Synergy between the LHC and the ILC

Georg Weiglein

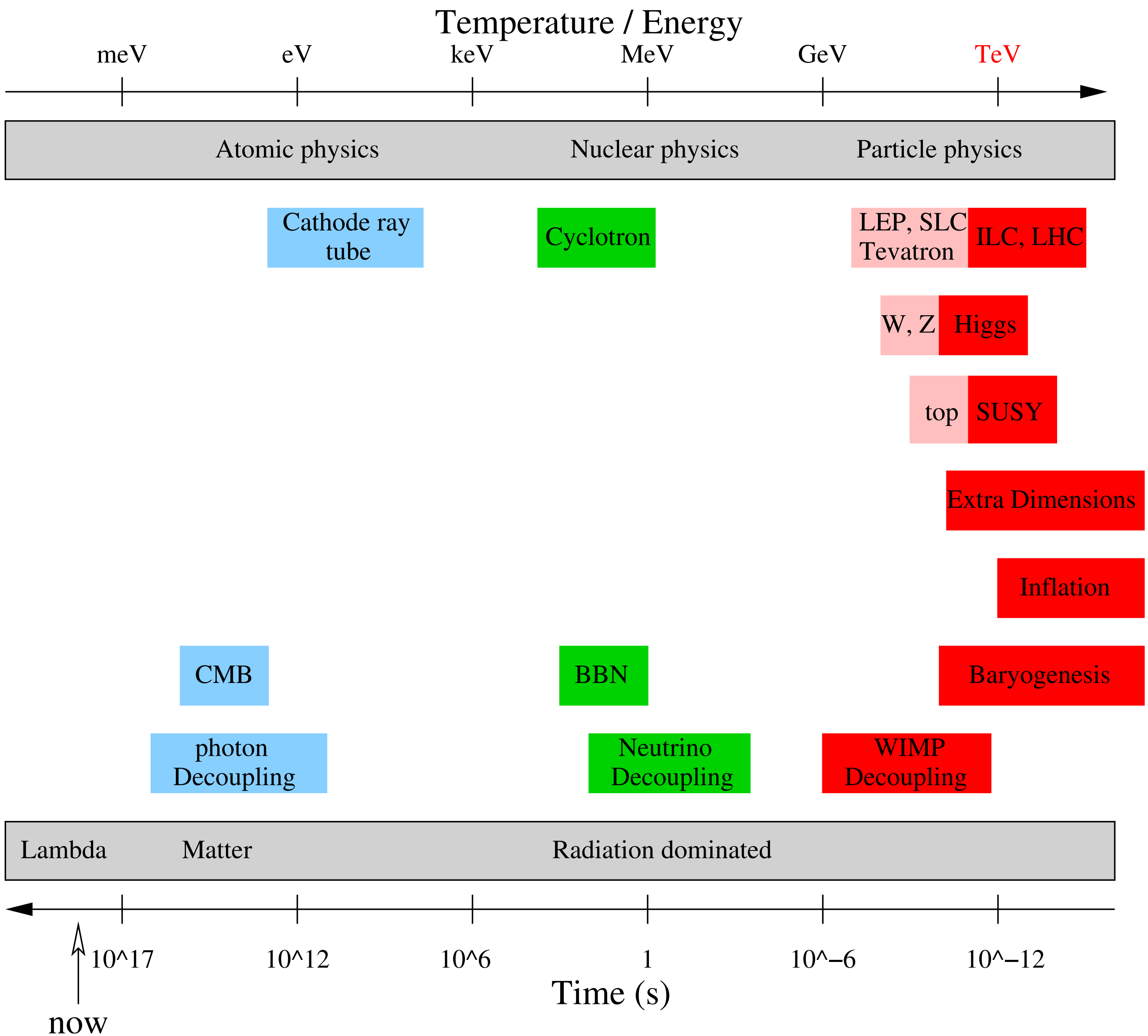
IPPP Durham

DESY, Zeuthen, 10/2006

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

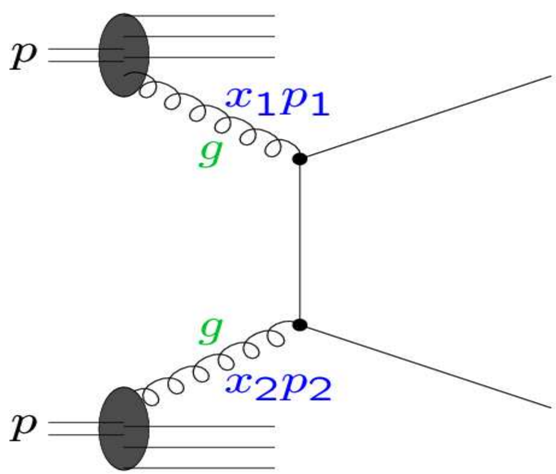
www.ippp.dur.ac.uk/∼georg/lhcilc

Particle physics is about to enter a new territory: the TeV scale $(1\ \text{TeV} \approx 1000 \times m_{\text{proton}} \Leftrightarrow 2 \times 10^{-19}\ \text{m})$



Physics at the LHC and ILC in a nutshell

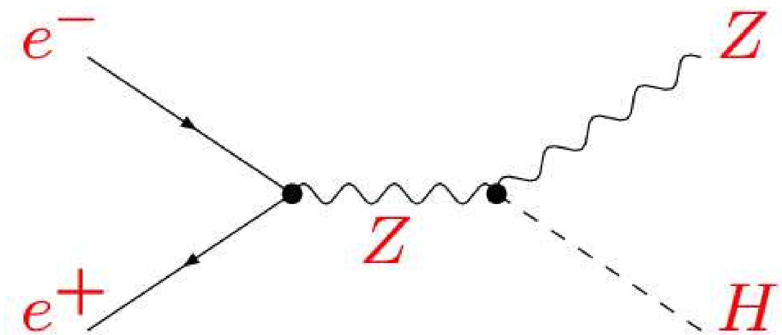
LHC: pp scattering at 14 TeV



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

LHC / ILC complementarity

The results of LHC and ILC will be highly complementary

LHC: good prospects for producing new heavy states
(in particular strongly interacting new particles)

ILC: direct production (in particular colour-neutral new particles)
$\oplus$ high sensitivity to effects of new physics via precision measurements

LHC / ILC synergy during concurrent running

LHC: $\gtrsim 2007$, expected to run for about 15–20 years

ILC: $\gtrsim 2015$?

Expeditious realisation of the ILC
$\Rightarrow$ period of concurrent running

During concurrent running: LHC $\otimes$ ILC

$\Rightarrow$ Information obtained at the ILC can be used to improve analyses at the LHC and vice versa

$\Rightarrow$ Enable improved strategies, dedicated searches

Interplay between lepton and hadron colliders: some examples from the past

LEP $+$ SLC $+$ Tevatron led to many success stories:

SM at quantum level, top quark, prediction of Higgs mass

HERA observation of high Q^2 events $\Rightarrow$ dedicated leptoquark searches at the Tevatron, results fed back to HERA analyses

Belle discovery of X(3872) $\Rightarrow$ dedicated search at CDF & D0

$\Rightarrow$ independent confirmation

LHC and ILC will explore a new energy domain

$\Rightarrow$ expect ground-breaking discoveries

$\Rightarrow$ large potential for synergy

What is the physics gain of LHC / ILC synergy?

Exploring physics gain from LHC / ILC interplay requires:

What is the physics gain of LHC / ILC synergy?

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

What is the physics gain of LHC / ILC synergy?

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

What is the physics gain of LHC / ILC synergy?

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

$\Rightarrow$ LHC / ILC Study Group *www.ippp.dur.ac.uk/∼georg/lhcilc*

World-wide working group, started in 2002

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

What is the physics gain of LHC / ILC synergy?

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

$\Rightarrow$ LHC / ILC Study Group *www.ippp.dur.ac.uk/∼georg/lhcilc*

World-wide working group, started in 2002

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

First report: [*G. W. et al., hep-ph/0410364, Phys. Rept. 426 (2006) 47*]

122 authors from 75 institutions

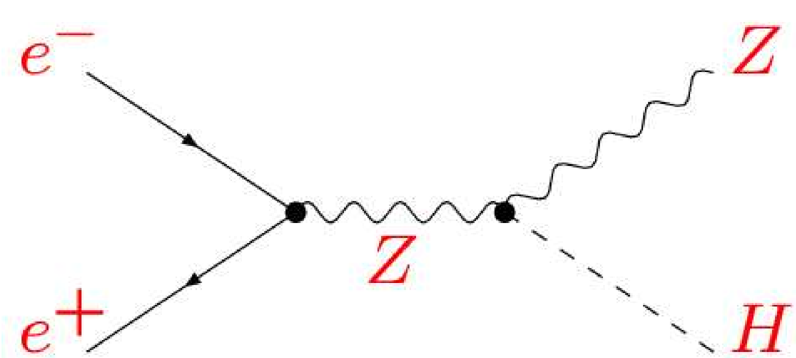
If a Higgs candidate has been detected at the LHC and/or the ILC: experimental questions

- Is it a Higgs boson?
- What are its mass, spin and $\mathcal{CP}$ properties?
- What are its couplings to fermions and gauge bosons? Are they really proportional to the masses of the particles?
- What are its self-couplings?
- Are its properties compatible with the SM, the MSSM, the NMSSM, . . . ?
- Are there indications that there are more than one Higgs bosons?
- Are there indications for other new states that influence Higgs physics?

