Multilepton signatures of natural supersymmetry in ATLAS

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Introduction - Supersymmetry

Idea: Assign each particle in the standard model a supersymmetric partner with different spin by 1/2.

- SUSY can provide a solution to the Hierarchy Problem
- No Superpartners observed so far - if it exists, SUSY must be a broken symmetry
- SUSY breaking introduces new parameters - rich parameter space

→ Minimal Supersymmetric Standard Model (MSSM)

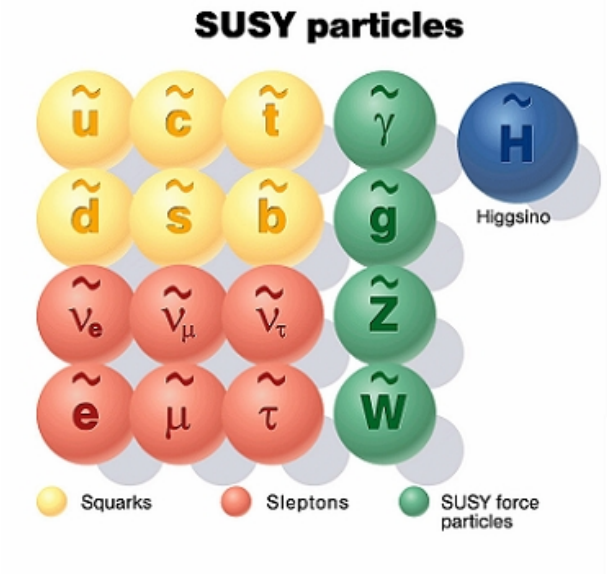

Figure: Illustration by DESY at Hamburg.

p(henomenological)MSSM

- The MSSM has 105 free parameters $\rightarrow$ too large to study in complete generality.
- Reduction of the parameters with experimentally motivated constraints.

$\rightarrow$ 19 or 20 parameter for the pMSSM:

10 sfermion masses	$m_{\tilde{L}1,2}$	$m_{\tilde{e}1,2}$	m_{L3}	$m_{\tilde{e}3}$	$m_{\tilde{Q}1,2}$
	$m_{\tilde{u}1,2}$	$m_{\tilde{d}1,2}$	$m_{\tilde{Q}3}$	$m_{\tilde{u}3}$	$m_{\tilde{d}3}$
3 gaugino masses	M_1	M_2	M_3		
3 Higgs/Higgsino	$tan\beta$	μ	M_A		
3 tri-linear couplings	A_t	A_b	A_τ		
Gravitino	$(m_{3/2})$				

Analysis of pMSSM models

- Cahill-Rowley, Hewett, Ismail, Rizzo (arXiv:1307.8444): pMSSM Studies at the 7, 8 and 14 TeV LHC.
- Random choice of parameters $\rightarrow$ many millions of models (SOFTSUSY).
- Reduction of the models on the basis of the following constraints:
  - Collider (pre-LHC)
  - Flavor
  - Precision measurement
  - Dark matter
  - Theoretical constraints
- Selection of a set of models with low fine tuning & neutralino LSP.
  - Prediction of a Higgs mass of 126 ± 3 GeV.
  - LSP saturates the WMAP relic density.
  - Better than 1% fine tuning (low-FT).
- Further study of these models ($\sim 10,000$).

$m_{\tilde{L}(e)1,2,3}$	100 GeV - 4 TeV
$m_{\tilde{Q}(q)1,2}$	400 GeV - 4 TeV
$m_{\tilde{Q}(q)3}$	200 GeV - 4 TeV
$\lvert M_1 \rvert$	50 GeV - 4 TeV
$\lvert M_2 \rvert$	100 GeV - 4 TeV

$\lvert \mu \rvert$	100 GeV - 4 TeV
M_3	400 GeV - 4 TeV
$\lvert A_{t,b,\tau} \rvert$	0 GeV - 4 TeV
M_A	100 GeV - 4 TeV
$tan\beta$	1 - 60
$m_{3/2}$	1 eV - 1 TeV ($\tilde{G}$ LSP)

arXiv:1307.8444

Analysis of pMSSM models

- Authors tested these models on published ATLAS results.
- Exclusion of the models:

Search	LSP Neutralino	LSP Gravitino	Low-FT
2-6 jets	26.7%	21.6%	44.9%
multijets	3.3%	3.8%	20.9%
1-lepton	3.3%	6.0%	20.9%
SS dileptons	4.9%	12.4%	35.5%
Medium Stop (2l)	0.6%	8.1%	4.9%
Medium/Heavy Stop (1l)	3.8%	4.5%	21.0%
Direct Sbottom (2b)	6.2%	5.1%	12.1%
3rd Generation Squarks (3b)	10.8%	9.9%	40.8%
3rd Generation Squarks (3l)	1.9%	9.2%	26.5%
3 leptons	1.4%	8.8%	32.3%
4 leptons	3.0%	13.2%	46.9%
Z + jets + MET	0.3%	1.4%	6.8%

ATLAS-CONF-2012-153

arXiv:1307.8444

→ Surprisingly high exclusion with four leptons analysis.

Analysis of models with multilepton final states

Analysis details

- Goal: understand the high exclusion of the four leptons analysis.
- Generation of 4771 excluded models with Herwig++.
- Analysis of the models:
  - Kinematic cuts applied on generated leptons and jets.
  - Without detector simulation.
  - Each model generated with at least 50,000 events.

Overview of the 4 leptons analysis

- ATLAS-CONF-2013-036: Search for supersymmetry in events with four or more leptons in 21 fb^{-1} of pp collisions at $\sqrt{s} = 8$TeV with the ATLAS detector
- arXiv:1405.5086v1: Search for supersymmetry in events with four or more leptons in $\sqrt{s} = 8$TeV pp collisions with the ATLAS detector
- Explanation of the different signal regions:

SR	$N(\ell + e, \mu)$	$N(\tau)$	Z Candidate	E_T^{miss}[GeV]		m_{eff}[GeV]
SR0noZa	≥ 4	≥ 0	extended veto	> 50		-
SR0noZb	≥ 4	≥ 0	extended veto	> 75	or	> 600
SR1noZa	$= 3$	≥ 1	extended veto	> 50		-
SR1noZb	$= 3$	≥ 1	extended veto	> 100	or	> 400
SR2noZa	$= 2$	≥ 2	extended veto	> 75		-
SR2noZb	$= 2$	≥ 2	extended veto	> 100	or	600
SR0Z	≥ 4	≥ 0	request	> 75		-
SR1Z	$= 3$	≥ 1	request	> 100		-
SR2Z	$= 2$	≥ 2	request	> 75		-

arXiv:1405.5086v1

- Z veto or request.
- Background exclusion: require E_T^{miss} or m_{eff}.

Analysis of the models

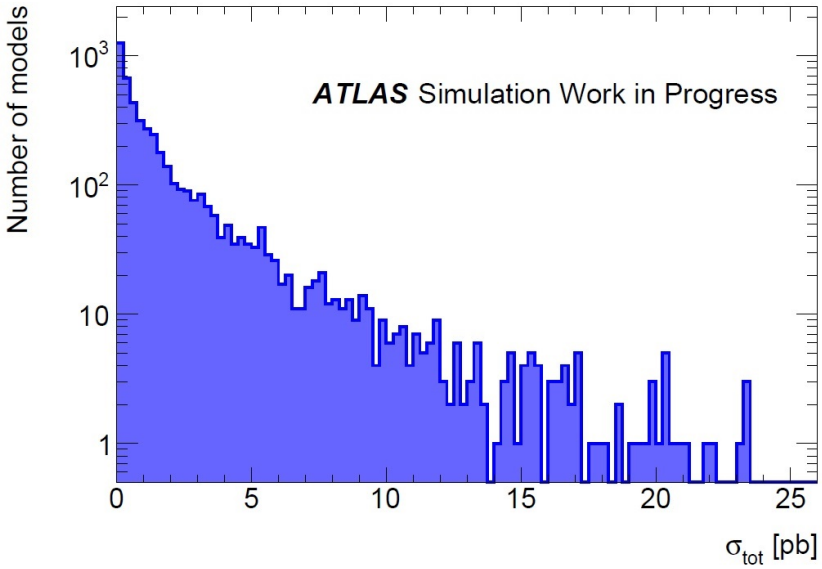

Figure: Total cross-section.

