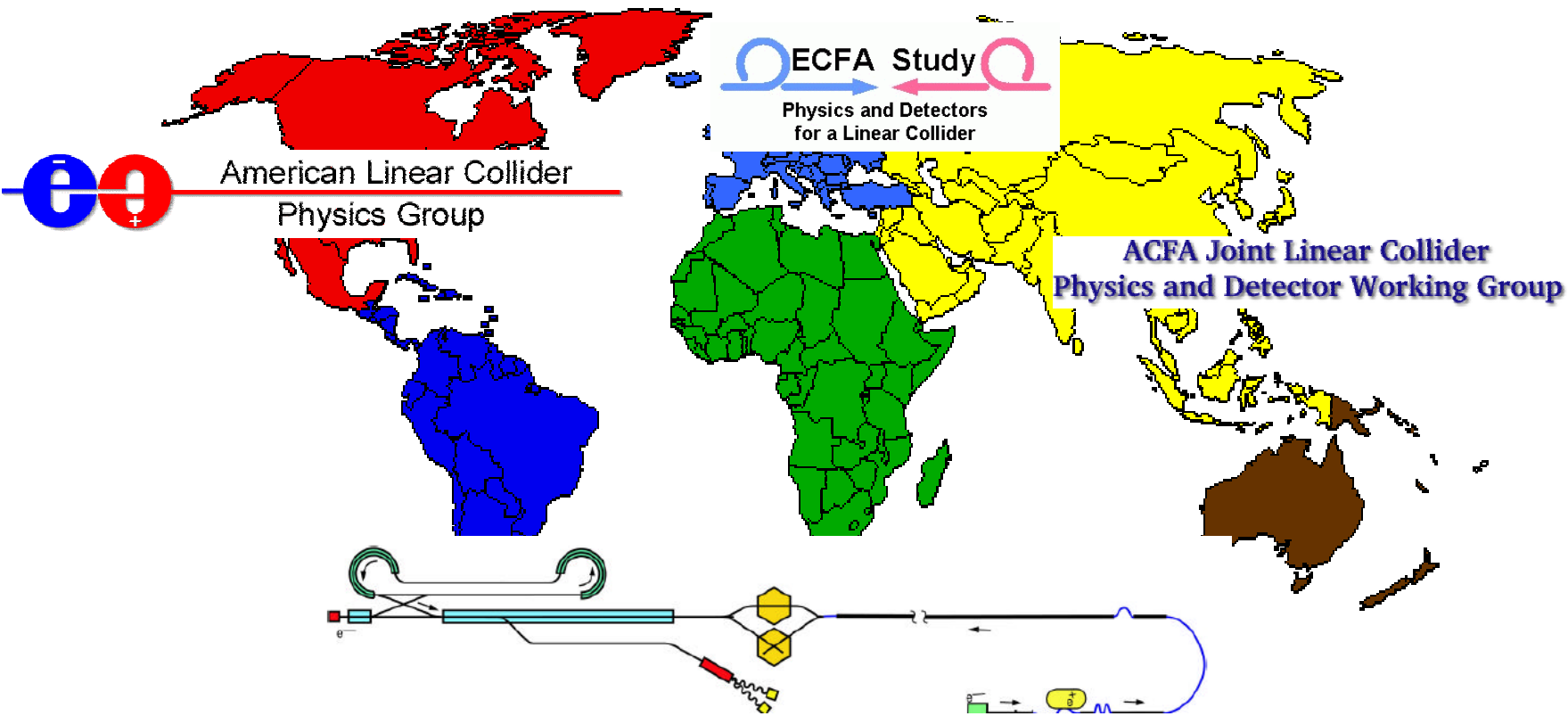
Physics of the Linear Collider

F. Richard LAL/Orsay



Outline

- Which machine ?
- (Which detector ?)
- For which physics ? Possible scenarios

  Origin of mass EWSB Main emphasis

  Hierarchy of masses SUSY

  Input to Cosmology

➔ Major ongoing effort in Americas, Asia, Europe

➔ Apologies: incomplete picture in 30' + personal biases

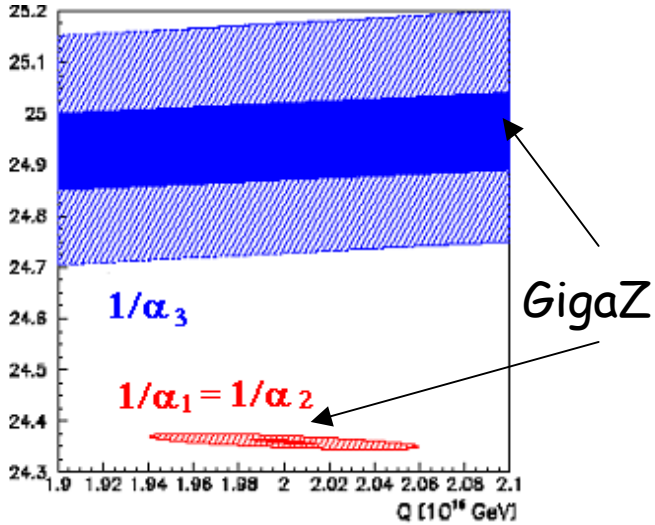
Machine

- The baseline is an e+e- LC operating from M_Z to 500 GeV with polarized e- (80 %) and collecting 500 fb-1 in the 1st 4 years of running
- Upgradeable to ~ 1 TeV 500fb-1 /year

Options :

- e+ polarization (60%) needed at GigaZ and with transverse polarization
- e-e- ~ easy — ~$\mathcal{L}_{e^+e^-}/3$ $\sqrt{s_{\gamma\gamma}} \sim 0.8\sqrt{s}$
- $\gamma\gamma$ γe more involved — High pol. xssing angle

Which Scenario for EWSB?



