Dark Matter and SUSY searches at the LHC

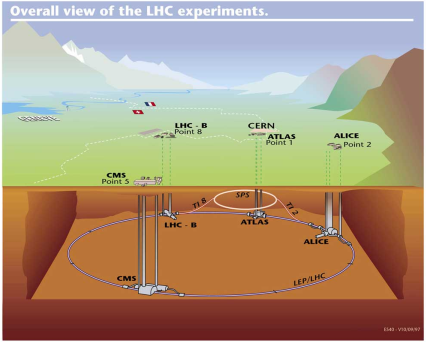
9th Patras Workshop on Axions, WIMPs and WISPs

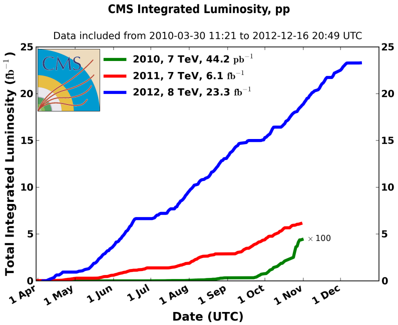
Stefan Wayand for the ATLAS & CMS collaboration | June 25, 2013

INSTITUTE OF EXPERIMENTAL NUCLEAR PHYSICS

Outline

The LHC



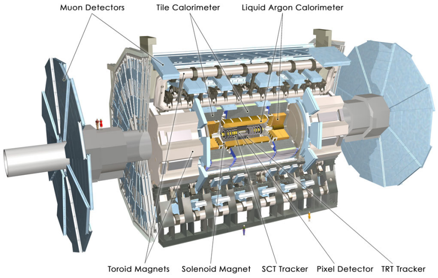


$\mathcal{L}_{int}$ for physics

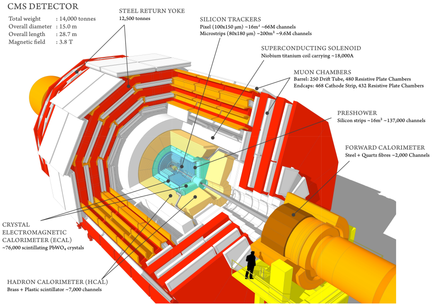
- ~ 5 fb^{-1} for ATLAS and CMS at 7 TeV pp collisions
- ~ 20 fb^{-1} for ATLAS and CMS at 8 TeV pp collisions

The Detectors

ATLAS



CMS

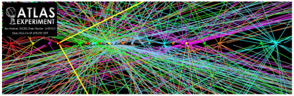


- Thanks to thousands of people both detectors performing very well
- Grid Computer infrastructure allowing fast analysis

The Reconstructed Objects

Objects and Kinematics

Objects	typical values	description
μ	$>$10 GeV	Muons (with isolation requirements)
e	$>$10 GeV	Electrons (with isolation requirements)
γ	$>$20 GeV	Photons
τ_h	$>$20 GeV	hadronically decaying τ
jet	$>$20 GeV	hadronization of q or g
b-jet	$>$20 GeV	Jets coming from b-quarks
jet activity	res. $\sim$ 10 GeV	Jet activity $\sum \lvert E_T \rvert$
missing energy	res. $\sim$ 20 GeV	Missing transverse Energy -$\sum \vec{p}_T$



Reconstruction multiple interactions (PU).
$<$21$>$ Interactions per bunch crossing in 2012

Building your Analysis

- Look for the Objects in the final state
- Take a trigger which contains your objects
- Simulate the signal
- Consider all backgrounds processes
  - Use data driven background determination for main backgrounds
  - Use MC for rare backgrounds
- Find a way to maximize the signal over background ratio
  - Sequential cuts
  - Shape analysis
  - Multivariate methods
- Determine uncertainties
  - Trigger
  - ...
- Make the interpretation

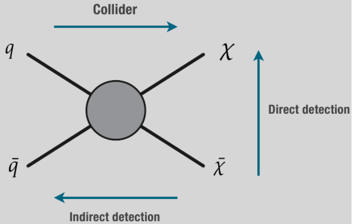
Motivation for Dark Matter

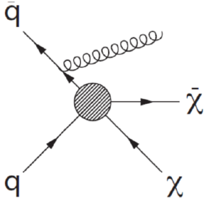
Dark Matter

- ....
- ....
- Not needed at this workshop

Dark Matter production

- Direct DM searches use interaction between Wimps and SM particles
- If Wimps interact with SM they can be produced direct at LHC



