Physics scenarios at ILC

Physics at Future Colliders workshop
2005/2006

A.F.Żarnecki
08-03-2006

The TeV ILC planned for 2015, overlaps with LHC.

Parameters defined by ILCSC scope-panel for ITRP

http://www.fnal.gov/directorate/icfa/LC_parameters.pdf

Baseline
- $\sqrt{s}$ = 200-500 GeV,
- integrated $\mathcal{L}$uminosity 500 fb^{-1} over 1st 4 years
- 80% electron polarisation
- 2 interaction regions with easy switching

Upgrade
- Anticipate $\sqrt{s} \rightarrow$ 1 TeV, $\int\mathcal{L} = 1\ ab^{-1}$ over 4 years

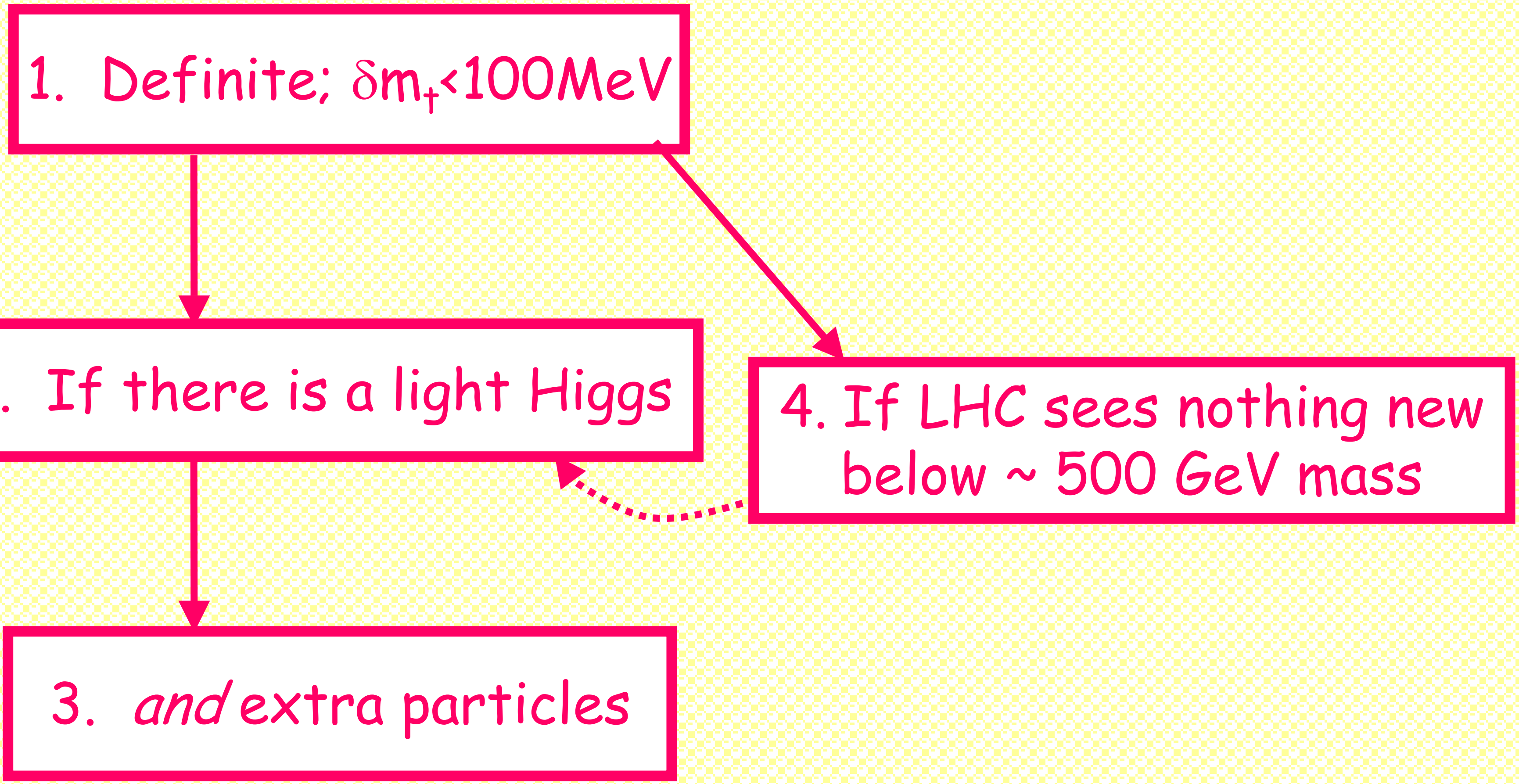
ITRP wants highest possible

Options
- e^-e^- collisions,
- 50% positron polarisation,
- "GigaZ"; high $\mathcal{L}$ at Z and at WW threshold,
- Laser backscatter for $\gamma\gamma$ and γe collisions,
- Doubled $\mathcal{L}$ at 500 GeV.

Choice among options to be guided by physics needs.

Programme for the TeV ILC

- will depend on what appears, but ILC is needed in every scenario .



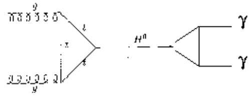
If there is a light Higgs of any kind, seen or unseen at LHC, ILC will:

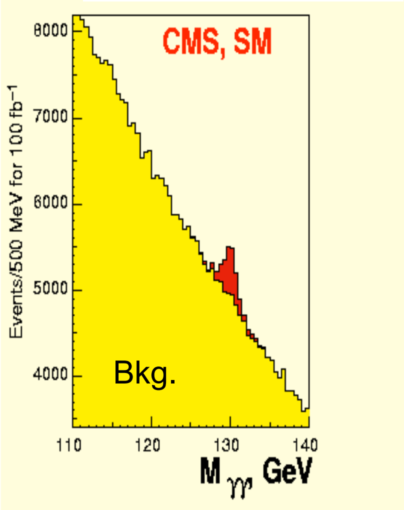
- *see it,*
- *measure its precise mass,*
- *measure its total and partial widths (BRs), determine its couplings to other particles,*
- *measure its spin and parity,*
- *measure Higgs selfcoupling.*

Many different scenarios have been investigated...

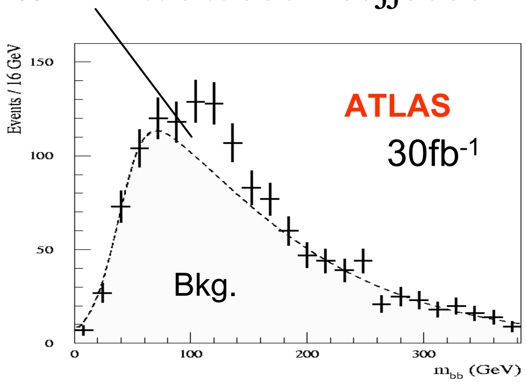
LHC Higgs signal

H→γγ



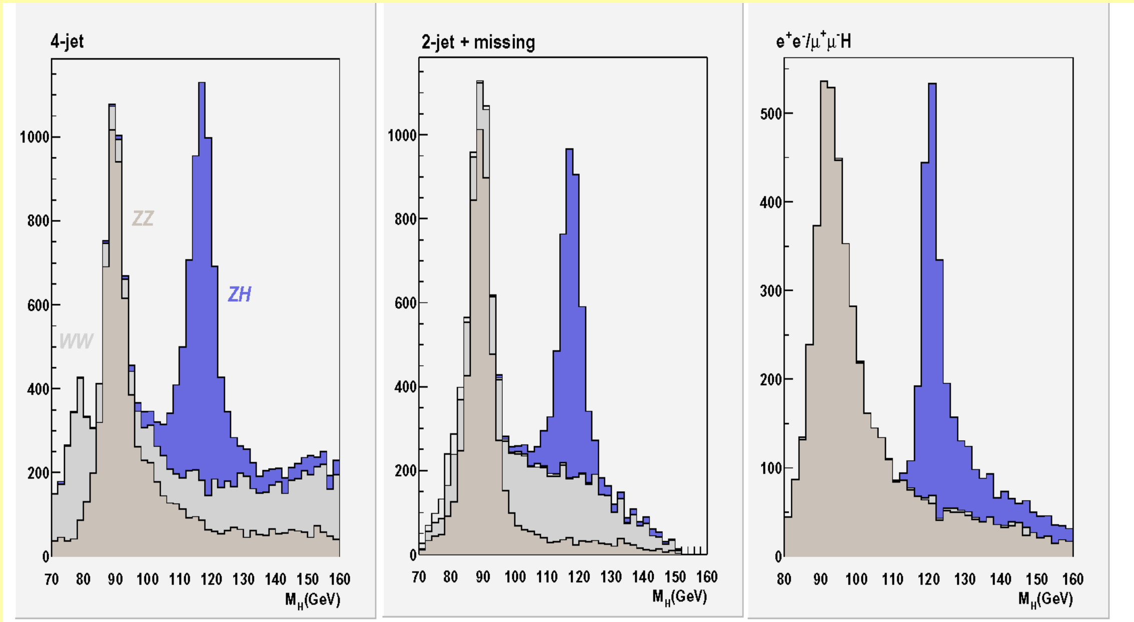


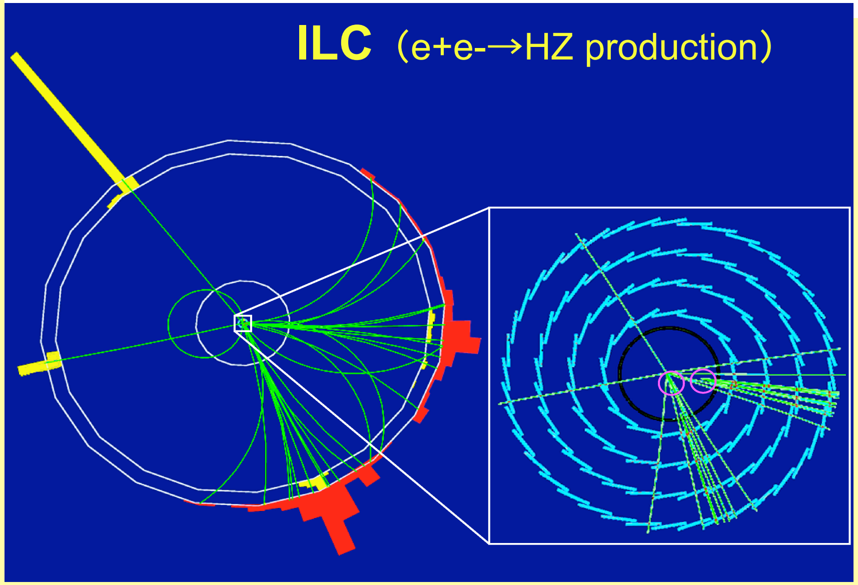
ttH→WbWbbb→*l*νjjbbbb



Satoru Yamashita, ACFA LCWS 7
Nov.9 2004

ILC Higgs signal



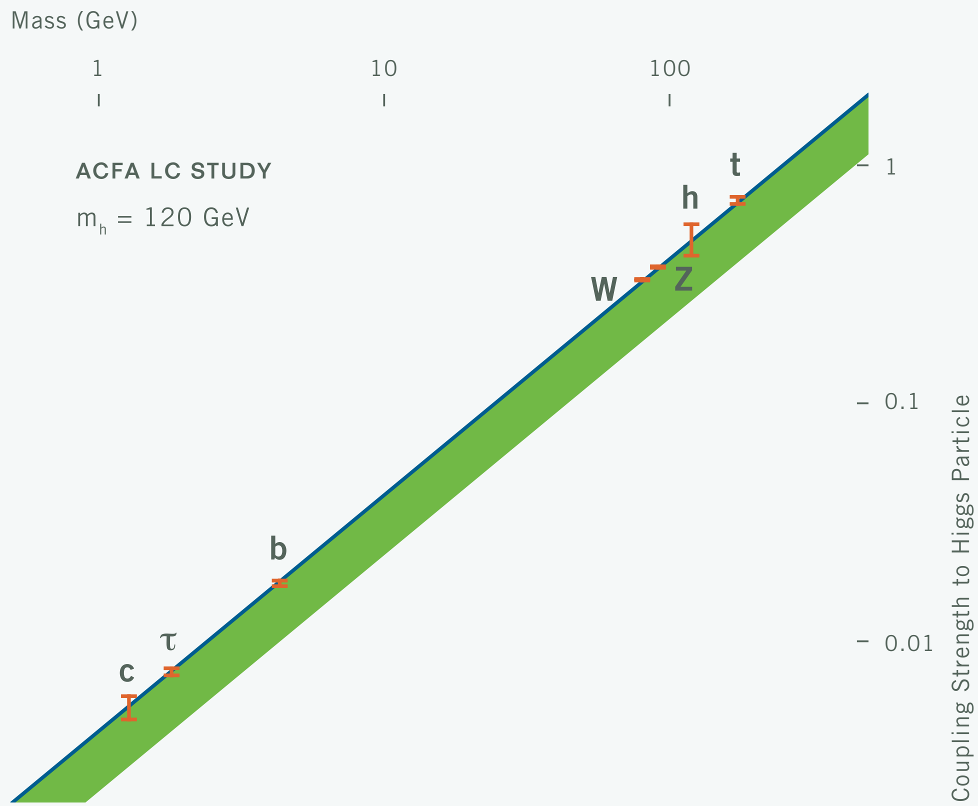


Typical numbers

Tagging efficiency
~ 30-50 %

S/N > 1

ILC experiments will have the unique ability to make model-independent tests of Higgs couplings to other particles, at the percent level of accuracy



This is right sensitivity to discover extra dimensions, a new source of CP violation, or other novel phenomena

An Optimistic Conclusion: PDG 2016 ?

GAUGE AND HIGGS BOSONS

H

$J^{PC}=0^{++}$ [a]

Charge = 0

Mass m=120.0±0.040 GeV [b]

Full Width Γ =3.6 ±0.2 MeV[a]

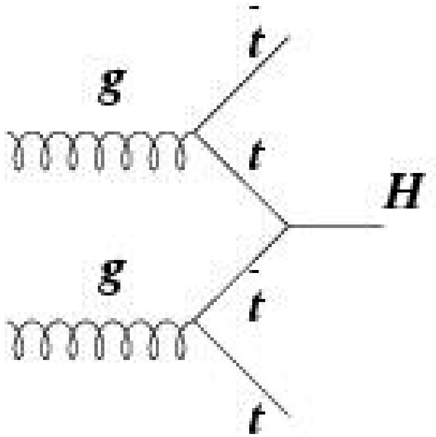
H DECAY MODES[b]	Fraction
bb	(67.8 ±1.6) %
cc	(3.08 ± 0.25)%
ττ	(6.8 ±0.35)%
gg	(7.04 ± 0.5)%
γγ	(0.21 ±0.0 5)%
WW	(13.3 ± 1.3)%

SUMMARY TABLES OF PARTICLE PROPERTIES
Extracted from the Particle listings of the
Review of Particle Physics
Published in Eur. Jour. Phys **C3**, 1 (2014)
Available at http://www.eilamgross.com

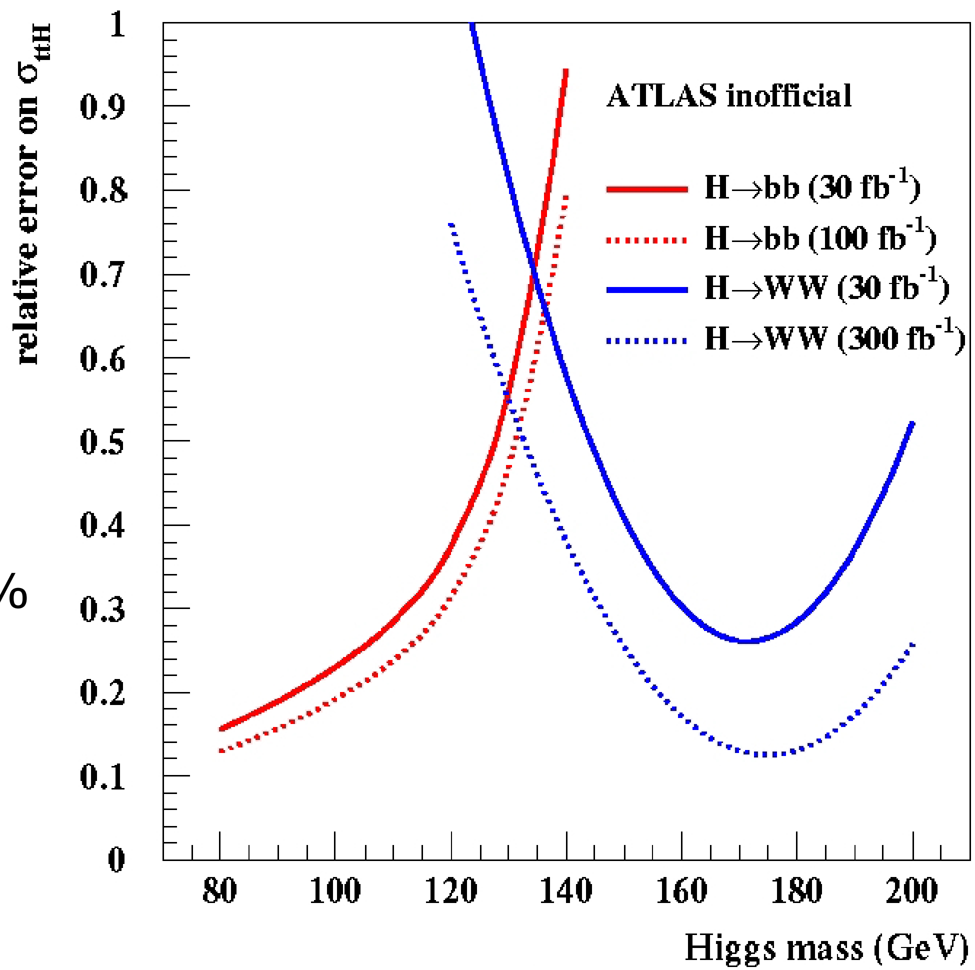
Like the Z boson measurements at LEP

[a] LC, [b] LC/LHC

ttH production Yukawa coupling at LHC

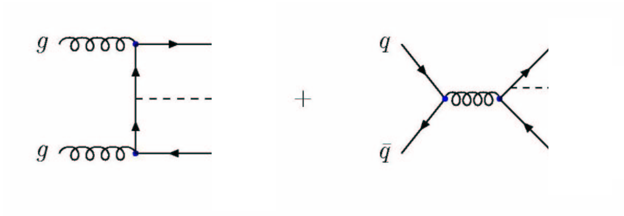


statistical error only:



- controllable QCD uncertainties (Spira et al, Dawson at al) 10-15%
- rather low rate
- final States H→bb and H→WW being analysed in ATLAS (more to come…)

Example 1:Precision Measurements of tt-Higgs Coupling



LHC measures g_{tth}^2 BR(h →X)

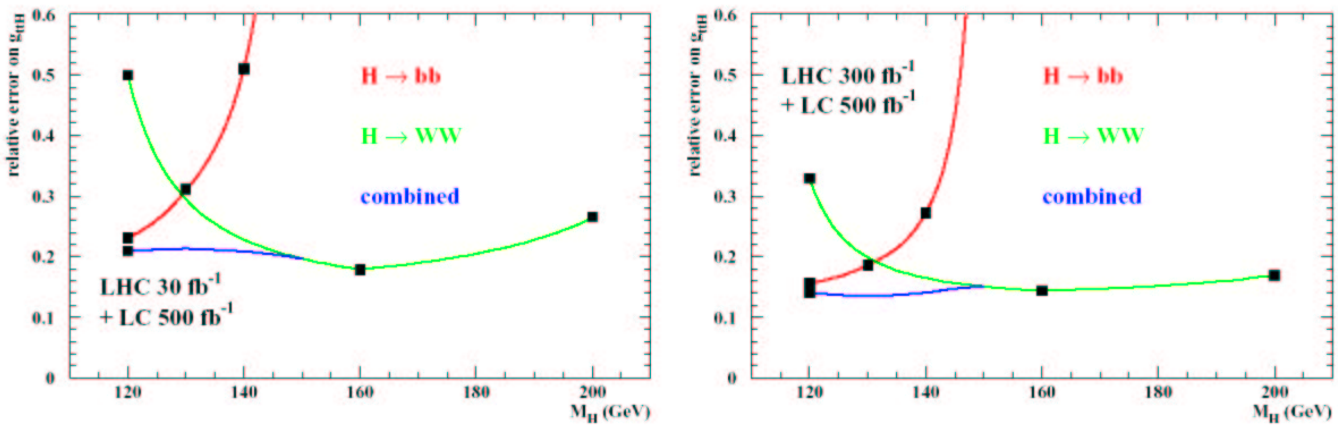
h → bb and h → W^+W^- final states studied at LHC

