Linear Collider, Physics and Status

presented by H. Yamamoto
Tohoku University

KEK, March 1, 2004

Reference: 'GLC project' (the roadmap report)
http://lcdev.kek.jp/RMdraft

GLC parameters

- Max c.m. energy : 500 GeV, upgradable to ~1 TeV.
- Luminosity : $1 \sim 3 \times 10^{34}$/cm^{2}s $\longrightarrow$ 500 fb^{-1} over 2-4 years.
- Start physics running around 2015.

	warm (NLC/GLC)	cold (Tesla)
#bunch/train	192	2820
#train/s	150 Hz	5 Hz
bunch sp.	1.4 ns	337 ns
train length	269 ns	950 μs
gap/train	6.6 ms	199 ms

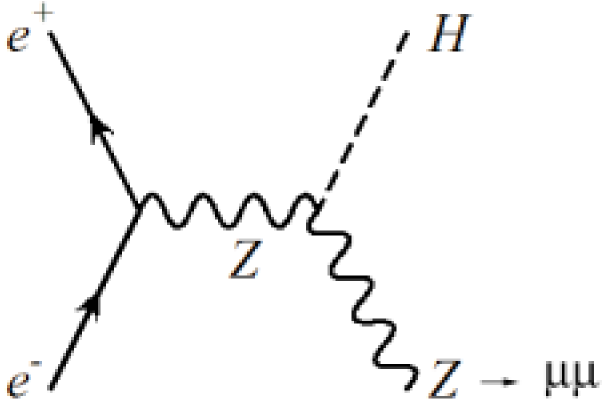
Readout/DAQ tougher for cold.
Bunch identification easier for cold.

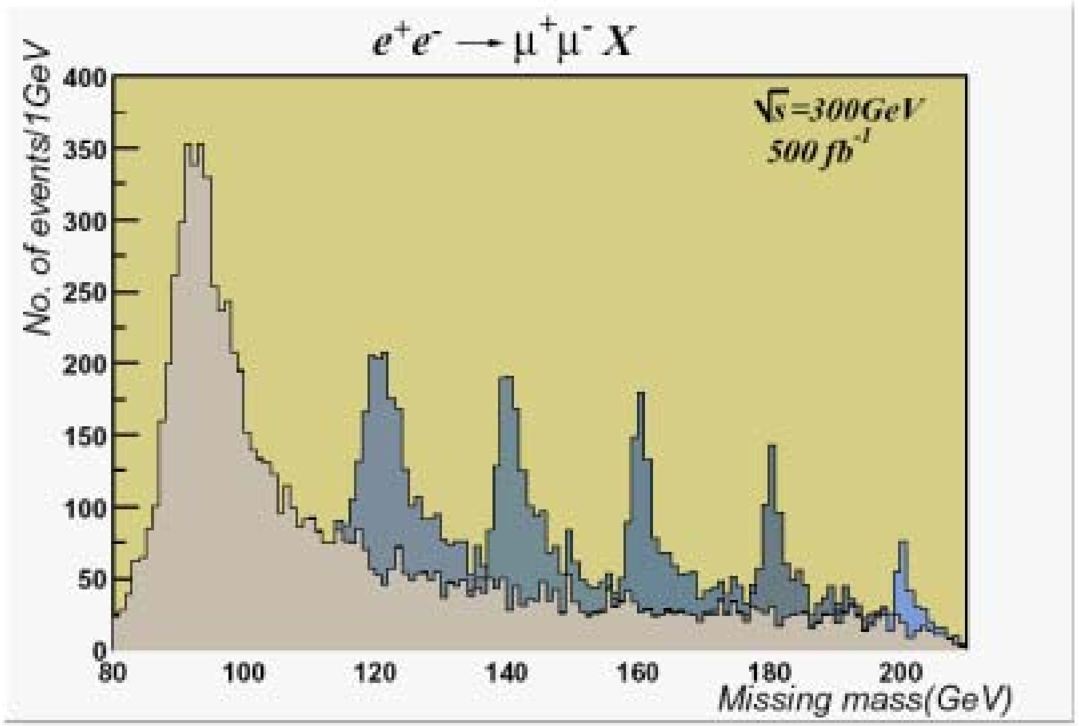
Higgs Studies

'Gold-plated' mode

$e^+e^- \longrightarrow ZH$

$Z \longrightarrow \mu^+\mu^-, e^+e^-$





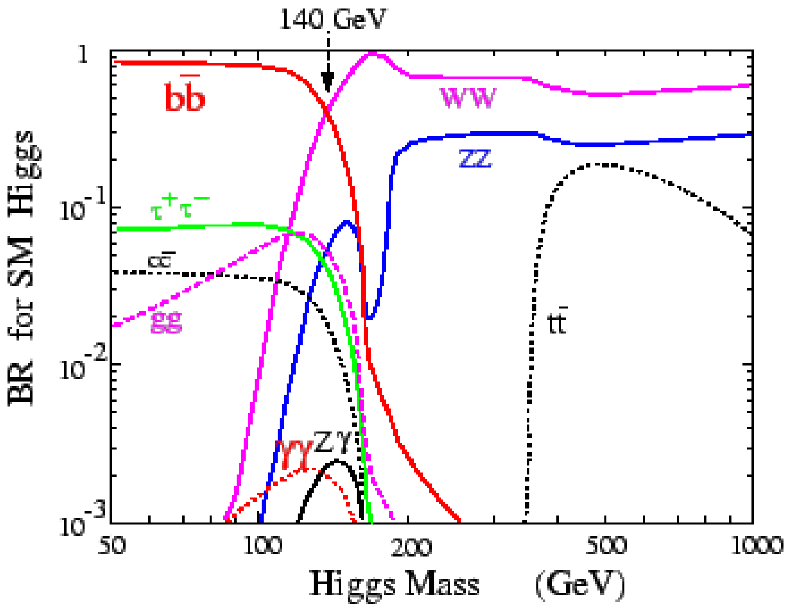
Plot $\ell\ell$ recoil mass (Higgs not directly measured).

Decay-independent measurements of Higgs mass, production rate.

Detecting Higgs decays $\longrightarrow$

absolute Brs, background reduction($ee \rightarrow ZZ$).

SM HIggs branching fractions



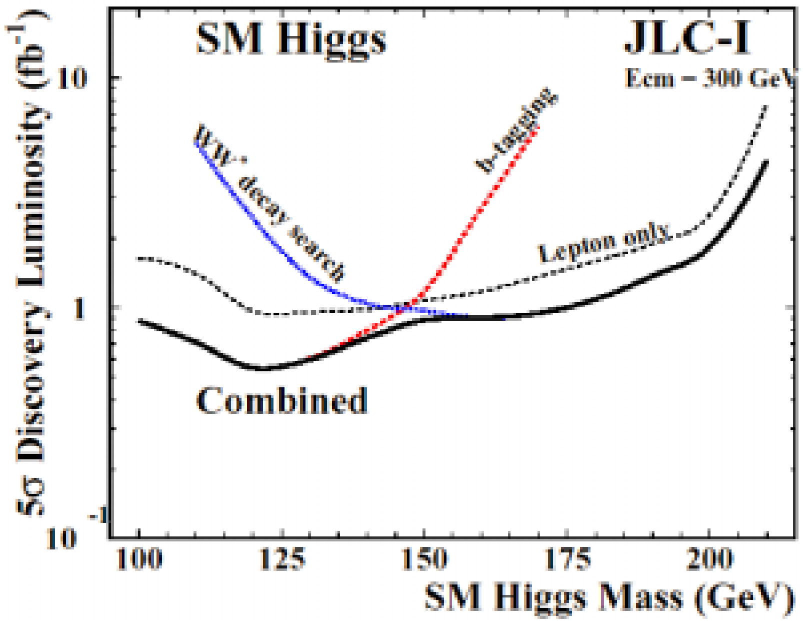
Dominant decay :

$b\bar{b}$ $(m_h < 140$ GeV)

WW $(m_h > 140$ GeV)

b-tag by vertexing.

SM Higgs Sensitivity

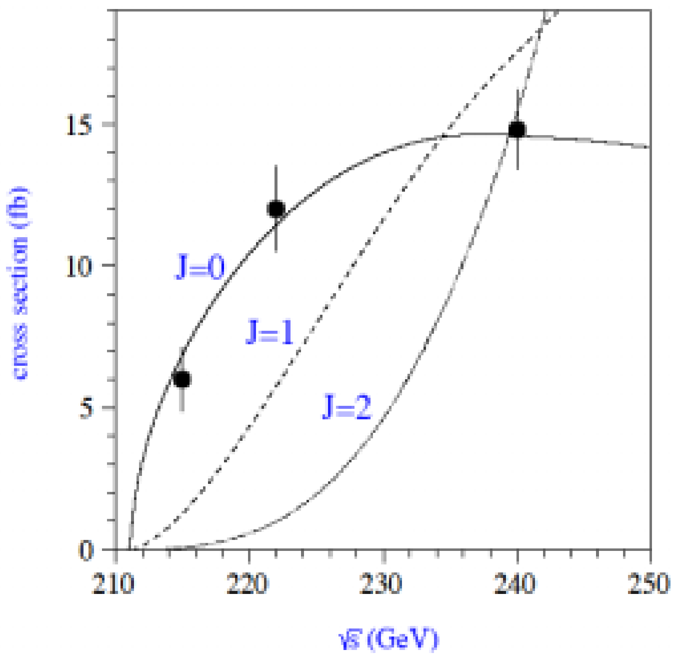


- 5σ discovery in ~ 1 day.
- LHC : 5σ in ~ 1 year.
  GLC starts 5-8 years later $\longrightarrow$
  'discovery machine' after one week.
- 500 fb^{-1} $\longrightarrow$ 10^5 Higgs detected in clean environments.