Higgs physics at the ILC

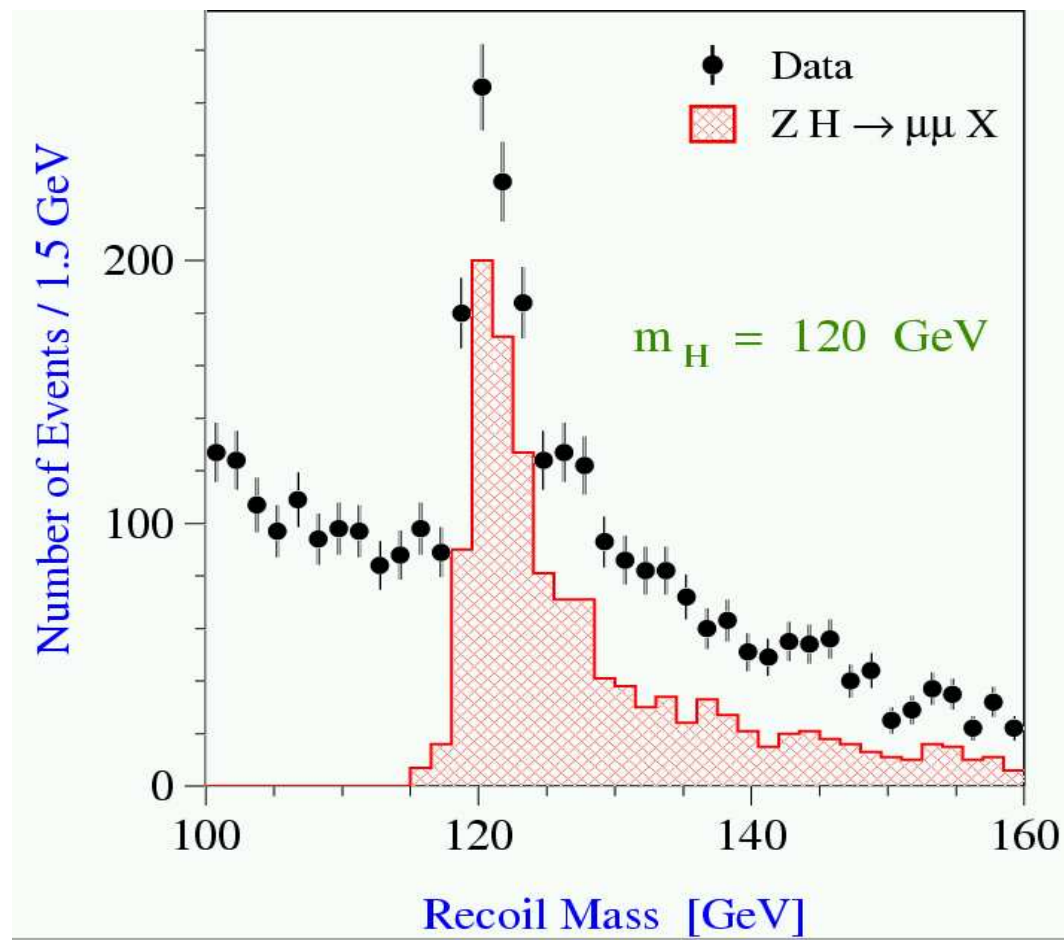
"Golden" production channel: $e^+e^- \to ZH$, $Z \to e^+e^-, \mu^+\mu^-$

Higgs discovery possible independently of decay modes (from recoil against Z boson)



$\Delta\sigma_{\mathrm{HZ}}/\sigma_{\mathrm{HZ}} \approx 2\%$
($E_{\mathrm{CM}} = 350$ GeV,
$\int \mathcal{L}dt = 500$ fb^{-1})

[P. Garcia-Abia, W. Lohmann '00]



The ILC will be a “Higgs factory”

Example: $E_{\rm CM} = 800$ GeV, 1000 fb^{-1}, $M_{\rm H} = 120$ GeV:

$\Rightarrow$ ≈ 160000 Higgs events in “clean” experimental environment

$\Rightarrow$ Precise measurement of Higgs mass and couplings, determination of Higgs spin and quantum numbers, . . .
Mass determination for a light Higgs:

$$\delta M_{\rm H}^{\rm exp} \approx 0.05 \text{ GeV}$$

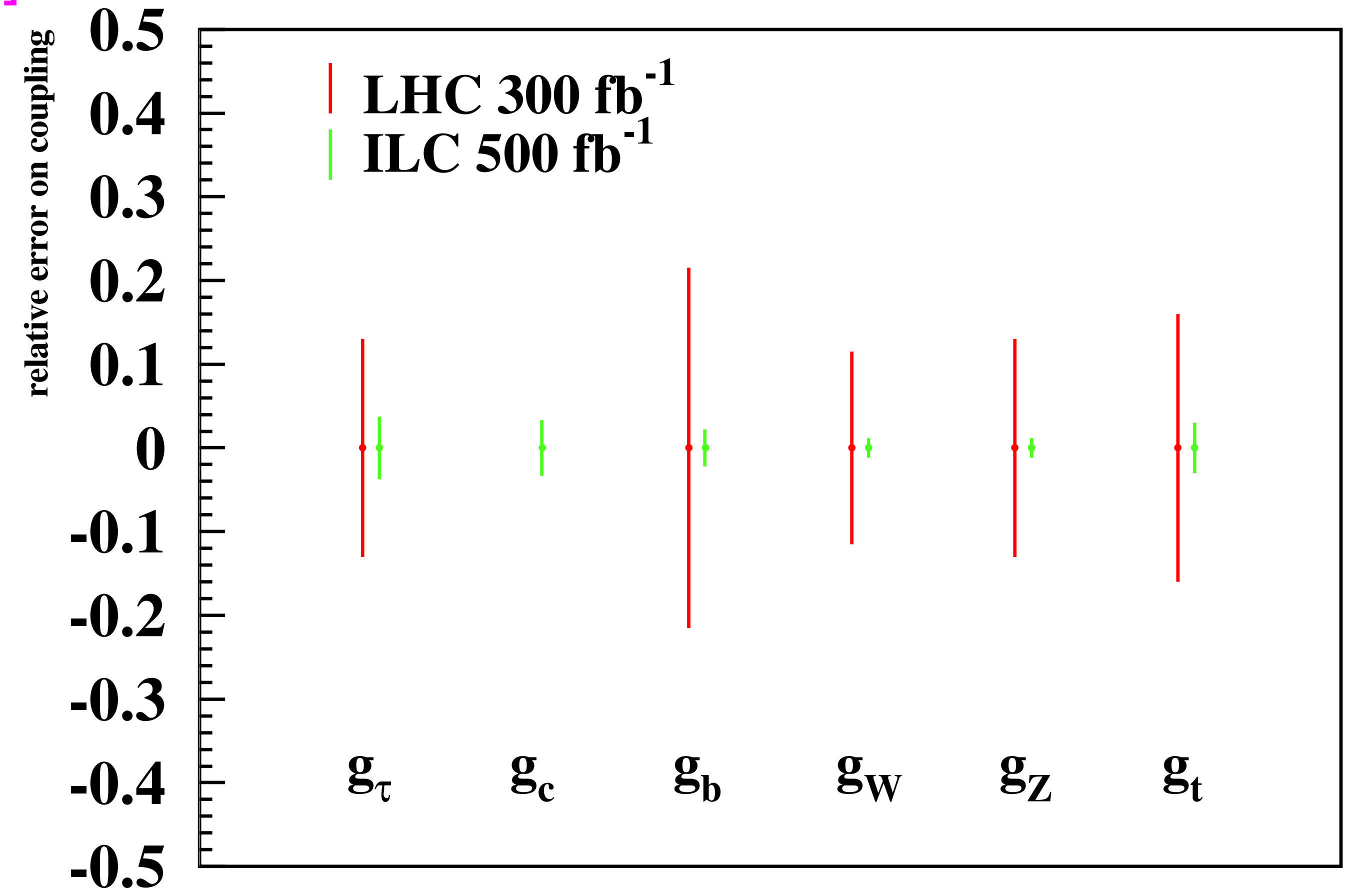
$\Rightarrow$ Verification of Higgs mechanism in model-independent way

distinction between different possible manifestations: extended Higgs sector, invisible decays, Higgs–radion mixing, . . .

Higgs coupling determination: LHC vs. ILC

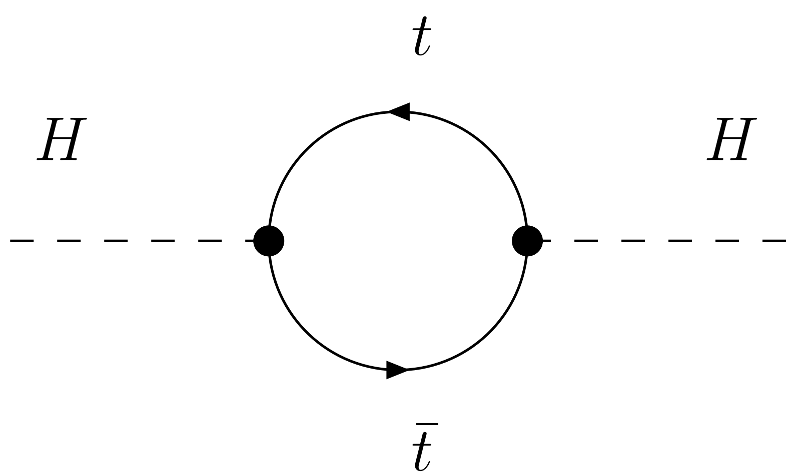
Comparison: LHC (with mild theory assumptions) vs. ILC (model-independent)

[*M. Dührssen, S. Heinemeyer, H. Logan, D. Rainwater, G. W., D. Zeppenfeld '04*]
[*K. Desch '06*]



