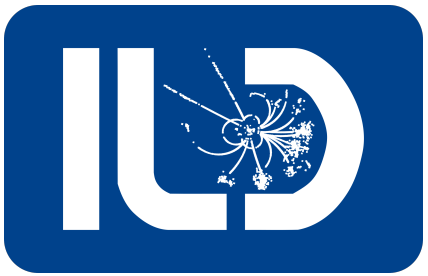


[15 mins incl. questions]

Study of

Higgs couplings to leptons

and

Higgs CP properties

at the ILC

Daniel Jeans, KEK
for the International Large Detector group

ICHEP 2018, Seoul

The International Linear Collider Project

Higgs coupling to leptons

- BR (H → μ μ)
- BR (H → τ τ)

Higgs CP properties in

- H → τ τ
- H → ZZ, WW

Summary

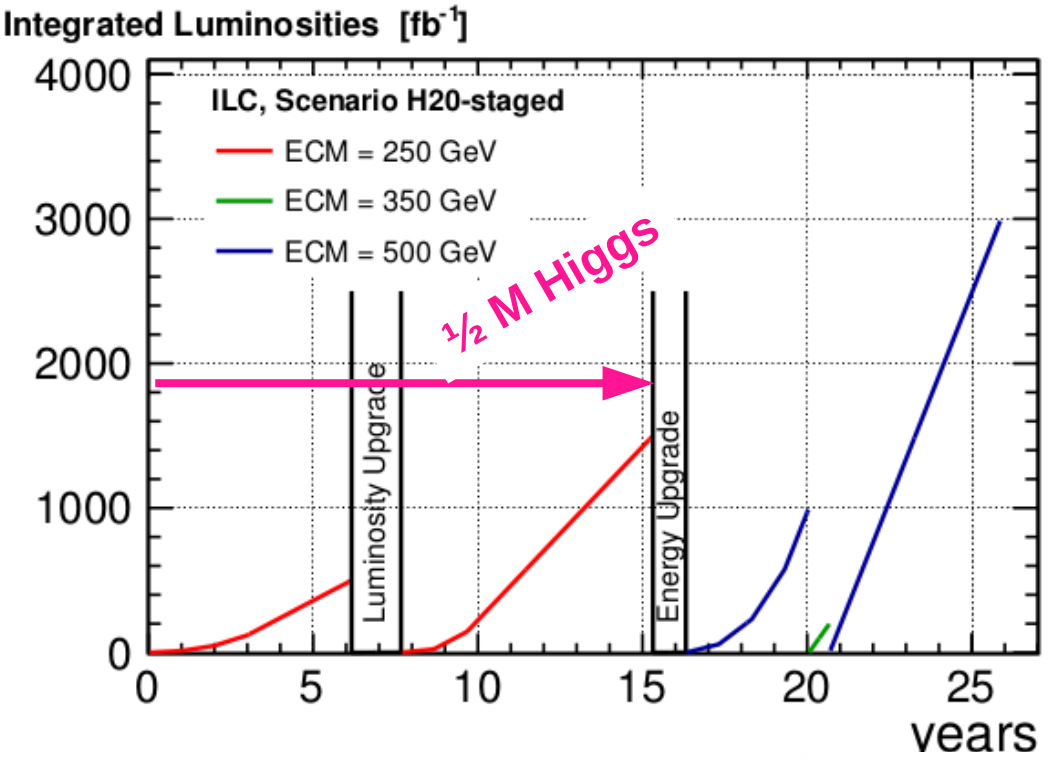
International Linear Collider

electron – positron collisions
SCRF accelerating technology
beam polarisation:
e⁻ 80%, e⁺ 30%
luminosity ~10^{34} cm^{-2} s^{-1}

