ILC Project
Overview and Status

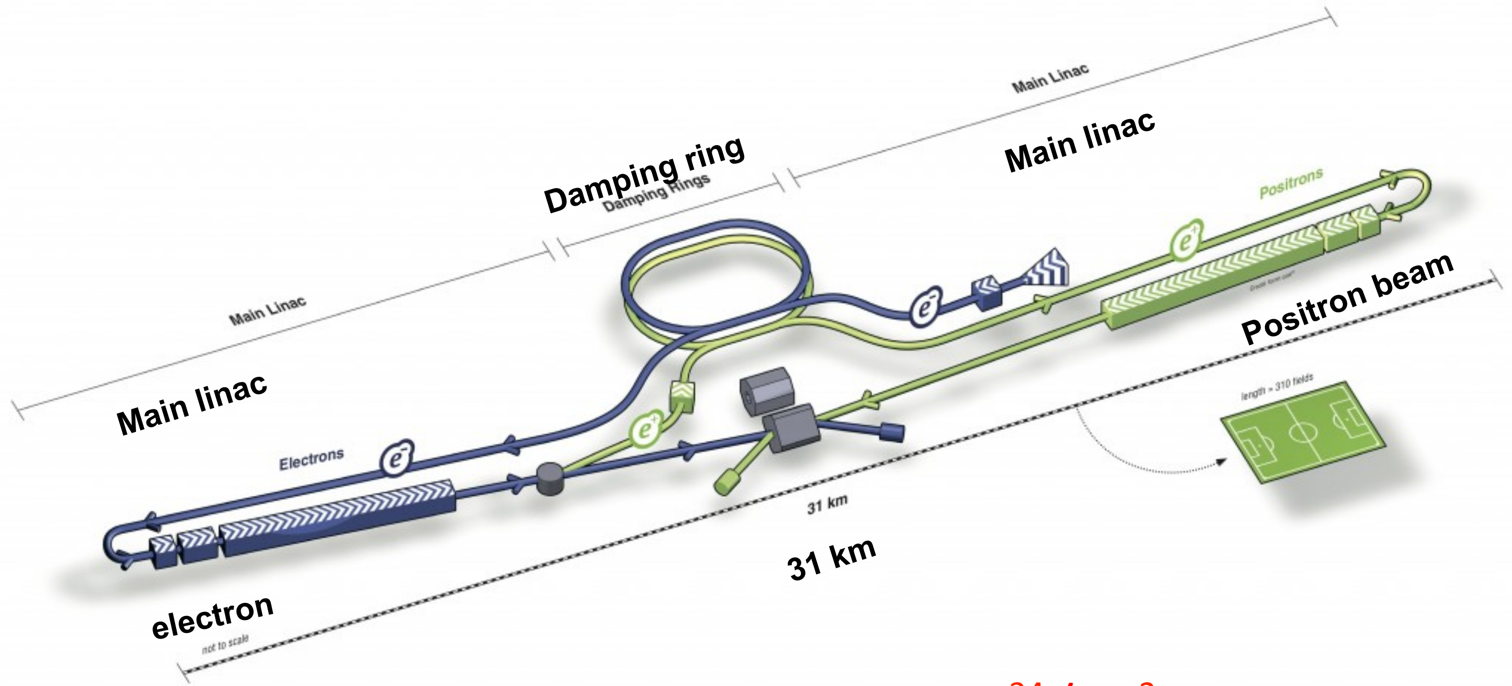
Hitoshi Yamamoto, Tohoku University
Higgs and BSM Workshop
Weihai, August 16, 2015

Plan:

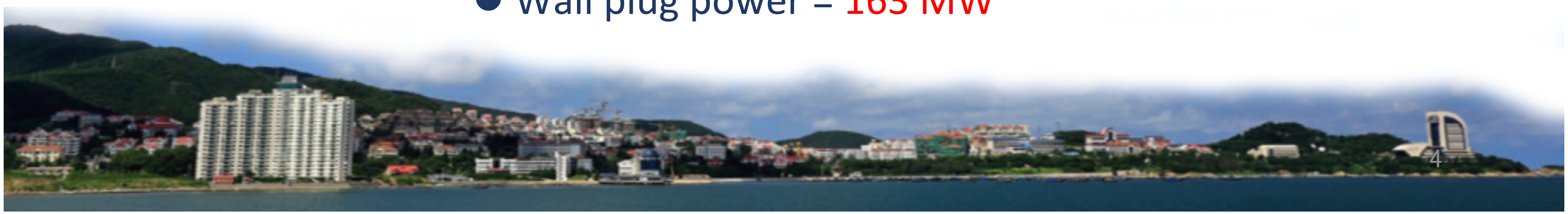
1. ILC parameters and the sample running scenario
2. ILC physics
   - Higgs, top, SM process
   - New particles
3. Project/political status

ILC : Parameters and the Sample Running Scenario

Baseline: 500 GeV Ecm



- Ecm = 500 GeV, L = 1.8 x 10^{34} /cm^2s
- Polarization (e+/e-) = ±0.3/±0.8
- 2x10^{10} particles/bunch, 1312 bunch/train, 5 trains/sec
- Beam size at IP : σy = 5.9nm, σx = 474nm, σz = 300μm
- Average accelerating gradient = 31.5 MV/m
- Wall plug power = 163 MW



ILC500 at Lower Energies

(The baseline 500 GeV machine running at lower energies)

- 250 GeV CM (Higgs factory)
    - Average accelerating gradient = 14.7 MV/m
    - Wall plug power = 122 MW
    - L = 0.75 x 10^{34} /cm^{2}s
    - Run the linac at 10 Hz, alternate e+ production and luminosity (125 GeV e- beam is not enough to produce enough e+'s)

- 350 GeV CM (top threshold scan)
    - Average accelerating gradient = 21.4 MV/m
    - Wall plug power = 121 MW
    - L = 1.0 x 10^{34} /cm^{2}s

Bunch population/pattern, polarizations are the same as for the baseline 500 GeV

Luminosity Upgrade Plan

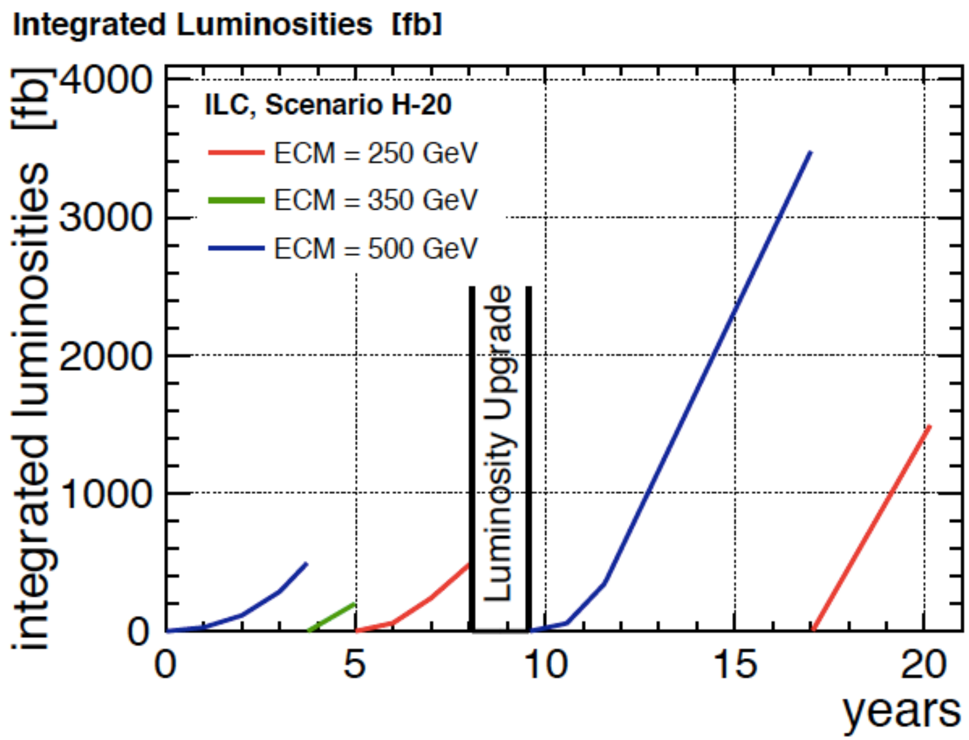
- 250 GeV CM
  - X4 luminosity @ 3E34/cm^{2}s
  - x2 Nbunch, x2 rep rate (10Hz); 122 → 200 MW wall plug
    - Use a longer undulator to produce enough e+'s by 125 GeV e-beam: no need to alternate e+ production and luminosity
- 500 GeV CM
  - x2 luminosity @3.6E34/cm^{2}s
  - x2 Nbunch; 163 → 204 MW wall plug

Standard Sample ILC Running Scenario

- Up to 500 GeV for 20 years total (~25 yrs for LHC)
- Realistic ramp up profile and shutdown time for upgrades
- Approved by the LCB (Linear Collider Board)

Total
250GeV 1500fb-1
350GeV 200fb-1
500GeV 4000fb-1

Actual running scenario will depend on results from LHC and early phase of ILC, etc.



