Essentiality of Hadron Collider and Linear Collider Programs for Exploring New Physics

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LCWS'02 – Jeju, Korea
29/08/02

$$\mathrm{HC} + \mathrm{LC} > \mathrm{HC}$$

$$\mathrm{HC} \oplus \mathrm{LC} > \mathrm{HC} + \mathrm{LC}$$

$$\mathrm{HC} \otimes \mathrm{LC} > \mathrm{HC} \oplus \mathrm{LC}$$

Introduction

Past years' worldwide activity made a clear case for a Linear Collider in the TeV regime as next big project in accelerator-based HEP

Well studied in:
- TESLA TDR
- Snowmass report
- ACFA Report

Excerpt from the common statement of the Snowmass2001 Physics groups:

(all physics groups and contributors from all regions)

- There are fundamental questions concerning electroweak symmetry breaking and physics beyond the Standard Model that cannot be answered without a physics program at a Linear Collider overlapping that of the Large Hadron Collider. We therefore strongly recommend the expeditious construction of a Linear Collider as the next major international High Energy Physics project.

Introduction

Relationship between Hadron Colliders (HC) and Linear Collider (LC):

1. Since the LC will start after the start of LHC, it must add significant amount of information:

$$HC+LC$$

2. Neither LC nor HC's can draw the whole picture alone. There are probably pieces which can only be explored by the LHC due to the higher mass reach. Joint interpretation of the results will improve the overall picture:

$$HC \oplus LC$$

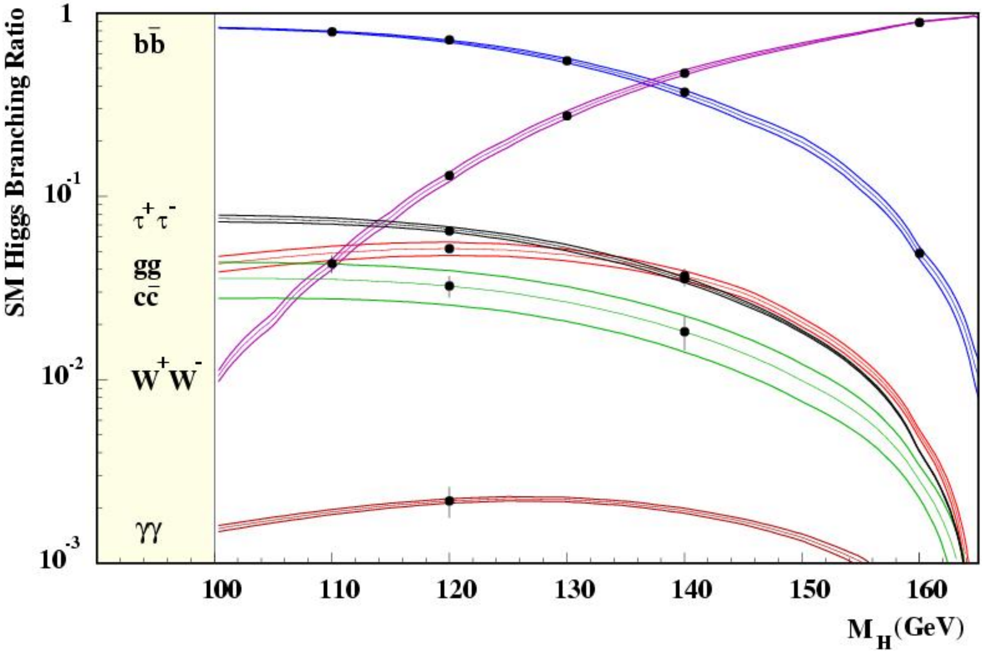
3. Overlapping running of both machines will further increase the potential of both machines and might be mandatory, depending on the physics scenario realized:

$$HC \otimes LC$$

Start with recalling point 1.: Examples ⇨

HC + LC > HC

Highlight 1: Higgs precision analyses

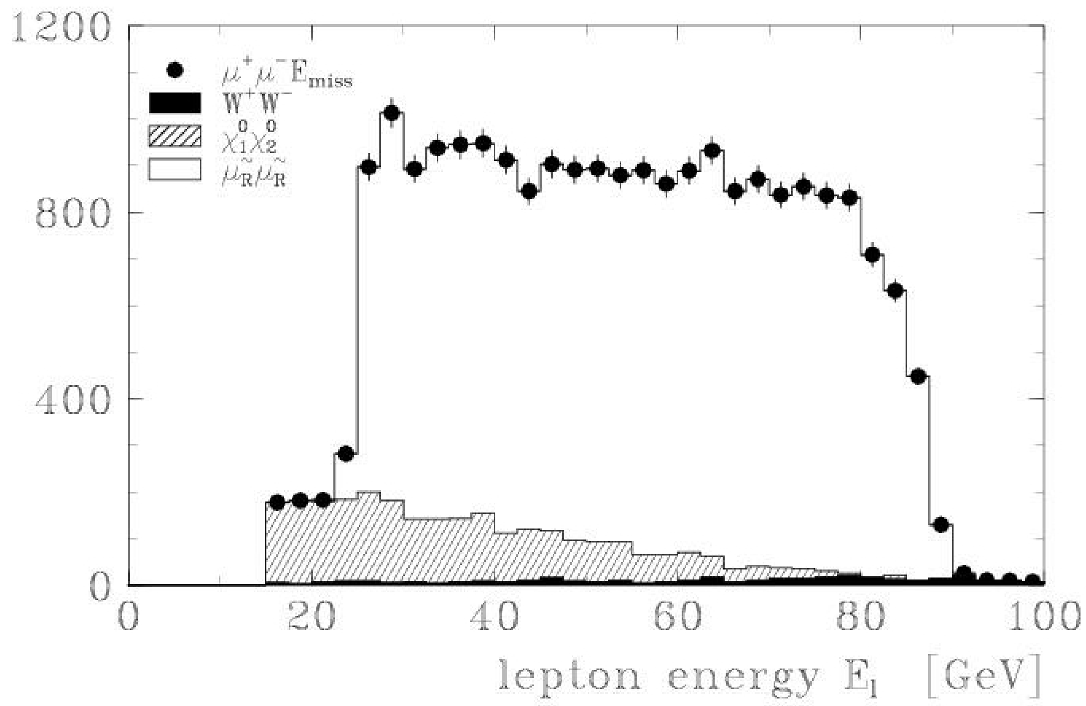


LC: properties of a light(ish) Higgs boson at the percent-level
⇨ experimental verification of Higgs mechanism in all essential elements

