The International Linear Collider (*ILC*)

Physics Case and Project Status

Juan A. Fuster Verdú, IFIC-Valencia

St. Petesburg (Russia), Aug. 31- Sep. 5, 2015

Thanks for providing material and discussions to:

K. Fujii, S. Komamiya, L. Linssen, R. Poeschl, Ph. Roloff, N. Walker, H. Yamamoto

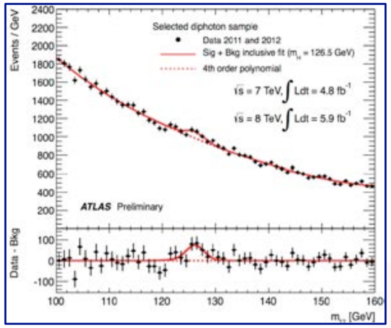
Outline

- Introduction
- The ILC accelerator (highlights)
- Physics potential at the ILC (highlights)
- ILC Detector Concepts
- Summary

ILC: From Design to reality

1980 ~
- Basic Study started

2004
- SCRF Technology selected



Higgs discovered

LHC

2005 2006 2007 2008 2009 2010 2011 2012 2013

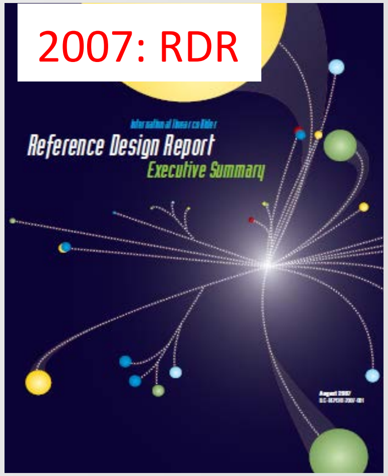
ILC - GLOBAL DESIGN EFFORT (GDE)

LCC

Linear Collider Collaboration

Ref. Design Report (RDR)

2007: RDR



2013: TDR

COMPLETED

A. Yamamoto - ICHEP 2014

J. Fuster

The new Linear Collider Collaboration

ICFA
Chair: J. Mnich

FALC
Chair: J. Womersley

Program Adv. Committee
PAC – Chair: N. Holtkamp

Linear Collider Board
LCB – Chair: S. Komamiya

KEK

KEK LC Project Office

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

Linear Collider Collab.
LCC Directorate
Director: L. Evans

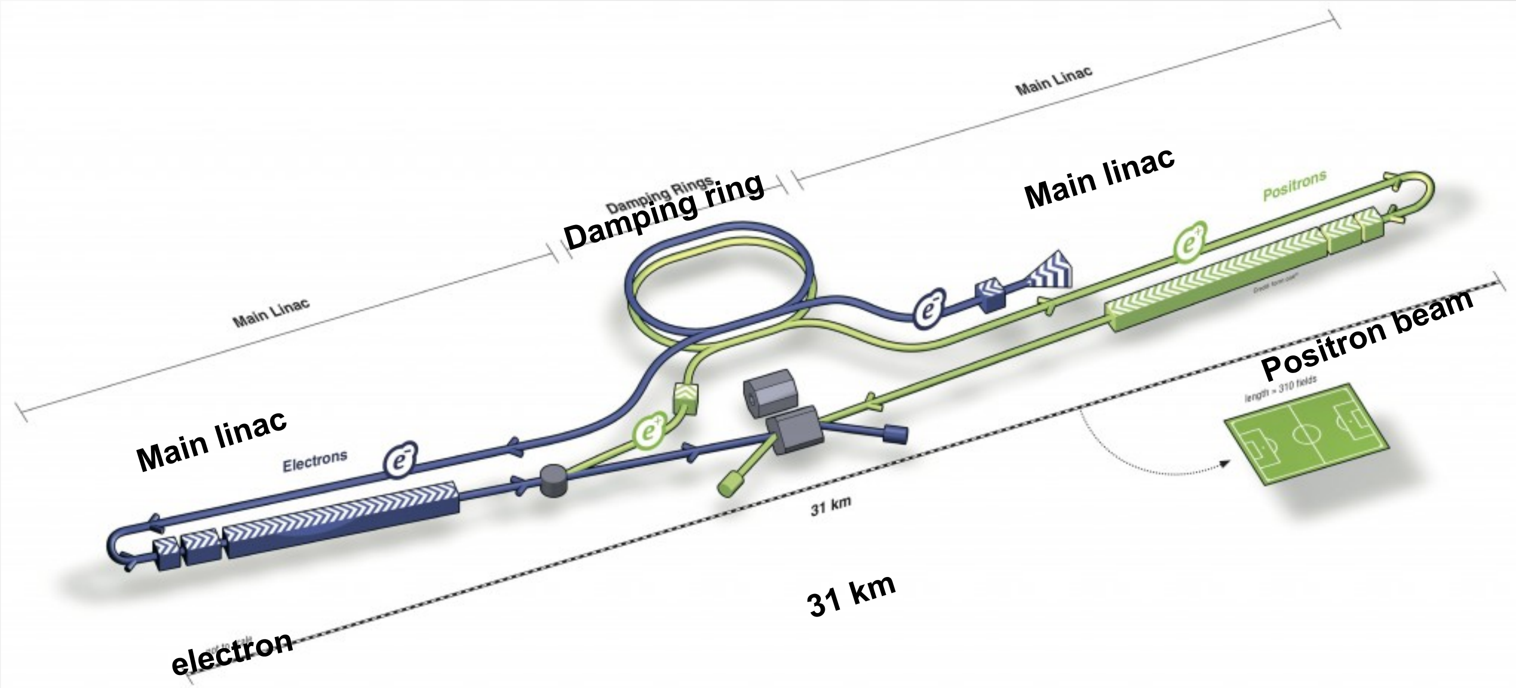
Deputy (Physics)
H. Murayama

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

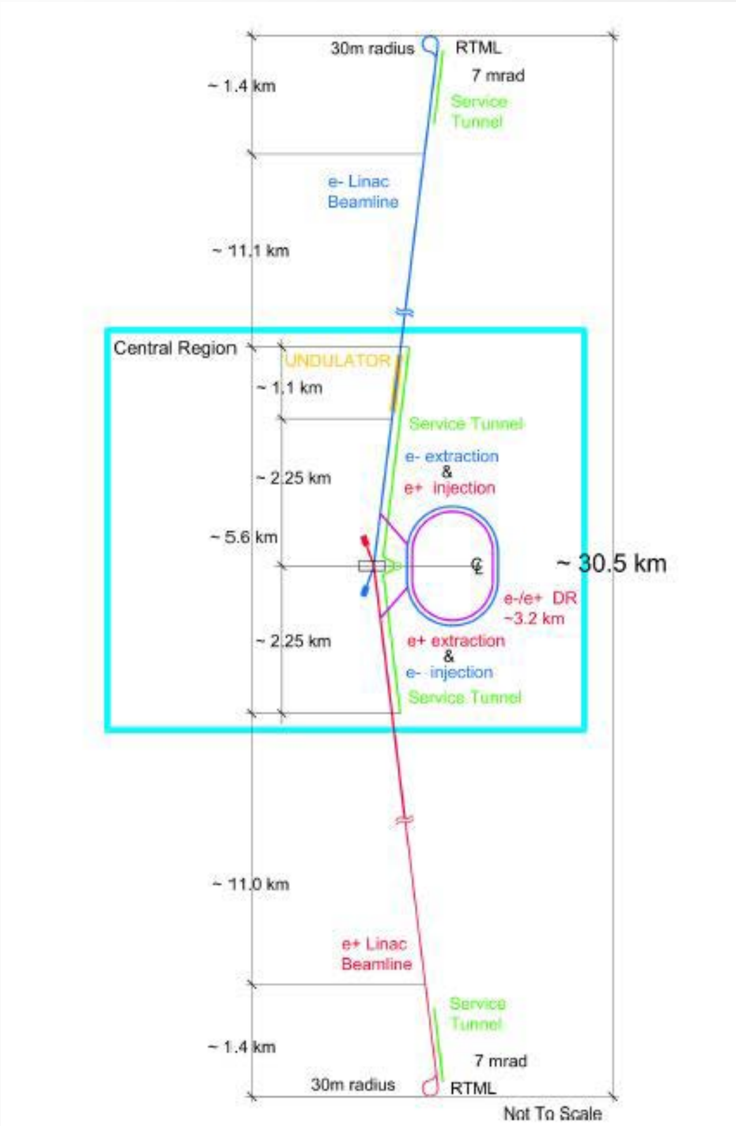
CLIC
S. Stapnes

Physics & Detectors
H. Yamamoto

ILC (International Linear Collider)



- 500 GeV CM with 31 km → upgrade later to ~ 1TeV CM with 50 km
- Beam size at IP : 6 nm x 500 nm x 300 mm
- Luminosity ~ 2 x 10^{34} /cm^{2}s with the possibility to increase (x2)
- Polarization >80% e^-; 30-40% e^+



S. Komamiya - LP 2015

- Main advantages (linear colliders):
  - No energy loss due to synchrotron radiation ($\Delta E \sim (E/m)^4 R^{-1}$)
  - Extendibility (Length ~ Energy)
  - Polarization
  - Energy scanning

Demonstrated in TDR (Beam Rep. rate, Pulse duration, Average current)

Progress in 2014-2015 (FF beam size (y), E gradient in SCRF acc. cavity)

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
FF beam size (y)	5.9 nm
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q_0 = 1E10

