Detect Nearly Degenerated Gauginos at LHC

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LHC Early Phase for ILC 07
BSM: $\not{E}$ and all other processes Working Group
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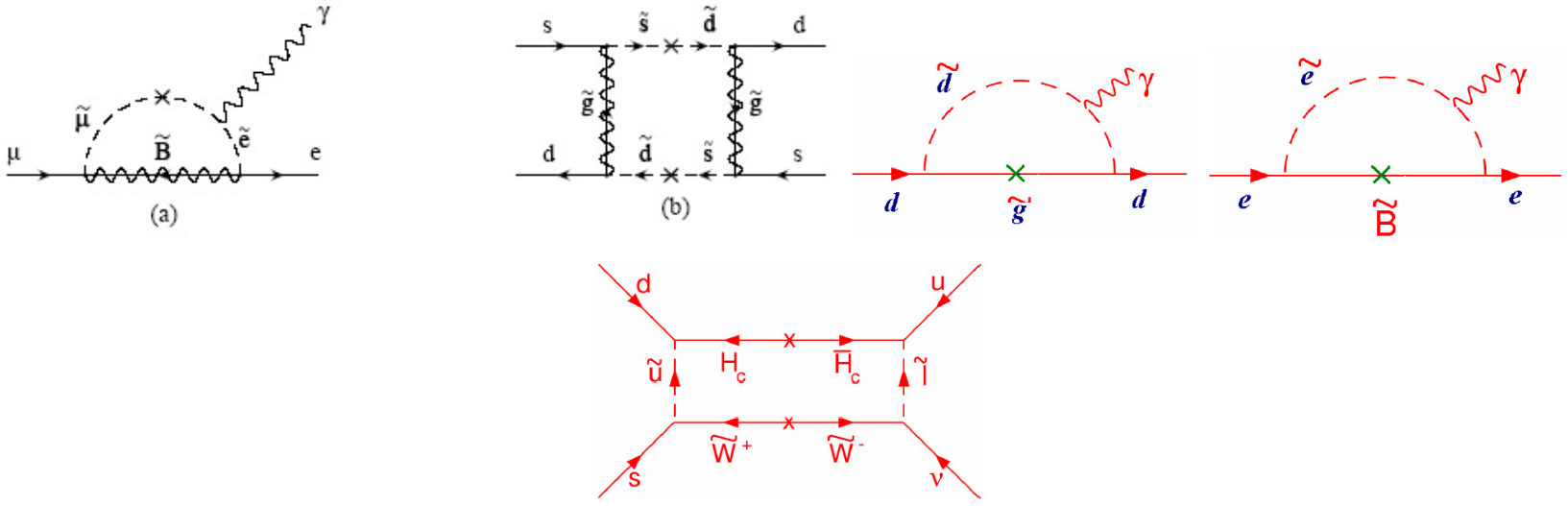
Heavy Scalars Scenario in SUSY

Low energy SUSY is elegant but .....

How SUSY is broken and more than that

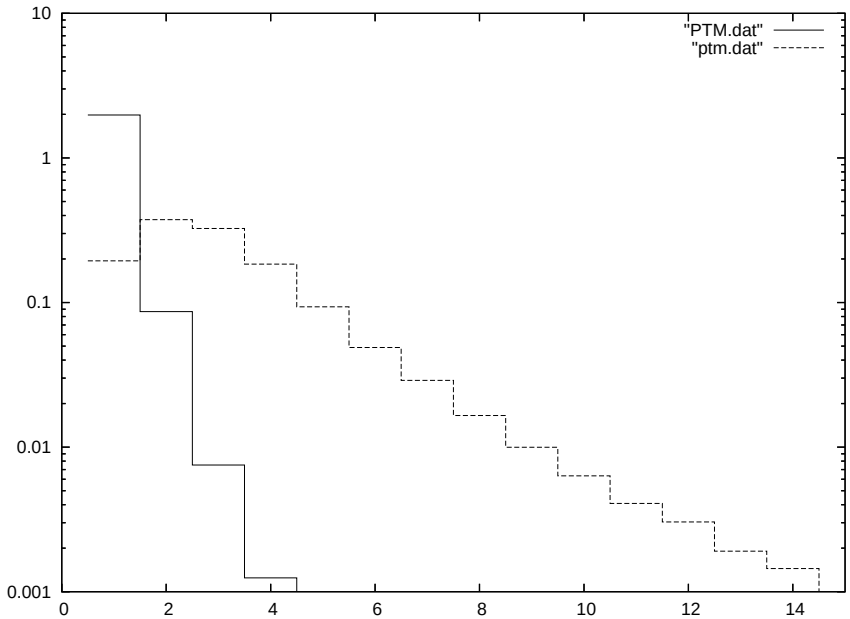
- $d = 5$ proton decay ($QQQ\ell/M_{\rm Pl}$ unless additional discrete symmetries(possible))
- SUSY flavor ($b \to s\gamma, \mu \to e\gamma, B - \bar{B}$ mixing,...)
- SUSY CP (neutron EDM,...)
- ...



