Physics at the International Linear Collider

Project Status

The ILC Physics Case

Synergy of LHC and ILC

Klaus Desch
University of Hamburg
LHC days 2004
Split, Croatia
08/10/04

The International Linear Collider (ILC)

ILC planned for 2015, overlaps with LHC.

Parameters defined by ILCSC scope-panel
http://www.fnal.gov/directorate/icfa/LC_parameters.pdf

Baseline	$\sqrt{s}$ = 200-500 GeV, integrated Luminosity 500 fb^{-1} over 1st 4 years 80% electron polarisation 2 interaction regions with easy switching
Upgrade	Anticipate $\sqrt{s} \rightarrow$ 1 TeV, $\int L$ = 1 ab^{-1} over 4 years
Options	e^-e^- collisions, 50% positron polarisation, "GigaZ"; high L at Z and at WW threshold, Laser backscatter for $\gamma\gamma$ and γe collisions, Doubled L at 500 GeV.

Choice among options to be guided by physics needs.

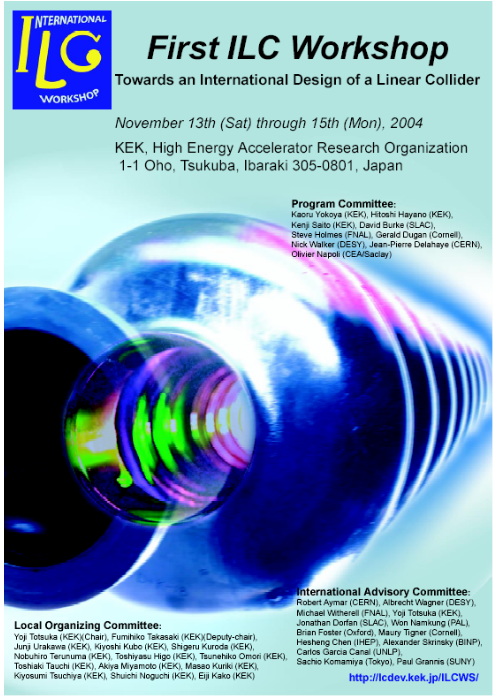
The International Linear Collider (ILC)

Technology Choice:

International Technology Recommendation Panel in August 04 recommended
'that the ILC be based on superconducting RF technology'

ILCSC + ICFA unanimously accepted the recommendation

First workshop on global ILC design at KEK, Nov 13-15.



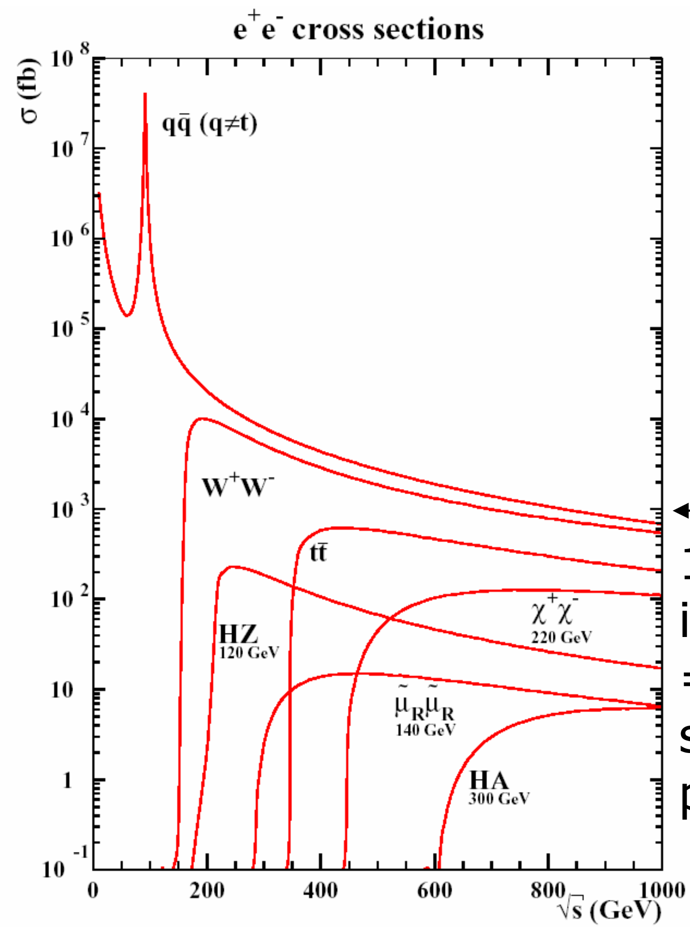
Goal:

Technical Design in 2007

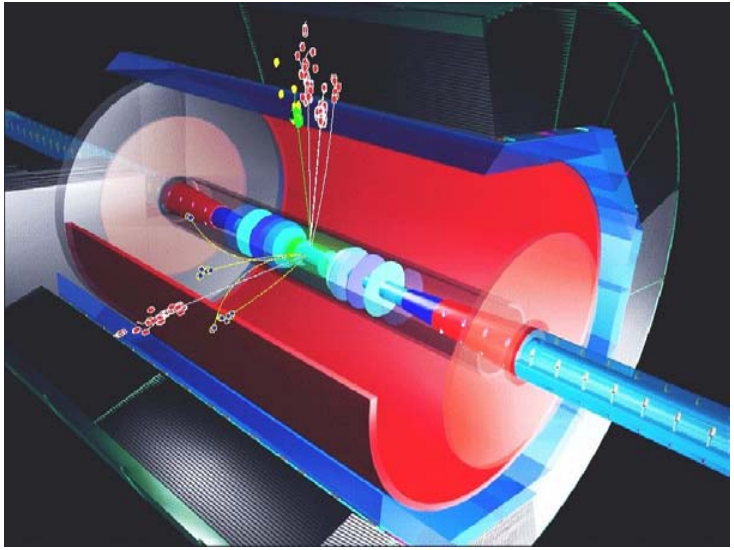
Use exisiting TDRs (TESLA,NLC,GLC) as input!

