ILC AND CLIC AS FUTURE HIGGS FACTORIES

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on behalf of the
ilc international development team physics & detector group

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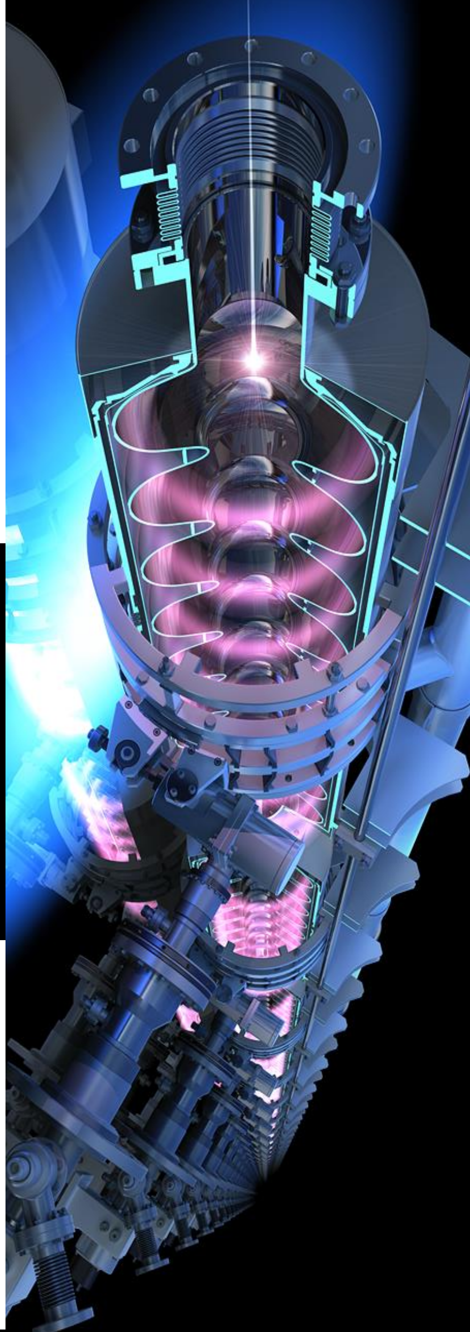
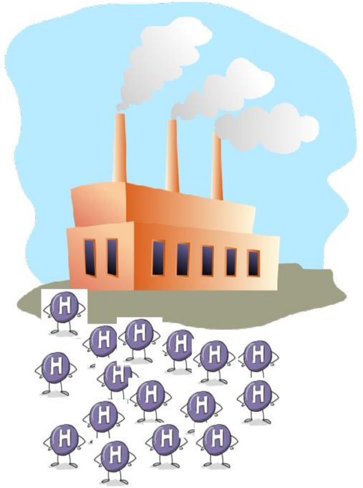


OVERVIEW

- **WHY HIGGS FACTORIES?** (*brief reminder*)
- **DETECTOR CONCEPTS & TECHNOLOGIES at LCs**
- **HIGHLIGHTS FROM HIGGS PHYSICS AT LINEAR COLLIDERS**
- **SUMMARY**

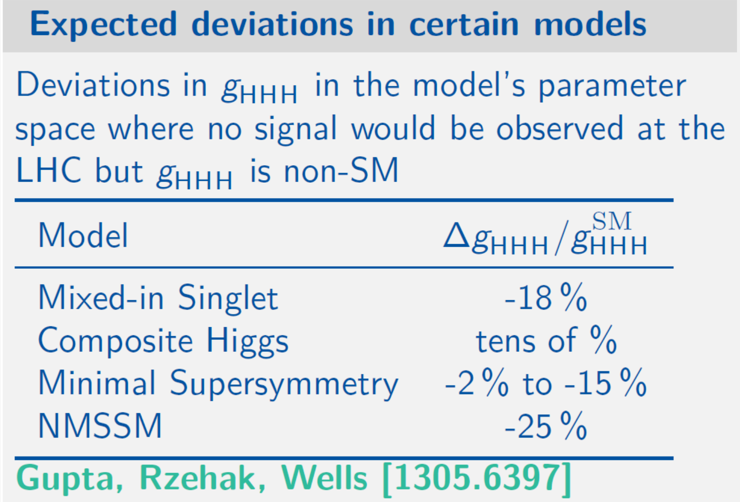
WHY HIGGS FACTORIES?

- Higgs discovery ended era of reductionism and symmetries in particle physics [1]
- Never seen before fundamental scalar is discovered, unique (with exception of gravity) in its self-coupling
- Higgs discovery opened several important questions of nature of relativistic vacuum:
  - *How can we accommodate it in energy density of the Universe?*
  - *Why the Higgs is not enormously massive (even Planckian)?*



- No New Physics discovery at LHC
- With the LHC resolution to probe Higgs compositeness, the Higgs could be as elementary as pion. *So, how pointlike is it?*
- *λ can be significantly modified by New Physics*.

  HL-LHC will probe λ with 50% uncertainty [2]

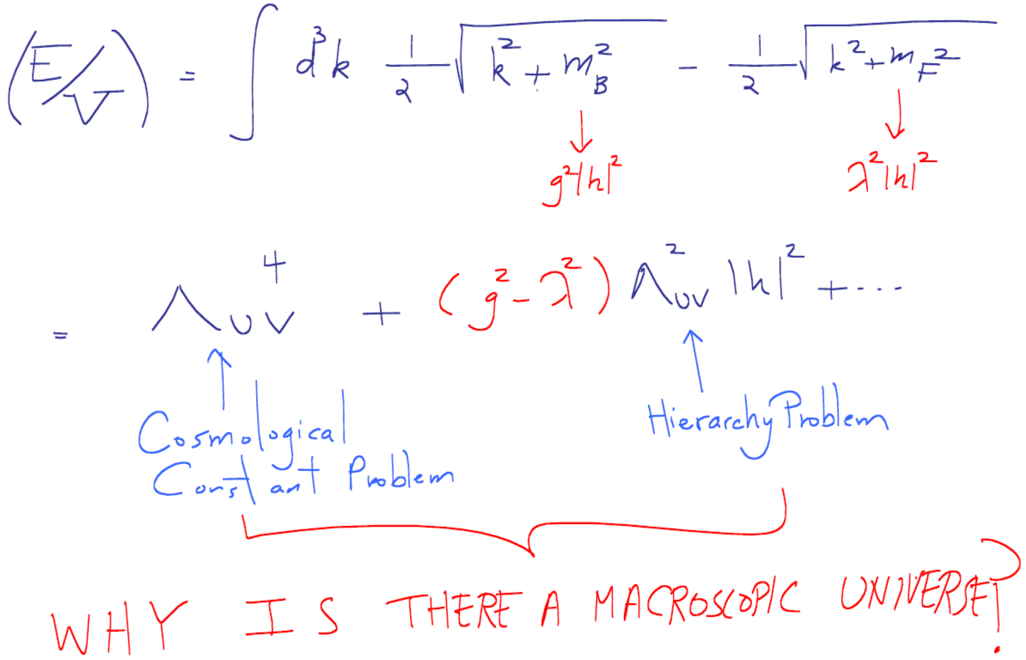


Expected deviations in certain models

Deviations in $g_{\rm HHH}$ in the model's parameter space where no signal would be observed at the LHC but $g_{\rm HHH}$ is non-SM

Model	$\Delta g_{\rm HHH}/g_{\rm HHH}^{\rm SM}$
Mixed-in Singlet	-18 %
Composite Higgs	tens of %
Minimal Supersymmetry	-2 % to -15 %
NMSSM	-25 %

Gupta, Rzehak, Wells [1305.6397]



$$\left(\frac{E}{V}\right) = \int d^3k \; \frac{1}{2}\sqrt{k^2 + \underset{\downarrow\; g^2|h|^2}{m_B^2}} - \frac{1}{2}\sqrt{k^2 + \underset{\downarrow\; \lambda^2|h|^2}{m_F^2}}$$

$$= \Lambda_{UV}^4 + (g^2 - \lambda^2)\,\Lambda_{UV}^2\,|h|^2 + \dots$$

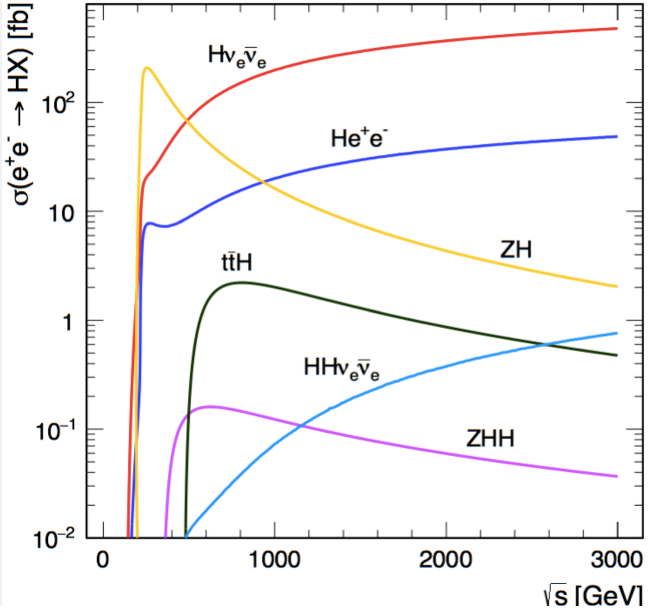
Cosmological Constant Problem

Hierarchy Problem

WHY IS THERE A MACROSCOPIC UNIVERSE?

[1]

LINEAR COLLIDERS

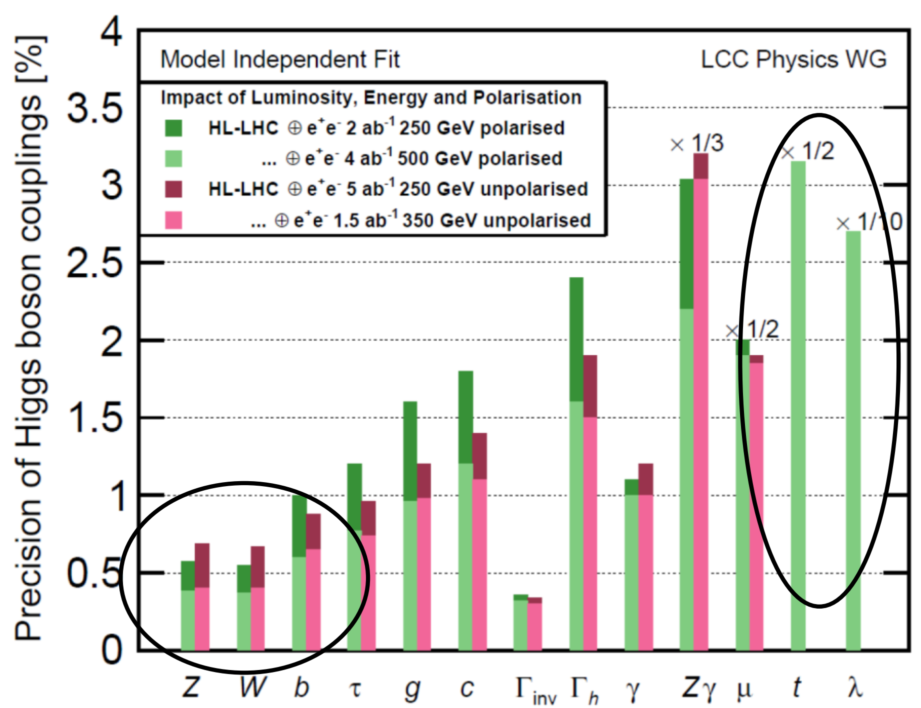


- Come as mature technological options developed for decade(s) – 'ready to take'
  - Added value in detector realization (triggerless, power pulsing)
- Staged, upgradable machines ⇒ high center-of-mass energy reach
  - Various Higgs production mechanisms accessible over the energy scale span
  - Enhanced sensitivity to BSM, also in the Higgs sector

- Linear colliders benefit from additional statistics from WW-fusion to access the rare decays (γγ, μμ, Zγ)

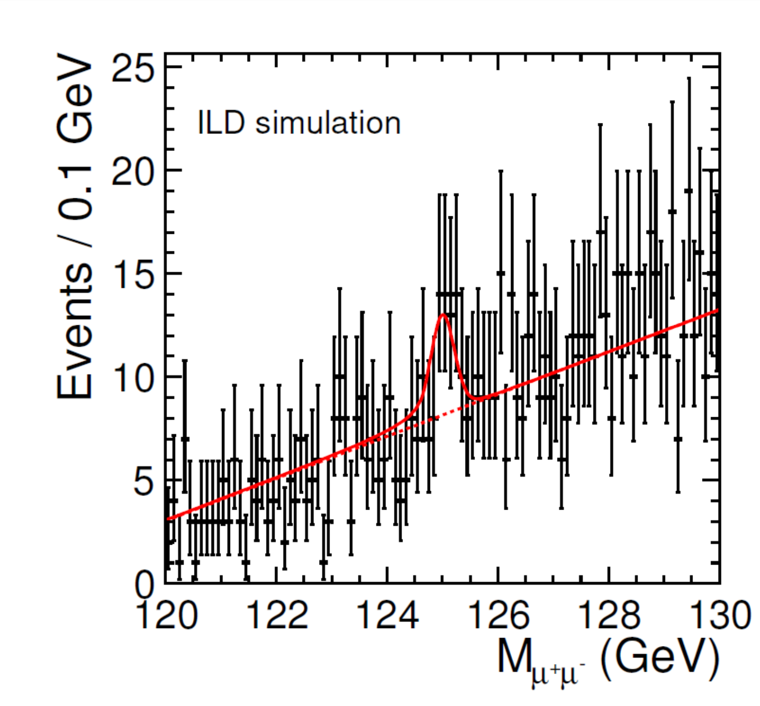
-Double Higgs production at higher energies enables self-coupling measurement

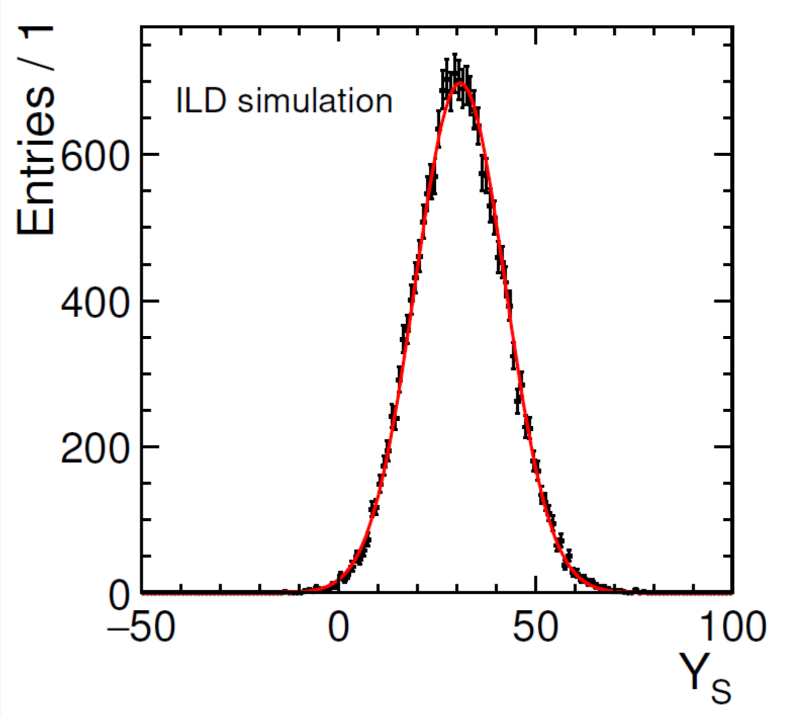
-Other processes (like ttH) bring added value (i.e. CPV measurements)

