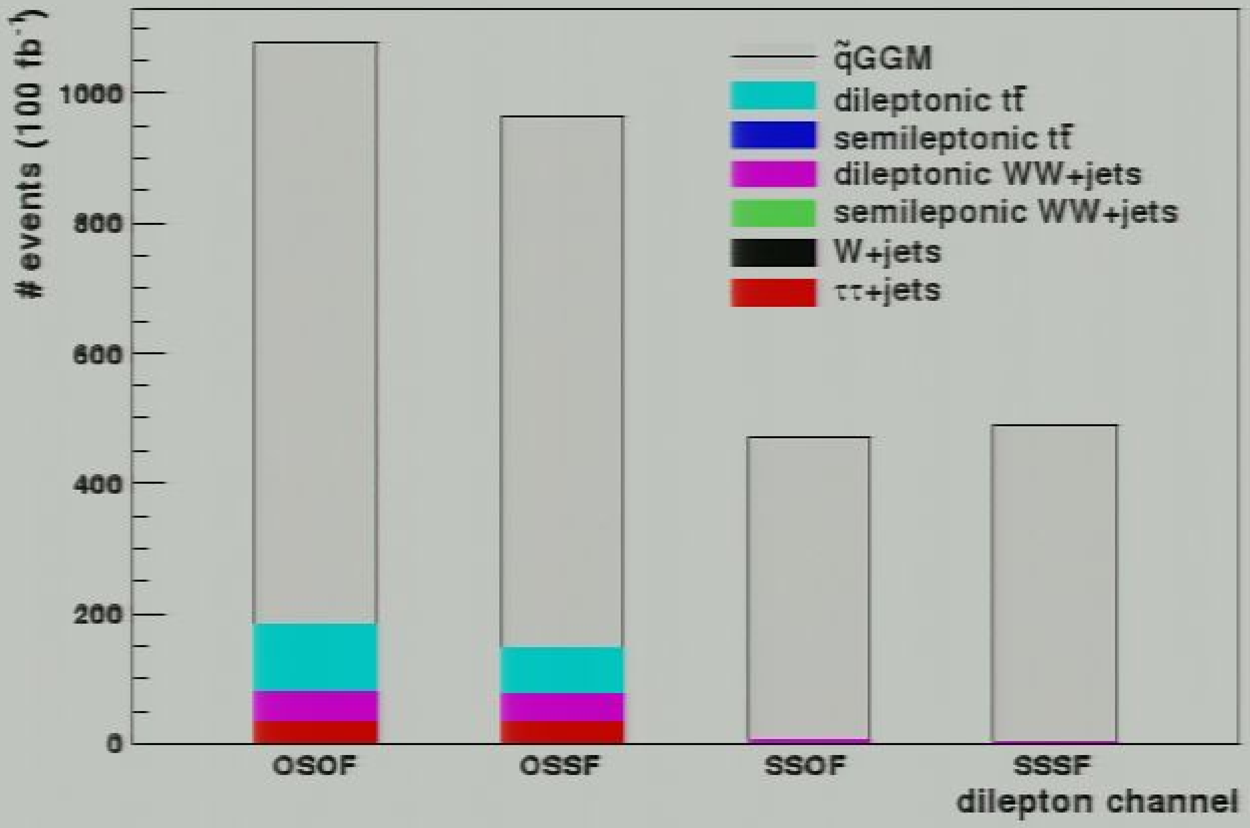
Detector effects are not taken into account

