HEP and ILC

SY Choi (Chonbuk, Korea)

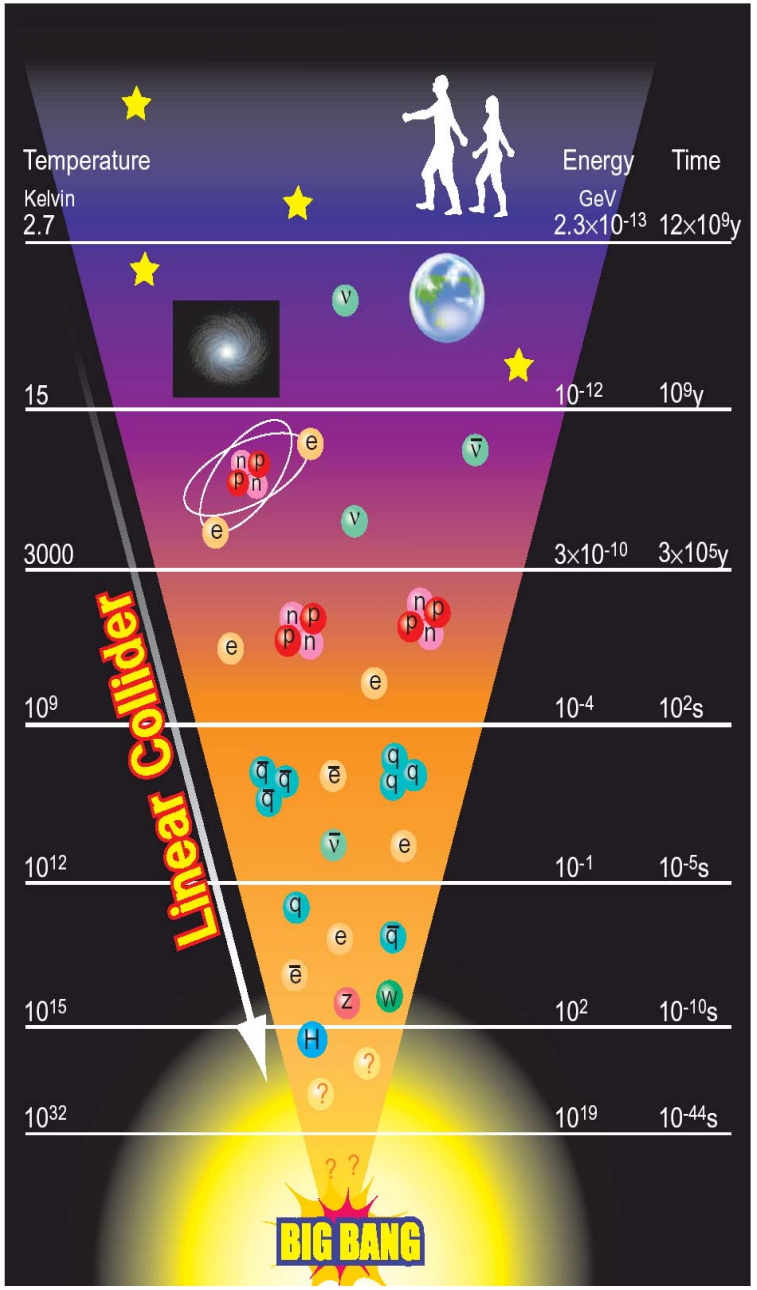
Highlighting “central HEP targets of ILC” based on Physics Chapter of RDR and many review talks/reports

Leaving “cosmological connections to LHC/ILC” to a special presentation by S. Matsumoto

High Energy Physics

Elementary constituents
and basic interactions
at the smallest scale

Origin and evolution
of the whole Universe

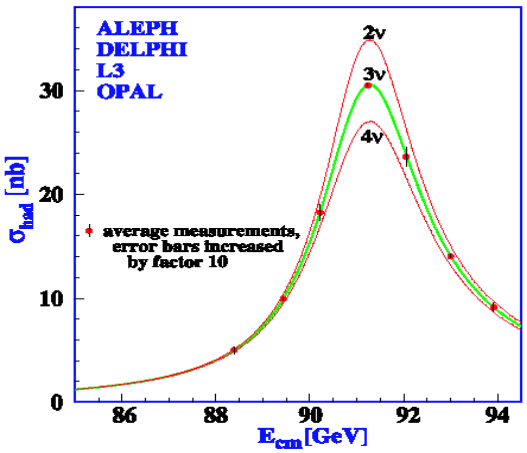


Terascale

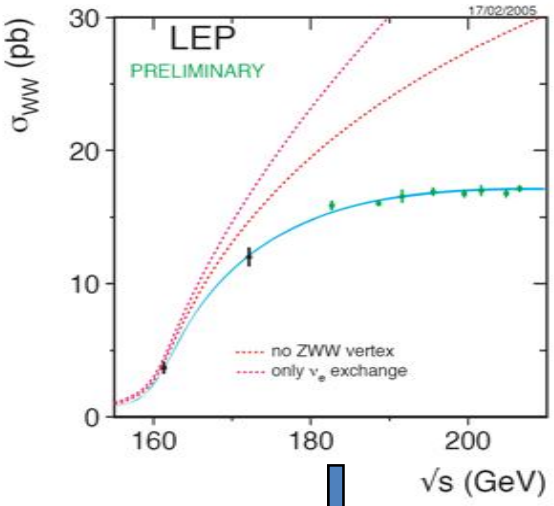
$d = 10^{-18}\ m \Leftrightarrow E = 1\ TeV$
$\Leftrightarrow T = 10^{16}\ K \Leftrightarrow t = 10^{-12}\ s$

Standard Model @ E ~ 0.1 TeV

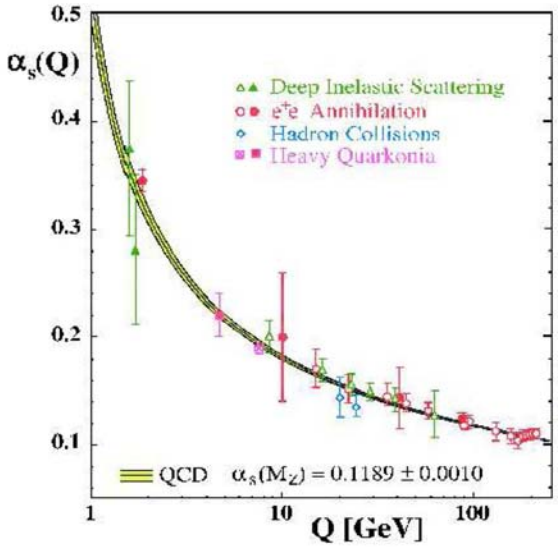
3 generations



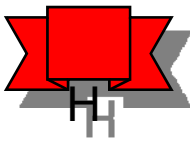
SU(2) x U(1)

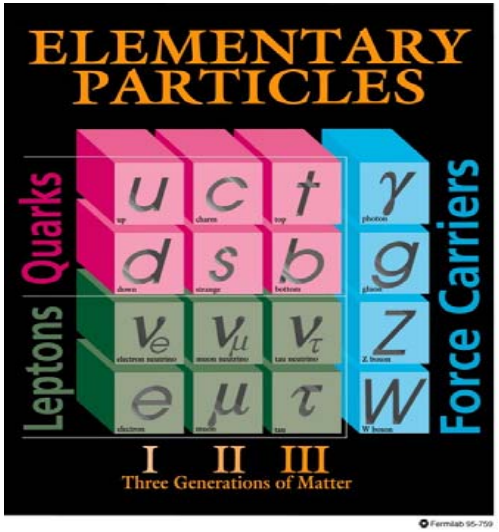


SU(3)



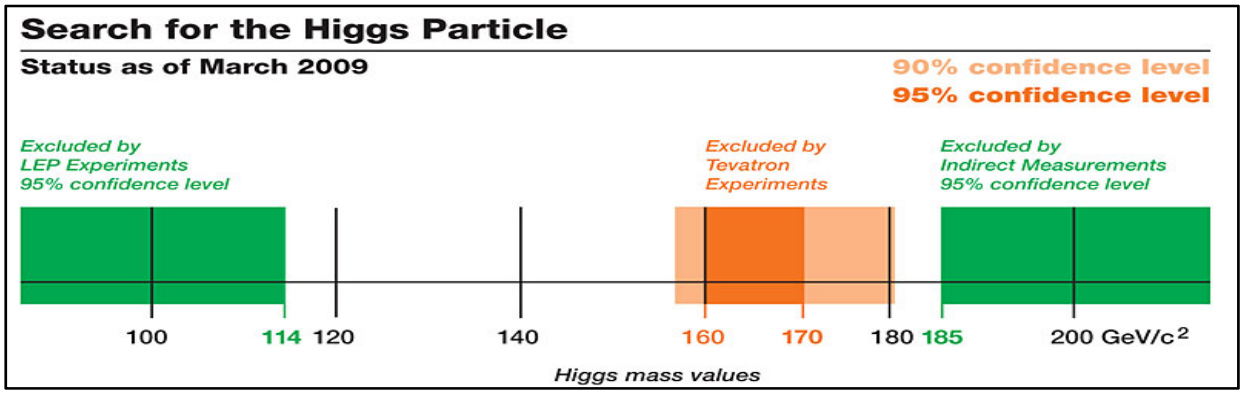
S
M





Why Terascale?

Higgs Mass Bound



EWSB Scale = 246 GeV

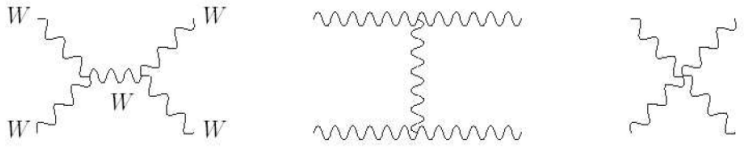
CDM Particle Mass

$$\Omega_X \sim 0.2 \quad \text{for} \quad \langle \sigma v \rangle = \frac{\pi \alpha^2}{8 m_X^2} = 0.1\,\text{pb} \quad \text{or} \quad m_X = 100\,\text{GeV}$$

Electroweak Baryogenesis

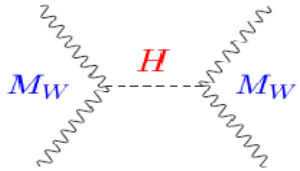
[Talk by S. Matsumoto]

Tree-level Unitarity for $W_L W_L \rightarrow W_L W_L$



Probability ~ (E/TeV)²

+



M_H < 1 TeV !

