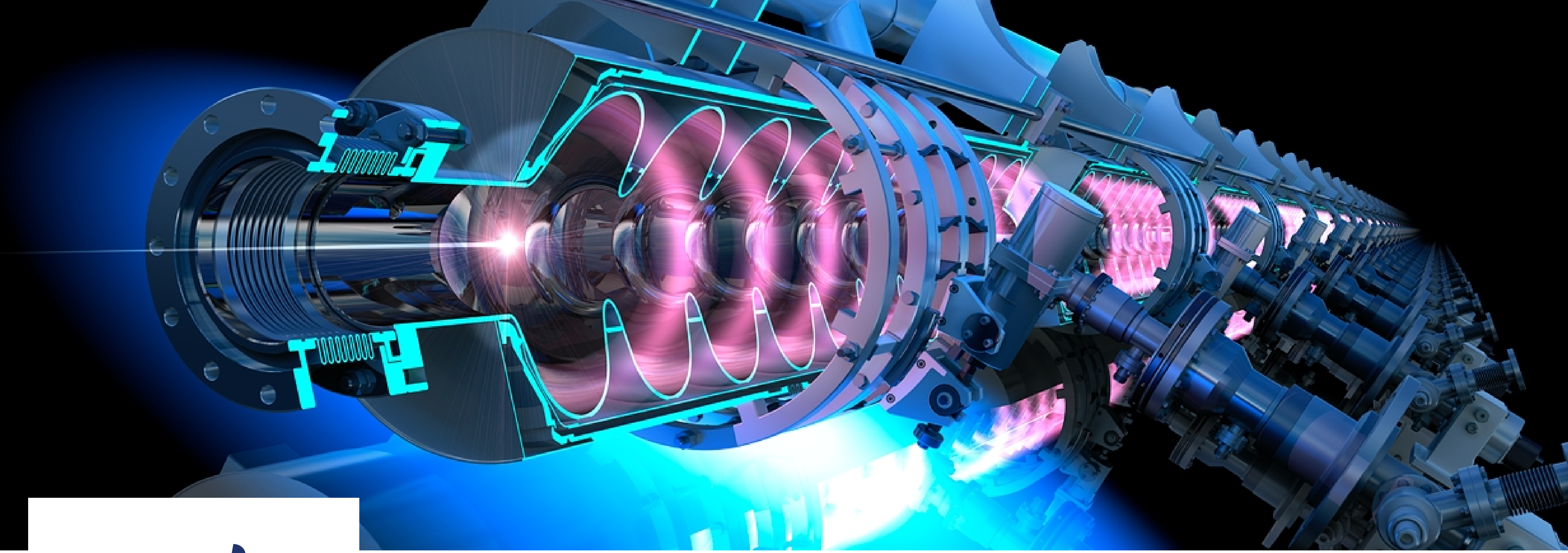


ILC physics

Daniel Jeans, KEK

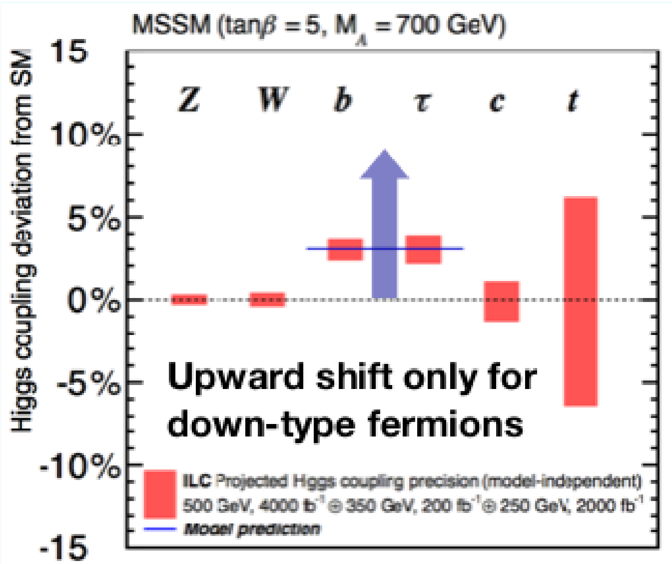
IAS HEP, Jan 2020

(almost all) studies based on full detector simulation,
including beam parameters / lumi. spectrum,
backgrounds, realistic reconstruction & analysis

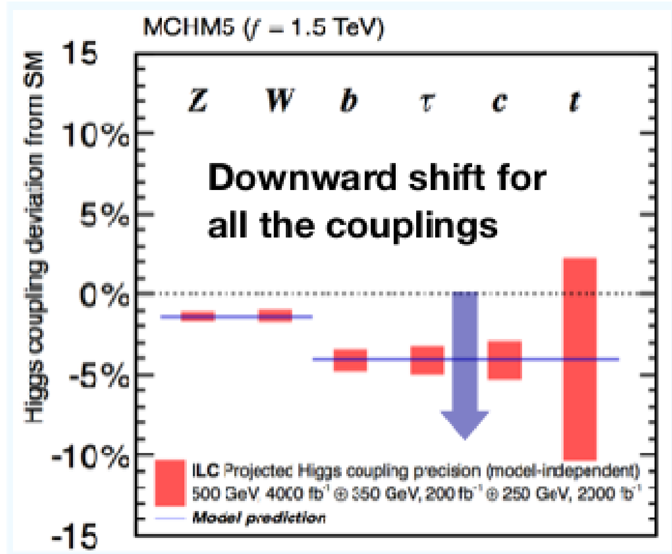
performed by a relatively small number of
dedicated (& mostly young) researchers

why measure the Higgs?

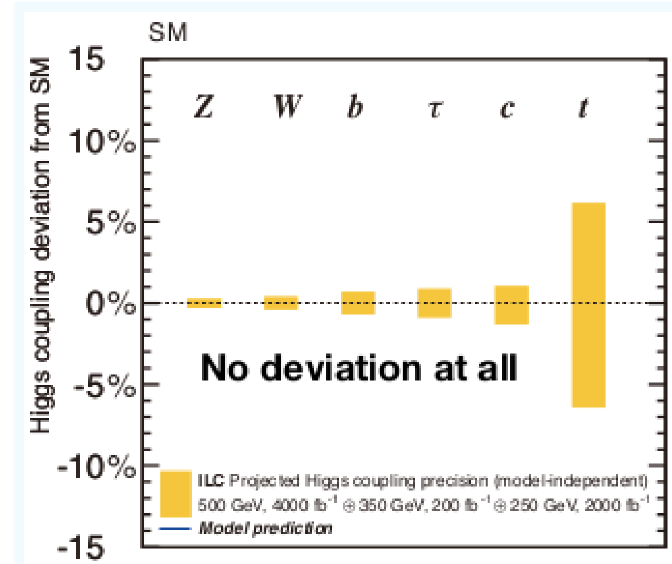
a new symmetry
e.g. SUSY



a deeper structure
e.g. composite Higgs



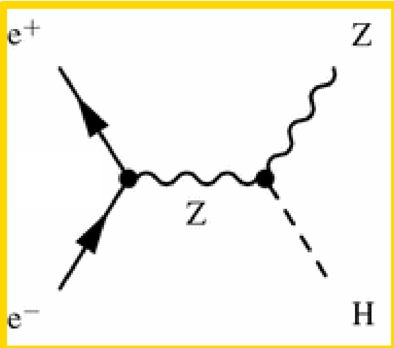
SM-like
multi-verse ?

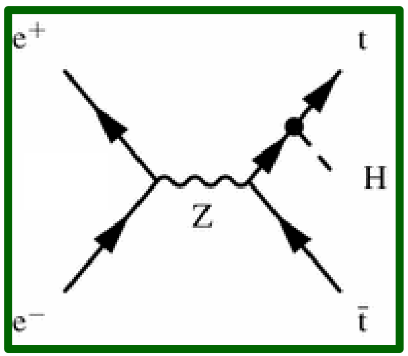


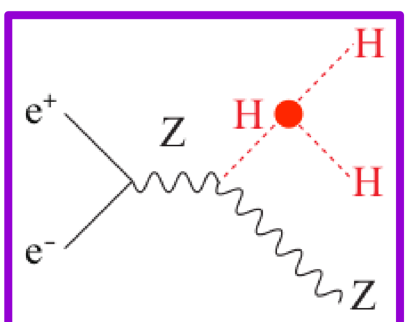
deeper physics leaves fingerprints on Higgs

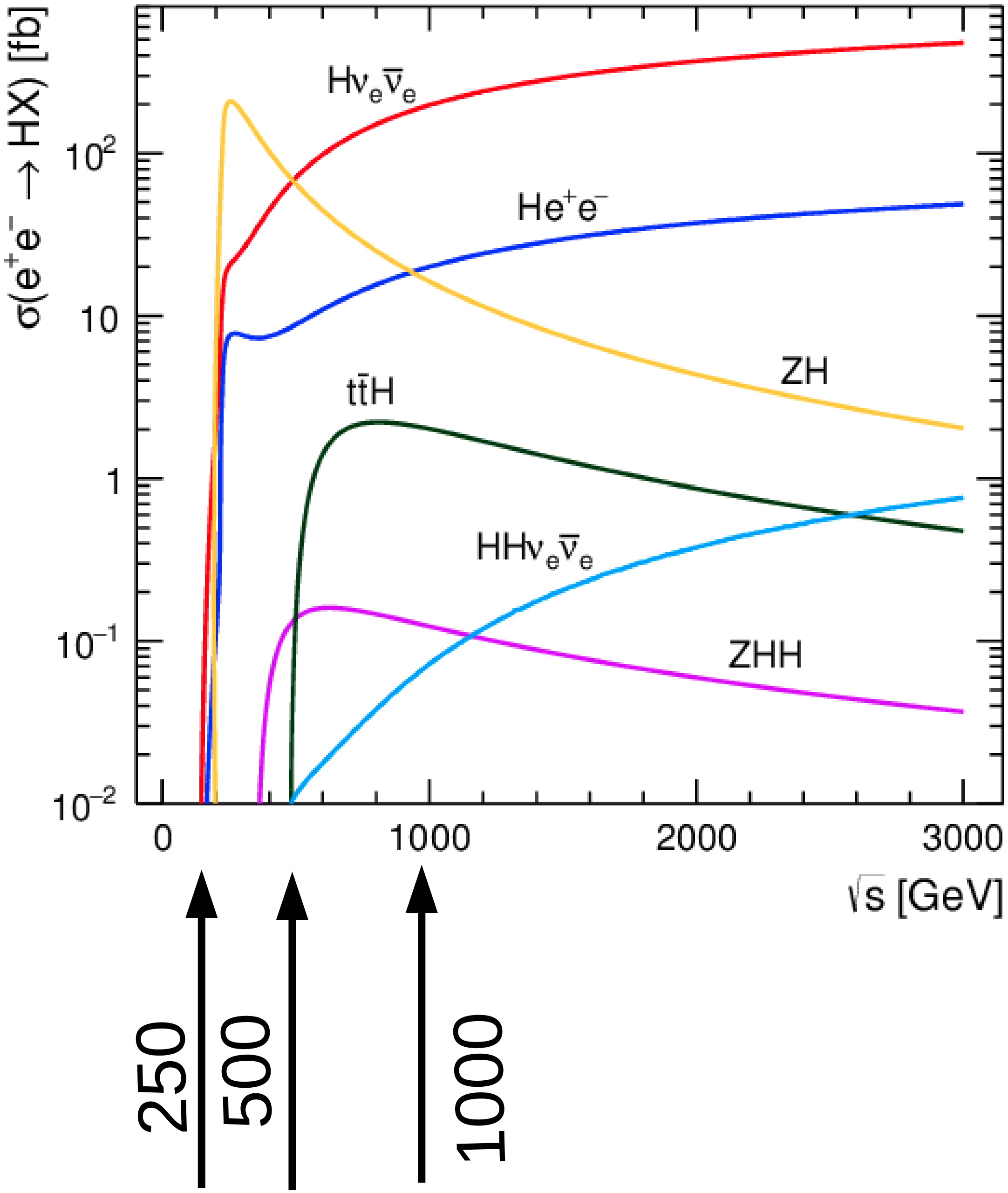
TeV-scale new physics → few-% deviations in couplings

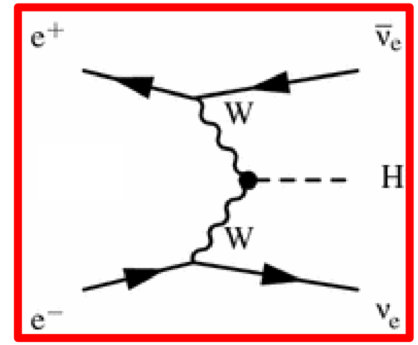
Higgs production in electron-positron collisions