HC: possibly heavy Higgses

HC + LC > HC

Highlight 2: Precision analysis of SUSY particles

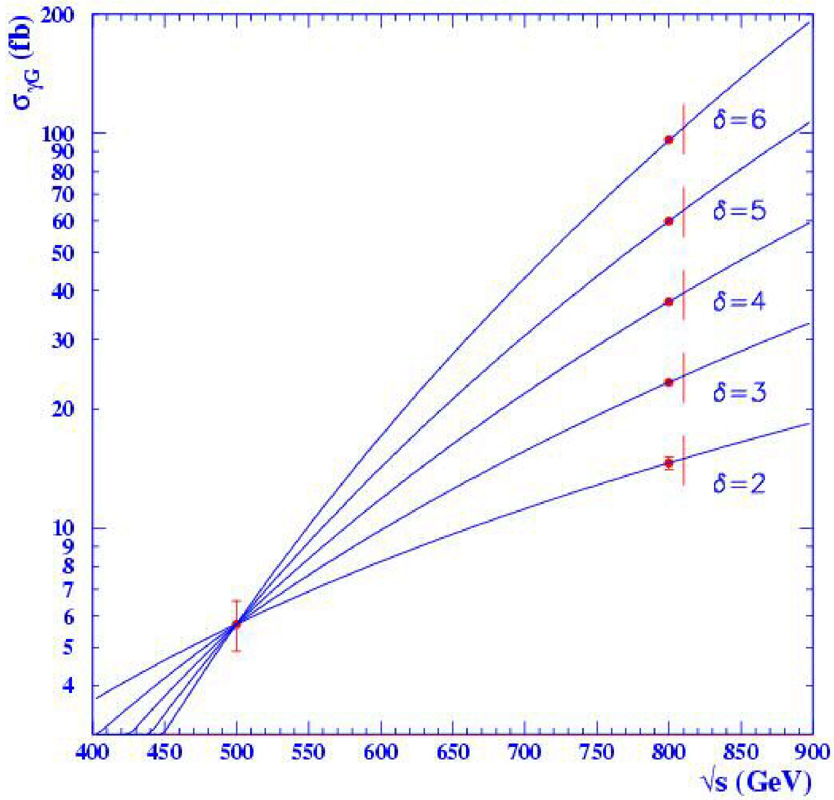


LC: masses, couplings of colourless part of spectrum with high precision

HC: coloured sparticles

HC + LC > HC

Highlight 3: High sensitivity to XD models

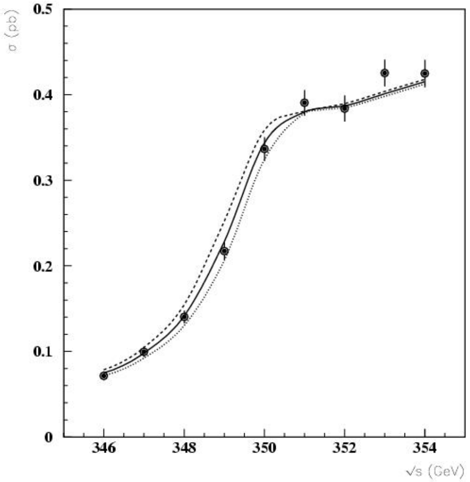


LC,HC: discovery of XD effects

LC: measure quantum numbers(Spin2?), number of dimensions, mixing effects (radions), distinguish from other models (Z'…)

HC + LC > HC

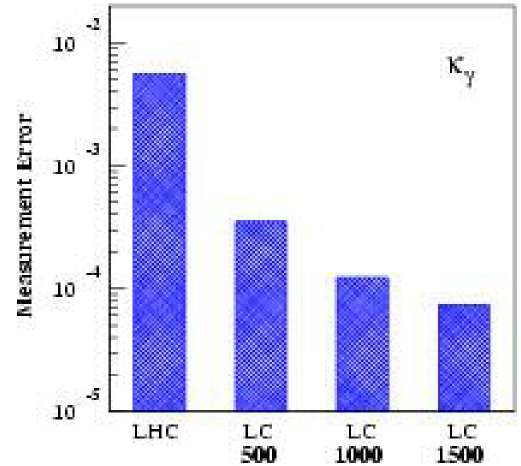
Highlight 4: Ultrahigh precision for SM processes:



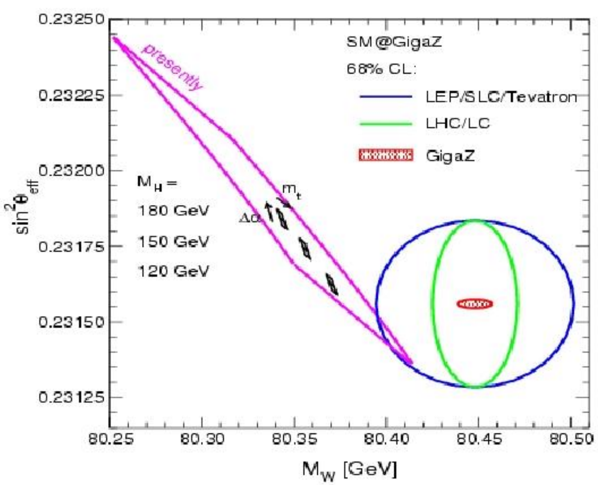
top

$\Delta m_{top} = 100$ MeV

TGC's



GigaZ



$\Delta \sin^2\theta_W = 0.000013$

$\Delta m_W = 6$ MeV

But we can do better…

Combined interpretation of HC and LC data

There are things,
which HC can (possibly) do better than LC…
Combined information gives more complete picture