Count the leptons



Monoleptonic:dileptonic ~ 3:1
agrees up to order one number with what we expect

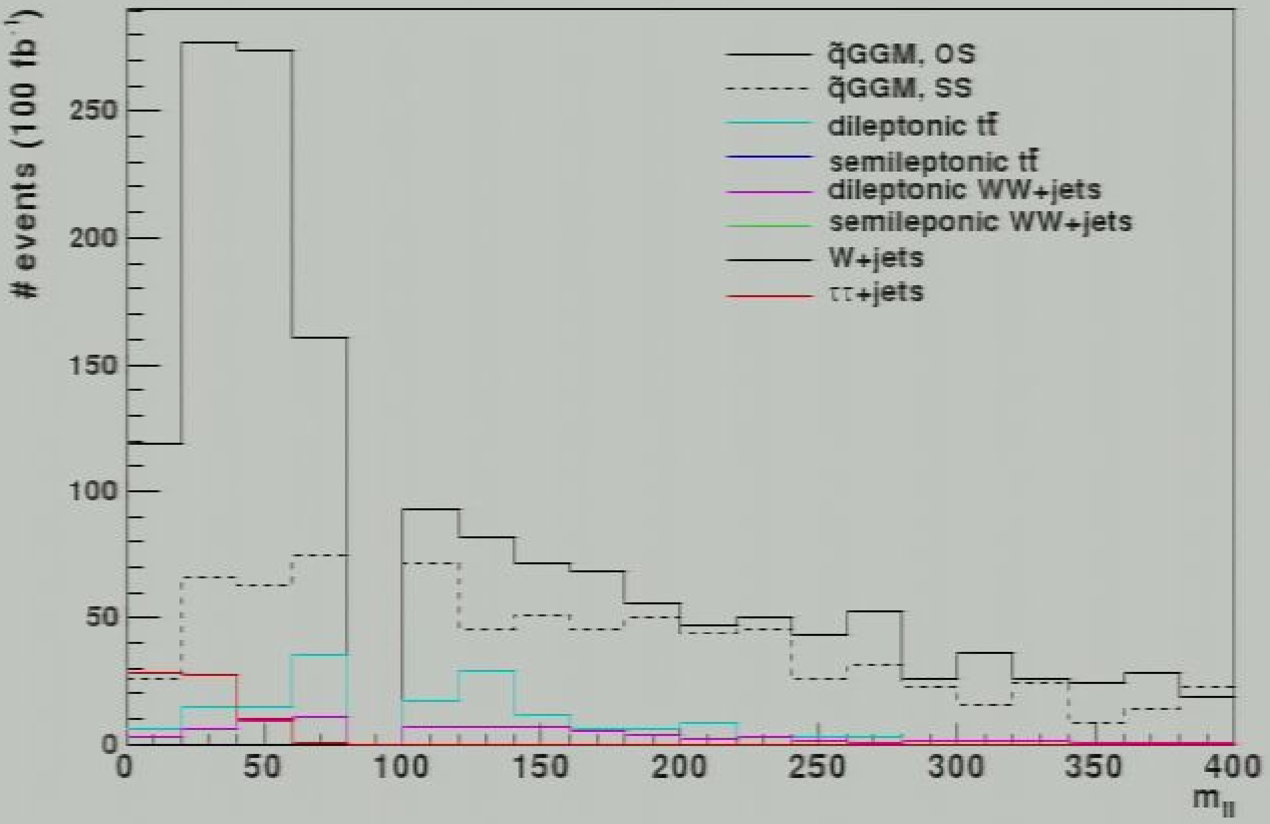
Structure of the 2l channel



$\mathrm{OSOF} \sim \mathrm{OSSF} > \mathrm{SSOF} \sim \mathrm{SSSF}$

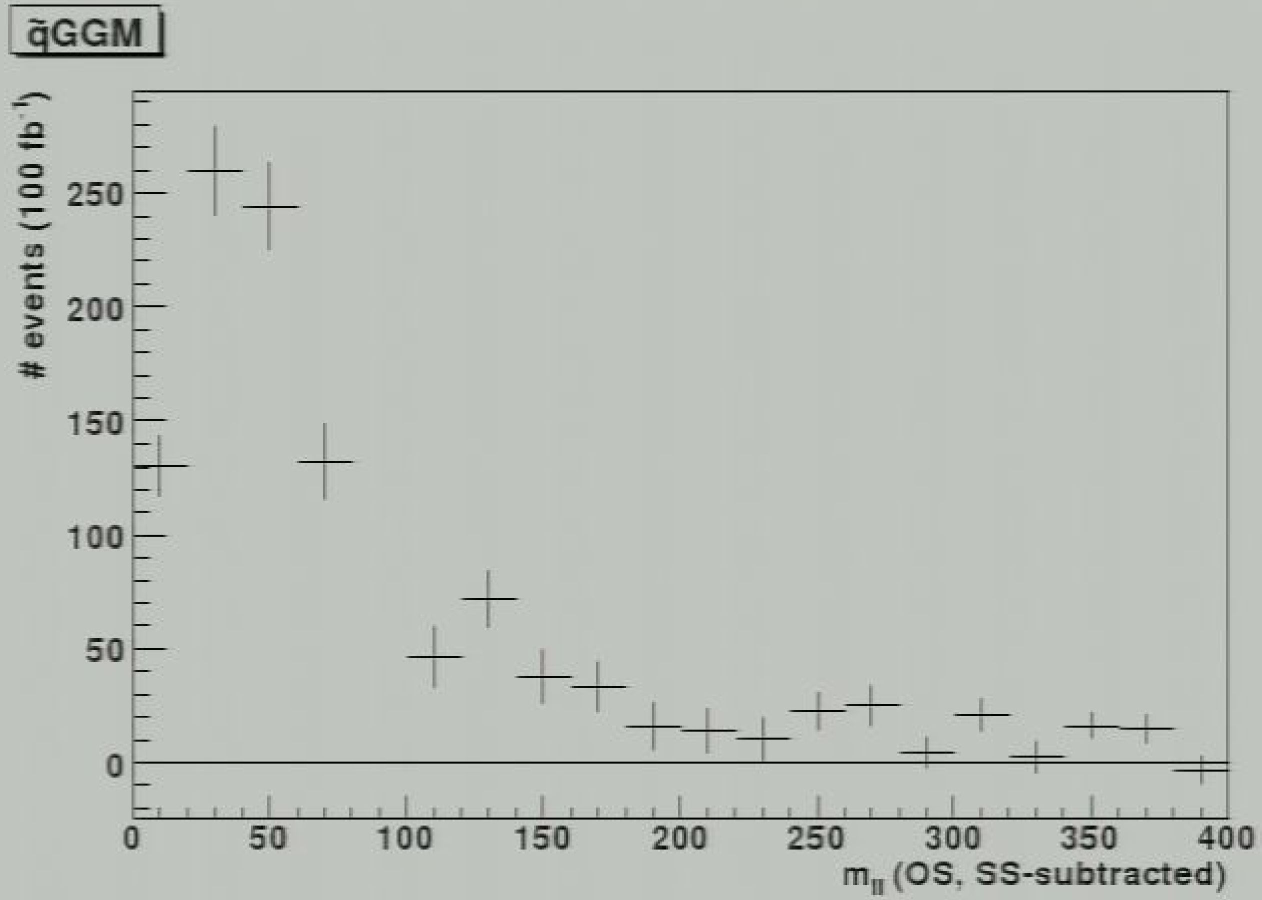
OSSF is bit smaller than OSOF due to Z misreconstruction