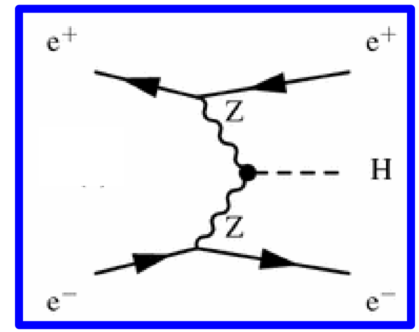


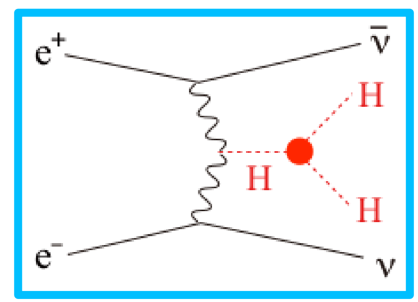




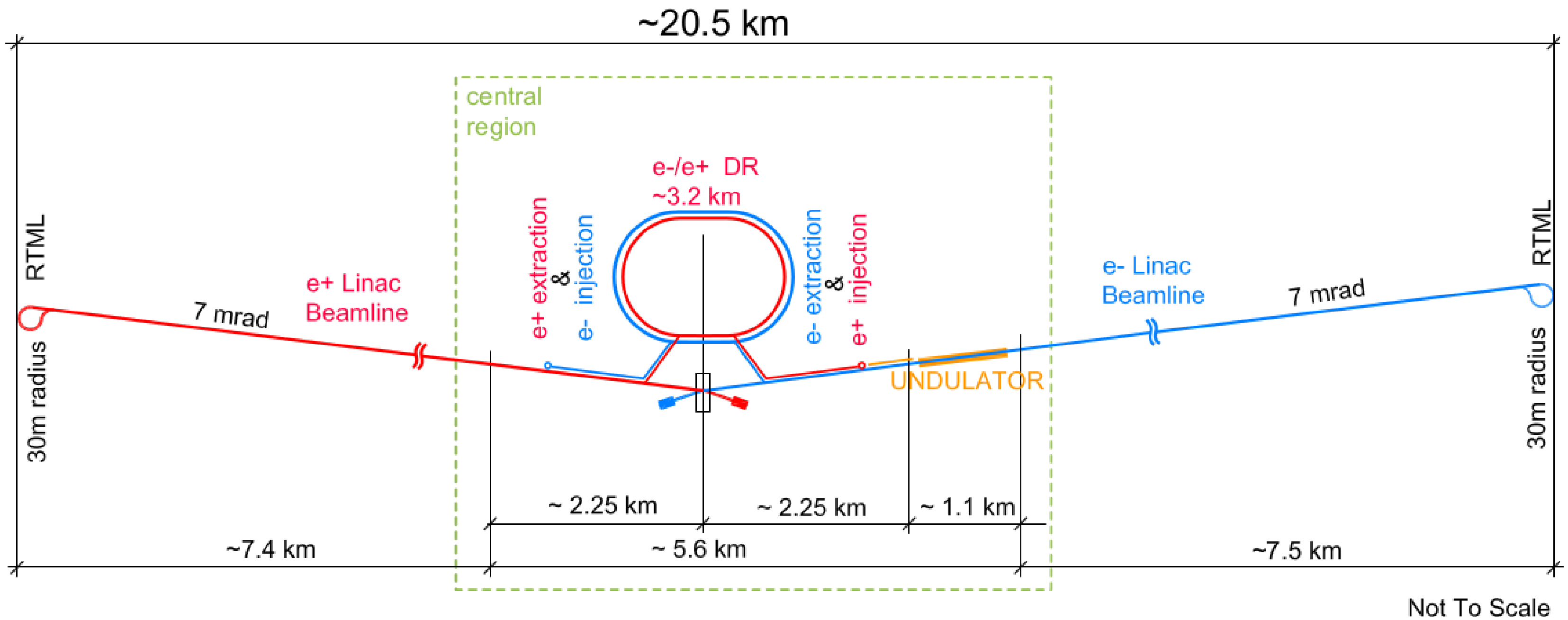




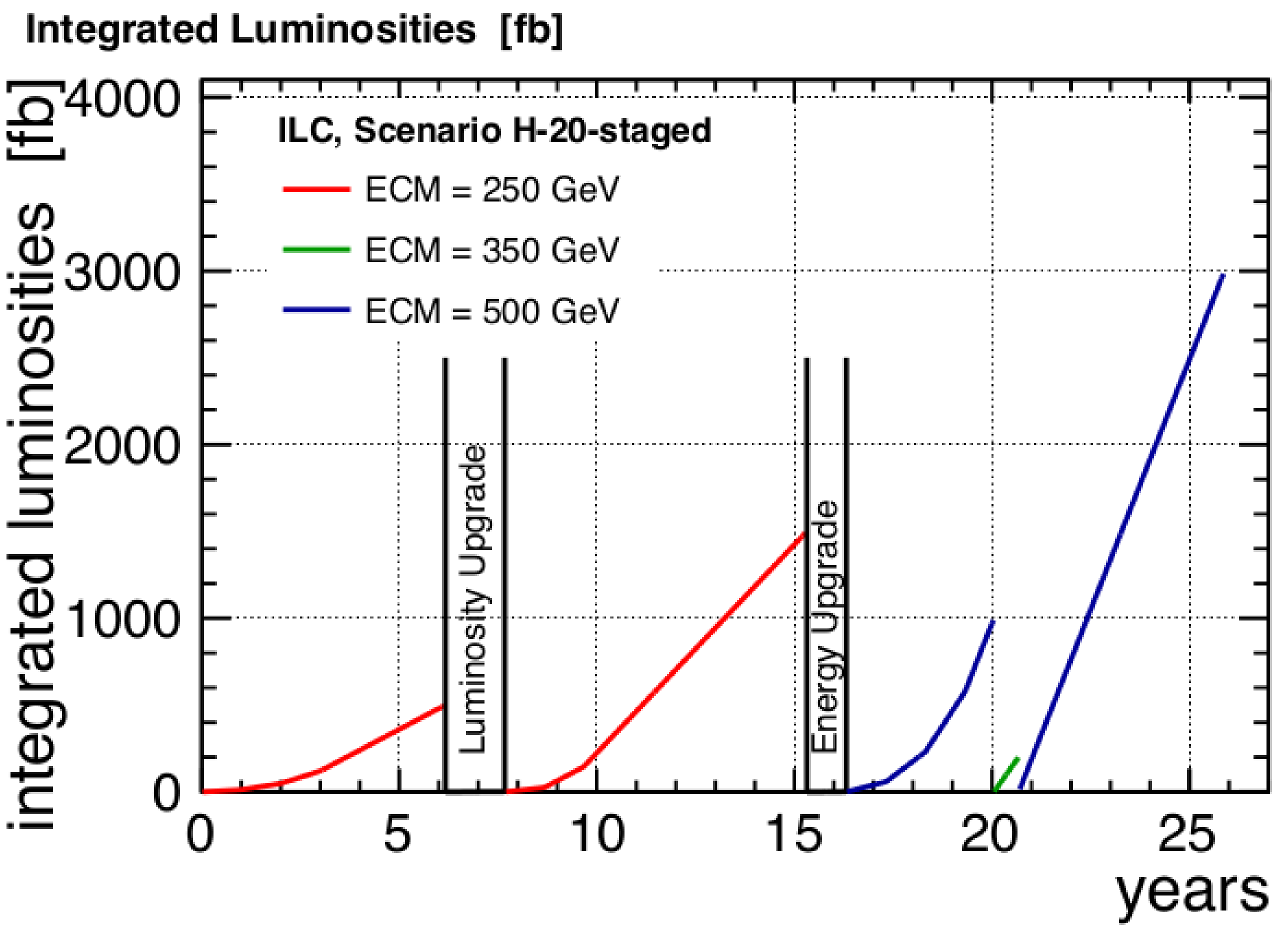




Quantity	Symbol	Unit	Initial	Upgrades	
Centre-of-mass energy	$\sqrt{s}$	GeV	250	500	1000
Luminosity	$\mathcal{L}$	($10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	1.35	1.8	4.9
Repetition frequency	f_{rep}	Hz	5	5	4
Bunches per pulse	n_{bunch}	1	1312	1312	2450
Bunch population	N_{e}	10^{10}	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	554	366
Beam current in pulse	I_{pulse}	mA	5.8	5.8	7.6
Beam pulse duration	t_{pulse}	μs	727	727	897
Average beam power	P_{ave}	MW	5.3	10.5	27.2
Norm. hor. emitt. at IP	$\gamma\epsilon_{\mathrm{x}}$	μm	5	10	10
Norm. vert. emitt. at IP	$\gamma\epsilon_{\mathrm{y}}$	nm	35	35	35
RMS hor. beam size at IP	σ^*_{x}	nm	516	474	335
RMS vert. beam size at IP	σ^*_{y}	nm	7.7	5.9	2.7
Site AC power	P_{site}	MW	129	163	300
Site length	L_{site}	km	20.5	31	40



a staged machine & staged physics program



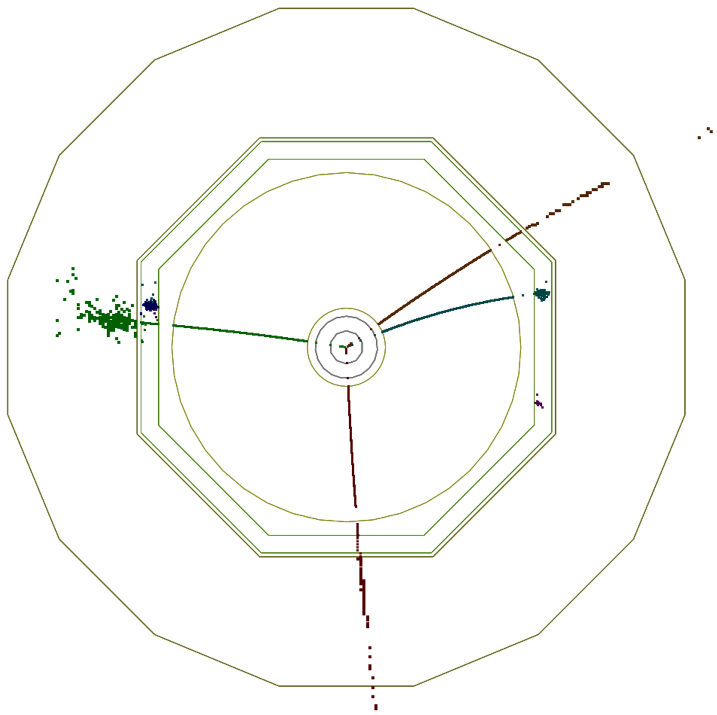
TDR design for 250 & 500 GeV,
reasonable ideas on how to get to 1 TeV

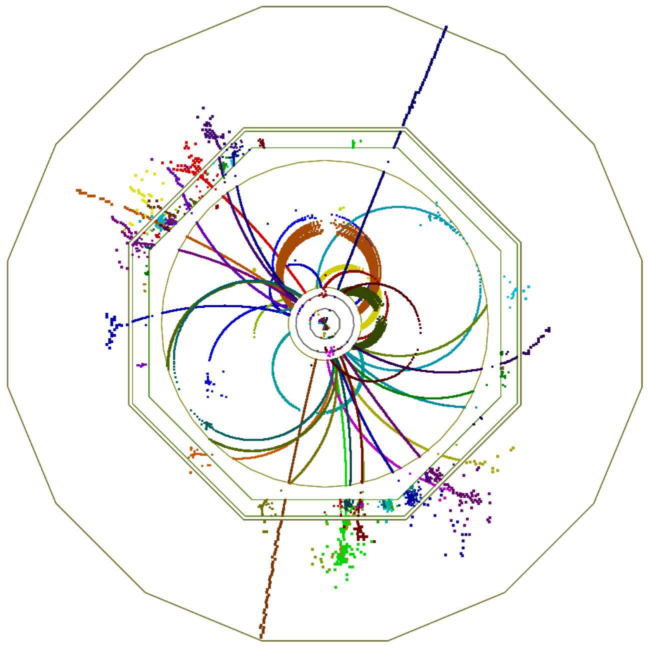
too early to propose a longer-term future,
but one can imagine installing
improved and/or new accelerator technologies

