Measuring the branching ratio of $h \to \mu^+\mu^-$ at the International Linear Collider

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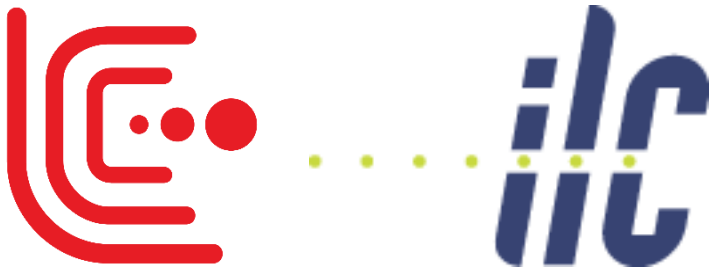
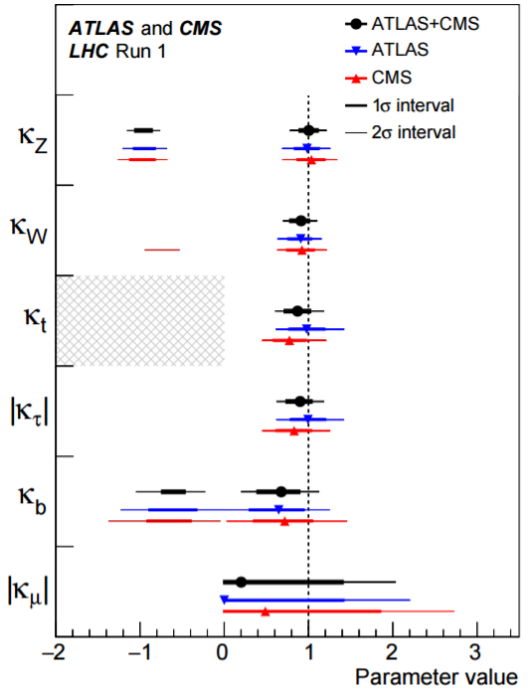
DPG Würzburg18



Introduction

Discovery of Higgs-like boson at the LHC
--> Last particle of SM? Or beyond SM?

Goal: model-independent determination of
EWSB sector with precise measurements
- mass-coupling relation
- any deviation shows the existence of BSM



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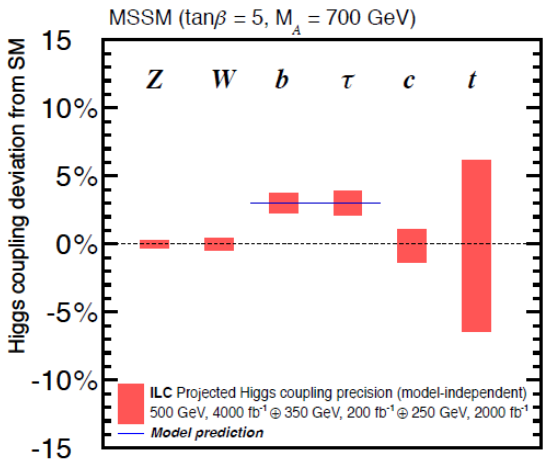
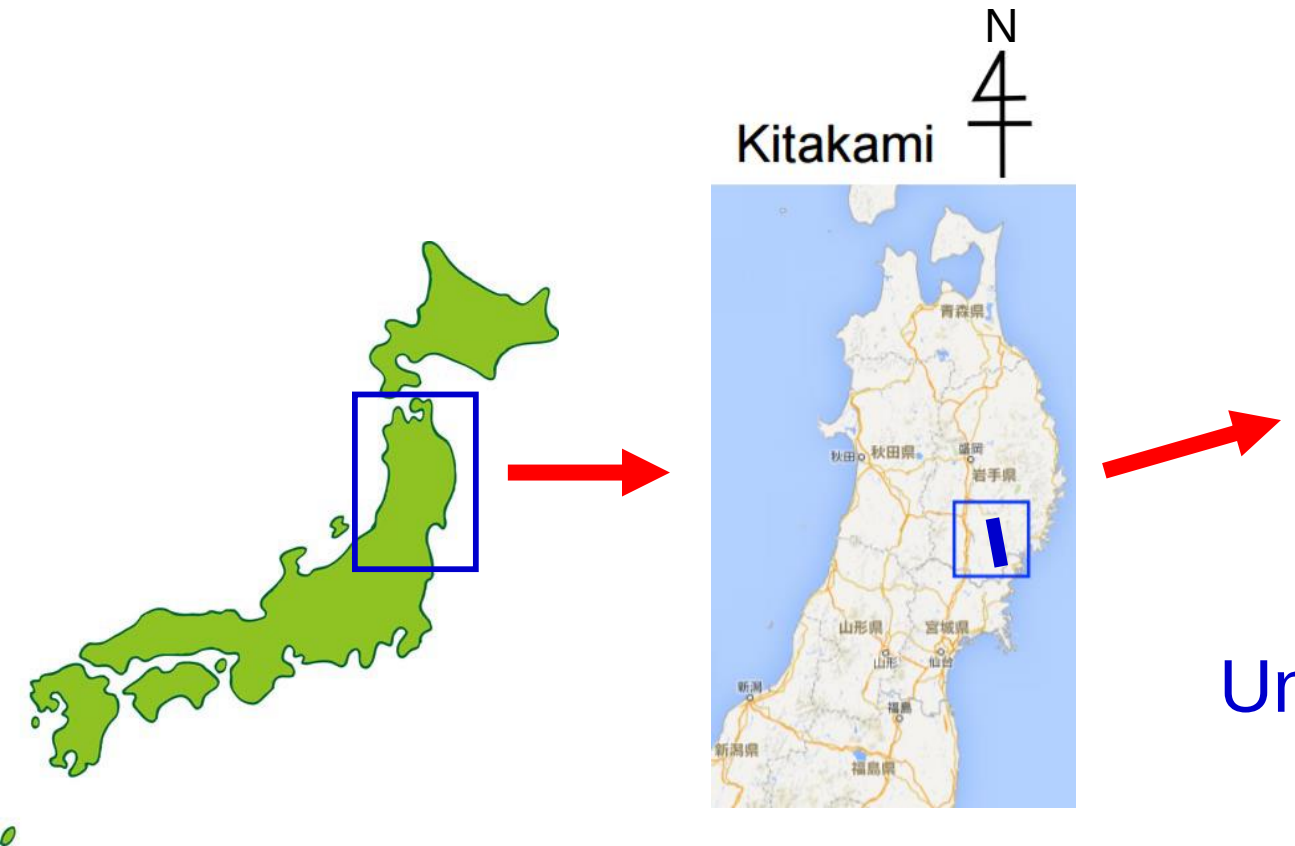


