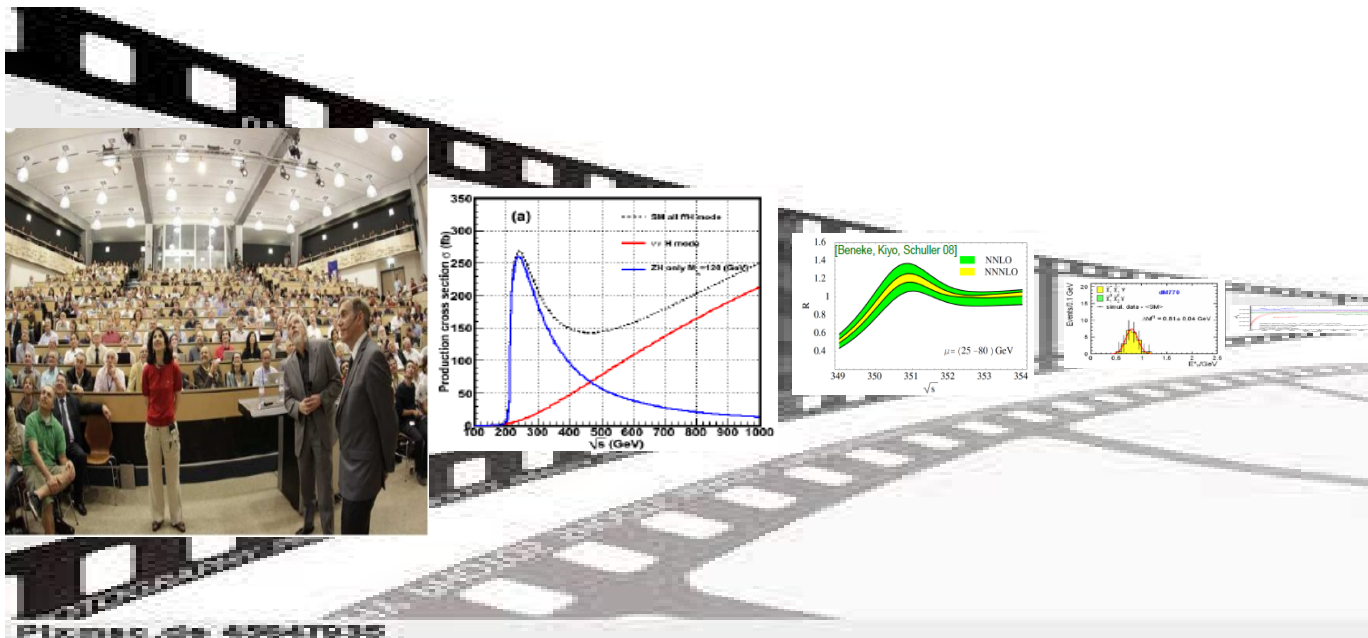


# *Do we need a LC to find BSM Physics?*

**G. Moortgat-Pick**  
**(Uni Hamburg/DESY)**



LINEAR COLLIDER COLLABORATION

# *Status LHC results -- in short*

- **Discovery of a SM-like Higgs around  $m_H \sim 125$  GeV**
  - Is an absolute revolution!
  - Completely new type
  - Not clear whether a SM-Higgs
- **Limits in SUSY coloured sector (approx.):**
  - $m_g, m_q > 1$  TeV
  - 3<sup>rd</sup> generation: much weaker
- **Limits on  $Z'$ ,  $W'$ :  $\sim 2$  TeV**
- **And more limits on ED, exotics, 4<sup>th</sup> generation etc.**

*'The properties of the Higgs boson, to be discovered at the LHC, must be thoroughly investigated in a good condition at the ILC'*

*(K. Kawagoe, Feb 12)*

**Physics left for a Linear Collider? Which energy steps?**

# What is the motivation?

- We have a Higgs! **That's great.**
- Why do we need to know all its properties with best precision? **Because that's the bridge between 'micro' and 'macro' cosmos.**
- We have the Top! **That's great.**
- Why do we need to know all its properties with best precision? **Because that's the bridge to understand dynamics of EWSB.**
- **Excellent top physics at LHC (and HL-LHC) That's great!**
- Do we really also need the LC?

***...a great chance might just be ahead....***

March 27<sup>th</sup> 2013



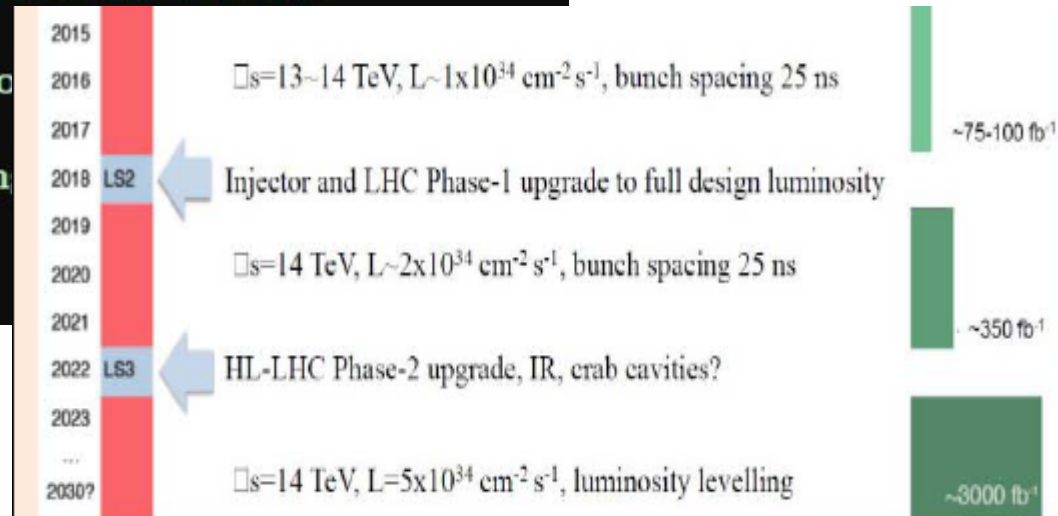
Prime Minister  
MEXT Minister  
Federation of Diet Members  
Head of Industry alliance  
...

Very encouraging politics!

