



Study of

Higgs couplings to leptons

and

Higgs CP properties

at the ILC

Daniel Jeans, KEK

for the

International Large Detector

concept group



ICHEP 2018, Seoul

International Linear Collider

electron – positron collisions

beam polarisation:

e^- 80%, e^+ 30%

luminosity $\sim 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

0.5 M Higgs in ~ 11 years

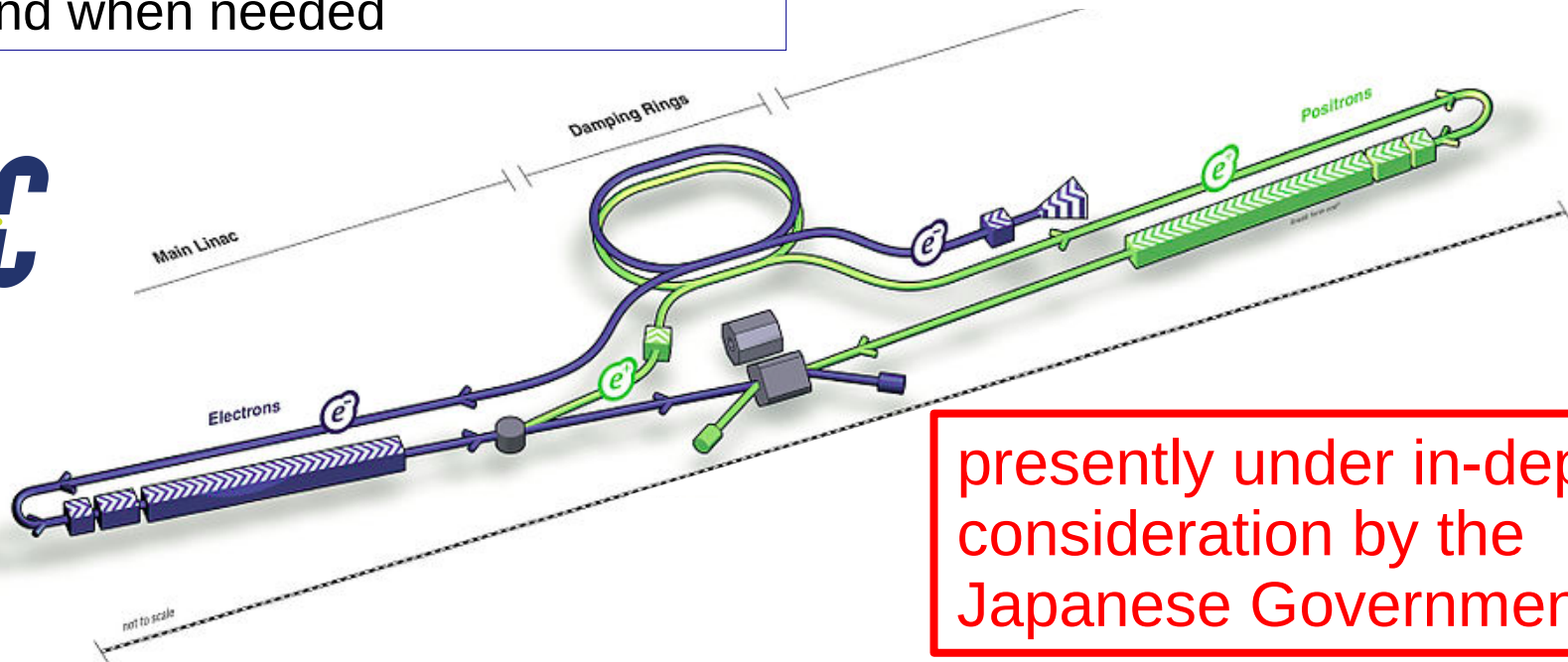
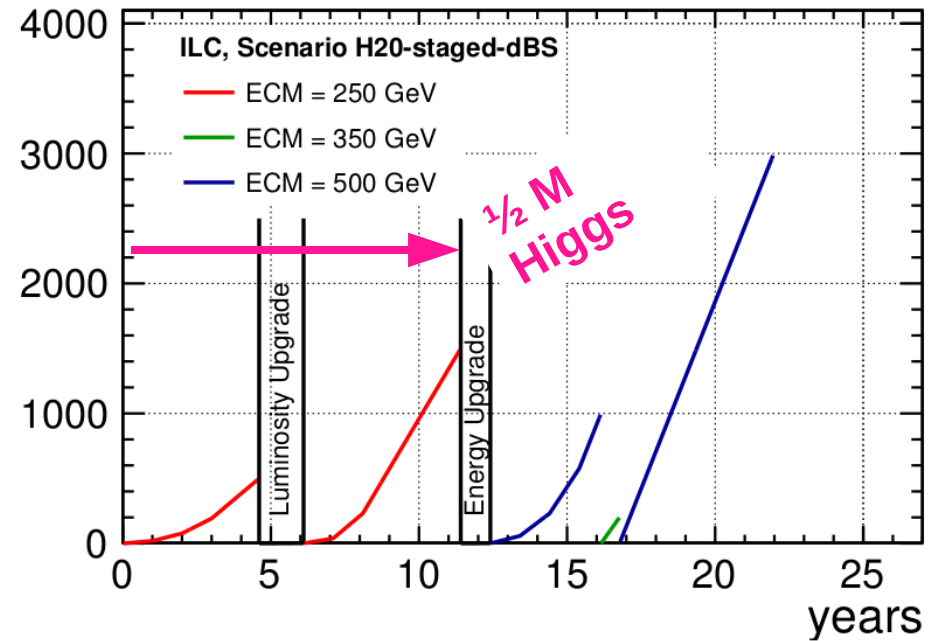
start with collisions at 250 GeV