Precision Higgs physics

Large coupling of Higgs to top quark

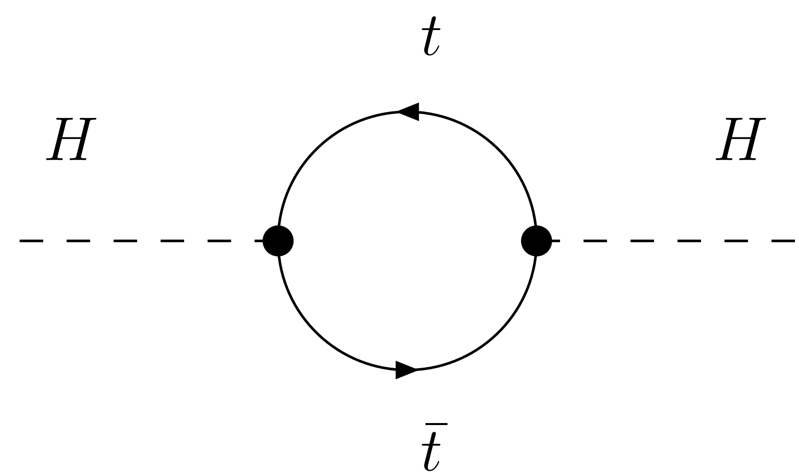


One-loop correction $\sim G_\mu m_t^4$

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

Precision Higgs physics

Large coupling of Higgs to top quark



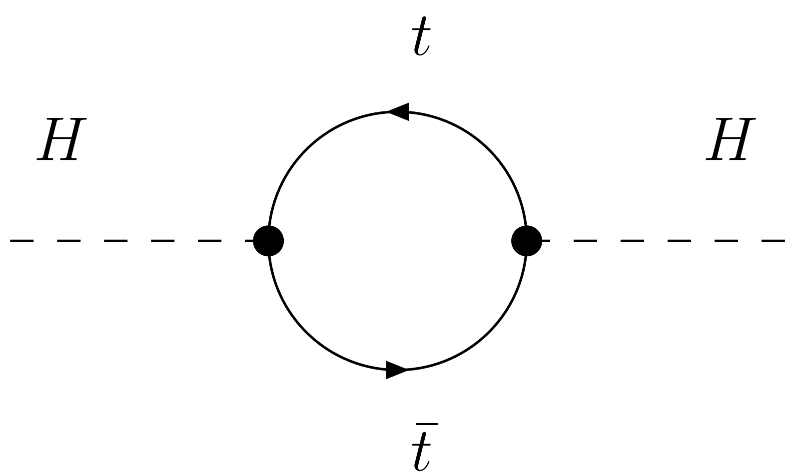
One-loop correction $\sim G_\mu m_\mathrm{t}^4$

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

SUSY as an example: $\Delta m_\mathrm{t} \approx \pm 2\ \mathrm{GeV} \Rightarrow \Delta m_\mathrm{h} \approx \pm 2\ \mathrm{GeV}$

Precision Higgs physics

Large coupling of Higgs to top quark



One-loop correction $\sim G_\mu m_t^4$

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

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

LHC: $\Delta m_h \approx 0.2$ GeV, $\Delta m_t \gtrsim 1$ GeV, ILC: $\Delta m_t \lesssim 0.1$ GeV

LHC / ILC interplay in determination of the top Yukawa coupling (model-independent)

LHC / ILC interplay in determination of the top Yukawa coupling (model-independent)

Only crude measurement of tth coupl. at 500 GeV ILC (light Higgs)

Precision measurement requires ILC with 800–1000 GeV

LHC measures $(\sigma \times \mathrm{BR})$

LHC / ILC interplay in determination of the top Yukawa coupling (model-independent)

Only crude measurement of tth coupl. at 500 GeV ILC (light Higgs)

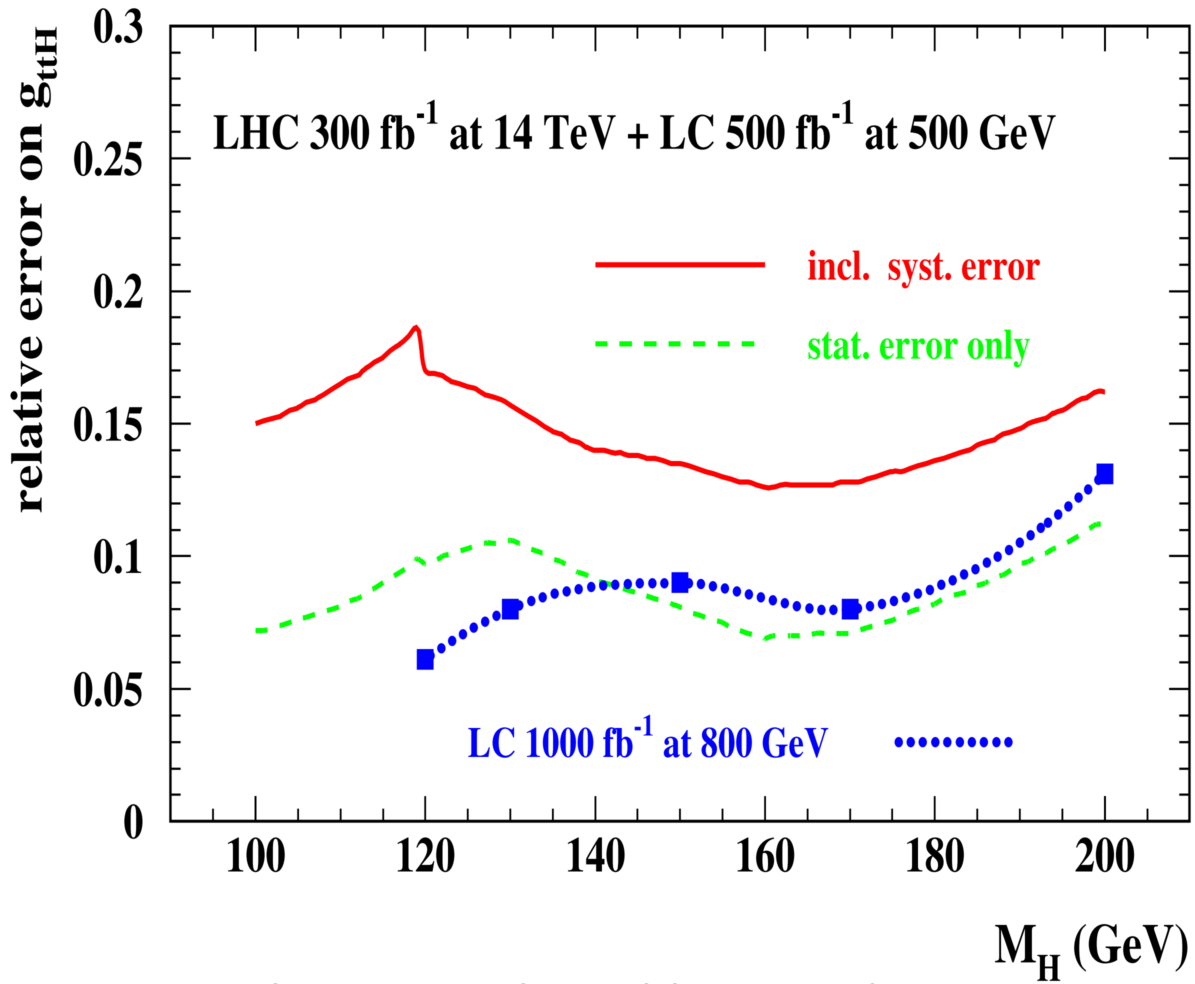
Precision measurement requires ILC with 800–1000 GeV

LHC measures ($\sigma \times \mathrm{BR}$)

$\Rightarrow$ Yukawa coupling can be extracted if precise measurement of Higgs BR's from ILC are used

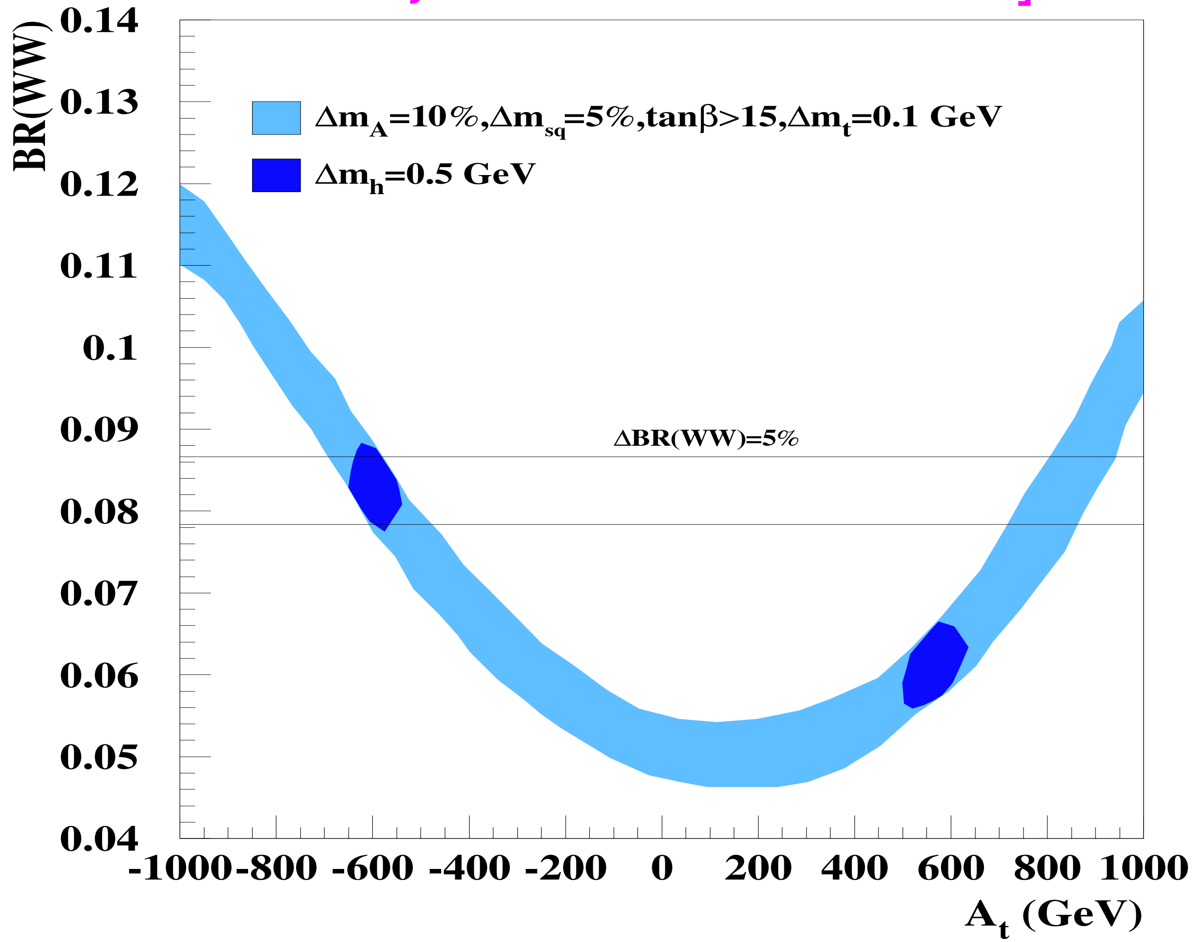
LHC $\oplus$ ILC (500 GeV):

