Warszawa ECFA

Alternatives, EW, Top (and QCD)

Summary

On behalf of all speakers

ECFA 9-12 June Warszawa – Helenka Przysiezniak Frey @ U.of Montreal + CNRS

Initial studies of top pair production
(Andreas Moll, Alexei Raspereza)

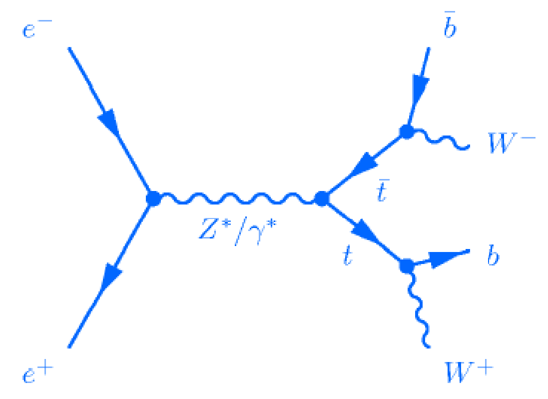
Goal: estimate statistical error on top mass+width for ILC from direct reconstruction of top decays. This method provides a consistency check and is complementary to the threshold scan technique.

Tools used in this analysis:

Mokka – flexible geant4 based detector simulation framework

Marlin – modular and detector independent reconstruction software

- btag information from LCFIVertex package used
- kinematic fitting applied

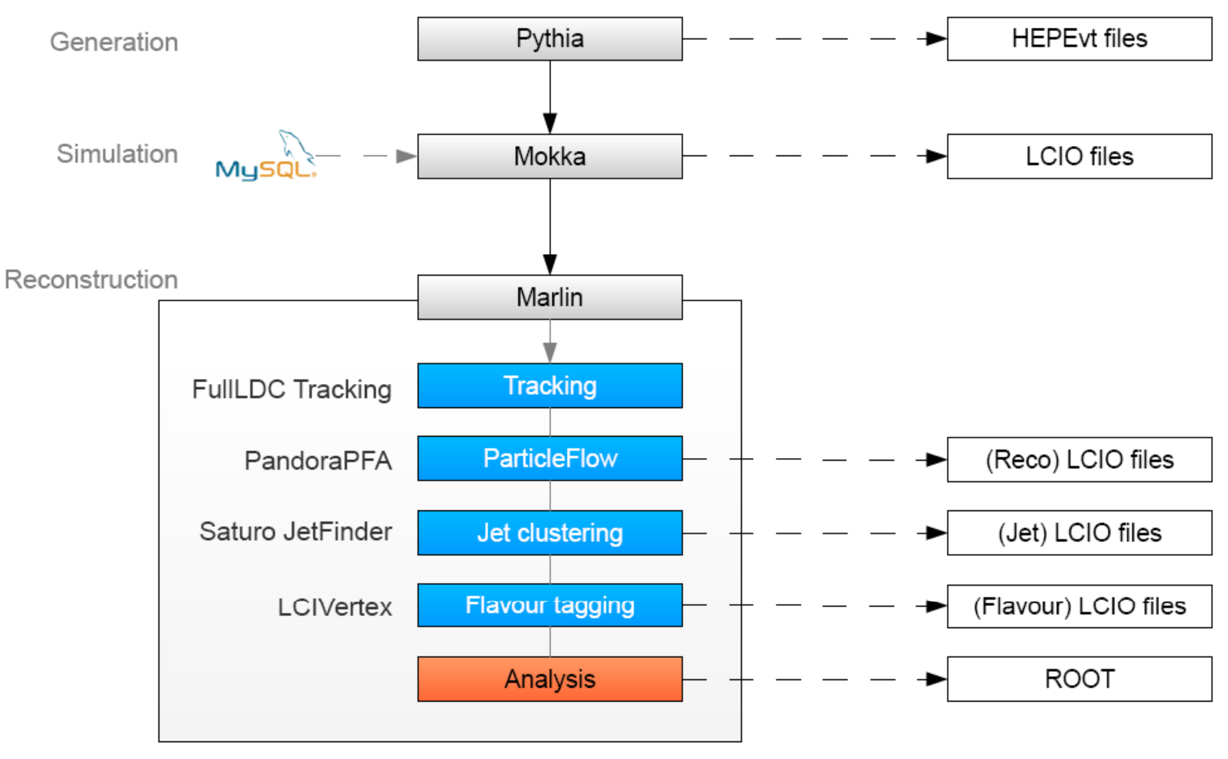


fully hadronic $t\bar{t}$ decay mode used:

$$t\bar{t} \to (W^+ b)(W^- \bar{b})$$

$W \to q\bar{q}$ *branching ratio 44.4 %*

$$\boxed{t\bar{t} \to 6\ jets}$$



Generation — Pythia → HEPEvt files

Simulation — MySQL → Mokka → LCIO files

Reconstruction — Marlin

FullLDC Tracking — Tracking

PandoraPFA — ParticleFlow → (Reco) LCIO files

Saturo JetFinder — Jet clustering → (Jet) LCIO files

LCIVertex — Flavour tagging → (Flavour) LCIO files

Analysis → ROOT

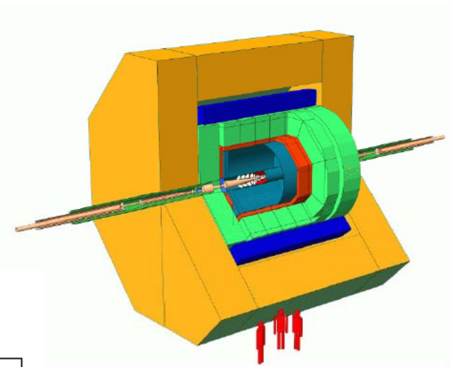
Initial studies of top pair production
(Andreas Moll, Alexei Raspereza)

