Virtual Workshop - April 22, 2020

The International Linear Collider

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University of Oregon

Ref: arXiv:1903.01629

Introduction - the ILC

- **International community** plans initial ILC phase at 250 GeV.
- e^+e^- at 250 GeV addresses **compelling physics** questions:
  - EW symmetry breaking and Higgs physics,
  - Searches, more.
- ILC is **technically mature** with detailed, manageable cost estimate.
- Linear Colliders offer **natural evolution** to higher e^+e^- energy:
  - 350/380 GeV, 500 GeV, and higher.
- Upgradability well defined - **500 GeV ILC design** exists - TDR.
- **Political support** in Japan very strong with decision anticipated.
- ICFA & KEK planning **next framework**, beyond LCC/LCB.

Advantage of Higgs Studies at ILC

Very low backgrounds and simple reactions in e^+e^-.

Environment allows for **detectors of unprecedented accuracy.**

Also, all decay modes are observed in e^+e^-,

with **small, calculable backgrounds.**

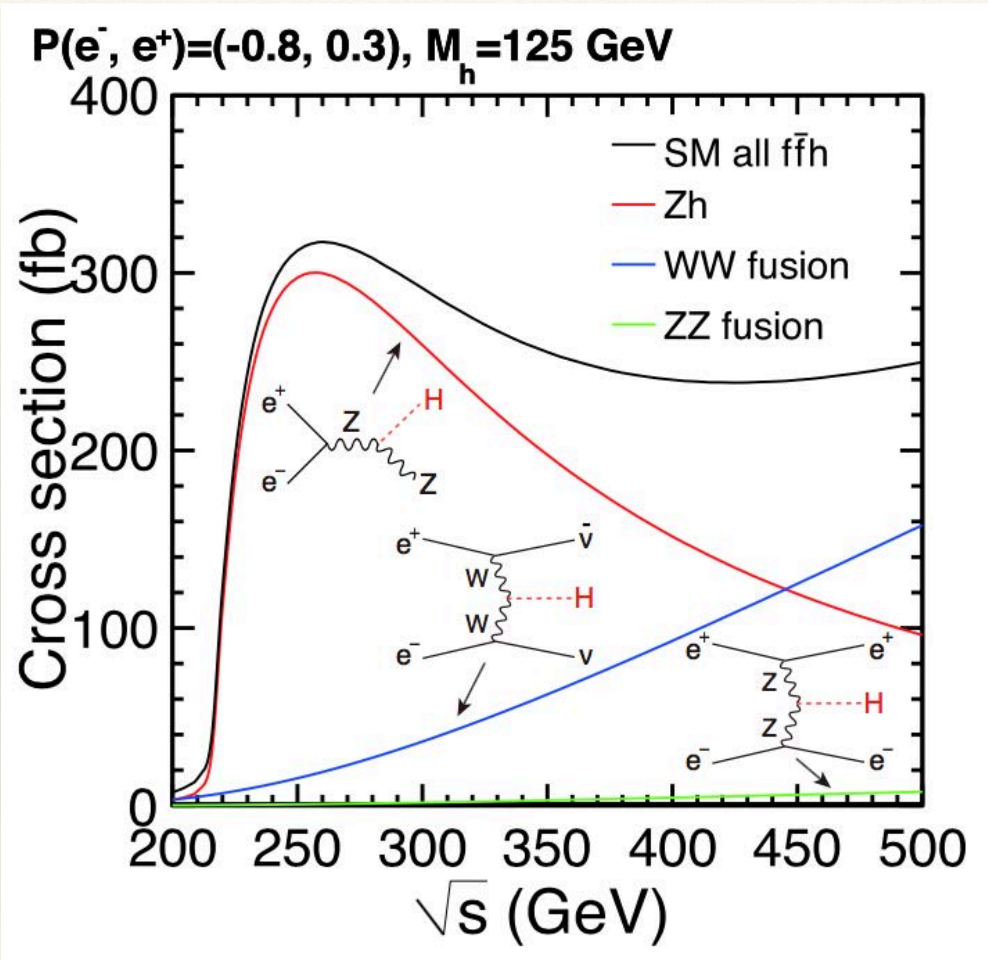
Higher precision, **model-independent** measurements feasible.

Sub-1% coupling measurements achievable.

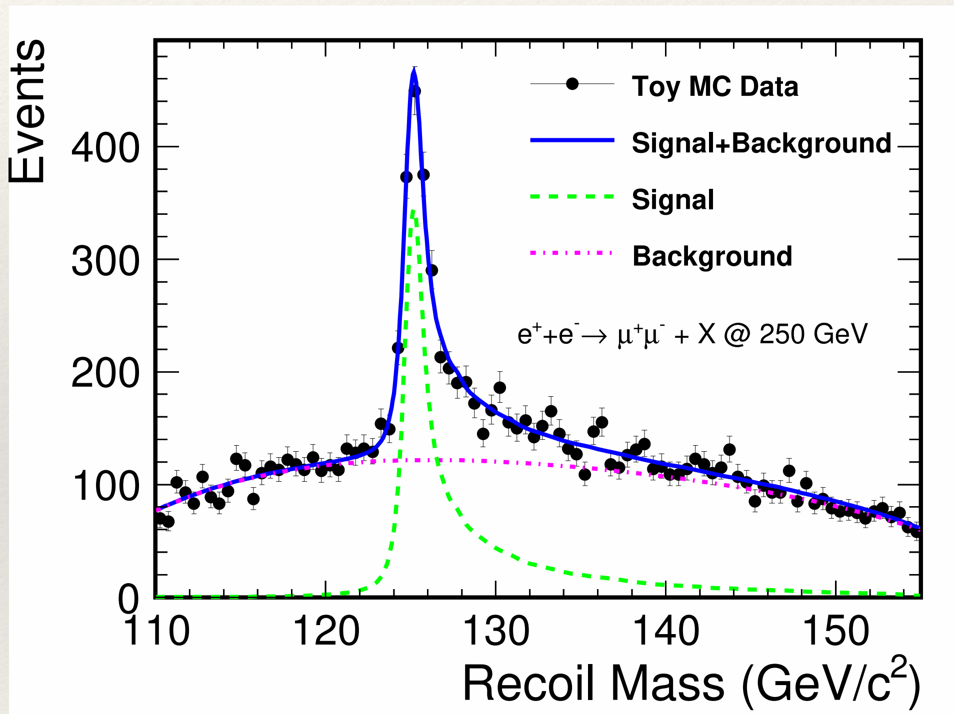
Polarization enhances sensitivity.

