Testing the Supersymmetric Coupling Relations with Monojets at the LHC

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Stiftung/Foundation

in collaboration with
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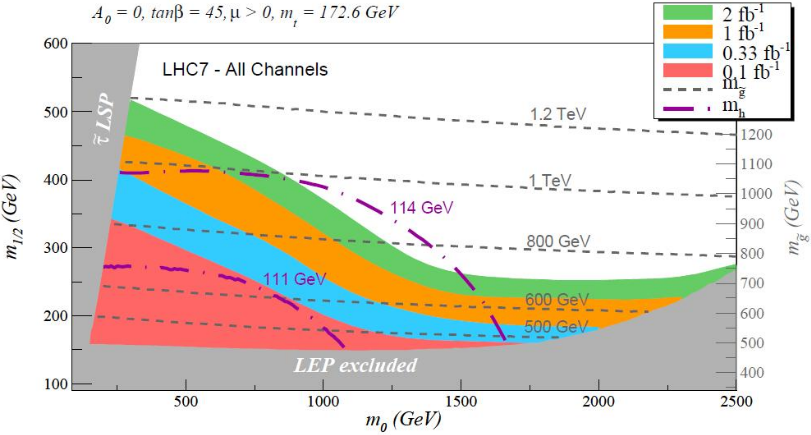
Outline

SUSY Discovery Potential with $\sqrt{S} = 7$ TeV.

[Baer, Barger, Lessa and Tata, JHEP **1006**, 102, 2010]



⇒ Discovery of new physics might be around the corner!

How do we know that new physics is SUSY?

Test of Supersymmetric Coupling Relations

Supersymmetry predicts:

$$g_i(V_i f f') = \hat{g}_i(\tilde{V}_i f \tilde{f}')$$

Proposed analysis:

Linear Collider

- $\hat{g}(\tilde{W}\tilde{\nu}_e e)$ via $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$ or $\tilde{\nu}_e\tilde{\nu}_e$.
  [Feng, Peskin, Murayama, Phys. Rev.D52, 1418, 1995],
  [Cheng, Feng, Polonsky, Phys. Rev.D57, 152, 1998],
  [Choi et al., Eur. Phys. J. C14, 535, 2000],
  [Nojiri, Pierce, Yamada, Phys. Rev.D57, 1539, 1998],
  [Freitas, Manteuffel, Zerwas, Eur. Phys. J. C40, 435, 2005]
- $\hat{g}(\tilde{B}\tilde{e}_R e)$ and $\hat{g}(\tilde{W}\tilde{e}_L e)$ via $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$ or $\tilde{e}\tilde{e}$.
  [Choi et al., Eur. Phys. J. C22, 563, 2001],
  [Nojiri, Fujii, Tsukamoto, Phys. Rev.D54, 6756, 1996],
  [Freitas, Manteuffel, Zerwas, Eur. Phys. J. C34, 487, 2004],
  [Cheng et al., Phys. Rev.D57, 152, 1998], [Nojiri et al., Phys. Rev.D57, 1539, 1998]
- $\hat{g}(\tilde{g}\tilde{q}q)$ via $e^+e^- \rightarrow \tilde{g}\tilde{q}q$.
  [Brandenburg et. al., Eur. Phys. J. C58, 291, 2008]

Test of Supersymmetric Coupling Relations

LHC

- $\hat{g}(\tilde{g}\tilde{q}_L q)$ via $PP \to \tilde{q}_L\tilde{q}_L$.
  [Freitas, Skands, JHEP **0609**, 043, 2006],
  [Freitas, Skands, Spira, Zerwas, JHEP **0707**, 025, 2007]
- $\hat{g}(\tilde{W}\tilde{q}_L q)$ via $PP \to \tilde{q}_L\tilde{q}_L^*$ with $\tilde{W}$ exchange in t- and u-channel.
  [Bornhauser, Drees, Dreiner, Kim, Phys. Rev.D80, 095007, 2009]
  $\longrightarrow$ see talk by *Jong Soo Kim* on Friday.
- $hh\tilde{t}\tilde{t}$ coupling via $\tilde{t}$ and $\tilde{b}$ mass matrix measurement.
  [Blanke, Curtin, Perelstein, arXiv:1004.5350 [hep-ph]]
  $\longrightarrow$ see talk by *David Curtin* on Monday.