Towards detectors for the ILC

High Luminosity and clean environment call for a ultra-high precision detector!
Important sub-detectors are challenging (and different from LHC det's)



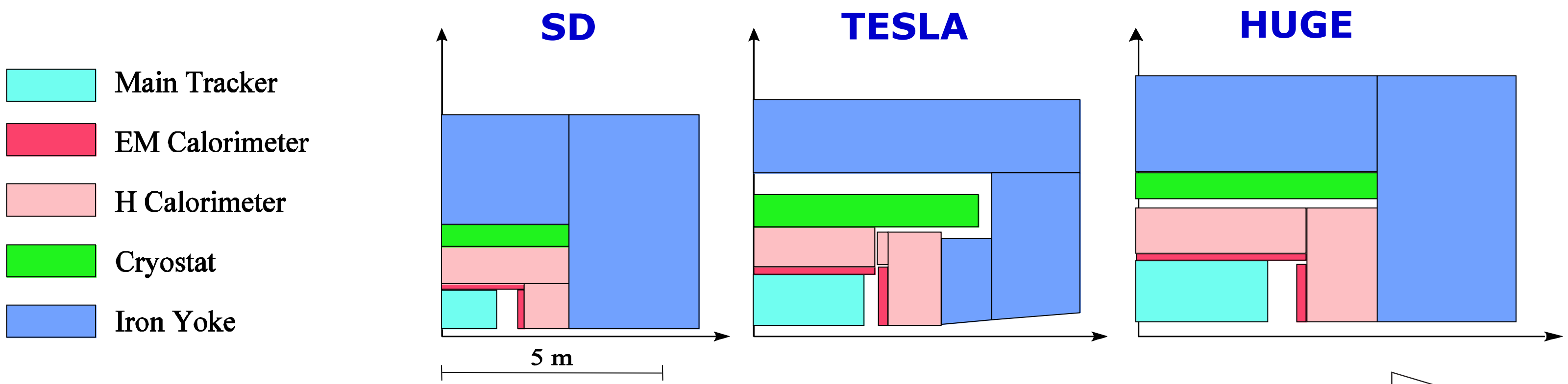
10^6 events in 1 ab^{-1} = o($^0/_{00}$) statistical precision



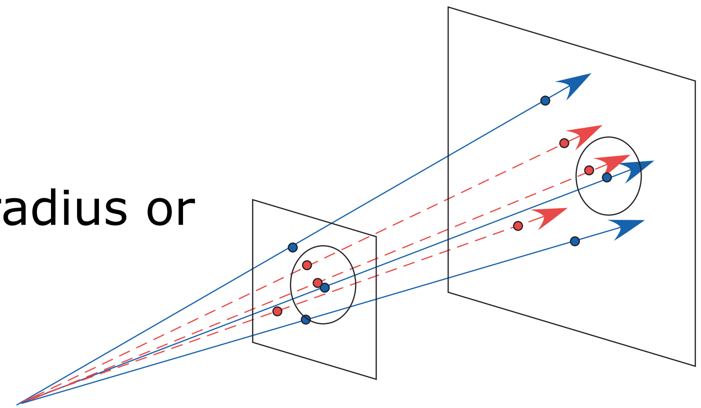
Challenges:
- 'Particle flow' paradigm
- Excellent momentum resolution
- Precision vertexing

Towards detectors for the ILC

2-3 global concepts are emerging



Main design issues
- Si or gaseous tracking ?
- Si/W ECAL (1x1cm) at small-medium radius or coarser Sc/W ECAL at larger radius ?



Particle separation at Calo surface:

$B \times L^2 / R_{Moliere}$

Those are open concepts not collaborations!
Many sub-detector R&D items in common

The ILC Physics Case

Physics case worked out in much detail over the past decade and well documented (TESLA TDR, Snowmass report, ACFA study etc.)

For a recent short summary, see e.g.

`Hewett et al, "The linear collider physics case: international response to technology independent questions posed by the ITRP", hep-ph/04xxxxx`

Whatever LHC will find, ILC will have a lot to say!

'What' depends on LHC findings:

1. If there is a 'light' Higgs (consistent with prec.EW)
2. If there is a 'heavy' Higgs (inconsistent with prec.EW)
3. 1./2. + new states (SUSY, XD, little H, Z', …)
4. No Higgs, no new states (inconsistent with prec.EW)

1. If there is a light Higgs

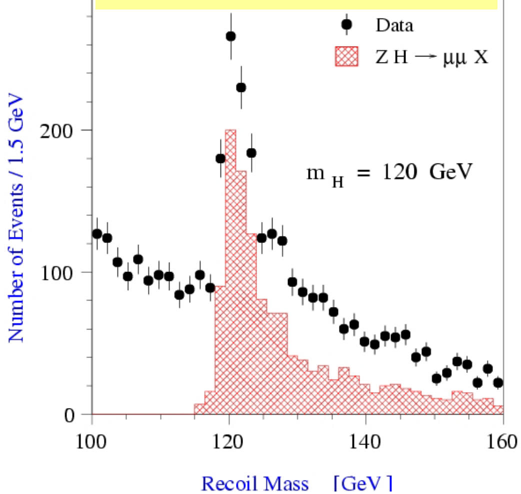
Only with ILC we can prove that the Higgs mechanism is at work!
(or maybe not…)

Higgs will become SM precision physics – look for deviations beyond SM

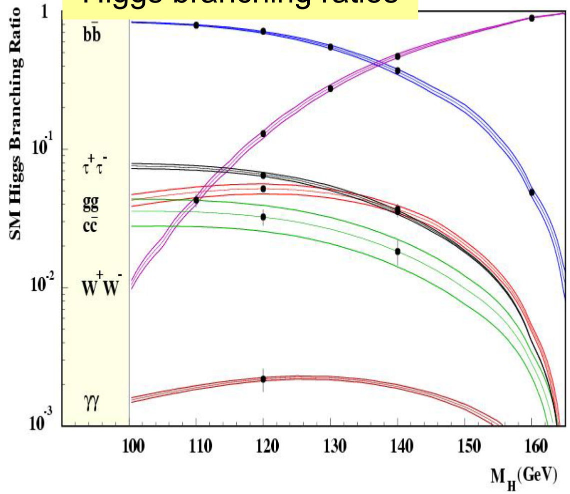
- structure of Higgs sector
- SUSY Higgs?
- Mixing with other scalars (Radions, …)

Model-independent measurements at %-level possible

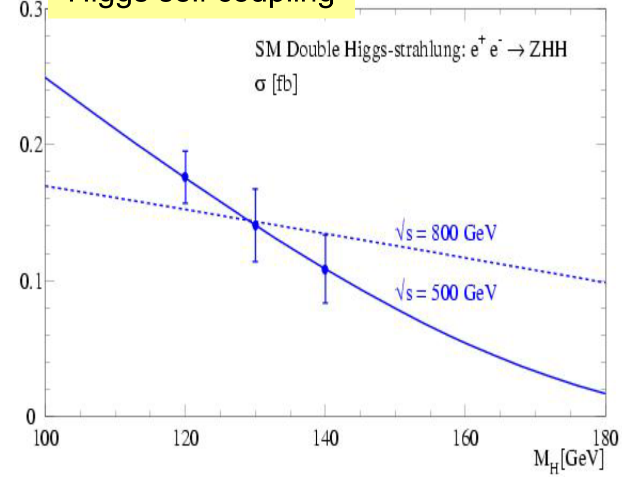
model-indep. HZ coupling



Higgs branching ratios



Higgs self coupling



2. If there is a heavy Higgs

A heavy Higgs is 'beyond SM' discovery!

