Measuring Lepton Flavor Violation at the ATLAS experiment in the decay $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0 \, \tau^{\pm}\mu^{\mp}$

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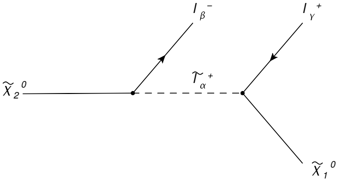
Lepton Flavor Violation at ATLAS

Is the LFV decay

$$\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0 \, \tau^{\pm}\mu^{\mp}$$

at ATLAS observable?



tasks

- parameter scan to find the highest BR in case of LFV
- simulation and reconstruction of events with LFV-mixing
- analysis to decide whether signal of LFV-decay is observable

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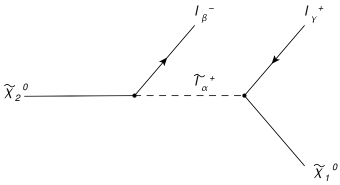

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Overview

1. parameter scan of the LFV-mixing-parameters
   - method of the parameter scan
   - results of the parameter scan
2. monte carlo simulation and analysis
   - ATLAS simulation chain
   - signal and background
   - cutflow
   - analysis of the di-lepton edge
3. summary

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model independent realisation of lepton-flavor-mixing

Lagrangian with sleptons in super-PMNS-basis

$$\mathcal{L}_{\tilde{l}}^{mass} = -\Phi_e^\dagger \mathcal{M}_{\tilde{e}}^2 \Phi_e - \Phi_\nu^\dagger \mathcal{M}_{\tilde{\nu}}^2 \Phi_\nu$$

The 6 x 6 matrix $\mathcal{M}_{\tilde{e}}^2$ is then given by

$$\mathcal{M}_{\tilde{e}}^2 = \begin{pmatrix} \hat{m}_{\tilde{L}}^2 + m_e^2 + D_{eLL} & \frac{v_1}{\sqrt{2}} \hat{T}_E^\dagger - \mu m_e tan\beta \\ \frac{v_1}{\sqrt{2}} \hat{T}_E - \mu m_e tan\beta & \hat{m}_{\tilde{E}}^2 + m_e^2 + D_{eRR} \end{pmatrix}$$

Variation of the matrix elements allows the model independent tuning of lepton-flavor-mixing in the MSSM.

[e.g. $(m_{\tilde{E}}{}^2)_{23}$ for $\tau - \mu$ -mixing]

parameters and bounds

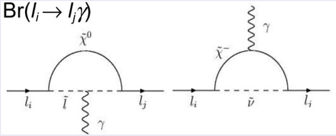
ATLAS benchmark points

name	$m_0[GeV]$	$m_{1/2}[GeV]$	$A_0[GeV]$	$tan\beta$	$sgn(\mu)$	characteristics
SU1	70	359	0	10	+	coannihilation region
SU2	3550	300	0	10	+	focus point
SU3	100	300	-300	6	+	bulk region
SU4	200	160	-400	10	+	low mass point
SU6	320	375	0	50	+	funnel region
SU8.1	210	360	0	40	+	variant of coannihilation region
SU9	300	425	20	20	+	point in bulk region

low energy bounds

decay	BR*
$\mu^- \longrightarrow e^- \gamma$	$< 1.2 \cdot 10^{-11}$ (MEGA)
$\mu^- \longrightarrow e^- e^+ e^-$	$< 1 \cdot 10^{-12}$ (SINDRUM)
$\tau^- \longrightarrow e^- \gamma$	$< 1.1 \cdot 10^{-7}$ (BaBar)
$\tau^- \longrightarrow \mu^- \gamma$	$< 6.8 \cdot 10^{-8}$ (Belle)
$\tau^- \longrightarrow \mu^- \mu^+ \mu^-$	$< 1.9 \cdot 10^{-7}$ (Belle)

