Future accelerators: SLHC and ILC

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1. General aspects
    - Fundamental questions about the Universe
    - Proposed Facilities
    - Tevatron vs LHC
    - SLHC, ILC; CLIC, VLHC
2. Physics
    - Higgs
    - Gauge Boson Couplings
    - Top Physics
    - Supersymmetry
    - Other scenarios
    - Cosmology Connection
3. Detector Challenges
    - Detector Challenges
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4. More Information
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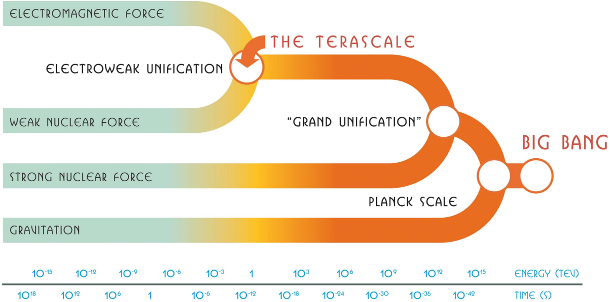
Fundamental questions about the Universe

Very deep questions are still unanswered in particle physics:

- Are there a unified framework for the fundamental interactions?
- Do the properties of the particles give any insight in the nature and origin of the matter?
- Do the properties of the particles give any insight in the properties of the space-time?
- What is dark matter and dark energy?



Fundamental questions about the Universe

Standard model goes in the right direction of unification, but it is needed to know what is the mechanism of spontaneous symmetry breaking, so the Higgs boson, still undiscovered. Two approaches to unification are Grand Unification and Supersymmetry. Could be discovered at the Terascale

Scale hierarchy could be solved with supersymmetry

String Theory could help to combine quantum mechanics and gravity. But, which is the space-time dimension?

Many questions are related to the flavor dynamics:

- What are neutrinos telling us?
- Why there are three generations?
- What happened with primordial antimatter?...

The connection with astrophysical discoveries is essential:

- What is dark matter?
- What is dark energy?

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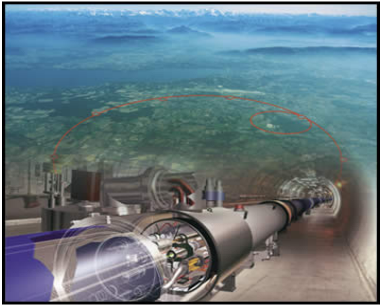
Proposed Facilities



Particle accelerators to explore the Terascale:

- Hadronic Colliders (Tevatron, LHC, SLHC,...)
- Linear e^+e^- Colliders (ILC, CLIC,...)
- B Factories (Super-Belle, Super-B ???)

Nature's Particle Sources:

- Gamma ray photons
- Neutrinos from the Sun and the atmosphere
- Terrestrial sources (Double beta-decay,...)
- Muon Colliders?, Neutrino-Factories?..

Tevatron vs LHC

Luminosity:

$$L = \frac{\gamma f k_B N_b N_{b'}}{4\pi\epsilon_n\beta^*} F$$

where γ is the Lorentz factor, f the revolution frequency, and F the reduction factor due to the crossing angle (300 microrad in LHC). The denominator is essentially the beam transverse area multiplied by γ. Parameters like the normalized emittance, betatron function,... are shown in the Table.

The main limit comes from the beam-beam effect, measured by $\xi = N_{b,b'} r_p / 4\pi\epsilon_n$, where r_p is the classical radius of the proton. ξ should not exceed about 0.006

Other limitating factor, due e.g. to the heat input to the cryogenic system, is the total synchrotron radiation total power $P_s = Z_0 e^2 c N_{b,b'} k_B f \gamma^4 / 3\rho$, where Z_0 is the impedance of the space free and ρ the magnetic bending radius

Parameter	Tevatron	LHC
Number of bunches, k_B	36	2808
Beam particles per one bunch N_b	$2.7\ 10^{11}$	$1.15\ 10^{11}$
Other Beam particles per bunch $N_{b'}$	$3.0\ 10^{10}$	$1.15\ 10^{11}$
β-value, β^* (cm)	35	55
Normalized Emittance , ϵ_n (microns)	≈ 3	3.75
Bunch separation , Bsep (nsec)	396	25
Collisions/crossing, n_c	2.3	≈ 20
Energy , E(GeV/particle)	980	7000
Peak Luminosity $L_p (cm^{-2} sec^{-1})$	$\approx 2\ 10^{32}$	$\approx 10^{34}$

SLHC,ILC,CLIC,VLHC

VLHC, USA Project; SLHC,three phases :

- Phase 0, maximum performance, no new hardware
- Phase 1, Only new hardware in the LHC insertions and/pr injector complex
- Phase 2, New hardware in LHC arcs and/or injector complex

Luminosity:

$$L = \frac{\gamma f_{rep} k_B N_b N_{b'}}{4\pi \epsilon_{nx}^{1/2} \beta_x^{1/2*} \epsilon_{ny}^{1/2} \beta_y^{1/2*}} F \propto \frac{\eta_{beam}^{AC} P_{AC}}{\epsilon_{ny}^{1/2}} \frac{\delta_{BS}^{1/2}}{E}$$

where η_{beam}^{AC} is the main-to beam power transfer efficiency, δ_{BS}, the bremmstrahlung parameter, and P_{AC} the total power consumption

Parameter	SLHC	VLHC (230 Km. circ.)
k_B	up to 2xLHC	37152
N_b	up to 1.7 10^{11}	7.5 10^{9}
$N_{b'}$	up to 1.7 10^{11}	7.5 10^{9}
β^* (cm)	up to 25	71
ϵ_n (microns)	as LHC	0.2
Bsep (nsec)	up to 12.5	18.8
E(GeV/particle)	up to 14000	100000
F,crossing angle	424 microrad	
$L_p (cm^{-2} sec^{-1})$	up to 10^{35}	$> 2\ 10^{34}$

Parameter	ILC (500 GeV)	CLIC (3 TeV)
k_B	2625	312
N_b	2 10^{10}	3.7 10^{9}
$N_{b'}$	2 10^{10}	3.7 10^{9}
β_x^* (cm)	2	0.69
β_y^* (cm)	0.04	0.0068
ϵ_{nx} (microns)	10	0.66
ϵ_{ny} (microns)	0.04	0.02
Bsep (nsec)	369	0.5
f_{rep} (Hz)	5	50
P_{AC} (MW)	230	392
η_{AC} (%)	9.4	7.1
E(GeV/particle)	500	3000
$L_p (cm^{-2} sec^{-1})$	2 10^{34}	5.9 10^{34}

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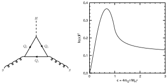
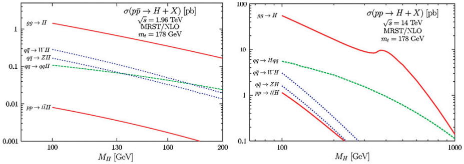
Higgs



The main process of Higgs production in Hadron Colliders is gluon-gluon fusion:

$$\sigma(p^{\pm} p \longrightarrow H\ something) = \frac{G_F \alpha_s^2}{32\pi\sqrt{2}} |\eta(\epsilon)|^2 x(gg\ lumin.)$$

For low Higgs mass, $p^{\pm} p \longrightarrow VH$ is preferred due to smaller background. At high Higgs mass $pp \longrightarrow qqVV \longrightarrow qqH$ starts to be competitive