The ILC accelerator: SRF facilities worldwide

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

The ILC accelerator: SRF facilities worldwide

AMTF @DESY/E-XFEL, CM

700 out of 800 cavities completed <30 MV/m>

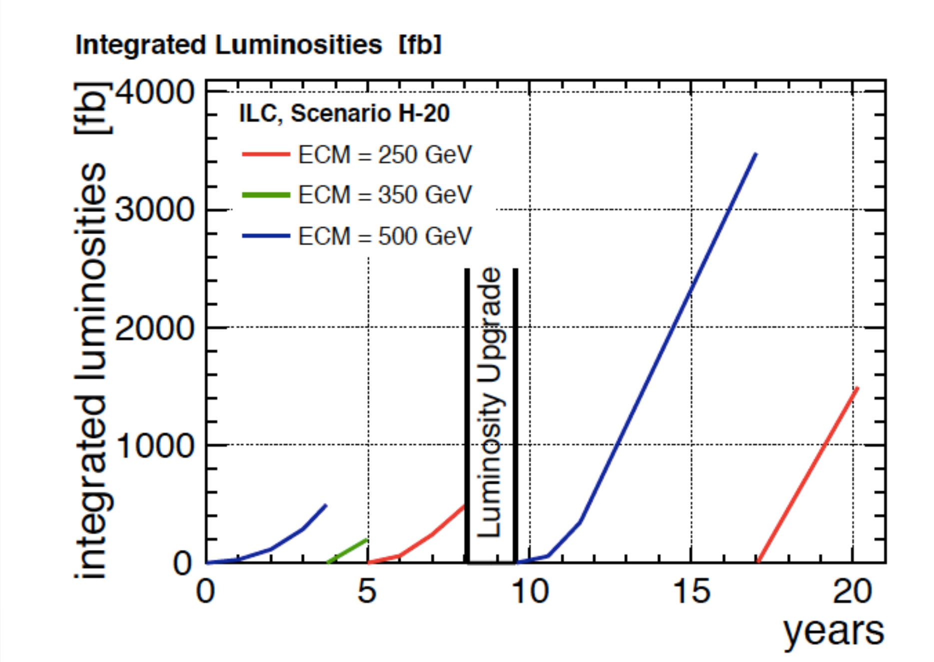
STF-CFF @ KEK

Individual cavity gradient of 35 MV/m

ASTA @ FNAL, TEDF @ JLab

Crymodule test facility at Fermilab reached <31.5 MV/m> exceeding ILC expects

Scenario	Stage	500			500 LumiUP		
	$\sqrt{s}$ [GeV]	500	350	250	500	350	250
G-20	$\int \mathscr{L} dt$ [fb^{-1}]	1000	200	500	4000	-	-
	time [years]	5.5	1.3	3.1	8.3	-	-
H-20	$\int \mathscr{L} dt$ [fb^{-1}]	500	200	500	3500	-	1500
	time [years]	3.7	1.3	3.1	7.5	-	3.1

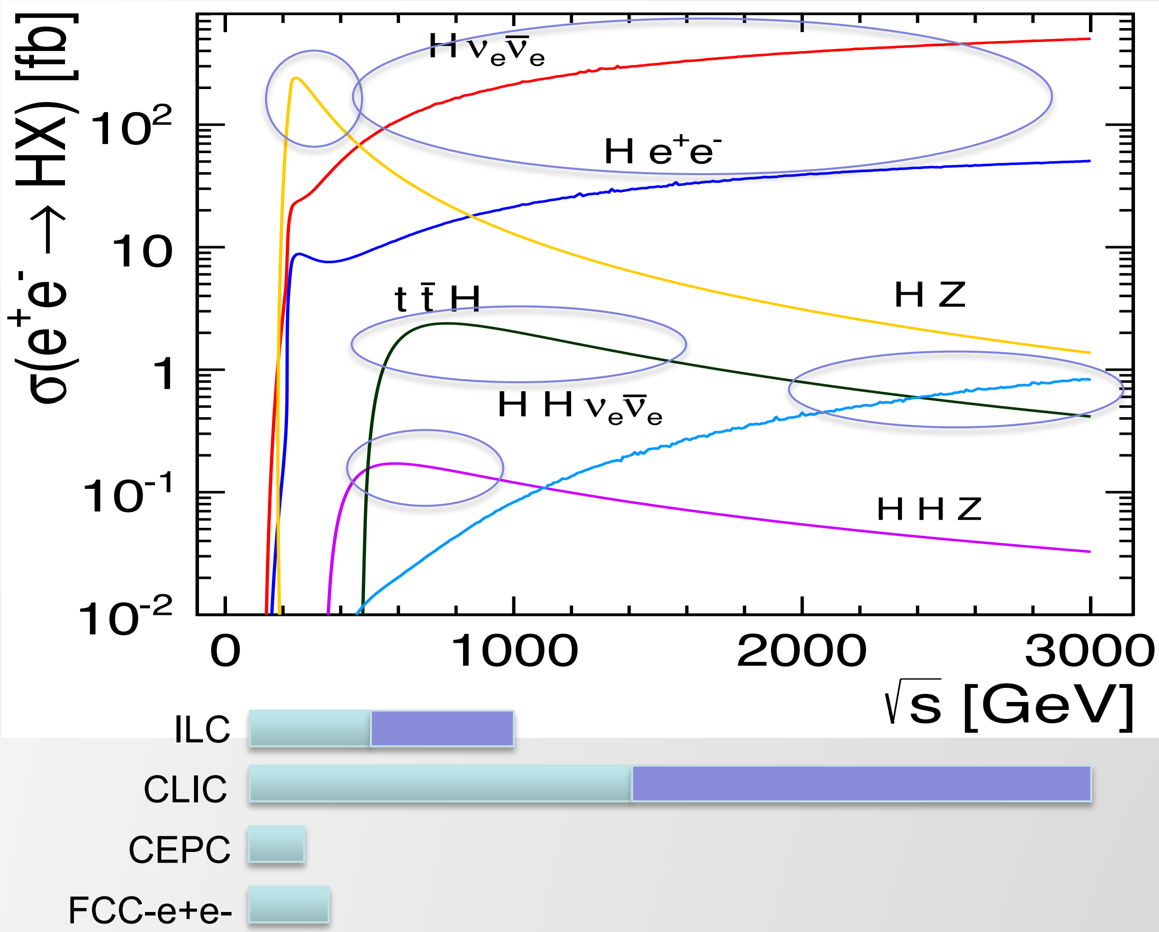


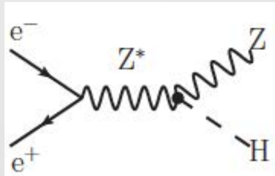
T. Barklow et al., arXiv:1506.07830

Recommended scenario (~20 years program):

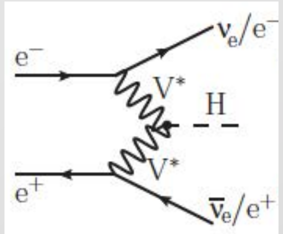
- Starting at 500 GeV (500 fb^{-1}), then 350 (200 fb-1) and 250 GeV (500 fb^{-1}).
- Luminosity upgrade (1312 → 2625 bunches per pulse) then 3500 fb^{-1} at 500 GeV and 1500 fb^{-1} at 250 GeV.

Obviously, actual running scenario will depend on physics outcomes from LHC and ILC, and other factors

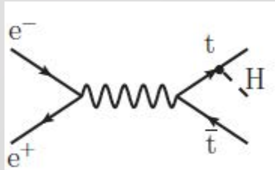




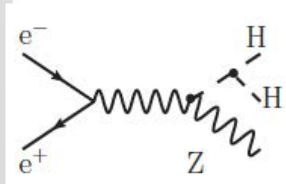
Mass
g_Z (m.i.)
BR´s
(LHC)-invisible



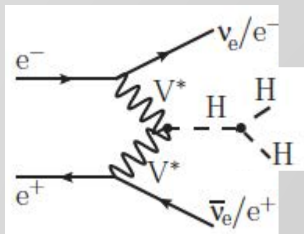
Γ_{tot}



g_t (ILC,CLIC)



g_{HHH} (ILC500)

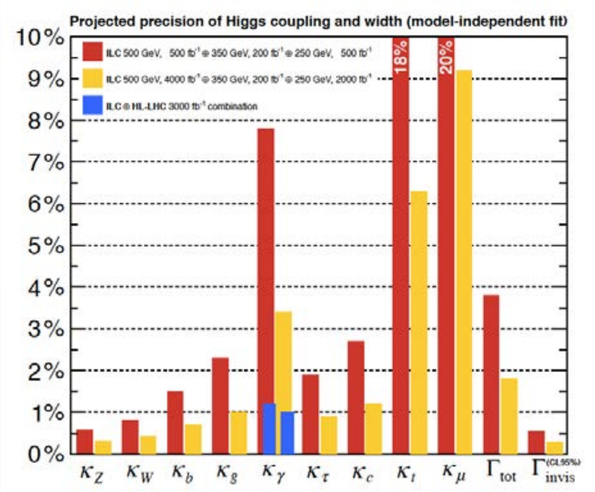


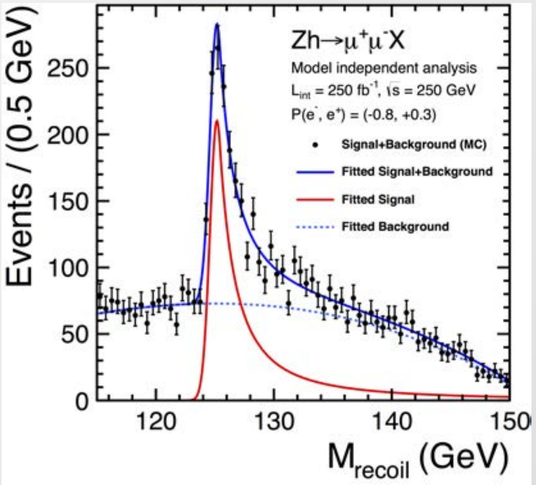
g_{HHH} (ILC1000, CLIC)

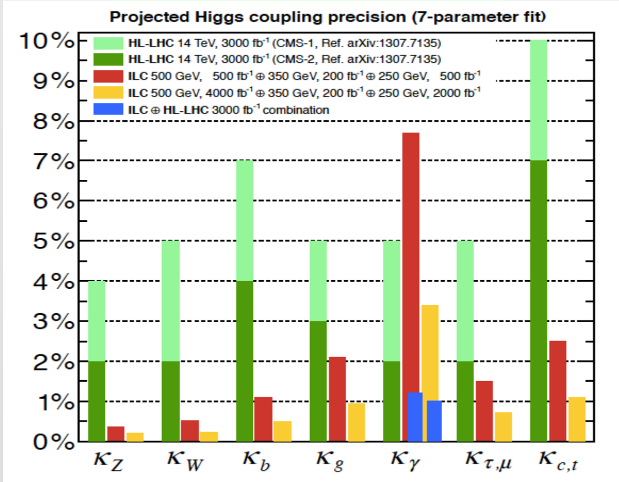
Many processes at different √s needed & accessible