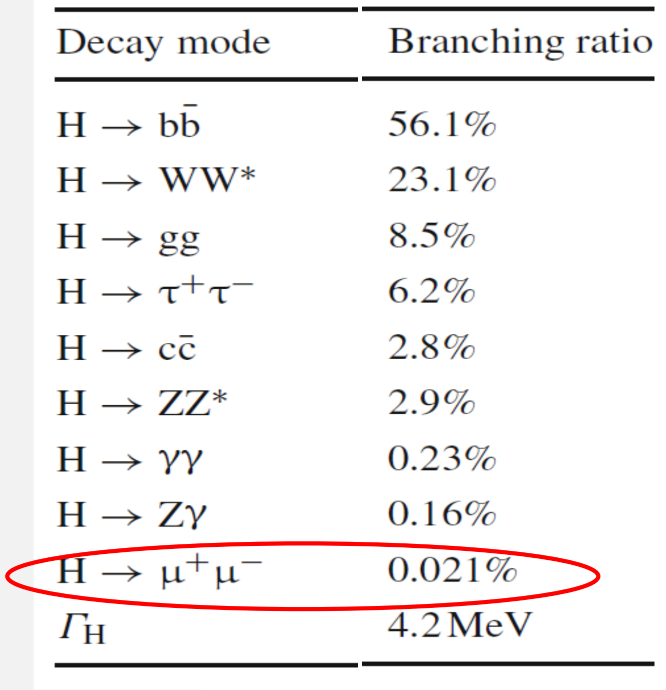


- Beam polarization
  - 80% e- beam @ CLIC, (80%, 30%) (e-,e+) @ ILC
  - Chiral nature of charge currents results in significant sensitivity of WW-fusion cross-section on polarization scheme (~2·$\mathcal{L}$)
  - Provides new observables sensitive to New Physics
  - Helps characterization of newly discovered particles/models
  - Statistical uncertainty reduction in combination

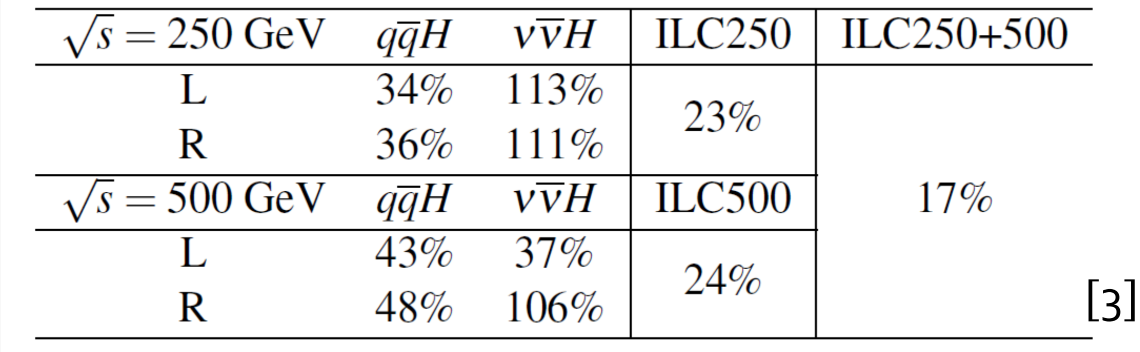
High-energy, polarization, combination ➡ access to rare Higgs decays





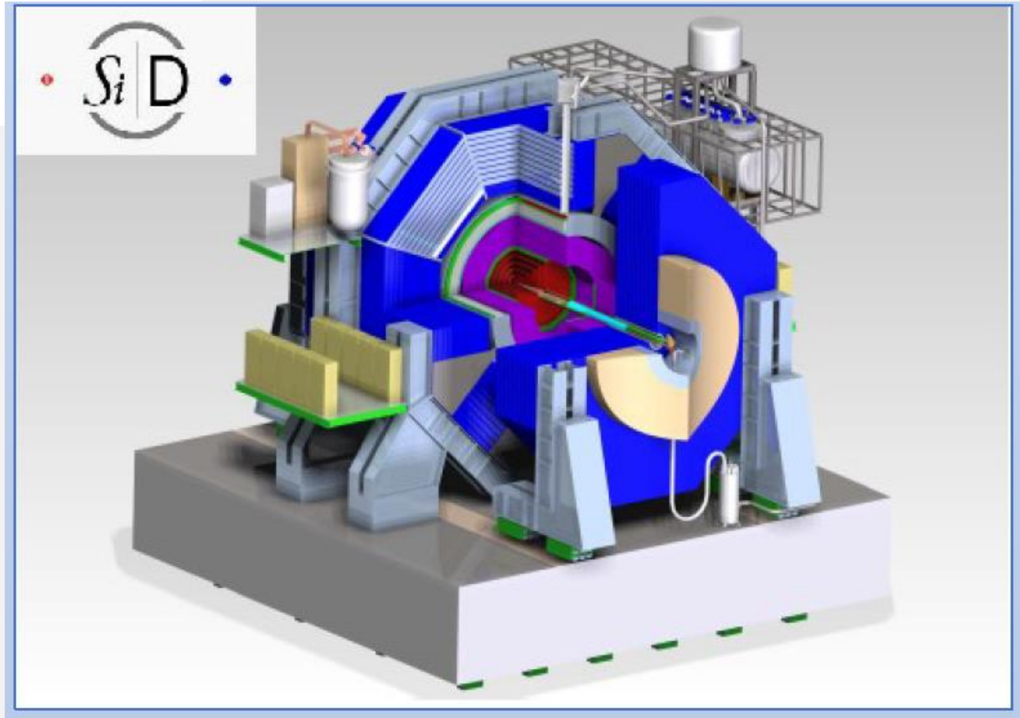


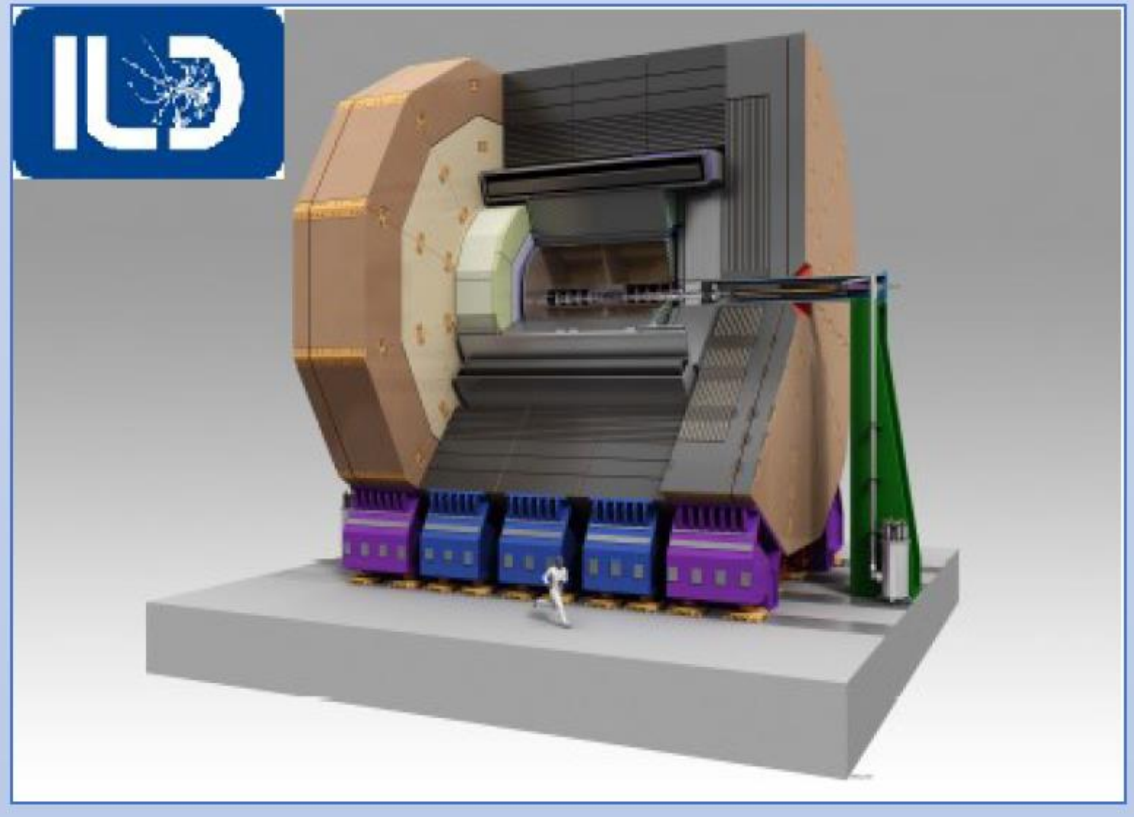
Decay mode	Branching ratio
$H \to b\bar{b}$	56.1%
$H \to WW^*$	23.1%
$H \to gg$	8.5%
$H \to \tau^+\tau^-$	6.2%
$H \to c\bar{c}$	2.8%
$H \to ZZ^*$	2.9%
$H \to \gamma\gamma$	0.23%
$H \to Z\gamma$	0.16%
$H \to \mu^+\mu^-$	0.021%
Γ_H	4.2 MeV



$\sqrt{s} = 250$ GeV	$q\bar{q}H$	$\nu\bar{\nu}H$	ILC250	ILC250+500
L	34%	113%	23%	17%
R	36%	111%		
$\sqrt{s} = 500$ GeV	$q\bar{q}H$	$\nu\bar{\nu}H$	ILC500	
L	43%	37%	24%	
R	48%	106%		

[3]





SiD Detector

- 5 T field
- More compact
- All Si

ILD Detector

- 3.5 T field
- Optimized for CM energies 90 GeV - 1 TeV
- Si/gaseous tracking
- Particle flow calorimetry
- Mature design and available technologies

Track momentum resolution: $\sigma_{1/p} < 5 \cdot 10^{-5}\ \text{GeV}^{-1}$ CMS/40

Impact parameter resolution: $\sigma_d < 5\mu m \oplus 10\mu m \frac{1\ \text{GeV}}{p\ \sin^{3/2}\Theta}$ CMS/4

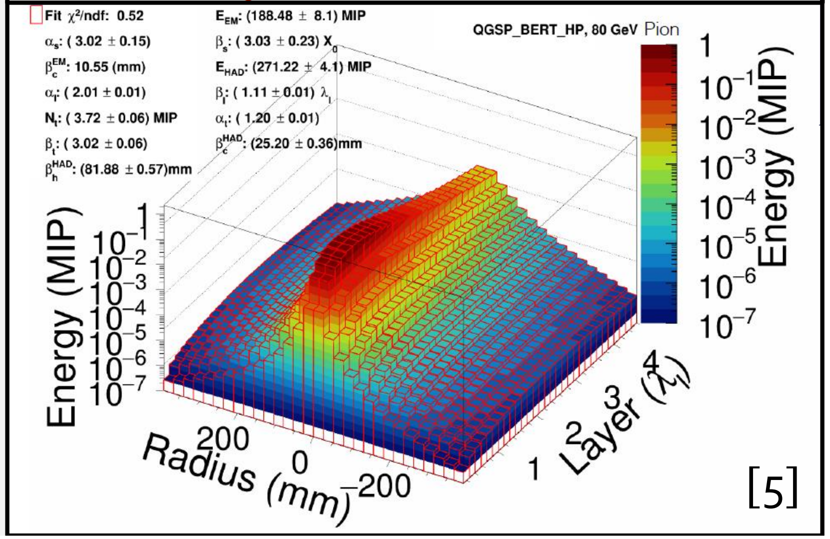
Jet energy resolution: $\sigma_E/E = 3 - 4\%$ (for highest jet energies) ATLAS/2

Hermecity: $\Theta_{min} = 5$ mrad ATLAS/3

Collaboration
High precision design

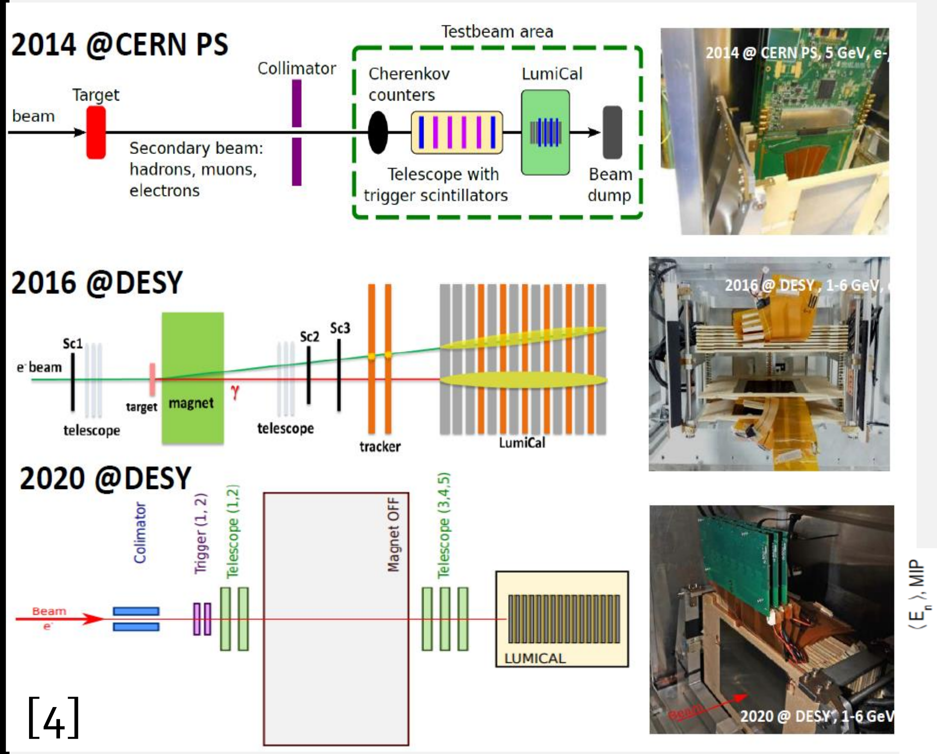
Calorimeter for ILC

High granularity calorimeter
=> detailed spatial information of the showers



[5]

Demonstrated feasibility of detector technologies

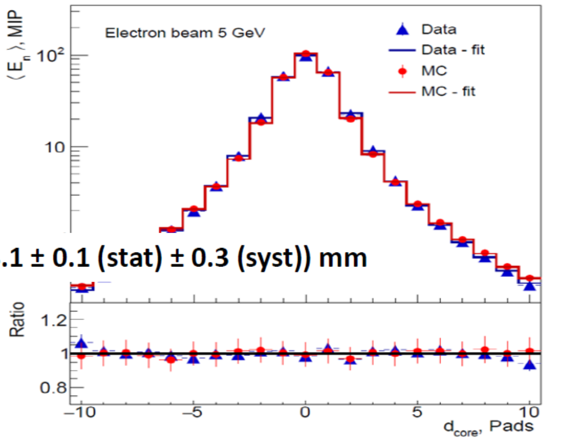


[4]

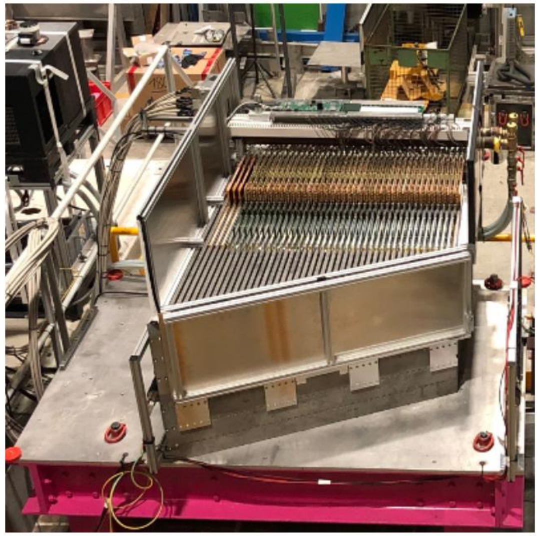
Test-beams @ CERN SPS in 2018:

- 38 layers (72x72 cm²: 4 boards each) with 1.7 cm steel absorber (4λ)
- ~ 22'000 channels, < 1‰ dead channels
- Very stable running, basically noise-free!

