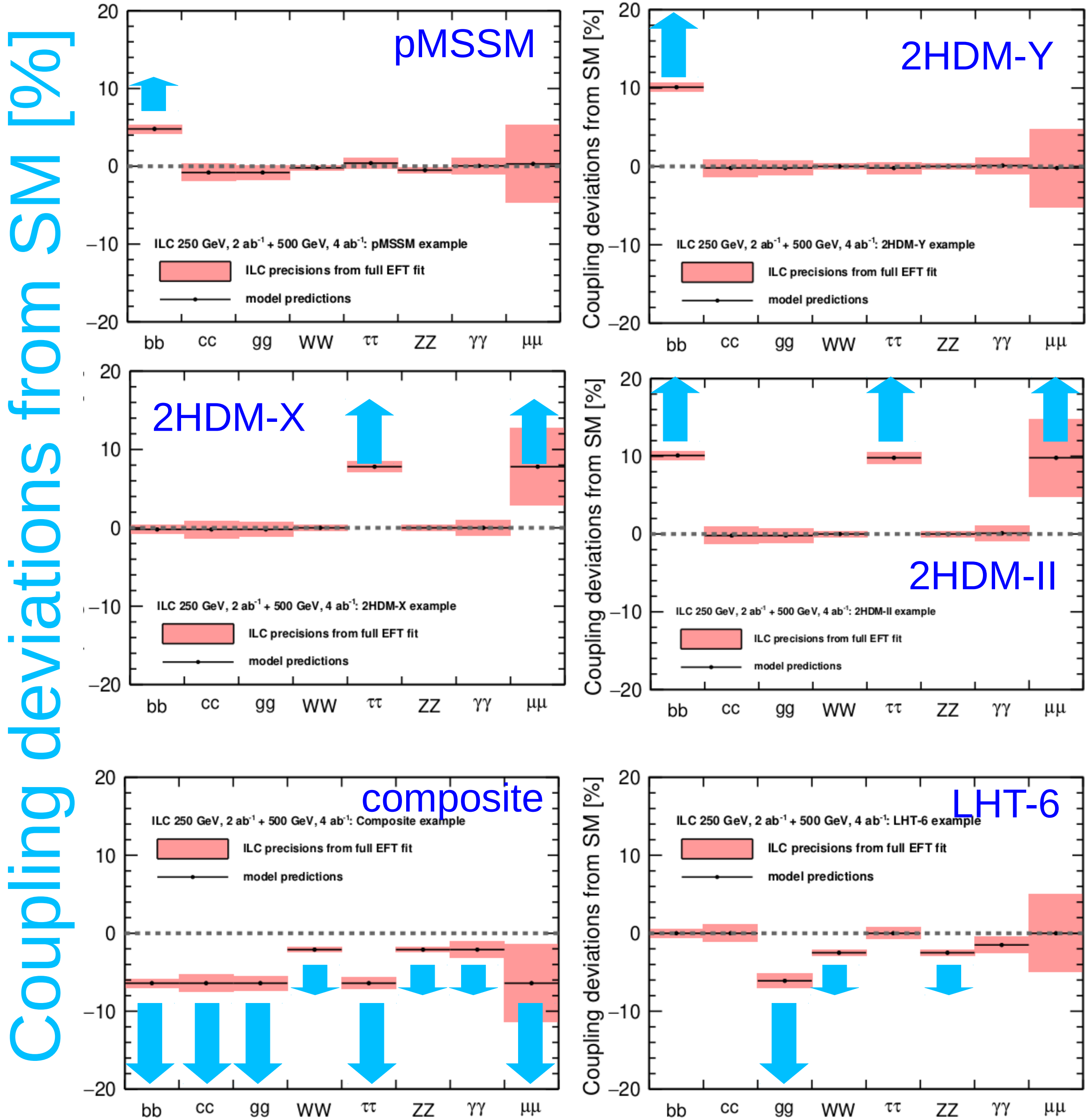
Precision Higgs physics at the ILC, and its impact on detector design

Daniel Jeans / KEK
Linear Collider Collaboration – physics & detectors

ICHEP 2020

fingerprints of new physics on Higgs couplings



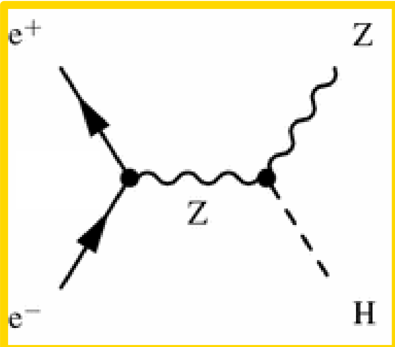




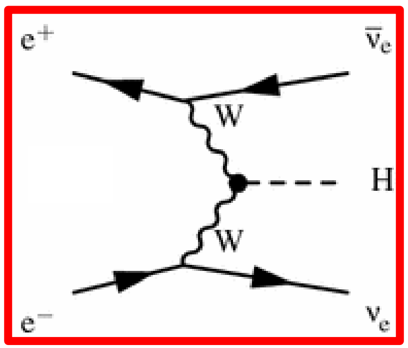
arXiv:1708.08912

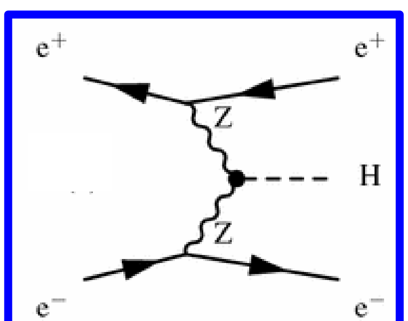
Higgs couplings can reveal physics beyond the SM

Higgs production in electron-positron collisions

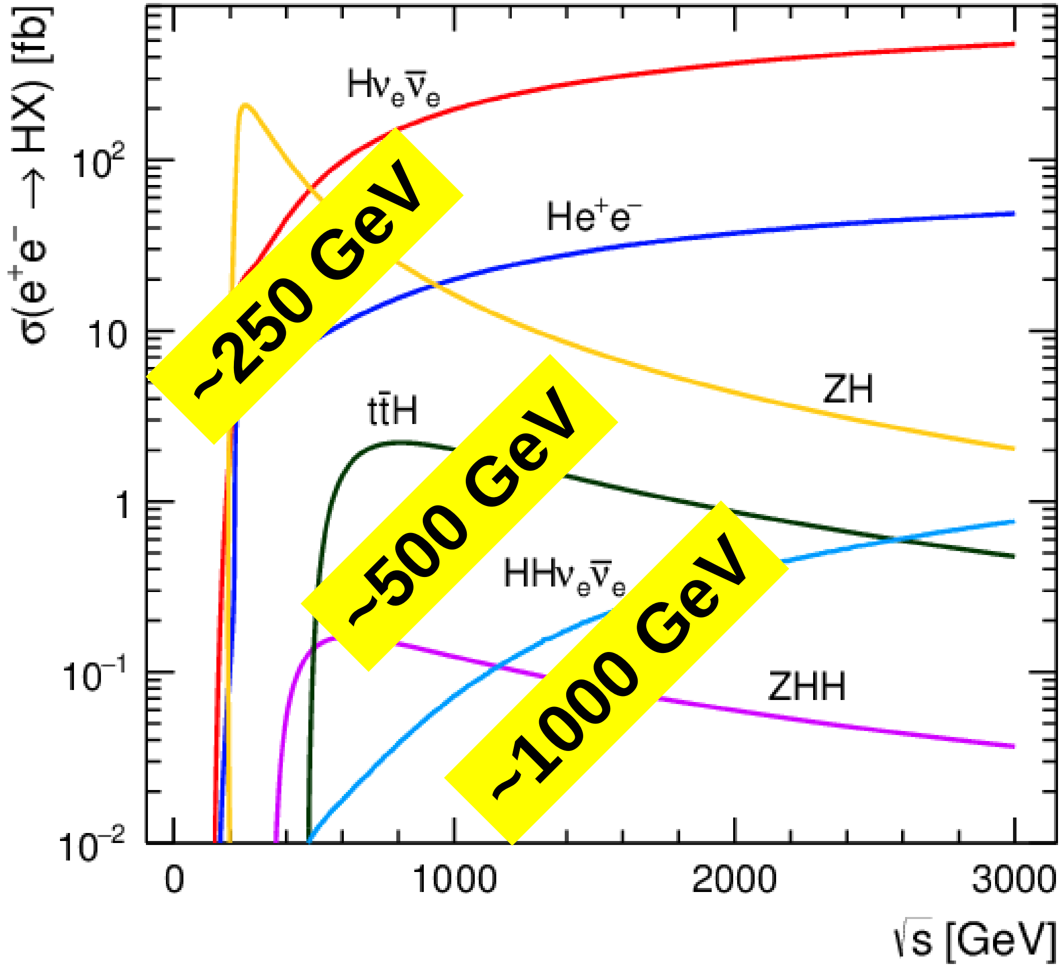


associated Higgs production





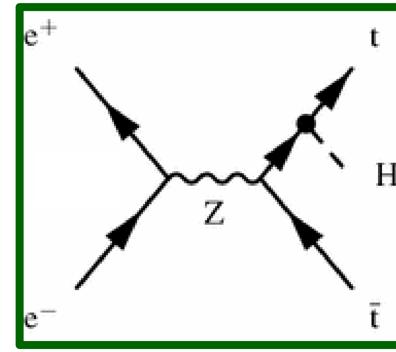
WW & ZZ fusion



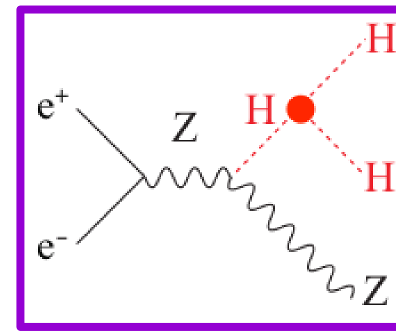
Higgs studies start at **250 GeV**

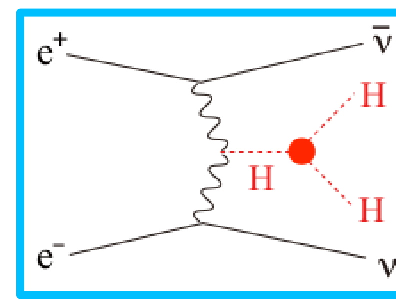
for full set of Higgs measurements, add collisions at ~**500** & ~**1000 GeV**

detectors for full energy range



top quark Yukawa





Higgs boson self-coupling

International Linear Collider

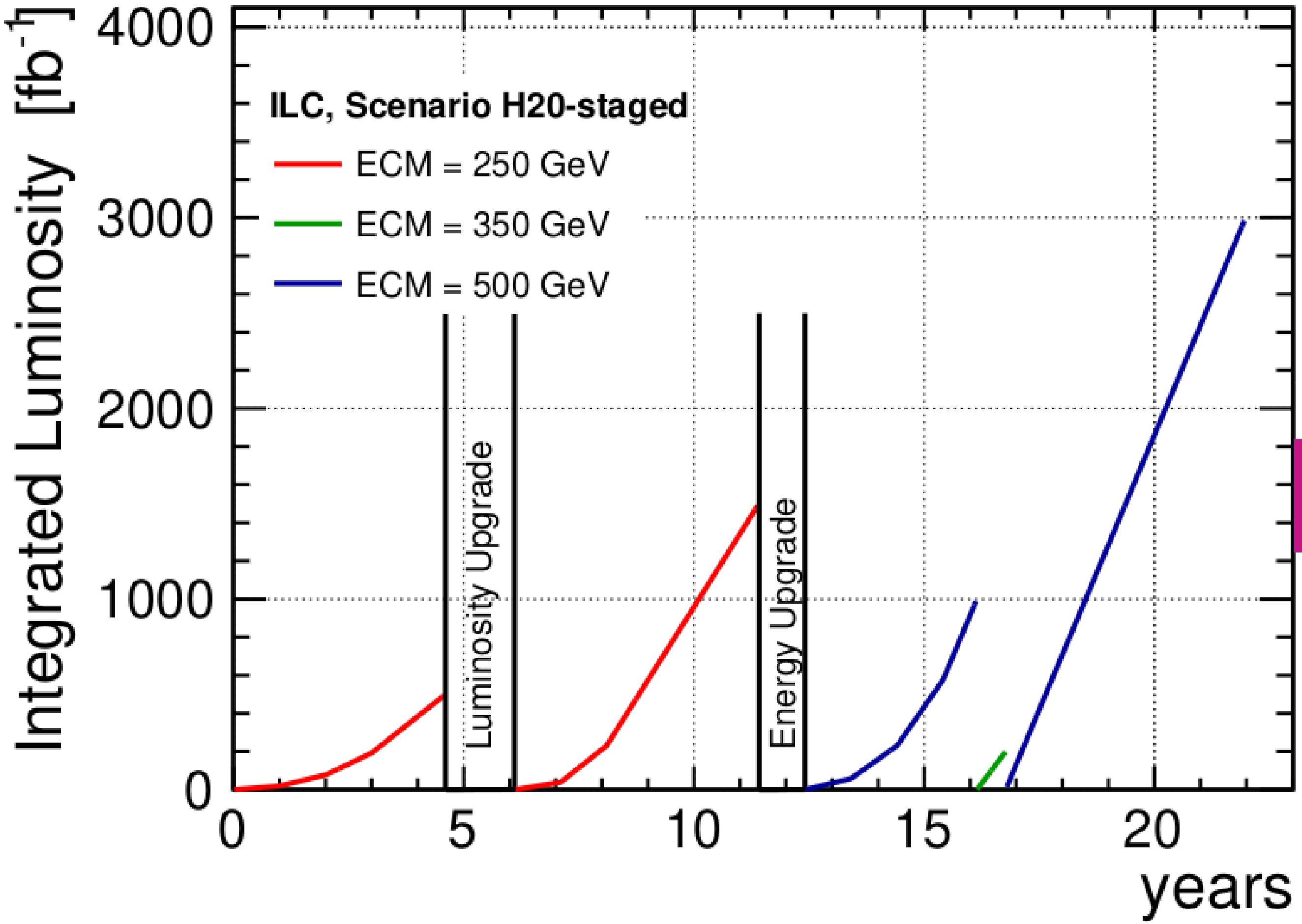
collide electron & positron beams

CM energy : initial 250 GeV; upgrade to 1000+ GeV

longitudinally polarised beams [electron 80%; positron 30%]