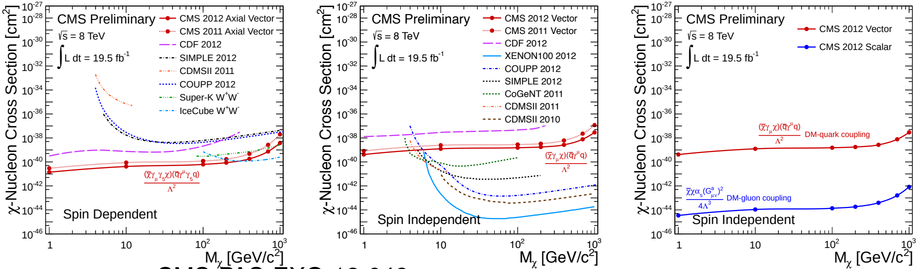


- Hard to trigger such events
  - $\rightarrow$ use events with ISR
  - leads to events with missing energy and only one Jet

Exclusion for Dark Matter scenarios

Mono Jet Analysis

- Make assumptions on interaction for cross section limits
  - axial vector interacktion = $\frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma_\mu\gamma_5 q)}{\Lambda^2}$ [spin dependent]
  - vector interacktion = $\frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma_\mu q)}{\Lambda^2}$ [spin independent]
  - scalar interacktion = $\frac{(\bar{\chi}\chi)\alpha_s(G^a_{\mu\nu})^2)}{\Lambda^2}$ [spin independent]
  - cutoff $\Lambda = \frac{M}{\sqrt{g_\chi g_q}}$

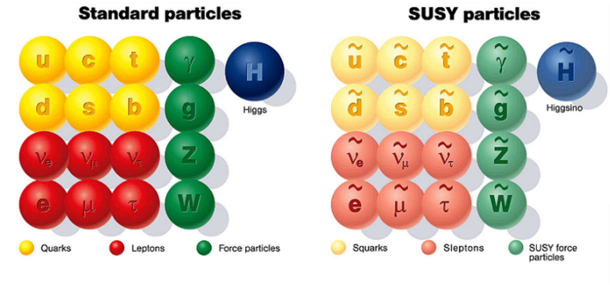


CMS-PAS-EXO-12-048

SUSY

SUSY

- Is a well defined theory
- Cross section is in LHC range
- Provides a Dark Matter candidate (LSP)

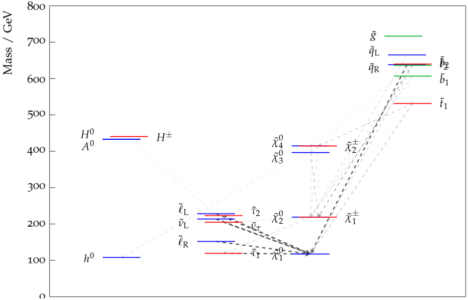


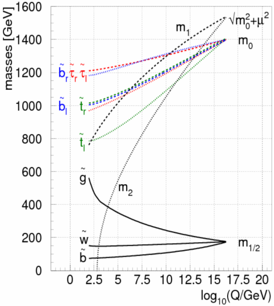
$$\begin{pmatrix} \tilde{\chi}_1^0 \\ \tilde{\chi}_2^0 \\ \tilde{\chi}_3^0 \\ \tilde{\chi}_4^0 \end{pmatrix} = M \begin{pmatrix} \tilde{B} \\ \tilde{W}^3 \\ \tilde{H}_1 \\ \tilde{H}_2 \end{pmatrix}$$