Moliere radius



❑ R_M = 8.1 ± 0.1 (stat) ± 0.3 (syst)) mm



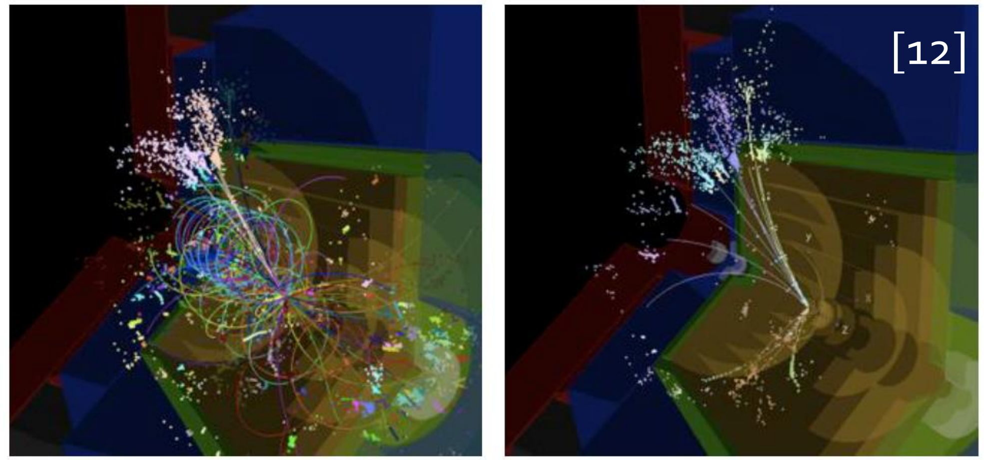
← Beam:

- Muons
- Electrons, 10-200 GeV
- Pions, 10-200 GeV

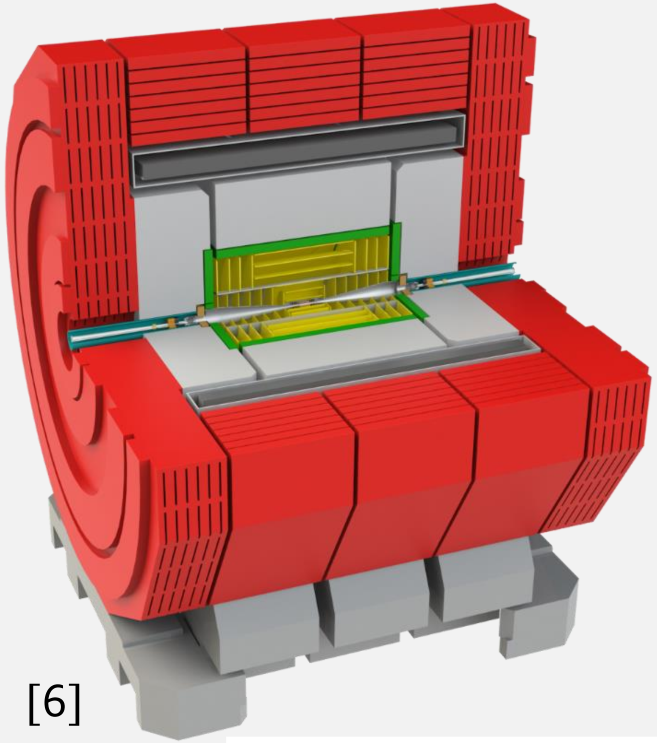
Total: ~100M events

CLIC det

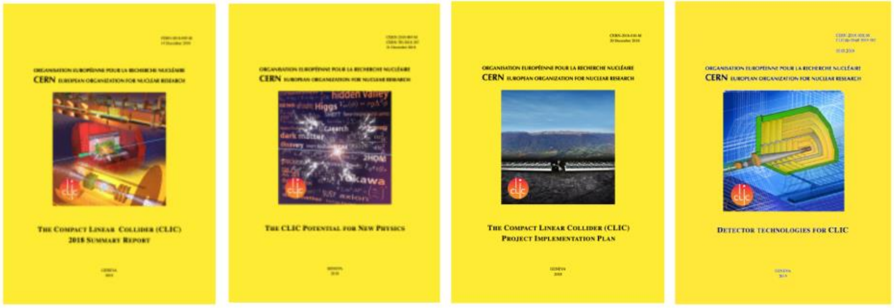
- 4 T field
- Ultra low-mass VTX
- All Si tracking
- Particle flow calorimetry
- Time-stamped readout (10 ns) due to pronounced Beamstrahlung background at higher energies

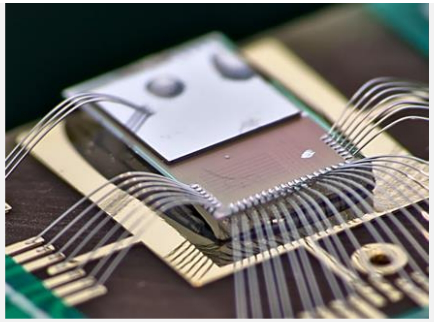

[12]

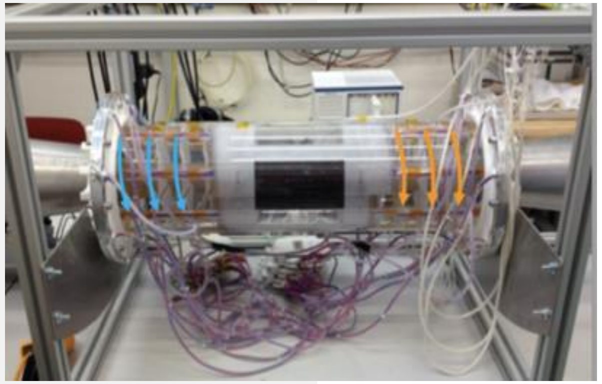
CLIC requirements
for vertex and tracker detectors
triggered comprehensive technology
R&D programme


[6]

- 4 Yellow Reports 2018


Summary Report
Physics Potential
Project Implementation
Detector Technologies


[7]



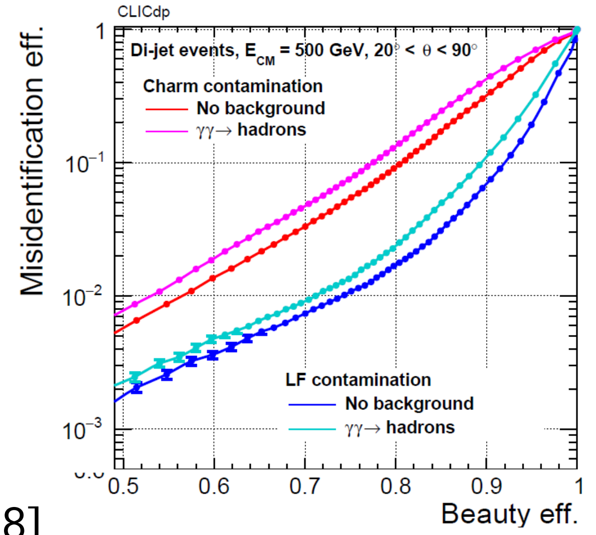
- Feasibility of air cooling demonstrated in simulation & full vertex detector mockup

- Full efficiency obtained from hybrid assemblies of 50µm thin sensors that satisfy CLIC time-stamping requirements

SIMILAR PERFORMANCE OF LC DETECTORS

c/b-tagging, Higgs branching ratios

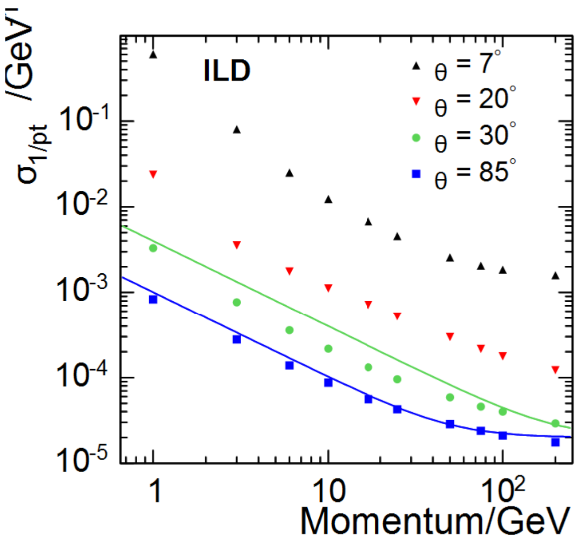
b-tagging @ CLIC



[8]

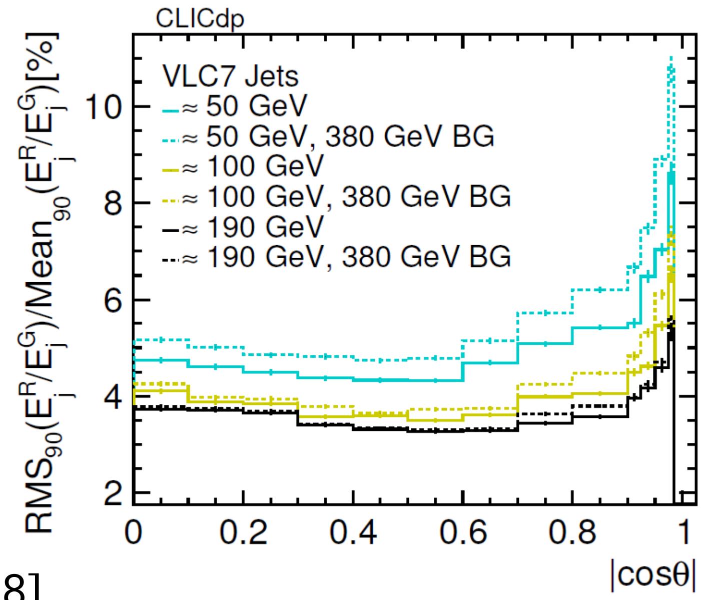
Higgs recoil mass, smuon endpoint,
Higgs coupling to muons

p_T resolution for muons:



Separation of W/Z/H di-jets

3%–4% jet energy resolution gives ~ 2.6 – 2.3σ W/Z separation



[8]

Particle Flow is the 'key word'.
Only neutral particles ID (γ (30%), neutral hadrons (10%)) are left to calorimeters.

PHYSICS PROGRAMME AT A LC

- **HIGGS PHYSICS**

HIGGS COUPLINGS: model-independent measurements
κ-framework
EFT approach
HIGGS SELF-COUPLING
HIGGS AS A PROBE TO DARK SECTOR AND BSM IN GENERAL
CPV IN THE HIGGS SECTOR

High E

- **t-PHYSICS**

top-quark mass
electroweak couplings
rare decays

Low E

top Yukawa coupling
CP properties
BSM constraints

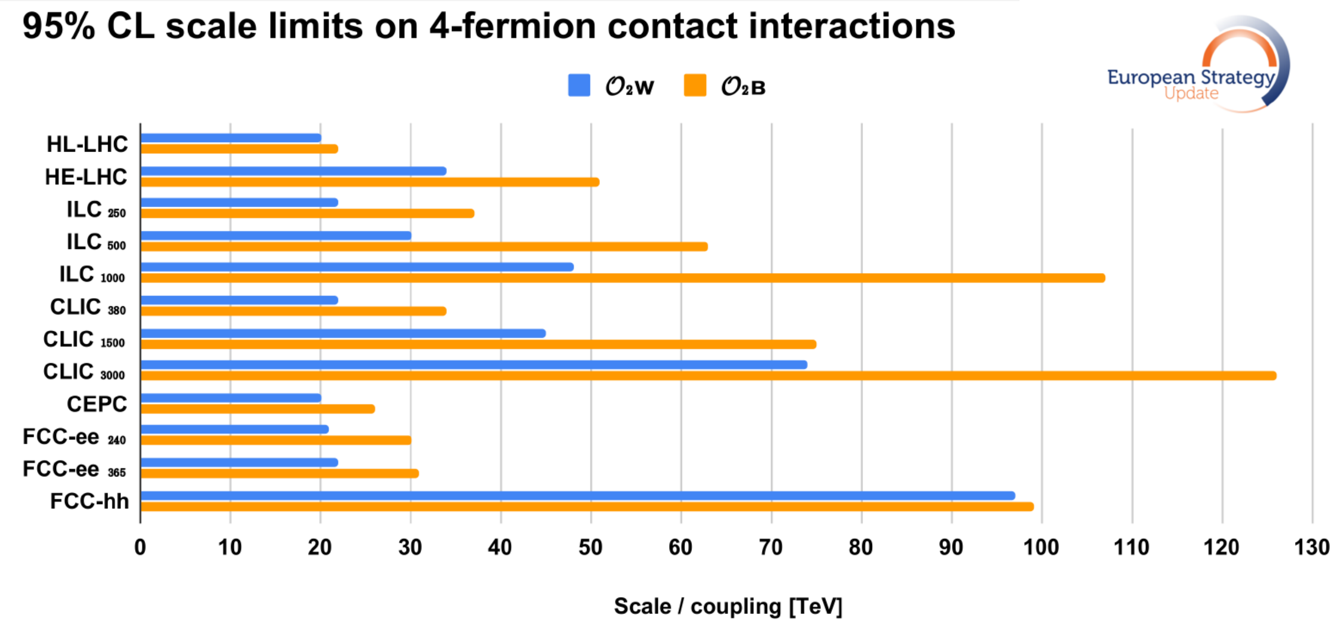
High E

- **BSM**

direct searches
models with weak couplings or soft signatures
indirect searches
high sensitivity

High E

95% CL scale limits on 4-fermion contact interactions

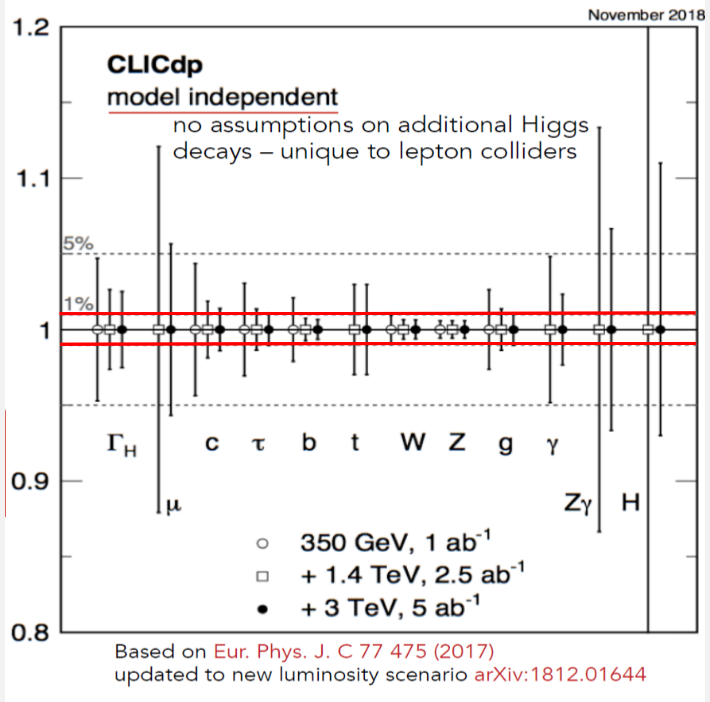


Due to staged realization of LCs, these are ideal machines to explore large physics span, with indirect access to the ~ 100 TeV scale