Solution: Heavy Scalars

- Gauge unification does not require light scalars because they are all in one GUT mupltiplet.
- String theory does not imply low energy SUSY.
- Dark matter: R-parity. Everything in this session. ($\not{E}$)
- Nothing protects scalar masses within SUSY theory. (can be generated from D-term; -inos are protected by R-symmetry)

Nearly Degenerate: Phenomenology Challenge



Trilepton: $\chi_2^0\chi_1^\pm \to \ell\ell\ell + \not{E}_T$

- lepton p_T: too soft below acceptance ($p_T > 10$ GeV)
- $\not{E}_T$: $\Sigma p_T^i = 0$

Nearly Degenerate: Theoretical Motivation

Nearly Degenerated Gauginos

$$\Delta = m_{\chi_1^\pm} - m_{\chi_1^0}; \qquad (m_{\chi_2^0}, (m_{\chi_3^0}) \sim m_{\chi_1^\pm})$$

Already studied: Wino LSP in AMSB Feng, Moroi, Randall, Strassler and Su,1999
$M_2 < M_1$, $\Delta \sim m_\pi$

$$\Gamma_{\chi_1^\pm} \sim 10^{-22}\ \mathrm{GeV}$$

signature: Charge track

Cases Studied: well-tempered neutralino Arkani-Hamed, Delgado,Giudice, 2006

- Bino-Wino LSP $M_1 \simeq M_2, \quad \Delta \sim \mathcal{O}(\mathrm{GeV})$
- Bino-Higgsino LSP $M_1 \simeq \mu, \quad \Delta \sim \mathcal{O}(\mathrm{GeV})$

$$\Gamma_{\chi_1^\pm} \sim 10^{-9}\ \mathrm{GeV}$$

Simulation Tools

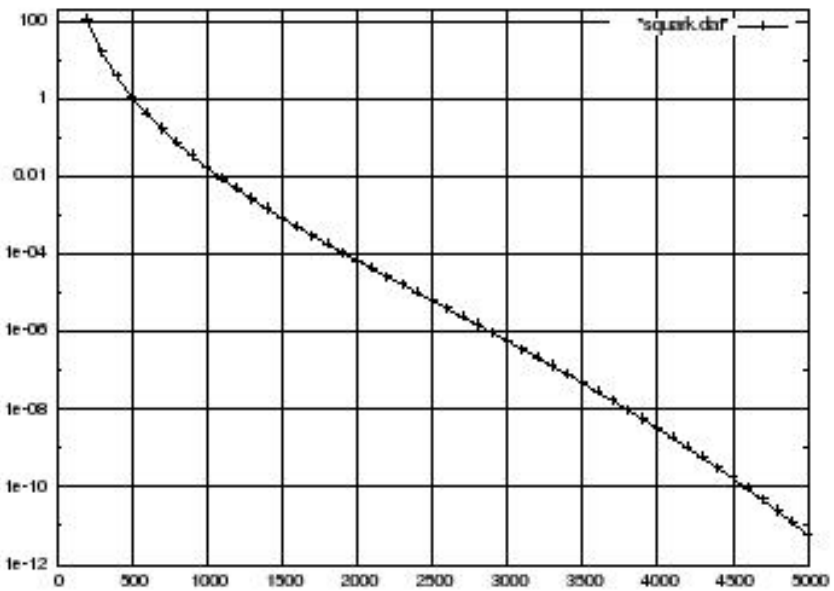
- HELAS 3
- SMadGraph
- Sample Monte Carlo Integration

Weak Boson Fusion

Possible Signature

- Gaugino pairs from WBF
- Gauginos decay from squark pair
- Gauginos decay from gluino pair (long lived gluino or large irreducible background(4jets+Z))

Squark Production



σ(pb) vs M_s

Sample Spectrum

Mixed Bino-Wino LSP

$$M_1 = M_2 = 90 \text{ Gev}, M_3 = 600 \text{ GeV}$$

$$\mu = 1 \text{ Tev}$$

$$tan\beta = 2$$

$$M_{\tilde{f}} = 5 \text{ TeV}$$

$$m_{\chi_1^0} = 85.4 \text{ GeV}, m_{\chi_1^\pm} = 92.5 \text{ GeV}, \Delta = 7 \text{ GeV}$$

Signal

1. Two tagging Jets + $\not{E}_T$
2. Two tagging Jets + $\not{E}_T$ + soft muons

Similiar signature

1. Invisible Higgs **Eboli, Zeppenfield,2000**
2. wino LSP **Datta, Konar, Mukhopadhyaya,2001**

Background

1. 2 Jets + Z with $Z \to \nu\bar{\nu}$
   $\mathrm{Br}(Z \to \mathrm{invisible}) \sim 20\%$
2. 2 Jets + single $W^{\pm}$ with vetoing central lepton
   $W^{\pm} \to \nu X$ with 30% BR No lepton within $P_T > 10\mathrm{GeV}, |\eta| < 3.0$ ($W \to \mathrm{Jets}$ are not considered because of $\not{P}_T$ cut
3. SUSY Background $\tilde{q} \to q\chi_1^0$

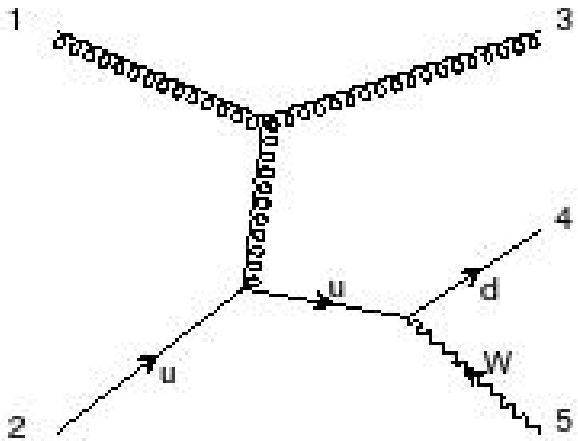
$\alpha_s(\mu_R)$, $\mu_R = \sqrt{[(p_T^{j1})^2 + (p_T^{j2})^2 + \not{E}_T^2]/3}$, $\mu_F = \sqrt{\hat{s}/4}$