LEP/SLD/Tevatron legacy:

- SM/MSSM compatible with PM
- MSUSY 1-10 TeV ~GUT with some small but interesting discrepancy

-> A light Higgs is expected <250 GeV

However:

- A^b_{FB} (NuTeV) not understood Th/exp
- Could be a fake (Peskin-Wells) if there are extra contributions as in alternate schemes to SM/MSSM

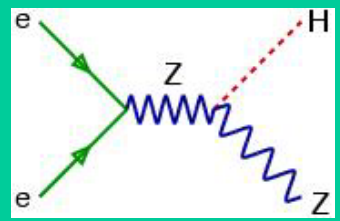
3 EWSB scenarios for LC:

MSSM	PM on Higgs couplings with ~10^5 HZ
mH > 200 GeV	Direct/Indirect signals of new physics
S.I. no Higgs	PM at TeV primarily with WW final states

-> Can LC can provide sufficient observables, with proper accuracy, to cope with these 3 scenarios (including GigaZ/W)

Scénario 1
Is this the MSSM Higgs ?

- Quantum numbers: spin with scan
- CP from ZH angles



Γ_{ff} and $g_{ZZ/WWH}$ at %

$\Gamma_{\gamma\gamma}$ ~20 % at % with $\gamma\gamma$ coll

g_{ttH} 7-15% mH 120-200 GeV

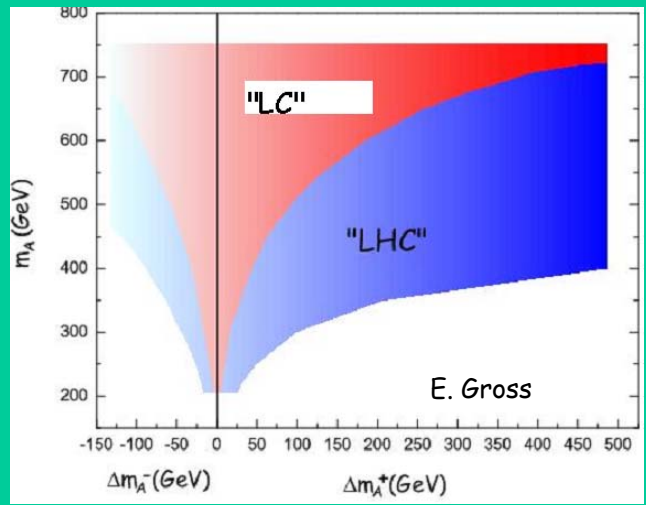
λ_{HHH}~20%(10%) $\sqrt{s}$ 500(800)GeV

- Within MSSM: mA from bb/WW
- Beyond MSSM:NMSSM, CP violation

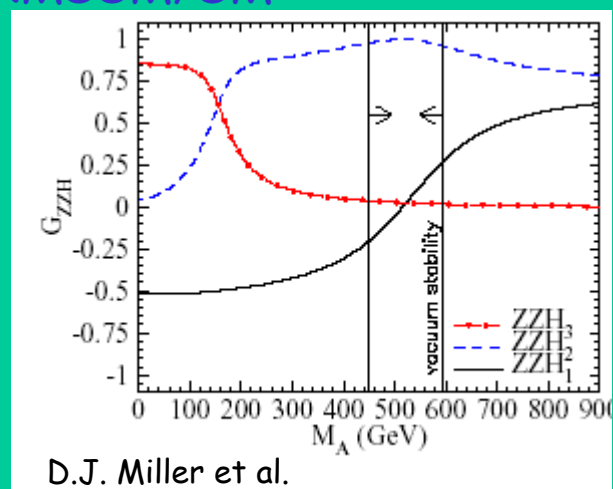
-> Measurable changes on g_{ZZH} , in some cases serious reduction of σ_{HZ}

Robustness of LC:

can stand ~SM/100



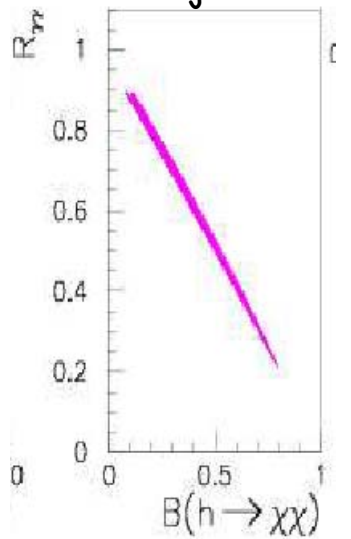
NMSSM/SM



D.J. Miller et al.

