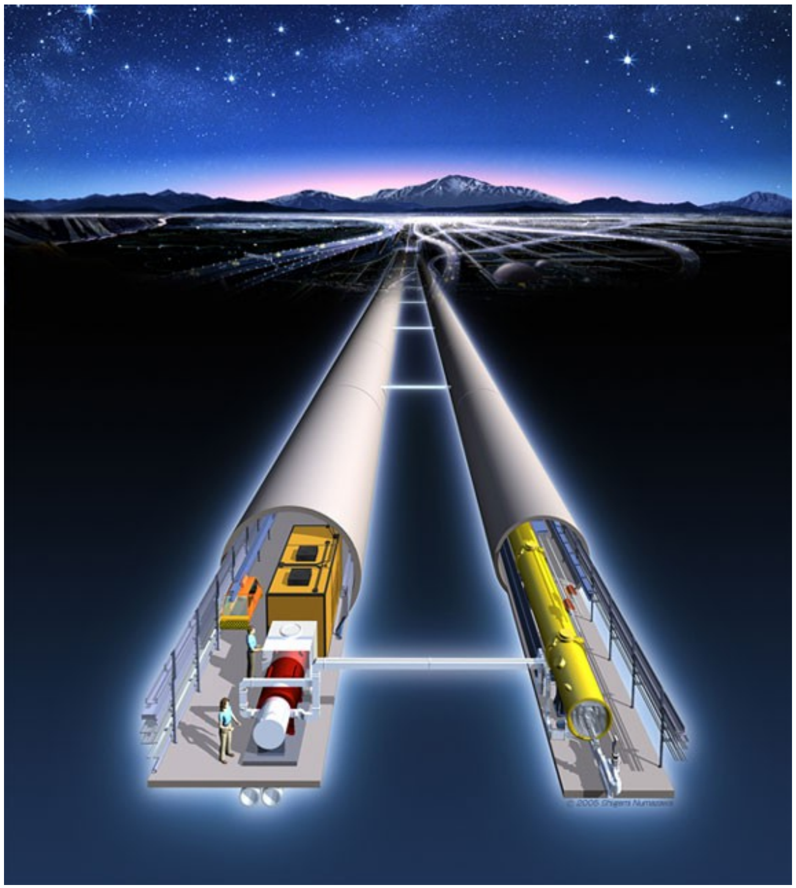
LCWS2016

Higgs and Top Physics at LC



Roman Pöschl

CNRS IN2P3 Les deux infinis

LAL Laboratoire de l'Accélérateur Linéaire

Université Paris Sud – Comprendre le monde, construire l'avenir®

P2IO Physique des 2 Infinis et des Origines

E-JADE

université PARIS-SACLAY

R.P. is indebted to many authors from whom I have reused their material

LCWS2016 Morioka/Japan – December 2016

Outline of talk

- Chapter 1: Introduction

- Chapter 2: Higgs Physics at the ILC

- Chapter 3: Top Physics at the ILC

Many thoughts, argumentations, plots taken from:

The ILC's Potential for Discovering New Particles

Document Supporting the ICFA Response Letter to the ILC Advisory Panel

The LCC Physics Working Group

Work in progress

1. Introduction

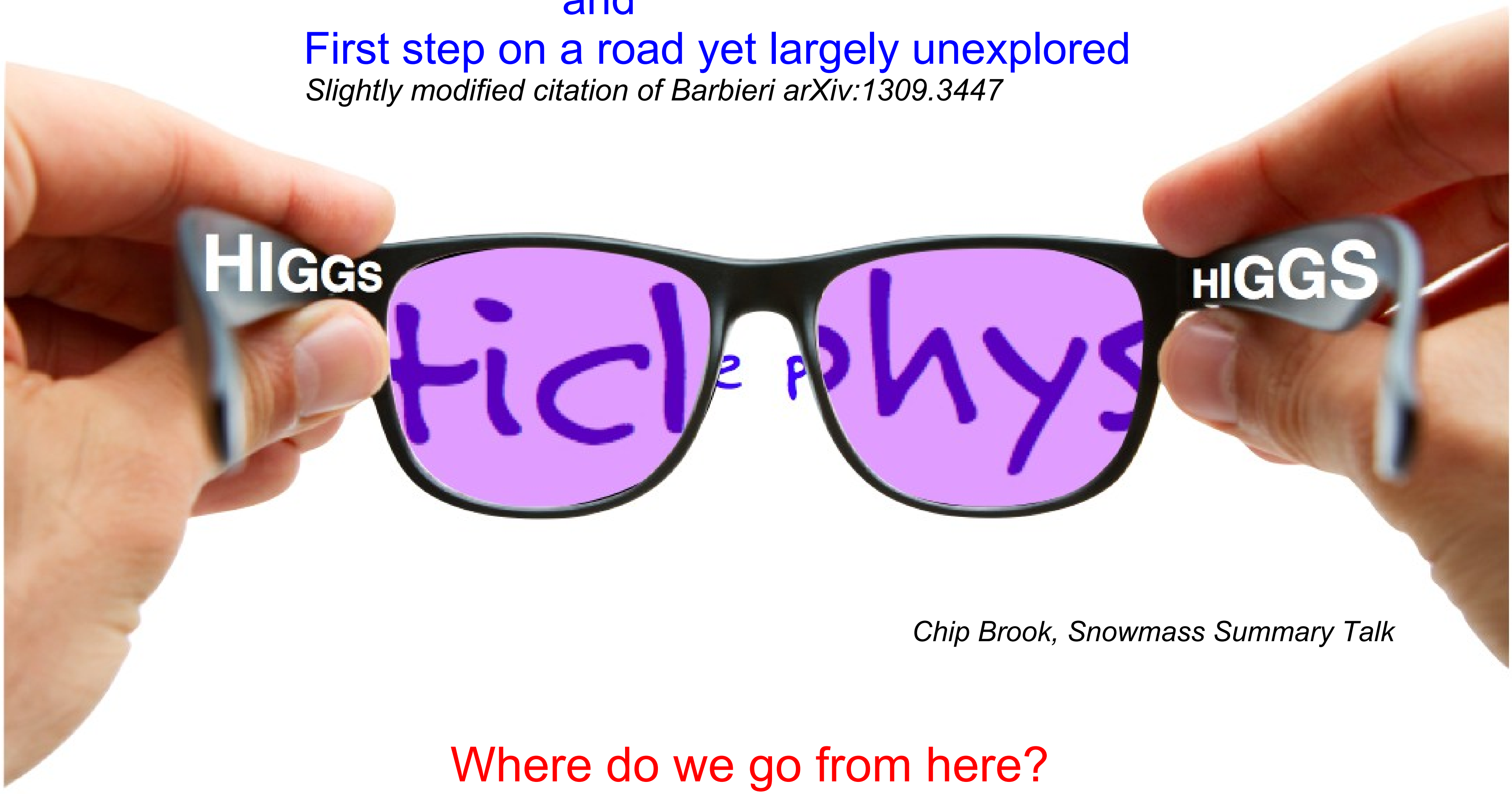
New view on Particle Physics ...

Coronation of the Standard Model

and

First step on a road yet largely unexplored

Slightly modified citation of Barbieri arXiv:1309.3447



Chip Brook, Snowmass Summary Talk

Where do we go from here?

Open questions

How to make progress?

1) Collisions at energies well above the electroweak scale
- Requires now and in the foreseeable future Hadron colliders
- Direct production of new particles
- Produce large number of rare particles and study rare decays
- First precision measurements of key particles of electroweak theory

-> High energy, High luminosity LHC

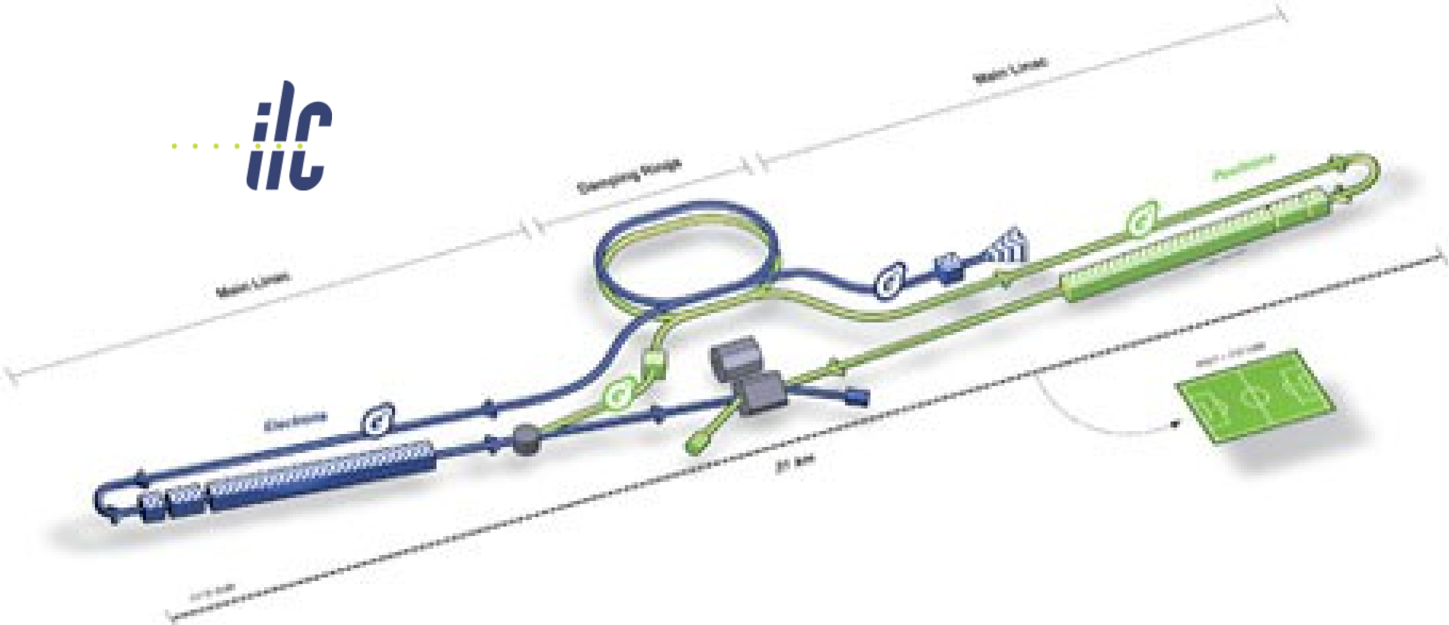
2) e+e-Collisions at energies at the electroweak scale
- Probe the electroweak scale with high precision
- ... in particular particles that carry the “imprint of the Higgs Field such as W, Z and top”

-> LC

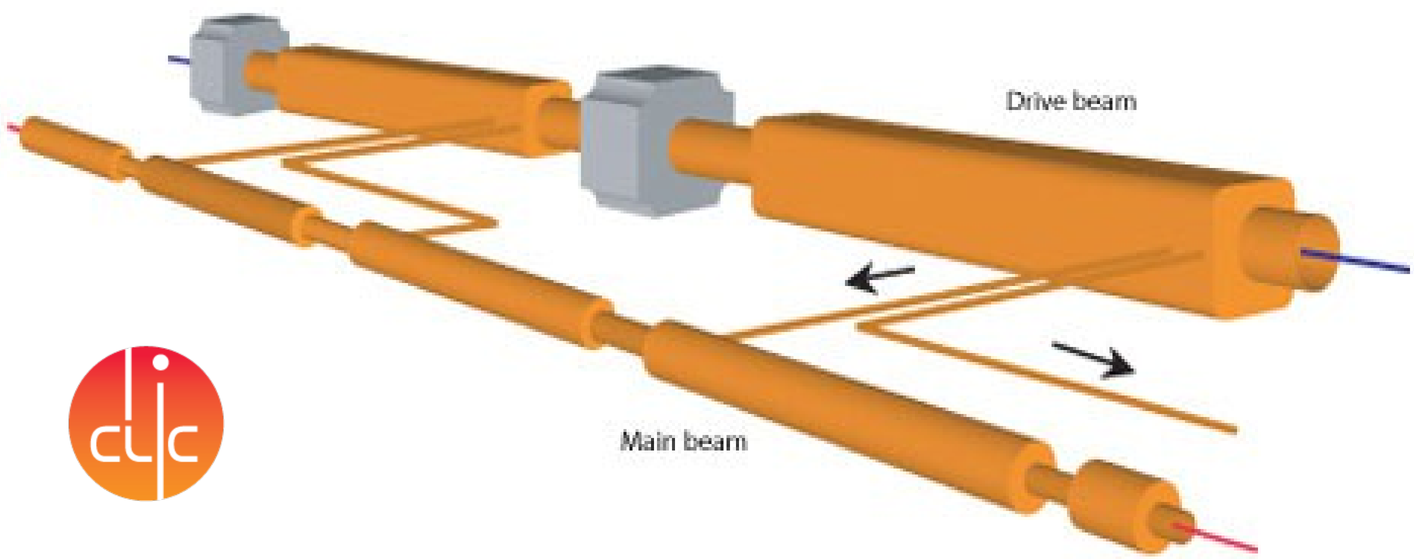
3) e+e- collisions at 'smaller' energies
- Requires high luminosity to get sensitive to tiny quantum effects

-> SuperKEKB

Linear Electron-Positron Colliders Projects



Energy: 0.1 - 1 TeV
Electron (and positron) polarisation
TDR in 2013
+ DBD for detectors
Footprint 31 km



Energy: 0.4 - 3 TeV

CDR in 2012

Footprint 48km

Detector requirements

Track momentum: $\sigma_{1/p} < 5 \times 10^{-5}$/GeV (1/10 x LEP)

(e.g. Measurement of Z boson mass in Higgs Recoil)

Impact parameter: $\sigma_{d0} < [5 \oplus 10/(p[GeV]\sin^{3/2}\theta)]$ μm(1/3 x SLD)

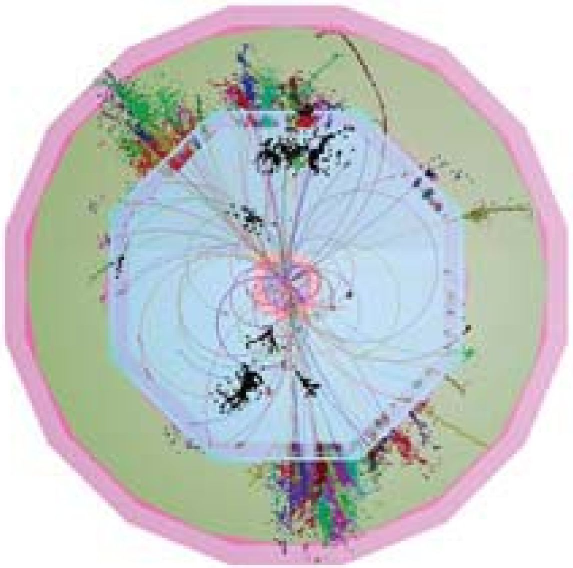
(Quark tagging c/b)

Jet energy resolution : $dE/E = 0.3/(E(GeV))^{1/2}$ (1/2 x LEP)

(W/Z masses with jets)

Hermeticity : $\theta_{min} = 5$ mrad

(for events with missing energy e.g. SUSY)



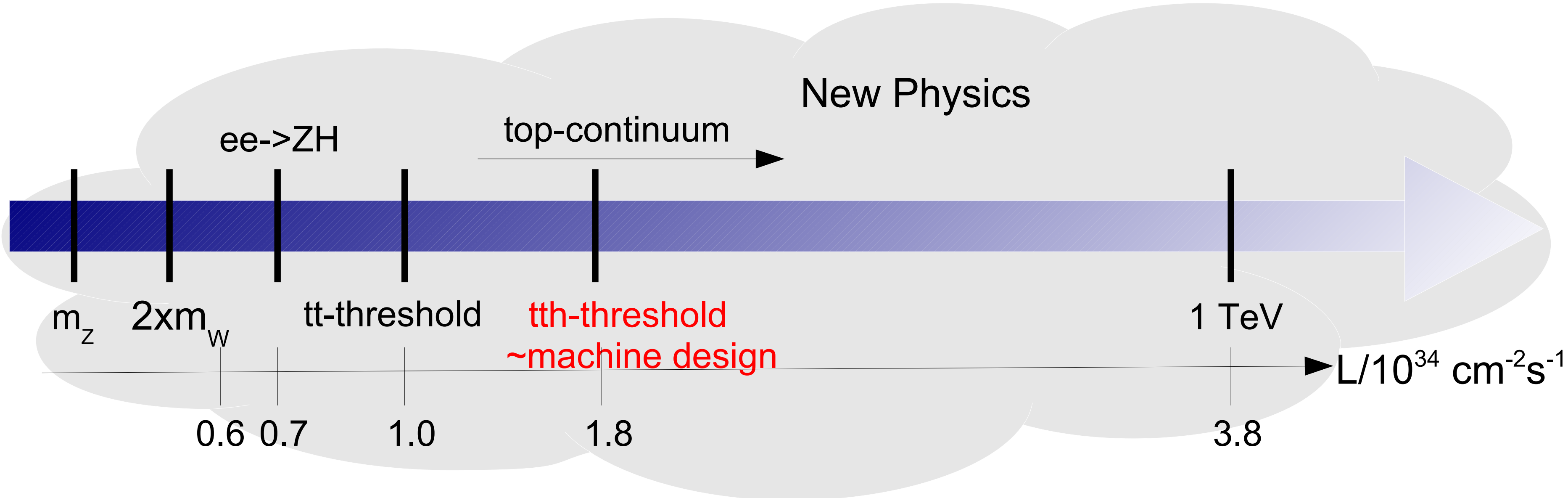
Final state will comprise events with a large number of charged tracks and jets(6+)

- High granularity
- Excellent momentum measurement
- High separation power for particles

- Particle Flow Detectors

  ILD, SiD and CLIC Detector

LC Physics program

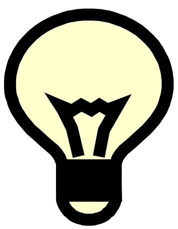


- All Standard Model particles within reach of LC
  - High precision tests of Standard Model over wide range to detect onset of New Physics
- Machine settings can be “tailored” for specific processes
  - Centre-of-Mass energy
  - Beam polarisation

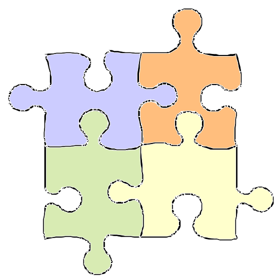
$$\sigma_{P,P'} = \frac{1}{4}[(1 - PP')(\sigma_{LR} + \sigma_{RL}) + (P - P')(\sigma_{RL} - \sigma_{LR})]$$

- **Background free** searches for BSM through beam polarisation

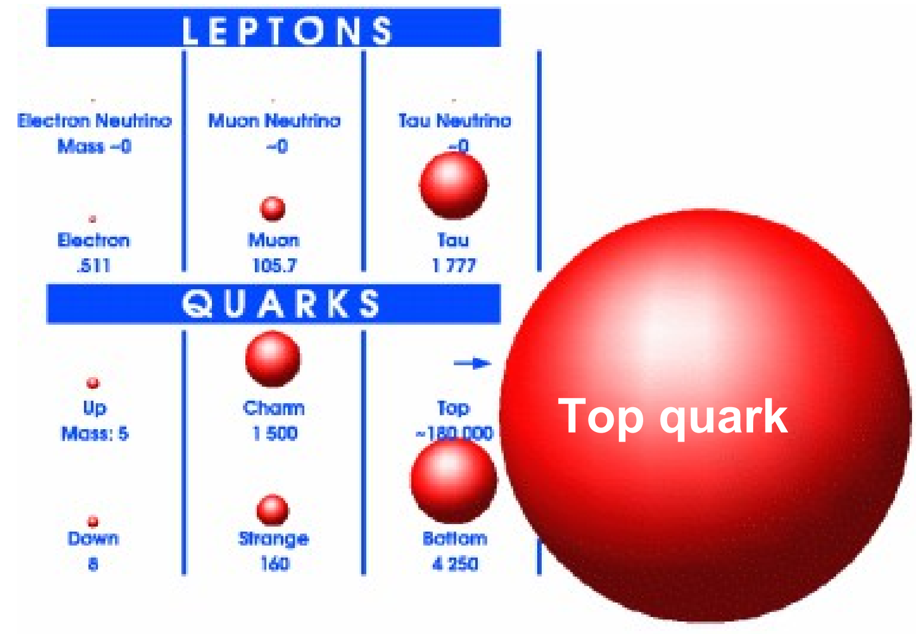
An enigmatic couple



Elementary Scalar?



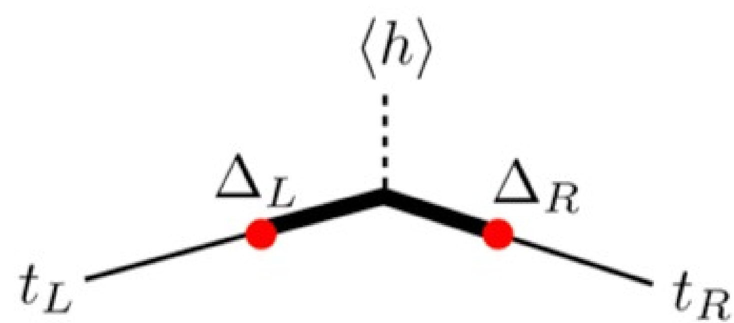
Composite object?



- Higgs and top quark are intimately coupled!
  Top Yukawa coupling O(1) !
  => Top mass important SM Parameter

- New physics by compositeness?
  Higgs <u>and</u> top composite objects?

