Physics at International Linear Collier
- Complementarity with LHC Physics

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Why Linear Collider?

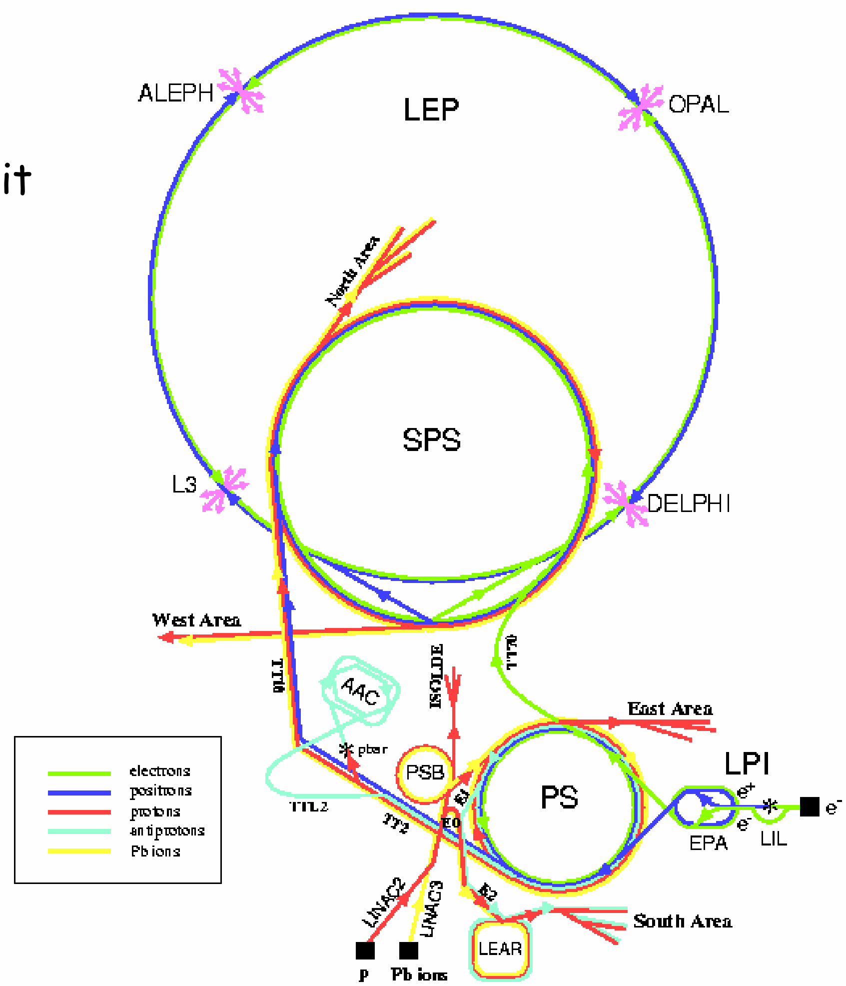
Highest energy e+e- collider: LEP (Large Electron Positron collider @ CERN 1989-2000)
Beam energy: 45.6-104 GeV
Storage ring circumference: 27 km

Charged particles accelerated in a curved orbit
➔ Synchrotron radiation

Its energy loss*:
→ $\alpha\ E^4/r$

Limiting factor for going to higher E

Solution ➔ Linear collider



* LHC uses the same LEP tunnel but the proton energy loss is 10^{-13} smaller than electron at the same energy

e+e- Linear Colliders

1st high energy linear collider (1989-1998):

- SLC (SLAC Linear Collider, $\sqrt{s}$ up to 50 GeV)
- Competitor of LEP

Regional Linear Collider Projects:

- TESLA (Teraelectronvolt Energy Superconducting Linear Accelerator)
- NLC (Next Linear Collider)
- Global Linear Collider (GLC)

International Linear Collider (ILC):

- World wide project
- Superconducting radio-frequency technology recommended in Aug. 2004
- Reference Design Report (Physics, Accelerator, Detector) released in 2007

Compact LInear Collider (CLIC):

- Nominal $\sqrt{s}$=3 TeV (for physics up to multi-TeV)

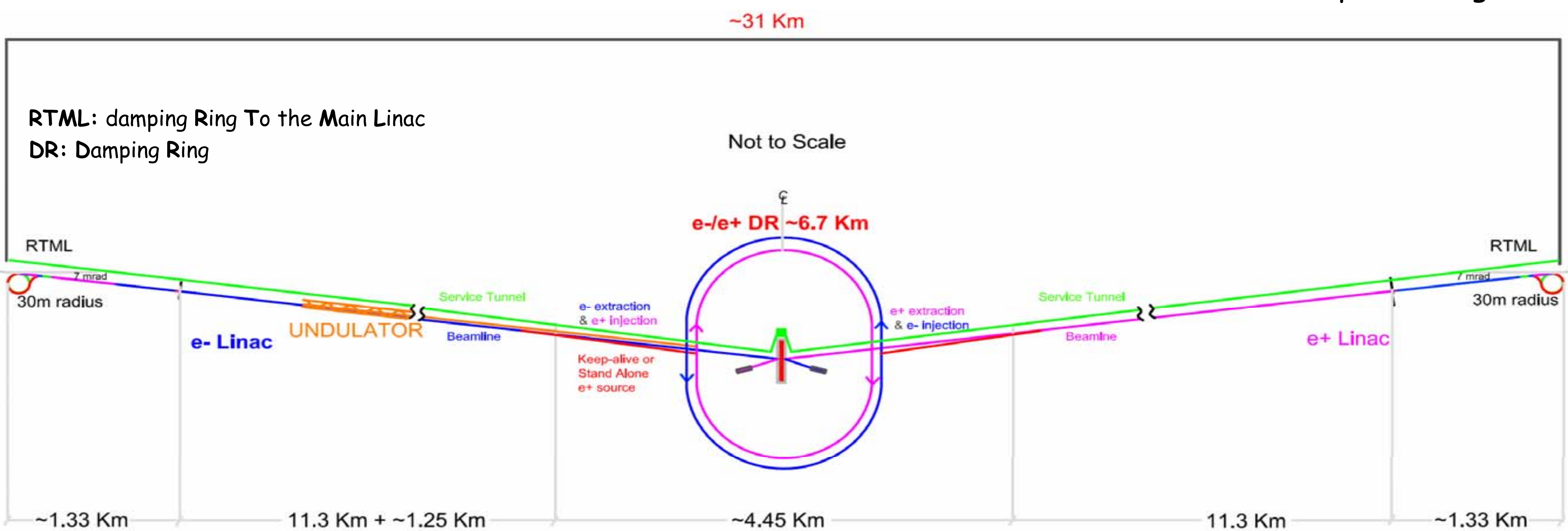
The Current Status of the ILC

Baseline design:
- $\sqrt{s}$=200-500 GeV, upgradeable to 1 TeV
- High luminosity: $2 \cdot 10^{34}$ cm^{-2}s^{-1} [SLC: $2.5 \cdot 10^{30}$ cm^{-2}s^{-1}]
  - ➔ 500 fb^{-1} in 1st 4 years
- Polarized beams: (e-: 80%, e+: 60%)
- e^-e^-, $\gamma\gamma$ options

Site study/selection on going

Cost estimation (2007): ~6.6b

Use 16,000 superconducting cavities to accelerate electrons and positrons to 99.9999999998 % of the speed of light



Schematic Layout of the 500 GeV Machine

Quasi-Ideal Detectors for Discovery & Precision

- Vertex detector:
  - Heavy flavors (b,c,t) tagging
  - ~1/5 r, ~1/30 pixel size (LHC), $\sigma_{\rm ip} = 5\mu{\rm m} \oplus 10\mu{\rm m}/p\sin^{3/2}\theta$
- Tracking detector:
  - excellent momentum (P) resolution
  - ~1/6 material, ~1/10 resolution (LHC),
  - $\sigma(1/p) = 5\times10^{-5}/\text{GeV}$ (1/10 LEP)
- Calorimetry: high granularity
  - ~1/200 (LHC)

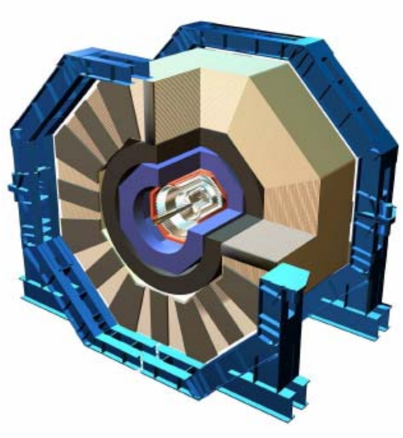
➔ **Particle Energy Flow:**
~1/2 jet resolution (LHC)
$\sigma_E/E = 0.3/\sqrt{E(\text{GeV})}$

- Muon identification capability
- Hermeticity
- Precise diagnostics for initial state (polarization, lumi, energy)

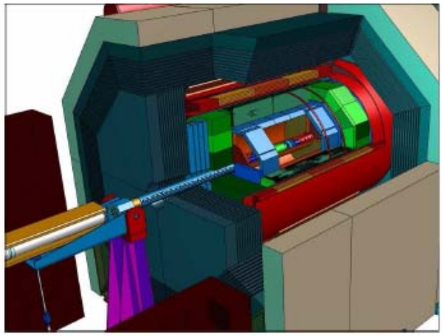
Four Detector Concepts

Now merged as ILD

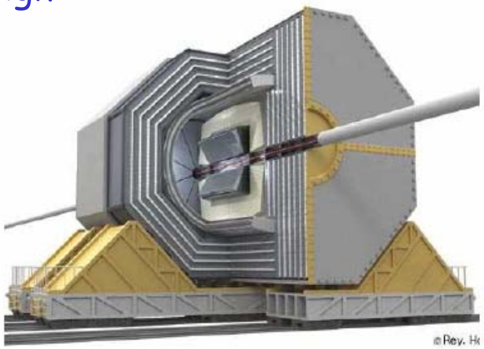
Adapted from TESLA design



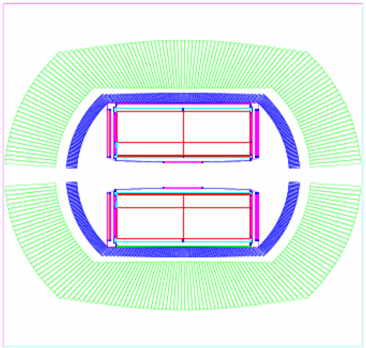
SiD(Sillicon Detector)



LDC(Large Detector Concept)



GLD(Global Large Detector)



4th

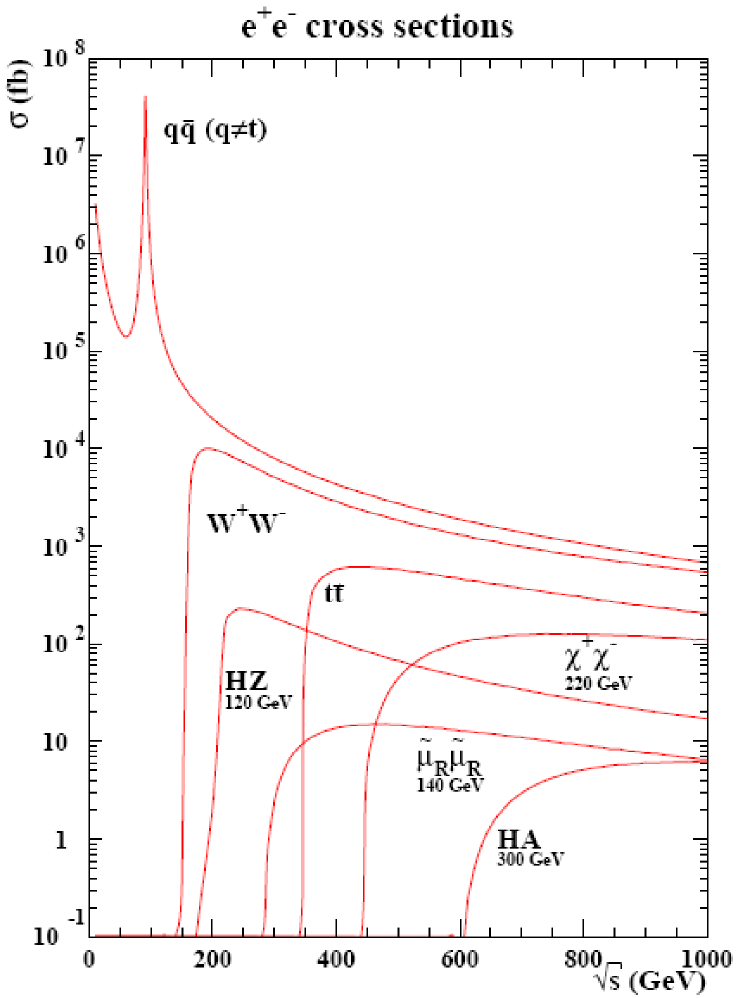
Component \ Concept	SiD	LDC	GLD	4ème
Tracking	Silicon	TPC	TPC	TPC
Magnetic field	5T	4T	3T	3.5T
ECAL	SiW	SiW	W/Scintillator	Scintillant & Cerenkov

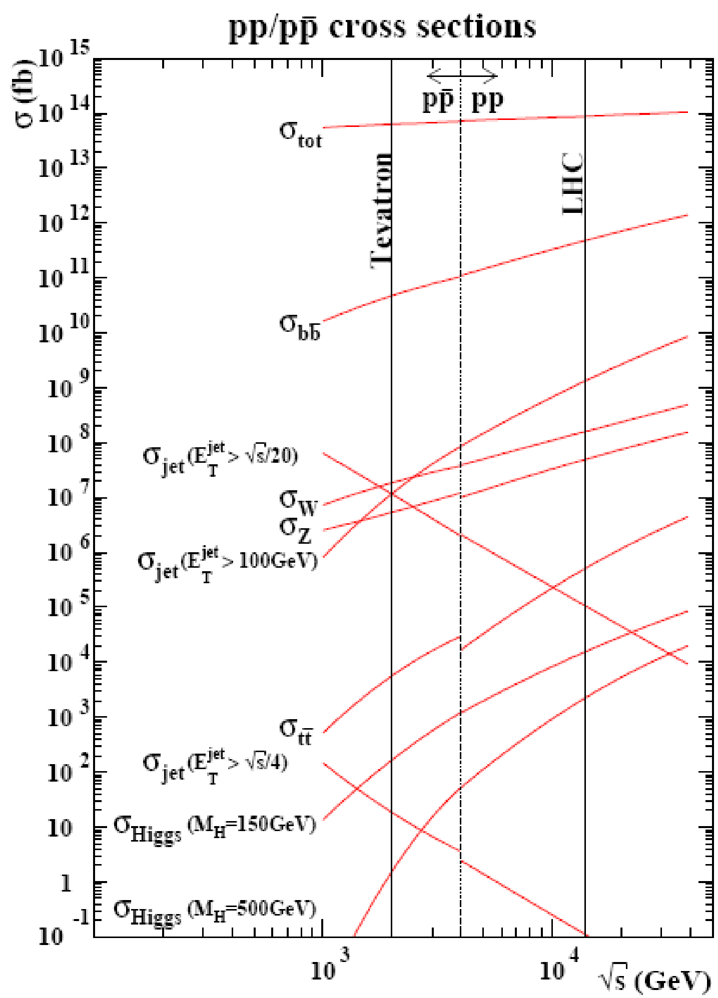
Other differences: Size, Muons: instrumented iron or double solenoid

→R&D to optimize performance & price and to make choice

(One interaction point → at most two detectors in push-pull option)

Clean Experimental Environment (1)





σ_{qqbar} < 10 pb
$\sqrt{s} \geq 350$ GeV → a top factory

σ_{tot} ~ 80 mb
➔ 10^{10} more "noisy" than @ ILC

Clean Experimental Environment (2)

ILC:

Point-like initial beams
Well defined/known $\sqrt{s}$
Event rate/s = $\sigma \cdot L$
$< 10[pb] \cdot 2 \cdot 10^{34}[cm^{-2}]$
$= 0.2$

➔ ILC can record every interaction without trigger

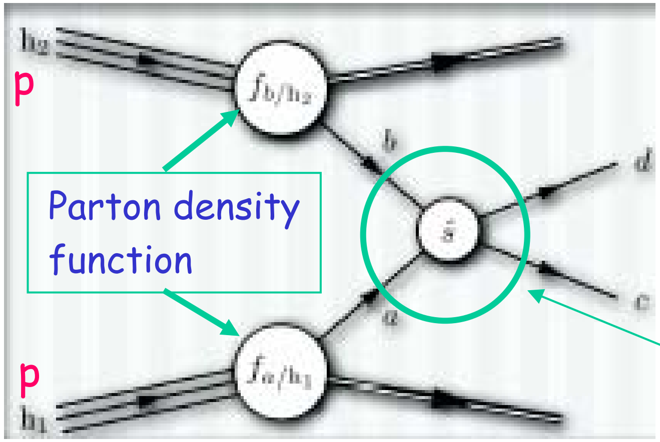
LHC:

Proton (composed) initial beams
Fractional $\sqrt{s}$ involved in parton interactions

Event rate/s = $\sigma \cdot L$
$\sim 80[mb] \cdot 10^{34}[cm^{-2}]$
$\sim 10^9$

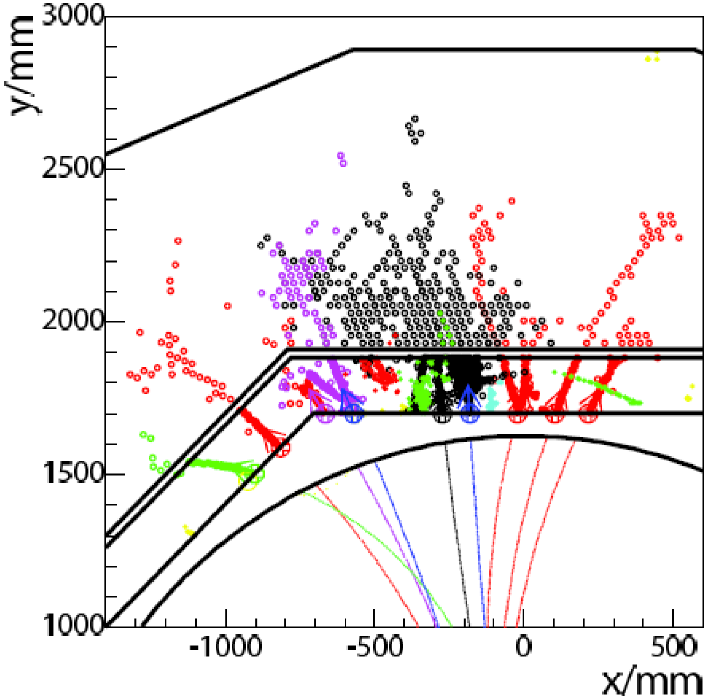
➔ Need 10^7 rate reduction (trigger)
➔ Danger to miss small rate/P_T New Physics
➔ Challenge in data handling

