LCVision: Scenarios for Construction and Operation

LC Vision Community Event
Jan 9, 2025

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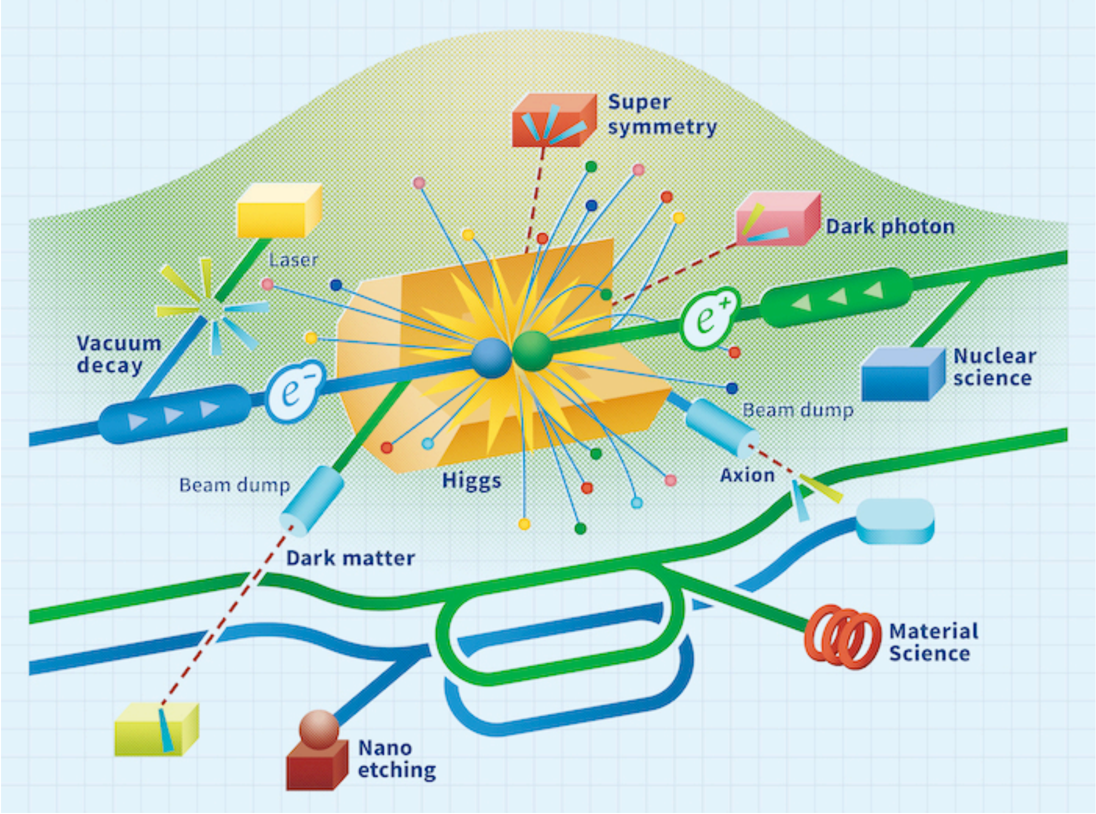