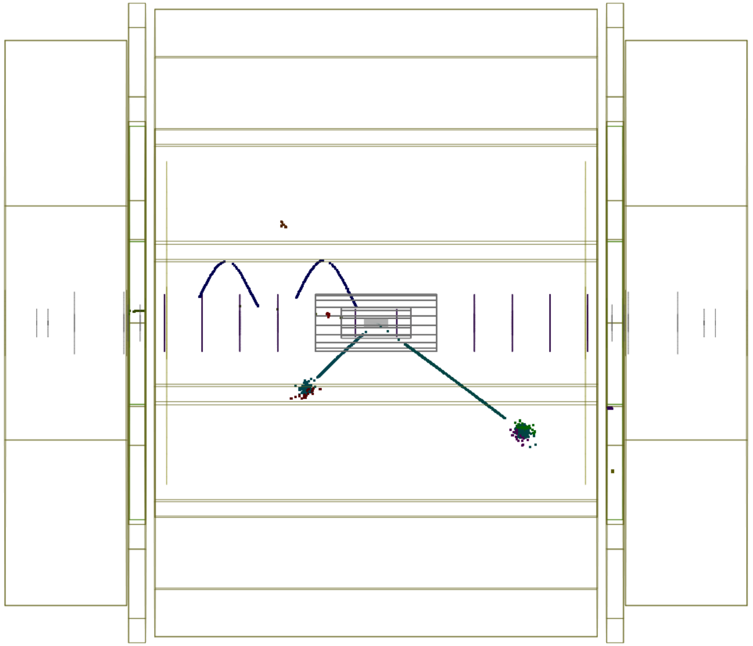
ILC will provide beams of polarised electrons and positrons
electron: 80% , positron : 30 % polarisation

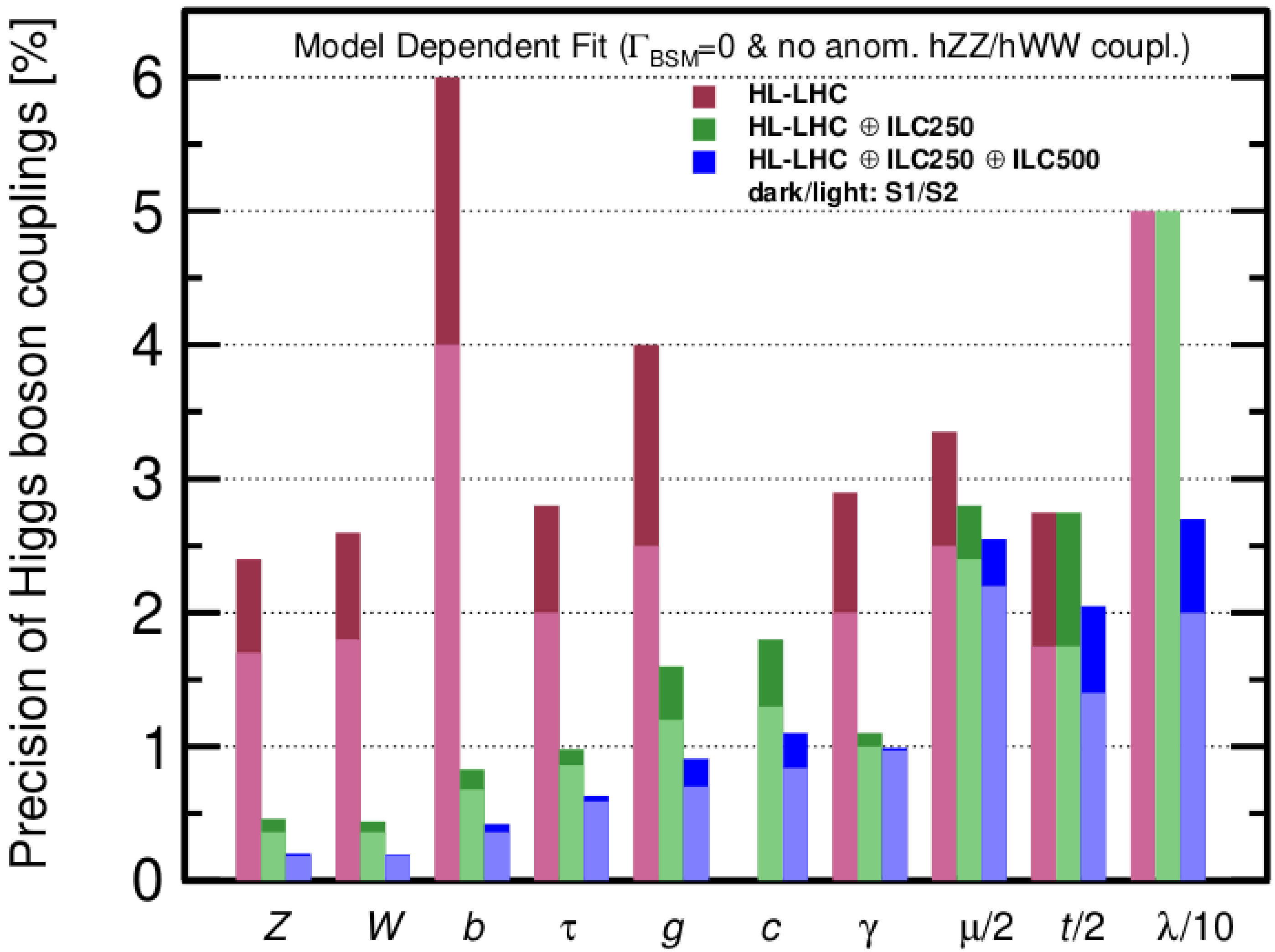
energy and sign of polarisation can “easily” be tuned

	E_{CM} (GeV)	$\int \mathcal{L}$ (fb^{-1})	fraction with $\mathrm{sign}(P(e^-), P(e^+)) =$ $(-+)$	$(+-)$	$(--)$	$(++)$
ILC250	250	2000	45%	45%	5%	5%
ILC350	350	200	67.5%	22.5%	5%	5%
ILC500	500	4000	40%	40%	10%	10%
GigaZ	91.19	100	40%	40%	10%	10%
ILC1000	1000	8000	40%	40%	10%	10%

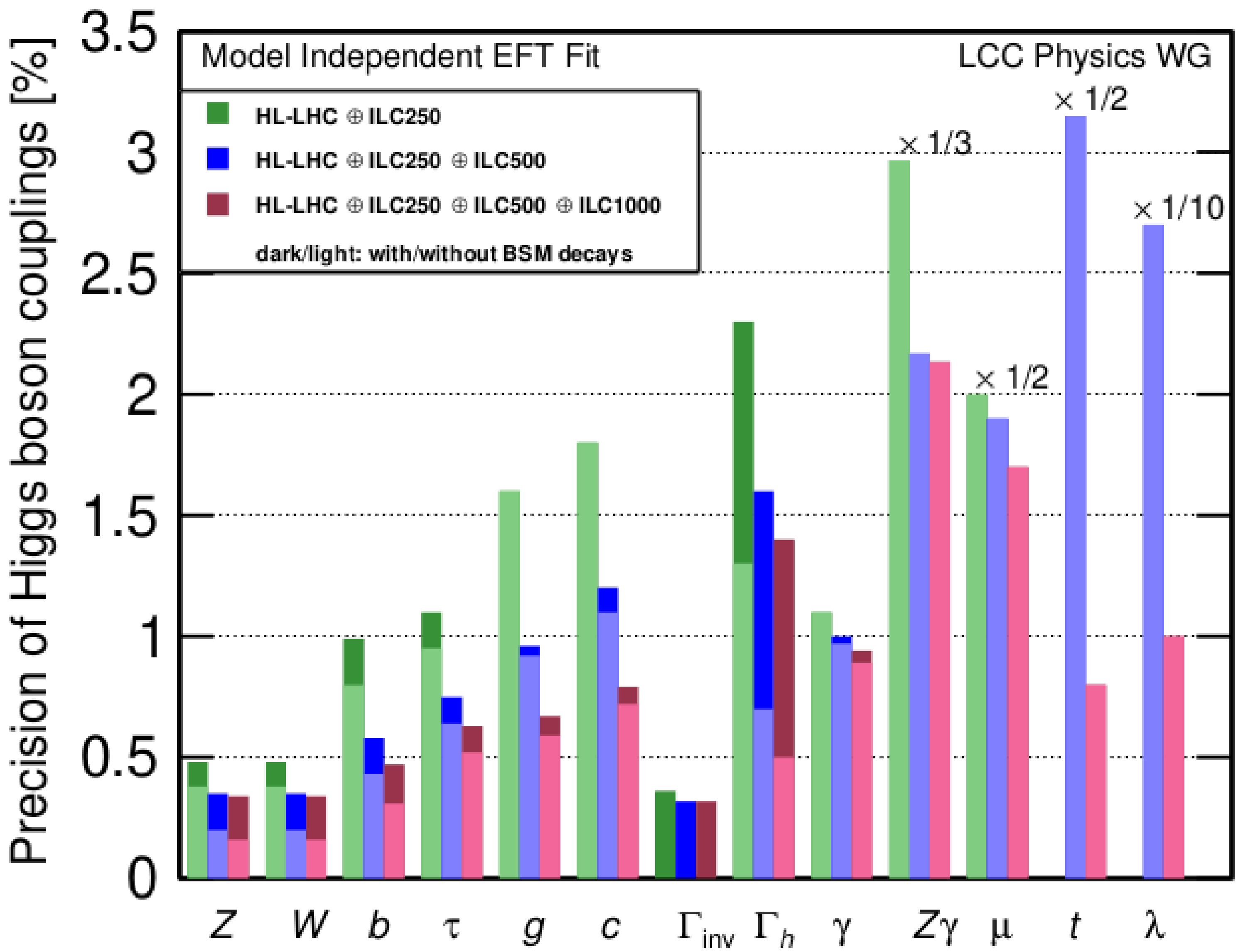








Model Dependent Fit (Γ_{BSM}=0 & no anom. hZZ/hWW coupl.)
HL-LHC
HL-LHC ⊕ ILC250
HL-LHC ⊕ ILC250 ⊕ ILC500
dark/light: S1/S2
Precision of Higgs boson couplings [%]
0
1
2
3
4
5
6
Z
W
b
τ
g
c
γ
μ/2
t/2
λ/10

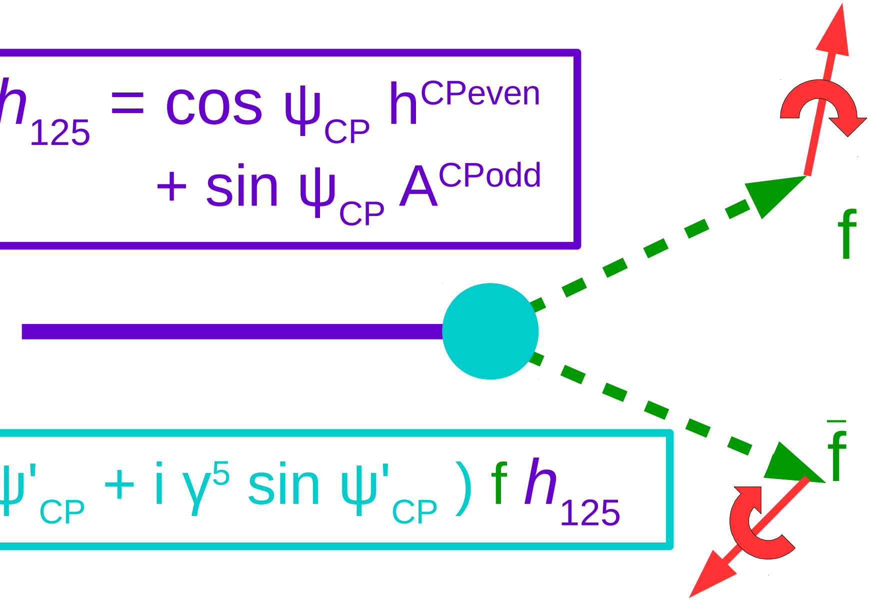


Model Independent EFT Fit
LCC Physics WG
HL-LHC ⊕ ILC250
HL-LHC ⊕ ILC250 ⊕ ILC500
HL-LHC ⊕ ILC250 ⊕ ILC500 ⊕ ILC1000
dark/light: with/without BSM decays
Precision of Higgs boson couplings [%]
× 1/3
× 1/2
× 1/2
× 1/10
Z W b τ g c Γinv Γh γ Zγ μ t λ

CP violation in Higgs sector

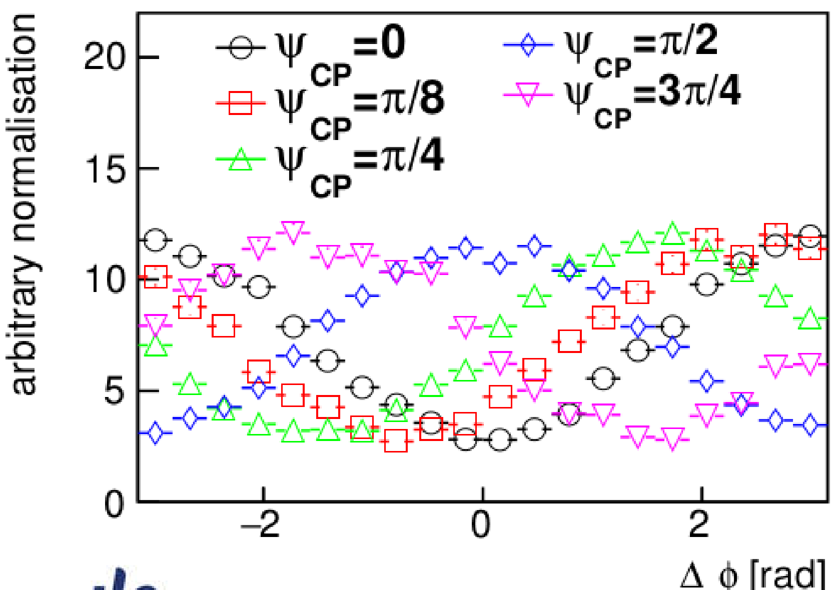
spin correlations between
tau leptons from Higgs decay

