General Features of SUSY Signals at the ILC: Staus and Neutralinos (Jet Resolution and Tracking)

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in collaboration with

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Outline

- Brief introduction to the LHC inverse problem SUSY at the ILC
- Staus
- Associated neutralino production
- Summary and outlook

Introduction

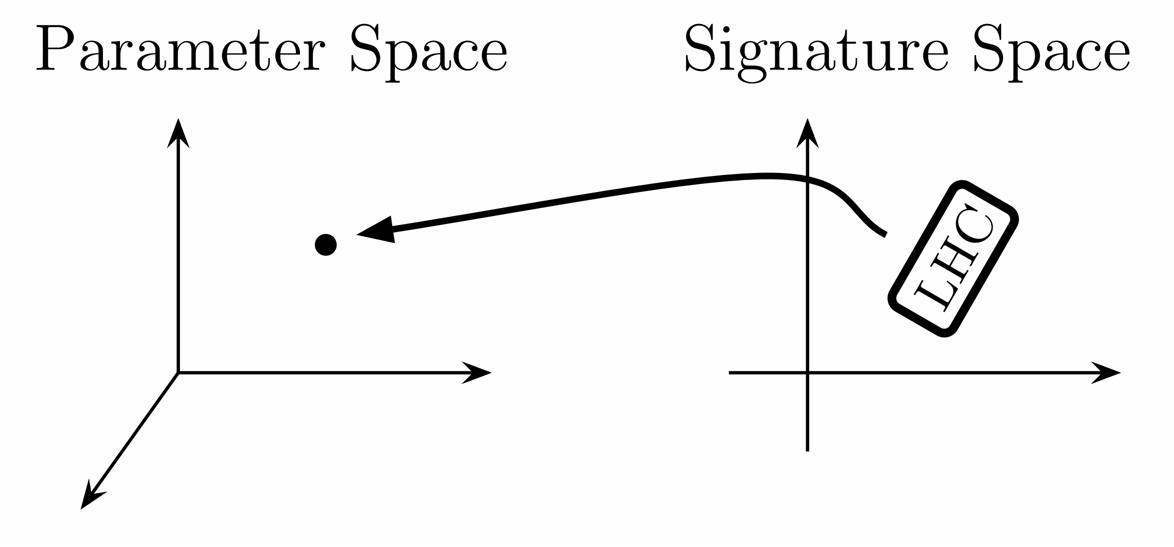
What's in a name?

Theorists: parameters ⇒ observables

Experimentalists: observables ⇒ parameters

N. Arkani-Hamed, G. L. Kane, J. Thaler, L.-T. Wang, *Supersymmetry and the LHC inverse problem*, JHEP 0608, 070 (2006) [hep-ph/0512190]

Question: parameters ⇔ observables – a one-to-one map?



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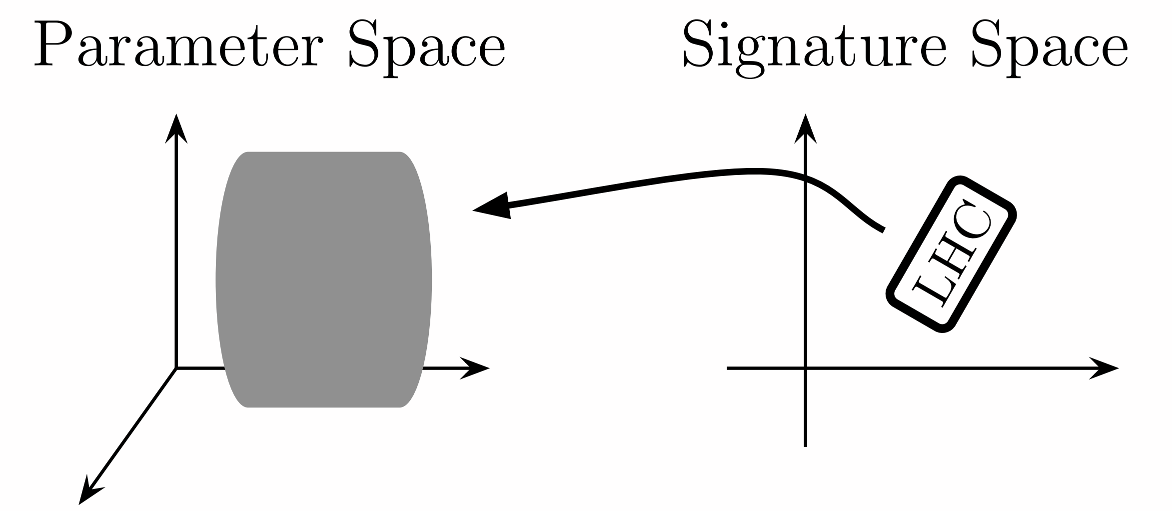