linear accelerator

→ future energy upgrades possible,
if and when needed

see talk by
J. Reuter

Integrated Luminosities [fb^{-1}]



presently under in-depth
consideration by the
Japanese Government



ILC 250 physics program

2 ab^{-1} over ~ 11 years

electro-weak symmetry breaking

comprehensive and precise study of Higgs sector

see talk by T. Ogawa

electro-weak processes

LEP2 + beam polarisation
+ better detectors
+ 1000 times more data

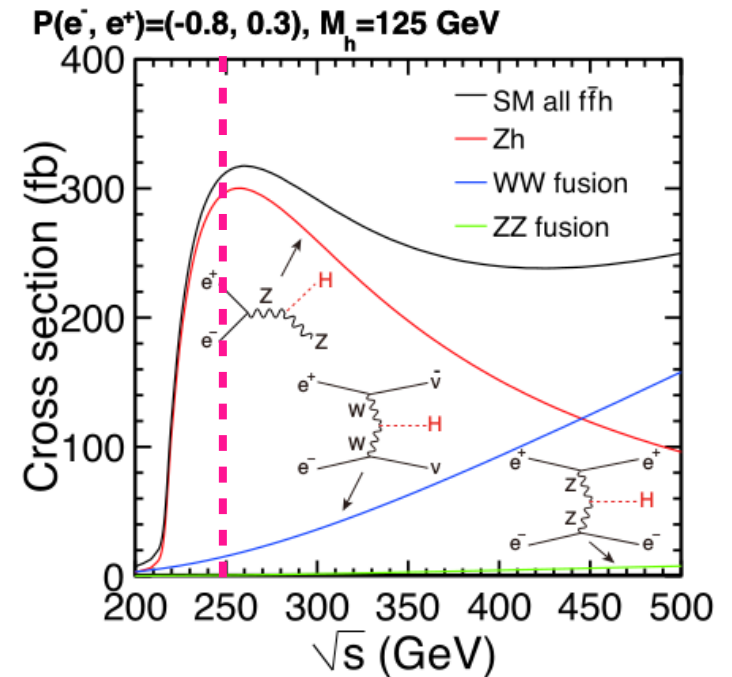
see talk by S. Bilokin

→ indirect probe of BSM physics

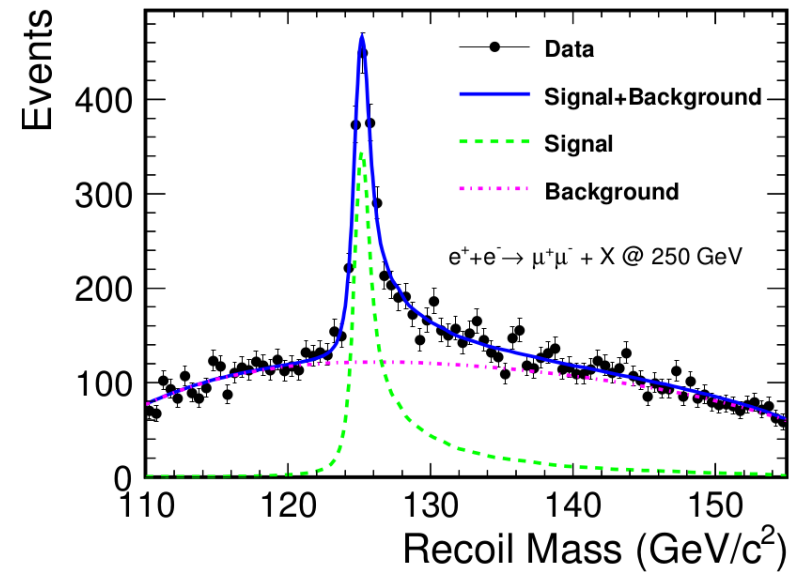
direct searches for BSM particles

profit from trigger-less readout, efficiency for lower energy signatures

see talks by M. Berggren, Y. Wang



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

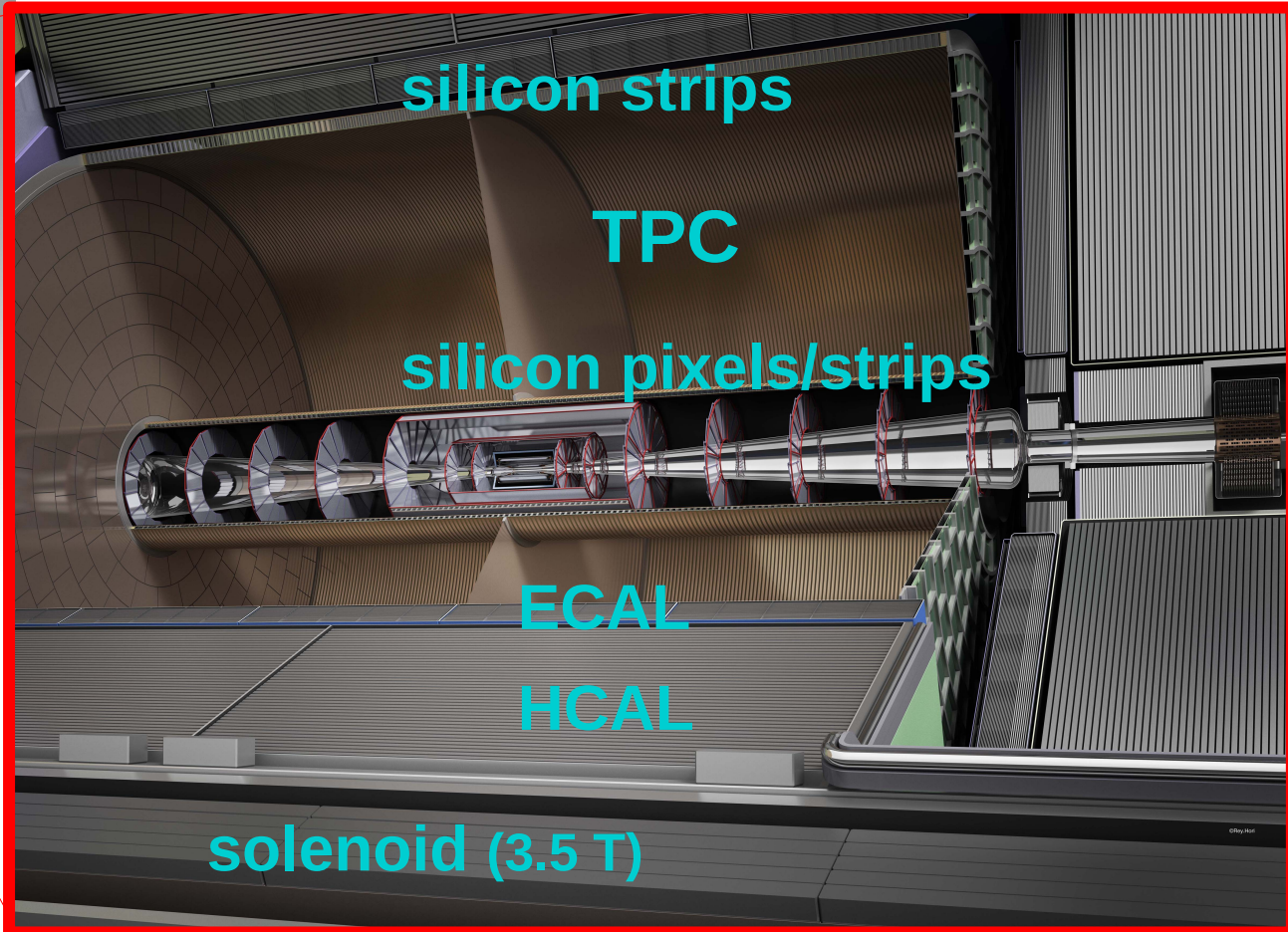
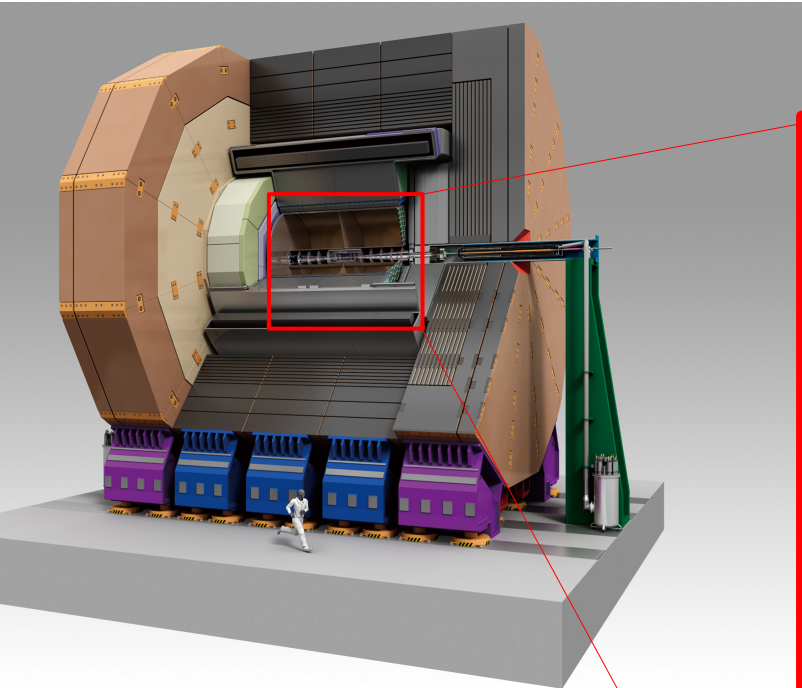