Basic Cuts

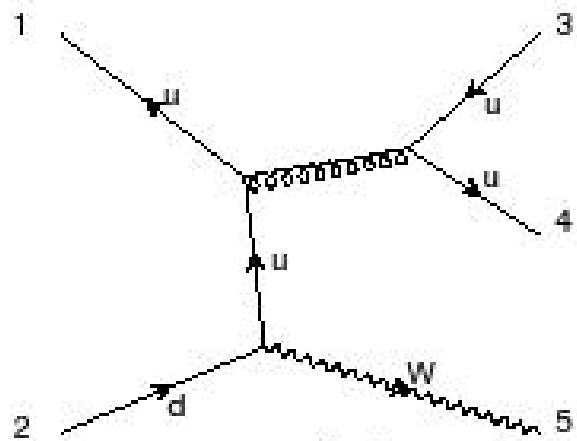
acceptance

- $\not{E}_T > 100$ GeV
- $p_T^j > 30$ GeV
- $|\eta_j| < 5.0$
- $\Delta R_{jj} > 0.4$

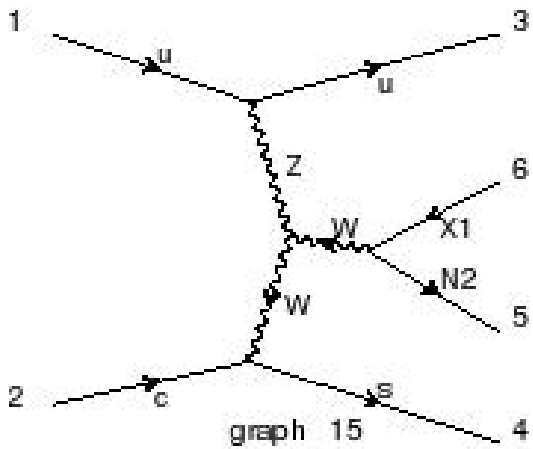
Cuts to be Improved



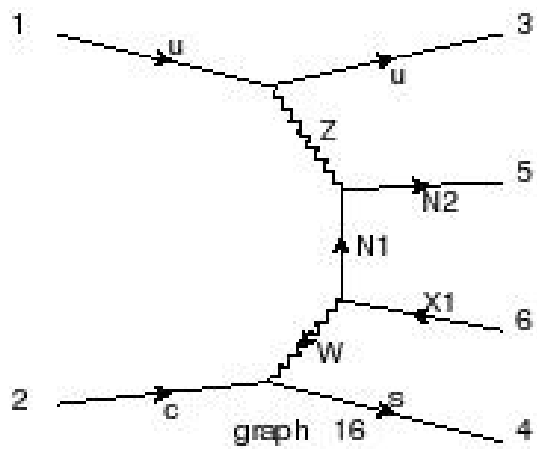