ILC Model independent tests

Model dependent: LHC comparison



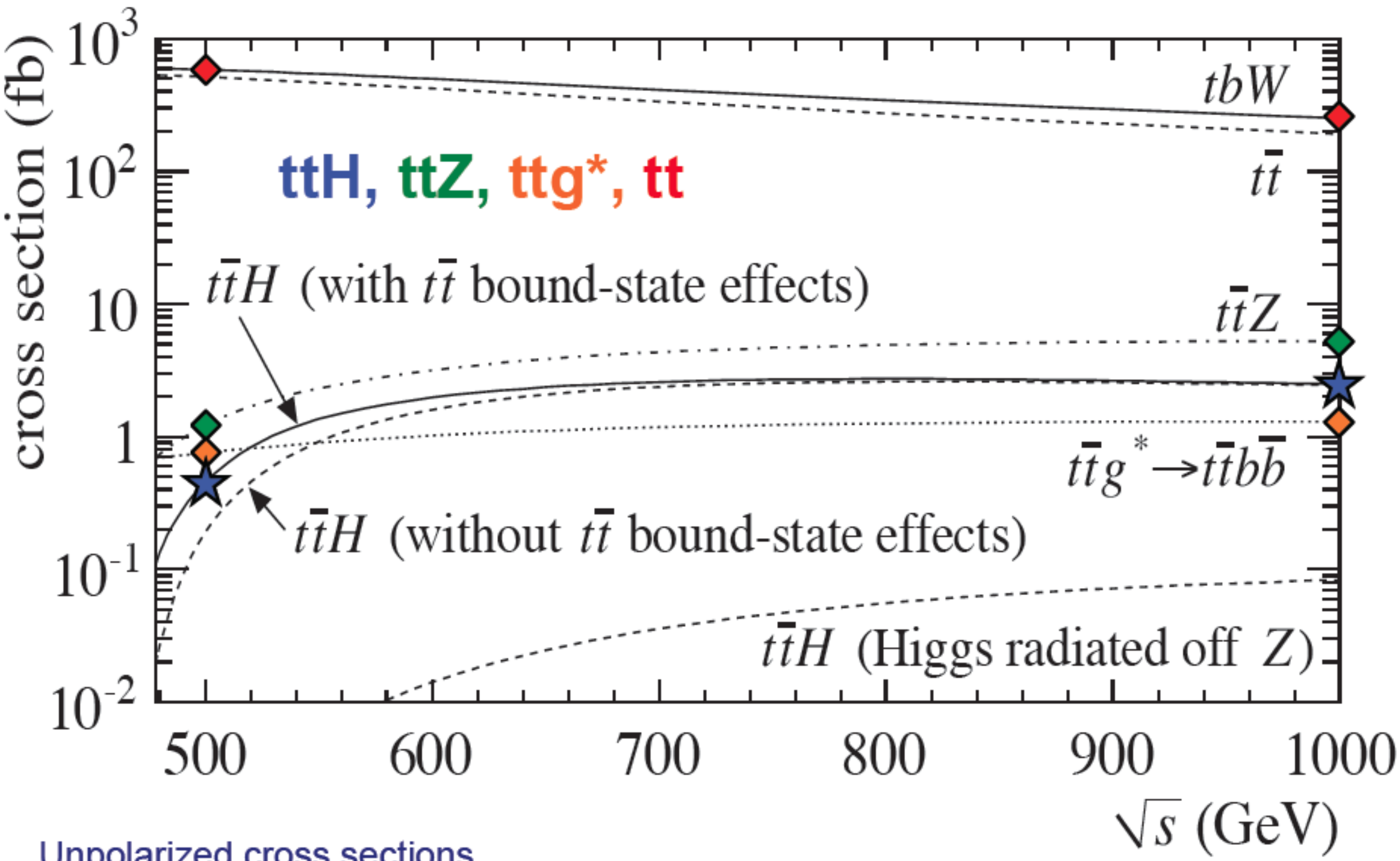




Model Independent tests allow for:

- No assumption for generation universality, unitarity, nor on BSM
- Apart from g, t, μ, accuracy is ~1 % or less (Level that is meaningful in distinguishing models)
- The total Higgs width is extracted with a few percent uncertainty
- Several channels (e.g.: H→cc, gg) very difficult in hadron collisions
- Coupling to the photon benefits from combination with HL-LHC which would provide Γ(H→γγ)/Γ(H→ZZ*)

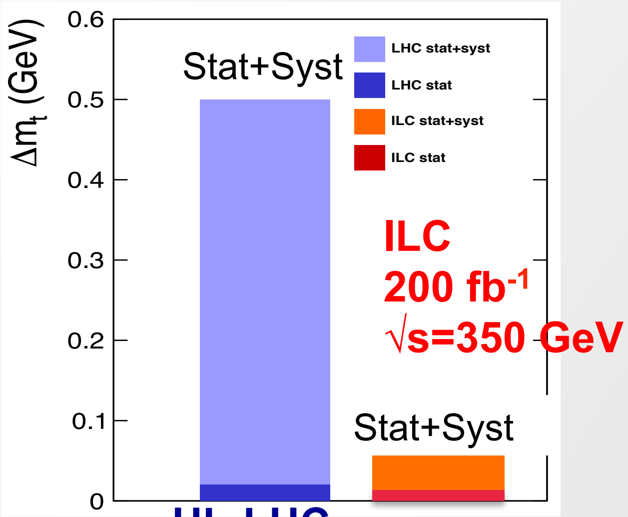
Cross Sections



Unpolarized cross sections.
For ttH: m_H = 120 GeV

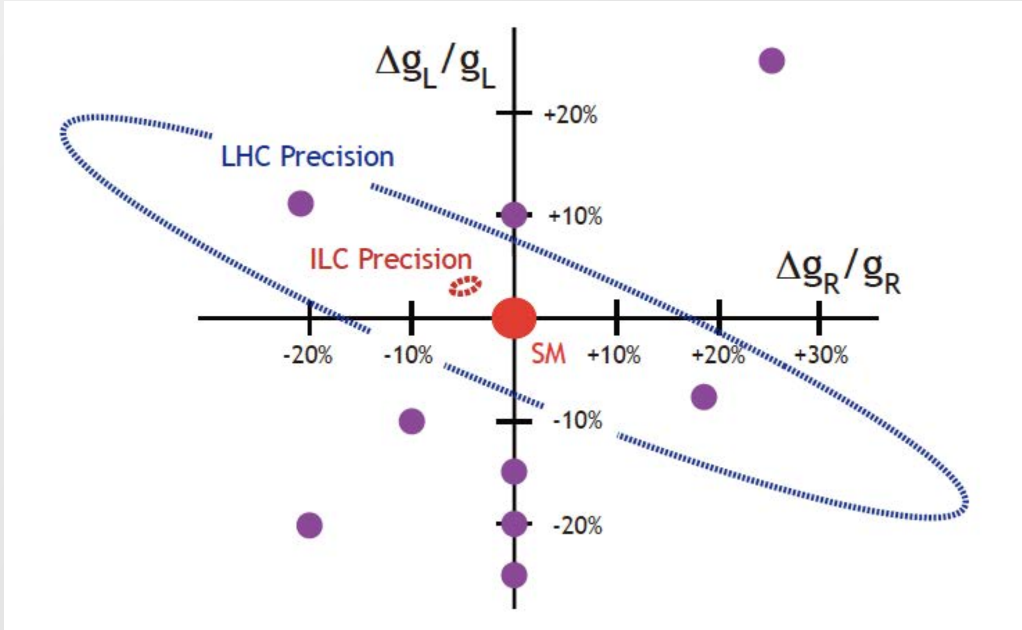
ILC physics potential: top physics

Top mass @ 350 GeV (MS-bar)



HL-LHC
3000 fb^{-1}
$\sqrt{s}$=13-14 TeV

BSM: Anomalous top couplings @ >500 GeV

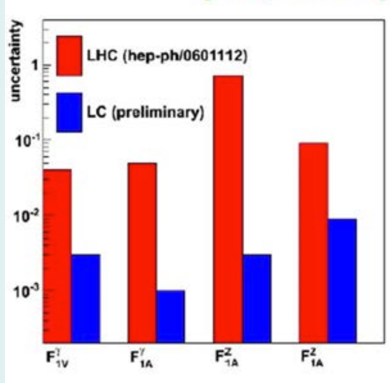


Top mass: Well defined mass scheme

Top anomalous couplings:

- Distinguish variety of BSM models.
- Use beam polarization (separates γ and Z, R and L

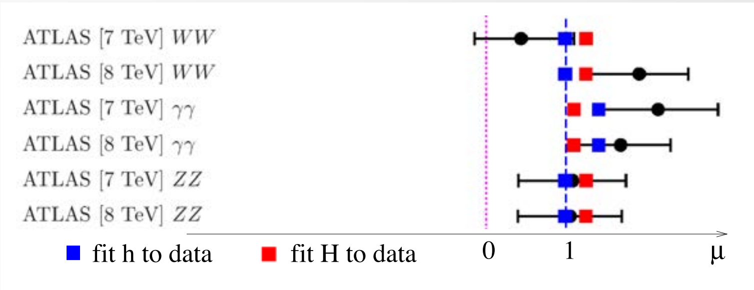
[Vos, Rouëné]



One example:

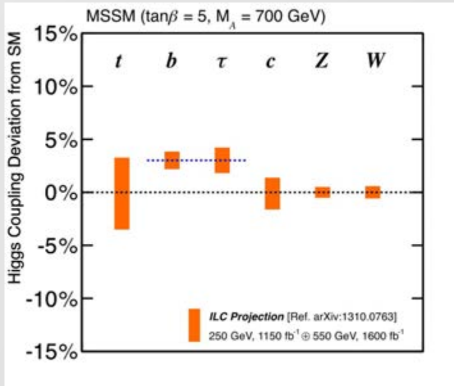
Fit LHC and Tevatron „signal strength“ parameters to the MSSM taking into account limits, B-physics constraints etc.