J. List, in Accelerator: Physics, Performance, and R&D for Future Facilities, 28/7

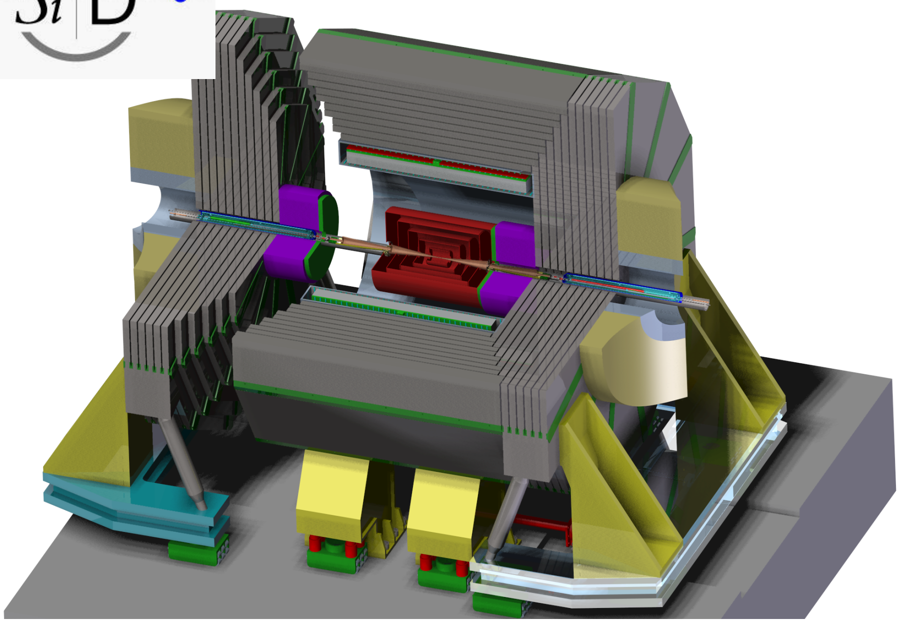
superconducting technology : reduced energy consumption

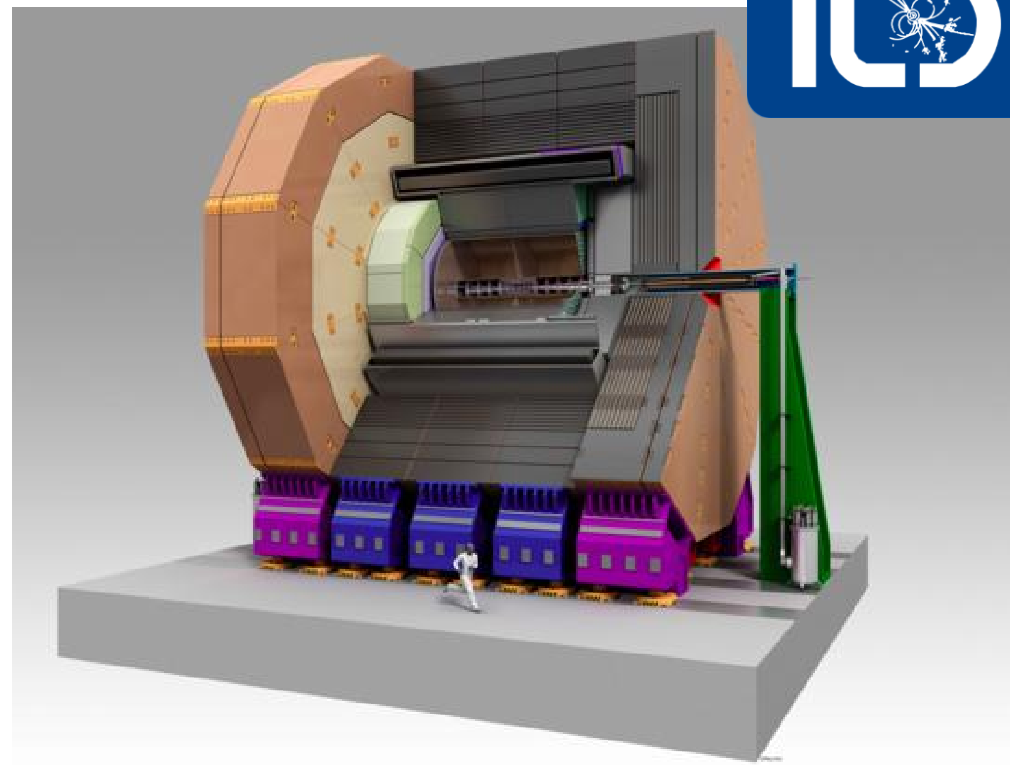


upgradable to
1 TeV and above

2000 fb^{-1} @ 250 GeV
4000 fb^{-1} @ 500 GeV
200 fb^{-1} @ 350 GeV

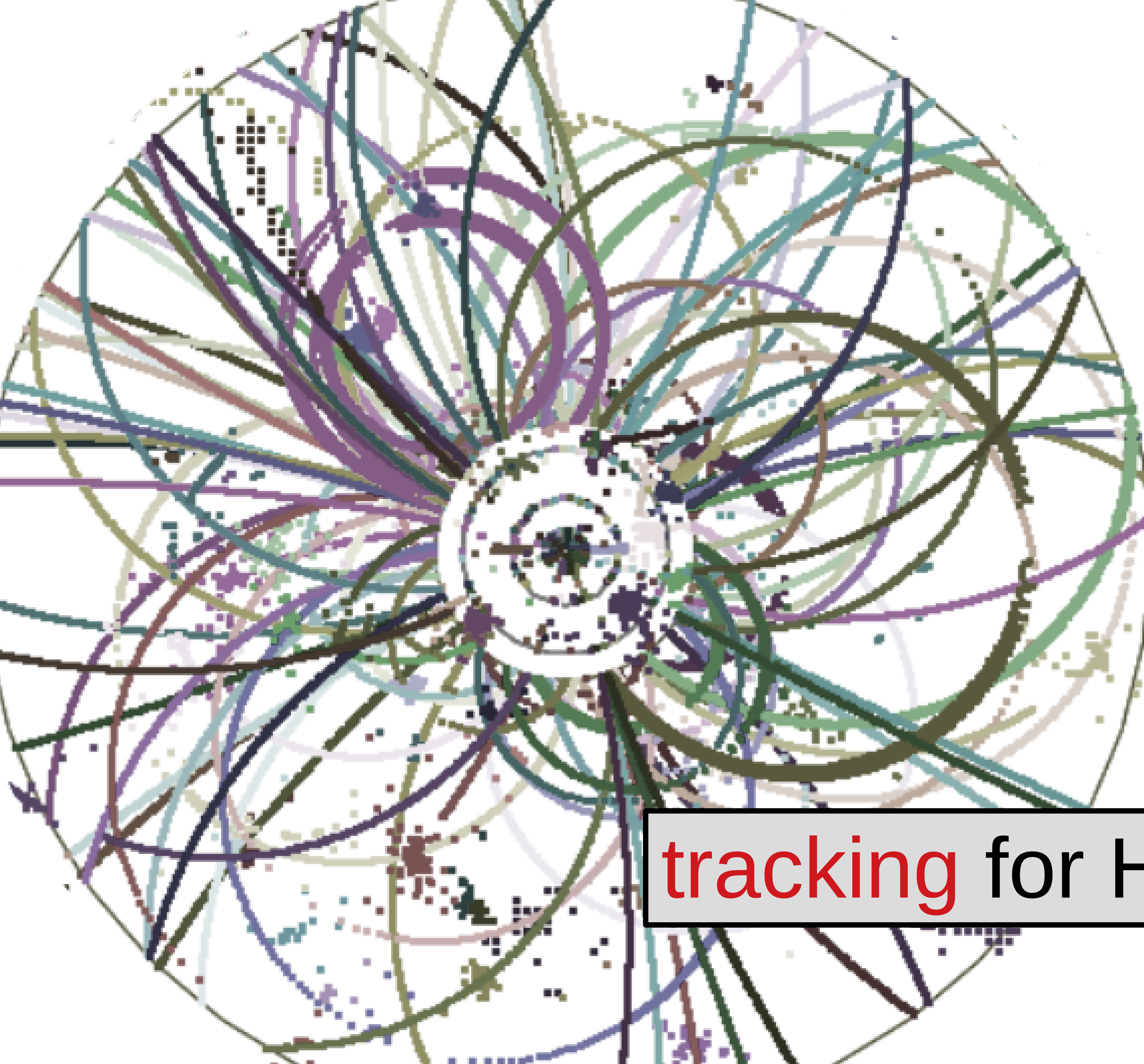
ILC interaction point shared by two detectors





two groups developing detector designs for ILC

SiD	A. White, Detectors for Future Facilities, 29/7
ILD	T. Tanabe, Detectors for Future Facilities, 31/7

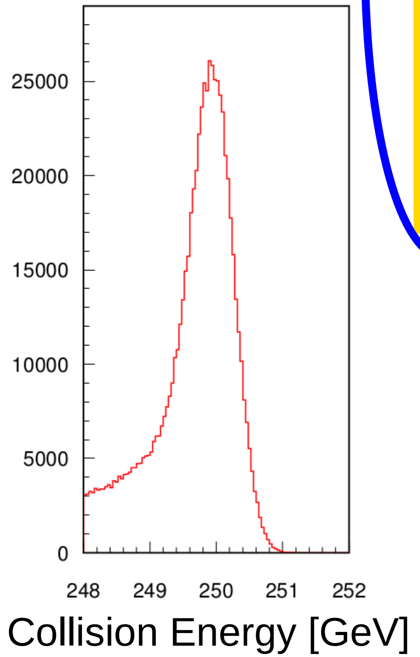


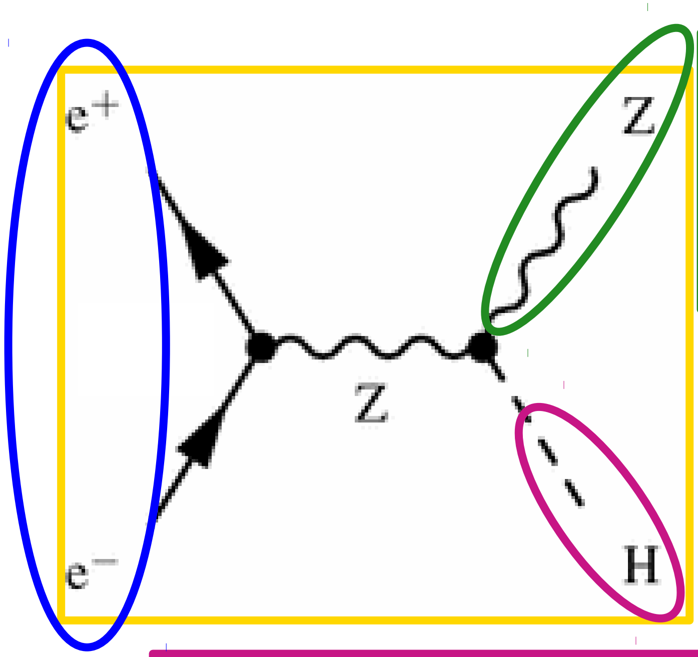
tracking for Higgs

Higgs-strahlung

key to measurements independent of Higgs decay

initial 4-momentum
well-known
nominal CM energy
+ beam energy spread
[<0.2% / beam]
+ beamstrahlung
energy loss





4-momentum of Z measured by detector

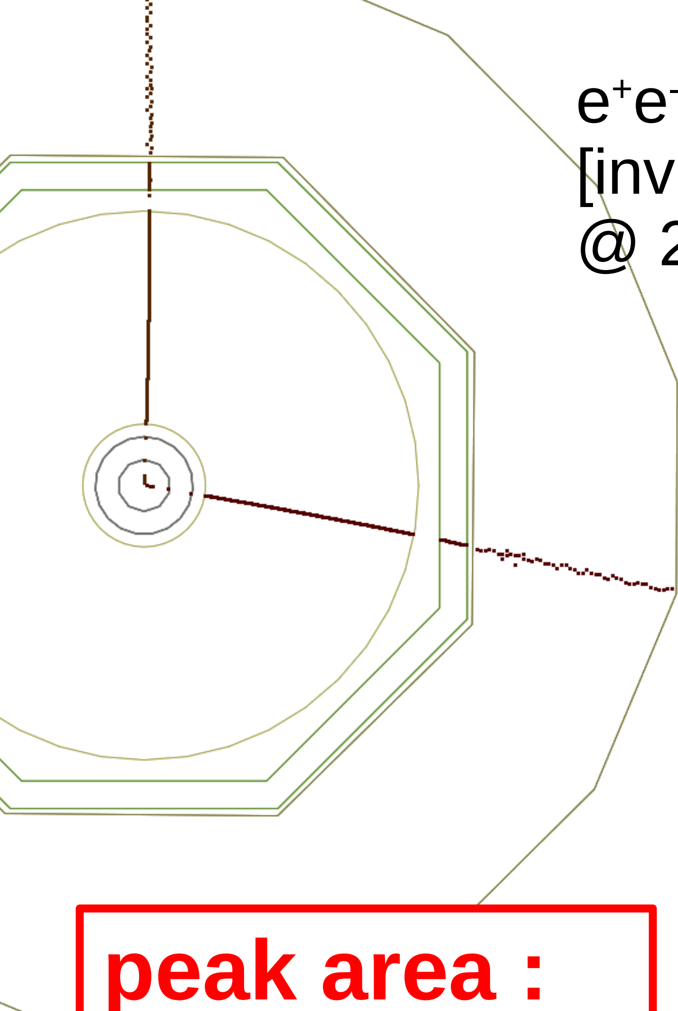
→ infer recoiling system's 4-momentum

precision depends on:
- collision energy spectrum
- Z measurement precision

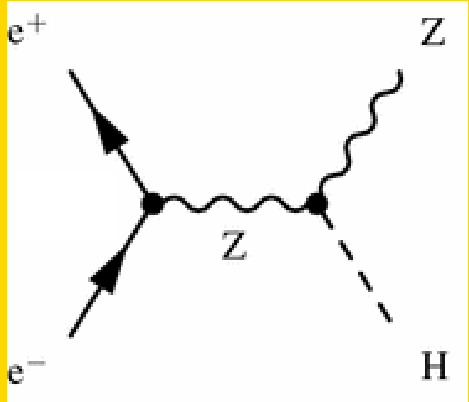
defines required momentum resolution

smearing due to Z momentum ~ smearing due to beam energy spread

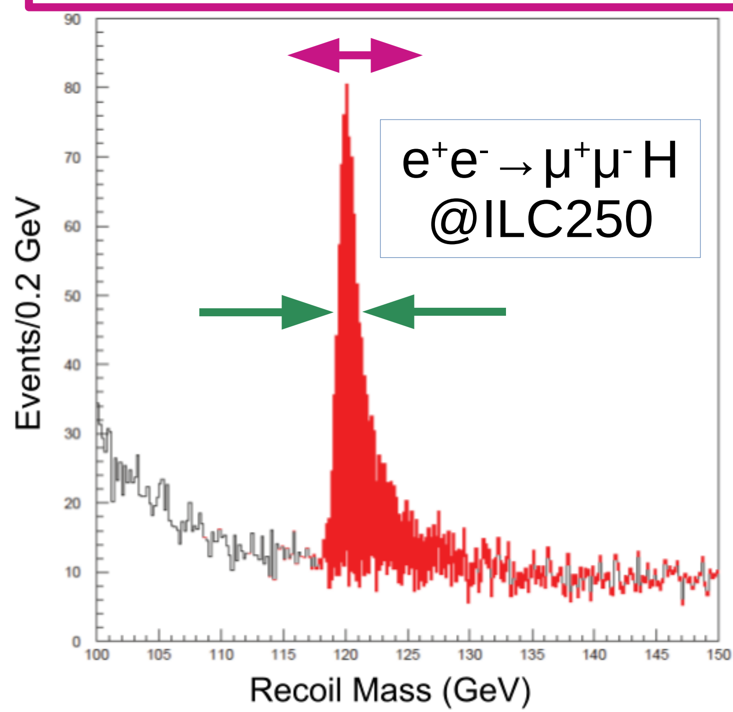
$dp_T/p_T \sim$ few x 10^{-5} p_T @ high momentum