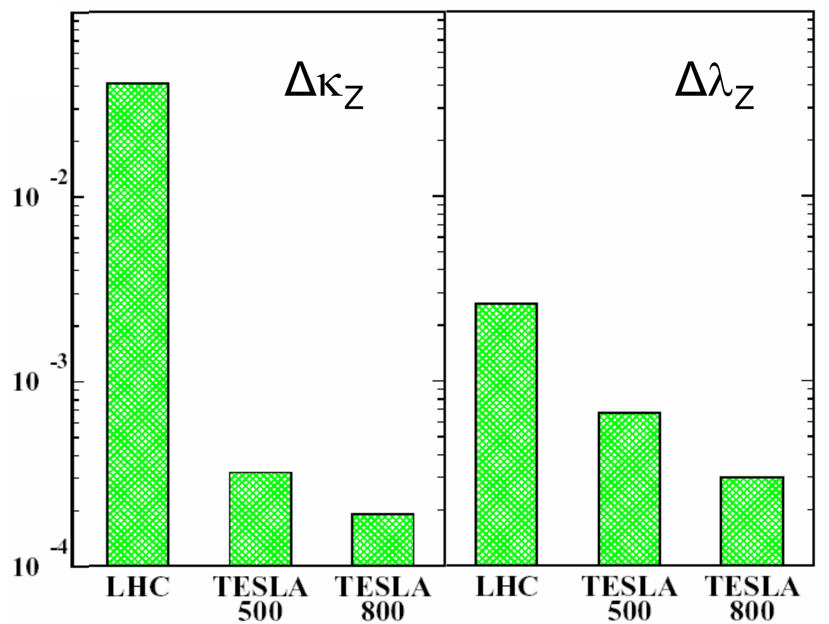
If no new states are found directly, the path to the new physics will be shown by precision measurements through virtual effects

e.g.

contact interactions:

		LHC Λ [TeV]				LC Λ [TeV]			
model		LL	RR	LR	RL	LL	RR	LR	RL
eeqq:	Λ_+	20.1	20.2	22.1	21.8	64	24	92	22
	Λ_-	33.8	33.7	29.2	29.7	63	35	92	24
$ee\mu\mu$:	Λ_+					90	88	72	72
	Λ_-					90	88	72	72
eeee:	Λ_+					44.9	43.4	52.4	52.4
	Λ_-					43.5	42.1	50.7	50.7

triple gauge couplings:



+ prec. Higgs measurements
+ prec. top quark measurement (e.g. Δm_{top} 100 MeV)

3. If there are new states accessible at ILC

In many cases these states will be discovered already at LHC.

Precision at e^+e^- is often vital to understand what is going on.

Many examples (SUSY, Extra dimensions, little Higgs, …)

Two (recent examples):

1. Dark Matter

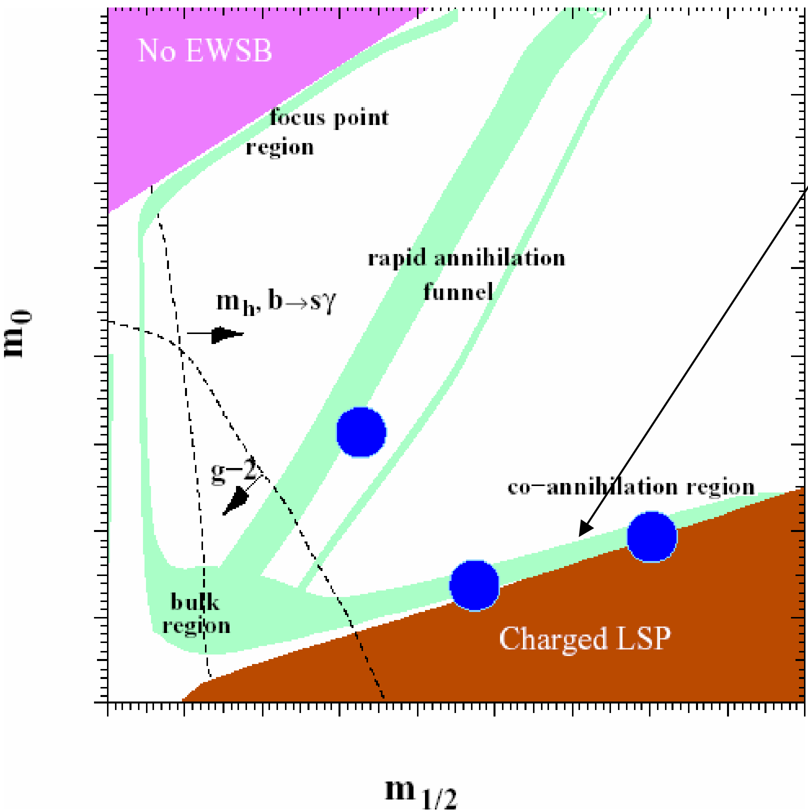
2. Split SUSY

Dark Matter

If SUSY LSP responsible for Cold Dark Matter, need accelerators to show that its properties are consistent with CMB data

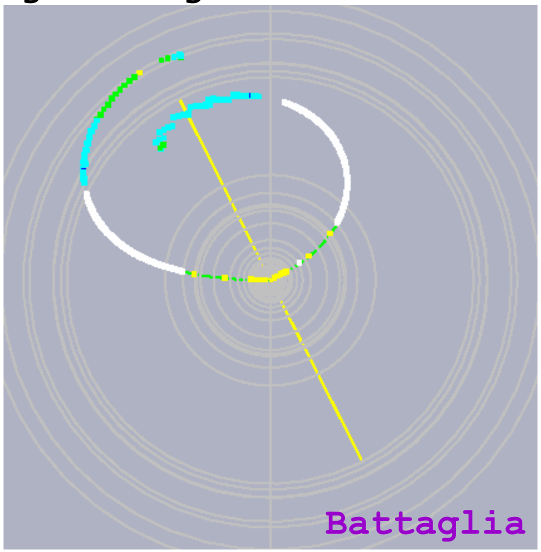
- Future precision on Ωh^2 ~ 2% (Planck) – match this precision!