M_{ll} in 2l channel



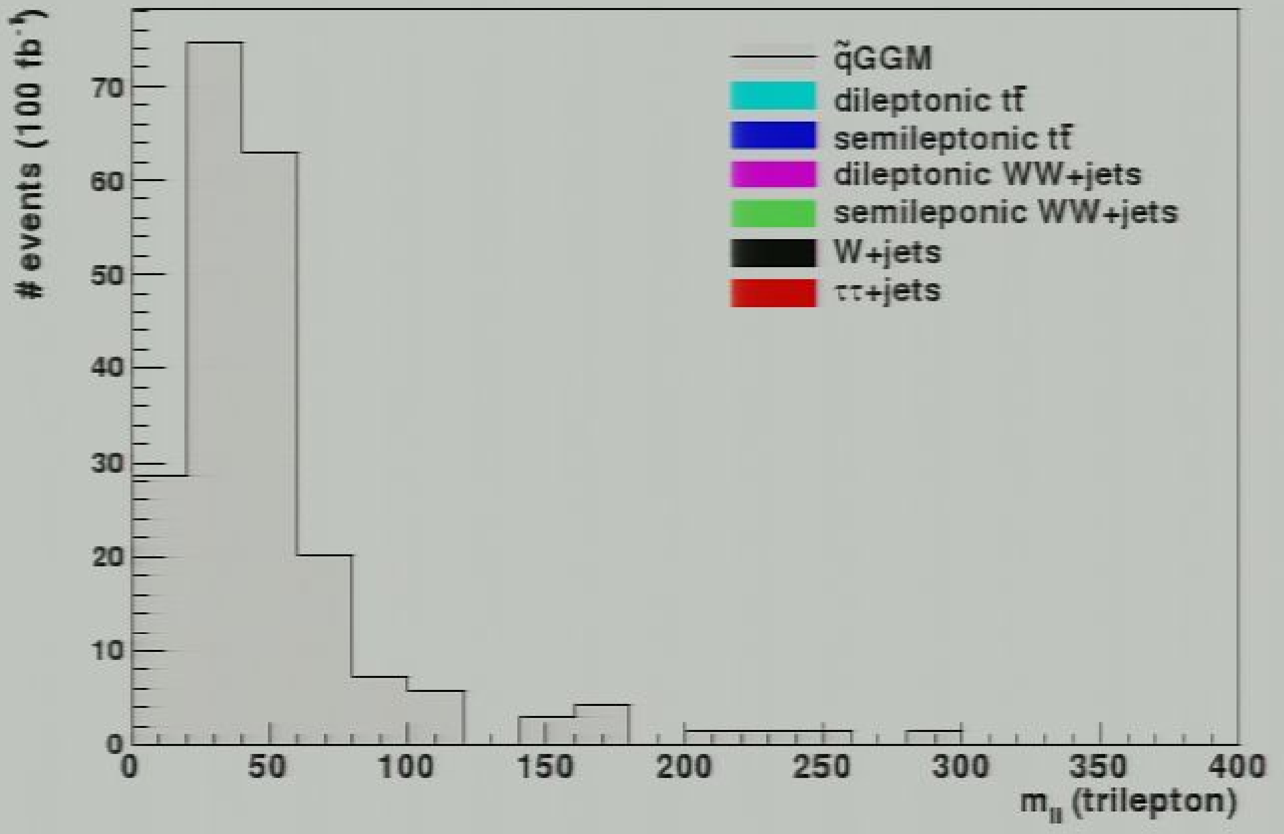
Same sign signal has no structure, OS sign signal has a bump.

