Parameters for ILC Staging

ILC Parameters Joint Working Group

T. Barklow, J. Brau, K. Fujii, J. Gao, J. List, N. Walker, K. Yokoya

Background

WHY STUDY STAGING?

- Construction of the full 500 GeV ILC from the start remains the preferred plan of the LCC
- It has been suggested that a staged approach might be necessary, starting at a lower energy for a few years, before upgrading to 500 GeV.
- This study is meant to prepare to discuss staging should it be necessary, but the full 500 GeV machine remains the main plan of the LCC for the ILC

Background

- Following the Higgs boson discovery, the Japan Association of High Energy Physicists (JAHEP) recommended that the ILC physics studies start with a precision study of the Higgs boson, evolving into studies of the top quark, dark matter particles, and Higgs self-couplings, through accelerator upgrades.
- A more specific scenario suggested was:
  - A Higgs factory with a centre of mass energy of approximately 250 GeV shall be constructed as the first phase.
  - The machine shall be upgraded in stages up to a centre of mass energy of ~ 500 GeV which is the baseline energy of the overall project.
  - Technical extendibility to a 1 TeV region shall be preserved.

ILC Accelerator Physicists Respond

- Staging represents a significantly different construction scenario from the TDR (full 500 GeV from start)
  - impact on the overall schedule and associated sub-system planning.
- The impacts were addressed by Dugan, Harrison, List and Walker in their note, “Implications of an Energy-Phased approach to the realization of the ILC."
  - note intended to outline major changes arising from this phased energy approach.
  - noted - multiple steps in staging undesirable.

LCC creates Joint WG

- Charge:
  - The ILC parameter working group reports to the LCC Directorate. It consists of members from both the ILC accelerator and the physics & detector groups where each team selects a co-convener for this working group.
  - This working group prepares information on ILC machine parameters and staging scenarios as well as potential upgrade paths in a form readily usable by the LCC. In doing so, the WG will take into account technical machine constraints and physics and detector needs regarding the fundamental ILC machine parameters such as energy, luminosity, crossing angles, etc.
  - <u>The first task for the working group is to prepare multiple scenarios for staging up to about 500 GeV.</u> The report should contain the pros and cons of each scenario as well as luminosities needed at each energy to produce corresponding physics results.

LCC creates Joint WG

- Joint WG Membership:
  - machine: Jie Gao, N. Walker (co-convener), K. Yokoya,
  - physics & detectors: T. Barklow, J. Brau (co-convener), K. Fujii, J. List

contributions to study from
Mikael Berggren, Roberto Contino, Christophe Grojean, Benno List, Maxim Perelstein, Michael Peskin, Roman Pöschl, Juergen Reuter, Tomohiko Tanabe, Mark Thomson, Junping Tian, Graham Wilson and all members of the ILC Physics Working Group.

Considerations

- Start at 250 GeV (this is JAHEP recommendation - but, also studying 350 GeV start)
- Optimize <u>early</u> physics production
- Optimize overall physics reach
- Consider realistic ramp-up and upgrade timeframes
- Operations at 75% for 8 months/calendar year
  - 1.6×10^7 seconds/year (= 60% for 10 months)
- <u>The studied ~ 25 calendar year programs would be revised by discoveries of the future</u>

Development of study

- Considered about ten scenarios with variants
- Emphasized Higgs precision, initially
- Confirmed importance of high energy running for Higgs precision
- ttH threshold near 500 GeV argues for pushing ~ 500 GeV machine design to ~ 550 GeV
    - 550 GeV NOT explicitly in our scenario studies
- Reduced number of scenarios to make message clear
  - chose 3 with variants

Main Physics Goals vs. Energy

250 GeV

- precision Higgs couplings and branching ratios, in particular g_{HZZ} and BR(H → bb)
- precision Higgs mass
- search for invisible and exotic Higgs decay modes

350 GeV

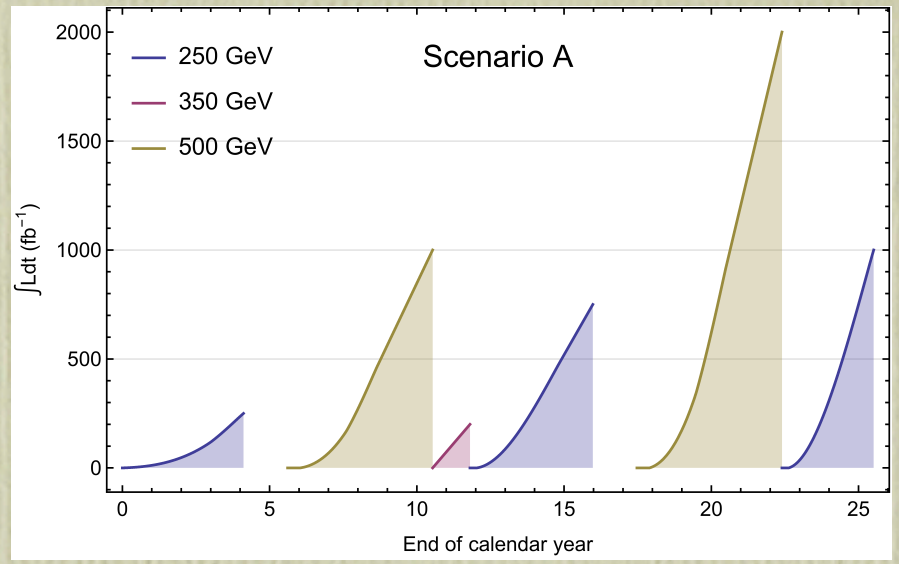
- top quark mass from threshold scan
- precision **W** couplings
- precision Higgs couplings, in particular **g**HWW, and overall normalization of Higgs couplings

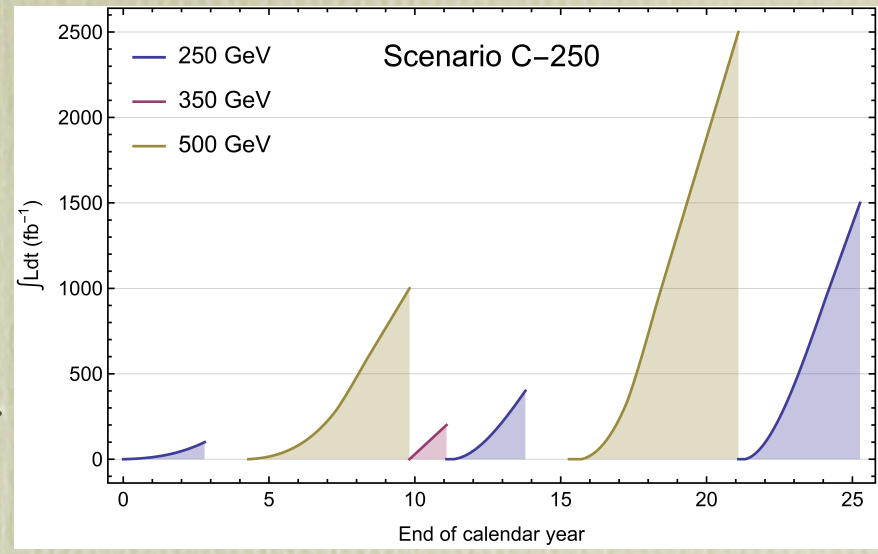
500 GeV

- precision Higgs couplings
- precision electroweak couplings of the top quark
- Higgs couplings to top
- Higgs self-coupling
- precision **W** couplings
- precision search for **Z**′
- search for supersymmetry
- search for Dark Matter
- search for extended Higgs states

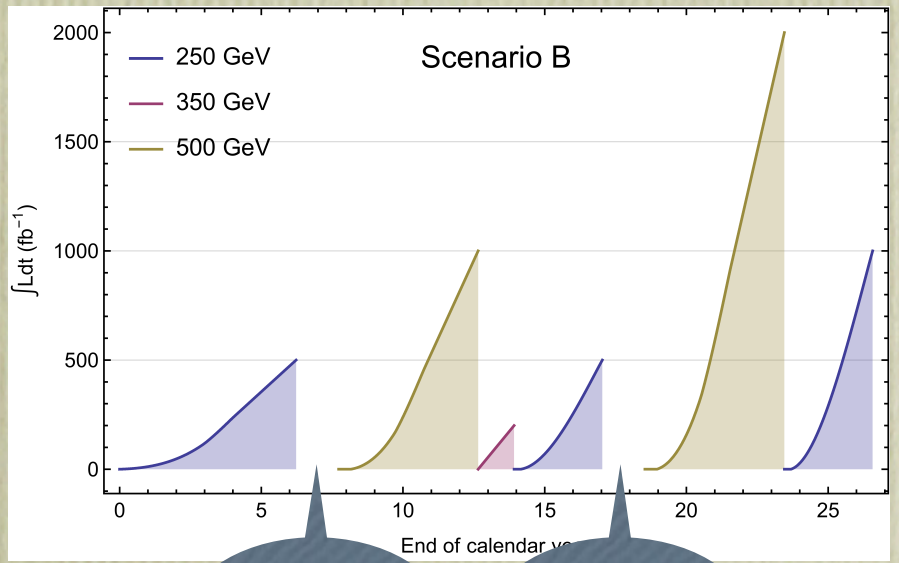
Scenarios

- A: run for 250 fb^{-1} during initial 250 GeV phase (4.1 calendar years) then upgrade to 500 GeV
- B: run for 500 fb^{-1} @ 250 GeV before beginning 500 GeV upgrade (6.2 calendar years)
- C: run for 100 fb^{-1} @ 250 GeV (2.8 calendar years, minimum time required to produce all cryomodules) and then upgrade to 500 GeV
  - variants of C: 250 GeV or 500 GeV emphasis in last phase (C-250 and C-500)