Large field of joint analyses
Studies started but still a lot work to be done

Examples ⇨

HC ⊕ LC > HC + LC

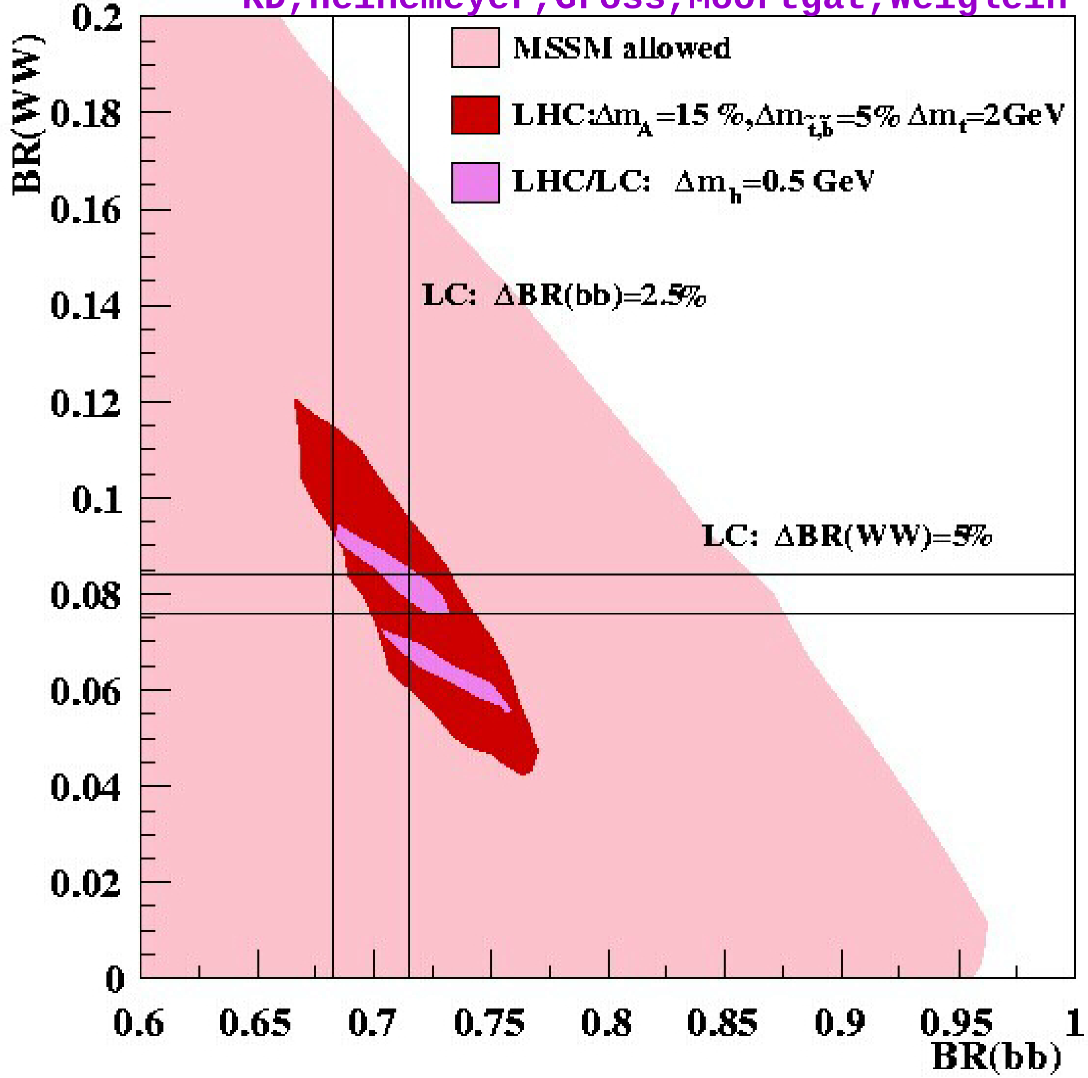
Measurement of
$m_A, m_h, m_{\tilde{t}}, m_{\tilde{b}}, m_{top},$

$\tan\beta$

Highly constrains
h-branching ratios
in MSSM

Comparison with
LC-measured BR's
is a very sensitive
consistency test
of the MSSM

KD,Heinemeyer,Gross,Moortgat,Weiglein



HC ⊕ LC > HC + LC

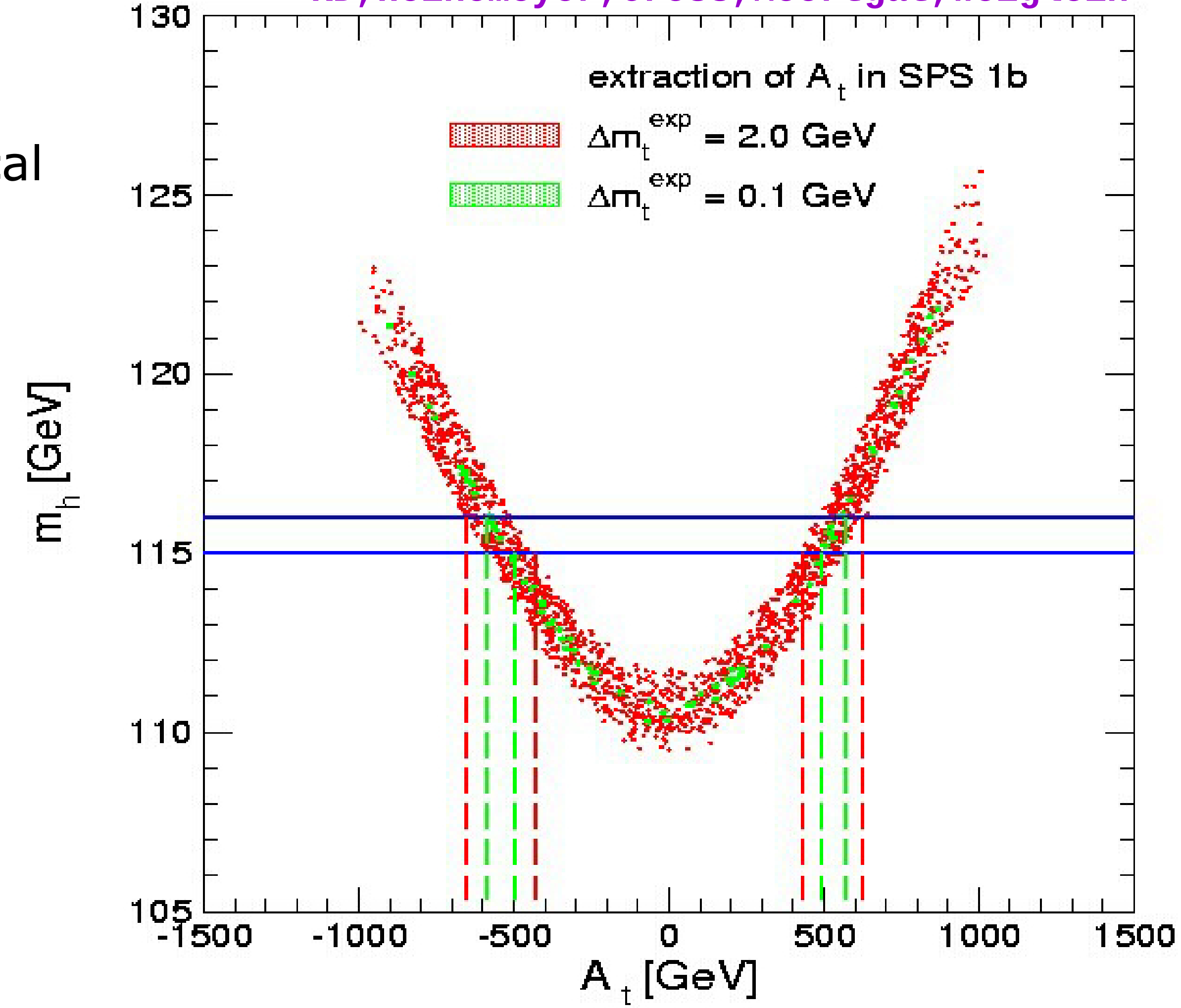
Precise knowledge of
top quark mass
often reduces theoretical
uncertainties.