ILC Physics

Highlights only!

Two documents:

- 'ILC Operating Scenarios'
  - By the ILC parameters Working Group of LCC
  - arXiv:1506.07830
- 'Physics Case for the International Linear Collider'
  - By the Physics Working Group of LCC
  - arXiv:1506.05992

Both are found at http://www.linearcollider.org/P-D/Documents

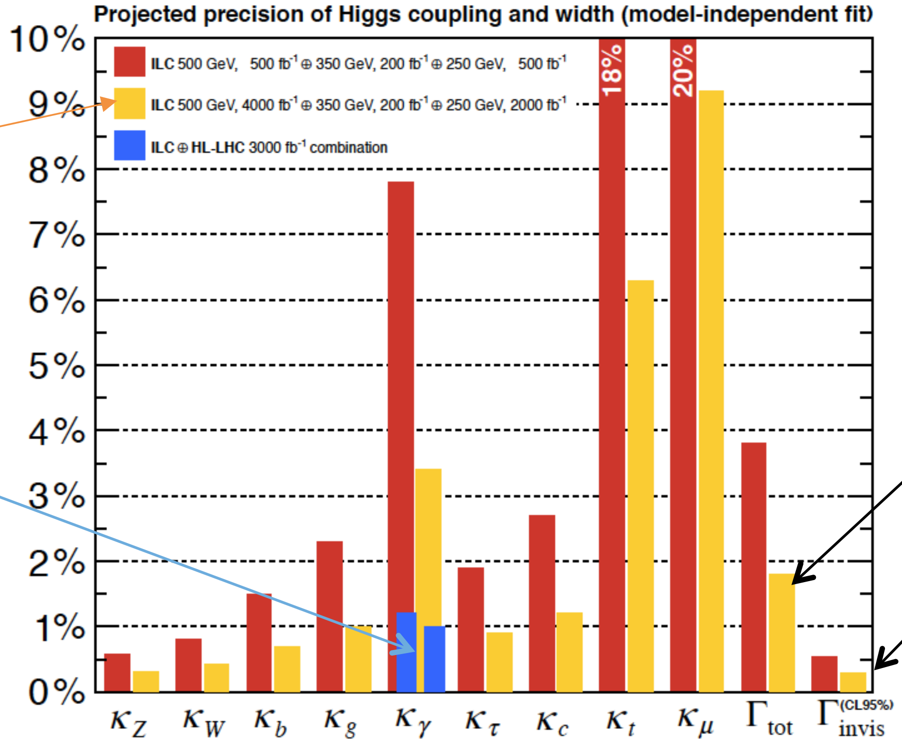
These are 'Standard references'

(the Snowmass numbers are obsolete!)

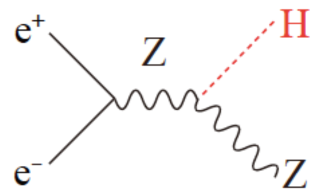
Higgs Couplings

ILC500 Sample Running Scenario

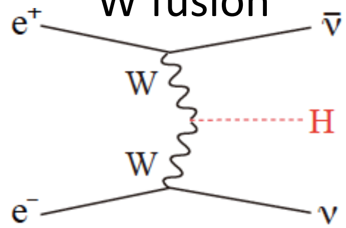
κ_γ /κ_Z by LHC and κ_Z by ILC



Higgsstrahlung



W fusion

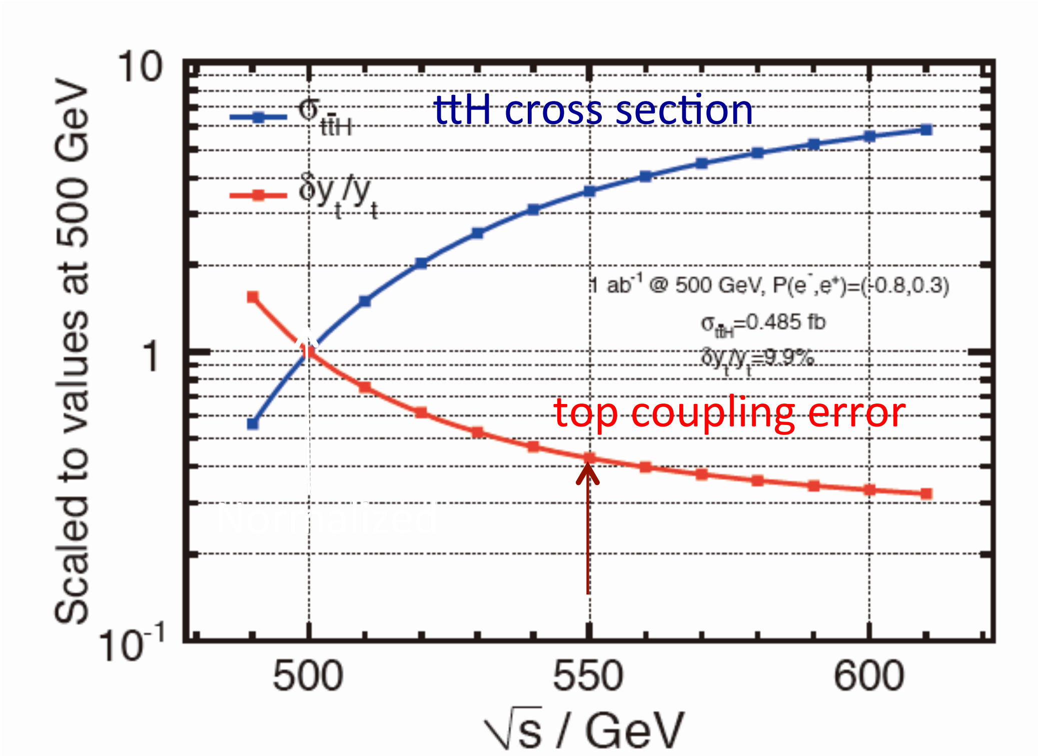


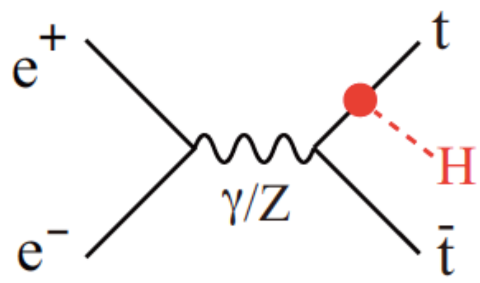
Γ_{tot} : 1.8%

Γ_{invis} <0.3% (90%CL)

- No assumption for generation universality, unitarity, nor on BSM.
- Absolute measurements of decay rates using tagged Higgs
- Apart from γ, t, μ, accuracy is ~1 % or less
  - Level that is meaningful in distinguishing models

