PHYSICS AT THE TERA SCALE
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Parallel Session Summary
of
Supersymmetry and Beyond the SM

C. Sander (Hamburg)

2nd Annual Workshop – Aachen 28th November 08

Contributions

- Overall 18 Contributions (exp: 8, theo: 9, tools: 1)
- Supersymmetry: 14 contributions – other Models: 4
- Very active area: many contributions have to be rejected due to time contraints

Thursday, 27 November 2008

09:00	[58] **Phenomenology of the constrained NMSSM at the LHC** by Abdel DJOUADI (Orsay) (SuperC: 09:00 - 09:20)
	[59] **Rapidity Gap Events in Squark Pair Production** by Kim JONG-SOO (SuperC: 09:20 - 09:40)
	[60] **Search for MSugra in Inclusive Lepton Channel** by Daniel TEYSSIER (Aachen) (SuperC: 09:40 - 10:00)
10:00	[54] **SUSY Di- and Trileptons at CMS** by Martin NIEGEL (KIT) (SuperC: 10:00 - 10:20)
	break (10:20 - 10:40)
	[61] **Inclusive SUSY searches at ATLAS** by Jan SUNDERMANN (Freiburg) (SuperC: 10:40 - 11:10)
11:00	[62] **QCD suppression in Full-Hadronic SUSY** by Sergei BOBROWSKYI (Hamburg) (SuperC: 11:10 - 11:30)
	[78] **Threshold resummation for squark-antisquark and gluino-pair production at the LHC** by Anna KULESZA (Aachen) (SuperC: 11:30 - 11:50)
	[67] **NNLO corrections to squark-antisquark-production at the LHC** by Ulrich LANGENFELD (DESY) (SuperC: 11:50 - 12:10)
12:00	

15:00	[68] **Three Loop Corrections to the MSSM Higgs Boson Mass** by Philipp KANT (Wuppertal) (SuperC: 15:00 - 15:20)
	[69] **Data-Driven Background Estimation for the One-Lepton SUSY Search Mode** by Till EIFERT (CERN) (SuperC: 15:20 - 15:40)
	[70] **Search for GMSB SUSY** by Mark TERWORT (Hamburg) (SuperC: 15:40 - 16:00)
16:00	[71] **Reconstruction of SUSY Parameters from LHC Observables with Fittino** by Mathias UHLENBROCK (Bonn) (SuperC: 16:00 - 16:20)
	[72] **Model Independent Search for New Physics** by Stefan SCHMITZ (Aachen) (SuperC: 16:20 - 16:40)
	[74] **s-channel production of heavy vector bosons in a three-site higgsless model** by Christian SPECKER (Wuerzburg) (SuperC: 16:40 - 17:00)
17:00	break (17:00 - 17:20)
	[73] **Search for Heavy Gauge Bosons with CMS** by Walter BENDER (Aachen) (SuperC: 17:20 - 17:40)
	[75] **Rare meson decays into light neutralinos** by Ben O'LEARY (Aachen) (SuperC: 17:40 - 18:00)
18:00	[76] **Flavor and precision physics in a warped extra dimension** by Sandro CASSAGRANDE (Mainz) (SuperC: 18:00 - 18:20)
	[77] **Neutralino dark matter in SO(10) SUSY GUT models** by Jari LAAMANEN (Dortmund) (SuperC: 18:20 - 18:40)

Sorry for everything not covered in this talk

Shortcomings of the SM:

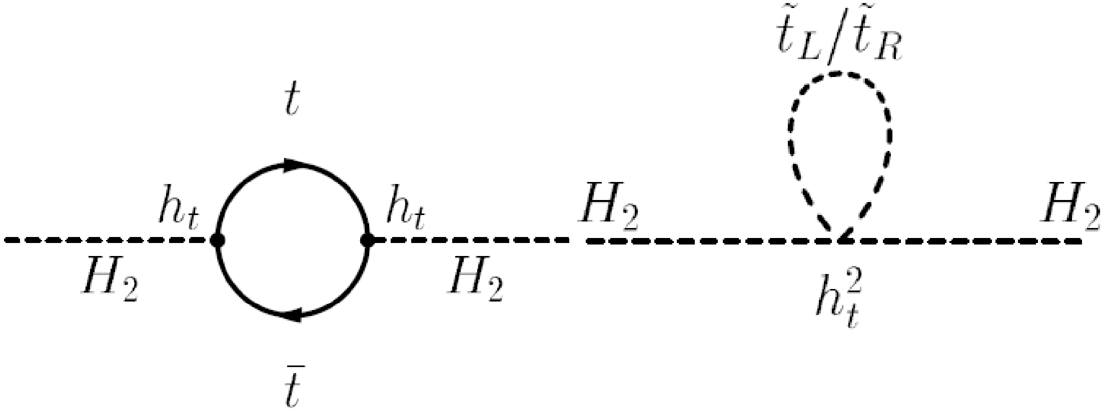
- Why are there 3 Generations ?
- Why is electric charge of electron and proton equal ?
- Why are ~17 orders of magnitude between EW and Planck scale ?
- How can the fine tuning problem be solved ?
- Should the gauge couplings unify at high energies ? In the SM they do not !
- Can the large numbers of free parameters 19 (+7(9) from νs) in the SM be reduced ?
- What is the nature of dark matter and dark energy ?
- Why is the gravitational force so weak? How can the gravity be included in one formal description of all forces ?
- ...

There are many models which address one or more of these question !

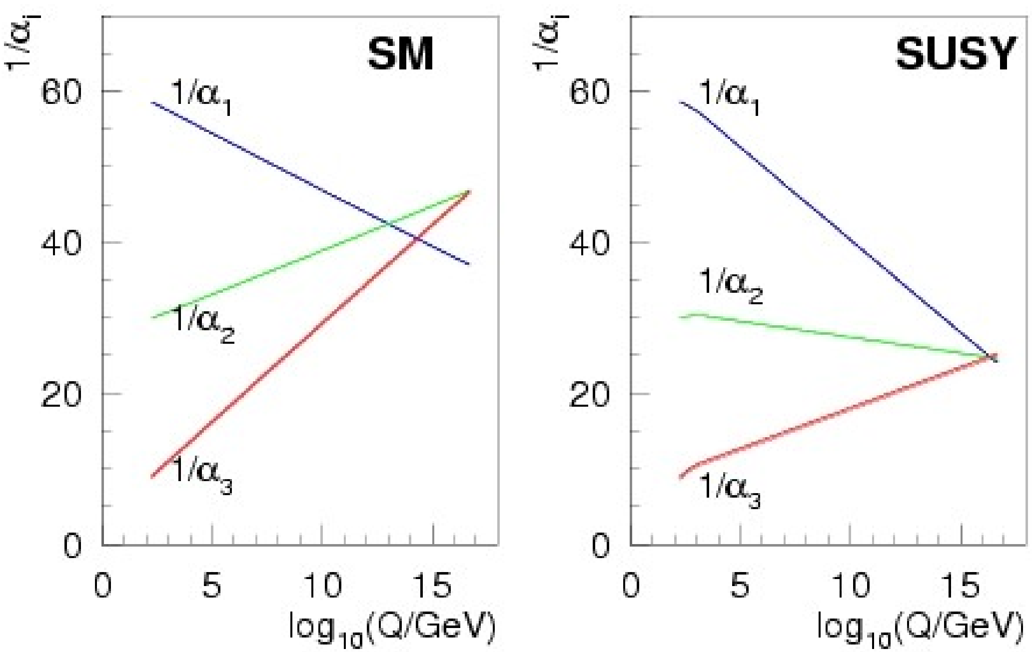
Supersymmetry

- **Last possible symmetry:** between fermions and bosons
- Each SM particle gets a SUSY partner equal in all quantum numbers except for spin (±½)
  - → Opposite sign of loop corrections solve fine tuning problem
  - → New particles change slope of running couplings → gauge unification
  - → Graviton $(s=2) \leftrightarrow g/W/Z/\gamma\ (s=1)$
  - → Provides perfect DM candidate
  - → “Natural” EWSBreaking
- No candidates for supersymmetric partners discovered so far
  - → SUSY has to be broken, but sparticles should have masses of ~1 TeV to keep advantages of SUSY

cancellation of loop corrections:



unification of gauge couplings:

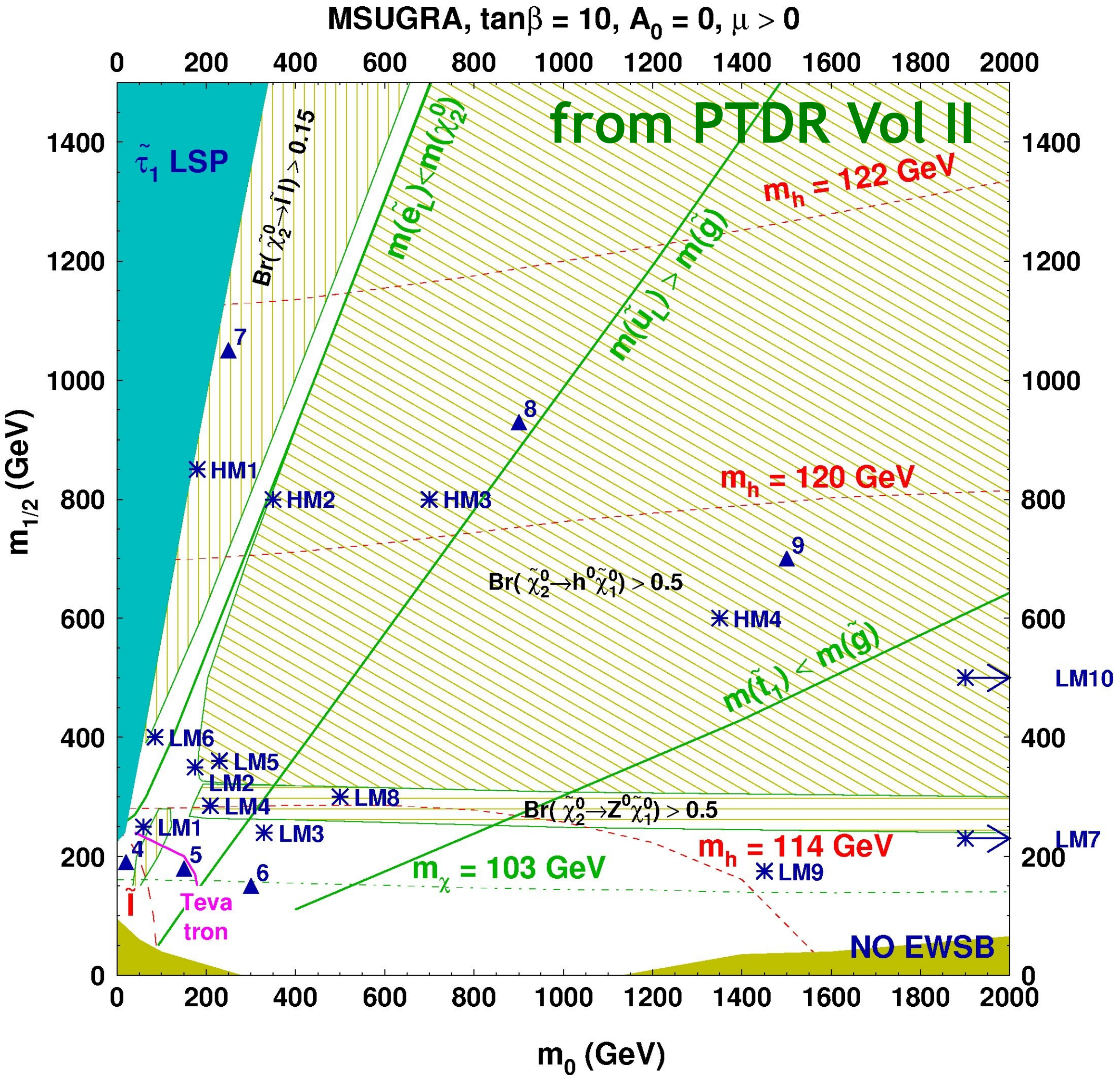


mSUGRA

- Very popular breaking scenario by coupling to (yet unknown) supergravity sector