√s=350 GeV LC obtains precision BRs

M_h=120 GeV, δBR(h→bb)≈ 2.4%,

M_h=200 GeV, δBR(h→ W^+W^-) ≈ 2.1%

LC+LHC⇒Model independent g_{tth}

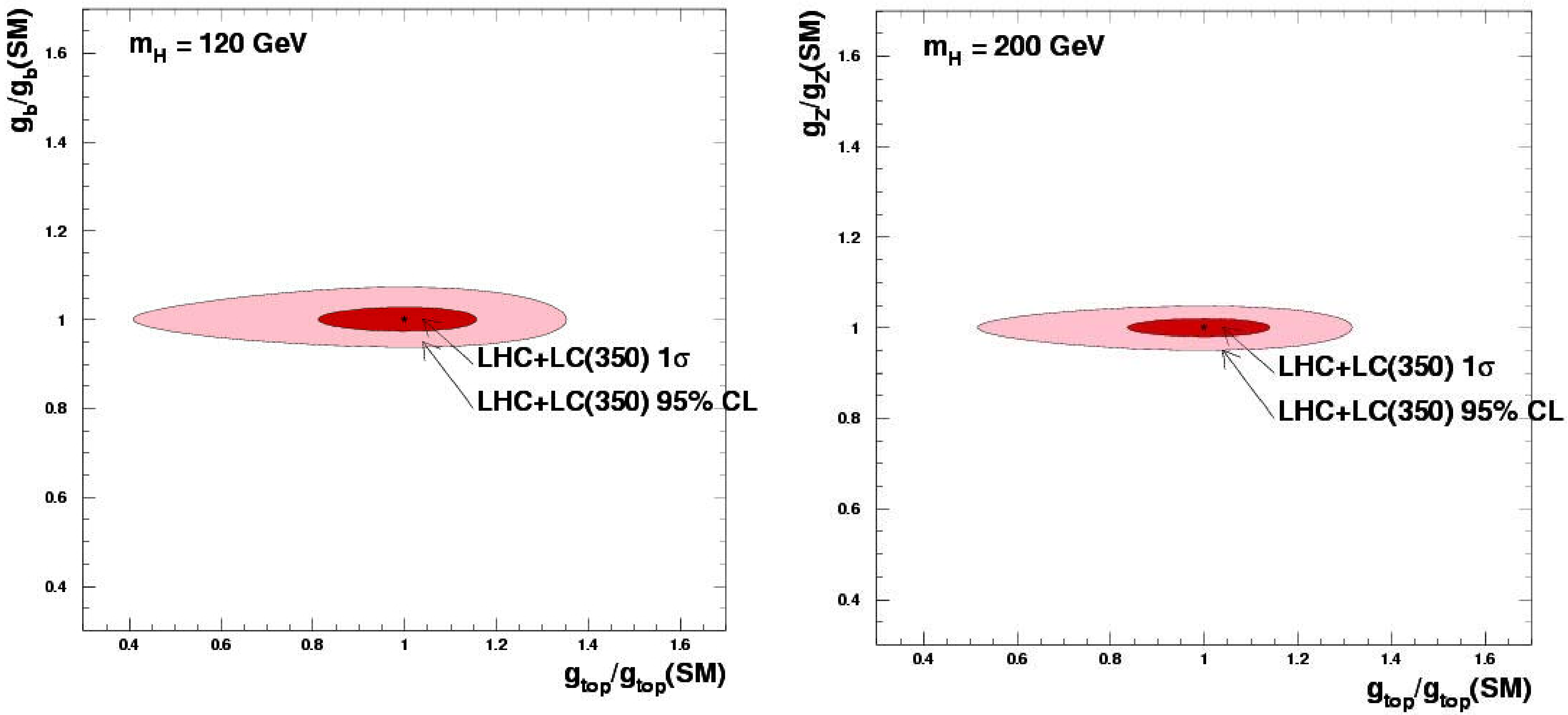


Desch & Schumacher, hep-ph/0407159

First Very Preliminary Result

Error on g_{ttH} 16.8% (@120 GeV) 14.9% (@200 GeV)

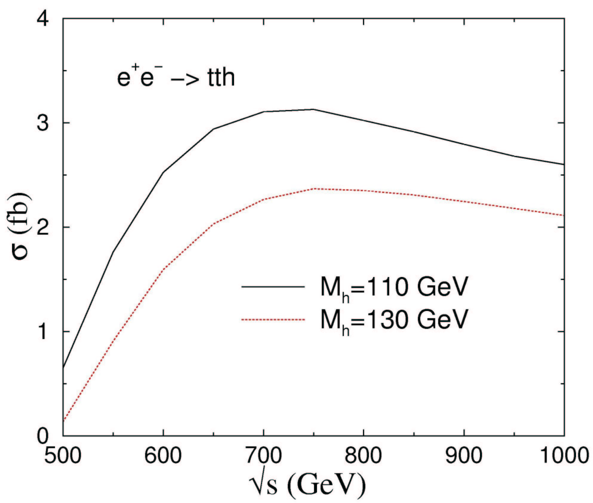
HFITTER:



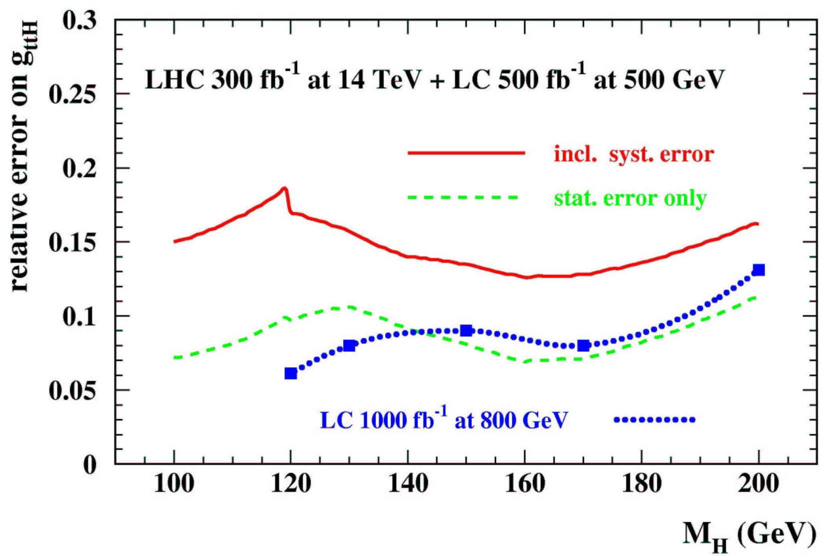
Looks promising…
Next: BG uncertainties, closer look at SF uncertainties

$\sqrt{s}$=800 GeV LC improves g_{tth} further

Cannot observe $e^+e^- \rightarrow tth$ at $\sqrt{s}$ =500 GeV LC



Dawson & Reina, Beenacker et al



Desch & Schumacher, hep-ph/0407159

Combine LHC data on heavy Higgs with LC data on the light Higgs

Desch, Gross, Heinemeyer, Weiglein

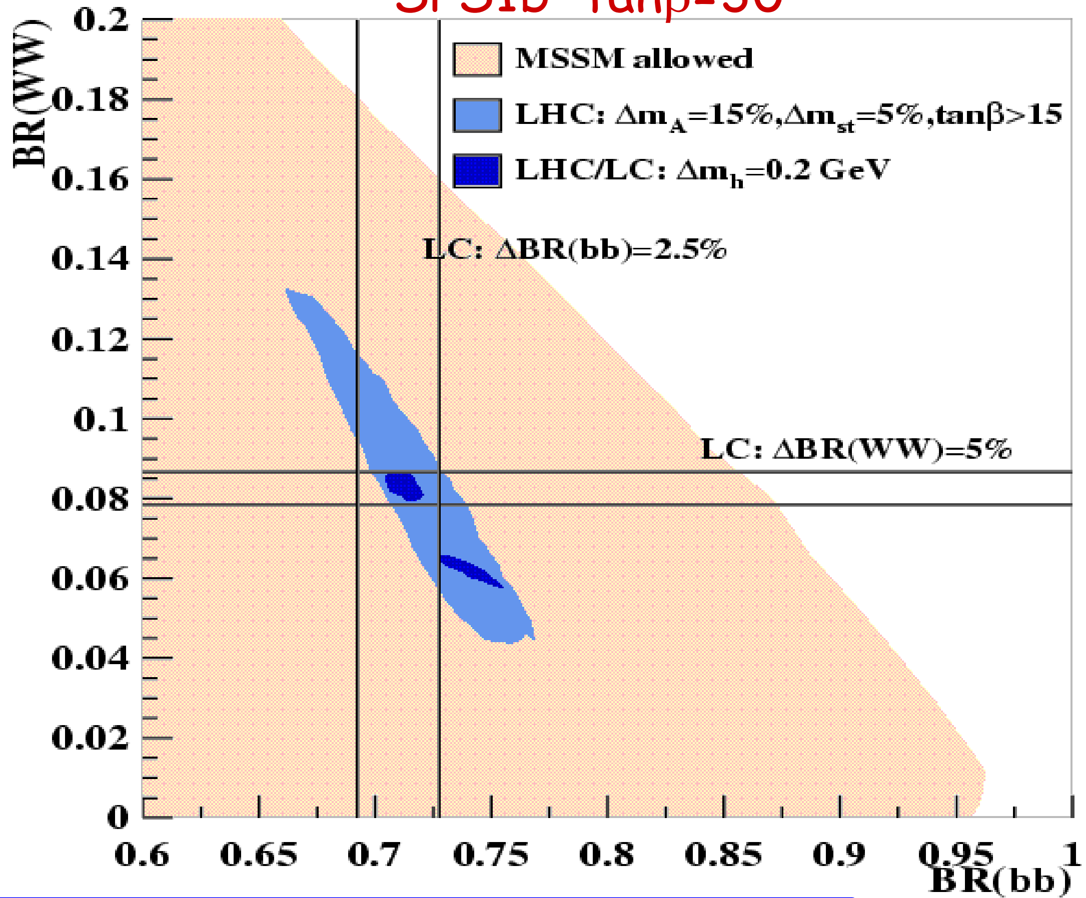
Assume:

LHC information on M_A and tan β

⊕ (LHC⊗LC) information on stop/bottom masses

⊕ LHC/LC measurement of m_H

SPS1b tanβ=30

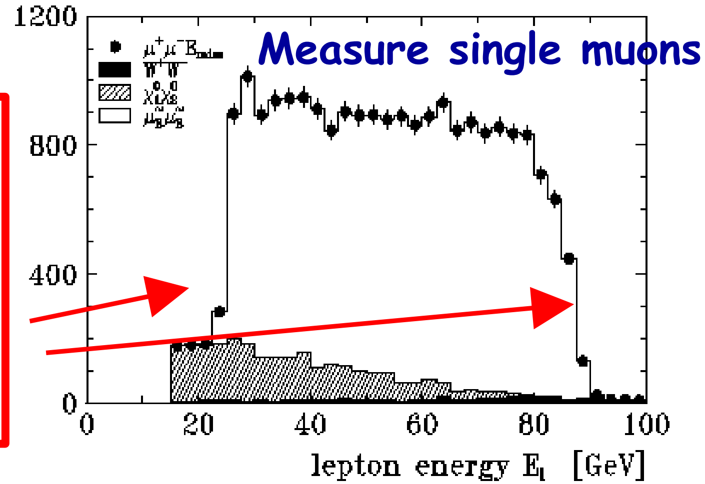


Comparison of MSSM predictions based on LHC data with BR's measured at the LC leads to very sensitive tests.

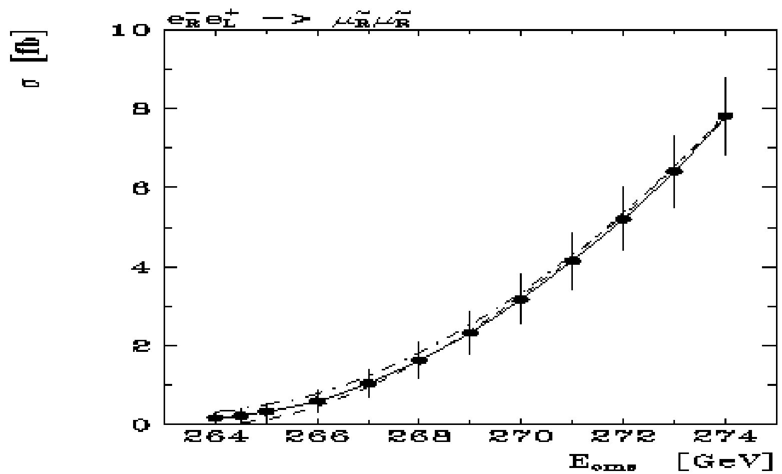
Supersymmetry at a LC

Kinematics: end-points allows to measure sparticle masses precisely

$e^-_L e^+_R \to \tilde{\mu}_L \tilde{\mu}_R \to \mu \tilde{\chi}^0_2$

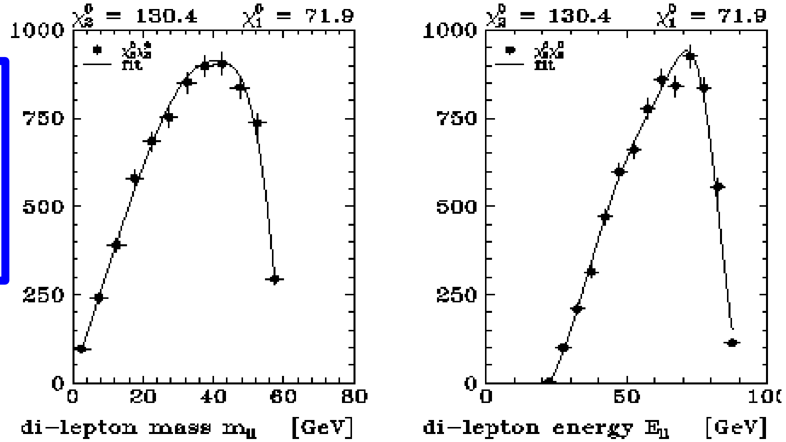


$\tilde{\mu}$ Threshold Scan

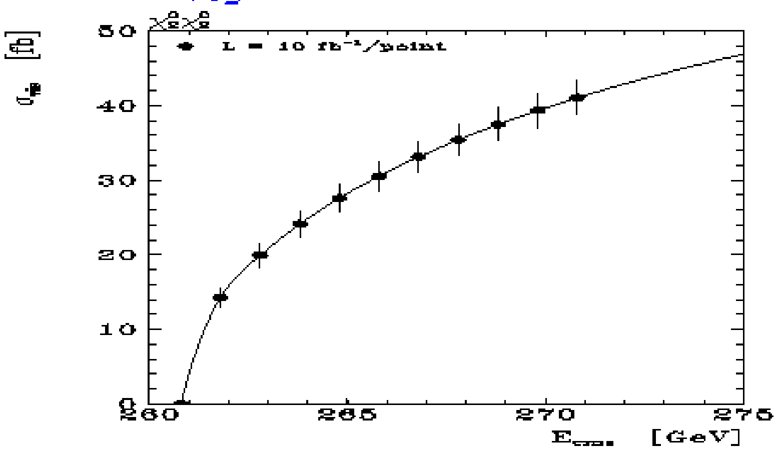


Precision on masses of order 0.5-0.1%

$e^-_L e^+_R \to \tilde{\chi}^0_2 \tilde{\chi}^0_2 \to \mu\mu \tilde{\chi}^0_1$

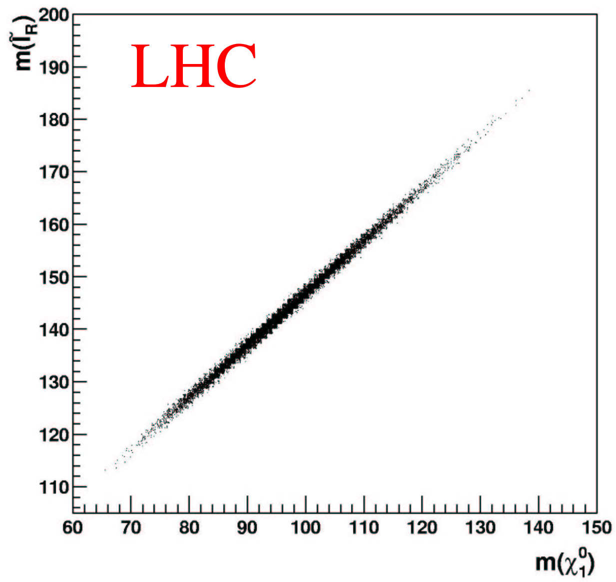


χ^0_2 Threshold Scan



LHC & LC improves SUSY mass resolution

- LSP mass constrained at LHC at 10% level
- LSP mass at LC to < 1%



⇒LC input improves accuracy significantly

Weiglein, LHC/LC Study

Using the χ^0 from the LC

300 fb^{-1}@LHC

Takes into account 1% energy scale uncertainties

ΔM values 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	6.3
$\Delta m_{\tilde{\ell}_L}$	5.0	1.6	1.9
$\Delta m_{\tilde{\chi}_4^0}$	5.1	2.25	2.4

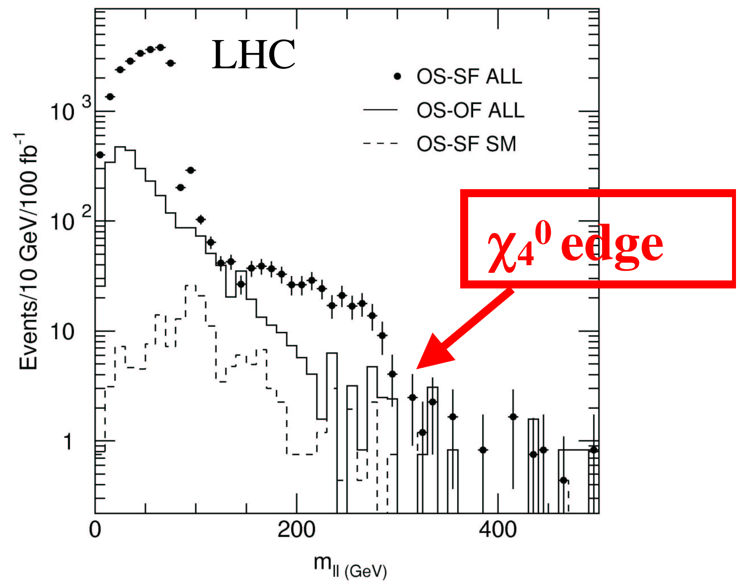
Numbers are preliminary

Significant improvements with an LC if m(χ) measured to better than 1%

Look for heaviest neutralino at LHC with LC prediction

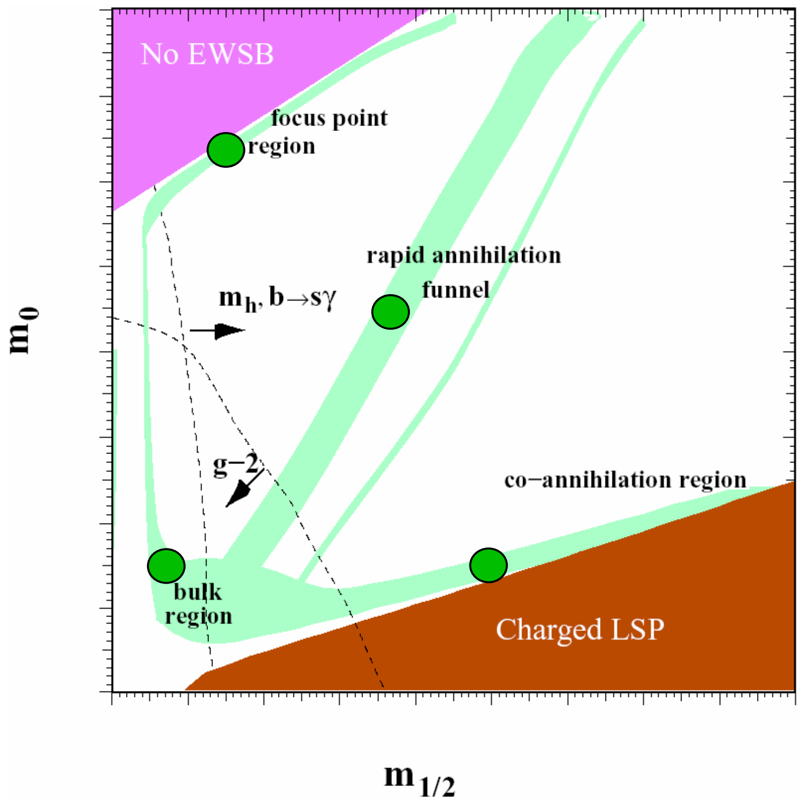
- This example requires that machines run at same time
- With LC input, LHC measures:
  - $\Delta(M\chi_1^0)$ =2.5 GeV
- Without LC input, LHC measures:
  - $\Delta(M\chi_1^0)$ =5 GeV
- Mismatch between LC/LHC results implies new physics
- Marginal signal at LHC found with LC input

Invariant mass spectrum of heavy neutralino/chargino decay chains



Desch, Kalinowski, Moortgat-Pick, Nojiri, Polesello

Neutralino DM in mSUGRA



Cosmology excludes much of parameter space (Ω_χ too big)

Cosmology focuses attention on particular regions (Ω_χ just right)

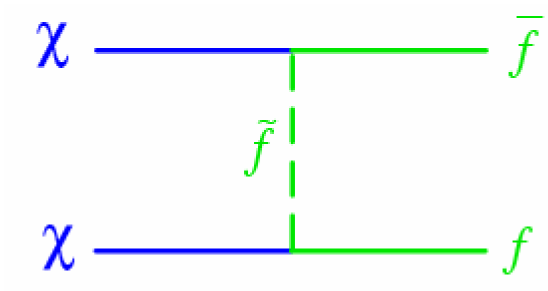
Choose 4 representative points for detailed study