Basic Parameters

an overview from cruising altitude

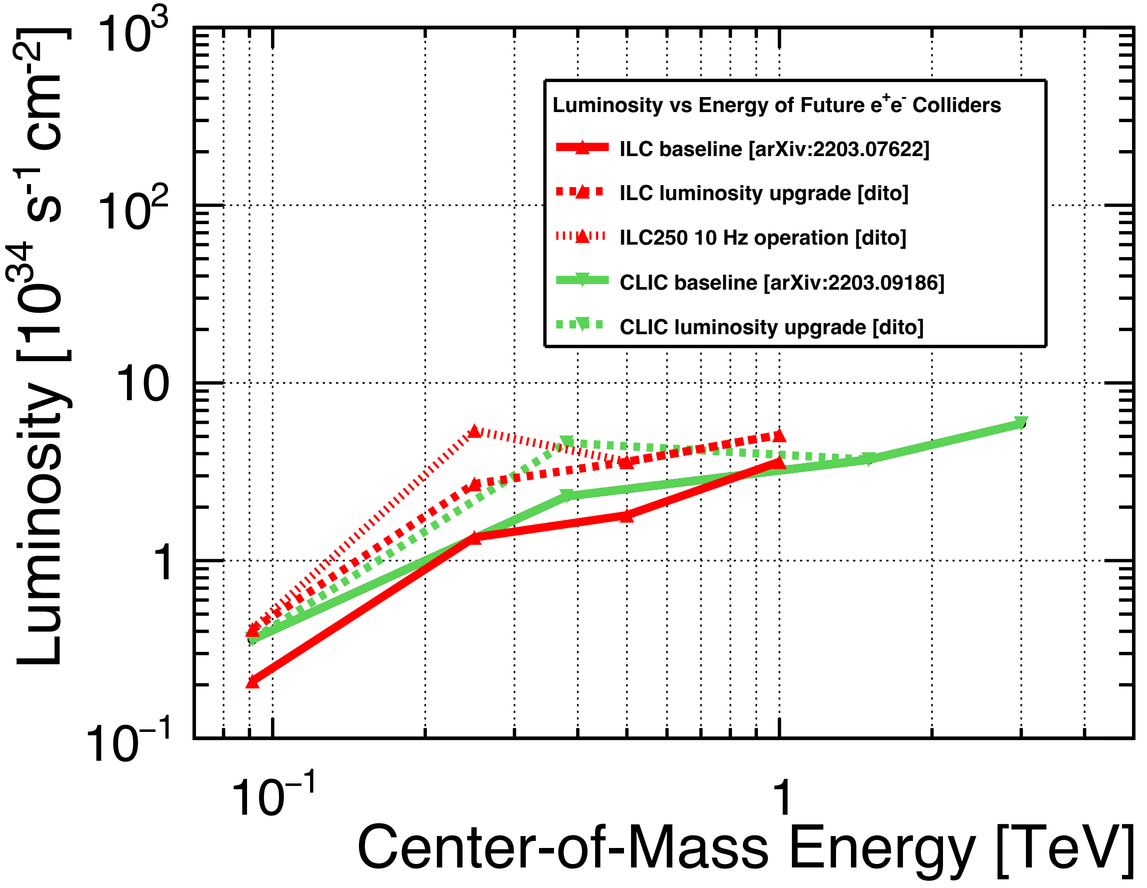
- **Linear Colliders are stageable in energy and luminosity**
  - energy scales with length for given technology => construction cost & land usage
  - luminosity scales with power consumption => construction & operation cost
- **Pure physics optimisation:**
  - build facility for highest energy & highest luminosity
  - run at lower energies for specific measurements if physics program demands (e.g. threshold scans)
- **Resources are finite:**
  - How to balance scientific ambitions vs realistic resource consumption?
  - All Linear Colliders offer the possibility of step-wise construction — aka “staging”
  - **LCVision philosophy: prioritize upgrades via advanced technologies over tunnel prolongation and “more of the same”**
- **Need to define as baseline:**
  - initial footprint & civil construction
  - candidates for initial acceleration technology

Physics vs E$_{CM}$ for a polarised e+e- Linear Collider

and minimal integrated luminosity - see yesterday's talks

- **250 GeV, ~2ab-1:**
  - precision Higgs mass and total ZH cross-section
  - Higgs -> invisible (Dark Sector portal)
  - basic ffbar and WW program
  - optional: WW threshold scan
- **Z pole, few billion Z's: EWPOs 10-100x better than today**
- **350 GeV, 200 fb-1:**
  - precision top mass from threshold scan
- **500…600 GeV, 4 ab-1:**
  - Higgs self-coupling in ZHH
  - top quark ew couplings
  - top Yukawa coupling incl CP structure
  - improved Higgs, WW and ffbar
  - probe Higgsinos up to ~300 GeV
  - probe Heavy Neutral Leptons up to ~600 GeV
- **800…1000 GeV, 8 ab-1:**
  - Higgs self-coupling in VBF
  - further improvements in tt, ff, WW, ….
  - probe Higgsinos up to ~500 GeV
  - probe Heavy Neutral Leptons up to ~1000 GeV
  - searches, searches, searches, …

