LHC/LC Study Group:Status Report

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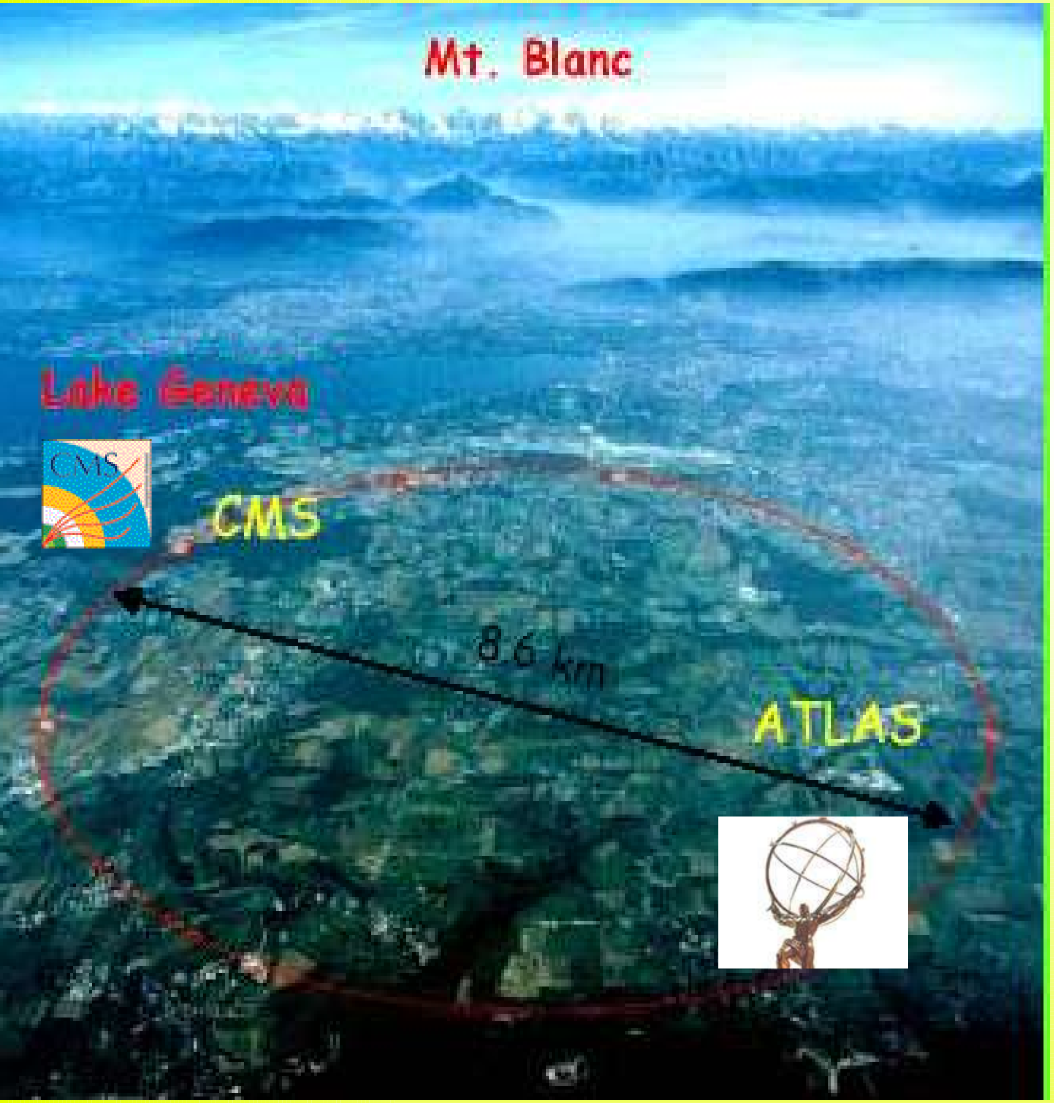
IISc

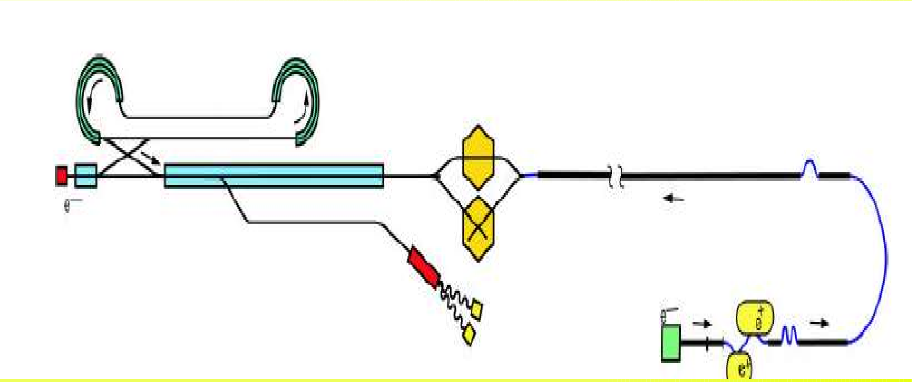
6^{th} ACFA Workshop on Physics and Detector at Linear Colliders.

Dec. 15-17, 2003.

LHC LC interplay



Worldwide Study of the Physics and Detectors for Future Linear $e^+ e^-$ Colliders



High Energy Frontier in HEP

LHC : Preparations full steam ahead.
Hopefully start in 2007

LC : (?) European, American and Asian Study Groups

Worldwide Study

- No Sanction, No Budget so far apart from R&D. Likely startup 2014?

- BUT the HEP Community world wide convinced of the need for LC

However there was NO TALK between the LHC and LC experimental communities. In 2002 a LC/LHC study group was formed first in Europe and then soon it took a worldwide character. LHC/LC GROUP

Aims of the LHC/LC Study Group

- To investigate how analyses at the LHC could profit from results obtained at the LC and Vice Versa

- Study how information obtained at both machines can be put **together** to explore, more *conclusively and effectively*,

EW Symmetry breaking, SUSY breaking mechanism and Underlying Structure of SUSY theories if the attractive SUSY solution has been used by Nature, Alternative Theories... Xtra Dimensions..

Aims of the LHC/LC Study Group

- Collaborative Effort of the Hadron Collider (LHC) and the Linear Collider (LC) Community.

- Physics case for both the machines well established, each with its own virtues.

- Aim of the LHC/LC group NOT to compare which collider can do better, but more

- How the two can complement each other?
Combined studies might give pointers to new bench marks for measurements at LHC. Might affect analysis if **not** the triggering.

Aims of the LHC/LC Study Group

- Make members of both experimental communities aware of which kind of inputs they can expect from the other collider and also critically analyse what information from the other collider can help get more physics out of the data.
- Aim : identify issues where the cross-talk between two colliders can increase the utility of *BOTH*.
- Possibilities of cross talk analysed assuming that the LC will come into operation half a decade after the LHC kicks off.
- Generic situation: Tevatron and LHC see some new physics but the nature of new physics not clear. Analyse possibilities of cross talk in this situation.

LHC/LC Study Group Activities

- Initiative started in ECFA/DESY framework
- Working Group contains 188 members from among Theorists, CMS, ATLAS, Members of *all* the LC study Groups + Tevatron contact persons.
- Working Group Coordinators:
  Georg Weiglein, Frank Paige and R.G.
- Web Page :
  www.ippp.dur.ac.uk/~georg/lhclc
- Mailing List :
  LHC-LC@listserv.fnal.gov
- Meetings:
  October 7, 2002 CERN; July 5, 2002 CERN,
  April 12-15, 2002, St. Malo
  Dec. 12, 2002, Fermilab, U.S.A
  (Jan. 2003, Mumbai, ILCWG meeting)
  Feb. 14, 2003, CERN, May 9, 2003 CERN

May 24 to Jun 9, 2003, Les Houches Workshop

Particle Physics + Cosmology

Cross talk between Particle Physics and Cosmology also in the framework of LC/LHC study group.

I will give one example: DM candidate.