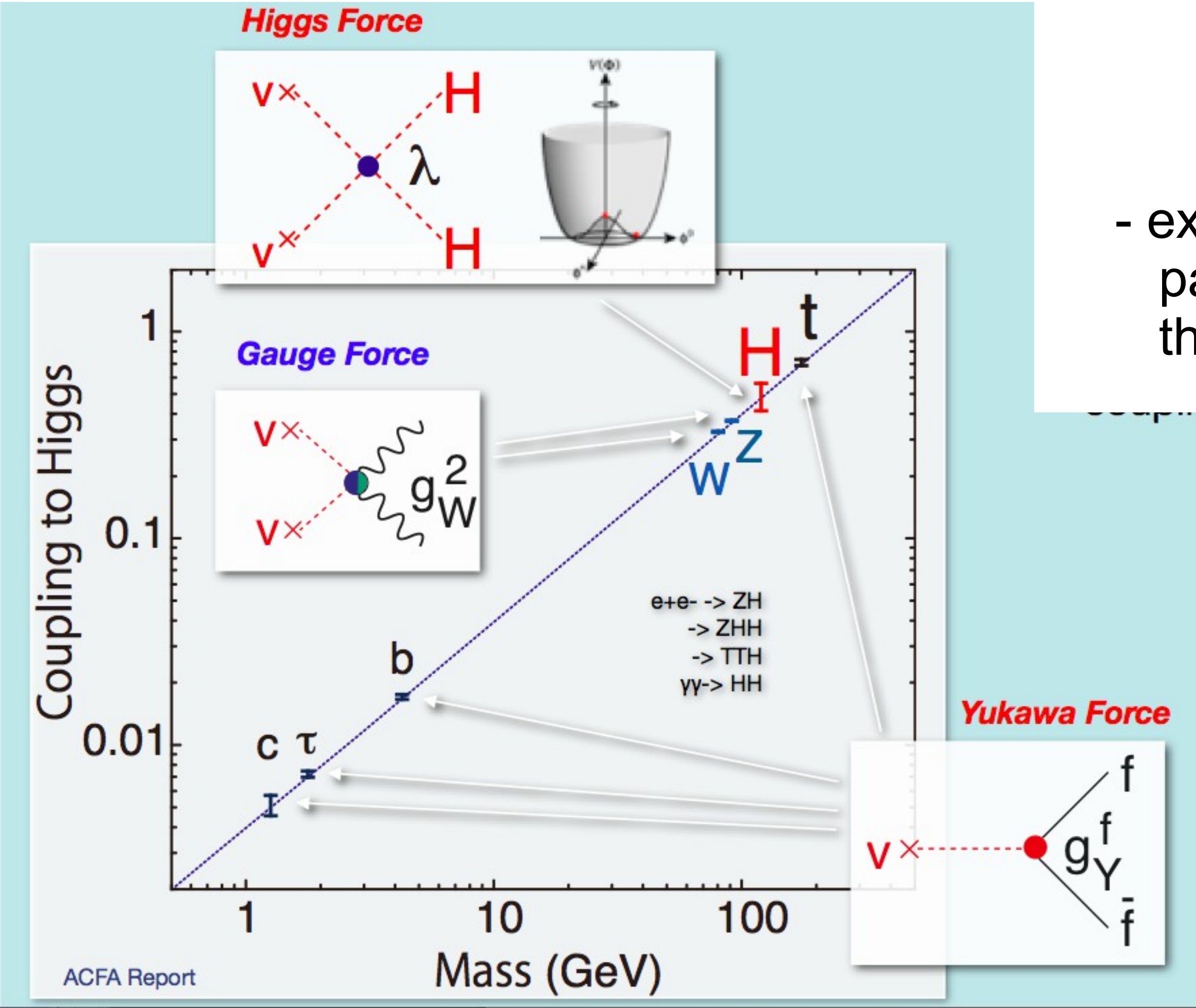
- LC perfectly suited to decipher both particles



Courtesy of S. Rychkov

2. Higgs Physics at the ILC

Precision Higgs Physics



- exact correlation between particle masses couplings to the Higgs in Standard Model

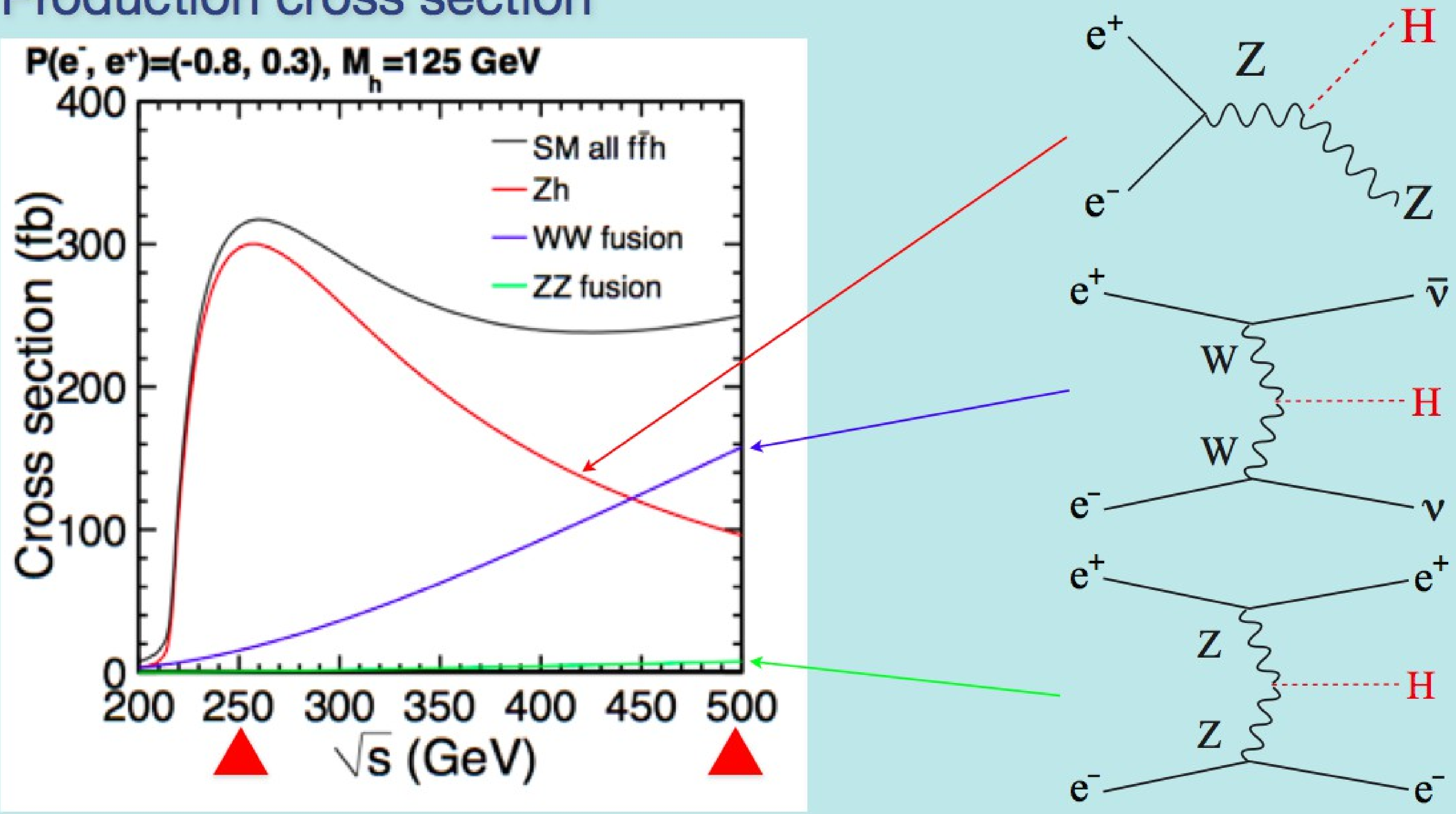
- Any tiny deviation is New Physics

	ΔhVV	$\Delta h\bar{t}t$	$\Delta h\bar{b}b$
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	< 1%	3%	10%[a], 100%[b]
LHC 14 TeV, 3 ab^{-1}	8%	10%	15%

- Need precision on Higgs couplings at 1% level

Single Higgs Production at the LC

Production cross section

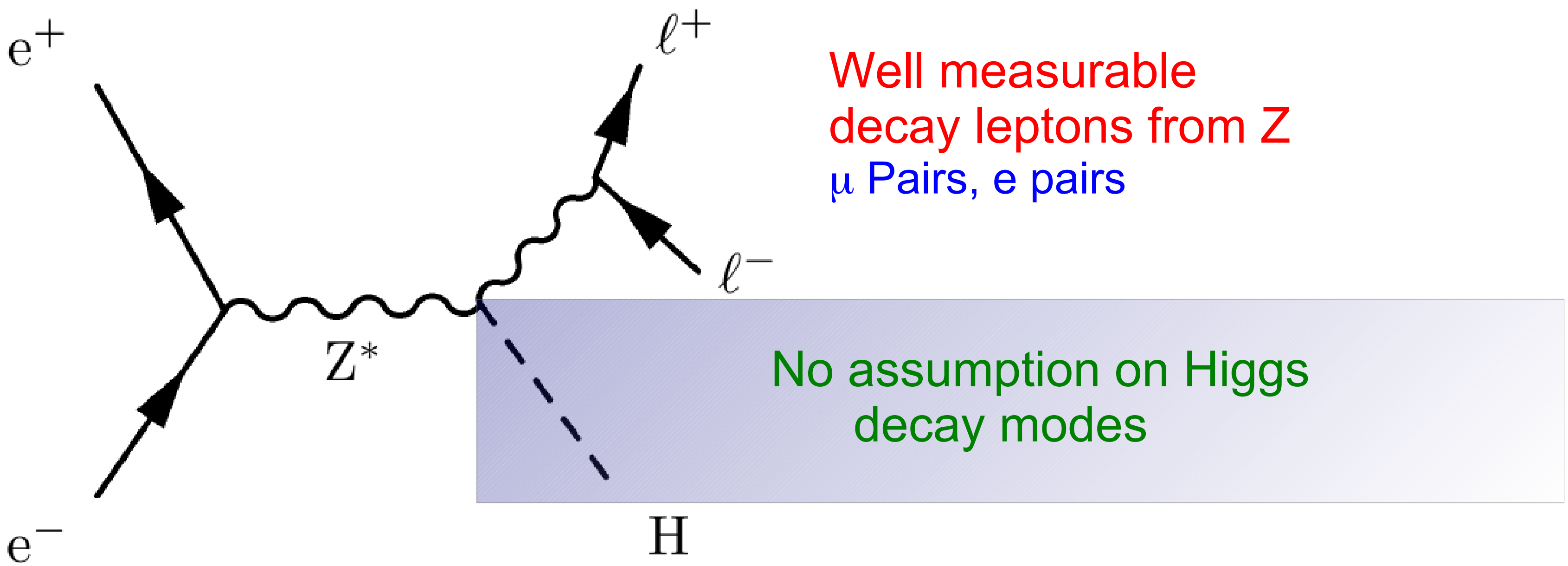


ZH dominates at 250 GeV
(~80k ev: 250 fb^{-1})

ννH takes over at 500 GeV
(~125k ev: 500 fb^{-1})

K. Fujii, LC School 2014

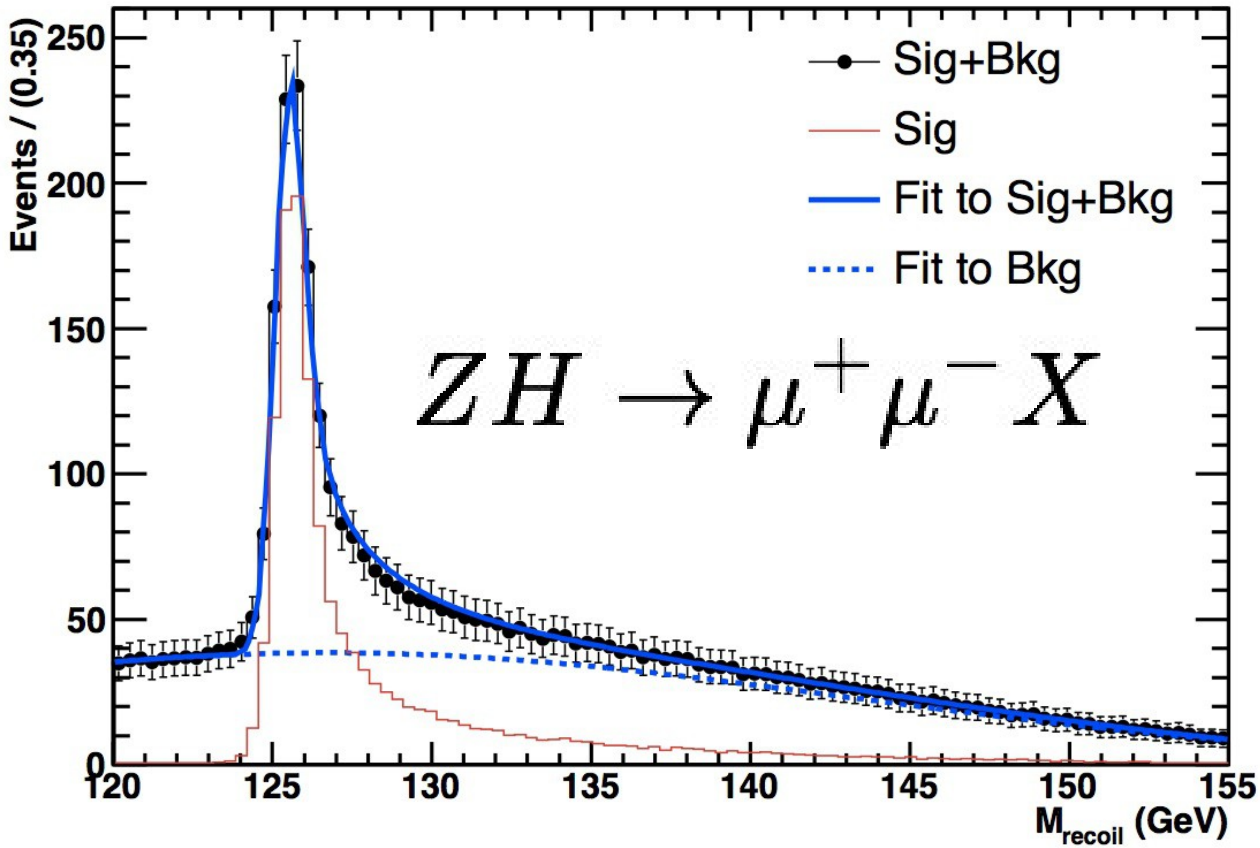
Higgs Mass and ZZH coupling by
Model Independent
measurement



Well measurable decay leptons from Z
μ Pairs, e pairs

Higgs Recoil Mass: $M_h^2 = M_{recoil}^2 = s + M_Z^2 - 2E_Z\sqrt{s}$

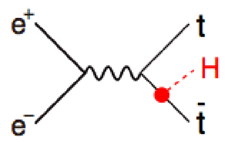
Full simulation study at 250 GeV



$$M_h = 125.3 \pm 0.03\,\text{GeV}$$

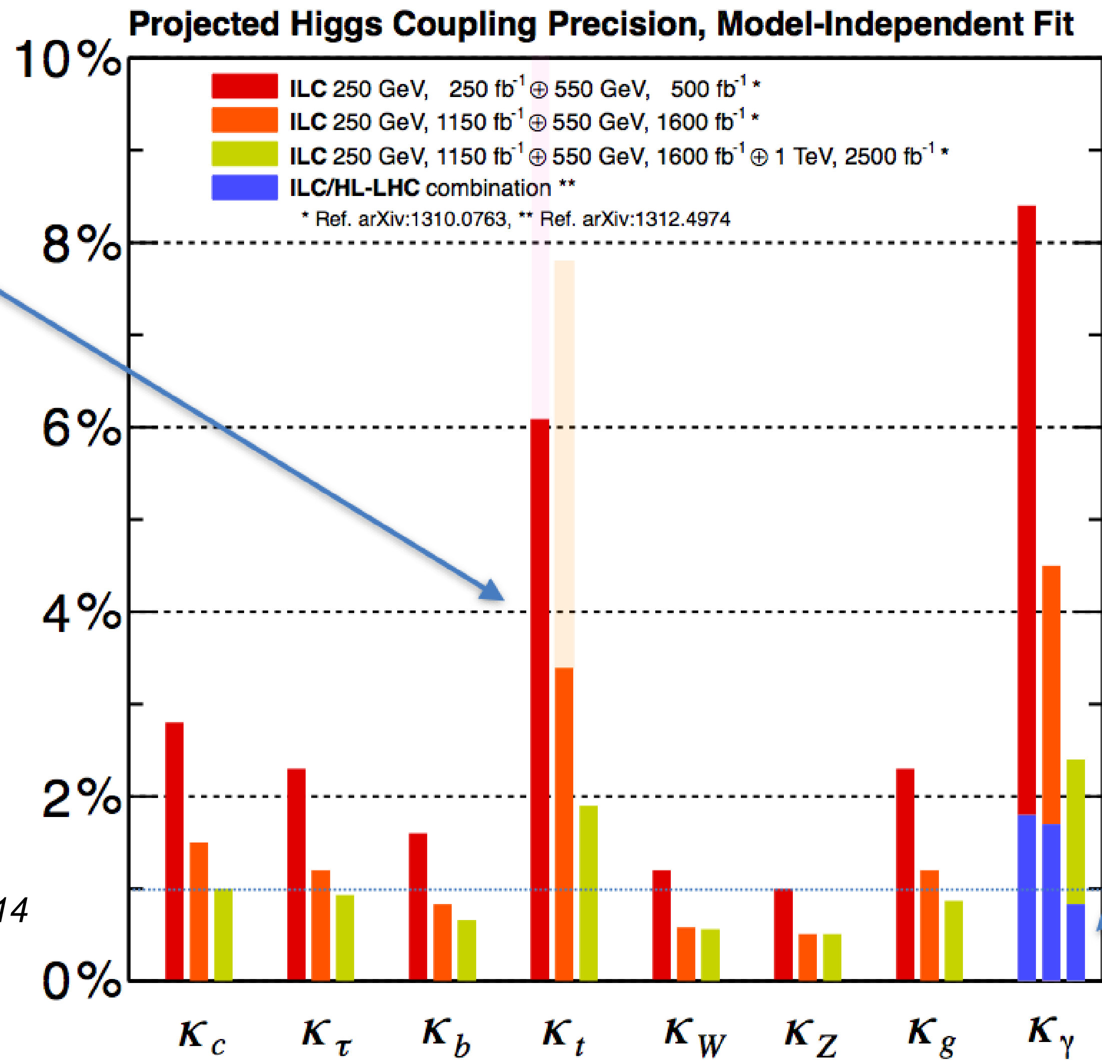
$$\sigma_{ZH} = 10.32 \pm 0.37\,\text{fb},\ 3.6\%$$

Individual Couplings to the Higgs



Top Yukawa improves by going to 550 GeV

Near threshold → a factor of 4 enhancement of σ_{tth} by going from 500GeV to 550 GeV



T. Tanabe, K. Fuji, LCWS14

LHC can precisely measure

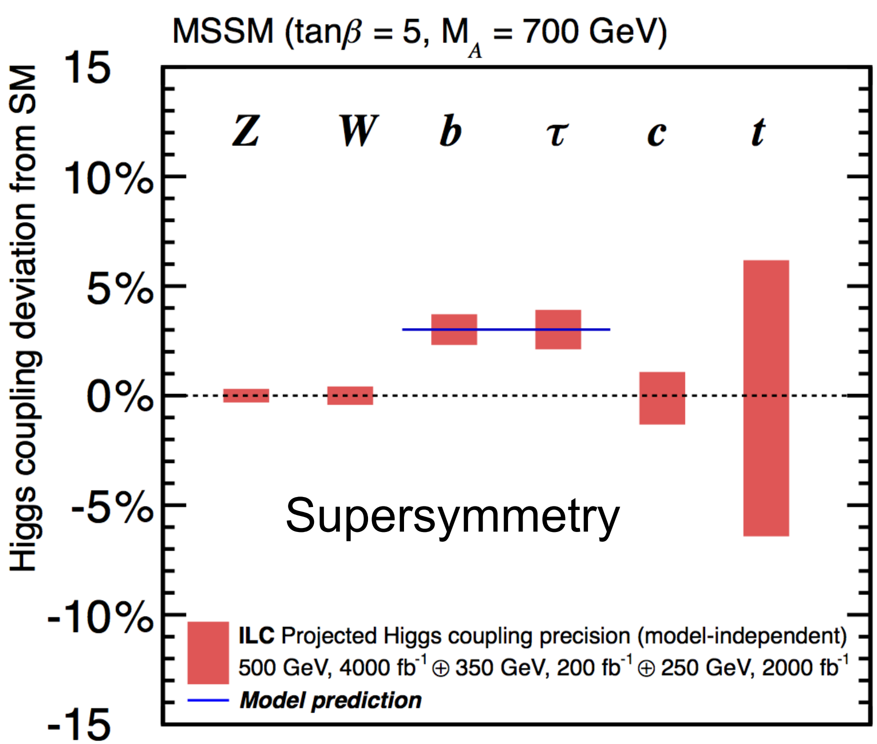
$BR(h\to\gamma\gamma) / BR(h\to ZZ^*) = (K_\gamma / K_Z)^2$

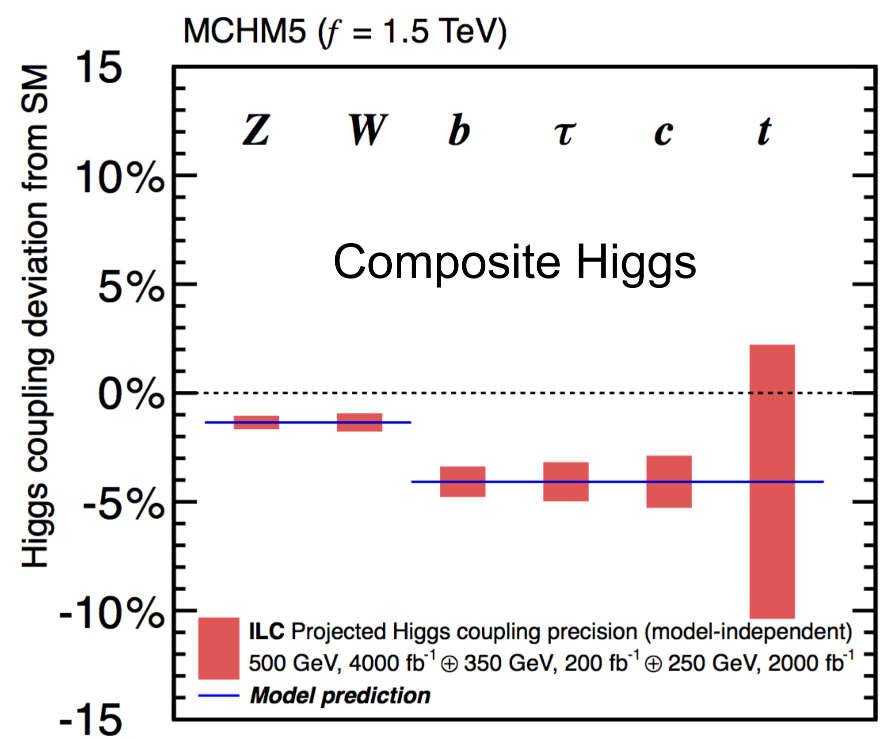
ILC can precisely measure K_Z

Better hγγ with LHC/ILC synergy

Precise measurements of relevant Higgs couplings

Coupling precision after full ILC programme

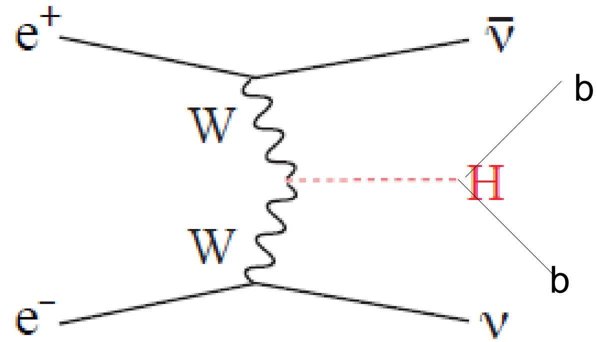


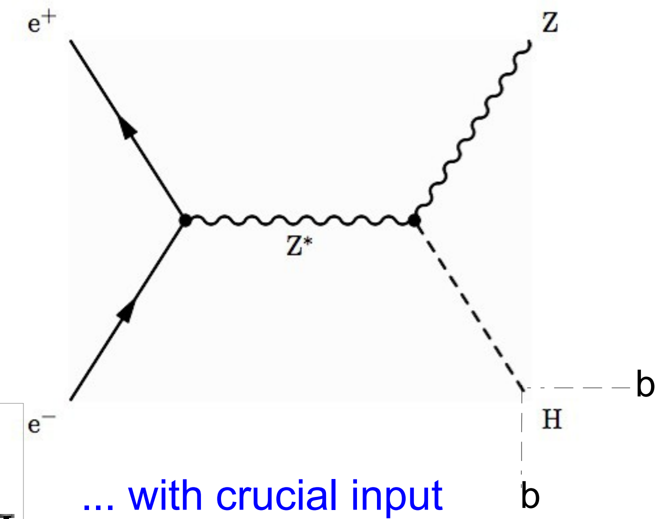


- Different new physics models lead to different patterns
- Full pattern can **only** be measured at Linear Collider

The Total Higgs Width

Can be derived from model independant measurements

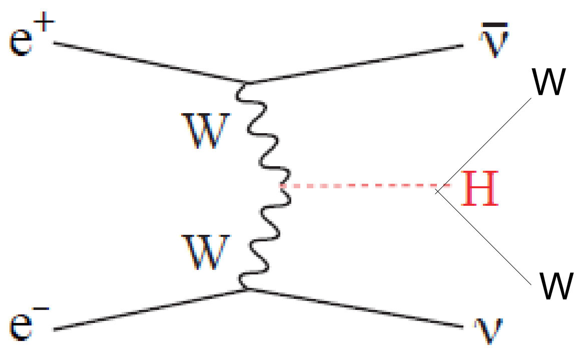


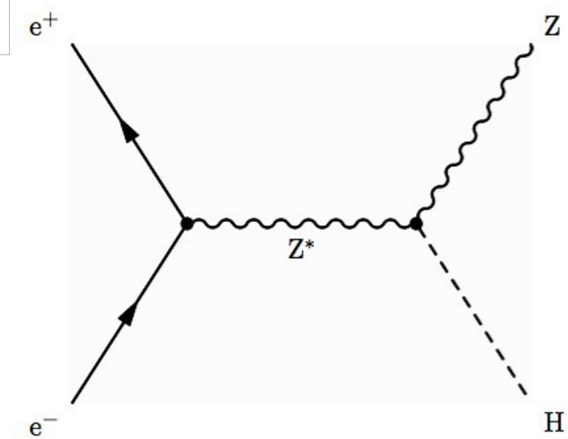


Requires running at 500 GeV

$$\Gamma_t \sim \frac{(\sigma_{\nu\bar{\nu}b\bar{b}}/\sigma_{Zb\bar{b}})^2}{(\sigma_{\nu\bar{\nu}WW}/\sigma_{ZH})} \times \sigma_{ZH}$$

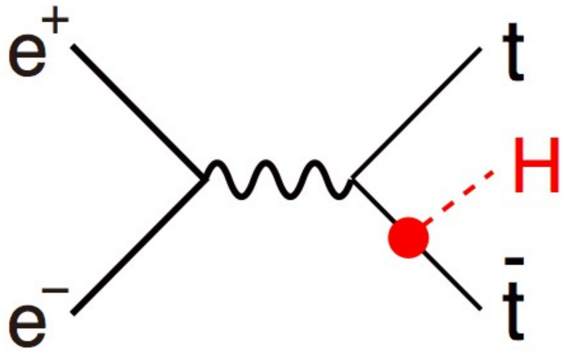
... with crucial input from 250 GeV running





