Strategies for leptonic SUSY-searches in and beyond mSUGRA

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Outline

- Supersymmetry (SUSY)
- Phenomenology in the MSSM
- Basic Analysis Concepts
- Summary / Outlook

Supersymmetry (SUSY)

- New **symmetry** between **Fermions** and **Bosons:**
- Has a **stable** and **only weak interacting** lightest particle every SUSY-particle-decay ends with in a large region of parameter-space: **LSP** (**L**ightest **S**upersymmetric **P**article)

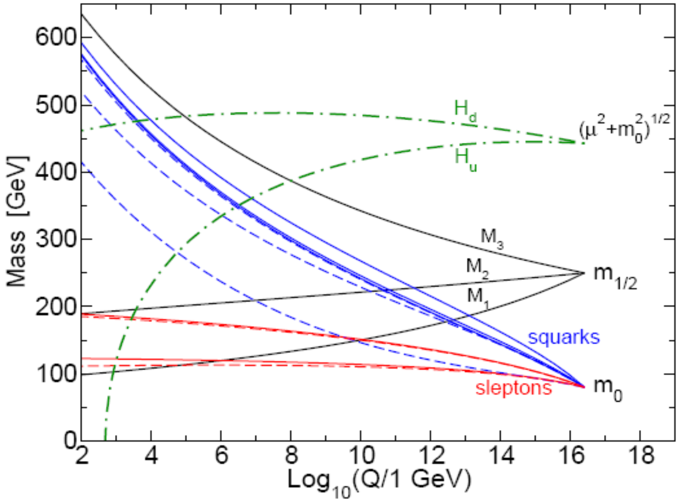
- Following tabular shows the particle-content of the "**M**inimal **S**upersymmetric **S**tandard **M**odel" (**MSSM**)

R–Parität = +1			R–Parität = −1			R–Parität = −1		
Teilchen	Symbol	Spin	Teilchen	Symbol	Spin	Teilchen	Symbol	Spin
Lepton	ℓ	$\frac{1}{2}$	Slepton	$\tilde{\ell}_L, \tilde{\ell}_R$	0			
Neutrino	ν	$\frac{1}{2}$	Sneutrino	$\tilde{\nu}$	0			
Quark	q	$\frac{1}{2}$	Squark	$\tilde{q}_L, \tilde{q}_R$	0			
Gluon	g	1	Gluino	$\tilde{g}$	$\frac{1}{2}$			
Photon	γ	1	Photino	$\tilde{\gamma}$	$\frac{1}{2}$			
Z–Boson	Z	1	Zino	$\tilde{Z}$	$\frac{1}{2}$			
W–Boson	$W^\pm$	1	Wino	$\tilde{W}^\pm$	$\frac{1}{2}$	Neutralino	$\tilde{\chi}_i^0$	$\frac{1}{2}$
Higgs	$H^0, H^\pm$	0	Higgsino	$\tilde{H}_1^0, \tilde{H}_2^+$	$\frac{1}{2}$	Chargino	$\tilde{\chi}_i^\pm$	$\frac{1}{2}$
	h^0, A^0	0		$\tilde{H}_1^-, \tilde{H}_2^0$	$\frac{1}{2}$			

$\tilde{\chi}_1^0$ is often the LSP!

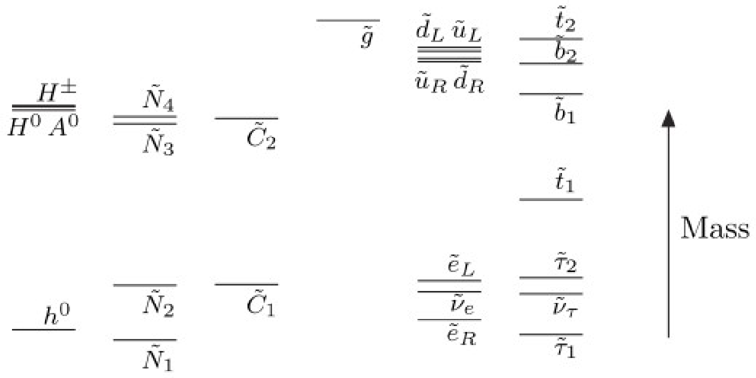
- Even the **constraint MSSM** has **plenty of free parameters** determing the mass-spectra.
- In principle 2 extreme search-strategies possible:

1.) Look for **strongly constrained** SUSY-modells (eg. **mSUGRA)**



Pro:
- Gives **exact predictions** what to search for

→ **Easy to design!**



Contra:
- Covers small area of SUSY-parameter-space

→ **Most likely not realized by nature!**

2.) Try to cover a **larger area in parameter-space** with a **less modeldependent** analysis using common information among the different models / regions in parameter-space

Pro:

- Increases the probability to find new signals, because of the larger coverage in parameter-space

Contra:

- Harder to design
- More difficult to handle statistics properly because of multiple comparisons

❖ At LHC, production of Squarks and Gluinos dominates. These decay often via charginos and neutralinos into the LSP and SM-particles.
→ Study the impact of **different mass-spectra** on the kinematics

Which Mass-Pattern occur in the MSSM?

- To get a feeling for the many possible mass-spectra in the MSSM **scan the free parameters** and **calculate the mass-spectrum** for each combination of paramters. („**SUSY without prejudice**" arXiv:0812.0980v3 [hep-ph])

- Restrict the Scan to the so called **phenomenological MSSM** (**pMSSM**) containing **19 free parameters.**

- **The pMSSM contains following constrains:**

1.) CP-Conservation (i.e. no new phases)
2.) Minimal flavor violation
3.) First two generations of fermions are degenerate

Which Mass-Pattern occur in the MSSM?

- Further introduce the additional **constrains** to scan only ranges leading to **phenomenologically viable models:**

1.) The **Neutralino1** is the LSP

2.) Stay above the **LEP and Tevatron-limits** given by the direct search for supersymmetric particles.