$$\Delta m_h^{theo} \approx \Delta m_{top}^{\exp}$$

Example:
determination of
stop mixing parameter

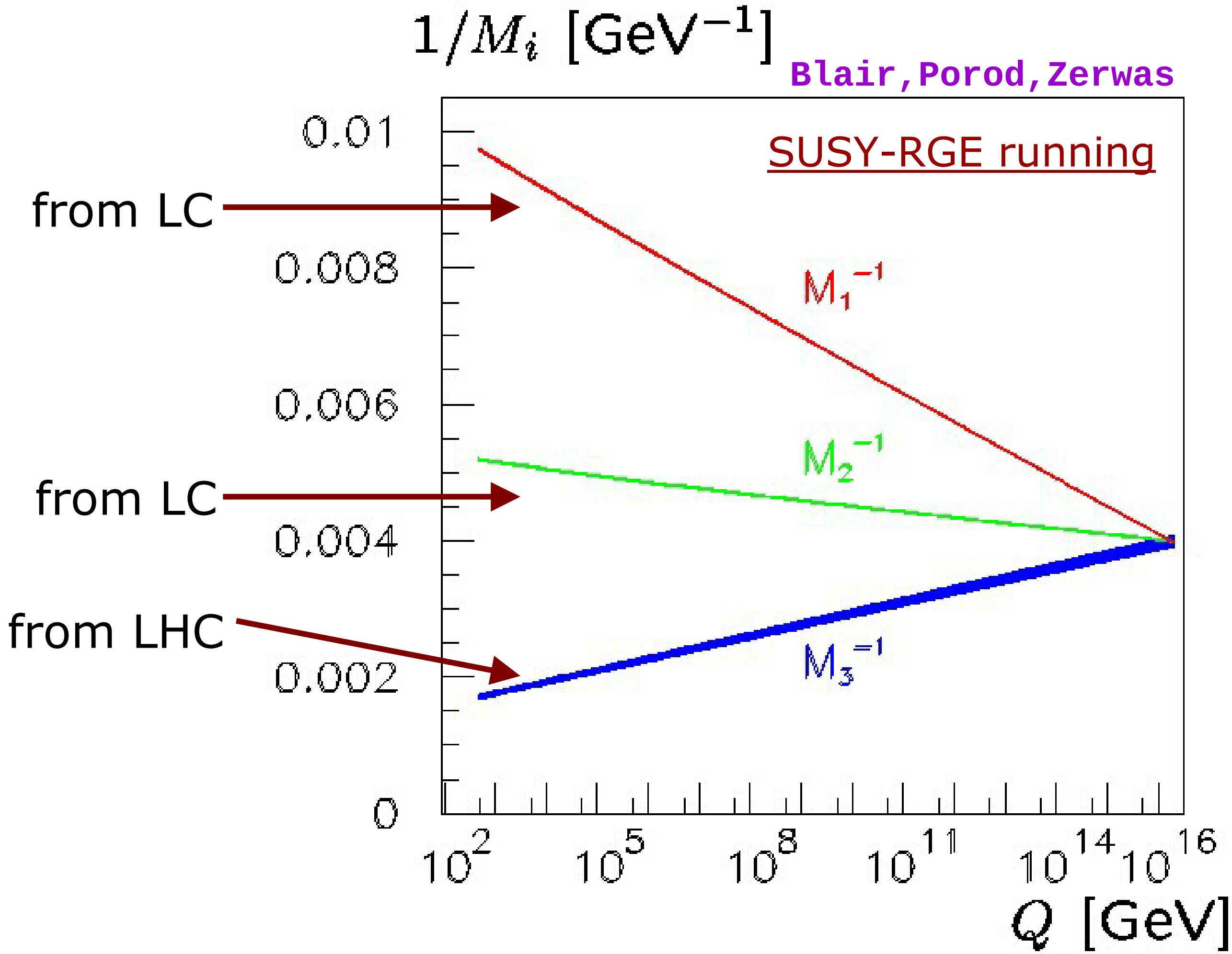
A_t

KD,Heinemeyer,Gross,Moortgat,Weiglein



HC ⊕ LC > HC + LC

MSSM: 105 parameters: some from HC, some from LC
Only joint interpretation allows us to
reconstruct fundamental High-energy theory: GUT? SSB-Mechanism?

