

Testing SUSY with Monojets at the LHC

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Stiftung / Foundation



in collaboration with
B. Allanach and *H. Haber*
arXiv:1010.4261 [hep-ph]

Outline

1 Introduction

- Measuring SUSY Coupling Relations
- Monojets in the MSSM

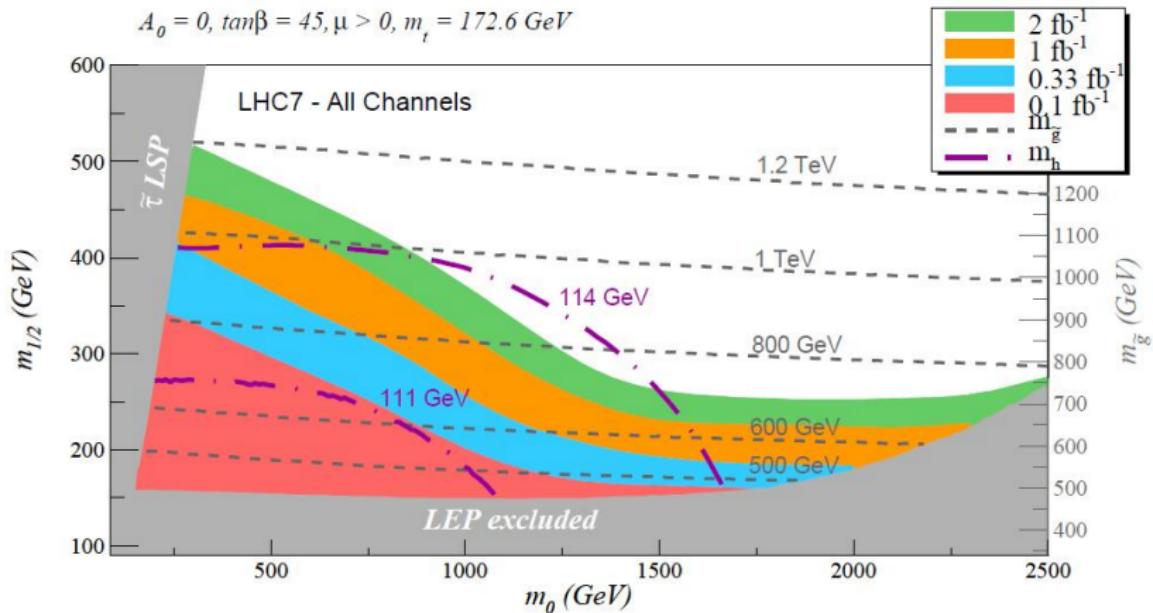
2 Reconstruction of the $\tilde{\chi}_1^0$ - \tilde{q} - q Coupling

- Bino LSP Scenarios
- Wino LSP Scenarios

3 Summary and Outlook

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

[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:

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

Can be tested at LHC with

Monojets,
i.e. one hard jet + \cancel{E}_T .

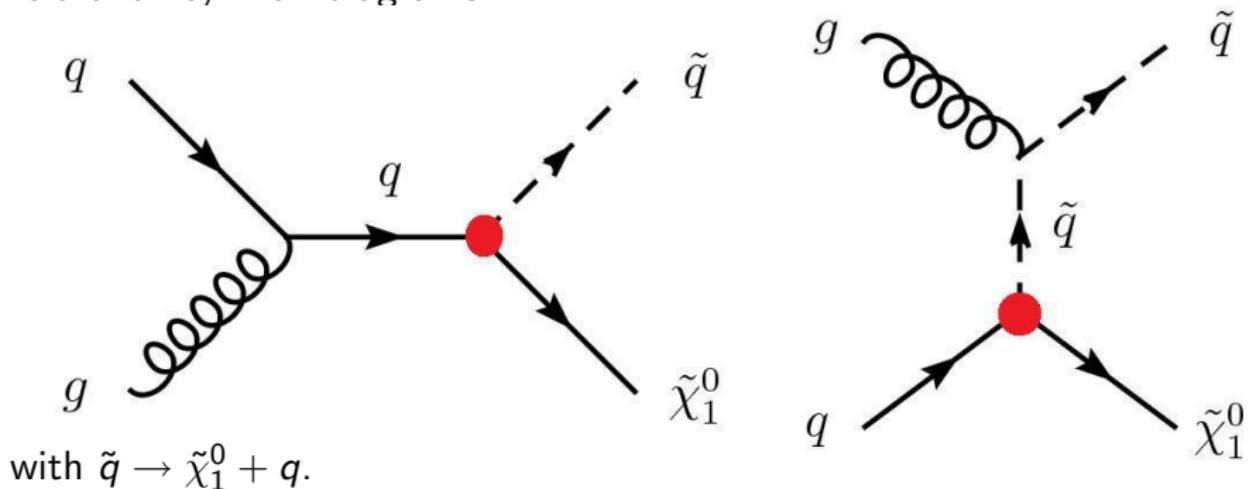
⇒ allows measurement of $\hat{g}_1(\tilde{B}\tilde{q}_R q)$ and $\hat{g}_2(\tilde{W}\tilde{q}_L q)$.