Determination of Higgs Parameters

- $\sigma_{m_h} = 40$ MeV (decay-independent)
  ($m_h = 120$ GeV with 500 fb^{-1})

- Spin by energy scan of $e^+e^- \to ZH$.
  ($m_h = 120$ GeV with 20 fb^{-1}/point)



Threshold behavior :

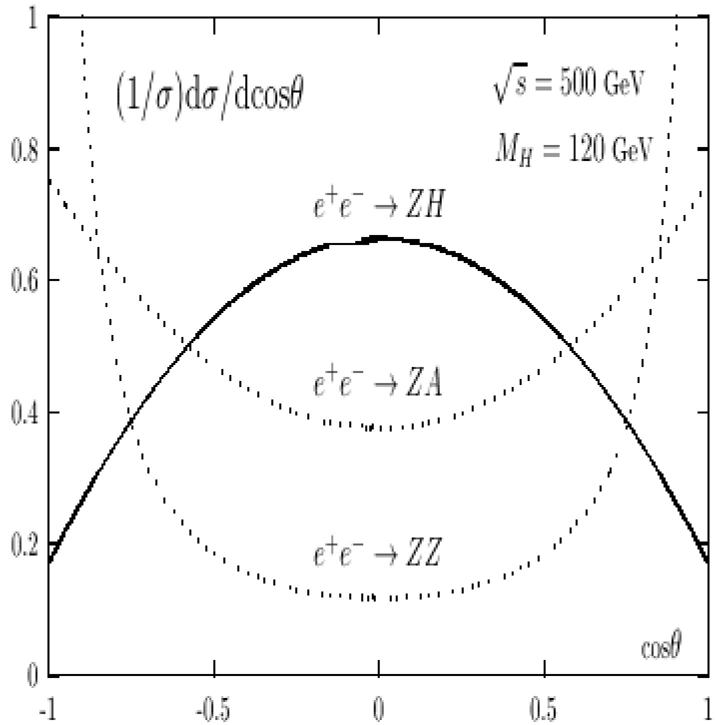
$$\sigma \propto \beta^n$$

$n = 1$ for $J = 0$,
$n > 1$ for $J = 1, 2$.

$$\beta^2 = \left(1 - \frac{(m_Z + m_H)^2}{s}\right) \times \left(1 - \frac{(m_Z - m_H)^2}{s}\right)$$

β : 'average' of Z, H

- CP by angular distributions in $e^+e^- \to ZH$.



H: CP+, A: CP−

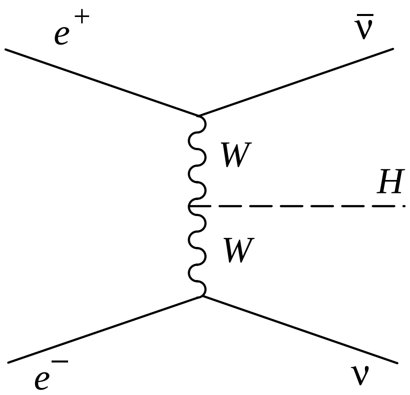
In the limit $\sqrt{s} \gg m_Z$

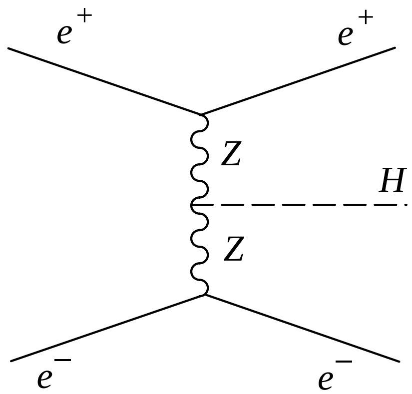
$$\sigma_{e^+e^- \to ZA} \propto 1 + \cos^2\theta_Z$$
$$\sigma_{e^+e^- \to ZH} \propto \sin^2\theta_Z$$

θ_Z: angle of Z wrt beam.

($Z \to f\bar{f}$ can also be used.)

- ZZH, WWH couplings to a few % by $ee \to ZH$ and $ee \to \nu\bar{\nu}H(W$ fusion$), e^+e^-H(Z$ fusion$)$.

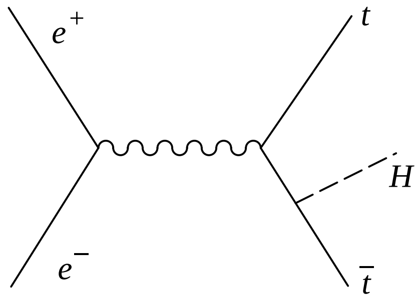




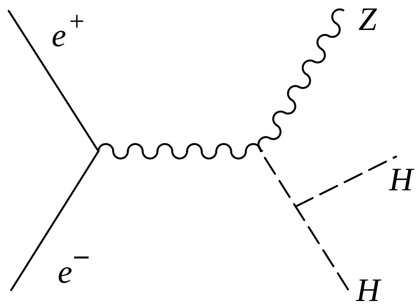
- Higgs total width to 5% by $Br(H \to WW)$ and $\Gamma(H \to WW)$ (from the WWH coupling obtained above)

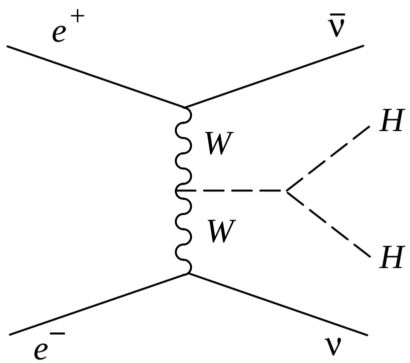
- Couplings to b, c, τ by $Br(H \rightarrow f\bar{f})$.
  (b, c-tagging by vertexing essential)

- Coupling to t by $ee \rightarrow t\bar{t}H$.



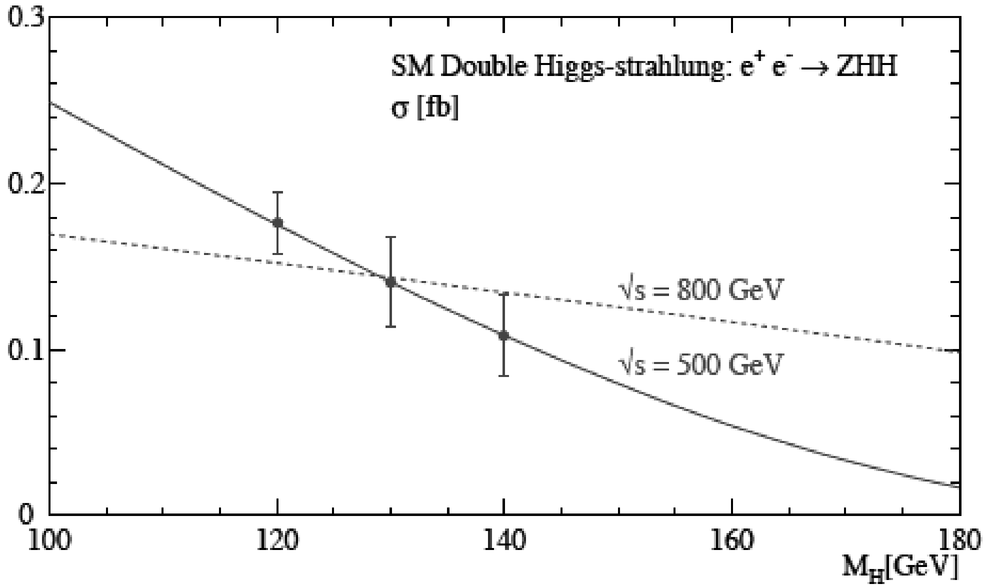
- Higgs self coupling by $ee \rightarrow ZHH$ and $\nu\bar{\nu}HH$.



