Prospects for the ILC project

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LIO international conference on Future colliders and the origin of mass

June 21, 2021

Thanks to Jenny List, Daniel Jeans and Shin Michizono

International Linear Collider (ILC)

- The next generation energy-frontier electron-positron collider.
- Project promotion, accelerator design and R&D works have been coordinated in the international framework since 2004.
- In 2017, a consensus was made that the ILC should start as a 250GeV Higgs Factory while keeping potential of energy upgrade at later stage.
- The International Committee for Future Accelerators (ICFA) is promoting the idea that the ILC should realize in a stepwise way, and setup International Development Team (IDT) in August, 2020. IDT recently published “Proposal for the ILC Pre-lab” as a first milestone towards realizing the ILC.

Contents of this talk

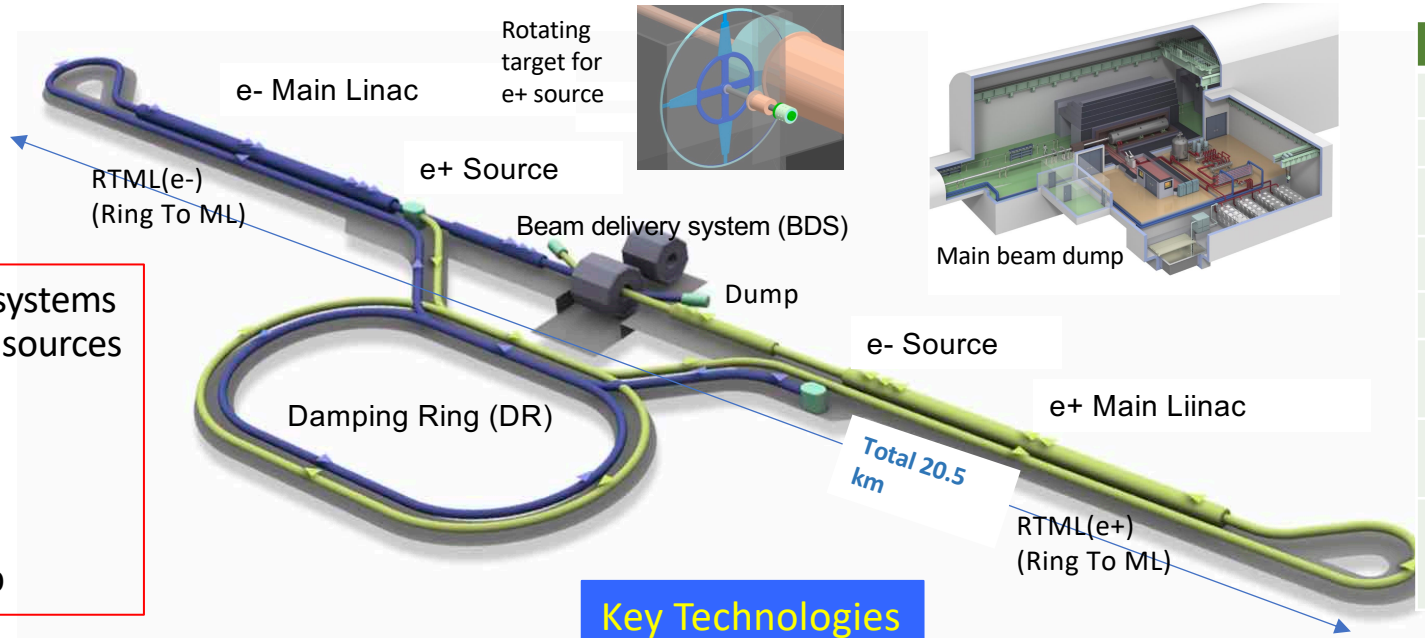
- Status of the ILC project
- ILC Pre-lab proposal
- Recent activities on Physics at ILC

A brief history of the ILC

- R&Ds for e+e- linear colliders started in late 1980's in US, Europe and Japan.
- ICFA chose superconducting RF technology as a basic linear collider technology in 2004.
- The Japanese HEP community proposed to host ILC as a global project after the Higgs discovery in 2012.This was welcomed by worldwide HEP communities
- The global design team (GDE) led by Barry Barish completed the ILC Technical Design Report (TDR) in 2013.
- ICFA endorsed ILC250 as a Higgs Factory in 2017.
- The proposal to host the ILC in Japan has been investigated by the Japanese government. MEXT will continue to discuss the ILC project with other governments while having an interest in the ILC project.