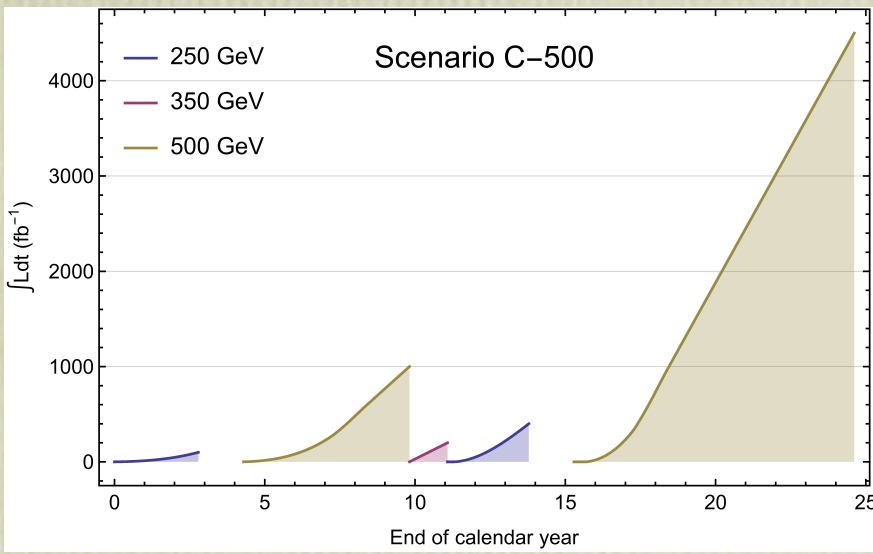


Projected evolution of integrated luminosity with realistic ramp-up and upgrade timelines



Energy Upgrade

Lumi Upgrade



Note
- time is in <u>calendar years</u>

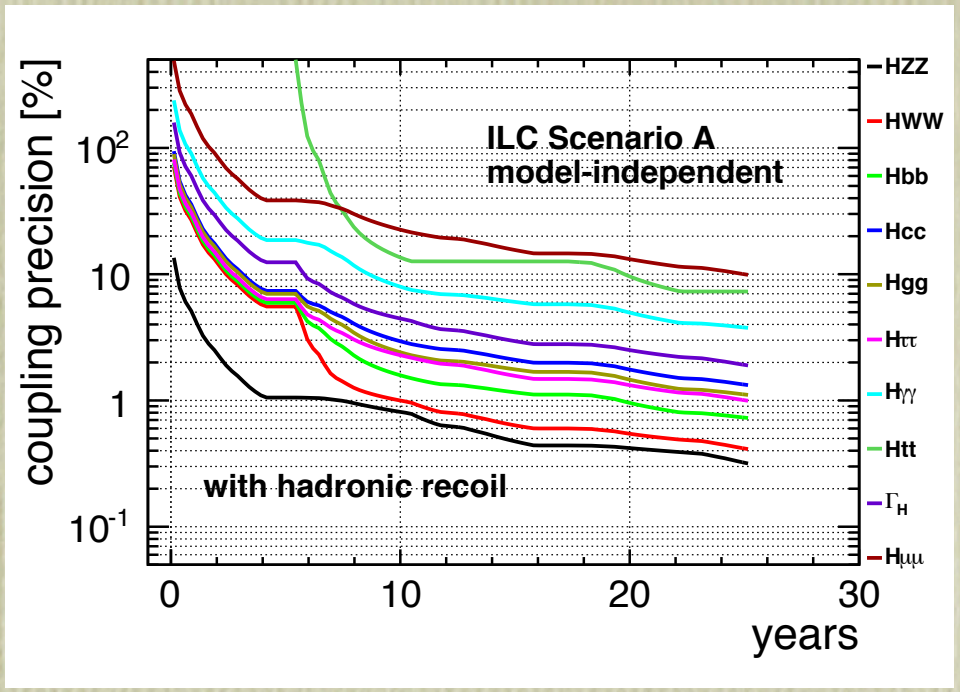
Summary of scenarios

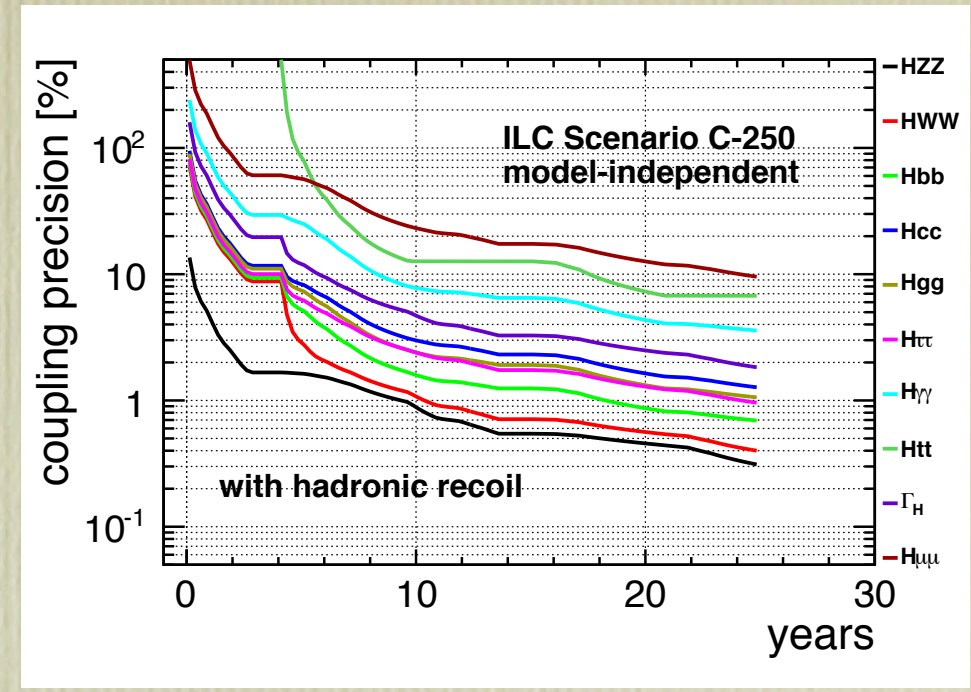
	$\int \mathcal{L} dt$ [fb^{-1}]			
$\sqrt{s}$	A	B	C-250	C-500
250 GeV	2000	2000	2000	500
350 GeV	200	200	200	200
500 GeV	3000	3000	3500	5500

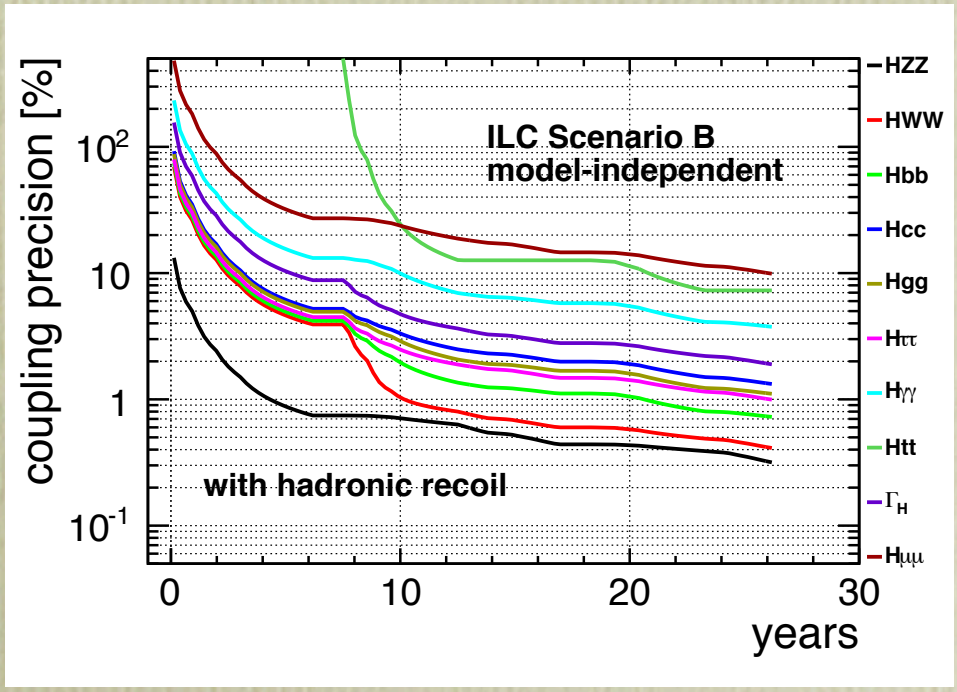
Table 1: Proposed total target integrated luminosities for $\sqrt{s} = 250, 350, 500$ GeV.