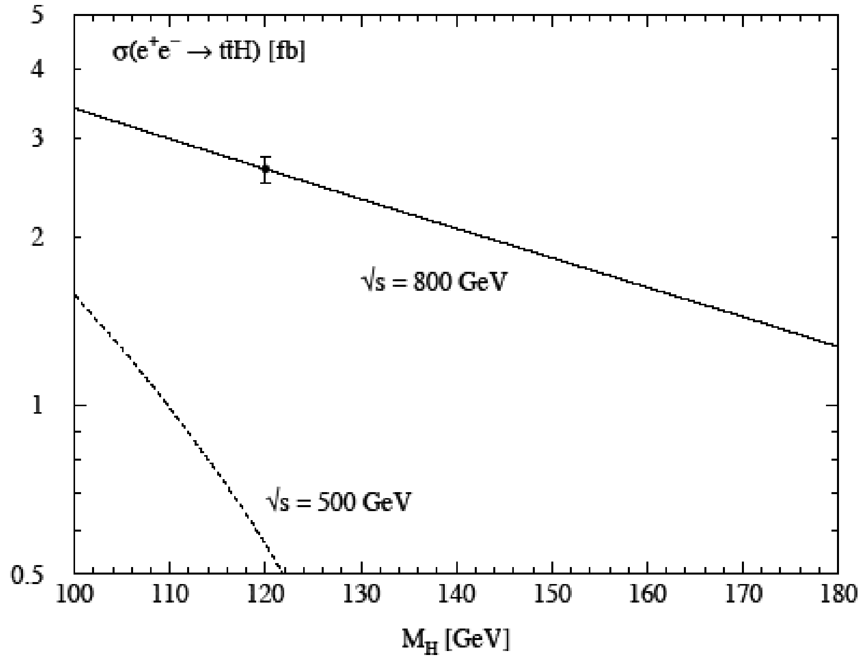


$e^+e^- \to ZHH, t\bar{t}H$

ZHH

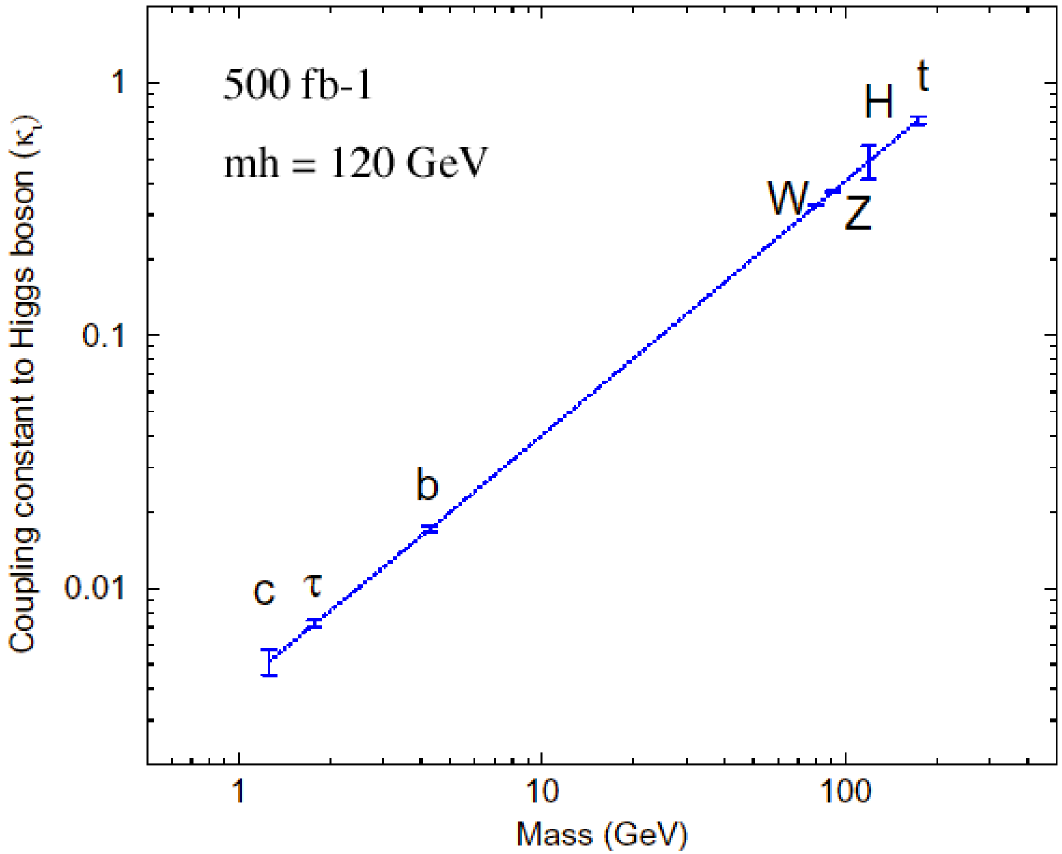


$t\bar{t}H$



$t\bar{t}H$ require a large E_{cm} (error bars: 1000 fb^{-1})

Higgs Coupling Sensitivities



$\sqrt{s} = 300$ GeV (b, c, τ, W, Z), 500 GeV (H), 700 GeV (t).

SM Higgs : coupling $\propto$ particle mass.

Supersymmetric Particles

- GLC can pair-create many sparticles in variety of models.
- Precision measurements of masses and mixings.
- Determine qunatum numbers: spin, hypercharge etc.
- Beam polarization can be useful above and often reduce backgrounds.

For example,

$$e^+e^- \longrightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^- , \quad \tilde{\mu}_R^\pm \longrightarrow \mu^\pm \tilde{\chi}_1^0$$

or

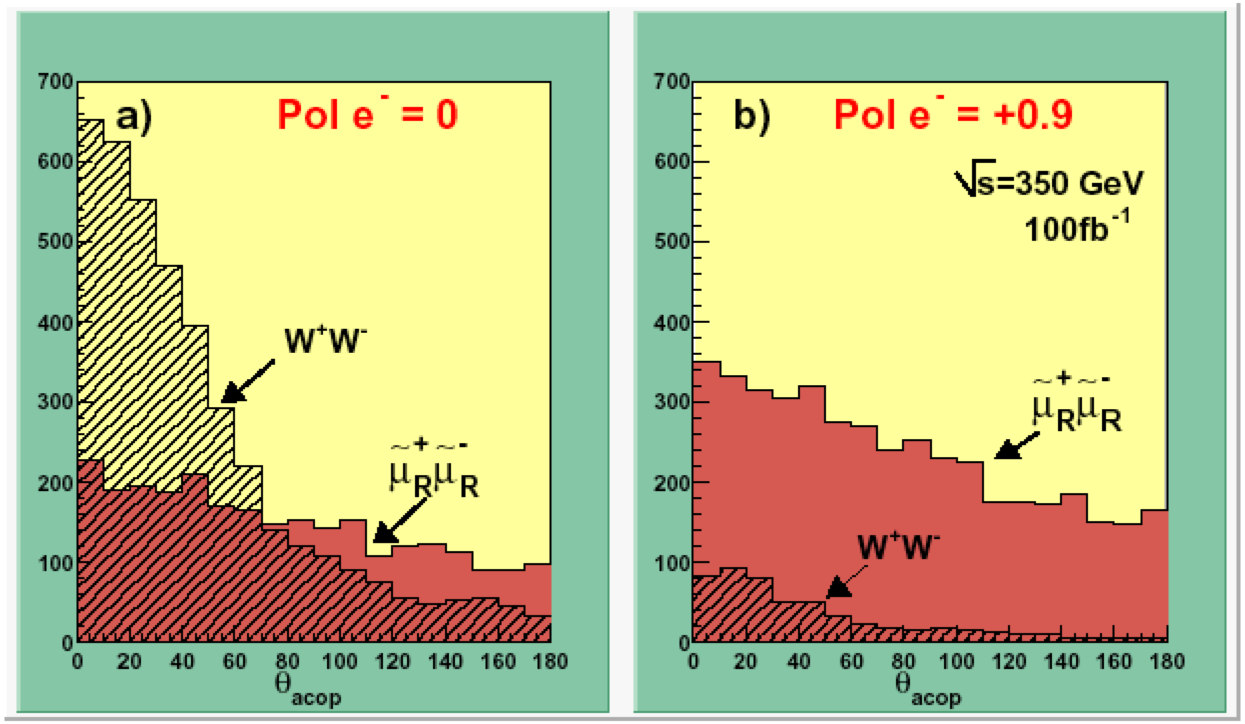
$$e^+e^- \longrightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- , \quad \tilde{\chi}_1^\pm \longrightarrow W^\pm \tilde{\chi}_1^0$$

etc.

Detection of Smuon

$$e^+e^- \longrightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^- , \qquad \tilde{\mu}_R^\pm \longrightarrow \mu^\pm \tilde{\chi}_1^0$$

Signal: $\mu^+\mu^-$ + nothing ($\tilde{\chi}^0$'s)
Plot the acolinearity of $\mu^+\mu^-$.