  → Only 5 new parameters

- m_0: unified mass breaking term of scalar particles
- $m_{1/2}$: unified mass breaking term of gauginos
- $\tan\beta$: ratio of VEVs of the two higgs dubletts
- A_0: unified trilinear coupling
- sign μ: sign of higgs potential parameter



GUT relation are convenient:

$$M_1 = (5\tan(\theta_W)/3)M_2$$

In principle there are no theoretical and experimental bounds on lightest neutralino mass   Talk from Ben O' Leary

CMS benchmark points in m_0-$m_{1/2}$-plane

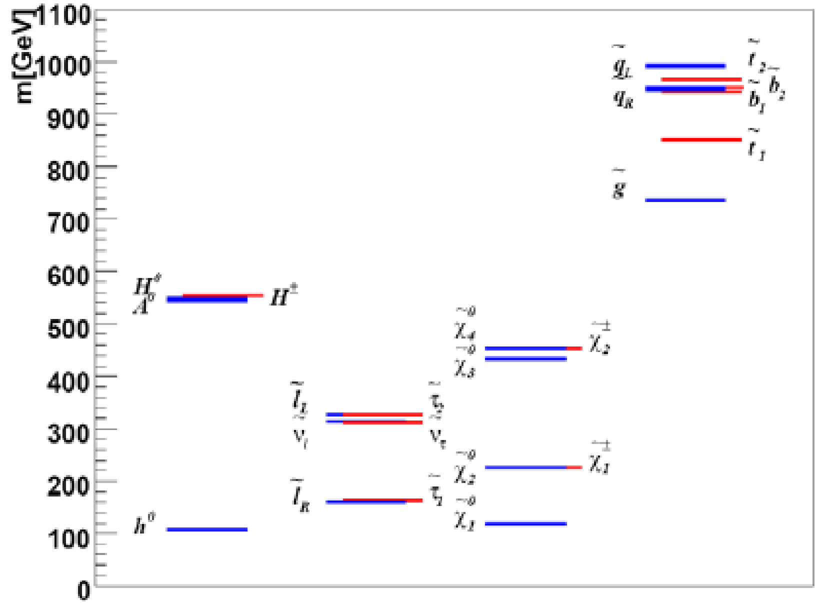
Gauge Mediated Symmetry Breaking

- SUSY good candidate for BSM physics
- SUSY breaking: mediated via gravity, gauge interactions, ...
- GMSB described by 6 fundamental parameters

Par.	Description
Λ	SUSY breaking scale
M	Messenger mass scale
tanβ	Ratio of Higgs VEVs
N	Number of messenger multiplets
sign(μ)	Sign of Higgs mass parameter
C_{grav}	Scale factor of Gravitino coupling ($\sim 1/C^2_{grav}$)

Present GMSB limits from TeVatron searches:

Par.	Λ	$m_{Neutralino}$	$m_{Chargino}$
Limit	> 80 TeV	> 110 GeV	> 200 GeV



Features:

- Lightest SUSY particle (LSP): Goldstino/Gravitino (m ≤ keV)
- 2nd lightest SUSY particle (NLSP): Neutralino or Slepton
- Missing energy from Gravitino
- Final state: hard photons, leptons

Talk from Mark Terwort

constrained NMSSM

A good combination will be then the cNMSSM=NMSSM+mSUGRA:

the original SUSY/SUGRA models are of this type [Fayet, Nilles, ..]

- The most general superpotential compatible with SUSY, $\mathrm{R_P}$ etc.., is

$$\mathcal{W} = \mathrm{Y_u \hat{u}_R \hat{H}_u . \hat{Q} + Y_d \hat{d}_R \hat{H}_d . \hat{Q} + Y_l \hat{l}_R \hat{H}_d . \hat{L}} - \lambda \mathrm{S \hat{H}_u . \hat{H}_d} + \frac{1}{3}\kappa \mathrm{\hat{S}}^3$$

- The collection of universal soft SUSY breaking terms at $\mathrm{M_{GUT}}$ is

$$\mathrm{M_{1/2}} \equiv \mathrm{M_1 = M_2 = M_3}$$
$$\mathrm{m_0} \equiv \mathrm{m_{H_u} = m_{H_d} = m_S = m_{\tilde{Q}} = m_{\tilde{t}} = m_{\tilde{b}} = m_{\tilde{L}} = m_{\tilde{\tau}}}$$
$$\mathrm{A_0} \equiv \mathrm{A_t = A_b = A_\tau = A_\lambda = A_\kappa}$$

$\Rightarrow$ five continuous parameters $\mathrm{M_{1/2}, m_0, A_0}, \lambda, \kappa$

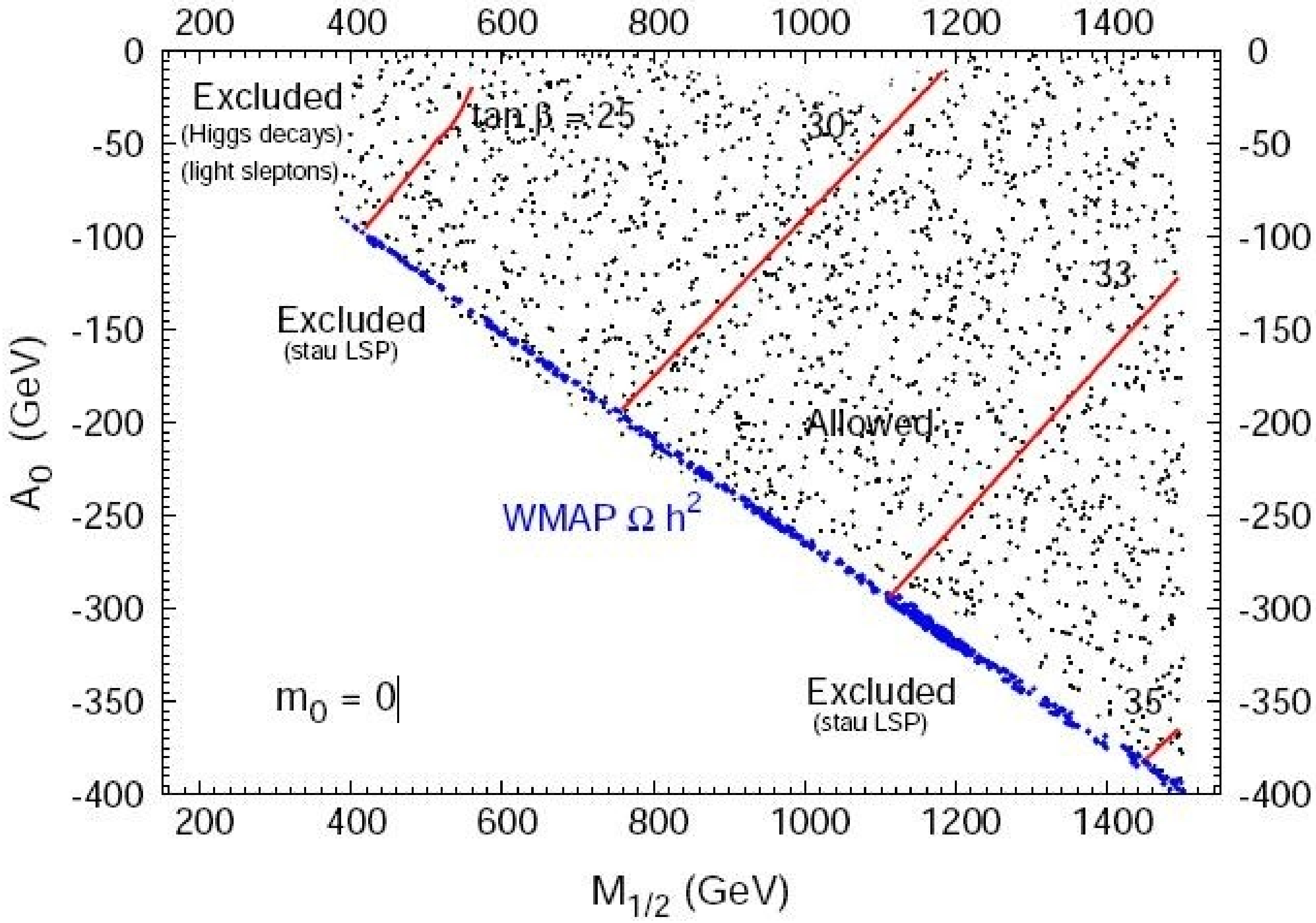
(as in cMSSM: $\mathrm{M_{1/2}, m_0, A_0}, \mu^2, \mathrm{B}\mu \Rightarrow \mathrm{M_{1/2}, m_0, A_0}, \tan\beta, \epsilon_\mu$)

- practical purposes (RGEs, numerics): trade $\kappa \leftrightarrow \tan\beta$
- requiring correct $\mathrm{M_Z}$ value: $\Rightarrow \tan\beta = \tan\beta(\mathrm{M_{1/2}, m_0, A_0}, \lambda)$
- minimization of scalar Higgs potential: $\Rightarrow \mathrm{s}$ but also $\kappa, \mathrm{m_S^2}$

constrained NMSSM : $\mathrm{M_{1/2}, m_0, A_0}, \lambda$

Talk from Abdelhak Djouadi

constrained NMSSM cont



with $m_0 = 0, \lambda = 10^{-2}$ assumed and tanβ fixed by of other parameters.