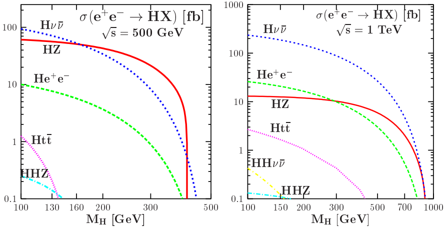
$$\sigma(e^+ e^- \longrightarrow HZ) =$$

$$\frac{G_F^2 M_Z^4}{96\pi}(1 + (1 - 4sin^2\theta_W)^2)\frac{8k}{\sqrt{s}}\left[\frac{k^2 + 3M_Z^2}{(s - M_Z^2)^2 + M_Z^2\Gamma^2}\right]$$

where k is the center of mass Z boson momentum

$$\sigma(e^+ e^- \longrightarrow H\nu\bar{\nu}) \approx$$

$$\frac{G_F^3 M_W^4}{4\sqrt{2}\pi^3}\left[ln\frac{s}{(M_H^2)} - 2\right]$$



Higgs

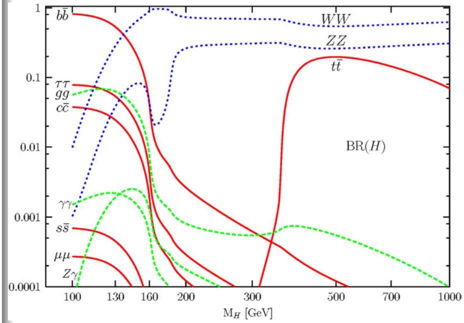
$$\sigma(H \to f\bar{f}) = \frac{G_F m_f^2 M_H}{4\pi\sqrt{2}} N_c (1 - \frac{4m_f^2}{M_H^2})^{3/2}$$

$$\sigma(H \to W^+W^-) = \frac{G_F M_H^3}{32\pi\sqrt{2}}(1-x)^{1/2}(4 - 4x + 3x^2)$$

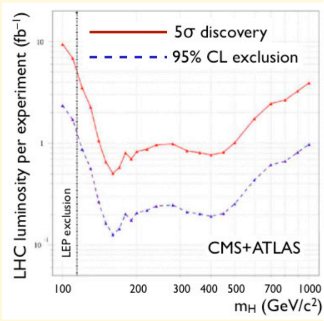
where $x = \frac{4M_W^2}{M_H^2}$

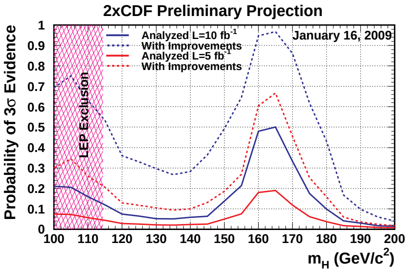
$$\sigma(H \to ZZ) = \frac{G_F M_H^3}{64\pi\sqrt{2}}(1-x')^{1/2}(4 - 4x' + 3x'^2)$$

where $x' = \frac{4M_Z^2}{M_H^2}$



Higgs discovery potential at LHC





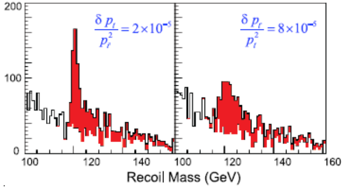
LHC (also could do the Tevatron) will be able to see the SM Higgs or exclude it and measure its properties, but not with enough precision. So, the need for future accelerators

SM Higgs properties

HIGGS mass.

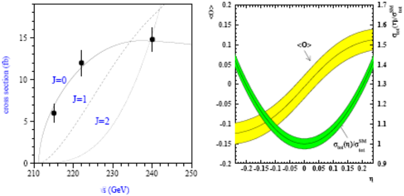
LHC can measure the Higgs mass with an statistical accuracy of about 0.1 %, with $300 fb^{-1}$,using the channel $H \rightarrow ZZ^* \rightarrow 4l$, for masses lower than 300 GeV.The absolute energy scale systematic uncertainty will be also about 0.1% up to masses of the order 400 GeV. Higgs width will be measured at the level of few ten %

The ILC will determine the Higgs mass by the recoil mass technique in the process $e^+e^- \rightarrow ZH \rightarrow Hll, Hq\bar{q}$
A $\Delta M_H \sim 40\ MeV$ can be reached , for $M_H \sim 120\ GeV$, at $\sqrt{s} = 350\ GeV$, with $500\ fb^{-1}$
Higgs width will be measured at the level of some %



SM Higgs properties

HIGGS spin and parity. Also Higgs-strahlung can be used at ILC to determine J^P from the rise of the cross section with $\sqrt{s}$ and from the angular correlations. The amount of CP-odd state η can be determined from the angular distributions:



$$\frac{d\sigma}{dcos\theta_Z} = \frac{G_F^2 M_Z^6 \beta}{16\pi D_Z(s)}(v_e^2+a_e^2)(1+\frac{s\beta^2}{8M_Z^2}sen^2\theta_Z+\eta\frac{v_e a_e}{v_e^2+a_e^2}\frac{2s\beta}{M_Z^2}cos\theta_Z+\eta^2\frac{s^2\beta^2}{4M_Z^4}(1-sen^2\theta_Z/2))$$

$$\beta = \sqrt{(s-(M_Z+M_H)^2)(s-(M_Z-M_H)^2/s}, D_Z(s) = (s-M_Z^2)^2 + M_Z^2\Gamma_Z^2$$

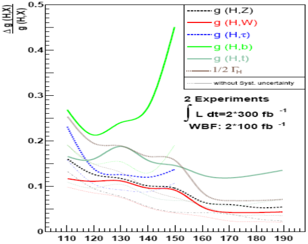
The optimum observable:

$$< O >\sim \frac{d\sigma_{CP-odd}}{dcos\theta_Z} / \frac{d\sigma_{SM}}{dcos\theta_Z}$$

$\Delta\eta \approx 0.032$ can be reached with 500 pb^{-1}

SM Higgs properties. Higgs couplings

LHC typical accuracies of H couplings to bosons and fermions are $\sim$ 10-30%.It is not sensitive to measure autocouplings



[M. Dührssen et al. '04]

SLHC autocouplings measurements are very difficult due to the large level of background.
$gg \rightarrow HH \rightarrow W^+W^-W^+W^- \rightarrow l^{\pm}l^{\pm}4j\nu\nu$ is an interesting channel, using like-sign leptons . This allows measurements of λ_{HHH} with statistical errors of $\sim 20\%$.
At ILC, a factor ~ 2 better is possible for $M_H < 140 GeV$, in the $e^+e^- \rightarrow HHZ \rightarrow 4b2l$, better if using polarized beams

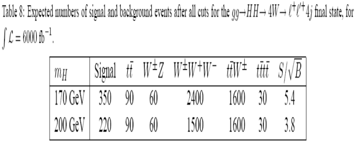


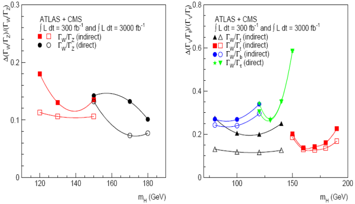
Table 8: Expected numbers of signal and background events after all cuts for the $gg \rightarrow HH \rightarrow 4W \rightarrow \ell^+\ell'^+4j$ final state, for $\int \mathcal{L} = 6000\ \text{fb}^{-1}$.

m_H	Signal	$t\bar{t}$	$W^{\pm}Z$	$W^{\pm}W^+W^-$	$t\bar{t}W^{\pm}$	$t\bar{t}t\bar{t}$	$S/\sqrt{B}$
170 GeV	350	90	60	2400	1600	30	5.4
200 GeV	220	90	60	1500	1600	30	3.8

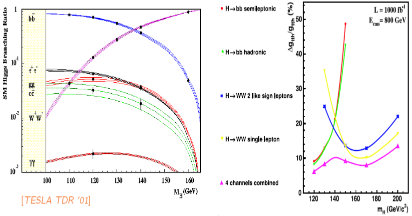
SM Higgs properties. Higgs couplings

SLHC model-independent couplings to fermions and bosons can be obtained by measuring the ratios of rates for two different final states:

- directly
- indirectly, considering the loop graphs with an intermediate boson as e.g. $H \rightarrow \gamma\gamma$, related to HWW coupling



ILC will be able to measure the Higgs couplings to fermions and bosons with few % accuracy (cross sections are proportional to g^2_{HVV}, g^2_{Hff} so the precision is 1/2 the precision to rates)



[TESLA TDR '01]