Sign subtraction



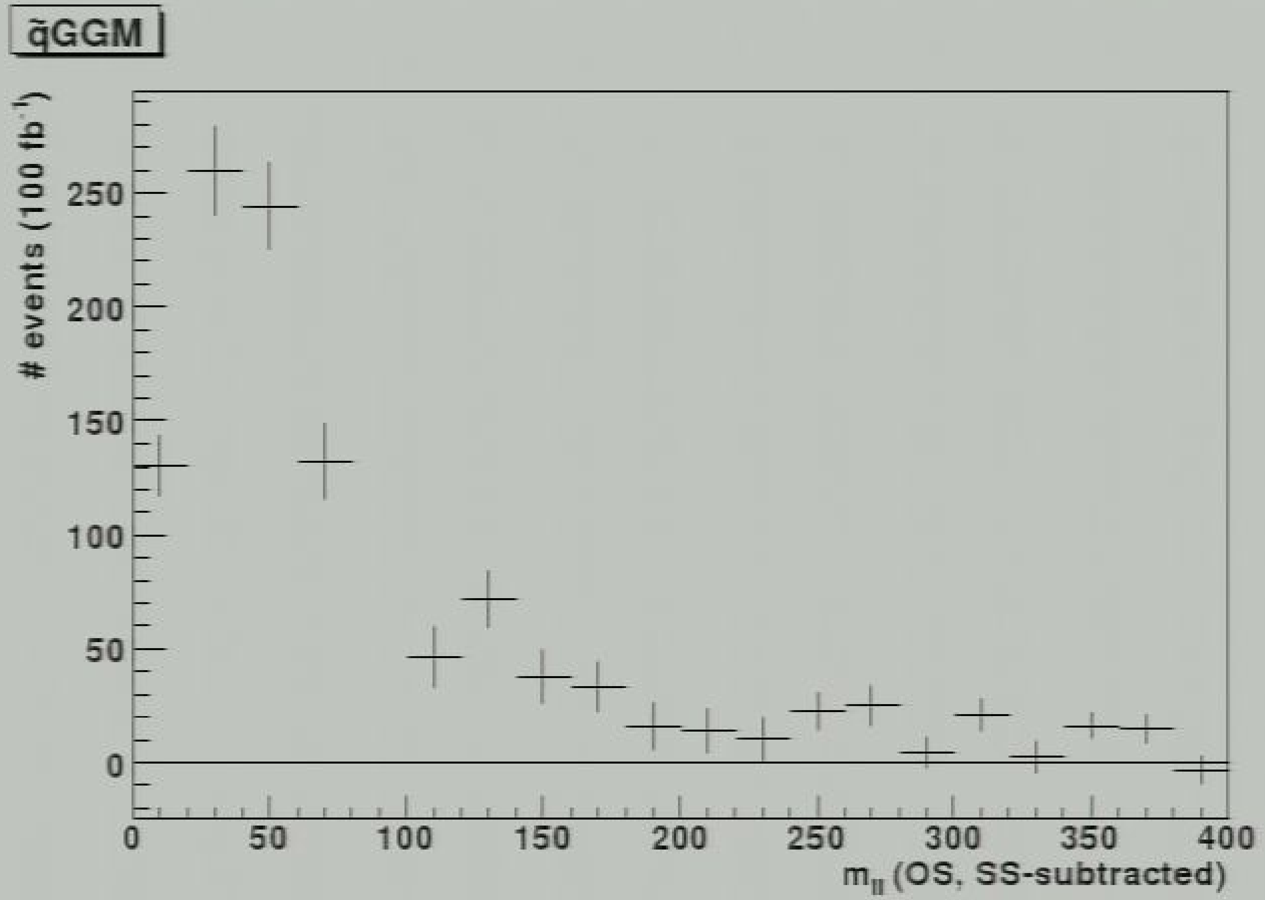
Predicted bumps are at 31 GeV and 40 GeV sitting one on top of each other.

3l channel



OS pairing in 3l channel. The structure is the same as it is in the 2l channel.