* status of may 2010



parameter scan flow

Parameter scan using SPheno (W. Porod) to find the highest branching ratio within the experimental bounds:

example for $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0\ \tau^- \mu^+$

- variation of one (up to two) of the four parameters $(m^2_{\tilde{E}})_{23}$, $(m^2_{\tilde{L}})_{23}$, $(T_e)_{23}$ or $(T_e)_{32}$
- considering low energy bound $\tau^- \longrightarrow \mu^- \gamma < 6.8 \cdot 10^{-8}$
- searching for the highest BR without violating the low energy bound

overview over the results

results

- @ SU3: only small BR or no three-body-decays
- @ SU4: considerable BR

parameter	scan area	max. BR
$(m^2_{\tilde{e}})_{23}$	$0 \to 19000$	$2.0 \cdot 10^{-3}$
$(m^2_{\tilde{L}})_{23}$	$0 \to 19000$	$8.9 \cdot 10^{-5}$
$(T_e)_{23}$	$0 \to 2000$	$1.8 \cdot 10^{-5}$
$(T_e)_{32}$	$0 \to 2000$	$2.0 \cdot 10^{-5}$
$(m^2_{\tilde{e}})_{23}$ & $(m^2_{\tilde{L}})_{23}$	$0 \to 15000$ & $0 \to 15000$	$2.0 \cdot 10^{-3}$
$(m^2_{\tilde{e}})_{23}$ & $(T_e)_{23}$	$0 \to 15000$ & $-300 \to 300$	$1.9 \cdot 10^{-3}$
$(m^2_{\tilde{L}})_{23}$ & $(T_e)_{23}$	$0 \to 15000$ & $-300 \to 300$	$2.1 \cdot 10^{-2}$
$(m^2_{\tilde{L}})_{23}$ & $(T_e)_{32}$	$0 \to 15000$ & $-300 \to 300$	$4.9 \cdot 10^{-5}$
$(T_e)_{23}$ & $(T_e)_{32}$	$-500 \to 500$ & $-500 \to 500$	$3.2 \cdot 10^{-5}$

highest BR of $2.1 \cdot 10^{-2}$ for $(m^2_{\tilde{L}})_{23} = 15000\ \text{GeV}^2$ and $(T_e)_{23} = -250$ GeV

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event generation with Pythia 6.4

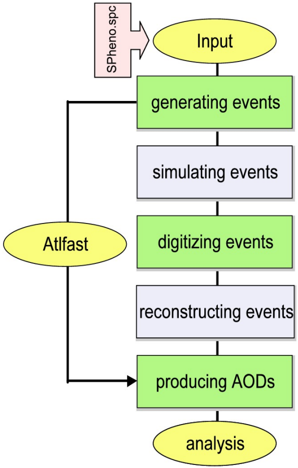
- SUSY-spectrum of SPheno as LesHouches-inputfile
- production of particle four vectors from specified processes

Atlfast II

- simulation, reconstructing and digitizing the events
- producing of Analysis Object Data (AOD)
- using Athena version 14.2.25.8 with ATLAS-GEO-02-01-00

Analysis

- combining with background
- finding appropriate cuts



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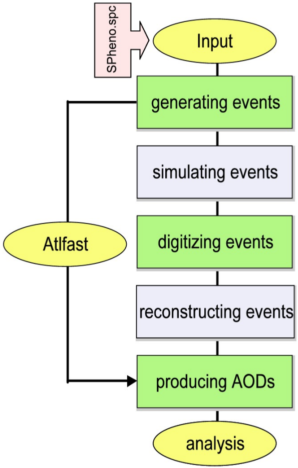

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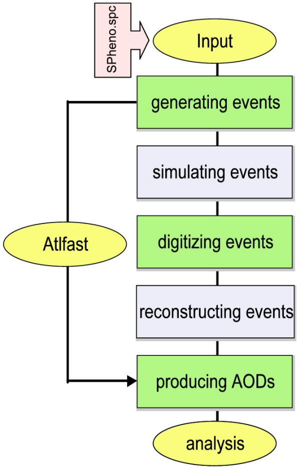