Energy extendability (to 500-1000 GeV) accesses top Yukawa and triple-Higgs couplings

Higgs Boson Cross Section



BASED ON FULL ILC DETECTOR SIMULATION (ILD)

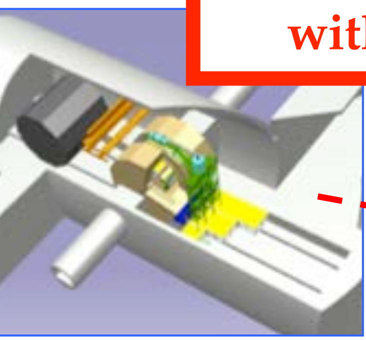


arXiv:1604.07524, PRD94 (2016) 113002

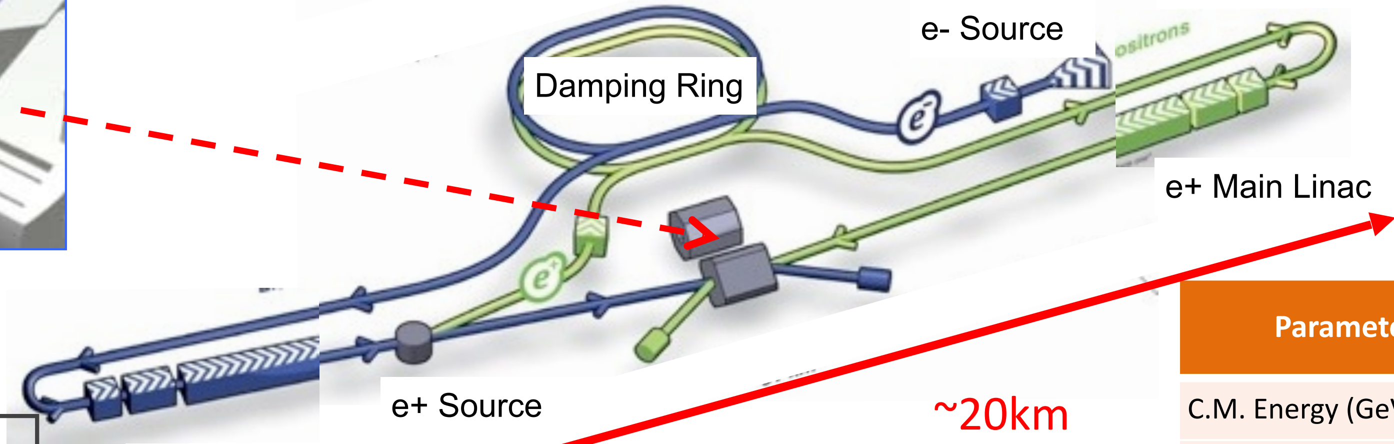
International Linear Collider (ILC)

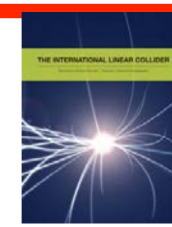
Design from two decades of GDE-led dedicated R&D, with significant DOE/NSF support on detectors.

ILC TDR is 5-volumes, published 12 June 2013



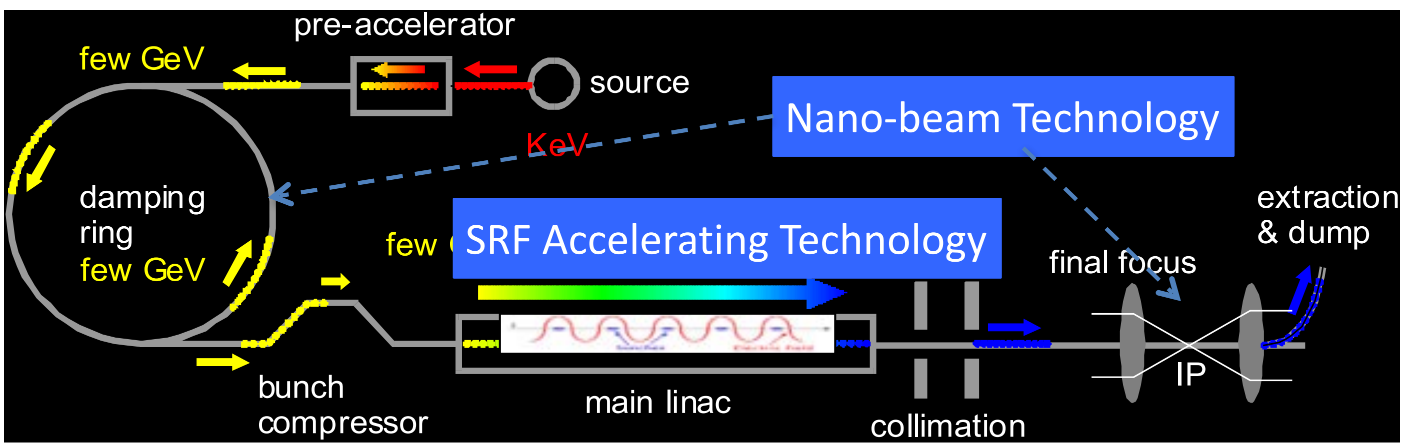
Physics Detectors





arXiv:
1711.00568
1903.01629

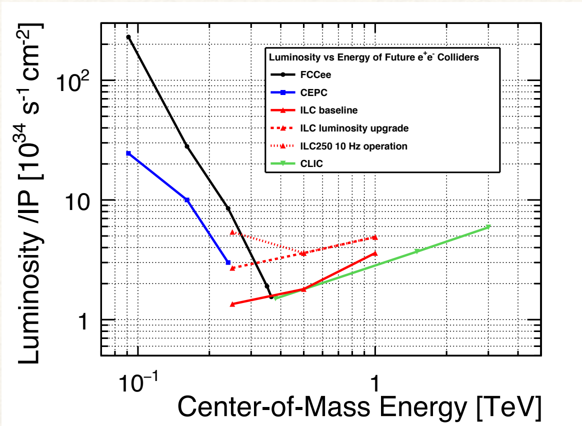
Key Technologies

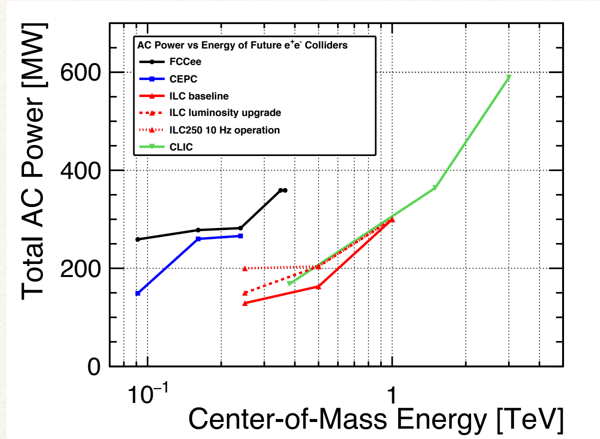


Parameter	Initial stage	TDR
C.M. Energy (GeV)	250	500
Length (km)	20	31
Luminosity ($\times10^{34}$)	1.35 (2.7, 5.4)	1.8
Repetition (Hz)	5 (10)	5
Beam Pulse Period (ms)	0.73	0.73
Beam Current (mA in pulse)	5.8	5.8
Beam size (y) at FF (nm)	7.7	5.9
SRF Cavity Gr (MV/m), Q_0	31.5, 1×10^{10}	31.5, 1×10^{10}
Site Power (MW)	129	163

Polarized electrons (± 80%) and positrons (± 30%)

