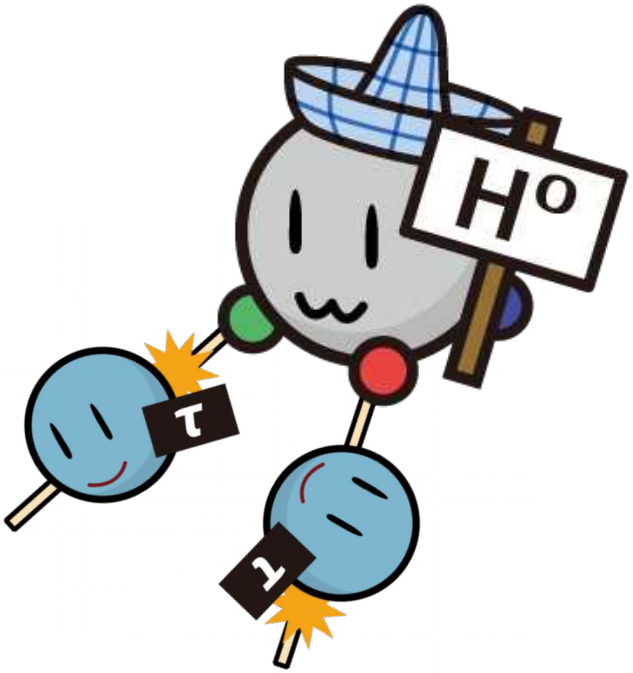
Higgs → $\tau^+\tau^-$ at ILC: coupling strength and CP properties

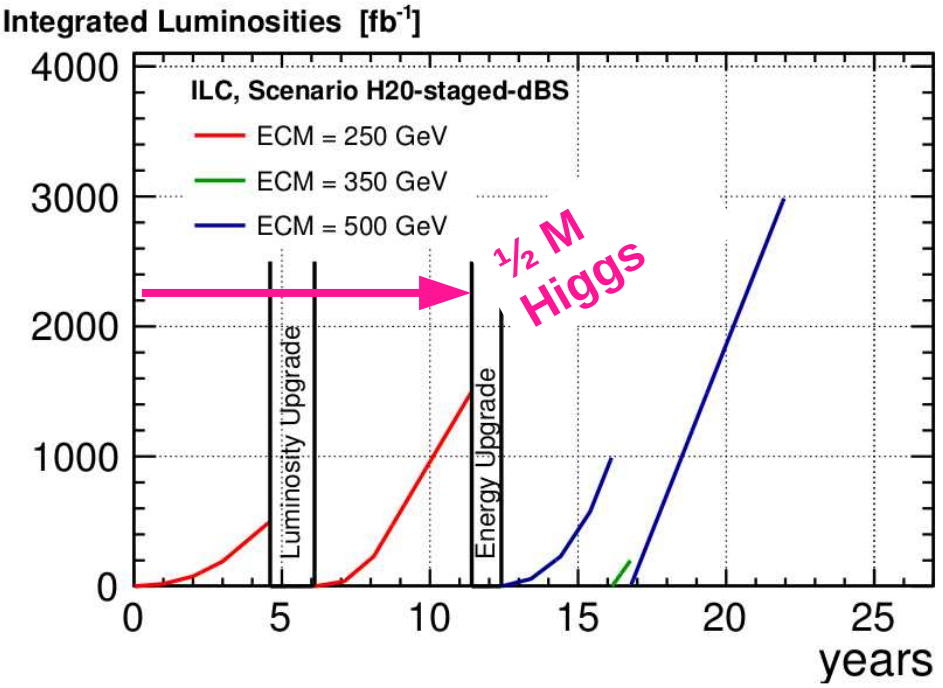


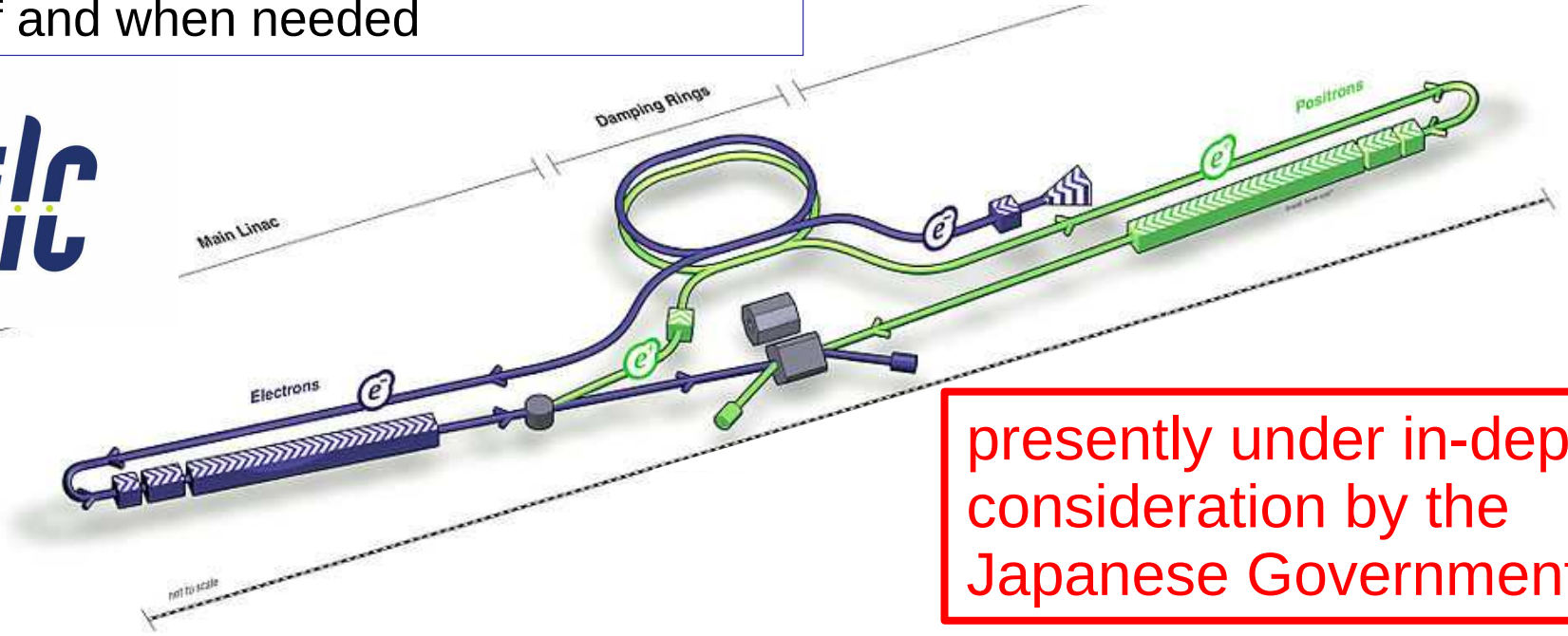
Daniel Jeans, KEK
for the
International Large Detector
concept group
Higgs Couplings 2018, Tokyo

