Probing leptonic LSP decays in bilinear RPV

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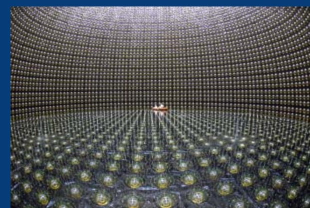
Wednesday, 25. November 2009



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Overview

1. Bilinear R parity violation
2. ATLAS Benchmark Points
3. Phenomenology of bRPV decays
4. Analysis in the leptonic channel
5. Conclusion/Outlook

Motivation

What is R parity?

Lepton number violation terms and baryon number violation terms are allowed in the superpotential in contrast to a SM Lagrangian

B and *L* violation has never been seen experimentally → Proton decay

Introduction of a new symmetry, which is a combination of *B* and *L* (and S)

$$P_R = (-1)^{3B+L+2S}$$

⟶ SM particles: $P_R = 1$
⟶ SUSY partners: $P_R = -1$

Conservation of P_R has important phenomenological consequences:

- LSP is absolutly stable
- SUSY decay products contain an odd number of LSPs
- Sparticles can only be produced in pairs

Bilinear P_R violation

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$\longrightarrow$ SUSY partners: $P_R = -1$

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- Sparticles can only be produced in pairs

no need for conservation

Bilinear P_R violation

The model

bRPV Superpotential/ Lagrangian

$$W = \varepsilon_{ab}\left(\underbrace{h_U^{ij}\hat{Q}_i^a\hat{U}_j\hat{H}_u^b + h_D^{ij}\hat{Q}_i^b\hat{D}_j\hat{H}_d^a + h_E^{ij}\hat{L}_i^b\hat{R}_j\hat{H}_u^a - \mu\hat{H}_d^a\hat{H}_u^b}_{\text{MSSM superpotential}} + \underbrace{\varepsilon_i\hat{L}_i^a\hat{H}_u^b}_{\text{RPV term}}\right)$$

MSSM superpotential

RPV term

→ Corresponding RPV soft SUSY breaking term $L_{soft}^{BRpV} = -B_i\varepsilon_{ab}\varepsilon_i\tilde{L}_i^a H_u^b$

$$\boxed{L_{soft} = L_{soft}^{MSSM} - B_i\varepsilon_{ab}\varepsilon_i\tilde{L}_i^a H_u^b}$$

Fields: $H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$ $H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$ $\tilde{L}_i = \begin{pmatrix} \tilde{L}_i^0 \\ \tilde{l}_i^- \end{pmatrix}$ → Higgs/Slepton-mixing

Bilinear P_R violation

The model

Neutrino masses and mixings

Basis of neutral fermions:

$$\psi^{0T} = (\underbrace{-i\lambda', -i\lambda^3, \tilde{H}_d^1, \tilde{H}_u^2}_{\text{MSSM Neutralinos (wino, bino, Higgsinos)}}, \overbrace{\nu_e, \nu_\mu, \nu_\tau}^{\text{SM Neutrinos}})$$

Mass terms in the Lagrangian are given by:

$$L_m = -\frac{1}{2}\left(\psi^0\right)^T \mathbf{M_N} \psi^0 + h.c.$$

$$\mathbf{M_N} = \begin{pmatrix} M_{\chi^0} & m^T \\ m & 0 \end{pmatrix}$$

M_{χ^0}: 4x4 MSSM neutralino mixing matrix

m^T: 4x3 RPV matrix

Bilinear P_R violation

The model

$$\mathbf{M_N} = \begin{pmatrix} M_{\chi^0} & m^T \\ m & 0 \end{pmatrix}$$

Approximate diagonalization of $\mathbf{M_N}$

$\mathbf{M_N}$ can be block-diagonalized for small RPV parameters via the Seesaw-like diagonalization: $\mathbf{M_N} = diag(M_{\chi^0}, m_{eff})$

$$m_{eff} = -mM_{\chi^0}m^T = \frac{M_1 g^2 + M_2 g'^2}{4\det} \begin{pmatrix} \Lambda_e^2 & \Lambda_e\Lambda_\mu & \Lambda_e\Lambda_\tau \\ \Lambda_\mu\Lambda_e & \Lambda_\mu^2 & \Lambda_\mu\Lambda_\tau \\ \Lambda_\tau\Lambda_e & \Lambda_\tau\Lambda_\mu & \Lambda_\tau^2 \end{pmatrix}$$

where $\Lambda_i = \varepsilon_i v_d + \mu v_i$ „alignment parameters“

A final diagonalization of M_{χ^0} leads to the neutralino masses $m_{\chi_i^o}$
and a diagonalization of m_{eff} leads to one tree level neutrino mass.

The model

Some consequences of this model

- **largest neutrino mass** at tree level $$m_\upsilon = \frac{M_1 g^2 + M_2 g'^2}{4\det} \left|\vec{\Lambda}\right|^2$$

- **mixing angles** at tree level $$\tan\theta_{23} = \frac{\Lambda_\mu}{\Lambda_\tau}$$ $$\tan\theta_{13} = -\frac{\Lambda_e}{\sqrt{\Lambda_\mu^2 + \Lambda_\tau^2}}$$

- remaining neutrino masses at 1-loop-level

- Higgs sector mixing with slepton sector

- **correct scales** of mass differences Δm_{ij}^2

Benchmark scenarios

<u>mSUGRA</u>

SUSY has to be broken! **mSUGRA** (105 parameters → 5 parameters)

$$M_3 = M_2 = M_1 = m_{1/2}$$

$$\mathbf{m}^2_{\tilde{Q}} = \mathbf{m}^2_{\tilde{u}} = \mathbf{m}^2_{\tilde{d}} = \mathbf{m}^2_{\tilde{L}} = \mathbf{m}^2_{\tilde{e}} = m_0 \mathbf{1} \quad m^2_{H_u} = m^2_{H_d} = m^2_0$$

$$\mathbf{a}_u = A_0 \mathbf{y}_u \quad \mathbf{a}_d = A_0 \mathbf{y}_d \quad \mathbf{a}_e = A_0 \mathbf{y}_e$$

$$\tan\beta$$

$$\mathrm{sgn}(\mu)$$

Planck scale

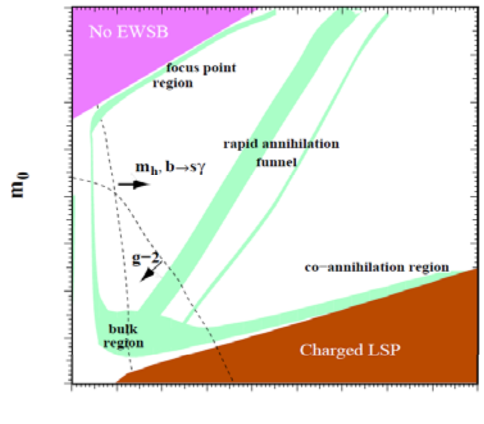
RGE

SPheno 3.0

SUSY spectrum & couplings **electroweak scale**

ATLAS benchmark points

Benchmark scenarios



SUSY benchmark points

Special benchmark points for ATLAS:

Name	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	tan β	sgn μ	Characteristics
SU1	70	350	0	10	+	Coanihilation region
SU2	3550	300	0	10	+	Focus point region
SU3	100	300	-300	6	+	Bulk region
SU4	200	160	-400	10	+	Low mass point
SU6	320	375	0	50	+	
SU8.1	210	360	0	40	+	Funnel region
SU9	300	425	20	20	+	

(ATLAS CSC Note)

→ Which one to use for event generation?