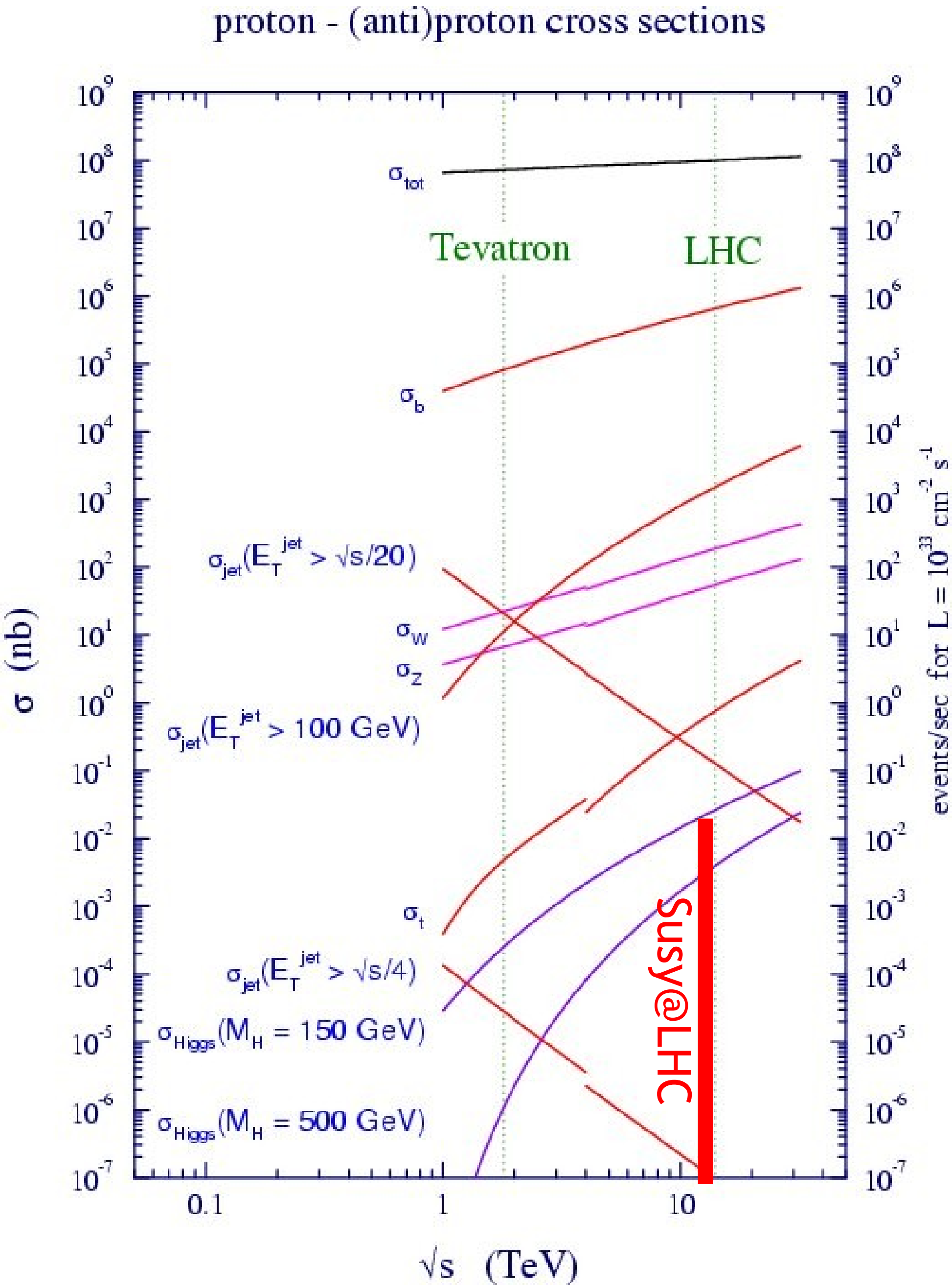
All constraints (theory, LEP, Higgs, DM, B-meson) imposed except (g-2).

A model with essentially one free parameter, $M_{1/2}$!

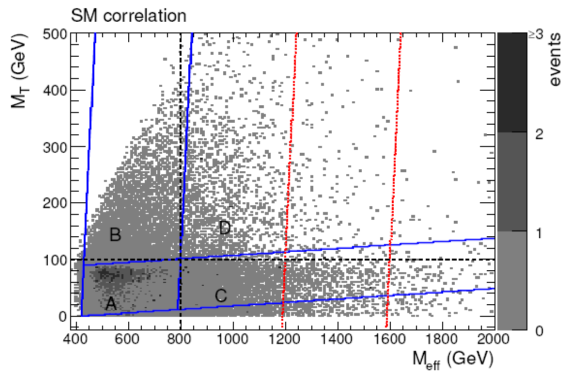
Talk from Abdelhak Djouadi

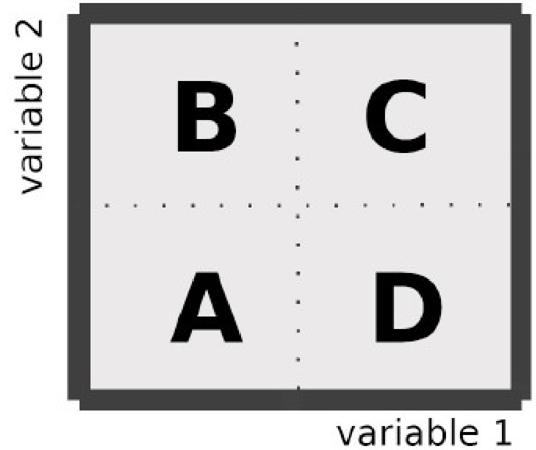
SUSY Searches

- Even in optimistic SUSY scenarios (σ ~10 pb) more than 7 orders of magnitude larger SM background
- Robust and stable pre-selection/trigger needed
- Presented searches for many different signatures:
  - Inclusive searces in all-hadronic decay mode ($\not{E}_T$, N jets + 0 leptons)
  - Inclusive searches with jets and leptons
  - Exclusive searches (with leptons)
  - Special signatures in GMSB models (Di-Photon production or HCSP)
  - ....
- All presented studies assume R-parity conservation!

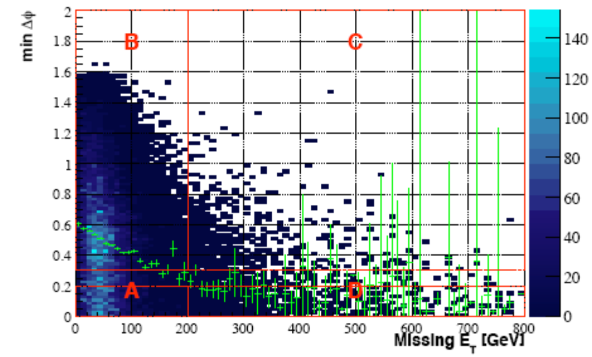


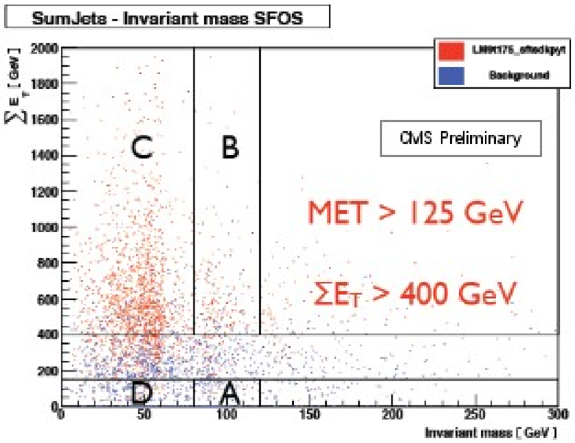
Data Driven Background Estimation



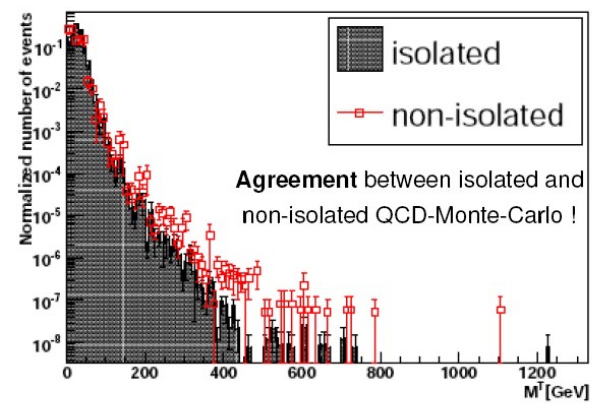


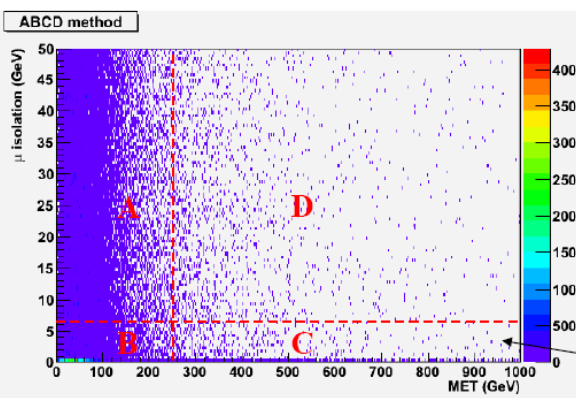
"ABCD" Method

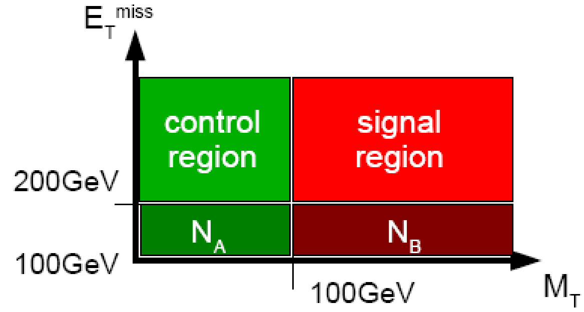


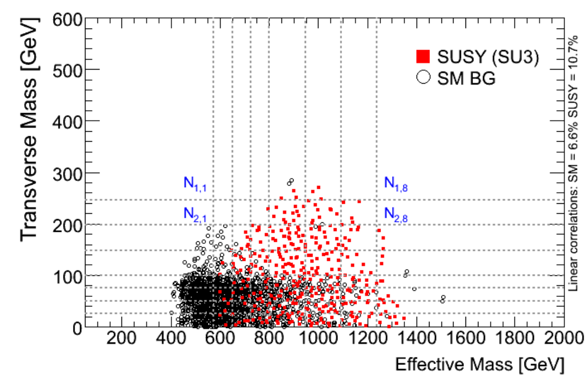


- Signal region C defined by cuts on various variables
- Do all cuts except on two (uncorrelated) vars with sufficient separation power
- Use $N_C = N_D \cdot N_B / N_A$ to estimate bg events in C





