The LHC/ILC Connection

Sven Heinemeyer, IFCA (CSIC – UCSA)

Ithaca, 04/2007

1. The LHC and the ILC
2. Past
3. Recent past – present
4. Present/last week – future
5. Conclusions

1. The LHC and the ILC

The (un)official (optimistic?) LHC timeline:

2007 (11/07): fixing the inner triplets
collisions at $\sqrt{s} = 2 \times 450$ GeV cancelled
2008: 0.1 fb^{-1} – $\mathcal{O}$(few) fb^{-1} (at best) ⇒ first physics results?
2009: $\mathcal{O}$(few) fb^{-1} ⇒ first physics results?
2010 – 2012: 10 fb^{-1} per year ⇒ physics results with "low" luminosity
2013 – ?: 100 fb^{-1} per year ⇒ physics results with "high" luminosity
2015 + X (X > 0): upgrade to SLHC?

The (un)official (optimistic!) ILC timeline:

2005: Baseline design (accomplished!)
2006: Reference design (accomplished)
2009: Technical design (report)
2009: decision about site (and money!) ⇒ **THE CRUCIAL POINT**
2010: start digging the tunnel, . . .
2015: first collisions, first physics?

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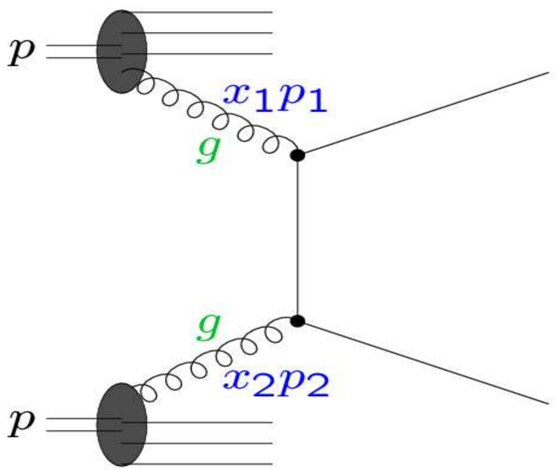
2010: start digging the tunnel, . . .
2015: first collisions, first physics? ⇒ **2015** is the crucial date here

⇒ concurrent running possible

Physics at the LHC and the ILC in a nutshell:

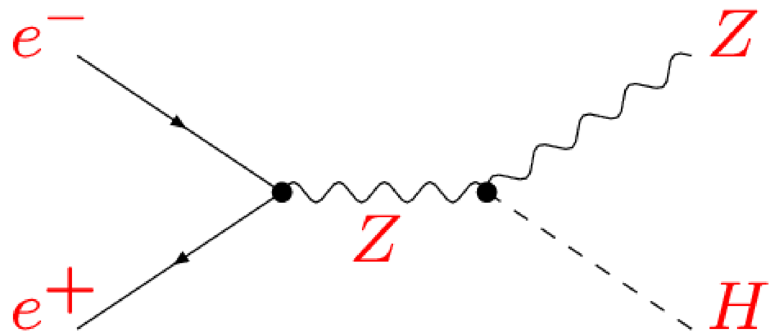
LHC: pp scattering at 14 TeV



Scattering process of proton constituents with energy up to several TeV,
strongly interacting

$\Rightarrow$ huge QCD backgrounds,
low signal–to–background ratios

ILC: e^+e^- scattering
at $\approx$0.5–1 TeV



Clean exp. environment:
well-defined initial state,
tunable energy,
beam polarization, GigaZ,
$\gamma\gamma$, $e\gamma$, e^-e^- options, . . .

$\Rightarrow$ rel. small backgrounds
high-precision physics

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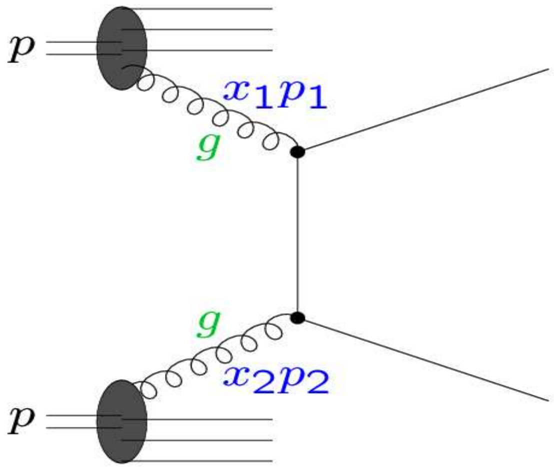

interaction rate of 10^9 events/s

$\Rightarrow$ can trigger on only
1 event in 10^7

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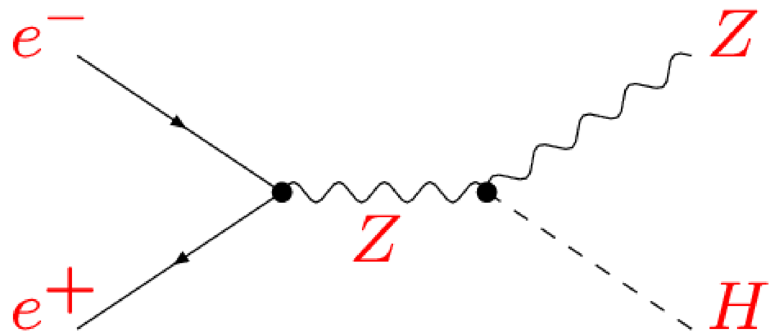

untriggered operation

$\Rightarrow$ can find signals of unexpected new physics (direct production + large indirect reach) that manifests itself in events that are not selected by the LHC trigger strategies

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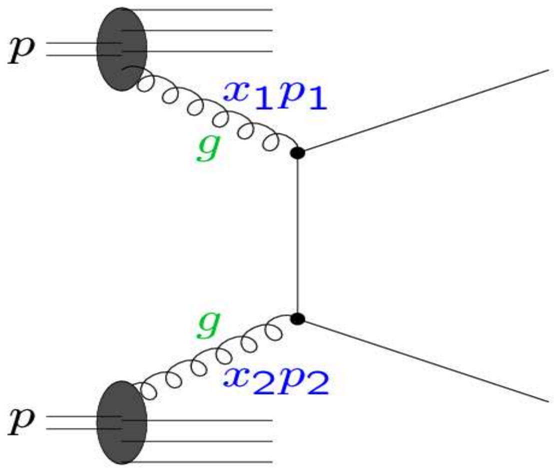

interaction rate of 10^9 events/s

$\Rightarrow$ can trigger on o

1 event in 10^7

$\Rightarrow$ Concurrency is an issue

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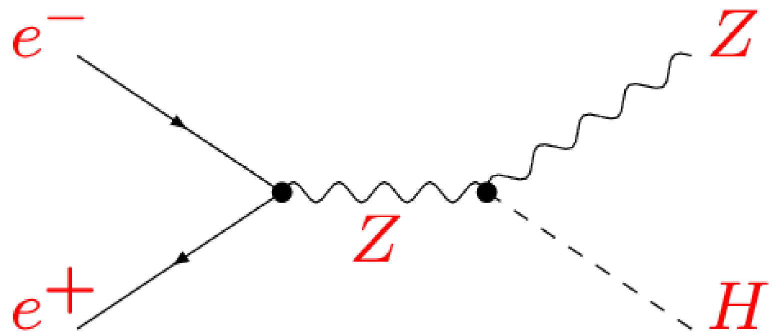

untriggered operation

ls of unexpected

(direct production + large indirect reach) that manifests itself in events that are not selected by the LHC trigger strategies

Reality: ILC will start in 2015 earliest

World of High Energy Physics in the year 2015:

Both LHC detectors will have accumulated ~ 300 fb^{-1}

Initial LHC physics goals are accomplished:

- state compatible with a Higgs found
  (except in especially designed tricky scenarios)
  corresponding couplings measured to 10–30%
- SUSY-like signatures observed (if realized at the EW scale)
- Extra dimensions or . . . -like signatures observed

LHC may await luminosity upgrade

LHC will focus on

- Improvement in "Higgs-like" couplings (is it a Higgs?)
- Improvement of accuracy of new parameters (masses, . . .)
- Extension of high mass discovery region
- Extension of sensitivity to rare processes

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- There is a world wide consensus about the ILC
  (ACFA, ECFA, ICFA, XCFA, . . .)
  only some people tend to forget . . .
- The EPP2010:
  strongly recommended the ILC
- The European Strategy Group:
  "What are (early) LHC results?" ⇒ could be a "moving target"
  ⇒ decisions could be "politics driven", not physics driven

Equally important: the physics itself

Reality: ILC will start in 2015 earliest

Q: Does the ILC decision have to wait for physics results of the LHC?

A: NO! The ILC physics case and it has been made **many**^{2} times

The ILC will add precision
The ILC can make discoveries } Complementarity

This has been shown for basically all (thinkable) physics aspects:

- Top/QCD
- electroweak precision observables
- Higgs (SM and beyond)
- Strong electroweak symmetry breaking
- Supersymmetry (SUSY)
- Extra dimensions, KK towers
- . . .

⇒ the ILC adds “model independence”!

Reality: ILC will start in 2015 earliest

Q: Does the ILC decision have to wait for physics results of the LHC?

A: NO! The ILC physics case and it has been made **many**^{2} times

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The ILC can make discoveries
} Complementarity

A': But there is more:

Reality: ILC will start in 2015 earliest

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A: NO! The ILC physics case and it has been made **many**^{2} times

The ILC will add precision
The ILC can make discoveries
} Complementarity

A': But there is more:

Information obtained at the ILC
can be used to improve LHC analyses
and vice versa
⇒ Enable improved strategies,
dedicated searches
} Synergy / Concurrency

ILC physics case does not rely on Synergy/Concurrency, but it helps!

What is the physics gain of LHC / ILC synergy?
What is the added value of concurrent running?

Exploring physics gain from LHC / ILC interplay requires:

- Detailed information on how well LHC and ILC can measure wide variety of observables in different scenarios

- Close collaboration of experts from LHC and ILC as well as from theorists and experimentalists

⇒ LHC / ILC Study Group

`www.ippp.dur.ac.uk/~georg/lhcilc`

World-wide working group, started in spring 2002

Collaborative effort of Hadron Collider and Linear Collider experimental communities and theorists

2. Past

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www.ippp.dur.ac.uk/∼georg/lhcilc

World-wide working group, started in spring 2002

Collaborative effort of Hadron Collider and Linear Collider experimental communities and theorists

First report has been completed: **hep-ph/0410364**:
122 authors from 75 institutions, 472 pages,
appeared as G. Weiglein et al., *Phys. Rept.* 426 (2006) 47
(still waiting for the party :-)

Just a few most prominent examples:

– direct SUSY mass determination
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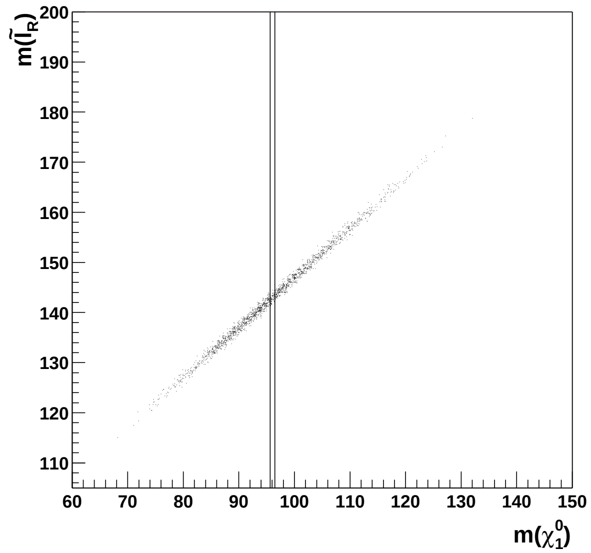
– BSM Higgs sector: indirect bounds
– . . .