Central Problems

Electroweak symmetry breaking
Unification of forces
Microscopic spacetime structure
Connection with cosmology

SUSY or Extra-D or Strong Dynamics or …

Impact across all microscopic scales + cosmology

Genuine Path to the Ultimate Destination

Measure masses and mixings of new states,
decay widths and branching ratios,
production cross sections ....

Determine spin and parity,
gauge quantum #'s and couplings.

Reconstruct the Terascale Lagrangian as model independently as possible with great precision.

Shed light on the physics at the fundamental (GUT or Planck or TeV) scale.

Probably

ILC

[??
?]

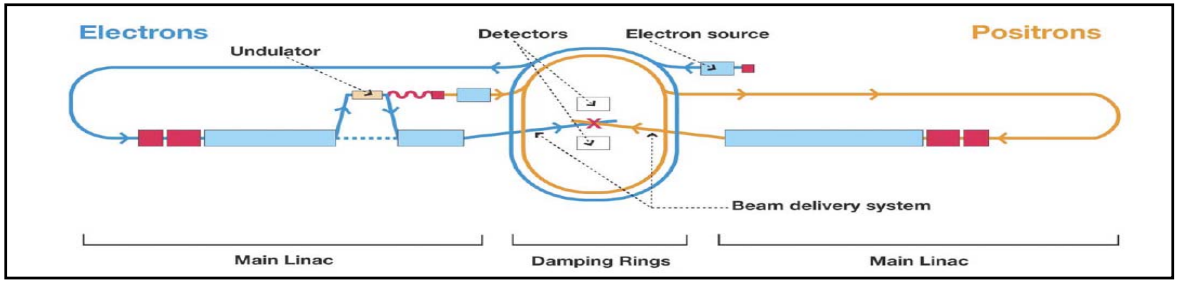
LHC ⇒ ILC : The ILC physics case must be built on the LHC.

Targets of ILC (+LHC)

Model-independent and high-resolution picture at the Terascale

Unification of matter and interactions

ILC = International e^+e^- linear collider



Characteristics

0.5 to 1 TeV (to CLIC w/ 3 TeV)
300 $fb^{-1}/y \Rightarrow 1\ ab^{-1}$ in total
90/60% e^-/e^+ polarization

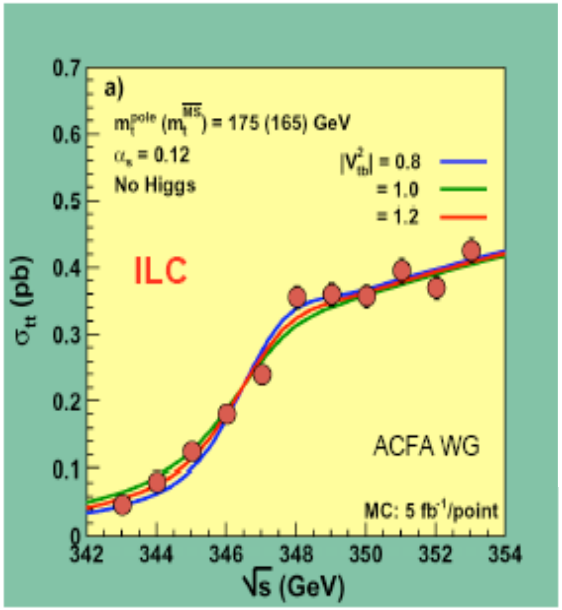
Satellite modes

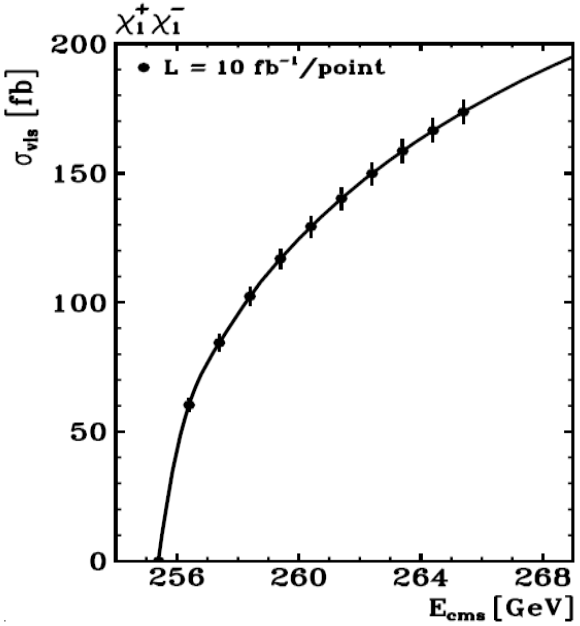
GigaZ: 10^9 Z bosons
e^-e^- w/ same E / reduced L
$\gamma e/\gamma\gamma$ via Compton backscattering

Tunable CM Energy

Precise mass and unambiguous spin determinations from threshold scans

Top quark

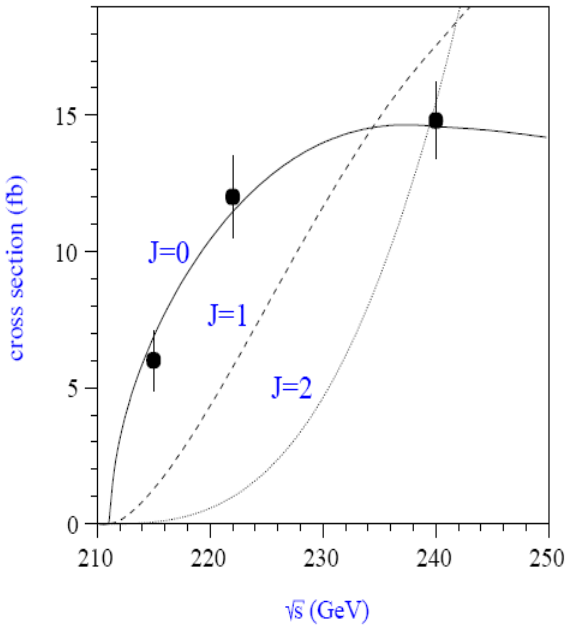




Chargino

[Martyn]

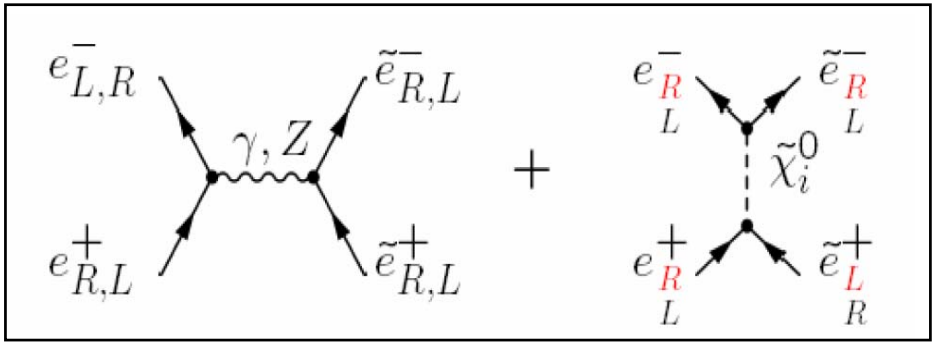
$e^+e^- \rightarrow ZH$

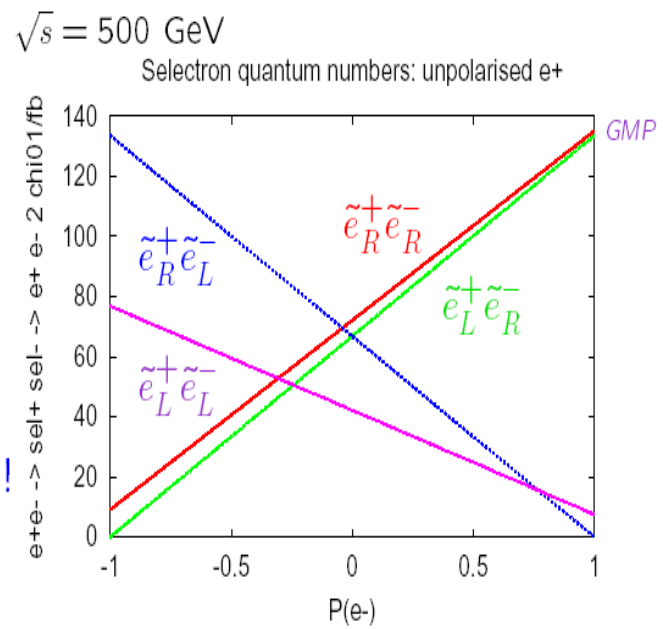


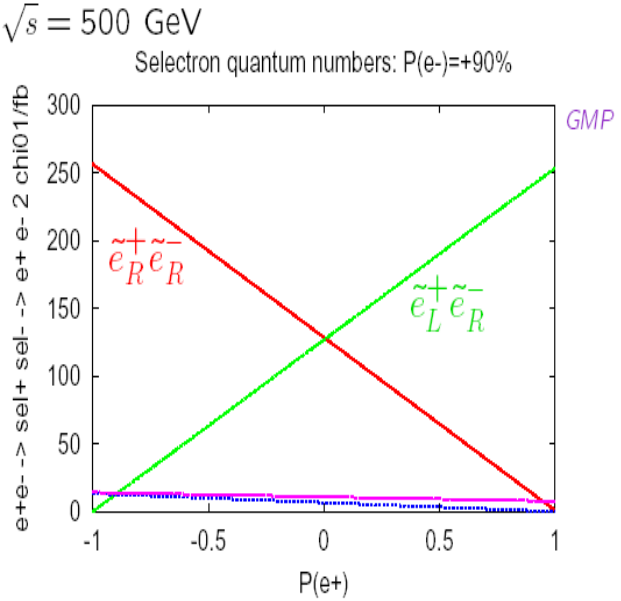
[Miller ea] ⇒ [Lohmann ea]