Sign subtraction



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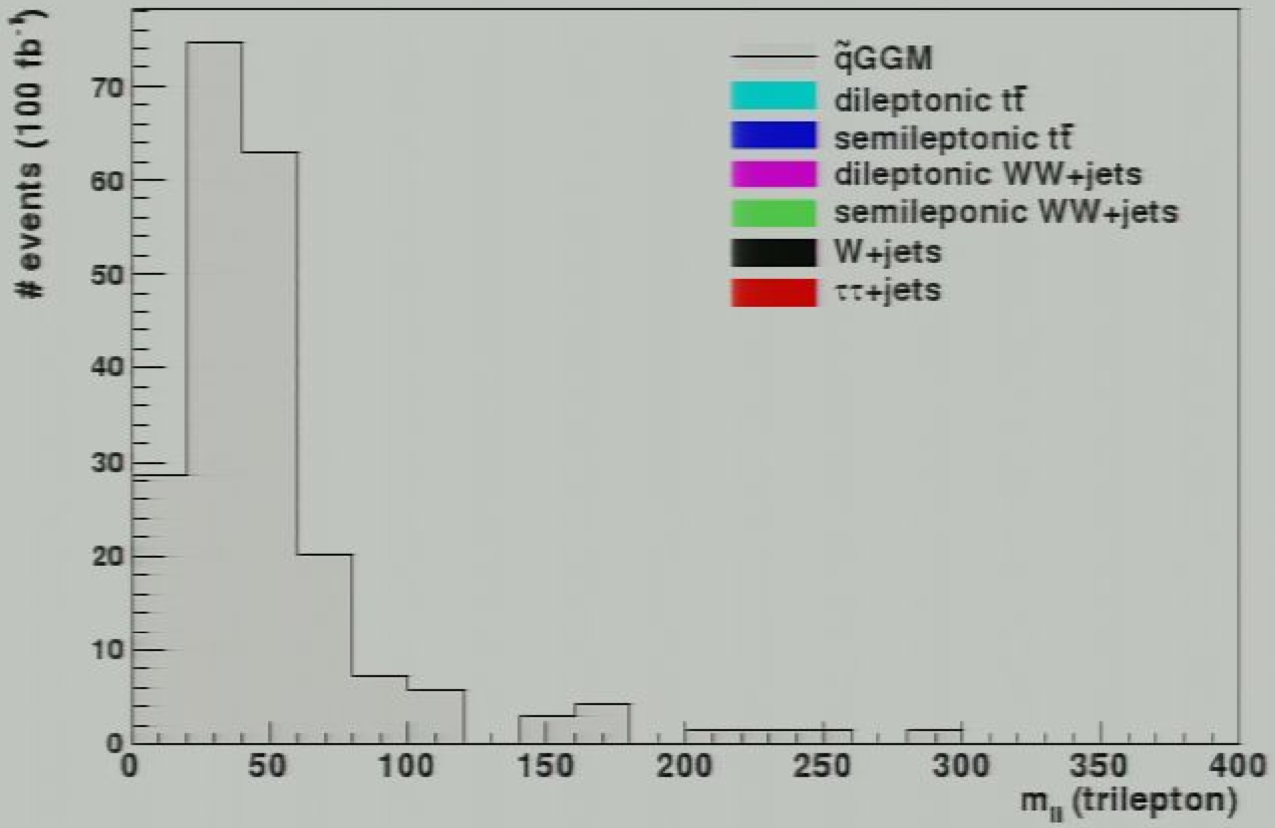
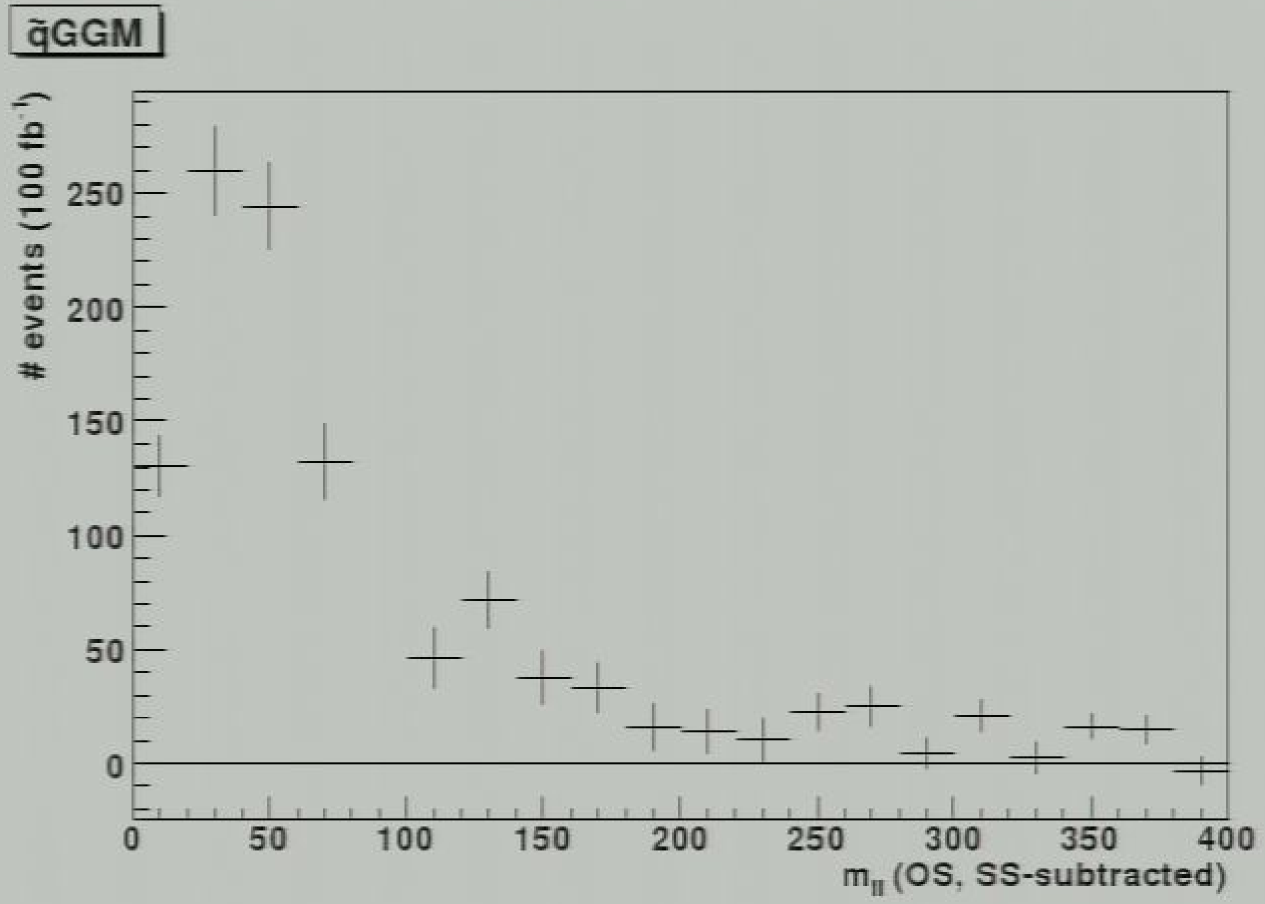


OS pairing in 3l channel. The structure is the same as it is in the 2l channel.