κ_t (by e+e-→ttH): 500 GeV vs 550 GeV



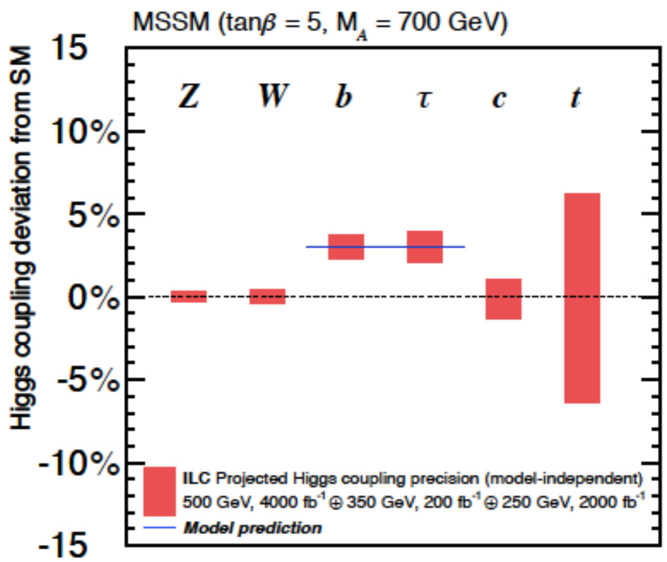


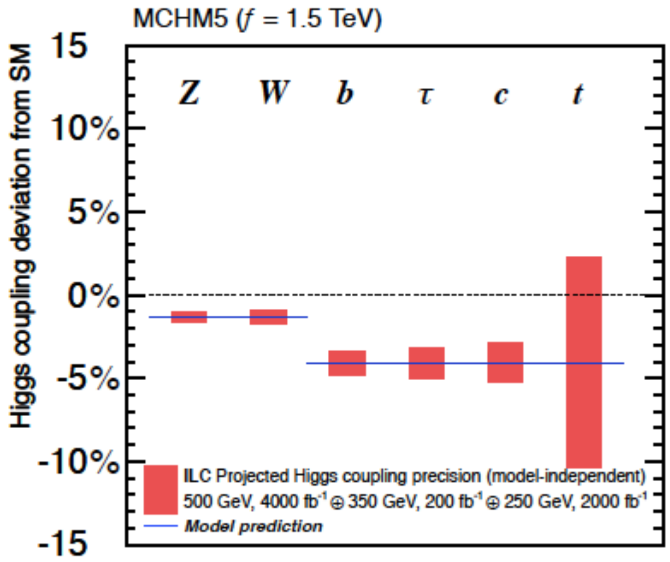
- e+e- → ttH cross section increases by nearly x4 by 500 GeV →550 GeV

  → κ_t error changes fro 6% to 3%

  by running at 550 GeV instead of 500 GeV

Higgs Couplings
model discrimination

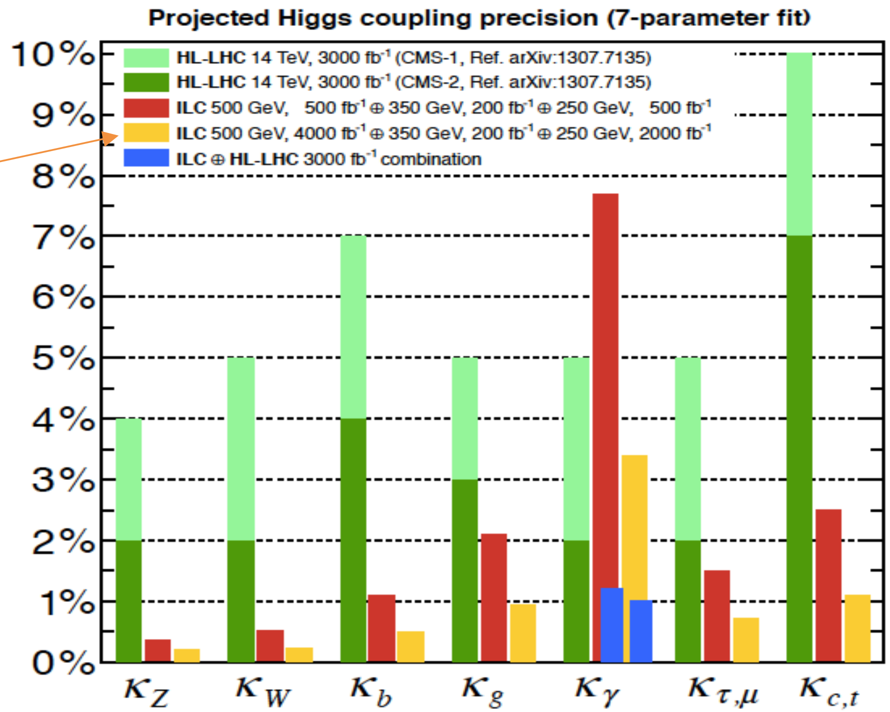




- The pattern of deviation from SM tells BSM models apart
- In general, Higgs couplings needs to be measured to ~1%

Higgs Couplings: compare with LHC

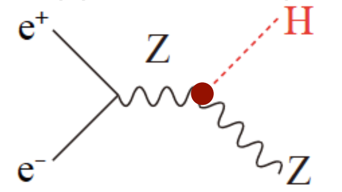
ILC500 Sample Running Scenario



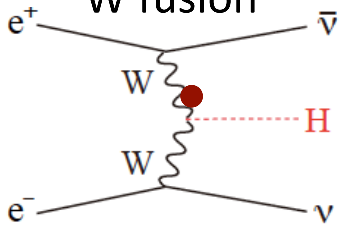
- All assume generation universality, no BSM, unitarity → Fit :
  - CMS-1: HL-LHC pessimistic (sys err : no change)
  - CMS-2: HL-LHC optimistic (sys.err : theory = 1/2, exp. $N^{-1/2}$)
- Apart from γ, ILC (H20) is 1/5 ~ 1/15 of HL-LHC
  - Statistical power of ILC: ~50 HL-LHC running simultaneously

Notes on Higgs Couplings

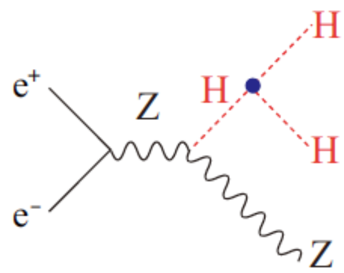
Higgsstrahlung

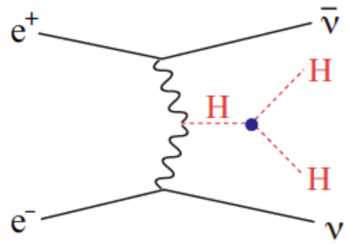


W fusion



- For κ_Z and κ_W , production rates give high precision
  - e+e- → ZH for κ_Z and e+e- → $\nu\nu$H for κ_W [with Br(H→bb)]
- In general for κ_X , Γ_{tot} is necessary in addition to Br(H→x)
  - Γ_{tot} = Br(H→ZZ)/Γ(H→ZZ) with Γ(H→ZZ) from κ_Z
  - Γ_{tot} = Br(H→WW)/Γ(H→WW) with Γ(H→WW) from κ_W
  - W mode is far more powerful than Z mode





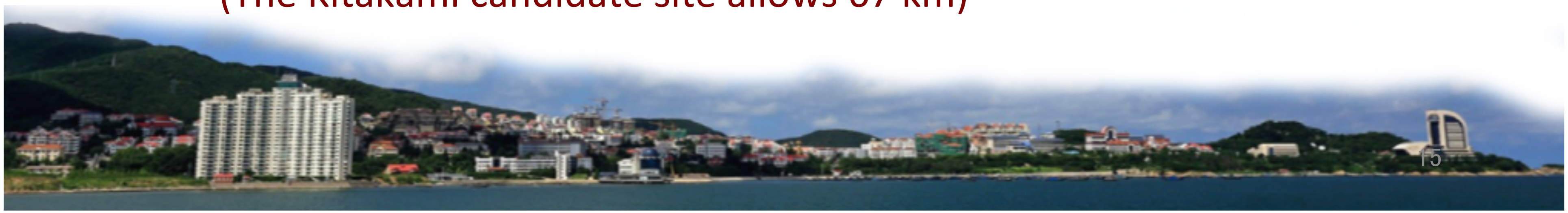
- Higgs self coupling
  - 1TeV: 16% with 2000 fb-1, 10% with 5000 fb-1
  - 500 GeV: 27 % with 4000 fb-1