CMSSM

CMSSM

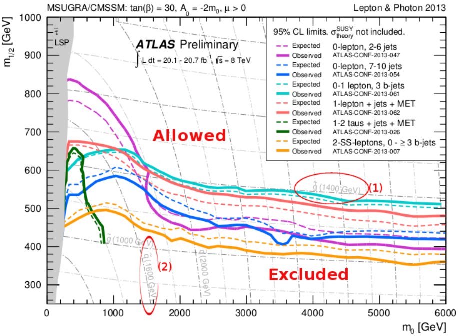
- Has only four GUT scale parameters
  - Common masses for spin 0 and spin 1/2: m_0 and $m1/2$
  - Ratio of the vevs for two Higgs doublets: $\tan\beta$
  - Trilinear coupling: A_0
- Predicts masses by running couplings and masses from GUT scale





The well known CMSSM

- Strong production dominates over the excluded parameter space
- Searches for jet activity and missing energy are most sensitive



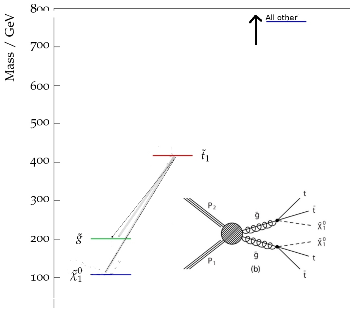
Mass limits in CMSSM

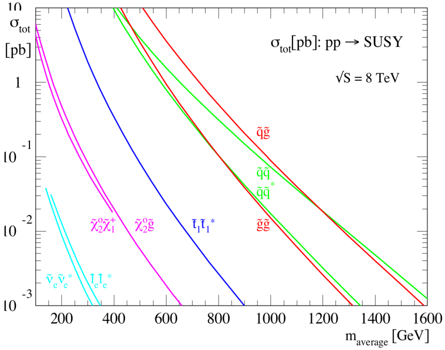
- $m_{\tilde{g}} > 1200$ GeV (1)
- LSP(Bino like): $m_{\tilde{\chi}_1^0} \approx 0.4\ \mathrm{m}_{1/2}$

  $\rightarrow$ LSP > 220 GeV
- $m_{\tilde{q}} > 1800$ GeV (2)
- $\mathrm{m}_{higgs} = 126$ GeV $\rightarrow \mathrm{m}_{stop} \approx 3$ TeV

  (Beware: only valid for two Higgs doublets, not for extended Higgs sector)

Simplified Models (SMS)

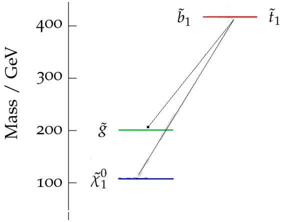




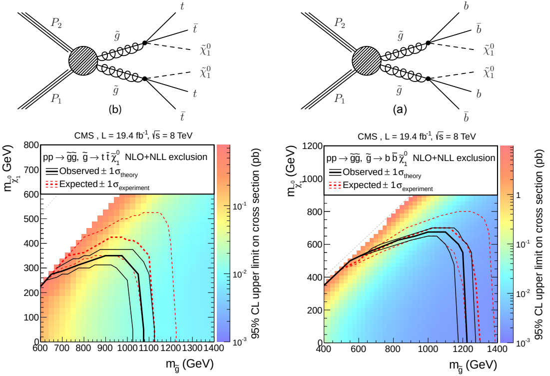
What is it good for

- Only consider one Feynman diagram → 3 (mass) parameters
- Clear signatures, because of 100 % branching
- Combination of different SMS can reproduce other SUSY models

Gluino-mediated bottom- and top-squark production

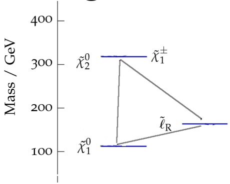


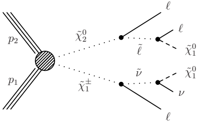
- Gluino production has large cross section
- Coloured particles $\rightarrow$ large jet activity
- Analyse the result in missing energy (from $\tilde{\chi}_1^0$) and jet activity

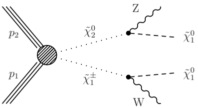


arXiv:1305.2390

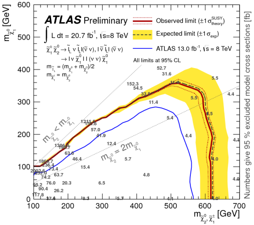
Search for direct production of charginos and neutralinos (EWKino)