Scénario 1
Beyond MSSM (suite)

F. Boudjema et al

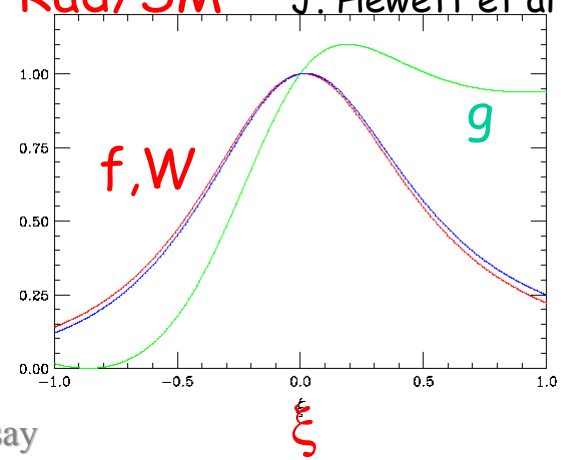


- Detection does not depend on final state BR
  Example Invisible decays:
  Long list of channels:
  - h-> $\tilde{\chi}\tilde{\chi}$ with non-universal gaugino masses
  - $\tilde{\chi}\tilde{G}$ within GMSB
  - Gravitons GG, Graviscalar mixing
  - Majorons JJ, ADD ν_L ν_{RKK}....

  -> High sensitivity 5σ BR_{inv}=2%

- Mixing with an other scalar field
  Radion Γ_{gg} at 5%

Rad/SM J. Hewett et al



Quantum level consistency

M_HDirect=M_HIndirect ?

GigaZ $\delta\sin^2\theta_W \sim 10^{-5}$ with Pe+

WW_{th} $\delta M_W \sim 6$MeV E from Z at 510^{-5}

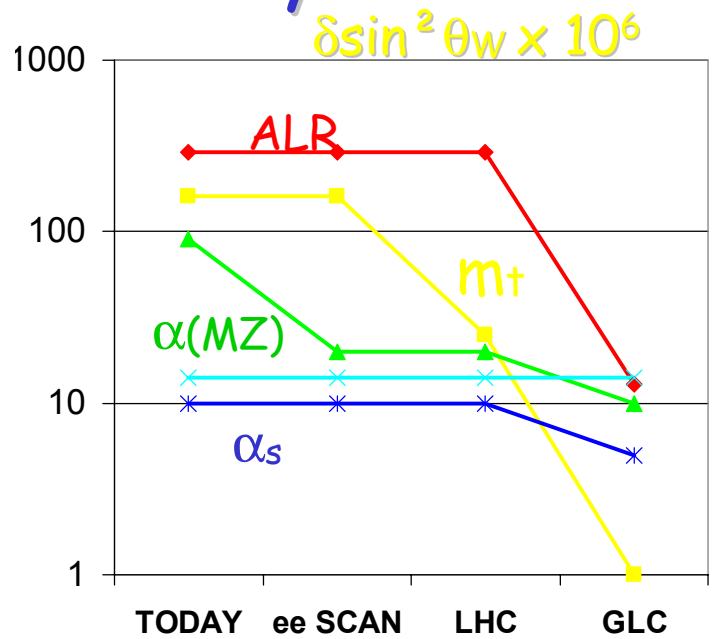
Improved experimental inputs

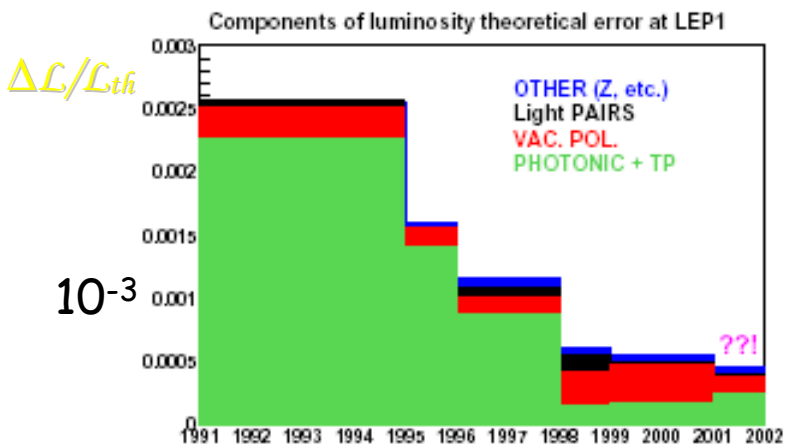
Improved theory (Loopverein)

δM_HIndirect~5% (~50 % at LEP/SLD)

(WW_{th} gives δM_H ~10%)