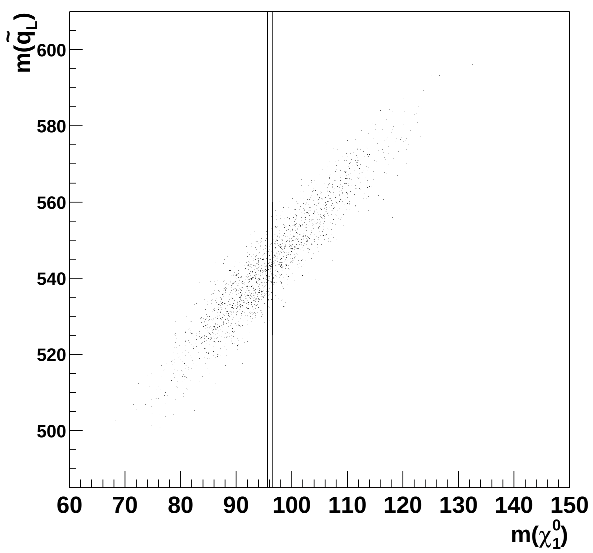
Example I: direct SUSY mass determination

[*hep-ph/0410364*]

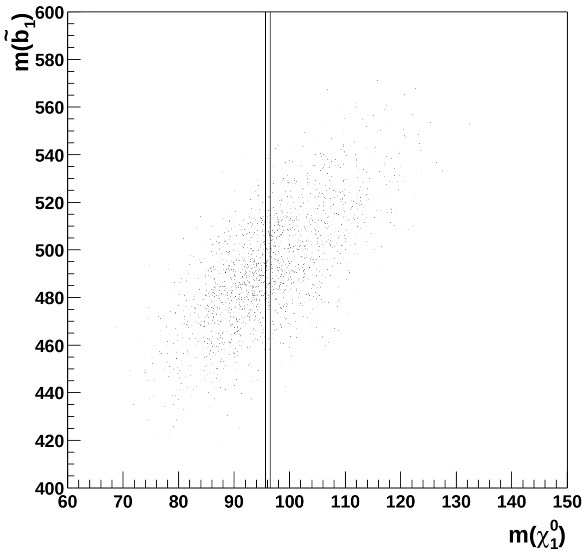
mass of $\tilde{l}_R$



mass of $\tilde{q}_L$



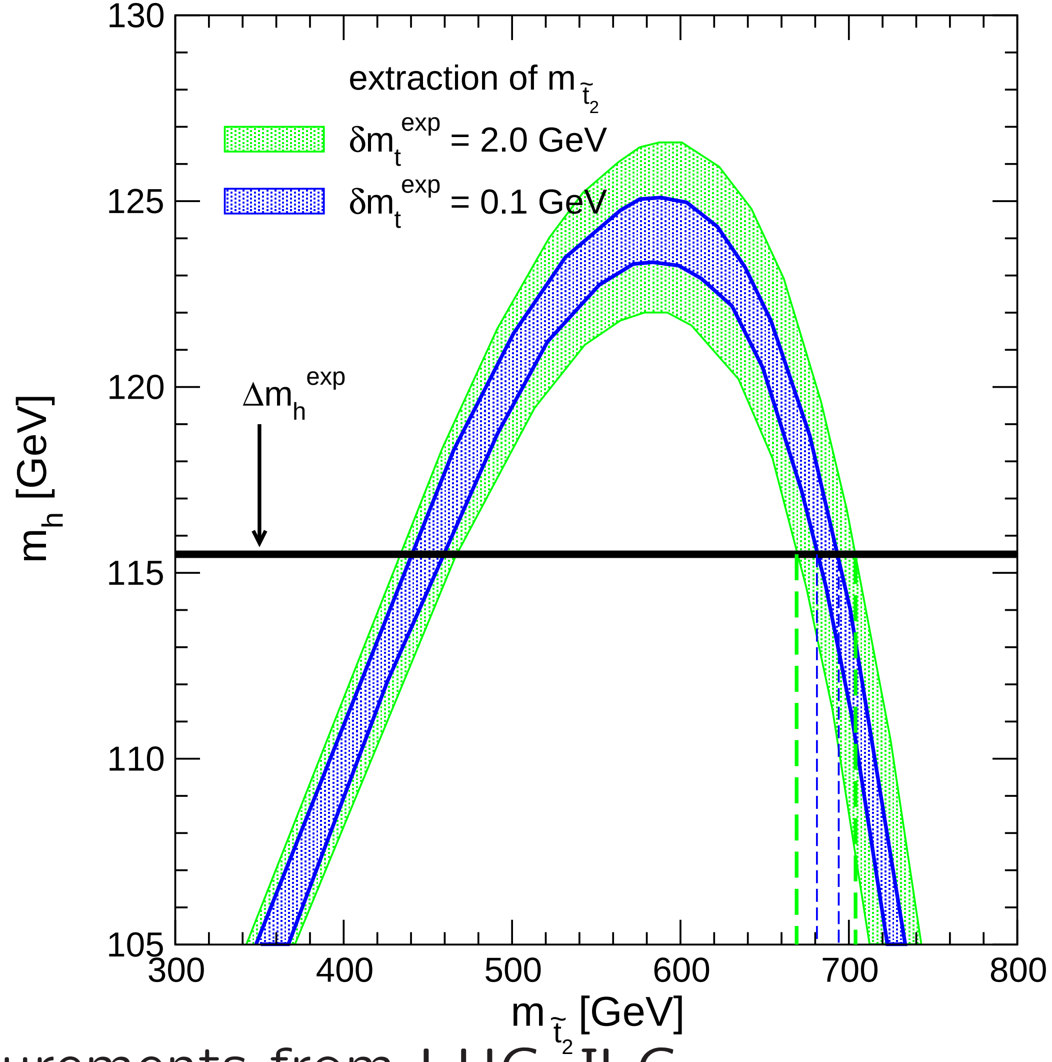
mass of $\tilde{b}_1$



⇒ drastic improvement from ILC LSP measurements

Example II: indirect SUSY mass determination

[*hep-ph/0410364*]



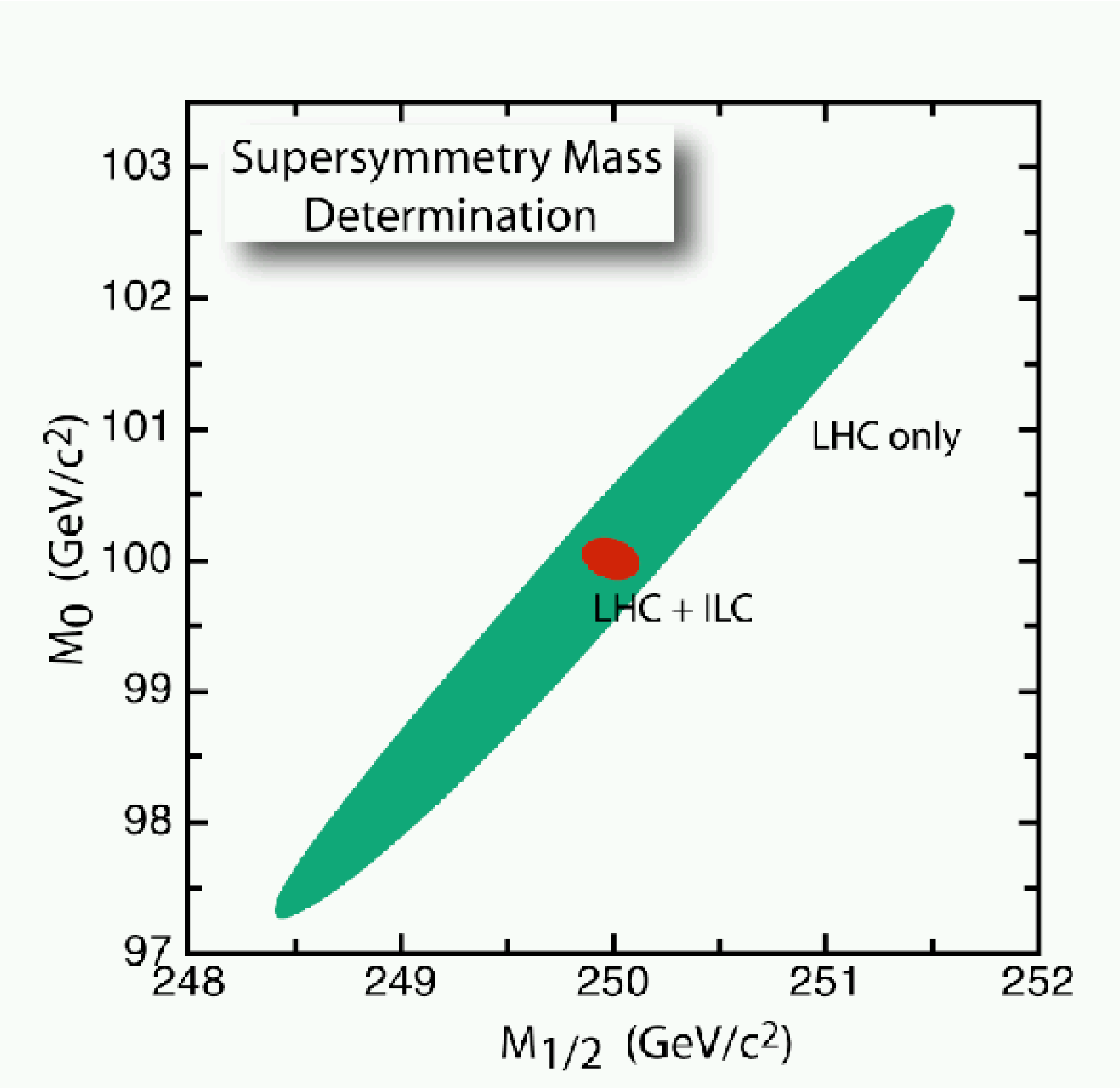
input: mass measurements from LHC, ILC

light Higgs and top mass measurements from ILC

⇒ indirect determination of $m_{\tilde{t}_2}$ possible in combined LHC/ILC analysis