## Possible Timeline

- July 2013
  - Non-political evaluation of 2 Japanese candidate sites complete, followed by down-selecting to one
- End 2013
  - Japanese government announces its intent to bid
- 2013~2015
  - Inter-governmental negotiations
  - Completion of R&Ds, preparation for the ILC lab.
- ~2015
  - Inputs from LHC@14TeV, decision
- 2015~16
  - Construction begins (incl. bidding)
- 2026~27
  - Commissioning

LHC timeline



**ILC might start @ times HL-LHC!**

# Preface

- **Discovery of a SM-like Higgs around  $m_H \sim 125$  GeV**
  - Is an absolute revolution!
  - Completely new type
  - Not clear whether a SM-Higgs
- **In short -- some LC capabilities:**

*As e.g.  $\Delta m_{top} \sim 0.1$  GeV,  $\text{coup}_{tH} \sim 3\%$ ,  
 $H$ : BR's  $\sim 1(b)$ -7(c)%,  $\Gamma_h \sim 5\%$ ,  $\Delta\lambda \sim 17\%$*

*'The properties of the Higgs boson, to be discovered at the LHC, must be thoroughly investigated in a good condition at the ILC'*  
*(K. Kawagoe, Feb 12)*

*Further improvement via lumi-upgrade, see Tians'talk!  
( $\text{coup}_{tH} \sim 2\%$ ,  $\Delta\lambda \sim 10\%$ )*

- **Very active: many new LC studies and reports....**
  - *ILC TDR (since June 12, 2013)*
  - *CLIC CDR 2012*
  - *Collection of LC notes (DESY123h) online*
  - *2 more LC reviews under work*

*Focus of my talk  
( in p. 1<sup>st</sup> article in  
Desy123h, 1210.0202)*

# The LC physics offer

- A 'staged' approach:

- $\sqrt{s}=250$  GeV, 'Higgs cross section, mass + couplings'
- $\sqrt{s}=350$  GeV, 'Higgs width + top mass'
- $\sqrt{s}=500$  GeV, 'Special Higgs- and top couplings+BSM'
- ( $\sqrt{s}=91$  GeV, 'Precision frontier + indirect BSM frontier')
- $\sqrt{s}\geq 1000$  GeV, 'Closing the Higgs picture?'

- **High rates!**

	250 GeV	350 GeV	500 GeV	1 TeV	1.5 TeV	3 TeV
$\sigma(e^+e^- \rightarrow ZH)$	240 fb	129 fb	57 fb	13 fb	6 fb	1 fb
$\sigma(e^+e^- \rightarrow H\nu_e\bar{\nu}_e)$	8 fb	30 fb	75 fb	210 fb	309 fb	484 fb
Int. $\mathcal{L}$	250 fb <sup>-1</sup>	350 fb <sup>-1</sup>	500 fb <sup>-1</sup>	1000 fb <sup>-1</sup>	1500 fb <sup>-1</sup>	2000 fb <sup>-1</sup>
# ZH events	60,000	45,500	28,500	13,000	7,500	2,000
# $H\nu_e\bar{\nu}_e$ events	2,000	10,500	37,500	210,000	460,000	970,000

- Plus 'new' features:

- Precise energy, threshold scans, polarization,  $\gamma\gamma$ -option



# Impact from LHC BSM limits

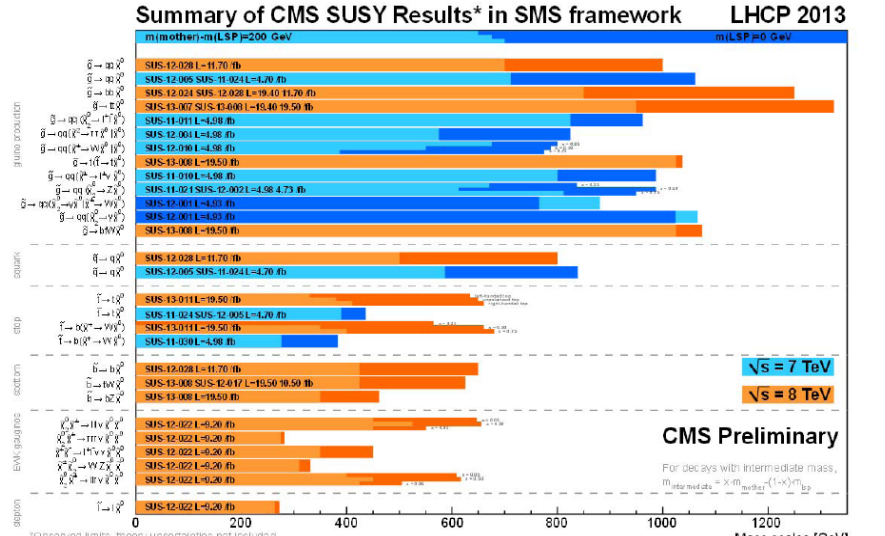
- **SUSY: still strongly motivated and beautiful, but**
  - so far, no hints of a signal, only rather high exclusion limits in the coloured sector
  - **Constrained models (CMSSM,...) + Simpl. Models under tension!**

ATLAS SUSY Searches\* - 95% CL Lower Limits  
Status: LHCP 2013

ATLAS Preliminary  
 $\int Ldt = (4.4 - 20.7) \text{ fb}^{-1}$   $\sqrt{s} = 7, 8 \text{ TeV}$