LHC/LC Study Group Recognition

Group Recognised by the International Linear Collider Steering Committee: ILCSC

Cornell

Newman Laboratory

Cornell University
Ithaca, NY 14853-5001

Telephone: 607-255-4951
Fax: 607-254-4552

Floyd R. Newman Laboratory for Elementary Particle Physics

Georg Weiglein <georg.weiglein@durham.ac.uk>,
Frank Paige <paige@bnl.gov>,
Rohini Godbole <rohini.godbole@cern.ch>

Dear Georg, Rohini and Frank,

On behalf of the International Linear Collider Steering Committee I am happy to tell you that the Committee was very pleased to hear about the successful launch of your group. Your studies of the interdependence of the LHC and Linear Collider programmes and the benefits to be obtained from simultaneous operation of the two colliders will form an important input to the case which we must make for the Linear Collider. We look forward to your reports on the detailed physics analyses and we expect to quote them extensively. The ILCSC voted unanimously to support of your group's activities (in spirit of course - we have no funds to offer).

Sincerely,

Maury Tigner

Chair, ILCSC

cc DJM

LHC/LC Study Group Document

http://www.dur.ac.uk/~georg/lhclc

DCPT/03/DD, IPPP/03/PP, . . .

hep-ph/yymmnnn

LHC / LC Study Group Working Document

ALL AUTHORS

[1] Institute 1

[2] Institute 2

Abstract

The LHC / LC Study Group investigates the possible interplay between the LHC and a future e^+e^- Linear Collider in testing the Standard Model and in searches for new physics. It is studied in particular to what extent analyses carried out at one of the machines can profit from results obtained at the other machine. Mutual benefits can occur both at the level of a combined interpretation of Hadron Collider and Linear Collider data and at the level of combined analyses of the data, where results obtained at one machine can directly influence the way analyses are carried out at the other machine. Topics under study comprise the physics of weak and strong electroweak symmetry breaking, Supersymmetric models, new gauge theories, models with extra dimensions, and electroweak and QCD precision physics. The present report summarizes the status of the work that has been carried out within the LHC / LC Study Group so far. Possible topics for future studies are outlined.

Draft, October 27, 2003

Contains work discussed at ~ 5 meetings, in particular at Les Houches.

LES HOUCHES

centre de physique

Already ~ 390 pages, 107 authors, 40 contributions, Draft avaialble on the web page.
15 Dec. 2003 Final Draft??
At present contains mainly comparisons between the two machines, but a few good examples of complementarity and/or cross-talk are identified and studied as well.

Very much Work in Progress: Status Report.

LHC/LC Study Group Document

1) Electroweak Symmetry Breaking (Weakly)

   H. Haber, G. Weiglein, A deRoeck, R.G. (*)

2) Strong Electroweak Symmetry breaking

   T. Barklow, K. Moenig

3) Supersymmetric Models

   K. Desch K. Kawagoe, M. Njoiri, F. Paige, G. Pollesello

4) New Gauge Theories

   S. Riemann

5) Models with Extra Dimensions

   J. Hewett

6) Exotics

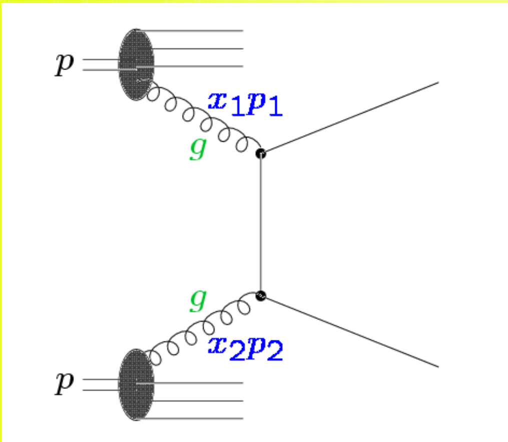
   J. Gunion

7) Electroweak and QCD precision tests

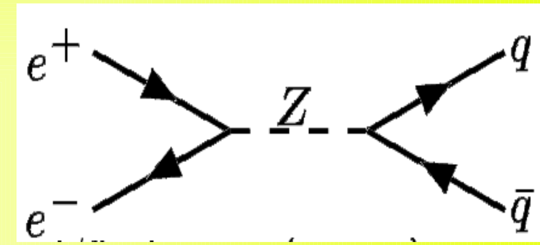
   E. Boos, S. Heinemeyer, J. Stirling, A deRoeck

(*) = main chapter editors/organizers

LHC/LC



Different characteristics of the two machines
Þ Different virtues



LHC pp collisions Öat ?s = 14 TeV

⇒ Strong point: larger mass reach for direct discoveries

- Kinematics: can use conservation of p_t
- Composite nature of colliding protons
- ⇒ underlying events and ⇒ √s of the hard interaction not fixed.
- Strongly interacting particles
- ⇒Large QCD backgrounds.
- Big ADVANTAGE: Under Construction

e+e- collisions at √s = 0.5-1.0 TeV

Strong point: high precision physics

- Kinematics: mom. conservation used to analyze the decays,…
- Well defined initial state, beam polarization, √s ......
- Backgrounds smaller than LHC
- Options: γγ, eγ , e⁻e⁻ colliders open up more avenues.
- We still are not sure of IF, WHEN and WHERE Construction will happen.

LHC/LC

Many scenarios for cross talk possible:

1) LC data help clear up the underlying structure of new physics of which Tevatron and LHC give some glimpse. **LHC + LC**

2) Combined interpretation of LHC/LC data

In particular to reduce possible model dependencies

$$\mathbf{LHC} \oplus \mathbf{LC} > \mathbf{LHC} + \mathbf{LC}$$

3) Combined Analyses of LHC/LC data : if the machines have an overlap in time, LC results could influence the second phase of LHC. Trigger dedicated search efforts at the LHC due to LC data, LC results can provide input to the upgrade options for the LHC machines and detectors.

$$\mathbf{LHC} \otimes \mathbf{LC} > \mathbf{LHC} \oplus \mathbf{LC}$$

LHC/LC

Historical Examples of such Interplay:

1) The usual that Hadron colliders being the Discovery Machines and Lepton Colliders being the 'precision' machine:

Example: W & Z sighted at $S\bar{p}pS$, detailed study at LEP and LEP-II.

Other types of cross-talk:

Examples:

2)Upgrades of Tevatron II significantly affected by LEP/SLD/Run I results

3) Isolated lepton events from HERA suggested reanalysis of some of the LEP data.

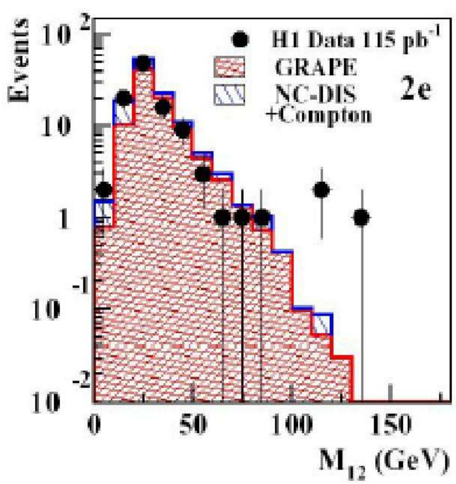
LHC/LC

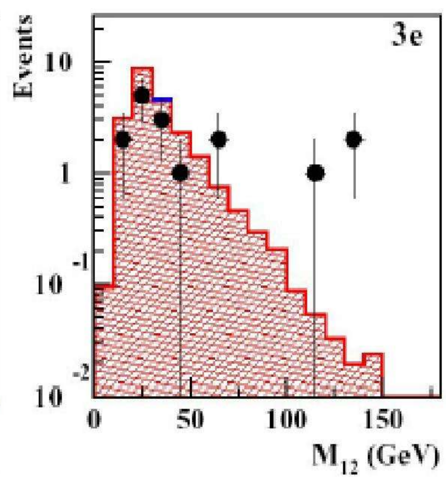
HC ⊗ LC   >   HC ⊕ LC

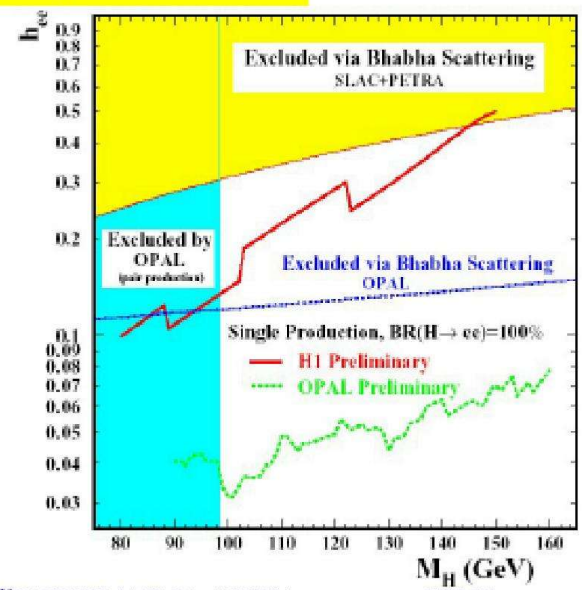
One more remark:

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



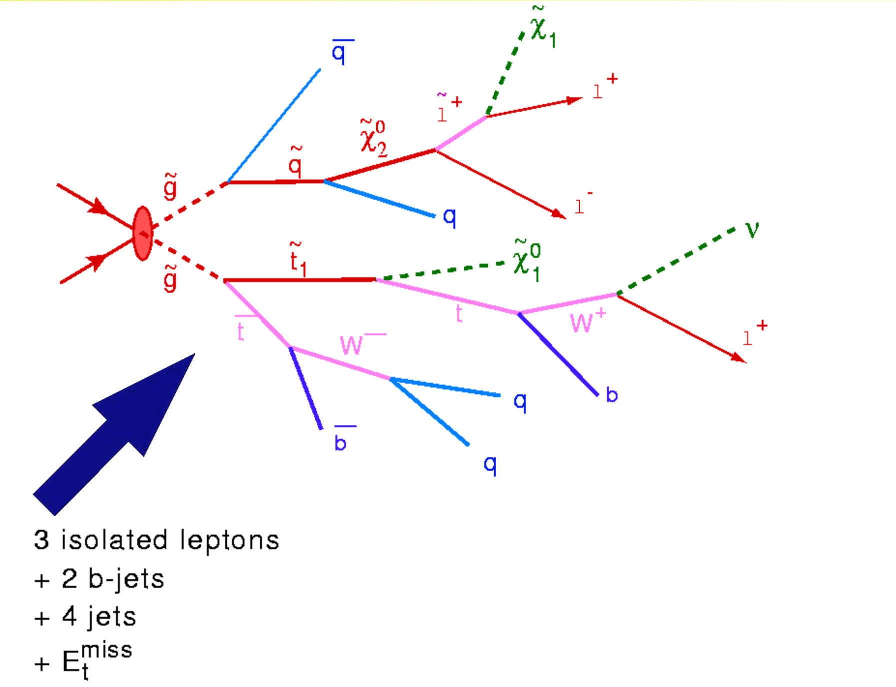




Supersymmetry

Supersymmetry (SUSY) ®assumes a new hidden symmetry between the bosons (particles with integer spin) and fermions (particles with half integer spin) to explain the Hierarchy problem (Planck « Electro-weak scale)

⇒Lots of new particles (squarks, sleptons,…) predicted with masses in the range from 10's of GeV's up to several TeV range



Supersymmetry is broken
We don't see the superpartners

E.g. Minimal supersymmetric model

105 new parameters! :masses, mixing angles…

SUSY breaking mechanisms:

reduce # of parameter

a) Minimal SUSY Gravity (msugra)

b) Gauge mediated SUSY breaking

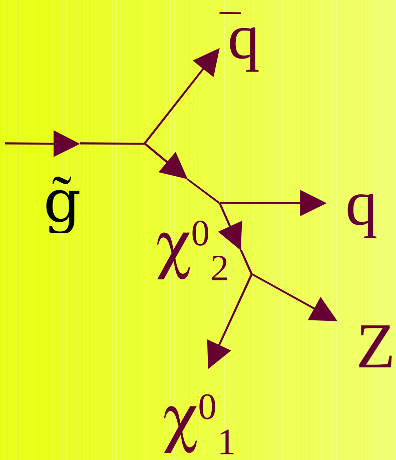
c) Anomaly mediated SUSY breakingd) Gravitino mediated SUSY breaking… etc.

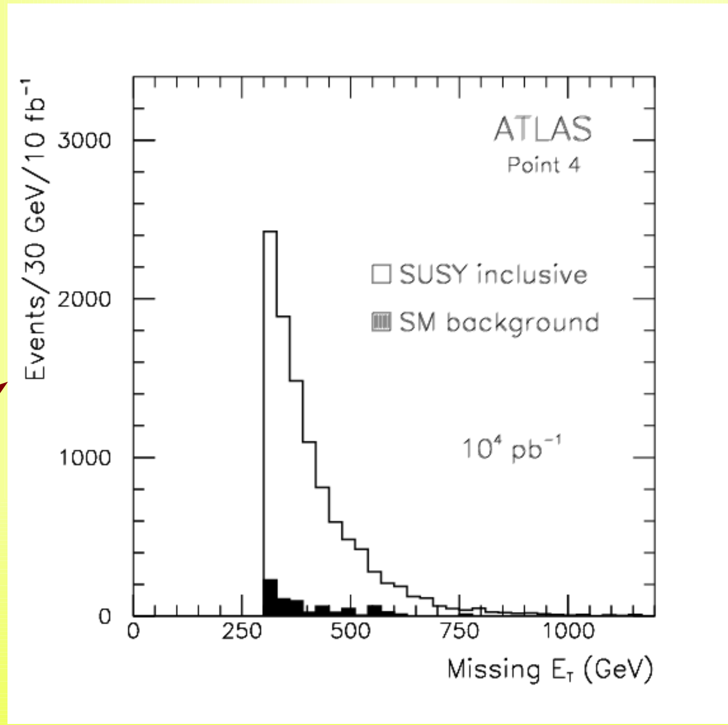
Lightest SUSY particle stable: **LSP** the dark matter candidate

Why time is ripe now?

Studies at LHC moving from 'discovery' mode to 'spectroscopy' mode

e.g. Jets + missing E_T due to gluino pair production.





Now Studies focussing on sparticle mass measurements, SUSY parameter determination,

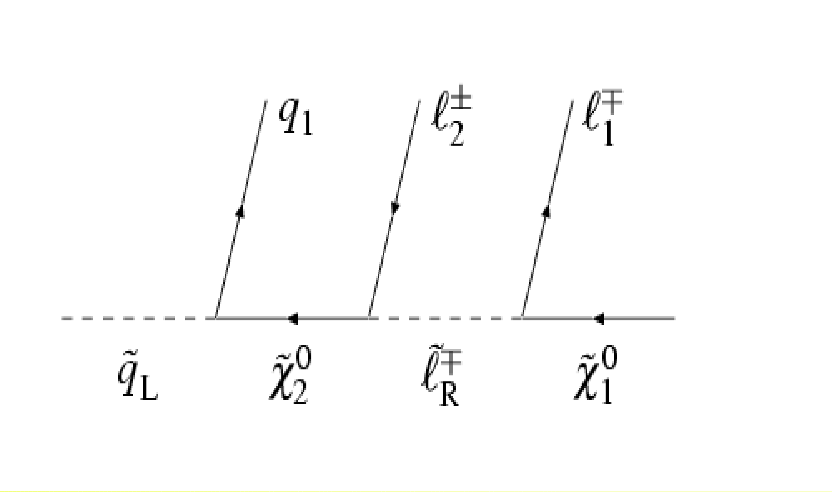
Model dependent

Model independent

Examples

Sparticle Mass determination at LHC: How will LC improve it?
[B. Gjelsten, J. Hisano, E. Lytken, K. Kawagoe ,D. Miller, U. Martyn, P. Osland, G. Polesello, M. Chiorboli and A. Tricomi]

Sparticle mass dtermination at LHC by using 'edges' from e.g. $\chi_2 \rightarrow \chi_1 \, l^+ l^-$