- Pandora Particle flow algorithm used
- Tracking in VTX/TPC/SiT/FTD
- Clustering of hits in ECAL/HCAL
- Selections cuts
- B-tag
- Kinematic fit

Mokka: geant4 based framework for full detector simulation

Detector used for simulation with Mokka: **LDCPrime_02Sc_p01**

⇨ Interpolation between the two detector concepts GLD and LDC



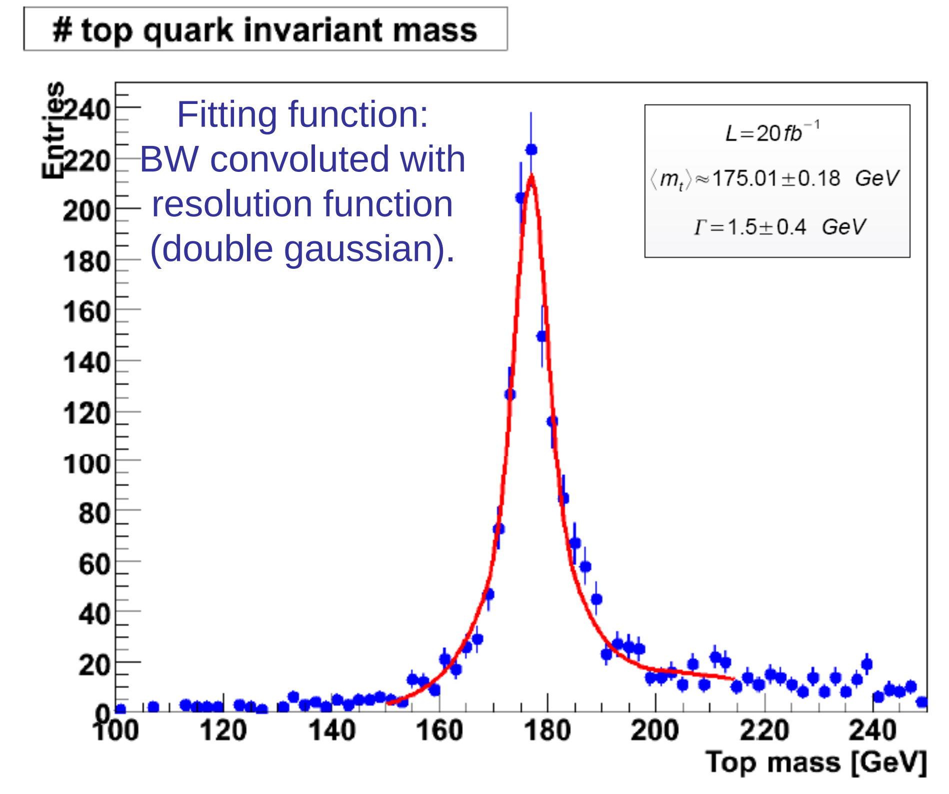
Magnetic field: 3.5 T

Tracking:

VTX	(inner radius = 1.5 cm)
TPC	($R = 1.7\,m$, $L = 4.4\,m$)
FTD	(acceptance down to 7 degrees in polar angle)

High granularity calorimeters:

ECAL	$W - Si$, $23\,X_0$, $1x1\,cm^2$
HCAL	Iron – Scintillator, ~4-6 λ, $3x3\,cm^2$



Fitting function:
BW convoluted with
resolution function
(double gaussian).

Conclusion

Top quark invariant mass reconstructed!!!

- full ILD detector simulation
- full hadronic bgd
- complete reco

Result extrapolated for higher lumi:
Δm_{top} = 50 MeV (stat) for 300 fb-1

Analysis will be used for
detector optimization
and performance studies
and should be included in LOI

A 4th generation scenario (François Richard)

Expect the unexpected (at the LHC) ! Like a heavy Higgs, or heavy fermions without SUSY.
Why not through a 4th generation? It is possible (!!) :

The 4th chiral generation is excluded by S/T constraints only for the mass degenerate case !!

$$\boxed{\Delta T \sim \frac{\Delta m^2}{(150 GeV)^2}} \qquad \boxed{\Delta S = \frac{N_c}{6\pi}\left(1 - 2Y \ln \frac{m_u^2}{m_d^2}\right)}$$

hence when ΔT=0 and ΔS=3/4π .
So one can play with the positive correlation between these variables
and easily pass the constraints when fermions are partially degenerate in mass

The main motivation for more than 3 generations is baryogenesis

Baryogenesis needs C+CP violation & strong EW 1st order transition
SM alone ?
Not enough CPV and insufficient EW transition
MSSM alone ?
New phases but severely constrained by EDM and EW transition not strong enough
→ extra particles needed, strongly coupled to the Higgs field, scalars or fermions
(cf. Carena etal. hep-ph 0410352)