International Linear Collider

e^+ e^- collisions @ 250 GeV
beam polarisation:
e^- 80%, e^+ 30%
luminosity ~10^{34} cm^{-2} s^{-1}
0.5 M Higgs in ~11 years

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





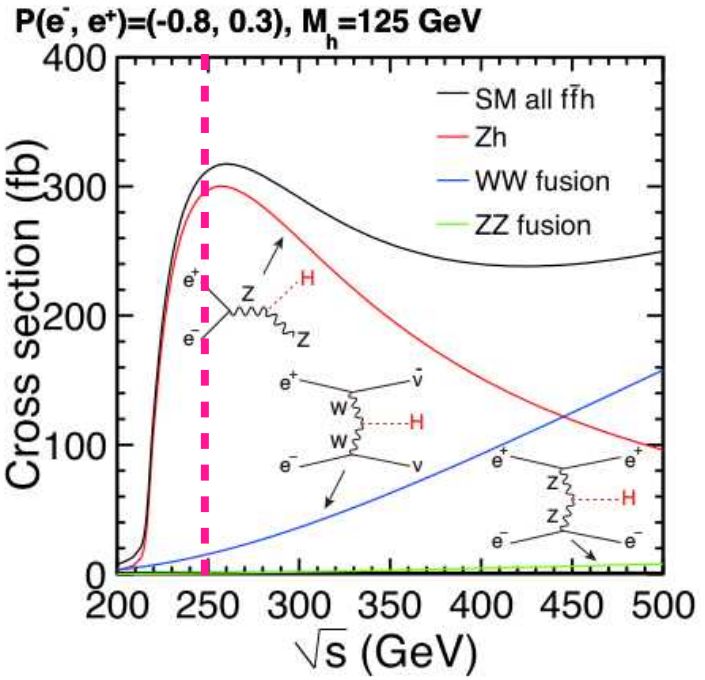
presently under in-depth consideration by the Japanese Government

Higgs physics at ILC 250

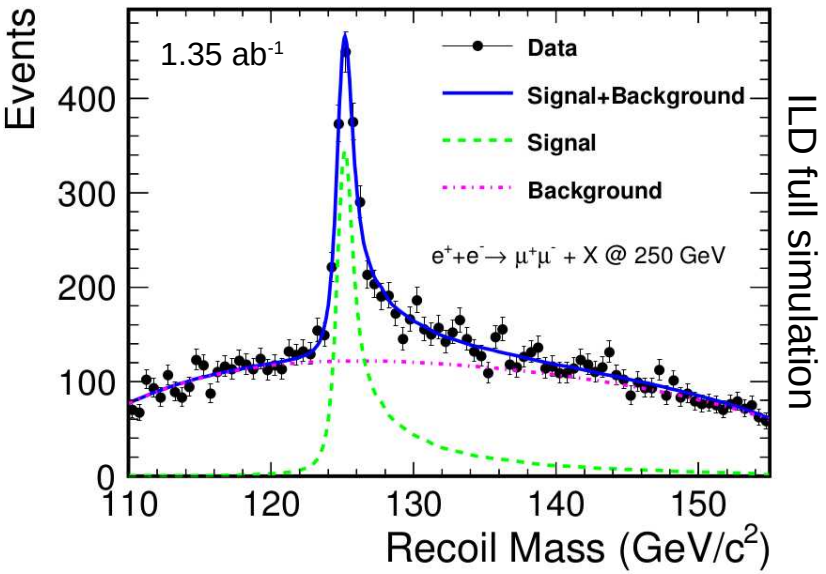
comprehensive and precise study of Higgs sector [see F. Simon's plenary talk]

At 250 GeV, Higgs boson usually produced with a Z:
"Higgs-strahlung"

Z boson and its momentum used to tag Higgs events:
"recoil mass" method



Phys.Rev. D94 (2016) no.11, 113002



Higgs decays to tau leptons

as most massive lepton,
tau enjoys strongest coupling to Higgs

tau lepton has somewhat short lifetime : 2.9×10^{-13} s

decays within detector
characteristic “narrow jet”

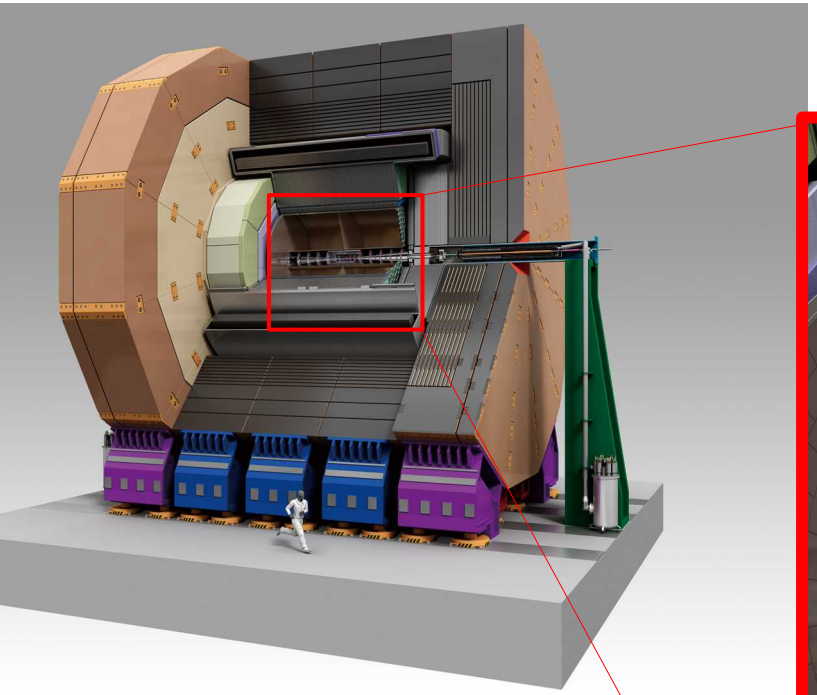
decay products displaced from interaction point