Phenomenology

Comparison of SU points for LSP decay

Chosen LSP-decay to investigate: $\tilde{\chi}_1^0 \rightarrow \mu^{\pm} + \tau^{\mp} + \nu$

Name	$m_{\chi 10}$	Decay length [m]	BR(2BD)	BR(3BD-non/semilept.)	BR(3BD-leptonic)	BR(χ^{10} -> τ τ ν)	BR(χ^{10} -> μ τ ν)
SU1	139	$1,2\ 10^{-4}$	0,32	0,02	0,66	0,33	0,10
SU2	120	$2,0\ 10^{-3}$	0,85	0,09	0,06	0,01	0,01
SU3	118	$2,9\ 10^{-4}$	0,46	0,05	0,49	0,25	0,08
SU4	60	0,1	~0	0,36	0,64	0,30	0,08
SU6	152	$4,1\ 10^{-4}$	0,73	0,01	0,26	0,14	0,03
SU8.1	145	$3,1\ 10^{-4}$	0,48	0,01	0,51	0,28	0,06
SU9	173	$2,0\ 10^{-5}$	0,88	0,01	0,11	0,06	0,01

(data created with Spheno 3beta36, W. Porod , arXiv:hep-ph/0301101)

Phenomenology

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SU9	173	[illegible]	[illegible]	…01	0,11	0,06	0,01

Selection criteria:

- high BR(3BD-leptonic)
- high $\dfrac{Br(\tilde{\chi}_1^0 \rightarrow \mu^{\pm} + \tau^{\mp} + \nu)}{Br(\tilde{\chi}_1^0 \rightarrow \tau^{\mp} + \tau^{\mp} + \nu)}$

(data created with Spheno 3beta36, W. Porod , arXiv:hep-ph/0301101)

Phenomenology

Comparison of possible leptonic decay channels with μ in the final state

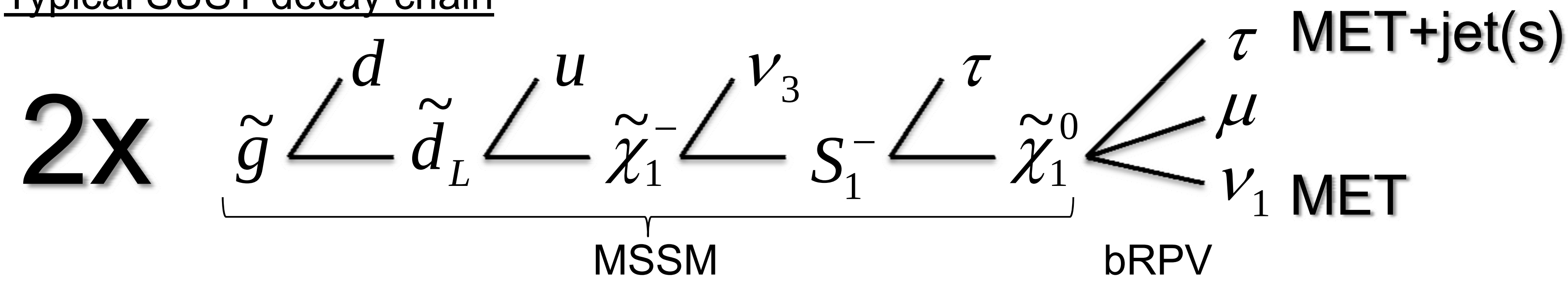
$\tilde{\chi}_0^1 \rightarrow \mu^{\pm} + e^{\mp} + \nu$	0,0140%
$\tilde{\chi}_0^1 \rightarrow \mu^{+} + \mu^{-} + \nu$	0,0671%
$\tilde{\chi}_0^1 \rightarrow \mu^{\pm} + \tau^{\mp} + \nu$	7,9195%

(SU3 ATLAS benchmark point)

Group in Valencia working on
$\tilde{\chi}_0^1 \rightarrow W\mu$ (ATL-COM-PHYS-2009-543)

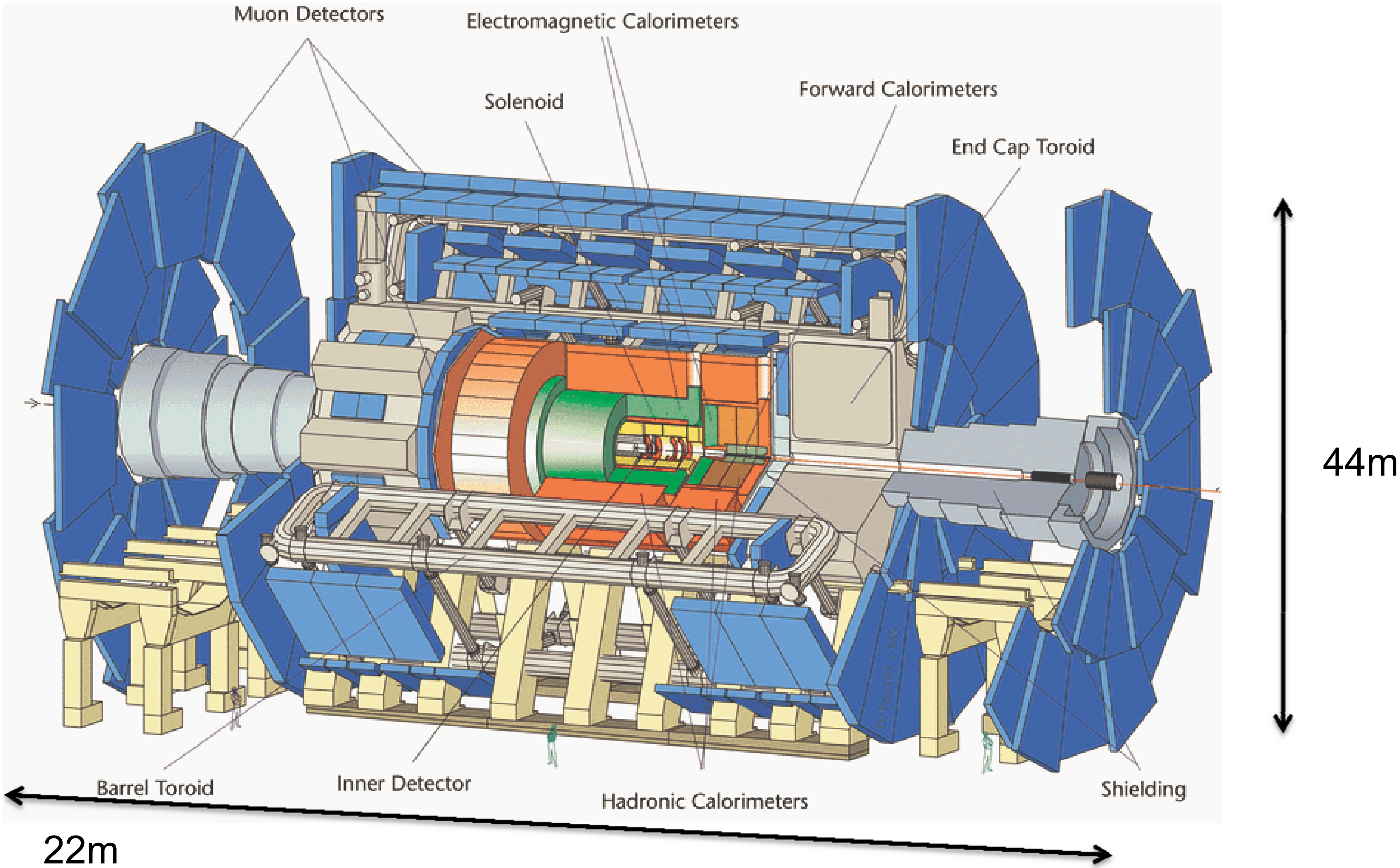
→ ATLAS has a dedicated muon spectrometer
→ Workgroup is interested in muons

Typical SUSY decay chain



→ **problem:** SUSY/MSSM background (jets, MET, …)

ATLAS detector



Experimental work

Workflow

<u>Reconstruction chain</u>

SPheno

bilinear RPV model

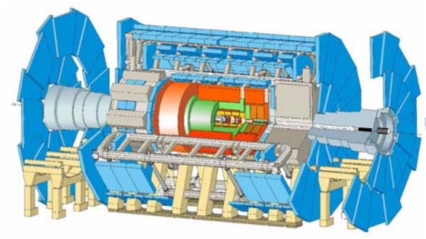
Generation

Simulation

Digitization

Reconstruction

GRID



2009?

Trigger

backgrounds

cuts

Analysis

SUSY? bRPV?