Sign subtraction



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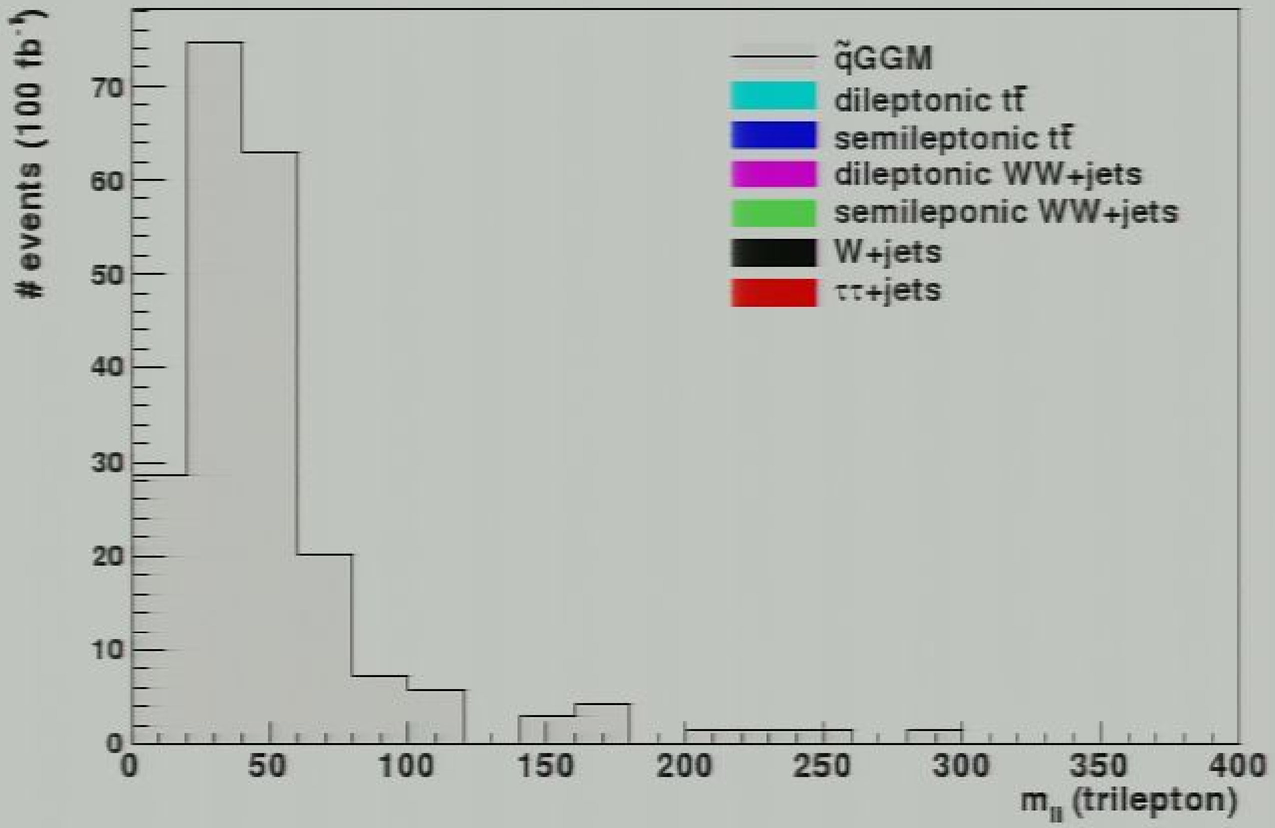
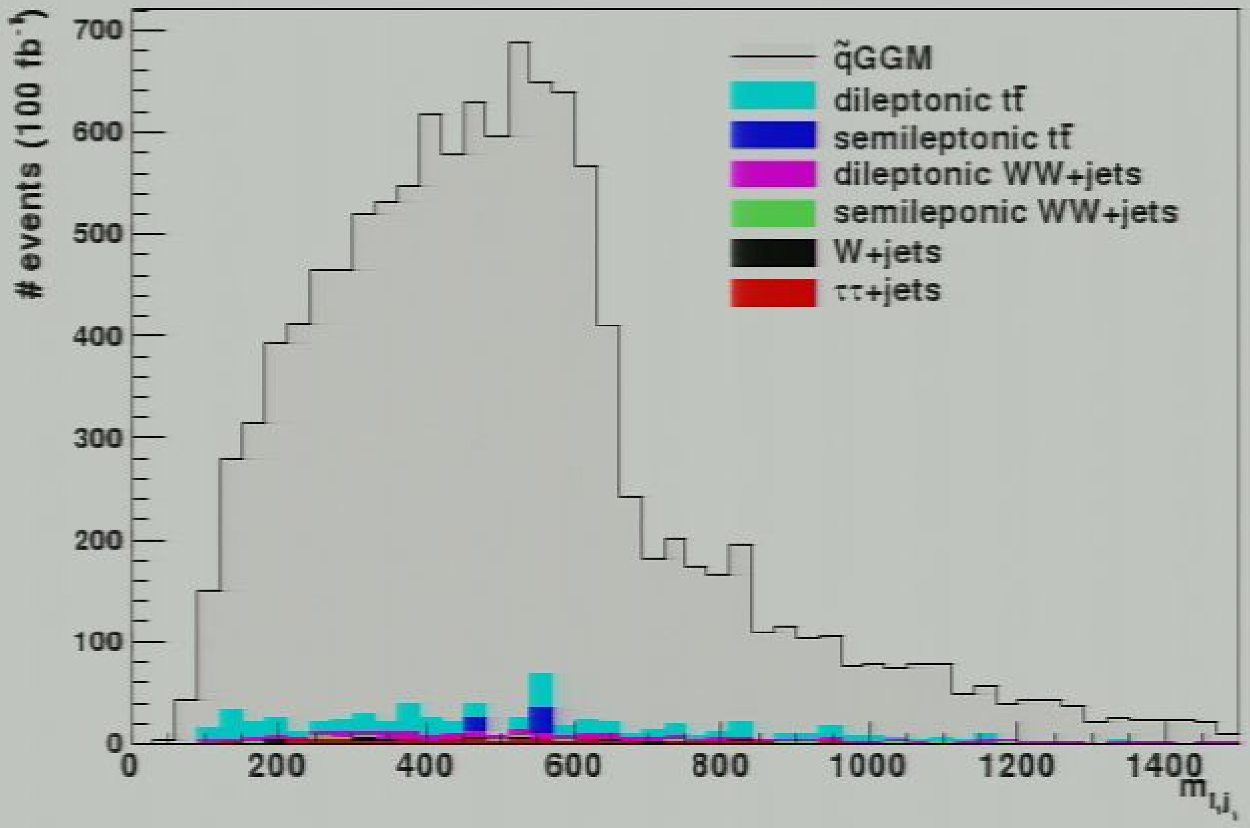