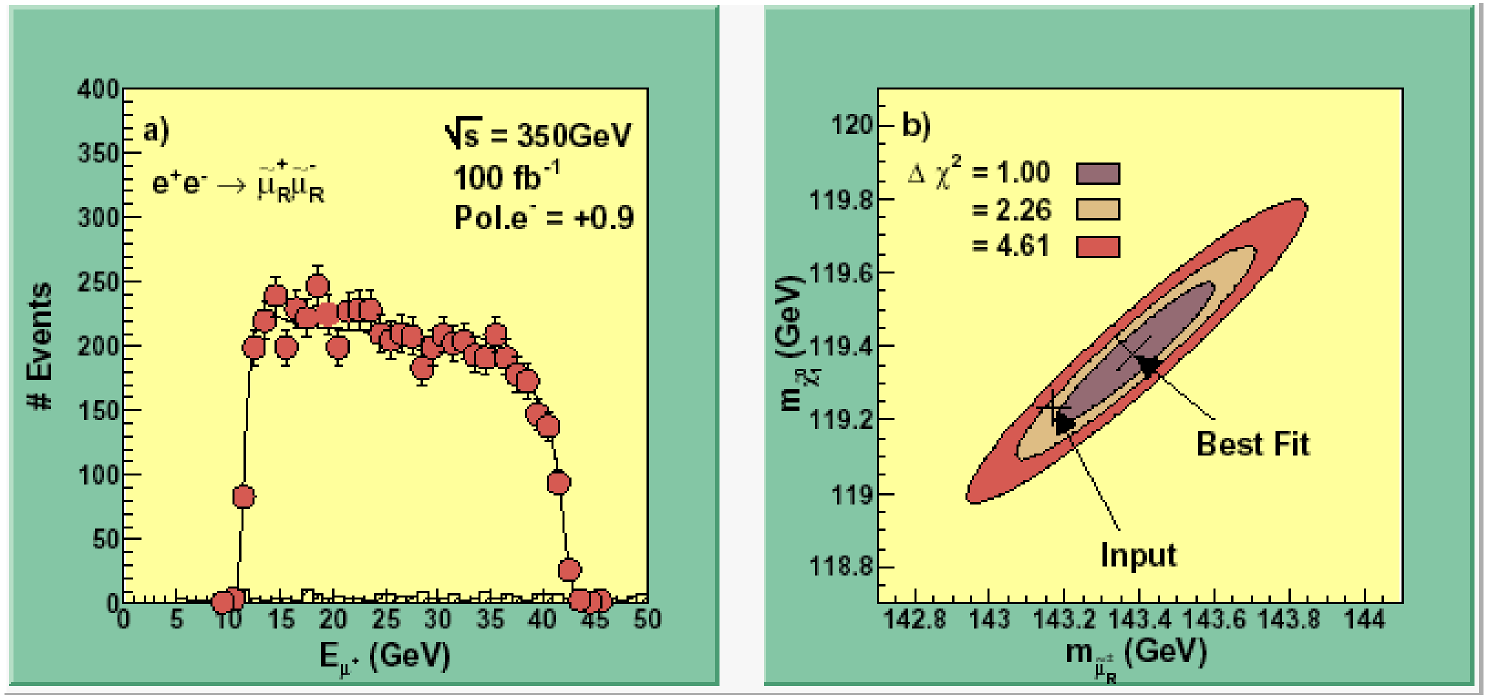


Right-handed e^- beam reduces the W^+W^- background.

Smuon Pair Production

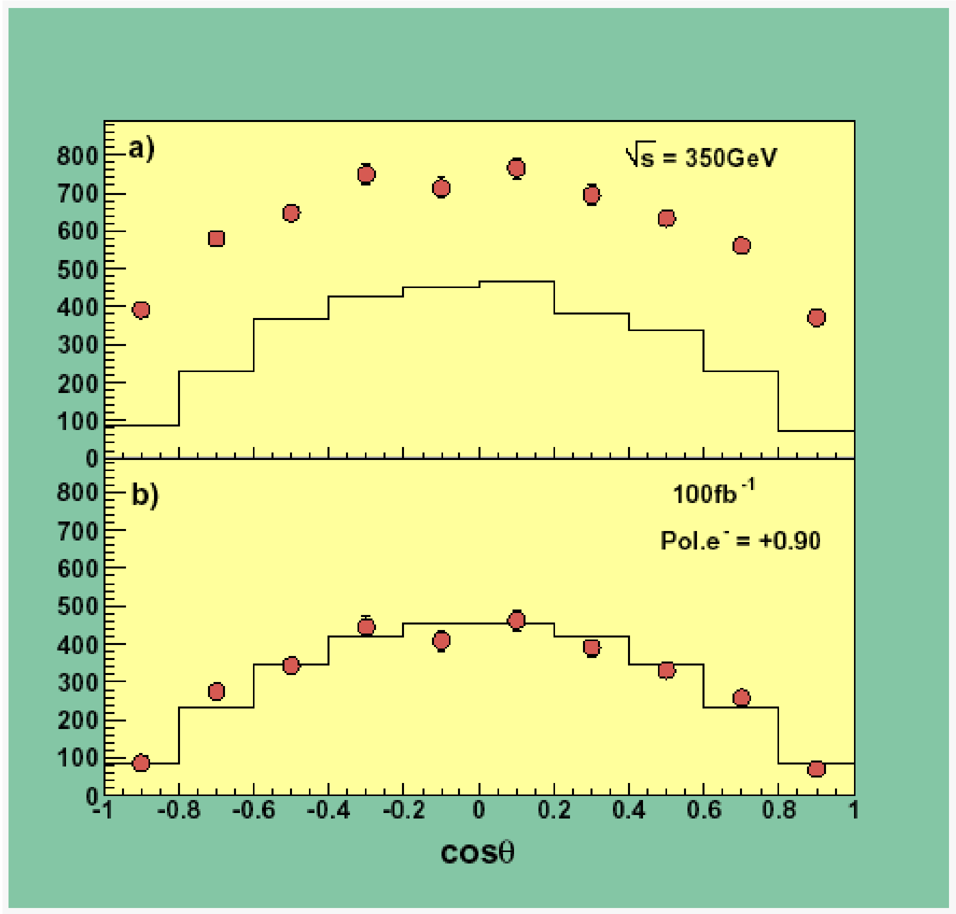
Determination of masses of $\tilde{\mu}_R$ and χ^0

From the (end point of) $\mu^{\pm}$ spectrum.



Smuon Pair Production

Determination of $\tilde{\mu}_R$ spin



Angular distribution of $\tilde{\mu}_R$ w.r.t. beam axis.
a) With double solutions.
b) Wrong solution removed (found to be flat).

$\sin^2\theta \quad \rightarrow \quad \tilde{\mu}_R$ spin $= 0$.

Similar analyses for $e^+e^- \rightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^-$ and $\tilde{\chi}_1^+ \tilde{\chi}_1^-$

Determination of SUSY Parameters

Example:

Charginos $\tilde{\chi}^{+}_{1,2}$ are mixture of Wino and Higgino:

$$\text{Mass term} = (\tilde{W}^{+}\ \tilde{H}^{+}) \begin{pmatrix} M_2 & \sqrt{2} m_W \cos\beta \\ \sqrt{2} m_W \sin\beta & \mu \end{pmatrix} \begin{pmatrix} \tilde{W}^{-} \\ \tilde{H}^{-} \end{pmatrix}$$

With e^{-}_{R} beam:

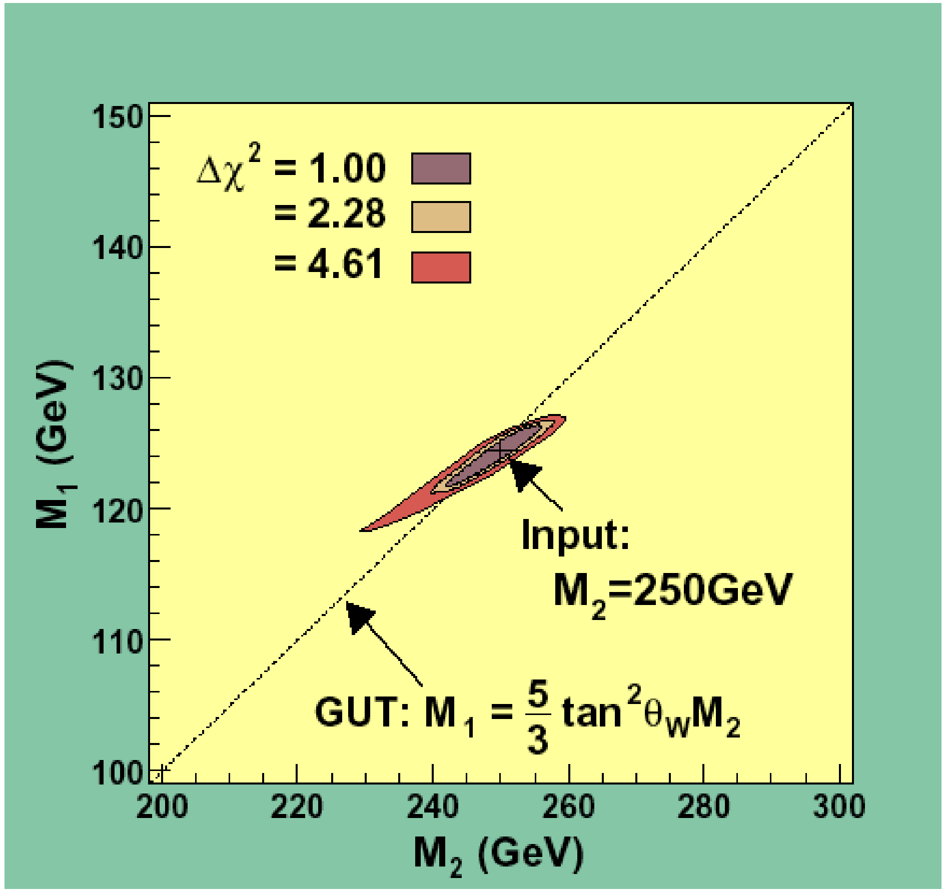
- only $\tilde{H}^{\pm}$ component of $\tilde{\chi}^{+}_{1}$ contribute to $\tilde{\chi}^{+}_{1}\tilde{\chi}^{-}_{1}$ creation.
- depends on $\tilde{B}$ in $\tilde{e}^{+}_{R}\tilde{e}^{-}_{R}$ creation.