MEXT=Ministry of Education, Culture, Sports, Science and Technology

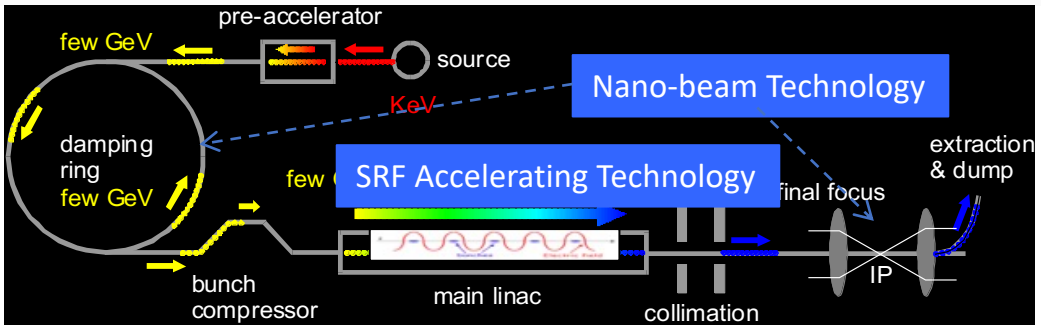
ILC 250GeV Accelerator Facility



Area systems
e-/e+ sources
DR
RTML
ML
BDS
Dump

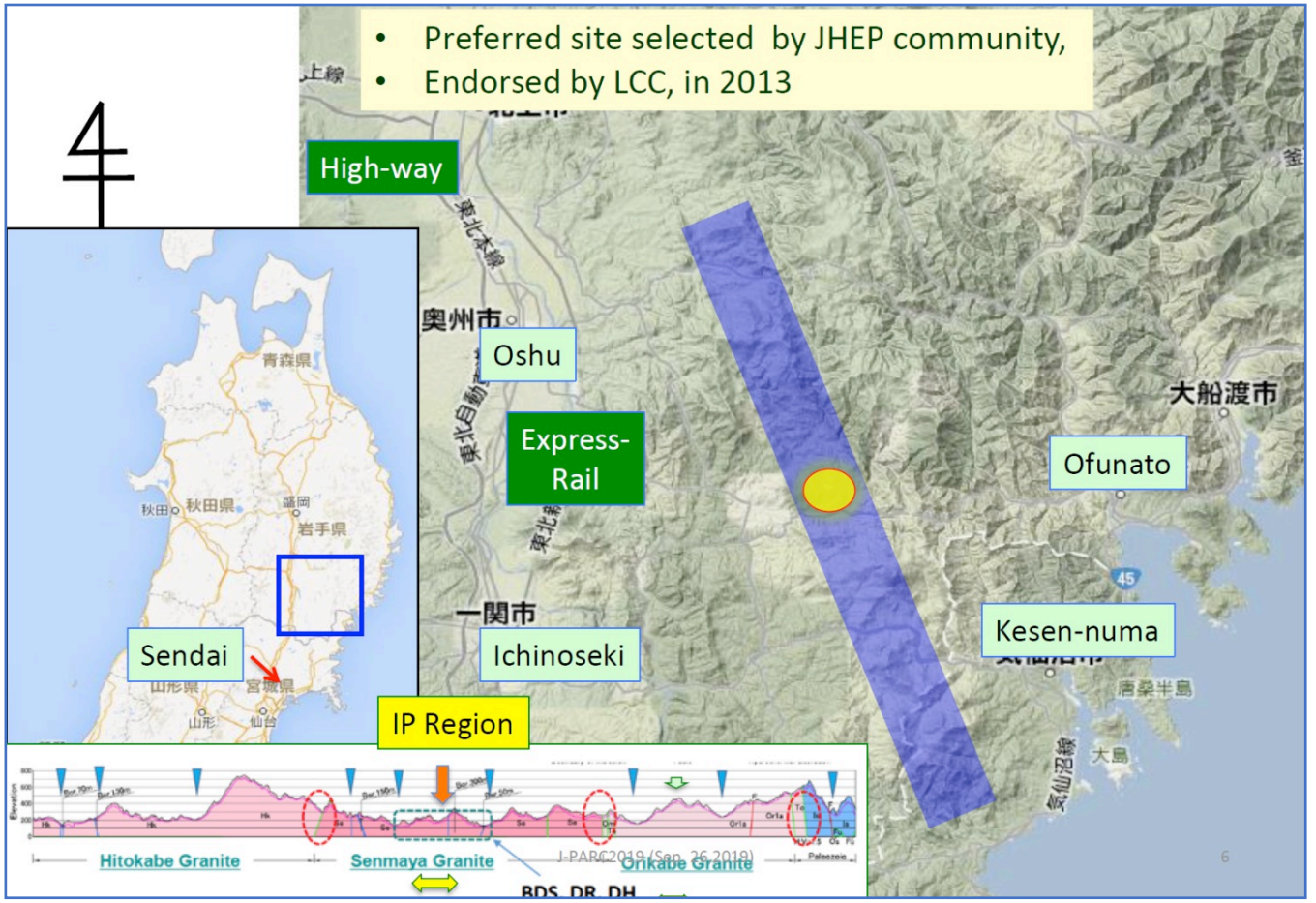
Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	**7.7** nm@ 250GeV
SRF Cavity G. Q_0	**31.5** MV/m (**35** MV/m) Q_0 = 1x10 ^{10}

Key Technologies



8,000 SRF cavities will be used.

ILC site candidate location in Japan: Kitakami



A site -specific design has proceeding since then.

LCC= Linear Collider Collaboration set up by ICFA

From 2020 Update of the European Strategy for Particle Physics

3. High-priority future initiatives

A. An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

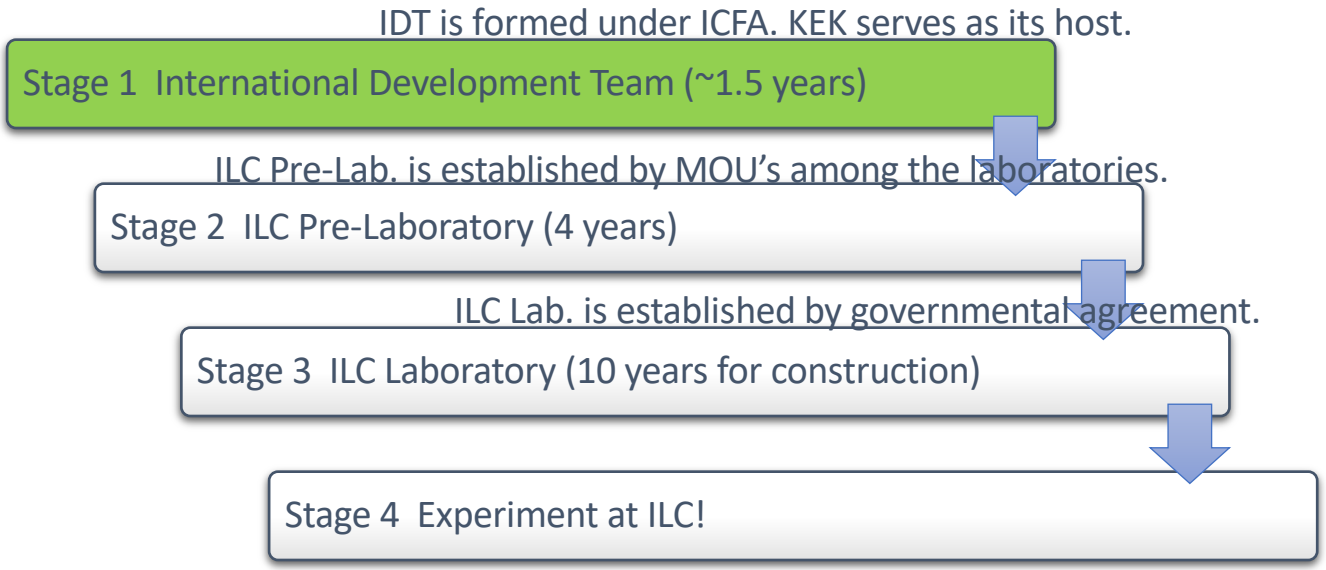
• ***the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors;***