1 TeV Option

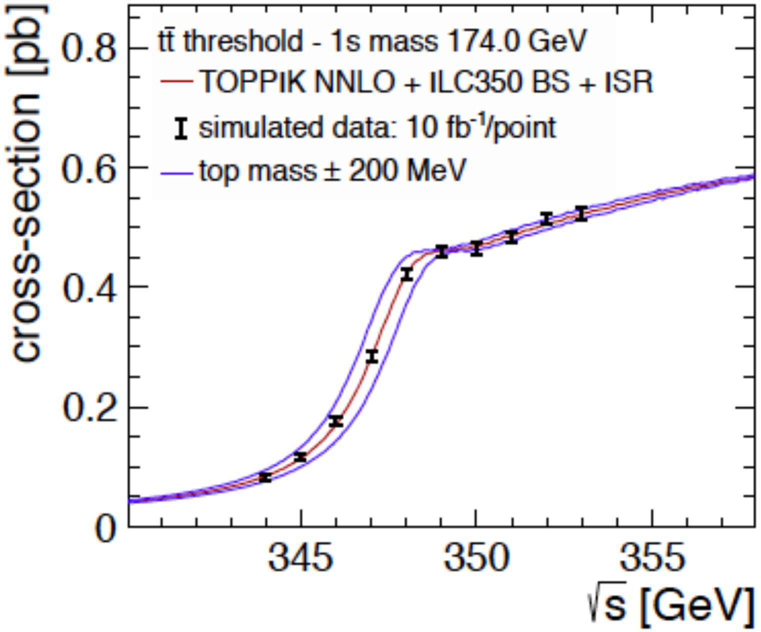
- Extend the total length to 50 km
- Add 45 MV/m cavities (keep the old ones)
  - Average accelerating gradient = 38.2 MV/m
- Wall plug power = 300 MW
- Beam size at IP : σy = 2.8 nm, σx = 481 nm, σz = 250 μm
  - Smaller by the boost
- 2450 bunches/train, 4 trains/s
- L = 3.6 x 10^{34} /cm^{2}s

- Upgrade: x1.4 luminosity @4.9E34/cm^{2}s
- Aggressive beam parameters: smaller σx and σz
  Same wall plug power (300 MW)

(The Kitakami candidate site allows 67 km)



Top at Threshold (@~350 GeV)



Plot: 10 points w/ 10fb-1 each
100 fb-1 total

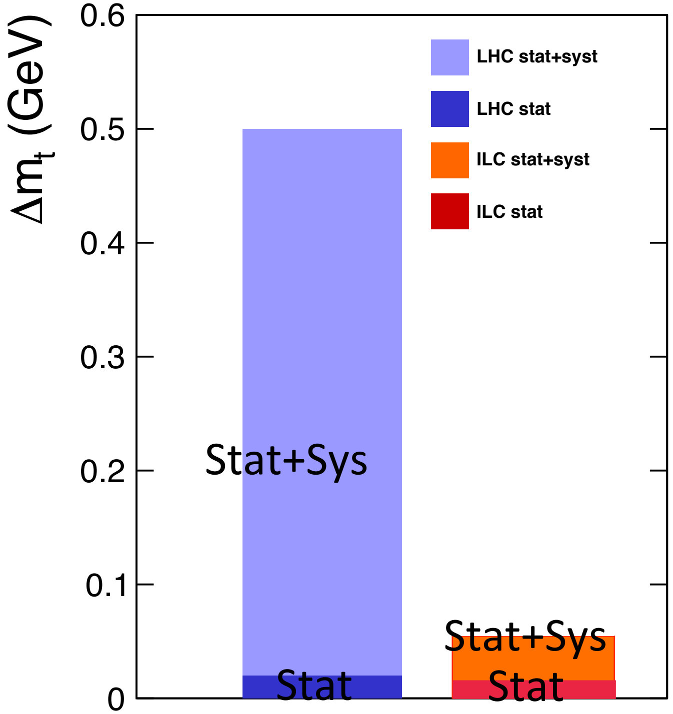
Sample scenario: 20 fb-1 each
200 fb-1 each

- Theoretically worked out to high Precision
- Threshold scan determines Re(pole) to 50 MeV (mostly theoretical)
- The msbar top mass can be obtained from Re(pole) with 10 MeV theoretical uncertainty

Bonus: Sensitivity to ttH coupling at threshold (vertex correction)

Top Mass @ Threshold

msbar top mass precision
(sample running scenario)



HL-LHC
3000 fb^{-1}
$\sqrt{s}$=14 TeV

ILC
200 fb^{-1}
$\sqrt{s}$=350 GeV

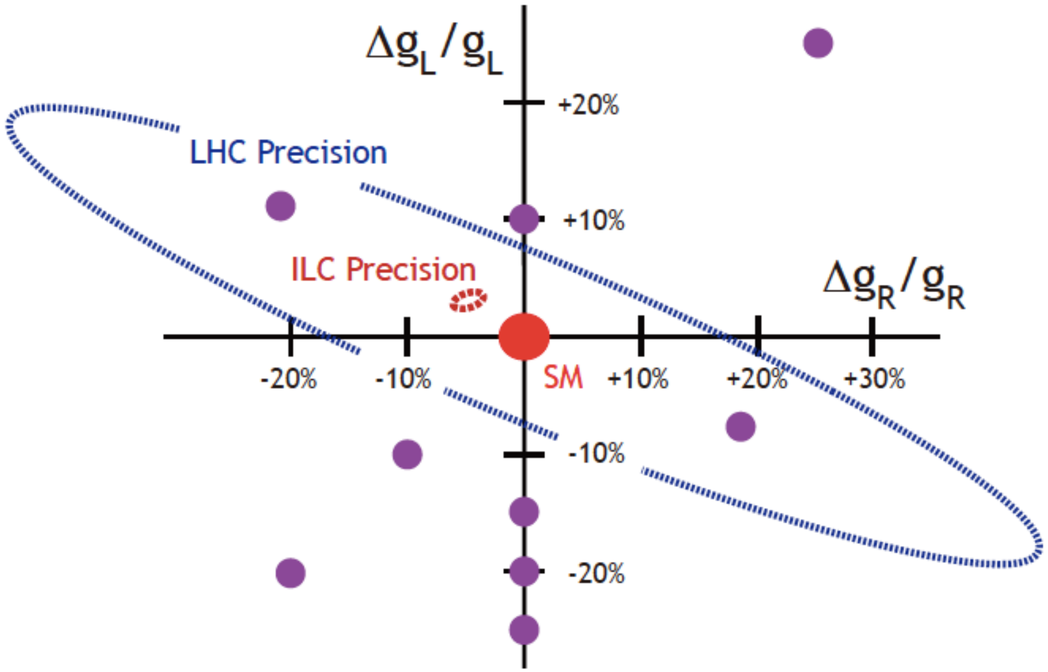
Statistical errors
mt: 17 MeV
Γt: 26 MeV
ttH coupling: 4.2%

Theoretical systematic error is likely to go down significantly for ILC.

