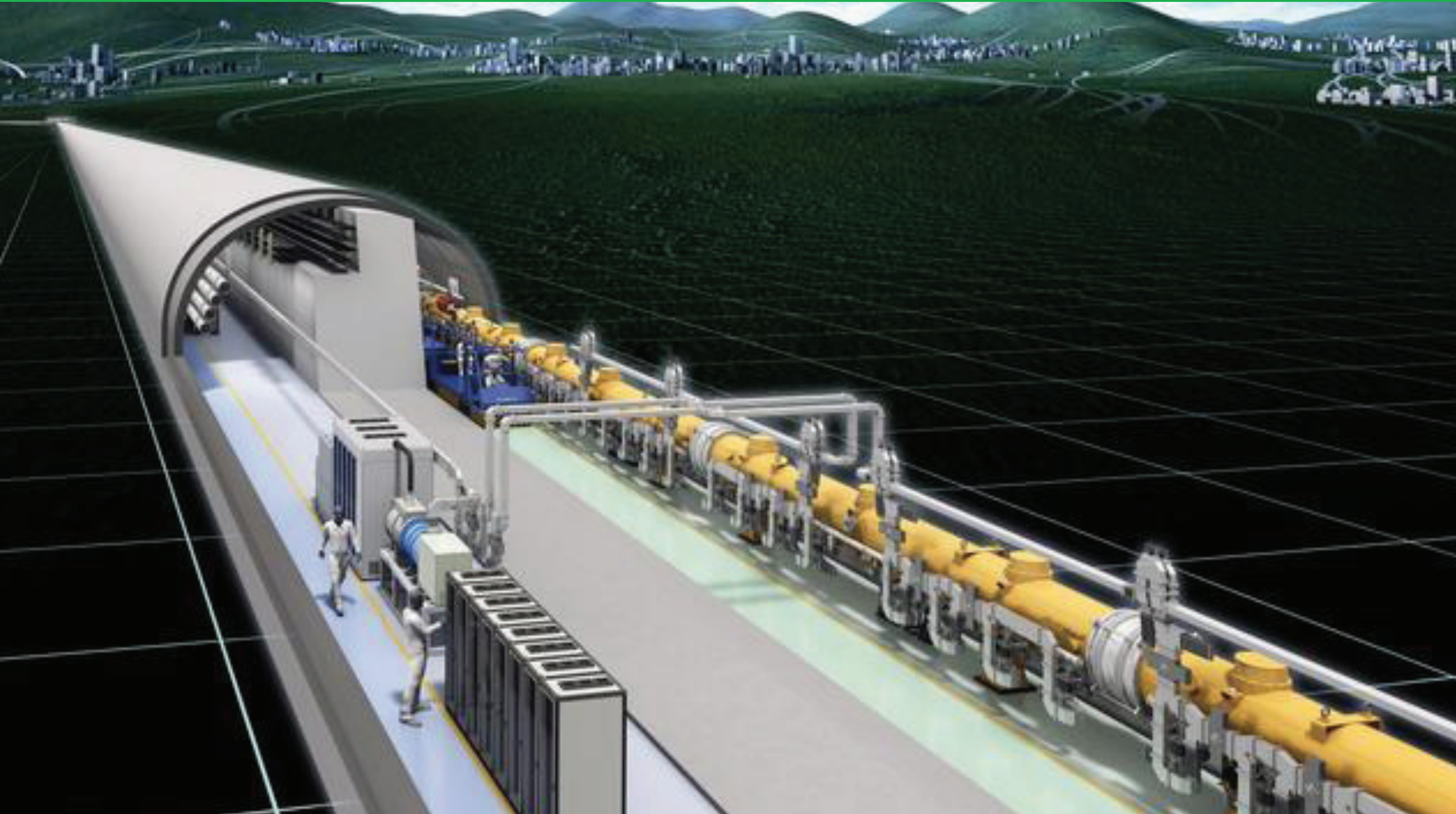
International Linear Collider, the Latest Status towards Realization

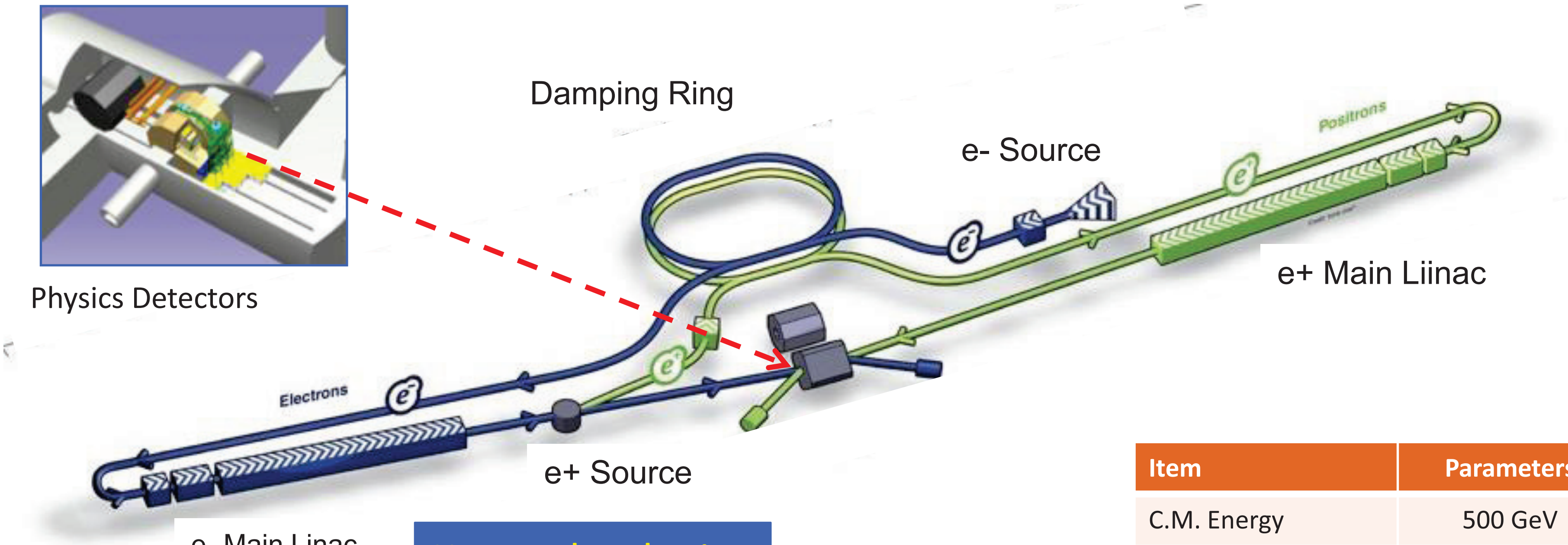
IPAC2016 Busan, Korea

9th May 2016

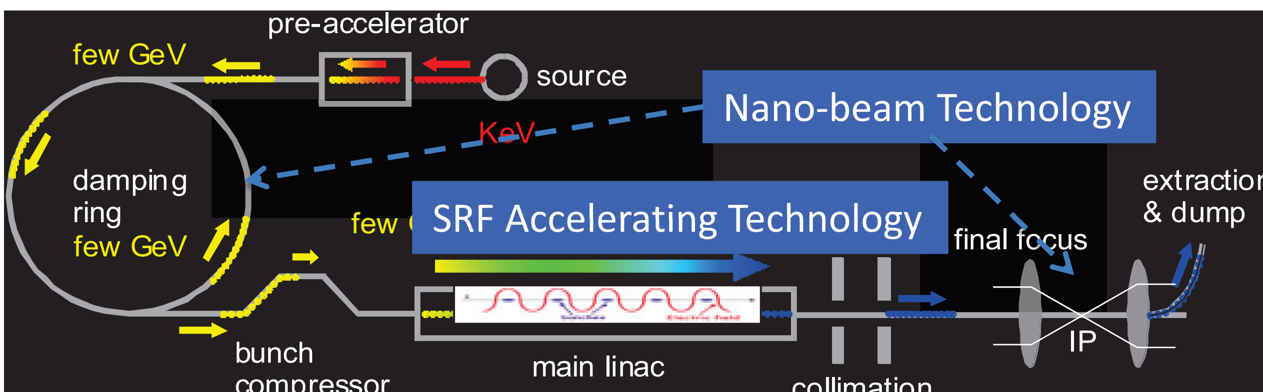
Sachio Komamiya The University of Tokyo



ILC Acc. Design Overview (in TDR)



Key Technologies



Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	**5.9** nm
SRF Cavity G. Q_0	**31.5** MV/m Q_0 = 1x10^{10}

Many accelerator slides are stolen from Akira Yamamoto and other scientists.

Advantages of linear collider

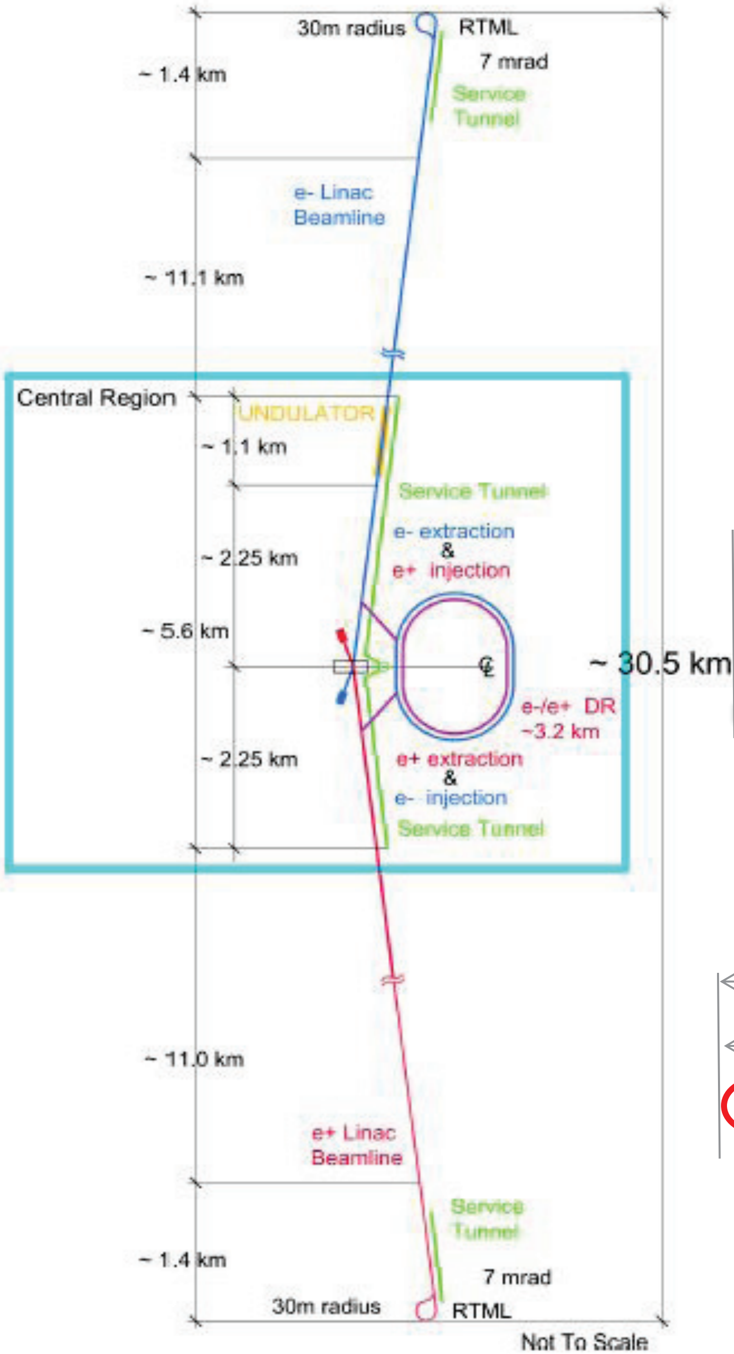
(1) **No energy loss due to synchrotron radiation**

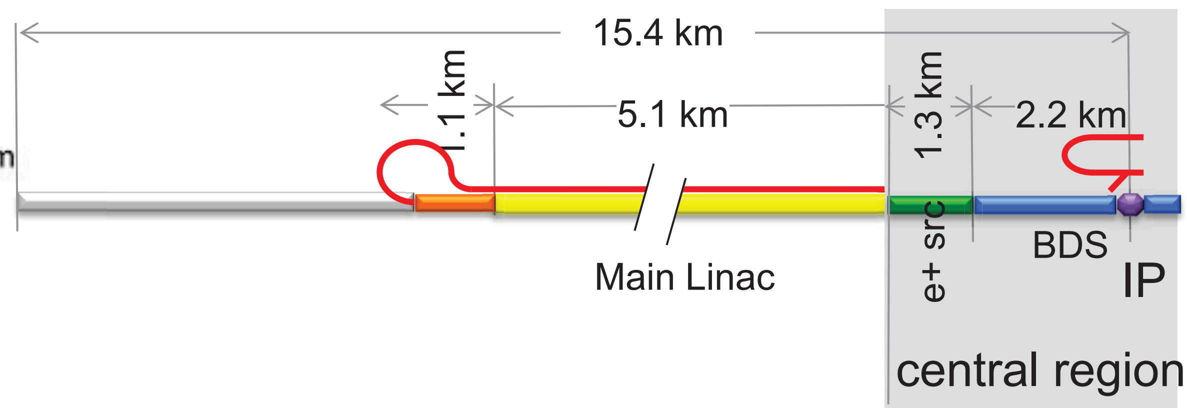
(c.f. circular colliders $\Delta E \propto -(E/m)^4 R^{-1}$)