Gauge Boson Couplings

Triple and quartic gauge boson couplings are fixed, in the SM, by gauge invariance and renormalizability. Extensions of the SM lead to deviations. Parameterization in terms of effective terms will allow to extract information about the scale energy Λ of the new physics.
For TGV:

$$\begin{aligned}\mathcal{L}_{WWV} &= g_{WWV}\Big[i g_1^V V_\mu \left(W_\nu^- W_{\mu\nu}^+ - W_{\mu\nu}^- W_\nu^+\right) + i\kappa_V W_\mu^- W_\nu^+ V_{\mu\nu} + i\frac{\lambda_V}{M_W^2} W_{\lambda\mu}^- W_{\mu\nu}^+ V_{\nu\lambda} \\ &\quad + g_4^V W_\mu^- W_\nu^+ \left(\partial_\mu V_\nu + \partial_\nu V_\mu\right) + g_5^V \epsilon_{\mu\nu\lambda\rho} \left(W_\mu^- \partial_\lambda W_\nu^+ - \partial_\lambda W_\mu^- W_\nu^+\right) V_\rho \\ &\quad + i\tilde{\kappa}_V W_\mu^- W_\nu^+ \tilde{V}_{\mu\nu} + i\frac{\tilde{\lambda}_V}{M_W^2} W_{\lambda\mu}^- W_{\mu\nu}^+ \tilde{V}_{\nu\lambda}\Big],\end{aligned}$$

using the antisymmetric combinations $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$ and their duals $\tilde{V}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma} V_{\rho\sigma}$.

where $g_{WW\gamma} = e$, $g_{WWZ} = e\cot\theta_W$, $g_1^V = \kappa_V = 1$, all other couplings=0 in the SM.
The most sensitive channels are:

- At ILC, $e^+e^- \rightarrow W^+W^-$, analyzing the angular distribution and polarization of the W
- At SLHC, $W\gamma(Z) \rightarrow l\nu\gamma(ll)$

For QGV, genuine quartic vertices are parameterized by:

$$\begin{aligned}\mathcal{L}_4 &= \alpha_4 \left[\mathrm{Tr}\left(V_\mu V_\nu\right)\right]^2 , \\ \mathcal{L}_5 &= \alpha_5 \left[\mathrm{Tr}\left(V_\mu V^\mu\right)\right]^2 , \\ \mathcal{L}_6 &= \alpha_6 \, \mathrm{Tr}\left(V_\mu V_\nu\right) \mathrm{Tr}\left(T V^\mu\right) \mathrm{Tr}\left(T V^\nu\right) , \\ \mathcal{L}_7 &= \alpha_7 \, \mathrm{Tr}\left(V_\mu V^\mu\right) \left[\mathrm{Tr}\left(T V^\nu\right)\right]^2 , \\ \mathcal{L}_{10} &= \frac{\alpha_{10}}{2} \left[\mathrm{Tr}\left(T V_\mu\right) \, \mathrm{Tr}\left(T V_\nu\right)\right]^2 .\end{aligned}$$

The most sensitive channels are:

- At ILC, $e^+e^- \rightarrow llV^*V^* \rightarrow llVV$, $e^+e^- \rightarrow VVV$,
- At SLHC, $pp \rightarrow qqVV \rightarrow VVjj$), fully leptonic states, or via off-resonance production $V^* \rightarrow VVV$

Gauge Boson Couplings

Results of the single parameter fits (1σ) to the different triple gauge couplings at the ILC for $\sqrt{s} = 500\,\mathrm{GeV}$ with $\mathcal{L} = 500\ \mathrm{fb}^{-1}$ and $\sqrt{s} = 800\,\mathrm{GeV}$ with $\mathcal{L} = 1000\ \mathrm{fb}^{-1}$; $\mathcal{P}_{e-} = 80\%$ and $\mathcal{P}_{e+} = 60\%$ has been used.

coupling	error $\times 10^{-4}$	
	$\sqrt{s} = 500\,\mathrm{GeV}$	$\sqrt{s} = 800\,\mathrm{GeV}$
Δg_1^Z	15.5	12.6
$\Delta\kappa_\gamma$	3.3	1.9
λ_γ	5.9	3.3
$\Delta\kappa_Z$	3.2	1.9
λ_Z	6.7	3.0
g_5^Z	16.5	14.4
g_4^Z	45.9	18.3
$\tilde{\kappa}_Z$	39.0	14.3
$\tilde{\lambda}_Z$	7.5	3.0

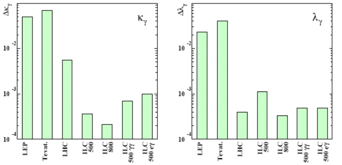
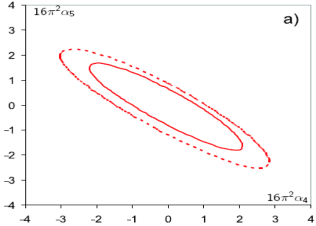
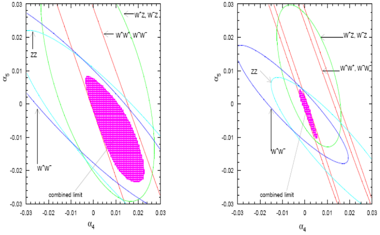


FIGURE 3.3. Comparison of $\Delta\kappa_\gamma$ and $\Delta\lambda_\gamma$ at different machines. For LHC and ILC three years of running are assumed (LHC: 300 fb^{-1}, ILC $\sqrt{s} = 500\,\mathrm{GeV}$: 500 fb^{-1}, ILC $\sqrt{s} = 800\,\mathrm{GeV}$: 1000 fb^{-1}). If available the results from multi-parameter fits have been used.

ILC (1-2 σ for 1 ab^{-1}, 1 TeV, polarized beams)



SHLC (1 σ contours for $100 fb^{-1}$, and $6000 fb^{-1}$)

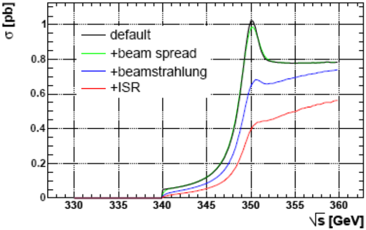


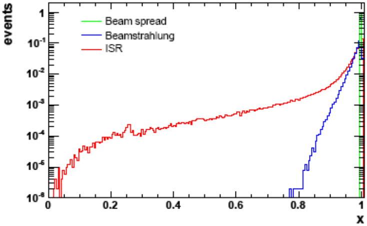
Top Physics

The top quark is the most strongly coupled quark, to EWSB sector. Top Yukawa couplings can help to discriminate SM and BSM scenarios
Given the large top quark cross section in hadron colliders, top physics will almost be completed in the first years of LHC. But some issues, as rare decays, will need more statistics.
On the other side, e^+e^- linear colliders will increase the precision of the quark top properties, as the mass, a fundamental parameter of the SM, very much related to the Higgs boson mass.
Because top has a large width ($\Gamma_t \sim 1.5 GeV$), will decay before hadronization, highly suppresssing non-perturbative effects.

