Indirect constraints on the (C)MSSM parameter space

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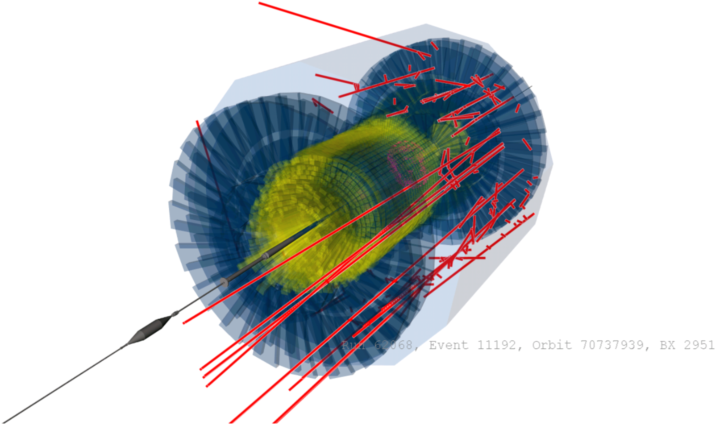
ETH Zurich – Switzerland

CKM Workshop, Rome – September 11, 2008

Contents

The LHC has turned on!

Busy beam "event" lighting up the CMS detector, Sep. 10, 2008



- last moment to circumscribe the SUSY playground for LHC. . .
  - ⇒ global fit to today's experimental data

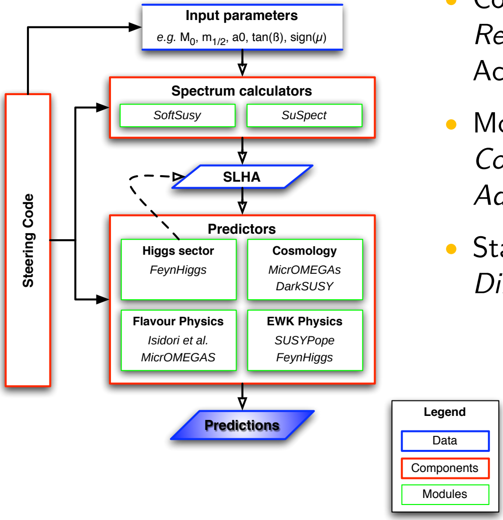
Using external constraints: the CMSSM case

- Today's external constraints
  - Low Energy (precision) data:
    - Flavour Physics (in particular B Physics)
    - Other low-energy observables (*e.g.*, $g-2$)
  - High energy (precision) data:
    - Precision electroweak observables (*e.g.*, m_{top}, m_{W})
  - Cosmology/Astroparticle data:
    - *e.g.*, relic density
- How to exploit this information?
  - ⇒ state-of-the-art theoretical predictions ("tools")
  - ⇒ a framework to consistently combine the tools
- Collaboration between experiment and theory

Buchmüller, Oliver (CERN) – Exp.
De Roeck, Albert (CERN & Uni. Antwerpen) – Exp.
Flächer, Henning (CERN) – Exp.
Isidori, Gino (INFN Frascati) – Theo.
Paradisi, Paride (Tech. Uni. München) – Theo.
Weiglein, Georg (Durham) – Theo.
Cavanaugh, Richard (Uni. of Florida) – Exp.
Ellis, John (CERN) – Theo.
Heinemeyer, Sven (Santander) – Theo.
Olive, Keith (Uni. of Minnesota) – Theo.
Ronga, Frédéric (CERN) – Exp.

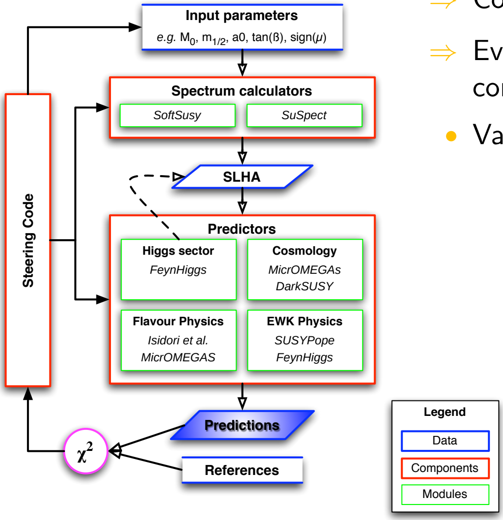
Combining today's constraints

Common framework for indirect constraints



- Consistency
  Relies on the SUSY Les Houches Accord *(SLHA)*
- Modularity
  Compare calculations
  Add/remove predictions
- State-of-the art calculations
  Direct use of code from experts

Use-case: fit today's data (χ^2 minimisation)



⇒ Constrain SUSY parameter space

⇒ Even more interesting when combined with discoveries!...