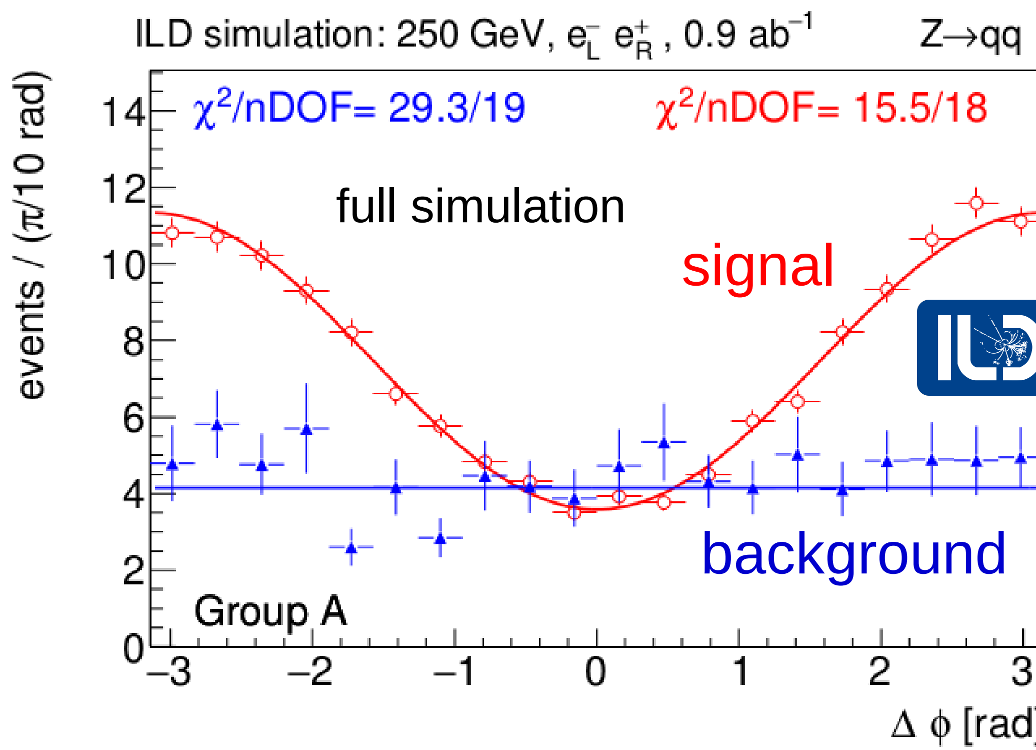
$$h_{125} = \cos\psi_{CP}\, h^{CPeven} + \sin\psi_{CP}\, A^{CPodd}$$



$$g\, \bar{f}\, (\cos\psi'_{CP} + i\,\gamma^5 \sin\psi'_{CP})\, f\, h_{125}$$

MC-level





arXiv:1804.01241

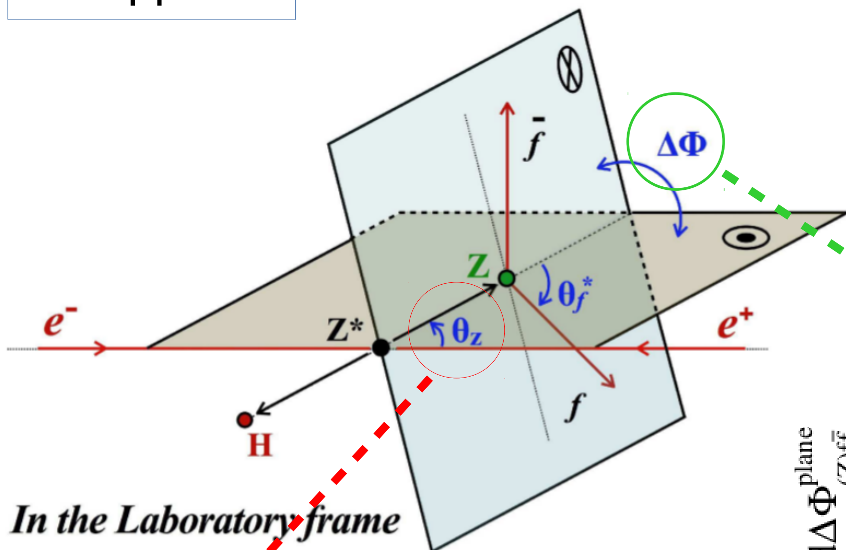
ILC250 : measure ψ_{CP} to ~4°

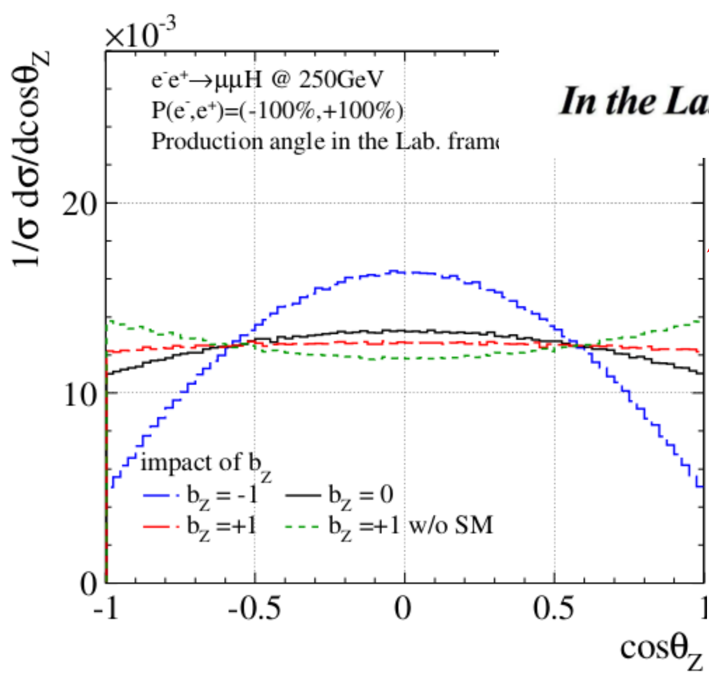
CP violation in Higgs sector : HVV coupling

$$\mathscr{L}_{ZZH} = M_Z^2\underbrace{\left(\frac{1}{v}+\frac{a_Z}{\Lambda}\right)}_{\text{“kappa”}}Z_\mu Z^\mu H + \frac{b_Z}{2\Lambda}\hat{Z}_{\mu\nu}\hat{Z}^{\mu\nu}H + \frac{\tilde{b}_Z}{2\Lambda}\hat{Z}_{\mu\nu}\tilde{\hat{Z}}^{\mu\nu}H$$

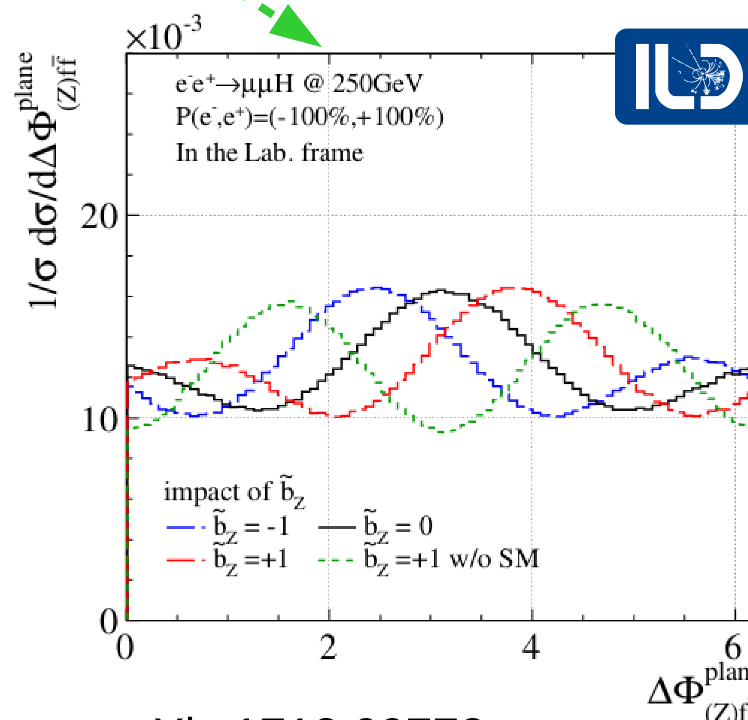
[%/TeV]–level sensitivity on a_Z/Λ, b_Z/Λ, $\tilde{b}_Z/\Lambda$

combination of 250+500 GeV disentangles contributions





can, and must, dig much deeper than “kappa”

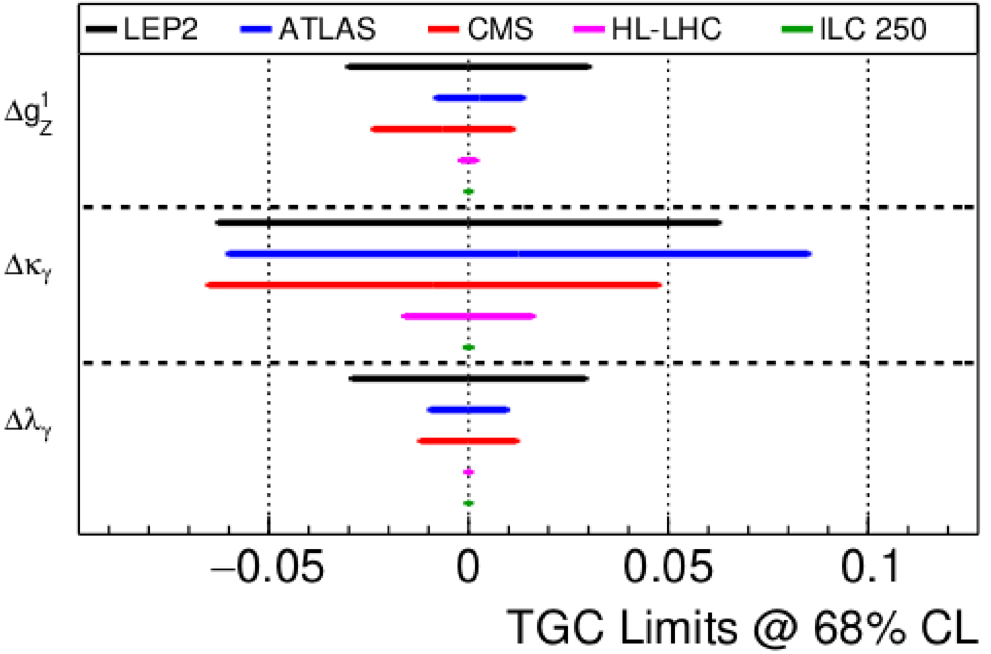


arXiv:1712.09772

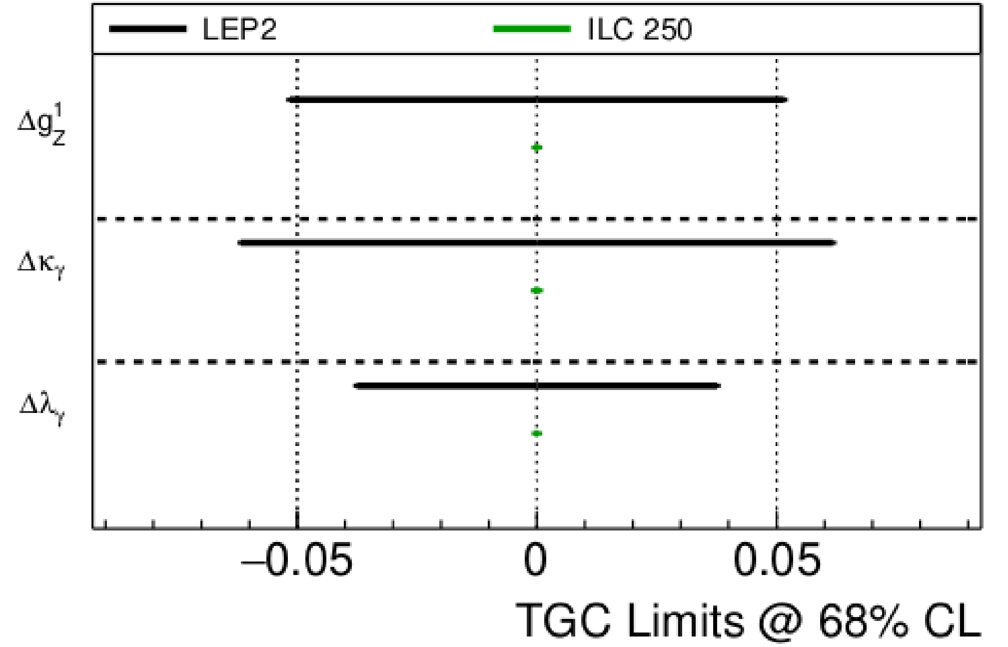
electro-weak measurements

W-pair production @ 250 GeV

single parameter



3-parameter fit



large samples of W bosons:
- directly reconstructed mass [~1 MeV] & width [~ 3 MeV]
- branching ratios [well below per-mille]

dedicated threshold scan @ 161 GeV would give
- complementary & orthogonal measurements