- WMAP points to certain difficult regions in parameter space:



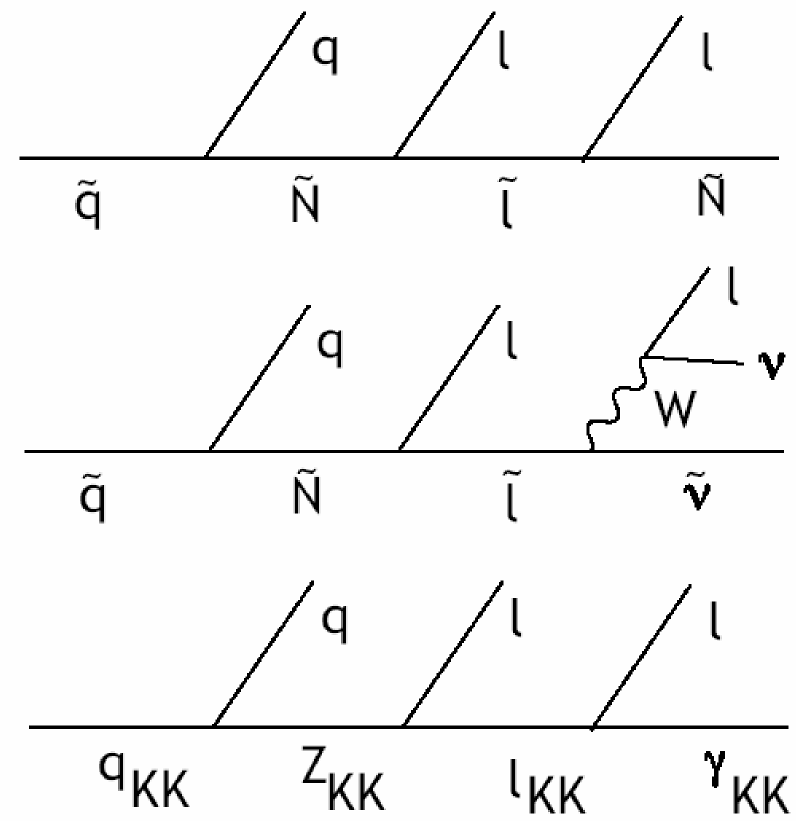
small $\Delta M = M_{\tilde{\ell}} - M_{\chi_1^o}$

e.g. smuon pair production at 1TeV
only two very soft muons!
need to fight backgrounds



Dark Matter

What is the DM made of?



conventional SUSY

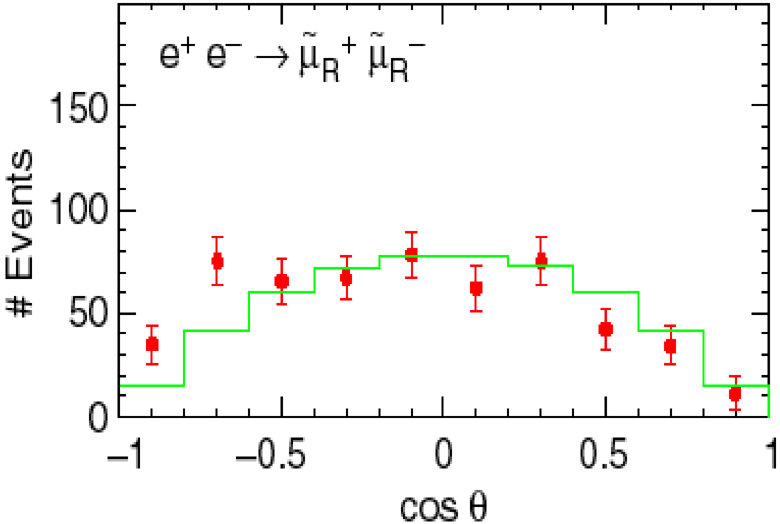
neutrino LSP - Murayama

"bosonic supersymmetry" - Cheng, Matchev, Schmaltz

Dark Matter

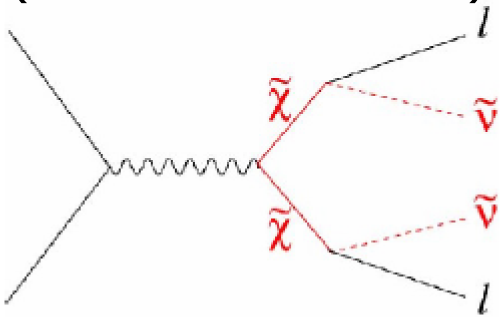
Spin determination at ILC is simple!

Spin 0: ~$\sin^2\theta$



Tsukamoto et al

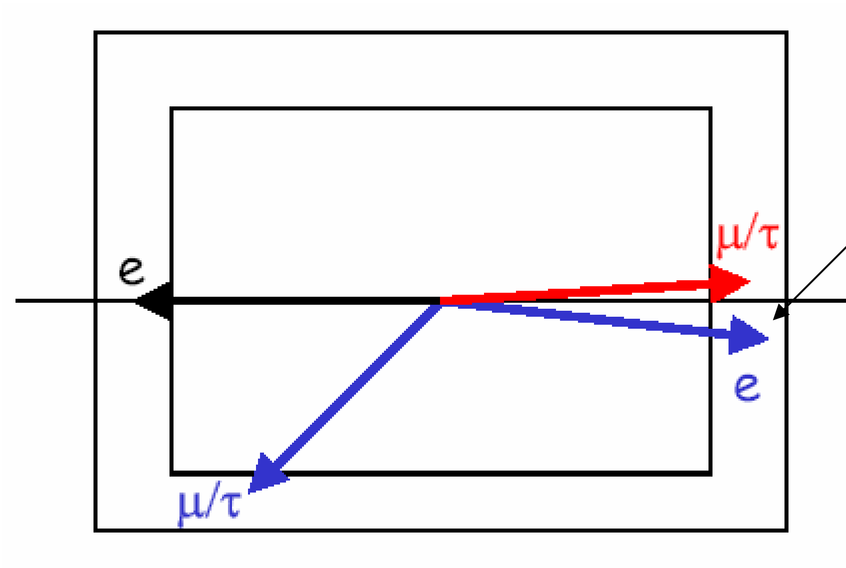
or are they charginos after all?
(if sneutrino = LSP)