Beam Polarization

Directly revealing the chiral structure







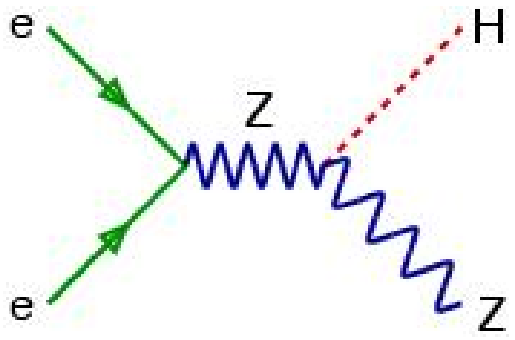
[Moortgat-Pick]

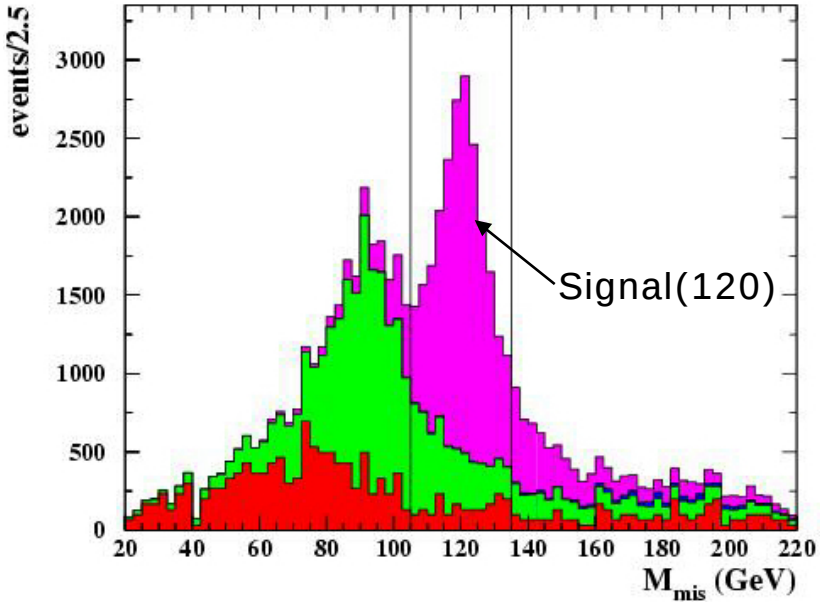
Fixed CM System

Reconstruct the invisible final states

Mass reconstruction of the invisible Higgs boson

$m^2_H = (p_{initial}-p_{visible})^2$





[Schumacher]

Higgs Roadmap

Discover the Higgs boson(s) at LHC

Determine its properties/profile

Mass, spin and parity

Decay patterns

Measure Yukawa like patterns

Fermion/gauge boson couplings

Observe rare decay modes

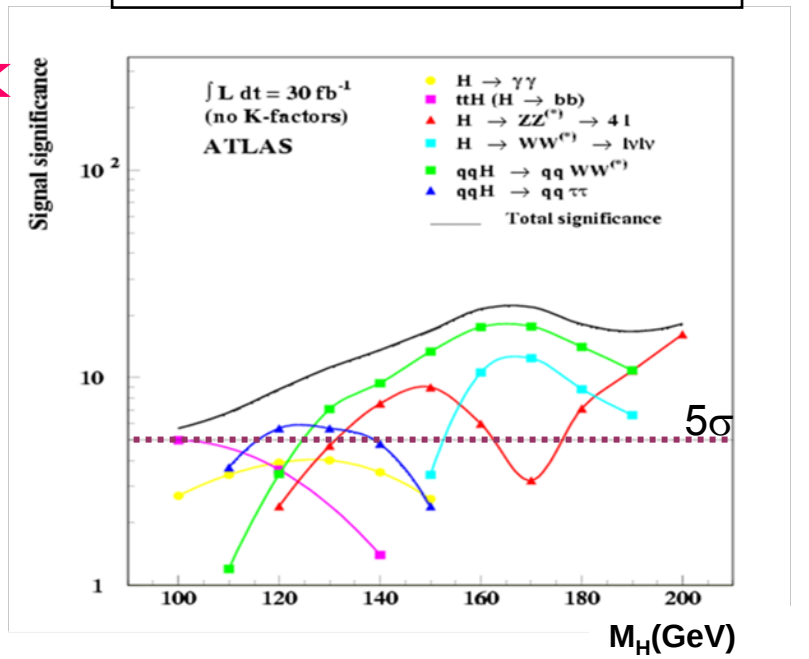
Unexpected decay modes?

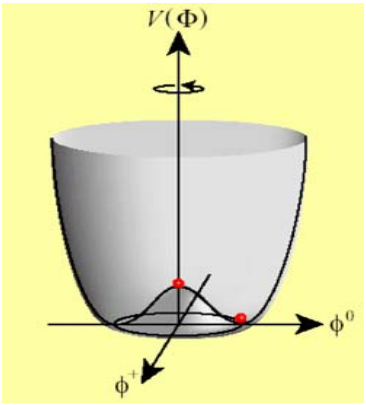
Measure the total width

Reconstruct the Higgs potential

Is it SM, SUSY, composite, …?

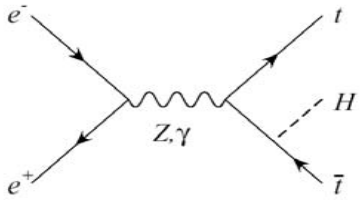
Higgs Discovery @ LHC



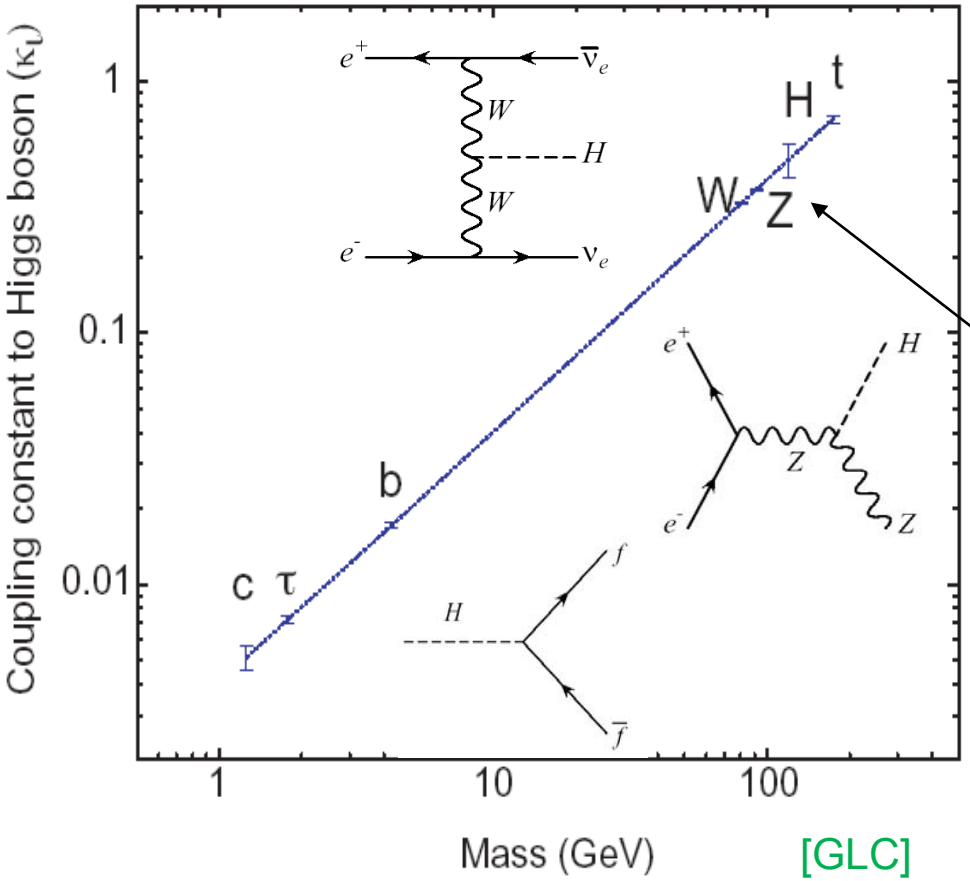


Couplings: $\kappa_i = m_i/v$

Coupling-Mass Relation

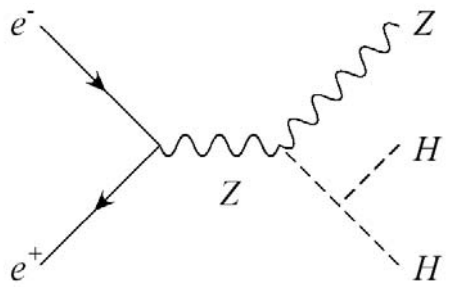


(E_{cm} >700 GeV)



[GLC]

LHC: ~10% for ratios of coupling constants
ILC: a few % determination of absolute values



