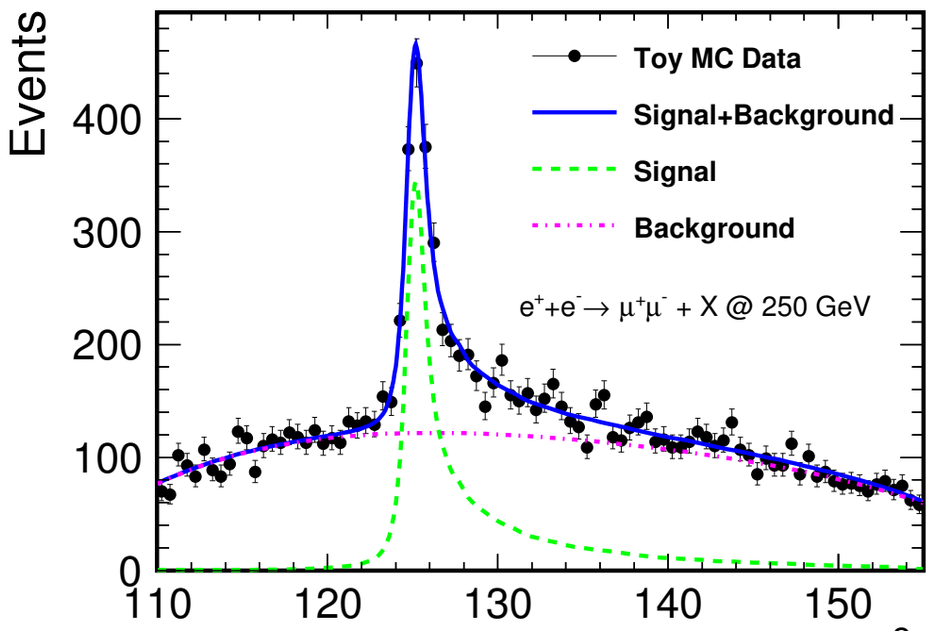
The Higgs Boson and the International Linear Collider



M. E. Peskin
HPNP 2021
March 2021

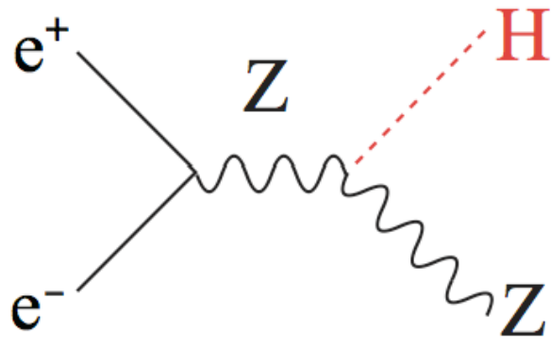
Let’s first discuss the study of the Higgs boson at any e+e- “Higgs factory”.

These go beyond the usual advantages for any high-energy physics precision measurement:

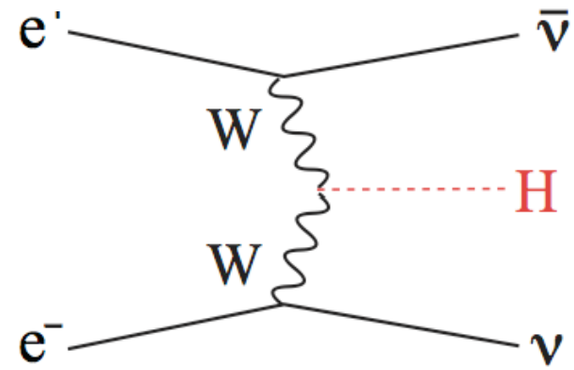
low backgrounds
ability to reconstruct the full event
access to W, Z in hadronic decay modes
use of beam polarization

The important production modes for the Higgs boson at e^+e^- colliders are:

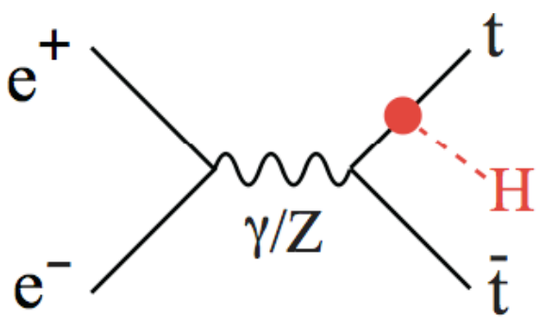
Higgsstrahlung



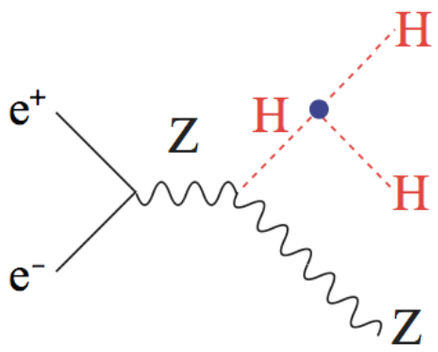
vector boson fusion

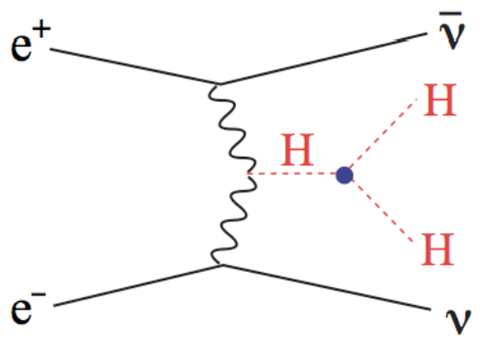


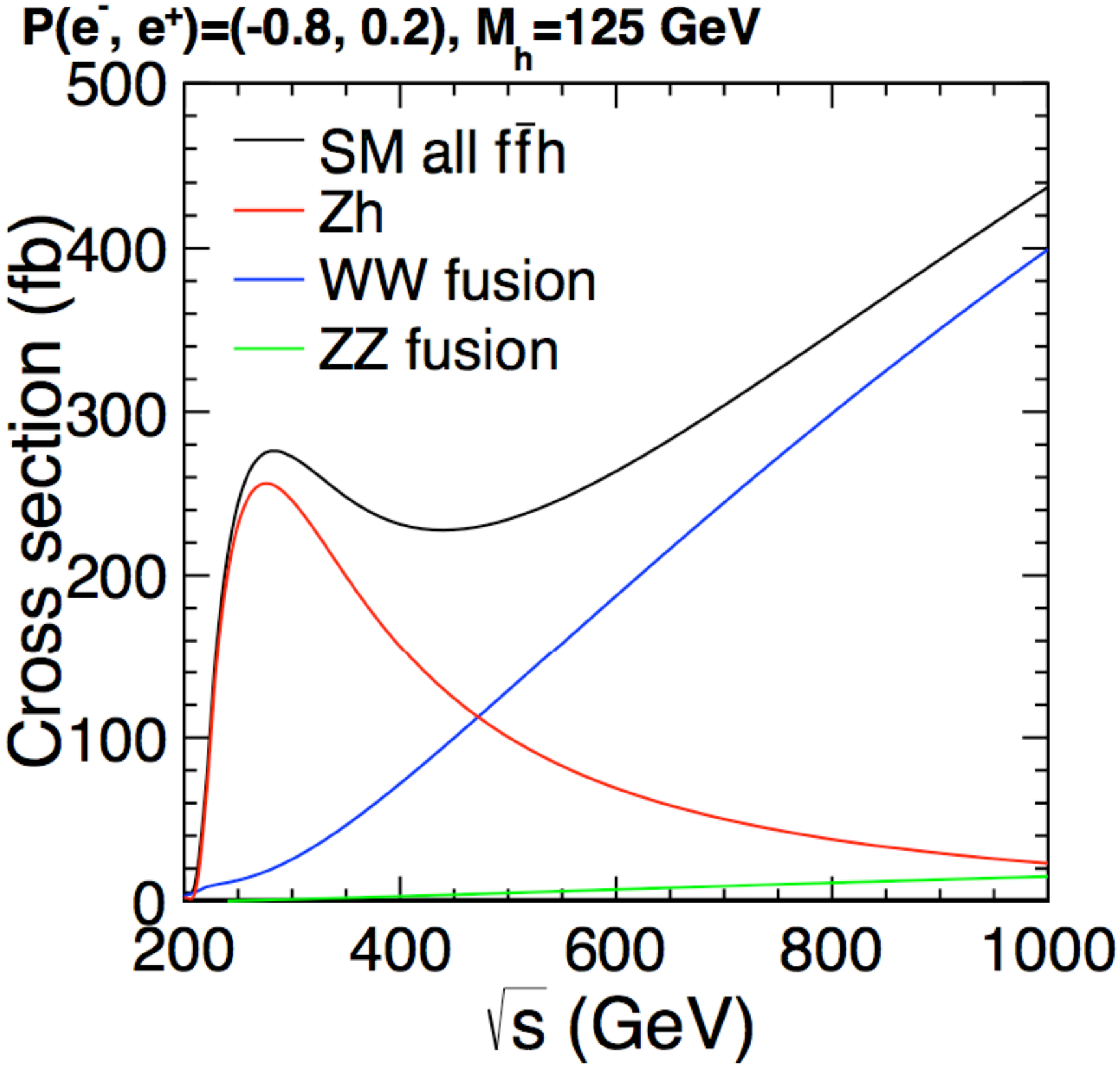
associated production with top



Higgs pair production






P(e⁻, e⁺)=(-0.8, 0.2), M_h=125 GeV
SM all ffh
Zh
WW fusion
ZZ fusion
Cross section (fb)
0
100
200
300
400
500
200
400
600
800
1000
√s (GeV)

These four reactions have different advantages for the precision study of Higgs decays:

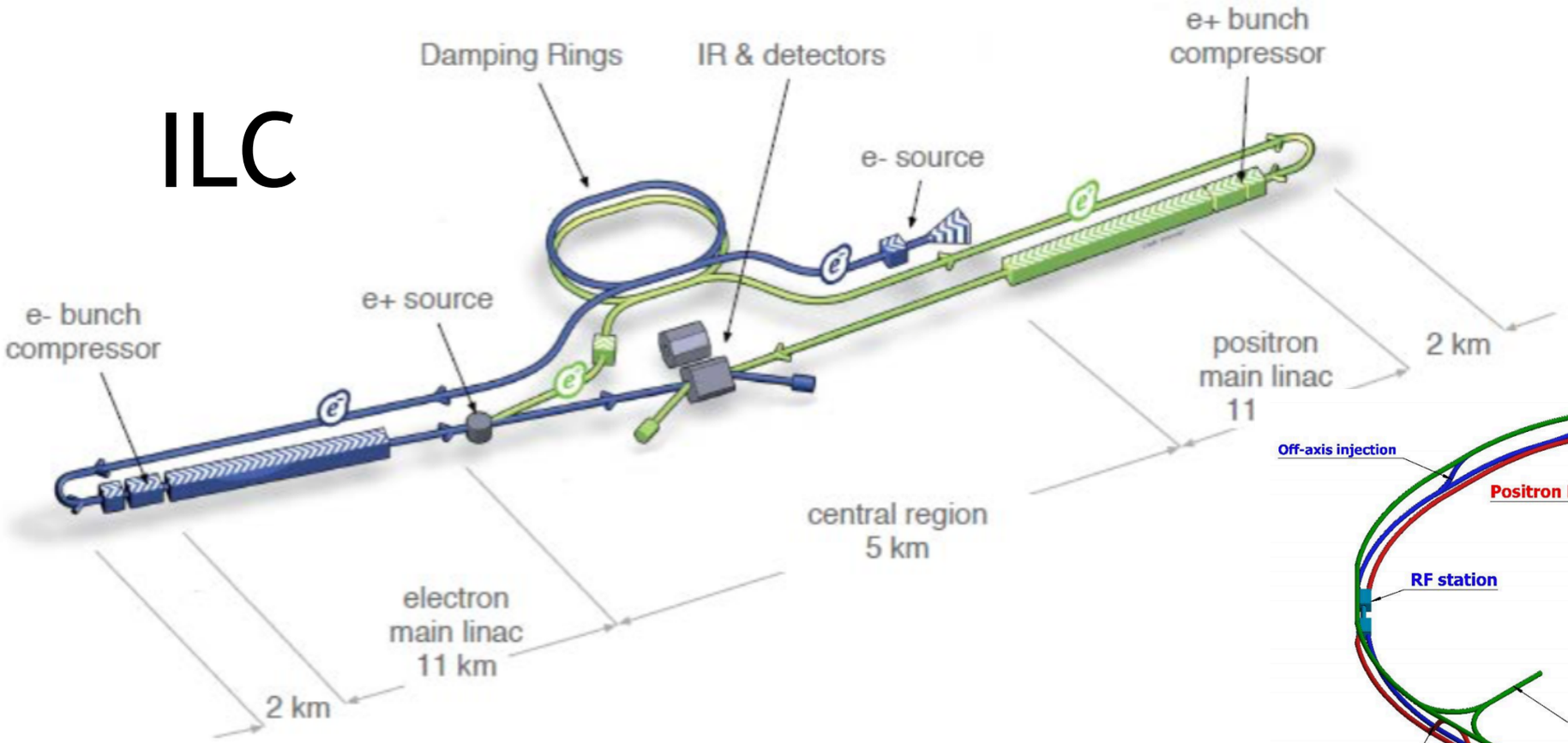
Higgsstrahlung:
- available at the lowest CM energy
- tagged Higgs decay, access to invisible and exotic modes
- absolute normalization from the Zh total cross section

WW fusion:
- high statistics at high energy
- same couplings in different combinations

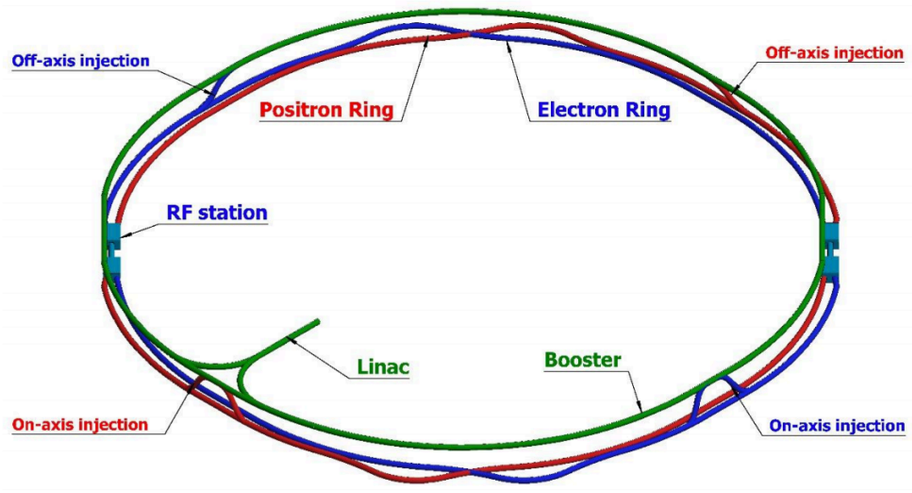
associated production with top:
- access to the Higgs coupling to top

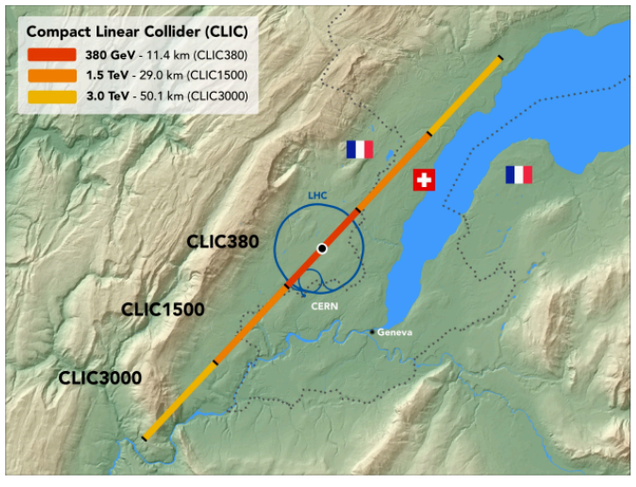
Higgs pair production:
- access to the Higgs self-coupling