International Large Detector

one of two detector concepts being developed for ILC

high precision detector optimised for
particle flow reconstruction



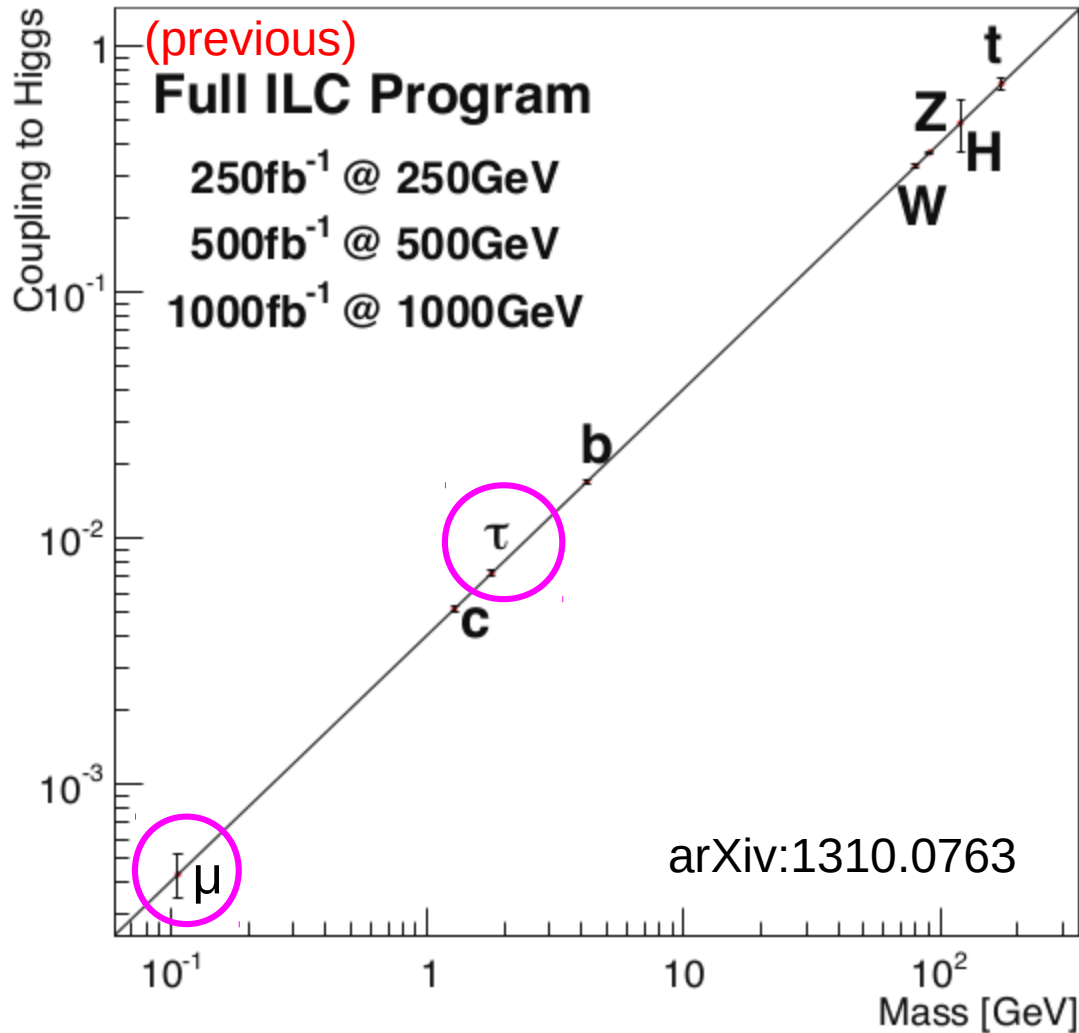
silicon, gaseous
tracking systems

$$\sigma_{d0} \rightarrow 5 \mu\text{m}$$

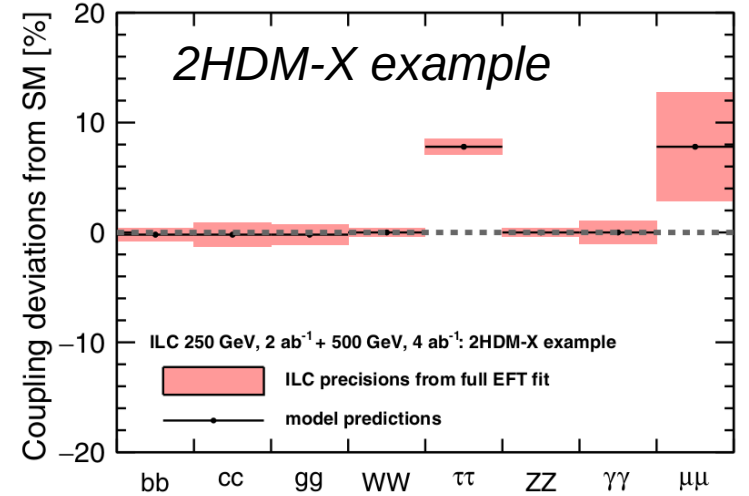
$$\sigma_{pT}/p_T \rightarrow 2 \times 10^{-5} p_T$$

