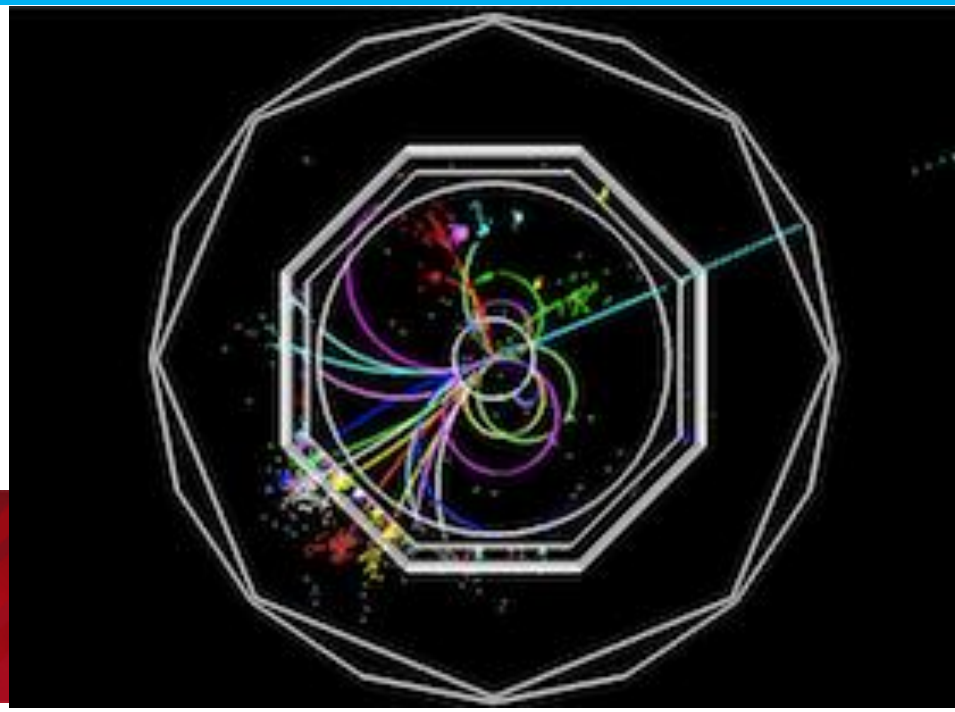
The View from Japan

after the discovery of a Higgs Boson

10 March 2013
IOP 2013
University of Liverpool



Department of Physics, School of Science, and
International Center for Elementary Particle Physics,
The University of Tokyo
Chair: High Energy Physics Committee of Japan Sachio Komamiya

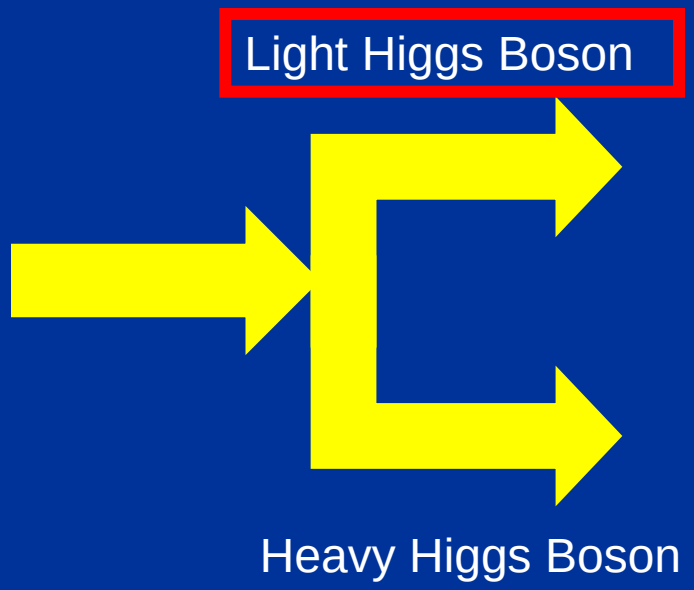
Until 4th July 2012, for more than 20 years, we keep agitating that a Revolution in the field of particle physics is inevitable.

⇒ Discovery of a Higgs Boson = The July Revolution has started

⇒ This is just a start of an enormous revolutionary era overwhelming the Standard Model = the Ancien Regime.

Higgs Boson mass is responsible for a big branching in the particle physics history

~125 GeV Higgs Boson is categorized as a light Higgs Boson



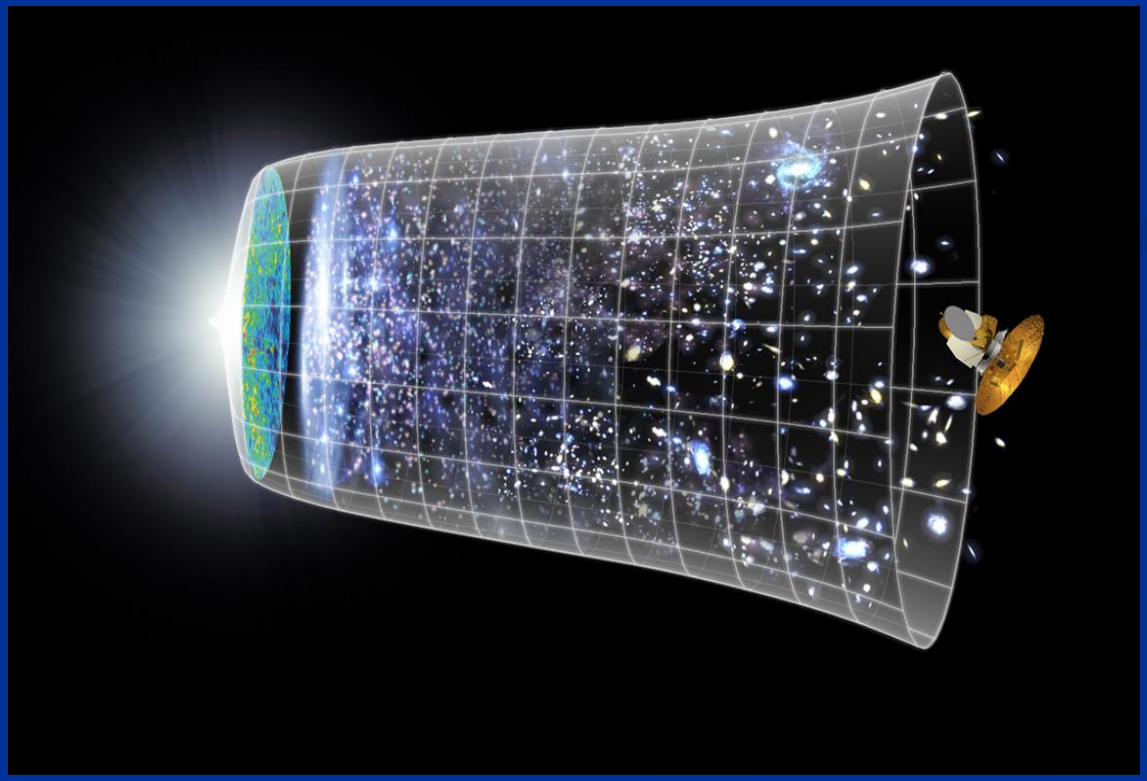
Elementary Higgs Boson
Supersymmetry ?
Stabilization of Higgs mass

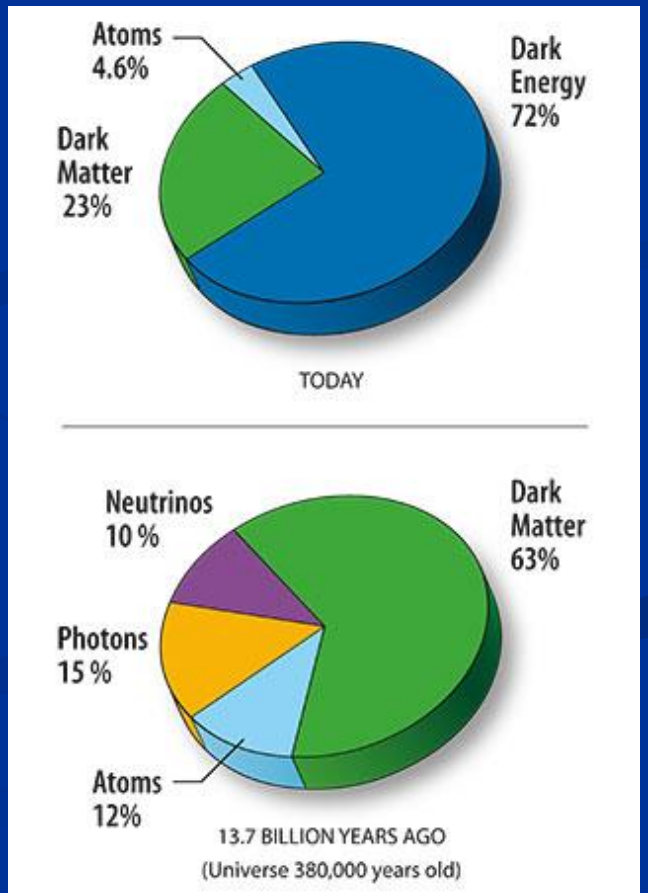
Composite Higgs Boson
Technicolor etc. ???
(Fermion Monism ?????)

Higgs Boson is a window beyond the Standard Model

From Higgs to the Universe

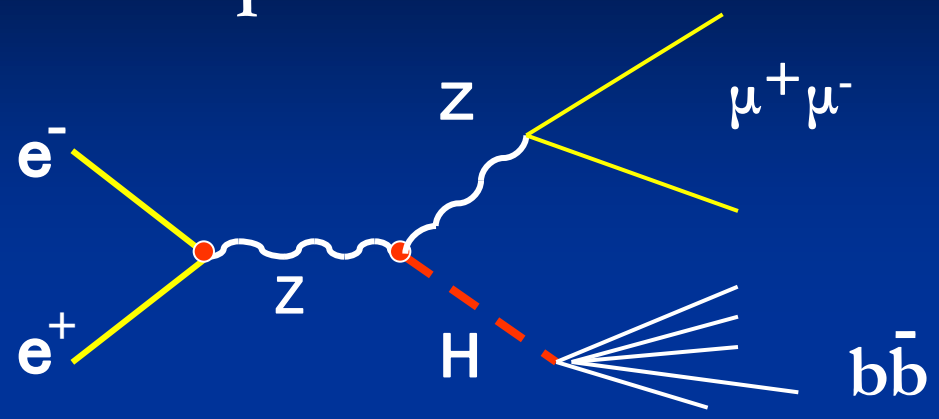
Investigation of Higgs boson (scalar particle has the same quantum numbers as for the vacuum) can be the zeroth step to understand inflation of the universe and dark energy.