Experimental work

Trigger

$$\tilde{g} \to d\,\tilde{d}_L,\quad \tilde{d}_L \to u\,\tilde{\chi}_1^-,\quad \tilde{\chi}_1^- \to \nu_3\,S_1^-,\quad S_1^- \to \tau\,\tilde{\chi}_1^0,\quad \tilde{\chi}_1^0 \to \tau\,\mu\,\nu_1$$

jet(s)

MET

<u>Reasonable Triggers</u>

Signal final state signature:
mu, jets, missing E_T

mu10_j18 | mu4_j10 | mu10

Trigger	Signal efficiency (%)
mu10	69.9
mu4_j10	79.8
mu10_j18	69.9

Trigger	ttbar efficiency (%)
mu10	44.1
mu4_j10	55.5
mu10_j18	44.1

mu10_j18	Background eff. (%)
single top	48.9
W+jets	43.6
Z+jets	53.6
WW+WZ+ZZ	42.4
QCD dijets	0.0794

(Torro, Mitsou, Garcia ATL-COM-PHYS-2009-543)

→Trigger **mu10_j18** chosen
→ most restrictive
→ very good QCD background reduction

Background

Standard model backgrounds:

- ttbar (*)
- single top
- W+jets
- Z+jets
- WW+WZ+ZZ
- QCD dijets

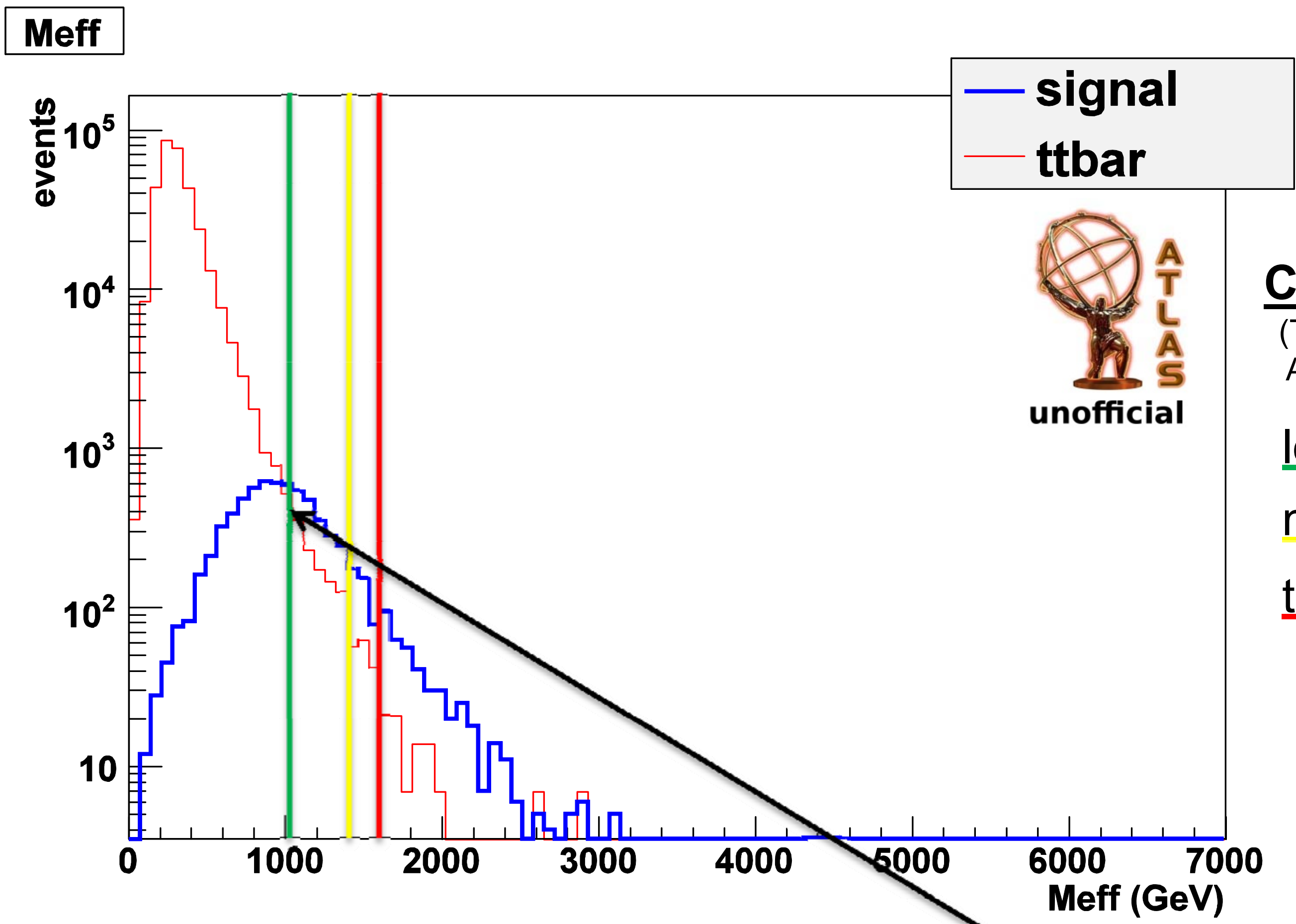
after triggering:
QCD and ttbar dominant background

Observables to study SUSY signals:

- effective mass $$M_{eff} = E_T^{miss} + \sum_{1...4} p_T^{jet} + \sum p_T^{e} + \sum p_T^{\mu}$$
- missing energy E_T^{miss}
- transverse sphericity $$S_T = \frac{2\lambda_2}{\lambda_1 + \lambda_2}$$ λ_1, λ_2 eigenvalues of sphericity tensor

Experimental work

Effective mass



Cut suggestions:
(Torro, Mitsou, Garcia ATL-COM-PHYS-2009-543)