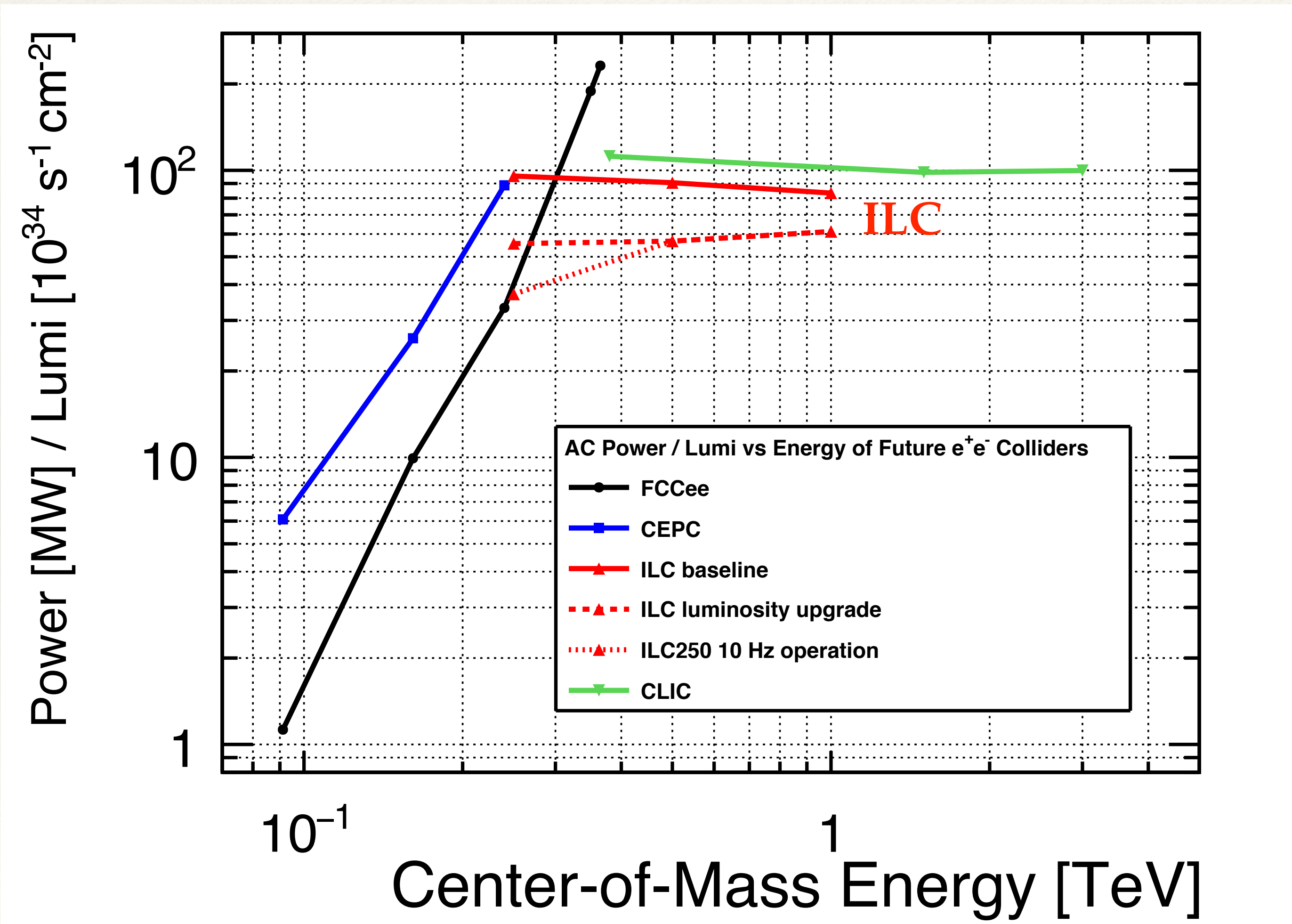
based on S. Michizono, 8 Nov 2017





Linear and Circular Higgs Factory Parameter Comparison

Lumi & Power

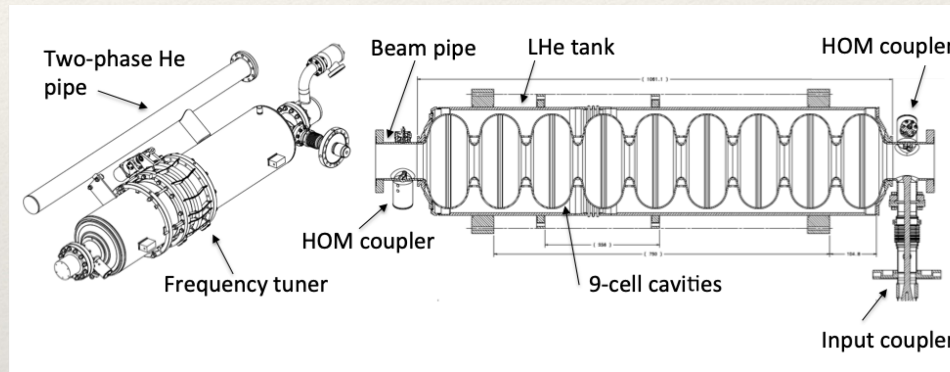


Linear Collider provides power efficient lumi. for > 250 GeV

SCRF Industrialization Critical for ILC

Parameters	Value
C.M. Energy	250 GeV
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Av. field gradient	31.5(35) MV/m +/-20% **Q_0 = 1E10**
# 9-cell cavity	~8,000 (x 1.1)
# cryomodule	~900
# Klystron	~240