pp-collision vs e^+e^- collision

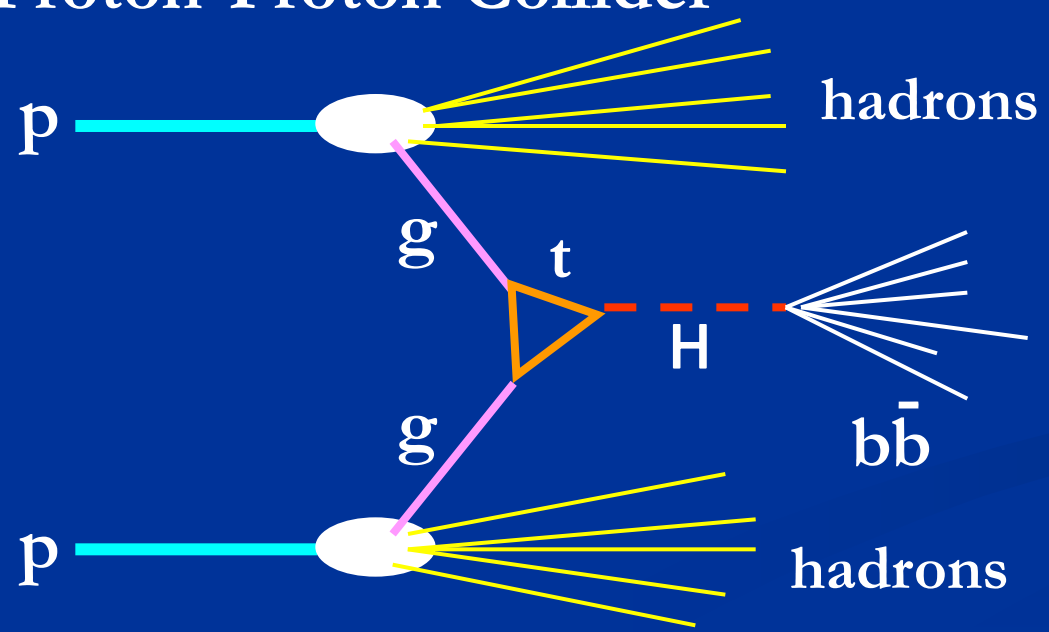
Electron-positron collider



Ex. Higgs Boson

Electron and positrons are pont-like elementary particles ⇒ Clean environment. Processes are simple.
Prediction: O(0.1-1%)
State-of-the-are detector can be build

Proton-Proton Collider

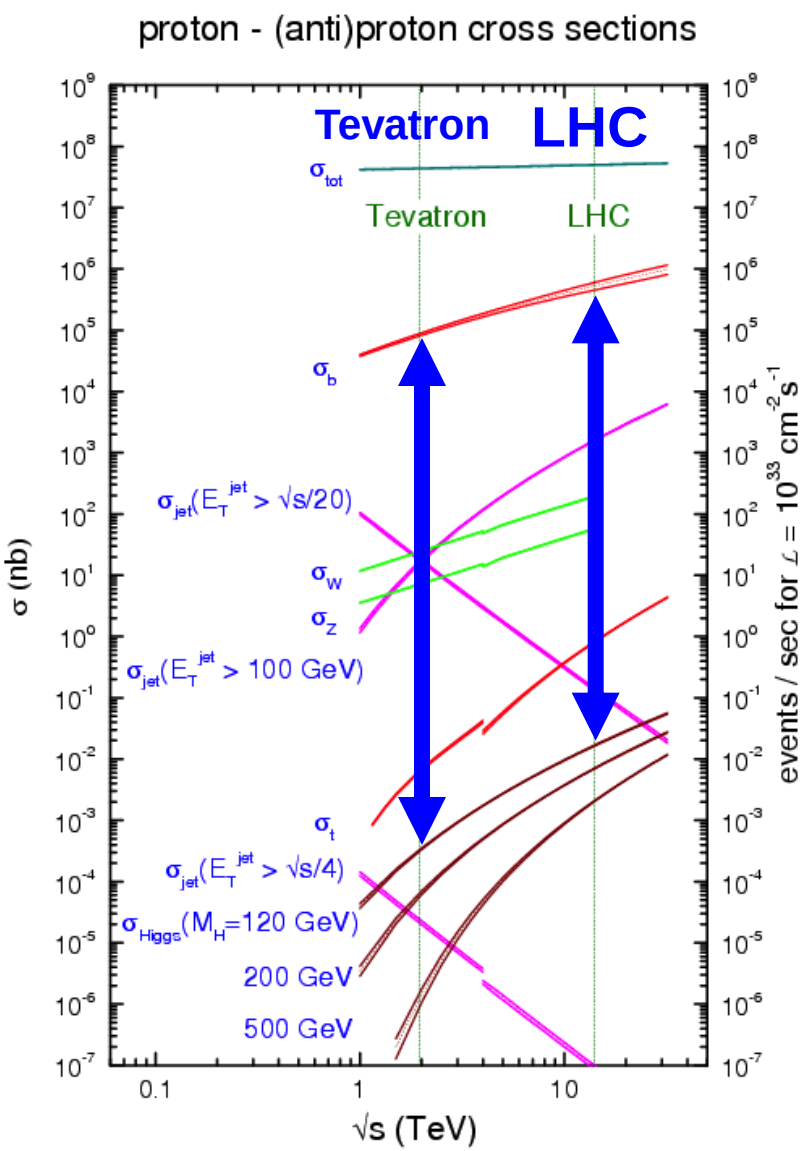


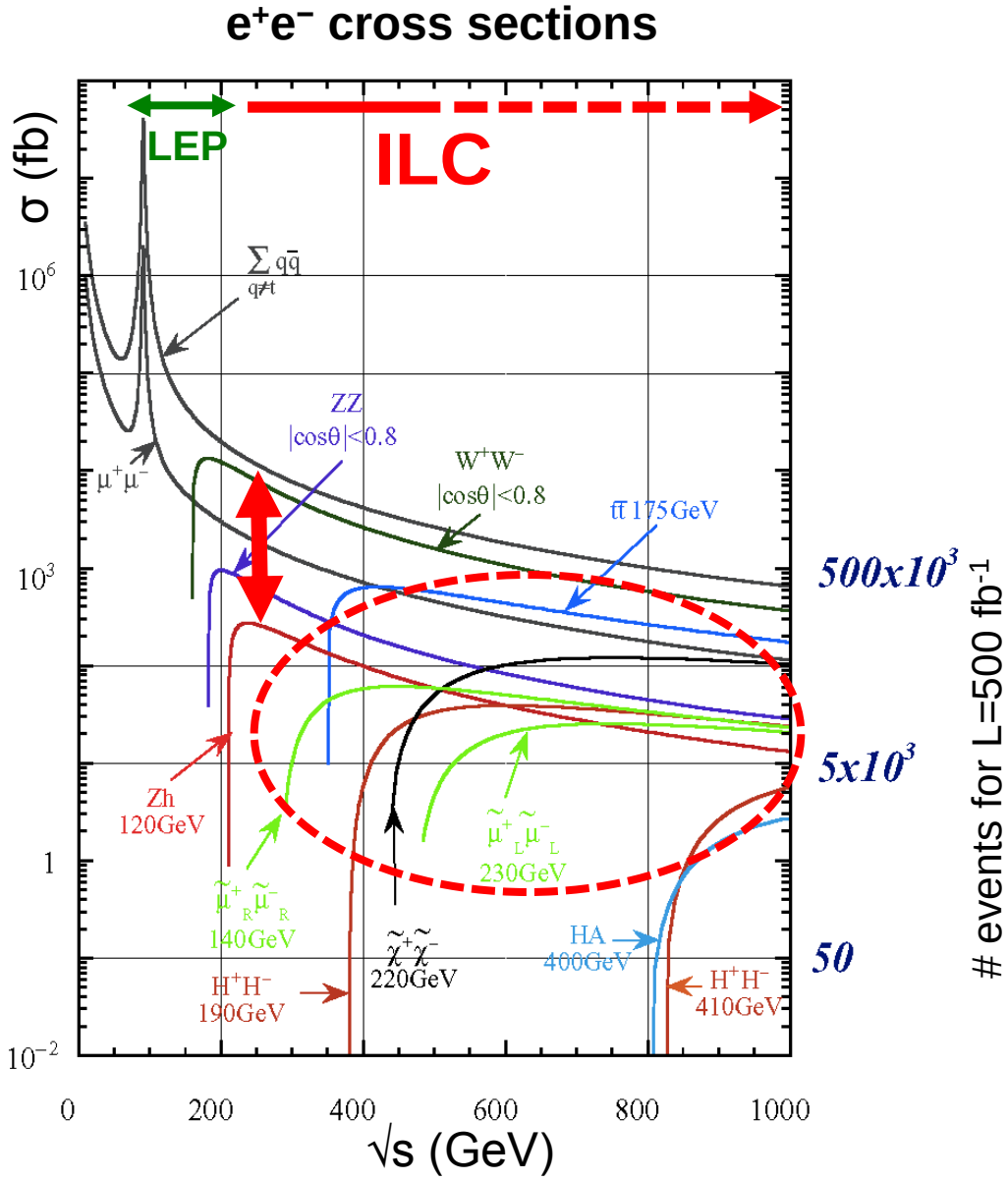
Proton is a composite particle
⇒ processes are omplicated
NNLO O(10%)

High radiation
High event rate

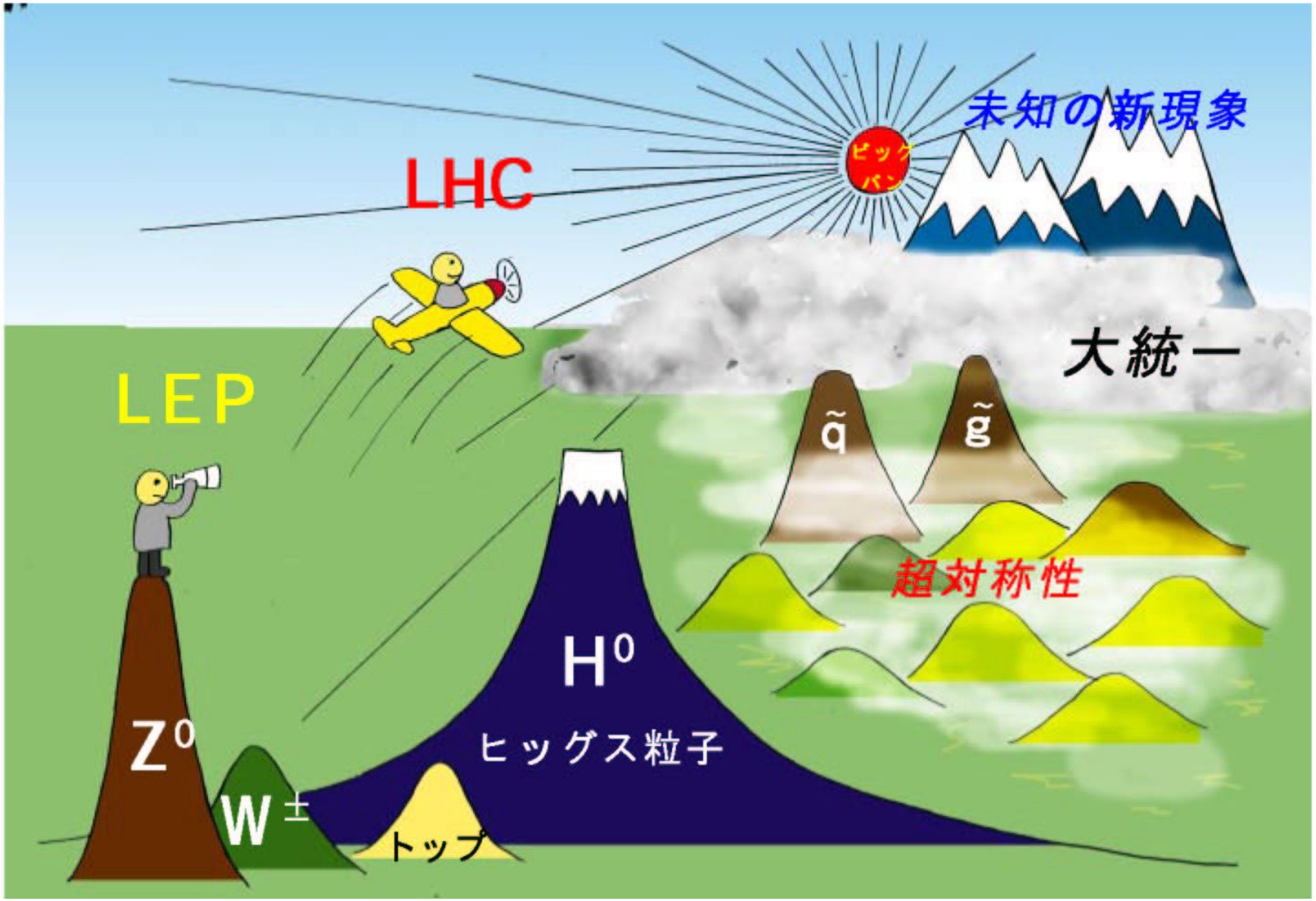
⇒ need a high-tech detector and powerful computing system

