Physics and Detectors in ILC

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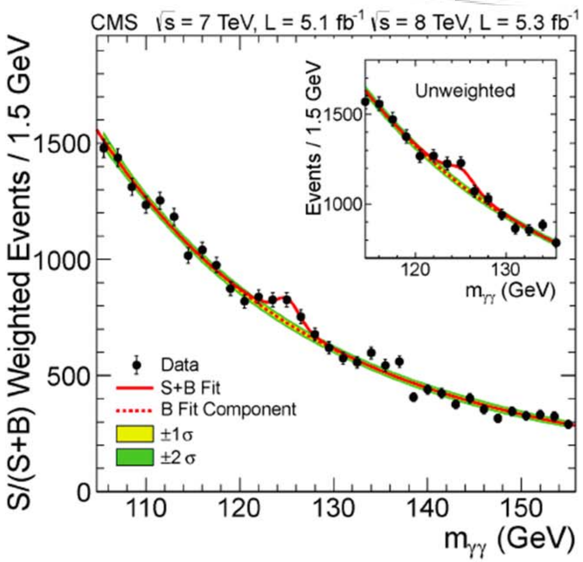
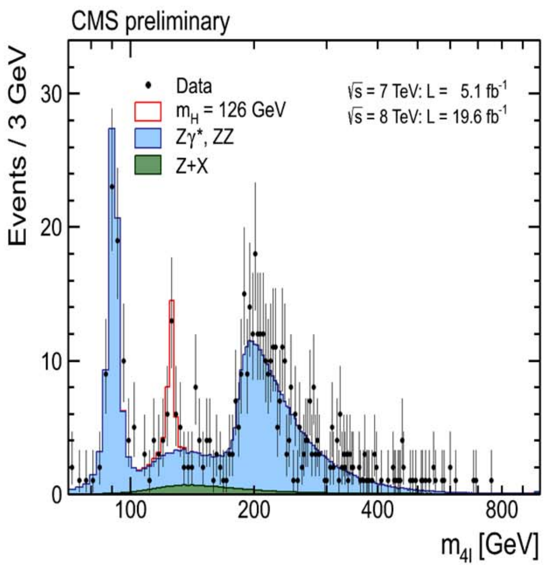
Discovery of Higgs-like Particle at LHC





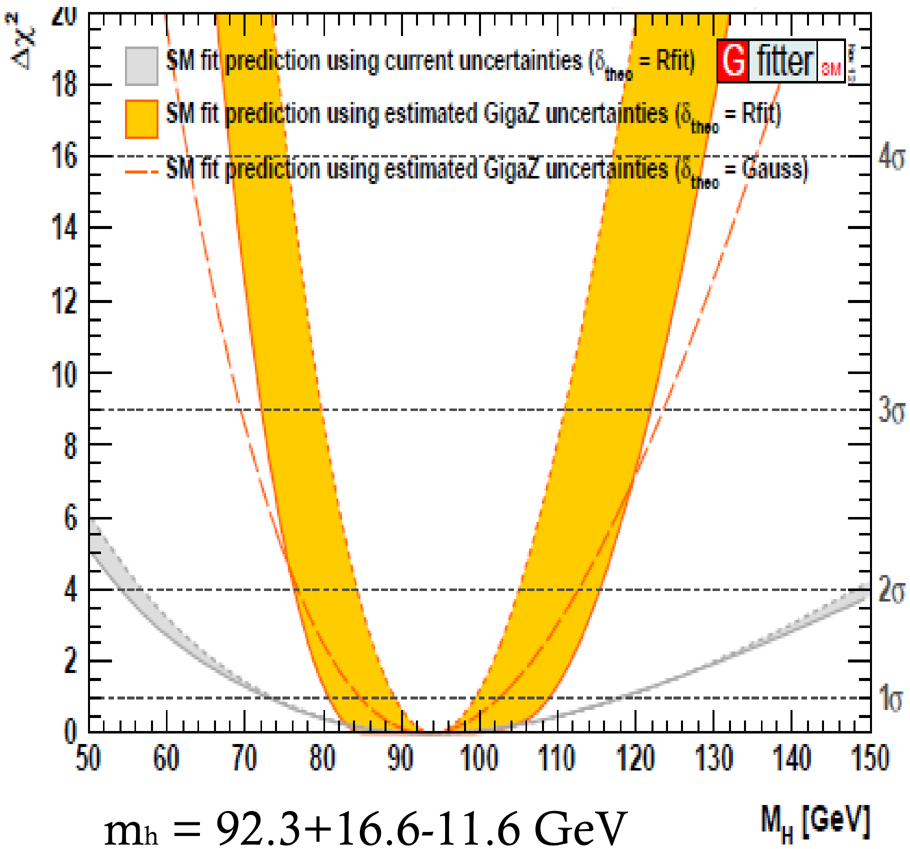
Signal strengths are consistent with the SM expectations

Excludes the possibility of the resonance being a spin 1 particle via the Landau-Yang theorem

Disfavors the possibility of the resonance being a pseudoscalar particle
→ favor 0^+ over 0^- by 2.5σ

Is that all?

- SM does not contain any candidate particles to constitute the needed CDM.
- SM is not sufficient source of CP violation needed to explain baryogenesis



m_h = 92.3+16.6-11.6 GeV

M_H=126 GeV would be excluded at almost 4σ level in a pure SM fit
→ The idea that asymmetry comes from a single Higgs field is just a guess among many other possibilities.
→ requires additional contributions from new particles at the TeV mass scale
→ precise measurements of Z and W properties can reveal effects associated with Higgs boson compositeness or strong interactions.

Toward to Another New Era

Since Snowmass 2001, there has been consensus that e+e- linear collider is needed

ILC and CLIC are now under Linear Collider Collaboration(LCC)

LINEAR COLLIDER COLLABORATION

ILC(250~1000 GeV)	CLIC(350~3000 GeV)
- TDR on June 12 was followed after CDR - Construction can started in two years after approval (~2016)	- CDR was issued in 2012 - TDR will be ready in a few years - Construction will be around 2022 near CERN

Primary goal of the TDR is "Realize the ILC"

Contributing Institutes in TDR

12 개 대학교 및 연구소

- 강릉대학교
- 건국대학교
- 경북대학교
- 서울대학교
- 성균관대학교
- 연세대학교
- 이화여자대학교
- 전북대학교
- 포항가속기실험실(PAL)
- 한국과학기술원(KAIST)
- 한국고등과학원(KIAS)
- 한양대학교

International Organization

LC Board
Chair : Sachio Komamiya

LCC (LC Collaboration)