• ***Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.***

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

Stepwise realization of the ILC

ICFA decided to form International Development Team (IDT) in order to carry out preparation works to establish the ILC Pre-lab in August 2020.



International Development Team (IDT)

Proposal for the ILC Pre-lab

arXiv:2106.00602

- The ILC Pre-lab will be organized as an international collaboration of laboratories worldwide based on MoUs.
- Its purposes are:

✓ Complete of technical preparations and engineering design documents for the accelerator complex.

✓ Design studies of the civil engineering and site infrastructure works, and environmental impact assessment

✓Community audience to develop the ILC physics programme

✓Provision of information to national authorities and to Japanese regional authorities to facilitate development of the ILC Laboratory

✓Coordination of outreach and communication work

This proposal describe:

- Pre-lab organization and start-up process
- Pre-lab work plan

a. Accelerator (18 work packages for accelerator preparation activities, Engineering design and documentation)

b. Civil construction and site-related tasks

c. Preparation for physics programme

- Reference cost and required human resources

This document will be used for discussion and negotiation among interested laboratories and explanation to funding agencies and governments.

Current status of the project

- KEK submitted the proposal of the ILC Pre-lab to MEXT in early June.
- KEK and the Japanese HEP research community compiled a report on the progress and outlook for solving remaining issues of the ILC, and submitted it to MEXT. Many of technical issues will be solved by the ILC Pre-lab.
- MEXT will soon review two documents to evaluate the plan to solve the remaining issues.
- MEXT will begin dialogue with government agencies in relevant counties concerning the ILC project.
- The next task of the IDT is to facilitate discussions among laboratories interested in participating the ILC Pre-lab.

- Even at the stage of starting the ILC Pre-lab, it is foreseen that discussions among the Japanese government and potential foreign partners will take place concerning the ILC project itself.
- It is very important that the international physics community interested in the ILC will continue communicating the importance of the ILC and their activities to the public and government authorities of their countries.

Physics at the ILC

- Physics at the ILC was studied well from early days of the TDR (2013).

  Higgs, Top, direct and indirect searches for new physics, Higgs self-coupling measurement, etc.

- Significant efforts were made in the process of the 2020 Update of the European Strategy for Particle Physics to clarify physics case of ILC 250 GeV and its higher energy extension
- Now, IDT-WG3 (Physics and Detectors) is leading new activities aiming to expand the community, support newcomers to get involved in physics and detector studies, encourage new ideas for experimentations at the ILC.

WG3 page: https://linearcollider.org/team/wg3/

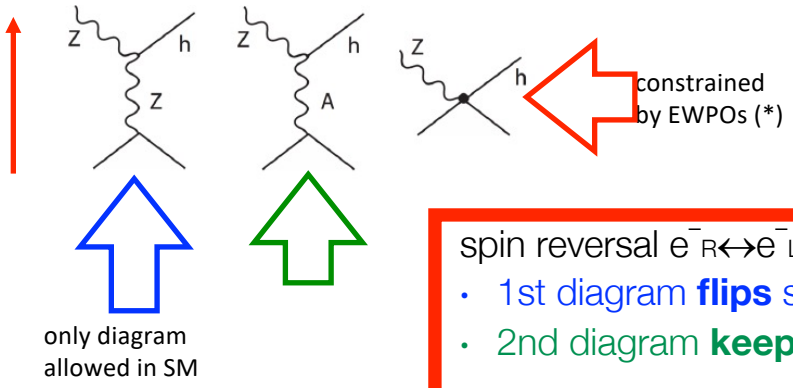
(Chair Hitoshi Murayama, Deputy coordinators, Jenny List and Claude Vallee)