Cross Sections



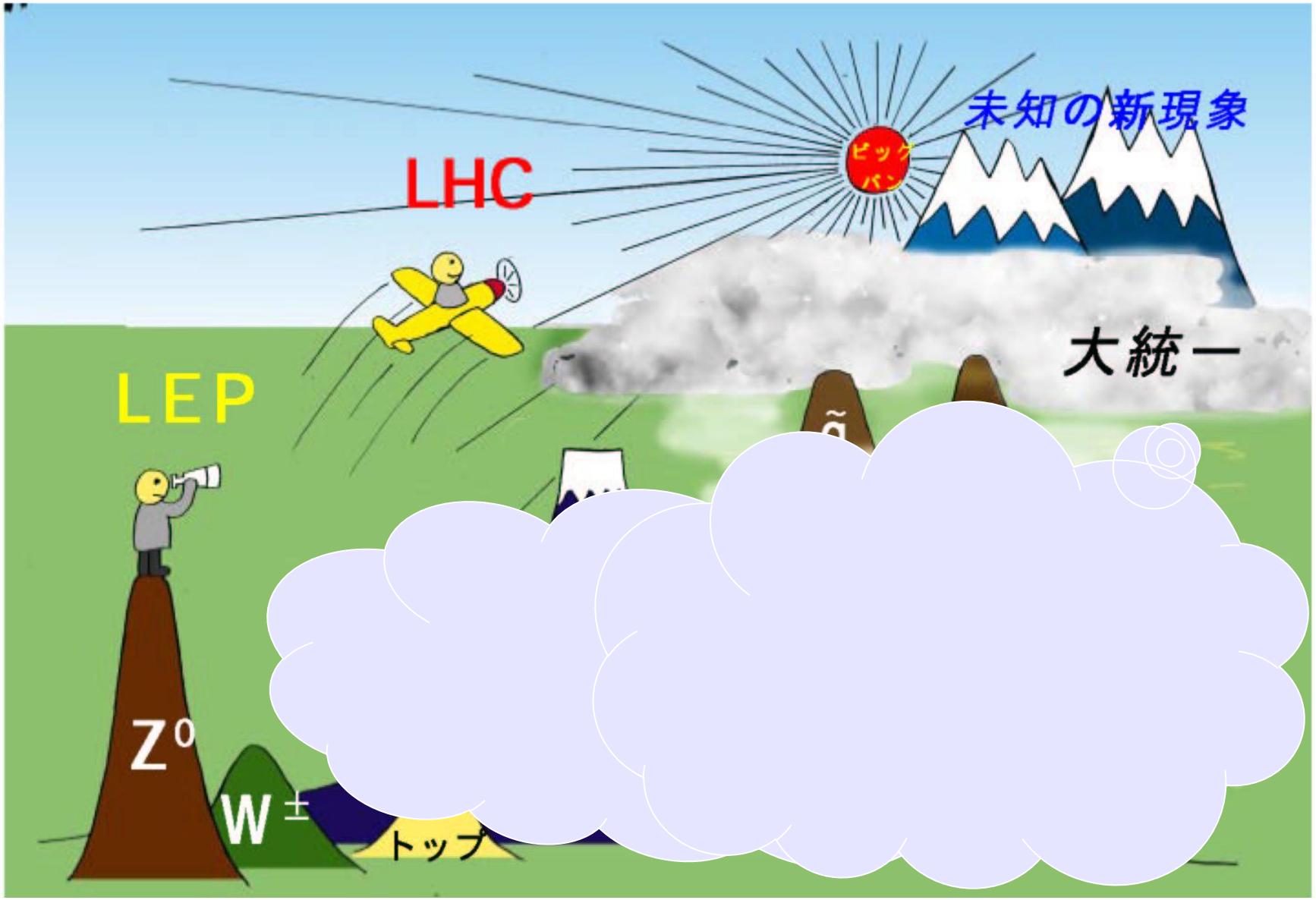


Propaganda plot of LHC for MEXT



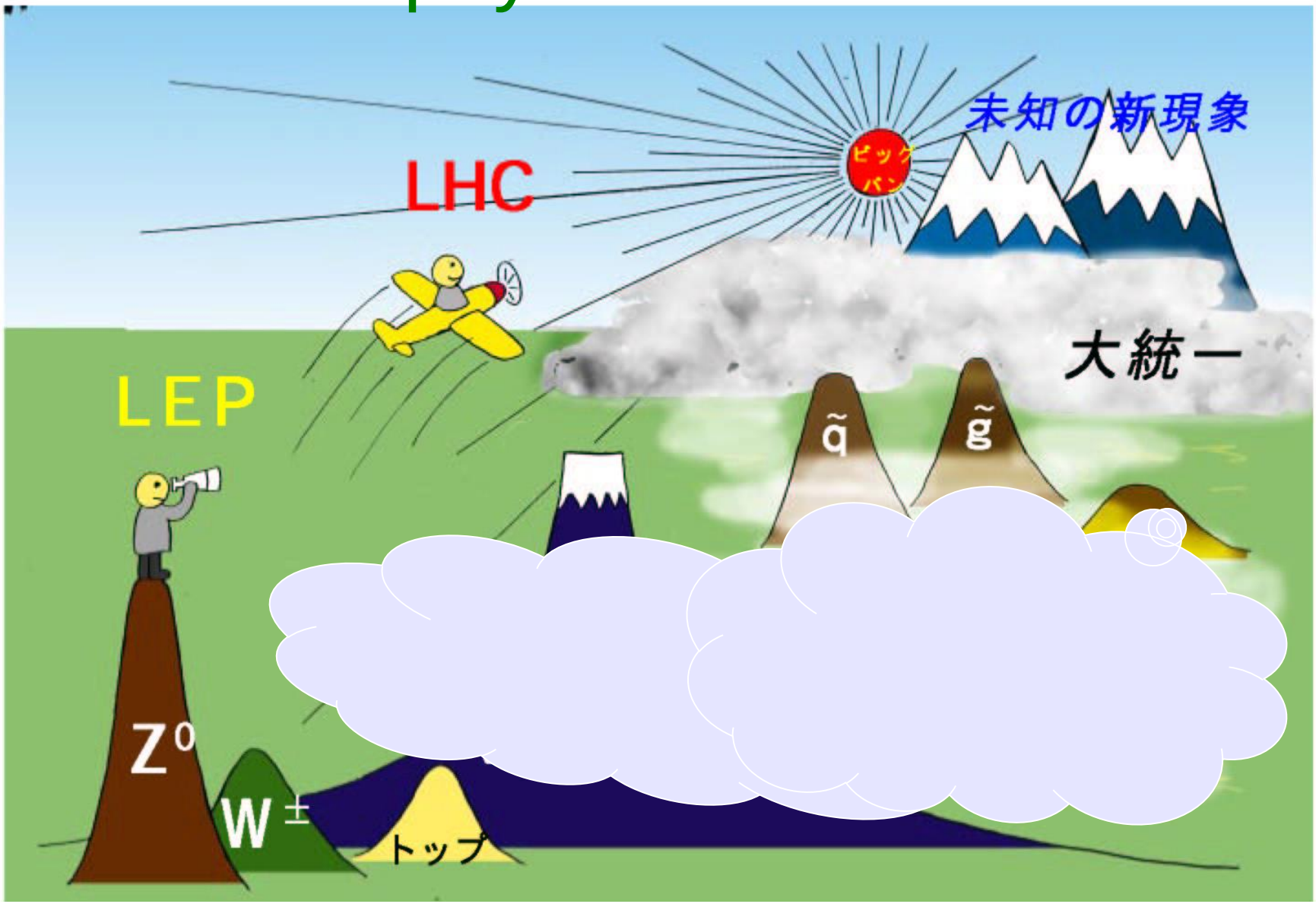
LHC overlooks new phenomena including Higgs Boson and SUSY

Actual situation would be ……..



LHC overlooks new phenomena including Higgs Boson and SUSY

Since LHC physicists are excellent



LHC overlooks new phenomena including Higgs Boson and SUSY

Story of Top Quark and Higgs Boson

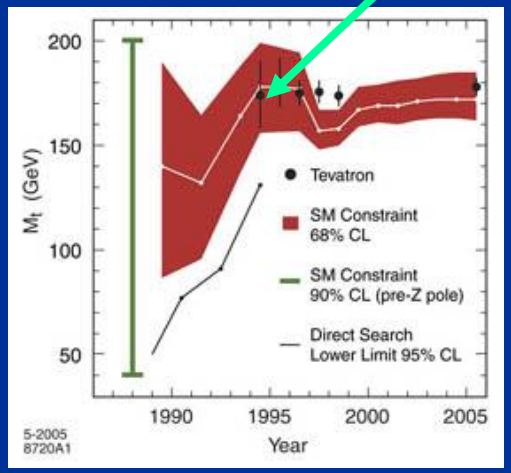
Importance of interplay between hadron and e^+e^- colliders

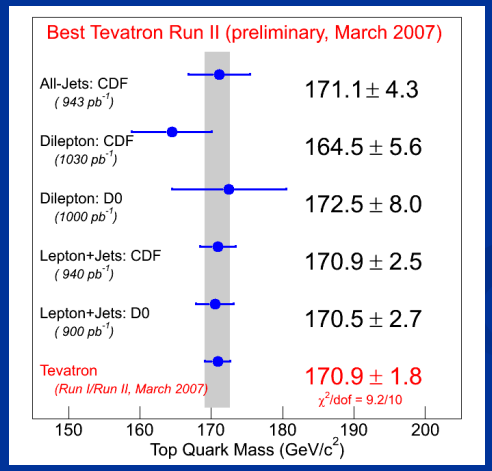
From precise electro-weak measurements at LEP, top mass was predicted

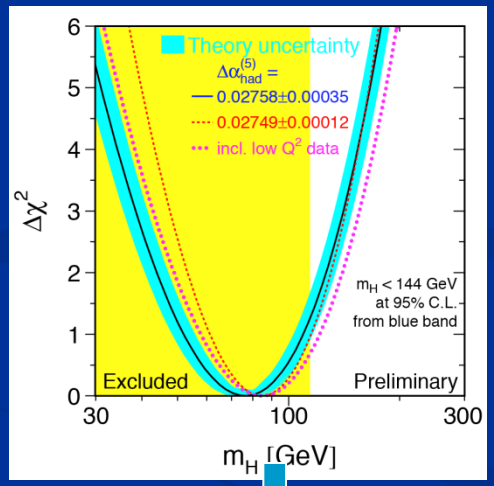
Discovery to Top

Precise Measurement of Top mass at the TEVATRON

Higgs mass is restricted into a narrow mass range using precise top mass and LEP/SLC electro-weak data
114 GeV $< M_H \lesssim 160$ GeV