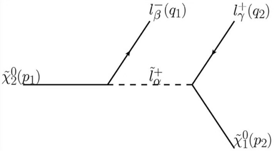
used monte carlo data samples

inclusive LFV signal

- SUSY cascade decays

$$\begin{array}{llll} pp \rightarrow & \tilde{q}_\alpha \tilde{q}_\beta \rightarrow & \tilde{q}_\alpha \rightarrow \tilde{\chi}^0_2\, q_\alpha & \tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1\, \tau^- \mu^+ \\ & \tilde{g}\,\tilde{g} \rightarrow & \tilde{g} \rightarrow \tilde{\chi}^0_2\, g & \\ & \tilde{q}_\alpha \tilde{g} \rightarrow & & \end{array}$$

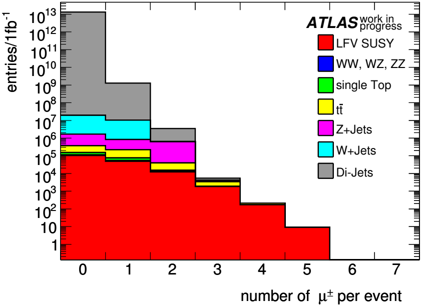
- event generation at 10 TeV
- cross section of 167.08 pb, therefore use of 170000 events (1 fb^{-1})!



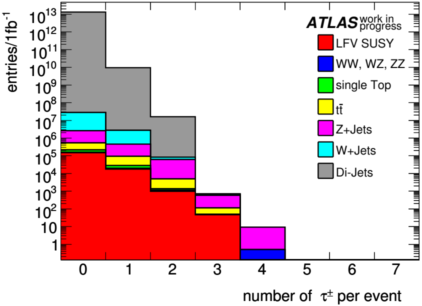
standard model background

- $t\bar{t}$, WW, WZ, ZZ, single top, Z + jets, W + jets, Di - jets

muons and taus in the final state



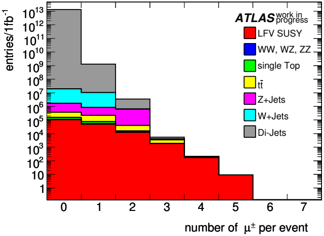
distribution of number of muons in the final state (reco)

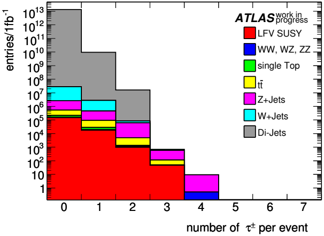


distribution of number of taus in the final state (reco)

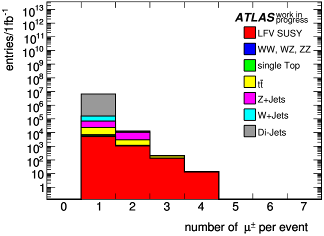
cut on at least one muon and one tau

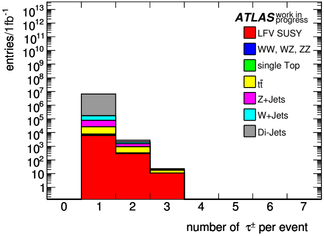
before cut on muons and taus:





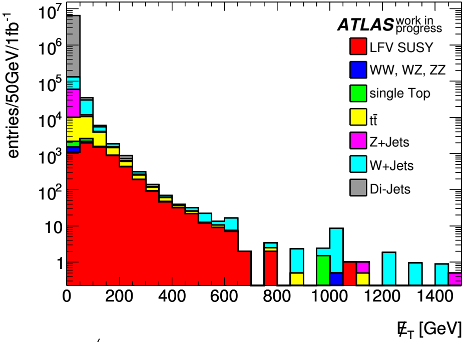
after cut on muons and taus:





cuts on $\not{E}_T$, M_{eff} and S_T

missing energy $\not{E}_T$ cut to reduce SM background



distribution of $\not{E}_T$

cut scenario I

$\not{E}_T$ (loose)	> 50 GeV
$\not{E}_T$ (medium)	> 100 GeV
$\not{E}_T$ (tight)	> 150 GeV