Recent activities on ILC physics studies - overview

- IDT-WG3 “Physics Potential and Opportunities” group formed
  - Lead by Michael Peskin, Aidan Robson, Junping Tian
  - cf https://linearcollider.org/team/wg3/physics/
  - **… foster studies of the ILC’s physics case outside and across detector concepts …**
  - Established 6 topical groups with conveners:
    - **Higgs:** Shinya Kanemura (Osaka), Patrick Meade (Stony Brook), Chris Potter (Oregon), Georg Weiglein (DESY)
    - **Top/Heavy Flavour/QCD:** Adrian Irles (Valencia), Hua-Xing Zhu (Zhejian), Alexander Mitov (Cambridge), TBA
    - **BSM:** Mikael Berggren (DESY), Shigeki Matsumoto (IPMU), Werner Porod (Würzburg), Simone Pagan Griso (LBNL)
    - **Electroweak:** Taikan Suehara (Kyushu), Wolfgang Kilian (Siegen), Graham Wilson (Kansas)
    - **Global Interpretations:** Tim Cohen (Oregon), Christophe Grojean (DESY), Sven Heinemeyer (Santander), Sunghoon Jung (Seoul)
    - **Modelling and Precision Calculation:** Gudrun Heinrich (KIT), Stefan Hoeche (Fermilab), Juergen Reuter (DESY), Zhao Li (IHEP)
  - **first public, scientific meeting held May 27, 15:00-17:00 CEST, > 100 participants**
  - repeat ~monthly, https://agenda.linearcollider.org/category/266/, next dates:
    - **June 17 - emphasis on global interpretations, further contributions from EW and BSM**
    - **July 15, Aug 12, Sep 16, …**
  - **sign-up for mailing lists, overall WG3 and topical lists: https://agenda.linearcollider.org/event/9154/**
- Complemented by rich physics activities within the detector concepts, in particular in ILD

Polarisation & Higgs Couplings

- **THE key process** at a Higgs factory: **Higgsstrahlung $e^+e^- \rightarrow Zh$**
- **A_{LR}** of Higgsstrahlung: very important to **disentangle** different **SMEFT operators!**

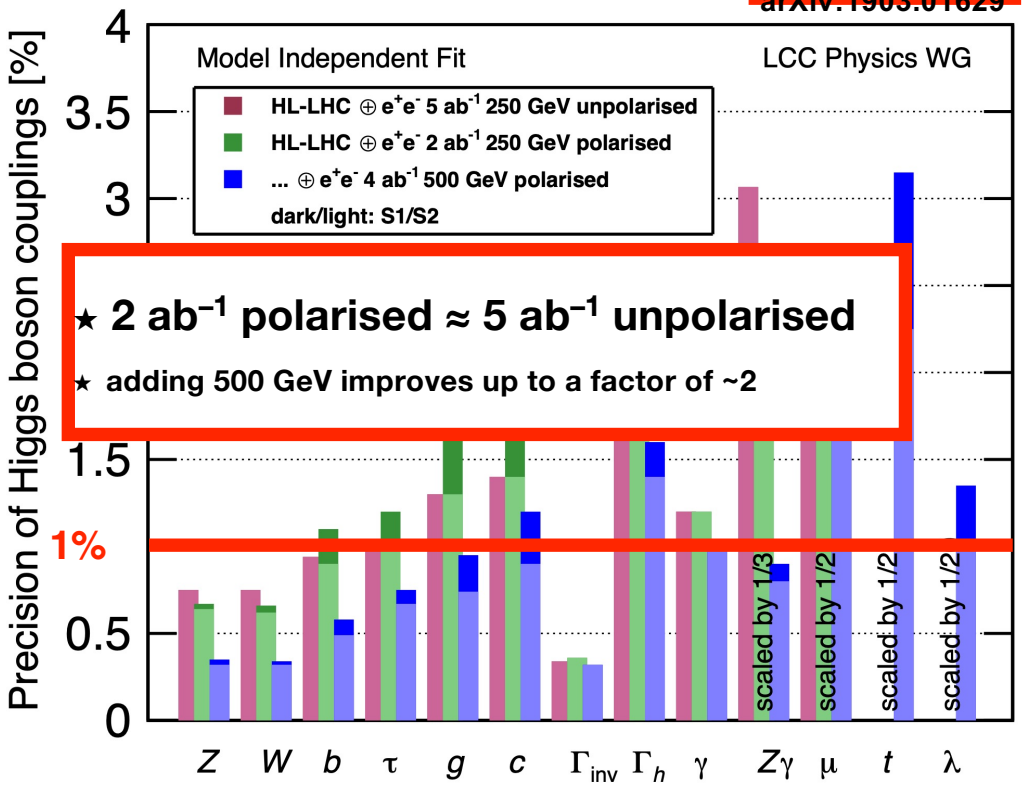


spin reversal $e^-_R \leftrightarrow e^-_L$:

- 1st diagram **flips** sign
- 2nd diagram **keeps** sign

⇒ **A_{LR} lifts degeneracy between operators!**

arXiv:1903.01629



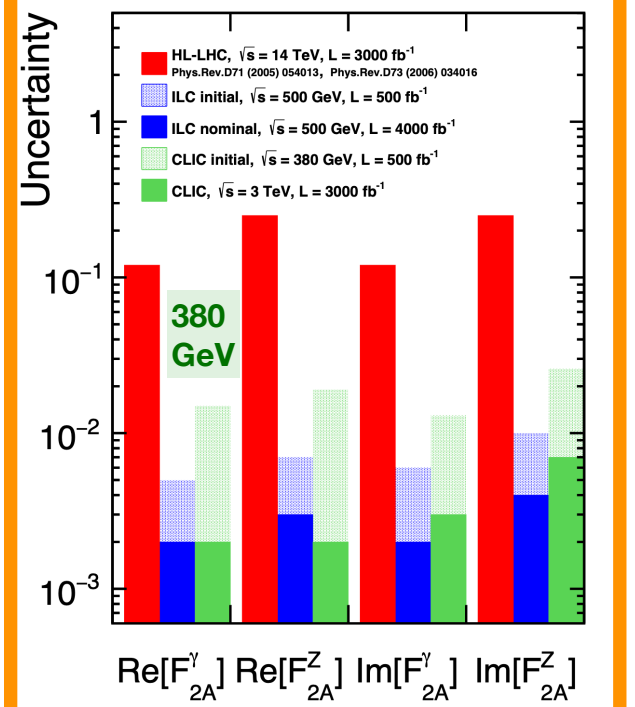
Recent activities on ILC physics studies - top