Model	$\epsilon, \mu, \tau, \gamma$	Jets	$E_{T}^{\text{miss}}$	$Ldt \text{ (fb}^{-1}\text{)}$	Mass limit	Reference
MSSUGRA/CMSSM	0	2-4 jets	Yes	20.3	1.8 TeV	ATLAS CONF-2013-047
MSSUGRA/CMSSM	1 e, $\mu$	4 jets	Yes	3.8	1.3 TeV	ATLAS CONF-2013-104
MSSUGRA/CMSSM	0	7-10 jets	Yes	20.3	1.1 TeV	ATLAS CONF-2013-054
$\tilde{g} \rightarrow q\bar{q}$	0	2-4 jets	Yes	20.3	4 GeV	ATLAS CONF-2013-047
$\tilde{g} \rightarrow q\bar{q} + \tilde{g}$	0	2-4 jets	Yes	20.3	4 GeV	ATLAS CONF-2013-047
$\tilde{g} \rightarrow q\bar{q} + \tilde{g}$	1 e, $\mu$	2-4 jets	Yes	4.7	1.3 TeV	1208.4888
(Sino mod $\tilde{g} \rightarrow q\bar{q} + \tilde{g}$ )	1 e, $\mu$	2-4 jets	Yes	4.7	900 GeV	ATLAS CONF-2013-007
$\tilde{g} \rightarrow q\bar{q} + \tilde{g}$	2 e, $\mu$ (SB)	3 jets	Yes	20.7	1.3 TeV	1208.4888
GMSB (NLSP)	2 e, $\mu$	2-4 jets	Yes	4.7	1.3 TeV	1208.4888
GMSB (NLSP)	1.5 $\tau$	0-2 jets	Yes	20.7	1.3 TeV	ATLAS CONF-2013-026
GGM (bino NLSP)	2 $\tau$	0	Yes	4.8	1.0 TeV	1209.0753
GGM (bino NLSP)	1 e, $\mu$ + $\tau$	0	Yes	4.8	819 GeV	ATLAS CONF-2012-144
GGM (higgsino NLSP)	$\tau$	1 b	Yes	4.8	819 GeV	1211.1167
GGM (higgsino NLSP)	2 e, $\mu$ (Z)	0-3 jets	Yes	5.8	900 GeV	ATLAS CONF-2012-152
Quasistable LSP	0	mono jet	Yes	10.5	900 GeV	ATLAS CONF-2012-147
$\tilde{g} \rightarrow q\bar{q}$	0	3 b	Yes	12.8	1.1 TeV	ATLAS CONF-2012-145
$\tilde{g} \rightarrow q\bar{q}$	2 e, $\mu$ (SB)	0-3 b	No	20.7	900 GeV	ATLAS CONF-2013-007
$\tilde{g} \rightarrow q\bar{q}$	0	7-10 jets	Yes	20.3	1.8 TeV	ATLAS CONF-2013-054
$\tilde{g} \rightarrow q\bar{q}$	0	3 b	Yes	12.8	1.8 TeV	ATLAS CONF-2012-145
$\tilde{b}_1 \rightarrow b\tilde{g}$	0	2 b	Yes	20.1	1.0 TeV	ATLAS CONF-2013-003
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$ (SB)	0-3 b	Yes	20.7	1.0 TeV	ATLAS CONF-2013-007
$\tilde{b}_1 \rightarrow b\tilde{g}$	1.2 e, $\mu$	1-2 b	Yes	4.7	167 GeV	1208.4305, 1209.2102
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$	0-2 jets	Yes	20.3	320 GeV	ATLAS CONF-2013-048
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$	0-2 jets	Yes	20.3	1.0 TeV	ATLAS CONF-2013-048
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$	0-2 jets	Yes	20.3	1.0 TeV	ATLAS CONF-2013-053
$\tilde{b}_1 \rightarrow b\tilde{g}$	1 e, $\mu$	1 b	Yes	20.7	1.0 TeV	ATLAS CONF-2013-037
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$	0	Yes	20.6	1.0 TeV	ATLAS CONF-2013-024
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$ (Z)	1 b	Yes	20.7	1.0 TeV	ATLAS CONF-2013-025
$\tilde{b}_1 \rightarrow b\tilde{g}$	3 e, $\mu$ (Z)	1 b	Yes	20.7	1.0 TeV	ATLAS CONF-2013-025
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$	0	Yes	20.3	80-919 GeV	ATLAS CONF-2013-049
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$	0	Yes	20.3	320 GeV	ATLAS CONF-2013-049
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$	0	Yes	20.7	1.0 TeV	ATLAS CONF-2013-028
$\tilde{b}_1 \rightarrow b\tilde{g}$	2 e, $\mu$	0	Yes	20.7	1.0 TeV	ATLAS CONF-2013-035
$\tilde{b}_1 \rightarrow b\tilde{g}$	3 e, $\mu$	0	Yes	20.7	315 GeV	ATLAS CONF-2013-035
Direct $\tilde{g}\tilde{g}$ prod., long-lived $\tilde{g}$	0	1 jet	Yes	4.7	220 GeV	1210.2982
Stable $\tilde{g}$ , R-hadrons	0-3 e, $\mu$	0	Yes	4.7	300 GeV	1211.1597
GMSB, stable $\tilde{g}$ , low $\beta$	2 e, $\mu$	0	Yes	4.7	320 GeV	1211.1597
GMSB, $\tilde{g} \rightarrow q\bar{q} + \tilde{g}$ , long-lived $\tilde{g}$	2 $\tau$	0	Yes	4.7	320 GeV	1204.6150
$\tilde{g} \rightarrow q\bar{q} + \tilde{g}$ (RPV)	1 e, $\mu$	0	Yes	4.4	320 GeV	1210.7451
LFV $\tilde{g}\tilde{g} \rightarrow X, Y, Z, \nu\bar{\nu}$	2 e, $\mu$	0	Yes	4.6	1.0 TeV	1212.1272
LFV $\tilde{g}\tilde{g} \rightarrow X, Y, Z, \nu\bar{\nu} + \tilde{g}$	1 e, $\mu$	0	Yes	4.6	1.1 TeV	1212.1272
Nonlinear RPV CMSSM	1 e, $\mu$	7 jets	Yes	4.7	1.3 TeV	ATLAS CONF-2012-140
$\tilde{g}\tilde{g} \rightarrow q\bar{q} + \tilde{g}$	4 e, $\mu$	0	Yes	20.7	4.4 TeV	ATLAS CONF-2013-038
$\tilde{g}\tilde{g} \rightarrow q\bar{q} + \tilde{g}$	1 e, $\mu$	0	Yes	20.7	950 GeV	ATLAS CONF-2013-038
$\tilde{g}\tilde{g} \rightarrow q\bar{q} + \tilde{g}$	0	6 jets	Yes	4.6	566 GeV	1210.4813
$\tilde{g}\tilde{g} \rightarrow q\bar{q} + \tilde{g}$	2 e, $\mu$ (SB)	0-3 b	Yes	20.7	900 GeV	ATLAS CONF-2013-007
Scalar gluon	0	4 jets	Yes	4.6	100-287 GeV	1210.4826
WMP interaction (D5, Drazo $\tilde{g}$ )	0	mono jet	Yes	10.5	900 GeV	ATLAS CONF-2012-147

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



\*Observed limits, theory uncertainties not included. Only a selection of available mass limits. Probe "up 10 $\sigma$ " the quoted mass limit.