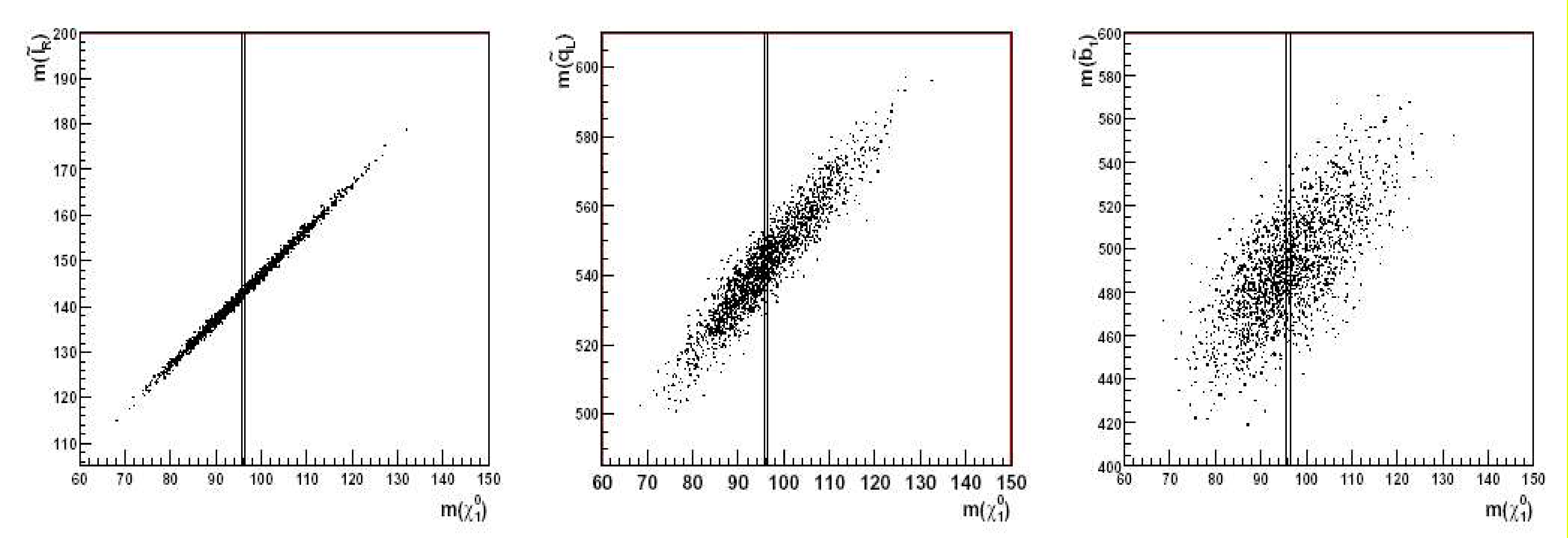
LSP is 'lost' and hence particle mass reconstruction has to be done using 'edges'

Problem: Strong corrleation between the sparticle mass and the LSP mass.

The Bottle Neck

Uncertainty in the knowledge of the LSP mass thus affects the accuracy with which sparticle masses can be determined.

Thus, e.g., $\Delta m_{gluino} \sim \Delta m_{LSP}$



Examples worked out for a particular point SPS1a from ATLAS and CMS. For this point both LC and LHC have reach for various lighter sparticles.

What can LC do?

Using LHC luminosity

$\mathscr{L} = 300\ \text{fb}^{-1}$

ΔM in GeV

	LHC	LHC+LC (0.2%)	LHC+LC (1.0%)
$\Delta m_{\tilde{\chi}_1^0}$	4.8	0.19	1.0
$\Delta m_{\tilde{l}_R}$	4.8	0.34	1.0
$\Delta m_{\tilde{\chi}_2^0}$	4.7	0.24	1.0
$\Delta m_{\tilde{q}_L}$	8.7	4.9	5.1
$\Delta m_{\tilde{b}_1}$	13.2	10.5	10.6

	LHC	LHC+LC (0.2%)	LHC+LC (1.0%)
$\Delta m_{\tilde{g}}$	8.0	6.4	6.5
$\Delta m_{\tilde{q}_R}$	11.8	10.9	10.9
$\Delta m_{\tilde{b}_1}$	7.5	5.7	5.7
$\Delta m_{\tilde{b}_2}$	7.9	6.3	10.6
$\Delta m_{\tilde{\ell}_L}$	5.0	1.6	1.9
$\Delta m_{\tilde{\chi}_4^0}$	5.1	2.25	2.4

Significant improvement in the accuracy of mass measurement of sparticles if LC accuracy is less than 1%.

What can LC do?(update)

	LHC	LHC+LC
$\Delta m_{\tilde{\chi}_1^0}$	4.8	0.05 (input)
$\Delta m_{\tilde{l}_R}$	4.8	0.05 (input)
$\Delta m_{\tilde{\chi}_2^0}$	4.7	0.08
$\Delta m_{\tilde{q}_L}$	8.7	4.9
$\Delta m_{\tilde{q}_R}$	11.8	10.9
$\Delta m_{\tilde{g}}$	8.0	6.4
$\Delta m_{\tilde{b}_1}$	7.5	5.7
$\Delta m_{\tilde{b}_2}$	7.9	6.2
$\Delta m_{\tilde{l}_L}$	5.0	0.2 (input)
$\Delta m_{\tilde{\chi}_4^0}$	5.1	2.23

Use of LC information can increase the accuracy substantially.

Detailed analysis of point SPS1a

Masses of heavier neutralinos, charginos and SUSY parameter determination

[K. Desch, J. Kalinowski, G. Moortgat-Pick, M.Nojiri, G. Polesello]

Feedback from LC into LHC studies and vice versa.

Heavier neutralinos/charginos : may be produced only at the LHC. Use LC input on lighter neutralino, chargino masses and slepton masses to correctly identify the χ_4^0 . Use the accurate parameter determination from LC for that. BUT only LHC will be able to see it.

Further feeding this value of m($\chi^0{}_4$) can increase the accuracy of parameter determination at LC.

Masses of heavier neutralinos, charginos

A step further: predicting sparticle masses from LC data.

LC can measure χ_1^0, χ_2^0 and χ_1^+ precisely

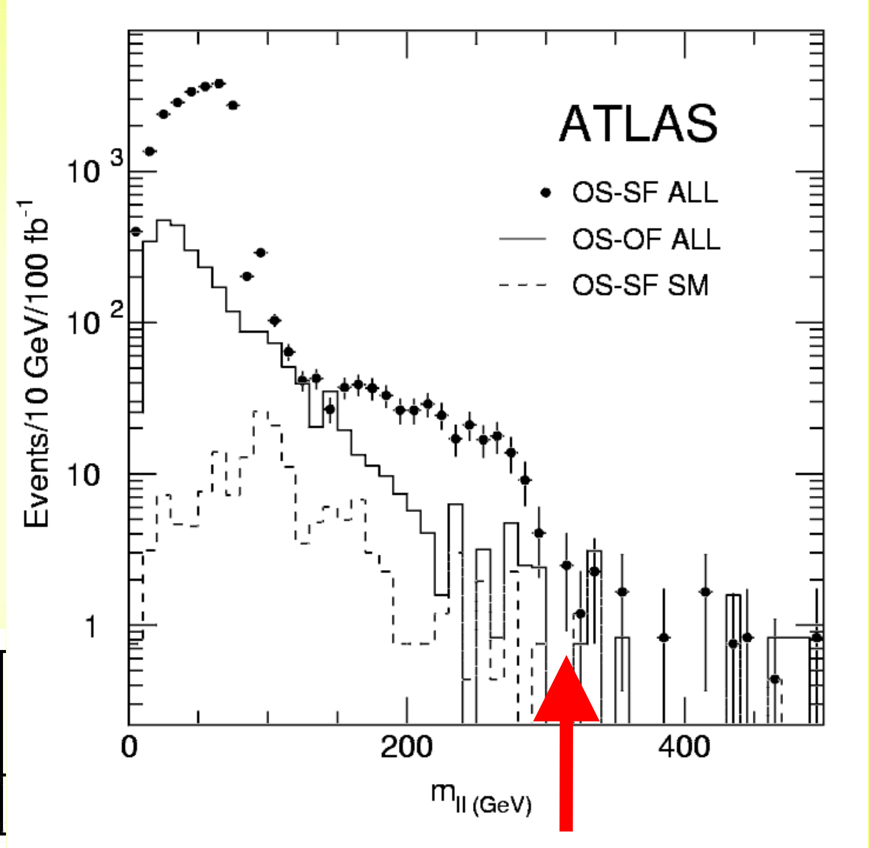
$\Rightarrow$ Measurements of masses, cross sections and the mixing angles (using polarized beams)

Determine the SUSY parameters

M_1, M_2 (U(2) and SU(2) gaugino masses)

μ (higgsino mass parameter) and tanβ

SUSY Parameters			
M_1	M_2	μ	$\tan\beta$
99.1 ± 0.3	192.7 ± 1.0	$\mu = 352.8 \pm 9.3$	$[7.4; 15.1]$