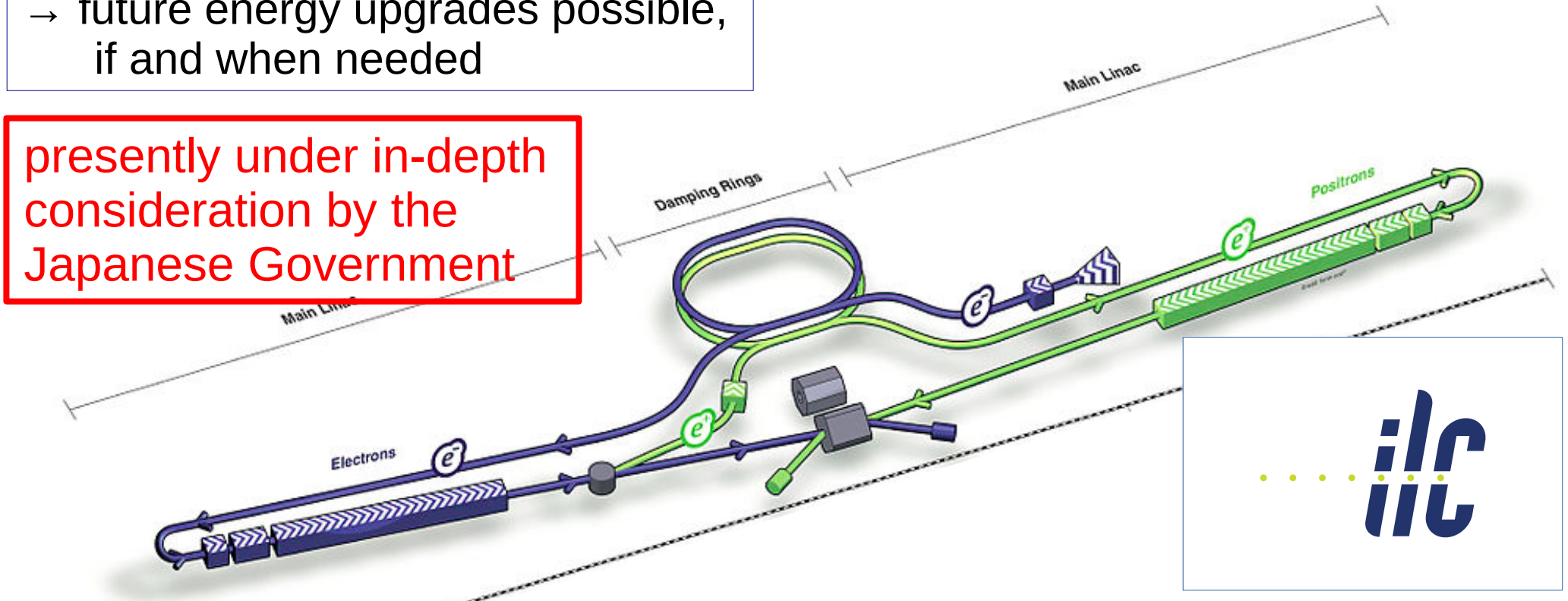
see talk by J. Reuter

start with collisions at 250 GeV

linear accelerator
→ future energy upgrades possible, if and when needed



presently under in-depth consideration by the Japanese Government



ILC 250 physics program

2 ab^{-1} over ~15 years

electro-weak symmetry breaking

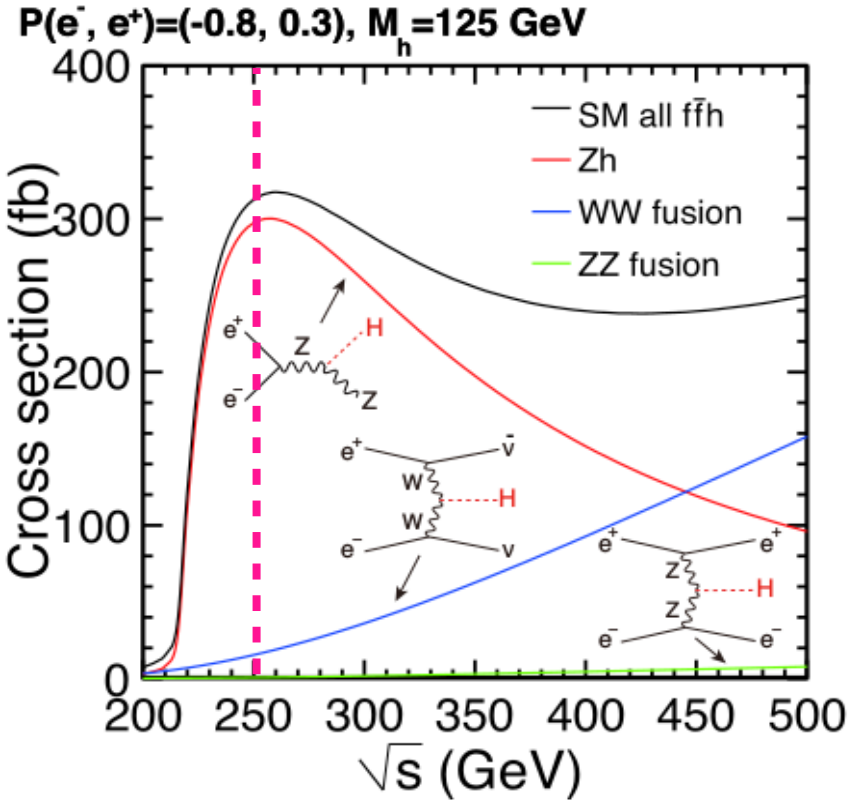
comprehensive and precise
study of Higgs sector