Bunch distance: 25 ns
➔ 25 interactions / bunch
➔ Event pile-up (800 charged particles $|\eta|<2.5$)
+ underlying events



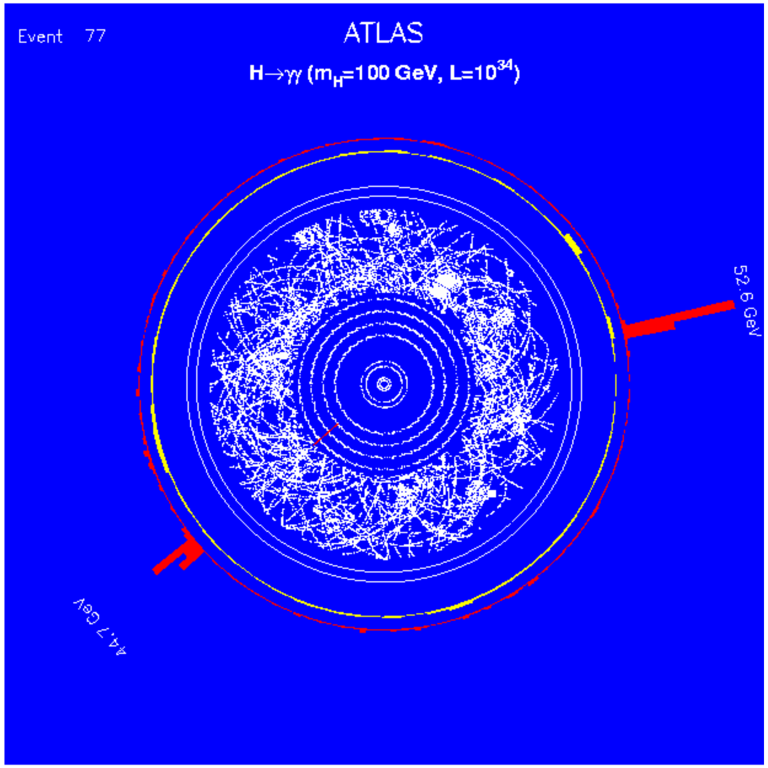
Clean Experimental Environment (3)

M.A. Thomson, physics/0607261



Pandora PFA (Particle Flow Algorithm)
100GeV jet (MOKKA simulation)
TESLA TDR detector

A simulated H→γγ event at ATLAS



http://atlas.web.cern.ch/Atlas/documentation/divers_poster/lhc/lhc.html

Selected Physics Topics at ILC

Main missions for present and future H.E. colliders:

- Clarify the Higgs sector (ElectroWeak Sym. Breaking mechanism)

- Search for new physics at the TeV scale (e.g. SUSY)

- Look for Dark Matter (DM) candidate(s)

Higgs Physics at ILC

Current limits on Higgs mass:

- Direct search (LEP): >114.4 GeV (95%CL)
- From precision data (radiative corrections): <154 GeV (95%CL)

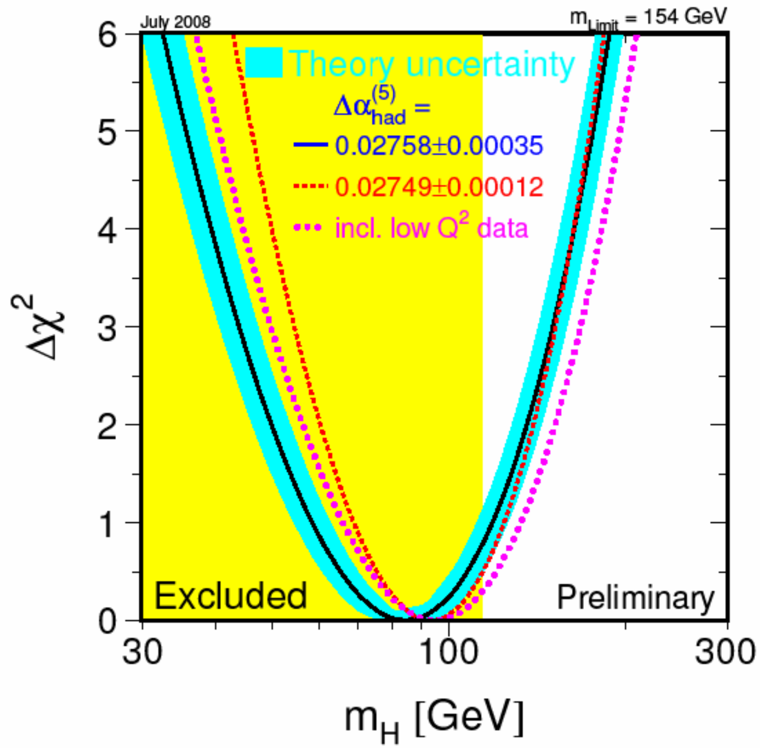
Precision measurements of Higgs properties at ILC

- Higgs mass
- Higgs spin and CP property
- Decay branching fractions
- Total decay width
- Coupling to gauge bosons
- Yukawa coupling to top quarks
- Trilinear Higgs couplings

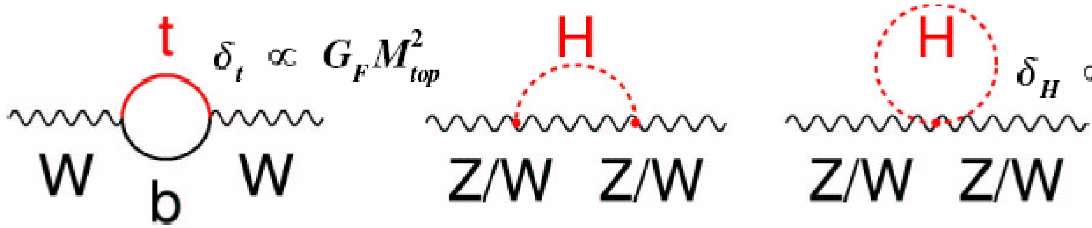
Constraints on SM m_H from Precision Data (1)

Use 17 input observables:

- Z lineshape (5): M_Z Γ_Z σ_h^0 Γ_{had}/Γ_l A_{FB}^l
- tau polarisation - A_e(1)
- left-right asymm -A_e (1)
- Z (b,c) properties (6): R_b^0 R_c^0 A_{FB}^b A_{FB}^c A_b A_c
- $\sin^2\vartheta_{eff}^{lept}(Q_{FB}^{had})$ (1)
- W properties (2): M_W Γ_W
- top quark mass (1) m_t=172.5±1.2 [GeV]



Sensitivity on m_t, m_H from EW radiative corrections:



$\delta_t \propto G_F M_{top}^2$ $\delta_H \propto \ln \frac{M_{Higgs}}{M_W}$

Constraints on SM m_H from Precision Data (2)

ICHEP 2008

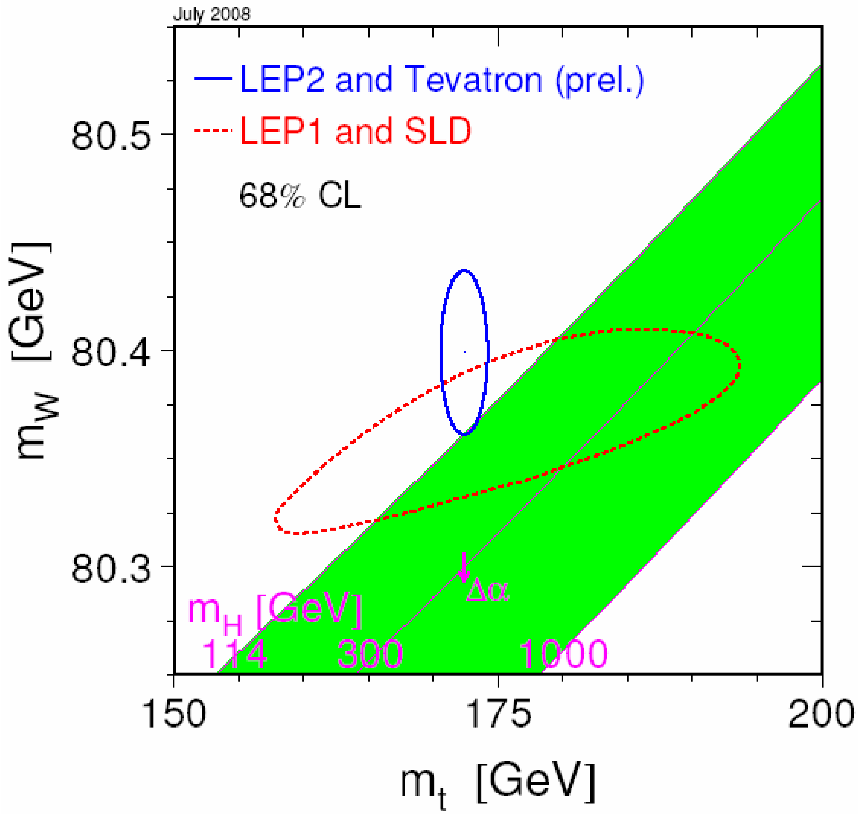
$$m_H = 84^{+34}_{-26}\ \mathrm{GeV} \quad < 154\ \mathrm{GeV}\ @\ 95\%\ \mathrm{CL}$$

If δm_t $1.2 \to 1.0$ GeV

$$m_H = 84^{+34}_{-26}\ \mathrm{GeV} \quad < 153\ \mathrm{GeV}\ @\ 95\%\ \mathrm{CL}$$

If δM_W $25 \to 15$ MeV

$$m_H = 71^{+25}_{-20}\ \mathrm{GeV} \quad < 119\ \mathrm{GeV}\ @\ 95\%\ \mathrm{CL}$$

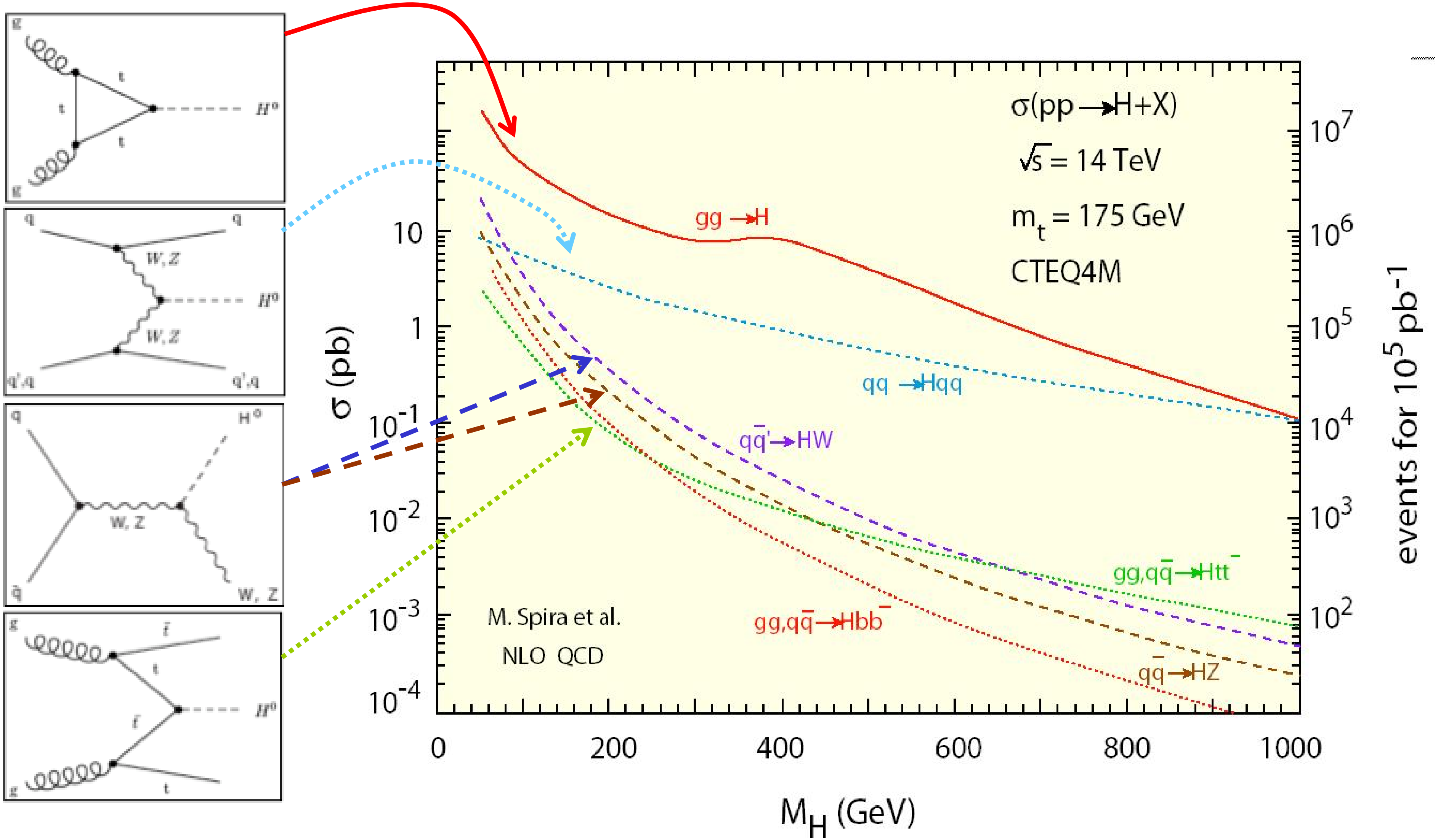


This illustrates the importance of

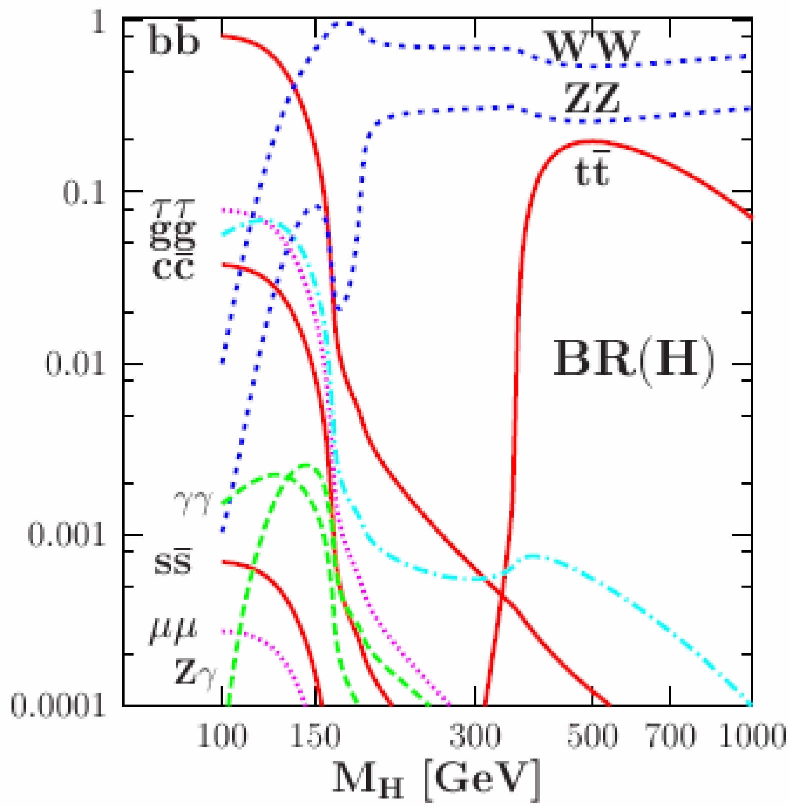
- precision measurements

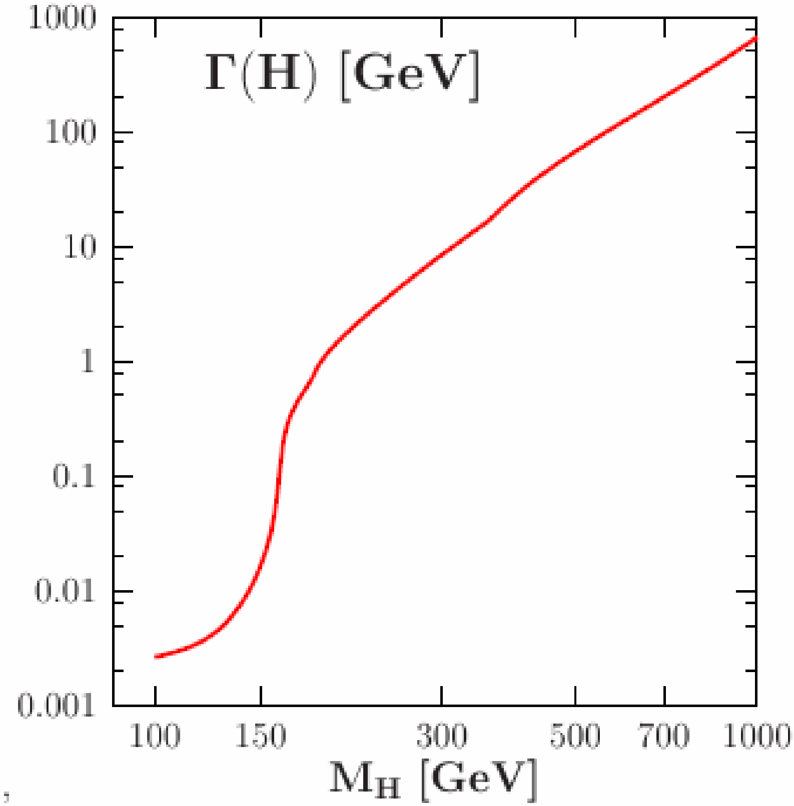
- complementarity of different data

SM Higgs Productions at LHC



SM Higgs Branching Fractions, Decay Width



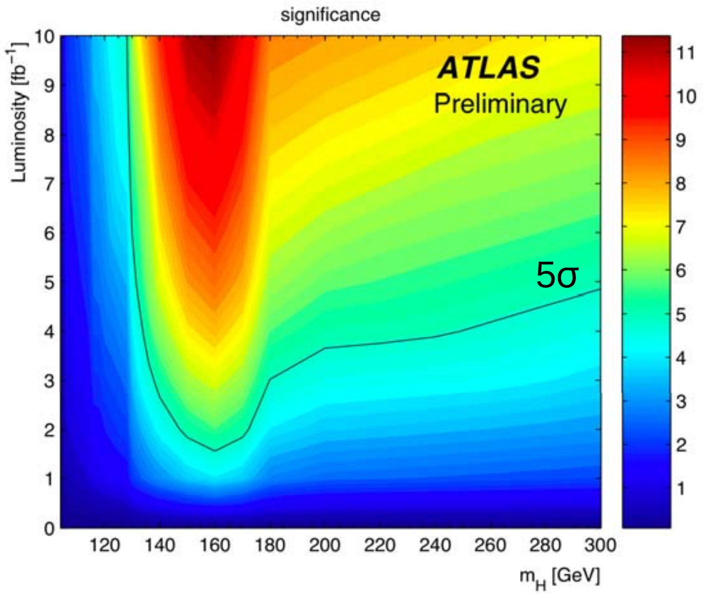


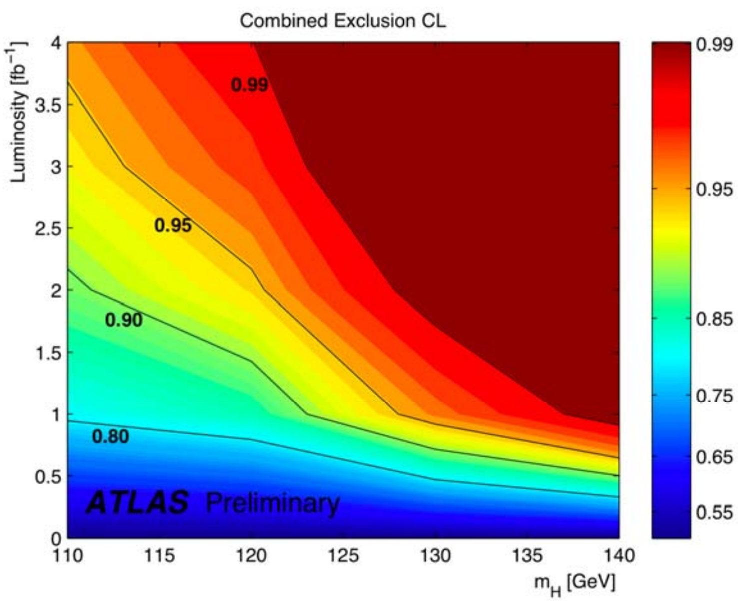
➔ Dominant decay modes:
- bb_{bar} at low mass (<140GeV)
- WW at high mass (>140GeV)