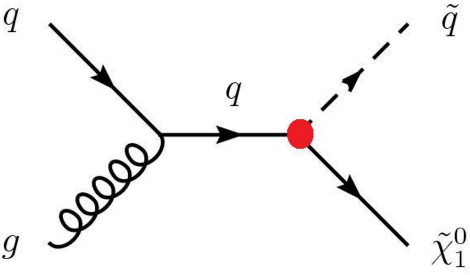
Another possibility for LHC:

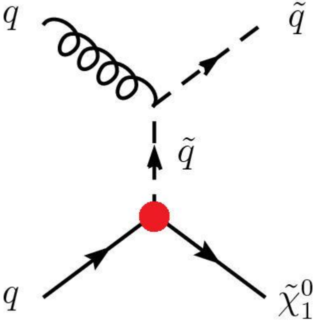
Monojets,
i.e. one hard jet + $\not{E}_T$.

$\Rightarrow$ allows measurement of $\hat{g}_1(\tilde{B}\tilde{q}_R q)$ and $\hat{g}_2(\tilde{W}\tilde{q}_L q)$.

Monojets in the MSSM

relevant Feynman diagrams:





with $\tilde{q} \rightarrow \tilde{\chi}_1^0 + q$.

main SM backgrounds

- $PP \rightarrow Z(\rightarrow \nu\nu)$+jet. Can be measured from $Z(\rightarrow \ell^+\ell^-)$+jet.
- $PP \rightarrow W(\rightarrow \ell\nu)$+jet.

Bino LSP Scenarios

Assume mSUGRA scenario

with $M_0 = 220$ GeV, $M_{1/2} = 180$ GeV, $A_0 = -500$ GeV, $\tan\beta = 10$, sgn(μ)=+1.

$$\Rightarrow m_{\tilde{\chi}_1^0} = 70 \text{ GeV}, \ m_{\tilde{u}_R} \approx m_{\tilde{d}_R} = 455 \text{ GeV}.$$

monojet cross section $\sigma(PP \to \tilde{q}_R \tilde{\chi}_1^0) = 520$ fb.

cuts

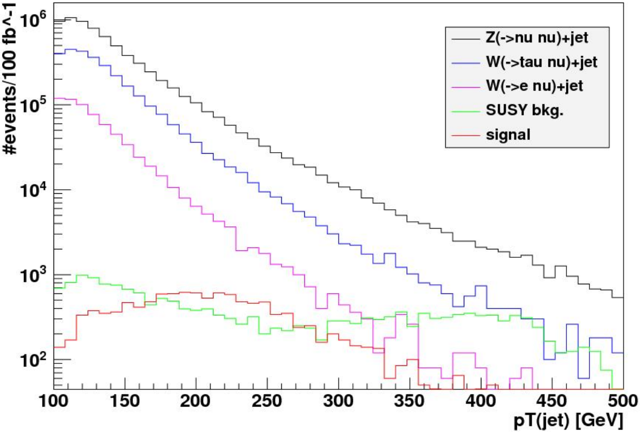
- Isolated lepton veto, 2nd jet veto.
- $p_T(1st\ jet) > 180$ GeV and $\not{p}_T > 180$ GeV.
- $m(1st\ jet) < 70$ GeV.

$$\Rightarrow \mathrm{S}/\sqrt{\mathrm{B_{SM}}} = 12 \ \& \ \mathrm{S}/\mathrm{B_{SUSY}} = 1.7 \quad \text{for } 300\mathrm{fb}^{-1} \text{ at } \sqrt{s} = 14 \text{ TeV}.$$

Coupling reconstruction: $\Delta\hat{g}_1(\tilde{B}\tilde{q}_R q)/\hat{g}_1(\tilde{B}\tilde{q}_R q) = 15\%$.

Problem: Monojets only visible in light bino LSP scenarios!