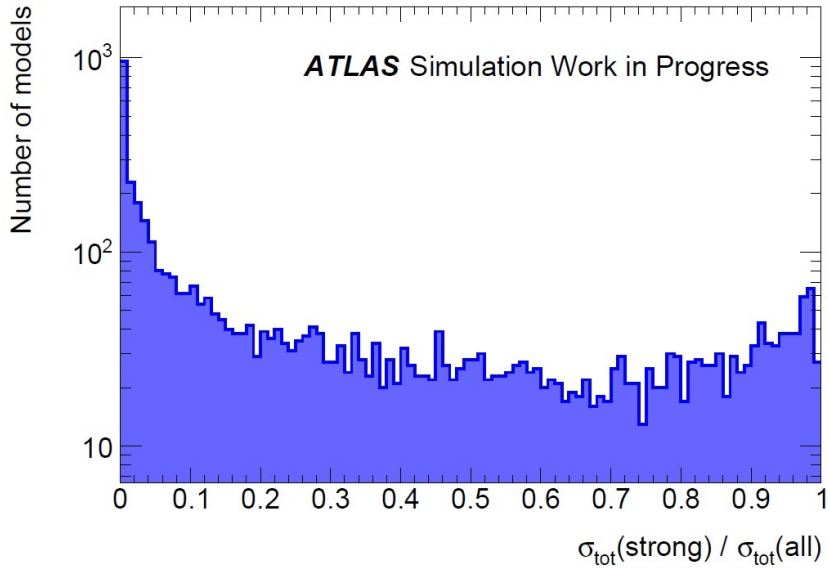

Figure: Strong production fraction.

- NLO + NLL cross-section used for strong production.
- Majority of models dominated by weak production.
- Next: calculate acceptance using analysis cuts.

Analysis of the models

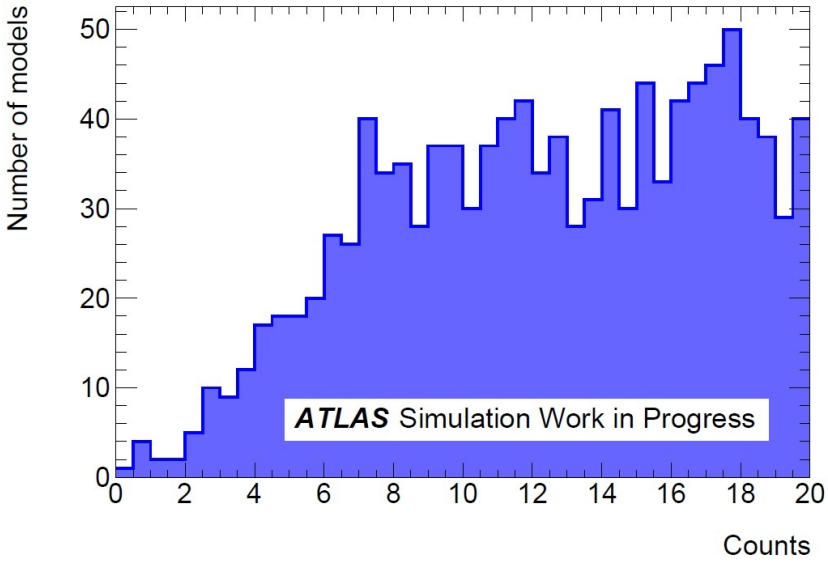

Figure: Yield in 20.3 fb^{-1} for events with four or more leptons (incl. taus).