loose: M_{eff}> 1TeV

medium: M_{eff}> 1.2TeV

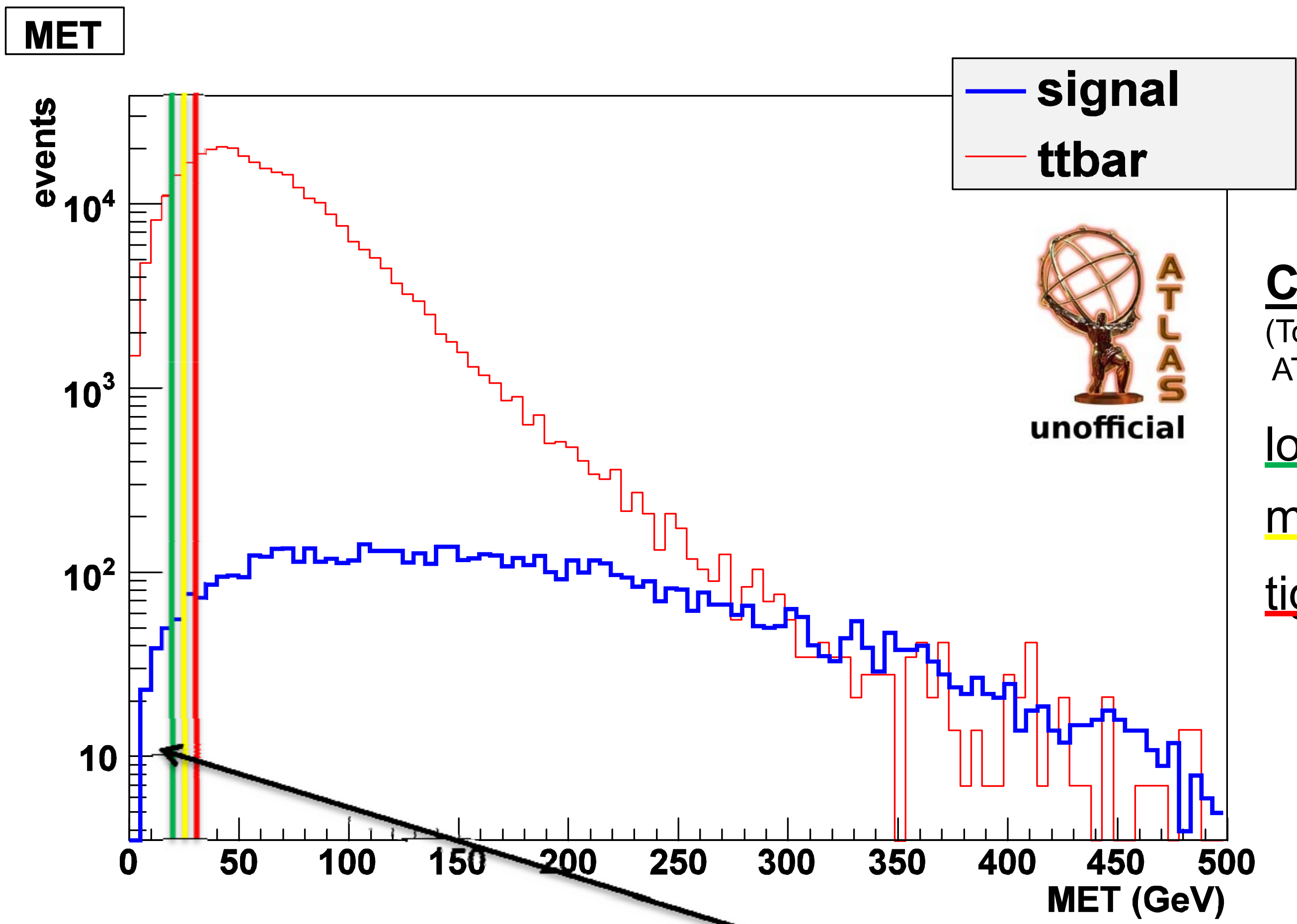
tight: M_{eff}> 1.3TeV

Trigger: mu10_j18,
$\int L$ = 2 fb^{-1}, CM=10TeV

Maximum of (SUSY) signal M_{eff} at higher energy

Experimental work

Missing energy



Cut suggestions:

(Torro, Mitsou, Garcia ATL-COM-PHYS-2009-543)

loose : E_T^{miss}> 20GeV

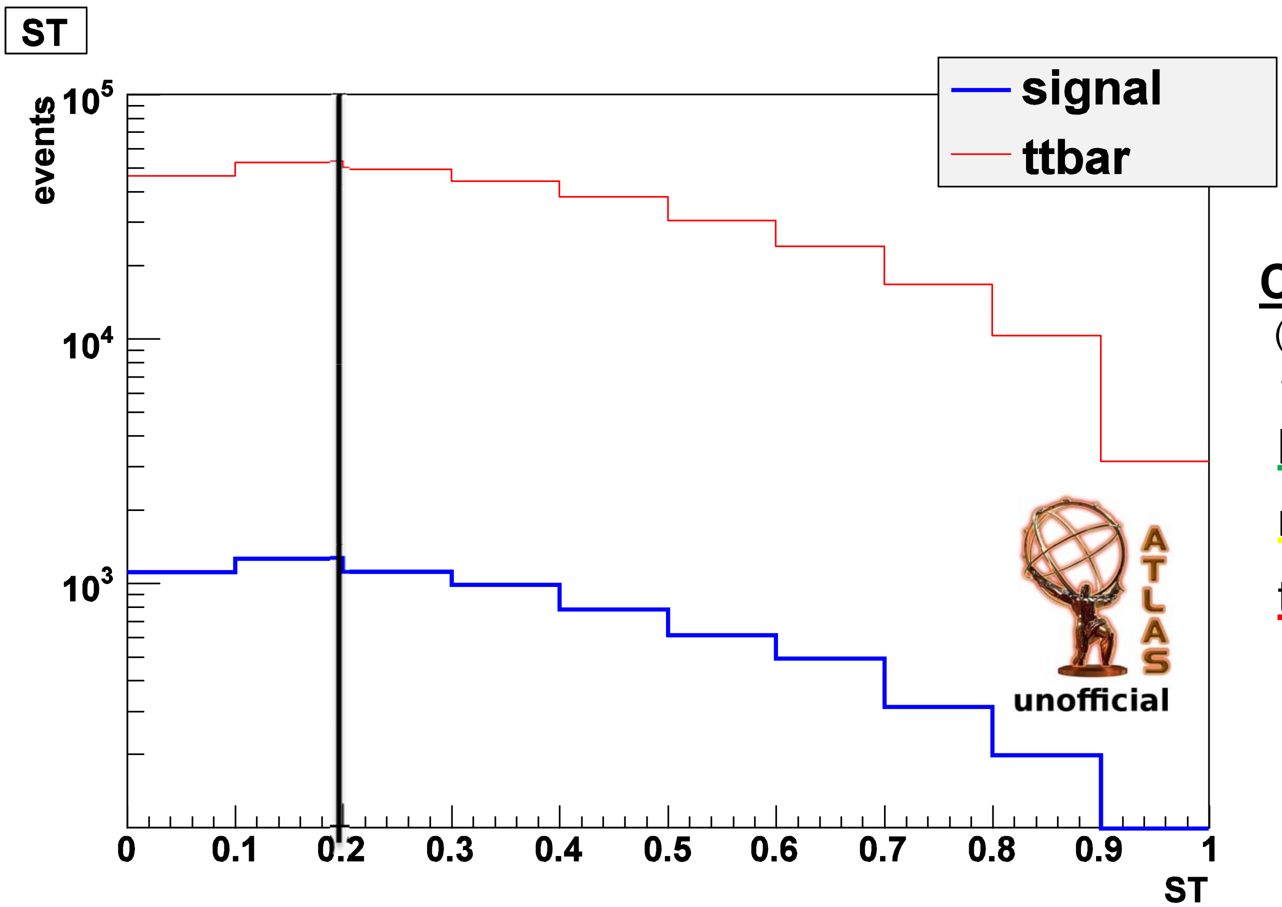
medium : E_T^{miss} > 25 GeV

tight : E_T^{miss} > 30 GeV

Trigger: mu10_j18,
$\int L$ = 2 fb^{-1}, CM=10TeV

Missing Et distribution down to nearly 0 GeV due to LSP decay ←→ SUSY RPC

Transverse Sphericity



Cut suggestions:
(Torro, Mitsou, Garcia
ATL-COM-PHYS-2009-543)

loose : S_T> 0.2

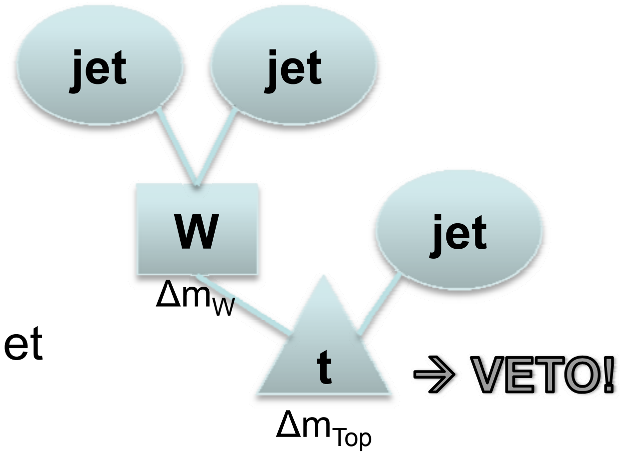
medium : S_T> 0.2

tight : S_T > 0.2

Trigger: mu10_j18,
$\int L$ = 2 fb^{-1}, CM=10TeV

Cut useful for QCD background reduction

Cuts



Top veto:

→ reconstruct single top to reduce background
→ looking for W candidate ($|\Delta m_W| = \pm 5$ GeV) plus jet
→ cut parameter: $|\Delta m_{Top}| = \pm 20, \pm 30, \pm 40$ GeV
→ works fine

Cut efficiencies:

M_{eff} medium cut

signal	ttbar
24.4%	0.2%

E_T^{miss} medium cut

signal	ttbar
97.5%	87.8%

S_T medium cut

signal	ttbar
65.0%	68.4%

medium Top veto

signal	ttbar
86.4%	90.1

„combined“ medium cut:

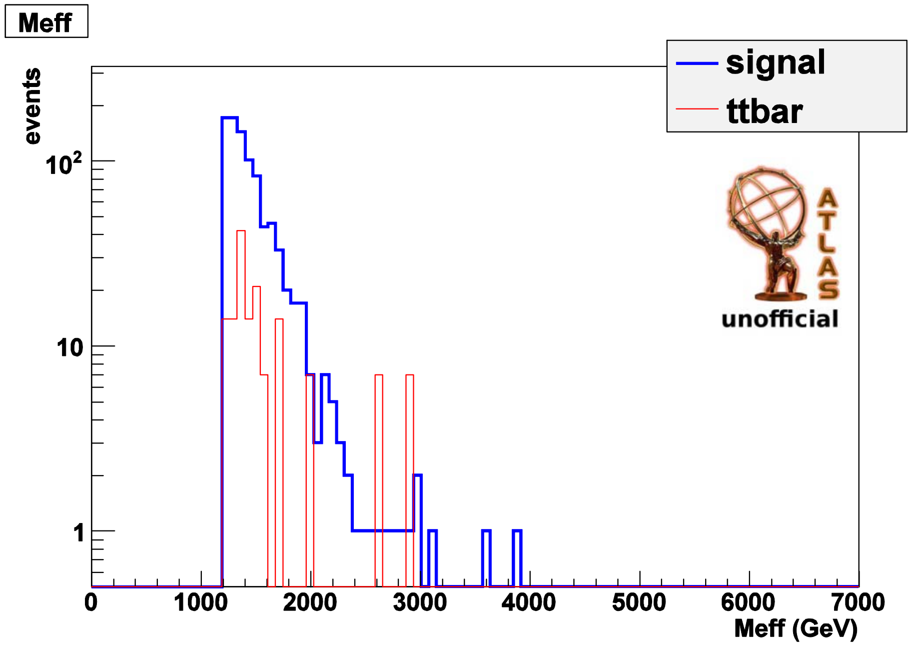
signal	ttbar
12.5%	0.04%

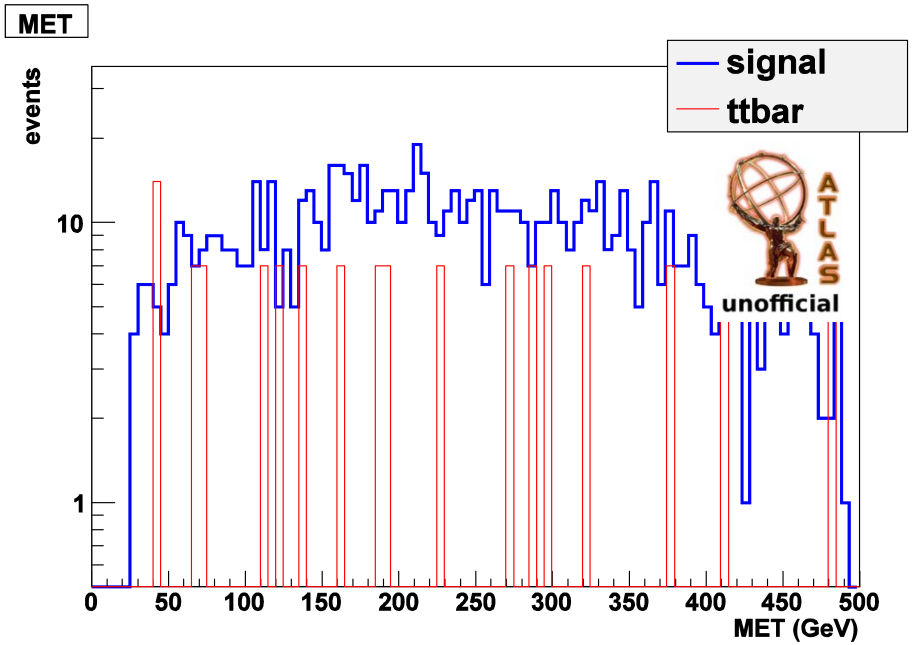
→ good ttbar reduction

Experimental work

Cuts

Distributions after cutting:





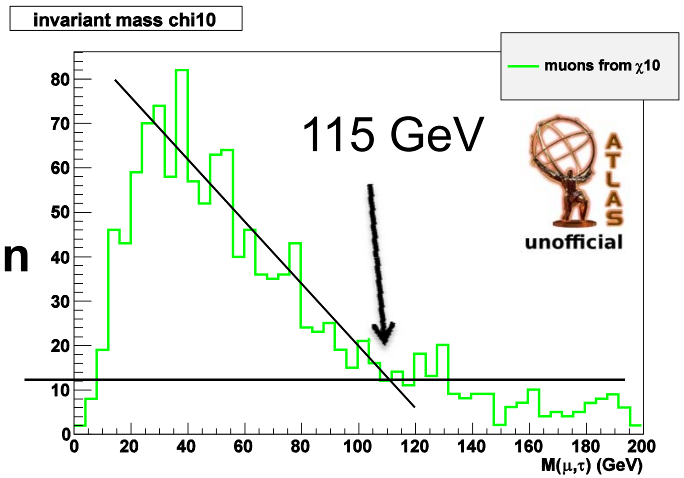
Trigger: mu10_j18,
Cuts: combined medium cuts
$\int L = 2\ fb^{-1}$, CM=10TeV

Conclusion/Outlook

Ongoing work/ Outlook

Ongoing work:

- **Further background** has to be added (QCD, W+jet, …)
- very good SM background reduction
- some work to do on SUSY **background reduction**
- **tau reconstruction** improvement
- idea: reconstruction of neutralino mass via **endpoint determination** of invariant mass $m_{\mu,\tau}$



Summary

- bRPV enables to access neutrino physics at the collider
- first studies concerning bRPV on ATLAS/LHC almost finished (Valencia group: χ→W μ)
- others on the way…

Vielen Dank für die Aufmerksamkeit!

Thank you for your attention!

References

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arXiv:hep-ph/0211276v1

Hirsch, Díaz, Porod, Romae, Valle: *Neutrino Masses an Mixings from Supersymmetry with Bilinear R-Parity Violation: A Theory for Solar and Atmospheric Neutrino Oscillations*.
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arXiv:hep-ph/0505105v1

Torro, Mitsou, Garcia: *Probing Bilinear R-Parity Violating Supersymmetry in the Muon plus Jets Channel.*
ATL-COM-PHYS-2009-543