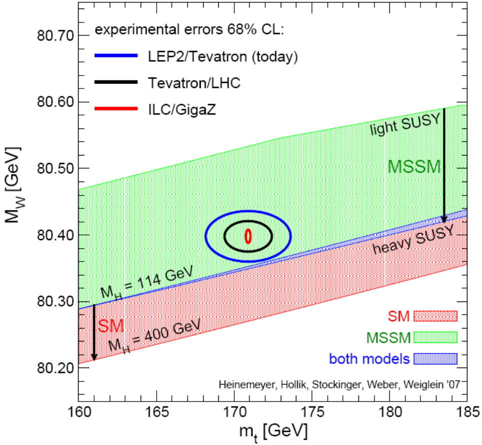
Top mass:

- At Tevatron and LHC, top mass will be determined by kinematic reconstruction, so giving the pole mass. This mass can not be determined better than $O(\Lambda_{QCD})$, because is affected by large long-scale contributions (IR divergences). The expected accuracy is of the order of 1 GeV
- At ILC will be determined from the rise of the cross-section around the energy , so giving the threshold mass. The translation to another short-distance mass will give rise to an additional uncertainty. The combined uncertainty expected is about 100-200 MeV (an accurate determination of the luminosity will be needed)





Top Physics



An example of the importance of the accuracy determination of the top mass: discrimination between SM and MSSM models, where the MSSM band is a scan over SUSY masses and the SM band a scan over SM Higgs masses

Supersymmetry

Supersymmetry is, probably, the most attractive extension of the SM. It solves the three big problems of the SM:

- Fine tuning, preventing M_H to acquire large radiative corrections, because quadratic divergent loops contributions of SM particles are exactly cancelled by its superpartners
- Allow to understand the origin of the electroweak symmetry breaking, in terms of the radiative corrections triggered by supersymmetry breaking. Also allow unification of the three gauge couplings at the scale of $\sim 2\ 10^{16}\ GeV$
- If R-parity is conserved, the lightest supersymmetric particle (LSP will be stable and could account for the cold dark matter of the Universe

The MSSM is the most economical model and its content is given by:

$$\begin{array}{llll}
\left[u,d,c,s,t,b\right]_{L,R} & \left[e,\mu,\tau\right]_{L,R} & \left[\nu_{e,\mu,\tau}\right]_{L} & \text{Spin } \frac{1}{2} \\
\left[\tilde{u},\tilde{d},\tilde{c},\tilde{s},\tilde{t},\tilde{b}\right]_{L,R} & \left[\tilde{e},\tilde{\mu},\tilde{\tau}\right]_{L,R} & \left[\tilde{\nu}_{e,\mu,\tau}\right]_{L} & \text{Spin } 0 \\
g \quad \underbrace{W^{\pm}, H^{\pm}} & \underbrace{\gamma, Z, H_1^0, H_2^0} & & \text{Spin } 1 \ / \ \text{Spin } 0 \\
\tilde{g} \quad \tilde{\chi}^{\pm}_{1,2} & \tilde{\chi}^{0}_{1,2,3,4} & & \text{Spin } \frac{1}{2}
\end{array}$$

Assuming universality (flavor-blind) of the soft-SUSY breaking terms, leads to two a benchmark scenario cMSSM, with only five free parameters:

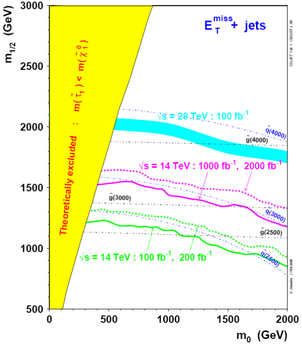
- m_0, the soft term scalar masses (sfermions and Higgs)
- $m_{1/2}$,the soft term gaugino masses (bino, wino, gluino)
- A_0,trilinear scalar interactions
- $tan\beta$,ratio of vacuum expectation values of tho Higgs doublets
- $sign(\mu)$, sign of the Higgsino mass parameter

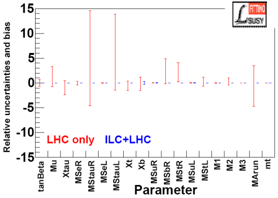
Supersymmetry

LHC-SLHC and ILC will be complementary to the SUSY searches

- ILC limited by kinematics to uncolored particles. Signals are clear and backgrounds are low. A precise determination of masses and spin will be possible.
- squark and gluinos up to 3 TeV are detectable at SLHC
- A big improvement in the accuracies will be obtained from combined analysis of LHC and ILC

	LHC [GeV]	LHC + ILC [GeV]
$\Delta m_{\tilde{\chi}_1^0}$	4.8	0.05
$\Delta m_{\tilde{\chi}_2^0}$	4.2	0.08
$\Delta m_{\tilde{l}_L}$	4.8	0.05
$\Delta m_{\tilde{b}_1}$	7.1	5.7
$\Delta m_{\tilde{q}_L}$	8.7	4.9
$\Delta m_{\tilde{q}_R}$	7-12	5-11
$\Delta m_{\tilde{g}}$	8.0	6.5

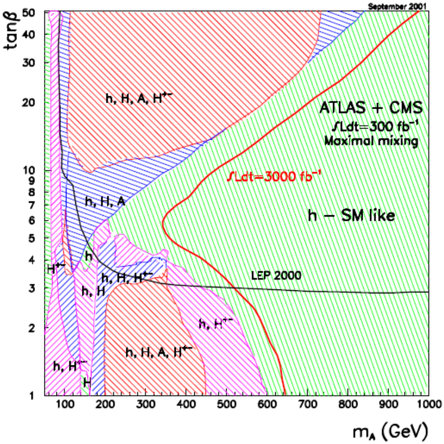




Higgs in MSSM

LHC-SLHC and ILC will be also complementary in SUSY Higgs searches. ILC will be kinematically limited.

The Figure shows the regions in which LHC-SLHC will can reach more than 5σ discoveries. In the left regions two or more Higgs bosons can be discovered. In the right region, only h can be discovered



Other scenarios

Other BSM models include:

- Large, warped or Universal extra dimensions, with direct Kaluza-Klein graviton or resonances production. There exists different models, in which LHC have sensitivity to discover them and SLHC improves significantly the mass region and the determination of the number of extra-dimensions. The ILC will pay an essential role better determining the number of extra dimensions and stablishing the gravitational nature of the KK resonances
- Strong Interaction Models, as Little Higgs models or Strong Electroweak Symmetry Breaking
- New gauge bosons remnants from breaking of GUT's, with masses up to about 5 TeV, will be searched at LHC-SLHC in Drell-Yan processes $q\bar{q} \longrightarrow Z' \longrightarrow l^+l^-$. Then ILC will extend the sensitivity to new scales and will measure the couplings to SM fermions very precisely, to discriminate between models. Also W' will be searched in both facilities.
- Compositeness, up to scales of 40 TeV (LHC), 60 TeV (SLHC) and 100 TeV (ILC)
- ...

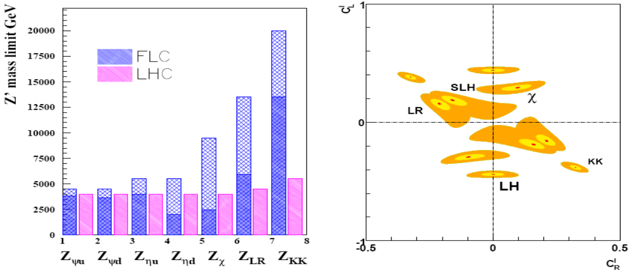


FIGURE 6.10. Left: the mass range covered by the LHC and the ILC (FLC) for a Z' boson in various scenarios; for the ILC the heavy hatched region is covered by exploiting the GigaZ option (sensitive to the Z–Z' mixing) and the high energy region (sensitive to the γ, Z–Z' interference) [15, 236]. Right: the ILC resolving power (95% CL) for $M_{Z'} = 1, 2$ and 3 TeV for left– and right–handed leptonic couplings (c^l_L and c^l_R) based on the leptonic observables $\sigma^\mu_{\rm pol}$, A^μ_{LR} and A^μ_{FB}; the smallest (largest) regions correspond to $M_{Z'} = 1$ TeV (3 TeV) [237]. In both figures $\sqrt{s} = 500$ GeV and $\mathcal{L} = 1$ ab^{-1} are assumed.

Cosmology Connection

Dark matter accounts for ~ 20 % of the energy density of the Universe. To stablish the inter-relations between particle physics and cosmology is an important goal of the future physics developments.

ILC can play an important role on that direction. Many extensions of the SM predicts stable weakly interacting particles(WIMPS), in general electrically neutral, as:

- Supersymmetry. In the case of R-parity conservation, the LSP, neutralino in many models, but also exists the possibility of axinos or gravitinos, could play the DM role
- Extra-dimensions. In the case of Universal extra-dimensions, a called KK-parity is conserved, so the lightest Kaluza-Klein particle (LKP) is stable and DM candidate. Also in warped models an stable KK particle (LZP) exists
- Little Higgs models. A discrete symmetry called T-parity can be introduced. The lightest T-odd particle (LTP) should be the DM candidate

Cascade decays with large missing energy is the characteristic signature of WIMPS

Cosmological data currently (WMAP)predicts the DM with 6% accuracy, and will be improved by PLANCK to the percent level. The WIMP candidates must have their cosmological relic density, inversely proportional to their annihilation cross section $\sigma_{ann} = \sigma(WIMP + WIMP \longrightarrow SM\ particles)$ falling in the range of the satellites measurements.

