Physics Case for the ILC Options

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at LCWS05, SLAC

on Mar/18, 2005

ILC-I (base design)

$\sqrt{s} = 200\text{-}500$ GeV — Zh, $\nu\bar{\nu}h$, $t\bar{t}$, W^+W^-

$L > 100\ fb^{-1}$/year — $> 10^4$ h, m_t, W-couplings

$P(e^-) \sim 80\%$ — quantum #'s of new particles, EW tests

Physics case independent of LHC

Needed as early as possible for ILC-LHC synergy.

* next pages.

ILC-II, options

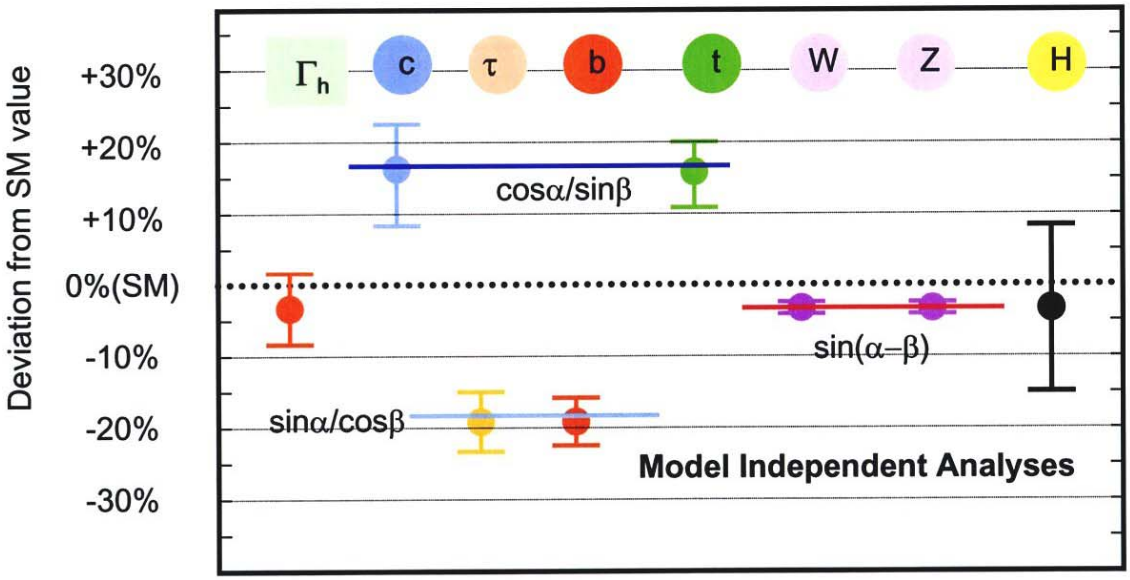
$\sqrt{s} = 1$ TeV	tunnel length, MV/m
e^-e^-, $e^-\gamma$, $\gamma\gamma$	2'nd int. region, crossing angle
Giga Z	
e^+ polarization	e^+ source, pol. scheme
fixed target (beam dump)	additional detector

} Inputs from LHC

cf. Kanemura et al
$eN \to \tau X$ measures $e\tau$ FCNC
10^3 times better than $\tau \to \mu\gamma$, $\mu\eta$, ...

SUSY or 2HDM

ILC



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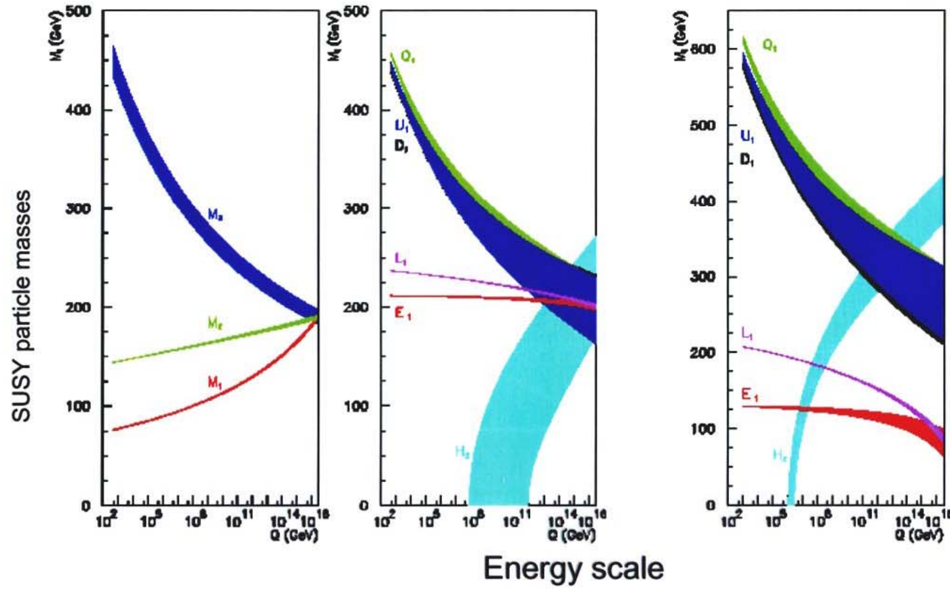
Determining SUSY breaking mechanism