LC Collaboration Director
Lyn Evans

Deputy Director
Hitoshi Murayama

ILC accelerator
Mike Harrison

CLIC accelerator
Steinar Stapnes

ILC/CLIC Phys./Det.
Hitoshi Yamamoto

Lyn Evans

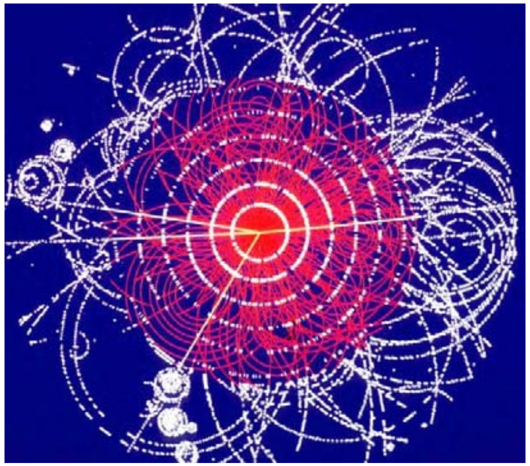
LHC versus ILC

- Cleanness experimentally and physically

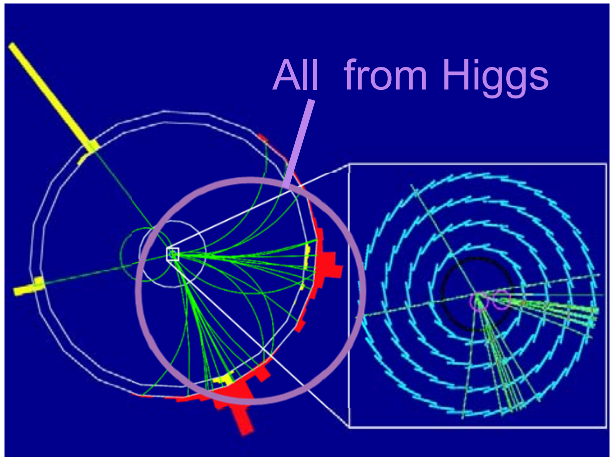
Trigger-less data taking

Less theoretical uncertainty

LHC



ILC



Strategy of Post-Higgs-like Particle

Energy flexibility

1st Stage : Higgs factory(Threshold ILC Higgs program) → 250 GeV

Baseline : Full ILC program → 500 GeV

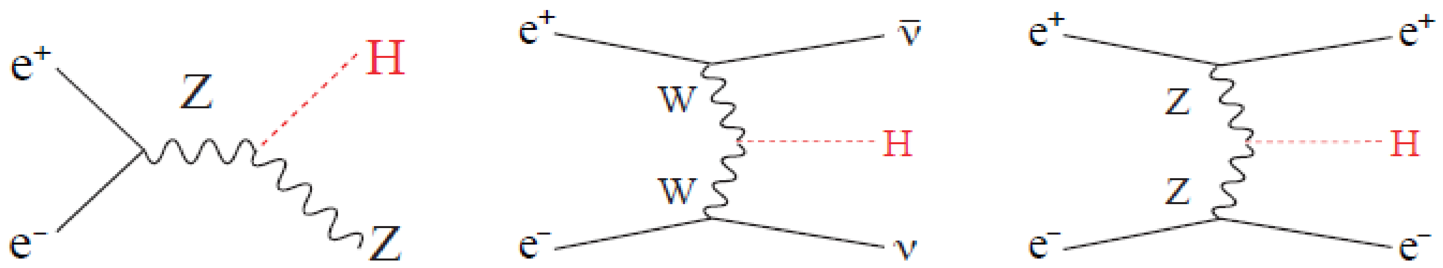
Expandability : Extension of ILC program → 1 TeV

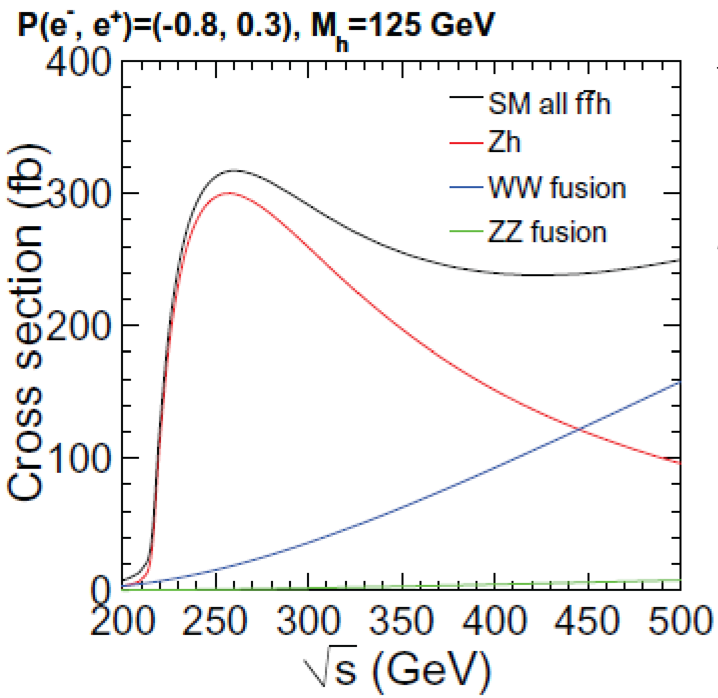
BUT,

Strongly depend on situation in particle physics at the time of ILC operation (new discoveries and measurements from LHC),
as well as the possibility of special running at the Z-pole

Higgs Physics at 250 GeV

- Leading diagrams for Higgs production processes



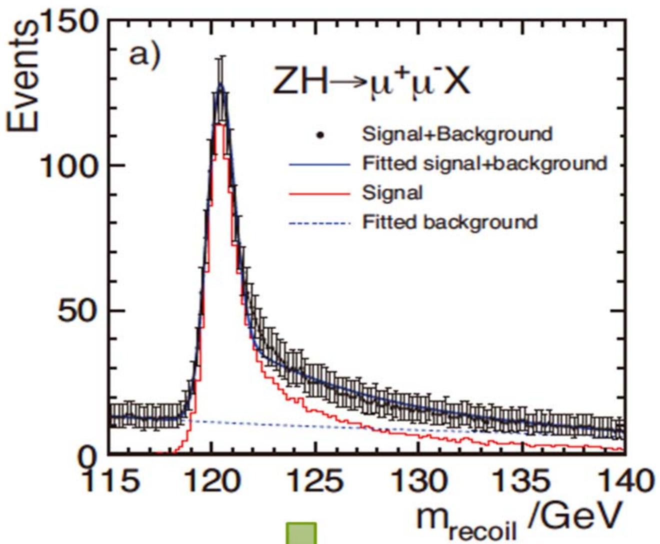


Very difficult to separate from SM backgrounds at LHC

Cross section at 250 GeV is about 300 fb.
Typical luminosity is about 10^{34} cm^{-2} s^{-1}.

Total Higgs per one year is about $3\text{x}10^4$.

Higgs measurement at 250 GeV



statistical precision is 40 MeV

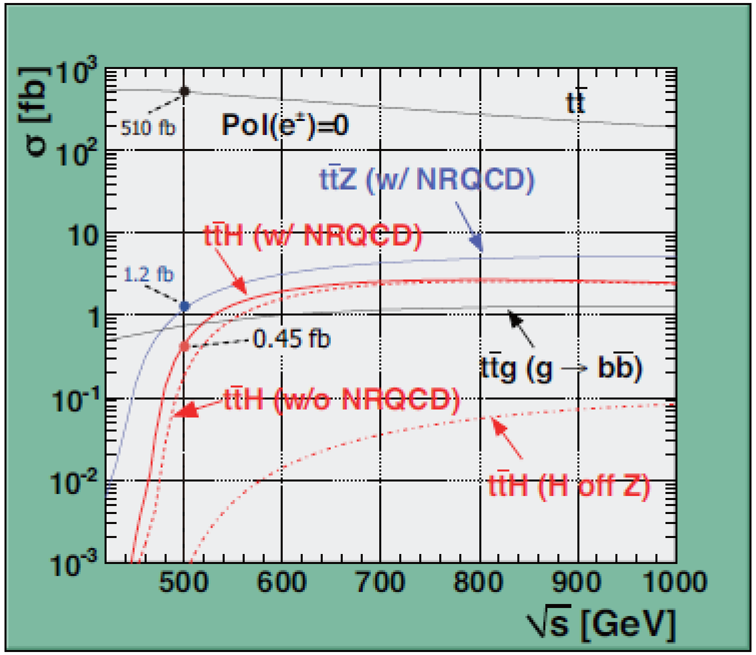
Defines momentum resolution requirement in tracking detector design :