→ both h and H provide a reasonable fit

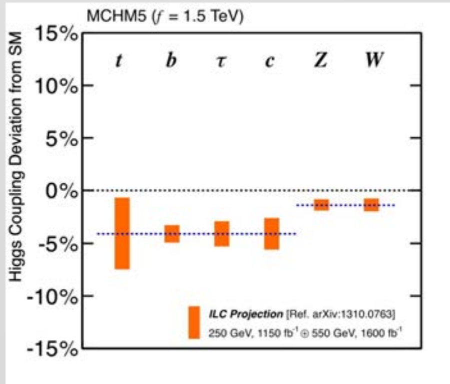


[Bechtle, Heinemeyer, Stal, Stefaniak, Weiglein, Zeune arXiv:1211.1955]

Supersymmetry



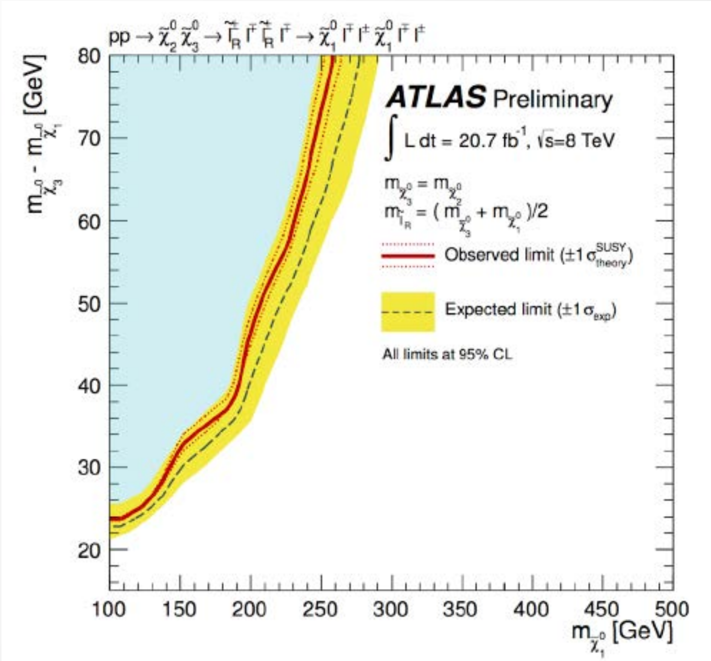
Composite Higgs

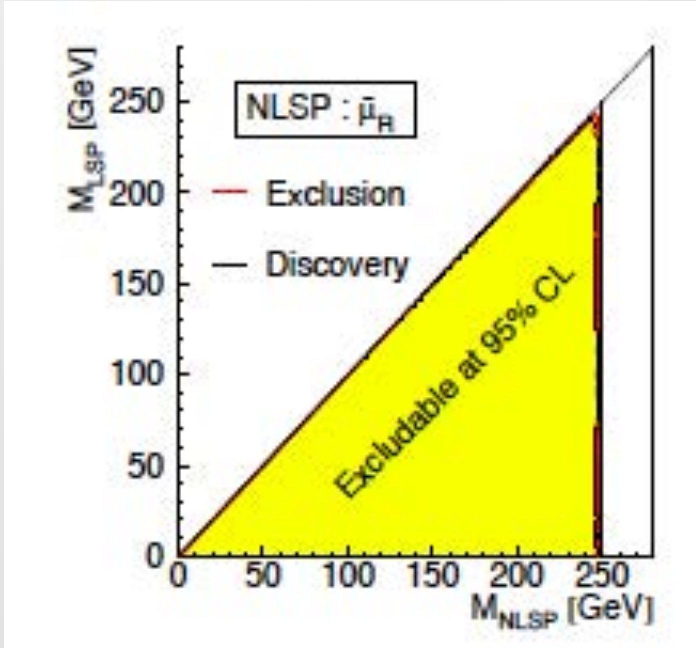


ILC 250+550 LumiUP

- tiny differences between best fit and SM
- tiny differences between h and H hypotheses
- $\Delta\mu/\mu \lesssim 5\%-20\%$
- In general precision at ~% or better is requiried

New Physics: direct searches complementarity with LHC





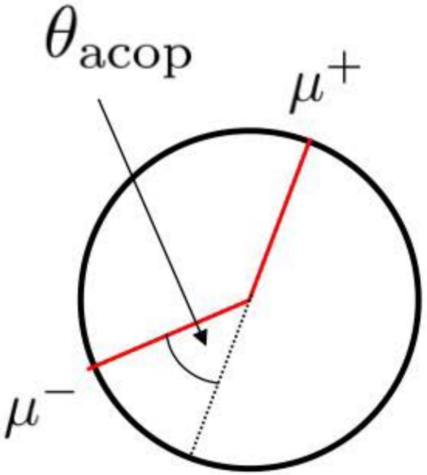
LHC:
Difficulty when mass difference is small

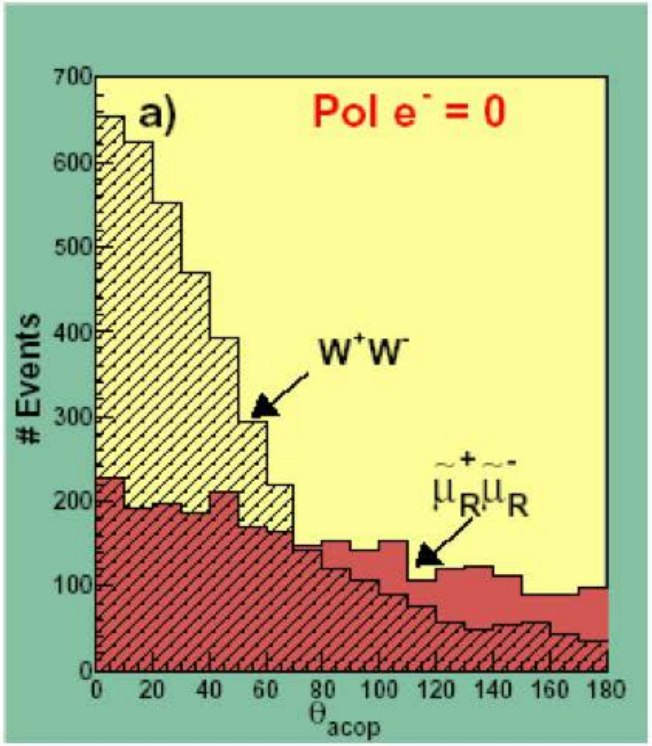
ILC:
Good sensitivity up to kinematic limit for (essentially) any mass difference

In general (even when no near degeneracy):

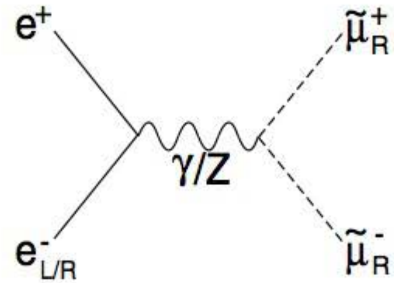
LHC can reach higher energy but could miss important phenomena. Tevatron could not have a clear signal of the Higgs though 20000 Higgs events were produced.

New Physics: direct searches (power of beam polarization)

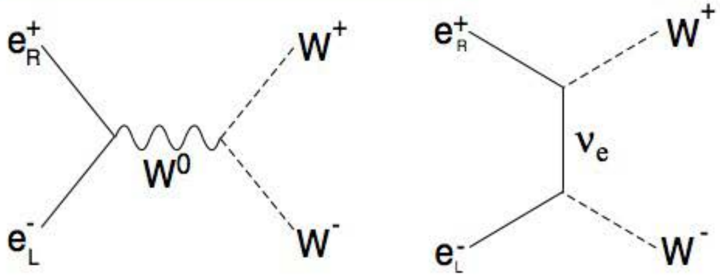




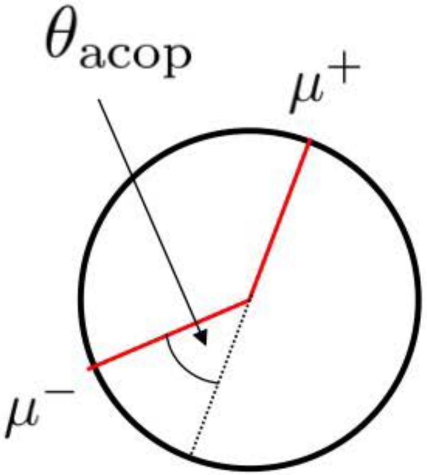
signal

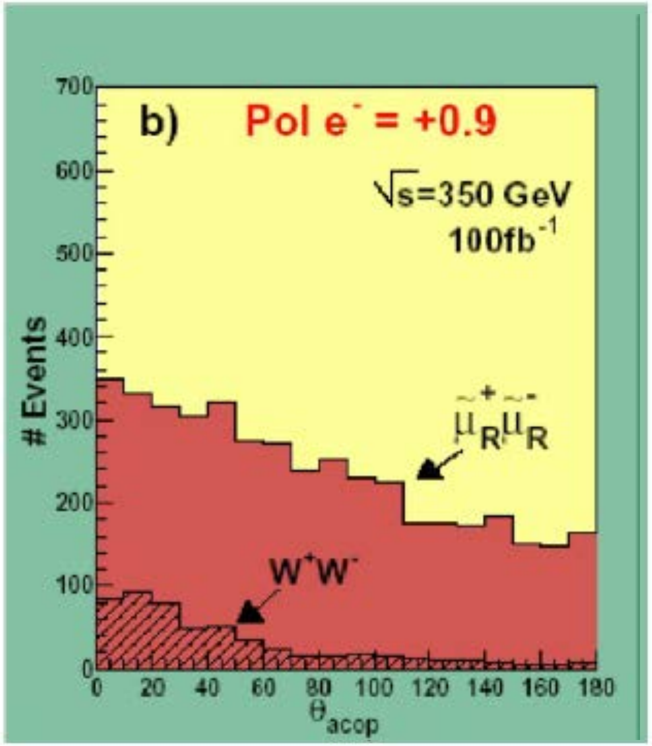


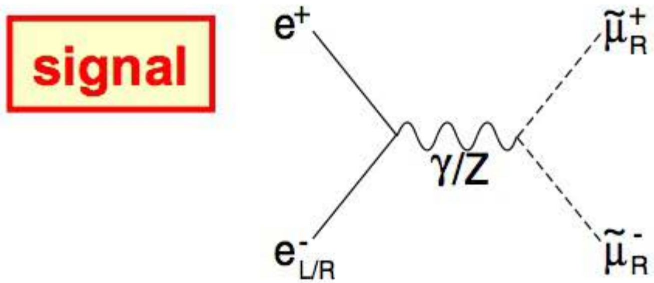
SM background

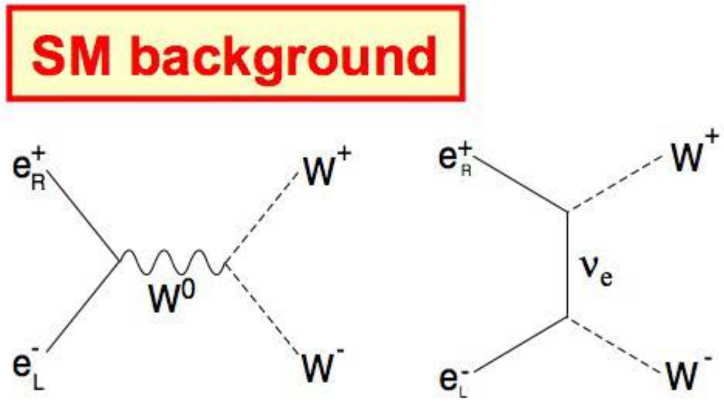


New Physics: direct searches (power of beam polarization)