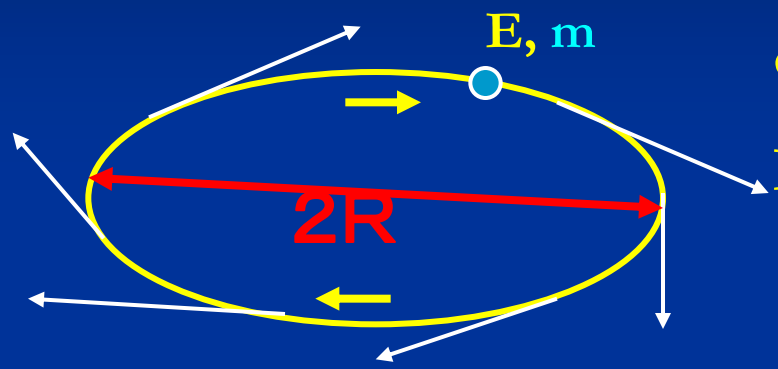


Discovery of "Higgs" at LHC

Precise measurements of Higgs properties at **ILC**

Limit of High Energy Circular e+e- Colliders

Reaction is simple, experiment is clean but…



Electron and positrons loose energy due to synchrotron radiation

Energy loss per trun ΔE is given by

$$\Delta E \propto (E/m)^4/R$$

E：particle energy
m：particle mass R：radius

Like a bankruptcy by loan interest

Recover the energy loss and obtain higher collision energy

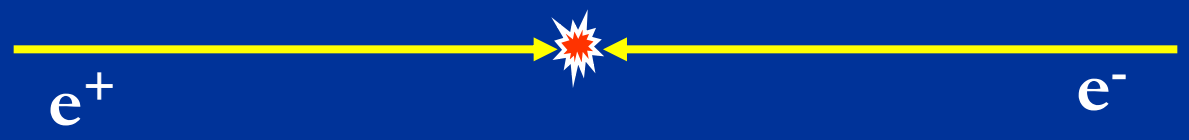
（1）Use heavier particle (proton mass/electron mass＝1800）⇒ LHC

（2）Larger radius ⇒ LEP（27km） ⇒ large radius

Electron Positron Linear Collider is inevitable

Large radius R ⇒ Ultimate radius R=∞ !

Straight beam line ⇒ No synchrotron radiation
（Linear Collider）

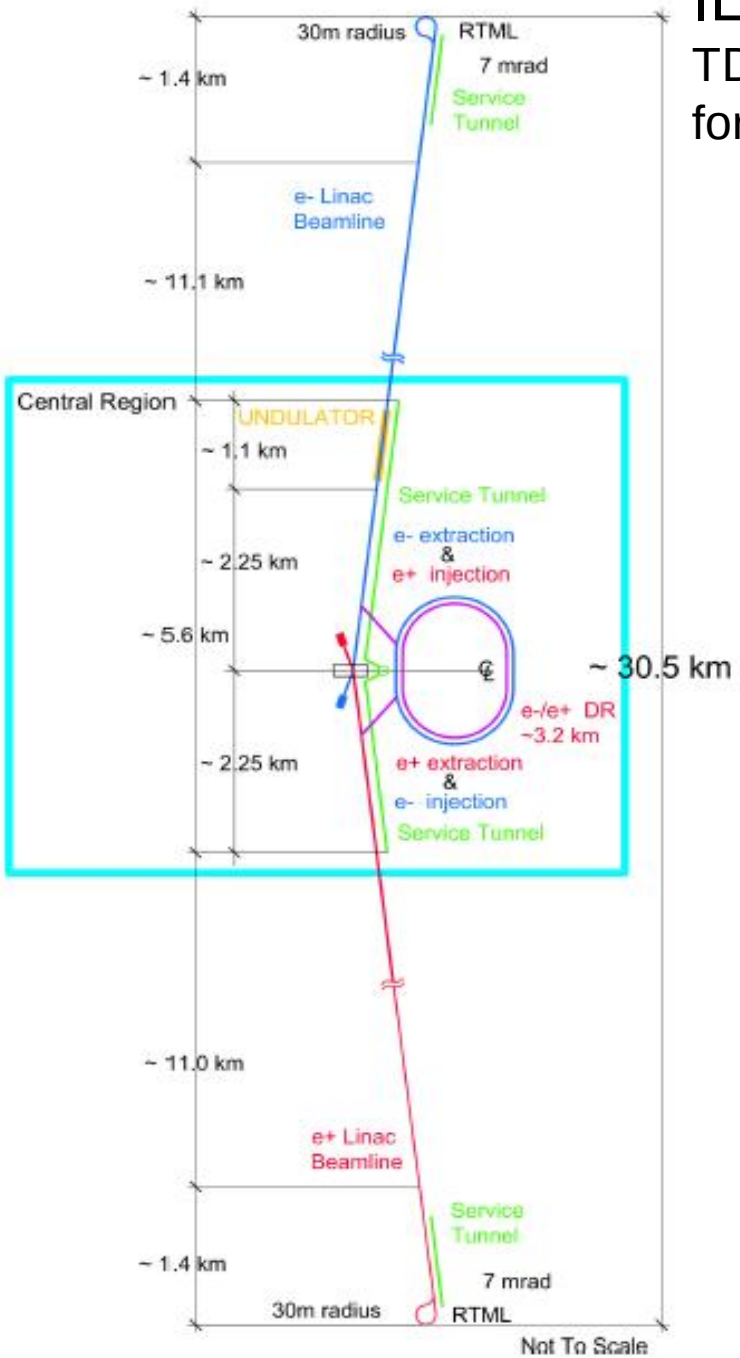


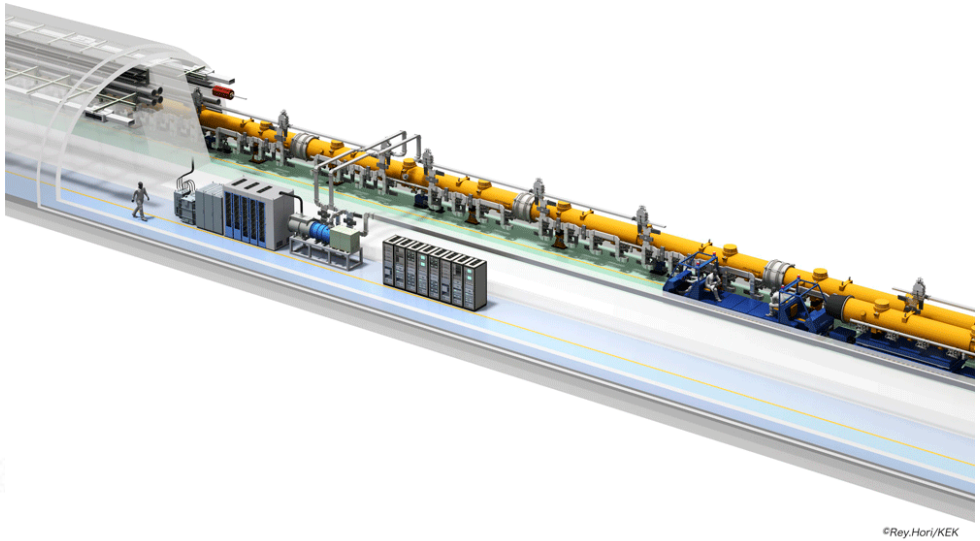
Electrons are accelerated from one side positon from the other side. Collide the beams at the center

Reduce construction cost ⇒ High acceleration gradient
Reduce running cost (electric power) ⇒ Squeeze the beam size as small as possible at the interaction point ⇒ round beam is unstable ⇒ very flat beam

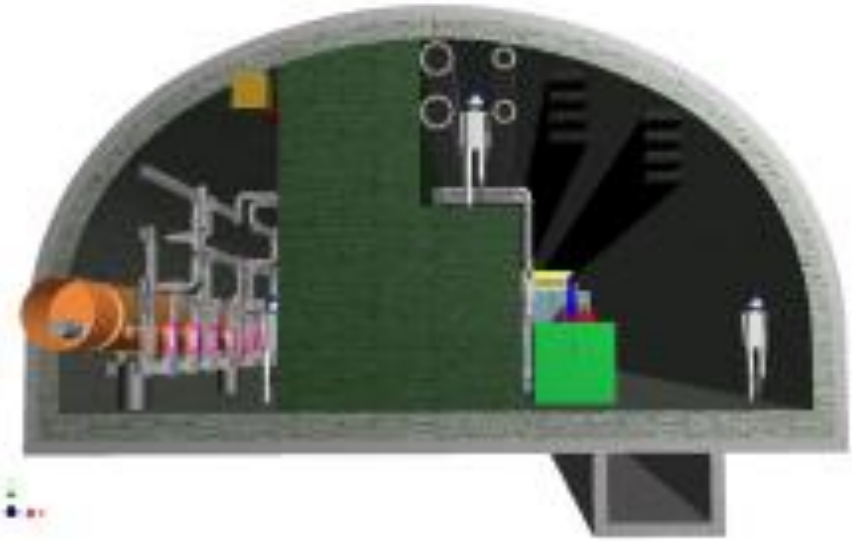
ILC = International Linear Collider

TDR design of ILC
for Ecm = 500 GeV





Tunnel design for Mountain Range site



Higgs Boson

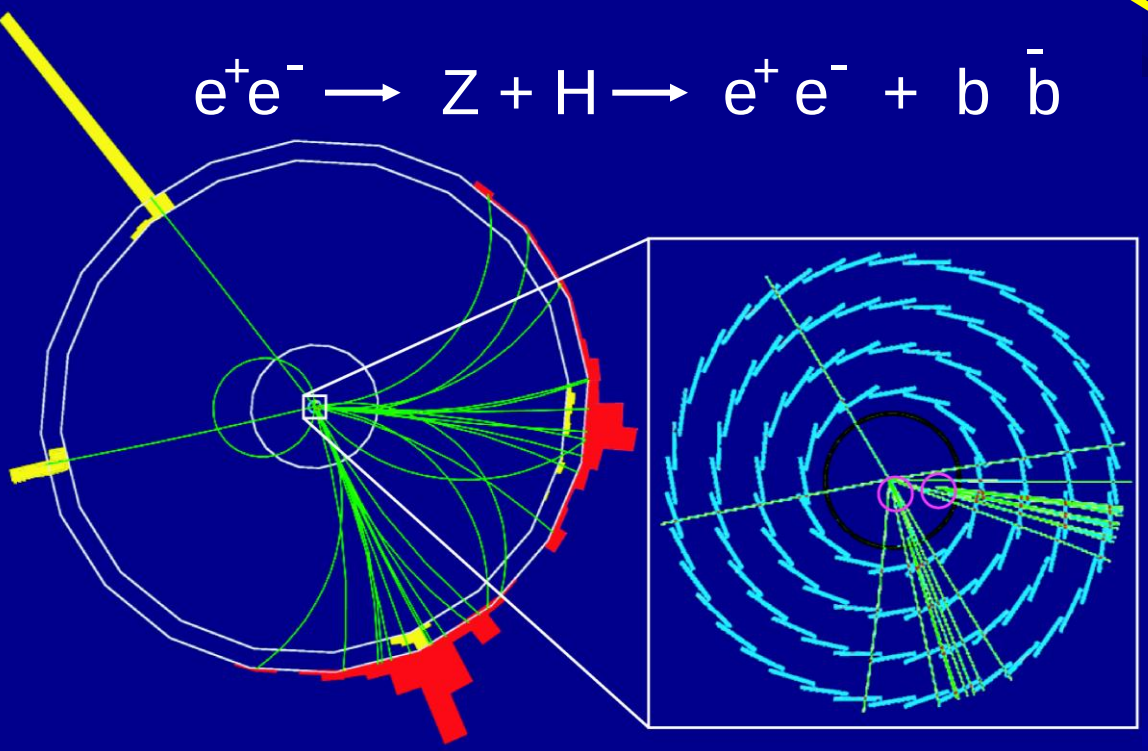
Precise measurement of Higgs Boson
⇒Deduce Principal Low in the Nature