Baer et al., ISAJET   Gondolo et al., DARKSUSY   Belanger et al., MICROMEGA

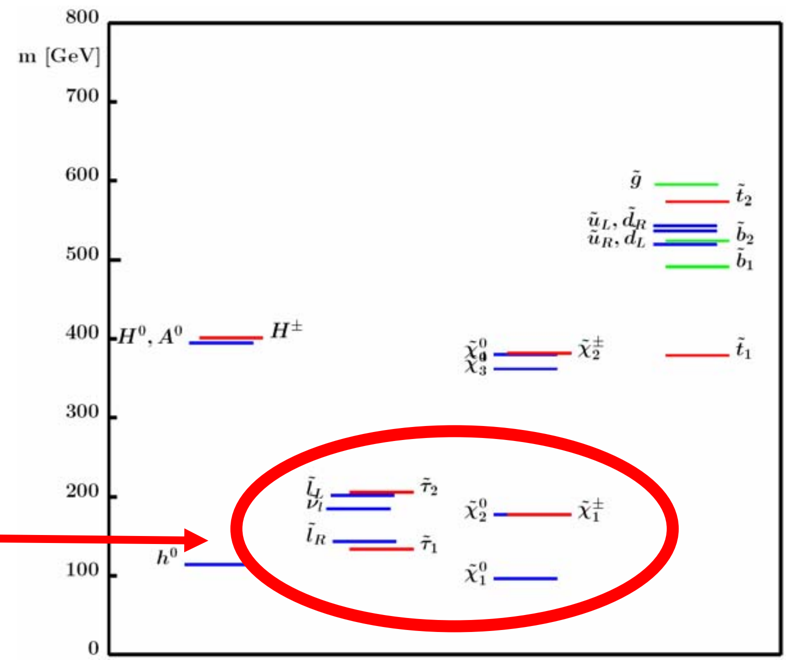
BULK REGION LCC1 (SPS1a)

$m_0, M_{1/2}, A_0, \tan\beta$ = 100, 250, -100, 10 [μ>0, $m_{3/2}$>m_{LSP}]

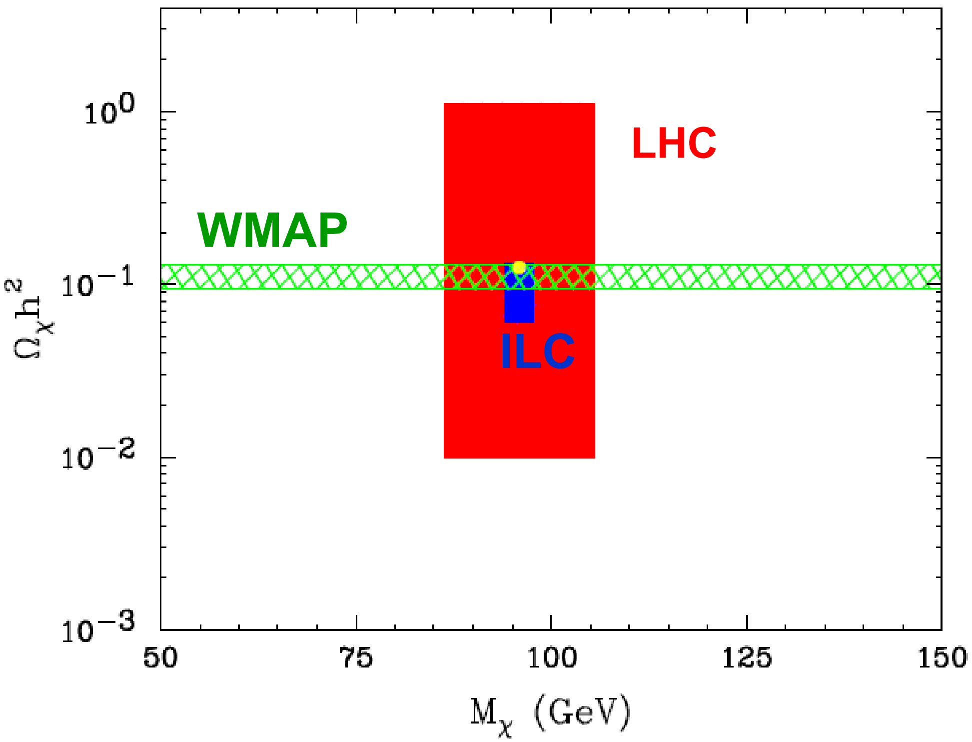
- Correct relic density obtained if χ annihilate efficiently through light sfermions:



- Motivates SUSY with light $\chi, \tilde{l}$



Allanach et al. (2002)

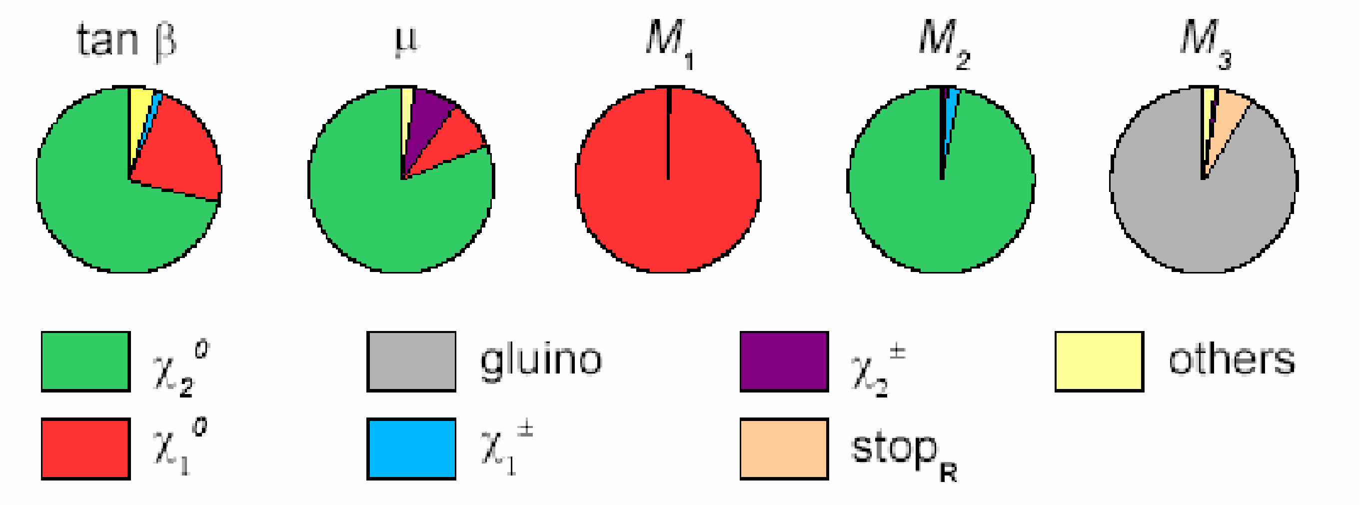


Accuracies of determining the LSP mass and its relic density

[Alexander et al., hep-ph/0507214]

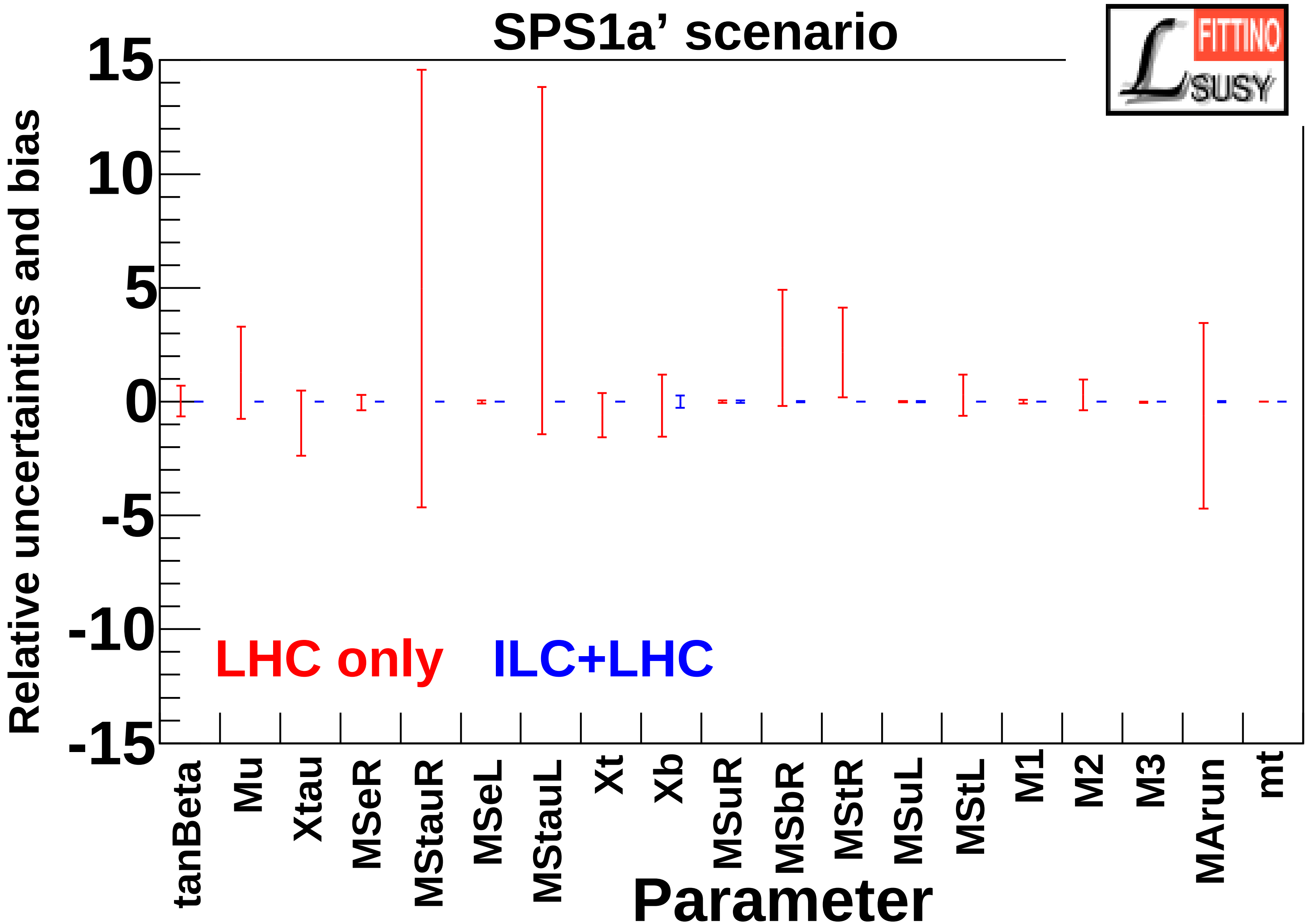
Sensitivity of pMSSM parameters to experimental inputs (Lafaye, for SPA project, Beijing 17/8/04)

Vary parameter by $\pm 1\sigma$ and determine individual $\Delta\chi^2$ contribution of the various observables using Fittino



Only a combined LHC and LC study allows a complete fit without fixing any parameter

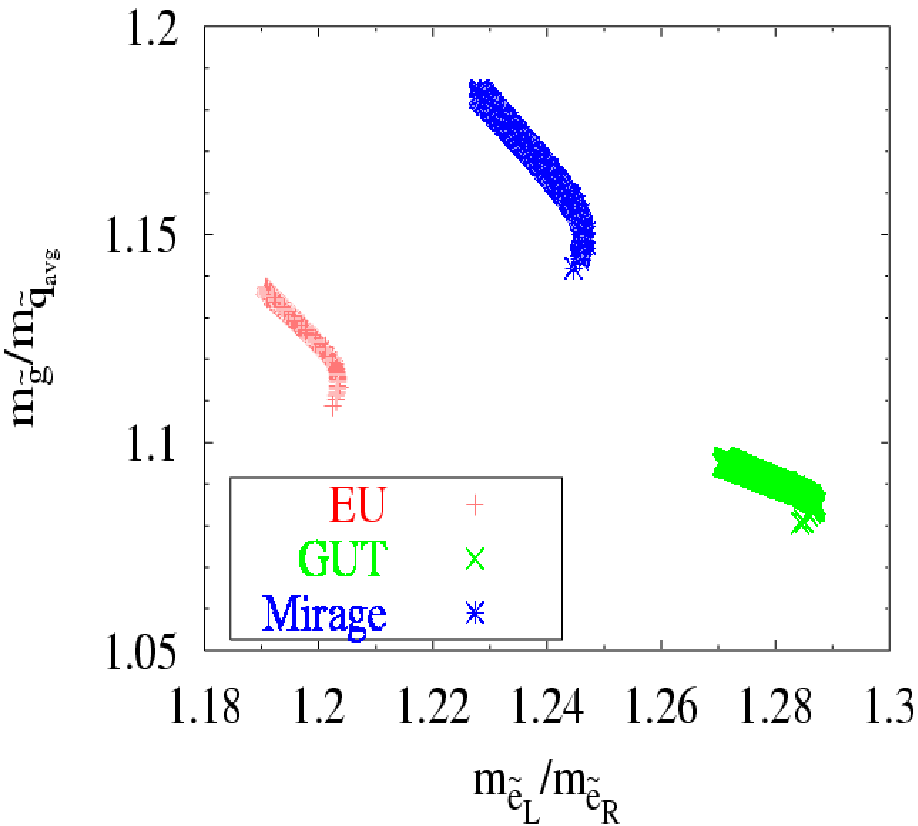
Comparison of LHC and ILC+LHC



Ultimate SUSY Synergy: Learning about SSB

Allanach,Grellscheid,Quevedo

Discrimination between different SUSY-breaking scenarios

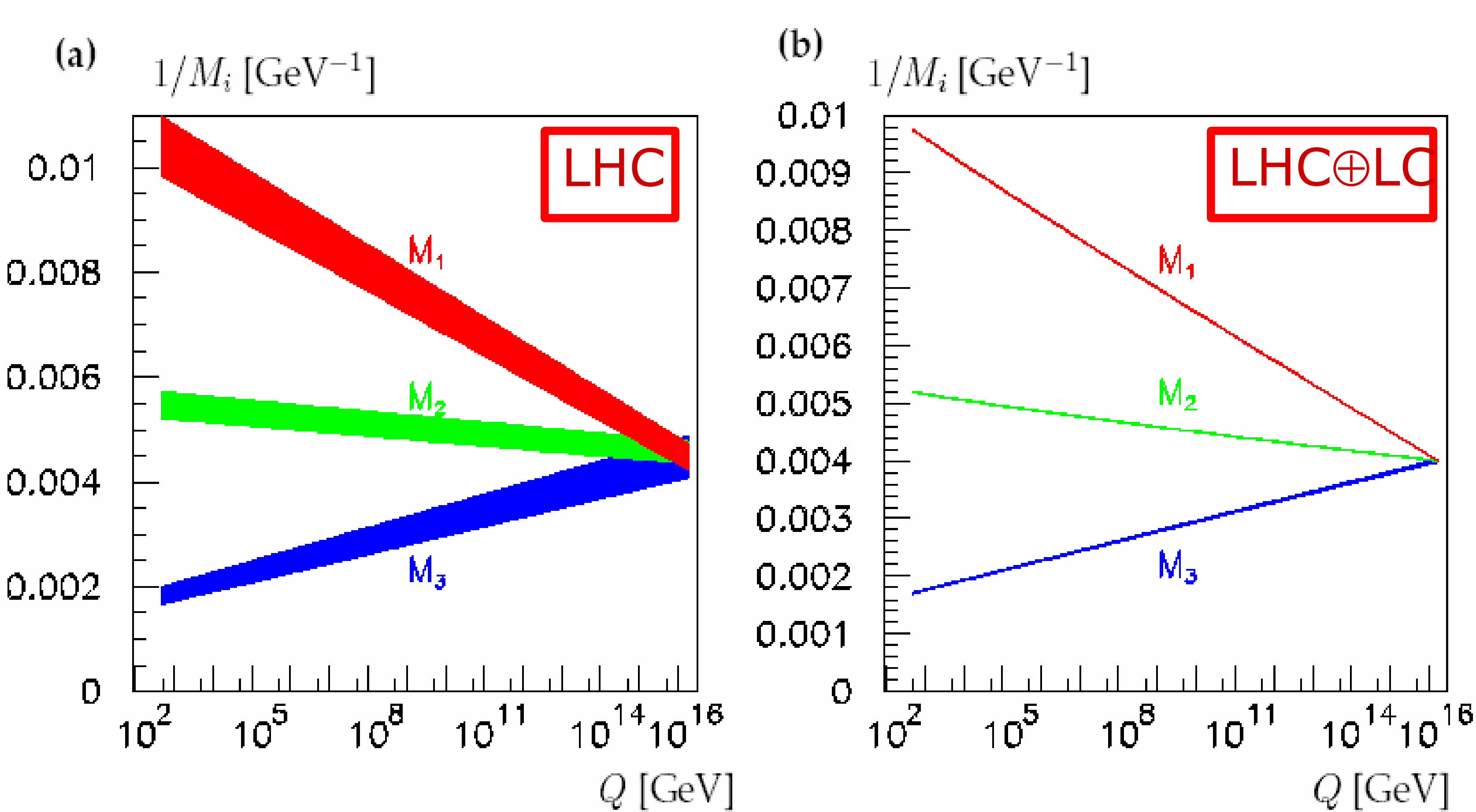


Need information from slepton and squark sector!
Need percent level accuracy

Ultimate SUSY Synergy: Learning about SSB

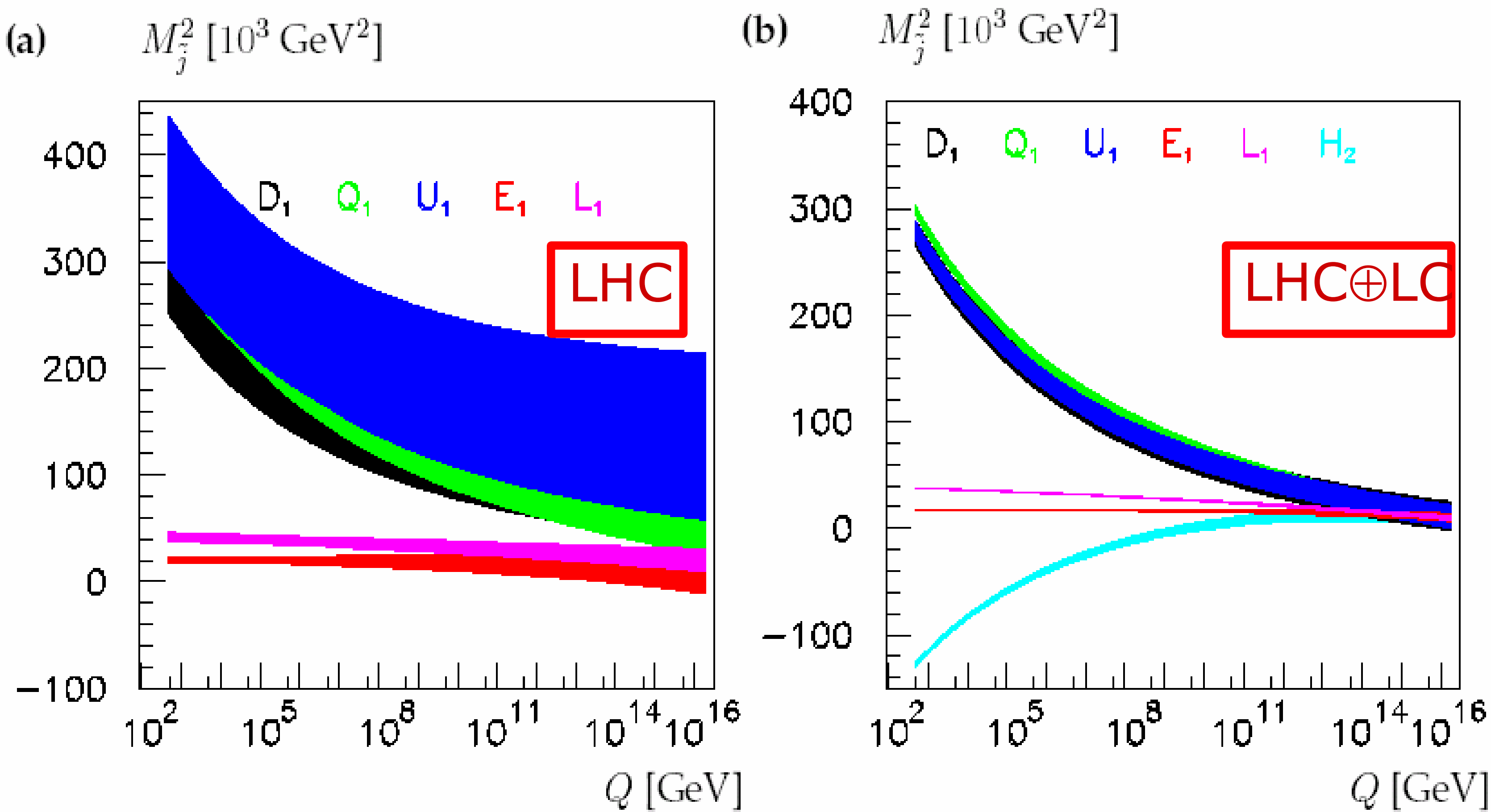
Blair, Martyn, Polesello, Porod, Zerwas

Model-independent bottom-up approach: Combined information on Low-Energy SUSY parameters as input to RGE evolution



Ultimate SUSY Synergy: Learning about SSB

Blair,Martyn,Polesello,Porod,Zerwas



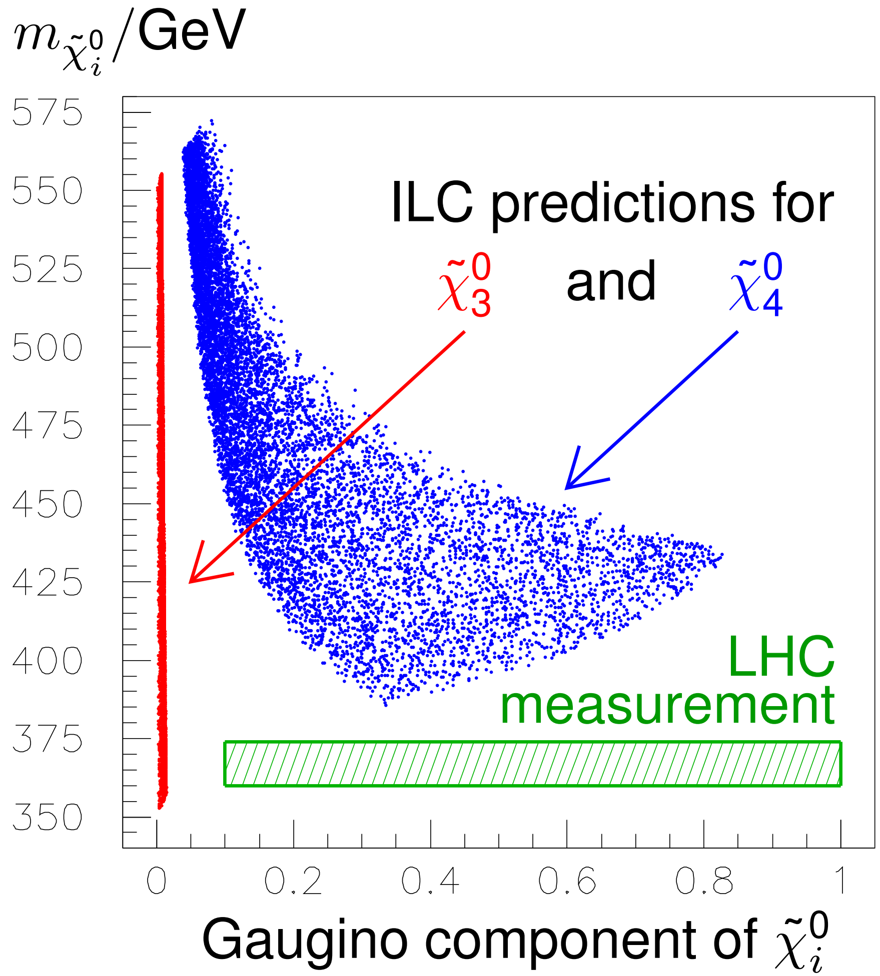
SUSY searches at LHC

- With input from ILC measurements: $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_2^0}$, $m_{\tilde{\ell}}$, $m_{\tilde{\nu}}$

  → Precision of 2% for $m_{\tilde{\chi}_3^0}$ may be possible:

  $$m_{\tilde{\chi}_i^0} = (367 \pm 7) \text{ GeV}$$

  → Compatible with mass predictions in MSSM, however, not with predictions for small gaugino component!