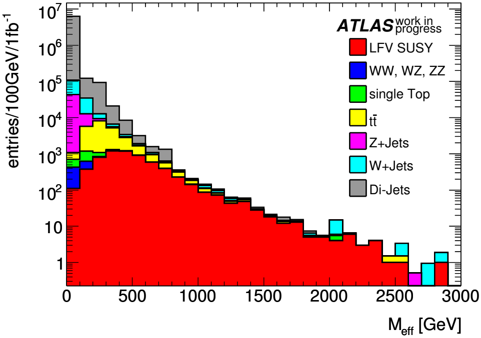
cut scenario II

$\not{E}_T$ (loose)	> 45 GeV
$\not{E}_T$ (medium)	> 50 GeV
$\not{E}_T$ (tight)	> 75 GeV

cuts on $\not{E}_T$, M_{eff} and S_T

effective mass M_{eff} as possibility to reduce background

$$M_{eff} \equiv \not{E}_T + \sum_{i=1}^{4} p_{T_i}^{jet} + \sum_{i=1} p_{T_i}^{lep}$$



distribution of M_{eff}

cut scenario I

M_{eff} (loose)	$>$ 300 GeV
M_{eff} (medium)	$>$ 400 GeV
M_{eff} (tight)	$>$ 500 GeV

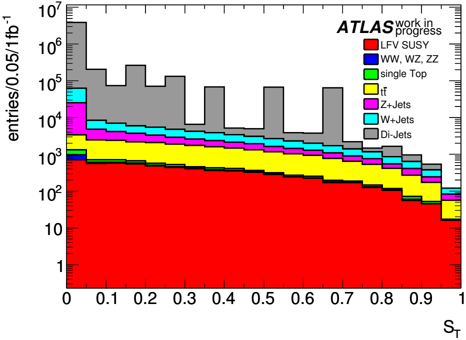
cut scenario II

M_{eff} (loose)	$>$ 300 GeV
M_{eff} (medium)	$>$ 350 GeV
M_{eff} (tight)	$>$ 400 GeV

cuts on $\not{E}_T$, M_{eff} and S_T

transverse sphericity S_T as useful cut to reduce QCD background

$$S_T \equiv \frac{2\lambda_2}{\lambda_1+\lambda_2}$$ with $\lambda_{1/2}$ being eigenvalues of sphericity tensor S_{ij}



distribution of S_T

cut scenario I	
S_T (loose)	> 0.02
S_T (medium)	> 0.05
S_T (tight)	> 0.10

cut scenario II	
S_T (loose)	> 0.01
S_T (medium)	> 0.02
S_T (tight)	> 0.035

cuts on $\not{E}_T$, M_{eff} and S_T

testing all combinations of loose, medium and tight cuts for the three parameters $\not{E}_T$, M_{eff} and S_T

overview over the best results of all tested cut scenarios

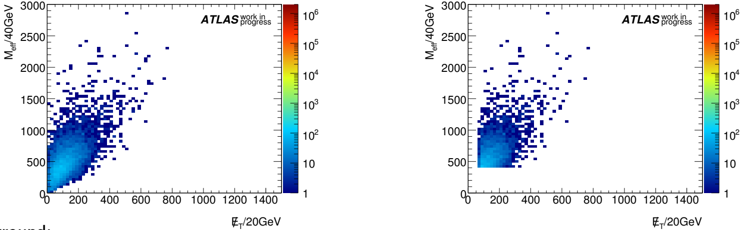
S_T	M_{eff}	$\not{E}_T$	S	B	S/B	$S/\sqrt{B}$
loose	medium	tight	3426	3192	1.07	60.64
loose	tight	loose	3464	3899	0.89	55.48
loose	tight	medium	3396	3108	1.09	60.91
loose	tight	tight	3039	2259	1.35	63.94
medium	tight	tight	2964	2166	1.37	63.68