Top Pair Production at 500 GeV

e+e- → ttbar

Anomalous top-Z couplings

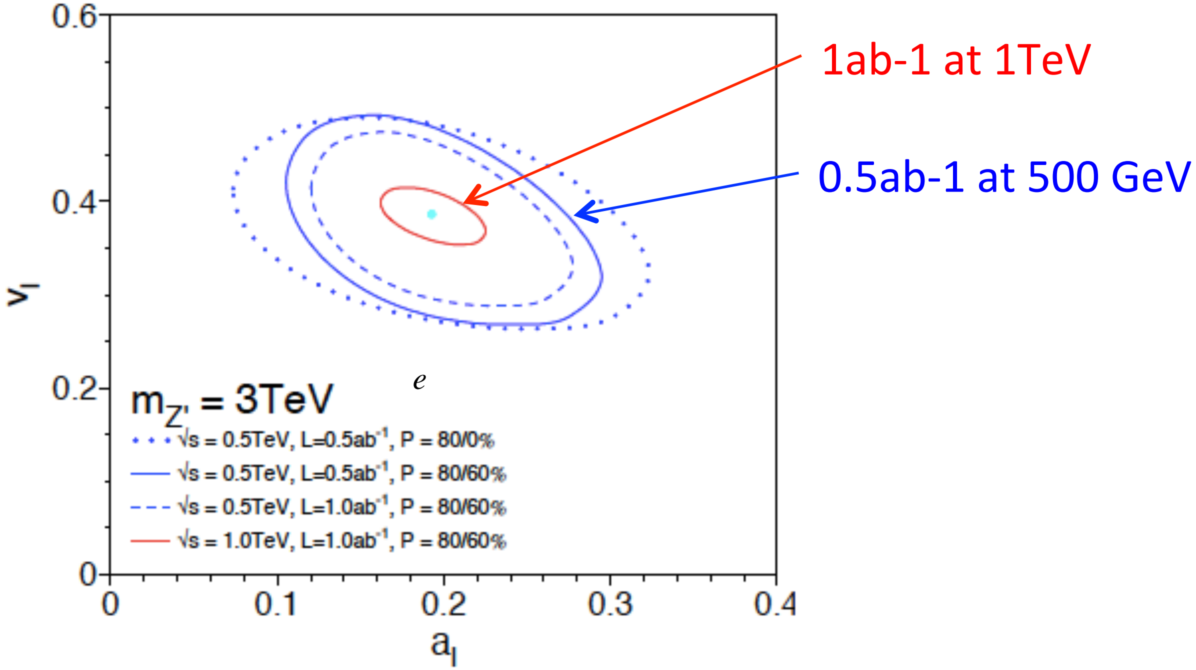


Distinguish variety of BSM models

Use beam polarization
(separates γ and Z, R and L)

Z' at ILC: TDR Study

e+e-→l+l-



Can determine the couplings (V and A) of Z' to leptons
Electron polarization is essential, positron polarization helps
ILC sample running scenario: 4ab-1 at 500 GeV

Hadron and Lepton Machines

FNAL Tevatron

Tevatron has a long list of glorious physics achievements (top discovery etc.)

For Higgs, however, Tevatron did not see clear signal even though ~20000 Higgs were produced. Needed to wait for LHC (~1M Higgs produced in Run 1)

At ILC, only a handful of Higgs (tens) will be needed

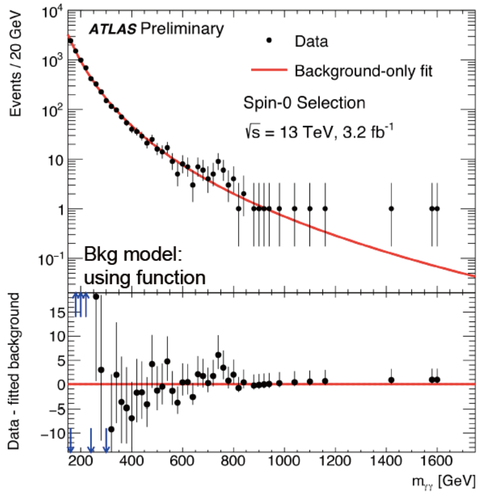
1 day of ILC@250GeV (lum.up.) ∼ 10 days of HL-LHC

Note: signals are quite complementary for ILC and LHC

e.g. LHC is good at colored particles, ILC at non-colored particles

X750

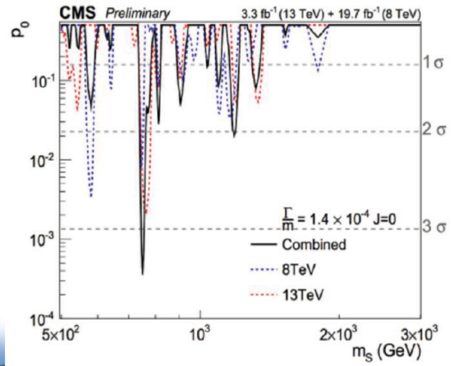
New particle fund?



8 TeV/13 TeV Combined p-value

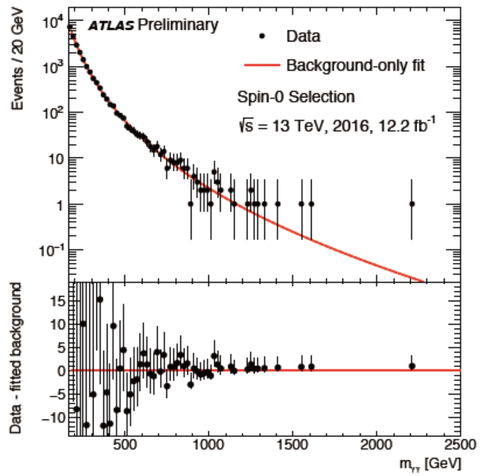
(assuming narrow width spin 0 resonance decaying to $\gamma\gamma$)

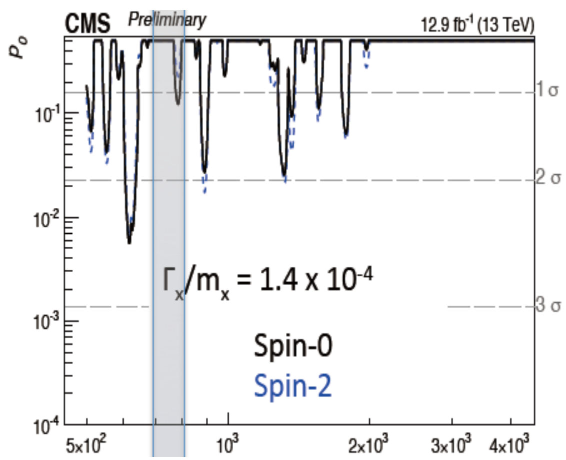
Maximum local significance: 3.4 sigma @ 750 GeV



No significant signal

ICHEP 2016





X750 and ILC

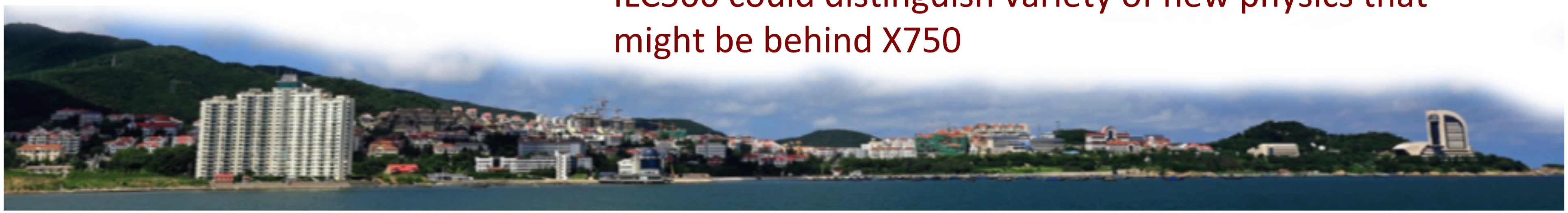
It is an excellent exercise opportunity for ILC

- Response to LHC results at higher energy
- LCC Physics WG produced a document (arChiv:1607.03829v28[hep-ph]):

	hWW hZZ	$hb\bar{b}$ $h\tau\tau$	$h\gamma\gamma$ hgg	$ht\bar{t}$	$h \to$ invis.	$h\tau\mu$	$t\bar{t}Z$	$e^+e^- \to$ $\gamma+$ invis.
Vectorlike fermions		X	X	X			X	
2 Higgs doublet	X	X	X	X				
Higgs singlet	X	X		X				
NMSSM	X	X	X	X	X			X
Flavored Higgs	X	X	X			X		
NR bound state		X		X				
Pion of new forces		X	X	X	X		X	X
RS radion	X	X	X	X			X	
RS graviton	X	X		X			X	

Table 2: Anomalies in precision measurements expected to be visible at the ILC for the models of the Φ discussed in this section.