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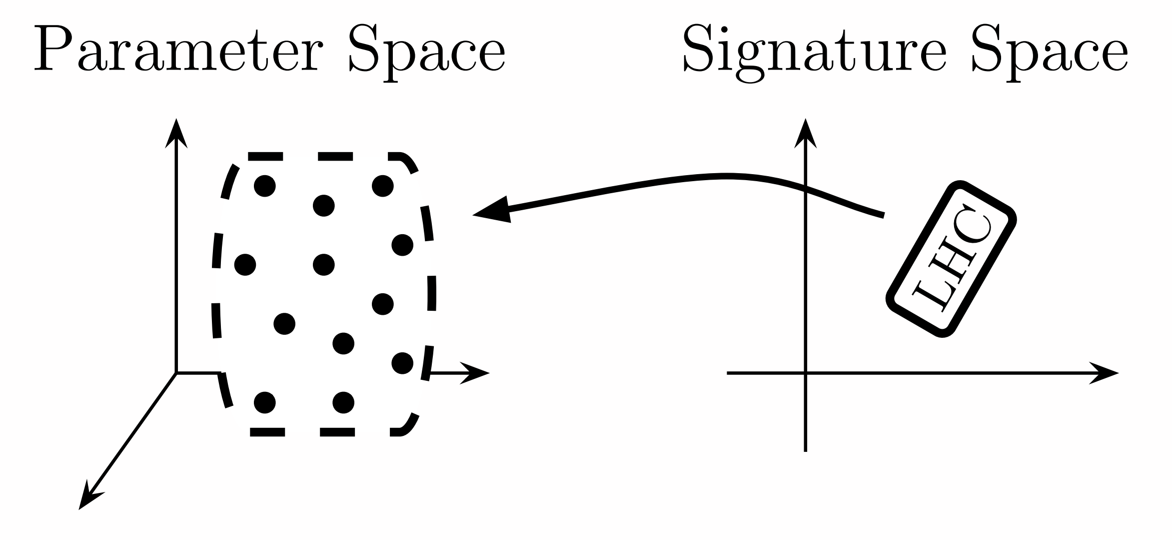

Introduction contd.

hep-ph/0512190: scan over (restricted) MSSM parameter space, simulation of different "models". **Existence proof: there are distinct MSSM models that are indistinguishable at LHC with standard set of observables even without SM background.**

The LHC can only measure **mass differences** accurately, initial state (= c.m. energy per collision) not well defined.
In addition, multiparton final states dominate. In general, "messy" final states $\Rightarrow$ **soft particles not visible**.

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Question: given the list of MSSM "models" that turned out to be indistinguishable at the LHC in hep-ph/0512190, can the ILC distinguish them, using which observables?

Why Bother?

is it an amoeba or is it Sharon Stone?

decoding the compositions of primary constituents

- Just like decoding DNA we have to decode the signals we will observe. And we do expect more similarities than differences, so fast discrimination will require smart and simple measurements.

M. Spiropulu, talk at SUSY07

Our Project - Overview

- Take a degenerate pair of “random” MSSM models
- Simulate signal events with Pythia and CompHEP, and feed in appropriate beamspectrum generated via Whizard/GuineaPig, including ISR, cold-specific beamstrahlung, beamspread
- Add SM background (1016 different processes), produced by Tim Barklow (SLAC) via Whizard, stored on SLAC tape (1.7 TB)
- Pipe through detector simulation
  Java-based fast detector simulation, code developed by SLAC ILC group: `org.lcsim`, SiD detector concept
- Analyze $500\ \text{fb}^{-1}$ of “data” with appropriate cuts
  Several iterations necessary to find best cuts

Degeneracies

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At the LHC indistinguishable

- **Models with small mass differences of particles that decay in cascades**
- **Models with fixed mass eigenvalues but different mixing components (bino versus wino)**
- **Models with the same differences in masses of cascade-decaying particles, but different absolute masses**

Particle Accessibility and Observability

particles	accessible at 0.5 TeV	visible at 0.5 TeV	access. at 1 TeV
selectrons, smuons	22	19	116
staus	28	18	125
$\tilde{\chi}_1^\pm$	53	49	78
$\tilde{\chi}_1^\pm \tilde{\chi}_2^\mp$	7	0	16
$\tilde{\chi}_1^0 \tilde{\chi}_1^0$ only	91	3	1
$\tilde{\chi}_1^0 \tilde{\chi}_2^0$	46	5	178
nothing	61	0	1
total with ≥ 1 spart. acc.	185	82	241

It is highly probable that a 0.5 TeV ILC is not enough.

Staus

The SUSY LHC Inverse Problem and the ILC

Staus
- Staus
- Tau ID
- Cuts
- Stau Signal and Background
- Stau Statistics

Associated Neutralino Production

Summary and Outlook

We study the channel

$$e^+e^- \to \tilde{\tau}^+\tilde{\tau}^- \to \tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0 .$$

Staus are pair produced via s-channel γ and Z exchange, no t-channel contribution. The left- and right-handed staus mix to form two mass eigenstates, which have mixing dependent couplings to the Z boson.