## • Further hints from theory?

# Further SUSY facts

- Low energy experiments,  $(g-2)_\mu$ :
  - favours rather **low SUSY masses** in electroweak sector:

$$\delta a_\mu(\text{N.P.}) = \mathcal{O}(C) \left(\frac{m_\mu}{M}\right)^2, \quad C = \frac{\delta m_\mu(\text{N.P.})}{m_\mu}$$

- C very model dependent, SUSY/ED  $\sim \mathcal{O}(\alpha/4\pi \dots)$
- **LHC results** prefer **rather heavy coloured sector** in 1<sup>st</sup> +2<sup>nd</sup> generation
- **Way out: rather simple**
  - Decouple uncoloured and coloured sector and/or take **hybrid models** of SUSY breaking
  - Just **leave out the constrained minimal models**, that's all

**Remember: Minimal SUSY contains 105 new parameter... why should nature be too simple ?**



# Why 'should' light SUSY be preferred?

- **Minimization of 1-loop Higgs Potential:**

$$\frac{M_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u) \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2 \simeq -(m_{H_u}^2 + \Sigma_u^u) - \mu^2$$

- **To keep EWFT ~ 3%:**

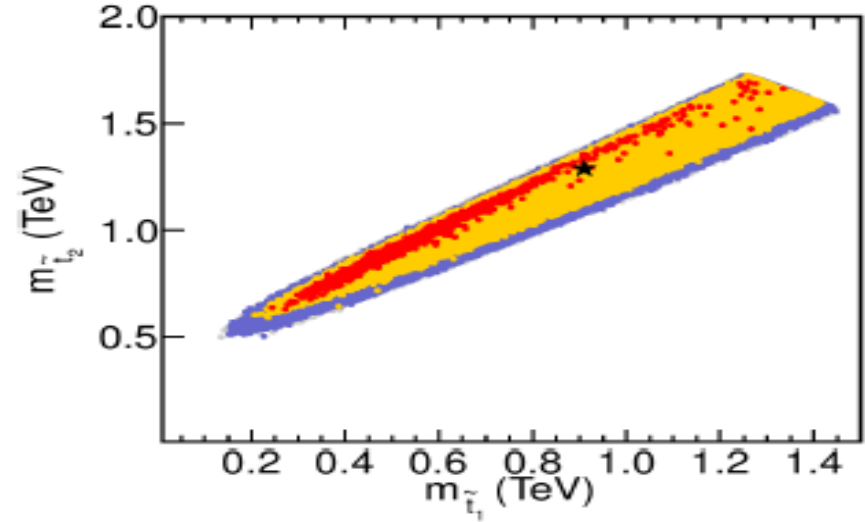
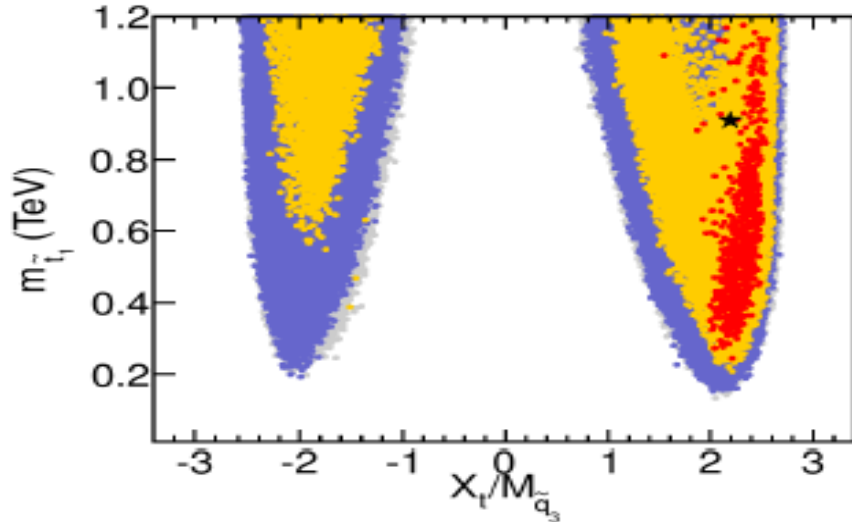
- rather small  $\mu$  (~200 GeV) required
- 'naturalness'
- Several 'natural' scenarios: light stops and light higgsinos,...

*Papucci, Ruderman, Weiler 2011*  
*Baer, Barger, Huang, Tata, 2012*

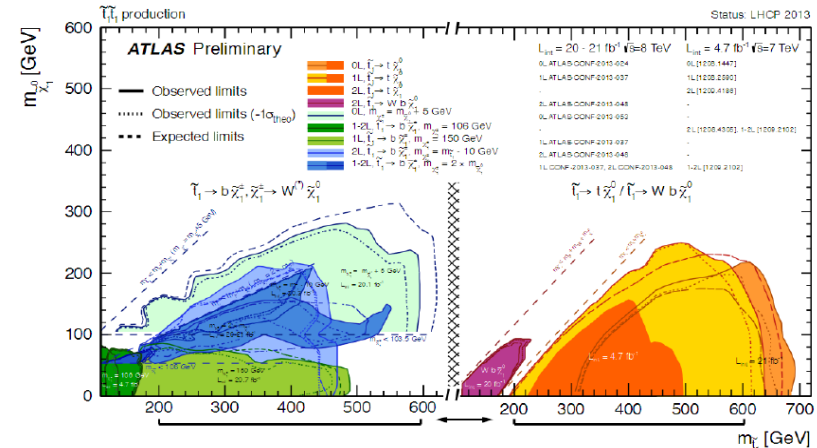
# MSSM interpretation of light Higgs

- Preferred values for stop masses from fits :

*Bechtle, Heinemeyer, Stal, Stefaniak, Weiglein, Zeune '12*



- $M_h \sim 125$  GeV requires large stop mixing  $\sim$  large  $X_t$ 
  - Rather large  $X_t = A_t - \mu \cot \beta$
- But  $m_{\tilde{t}_1}$  can still be light !