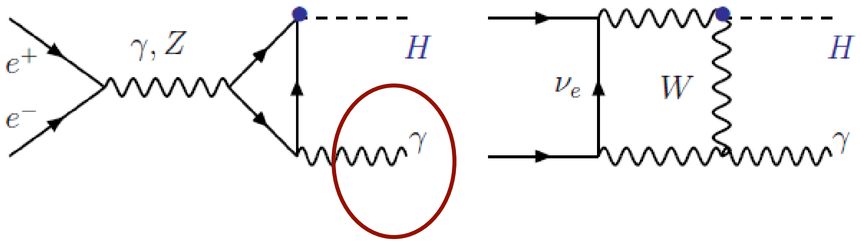
ILC500 could distinguish variety of new physics that might be behind X750



Direct X750 Production at ILC

Possible ways 1 TeV ILC can produce X750

- $\gamma\gamma \rightarrow$X750
  - gamma-gamma collider option
  - Almost guaranteed production
- e+e- $\rightarrow$ X750 γ
  - Effective X750-$\gamma\gamma$ vertex should exist
  - Production rate has uncertainty



No concrete proposal is advocated for actual upgrade/option scenarios.

ILC and X750 – a case study

- ILC can elucidate the physics behind X750 by precision measurements on Higgs, top etc.
- With energies ~1 TeV, ILC could produce X750 directly through e+e- at high energy or future $\gamma\gamma$ option
- ILC may be able to discover new particles related to X750 within its energy reach

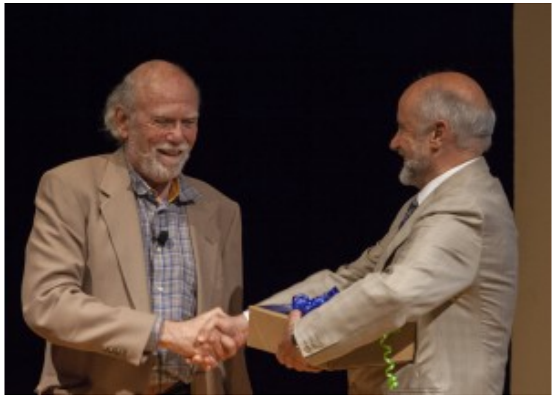
This is essentially what we have been advocating as goals of ILC
ILC provides excellent complementarity to LHC
- re-confirmed by the case study

ILC Project(Political) Status

ILC TDR Completed
June 12, 2013

Tokyo

Fermilab



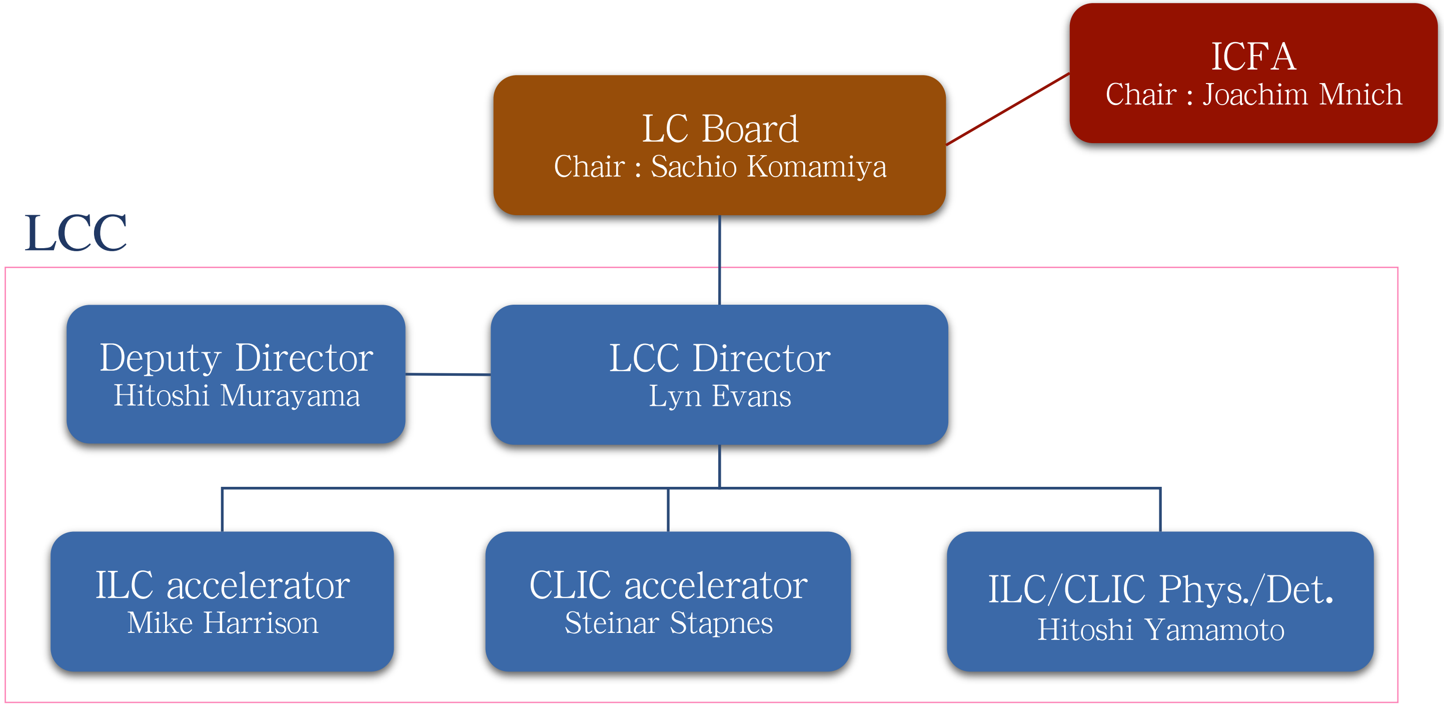
CERN

TDR 5 volumes

Culmination of many years of R&Ds

ILC is in principle ready to go technically (apart from some loose ends, cost reductions, etc.)

LCC (Linear Collider Collaboration)



- In full operation since June 2013
- Mandate is extended once and ends on December 31, 2016
- A new structure and its director is being discussed by an ICFA committee

International Supports

- European Strategy (March 22, 2013)
  - … 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.

- US P5 Report (March 23, 2014)
  - ‘As the physics case is extremely strong, all Scenarios include ILC support at some level through a decision point within the next 5 years’
  - ‘Unconstrained budget’ (Scenario C) :
    Play a world leading role in the ILC experimental program and provide critical expertise and components to the accelerator, should this exciting scientific opportunity be realized in Japan’

Also from ICFA, ACFA, KET(Germany), etc.

Science Council of Japan on ILC

Requested by MEXT; Report submitted on Sep 30 2013
(MEXT: Ministry of education, culture, sports, science and technology)

The conclusion of the report included:

- The Committee suggests that the government of Japan should (1) secure the budget required for the investigation of various issues to determine the possibility of hosting the ILC, and (2) conduct intensive studies and discussions among stakeholders, including authorities from outside high-energy physics as well as the government bodies involved for the next two to three years.

- In parallel, it is necessary to have discussions with the research institutes and the responsible funding authorities of key countries and regions involved outside of Japan, and to obtain clear understanding of the expected sharing of the financial burden.

MEXT ILC Advisory Panel

- $0.5M/year was appropriated for investigatory study in 2014 and 2015 each. $1M for 2016

- 'ILC Advisory Panel' was established under MEXT (Early 2014)
  - Report was to be completed end of March 2016 even though extendable (extended to 2017)
- Three working groups under the ILC Advisory Panel
  1. Particle&Nuclear Physics workging group

     On the ILC physics case with respect to other future projects
  2. TDR validation working group

     On the maturity of design and costing
  3. Human resources working group

     Can enough experts (exp. In accelerator) be secured?

Academic Experts Committee Interim Summary

June 25, 2015

Excerpts

‘The ILC is considered to be important because of its capability to investigate new physics beyond the Standard Model by exploring new particles and precisely measuring the Higgs boson and top quark. It should be also noted that the ILC might be able to discover a new particles which are difficult to be detected in LHC experiments.’