$e^+e^- \to \mu^+\mu^- h$
[invisible h decay]
@ 250 GeV



peak position:
Higgs mass ~ 14 MeV



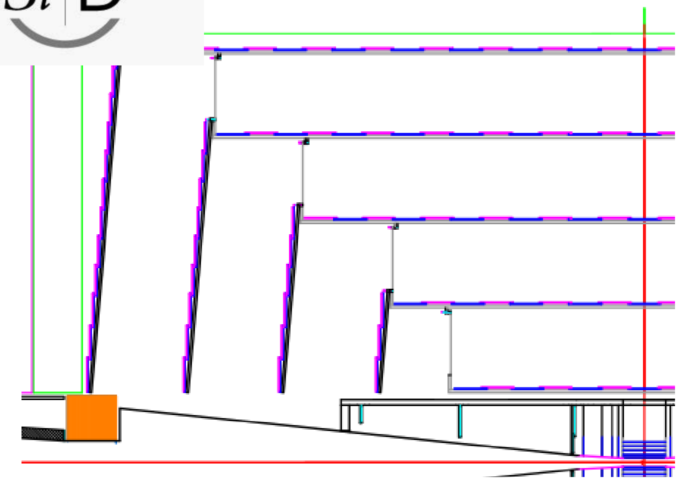
peak area :
total $e^+e^- \to Z\,H$ cross-section
→ independent of H decay

→ HZZ coupling strength ~ 0.4%

peak width:
→ drives precision

momentum resolution
⊕
beam energy spread

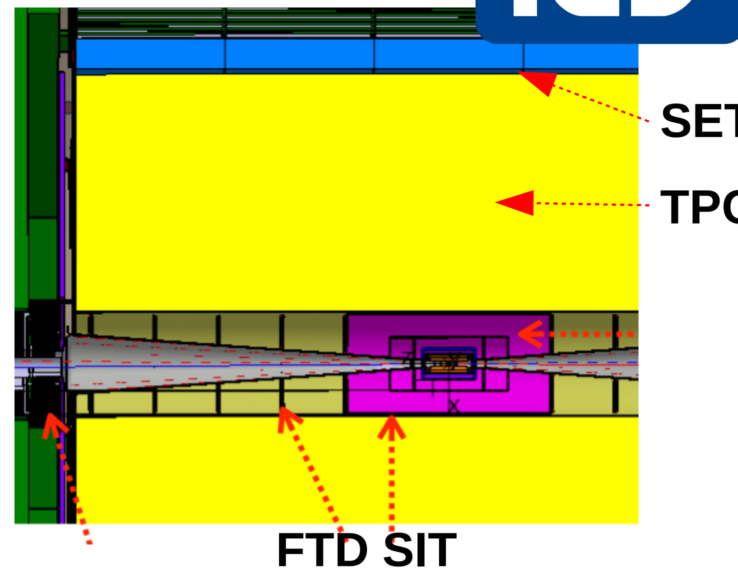
main tracking system



all-silicon tracking system

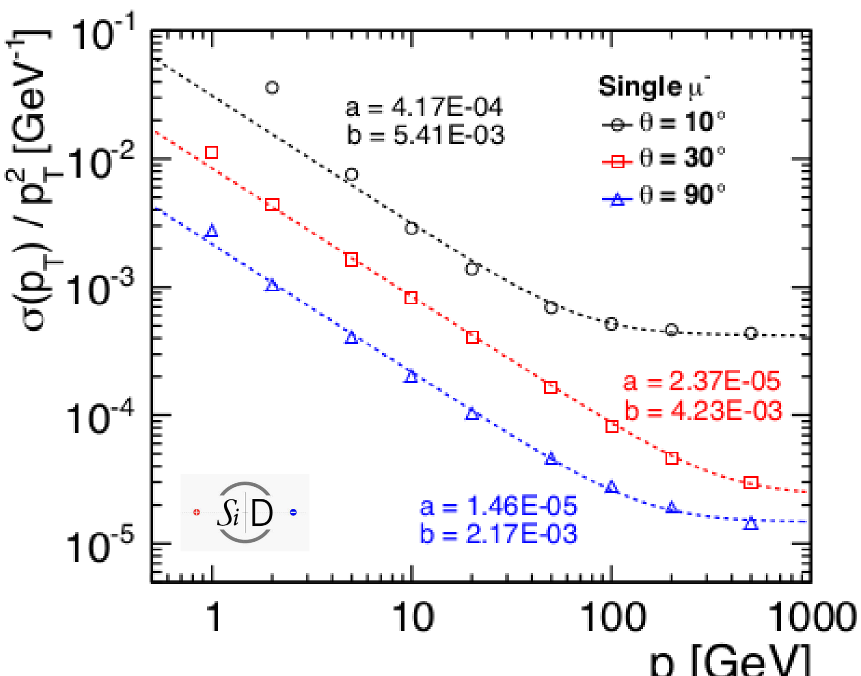
5 layers of strip sensors

contrasting approaches

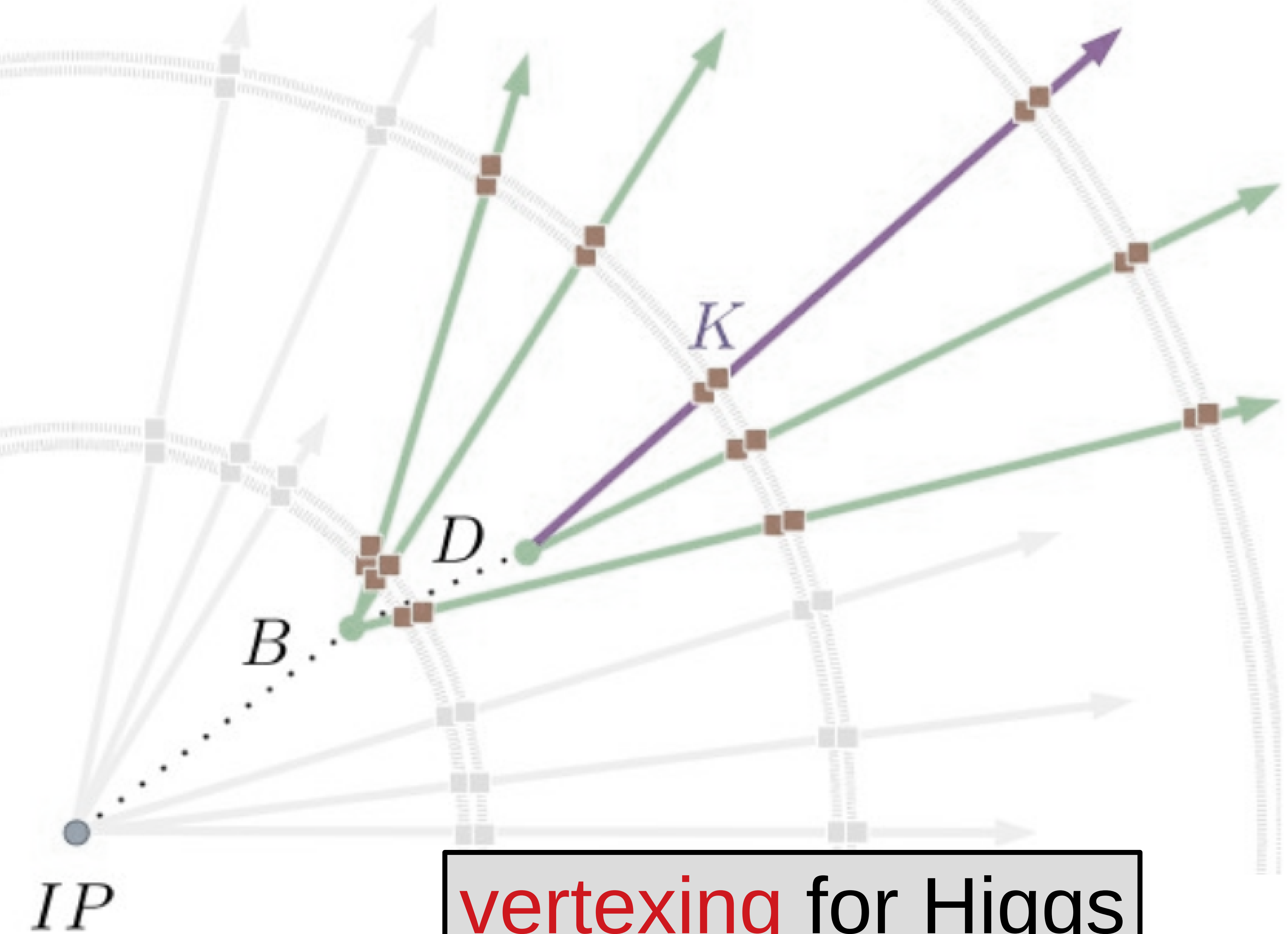


hybrid tracking system

Time Projection Chamber (**TPC**)
+ silicon (**SET, SIT, FTD**)



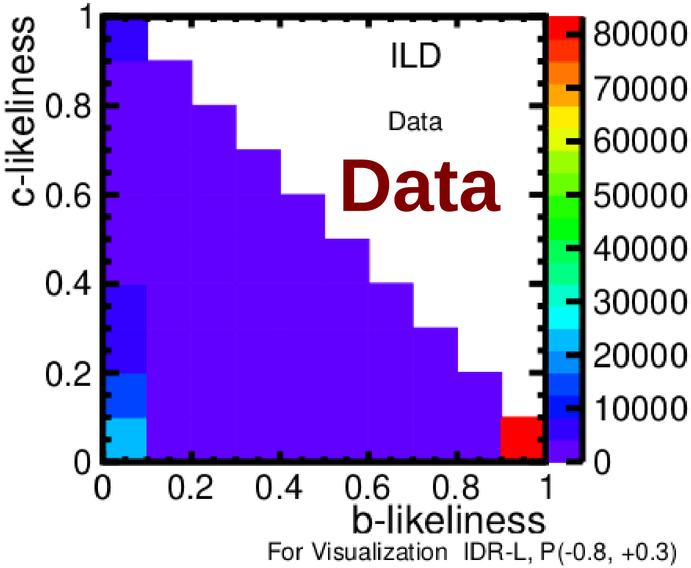
both achieve required performance



vertexing for Higgs

S. Bilokin

hadronic Higgs branching ratios



combine partial cross-sections

σ_{ZH} x BR (H → bb, cc, gg)