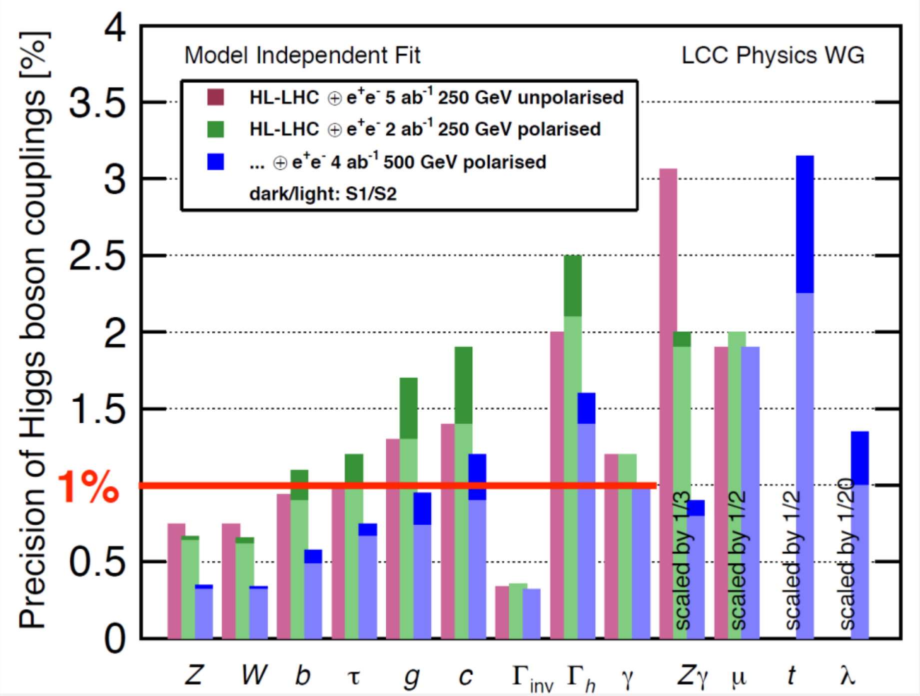
HIGGS COUPLINGS

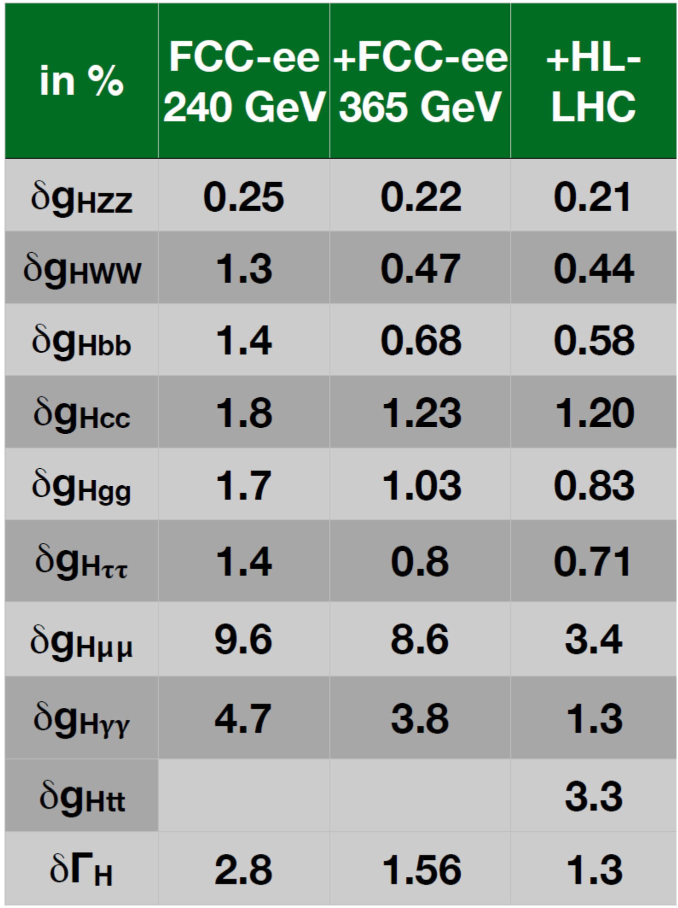
- Model independent approach*,
- Precision better than 1% for most couplings
- Clear improvement with energy
- Sinergy with HL-LHC

Already the single measurement of the HZ cross section at ILC 250 yields a very large improvement of the HL-LHC accuracies



Based on Eur. Phys. J. C 77 475 (2017)
updated to new luminosity scenario arXiv:1812.01644





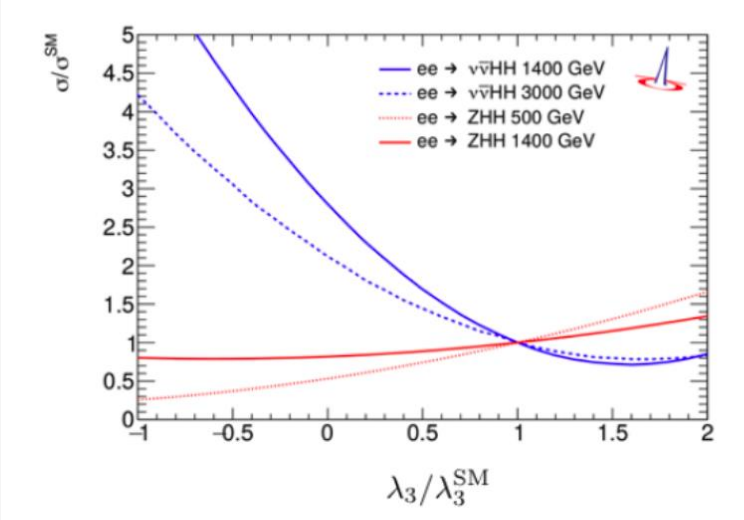
in %	FCC-ee 240 GeV	+FCC-ee 365 GeV	+HL-LHC
δg_{HZZ}	0.25	0.22	0.21
δg_{HWW}	1.3	0.47	0.44
δg_{Hbb}	1.4	0.68	0.58
δg_{Hcc}	1.8	1.23	1.20
δg_{Hgg}	1.7	1.03	0.83
$\delta g_{H\tau\tau}$	1.4	0.8	0.71
$\delta g_{H\mu\mu}$	9.6	8.6	3.4
$\delta g_{H\gamma\gamma}$	4.7	3.8	1.3
δg_{Htt}			3.3
$\delta\Gamma_H$	2.8	1.56	1.3

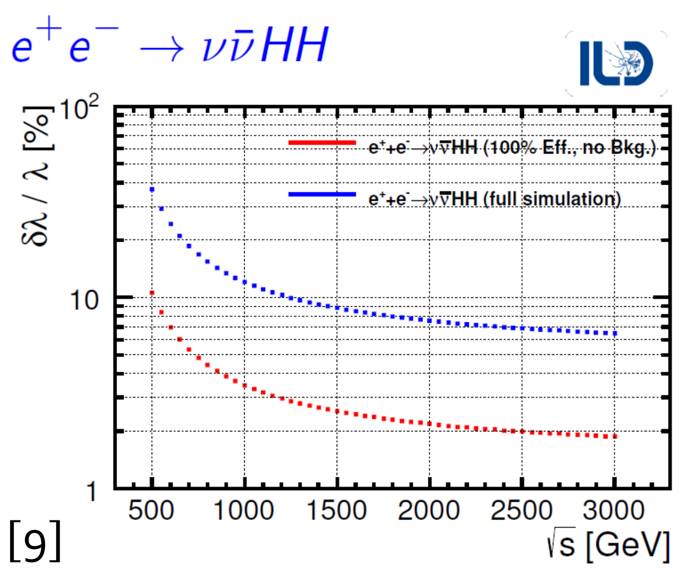
Statistical uncertainties are shown for 5 ab^{-1}@240 GeV and 1.5 ab^{-1}@365 GeV (from FCC-ee CDR)

** Level of accuracy <1% requires incorporation of loop-corrections → loss of strict model-independence*

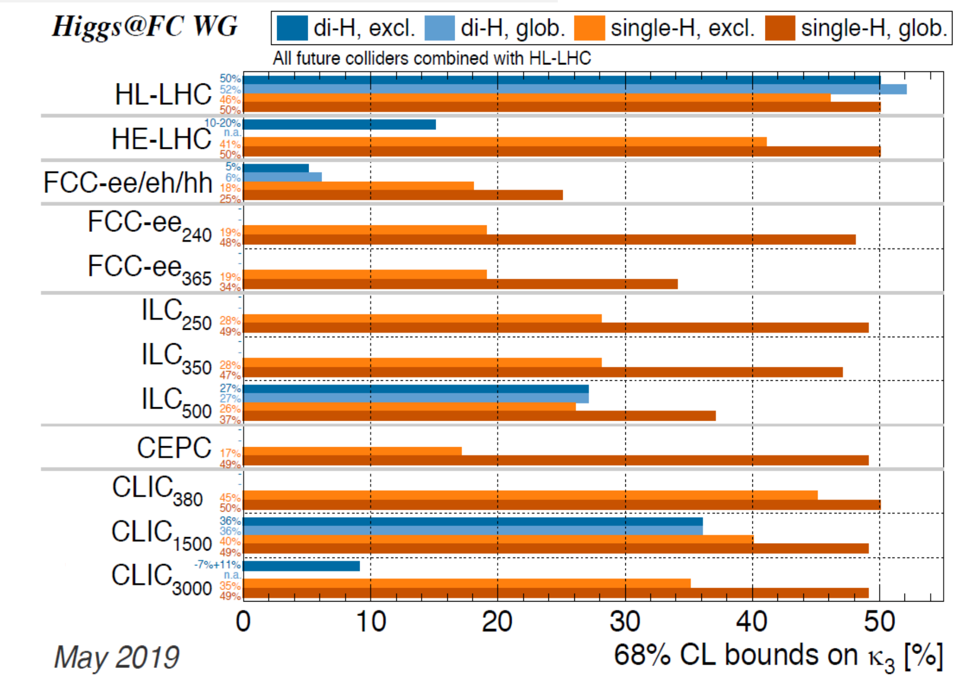
HIGGS SELF-COUPLING

- High energy (>1 TeV) e+e- collider is superior in determination of the Higgs self-coupling
- High energy (double) Higgs production is the most sensitive to deviations of the Higgs self-coupling
- λ is determined from the total rate of HH events (ILD) or template fit of m_{HH} and BDT output (CLICdp)
- Polarization (i.e. -80%) almost doubles the HHνν rate





[9]



e+e- colliders precision on λ in combination with HL-LHC:

Low energies:

ILC250 and FCCee365, ±35%

High energies:

HL-LHC: ~ ±50%

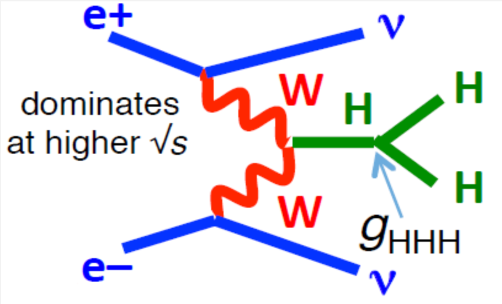
ILC500 ~ ± 27%

CLIC3000 ~ ± 9%

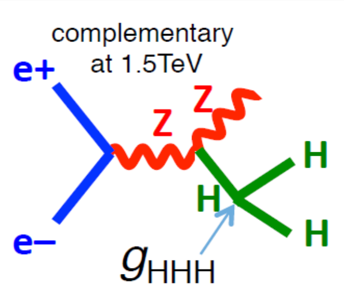
FCC-hh ~ ± 5%

[10]	$\Delta\lambda_{hhh}/\lambda_{hhh}$
4 ab^{-1} at ILC500	27%
+8 ab^{-1} at ILC1000	10%

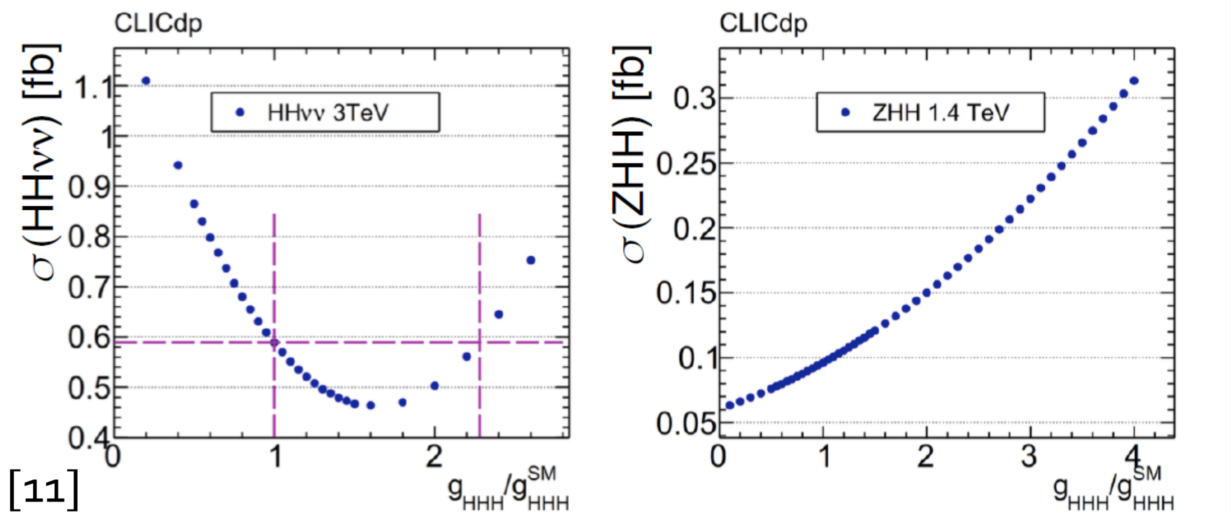
STAGING, COMBINATIONS – LC BENEFITS TO MEASURE λ



dominates at higher √s



complementary at 1.5TeV



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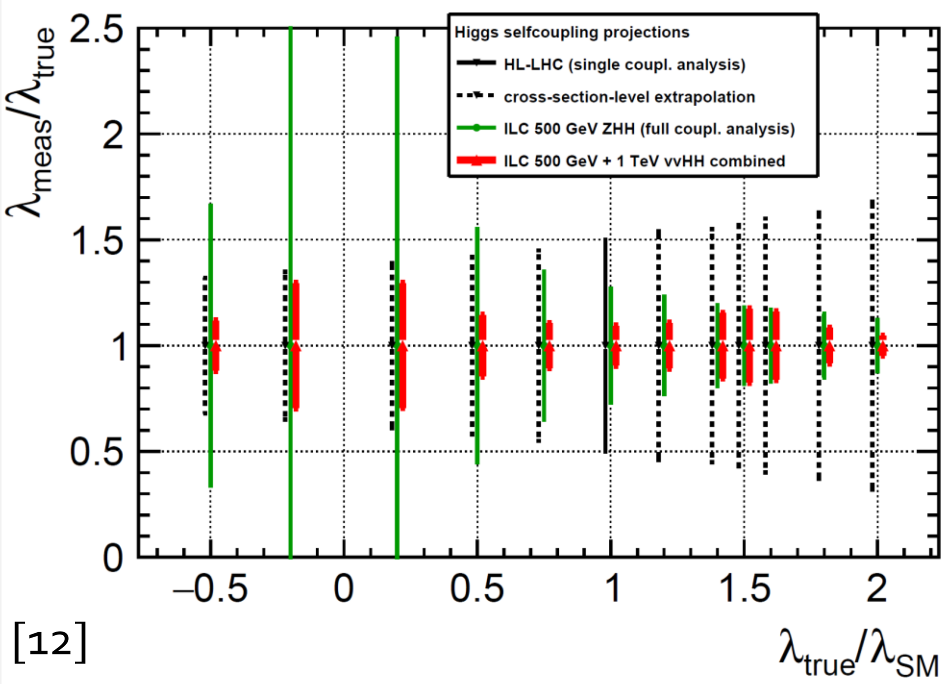
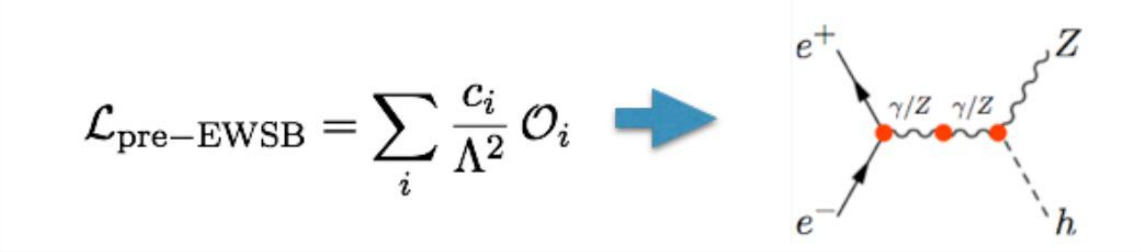