Other important problem to be solved is the baryon asymmetry of the Universe, which, as indicated by WMAP and primordial nucleosynthesis theory, should have been created after the inflationary period.

New physics BSM is needed to explain it and there are mainly two possibilities:

- Electroweak baryogenesis, generating the baryon asymmetry at the electroweak phase transition. Several scenarios include MSSM, NMSSM, 2HD models,...
- Leptogenesis, in which the root of baryon asymmetry is located near the GUT or Planck scale. Heavy neutrino mass scales are introduced by seesaw mechanism. CP-violating decays of heavy right-handed Majorana neutrinos generate the lepton asymmetry which is transferred to the quark-baryon sector.

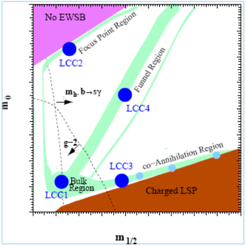
Dark Matter

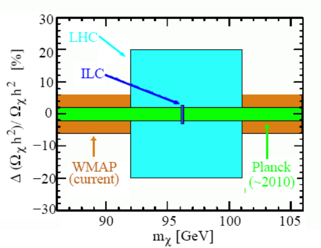
In the case of cMSSM, several scenarios allowed by WMAP measurements are being analyzed. Some benchmarks (LCC1, LCC2, LCC3, LCC4) corresponding, respectively, to the scenarios:

- Bulk region, where m_0, $m_{1/2}$ are small
- Focus point in which the neutralino has a significant higgsino component, enhancing the annihilation cross sections into final states with gauge and/or Higgs bosons
- Co-annihilation region which has near mass degeneracy between the LSP neutralino and the lightest stau
- A-funnel region, with large $tan\beta$ in which the s-channel exchangw of A-higgs become resonant

Results are shown in the Figure, for $A_0 = 0(-100\ GeV\ for\ LCC1)$, $\mu > 0$ (with axes scales depending of $tan\beta$)

Point	m_0	$m_{1/2}$	$\tan\beta$	$m_{\chi_1^0}$	ΔILC	$\Omega_\chi h^2$	Δ ILC	(Δ LHC)
LCC1	100	250	10	96.1	±0.05	0.192	± 0.24%	(7.2%)
LCC2	3280	300	10	107.9	±1.0	0.109	± 7.6%	(82%)
LCC3	213	360	40	142.6	±0.1	0.101	± 18%	(167%)
LCC4	380	420	53	169.1	±1.4	0.114	± 19%	(405%)





1 General aspects
- Fundamental questions about the Universe
- Proposed Facilities
- Tevatron vs LHC
- SLHC, ILC; CLIC, VLHC

2 Physics
- Higgs
- Gauge Boson Couplings
- Top Physics
- Supersymmetry
- Other scenarios
- Cosmology Connection

3 Detector Challenges
- Detector Challenges
- Radiation Background
- Vertex
- Tracking
- Calorimetry
- Muon chambers
- Magnets
- Trigger
- Data acquisition

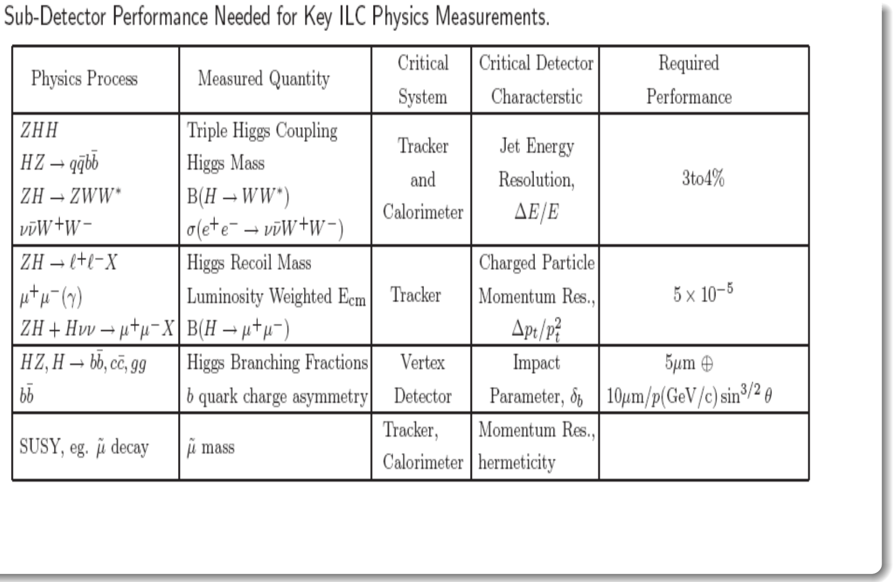
4 More Information

5 Questions

Detector challenges

- Processes with multijet final states, often accompanied by charged leptons or missing energy, will require very good jet energy resolution. In the case of ILC, will be needed a factor 2 better than LEP/SLC.
- Lepton identification need to be excellent, and acceptance must be high.
- Particle flow will be needed to separate neutral and charged contributions in a dense jet environment. That impose highly granular calorimetry
- Momentum resolution is particularly challenging. It´s crucial, e.g., at ILC in the Higgs-strahlung production in association with Z. It will demand minimal material to preserve lepton ID and high performance calorimetry.
- Very good determination of the beam energy is other of the important goals
- Vertex detection efficiency, angular coverage and impact parameter resolution will be very important to have a good tagging of heavy particles
- Radiation environment will be particularly important at SLHC, but also at ILC has to be considered, due to the demanding physics goals. For SLHC, radiation-hard silicon sensors and front-end electronics should be needed for the inner tracking
- The Trigger will need to cope with the high intensity and Beam Crossing reduced period at SLHC

Detector challenges

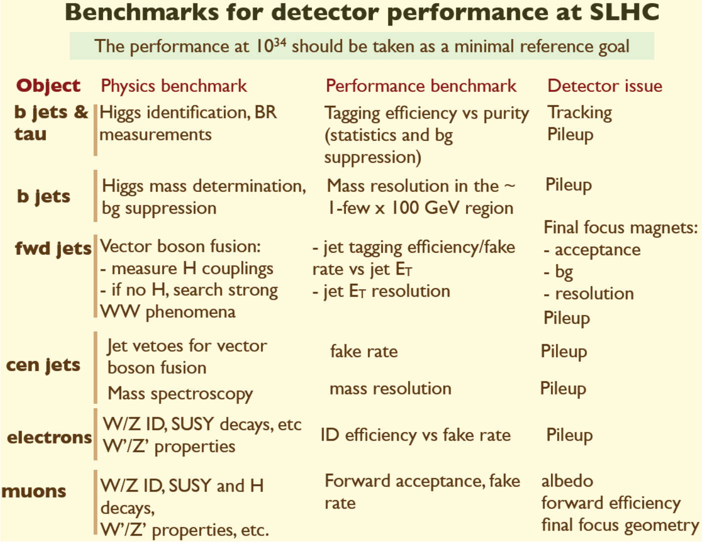


Sub-Detector Performance Needed for Key ILC Physics Measurements.