- Other possibility: Interpretation of measured gaugino as $\tilde{\chi}_4^0$: Incompatible with cross section measurements at ILC!

"NO Higgs" Physics

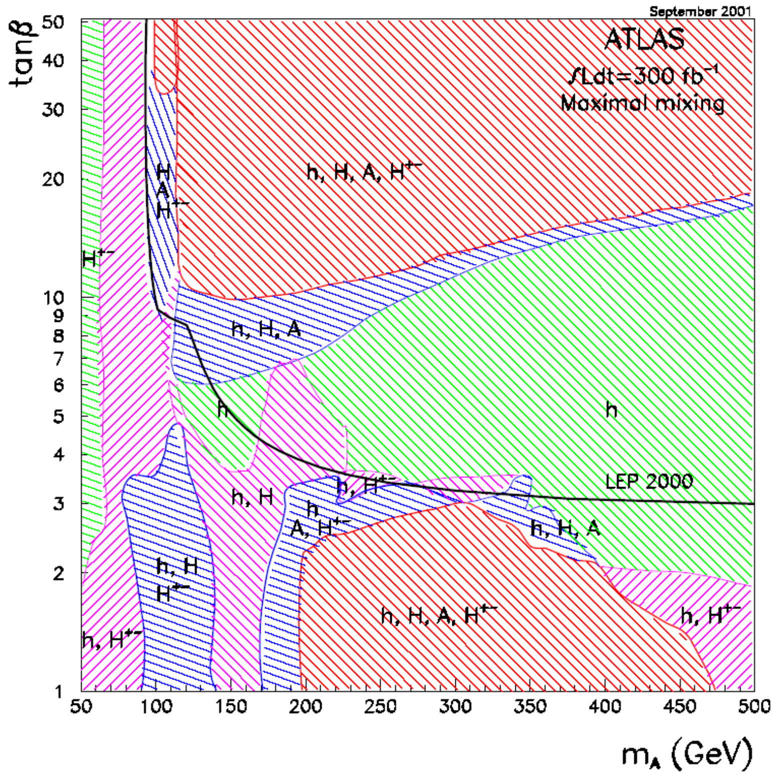
Higgs boson can be missed at LHC if:

* it does not exist ...

* it has non-standard couplings
  smaller/different from SM
  production cross section smaller

* it has non-standard decay channels (to new particles)
  invisible or
  with high background

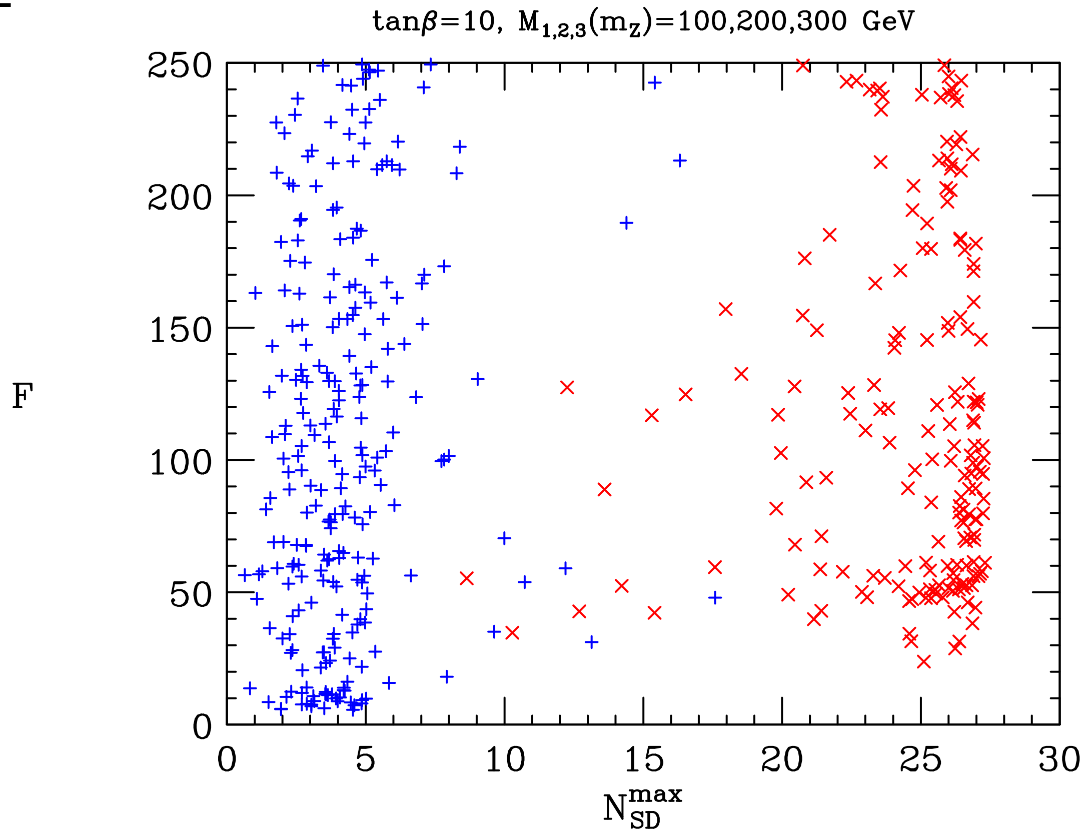
Heavy Higgses at LHC



LHC "wedge" in MSSM

In general 2HDM(II) light Higgs scalar can have same couplings...

LHC Discovery Potential in NMSSM



Standard decay modes:

$gg \to h/a \to \gamma\gamma$

associated Wh/a or $t\bar{t}h/a$ prod.

with $\gamma\gamma l^{\pm}$ in the final state

$t\bar{t}h/a$ prod. with $h/a \to b\bar{b}$

$b\bar{b}h/a$ prod. with $h/a \to \tau^+\tau^-$

$gg \to h \to ZZ^{(*)} \to$ 4 leptons

$gg \to h \to WW^{(*)} \to l^+l^-\nu\bar{\nu}$

$WW \to h \to \tau^+\tau^-$

$WW \to h \to WW^{(*)}$

$WW \to h \to invisible$

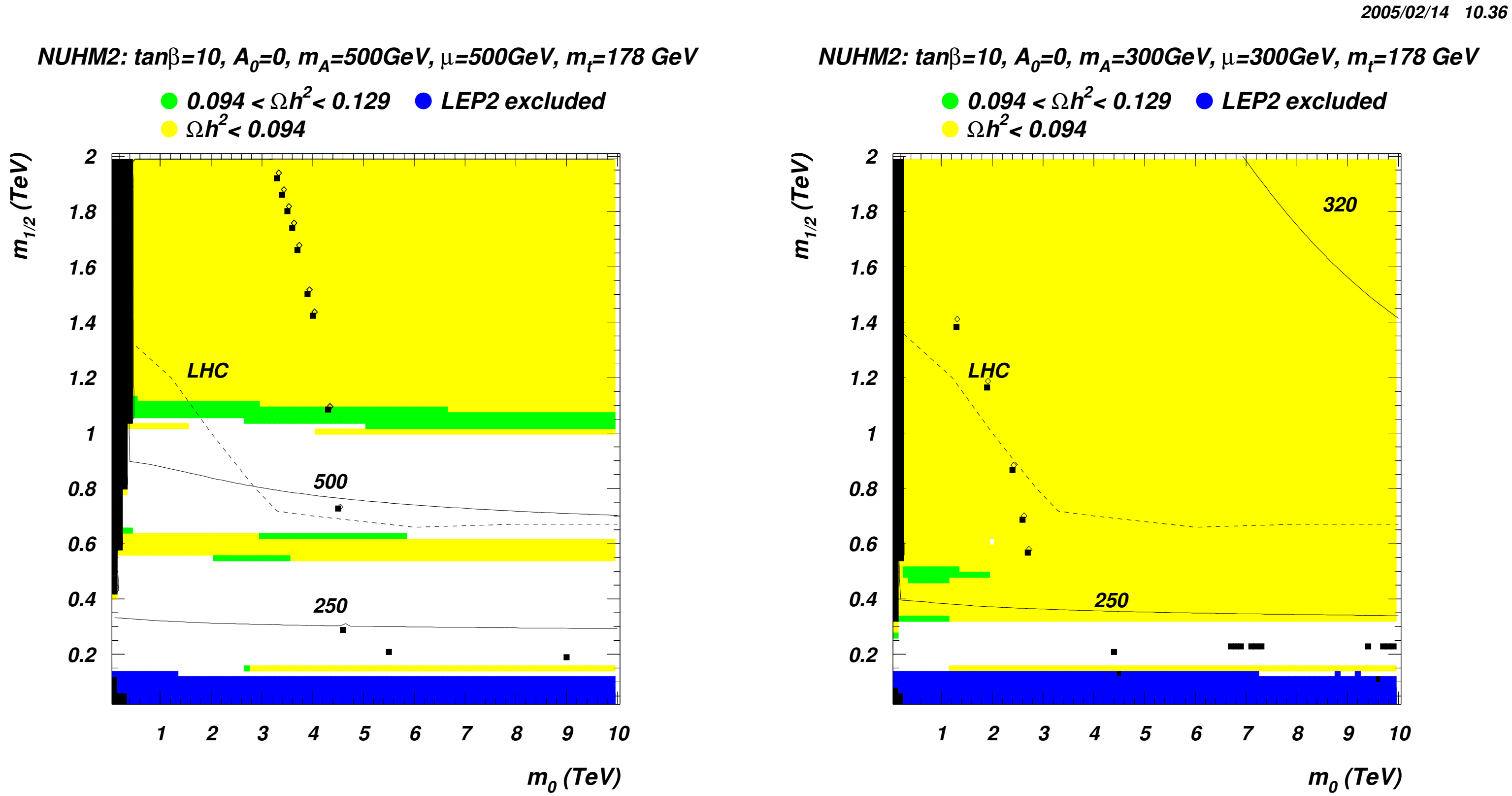
for an integrated luminosity: $L = 300 fb^{-1}$

see the talk of J. Gunion, at LHC-ILC on Wednesday

Investigation of different scenarios

Gravity-mediated SUSY with non-universal Higgs masses

[*H. Baer, A. Belyaev, A. Mustafayev, S. Profumo, X. Tata '05*] NEW!

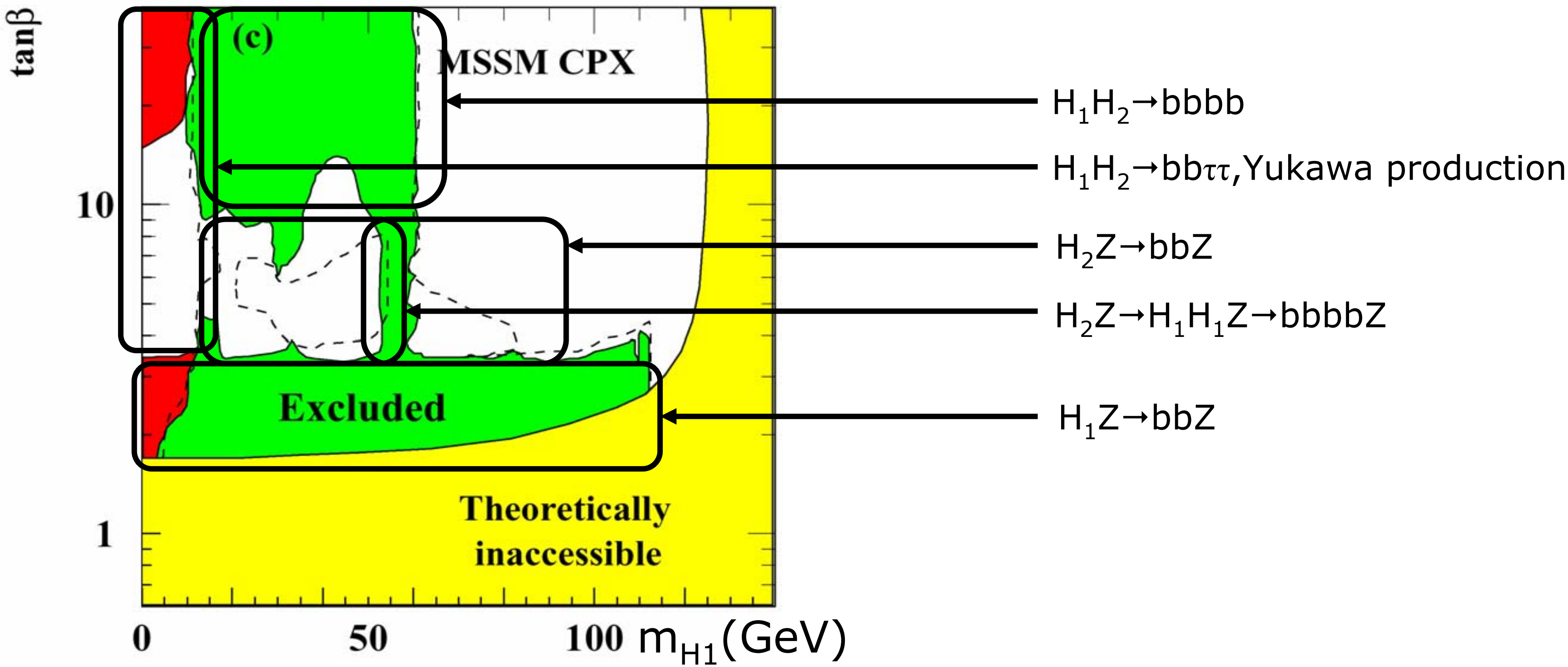


⇒ ILC reach can exceed LHC reach

⟶ *See talk by H. Baer at LHC / ILC meeting*

Identifying a scenario

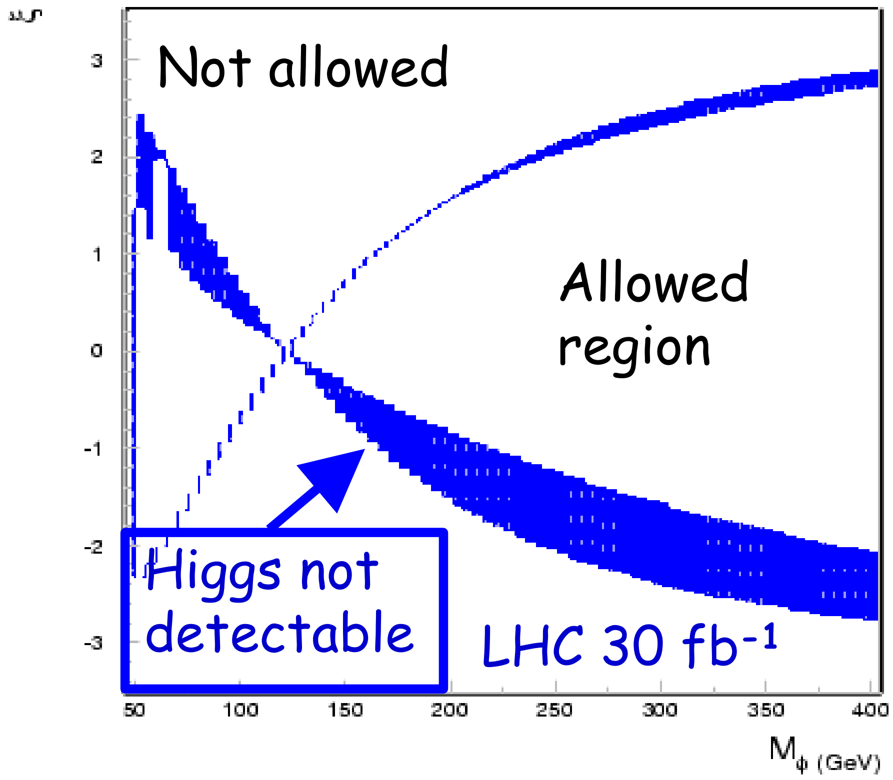
Another idea:
MSSM Higgs sector with CP-violation
LEP cannot exclude a very light (mainly CP-odd) Higgs
Detection of H2 seems guaranteed at LHC and ILC but H1 may be more difficult.
Question: could LHC see a low-mass (20-50) GeV bbbar resonance if ILC tells its mass?

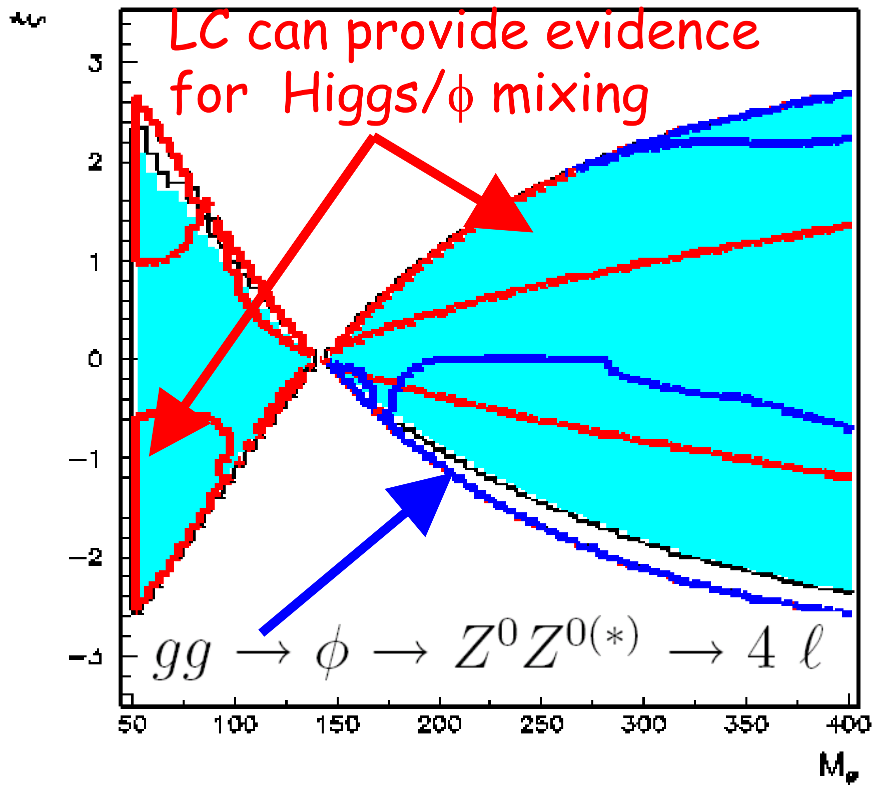


Higgs and Radion searches

Battaglia, ADR, DeCurtis, Dominici, Gunion

Detectability at the LHC versus mixing ξ and mass of the radion $M\phi$





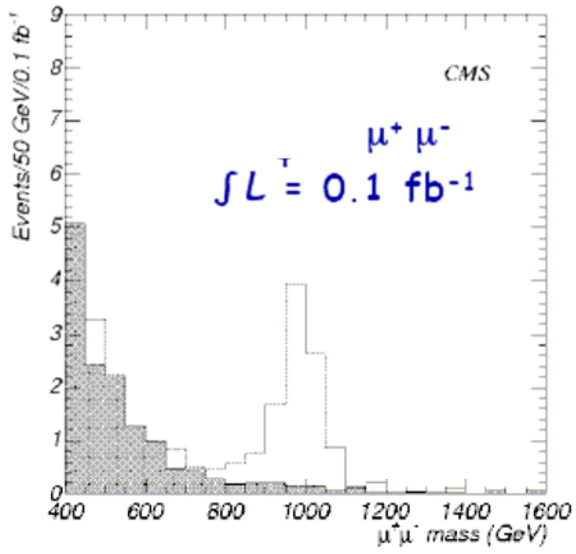
LHC has regions from the parameters space where it cannot find the Higgs
LC covers these regions and will always see the Higgs
LC can provide evidence for Higgs/ϕ mixing in a large region of phase space

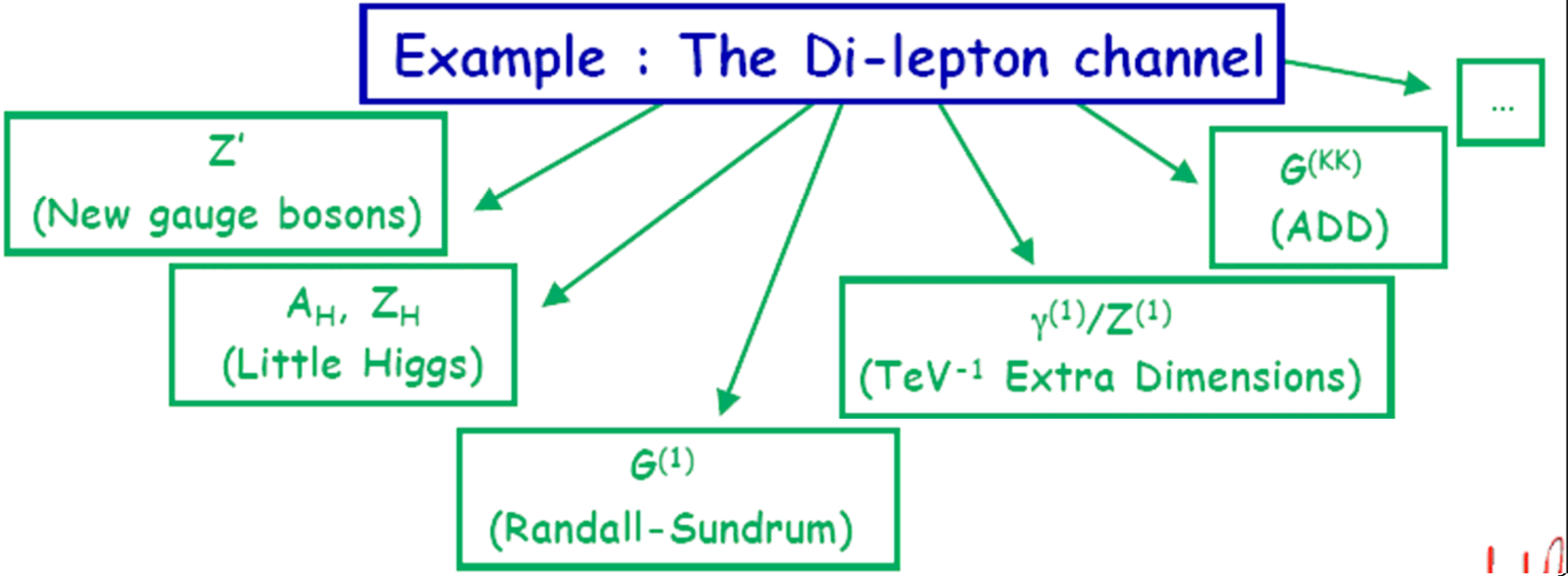
Search for new resonances

Seen or unseen at LHC...