Example III: fit to SUSY-GUT parameters

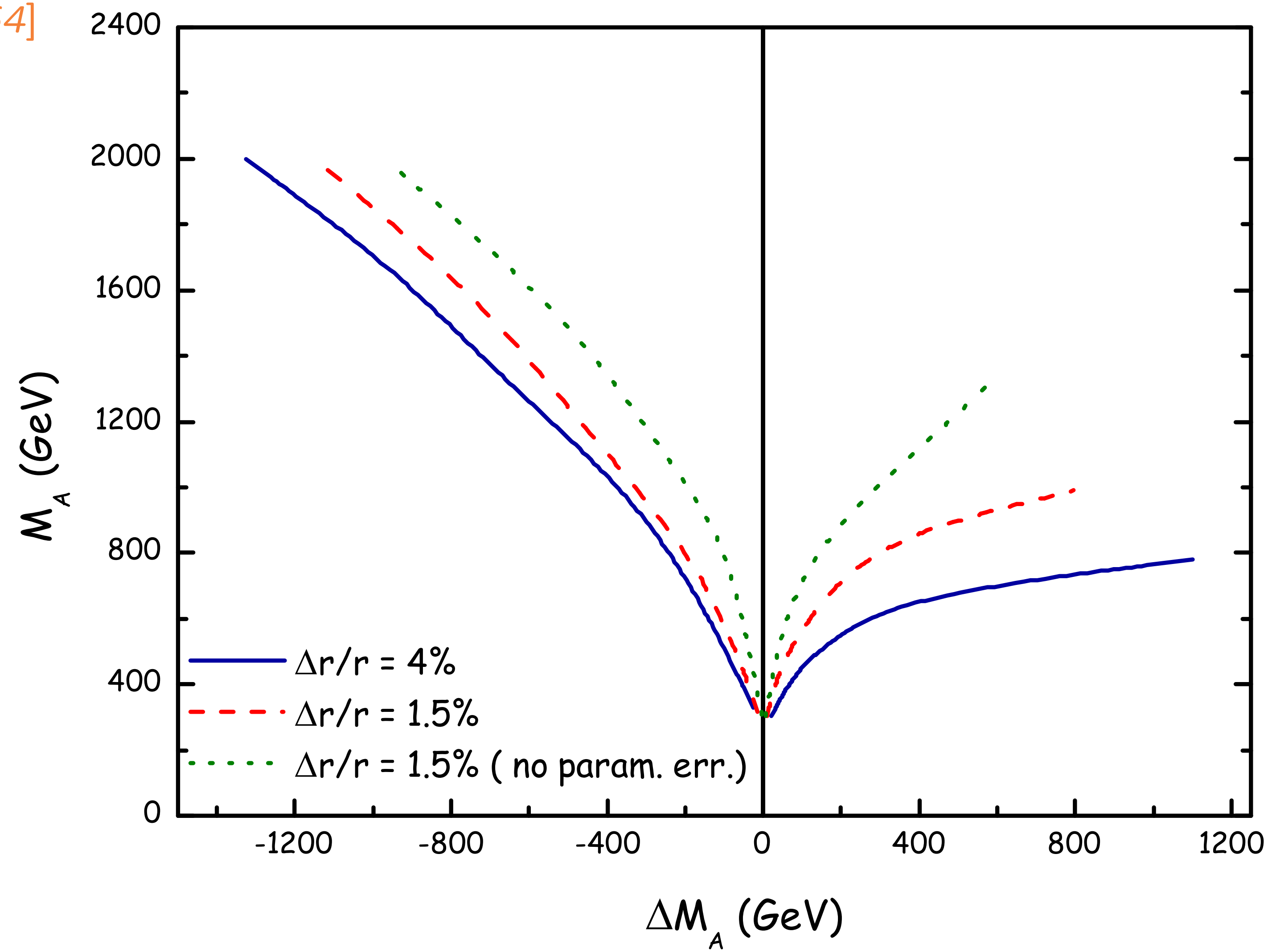
[*hep-ph/0410364*]



⇒ drastic improvement from combined LHC/ILC analysis

Example IV: indirect determination of heavy MSSM Higgs boson masses

[*hep-ph/0410364*]



input: mass measurements from LHC, ILC
light Higgs BR measurements from ILC

⇒ indirect determination of M_A possible in combined LHC/ILC analysis

3. Recent past – present

⇒ LHC / ILC Study Group

www.ippp.dur.ac.uk/∼georg/lhcilc

Activities continue(d) after the report!
(. . . but ATLAS/CMS physicists are very busy getting ready . . .)

Recent meetings:
– dedicated working group at Snowmass '05
– LHC/ILC working group meeting @ CERN, 12/05
– V(ancouver)LCW06: ILC workshop with LHC/ILC working group, 07/06
– LHC/ILC workshop @ Fermilab 04/07

⇒ try to coordinate on-going activities

⇒ some recent (2005–2006) results

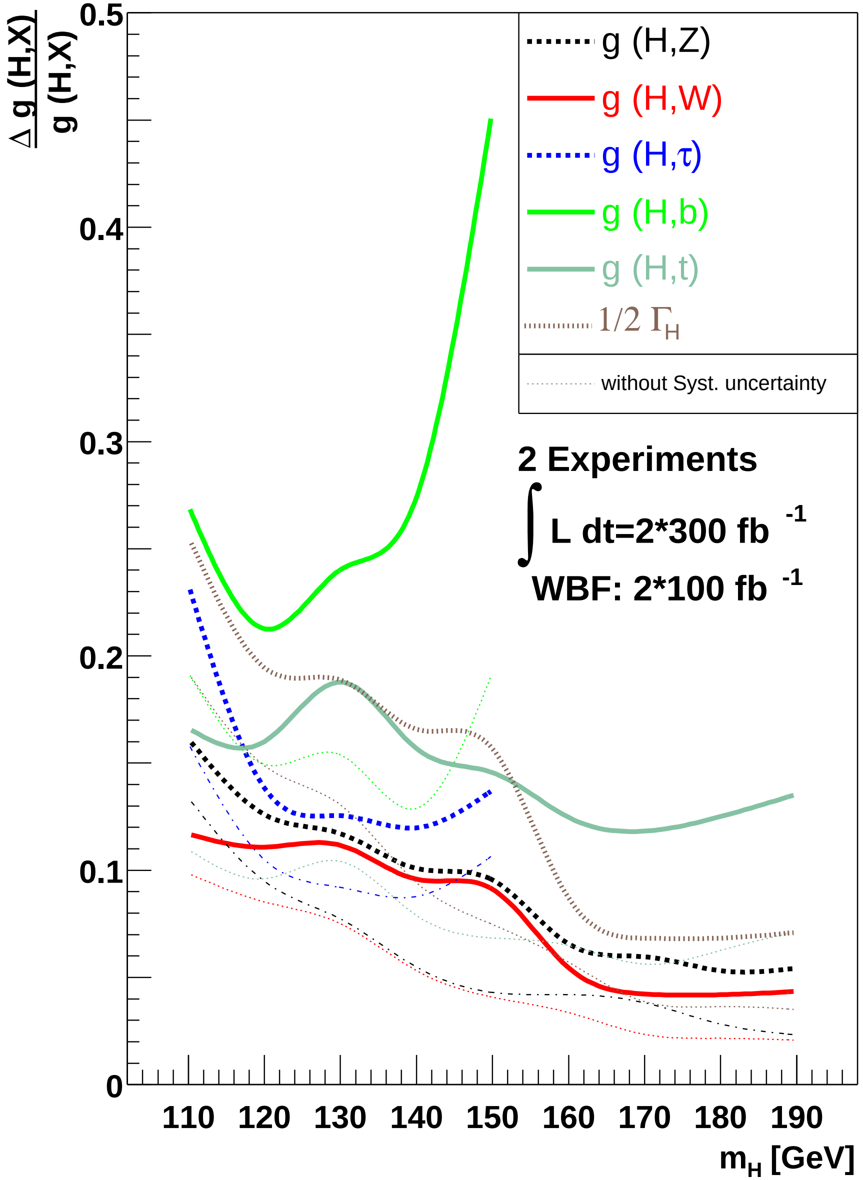
(partially presented at LHC/ILC Study group meetings,
partially at other ILC meetings (e.g. here))

⇒ results for SM Higgs, SUSY, Z'

Example I: SM Higgs: determination of $g_{Ht\bar{t}}$:

[*M. Dührssen et al. '05*]

LHC alone (model dep.)



LHC measurements:

– mass: $\delta M_h \approx 200$ MeV

– couplings:
$(2 * 300 + 2 * 100)$ fb^{-1} :
typical accuracies of
20-30% for $m_H \leq 150$ GeV
10% accuracies for HVV
couplings above
WW threshold

Assumption:

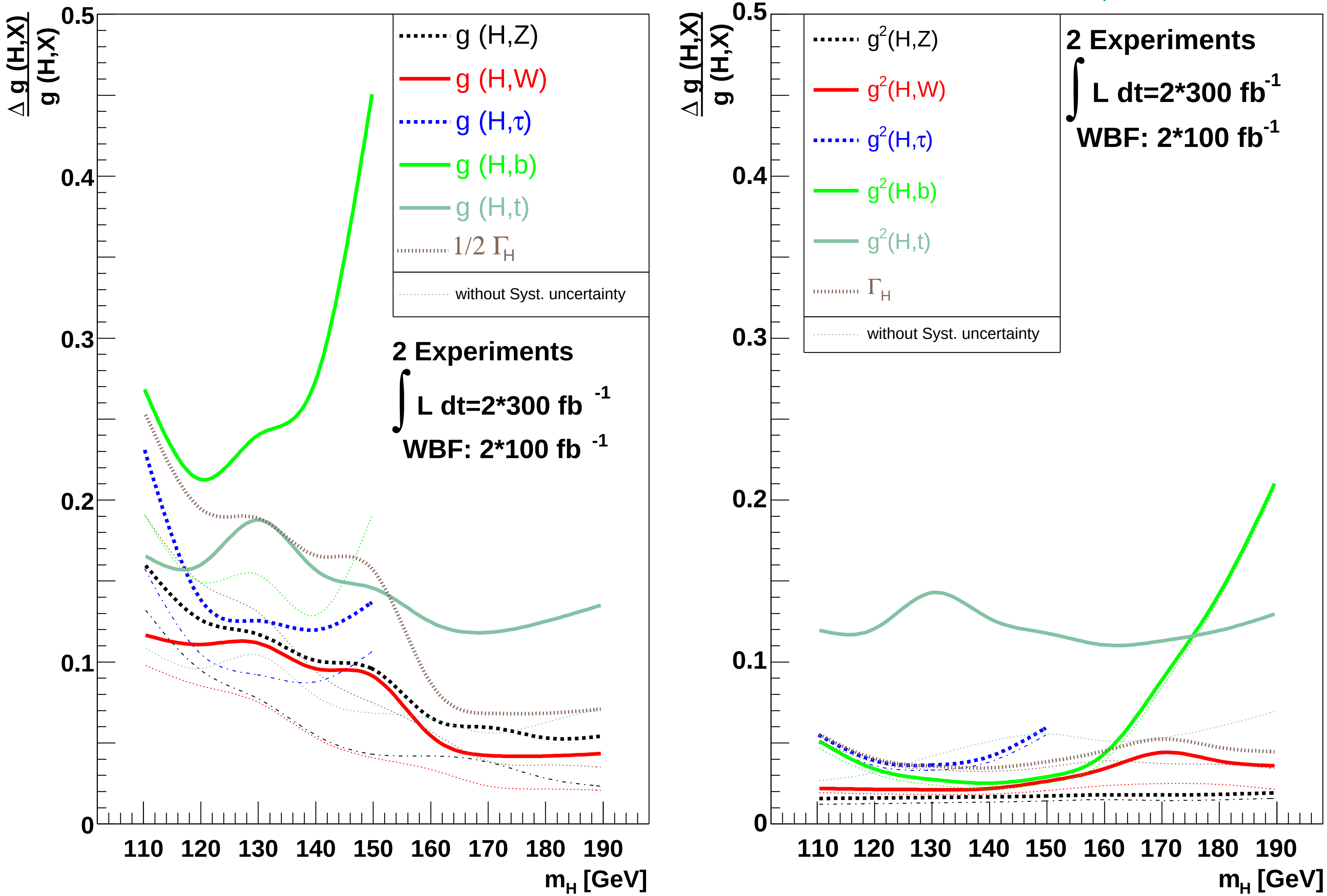
– $g^2_{HVV} \leq g^2_{HVV,\text{SM}} \times 1.05$
– SM rates for the Higgs