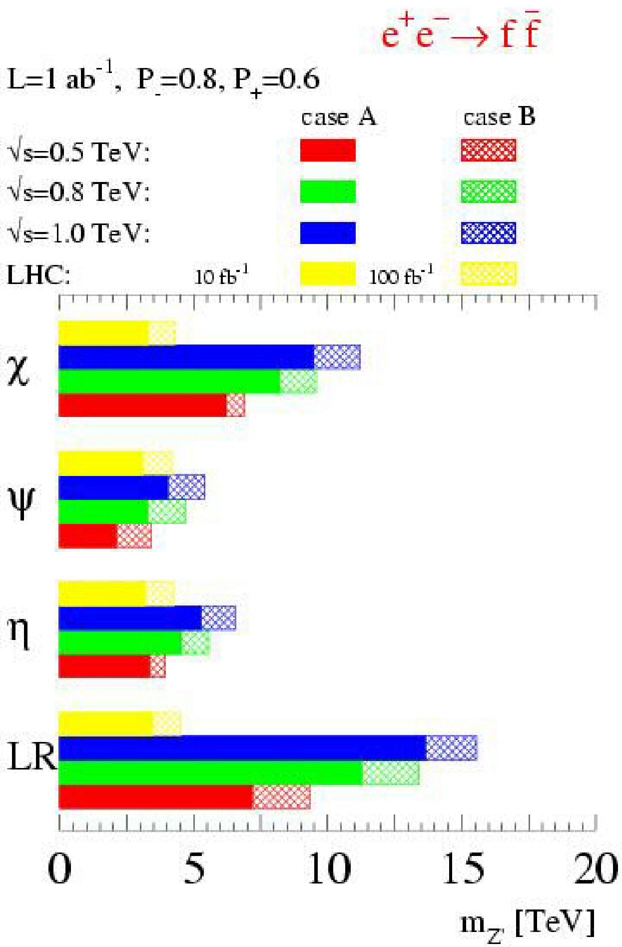


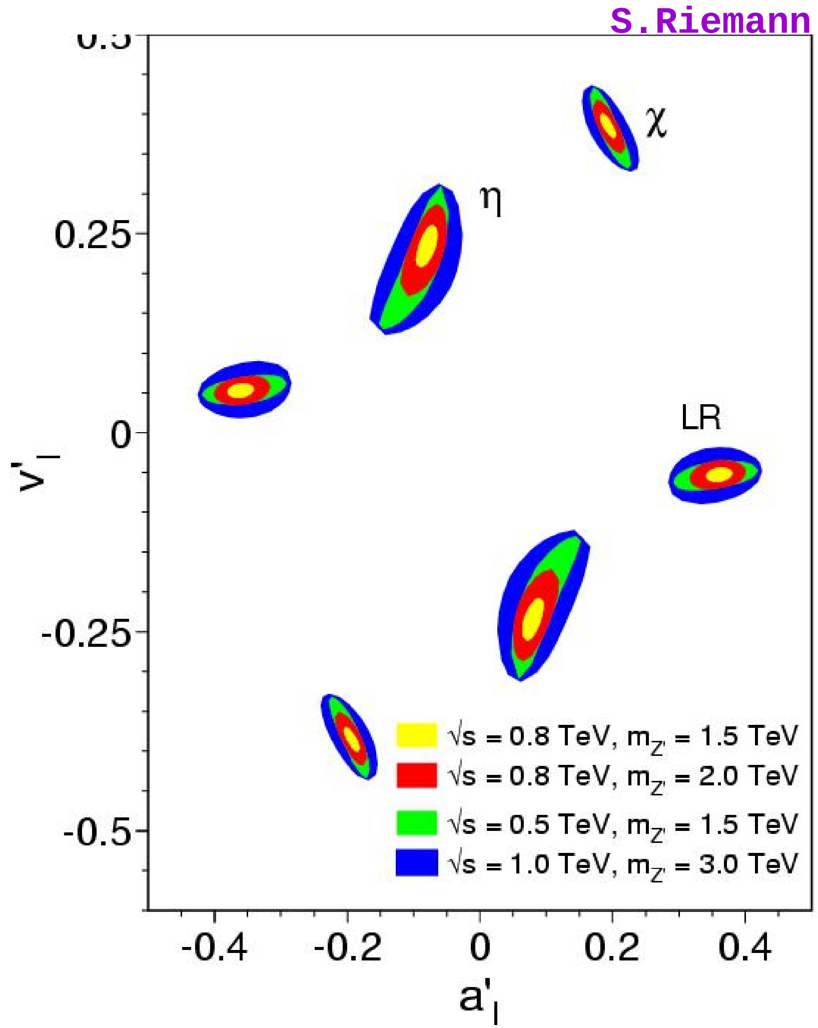
HC ⊕ LC > HC + LC

New Bosons

LC: high indirect mass reach
LHC: direct reach ~3-4 TeV

If LHC observes a Z′,
LC can measure couplings





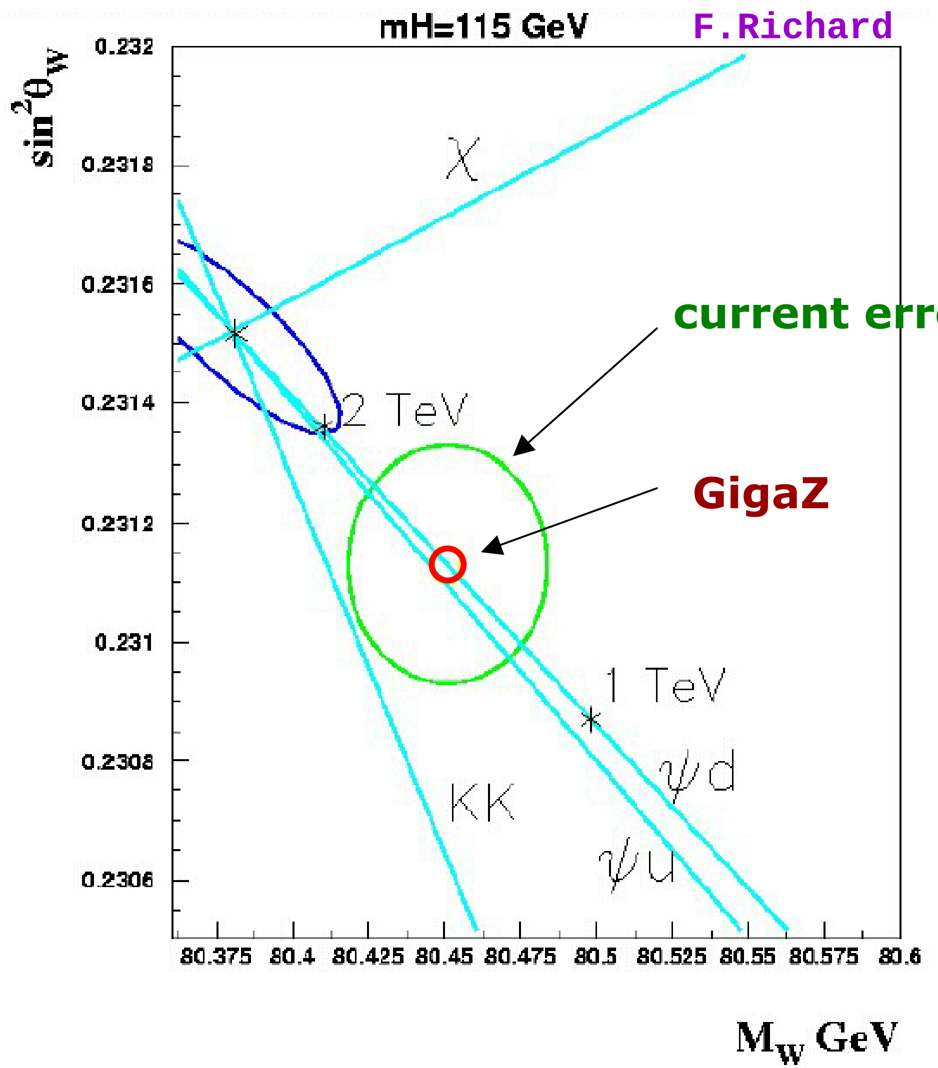
$HC \oplus LC > HC + LC$

New Bosons

GigaZ important
to pin down the model:

$\Delta\sin^2\theta_W = 0.000013$

$\Delta m_W = 6$ MeV



But we can do even better…

Combined >analyses< of HC and LC data

With simultaneous running of LHC and LC:

Results from one machine can have immediate impact on the analyses of the other

Results of one machine can guide the searches for the other

Might redesign trigger etc.