Example: Di-lepton Resonance

May be seen very early: first weeks



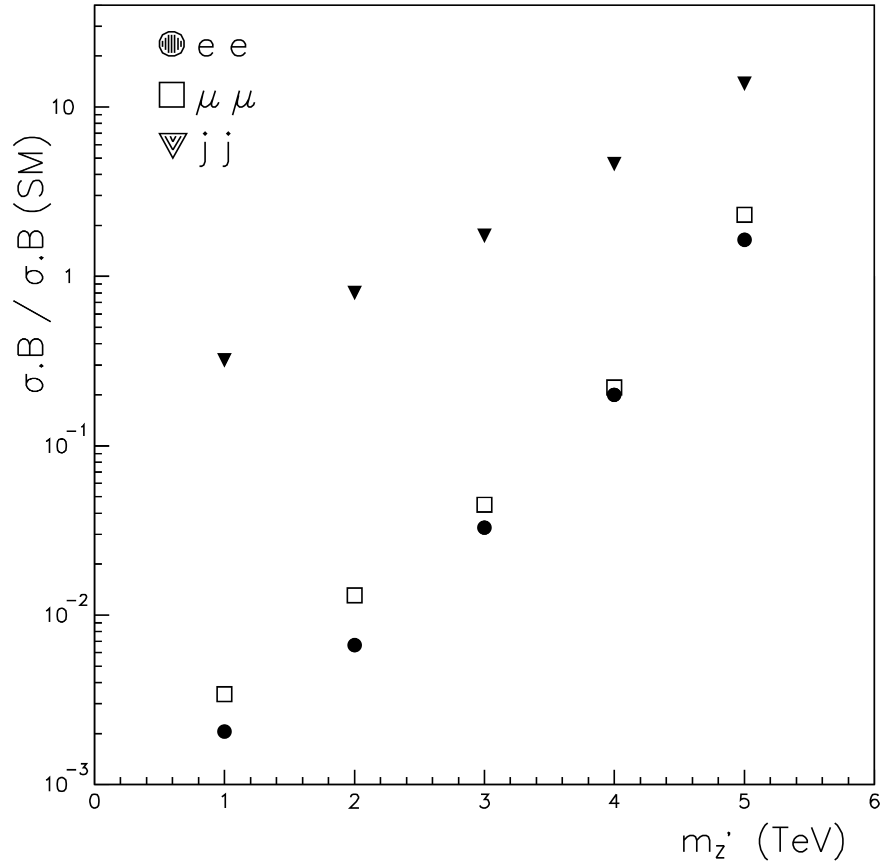


Z' bosons at the LHC

- Higher energy and more statistics than Tevatron
- Discovery in leptonic channels $pp \to Z' + X \to l^+ l^- + X$ up to $M_{Z'} \sim 5$ TeV
- Jet channel also possible, but large QCD background

ATLAS TDR '99

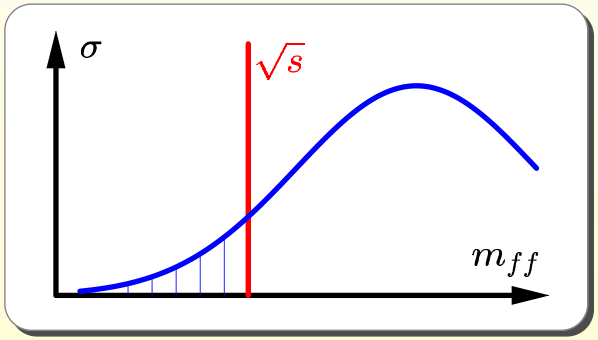
5σ discovery contours:



Z' bosons at a future linear collider

Heavy Z' bosons $M_{Z'} > 1$ TeV:

- Small Z–Z' mixing
  $\rightarrow$ negligible effect on Z-pole data



- Propagator effects of Z' modify

$$e^+e^- \xrightarrow{\gamma, Z, Z'} f\bar{f}$$

$\rightarrow$ High luminosity 500–1000 fb^{-1} allows sensitivity for $M_{Z'} \gg \sqrt{s}$

- Sensitive observables:
  - total cross-section σ_{tot}
  - forward-backward asymmetry A_{FB}
- With e^- beam polarization
  - left-right asymmetry A_{LR}
  - polarization asymmetry A_{pol}

$$A_{\text{FB}} = \frac{\sigma_{\text{F}} - \sigma_{\text{B}}}{\sigma_{\text{tot}}}$$

$$A_{\text{LR}} = \frac{\sigma_{\text{L}} - \sigma_{\text{R}}}{\sigma_{\text{tot}}}$$

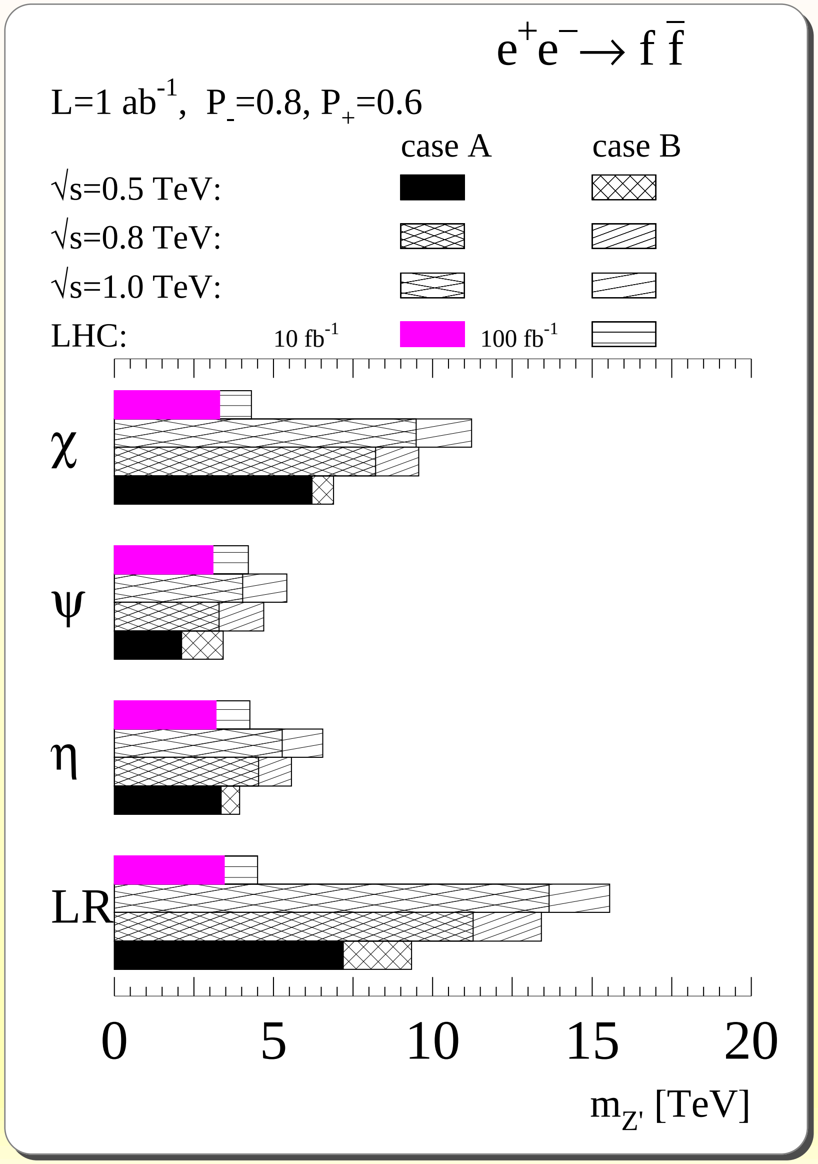
$$A_{\text{pol}} = \frac{(\sigma_{\text{L}} - \sigma_{\text{R}})_{\text{F}} - (\sigma_{\text{L}} - \sigma_{\text{R}})_{\text{B}}}{\sigma_{\text{tot}}}$$

Projected sensitivity

- Look for deviations from SM background
$$e^+e^- \xrightarrow{\gamma^*,Z^*} f\bar{f}$$
- Assume $P(e^-) = 80\%$
$P(e^+) = 60\%$
(slight improvement from e^+ pol.)
- Combine all observables
σ_{tot}, A_{FB}, A_{LR}, A_{pol}

case A,B : different assumptions about sys. errors

S. Riemann '00

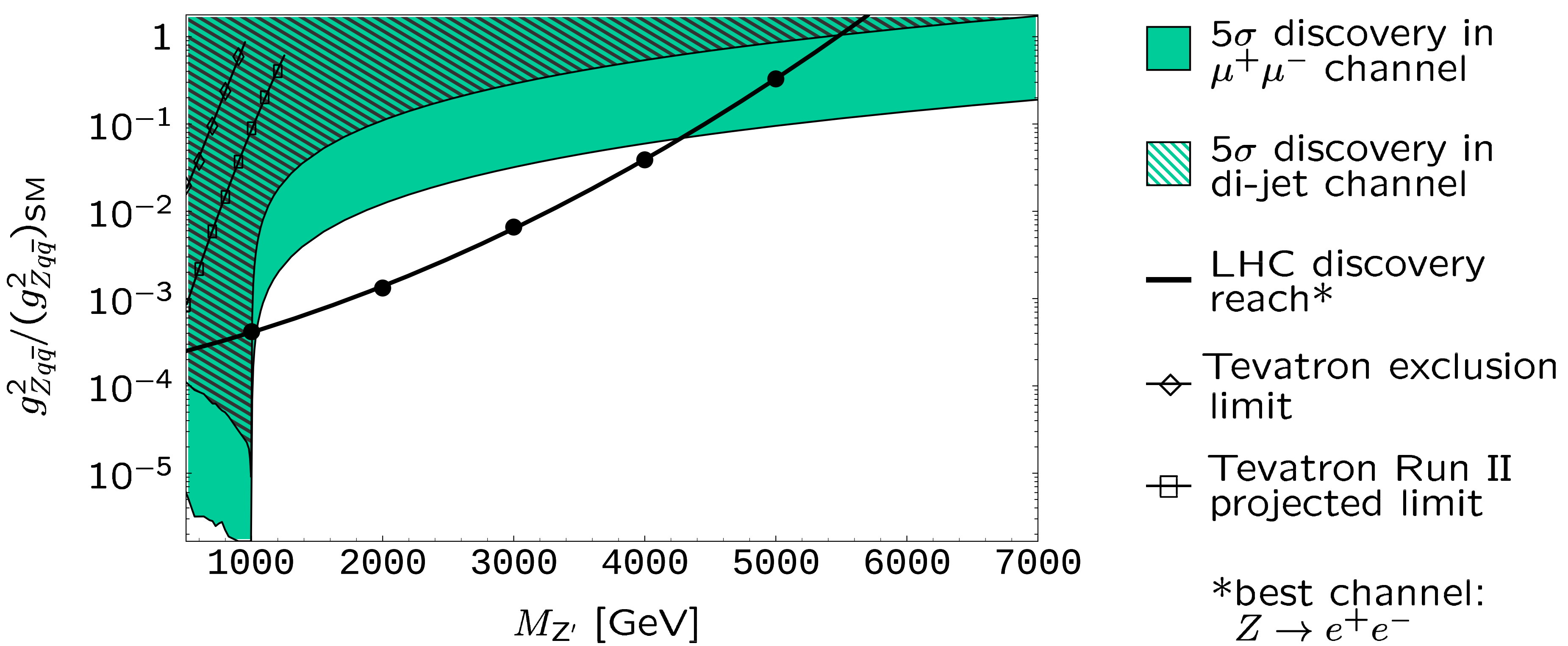


Special case: $Z_{\mathrm{B-L}}$

Z' has pure $B-L$ couplings $\rightarrow$ corresponding to $z_u = z_q$

$\Rightarrow$ No mixing between Z and Z' (i.e. no constraints from Z-pole)

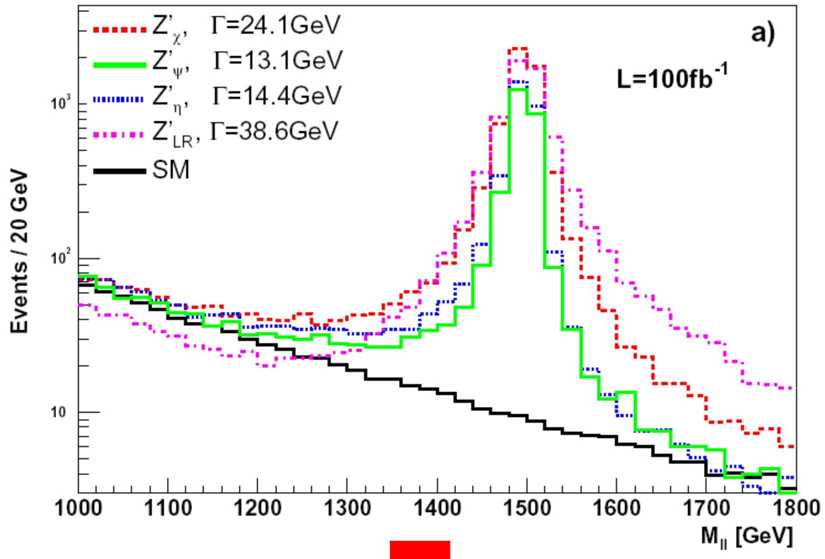
$\sqrt{s} = 1000$ GeV, $\int \mathcal{L} = 1000$ fb^{-1}

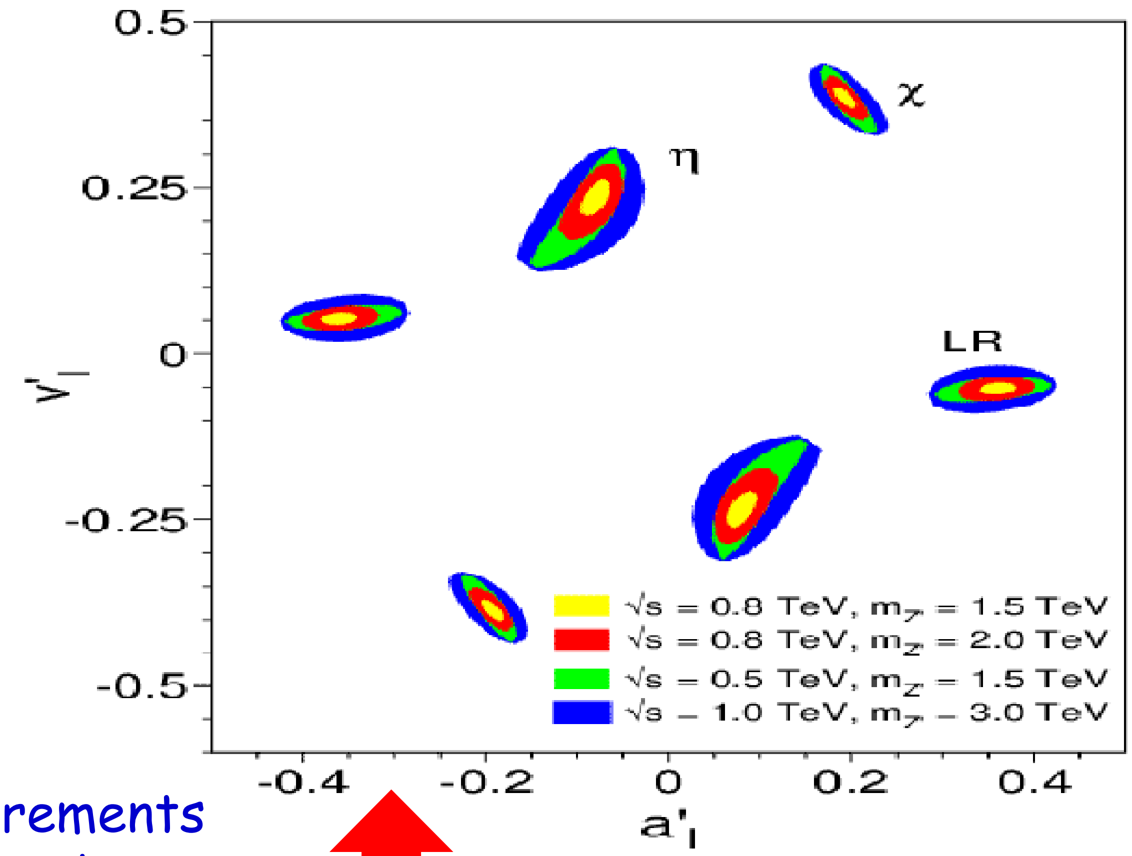


New Gauge Theories

Dilepton invariant mass spectrum

Bourlikov, Godfrey, Hewett, Richard, Riemann, Rizzo



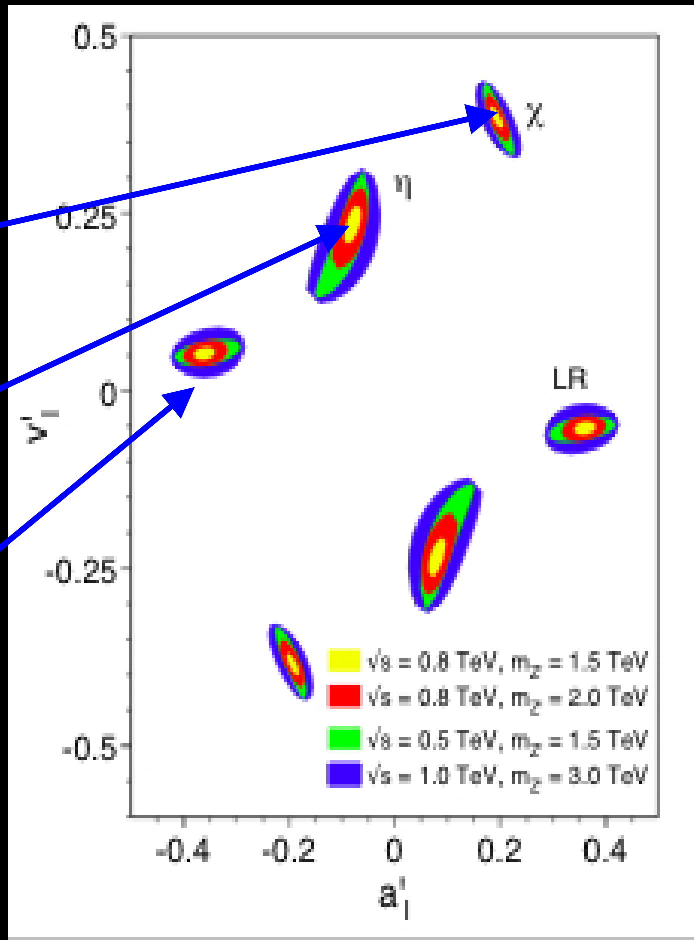


Discover of an extra gauge boson at the LHC ⇒ measure the mass

Mass at LHC + precision LC measurements Allows to determine the couplings and distinguish between different scenarios