$$\frac{\Delta p}{p^2} = 5 \times 10^{-5}\ (GeV/c)^{-1}$$

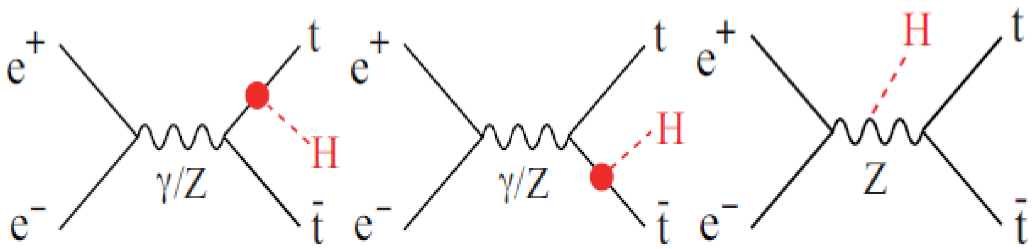
- Measurements of
- Higgs mass
- cross section
- BRs (including invisible) from the recoil mass
- Total Higgs width
- Higgs couplings
- Threshold scan provides the spin and CP properties

Channel	Measurement	Observable
ZH	Recoil mass distribution	m_H
ZH	$\sigma(HZ) \times BR(H \to \text{invisible})$	Γ_{inv}
ZH	$H \to b\bar{b}$ mass distribution	m_H
$H\nu_e\bar{\nu}_e$	$H \to b\bar{b}$ mass distribution	m_H
ZH	$\sigma(HZ) \times BR(Z \to \ell^+\ell^-)$	g^2_{HZZ}
ZH	$\sigma(HZ) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$
ZH	$\sigma(HZ) \times BR(H \to c\bar{c})$	$g^2_{HZZ} g^2_{Hcc}/\Gamma_H$
ZH	$\sigma(HZ) \times BR(H \to gg)$	
ZH	$\sigma(HZ) \times BR(H \to \tau^+\tau^-)$	$g^2_{HZZ} g^2_{H\tau\tau}/\Gamma_H$
ZH	$\sigma(HZ) \times BR(H \to WW^*)$	$g^2_{HZZ} g^2_{HWW}/\Gamma_H$
ZH	$\sigma(HZ) \times BR(H \to ZZ^*)$	$g^2_{HZZ} g^2_{HZZ}/\Gamma_H$

Physics at 500 GeV

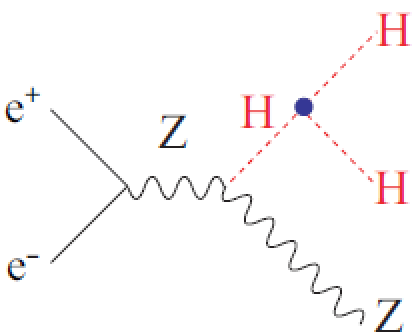


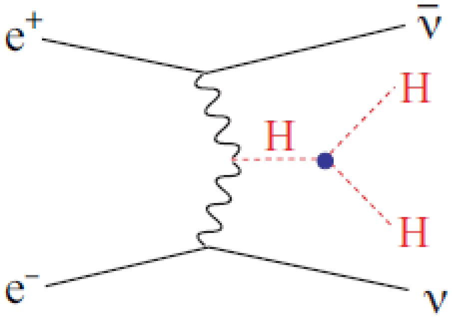
- Three diagrams contributing to $e^+e^- \rightarrow t\bar{t}h$

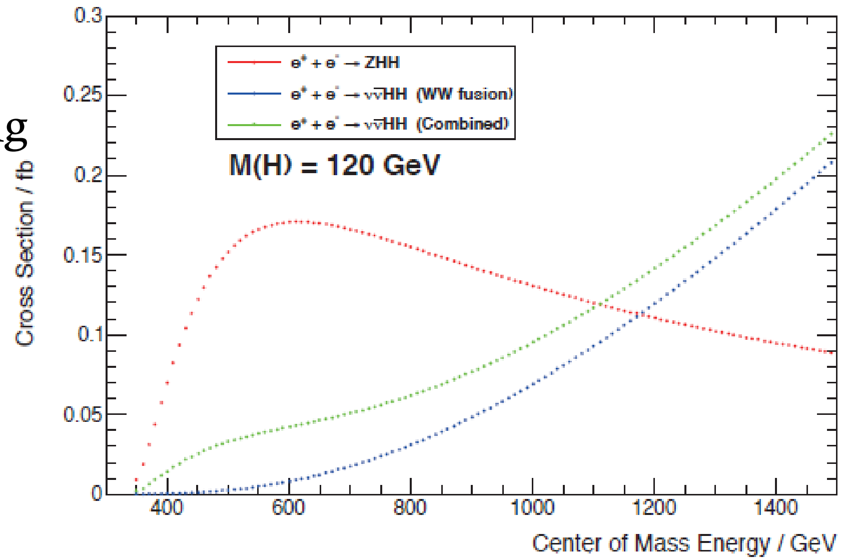


top Yukawa coupling
Higgs self-coupling

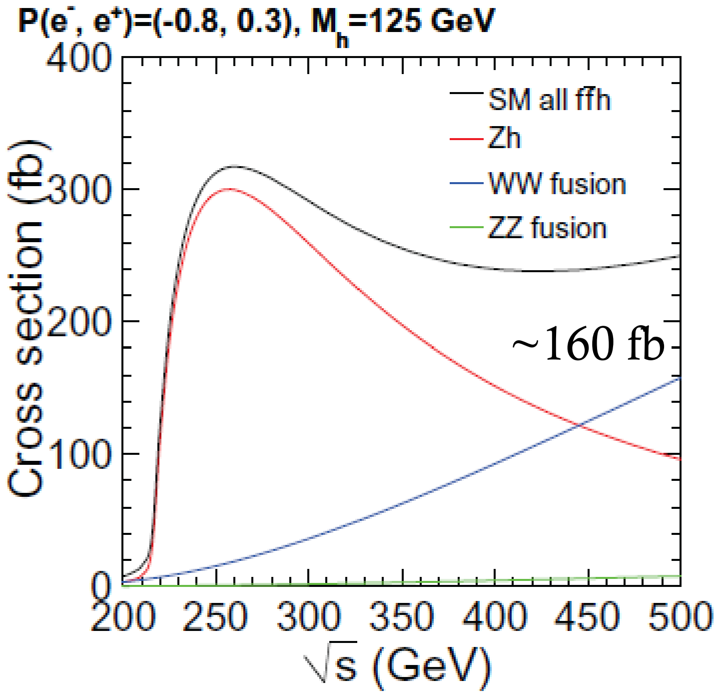
- Relevant diagrams containing triple Higgs coupling