Impact on further direction (e.g. Super LHC, more lumi or more energy?)

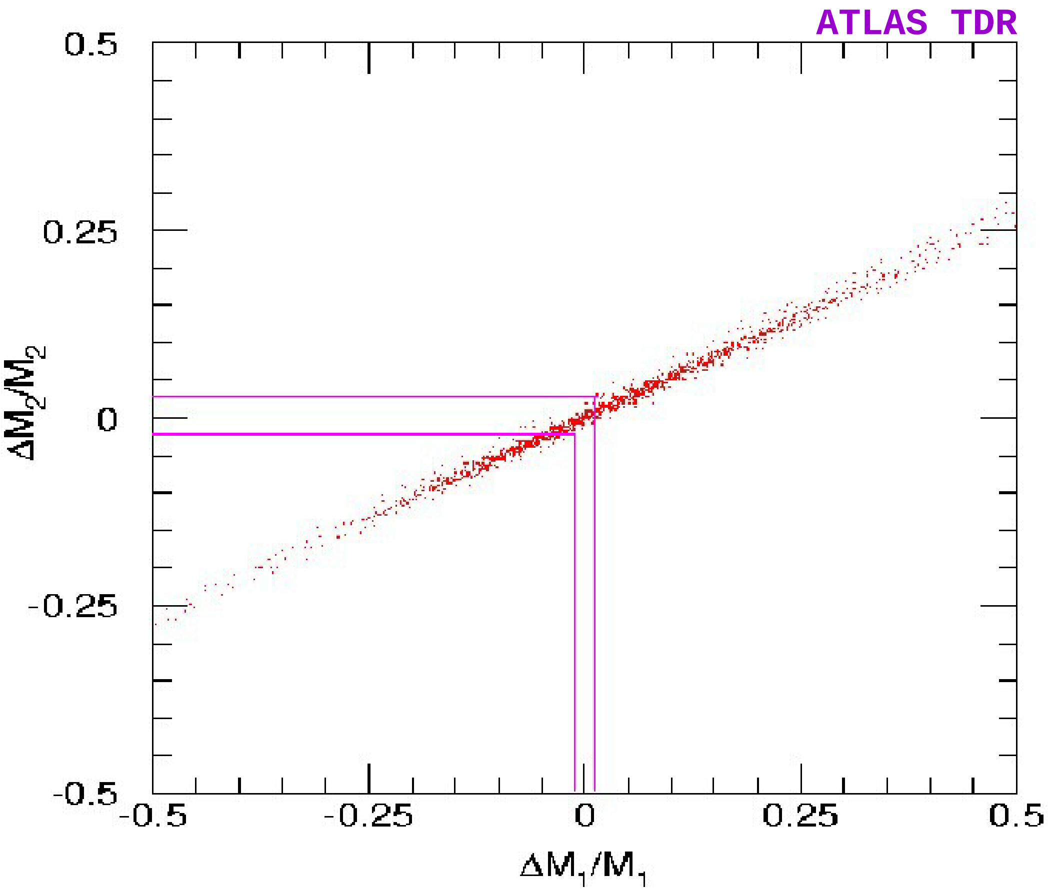
Impact next (multi-TeV) machine planning (c.f. LEP $\otimes$ SLC $\otimes$ Tevatron!)

Examples ⇨

HC ⊗ LC > HC ⊕ LC

At LHC, mass reconstruction of SUSY particles depends on knowledge Of LSP-mass.

Precise measurement of LSP-mass at LC improves mass resolution for heavier states at LHC