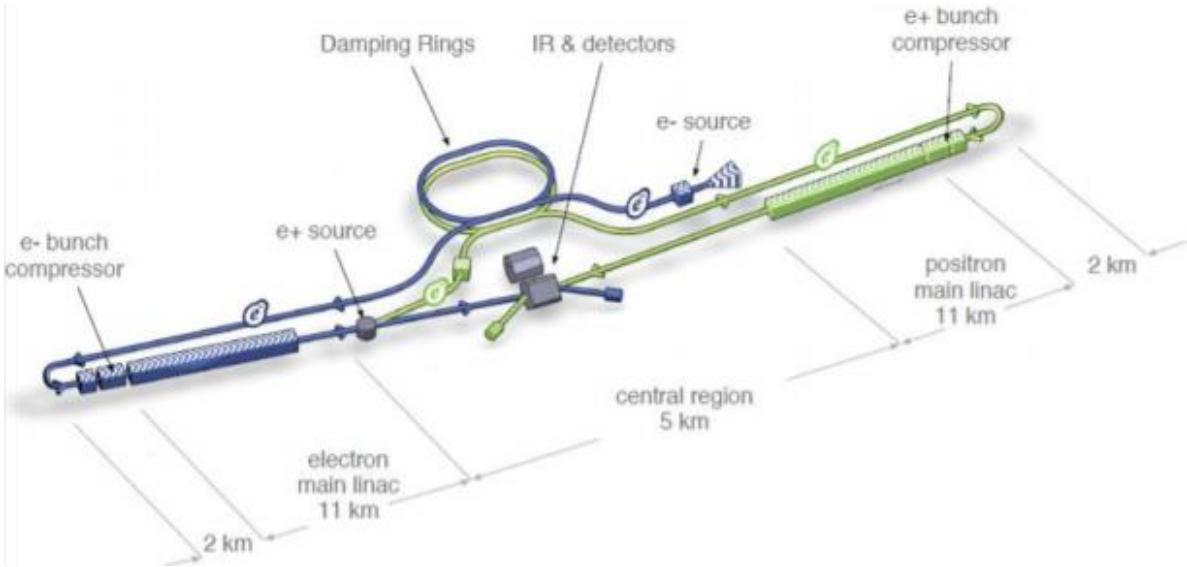
arXiv: 1506.05992 [hep-ex]

ILC

The International Linear Collider

- e^+e^- collider, E_{CM} = 250 - 500 GeV (upgradable to 1 TeV)
- polarized beam (e^-: $\pm$0.8, e^+: $\mp$0.3)
- clean environment, known initial state





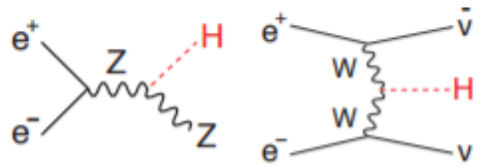
Under political consideration in Japan

Key Point

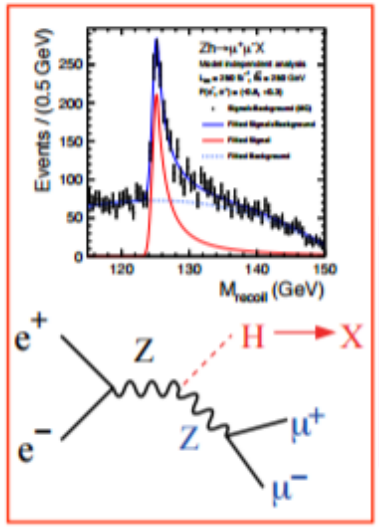
K. Fujii's talk, LCWS2014

LHC: all measurements are $\sigma \times \mathrm{BR}$

ILC: $\sigma \times \mathrm{BR}$ measurements + σ measurement



$$g^2_{HAA} \propto \Gamma(H \to AA) = \Gamma_H \cdot BR(H \to AA)$$



σ×BR

BR

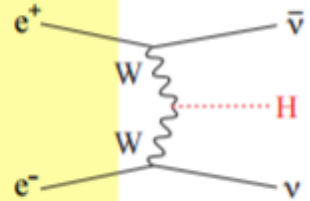
g coupling

The Key

σ from recoil mass

Γ_H total width

WW-fusion is crucial for precision total width measurement → Ecm > 350GeV



Z→qq is also usable.