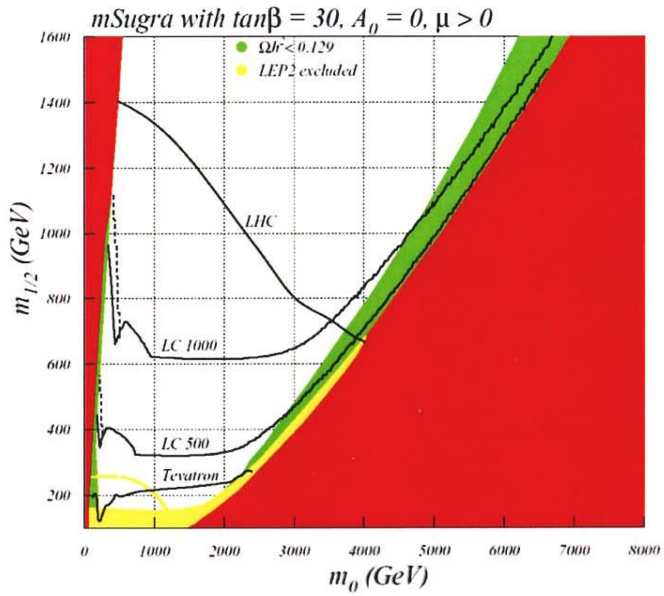
LHC+ILC
Combined analysis → **SUSY breaking** scenario