Recall that LEP/SLD did much better than anticipated





Scénario 2
mH > 200 GeV

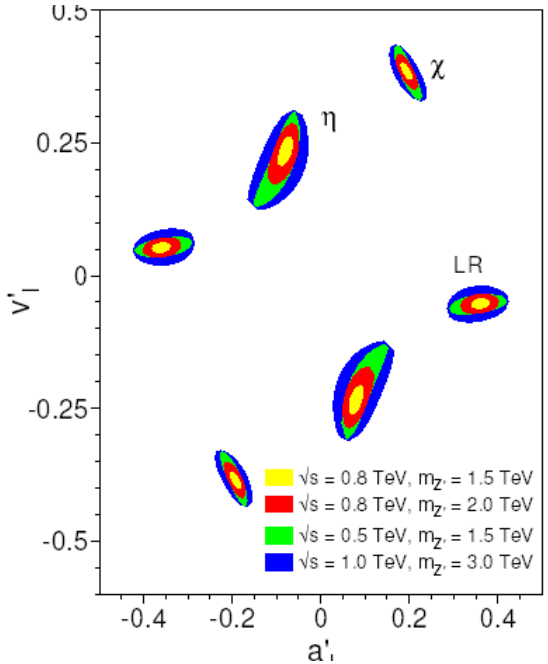
mH inconsistent with SM/MSSM

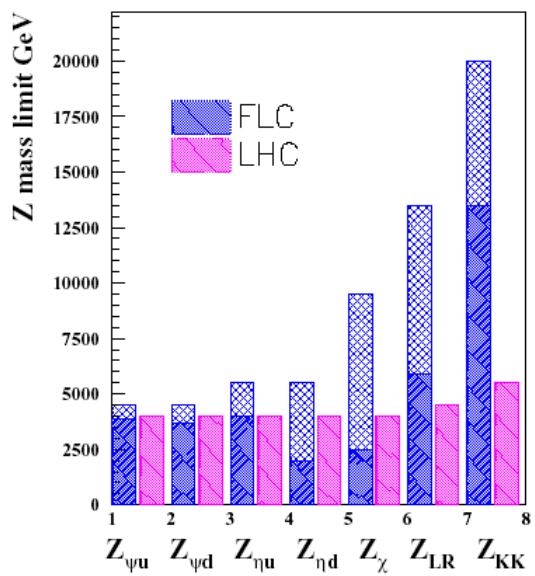
-> find the 'guilty part'

- With direct evidence at LHC : e.g. Z'

  -> Decipher the message, Z-Z' mixing at GigaZ, interference at high √s
- Many scenarios, well separated if Z' mass given by LHC
- In UED no Z' ff coupling, isospin violation seen with ρ at GigaZ
- If no evidence at LHC

  -> Use LC to estimate the new scale





Little Higgs with mH>200 GeV

-> From LEP/SLD Most Z' scénarios do not favor mH>200 GeV
What about Little Higgs ?

A viable alternative (hierarchy) to SUSY:

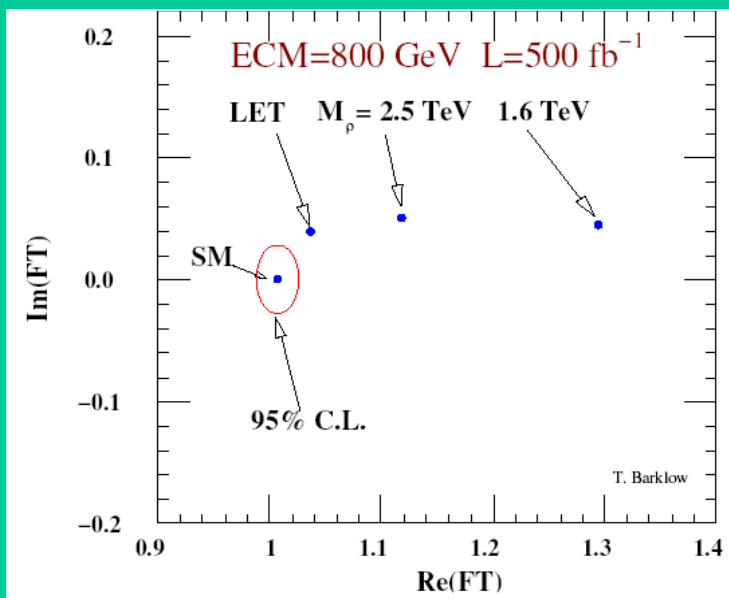
H ~ PG boson of a broken symmetry (several groups possible), perturbative theory up to 10-100 TeV

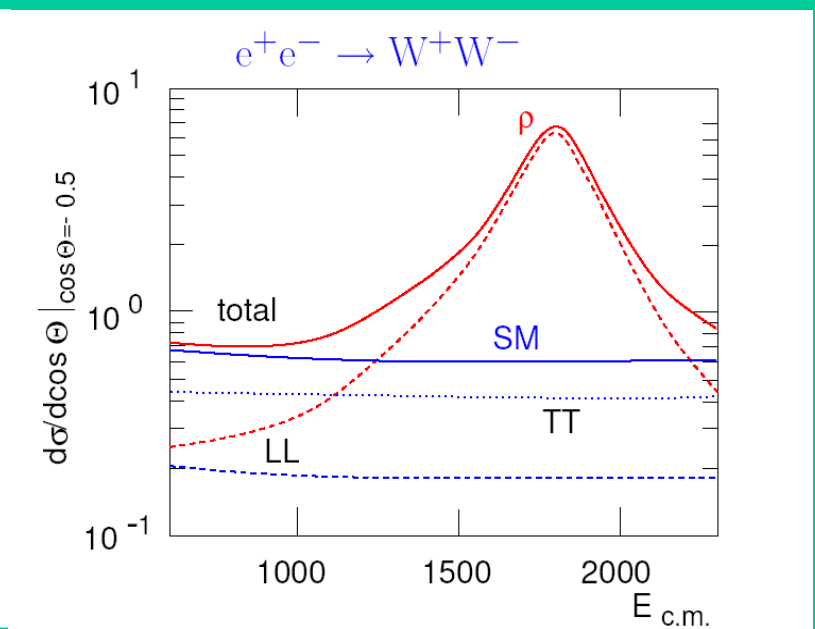
- Cancellation of quadratic divergences on mH^2
  -> New objects: B' W' t' H'...
- B' can contribute to ρ and can 'hide' a heavy Higgs
- mH>200 GeV possible given $\sin^2\theta_{eff}$ + M_W from LEP/SLD with $mB' > 2$ TeV and adjusting $g'_B/g'_{SM} < 1$
- If LHC finds e.g. B' -> LC to identify the LH scheme
- If not, LC can predict mB' and indicate upgrade $\mathcal{L}/\sqrt{s}$ needed at LHC (or at future colliders)
  -> Strong LHC/LC synergy