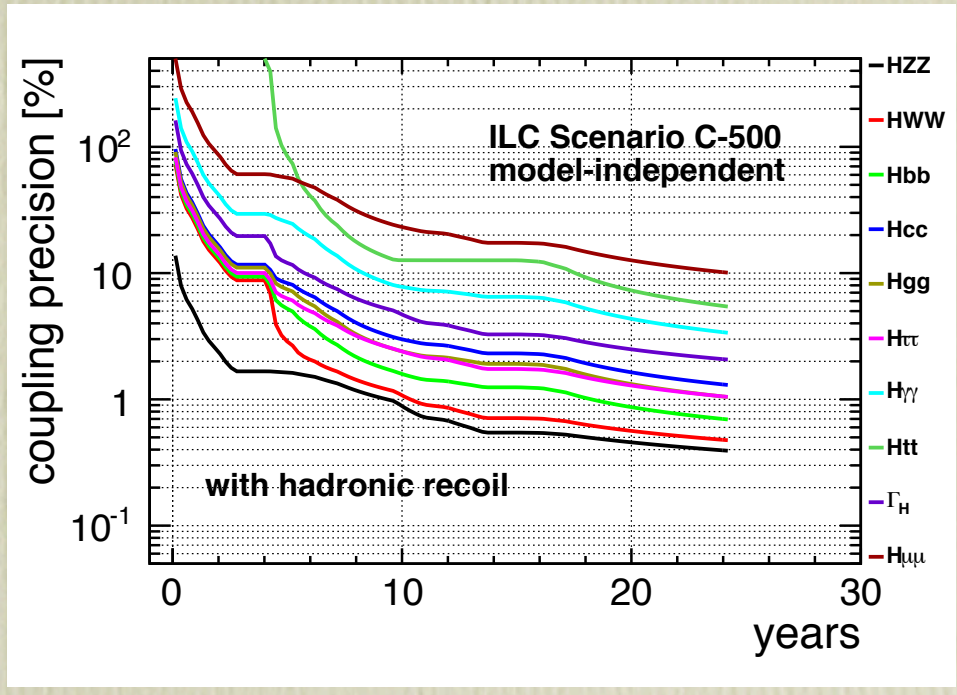
	total run time *before*		
	500 GeV	Lumi upgrade	TeV upgrade
Scenario	[years]	[years]	[years]
A	4.1	16.0	25.5
B	6.2	17.1	26.6
C-250	2.8	13.8	25.3
C-500	2.8	13.8	24.6

Table 5: Cumulative running times for the four scenarios, including ramp-up and installation of upgrades. Not included: calibration and physics runs at Z pole and WW-threshold or scanning of new physics thresholds.


ILC Scenario A
model-independent
with hadronic recoil
coupling precision [%]
years
HZZ
HWW
Hbb
Hcc
Hgg
Hττ
Hγγ
Htt
Γ_H
Hμμ

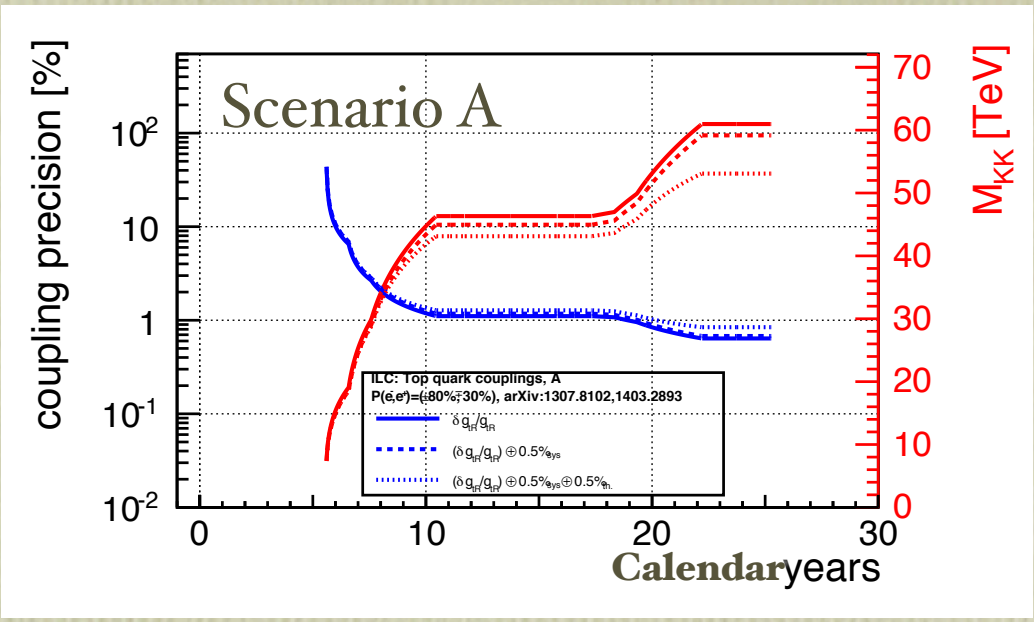

ILC Scenario C-250
model-independent
with hadronic recoil
coupling precision [%]
years
HZZ
HWW
Hbb
Hcc
Hgg
Hττ
Hγγ
Htt
Γ_H
Hμμ

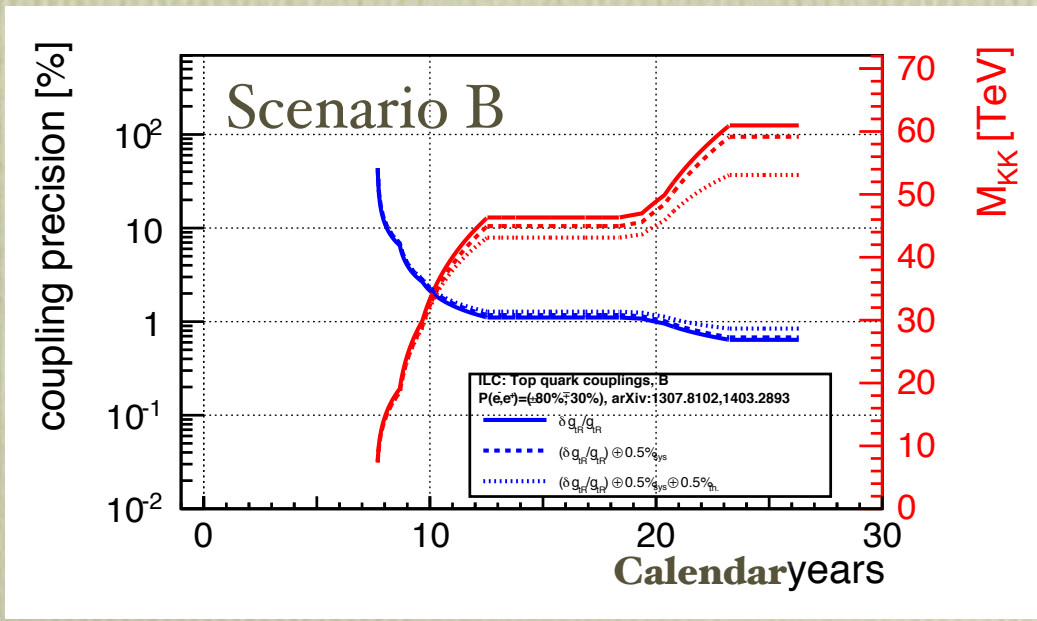

ILC Scenario B
model-independent
with hadronic recoil
coupling precision [%]
years
HZZ
HWW
Hbb
Hcc
Hgg
Hττ
Hγγ
Htt
Γ_H
Hμμ

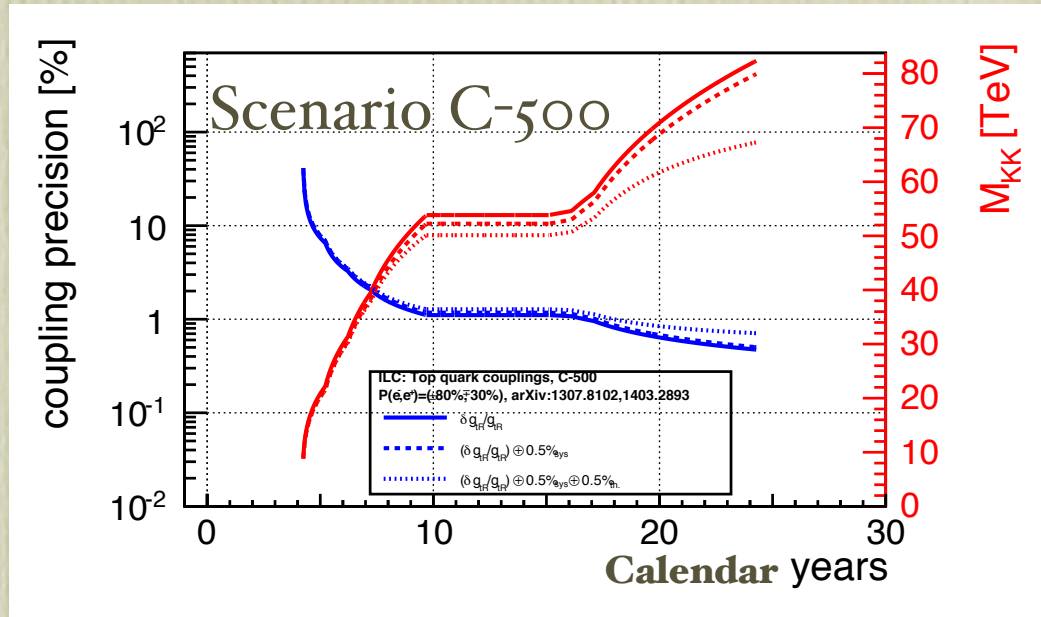

ILC Scenario C-500
model-independent
with hadronic recoil
coupling precision [%]
years
HZZ
HWW
Hbb
Hcc
Hgg
Hττ
Hγγ
Htt
Γ_H
Hμμ