SCRF Linac
(5km) x 2



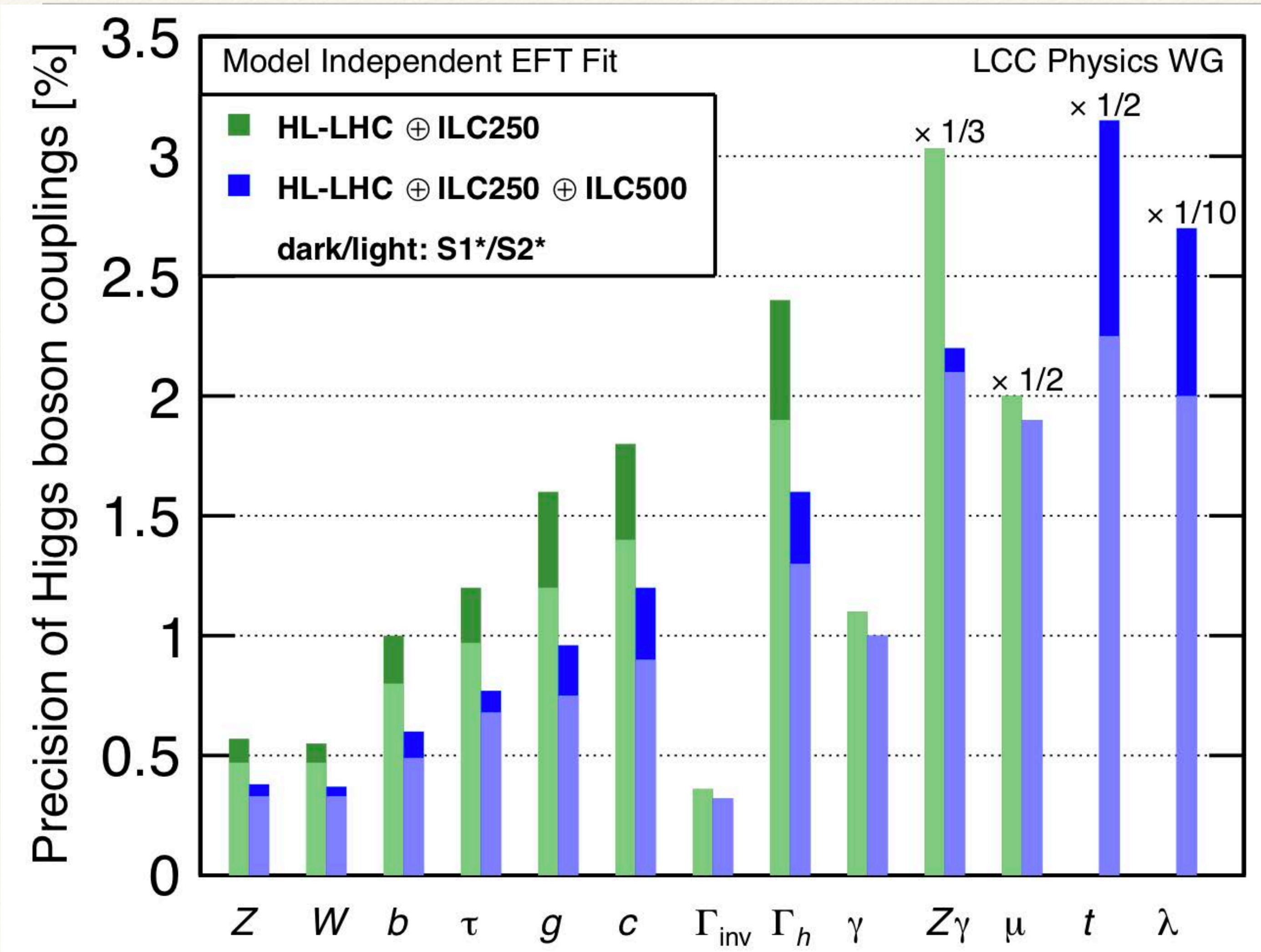
High quality

~8,000 x 1.1(Yield = 90%)
~ 9,000 cavities of mass-production

Many accelerator projects, world-wide, applying and advancing SCRF technology.
SCRF cavity production w/ N-infusion (Fermilab) pushing performance (see extras).

Higgs Couplings (EFT)

Model Independent



arXiv:1903.01629

Effective Field Theory (EFT) (rather than coupling modifier κ approach) **delivers highly model-independent Higgs couplings.**

Phys. Rev D97, 053003 (2018)

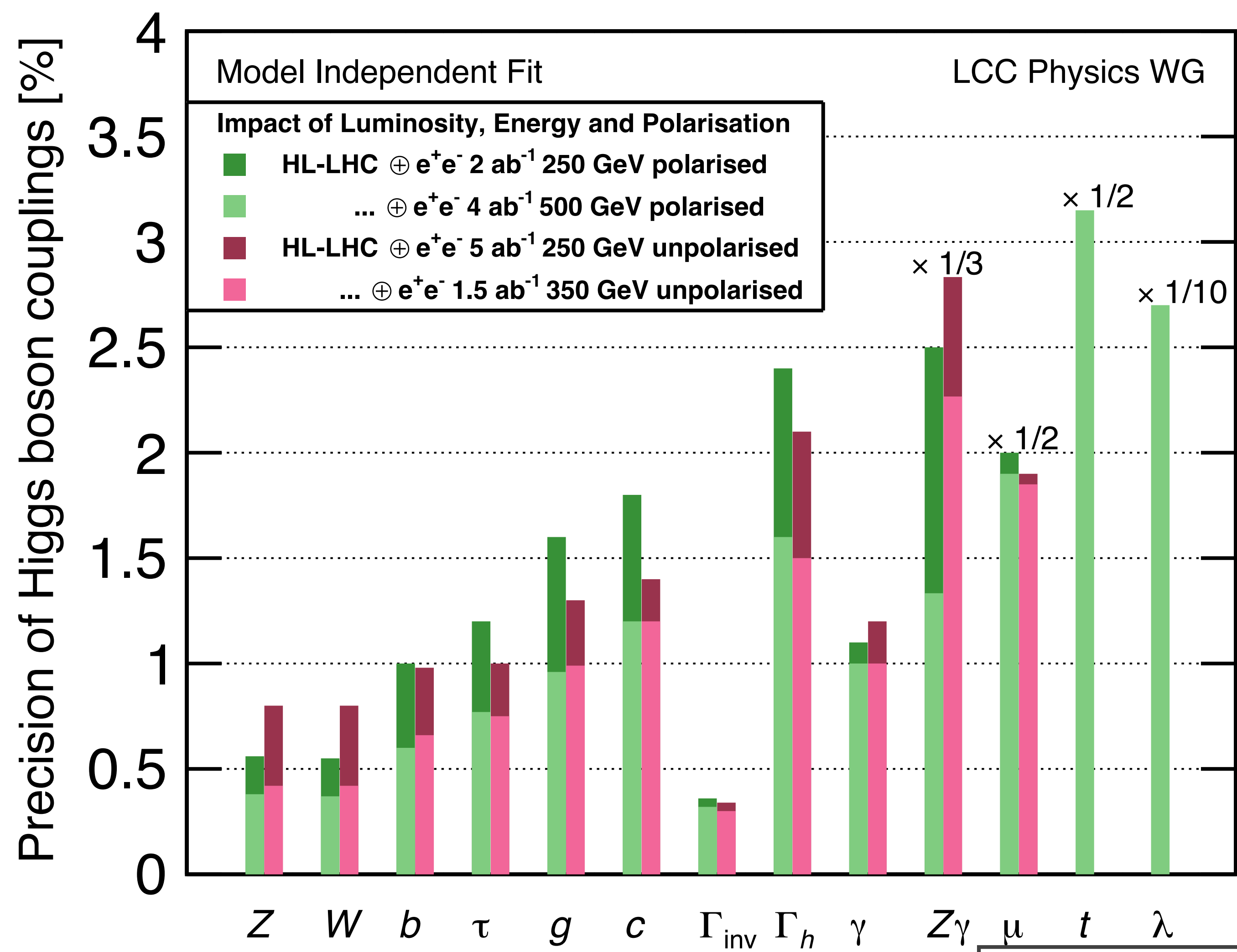
Polarization Trades Off Against Increased Luminosity

- Increased sensitivity relative to unpolarized collisions.

LC - current, unimproved projections (S1*)