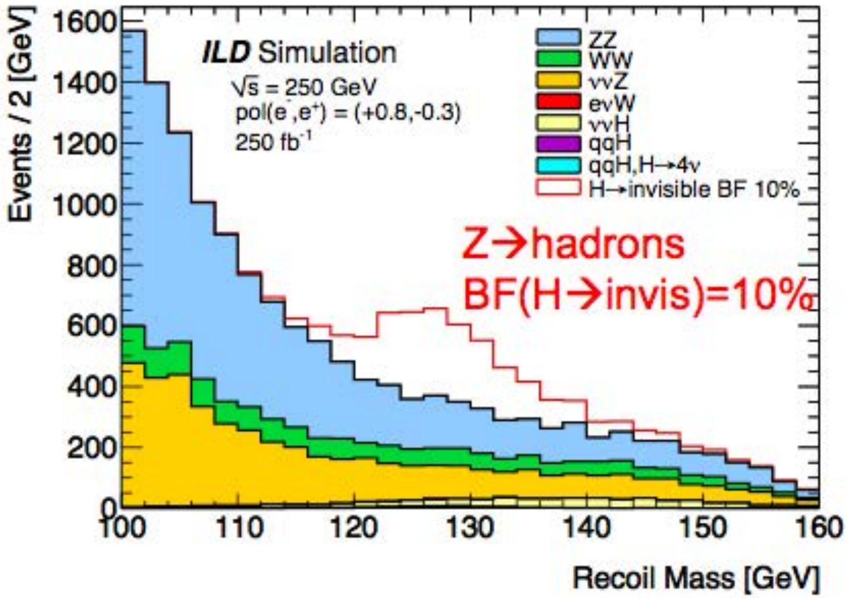






WIMP searches at colliders are complementary to direct/indirect searches.
Examples at the ILC:

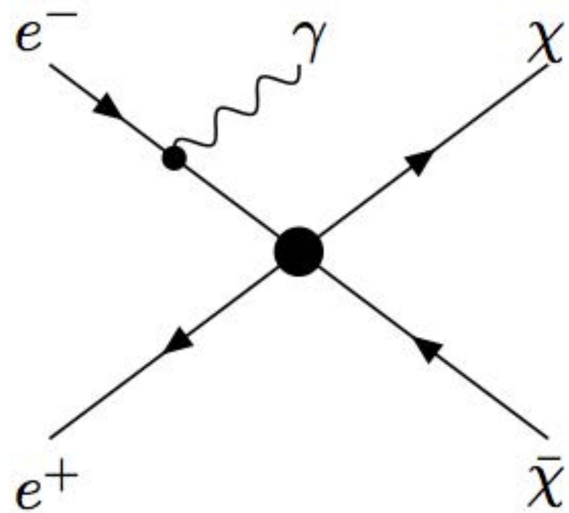
Higgs Invisible Decays



BR(H→invis.) < 0.4% at 250 GeV, 1150 fb^{-1}

Impact of jet energy resolution

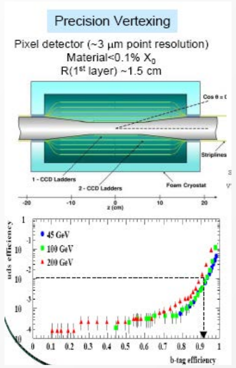
Monophoton Searches

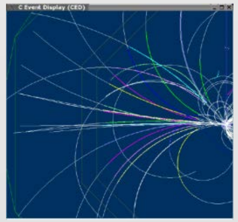


→ DM mass sensitivity nearly half √s

Soft photons, forward detectors

ILC Detectors: Detector R&D major challenges

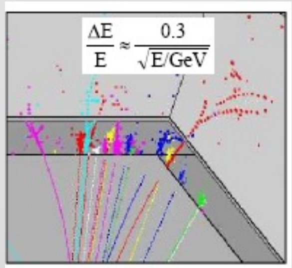




- **Vertex,** "flavour tag" (heavy quark and lepton identification)

  vtx 1-2 cm;

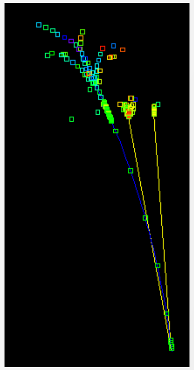
  $$(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-) \qquad \sigma_{ip} = 5\mu m \oplus 10-15\mu m / p\sin^{3/2}\theta$$

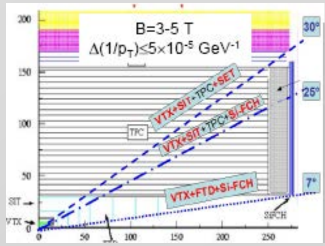


- **Tracking**, "recoil mass"

  B=3.5-5 T

  $$(e^+e^- \to Zh \to \ell^+\ell^- X) \qquad \sigma(1/p) \leq 2\times10^{-5}\mathrm{GeV}^{-1}$$



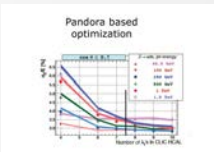


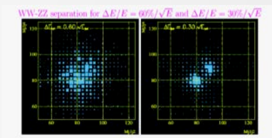
- **Jet Energy Rec.** → Tracker+Calorimetry

  Di-jet mass Resolution, Event Reconstruction, Hermitcity,

  Detector coverage down to very low angle

  $$\sigma_E / E = 0.3/\sqrt{E(\mathrm{GeV})}$$



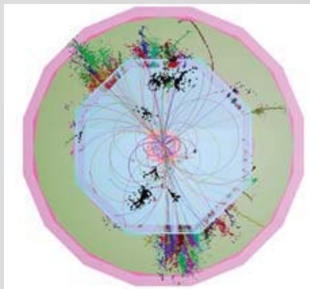


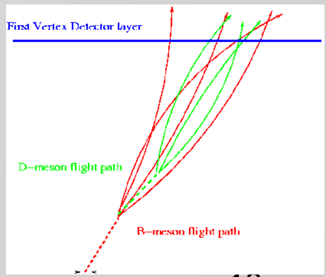
- **Particle Flow Detectors,**

  High granularity,

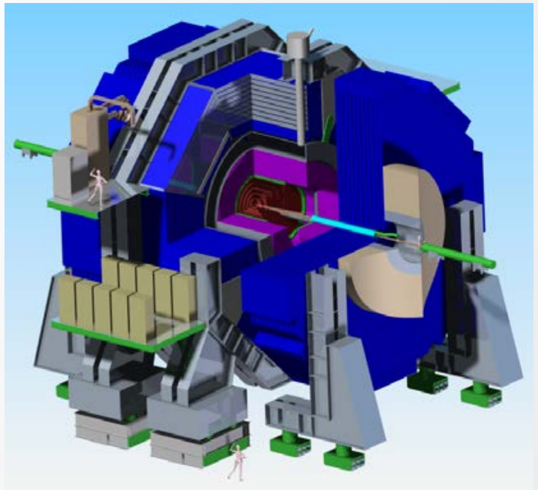
  Excellent momentum measurement,

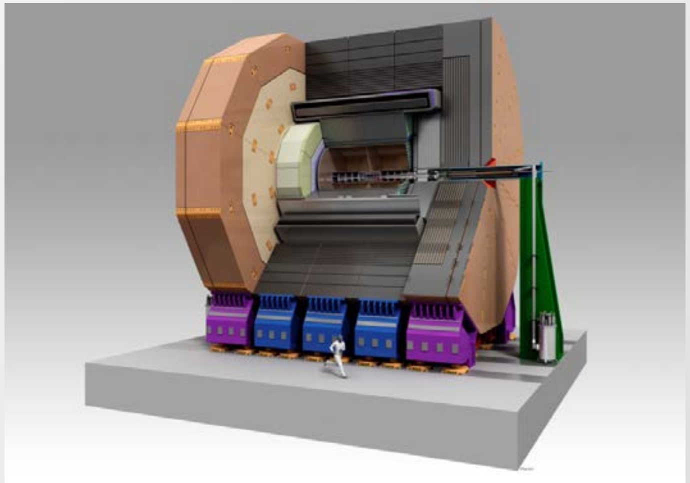
  High separation power of particles





ILC Detectors: SID and ILD





Major accomplishment has been to produce the Detailed Baseline Design report of the detectors for the ILC-TDR

Successful cooperation between ILC and CLIC

http://www.linearcollider.org/ILC/Publications/Technical-Design-Report

ILC Detector Concepts: SID and ILD

Compact, pure Silicon based tracking, large B-field

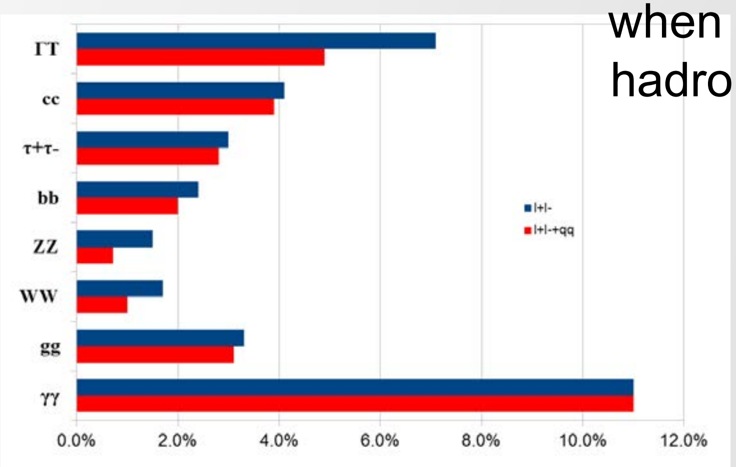
Two Detector Concepts for the ILC: SiD and ILD