Top RH coupling & sensitivity of KK mass scale in extra dimension model

F. Richard, arXiv:1403.2893







Note - the choice of this benchmark point is under recent discussion in the Physics Working Group

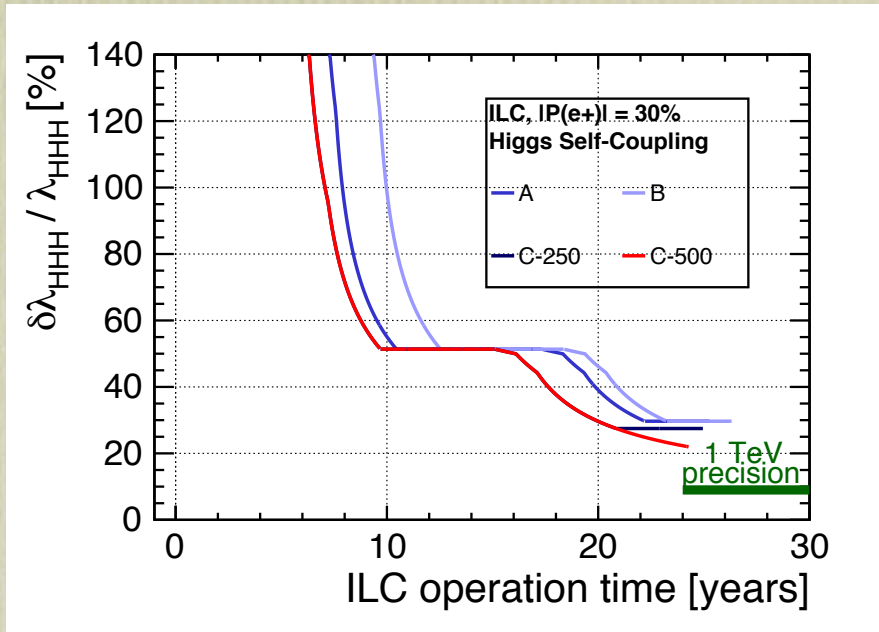
Higgs self-coupling

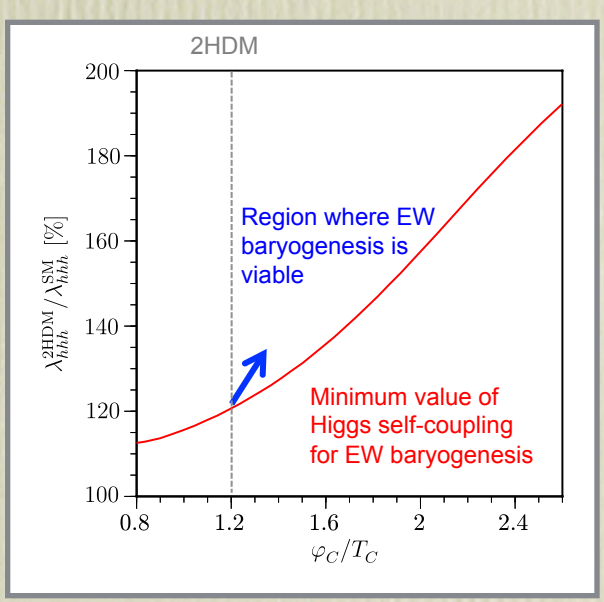
$\sqrt{s} \gtrsim 450$ GeV

~20% precision (5σ SM) achieved at end of C-500 run

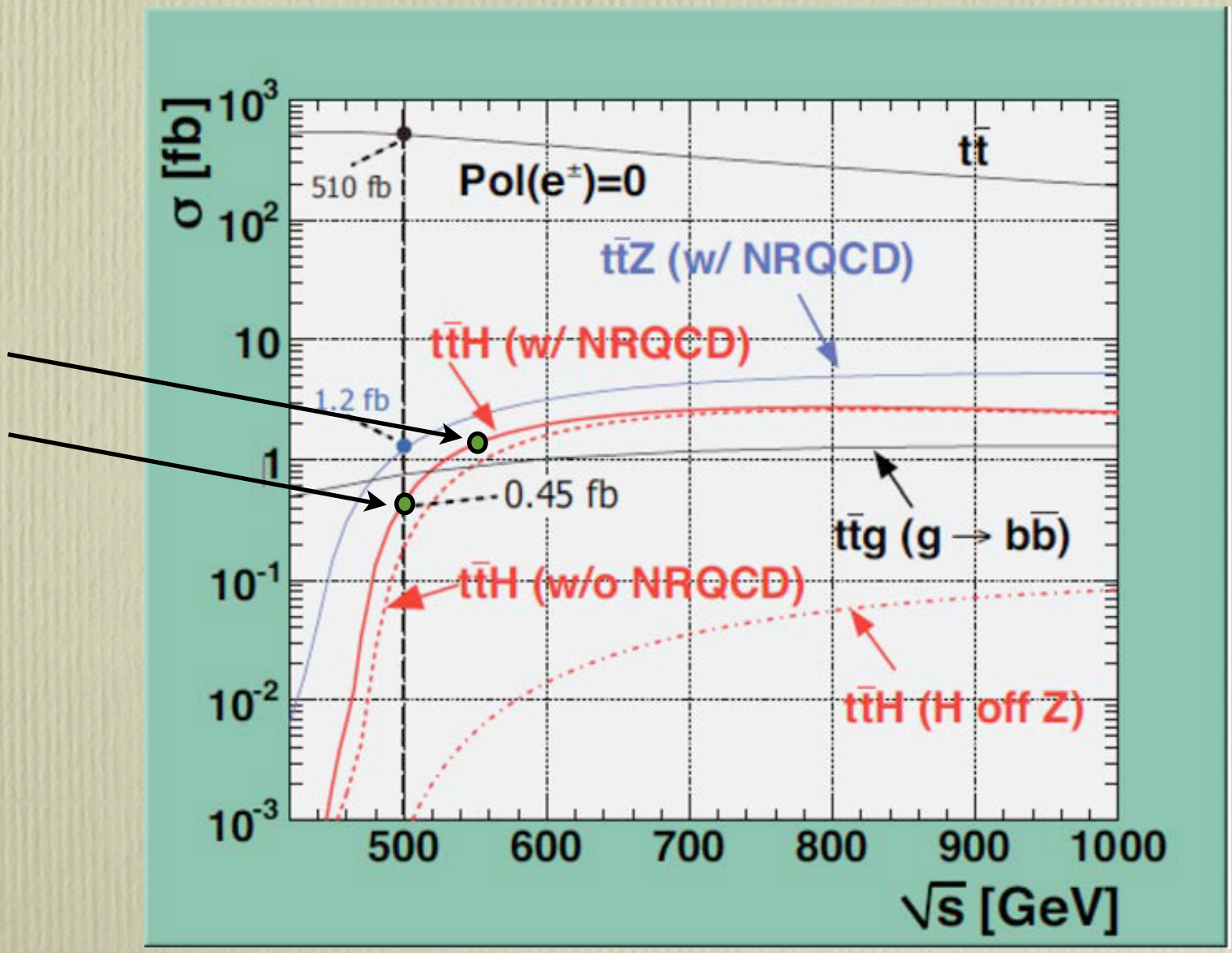
This precision is sufficient to <u>begin</u> testing BSM models, such as the EW baryogenesis model shown in Fig (arXiv:1211.5883)