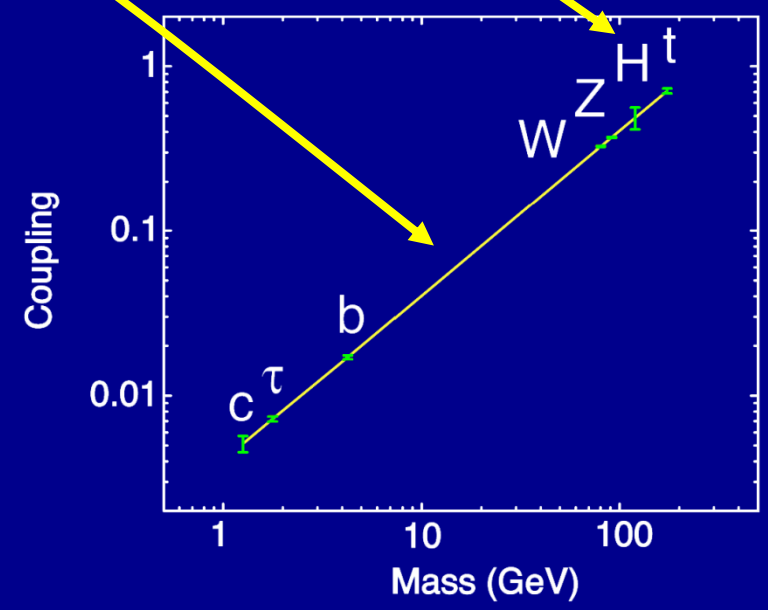
ILC in the first phase is the Higgs Boson Factory

O(10^5) such events will be collected and studied.

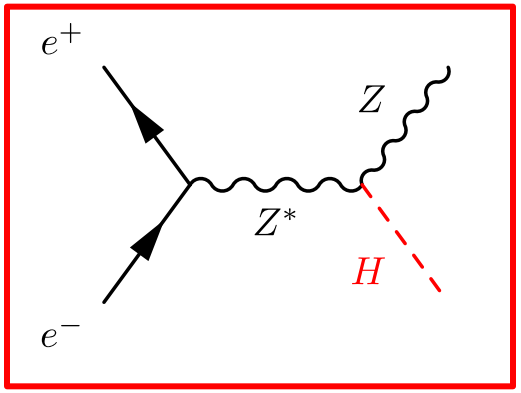
Origin of mass ⟷ Structure of the ‘vacuum`

$e^+e^- \longrightarrow Z + H \longrightarrow e^+e^- + b\,\bar{b}$

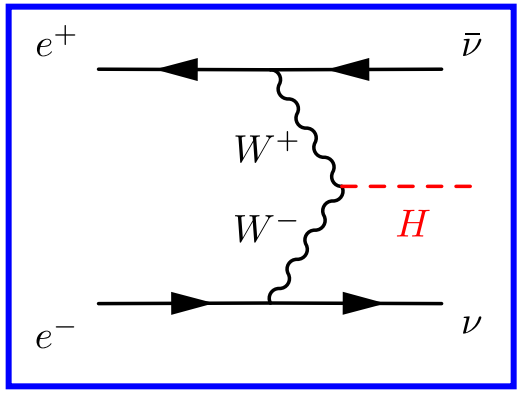




Higgs Measurements at ILC



250 GeV~
Higgs-strahlung



350 GeV~
WW fusion

	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$				
$\sqrt{s}$ and $\mathcal{L}$ (P_{e^-}, P_{e^+})	$250\,\mathrm{fb}^{-1}$ at $250\,\mathrm{GeV}$ (-0.8,+0.3)		$500\,\mathrm{fb}^{-1}$ at $500\,\mathrm{GeV}$ (-0.8,+0.3)		$1\,\mathrm{ab}^{-1}$ at $1\,\mathrm{TeV}$ (-0.8,+0.2)
mode	Zh	$\nu\bar{\nu}h$	Zh	$\nu\bar{\nu}h$	$\nu\bar{\nu}h$
$h \to b\bar{b}$	1.1%	10.5%	1.8%	0.66%	0.47%
$h \to c\bar{c}$	7.4%	-	12%	6.2%	7.6%
$h \to gg$	9.1%	-	14%	4.1%	3.1%
$h \to WW^*$	6.4%	-	9.2%	2.6%	3.3%
$h \to \tau^+\tau^-$	4.2%	-	5.4%	14%	3.5%
$h \to ZZ^*$	19%	-	25%	8.2%	4.4%
$h \to \gamma\gamma$	29-38%	-	29-38%	20-26%	7-10%
$h \to \mu^+\mu^-$	100%	-	-	-	32%

ILC TDR, m_H=125 GeV, BRs from LHC HXSWG assumed.

Importance of Precise Measurement of Higgs Properties

Decoupling Theory　Light Higgs Boson ~ SM Higgs Boson

Just for example:　Two Doublet Model（SUSY)

Coupling of h = 125 GeV Higgs and weak gauge bosons

V = W, Z

$$g(hVV)/g(hVV)_{SM}$$
$$= \sin(\beta-\alpha)$$
$$\sim 1-2c^2 m_Z^4 \cot^2\beta/m_A^4$$
$$\sim 1-0.3\%(200\ \mathrm{GeV}/m_A)^4$$

Coupling of h and SU2(2) I_w=1/2 quark

$$g(htt)/g(htt)_{SM} = g(hcc)/g(hcc)_{SM}$$
$$= \cos\alpha/\sin\beta = \sin(\beta-\alpha) + \cot\beta\cos(\beta-\alpha)$$
$$\sim 1-2c\cdot m_Z^2\cot^2\beta/m_A^2$$
$$\sim 1-1.7\%(200\ \mathrm{GeV}/m_A)^2$$

Deviations from the Standard Model Higgs couplings are very small even for ILC precise measurements.

Coupling of h and quarks and leptons with $I_w = -1/2$

$g(hbb)/g(hbb)_{SM} = g(h\tau\tau)/g(h\tau\tau)_{SM}$
$= -\cos\alpha/\cos\beta = \sin(\beta-\alpha) - \tan\beta\cos(\beta-\alpha)$
$\sim 1 + 2c \cdot m_Z^2/m_A^2$
$\sim 1 + 40\%(200\ \mathrm{GeV}/m_A)^2$

The deviations must be seen at ILC even for m_A ~500GeV.

Very difficult for LHC

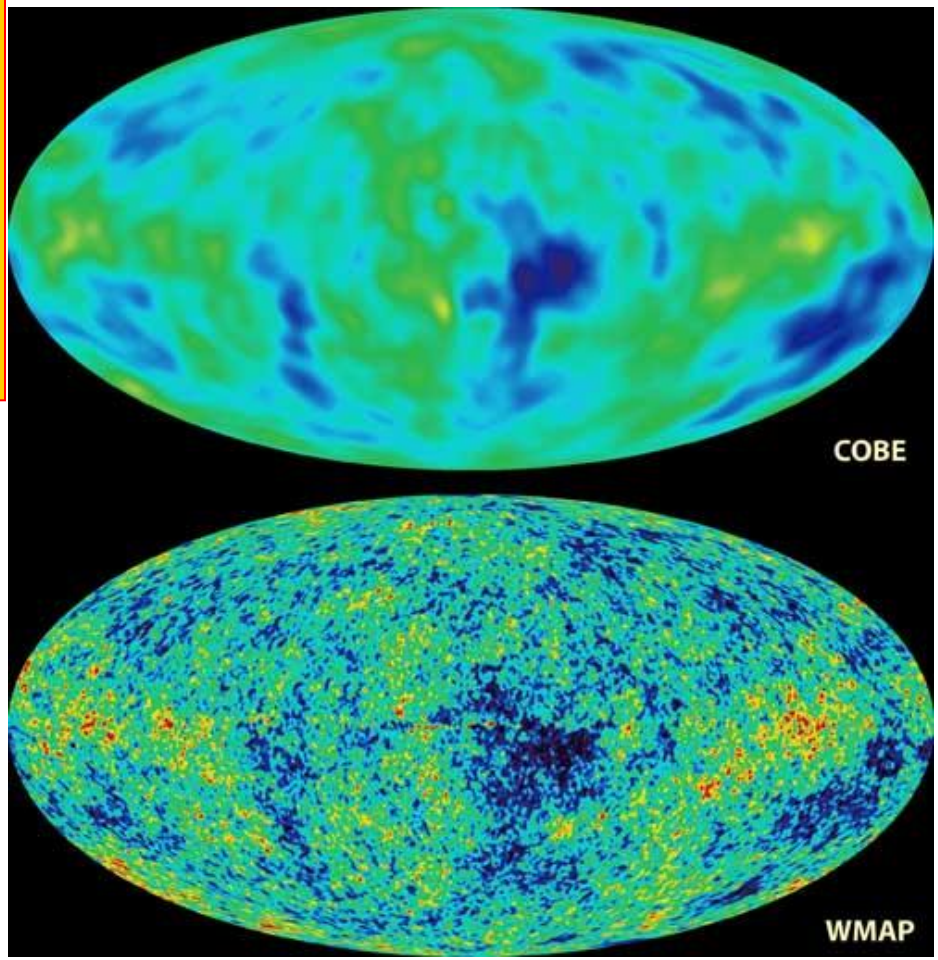
Impact of Precise Measurement

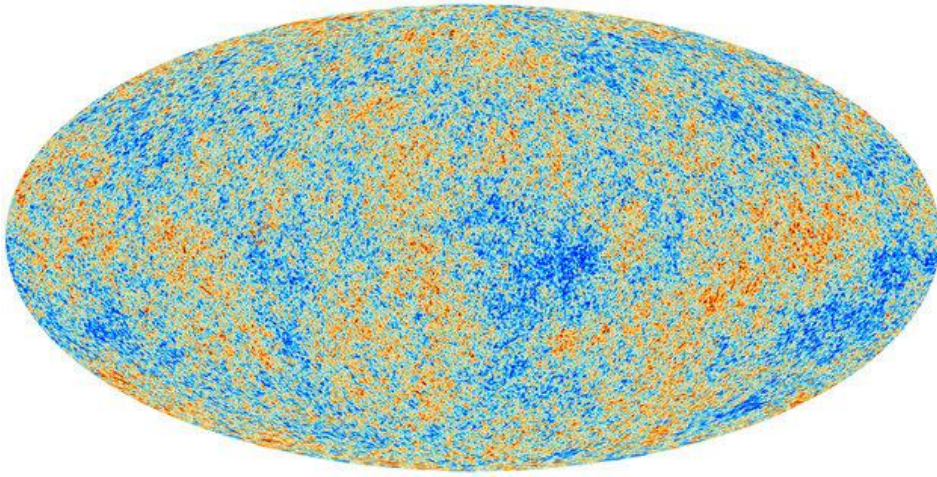
A. Wagner

COBE 1990
Angular resolution = 10°
Temperature fluctuation 10^{-5}K

WMAP 2003
Angular resolution = 10'
τ(the Universe) =13.69±0.13 Gyr
Polarization measurement