- Various modes:
  - Overall best minimum (`Minuit`)
  - χ^2 scan
  - Markov chain Monte Carlo

χ^2 fit of the CMSSM parameters

- Multi-parameter χ^2 fit:

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_j^M \frac{(f_{\mathrm{SM}_j}^{\mathrm{obs}} - f_{\mathrm{SM}_j}^{\mathrm{fit}})^2}{\sigma(f_{\mathrm{SM}_j})^2}$$

C_i: experimental constraint

P_i: predicted value for a given CMSSM parameter set

- fitting for all CMSSM parameters:
  - m_0 – common scalar mass (at GUT scale)
  - $m_{1/2}$ – common gaugino mass (at GUT scale)
  - a_0 – tri-linear mass parameter (at GUT scale)
  - $\tan\beta$ – ratio of Higgs vacuum expectation values
  - sign(μ) – sign of Higgs mixing parameter (fixed)
- including relevant SM uncertainties (m_{top}, m_{Z}, $\Delta\alpha_{\mathrm{had}}^{(5)}$)

Details in O. Buchmüller *et al.*, PLB 657/1-3 pp. 87-94

List of available predictions [relevant today already]

Low energy observables

$R(b \to s\gamma)$	Isidori & Paradisi	micrOMEGAs
$R(B \to \tau\nu)$	Isidori & Paradisi	
$BR(K \to \tau\nu)$	Isidori & Paradisi	
$R(B \to X_s \ell\ell)$	Isidori & Paradisi	
$R(K \to \pi\nu\bar{\nu})$	Isidori & Paradisi	
$BR(B_s \to \ell\ell)$	Isidori & Paradisi	micrOMEGAs
$BR(B_d \to \ell\ell)$	Isidori & Paradisi	
$R(\Delta m_s)$	Isidori & Paradisi	
$R(\Delta m_s)/R(\Delta m_d)$	Isidori & Paradisi	
$R(\Delta m_K)$	Isidori & Paradisi	
$R(\Delta_0(K^*\gamma))$	SuperIso*	
$\Delta(g-2)$	FeynHiggs	

Higgs sector observables

m_h^{light}	FeynHiggs

Cosmology observables

Ωh^2	micrOMEGAs	DarkSUSY
σ_p^{SI}	DarkSUSY*	

Electroweak observables

$\Delta\alpha_{\text{had}}^{(5)}(m_Z^2)$	SUSY-Pope
m_Z	SUSY-Pope
σ_{had}^0	SUSY-Pope
R_l	SUSY-Pope
$A_{\text{fb}}(\ell)$	SUSY-Pope
$A_\ell(P_\tau)$	SUSY-Pope
R_b	SUSY-Pope
R_c	SUSY-Pope
$A_{\text{fb}}(b)$	SUSY-Pope
$A_{\text{fb}}(c)$	SUSY-Pope
A_b	SUSY-Pope
A_c	SUSY-Pope
$A_\ell(\text{SLD})$	SUSY-Pope
$\sin^2\theta_w^\ell(Q_{\text{fb}})$	SUSY-Pope
m_W	SUSY-Pope
m_t	SUSY-Pope

* not used in this study

What's new?

- Extensive sampling of the CMSSM parameter space:
  - 25 million Markov chain Monte Carlo points
  - all constraints included (in particular from flavour physics)
  - overall best fit point determined using `Minuit`
- All constraints updated to most recent values
  - W and top masses (latest Tevatron results)
  - B physics ($B \to \tau\nu$, $b \to s\gamma$)
  - $g - 2$

⇒ Prospects for LHC discoveries

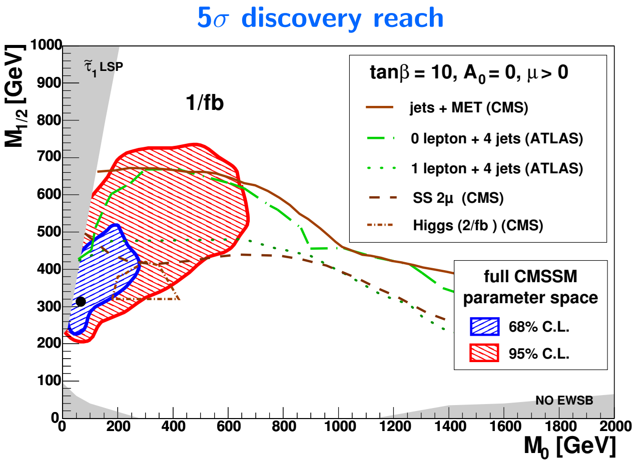
⇒ Influence of various constraints

  - "Re-weighting" of χ^2 on 25 million points
  - removal/inclusion of constraints, scaling of constraints' error