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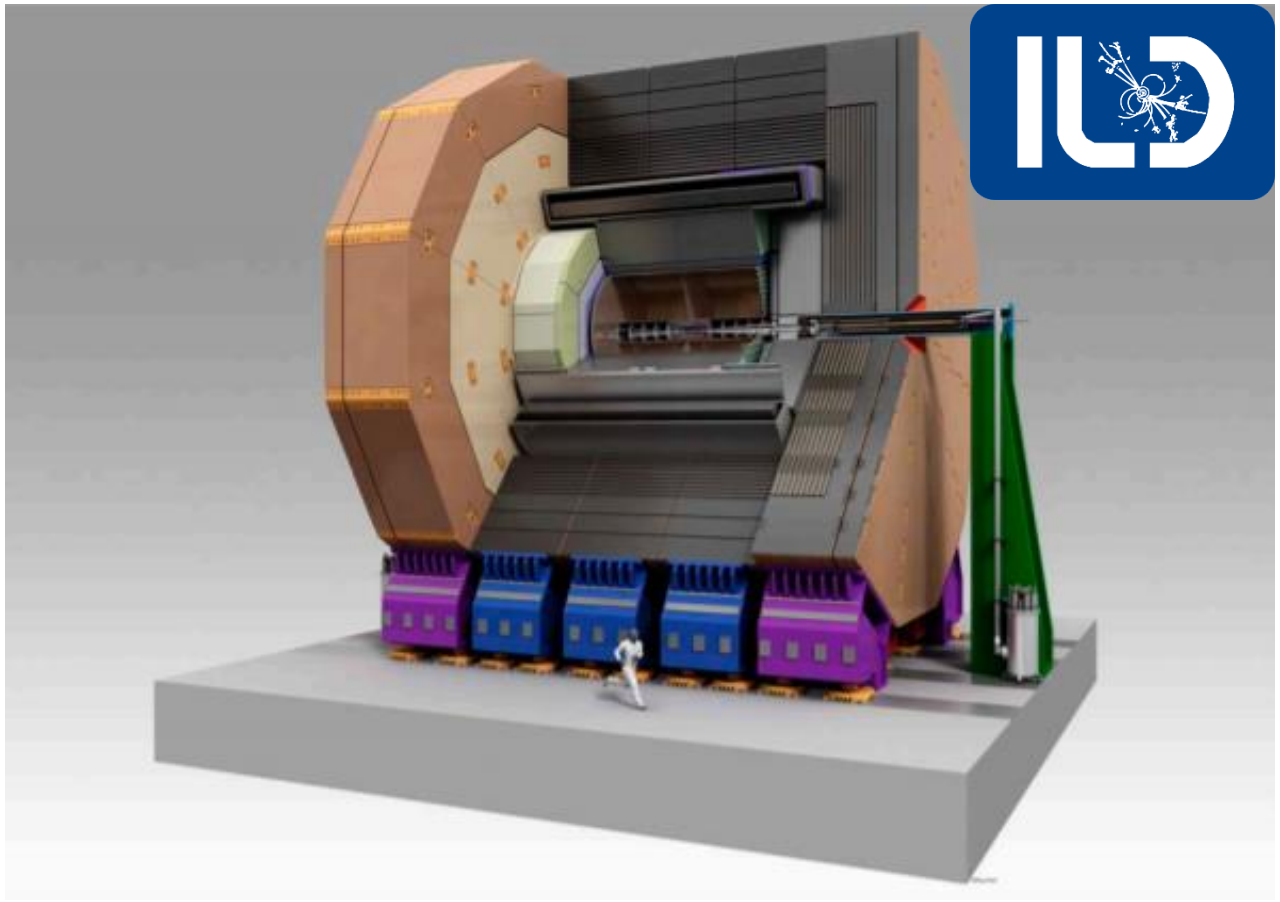
Detector Concept at the ILC

ILD (International Large Detector)



Tracker: Vertex, TPC
Calorimeter: ECAL, HCAL
3.5T magnetic field
Yoke for muon, Forward system

Requirements:

- Impact parameter resolution

  $\sigma_{r\phi} < 5 \oplus \frac{10}{p\sin^{3/2}\theta}\ \mu\text{m}$

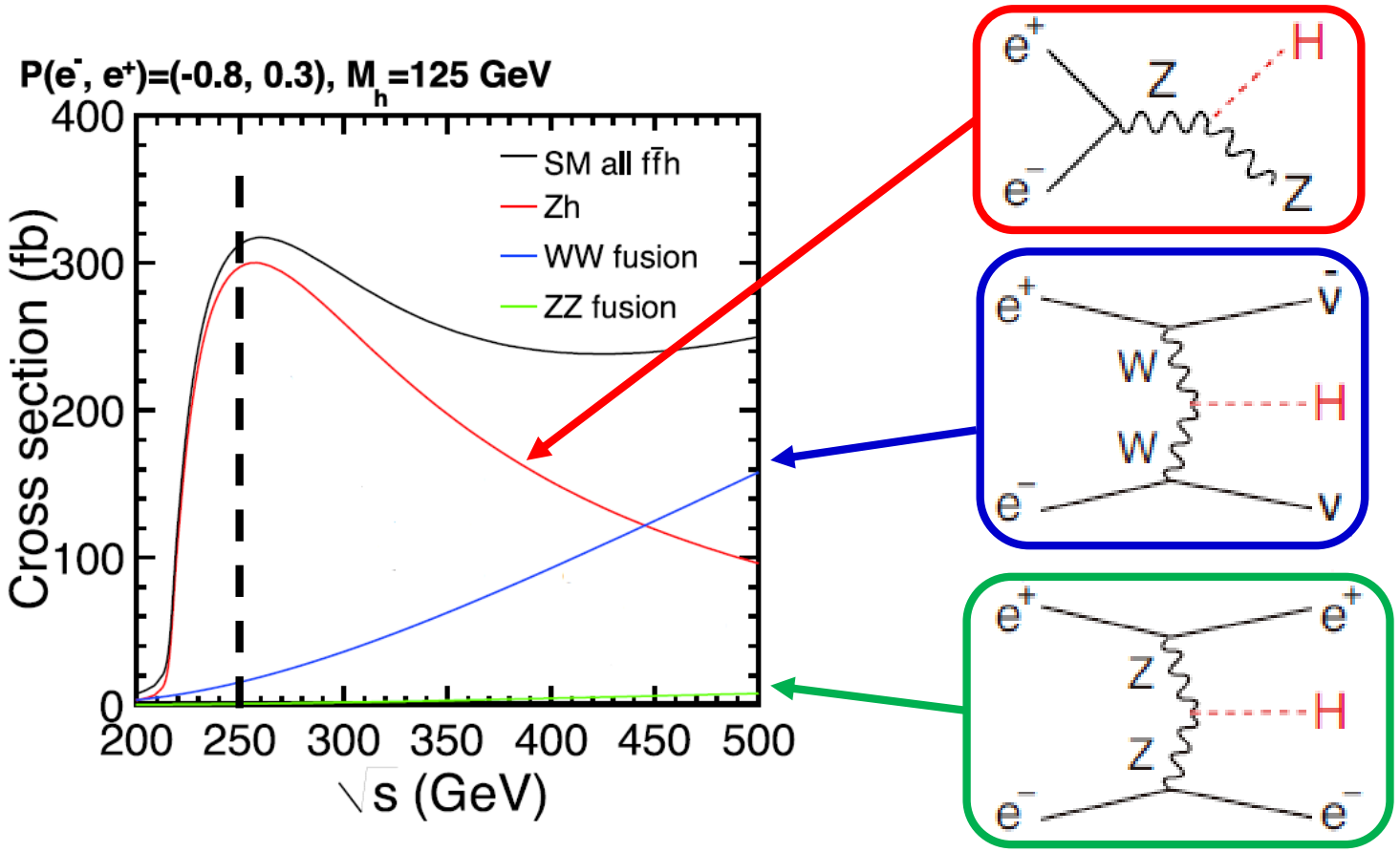
- **Momentum resolution**

  σ_{1/p_T} < 2*10^{-5} GeV^{-1}

- Energy resolution

  σ_E/E = 3 - 4%

Higgs Production at the ILC



250 GeV: Zh dominant

500 GeV: WW-Fusion + Zh

Higgs Decaying into Muons

- Can be used for testing
  - $y_f \propto m_f$
  - mass generation mechanism between 2nd/3rd leptons (κ_μ/κ_τ) and 2nd lepton/quark (κ_μ/κ_c)
- Good benchmark for detector optimization
- Challenging: tiny branching ratio ($\mathrm{BR}(h \to \mu^+\mu^-)$ = **2.2*10^{-4}**)

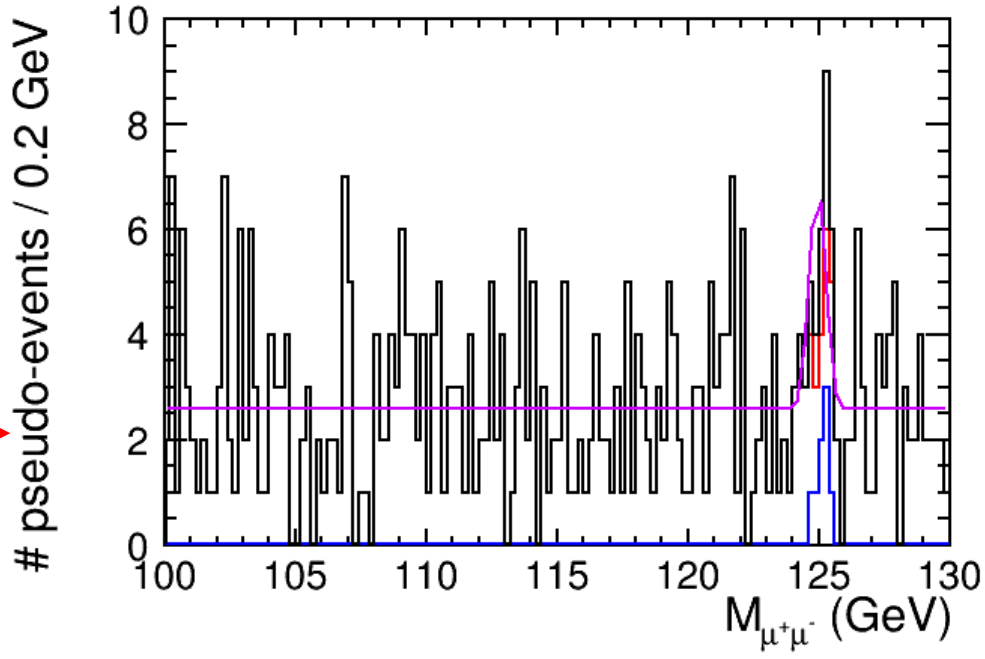
- **Analyzed 8 channels in total**: 2*E_{CM} (250/500 GeV), 2*beam polarization (left/right), 2*final states ($q\bar{q}h/\nu\bar{\nu}h$)

arXiv:1801.07966 [hep-ex]
(LCWS2017 proceedings)

Brief Summary of Analysis

- Geant4-based full detector simulation with ILD model
- Included all available MC samples

1. select $h \to \mu^+\mu^-$ candidate
2. channel-specific analysis
3. multivariate analysis
   - further background rejection
4. toy MC with $M_{\mu^+\mu^-}$
   - extract final precision