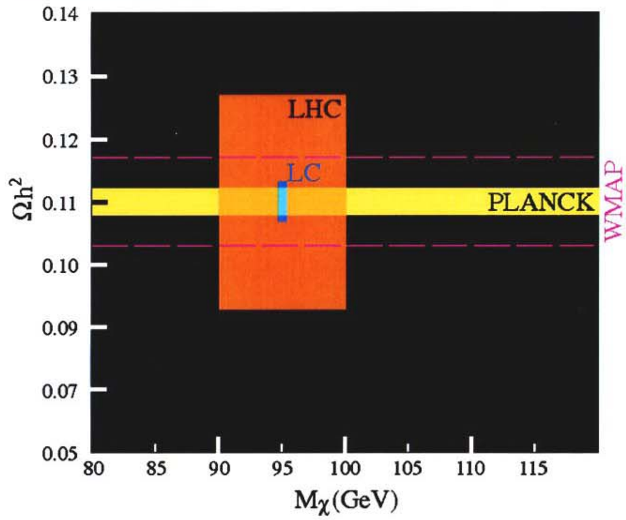


Super Gravity (mSUGRA) **Gauge Mediation**

G.A.Blair, W.Porod,and P.M.Zerwas

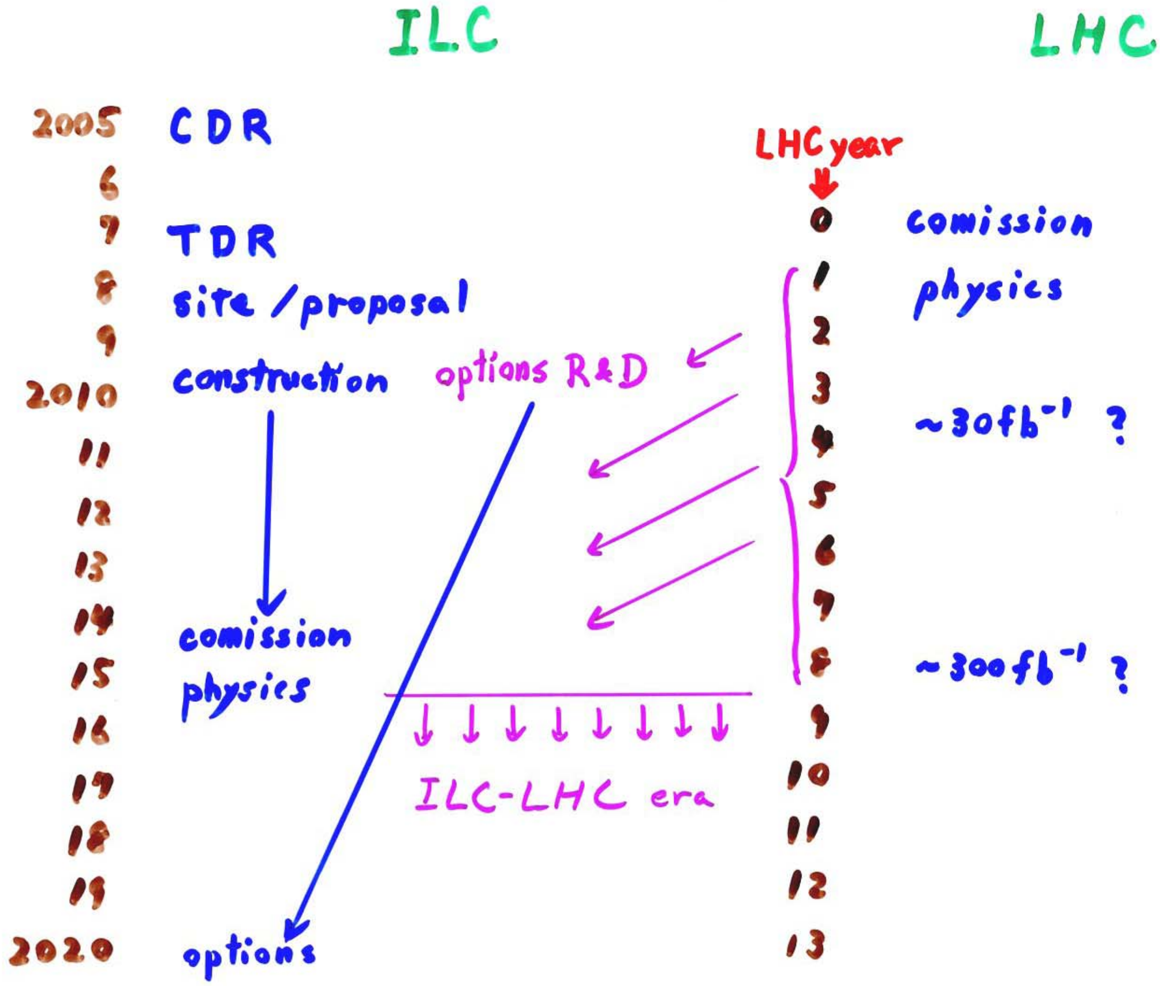
Cosmology: Dark Matter = LSP ?!





WMAP .094 < Ωh^2 < .128 (2 sigma)

'WMAP'	7 %
LHC	~15 %
'Planck'	~2 %
ILC	~3 %



ILC
LHC
2005 CDR
6
7 TDR
8 site / proposal
9
2010 construction
options R&D
11
12
13
14 comission
15 physics
16
17
18
19
2020 options
ILC-LHC era
LHC year
0 comission
1 physics
2
3
4 ~30fb^{-1} ?
5
6
7
8 ~300fb^{-1} ?
9
10
11
12
13

$e^- e^-$

easy to realize

$L_{e^-e^-} \sim (0.1 - 0.3)\, L_{e^+e^-}$

3 physics channels

$e_L^- \; e_L^- \rightarrow \nu_L \nu_L W^- W^-$ .... $W^- W^-$ scattering

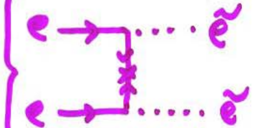
$\rightarrow \nu_L \nu_L H^{--}$ ....