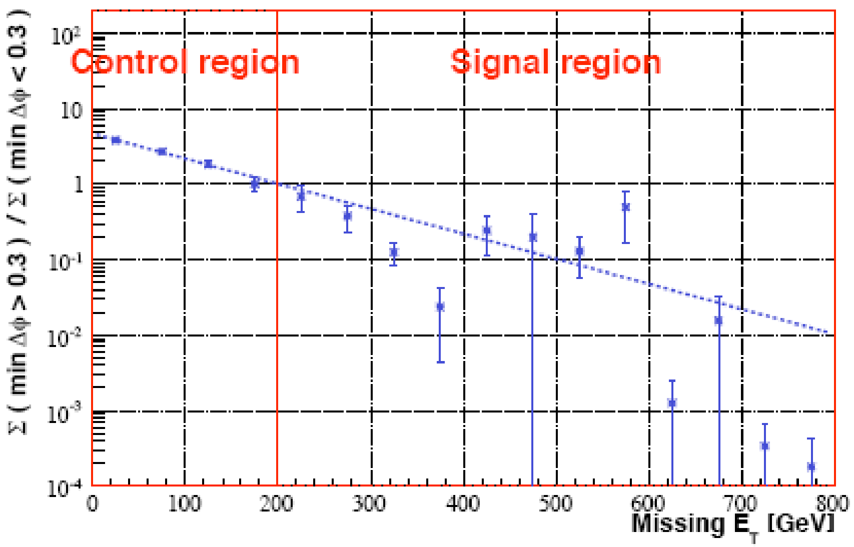




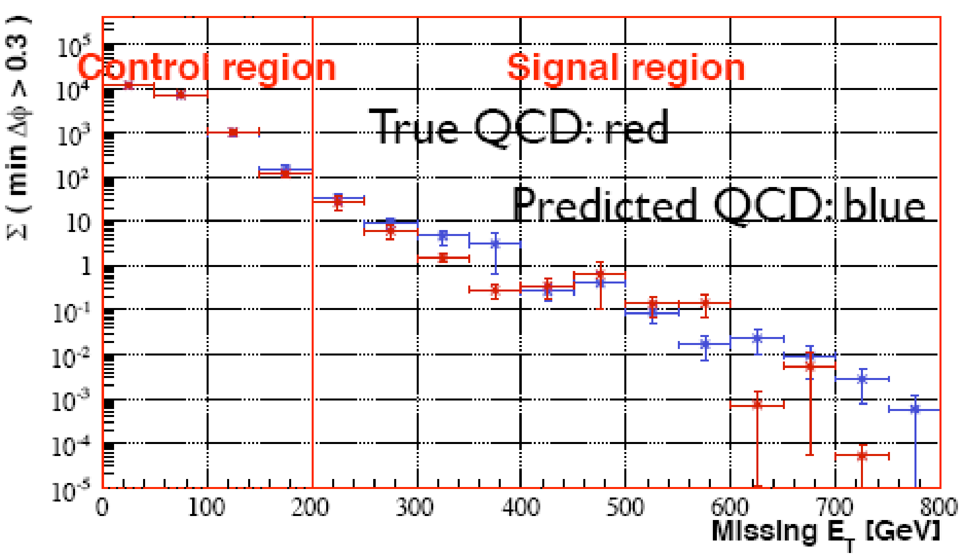
Extended ABCD Method

- The ratio is fitted in the background region (A, B) of the variable with better separation power
- The region D is scaled bin-wise with the fit result to give an estimation of QCD events in the signal region C
- For that purpose, we need variables that are correlated in a stable way
- The correlation can be influenced by the selection
- **AIM:** Find not correlated variables with enough separation power

Exponential fit of the ratio



QCD estimation



Talk from Sergei Bobrowskyi

Tiles Method

- Segment data in two discriminating variables into tiles (min 2x2).
- Expected total number of events in (2x2) tiles:

$$N^A = \varepsilon_{SM}^{A} N_{SM} + \varepsilon^{S}_{A} N_s$$
$$N^B = \varepsilon_{SM}^{B} N_{SM} + \varepsilon^{S}_{B} N_s$$
$$N^C = \varepsilon_{SM}^{C} N_{SM} + \varepsilon^{S}_{C} N_s$$
$$N^D = \varepsilon_{SM}^{D} N_{SM} + \varepsilon^{S}_{D} N_s$$

- Normalisation of the efficiencies implies:

$$N_{SM} + N_s = N^A + N^B + N^C + N^D$$

- System of four independent linear equations
- Once confronted with observations ($N^A = N^a_{obs}$ etc.), we have 10 unknowns.
- Taking the SM tile efficiencies from MC, we are left with 6 unknowns
- Further requiring that the signal variables are independent, one can write

$$\varepsilon^S_A = (1-\varepsilon^S_1)(1-\varepsilon^S_2), \quad \varepsilon^S_B = \varepsilon^S_1 (1-\varepsilon^S_2),$$
$$\varepsilon^S_C = (1-\varepsilon^S_1) \varepsilon^S_2, \quad \varepsilon^S_D = \varepsilon^S_1 \varepsilon^S_2$$

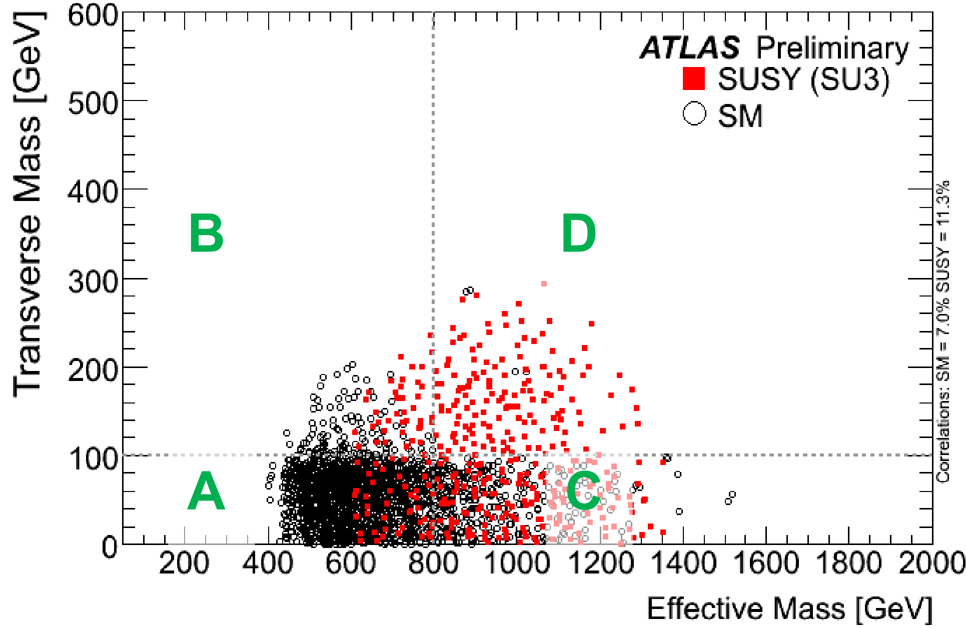
- And we can solve the sys. of four lin. eq. !

☑ SM correlation taken into account

☑ Signal contamination no problem

☑ No assumption made on signal except that it is uncorrelated btw. 2 variables

✘ Assumes SM eff. well described by MC



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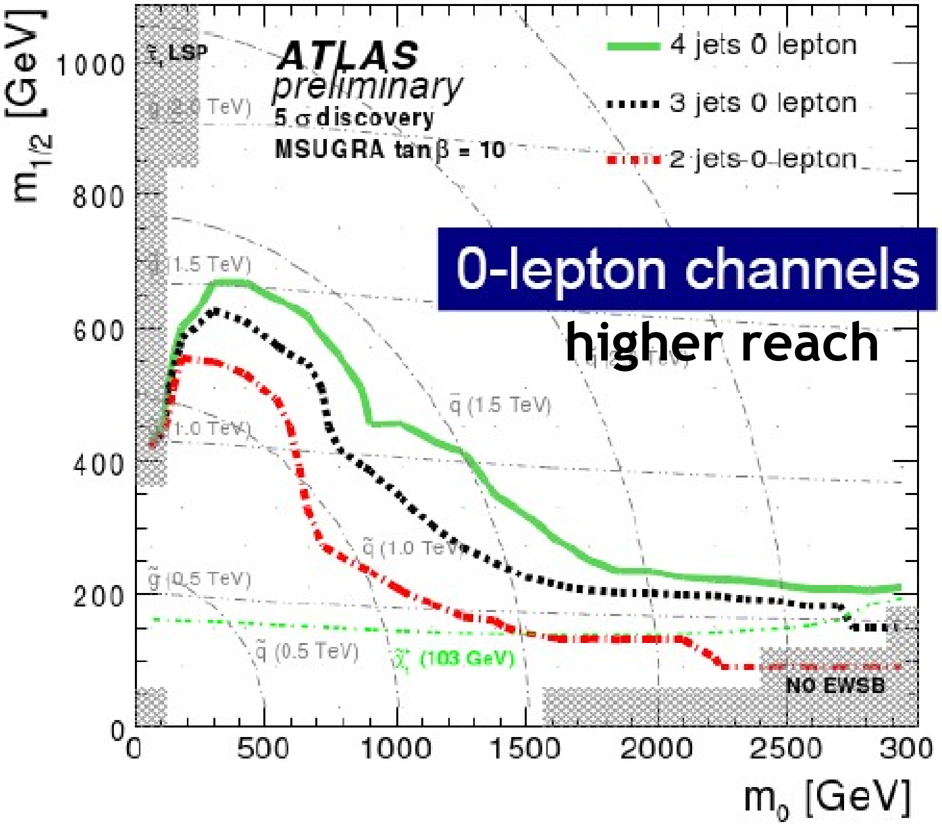
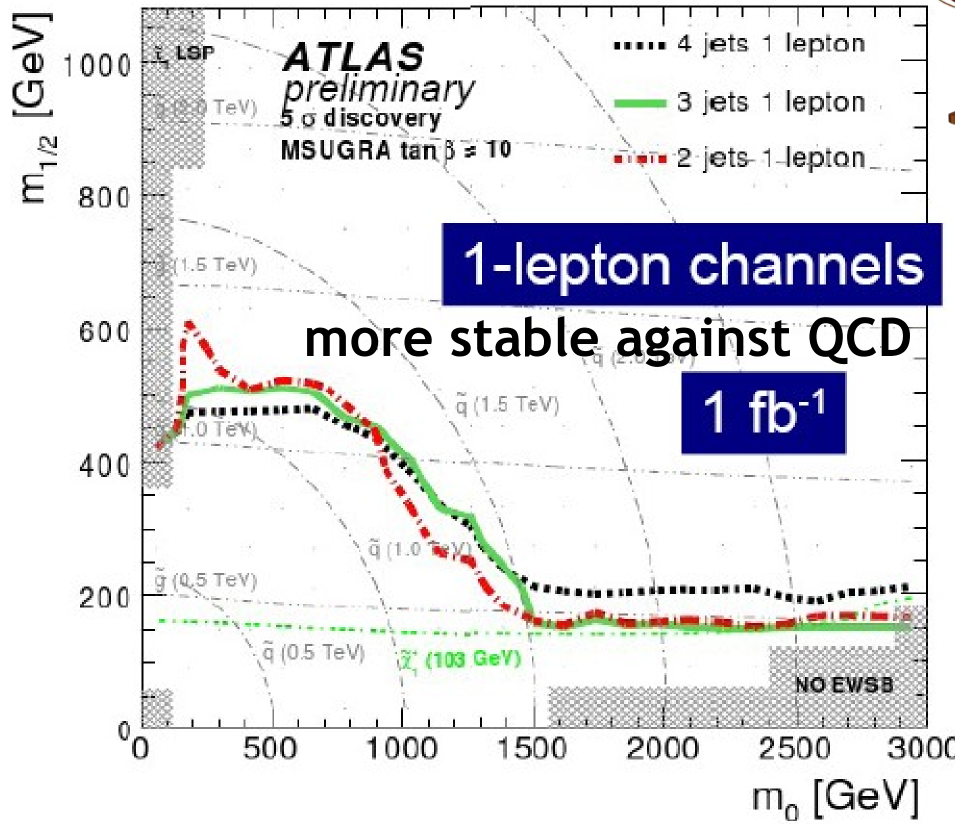
Method can be extended to more than 2×2 tiles