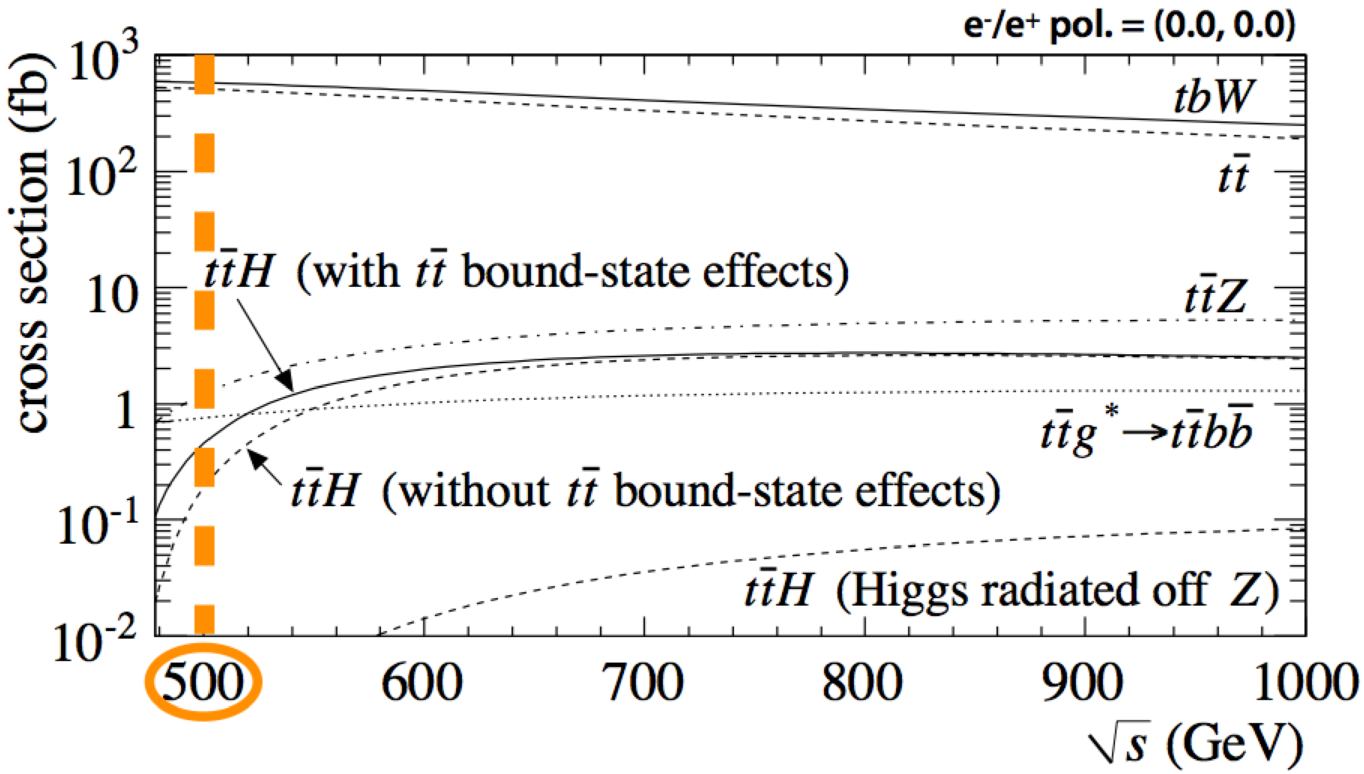
Current prospects - $\delta\Gamma_{tot}$ ~ 5% @ 500 GeV
~ 4% @ 1 TeV (2% technically possible)

Top Yukawa Coupling



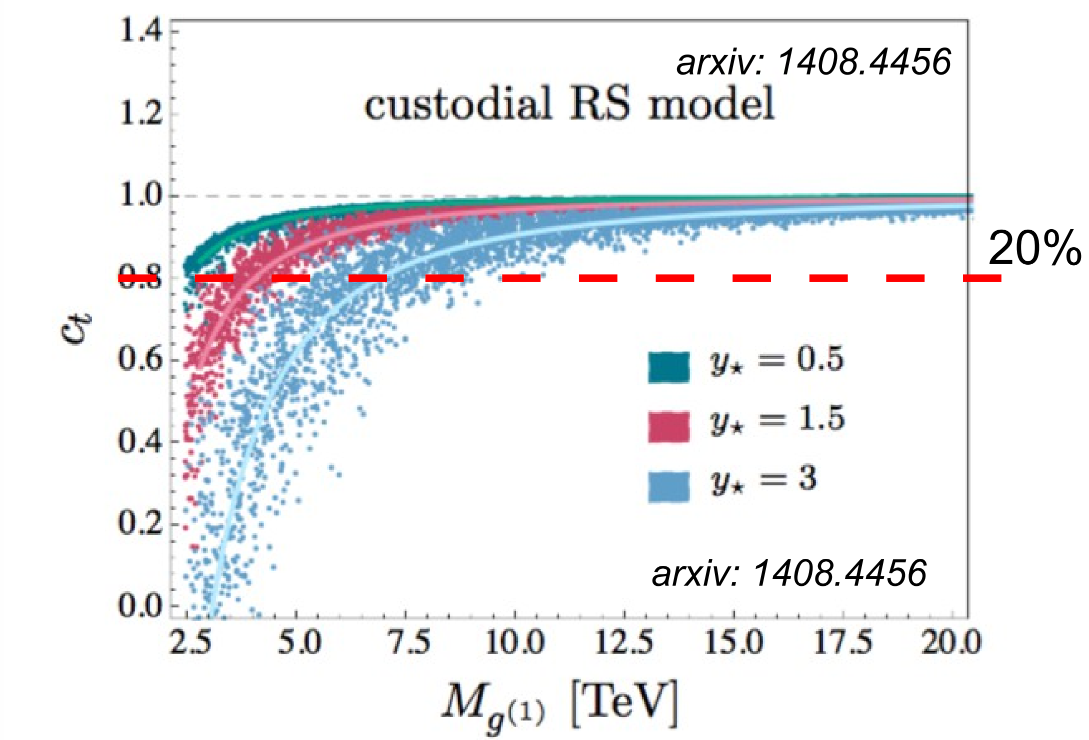
- Coupling of Higgs to heaviest particle known today

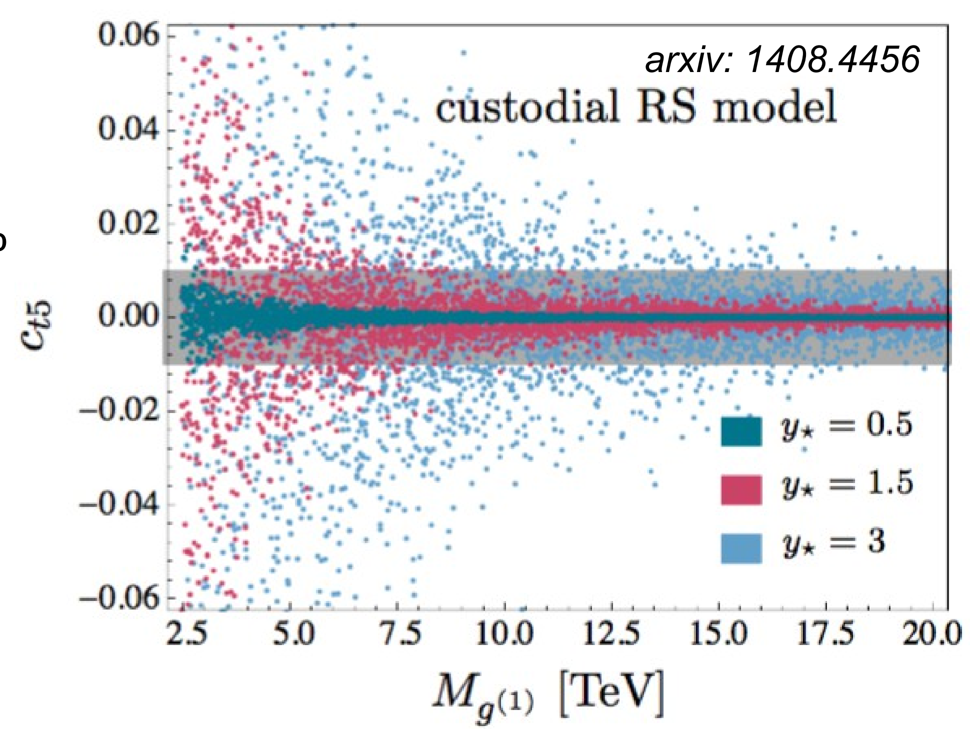
- Up to eight final state jets



ΔgttH / gttH	500 GeV	+ 1 TeV
Snowmass	7.8%	2.0%
H20	6.3%	1.5%

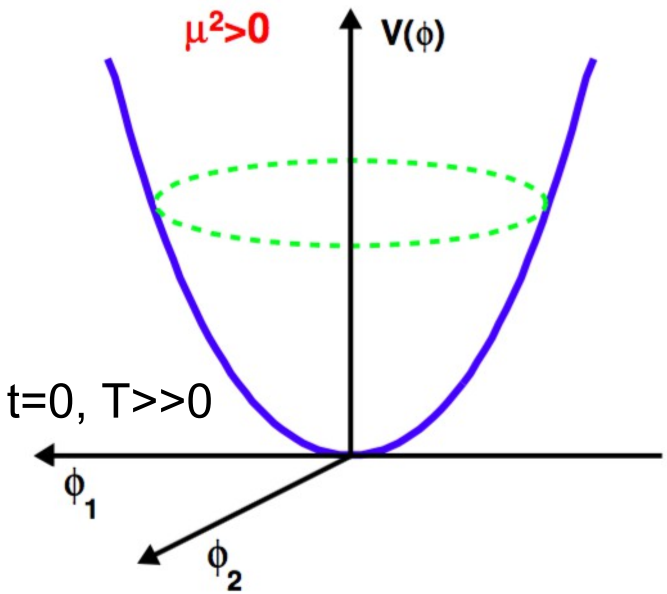
Top-Higgs couplings in “presence” of heavy particles



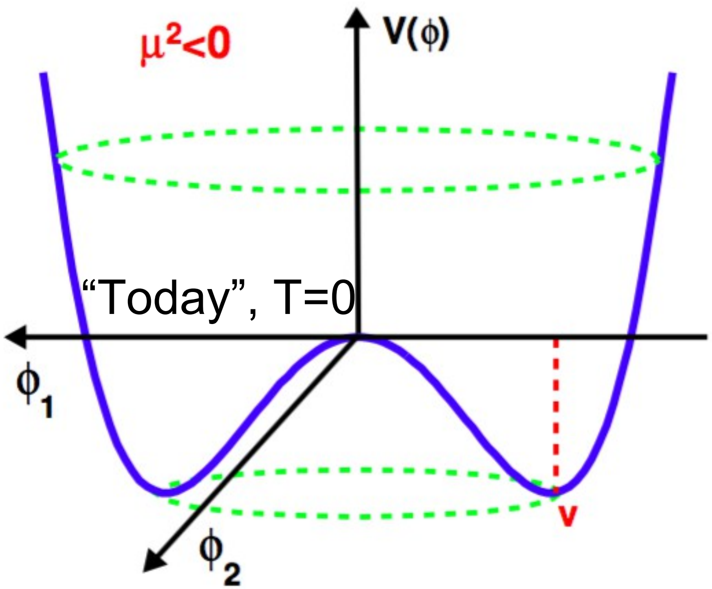


- Heavy particles, e.g. (Kaluza Klein) “duplicas” of SM particles provoke sizable effects
- Sensitivity to CP Violation !?

The Higgs Potential



Perfect (electroweak) symmetry and massless particles

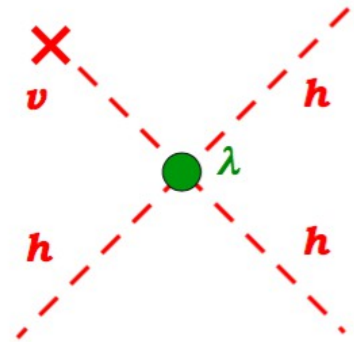


Broken (electroweak) symmetry and massive particles

Two questions:

- Shape of “today's” Higgs Potential?

$$V(\eta) = \frac{1}{2} m^2 \eta^2 + \lambda v \eta^3 + \frac{1}{4} \lambda \eta^4$$ => Triple Higgs-self coupling

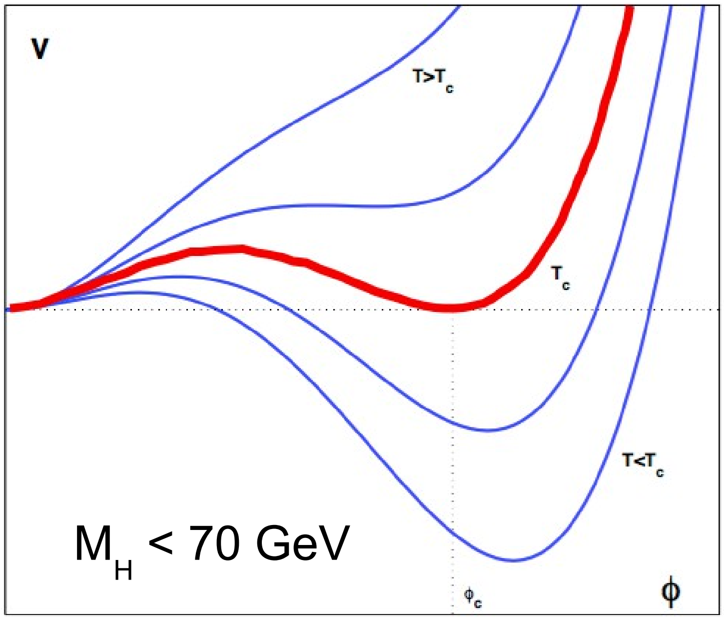


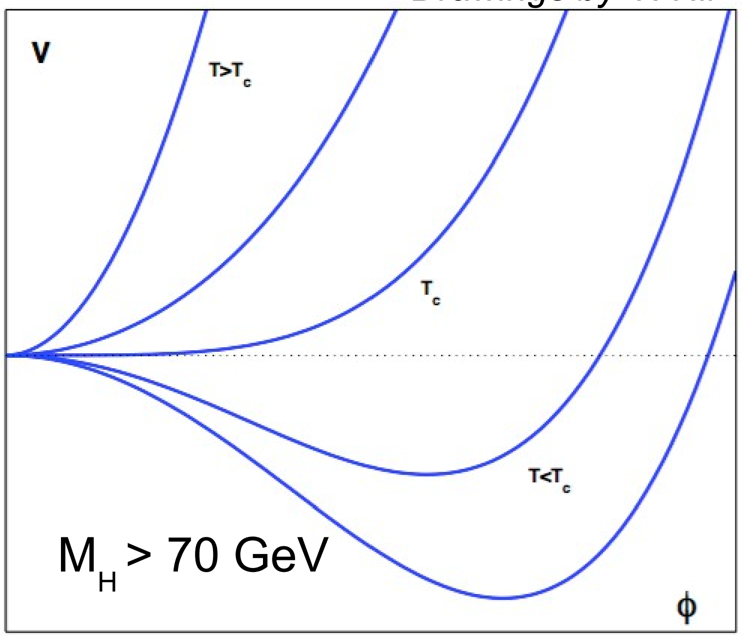
- Transition from symmetric, unbroken to broken phase?

Phase Transition in SM

Electroweak Baryogenesis requires 1st Order PT

Drawings by Y. Nir





- Coexistence Two minima at **0 and v_c at T_C**

=> 1st order phase transition
and development into "today's" shape at T=0

- No coexistence of two minima at **0 and v_c**

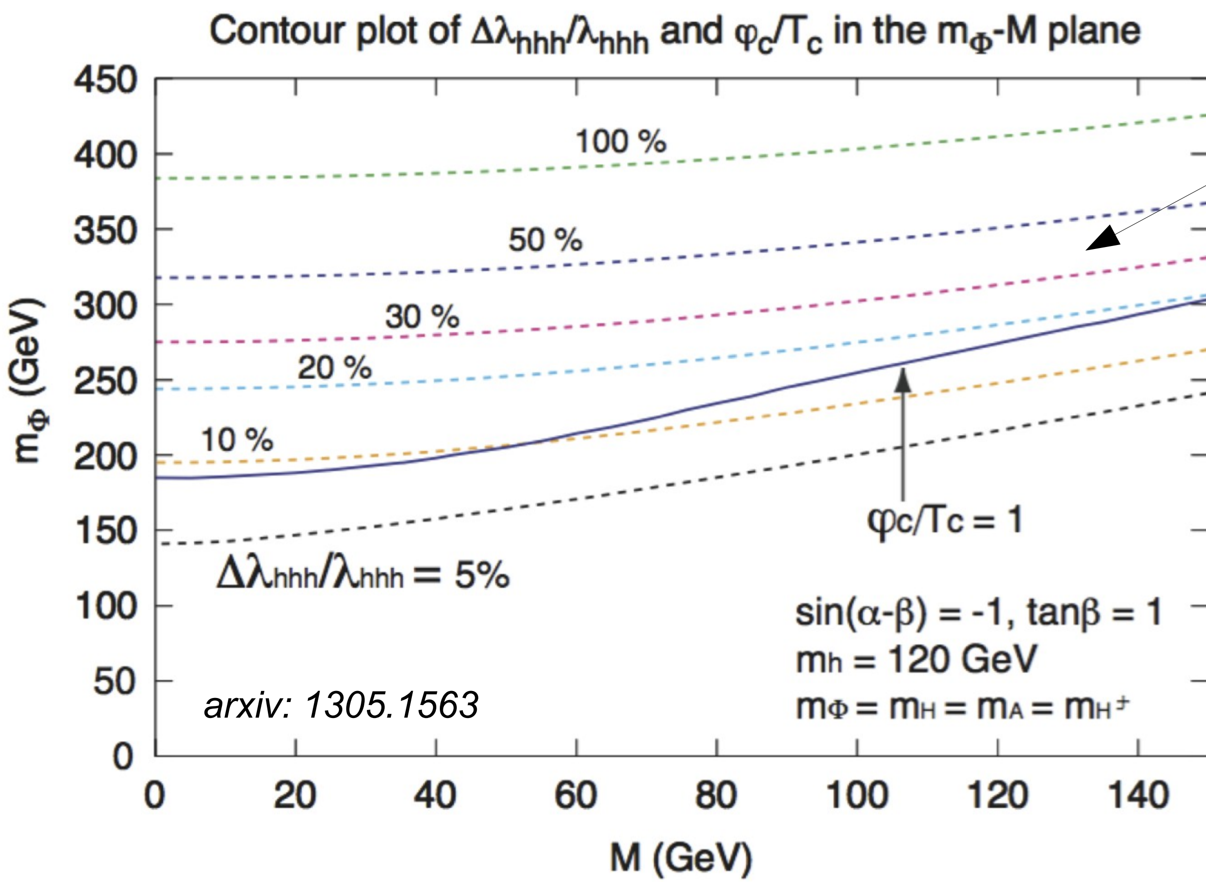
=> Cross over into
"today's" shape at T=0

The discovered Higgs is too heavy to provoke a 1st order phase transition

=> New physics needed

New Particles – Extended Higgs Sector

Heavy Higgs Mass

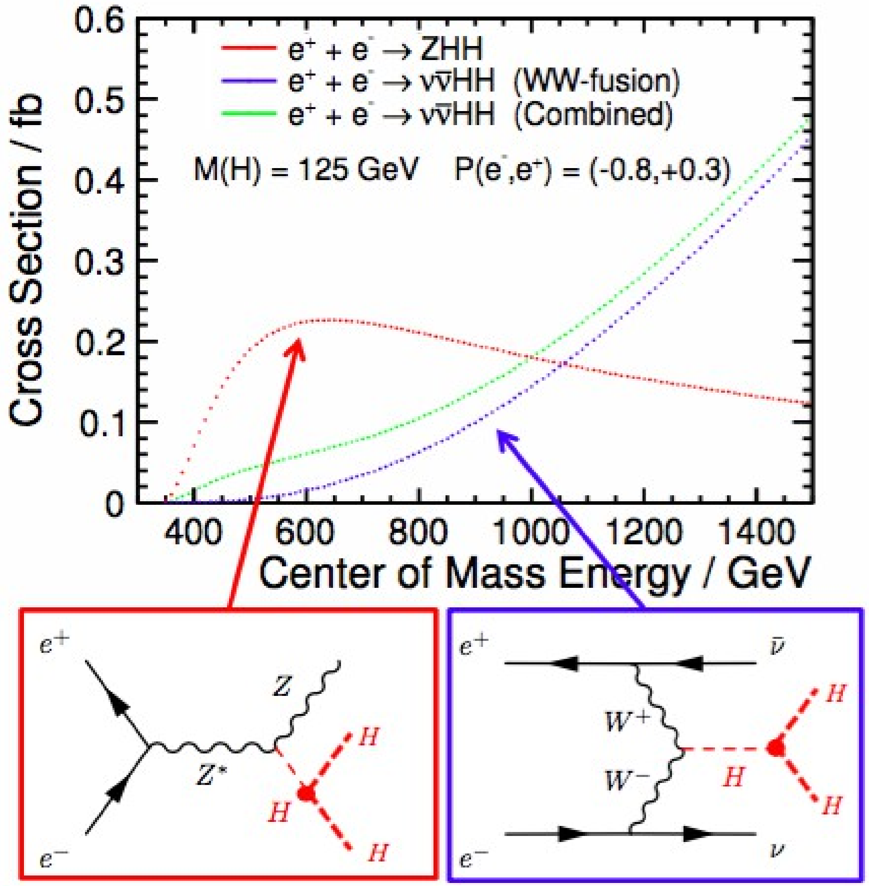


Deviations of λ from SM Value

- New (bosonic) particle may modify λ and enable 1st order phase transition
- Impact on measurements and achievable precisions of λ ?

Higgs self-coupling – Current status

Cross section vs CM energy (e+e-)



Diagrams with triple-Higgs coupling

Expected precision based on
full detector simulation studies:

ILC	ILC
500 GeV, 4 ab-1 **δλ = 27%**	500 GeV, 4 ab-1 & 1 TeV, 8 ab-1 **δλ = 10%**

References:
J. Tian, LC-REP-2013-003
M. Kurata, LC-REP-2014-025
C. Duerig, Ph.D. thesis at DESY, 2016
HH→bbbb, bbWW* combination

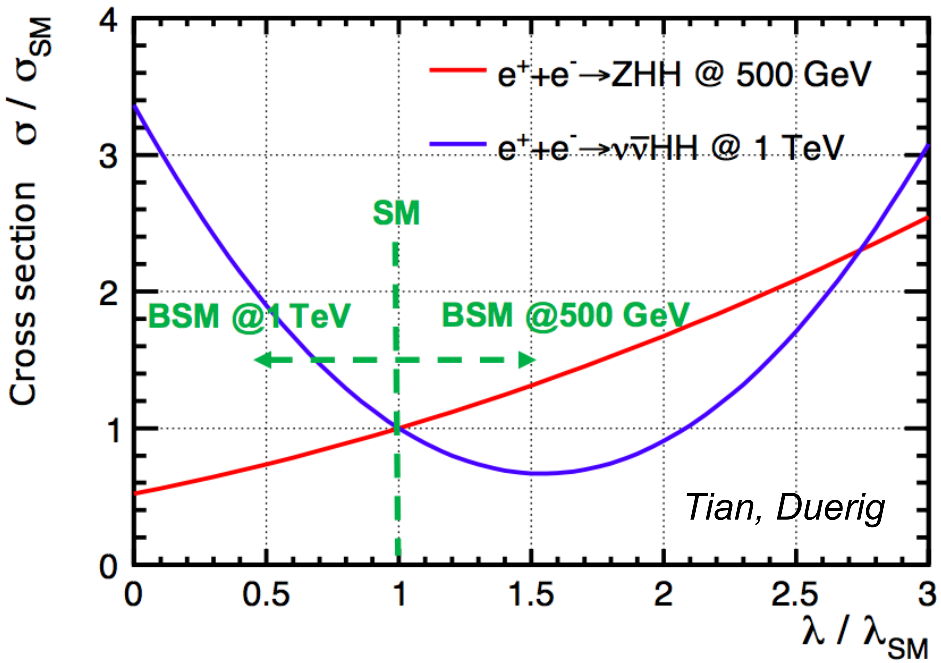
CLIC	CLIC
1.4 TeV, 1.5 ab-1 **δλ = 21%**	1.4 TeV, 1.5 ab-1 & 3 TeV, 2 ab-1 **δλ = 10%**

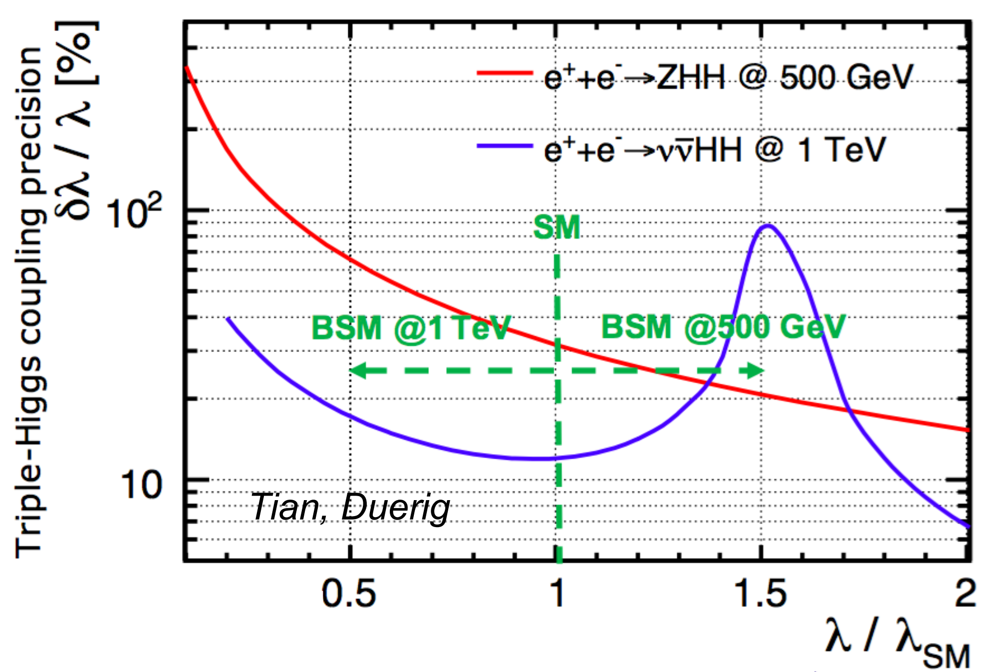
References:
arXiv: 1307.5288
HH→bbbb only, upgrade in progress including bbWW*

T. Tanabe, Higgs Coupling 2016

Higgs self-coupling – Sensitivities

Manifestation of new physics in observables and extracted results?