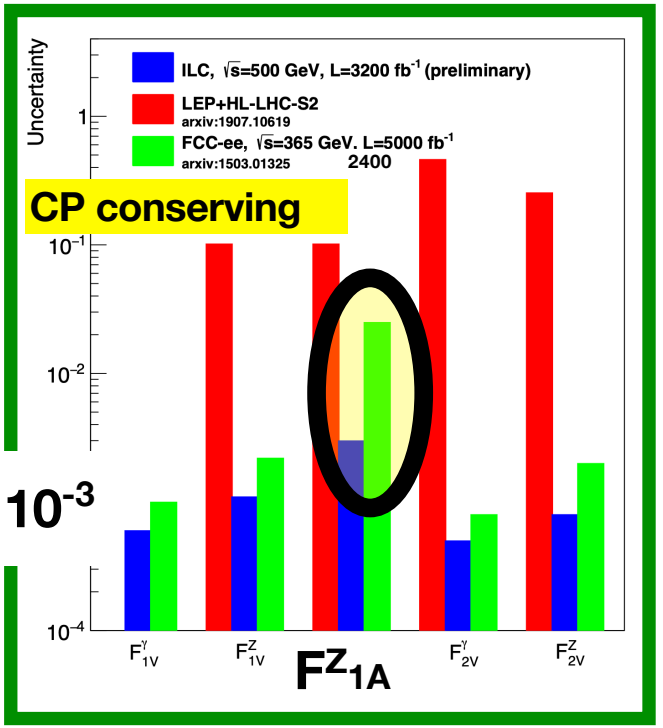
- e^+e^- -> tt: possible above ~360 GeV
- **near threshold: no boost => little sensitivity to *axial* coupling**
- beam **polarisation disentangles Z and γ** exchange
- few **10^{-3} for all couplings requires ≥ 500 GeV *and* polarisation**
- probes **BSM** into the **multi-ten TeV regime**

full SM-EFT:

- **500 GeV improves** various coefficients **by 2 orders of magnitude**
- **4-fermion operators profit quadratically from higher energies**

CP violating





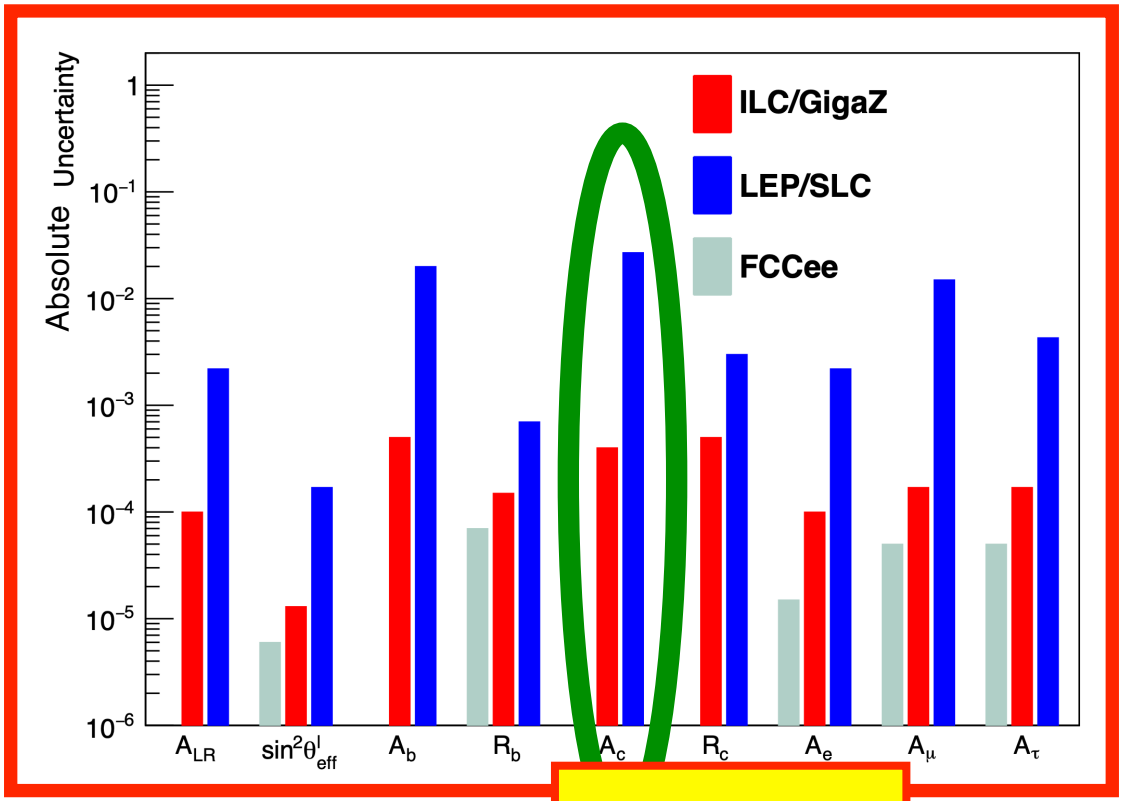
[ILD-PHYS-PUB-2019-007, arXiv:1908.11299, Eur.Phys.J. C78 (2018) no.2, 155]

Polarisation & Electroweak Physics at the Z pole

new detailed studies by ILD:

- at least factor 10, often ~50 improvement over LEP/SLC
- note in particular:
  - **A_c nearly 100 x better** thanks to excellent charm / anti-charm tagging:
    - excellent vertex detector
    - tiny ILC beam spot
    - Kaon-ID via dE/dx in ILD's TPC