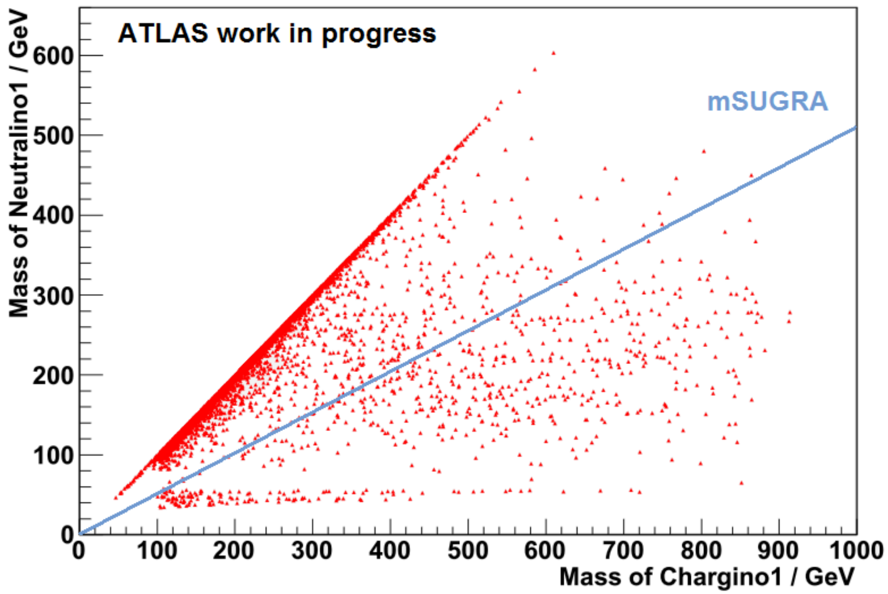
3.) Respect indirect measurements for new physics like $\mathbf{b \rightarrow s\gamma}$ or $\mathbf{(g-2)_\mu}$

4.) Respect **WMAP** – measurements to avoid that the relic density of LSPs overcloses the universe.

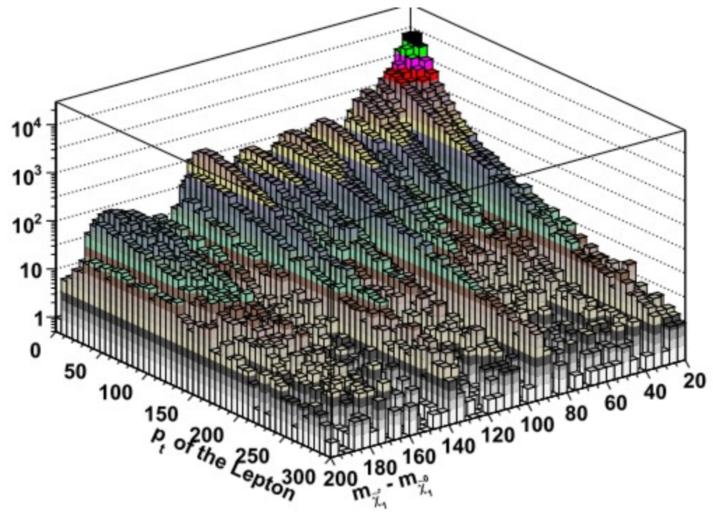
5.) …

Which Mass-Pattern occur in the MSSM?

- mSUGRA predicts:
  $M_1 : M_2 : M_3 = 1:2:6$
  $\rightarrow m_{LSP} : m_{C1} : m_{Gluino} = 1:2:6$
- Many different mass-spectra and topologies in the pMSSM.
  → Analyses optimized for mSUGRA not ideal !



- Mass-difference of C1 and N1 has strong influence on **Lepton-P_T**
- Many Models with strongly degenrate C1 and N1
  → **low-P_T Leptons**



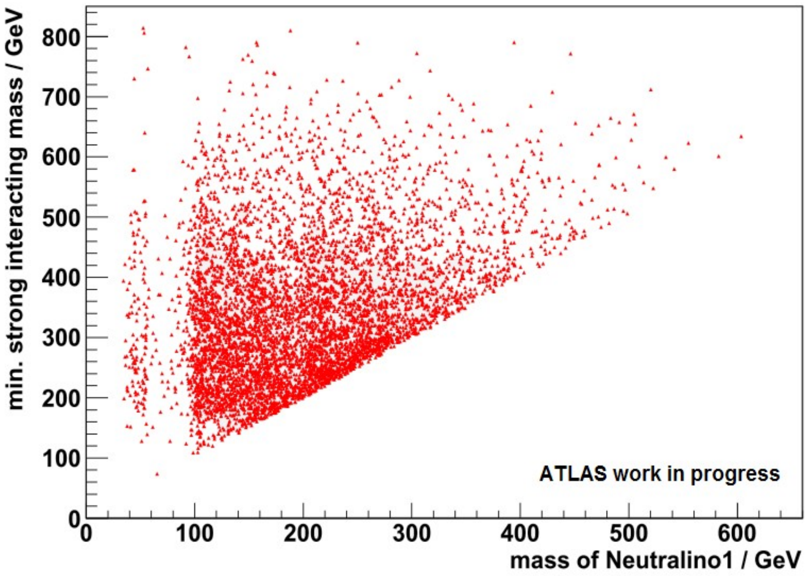
Which Mass-Pattern occur in the MSSM?