Perform global fit $(M_1, M_2, \tan\beta, \mu)$ to

$$\sigma(e^{+}e^{-}_{R} \rightarrow \tilde{e}^{+}_{R}\tilde{e}^{-}_{R})\,, \quad \sigma(e^{+}e^{-}_{R} \rightarrow \tilde{\chi}^{+}_{1}\tilde{\chi}^{-}_{1})\,, \quad m_{\tilde{\chi}^{0}_{1}}\,, \quad m_{\tilde{\chi}^{+}_{1}}\,.$$

Determination of SUSY Parameters (cont'd)

$\sqrt{s} = 500 GeV$, 50 fb^{-1}

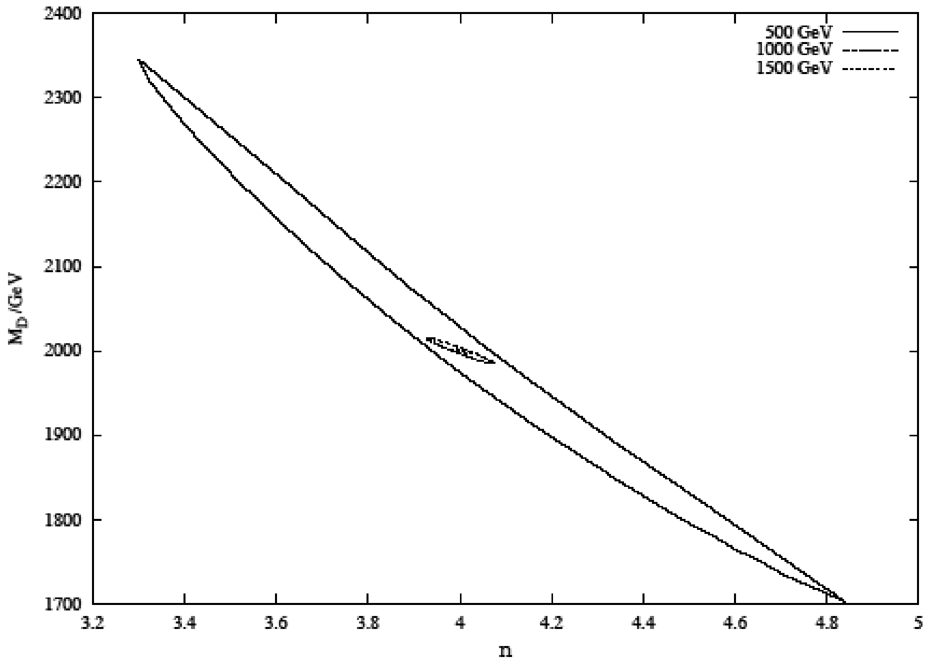


Serves as a test of GUT relation (or other mechanisms).

Large Extra Dimensions

$e^+e^- \to \gamma G$ (G: gravitational Kaluza-Klein mode)

Single γ and missing energy



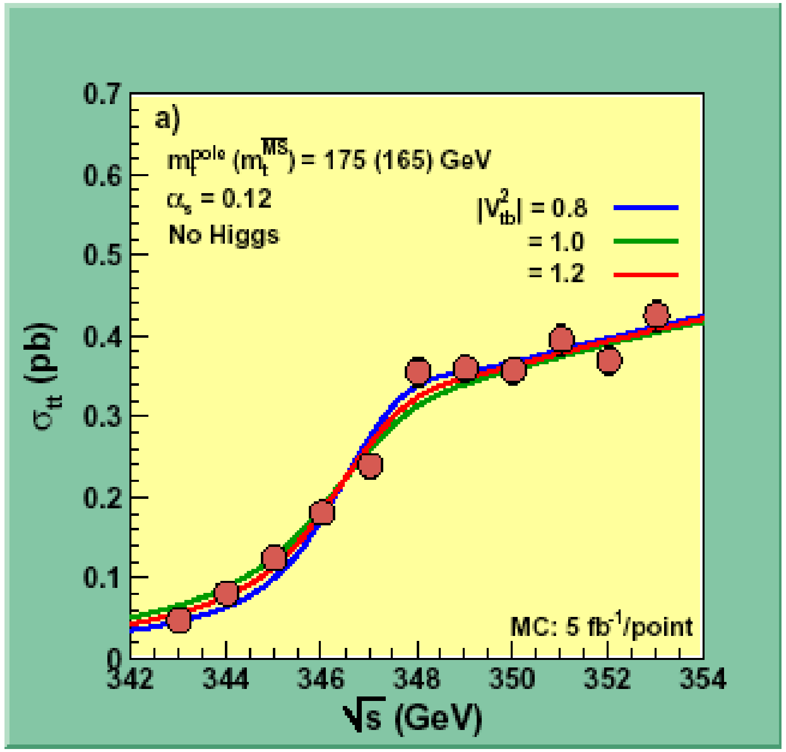
M_D: fundamental grav. scale
n: number of extra dimensions

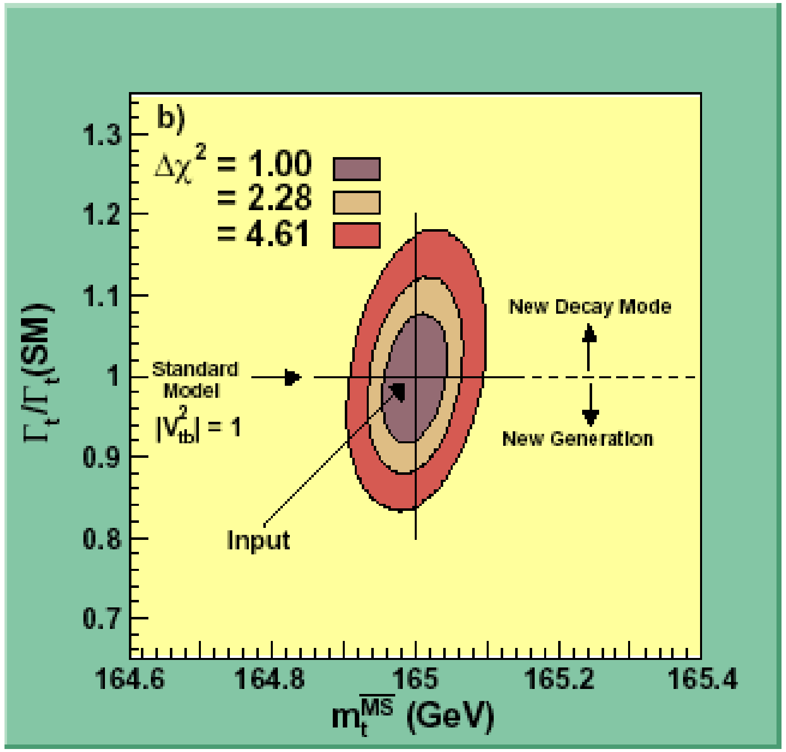
2σ contours for
$\sqrt{s} = 500$ GeV
500 fb^{-1}

Can exclude up to 5.8 TeV for $n = 2$.
$e^+e^- \to f\bar{f}$ has a similar sensitivity.

Top Studies (top factory)