Other LHC analysis:

- $\hat{g}_3(\tilde{g}\tilde{q}_L q)$ via $PP \rightarrow \tilde{q}_L \tilde{q}_L$.
 [Freitas, Skands, Spira, Zerwas, JHEP **0609**, 043, 2006 & JHEP **0707**, 025, 2007]
- $\hat{g}_2(\tilde{W}\tilde{q}_L q)$ via $PP \rightarrow \tilde{q}_L \tilde{q}_L^*$ with \tilde{W} exchange in t- and u-channel.
 [Bornhauser, Drees, Dreiner, Kim, Phys. Rev. D80, 095007, 2009]
- $\tilde{H}\tilde{t}_1 b$ coupling via $PP \rightarrow \tilde{t}_1 \tilde{t}_1^* b\bar{b}$.
 [Bornhauser, Drees, SG, Kim, arXiv:1011.5508 [hep-ph]; work in progress]

Monojets in the MSSM

relevant Feynman diagrams:



main SM backgrounds

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

Remark: $\tilde{\chi}_1^0\tilde{q}\bar{q}$ vertex important for DM annihilation & direct detection.

Bino LSP Scenarios

Assume mSUGRA scenario

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

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

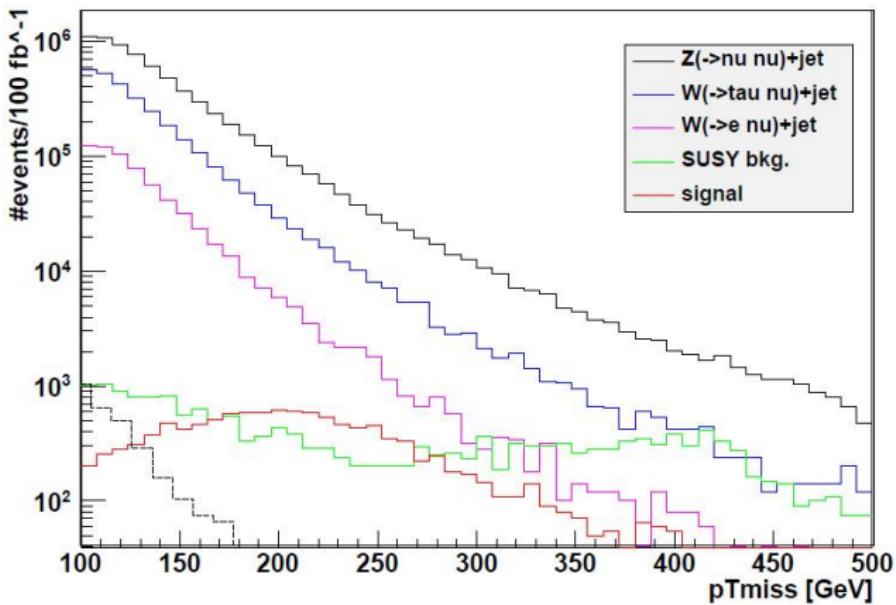
monojet cross section $\sigma(PP \rightarrow \tilde{q}_R \tilde{\chi}_1^0) = 520 \text{ fb}$.

cuts

- Isolated lepton veto, 2nd jet veto.
- $p_T(1st \text{ jet}) > 180$ GeV and $\beta_T > 180$ GeV.
- $m(1st \text{ jet}) < 70$ GeV.

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

Missing p_T Distributions



- SM backgrounds fall off exponentially.
- Signal distribution has a peak at $\beta_T \approx (m_{\tilde{q}}^2 - m_{\tilde{\chi}_1^0}^2)/m_{\tilde{q}}^2$.

Bino LSP Scenarios

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

cuts

- Isolated lepton veto, 2nd jet veto.
- $p_T(1st \text{ jet}) > 180$ GeV and $\beta_T > 180$ GeV.
- $m(1st \text{ jet}) < 70$ GeV.

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

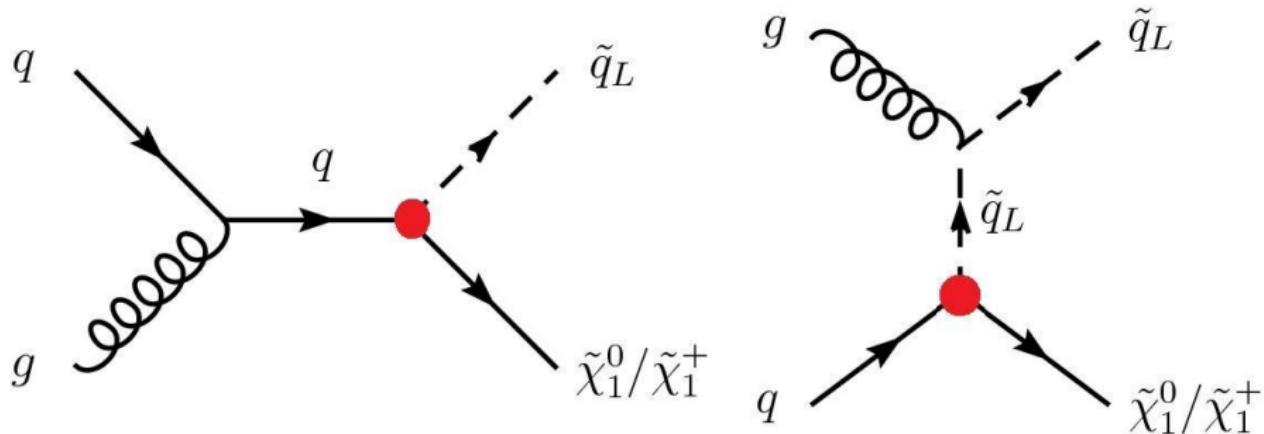
\Rightarrow Signal only visible for light (bino LSP) scenarios.