➔ Narrow resonance at low mass
smaller than intrinsic detector resolution

➔ Broad structure at high mass

Expected SM H Searches with 1st LHC Data



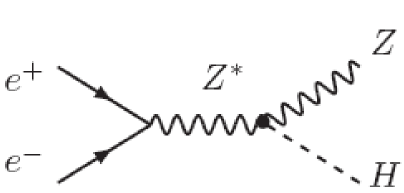


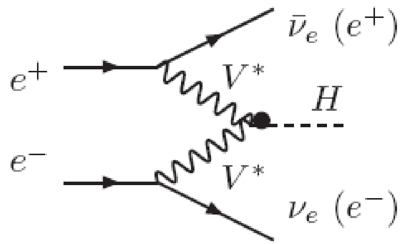
Combining several analysis channels

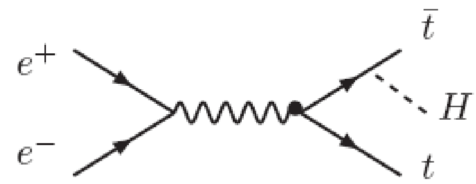
➔ Discovery (5σ):
- Need ~20 fb^{-1} to probe down to m_H=115 GeV
- 10 fb^{-1} will allow 5σ discovery if m_H=127–440 GeV
- 3.3 fb^{-1} : 5σ discovery for m_H=136–190 GeV
- Just under 2 fb^{-1} : 5σ discovery for m_H=160 GeV

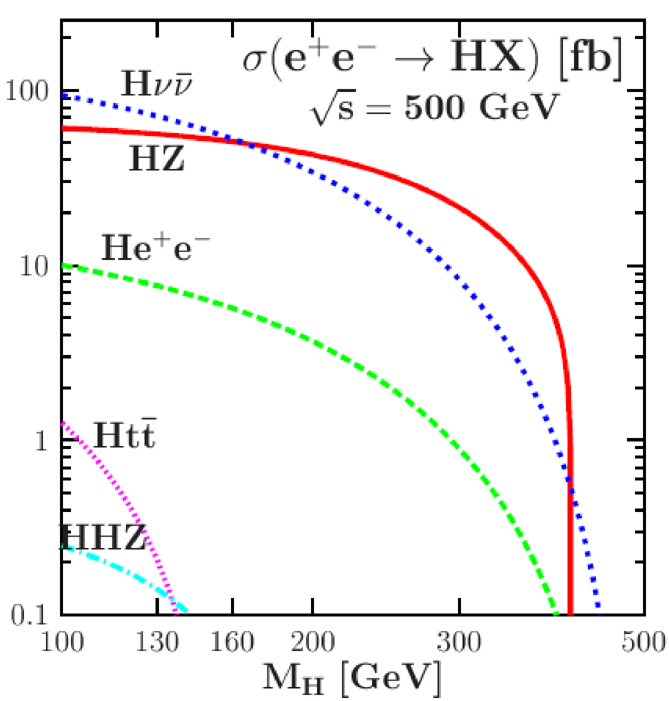
➔ Exclusion:
- 2.8 fb^{-1} will allow exclusion at 95% CL of m_H=115 GeV (i.e. just above the LEP limit)
- 2 fb^{-1} : exclusion at 95% CL in m_H=121–460 GeV
- Less than 2 fb^{-1} should be enough to exclude region around $m_H \approx 2m_W$

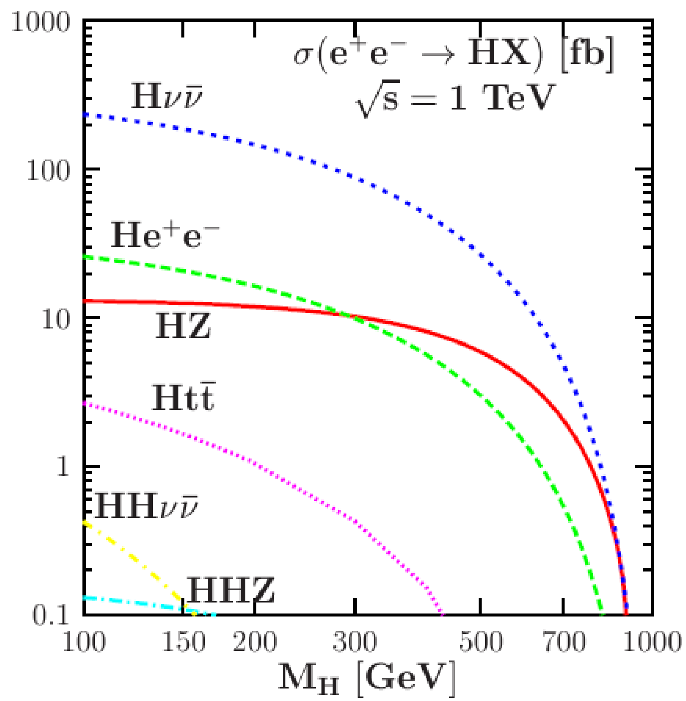
SM Higgs Production at ILC

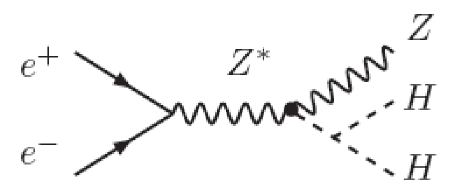


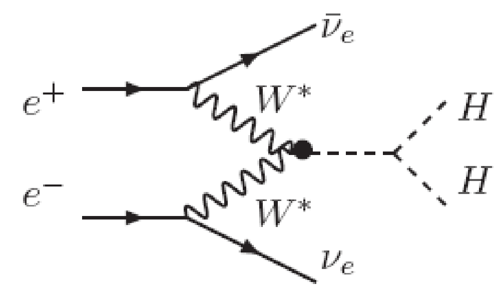






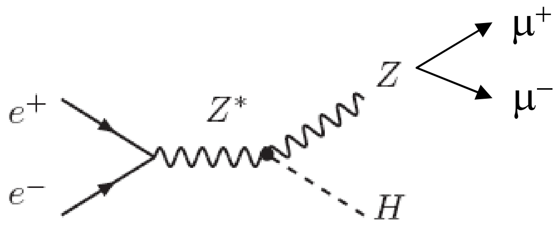






➔ Higgs-strahlung process $e^+e^- \to HZ$: dominant golden process at $\sqrt{s}$=500GeV

Precise Higgs Mass Measurement at ILC (1)



Golden channel: $Z \rightarrow \mu^+\mu^-$ in Higgs-strahlung process

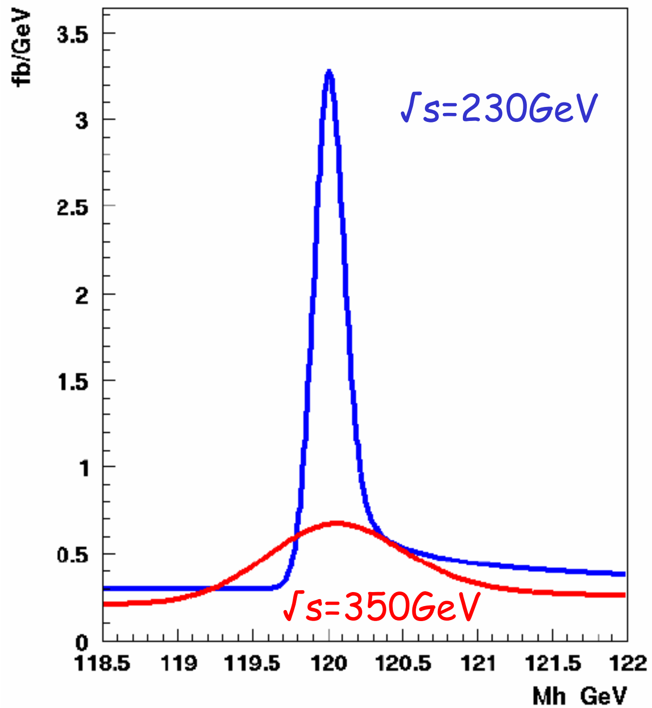
Recoil mass method:
$$m_H^2 = p_H^2 = (p_{e^+} + p_{e^-} - p_Z)^2 = s + m_Z^2 - 2E_Z\sqrt{s}$$

No Higgs decay information used ➔ **Model independent analysis**

At ILC, the beam energy (E_{beam}) is tunable

For a 120 GeV Higgs, one can tune E_{beam} to an optimum value:

$E_{beam} \sim m_H + 100$ GeV
~ 230 GeV



Precise Higgs Mass Measurement at ILC (2)

Experimental condition:

$\sqrt{s}$=230 GeV

L=500fb^{-1}

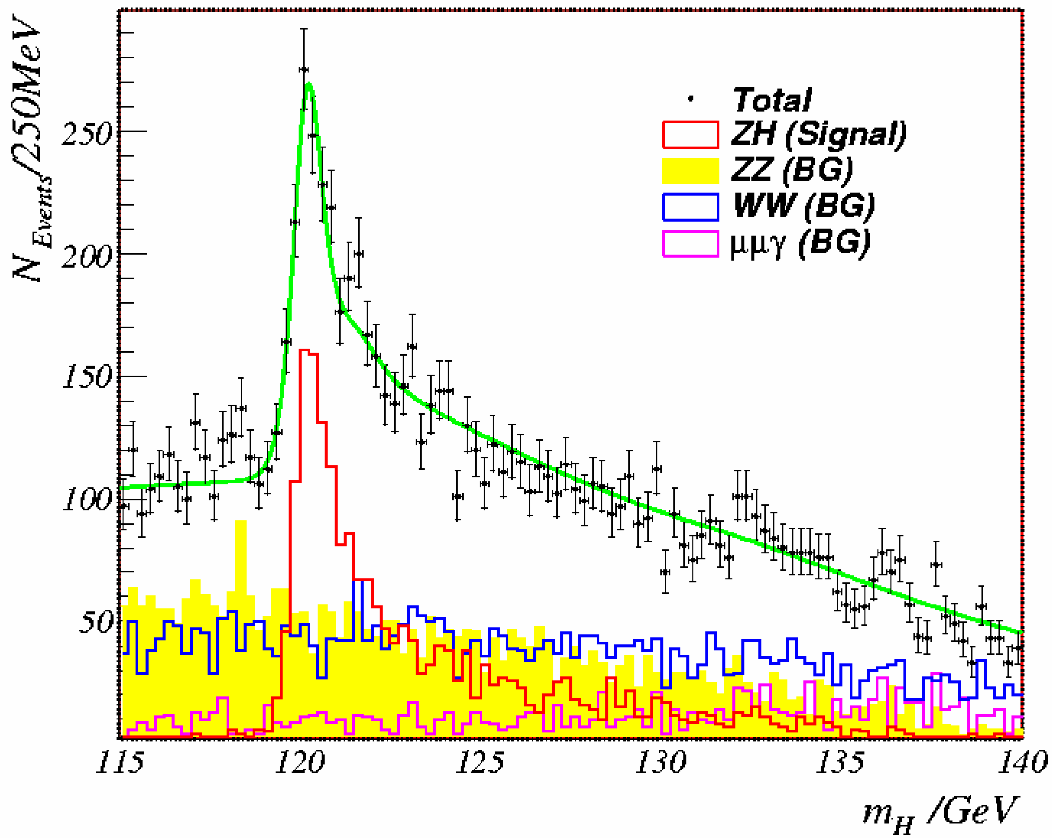
m_H=120 GeV

Preliminary result with μ channel:

δm_H = 36 MeV

(model independent result)

RUAN Manqi



LHC:

L=30fb^{-1}

m_H=120 GeV (input)

δm_H ~ 200 MeV

by combining several decay modes

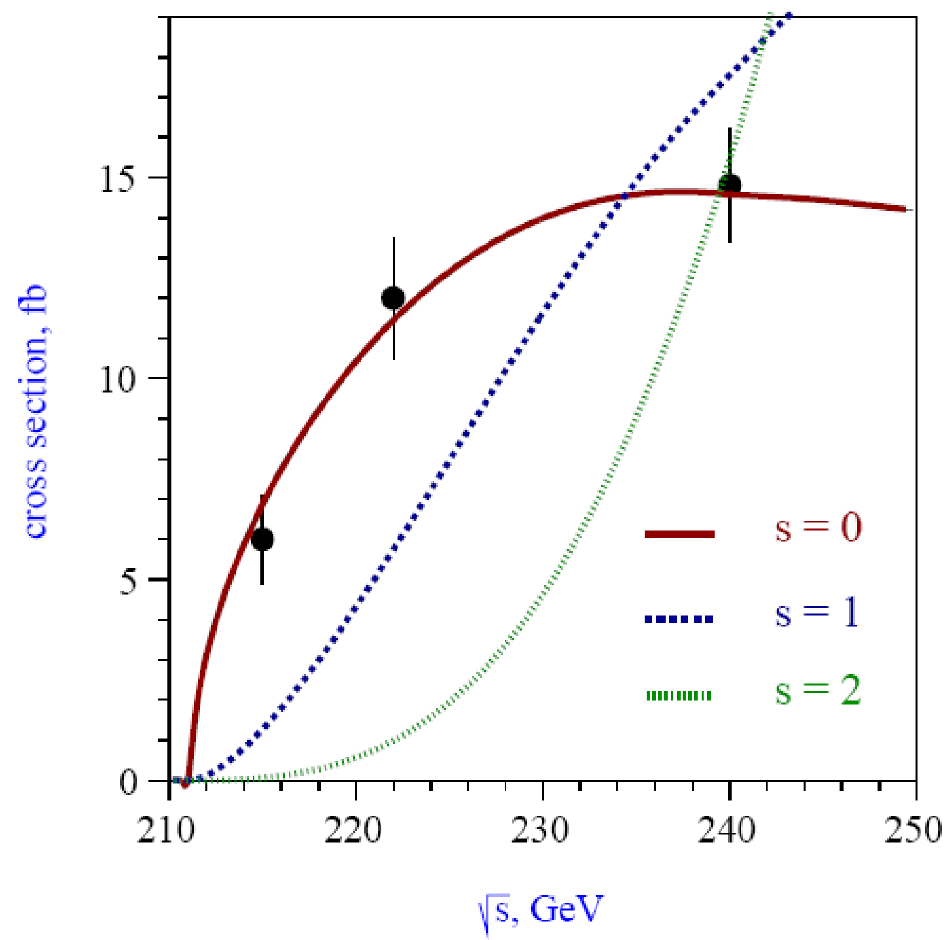
Higgs Spin

Based on Higgs-strahlung process with Z→e+e-, μ+μ− decay modes

m_H=120 GeV

L=20fb^{-1} at √s=215, 222, 240GeV

M.T. Dova, P. Garcia-Abia, W. Lohmann, hep-ph/0302113



➔ 20fb^{-1} data at three energies sufficient to determine the spin of the Higgs boson

➔ Capability of performing threshold scan is again a unique feature of ILC

CP Property of the Higgs Boson (1)

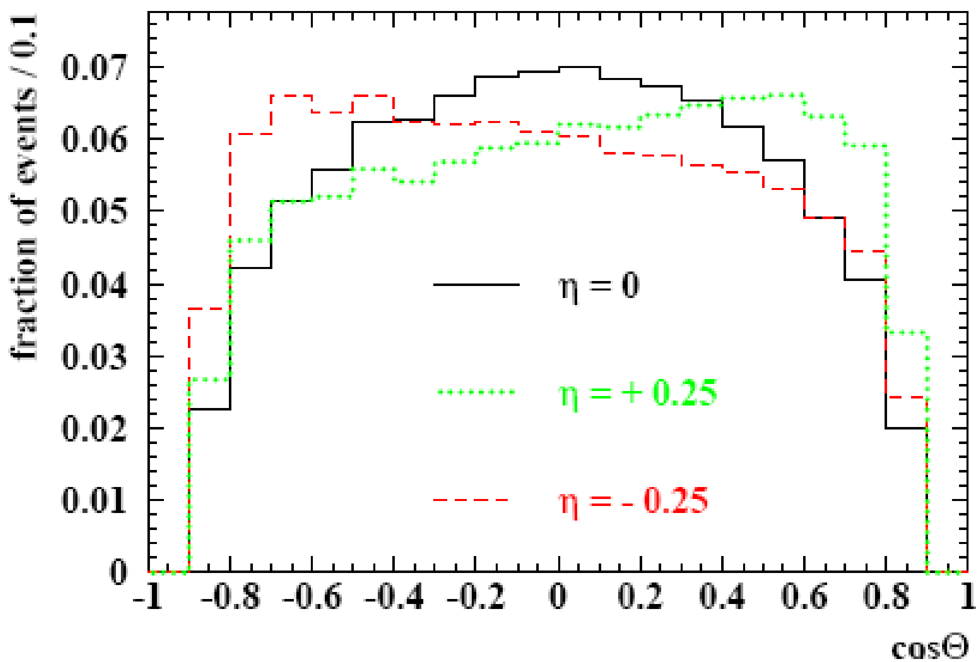
SM: does not predict any observable effect of CP violation
➔ Look for new CP violation source to describe the baryon asymmetry of the universe