high granularity calorimetry
jet energy resolution 3-4%

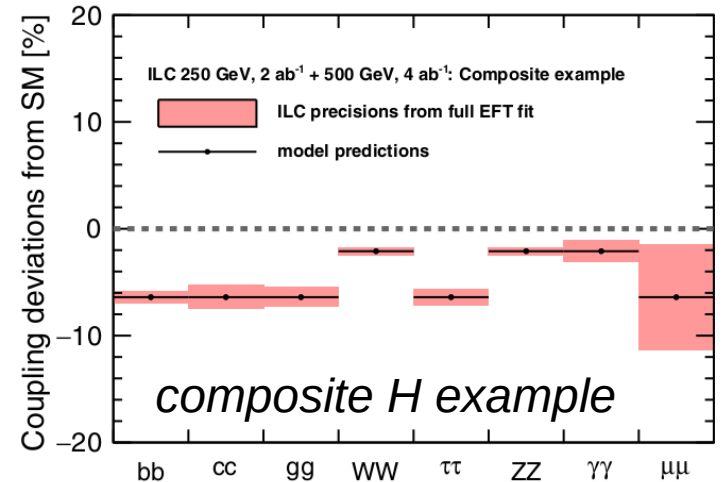
test the lepton Yukawa – mass relation



different BSM scenarios
 → patterns of deviations from SM



Phys. Rev. D 97, 053003



Higgs boson coupling to $\tau\tau$

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

isolated narrow jets,

1 or 3 charged particles

total jet charge ± 1

invariant mass $< 2 \text{ GeV}/c^2$

estimate momenta of ν from τ decay

→ **colinear** approximation

various cuts to reduce backgrounds

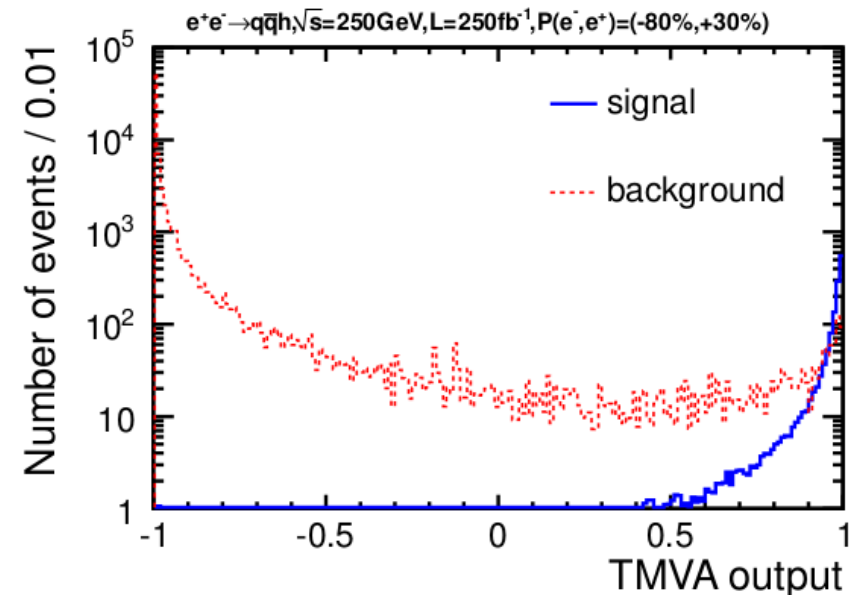
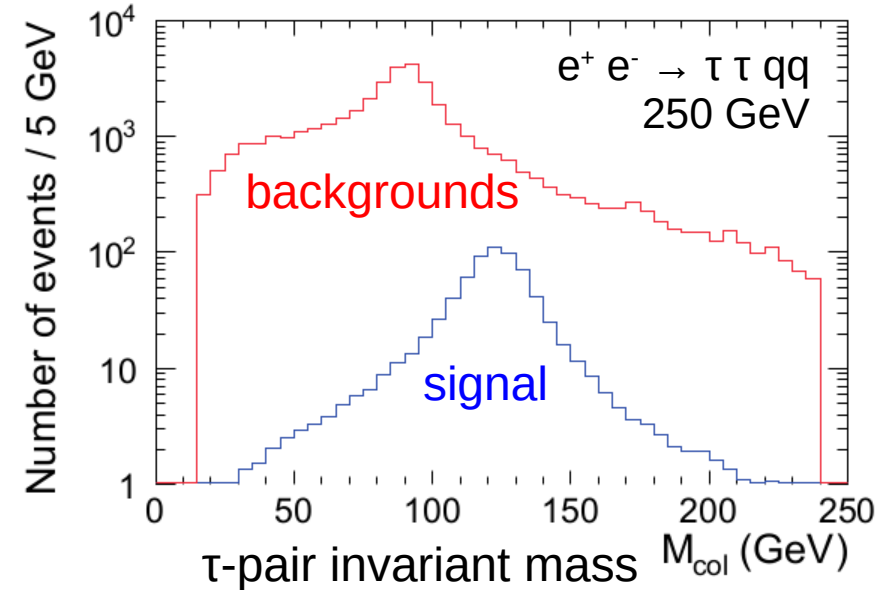
final multivariate analysis [BDT]

expected precision at ILC on

$$\sigma(h) \cdot \text{BR}(h \rightarrow \tau\tau):$$

$$1.2 \% \left[\text{ILC250} / 2 \text{ ab}^{-1} \right]$$

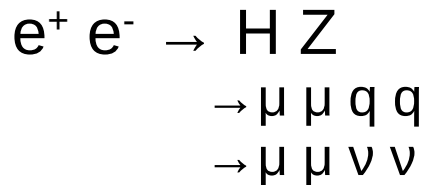
$$1.0 \% \left[+ \text{ILC500} / 4 \text{ ab}^{-1} \right]$$



Higgs boson coupling to $\mu\mu$

challenge: small sample due to tiny BR ($h \rightarrow \mu\mu$) $\sim 2 \times 10^{-4}$ [in SM]

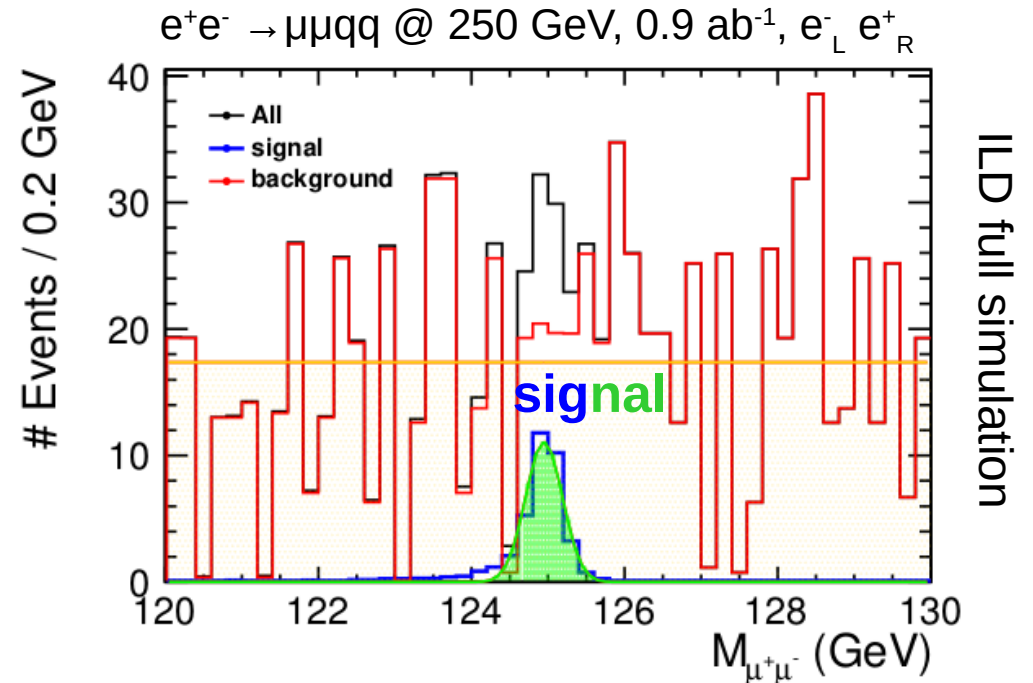
Full detector simulation,
realistic reconstruction
algorithms