Talk from Till Eifert

Discovery Reach for Atlas

mSUGRA with tanβ=10





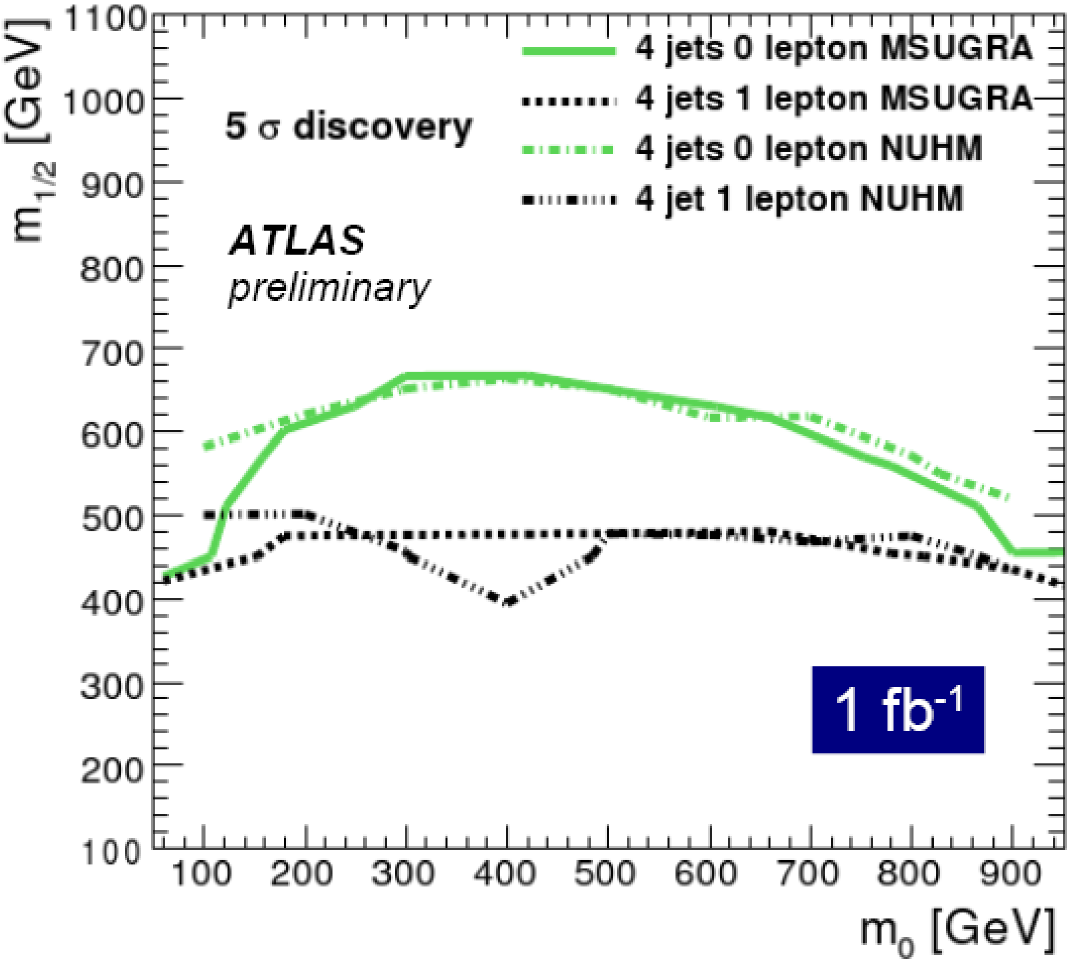
0-lepton channels: 4-jets channel gives highest reach
1-lepton channels: 2,3,4-jets channels with comparable sensitivity
For 100 pb^{-1} low jet multiplicities very promising also in 0 lepton mode

Talk from Jan E. Sundermann

Discovery Reach for Atlas cont

mSUGRA vs. NUHM

- NUHM (non-universal-higgs-model): Adjust values of μ and M_A to be compatible with CDM constraints
- 5σ discovery reach contours
- Comparison of 0 and 1-lepton measurements



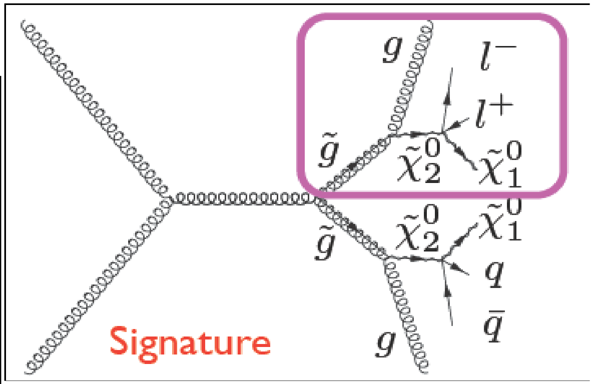
mSUGRA vs. NUHM: reach in 0 and 1-lepton channels comparable

Talk from Jan E. Sundermann

Dilepton Mass Edge Reconstruction

Selection Cuts

- 2 isolated leptons
  - Tracker isolation
- 4 Jets (120,80,80,80) GeV
- MET 50 GeV



expected mass edgeresolution:

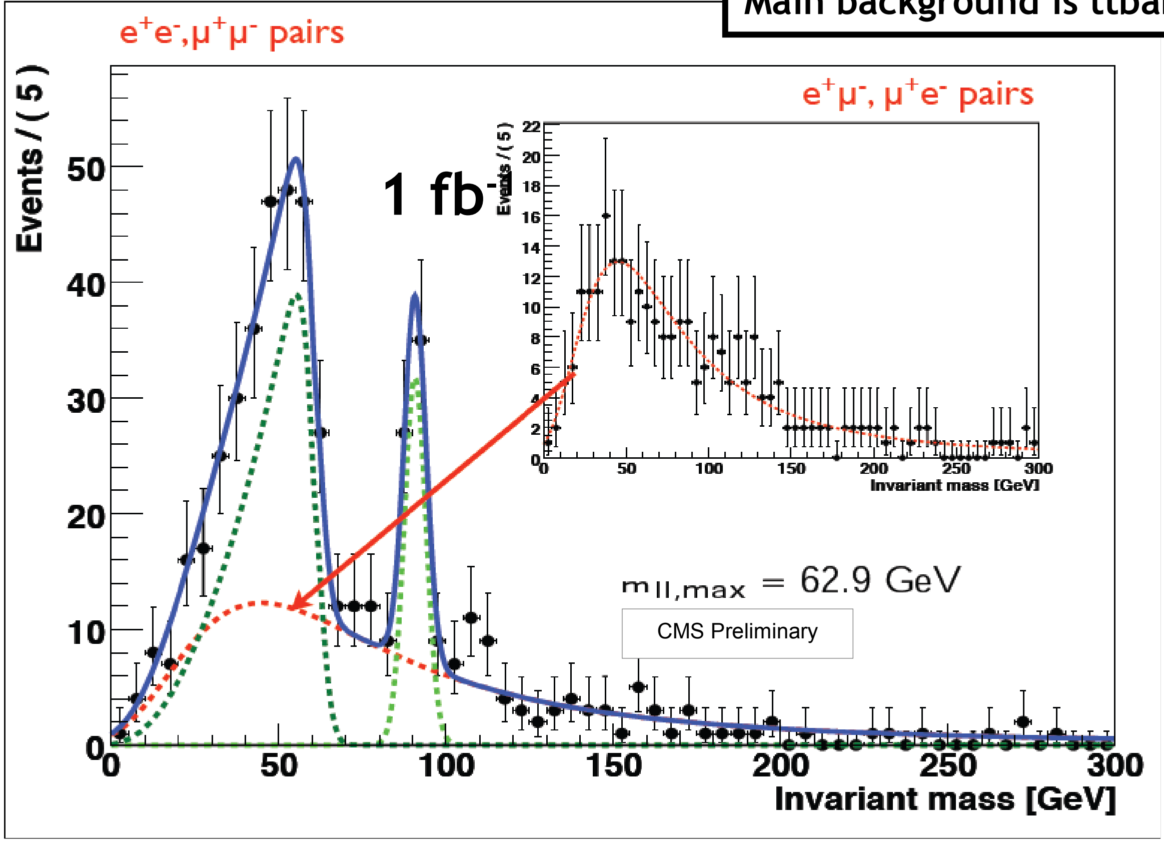
$$\Delta m_{\tilde{\chi}_2^0-\tilde{\chi}_1^0} = (62.8 \pm 0.8_{stat.}\ ^{+1.4}_{-1.7}\ _{syst.})\ \text{GeV}$$