validated by detailed simulation

see Tables XVIII and XIX of arXiv:1903.01629



arXiv:1903.01629

Polarization Trades Off Against Increased Luminosity

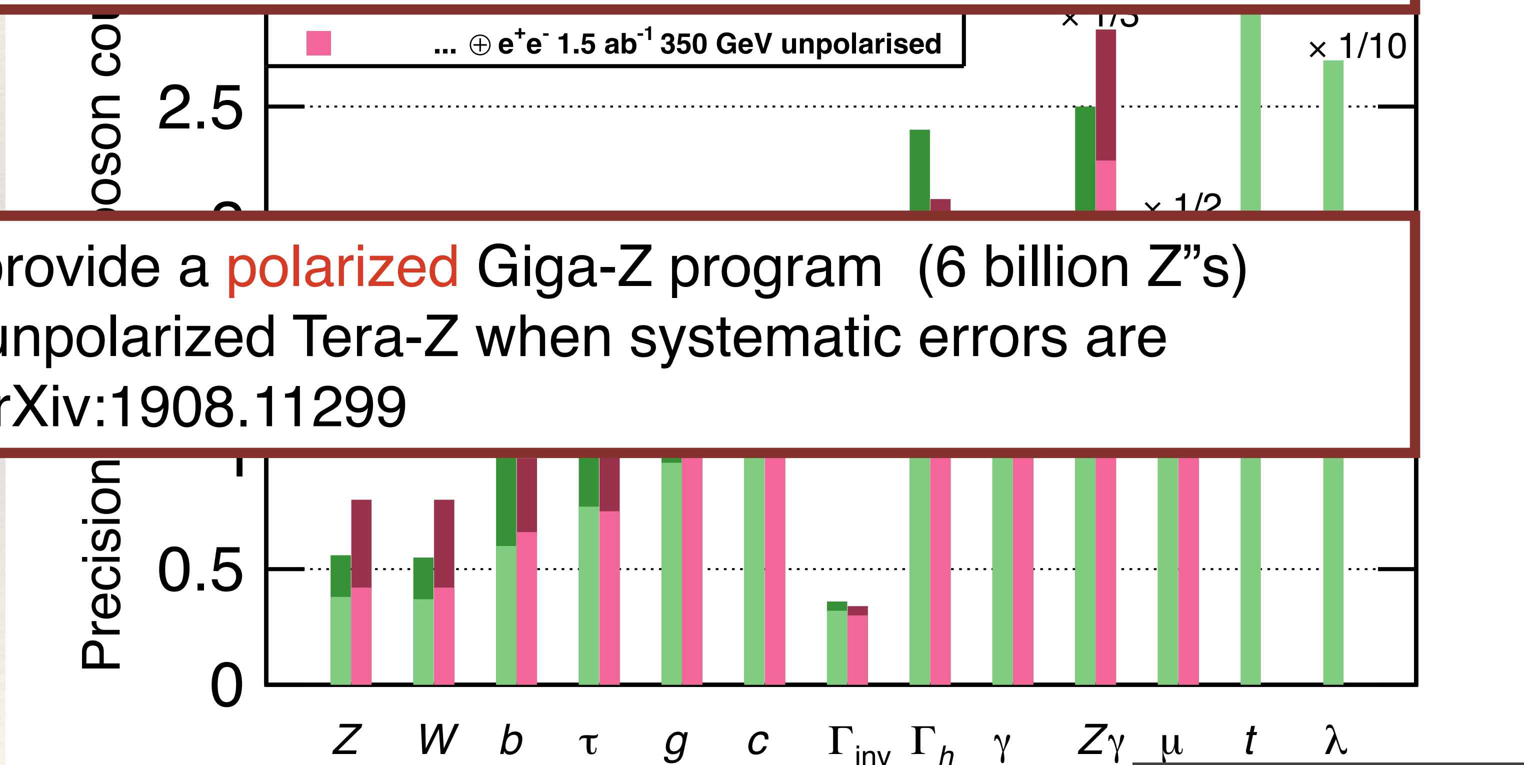
- Increased sensitivity relative to unpolarized collisions.

For Higgs coupling measurements, polarization compensates for lower 250 GeV integrated luminosity (2 vs 5 ab^{-1}) by
1.) increased rates, and
2.) removing some correlations between EFT operators.

projections (S1*)

validated by

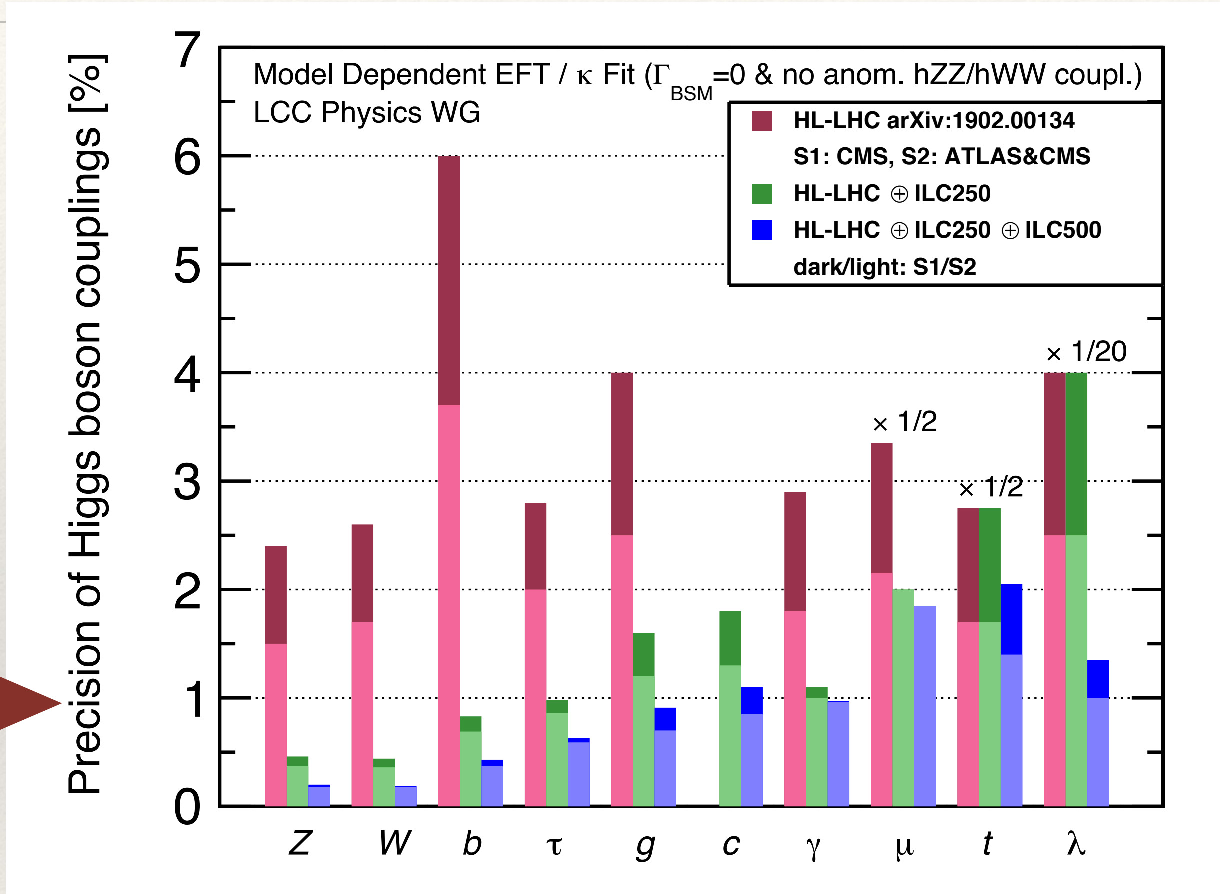
see Tables XVIII and XIX of arXiv:1903.01629



ALSO - ILC can provide a polarized Giga-Z program (6 billion Z"s) competitive with unpolarized Tera-Z when systematic errors are accounted; see arXiv:1908.11299

arXiv:1903.01629

HL-LHC Comparison (model-dependent)



1 %

- S1, current projection
- **/model-dependent**
- S2, improved
- **/model-dependent** (HL-LHC adopted)