see talk by
T. Ogawa

electro-weak processes
LEP2 + polarisation
~ 1000 times more data

see talk by
S. Bilokin

→ indirect bounds on new physics beyond SM



direct searches for BSM particles

profit from trigger-less readout

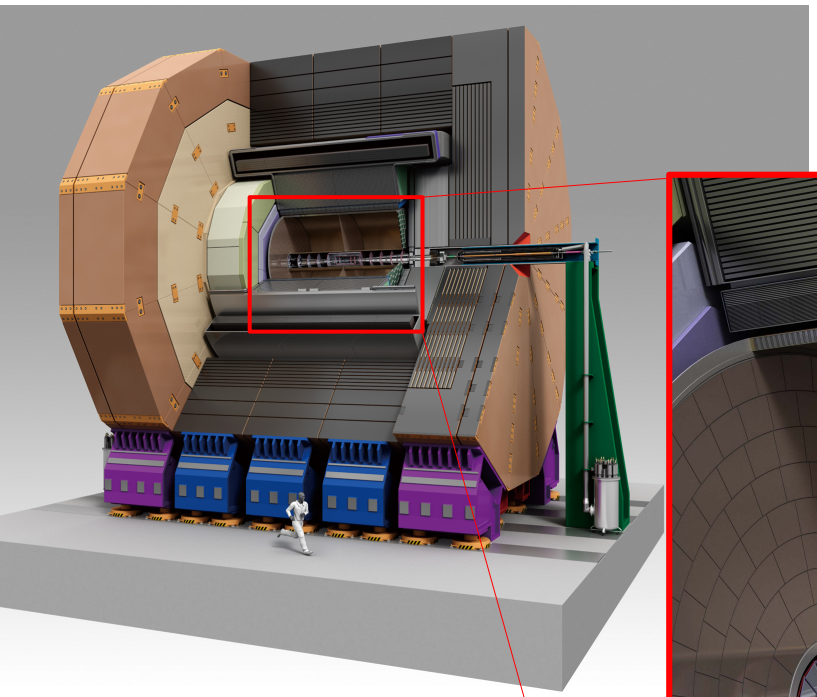
efficiency for lower
energy signatures

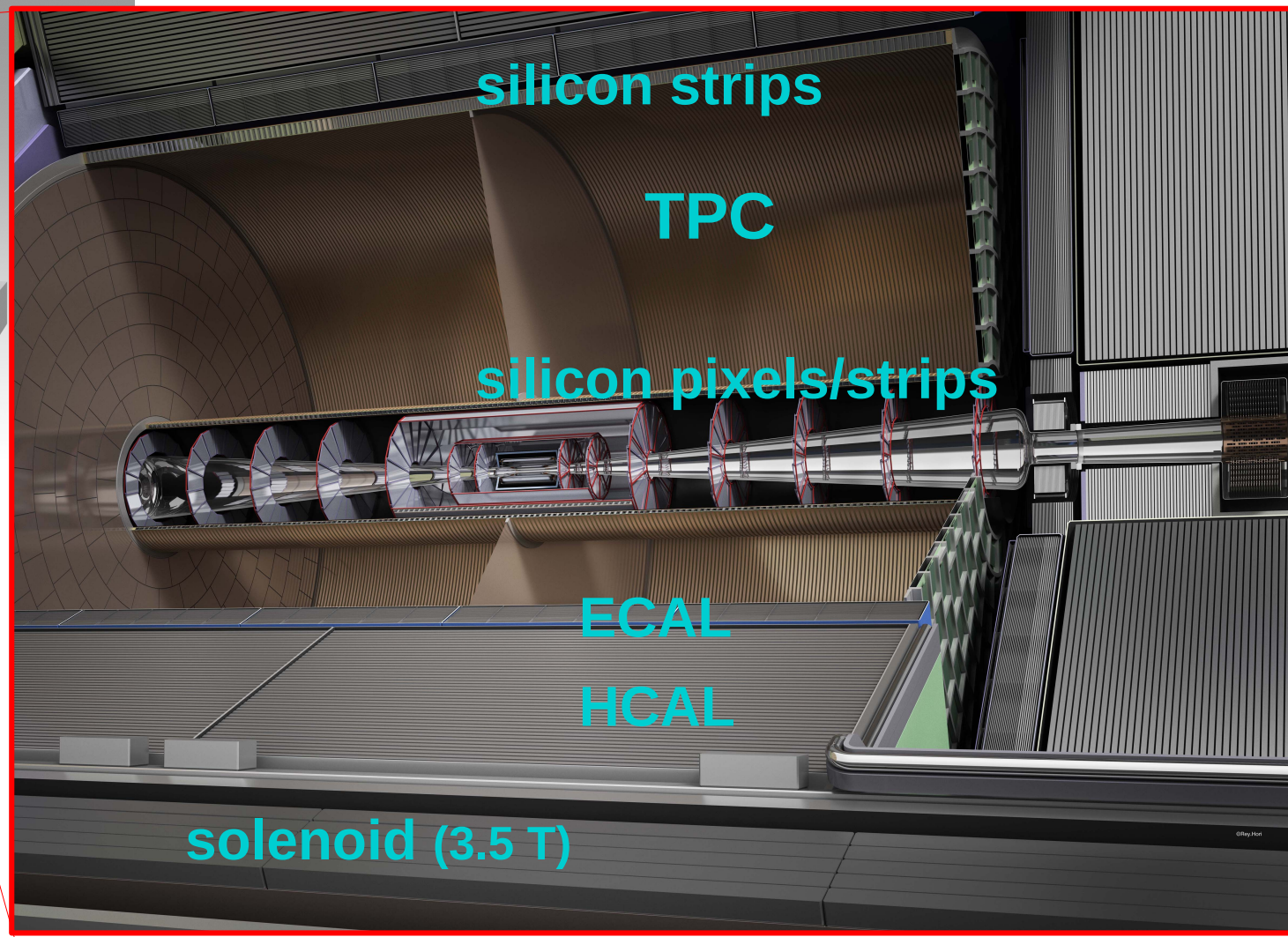
see talks by
M. Berggren,
Y. Wang

International Large Detector

one of two detector concepts being developed for ILC

high precision detector optimised for
particle flow reconstruction





silicon, gaseous tracking systems

high granularity calorimetry

The International Linear Collider Project

Higgs coupling to leptons

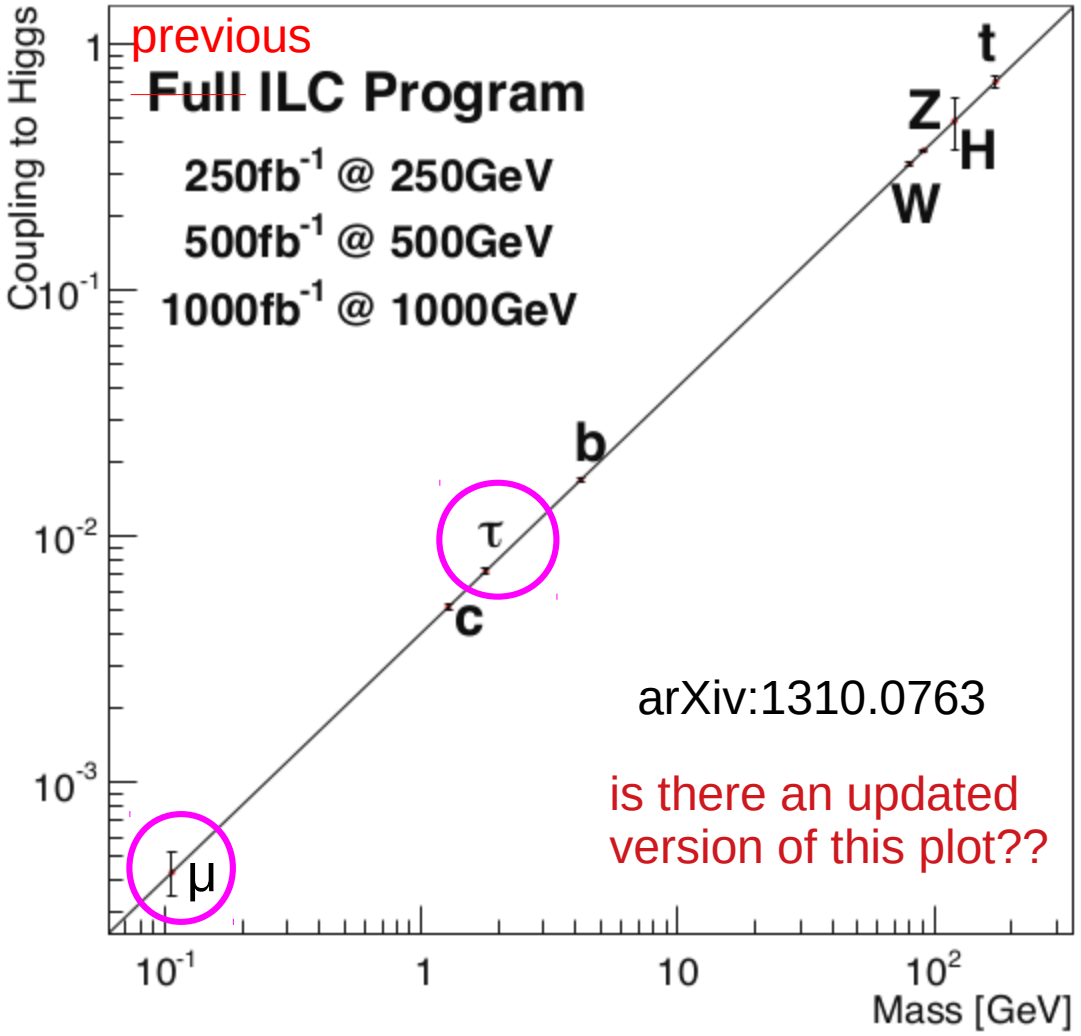
- BR (H → μ μ)
- BR (H → τ τ)