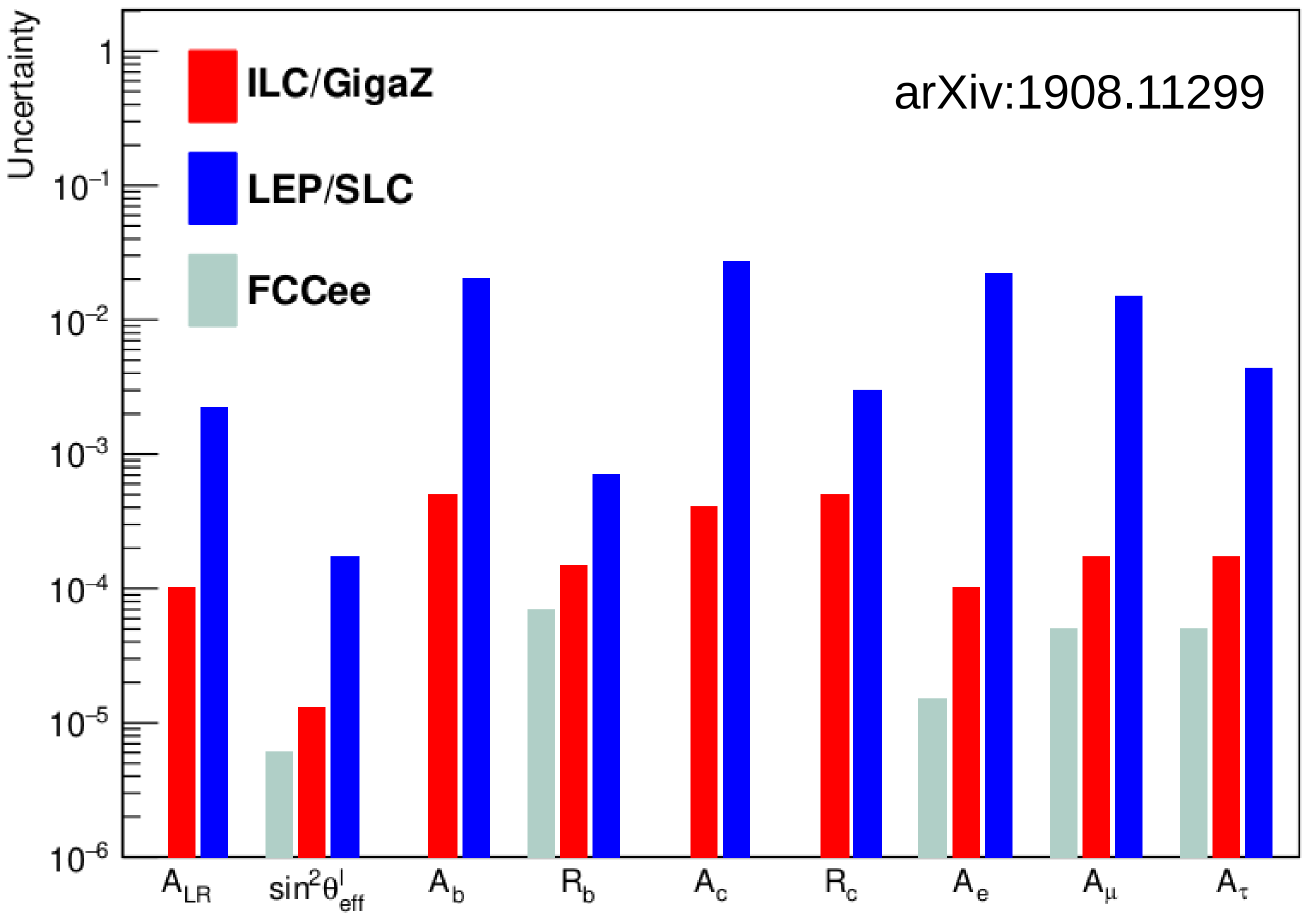
Z boson:

via the radiative return

~ 9×10^7 on-shell Z^0 @ ILC250

possibly a dedicated Z-pole run

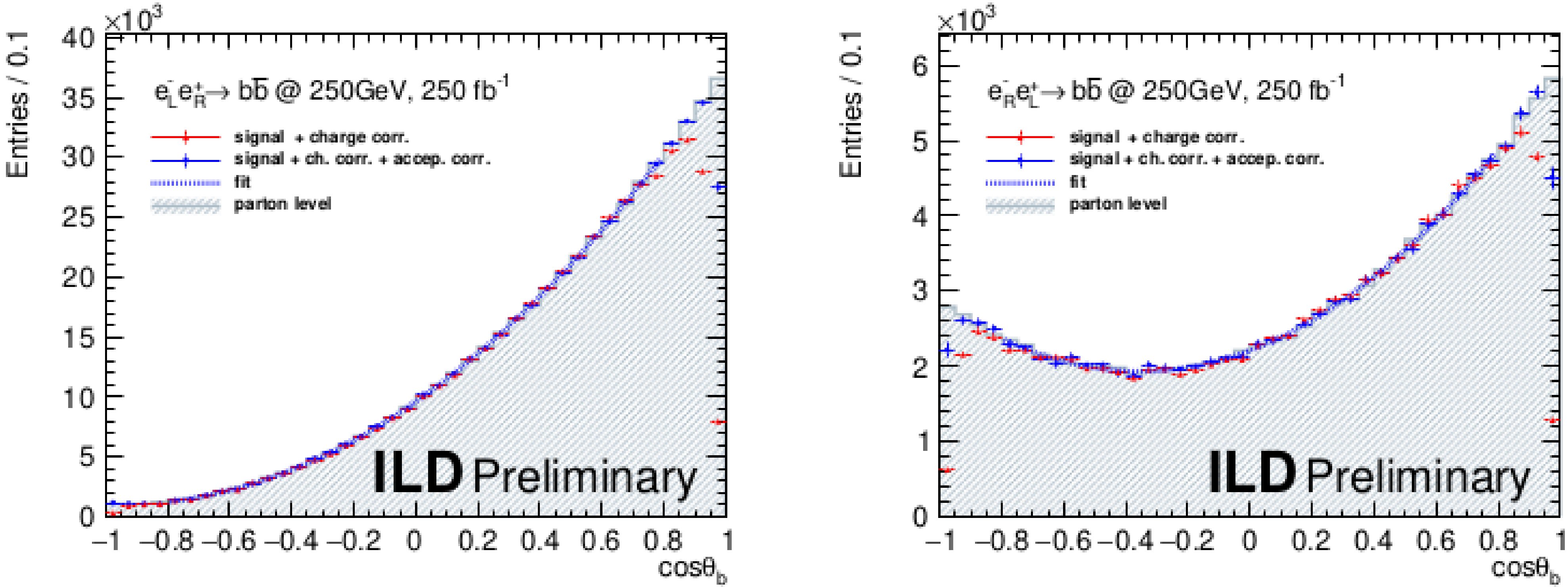
~ 5×10^9 Z^0 @ 91 GeV



electro-weak couplings of beauty

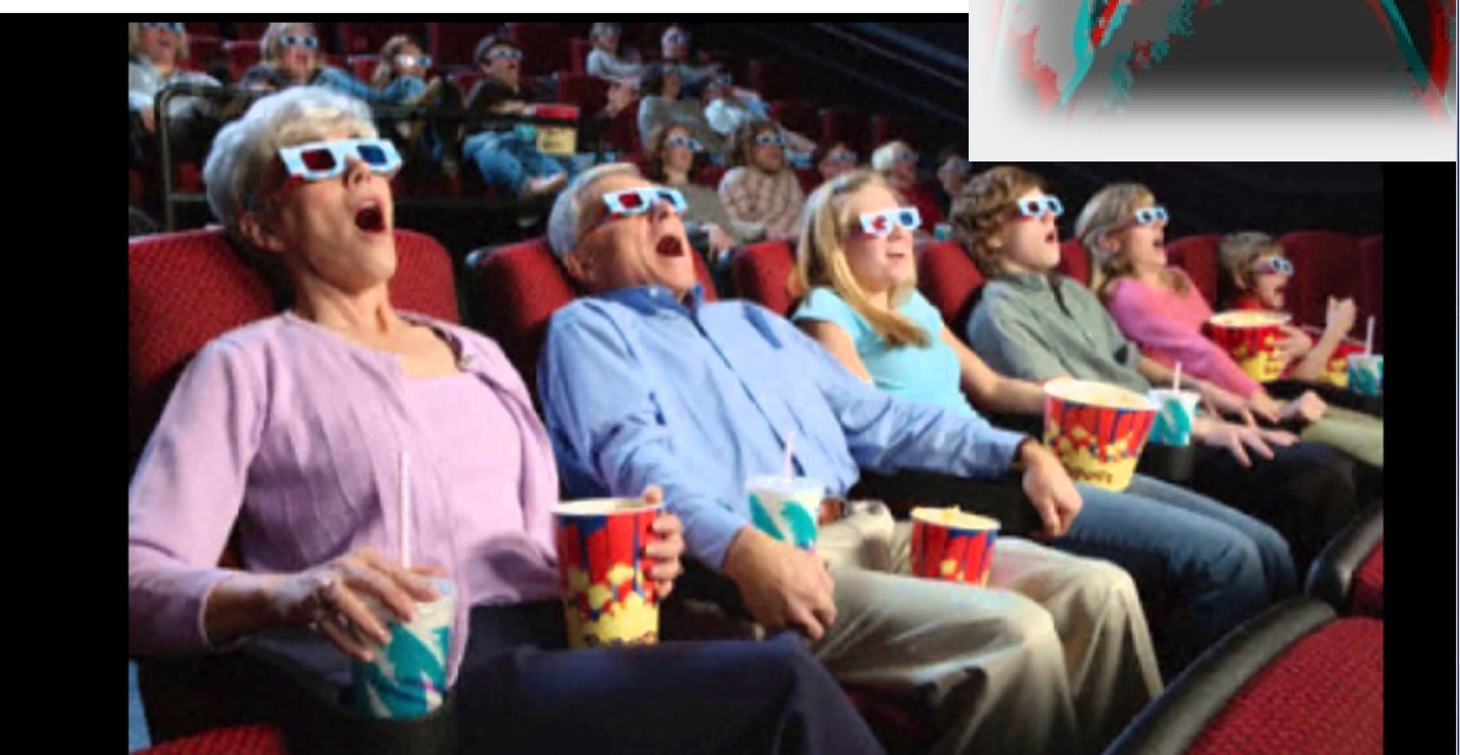
$$\frac{d\sigma}{d\cos\theta_b}(e^-_L e^+_R \to b\bar{b}) \sim (L_e L_b)^2(1+\cos\theta_b)^2 + (L_e R_b)^2(1-\cos\theta_b)^2$$

$$\frac{d\sigma}{d\cos\theta_b}(e^-_R e^+_L \to b\bar{b}) \sim (R_e R_b)^2(1+\cos\theta_b)^2 + (R_e L_b)^2(1-\cos\theta_b)^2$$