Details in: O. Buchmüller *et al.*, arXiv:0808.4128

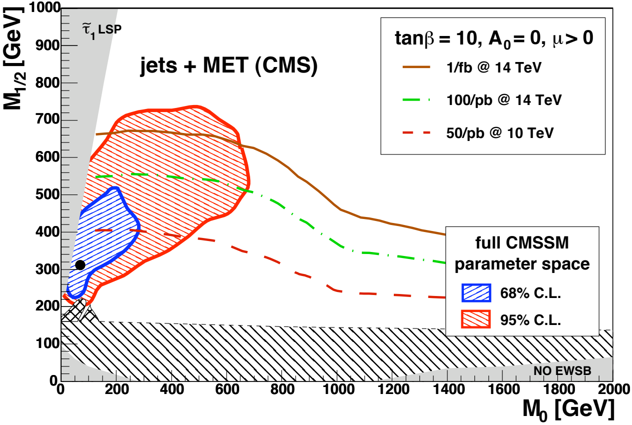
Prospects for LHC discoveries

Sparticle searches



Sparticle searches

5σ discovery reach



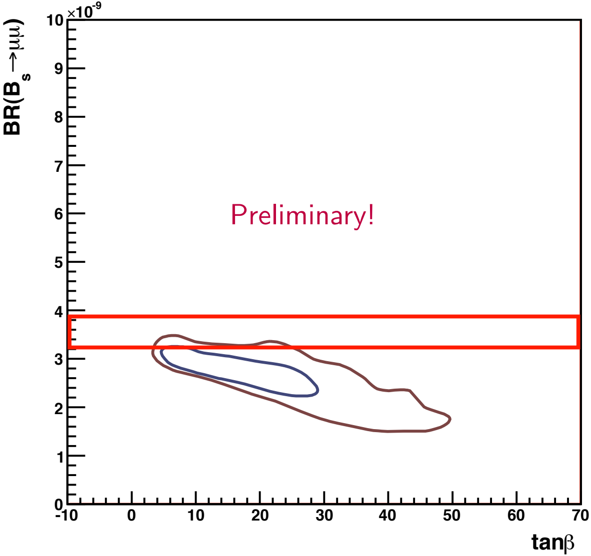
If CMSSM is realised in nature, a signal will be seen fairly early!

Otherwise, exclusion will be possible. . .

Including direct searches at LEP and Tevatron (dashed areas).

Prediction for $B_s \to \mu\mu$

Best fit point: $BR(B_s \to \mu\mu) = 2.9 \times 10^{-9}$



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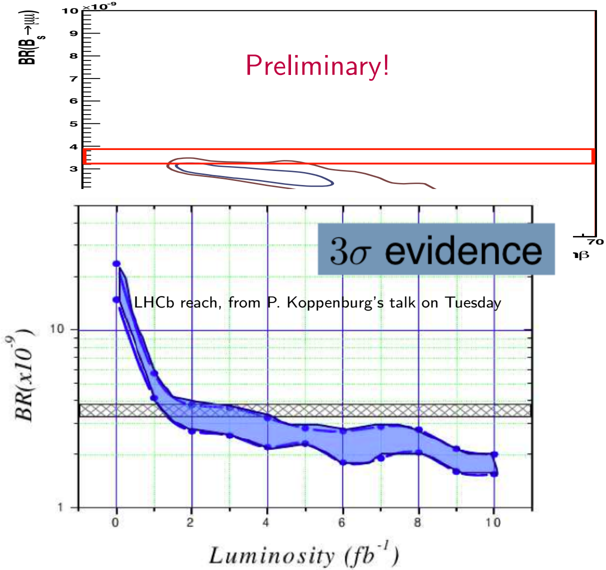

If CMSSM (and minimal flavour violation) is realised in nature this will not be a free lunch…