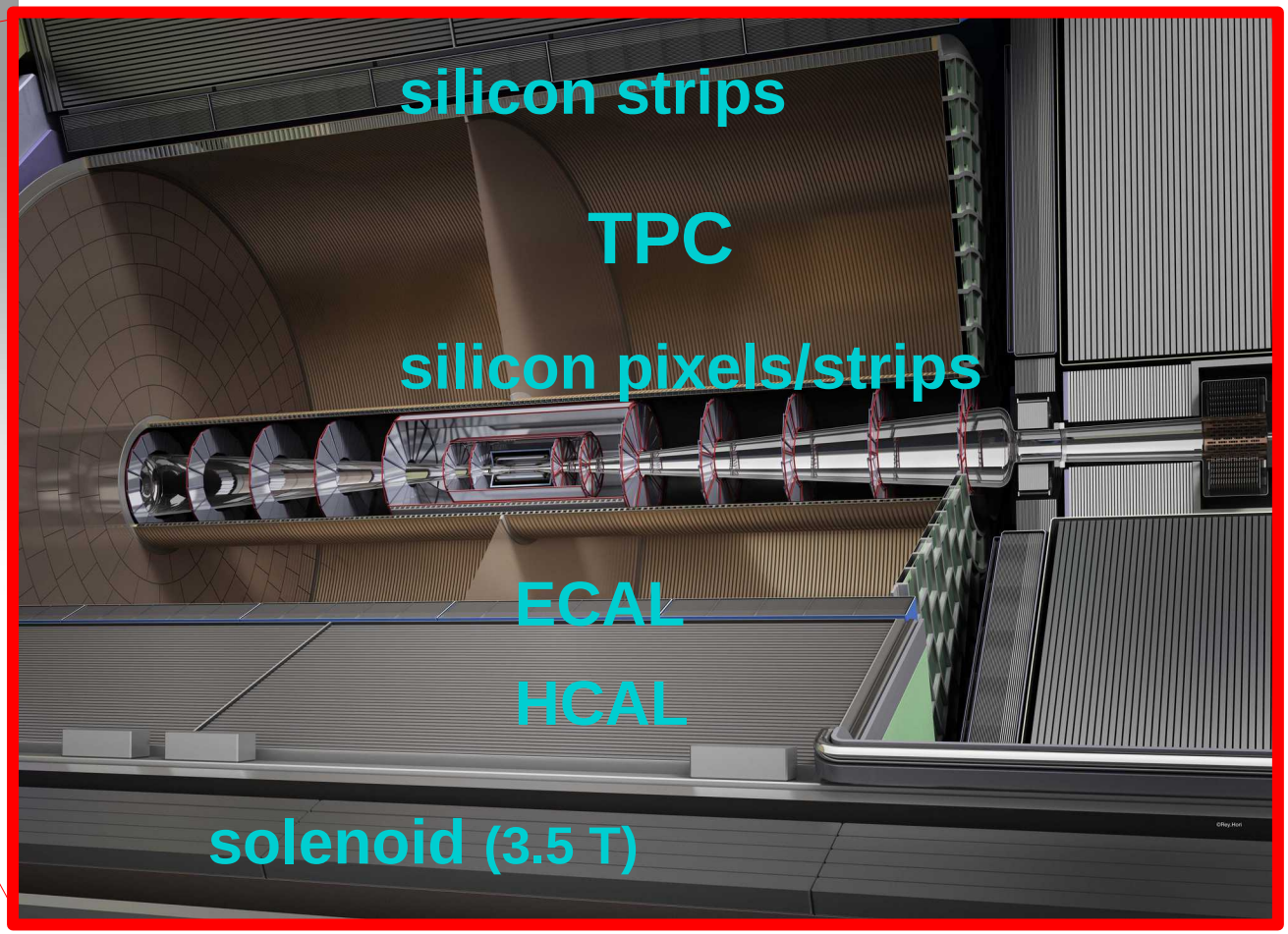
distribution of decay products
→ tau spin orientation