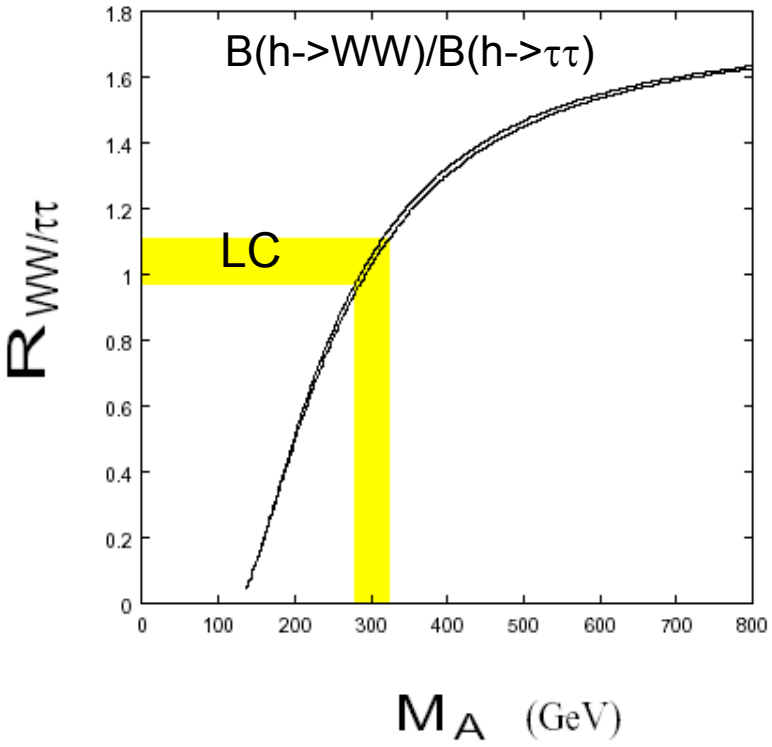
Higgs self-coupling

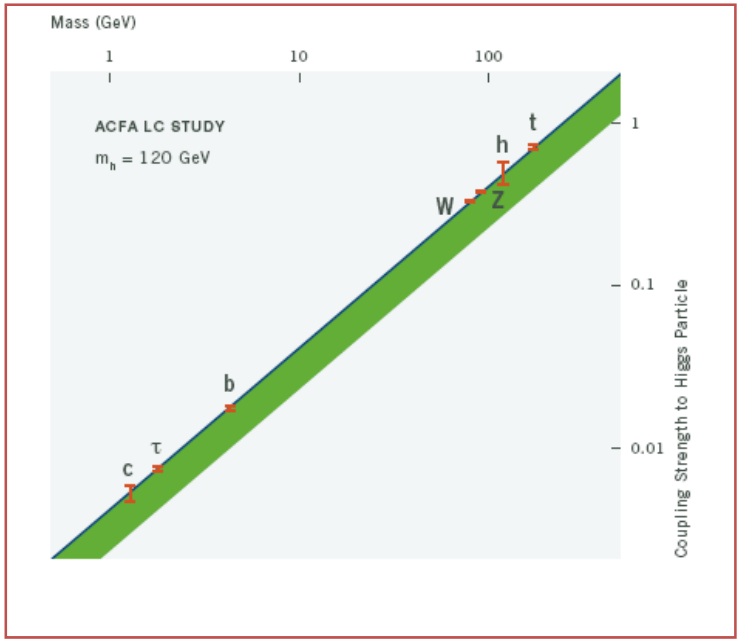
m_H=120 GeV, E_{cm}=300-500 GeV, L=500 fb^{-1}

Revealing New Physics Effects

Heavy MSSM Higgs bosons

Radion-Higgs mixing





[ACFA Studies]

Direct New Physics Searches

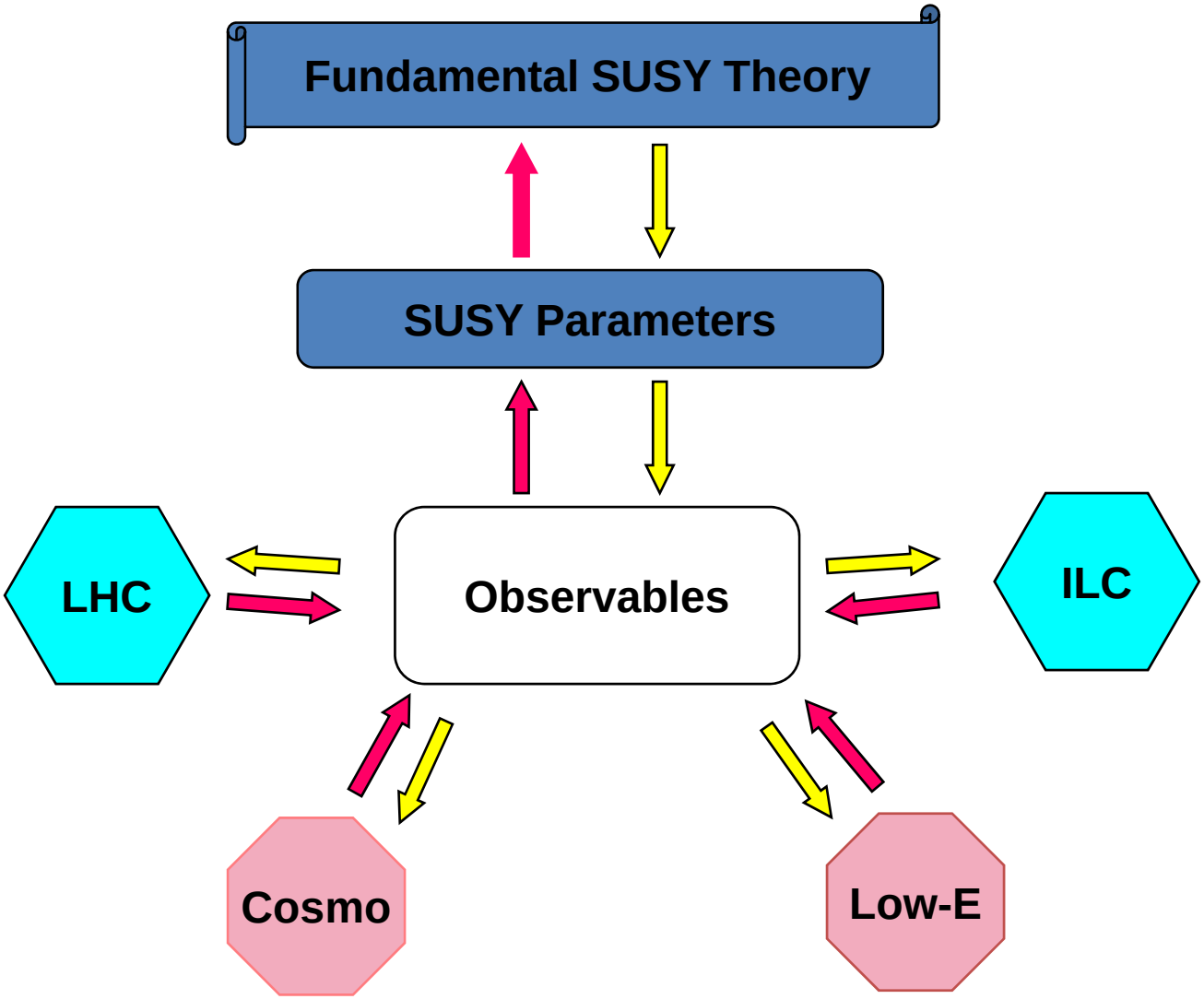
Natural solutions to the hierarchy problem
⇒ NP signals around 1TeV range

First NP signals likely to be obtained at LHC

ILC necessary to figure out the NP

A case study for the SUSY path

SUSY Path


Fundamental SUSY Theory
SUSY Parameters
LHC
Observables
ILC
Cosmo
Low-E

Requirements

- **Precise and efficient theoretical predictions**
  - ⇔ **Higher-order corrections and automatic calculation tools**
  - ⇔ **Consistent RGE programs**

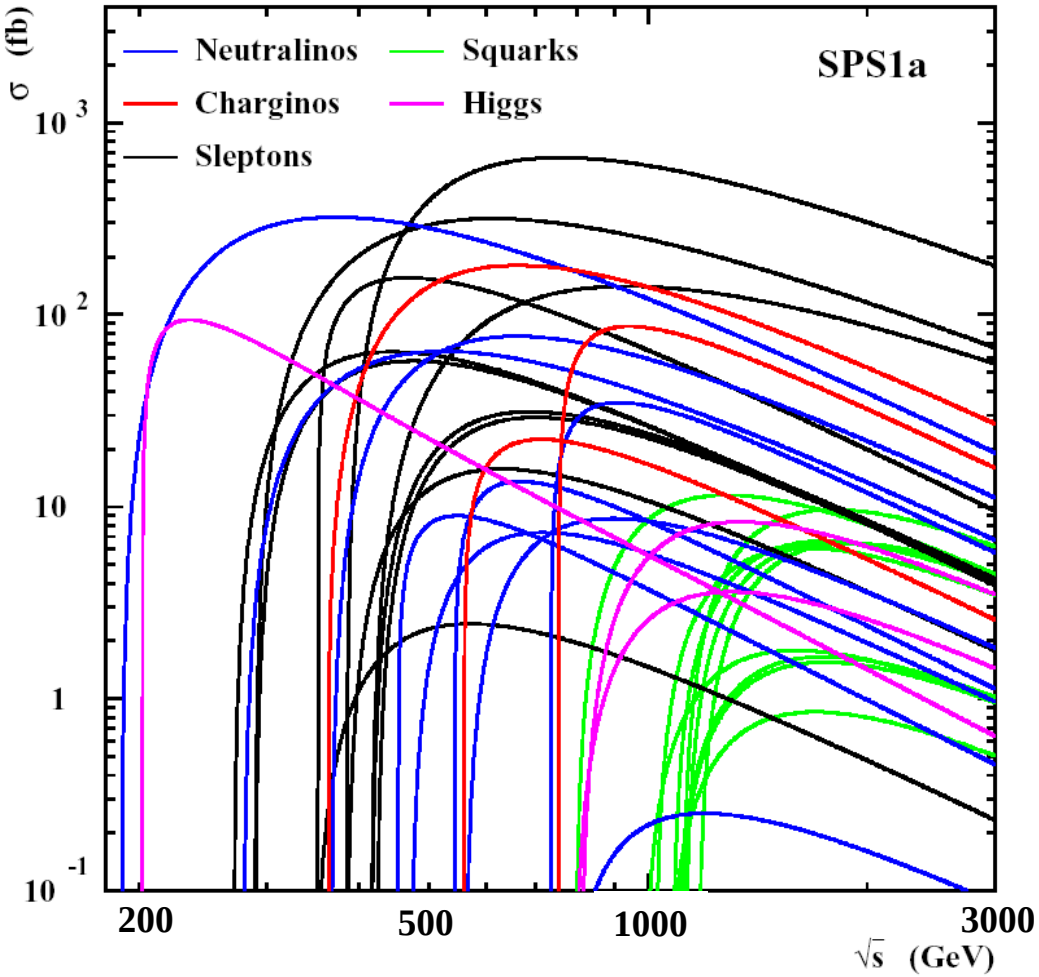
- **Excellent accelerator and detector performance is a must**
  - ⇔ **Physics/detector-oriented benchmarks**
  - ⇔ **Detector performance evaluations**

- **Overall (model-independent) combined analyses are urgent?!**
  - ⇔ **New benchmarks for Cos/LHC/ILC**
  - ⇔ **Perform full simulations for the LHC/ILC/Cos points within one year. Remember that LHC will re-start running in 2009.**

- **R-parity, CP and flavor violating phenomena**
  - ⇔ **Neutrino and LE flavor physics**
  - ⇔ **EW baryogenesis**
  - ⇔ **Direct CP violation**
  - ⇔ **…**

- **In addition: NMSSM, GDM and other SUSY breaking scenarios**

Production



Democratic: cross sections in the 10 ~ 1000 fb range
⇒ O(10^3 ~ 10^5) events

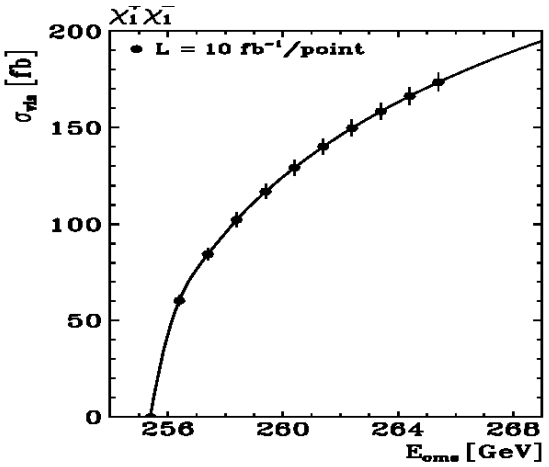
Various ILC options are vital!