Example I: SM Higgs: determination of $g_{Ht\bar{t}}$:

NEW

[*M. Dührssen et al. '05*]

LHC alone (model dep.) $\quad$ LHC $\oplus$ ILC @ $\sqrt{s} = 500$ GeV



Example I: SM Higgs: determination of $H\gamma\gamma$ coupling:

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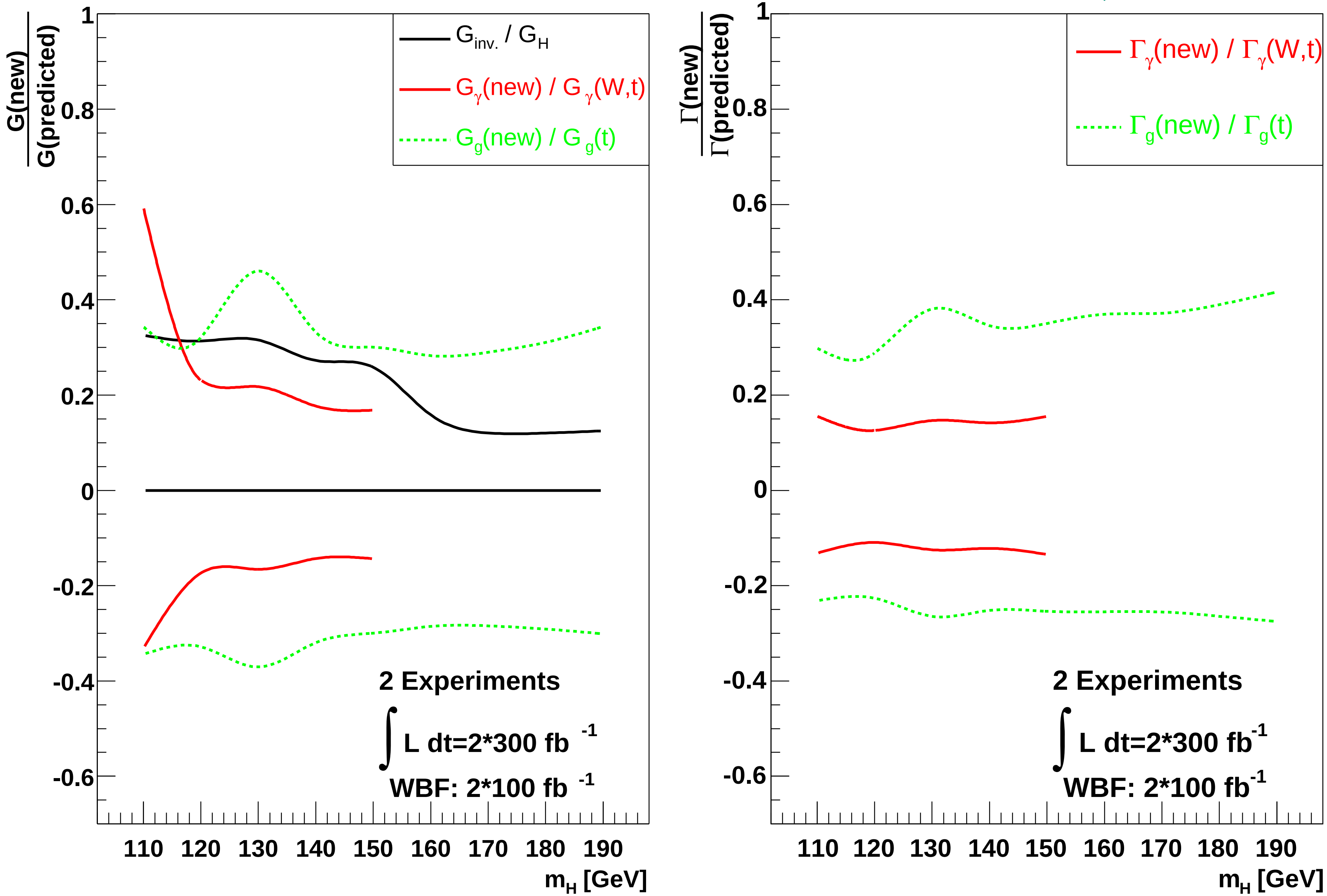
LHC alone (model dep.) | LHC $\oplus$ ILC @ $\sqrt{s} = 500$ GeV



Example: SUSY

In order to establish SUSY experimentally:

Need to demonstrate that:

- every particle has superpartner
- their spins differ by 1/2
- their gauge quantum numbers are the same $\longrightarrow$ example II
- their couplings are identical
- mass relations hold $\longrightarrow$ example III

finally: determine SUSY Lagrangian parameters $\longrightarrow$ example IV

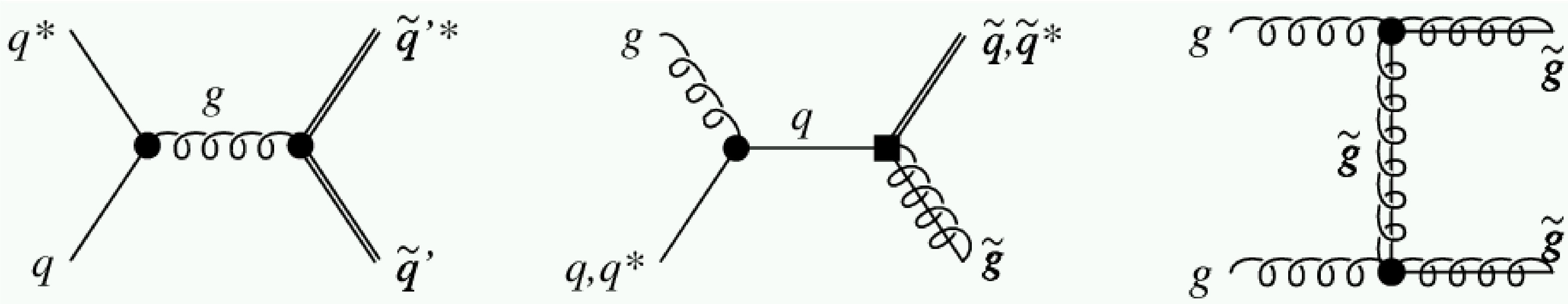
$\Rightarrow$ We need both: hadron colliders (Tev./LHC) and high luminosity ILC

Example II: determination of SUSY QCD coupling:

NEW

[A. Freitas, P. Skands '06]

Measure squark/gluino production at the LHC



$\rightarrow$ measurement of decay chains

Measure accurately corresponding branching ratios that appear in the LHC decay chains at the ILC

$\Rightarrow$ Determination of absolute SUSY QCD production cross sections at the LHC $\sim \tilde{g}_s^4$ to $\sim 20\%$

$\Rightarrow$ $\tilde{g}_s$ measurement to $\sim 5\%$

Example III: SUSY: parameter determination in a "heavy" scenario: **NEW**

[*K. Desch, J. Kalinowski, G. Moortgat-Pick, K. Rolbiecki, J. Stirling '06*]

heavy CMSSM scenario (but "CMSSM" not used in analysis):
$m_{1/2} = 144$ GeV, $m_0 = 2$ TeV, $A_0 = 0$, $\tan\beta = 20$, $\mu > 0$
$\Rightarrow$ squark and slepton masses $\mathcal{O}(2$ TeV$)$