$\rightarrow W^- W^-$ .... heavy Majorana ν's @ TeV

$\rightarrow \tilde{e}_L^- \tilde{e}_L^-$

$e_L^- \; e_R^- \rightarrow \tilde{e}_L^- \tilde{e}_R^-$

$e_R^- \; e_R^- \rightarrow \tilde{e}_R^- \tilde{e}_R^-$



Majorana neutralino's

S-wave threshold

$\Rightarrow m_{\tilde{e}}$

$\gamma\gamma$

Compton back scattering of laser light off beam e^-

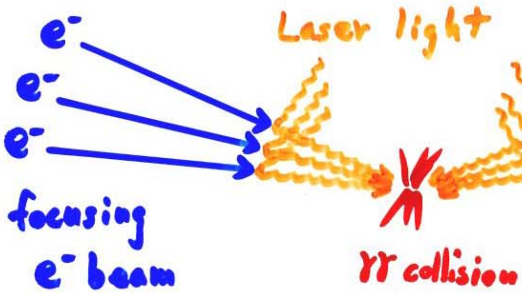
Large crossing angle ⇒ 2'nd int. region.

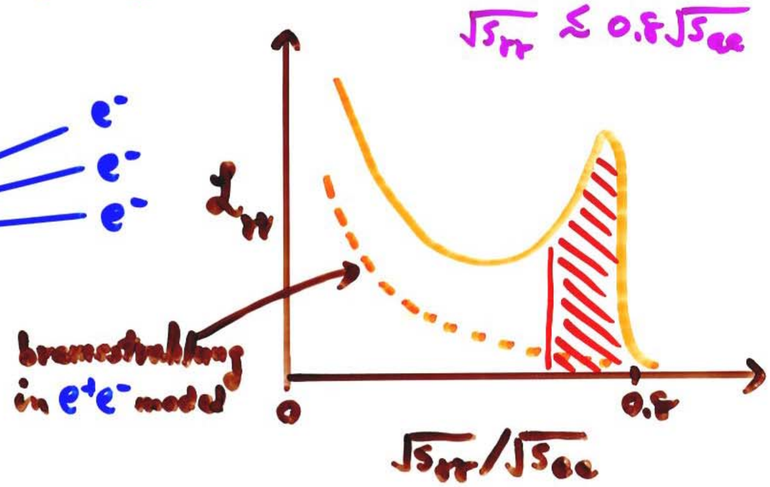
Laser cavity for long beam bunch.

Polarized Laser light → Compton scattering → Polarized high energy γ's

Higg $\sqrt{s_{\gamma\gamma}}$ $\gamma\gamma$ scattering

$\sqrt{s_{\gamma\gamma}} \lesssim 0.8\sqrt{s_{ee}}$





$\gamma\gamma$

$J_X = 0$ s-channel production of h, H, A and their mixture if $\not{CP}$

circular pol. $\Rightarrow J_z = 0$ enhances S/N of h, H, A signals

$J_z = \pm 2$ spin 2 effect search

linear pol. $\Rightarrow CP = \pm$ select h, H vs A

aid $\not{CP}$ search

$J^{PC} = 0^{++}$ $\Rightarrow$ s-wave threshold for $\tilde{\ell}^+ \tilde{\ell}^-$, $\tilde{t}_1 \bar{\tilde{t}}_1$, ...

Large cross sections : σ_{WW} , $\sigma_{\tau\bar{\tau}}$, ...

$$\mathcal{L}_{\gamma\gamma}(\sqrt{s_{\gamma\gamma}} > 0.8\sqrt{s_{\gamma\gamma,max}}) \sim (0.1-0.3)\,\mathcal{L}_{e^+e^-}$$

We need $\gamma\gamma$ because

sensitive to new particles

if light h : $\Gamma(h\to\gamma\gamma)\, B(h\to b\bar{b}) \sim 2\%$

$\Rightarrow \Gamma(h\to\gamma\gamma) \sim 2\%$

$\not{CP}$ by $\gamma\gamma$ polarization — far more sensitive than $e^+e^-\to hZ$ because $h\gamma\gamma$ is a loop amp.

if $m_{H,A} < 0.8\sqrt{s_{e^+e^-}}$: Possible discovery

CP & $\not{CP}$

↳ mixing (ϵ) and direct (ϵ')

$$\gamma\gamma \to H,A \to t\bar{t},\ W^+W^-$$
$$\gamma\gamma \to \text{QED} \to t\bar{t},\ W^+W^-$$

interference allows us to measure the phase of $\phi\gamma\gamma$ vertex.