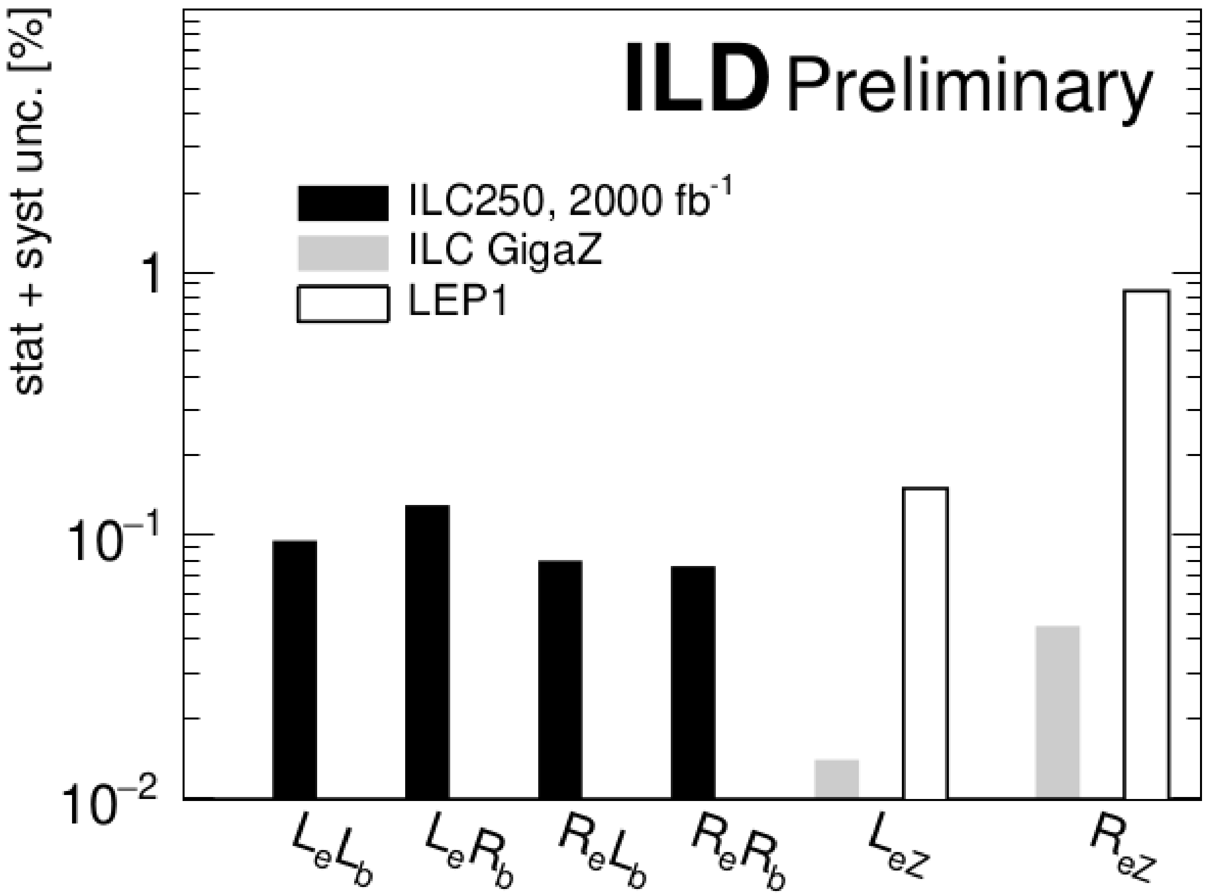
a *beautiful* example of the difference between left- and right-handed couplings beam polarisation allows us to see this L-R difference

beam polarisation
allows us to see
this L-R difference



electro-weak couplings of beauty

$$\frac{d\sigma}{d\cos\theta_b}(e^-_L e^+_R \to b\overline{b}) \sim (L_e L_b)^2(1+\cos\theta_b)^2 + (L_e R_b)^2(1-\cos\theta_b)^2$$
$$\frac{d\sigma}{d\cos\theta_b}(e^-_R e^+_L \to b\overline{b}) \sim (R_e R_b)^2(1+\cos\theta_b)^2 + (R_e L_b)^2(1-\cos\theta_b)^2$$

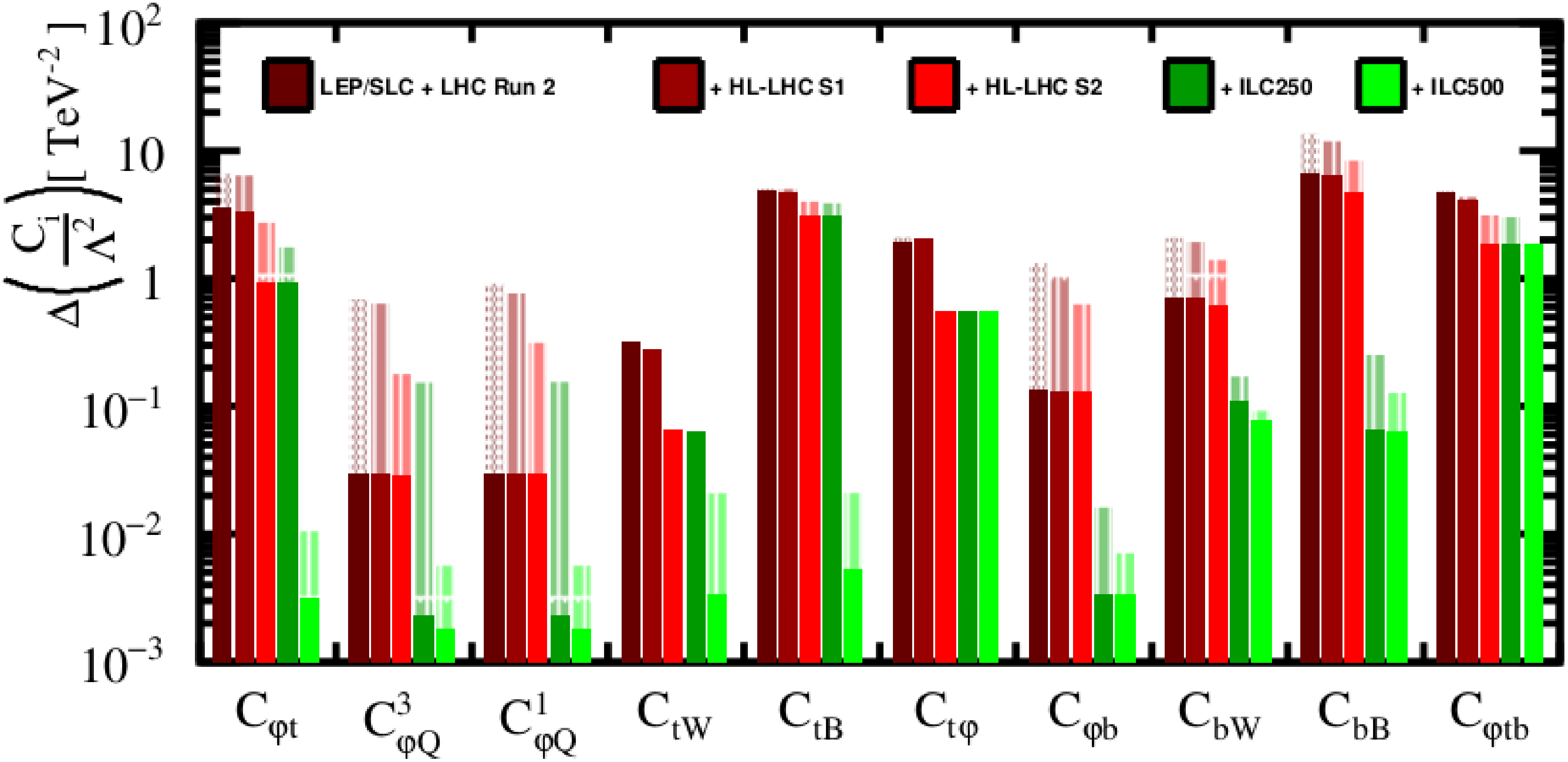


PoS(EPS-HEP2019)624

top quark

electroweak couplings

arXiv:1907.10619

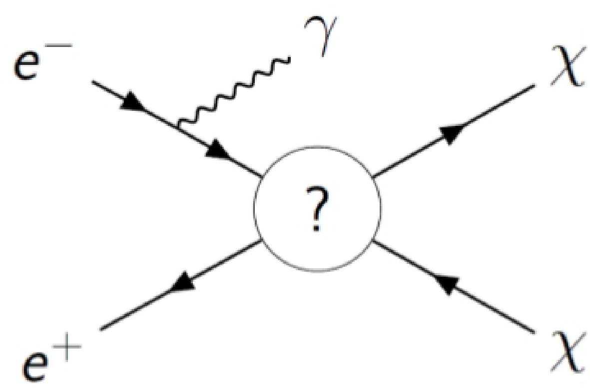


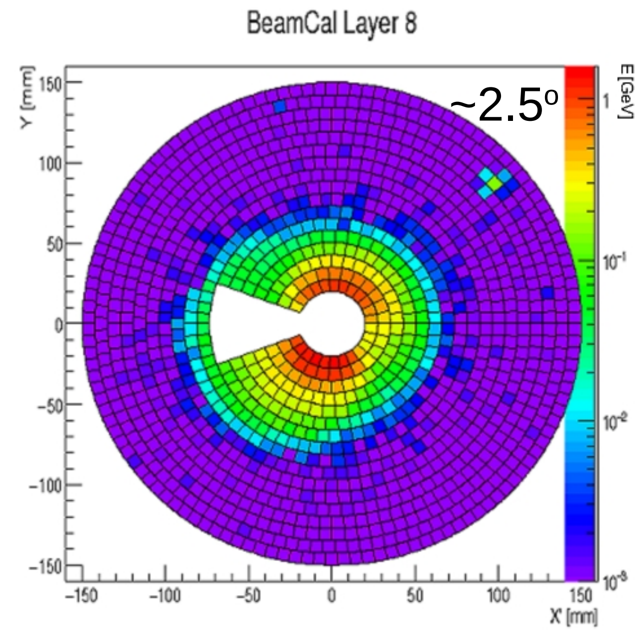
+ mass & width from threshold scan @ ~350 GeV