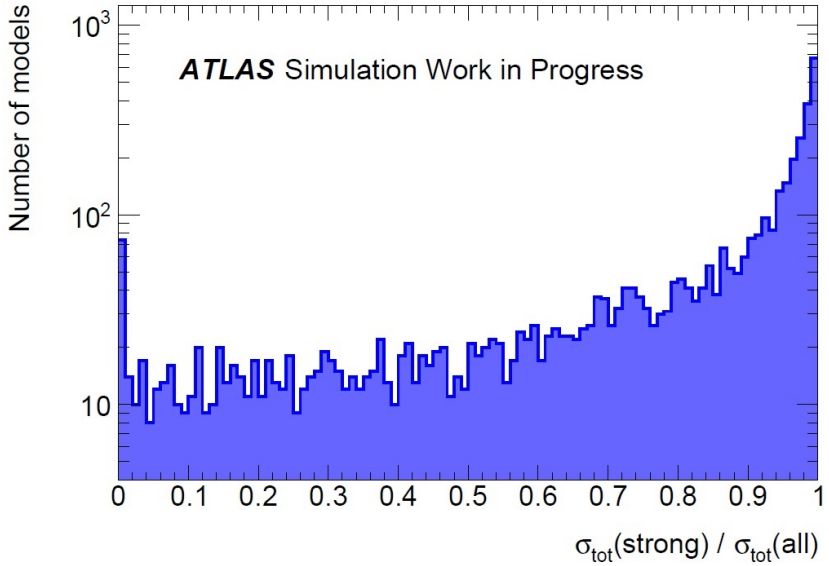

Figure: Strong production fraction for events with four or more leptons (incl. taus).

- Loss of $\sim$ 1% of the models due to insufficient Monte Carlo statistics.
- Mostly strong production for events with four leptons in acceptance.

Analysis of the models

Investigated SUSY production modes for a typical model with large shift in strong production fraction when requiring four or more leptons.

- Higgsino like chargino / neutralino production dominates, but has low multi-lepton branching fraction.
- Slepton + sneutrino production does not produce a four leptons signature.
- Gluino decays produce top quarks and charginos / neutralinos $\rightarrow$ more multi-lepton events.
- Further studies in progress.

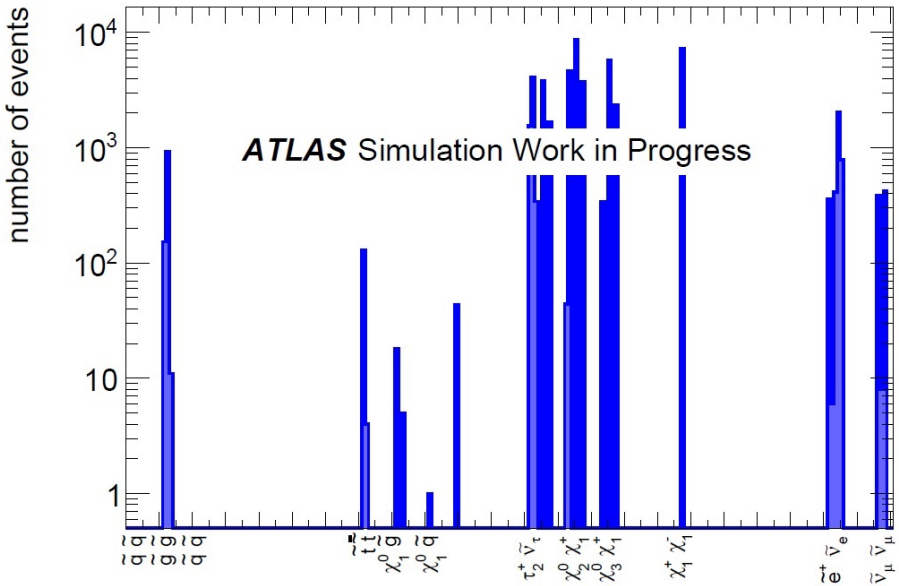

Figure: Processes for model number 9029.