1 TeV running will bring precision to ~10%

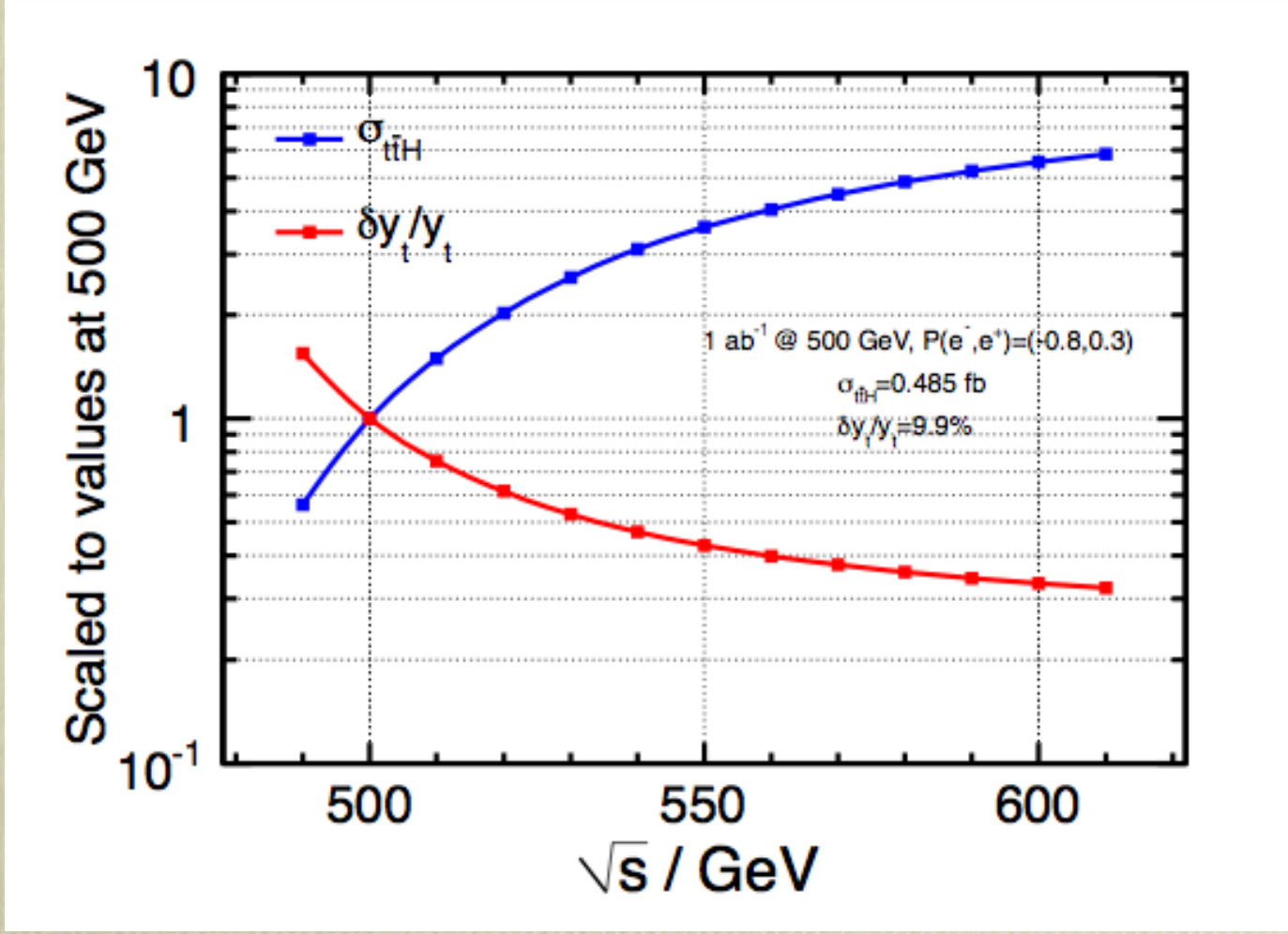




$t\bar{t}H$ & $\sqrt{s} \sim 500 - 550$ GeV



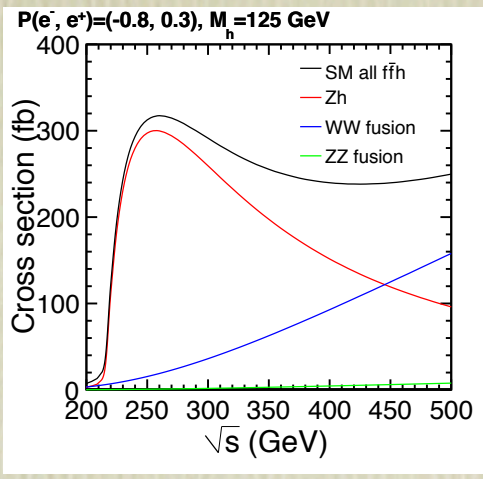
$t\bar{t}H$ & $\sqrt{s} \sim 500 - 550$ GeV



550 GeV is 2.4 improvement over 500 GeV

Start at 350 GeV?

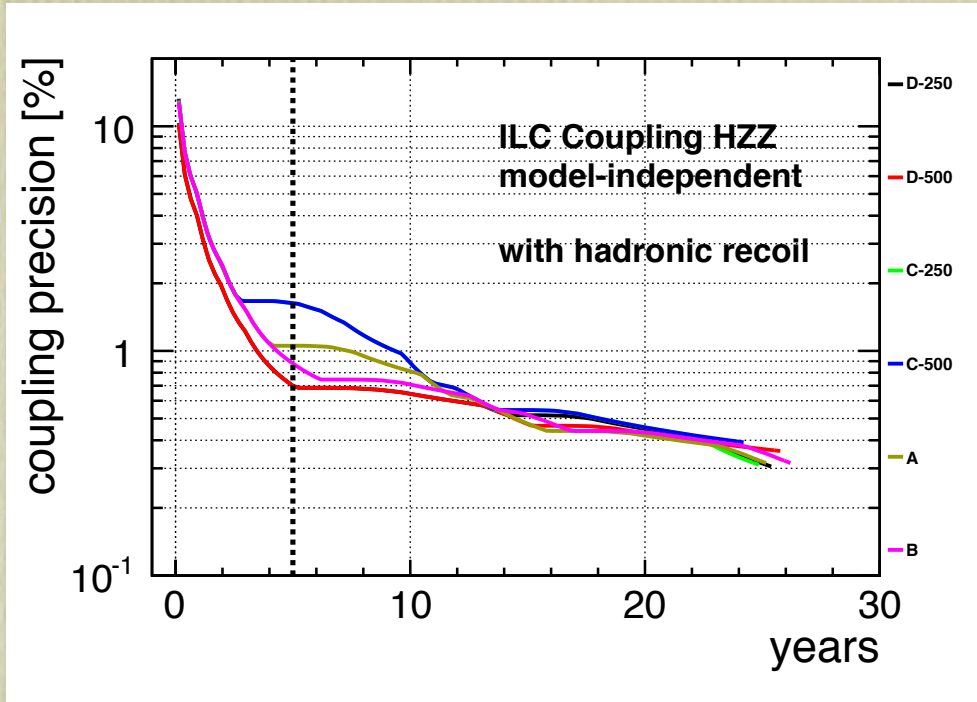
- If staging is necessary, starting at 350 GeV presents scientific advantages over 250 GeV. Therefore, we discuss this possibility.
- At 350 GeV, Higgs production comes largely from the Higgsstrahlung process, but the important WW-fusion process is rising, increasing three-fold from 250 GeV to 350 GeV.

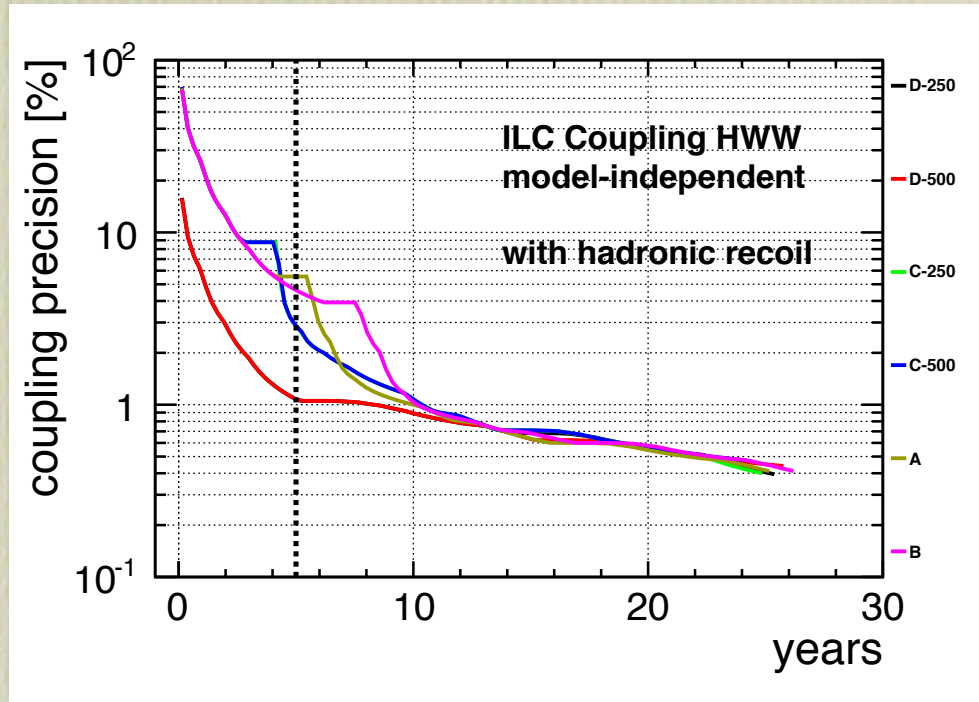


- This increase enables precise measurements of both the Z-Higgs coupling (g_{HZZ}) and the W-Higgs coupling (g_{HWW}) at 350 GeV.
- These critical measurements are important to the determination of the total Higgs width (Γ_H), and the most precise model independent determination of all the couplings, testing the standard model, and measuring invisible or exotic decays of the Higgs boson.
- Top pair production is open, enabling measurements of top mass ($\lesssim$ 100 MeV) and top Electroweak couplings.
- Furthermore, the main advantage of 250 GeV (the Higgs mass measurement) might be comparably achieved with measurements at 350 GeV using hadronic decays

- Starting run at 350 GeV (D-500) has superior early precision on both HZZ and HWW couplings
  - red - D-500