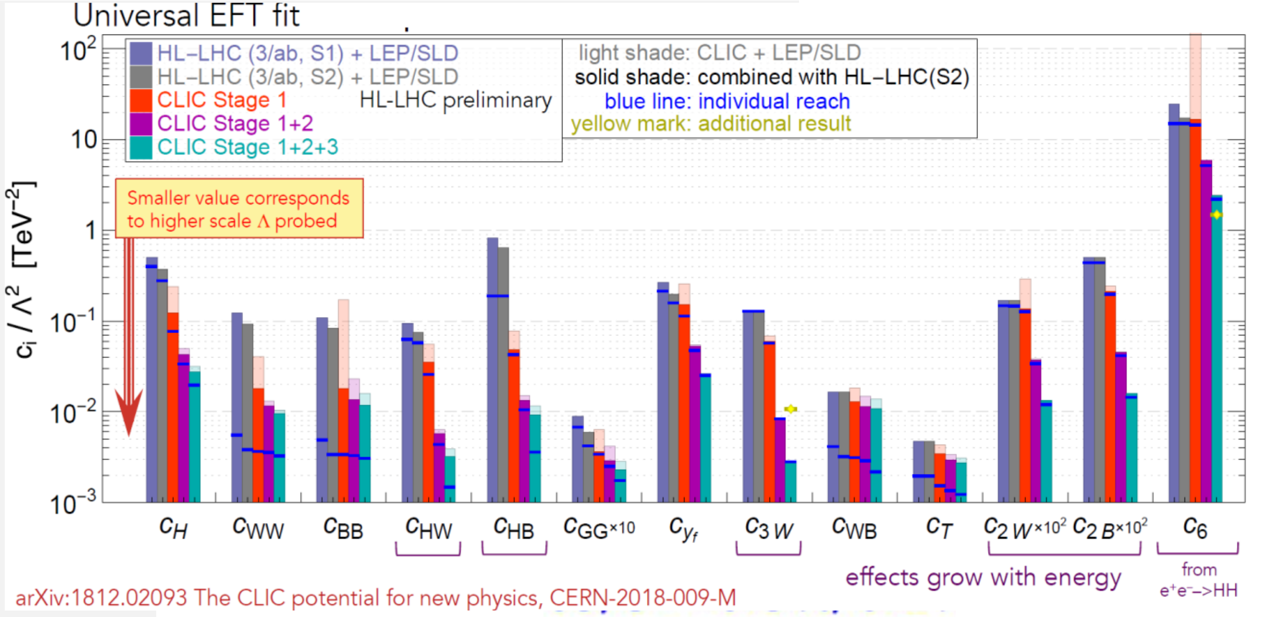
[12]

- It’s important to have (high) energy staging: 1.4(5) TeV complementarity to 3 TeV CLIC
- Different behavior of ZHH and double-Higgs production in WW-fusion, for non-SM values of triple Higgs couplings resolves ambiguity from interference
- Statistical uncertainty reduction in combination
- **Clear gain of high(er) center-of-mass energy sensitivity to non-SM values of λ**

HIGGS AS A PROBE TO BSM

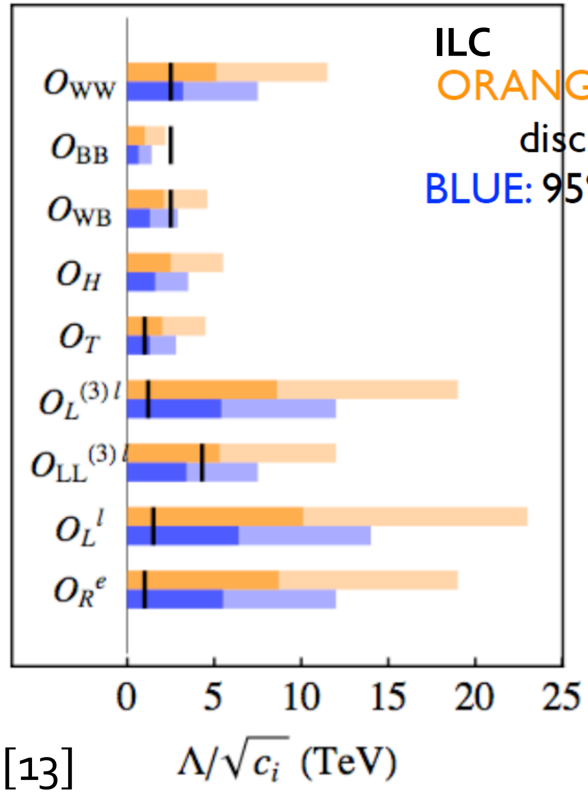


$$\mathcal{L}_{\text{pre-EWSB}} = \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i$$



arXiv:1812.02093 The CLIC potential for new physics, CERN-2018-009-M

- BSM physics can manifest itself in the Higgs sector in several ways:
  - Contribution from the higher order operators (EFT approach)
  - Higgs compositeness
  - Extended Higgs sector
  - DM portal
  - CPV



ILC

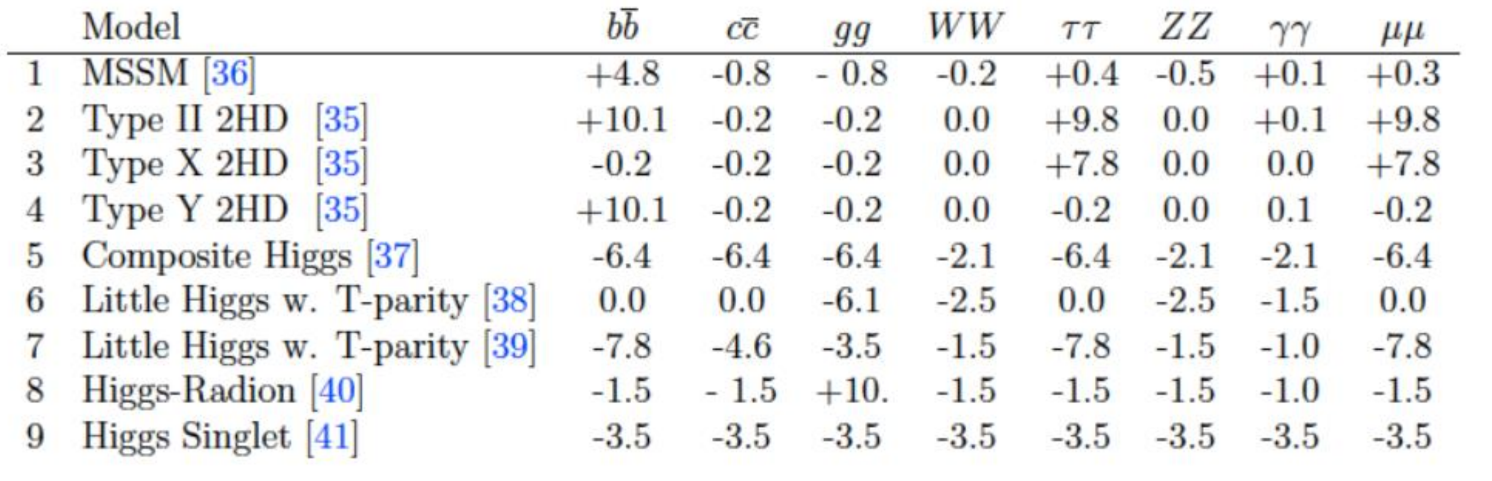
ORANGE: 5-sigma discovery

BLUE: 95% c.l. reach

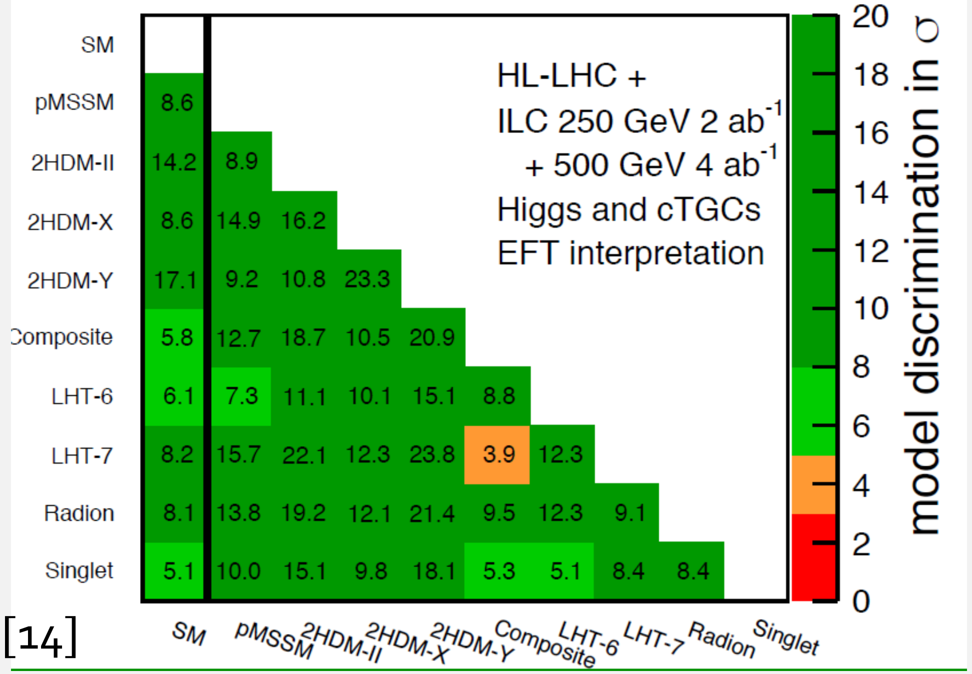
[13]

High energy Higgs production is the most sensitive to contributions from the 6D operators in the EFT approach and thus can probe the highest New Physics scale Λ

HIGGS AS A PROBE TO BSM – EFT INTERPRETATIONS

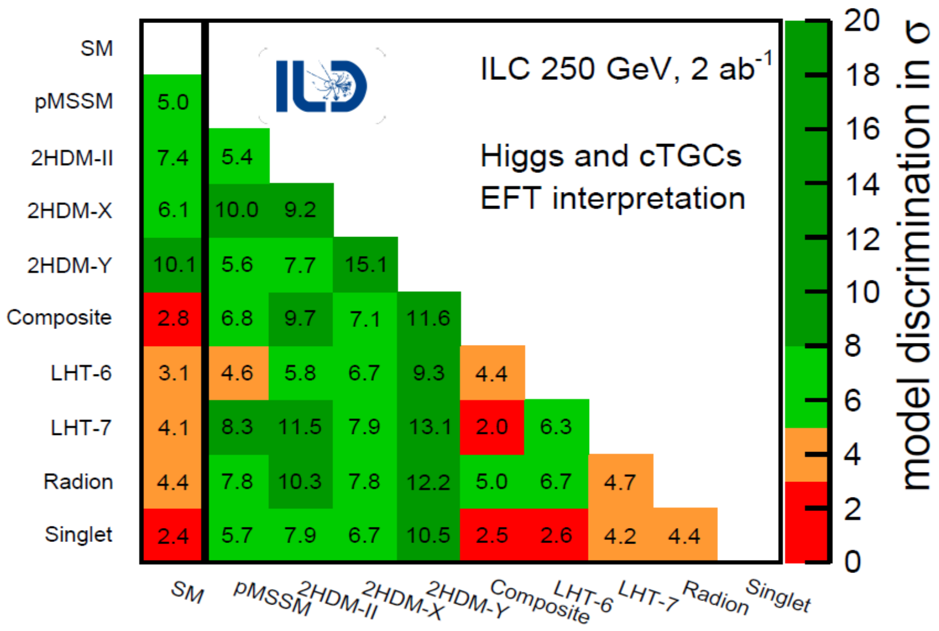


	Model	$b\bar{b}$	$c\bar{c}$	gg	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$\mu\mu$
1	MSSM [36]	+4.8	-0.8	- 0.8	-0.2	+0.4	-0.5	+0.1	+0.3
2	Type II 2HD [35]	+10.1	-0.2	-0.2	0.0	+9.8	0.0	+0.1	+9.8
3	Type X 2HD [35]	-0.2	-0.2	-0.2	0.0	+7.8	0.0	0.0	+7.8
4	Type Y 2HD [35]	+10.1	-0.2	-0.2	0.0	-0.2	0.0	0.1	-0.2
5	Composite Higgs [37]	-6.4	-6.4	-6.4	-2.1	-6.4	-2.1	-2.1	-6.4
6	Little Higgs w. T-parity [38]	0.0	0.0	-6.1	-2.5	0.0	-2.5	-1.5	0.0
7	Little Higgs w. T-parity [39]	-7.8	-4.6	-3.5	-1.5	-7.8	-1.5	-1.0	-7.8
8	Higgs-Radion [40]	-1.5	- 1.5	+10.	-1.5	-1.5	-1.5	-1.0	-1.5
9	Higgs Singlet [41]	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5



	SM	pMSSM	2HDM-II	2HDM-X	2HDM-Y	Composite	LHT-6	LHT-7	Radion	Singlet
SM										
pMSSM	8.6									
2HDM-II	14.2	8.9								
2HDM-X	8.6	14.9	16.2							
2HDM-Y	17.1	9.2	10.8	23.3						
Composite	5.8	12.7	18.7	10.5	20.9					
LHT-6	6.1	7.3	11.1	10.1	15.1	8.8				
LHT-7	8.2	15.7	22.1	12.3	23.8	3.9	12.3			
Radion	8.1	13.8	19.2	12.1	21.4	9.5	12.3	9.1		
Singlet	5.1	10.0	15.1	9.8	18.1	5.3	5.1	8.4	8.4	

[14]



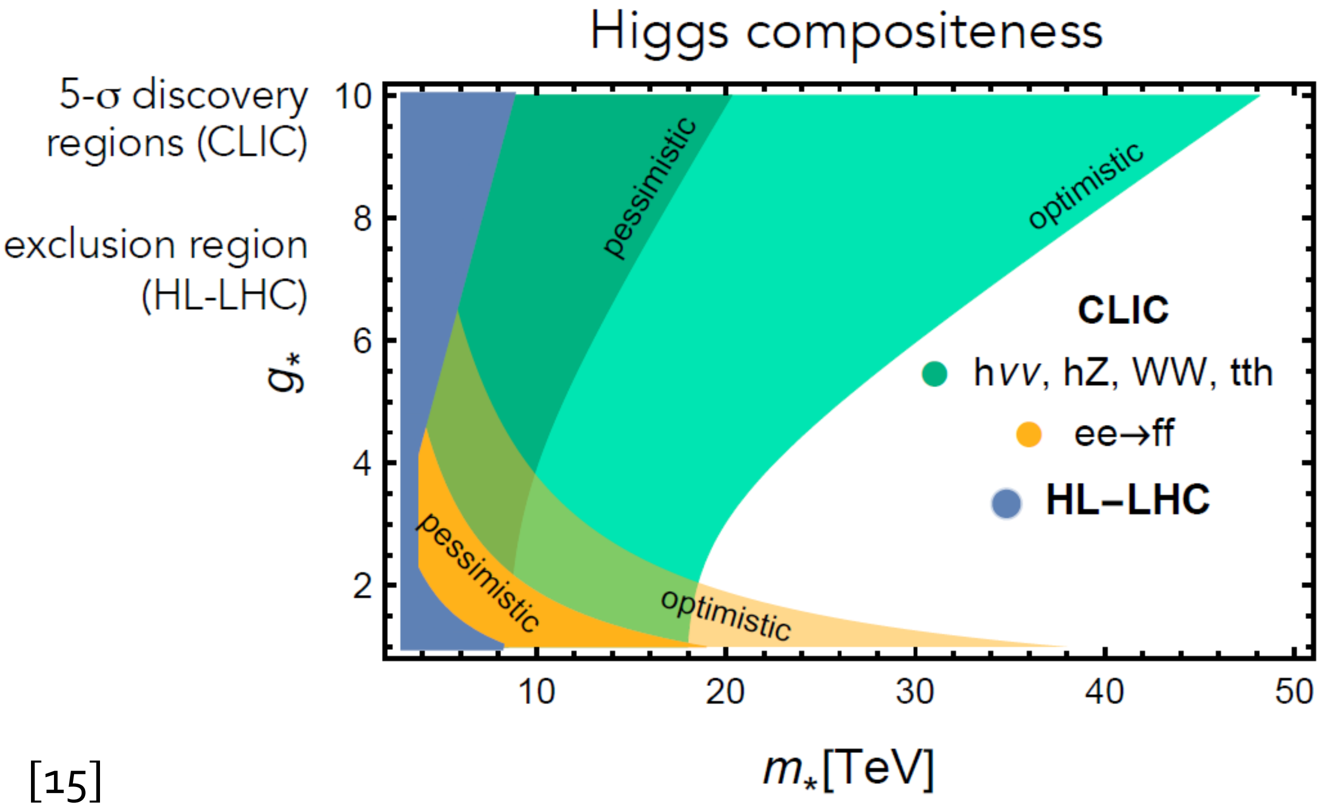
	SM	pMSSM	2HDM-II	2HDM-X	2HDM-Y	Composite	LHT-6	LHT-7	Radion	Singlet
SM										
pMSSM	5.0									
2HDM-II	7.4	5.4								
2HDM-X	6.1	10.0	9.2							
2HDM-Y	10.1	5.6	7.7	15.1						
Composite	2.8	6.8	9.7	7.1	11.6					
LHT-6	3.1	4.6	5.8	6.7	9.3	4.4				
LHT-7	4.1	8.3	11.5	7.9	13.1	2.0	6.3			
Radion	4.4	7.8	10.3	7.8	12.2	5.0	6.7	4.7		
Singlet	2.4	5.7	7.9	6.7	10.5	2.5	2.6	4.2	4.4	