Exclusion of the models

- $\sim$ 99.9% of models have more than 5 MC events with four or more leptons.
- $\sim$98% of models have more than 5 MC events in at least one SR.

$\rightarrow$ Other 2% not considered further, more events needed.

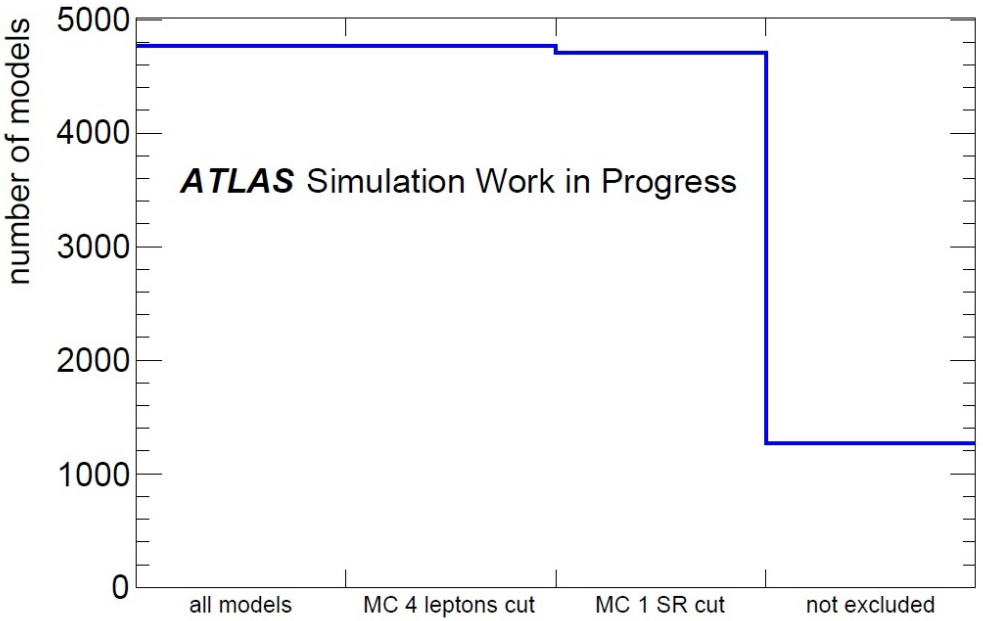

Figure: Exclusion of the models.

$\rightarrow$ Over 70% of the analysed models could be excluded by a single signal region alone.

Exclusion of the models

excl. only by SR	Number of excl. models		$N(\ell + e, \mu)$	$N(\tau)$	Z Candidate
	Total	Unique			
SR0noZa/b	2771	231	≥ 4	≥ 0	extended veto
SR1noZa/b	2968	350	$= 3$	≥ 1	extended veto
SR2noZa/b	1267	1	$= 2$	≥ 2	extended veto
SR0Z	1655	137	≥ 4	≥ 0	request
SR1Z	698	4	$= 3$	≥ 1	request
SR2Z	238	7	$= 2$	≥ 2	request

- Significant contributions from multiple signal regions, including those with taus.
- Caution: No detector effects included!

Conclusions & Outlook

- The sensitivity of the ATLAS four leptons SUSY search to pMSSM models with low fine-tuning has been studied.
- Events with four leptons in acceptance arise predominantly from squark and gluino production (strong interaction).
- Of the models claimed to be excluded, we confirm about 70 %. There are some caveats:
  - No attempt yet to describe detector efficiency.
  - No consideration of models that were not excluded in the paper with four leptons analysis.
- Nevertheless, the four leptons signature appears powerful in these models with low fine-tuning.
- Next steps:
  - Extension to complete model set.
  - Inclusion of detector efficiency estimates.
  - Further study of signatures, which SRs perform best, etc.
  - Reoptimisation for low-FT pMSSM signatures.

Thank you for your attention!