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

Can we do better?

Monojets in Wino LSP Scenarios

relevant Feynman diagrams:



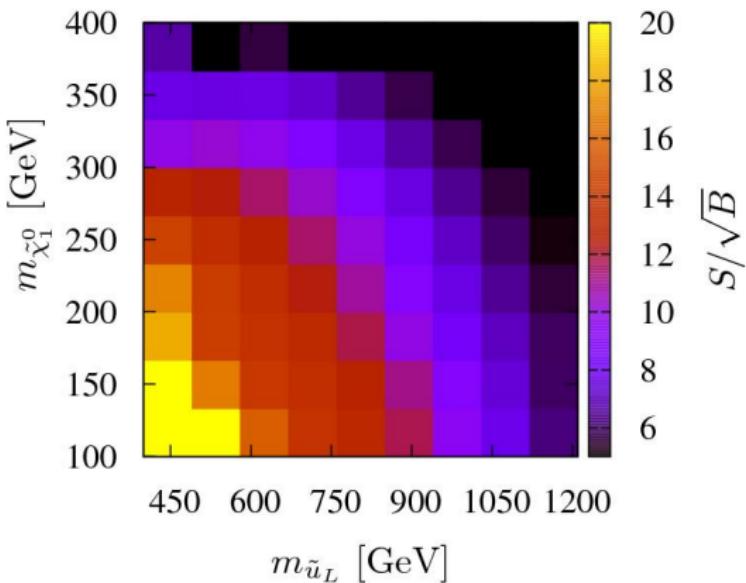
with $\tilde{q}_L \rightarrow \tilde{\chi}_1^0/\tilde{\chi}_1^+ + q$ and $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 + \pi^+$.

enhancement (compared to bino LSP) due to

- larger gauge coupling: $\hat{g}_2(\tilde{W}\tilde{q}_Lq) \approx 2\hat{g}_1(\tilde{B}\tilde{q}_Rq)$.
- more processes: $ug \rightarrow \tilde{u}_L\tilde{\chi}_1^0$ and $ug \rightarrow \tilde{d}_L\tilde{\chi}_1^+$.

Discovery Potential for Wino LSP Scenarios

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



\Rightarrow Monojet signal visible for $m_{\tilde{q}_L}$ up to 1.2 TeV!

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

Assume mAMSB scenario with

$M_0 = 200$ GeV, $M_{3/2} = 33$ TeV, $\tan \beta = 10$, and $\text{sgn}(\mu) = +1$.

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

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

cuts

- Isolated lepton veto.
- $p_T(2nd \ jet) < 50$ GeV.
- $p_T(1st \ jet) > 300$ GeV and $\beta_T > 300$ GeV.
- $m(1st \ jet) < 80$ GeV.

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

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

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

Assume mAMSB scenario with

$M_0 = 200$ GeV, $M_{3/2} = 33$ TeV, $\tan \beta = 10$, and $\text{sgn}(\mu) = +1$.

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error	$\Delta\sigma/\sigma$	$\Delta\hat{g}/\hat{g}$
luminosity	3%	1.5%
PDF uncertainty	17%	8.3%
NLO corrections	18%	9.0%
$\Delta\tilde{m} = 10$ GeV	7.3%	3.7%
statistics	5.8%	2.9%
	26%	13%

Remark: Assumptions about underlying model needed.

Summary and Outlook

Summary

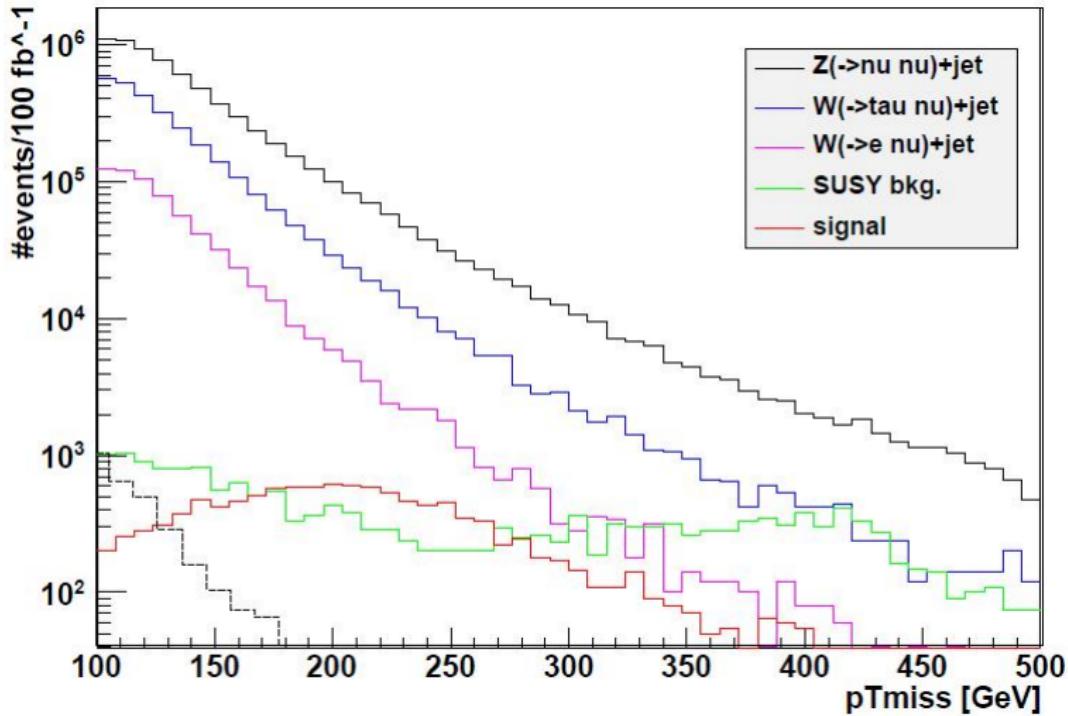
- New physics consistent with SUSY might be discovered soon!
- How do we know, that it is SUSY?
 - Test of SUSY coupling relations.
- Monojets can test $\tilde{\chi}_1^0$ - \tilde{q} - q coupling.
- Only possible for very light bino LSP scenarios.
- Wino LSP scenarios with $m_{\tilde{q}_L} \leq 1.2$ TeV can be tested.
 - Coupling reconstruction at 10% level possible.