Ns = 330, Nb = 366

Main background is ttbar

Invariant mass distribution can be used to measure dilepton invariant mass edge

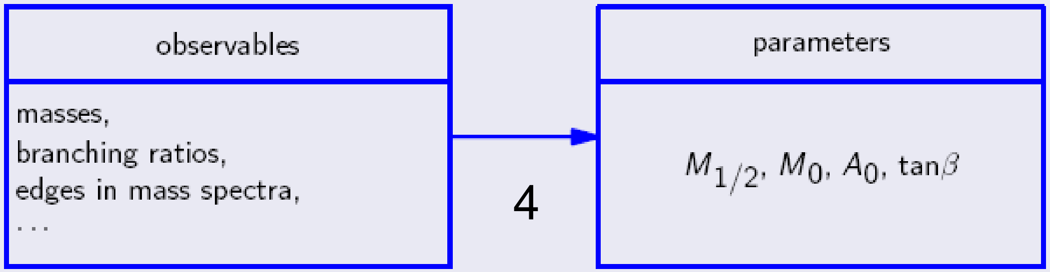
- SUSY edge
- Background Landau
  - from $e^+\mu^-$, μ^+e^- distribution
- Breit-Wigner convoluted with a gaussian
- Fit the whole invariant mass spectrum



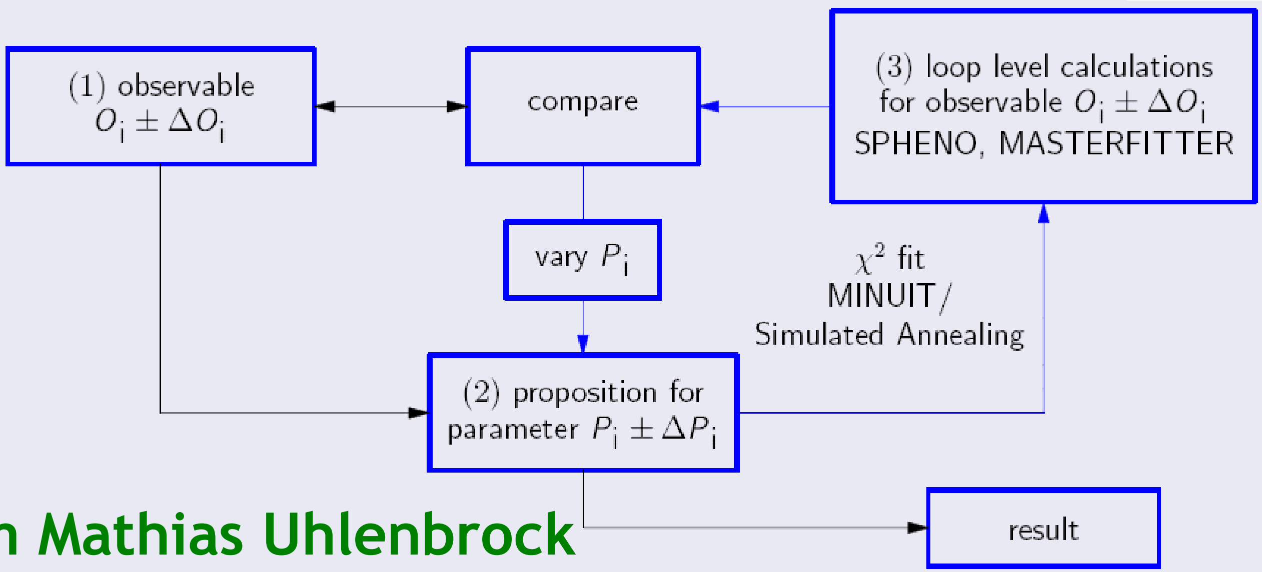
Talk from Martin Niegel (results from Niklas Mohr)

Parameter Reconstruction

- In general: observables $\neq$ parameters
- Reconstruction: mapping observables $\rightarrow$ parameters



- Difficulty: mapping not analytical due to higher order corrections
- But: theory gives mapping parameters $\rightarrow$ observables
- Strategy: vary parameters until predicted and measured observables in agreement



LHC observable (1 fb^{-1})
m_t
$m_{\tilde{q}_R} - m_{\tilde{\chi}_1^0}$
$m_{\ell\ell}^{\max}$
$m_{\tau\tau}^{\max}$
$m_{\ell\ell q}^{\max}$
$m_{\ell q}^{\mathrm{low}}$
$m_{\ell q}^{\mathrm{high}}$
$m_{\ell\ell q}^{\mathrm{thres}}$
m_{tb}^{w}
$\frac{\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\ell}\ell) \times \mathrm{BR}(\tilde{\ell} \to \tilde{\chi}_1^0 \ell)}{\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau) \times \mathrm{BR}(\tilde{\tau}_1 \to \tilde{\chi}_1^0 \tau)}$

low energy observable
σ_0^h (nb)
R_ℓ
A_{FB}^{ℓ}
A_ℓ(SLD)
Ωh^2
$\mathrm{R}(b \to s\gamma)$
$\Delta(g-2)_\mu$

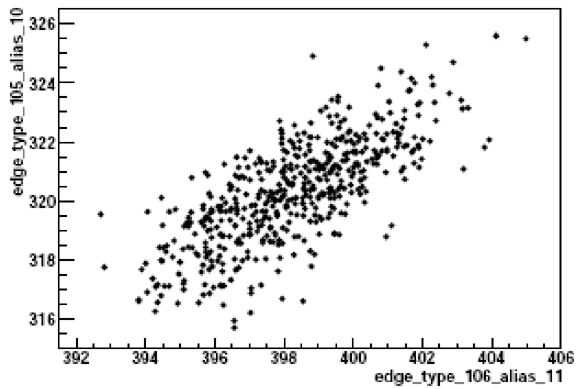
Talk from Mathias Uhlenbrock

Parameter Reconstruction cont

FITTINO $\mathcal{L}$ SUSY

observables

mass edge 2



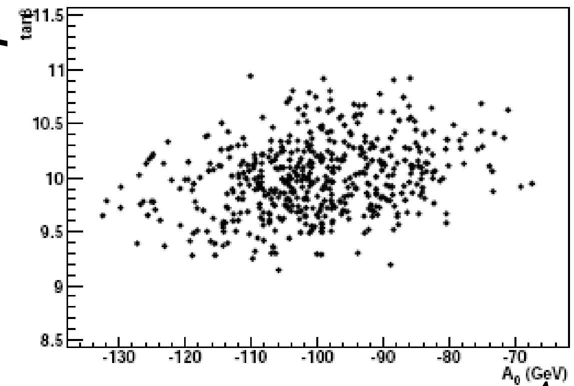
mass edge 1

fit

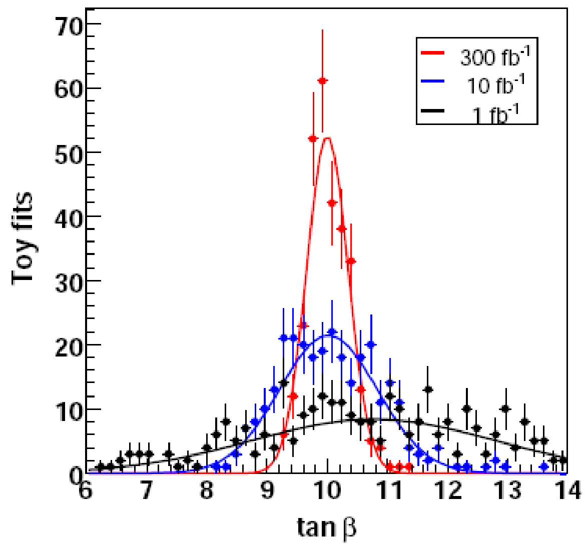
errors given by standard deviation

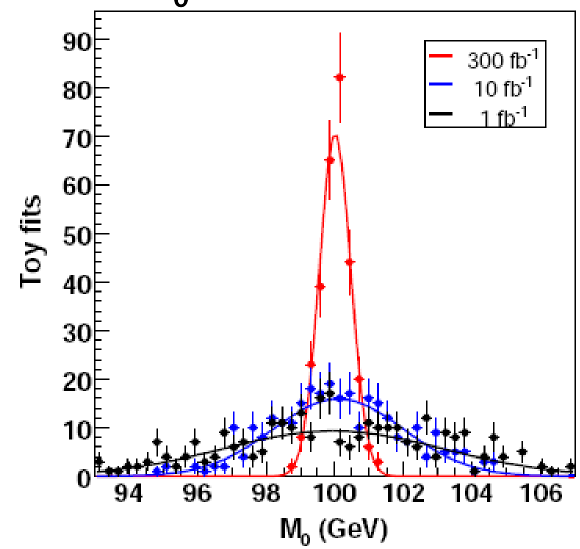
parameters

$\tan\beta$



A_0





Global Fits for different luminosities

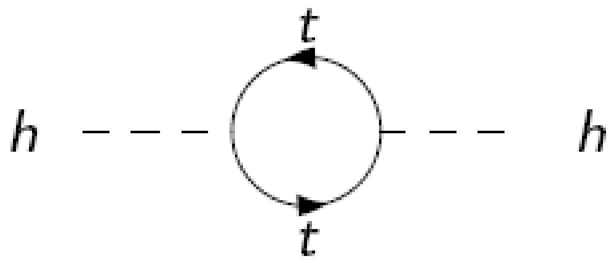
$\tan\beta$	M_0
300fb^{-1} : 10.02 ± 0.34 (3.39 %)	300fb^{-1} : 100.0 ± 0.4 (0.4 %)
10fb^{-1} : 10.01 ± 0.82 (8.19 %)	10fb^{-1} : 100.3 ± 1.9 (1.9 %)
1fb^{-1} : 10.68 ± 1.98 (18.54 %)	1fb^{-1} : 99.96 ± 3.15 (3.15 %)