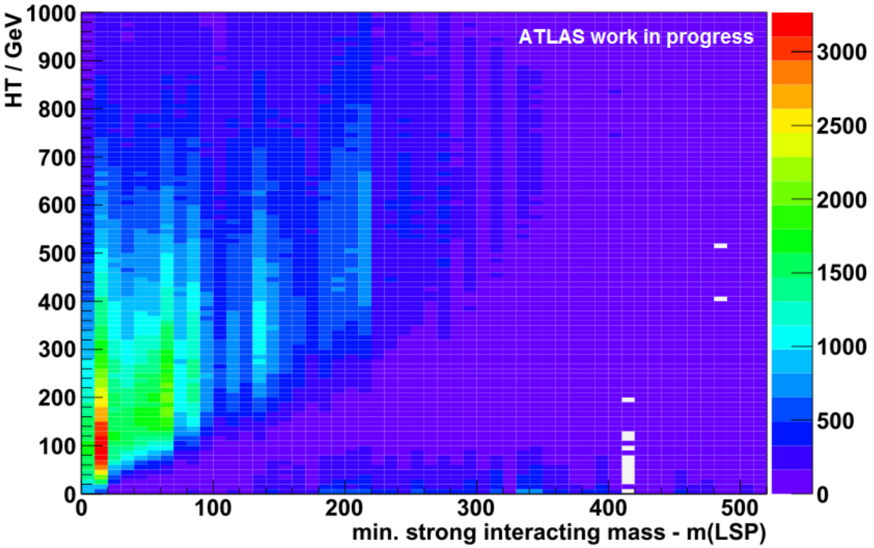
- Jet-P_T strongly correlated with the Mass-difference between the produced Squarks/Gluinos and the LSP

→ **Strong degeneration** will lead to **soft decay-products.**

- True H_T grows with growing mass-difference between the initially produced SUSY-particles and the LSP

(True H_T = scalar sum of truth-jet transverse momenta)





Simulated Datasets

❖ **mSUGRA**

- 8 x 8 Gridpoints ($\tan\beta = 10$, $A_0 = 0$, sign(μ) positive)
- m_0 = (60, 140, 220, … , 620) GeV
- $m_{1/2}$ = (150, 170, 190, … , 290) GeV

→ **Squark-** and **Gluino-masses** between **~350 GeV** and **~850 GeV**

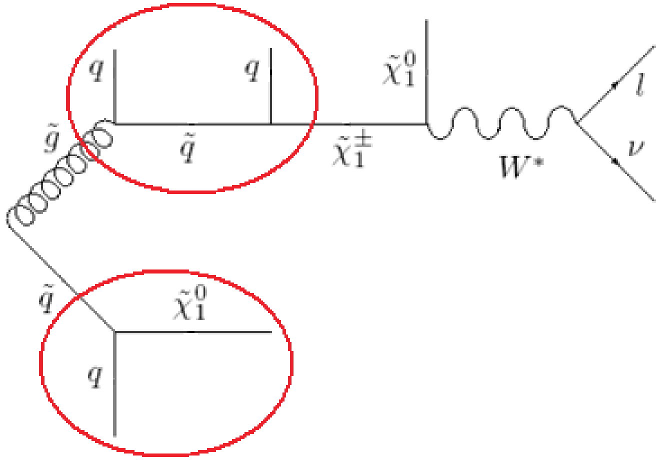
❖ **pMSSM**

- Pick mSUGRA-reference-points and change LSP/Gluino-mass-ratio and LSP/Chargino1-mass-ratio conserving the order:
  m(Gluino) > m(C_1) > m(N_1) for fixed m(C1).
- Grid with **3x7 points:**
  - m(C1) / m(N1) ≈ (1, **2**, 10)
  - m(gluino) / m(C1) ≈ (2, **3**, 4, 5, 7.5, 10, 12.5)
- Keep Field-Content untouched.

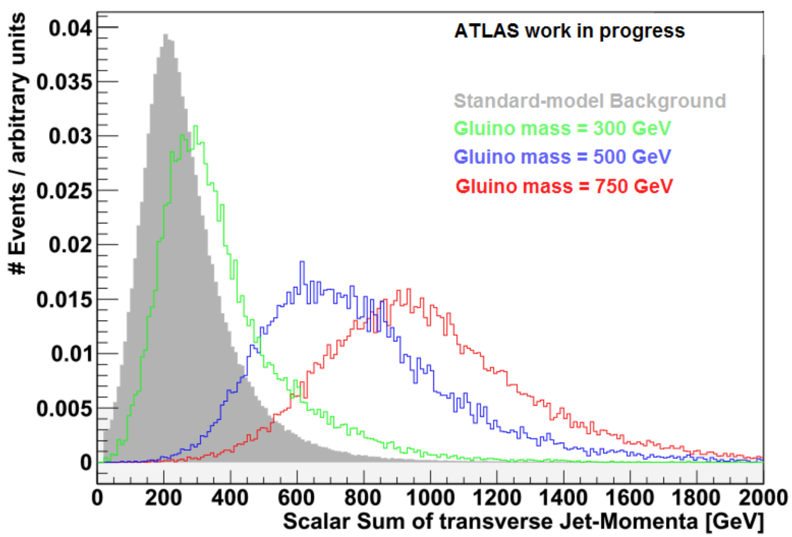
Impacts of different mass-spectra on the kinematics

- Which kinematic variables, used to select SUSY-like events are influenced by changing the SUSY-mass-spectrum?

1.) **Momenta of Jets** and related variables



- Strongly depend on the **mass** of the decaying **Squarks** and **Gluinos**
  → The **heavier** the Squarks and Gluinos, the **harder** the **Jets!**



→ **Heavier Squarks / Gluinos allow for a tighter selection of the jet-related phasespace.**

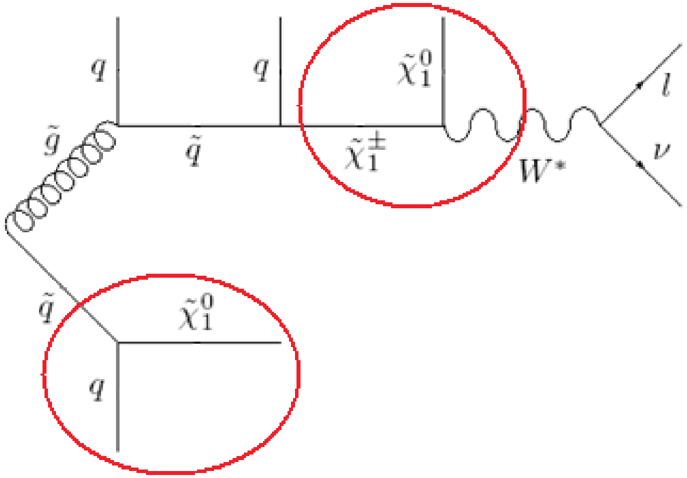
Impacts of different mass-spectra on the kinematics