pair of
prompt, isolated,
oppositely charged,
well-measured,
 μ candidates

cuts on “Z”, μ angles

Multivariate analysis to
suppress backgrounds

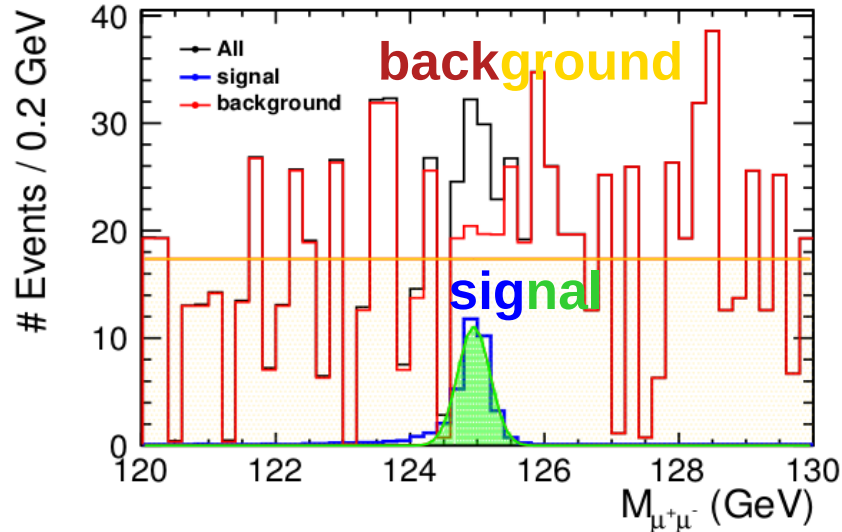


key: excellent momentum resolution
 \rightarrow narrow signal distribution
 $dp_T/p_T \rightarrow 2 \times 10^{-5} p_T$



$h \rightarrow \mu \mu$: estimating sensitivity

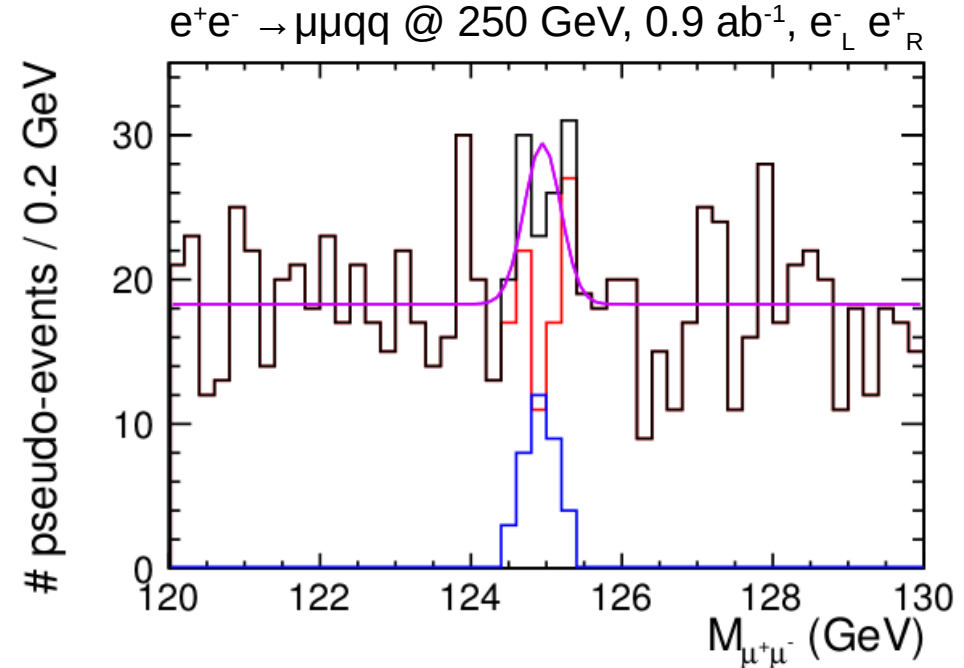
single pseudo-experiment



fit full simulation results to
gaussian (signal) +
constant (background)

fit results

- large ensemble of pseudo-experiments
- estimate measurement precision



expected relative precision on
 $\sigma(h) \cdot \text{BR}(h \rightarrow \mu \mu)$ at ILC :

20 % [ILC250 / 2 ab^{-1}]
 15 % [+ ILC500 / 4 ab^{-1}]

preliminary



does Higgs $\rightarrow \tau \tau$ conserve CP ?

baryogenesis at E-W scale?