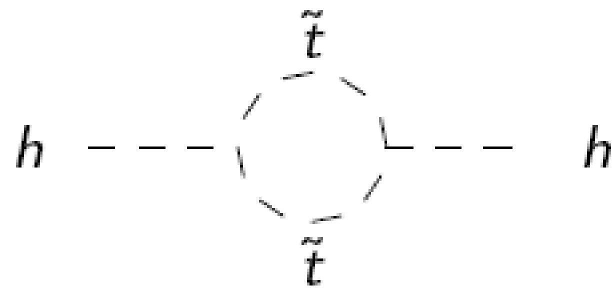
Talk from Mathias Uhlenbrock

3Loop Corr. to MSSM Higgs mass

simplifying assumptions

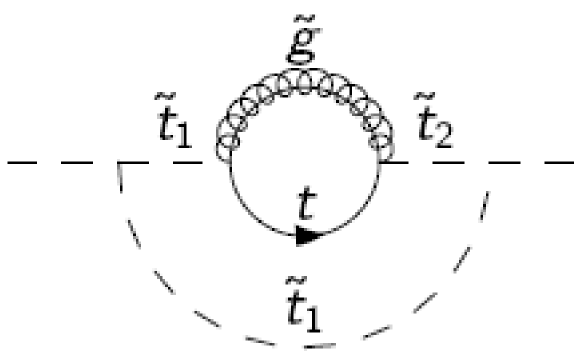
- effective potential approximation
- restrict to t, $\tilde{t}$ sector
  t, $\tilde{t}$, g, $\tilde{g}$, q and $\tilde{q}$ as internal particles
- assume mass hierarchy





$$
\begin{aligned}
m_q = 0, \quad m_t &\ll m_{\tilde{t}_1} = m_{\tilde{t}_2} = m_{\tilde{g}} = m_{\tilde{q}} \\
m_t &\ll m_{\tilde{t}_1} = m_{\tilde{t}_2} = m_{\tilde{g}} \ll m_{\tilde{q}} \\
m_t &\ll m_{\tilde{t}_1} \ll m_{\tilde{t}_2} = m_{\tilde{g}} \ll m_{\tilde{q}}
\end{aligned}
$$

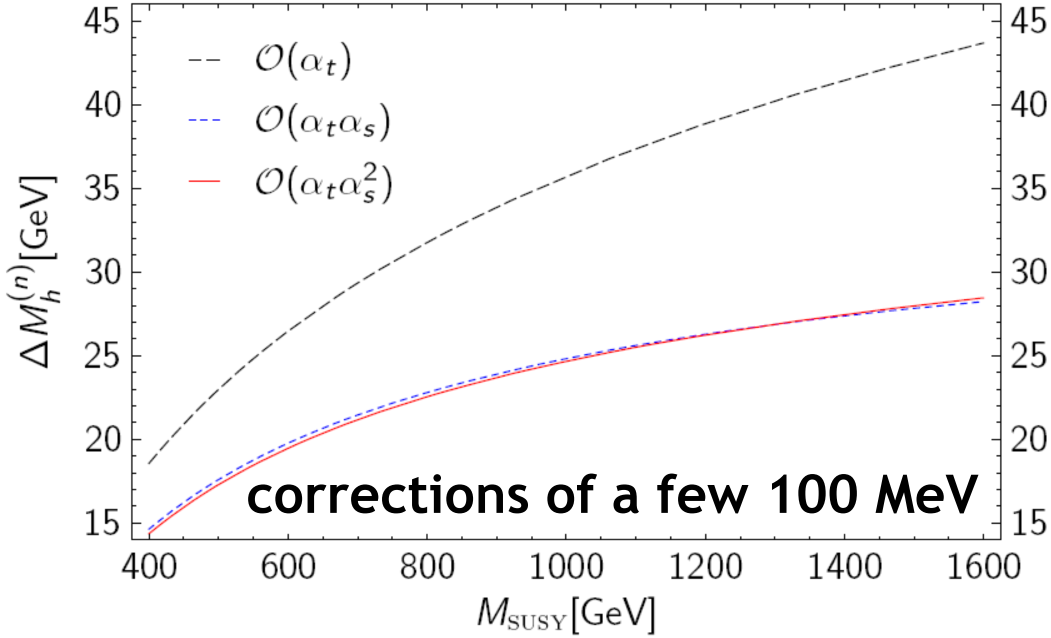
asymptotic expansion in small ratios of masses

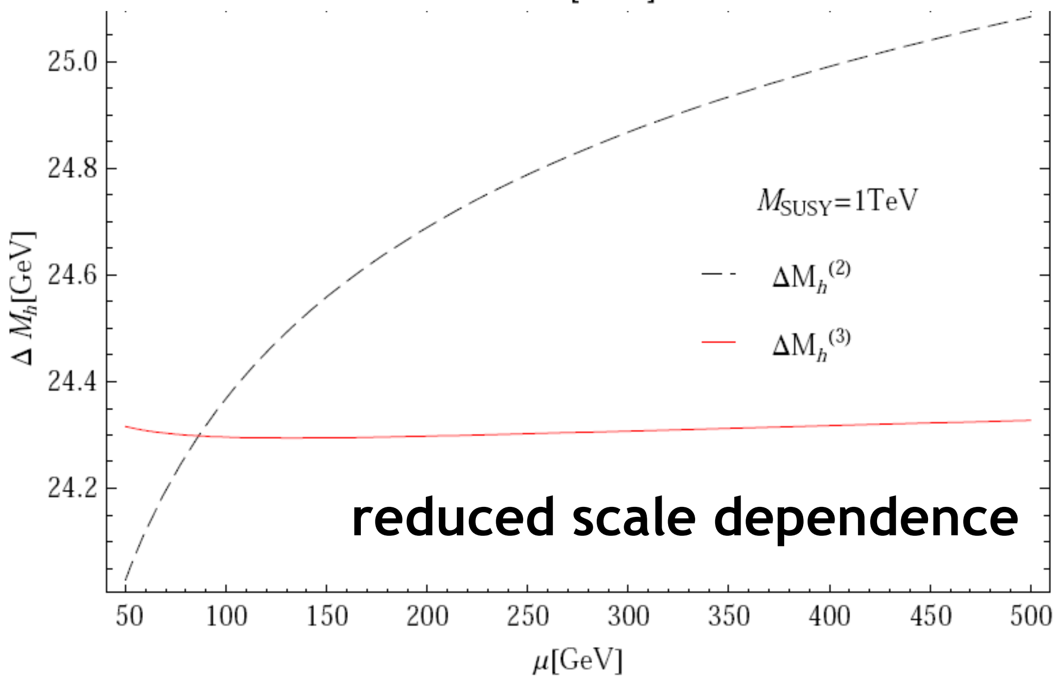


$$
\begin{aligned}
\Delta M_h \;=\; & -\frac{3 G_F M_t^4}{\sqrt{2}\pi^2}\Bigg\{ -L_{tS} + \frac{\alpha_s}{\pi}\left[4L_{tS} - 2L_{tS}^2\right] + \left(\frac{\alpha_s}{\pi}\right)^2 \Bigg[-\frac{1091}{324} - \frac{1}{27}\pi^2 - \frac{1}{9}\zeta_3 \\
& + \left(\frac{1591}{108} + 3L_{\mu t} - \frac{1}{3}\pi^2 + \frac{4}{9}\pi^2 \ln 2 - \frac{55}{18}L_{t\tilde{q}} - \frac{5}{6}L_{t\tilde{q}}^2\right) L_{tS} \\
& + \left(-\frac{19}{18} - \frac{3}{2}L_{\mu t} + \frac{5}{3}L_{t\tilde{q}}\right) L_{tS}^2 - \frac{53}{18}L_{tS}^3 \\
& + \left(-\frac{475}{108} + \frac{5}{9}\pi^2\right) L_{t\tilde{q}} + \frac{25}{36}L_{t\tilde{q}}^2 + \frac{5}{18}L_{t\tilde{q}}^3 \\
& + \mathcal{O}\left(\frac{M_S^2}{M_{\tilde{q}}^2}\right)\Bigg]\Bigg\}, \quad L_{tS} = \ln\frac{M_t^2}{M_{SUSY}^2}, \quad L_{\mu t} = \ln\frac{\mu^2}{M_t^2}, \quad L_{t\tilde{q}} = \ln\frac{Mt^2}{M_{\tilde{q}}^2}
\end{aligned}
$$

Talk from Philipp Kant

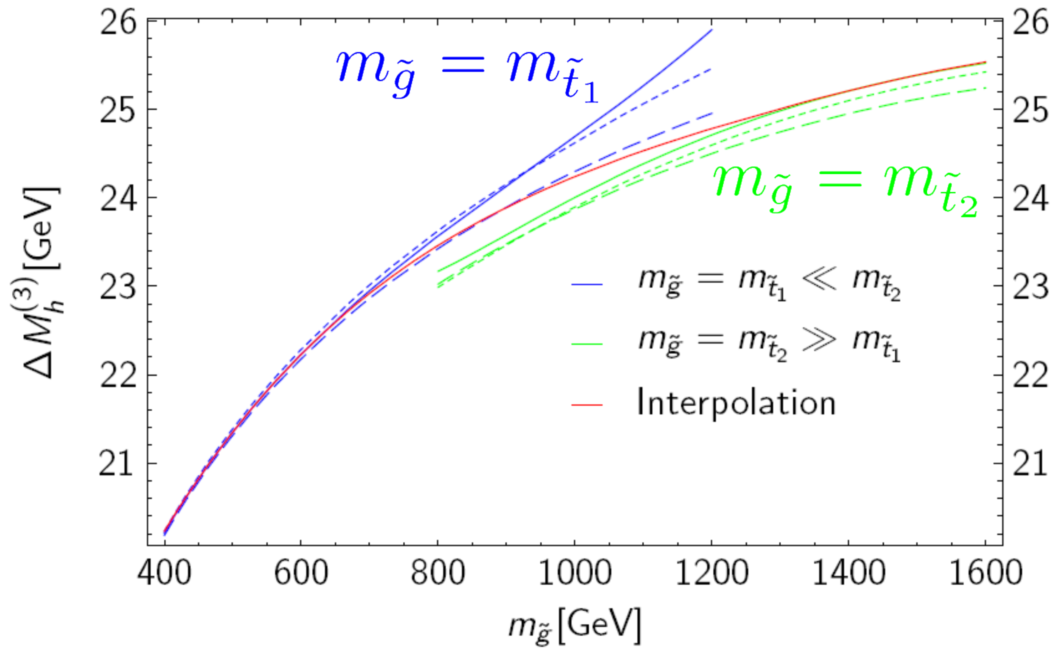
3Loop Corr. to MSSM Higgs mass cont





- important for possible discovery of MSSM
  light supersymmetric Higgs might be first trace of supersymmetry
- experimental accuracy
  $\delta M_h \approx 100 - 200$MeV at LHC, $\delta M_h \approx 50$MeV at ILC