with total σ_{ZH} measurement

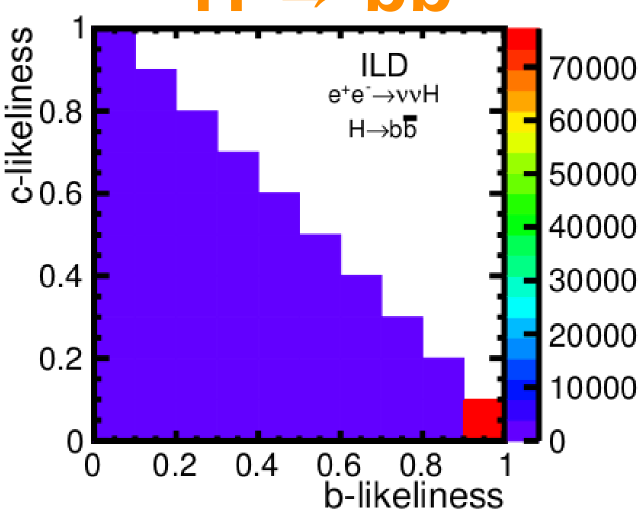
→ absolute BR measurement

b- and c-jet tagging

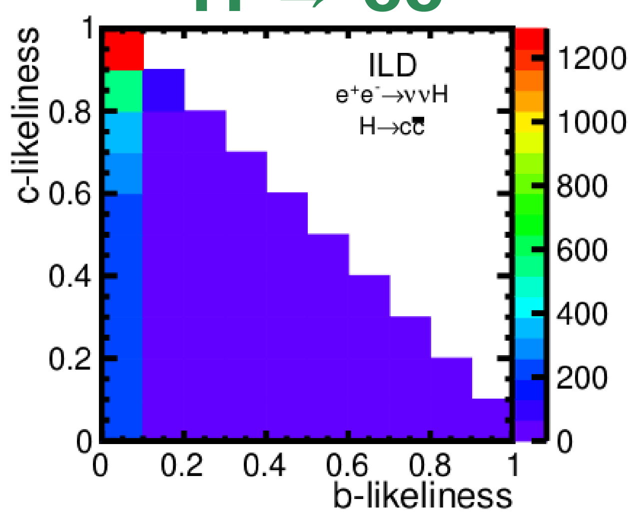
displaced vertices and tracks

secondary leptons

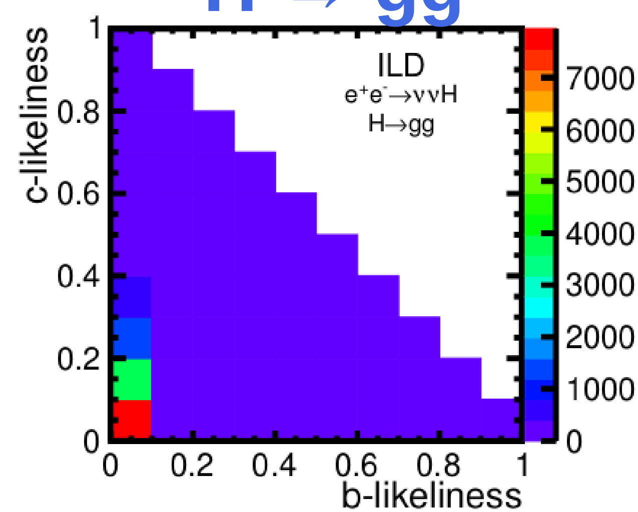
H → bb



H → cc



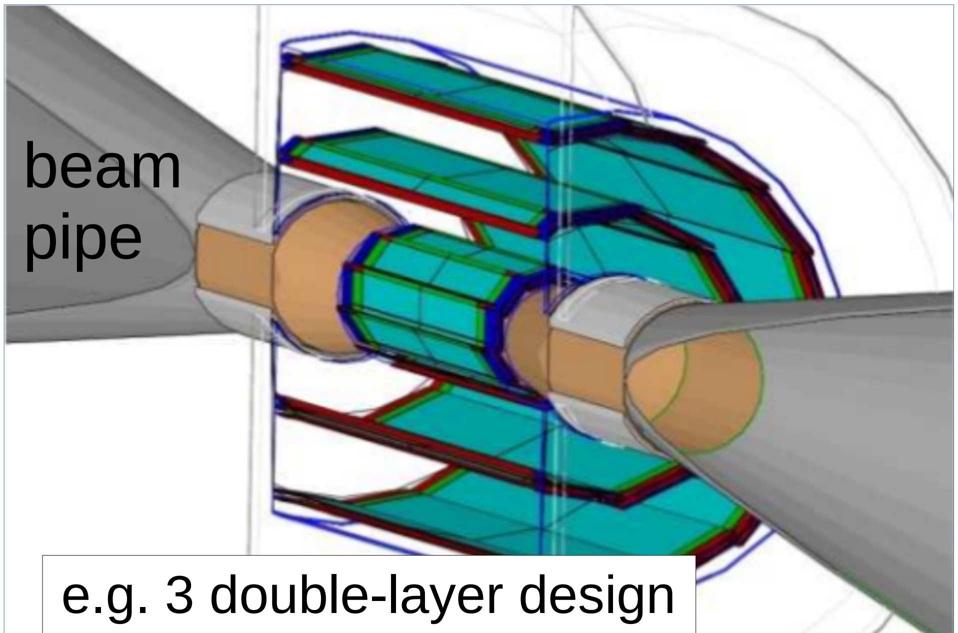
H → gg



250 fb^{-1}@250 GeV : **$\delta\ \sigma_{ZH} BR_{bb}$ ~ 1%** ; **$\delta\ \sigma_{ZH} BR_{cc}$ ~ 8%** ; **$\delta\ \sigma_{ZH} BR_{gg}$ ~ 7%**

arXiv:1207.0300, 1903.01629, 2003.01116

vertex detector



e.g. 3 double-layer design
[+ forward disks]

key aspects:

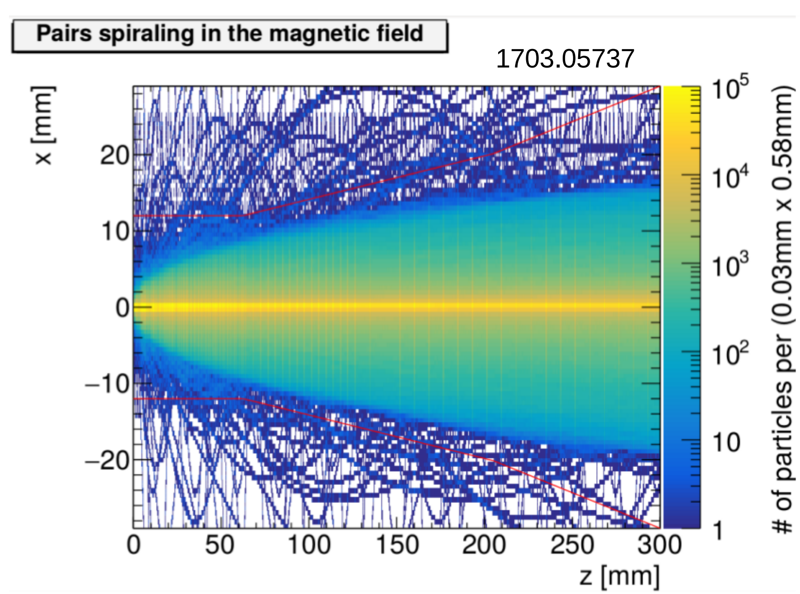
position resolution < 5 micron
→ sensor technologies

close to IP ~ 15 mm
→ machine backgrounds

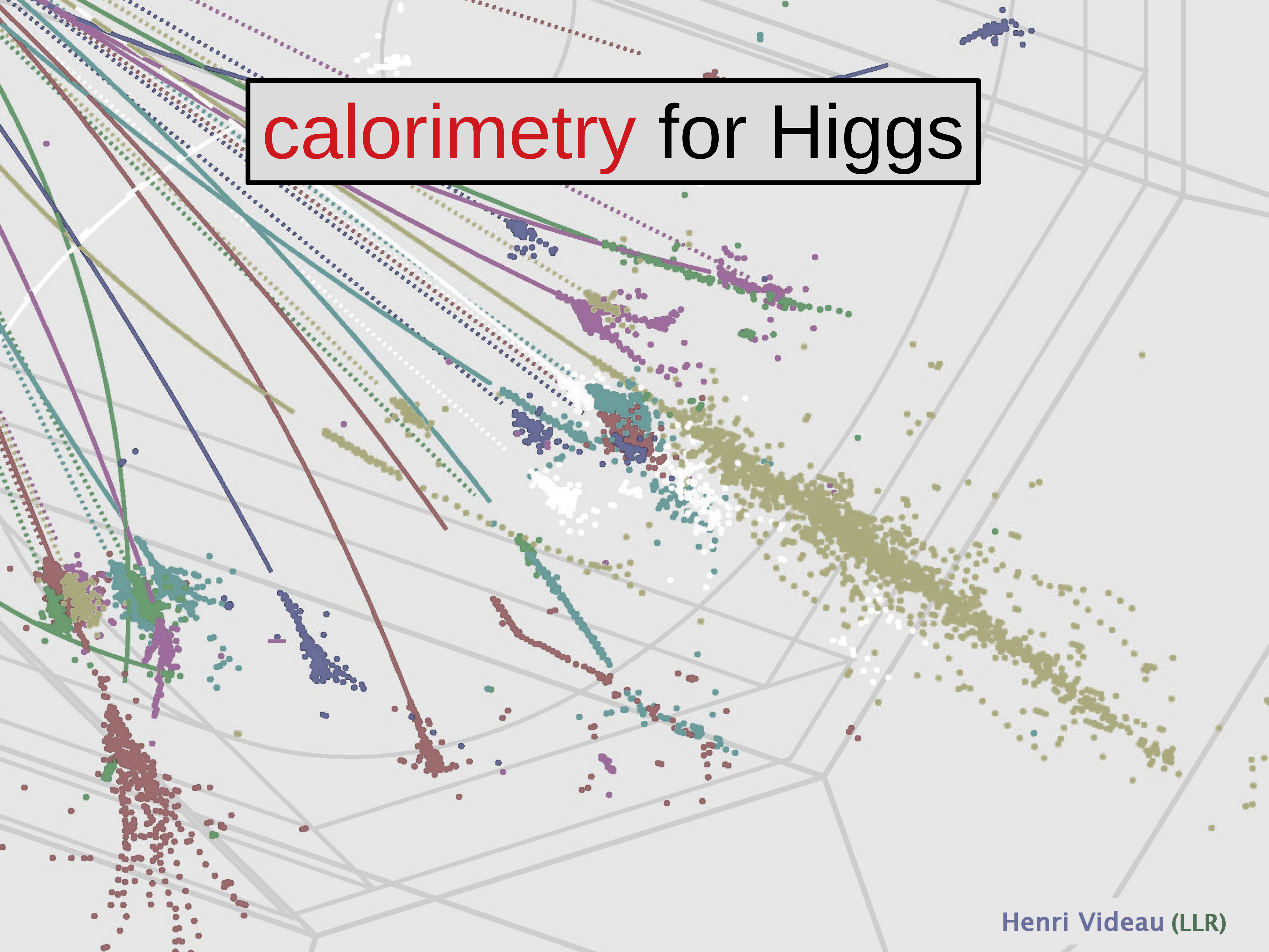
low mass < 0.3% X_0/layer
→ support, infrastructure

low energy $e^{+/-}$
beamstrahlung
background

constrained by
strong detector
solenoid 3.5~5 T



calorimetry for Higgs



Henri Videau (LLR)

majority of final states will have hadronic jets

hadronic final states dominate decays of W, Z, H, …

key figure of merit:

distinguish hadronic decays of W, Z (and H),

→ requires excellent Jet Energy Resolution

Particle Flow

tracker [excellent momentum resolution]

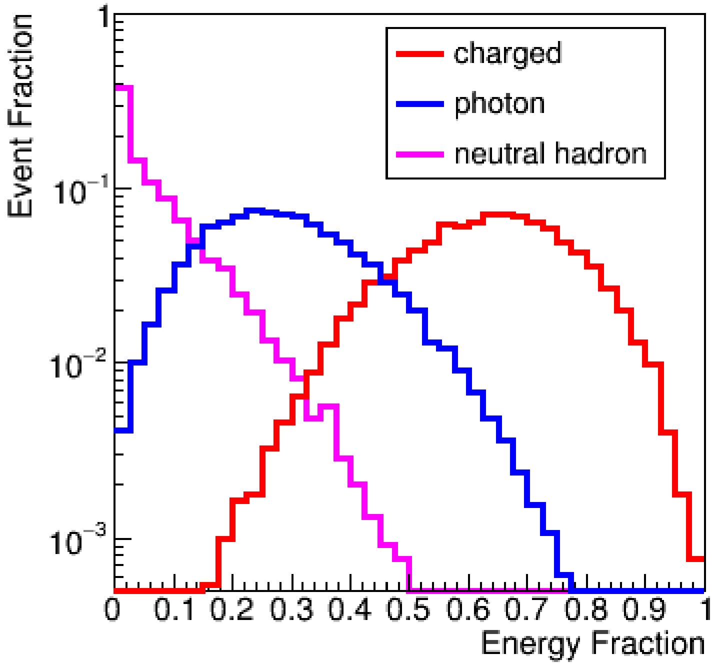
→ charged energy (~65%)

calorimeters

→ used to measure only

photon (~25%) and

neutral hadron (~10%) energy

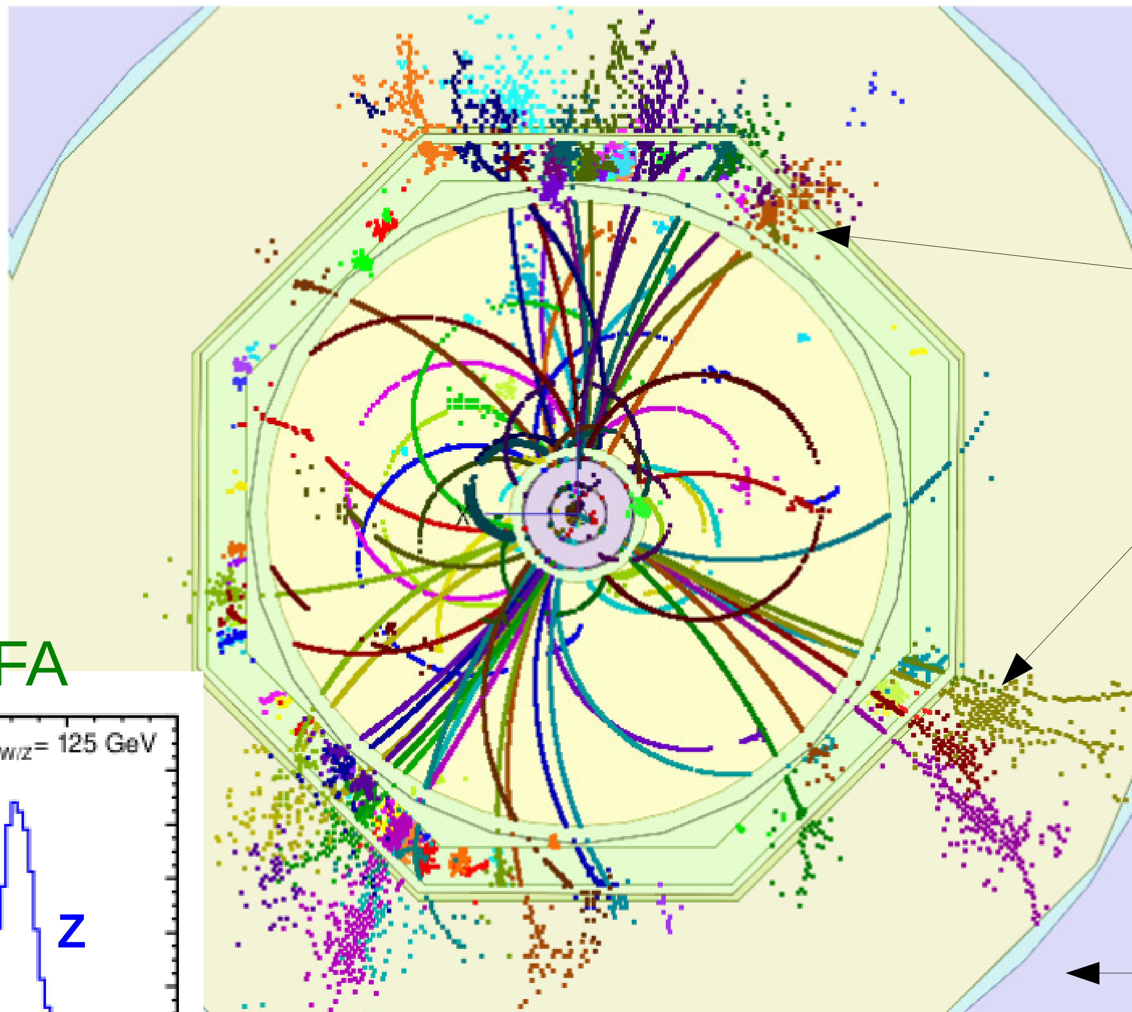


→ calorimeters must distinguish energy deposits from

charged and **neutral** particles

to distinguish **charged** and **neutral** calorimeter deposits :