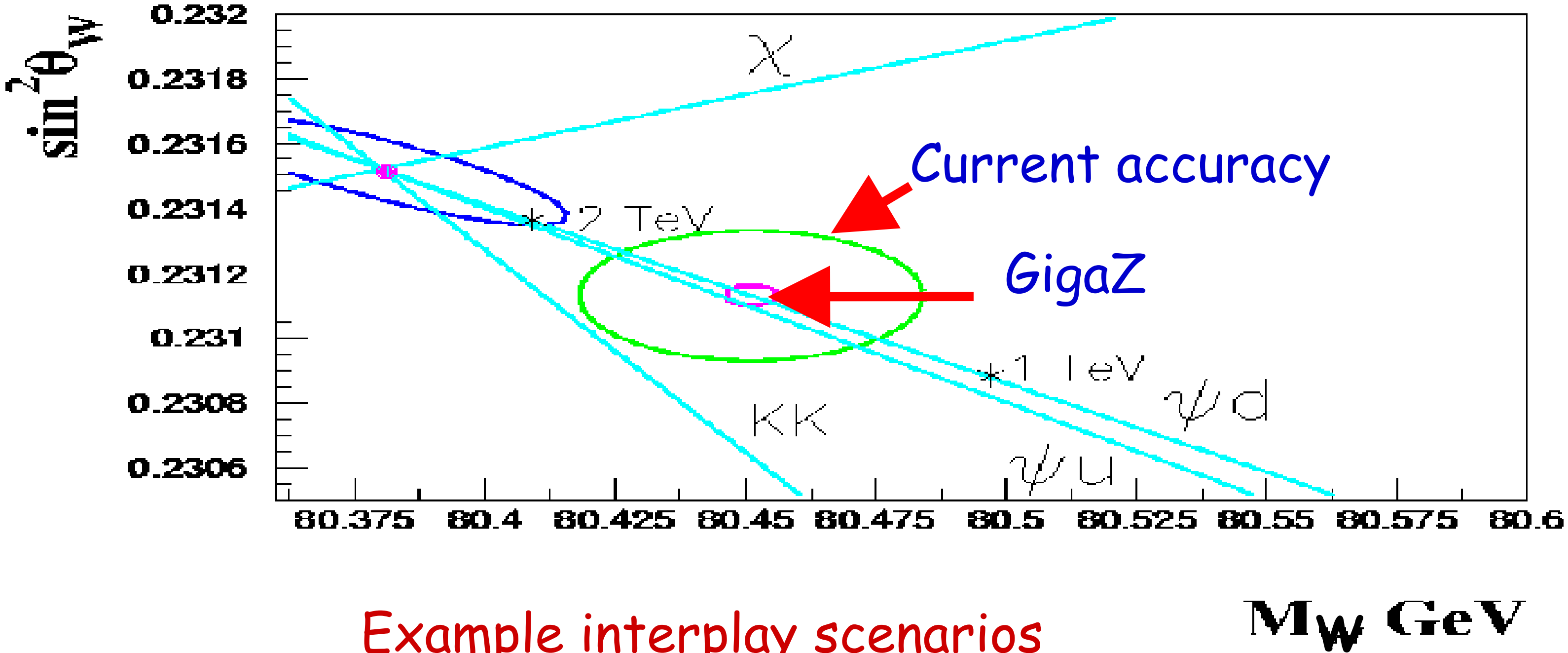
LHC/ILC Physics: new particle

- ILC measures couplings of Z' to find out what it means
- If here, related to origin of neutrino masses
- If here, related to origin of Higgs
- If here, Z' comes from an extra dimension of space
- These are great discoveries!



Precision measurements

Assume no Z′ etc. detected directly at the LHC
Revisit the Z with a Z- factory (Giga-Z: 10^9 Zs!)



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 5 GeV

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

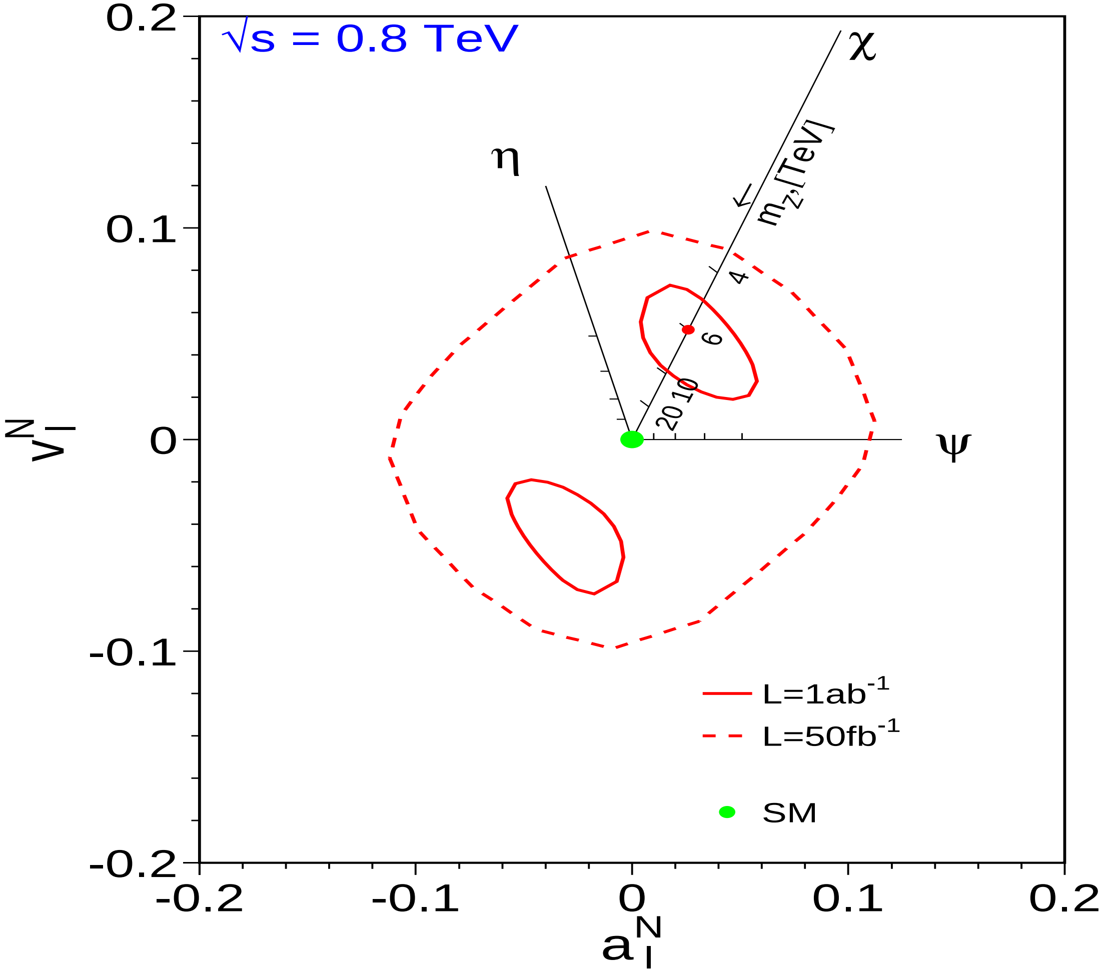
⇒ Giga-Z demonstrates that direct and indirect Higgs mass meas. disagree

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

No Z′ at LHC ⇒ situation is NOT hopeless!

$$m_{Z'} > 5 \text{ TeV}$$

$$a_f^N = a'_f \sqrt{\frac{s}{m_{Z'}^2 - s}}; \qquad v_f^N = v'_f \sqrt{\frac{s}{m_{Z'}^2 - s}}.$$

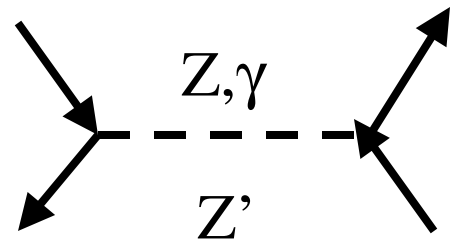


Reconstruction of a 6 TeV Z′(χ model) (95% C.L.):

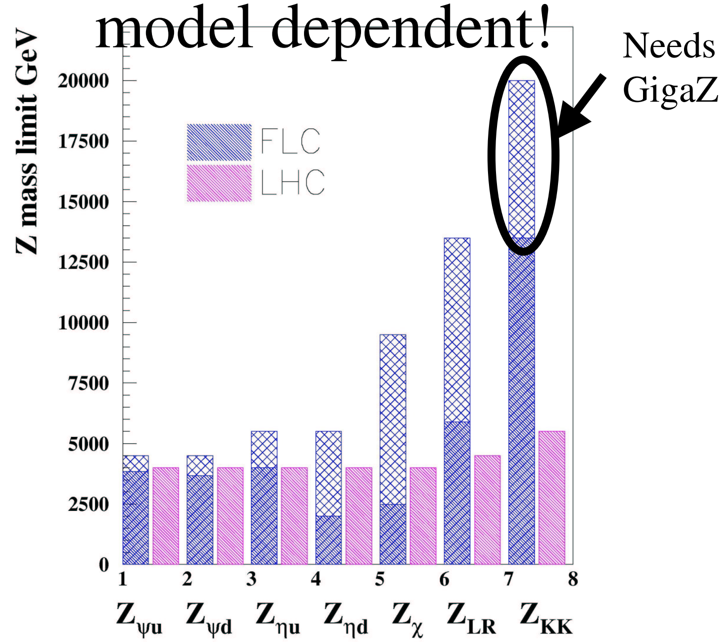
- $\mathcal{L}_{int} = 1ab^{-1}, \quad \Delta\mathcal{L}_{int} = 0.2\%$
- $P_- = 0.8, \quad P_+ = 0.6, \quad \Delta P_- = \Delta P_+ = 0.5\%$
- Δ sys(lept)=0.2%

More on new Z's

- We need to measure:
  - Z' mass and couplings
  - Determine underlying model
- Processes for Search
  - LHC: Drell-Yan
  - LC:$e^+e^- \rightarrow ff$
    - look for interference effects
- Kinematic limits:
  - LHC: $M_{Z'} < 5$ TeV, LC: $M_{Z'} < \sqrt{s}$



Results very model dependent!



Richard, hep-ph/0303107

Contact Interactions

- New interactions can be parametrized in terms of 4-fermion interactions if $\sqrt{s} \ll \Lambda$

$$L = \sum_{i,j=L,R} \eta_{ij} \frac{g^2}{\Lambda_{ij}^2} \left(\bar{f}_i \gamma^\mu f_i\right)\left(\bar{F}_i \gamma^\mu F_i\right) \qquad \Lambda \sim M_{Z'}$$

Reach in Tev: LHC LC

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_+					45	43	52	52
	Λ_-					44	42	51	51

If contact interaction is exchange of spin-1 Z', then angular distribution $(1\pm\cos\theta)^2$

95% cl limits.

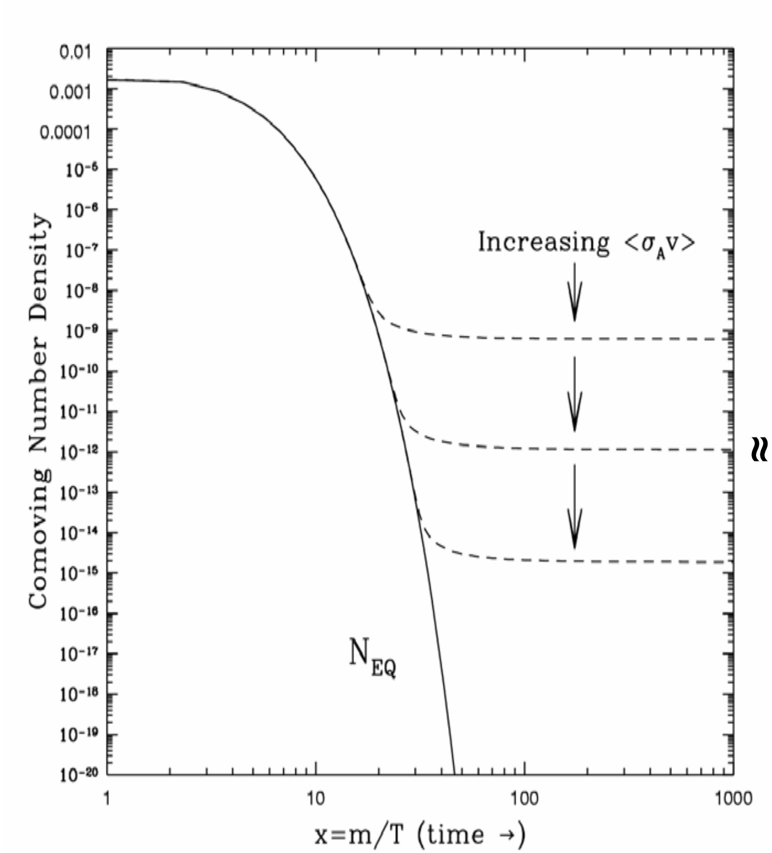
LHC: 100 fb^{-1}

LC: L=1 ab^{-1}, $\sqrt{s}$=500 GeV, P_-=.8, P_+=.6

Riemann, LHC/LC Study

SUPERWIMPS

Feng, Rajaraman, Takayama (2003)



- Consider SUSY again:
  Gravitons → gravitinos $\tilde{G}$
- What if the $\tilde{G}$ is the lightest superpartner?

WIMP → $\tilde{G}$ $\quad M_{Pl}^2/M_W^3 \sim$ month

- A month passes…then all WIMPs decay to gravitinos – a completely natural scenario with long decay times

Gravitinos naturally inherit the right density, but they interact only gravitationally – they are "superWIMPs"

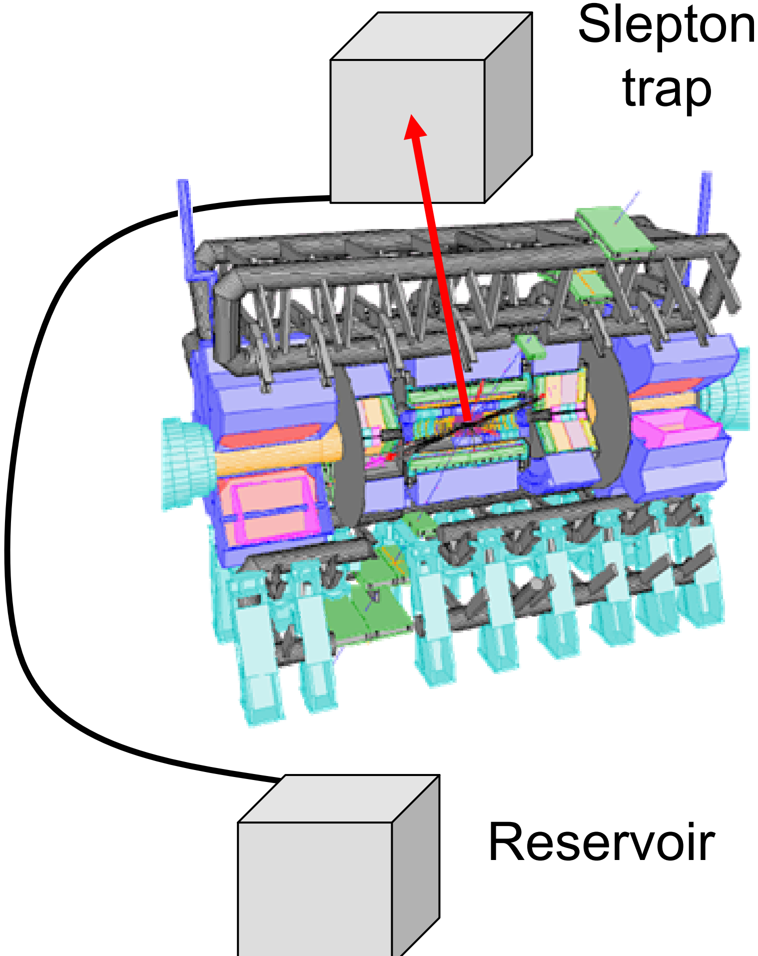
WORST CASE SCENARIO?

Looks bad – dark matter couplings suppressed by 10^{-16}

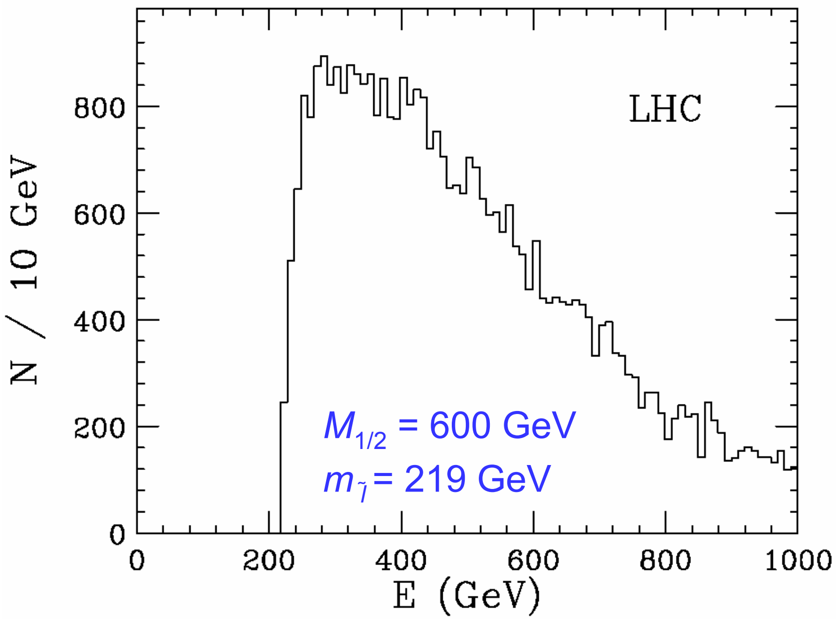
But, cosmology → decaying WIMPs are sleptons: heavy, charged, live ~ a month – can be trapped, then moved to a quiet environment to observe decays.

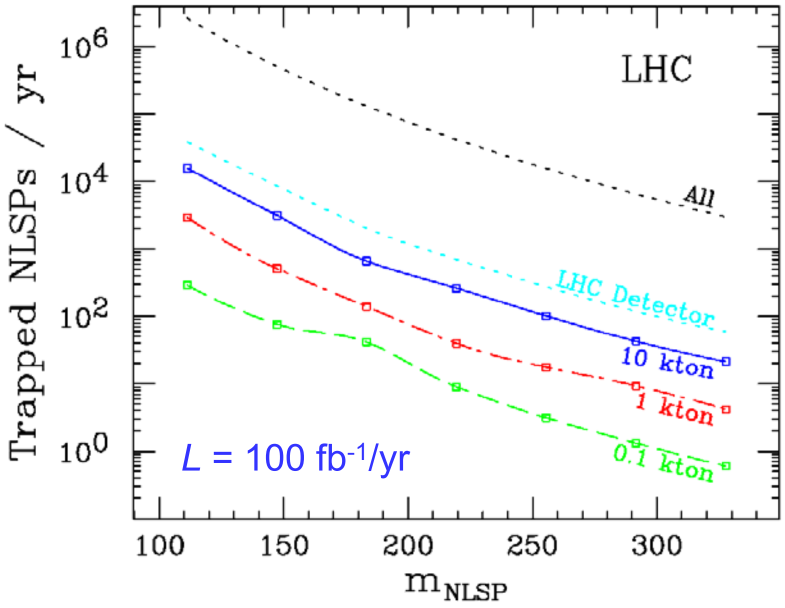
How many can be trapped?