All driven by Particle Flow paradigm

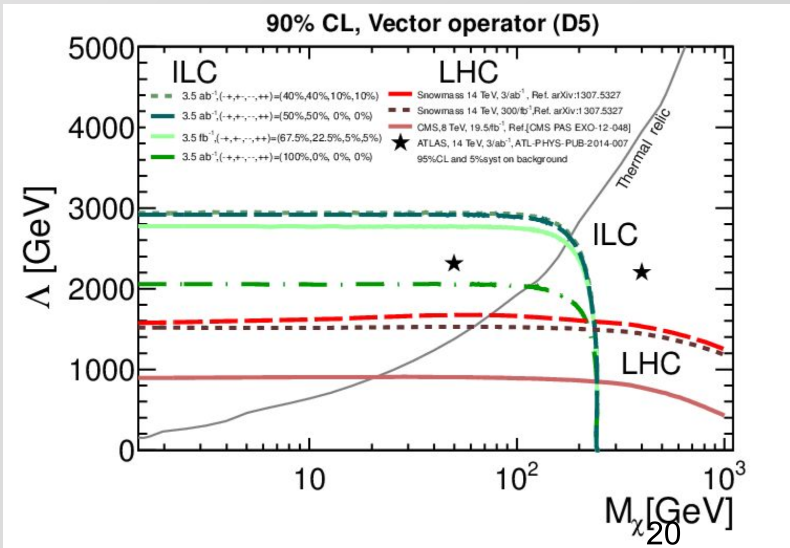
Large, gaseous & Si tracking, moderate B-field

- Consolidation of the detector designs (re-optimization)
- Intense studies of the physics reach

Potential improvement on Higgs couplings when including hadronic recoil



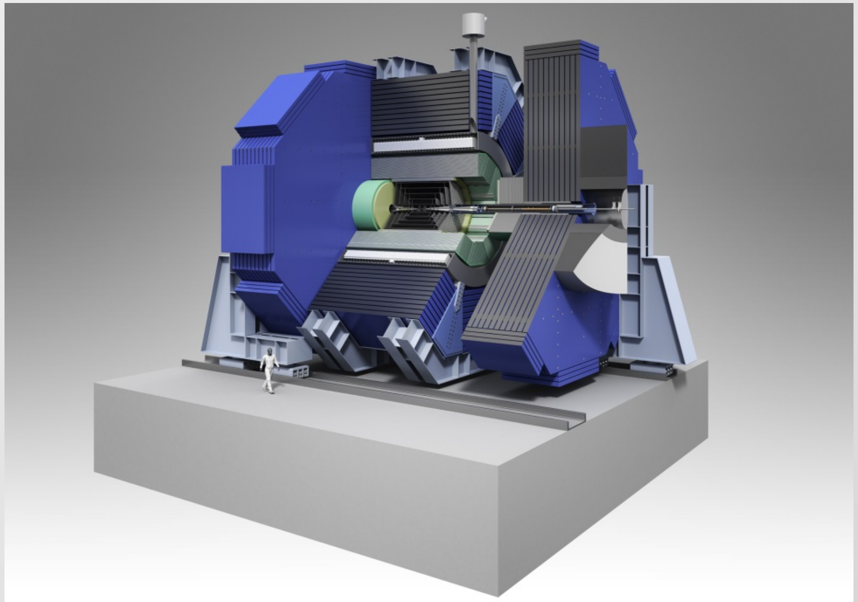
WIMP reach at ILC and LHC

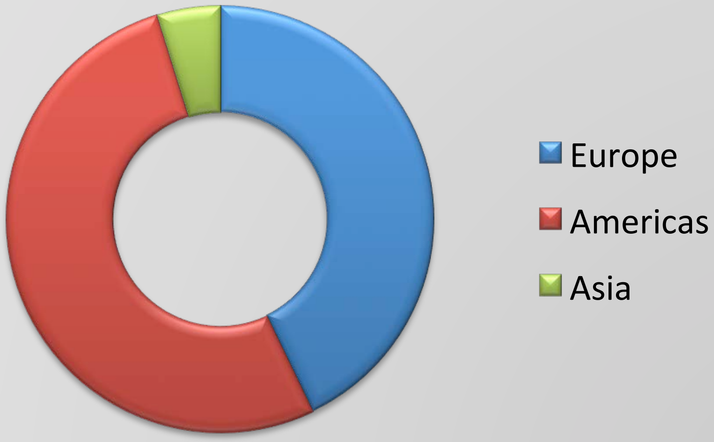


J. Fuster

SiD Consortium

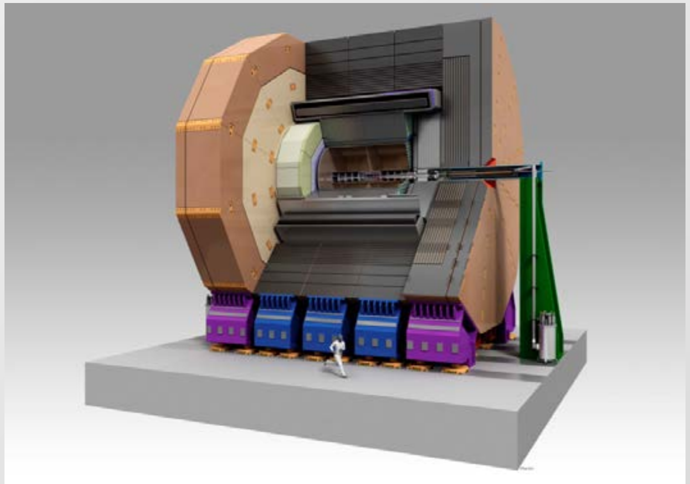
- Has been established, byelaws in place
- Spokespersons:
  Marcel Stanitzki
  Andy White
- Institute Board chair: Philip Burrows
- 22 Groups have signed on
- www.silicondetector.org

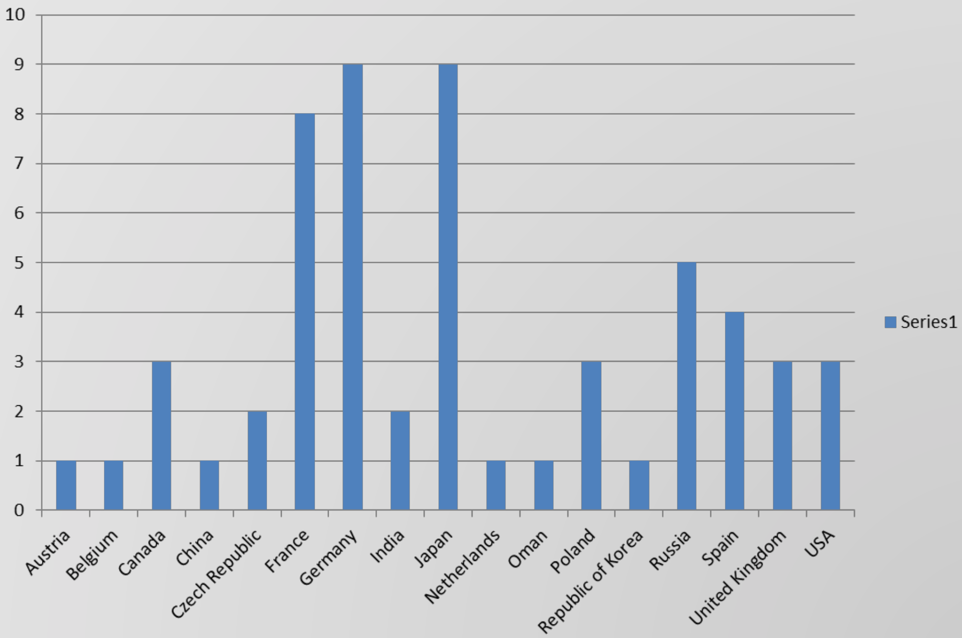




ILD Detector

- Spokesperson:
  Ties Behnke
- Institute Assembly chair:
  Jan Timmermans
- 64 Groups have signed on
- http://www.ilcild.org/





Summary

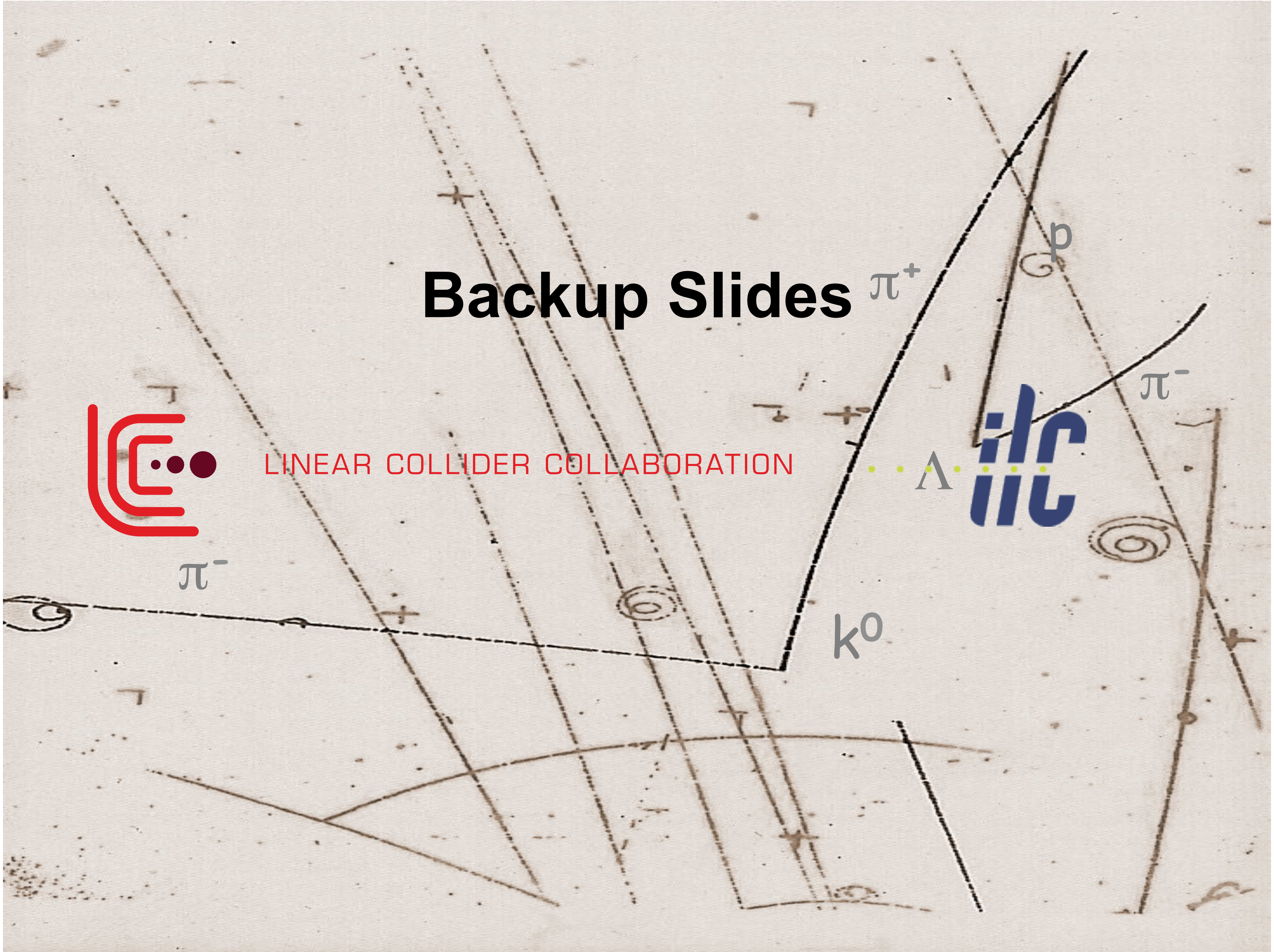
- The ILC is a truly global project under ICFA supervision
- The ILC accelerator technology based on SRF is matured and solid. Most of major worldwide accelerator facilities have proven to successfully produce main parts of the machine.
- The physics potential of the ILC goes in synergy with the LHC (including HL-LHC) providing new complementary features due to a cleaner environment, energy extendibility, beam polarization possibility, energy scan, etc...
- The ILC physics program covers the high precision studies of the Higgs and top physics and in addition the search for physics beyond the Standard Model.