Outlook

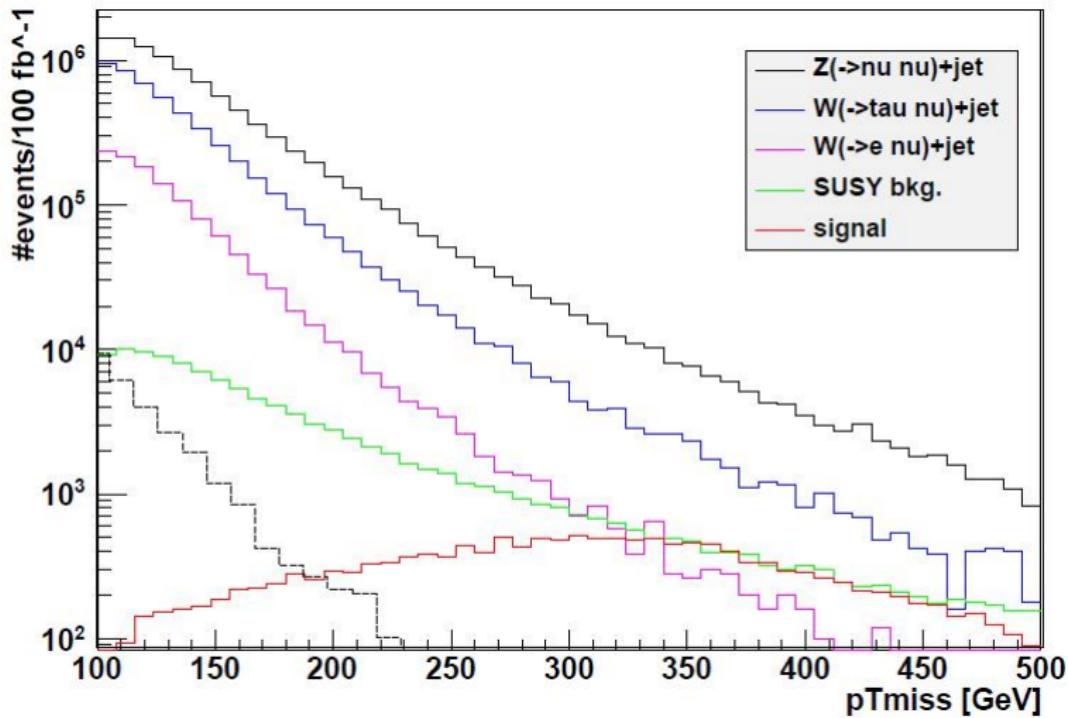
- Test of \tilde{H} - \tilde{t} - b coupling.
[Drees, SG, Kim, work in progress]
- Global fit including e.g. branching ratios.