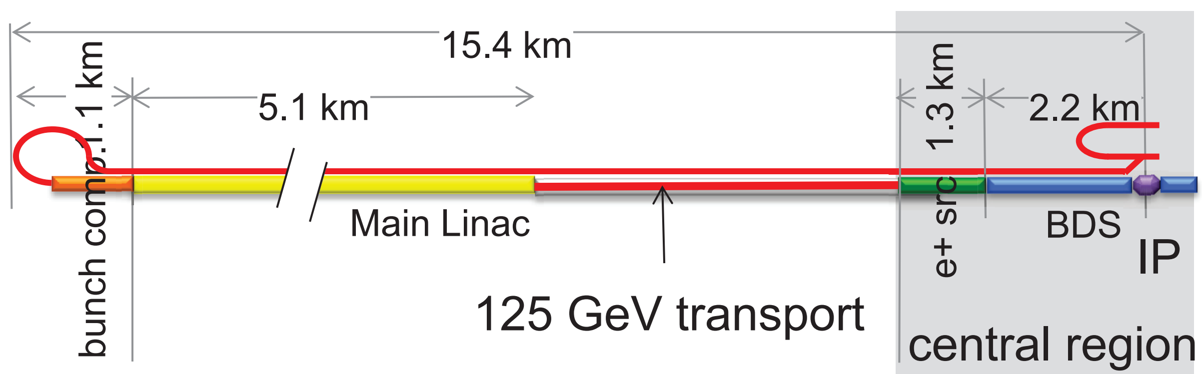
(2) **Extendability (length ⇒energy)**

(3) **Beam Polarization**

(4) **Energy Scanning**







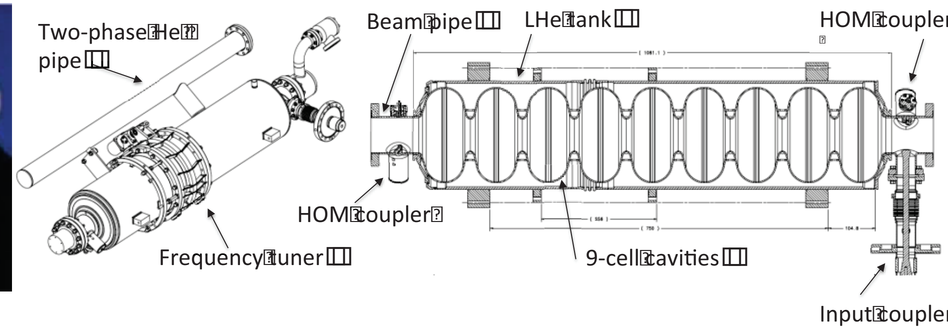
Technical Readiness for the ILC

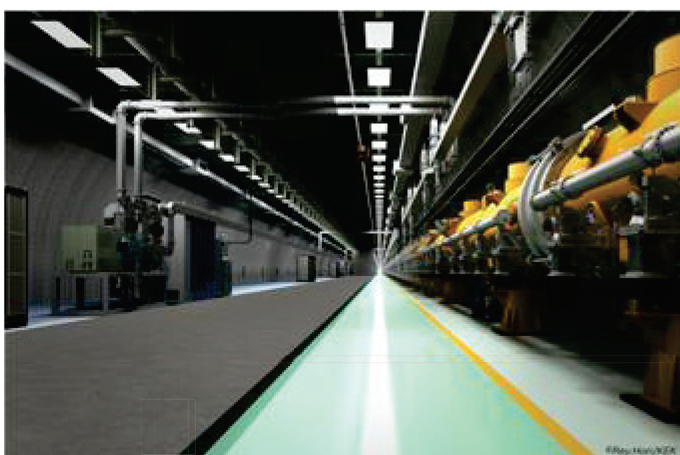
(1) Superconducting RF System

SRF Facilities anticipated for ILC Hub/Consortium

AMTF @DESY/E-XFEL, CM *STF-CFF @ KEK* *ASTA @ FNAL, TEDF @ JLab*

SCRF Linac Technology





1.3 GHz Nb 9-cellCavities	14,742
Cryomodules	1,701
SC quadrupole pkg	673
10 MW MB Klystrons & modulators	436 *

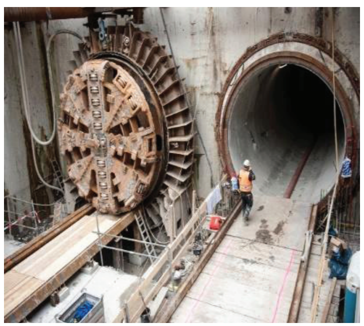
* site dependent

Approximately 20 years of R&D worldwide
→ Mature technology, overall design and cost

Construction of EU-XFEL

Tunnel construction

Jun/2010



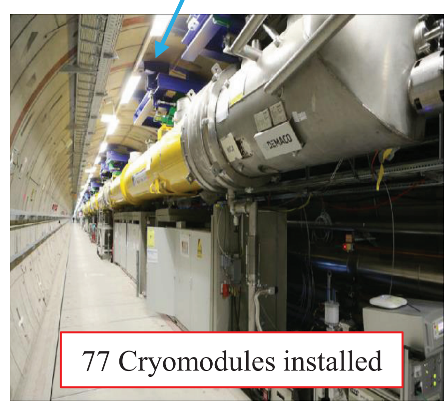
Jul/2011

Largest SCRF Linac (at present) & 1/20 scale of ILC

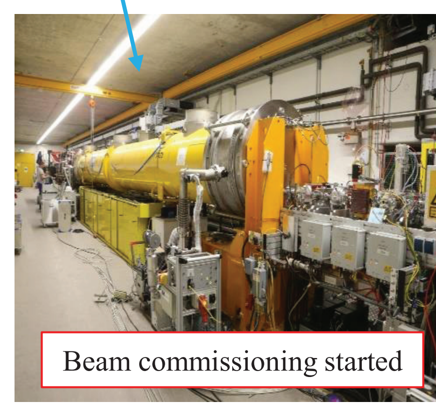
Short history for EU-XFEL:

- 2009 EU-XFEL organization started
- 2010 Tunnel excavation started
- 2011 Excavation finished
- 2012 Tunnel maintenance finished
- 2014 1st cryomodule installed
- 2015 Beam commissioning for injector started
- 2016 77 CMs installed; Beam commissioning for Main linac

Under construction



77 Cryomodules installed

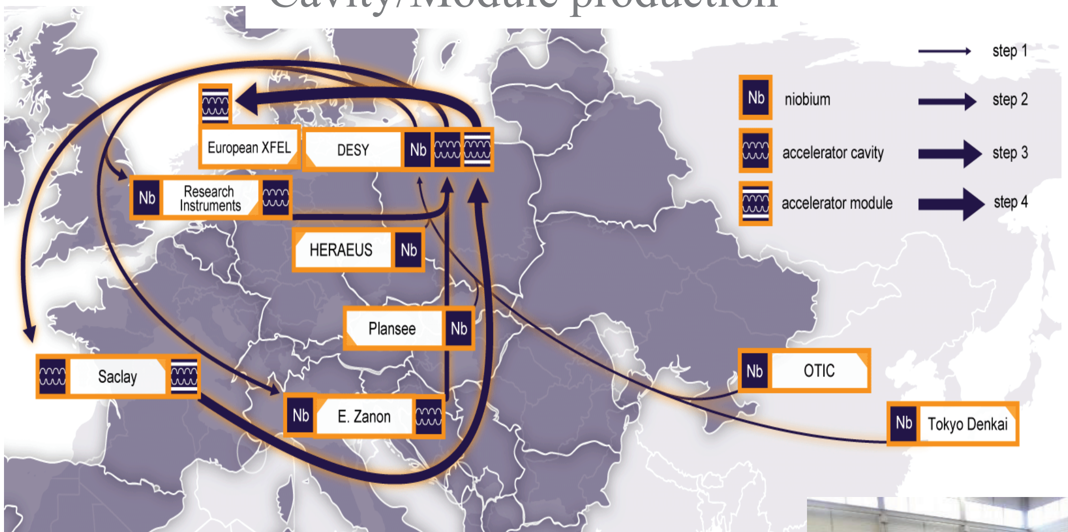


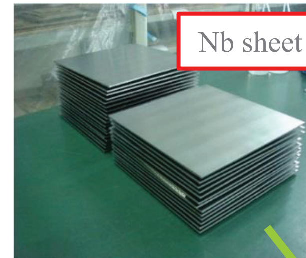
Beam commissioning started

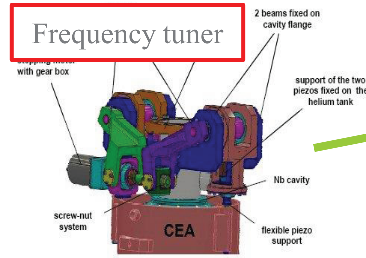
Courtesy of DESY

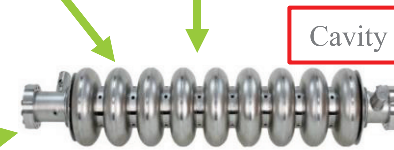
Production flow for SRF items in EU-XFEL

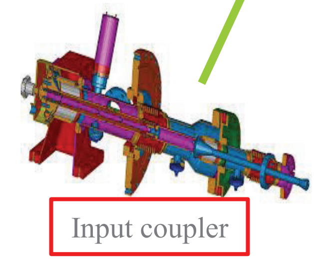
Cavity/Module production











Coupler testing

Cavity string
Module assembly

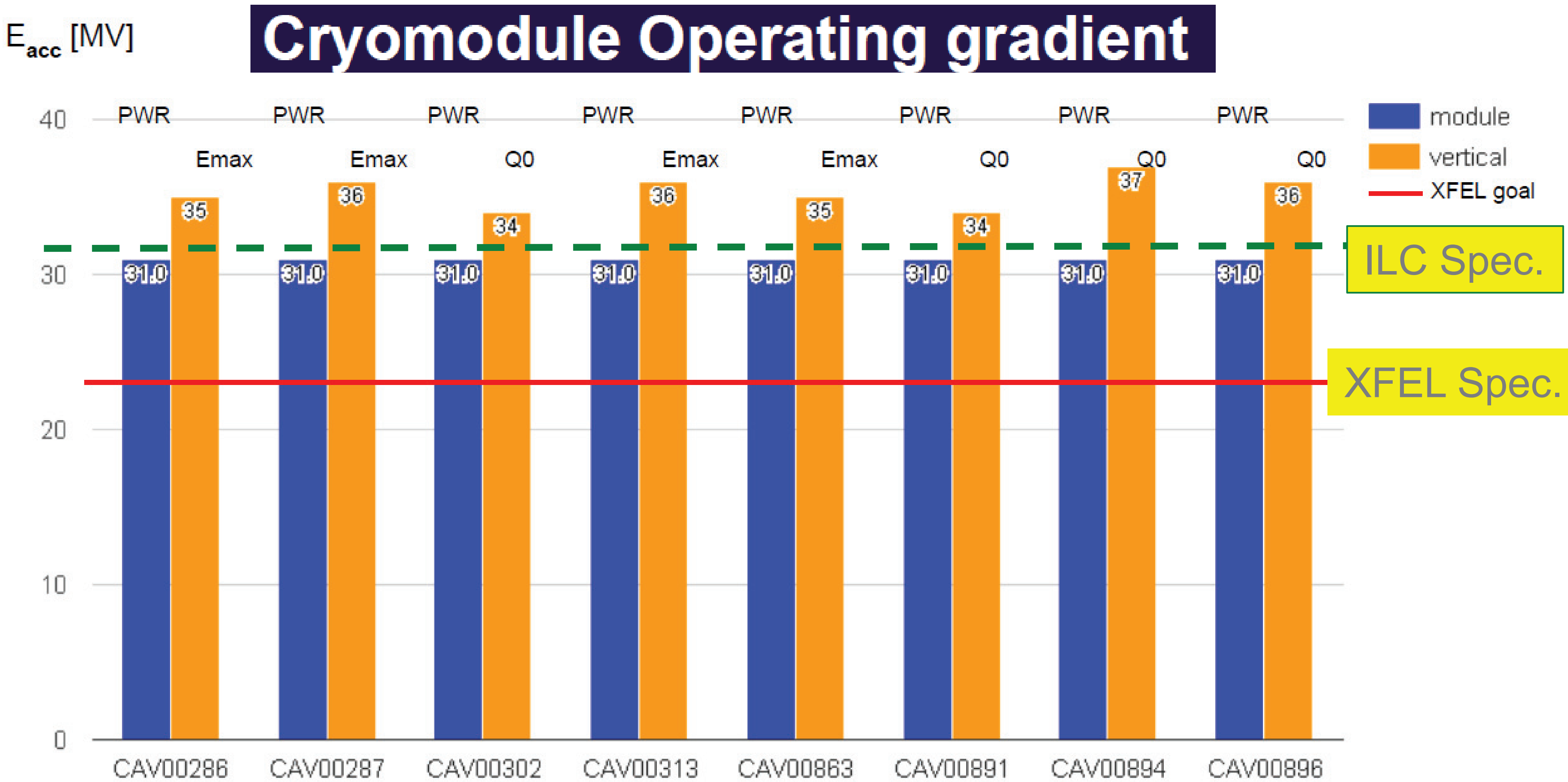
Cavity testing
Module testing

- ✓ ~14,000 Niobium sheets
- ✓ ~800 SC Cavities
- ✓ ~800 Input Couplers
- ✓ ~100 Cryomodules

~1/20 scale of ILC!