With a 4th generation :

- CPV fine
- Large Yukawa couplings to Higgs field (**strong** at scale ~TeV)
- However not enough to get the right EW transition

Hence include SUSY → 4MSSM (R. Fok G. Kribs **arXiv:0803.4207**)

A 4th generation scenario
(François Richard)

Predictions and present day results

- 300<Mt’,b’<450 GeV + lighter leptons
- Squarks ~ mass degenerate with quarks
- Higgs could be heavy through radiative corrections
- Spectacular & early signals at LHC
- Accessible at a TeV LC (heavy leptons)
- Interesting Tevatron results : searches exclude mt’<260 GeV & 140<mH<180 GeV and b-sector results could point to 4th gen.

$$m_h^2 = \sum_{f=t,t',b'} \frac{3}{2\pi^2}\frac{m_f^4}{v^2}\ln\frac{m_{\tilde{f}}^2}{m_f^2} \,.$$

Outlook and Conclusion

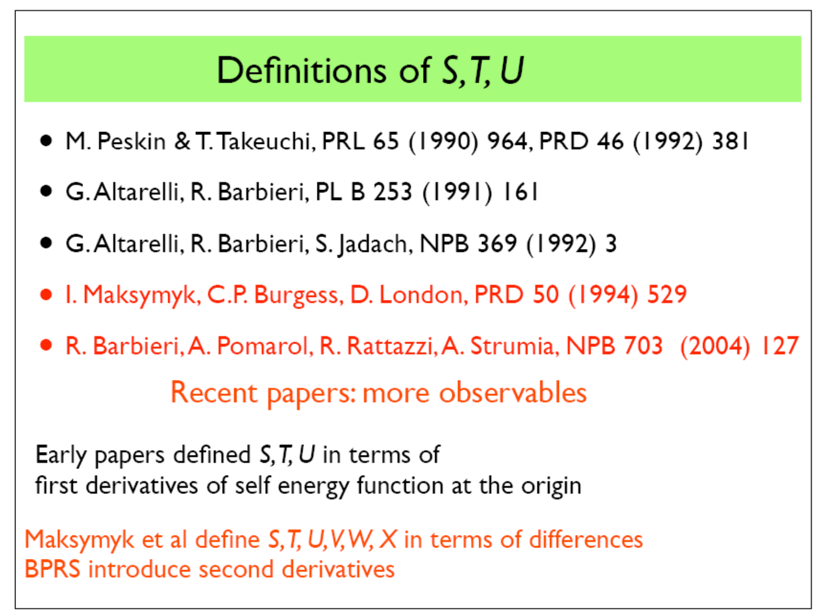
- At LHC an early discovery of the new fermions + SUSY squarks
- In addition to a heavy Higgs, which can easily be observed
- ILC very powerful in particular for leptons and for a light Higgs

- Requires SUSY but cannot be extrapolated to GUT because of the large Yukawa constants
- Allows for a heavy Higgs within SUSY
- Rich physics for a TeV LC
- $\rightarrow$ Could serve as an illustration of LHC/LC complementarity

STU in mHDM:
Precision constraints on multi-Higgs doublet models
(Per Osland
based on work with W.Grimus, L.Lavoura, OM Ogreid)

$$\rho = \frac{m_W^2}{m_Z^2 \cos^2\theta_W}$$

where ρ-1 = Δρ ≈ αT



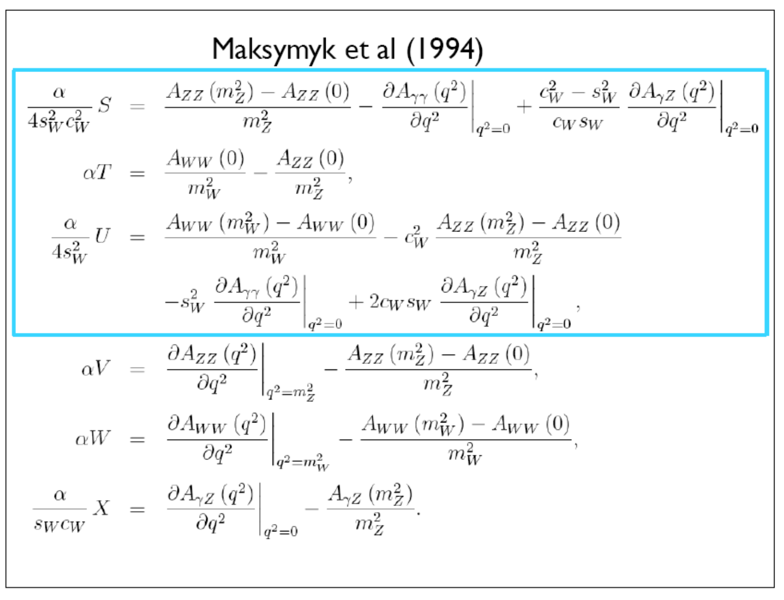
Definitions of *S, T, U*

- M. Peskin & T. Takeuchi, PRL 65 (1990) 964, PRD 46 (1992) 381
- G. Altarelli, R. Barbieri, PL B 253 (1991) 161
- G. Altarelli, R. Barbieri, S. Jadach, NPB 369 (1992) 3
- I. Maksymyk, C.P. Burgess, D. London, PRD 50 (1994) 529
- R. Barbieri, A. Pomarol, R. Rattazzi, A. Strumia, NPB 703 (2004) 127