In general the amplitude of a scalar boson ϕ having an arbitrary CP has

$$M_{\phi Z} = M_{HZ}\ (\mathrm{SM,\ CP\ even}) + \eta M_{AZ}(\mathrm{BSM,\ CP\ odd})$$

The η term causes a CP violation forward-backward asymmetry in the angular distribution of the production of $Z \to \mu^+\mu^-$ of Higgs-strahlung process

M. Schumacher, LC-PHSM-2001-003

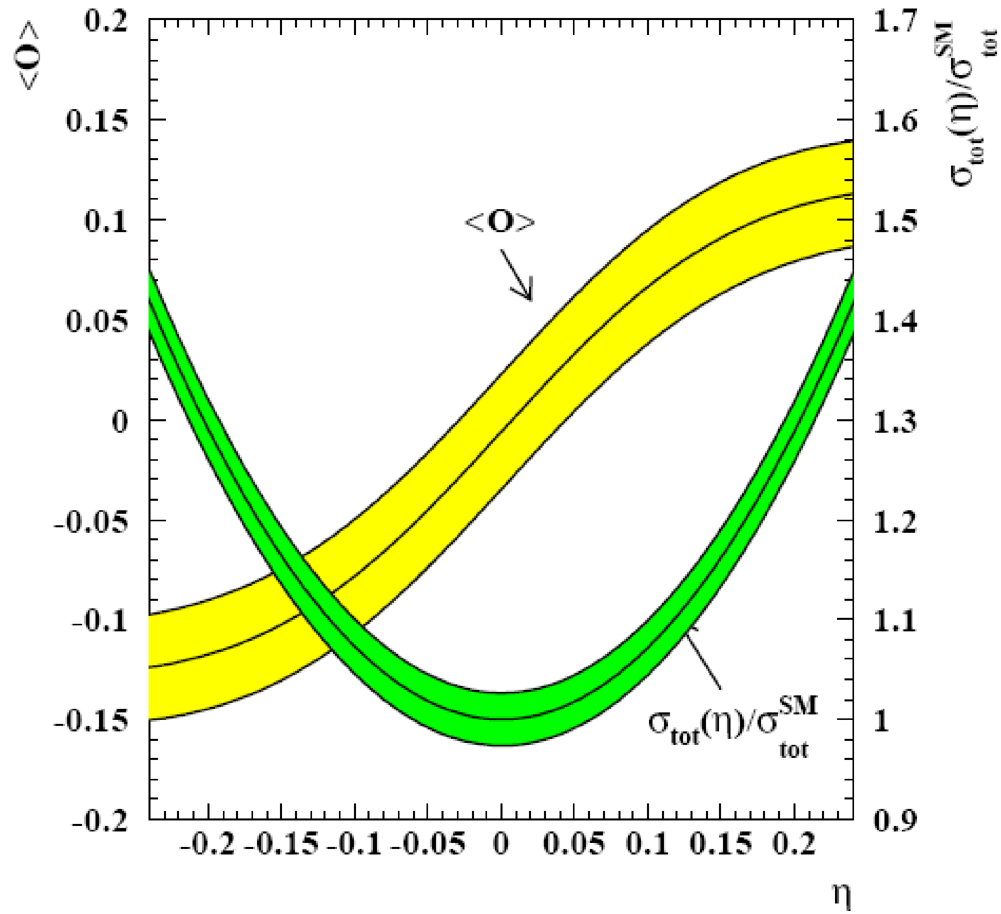


CP Property of the Higgs Boson (2)

Defining an optimal observable:

$$\mathcal{O} \equiv \frac{\sigma_{\mathcal{CP}}}{\sigma_{\mathrm{SM}}} \equiv \frac{2Re(\mathcal{M}^*_{ZA}\mathcal{M}_{ZA})}{|\mathcal{M}_{ZH}|^2}$$

M. Schumacher, LC-PHSM-2001-003



SM expectation: <O>~0

Any significant deviation implies CP violation

A model independent test

Measurement of Higgs Branching Fractions

This measurement is of utmost importance:

- Allows to disentangle between SM & BSM
- gg mode indirectly sensitive to Htt_{bar} Yukawa coupling, new strongly interacting particles couple to Higgs
- $\gamma\gamma$ and $Z\gamma$ modes sensitive to new heavy particles
- WW mode allows measurement of HWW in a model independent way

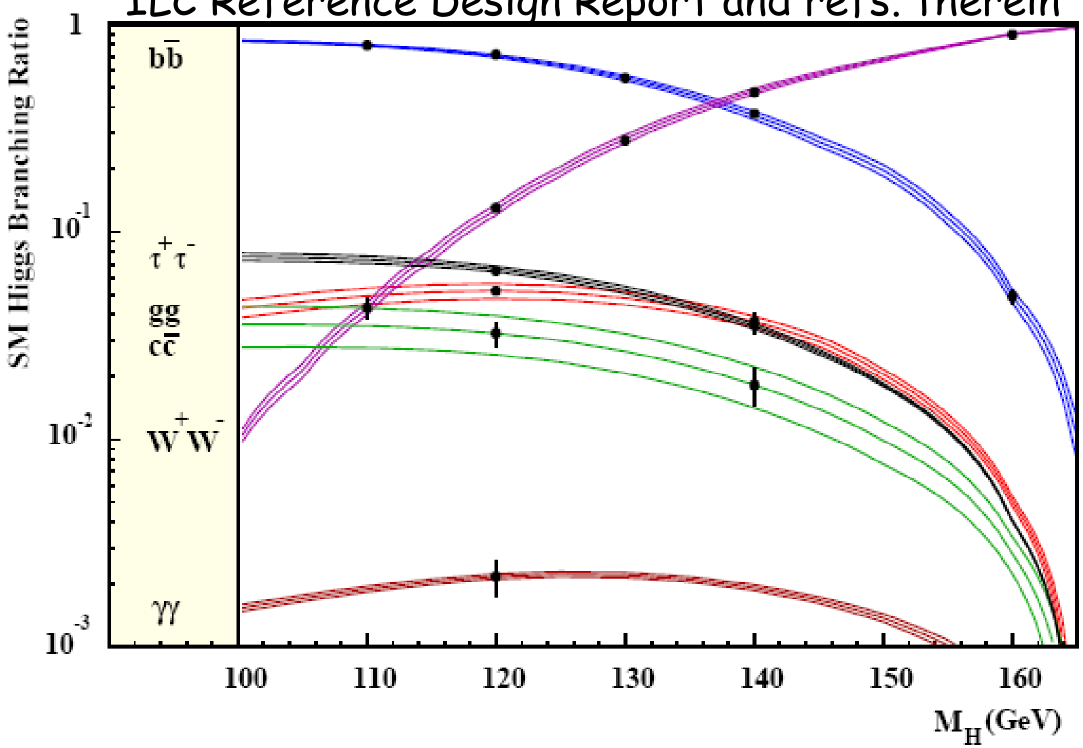
Absolute measurement only possible at ILC

At LHC, only relative Measurement is possible

m_H=120GeV, L=500fb^{-1}, $\sqrt{s}$=300-500GeV

Decay mode	Relative precision (%)
$b\bar{b}$	1.0–2.4
$c\bar{c}$	8.1–12.3
$\tau^+\tau^-$	4.6–7.1
gg	4.8–10
WW	3.6–5.3
$\gamma\gamma$	23–35

ILC Reference Design Report and refs. therein



The Higgs Total Decay Width

At low Higgs mass: indirect determination $\Gamma_H = \Gamma(H \to WW^*)/Br(H \to WW^*)$

J.A. Aguilar-Sasvedra et al., hep-ph/0106315: L=500fb^{-1}, $\sqrt{s}$=350GeV

Channel	$M_H = 120$ GeV	$M_H = 140$ GeV	$M_H = 160$ GeV
g_{HWW} from $\sigma(e^+e^- \to H\nu\nu)$	6.1%	4.5%	13.4 %
g_{HWW} from $\sigma(e^+e^- \to HZ)$	5.6%	3.7%	3.6 %
BR(WW) at $\sqrt{s} = 1$ TeV	3.4%	3.6%	2.0 %

T. Barklow, hep-ph/0312268: L=1 ab^{-1}, $\sqrt{s}$=1TeV

$\delta\Gamma/\Gamma$

At higher mass: direct determination from the reconstruction of lineshape

P. Bambade, F. Richard, hep-ph/0703173

ECM GeV	σ(Hμμ) fb	Average muon momentum,GeV	σ_{Mh} MeV	$\mathcal{L}$ (10%) fb^{-1}
350	3.1	71.5	455	500
290	3.2	53	200	100

For m_H=175GeV

Single event mass resolution

Lumi needed for $\delta\Gamma/\Gamma$=10%

The Higgs Couplings to Gauge Bosons

SM expectation:

$g_{HVV} \propto m_V$ with V=Z,W

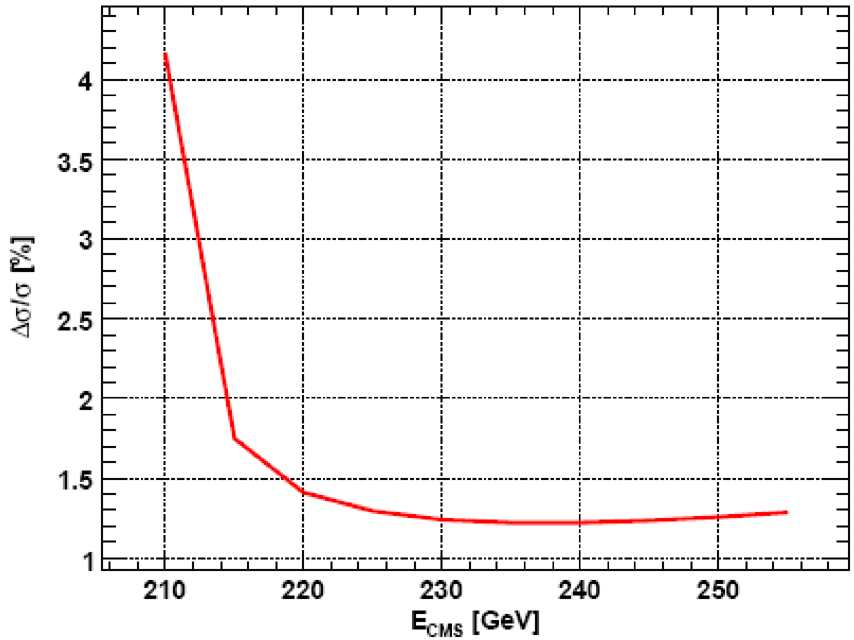
$\sigma \propto g^2$

W. Lohmann, M. Ohlerich, A. Raspereza and A. Schälicke: arXiv:0710.2602v1 [hep-ex]

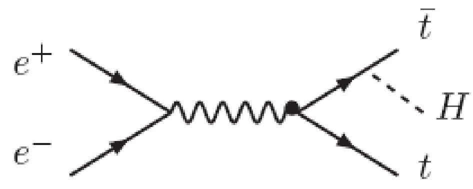
Assuming, m_H=120 GeV, L=500fb^{-1}

Model independent measurement (Higgs-strahlung process + recoil mass method):

$\sigma \cdot Br(Z \rightarrow e+e-, \mu+\mu-)$



The Higgs Yukawa Coupling to Top Quarks



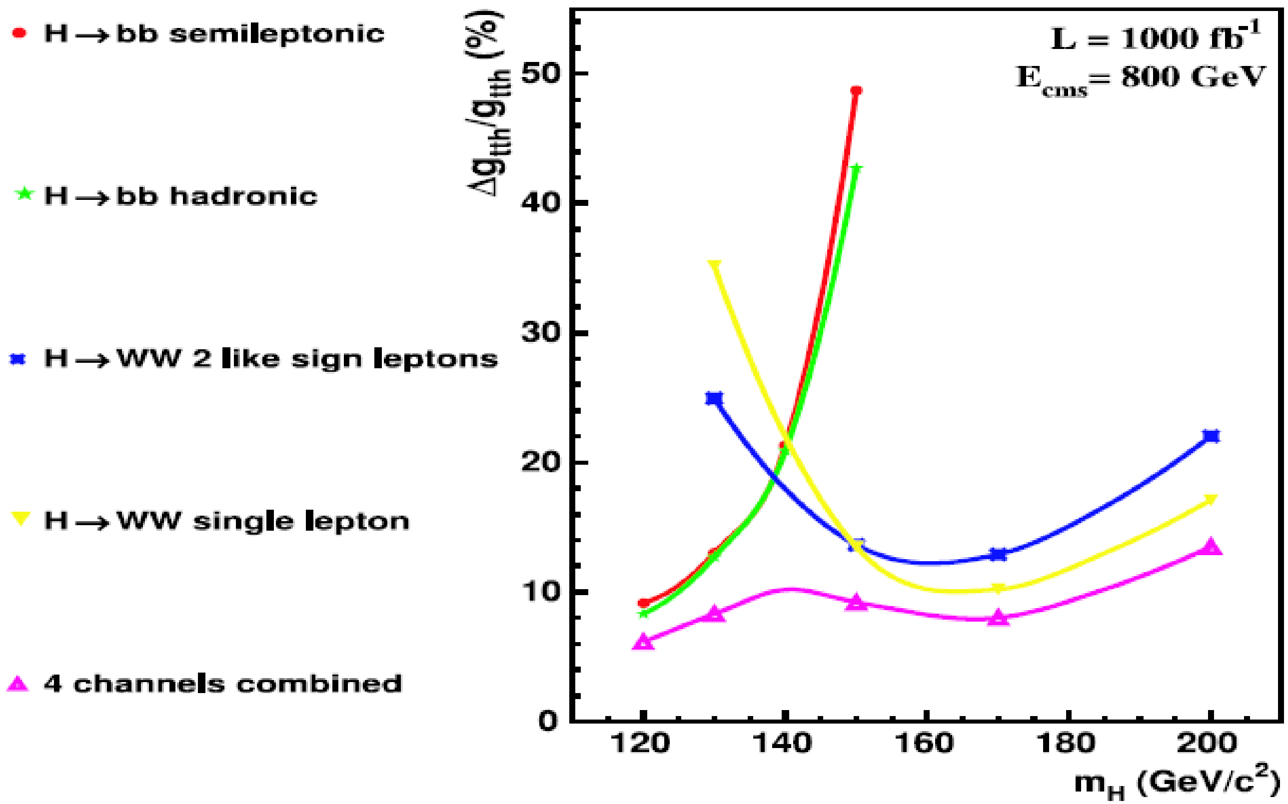
For m_H < 140GeV

Final state: $WWb\bar{b}b\bar{b}$

For m_H > 140GeV

Final state: $b\bar{b}+4W$

A. Gay, Eur. Phys. J. C49 (2007) 489



If W decays hadronically, up to 8 jets in final state

That's why the particle flow energy resolution is so important

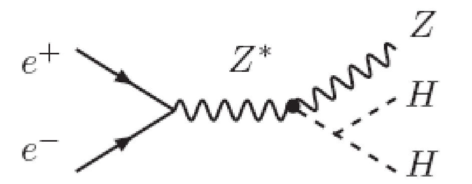
The measurement of this coupling is very difficult at LHC

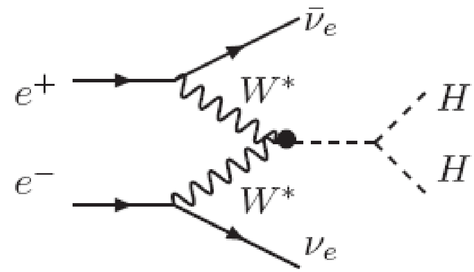
The Trilinear Higgs Coupling

SM expectation: $m^2_H = 4\lambda v^2$

with λ being its self-coupling,
vacuum exp. value $v \approx 246$ GeV

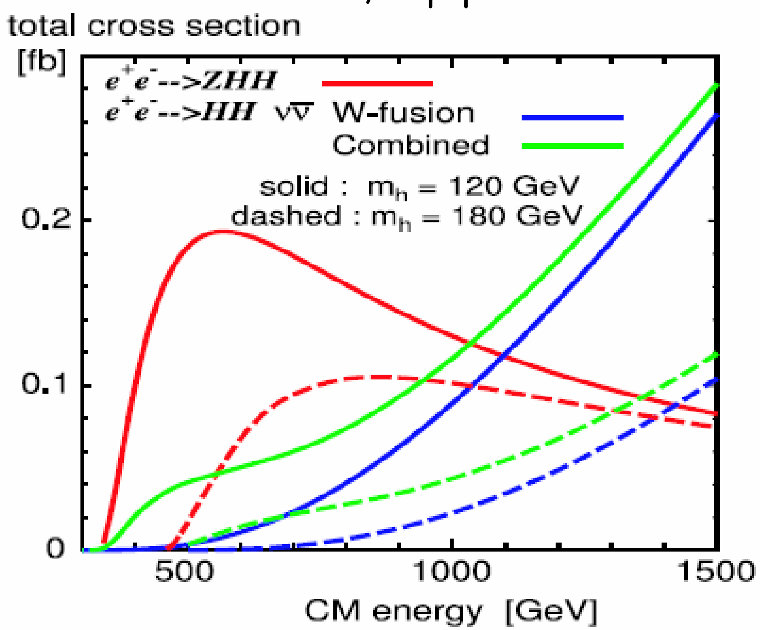
$\lambda_{HHH} = 6/\sqrt{2}\,\lambda v$



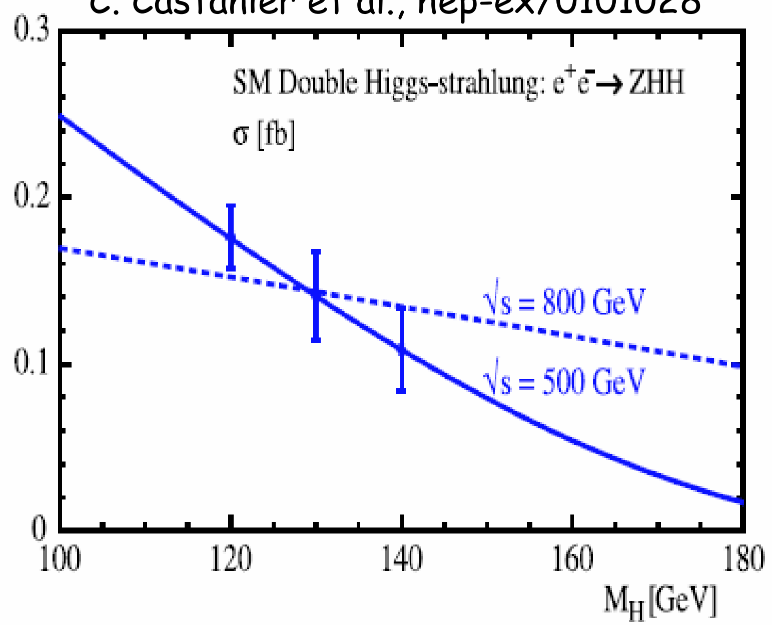


Could be the most decisive test of the electroweak symmetry breaking mechanism

Y. Yasui et al., hep-ph/0211047



C. Castanier et al., hep-ex/0101028



Impact of Higgs Coupling Measurements

SM mass-coupling relation: $m_i = k_i\ v$

For this test, the capability of making absolute measurement in a model independent way at ILC is crucial