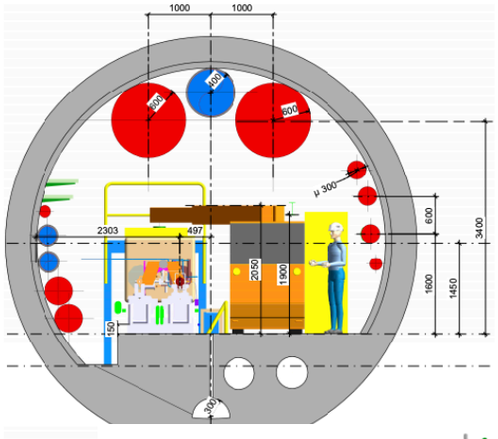
ILC



CEPC

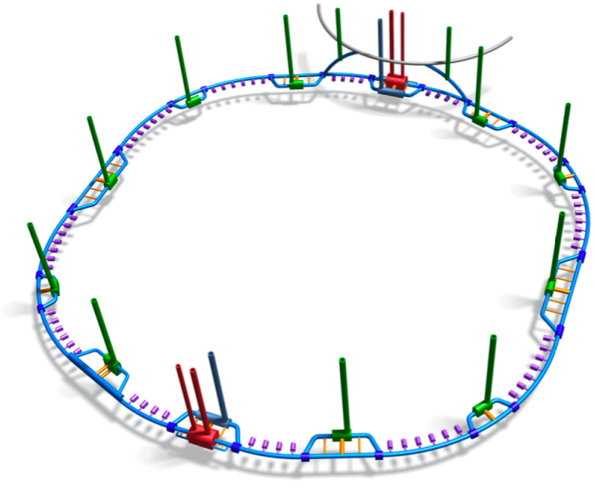


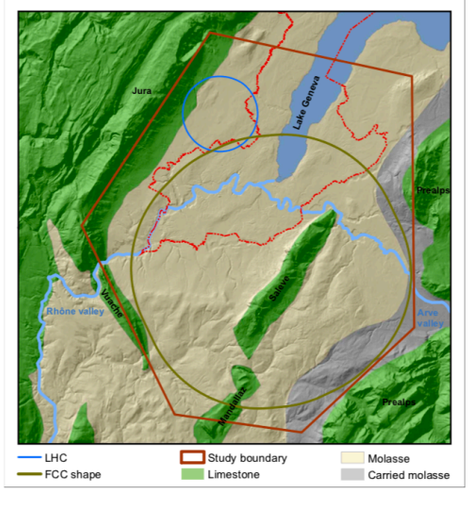


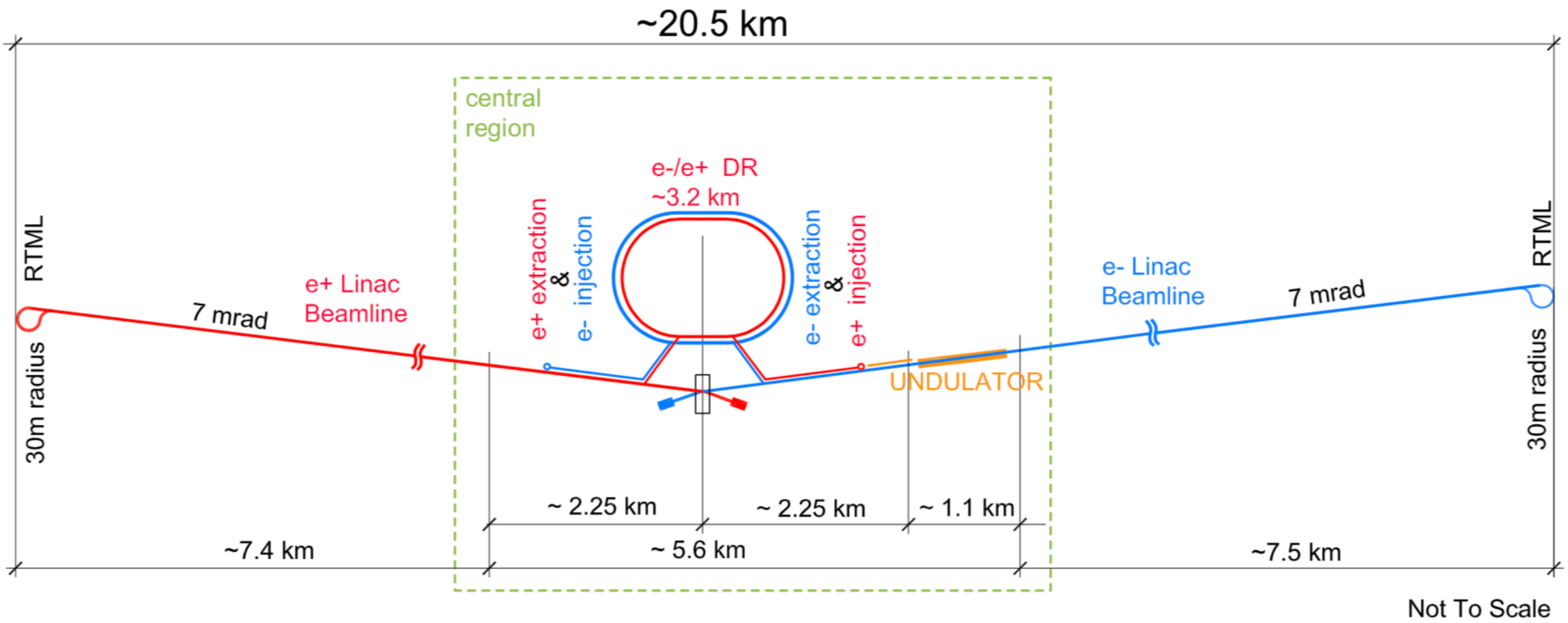


CLIC

FCC-ee

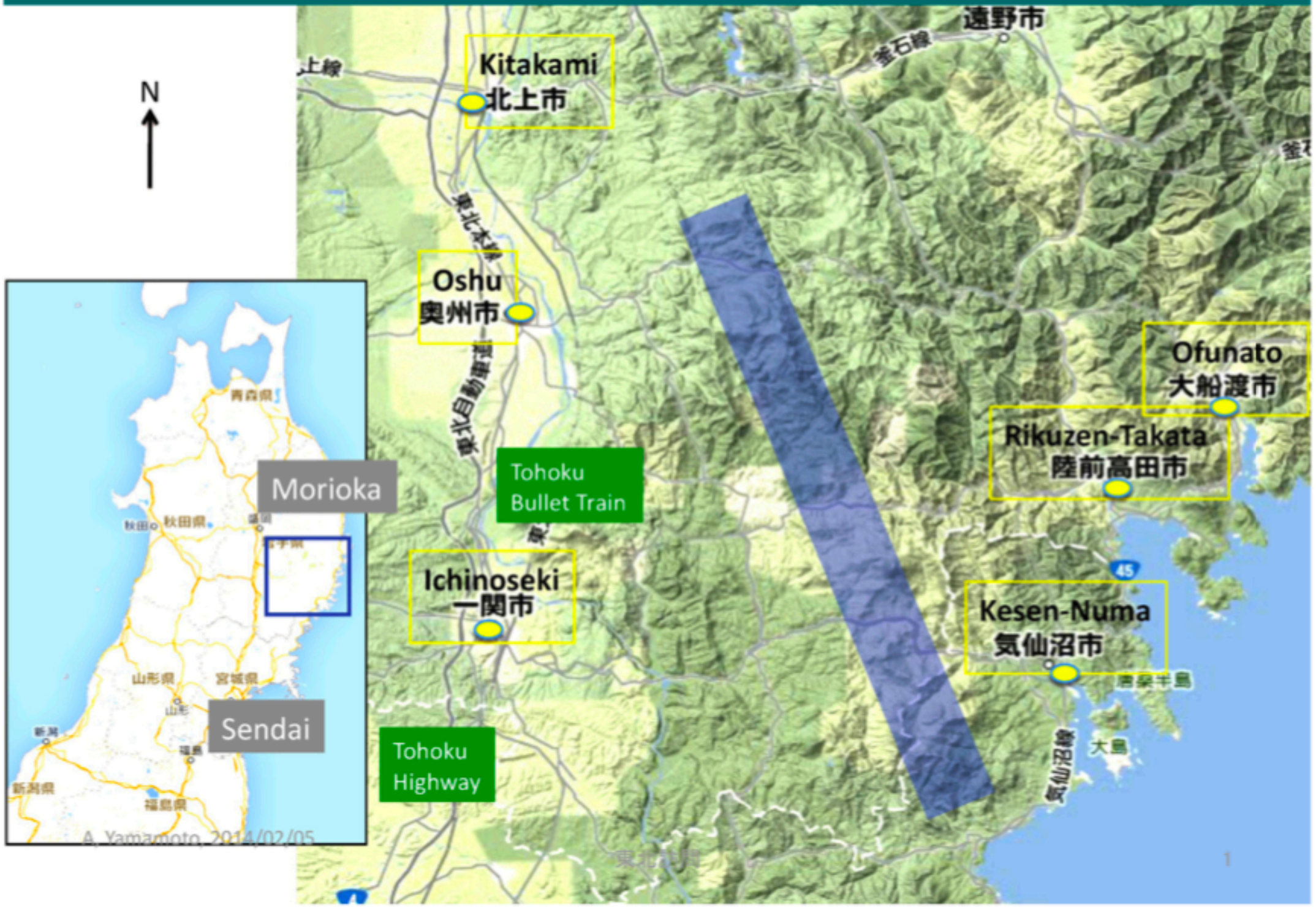


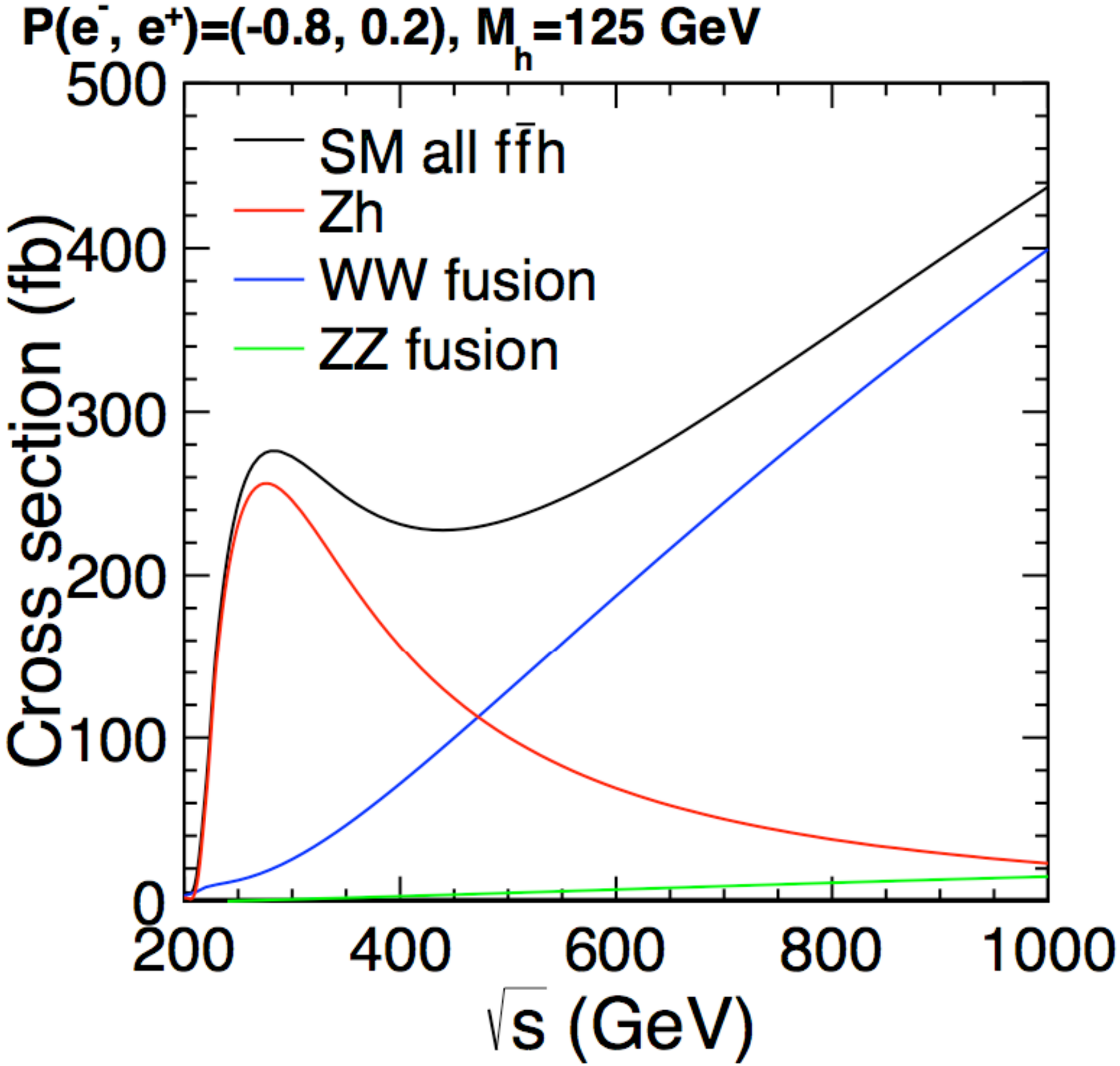




ILC ground plan (not to scale)