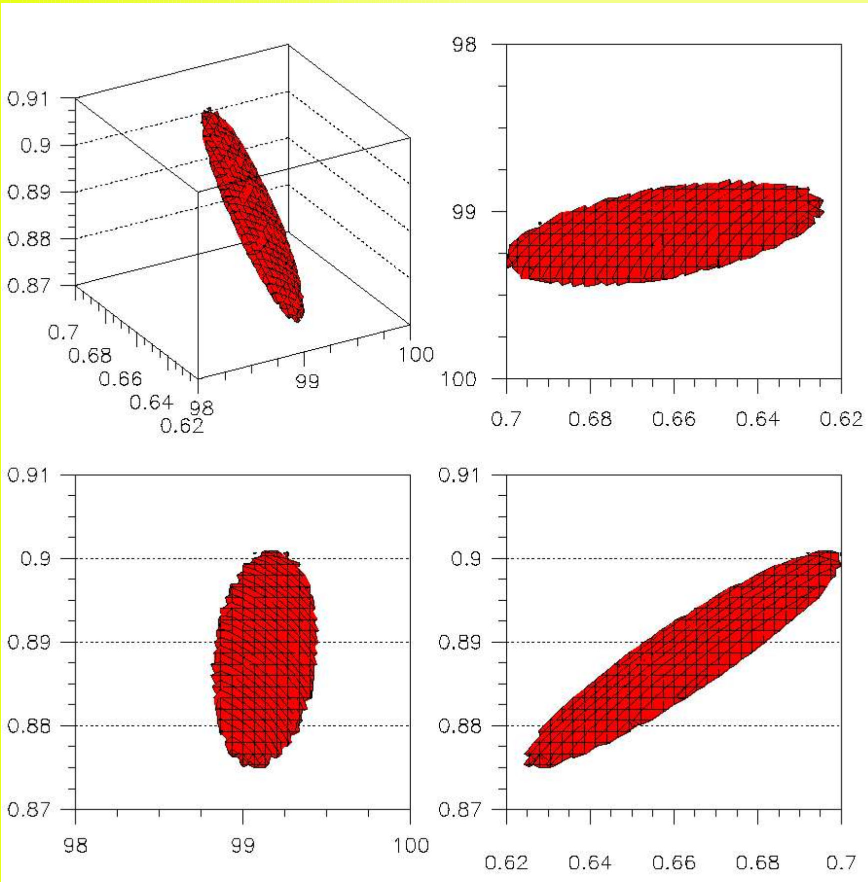


Predicts: m(χ^0_4)=378.3$\pm$ 8.8 GeV

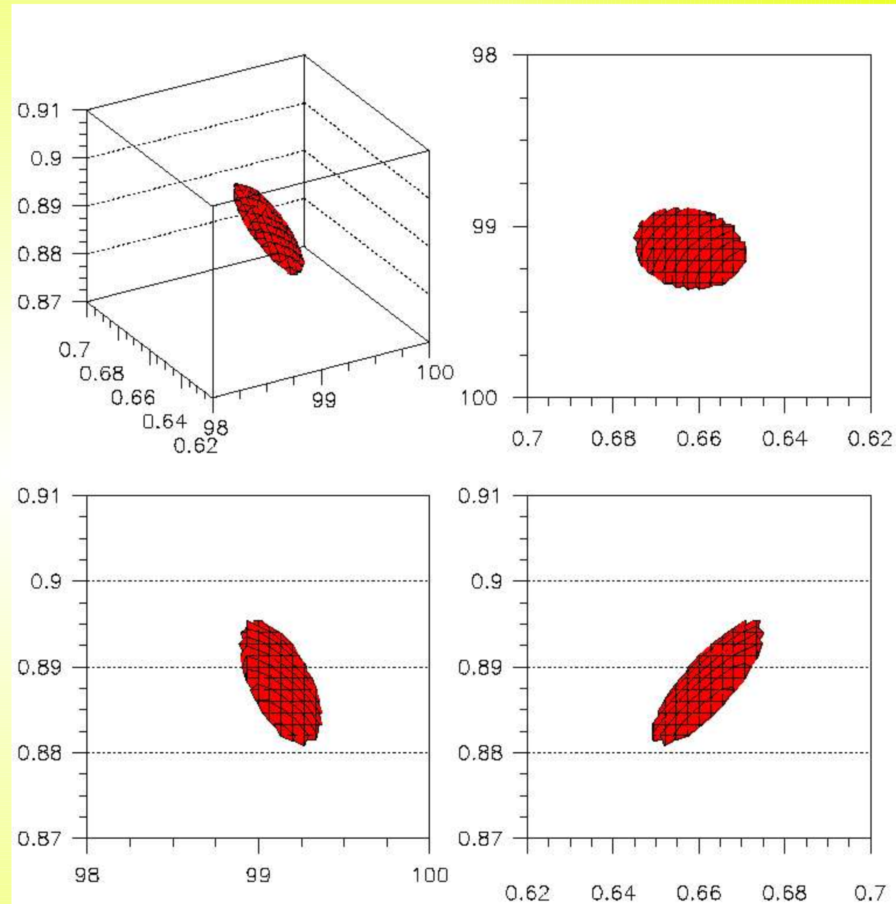
With a tailored analysis mass of $\geq\chi^0_4$ can be measured. With(out) using information from LC to 2.5 (5) GeV.

Feed this back into LC analysis

Determine M_1, mixing angles $\cos\Phi_L$, $\cos\Phi_R$. Plotted contours of $\Delta\chi^2 = 6$.



LC alone



LC + LHC

Significant improvement in precision with LC + LHC

Susy Parameters			
M_1	M_2	μ	$\tan\beta$
99.1 ± 0.3	192.7 ± 0.6	$\mu = 353.2 \pm 2.5$	$[8.6; 12.0]$

Some more examples in SUSY

[J. Hisano, M. Nojiri and K. Kawagoe]

Full reconstruction of the stop and sbottom mixing parameters with **LHC ⊗ LC**

- Take the set of electroweak SUSY parameters determined by the LC and LHC data.
- Take branching ratios of bottom (stop) measured by the LHC
- Take m_{b1} and m_{b2} from edge study (+ neutralino from the LC)

· Measure

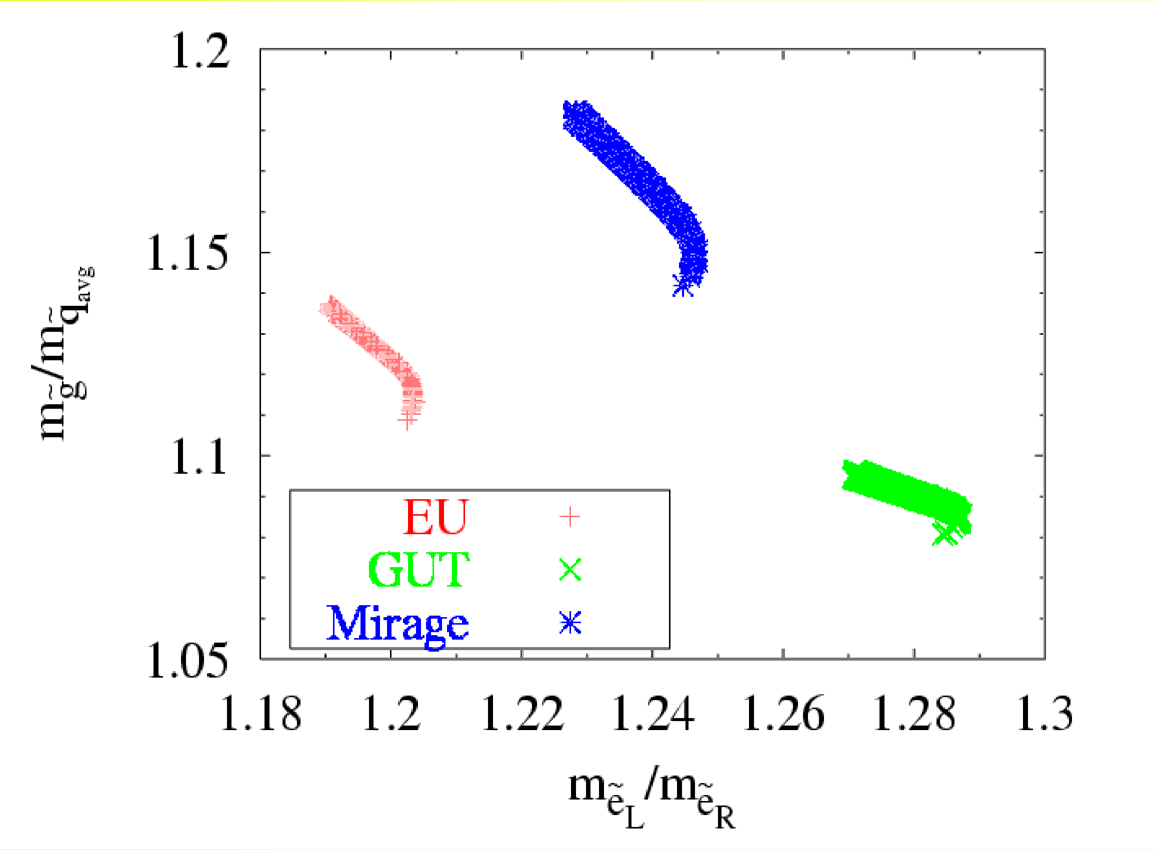
-tb invariant mass distribution

_rate of "edge events" in m_{tb} distribution (chargino chain)

_rate of events in the llb distribution (neutralino-2 chain)

Why do we need to measure masses accurately?