Quoted uncertainties obtained using

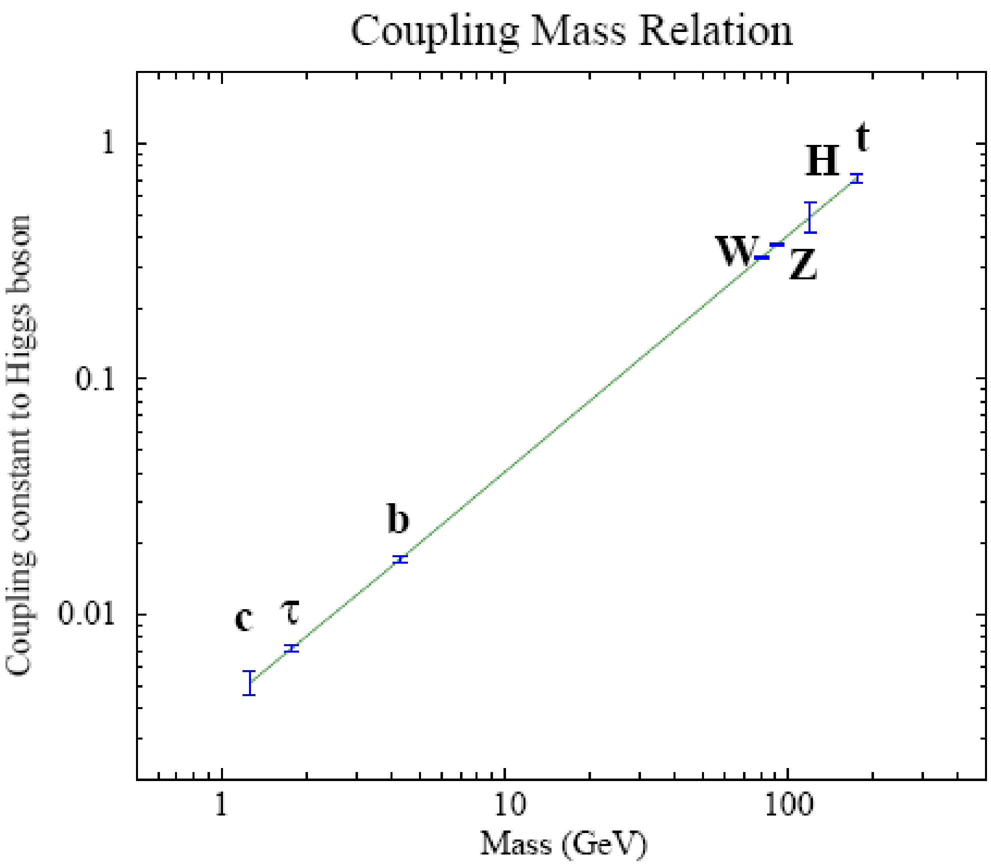
L=500 fb^{-1} and $\sqrt{s}$=300GeV

except for HHH:

L=1 ab^{-1} and $\sqrt{s}$=500GeV

and for Htt_{bar}:

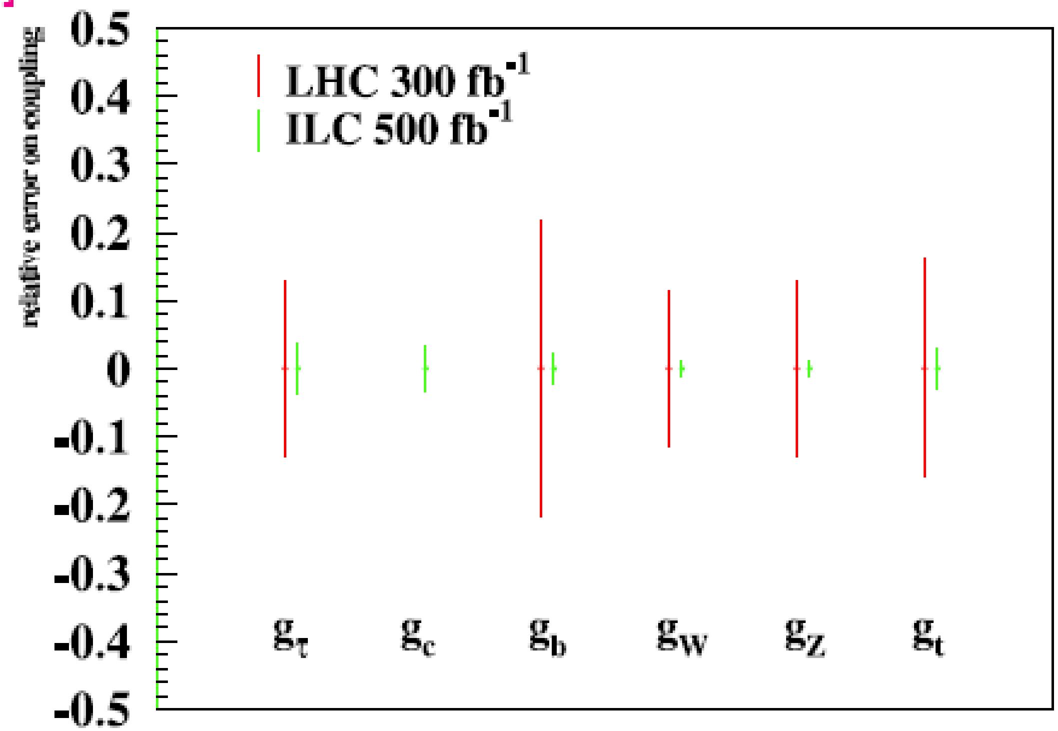
L=1 ab^{-1} and $\sqrt{s}$=800GeV



Higgs Coupling Determination: ILC vs. LHC

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*]



Why Beyond SM?

Despite its enormous success, the SM is believed to be an effective theory valid only at low energy.

A few known "problems":

- Saying nothing about quantum gravity
- The hierarchy problem (e.g. why the weak force is 10^{32} stronger than gravity?)
- No unification of gauge coupling constants at the Grand Unification scale
- Zero neutrino mass
- Baryogenesis
- No candidate for cold Dark Matter
- Quadratically divergent radiative corrections to m^2_H

Many Beyond SM Models

E.g. Supersymmetry (SUSY) models:

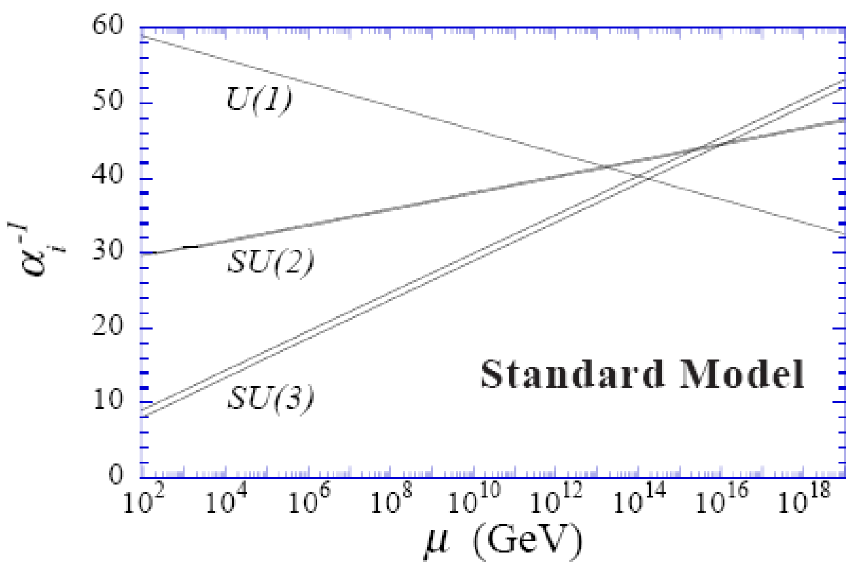
MSSM (the Minimal Supersymmetric extension of the SM)

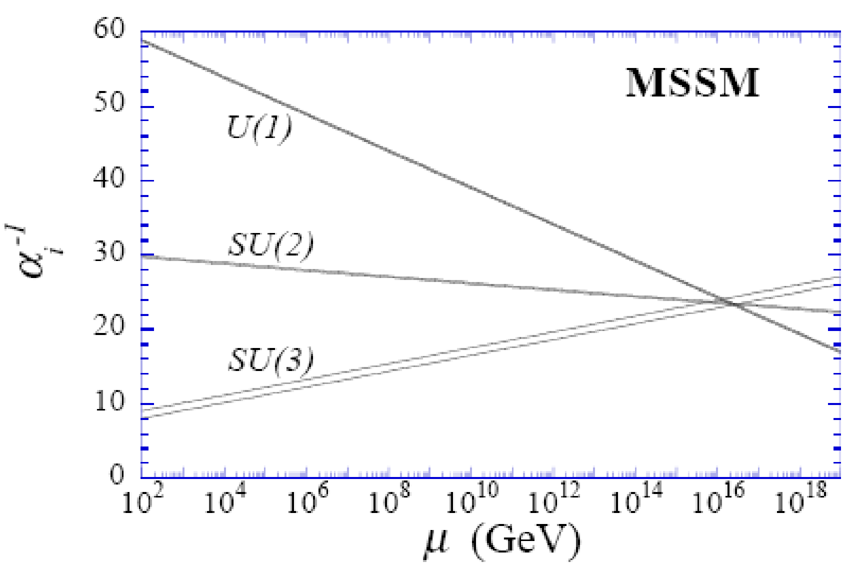
cMSSM (constrained MSSM) or mSUGRA (minimal supergravity) model

which have only 4 free parameters plus a sign:

m_0, $m_{1/2}$, A_0, $\tan\beta$, sign(μ)

All these models are able to solve the known problems, e.g. the coupling unification





Superpartners of the SM Particles

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks	Q	$(\tilde{u}_L \;\; \tilde{d}_L)$	$(u_L \;\; d_L)$	$(\,\mathbf{3},\ \mathbf{2}\,,\ \frac{1}{6})$
($\times$3 families)	$\overline{u}$	$\tilde{u}^*_R$	$u^\dagger_R$	$(\,\overline{\mathbf{3}},\ \mathbf{1},\ -\frac{2}{3})$
	$\overline{d}$	$\tilde{d}^*_R$	$d^\dagger_R$	$(\,\overline{\mathbf{3}},\ \mathbf{1},\ \frac{1}{3})$
sleptons, leptons	L	$(\tilde{\nu} \;\; \tilde{e}_L)$	$(\nu \;\; e_L)$	$(\,\mathbf{1},\ \mathbf{2}\,,\ -\frac{1}{2})$
($\times$3 families)	$\overline{e}$	$\tilde{e}^*_R$	$e^\dagger_R$	$(\,\mathbf{1},\ \mathbf{1},\ 1)$
Higgs, higgsinos	H_u	$(H_u^+ \;\; H_u^0)$	$(\tilde{H}_u^+ \;\; \tilde{H}_u^0)$	$(\,\mathbf{1},\ \mathbf{2}\,,\ +\frac{1}{2})$
	H_d	$(H_d^0 \;\; H_d^-)$	$(\tilde{H}_d^0 \;\; \tilde{H}_d^-)$	$(\,\mathbf{1},\ \mathbf{2}\,,\ -\frac{1}{2})$

$|\Delta s|=1/2$

Fermion←→Boson

Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\tilde{g}$	g	$(\,\mathbf{8},\ \mathbf{1}\,,\ 0)$
winos, W bosons	$\widetilde{W}^\pm \;\; \widetilde{W}^0$	$W^\pm \;\; W^0$	$(\,\mathbf{1},\ \mathbf{3}\,,\ 0)$
bino, B boson	$\widetilde{B}^0$	B^0	$(\,\mathbf{1},\ \mathbf{1}\,,\ 0)$

The mixing of $\tilde{W}^0$ and $\tilde{B}^0$ $\rightarrow$ zino ($\tilde{Z}$) and photino ($\tilde{\gamma}$)

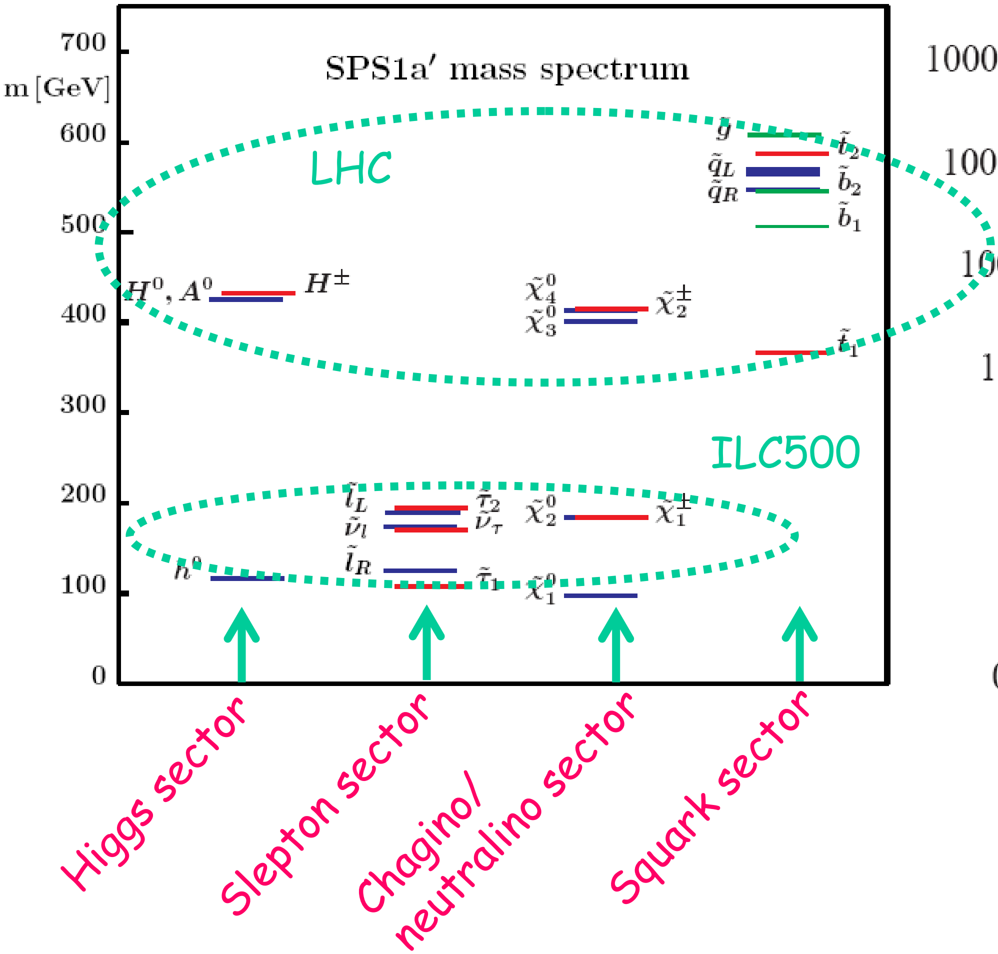
Gauginos: gluino, winos, bino, zino & photino

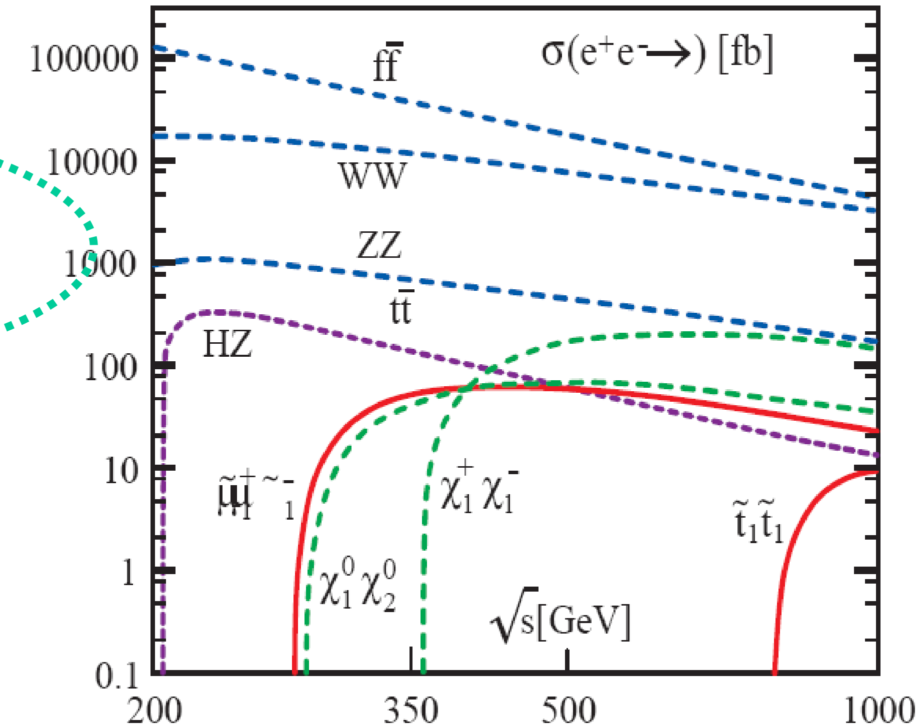
The mixing of gauginos and higgsinos $\rightarrow$ 2 charginos ($\tilde{\chi}^\pm_{1,2}$) and 4 neutralinos ($\tilde{\chi}^0_{1,2,3,4}$)

A Benchmark Scenario SPS1a' in cMSSM

Snowmass Points and Slopes

$$m_{1/2}=250 \text{ GeV},\ m_0=70 \text{ GeV},\ A_0=-300 \text{ GeV},\ \tan\beta=10 \text{ and } \mu>0$$