OS pairing in 3l channel. The structure is the same as it is in the 2l channel.

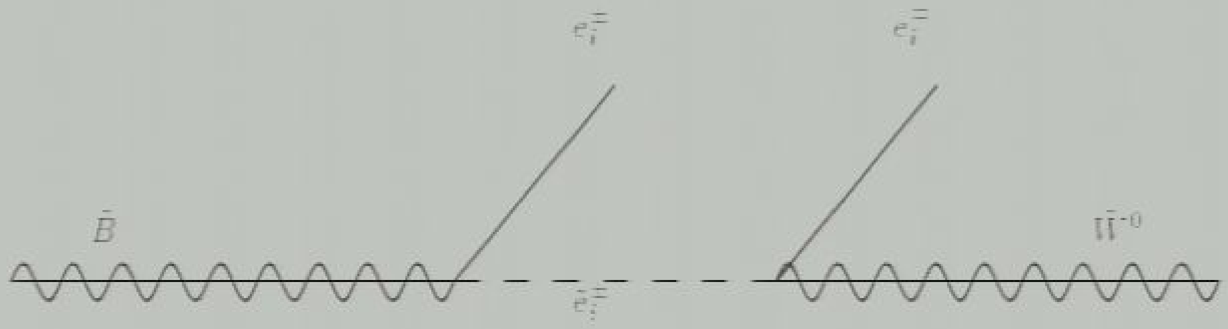
M_{jl} invariant mass



With the given spectrum the cascade $\tilde{q} \to \tilde{\chi} \to \tilde{l}$ is expected to give an edge at 625 GeV.

Why are active spectra different?

These spectra usually have strong OSSF excess:



The last neutralino can be either on or off-shell. We expect the 2l channel structure:

$$\text{OSSF} > \text{OSOF} > \text{SSOF} \sim \text{SSSF} .$$

2l channel – active spectra

What are the reason for the excess?

- OSOF – all the excess is due to OS random flavor pairs from neutralino decays
- OSSF – partially due to wino-like netralino decays and partially due to bino → wino decays.

Procedure:

1. Subtract OSSF-OSOF – get the shape of leptons from bino decays emitting correlated lepton pairs
2. Subtract OSOF-SSOF – get the shape of leptons coming from wino decays

Active spectrum example

- Predominantly squark production ($m_{\tilde q} \sim 950$ GeV)
- Relatively heavy Higgsinos

$$m(\tilde B) = 498 \text{ GeV} \quad m(\tilde e_r) = 402 \text{ GeV} \quad m(\tilde W) = 378 \text{ GeV}$$

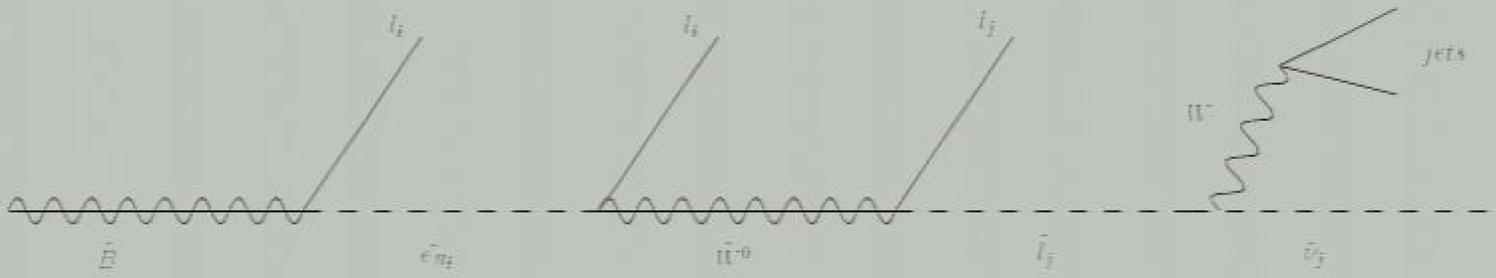
$$m(\tilde l) = 162 \text{ GeV} \quad m(\tilde \nu) = 142 \text{ GeV}$$

Where do we expect edges/bumps?