LHC: measurement of squark masses, $\delta m \approx 50$ GeV

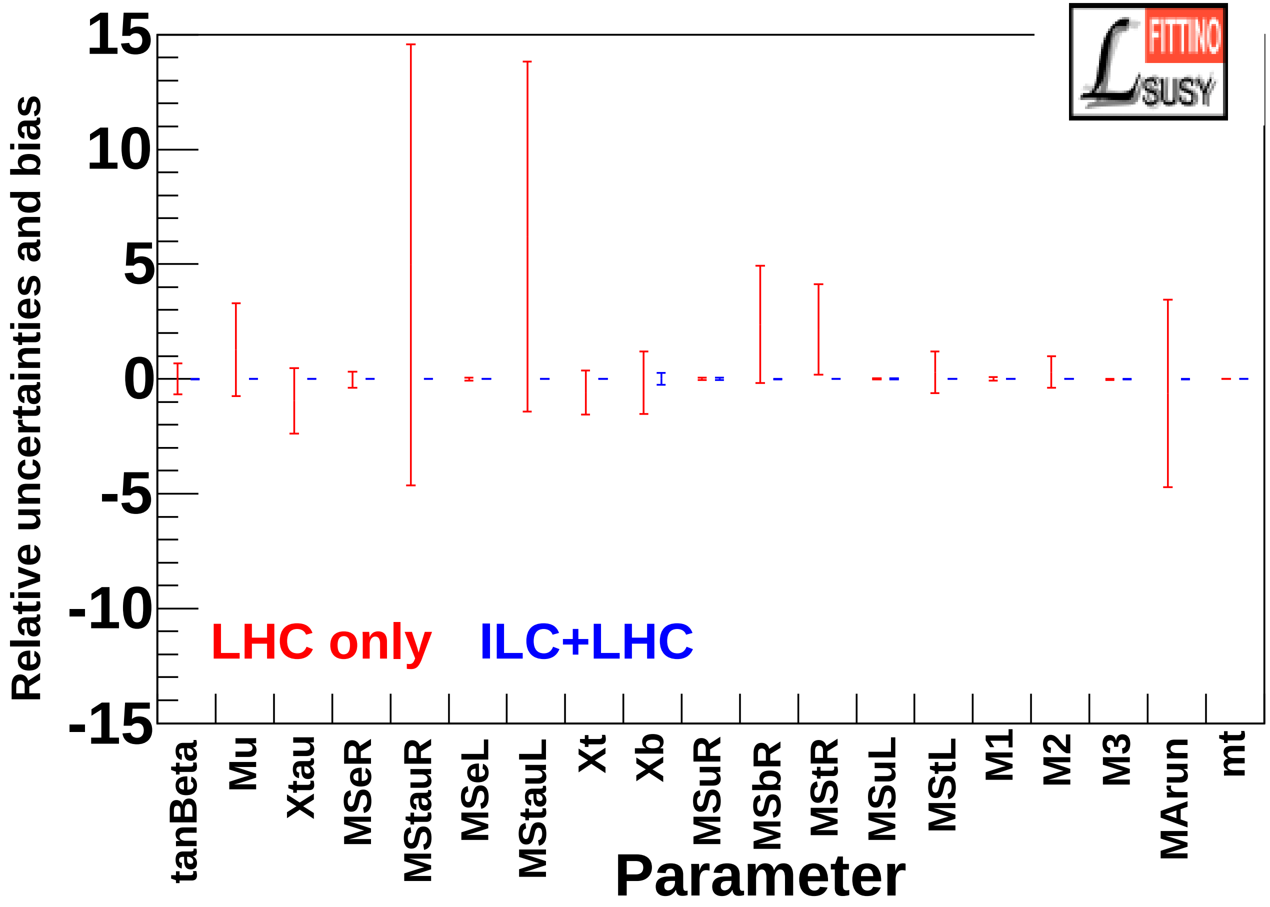
ILC: measurement of $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \dots$ incl. spin correlations,
A_{FB} for hadronic and leptonic decays

step 1: determination of M_1, M_2, μ, $m_{\tilde{\nu}}$
step 2: using leptonic A_{FB}: determination of $\tan\beta$ and $m_{\tilde{\nu}}$ better
step 3: using in addition hadronic $A_{FB} \oplus$ squark masses from LHC
$\Rightarrow$ independent determination of $m_{\tilde{l}}$, $m_{\tilde{\nu}}$
$\Rightarrow$ test of $SU(2)$ relation in $\tilde{l}$ sector

Example IV: SUSY: global fit for SUSY Lagrange parameters: NEW

[*P. Bechtle, K. Desch, P. Wienemann '05*]

Compare LHC and LHC $\oplus$ ILC :



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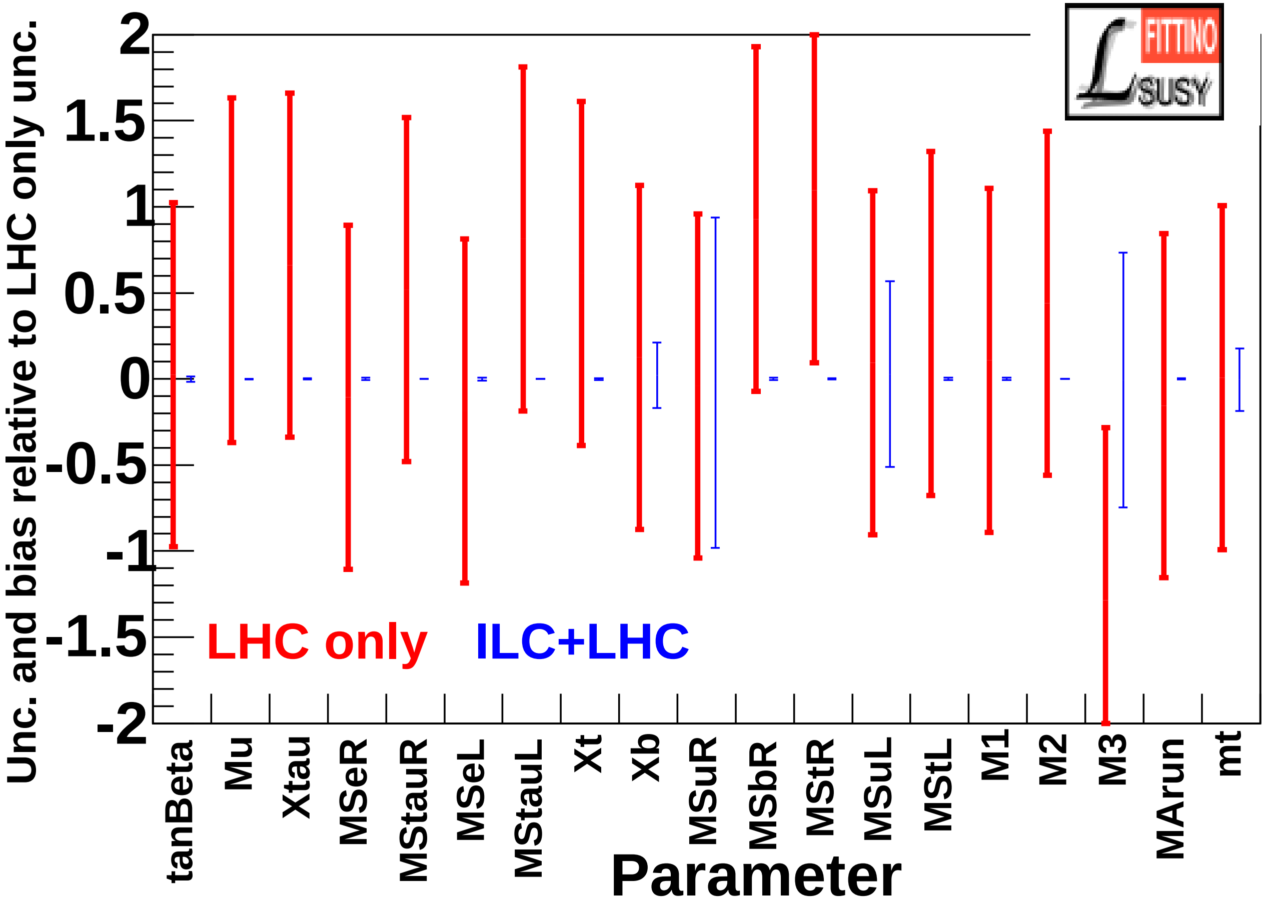


⇒ strong improvement from ILC measurements

Example V: models with Z': parameter determination:

NEW

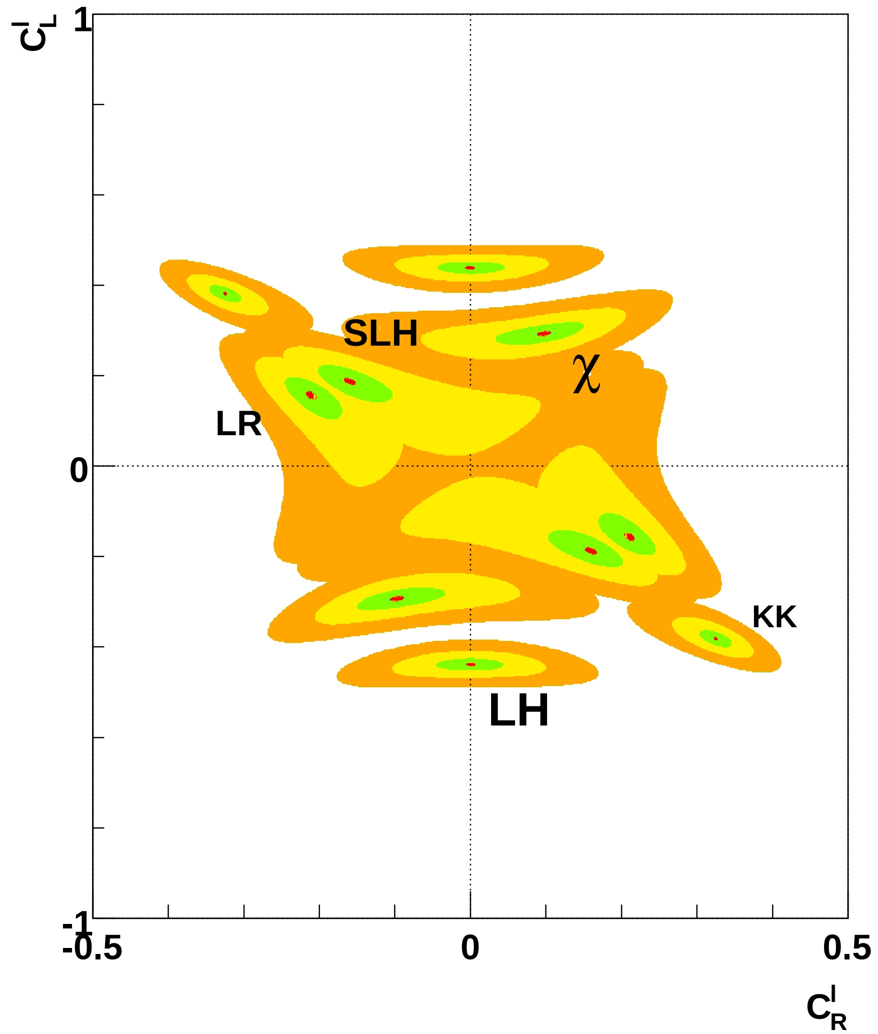
[S. Godfrey, A. Tomkins '06]

LHC: discovers single heavy resonance

ILC: measurement of indirect effects
($\sqrt{s} = 500$ GeV, $\mathcal{L}_{\rm int} = 1$ ab^{-1})

new: extended analysis to higher masses
$M_{Z'} = 1, 2, 3, 4,$ TeV

$\Rightarrow$ various models can be distinguished
up to $M_{Z'} \gtrsim 2-3$ TeV



4. Present/last week – future

⇒ LHC / ILC Study Group

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

Activities are continuing!

Last meetings:
workshop at Fermilab 04/07 (last week)

Where should we go? How should we develop?

A) same direction, but better

B) new direction(s) ⇒ Fermilab workshop

4. A) Same direction, but better

How far are we?

- Many possibilities of LHC / ILC synergy have been investigated

  $\Rightarrow$ LHC / ILC interplay is a very rich field

  $\Rightarrow$ great potential for important physics gain

  $\Rightarrow$ Needs to be worked out and confirmed in detailed case studies, experimental simulations

- Many of the analyses so far were mainly LHC analyses where at the very end some ILC input was injected
  (or the other way round)

  $\Rightarrow$ Aim should be LHC / ILC analyses that make use of the interplay from the start

- ATLAS and CMS are actively preparing for the start of data taking:
  CMS finished physics TDR,
  many new studies in ATLAS (full simulations, new scenarios)

  $+$ ongoing ILC studies

  $\Rightarrow$ Many new results, ideal input for LHC $\otimes$ ILC studies

⇒ Concurrency is an issue

The case of concurrent running:

Counter arguments:

– "Global fits etc. can be done without concurrent running, you just need the data."