ATLAS Collaboration: ATLAS CSC Note. Supersymmetry Searches with ATLAS

Backup Slides

Backup Slides

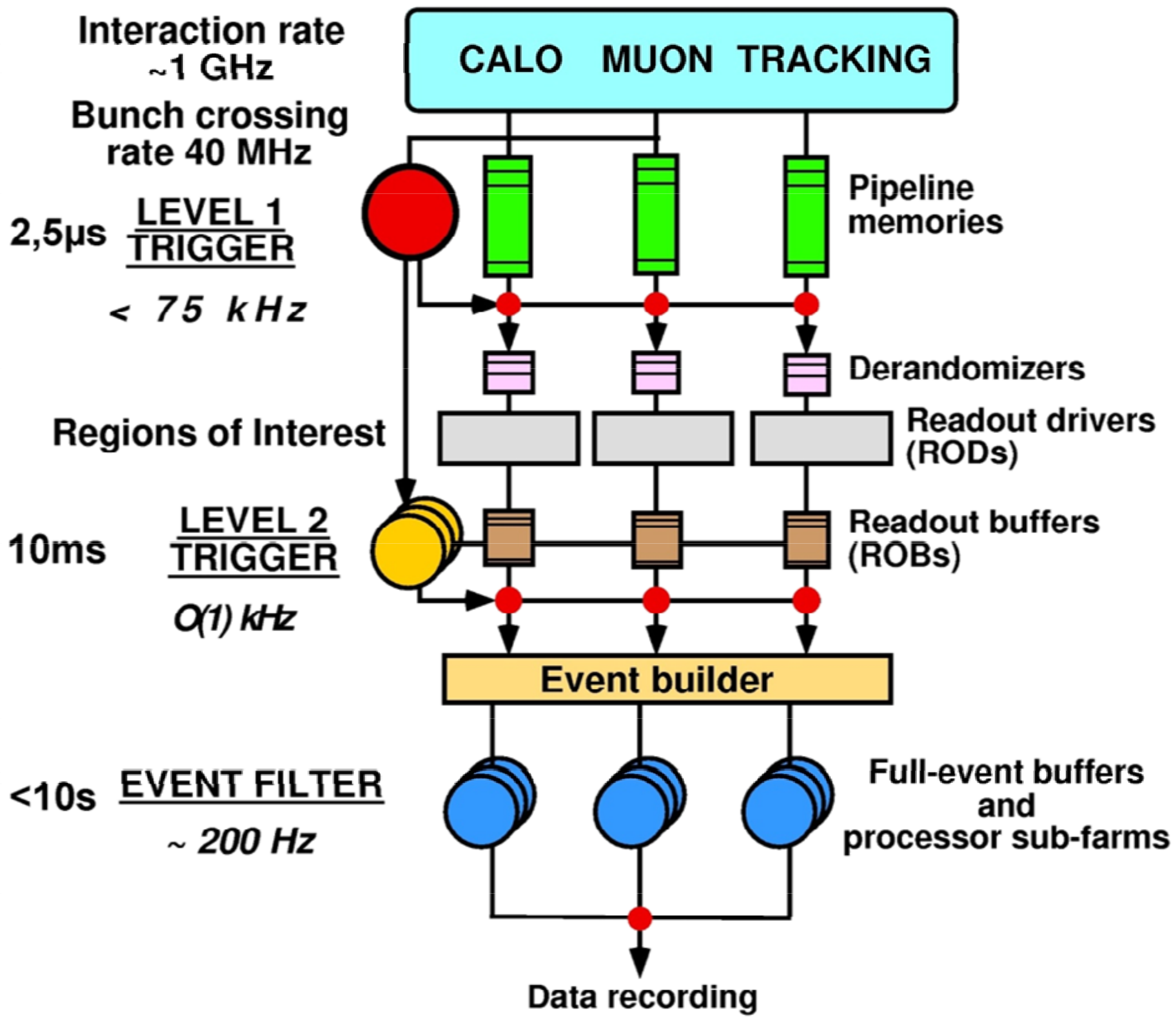
Mass matrizes

$$M_{\chi^0} = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'v_d & \frac{1}{2}g'v_u \\ 0 & M_2 & \frac{1}{2}gv_d & -\frac{1}{2}gv_u \\ -\frac{1}{2}g'v_d & \frac{1}{2}g'v_u & 0 & -\mu \\ \frac{1}{2}gv_d & -\frac{1}{2}gv_u & -\mu & 0 \end{pmatrix}$$

$$m = \begin{pmatrix} -\frac{1}{2}g'v_1 & \frac{1}{2}gv_1 & 0 & \varepsilon_1 \\ -\frac{1}{2}g'v_2 & \frac{1}{2}gv_2 & 0 & \varepsilon_2 \\ -\frac{1}{2}g'v_3 & \frac{1}{2}gv_3 & 0 & \varepsilon_3 \end{pmatrix}$$

Backup Slides

ATLAS Trigger



SPheno Parameters in bRPV

9 extra parameters for bRPV

Define them explicitly
OR
Constraints:
•Successful electroweak symmetry breaking corresponds to minimization of effective potential; technically: 3 extra tadpole equations linear in B_i

•Results from neutrino oscillation data (2 mass differences, 3 mixing angles) fix 5 bilinear parameters (ε_i,v_i)

•Remaining parameter should be of the same order as the others

Object Selection

Muons:
- combined muon
- pt > 6 GeV
- $|\eta| < 2.7$

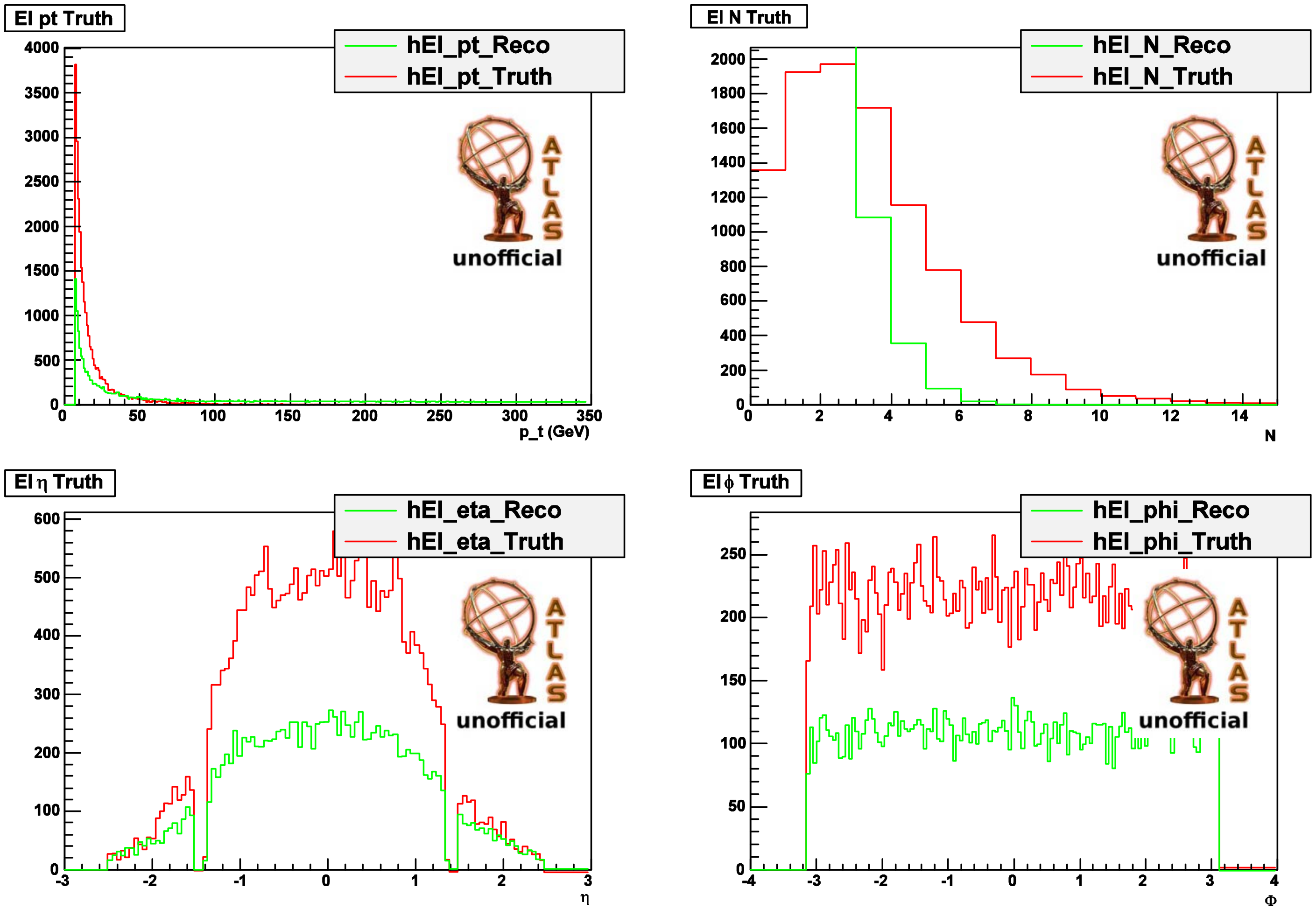
Jets:
- pt > 10 GeV
- $|\eta| < 2.5$

Electrons:
- cluster based electron
- isolation: ET < 10 GeV in isolation cone with $\Delta R < 0.1$
- pt > 7 GeV
- $|\eta| < 2.5$ and $|\eta| \notin [1.37,1.52]$

Taus:
- 1 / 3 tracks
- charge = ± 1
- pt > 10 GeV
- $|\eta| < 2.5$ and $|\eta| \notin [1.37,1.52]$