De Gouvêa et al

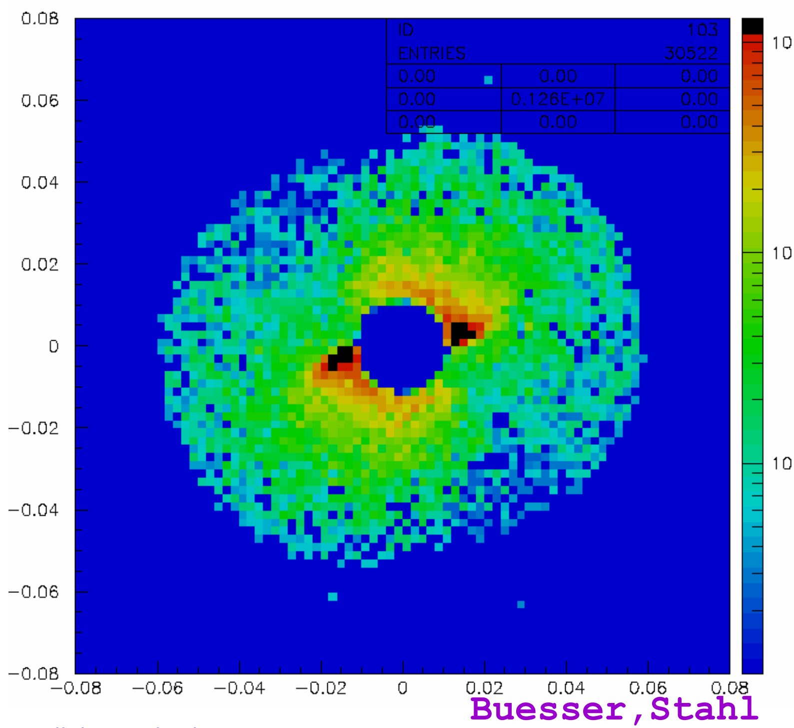
Dark Matter: Small ΔM

Huge background from two-photon processes: $e^+e^- \rightarrow \mu\mu ee$ etc



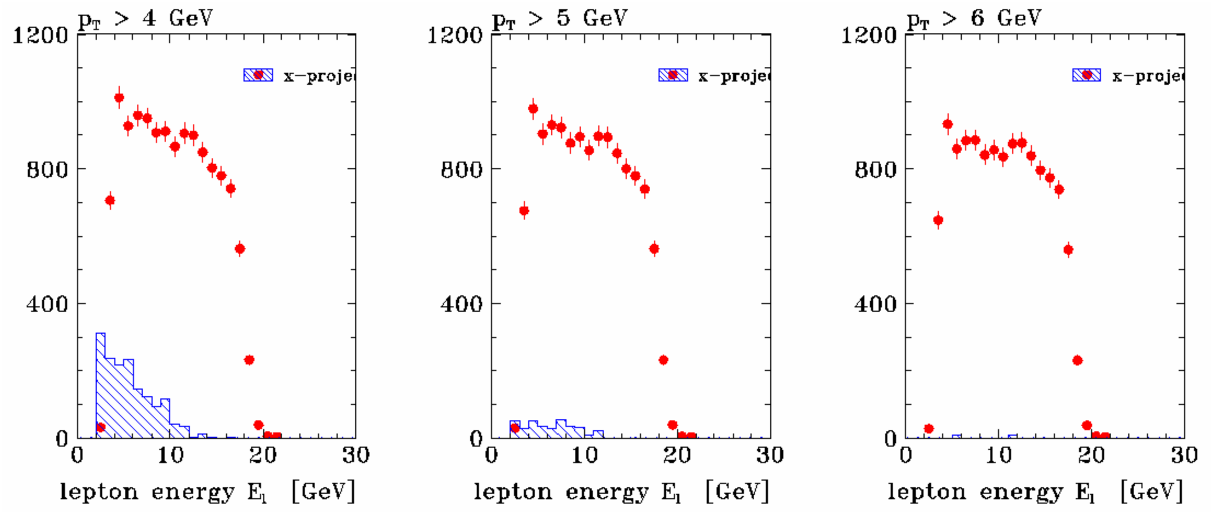
need to veto these scattered beam electrons at very low angles

several TeV/BX energy from beamstrahlung close to beampipe
→ need highly granular rad-hard, fast forward instrumentation



Dark Matter: Small ΔM

works for smuons down to ΔM ~ 5 GeV
more difficult for staus, but also ok for ΔM ~ 5 GeV
need more thinking below



smuons at
ΔM = 8 GeV

Results on Ωh^2:

ΔM (GeV)	5	7	9
δm(stau) (MeV)	420	400	150
$\Delta(\Omega h^2)$ (%)	5.0	3.1	1.6

Martyn, Zhang et al

Split SUSY at ILC

Split Supersymmetry (→ G.Giudice's talk)

Motivation: give up solving fine-tuning problem but retain
other goodies of SUSY (DM cand., GUT unification)
get rid of FCNC, p-decay problems

Realisation: all scalars except h are ultra-heavy
gauginos remain light

Collider consequences:

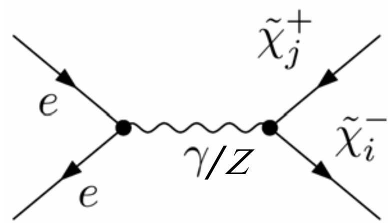
meta-stable gluinos (interesting for LHC)
charginos + neutralinos only through Drell-Yan at LHC (challenging)

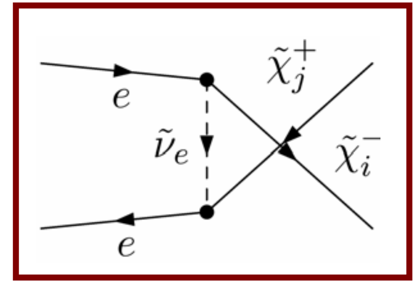
at ILC: precise measurement of chargino+neutralino+Higgs properties
allows us to test the model

Split SUSY at ILC

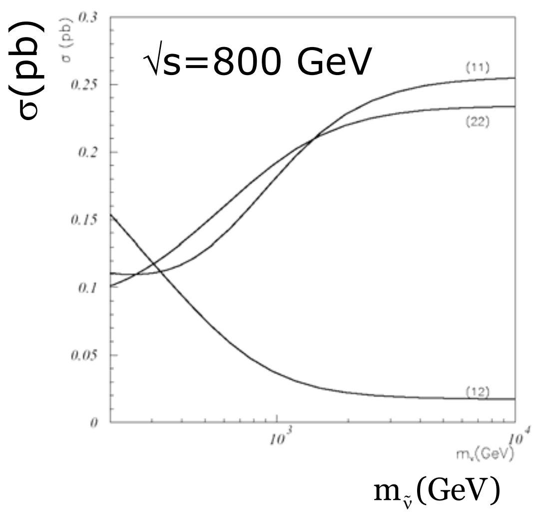
1. are the scalars really heavy?