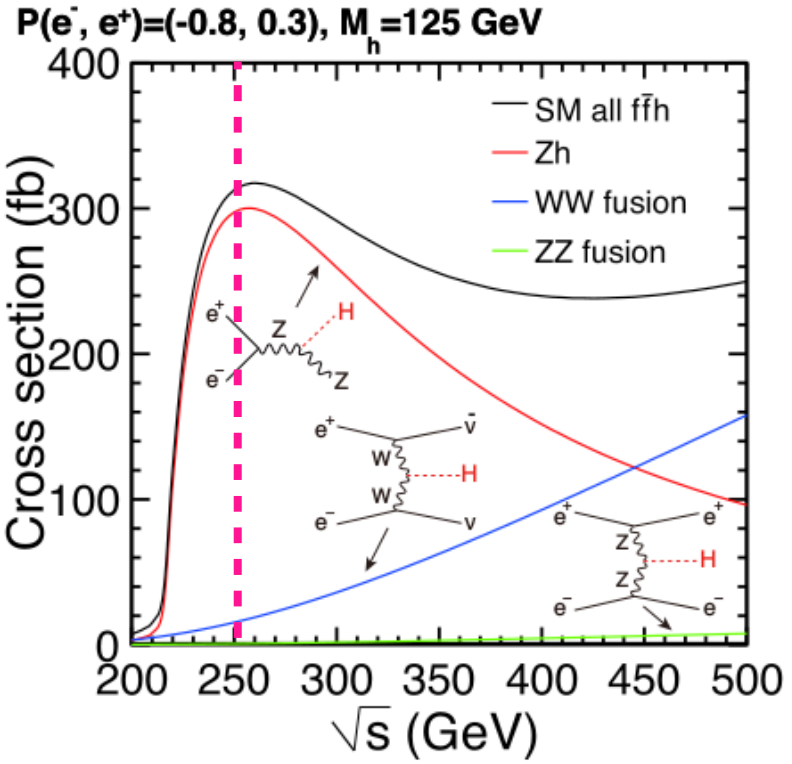
Higgs CP properties in

- H → τ τ
- H → ZZ, WW

Summary

test relation between leptonic Yukawa couplings and particle mass





in this talk, concentrate on measurements at ILC250

Higgs boson coupling to muons

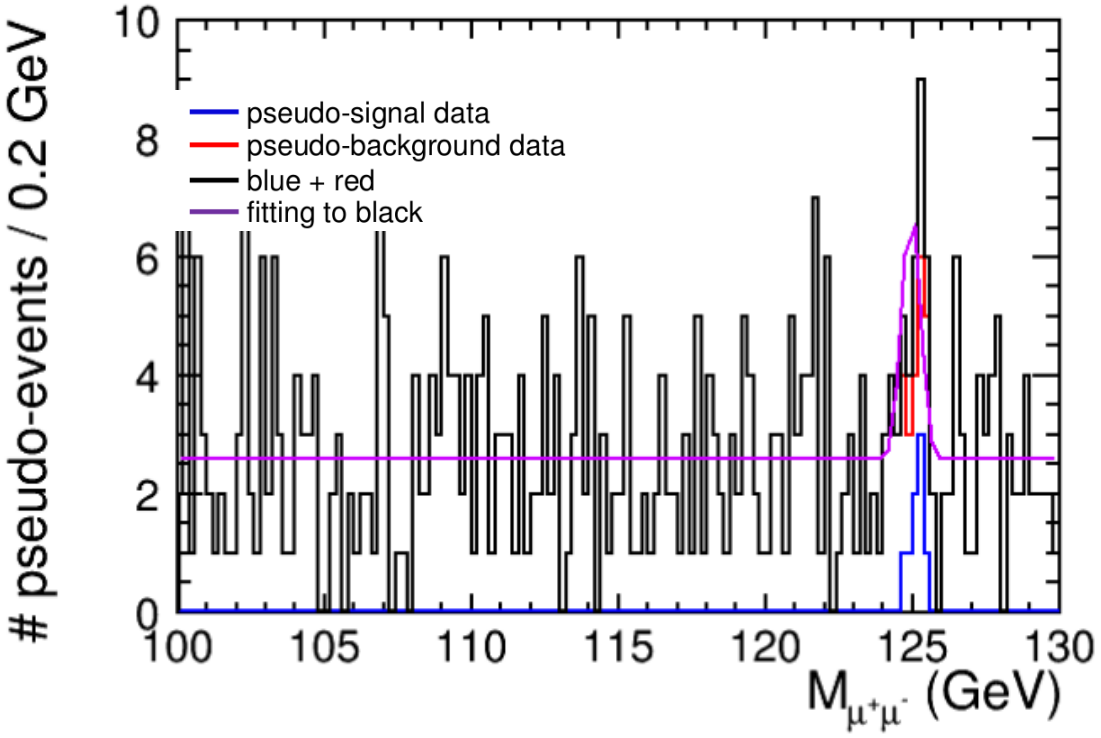
arXiv:1801.07966

challenge: small sample due to tiny BR (h → μ μ) ~ 2 x 10^{-4}

key: excellent momentum resolution

$$dp_T/p_T \sim 3 \times 10^{-5}\, p_T$$

based on ILD full simulation *preliminary*



Full detector simulation,
realistic reconstruction algorithms

$$e^+ e^- \rightarrow H Z$$

Two final states:

$e^+ e^- \rightarrow \mu \mu q q$

$e^+ e^- \rightarrow \mu \mu \nu \nu$

Multivariate analysis to
suppress backgrounds

expected relative precision on
σ (h + X) · BR (h → μ μ) at ILC :

20.5 % [ILC250 / 2 ab^{-1}]

15.4 % [+ ILC500 / 4 ab^{-1}]

preliminary

Eur. Phys. J. C75 (2015) no.12, 617

Higgs boson coupling to taus

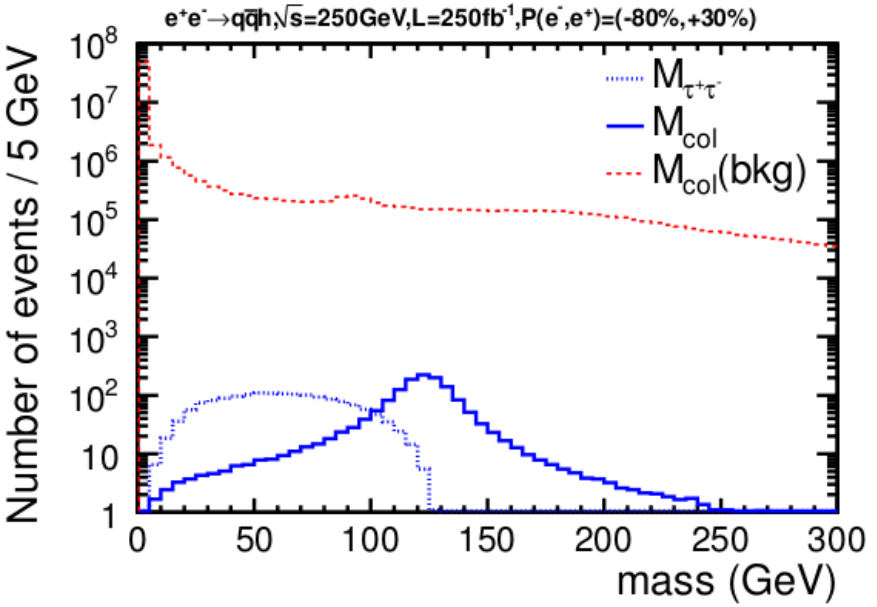
$e^+ e^- \rightarrow H Z \rightarrow \tau\tau + (ee, \mu\mu, q q)$

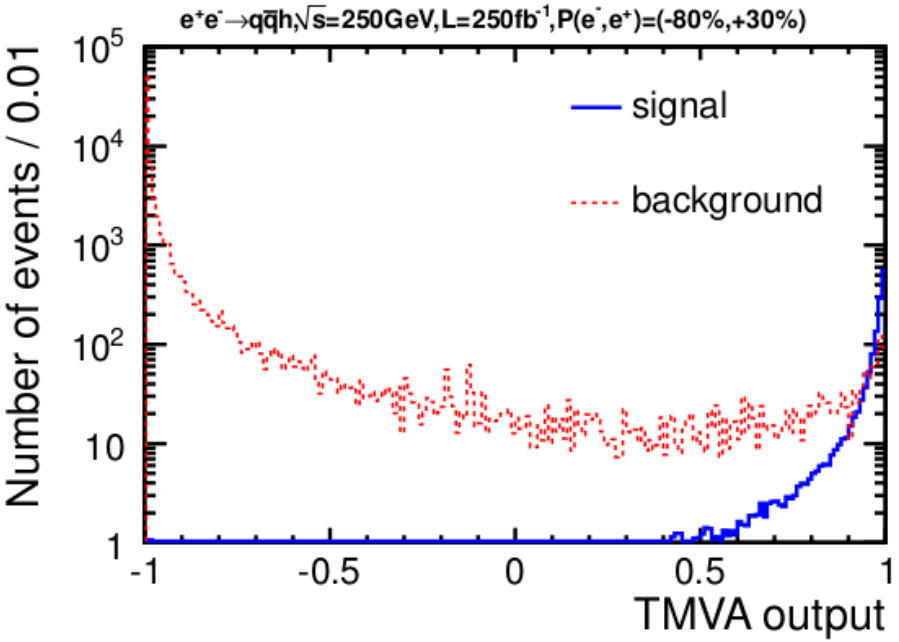
isolated narrow jets,
- 1 or 3 charged particles
- total jet charge ±1
- invariant mass < 2 GeV/c^2

colinear approximation to estimate
- tau neutrino momenta

various cuts to reduce backgrounds
- final multivariate analysis [BDT]

expected precision at ILC on
$\sigma (h + X) \cdot BR (h \rightarrow \tau\tau)$:
- 1.2 % [ILC250 / 2 ab^{-1}]
- 1.0 % [+ ILC500 / 4 ab^{-1}]





The International Linear Collider Project

Higgs coupling to leptons

- BR (H → μ μ)
- BR (H → τ τ)

Higgs CP properties in

- H → τ τ
- H → ZZ, WW

Summary

Do Higgs couplings conserve CP ?

e.g.

f f H coupling:

$$\mathcal{L}_{ffH} \sim g f \left(\cos\psi_{CP} + i\gamma^5 \sin\psi_{CP}\right) f H$$