LINEAR COLLIDER COLLABORATION

Summary

- An extensive detector R&D is being pursued to reach the physics requirements.
- Two Detector Concepts, SID and ILD, have been conceived to achieve the experimental goals. Performance studies are being carried out as a collaborative and coordinated effort.
- Due to time constraints, this talk could not cover the MEXT process and political developments in Japan. Please see S. Komamiya presentation at *XXVII International Symposium on Lepton Photon Interactions at High Energies*: http://indico.cern.ch/event/325831/timetable/#20150821.detailed

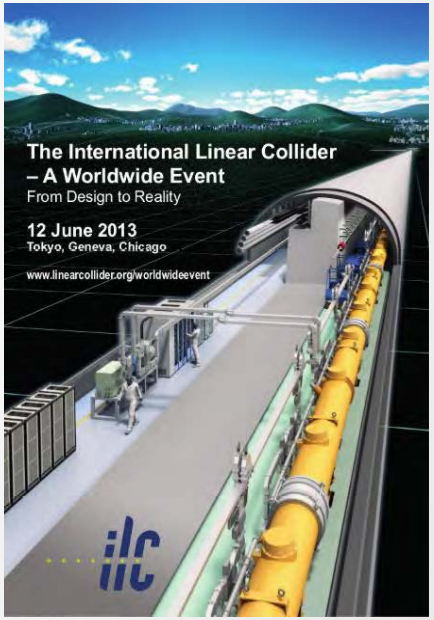
Backup Slides



LINEAR COLLIDER COLLABORATION

ILC: From Design to reality

Official Completion of ILC TDR
"From Design to Reality"
June 12, 2013:



TDR handed to LCC Director Lyn Evans

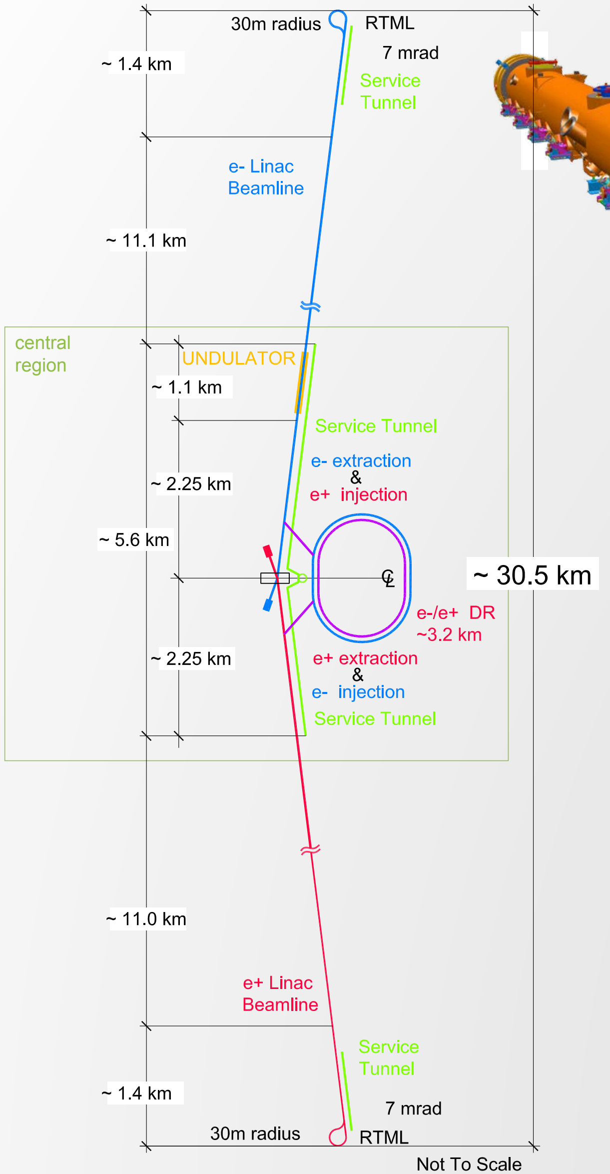

U. Tokyo

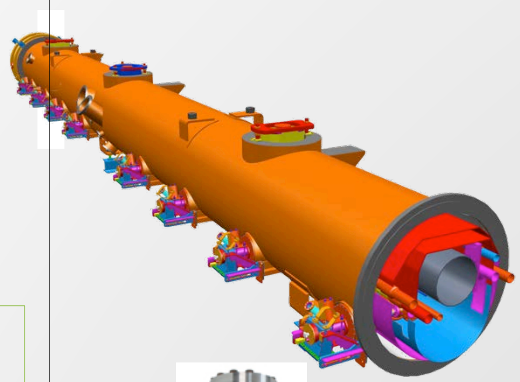

CERN


Fermilab

ILC TDR published in a Worldwide Event:

Tokyo → Geneva → Chicago





N. Walker – ILC Launch Event 2013

- 200-500 GeV E_{cm} e^+e^- collider
  L ~2×10^{34} $cm^{-2}s^{-1}$
  - upgrade: ~1 TeV
- SCRF Technology
  - 1.3GHz SCRF with 31.5 MV/m
  - 17,000 cavities
  - 1,700 cryomodules
  - 2×11 km linacs
- Developed as a truly global collaboration
  - **G**lobal **D**esign **E**ffort – **GDE**
  - ~130 institutes
  - http://www.linearcollider.org/ILC

ILC 500 GeV parameters

Physics	Max. E_{cm}	500 GeV
	Luminosity	1.8×10^{34} $cm^{-2}s^{-1}$
	Polarisation (e-/e+)	80% / 30%
	δ_{BS}	4.5%
Beam (interaction point)	σ_x / σ_y	574 nm / 6 nm
	σ_z	300 μm
	$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$	10 μm / 35 nm
	β_x / β_y	11 mm / 0.48 mm
	bunch charge	2×10^{10}
Beam (time structure)	Number of bunches / pulse	1312
	Bunch spacing	554 ns
	Pulse current	5.8 mA
	Beam pulse length	727 μs
	Pulse repetition rate	5 Hz
Accelerator (general)	Average beam power	10.5 MW (total)
	Total AC power	163 MW
	(linacs AC power	107 MW)

N. Walker – ILC Launch Event 2013

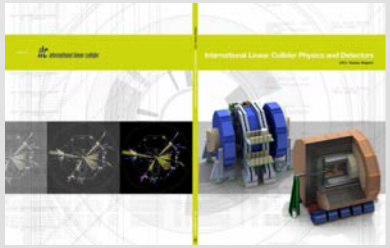
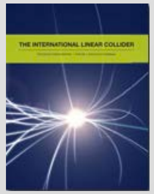
- Concept: increase n_b from 1312 → 2625
  - Reduce linac bunch spacing 554 ns → 336 ns

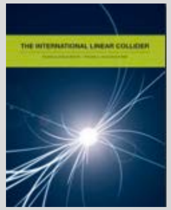
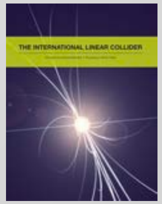
- Doubles beam power → ×2 L = 3.6×10^{34} $cm^{-2}s^{-1}$

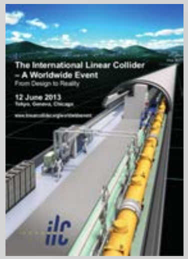
- AC power: 161 MW → 204 MW (est.)
  - shorter fill time and longer beam pulse results in higher RF-beam efficiency (44% → 61%)

Aug. 2007	Detector Concept Report, Four detector concepts: LDC, GLD, SiD, 4th
Oct. 2007	ILCSC calls for LOIs and appoints Research Director (RD)
Jan. 2008	RD forms detector management
Mar. 2008	IDAG formed, Three LOIs gropus identified
Mar. 2009	Three LOIs submitted (detector description, status of R&D, GEANT4 simulation, benchmark process, costs..)
Mar. 2009	IDAG began monitoring the progress
Aug. 2009	IDAG recommends validation of two (2) and ILCSC approves
Oct. 2009	Work plan of the validated groups
End 2011	Interim Report being produced http://www.linearcollider.org/about/Publications/interim-report
End 2012	Physics at the International Linear Collider (ILC TDR Vol. 2) Detailed Baseline Design Report (ILC TDR Vol. 4) http://www.linearcollider.org/ILC/Publications/Technical-Design-Report
June 12th 2013	Public TDR Launch event worldwide http://www.linearcollider.org/events/2013/ilc-tdr-world-wide-event