graph 5



graph 4

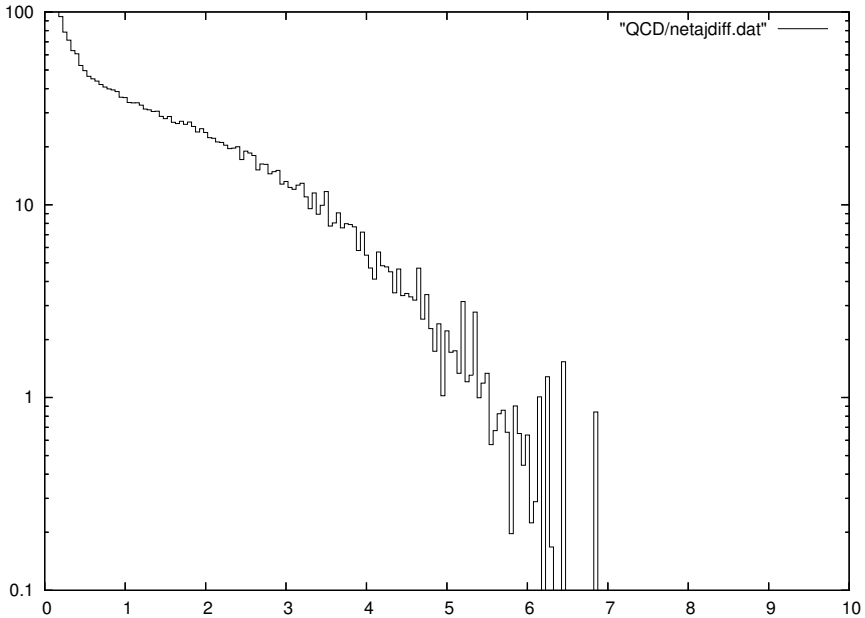


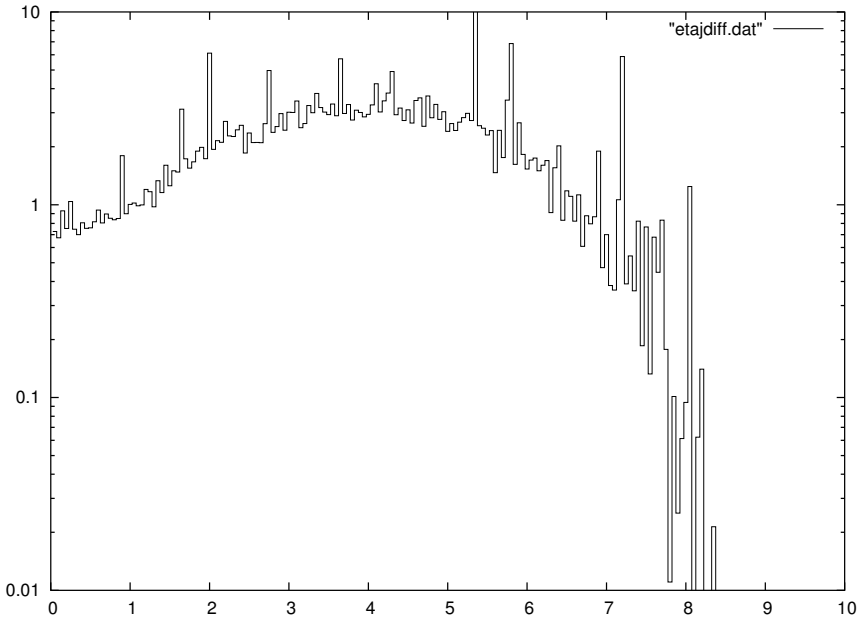
graph 15



graph 16

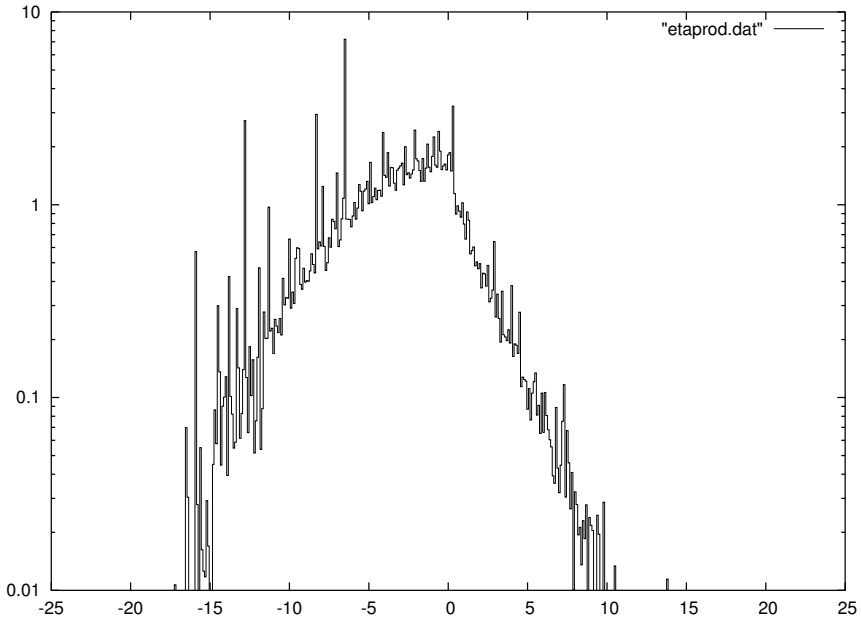
$$|\eta_{j_1} - \eta_{j_2}|$$

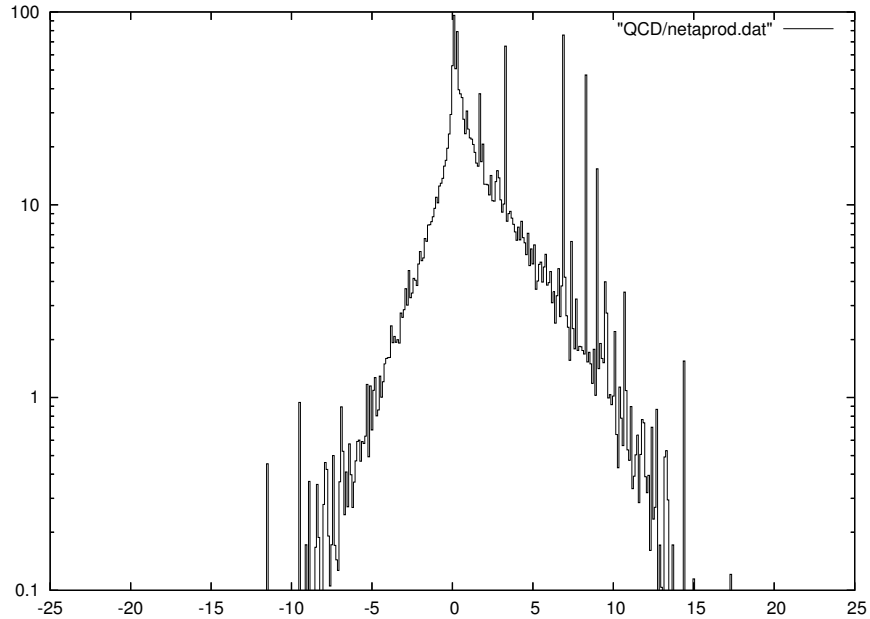




$$|\eta_{j1} - \eta_{j2}| > 4.4$$