SM: $\psi_{CP}=0$

Z Z H coupling

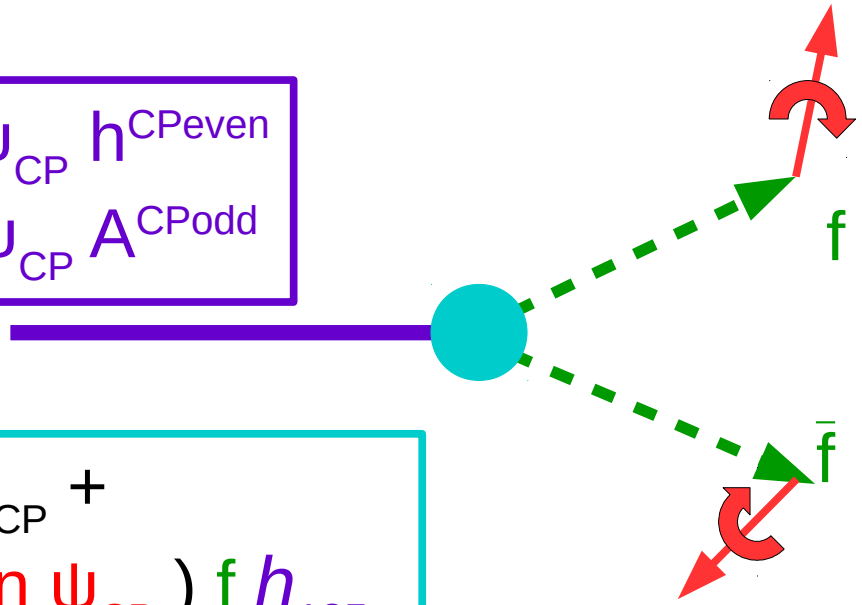
$$\mathcal{L}_{ZZH} \sim M_Z^2 \left(\frac{1}{v} + \frac{a_z}{\Lambda}\right) Z_\mu Z^\mu H + \frac{b_z}{2\Lambda} Z_{\mu\nu} Z^{\mu\nu} H + \frac{\tilde{b}_z}{2\Lambda} Z_{\mu\nu} \tilde{Z}^{\mu\nu} H$$

SM: $a_Z = b_Z = \tilde{b}_Z = 0$

CP in Higgs → tau tau

arXiv:1804.01241
to appear in PRD

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



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

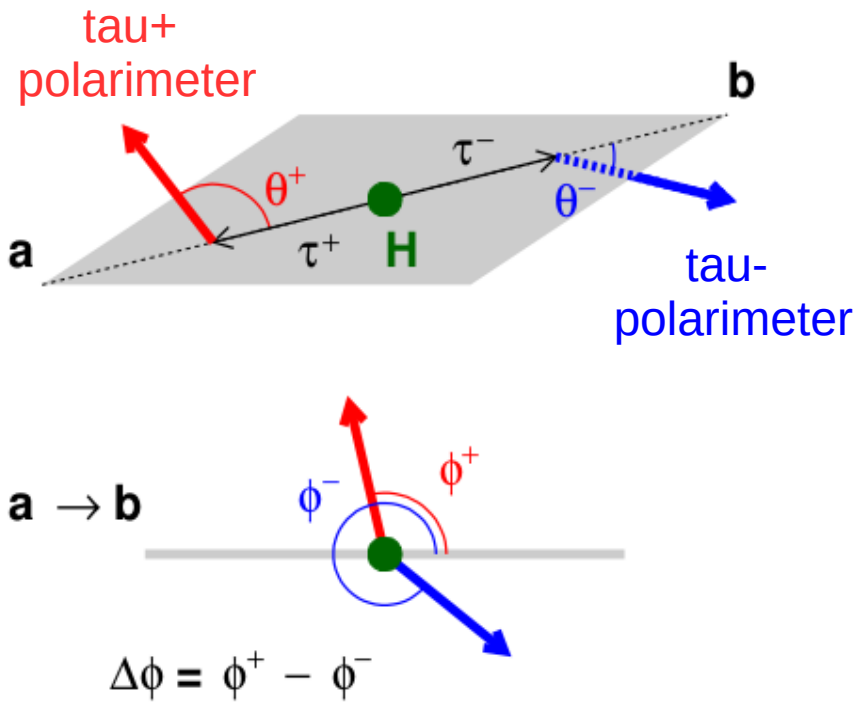
h is a spin 0 state:

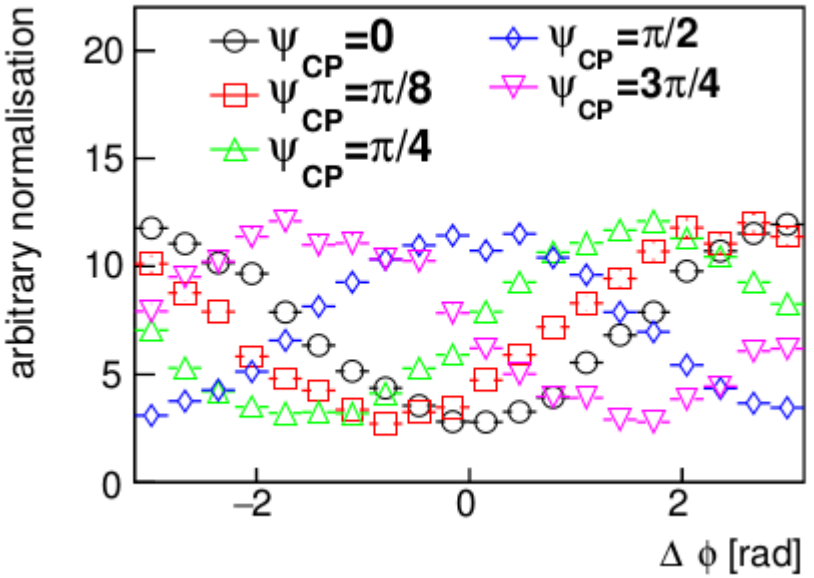
$|f\ \bar{f}\rangle = |\uparrow\downarrow\rangle + e^{2i\psi}\, |\downarrow\uparrow\rangle$

[ψ = 0 CP even,
π/2 CP odd]

CP of tau pair reflected in correlation between tau spin components transverse to tau momenta

distribution of tau decay products gives sensitivity to tau spin direction via *polarimeters*





distribution of Δφ is sensitive to CP mixing angle ψ_{CP}

to maximise analysing power of the polarimeters, should fully reconstruct tau decay kinematics (including the tau neutrino momenta)

tau polarimeters easy to extract in

$\tau^{\pm} \rightarrow \pi^{\pm} \nu$ [11% of tau decays]

$\tau^{\pm} \rightarrow \pi^{\pm} \pi^0 \nu$ [26% of tau decays]