B.Allanach,D.Grellscheid,F.Quevedo

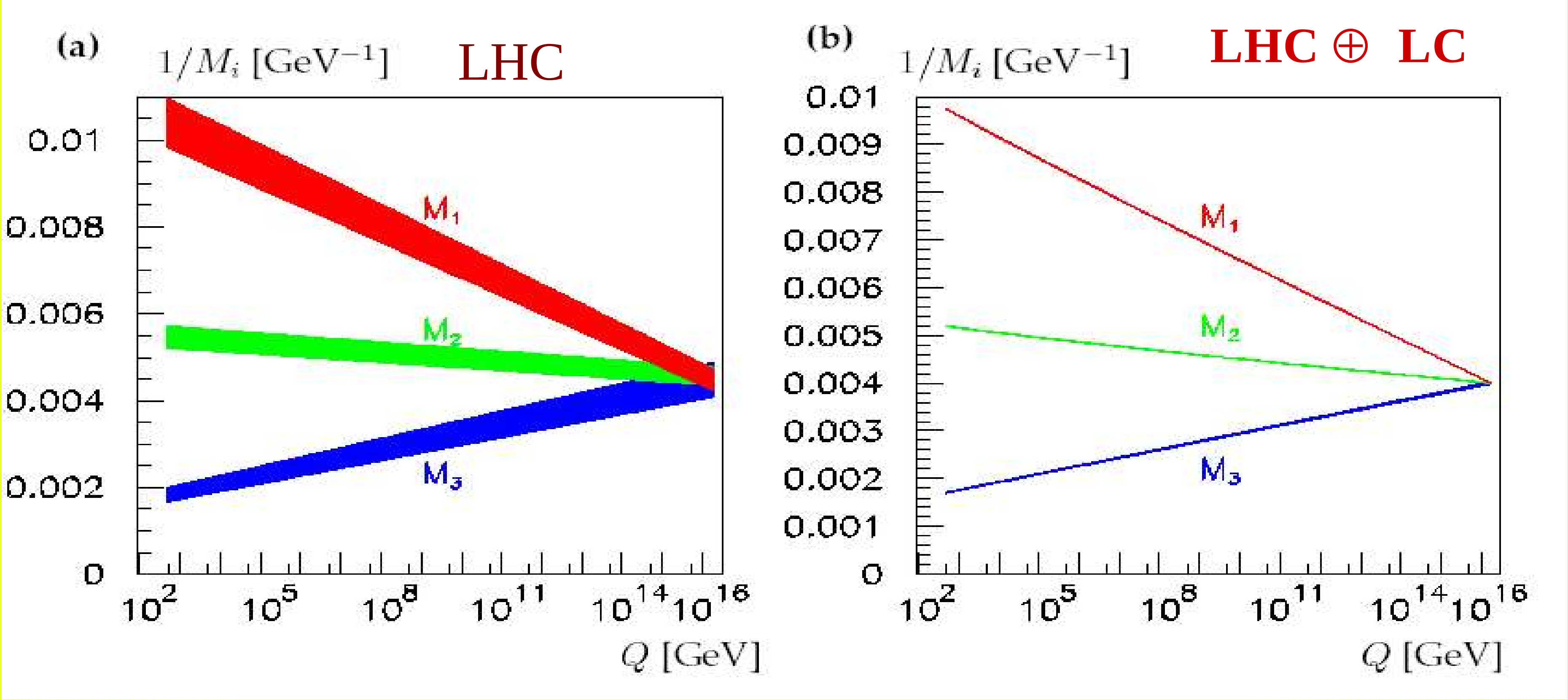


Discrimination between different SUSY breaking scenarios.

Need % level accuracy to distinguish between models.

Use of LC/LHC to determine pattern of SUSY breaking

From a combination of LHC and LC results, precise measurements of masses of SUSY particles, couplings: Evolution of gaugino mass parameters [G. Blair, U. Martyn W. Porod,, G. Polesello, P. Zerwas]



More optimistic gluino mass determination used

EW symmetry breaking

Higgs Physics:

1) [K. Desch, S. Heinemeyer and G. Weiglein]

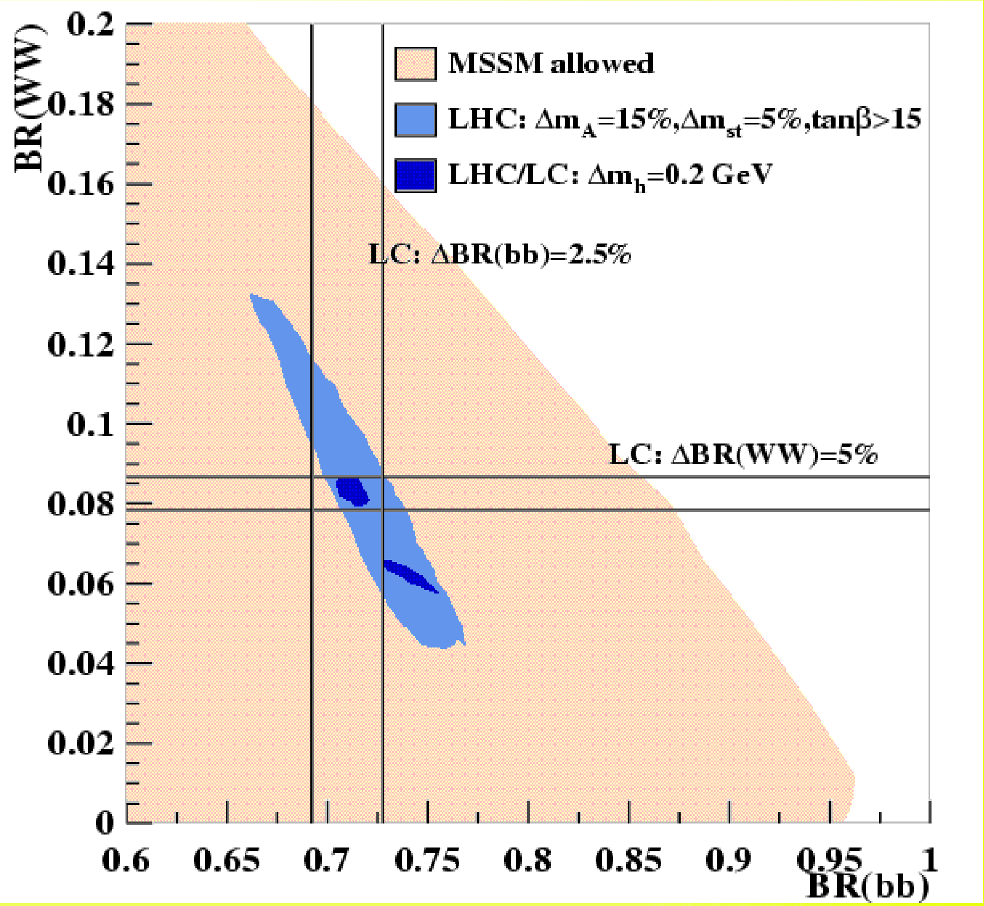
Assume:

1)LHC information on M_A and $\tan\beta$

2) ⊕ (LHC ⊗ LC) information on stop and bottom masses.