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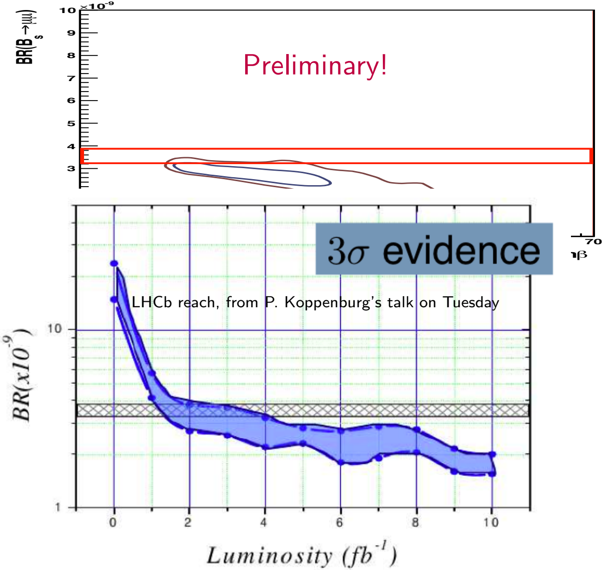


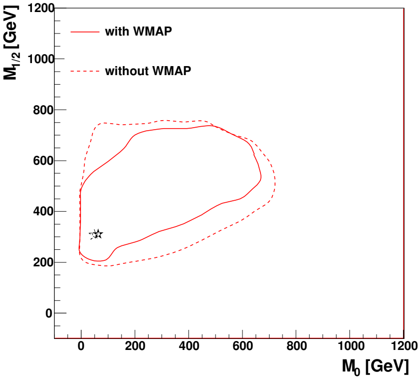
If CMSSM (and minimal flavour violation) is realised in nature this will not be a free lunch...

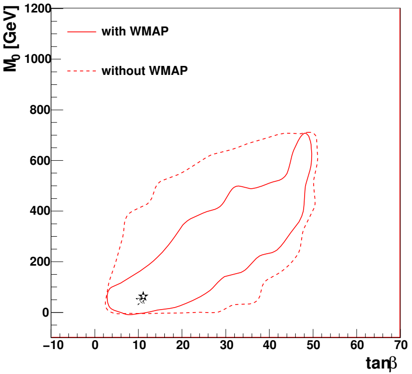
But: still an order of magnitude to go. Plenty of room for NP discovery!

Sensitivity to individual observables

How big is the influence of cosmological data?

Compare 95% CL with/without WMAP constraint

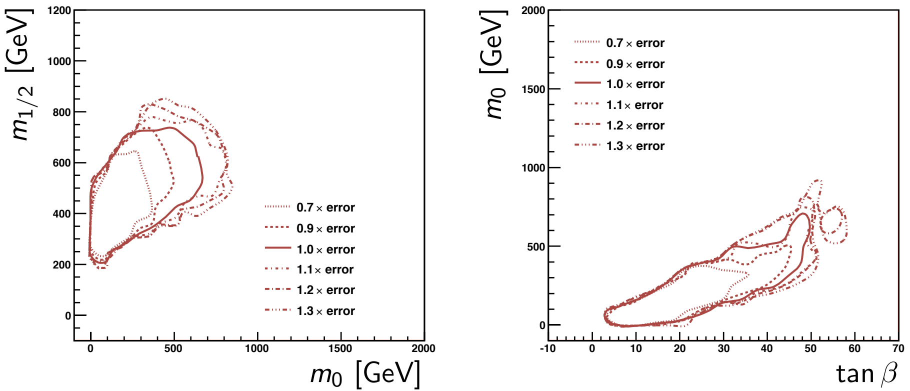




- Enforces correlation between m_0 and $\tan\beta$ (coannihilation "strips")
- Moderate influence

How big is the influence of $b \to s\gamma$?

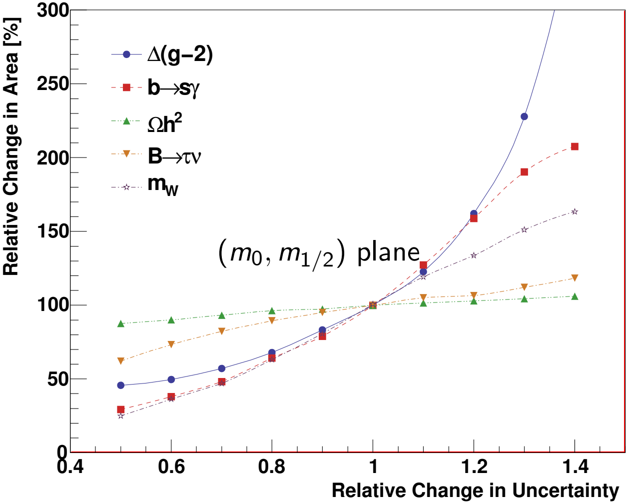
Compare 95% CL in various *error scaling* scenarios



- Reducing the error has a big effect on tan β
- Very sensitive observable

Quantifying the sensitivity

Percentage change in contour content as a function of relative uncertainty



- Importance of $g-2$, $b \to s\gamma$
- $B \to \tau\nu$ fairly sensitive
- Ωh^2 not so sensitive in these projections