Full tau reconstruction

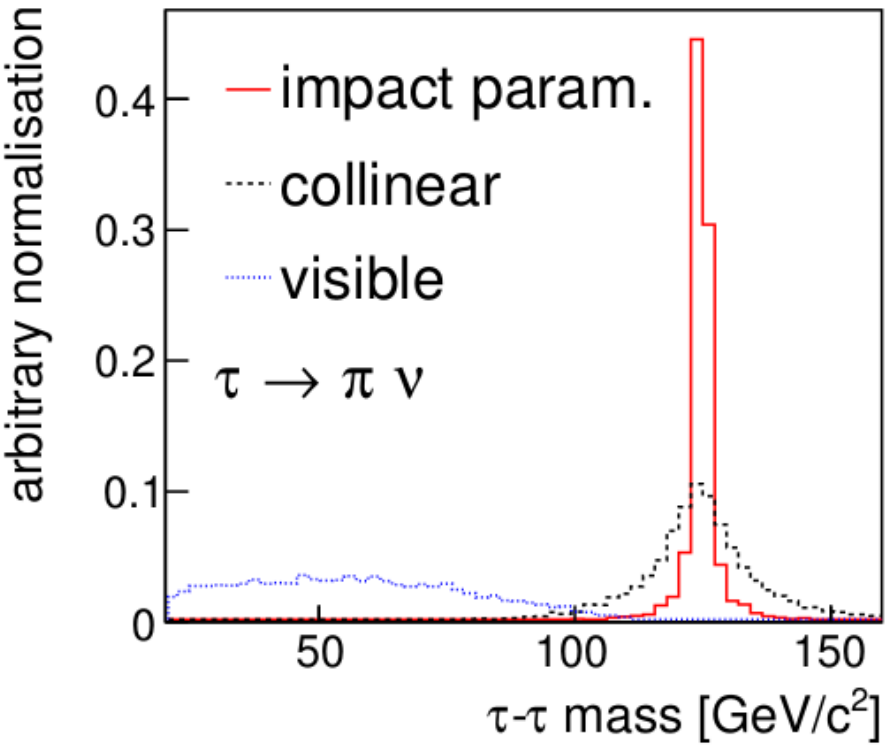
NIM A810 (2016) 51
arXiv:1507.01700

in a 2-tau system
with hadronic tau decays (1 ν / tau decay),

there are 6 unknowns / event:
2 x neutrino 3-momenta

6 constraints are available, if we know
the tau **production vertex**,
the **impact parameters** of
charged tau decay products,
→ defines plane of tau momentum
the p_T of the 2-tau system,
→ insensitive to ISR and beamstrahlung

ILD full simulation



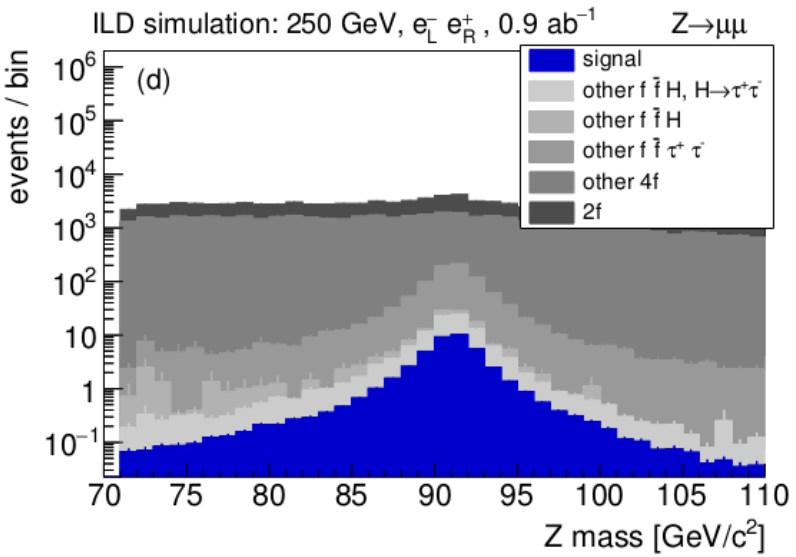
Method is applicable to
$e^+ e^- \rightarrow (Z \rightarrow \text{visible})\ (H \rightarrow \text{tau tau})$
at ILC

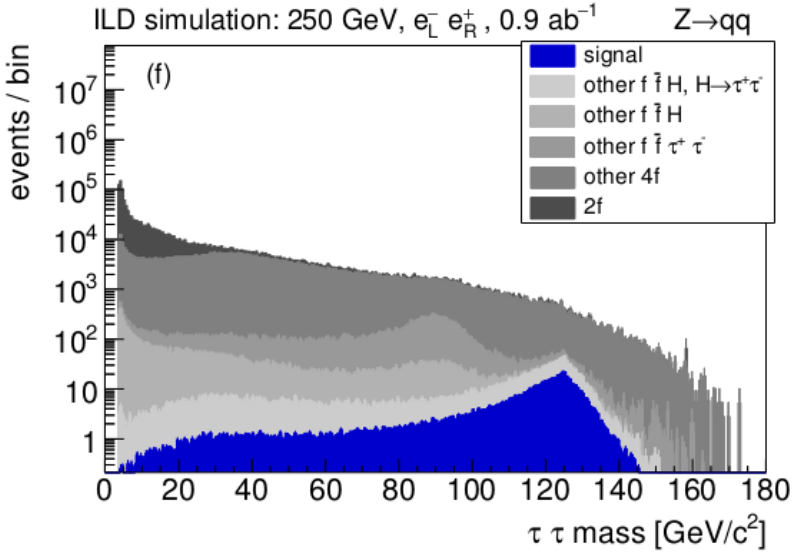
Vertex detector
Tracking
Photon measurement
Jet measurement

reconstruct Z → (e e / μ μ / jets) + 2 × (1-prong tau jets)

simple preselection

some distributions after reconstruction and pre-selection:





group events according to sensitivity to CP

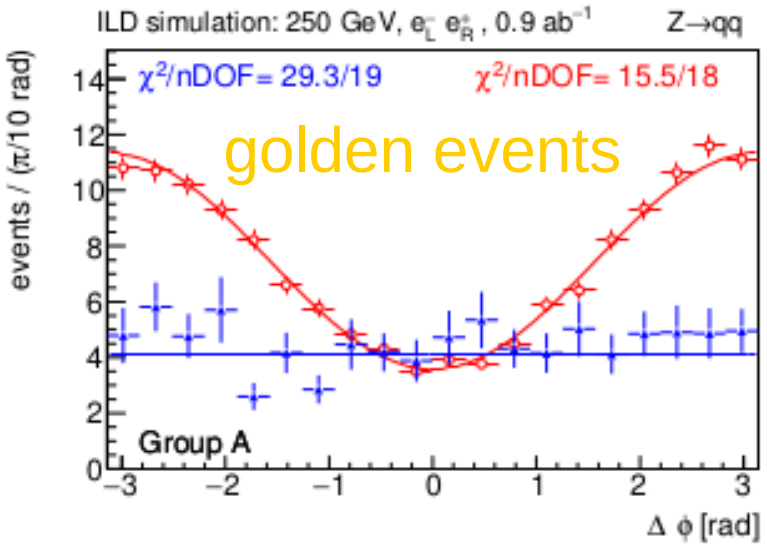
- quality of event reconstruction
- background contamination
- longitudinal polarimeter components