International Large Detector

one of two detector concepts being developed for ILC

high precision detector optimised for **particle flow** reconstruction





silicon, gaseous tracking systems

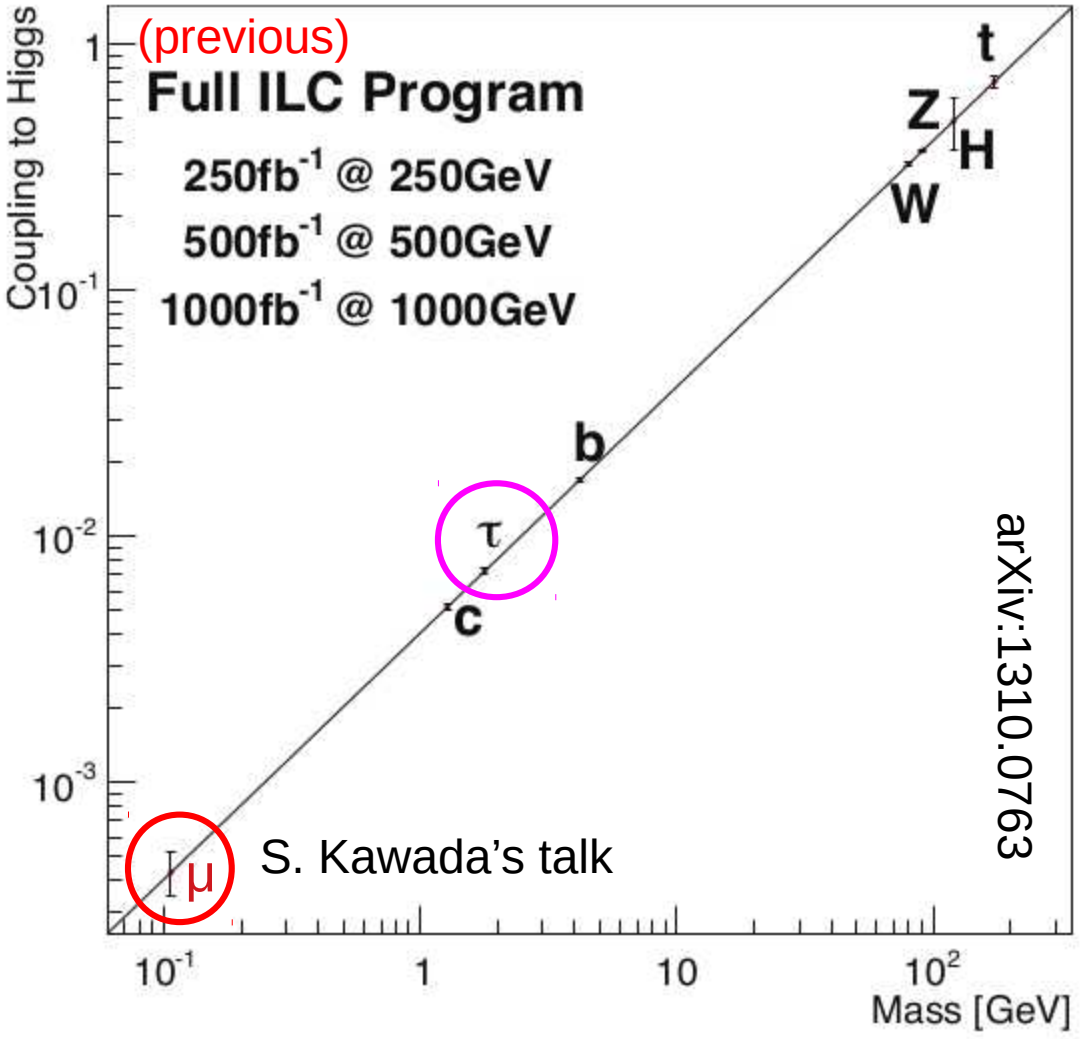
σ_{d0} → 5 μm

σ_{pT}/p_T → $2 \times 10^{-5}\ p_T$

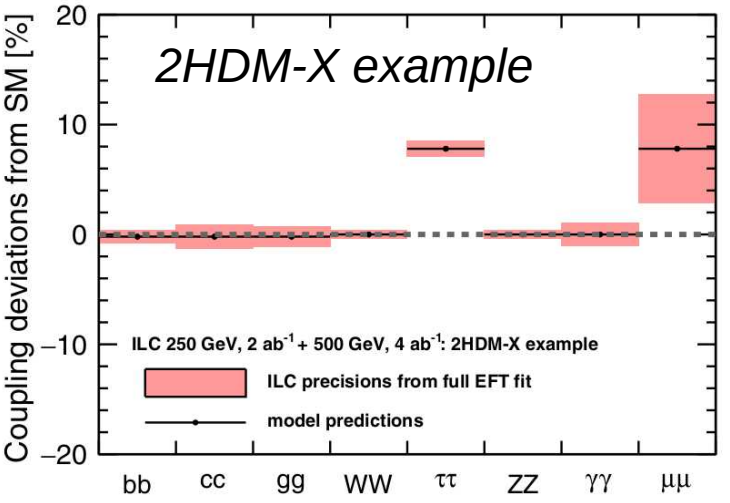
high granularity calorimetry

jet energy resolution 3-4%

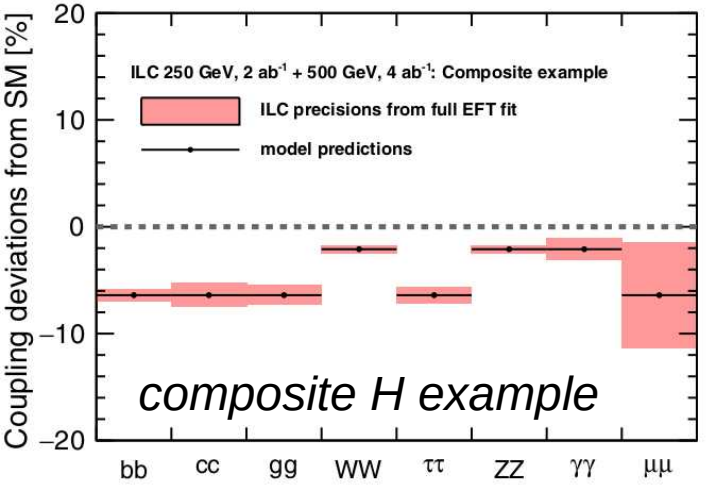
test the lepton Yukawa – mass relation



different BSM scenarios
→ patterns of deviations from SM



Phys. Rev. D 97, 053003



Higgs boson coupling to τ τ

Studied using events fully simulation in ILD,
all SM background processes,
realistic reconstruction algorithms