backup slides

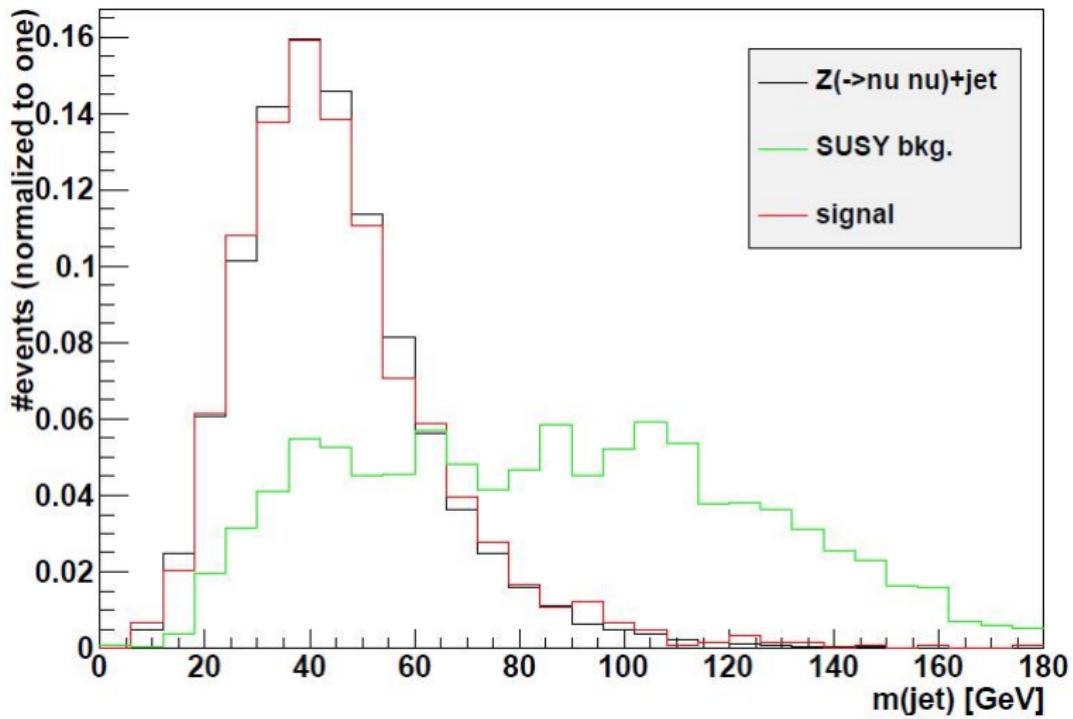
Jet- p_T Distribution: mSUGRA Scenario



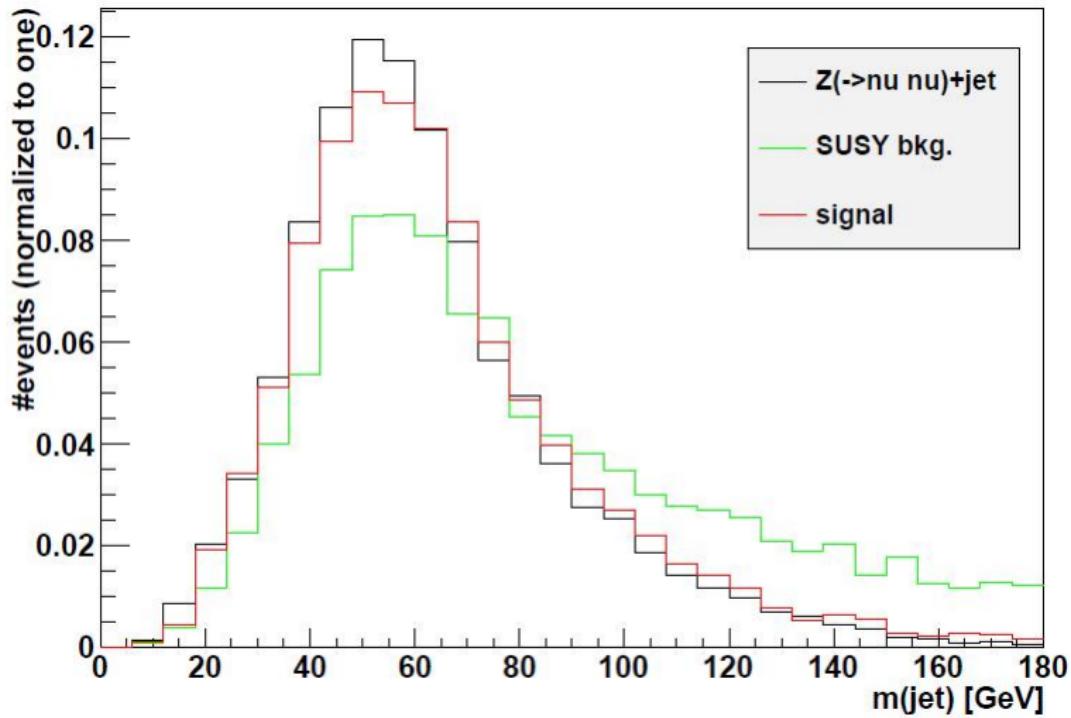
Jet- p_T Distribution: mAMSB Scenario



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}
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)
$p_T > 180$ GeV	3.28×10^6	32 300	22 300	12 (4.7)
$m(\text{jet}) < 70$ GeV	3.00×10^6	12 100	20 100	12 (4.4)
tau veto	2.75×10^6	9 950	20 000	12 (4.6)
b -jet veto	2.66×10^6	9 290	20 000	12 (4.6)