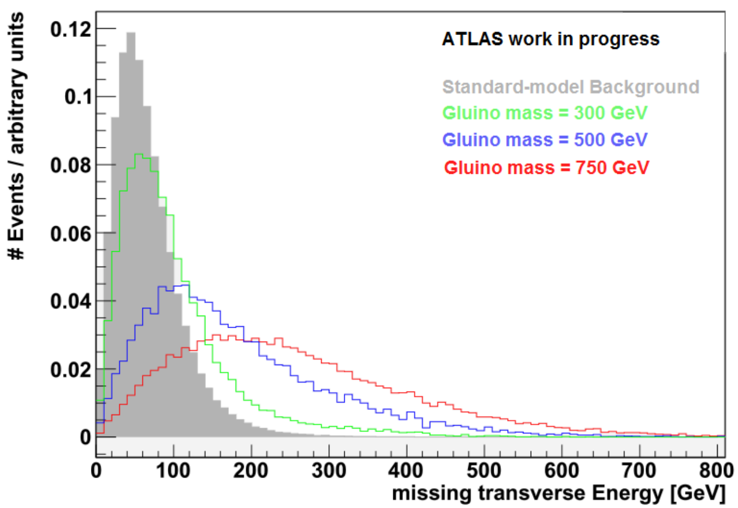
2.) Amount of **missing energy**

- Also strongly depend on the **mass** of the decaying **Squarks** and **Gluinos**
  → The **heavier** the Squarks and Gluinos, the **harder the LSPs**
  → **more missing Energy!**

- In addition dependency on the **mass of Chargino1** and the **LSP** itself

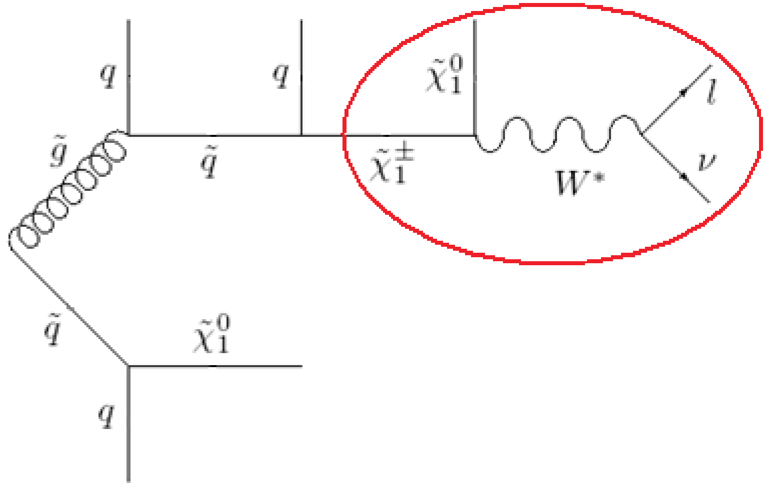
→ **heavier Squarks/Gluinos allow for a tighter selection of related phase-space**



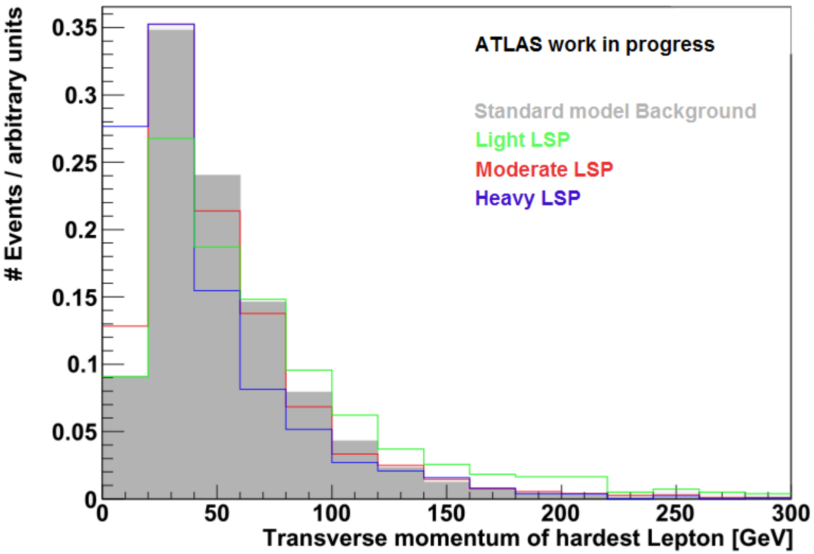


Impacts of different mass-spectra on the kinematics

3.) Momenta of the Leptons



- Strong dependecy on the mass of **Chargino 1** and **LSP itself.**
  → Mass Difference determines whether W is virtual / real
  → Determines **momentum of Lepton**



→ **Large Mass-Differences between Chargino1 and LSP allow for tighter Lepton-momentum-selection**

Event-Kinematics strongly determined by:

1) Mass of the initially produced SUSY-Particles (i.e. Squarks and Gluinos)

- Cross-section depends strongly on Gluino- and Squark -masses.
- Define variable $<m^{Strong}_{SUSY}>$ to take this into account.

$$< m^{Strong}_{SUSY} >= \frac{\sigma^{part}_{\tilde{g}\tilde{g}}}{\sigma^{tot}} 2m_{\tilde{g}} + \frac{\sigma^{part}_{\tilde{g}\tilde{q}}}{\sigma^{tot}} (m_{\tilde{g}} + m_{\tilde{q}}) + \frac{\sigma^{part}_{\tilde{q}\tilde{q}}}{\sigma^{tot}} 2m_{\tilde{q}} + \frac{\sigma^{part}_{\tilde{t}_1\tilde{t}_1}}{\sigma^{tot}} 2m_{\tilde{t}_1}$$

- $<m^{Strong}_{SUSY}>$ is a measure for the mean, strongly produced mass for a given Squark- and Gluino-mass.