Tau ID nontrivial, because the taus decay in the detector, predominantly into hadrons.

Main SM background from $\gamma\gamma \to \tau^+\tau^+$, $e^\pm\gamma \to e^\pm l^+l^-$, and from $e^+e^- \to W^+W^-$.

Cuts and tau ID adapted from T. Barklow, N. Graf (private communication), H. U. Martyn, hep-ph/0408226.

Tau ID

1. 2 jets with charged multiplicity of 1 (ρ or π or 3π-decay with $2\pi^0$s) or 3 (3 charged pions)
2. invariant mass of tau-jet $<$ 1.8 GeV
3. If the jet is 3-prong (charged multiplicity of 3), then none of the charged particles should be an electron or muon
4. If the jets are 1-prong, then we reject events where both jets are same-flavor leptons, that is, with an electron-positron- or a muon-pair, but we keep jets for example with an electron and a muon, or an electron and a pion, whereby a pion is defined as a charged tracked that is not identified as an electron or a muon.
   Alternatively, we allow leptonic tau decays into muons, but reject taus that decay leptonically into electrons.

Cuts

1. **No electromagnetic energy (or clusters) in $|\cos\theta| > 0.995$.**
2. $-0.75 < Q_\tau \cos\theta_\tau < 0.75$
   This reduces the W-pair background.
3. **Acoplanarity angle $\Delta\phi^{\tau\tau} > 40$ degrees**
   This cut reduces the W-pair and $\gamma\gamma$-induced background.
4. $|\cos\theta_{p_{missing}}| < 0.8$.
5. **Transverse momentum of the ditau system**
   $0.008\sqrt{s} < p_T^{\tau\tau} < 0.05\sqrt{s}$.
   This decreases the $\gamma\gamma$-induced background.
6. $p_T > 0.001\sqrt{s}$ **of each of the tau candidates**
   This cut is crucial to reduce the $\gamma\gamma$ and $e\gamma$ background.
7.

$$\sum p^{\tau}_{\perp,\vec{T}} < 0.00125\sqrt{s}\,(1 + 5\,\sin\Delta\phi^{\tau\tau}) = 0.00125\sqrt{s}\left(1 + 5\,\sqrt{1-\cos^2\theta_T^{\tau\tau}}\right)$$

Further decreases the $\gamma\gamma$ background.

Stau Signal and Background

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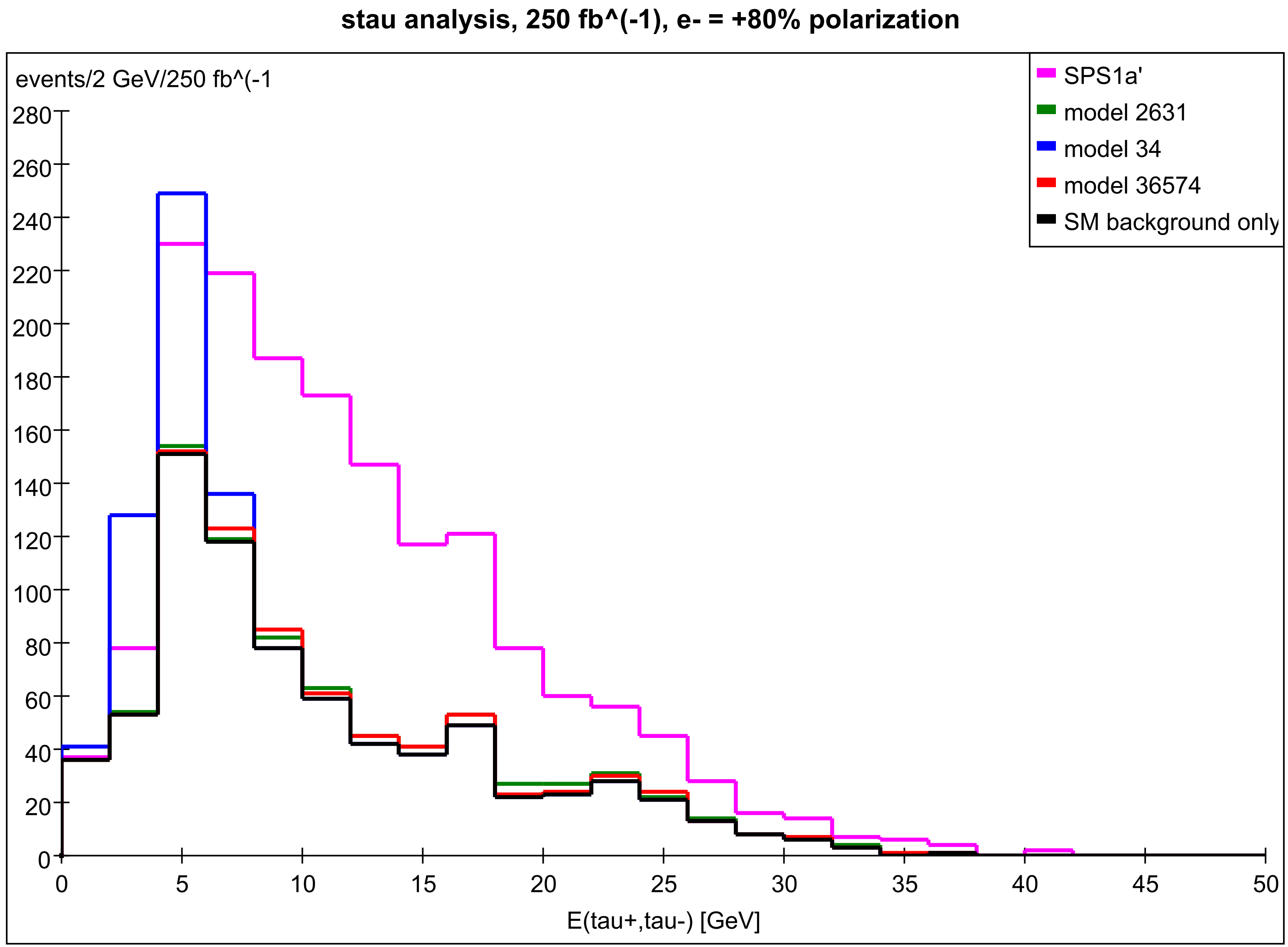