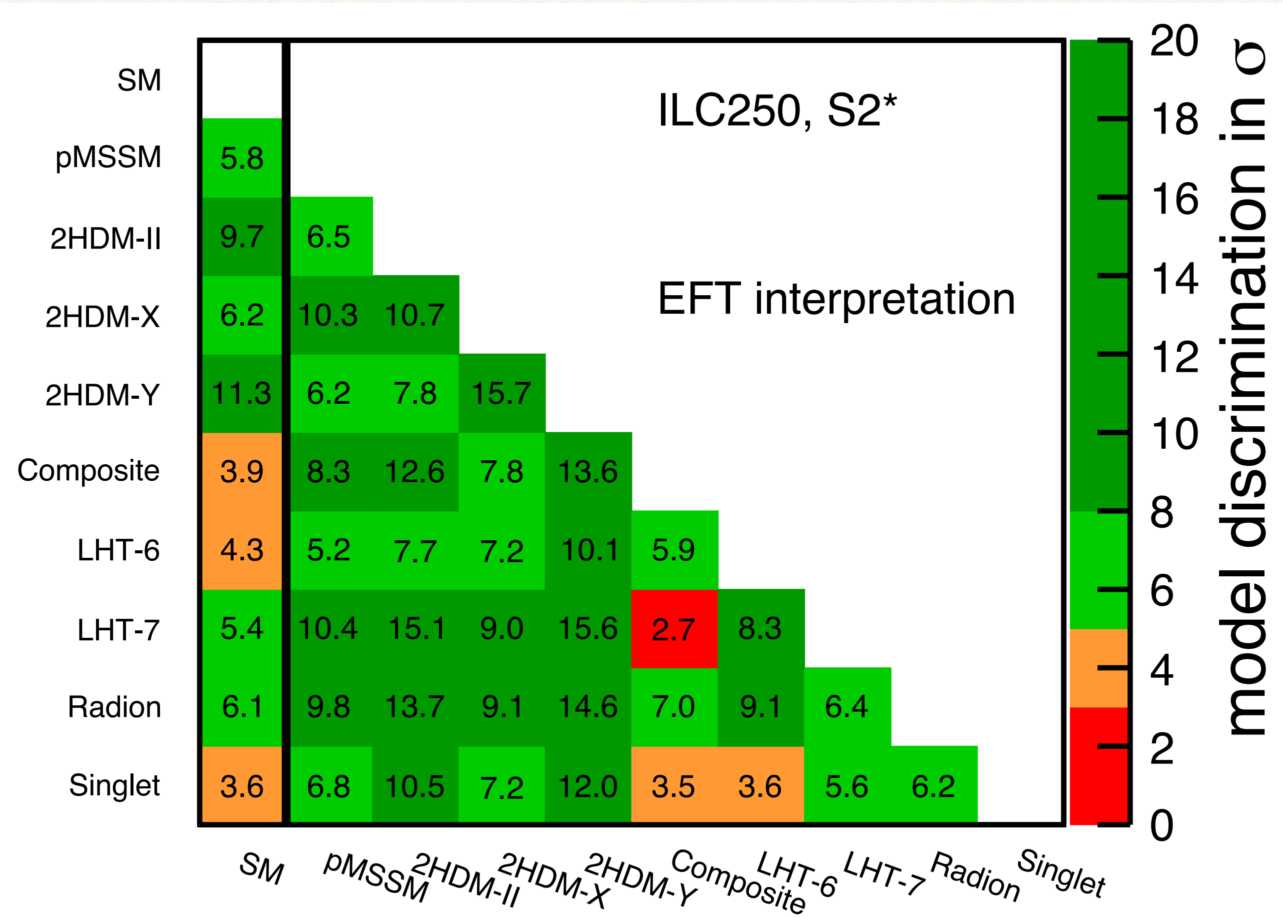
arXiv:1903.01629

Assume:

1.) Higgs boson has no decay modes beyond those predicted by SM,

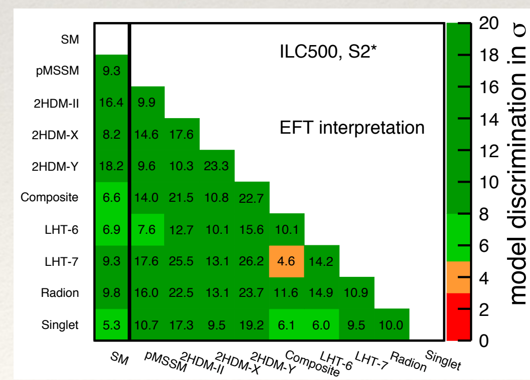
2.) Higgs boson WW & ZZ couplings modified only by rescaling.

BSM Model Discrimination



- ❖ **Studied nine(9) models that are <u>unlikely</u> to be discovered by HL-LHC.**
  - ❖ **Masses beyond reach.**

Improves (250+500)



- S1*, current projection **/model-independent**
- S2*, improved **/model-independent**

arXiv:1710.07621

The Broader Physics Program

The physics opportunities of the ILC emphasizes precise measurements of **most Higgs boson couplings.**

These are the centerpiece and FIRST PRIORITY.

But the ILC also provides:

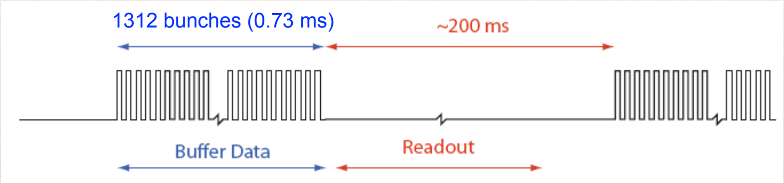
- search for **exotic modes of Higgs boson decay**
- search for **dark matter particles and other invisible states**
- search for **heavy resonances** through 2-fermion processes
- precise study of **W boson interactions** in $e^+e^- \rightarrow W^+W^-$

- precise measurement of the **top quark mass**
- precise measurement of **top quark electroweak couplings**

- precise measurement of **top quark Yukawa coupling (tth)**
- measurement of the **triple Higgs boson coupling**

ILC Experimental Advantages

- Radiation damage is mostly not an issue (except very forward).
  - collisions dominated by electroweak processes.
- Trigger-less operation - record every interaction (< 6Gb/sec).
- Bunch train structure allows pulse power w/ gas cooling.



- Relatively low event rates.
- Elementary interactions at known E_{cm} (e.g. $e^+e^- \rightarrow ZH$).
- Democratic Cross sections (e.g. $[e^+e^- \rightarrow ZH] \sim 1/2\,[e^+e^- \rightarrow d\bar{d}]$).
- Highly Polarized Electron Beam (~ 80% - & positron pol. 30%).
- Tunable center-of-mass energy.
- Beam polarization helps control systematics.

- THESE FEATURES ENHANCE PRECISION MEASUREMENTS

Physics Drives Detector Requirements

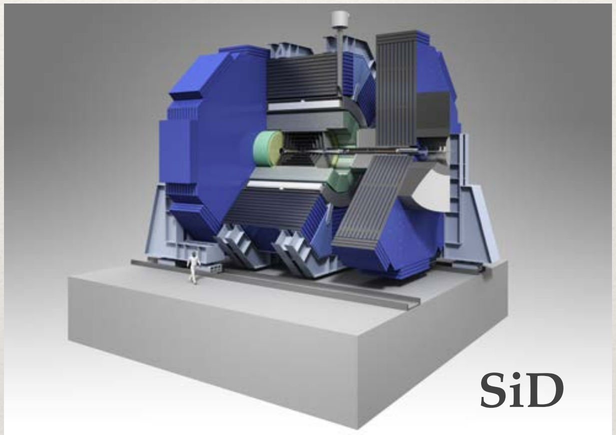
Physics Process	Measured Quantity	Critical System	Critical Detector Characteristic	Required Performance
$H \to b\bar{b}, c\bar{c}, gg, \tau\tau$ $b\bar{b}$	Higgs branching fractions b quark charge asymmetry	Vertex Detector	Impact parameter $\Rightarrow$ Flavor tag	$\delta_b \sim 5\mu m \oplus 10\mu m/(p\sin^{3/2}\theta)$
ZH→$\ell^+\ell^-$X $\mu^+\mu^-\gamma$ $ZH + H\nu\bar{\nu} \to \mu^+\mu^- X$	Higgs Recoil Mass Lumin Weighted E_{cm} BR (H →μμ)	Tracker	Charge particle momentum resolution, $\sigma(p_t)/p_t^2$ $\Rightarrow$ Recoil mass	$\sigma(p_t)/p_t^2 \sim few \times 10^{-5} GeV^{-1}$
ZHH $ZH \to q\bar{q}b\bar{b}$ ZH→ZWW* $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass BR (H → WW*) σ(e+e- → νν W+W-)	Tracker & Calorimeter	Jet Energy Resolution, σ_E/E $\Rightarrow$ Di-jet Mass Res.	~3% for E_{jet} > 100 GeV $30\%/\sqrt{E_{jet}}$ for E_{jet} < 100 GeV
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum resolution, Hermiticity $\Rightarrow$ Event Reconstruction	Maximal solid angle coverage