ILC Candidate site in Kitakami, Tohoku




P(e⁻, e⁺)=(-0.8, 0.2), M_h=125 GeV
SM all ffh
Zh
WW fusion
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Cross section (fb)
0
100
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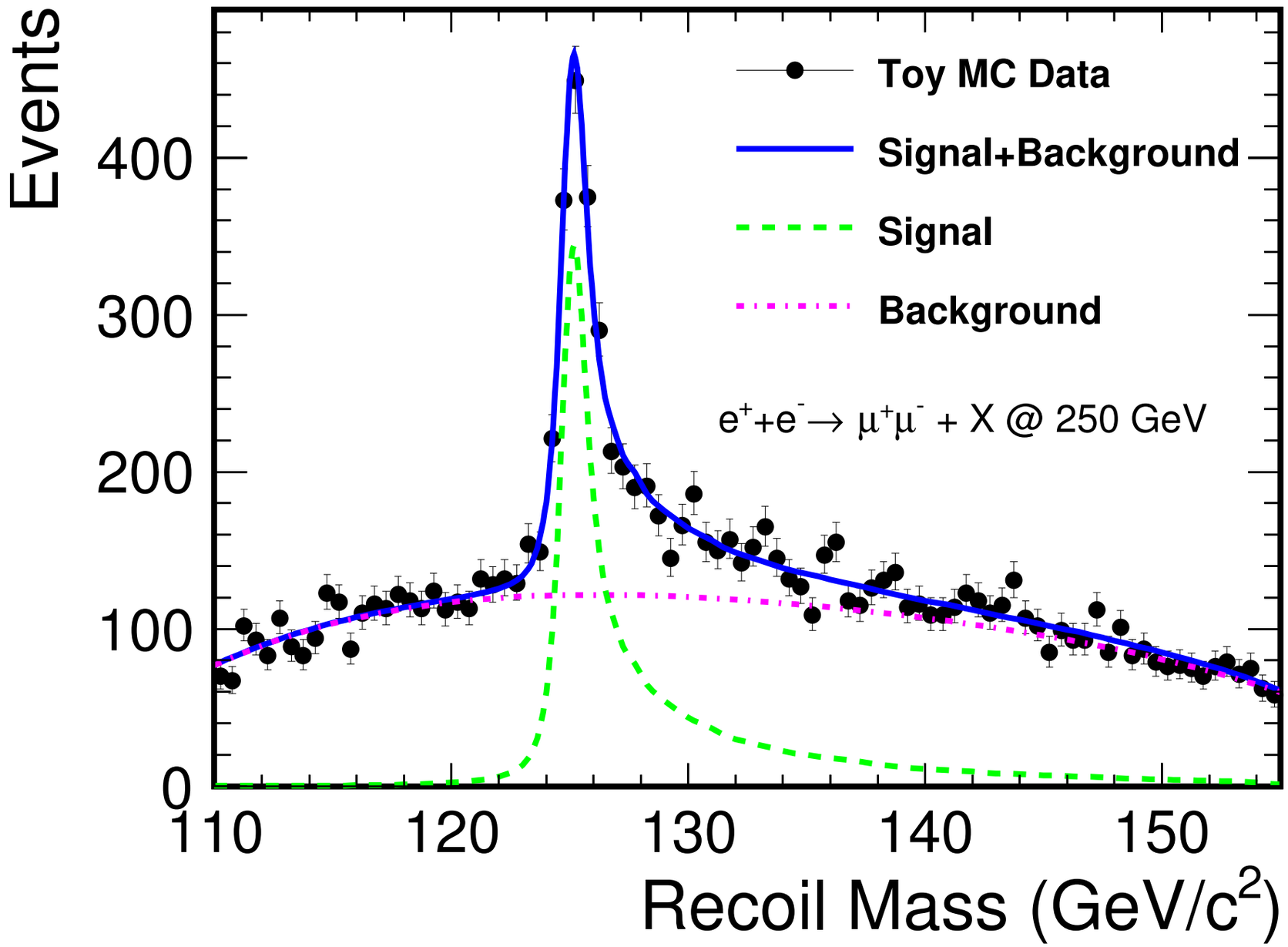
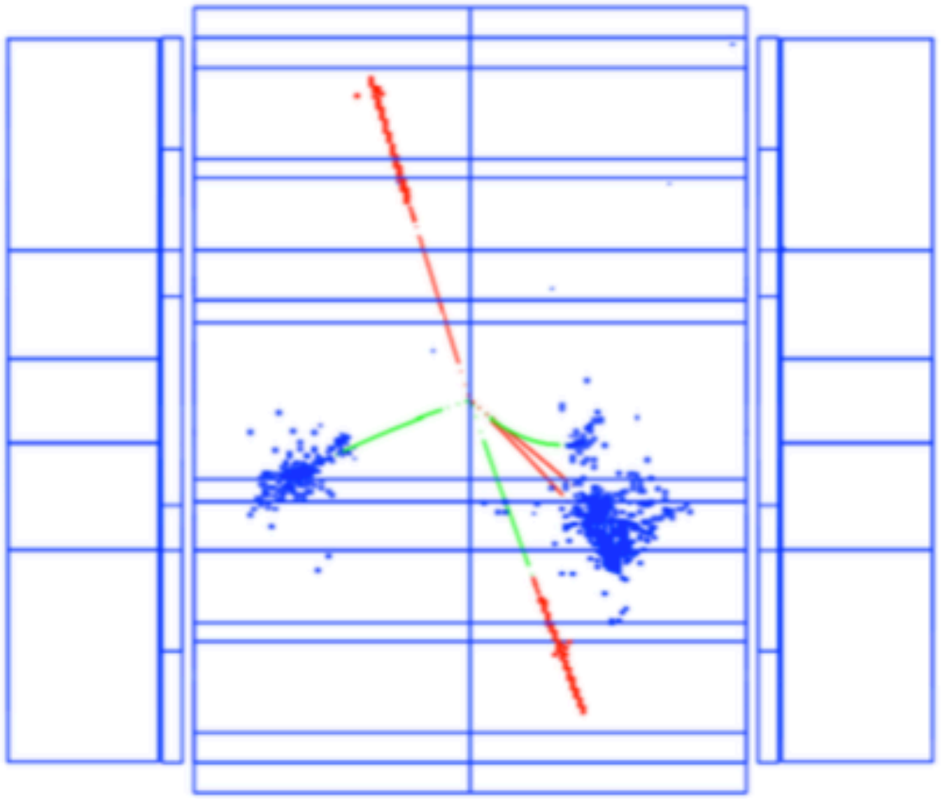
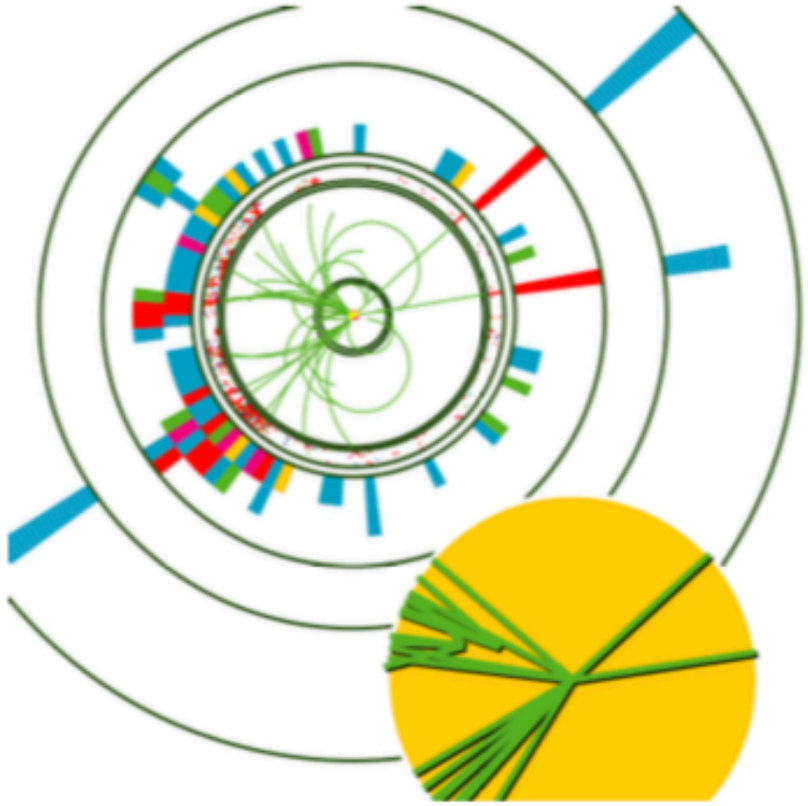
400
600
800
1000
√s (GeV)

measurement of the Higgs boson mass by the recoil technique (σ = 15 MeV)