Planck 2013
Angular resolution ~ 4'
τ(the Universe) =13.796±0.058 Gyr





History of International LC Community

1980s LC accelerator R&D starts at DESY, KEK, SLAC , CERN, …
1990s 5 different LC designs: TESLA , S-band, C-band, X-band, CLIC
1998 World-wide-studies of physics and detector for LCs was established
2003 ILC Steering Committee (ILCSC) formed
2004 Selected superconducting RF for the main linac
2005 Global Design Effort (GDE) formed (Barry Barish)
2007 Reference Design Report
2009 LOI process validated two detector concepts (ILD and SiD)
2012 Technical Design Report
2013 Feb. Linear Collider Collaboration (LCC=ILC+CLIC) formed (Lyn Evans)
2013 June TDR review will be completed

The Jump-Start Scenario (Very optimistic but not impossible)

2013 July Site evaluation by scientists will complete in Japan
2013 fall New organization within Japanese government is expected to be formed and in preparation to bid to host the ILC
2014-15 Intergovernmental negotiation
Linear Collider Collaboration (Lyn Evans and ILC sector) continue to refine the design and organization of the global lab for ILC
2015 International Review of the ILC project (LHC physics @13-14 TeV)
2015-16 Construction starts
2026-27 Commissioning of the ILC machine

Recommendations

Subcommittee for Future Project of High Energy Physics of Japan
Chair: Toshinori Mori (ICEPP, The University of Tokyo)
March 2012

The committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.

- **Should a new particle such as a Higgs boson with a mass below approximately 1 TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e^+e^- linear collider.** In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time. In parallel, continuous studies on new physics should be pursued for both LHC and the upgraded LHC version. Should the energy scale of new particles/physics be higher, accelerator R&D should be strengthened in order to realize the necessary collision energy.

- **Should the neutrino mixing angle θ_{13} be confirmed as large, Japan should aim to realize a large-scale neutrino detector through international cooperation, accompanied by the necessary reinforcement of accelerator intensity, so allowing studies on CP symmetry through neutrino oscillations.** This new large-scale neutrino detector should have sufficient sensitivity to allow the search for proton decays, which would be direct evidence of Grand Unified Theories.

It is expected that the Committee on Future Projects, which includes the High Energy Physics Committee members as its core, should be able to swiftly and flexibly update the strategies for these key, large-scale projects according to newly obtained knowledge from LHC and other sources.

It is important to complete and start the SuperKEKB including the detector, as scheduled. Some of the medium/small scale projects currently under consideration have the implicit potential to develop into important research fields in the future, such as neutrino physics and as such, should be promoted in parallel to pursue new physics in various directions. Flavour physics experiments such as muon experiments at J-PARC, searches for dark matter and neutrinoless double beta decays or observations of CMB B-mode polarization and dark energy are considered as projects that have such potential.

A Proposal for a Phased Execution of the International Linear Collider Project

The Japan Association of High Energy Physicists (JAHEP) endorsed the document on 18 October 2012

ILC shall be constructed in Japan as a global project based on agreement and participation by the international community.

Physics : Precision study of “Higgs Boson” , top quark, “dark matter” particles, and Higgs self-couplings,

Scenario : Start with a Higgs Boson Factory ~250 GeV. Upgraded in stages up to a center-of-mass energy of ~500 GeV, which is the baseline energy of the overall project. Technical extendability to a 1 TeV region shall be secured.

Japan covers 50% of the expenses (construction) of the overall project of a 500 GeV machine. The actual contributions, however, should be left to negotiations among the governments.

Support from Europe and USA

European Strategy

Chair: Tatsuya Nakada

e) There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*

Obviously the highest priority is for Europe is LHC and LHC Luminosity upgrade.
ILC should not interfere with the LHC upgrade (the timing and the budget)

HEPAP Facilities Subpanel :
Report on High Energy Frontier Facilities

Sally Dawson

US Participation in Japanese Hosted ILC

- Science drives the need for e^+e^- collider
  - ILC addresses absolutely central physics questions and is complementary to the LHC
  - Japanese hosted ILC could be under construction before 2024
- Parameters of a potential US contribution are not known and depend on international agreements
  - The US has made substantial contributions to detector and accelerator development through the global effort
  - Should an agreement be reached, the US particle physics community would be eager to participate in both the accelerator and detector construction

Union of Diet members to promote a construction of international laboratory for LC

31st July 2008 established a suprapartisan ILC supporters

(July 2008～)
President Kaoru Yosano
Deputy Yukio Hatoyama
Secretary-General Takeo Kawamura
、 Yoshihiko Noda
Director Norihisa Tamura
Masamitsu Naito

proposers

Akihito Ohhata、Koji Omi、Ikuo Kamei, Takeo Kawamura, Tetsuo Saito, Yoshiaki Takagi, Norihiko Tamura, Masamitsu Naito, Yoshihiko Noda, Yukio Hatoyama、Fumuhiro Himori, Kosuke Hori, Eisuke Mori, Kaoru Yosano、Hidekatsu Yoshii

New Officers (October 2011～)
Supreme advisor Kaoru Yosano
President Yukio Hatoyama
Acting president Takeo Kawamura
Secretary-general Tatsuo Kawabata
Deputy Tatsu Shionoya
Dupty President Tetsuo Saito
President of bureau Norihisa Tamura
Director of bureau Keisuke Tsumura
Deputy Takeshi Kai

Renewed on 1st Feb 2013
lead by Takeo Kawamura

Advanced Accelerator Association of Japan (AAA)

June 2008 established an industry-academy collaboration

Industry: 85 companies (Mitsubishi HI、Toshiba、Hitachi、Mitsubishi Electric、Kyoto Ceramic et al.) Academy: 38 institutes (KEK, Tokyo、Kyoto、Tohoku, Kyushu, RIKEN, JAEA et al.)
as of December 2011 AAA homepage http://aaa-sentan.org

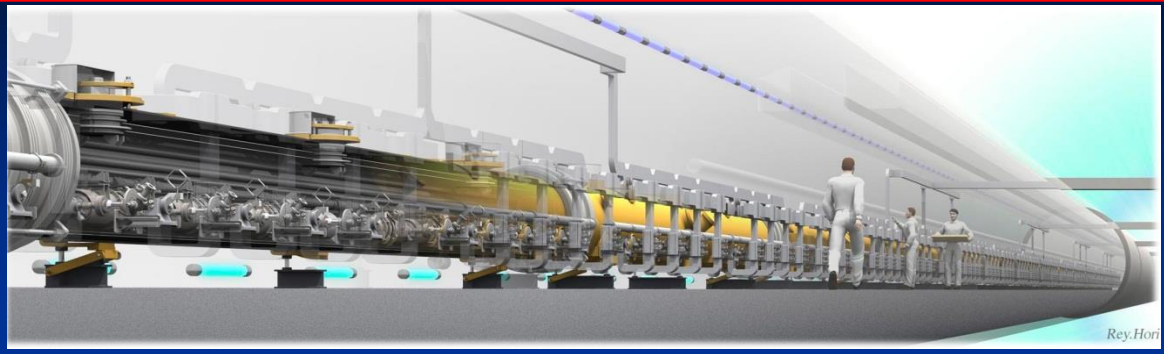
Supreme advisor Kaoru Yosano
President Emeritus Masatoshi Koshiba
President Takashi Nishioka (Mitsubishi HI)
Trustee Atsuto Suzuki (KEK)
〃 Akira Maru (Hitachi)、
〃 Yoshiaki Nakaya (Mitsubishi Electric)
〃 Yasuji Igarashi (Toshiba)、
〃 Akira Noda (Kyoto University)
〃 Keijiro Minami (Kyoto ceramic)
Auditor Sachio Komamiya (University of Tokyo)

December 2011 at AAA symposium

27 March 2013 LCC Director Lyn Evans met our Primeminister

Possibility of Japan to be a host of ILC

Some facts to believe Japan to host ILC, if we work very hard for the next few years.



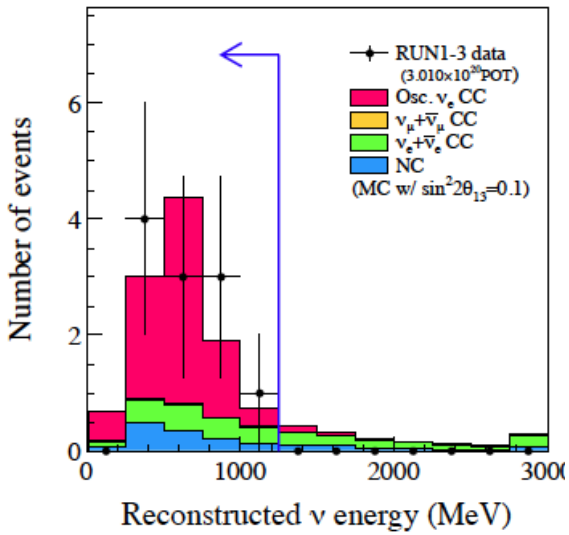
1) Discovery of "a Higgs Boson" at LHC
2) TDR of ILC project was completed end 2012.
3) CERN is expected to work on LHC upgrade
   Support from international community
4) Supports of Political and Industrial sectors
   ・Advanced Accelerator Association of Japan
5) Started site studies with dedicated funding
6) Agreement in the HEP community
   ・Report from subcommittee of future HEP projects of Japan (March 2012)
   ・Phased Excecution of ILC（October 2012）

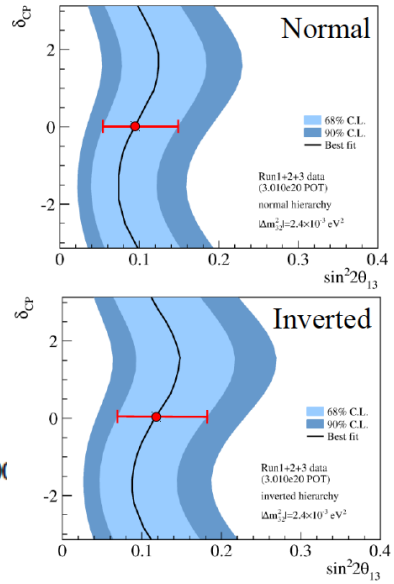
Projects of japan other than ILC

1)Neutrino Physics ☆
2)Super KEKB
3)J-PARK (other than neutrino)