1. highly detailed calorimeter readout
2. sophisticated reconstruction algorithms
3. minimal material before calorimeters



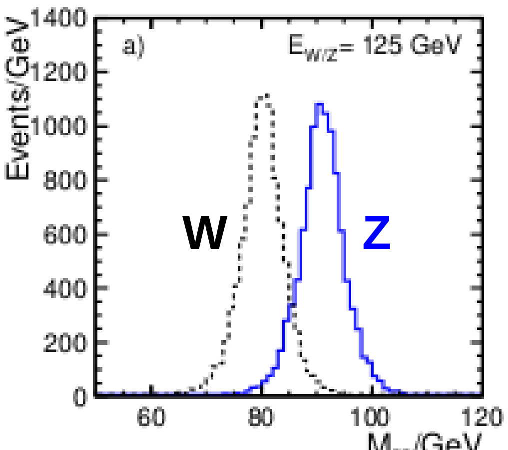
readout granularity

< 1 cm^3 in ECAL

< 30 cm^3 in HCAL

calorimeters both inside detector solenoid

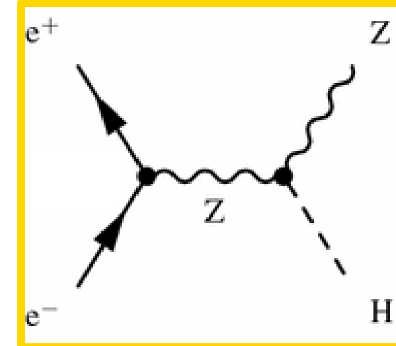
PandoraPFA

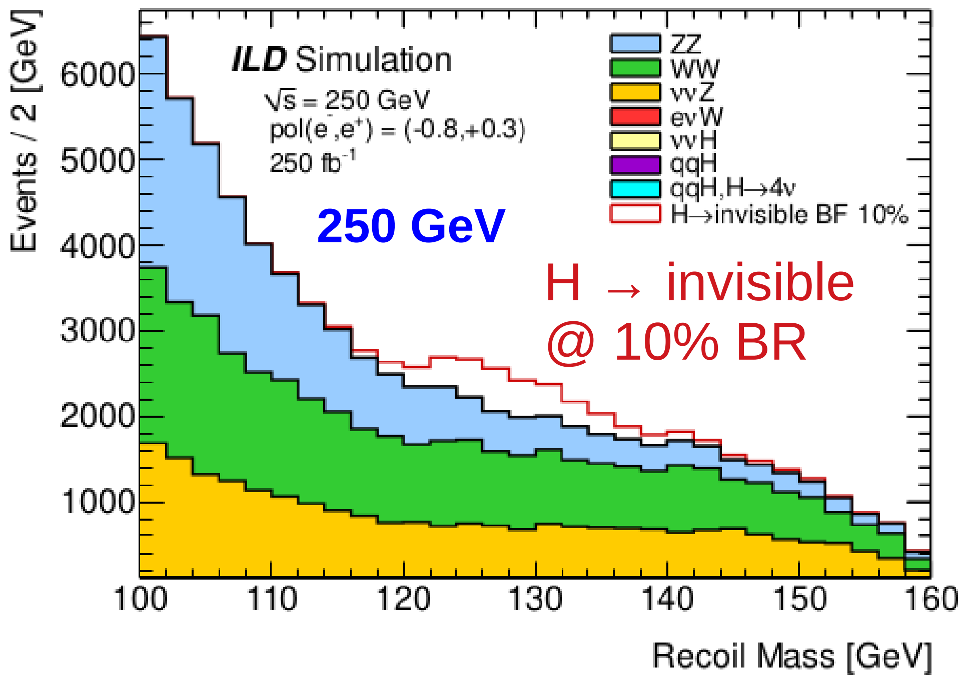


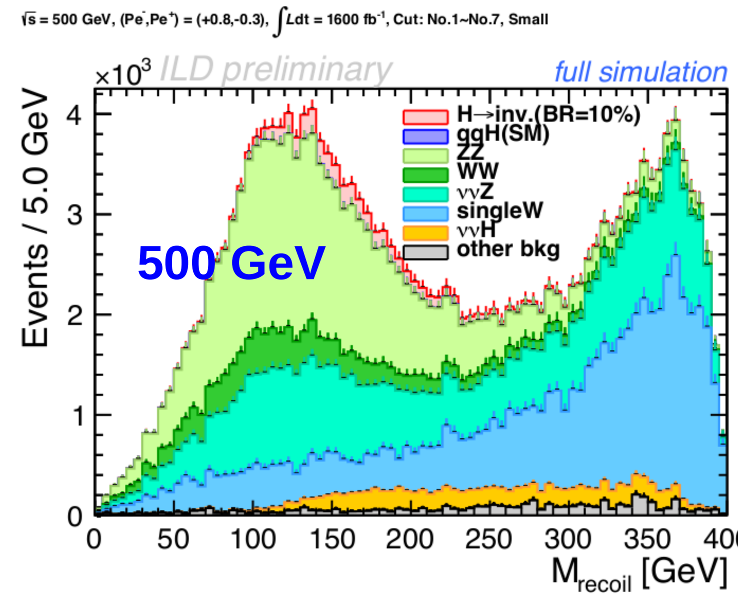
Higgs decay to invisible final states

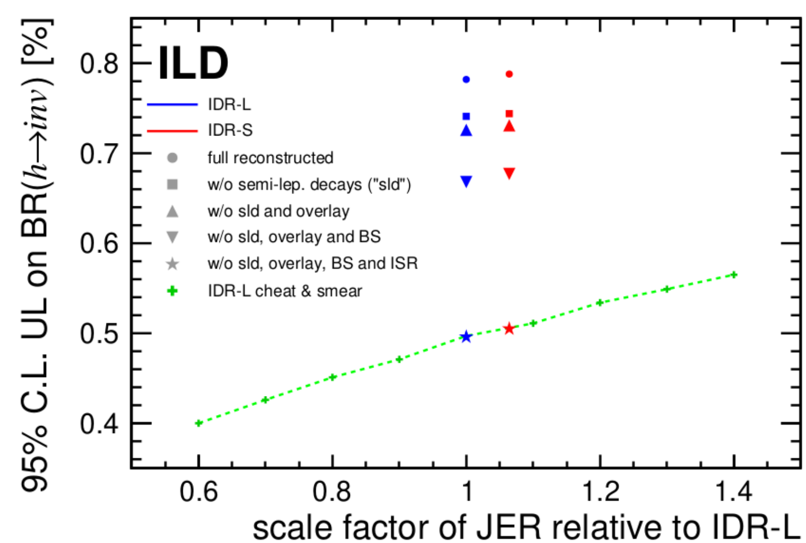
e.g. dark matter particles?

hadronic Z decays for maximum sensitivity









limit on additional invisible
Higgs decay BR: ~0.3%

arXiv:1909.07537, 2003.01116
ILD-PHYS-PUB-2019-003

summary of ILC detector requirements

charged track momentum resolution

$dp_T / p_T \sim$ few x $10^{-5}\ p_T$

→"recoil" H mass measurement

charged track impact parameter resolution

$\sigma_{d0} \sim 5\ \mu m$

→ identification of b, c, and τ decays

hadronic jet energy resolution

$\sigma_E / E \sim 3 \rightarrow 5$ % over wide energy range

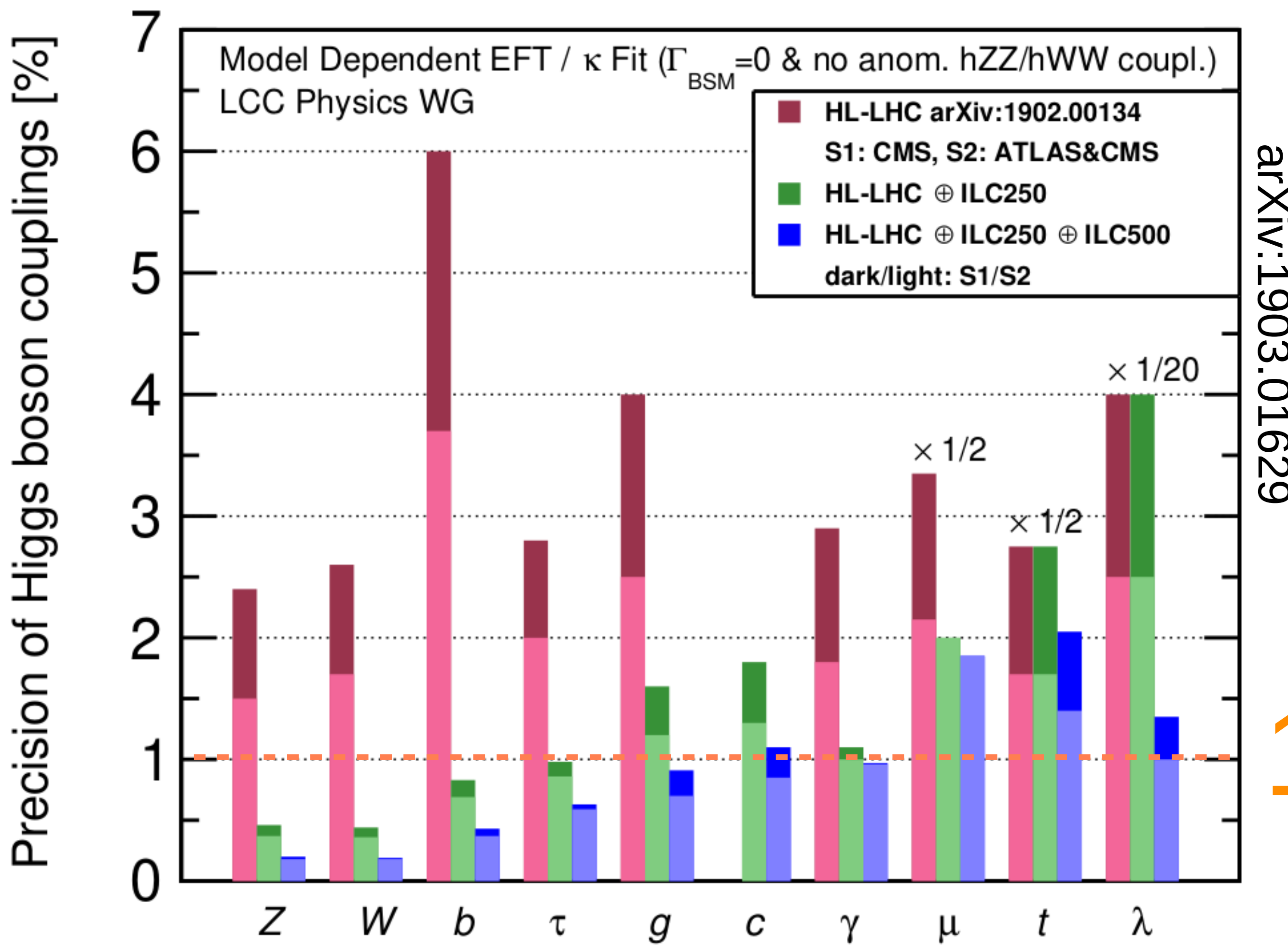
→ exploitation of hadronic final states;
distinguish W, Z, H

cover almost 4π solid angle

→ important for "missing momentum" searches

The ILC and its detectors will make high precision measurements of the Higgs sector

HL-LHC
+ ILC250
+ ILC500



1 %

...and point the way to physics beyond the Standard Model

end

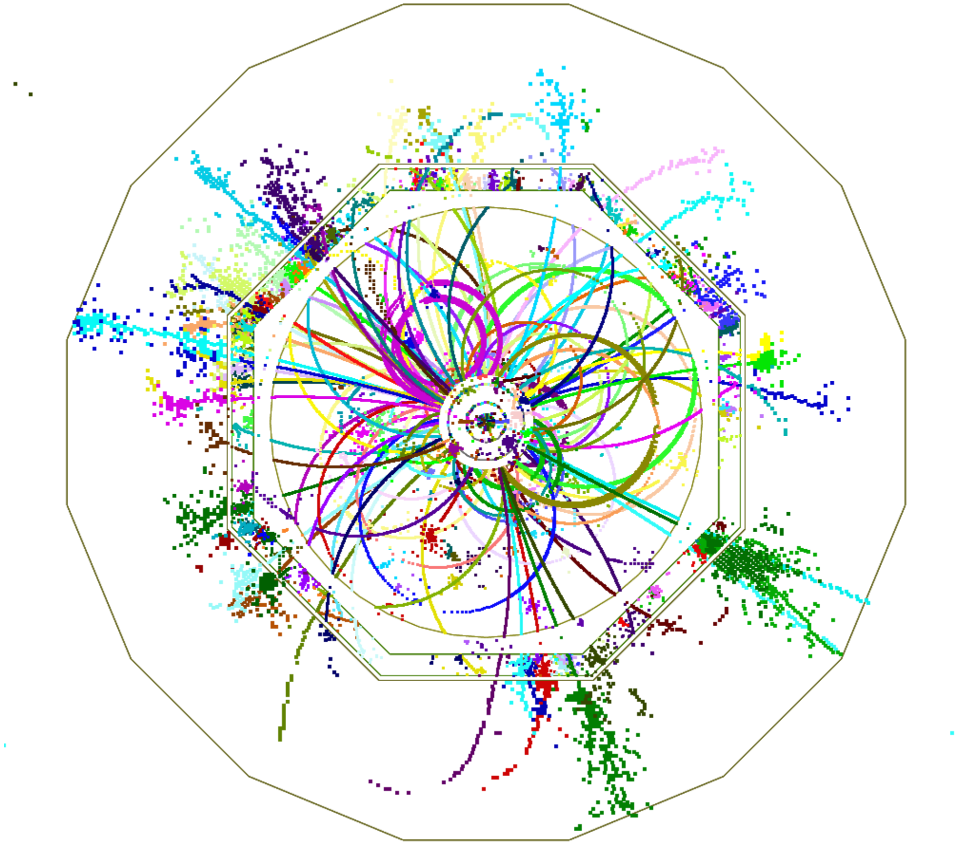
we invite you to join the ILC discussion session:

Friday, July 31

7:00 am Pacific
9:00 am Texas
4:00 pm Hamburg
11:00 pm Tokyo

https://stanford.zoom.us/j/99671238654?pwd=M2V2RCtYbTFrVi9Ub01kckh3WFVoZz09 backup

in addition to excellent momentum resolution, tracker should have



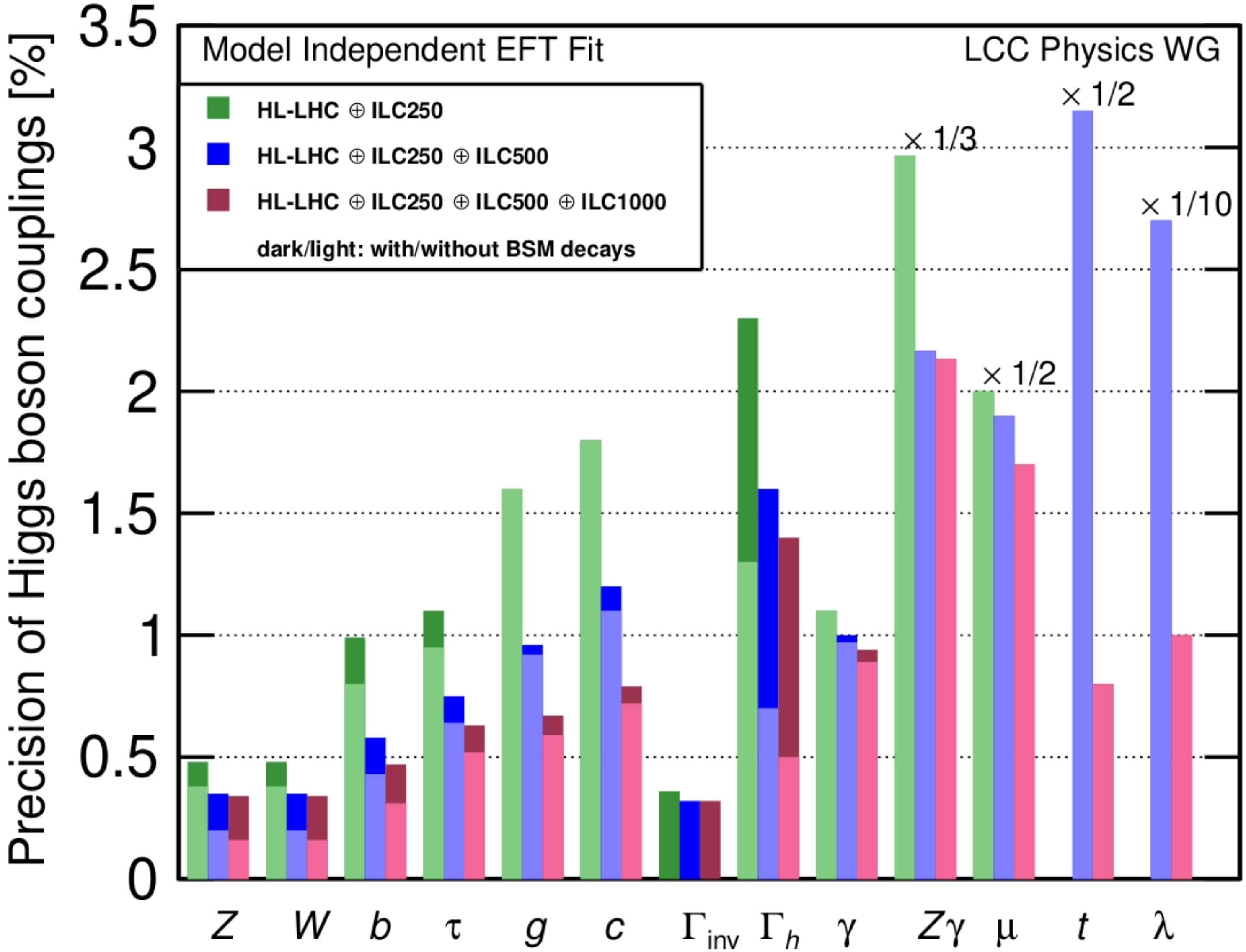
$e^+e^- \rightarrow$ tth [tt $\rightarrow$ 6q, h $\rightarrow$ bb]
@ 1 TeV

low mass

minimise multiple scattering
resolution at low momentum
Particle Flow

robust reconstruction

excellent efficiency in high multiplicity events

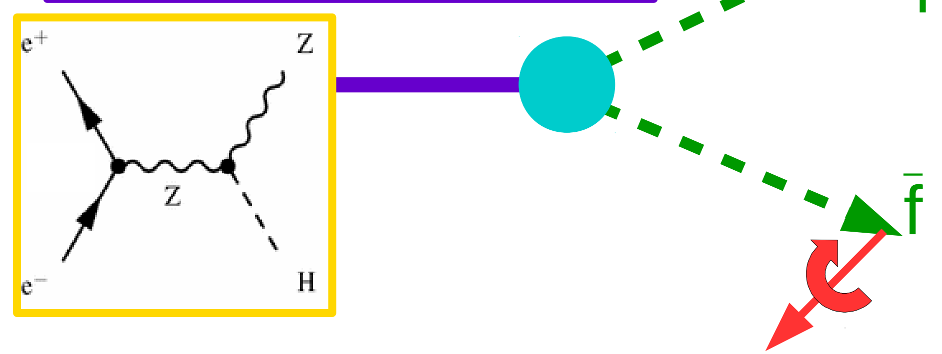


arXiv:1908.11299v4

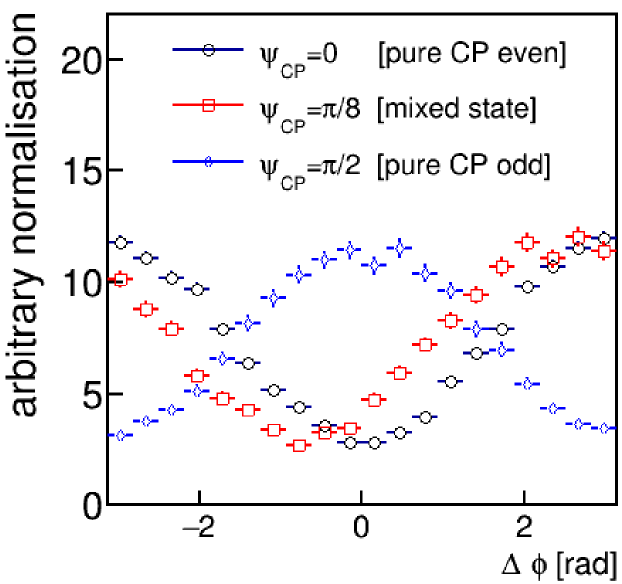
CP violation in H → $\tau^+ \tau^-$

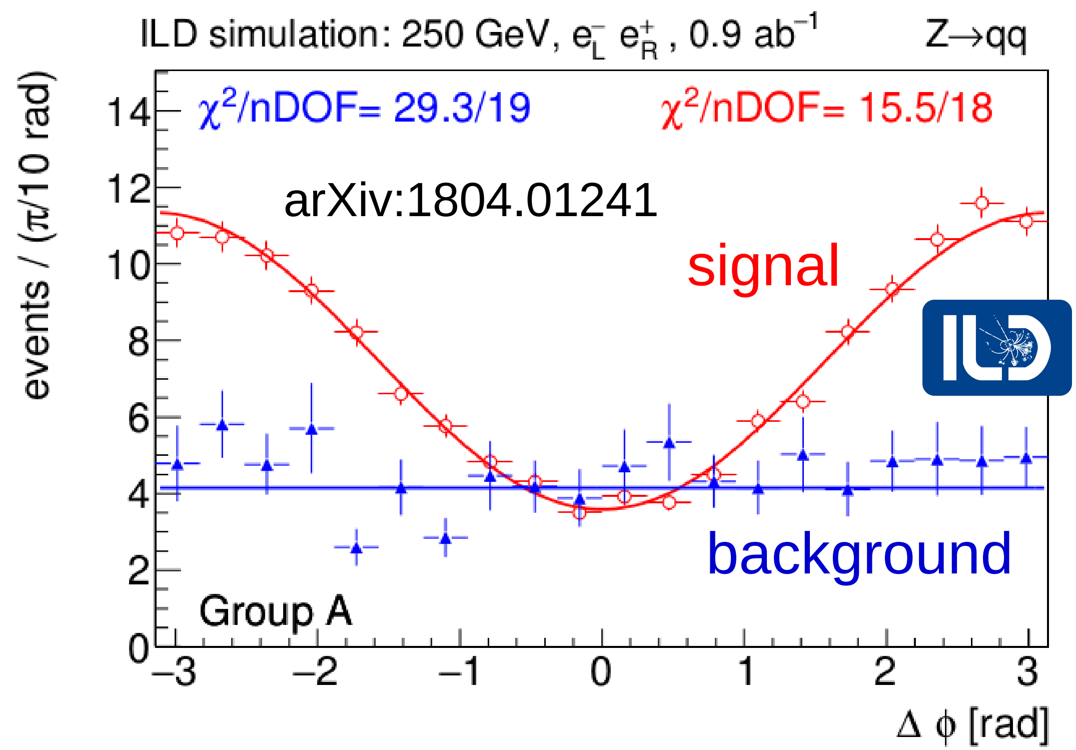
correlations between tau spins

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



- hadronic & leptonic Z decays
  → jet energy & tracker
- tau identification & spin reconstruction
  → vertex detector
  → calorimeter





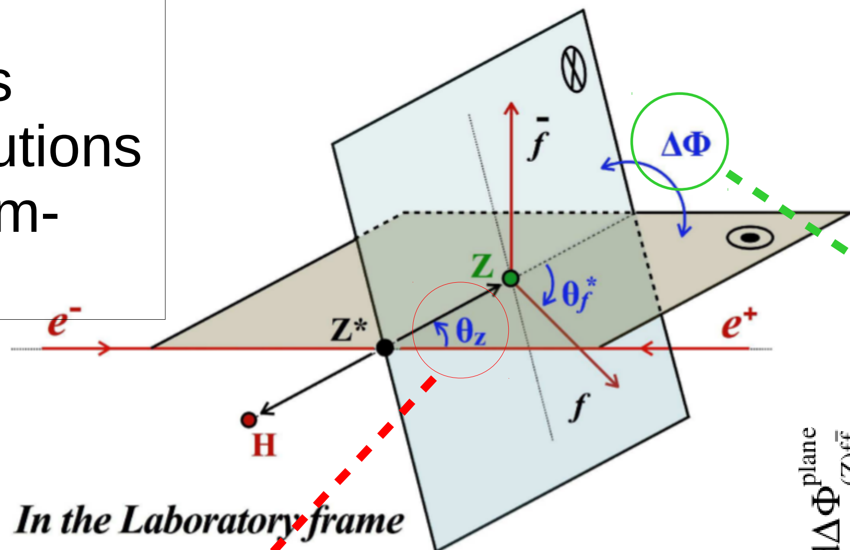
@ILC250, measure CP odd/even mixing angle ψ_{CP} to ~4°

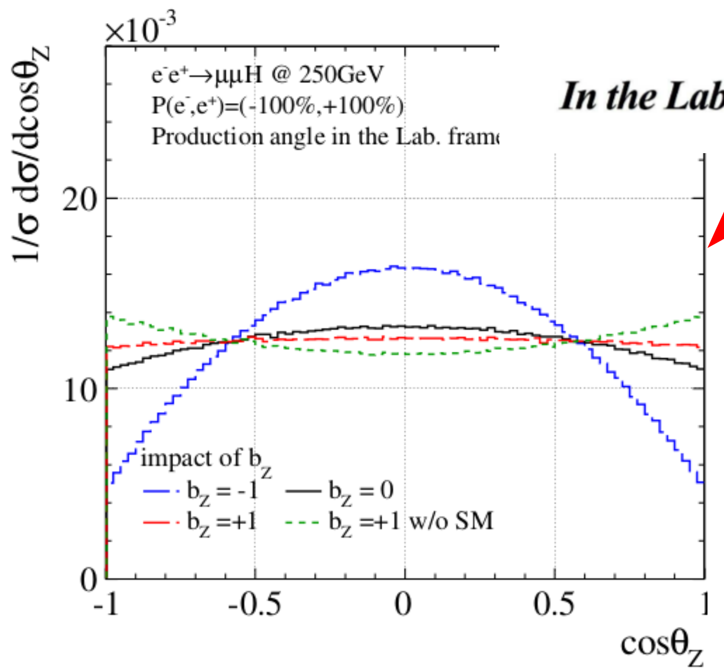
CP violation in Higgs sector : HVV coupling

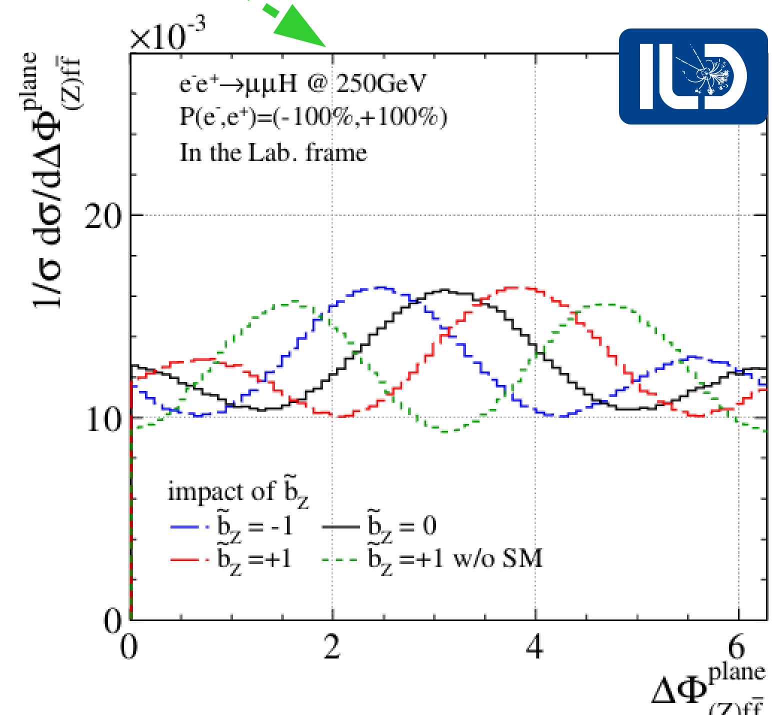
$$\mathscr{L}_{ZZH} = M_Z^2\left(\frac{1}{v}+\frac{a_Z}{\Lambda}\right)Z_\mu Z^\mu H + \frac{b_Z}{2\Lambda}\hat{Z}_{\mu\nu}\hat{Z}^{\mu\nu}H + \frac{\tilde{b}_Z}{2\Lambda}\hat{Z}_{\mu\nu}\tilde{\hat{Z}}^{\mu\nu}H$$

combination of e.g. 250+500 GeV helps disentangle contributions thanks to momentum-dependence