Physics Process	Measured Quantity	Critical System	Critical Detector Characterstic	Required Performance
ZHH $HZ \to q\bar{q}b\bar{b}$ $ZH \to ZWW^*$ $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass $\mathrm{B}(H \to WW^*)$ $\sigma(e^+e^- \to \nu\bar{\nu}W^+W^-)$	Tracker and Calorimeter	Jet Energy Resolution, $\Delta E/E$	3to4%
$ZH \to \ell^+\ell^- X$ $\mu^+\mu^-(\gamma)$ $ZH + H\nu\nu \to \mu^+\mu^- X$	Higgs Recoil Mass Luminosity Weighted $\mathrm{E_{cm}}$ $\mathrm{B}(H \to \mu^+\mu^-)$	Tracker	Charged Particle Momentum Res., $\Delta p_t/p_t^2$	5×10^{-5}
$HZ, H \to b\bar{b}, c\bar{c}, gg$ $b\bar{b}$	Higgs Branching Fractions b quark charge asymmetry	Vertex Detector	Impact Parameter, δ_b	$5\mu m \oplus$ $10\mu m/p(\mathrm{GeV/c}) \sin^{3/2}\theta$
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum Res., hermeticity	

Detector challenges

(from M. Mangano, April 2008)



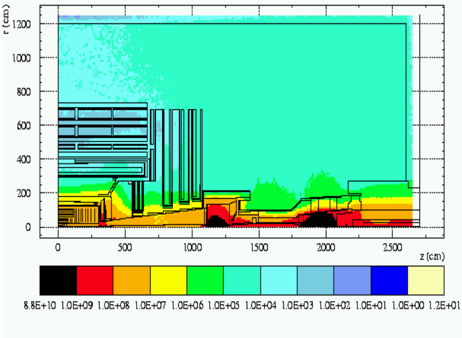
Benchmarks for detector performance at SLHC

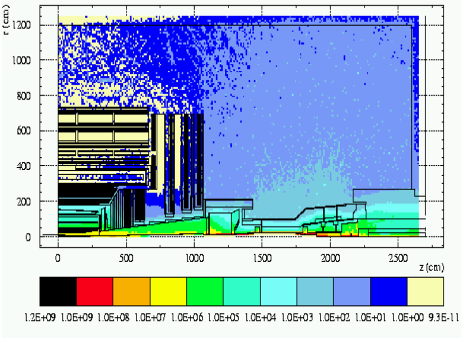
The performance at 10^{34} should be taken as a minimal reference goal

Object	Physics benchmark	Performance benchmark	Detector issue
b jets & tau	Higgs identification, BR measurements	Tagging efficiency vs purity (statistics and bg suppression)	Tracking Pileup
b jets	Higgs mass determination, bg suppression	Mass resolution in the ~ 1-few x 100 GeV region	Pileup
fwd jets	Vector boson fusion: - measure H couplings - if no H, search strong WW phenomena	- jet tagging efficiency/fake rate vs jet E_T - jet E_T resolution	Final focus magnets: - acceptance - bg - resolution Pileup
cen jets	Jet vetoes for vector boson fusion	fake rate	Pileup
	Mass spectroscopy	mass resolution	Pileup
electrons	W/Z ID, SUSY decays, etc W'/Z' properties	ID efficiency vs fake rate	Pileup
muons	W/Z ID, SUSY and H decays, W'/Z' properties, etc.	Forward acceptance, fake rate	albedo forward efficiency final focus geometry

Radiation Background

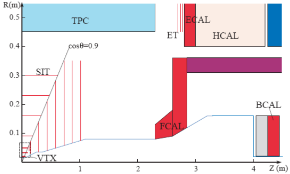
Radiation Background is the main limiting factor at the high luminosity aimed at SLHC. It will be dominated by pp secondaries. The following Figures show, respectively, the neutron flux (in $cm^{-2}\ s^{-1}$) at an instantaneous luminosity of $10^{35}\ cm^{-2}\ s^{-1}$, and the dose (in Gy) for an integrated luminosity of 2500 fb^{-1}



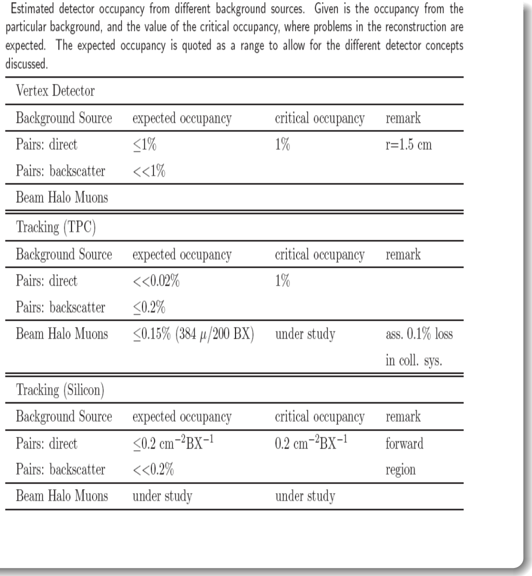


Radiation Background

At ILC, the main source of backgrounds are due to beamstrahlung, which produces electron-positron pairs in the forward-backward direction, and photons, also in that direction. The effect on the detectors is given by the primaries, but also secondary and tertiary particles produced by the interaction of the primaries with the Interaction Regions. Other sources of background are synchrotron radiation, due to the focusing elements, and beam-halo muons, due to the interactions in the colimation section.



Side view of the interaction region and very forward region of a typical ILC detector.



Estimated detector occupancy from different background sources. Given is the occupancy from the particular background, and the value of the critical occupancy, where problems in the reconstruction are expected. The expected occupancy is quoted as a range to allow for the different detector concepts discussed.

Vertex Detector			
Background Source	expected occupancy	critical occupancy	remark
Pairs: direct	$\leq$1%	1%	r=1.5 cm
Pairs: backscatter	<<1%		
Beam Halo Muons			
Tracking (TPC)			
Background Source	expected occupancy	critical occupancy	remark
Pairs: direct	<<0.02%	1%	
Pairs: backscatter	$\leq$0.2%		
Beam Halo Muons	$\leq$0.15% (384 μ/200 BX)	under study	ass. 0.1% loss in coll. sys.
Tracking (Silicon)			
Background Source	expected occupancy	critical occupancy	remark
Pairs: direct	$\leq$0.2 cm^{-2}BX^{-1}	0.2 cm^{-2}BX^{-1}	forward region
Pairs: backscatter	<<0.2%		
Beam Halo Muons	under study	under study	

Vertex

- At LHC pixel detectors are between 7-20 cm from the beamline, and the occupancy is $\sim 3\ 10^{-4}$
- At SLHC the dose and fluence of hadrons, at 7 cm, will be $100\ kGy, 5\ 10^{15}\ hadrons/cm^2$. The current approaches and concepts will not work. Probably, anually replacements will be needed. It is needed *R&D* as, e.g. CERN RD48 collaboration for defect-engineered silicon. Other *R&D* studies include:
  - 3D detectors
  - New sensor materials, as e.g. diamond CERN RD42 collaboration
  - Cryogenic Silicon Tracker development, operating at 130 K. CERN RD39 collaboration
  - Monolithic Pixel Detectors
- At ILC the beam pipe will expand conically, beyond $|z| \approx 7\ cm$, staying safely from the envelope of pair background. The vertex system will go from $\approx 1.5\ cm\ to\ \approx 6\ cm$. Silicon pixels in different technologies are being studied (FPCCD, CPCCD, DEPFET, MAPS,...). The main characteristics of the vertex system will be:
  - beam-pipe radius $\leq$ 15 mm.
  - $\approx 10^9$ pixels of $\leq 20\ \mu m^2$
  - layer thickness $\approx 0.1\%\ X_0$

Tracking

At SLHC hybrid pixel detectors with higher cell-sizes than current ones is foreseen between 20-60 cm. from the beamline. At radius higher than 60 cm. silicon microstrips, similar to CMS tracking system will be used, but pushing the existing technology to the new characteristics.