Courtesy of DESY

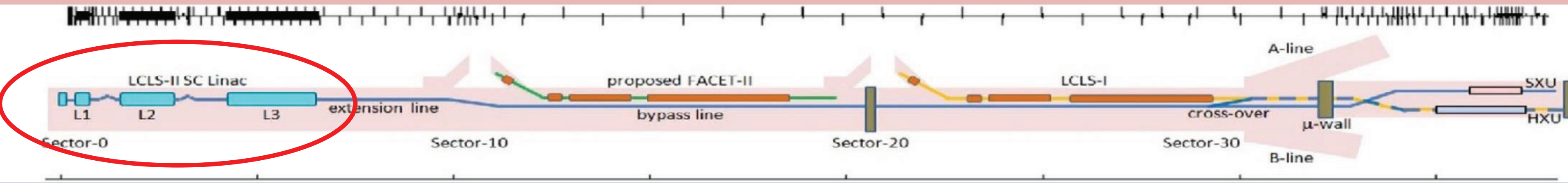
Cryomodule Performance : XM59



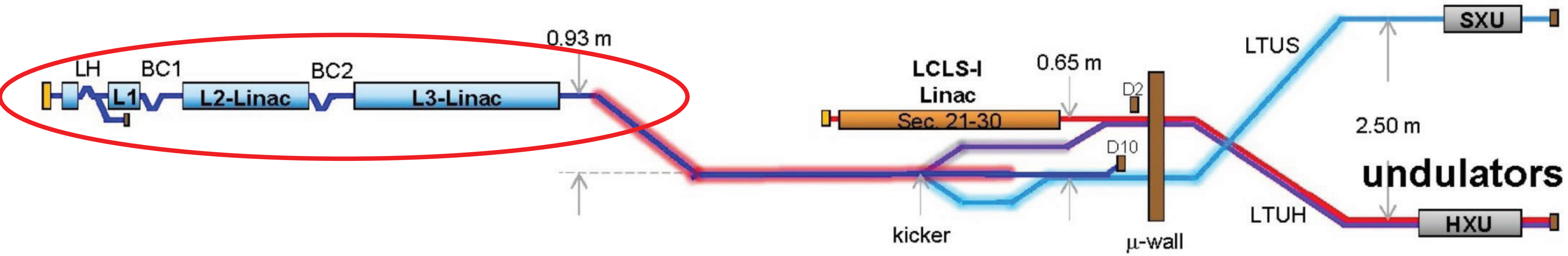
$$\langle E_{acc} \rangle = 31 \text{ MV/m}$$

XM59 is an excellent module, assembled after the change of CR procedure.

US LCLS-II SC accelerator Status



4GeV CW SC Linac in SLAC tunnel, using 35 cryomodules, which is similar to ILC



Proto-type Cryomodule (JLAB)

Proto-type Cryomodule (FNAL)

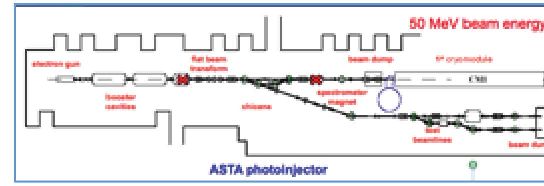
Fermilab : CM2 reached <31.5 MV/m >

CERN Courier December 2014

ACCELERATORS

ILC-type cryomodule makes the grade

For the first time, the gradient specification of the International Linear Collider (ILC) design study of 31.5 MV/m has been achieved on average across an entire ILC-type cryomodule made of ILC-grade cavities. A team at Fermilab reached the milestone in early October. The cryomodule, called CM2, was developed to advance superconducting radio-frequency technology and infrastructure at laboratories in the Americas region, and was assembled and installed at Fermilab after initial vertical testing of the cavities at Jefferson Lab. The milestone – an achievement for scientists at Fermilab, Jefferson Lab, and their domestic and international partners in superconducting radio-frequency (SRF) technologies – has been nearly a decade in the making, from



CM2 in its home at Fermilab's NML building, as part of the future Advanced Superconducting Test Accelerator. (Image credit: Fermilab.)

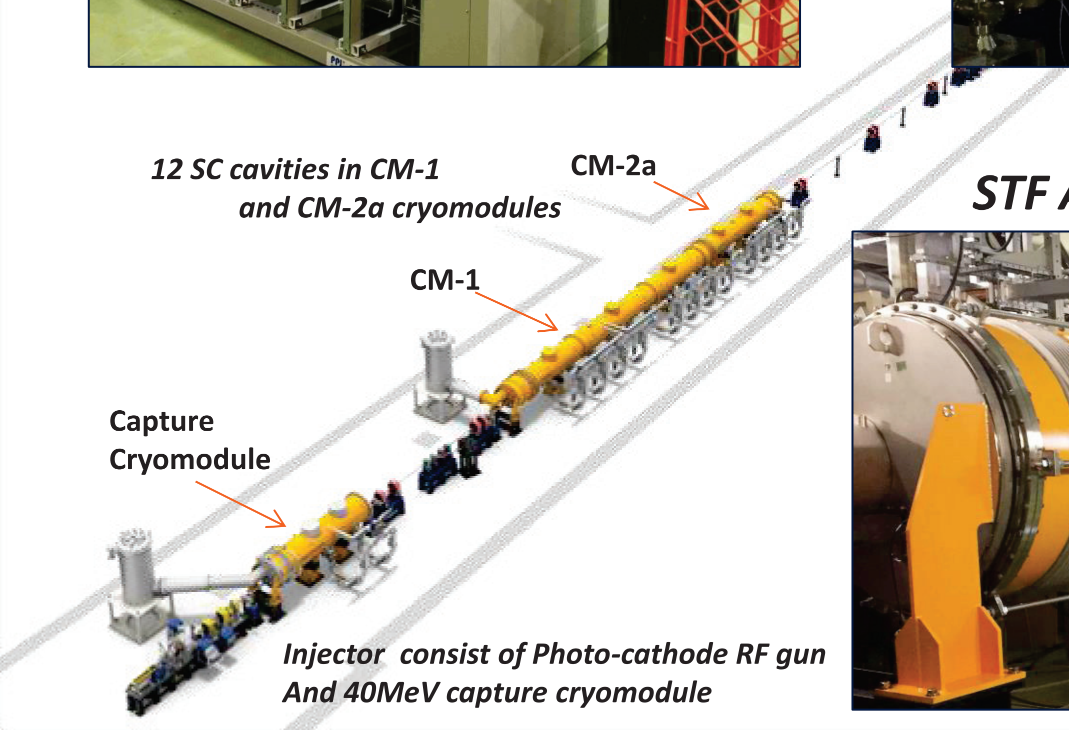
Cavity	Gradient (MV/m)
1	31.9
2	30.8
3	31.8
4	31.7
5	31.5
6	31.3
7	31.6
8	31.4

Cryomodule test at Fermilab reached < **31。5** > MV/m, exceeding ILC specification

STF Accelerator (ILC test SC accelerator in KEK/STF)

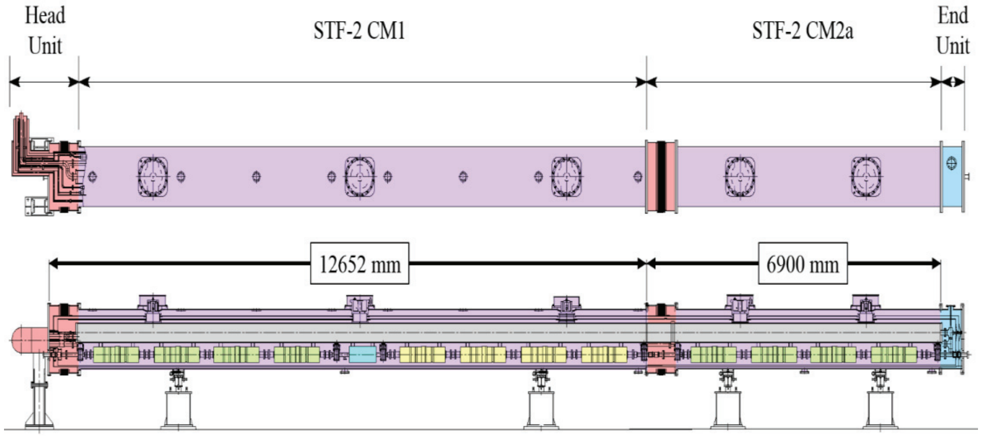
New MARX modulator for MBK

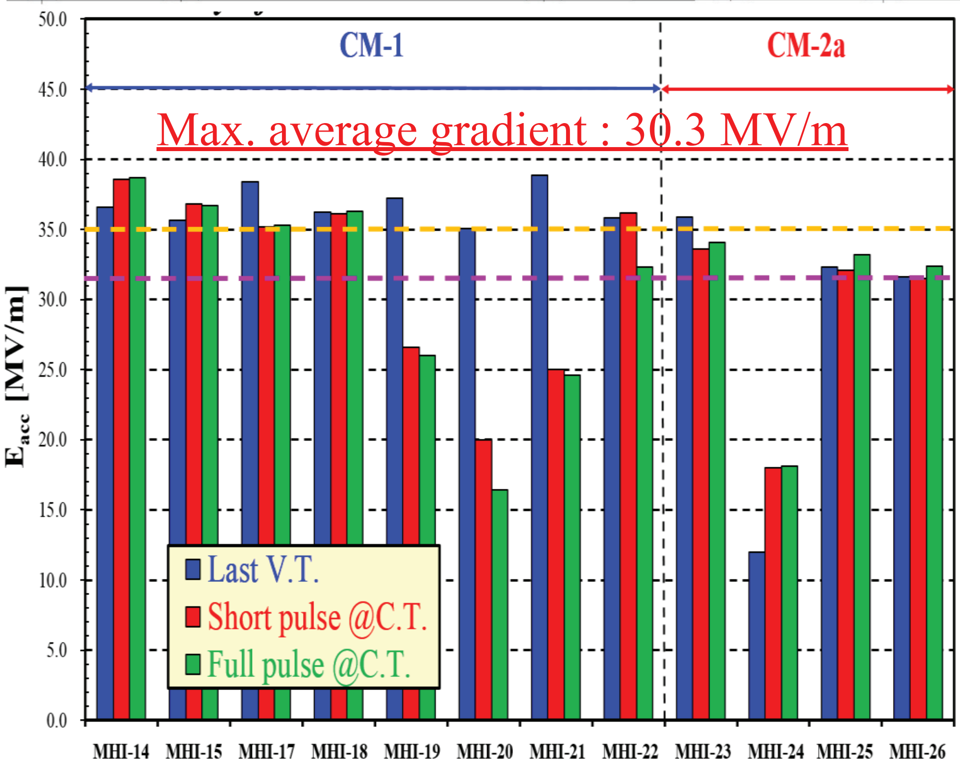
New RF power distribution (ILC-TDR design)



STF Accelerator (400MeV beam energy)

Cavity Performance in STF-2 Cryomodule





Assembly work and experiment were done with company persons in STF!(model case for ILC)

Results:

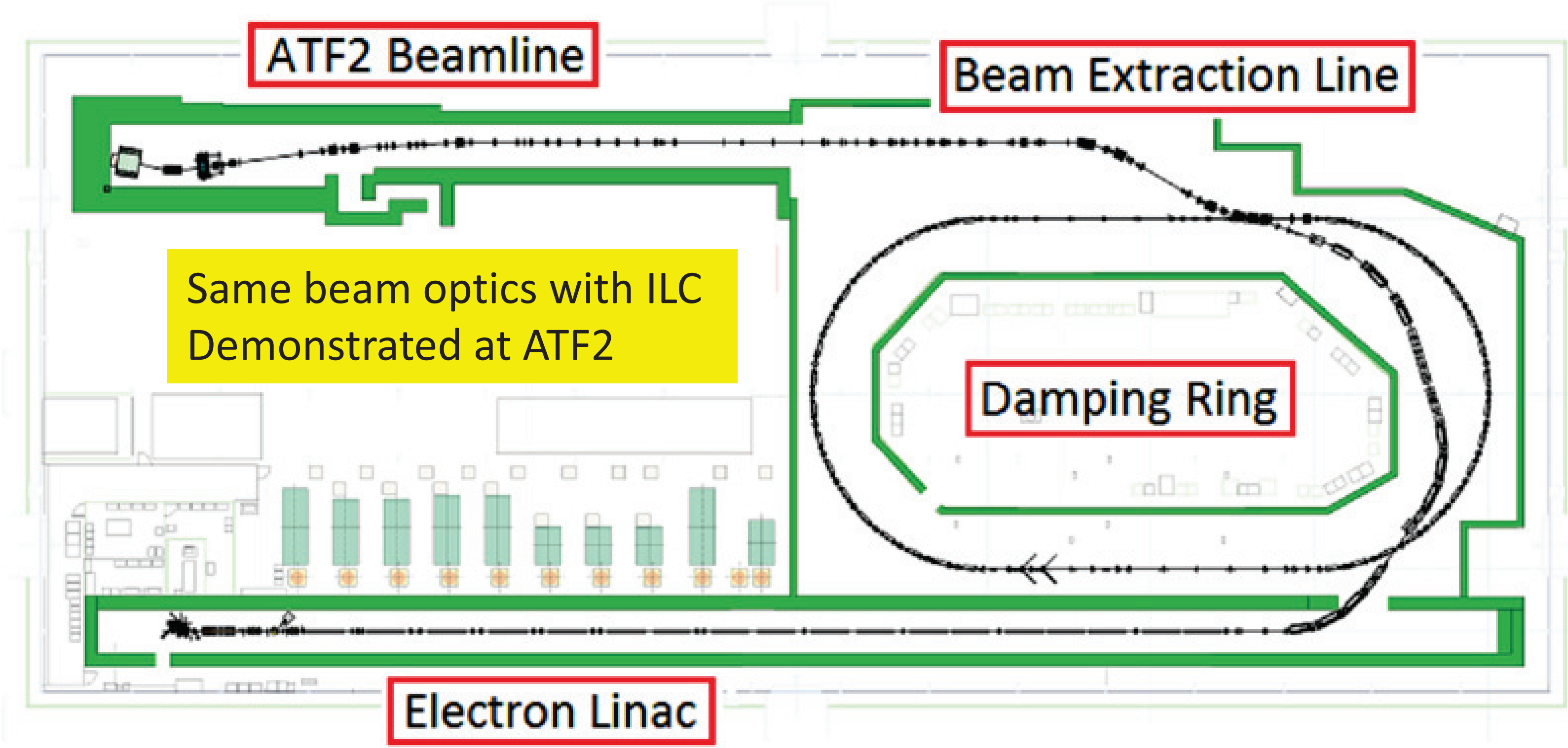
- 8 of 12 cavities above 31.5 MV/m
- Performance degradation for 3 cavities by field emission
- No problem for 12 input couplers
- No problem for 12 tuners & piezos

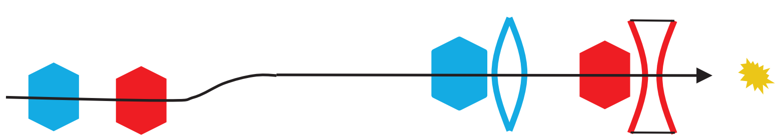
Future Plan:

- Q_0 measurement
- 12 cavities operation
- Beam commissioning

Waveguide system completed (just recently)

(2) Nano beam technology (Damping Ring &Final Focus)





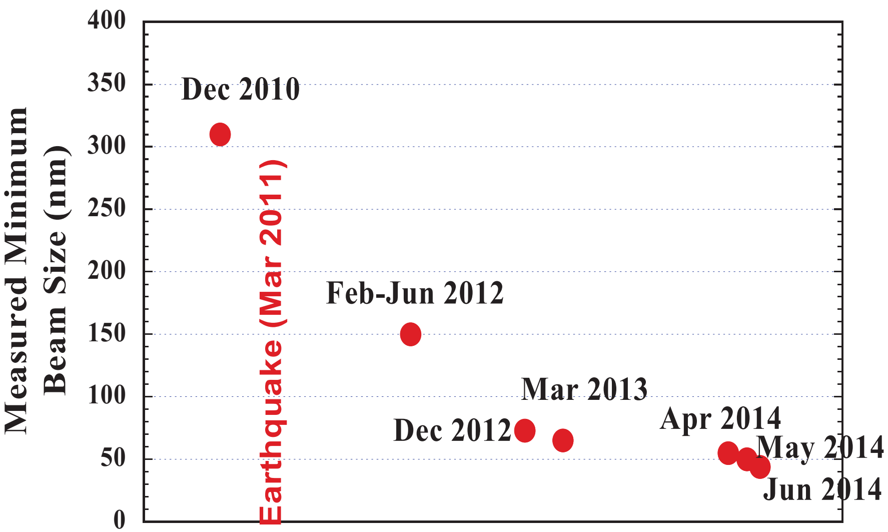
Local chromatic corrections

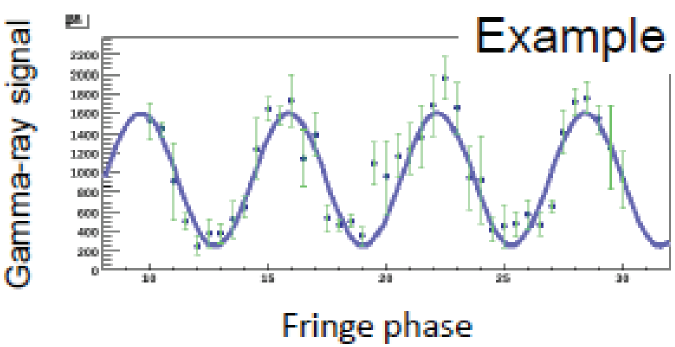
Goal 1:
- demonstrate optics, tunability

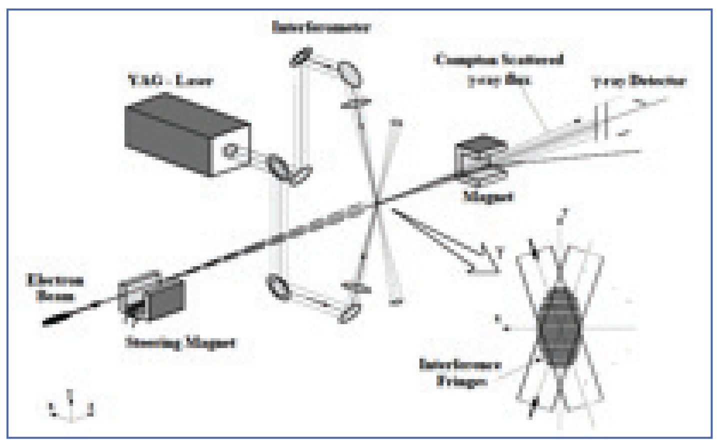
Goal 2:
- beam stabiization through feedback

From Kubo at al

Local chromatic correction at final focus progress at ATF2





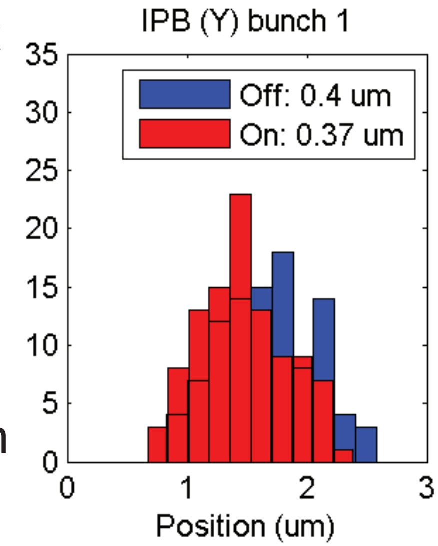


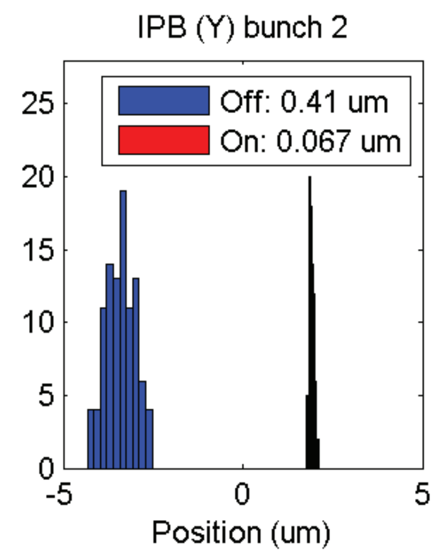
Average Beam Size 44 nm observed in 2014
(Goal : **37** nm, corresponding to **6** nm at ILC)

FONT feedback at IP

Two bunchlets run at ATF2

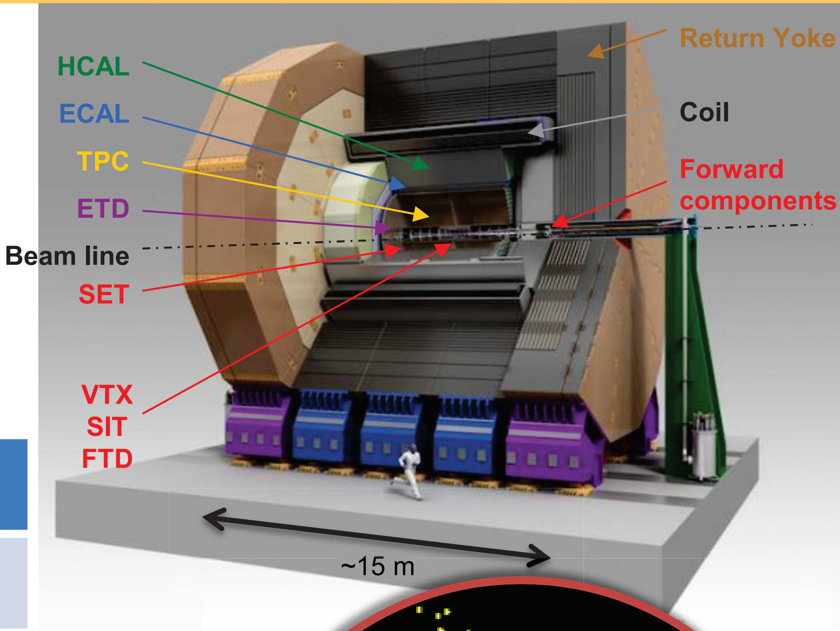
1st bunchlet
not corrected
2nd bunchlet
corrected
jitter 410nm to 67nm





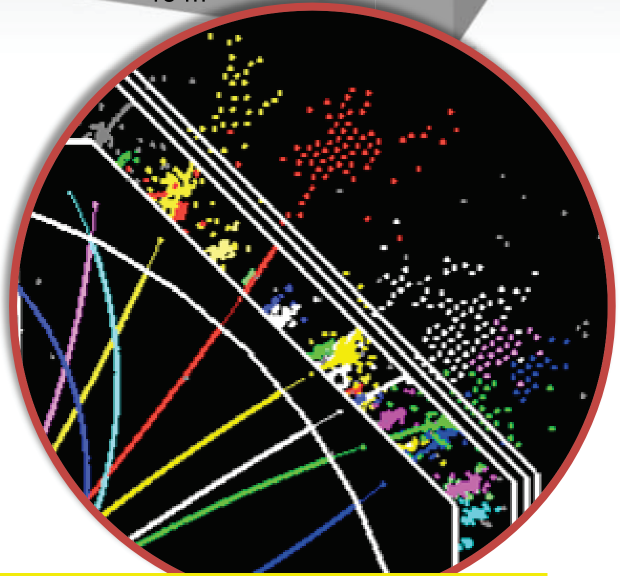
ILC Detector R&D (ILD, SiD)

- **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

International Organization after TDR

ICFA
Chair: J. Mnich

FALC
Chair: J. Womersley

Program Adv. Committee
PAC – Chair: N. Holtkamp

Linear Collider Board
LCB – Chair: S. Komamiya

KEK
Planning Office for the ILC

ILC Project Unit, Coordination Unit

Regional Directors
- B. Foster (EU)
- H. Weerts (AMs)
- A. Yamamoto (AS)