Scénario 3
No Higgs

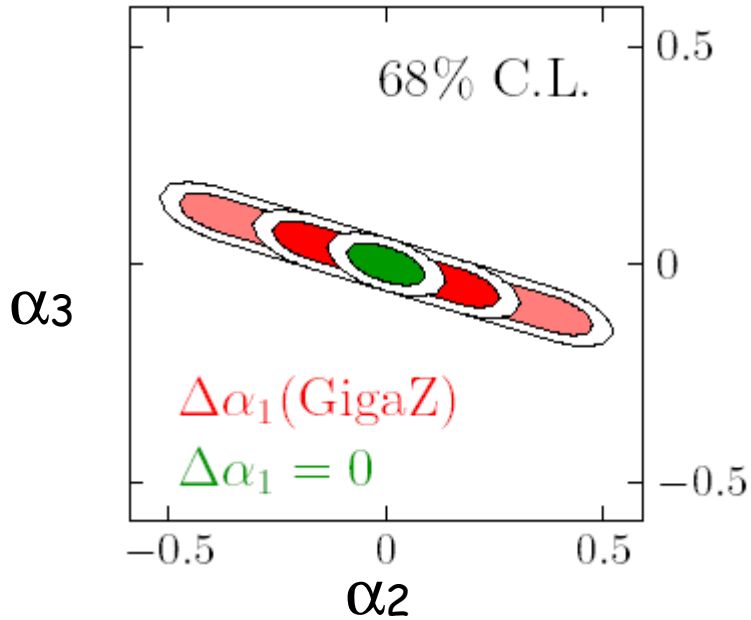
$W_L W_L$ will strongly interact resulting in:

- Production of a resonance ρ-type in e+e→W+W-
- $M\rho < \Lambda_{EWSB} = 4\pi v = 3$ TeV
- Without a resonance LET still observable





	√s GeV	ℒ fb^{-1}	Mρ 1.6TeV	LET
LC	0.5	300	16σ	3σ
LC	0.8	500	38σ	6σ
LC	1.5	200	204σ	5σ
LHC	14	100	6σ	5σ



if J=0,2 I=0,2 resonances
-> use e+e-→ννW^+W^-
also γγ →W^+W^-

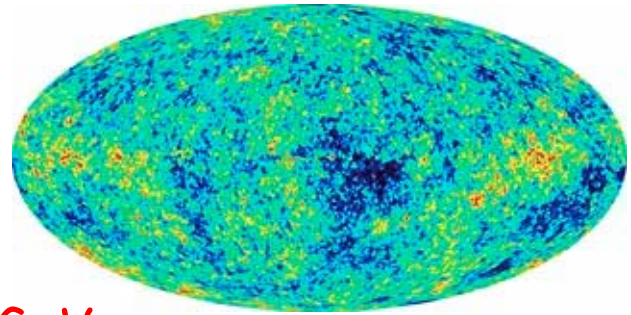
5 TGC conserving P, SU(2)$_{Cust}$
- 3 with WW+ GigaZ
- 2 with ννWW