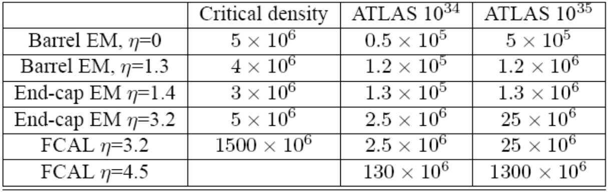
At ILC two different systems are being studied, having the corresponding advantages and challenges:

- Silicon Tracking
  - Position resolutions of 5-10 microns with good signal/noise performance
  - Fast charge collection to identify beam crossing and minimizing pileup
  - Excelent two-hit resolution
  - Minimal corrections for environmental factors
  - Power pulsed readout electronics will take advantage of the low duty cicle of ILC, with the goal to reduce power and then material of the cooling system
  - Long ladders, high density readout chips, thinned silicon wafers, double-sided detectors, 3D,...
  - New robust mechanical designs
  - Alignment,...
- Gaseous Tracking
  - Record a large number of track segments in three dimensions
  - Very little mass at the central volume
  - Capability of measure the ionization energy
  - A momentum resolution of $\sigma(1/p_T) \approx 5\ 10^{-5}\ GeV^{-1}$
  - to reach it, use TPC with gas amplification given by micropattern gas detectors (Gas Electron Multipiers, Micro Megas), instead of wire grids, with resolution of about 100 microns (achievable with a magnetic field of about 3-4 Tesla, after a long drift of 2 or more meters
  - or use cluster counting drift chambers, with low material and low drift velocity He-based gas, giving resolution of about 50 microns
  - a high performance of the field uniformity is needed
  - low material in the end planes is required

Calorimetry

At SLHC, several aspects have to be considered:

- Space charge effects which will affect the EM endcap of ATLAS and HC endcap of CMS, as well as Very Forward CMS Calorimeter. *R&D* is needed on those aspects.
- Voltage drop induced in the HV distribution, which could affect the EM endcap of ATLAS. A different liquid, instead Argon, should be evaluated
- Large increase in electronic noise, due to leakage current in the photosensors of the CMS Crystal ECAL. Recovery mechanisms have to be investigated
- The electronics need dedicated analysis in both experiments, due to the 10 times more radiation, mainly in the endcaps
- The effect of shorter bunch spacing (up to 12.5 nsec) need studies. Seems to be possible to continue sampling at 40 MHz, due to the excellent time resolution which would allow to assign correctly the bunch crossing
- Pile-up could degrade a little the performance. Need to be assessed



	Critical density	ATLAS 10^{34}	ATLAS 10^{35}
Barrel EM, η=0	5×10^6	0.5×10^5	5×10^5
Barrel EM, η=1.3	4×10^6	1.2×10^5	1.2×10^6
End-cap EM η=1.4	3×10^6	1.3×10^5	1.3×10^6
End-cap EM η=3.2	5×10^6	2.5×10^6	25×10^6
FCAL η=3.2	1500×10^6	2.5×10^6	25×10^6
FCAL η=4.5		130×10^6	1300×10^6

Calorimetry

At ILC, the resolution of the jet energy must be $\sigma_E/E \approx 3-4\%$, or $30\%/\sqrt{E}$, up to energies of 100 GeV, and over the full polar angle. This is about a factor of two better than current calorimeters. To reach this goal, two options are being studied:

- Single Particle shower imaging in extremely fine grained and compact calorimeters, using the particle flow concept.
- Dual readout of scintillation and Cherenkov light of fibers or crystals, allowing separation of electromagnetic and hadronic components inside a shower (DREAM Calorimeter

Several technologies for ECAL and HCAL are under investigation.

- ECAL are compact and fine-grained sandwich calorimeters, using tungsten or lead as absorber and:
  - silicon pad diodes
  - monolithic active pixel sensors (MAPS), or
  - scintillator strips or tiles, as sensor planes.
- HCAL are fine-segmented sampling calorimeters, using:
  - Scintillator tiles or strips as sensor for analog read out, or
  - Gaseous Electron Multipliers (GEM), Micromegas, or Resistive Plate Chambers (RPC), for digital readout
- the DREAM concept
- Special calorimeters to instrument the very forward region, to read the luminosity fast and precisely

Calorimetry

Some Figures from the *R&D* work on calorimetry:

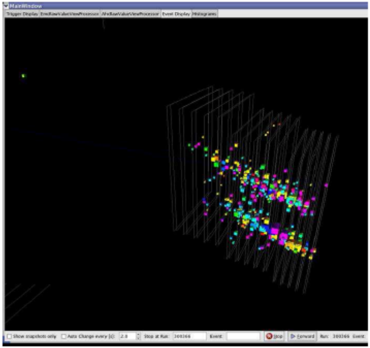


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FIGURE 5.17. Two electron showers recorded by the CALICE prototype detector in the test-beam at CERN.

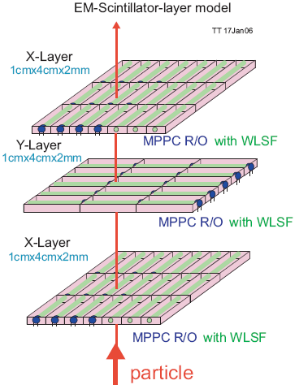


FIGURE 5.25. A possible strip sequence of the ECAL for GLD. Layers of scintillator strips are oriented perpendicular to each other. Each strip is equipped with a wavelength-shifting fiber (green) and readout by a MPPC (blue dots).

Calorimetry

Some Figures from the *R&D* work on calorimetry:

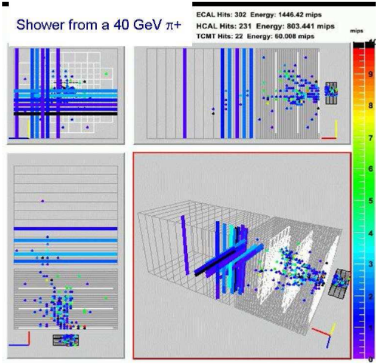


FIGURE 5.35. An event display of the shower of a 40 GeV pion recorded in the CERN test-beam in projections. The shower starts in the ECAL, continues into the HCAL and ends in the tail-catcher.

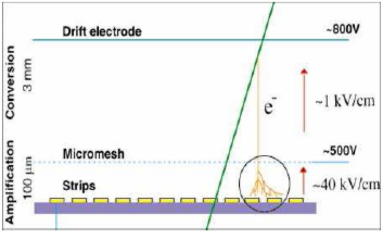


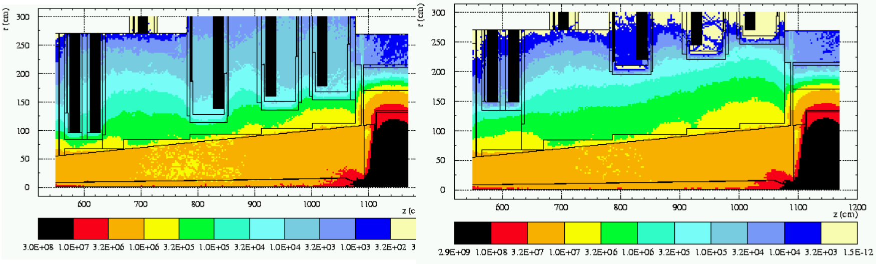
FIGURE 5.39. The working principle of Micromegas. Electrons from ionization drift in an electrical field to the mesh and induce an avalanche when crossing it. Signals can be picked up from anode strips or pads.

Muon Chambers

At high rapidity $\eta \leq 2.2$, the background radiation at SLHC produces a particle fluence, scaling with luminosity and mainly composed of neutron and photons, dominating the observed hit rate at low $\eta \leq 2.2$.

For that reason, increasing shielding around the beam pipe and at high η will be needed. Background rate will be reduced, being particularly effective at low-η, where neutrals dominate the observed hit rate in the muon detectors. This will cause a cut in the high-η acceptance

The Figures show the neutron fluence ($cm^{-2}\ s^{-1}$), in the low radius, high-η of the CMS endcap muon detector for $\eta < 2.4$ and current LHC and possible shielding of SLHC, for $\eta < 2$



Much of the on-board trigger and readout electronics will have to be replaced, to cope with the 80 MHz bunch-crossing

Magnets

Magnetic fields are essential to accuracy measurements of the momentum of charged particles. For a particle of charge q and momentum p, the relation between the deflection angle ϕ, the sagitta, s, the path length L, the magnetic field B, and the bending radius ρ is:

$$\phi \approx L/\rho = \frac{qBL}{\rho}, s \approx \frac{qBL^2}{8p}, \sigma_p/p \approx p/(BL)^2$$

For that reason a large coil radius R (large L) gives better momentum resolution. On the other side, the ratio of stored energy to cold mass (E/M) is a good performance measure in superconducting magnets. In ideal solenoids with perfect axial field, it is related to the hoop stress c_h and average density d by:

$$(E/M) \approx c_h/2d$$

This ratio is related to the enthalpy of the coil, determining the temperature rise after a quench. To reduce that temperature increase, high mass coils are favored, in spite of the usual ILC experiments requirements. CMS solenoid has a E/M value of 12 kJ/kg, and values up to 20 kJ/kg seem possible to achieve, if having a highly redundant and reliable safety system to protect the magnet in case of quench.
The following Figures show the progress and specifications of old, current and future detector solenoids

Magnets

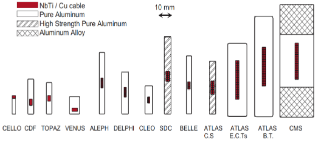
Progress of detector solenoid magnets in high energy physics.