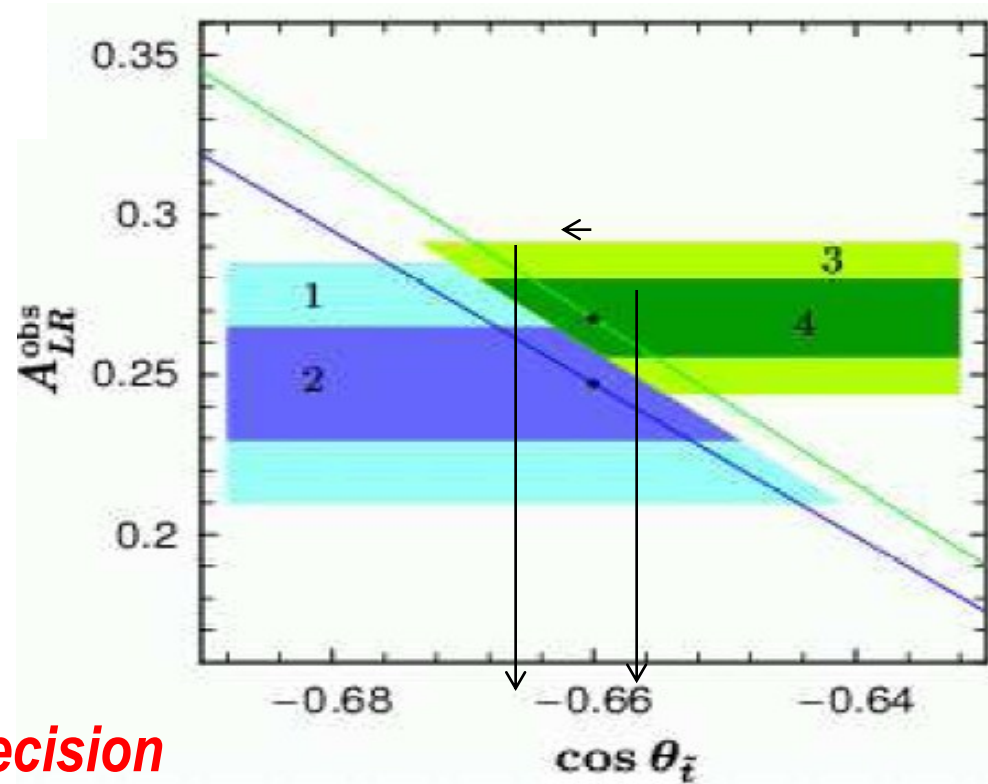


# *Start with stops: features at a LC*

- With polarized beams:  $A_{LR}$  applicable

*Eberl, Kraml, '05*

$\mathcal{L}_{\text{int}}$	$P_{e^-}$	$P_{e^+}$	$\Delta m_{\tilde{t}_1}$	$\Delta \cos \theta_{\tilde{t}}$
100 fb <sup>-1</sup>	$\mp 0.9$	0	1.1%	2.3%
500 fb <sup>-1</sup>	$\mp 0.9$	0	0.5%	1.1%
100 fb <sup>-1</sup>	$\mp 0.9$	$\pm 0.6$	0.8%	1.4%
500 fb <sup>-1</sup>	$\mp 0.9$	$\pm 0.6$	0.4%	0.7%



- Mixing angle  $\Delta \cos \theta_{\tilde{t}} < 1\%$

- If  $\Delta X_{\tilde{t}} \pm 1\%$ :  $\Delta m_h = \pm 0.2 \text{ GeV}$

→ *matches long-term LHC precision*

- If  $\Delta X_{\tilde{t}} \pm 10\%$ :  $\Delta m_h = \pm 1.5 \text{ GeV}$

→ *Too big to check the consistency of the model!*

# Higgsino-like scenarios

- Can be embedded in hybrid gauge-gravity mediation
  - ‘M’ driven by gauge-mediation
  - ‘ $\mu$ ’ driven by gravity mediation
- Two examples as ‘prototypes’ under study

*Bruemmer,List,GMP,  
Rolbiecki,Sert’13*

$$\begin{aligned} M_1 &= 1.70 \text{ TeV}, M_2 = 4.36 \text{ TeV}, \mu = 165.66 \text{ GeV}, \tan\beta|_{m_Z} = 44, \\ M_{\tilde{\kappa}_1^0} &= 165.77 \text{ GeV}, M_{\tilde{\kappa}_1^{\pm}} = 164.17 \text{ GeV}, M_{\tilde{\kappa}_2^0} = 166.87 \text{ GeV}, m_h = 124 \text{ GeV}; \\ M_1 &= 5.30 \text{ TeV}, M_2 = 9.51 \text{ TeV}, \mu = 167.22 \text{ GeV}, \tan\beta|_{m_Z} = 48, \\ M_{\tilde{\kappa}_1^0} &= 167.36 \text{ GeV}, M_{\tilde{\kappa}_1^{\pm}} = 166.59 \text{ GeV}, M_{\tilde{\kappa}_2^0} = 167.63 \text{ GeV}, m_h = 127 \text{ GeV}. \end{aligned}$$

- **Higgsino masses:**  $m_{\chi_{01}} \sim 165 \text{ GeV}, m_{\chi_{02}} \sim 167 \text{ GeV}, m_{\chi_{\pm 1}} \sim 166 \text{ GeV}$
- **Feature:**  $\Delta m(\chi_{\pm 1}-\chi_{01}) \sim 770 \text{ MeV} (1.6 \text{ GeV}), \Delta m(\chi_{02}-\chi_{01}) \sim 1.04 (2.7) \text{ GeV}$ 
  - Challenges: mass degeneration, many  $\pi$ 's, soft  $\gamma$ ,  $E_{\text{miss}}$  from decay
  - How to resolve such scenarios?

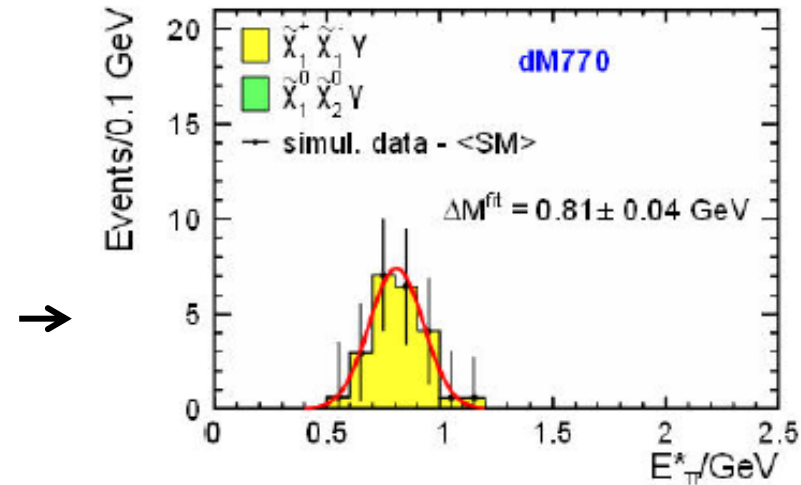
# Apply ISR method

- Accessible processes:  $e^+e^- \rightarrow \chi^0_1 \chi^0_2, \chi^+_1 \chi^-_1$ 
  - Decays:  $\chi^-_1$  mainly hadronic,  $\chi^0_2$  mainly in  $\gamma$ 's
- Measure masses via ISR method:
  - Take only events with hard  $\gamma$  from ISR
  - Get also rid of SM background two photons
- Measure process at two energies,  $\sqrt{s}=350$  and  $500$  GeV
  - Use recoil mass and semihadronic channel