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

<u>final states</u>

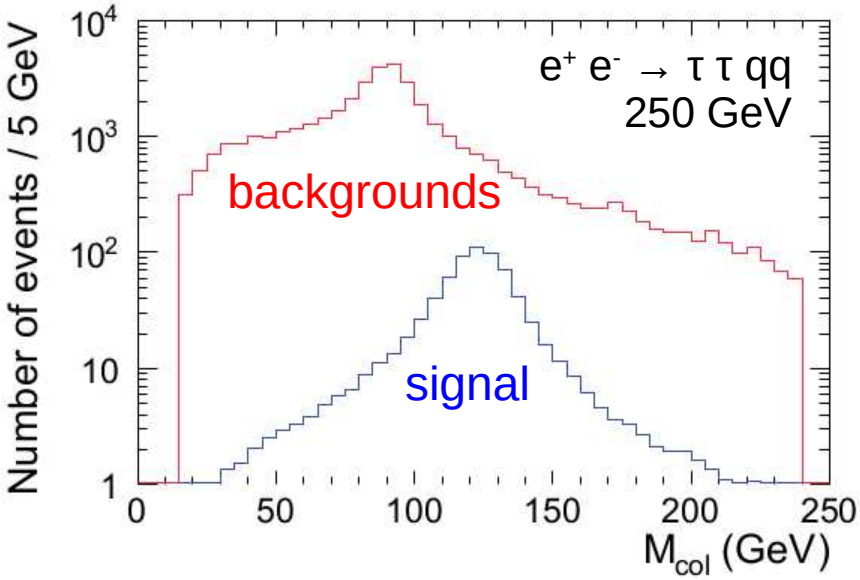
$e^+ e^- \rightarrow H Z \rightarrow \tau \tau + (ee, \mu \mu, q q)$

<u>event reconstruction and selection</u>

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

various cuts to reduce major backgrounds

colinear approximation to estimate
- momenta of ν from τ decay

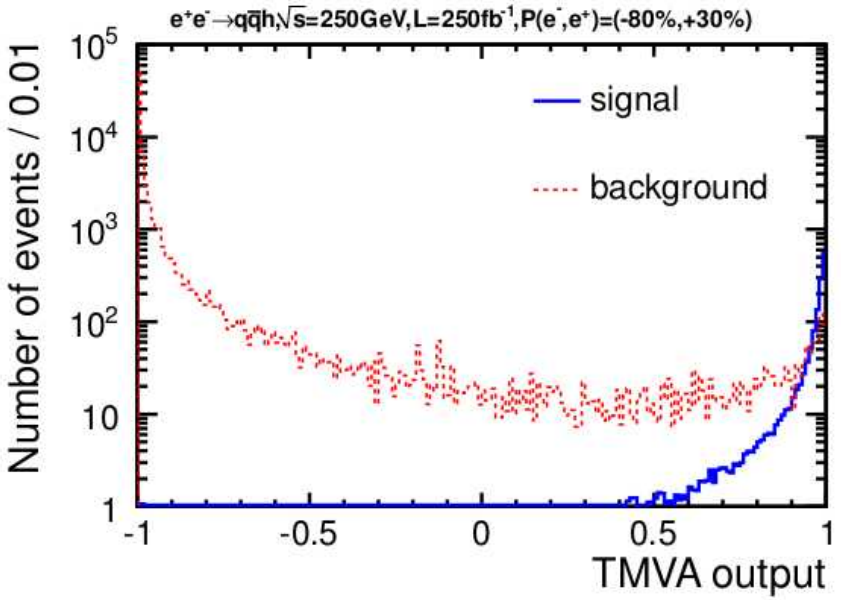


τ-pair invariant mass
colinear approximation

Higgs boson coupling to τ τ

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

final event selection and
background rejection using
multivariate analysis [BDT]



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

This measurement then combined with
- measured total cross-section $\sigma (h)$ to give $BR (h \rightarrow \tau \tau)$,
- measured total decay width Γ_H to extract Yukawa coupling g(hττ)

δ g(hττ) ~ 1.16% using full E.F.T. fit, 2 ab^{-1} at ILC250 + HL-LHC, LEP, ...

Phys.Rev. D97 (2018) no.5, 053003

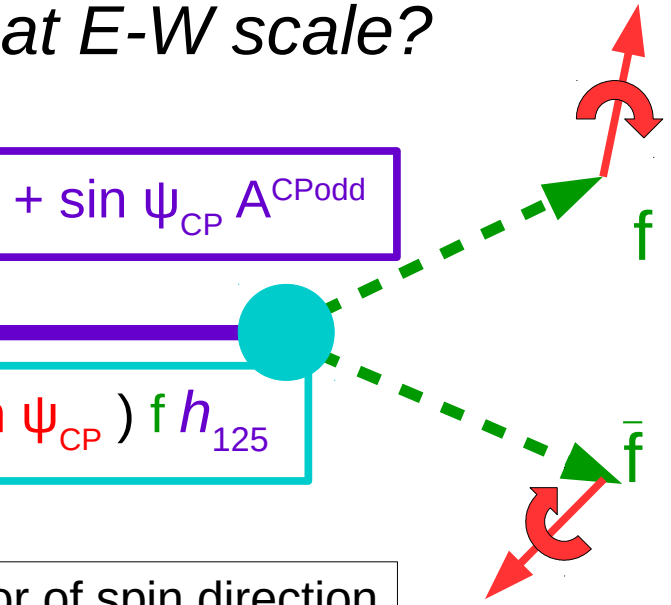
does Higgs → τ τ conserve CP ?

baryogenesis at E-W scale?