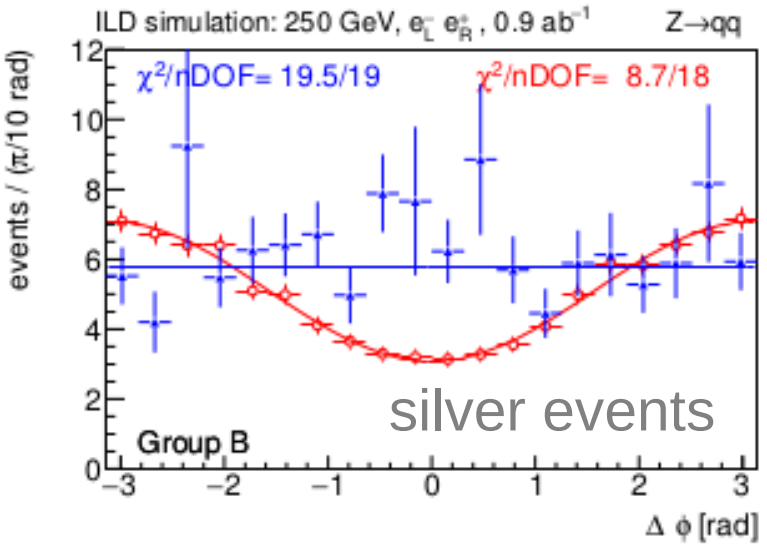
CP sensitive observable Δφ

arXiv:1804.01241
to appear in PRD

signal background

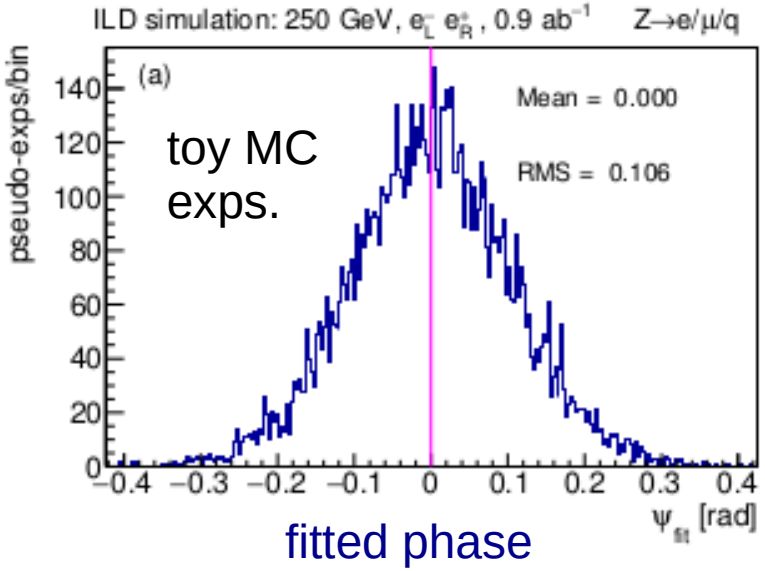
error bars:
MC statistics





signal distribution: phase of modulation is sensitive to CP
backgrounds: consistent with flat distribution

simultaneous unbinned likelihood fit to Δφ distributions in all channels

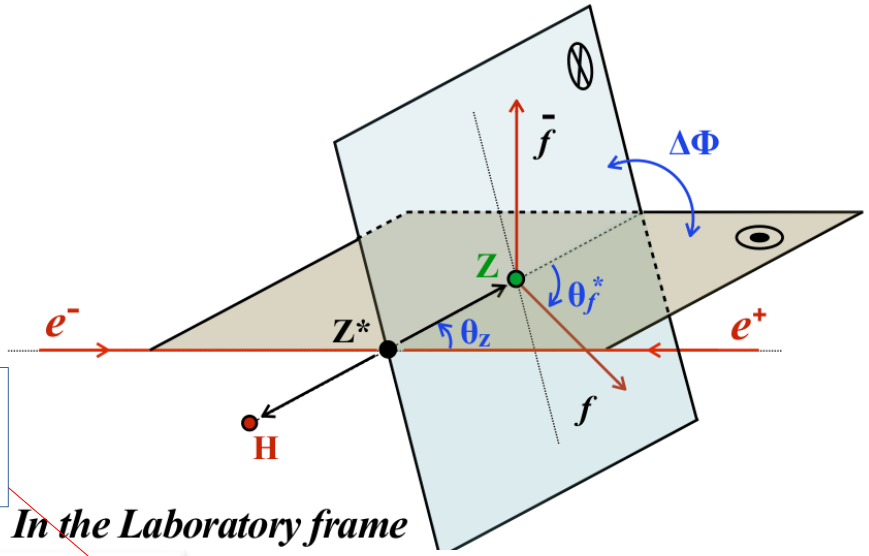


with 2 ab^{-1} of ILC250 data, can measure ψ_{CP} with a precision of **75 mrad (4.3 deg)**

CP properties of HZZ coupling

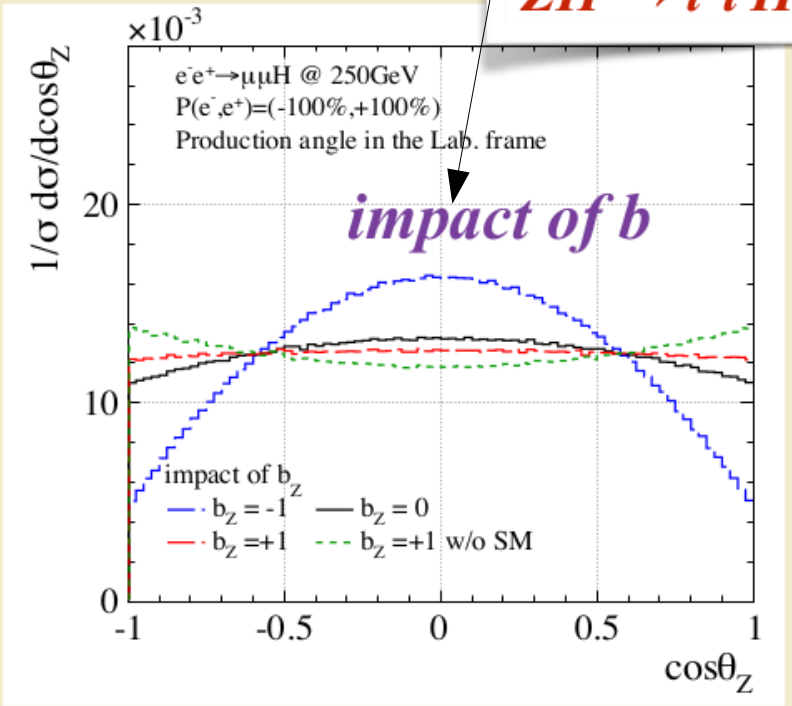
T. Ogawa @ LCWS17
(full analysis ongoing)

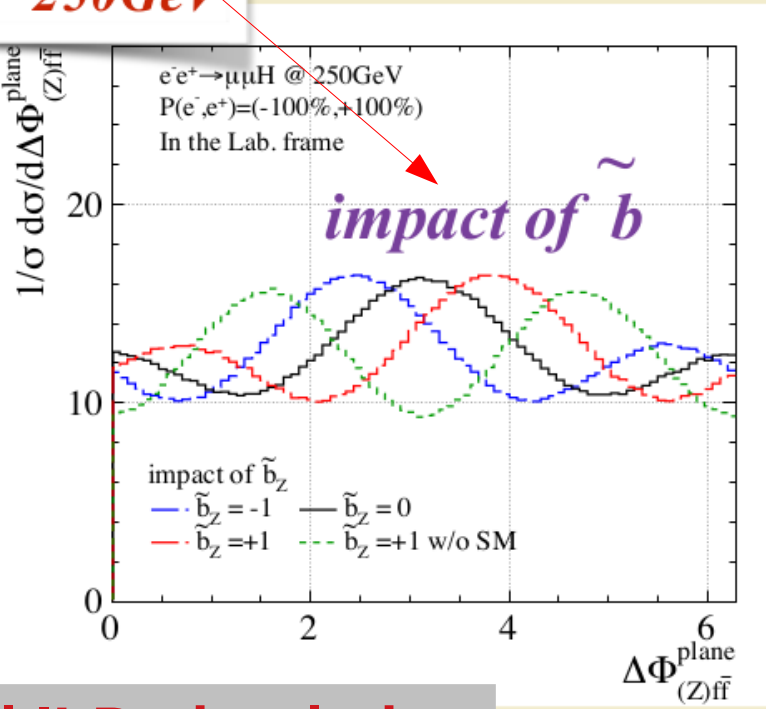
decay distributions in
$e^+ e^- \rightarrow H (Z \rightarrow f \bar{f})$



$$\mathcal{L}_{ZZH} \sim M_Z^2 \left(\frac{1}{v} + \frac{a_z}{\Lambda}\right) Z_\mu Z^\mu H + \frac{b_z}{2\Lambda} Z_{\mu\nu} Z^{\mu\nu} H + \frac{\tilde{b}_z}{2\Lambda} Z_{\mu\nu} \tilde{Z}^{\mu\nu} H$$