$e^+e^- \to t\bar{t}$

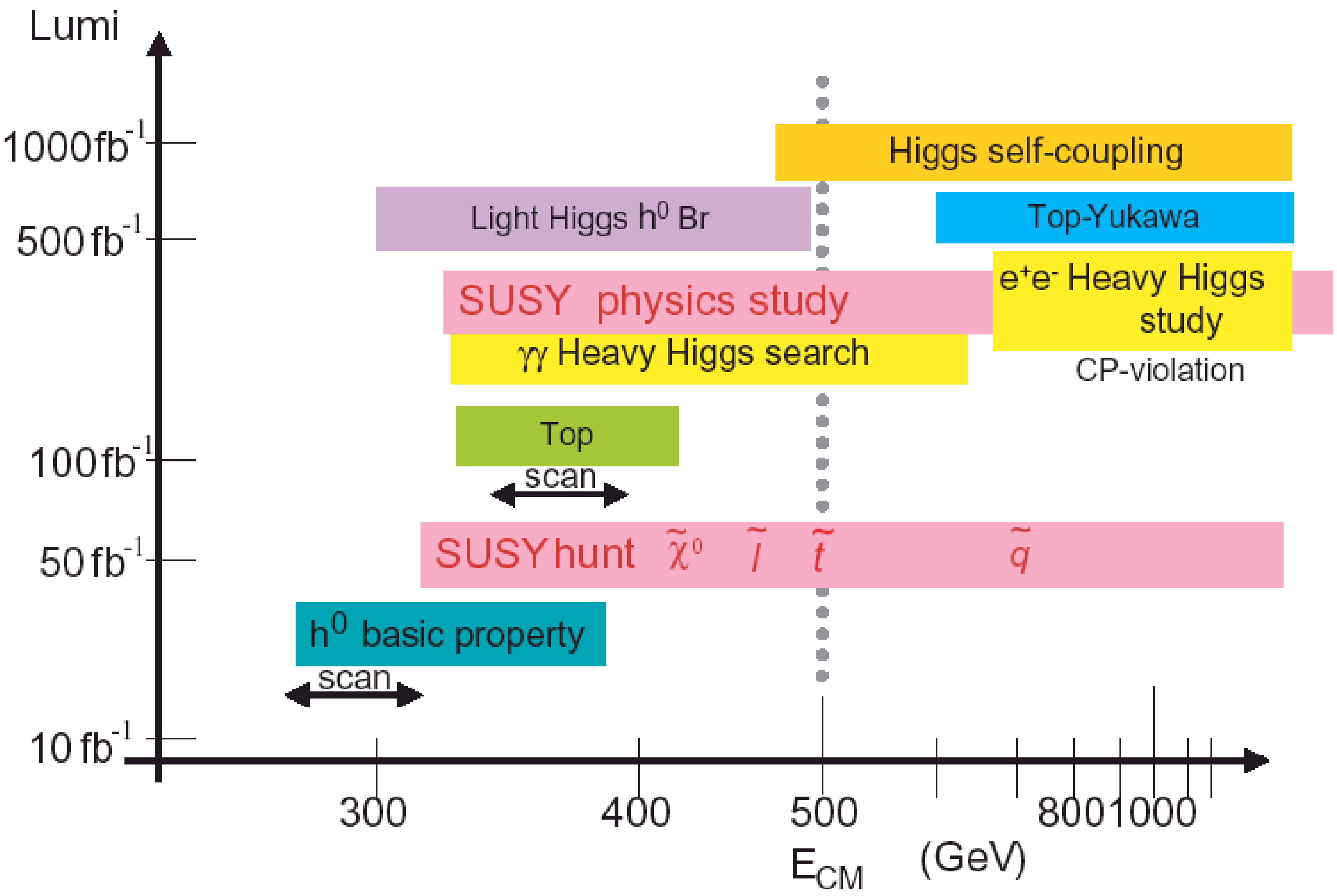




5 fb^{-1}/point $\to \sigma_{m_t} \sim 50$ MeV (LHC: $1 \sim 2$ GeV)

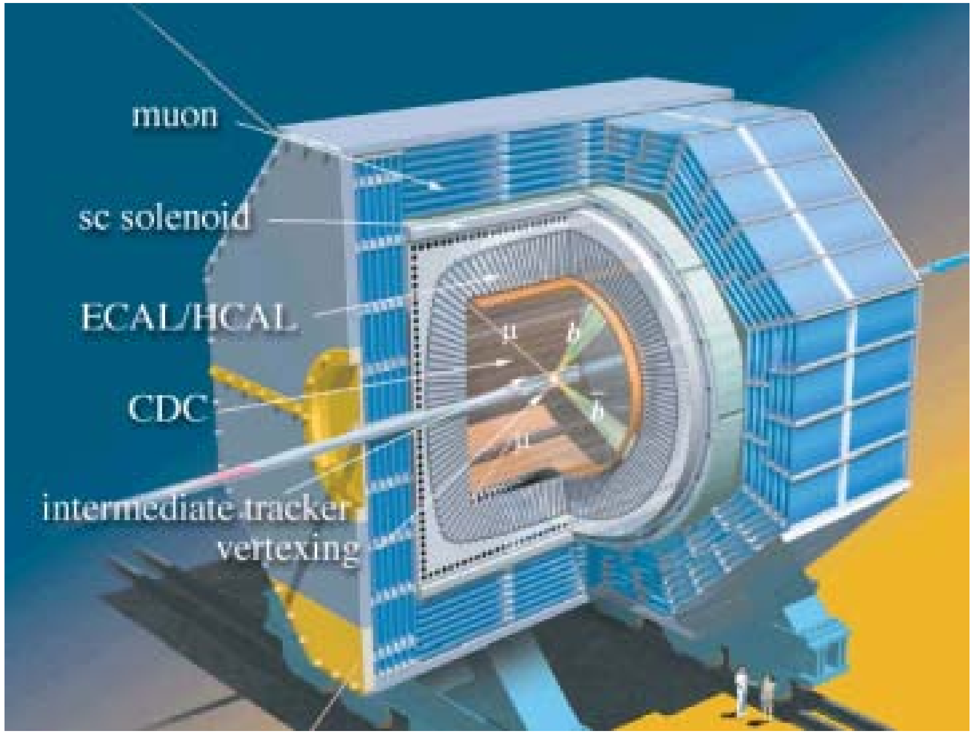
Detailed study of top production/decays.

(New generation, new decay modes, CP violations)



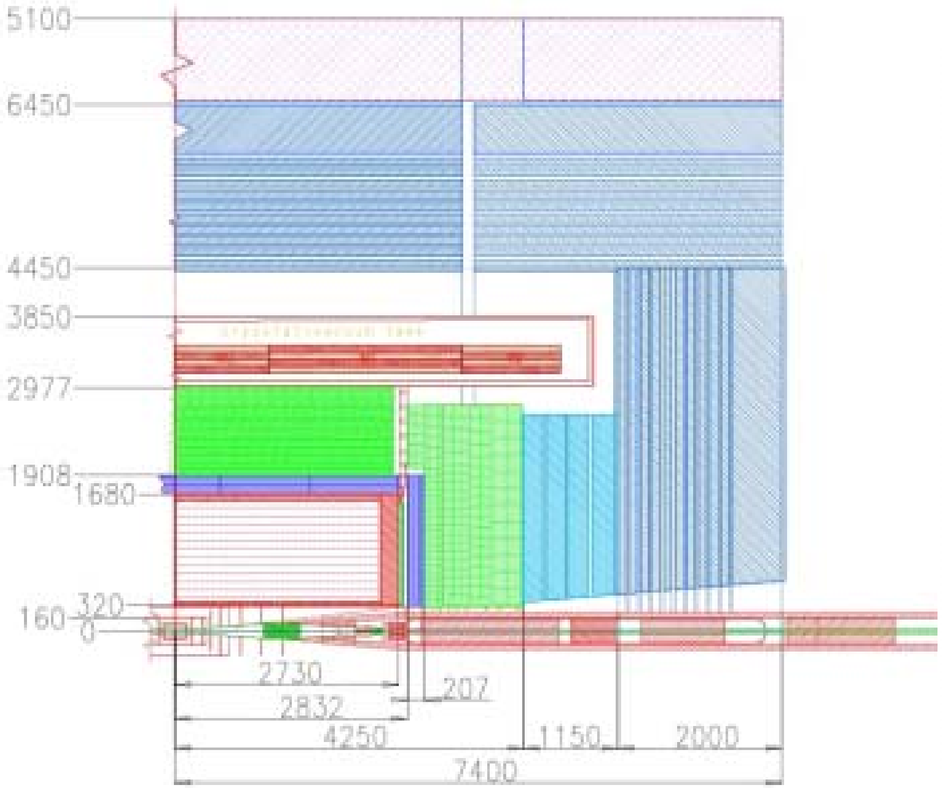
Lumi
1000fb-1
500 fb-1
100 fb-1
50 fb-1
10 fb-1
Higgs self-coupling
Light Higgs h0 Br
Top-Yukawa
SUSY physics study
e+e- Heavy Higgs study
γγ Heavy Higgs search
CP-violation
Top
scan
SUSY hunt
h0 basic property
scan
300
400
500
800
1000
ECM (GeV)

LC detector (GLC)

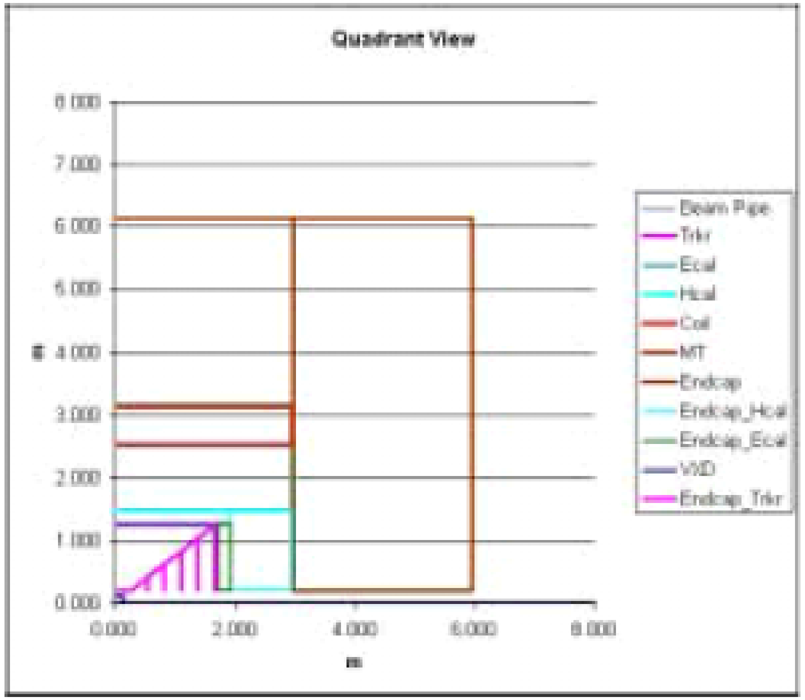


- Pixel-based vertex detector.
- High B-field ($\geq 3T$)
  (For p-resolution.
  Also, squeeze pair background)
- ECAL&HCAL within B-field.
- Flux-return as muon detector.
  (catches hadronic shower tail)