Phys.Rev. D98 (2018) no.1, 013007

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

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



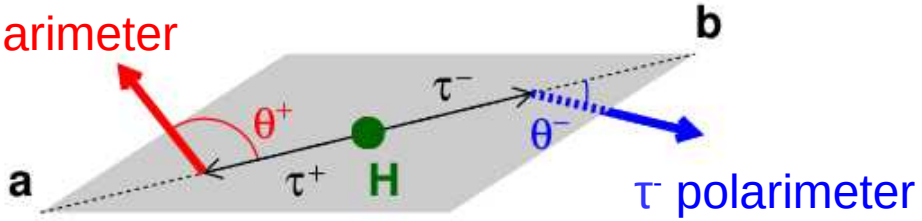
h is a spin 0 state:

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

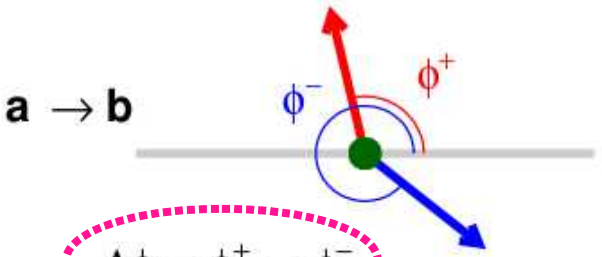
[ψ_{CP} = 0 CP even, π/2 CP odd]

"**polarimeter**" - estimator of spin direction from τ decay products

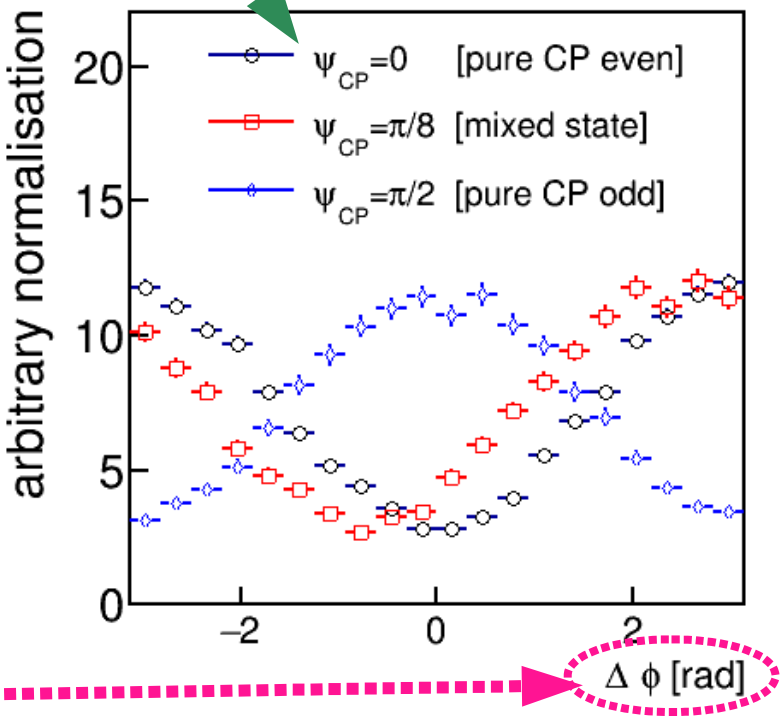
τ⁺ polarimeter



τ⁻ polarimeter



$\Delta\phi = \phi^+ - \phi^-$



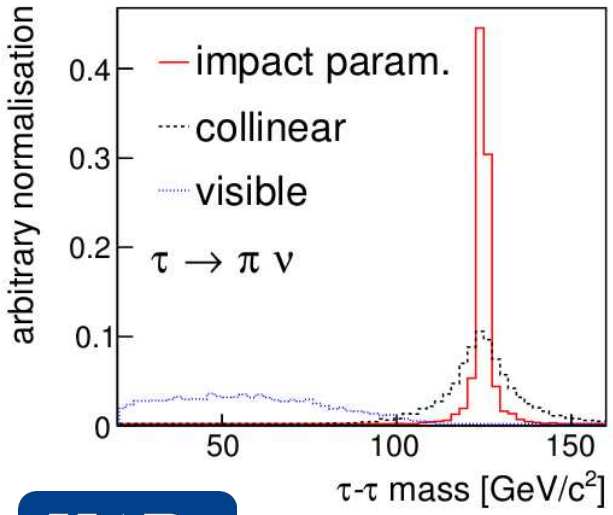
CP in h → τ τ : sensitivity

Phys.Rev. D98 (2018) no.1, 013007

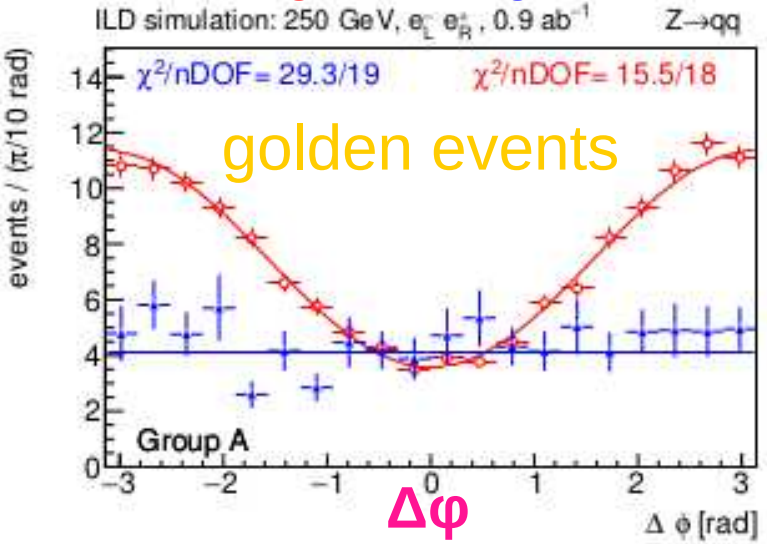
In Higgs-strahlung process, fully reconstruct momentum of hadronically decaying tau leptons. Using constraints from
- interaction point
- recoiling transverse momentum
- impact parameters
- tau lepton mass

NIM A810 (2016) 51, arXiv:1507.01700

$\tau^{\pm} \rightarrow \pi^{\pm} \nu$	[B.R. 11%]
$\tau^{\pm} \rightarrow \pi^{\pm} \pi^{0} \nu$	[B.R. 26%]