2) Mass-Differences of the decaying SUSY-Particles.

- Masses of the particles in the cascade determine how much of the initial energy (Mass of Squarks and Gluinos) is available for the boost of the decay-products

Analysis Concept:

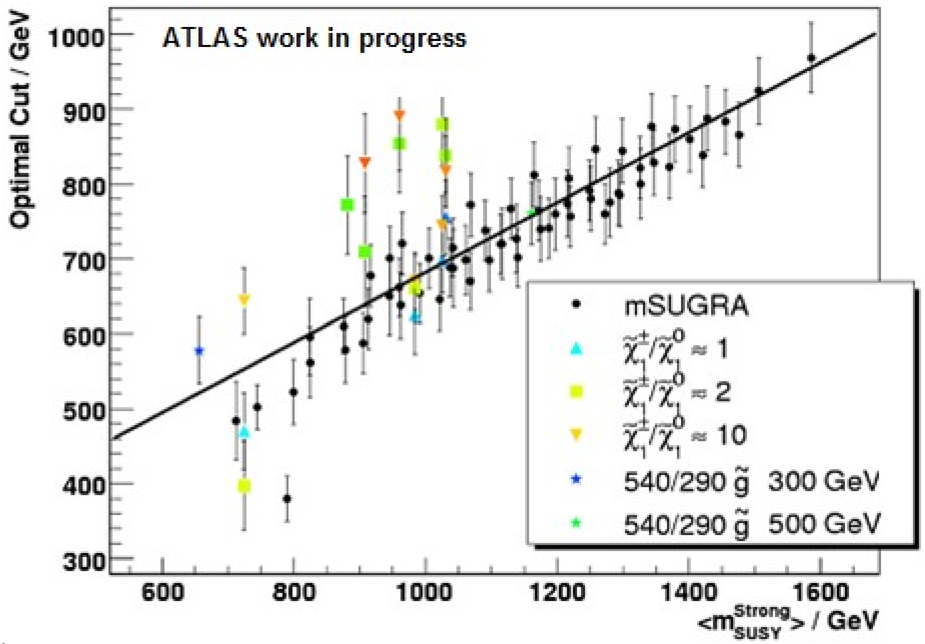
- Instead of using **fixed cuts** for a SUSY-search, **parametrize Cut values by mass-parameters**, that describe the change in the kinematics shown on the previous slides.

Dependencies of the optimal cutvalue for several kinematic distributions on <m> in the mSUGRA-model

- **Functional dependencies** observable:

- Optimal cut on **H_T increases linear with $<m^{Strong}_{SUSY}>$.**

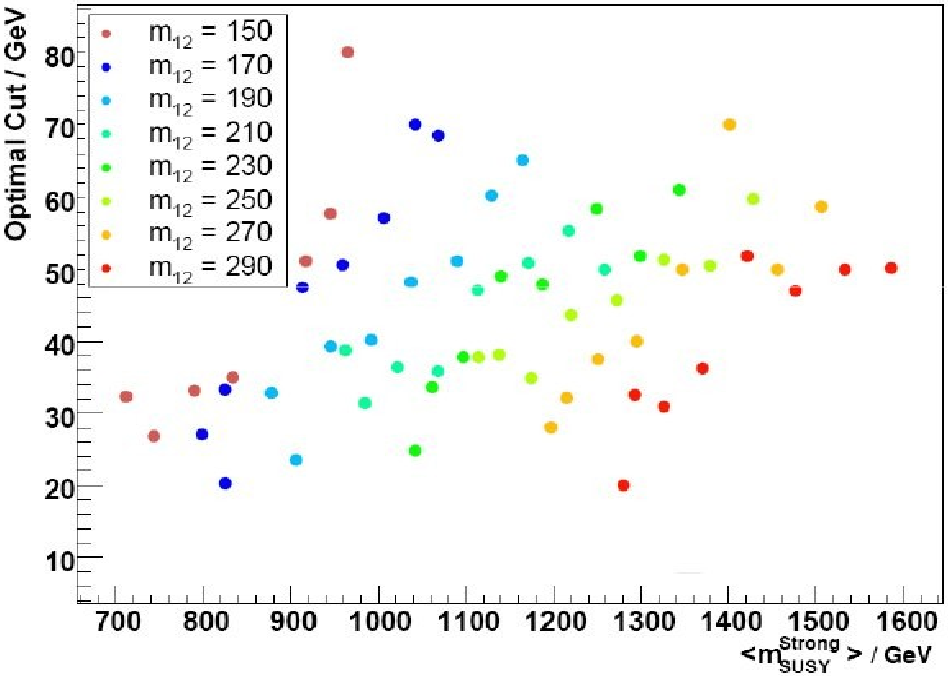
→ Although there are **plenty of different SUSY-models**, the **optimal cutvalue** can be described by a **linear function** with **one parameter**



Scalar sum of Jet-transverse momenta for **semileptonic** final states

Dependencies of the optimal cutvalue for several kinematic distributions on <m> in the mSUGRA-model

- Optimal cut on **4th hardest jet** is growing **in $<m^{Strong}_{SUSY}>$** for **fixed Gluino-masses.**
- Offset grows with $m_{1/2}$
- Construct function dependend on Gluino mass to correct offset
- Possible to describe all points with one linear function



P_T of 4th hardest Jet

for semi**leptonic** final states

Dependencies of the optimal cutvalue for several kinematic distributions on <m> in the mSUGRA-model