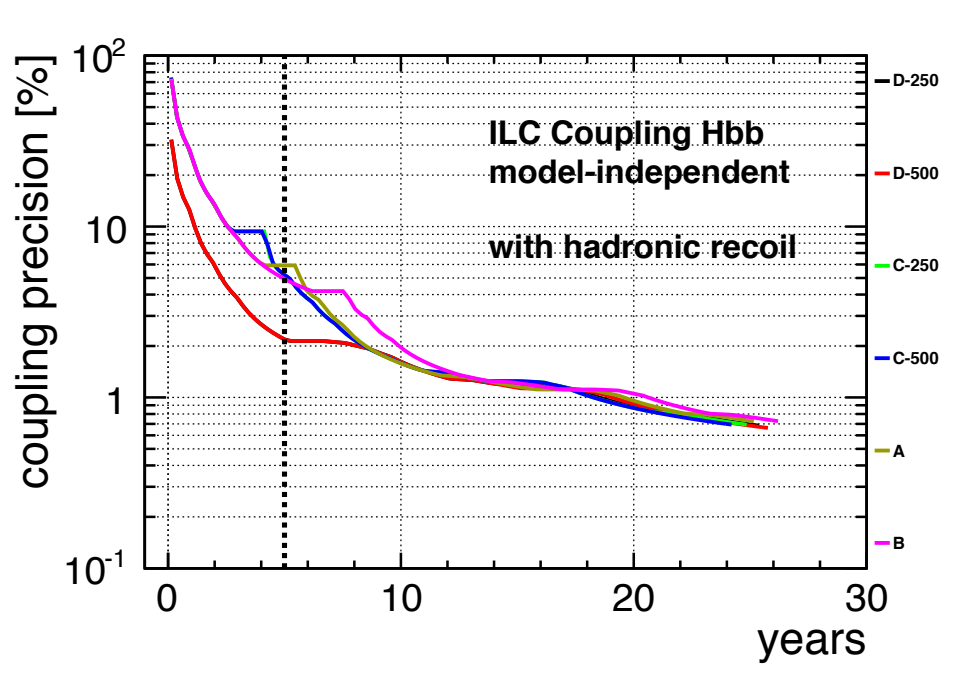
    (lower curve)

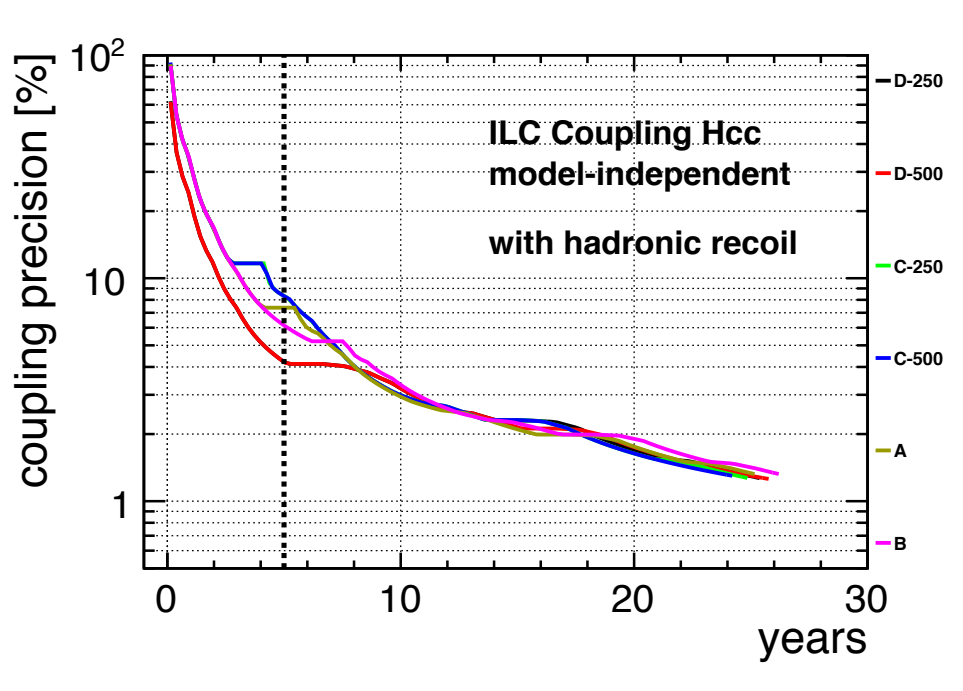




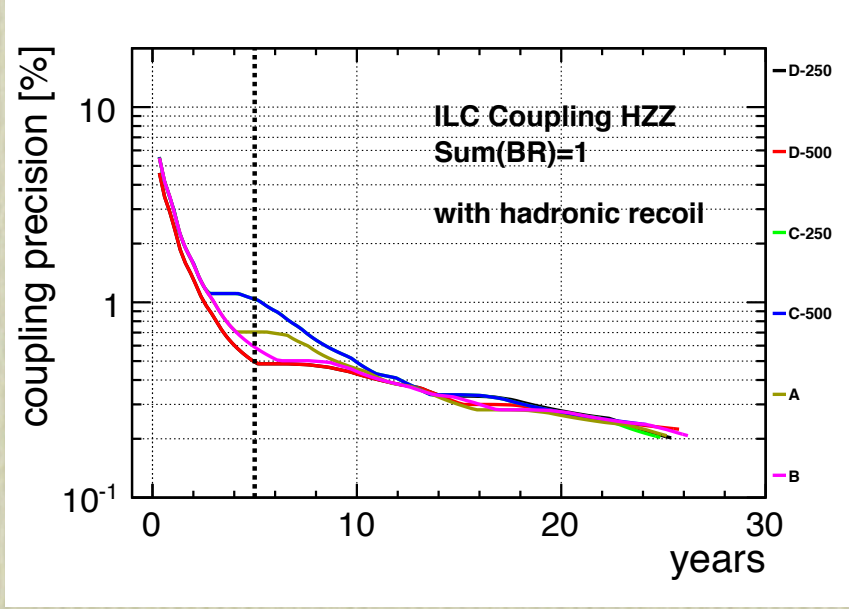
- Starting run at 350 GeV (D-500) also has superior early precision for fermion decay modes
  - red - D-500

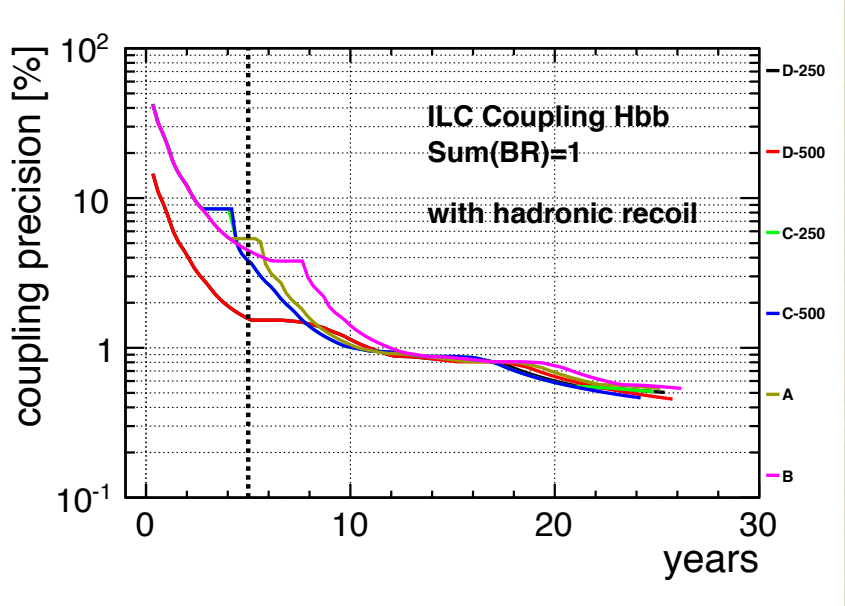
(lower curve)