Physics at 500 GeV

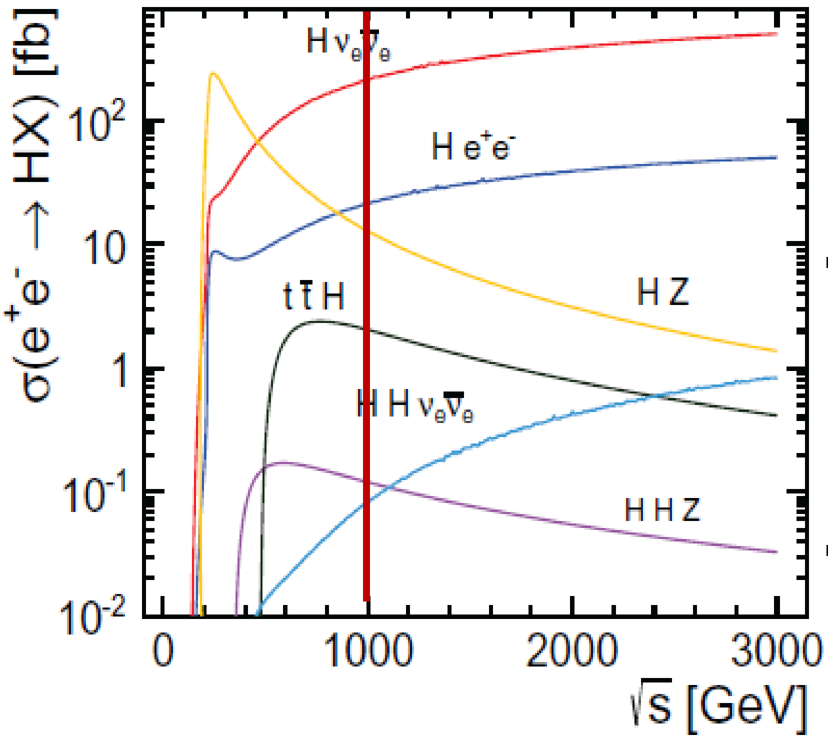


WW fusion process provides a unique opportunity to measure directly HWW coupling with high precision
(this process can be enhanced with beam polarization by 2.34)

Background separation is easier than 250 GeV

$$\sigma(H\nu_e\overline{\nu_e}) \times BR(H \to WW^*) \propto \frac{g^4_{HWW}}{\Gamma_H}$$

Physics at 1000 GeV



- top Yukawa coupling $e^+e^- \to t\bar{t}h$
  - slowly decreases toward 1000 GeV,
  - while e+e- → t tbar background decreases much more rapidly

- BRs to various modes including h→ mu+mu-
  - WW fusion process dominates (~ 400 fb)
  - muon Yukawa coupling
    → insight into physics of lepton mass generation

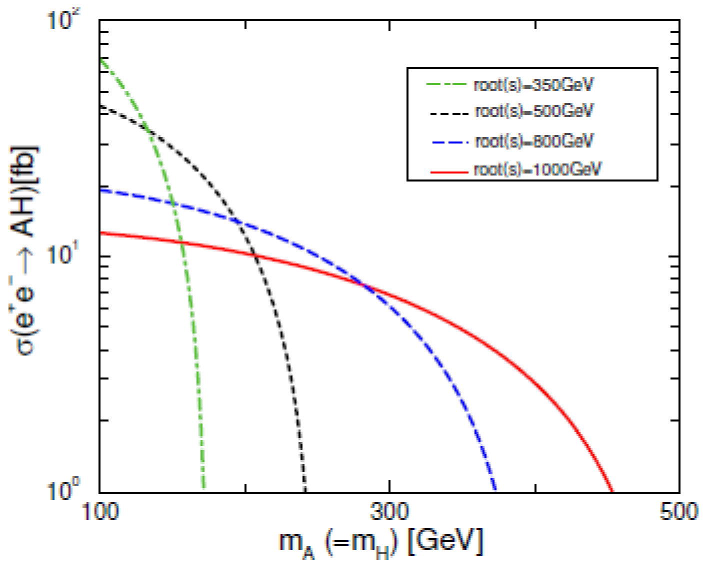
- $HH\nu\bar{\nu}$ becomes sizable
  - sensitivity to self-coupling is potentially higher since contribution from background diagrams is smaller

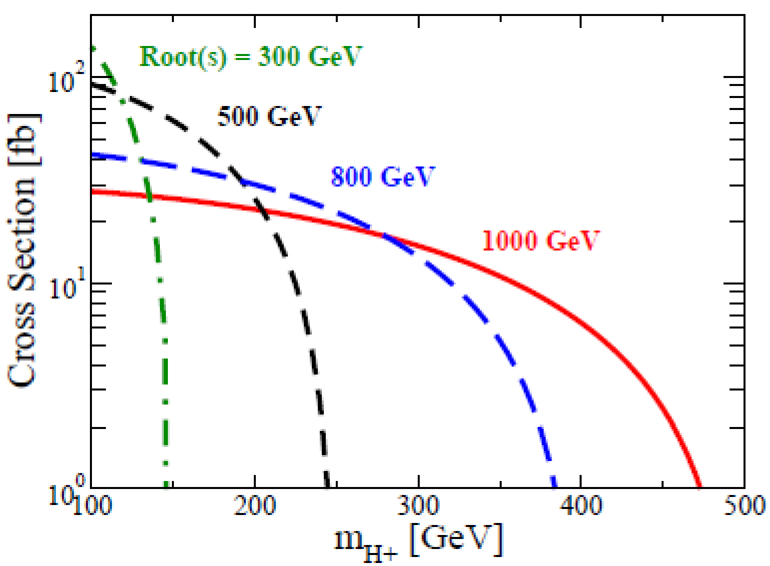
- and can be used for Higgs self-coupling with HHZ
  - strong test of the SM prediction

$$\frac{g_{HWW}}{g_{HZZ}} = \cos^2\theta_W$$

Extended Higgs Search

Extended Higgs boson production





- Precise measurements of the mass is very important in order to distinguish MSSM from other models

$$m_{H^\pm} = (m_A^2 + m_W^2)^{\frac{1}{2}} \quad \text{at leading order}$$

- Higgs pair production observation in various decay channels
  → measurement of BRs
  → determine type of Yukawa interactions
  → discriminate between models

Impact of Beam Polarization

SLC experience

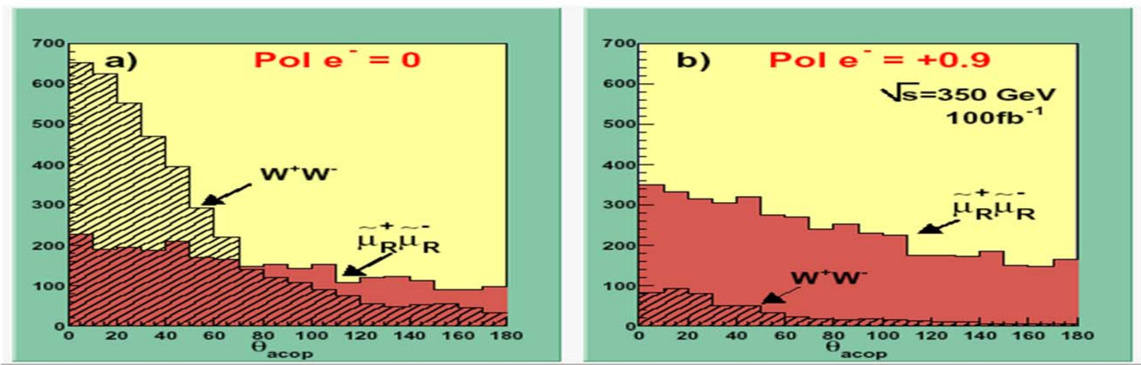
- Polarization
  - enhance event rate by $\frac{L}{L_0} = 1 - P_- P_+$
  - P_eff is enhanced by $P_{eff} = \frac{P_- - P_+}{1 - P_- P_+}$