Cutflow: mAMSB Scenario

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

Error Estimate: mSUGRA Scenario

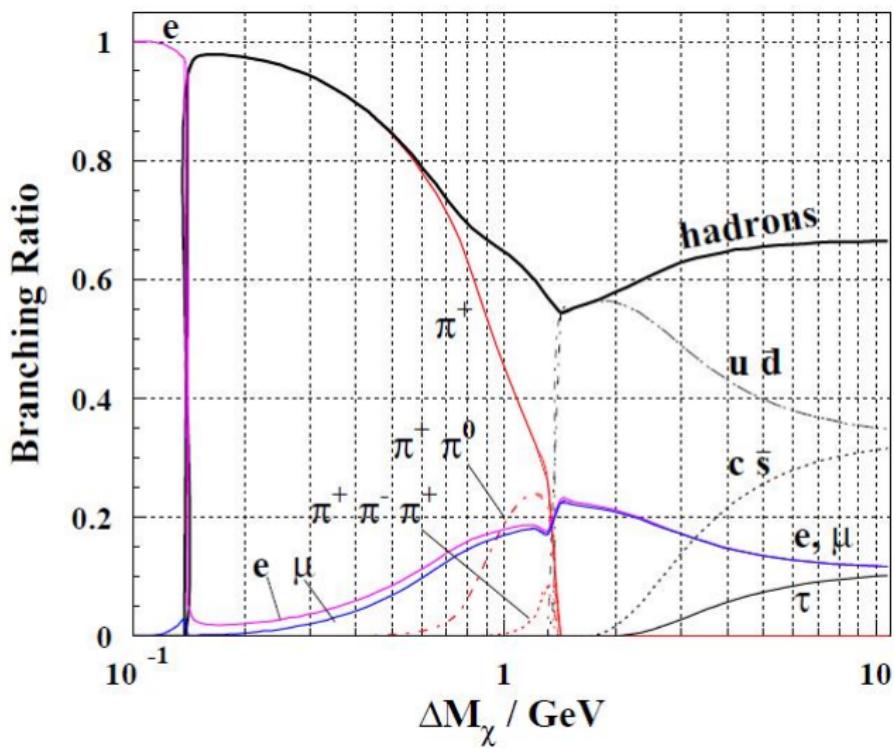
error	$\Delta\sigma_{\text{mono}}/\sigma_{\text{mono}}$	$\Delta\lambda/\lambda$
luminosity	3.0%	1.5%
PDF uncertainty	15%	7.3%
NNLO corrections	16%	8.0%
sparticle mass $\Delta\tilde{m} = 10 \text{ GeV}$	10%	5.2%
SUSY background	6.0%	3.0%
statistics (optimistic)	8.6%	4.3%
statistics (conservative)	23%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

Error Estimate: mAMSB Scenario

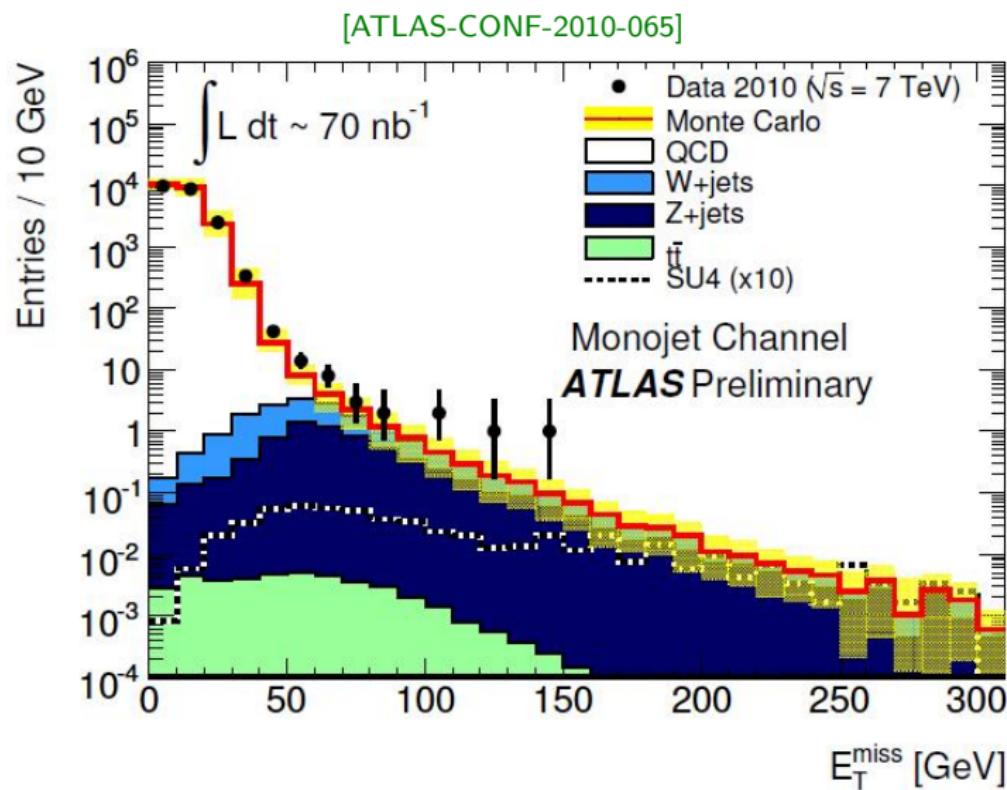
error	$\Delta\sigma_{\text{mono}}/\sigma_{\text{mono}}$	$\Delta\lambda/\lambda$
luminosity	3%	1.5%
PDF uncertainty	16%	7.8%
NNLO corrections	18%	9%
sparticle mass $\Delta\tilde{m} = 10 \text{ GeV}$	12%	6.2%
SUSY background	9.4%	4.7%
statistics (optimistic)	5.8%	2.9%
statistics (conservative)	15%	7.6%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