in addition : $\gamma\gamma \to W^+W^-, t\bar{t}$ ($J=0,2$) to supplement $e^+e^- \to W^+W^-, t\bar{t}$ ($J=1$) precision phys.

e^+ Polarization

e^+ source ~150 GeV e^- undulator, ~5 GeV e^- laser back-scattering } pol. γ → pol. e^+

T. Omori et al, K. Mönig

The roles of e^+ polarization in e^+e^- collisions

e^+e^- annihilation → $e_L \overline{e}_L$ & $e_R \overline{e}_R$ only (e-chirality)

W-exchange processes → $e_L \overline{e}_L$ only ($SU(2)_L$)

⇒ $P_{e^+} \sim 0.4$ helps enhancing of $\sigma(e_L \overline{e}_L \to X)$, and helps reducing b.g. from $e_L \overline{e}_L \to W^+W^-$ etc. ⇐ ★

It also increases P_{eff} from $P_{e^-} = 0.8$ to $P_{eff} = 0.95$

Transverse Pol. of both $e^\pm$ beams could be useful

★ ex.) $e^+e^- \to \tilde{\tau}_1^+ \tilde{\tau}_1^-$, $\tilde{\tau}_1^+ \to \tau^+ \tilde{\chi}_1^0$, $\tilde{\tau}_1^- \to \tau^- \tilde{\chi}_1^0$

ex: If

can be probed by $P_\perp(e^\pm)$

Giga Z

10^9 polarized Z's $\Rightarrow$ A_{LR} precision measurement

- LEP1 A_{FB}^{b} suffers from hadron/QCD uncertainty

but $\frac{\delta A_{LR}}{A_{LR}} \sim \frac{\delta P_{e^-}}{P_{e^-}} \sim 0.5\%$

With e^+ Polarization we can measure σ_{LR}, σ_{RL}, P_{e^-}, P_{e^+} from

$$\left.\begin{aligned}
\sigma_{++} &= \frac{1-P}{2}\frac{1+\bar{P}}{2}\sigma_{LR} + \frac{1+P}{2}\frac{1-\bar{P}}{2}\sigma_{RL} \\
\sigma_{+-} &= \frac{1-P}{2}\frac{1-\bar{P}}{2}\sigma_{LR} + \frac{1+P}{2}\frac{1+\bar{P}}{2}\sigma_{RL} \\
\sigma_{-+} &= \frac{1+P}{2}\frac{1+\bar{P}}{2}\sigma_{LR} + \frac{1-P}{2}\frac{1-\bar{P}}{2}\sigma_{RL} \\
\sigma_{--} &= \frac{1+P}{2}\frac{1-\bar{P}}{2}\sigma_{LR} + \frac{1-P}{2}\frac{1+\bar{P}}{2}\sigma_{RL}
\end{aligned}\right\} \Rightarrow A_{LR} = \frac{\sigma_{LR}-\sigma_{RL}}{\sigma_{LR}+\sigma_{RL}}$$

with 4×10^{-5} error

$\Rightarrow \delta \sin^2\theta_W^{eff} \sim 1\times10^{-5}$!!

Note $\frac{\delta G_F}{G_F}, \frac{\delta m_Z}{m_Z} \sim 2\times10^{-5}, \frac{\delta\alpha}{\alpha(m_Z^2)} \sim 25\times10^{-5}$ Powerful EW constraints!

Physics case for ILC-I (base)

$\sqrt{s} = 200 - 500$ GeV
L > 100 fb^{-1}/yr
$P(e^-) \sim 80\%$

is clear indep. of LHC.
but is much stronger if its comission is in the 1st 10 yr's of LHC

⇓

Proposed Time Schedule should be respected as much as possible

① Technological reliability
② Cost ③ Time Schedule
④ Flexibility to accomodate options later.

★ Longer tunnel for TeV
★ 2'nd Int. Sect. for $\gamma\gamma$

LHC scenarios

A: finds nothing (not even a Higgs) → n-page

- ⇒ ILC-I Zh search, $t\bar{t}$, W^+W^- prec. exp.
- ⇒ Giga-Z + $P(e^+)$ check our starting point.
- ⇒ TeV search
- ⇒ $\gamma\gamma$ $t\bar{t}$, W^+W^- prec. exp.