$\longrightarrow$ highest significance for the cut scenario
$\not{E}_T > 75$ GeV & $M_{eff} > 400$ GeV & $S_T > 0.01$

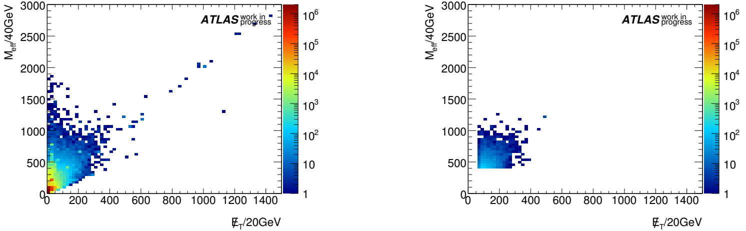
cuts on $\not{E}_T$, M_{eff} and S_T

$\not{E}_T$-M_{eff}-plane for cuts $\not{E}_T > 75$ GeV & $M_{eff} > 400$ GeV & $S_T > 0.01$

LFV signal:

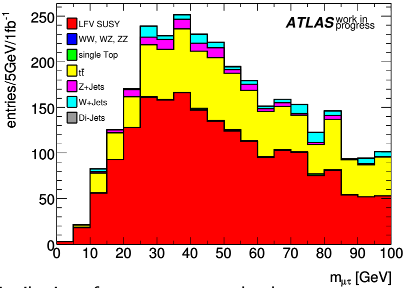


background:

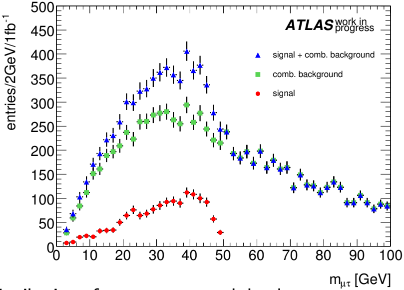


distribution of invariant mass $m_{\mu\tau}$

due to the kinematics of the three body decay an di-lepton edge is expected at $m_{ll}^{edge} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} = (109 - 59)$ GeV $= 50$ GeV:



distribution of $m_{\mu^\pm\tau^\mp}$ at reco level

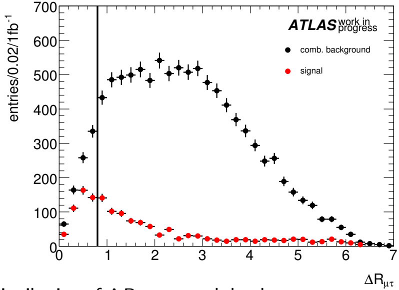


distribution of $m_{\mu^\pm\tau^\mp}$ at truth level

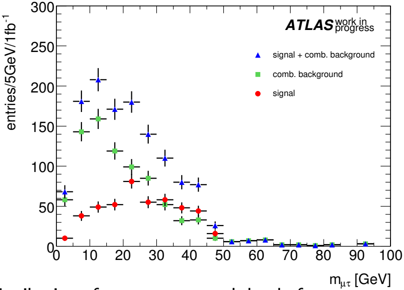
cut on opening angle $\Delta R_{\mu\tau}$

idea:

- particles of the same vertex have smaller opening angles because they are boosted
- particles of the combinatoric background are uniformly distributed