Tunable CM energy
Tunable beam polarization
High luminosity

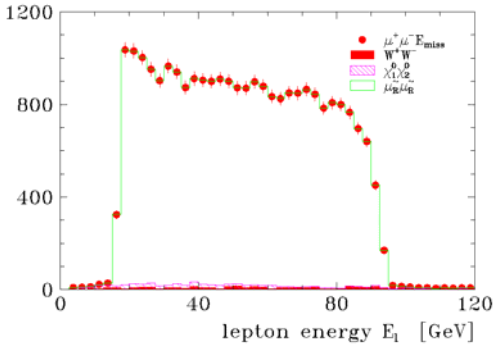
Mass

Spin

Threshold excitation



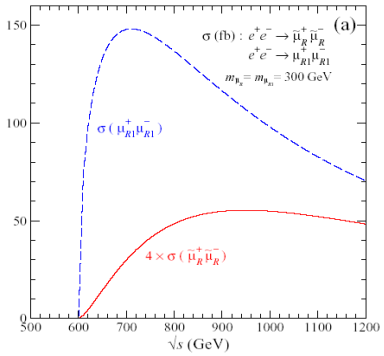
Decay edges



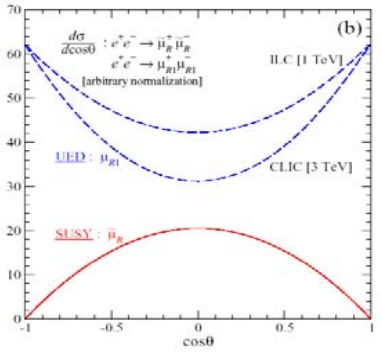
[Martyn]

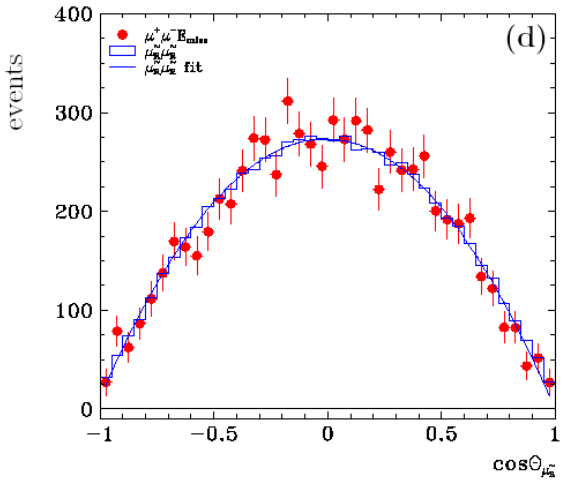
ILC ⇒ various methods

Threshold excitation



Angular distribution

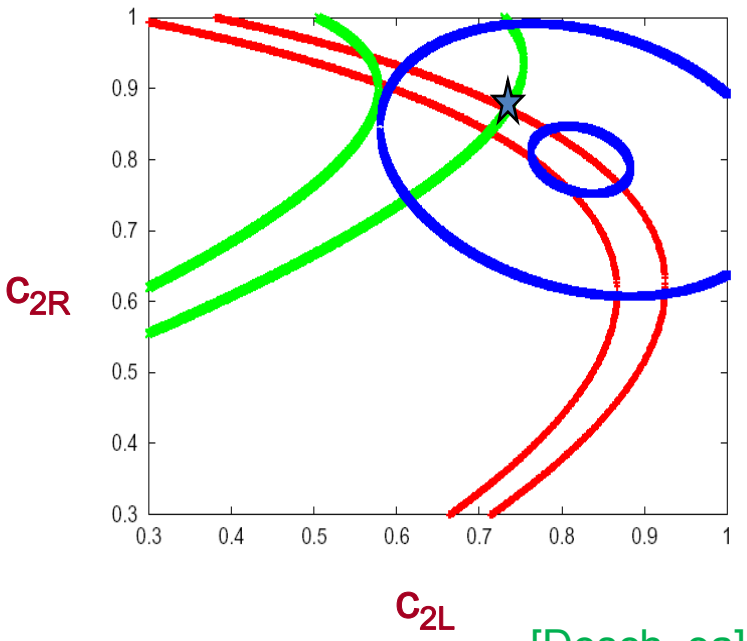




[SYC ea]

Mixing

Gaugino-higgsino mixing

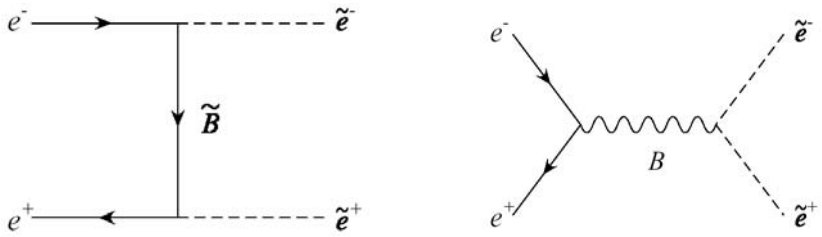


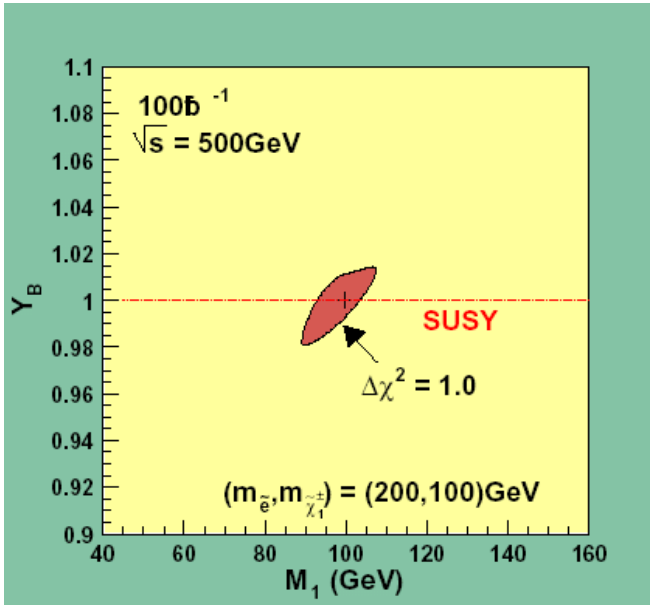
[Desch ea]