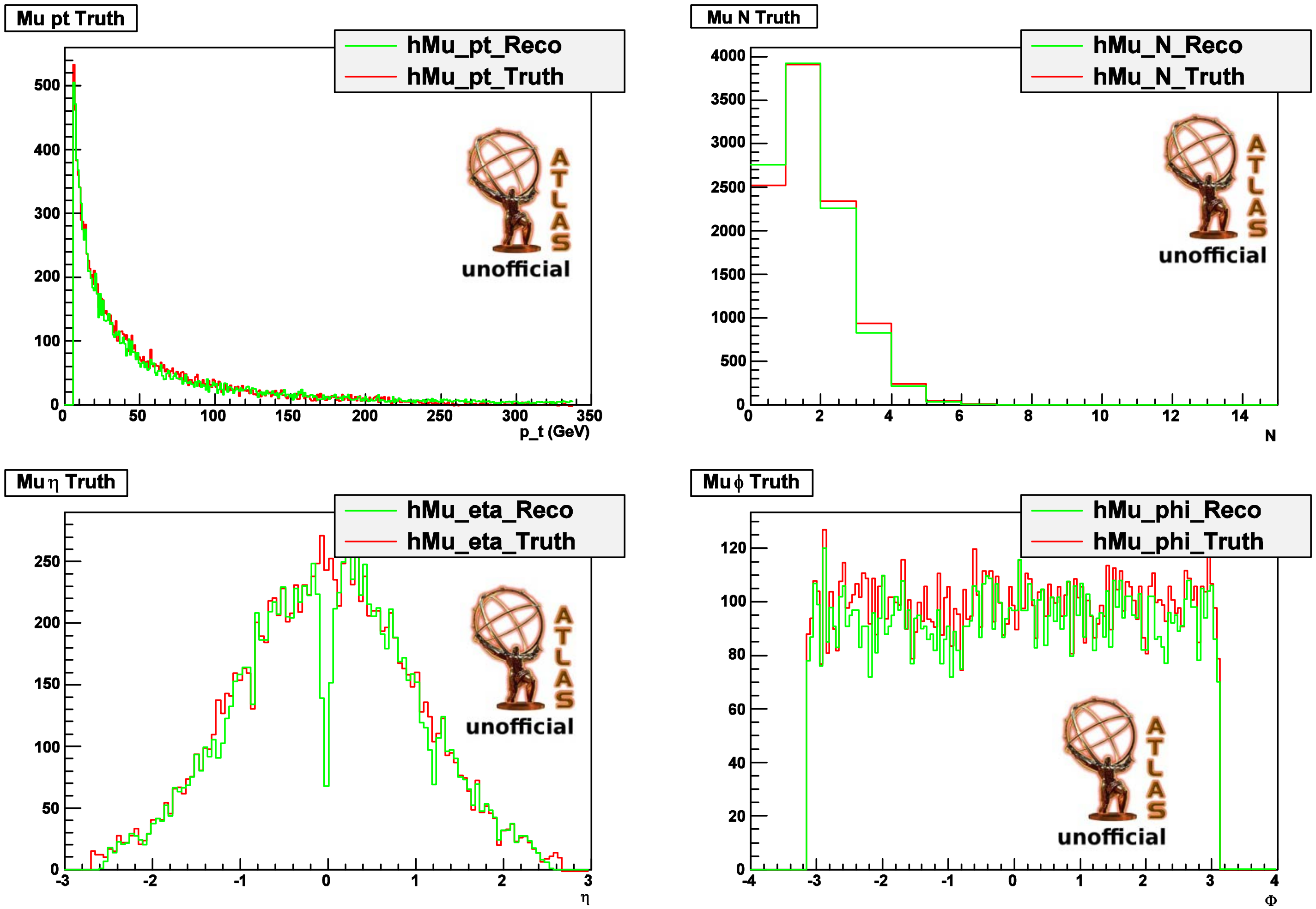
Overlap removal:
- remove electrons within $0.2<\Delta R<0.4$ to a jet
- remove jets within $\Delta R<0.2$ to an electron
- remove taus within $\Delta R<0.2$ to an electron

Object Selection



$\int L = 2\ fb^{-1}$ (SUSY signal), CM=10TeV

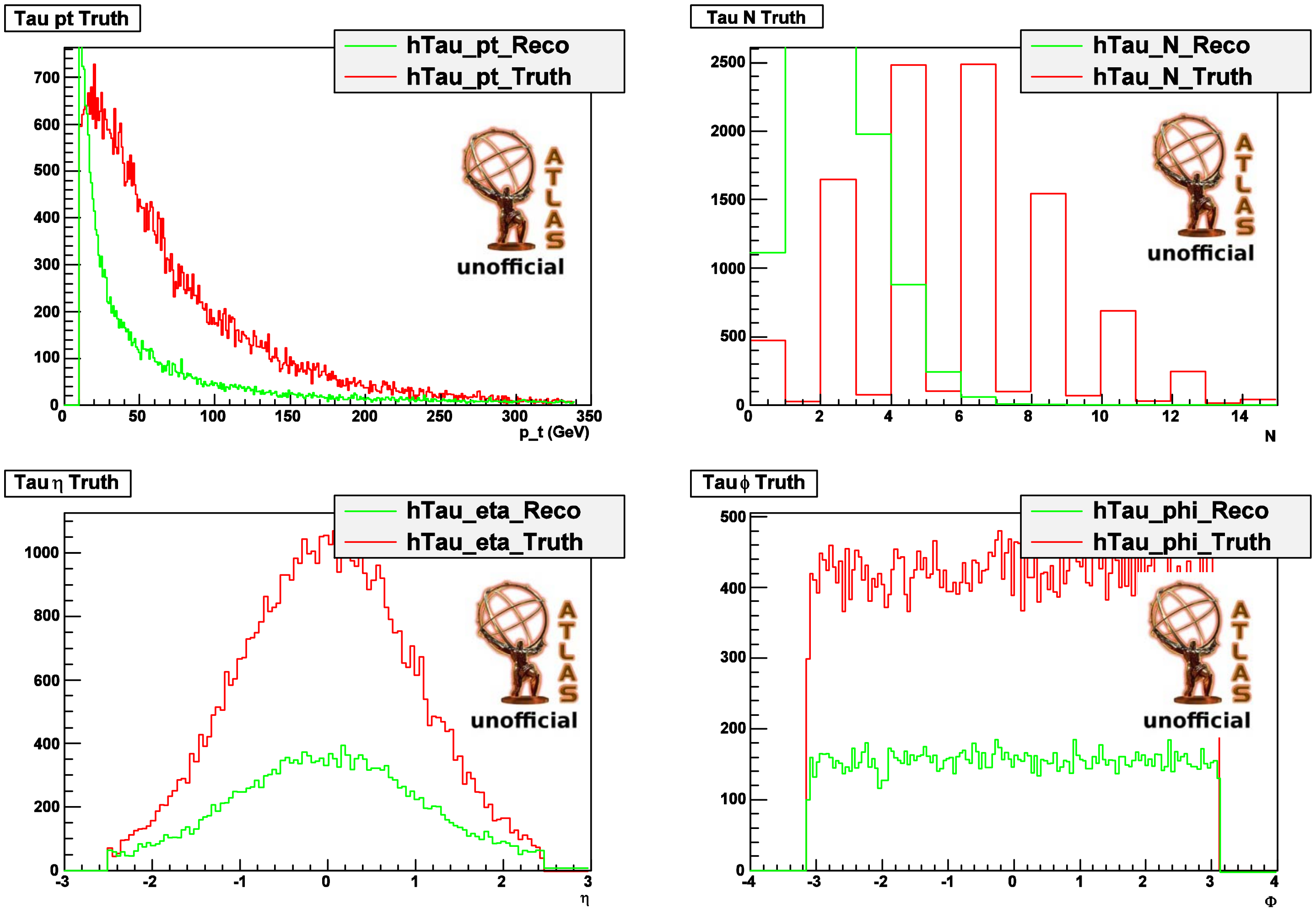
Object Selection



$\int L = 2\ fb^{-1}$ (SUSY signal), CM=10TeV

Object Selection

→ Needs to be improoved!!