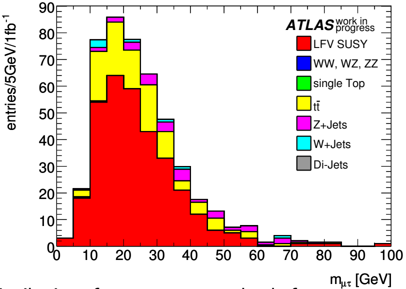


distribution of $\Delta R_{\mu\tau}$ at truth level



distribution of $m_{\mu^\pm\tau^\mp}$ at truth level after cut on $\Delta R_{\mu\tau} = 0.8$

results after cut on opening angle $\Delta R_{\mu\tau} = 0.8$



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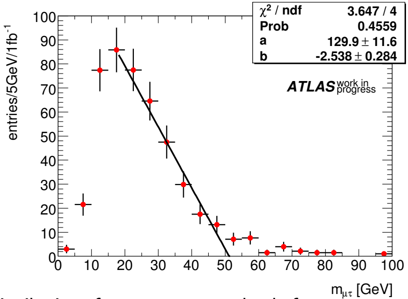


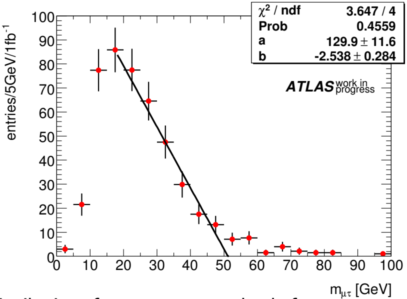
distribution of $m_{\mu^\pm\tau^\mp}$ at reco level after cut on $\Delta R_{\mu\tau} = 0.8$

- di-lepton edge is reconstructed with mass $m^{edge}_{\mu^\pm\tau^\mp} = (51.2 \pm 7.3)$ GeV
- in good agreement with $m^{edge}_{\mu^\pm\tau^\mp} = 50$ GeV

result

LFV decay $\tilde{\chi}^0_2 \longrightarrow \tilde{\chi}^0_1\ \tau^\pm\mu^\mp$ is observable at 1 fb^{-1} at ATLAS!

results after cut on opening angle $\Delta R_{\mu\tau} = 0.8$



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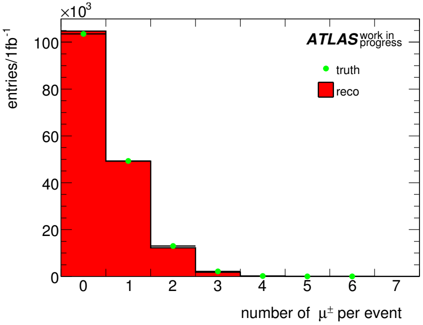
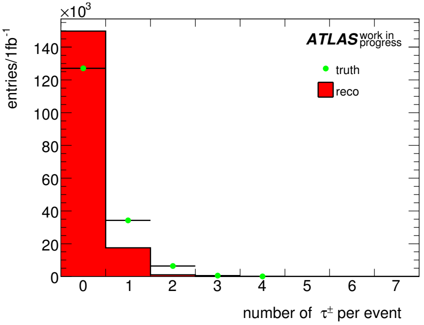
summary

- studied LFV decay $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0\, \tau^\pm \mu^\mp$ at 1 fb^{-1} for ATLAS
- mSUGRA parameter scan with SPheno by varying different matrix elements to get highest BR for LFV decay $(2.1 \cdot 10^{-2})$
- monte carlo event generation with Pythia and ATLAS detector simulation with ATLFAST II
- cut optimization to get a good significance $(S/\sqrt{B} = 63.94)$
- analysis of invariant mass distribution and di-lepton edge $(m^{edge}_{\mu^\pm\tau^\mp} = (51.2 \pm 7.3)\ GeV)$

LFV decay $\tilde{\chi}_2^0 \longrightarrow \tilde{\chi}_1^0\, \tau^- \mu^+$ is observable at 1 fb^{-1} at ATLAS

reconstruction efficiency - number of μ / τ in the final state





reconstruction efficiency - p_T distribution