Polarization	Enhancement factor	
$P(e^-) : P(e^+)$	$e^+e^- \to ZH$	$e^+e^- \to H\nu_e\bar{\nu}_e$
unpolarized	1.00	1.00
−80% : 0%	1.13	1.80
−80% : +30%	1.41	2.34

- at high energy, certain SM processes occur from $e_L^- e_R^+$

$$\rightarrow \frac{L}{L_0} = (1 - P_-)(1 + P_+)$$

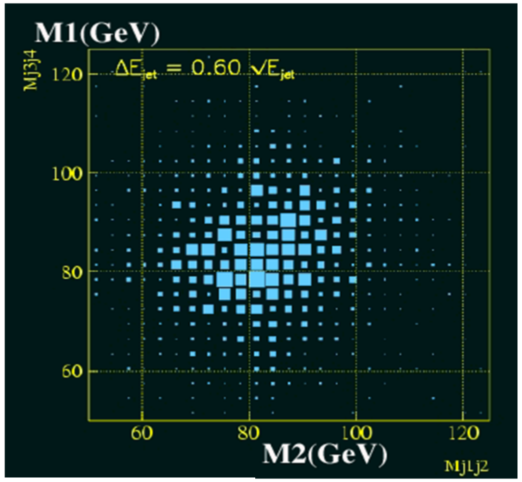
- suppression of WW production and WW fusion process



Jet Reconstruction

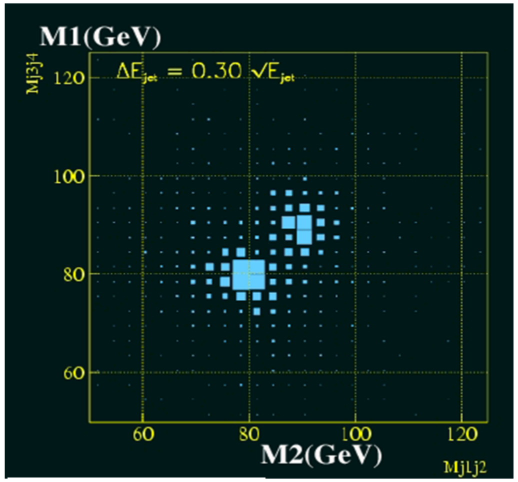
$$e^+e^- \rightarrow \nu\bar{\nu}WW, \nu\bar{\nu}ZZ \quad W/Z \rightarrow jj$$

Current



$$\frac{\sigma_E}{E} = \frac{0.6}{\sqrt{E}}$$

ILC



$$\frac{\sigma_E}{E} = \frac{0.3}{\sqrt{E}}$$

separate W and Z di-jet final states

- Precision of 3% for 100 GeV jets
- Event reconstruction techniques based on Particle Flow Algorithm for high-resolution jet energy reconstruction and di-jet mass performance.

Particle Flow Algorithm(PFA)

- Charged particles
  - use trackers
- Neutral particles
  - use calorimeters
- Remove double-counting of charged showers
  - requires high granularity

New detector technologies :
highly efficient tracking systems
highly granular EM and HAD calorimeters

+

New generation vertex detectors:
Flavour and quark-charge tagging

#ch	ECAL	HCAL
ILC (ILD)	100M	10M
LHC	76K(CMS)	10K(ATLAS)

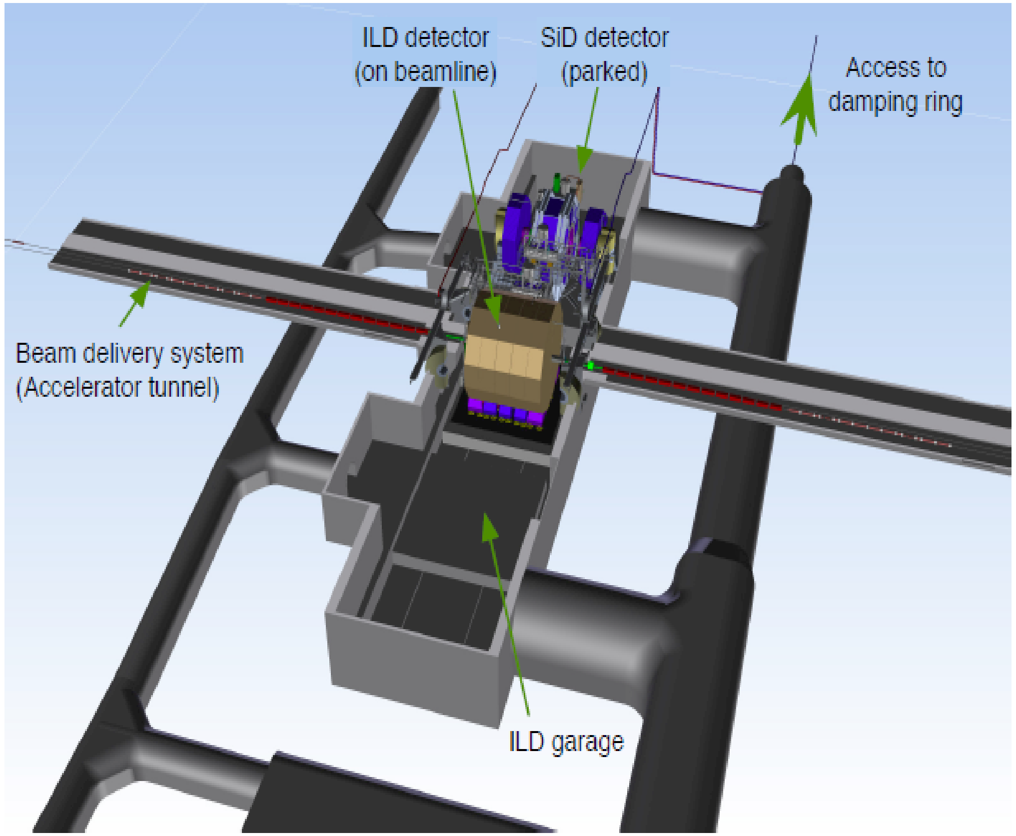
$X10^3$ for ILC
→ need new technologies !

Performance Requirements(Detector View)

- anti-DID for background charged particles out of the detector
- time stamping at single-bunch level to reduce overlapping events
- Luminosity, beam energy, polarization measurements are needed
- very low material(detectors+supports) budget for inner detectors
- very good hermeticity and minimized dead space
- reduction of heat load and need for cooling ("power pulsing")

Two Detectors Sharing One IP

"push-pull arrangement" : one taking data, the other is out of beam in a close-by maintenance position



- cross-checking and confirmation
- reliability
- insurance against mishaps
- complimentary strengths
- competition between collaborations
- increased number of involved scientific personnel

The time for transition must be on the order of one day to maximize integrated luminosity : ~ 100 moves over the life of experiment