– "You can always re-analyze the data."

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My answer:

– Ask the people who try to re-analyze Tevatron Run I data . . .
– There are nice examples that profit from the joint analysis of concurrent data
– We want to disentangle the new physics as soon as possible

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– We want to disentangle the new physics as soon as possible

⇒ What LHC physics do we lose by not having the ILC at the same time?

⇒ More concurrency examples are nice (but not crucial)

SUSY example for concurrent running:

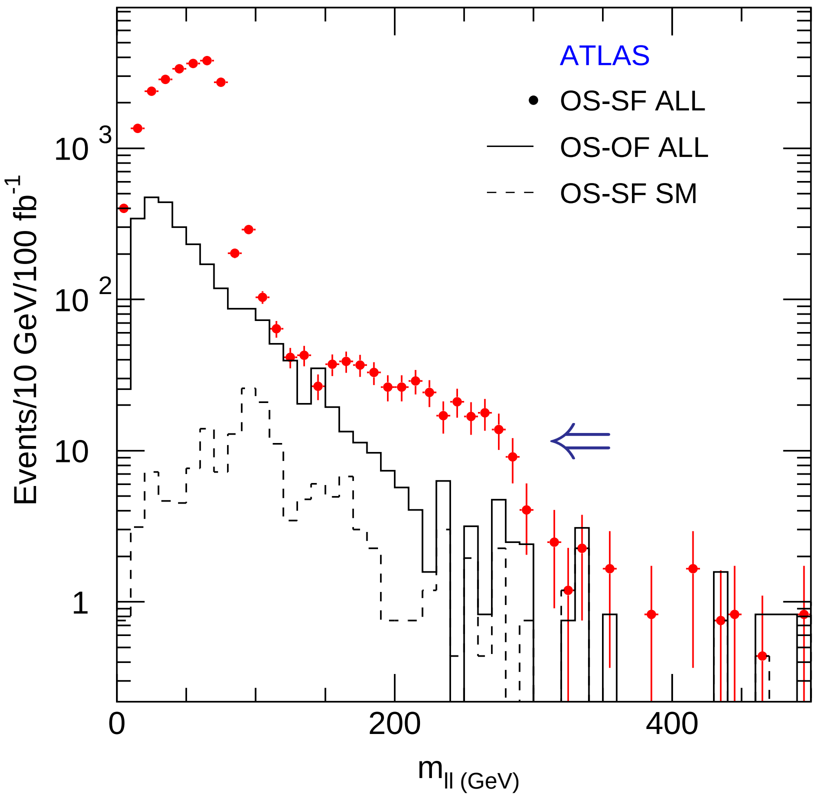
[*K. Desch, J. Kalinowski, G. Moortgat-Pick, M. Nojiri, G. Polesello '04*]

$\rightarrow$ Measurement of $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm$ at the ILC

$\Rightarrow$ determination of all parameters in the chargino/neutralino sector

$\Rightarrow$ prediction of neutralino masses that are too heavy for the ILC

$\Rightarrow$ tell the LHC where to look $\Rightarrow$ "one-bin" search, high statistical power



The $\tilde{\chi}_4^0$ can be identified at the LHC via this dilepton "edge"

$\Rightarrow$ Determination of $m(\tilde{\chi}_4^0)$ with high precision + significance

$\Rightarrow$ Crucial test of the model

$\Rightarrow$ Information can be fed back into ILC analysis

4. B) New directions

Decision for the ILC will take place roughly at the same time we have data from the LHC . . .

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> What could be the impact of results from early data at the LHC on the ILC?

A scientifically well-founded investigation of this issue requires expertise on the experimental aspects at both the LHC and the ILC and on the possible theoretical interpretations of signals of new physics.

⇒ investigate various possible scenarios of early LHC data
("early LHC data" = up to 10 fb^{-1})

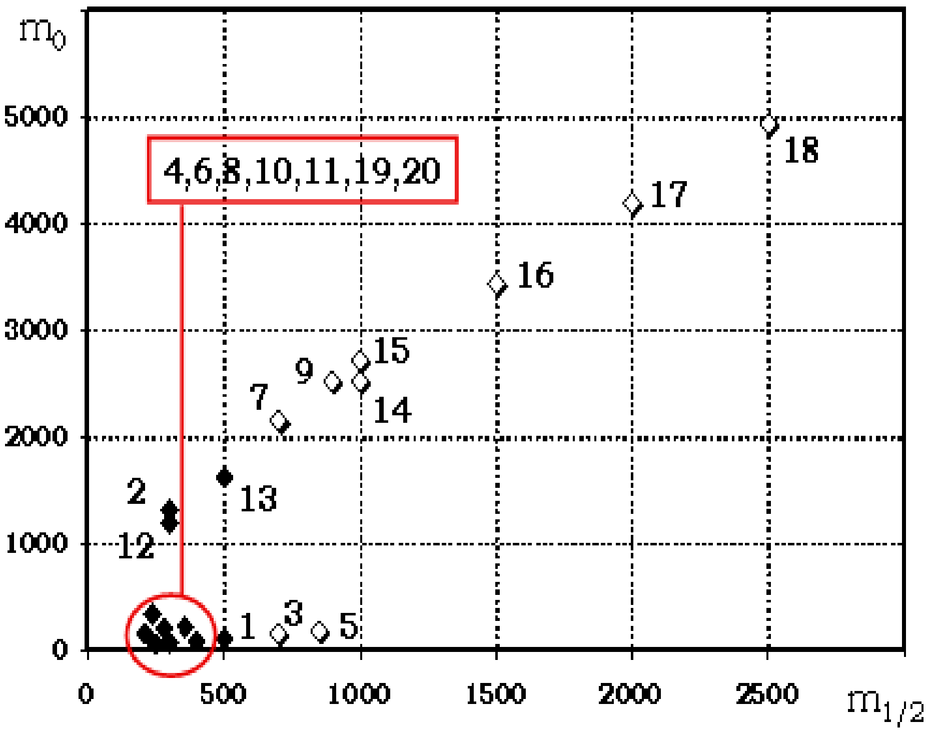
⇒ 3 physics examples for early LHC data

Example I: SUSY discovery potential of CMS/ILC implications

[A. Drozdetskiy, S.H., G. Weiglein et al. '06]

SUSY discovery potential of CMS in the same sign di-muon channel

Framework: CMSSM, used only for data generation, not for exp. analysis



10 fb^{-1} can test the CMSSM up to $m_{1/2} \lesssim 650$ GeV

$\Rightarrow$ ILC reach in CMSSM

open questions:

Evidence for CMSSM?

ILC implications beyond CMSSM?

$\Rightarrow$ model indep. interpretation?

Example II:

The LHC finds only a state compatible with a SM-like Higgs
and nothing else

Q: Do we still need the ILC?

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A: Of course!

Example II:

The LHC finds only a state compatible with a SM-like Higgs

and nothing else

Q: Do we still need the ILC?

A: Of course! Or better: even more!

In fact: one of the best ILC cases (just hard to sell to the politicians)

The ILC provides:

– precise Higgs coupling measurements

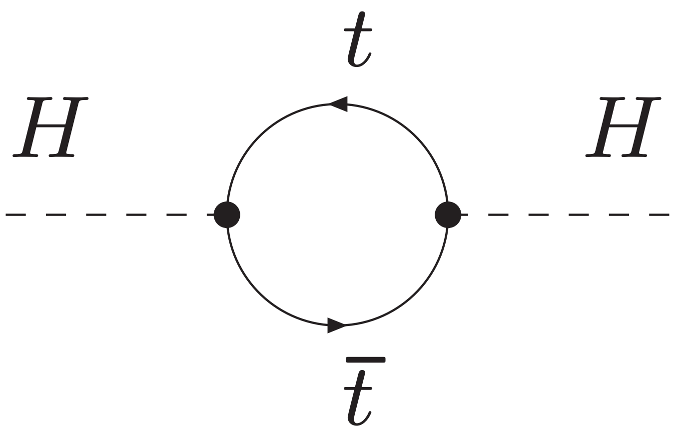
– precision observable measurements with the GigaZ option

⇒ Only the ILC can find deviations from the SM predictions via the various precision measurements

⇒ Only the ILC can point towards extensions of the SM

Example III: LHC data points towards certain extensions of the SM:

Nearly any model: large coupling of the Higgs to the top quark:



$\Rightarrow$ one-loop corrections $\Delta M_H^2 \sim G_\mu m_t^4$

$\Rightarrow$ M_H depends sensitively on m_t in all models where M_H can be predicted (SM: M_H is free parameter)

$\Rightarrow$ What can the LHC do with 10 fb^{-1}?

SUSY as an example: $\Delta m_t \approx \pm 2$ GeV $\Rightarrow$ $\Delta M_h \approx \pm 2$ GeV

$\Rightarrow$ Precision Higgs physics needs precision top physics

$\Rightarrow$ LHC precision of M_h requires ILC precision of m_t, 500 GeV sufficient

⇒ investigate various possible scenarios of early LHC data
("early LHC data" = up to 10 fb^{-1})

⇒ Workshop at Fermilab on the LHC/ILC interplay: 04/07 (last week)

New questions/the charge:

1. Could there be cases that would change the consensus about the physics case for an ILC with an energy of about 500 GeV?

2. What could be the impact of early LHC results on the choice of the ultimate ILC energy range and the ILC upgrade path? Could there be issues that would need to be implemented into the ILC design from the start?

3. What are the prospects for LHC / ILC interplay based on early LHC data?

⇒ investigate various possible scenarios of early LHC data
("early LHC data" = up to 10 fb^{-1})

⇒ Workshop at Fermilab on the LHC/ILC interplay: 04/07 (last week)

1/2 plenary talks: focusing on (the absence) of various signals
⇒ more signal driven than model driven

1/2 working groups:

– discovery of a state compatible with a Higgs
– no evidence for a Higgs boson
– detection of states beyond the SM
(→ missing energy signals, leptonic resonances,
multi-gauge-boson signals, . . .)

→ distinguish between assumed experimental signatures (e.g. kinematic edges) and their possible interpretations within certain models

→ possible theoretical uncertainties should be carefully investigated

Some workshop results:

– some slides from the plenary talks

– some slides from the summary talks

⇒ focus mainly on (absence of) Higgs

⇒ gives a flavor of the spirit of the workshop

. . . no real/definite results yet

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Got interested?

⇒ working group activities continue

⇒ next meeting at SLAC, October/November 2007 talk by Kyle Cranmer on

Impact of an Early "Higgs" observation at the LHC

The first questions we would ask

BROOKHAVEN NATIONAL LABORATORY

Quick questions:

- What is the mass roughly? Light or Heavy?
- What kind of decays? Fermions or Bosons)?
  - how many modes are available?
- Does the rate seem roughly consistent with the Standard Model?