R/G for $L^{\pm}[11]$ and B for $R^{\pm}[11]$

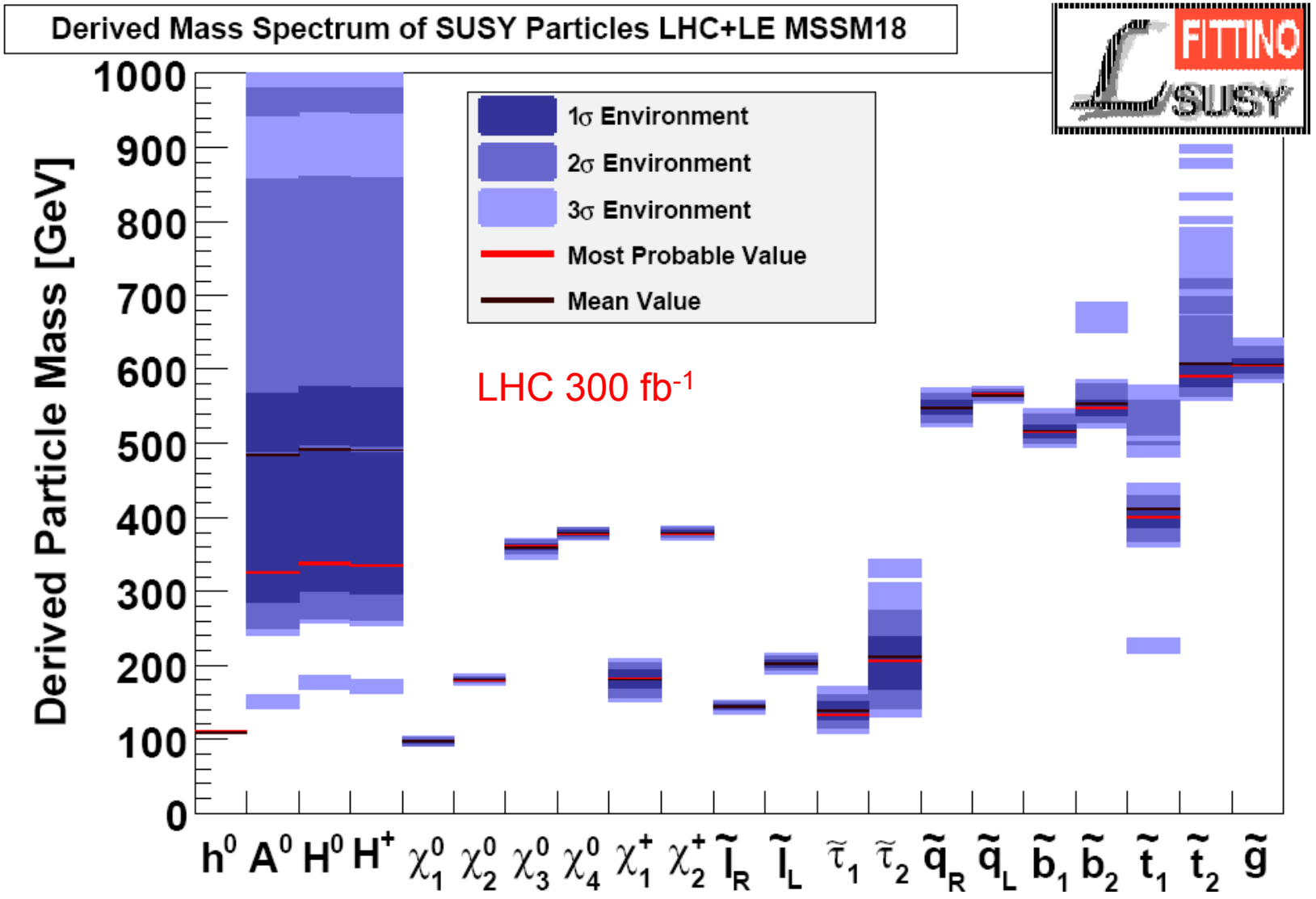
Yukawa=Gauge

$$g_{\tilde{B}\bar{e}_R e} = g_{Bee}$$

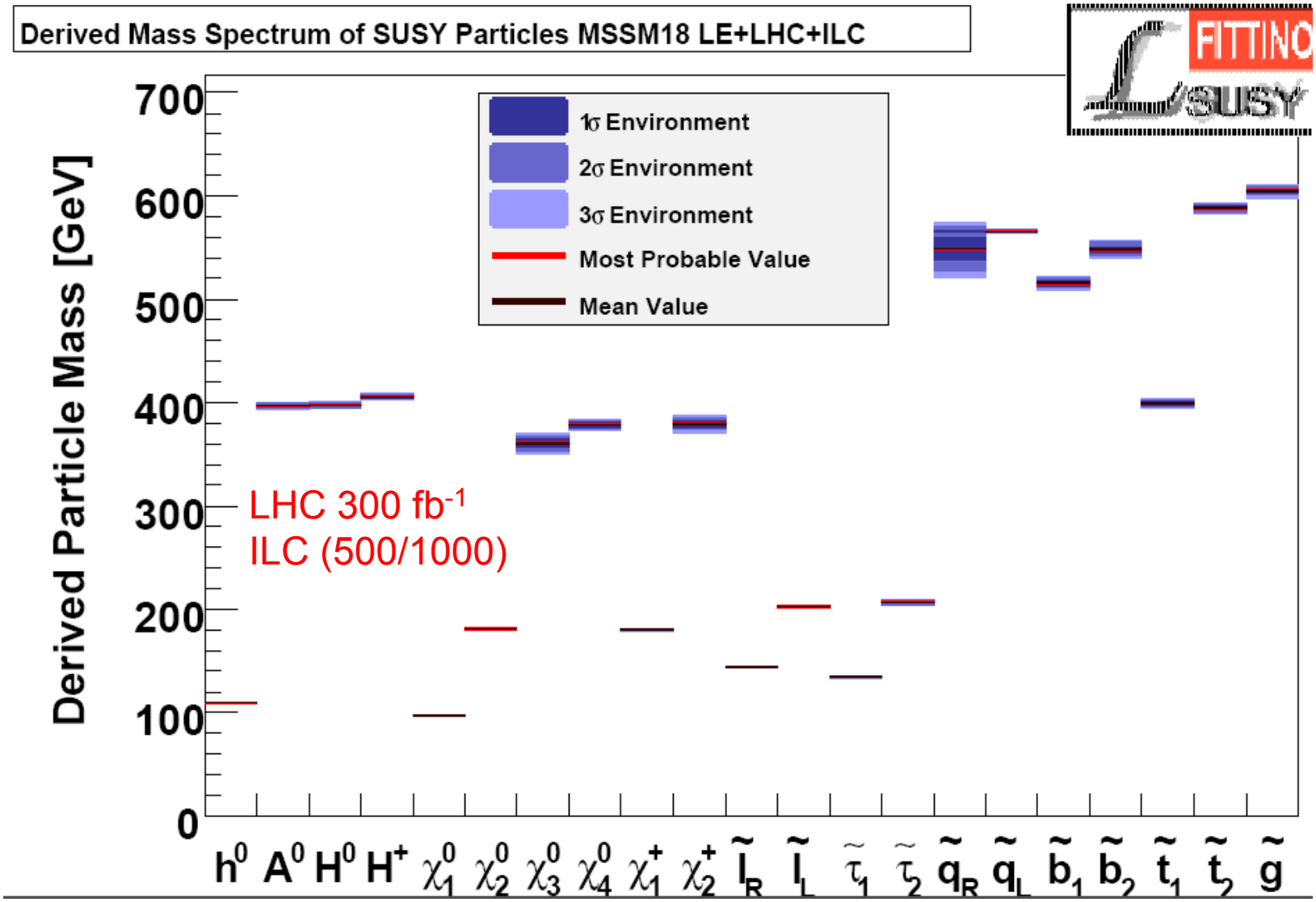




[Nojiri, Fujii, Tsukamoto]

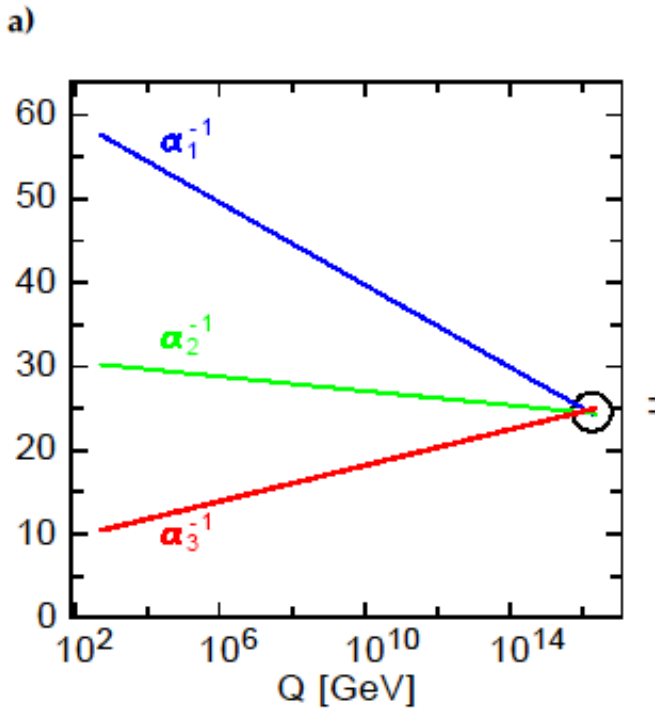


[Bechtle, Wienemann, Uhlenbrock, Desch]

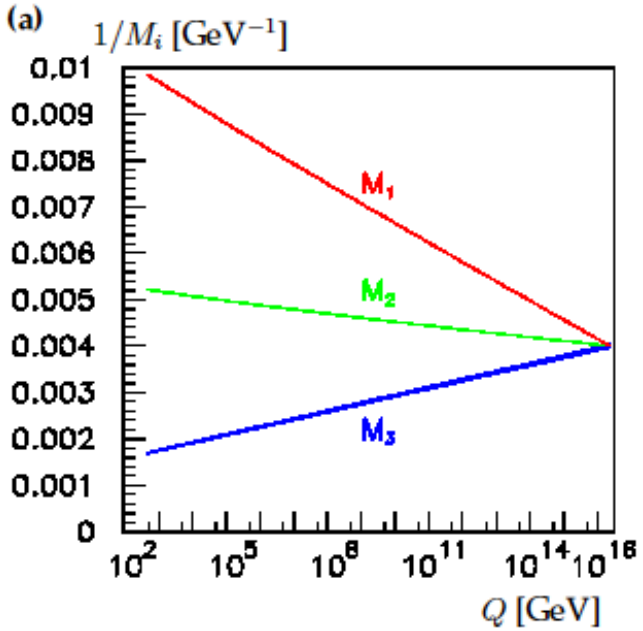


[Bechtle ,Wienemann, Uhlenbrock, Desch]