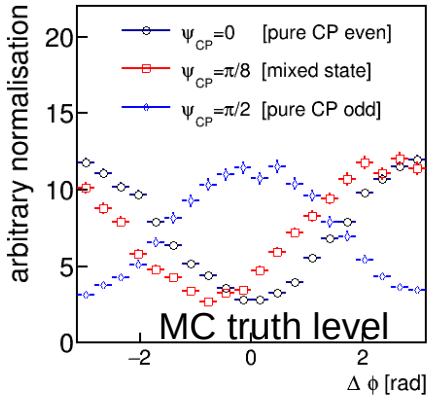


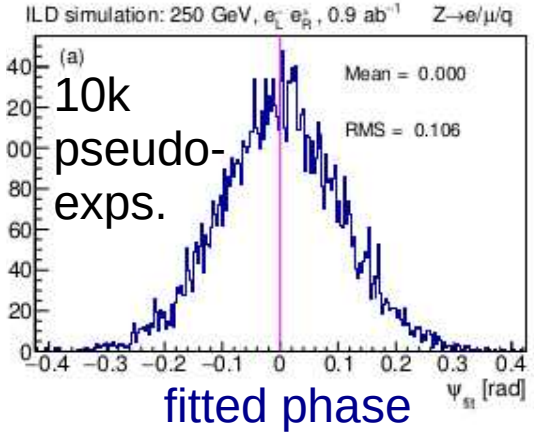
signal background



Δφ

signal: **phase** of Δφ → CP
backgrounds: flat





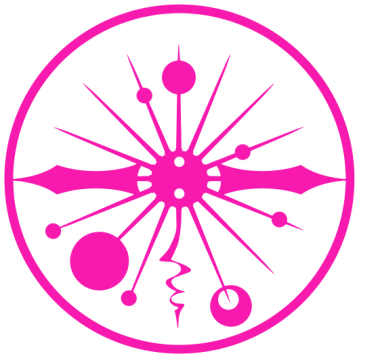
fitted phase

pseudo-experiments: likelihood fit to Δφ distributions

with 2 ab^{-1} @ ILC250, can measure mixing between even and odd CP components:
$\delta \psi_{CP}$ = **75 mrad** (4.3 deg)

#ILCsupporters

Summary



International Linear Collider will enable
comprehensive set of precision Higgs measurements,
shining light on physics beyond the SM

ILC-250 stage:

$\sigma(h) \cdot BR(h \rightarrow \tau\tau)$ with a precision of 1.2 % [1.0 % w/ ILC500]
→ several times more precise than current HL-LHC projections
→ signatures of BSM physics ?

CP mixing in $h \rightarrow \tau\tau$ decays with a precision of 75 mrad
→ Electro-Weak baryogenesis ?

backup

full τ momentum reconstruction

NIM A810 (2016) 51
arXiv:1507.01700

in Higgs-strahlung $e^+ e^- \rightarrow ZH$, $H \rightarrow \tau\tau$

visible Z decay:

→ τ production vertex

→ p_T of di-τ system

excellent vertex detector:

→ trajectory of τ decay products

→ plane of τ momentum

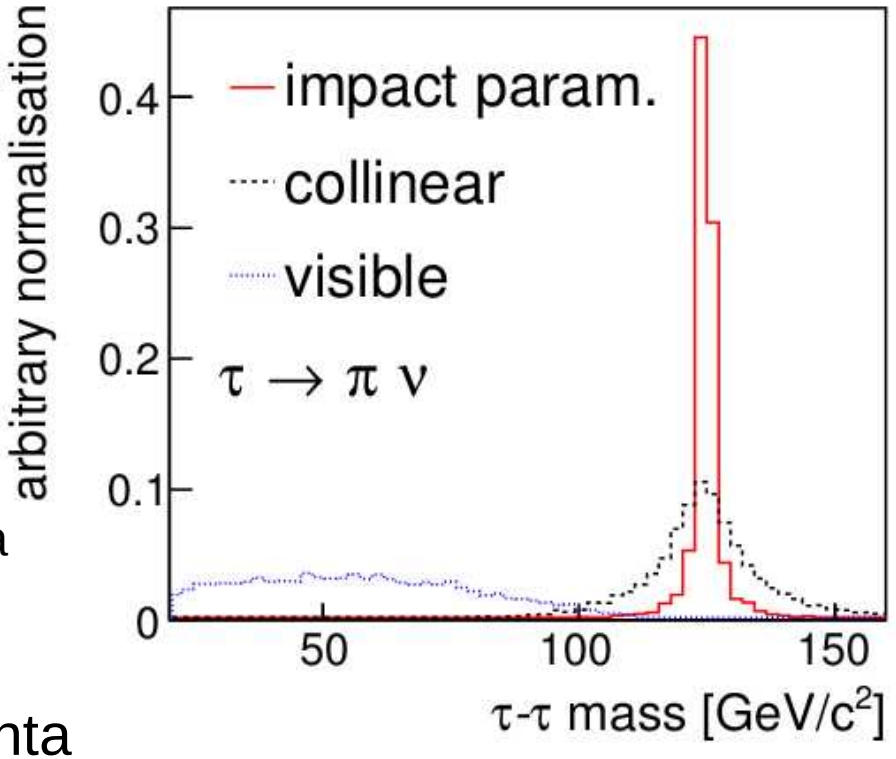
6 constraints to solve for

6 unknowns / event with hadronic τ decays

2 × neutrino 3-momenta

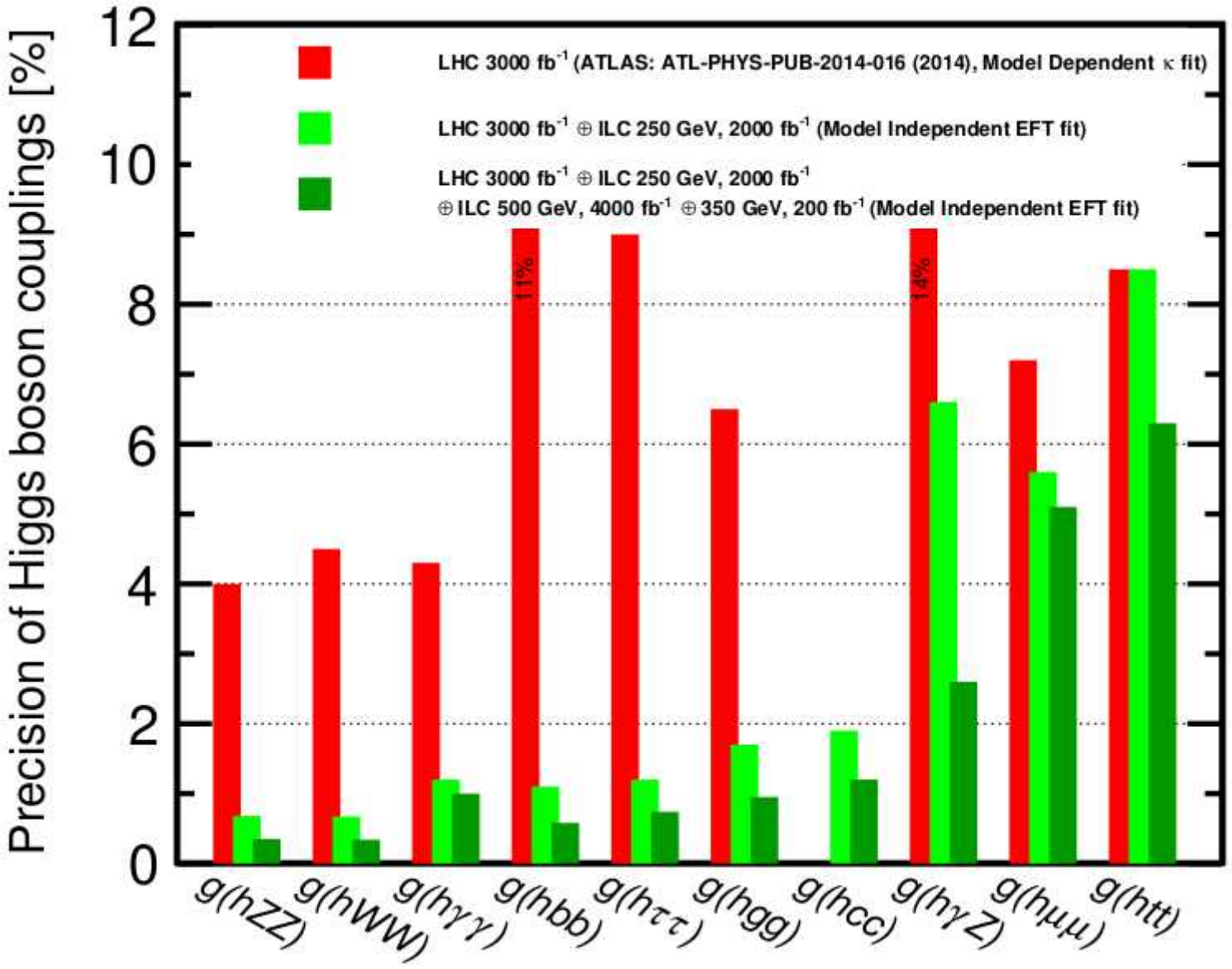
polarimeter → spin estimator from decay products' momenta

ILD full simulation



optimal information on τ momentum and spin
relies on excellent detector performance:
impact parameter, tracking, photon and jet measurement

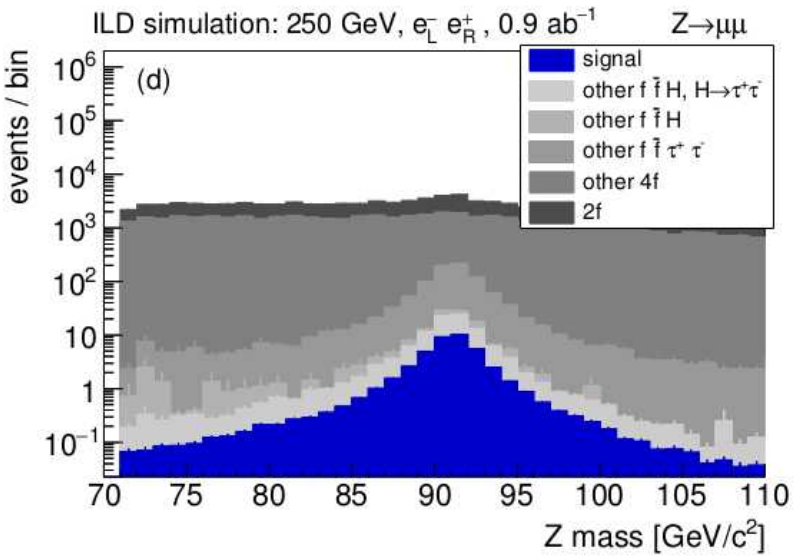
arXiv:1710.07621

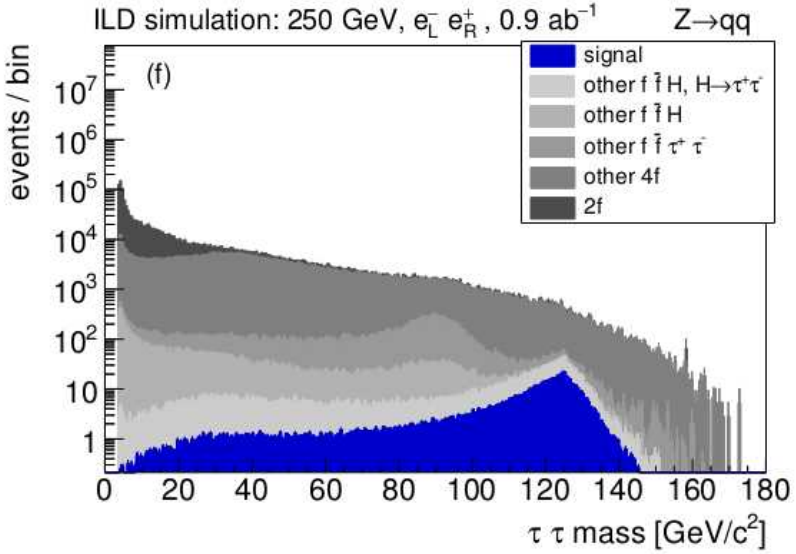


reconstruct Z → (e e / μ μ / jets) + 2 × (1-prong tau jets)

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