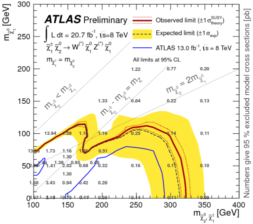






- Very low cross section
- Final state contains leptons $\rightarrow$ good background separation
- SM WZ production is main background, suppress with M_T and $m_{\ell\ell}$

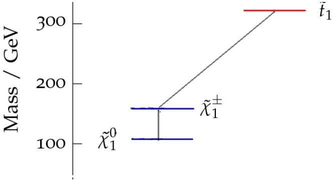


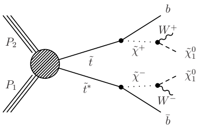


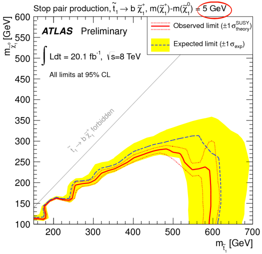
$m_{\ell\ell}$ = invariant mass of 1rd and 2rd lepton
M_T = transverse mass of missing energy and 3rd lepton

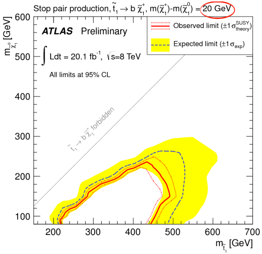
ATLAS-CONF-2013-035

Search for direct stop pair production









- Direct stop production
- Final state contains at least 2 b-jets
- The final state is very sensitive to $m_{\tilde{\chi}_1^{\pm}}$ - $m_{\tilde{\chi}_1^0}$