Monojet p_T Distributions



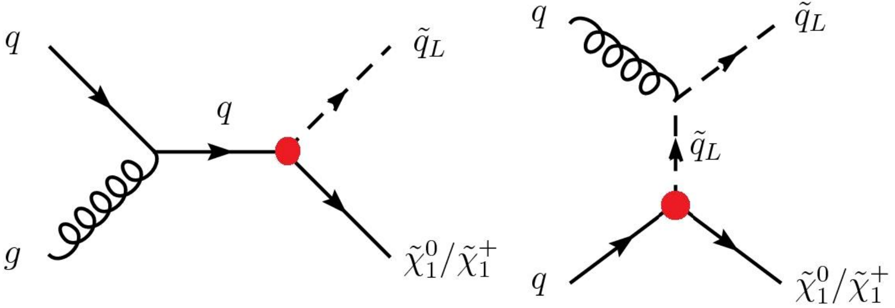
- SM backgrounds fall off exponentially.
- Signal distribution has a peak.

Remark: Simulation of signal and backgrounds done with Herwig++2.4.2.

Can we do better?

Monojets in Wino LSP Scenarios

relevant Feynman diagrams:



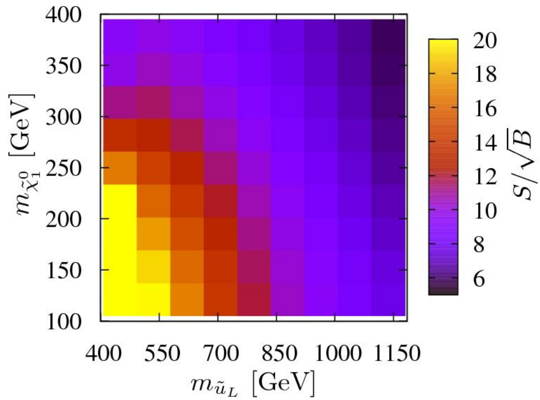
with $\tilde{q}_L \to \tilde{\chi}_1^0/\tilde{\chi}_1^+ + q$ and $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 + \pi^+$.

enhancement (compared to bino LSP) due to

- Larger gauge coupling: $\hat{g}_2(\tilde{W}\tilde{q}_L q) \approx 2\hat{g}_1(\tilde{B}\tilde{q}_R q)$.
- More Processes: $ug \to \tilde{u}_L\tilde{\chi}_1^0$ and $ug \to \tilde{d}_L\tilde{\chi}_1^+$.

Discovery Potential for Wino LSP Scenarios

Assume wino-like $\tilde{\chi}_1^0$, $m_{\tilde{u}_L} = m_{\tilde{d}_L}$ and $100\mathrm{fb}^{-1}$ at $\sqrt{s} = 14$ TeV.



⇒ Monojet signal visible for $m_{\tilde{q}_L}$ up to 1.3 TeV!

Reconstruction of the Coupling $\hat{g}_2(\tilde{W}\tilde{q}_L' q)$

Assume mAMSB scenario with
$M_0 = 200$ GeV, $M_{3/2} = 33$ TeV, $\tan\beta = 10$, and sgn(μ)=+1.

$$\Rightarrow m_{\tilde{u}_L} \approx m_{\tilde{d}_L} = 720 \text{ GeV and } m_{\tilde{\chi}_1^0} \approx m_{\tilde{\chi}_1^+} = 107 \text{ GeV.}$$

monojet cross section $\sigma(PP \to \tilde{q}_L \tilde{\chi}_1^0) = 470$ fb.

cuts

- Isolated lepton veto.
- $p_T(2nd\ jet) < 50$ GeV.
- $p_T(1st\ jet) > 300$ GeV and $\not{p}_T > 300$ GeV.
- $m(1st\ jet) < 80$ GeV.

$$\Rightarrow \mathrm{S}/\sqrt{\mathrm{B}_{\mathrm{SM}}} = 17 \ \&\ \mathrm{S}/\mathrm{B}_{\mathrm{SUSY}} = 1.1 \quad \text{for } 100\mathrm{fb}^{-1} \text{ at } \sqrt{s} = 14 \text{ TeV.}$$

Main SUSY background: $PP \to \tilde{\chi}_1 \tilde{\chi}_1 + jet$ (without $\tilde{q}$).