[*K. Desch, M. Schumacher '04*]



SUSY Higgs at LHC $\oplus$ ILC: determination of the trilinear coupling A_t

[*K. Desch, E. Gross, S. Heinemeyer, G. W., L. Zivkovic '04*]



$\Rightarrow$ ILC precision measurements of light Higgs properties
$+$ LHC information on heavy Higgses
gives sensitivity to parameters in the stop sector

Higgs–radion mixing

[*M. Battaglia, S. De Curtis, A. De Roeck, D. Dominici, J. Gunion '03*]

Models with 3-branes in extra dimensions predict radion ϕ, can mix with the Higgs

Higgs–radion mixing

[*M. Battaglia, S. De Curtis, A. De Roeck, D. Dominici, J. Gunion '03*]

Models with 3-branes in extra dimensions predict radion ϕ, can mix with the Higgs

$\Rightarrow$ Higgs properties modified, can be difficult to detect at the LHC

Higgs–radion mixing

[*M. Battaglia, S. De Curtis, A. De Roeck, D. Dominici, J. Gunion ’03*]

Models with 3-branes in extra dimensions predict radion ϕ, can mix with the Higgs

$\Rightarrow$ Higgs properties modified, can be difficult to detect at the LHC

LHC may observe radion instead

Higgs–radion mixing

[*M. Battaglia, S. De Curtis, A. De Roeck, D. Dominici, J. Gunion '03*]

Models with 3-branes in extra dimensions predict radion ϕ, can mix with the Higgs

$\Rightarrow$ Higgs properties modified, can be difficult to detect at the LHC

LHC may observe radion instead

ILC guarantees Higgs observation over full parameter space

$\Rightarrow$ precision measurements at ILC crucial to disentangle the nature of the observed state

Higgs–radion mixing

[*M. Battaglia, S. De Curtis, A. De Roeck, D. Dominici, J. Gunion ’03*]

Models with 3-branes in extra dimensions predict radion ϕ, can mix with the Higgs

$\Rightarrow$ Higgs properties modified, can be difficult to detect at the LHC

LHC may observe radion instead

ILC guarantees Higgs observation over full parameter space

$\Rightarrow$ precision measurements at ILC crucial to disentangle the nature of the observed state

LHC: large sensitivity to production of Kaluza-Klein excitations

Electroweak symmetry breaking without Higgs

If no light Higgs boson exists

$\Rightarrow$ dynamics of electroweak symmetry breaking can be probed in quasi-elastic scattering processes of W and Z at high energies

Electroweak symmetry breaking without Higgs

If no light Higgs boson exists

$\Rightarrow$ dynamics of electroweak symmetry breaking can be probed in quasi-elastic scattering processes of W and Z at high energies

LHC / ILC sensitive to different scattering channels, yield complementary information

LHC: direct sensitivity to resonances

ILC: detailed measurements of cross sections and angular distributions

Electroweak symmetry breaking without Higgs

If no light Higgs boson exists

$\Rightarrow$ dynamics of electroweak symmetry breaking can be probed in quasi-elastic scattering processes of W and Z at high energies

LHC / ILC sensitive to different scattering channels, yield complementary information

LHC: direct sensitivity to resonances

ILC: detailed measurements of cross sections and angular distributions

$\Rightarrow$ combination of LHC results with ILC data on cross-section rise essential for disentangling new states

SUSY at LHC and ILC

LHC: good prospects for strongly interacting new particles

long decay chains $\Rightarrow$ complicated final states,

e.g.: $\tilde{g} \to \bar{q}\tilde{q} \to \bar{q}q\tilde{\chi}_2^0 \to \bar{q}q\tilde{\tau}\tau \to \bar{q}q\tau\tau\tilde{\chi}_1^0$

Many states are produced at once, difficult to disentangle

SUSY at LHC and ILC

LHC: good prospects for strongly interacting new particles

long decay chains $\Rightarrow$ complicated final states,

e.g.: $\tilde{g} \to \bar{q}\tilde{q} \to \bar{q}q\tilde{\chi}_2^0 \to \bar{q}q\tilde{\tau}\tau \to \bar{q}q\tau\tau\tilde{\chi}_1^0$

Many states are produced at once, difficult to disentangle

$\Rightarrow$ It quacks like SUSY!

SUSY at LHC and ILC

LHC: good prospects for strongly interacting new particles

long decay chains $\Rightarrow$ complicated final states,

e.g.: $\tilde{g} \to \bar{q}\tilde{q} \to \bar{q}q\tilde{\chi}_2^0 \to \bar{q}q\tilde{\tau}\tau \to \bar{q}q\tau\tau\tilde{\chi}_1^0$

Many states are produced at once, difficult to disentangle

$\Rightarrow$ It quacks like SUSY!

But ist it really SUSY? Which particles are actually produced?

Main background for SUSY is SUSY itself!

SUSY at LHC and ILC

LHC: good prospects for strongly interacting new particles

long decay chains $\Rightarrow$ complicated final states,

e.g.: $\tilde{g} \to \bar{q}\tilde{q} \to \bar{q}q\tilde{\chi}_2^0 \to \bar{q}q\tilde{\tau}\tau \to \bar{q}q\tau\tau\tilde{\chi}_1^0$

Many states are produced at once, difficult to disentangle

$\Rightarrow$ It quacks like SUSY!

But ist it really SUSY? Which particles are actually produced?

Main background for SUSY is SUSY itself!

SUSY phenomenology investigated in detail for SPS 1a benchmark point: “best case scenario”

more results needed for less favourable points (in progress at ATLAS & CMS)

It quacks like SUSY, but . . .

It quacks like SUSY, but . . .

- does every SM particle really have a superpartner?
- do their spins differ by $1/2$?
- are their gauge quantum numbers the same?
- are their couplings identical?
- do the SUSY predictions for mass relations hold, . . . ?

Even when we are sure that it is actually SUSY, we will still want to know:

Even when we are sure that it is actually SUSY, we will still want to know:

- is the lightest SUSY particle really the neutralino, or the stau or the sneutrino, or the gravitino or . . . ?
- is it the MSSM, or the NMSSM, or the mNSSM, or the N^2MSSM, or . . . ?
- what are the experimental values of the 105 (or more) SUSY parameters?
- does SUSY give the right amount of dark matter?
- what is the mechanism of SUSY breaking?

We will ask similar questions for other kinds of new physics

When and how will we find out?

- How much will we learn from the LHC alone?
- How much more will we know once we have ILC data?
- What is the added value from the interplay of the LHC and the ILC?

When and how will we find out?

- How much will we learn from the LHC alone?
- How much more will we know once we have ILC data?
- What is the added value from the interplay of the LHC and the ILC?