$ZH \rightarrow l^+l^-H$, $\sqrt{s} = 250GeV$





Full ILD simulation

Summary

As part of its comprehensive set of
precision measurements of the Higgs sector,
detectors at **ILC250** will measure:

$\sigma (h + X) \cdot BR (h \rightarrow \mu \mu)$ with a precision of 20.5 %
$\sigma (h + X) \cdot BR (h \rightarrow \tau \tau)$ with a precision of 1.2 %
CP mixing in $h \rightarrow \tau \tau$ with a precision of 75 mrad
CP properties of HZZ, HWW couplings

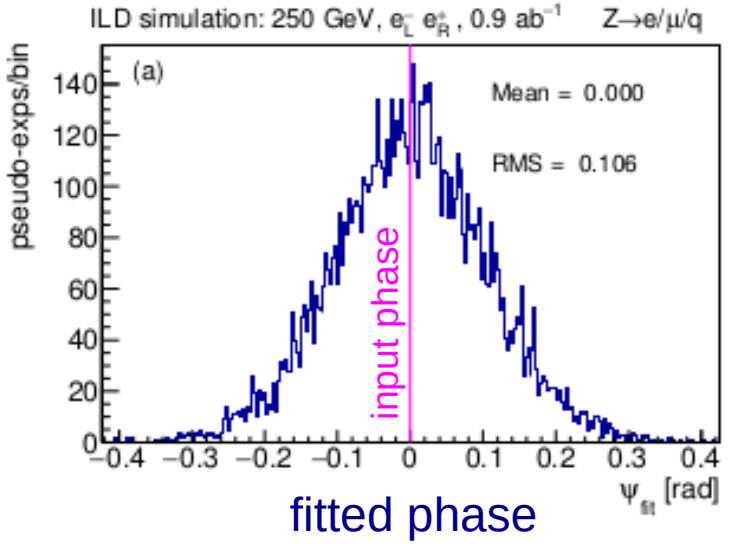
backup

estimating measurement sensitivity

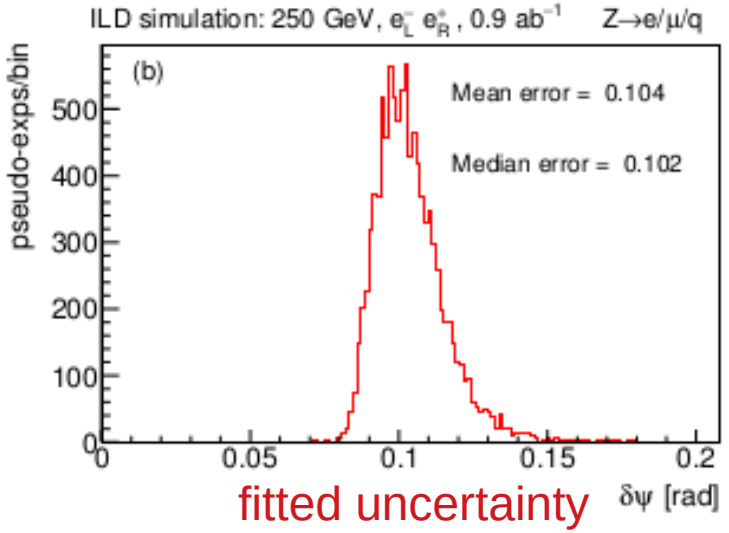
unbinned maximum likelihood fit: simultaneously in all sensitivity bins and selection channels
fit a single parameter: the phase of Δφ distribution

perform series of toy pseudo-experiments using simulated distributions

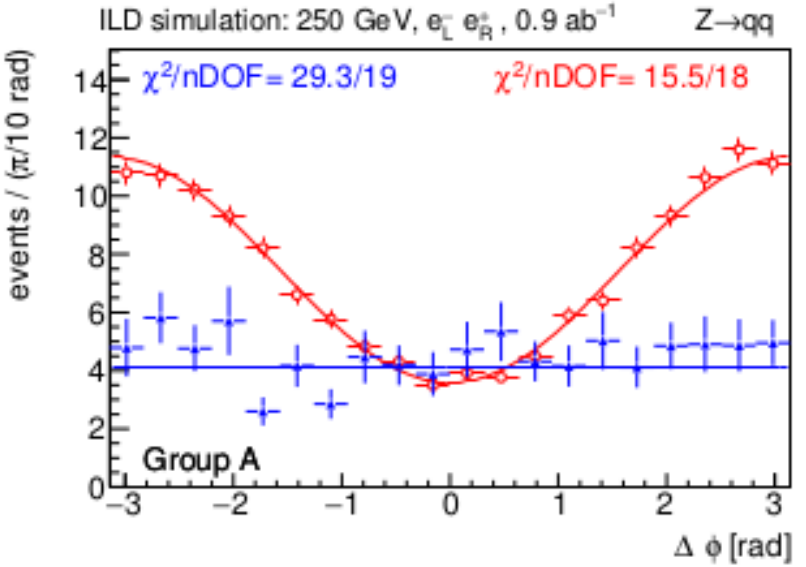
results of 10k pseudo-exps

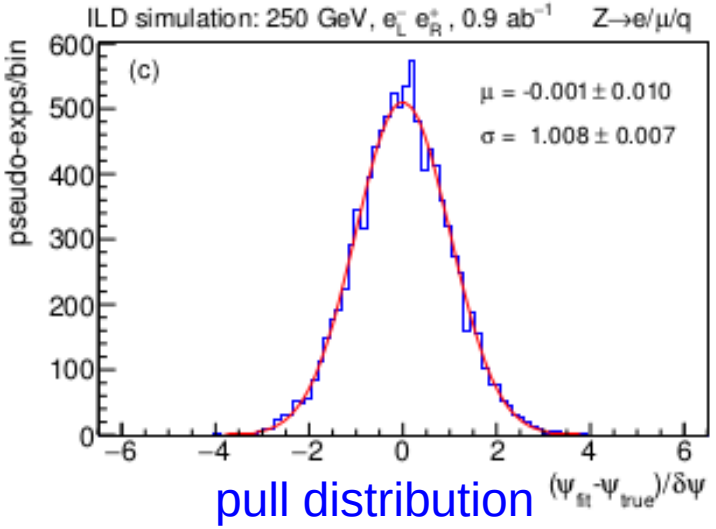


fitted phase



fitted uncertainty





pull distribution

Benchmarking

1 ab^{-1}, unpolarised beams

		$\delta\psi_{CP}$ [mrad]
signal only	perfect reconstruction	25
signal only	realistic reconstruction	75
signal + background	realistic reconstruction	116
only $Z \rightarrow qq$	realistic background, reconstruction	122
only $Z \rightarrow \mu\ \mu$,	realistic background, reconstruction	412

250 GeV ILC, 2 ab^{-1}

full analysis	realistic background, reconstruction	75