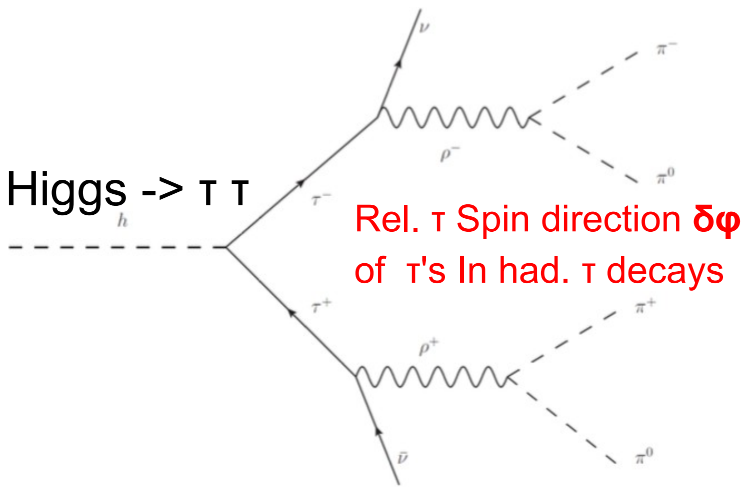


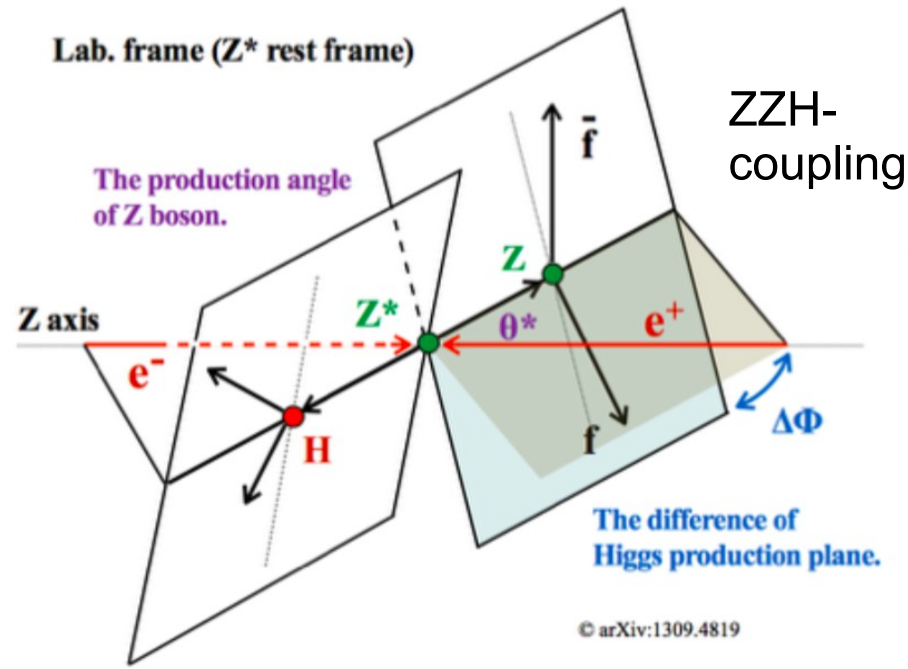


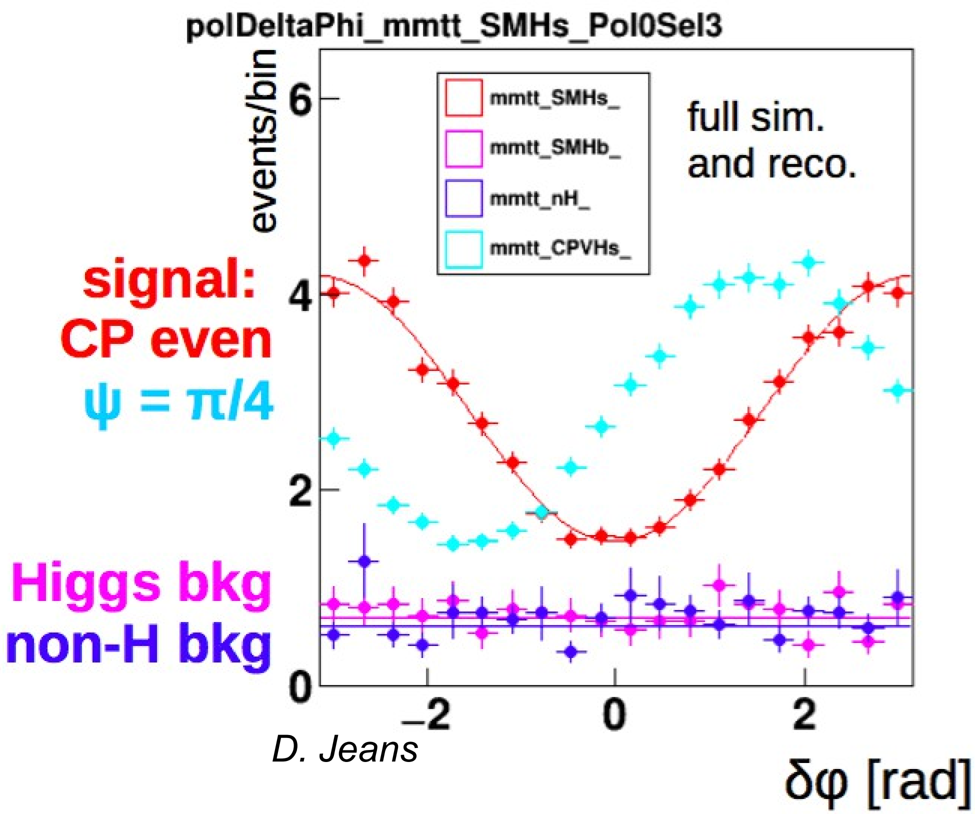
- Remarkable sensitivity of 500 GeV machine in case of large upward deviation
- 1 TeV machine superior for large upward and downward deviations

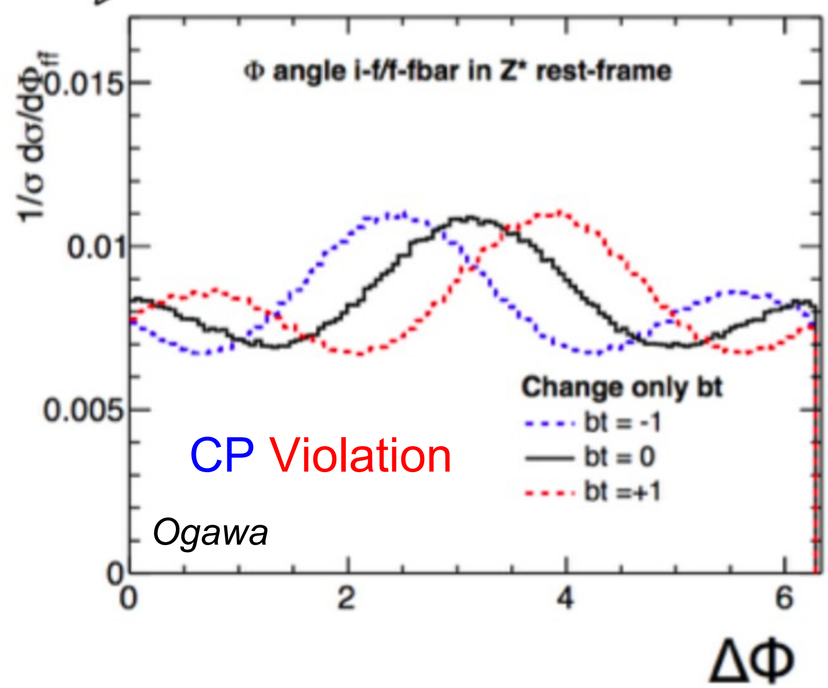
T. Tanabe, Higgs Coupling 2016

CP Violation in Higgs studies

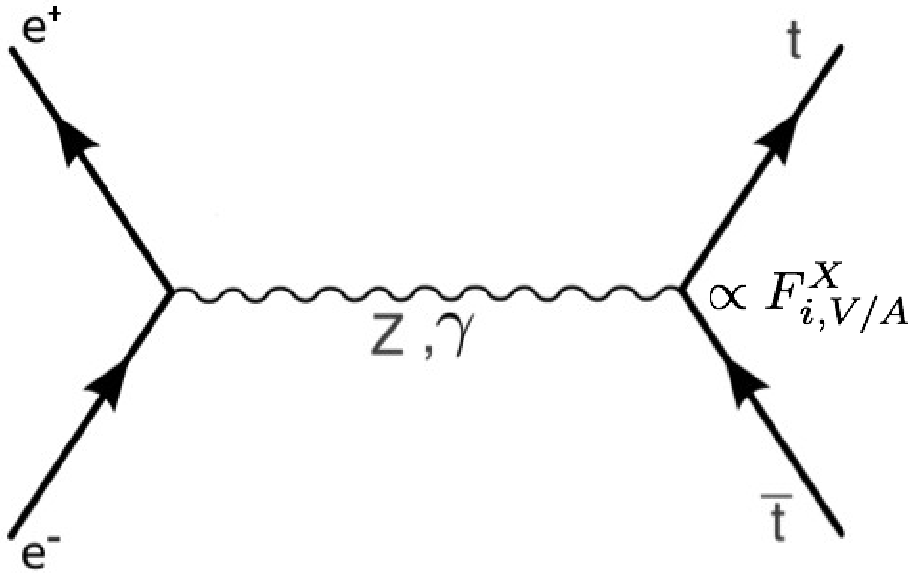


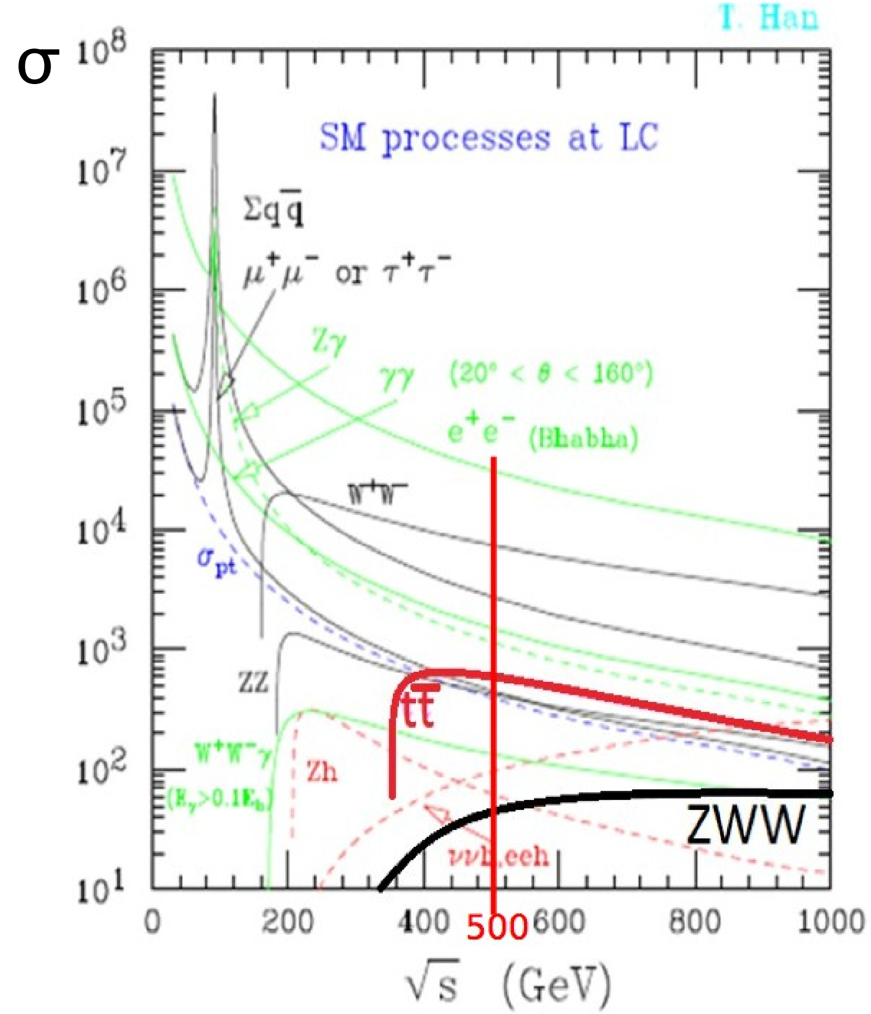






3. Top physics at the ILC





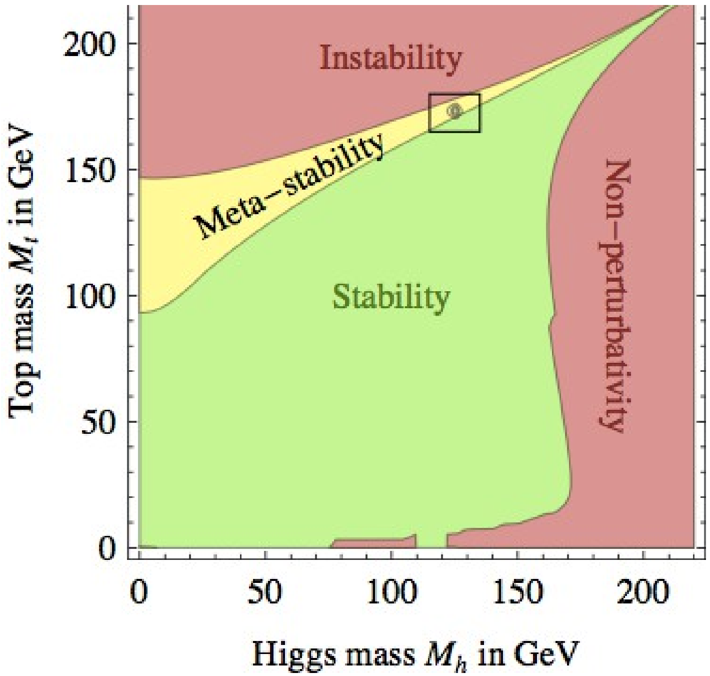
- Top quark production through electroweak processes
  no competing QCD production => Small theoretical errors!

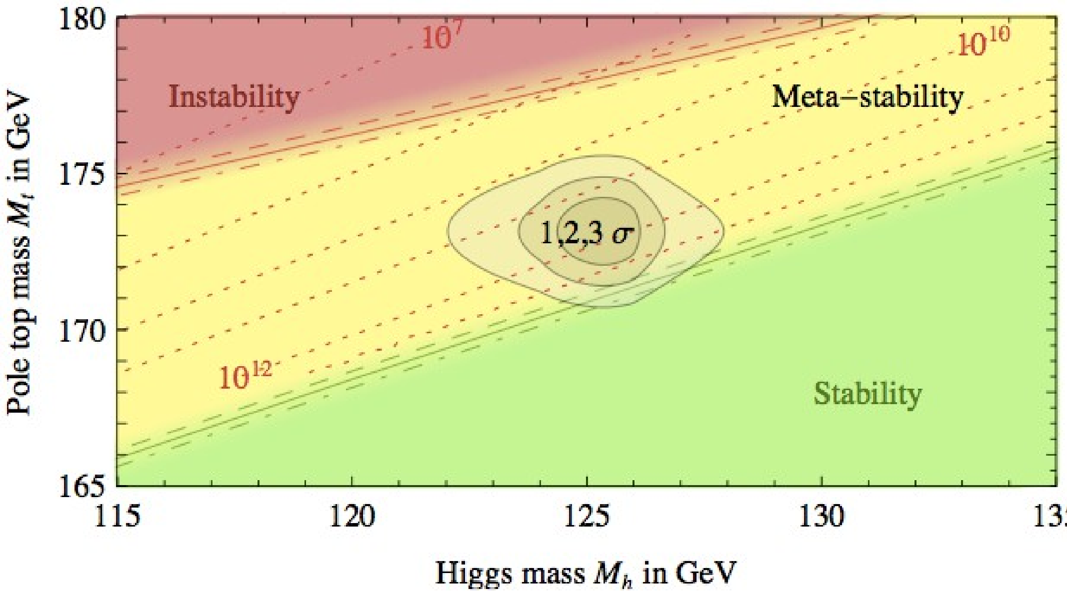
- High precision measurements
  -Top quark mass at ~ 350 GeV through threshold scan
  - Polarised beams allow testing chiral structure at ttX vertex
    => Precision on form factors F

Vacuum stability and Top Quark Mass

Degrassi et al. arXiv:1205.6497

$$M_h\ [\mathrm{GeV}] > 129.4 + 1.4\left(\frac{M_t\ [\mathrm{GeV}] - 173.1}{0.7}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{\mathrm{th}}\ .$$

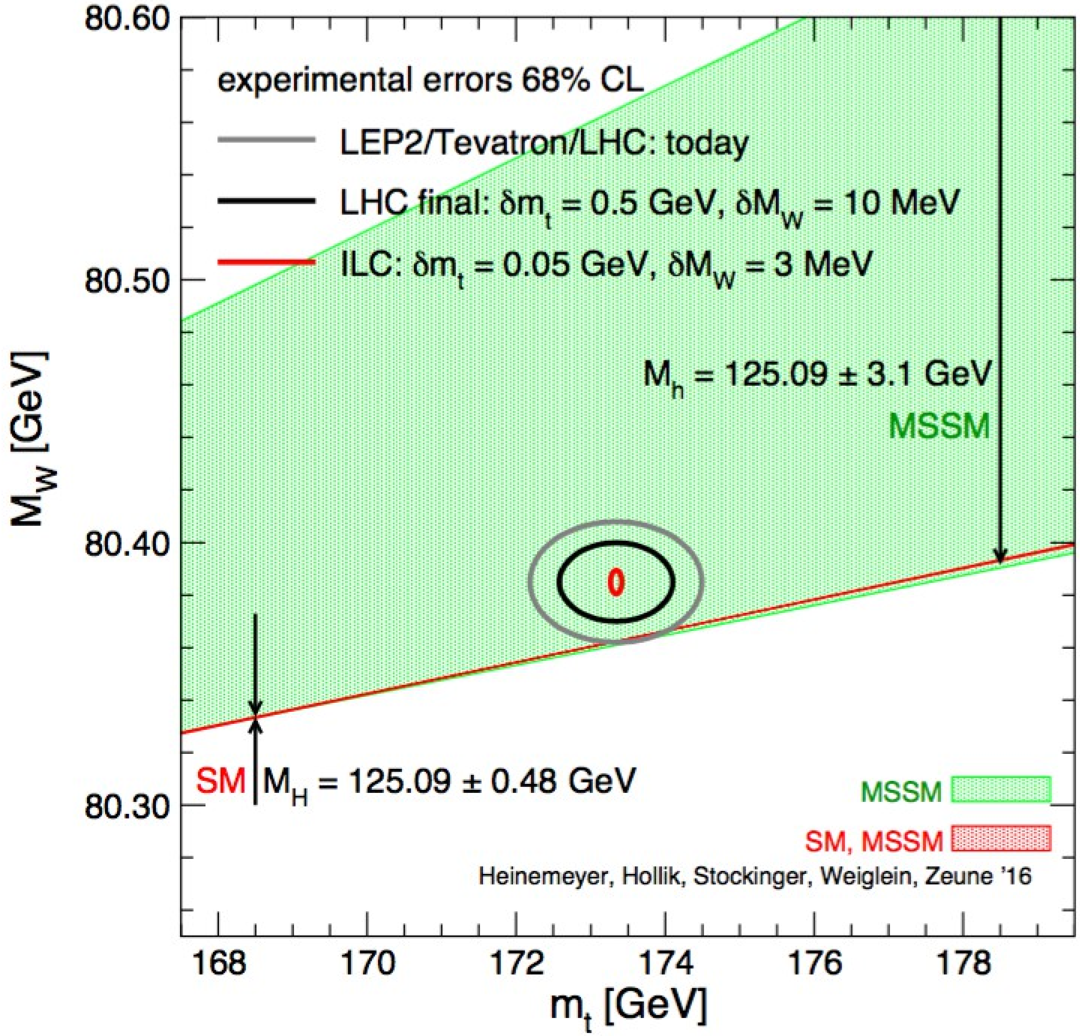




Type of error	Estimate of the error	Impact on M_h
M_t	experimental uncertainty in M_t	±1.4 GeV
α_s	experimental uncertainty in α_s	±0.5 GeV
Experiment	**Total combined in quadrature**	**±1.5 GeV**
λ	scale variation in λ	±0.7 GeV
y_t	$\mathcal{O}(\Lambda_{\mathrm{QCD}})$ correction to M_t	±0.6 GeV
y_t	QCD threshold at 4 loops	±0.3 GeV
RGE	EW at 3 loops + QCD at 4 loops	±0.2 GeV
Theory	**Total combined in quadrature**	**±1.0 GeV**

Uncertainty on **(pole)** top quark mass dominates uncertainty on stability conditions

Top Mass, Higgs Mass and BSM – SM vs. MSSM



Precise Top (and W) mass crucial to test compatibility of measured Higgs mass

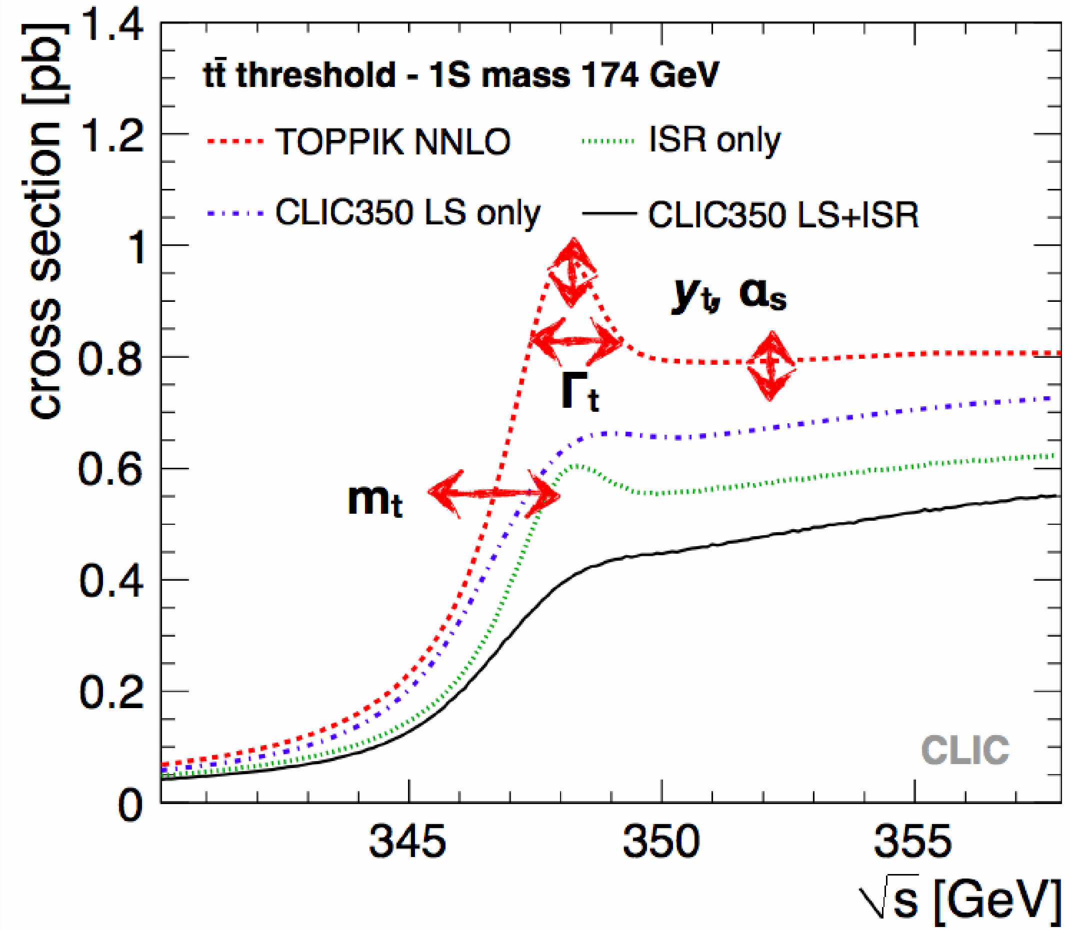
MS might not be sufficient to explain Higgs mass