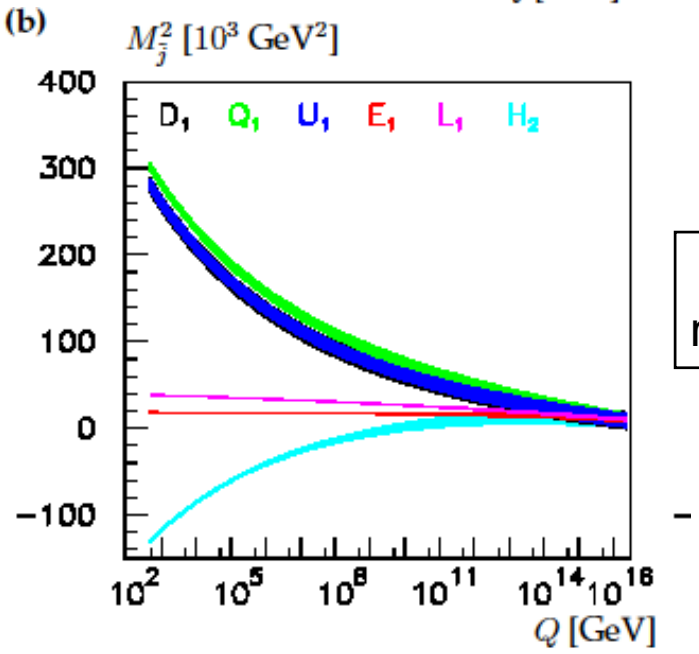
GUT



Gauge couplings



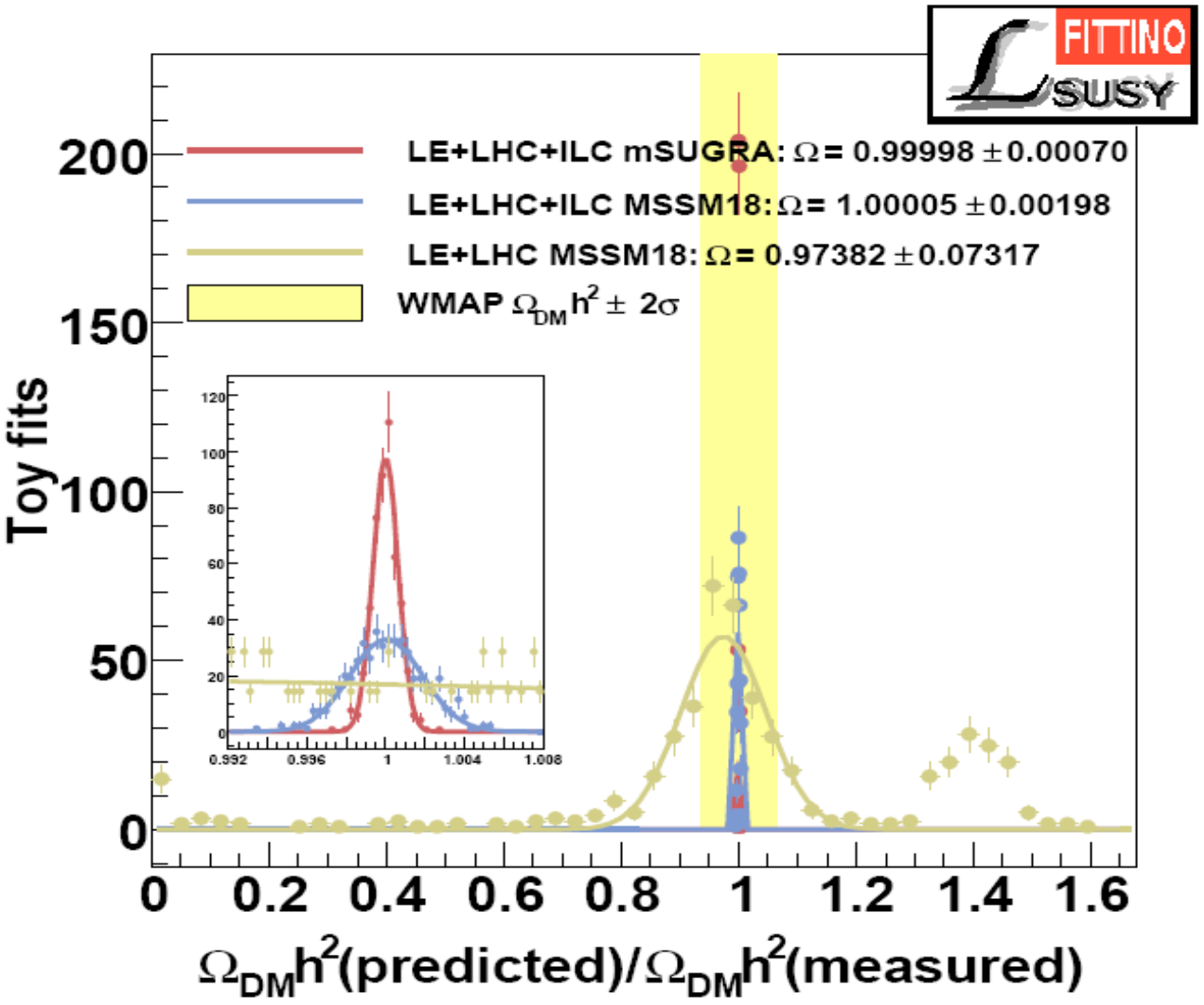
Gaugino masses



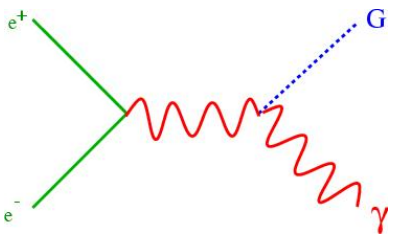
Scalar masses

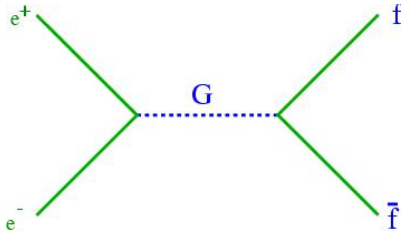
[LHC/LC report]

Prediction for DM Density



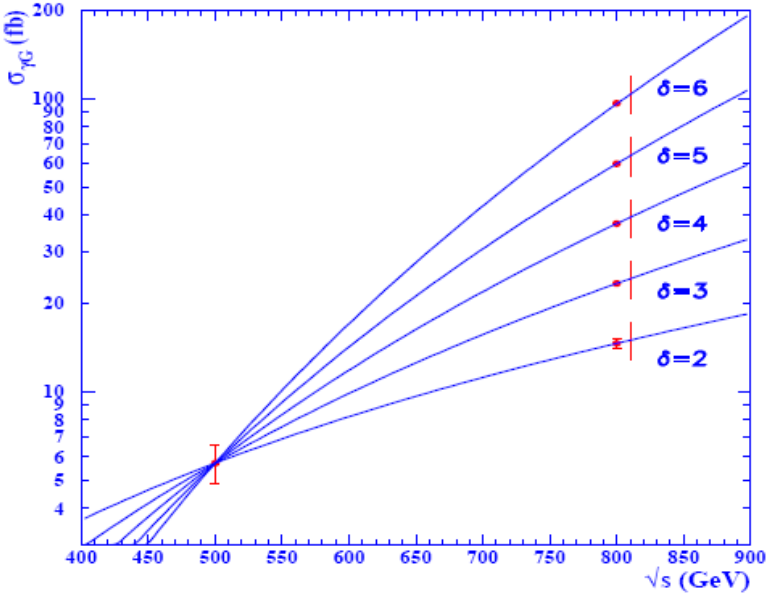
Large Extra Dimensions [ADD]

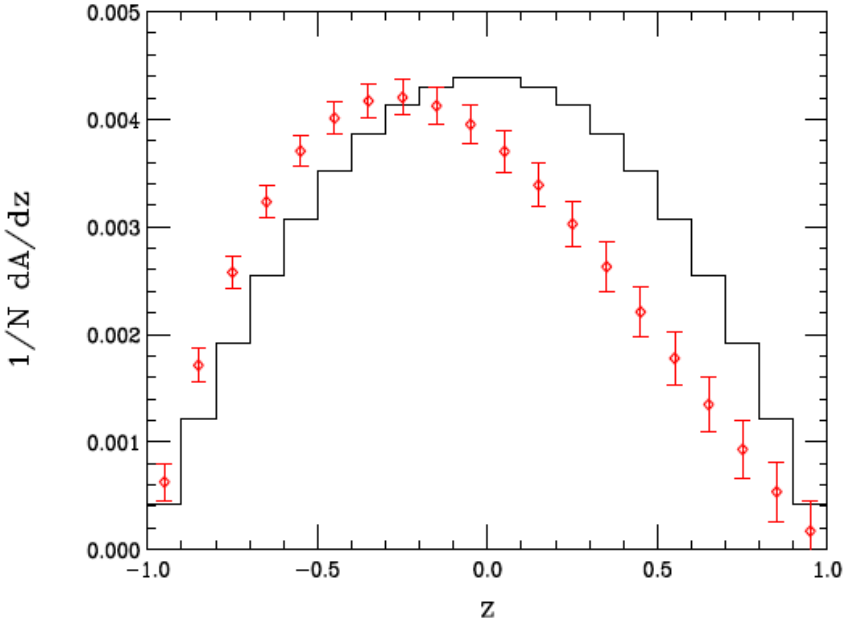




Real graviton emission

Azimuthal asymmetry with transverse polarization

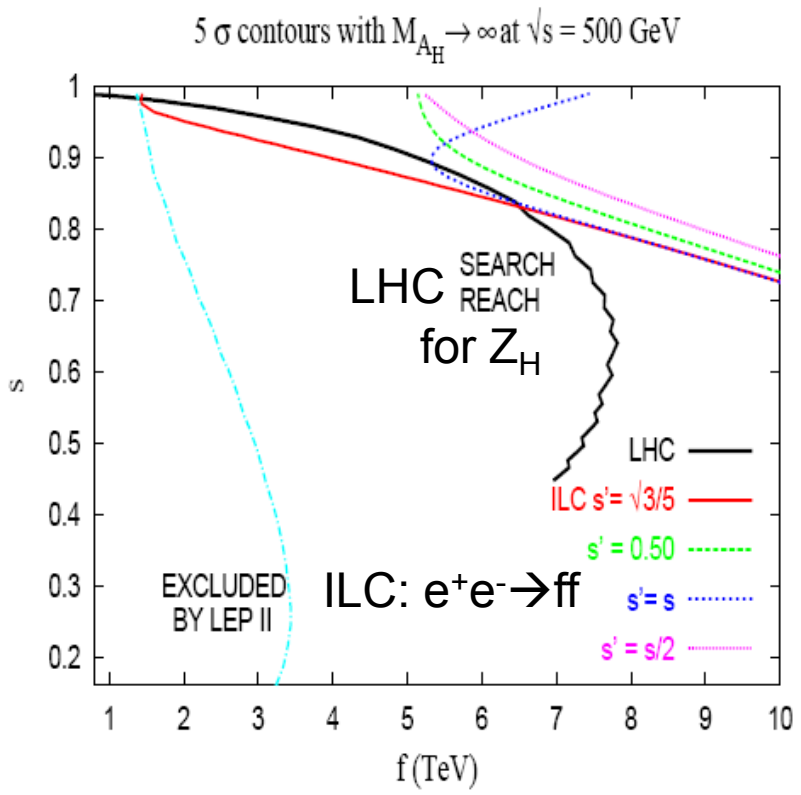


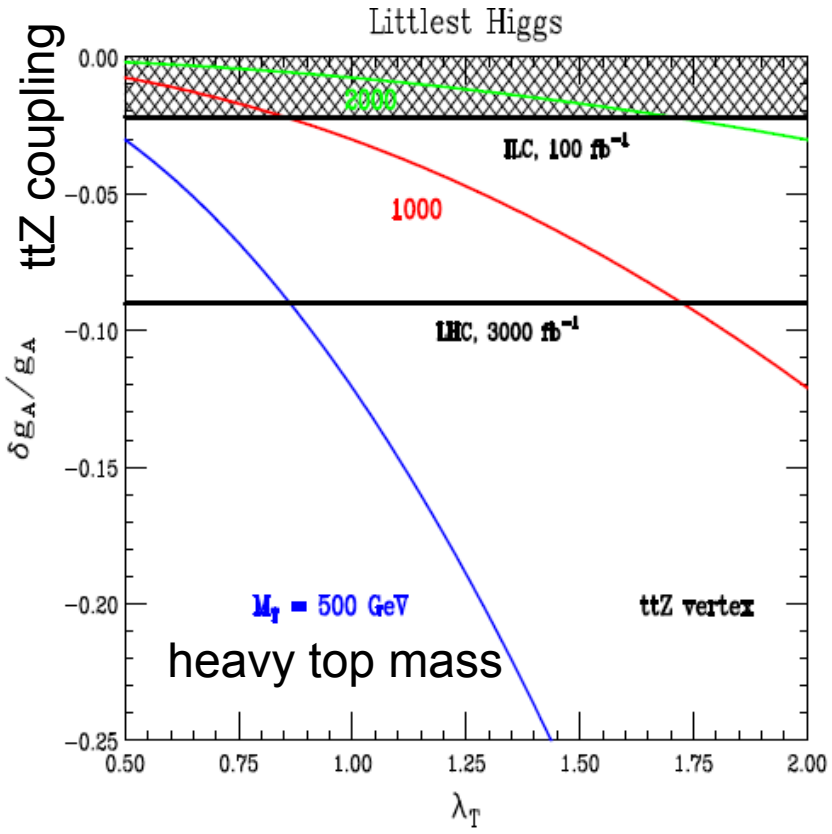


[Wilson; Rizzo]