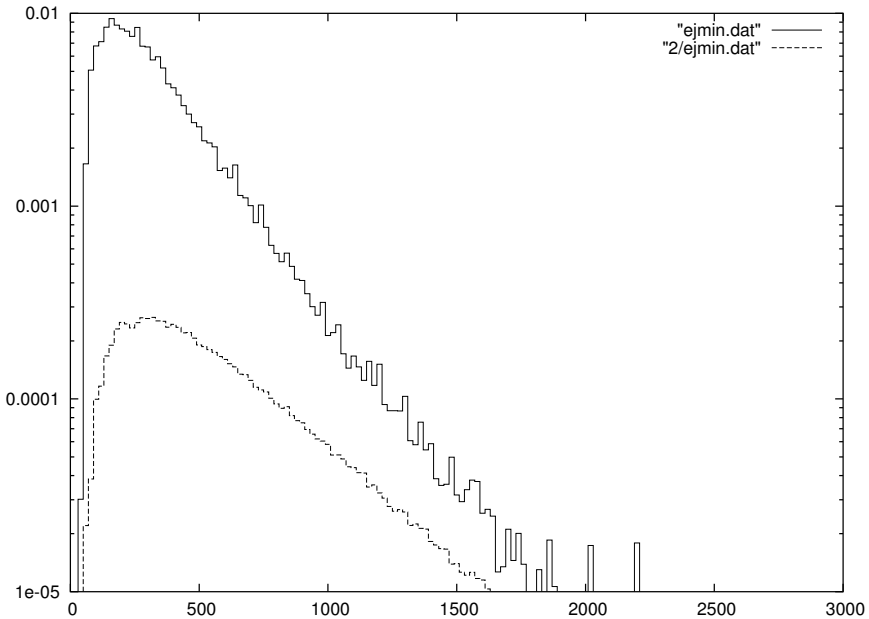
$\eta_{j_1}\eta_{j_2}$

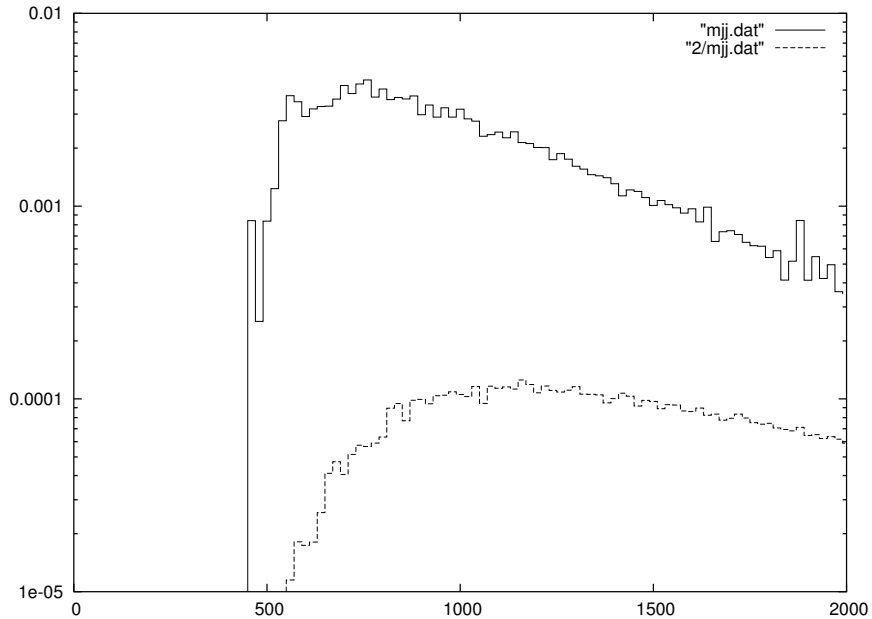




$$\eta_{j1}\eta_{j2} < 0$$

M_{jj}, $E_j^{\min}$

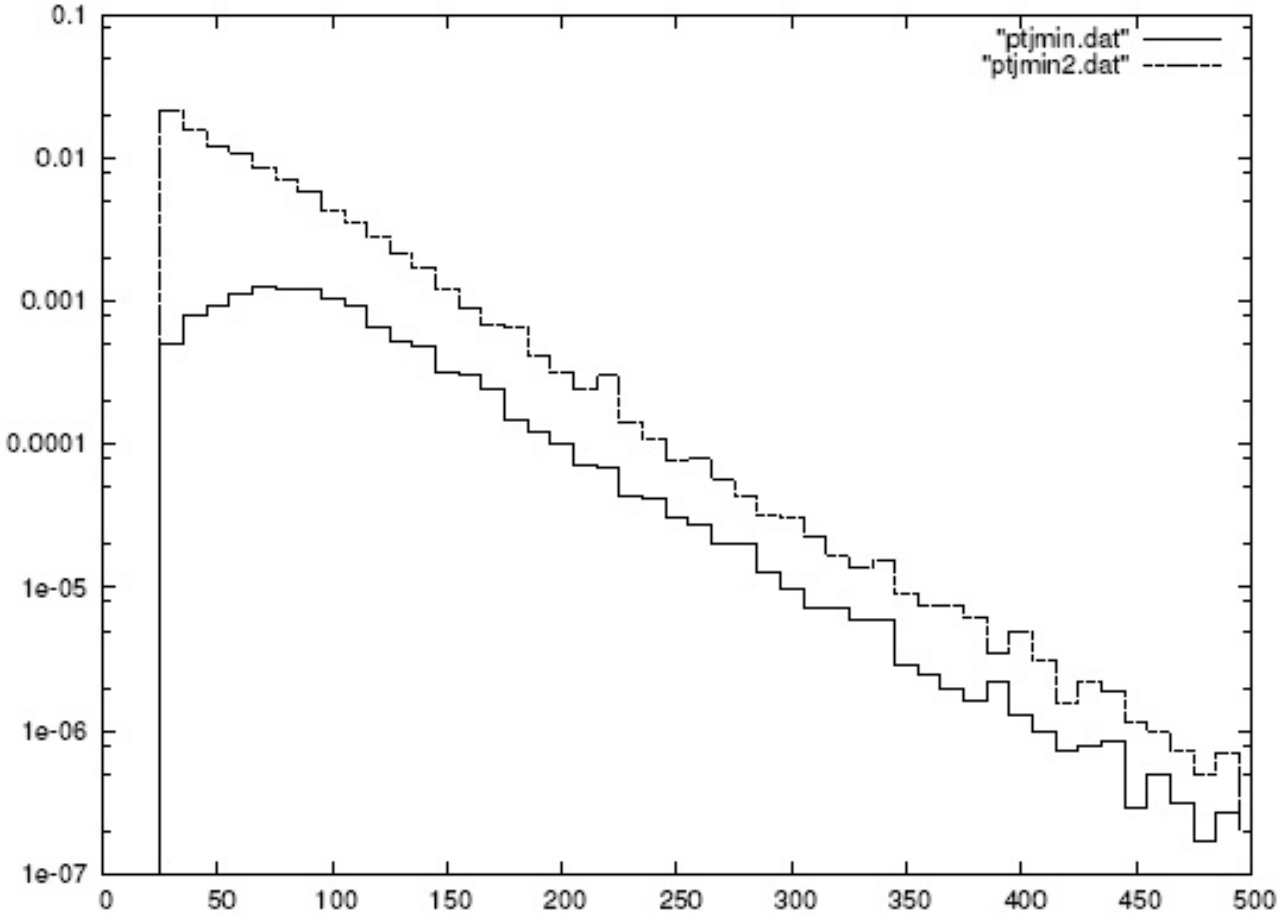




$$M_{jj} > 1200 \text{ GeV}$$