LHC may not reach sufficient discriminative power

A lepton collider will

Threshold scan

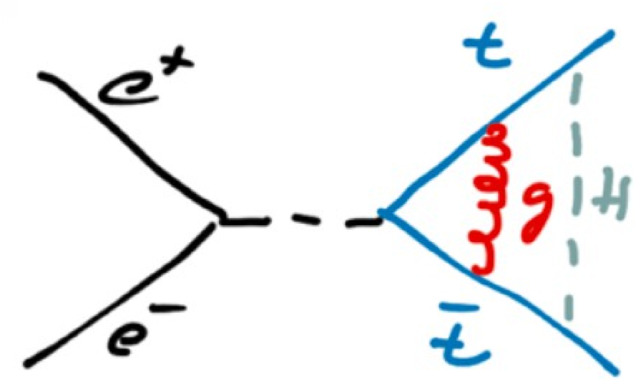
Small size of ttbar "bound state" at threshold ideal premise for precision physics



Cross section around threshold is affected by several properties of the top quark and by QCD

- Top mass, width Yukawa coupling

- Strong coupling constant

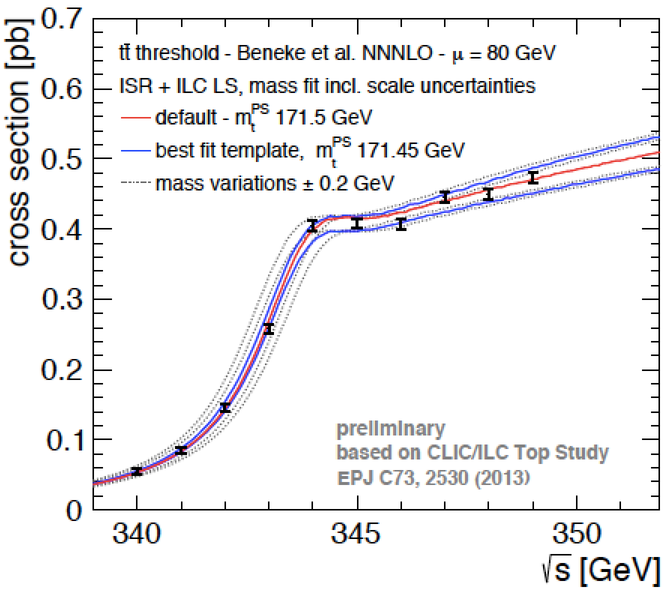


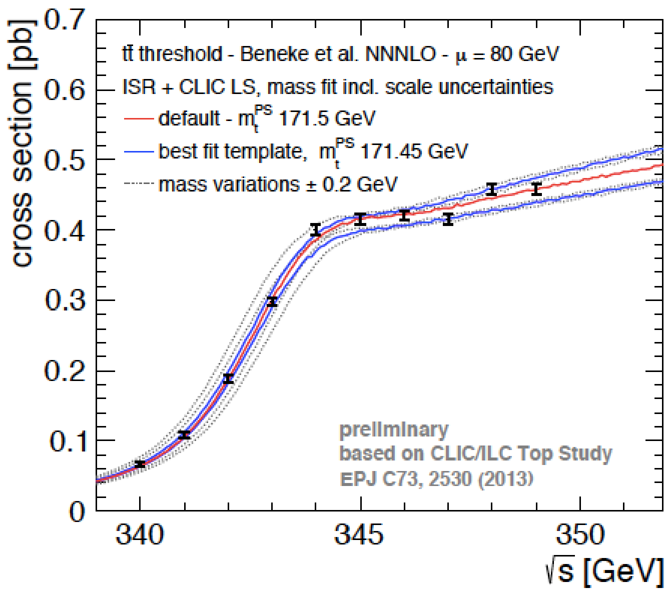
Effects of some parameters are correlated:
Dependence on Yukawa coupling rather weak,
Precise external α_s helps

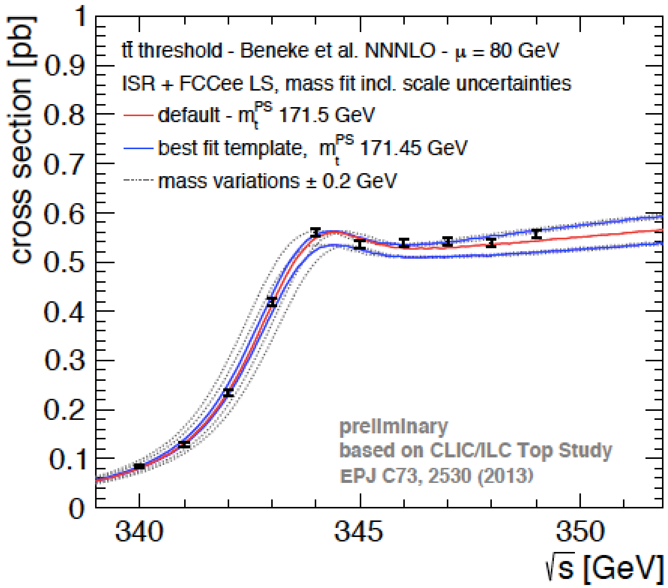
-> α_s discussion in top/QCD parallel by Kluth

F. Simon, Top@LC15 Valencia

Top threshold scans at different e+e- colliders







ILC

Fit uncertainty:
28.5 MeV (18 MeV stat)

Scale uncertainty:
40 MeV

CLIC

Fit uncertainty:
31 MeV (21 MeV stat)

Scale uncertainty:
42 MeV

FCC-ee

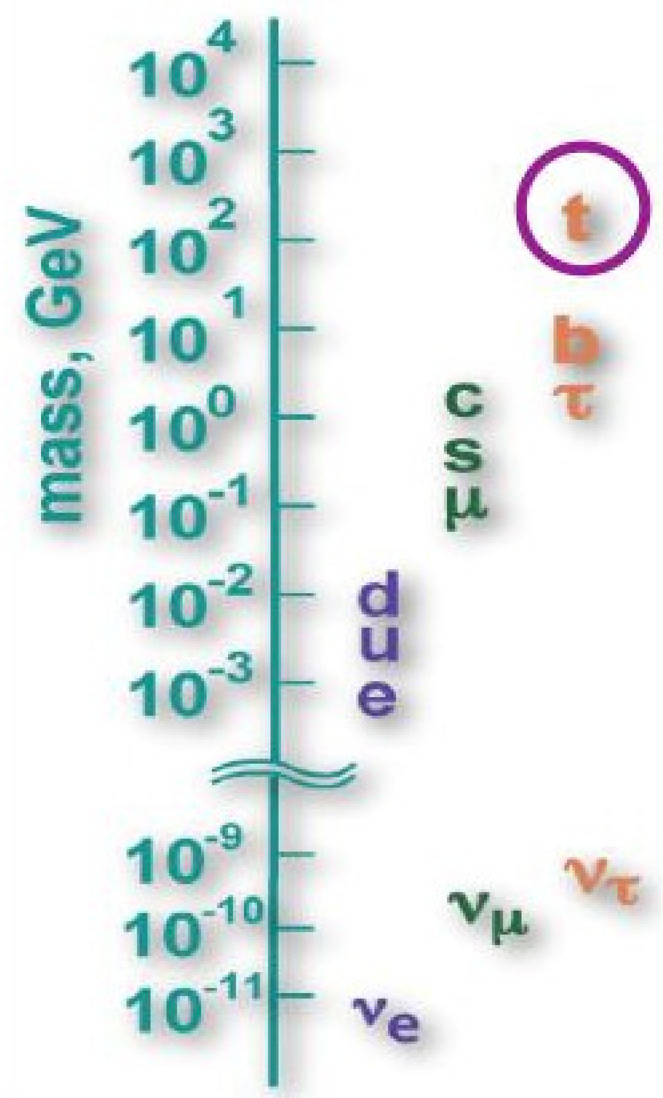
Fit uncertainty:
27 MeV (15 MeV stat)

Scale uncertainty:
40 MeV

New ideas on top mass determination see talks by Fuster, Maier and Marquardt

F. Simon Top@LC16

Top Quark and Flavor Hierarchy

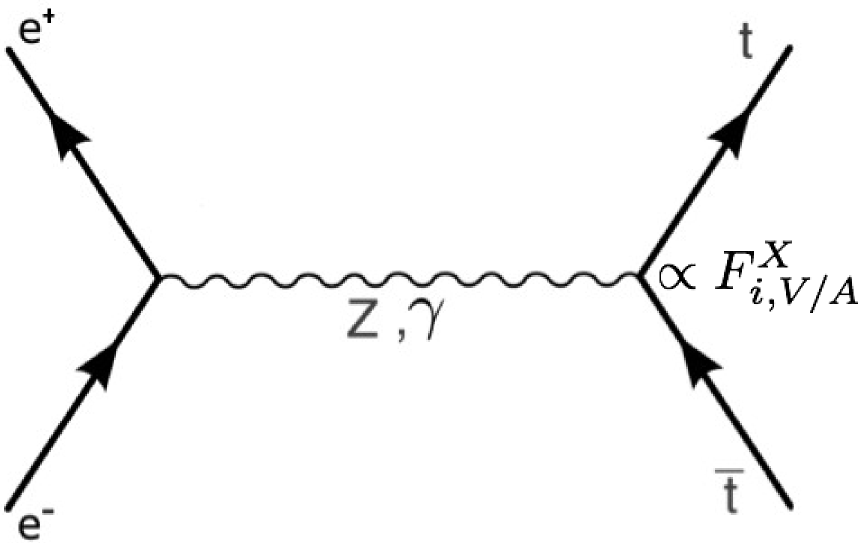


- SM does not provides no explanation for mass spectrum of fermions (and gauge bosons)

- Fermion mass generation closely related to the origin electroweak symmetry breaking

- Expect residual effects for particles with masses closest to symmetry breaking scale
  - A_{FB} anomaly at LEP for b quark

Strong motivation to study chiral structure of top vertex in high energy e+e- collisions



Manifestation of New Physics:

- Modification of Ztt coupling
  Mixing between top and partners
  Mixing Z/Z'

- s-channel exchange of New Z'
  Including interference effects

$$\Gamma_\mu^{ttX}(k^2,q,\bar{q}) = -ie\left\{\gamma_\mu\left(F_{1V}^X(k^2)+\gamma_5 F_{1A}^X(k^2)\right)+\frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\mu\left(iF_{2V}^X(k^2)+\gamma_5 F_{2A}^X(k^2)\right)\right\}, \quad (2)$$

$$\text{Pure } \gamma \text{ or pure } Z^0 : \sigma \backsim (F_i)^2 \Rightarrow \text{ No sensitivity to sign of Form Factors}$$

$$Z^0/\gamma \text{ interference } : \sigma \backsim (F_i) \Rightarrow \text{ Sensitivity to sign of Form Factors}$$

Disentangling

At ILC **no** separate access to ttZ or ttγ vertex, but ...

ILC 'provides' two beam polarisations

$P(e^-) = \pm 80\%$ $P(e^+) = \mp 30\%$

There exist a number of observables sensitive to chiral structure, e.g.

$$\sigma_I \qquad A^t_{FB,I} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)} \qquad (F_R)_I = \frac{(\sigma_{t_R})_I}{\sigma_I}$$

x-section — Forward backward asymmetry — Fraction of right handed top quarks

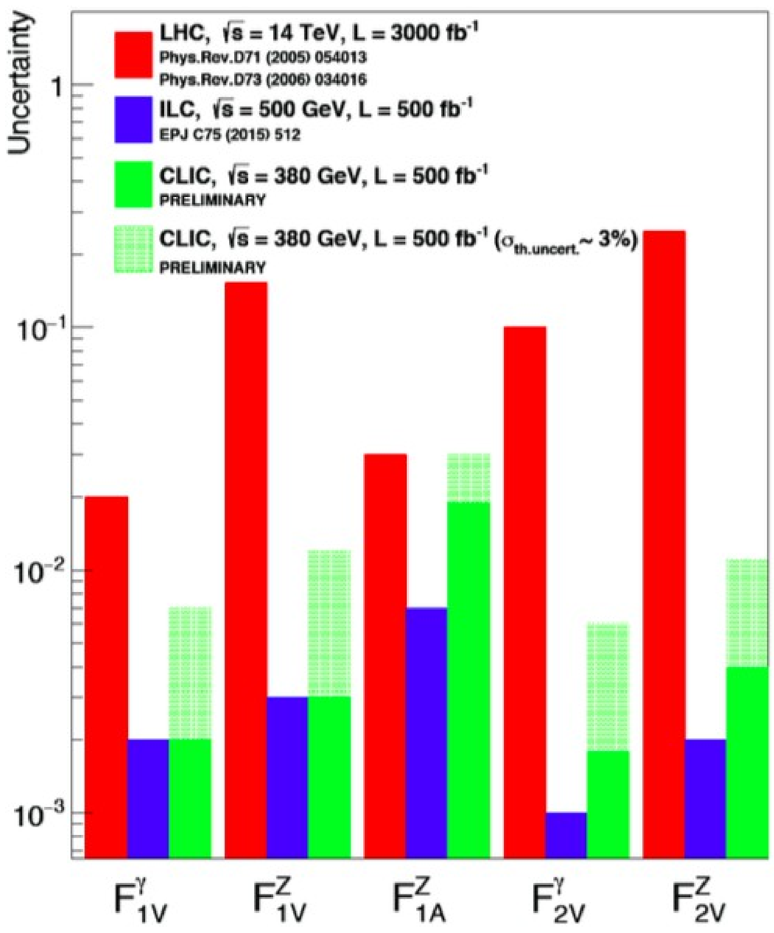
⇩

Extraction of relevant unknowns

$$F^\gamma_{1V},\ F^Z_{1V},\ F^\gamma_{1A} = 0,\ F^Z_{1A}$$
$$F^\gamma_{2V},\ F^Z_{2V}$$

or equivalently $g^\gamma_L,\ g^\gamma_R,\ g^Z_L,\ g^Z_R$

Accuracy on CP conserving couplings



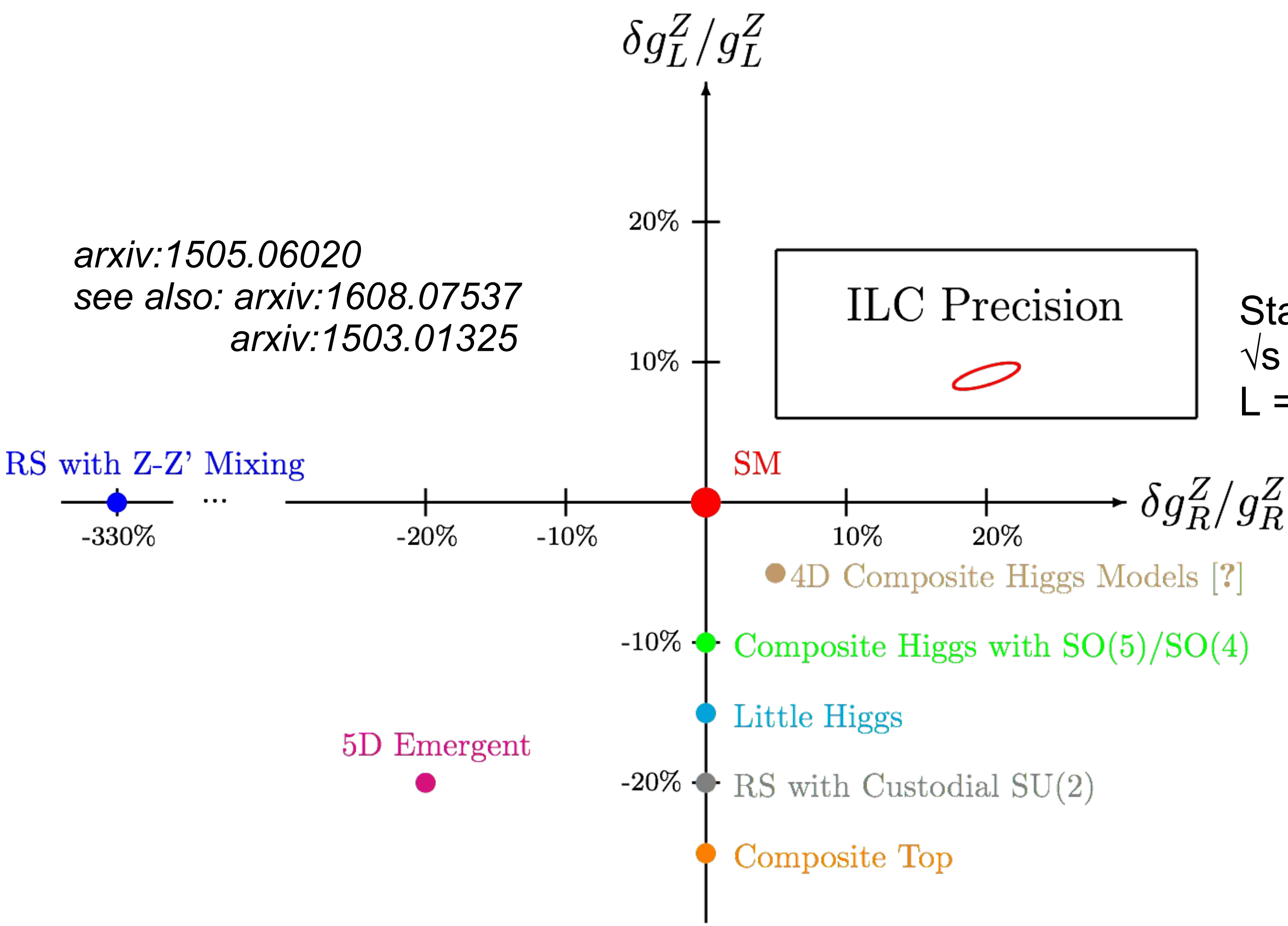
- ILC might be up to two orders of magnitude more precise than LHC (√s = 14 TeV, 3000 fb-1)
- Large disentangling of couplings for ILC thanks to polarised beams
- One variable at a time for LHC
  LHC projections from 8 years old study
- Note
  Minimal Lumi scenario for ILC
  Maximal Lumi scenario for CLIC
  Maximal Lumi scenario for LHC
- CP Violating couplings see talk by Vos
- Alternative by Matrix Element Method see talk by Sato

LC promises to be high precision machine for electroweak top couplings

Sensitivity to New Physics

Top is primary candidate to be a messenger new physics in many BSM models
Incorporating compositeness and/or extra dimensions

arxiv:1505.06020
see also: arxiv:1608.07537
arxiv:1503.01325



Statistical error:
√s ~ 500 GeV
L = 500 fb^{-1}

Precision expected for top quark couplings will allow distinguishing between models

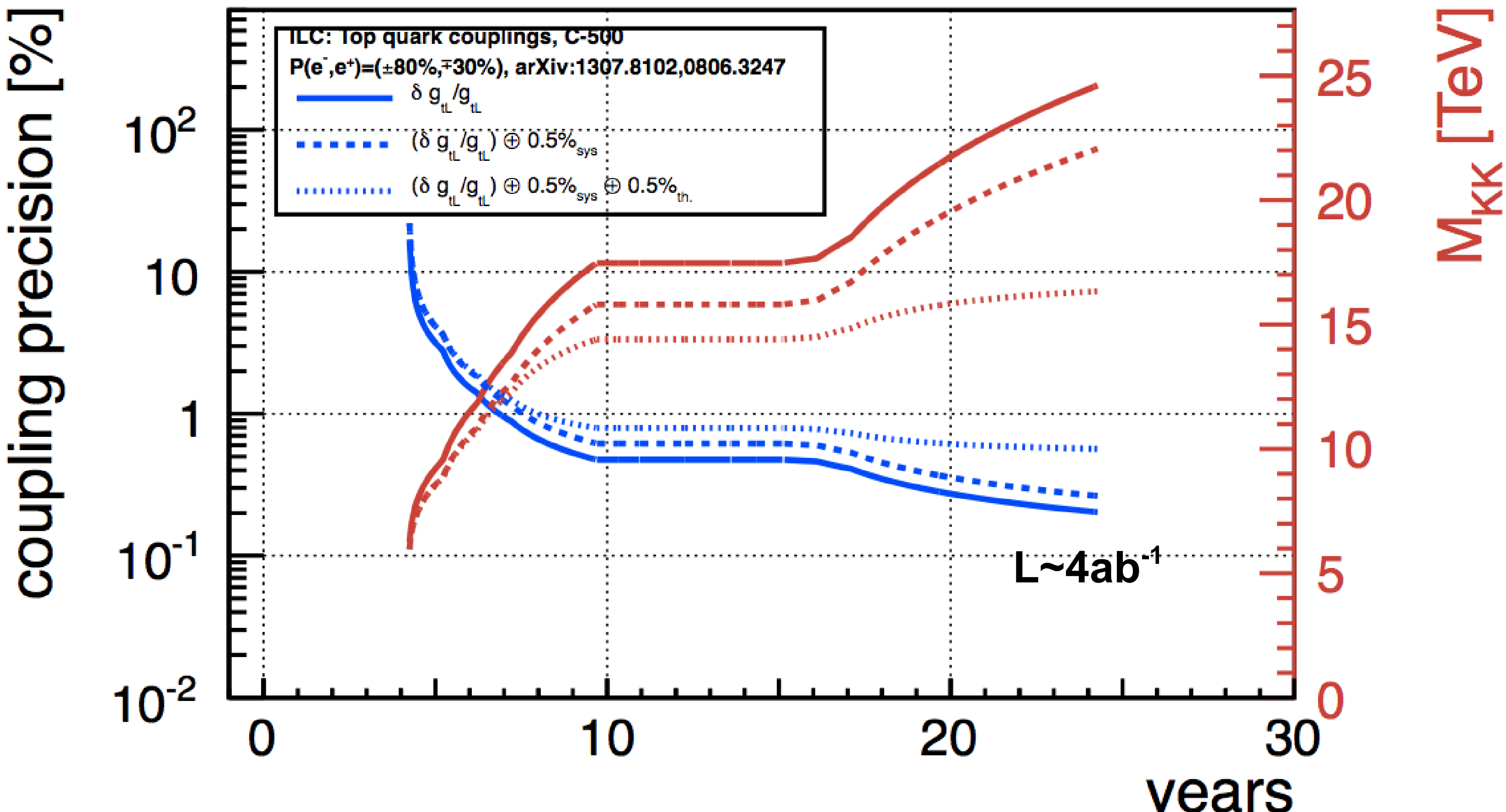
Remark: All presented models are compatible with LEP elw. precision data

Interpretation in EFT Framework, see talk by Vos

Example for physics reach

New physics reach for typical BSM scenarios with composite Higgs/Top and or extra dimensions

Based on phenomenology described in Pomerol et al. arXiv:0806.3247



Can probe scales of ~25 TeV in typical scenarios

(… and up tp 80 TeV for extreme scenarios)

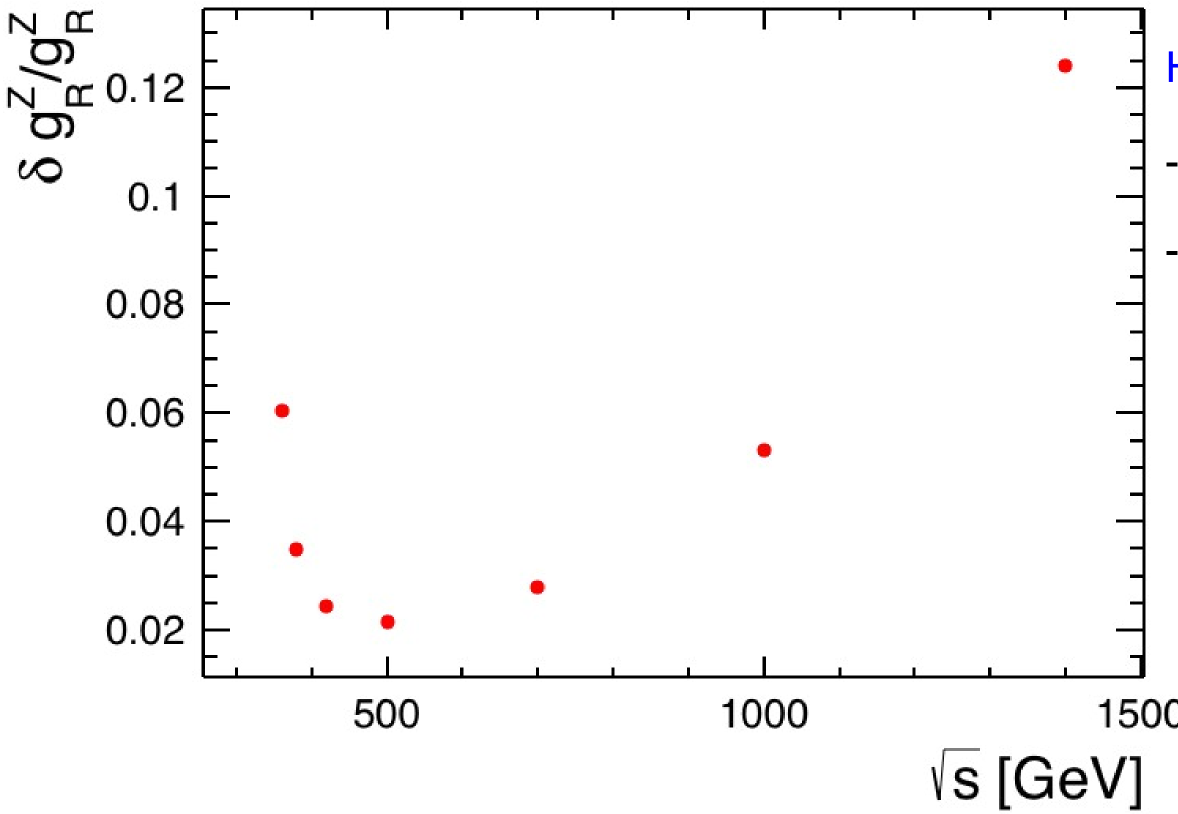
=> Important guidance for e.g. 100 TeV pp-collider

Different centre of mass energies

... simplified discussion

Small cms energies:

- Vanishing axial vector coupling
- QCD uncertainties
- Lumi decreases at linear colliders



High cms energies:

- Quickly decreasing cross section
- ... partially compensated by increasing luminosity

Broad minimum between 400 and 700 GeV

$\sqrt{s}$ ~ 500 GeV is “sweet spot” for coupling measurements

However:
- Sensitivity to CP violating Higgs at smaller cms energies
- New physics at higher energies may increase cross section

Summary

- LC is versatile machine for precision physics at the TeV scale

Polarised beams to test chiral theory!