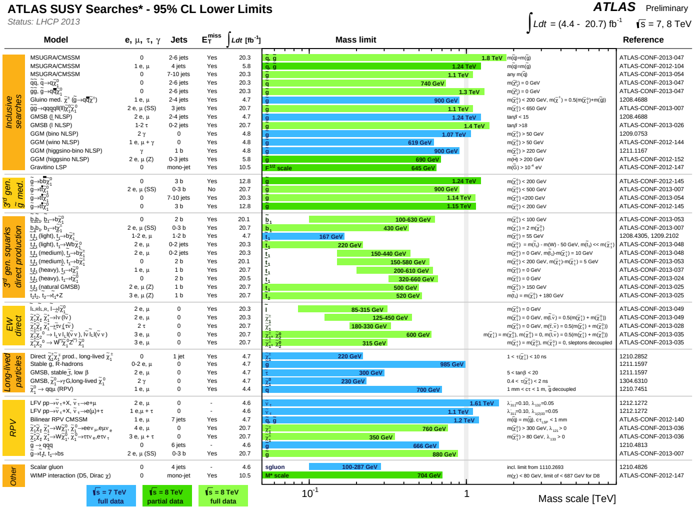
SMS interpretation

- SMS exclusions assumes 100% BR

→ Only probe masses

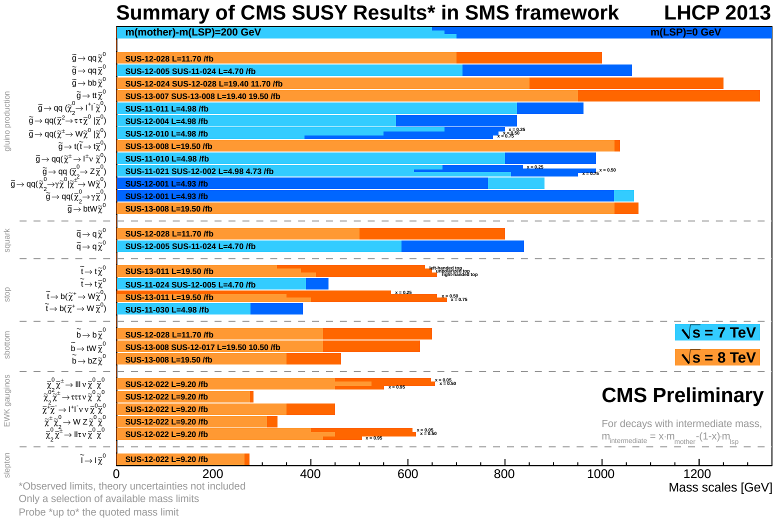
ATLAS-CONF-2013-053

ATLAS-Summary



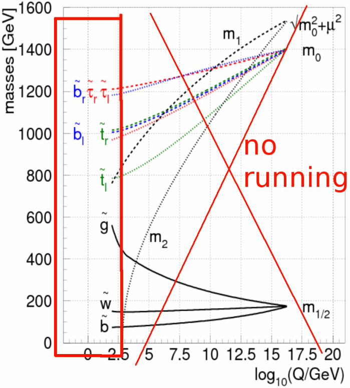
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

CMS-Summary


Summary of CMS SUSY Results* in SMS framework
LHCP 2013
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
SUS-12-028 L=11.70 /fb
SUS-12-005 SUS-11-024 L=4.70 /fb
SUS-12-024 SUS-12-028 L=19.40 11.70 /fb
SUS-13-007 SUS-13-008 L=19.40 19.50 /fb
SUS-11-011 L=4.98 /fb
SUS-12-004 L=4.98 /fb
SUS-12-010 L=4.98 /fb
SUS-13-008 L=19.50 /fb
SUS-11-010 L=4.98 /fb
SUS-11-021 SUS-12-002 L=4.98 4.73 /fb
SUS-12-001 L=4.93 /fb
SUS-12-001 L=4.93 /fb
SUS-13-008 L=19.50 /fb
SUS-12-028 L=11.70 /fb
SUS-12-005 SUS-11-024 L=4.70 /fb
SUS-13-011 L=19.50 /fb
left-handed top
unpolarized top
right-handed top
SUS-11-024 SUS-12-005 L=4.70 /fb
SUS-13-011 L=19.50 /fb
SUS-11-030 L=4.98 /fb
SUS-12-028 L=11.70 /fb
SUS-13-008 SUS-12-017 L=19.50 10.50 /fb
SUS-13-008 L=19.50 /fb
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
SUS-12-022 L=9.20 /fb
√s = 7 TeV
√s = 8 TeV
CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother -(1-x)·m_lsp
0
200
400
600
800
1000
1200
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

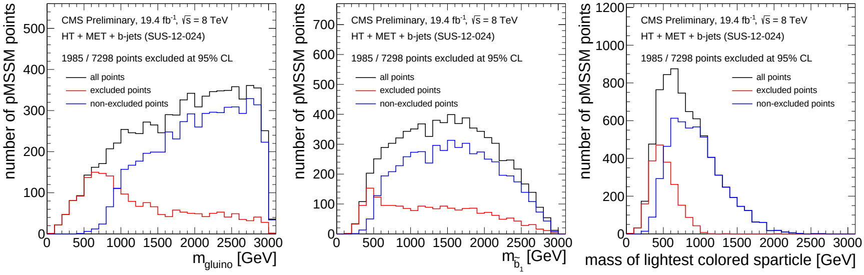
Phenomenological MSSM

- 19 parameters to explore MSSM at SUSY scale
  - M_1, M_2 and M_3 (gaugino masses)
  - $\tan\beta$, μ, m_A
  - 10 sfermion mass parameters
  - A_t, A_b and A_τ
- Produced over 7k model points
  - sparticle masses up to 3 TeV
- Consider several constraints
- Uses SMS results to test each parameter point



Results from the pMSSM

Karlsruhe Institute of Technology



Phenomenological MSSM

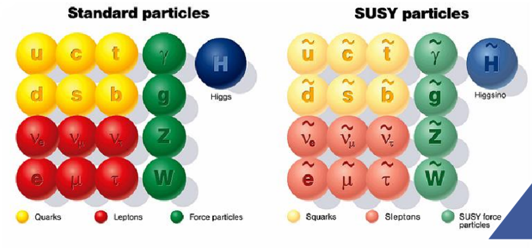
- LHC has an influence on MSSM
- BLUE line are still allowed scenarios

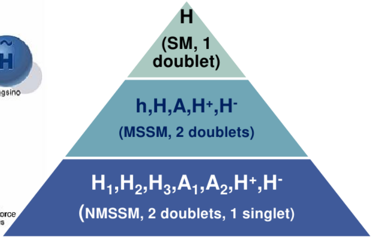
CMS-PAS-SUS-12-024

The NMSSM

Higgs mass IS below 130 GeV, as PREDICTED by SUSY!