*Berggren, List, Sert*

→ Determine MSSM parameters

$\sqrt{s} = 500$ GeV	input	lower	upper
$M_1$ [TeV]	5.3	$\sim 3$	110
$M_2$ [TeV]	9.51	$\sim 7$	$\sim 15$
$\mu$ [GeV]	167.22	165.2	167.4



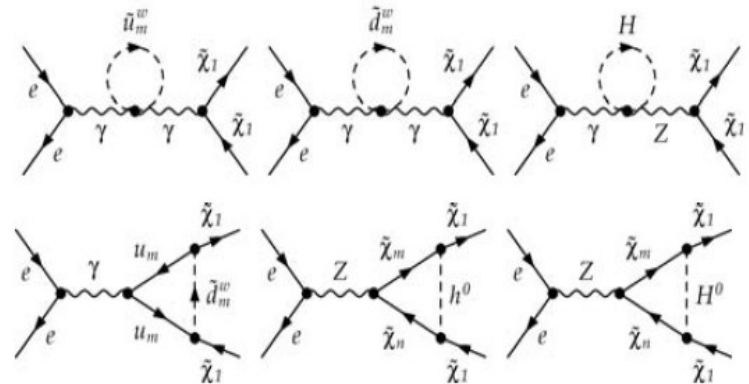
# LC: Parameters from $e^+e^- \rightarrow \tilde{\chi}^+_1 \tilde{\chi}^-_1 @ NLO$

- In the past: parameter determination at tree level
  - Extracted from  $\sigma_{L,R}$  polarized cross sections and masses  $m_{\tilde{\chi}^+_1}$  and  $m_{\tilde{\chi}^0_1}$  with  $500 \text{ fb}^{-1}$

SUSY Parameters				Mass Predictions		
$M_1$	$M_2$	$\mu$	$\tan \beta$	$m_{\tilde{\chi}^\pm_2}$	$m_{\tilde{\chi}^0_3}$	$m_{\tilde{\chi}^0_4}$
$99.1 \pm 0.2$	$192.7 \pm 0.6$	$352.8 \pm 8.9$	$10.3 \pm 1.5$	$378.8 \pm 7.8$	$359.2 \pm 8.6$	$378.2 \pm 8.1$

- However: Loop effects known to be relevant

- Sensitivity to parameters arising from loops, e.g. stop-sector



*Bharucha, Kalinowski, Moortgat-Pick, Rolbiecki, Weiglein 2012*

- Now: Strategies for parameter determination still applicable?

# LC: Parameters from $e^+e^- \rightarrow \chi^+ \chi^-$ @ NLO

- **Strategy:** Use NLO corrected masses and  $\sigma_{L,R}$  at  $\sqrt{s}=350,500$ 
  - Use in addition  $A_{FB}$
  - Fit of  $M_1, M_2, \mu, \tan\beta$  and stop sector  $m_{\tilde{t}_1}, m_{\tilde{t}_2}$  and  $\cos\theta_{\tilde{t}}$
  - Compare mass accuracy from
    - Threshold scans
    - Continuum measurement

*Bharucha, Kalinowski, Moortgat-Pick, Rolbiecki, Weiglein 2012*

Parameter	Threshold fit	Continuum fit
$M_1$	$125 \pm 0.3$ ( $\pm 0.7$ )	$125 \pm 0.6$ ( $\pm 1.2$ )
$M_2$	$250 \pm 0.6$ ( $\pm 1.3$ )	$250 \pm 1.6$ ( $\pm 3$ )
$\mu$	$180 \pm 0.4$ ( $\pm 0.8$ )	$180 \pm 0.7$ ( $\pm 1.3$ )
$\tan\beta$	$10 \pm 0.5$ ( $\pm 1$ )	$10 \pm 1.3$ ( $\pm 2.6$ )
$m_{\tilde{\nu}}$	$1500 \pm 24$ ( $^{+60}_{-40}$ )	$1500 \pm 20$ ( $\pm 40$ )
$m_{\tilde{t}_1}$	$400^{+180}_{-120}$ (at limit)	—
$m_{\tilde{t}_2}$	$800^{+300}_{-170}$ ( $^{+1000}_{-290}$ )	$800^{+350}_{-220}$ (at limit)

→ Relevance of **threshold scans and sensitivity to heavy masses**

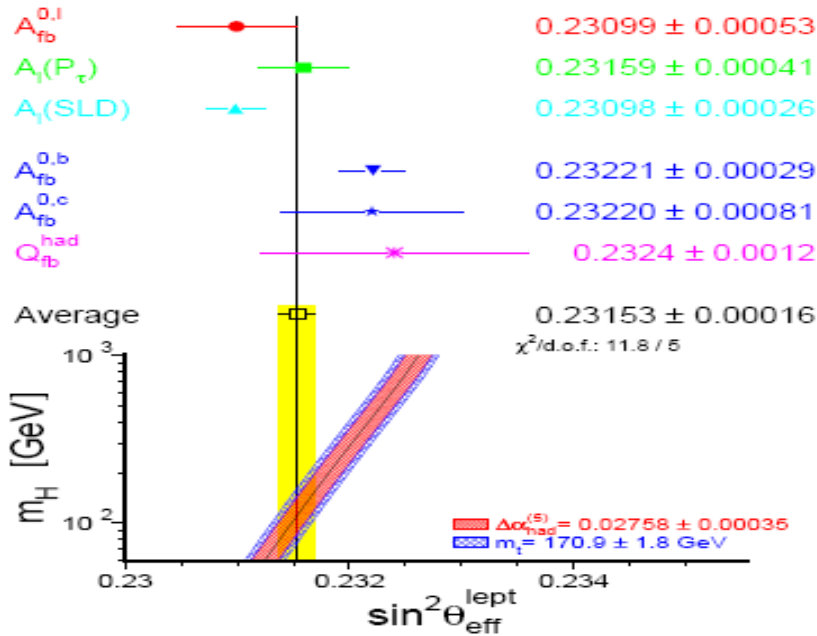
- **Impact also on dark matter prediction:**
  - Precision needed for accurate DM prediction: accuracy of the NLO corrected parameters → 5% uncertainty in DM prediction



# *What if nothing else than $H$ is found now?*

- Since  $m_H$  is free parameter in SM at tree level
  - Crucial relations exist, however, between  $m_{\text{top}}$ ,  $m_W$  and  $\sin^2\theta_{\text{eff}}$
  - If nothing else appears in the electroweak sector, these relations have to be urgently checked in order to
    - a) distinguish between SM and Higgs in BSM models (remember  $\Delta m_H \sim m_{\text{top}}^4$  in BSM! )
    - b) Close the SM picture ?
- Which strategy should one aim?
  - exploit precision observables and check whether the measured values fit together at quantum level
  - $m_Z$ ,  $m_W$ ,  $\alpha_{\text{had}}$ ,  $\sin^2\theta_{\text{eff}}$  und  $m_{\text{top}}$
- Exploit 'GigaZ' option: high lumi run at  $\sqrt{s} = 91$  GeV  
Pe-=80% and Pe+=60% required ! (If only Pe-=90% : precision ~factor 4 less!)