- Higgs and top quark are physics guaranteed

(My conviction) both are messengers to New Physics

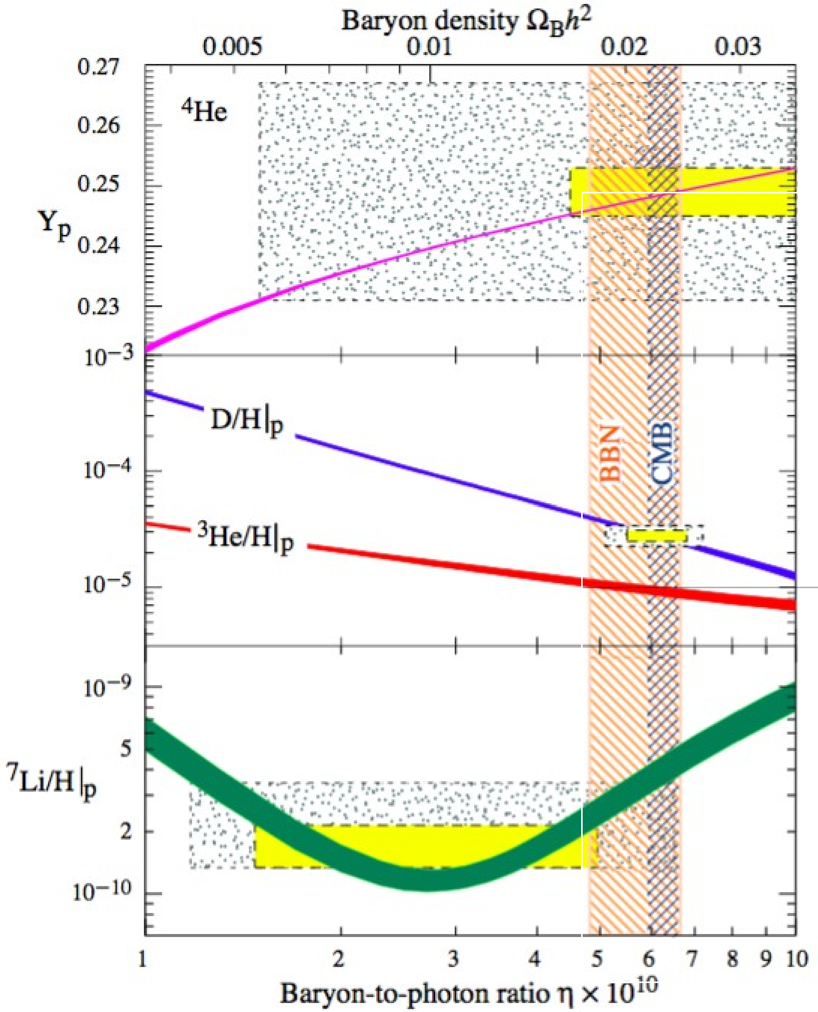
- Exciting Discovery potential

Full set of SM couplings to Higgs
Discovery of invisible decays by Higgs-strahlung
Direct Measurement of Higgs self-coupling: **Unique at LC**
Direct Top-Higgs coupling: **LC only e+e- machine**
Precision of top couplings: **Unique at LC**
Top physics programme completed by superb mass measurement

Backup ....

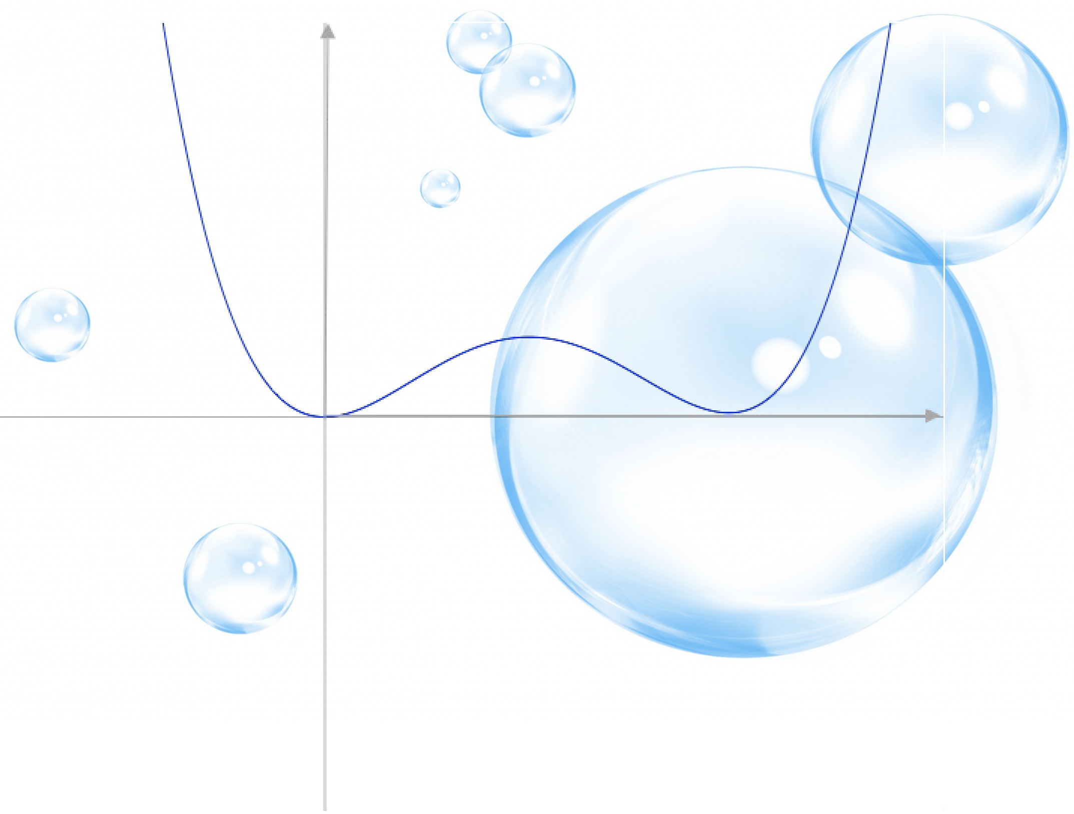
Higgs self coupling - introduction

Baryon Asymmetry of the Universe BAU



Abundance of light elements

Sakharov conditions for BAU include
First order Phase Transition
(of electroweak vacuum)

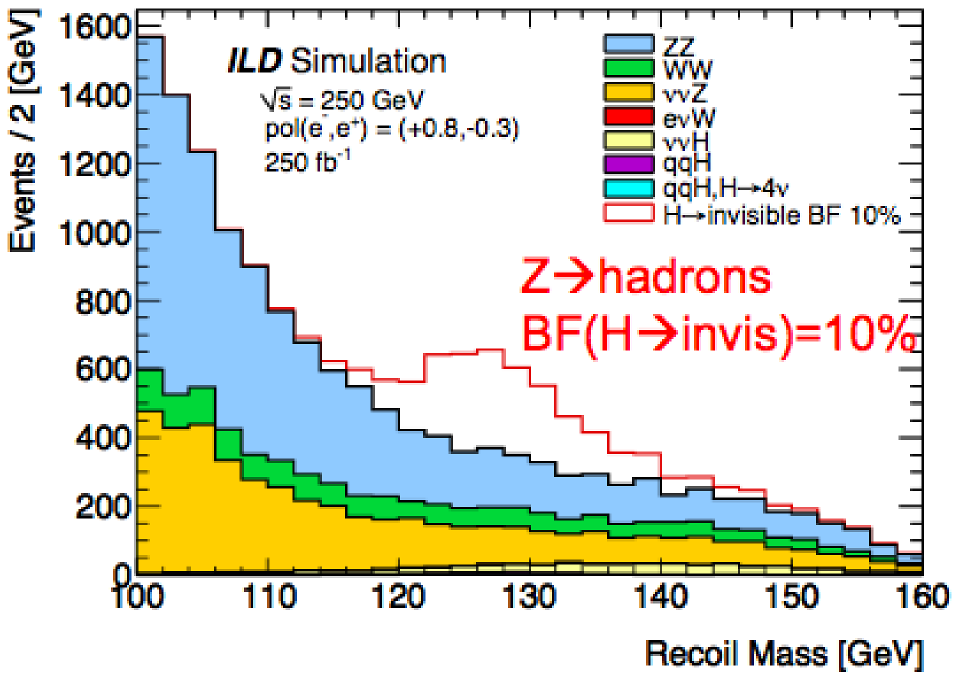


Coexistence of two phases at T = T_c

Two minima at 0 and v_c in scalar potential

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

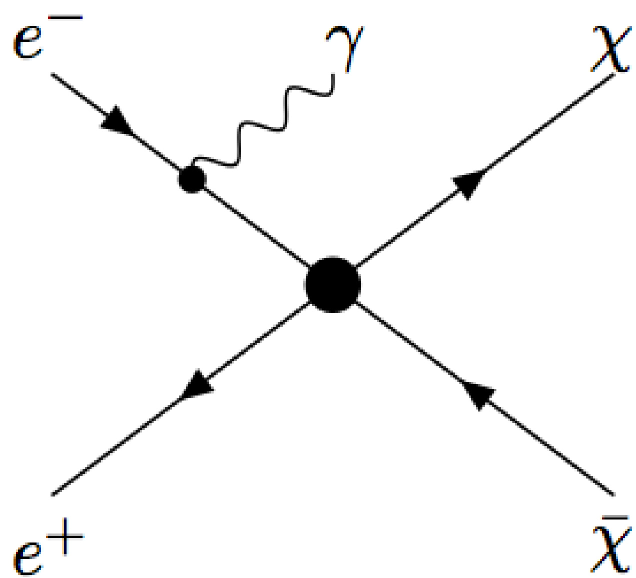
Higgs Invisible Decays



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

Impact of jet energy resolution

Monophoton Searches



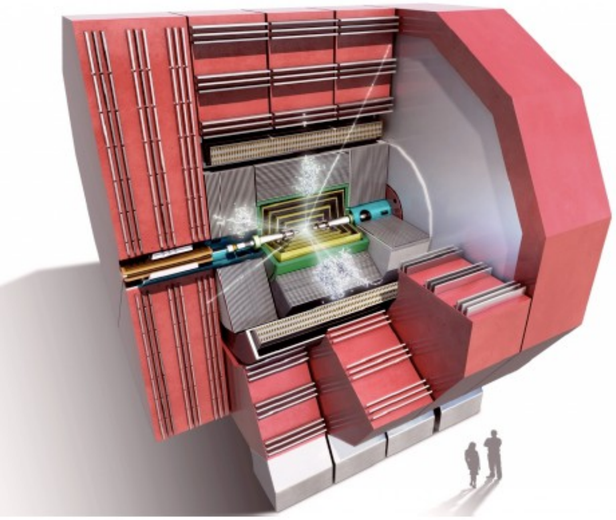
→ DM mass sensitivity nearly half √s

Soft photons, forward detectors

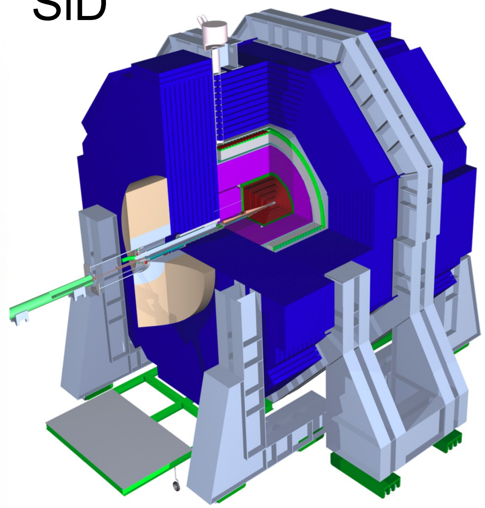
Tomohiko Tanabe
ILD Meeting 2014

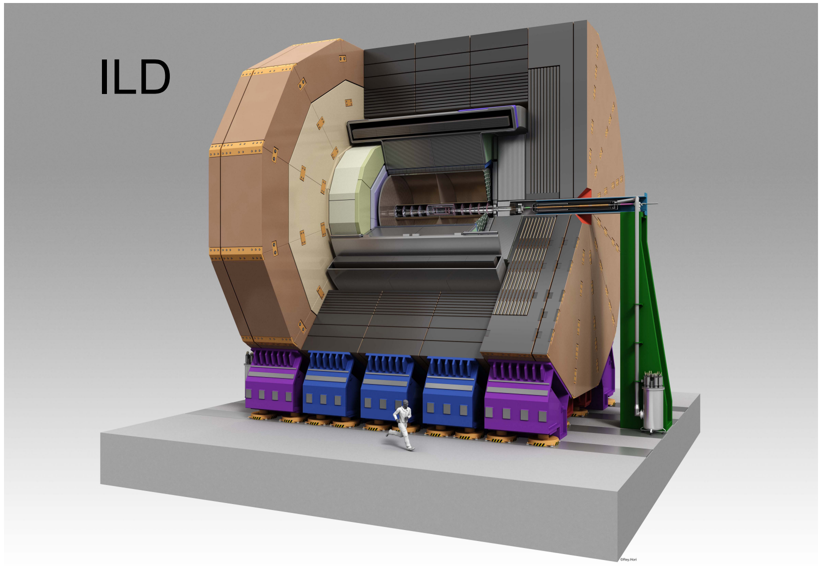
Detector concepts

CLIC Detector



SiD





Highly granular calorimeters

Central tracking
with silicon

Central tracking
with TPC

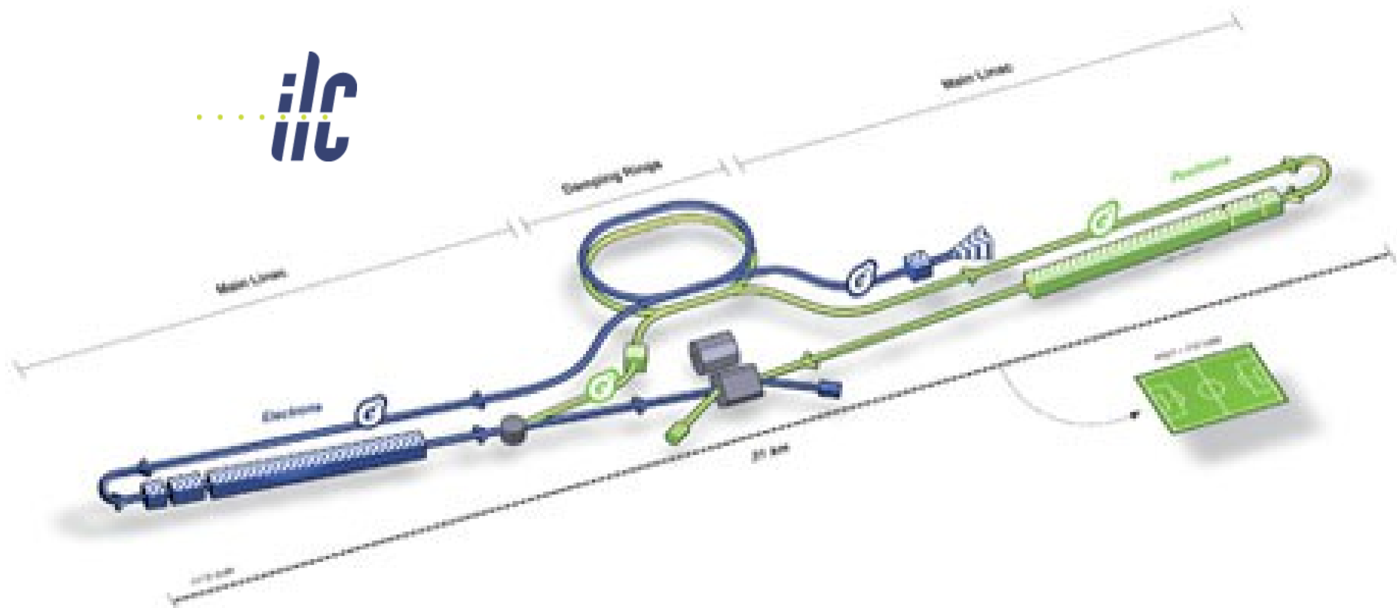
Inner tracking with silicon

- CDR 2012
  Revised since

- LOI's Validated by IDAG in 2009
- Publication of **D**etector **B**aseline **D**esign in 2013, together with TDR

Concepts based on input from physics studies and detector R&D organised in R&D collaborations

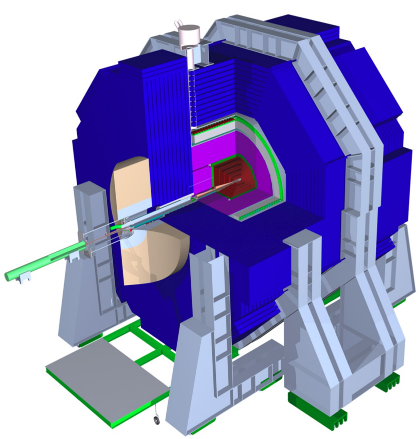
ILC Project - Machine and detectors



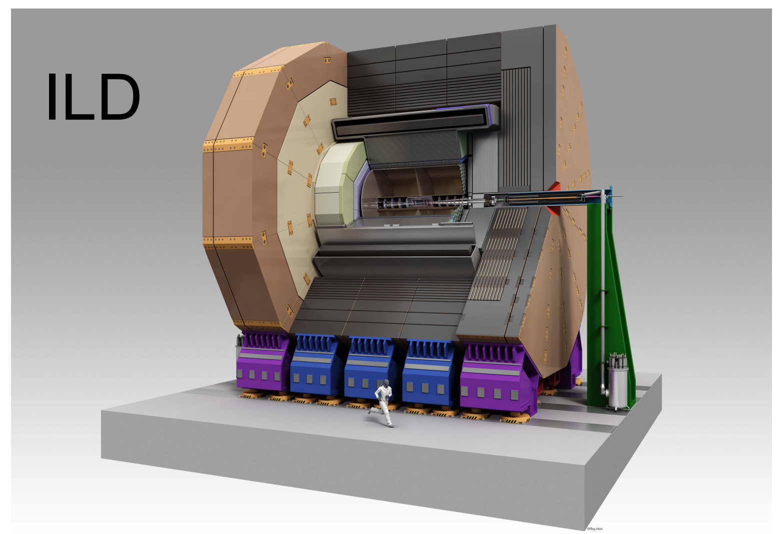
ILC design parameters	
$\sqrt{s}$	91-500 GeV
$\mathcal{L}$	2×10^{34} cm^{-2}s^{-1}
P_{e^-}	>80%
P_{e^+}	~30%
Length	~31 km

-> Talk by Steinar Stapnes

SiD



ILD



Talks by:

Imad Laktineh
Frank Simon
Marek Idzik
Lucie Linssen

Machine TDR in 2013 + DBD for detectors

ILC Basic Parameters and Comments

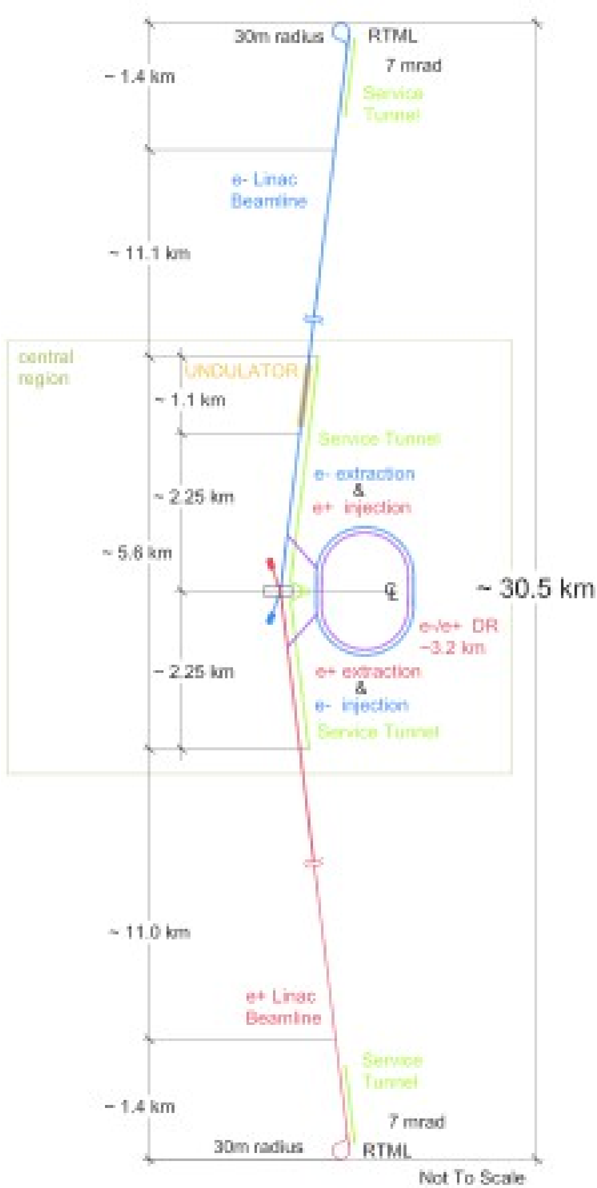
ILC design parameters		Comment
$\sqrt{s}$	91-500 GeV	500 GeV is baseline Option to upgrade to 1 TeV
$\mathcal{L}$	$2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	~Factor 4 technically possible
P_{e^-}	>80%	Proven by SLC
P_{e^+}	upto 30%	~Conservative estimate
Length	~31 km	Current site allows for 50km

- Discussion on possible running scenarios has started

- Luminosity and running time to achieve at a ~25 years research programme That includes running at 250 GeV, 350 GeV, 500 GeV and 1 TeV

- No official statement yet but integrated luminosities indicated in following transparencies are realistic

ILC in a Nutshell



- **SCRF Technology**
  - 1.3GHz SCRF with 31.5 MV/m
  - 17,000 cavities
  - 1,700 cryomodules
  - 2×11 km linacs