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

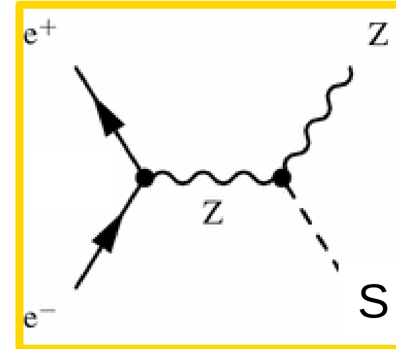




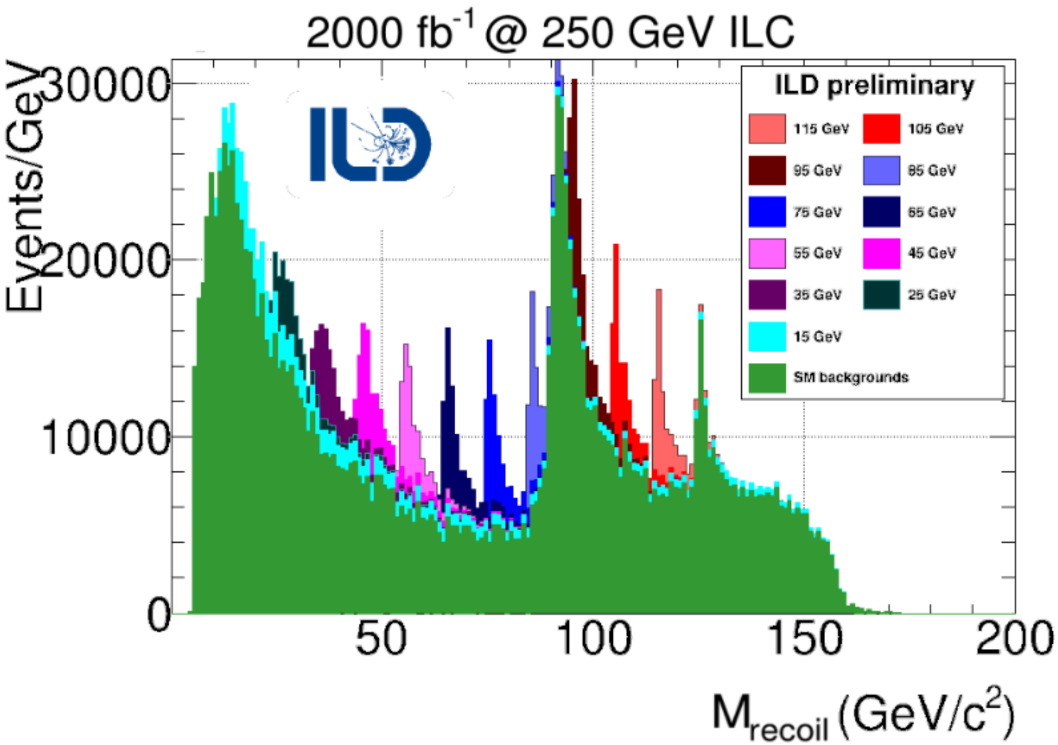


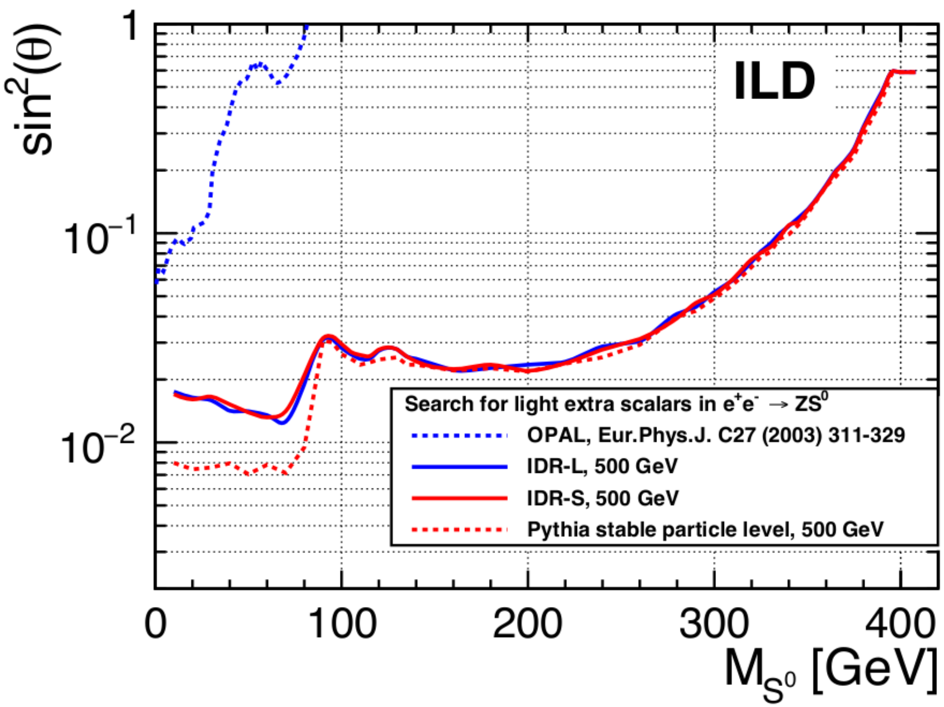
arXiv:1712.09772

additional light scalars



search for additional light scalars,
produced via Higgs-strahlung

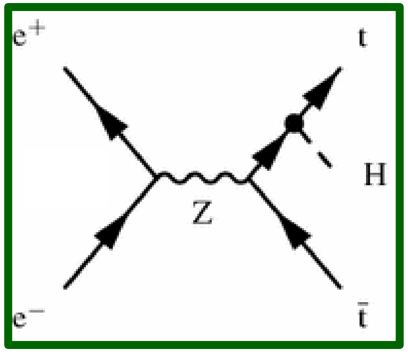




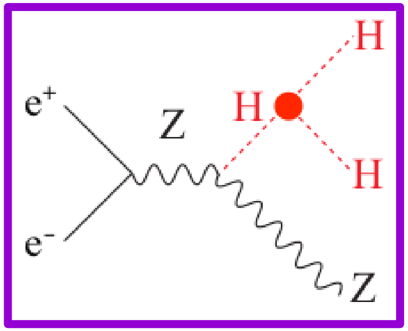
PoS(ICHEP2018)630,

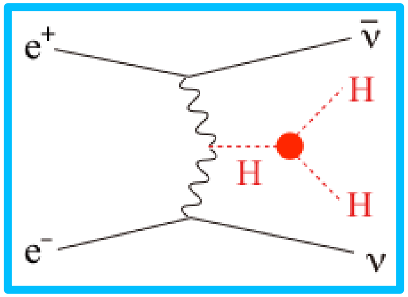
ILD-PHYS-PUB-2019-011

500/550 GeV opens direct access to



top Yukawa coupling





Higgs self-interaction

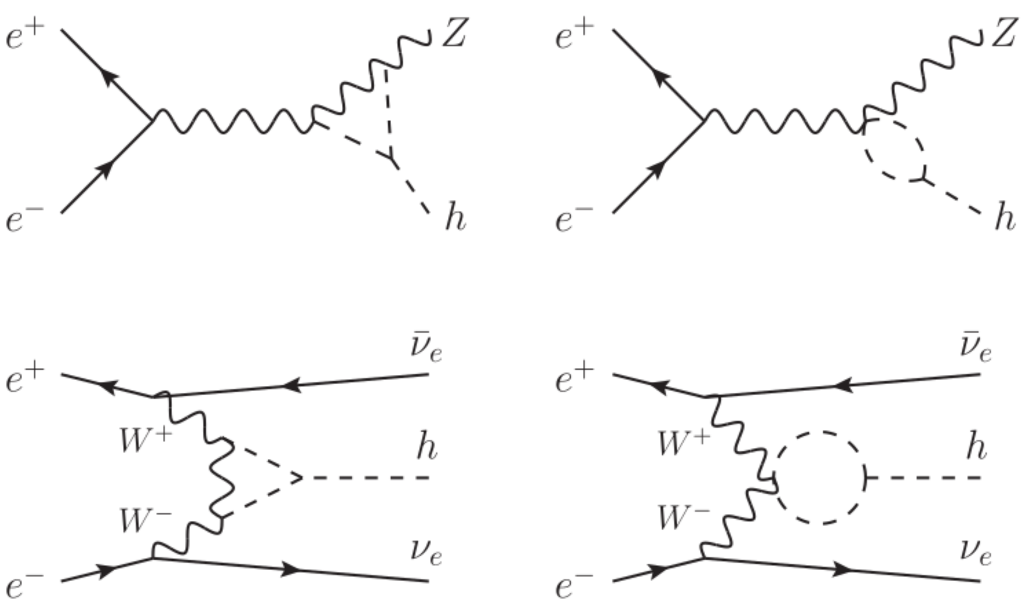
→ shape of Higgs potential

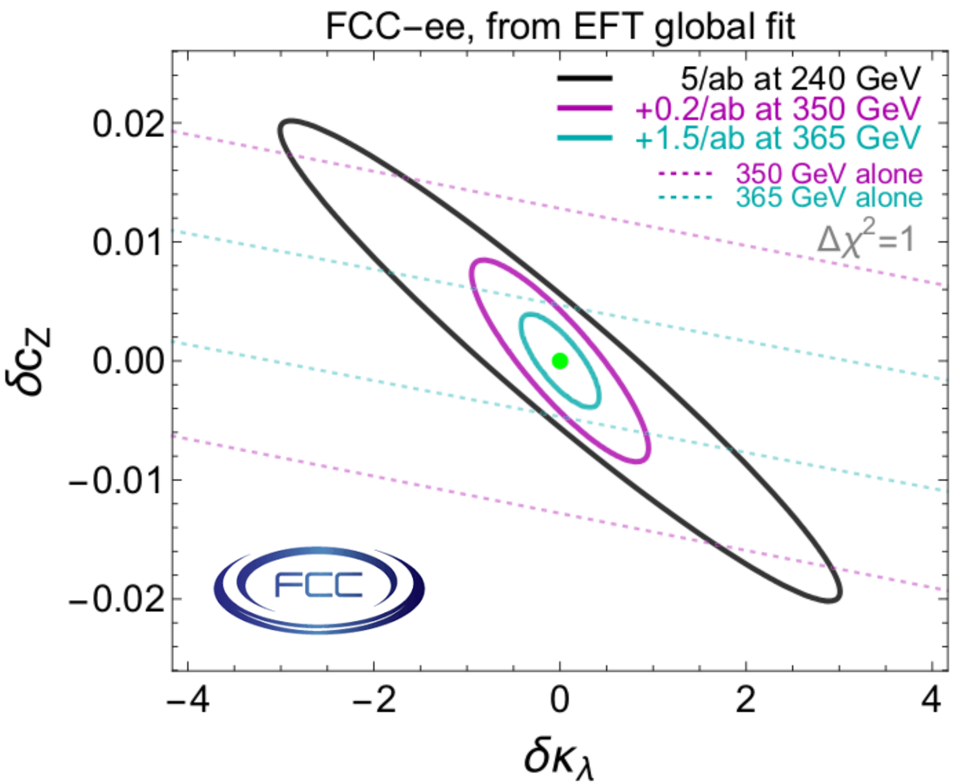
→ EW phase transition

higgs self-coupling

indirect : loop corrections modify Higgs production x-sec,
in an energy dependent way

cross-section measurements at well-spaced energy points
provides some sensitivity to the self-coupling