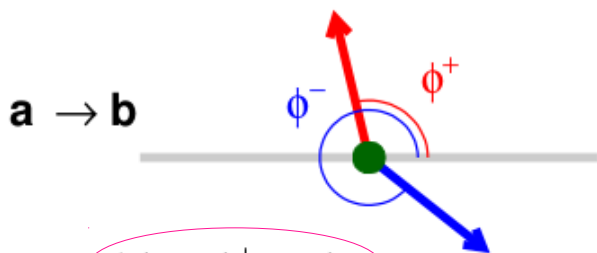
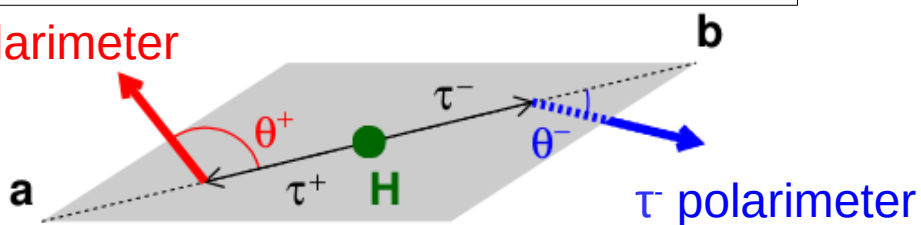
arXiv:1804.01241
to appear in PRD

$$h_{125} = \cos \psi_{CP} h^{CP\text{even}} + \sin \psi_{CP} A^{CP\text{odd}}$$

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

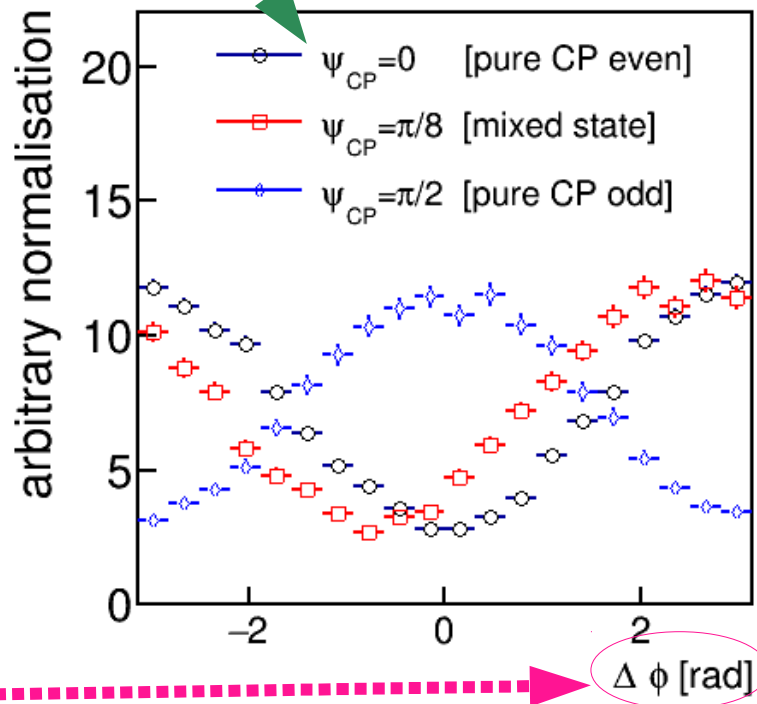
“**polarimeter**” - estimator of spin direction from τ decay products

τ^+ polarimeter



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

h is a spin 0 state:
 $|f \bar{f}\rangle = |\uparrow \downarrow\rangle + e^{2i \psi_{CP}} |\downarrow \uparrow\rangle$
 $[\psi_{CP} = 0 \quad \text{CP even,}$
 $\pi/2 \quad \text{CP odd}]$



full τ 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

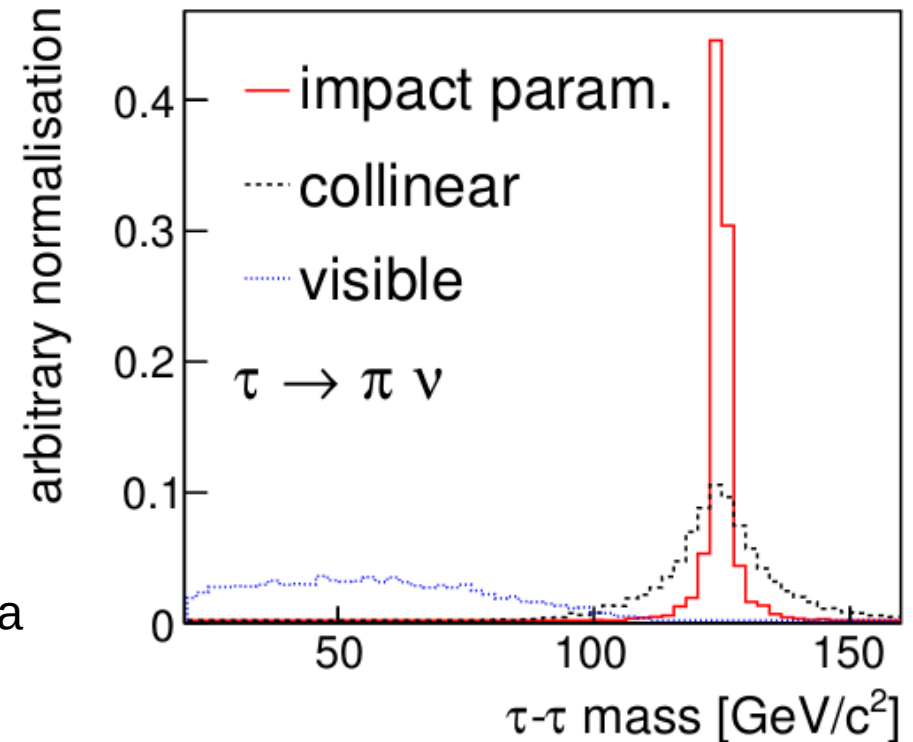
excellent vertex detector:

- 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

ILD full simulation

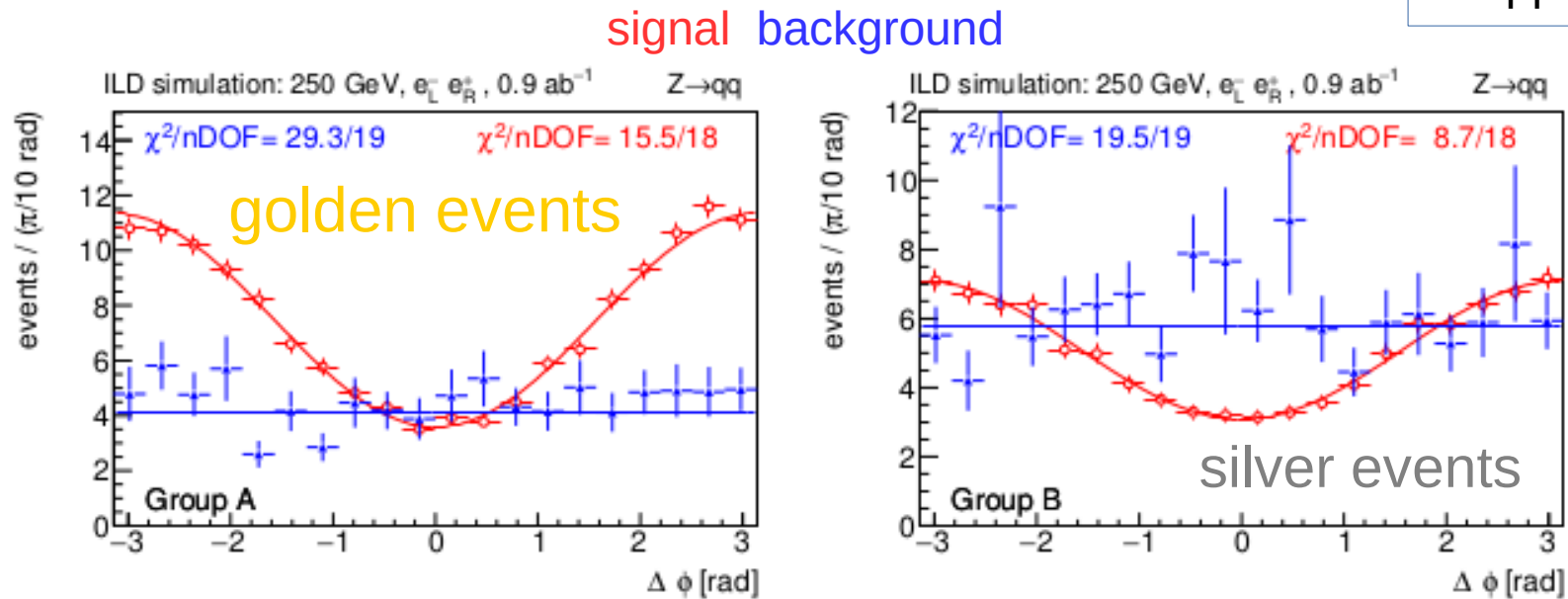


optimal information on τ momentum and spin
relies on excellent detector performance:
impact parameter, tracking, photon and jet measurement



CP in $h \rightarrow \tau \tau$: sensitivity

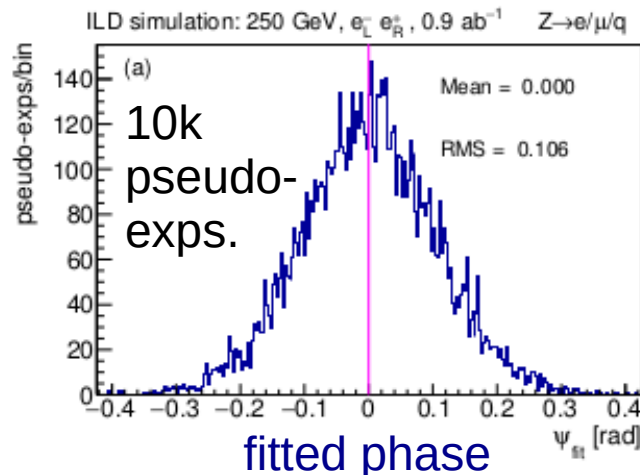
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signal distribution:
backgrounds:

phase of $\Delta\phi$ distribution sensitive to CP
consistent with flat distribution

pseudo-experiments:
simultaneous
likelihood fit to
 $\Delta\phi$ distributions
in all channels



with 2 ab^{-1} @ ILC250,
measure ψ_{CP} to
75 mrad (4.3 deg)



Summary

International Linear Collider will enable comprehensive set of Higgs measurements, shining light on BSM physics

Initial ILC250 stage:

$\sigma (h) \cdot BR (h \rightarrow \tau \tau)$ with a precision of 1.2 % [1% w/ ILC500]
→ several times more precise than HL-LHC projections

$\sigma (h) \cdot BR (h \rightarrow \mu \mu)$ with a precision of 20% [15% w/ ILC500]
→ statistically limited
→ similar to HL-LHC projections with ILC500

CP mixing in $h \rightarrow \tau \tau$ with a precision of 75 mrad
→ baryogenesis at electro-weak scale ?