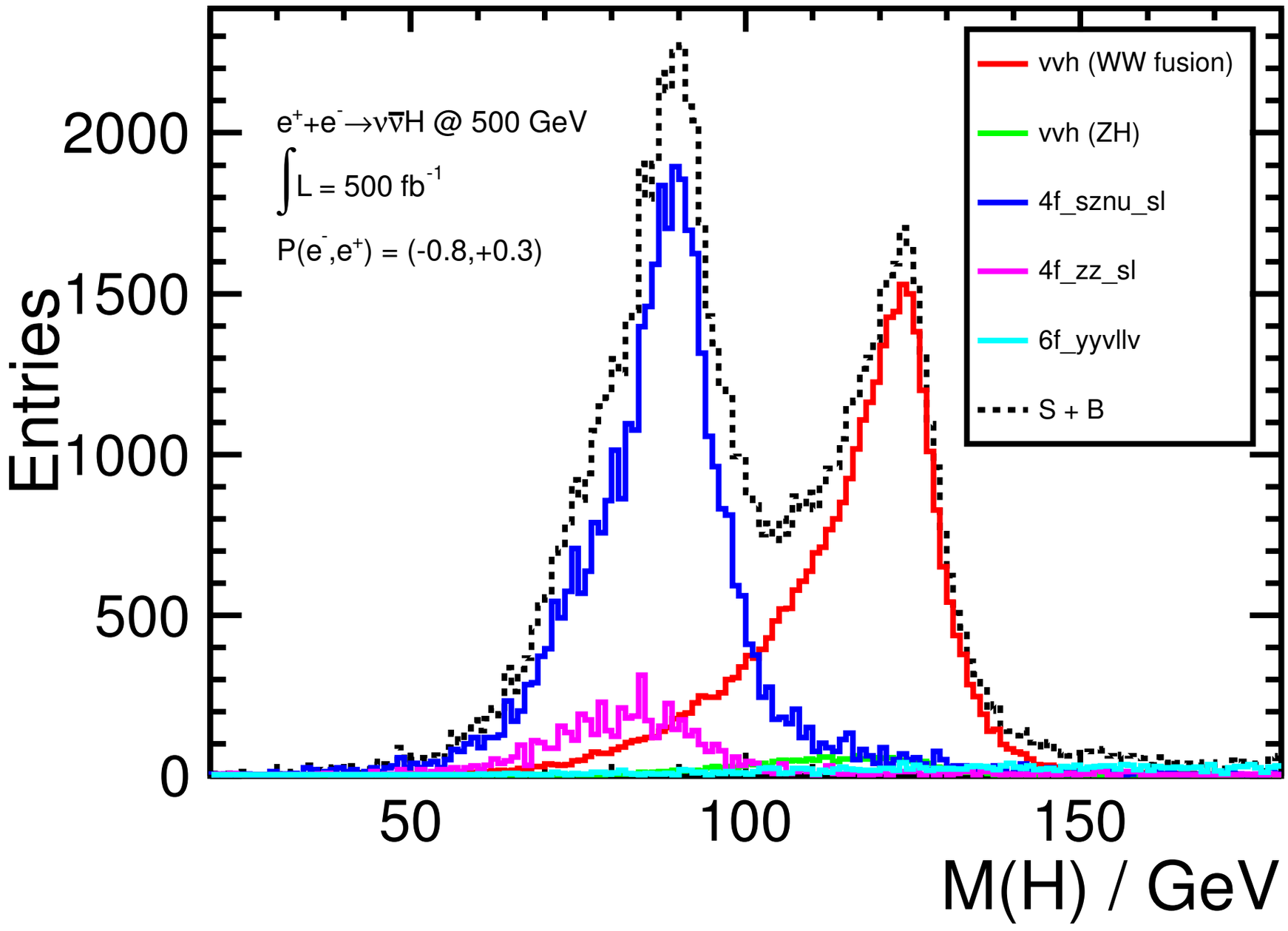


arXiv:1903.01629





$$e^+e^- \to \nu\bar{\nu} + b\bar{b}$$



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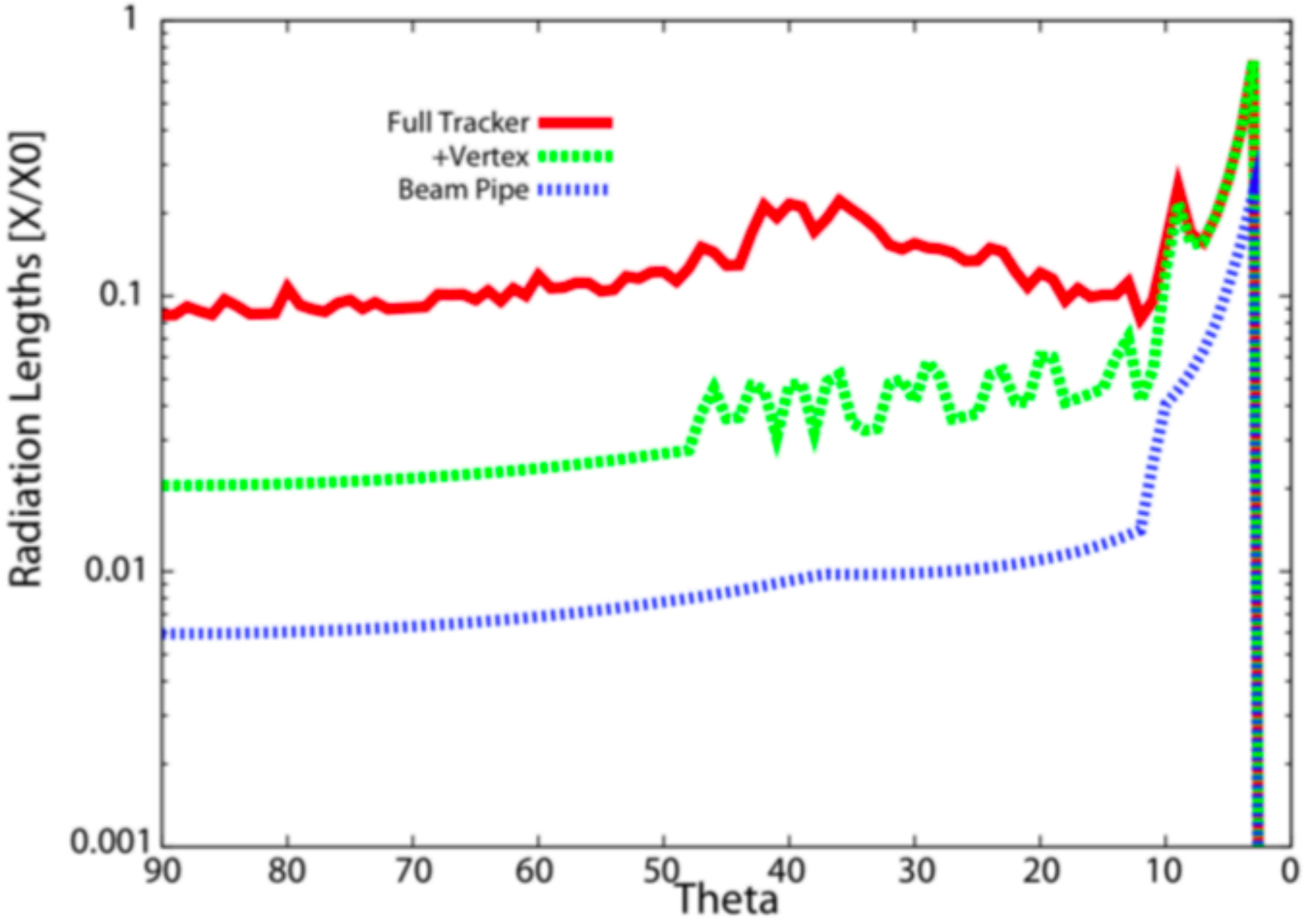
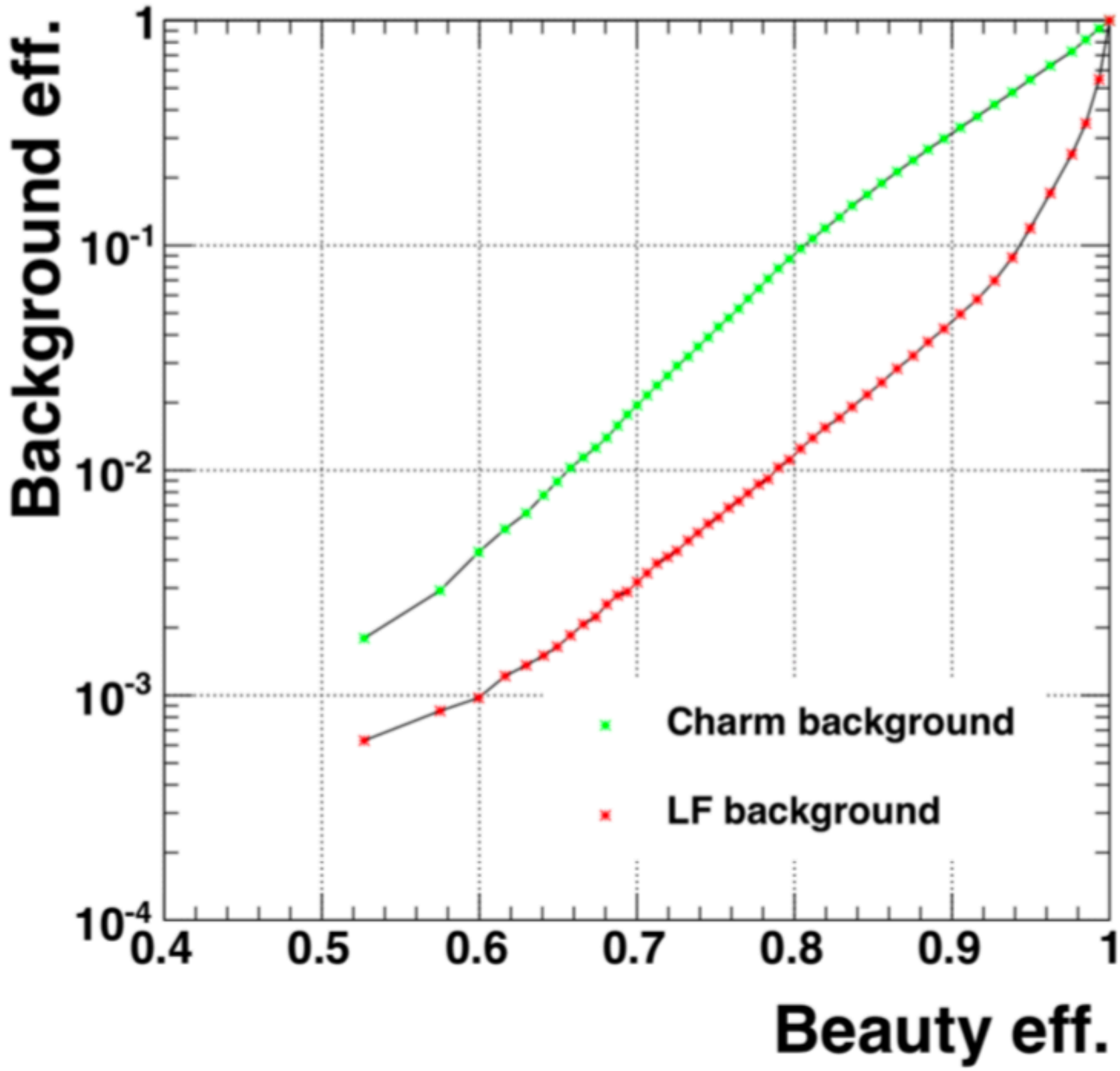
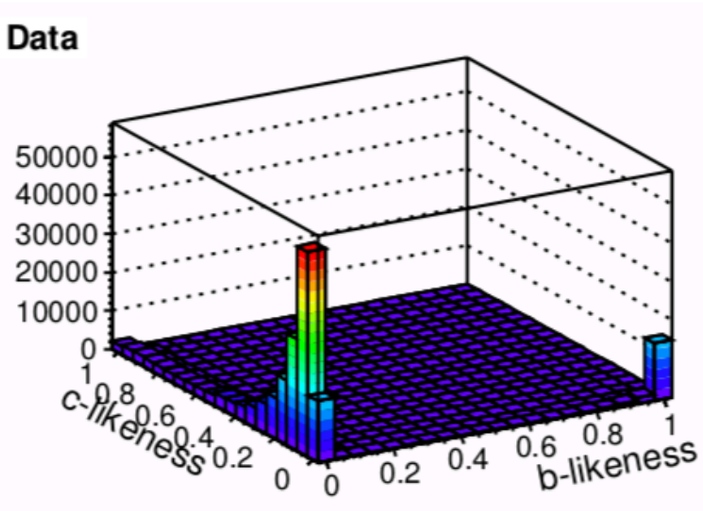
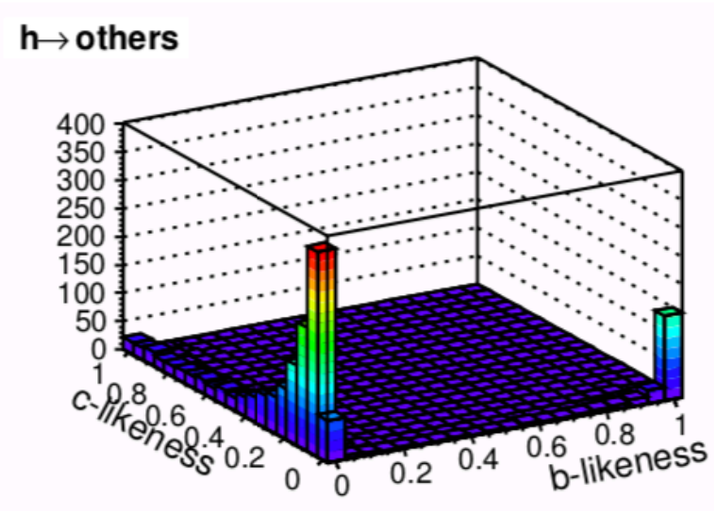
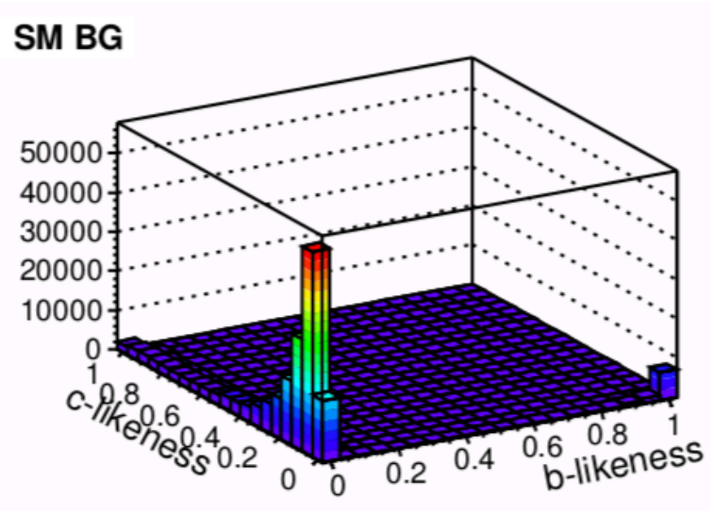