Site Candidates from Japan

- Kyushu
  - Sefuri mountains
- Tohoku
  - Kitakami mountains

Strong and stable granite bedrocks

One of them will be chosen based on
- Geology and technical aspects
- Infrastructure and economic ripple effects

and

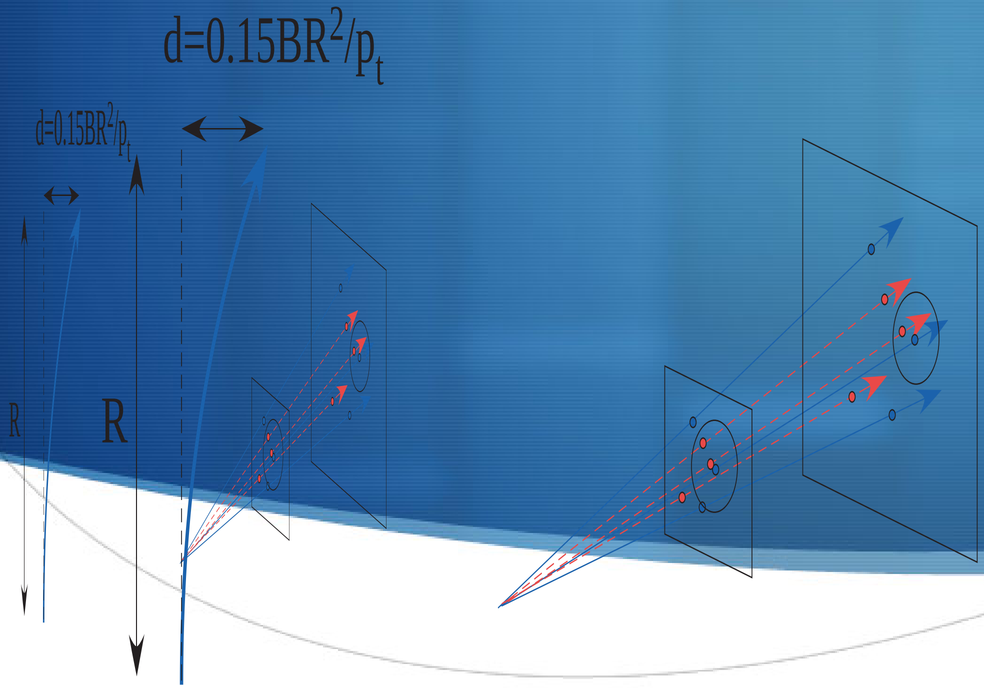
It should take few years to evaluate whether Japan host

General Considerations

- Calorimeters inside solenoid
  - For good jet reconstruction
- Low mass for tracking&vertexing
  - Thinned silicon sensors
    - e.g. ~50 μm for pixel vertex detectors
  - Light support structures
    - e.g. advanced endplate for TPC
- High granularity esp. for calorimeters&vertexing
  - Fine-granularity calorimeter readout
    - Silicon pad, SiPM, RPC, GEM etc.
  - State-of-the-art pixel technologies for vertexing
    - CMOS, FPCCD, DEPFET, SOI, 3D…
  - Front-end electronics embedded in/near the active area (cabling!)

Basic Concepts

- **Jet energy resolution is the key in the ILC physics**
- Separation of particles to get good jet energy resolution
  - **Fine segmentation of calorimeter** → resolve particles (intrinsic limit from Moliere radius)
  - **Large radius of calorimeter** → spatially separate particles by large detector
  - High B field → separate charged/neutrals



Often quoted "**Figure of Merit**":

$$\frac{BR^2}{\sqrt{\sigma^2 + R_M{}^2}}$$

σ : CAL granularity

R_M: Effective Moliere radius

Strategy of Design for multi-purpose detector

- SiD (compact and cost-constrained)
  - high B field (5 tesla)
  - small ECAL ID
  - small calorimeter volume
    finer ECAL granularity
  - silicon main tracker

- ILD (large)
  - medium B field (3.5 tesla)
  - large ECAL ID
    particle separation for PFA
  - redundancy in tracking
  - TPC for main tracker

Two detectors provide flexibility for operation at energies up to the TeV range

Silicon Detector (SiD)

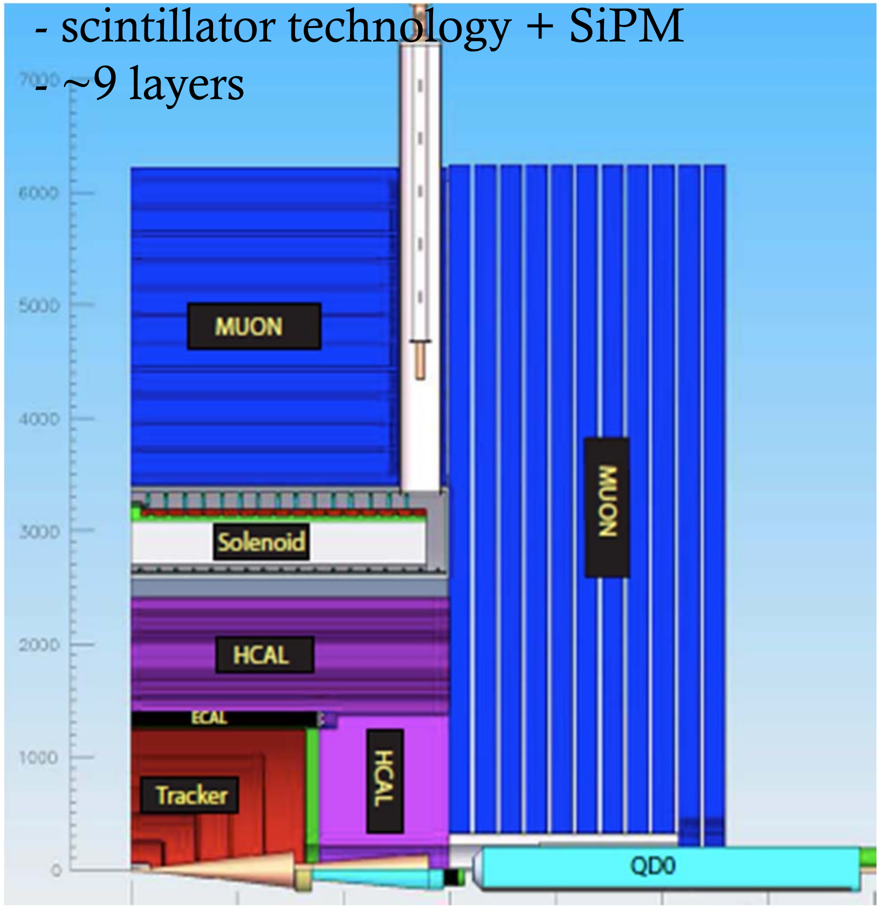
- Vertex pixel detector
  - 5 barrels (pixel~ 20x20 μm^2)
  - [4 disks+ (3 disks at a larger distance)]/side
  - Technology open (3D)

- Si-strip-trackers
  - AC-SSSD (50 μm pitch)
  - 5 barrels (outer cylinder radius is 1.25 m)
  - 4 disks/side

- ECAL (26 X_0)
  - Si-W 30 layers, pixel ~3.5x3.5mm^2
  - first 20 layers has a thinner absorber

- HCAL (4.5 nuclear interaction lengths)
  - digital HCAL with RPC or GEM with individual readout (10x10 mm)^2
  - 40 layers