Above 5σ model discrimination already with 250 Gev ILC

- Substantial improvement at higher energies + polarization
- New Physic can be probed at a discovery limit for almost all models unreachable at HL-LHC

HIGGS AS A PROBE TO BSM

- BSM physics can manifest itself in the Higgs sector in several ways:
  - Contribution from the higher order operators (EFT approach)
  - Higgs compositeness
  - Extended Higgs sector
  - DM portal
  - CPV



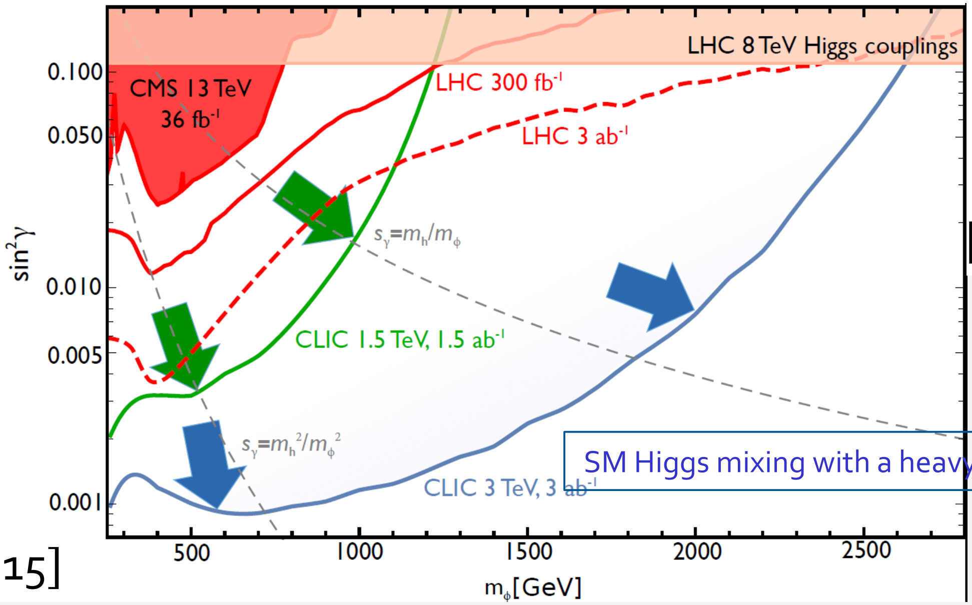
[15]

The scale of compositeness can be probed significantly higher from the high-energy collider kinematic limit

HIGGS AS A PROBE TO BSM

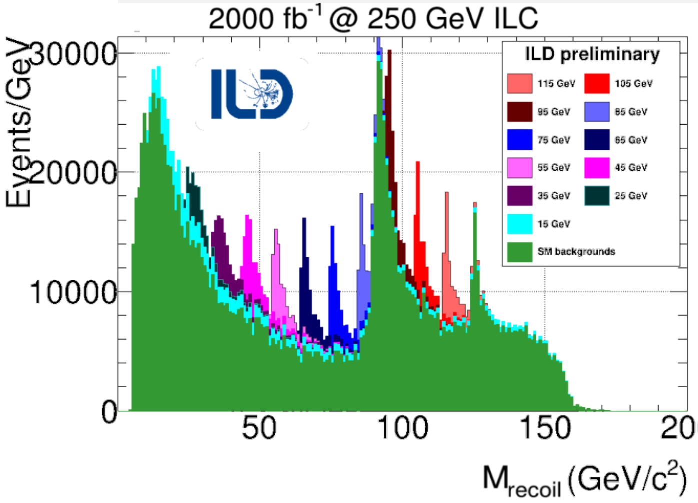
- BSM physics can manifest itself in the Higgs sector in several ways:
  - Contribution from the higher order operators (EFT approach)
  - Higgs compositeness
  - <u>Extended Higgs sector</u>
  - DM portal
  - CPV

- In majority of BSM models, SM Higgs comes with additional Higgses (2HDM, SUSY in general, compositeness,..etc.)
- Can be a lighter scalar than SM Higgs – it is important to be capable of probing such states at future colliders
- If SM Higgs is the lightest, other states are nearly mass-degenerated

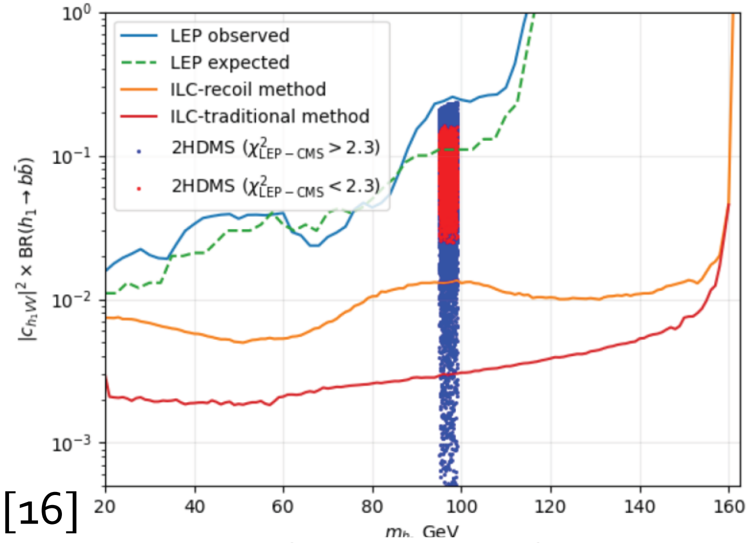


SM Higgs mixing with a heavy singlet state ϕ

[15]



[15] $e^+e^- \to Z\, S^0 \to \mu^+\mu^- + inv$



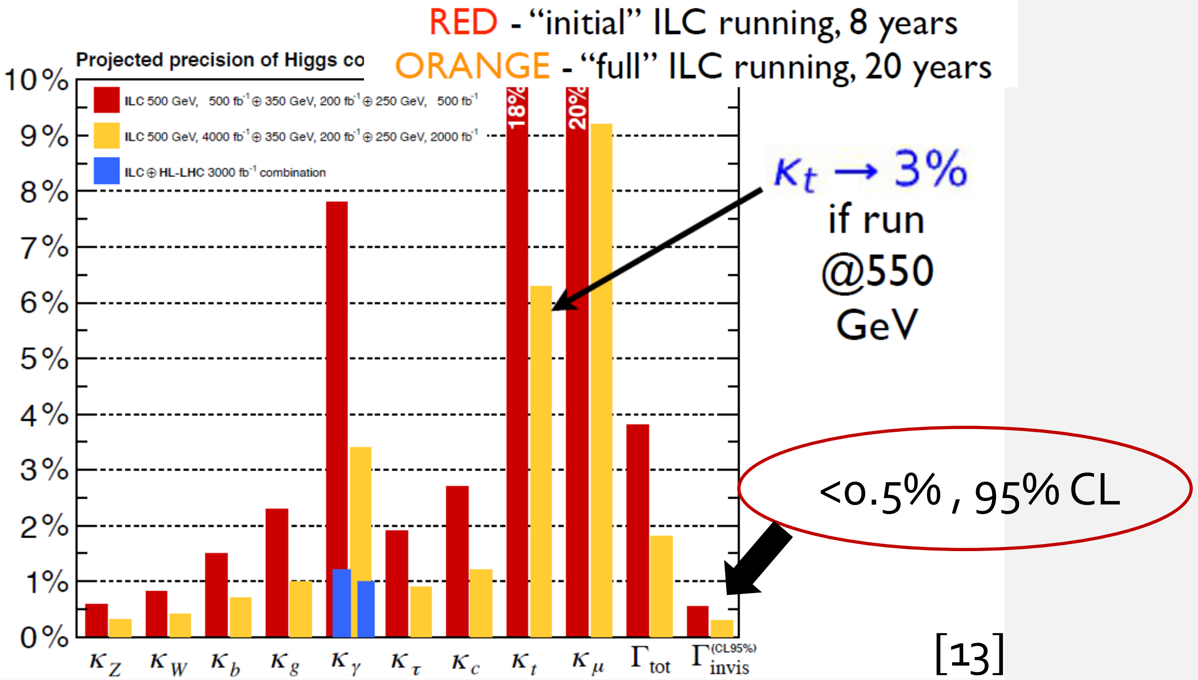
[16]

$$\mu_{\mathrm{CMS}} = \frac{\sigma(pp \to h_1 \to \gamma\gamma)}{\sigma(pp \to H_{\mathrm{SM}} \to \gamma\gamma)} = 0.6 \pm 0.2$$

ILC can clearly distinguish 2HDMS with 96 GeV scalar from the SM

HIGGS TO INVISIBLE

- BSM physics can manifest itself in the Higgs sector in several ways:
  - Contribution from the higher order operators (EFT approach)
  - Higgs compositeness
  - Extended Higgs sector
  - DM portal
  - CPV



RED - "initial" ILC running, 8 years

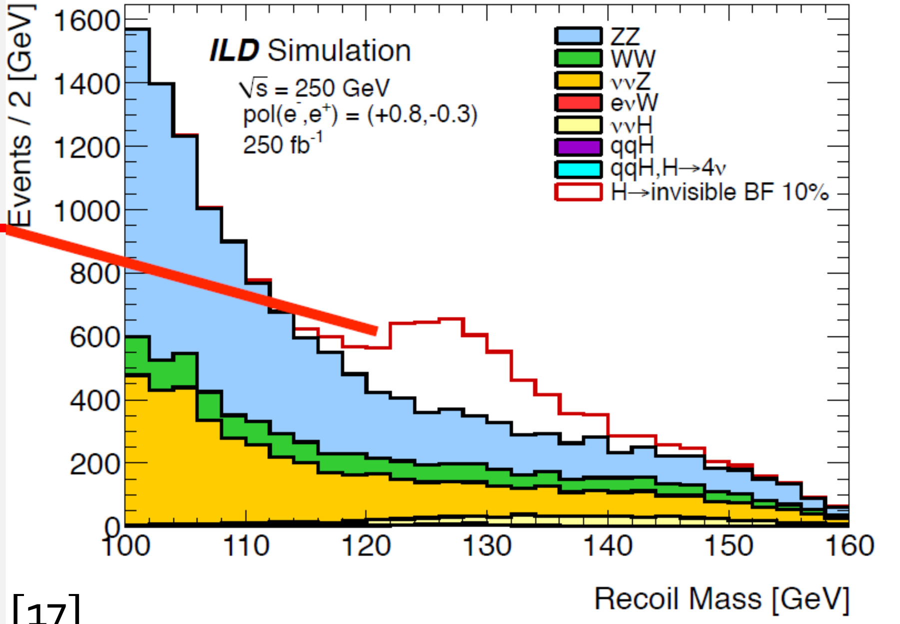
ORANGE - "full" ILC running, 20 years

$\kappa_t \rightarrow 3\%$ if run @550 GeV

<0.5% , 95% CL

[13]

$H \rightarrow inv.$



[17]

- Looking at the recoil mass under the condition that nothing observable is recoiling against the *Z* boson (only one Z per event)
- Access to DM connected to SM particles through a specific set of operators (portals)

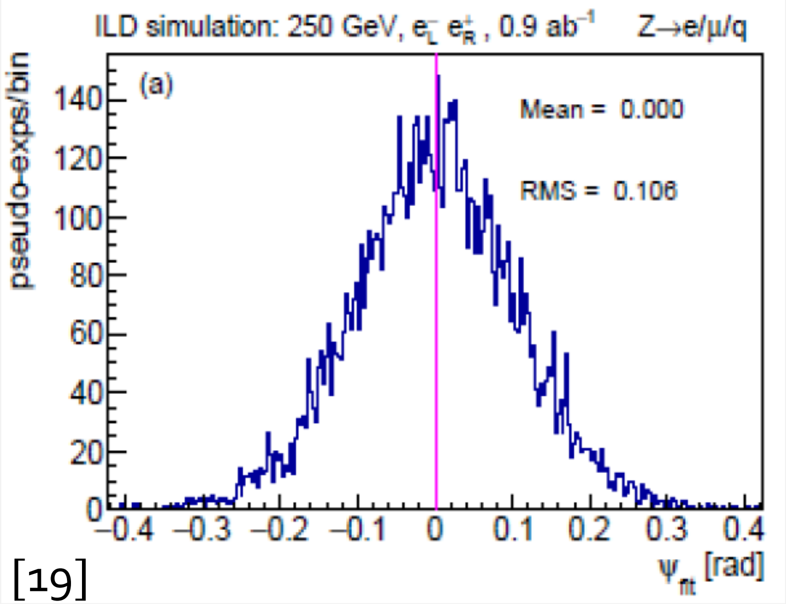
$$\frac{1}{2}\epsilon_Y F^Y_{\mu\nu} F'^{\mu\nu} \qquad \epsilon_H |H|^2 |\Phi|^2 \qquad \epsilon_a \frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}$$

CPV IN THE HIGGS SECTOR

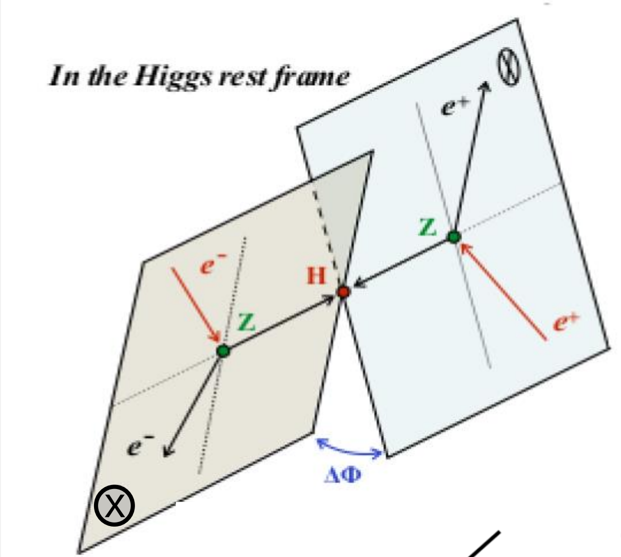
- More difficult than just a spin/parity determination: Higgs can be a mixture of different CP eigenstates

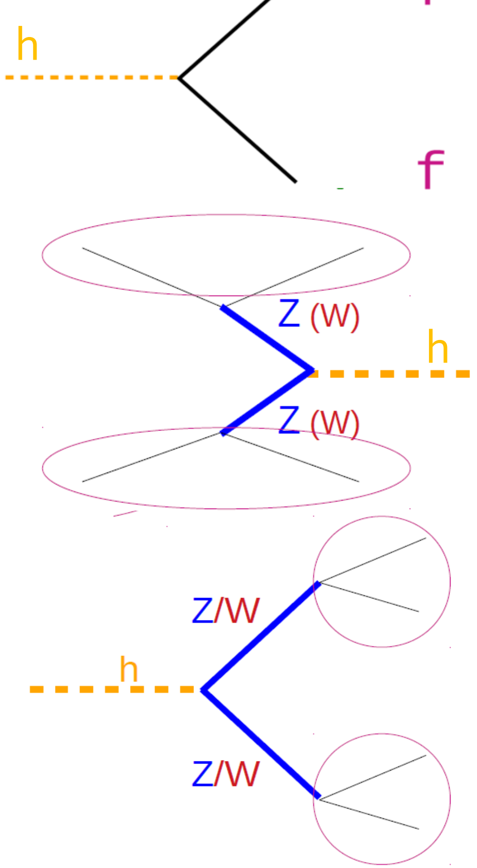
$$h = H\cdot \cos\psi \;+\; A\cdot \sin\psi$$

- Can be measured in Hff and HVV vertices, both in Higgs production and decays
- Hff (HVV) sensitive to CPV contributions at the tree (loop) level
- Only lose bounds (at present) on a quantum superposition od different CP states (i.e. $\psi<43°$, 95% CL, LHC [18])



[19]