Results

arXiv:1801.07966 [hep-ex]
(LCWS2017 proceedings)
ATLAS-PHYS-PUB-2013-004
CERN-LHCC-2015-10

precision for $\frac{\Delta(\sigma \times \mathrm{BR})}{(\sigma \times \mathrm{BR})}$

250 GeV	$q\bar{q}h$	$\nu\bar{\nu}h$
L	32.5%	108.6%
R	28.1%	110.4%

500 GeV	$q\bar{q}h$	$\nu\bar{\nu}h$
L	44.5%	37.0%
R	49.5%	74.5%

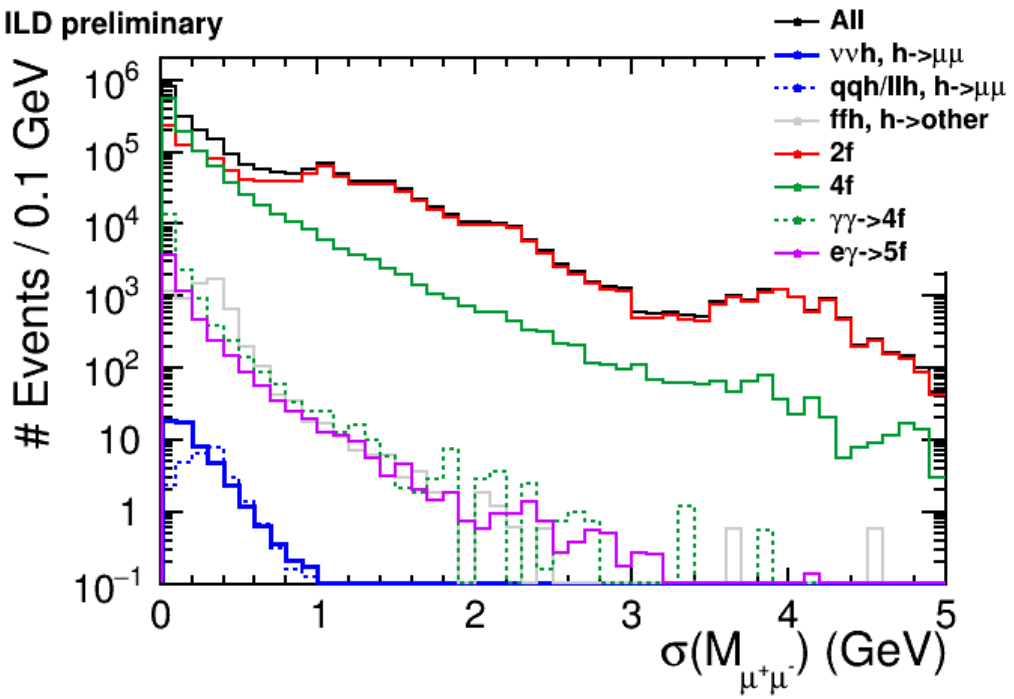
ILC250 combined = 20.5% (“theoretical limit” = 10.4%)
ILC250+500 combined = **15.4%** (“theoretical limit” = 7.1%)
HL-LHC: 10-21%

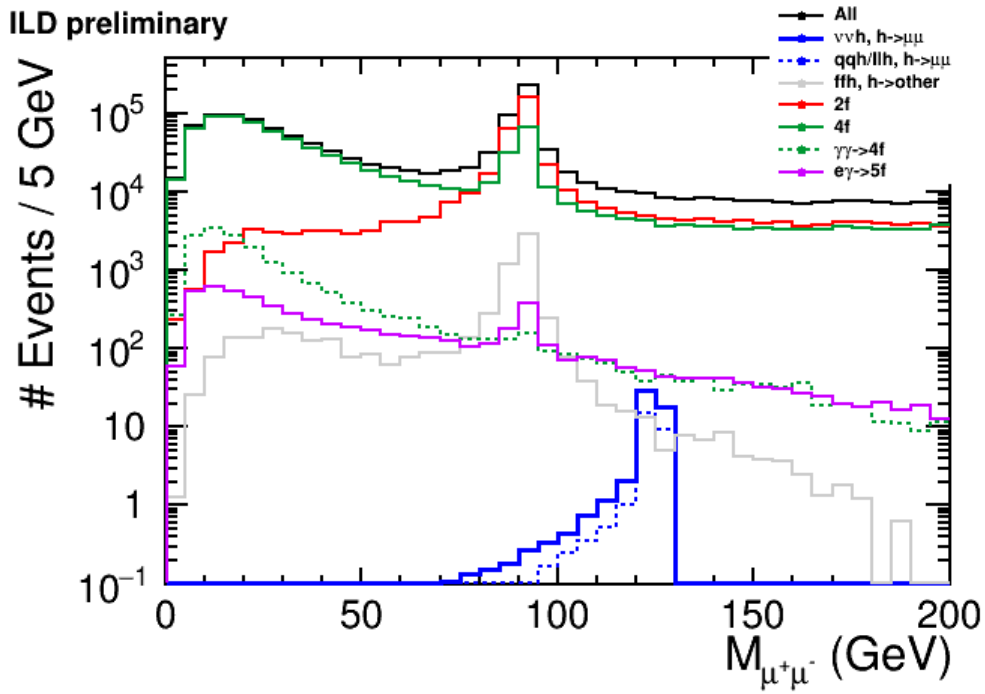
※theoretical limit = 100% efficiency, no backgrounds, no detector effects

signal
other colors: SM background
plots from nnh500-L

Impact of Momentum Resolution

- Momentum resolution (P_t resolution) is most important
  - directly affect to $M_{\mu^+\mu^-}$, $\sigma\left(M_{\mu^+\mu^-}\right)$, ...