- Optimal cut on **4th hardest jet** is growing **in $<m^{Strong}_{SUSY}>$** for **fixed Gluino-masses.**
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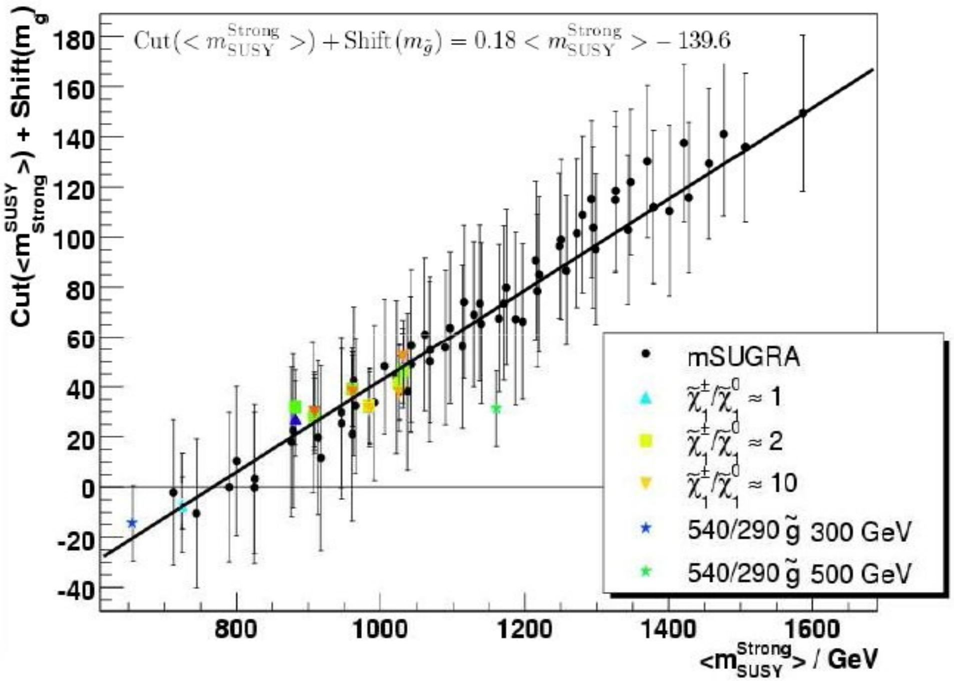


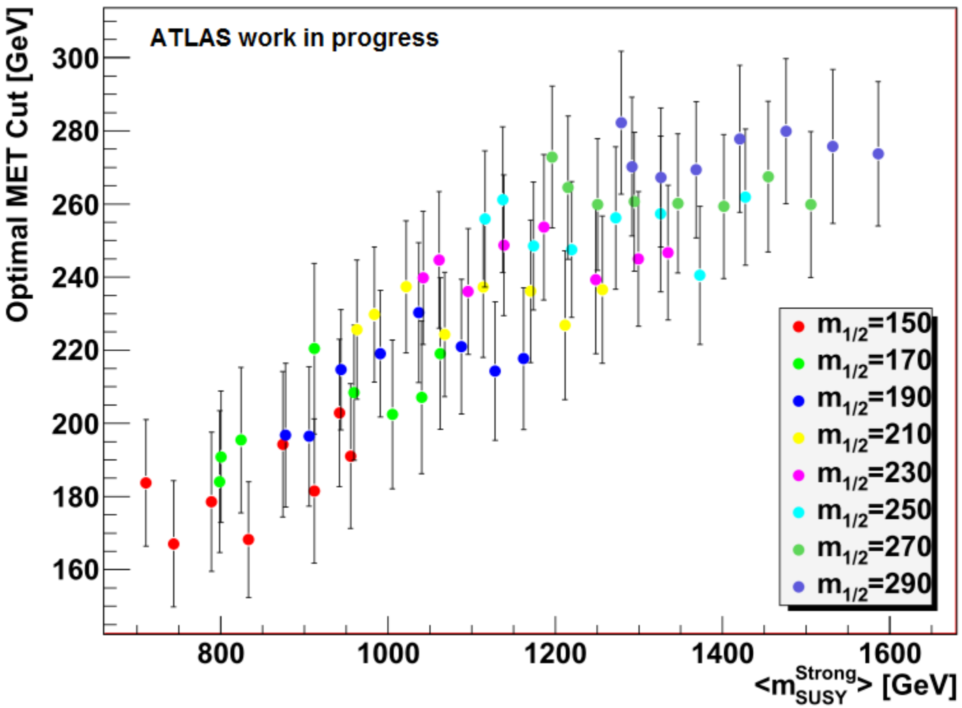
P_T of 4th hardest Jet

for semi**leptonic** final states

Dependencies of the optimal cutvalue for several kinematic distributions on <m> in the mSUGRA-model

- Optimal cut on **missing tranverse energy** is **constant in $<m^{Strong}_{SUSY}>$** for **fixed Gluino-masses.**

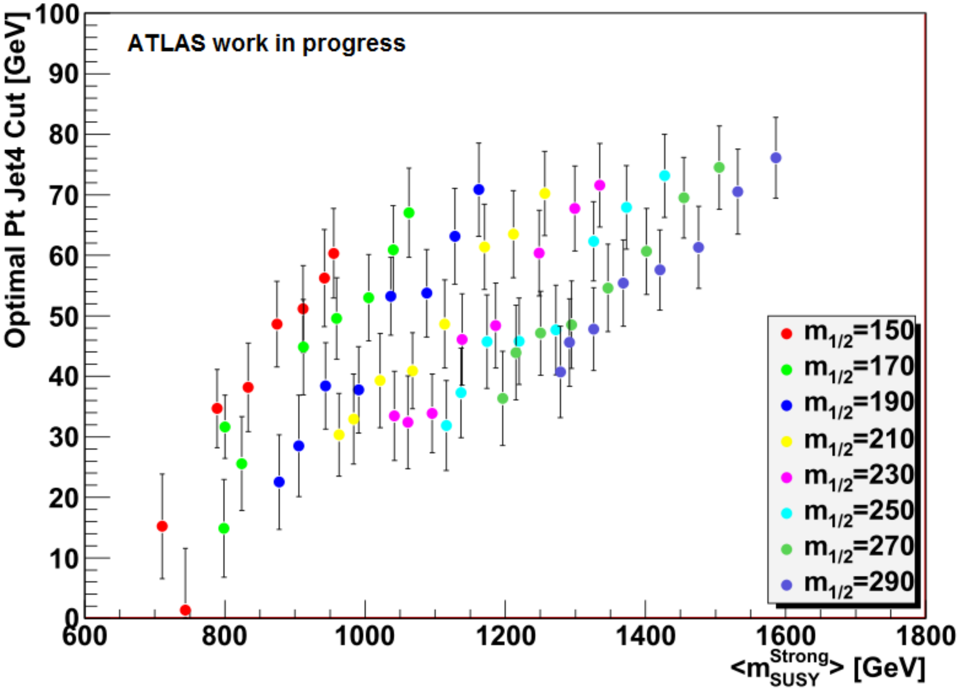
→ Again although the **mass-spectra differ strongly**, the description of the **optimal cutvalue** is **fairly simple.**