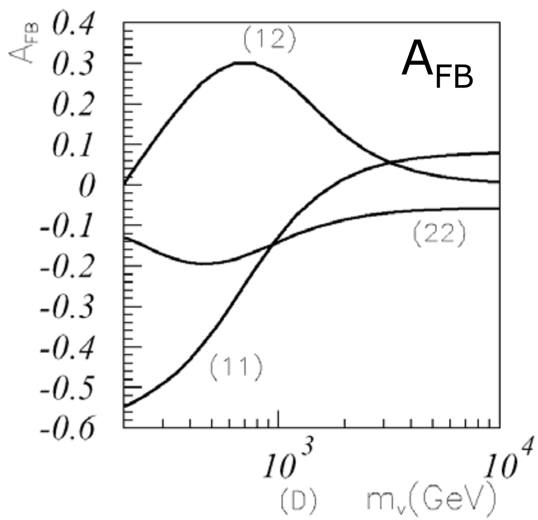
sensitivity to (heavy) sneutrino
in t- channel chargino production

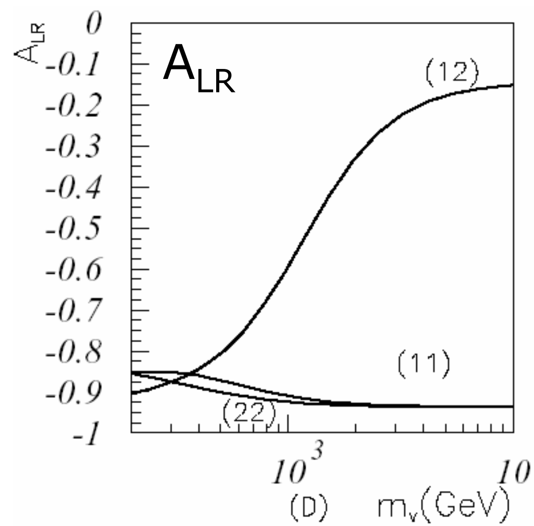




- through total cross section
- through forward-backward asymmetry
- through LR polarisation asymmetry







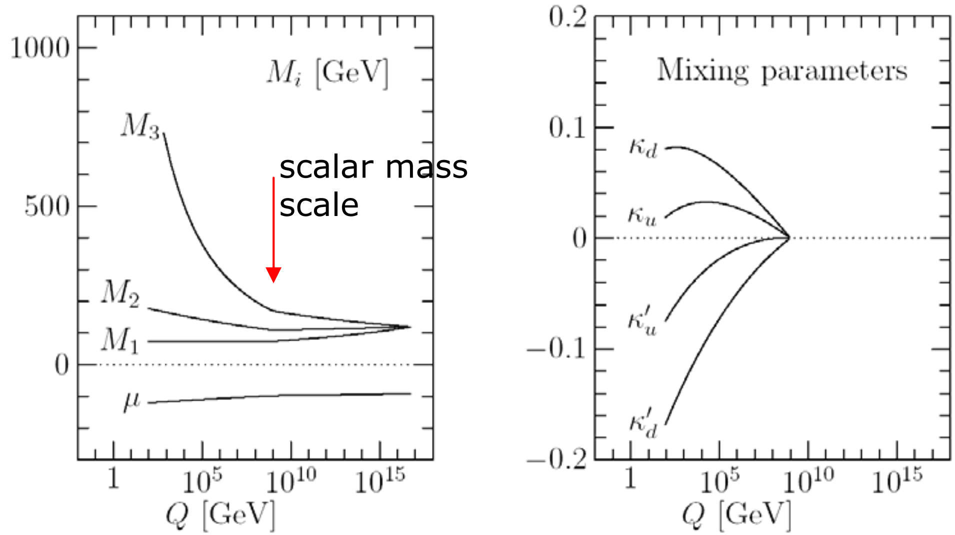
$m(\chi^+_1)$ = 148 GeV
$m(\chi^+_2)$ = 267 GeV

sensitive to $m_{\tilde{\nu}} \sim$ 10 TeV

Zhu hep-ph/0407072

Split SUSY at ILC

2. how heavy are the scalars?



Chargino/Neutralino mixings receive non-SUSY RGE corrections different from low-scale SUSY

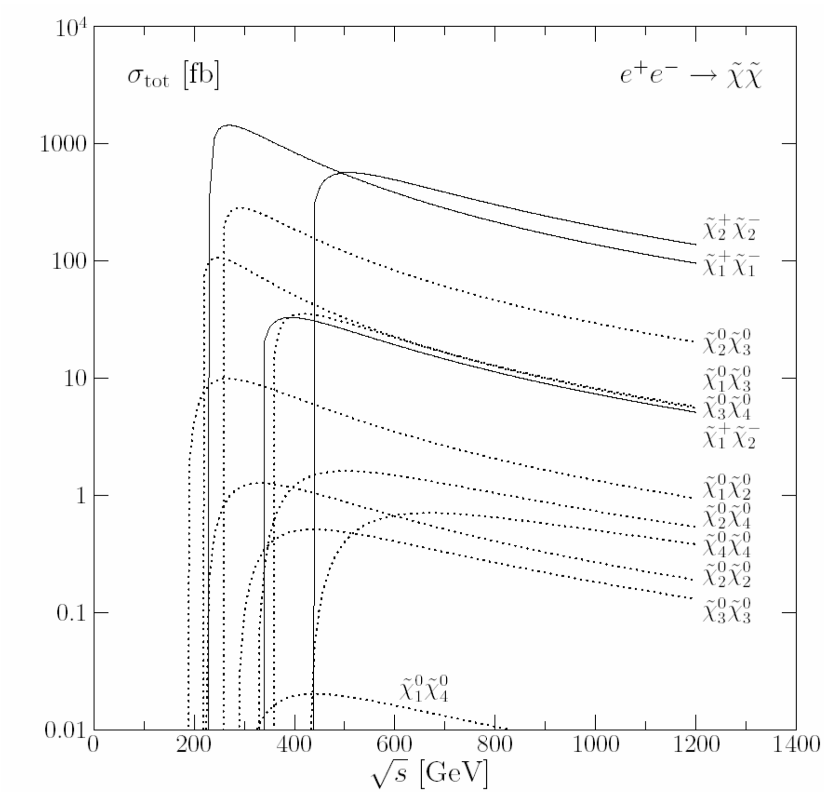
$$\frac{\tilde{g}_u}{g \sin\beta} \equiv 1 + \kappa_u = 1 + 0.018 \qquad \frac{\tilde{g}_d}{g \cos\beta} \equiv 1 + \kappa_d = 1 + 0.081$$

$$\frac{\tilde{g}'_u}{g' \sin\beta} \equiv 1 + \kappa'_u = 1 - 0.075 \qquad \frac{\tilde{g}'_d}{g' \cos\beta} \equiv 1 + \kappa'_d = 1 - 0.17$$