- $\tilde B \to \tilde e_r \to \tilde W$: edge in m_{ll} at 100 GeV (OSSF)
- $\tilde W \to \tilde l \to \tilde \nu$: bump in m_{ll} around 82 GeV (OS)
- $\tilde B \to \tilde l \to \tilde \nu$: bump in m_{ll} around 113 GeV (OS)

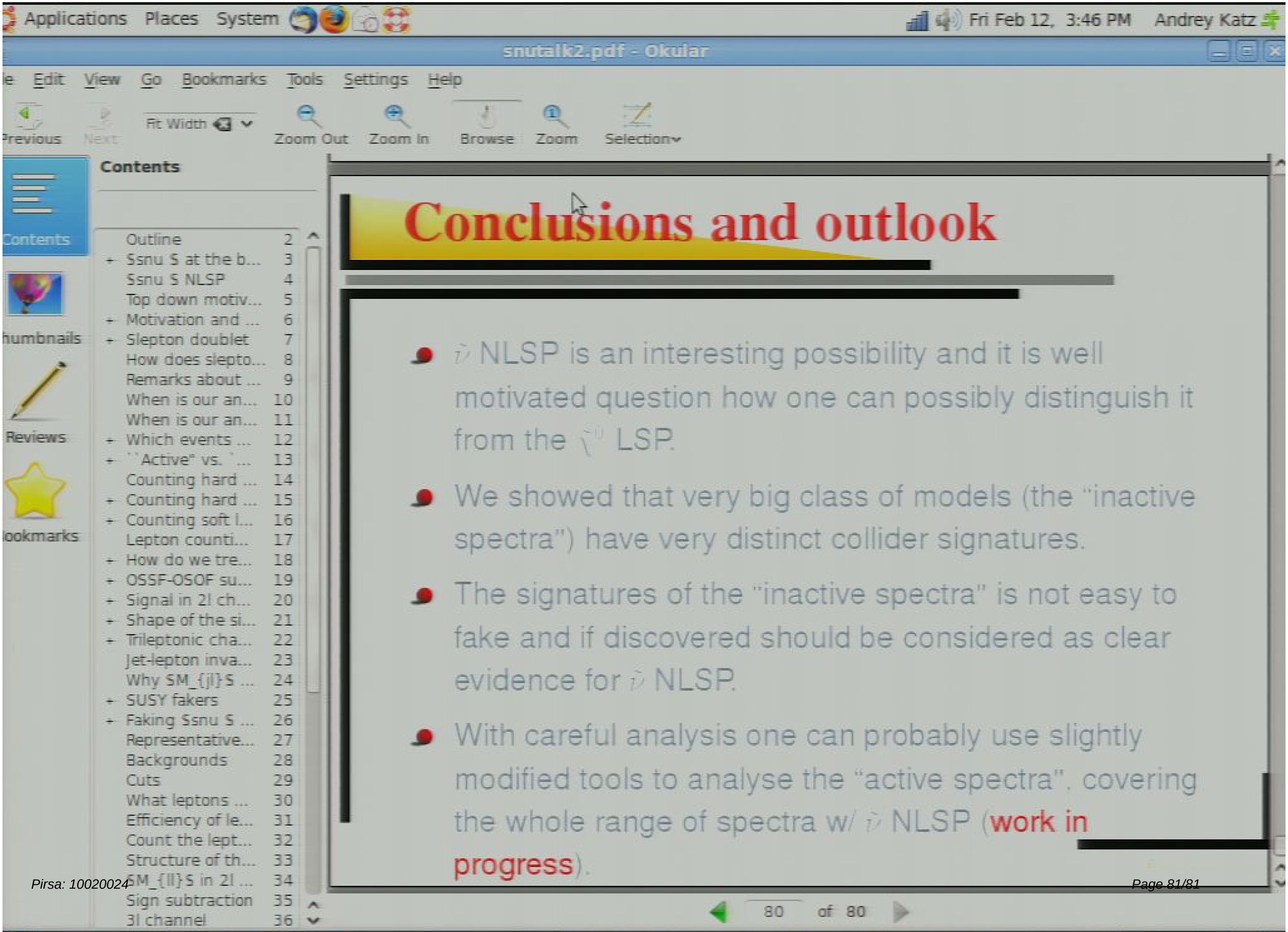
Trileptons in active spectra

Now we can get 3l even from the same decay chain, e.g.



Conclusions and outlook

- $\tilde{\nu}$ NLSP is an interesting possibility and it is well motivated question how one can possibly distinguish it from the $\tilde{\chi}^0$ LSP.
- We showed that very big class of models (the “inactive spectra") have very distinct collider signatures.
- The signatures of the “inactive spectra" is not easy to fake and if discovered should be considered as clear evidence for $\tilde{\nu}$ NLSP.
- With careful analysis one can probably use slightly modified tools to analyse the “active spectra", covering the whole range of spectra w/ $\tilde{\nu}$ NLSP (work in progress)



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