Summary

- New global fits to the CMSSM
  - CPU (and disk) intensive 25 million MCMCs
  - latest experimental and theoretical input
- Prospects for the CMSSM at LHC
  - $\Rightarrow$ the end of a long story?
- Sensitivity to individual observables
  - $(g-2)_\mu$ and $\mathrm{BR}(b \to s\gamma)$ are the winners
  - $\mathrm{BR}(B_u \to \tau\nu_\tau)$ also makes a difference
  - moderate influence of Ωh^2
- Now we'll be busy understanding new data (back to reality. . .)

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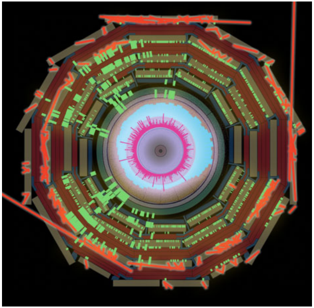


Backup slides

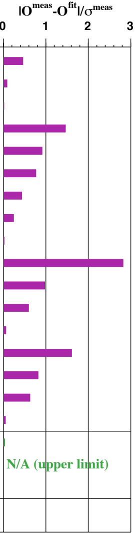
Experimental constraints

Observable	Constraint	Add. Th. Unc.
m_W [GeV]	80.399 ± 0.025	0.010
$a_\mu^{\rm exp} - a_\mu^{\rm SM}$	$(30.2 \pm 8.8) \times 10^{-10}$	2.0×10^{-10}
m_h [GeV]	> 114.4 (see text)	3.0
$\mathrm{BR}^{\rm exp}_{b\to s\gamma}/\mathrm{BR}^{\rm SM}_{b\to s\gamma}$	$1.117 \pm 0.076_{\rm exp} \pm 0.082_{\rm th(SM)}$	0.050
m_t [GeV]	172.4 ± 1.2	–
$\Omega_{\rm CDM} h^2$	0.1099 ± 0.0062	0.012
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$< 4.7 \times 10^{-8}$	0.02×10^{-8}
$\mathrm{BR}^{\rm exp}_{B\to\tau\nu}/\mathrm{BR}^{\rm SM}_{B\to\tau\nu}$	$1.15 \pm 0.40_{[\rm exp+th]}$	–
$\mathrm{BR}(B_d \to \mu^+\mu^-)$	$< 2.3 \times 10^{-8}$	0.01×10^{-9}
$\mathrm{BR}^{\rm exp}_{B\to X_s\ell\ell}/\mathrm{BR}^{\rm SM}_{B\to X_s\ell\ell}$	0.99 ± 0.32	–
$\mathrm{BR}^{\rm exp}_{K\to\mu\nu}/\mathrm{BR}^{\rm SM}_{K\to\mu\nu}$	$1.008 \pm 0.014_{[\rm exp+th]}$	–
$\mathrm{BR}^{\rm exp}_{K\to\pi\nu\bar\nu}/\mathrm{BR}^{\rm SM}_{K\to\pi\nu\bar\nu}$	< 4.5	–
$\Delta M^{\rm exp}_{B_s}/\Delta M^{\rm SM}_{B_s}$	$1.11 \pm 0.01_{\rm exp} \pm 0.32_{\rm th(SM)}$	–
hline $\frac{(\Delta M^{\rm exp}_{B_s}/\Delta M^{\rm SM}_{B_s})}{(\Delta M^{\rm exp}_{B_d}/\Delta M^{\rm SM}_{B_d})}$	$1.09 \pm 0.01_{\rm exp} \pm 0.16_{\rm th(SM)}$	–
$\Delta\epsilon^{\rm exp}_K/\Delta\epsilon^{\rm SM}_K$	$0.92 \pm 0.14_{[\rm exp+th]}$	–

CMSSM and SM EWK fits [previous study]

CMSSM

Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	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
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95
Ωh^2	0.113 ± 0.009	0.113

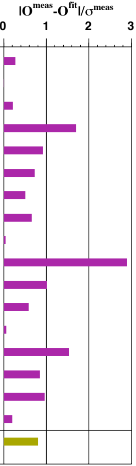


O. Buchmüller *et al.*, PLB 657/1-3 pp. 87-94

$$\chi^2/\text{ndof} = 17.0/13 \ (20\% \text{ prob.})$$

SM

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



arXiv:hep-ex/0612034

$$\chi^2/\text{ndof} = 18.2/13 \ (15\% \text{ prob.})$$