Kilian et al hep-ph/0408088

Split SUSY at ILC

Those can be measured from precise mass + cross section measurements of the complete chargino+neutralino sector



ILC precisions from detailed simulations (for SPS1a param.)

	m [GeV]	Δm [GeV]
$\tilde{\chi}_1^\pm$	176.4	0.55
$\tilde{\chi}_2^\pm$	378.2	3
$\tilde{\chi}_1^0$	96.1	0.05
$\tilde{\chi}_2^0$	176.8	1.2
$\tilde{\chi}_3^0$	358.8	3 – 5
$\tilde{\chi}_4^0$	377.8	3 – 5

(still room for improvements…)

→ measure anomalous Yukawa couplings to precision of 0.01 to 0.1

add. possibility: directly measure $e^+e^- \to \chi^+\chi^- h$ (o(0.1fb) cross section)

Kilian et al hep-ph/0408088

4. If there is no Higgs and no new states at LHC

1. Make sure that the LHC hasn't missed anything
   (invisible or purely hadronically decaying Higgs, very narrow resonances with low productions rates, 'Higgs continuum' …)

2. If there is really nothing,
   this is discovery of BSM physics!
   Someone is fooling us in the loops and faking a light Higgs

   Measure what's in the loops! precision counts!

   e+e- -> 0 fermions (ee->$\gamma\gamma$, e.g. NC-QED)
   e+e- -> 2 fermions (including t tbar !!!)
   e+e- -> 4 fermions (TGC's)
   e+e- -> 6 fermions (QGC's, strong EWSB…)

   Reach deep into multi-TeV region!

   + make full use of LC options
     - polarized beams
     - tunability of energy (measure slopes of cross sections)
     - $\gamma\gamma$, eγ options

LHC+ILC Synergy

$\text{LHC} \oplus \text{ILC}$

εργον	work
συν–	together

$\text{LHC} \otimes \text{ILC}$

What can we learn if the analyses at both machines are performed in coherent fashion?

Worldwide LHC/LC study group

Report available at **`www.ippp.dur.ac.uk/~georg/lhclc`**

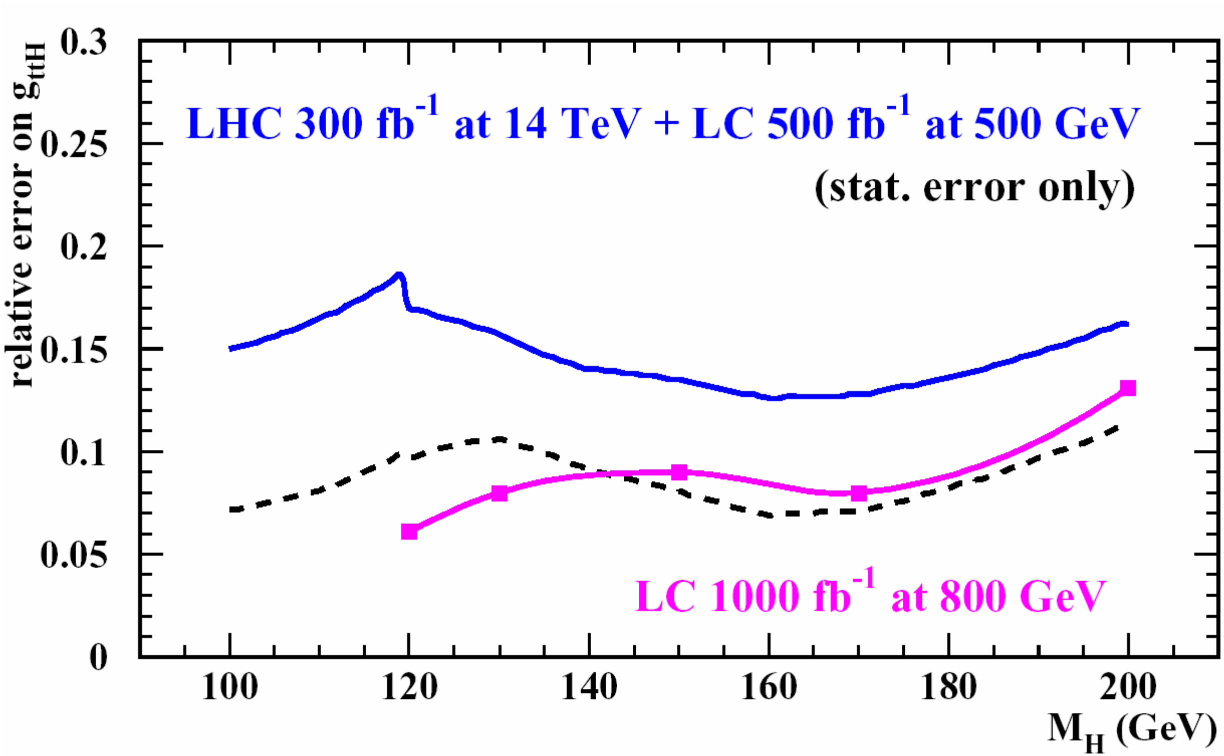
Studies so far (naturally) were focused on what the individual machines >can< do alone.

Going further needs new way of thinking in the communities (interesting!). "can I make it with a little help from my friends ??"

→ Examples

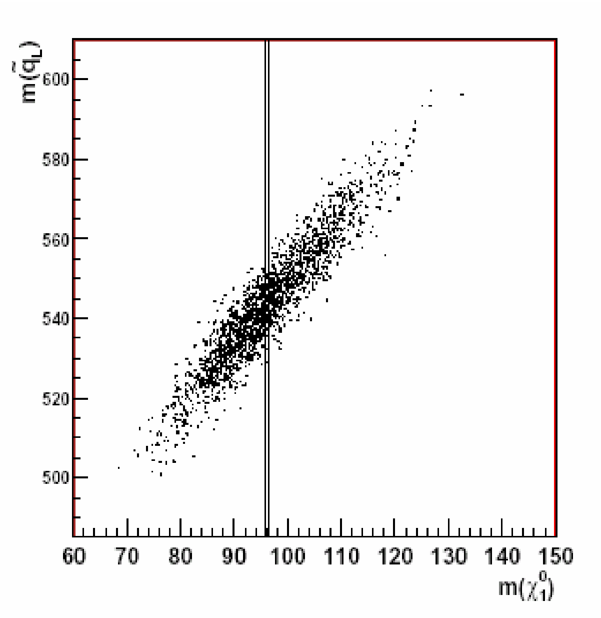
Example 1: Top Yukawa Coupling

LHC is sensitive to top Yukawa coupling of light Higgs through tth production. LC BR measurement (h→bb and h→WW) turns the rate measurement into an absolute coupling measurement
(LC can only do it at high energy (> 800 GeV))



Example 2: Sparticle Masses

Squark and Gluino mass determination errors dominated by huge correlation with unknown LSP mass



Feeding the precise neutralino, chargino and slepton masses into the LHC analyses improves errors for squarks and gluino

mass errors (GeV)	LHC	LHC+LC
$\tilde{q}_L$	8.7	4.9
$\tilde{b}_1$	7.5	5.7
$\tilde{b}_2$	7.9	6.2
$\tilde{g}$	8.0	6.5

often dominated by LHC energy scale systematics

Polessello et al

Is there a case for overlapping running?