Impact of Momentum Resolution

- Studied what will happen when we change the momentum resolution artificially
  - 13 benchmark points
  - smeared MCParticle momentum of $h \to \mu^+\mu^-$ candidate
  - Gaussian-smeared with **constant number**
    - no momentum/angular dependencies
  - replace $M_{\mu^+\mu^-}$ to $M^{\text{smear}}_{\mu^+\mu^-}$ in toy MC

Resolution (GeV^{-1})
$1*10^{-3}$
$5*10^{-4}$
$3*10^{-4}$
$2*10^{-4}$
$1*10^{-4}$
$5*10^{-5}$
$3*10^{-5}$
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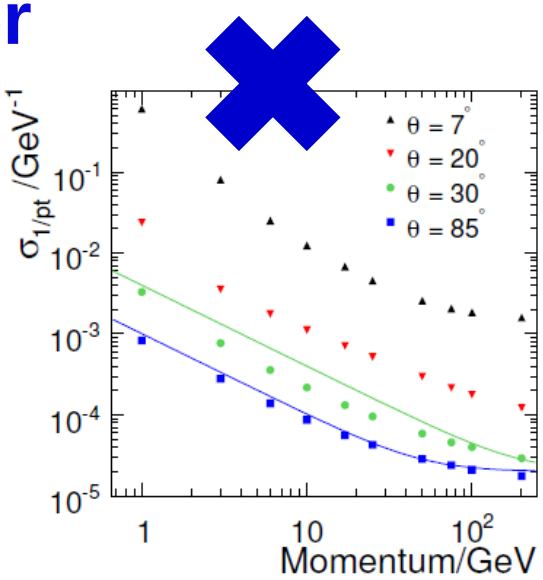
$2*10^{-6}$
$1*10^{-6}$



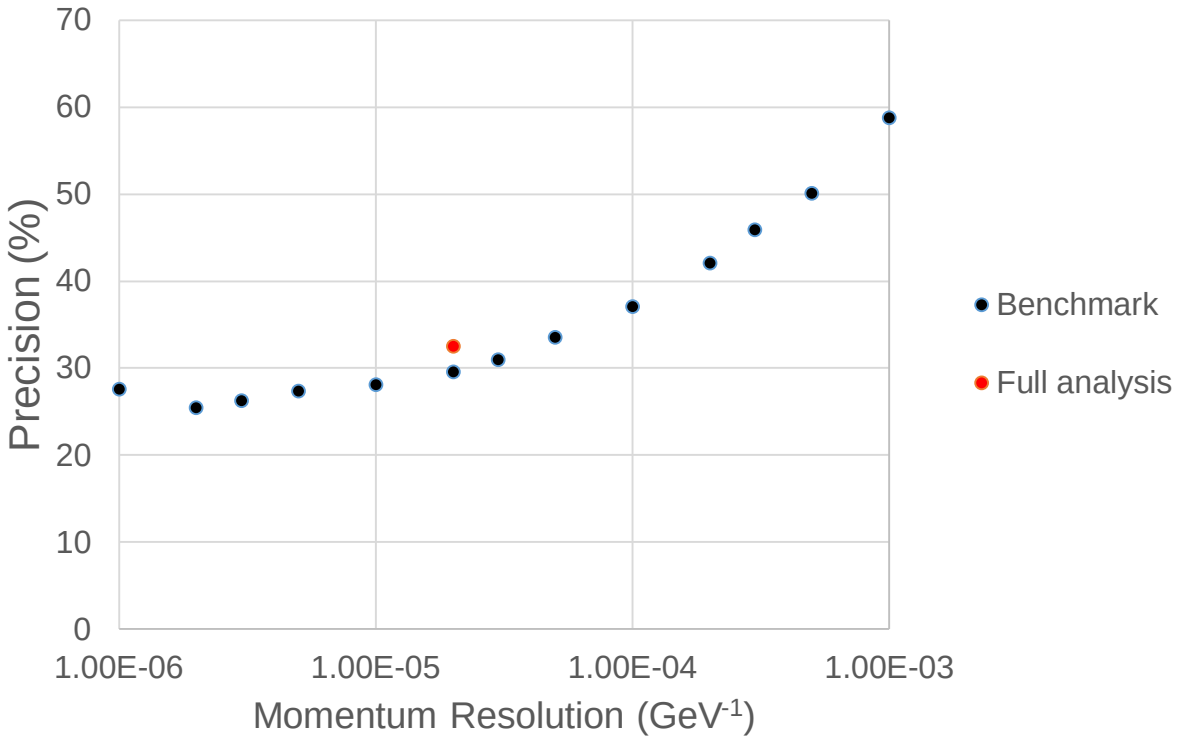
from ILC-DBD

Studied the impact to final number:
$\frac{\Delta(\sigma\times\text{BR})}{(\sigma\times\text{BR})}$ in this study