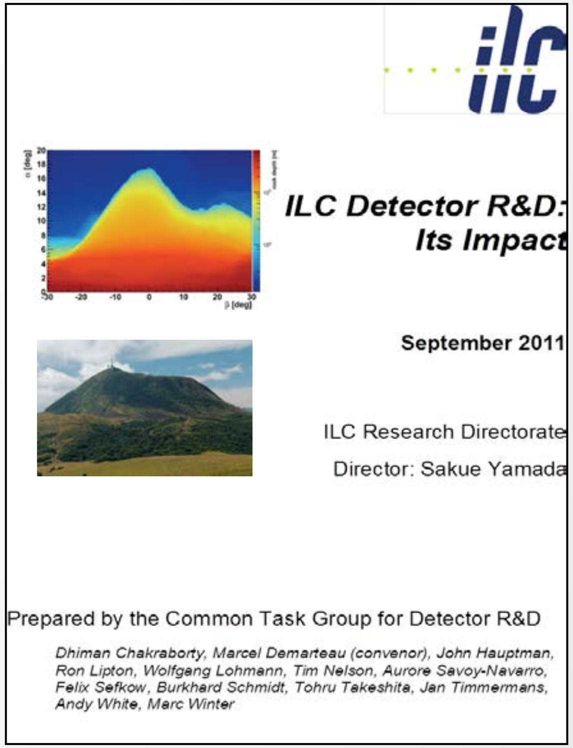


Spinoffs derived from LC detector R&D


ILC Detector R&D:
Its Impact

September 2011

ILC Research Directorate
Director: Sakue Yamada

Prepared by the Common Task Group for Detector R&D

Dhiman Chakraborty, Marcel Demarteau (convenor), John Hauptman, Ron Lipton, Wolfgang Lohmann, Tim Nelson, Aurore Savoy-Navarro, Felix Sefkow, Burkhard Schmidt, Tohru Takeshita, Jan Timmermans, Andy White, Marc Winter

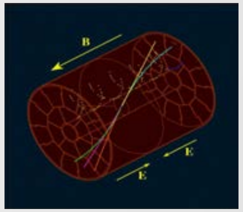
An study of the spinoffs derived by the LC detector R&D has been performed (worth reading!)

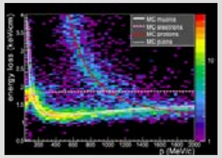
It includes:

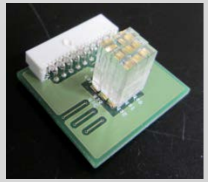
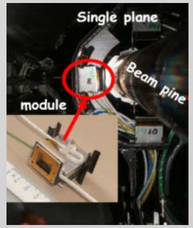
- HEP applications:
  - ✓ vertex developments (ALICE-ITS, CBM-FAIR,Star, BelleII)
  - ✓ TPC Micromegas (T2K)
  - ✓ Calorimeters (CMS)
  - ✓ Luminomiter and beam instrumentation (LHC, CMS)
  - ✓ trigger development (LHC, CAST)
  - ✓ software (Belle II, NOVA, AIDA, CLIC, μ-collider)

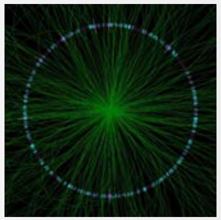
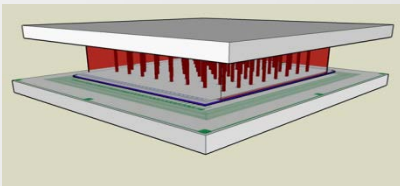
- None HEP applications:
  - ✓ X-ray imaging (astronomy, medicine, proton tomography, volcano tomography)
  - ✓ ASICs for Balloon experiments



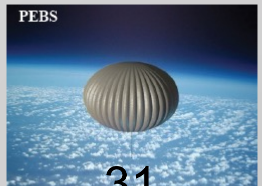








The ILC project: support from scientific strategy processes

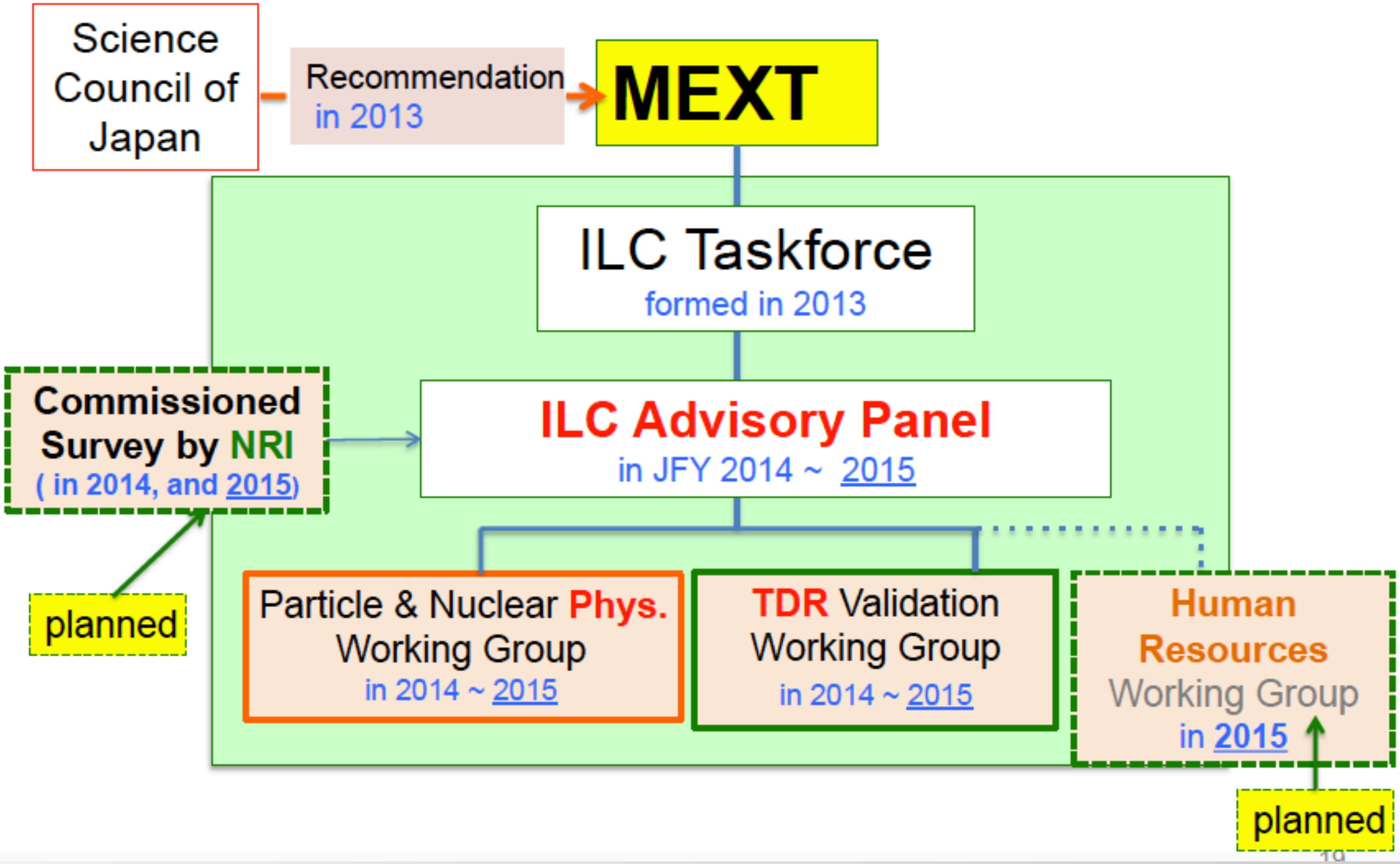
ICFA Statement on its Support of the ILC, its Endorsement of the Strategic Plans of Europe, Asia and the United States, and its Encouragement of International Studies of Future Circular Colliders

ICFA endorses the particle physics strategic plans produced in Europe, Asia and the United States and the globally aligned priorities contained therein. Here, ICFA reaffirms its support of the ILC, which is in a mature state of technical development and offers unprecedented opportunities for precision studies of the newly discovered Higgs boson. In addition, ICFA continues to encourage international studies of circular colliders, with an ultimate goal of proton-proton collisions at energies much higher than those of the LHC.

J. Mnich (ICFA chair) – ICHEP 2014

- For κ_Z and κ_W , production rates give high precision
  - e+e- → ZH for κ_Z and e+e- → $\nu\nu$H for 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: 350 GeV or higher running is needed
- For κ_γ , LHC and ILC are combined
  - Br(H→$\gamma\gamma$)/Br(H→ZZ) by LHC and Br(H→ZZ) by ILC
- For κ_t (ttH final state)
  - Error 6% → 3% by going from 500 GeV to 550 GeV
- Physics: Higgs self coupling
  - 1TeV: 16% with 2000 fb-1, 10% with 5000 fb-1
  - 500 GeV: 27 % with 4000 fb-1 (H20)

ILC being studied by the MEXT Japan



Summary of the ILC Advisory Panel's Discussions to Date

August 2015

As an official process of the Japanese Government towards the approval

⇒ ICFA will respond to this report

1. Discussion background …
2. Overview of discussions

(1) Science Merit of the ILC Project

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.

ILC experiments are able to search for new particles, different from the ones that LHC experiments have been searching for. In case these new particles are supersymmetric particles, ILC and LHC experiments can study them complementally. On the other hand ILC experiments can carry out more precise measurement of the Higgs boson and the top quark, which are beyond the reach of LHC experiments.

…

(2) Validation of TDR

(3) International Collaboration

(4) Social effect of the ILC Project **Economic effects, Industrial Spin-off**

Recommendation 1: The ILC project requires huge investment that is so huge that a single country cannot cover, thus it is indispensable to share the cost internationally. From the viewpoint that the huge investments in new science projects must be weighed based upon the scientific merit of the project, a clear vision on the discovery potential of new particles as well as that of precision measurements of the Higgs boson and the top quark has to be shown so as to bring about novel development that goes beyond the Standard Model of the particle physics.

⇒ Discovery is not guaranteed but clear vision of discovery potential is demonstrated.

Recommendation 2: Since the specifications of the performance and the scientific achievements of the ILC are considered to be designed based on the results of LHC experiments, which are planned to be executed through the end of 2017, it is necessary to closely monitor, analyze and examine the development of LHC experiments. Furthermore, it is necessary to clarify how to solve technical issues and how to mitigate cost risk associated with the project.

⇒ Surely we will monitor LHC physics.

MEXT is contacting governments during the 13 TeV Run.

Recent ILC Progress Report by LCC answers most of the technical items.

Recommendation 3: While presenting the total project plan, including not only the plan for the accelerator and related facilities but also the plan for other infrastructure as well as efforts pointed out in Recommendations 1 & 2, it is important to have general understanding on the project by the public and science communities.

⇒ Public relation will be reinforced by KEK and the Industry Supporters (AAA).

Discussions with scientists of the other fields have been undertaken.

The ILC accelerator: candidate site in Kitakami