# Higgs story has just started ... $\sqrt{s}=91 \text{ GeV}$



**LEP:**

$$\sin^2\theta_{\text{eff}}(A_{\text{FB}}^b) = 0.23221 \pm 0.00029$$

**SLC:**

$$\sin^2\theta_{\text{eff}}(A_{\text{LR}}) = 0.23098 \pm 0.00026$$

**World average:**

$$\sin^2\theta_{\text{eff}} = 0.23153 \pm 0.00016$$

**Goal GigaZ:  $\Delta \sin\theta = 1.3 \cdot 10^{-5}$**

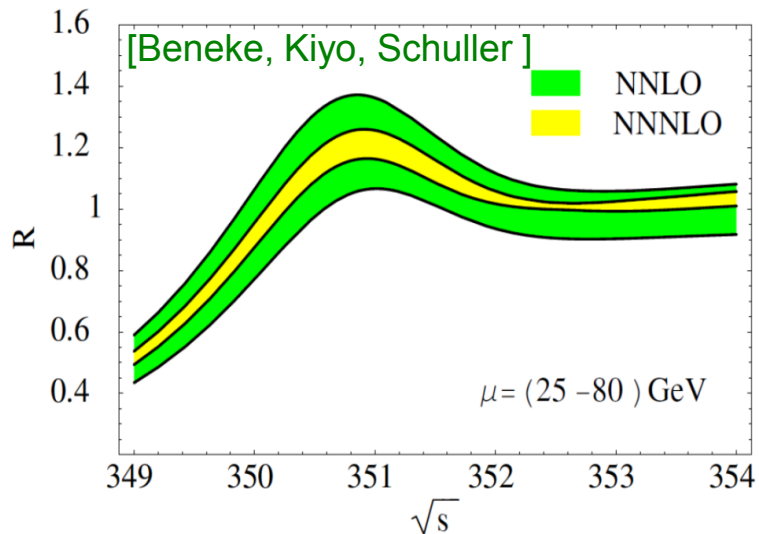
- **Uncertainties from input parameters:  $\Delta m_Z$ ,  $\Delta \alpha_{\text{had}}$ ,  $m_{\text{top}}$ , ...**  
*Heinemeyer, Kraml, Porod, Weiglein*

- $\Delta m_Z = 2.1 \text{ MeV}$ :  $\Delta \sin^2\theta_{\text{eff}}^{\text{para}} \sim 1.4 \times 10^{-5}$
- $\Delta \alpha_{\text{had}} \sim 10 \text{ (5 future)} \times 10^{-5}$ :  $\Delta \sin^2\theta_{\text{eff}}^{\text{para}} \sim 3.6 \text{ (1.8 future)} \times 10^{-5}$
- $\Delta m_{\text{top}} \sim 1 \text{ GeV (Tevatron/LHC)}$ :  $\Delta \sin^2\theta_{\text{eff}}^{\text{para}} \sim 3 \times 10^{-5}$
- $\Delta m_{\text{top}} \sim 0.1 \text{ GeV (ILC)}$ :  $\Delta \sin^2\theta_{\text{eff}}^{\text{para}} \sim 0.3 \times 10^{-5}$

# Higgs story has just started ... $\sqrt{s}=91 \text{ GeV}$

$A_{fb}^{0,l}$   
 $A_1(P_\tau)$   
 $A_1(\text{SLD})$   
 $A_{fb}^{0,b}$   
 $A_{fb}^{0,c}$   
 $Q_{fb}^{\text{had}}$

- But such a precision requires  $\Delta m_{\text{top}} = 0.1 \text{ GeV}$



$\sqrt{s}=350 \text{ GeV}$

Important shift due to non-logarithmic NNNLO terms

• Unce

- LC: Peak position remains stable:  $\Delta m_t = 100 \text{ MeV}$
- includ. exp uncertainty + theo. uncertainty !
- expected accuracy confirmed by full simulation studies!
- Dedicated threshold scan required with about  $\sim 100 \text{ fb}^{-1}$