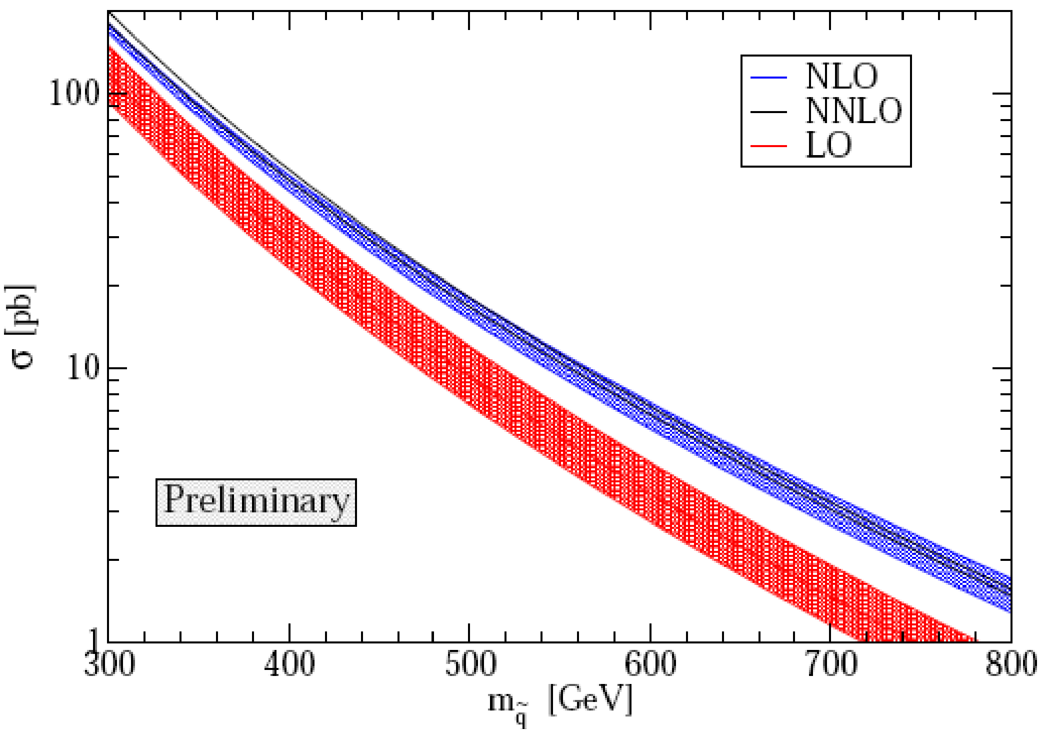
non-degenerated spectrum

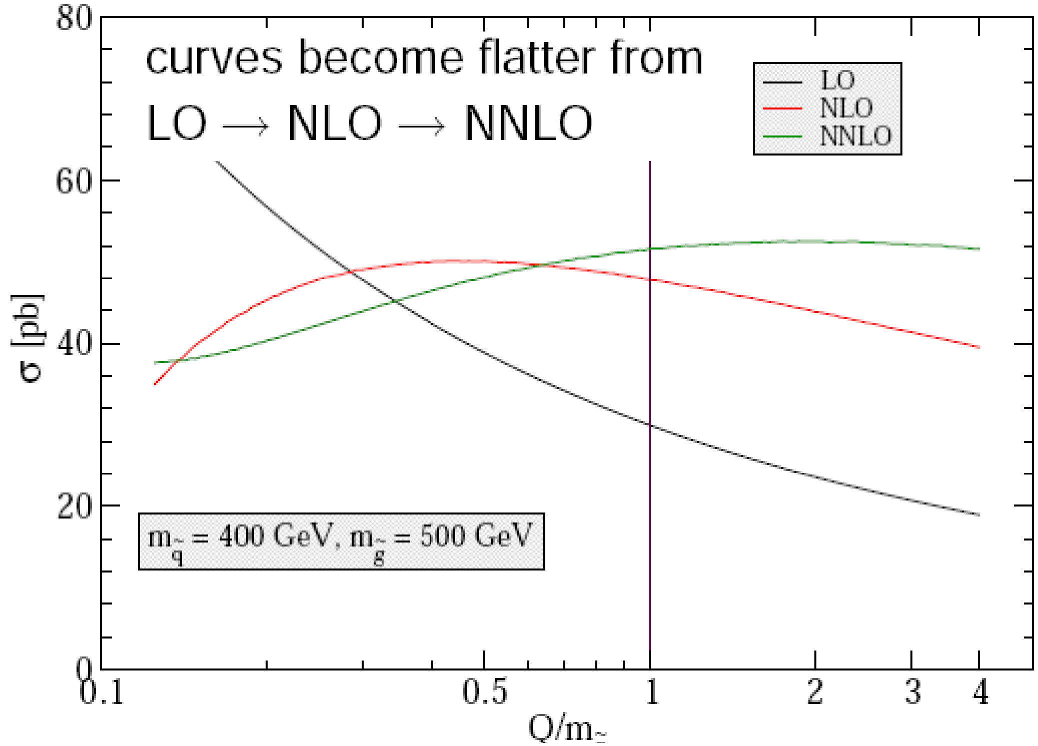


Talk from Philipp Kant

NNLO Corr. Squark-Antisquark Prod.

- Full NNLO: Very complex calculation
- Particles are produced near kinematical production threshold
- Therefore: Soft gluon resummation (Tool for calculating approximated N^kLO results)

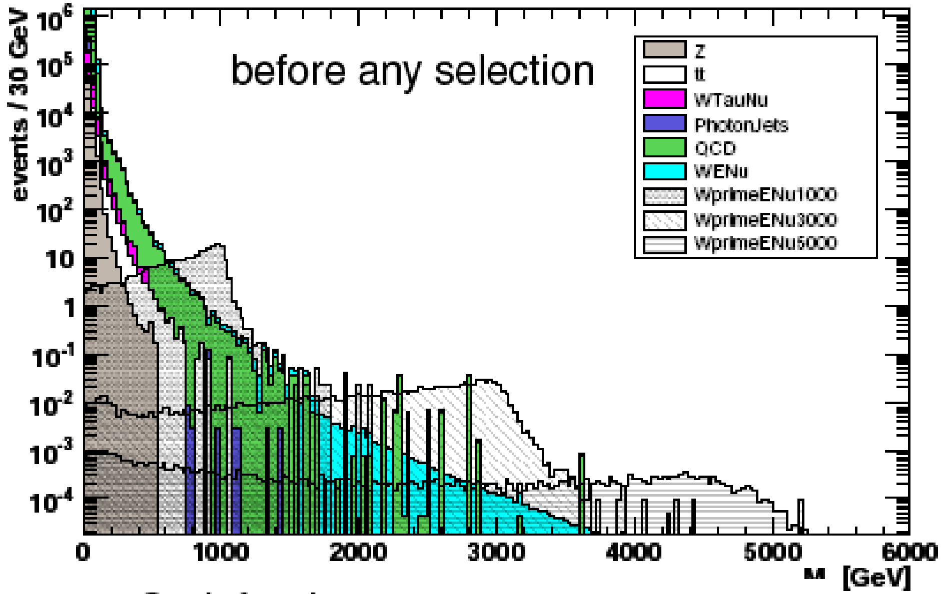




- NNLO correction are about 5 – 10% of the NLO cross section
- Raising of mass bounds: 100 pb 310 GeV LO, 340 GeV NLO, 345 GeV

Talk from Ulrich Langenfeld

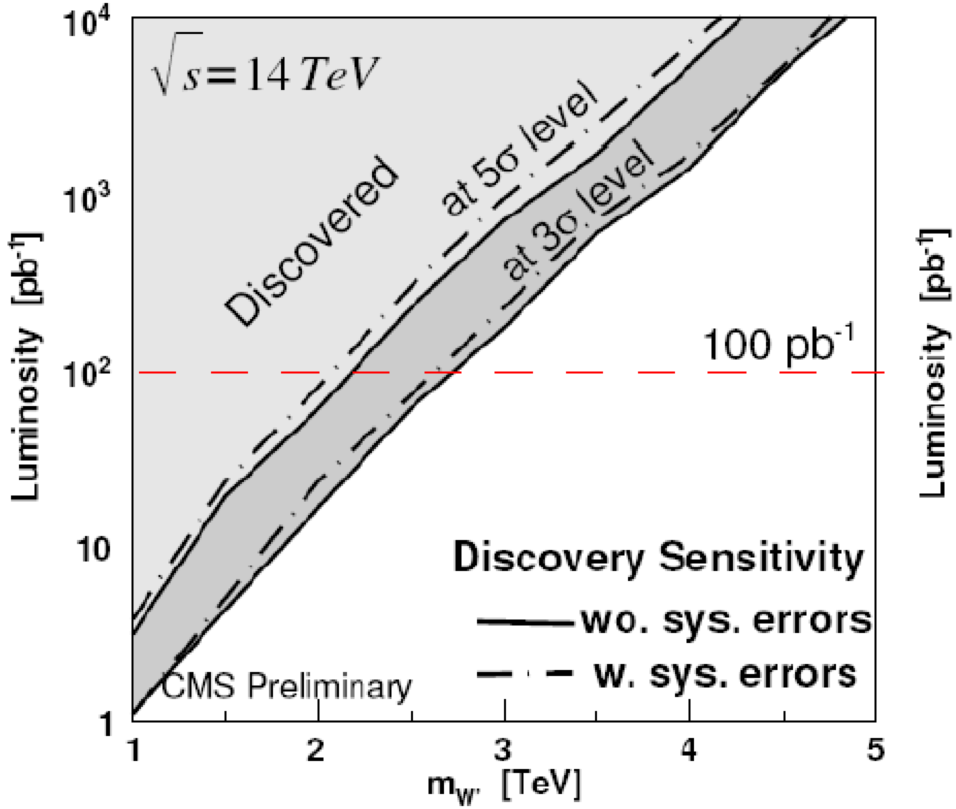
W' Searches at CMS



- Satisfy trigger
- Exactly one electron $E_{T,e} > 30$ GeV
- High E_T electron isolation criteria
- Topological selections:
  - Cut on the angle between electron and MET
  - Cut on the energy ratio between electron and MET

transverse mass:

$$m_T = \sqrt{2 \cdot MET \cdot E_T^{el} \cdot (1 - \cos(\Delta\,\phi))}$$



- Evidence at about ~2.5 TeV
- Discovery at about 2 TeV

Talk from Walter Bender

Summary

- Most of the BSM activities in the alliance are SUSY related
- mSUGRA is popular but also studies with other breaking scenarios were presented
- Data taking slowly approaching: focus is shifted to data driven background estimation instead of “simple” MC studies
- Progress on the theory side is manifold:
  - Higher order corrections to Higgs masses and squark production cross sections become available
  - ... a lot of more very interesting presentations were given (often with direct relation to the LHC)