Linear Collider Collab.
LCC
- Director: L. Evans

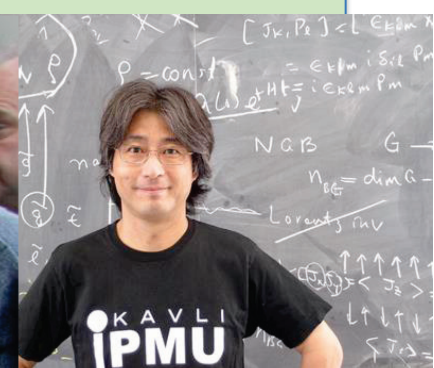
Deputy (Physics)
– H. Murayama

Assoc. Directors

ILC
– M. Harrison
(Deputy)
H. Hayano, N. Walker

CLIC
– S. Stapnes

Physics & Detectors
– H. Yamamoto



ILC Site Candidate Location in Japan: Kitakami

Supports from the World

European Strategy approved by CERN Council, EC June 2013

Chair: Tatsuya Nakada (Swiss Federal Institute of Technology Lausanne)

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.*

Asia ACFA-HEP Statement on ILC

Chair: Mitsuaki Nozaki (KEK) July 2013

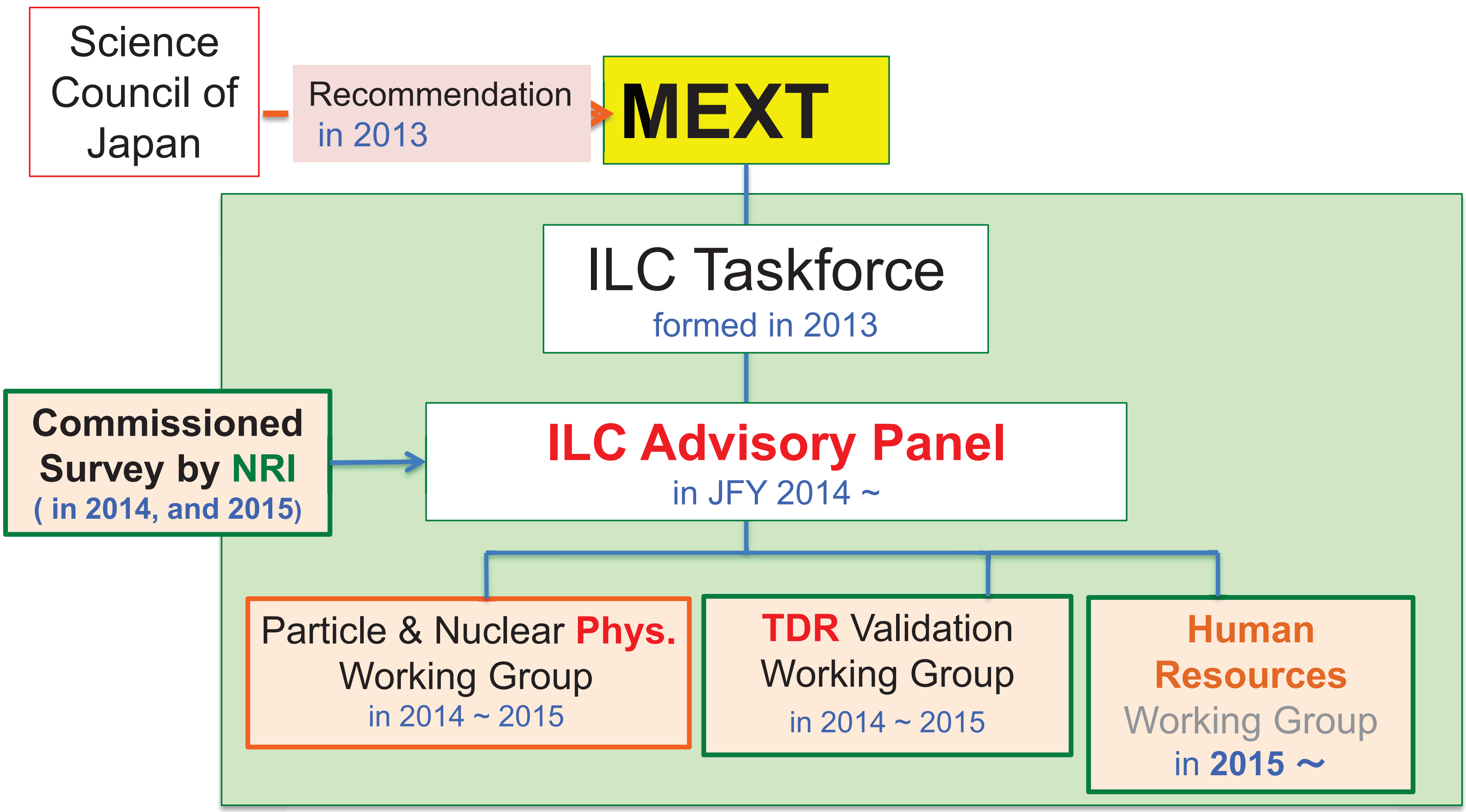
USA

Particle Physics Project Prioritization Panel (P5) Report, May 2014

Chair: Steve Ritz (UC Santa Cruz)

The Position of MEXT and the Japanese Government towards the ILC

ILC being studied officially by the MEXT Japan



Federation of **Diet members** to promote a construction of international laboratory for ILC

31st July 2008 established a suprapartisan ILC supporters

White House July 2014

Renewed on 1st Feb 2013
lead by Takeo Kawamura

(July 2008～)

President	Kaoru Yosano
Deputy	Yukio Hatoyama
Secretary-General	Takeo Kawamura
Directors	Yoshihiko Noda
Director	Norihisa Tamura
	Masamitsu Naito

New Officers

Supreme advisor	Kaoru Yosano
President	Takeo Kawamura
Secretary-general	Tatsu Shionoya

> 150 Diet Members

Supporter of Industrial Sector : Advanced Accelerator Association of Japan (AAA)

Established in June 2008 ⇒ Reformed as a general incorporated organization in 2014

Industry: 100 companies (Mitsubishi HI、Toshiba、Hitachi、Mitsubishi Electric、Kyoto Ceramic et al.) Academy: 40 institutes (KEK, Tokyo、Kyoto、Tohoku, Kyushu, RIKEN, JAEA et al.)

AAA homepage http://aaa-sentan.org

Supreme advisor	Kaoru Yosano
President Emeritus	Masatoshi Koshiba
President	Takashi Nishioka (Mitsubishi HI)
Trustee	Masanori Yamauchi (KEK)
〃	Akira Maru (Hitachi)、
〃	Yasuyuki Ito (Mitsubishi Electric)
〃	Shigenori Shiga (Toshiba)、
〃	Akira Noda (Kansei University)
〃	Masayuki Inagaki (Kyoto ceramic)
Auditor	Sachio Komamiya (The University of Tokyo)

Necessary steps towards the approval

1. Technology Choice (2003)

2. R&D and design of the machine/detectors by the international team
   ⇒ Technical Design Report (2013)

3. Official investigation and reviews of the ILC project by MEXT (now)

4. To facilitate / prepare intergovernmental discussions for sharing of cost human resources and the schedule without commitment (starting).

5. MEXT green signal
6. Endorsement of CSTP (Council of Science, Technology and Innovation; chair: Prime Minister)
7. Cabinet decision

8. International agreement with commitment ⇒ Establishment of ILC Lab

Time line for the ILC project

Years need

2 Preparation period Continuation of high-tech R&D (now)

4 Preparation for the ILC construction (with real budget)

9 Construction

6th year - Start Installation

7th year- Start of step-by-step accelerator test

1 Beam Commissioning

~8 Physics Run (500 GeV, 350 GeV, 250 GeV)

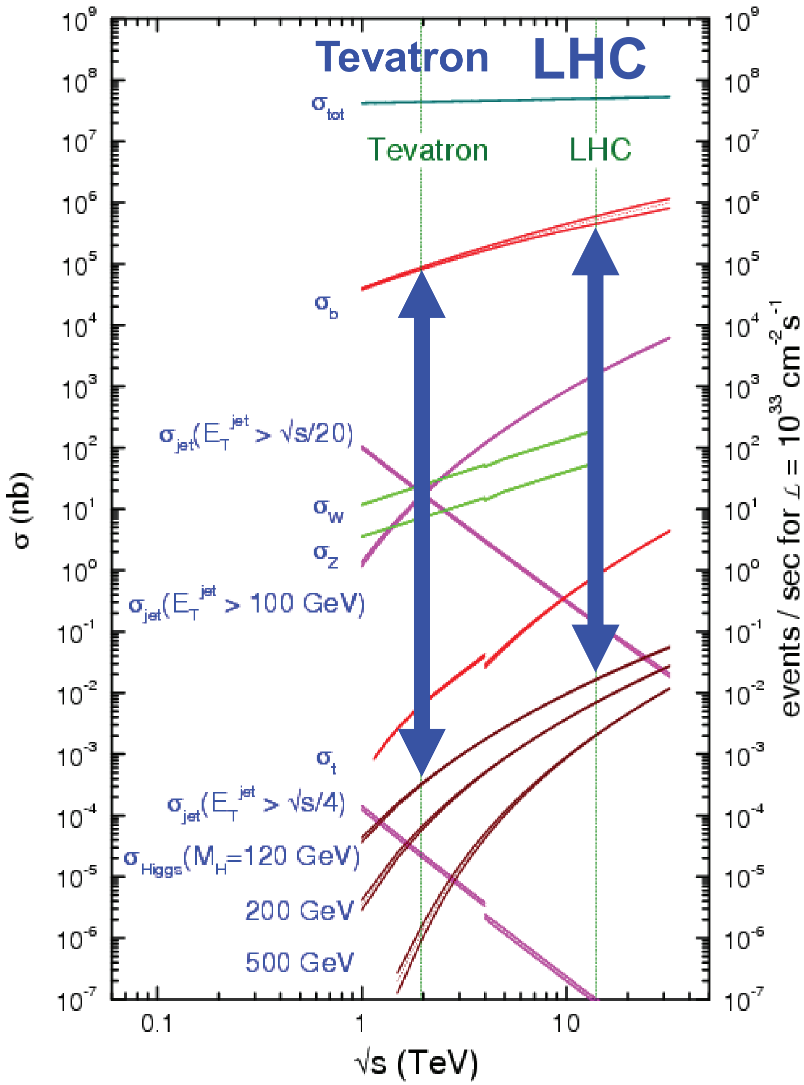
~ Run with Luminosity upgrade (500 GeV, 250 GeV)

TBD Energy upgrade (~ 1TeV)