new physics searches

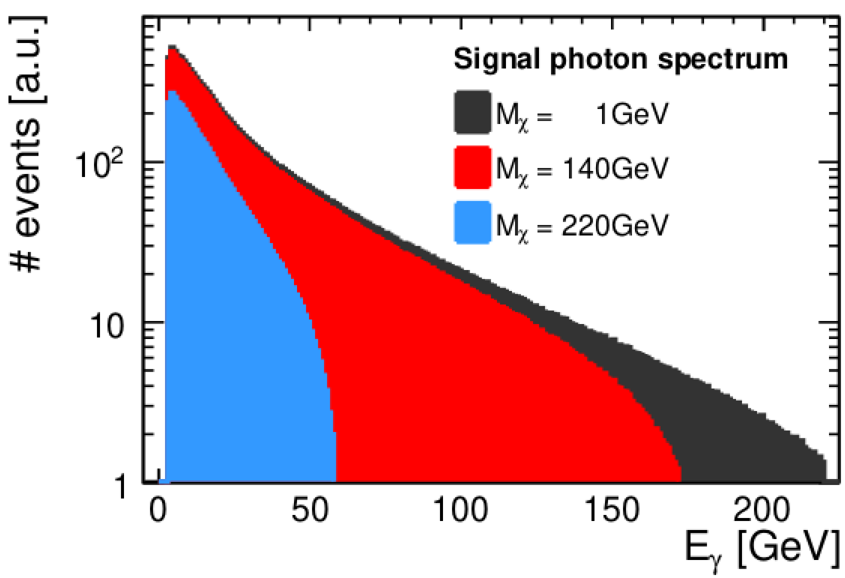
WIMP search with mono-photon signature

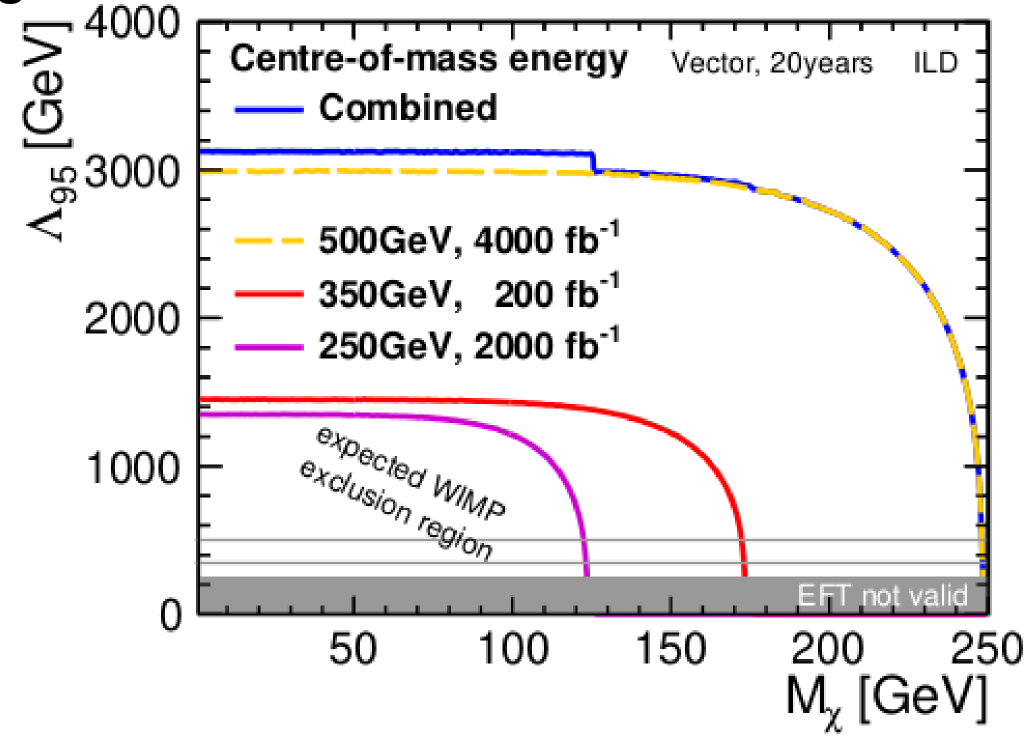
arxiv:2001.03011

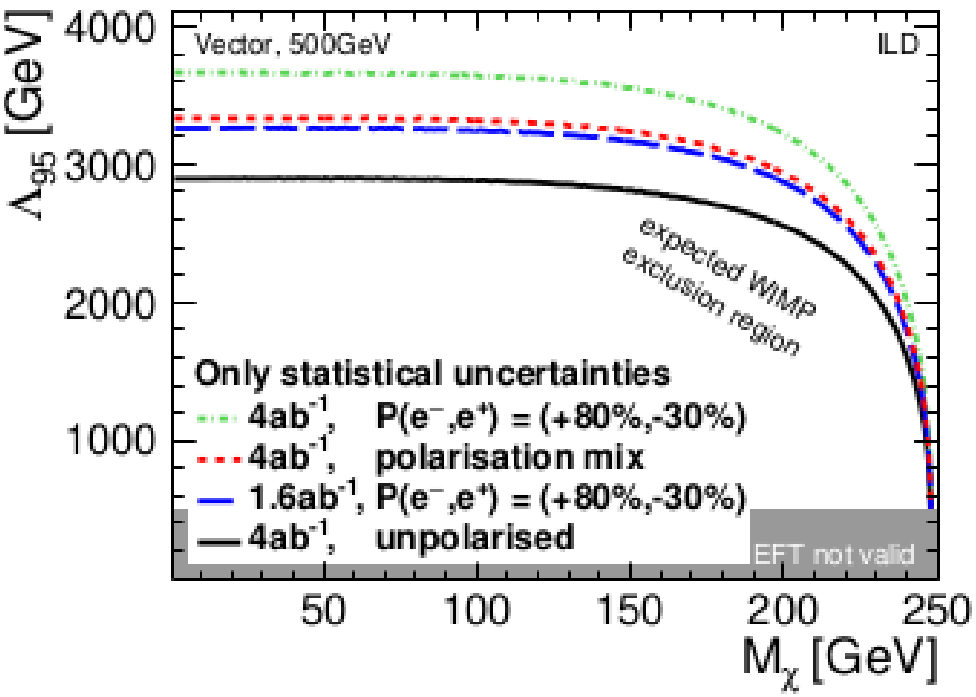


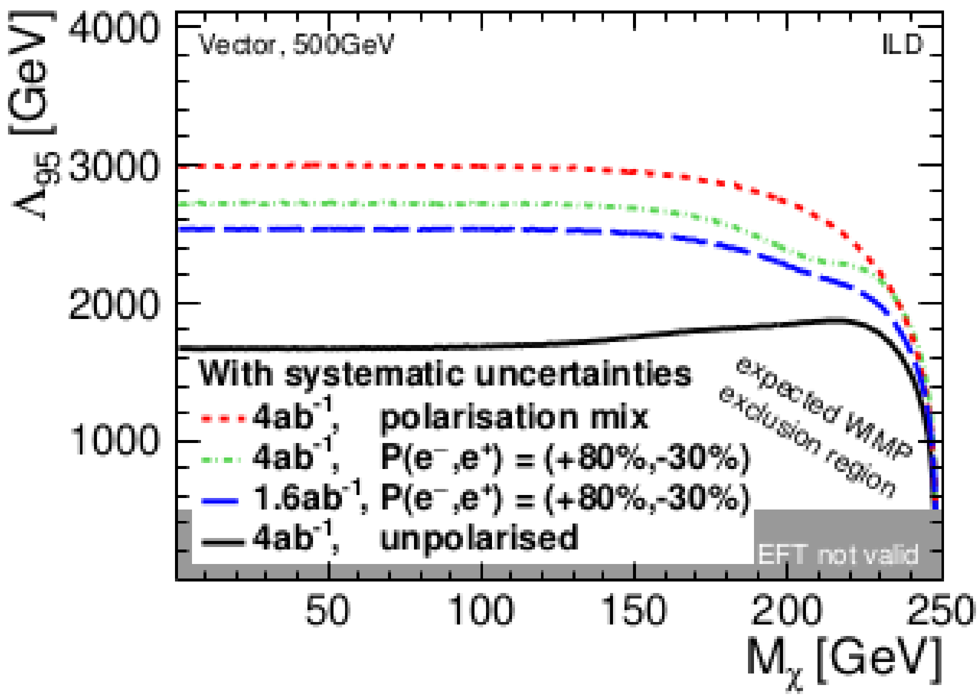


strong emphasis on
very forward region & hermiticity
to reject Bhabha scattering









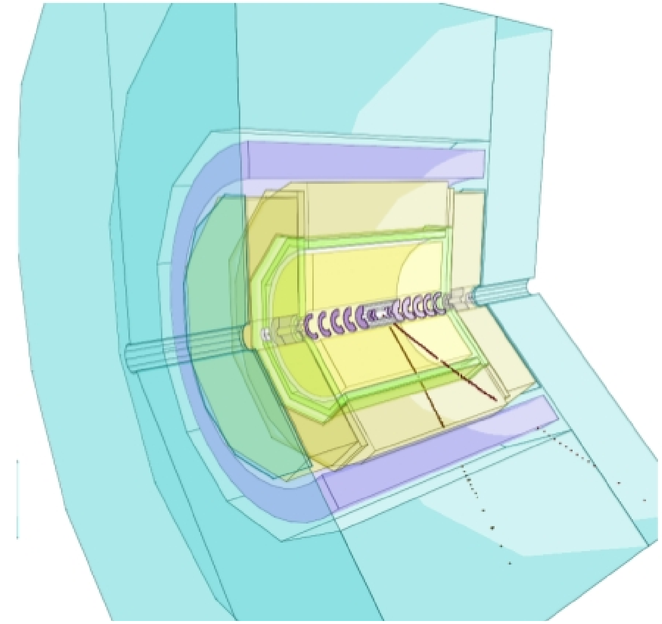
appropriate beam polarisation to suppress leading background $e^+ e^- \to \nu\, \nu\, \gamma$, maximises statistical precision

combination of datasets with different polarisations (and therefore different S/B) can provide “in situ” control of systematic uncertainties

sensitivity to natural SUSY

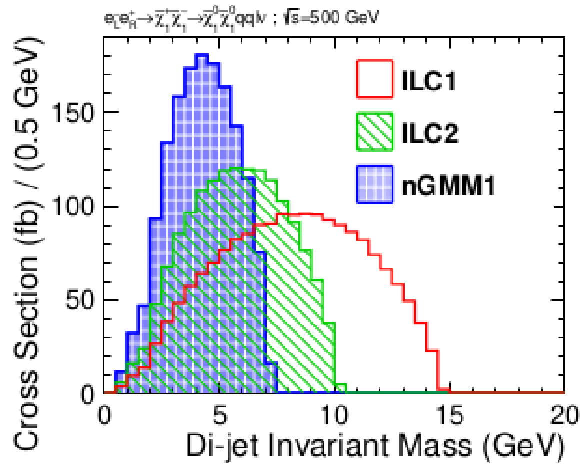
arXiv:1912.06643

studied in 3 scenarios of “natural” SUSY
- LSP is typically Higgsino
- small mass splitting to NLSP

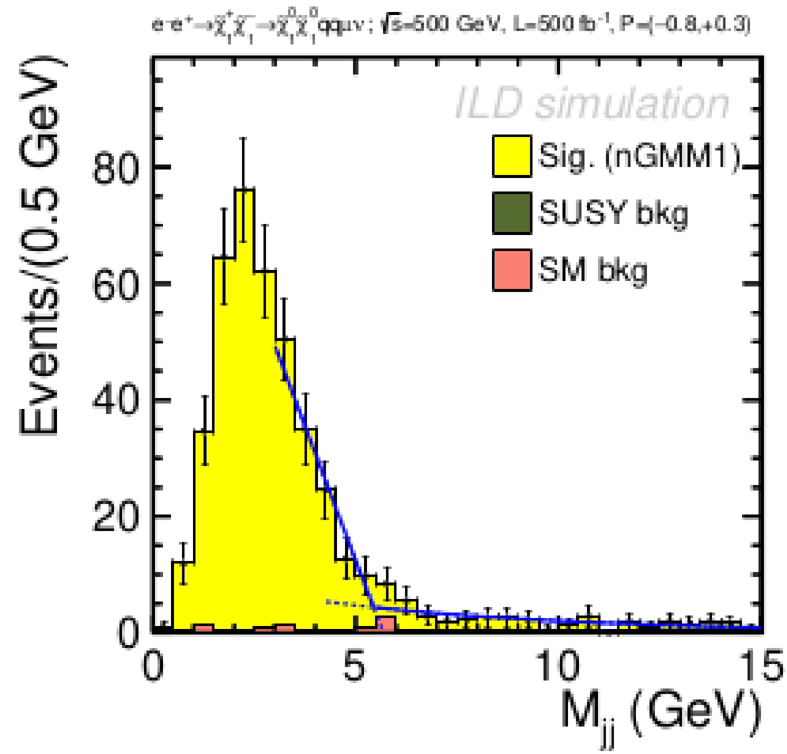


chargino channel

$$e^-_L e^+_R \to \tilde{\chi}^+_1 \tilde{\chi}^-_1 \to \tilde{\chi}^0_1 \tilde{\chi}^0_1 qql\nu$$



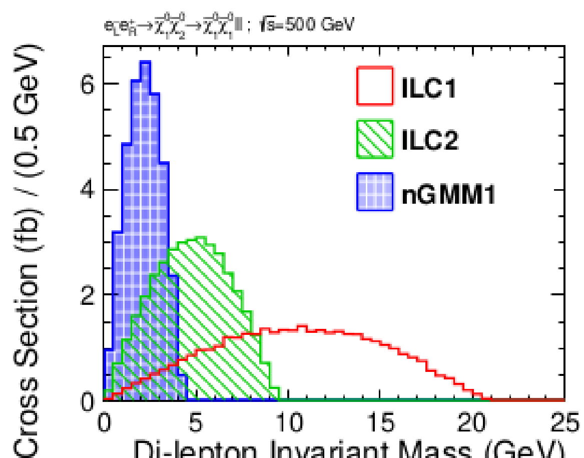
(a) chargino channel



(c) nGMM1

neutralino channel

$$e^-_L e^+_R \to \tilde{\chi}^0_1 \tilde{\chi}^0_2 \to \tilde{\chi}^0_1 \tilde{\chi}^0_1 ll$$



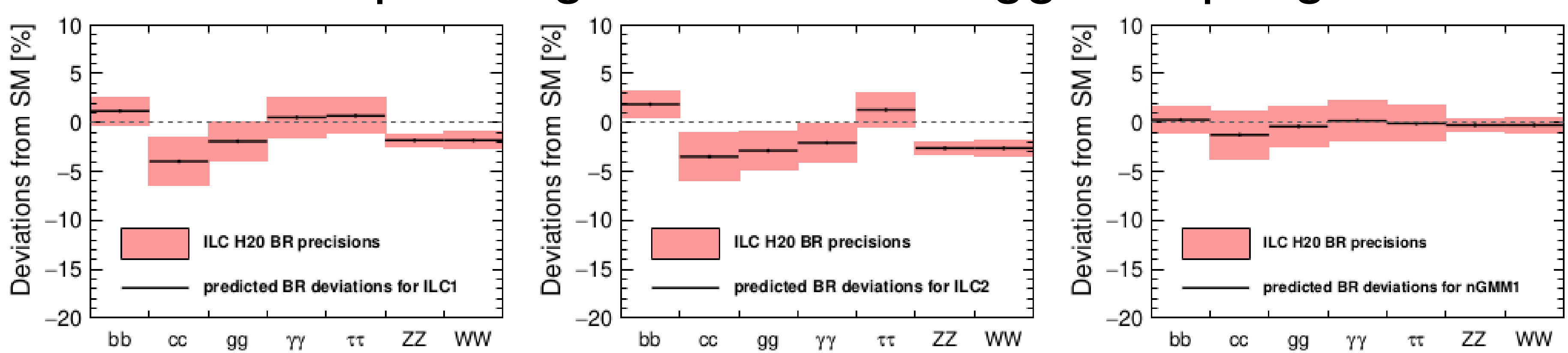
(d) neutralino channel

arXiv:1912.06643

endpoints of various distributions sensitive to new particle masses

$\sqrt{s} = 500$ GeV only		ILC1	ILC2	nGMM1
Model mass [GeV]	$m_{\tilde{\chi}_1^0}$	102.7	148.1	151.4
	$m_{\tilde{\chi}_2^0}$	124.0	157.8	155.8
	$m_{\tilde{\chi}_1^\pm}$	117.3	158.3	158.7
Precision	$\delta m_{\tilde{\chi}_1^0}/m_{\tilde{\chi}_1^0}$	0.5 %	0.7 %	1.0 %
$(\mathscr{P}_{-+}, \mathscr{L} = 500\ \mathrm{fb}^{-1})$	$\delta m_{\tilde{\chi}_2^0}/m_{\tilde{\chi}_2^0}$	0.5 %	0.7 %	1.0 %
$\oplus\ (\mathscr{P}_{+-}, \mathscr{L} = 500\ \mathrm{fb}^{-1})$	$\delta m_{\tilde{\chi}_1^\pm}/m_{\tilde{\chi}_1^\pm}$	0.5 %	0.7 %	1.0 %
Scaled precision	$\delta m_{\tilde{\chi}_1^0}/m_{\tilde{\chi}_1^0}$	0.3 %	0.4 %	0.5%
$(\mathscr{P}_{-+}, \mathscr{L} = 1600\ \mathrm{fb}^{-1})$	$\delta m_{\tilde{\chi}_2^0}/m_{\tilde{\chi}_2^0}$	0.3 %	0.4 %	0.5%
$\oplus\ (\mathscr{P}_{+-}, \mathscr{L} = 1600\ \mathrm{fb}^{-1})$	$\delta m_{\tilde{\chi}_1^\pm}/m_{\tilde{\chi}_1^\pm}$	0.3 %	0.4 %	0.5%