THE UNIVERSITY of WISCONSIN MADISON

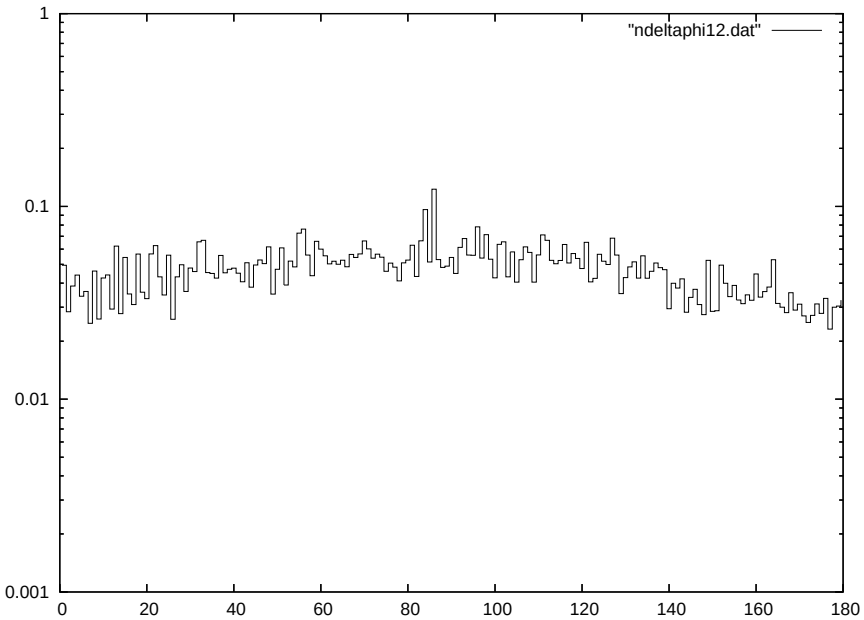
p_T^j

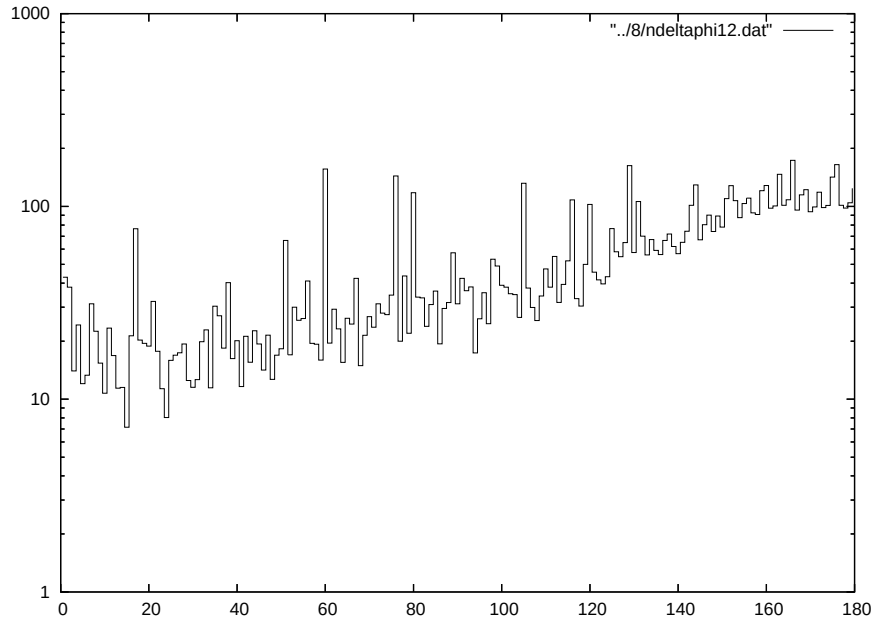


$p_T^j > 60$ GeV

Another handle $\Delta\phi_{jj}$

2-body PS (with Z-kick) vs 3-body PS





$$\Delta\phi_{jj} < \pi/3$$

May hurt signal...