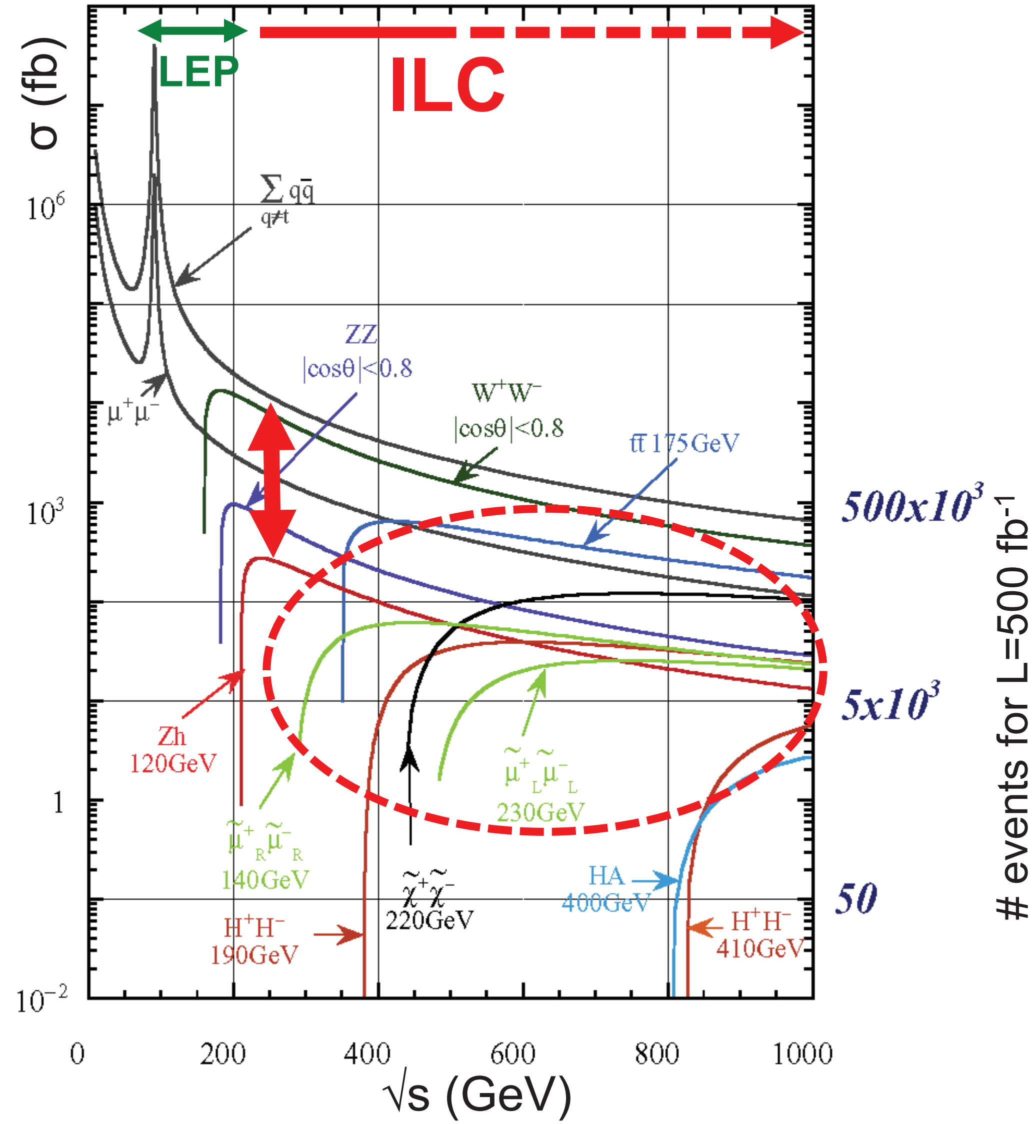
Physics at ILC

Cross Sections

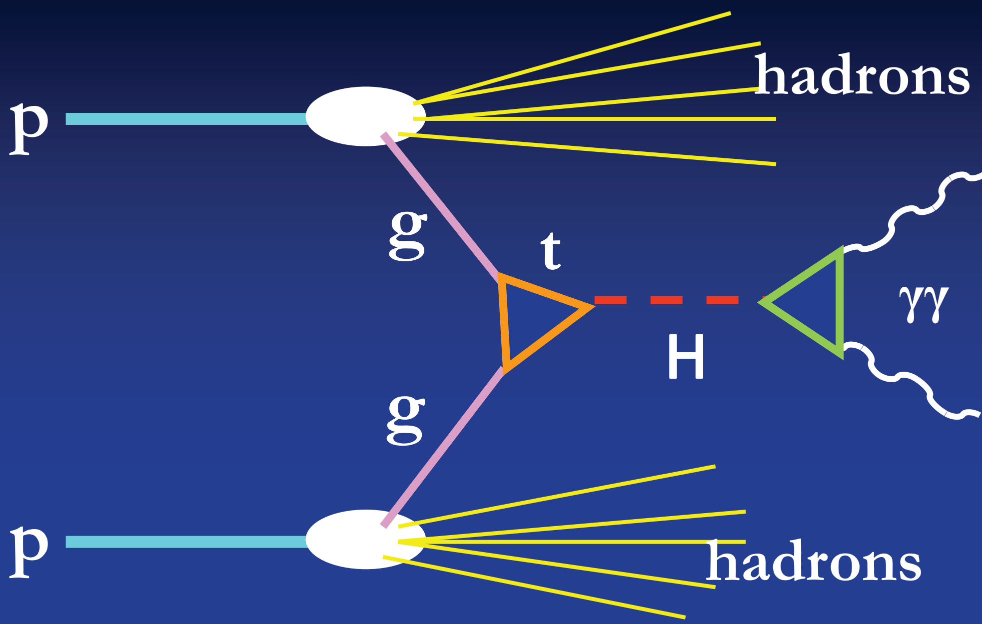
proton - (anti)proton cross sections

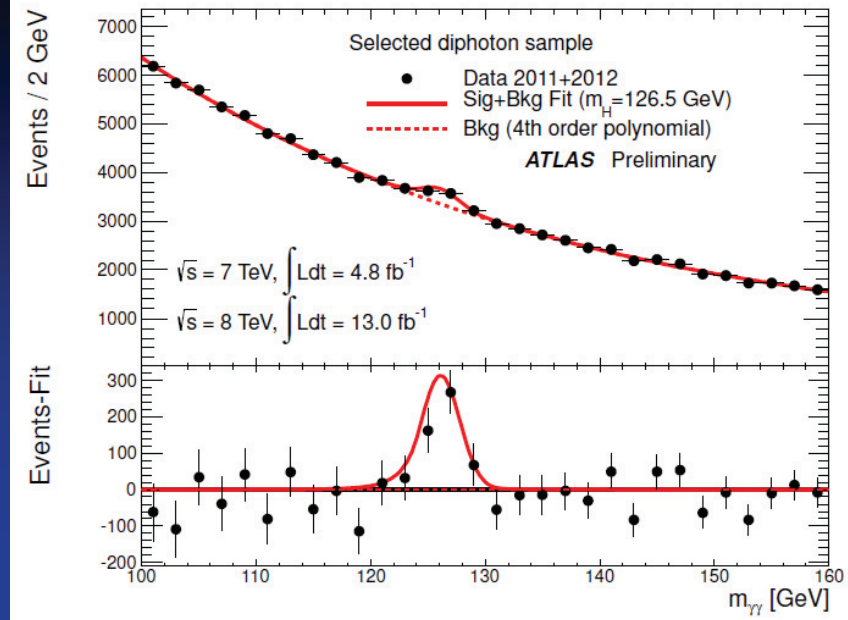


e^+e^- cross sections

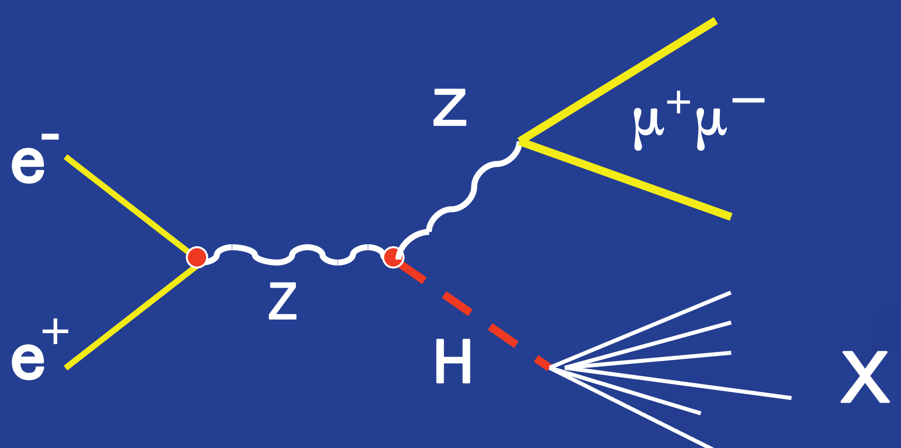


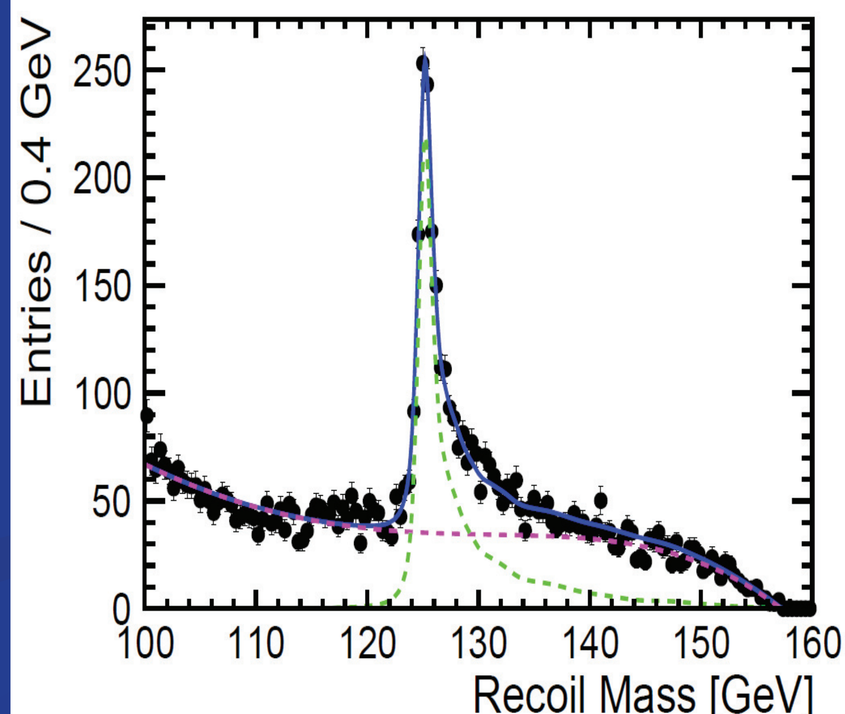
LHC **H→γγ Invariant mass of γγ**





ILC **Recoil mass of Z($\mu^+\mu^-$)**

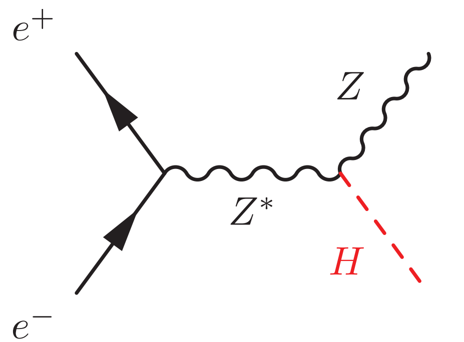




Precise Higgs Boson measurement is not the aim of ILC. It is just means to find the direction of physics beyond the Standard Model.

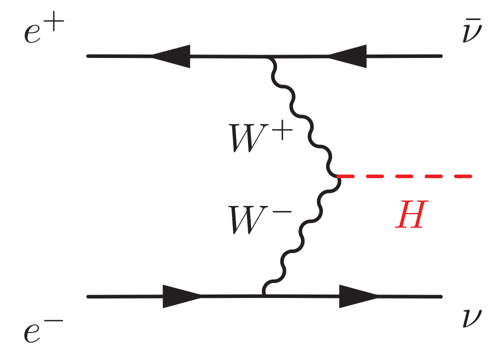
"Triple Jump" of Higgs Boson Studies at ILC

Hop

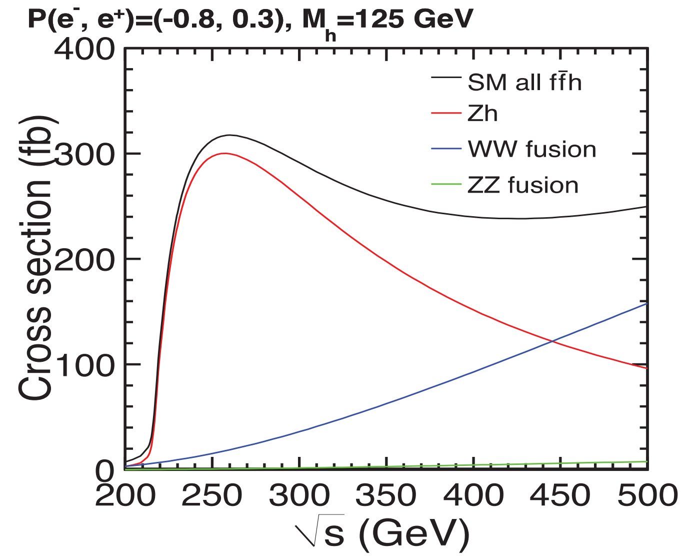


Higgs-strahlung
peaks around **250 GeV**
Measure decay modes

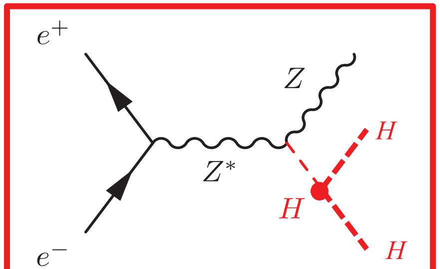
Step

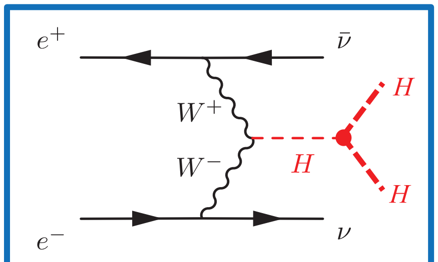


WW fusion determines the Higgs total width at **500 GeV**
Normalization of partial widths