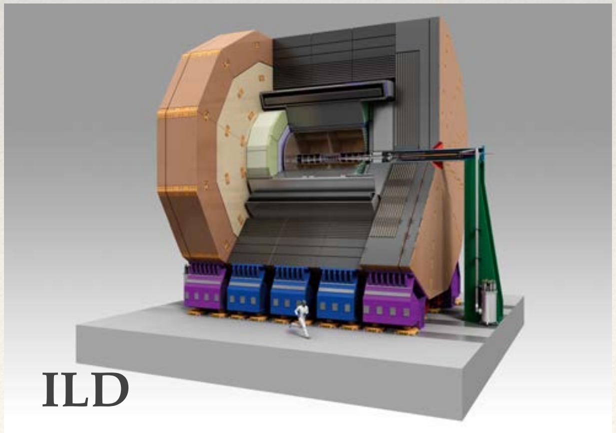
Integrated Detectors

- Two Validated detector concepts.
- Complementary: tracking technology, magnetic field, calorimetry, etc.
- Expect new ideas & concepts to be considered as project matures.
  - Collaborators welcome.

Design Goals:	High efficiency High resolution Low fake rate Control of systematics

SiD		ILD
Silicon	Tracking	TPC w/ silicon
6.0 m	Outer Radius	7.8 m
5 Tesla	B Field	3.5 Tesla



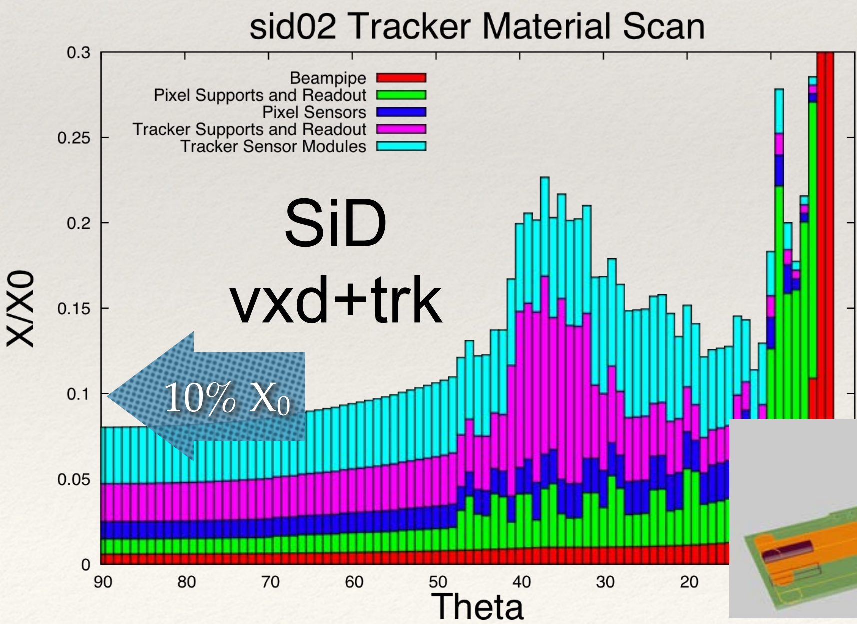


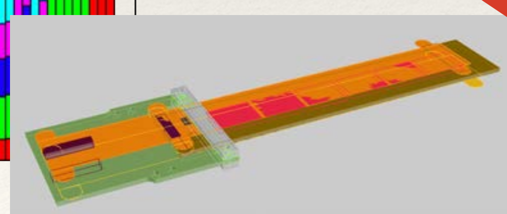
Unprecedented subDetectors (examples)

Silicon tracking w/ gas cooling → Low material

SiD Tracker Design

- ❖ Linkage between readout/mechanics/ powering/cooling studies.
- ❖ Maintain low mass construction.
- ❖ Tracking material from SiD design:

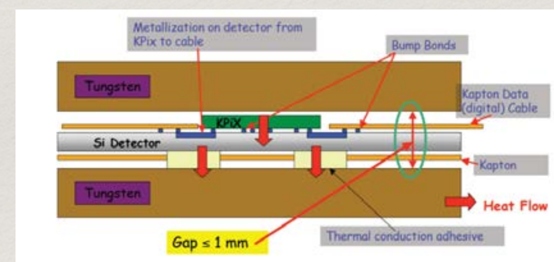


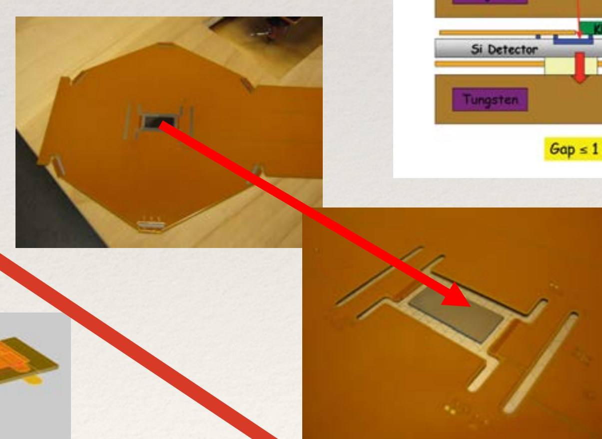


Silicon-tungsten ECal - very high granularity

SiD ECal Design

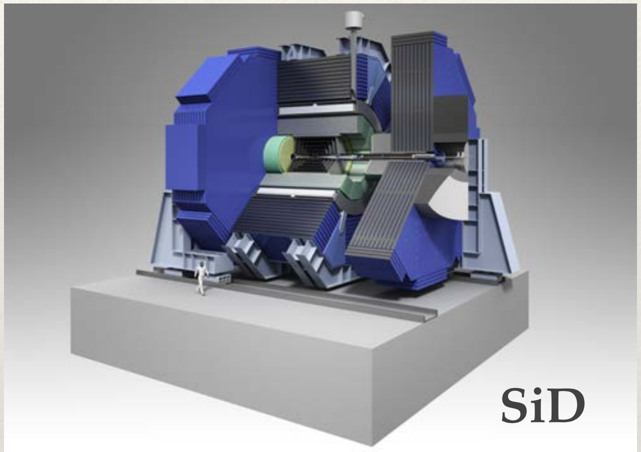
- ❖ 6 inch wafers, 1024 13 mm² pixels
- ❖ KPiX readout/cable bump-bonded directly
- ❖ 1 mm readout gaps -> 13 mm eff. Moliere radius
- ❖ Tungsten thermal bridge

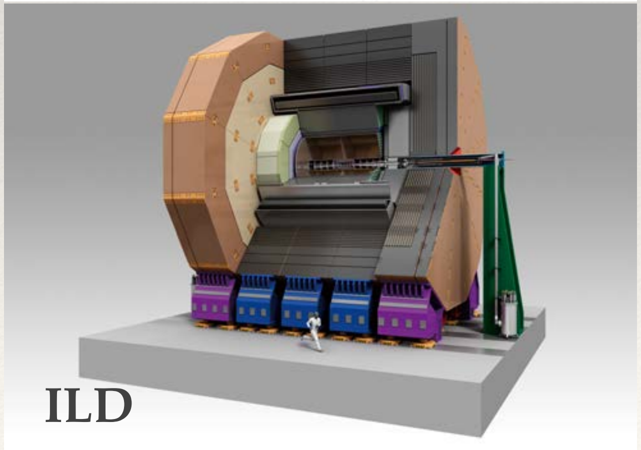




Detector Requirements Achieved in Designs

- Clean events with low backgrounds enable unprecedented detector performance motivated by physics goals.
  - High granularity
  - Dense integration
  - Super light materials
  - Low power/pulse power
  - Air cooling
- Physics simulations are based on realistic detector models.
- Renewed US Detector R&D support needed to re-establish US roles.