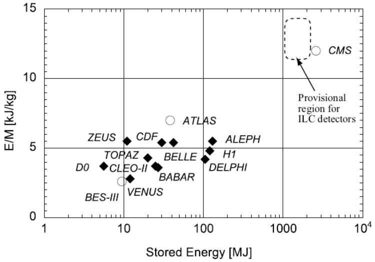
Name	Laboratory	B [T]	R [m]	L [m]	E [MJ]	X [x_0]	E/M [kJ/kg]
CDF	Tsukuba/FNAL	1.5	1.5	5.07	30	0.84	5.4
TOPAZ*	KEK	1.2	1.45	5.4	20	0.70	4.3
VENUS*	KEK	0.75	1.75	5.64	12	0.52	2.8
AMY*	KEK	3	1.29	3	40	#	
CLEO-II	Cornell	1.5	1.55	3.8	25	2.5	3.7
ALEPH*	Saclay/CERN	1.5	2.75	7.0	130	2.0	5.5
DELPHI*	RAL/CERN	1.2	2.8	7.4	109	1.7	4.2
ZEUS	INFN/DESY	1.8	1.5	2.85	11	0.9	5.5
H1	RAL/DESY	1.2	2.8	5.75	120	1.8	4.8
BABAR	INFN/SLAC	1.5	1.5	3.46	27	#	3.6
D0	Fermi	2.0	0.6	2.73	5.6	0.9	3.7
BELLE	KEK	1.5	1.8	4	42	#	5.3
BES-III+	IHEP	1.0	1.45	3.5	9.5	#	2.6
ATLAS							
Central	ATLAS/CERN	2.0	1.25	5.3	38	0.66	7.0
Barrel	ATLAS/CERN	1	4.7-9.7	5	26	1080	
Endcap	ATLAS/CERN	1	0.825-5.35	5	2 × 250	-	
CMS+	CMS/CERN	4	6	12.5	2600	#	12

* operation complete

+detector under construction

#EM calorimeter inside solenoid, so small radiation length, X, not a goal





Superconducting detector solenoids for ILC compared with detector solenoids at LHC.

Parameters	unit	LHC		ILC				
		ATLAS CS	CMS	GLD	LDC	SiD	4th Inner	4th Outer
Basic requirements								
Clear-bore radius	m	7	1.18	4.00	3.00	2.5	3.0	
Central magnetic field	Tesla	2	4	3	4	5	3.5	1.5
Design parameters								
Coil inner radius	m	1.23	3.25	(4.0)	3.16	2.65	3	5.4
Coil half length	m	2.7	6.25	4.43	3.3	2.5	4	5.5
Coil layers		1	4	2	4	6	6	
Cold mass thickness	m	0.04	0.3	0.4	0.3	0.4	0.3	
Maximum field in coil	Tesla	2.6	4.6	3.5	4.6	5.8	5.8	
Nominal current	kA	7.73	20			1.8	2.0	
Stored energy	GJ	0.04	2.6	1.6	1.7	1.4	2.8	
Cold mass weight	ton	5.7	220	78	130			
E/M	kJ/kg	7	12.3	20	13	12	12.6	

Trigger

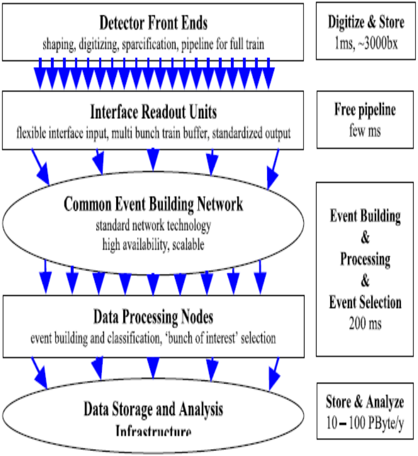
At SLHC:

- Higher luminosity consequences:
  - Increased occupancy, degrading the performance of the trigger, due to pile-up increase and larger event size
  - For fixed readout bandwidth, reduced the maximum allowed level-1 rate. That implies raising the transverse-momentum thresholds on candidates and using less inclusive triggers
  - Radiation damage could cause problems on the level-1 and front-end electronics. That needs assessment
- Reduced BC period to 12.5 ns
  - could be needed to rebuild the level-1 processor systems to work at 80 MHz
  - or keep some of the level-1 trigger processor electronics at 25 ns, forming time-frames, to be treated offline to reconstruct the hit time
- Trigger types:
  - For high p_T discovery. No big rate problems
  - For Higgs precise measurements. Exclusive menus targeted to the final states to be studied
  - Control and calibration with low thresholds, which can be pre-scaled
  - Others...

Data acquisition

At SLHC and ILC, the main aspects to be considered are:

- the readout network technologies, following the foreseen LHC computing and Grids projects
- the complexity handling
- ILC will have less data throughput than SLHC, but larger readout channels
- LHC and SLHC has a continuous rate of equidistant bunch crossings, but ILC will have a pulsed operation mode, as shown in the Figure. Note that roughly 3000 collisions will be expected in 1 ms, so readout will will have to perform zero suppression and data condensation



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Questions

- General
    - ¿Cuáles de las respuestas a las preguntas fundamentales sobre el Universo podrá contestar el LHC?, el SLHC?, el ILC?. Comentar las posibles respuestas.
- Aceleradores
    - Un colisionador lineal pretende lograr una energía en centro de masas de 1 TeV.Traza una curva de longitud versus gradiente de campo, asumiendo un factor de eficacia de las cavidades del 70 %. ¿Qué gradiente se requiere para una longitud de 25 Km?
    - Suponiendo una frecuencia de repetición de 200 Hz y un radio medio del haz. $\sigma_x = \sigma_y = 60nm$, ¿qué intensidad del haz se requiere, en el colisionador lineal anterior, para alcanzar una luminosidad de 10^{34} cm^{-2} seg^{-1}?. En dichas condiciones, ¿cuál es la potencia media del haz?
    - Con los datos de las Tablas estima el tamaño de los haces en el SLHC, ILC y CLIC
- Física
    - Dibuja diagramas de producción de Higgs, al orden más bajo, y razona cuáles son los más importantes o más interesantes, en los futuros aceleradores SLHC e ILC.
    - ¿Por qué crees que una medida precisa de los autoacoplamientos del bosón de Higgs es importante?
    - Muestra en un diagrama la relación entre las constantes de acoplamiento del Higgs a los diferentes bosones y fermiones fundamentales, con la masa de dichos bosones y fermiones. ¿Qué parámetro del modelo estándar podemos determinar de dicha dependencia?
    - ¿Qué crees que pueden aportar SLHC e ILC a la Física del quark top?

Questions

- Detectores
  - ¿Por qué la mayor luminosidad de SLHC, comparada con LHC, exige mayor granularidad en los detectores de vértices?
  - Explica el concepto de "particle-flow" e indica los requerimientos de los detectores para utizarlo de forma eficaz
  - Indica los pros y los contras de los diferentes métodos de "tracking" propuestos por los Conceptos de Detector de ILC
  - Indica, en tu opinión, cuales son las ventajas e inconvenientes de tener un solenoide más potente en un detector para ILC