Missing transverse energy
for **dileptonic** final states

Dependencies of the optimal cutvalue for several kinematic distributions on <m> in the mSUGRA-model

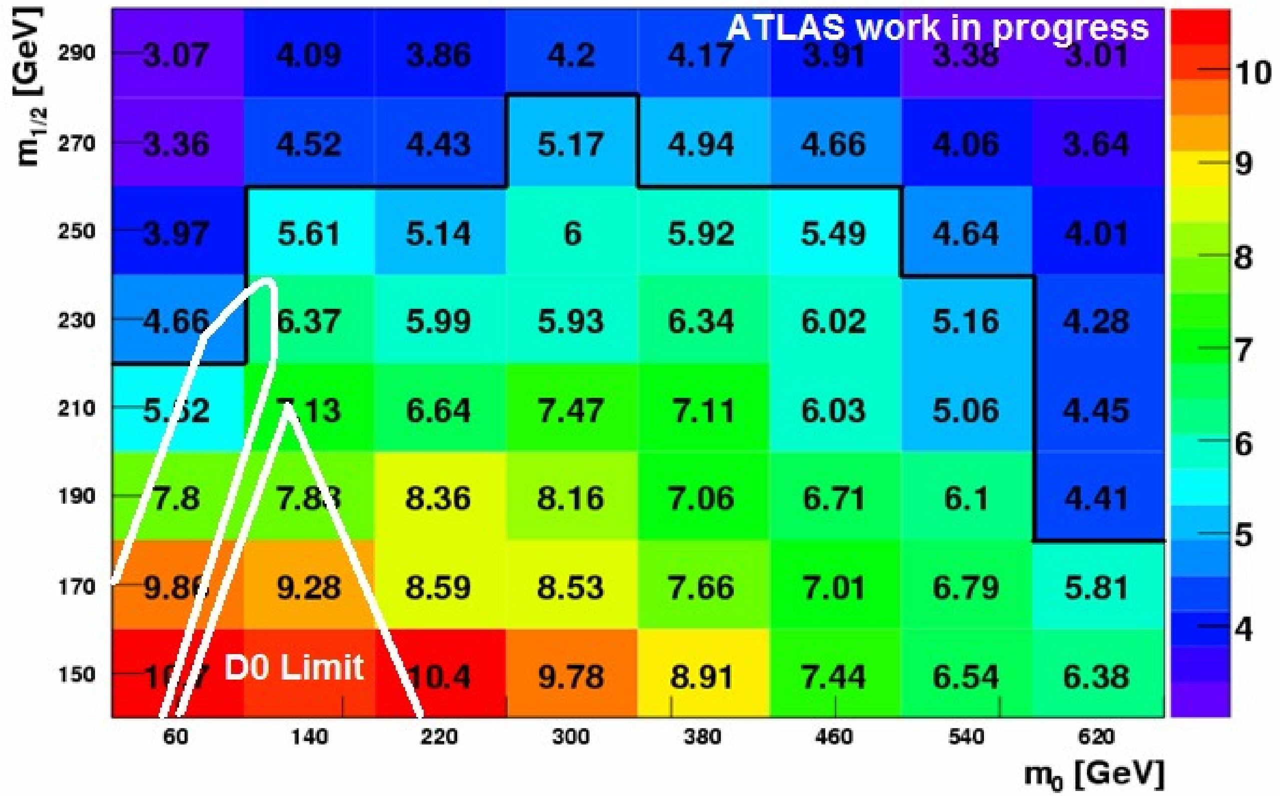
- **Linear dependency** visible:
- Optimal cut on **4th hardest jet** is growing **in $<m^{Strong}_{SUSY}>$** for **fixed Gluino-masses.**
- Offset grows with $m_{1/2}$
- Apply same shifting method as for 1 lepton channel