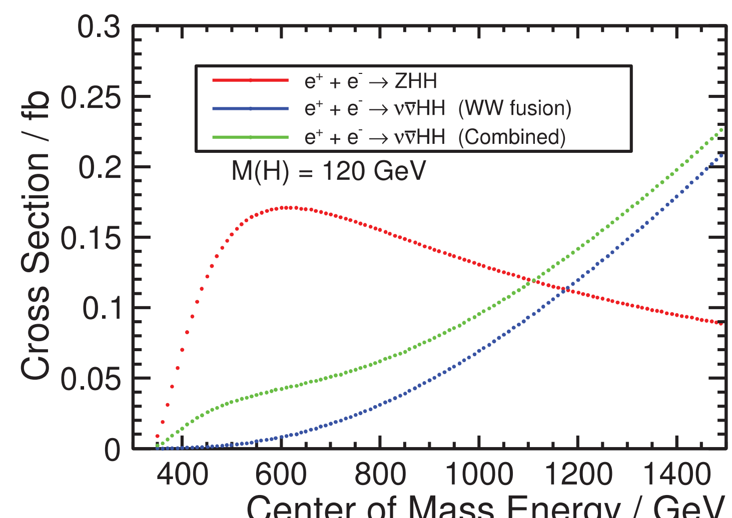


and Jump





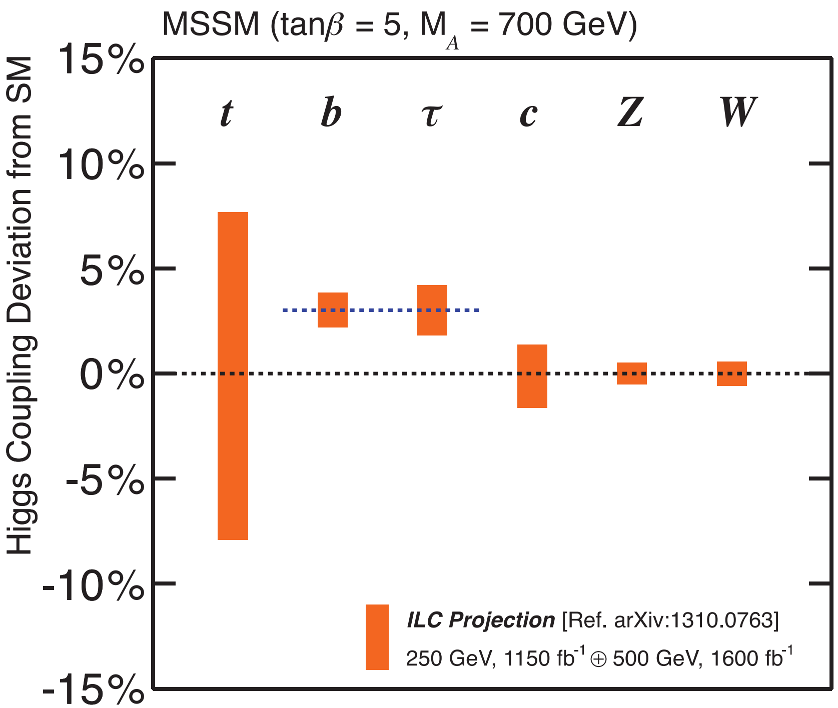
Higgs self-coupling ≧ 500 GeV



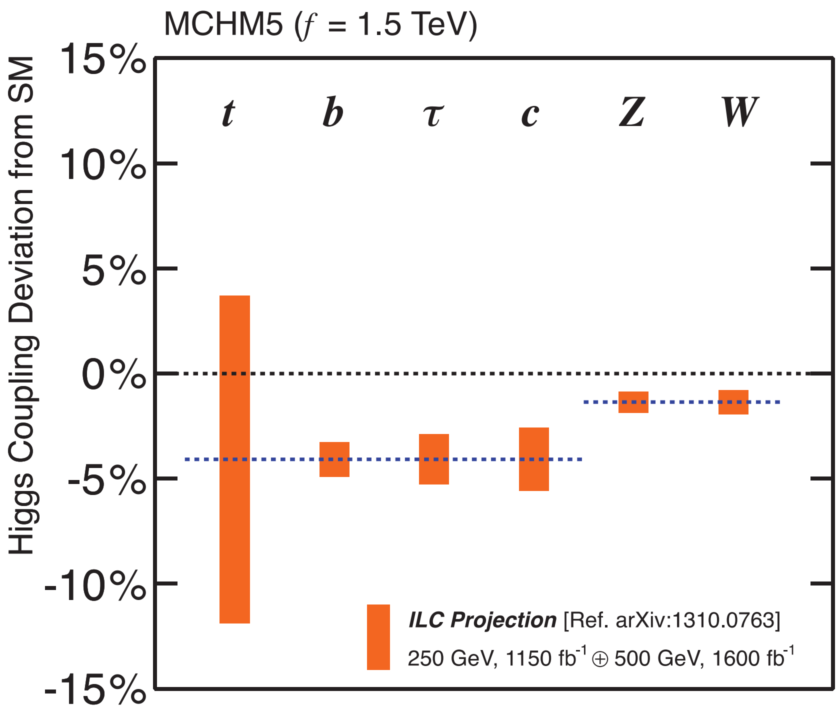
Precise Measurement of Higgs Coupling

Higgs boson: elementary or composite?

Supersymmetry
(MSSM)



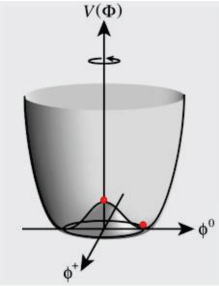
Composite Higgs
(MCHM5)

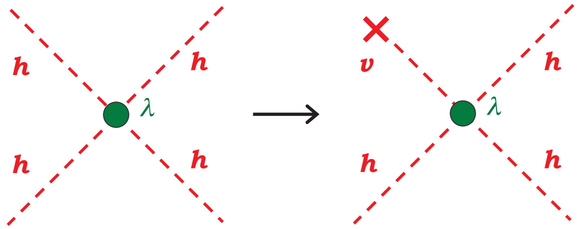


ILC 250+500 LumiUp

Able to distinguish models with specific patterns

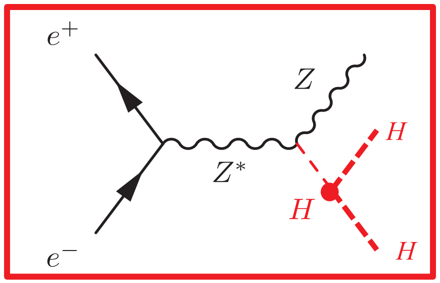
Higgs Self-coupling



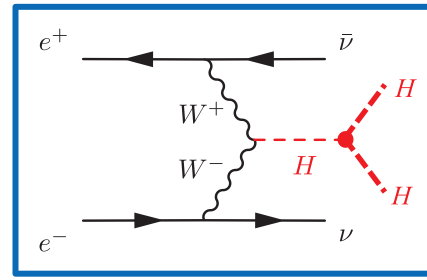


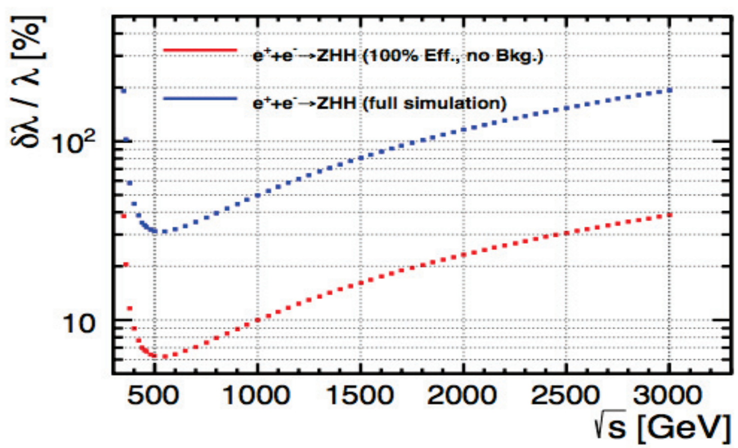
The cross sections are very small. There are Interferences between two Higgs processes and self-coupling. ⇒ difficult measurement

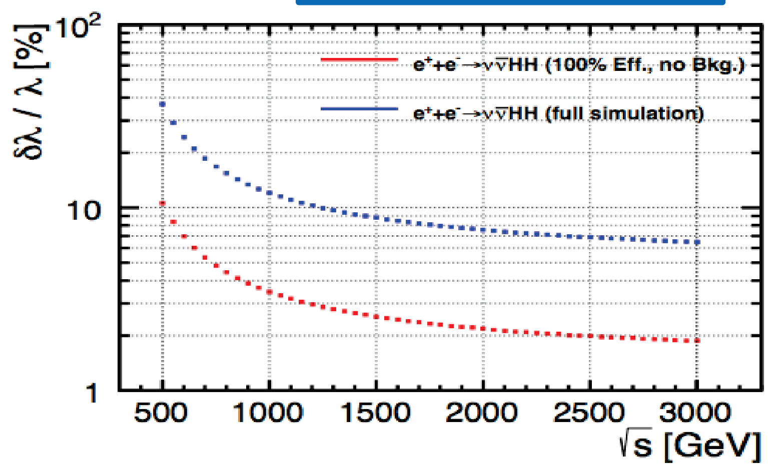
ZHH



ννHH







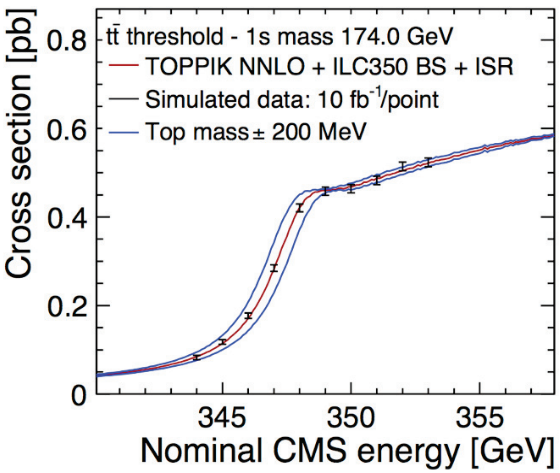
Current studies ⇒ $\Delta\lambda/\lambda \sim 30\%$ at 500 GeV, $\delta\lambda/\lambda \sim 10\%$ at 1 TeV

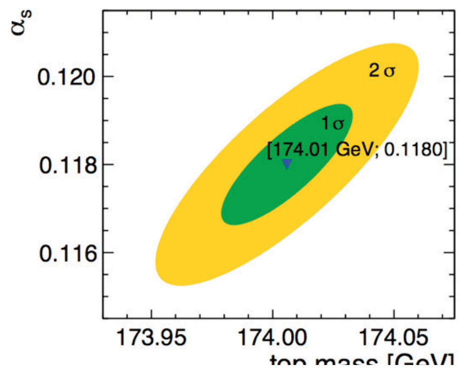
Large rooms for improvement

If λ is large and the EW phase transition is first order one, baryon asymmetry in the universe can be explained by the EW baryogenesis.

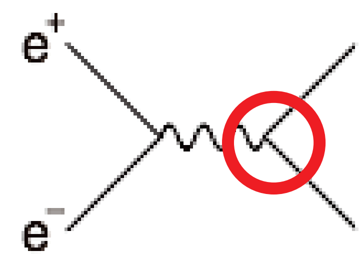
Impact of Top quark precise measurements

Precise top quark mass is measured by energy scanning ⇒ vacuum stability
Beam polarization is essential to distinguish left/right-handed couplings.