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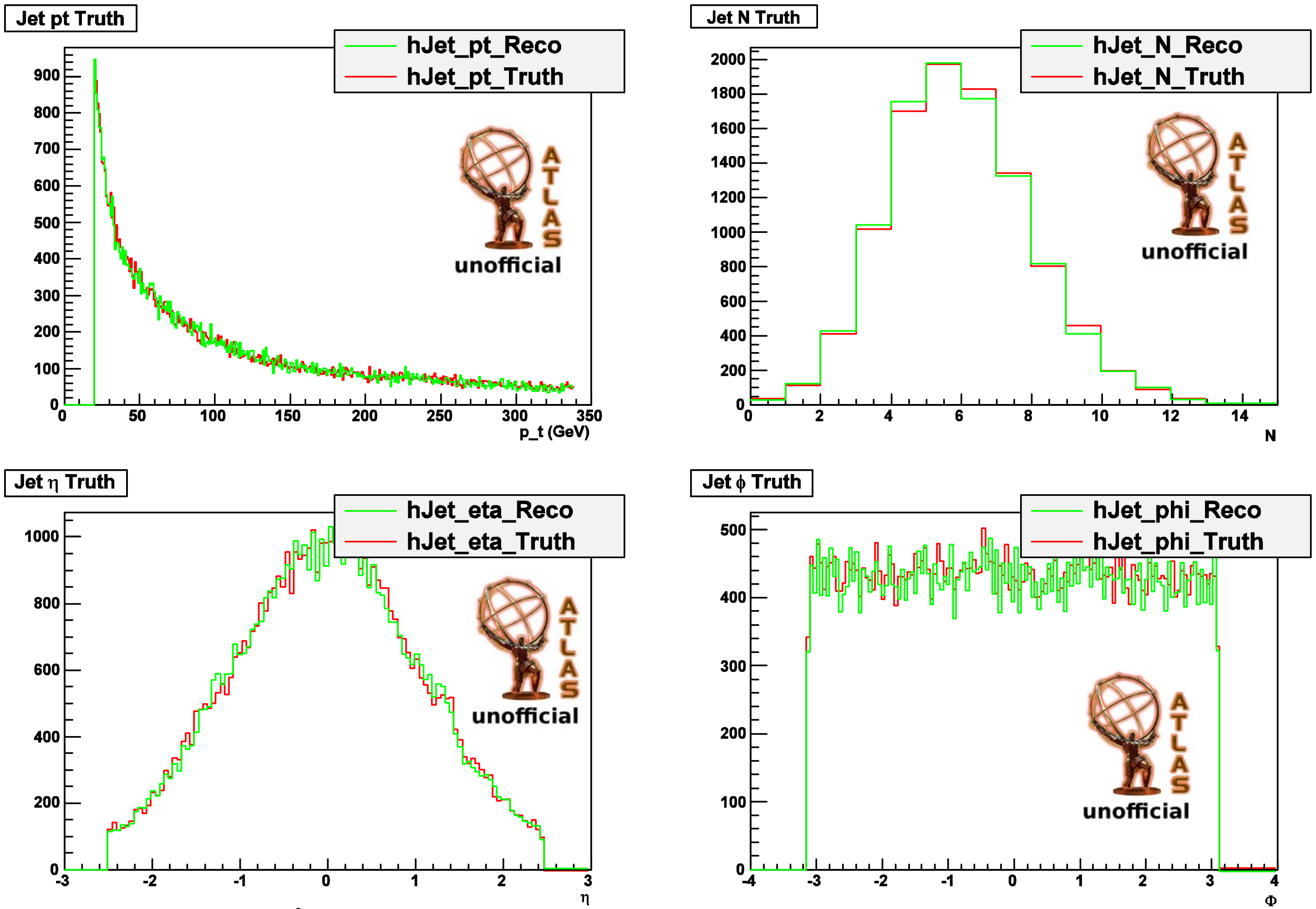
Object Selection



$\int L = 2\ fb^{-1}$ (SUSY signal), CM=10TeV

(More) cuts

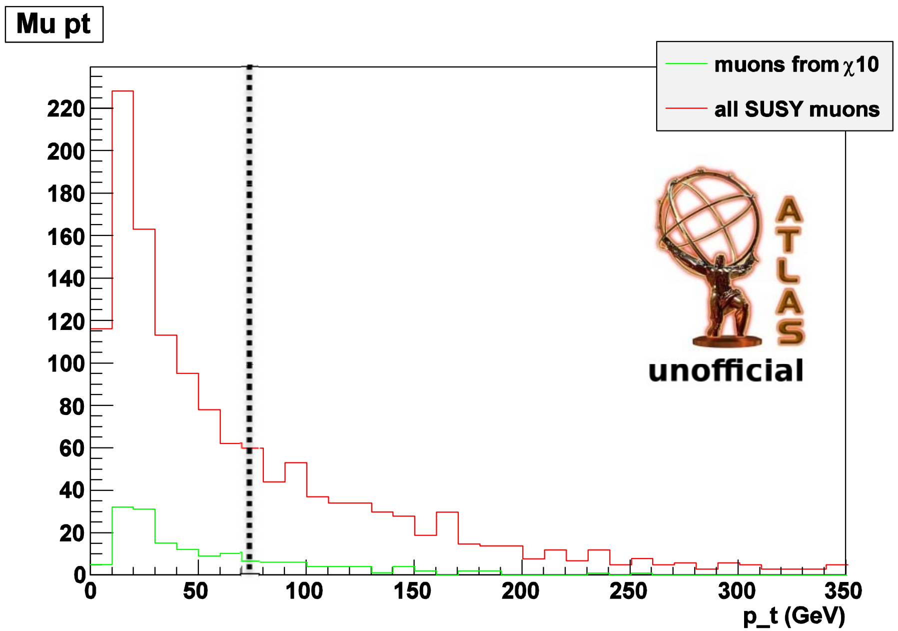
Loose cuts	Signal	ttbar
M_{eff}	46.0%	0.5%
E_T^{miss}	98.3%	92.3%
S_T	65.0%	68.4%
Top veto	96.3%	93.0%
combined	**25.3%**	**0.11%**

Medium cuts	signal	ttbar
M_{eff}	24.4%	0.2%
E_T^{miss}	97.5%	87.8%
S_T	65.0%	68.4%
Top veto	86.4%	90.1%
combined	**12.5**	**0.04**

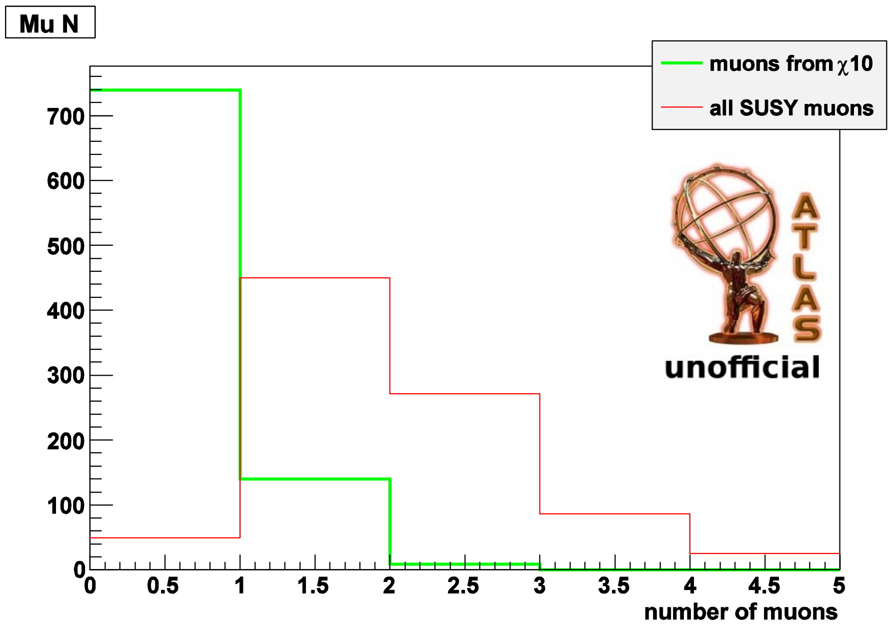
Tight cuts	signal	ttbar
M_{eff}	17.8	0.1
E_T^{miss}	96.4	82.5
S_T	65.0	68.4
Top veto	82.9	87.0
combined	**8.5%**	**0.036%**

Signal channel/ SUSY background

pt distribution of all muons and signal muons



Number of all muon/ signal muons per event



- Remaining SUSY background from SUSY decay chain
- Further cuts needed to separate χ decay products from SUSY background
- tau reconstruction has to be improved