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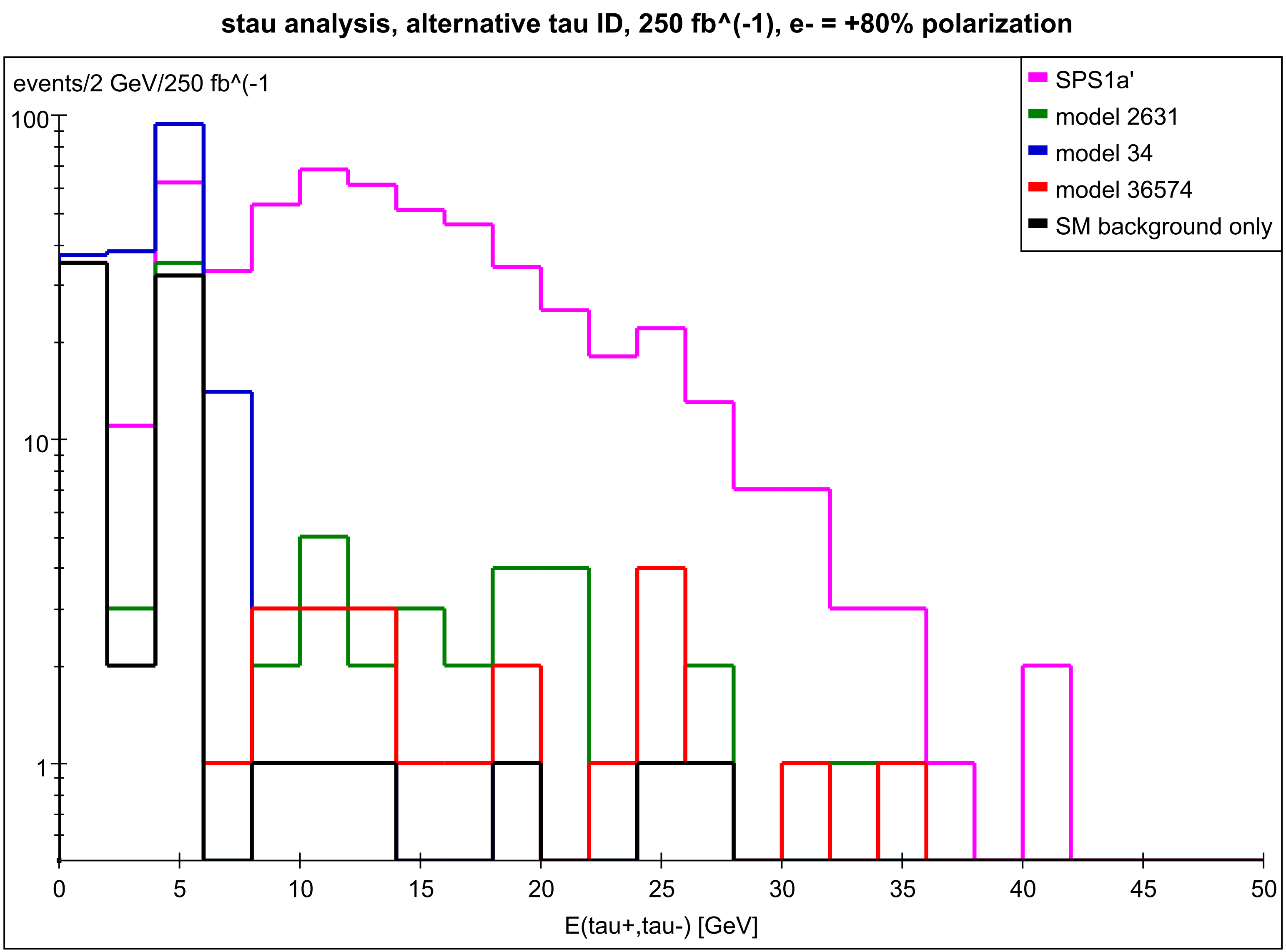