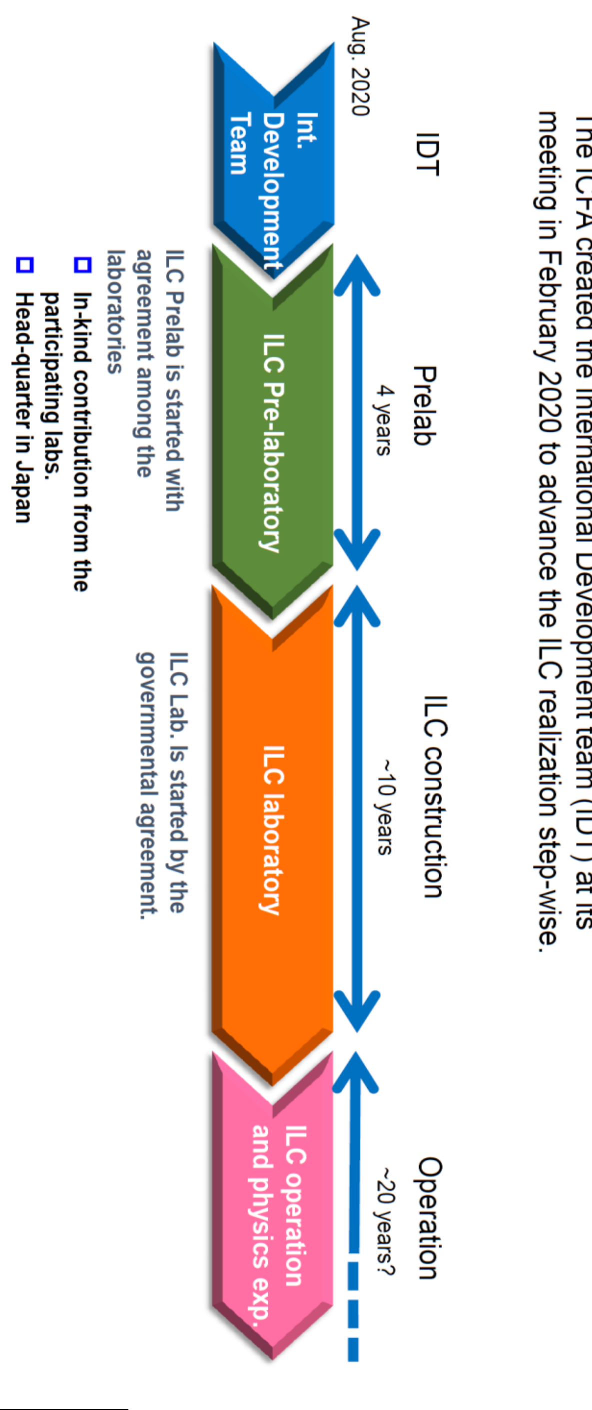
Collider	$\Delta\psi_{CP}$
HL-LHC	8°
HE-LHC	–
CEPC	–
FCC-ee$_{240}$	10°
ILC$_{250}$	4°

250 GeV – benefit from polarization & combination (Hττ)
500+ GeV – associated Htt production
1 TeV – ZZ-fusion, Higgs production
3 TeV – WW-fusion, Higgs decay

SUMMARY

Linear colliders as candidates for future Higgs factories are well studied (physics) and technologically mature (detector) projects ready to be deployed

- All future e+e- projects bring significant added value to the projected HL-LHC sensitivities in the Higgs sector…
- … enabling discrimination of BSM models inaccessible at HL-LHC
- Already lowest energy phases brings sensitivity far beyond the projected HL-LHC precision on Higgs couplings
- Higher center of mass energies significantly extends physics span of a LC (Higgs self-coupling, BSM scenarios in the Higgs sector)
  ➡ Energy upgrade is important – genuine advantage of a LC
- Additional enhancement comes from polarization (precision, model discrimination)


The ICFA created the International Development team (IDT) at its meeting in February 2020 to advance the ILC realization step-wise.

ILC Prelab is started with agreement among the laboratories

☐ In-kind contribution from the participating labs.

☐ Head-quarter in Japan

ILC Lab. Is started by the governmental agreement.

CEPC Workshop

08.11.-12.11. 2021

Nanjing, China

The 2021 International Workshop on the High Energy Circular Electron Positron Collider

THANK YOU

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BACK UP

HIGGS COUPLINGS

How well do we need to know Higgs couplings?

- In many BSM models one expects only % level deviations from the SM couplings for BSM particles in the TeV range
- Higgs to EW bosons couplings are particularly sensitive to BSM; λ even more
- Example, 2HDM-type model in decoupling limit [B1]

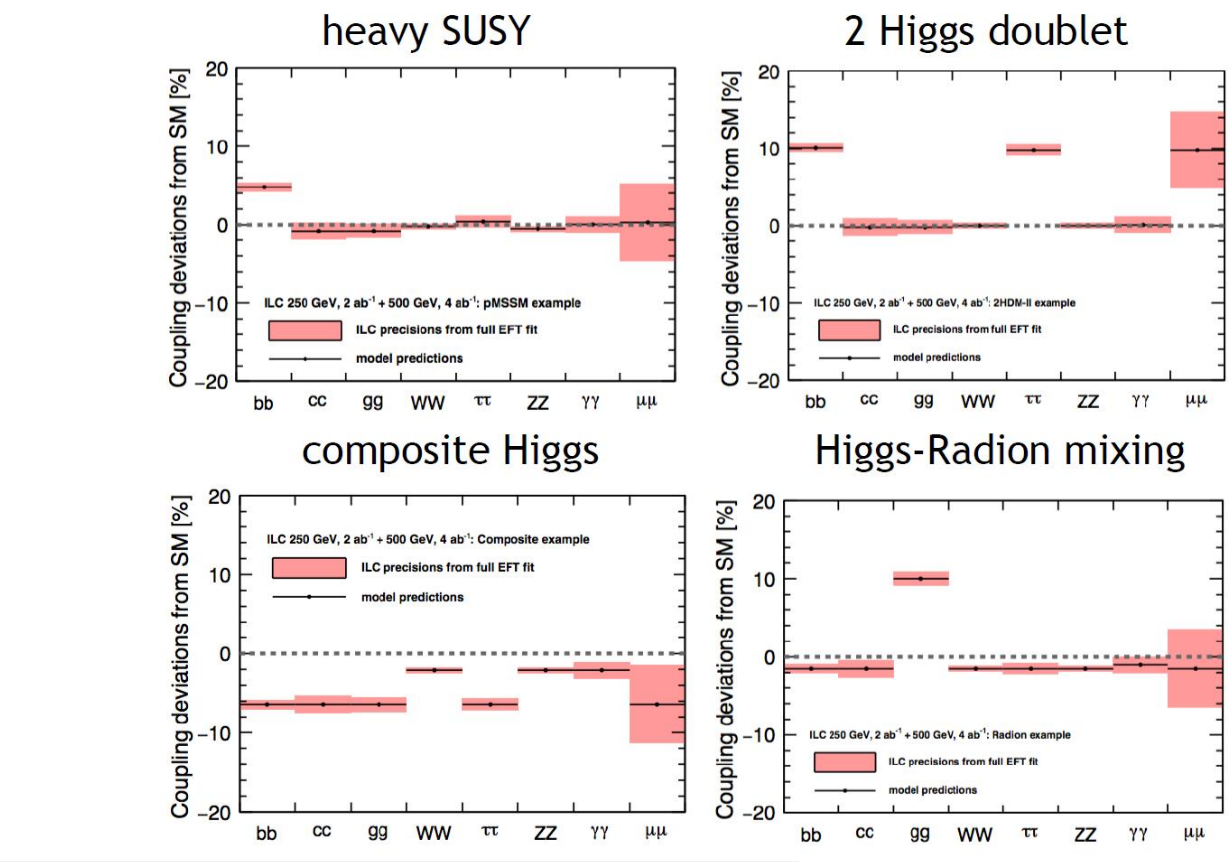
$$\frac{g_{hVV}}{g_{h_{\mathrm{SM}}VV}} \simeq 1 - 0.3\% \left(\frac{200\ \mathrm{GeV}}{m_A}\right)^4$$

$$\frac{g_{htt}}{g_{h_{\mathrm{SM}}tt}} = \frac{g_{hcc}}{g_{h_{\mathrm{SM}}cc}} \simeq 1 - 1.7\% \left(\frac{200\ \mathrm{GeV}}{m_A}\right)^2$$

$$\frac{g_{hbb}}{g_{h_{\mathrm{SM}}bb}} = \frac{g_{h\tau\tau}}{g_{h_{\mathrm{SM}}\tau\tau}} \simeq 1 + 40\% \left(\frac{200\ \mathrm{GeV}}{m_A}\right)^2 .$$

The models below are outside the HL-LHC reach

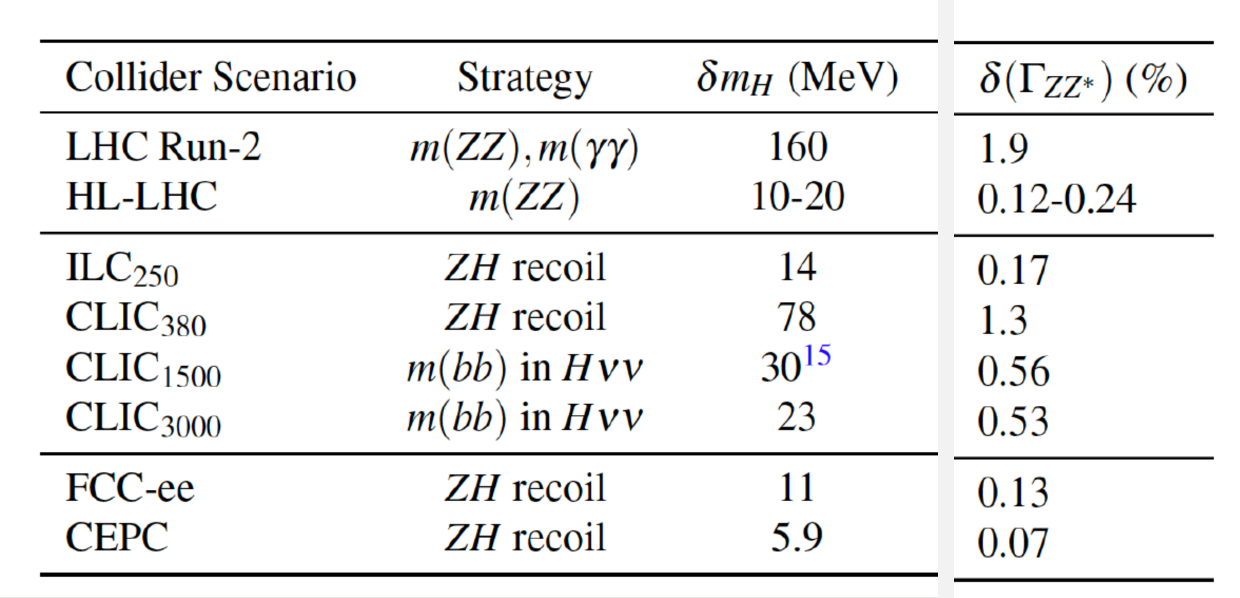
[T. Barklow et al. '17]



Percent order accuracy on Higgs couplings offers access to various BSM scenarios

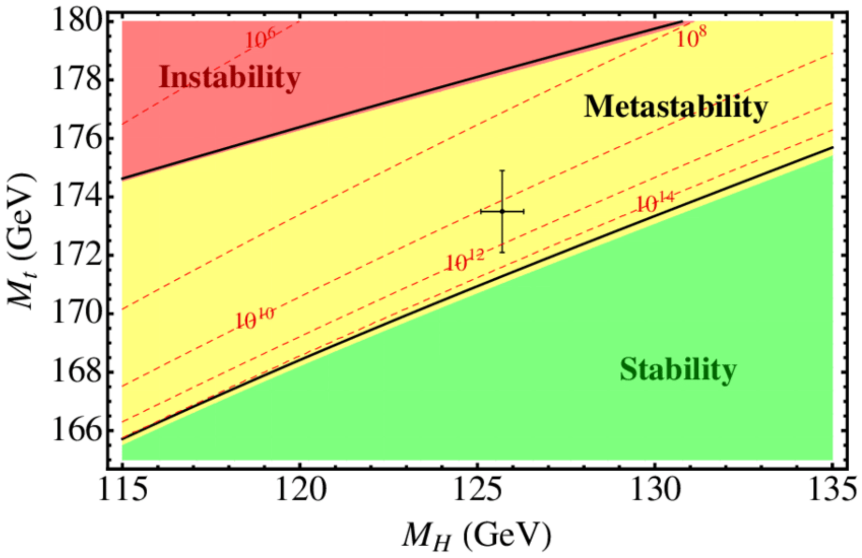
HIGGS MASS

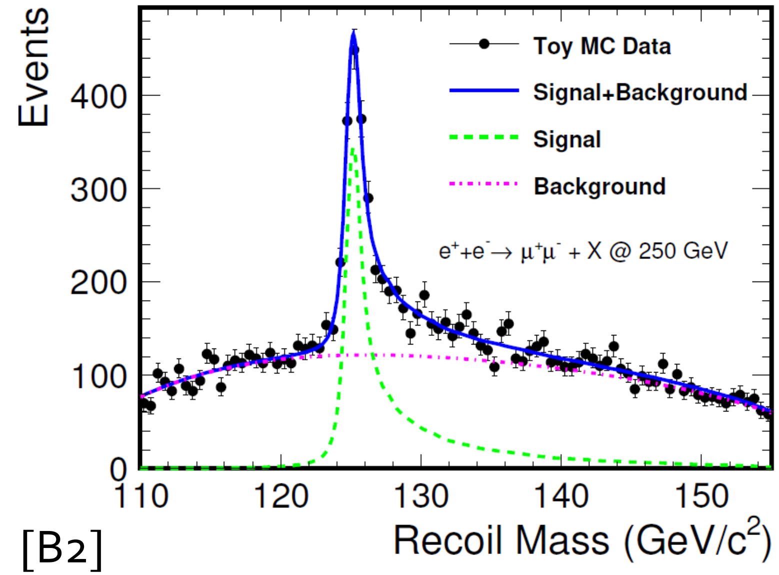
- Which precision of the Higgs mass is needed?
  - Vacuum stability (at least several GeV)
  - Impact on H→ZZ* width (a few tens of MeV)
- Current precision 160 MeV
- Comparable precision with HL-LHC



Collider Scenario	Strategy	δm_H (MeV)	$\delta(\Gamma_{ZZ^*})$ (%)
LHC Run-2	$m(ZZ), m(\gamma\gamma)$	160	1.9
HL-LHC	$m(ZZ)$	10-20	0.12-0.24
ILC_{250}	ZH recoil	14	0.17
CLIC_{380}	ZH recoil	78	1.3
CLIC_{1500}	$m(bb)$ in $H\nu\nu$	30[15]	0.56
CLIC_{3000}	$m(bb)$ in $H\nu\nu$	23	0.53
FCC-ee	ZH recoil	11	0.13
CEPC	ZH recoil	5.9	0.07

M. Cepeda, Higgs precision measurements at future colliders, IFT UAM-CSIC, Madrid, Spain, July 2019





[B2]

HIGGS WIDTH

- Being less than 5 MeV, Higgs decay width can not be *directly* measured at any proposed e+e- collider
- Can be determined from individual decays (quasi-direct measurement), i.e. H→WW decays in WW-fusion, H→ZZ in HZ)

$$\sigma(\mathrm{ee} \to \mathrm{ZH}) \cdot \mathrm{BR}(\mathrm{H} \to \mathrm{ZZ}) \propto \frac{g^4_{\mathrm{HZ}}}{\Gamma}$$

- In a combination of measurements:

$$\frac{\sigma(\mathrm{ee}\to\mathrm{ZH})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{WW})\cdot\sigma(\mathrm{ee}\to\mathrm{ZH})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{bb})}{\sigma(\mathrm{ee}\to\nu\nu\mathrm{H})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{bb})}$$