Recent papers: more observables

Early papers defined *S, T, U* in terms of
first derivatives of self energy function at the origin

Maksymyk et al define *S, T, U, V, W, X* in terms of differences
BPRS introduce second derivatives



Maksymyk et al (1994)

$$\begin{aligned}
\frac{\alpha}{4s_W^2c_W^2}S &= \frac{A_{ZZ}(m_Z^2)-A_{ZZ}(0)}{m_Z^2} - \left.\frac{\partial A_{\gamma\gamma}(q^2)}{\partial q^2}\right|_{q^2=0} + \frac{c_W^2-s_W^2}{c_W s_W}\left.\frac{\partial A_{\gamma Z}(q^2)}{\partial q^2}\right|_{q^2=0}\\
\alpha T &= \frac{A_{WW}(0)}{m_W^2} - \frac{A_{ZZ}(0)}{m_Z^2},\\
\frac{\alpha}{4s_W^2}U &= \frac{A_{WW}(m_W^2)-A_{WW}(0)}{m_W^2} - c_W^2\,\frac{A_{ZZ}(m_Z^2)-A_{ZZ}(0)}{m_Z^2}\\
&\quad -s_W^2\left.\frac{\partial A_{\gamma\gamma}(q^2)}{\partial q^2}\right|_{q^2=0} + 2c_W s_W\left.\frac{\partial A_{\gamma Z}(q^2)}{\partial q^2}\right|_{q^2=0},\\
\alpha V &= \left.\frac{\partial A_{ZZ}(q^2)}{\partial q^2}\right|_{q^2=m_Z^2} - \frac{A_{ZZ}(m_Z^2)-A_{ZZ}(0)}{m_Z^2},\\
\alpha W &= \left.\frac{\partial A_{WW}(q^2)}{\partial q^2}\right|_{q^2=m_W^2} - \frac{A_{WW}(m_W^2)-A_{WW}(0)}{m_W^2},\\
\frac{\alpha}{s_W c_W}X &= \left.\frac{\partial A_{\gamma Z}(q^2)}{\partial q^2}\right|_{q^2=0} - \frac{A_{\gamma Z}(m_Z^2)}{m_Z^2}.
\end{aligned}$$

There are 3 kinds of scalars
• scalar SU(2) doublets (1 charged and 1 neutral component)
• charged SU(2) singlets
• neutral SU(2) singlets
where the neutral fields have vevs

STU in mHDM: Precision constraints on multi-Higgs doublet models
(Per Osland based on work with W.Grimus, L.Lavoura, OM Ogreid)

Scalars couple to W and Z via covariant derivatives, except for the neutral singlets
S,T,U expressions were shown in the talk while V,W,X given in arXiv0802.4353

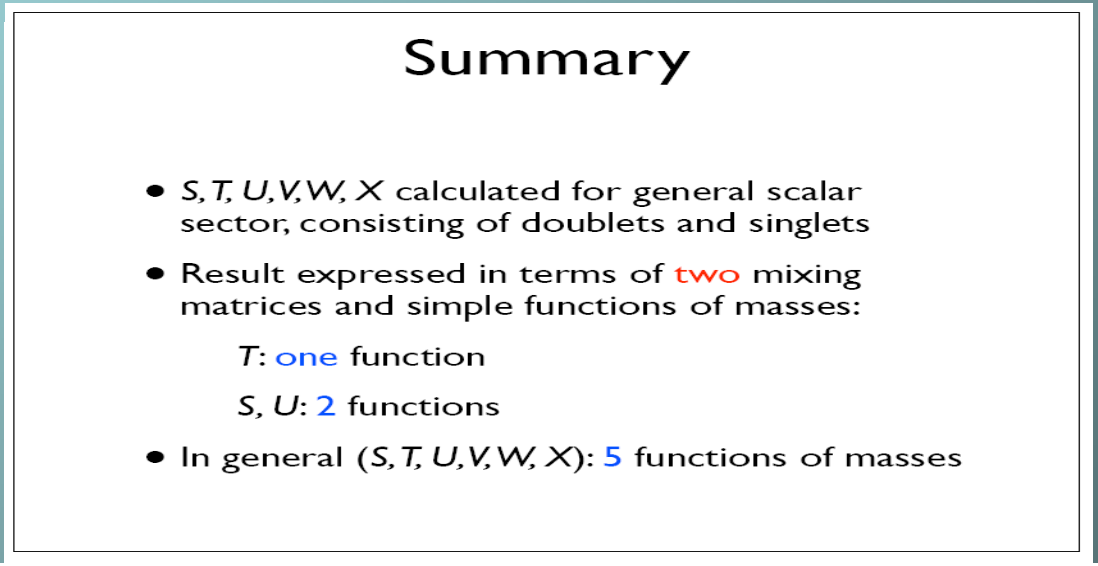
Applications with 2HDM :

• In the limit of $m_Z=m_W$, with partial degeneracy m_2=(charged)=$\mu_3=\mu_4$ (neutrals), T~0

• In the limit of CP conservation while applying the custodial symmetry $m_2=\mu_4$,T~0

• In twisted custodial symmetry,
T does not vanish but can be made close to 0 by a suitable choice of masses.

