Supersymmetry at the Terascale

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Motivation

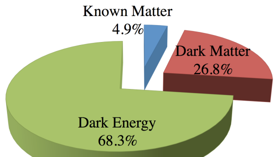
Standard Model of particle physics
→ **major achievement of particle physics** in the 20th century

But fundamental open questions:

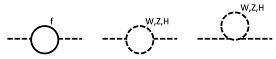
Grand unification: Do the electroweak and the strong force unify at large energies?

Gravity: How can gravity be included?

Dark Matter: Can particle physics help to explain cosmological observations?



Hierarchy problem: Corrections to Higgs boson mass: over 30 orders of magnitude?



Corrections at loop level:
$\delta m_H^2 \sim \Lambda^2(4m_t^2 - 2m_W^2 - 2m_Z^2 - 2m_H^2)$
→ If no new physics at scale Λ, cancellation with large fine tuning needed!

Solution: Supersymmetry (SUSY):
Cancellation of loops with additional particles, even if partner particles heavier (dependence reduced from Λ^2 to $\ln(\Lambda^2/m_{\tilde{f}})$)

Naturalness constrains mainly 3rd generation due to strong Yukawa coupling, and with
$-1/2\, m_Z^2 = -|\mu|^2 + m^2_{Hu}$
for heavy superpartners, contributions on right must be fine tuned against each other to achieve electroweak symmetry breaking:

- Top squark corrects m^2_{Hu} at one loop: with $\mu \sim$ 150-200 GeV → $m_{\tilde{T}}$ = 1-1.5 TeV
- Gluinos correct m^2_{Hu} at two loops: should be lighter than several TeV

Search for light gluinos decaying to 3rd generation squarks

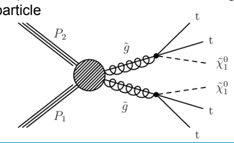
Early results with 7 TeV data
PRD 87, 052006 (2013)

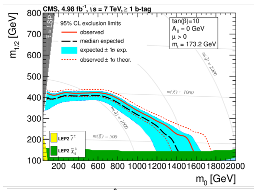
- Analysis of DESY group based on final states with a single lepton, one or more b-quark jets, and missing transverse energy
- Background determination in data-driven way based on control regions

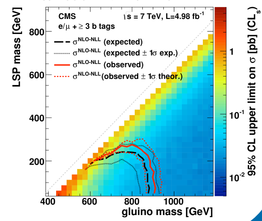
Interpretation with full and simplified models

No signal observed → set limits on different models:

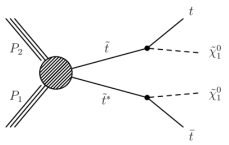
- Constrained Minimal Supersymmetric Model (CMSSM) with tanβ=10, A_0=0 GeV and μ>0
- Simplified model describing gluino pair production, with each gluino decaying on-shell to two top quarks and a neutralino, the lightest SUSY particle

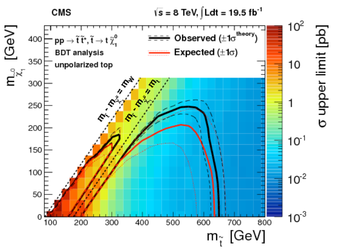






Search for direct production of top squarks



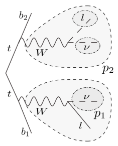


Results with 8 TeV data
EPJC 73 (2013) 2677

Naturalness predicts top squarks within the reach of LHC!
→ Search for **directly produced top squarks**, a challenging analysis due to low signal cross section and large background from semi-leptonic top quark decays.
Background rejection: with several variables fed into a boosted decision tree, important for signal-background separation: variable called M_{T2}^W (from arXiv: 1203.4813 [hep-ph]), defined as:

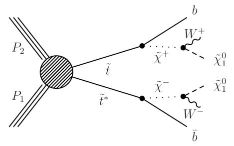
$$M_{T2}^W = \min\left\{ m_y \text{ consistent with: } \left[\begin{array}{l} \vec{p}_1^T + \vec{p}_2^T = \vec{E}_T^{\text{miss}},\ p_1^2 = 0,\ (p_1+p_\ell)^2 = p_2^2 = M_W^2, \\ (p_1+p_\ell+p_{b_1})^2 = (p_2+p_{b_2})^2 = m_y^2 \end{array} \right] \right\}$$

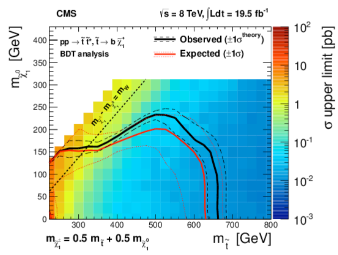
Determination of remaining background mainly dependent on Monte Carlo simulation, validated in several control regions.



No signal found, limits set on two different simplified models describing direct top squark production, with different decays of the top squark:

- $\tilde{t} \to b\tilde{\chi}_1^0$
- $\tilde{t} \to b\tilde{\chi}_1^{\pm}$, and $\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0$, for several mass differences between top squark and neutralino, defined as: $m_{\tilde{\chi}_1^{\pm}} = x \cdot m_{\tilde{t}} + (1-x) \cdot m_{\tilde{\chi}_1^0}$ with x = (0.25, 0.5, 0.75)





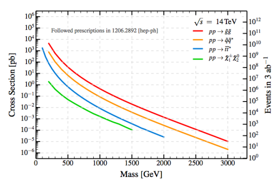
Future Studies

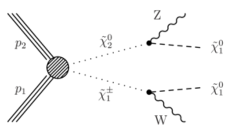
LHC Future
CMS PAS FTR-13-014

- Expected luminosity with **Run II: 300 fb-1**
- Planned Phase II Upgrade followed by **Run III (HL-LHC)** could **enhance luminosity by factor 10**

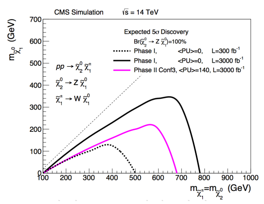
→ Important for measurement of processes with low cross section!

Higgsinos masses should not be too far above the weak scale:
→ Most interesting, but lowest cross section compared to other SUSY production processes
→ Check reach with HL-LHC





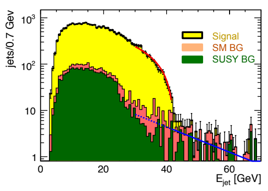
Study of the reach for a simplified model describing neutralino chargino production:
→ Clean signature in events with ≥3 lepton + missing energy final states



LHC and the ILC
arXiv:1307.8076
Phys.Rev. D82 (2010) 055016

LHC Run III: good coverage of large SUSY phase space, but in several scenarios a few (light) SUSY partners might only be precisely measureable in future lepton colliders:
At a future linear collider like the **ILC**, nearly all sleptons and electroweakinos are accessible either in pair or associated production.

Example studied by DESY groups: phenomenological MSSM with $\tilde{\tau}_1^{\pm}$ co-annihilation



Summary

- After the discovery of a Higgs boson at the LHC with a mass within the range predicted for the lightest SUSY Higgs boson, the **understanding of the loop corrections** to its mass becomes even more pressing
- **Run I** covered part of the parameter range testing naturalness
- The increase in center-of-mass energy in **Run II** will open **access to large new part of parameter space** already with a few fb^{-1}
- **Run III** – delivering higher luminosity – needed to test **processes with low cross section**
- **Future linear collider** might be the only possibility for **precision measurements** of light sleptons and electroweakinos

Search for Supersymmetry remains a hot topic!

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