$HC \otimes LC > HC \oplus LC$

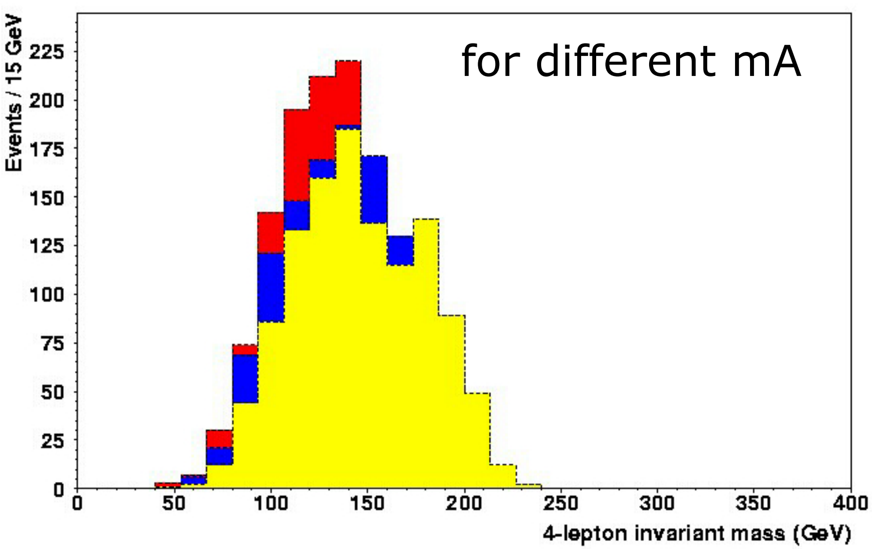
SUSY/Higgs

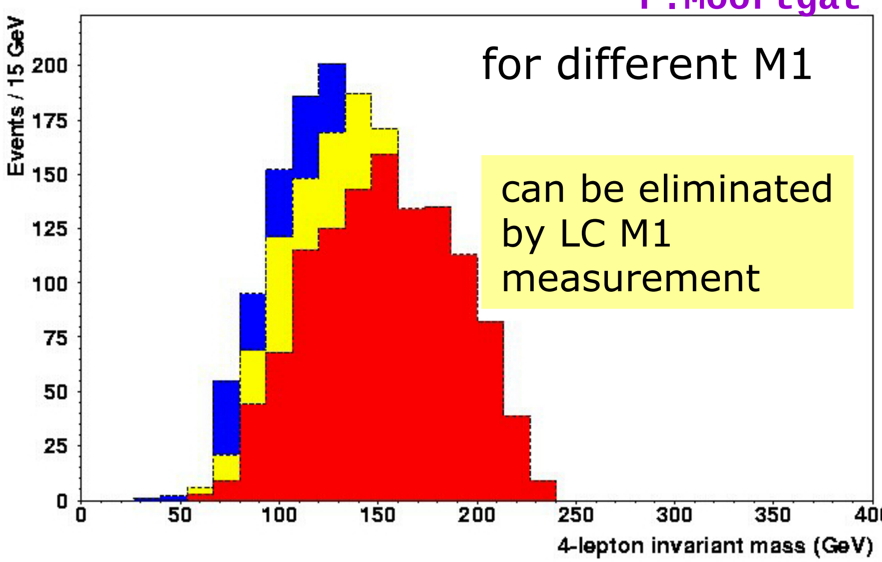
Specific worked-out example: $A \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow \ell\ell\ell\ell \tilde{\chi}_1^0 \tilde{\chi}_1^0$

Use 4-lepton-mass as estimator for m_A

$m_A = 330\,GeV$	$\rightarrow$		$-8\,GeV$	$M_1 = 50\,GeV$	$\rightarrow$		$+17\,GeV$
$m_A = 340\,GeV$	$\rightarrow$		$-4\,GeV$	$M_1 = 55\,GeV$	$\rightarrow$		$+5\,GeV$
$m_A = 350\,GeV$	$\rightarrow$	$< M_{llll} > =$	$137\,GeV$	$M_1 = 60\,GeV$	$\rightarrow$	$< M_{llll} > =$	$137\,GeV$
$m_A = 360\,GeV$	$\rightarrow$		$+4\,GeV$	$M_1 = 65\,GeV$	$\rightarrow$		$-4\,GeV$
$m_A = 370\,GeV$	$\rightarrow$		$+8\,GeV$	$M_1 = 70\,GeV$	$\rightarrow$		$-15\,GeV$

F.Moortgat





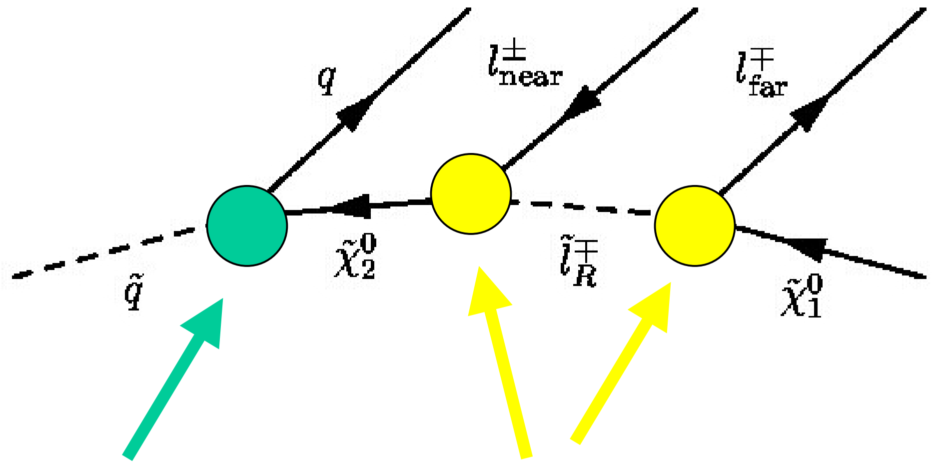
$HC \otimes LC > HC \oplus LC$

Cascade decays of squarks: if heavy, only accessible at LHC
hard to measure properties, if BR’s of lower members of decay chain unknown.

F.Paige

A.Parker
D.Tovey

Example:



only accessible at LHC

if these are known from LC

Different final states have different acceptance corrections
Can be combined if relative BR’s are known