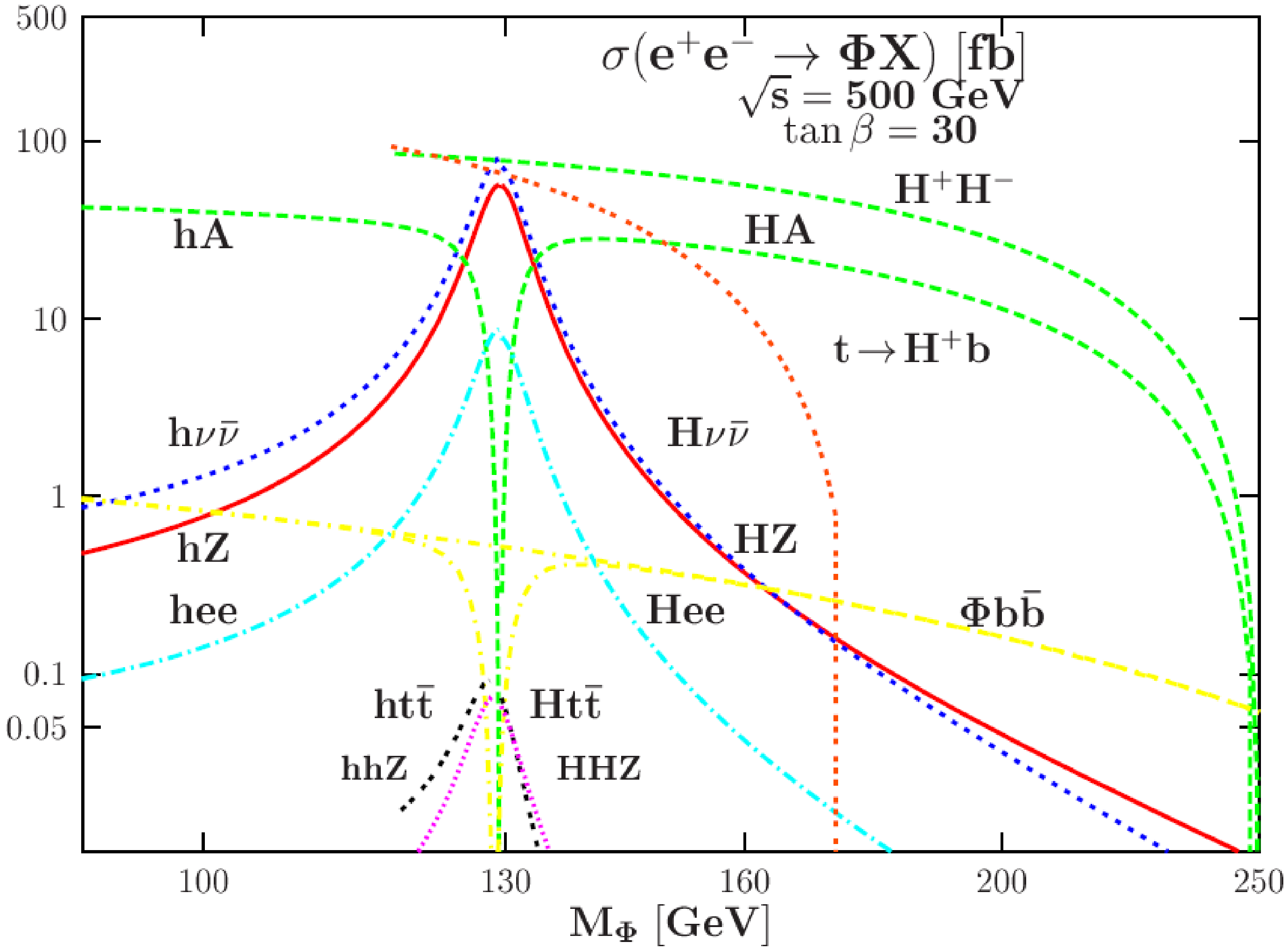




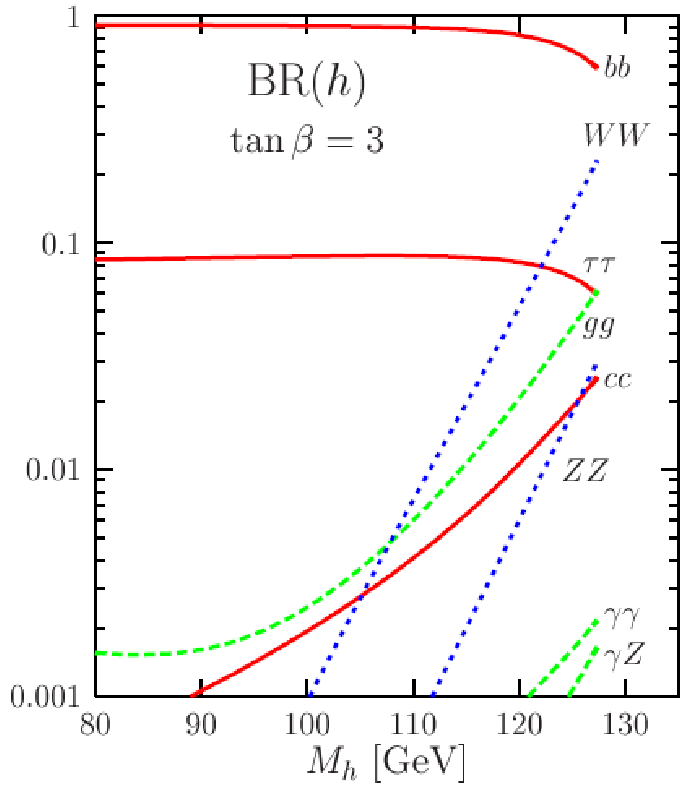
➔ SM backgrounds are only 1-2 orders of magnitude larger

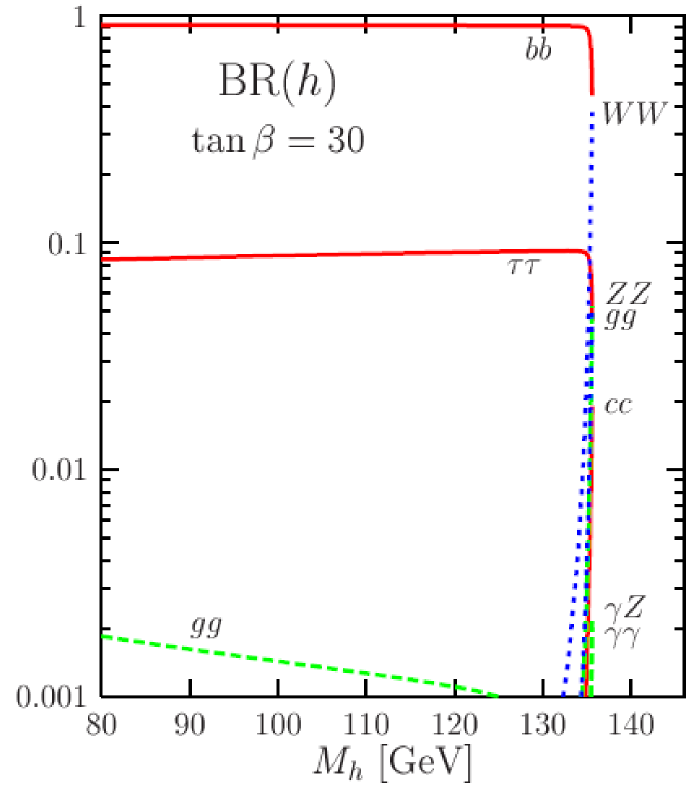
SUSY Higgs Sector: Production

A. Djouadi, hep-ph/0507173



SUSY Higgs Sector: Light Scalar Boson h

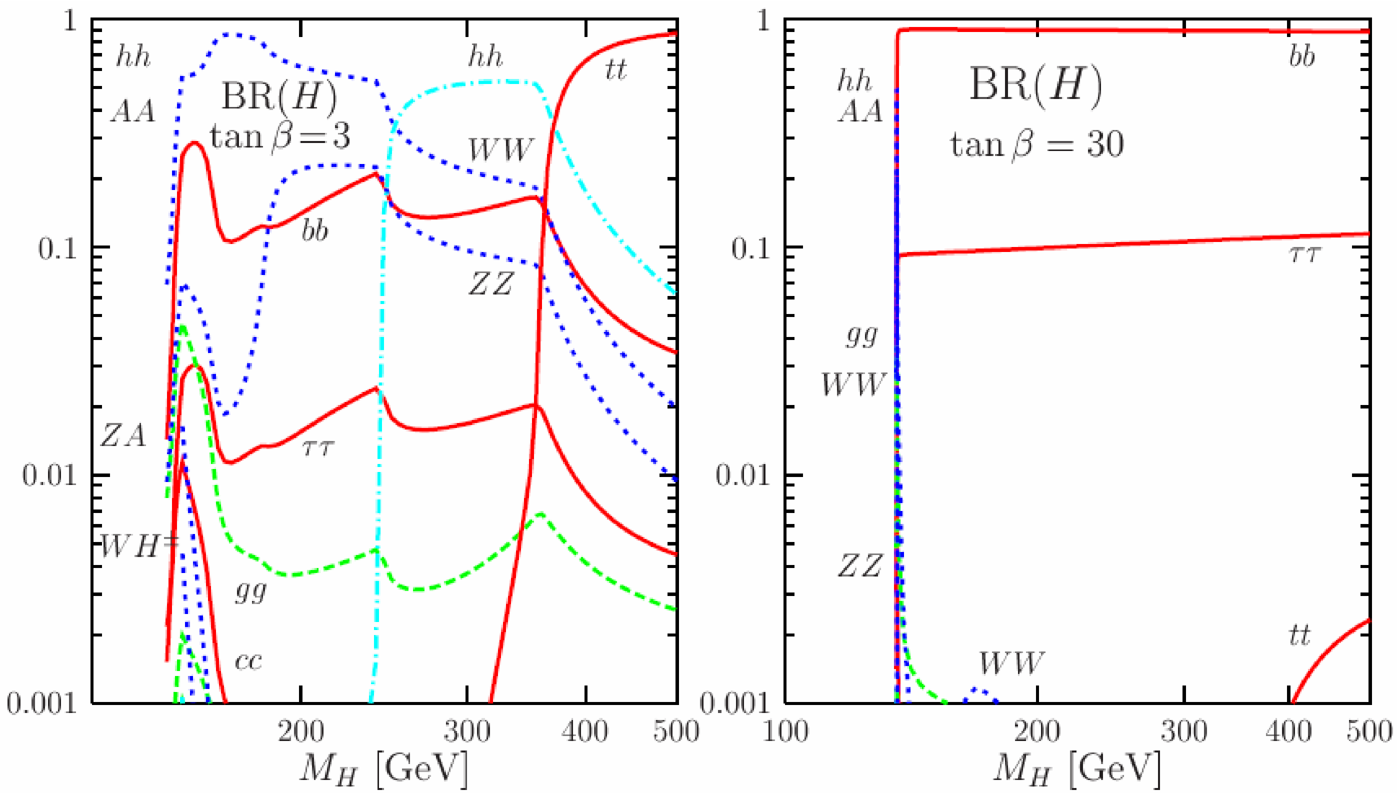




➔ 2 dominant decay channels have little dependence on tanβ

- Light SUSY boson h is SM-like, in particular in the decoupling limit
- h can be detected in entire MSSM parameter space

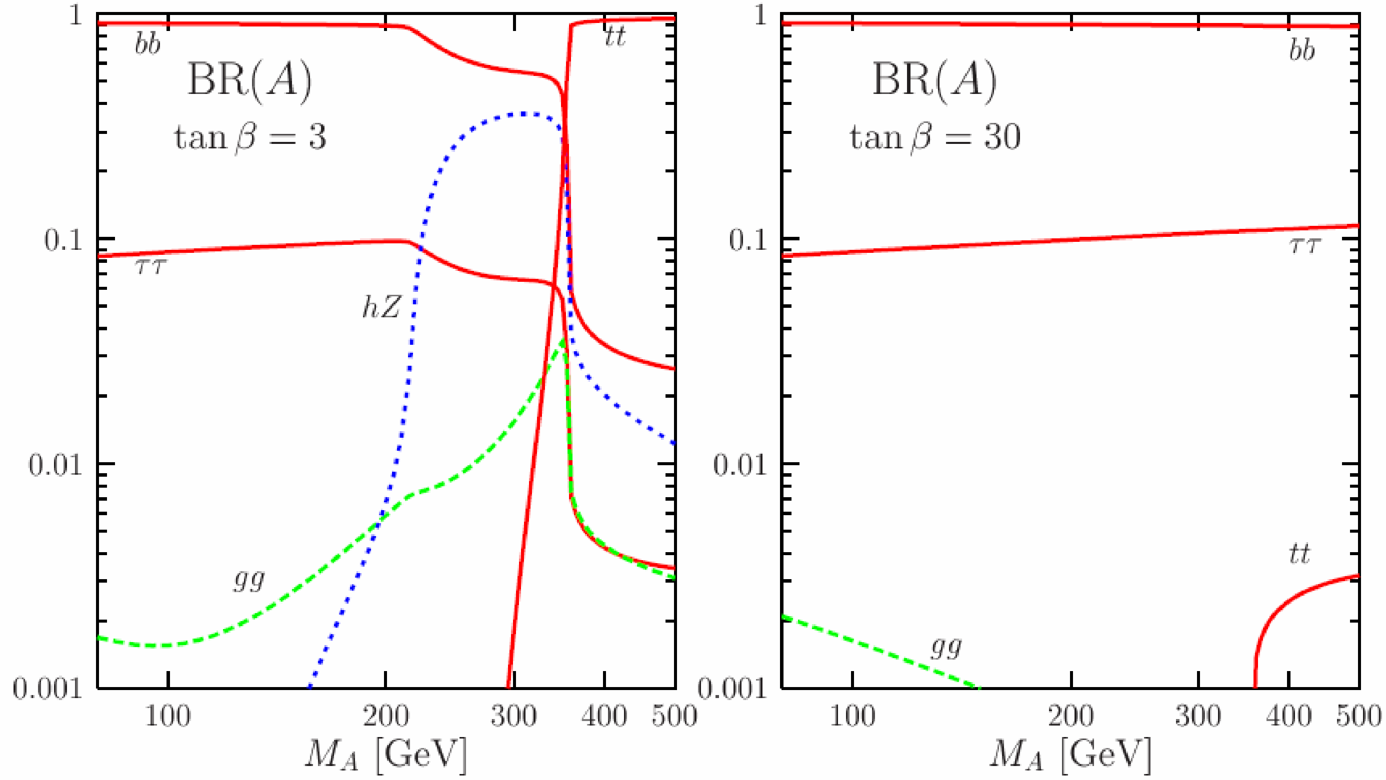
SUSY Higgs Sector: Heavy Scalar Boson H



➔ At large tanβ, two dominant decay modes similar as light boson h

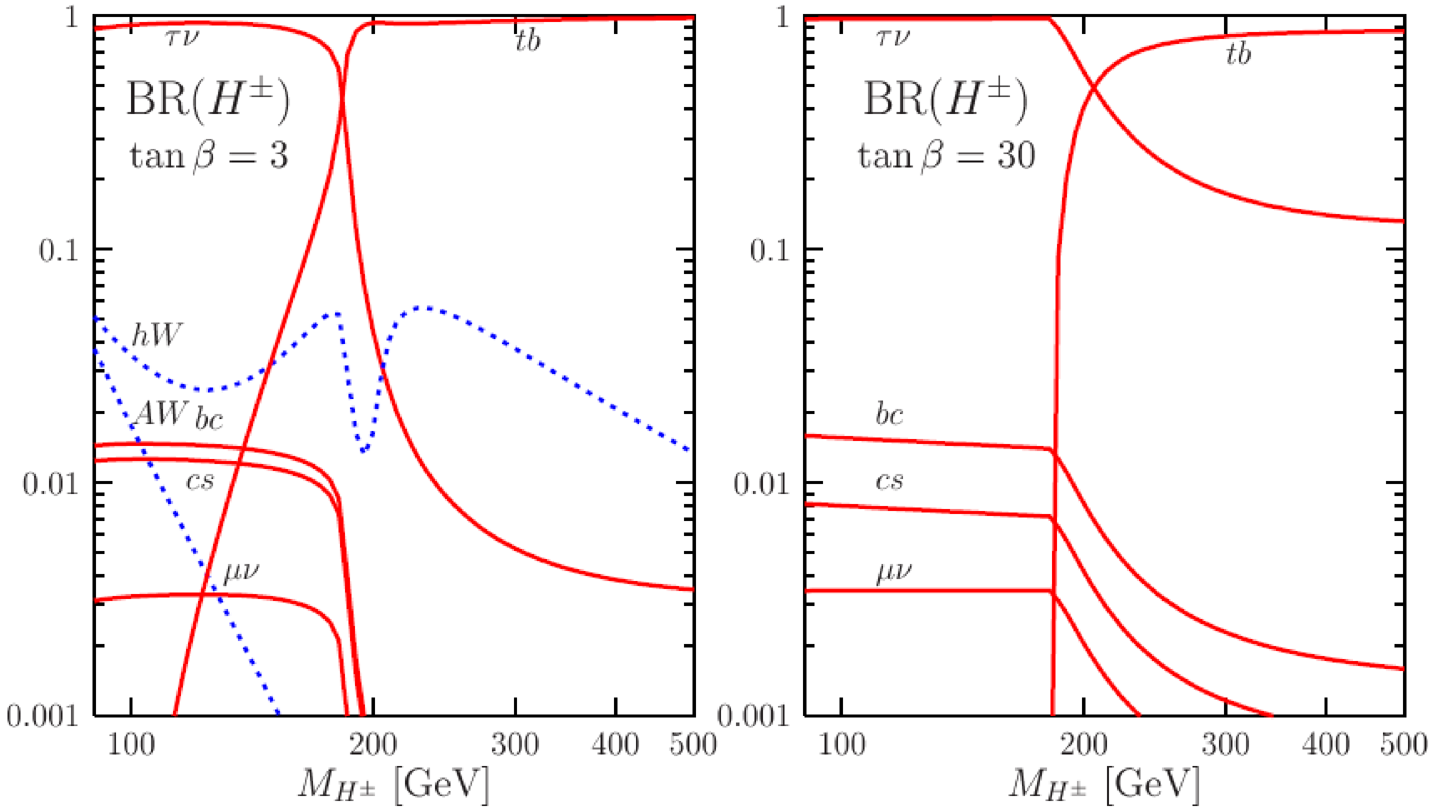
- Boson H can be discovered if $m_H < \sqrt{s}$ (if not, increase $\sqrt{s}$)

SUSY Higgs Sector: Pseudoscalar Boson A



- Boson A similar to heavy boson H
- Photon collider option has larger mass reach for A and H

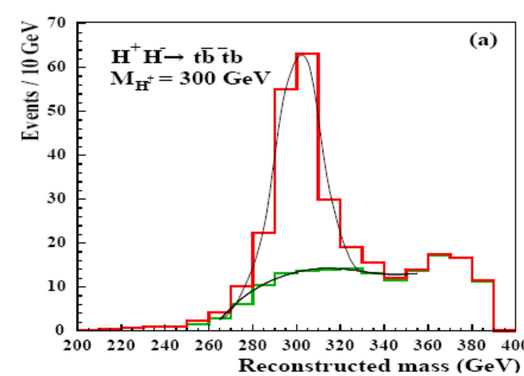
SUSY Higgs Sector: Charged Bosons H±



Dominant decay mode:

- H→τν at low mass (if M_H<m_t, $10fb^{-1}$ sufficient for a detection)
- H→tb at high mass (ex, M_H=300GeV, √s=800GeV, L=800fb)

J.A. Aguilar-Saavedra *et al.*, TESLA Technical Design Report



An Example of SUSY Measurements at ILC

H.U. Martyn, hep-ph/0302024, J.A. Aguilar-Saavedra et al., Eur. Phys. J. C46 (2006) 43

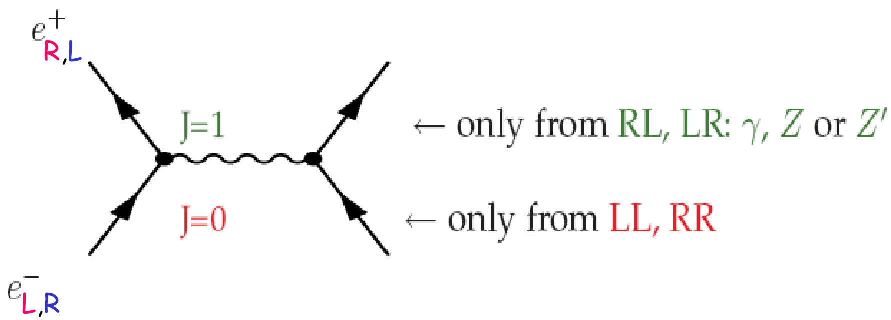
		m [GeV]	Δm [GeV]	Comments
Chagino/ neutralino sector	$\chi_1^\pm$	183.7	0.55	simulation threshold scan, 100 fb^{-1}
	$\chi_2^\pm$	415.4	3	estimate $\chi_1^\pm\chi_2^\mp$, spectra $\chi_2^\pm \to Z\chi_1^\pm, W\chi_1^0$
	χ_1^0	97.7	0.05	combination of all methods
	χ_2^0	183.9	1.2	simulation threshold scan $\chi_2^0\chi_2^0$, 100 fb^{-1}
	χ_3^0	400.5	3–5	spectra $\chi_3^0 \to Z\chi_{1,2}^0$, $\chi_2^0\chi_3^0, \chi_3^0\chi_4^0$, 750 GeV, $\gtrsim 1$ ab^{-1}
	χ_4^0	413.9	3–5	spectra $\chi_4^0 \to W\chi_1^\pm$, $\chi_2^0\chi_4^0, \chi_3^0\chi_4^0$, 750 GeV, $\gtrsim 1$ ab^{-1}
Slepton sector	$\tilde{e}_R$	125.3	0.05	e^-e^- threshold scan, 10 fb^{-1}
	$\tilde{e}_L$	189.9	0.18	e^-e^- threshold scan 20 fb^{-1}
	$\tilde{\nu}_e$	172.5	1.2	simulation energy spectrum, 500 GeV, 500 fb^{-1}
	$\tilde{\mu}_R$	125.3	0.2	simulation energy spectrum, 400 GeV, 200 fb^{-1}
	$\tilde{\mu}_L$	189.9	0.5	estimate threshold scan, 100 fb^{-1}
	$\tilde{\tau}_1$	107.9	0.24	simulation energy spectra, 400 GeV, 200 fb^{-1}
	$\tilde{\tau}_2$	194.9	1.1	estimate threshold scan, 60 fb^{-1}
Lightest Squark	$\tilde{t}_1$	366.5	1.9	estimate b-jet spectrum, $m_{\mathrm{min}}(\tilde{t}_1)$, 1TeV, 1000 fb^{-1}

ILC provides many measurement possibilities/methods, e.g.:

- Beam polarization
- Threshold scan (tunable beam energy)
- e-e- option (in additional to e+e-)
- Clean environment (e.g. end-point method)

Polarized Beams

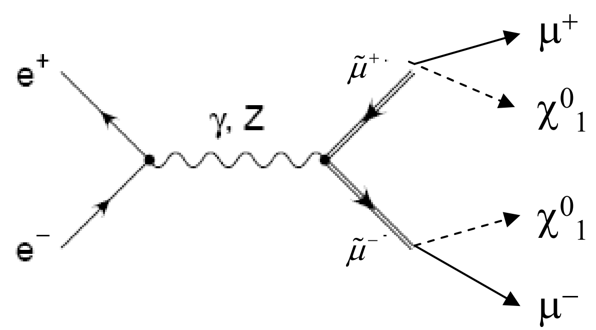
- Direct analysis of the interaction structure of New Physics
- Increased sensitivity to non-standard & SM couplings
- Enhanced signal and suppressed background rates



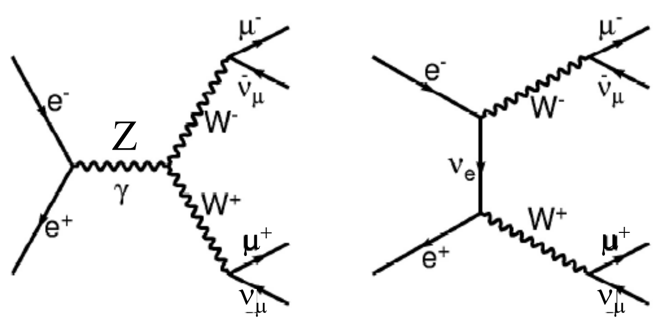
←SM vector bosons

←New Physics models

Example: smuon pair productions (signal):



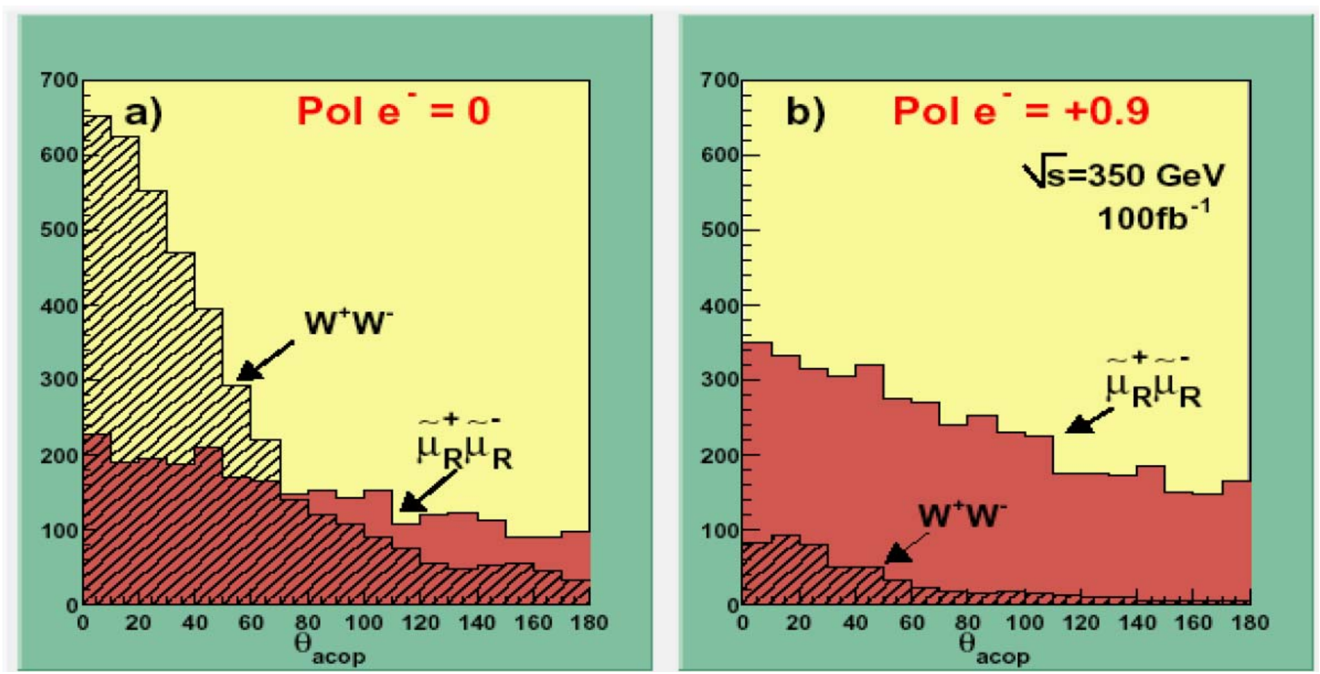
Dominant SM background:



➔ Experimental signature: muon pairs + missing E

Improved S/B Ratio with Polarized Beams

(e-, e+) Polarization	Signal (S) $\sigma(\tilde{\mu}_R^+\tilde{\mu}_R^-)$ [fb]	$\sigma(\tilde{\mu}_L^+\tilde{\mu}_L^-)$ [fb]	Background (B) $\sigma(W^+W^-)$ [fb]
$(-80\%, -80\%)$	11.44	5.06	1448
$(-80\%, +80\%)$	21.23	37.74	12995
$(+80\%, -80\%)$	82.99	8.37	198
$(+80\%, +80\%)$	11.44	5.06	1448
$(-80\%, 0)$	16.34	21.40	7241
$(+80\%, 0)$	47.21	6.72	824



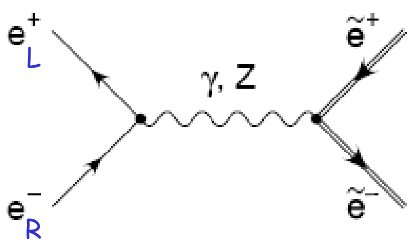
Threshold Scan & e-e- Option

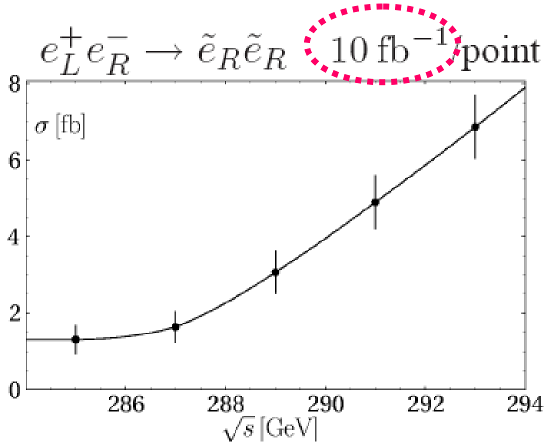
A. Freitas et al, hep-ph/0211108, H.U. Martyn, hep-ph/0302024

s-channel, P-wave

$$\sigma_{\tilde{\ell}\tilde{\ell}} \sim \beta^3, \text{where } \beta = \sqrt{1 - 4\, m_{\tilde{\ell}}^2/s}$$

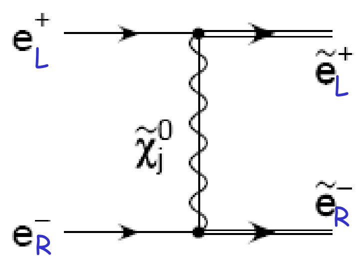
$\beta<1$ ➔ β^3 less steeper than β

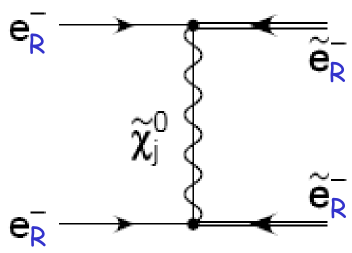




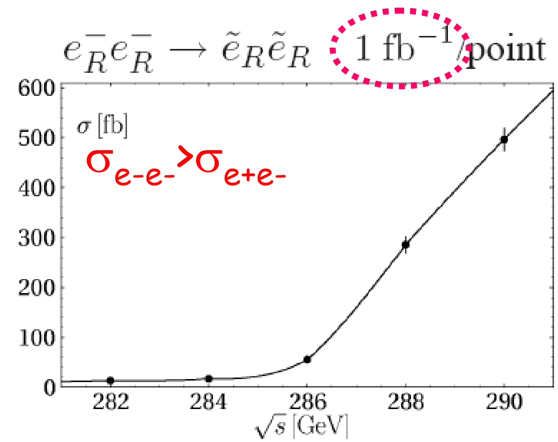
t-channel, S-wave

$$\sigma_{\tilde{e}\tilde{e}} \sim \beta$$



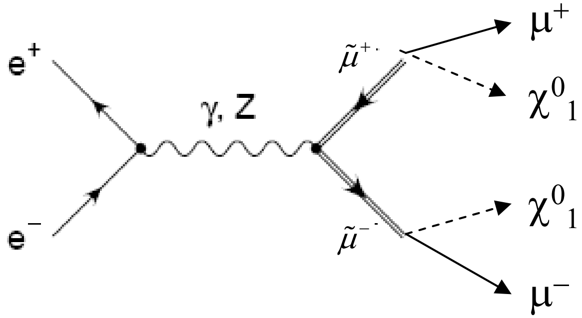


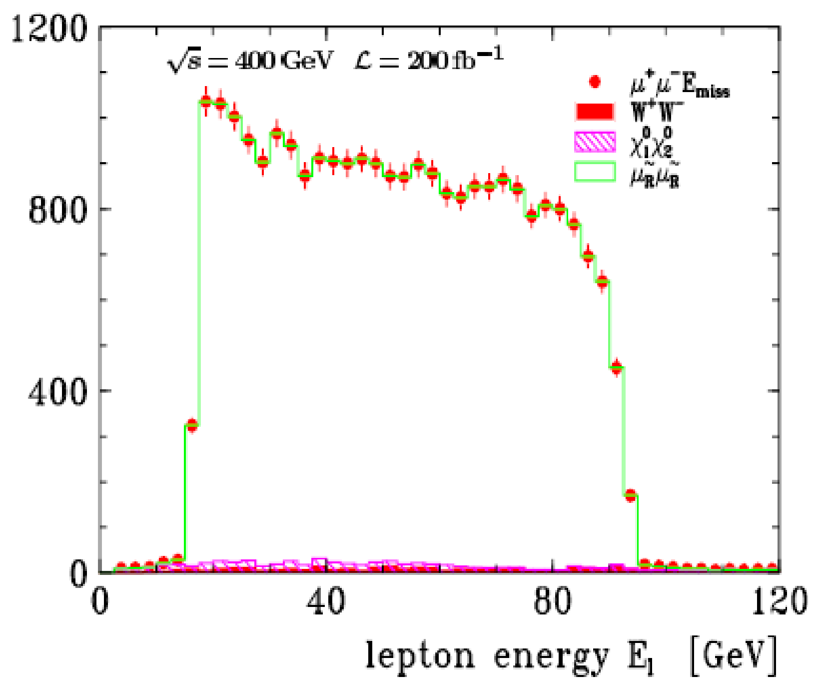
t-channel process in e+e- does not provide the required final state



➔ ILC allows proper choice of E_e and P_e to disentangle different states & quantum numbers

End-point Method





The measured energy spectrum provides two end-points (E_{min}, E_{max})

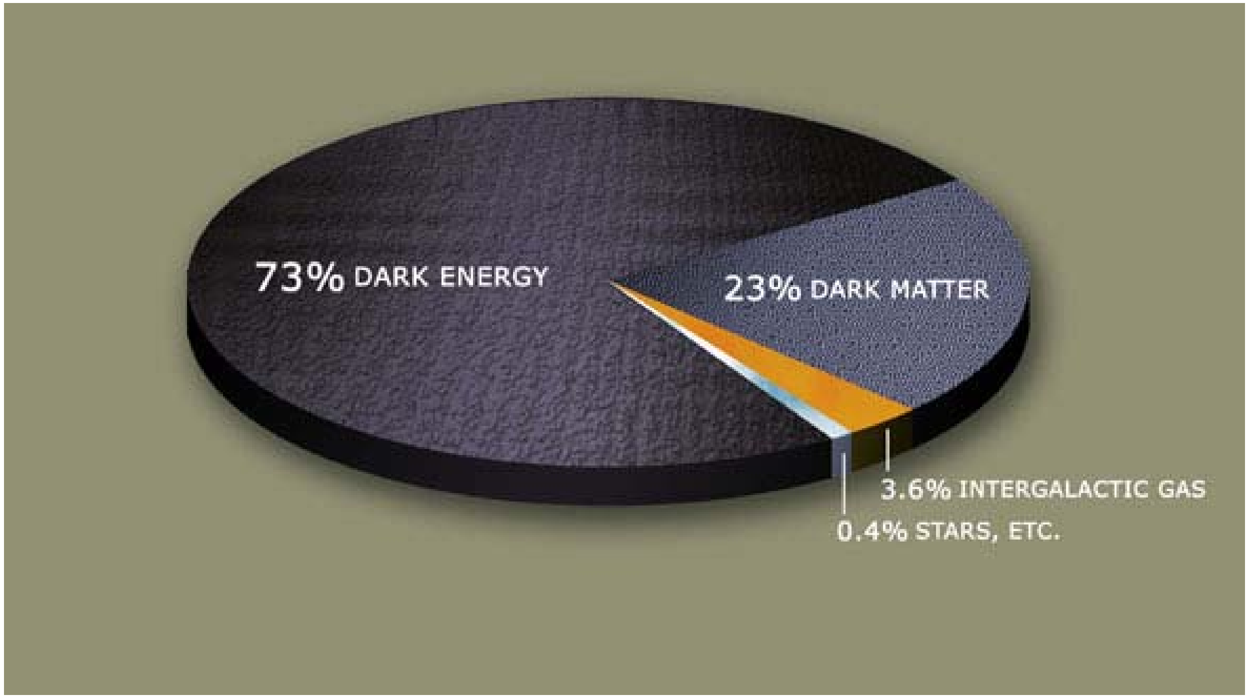
In two-body decays, the end-points are related to masses of the final states:

$$E_{\max,\min} = \frac{m_{\tilde{\mu}}}{2}\left(1 - \frac{m^2_{\chi 2}}{m^2_{\tilde{\mu}}}\right)\gamma(1 \pm \beta) \qquad \text{with } \beta = \sqrt{1 - \frac{4m^2_{\tilde{\mu}}}{s}},\ \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

➔ Slepton and neutralino mass can thus be derived with high precision

Dark Matter Content of the Universe

What we know with good precision:



What we do not know:

- What is dark matter?
- How is it generated?
- Is it related to SUSY?