‘… it is necessary to closely monitor, analyze and examine the development of LHC experiments’

‘…it is important to have general understanding on the project by the public and science communities’

US-Japan on ILC

- Japanese federation of diet members for the ILC visited Washington DC
  - April 26-30, 2015
  - Round table with US counterpart at Hudson Institute
  - Round table at JSPS Washington DC branch
- MEXT visited Washington DC
  - 1st visit: February 11-12, 2016 (together with the 'federation')
  - 2nd visit: May 25, 2016 to talk to DOE
- MEXT-DOE joint 'discussion group' has started
  - Agreed to collaborate on cost reduction of ILC
    - Focused on SRF technology

US-Japan agreement on HEP

Ambassador: Caroline Kennedy　　MEXT Minister: Hakubun Shimomura

DOE: Jim Siegrist　　KEK DG: Masa Yamauchi

One item: Key Accelerator Technologies, including

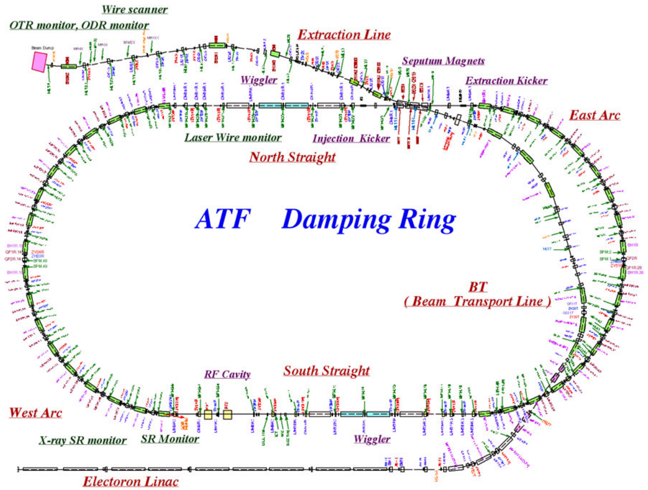
- Linear Collider Technologies
- High Intensity/Luminosity Accelerator Technologies
- Superconducting Accelerator Technologies, and
- Advanced Accelerator Technologies

Summary

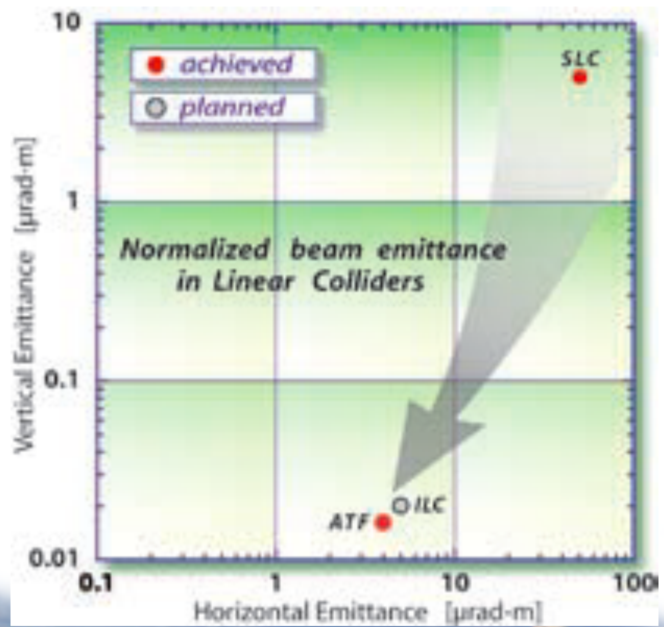
- ILC's cleanliness and control lead to significantly extended discovery potential for new physics that is complementary to HL-LHC.
- If LHC finds a new particle or a new phenomenon, ILC can elucidate physics behind it by precision measurements on Higgs, top, and fermion pair productions
- ILC may find new particles that are difficult at LHC
- The ILC technology is now ready
- Political supports are strong both domestically and internationally
- Japanese government is seriously evaluating cases for the ILC, and in parallel, initiating high-level contacts with other countries

Backup

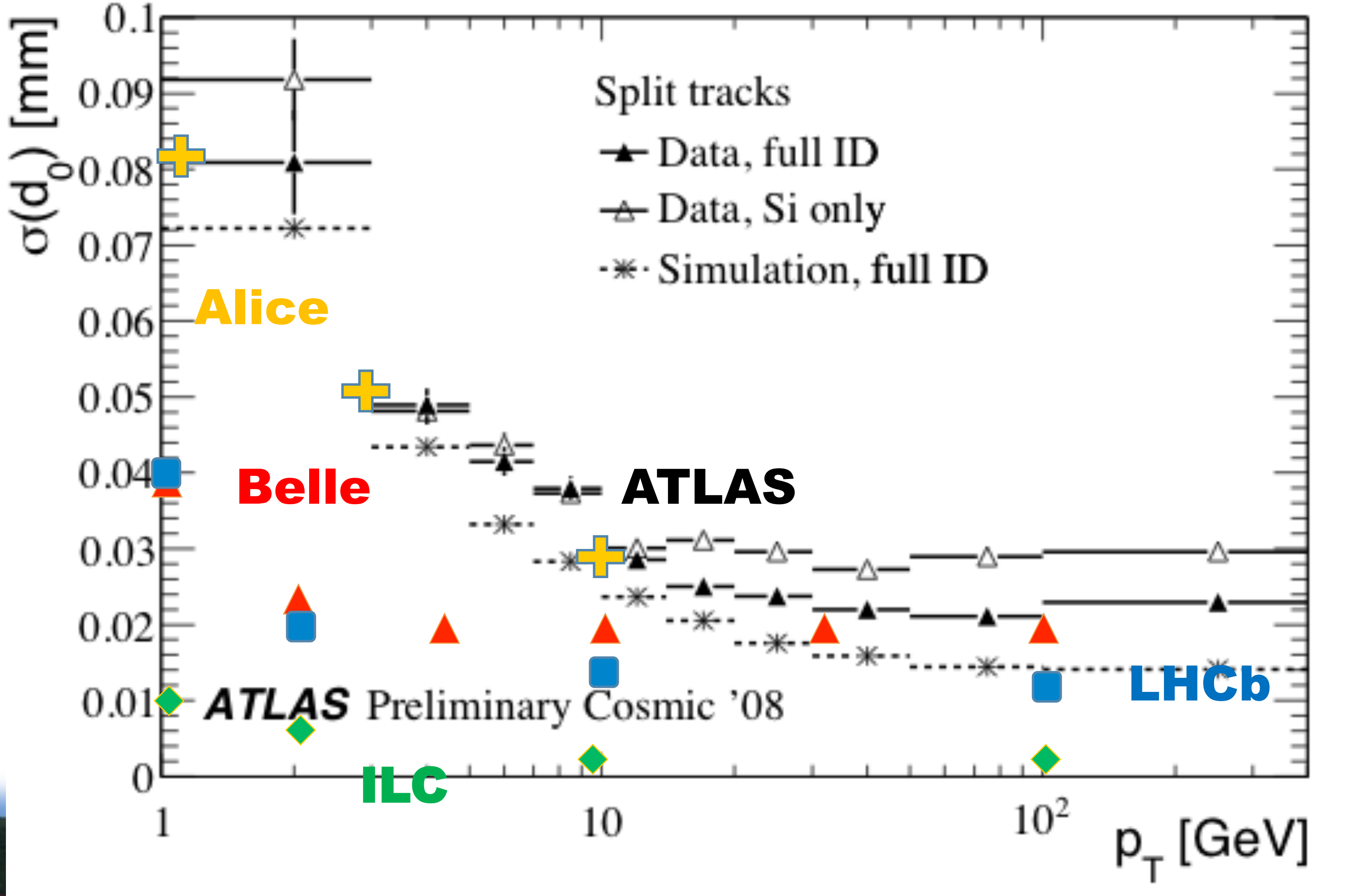
Small Emittance and Focusing



- Low emittance : KEK ATF (Accelerator Test Facility)
  - Achieved the ILC goal.
- Small vertical beam size : KEK ATF2
  - Goal = 37 nm, 44 nm achieved
    - No basic problem seen.
- Stabilize the beam at nm scale: KEK ATF2
  - Feedback system successful (FONT)