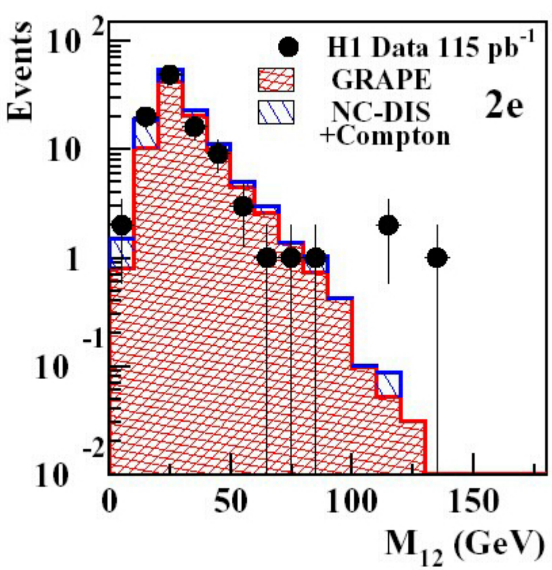
ongoing work…

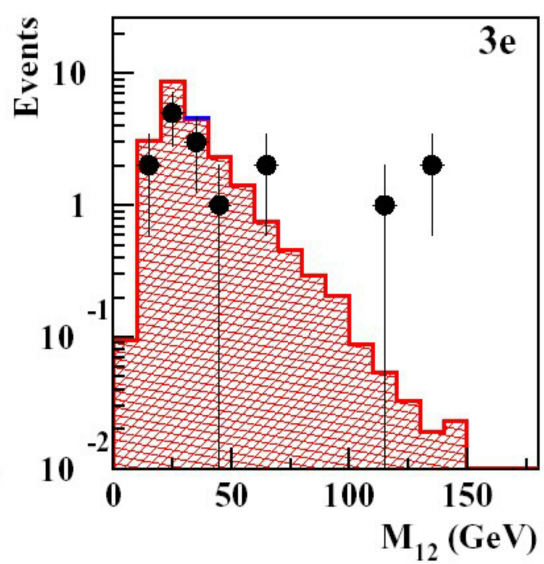
$HC \otimes LC > HC \oplus LC$

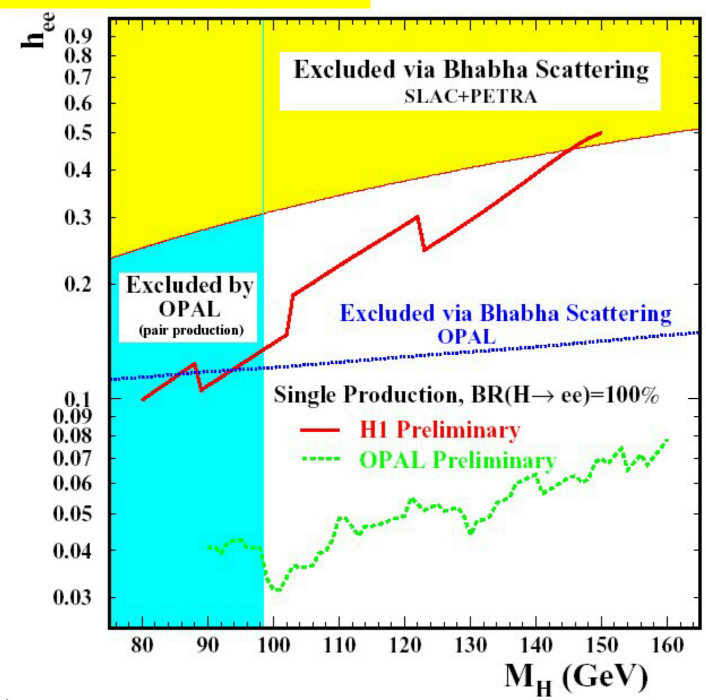
One more remark:

Current models are only guidelines
It might well be that LC discovers something which
- has not been looked at LHC
- was not triggered on
- needs (small) detector modifications

Recent example: HERA <-> LEP isolated lepton events







LHC/LC study group

I have only been giving examples…
A comprehensive study is needed to work out more quantitative results

“LHC/LC study group” formed in April 2002

Goals: ⊕: how to combine information from HC and LC?

⊗: how can LHC analyses profit from LC and vice versa?

Coordinators:
G.Weiglein
F.Paige

www.ippp.dur.ac.uk/~georg/lhclc

>100 members of ATLAS,CMS,LC working groups, theory,
Tevatron contact: H.Schellman
active group

Next meeting: 07/10/2002, CERN

LHC/LC study group

- **Ongoing / planned SUSY studies:**

Constraints on mSUGRA parameters (later also for GMSB, AMSB scenario) from combining LHC and LC data
A. Parker (Cambridge group), G. Polesello

Reconstruction of the fundamental theory from LHC and LC data
G. Blair, W. Porod, P. Zerwas, CMS

Required accuracy to separate SUSY models
B. Allanach, D. Grellscheid, F. Quevedo

LHC / LC complementarity in determination of low-energy SUSY parameters
Example: tan_beta determination
M. Beccaria, C. Lester, F. Renard, P. Richardson, C. Verzegnassi

Improvement of LHC analyses (e.g. of cascade decays) by including input on masses and BR's from LC?
Example: Figs 20-30 and 20-31 from the ATLAS TDR with LC accuracy on LSP indicated
A. Parker (Cambridge group), D. Tovey

Are there channels or analyses that are not feasible at one of the machines, but could become possible by using input from both machines?
Example: using input from measurements of the properties of colorless gauginos at the LC, is it possible to determine couplings of squarks to colorless gauginos from cascade decays at the LHC?
A. Parker (Cambridge group), D. Tovey

LHC/LC study group

Is it possible to perform consistency tests of the MSSM in the neutralino/chargino sector by combining LC information on light states with LHC information on heavier states?
B. Gaissmaier, J. Kalinowski, G. Moortgat-Pick, G. Polesello

Slepton production at the LHC and the LC
M. Berggren, E. Boos, A. Djouadi, A. Freitas, B. Gaissmaier, G. Moortgat-Pick

Stop and sbottom decays into Higgs singlets
S. Kraml, W. Porod

Does precise measurement of m_top and alpha_s at LC help in LHC analyses?
S. Heinemeyer, G. Weiglein, M. Winter

- **Ongoing / planned Higgs studies:**

SUSY Higgs physics: what can be gained from combining LC information on properties of the light Higgs with LHC information on the heavy Higgs states?
K. Desch, E. Gross, S. Heinemeyer, F. Moortgat, M. Schumacher, G. Weiglein

SUSY Higgs physics: how can LHC and LC results in a scenario where the LHC sees a part of the SUSY spectrum and only a light Higgs be used for determining SUSY parameters?
D. Asner, K. Desch, E. Gross, S. Heinemeyer, M. Schumacher, G. Weiglein

LHC/LC study group

Decays of heavy Higgses into light Higgses at the LHC: how can one make use of LC input?
E. Duchovni, U. Ellwanger, L. Fano, J. Gunion, C. Hugonie, D. Miller, S. Moretti

Can LC data on Gamma(H --> glu glu) be useful for prediction of sigma(glu glu --> H) at the LHC?
K. Desch, R. Harlander

Scenario with a relatively heavy SM-like Higgs: disentangling new physics using LHC and LC results
F. Richard

How can one exploit the m_top and alpha_s measurement at the LC for (SUSY) Higgs physics at the LHC?
S. Heinemeyer, G. Weiglein, M. Winter

- **Ongoing / planned electroweak physics studies:**

Rare top-quark decays, top couplings
S. Slabospitski

Determination of triple gauge-boson couplings, quartic couplings, electroweak precision measurements
U. Baur, D. Bourilkov, A. Denner, S. Dittmaier, K. Moenig, M. Roth, D. Wackeroth

Top polarization
E. Boos, S. Weinzierl

LHC/LC study group

- **Ongoing / planned QCD studies:**

Study of BFKL phenomena at LHC and LC with different systematics

- **Ongoing /planned studies in alternative theories:**

Using measurement of Z' mass at the LHC for determination of Z' couplings at the LC
(see e.g. LC-TH-2001-007 and references therein)
Investigating the origin of an extra Z': extended gauge group or KK excitation?
G. Azuelos, P. Bambade, D. Bourilkov, F. Richard, S. Riemann

Using LHC results on resonances in strongly interacting gauge-boson sector as input for LC analyses
G. Azuelos, T. Barklow, W. Kilian, ATLAS

Radion physics
M. Battaglia, E. Boos, D. Bourilkov, J.A. Hewett, T. Rizzo

Summary and Conclusions

- Physics case of LC well studied: worldwide consensus
- Relationship to Hadron Colliders:
  Optimal combination of the strengths of either machine
- Many examples for useful combination exist – some have to be worked out more quantitatively
- Important cases exist where overlapping running of LHC and LC can qualitatively improve overall physics output w.r.t. sequential running – quantitative studies have started
- This means theoretical and experimental work!
  ⇨ "LHC/LC study group" welcomes active members!!

Special thanks to G.Weiglein + F.Paige for their help!

Grand View

From Report of
Global Science Forum
Consultative Group HEP