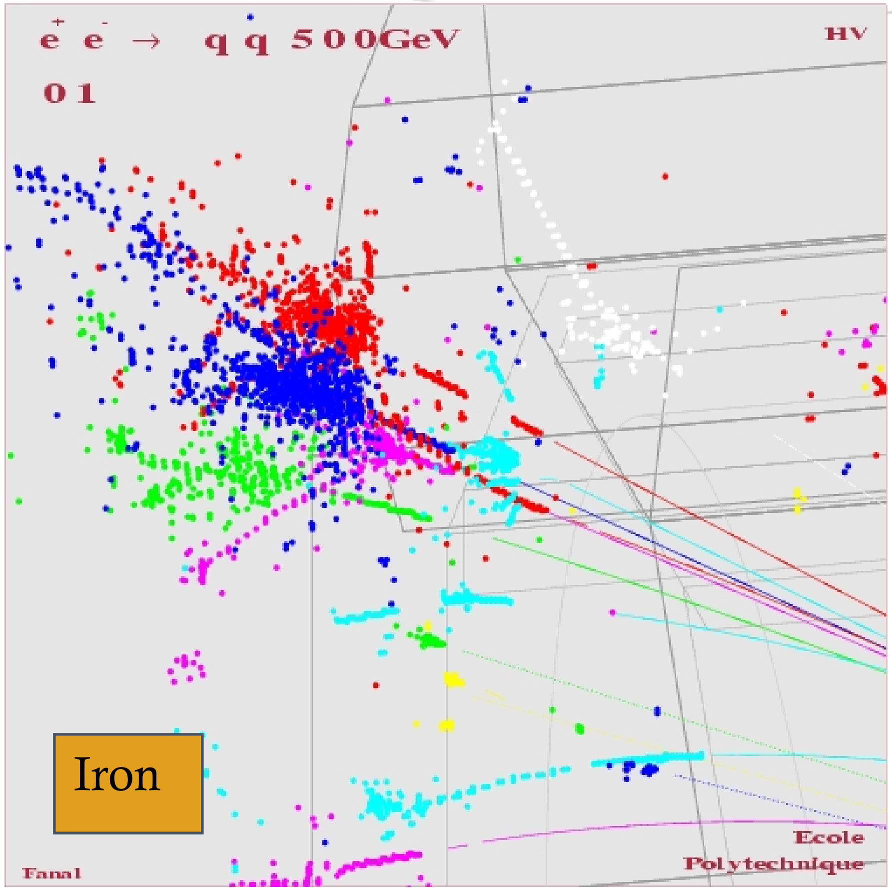
- Muon System
  - scintillator technology + SiPM
  - ~9 layers

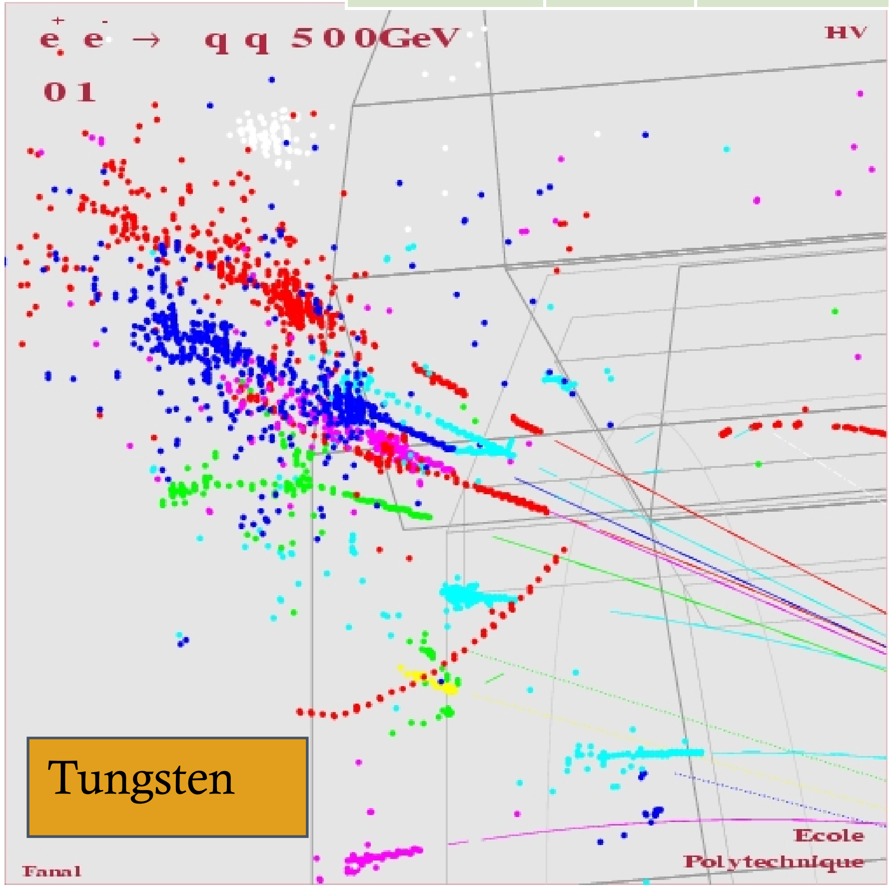


- Luminosity
  - LumiCal for precise measurement
  - BeamCal for fast estimation

Moliere radius (Iron vs. Tungsten)

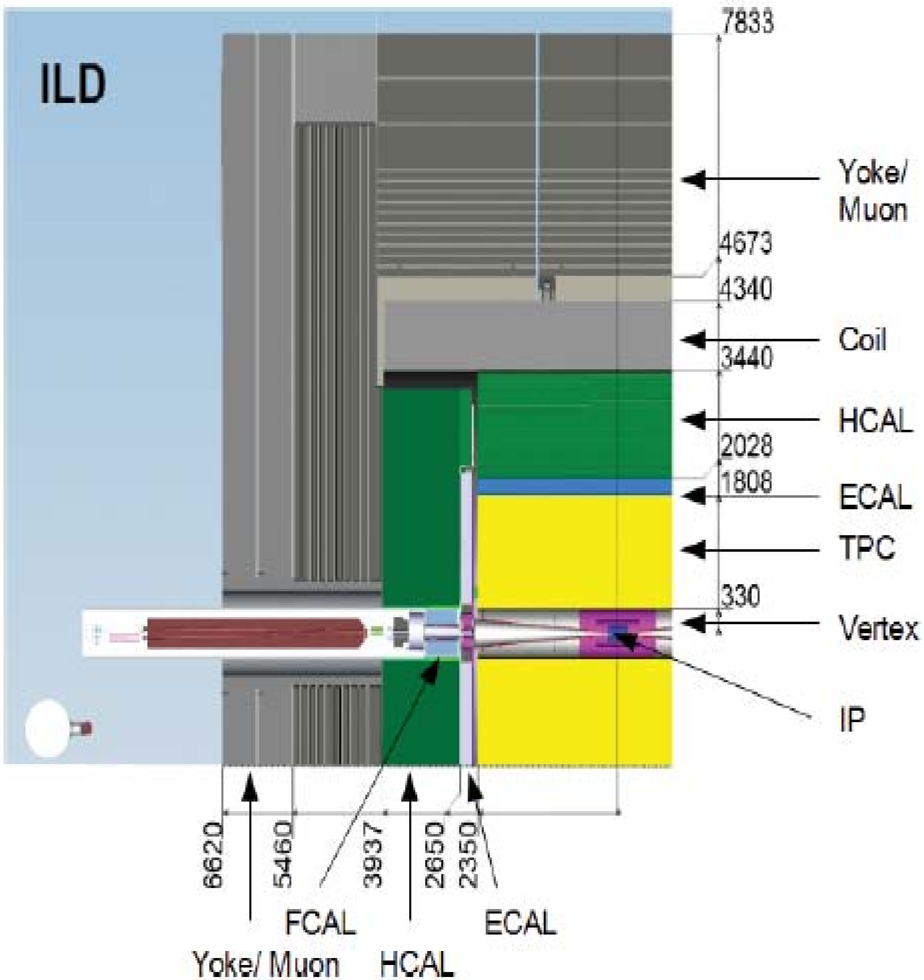
	iron	tungsten
Z	26	74
X_0 (g/cm^2)	13.84	6.76
density	7.874	19.3
X_0 (cm)	1.76	0.35
R_M (mm)	13	7