• For inert or dark scalar, with μ_4 being the SM Higgs
T will vanish in the limits of $m_2=\mu_3$ or $m_2=\mu_4$



Summary

- S, T, U, V, W, X calculated for general scalar sector, consisting of doublets and singlets
- Result expressed in terms of two mixing matrices and simple functions of masses:

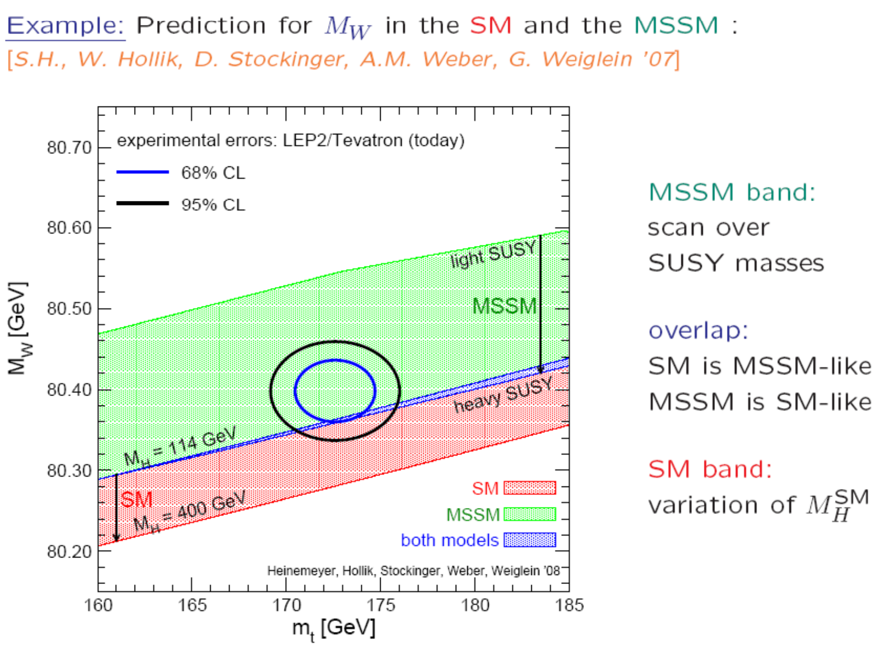
  T: one function

  S, U: 2 functions
- In general (S, T, U, V, W, X): 5 functions of masses

Constraining SUSY with Electroweak Precision Observables (Sven Heinemeyer

based on collaboration with W.Hollik, AM Weber and G.Weiglein)

Search for indirect effects of SUSY via Precision Observables (POs)
by comparing EW POs (m_W, $\sin^2\theta_{eff}$,Γ_Z,…) with theory (SM, MSSM, …)
Test of the theory at quantum level by its senstitivy to loop corrections.
Very high accuracy of measurements and theoretical predictions needed.

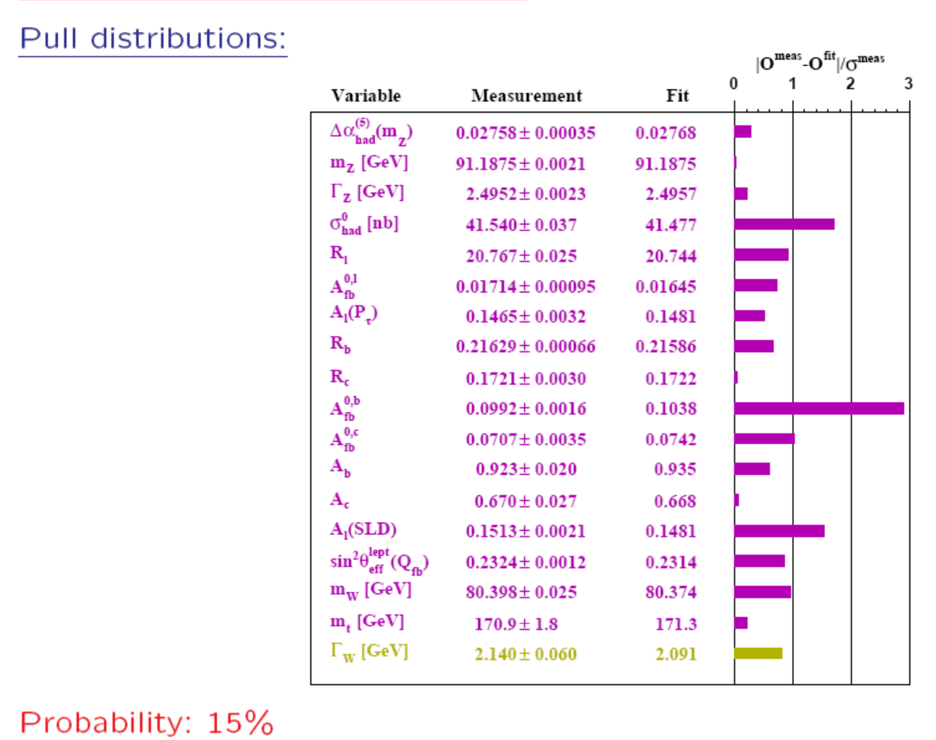


Example: Prediction for M_W in the SM and the MSSM :
[S.H., W. Hollik, D. Stockinger, A.M. Weber, G. Weiglein '07]

MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of M_H^{SM}



Results for EWPO fit in the SM: [LEPEWWG '08]

Pull distributions:

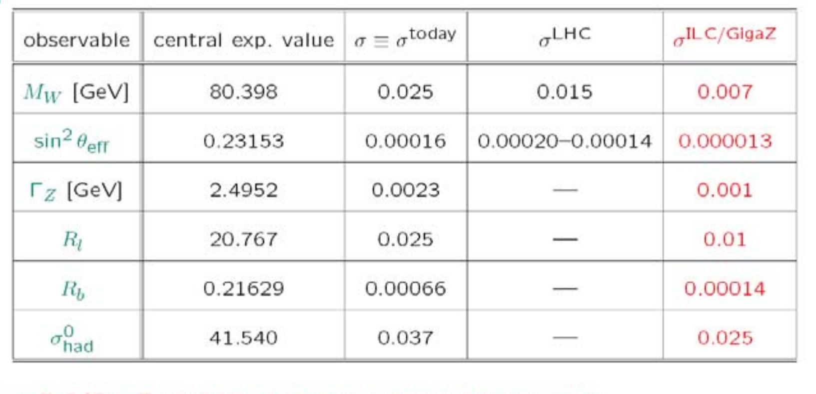
Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
m_t [GeV]	170.9 ± 1.8	171.3
Γ_W [GeV]	2.140 ± 0.060	2.091

Probability: 15%

Constraining SUSY with Electroweak Precision Observables

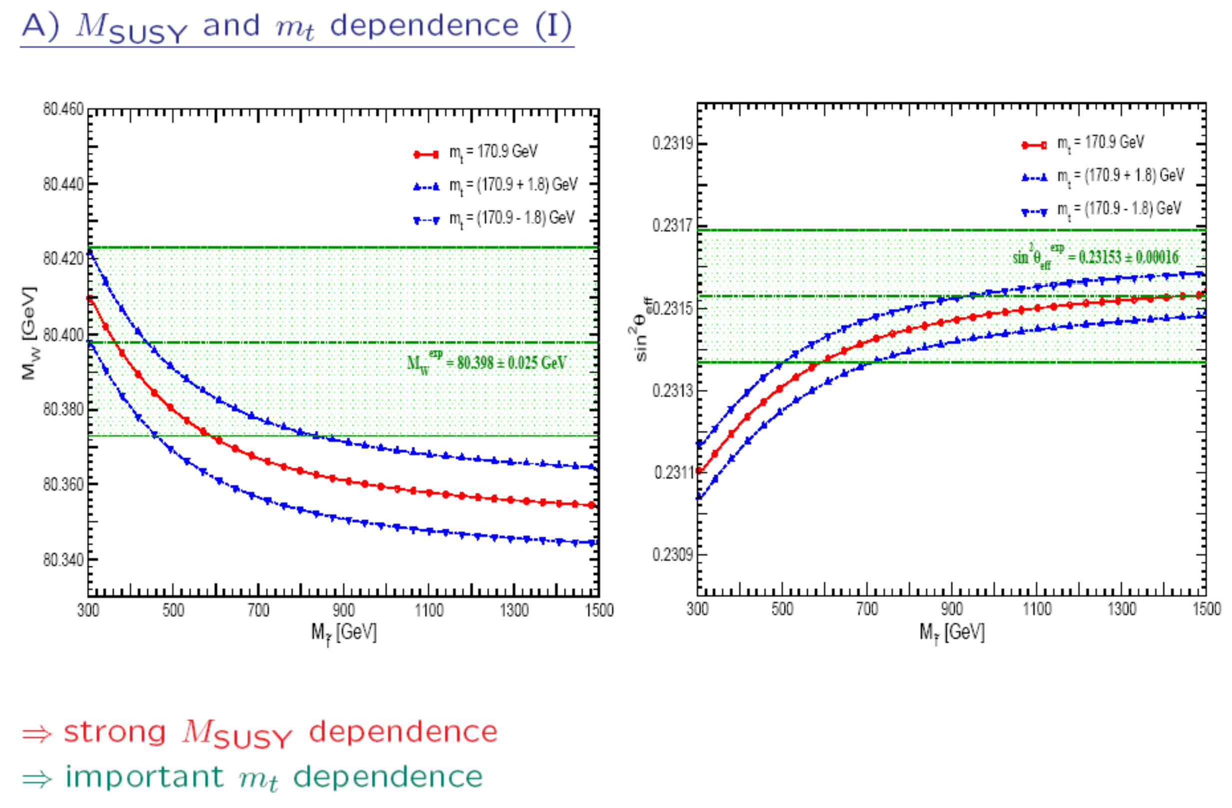
(Sven Heinemeyer based on collaboration with W.Hollik, AM Weber and G.Weiglein**)**

Perform fit
with MSSM predictions
of EW POs



observable	central exp. value	$\sigma \equiv \sigma^{\text{today}}$	σ^{LHC}	$\sigma^{\text{ILC/GigaZ}}$
M_W [GeV]	80.398	0.025	0.015	0.007
$\sin^2\theta_{\text{eff}}$	0.23153	0.00016	0.00020–0.00014	0.000013
Γ_Z [GeV]	2.4952	0.0023	—	0.001
R_l	20.767	0.025	—	0.01
R_b	0.21629	0.00066	—	0.00014
σ^0_{had}	41.540	0.037	—	0.025