Hamaguchi, Kuno, Nakaya, Nojiri (2004)
Feng, Smith (2004)



Large Hadron Collider

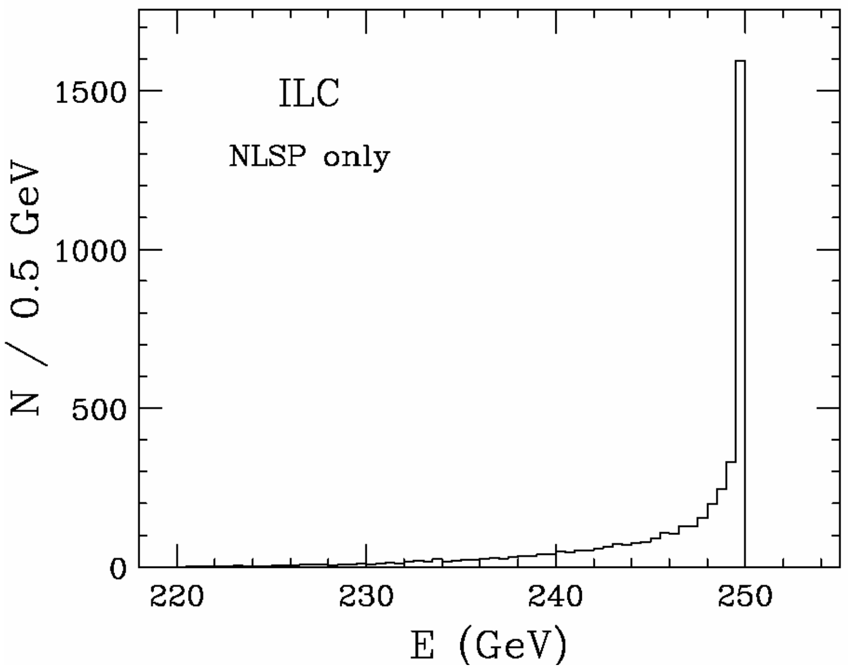


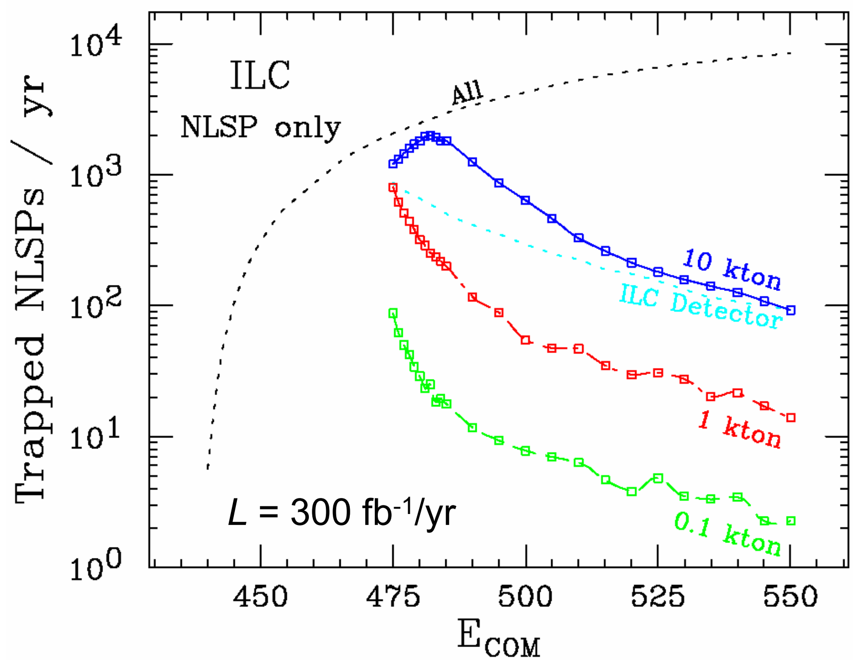


If squarks, gluinos light, many sleptons, but most are fast:
O(1)% are caught in 10 kton trap

International Linear Collider

$m_{\tilde{\tau}_R}$ 219.3 GeV } NLSP only





Can tune beam energy to produce slow sleptons:

75% are caught in 10 kton trap

Shufang Su, LCWS05

Identifying a scenario

2 suggestions from J. Ellis:

„Suppose that the LC discovers a (meta)stable massive charged particle, such as a stau in a model with a gravitino LSP. It might be that the LHC experiments would/could modify their trigger and/or even their TOF systems so as to collect these more efficiently.“

„Alternatively, suppose that the LC discovers a massive charged particle that decays rapidly into a lighter neutral particle with a very small mass difference, as occurs in models with a neutralino LSP in the coannihilation region. Perhaps the LHC experiments would/could modify their lepton p_T triggers (replacing them by some other event characteristic? at the expense of some other triggers?) so as to collect these more efficiently.“

Other ideas from previous CERN meeting:

- heavy stable charged particles (R- hadrons)
  ILC input: charginos/neutralinos (not too light but not too heavy)
  - then use GUT relation to predict m(gluino)

- heavy charginos with low-pt leptons ?
  ILC can predict chi03/chi04/chi+2 from chi01/chi02/chi+1
  if cascades at LHC are complicated mass/coupling predictions may help

- going down in energy ?
  (move from g-dominated to q-dominated pdf's to reduce bkgd if low-mass hadronic resonance exisits)

- very light rare di-lepton resonance (e.g. gg->“A”-> mumu in CPV MSSM)

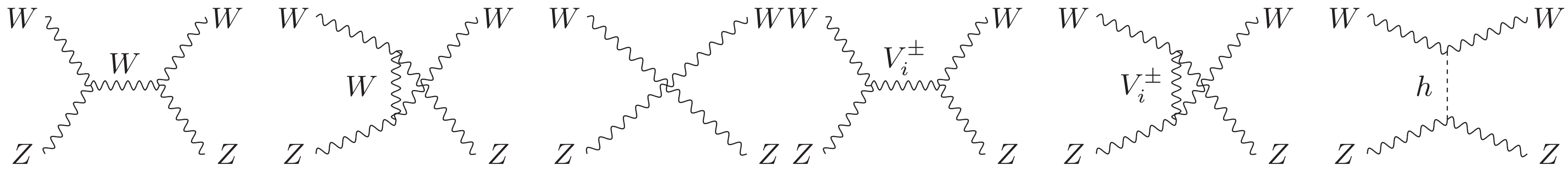
- Z’ with BR(Z’->hadrons) = 1:
  open a mass-window in jet-jet trigger

Collider Phenomenology

(Birkedal, Matchev, Perelstein)

Common feature of the Higgless models: the scale of perturbative unitarity violation is raised by new massive vector bosons whose masses and couplings are constrained by *unitarity sum rules*.

Example: $W_L Z_L$ elastic scattering



A good test → analysis of the vector boson fusion at future colliders

(the most promising channel for Higgsless models with fermion delocalization since the KK resonances are fermiophobic)

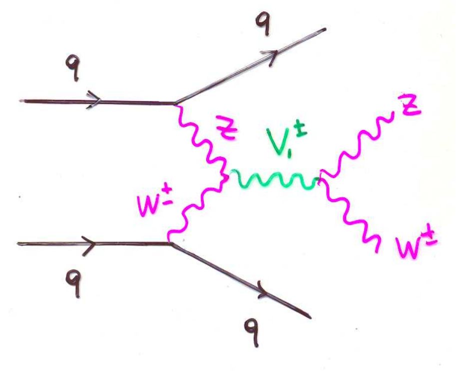
Birkedal, Matchev, Perelstein: simplifying assumption that the sum rules are saturated by the first KK resonance V^1

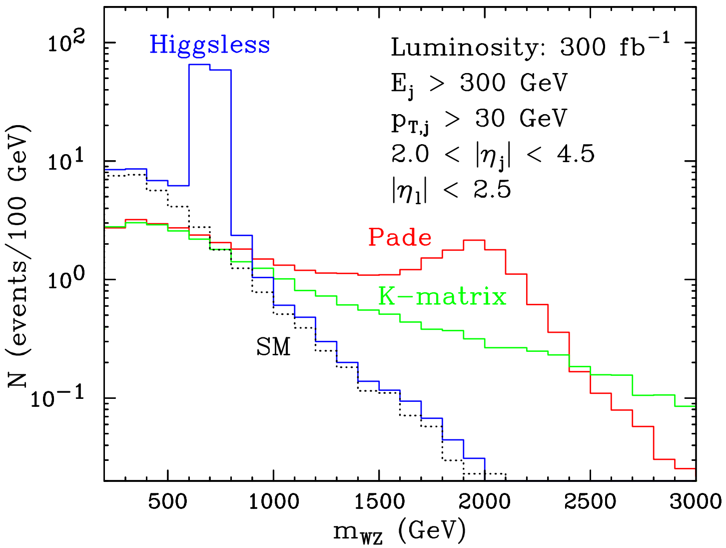
$$g_{WV^1Z} < \frac{g_{WWZ} M_Z^2}{\sqrt{3} M_V^1 M_W}, \qquad \Gamma(V^1) = \frac{\alpha (M_V^1)^3}{144 s_W^2 M_W^2}$$

a very narrow and light resonance in WZ scattering

Higgsless Models @ the LHC

(Birkedal, Matchev, Perelstein)





Typical final state includes two forward jets + a pair of vector bosons

Cuts to suppress the SM BCKGND and possible signal from Drell-Yan:

$$2 < |\eta| \leq 4.5,\ E > 300GeV,\ p_T > 30GeV$$

The gold-plated final state is $2j + 3l$+missing E_T

Discovery reach @ LHC (10 events)

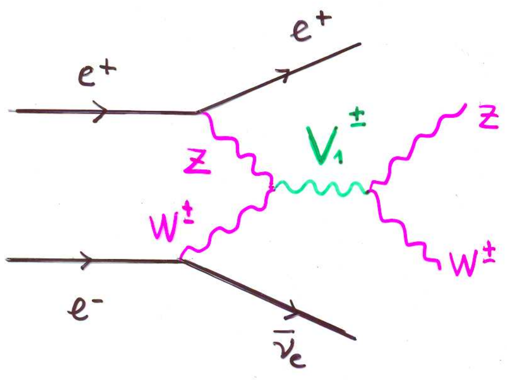
$M_V^1 \leq 550(1000)\ GeV$ with 10(60) fb^{-1}

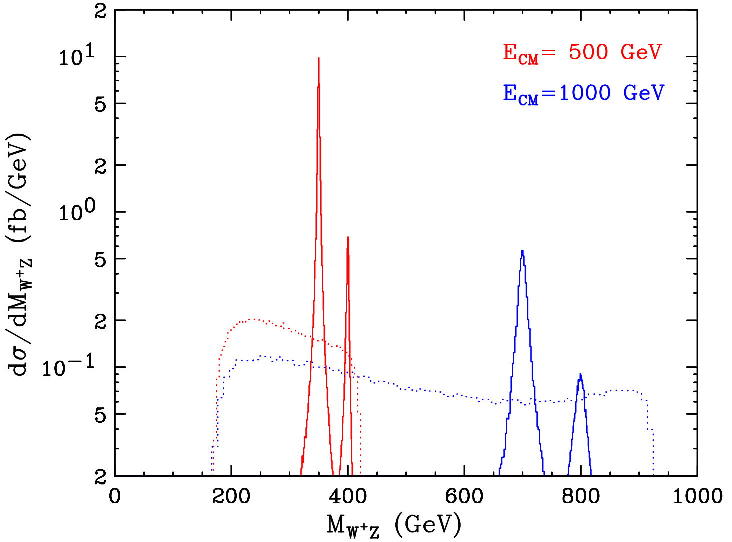
To identify the resonance as a part of a Higgsless model → test the *unitarity sum rules*: **measure of the mass and couplings → a task for the ILC**

Higgsless Models @ the ILC

(Birkedal, Matchev, Perelstein)

The first KK excitations of the Higgsless models are expected to be below 1 TeV and can be produced @ the ILC by bremsstrahlung of W and Z off the initial state e^+ and e^-.





The ILC searches appear promising.

Further studies to be done, for example: study of the W^+W^- channel, include the electron beam polarization, consider the production of longitudinally polarized gauge bosons, consider the beam energy spread issues.

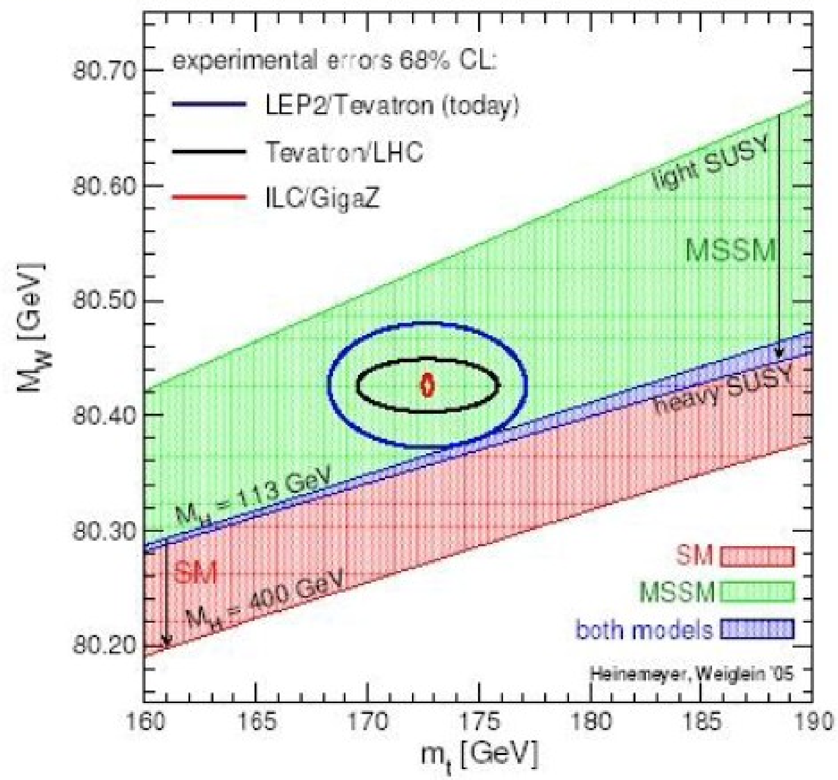
Motivation: Why is the top quark so interesting?

- Top quark sector of the SM is NOT established yet!
  - Possible anomalous couplings in $tbW, t\bar{t}Z/\gamma$
  - Does the top mass come from a single Higgs? $(y_t \Leftrightarrow m_t)$
- Top quark plays a key role in EWSB
  - Many models distinguish top from light quarks
  - Precise top mass determination is clue to New Physics

MSSM parameters varied

SM Higgs varied

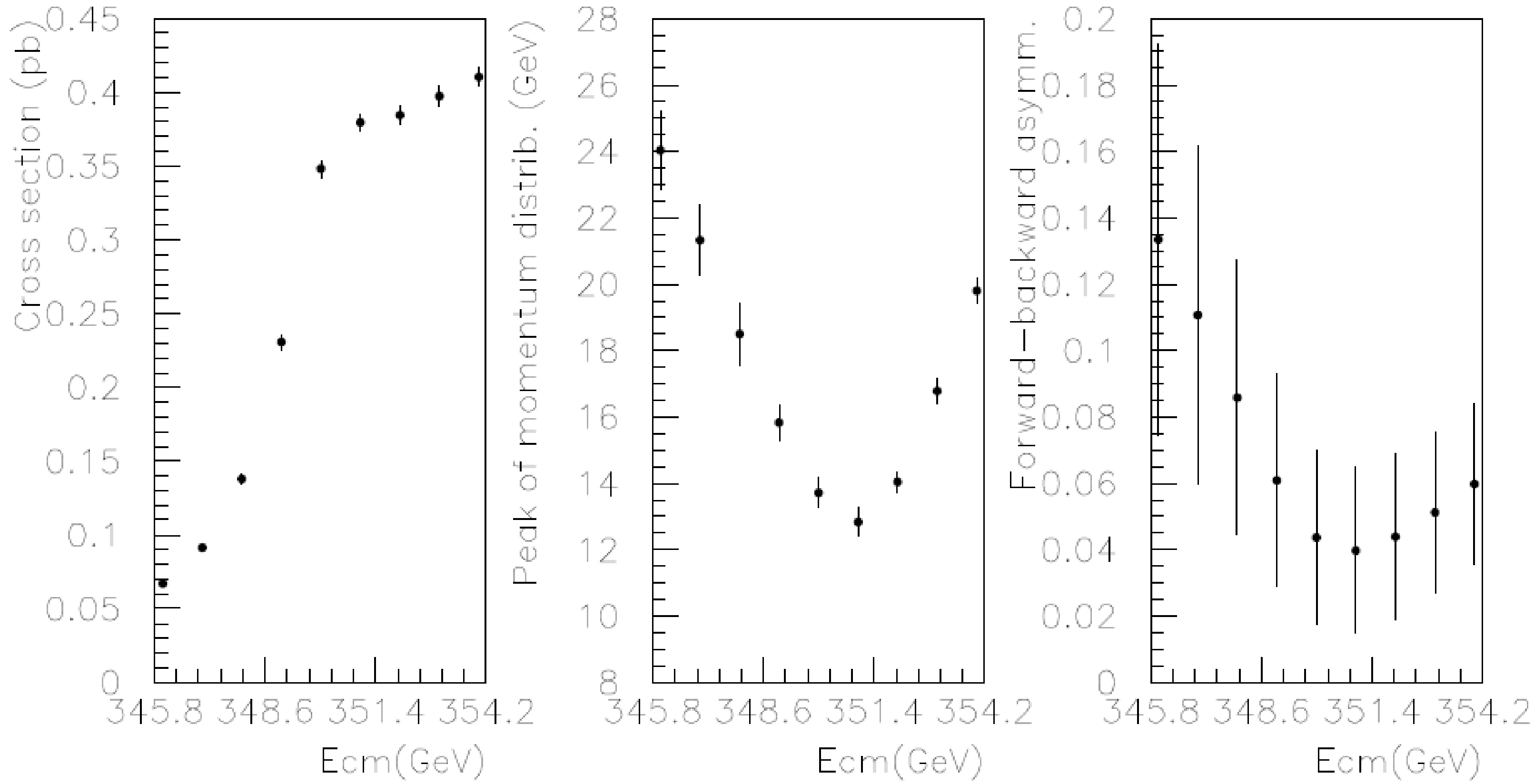
(Heinemeyer+Weiglein Snowmass)



Top Threshold: experimental studies

9+1 point threshold scan at TESLA ($\mathcal{L} = 300\ \text{fb}^{-1}$): Martinez + Miquel

Use of σ_{tot}, peak of the top momentum distribution and A_{FB} as observables:



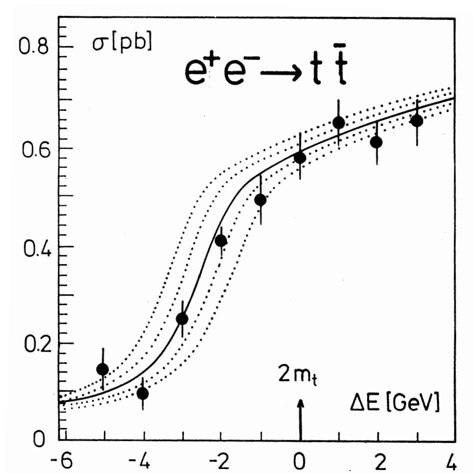
⋆ Exp. accuracy with multi-parameter fit (3% TH-error on σ_{tot}, beam spectrum known):

→ $\Delta m_t \sim 20$ MeV, $\Delta\Gamma_t \sim 30$ MeV, $\Delta\alpha_s \sim 0.0012$

High Precision Top Mass

Threshold Scan: $\sqrt{s} \simeq 350$ GeV (Phase I)

- ▷ count number of $t\bar{t}$ events
- ▷ color singlet state
- ▷ background is non-resonant
- ▷ physics quite well understood (renormalons, summations)



$\rightarrow \delta m_t^{\rm exp} \simeq 50$ MeV
$\rightarrow \delta m_t^{\rm th} \simeq 100$ MeV
(param. est. $\rightarrow$ many authors)

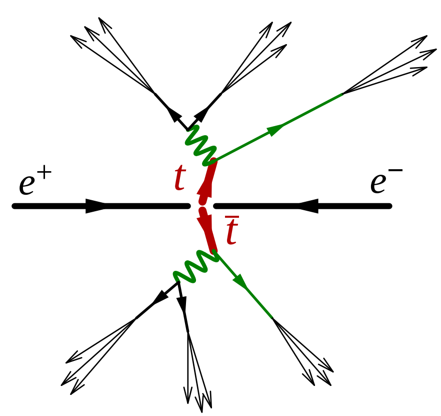
What mass?