Reconstruction of the Coupling $\hat{g}_2(\tilde{W}\tilde{q}'_L q)$

Assume mAMSB scenario with
$M_0 = 200$ GeV, $M_{3/2} = 33$ TeV, $\tan\beta = 10$, and sgn(μ)=+1.

$$\Rightarrow m_{\tilde{u}_L} \approx m_{\tilde{d}_L} = 720 \text{ GeV and } m_{\tilde{\chi}_1^0} \approx m_{\tilde{\chi}_1^+} = 107 \text{ GeV}.$$

error	$\Delta\sigma/\sigma$	$\Delta\hat{g}/\hat{g}$
luminosity	3%	1.5%
PDF uncertainty	16%	7.8%
NNLO corrections	12%	6.2%
statistics	5.8%	2.9%
$\Delta\tilde{m} = 10$ GeV	12%	6.2%
SUSY background	9.4%	4.7%
	29%	15%

NLO corrections calculated with `Prospino`
[Plehn, Czech. J. Phys.55: B213-B220, 2005.]

Summary and Outlook

Summary

- New physics consistent with SUSY might be discovered soon!
- How do we know, that it is SUSY?
  $\longrightarrow$ Test of SUSY coupling relations.

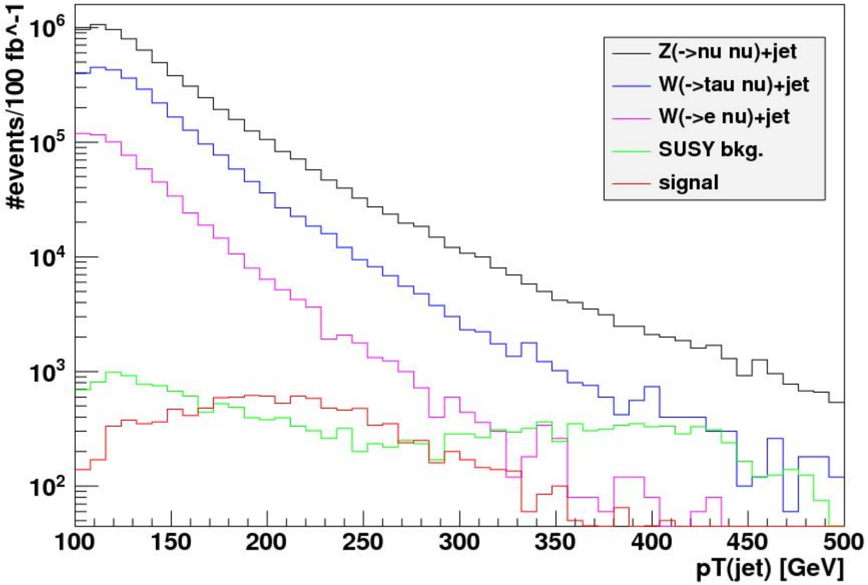
- Monojets can test $\tilde{\chi}^0_1$-$\tilde{q}$-q coupling.
- Only possible for very light bino LSP scenarios.
- Coupling can be tested at 10% level for wino LSP.

Outlook

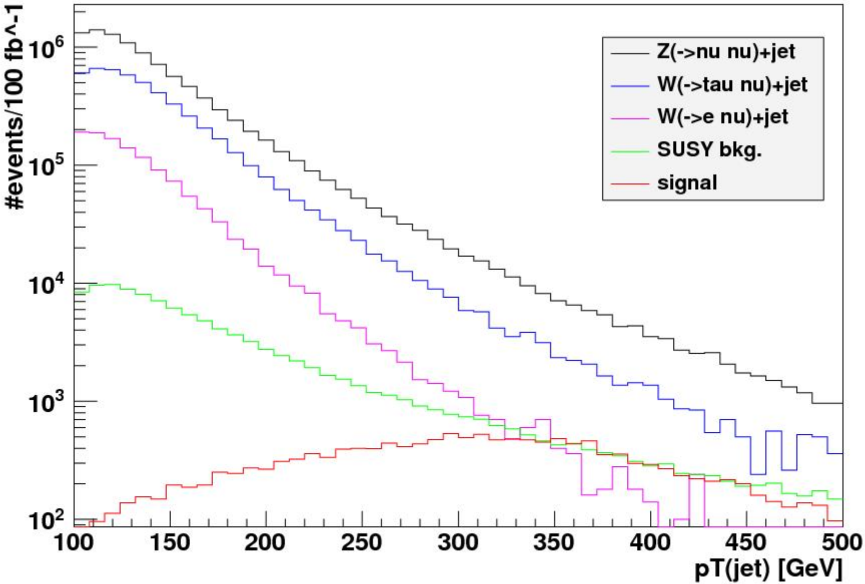
- Investigate Wino LSP parameter space.
- Test of $\tilde{H}^+$-$\tilde{t}$-b coupling.
  [Bornhauser, Drees, SG, Kim, work in progress]
  $\longrightarrow$ see talk by *Jong Soo Kim* on Friday.