Stau Statistics

- **Models with at 0.5 TeV accessible staus: 28**
- **Models with visible staus (incl. tau decays into electrons): 11**
- **Models with visible staus with alternative tau ID (no electrons): 18**
  despite reducing signal by approx. 30%.

Recall, current SiD design has no tracking information below $\sim$142 mrad. Significant background from $\gamma\gamma \rightarrow \mu^+\mu^-$: one muon is forward and too energetic to deposit energy into a cluster and thus missed, one of the beam electrons is kicked out and detected, leading to a detected final state of one electron, one muon, mimicking tau pairs.

Forward tracking important!

Associated $\tilde{\chi}_2^0\tilde{\chi}_1^0$ Production

$$\tilde{e}^+\tilde{e}^- \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to Z/H\tilde{\chi}_1^0\tilde{\chi}_1^0,\ Z/H \to jj, l^+l^-$$

via

- **Z-exchange in s-channel coupling to wino and higgsino content of $\tilde{\chi}^0$s**
- **$\tilde{e}$-exchange in t, u-channels coupling to their wino and bino content**

If $\tilde{e}$ heavy, Z-exchange dominates $\Rightarrow$ associated $\tilde{\chi}_2^0\tilde{\chi}_1^0$ production suppressed if neutralinos have large bino content, which is often the case.

$\tilde{\chi}_2^0\tilde{\chi}_1^0 \to W^\pm\tilde{\chi}^\mp\tilde{\chi}_1^0,\ W \to jj,\ \tilde{\chi}^\pm \to \tilde{\chi}_1^0 +$ **very soft jets**

Cuts

Main backgrounds from $e^+e^- \to ZZ \to jj/ll\,\nu\bar{\nu}$, $e\gamma \to W\nu \to jj\nu$, and $\gamma\gamma \to ll$.

1. **Precisely one lepton pair (electrons or muons) or one jet-pair**
2. **Missing energy > 300 GeV**
   This removes the majority of Z and W background.
3. **$p_T > 0.14\sqrt{s}$ for each lepton or jet**
   This cut removes the most of the ubiquitous $\gamma\gamma$ and $e\gamma$ backgrounds
4. **Angle between the leptons or the jet pair < 95 degrees**
   This further removes the background from W's.

Neutralino Statistics

- Models with at 0.5 TeV accessible $\tilde{\chi}_2^0\tilde{\chi}_1^0$: 46
- Models with visible $\tilde{\chi}_2^0\tilde{\chi}_1^0$ (jet energy resolution $30\%/\sqrt{E}$): 5

Reduction of W background peak from $e\gamma$:

- Improve on jet energy resolution
- Positron polarization

Neutralino Signal and Background

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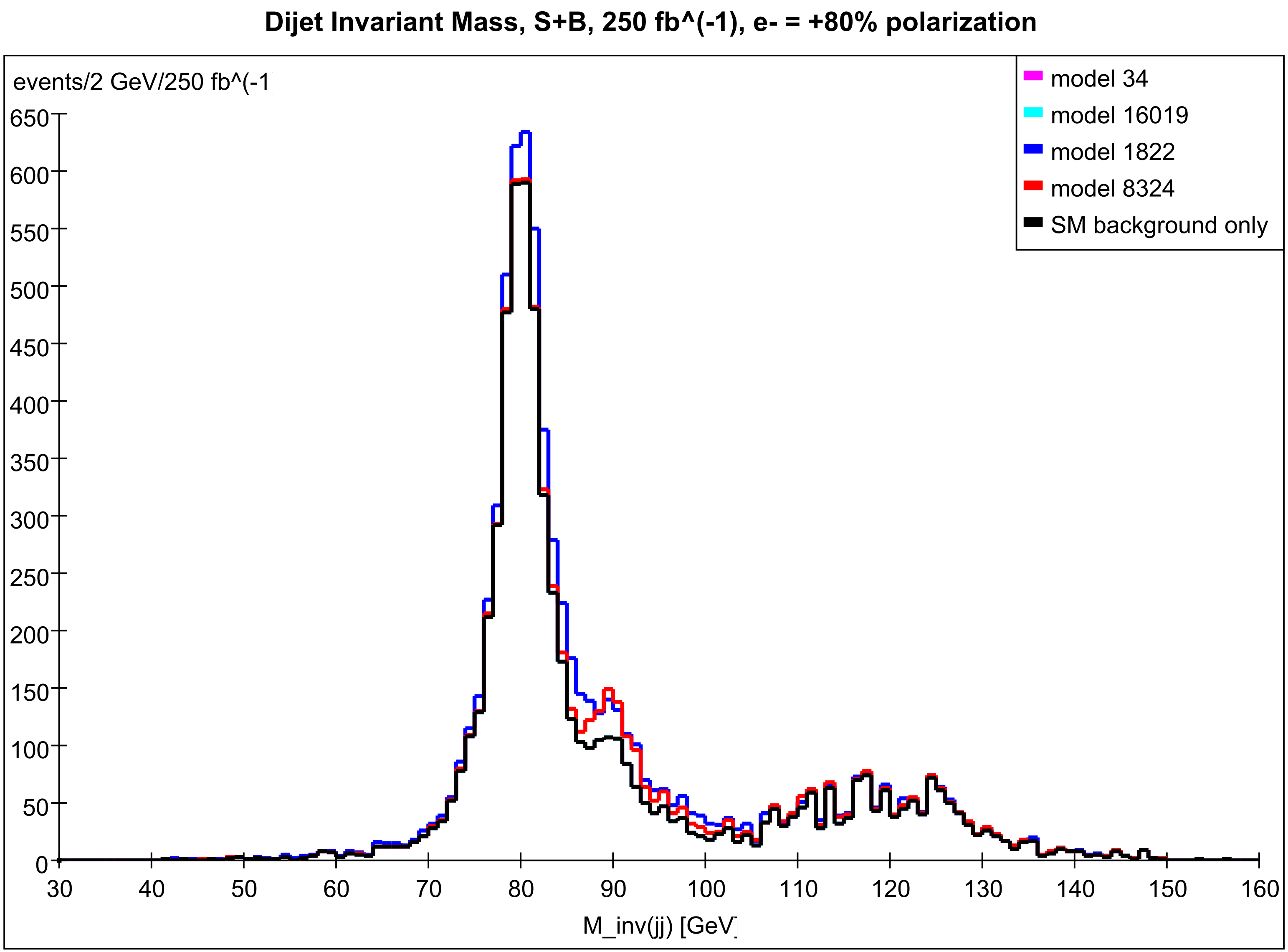
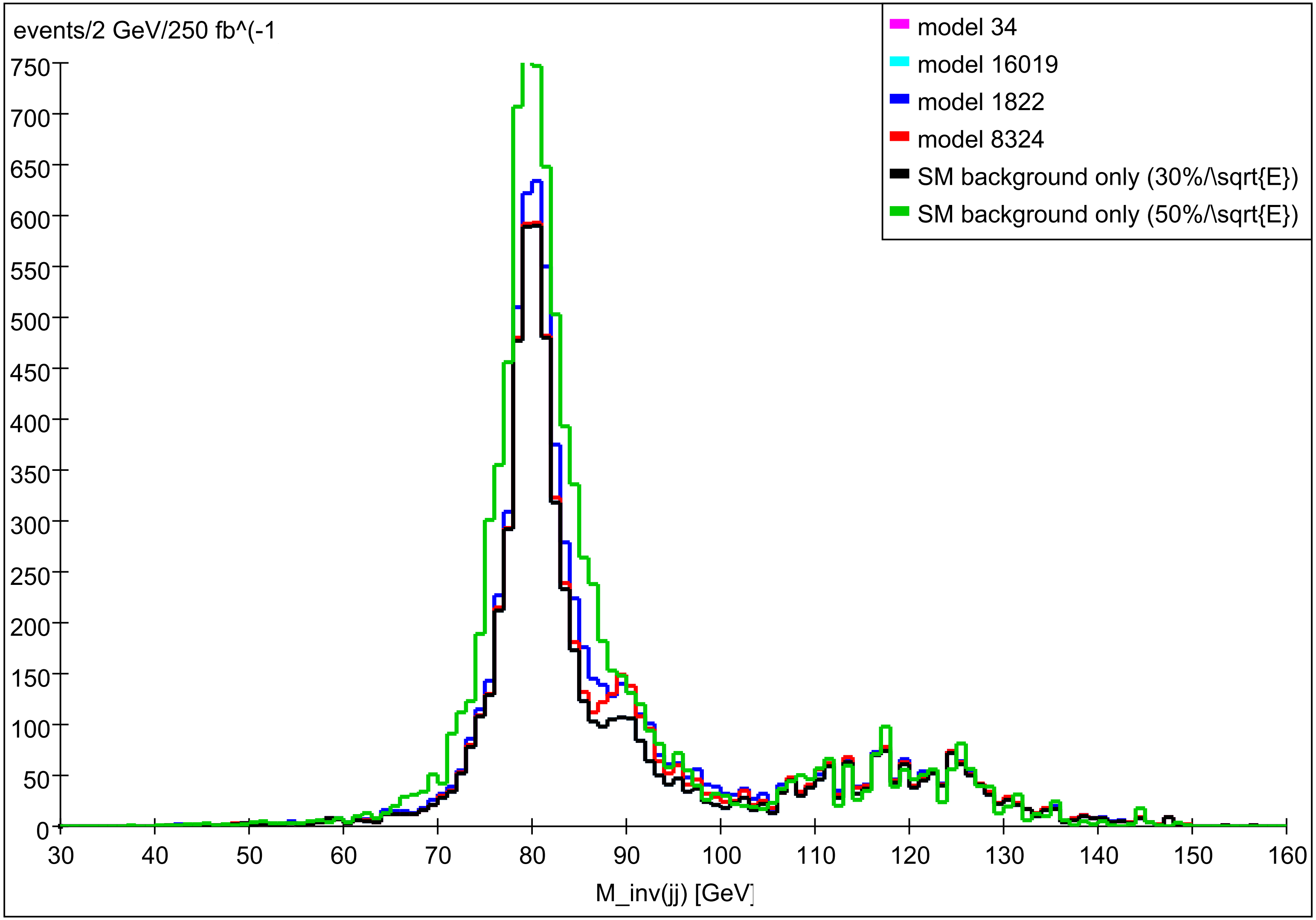