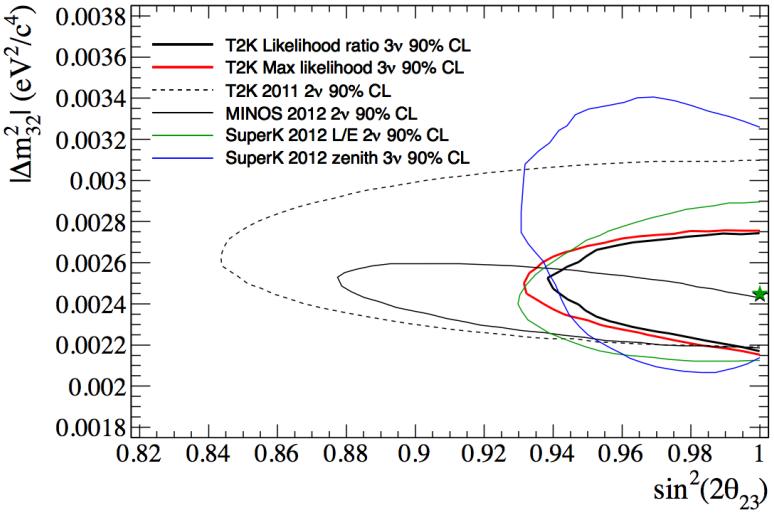
T2K (Tokai to Kamioka) experiment

3.2σ Evidence of ν_e appearance from ν_μ beam





World best measurement of θ_{23}



Next goals

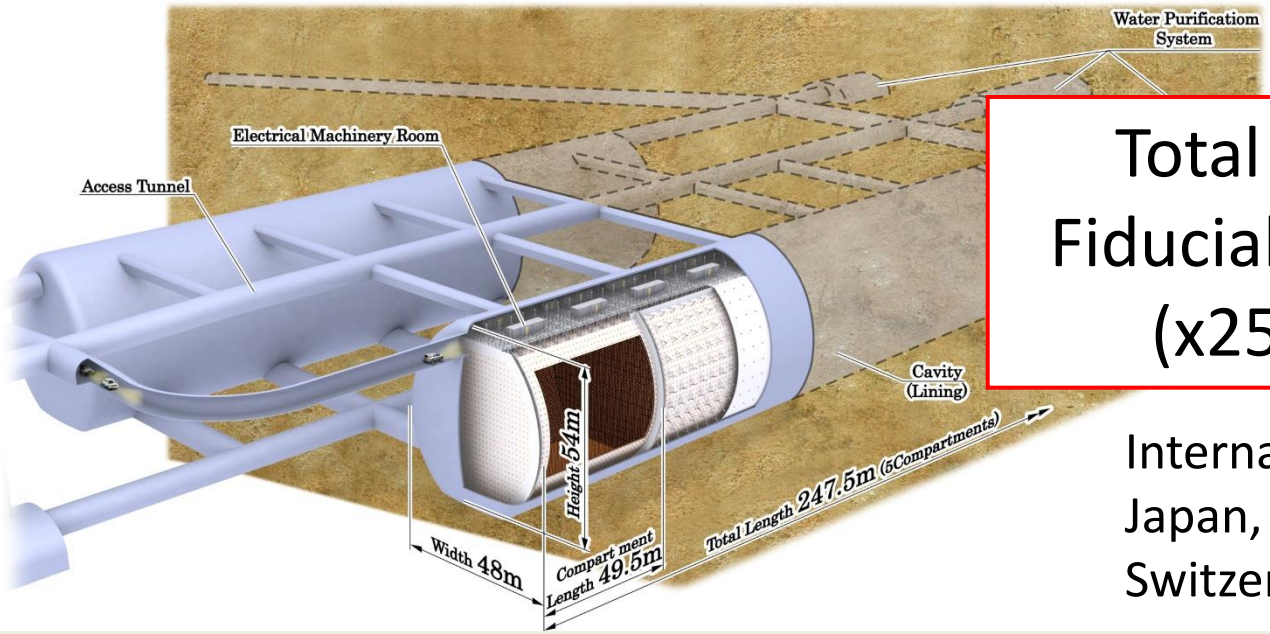
5σ appearance observation before Summer 2013 w/ ~8x10^{20}POT

Realize >750kW

Appearance & disappearance precision measurements

Start to explore CPV and mass hierarchy

Hyper-Kamiokande project



arXiv:1109.3262

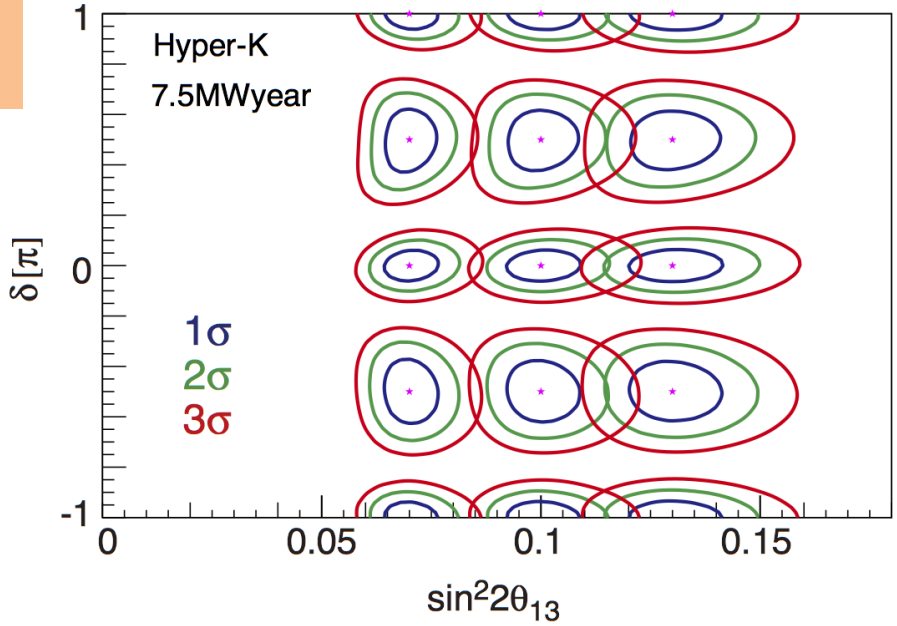
Total mass: 1Mton
Fiducial mass: 560kton
(x25 of Super-K)

International WG
Japan, Canada, Spain,
Switzerland, Russia, UK, US

- Exploring the full picture of neutrino mixing
  - Neutrino beam from J-PARC (≥1MW expected)
    - CP asymmetry in lepton sector
  - Atmospheric neutrino
    - Determination of mass hierarchy and θ_{23} octant
- Search for proton decay (Sensitivity: $\tau/B(e^+\pi^0) > 10^{35}$ years)
- Measurements of solar and astrophysical neutrinos

CP asymmetry in lepton sector

- 3σ CPV measurement for 74% of δ ($\sin^2 2\theta_{13}$=0.1)
- CP phase δ measurement
  - <10° if δ=0
  - <20° if δ=90°

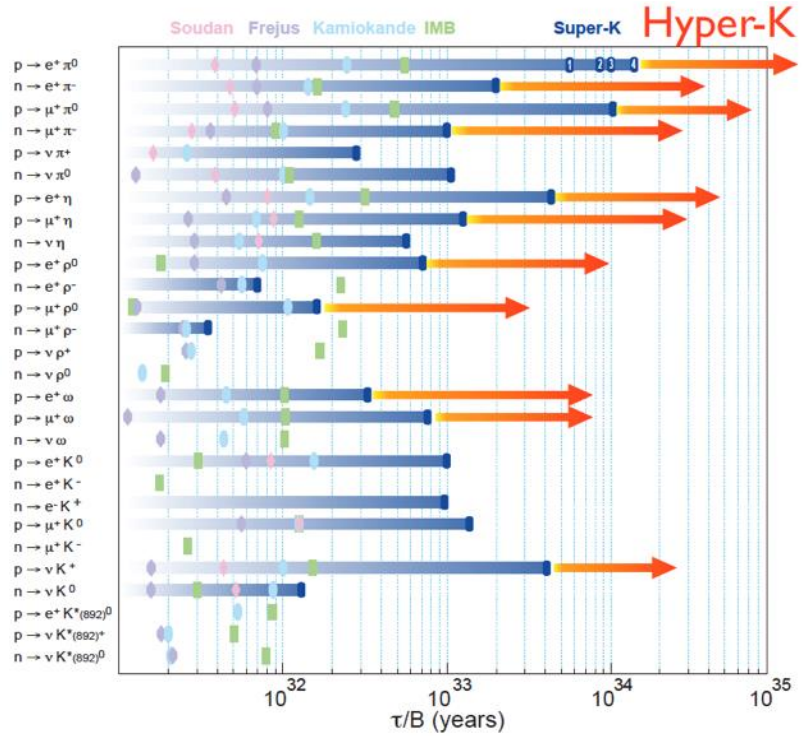


Search for proton decay

- $p \to e^+\pi^0$:
  - 1.3×10^{35}yrs (90%CL)
  - 5.7×10^{34}yrs (3σ)
- $p \to \nu K^+$:
  - 2.5×10^{34}yrs (90%CL)
  - 1.0×10^{34}yrs (3σ)

With 10 years data

~10 times sensitivity than current Super-K limits



Comments on LB Neutrino Physics

What is the goal beyond θ_{13} and δ ?

CKM imaginary phase cannot explain the CP violation in the universe (baryon dominance over anti-baryon)
With the same reason neutrino δ may not explain the CP violation in the Universe.

⇒ Large neutrino detectors are also for nucleon decay searches.
Nucleon decay is a direct window of GUTs （$p \rightarrow \pi^0 e^+$, $p \rightarrow \nu K^+$）

（Detector mass）・（Run time） ∝ （GUT energy scale）$^{1/4}$

Size and budget of neutrino detectors (including nucleon decay) become large.
⇒ ICFA established neutrino panel (members are already selected)

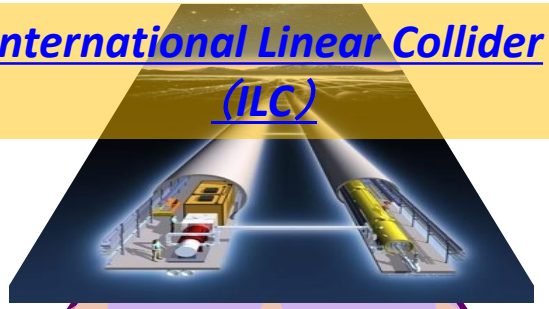
It is very important to see the projects in Europe (CERN) and in USA (Fermilab). International cooperation may be inevitable.