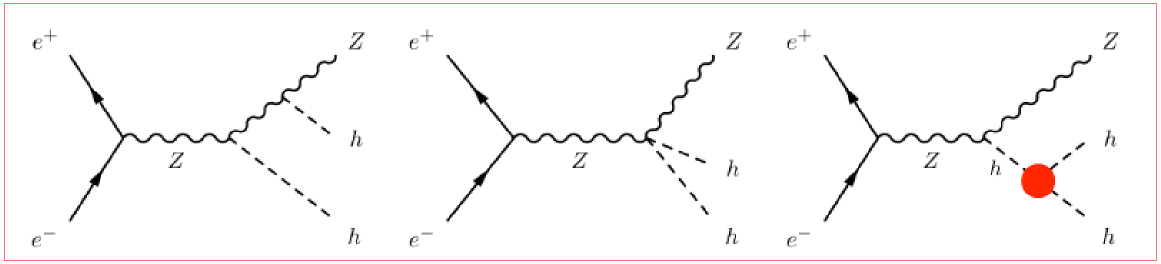


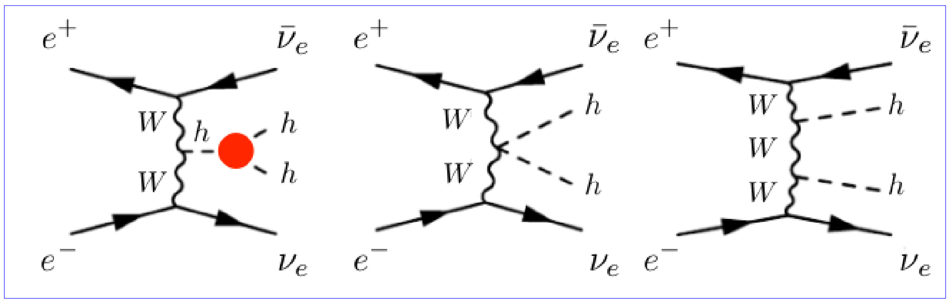


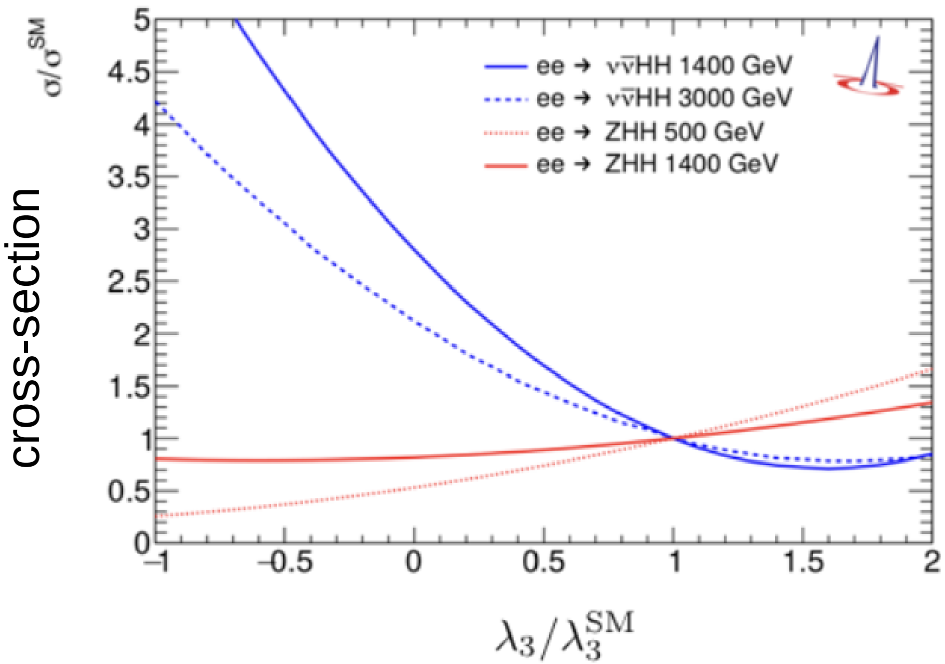
Eur. Phys. J. Special Topics 228, 261 (2019)

higgs boson self-coupling

at energies > 500 GeV, *direct* access to di-Higgs production

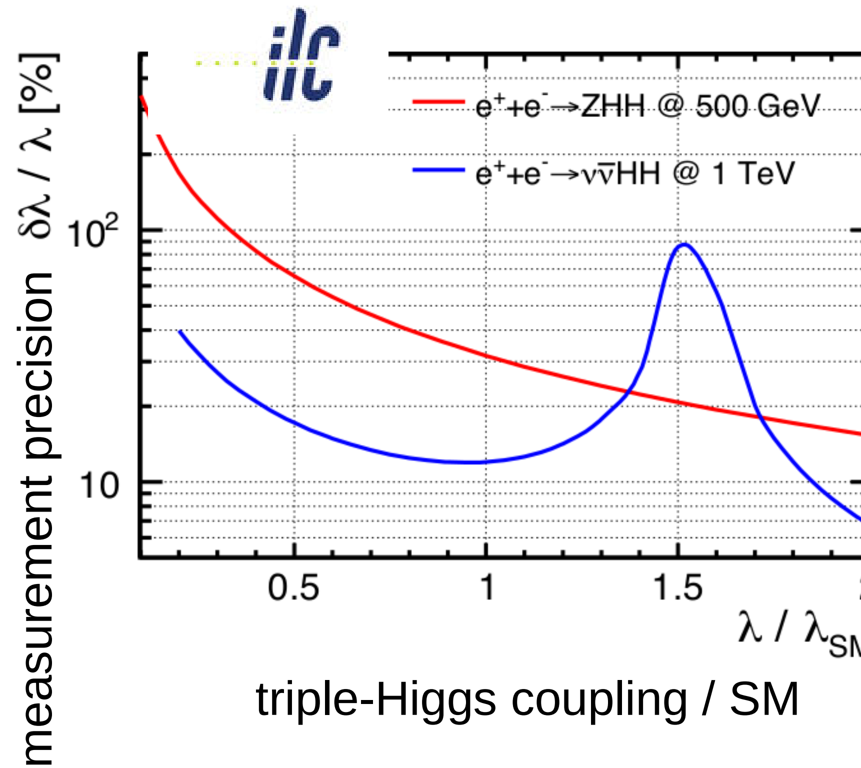




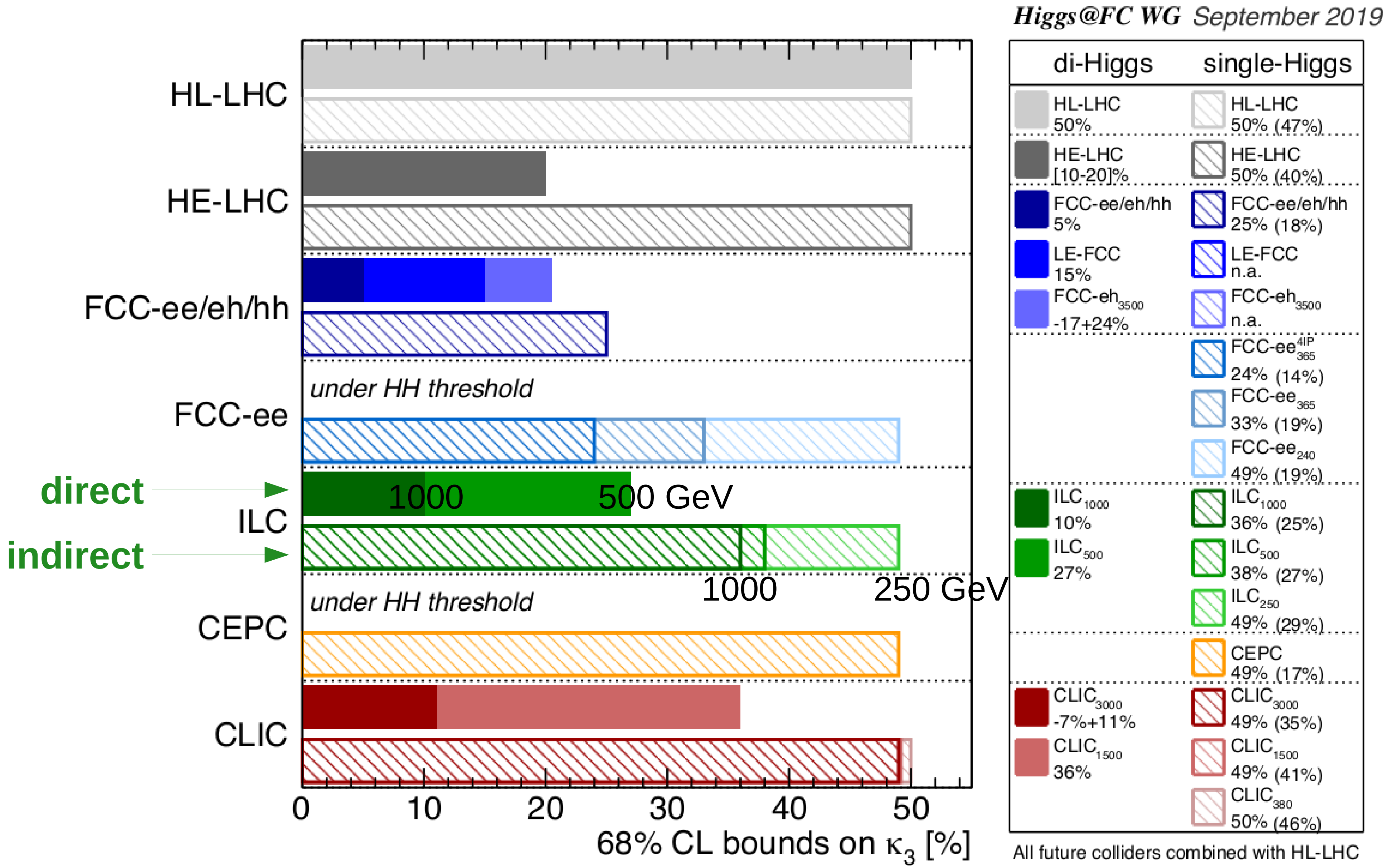


cross-section

triple-Higgs coupling / SM



triple-Higgs coupling / SM



HL-LHC ⊕ ILC 250 → 500 → 1000 GeV

direct approach : ~10~25 %

indirect approach : ~35~50 %

→ consistency test

Higgs mechanism intertwined with entire EW sector

improved measurements of W, Z, t are an essential
ingredients to more precisely constrain EWSB & Higgs

Z
→ on-resonance @ 91 GeV
→ radiative returns at higher energies

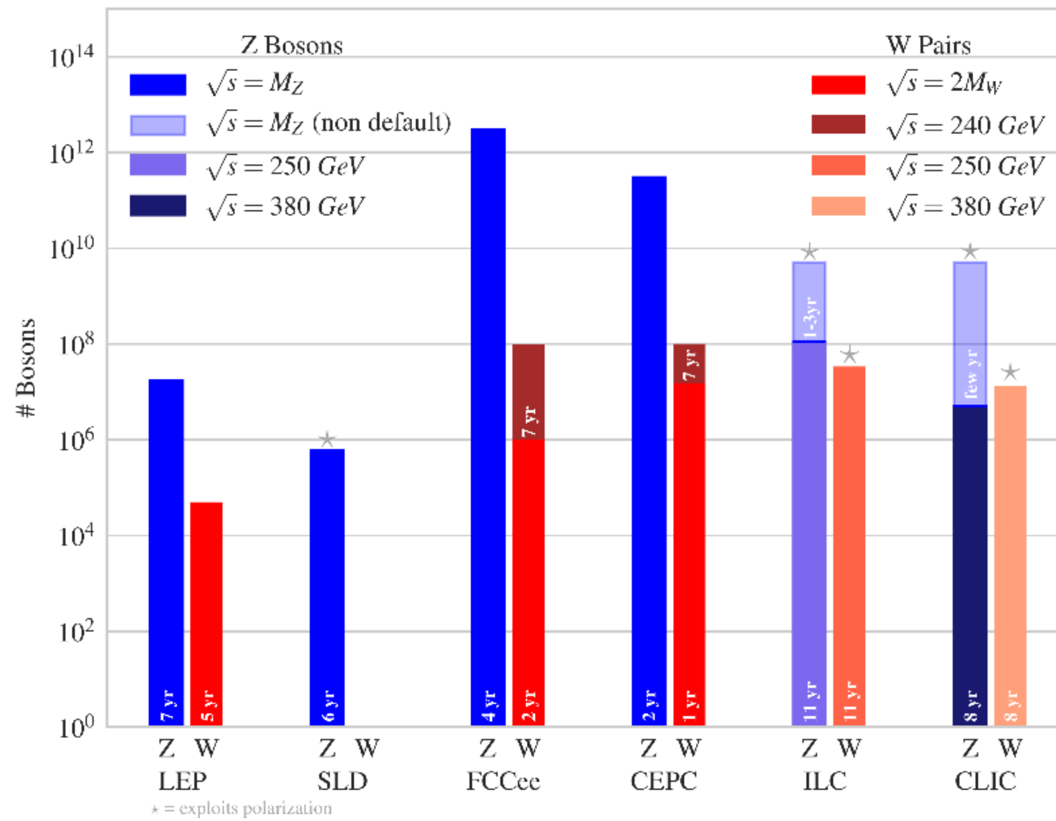
W
→ pair production @ 161+ GeV

top quark
→ pair production @ 350+ GeV

luminosities many *orders of magnitude* beyond LEP, SLC

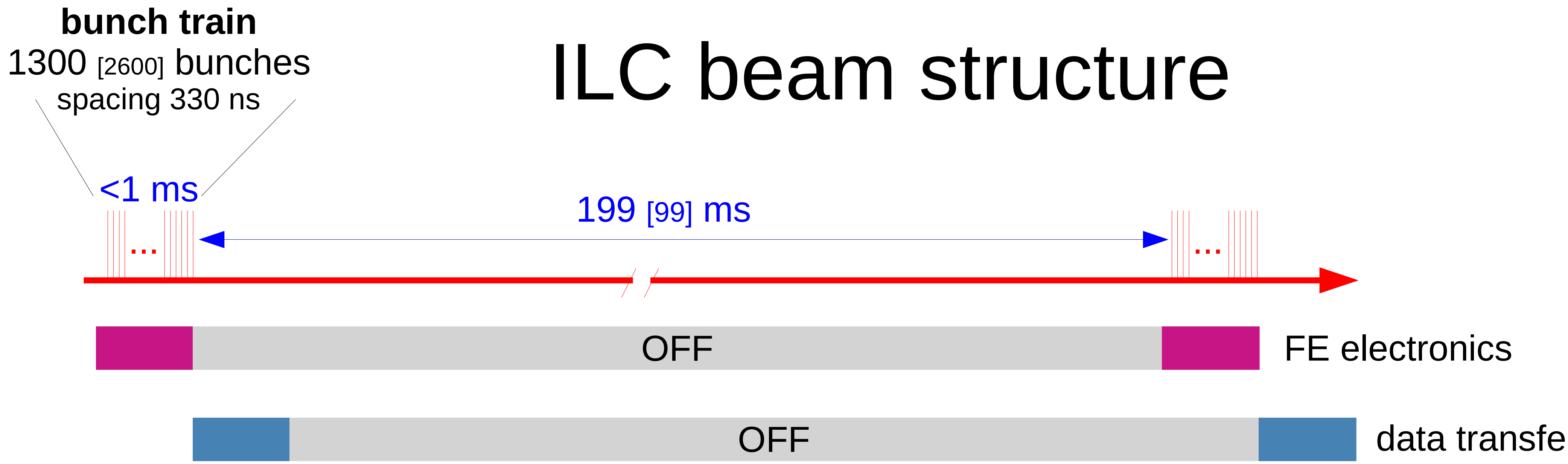
+ significantly longer energy lever arm

CERN-ESU-004



G. Wilson, in “Top quark and electroweak physics”, 28/7

ILC beam structure



"power-pulsing"

allows reduction, by factor ~100, of
→ in-detector electronics power
→ detector cooling requirements

less in-detector cooling & power infrastructure
→ more precise measurements