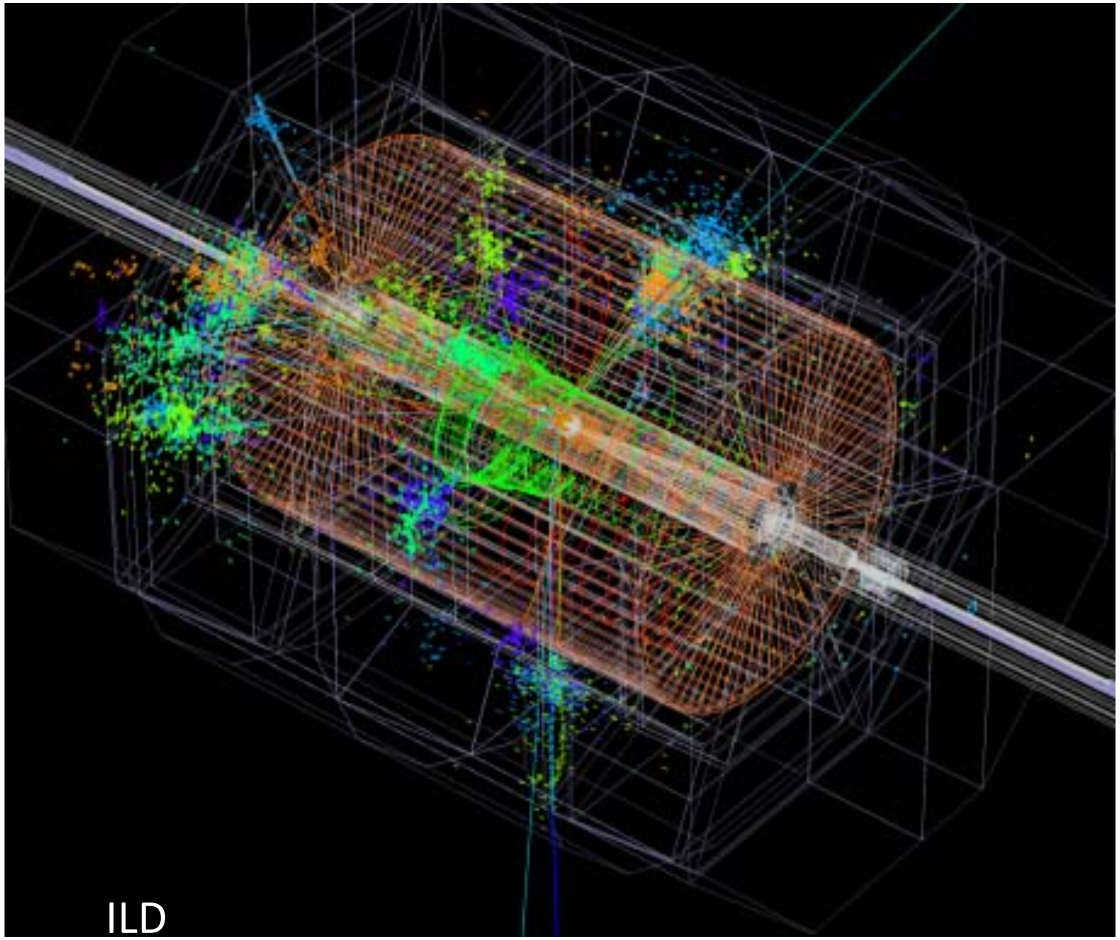
Impact parameter resolution



PFA
(particle flow algorithm)

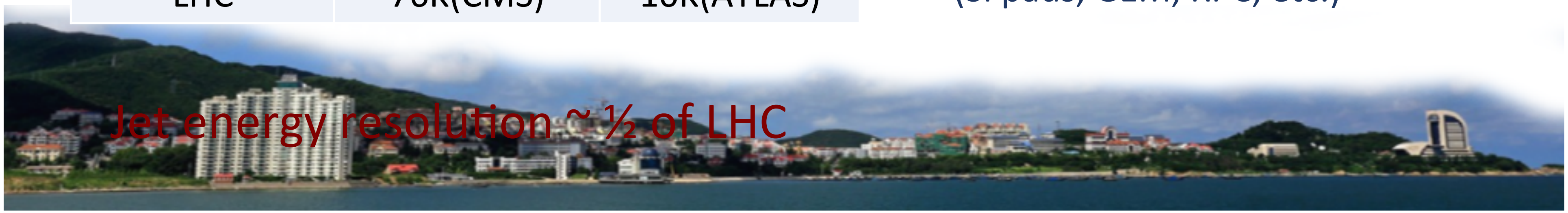
Jet Energy Measurement:

- Charged particles
  - Use trackers
- Neutral particles
  - Use calorimeters
- Remove double-counting of charged showers
  - Requires high granularity



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

$X10^3$ for ILC
Need new technologies !
(Si pads, GEM, RPC, etc.)

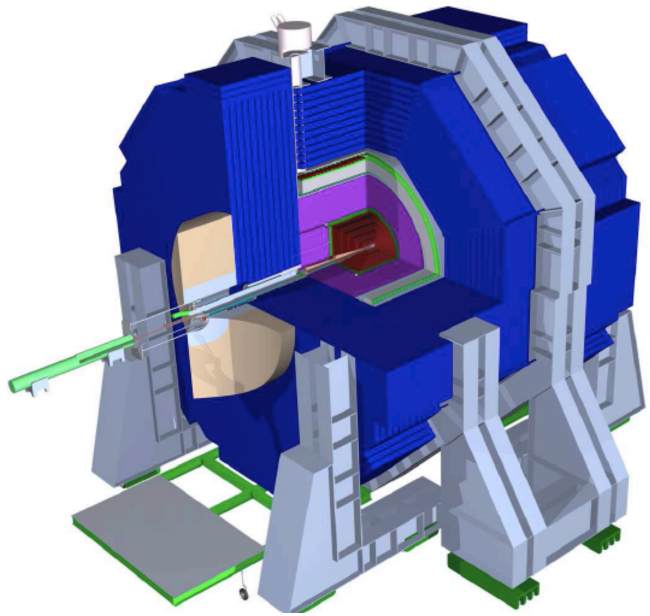


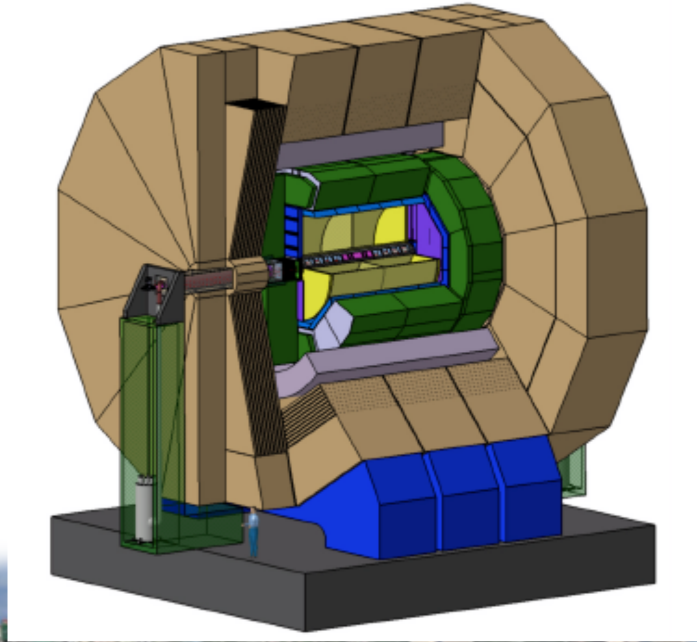
Jet energy resolution ~ ½ of LHC

Two Detectors

Based on PFA idea

- SiD
    - High B field (5 Tesla)
    - Small ECAL ID
    - Small calorimeter volume
        - Finer ECAL granularity
    - Silicon main tracker
- ILD
    - Medium B field (3.5 Tesla)
    - Large ECAL ID
        - Particle separation for PFA
    - TPC for main tracker





MEXT on the ILC

MEXT: Ministry of education, culture, sports, science and technology