backup slides

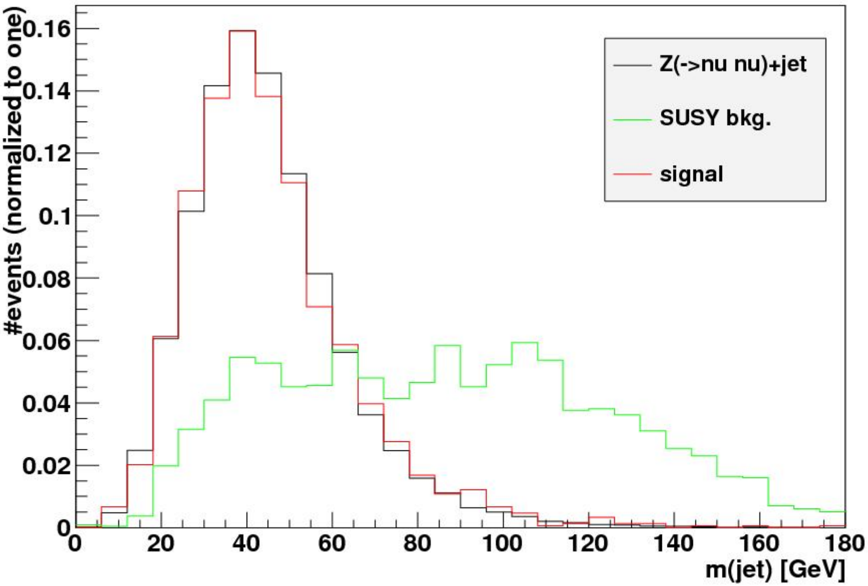
Jet-p_T Distribution: mSUGRA Scenario



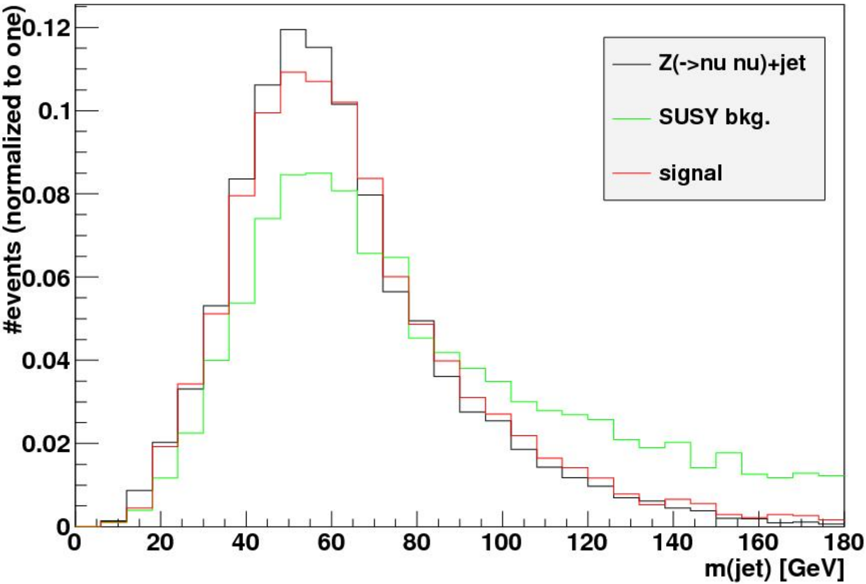
Jet-p_T Distribution: mAMSB Scenario



Jet Invariant Mass: mSUGRA Scenario



Jet Invariant Mass: mAMSB Scenario



Mass Spectrum: mSUGRA Scenario

sparticle	mass [GeV]	sparticle	mass [GeV]
$\tilde{\chi}_1^0$	70.2	$\tilde{\chi}_4^0$	365
$\tilde{\chi}_1^+$	132	$\tilde{\chi}_2^+$	370
$\tilde{\chi}_2^0$	133	$\tilde{b}_1$	378
$\tilde{\tau}_1$	189	$\tilde{b}_2$	443
$\tilde{t}_1$	226	$\tilde{u}_R/\tilde{c}_R$	454
$\tilde{\nu}_\tau$	230	$\tilde{d}_R/\tilde{s}_R$	455
$\tilde{e}_R/\tilde{\mu}_R$	234	$\tilde{g}$	456
$\tilde{\nu}_e/\tilde{\nu}_\mu$	242	$\tilde{u}_L/\tilde{c}_L$	463
$\tilde{e}_L/\tilde{\mu}_L$	255	$\tilde{d}_L/\tilde{s}_L$	470
$\tilde{\tau}_2$	259	$\tilde{t}_2$	477
$\tilde{\chi}_3^0$	359		

Mass Spectrum: mAMSB Scenario

sparticle	mass [GeV]	sparticle	mass [GeV]
$\tilde{\chi}_1^0$	106.5	$\tilde{\chi}_4^0$	593
$\tilde{\chi}_1^+$	106.7	$\tilde{\chi}_2^+$	594
$\tilde{\tau}_1$	113	$\tilde{b}_1$	634
$\tilde{\nu}_\tau$	135	$\tilde{t}_2$	688
$\tilde{\nu}_e/\tilde{\nu}_\mu$	138	$\tilde{u}_L/\tilde{c}_L$	722