Cold Dark Matter density:

$0.094 < \Omega_{DM}h^2 < 0.129$

(WMAP 2σ range)

WMAP: Wilkinson Microwave Anisotropy Probe

Constraint on the SUSY Phase Space

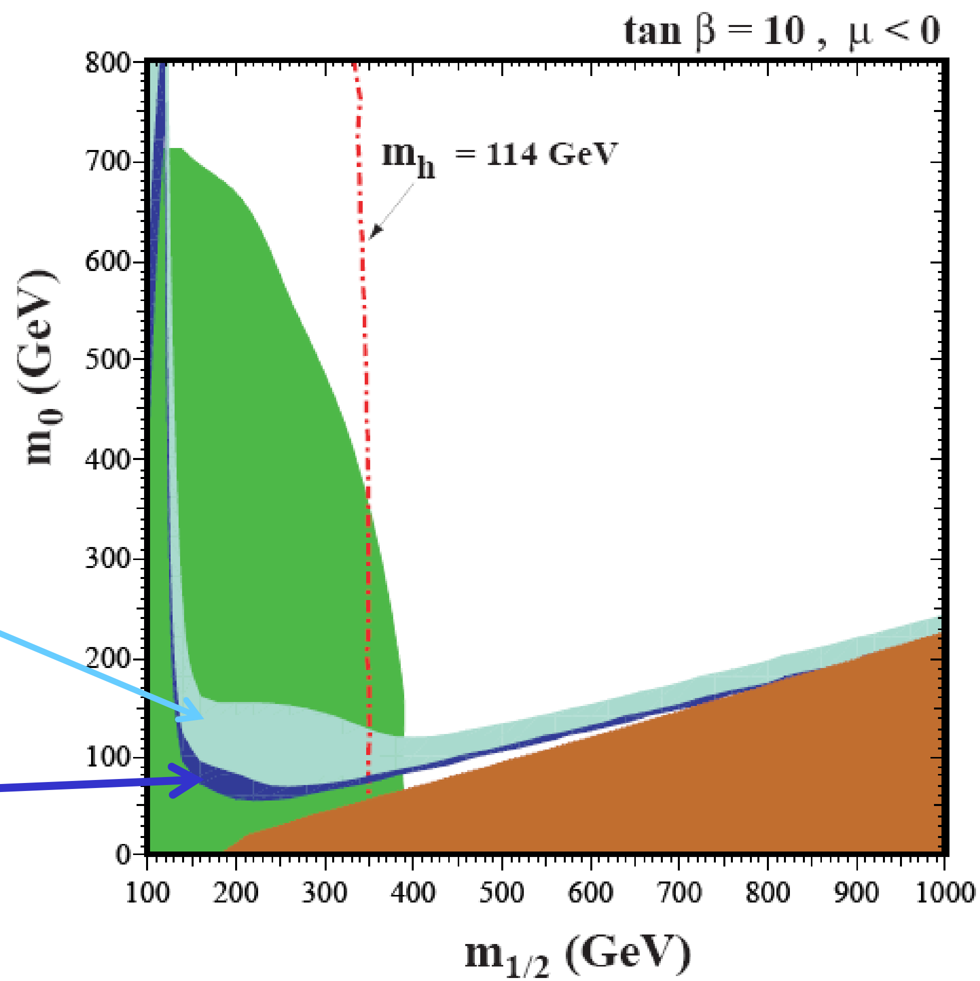
One best SUSY DM candidate:
LSP (Lightest Susy Particle) χ_1

Corresponding DM density:
$\Omega_{DM} \propto m_{\chi 1} \cdot N_{\chi 1}$

Old constraint:
$0.1 < \Omega_{DM} h^2 < 0.3$

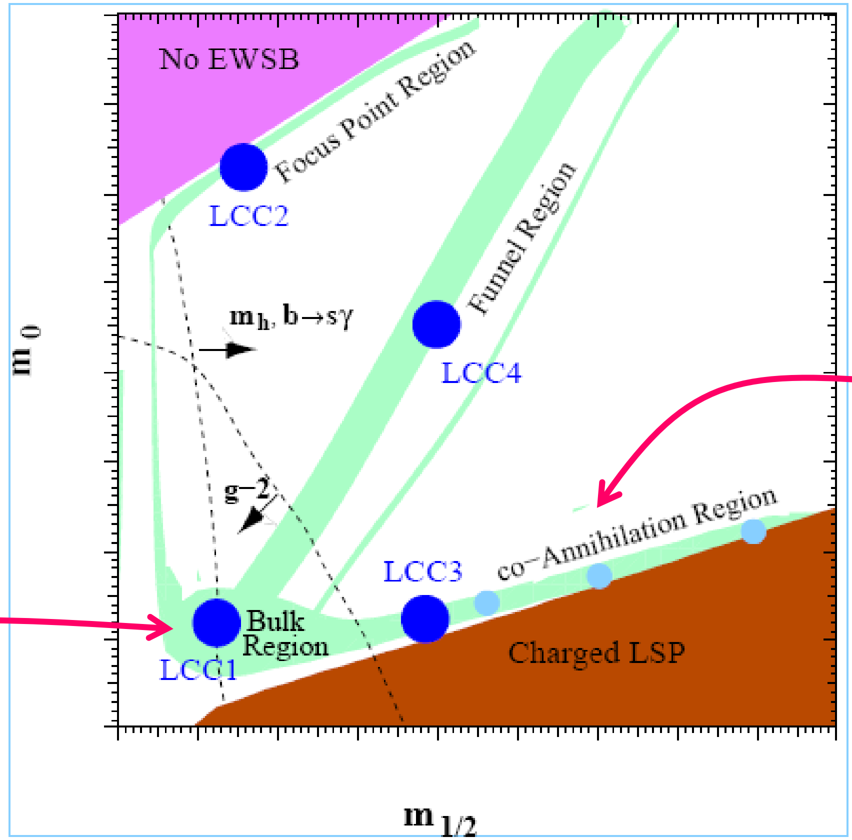
New constraint:
$0.094 < \Omega_{DM} h^2 < 0.129$

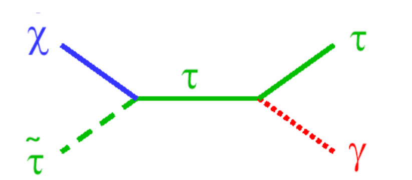
J. Ellis et al., hep-ph/0303043

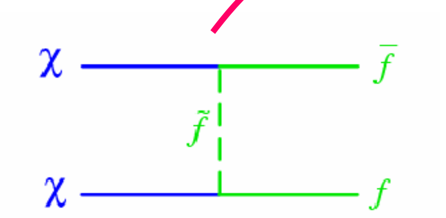


SUSY Benchmark Scenarios

J. Ellis et al., hep-ph/0303043, E. Baltz et al., hep-ph/0602187





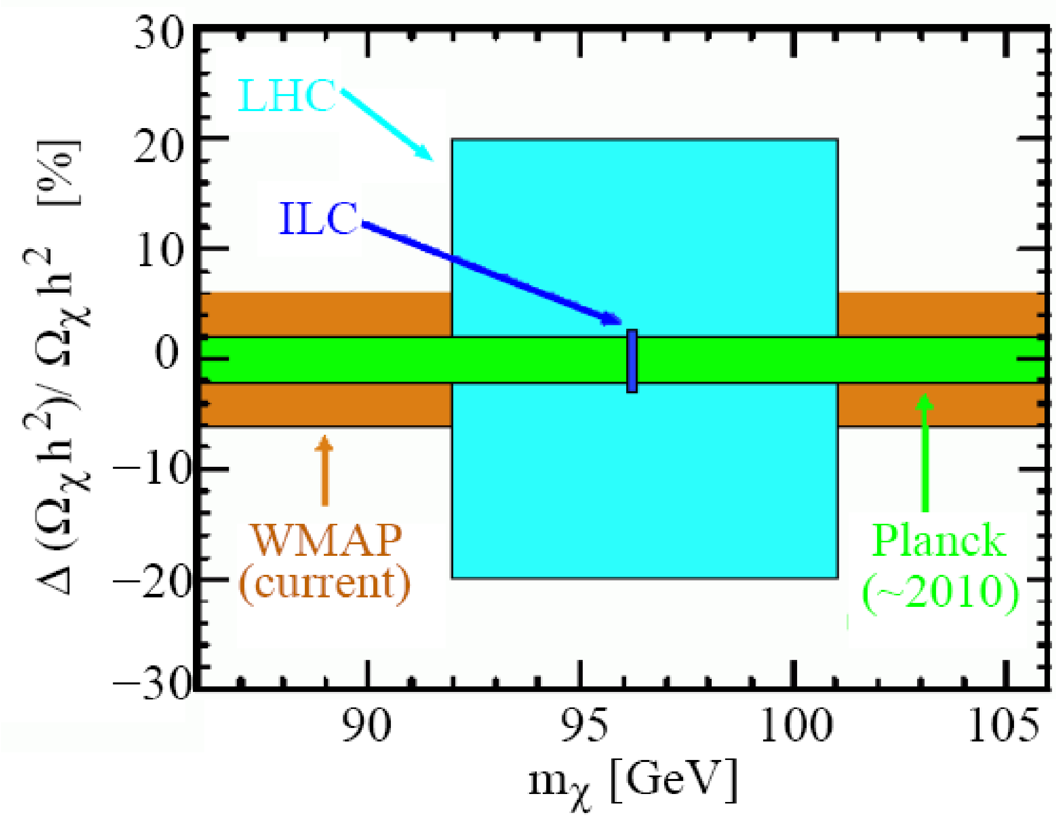


LCC: Linear Collider Cosmo benchmark points

A Comparison of DM Precision Reach

SPS1a' scenario

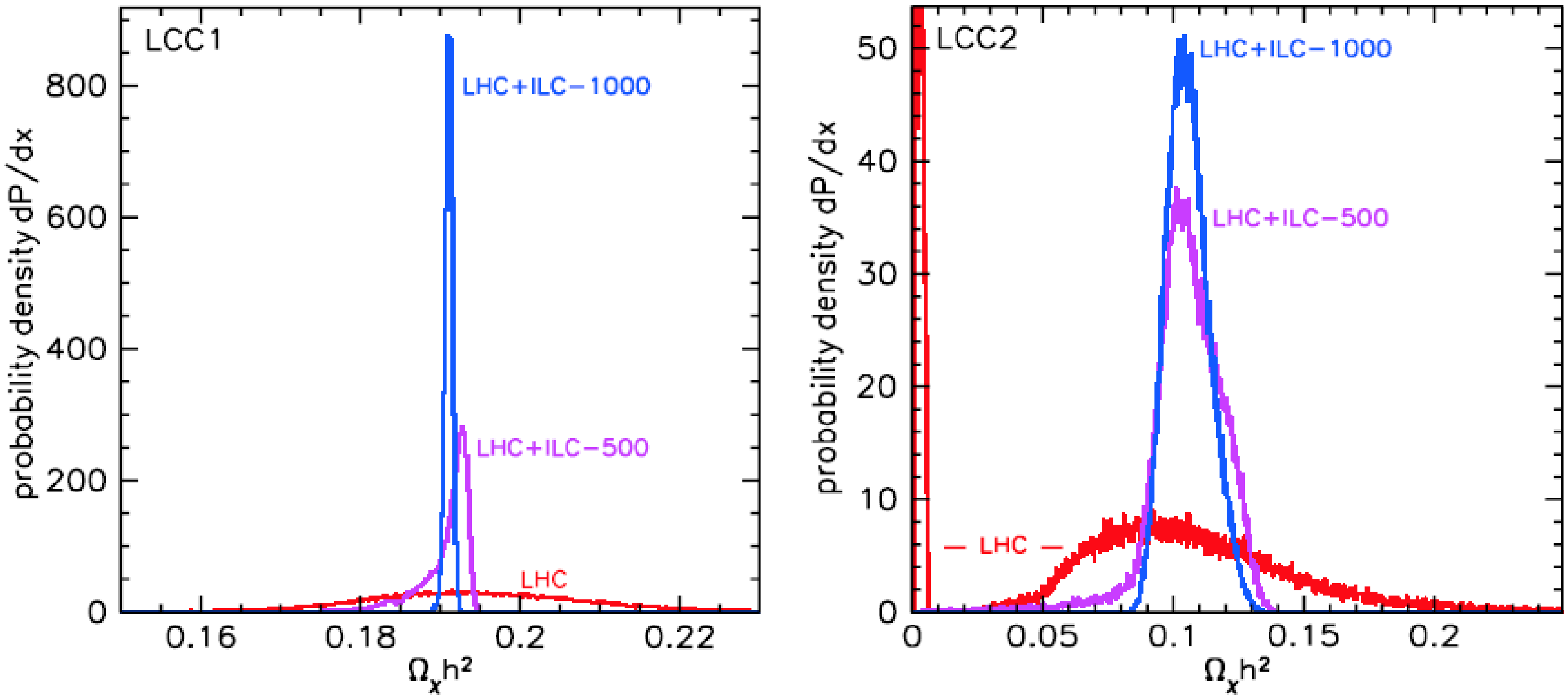
ILC Reference Design Report and references therein



Expected Planck precision ~ 2% but tell us nothing on the nature of DM
ILC will have the precision to clarify the connection of cosmology and SUSY

Synergy LHC+ILC

E. Baltz et al., hep-ph/0602187

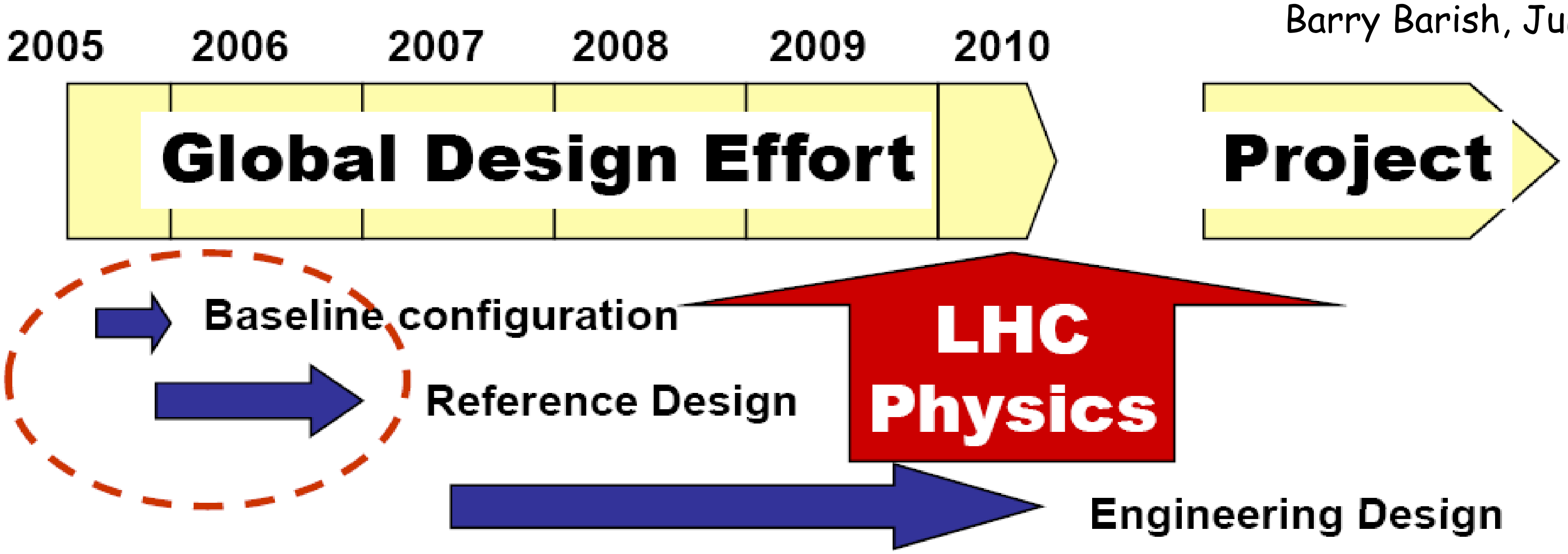


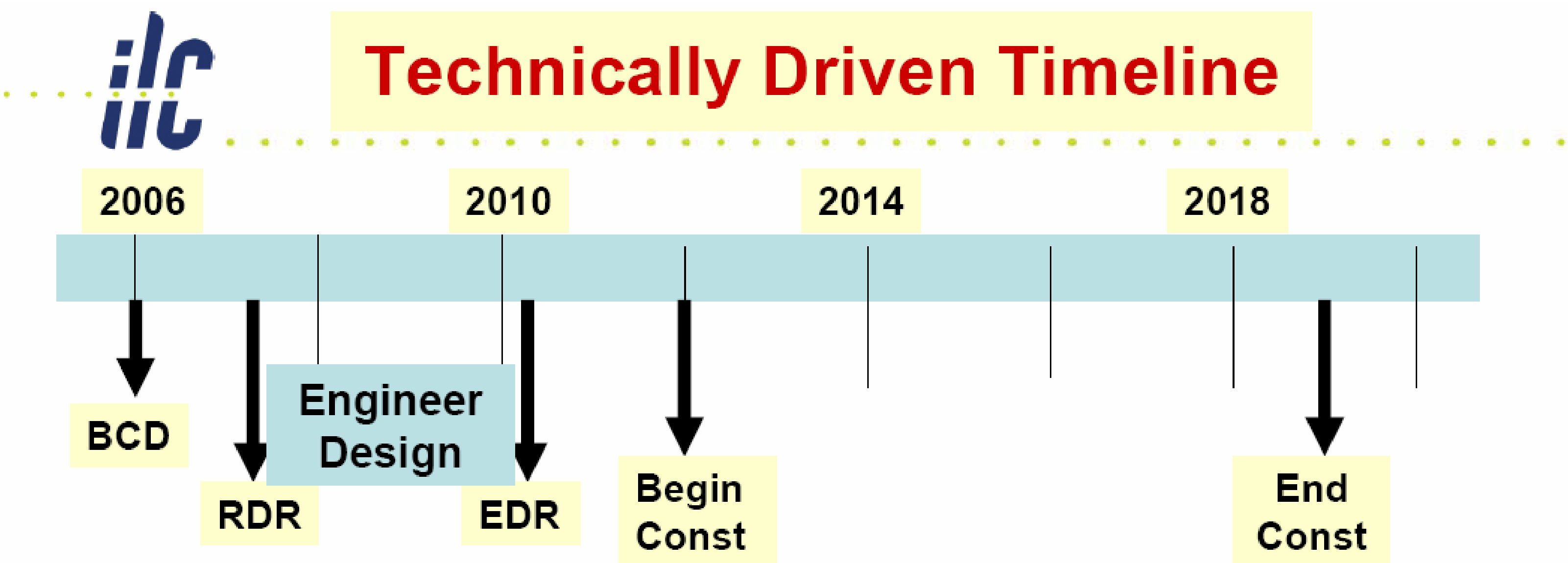
There are endless examples showing the gain of synergy LHC+ILC

But for this to work, ILC has to be built before the end of LHC

ILC Timeline and Prospects

Barry Barish, June 07





Summary

ILC has a rich and well established physics programme

ILC is a precision and complementary machine to LHC

ILC may have a revolutionary impact on our understanding of the matter, interactions, time-space structure of the universe