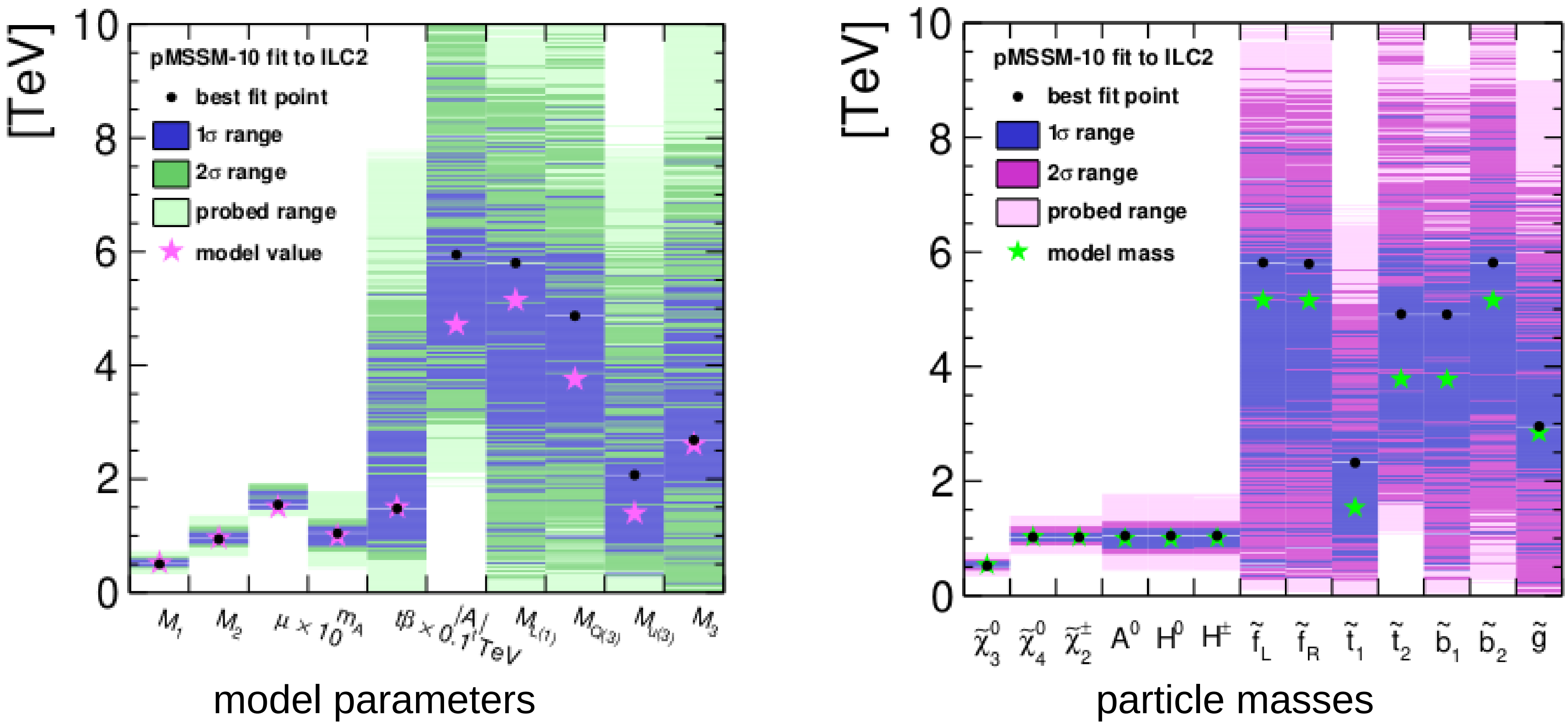
corresponding variations in Higgs couplings



(a) ILC1 (b) ILC2 (c) nGMM1

arXiv:1912.06643

measured parameters of new particles can then be used to extract model parameters and predict masses of other particles in the model



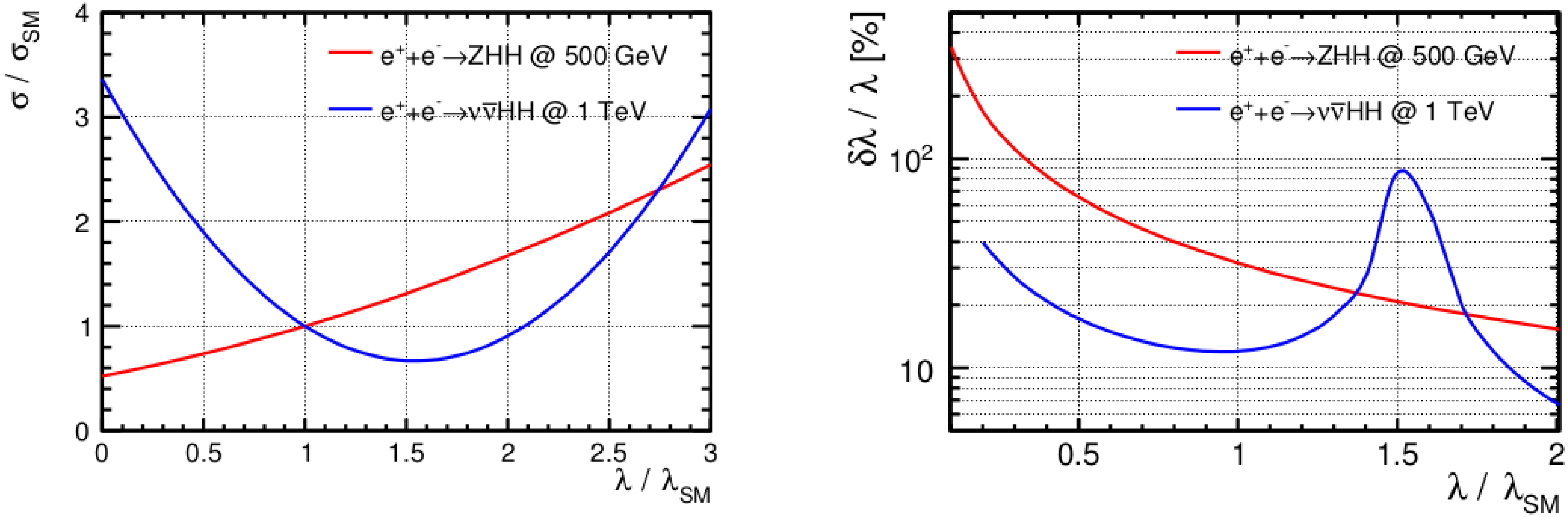
→ specific guidance for future studies / facilities

summary

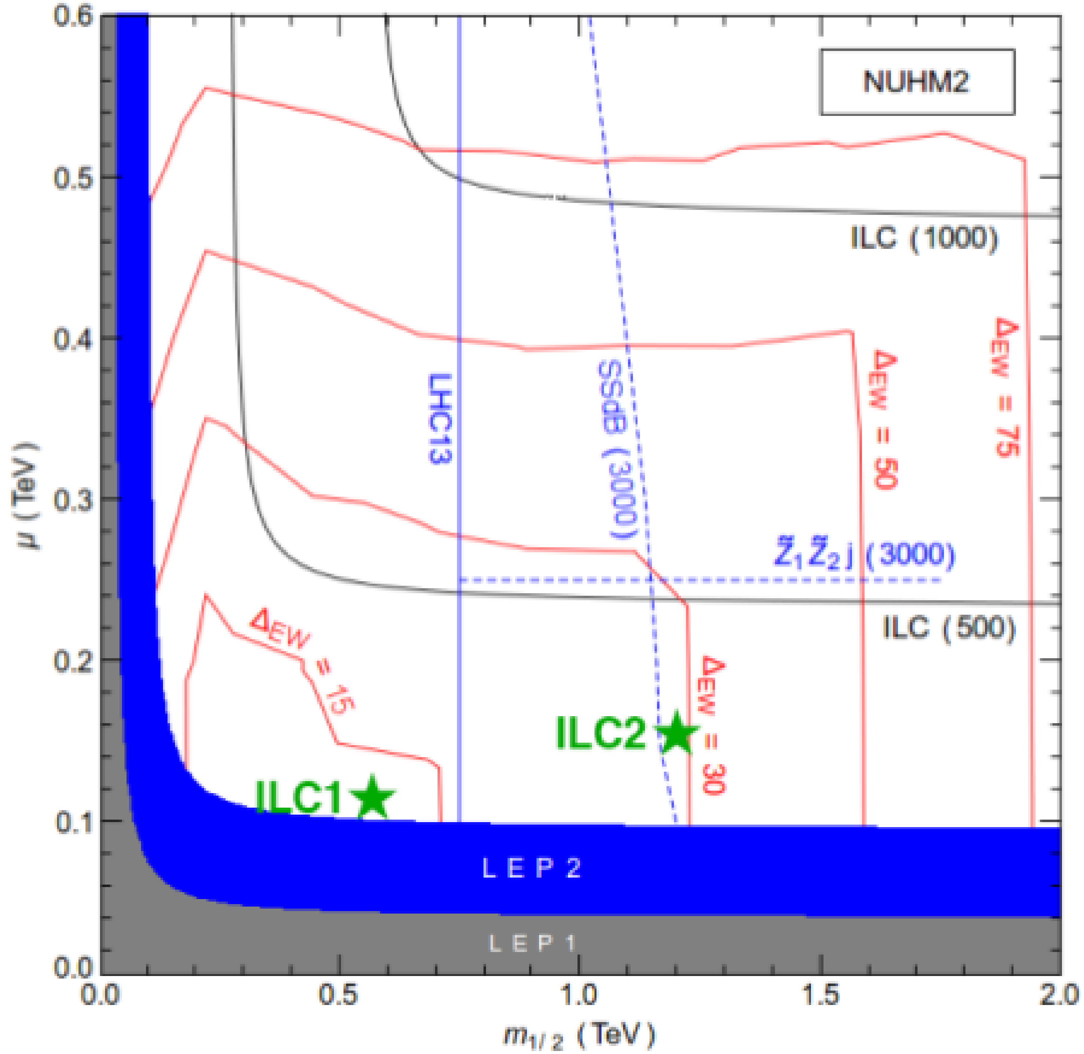
main target: Higgs
- well-established physics capabilities @ 250 GeV and beyond

electroweak:
- large numbers of Z & W,
  - orders of magnitude more than LEP/SLC
- top quarks
- beam polarisation and wide energy range
  - increase sensitivity to anoumalous couplings

new particle searches:
- sensitive to soft or invisible new particle signatures
- beam polarisation can help find it,
  - and to untangle its nature



σ / σ_{SM}
$e^+ + e^- \to ZHH$ @ 500 GeV
$e^+ + e^- \to \nu\bar{\nu}HH$ @ 1 TeV
λ / λ_{SM}
$\delta\lambda / \lambda$ [%]
$e^+ + e^- \to ZHH$ @ 500 GeV
$e^+ + e^- \to \nu\bar{\nu}HH$ @ 1 TeV
λ / λ_{SM}


NUHM2
ILC (1000)
ILC (500)
LHC13
SSdB (3000)
$\tilde{Z}_1\tilde{Z}_2 j$ (3000)
Δ_{EW} = 15
Δ_{EW} = 30
Δ_{EW} = 50
Δ_{EW} = 75
ILC1
ILC2
L E P 2
L E P 1
μ (TeV)
$m_{1/2}$ (TeV)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
0.5
1.0
1.5
2.0