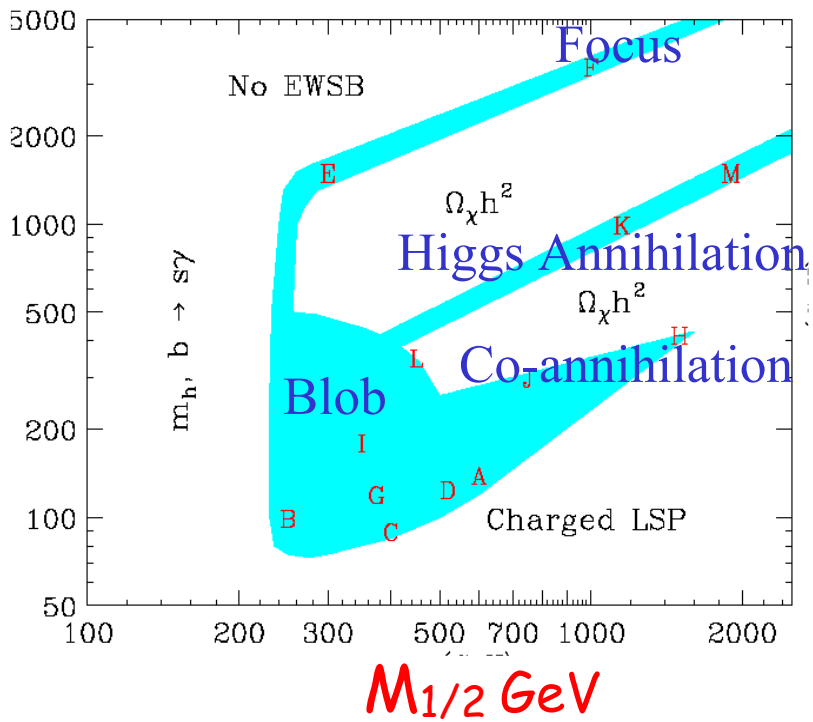
$\alpha = (\Lambda_{EWSB}/\Lambda)^2$

•All LC limits reach $\Lambda > \Lambda_{EWSB}$

The SUSY scenario

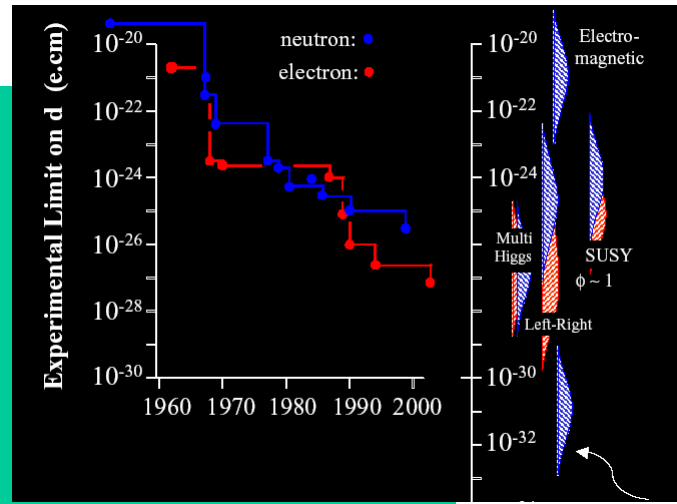
- SUSY is the leading theory:
  - compatible with PM (light H)
  - mass hierarchies up to M_{Planck}
  - compatible with GUT
  - link to cosmology (e.g. DM)
- No unique SSB mechanism
- Essential goals of LC after SUSY discovery by LHC:
  - to understand SSB
  - to determine mass and couplings of the LSP for cosmology
- Using mSUGRA, for pedagogy, 4 regions consistent with DM





Caveat: Flavor constraints

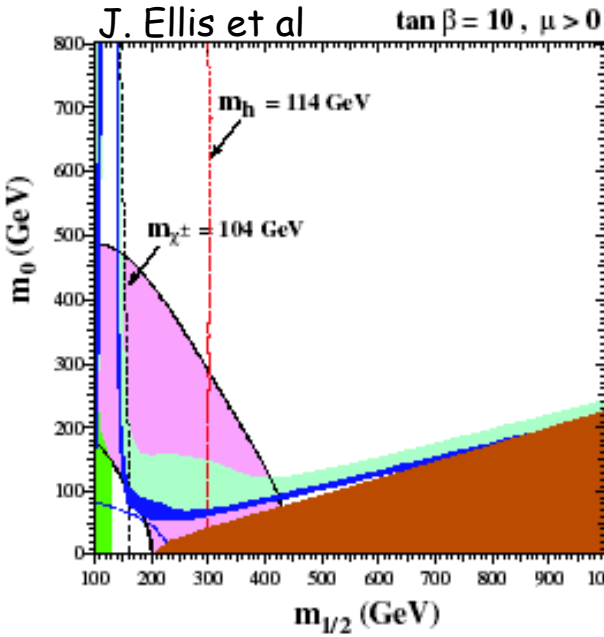
B.E. Sauer



- Flavor : FCNC CP ε_K EDM τp
  -> Heavy sfermions (1st 2 generations)
  -> For CP, hidden symmetry (LR) avoiding phases or cancellation (?) of phases
- 3 possible scenarios:
  - All scalars very heavy h and possibly $\chi\ \chi'\ \chi^{\pm}$ and $\tilde{g}$ accessible at LHC/LC
    DM -> χ Wino(M2<M1)/Higgsino (low μ) $\chi\ \chi'\ \chi^{\pm}$ ~ mass degen.
  - $\tilde{\tau}\ \tilde{t}\ \tilde{b}$ scalars could also be observed
    DM -> co-annihilation χ Bino and $\tilde{\tau}$ ~ mass degen. < 500 GeV
  - Phases ~0 most sparticles could be accessible ('blob') at LC/LHC

DM at LC

- LC will accurately measure $m\chi$ and couplings, i.e. Higgsino/Wino/Bino content (polar.)
  -> Essential input to cosmology
  -> Input for non-accelerator searches
- In the 'blob' (B) mSugra scenario, LC accuracy on $m\chi$ ~0.1 GeV, $m\tilde{\tau}$ ~0.6 GeV
  -> Prediction of $\Omega_{DM}h^2$ with an accuracy ~ CMB anisotropies
  -> A mismatch would reveal extra sources of DM (Axions, heavy objects)
  Also access to $m\tilde{e}_L$, $m\tilde{e}_R$ $m\tilde{\nu}$ up to ~TeV
- Less precise, but still possible (cf. LEP2) in a mass degenerate scénario



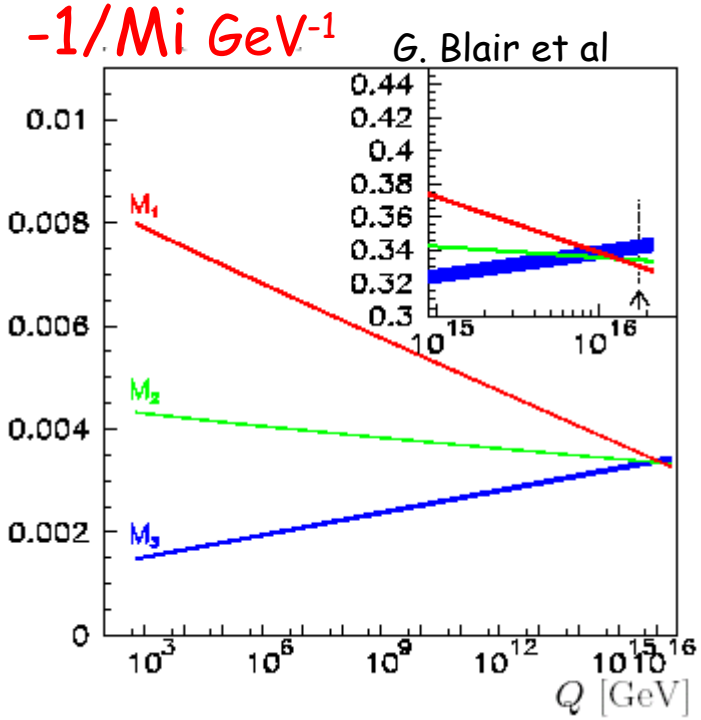
'WMAP'	7 %
LHC	~15 %
'Planck'	~2 %
LC	~3 %