SUSY at the ILC: clean signatures, small backgrounds

$\Rightarrow$ precise determination of masses, spin, couplings, mixing angles, complex phases . . . ,

good prospects for weakly interacting SUSY particles

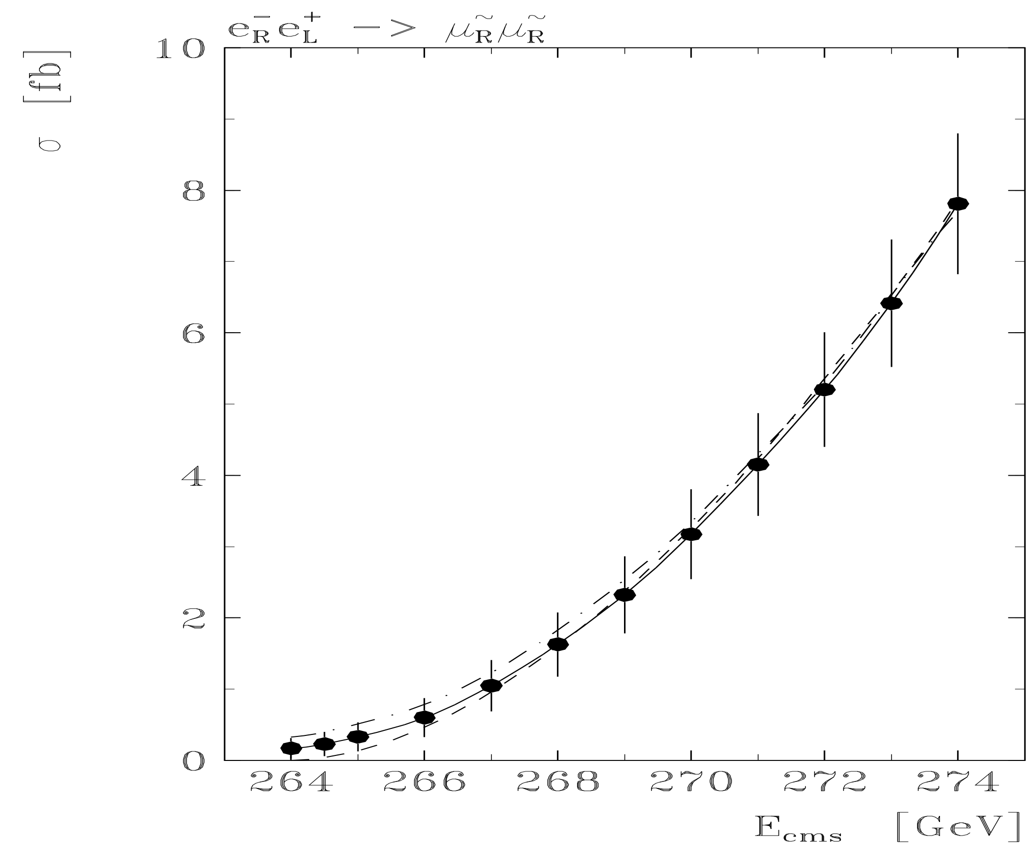
precision measurement of mass of lightest SUSY particle (factor 100 improvement)

Production of new particles at the ILC

Tunable energy $\Rightarrow$ can run directly at threshold

Example: Determination of mass and spin of SUSY particle $\tilde{\mu}_R$ from production at threshold:

[*TESLA TDR '01*]



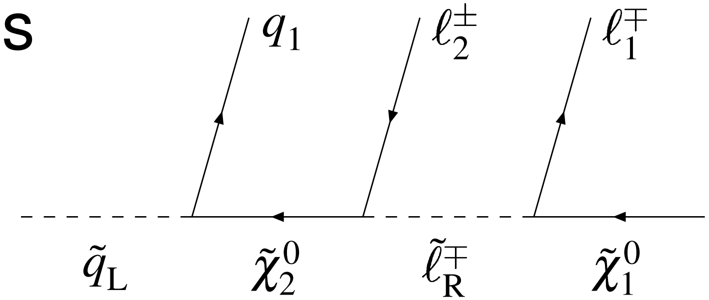
$$\Rightarrow \quad \frac{\Delta m_{\tilde{\mu}_R}}{m_{\tilde{\mu}_R}} < 1 \times 10^{-3}$$

$\Rightarrow$ test of $J = 0$ hypothesis

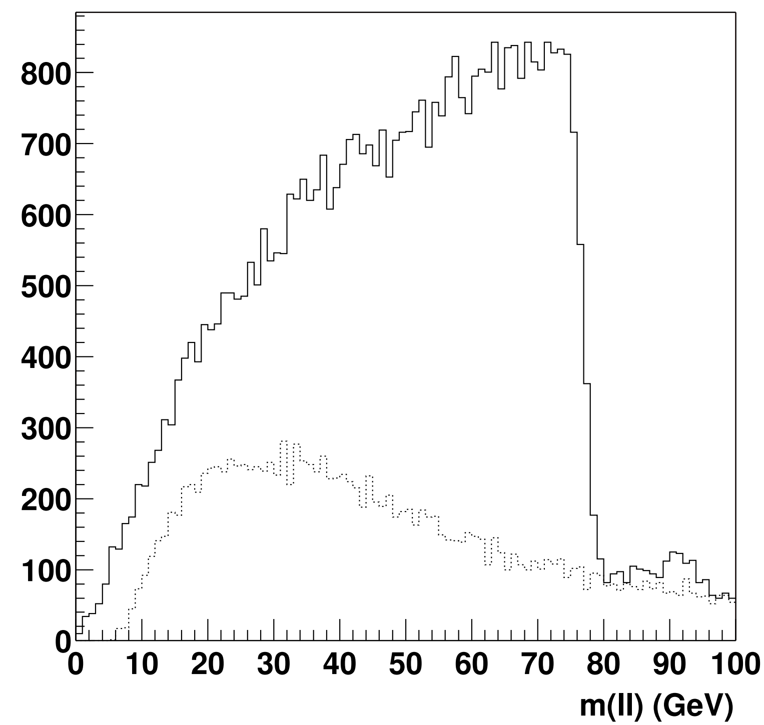
SUSY analyses at the LHC

[*M. Chiorboli, B.K. Gjelsten, J. Hisano, K. Kawagoe, E. Lytken, U. Martyn, D. Miller, M. Nojiri, P. Osland, G. Polesello, A. Tricomi ’03*]

Cascade decays: complicated decay chains for squarks and gluinos



Main tool: dilepton “edge” from $\tilde{\chi}_2^0 \to \ell^+\ell^-\tilde{\chi}_1^0$



Information from kinematical edges and thresholds

$$(m_{ll}^2)^{\text{edge}} = \frac{(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2)(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{l}_R}^2}$$

$$(m_{qll}^2)^{\text{edge}} = \frac{(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2)(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{\chi}_2^0}^2}$$

$$(m_{ql}^2)^{\text{edge}}_{\text{min}} = \frac{(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2)(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2)}{m_{\tilde{\chi}_2^0}^2}$$

$$(m_{ql}^2)^{\text{edge}}_{\text{max}} = \frac{(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2)(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{l}_R}^2}$$

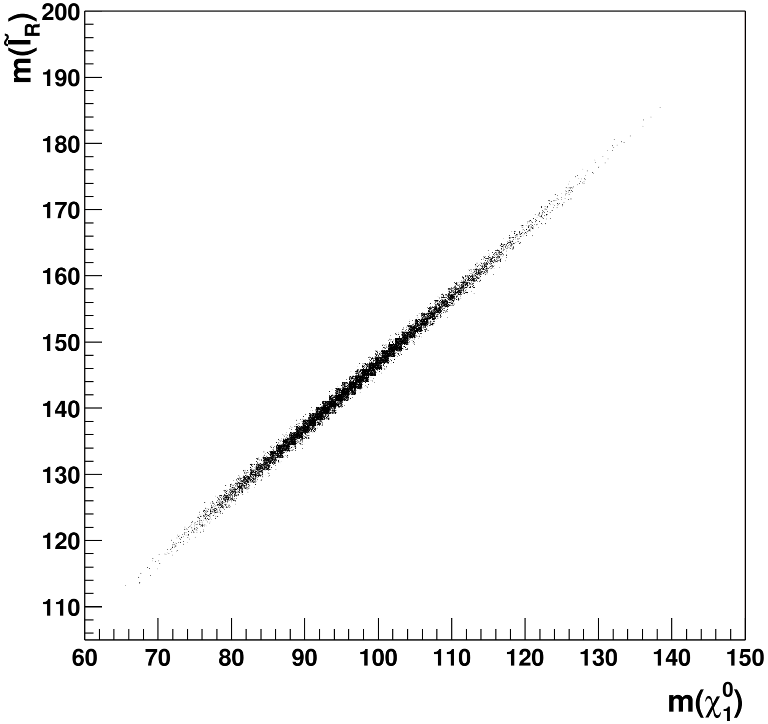
$$\begin{aligned}(m_{qll}^2)^{\text{thres}} = {} & [(m_{\tilde{q}_L}^2 + m_{\tilde{\chi}_2^0}^2)(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2)(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2) \\ & -(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2)\sqrt{(m_{\tilde{\chi}_2^0}^2 + m_{\tilde{l}_R}^2)^2(m_{\tilde{l}_R}^2 + m_{\tilde{\chi}_1^0}^2)^2 - 16 m_{\tilde{\chi}_2^0}^2 m_{\tilde{l}_R}^4 m_{\tilde{\chi}_1^0}^2} \\ & +2m_{\tilde{l}_R}^2(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2)(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\chi}_1^0}^2)]/(4m_{\tilde{l}_R}^2 m_{\tilde{\chi}_2^0}^2)\end{aligned}$$

$\Rightarrow$ Precise information on mass squared differences

From overconstrained system $\Rightarrow$ absolute mass determination

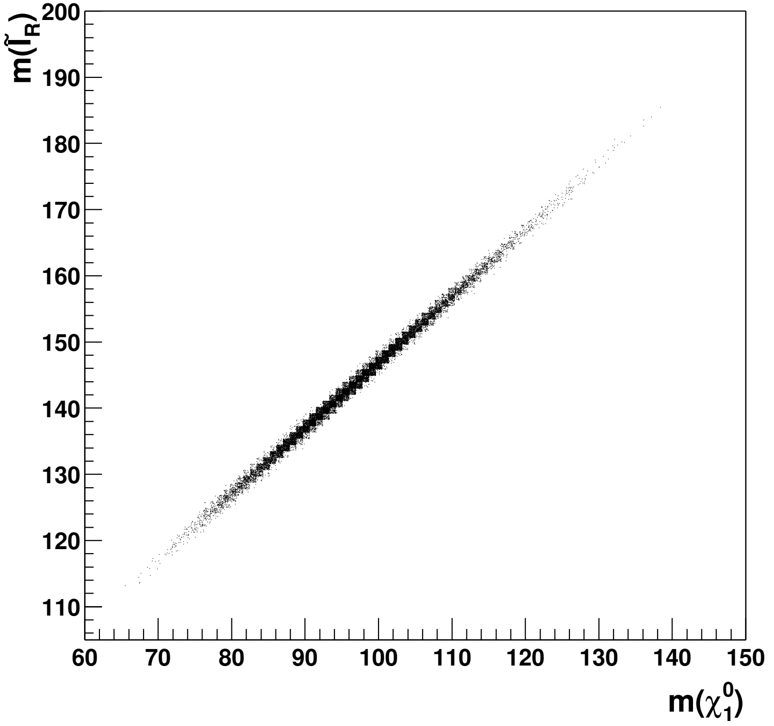
LHC analysis with ILC input: mass of lightest SUSY particle (LSP)