'Large' design (Tesla)
(gas-based central tracker)

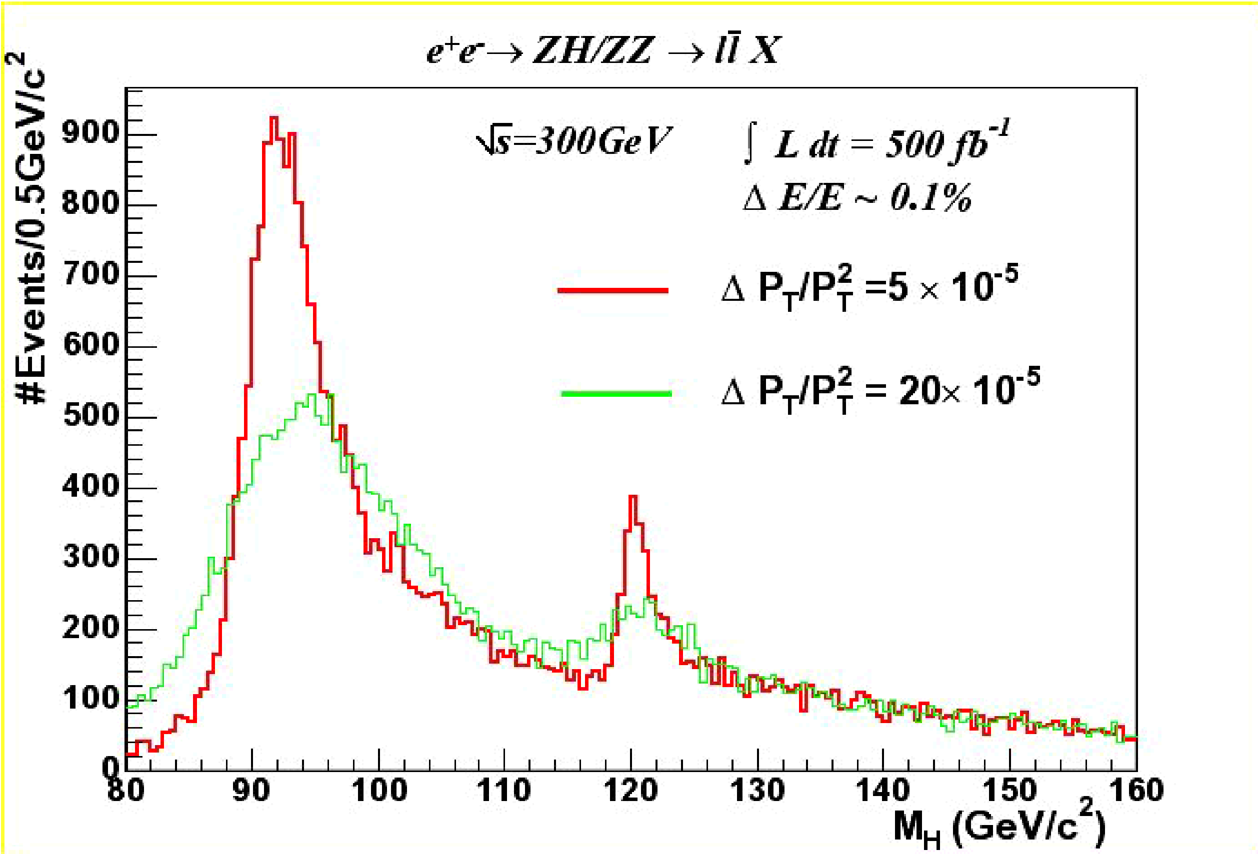


'Small' design (NLC Small Version)
(Silicon-based central tracker)



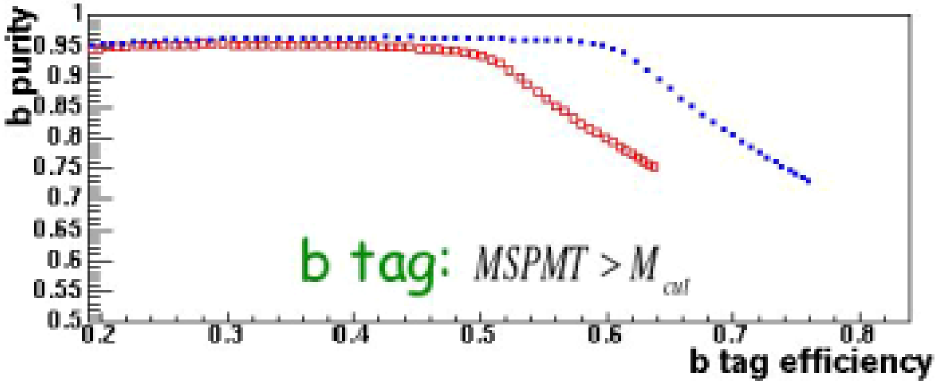
Tracking Requirement
($e^+e^- \to ZH$ recoil mass)

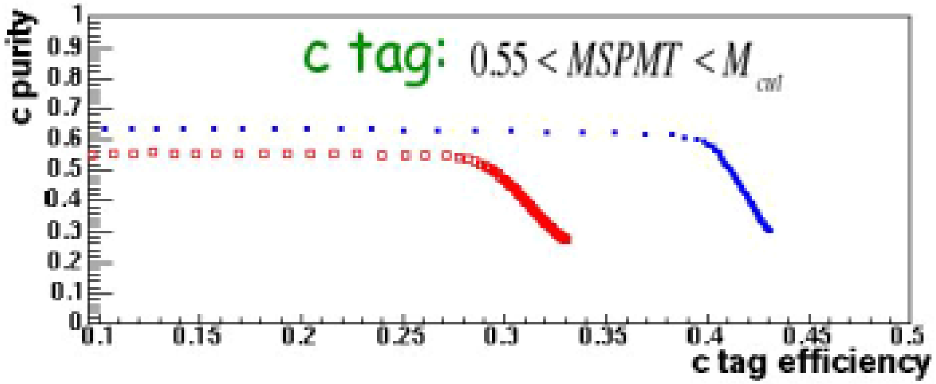
$\delta(1/p) \sim 2 \times 10^{-4}$ (typ. LHC) is not enough.
Needs at least 4 times better p resolution.



Vertexing Requirement ($H \to b\bar{b}, c\bar{c}$)

State of the art vertexing is needed.





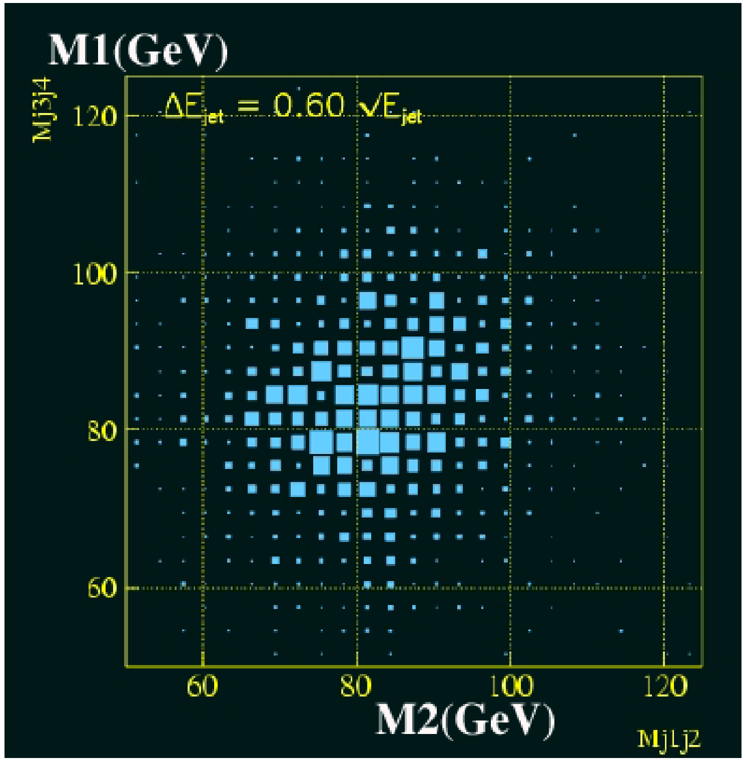
- #layer = 4
  $r = 2$ cm
  0.3% X_0/lyr
  (Far better than LHC)