$\tilde{e}_R/\tilde{\mu}_R$	150	$\tilde{b}_2$	723
$\tilde{e}_L/\tilde{\mu}_L$	194	$\tilde{d}_L/\tilde{s}_L$	726
$\tilde{\tau}_2$	179	$\tilde{u}_R/\tilde{c}_R$	726
$\tilde{\chi}_2^0$	298	$\tilde{d}_R/\tilde{s}_R$	732
$\tilde{t}_1$	521	$\tilde{g}$	745
$\tilde{\chi}_3^0$	584		

Cutflow: mSUGRA Scenario

cut	all SM	SUSY bkg.	signal	$S/\sqrt{B}$	$S_{\rm SUSY}/\sqrt{B}$
trigger	1.14×10^8	2.91×10^7	130 000	-	-
lepton veto	7.57×10^7	1.76×10^7	130 000	-	-
number(jets)=1	3.35×10^7	55 900	35 100	6.1 (2.3)	16 (5.9)
p_T(jet1) $>$ 180 GeV	3.28×10^6	32 300	22 300	12 (4.7)	30 (11)
m(jet1) $<$ 70 GeV	3.00×10^6	12 100	20 100	12 (4.4)	19 (7.0)
tau veto	2.75×10^6	9 950	20 000	12 (4.6)	18 (6.8)
b-jet veto	2.66×10^6	9 290	20 000	12 (4.6)	18 (6.8)

Cutflow: mAMSB Scenario

cut	all SM	SUSY bkg.	signal	$S/\sqrt{B}$	$S_{\mathrm{SUSY}}/\sqrt{B}$
trigger	3.81×10^7	1.04×10^6	44 100	-	-
lepton veto	2.52×10^7	621 000	43 800	-	-
$p_T(\text{jet2}) < 50$ GeV	1.73×10^7	111 000	16 200	3.9 (1.5)	31 (12)
$p_T(\text{jet1}) > 300$ GeV	171 000	11 000	8 390	20 (7.7)	47 (18)
$m(\text{jet1}) < 80$ GeV	135 000	6 020	6 370	17 (6.5)	34 (13)
tau veto	119 000	5 840	6 370	18 (7.0)	35 (13)
b-jet veto	115 000	5 290	6 320	19 (7.0)	34 (13)