W. Hollik: for me the observed Higgs boson with a mass consistent with Supersymmetry is the strongest hint for Supersymmetry!





The NMSSM

KIT Karlsruhe Institute of Technology

Many papers on NMSSM after M_H=126 GeV and hint of too high Br into $\gamma\gamma$, see arXiv:1301.6437, arXiv:1301.1325, arXiv:1301.0453, arXiv:1212.5243, arXiv:1211.5074, arXiv:1211.1693, arXiv:1211.0875, arXiv:1209.5984, arXiv:1209.2115, arXiv:1208.2555, arXiv:1207.1545, arXiv:1206.6806, arXiv:1206.1470, arXiv:1205.2486, arXiv:1205.1683, arXiv:1203.5048, arXiv:1203.3446, arXiv:1202.5821, arXiv:1201.2671, arXiv:1201.0982, arXiv:1112.3548, arXiv:1111.4952, arXiv:1109.1735, arXiv:1108.0595, arXiv:1106.1599, arXiv:1105.4191, arXiv:1104.1754, arXiv:1101.1137, arXiv:1012.4490, ...

NMSSM

Add singlet to Higgs-sector (singlet does not couple to anything)

$\rightarrow$ Solves μ problem

$\rightarrow$ Increases Higgs masses on tree level

- MSSM: $m_{\tilde{t}} \approx 3$ TeV, NMSSM: $m_{\tilde{t}} < 1$ TeV

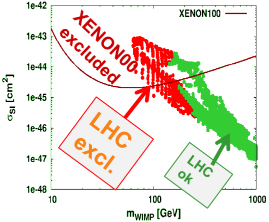
$\rightarrow$ LSP mostly super partner of the singlet ($\tilde{S}$)

- LSP light (50-130) GeV

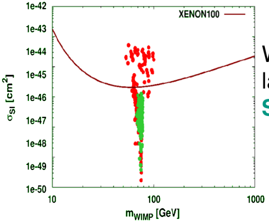
NMSSM Outlook

Karlsruhe Institute of Technology

MSSM **Present LHC-7TeV und Xenon100kg** NMSSM

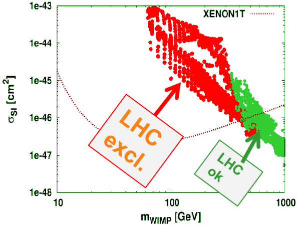


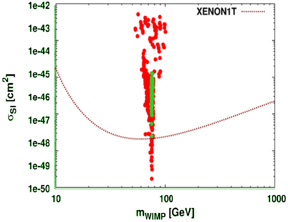
WIMP = largely **Bino**



WIMP = largely **Singlino**

Future reach LHC-14TeV und Xenon1T





Exploring x-sect of 10^{-46} cm^2

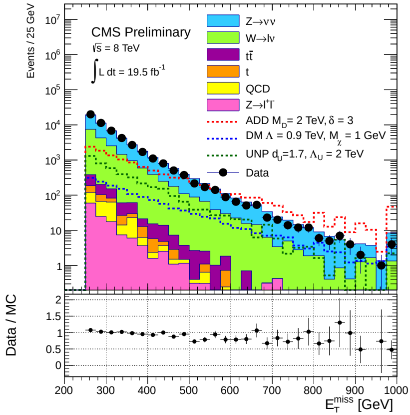
CMS-Talk Wim de Boer TAM 2013

Conclusion

- LHC is a beautiful machine for testing new physic scenarios
- ATLAS and CMS developed many different analysis
- Results are interpreted into many beyond SM scenarios
- No significant deviation from SM is observed
- We tested squarks and gluinos up to TeV range
- Looking forward to LHC at higher energy and higher luminosity

BACKUP

Mono Jet Result



Selection

- one jet with $p_T > 80$ GeV
- veto on event with $p_T > 30$ GeV