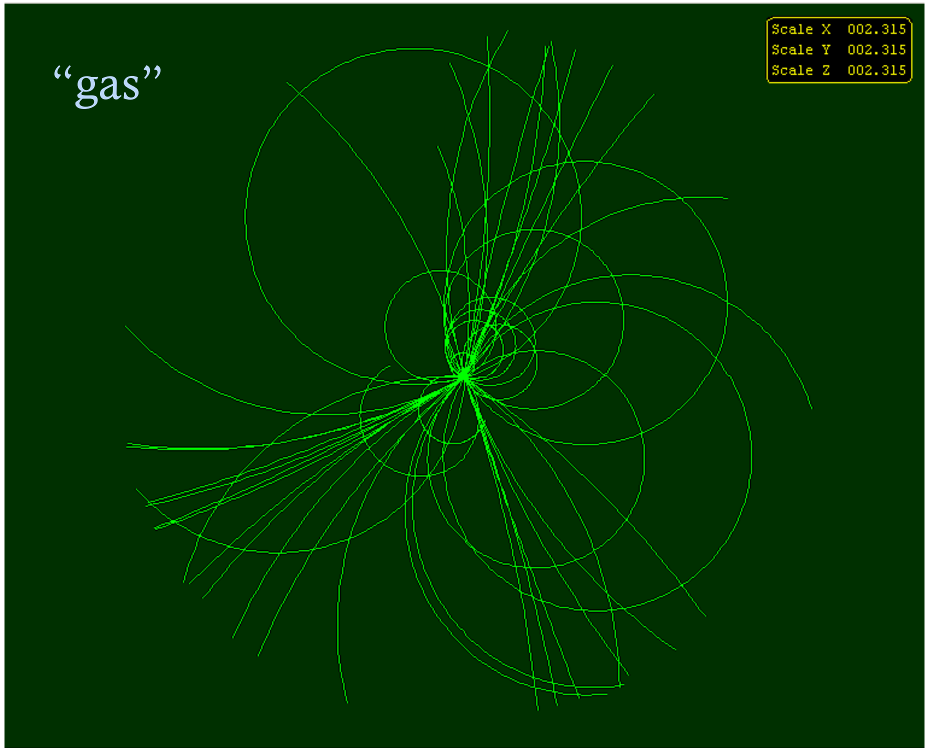


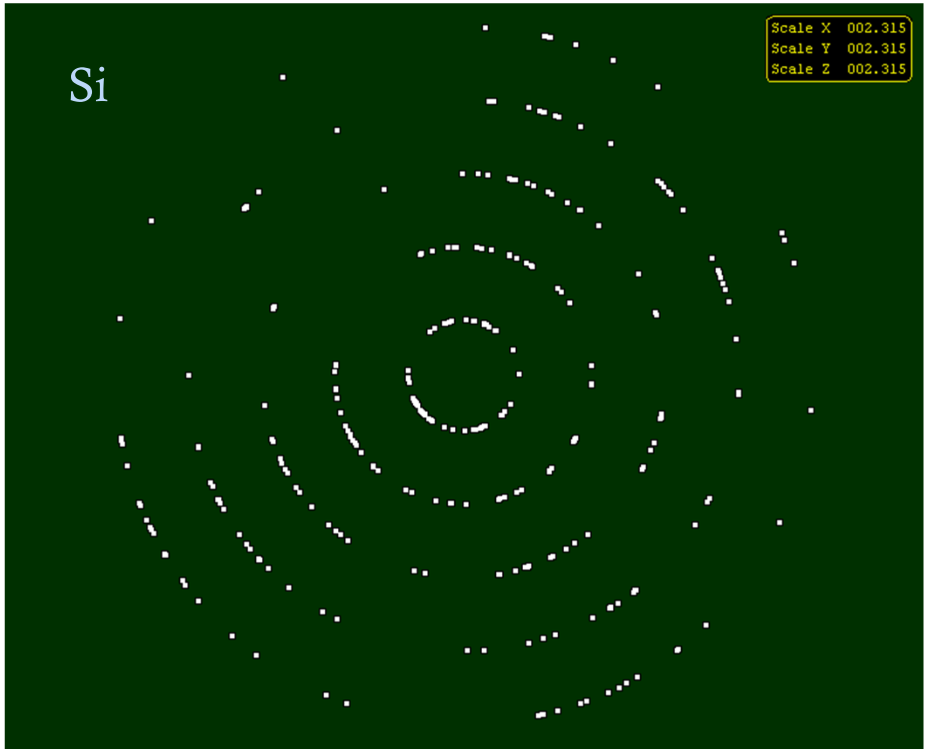
ILC Large Detector (ILD)

- Vertex pixel detector
  - 6 (3 pairs) or 5 barrels
  - Technology open
- Si-strip-trackers
  - 2 barrels between VTX and TPC
  - (2 pixel disks + 5 strip disks)/side
  - 1 barrel between TPC and ECAL
  - one behind end-plate of TPC
- Time Projection Chamber
  - up to 224 points/track
  - dE/dx-based particle identification
  - GEM or MicroMEGAS for amplification
- ECAL
  - Si-W or Scint-W (or hybrid)
- HCAL (4.5 nuclear interaction lengths)
  - Scint-tile (3x3 cm^2)or Digital (1x2 cm^2) HCAL



Pattern Recognition





Summary

- Major Physics Processes

Energy flexibility

Energy	Reaction	Physics Goal	Polarization
91 GeV	$e^+e^- \to Z$	ultra-precision electroweak	A
160 GeV	$e^+e^- \to WW$	ultra-precision W mass	H
250 GeV	$e^+e^- \to Zh$	precision Higgs couplings	H
350–400 GeV	$e^+e^- \to t\bar{t}$	top quark mass and couplings	A
	$e^+e^- \to WW$	precision W couplings	H
	$e^+e^- \to \nu\bar{\nu}h$	precision Higgs couplings	L
500 GeV	$e^+e^- \to f\bar{f}$	precision search for Z'	A
	$e^+e^- \to t\bar{t}h$	Higgs coupling to top	H
	$e^+e^- \to Zhh$	Higgs self-coupling	H
	$e^+e^- \to \tilde{\chi}\tilde{\chi}$	search for supersymmetry	B
	$e^+e^- \to AH, H^+H^-$	search for extended Higgs states	B
700–1000 GeV	$e^+e^- \to \nu\bar{\nu}hh$	Higgs self-coupling	L
	$e^+e^- \to \nu\bar{\nu}VV$	composite Higgs sector	L
	$e^+e^- \to \nu\bar{\nu}t\bar{t}$	composite Higgs and top	L
	$e^+e^- \to \tilde{t}\tilde{t}^*$	search for supersymmetry	B

A : crucial in Z resonance, EW couplings of t-quark, e+e- → ff precision measurements
H : opposite polarization enhances luminosity
L : processes occur dominantly from $e_L^- e_R^+$
B : by using $e_R^- e_L^+$, suppress the SM backgrounds

Backup Slides