B: finds a light Higgs only

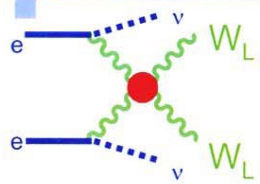
- ⇒ ILC-I precision Higgs, $t\bar{t}$, WW
- ⇒ $\gamma\gamma$ $\Gamma(h\to\gamma\gamma)$, $\not{CP}$, heavy H,A search
- ⇒ TeV $t\bar{t}h$, hhh, search

C: finds a heavy Higgs only

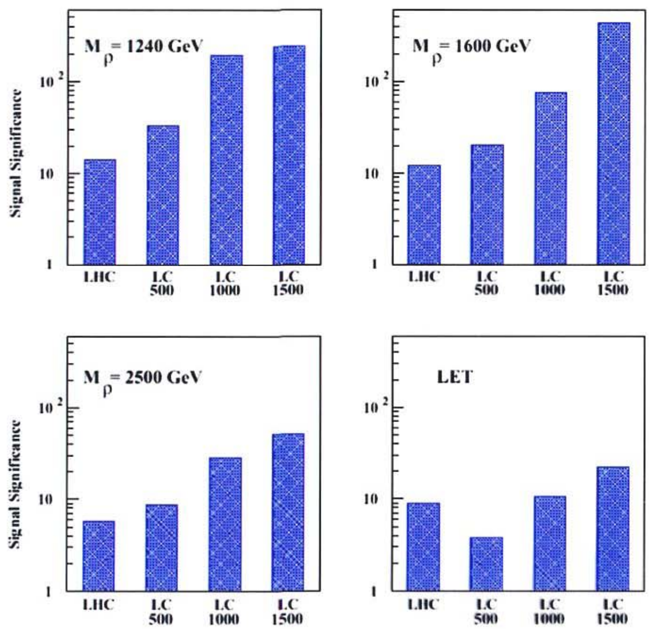
- ⇒ ILC-I confirm nothing lighter, prec.
- ⇒ TeV, $\gamma\gamma$ ZH, $\nu\bar{\nu}H$, $\gamma\gamma\to H$
- ⇒ Giga-Z + $P(e^+)$ hint of new phys. signal

D: finds many new particles, non-SM effects

- ⇒ ILC-I prec. spectroscopy
- ⇒ TeV " "
- ⇒ $\gamma\gamma$ J=0 channel, scalar sector

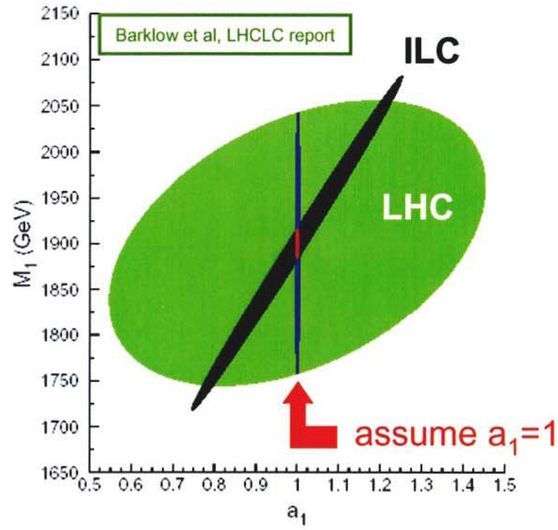


$\nu\bar{\nu}W^+W^-$, $\nu\bar{\nu}ZZ$



ILC is very sensitive to ννWW, ννZZ

sensitivity to new heavy resonances in ee →ννWW



M = 1.9 TeV
SM couplings (a=1)

ILC: 500 GeV, 500 fb^{-1}

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for making the toughest decision. I feel that

the most important decision for the ILC has already been made !

Our task is to identify and persue the best strategy to optimize the physics outputs with a reasonable cost. I think

ILC-I should start as early as possible ⇒ ILC-LHC synergy
" should leave the flexibility for

- TeV upgrade
- 2'nd Int. Sect. for $\gamma\gamma$ collider
- Giga-Z with e^+ polarization.

Let us work together !

to meet the deadline.