Does it look like the Standard Model Higgs?

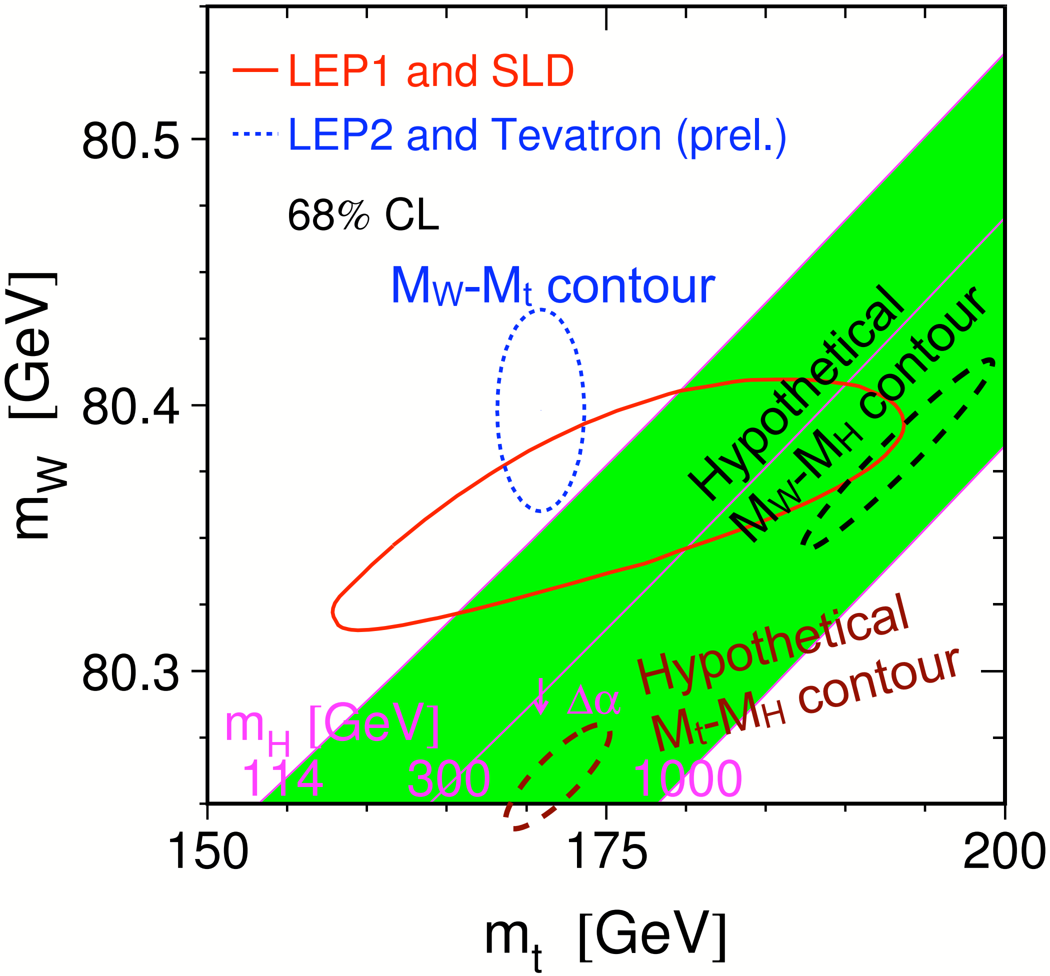
- More precise answers to the questions above
- Spin, CP, width, coupling measurements, etc.

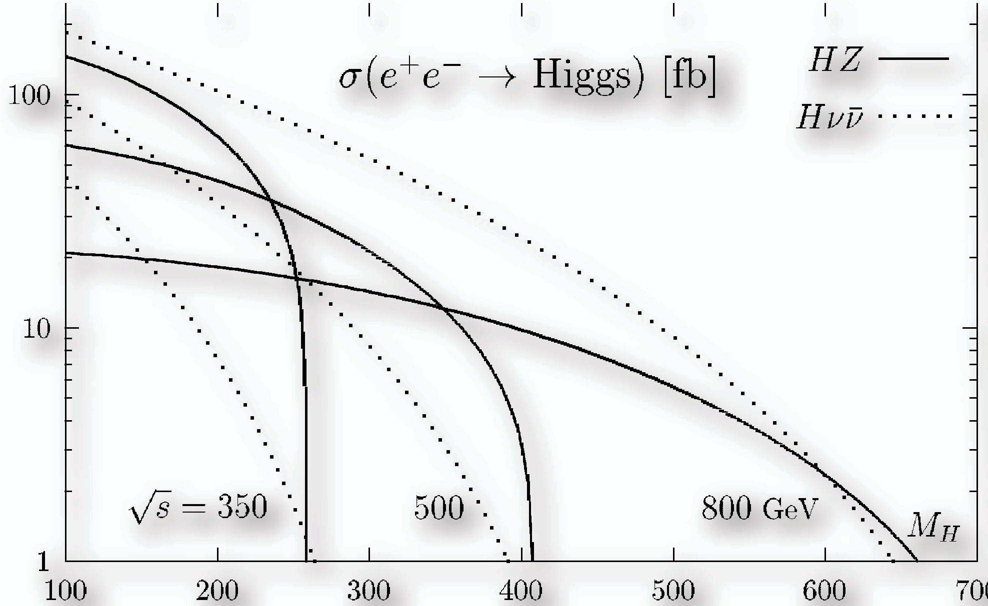
What is the impact on the ILC?

- Impact in the short term on design / planning
- Impact in the long term in terms of expected physics potential

What If We Find a Heavy Higgs?

BROOKHAVEN NATIONAL LABORATORY





Tesla TDR

µWhat if we find a Higgs with M_H>400 GeV? And LHC M_t ~ Tevatron

µContours of $\Delta\chi^2$ are not a goodness-of-fit measure

µIncompatibility of M_W, M_t, M_H a sign of physics beyond the SM

µObvious impact on ILC design if M_H>250, 400 GeV talk by Heather Logan on

Higgs Theory

Constraints from early LHC data:

WBF $\rightarrow H \rightarrow WW$ for 135–190 GeV puts a lower bound on HWW coupling (from production rate – decay BR $\leq 100\%$)

Small overlap in Inclusive $H \rightarrow WW$ and Inclusive $H \rightarrow ZZ$ for 150–160 GeV: can measure ratio of rates
$\rightarrow$ ratio of HWW and HZZ couplings-squared.

Higher mass: direct measurement of Higgs width bounds the inclusive production coupling: puts a (weak) lower bound on HZZ coupling.

Rate $= \sigma(gg \rightarrow H)\Gamma(H \rightarrow ZZ)/\Gamma_{\text{tot}}$; $\Gamma(H \rightarrow gg) \leq \Gamma_{\text{tot}}$

Rates provide SM check.
But general models will not be very constrained.

This scenario: Good case for studying the (discovered!) Higgs

$M_H \lesssim 180$ GeV: Standard 350–500 GeV ILC plan is ideal!

$M_H \sim 180$–250 GeV: Standard ILC plan is good.
Need more studies of what ILC can do in such a scenario.

Heavier SM-like Higgs: Inconsistent with SM EW precision fit!
Signal for BSM. But need to consider our ILC options.

If we discover a 500 GeV SM-like Higgs and no other new physics in the LHC Early Phase, do we:

- go straight for a 1 TeV ILC to study the Higgs?
- build GigaZ first to study EW precision (and maybe follow with the $t\bar{t}$ threshold and W pair production)?
- wait for more LHC data before making a decision on ILC?

LHC data is coming very soon!
Let's go beyond the standard scenarios and consider implications for ILC plans.

talk by Rick van Kooten on

Higgs Physics at the ILC: Implications of Early Results from the LHC

Overview

- Case 1: Detection of one state with properties that are compatible with those of a Higgs boson

→ ILC: precision measurement of properties

→ impact on machine energy, upgrade path

→ LHC/ILC interplay

e.g., Hey, it's light. Can we do enough with a lower-energy ILC?

- Case 2: No experimental evidence for a Higgs boson at the early stage of the LHC
  - Is actually there, but hard to detect at the LHC

→ LHC/ILC interplay *Possible to observe it with ILC?*

  - Is *really* not there

→ impact on machine energy, upgrade path (e.g., GigaZ, and/or very high energy)

→ LHC/ILC interplay

Single LHC State with M_h > 200 GeV?

- Far fewer fermion couplings now accessible!

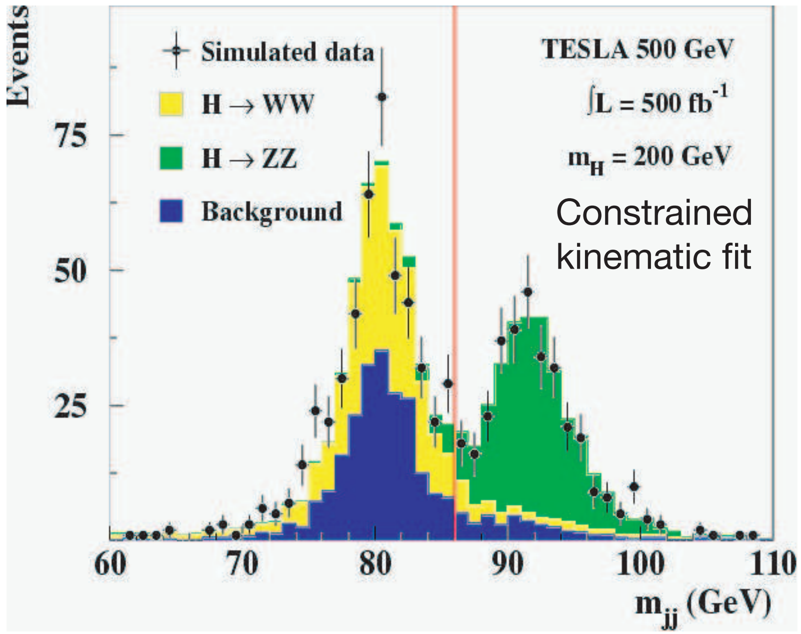
Desch, Meyer,
Eur.Phys.J.C35:171-176,2004

- Still look for them though!

- g_{ZZh} , g_{WWh} still determined to $2-9\%$ for $200 < m < 320$ GeV with 500 fb^{-1} at a 500 GeV ILC

- If $m_h > 350$ GeV skip initial ILC run at 500 GeV?

- Spin, other quantum numbers?



Start measuring width directly

- Demand detector requirements not thought of? ("standard" is the *W*/*Z* mass separation)

Single LHC State with M_h > 200 GeV?