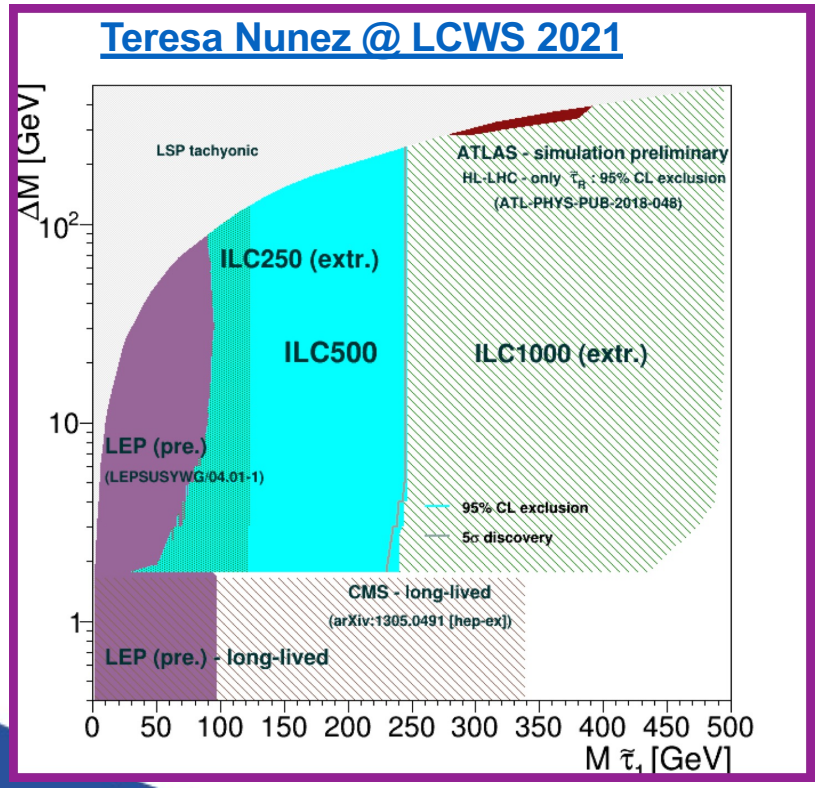
typically only factor 2-3 less precise than FCCee's unpolarised *TeraZ*
=> polarisation buys a factor of ~100 in luminosity

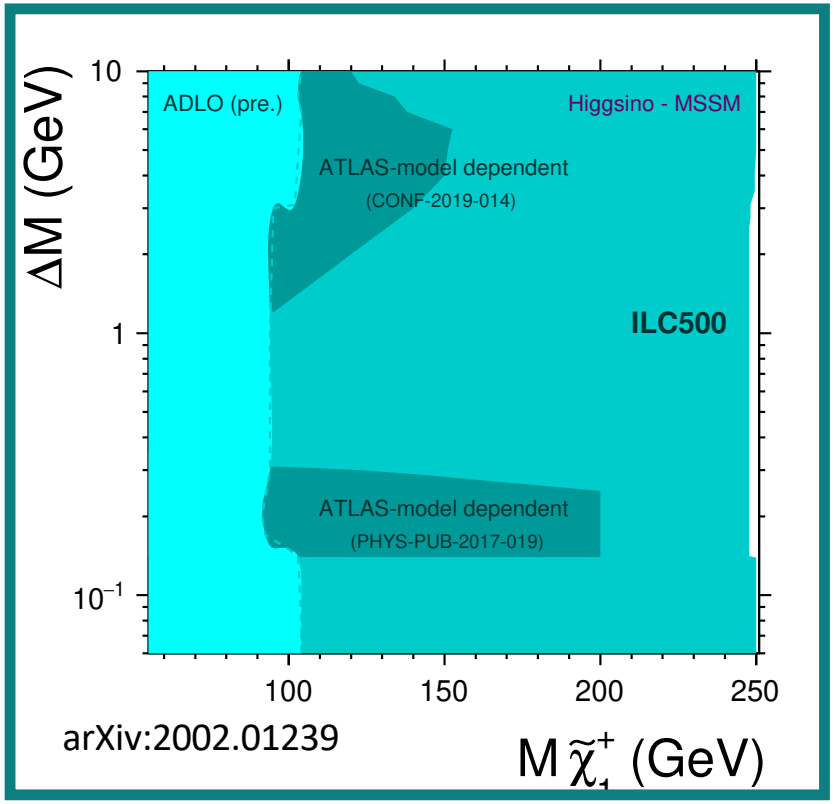


arXiv:1908.11299

Recent activities on ILC physics studies - BSM

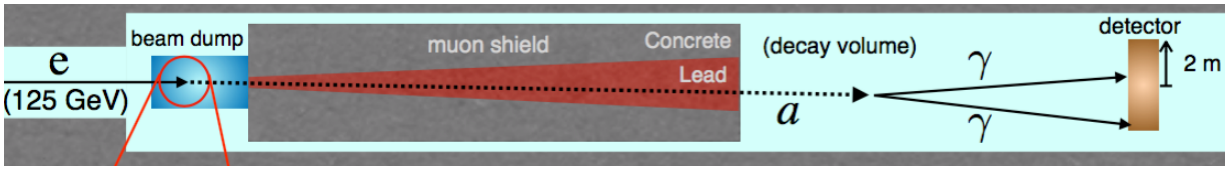
- Focussing on cases difficult for (HL-LHC), eg scalar taus or higgsinos
- ILC can probe for new particles with electroweak interaction up to ECM/2 - loop-hole free!