3) LHC/LC measurement of m_H

Comparison of MSSM prediction for the given point on assumed inputs with LC measurements tests the model sensitively.



Indirect determination of trilinear coupling A_t is also discussed.

EW symmetry breaking

F. Boudjema, G. Belanger and R.G.

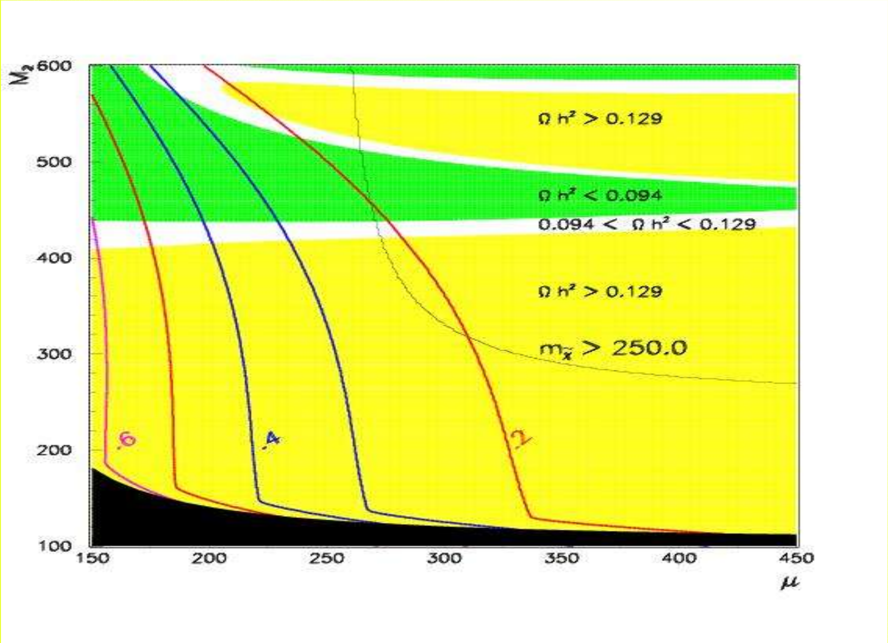
Invisible Higgs:

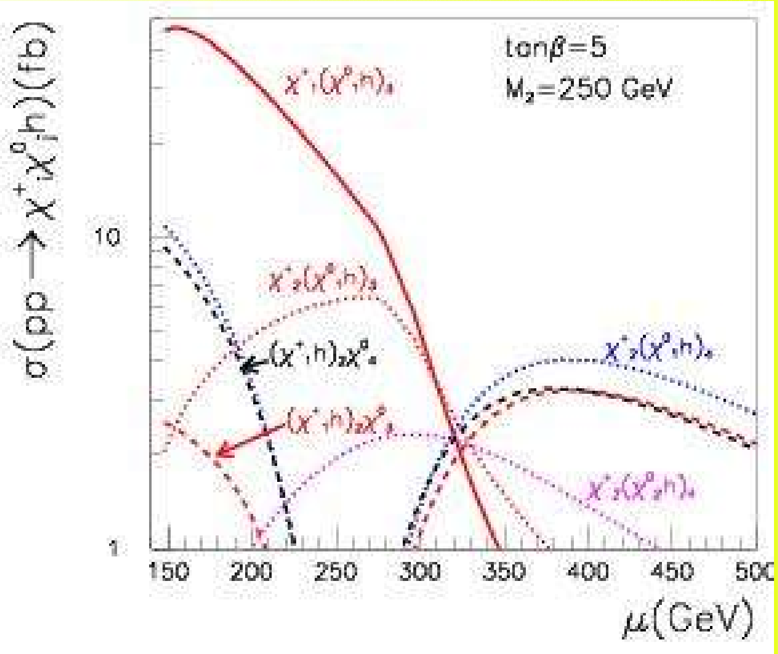
1) SUSY can make Higgs 'Invisible': for nonuniversal gaugino masses due to decays into neutralinos.

2) Cosmology constraints disfavour a big part of the region but still regions with large invisible b.r. Possible.

3) Direct detection of such a Higgs at LHC difficult.

4)If invisibility due to SUSY decays, production of h in χ^0_i decays



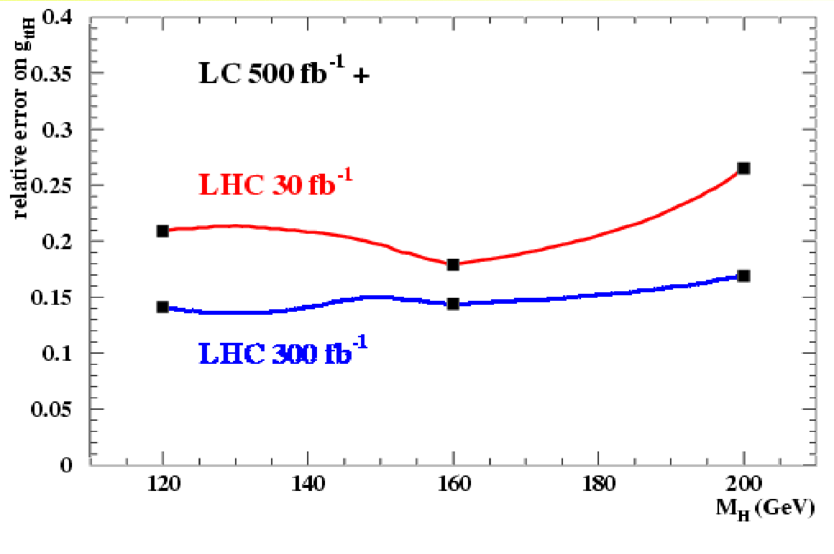


EW symmetry breaking

3) Higgs Self Coupling Measurements: U. Bauer, T. Plehn, D. Rainwater.

Measurements at LHC need inputs from LC on Higgs properties, such as HWW couplings, Total Higgs Width, top Yukawa Coupling. LC can do a better job of determination of self coupling for $M_H < 140$ geV and LHC for heavier Higgs.

4) Higgs t tbar Yukawa Coupling: S. Dawson, A. Juste, L. Reina, K. Desch M. Schumacher, D.Rainwater.



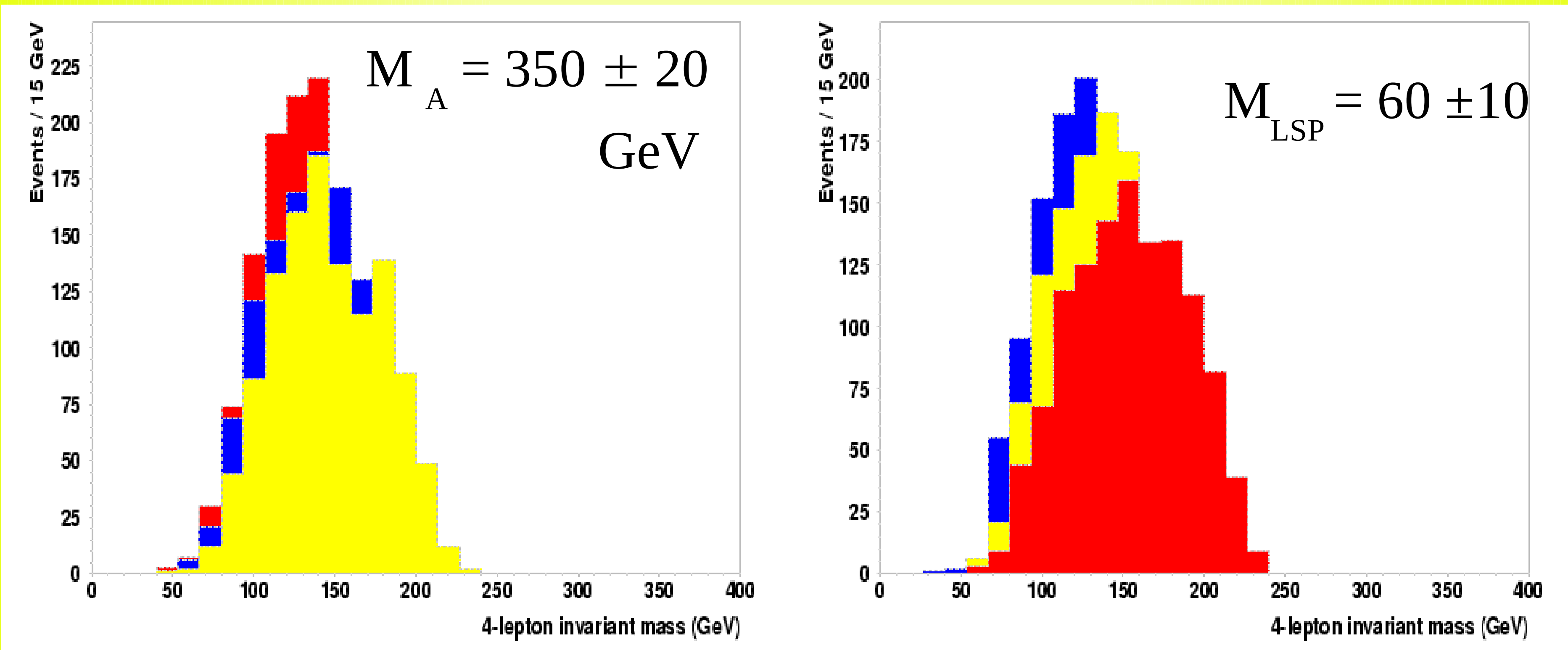
At an LC precisions measurement of t tH coupling requires 800 – 1000 GeV.
LHC measures σ X B.R.
Use LC measurements of Higgs B.R.