Reconstruction of the states in decay chain requires precise knowledge of LSP mass



LHC analysis with ILC input: mass of lightest SUSY particle (LSP)

Reconstruction of the states in decay chain requires precise knowledge of LSP mass



$\Rightarrow$ Precision measurement of m_{LSP} at ILC leads to significant improvement in determination of slepton, squark and gluino masses at the LHC

Detailed analysis for SPS1a benchmark scenario: potential of LHC (300 fb^{-1}) alone and LHC $\oplus$ ILC

	LHC	LHC$\oplus$ILC
$\Delta m_{\tilde{\chi}_1^0}$	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
$\Delta m_{\tilde{\mathrm{g}}}$	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

LHC$\oplus$ILC accuracy limited by LHC jet energy scale resolution

SPS 1a benchmark scenario:

favourable scenario for both LHC and ILC

$\Rightarrow$ ILC input improves accuracy significantly

Measurement of the SUSY QCD coupling at LHC $\oplus$ ILC

Measure squark / gluino production at the LHC using
ILC input on branching ratios that appear in the LHC decay chains

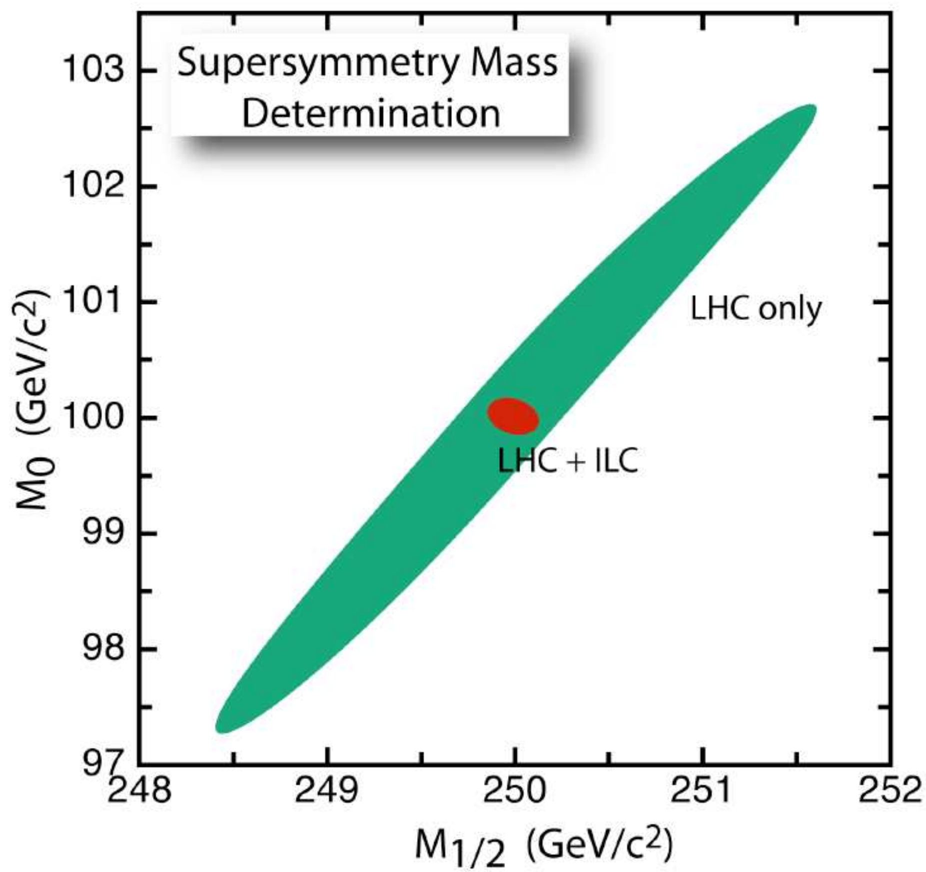
[*A. Freitas, P. Skands '06*]

$\Rightarrow$ Determination of absolute SUSY QCD production cross sections at the LHC

$\Rightarrow$ $\tilde{g}_{\mathrm{s}}$ measurement to $\sim 5\%$

Determination of GUT-scale parameters m_0*,* $m_{1/2}$ *in the mSUGRA scenario*

LHC only vs. LHC $\oplus$ ILC



$\Rightarrow$ Combined information from LHC and ILC yields drastic improvement

LHC / ILC interplay in SUSY searches

- Precise determination of the properties of the SUSY particles accessible at the ILC

  $\Rightarrow$ identify whether or not these particles appear in the decay cascades at the LHC

- Precision measurement of the LSP mass at the ILC $+$ masses and couplings of other accessible states
  $\rightarrow$ input for LHC analyses

  $\Rightarrow$ significantly improves precision of mass determination of heavier SUSY particles at the LHC
  $+$ access to couplings

- From part of the SUSY spectrum accessible at the ILC

  $\Rightarrow$ can predict the properties of heavier particles

  $\Rightarrow$ tell the LHC where to look

“Telling the LHC where to look”

ILC prediction transforms search for edge in di-lepton mass spectrum into single hypothesis test

$\Rightarrow$ Increase of LHC statistical sensitivity!

$\Rightarrow$ crucial for extracting statistically marginal signal at LHC

$\Rightarrow$ Optimised searches at the LHC:

Improved selection criteria, modified triggers, different running strategy, . . .

“Telling the LHC where to look”

ILC prediction transforms search for edge in di-lepton mass spectrum into single hypothesis test

$\Rightarrow$ Increase of LHC statistical sensitivity!

$\Rightarrow$ crucial for extracting statistically marginal signal at LHC

$\Rightarrow$ Optimised searches at the LHC:

Improved selection criteria, modified triggers, different running strategy, ...

Compare the situation at LEP, where we had a statistically marginal excess of Higgs-like events

“Telling the LHC where to look”

ILC prediction transforms search for edge in di-lepton mass spectrum into single hypothesis test

⇒ Increase of LHC statistical sensitivity!

⇒ crucial for extracting statistically marginal signal at LHC

⇒ Optimised searches at the LHC:

Improved selection criteria, modified triggers, different running strategy, . . .

Compare the situation at LEP, where we had a statistically marginal excess of Higgs-like events

Suppose a collider running concurrently with LEP had predicted a Higgs boson with $M_{\mathrm{H}} = 115 \pm 1 \ \mathrm{GeV}$

this would have certainly affected the running strategy of LEP

Example of LHC / ILC interplay

SUSY case study where the lightest neutralino and chargino states $(\chi_1^0, \chi_2^0, \chi_1^\pm)$ are precisely measured at the ILC

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

$\Rightarrow$ Identification of $(\chi_1^0, \chi_2^0, \chi_1^\pm)$ in LHC decay chains

Example of LHC / ILC interplay

SUSY case study where the lightest neutralino and chargino states $(\chi_1^0, \chi_2^0, \chi_1^\pm)$ are precisely measured at the ILC

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

$\Rightarrow$ Identification of $(\chi_1^0, \chi_2^0, \chi_1^\pm)$ in LHC decay chains

$\Rightarrow$ Determination of all parameters in neutralino/chargino sector

$\Rightarrow$ Prediction of masses, decay prop. of all neutralinos, charginos

$\Rightarrow$ Prediction of masses of particles that are too heavy to be produced at the ILC but are produced with low statistics at the LHC, e.g. heaviest neutralino: $m_{\tilde{\chi}_4^0} = 378.3 \pm 8.8$ GeV

Example of LHC / ILC interplay

SUSY case study where the lightest neutralino and chargino states $(\chi_1^0, \chi_2^0, \chi_1^\pm)$ are precisely measured at the ILC

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

$\Rightarrow$ Identification of $(\chi_1^0, \chi_2^0, \chi_1^\pm)$ in LHC decay chains

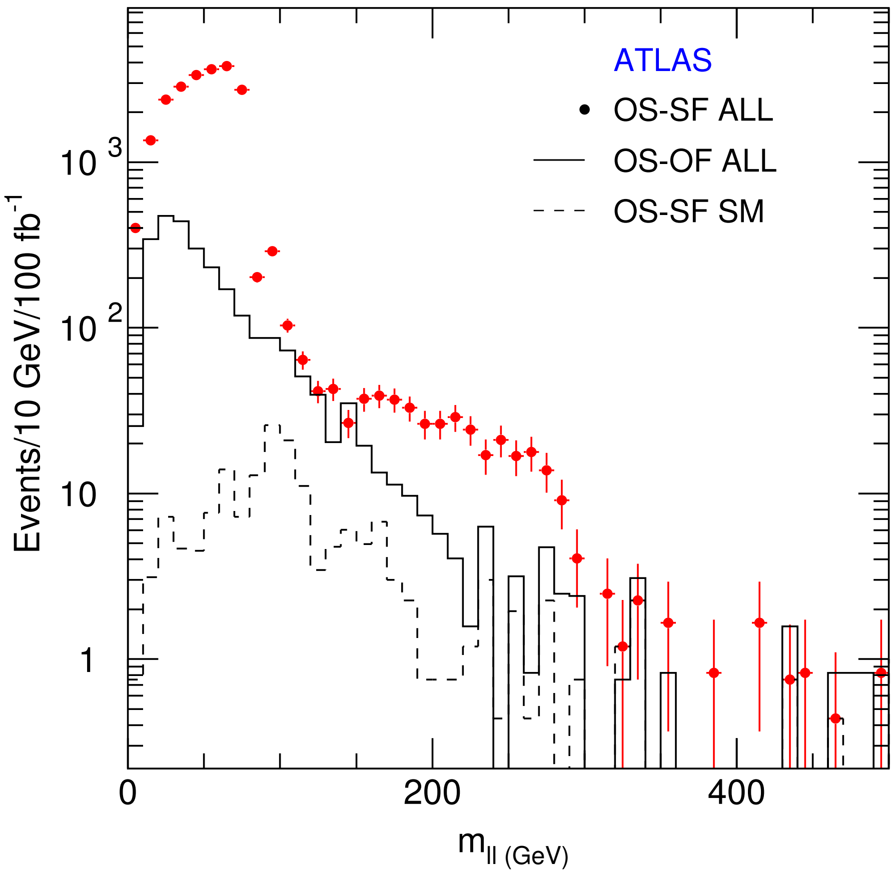
$\Rightarrow$ Determination of all parameters in neutralino/chargino sector