Neutralino Signal and Background

Dijet Invariant Mass, S+B, e- = +80% polarization



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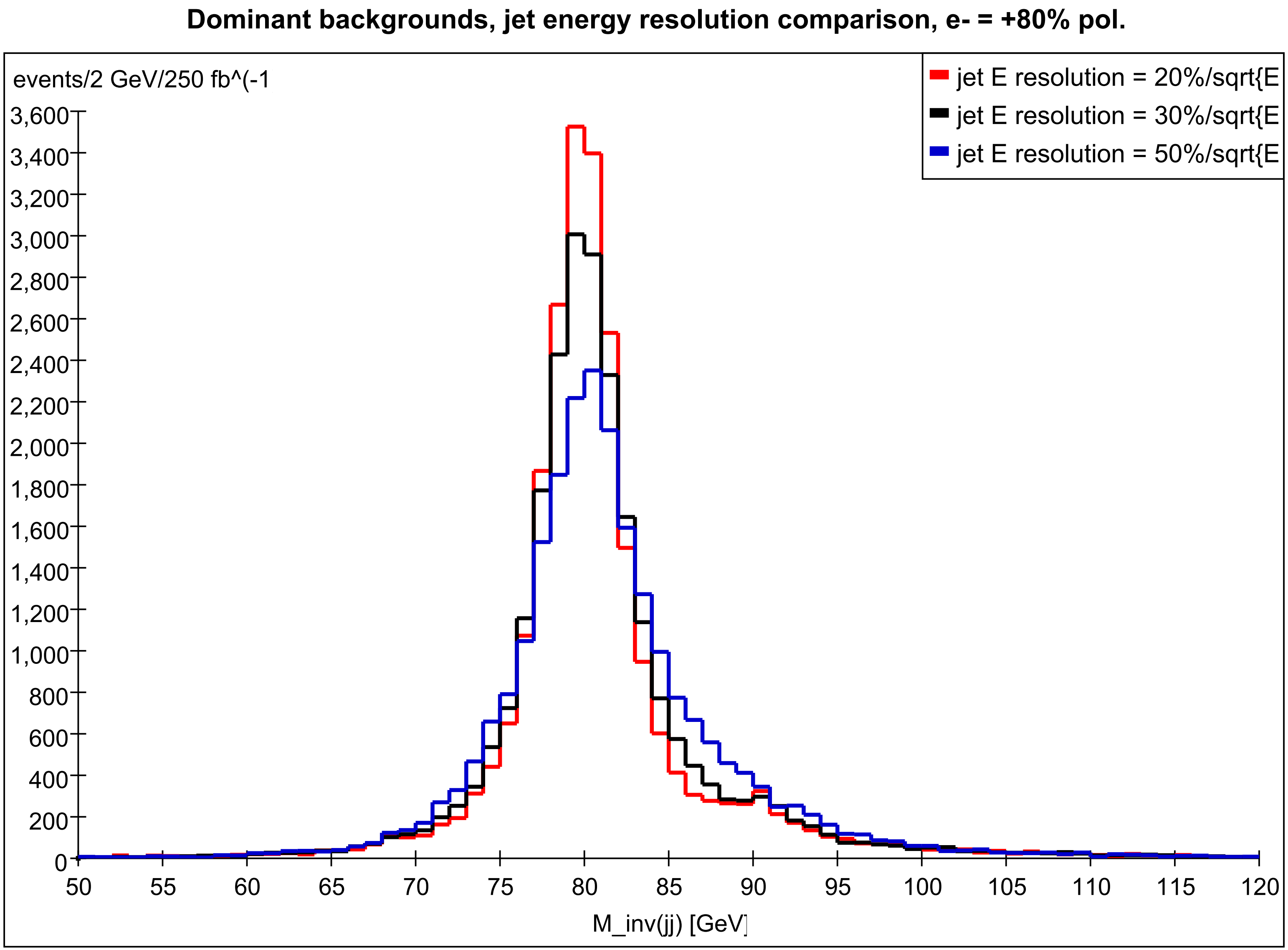
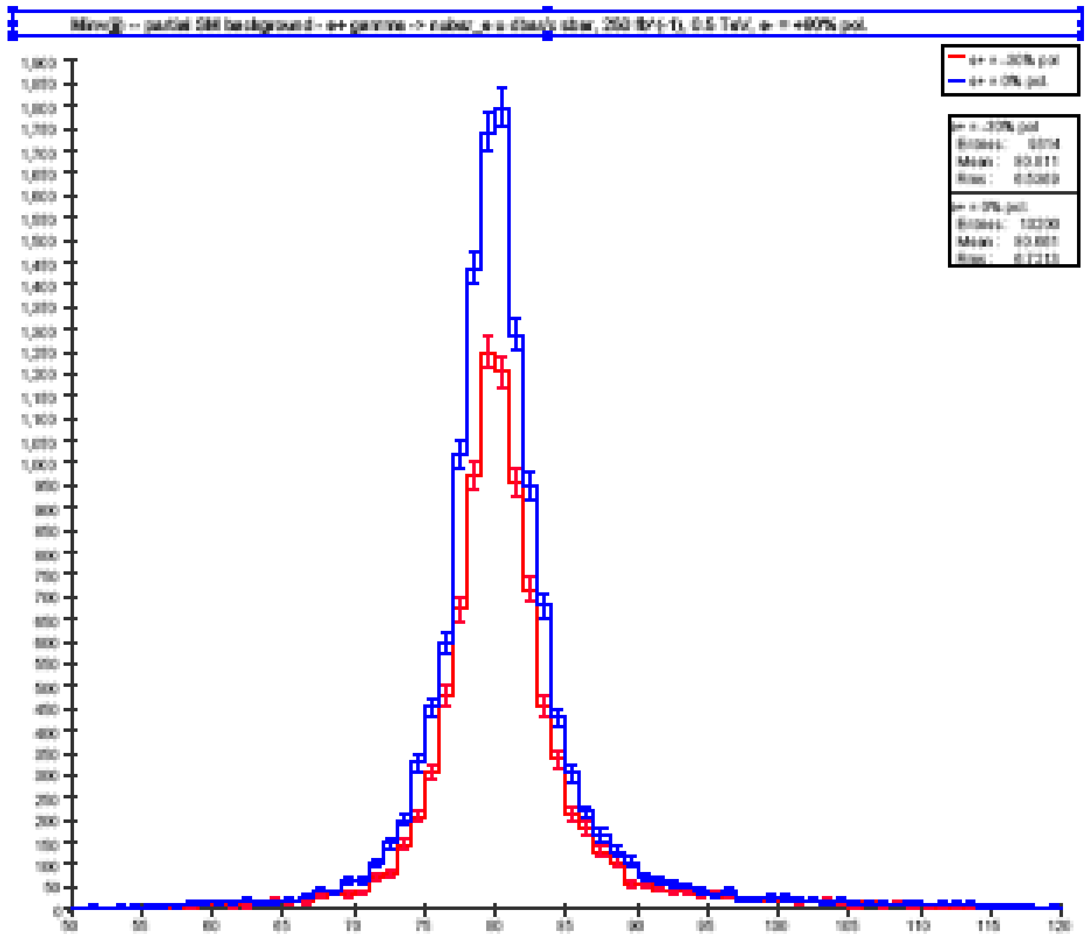


Neutralino Signal and Background

Partial SM background from $e\gamma \to W\nu$, positron beam unpolarized versus 30% polarized



Summary

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- Jet energy resolution crucial for associated $\tilde{\chi}_2^0\tilde{\chi}_1^0$ production
- For many of our sparticle searches (e. g. shown here $\tilde{\chi}_2^0\tilde{\chi}_1^0$) positron polarization can help significantly

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For more on our study see

- James Gainer's talk in Physics WG I (close-mass charginos, selectrons, smuons)
- Tom Rizzo's talk in Physics WG IV (stable charged particles)
- arXiv/0710.xxxx [hep-ph]

Outlook