Error Estimate: mSUGRA Scenario

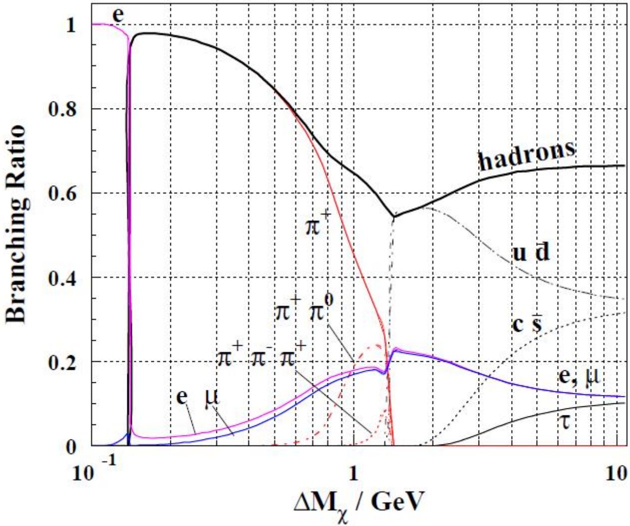
error	$\Delta\sigma_{\text{mono}}/\sigma_{\text{mono}}$	$\Delta\lambda/\lambda$
luminosity	3.0%	1.5%
PDF uncertainty	15%	7.3%
NNLO corrections	16%	8.0%
sparticle mass $\Delta\tilde{m} = 10$ GeV	10%	5.2%
SUSY background	6.0%	3.0%
statistics (optimistic)	8.6%	4.3%
statistics (conservative)	23%	11%
total (optimistic)	26%	13%
total (conservative)	34%	17%

Error Estimate: mAMSB Scenario

error	$\Delta\sigma_{\mathrm{mono}}/\sigma_{\mathrm{mono}}$	$\Delta\lambda/\lambda$
luminosity	3%	1.5%
PDF uncertainty	16%	7.8%
NNLO corrections	18%	9%
sparticle mass $\Delta\tilde{m} = 10$ GeV	12%	6.2%
SUSY background	9.4%	4.7%
statistics (optimistic)	5.8%	2.9%
statistics (conservative)	15%	7.6%
total (optimistic)	29%	15%
total (conservative)	32%	16%

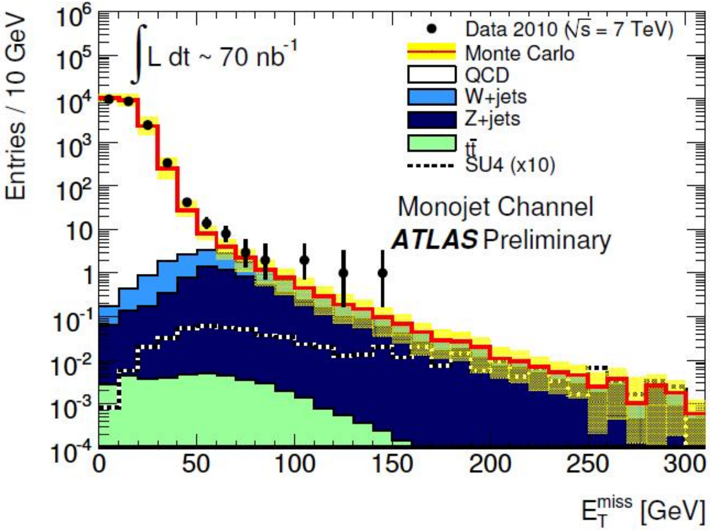
Wino Branching Ratios

[Barr et al., hep-ph/0208214]



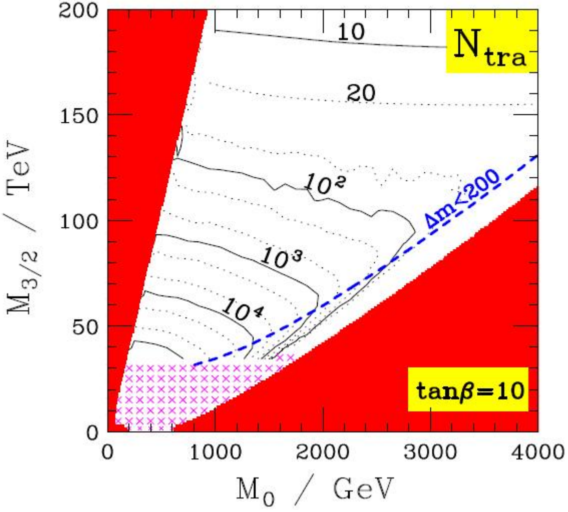
Monojet missing energy distribution at 7 TeV

[ATLAS-CONF-2010-065]



Number of detached Vertices for $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 + X$ for $100\,\mathrm{fb}^{-1}$

[Barr et al., hep-ph/0208214]



Discovery Reach for mAMSB for 100 fb^{-1}

[Barr et al., hep-ph/0208214]