Quest for Birth-Evolution of Universe
International Linear Collider (ILC)
Quest for Unifying Matter and Force
KEK DG keeps showing this ugly slide
Lepton CP Asymmetry
Scientific Activities
Technology Innovation
Encouraging Human Resources
Beyond Standard Physics
Power-Upgrade
Super-KEKB
J-PARC
LHC
KEK-B
Quark CP Asymmetry
Lepton
Quark
[Origin of Matter]
Quest for Neutrinos
Quest for 6 Quarks
[Origin of Force]
Higgs Particle [Origin of Mass]

Quest for Birth-Evolution of Universe

International Linear Collider (ILC)

Quest for Unifying Matter and Force



Lepton CP Asymmetry

Scientific Activities
Technology Innovation
Encouraging Human Resources

Beyond Standard Physics

Power-Upgrade

Super-KEKB

All roads lead to ILC

Lepton

Quark

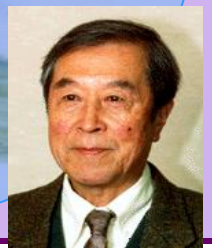
[Origin of Matter]

Quest for Neutrinos

ν_τ ν_μ ν_e

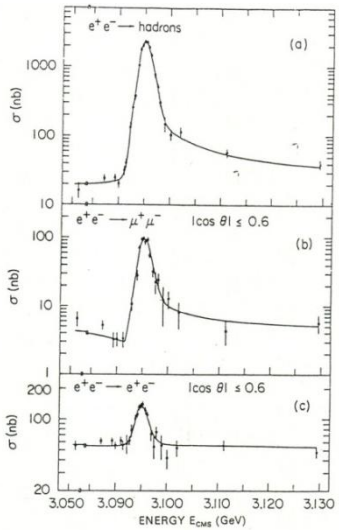
Quest for 6 Quarks

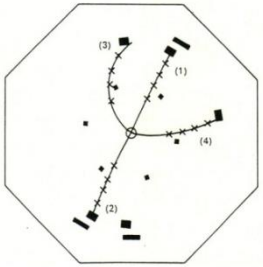
[Origin of Force]

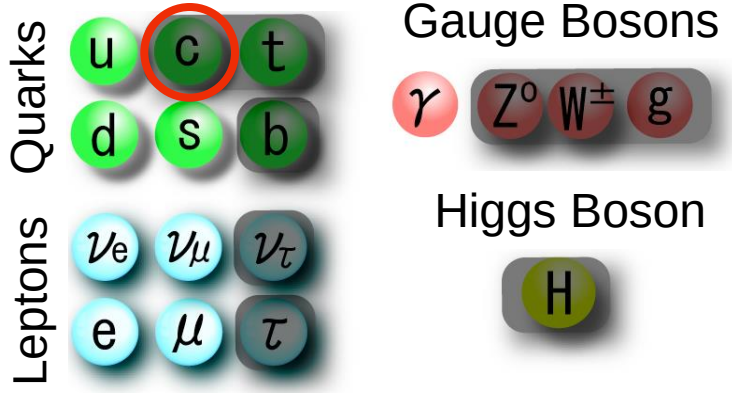


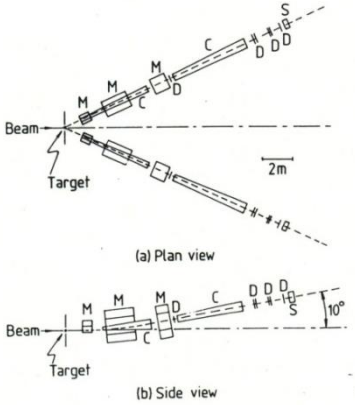
Higgs Particle [Origin of Mass]

There was a revolution in particle physics！
The 1974 November Revolution
Discovery of J/ψ（charm quark）

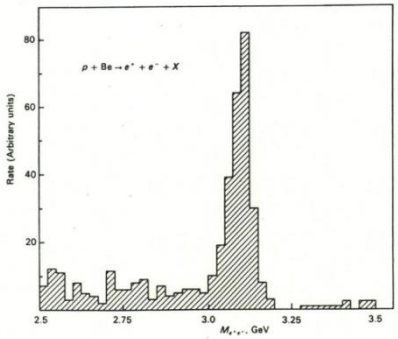








J/ψ＝$c\bar{c}$ bound state

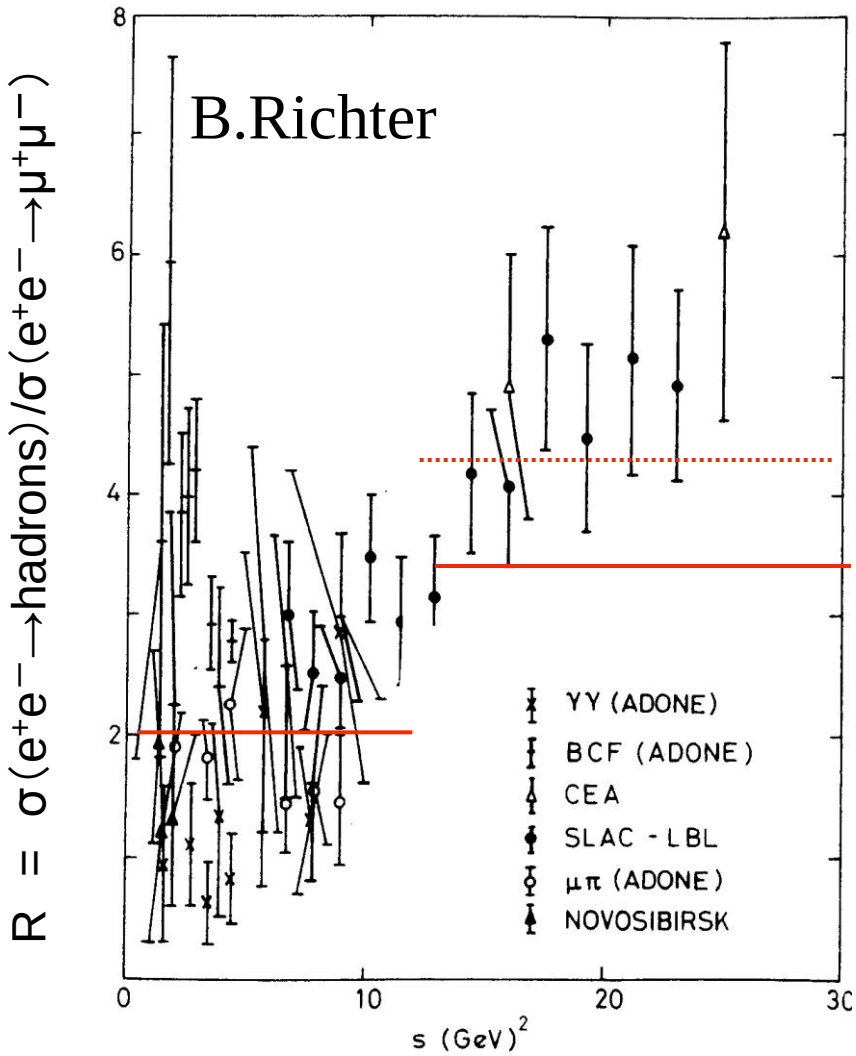


It becomes evident even for experimental physicists that quarks and leptons are the elementary particles of the same level. ⇒ base of The Standard Model

$e^+e^- \rightarrow \psi$ SLAC
Richter et al.

$J \rightarrow e^+e^-$ BNL
Ting（丁）et al.

Eve of the Revolution



R looks monotone increasing function with s (= Ecm^2). Parton model must be wrong

B.Richter

ICHEP 1974 Summer in London

J.Ellis

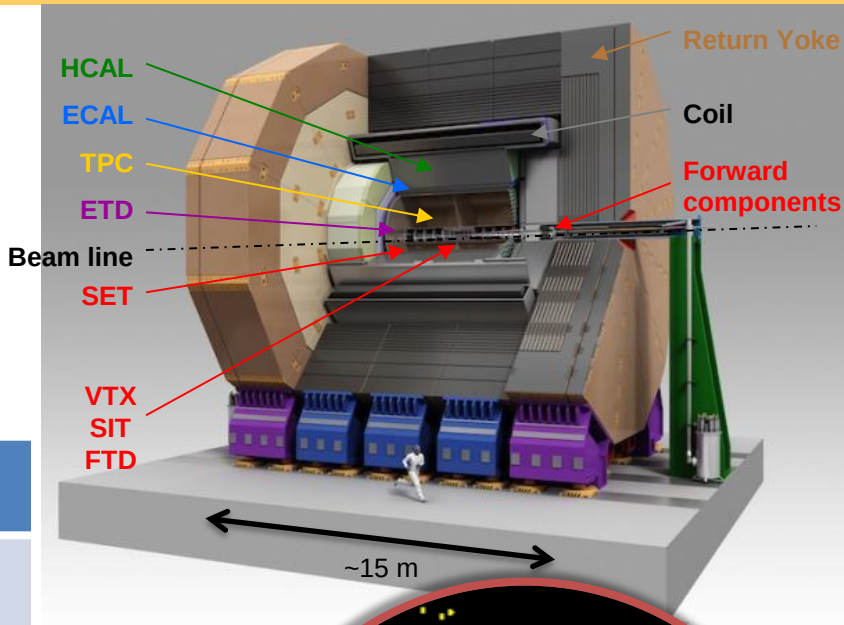
Table of Values of R

Value	Model	Source
0.36	Bethe-Salpeter bound quarks	Bohm et al, ref 42
2/3	Gell-Mann-Zweig quarks	
0.69	Generalized vector meson dominance	Renard, ref 49
~1	Composite quarks	Raitio, ref 43
10/9	Gell-Mann-Zweig with charm	Glashow et al, ref 31
2	Coloured quarks	
2.5 to 3	Generalized vector meson dominance	Greco, ref 30
2 to 5	" " " "	Sakurai, Gounaris, ref 47
$3^1/3$	Coloured charmed quarks	Glashow et al, ref 31
4	Han-Nambu quarks	Han and Nambu, ref 32
5.7±0.9	Trace anomaly and ρ dominance	Terazawa, ref 27
$5.8^{+3.2}_{-3.5}$	Trace anomaly and ε dominance	Orito et al, ref 25
6	Han-Nambu with charm	Han and Nambu, ref 32
6.69 to 7.77	Broken scale invariance	Choudhury, ref 18
8	Tati quarks	Han and Nambu, ref 32
8 ± 2	Trace anomaly and ε dominance	Eliezer, ref 26
9	Gravitational cut-off, universality	Parisi, ref 40
9	Broken scale invariance	Nachtmann, ref 39
16	$SU_{12} \times SU_{12}$) gauge models	Fritzsch & Minkowski , ref 34
$35^1/3$	$SU_{16} \times SU_{16}$) gauge models	Fritzsch & Minkowski , ref 34
~5000	High Z quarks)	Yock, ref 73
70,383	Schwinger's quarks)	Yock, ref 73
∞	∞ of partons	Cabibbo and Karl, ref 9
		Matveev and Tolkachev, ref 35
		Rozenblit, ref 36

ILC Detector R&D

Tanabe, ICEPP

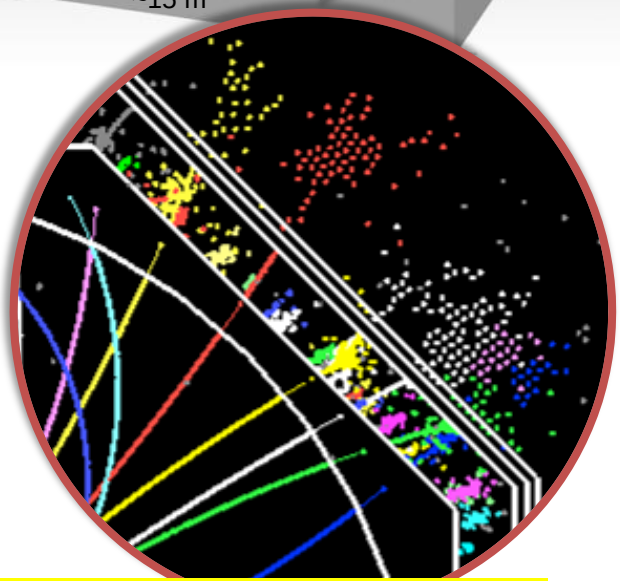
- **Vertex Detector: pixel detectors & low material budget**
- **Time Projection Chamber: high resolution & low material budget, MPGD readout**
- **Calorimeters: high granularity sensors, 5x5mm^2 (ECAL)、3x3cm^2 (HCAL)**



Sensor Size	ILC	ATLAS	Ratio
Vertex	5 × 5 mm^2	400 × 50 mm^2	x800
Tracker	1 × 6 mm^2	13 mm^2	x2.2
ECAL	5 × 5 mm^2 (Si)	39 × 39 mm^2	x61

Particle Flow Algorithm

Charged particles → Tracker,
Photons → ECAL, Neutral Hadrons → HCAL
Separate calorimeter clusters at particle level
→use *best* energy measurement for *each* particle.
→offers unprecedented **jet energy resolution**



State-of-the-art detectors can be designed for ILC