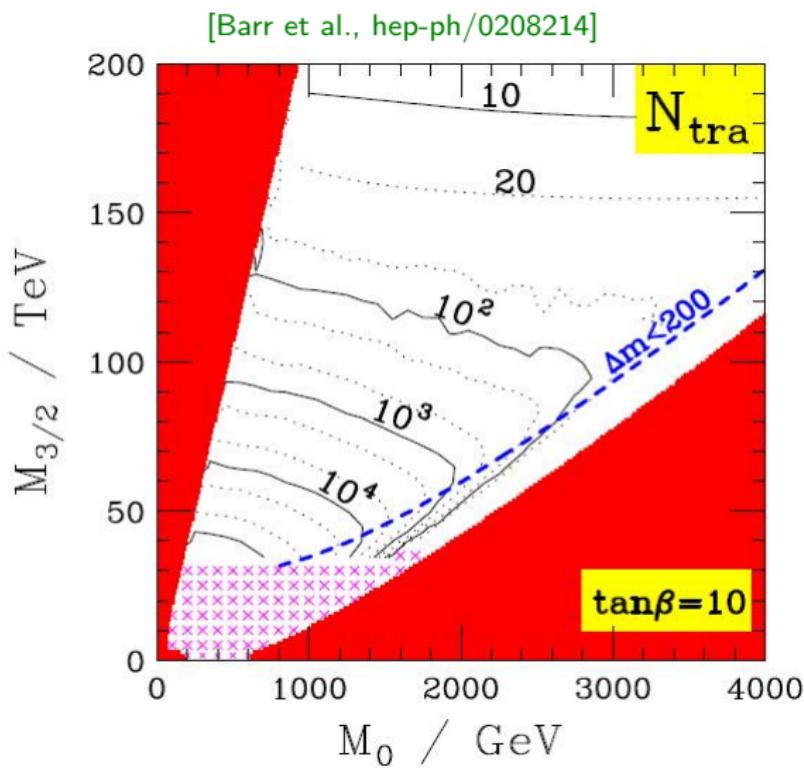
Wino Branching Ratios

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



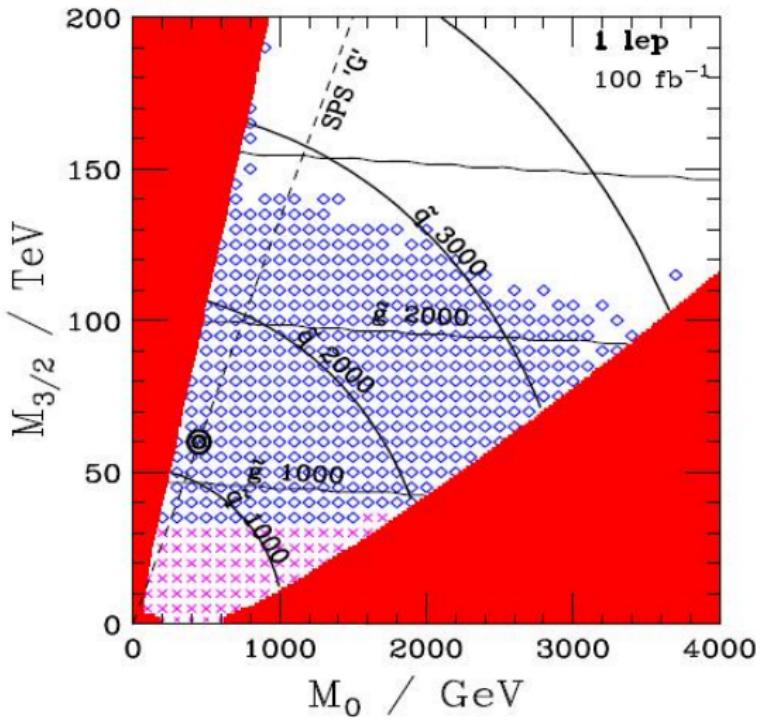
Monojet missing energy distribution at 7 TeV



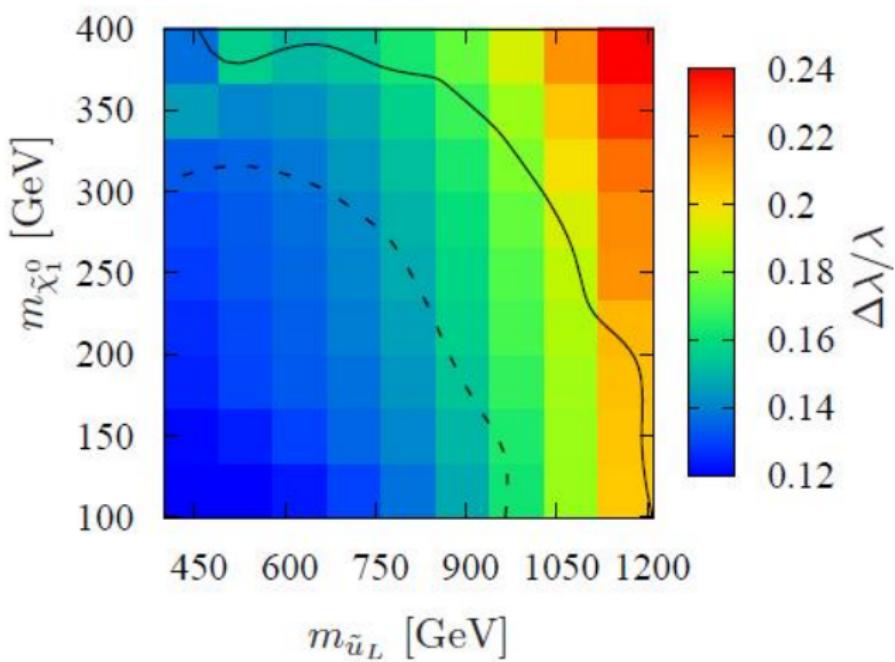
Number of detached Vertices for $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 + X$ for 100 fb^{-1} 