⇒ ILC/GigaZ precision yields a very strong improvement



A) M_{SUSY} and m_t dependence (I)

⇒ strong M_{SUSY} dependence

⇒ important m_t dependence

m_W, $\sin^2\theta_{\text{eff}}$ strong dependance
while Γ_Z relevant dependance
on m_t and m_{SUSY}

m_W, $\sin^2\theta_{\text{eff}}$, Γ_Z
strong dependance
on μ and on M_2 for small M_2

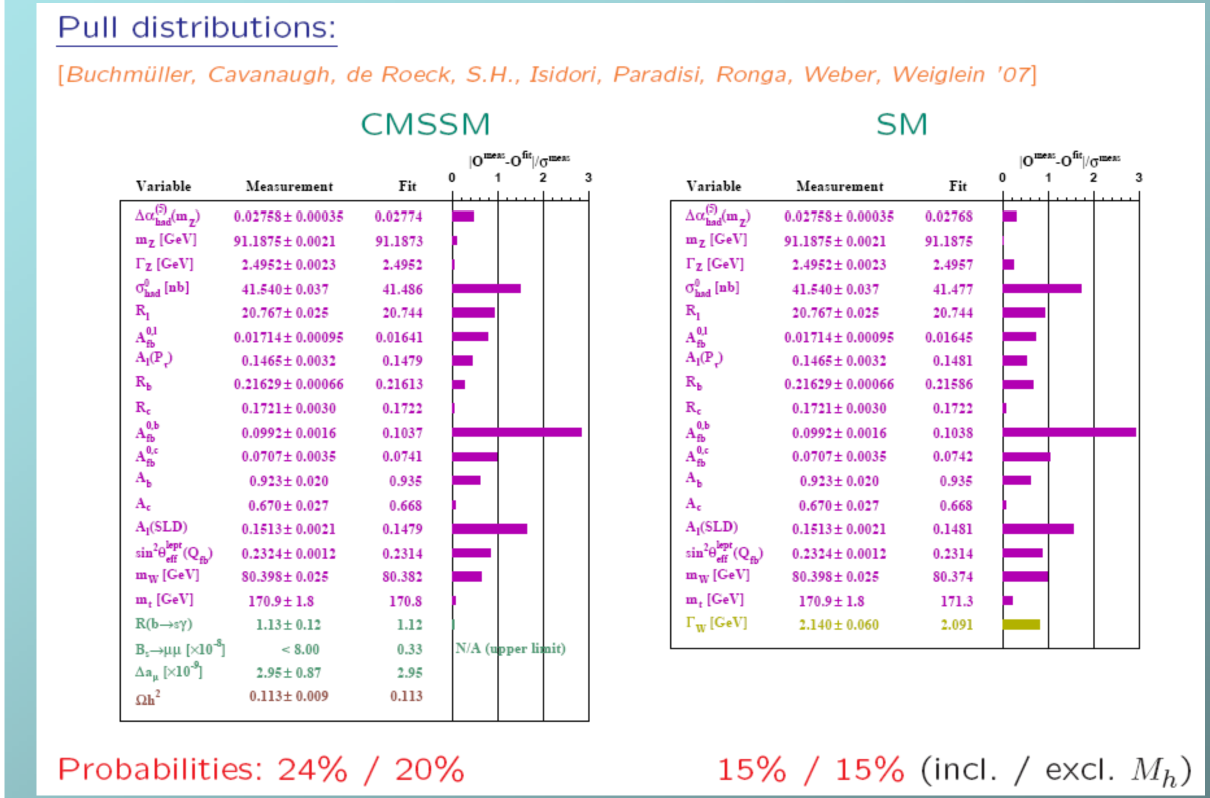
Also studied complex phases
in the squark sector
dependance
of EW POs predictions

Split SUSY model predictions
not at all dependant.

Constraining SUSY with Electroweak Precision Observables
(Sven Heinemeyer based on collaboration with W.Hollik, AM Weber and G.Weiglein)

In a scenario with no SUSY particles at the LHC,
looking at $\sin^2\theta_{eff}$
the ILC (1000)/GigaZ could detect SUSY directly or indirectly.

Made studies of the CMSSM/mSUGRA



Pull distributions:

[Buchmüller, Cavanaugh, de Roeck, S.H., Isidori, Paradisi, Ronga, Weber, Weiglein '07]

CMSSM

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ^0_{had} [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times 10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times 10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