- #layer = 5
  $r = 1$ cm
  0.3% X_0/lyr

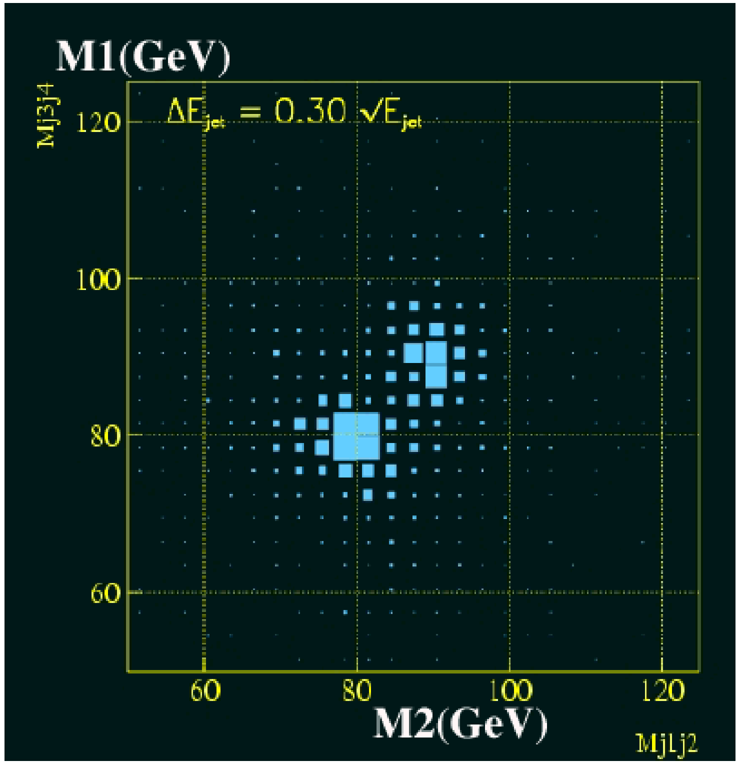
Calorimeter Requirement

($e^+e^- \rightarrow WWX, ZZX$, $W, Z \rightarrow$ 2jets)

$\delta E/E = 0.60/\sqrt{E}$ (jet) is needed for W/Z separation.



$\delta E/E = 0.60/\sqrt{E}$

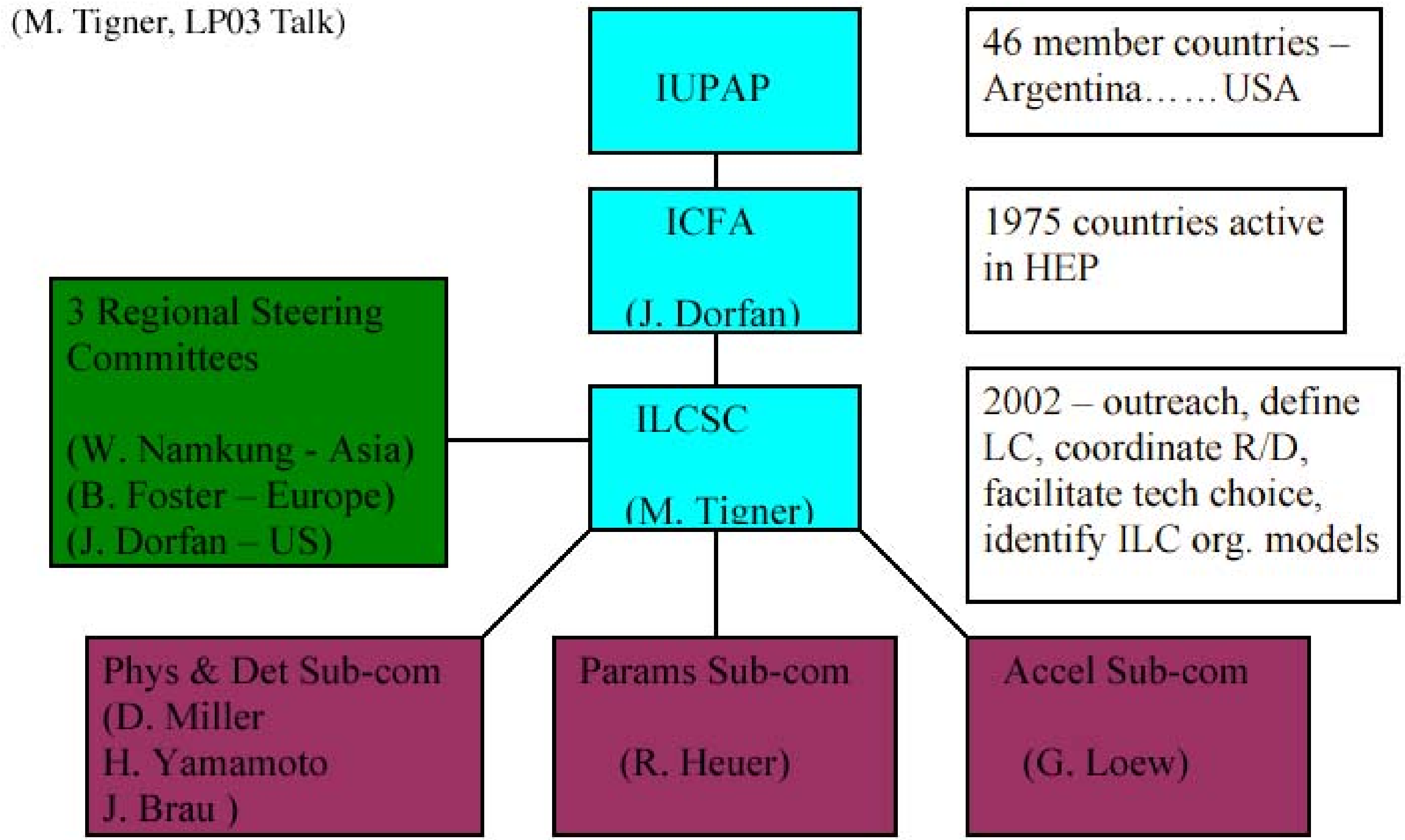


$\delta E/E = 0.30/\sqrt{E}$

LC Detector

- Resolutions far better than LHC are required in order to realize the basic physics goals of LC.
- The clean environment of LC makes them possible.
- Detector R&D's, however, are needed.
- Machine technology choice expected in 2004 (warm/cold). Be prepared for both for now.

International LC Organization



Define LC : Parameter Sub-committee

- R. Heuer (chair), F. Richard, S. Komamiya, D. Son, M. Oreglia

- The report has come out.

- Parameters:
  1. Initial max c.m. energy = 500 GeV.
  2. $\mathcal{L} = 1 \sim 3 \times 10^{34}$/cm^{2}s.
  3. 500 fb^{-1} in 4 years.
  4. Energy scanable.
  5. 2 IR's. One accomodates $\gamma\gamma$ option.
  6. Upgradable to ~ 1 TeV.

Technology choice : TRC

- G. Leow (chair). Large overlap with the acc. sub-comm. (TRC is older)
- Reviewed 4 options : Tesla, GLC-X/NLC, CLIC, GLC-C.
- The second report delivered in 2003.
  Ranked R&D's needed : R1-R4.

R1: Demontration of feasibility of machine.
R2: Finalize design and ensure reliability.
R3: R&D's for production.
R4: Technology/cost optimization.

TRC R1 Scores

	Tesla	GLC-X/NLC
RF freq.	1.3 GHz (L)	11.4 GHz (X)
RF temp.	SC ('cold')	room temp. ('warm')
Acc. grad.	35 MV/m	50 MV/m
$E\mathrm{cm}_{\mathrm{max}}$	0.8 TeV	1.0-1.3 TeV
R1 cleared?		
Modulator	yes	yes
Klystron	yes	yes
RF distribution	yes	yes
Acc. structure	yes(500 GeV) no(800 GeV)	no

Technology choice : ITRP (Wise-person's Committee)

- Charged by ILCSC to 'choose' technology by the end of 2004.
- Headed by Barry Barish.
  4 members from each region, 12 total.
  Nominated by each region considering -
  - International statue,
  - Experience with large-scale experiments,
  - Acc. phycisists, Theorists.
- Started working.

Organization Model

- ‘Globalization committee’ started July 2001 by Sugawara (then the director of KEK). Report delivered Dec 2002 :
  - GLCC (global linear collider center) to be formed by treaties among nations.
  - Pre-GLCC to be formed by agreements among labs before GLCC to do real works.

- A system to do real design work after the choice by the Wise-person’s comm. is envisaged :
  pre-GDO (global design organization) to generate CDR and then TDR of LC.

- pre-GLCC $\sim$ pre-GDO : the name is to be unified.

- pre-GDO task force (chair: S. Ozaki) was formed and started its work to define pre-GDO.

Conclusions

- A Linear Collider will sweep the TeV energy scale with precision measurements.

- It will dig deep into the underlying physics through determinations of quantum numbers, coupling constants and other physics parameters.

- Its great sensitivities make it also a discovery machine.

- Cross fertilization of LHC and LC require concurrent running.

- Detectors with resolutions much better than ever achieved are required for the goals.

- International efforts are gearing up to meet the challenges.