Central Jet Vetoing

No color connection between two Jets
QCD activity in central region
veto events with additional Jets(not the two tagging jets

- Zjj QCD: $P_{\mathrm{surv}} = 28\%$
- Wjj QCD: $P_{\mathrm{surv}} = 28\%$
- Zjj EW: $P_{\mathrm{surv}} = 82\%$
- Wjj EW: $P_{\mathrm{surv}} = 82\%$
- $\chi\chi jj$ WBF:$P_{\mathrm{surv}} = 82\%$

Rainwater, Ph.D. thesis 1999

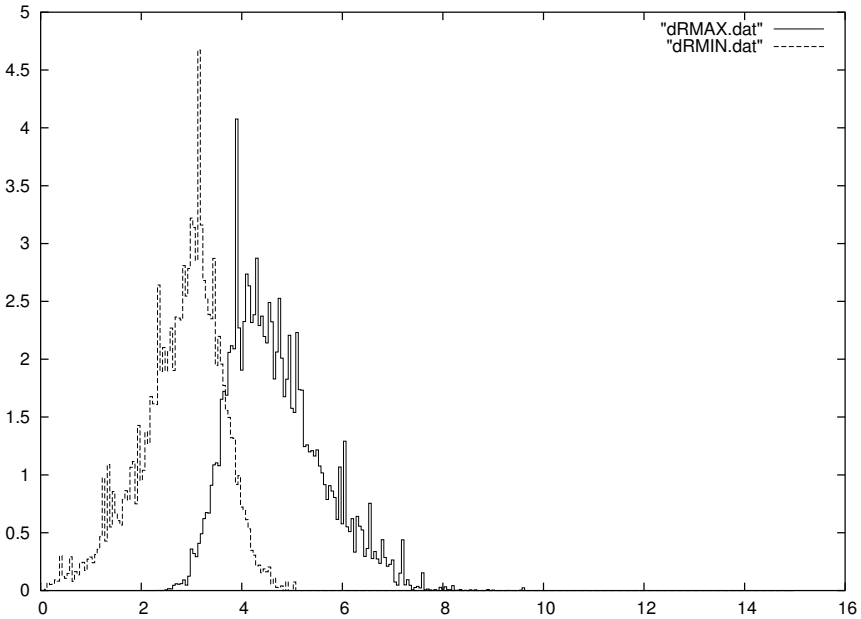
Results

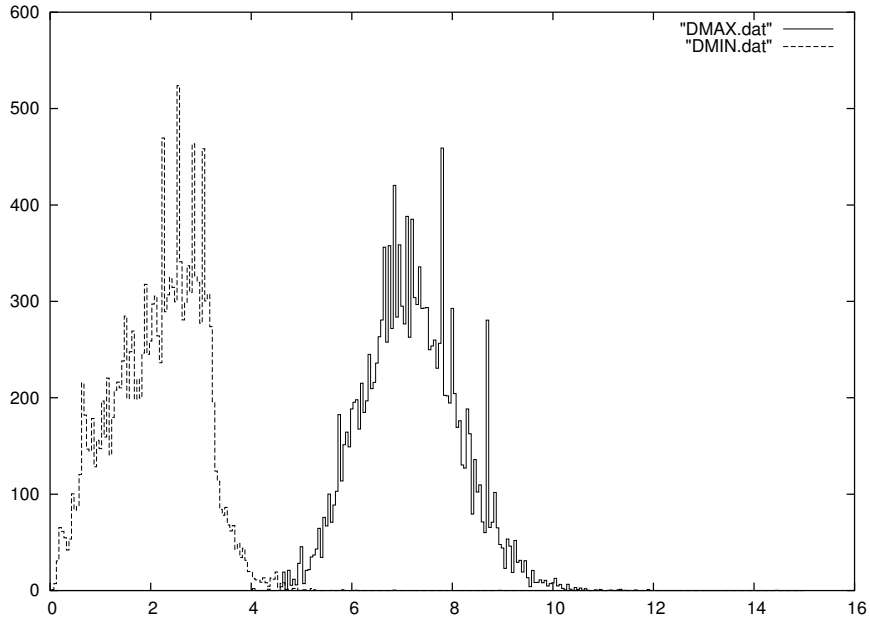
100fb^{-1}

Processes (fb)	Basic Cuts	η cut	ϵ	M_{JJ} cut	ϵ	p_T^J cut	ϵ	p_T^ℓ
$\chi_1^+\chi_1^- jj$	14.04	6.21	44%	4.67	75%	4.15	89%	1.017
$\chi_1^\pm\chi_2^0 jj$	25.98	6.86	26%	5.41	79%	3.97	73%	2.034
$\chi_1^\pm\chi_1^\pm jj$	15.01	5.66	38%	4.69	83%	3.66	78%	1.764
$\chi_1^\pm\chi_1^0 jj$	2.63	1.05	40%	0.80	76%	0.59	74%	
Total	57.66	19.78		15.57		12.37		4.82
$P_{\text{surv}}\sigma$	47.28	16.22		12.76		10.14		3.95
Zjj (EW)	1404	170	12 %	117.8	69%	87.1	74%	
$P_{\text{surv}}\sigma$	1151.3	139.4		96.6		71.4		
Zjj (QCD)	124.5 pb	3130	2.5%	967.9	31%	519.8	54%	
$P_{\text{surv}}\sigma$	34.8 pb	876.4		271		145.5		
Zjj Total	159.3 pb	1015.8		367.6		216.9		216.9
Wjj (EW)	199.3	37.9	19%	26.6	70 %	19.6	74%	9.12
$P_{\text{surv}}\sigma$	163.4	31.0		21.8		16.1		7.48
Wjj (QCD)	21.4 pb	631.2	2.9%	228.0	36%	121.2	53%	87.63
$P_{\text{surv}}\sigma$	5.99 pb	176.7		63.8		33.9		24.54
Wjj Total	6.15 pb	207.7		85.6		50.0		32.0
Total BG	165.5pb	1192.5		453.2		266.9		248.9
S/B	0.028%	1.36%		2.8 %		3.8%		1.6 %
$S/\sqrt{B}$				6σ		6.2σ		2.5 σ

Table: Summary Table for Invisible Channels, all numbers are in fb unless noted explicitly, η, M_{JJ} and p_T^J cuts