Figure corresponds to LC with 350 GeV

EW symmetry breaking: determination of M_A

[Mootgart Philip]

$$H, A \to \tilde{\chi}_2^0 \tilde{\chi}_2^0$$



Get Sensitivity from 4 lepton invariant mass.

LHC: Sensitivity dominated by uncertainty of the LSP mass measurement :**(LHC ⊗ LC)** Sensitive to M_A if mass of LSP known to better than 1%

Strong EW Symmetry breaking

[M. Arneodo, T. Barklow, S. Boogert, G. Cerminara, W. Kilian, C. Mariotti, K. Moenig, A.F. Osorio, G. Passarino]

If no light Higgs boson exists ⇒ The EW symmetry breaking dynamics has to be probed in W/Z scattering processes

LHC and LC sensitive to different/complementary channels

To make full use of the LHC data detailed information from LC and angular distributions etc. CRUCIAL. So a case of **(LHC ⊗ LC).**

Resonances at high energy not only directly accessible at the LHC, a combination with sub TeV data from LC on cross-sections essential for disentangling the new states.

Contact interactions, new gauge theories..etc.

[D. Bourikov, S. Godfrey, J. Hewett, F. Richard, S. Riemann, T. Rizzo]

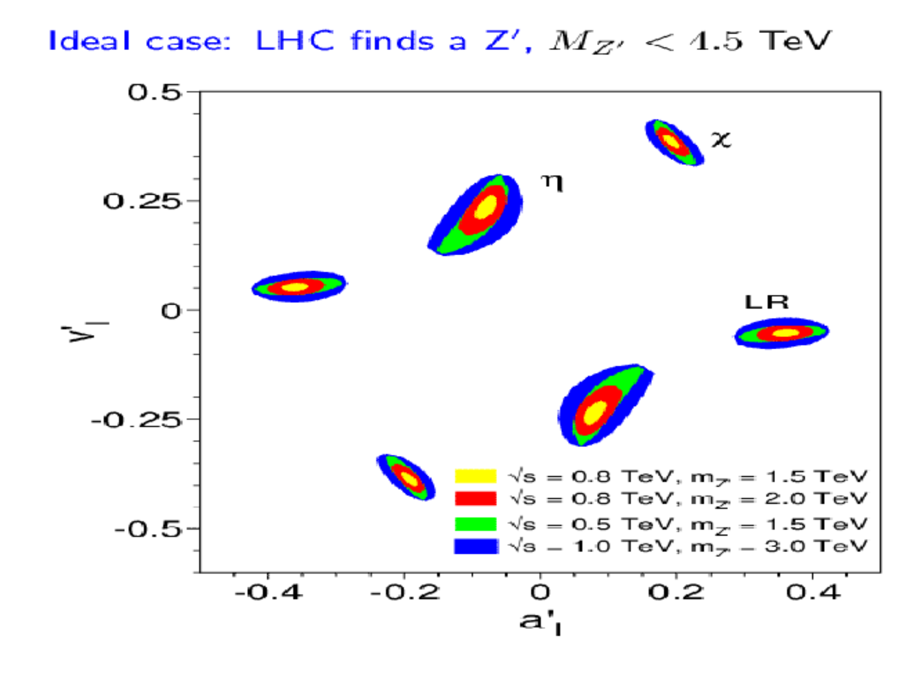
New Theoretical impetus due to Little Higgs Models etc.

Distinction between Z' and (say) KK excitations

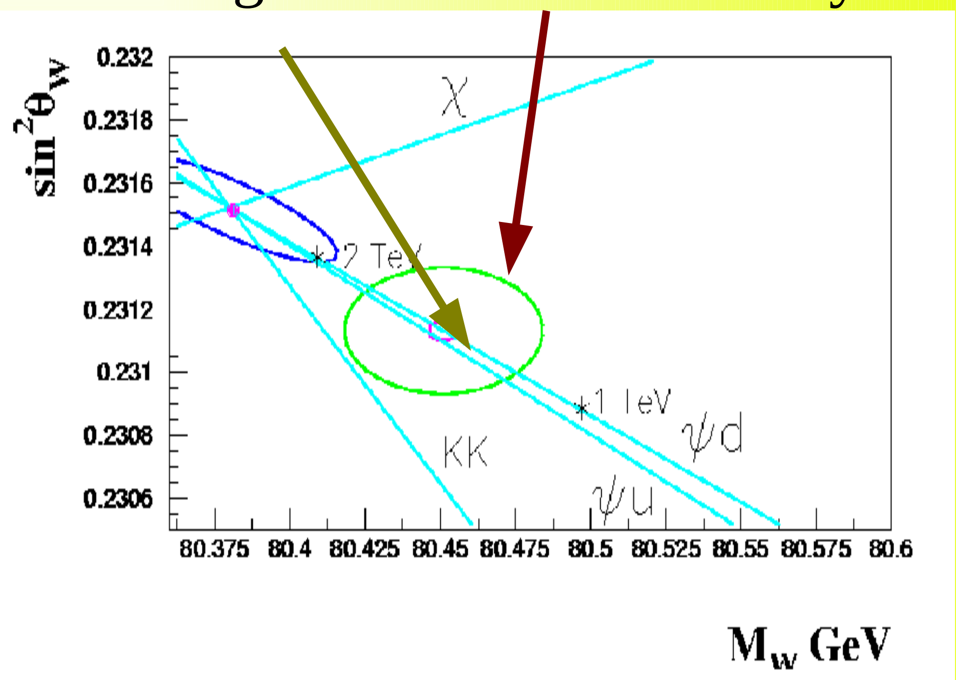
Scenario:LHC sees new DY resonance, measures mass

LC uses LHC pointer, measures couplings and then use precision measurements at a GigaZ to distinguish between different models by EW Precision measurements.

Measurement of Z' coupling



GigaZ vs Current accuracy



Contact interactions, new gauge theories..etc.

Example interplay scenarios

Little Higgs: assume LHC sees Higgs at 300 GeV

Giga-Z can estimate the mass of the Z’ (U(1) singlet), say within 5 GeV. Check if LHC sees it.

Universal extra dimensions: assume LHC sees a light Higgs only.

Giga-Z demonstrates that direct and indirect Higgs mass measurements disagree

Improve search strategy or increase energy of LHC (a little)

More

– Lots more on
  - Electroweak physics
  - QCD
  - Top physics
  - ADD extra dimensions
  - CP studies in the Higgs sector
  - Higgs potential
  - NMSSM studies
  - Little Higgs studies
  - ‘Invisible’ Higgs
  - Contact interactions
  - Radion-Higgs separation
  - etc… etc.

Conclusions

- Topics covered here just a small survey. Many more examples in the summary document, to appear (in as few days time
- Expect the first document to be a basis for future work, summarize where we are and give guidance for future studies
- LHC/LC study group started relatively recently – only scratched the surface so far.
  - Several studies still need to be worked out quantitatively
  - Certainly more ideas will come when we think a bit harder.

  If you have any, please do join us.
- Positive outcome is good synergy between LHC and LC enthusiasts

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LHC/LC is a rich field (and a lot of fun)

Special Thanks to Georg Weiglein and A. De Roeck