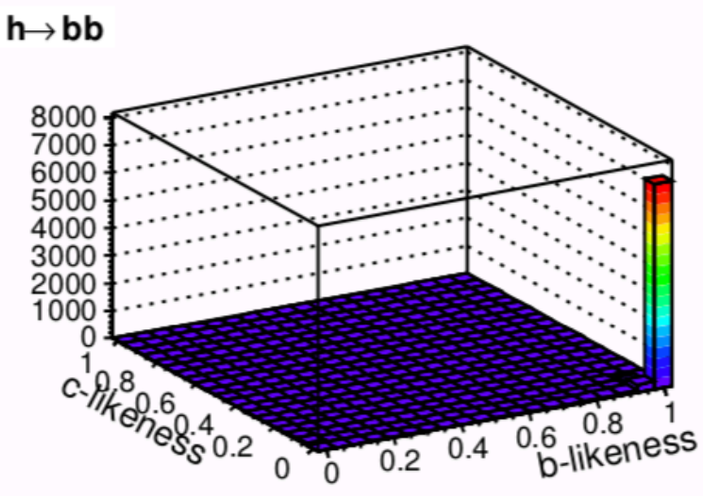
material budget for the SiD tracker

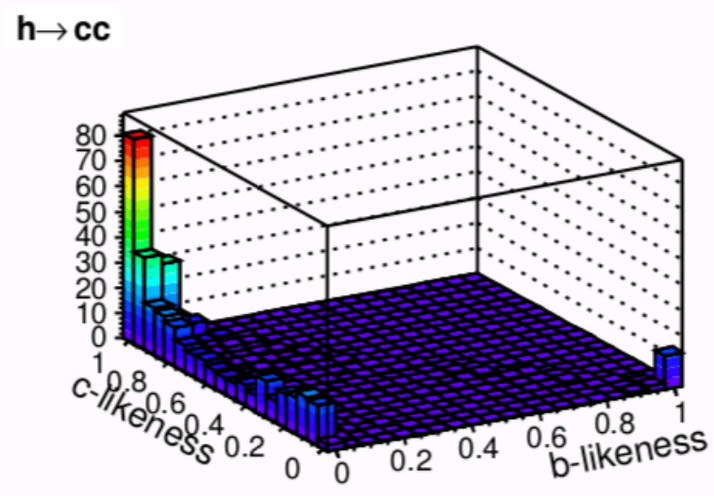

Background eff.
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0.4
0.5
0.6
0.7
0.8
0.9
1
Charm background
LF background
Beauty eff.

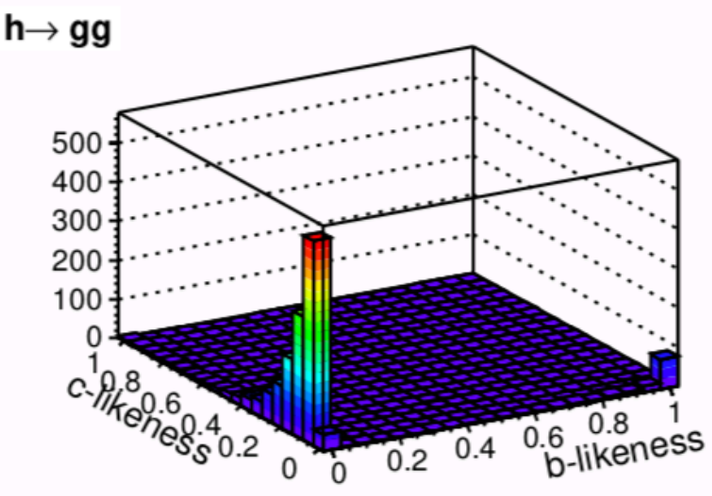






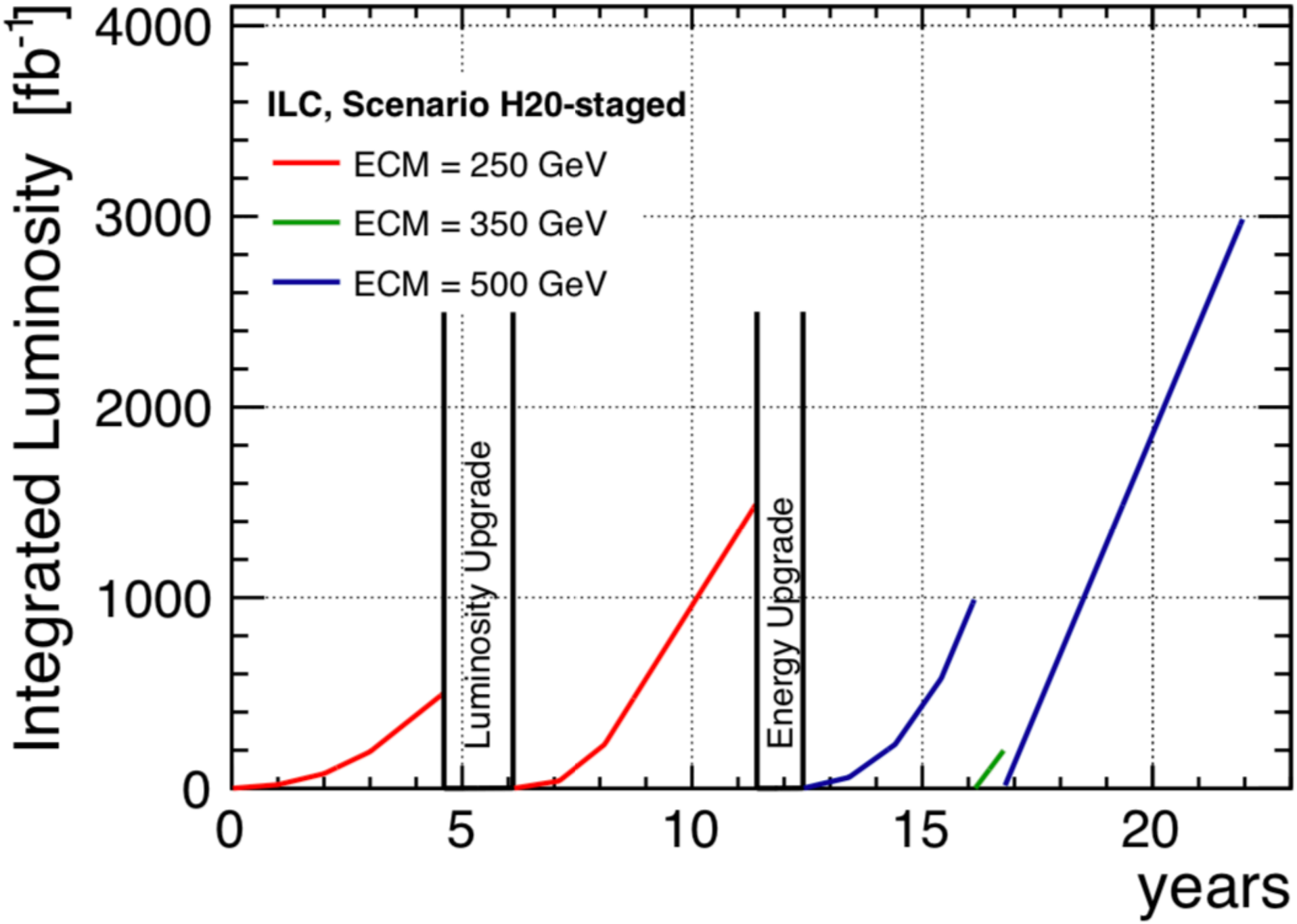






discrimination of hadronic Higgs decays - ILD simulation

ILC proposed run plan



total integrated luminosity at each stage:

	E_{CM} (GeV)	$\int \mathcal{L}$ (fb^{-1})
ILC250	250	2000
ILC350	350	200
ILC500	500	4000
GigaZ	91.19	100
ILC1000	1000	8000

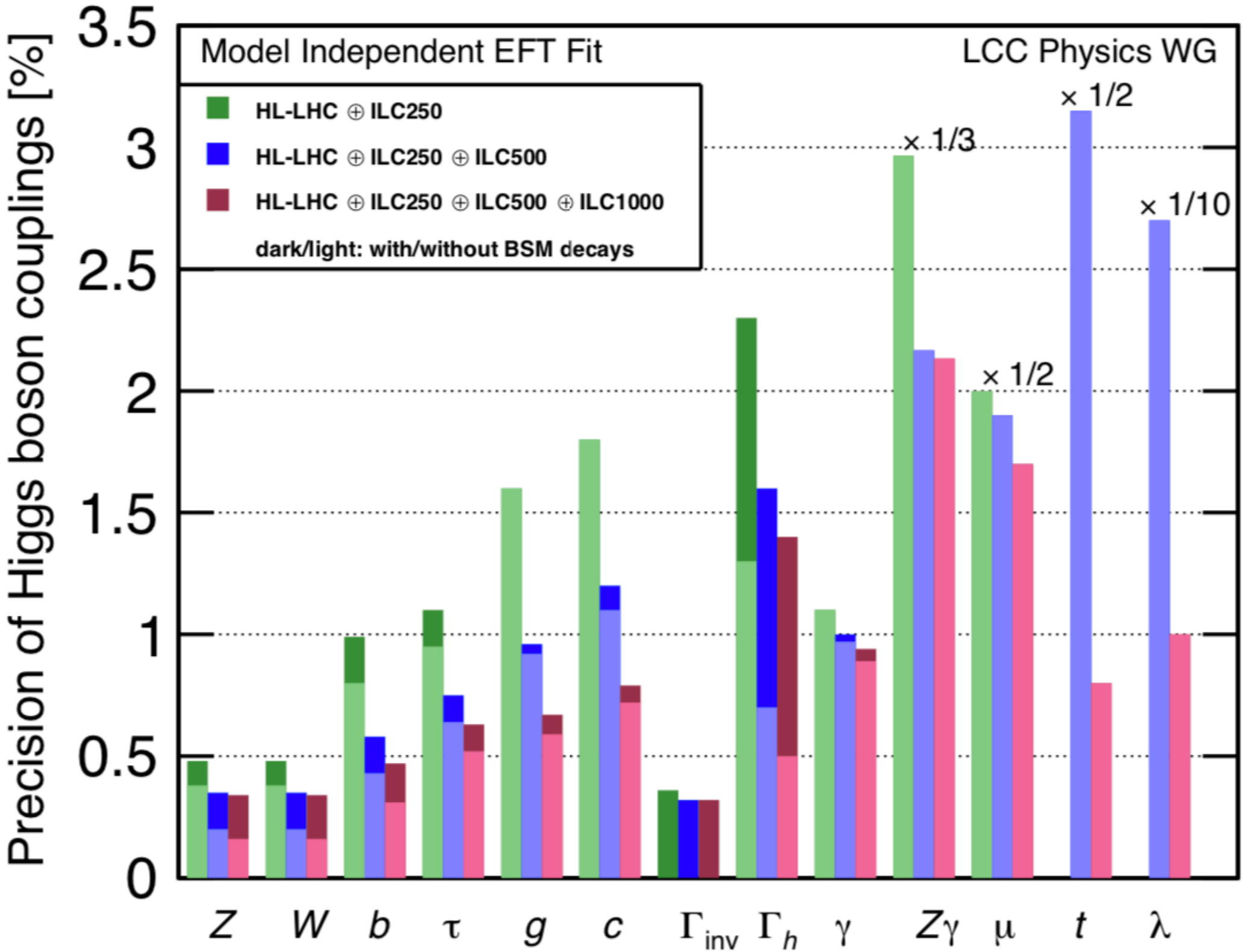
The measurement of Higgs boson branching ratios is quite straightforward for the ILC at 250 GeV.

Higgs events are readily isolated from background.
All standard Higgs decay modes are visible.

Measurement accuracies are such that 1% coupling measurements are feasible.

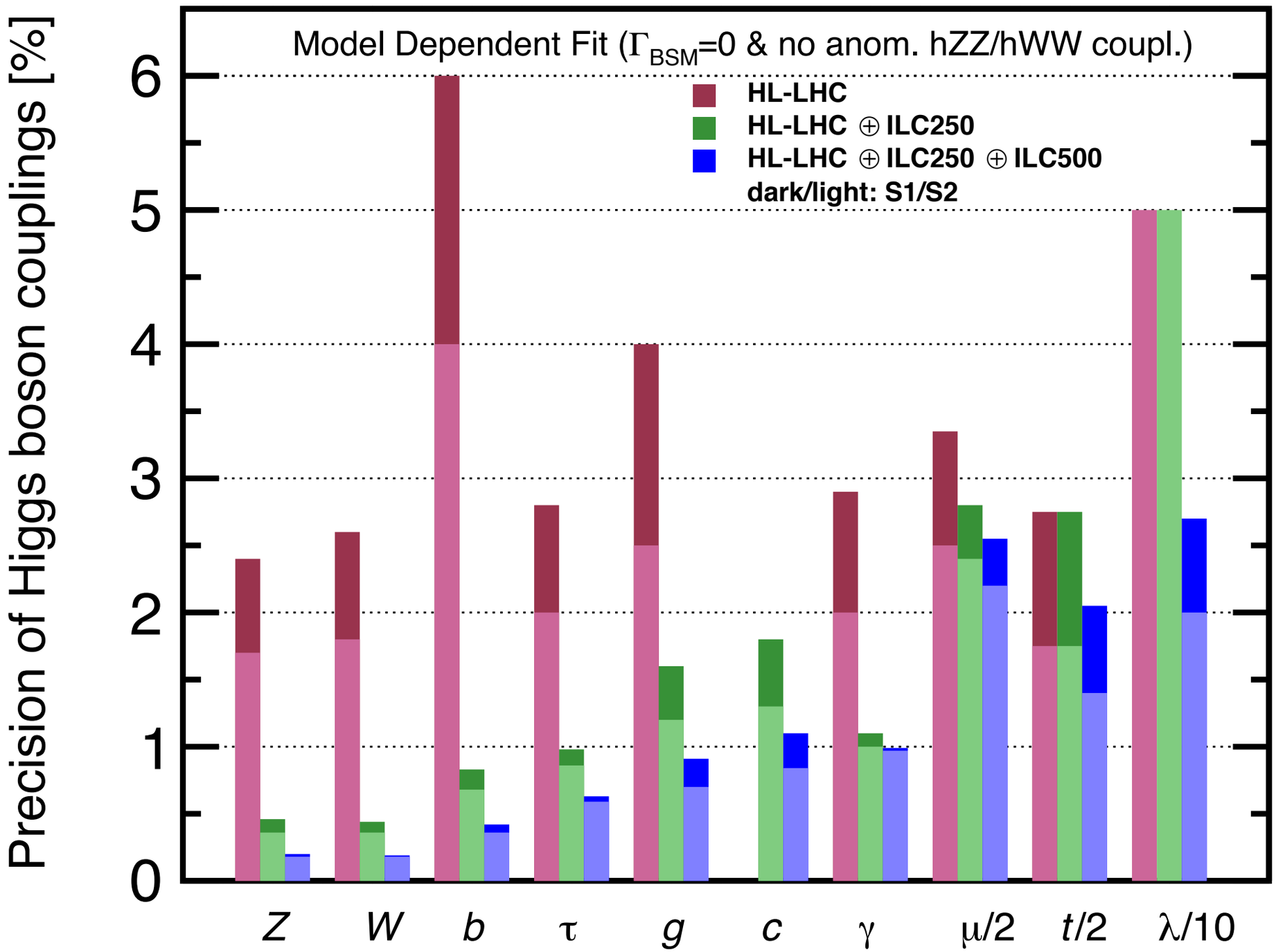
The absolute cross section for $e^+e^- \to Zh$ can be measured.

At 250 GeV, to first approximation, any Z boson with $E_{lab} = 110\ \mathrm{GeV}$ is recoiling against a Higgs boson.



arXiv:1908.11299

HL-LHC and ILC projections of Higgs coupling precision (in %) with the same model-dependent assumptions