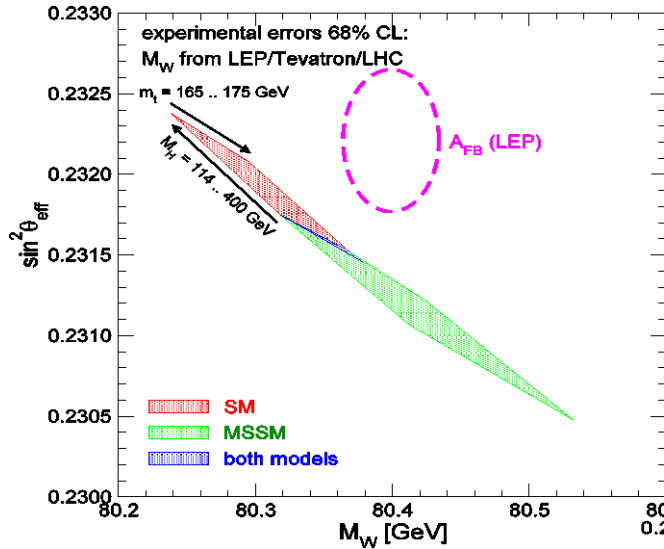
Weiglein

# To close the story... GigaZ

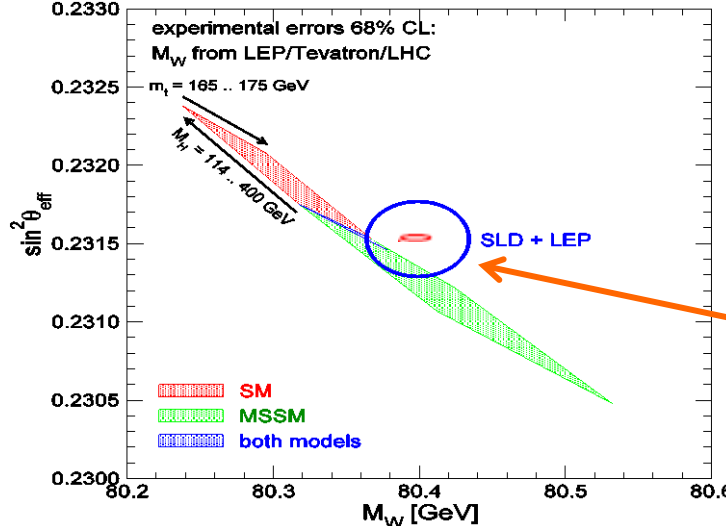
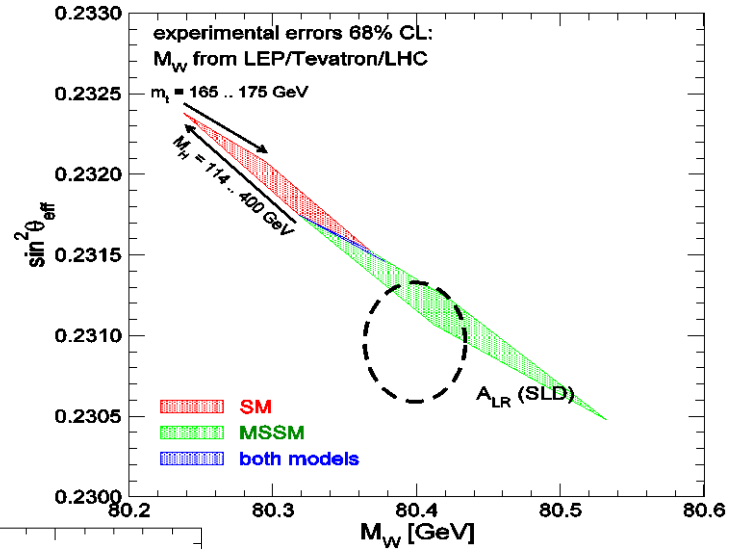
$\sqrt{s}=91 \text{ GeV}$

- Measure  $\sin^2\theta_{\text{eff}}$  via  $A_{LR}$  with high precision:  $\Delta\sin\theta=1.3 \cdot 10^{-5}$

Heinemeyer, Hollik, Weber, Weiglein



← LEP value  
 disfavours both,  
 SM+MSSM



World average →  
 happy with both!  
 Central value has  
 large impact !!!

↑  
 SLD value  
 disfavours SM

GigaZ  
 precision!

# What else could we learn? $\sqrt{s}=91 \text{ GeV}$

- Assume only Higgs@LHC but no hints for SUSY:

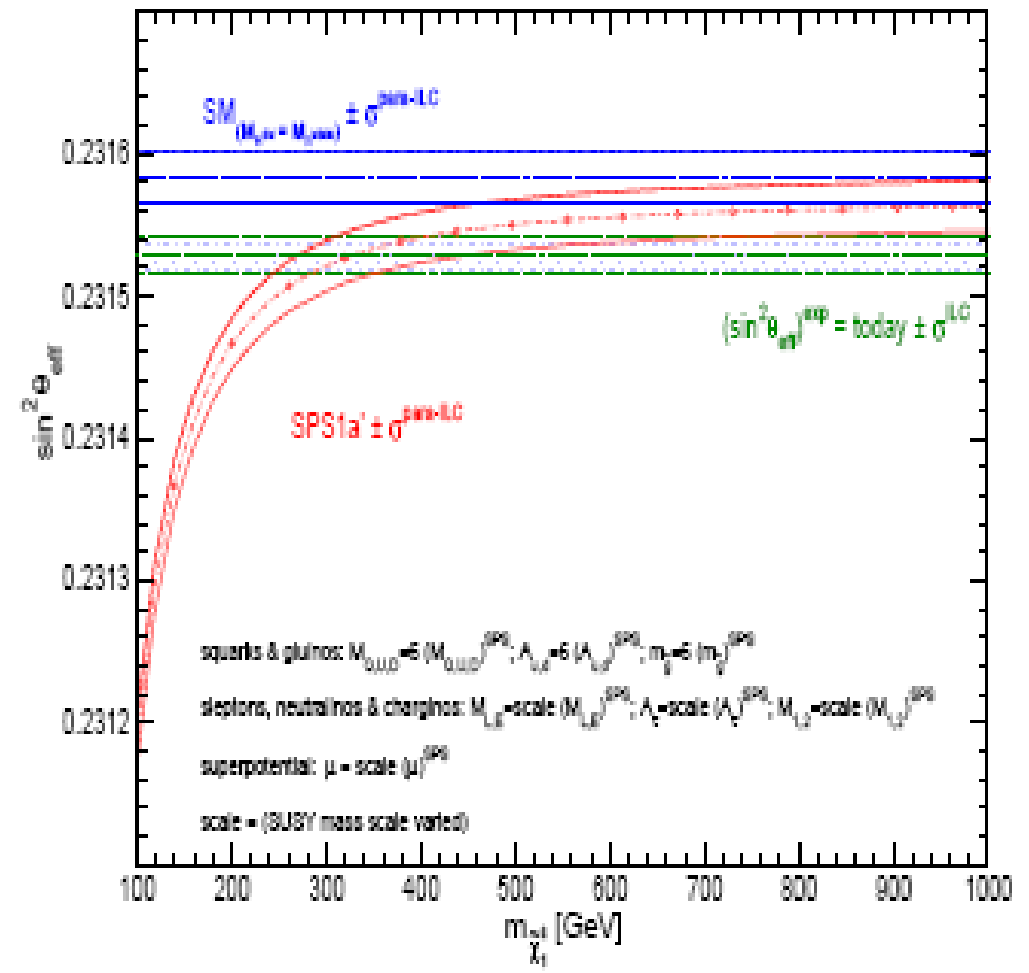
*Heinemeyer, Hollik, Weber, Weiglein*

- Really SM?
- Help from  $\sin^2\theta_{\text{eff}}$ ?

- If GigaZ precision:

- i.e.  $\Delta m_{\text{top}}=0.1 \text{ GeV}$ ...
- Deviations measurable

- $\sin^2\theta_{\text{eff}}$  can be the crucial quantity to reveal effects of NP!



# *In 20 years time.....we could tell a story*

- Once upon a time –it was July 4<sup>th</sup>– .....