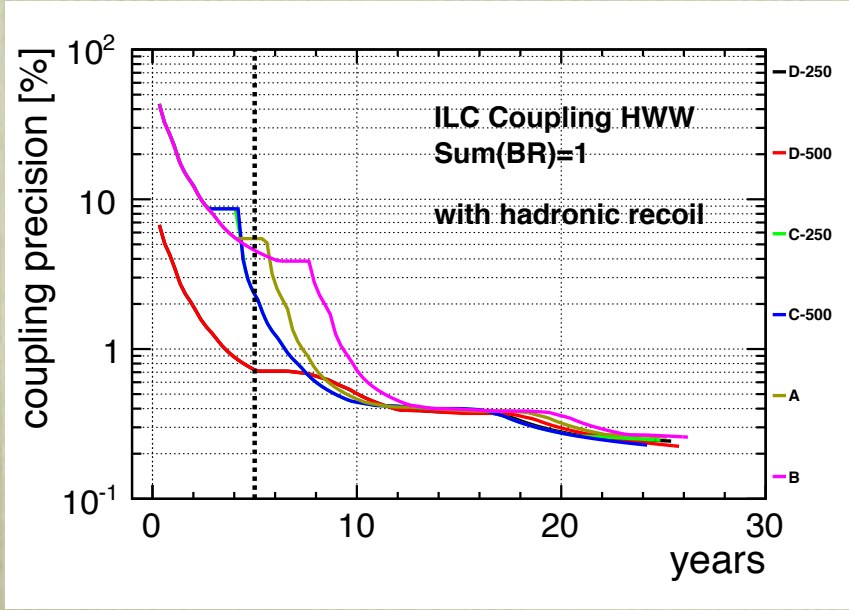


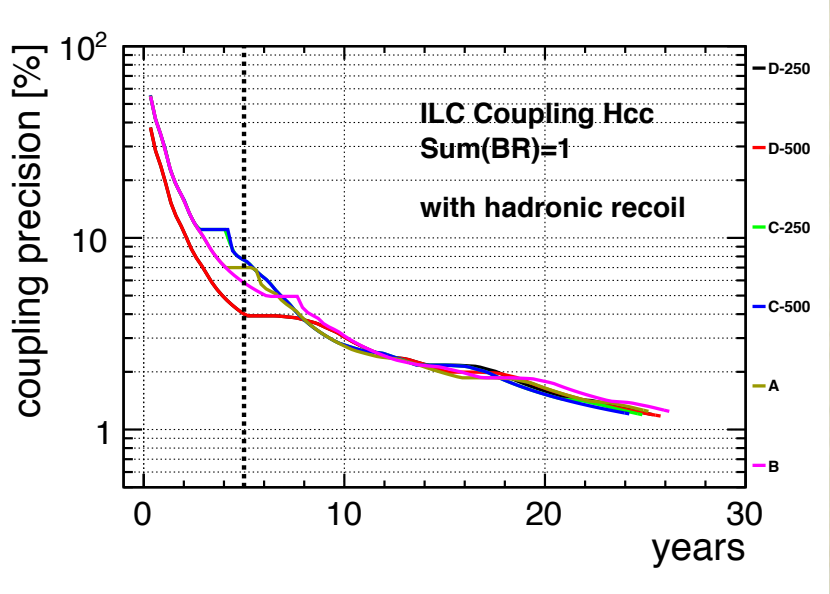


constrain Σ BR = 1









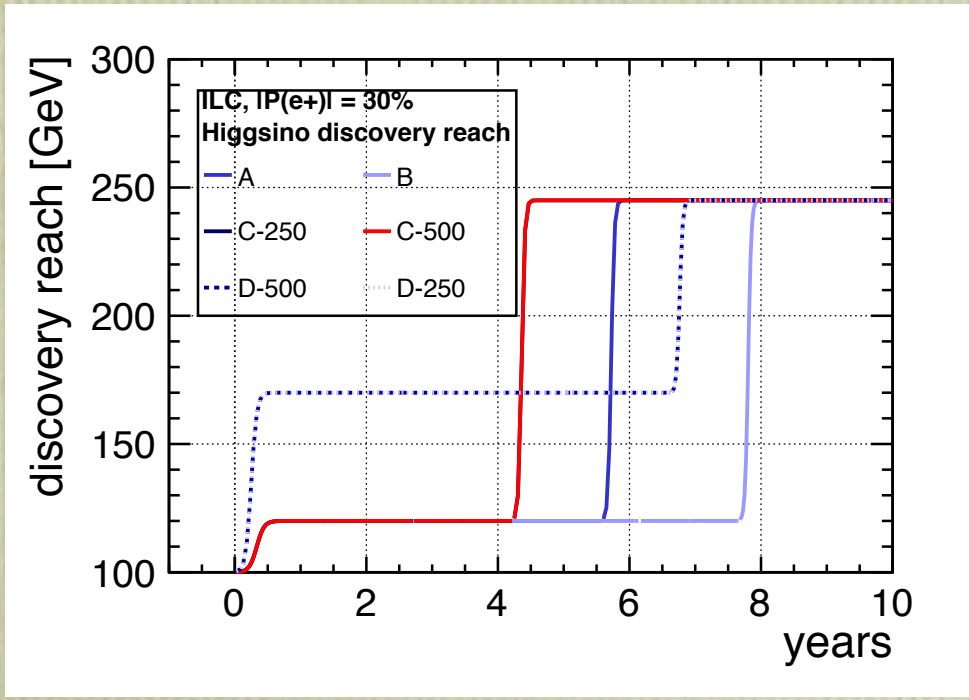
Accuracies in First 5 Years

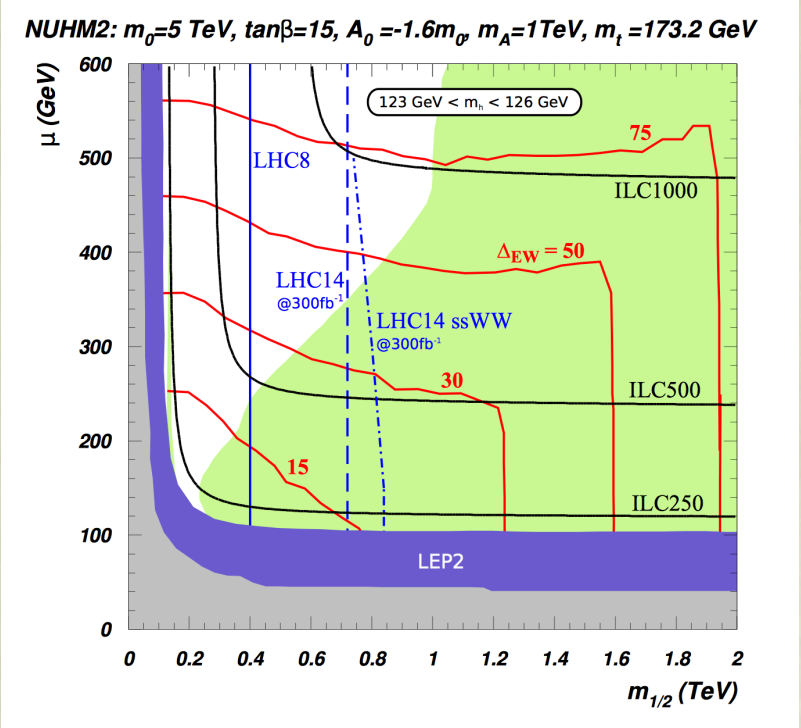
	HL-LHC	ILC Scenario B	ILC Scenario D-500
$\sqrt{s}$ (GeV)	1400	250	350
L (fb^{-1})	3000	360	470
$\gamma\gamma$	2-5 %	14.8 %	10.9 %
gg	3-5 %	4.8 %	2.9 %
WW	2-5 %	3.9 %	0.63 %
ZZ	2-4 %	0.63 %	0.49 %
$t\bar{t}$ (c$\bar{c}$)	7-10 %	5.3 %	3.7 %
$b\bar{b}$	4-7 %	3.8 %	1.3 %
$\tau^+\tau^-$	2-5 %	4.3 %	2.4 %
$\Gamma_T(h)$	5-8 %	7.3 %	2.1 %

Table 7: Expected accuracies $\Delta g_i/g_i$ of Higgs boson couplings for the end of the HL-LHC program and for the first five years of ILC running assuming either Scenario B or Scenario D-500. The couplings are derived from a seven parameter fit of $g_g, g_\gamma, g_W, g_Z, g_b, g_t, g_\tau$ using the model dependent constraints described in Section 10.3.7 of the first report of the LHC Higgs Cross Section Working Group [26]. The HL-LHC coupling errors are taken from the 2013 Snowmass Higgs Working Group Report [15].

Discoveries

- The ILC physics program could be significantly enhanced by discoveries with the LHC or the early ILC running
- Early higher energy running increases the probability for this to happen early at the ILC
- Example: Higgsino





Discoveries (cont.)

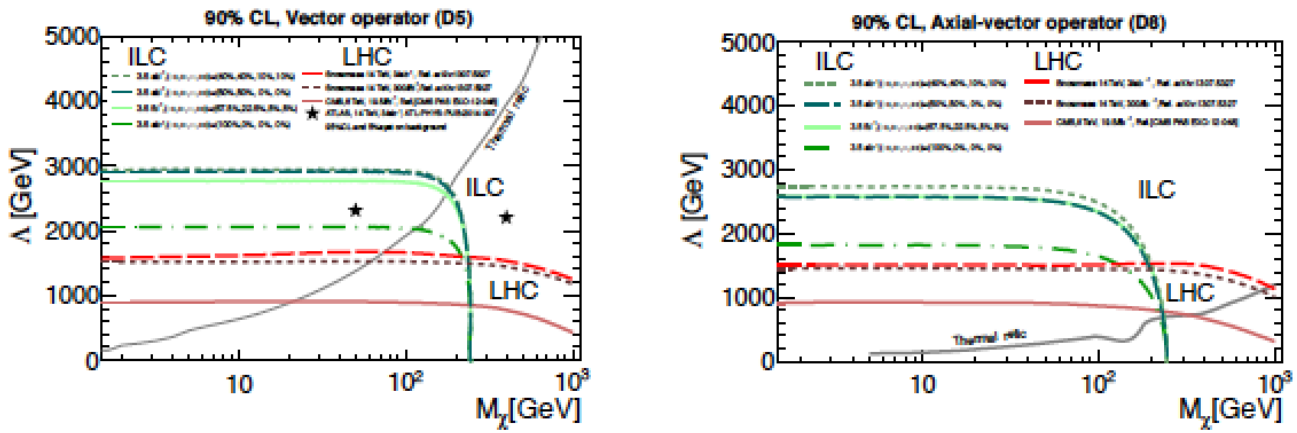


Figure 13: 90% CL reach for WIMP dark matter at LHC and ILC in the plane of effective operator scale vs WIMP mass. Left: For a vector operator mediating the WIMP interaction Right: For an axial-vector operator mediating the WIMP interaction