Annual International Workshops on Future Linear Colliders

2019 LINEAR COLLIDER WORKSHOP

- **October 28-Nov 1, 2019 - Sendai, Japan, LCWS2019**

- **2018 -Arlington, Texas**
- **2017 - Strasbourg, France**

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Hon . Ryu SHIONOYA, Secretary-General of the Federation of Diet Members for the ILC

Reaffirmed Japanese government's interest in hosting the ILC.

"US-Japan relation is stronger than ever, and the political and administrative aspects are both working towards the realization of the ILC."

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Melinda Pavek, Director of Science, Innovation and Development, US Embassy, Tokyo

"the U.S. Department of State is ready to assist our partner agencies in developing the next major particle physics facility in Japan—the ***International Linear Collider.****"*

February ICFA Meeting

- Two leading Japanese figures in the decision process came to SLAC to address ICFA.
  - **H. Masuko**, Deputy-Director General, MEXT.
  - **T. Kawamura**, Chairperson of the Federation of Diet Members for the ILC.
- Both gave encouraging statements.
- **Chris Fall,** Director of US DOE Office of Science, also appear in person and gave positive ILC statement.
- In response, ICFA released a statement (next slide).
  - https://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_22Feb2020.pdf

ICFA Statement on the ILC Project

February 22, 2020

ICFA was encouraged by the reports from Mr. H. Masuko, Deputy-Director General, MEXT Research Promotion Bureau and Hon. T. Kawamura, Chairperson of the Federation of Diet Members for the ILC, at the ICFA meeting held at the SLAC National Accelerator Laboratory, Stanford, USA, on the 20th February 2020.

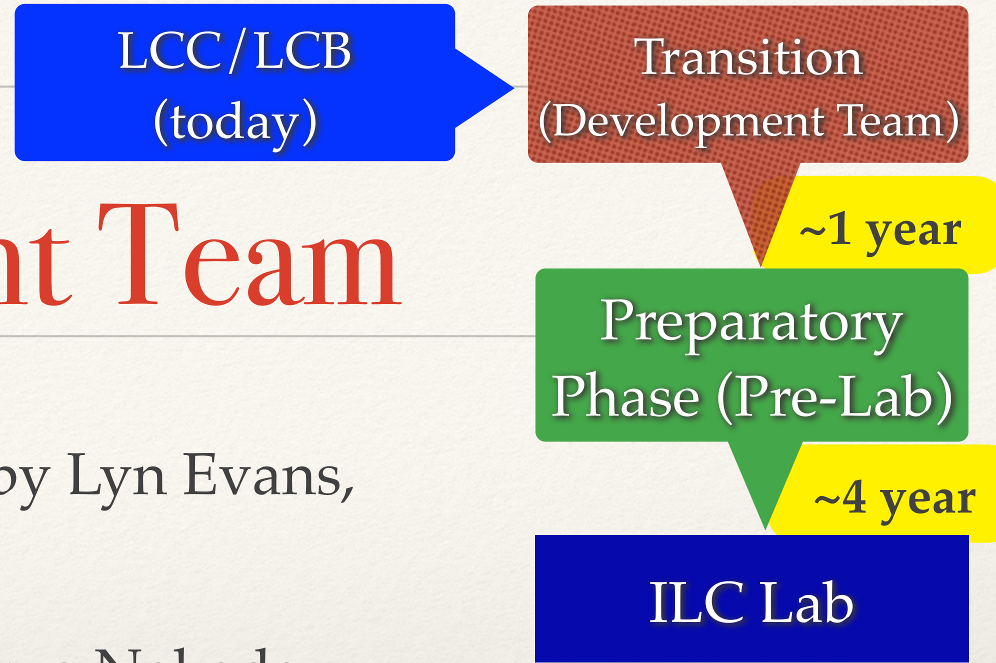
In view of progress towards realisation of the ILC in Japan, ICFA encourages the interested members of the high energy physics community, laboratories, and nations, to support and participate in these preparations aimed at the successful establishment of the ILC.

https://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_22Feb2020.pdf

- ICFA anticipates that these development activities could be completed in approximately one year, at which point it would be possible to launch the preparatory phase for the ILC, provided Japan expresses intent to do so together with international partners.

- In view of progress towards realisation of the ILC in Japan, ICFA encourages the interested members of the high energy physics community, laboratories, and nations, to support and participate in these preparations aimed at the successful establishment of the ILC.

Menlo Park, CA, USA



Development Team

- Linear Collider Collaboration, led by Lyn Evans, mandate ends June, 2020.
- ICFA, assisted by LCB, led by Tatsuya Nakada, planning a **transition phase**, led by an **international development team**, hosted by KEK. (**Transition** will last approx. 1-1.5 years.)
- **International development team** plans **pre-Lab preparatory phase** including technical, organizational and governance issues and the activities and resources required in the **pre-Lab preparatory phase.**
- Following about one year planning, if Japan has expressed intent with international partners, **pre-Lab preparatory phase** will be launched.

https://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_22Feb2020.pdf

Conclusion

- ILC is **technically sound**, ready for **construction start**.
- Staged ILC offers excellent science from **first stage** (250 GeV)
    - TeV-scale BSM physics impacts Higgs boson couplings at the **percent level.** (*polarization and model-independence critical*)
    - **Higher energy** upgrades will extend physics program.
    - All LHC scenarios leave a compelling **ILC discovery potential.**
- ICFA recently heard encouraging reports on status from leading Japanese political and governmental figures.
- ICFA preparing plan for transition from LCC/LCB.
- **US DOE and State encourages Japanese.**
- H**igh-level "signal"** within Japanese government soon.
- Join us as we transition to ILC Lab.

Ref: arXiv:1903.01629

Acknowledgement

- Support provided by US Department of Energy.

ILC References

- **International Linear Collider Technical Design Report**
  arXiv:1306.6327 – Volume 1: Executive Summary
  arXiv:1306.6352 – Volume 2: Physics
  arXiv:1306.6353 – Volume 3.I: Accelerator R&D in the Technical Design Phase
  arXiv:1306.6328 – Volume 3.II: Accelerator Baseline Design
  arXiv:1306.6329 – Volume 4: Detectors
- **Physics Case for the 250 GeV Stage of the International Linear Collider**
  arXiv:1710.07621
- **The International Linear Collider Machine Staging Report 2017**
  arXiv:1711.00568
- **The role of positron polarization for the initial 250 GeV stage of the International Linear Collider**
  arXiv:1801.02840
- **The International Linear Collider: A Global Project**
  arXiv:1903.01629
- **Tests of the Standard Model at the International Linear Collider**
  arXiv:1908.11299v2