SM

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1875	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957	
σ^0_{had} [nb]	41.540 ± 0.037	41.477	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21586	
R_c	0.1721 ± 0.0030	0.1722	
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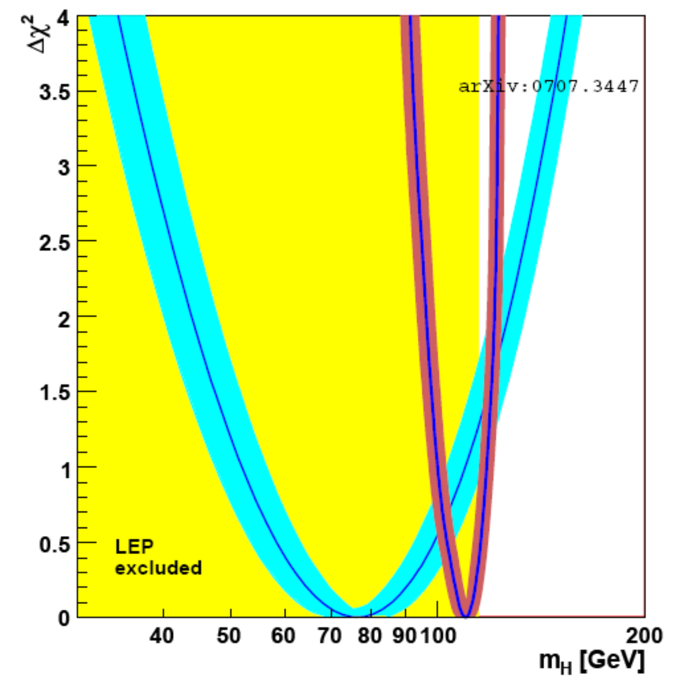
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.374	
m_t [GeV]	170.9 ± 1.8	171.3	
Γ_W [GeV]	2.140 ± 0.060	2.091	

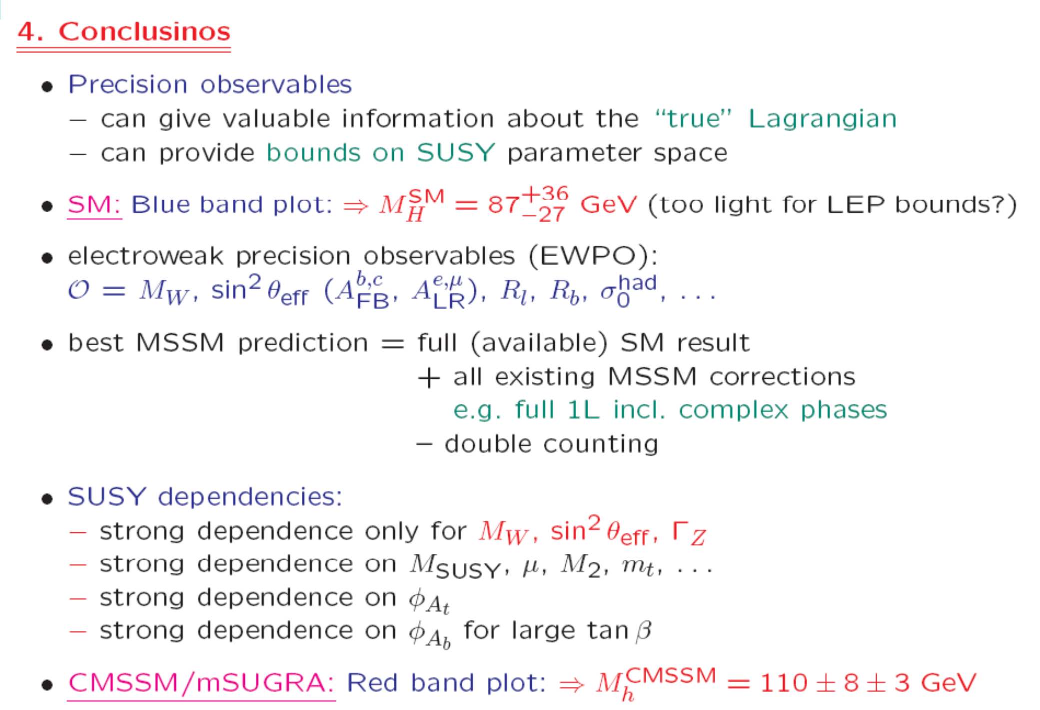
Probabilities: 24% / 20% 15% / 15% (incl. / excl. M_h)



Red band (CMSSM)
versus blue band (SM) !!!

Constraining SUSY with Electroweak Precision Observables

(Sven Heinemeyer based on collaboration with W.Hollik, AM Weber and G.Weiglein)



4. Conclusinos

- Precision observables
  - can give valuable information about the "true" Lagrangian
  - can provide bounds on SUSY parameter space
- SM: Blue band plot: ⇒ $M_H^{\mathrm{SM}} = 87^{+36}_{-27}$ GeV (too light for LEP bounds?)
- electroweak precision observables (EWPO):
  $\mathcal{O} = M_W,\ \sin^2\theta_{\mathrm{eff}}\ (A_{\mathrm{FB}}^{b,c},\ A_{\mathrm{LR}}^{e,\mu}),\ R_l,\ R_b,\ \sigma_0^{\mathrm{had}},\ \ldots$
- best MSSM prediction = full (available) SM result
  + all existing MSSM corrections
  e.g. full 1L incl. complex phases
  − double counting
- SUSY dependencies:
  - strong dependence only for M_W, $\sin^2\theta_{\mathrm{eff}}$, Γ_Z
  - strong dependence on M_{SUSY}, μ, M_2, m_t, ...
  - strong dependence on ϕ_{A_t}
  - strong dependence on ϕ_{A_b} for large $\tan\beta$
- CMSSM/mSUGRA: Red band plot: ⇒ $M_h^{\mathrm{CMSSM}} = 110 \pm 8 \pm 3$ GeV

Personal conclusions:

very nice session with extremely clear talks
and strong dynamical audience dependance