[Rizzo]

Little Higgs Models





f: global SB scale
s,s´: mixing angles of gauge SM

[Conley, Hewett, Le]

$$m_T/f = (\lambda_t^2 + \lambda_T^2)/\lambda_T$$

[Berger, Perelstein, Petriello]

Summary

Every ILC-related work has added/will add value to the essential role of ILC in probing Terascale physics and beyond.

More comprehensive/precision analysis of SUSY and other Terascale scenarios in demand and progress

ILC is a powerful micro/telescope toward the unification of interactions wherever it is realized.

LHC © ILC

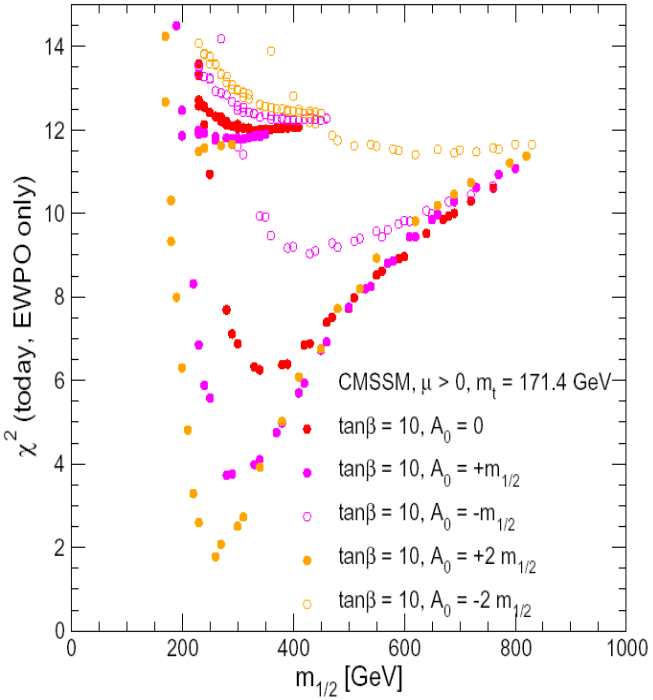
A Toad!

Back-up Slides

SUSY Mass Scale

[no firm prediction]

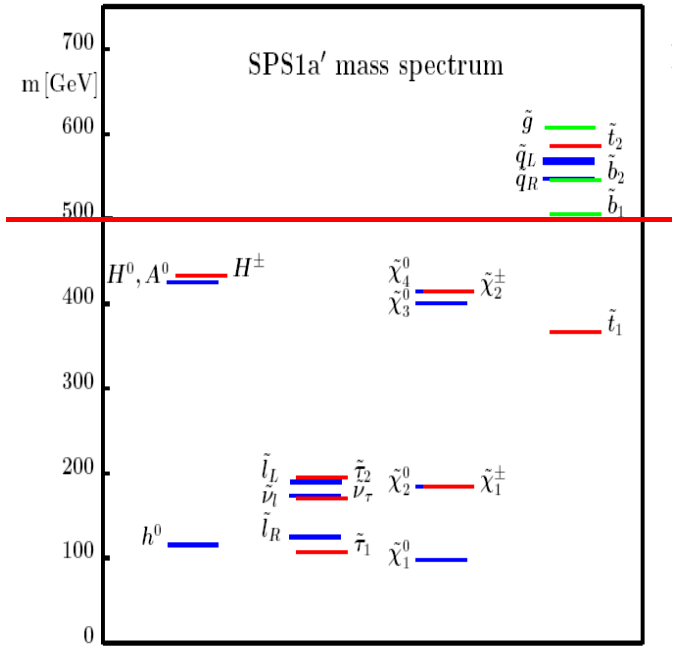
Low-E data + CDM w/ mod. tanβ



[Ellis ea]

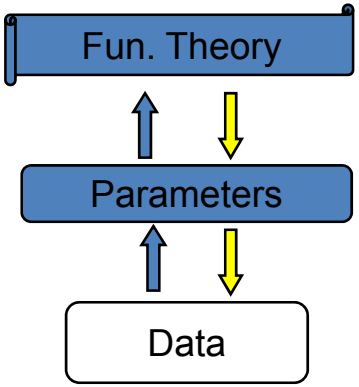
ILC1000

[SPS1a']



H S

A favorable scenario: all non-colored SUSY particles produced at ILC1000



The SPA Project

SPA Convention

renorm. schemes / LE parameters / observables

Program repository

th. /exp. analyses / LHC+ILC tools / SLHA

Theoretical and experimental tasks

short- and long-term sub-projects

Reference point SPS1a'

derivative of SPS1a, consistent with all data

Current and future developments

CP-MSSM, NMSSM, RpV, String effective th. etc

http://spa.desy.de/spa

Extracting SUSY Parameters at the Terascale

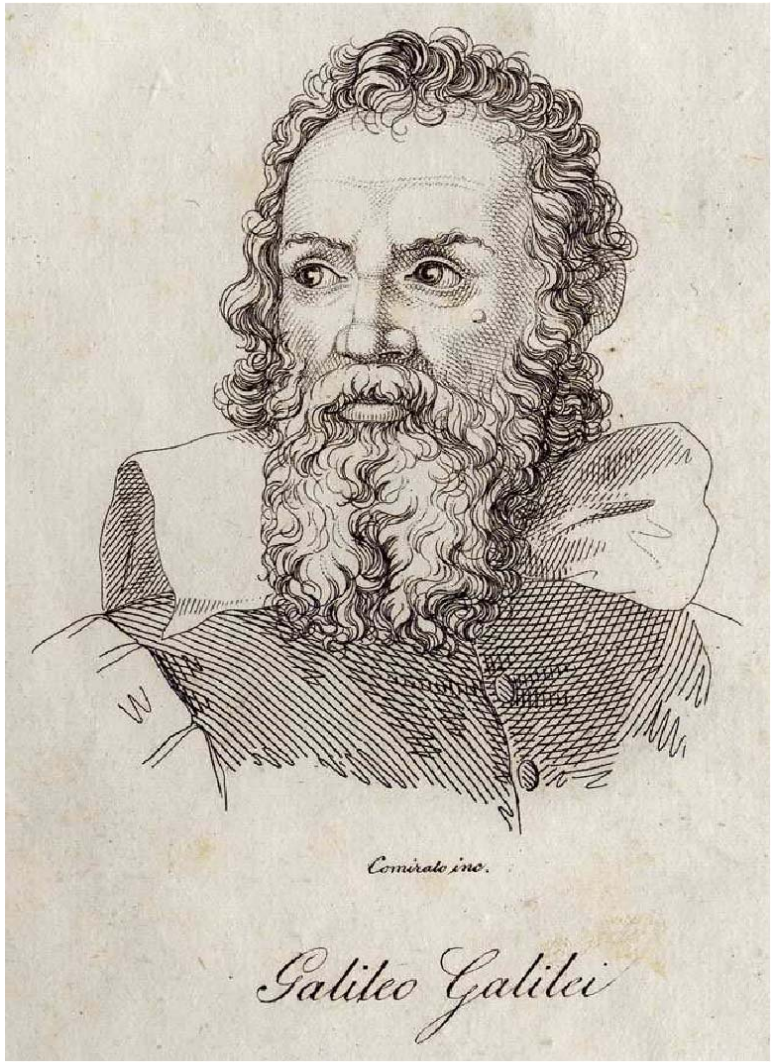
Gaugino, higgsino, scalar mass parameters, trilinear couplings, etc

SPA Project

Well-defined theoretical scheme and conventions for multi-loop LHC and ILC analyses

SFitter [Lafaye, Plehn, D. Zerwas]
Fittino [Bechtle, Desch, Weinemann]

EXC	LHC	LC	LHC+LC	SPS1a
M_1	102.5±5.3	102.3±0.1	102.2±0.1	102.2
M_2	191.8±7.3	192.5±0.7	191.8±0.2	191.8
M_3	578.±15.	→	588.±11.	589.4
$M_{\tilde{e}_L}$	198.7±5.1	198.7±0.2	198.7±0.2	198.7
$M_{\tilde{e}_R}$	138.2±5.0	138.2±0.05	138.2±0.05	138.2
$M_{\tilde{q}_L}$	550.±13.	→	553.3±6.5	553.7
$M_{\tilde{u}_R}$	529.±20.	→	532.±15.	532.1
$M_{\tilde{d}_R}$	526.±20.	→	529.±15.	529.3
A_t	-507.±91.	-501.9±2.7	-505.2±3.3	-504.9
μ	345.2±7.3	344.3±2.3	344.4±1.0	344.3
$\tan\beta$	10.2±9.1	10.3±0.3	10.06±0.2	10



Galileo Galilei

Io stimo più il trovar un vero, benchè di cosa leggiera, ch'l disputar lungamente delle massime questioni senza conseguir verità nissuna.

I attach more value to finding a fact, even about the slightest thing, than to lengthy disputations about the Greatest Questions that fail to lead to any truth whatever.