$\sqrt{s}_{\rm rise} \sim 2m_t^{\rm thr}$ + pert.series
(short distance mass: 1S $\leftrightarrow$ $\overline{\rm MS}$)

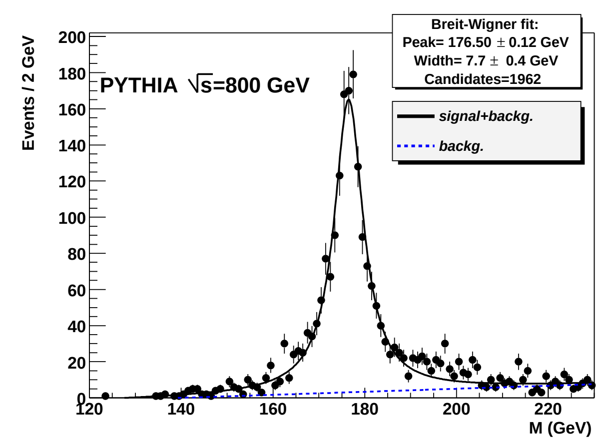
Reconstruction: any $\sqrt{s}$ (Phase I + II)

Chekanov,Morgunov:

- ▷ $e^+e^- \rightarrow 6$ jets ($y_{\rm cut}^6$)
- ▷ b-tagging
- ▷ $\vec{P}_1 + \vec{P}_2 < \Delta_p$
- ▷ $M_1 + M_2 < \Delta_M$



$\rightarrow \delta m_t^{\rm ex,stat} \simeq 100$ MeV
($\mathcal{L} = 300\,{\rm fb}^{-1}$)



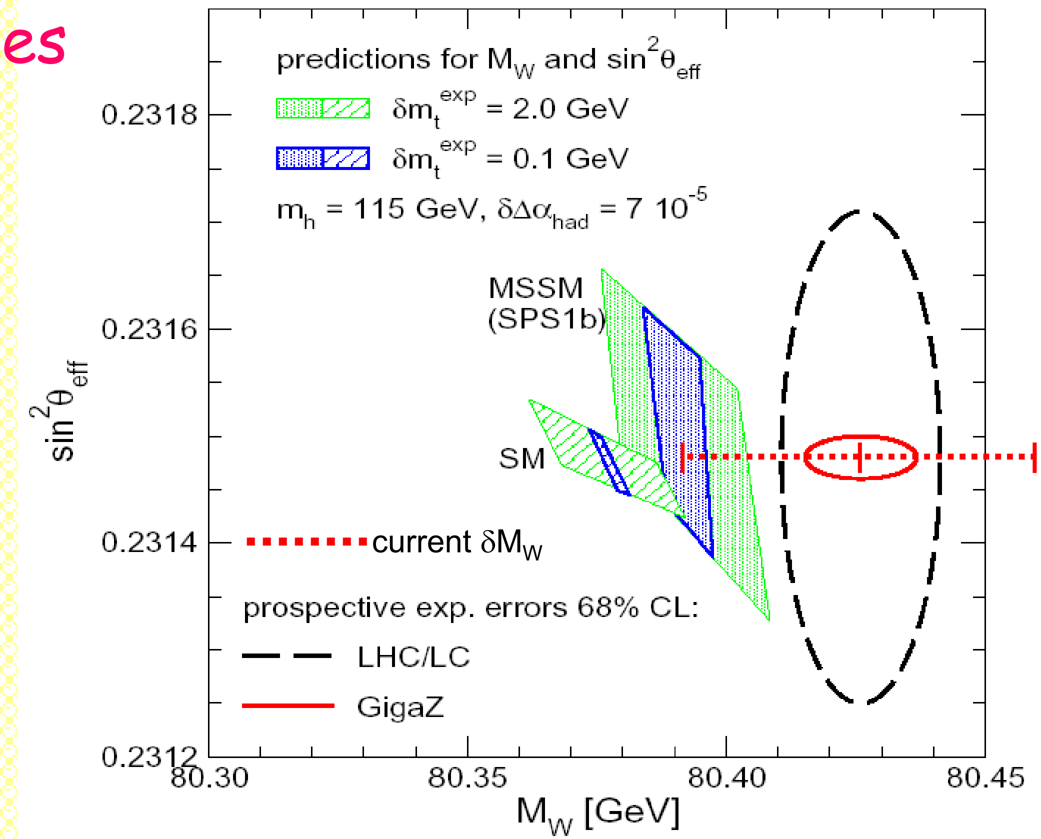
Precise m_t championed by Heinemeyer et al

(hep-ph/0306181, and LHC/LC report)

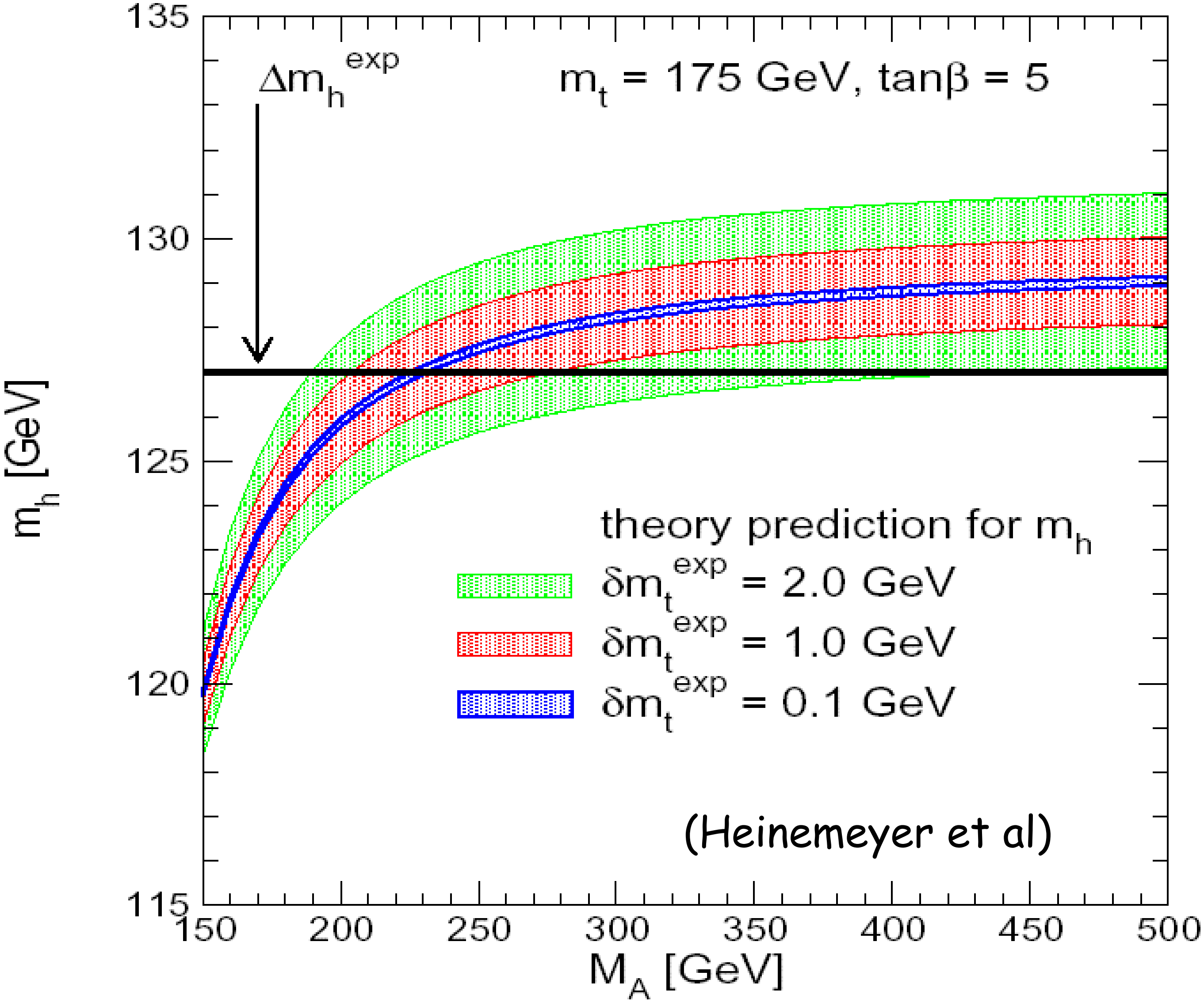
A couple of their examples

a) What it does for
The Standard Model →

"Unless $\delta m_t < 100 MeV$,
it is the dominant error
on many precision
measurements."



b) what precise m_t would do for MSSM



Example: tt-Z, tt-Photon

Comparison: lepton + jets, p_T-distribution (1σ limits)

talk by U. Baur

coupling	LHC (300 fb^{-1})	e^+e^- (snowmass)
$\Delta\widetilde{F}^{\gamma}_{1V}$	$^{+0.043}_{-0.041}$	$^{+0.047}_{-0.047}$, 200 fb^{-1}
$\Delta\widetilde{F}^{\gamma}_{1A}$	$^{+0.051}_{-0.048}$	$^{+0.011}_{-0.011}$, 100 fb^{-1}
$\Delta\widetilde{F}^{\gamma}_{2V}$	$^{+0.038}_{-0.035}$	$^{+0.038}_{-0.038}$, 200 fb^{-1}
$\Delta\widetilde{F}^{\gamma}_{2A}$	$^{+0.16}_{-0.17}$	$^{+0.014}_{-0.014}$, 100 fb^{-1}
$\Delta\widetilde{F}^{Z}_{1V}$	$^{+0.34}_{-0.72}$	$^{+0.012}_{-0.012}$, 200 fb^{-1}
$\Delta\widetilde{F}^{Z}_{1A}$	$^{+0.079}_{-0.091}$	$^{+0.013}_{-0.013}$, 100 fb^{-1}
$\Delta\widetilde{F}^{Z}_{2V}$	$^{+0.26}_{-0.34}$	$^{+0.009}_{-0.009}$, 200 fb^{-1}
$\Delta\widetilde{F}^{Z}_{2A}$	$^{+0.35}_{-0.35}$	$^{+0.052}_{-0.052}$, 100 fb^{-1}

$$\Gamma^V_\mu = ie\left\{\gamma_\mu\left(\tilde{F}^V_{1V} + \gamma_5\tilde{F}^V_{1A}\right) + \frac{(q-q')_\mu}{2m_t}\left(\tilde{F}^V_{2V} + \gamma_5\tilde{F}^V_{2A}\right)\right\}$$

- $\mathcal{O}(\%)$ precision at ILC
- polarization crucial: $P(e^-) = 0.8$

General needs:

$\longrightarrow$ coherent conventions
$\longrightarrow$ fully exploit of polarization
$\longrightarrow$ vary more than 1 coupling
$\longrightarrow$ optimized observables
$\longrightarrow$ QCD corrections

ttV at the LHC and the ILC

coupling	LHC, 300 fb^{-1}	e^+e^-
$\Delta\widetilde{F}^{\gamma}_{1V}$	$^{+0.043}_{-0.041}$	$^{+0.047}_{-0.047}$, 200 fb^{-1}
$\Delta\widetilde{F}^{\gamma}_{1A}$	$^{+0.051}_{-0.048}$	$^{+0.011}_{-0.011}$, 100 fb^{-1}
$\Delta\widetilde{F}^{\gamma}_{2V}$	$^{+0.038}_{-0.035}$	$^{+0.038}_{-0.038}$, 200 fb^{-1}
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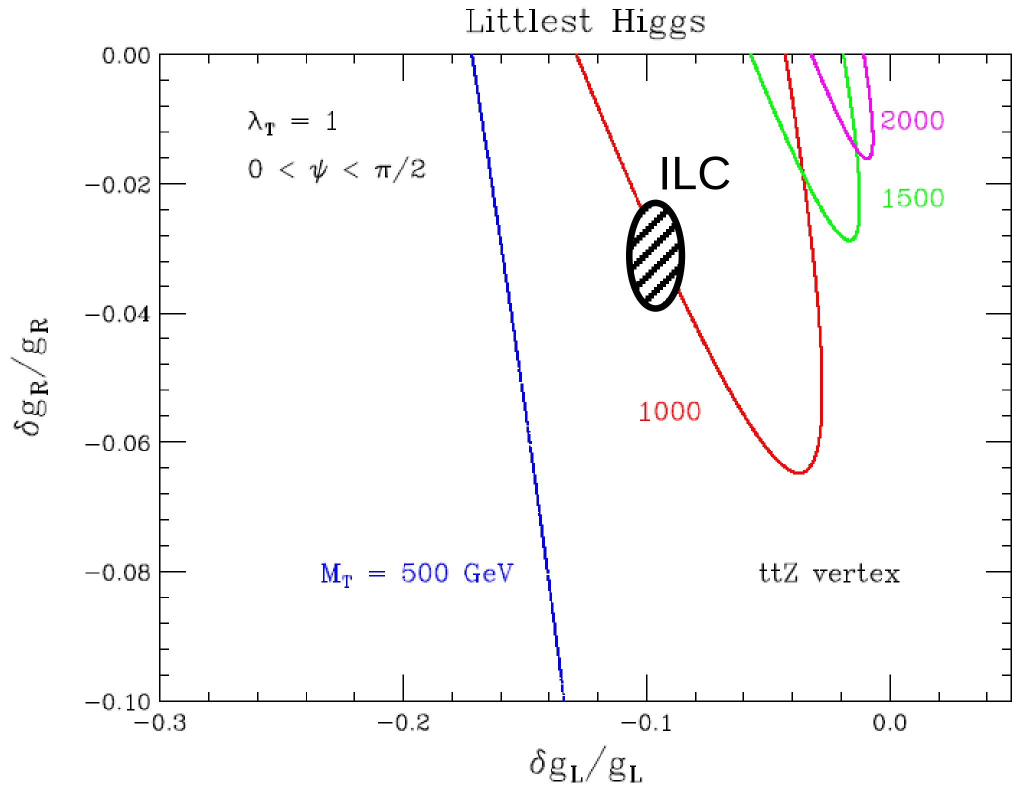


U. Baur

- Example: LHC (ILC) can measure F_{1Z} to 50% (1%), F_{2Z} to 8% (1%)
- Improvement from e^- polarization by a factor of 2-3 (talk by G. Moortgat-Pick)
  - ! Positron polarization not studied $\Rightarrow$ needs to be done!
  - ! Correlated analysis done only for LHC; ILC study varies couplings independently

Electroweak precision observables (EWPO):

– the W boson mass M_W
– the effective leptonic mixing angle $\sin^2\theta_{\rm eff}$

and in addition:

– the top quark mass m_t
– the Higgs boson mass m_h

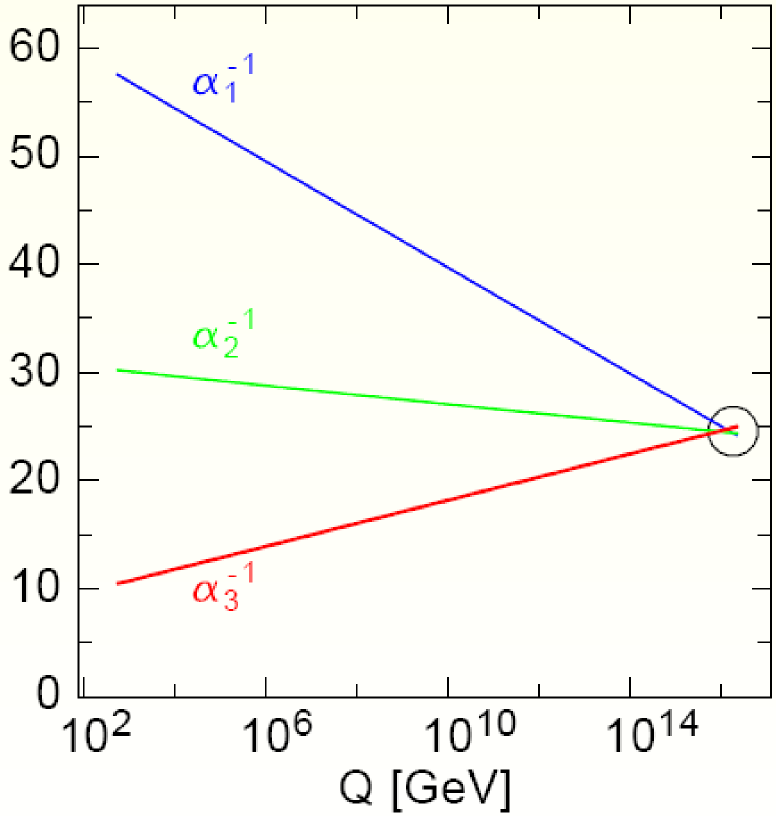
Experimental errors:

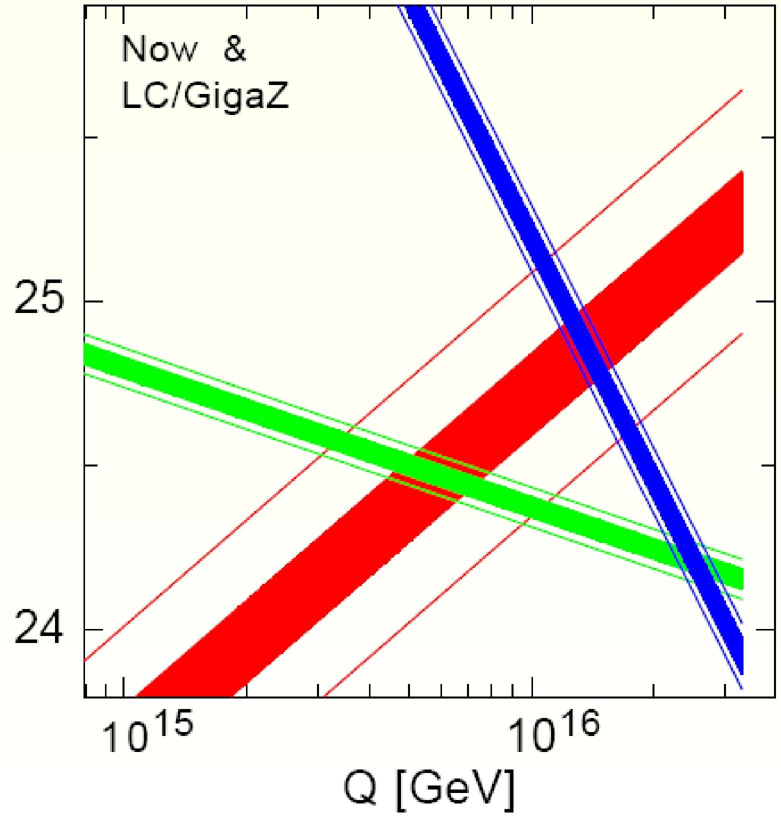
	today	LHC	LC	GigaZ
$\delta\sin^2\theta_{\rm eff}(\times 10^5)$	17	14-20	–	1.3
δM_W [MeV]	34	15	10	7
δm_t [GeV]	5.1	1-2	0.2	0.1
δm_h [MeV]	–	200	50	–

$\Rightarrow$ LC more capable than LHC
$\Rightarrow$ EWPO alone: no LHC/LC interplay

Motivation: α_s measurement

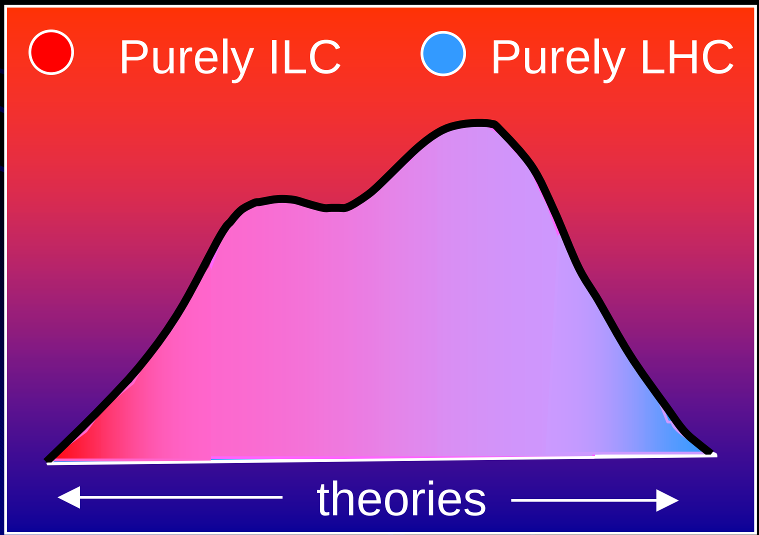
- High precision α_s determination is crucial for accurate prediction of signal/background processes.
- α_s the least precise input for coupling unification in SUSY, GUT's:





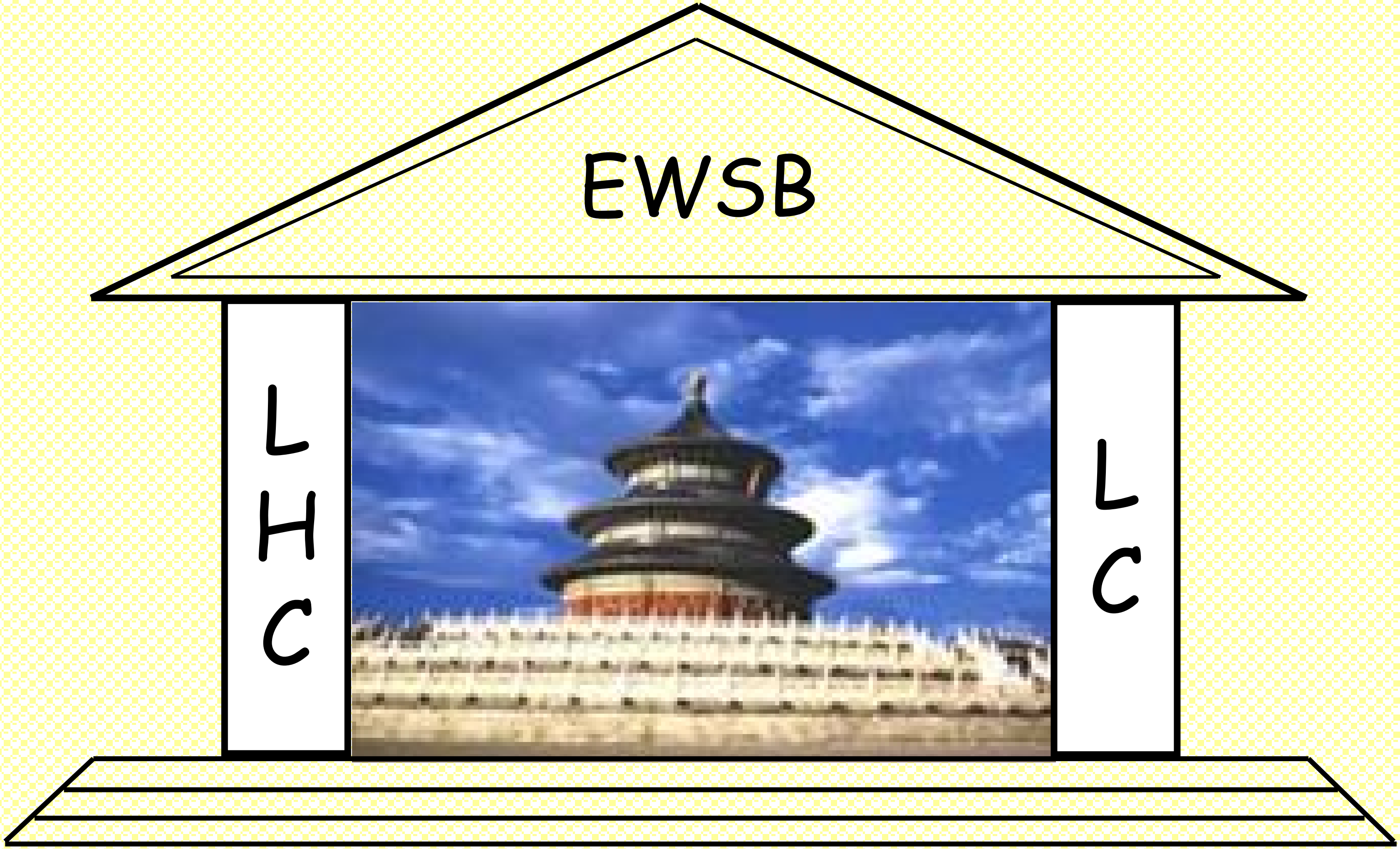
The Energy Frontier: why ILC?

- We expect the greatest richness at the energy frontier
- Few phenomena will manifest themselves in only one machine



- We will build on the foundation of LHC to make major discoveries at ILC

2020. Both pillars needed to see to the Temple of Unification



We need the LHC asap,
for lots of very good reasons.

We need 2 LCs

The TeV International Linear Collider,
also asap.

Then a multi-TeV CLIC

+ (maybe) a Larger Hadron Collider