MicrOMEGAs Pt B

LC and SSB

- Model independence (large set of observables LC+LHC) High accuracy SUSY needed to to access to the underlying SSB mechanism
- Lesson from LEP/SLD on GUT
- Subtle differences (loops) expected on Mi at unification
- LHC M_3 error (gluino), due to correlations, at ~10%
  -> with mχ from LC ΔM_3 improved by a factor ~10

-> Reconstruct fundamental param of an effective string theory



Summary: Why do we need a LC ?

- To provide the full picture on an SM/MSSM Higgs
- To provide an answer on EWSB with difficult or unexpected scénarios : heavy Higgs, reduced Higgs x-section
- To access to the SSB mechanism with LC+LHC measurements
- To predict precisely, within SUSY, $\Omega_{DM}h^2$
- To interpret unambiguously an unexpected discovery at LHC, e.g. a Z' or a KK ?
- To estimate mass scales beyond LC/LHC reach (~LEP/SLD):

  - Deviations on PM on Higgs couplings translated into, e.g., mA mH or Z' mass

  - Test of the theory at the quantum level which can reveal new mass scales (e.g. LEP/SLD and the Higgs mass)

-> New frontier: improved LHC or future colliders CLIC VLHC

Apologies

- Physics with CLIC
- SUSY and the neutrino sector
- Xtra dimensions: various schemes alternate or combined with SUSY
- Non-commutative effects
- Transverse polarization for Gravity induced effects
- SUSY and CP violation
- e-e-, $\gamma\gamma$ and γe physics
- …

Detector

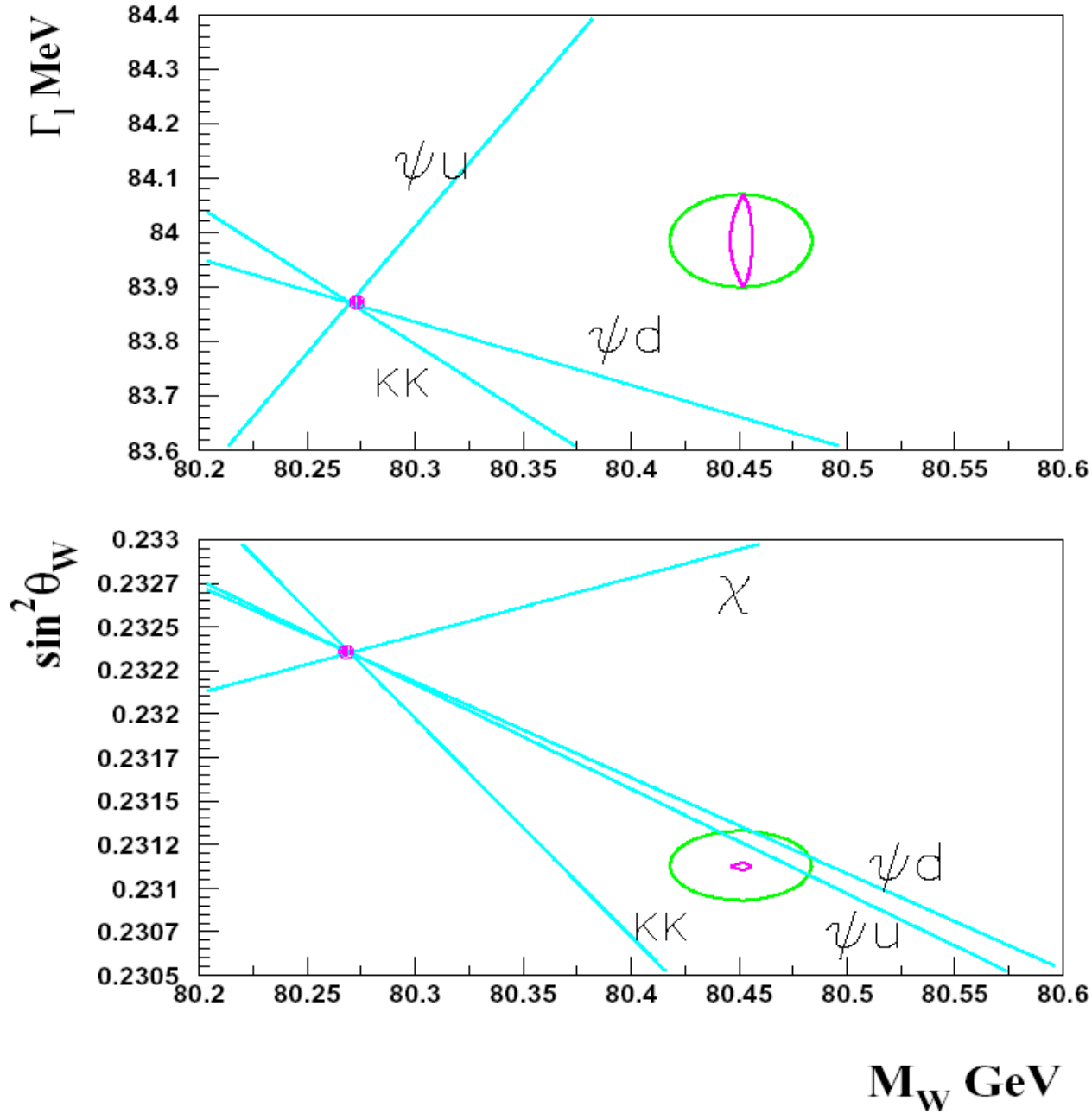
In many instances LC analyses will be systematics limited -> Aim at a ~perfect detector