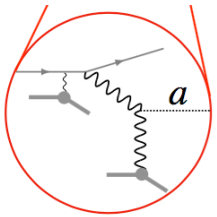


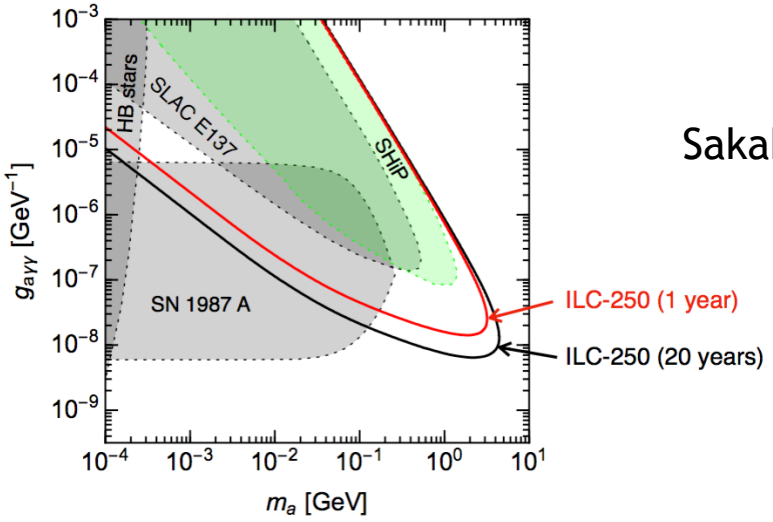


Recent activities on ILC physics studies – fixed target

- Exploring the possibility of fixed target / beam dump experiments at the ILC facility
- Example: searches for axion-like particles







Sakaki

c.f. M. Peskin at LCWS 2021

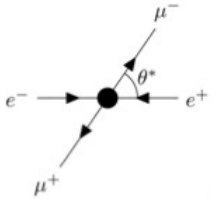
Recent activities on ILC physics studies – EW precision

- Influence of beam polarisarion and detector acceptance on electroweak precision studies
- Ongoing study on generator level

6 parameters: LEP/SLC parameters

σ_0^f ... total chiral cross section sum

$A_{e/f}$... initial / final fermion chiral asymmetry



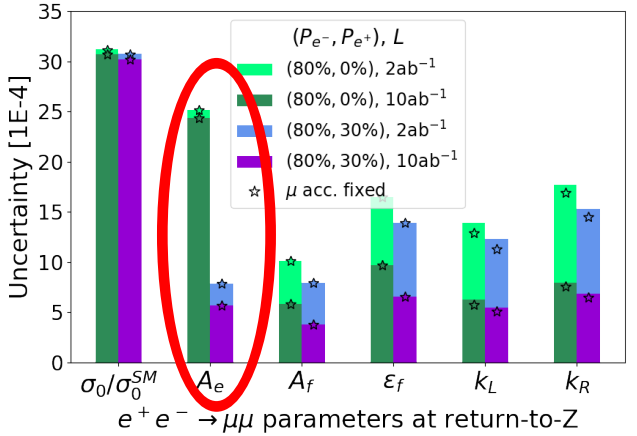
$$\frac{d\sigma^f_{LR}}{d\cos\theta} = \frac{3}{8}\sigma_0^f \frac{1+A_e}{2}\left[(1+k_L)+(\epsilon_f+2A_f)\cos\theta+(1-3k_L)\cos^2\theta\right]$$

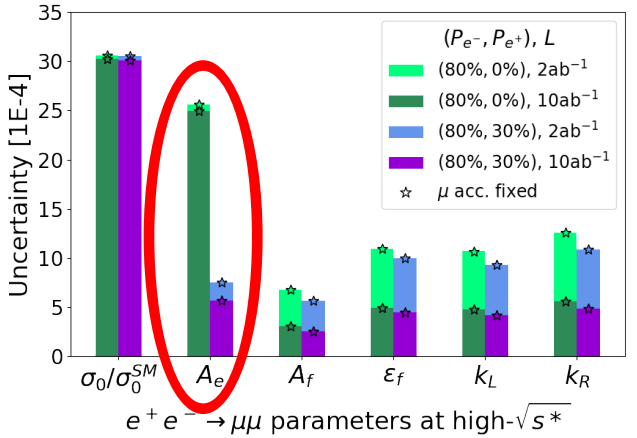
$$\frac{d\sigma^f_{RL}}{d\cos\theta} = \frac{3}{8}\sigma_0^f \frac{1-A_e}{2}\left[(1+k_R)+(\epsilon_f-2A_f)\cos\theta+(1-3k_R)\cos^2\theta\right]$$

Correction parameters

ε_f ... Z/γ interference correction

$k_{L/R}$ ... radiative correction factors



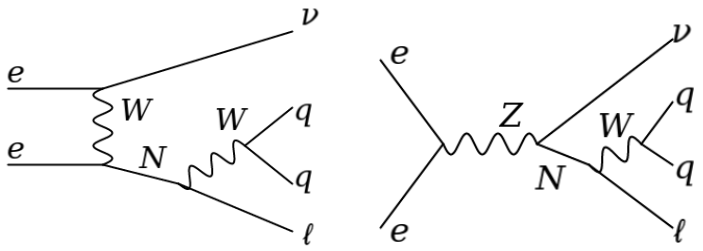


Dramatic improvement on A_e if positron polarisation available!