P_T of 4th hardest Jet

for **dileptonic** final states

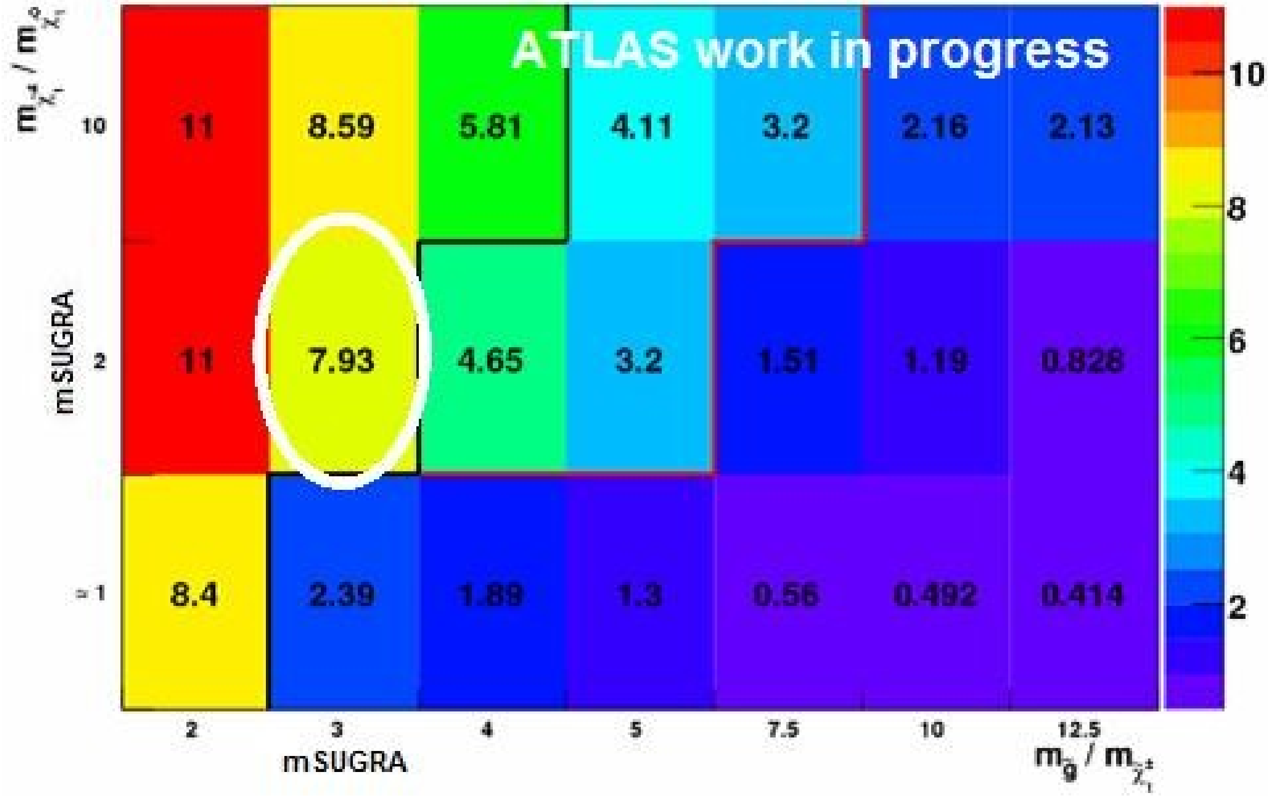
5σ Discovery-reach for 1-lepton-final-states at 10 TeV and L = 100pb^{-1}



mSUGRA-Discovery-potential in dependency of m_0 and $m_{1/2}$

- Shown method shows **high discovery potential in the mSUGRA-model.**
- Masses of Squarks/Gluinos discoverable up to **~600 GeV** in 2010.
- Discovery potential well **beyond Tevatron limits** already with **early data.**

5σ Discovery-reach for 1-lepton-final-states at 10 TeV and L = 100pb^{-1}



Discovery-potential beyond mSUGRA

- Apply parametrized selection **for non-mSUGRA points.**
- Also high sensitivity for points with **mass relations beyond mSUGRA.**
- Decrease in efficiency for **degenerate Chargino1 and Neutralino1 masses.**
- **Large Gluino masses** lead to **low production cross sections.**

Summary / Outlook

- The MSSM shows a **large amount of different SUSY-mass-spectra** leading to **various different topologies** to search for.

- Mass-dependencies of some kinematic variables can be understood and used to **parametrize the cutvalues on different mass-parameters.**

- This parametrization can be used to calculate the optimal cut for a given set of parameters, which **increases sensitivity.**

Work in progress:

- Only showed some values for non-SUGRA like mass-pattern.
  → Study influence of the change in the Mass-Pattern more systematically to cover as much potential signal-signatures as possible.

Backup

Minimal Supergravity (mSUGRA)

- Example of a **GUT-SUSY-Theory**
- Assumptions:

1.) **Scalar masses unify** at the GUT-Scale at a common mass called **m_0**

2.) **Gaugino-masses unify** at the GUT-Scale at a common mass called **$m_{1/2}$**

3.) **Trilinear couplings unify** also at a common coupling called **A_0**

5 Parameters left:

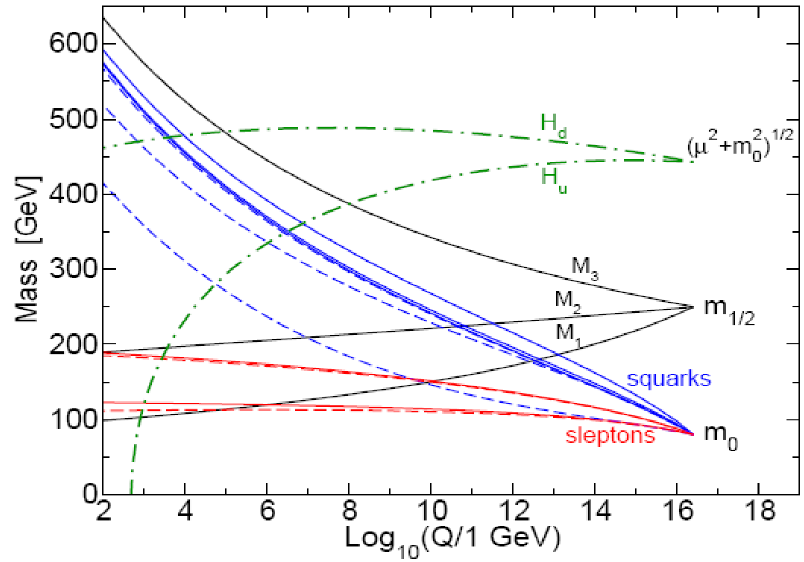
m_0 : unified scalar mass

$m_{1/2}$: unified gaugino mass

A_0 : unified trilinear coupling

$\tan(\beta)$: ratio of the two Higgs - VEVs

sign(μ): Higgsino-mass-parameter



- **Mass-Spectrum of the theory determined by the choice of these parameters**
- Study the impact of varying m_0 and $m_{1/2}$ on the mass-spectra for fixed A_0 , $\tan(\beta)$ and sign(μ).