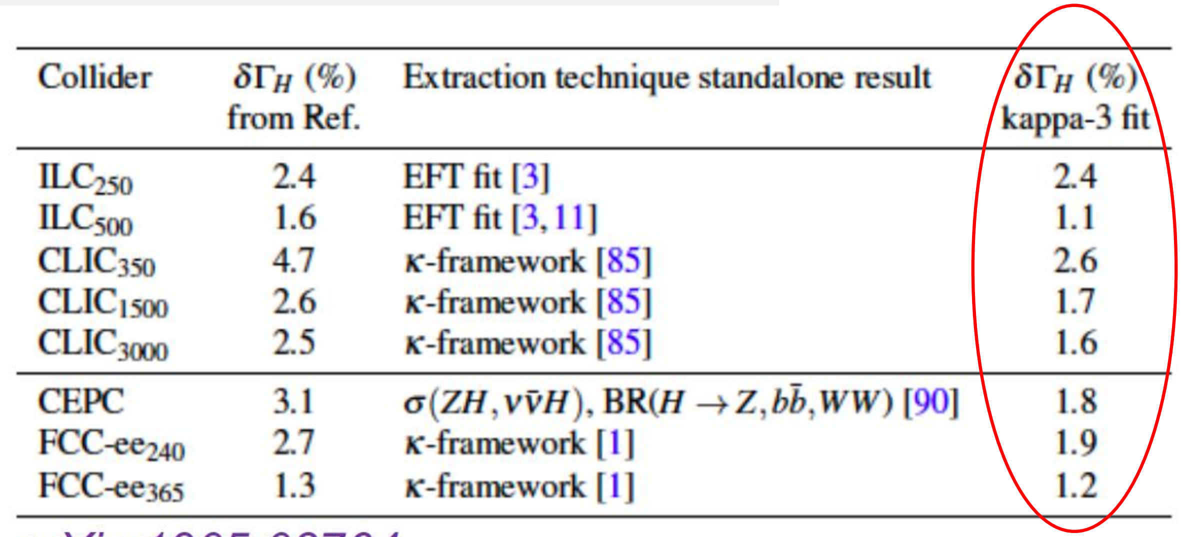
$$\propto \frac{g^2_{\mathrm{HZ}}\cdot\cancel{g^2_{\mathrm{HW}}}}{\Gamma}\cdot\frac{g^2_{\mathrm{HZ}}\cdot\cancel{g^2_{\mathrm{Hb}}}}{\cancel{\Gamma}}\cdot\frac{\cancel{\Gamma}}{\cancel{g^2_{\mathrm{HW}}}\cdot\cancel{g^2_{\mathrm{Hb}}}} = \frac{g^4_{\mathrm{HZ}}}{\Gamma}$$

- The ultimate precision is reached in a global fit, (model-independent or in the LHC-style, so called κ-framework):

$$\Gamma_H = \frac{\Gamma_H^{SM}\cdot\kappa_H^2}{1-(BR_{inv}+BR_{unt})}$$

- Or in a global (model-dependent) EFT fit (assumes the new physics scale $\Lambda >> M_H$)

Statistical accuracy of 1-2%



Collider	$\delta\Gamma_H$ (%) from Ref.	Extraction technique standalone result	$\delta\Gamma_H$ (%) kappa-3 fit
ILC$_{250}$	2.4	EFT fit [3]	2.4
ILC$_{500}$	1.6	EFT fit [3, 11]	1.1
CLIC$_{350}$	4.7	κ-framework [85]	2.6
CLIC$_{1500}$	2.6	κ-framework [85]	1.7
CLIC$_{3000}$	2.5	κ-framework [85]	1.6
CEPC	3.1	$\sigma(ZH,\nu\bar{\nu}H)$, BR$(H\to Z,b\bar{b},WW)$ [90]	1.8
FCC-ee$_{240}$	2.7	κ-framework [1]	1.9
FCC-ee$_{365}$	1.3	κ-framework [1]	1.2

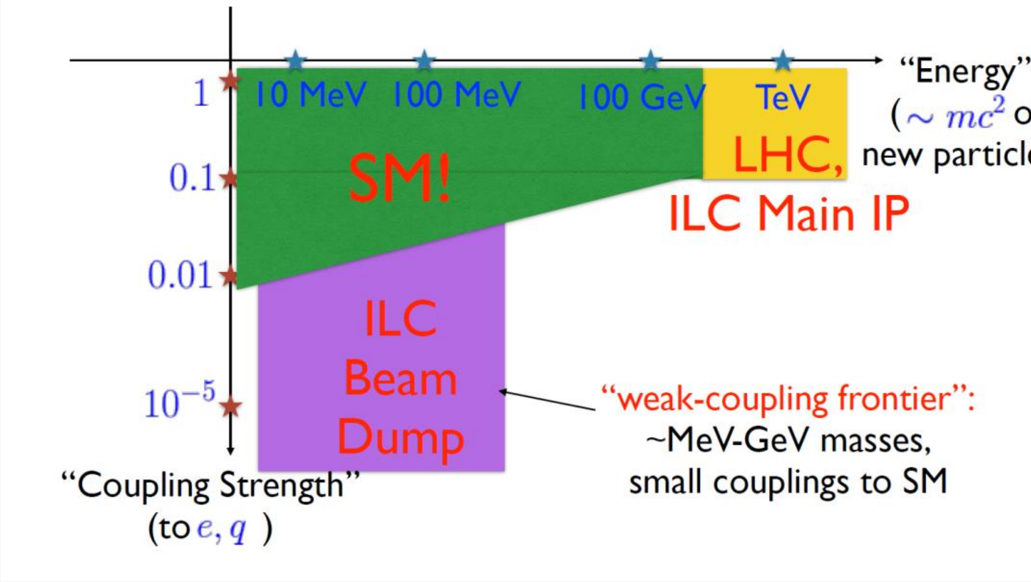
arXiv:1905.03764

ILCX

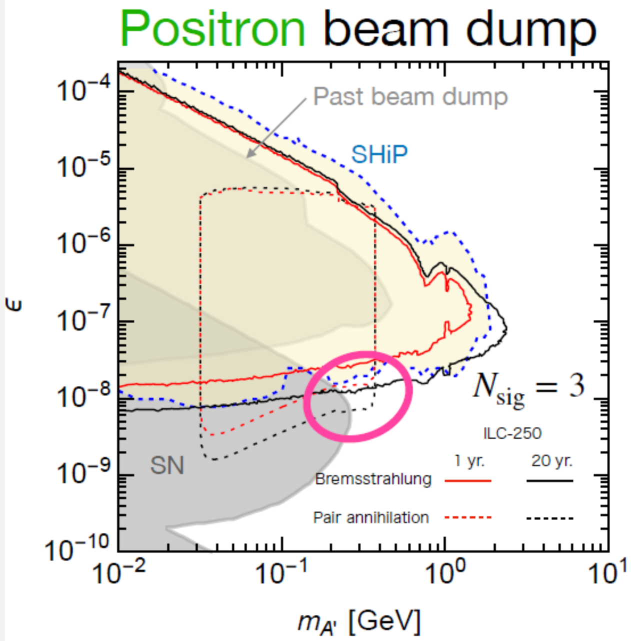
ILC comes with the collider program and rich auxiliary experiments

Dark sector (ILC-BDX), fixed-target and beam dump experiments (ILCX)

- The physics program at the ILC main IP will study physics at O(100 GeV) mass scale, with O(0.01-0.1) coupling strength
- Fixed-target experiments at ILC beam dumps offer access to a complementary regime: <10 GeV mass scale, <<1 coupling strength

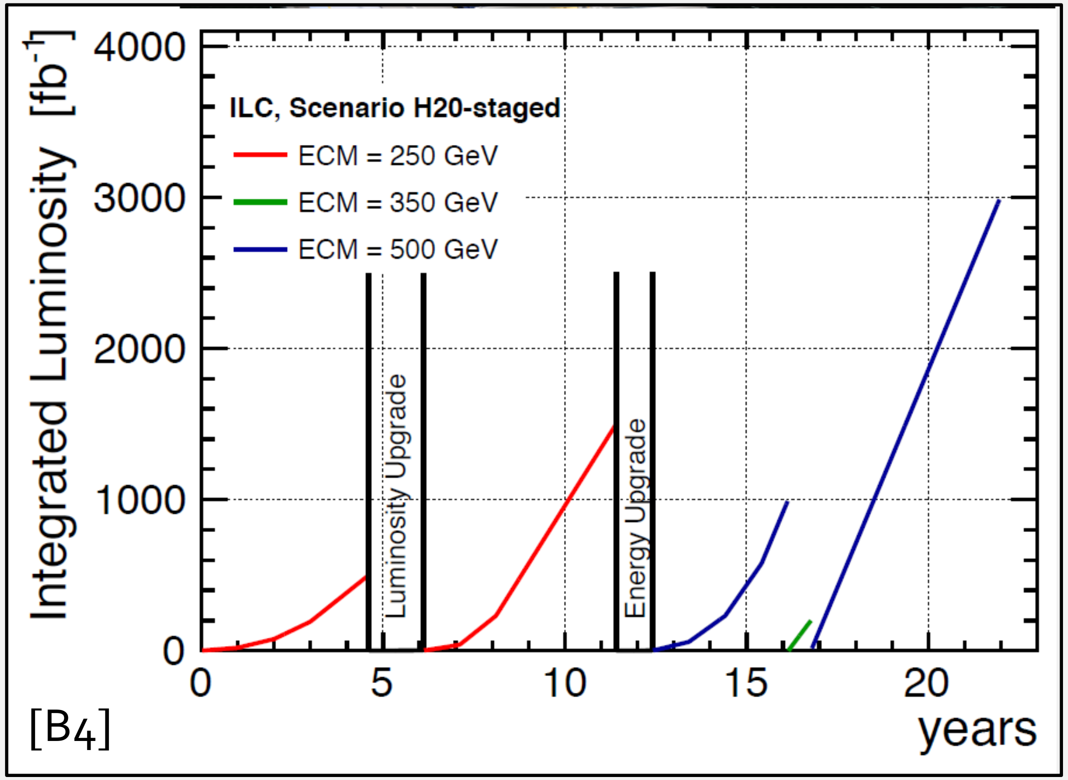


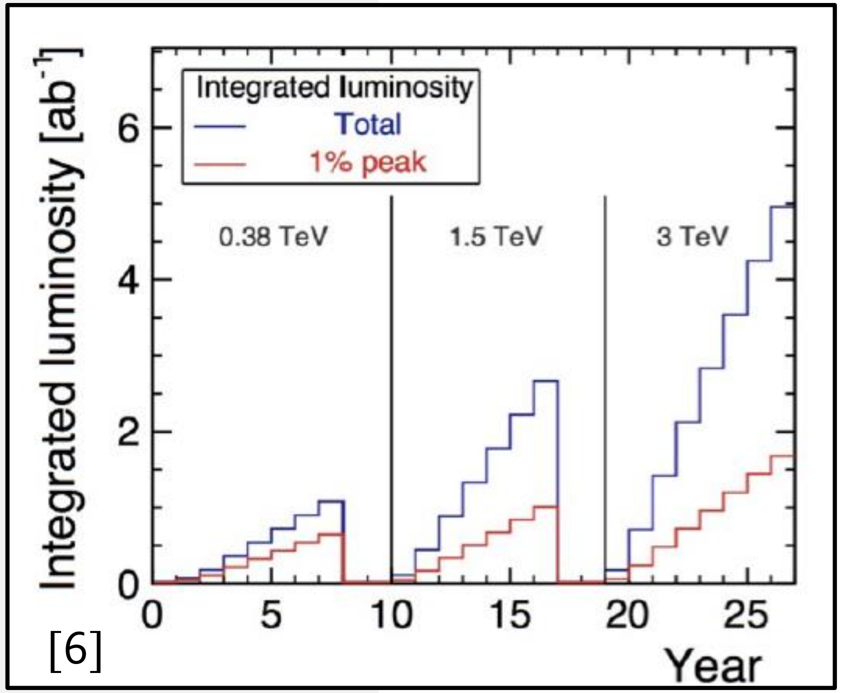
[B3]



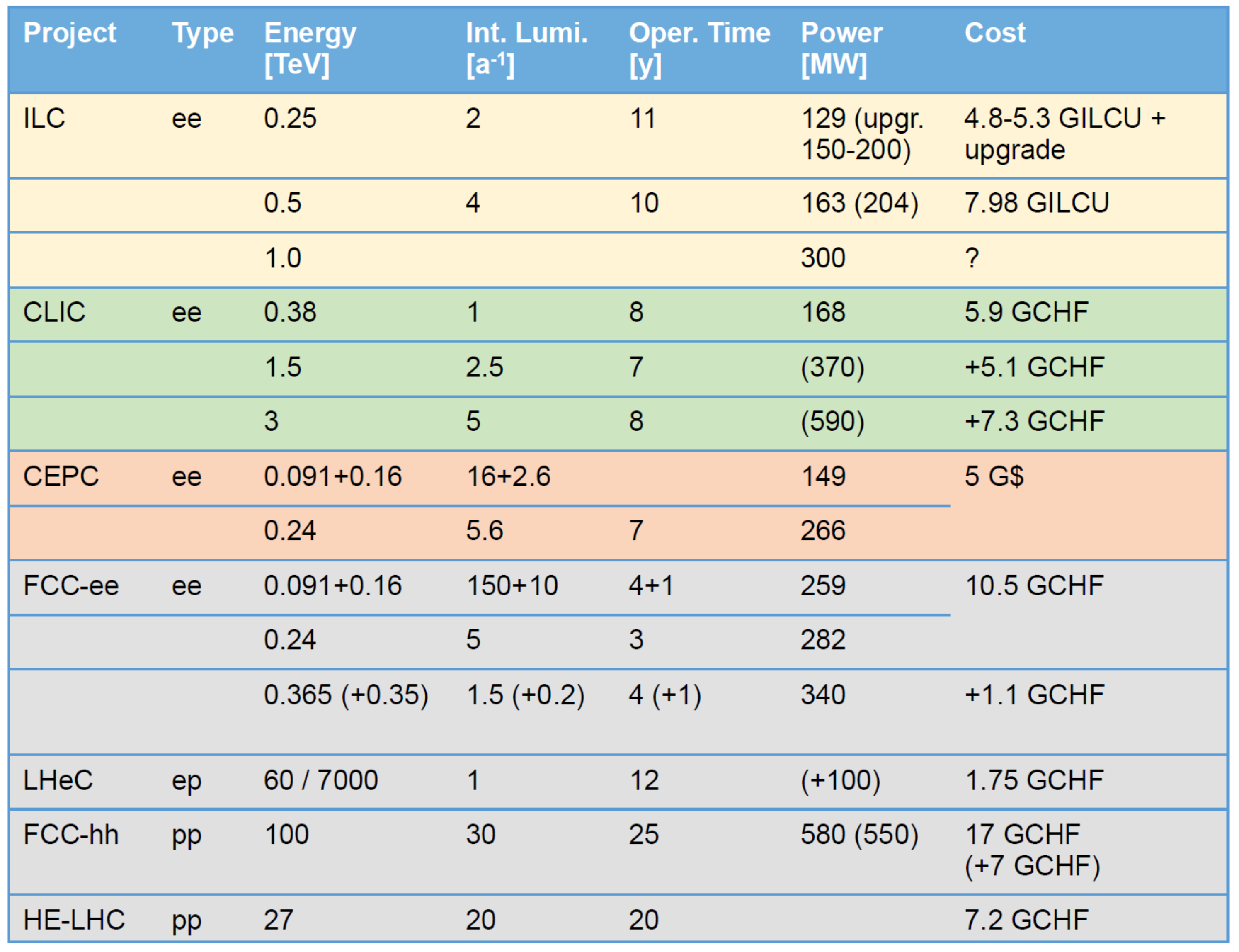
[B3]

LUMINOSITIES





COSTS



Project	Type	Energy [TeV]	Int. Lumi. [a^{-1}]	Oper. Time [y]	Power [MW]	Cost
ILC	ee	0.25	2	11	129 (upgr. 150-200)	4.8-5.3 GILCU + upgrade
		0.5	4	10	163 (204)	7.98 GILCU
		1.0			300	?
CLIC	ee	0.38	1	8	168	5.9 GCHF
		1.5	2.5	7	(370)	+5.1 GCHF
		3	5	8	(590)	+7.3 GCHF
CEPC	ee	0.091+0.16	16+2.6		149	5 G$
		0.24	5.6	7	266	
FCC-ee	ee	0.091+0.16	150+10	4+1	259	10.5 GCHF
		0.24	5	3	282	
		0.365 (+0.35)	1.5 (+0.2)	4 (+1)	340	+1.1 GCHF
LHeC	ep	60 / 7000	1	12	(+100)	1.75 GCHF
FCC-hh	pp	100	30	25	580 (550)	17 GCHF (+7 GCHF)
HE-LHC	pp	27	20	20		7.2 GCHF

[B5]