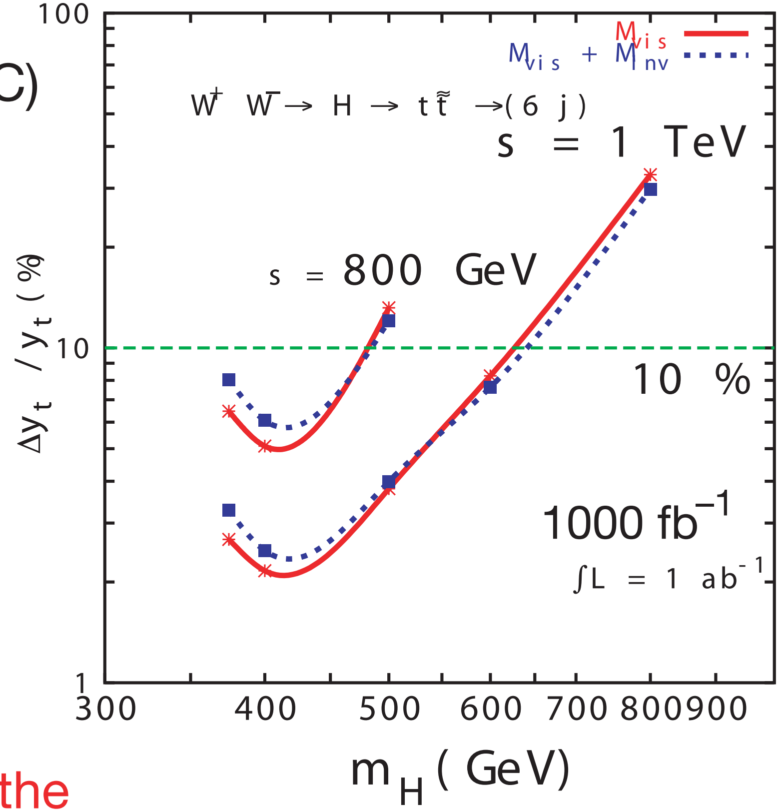
- If $m_h > 2m_{top}$ then $h \to t\bar{t}$
  (tough at LHC, more interplay w/ ILC)
  g_{tth} to better than 10% for
  $m_h < 650$ GeV

- What about the range
  200 GeV < $m_h < 2m_{top}$?

- How to get at other couplings?

- How far can the ILC realistically go in Higgs mass for measuring self-coupling? Will this determine the "top-end" of the upgrade path?

Alcarez, Morales, PRL 86, 3726 (2001)



Clearly a lot to be looked into...

No evidence of Higgs at early stage LHC

Possibly a more relevant question:

Are *WW* interactions perturbative up to the TeV scale?

Yes → Higgs-like state must be there

→ ILC can see the state(s) that is regulating the bad energy behavior   Initial energy 500 GeV ILC fine

No → New physics involved, some strong interactions

→ How are precision EW measurements being compensated?   Back to tension between possibly running ILC at higher initial energies but wanting EW precision from GigaZ and WW scans

Soooo, how soon can we know if WW interactions remaining perturbative at the LHC?

No evidence of Higgs at early stage LHC

- Is actually there, but difficult/impossible to detect at the LHC

Just a few examples:

Berger et al., Phys.Rev.D66:095001,2002

- $h \to \mathrm{jets}$ of no particular flavor content; in MSSM with very light $\tilde{b}$ with *R*-parity violating decays evading LEP limits

If $Br(h \to \mathrm{jets}) \approx (2-5) \times Br(h \to b\bar{b})$ difficult to observe at LHC; no problem at initial energy ILC

e.g., Boudjema, Belanger, Godbole; hep-ph/0206311

- MSSM with light stop quarks suppressing *ggh* coupling, reducing standard gluon-fusion discovery modes at LHC
  or
  enhanced branching fraction $Br(h \to \chi_1^0 \chi_1^0)$
  (LHC can detect invisible Br's up to ~0.25–0.30);
  no problem at initial energy ILC

$\tilde{t}\tilde{t}h$ possible

summary talk of WG1:

Observation of a Higgs-like state at the LHC

Constraints on SM-like Higgs from early LHC data

- Measuring M_H drastically reduces the parameter space of all models.
- Observation/non-observation of additional states is crucial.
- 10^{-1} fb not enough for a detailed coupling analysis, but measurements of relevant rates put bounds on couplings (HWW, HZZ, $H\tau\tau$, and indirectly $Ht\bar{t}$, HXX).
- 10^{-1} fb not enough for study of the Higgs potential.

$$\Downarrow$$

possible to establish consistency with the SM

Open questions for the Higgs working group

Scenarios for SM-like Higgs discovery at the LHC

- Low mass SM-like Higgs ($M_H \lesssim 2M_Z$ GeV):

  $\longrightarrow$ what can be improved in order to extract as much as possible from the first 10 fb^{-1} of data (e.g, $t\bar{t}H$, $H \to b\bar{b}$)
  $\longrightarrow$ what is most important in view of the ILC?
  $\longrightarrow$ what is the value added of Tevatron data?

- Intermediate mass SM-like Higgs ($180 \lesssim M_H \lesssim 2M_t$ GeV):

  $\longrightarrow$ How much precision do we need?
  $\longrightarrow$ Is there any sensitivity to $H \to tt^*$ (below $t\bar{t}$ threshold)?

- Heavier SM-like Higgs ($M_H \gtrsim 2M_t$):

  $\longrightarrow$ Implications for the ILC precision Higgs program?

Important theoretical input

- State-of-the-art Higgs computations

  → How accurate are current predictions of Higgs production and decay processes and the relevant backgrounds?
  → Do we need to do better? Identify the highest priority needs.

- The decoupling limit: Many models of physics beyond the SM possess significant parameter regimes in which the lightest Higgs scalar closely resembles the SM Higgs boson.

  → What are the first order corrections to the SM-like Higgs properties?
  → Do the systematics of the corrections to the SM-like Higgs observables distinguish among various possible models?
  → Can this be exploited by a precision Higgs program at the ILC?

Next steps

- → We will have a webpage soon!
- → List of important experimental and theoretical studies needed to address the open questions.
- → Provide a central location for various links to the relevant ATLAS, CMS and ILC Higgs studies.
- → Identify ongoing working group projects and contact information for project authors.
- → Incorporate subject areas of the newly expanded working group charge. Identify possible connections to other working group activities.
- → Be prepared ahead of time in anticipation of the next meeting of this workshop in the fall of 2007.

summary talk of WG4:

Missing Energy

Summary & questions

Question to answer:

What can the LHC learn us in preparing for the ILC?
(with 10 fb^{-1}ud)

"fb-1ud" = inverse femtobarn of understood data

- Given that LHC = coloured particles
  ILC = electroweak particles

- How much can we deduce in a model independent way?

- What can we learn apart from ILC energy scale --
are there other things that one would like to know?
(detector design?)

LHC 4 ILC ?

LHC :   gluon factory

colored states:
squarks, gluinos, etc.

+ R-parity

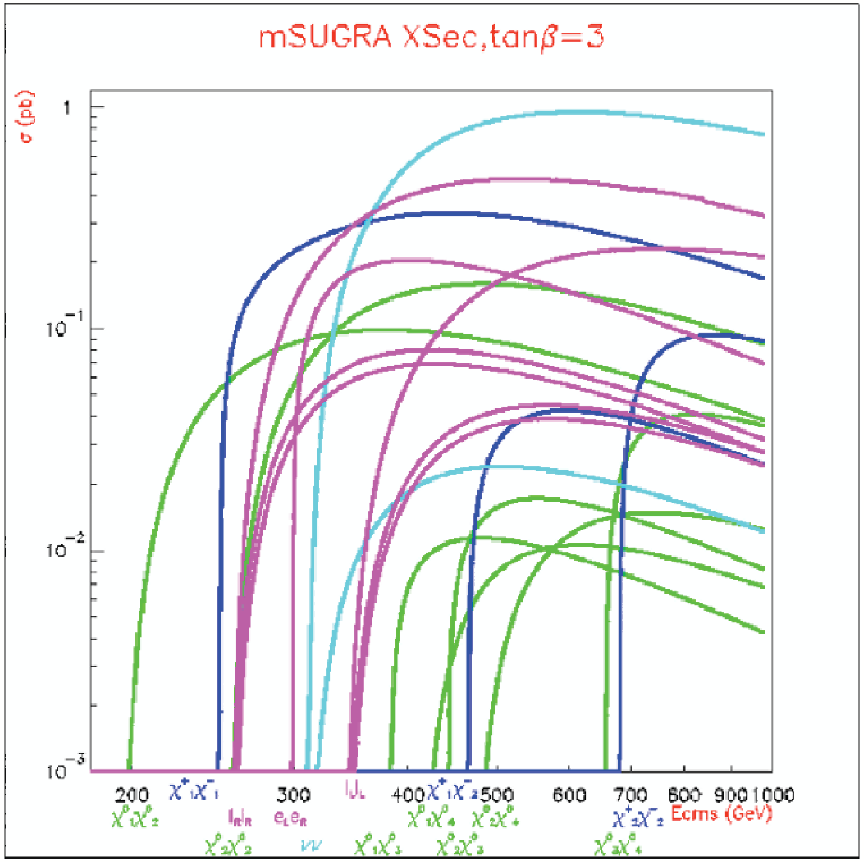
?

ILC :   electron factory

charginos, neutralinos,
sleptons, etc.

Not at all trivial.
New ideas needed!

Is the LHC going to reliable tell us something about this?



Questions 2

G. Wilson

- Suppose:
  - –A light Higgs is found. Consistent with SM, SUSY.
  - –Only a jets+MET signal is found at LHC.
- What is the minimum √shat involved in the signal ?
  - –Can we estimate the e^+e^- production threshold reliably ?
- Can the signal be produced in e^+e^- (does it couple to the √, W, Z, h) ?
  - –Presumably no info will be available.
  - –If it's a gluino, e^+e^- is probably irrelevant for direct tests ...
- Is there ANY robust logical inference on the masses of lighter particles that can be made, e.g. M_{LSP} ???

We may find that LHC can't tell very much of value in diagnosing this new physics.
And that ILC at any energy may not be a useful diagnostic tool for certain hadron collider signatures.

5. Conclusions

- LHC/ILC interplay is a very important, rich and active field

  LHC / ILC synergy has the potential to greatly enhance the physics program of both facilities

  Concurrency is an issue!

- First report (hep-ph/0410364) is an important step
  We cannot afford to slow down!

- There are new (2005–2006) results, e.g.: SM Higgs, SUSY, Z'

- Future: same direction, but better

  ATLAS and CMS are preparing for data taking + ongoing ILC studies
  $\Rightarrow$ ideal input for studying the LHC/ILC interplay
  $\Rightarrow$ There is a good case for concurrent running (more examples . . . ?)

- Future: new direction

  investigate various possible scenarios of early LHC data

  $\Rightarrow$ implications for the ILC (design, options, detectors)?

  $\Rightarrow$ workshop at Fermilab 04/07 $\Rightarrow$ next meeting at SLAC 10,11/07