$\Rightarrow$ Prediction of masses, decay prop. of all neutralinos, charginos

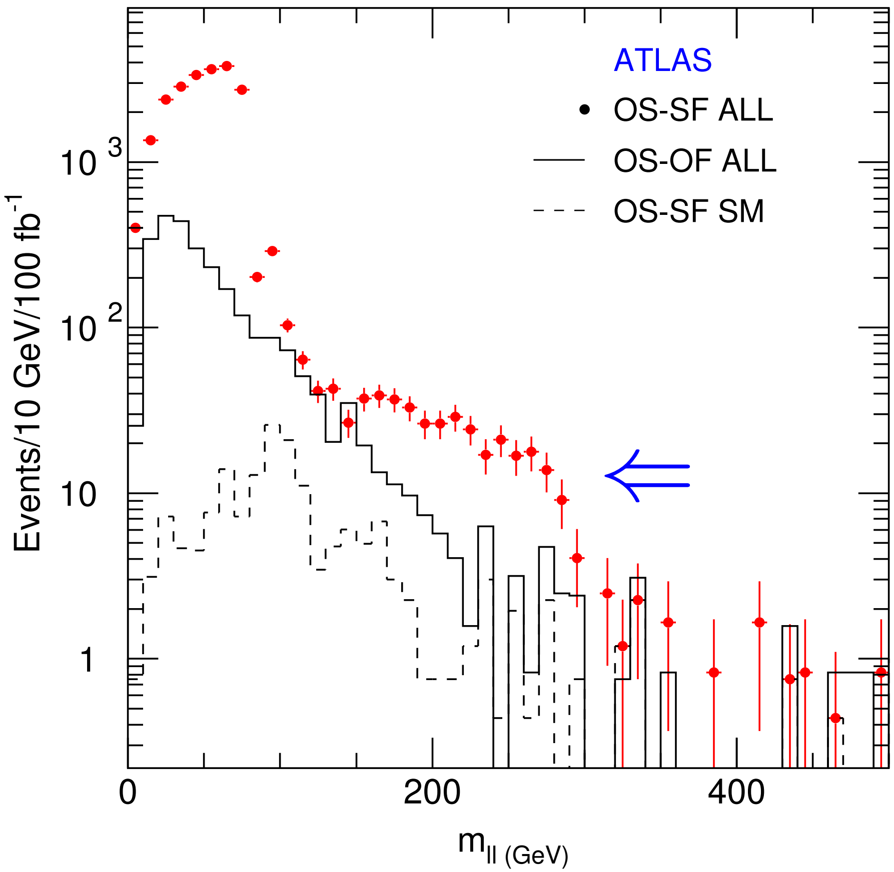
$\Rightarrow$ Prediction of masses of particles that are too heavy to be produced at the ILC but are produced with low statistics at the LHC, e.g. heaviest neutralino: $m_{\tilde{\chi}_4^0} = 378.3 \pm 8.8$ GeV

$\Rightarrow$ With this information the heaviest neutralino can be identified at the LHC using a dilepton "edge"

Search for the heaviest neutralino at LHC following the prediction from ILC



Search for the heaviest neutralino at LHC following the prediction from ILC

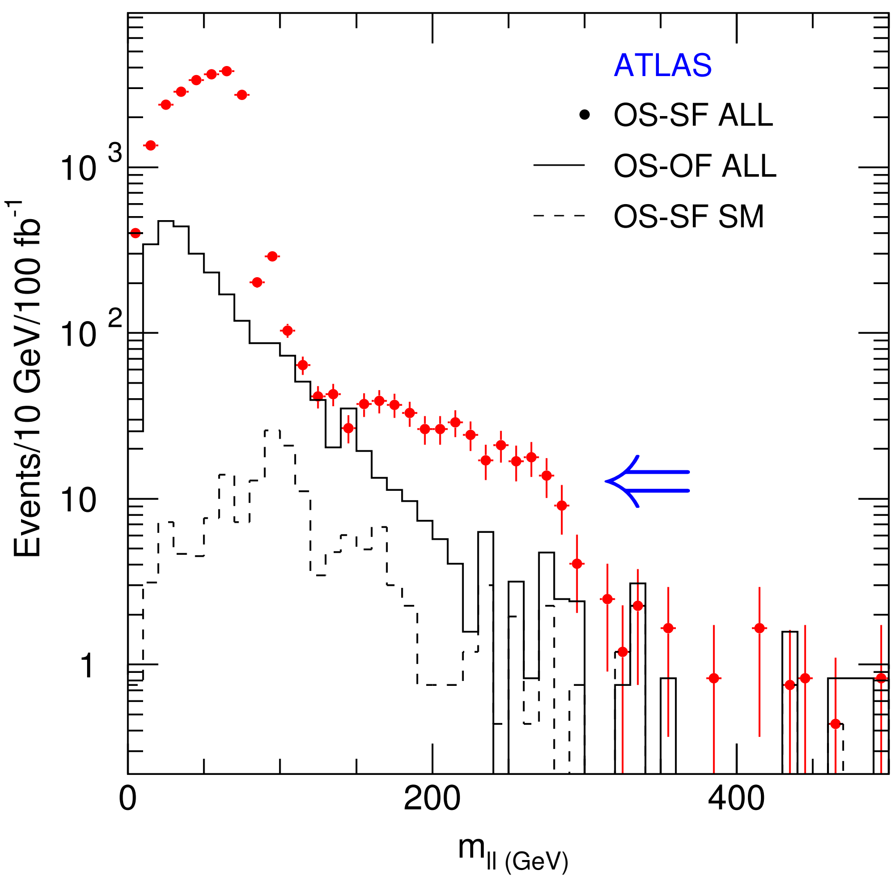


The new particle can be identified at the LHC via this "edge"

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

$\Rightarrow$ Crucial test of the model

Search for the heaviest neutralino at LHC following the prediction from ILC



The new particle can be identified at the LHC via this "edge"

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

$\Rightarrow$ Crucial test of the model

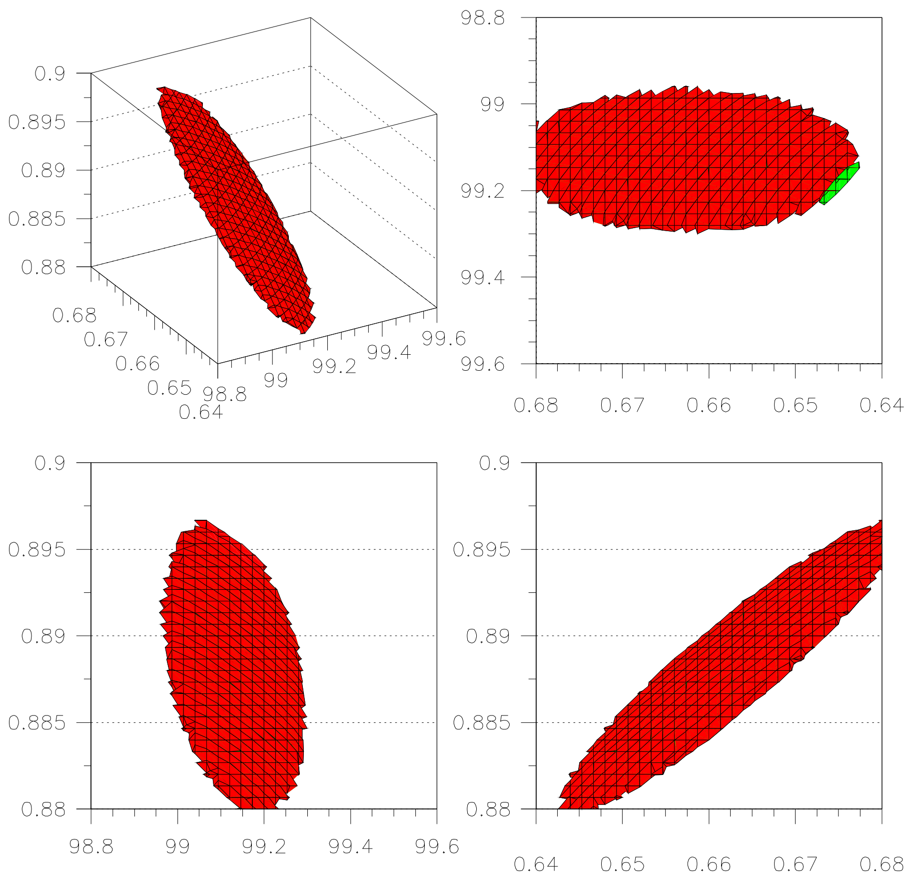
Feeding information on $m(\tilde{\chi}_4^0)$ back into ILC analysis