There are three good reasons to have ILC a.s.a.p.:

1. We do know how to build it!
2. We are curious!
3. There is a world-wide community that wants to do it!

Apart from that, will we gain in physics if LHC+ILC overlap in time?

Difficult question – need some prophetic knowledge… but

In the past it was often beneficial to have "interaction" between hadron and lepton machines (e.g. top indirect+direct→Higgs)

overlap in time allows to give feedback to running strategies
- tune trigger
- tune complex analyses (redoing them afterwards is difficult)
- impact on running schedule

→ 1 Example

A hint for the LHC

Nojiri et al

At the LC, the complete tree-level parameters of the chargino/neutralino system of the MSSM (M_1,M_2,μ,tanβ) can be extracted from mass + (polarized) cross section measurements of the lightest (χ^0_1, χ^0_2, $\chi^\pm_1$) states.

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

for 100/100 fb^{-1} LR/RL
at 400 and 500 GeV
Polarisation 80/60 (e^-/e^+)

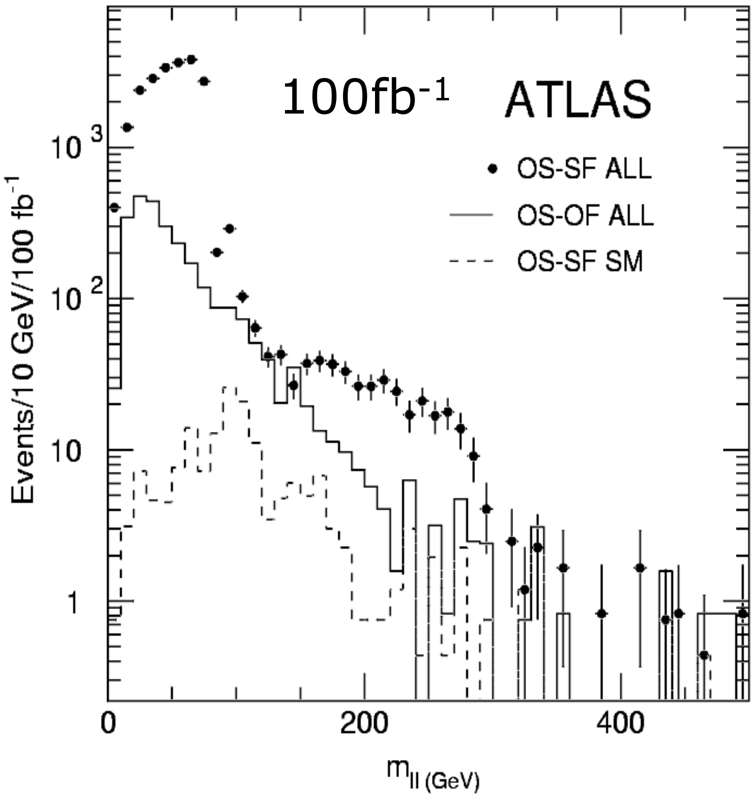
With these parameters all chargino and neutralino masses can be predicted, e.g.:

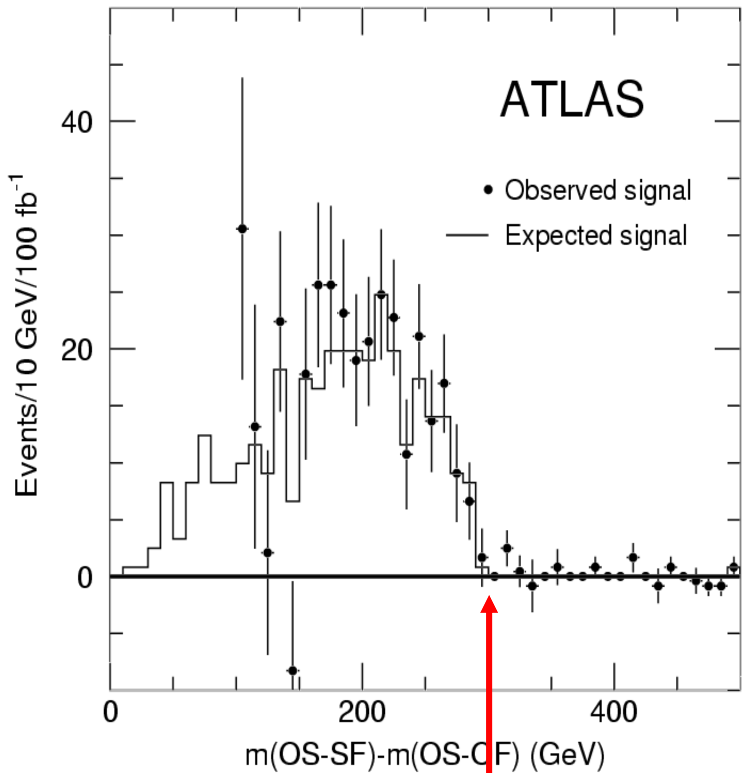
$$m(\chi^0_4) = 378.3 \pm 8.8 \text{ GeV}$$

χ^0_4 occurs occasionally also in squark decays leading to another (tiny) dilepton edge at the LHC:

A hint for the LHC

Polessello et al





LC prediction turns edge search into a single hypothesis test
→ increased stat. sensitivity

LC can predict position of this edge

LHC/ILC study continues!

- first study opened the field
- many contributions from theory and experiment

- next round of studies should be more focused on the case for overlapping running of LHC and ILC

We should construct specific examples of physics scenarios where LHC triggers can be optimized after ILC input.
I believe this can be done.

next meeting Nov 15 at CERN (VRVS available)

Conclusions

GLC,NLC,TESLA are merged into the International Linear Collider

Project has broad support from all committees (ICFA, ACFA, ECFA, HEPAP, GSF@OECD, …) and a large community

Collider technology is at our hands
Arrive at machine TDR in 2007 – collisions in 2015

Physics case is independent of LHC findings – however adjustments based on first LHC data possible

Challenging detector – R&D necessary now. When LHC detectors are ready, interesting opportunities for detector groups

LHC/ILC study continues – interesting to look at the broader physics picture.