Luminosity

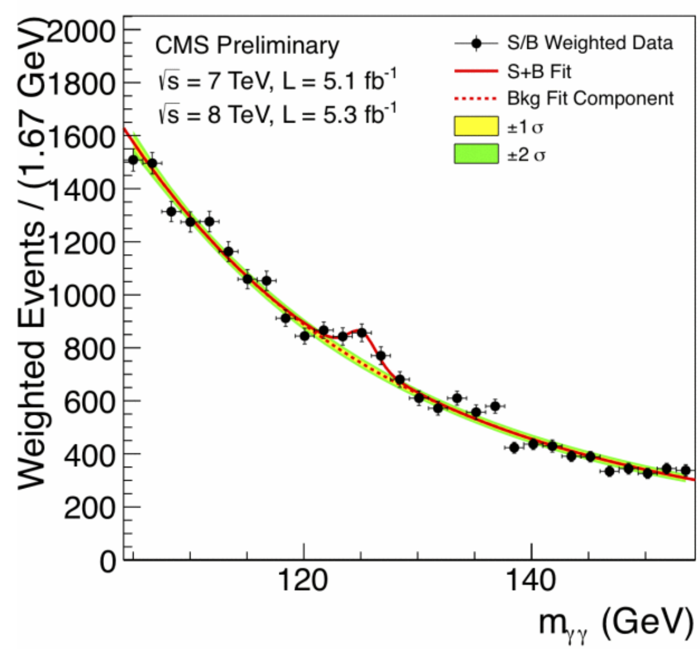
$$L \propto \frac{\eta_{RF} P_{RF}}{E_{cm}} \sqrt{\frac{\delta_{BS}}{\varepsilon_{n,y}}} H_D$$

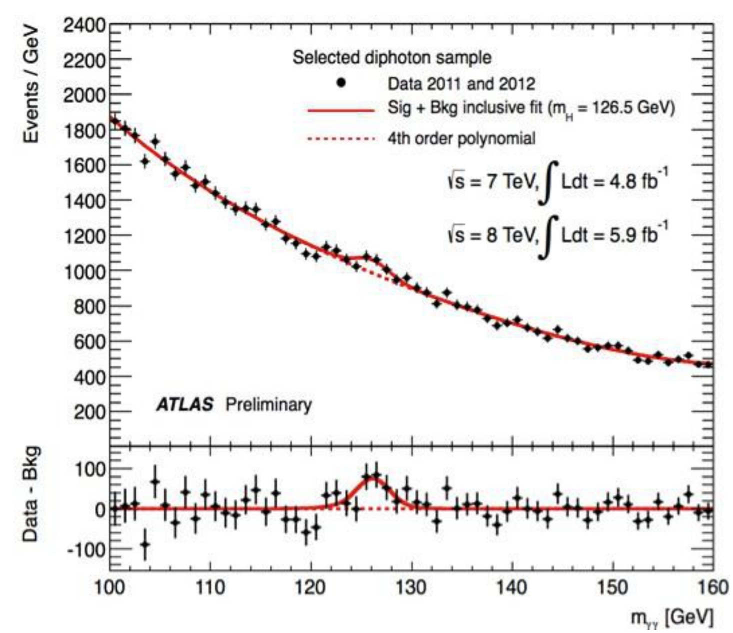
η_{RF} ~ 40% for SCRF technology

-> efficient technology

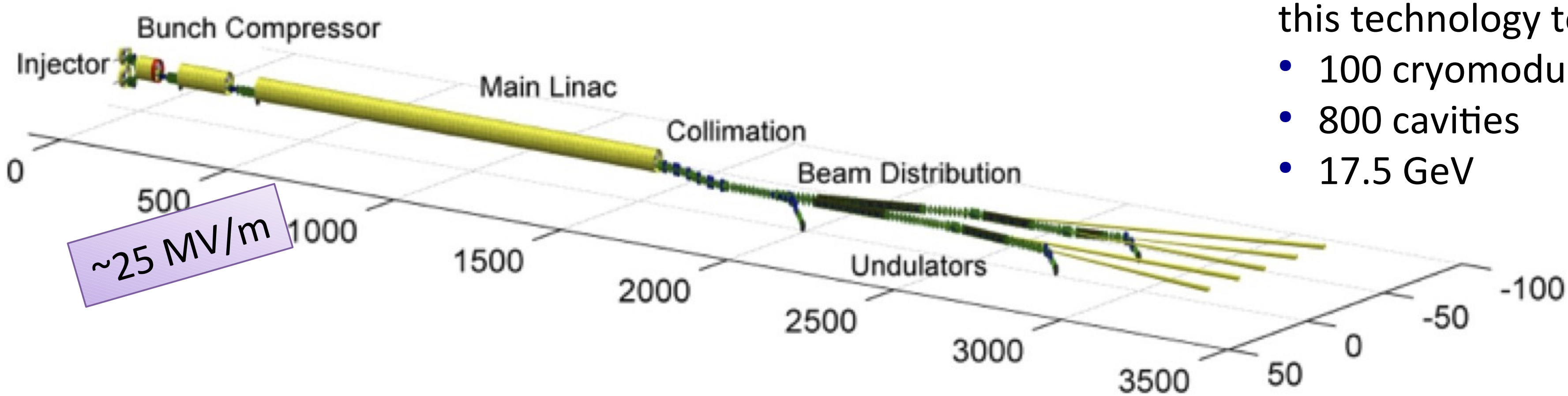
N. Walker, ILC School 2013

4th of July 2012





European XFEL Project: Location DESY Hamburg, Start 2015



Largest deployment of this technology to date

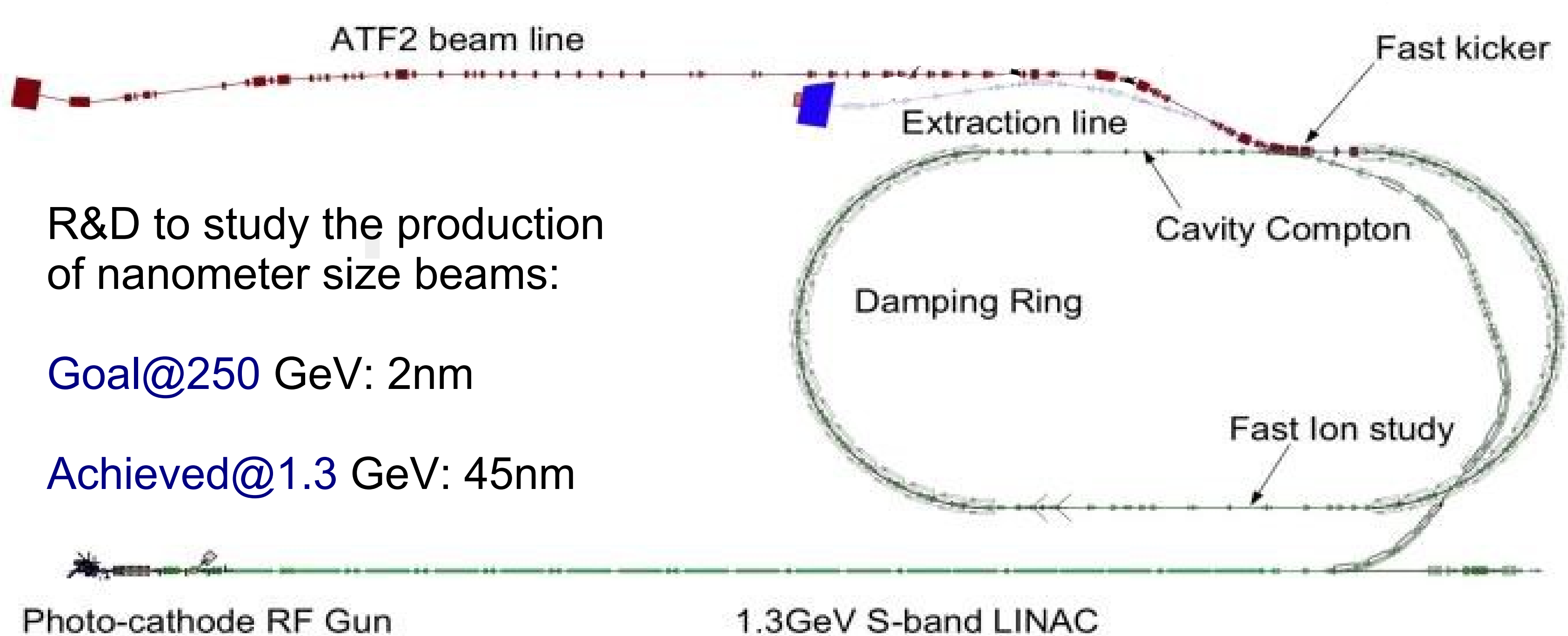
- 100 cryomodules
- 800 cavities
- 17.5 GeV

ATF at KEK Japan:

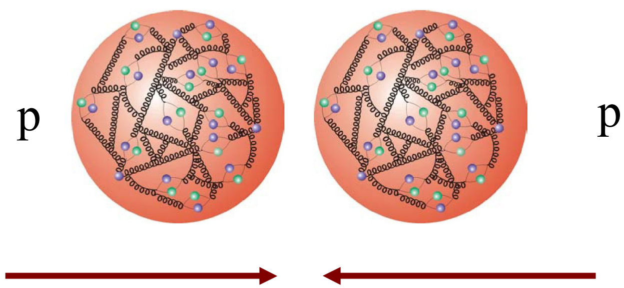
R&D to study the production of nanometer size beams:

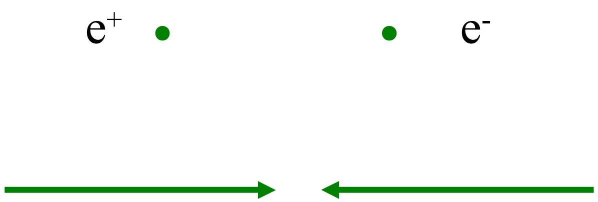
Goal@250 GeV: 2nm

Achieved@1.3 GeV: 45nm



Why e+e- collisions?





Proton:

Composed particle (hadron)
Unknown energy of collision partners
Parasitic reactions
Strong interaction
=> Considerable physics background
Advantage: Scan of energy Range within one experiment

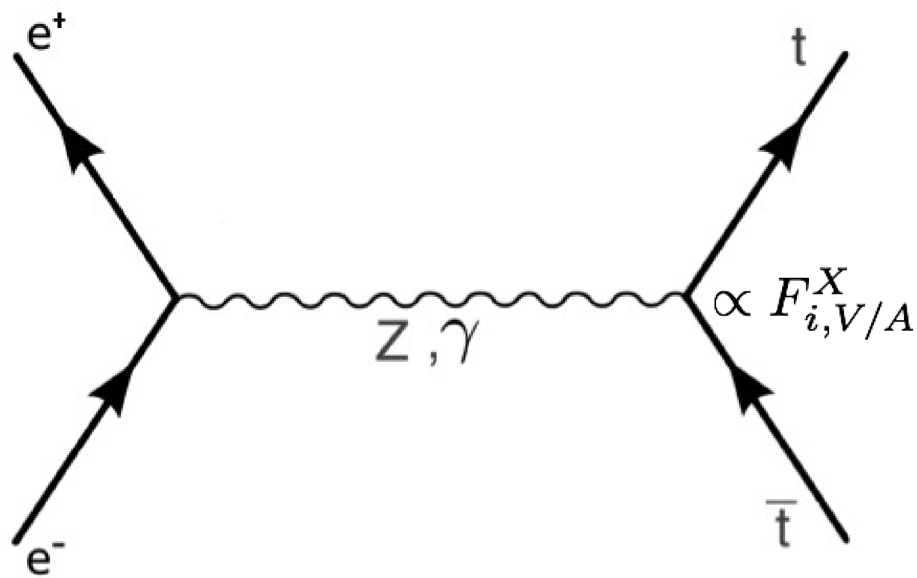
Electron:

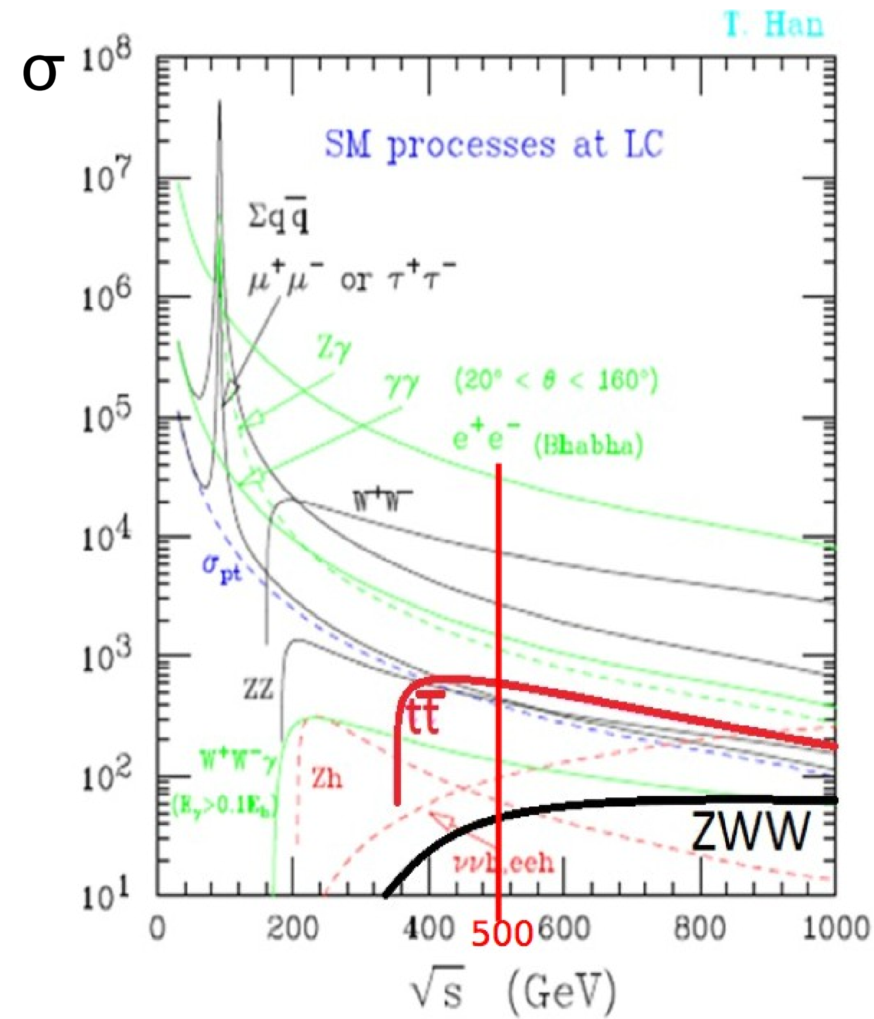
Elementary particle
Well known and adjustable energy of collision partners

Each energy point needs a New set of machine parameters

High precision measurements

Top Quark Physics at Electron-Positron Colliders





- Top quark production through electroweak processes
  no competing QCD production => Small theoretical errors!

- High precision measurements
  -Top quark mass at ~ 350 GeV through threshold scan
  - Polarised beams allow testing chiral structure at ttX vertex
    => Precision on form factors F

How do the particles get their masses?

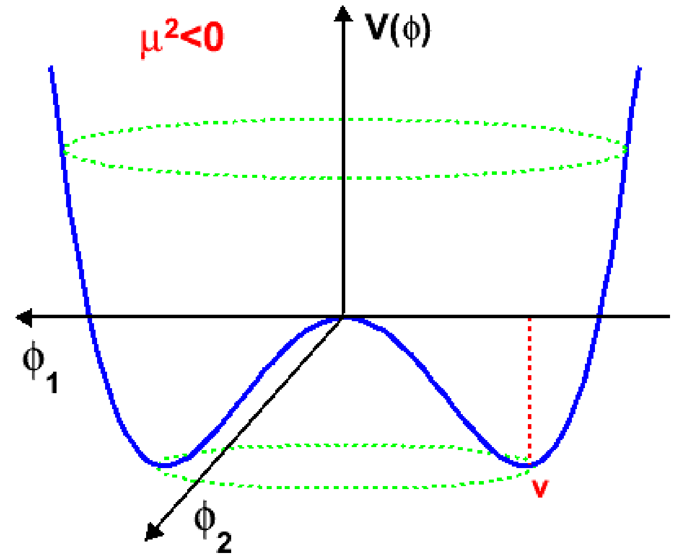
Higgs Mechanism

Scalar field which doesn't vanish in the vacuum

Choice in SM:
Doublet Field $\Phi = \begin{pmatrix} \phi^{+} \\ \phi^{0} \end{pmatrix}$ 4 degrees of freedom

Higgs Boson

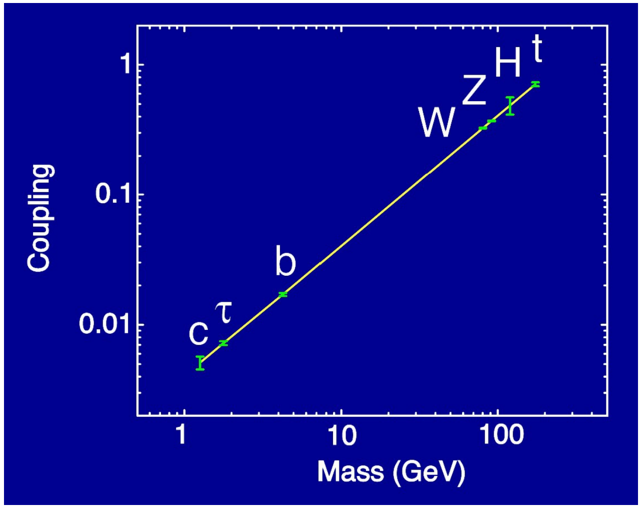
Longitudinally degrees of W,Z Bosons



Couplings to Higgs Boson in Standard Model

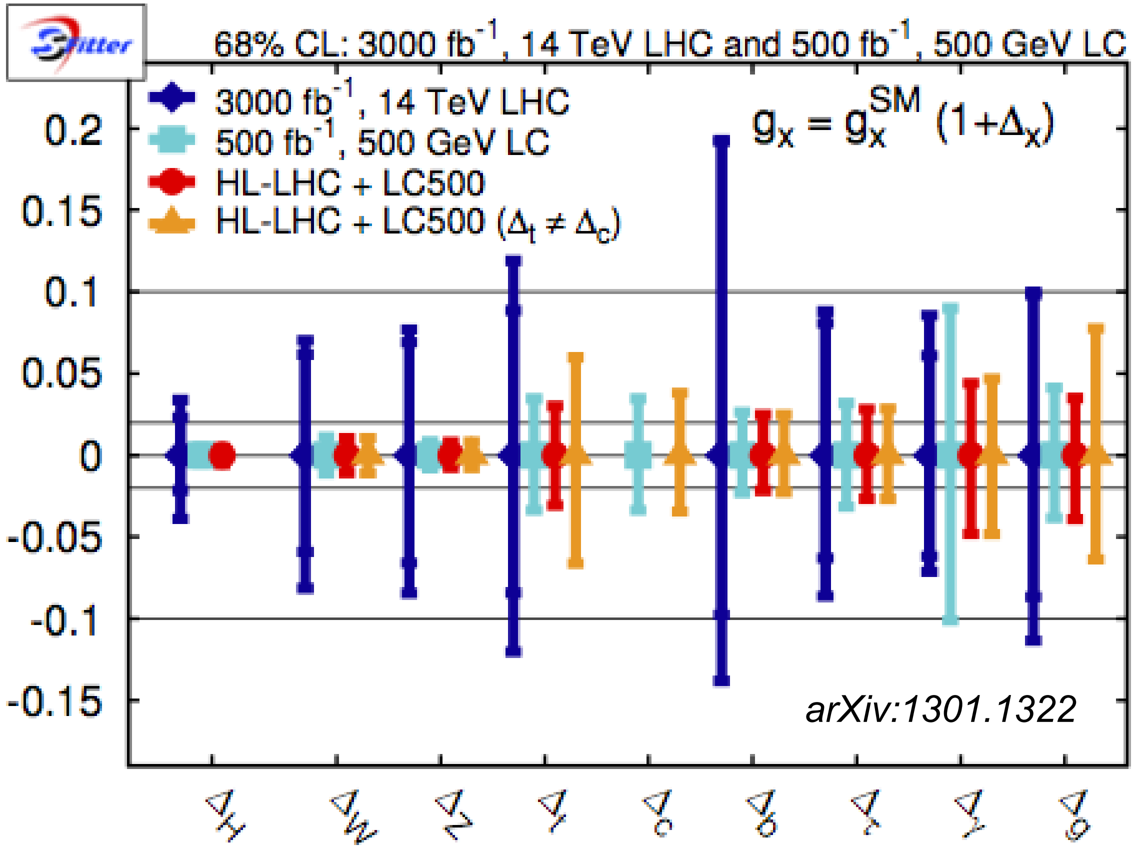
Increase with particle mass

$$g_{HVV} = \frac{m_V^2}{v}$$



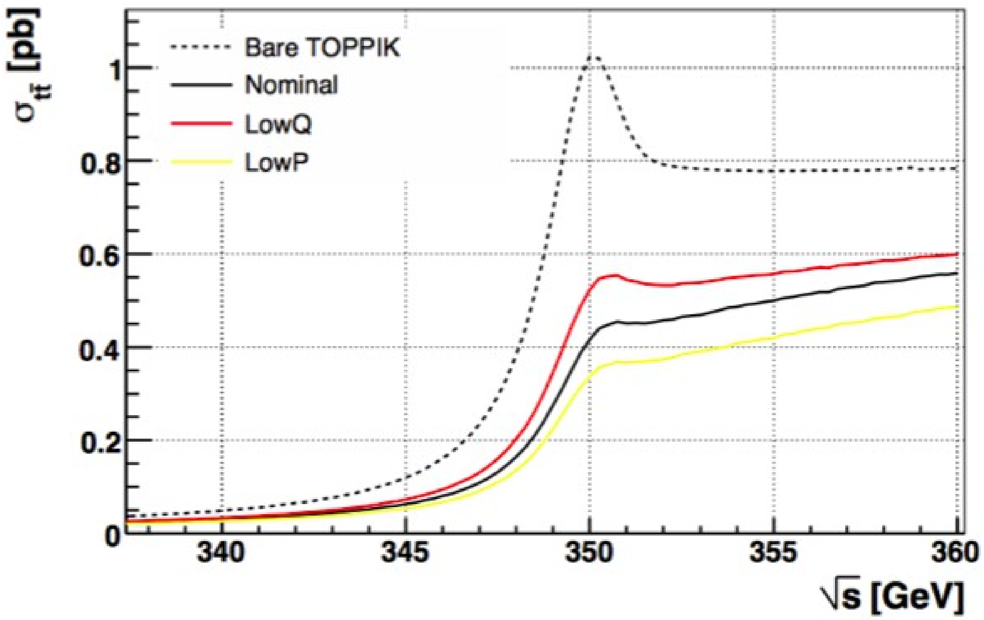
$$g_{Hf\bar{f}} = \frac{m_f}{v}$$

Individual Couplings to the Higgs



- A e+e- machine (Linear Collider) running at several energies will provide precise measurements of relevant Higgs couplings: Possibility to confirm the Higgs mechanism of the SM
- Precision matters: Detect deviations, for example due to extended Higgs sectors (SUSY,composite, ...):Expected on the 10% - 15% level in fermions,on the few % level in gauge bosons in typical Two-Higgs-Doublet models

Total tt Cross Section in e+e- Collisions



Principle: m_t **from** $\sigma_{tt}(m_t)$

Advantages:

- count number of $t\bar{t}$ events
- color singlet state
- background is non-resonant
- physics well understood (renormalons, summations)
- Top decay protects from non-pert effects

Much of the discriminating power of the approach related to the strong mass-dependence (ttbar resonance).

Peak position very stable in theory predictions (threshold mass scheme).