$\Rightarrow$ Improved accuracy of parameter determination at ILC

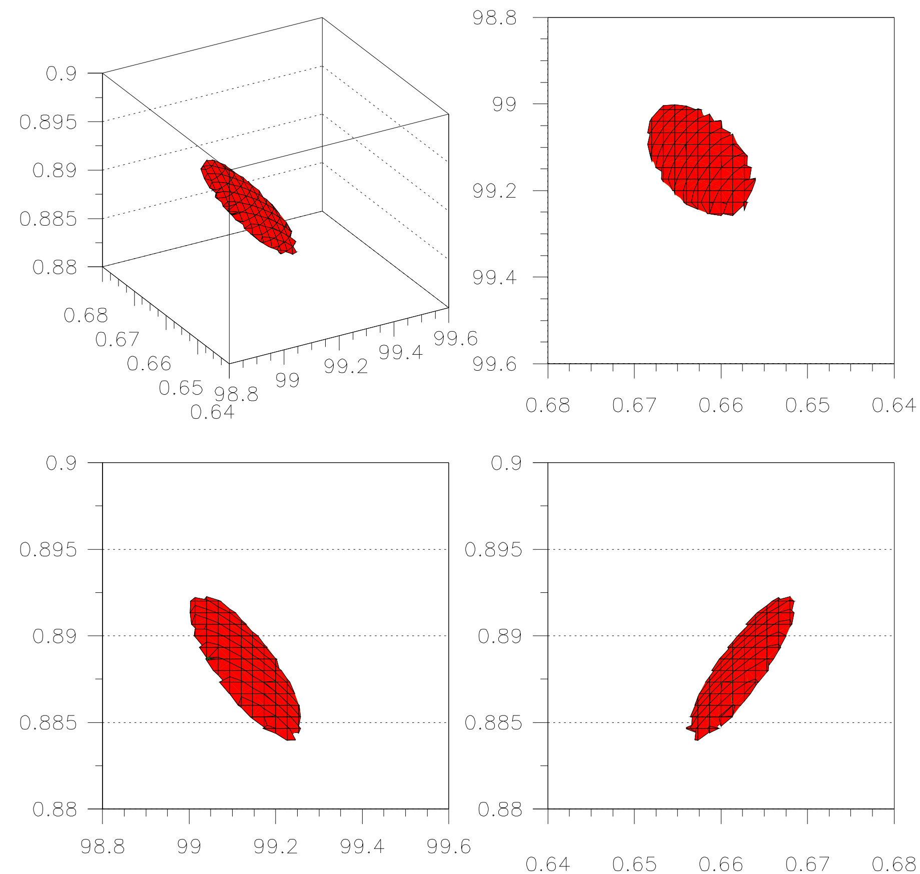
ILC analysis with LHC input

Determination of neutralino parameter M_1 and chargino mixing angles $\cos\phi_{\rm L}$, $\cos\phi_{\rm R}$:

ILC information alone



LHC $\oplus$ ILC information



SUSY parameter determination

SUSY contains many parameters that are not closely related to a specific experimental observable:

mixing angles, $\tan\beta$, complex phases, ...

Most observables depend on a variety of SUSY parameters

SUSY parameter determination

SUSY contains many parameters that are not closely related to a specific experimental observable:

mixing angles, $\tan\beta$, complex phases, . . .

Most observables depend on a variety of SUSY parameters

$\Rightarrow$ SUSY parameters need to be determined by global fits to a large set of observables

SUSY parameter determination

SUSY contains many parameters that are not closely related to a specific experimental observable:

mixing angles, $\tan\beta$, complex phases, ...

Most observables depend on a variety of SUSY parameters

$\Rightarrow$ SUSY parameters need to be determined by global fits to a large set of observables

$\Rightarrow$ Need combined LHC $\oplus$ ILC information for reliable determination of SUSY parameters

[*R. Lafaye, T. Plehn, D. Zerwas '04*] [*P. Bechtle, K. Desch, P. Wienemann '04*]

Determination of SUSY parameters: global fit

Comparison: LHC only vs. LHC $\oplus$ ILC for SPS1a' point

$m_0 = 100\,\mathrm{GeV}$, $m_{1/2} = 250\,\mathrm{GeV}$, $A_0 = -100\,\mathrm{GeV}$, $\tan\beta = 10$, $\mu > 0$

"bulk" region of mSUGRA scenario $\leftrightarrow$ "best case scenario"

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

LHC input:

mass measurements and precisions as above

$+$ assumption on $\tilde{t}_{1,2}$ mass measurement

$+$ ratios of Higgs branching ratios (see above)

Fittino: LHC only vs. LHC $\oplus$ ILC

Parameter	"True" value	ILC Fit value	Uncertainty (ILC+LHC)	Uncertainty (LHC only)
$\tan\beta$	10.00	10.00	0.11	6.7
μ	400.4 GeV	400.4 GeV	1.2 GeV	811. GeV
X_τ	-4449. GeV	-4449. GeV	20.GeV	6368. GeV
$M_{\tilde{e}_R}$	115.60 GeV	115.60 GeV	0.27 GeV	39. GeV
$M_{\tilde{\tau}_R}$	109.89 GeV	109.89 GeV	0.41 GeV	1056. GeV
$M_{\tilde{e}_L}$	181.30 GeV	181.30 GeV	0.10 GeV	12.9 GeV
$M_{\tilde{\tau}_L}$	179.54 GeV	179.54 GeV	0.14 GeV	1369. GeV
X_t	-565.7 GeV	-565.7 GeV	3.1 GeV	548. GeV
X_b	-4935. GeV	-4935. GeV	1284. GeV	6703. GeV
$M_{\tilde{u}_R}$	503. GeV	503. GeV	24. GeV	25. GeV
$M_{\tilde{b}_R}$	497. GeV	497. GeV	8. GeV	1269. GeV
$M_{\tilde{t}_R}$	380.9 GeV	380.9 GeV	2.5 GeV	753. GeV
$M_{\tilde{u}_L}$	523. GeV	523. GeV	10. GeV	19. GeV
$M_{\tilde{t}_L}$	467.7 GeV	467.7 GeV	3.1 GeV	424. GeV
M_1	103.27 GeV	103.27 GeV	0.06 GeV	8.0 GeV
M_2	193.45 GeV	193.45 GeV	0.10 GeV	132. GeV
M_3	569. GeV	569. GeV	7. GeV	10.1 GeV
$m_{A run}$	312.0 GeV	311.9 GeV	4.6 GeV	1272. GeV
m_t	178.00 GeV	178.00 GeV	0.050 GeV	0.27 GeV

χ^2 for unsmeared observables: 5.3×10^{-5}

$\Rightarrow$ most of the Lagrangian parameters can hardly be constrained by LHC data alone

$\Rightarrow$ precise determination of SUSY parameters only possible with LHC $\oplus$ ILC

Conclusions

Conclusions

- LHC and ILC will provide highly complementary results

Conclusions

- LHC and ILC will provide highly complementary results
- LHC / ILC interplay maximises the physics potential of both machines

Conclusions

- LHC and ILC will provide highly complementary results
- LHC / ILC interplay maximises the physics potential of both machines
- ATLAS and CMS are actively preparing for the start of data taking: CMS has just issued their physics TDR, many new studies in ATLAS (full simulations, new scenarios)

  $+$ ongoing ILC studies

  $\Rightarrow$ Many new results, ideal input for developing strategies for exploring the TeV scale with LHC and ILC

Conclusions

- LHC and ILC will provide highly complementary results

- LHC / ILC interplay maximises the physics potential of both machines

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

  $+$ ongoing ILC studies

  $\Rightarrow$ Many new results, ideal input for developing strategies for exploring the TeV scale with LHC and ILC

- The combined information from LHC and ILC $+$ accurate theory predictions promise a major breakthrough in our understanding of matter, space and time

Another aspect of the LHC / ILC Connection: early LHC data

Another aspect of the LHC / ILC Connection: early LHC data

The ILC will have to add a lot to whatever the LHC will find

Another aspect of the LHC / ILC Connection: early LHC data

The ILC will have to add a lot to whatever the LHC will find

There is a clear and solid physics case for ILC(500), not expected to be affected by the LHC results

Another aspect of the LHC / ILC Connection: early LHC data

The ILC will have to add a lot to whatever the LHC will find

There is a clear and solid physics case for ILC(500), not expected to be affected by the LHC results

But the start of data taking at the LHC will clearly be a phase transition in the LHC / ILC Connection

Another aspect of the LHC / ILC Connection: early LHC data

The ILC will have to add a lot to whatever the LHC will find

There is a clear and solid physics case for ILC(500), not expected to be affected by the LHC results

But the start of data taking at the LHC will clearly be a phase transition in the LHC / ILC Connection

The question will then be what the real data tell us about physics at the TeV scale

The answer to this question will influence the decision about the start of construction of the ILC and design considerations for possible LHC and ILC upgrades and the ultimate ILC energy reach

Another aspect of the LHC / ILC Connection: early LHC data

The ILC will have to add a lot to whatever the LHC will find

There is a clear and solid physics case for ILC(500), not expected to be affected by the LHC results

But the start of data taking at the LHC will clearly be a phase transition in the LHC / ILC Connection

The question will then be what the real data tell us about physics at the TeV scale

The answer to this question will influence the decision about the start of construction of the ILC and design considerations for possible LHC and ILC upgrades and the ultimate ILC energy reach

The particle physics community will have to come up with a convincing and scientifically solid conclusion on how to proceed