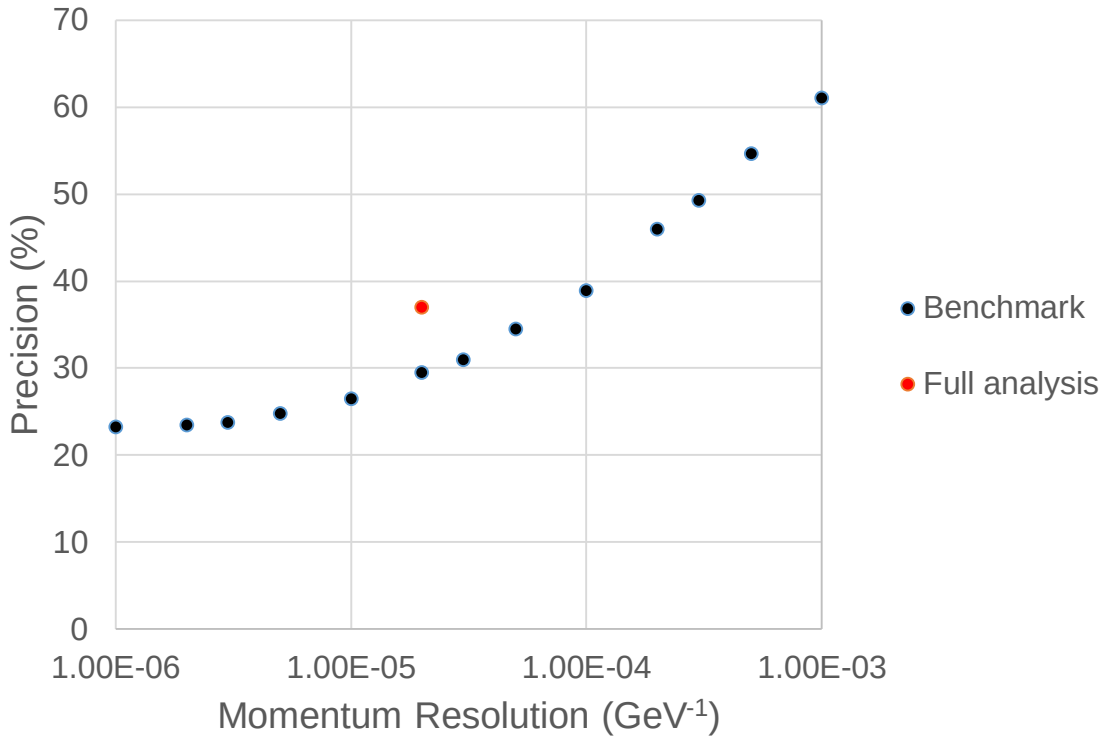
WORK IN PROGRESS

Results (Single Channel)

qqh250-L



nnh500-L

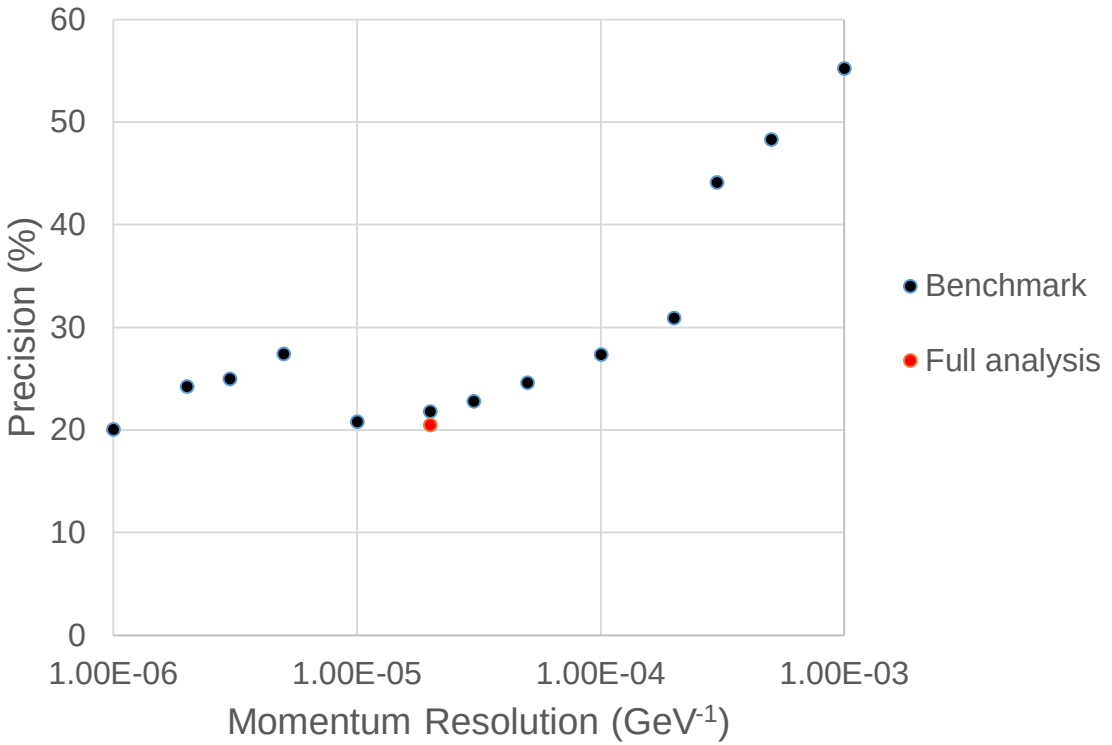


Performance will saturate around ~10^{-5} resolution.