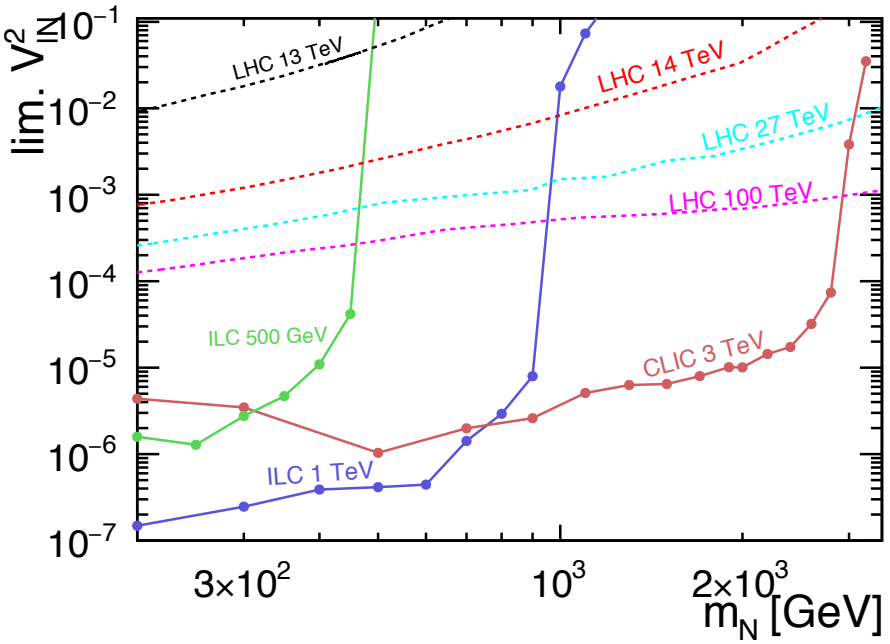
J. Beyer at 2nd Open Meeting of IDT-WG3-Phys
https://agenda.linearcollider.org/event/9239/

Recent activities on ILC physics studies – Heavy Neutrinos

- Probing for heavy neutrinos in ee -> qqlv channel
- Ongoing study on DELPHES-level



ILC adds significant reach beyond LHC - and even beyond FCC-hh !



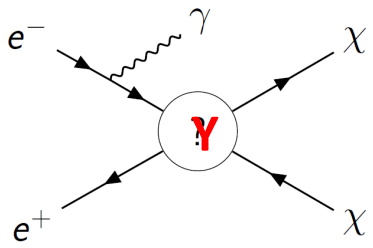
Dirac neutrinos

LHC analysis: [1812.08750], diff. assumption: $V_{eN} = V_{\mu N} \neq V_{\tau N} = 0$

K. Melaka at ILD Meeting https://agenda.linearcollider.org/event/9248/

Recent activities on ILC physics studies – Dark Matter with light Mediator

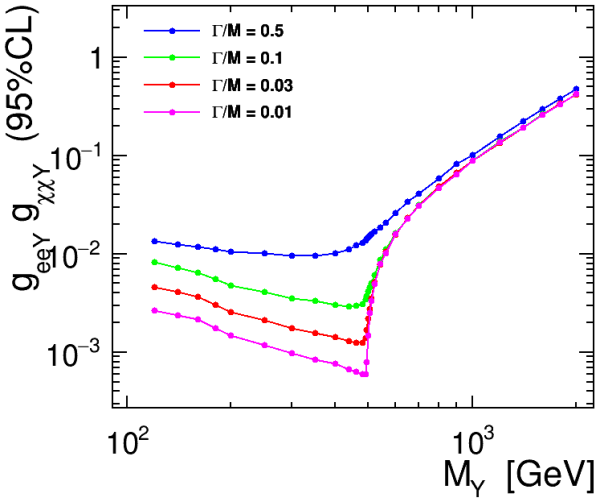
- Probing for Dark Matter in the mono-photon channel
- Considering light mediator Y with M_Y < ECM => EFT not sufficient



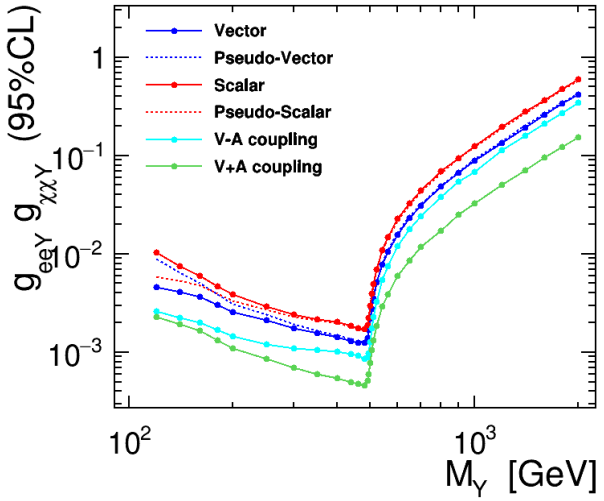
ILC sensitive to very small mediator couplings for M_Y < ECM

Consistent with EFT limits at M_Y > ECM

Vector mediator



$\Gamma/M = 0.03$



F. Zarnecki at ILD Meeting https://agenda.linearcollider.org/event/9223/

ILC Workshop on Potential Experiments (ILCX2021)

October 26 to 29, 2021, Tsukuba, Japan

- The first workshop organized by IDT.
- The workshop will address all the aspects of the collider program at the Interaction Point (IP), possible beam dump experiments, forward detectors near the IP, off-axis far detectors, experiments with extracted beams for particle physics and other areas of science, including e.g. nuclear physics, condensed matter physics.
- Three possibilities at the moment: (1) In-person, (2) Hybrid, (3) Fully online.

https://agenda.linearcollider.org/event/9211/

Summary

- In order to realize the ILC in a stepwise way, the international HEP community (ICFA) set up the International Development Team (IDT). IDT published “Proposal for the ILC Pre-lab” as the first milestone. The next goal is to establish the ILC Pre-lab by agreement among interested laboratories worldwide.
- During the Pre-lab phase, the technical preparation for construction of the ILC will be carried out. In parallel, the ILC Pre-lab will provide necessary inputs for intergovernmental negotiation.
- IDT is trying to expand community and encourage new ideas for experimentaions at the ILC