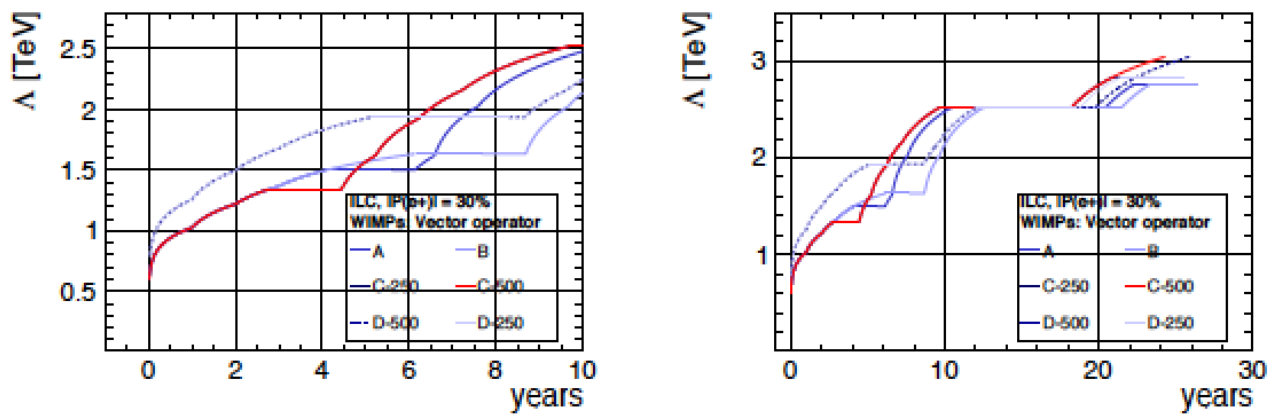


Figure 14: 90% CL reach for WIMP dark matter at ILC for a WIMP mass of 10 GeV in the vector operator case in our running scenarios. Left: zoom into the first 10 years Right: full running scenarios

Discoveries (cont.)

- The ILC is an ideal facility to follow up with energy scans at the threshold energy of production of pair-produced new particles
  - measure spin, mass, as well as mixing angles and complex phases
- This would add to the known ILC program and greatly enhance its scientific impact

Other issues

- Polarization mix
  - importance of positron polarization
- Model independency of $ZH \to q\bar{q}H$
- WW threshold
- Z-pole for physics
- Z-pole for calibration

Conclusions on Staging

- For 250 GeV start optimal physics scenario is C-500, with the largest fraction of lifetime operating at the highest possible energy, optimizing the possibility of discoveries of new physics & making the earliest measurements of important Higgs properties.

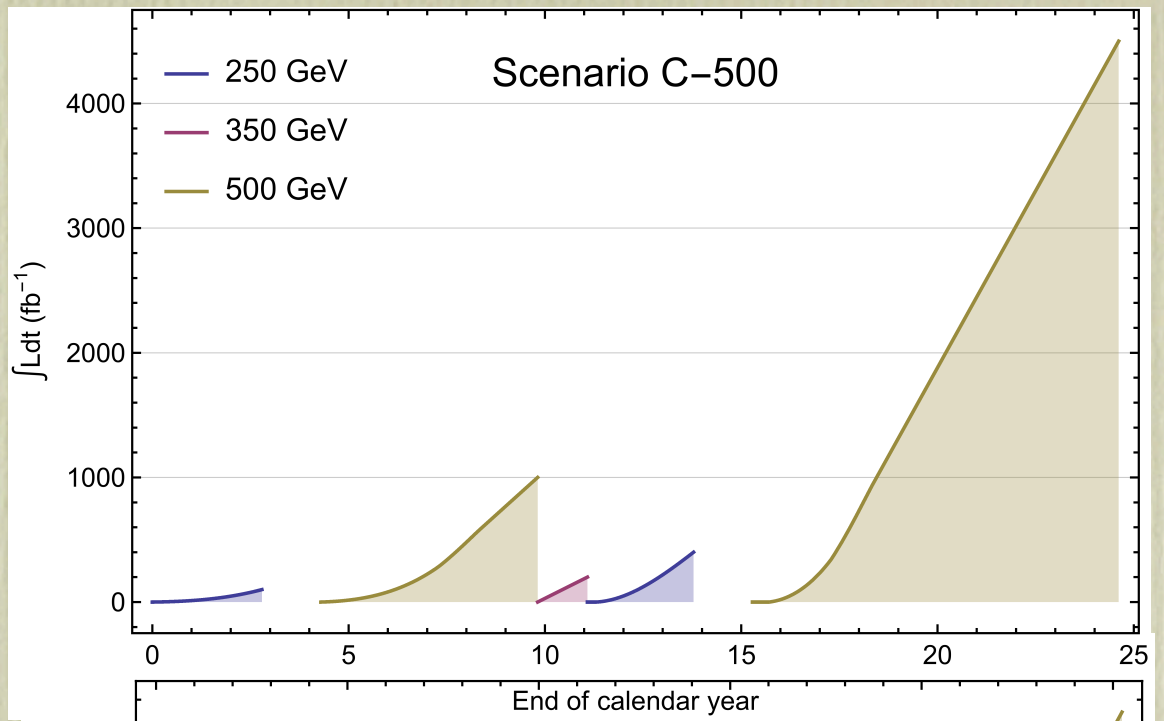
- Improved early physics reach by starting at 350 GeV, rather than 250 GeV. This would optimize the Higgs measurements, open up early measurements of the top mass and electroweak couplings, and increase discovery reach for new particles.

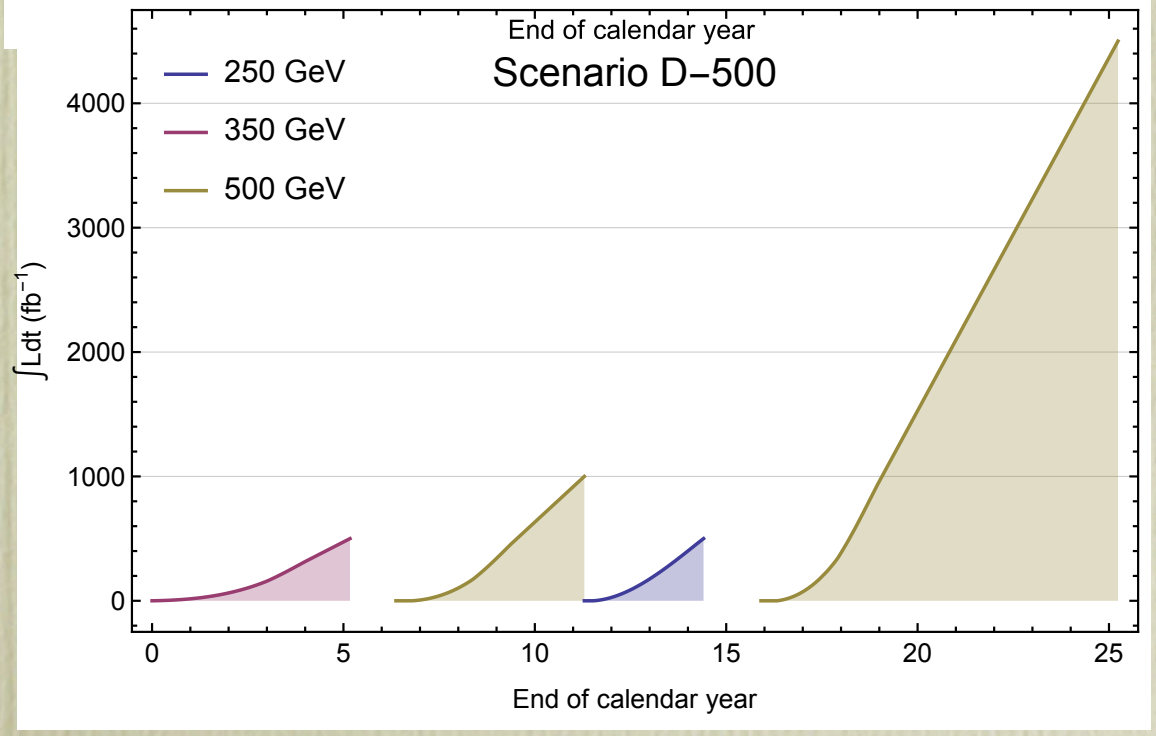
- The physics impact of the ILC is significantly improved if the maximum energy of the 500 GeV ILC is stretched to 550 GeV where the top Yukawa precision is more than a factor of two times better than at 500 GeV.

- Report emphasizes physics that we are absolutely certain will be done with the ILC and the operational accelerator plans for achieving the best outcomes for that physics.
  - precision measurements of the Higgs boson, the top quark, and possibly measurements of the W and Z gauge bosons.

- Each scenario has compelling and impactful scientific program, but discoveries by the LHC or early running of the ILC could expand ILC's scientific impact. Discoveries of pair-produced new particles would motivation operations at or near the threshold of new physics, a capability that is one of the particular operational strengths of the ILC.

Draft of report at http://pages.uoregon.edu/jimbrau/temp/main.pdf


Scenario C−500
250 GeV
350 GeV
500 GeV
∫Ldt (fb⁻¹)
0
1000
2000
3000
4000
0
5
10
15
20
25
End of calendar year


Scenario D−500
250 GeV
350 GeV
500 GeV
∫Ldt (fb⁻¹)
0
1000
2000
3000
4000
0
5
10
15
20
25
End of calendar year

Polarization

	fraction with $\mathrm{sgn}(P(e^-), P(e^+)) =$			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[%]	[%]	[%]	[%]
250 GeV	67.5	22.5	5	5
350 GeV	67.5	22.5	5	5
500 GeV	40	40	10	10

Table 2: Relative sharing between beam helicity configurations proposed for the various center-of-mass energies.