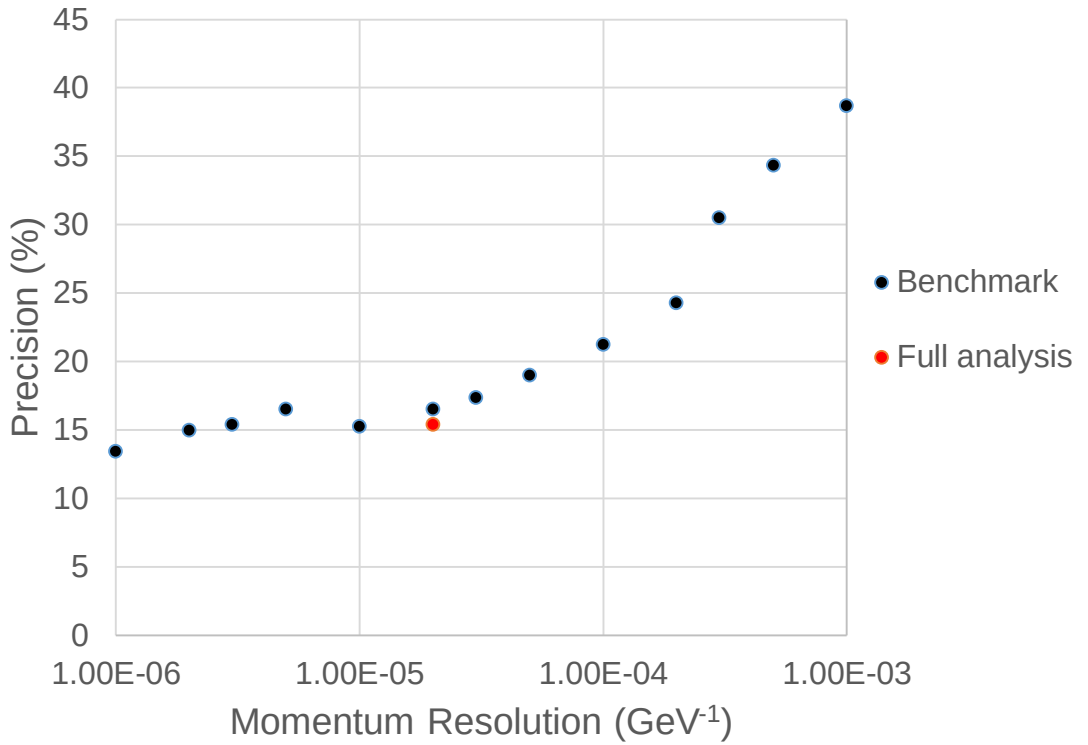
WORK IN PROGRESS

Results (Combined)

ILC250



ILC250+500



zig-zag shape: sometimes fitting failed, lack of results

Performance will saturate around ~15% at ~10^{-5} resolution.

Another Study: 1.4 TeV CLIC $h \to \mu^+\mu^-$

Eur. Phys. J. C (2015) 75:515

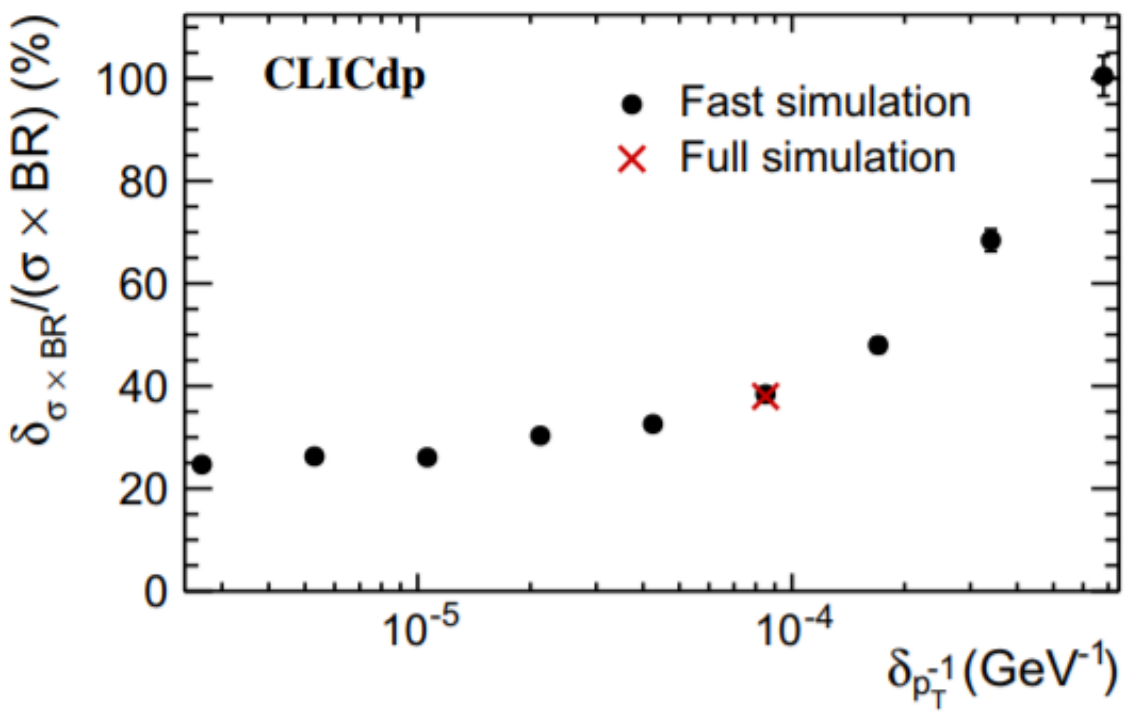


Fig. 11 Dependence of the relative statistical uncertainty of the $\sigma(H\nu\bar{\nu}) \times BR(H \to \mu^+\mu^-)$ on the transverse momentum resolution, δ_{1/p_T}, averaged over the signal sample in the whole detector

From paper:
To estimate the benefit of a better p_T resolution, the analysis was repeated by substituting the muon four-momenta reconstructed in the full simulation of the signal by the four-momenta obtained by a parametrisation of the momentum resolution for several different values of the detector resolution.

Full: 38%

- Similar tendency with us
- Performance will saturate around $1*10^{-5}$ (~25%)

Summary

- Precise measurement and extracting absolute Higgs couplings are possible at the ILC
- Studied $h \to \mu^+\mu^-$ channel with E_{CM} = 250/500 GeV at the ILC
  - can reach 15.4% precision for cross section times branching ratio
  - studied the impact of momentum resolution
    - performance will saturate around ~10^{-5} resolution, but need more studies