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

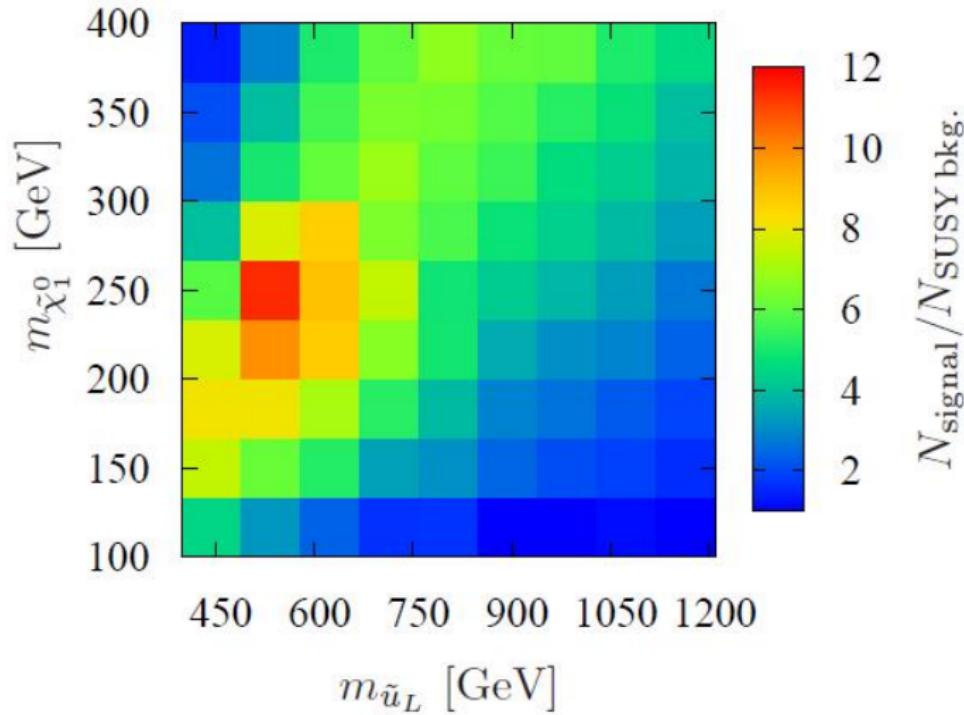
[Barr et al., hep-ph/0208214]

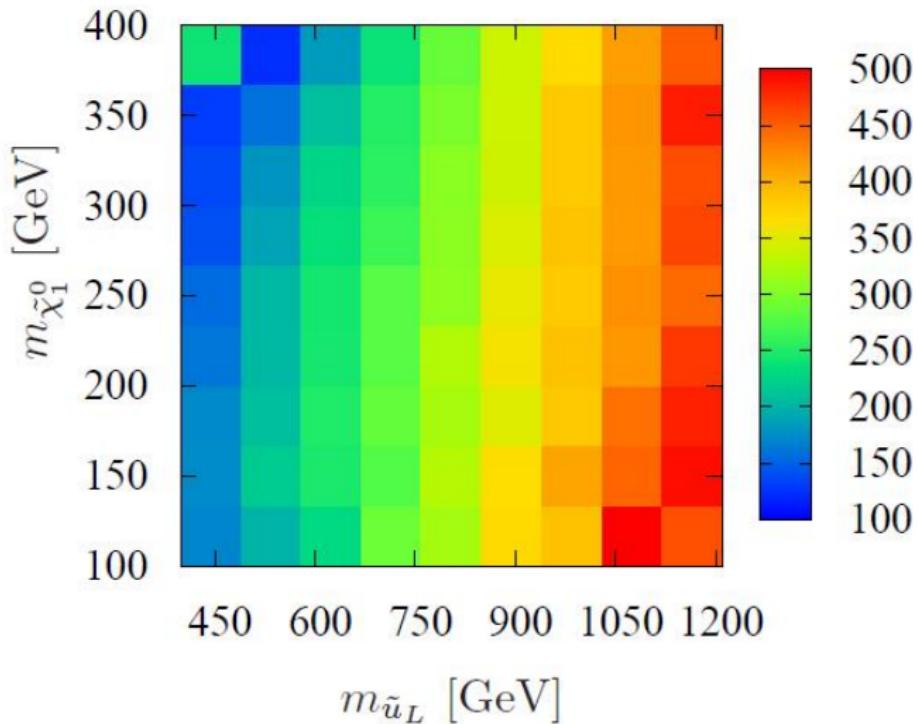


Precision of Reconstructed Coupling



Signal to SUSY Background Ratio



Lower Cut on Jet p_T 

Lower Cut on Jet Invariant Mass