Muons





$$\Delta R_{\ell J}^{\min} > 2.0$$

Result: soft muons

$$p_T^\ell > 3\ \mathrm{GeV}, \quad |\eta_\ell| < 3.0, \quad E_\ell < 15\ \mathrm{GeV}, \Delta R_{\ell J}^{\min} > 1.0$$

Processes (fb)	Cuts	$\Delta R_{\ell J}^{\min}$	ϵ
$\chi_1^+\chi_1^- jj$	0.50	0.44	88%
$\chi_1^\pm\chi_2^0 jj$	0.96	0.79	82%
$\chi_1^\pm\chi_1^\pm jj$	0.51	0.46	90%
Total	1.97	1.68	
$P_{\mathrm{surv}}\sigma$	1.62	1.37	
Wjj (EW)	4.53	3.02	67%
$P_{\mathrm{surv}}\sigma$	3.71	2.48	
Wjj (QCD)	35.67	23.04	64%
$P_{\mathrm{surv}}\sigma$	9.99	6.45	
Total BG	13.7	8.92	
S/B	11.7%	15.3%	
$S/\sqrt{B}$	4.38σ	$4.59\ \sigma$	

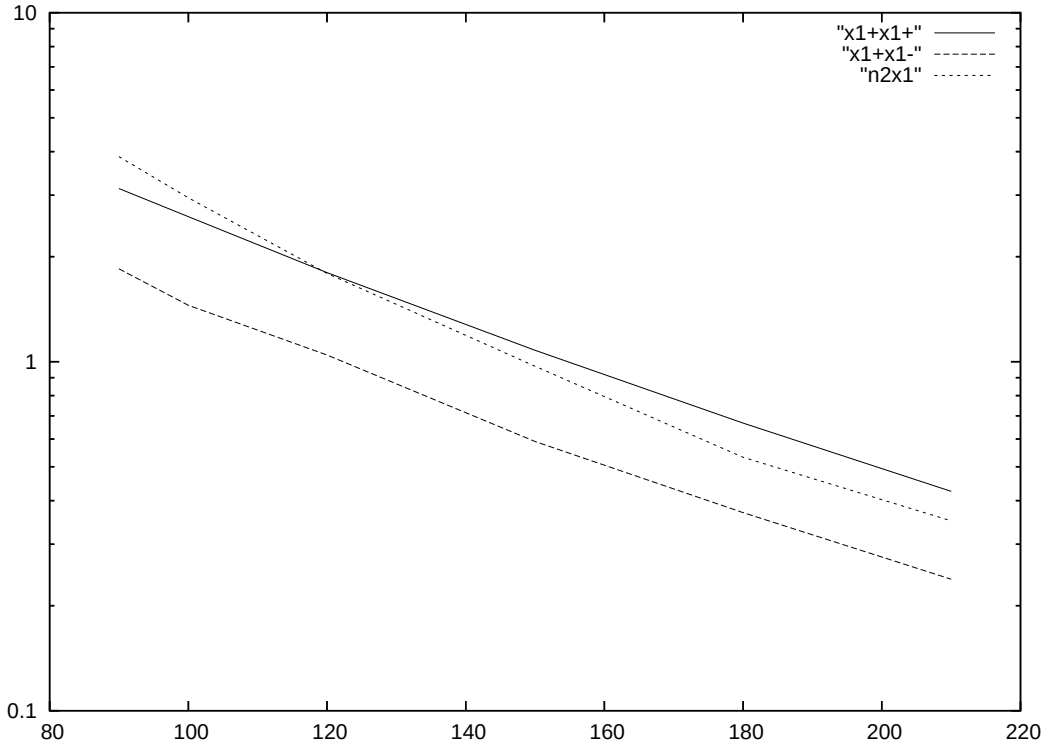
Table: Summary Table for Tagging soft muon Channels

Soft Muon: Continued and Combined with Invisible Channel

Processes (fb)	Cuts	$\Delta\phi_{JJ}$ cuts	ϵ	$\Delta\eta_J$ cut	ϵ	$\Delta R_{\ell J}^{\min}$	ϵ	p_T^{ℓ}
$\chi_1^+\chi_1^- jj$	0.50	0.15	30%	0.40	80%	0.37	93%	0.21
$\chi_1^\pm\chi_2^0 jj$	0.96	0.18	19%	0.60	63%	0.54	90%	0.44
$\chi_1^\pm\chi_1^\pm jj$	0.51	0.14	32%	0.42	95%	0.39	93%	0.32
Total	1.97	0.47		1.42		1.3		0.97
$P_{\rm surv}\sigma$	1.56	0.39		1.16		1.07		0.79
Wjj (EW)	4.53	0.57	13%	2.93	65%	2.42	83%	1.69
$P_{\rm surv}\sigma$	3.71	0.47		2.40		1.98		1.38
Wjj (QCD)	35.67	4.51	13%	19.57	55%	14.51	74%	12.44
$P_{\rm surv}\sigma$	9.99	1.26		5.48		4.06		3.48
Total BG	13.7	1.73		7.88		6.04		4.86
S/B	11.7%	22.5%		14.7%		17.7%		16.2%
$S/\sqrt{B}$	4.38 σ	3 σ		4.1σ		4.35 σ		3.5 σ

Table: Summary Table for Tagging soft muon Channels

Production Rate of Gaugino pairs from WBF



Mixed Bino-Wino LSP

σ(fb) vs $M_1 = M_2$

Conclusion

By triggering on large missing E_T plus forward/backward jets tagging, one may be able to detect nearly degenerate gauginos scenario. (cannot distinguish from Invisible Higgs from WBF)
Adding Soft muons will help the search.