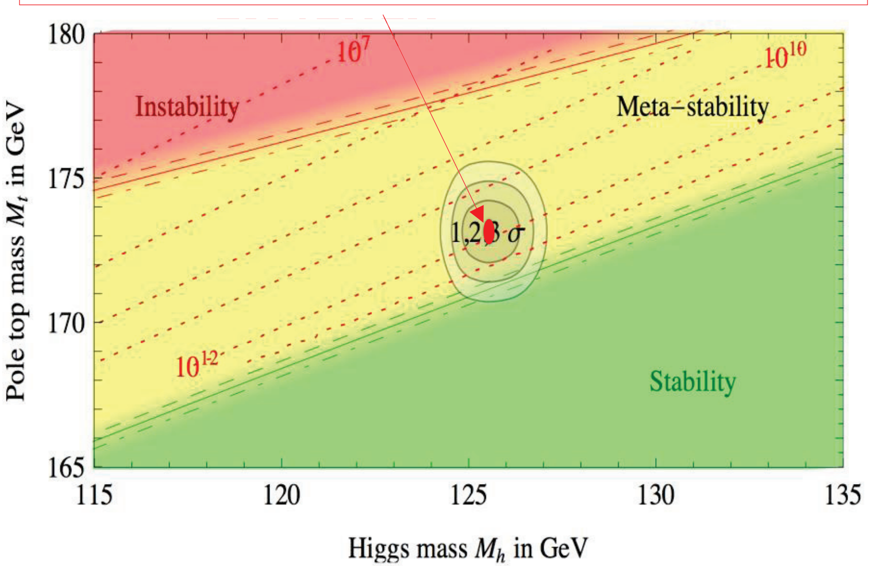


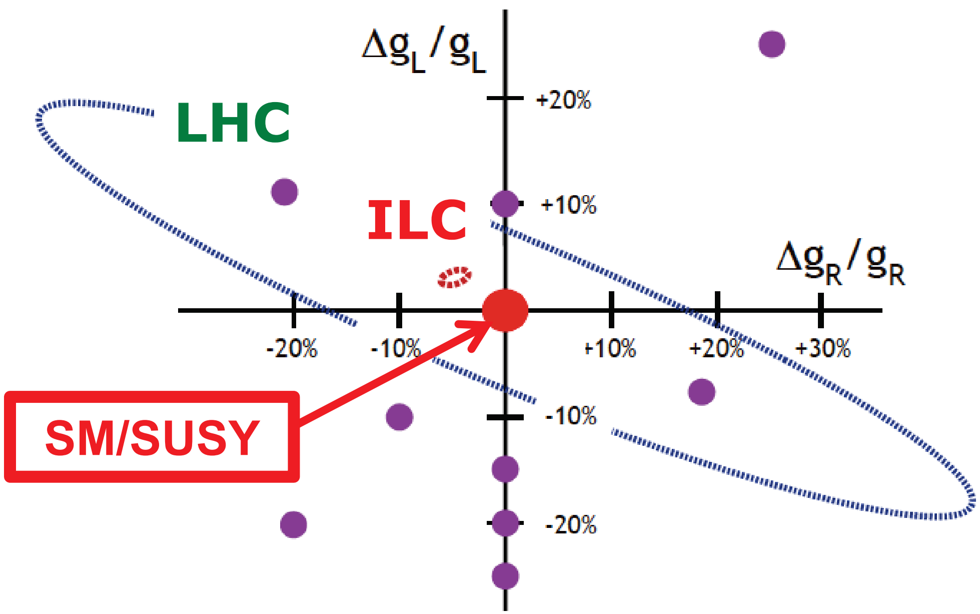
Deviation in ttZ coupling



$\Delta m_t(\overline{MS}) \simeq 100\,\mathrm{MeV}$ ⇒ 60 MeV

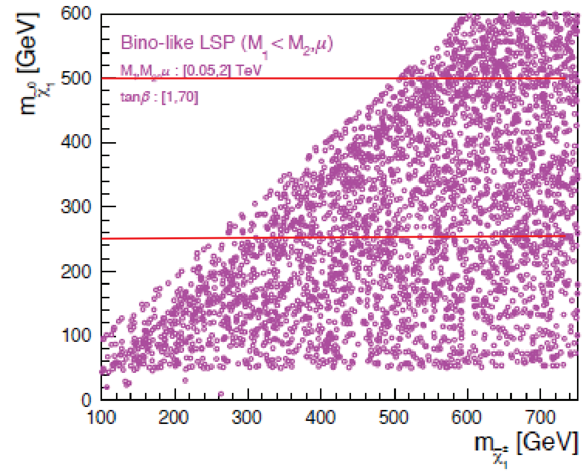
$\Delta m_H = 30\,\mathrm{MeV}$





LHC, Ref. arXiv:1311.2028
ILC, Ref. arXiv:1307.8102

Search for Light SUSY Particles
(Dark Matter Candidate)

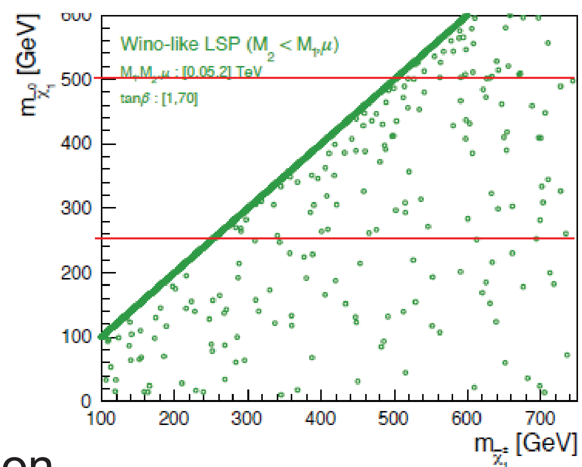


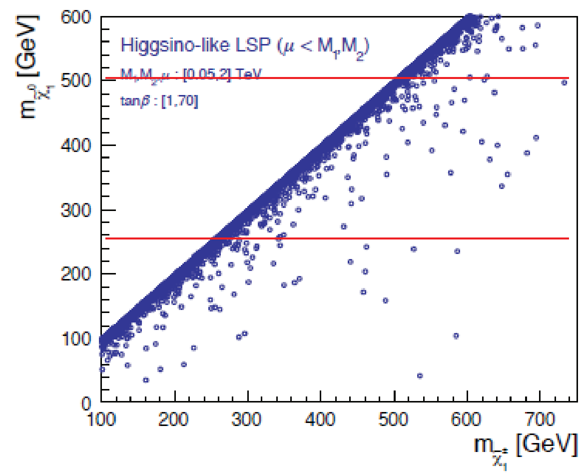
LSP (the Lightest SUSY particle)

U(1) gaugino	Bino-like	$M_1 < M_2, \mu$
SU(2) gaugino	Wino-like	$M_2 < M_1, \mu$
Higgs partner	Higgsino-like	$\mu < M_1, M_2$

NLSP (the Next Lightest SUSY particle)

(M_1, M_2, μ, tanβ) point is randomly chosen
$0.05<M_1,M_2,\mu<2$ TeV,
$1<\tan\beta<70$
Calculate LSP and the lightest Chargino masses

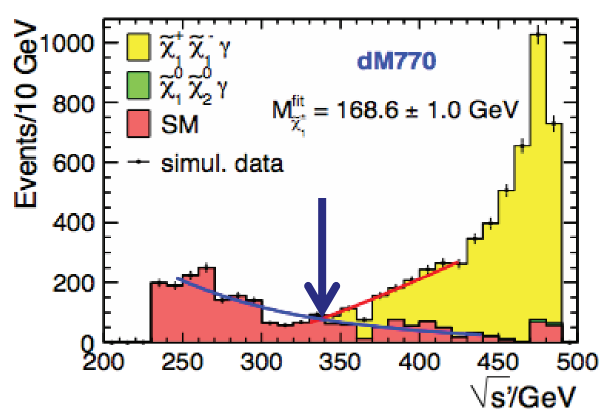


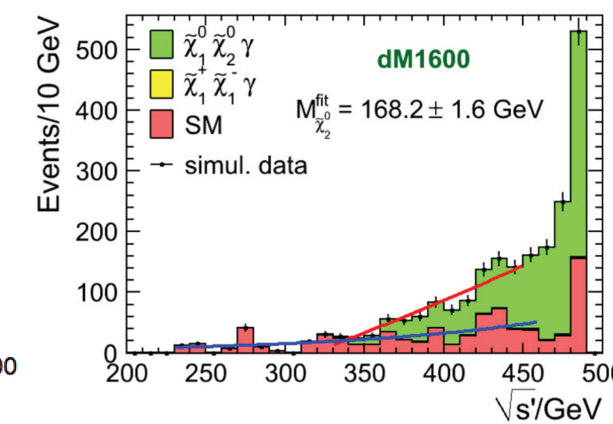


Tag the Initital State Radiation

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-\gamma$$

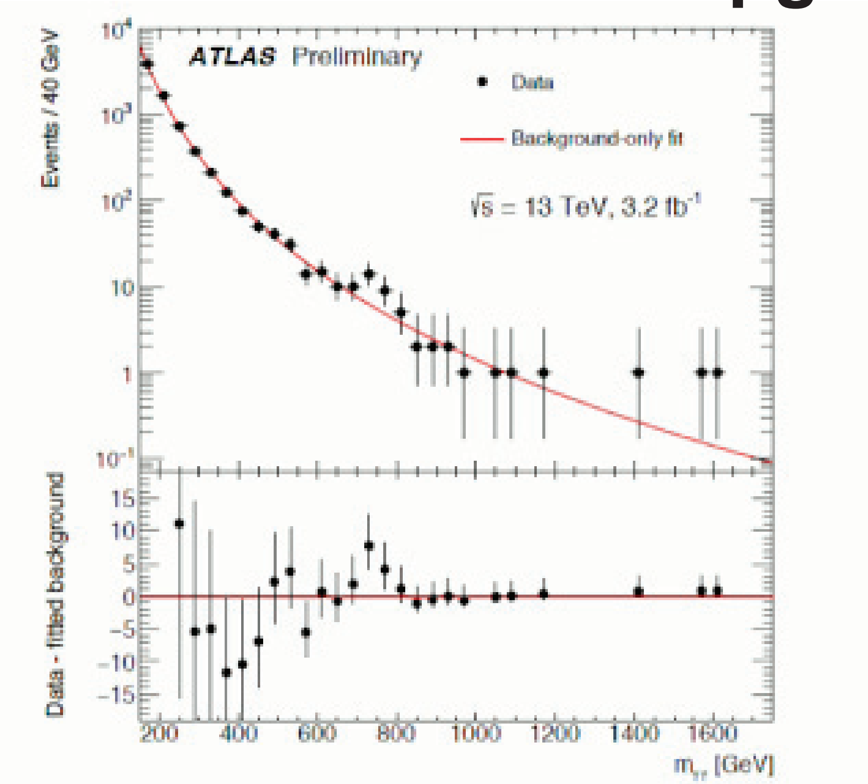
$$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_1^0\gamma$$

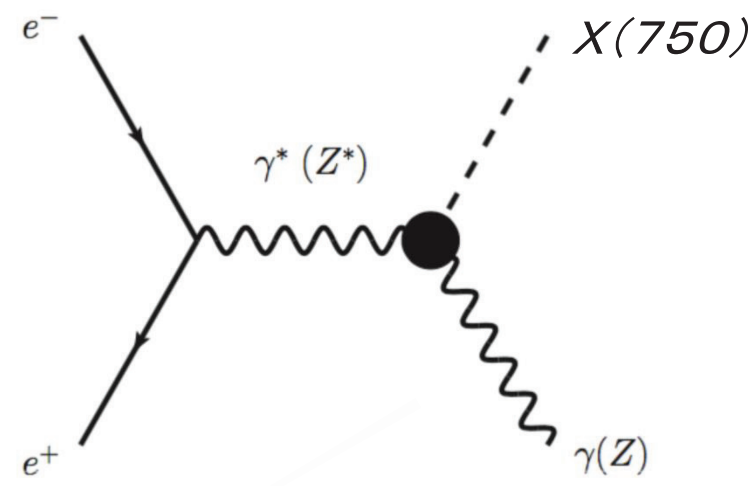




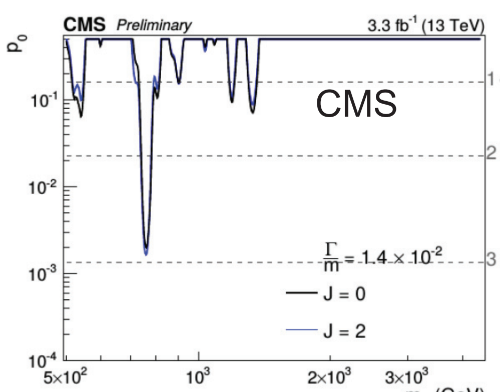
Detect even $\Delta M \sim 0$
$\Delta M = M(\text{NLSP}) - M(\text{LSP})$

~750 GeV peak found by ATLAS and CMS
⇒ ~1 TeV ILC upgrade, γγ-Collider ?

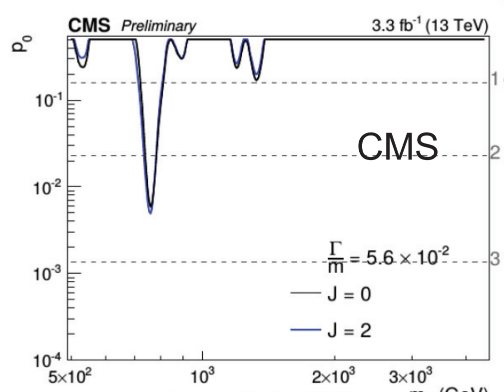




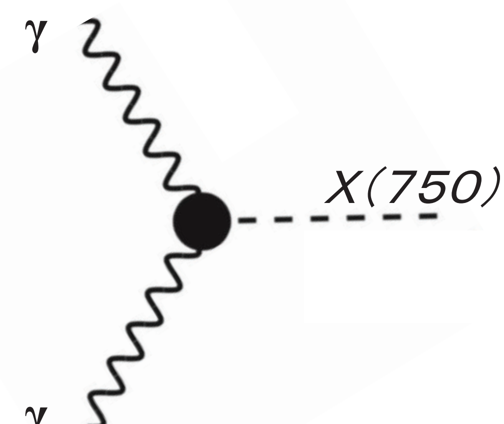
Power laser beams scattered by e^-
⇒ Face-to face Collision of Compton HE γ's



$\Gamma/m = 1.4\text{x}10^{-2}$



$\Gamma/m = 5.6\text{x}10^{-2}$



Energy frontier Colliders

Energy Frontier Colliders

Future Colliders must be planned and constructed by global efforts

Summary

- ILC is a truly global project. ICFA oversees the project.
- ILC is complementary/synergic to the LHC (including HL-LHC) .
  Clean environment, energy extendability, beam polarization, energy scanning
- Discovery of physics beyond "the Standard Model" is anticipated at ILC through precise Higgs/top studies, new particle searches in the clean experimental environment.
- The ILC accelerator technology is mature and solid.
  i.e. superconducting RF, beam focusing at collision
- Japan is seriously investigating hosting the ILC project as in the official process. Sign of willingness to participate in the project from governments outside Japan is essential.
- In Japan, the Federation of Diet Members, Industrial sectors, local governments powerfully support the ILC project.
- Diplomatic discussions has been already started among governments.