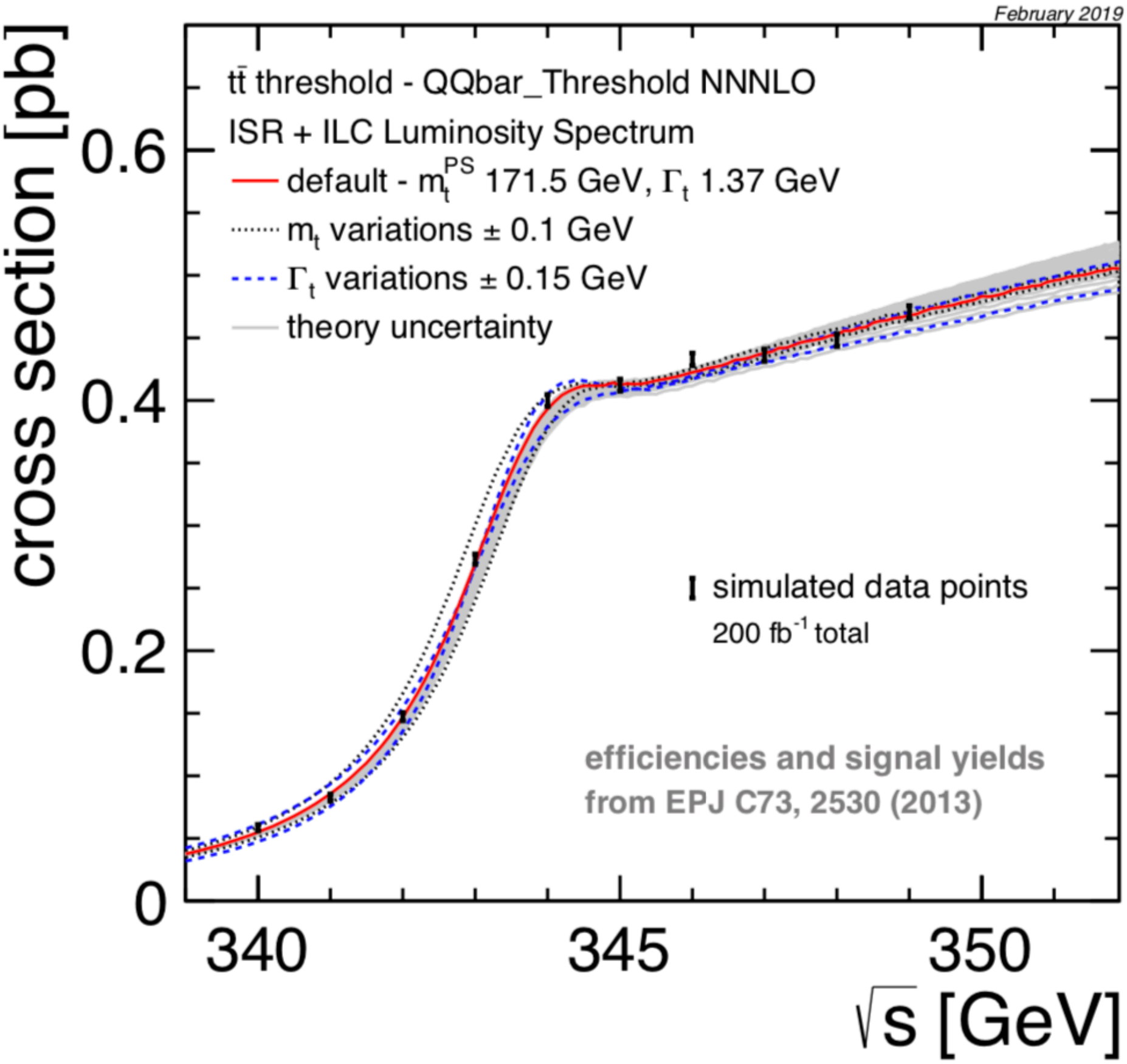


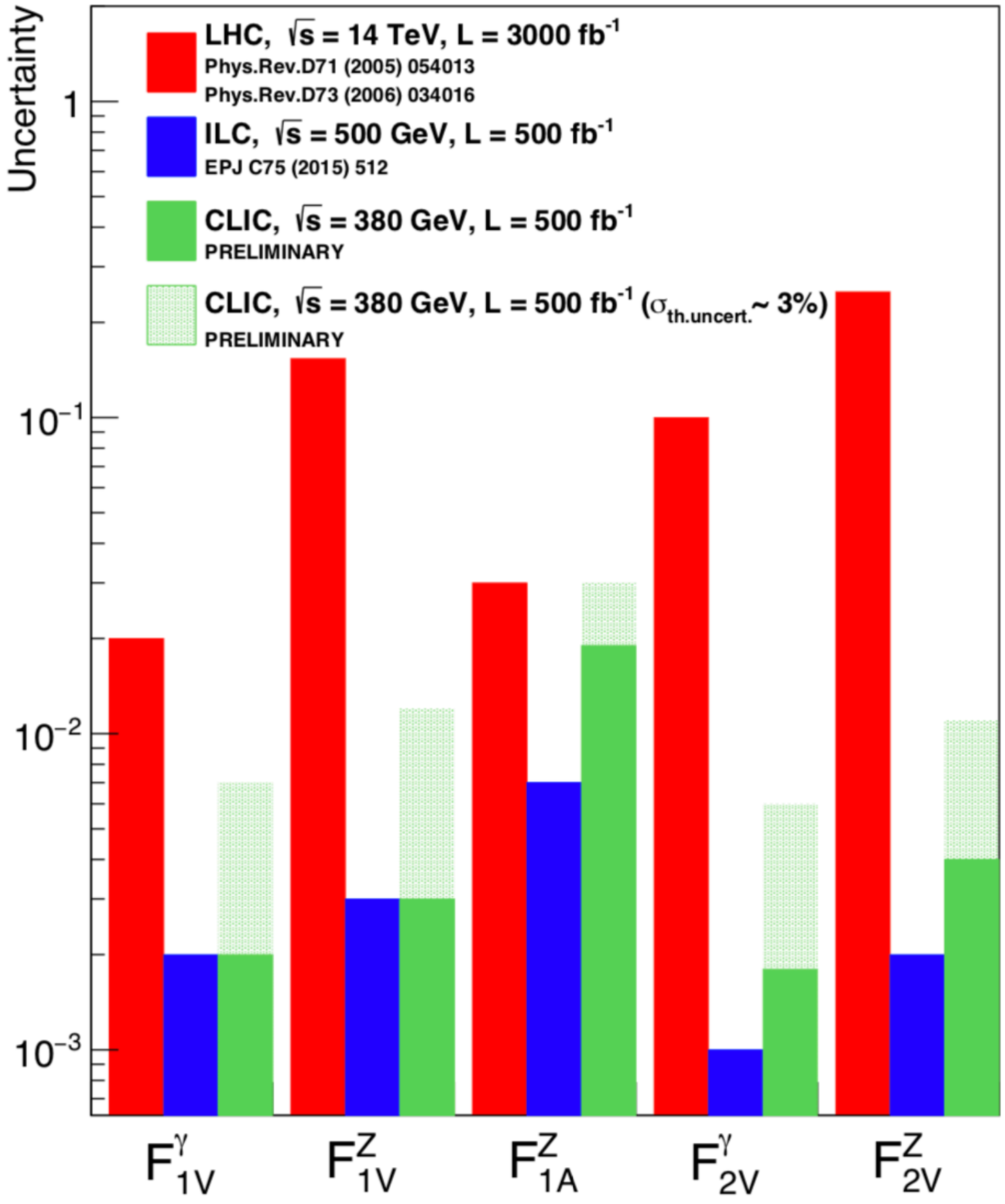
arXiv:1903.01629

At energies above 250 GeV, the precision study of the top quark becomes another important target of the ILC.

The reactions $e^+e^- \to f\overline{f}$ probe for new vector resonances in the mass range 15-20 TeV and for compositeness scales of 200-300 TeV.

Details of these studies can be found in arXiv: 1908.11299 .


February 2019
tt̄ threshold - QQbar_Threshold NNNLO
ISR + ILC Luminosity Spectrum
default - m_t^{PS} 171.5 GeV, Γ_t 1.37 GeV
m_t variations ± 0.1 GeV
Γ_t variations ± 0.15 GeV
theory uncertainty
simulated data points
200 fb^{-1} total
efficiencies and signal yields
from EPJ C73, 2530 (2013)
cross section [pb]
0
0.2
0.4
0.6
340
345
350
$\sqrt{s}$ [GeV]


Uncertainty
1
10^{-1}
10^{-2}
10^{-3}
LHC, $\sqrt{s}$ = 14 TeV, L = 3000 fb^{-1}
Phys.Rev.D71 (2005) 054013
Phys.Rev.D73 (2006) 034016
ILC, $\sqrt{s}$ = 500 GeV, L = 500 fb^{-1}
EPJ C75 (2015) 512
CLIC, $\sqrt{s}$ = 380 GeV, L = 500 fb^{-1}
PRELIMINARY
CLIC, $\sqrt{s}$ = 380 GeV, L = 500 fb^{-1} ($\sigma_{th.uncert.}$~ 3%)
PRELIMINARY
F_{1V}^{γ}
F_{1V}^{Z}
F_{1A}^{Z}
F_{2V}^{γ}
F_{2V}^{Z}

Finally, I will say a little about the timeline for funding and construction of the ILC.

The ILC is an expensive project, with cost comparable to the LHC. There is interest in Japan in hosting the ILC, and in fact a site is chosen, but this will not happen without the promise of substantial funding from other parts of the world.

Last summer, the ILC International Development Team was formed to begin a gradual process toward the required international collaboration.

The schedule envisioned for this process was shown by the IDT chair Tatsuya Nakada at the October 2020 Americas Workshop on Linear Colliders:

https://agenda.linearcollider.org/event/8622/

Rough timeline of the ILC under discussion

ILC IDT (~1.5 years)

- Prepare the work and deliverables of the ILC Pre-laboratory and workout with national and regional laboratories a scenario for their contributions
- Prepare a proposal for the organisation and governance of the ILC Pre-laboratory

In parallel:
Positive "signs" from the host country (Japan) government and agreements by the national/regional laboratories for providing their contributions.

ILC Pre-laboratory (~4 years)

- Complete all the technical preparation necessary to start the ILC project (infrastructure, environmental impact and accelerator facility)
- Prepare scenarios for the regional contributions to and organisation for the ILC.

In parallel:
Positive outcomes of the inter-governmental negotiation for the responsibility and cost sharing among the host (Japan) and partner countries

ILC laboratory

- Construction and commissioning of the ILC (~10 years)
- Followed by the operation of the ILC
- Managing the scientific programme of the ILC

T. Nakada,

T. Nakada at AWLC 2020

Working backward, the major detector(s) for the ILC will need to be on the schedule:

EoIs call at the start of the Pre-Lab (2022)
LoIs call and selection/collaboration-forming
during the Pre-Lab (2025?)
TDRs approval in the late 2020's

So it is timely to get involved now. Serious effort will be needed as the HL-LHC detector upgrades go to final construction.

Linear Collider Workshop 2021 March 15-18 (remote)
EoI Workshop October 26-30
(hopefully, in person in Tsukuba, Japan)

The 2020 update of the European Strategy for Particle Physics stated:

An electron-positron Higgs factory is the highest-priority next collider.

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

At the AWLC 2020, the US DOE and the US State Department gave messages supporting ILC. However, major US involvement will depend on the conclusions of the current Snowmass study and the P5 panel to follow.

I strongly encourage you to become involved in the Snowmass discussions.

We are on a path now to learn from experiment about the nature of the Higgs boson and the mechanism of electroweak symmetry breaking.

I strongly encourage you to learn more about this direction and to join this program.