Typical results:

$\rightarrow \delta m_t^{\mathrm{exp}} \simeq$ 50 MeV

$\rightarrow \delta m_t^{\mathrm{th}} \simeq$ 100 MeV

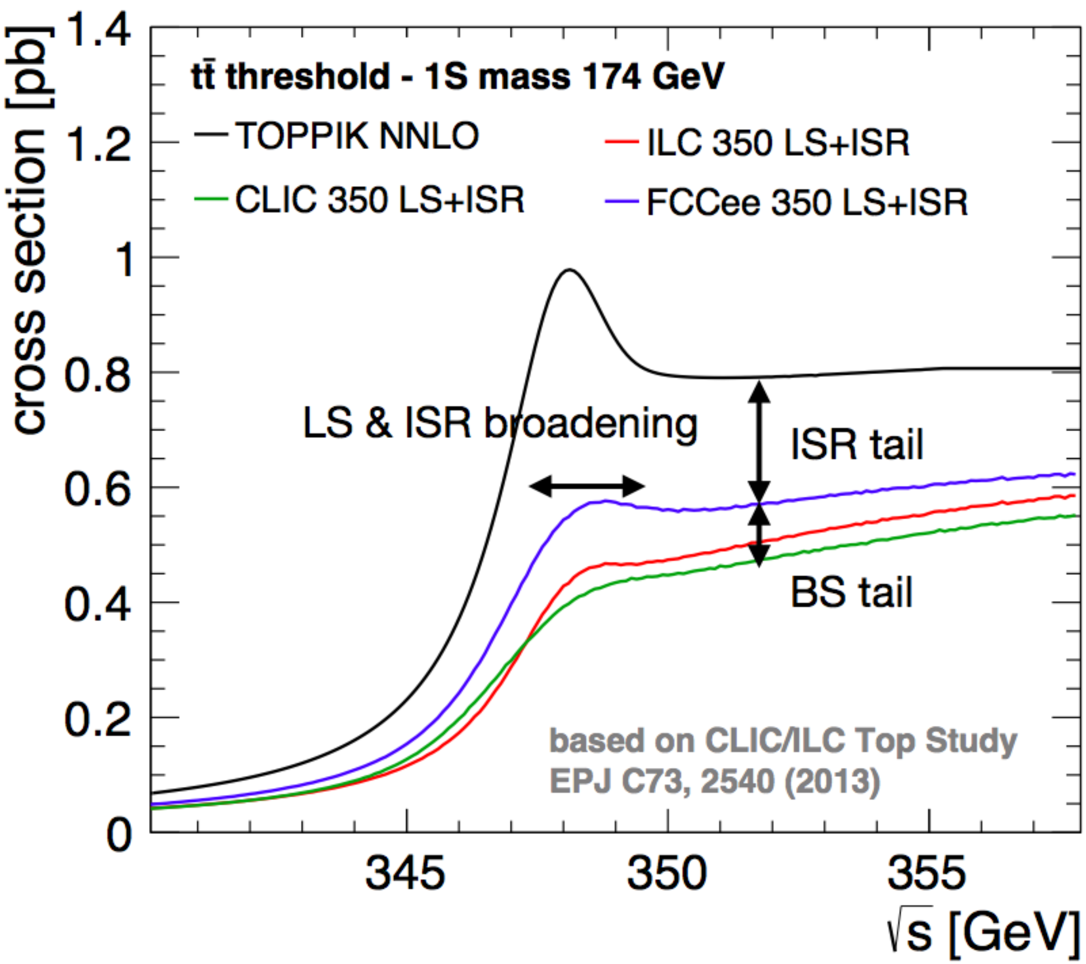
What mass?

$\sqrt{s}_{\mathrm{rise}} \sim 2m_t^{\mathrm{thr}} +$ pert.series

(short distance mass: 1S $\leftrightarrow \overline{\mathrm{MS}}$)

A. Hoang

Top Quark Mass – Influence of Luminosity Spectrum



- Initial State Radiation
  Lowers effective L at top energy
- BeamStrahlung
  Lowers effective L
  at top energy
  Not at FCCee Gaussian spectrum
- Luminosity spectrum & Initial State Radiation broadening
  Smearing of cross section
  Due to beam energy spread
  ILC and FCCee comparable
  Worse at CLIC

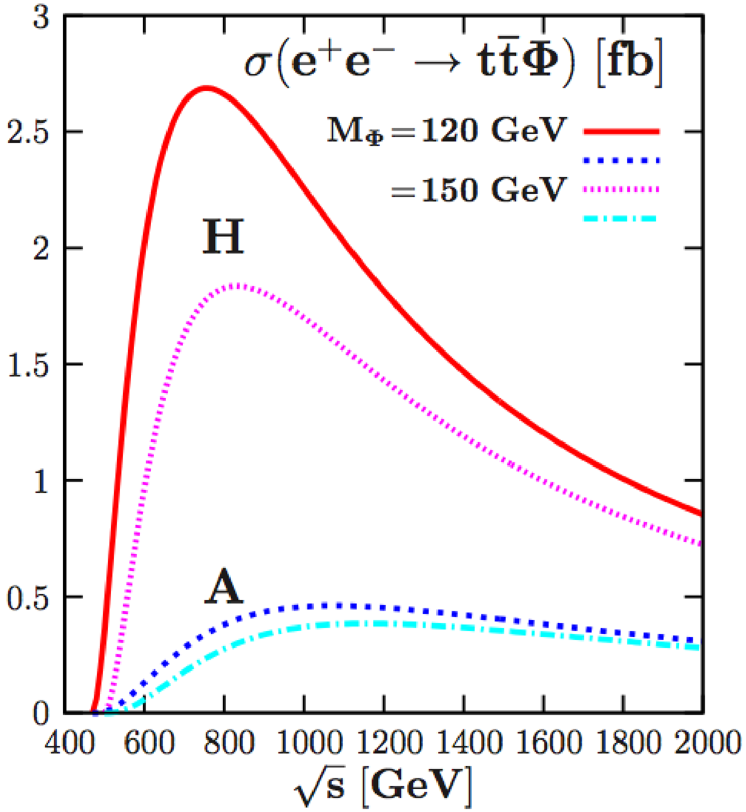
1) Main effect on L spectrum is ISR
   => Reduces Luminosity, smears out 1s bound state peak
2) LC somewhat smaller L due to BeamStrahlung

F. Simon
AWLC14

Higgs Quantum Numbers – CP via tth

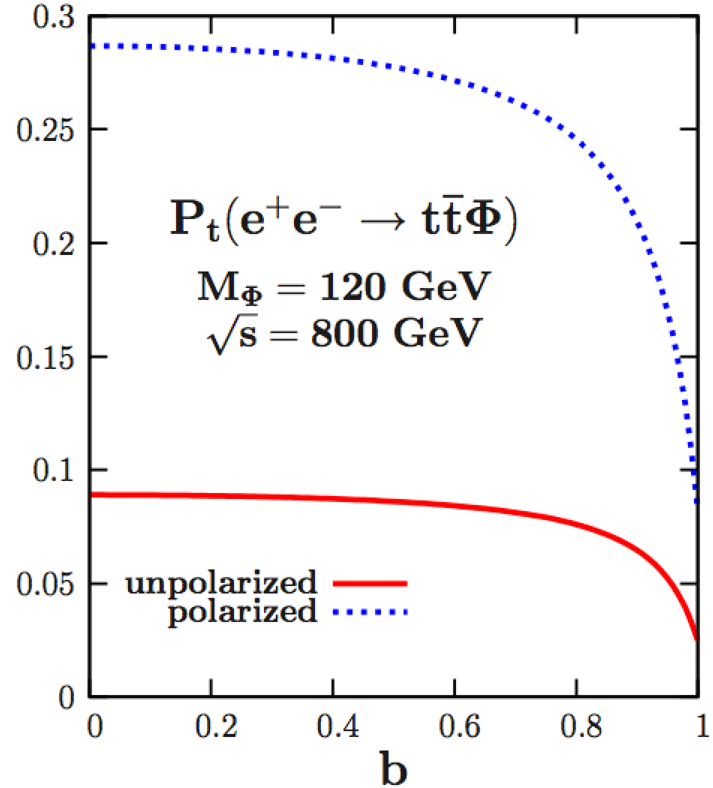
Direct coupling of top quark to CP odd and CP even scalar

Cross section



Dramatic differences for
CP odd and CP even scalar

Top quark polarisation



Sensitivity to CP odd admixture b
Merit of beam polarisation

Determination of CP nature of scalar boson in an unambiguous way

Godbole et al., LCWS07

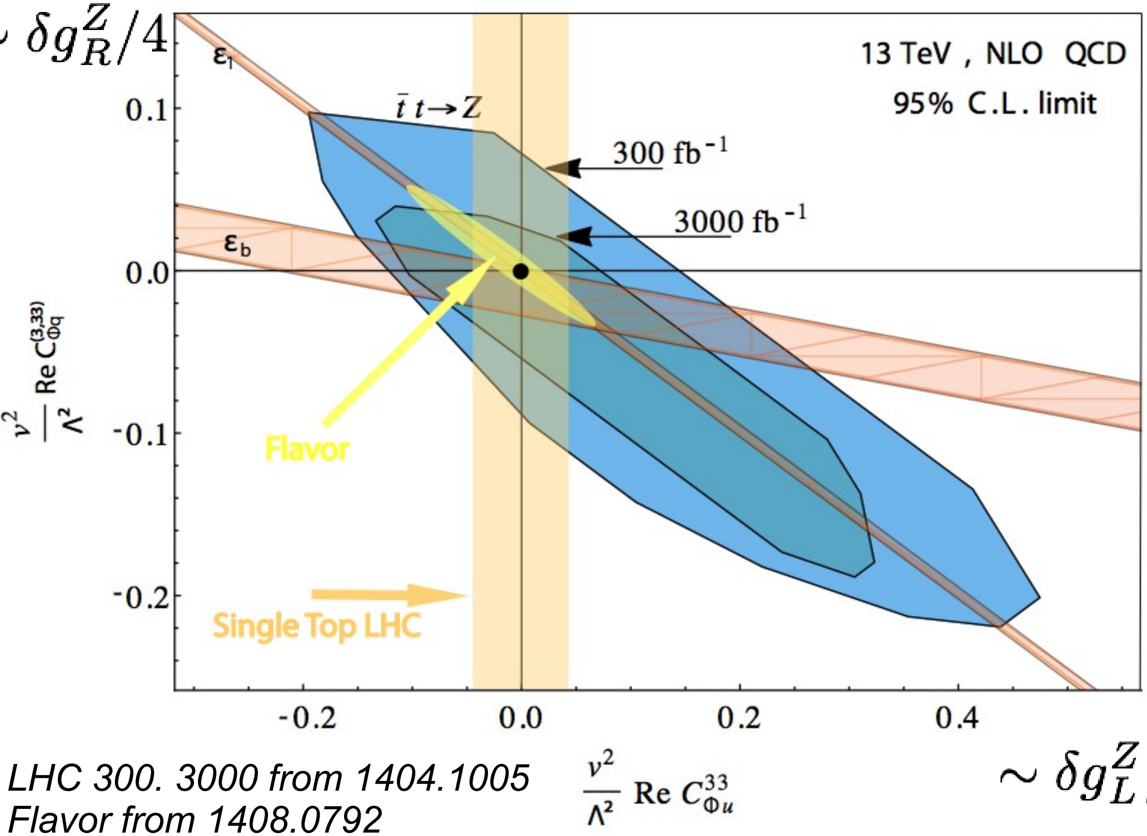
Results of full simulation study at $\sqrt{s}$ = 500 GeV and L=500 fb^{-1}

ArXiv: 1307.8102

Precision cross section ~ 0.5%, Precision A_{FB} ~ 2%, Precision λ_t ~ 3-4%

Accuracy on SM Z couplings compared with other experiments

$\sim \delta g_R^Z/4$



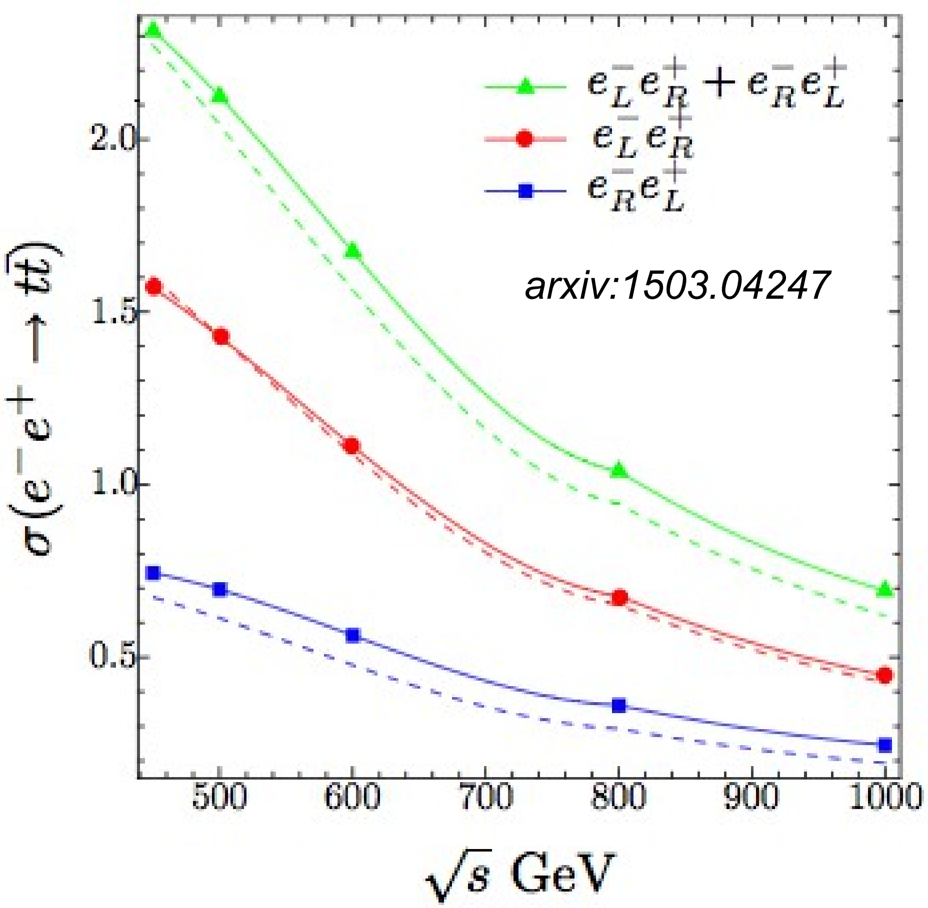
$\sim \delta g_L^Z/2$

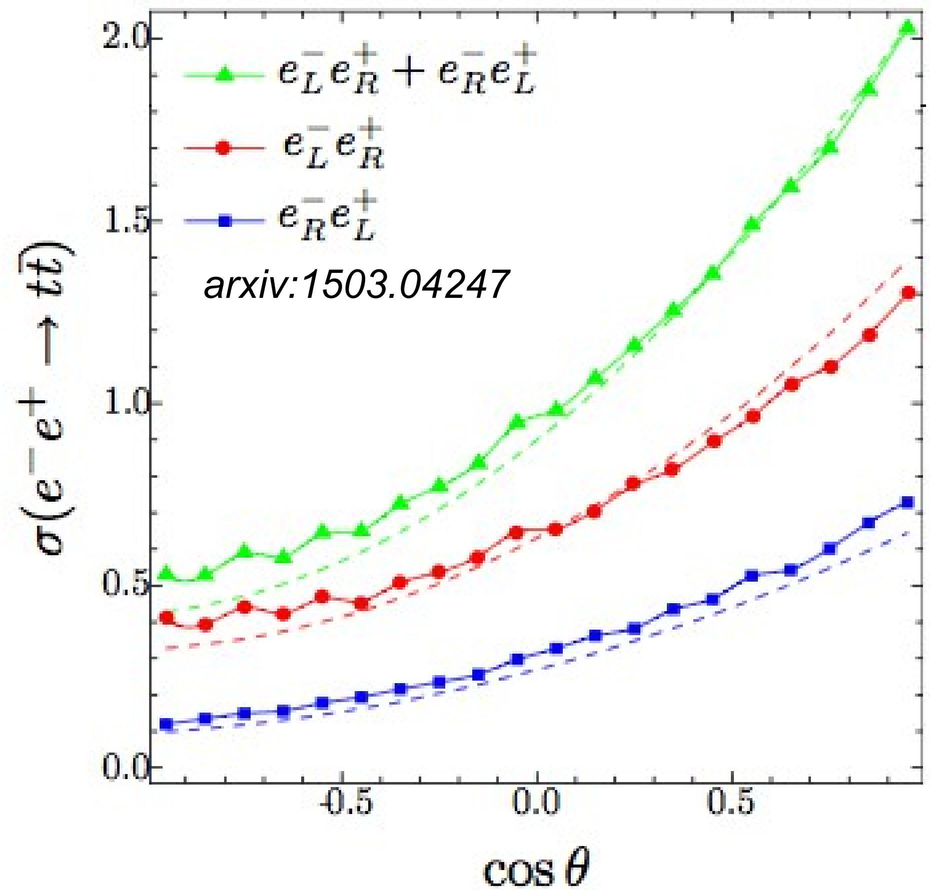
LHC 300. 3000 from 1404.1005
Flavor from 1408.0792
LHC Single top added by F. Richard

- ILC with polarised beams outperforms all present and future experiments (Stringent limits only from LEP)
- Before ILC single top at LHC and B factories can deliver complementary information
- In particular g_R can only be constrained by ILC!
- Maintaining this high level still requires substantial experimental and theoretical work

ILC promises to be high precision machine for electroweak top couplings

Detailed look at higher order elw. corrections - GRACE

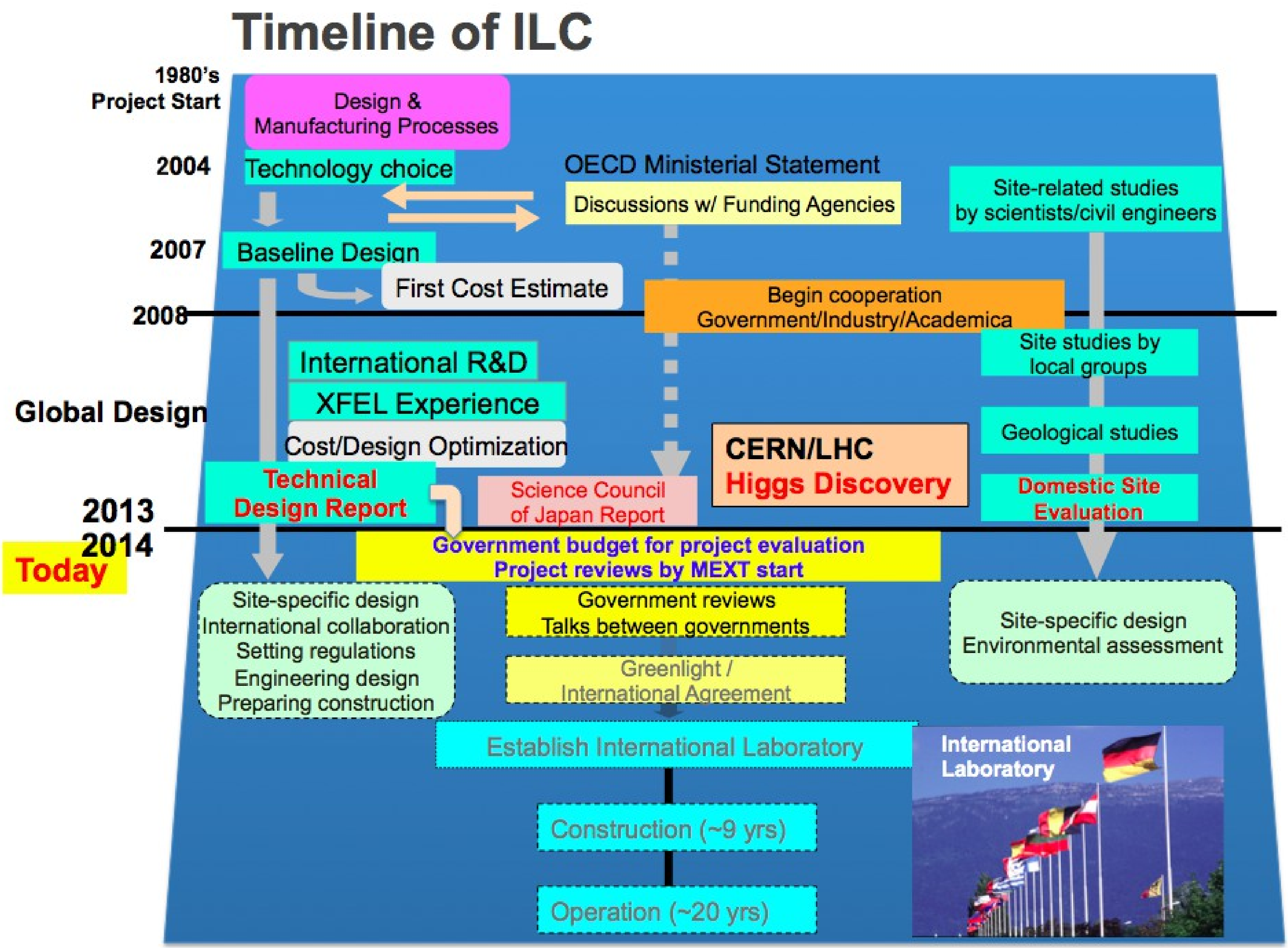




- Electroweak corrections manifest themselves differently for different beam polarisations

Beam polarisation important asset to disentangle SM and effects of new physics
Configuration $e_R^- e_L^+$ seems to lead to "simpler" corrections

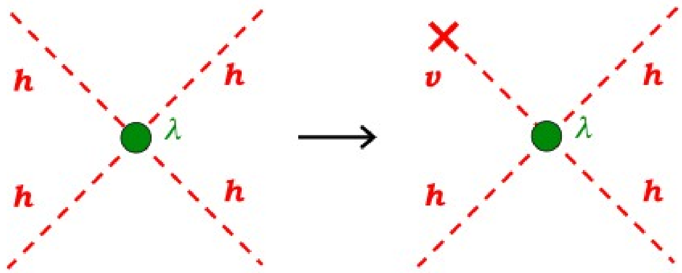
ILC Roadmap

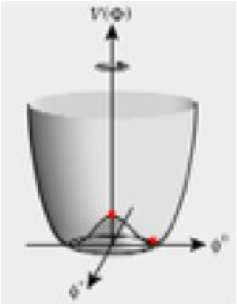


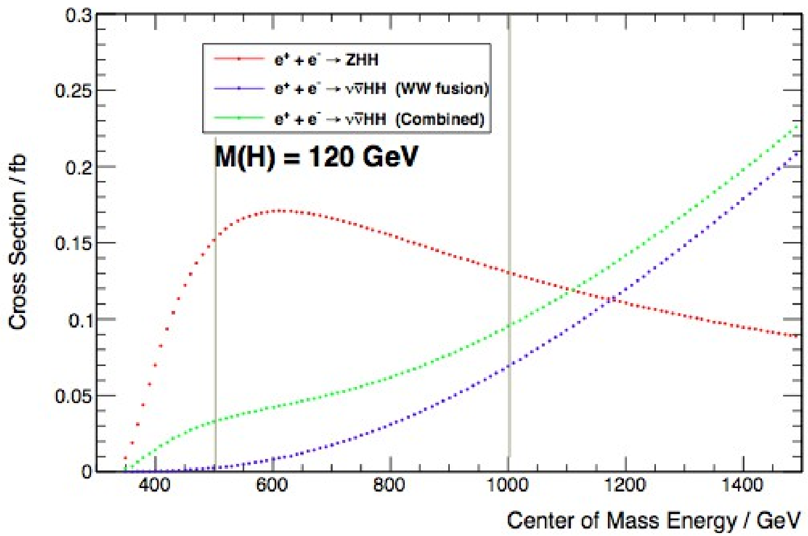
Remark R.P.: MEXT report in March 2016

Higgs self-coupling

Existence of hhh coupling =
Direct evidence of vacuum condensation

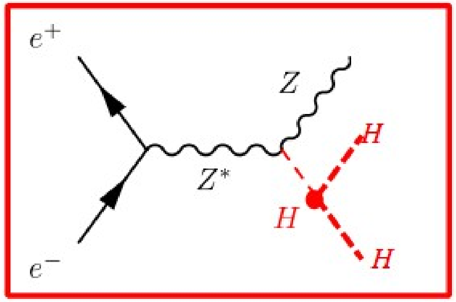


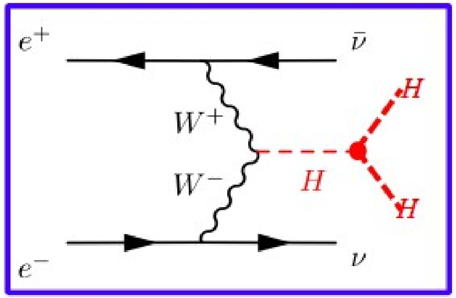




Challenging measurement because of:

- Small cross section (Zhh 0.2 fb at 500 GeV)
- Many jets in the final state
- ***Presence of interference diagrams***





arXiv:1310.0763	ILC500	ILC500-up	ILC1000	ILC1000-up
$\sqrt{s}$ (GeV)	500	500	500/1000	500/1000
$\int \mathcal{L}dt$ (fb^{-1})	500	1600‡	500+1000	1600+2500‡
$P(e^-, e^+)$	(−0.8, 0.3)	(−0.8, 0.3)	(−0.8, 0.3/0.2)	(−0.8, 0.3/0.2)
$\sigma(ZHH)$	42.7%		42.7%	23.7%
$\sigma(\nu\bar{\nu}HH)$	–	–	26.3%	16.7%
λ	83%	46%	21%	13%

T. Tanabe, K. Fuji, LCWS14

Hard(est) measurement, 10% accuracy seems possible

ILC Roadmap

$$V(\eta) = \frac{1}{2}m^2\eta^2 + \lambda v\eta^3 + \frac{1}{4}\lambda\eta^4$$