3 outstanding improvements/LEP-SLD can be fulfilled with LC detectors:

- Improved vertexing : c (ε=70% >80% pure), tau tagging
- $\delta E/E$~1/2 LEP 6/8 jets reconstruction
  WW/ZZ separation (+ $\nu\nu$)
- $\delta p/p^2$ ~1/10 LEP down to 100 mrad

Also:

- Hermeticity on energetic γ/e down to 5 mrad outstanding
- $\mathcal{L}$, Polarization, $\sqrt{s}$ very precise (Z physics)
  -> Machine Detector interface activity


Γ_l MeV
84.4
84.3
84.2
84.1
84
83.9
83.8
83.7
83.6
80.2
80.25
80.3
80.35
80.4
80.45
80.5
80.55
80.6
ψu
ψd
KK
sin$^2\theta_W$
0.233
0.2327
0.2325
0.2322
0.232
0.2317
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χ
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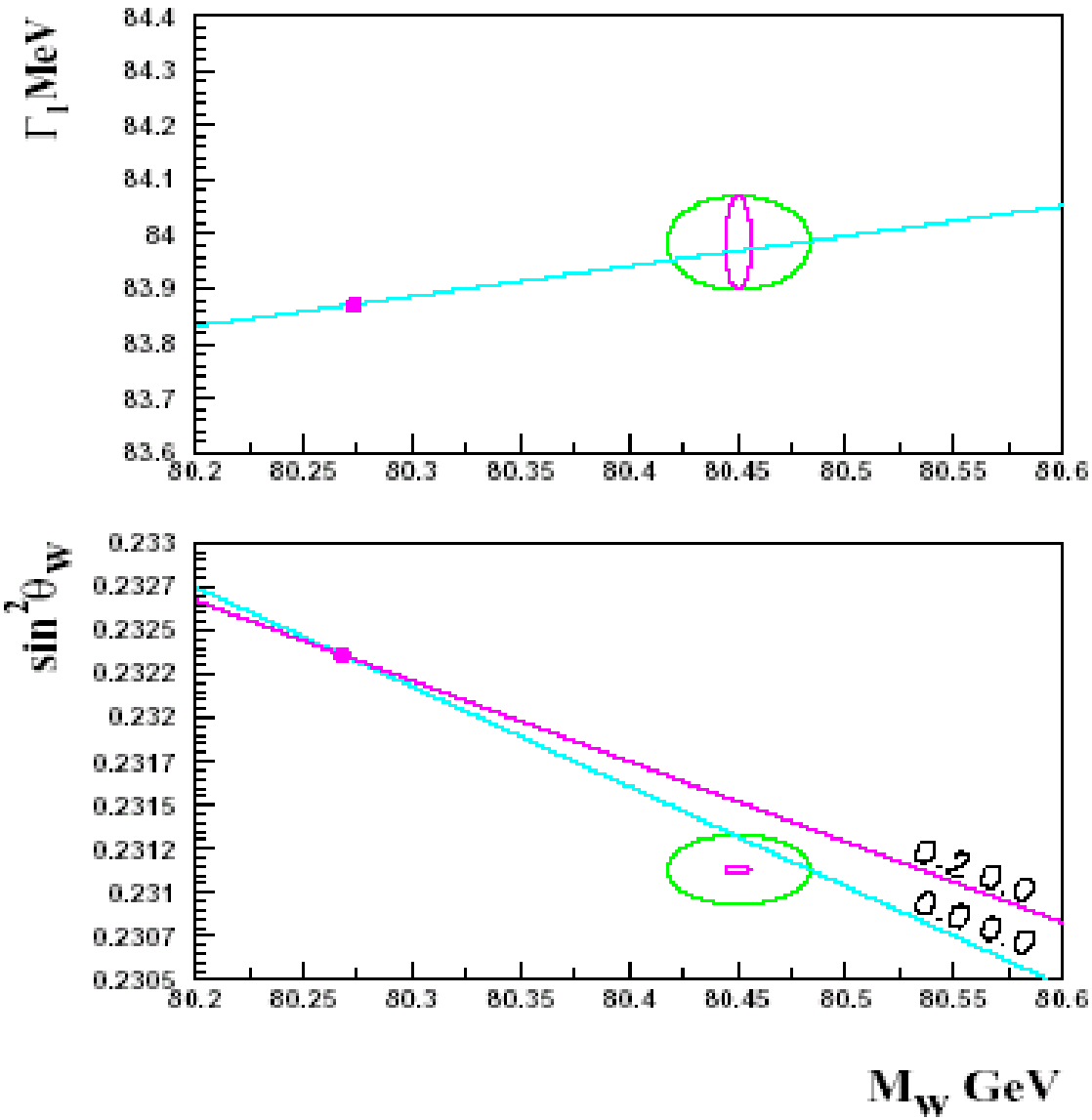
M_W GeV


Γ_l MeV
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$\sin^2\theta_W$
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M_W GeV