Based on classic ILC/CLIC luminosity assumptions limited by self-allowed power budget



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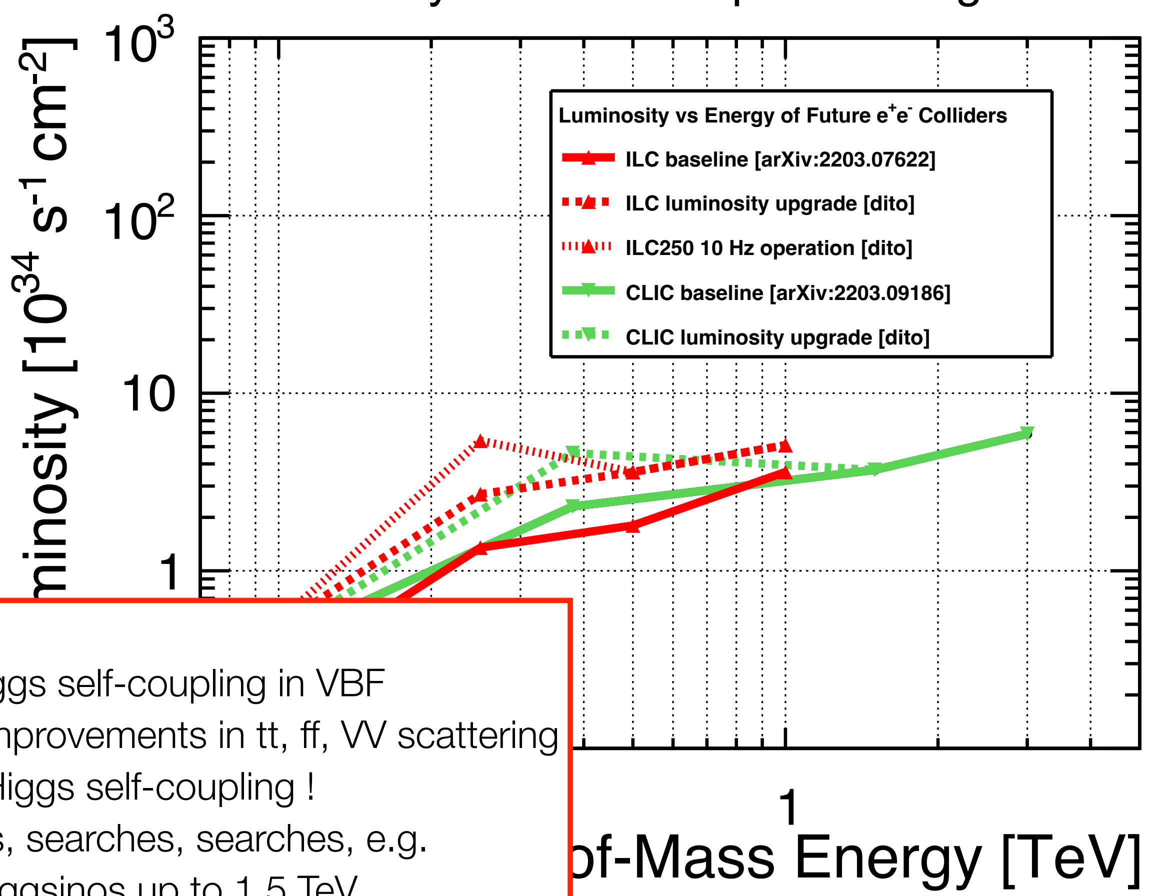

- **+ 1…3 TeV:**
  - more Higgs self-coupling in VBF
  - further improvements in tt, ff, VV scattering
  - quartic Higgs self-coupling !
  - searches, searches, searches, e.g.
  - probe Higgsinos up to 1.5 TeV
  - probe Heavy Neutral Leptons up to 3 TeV

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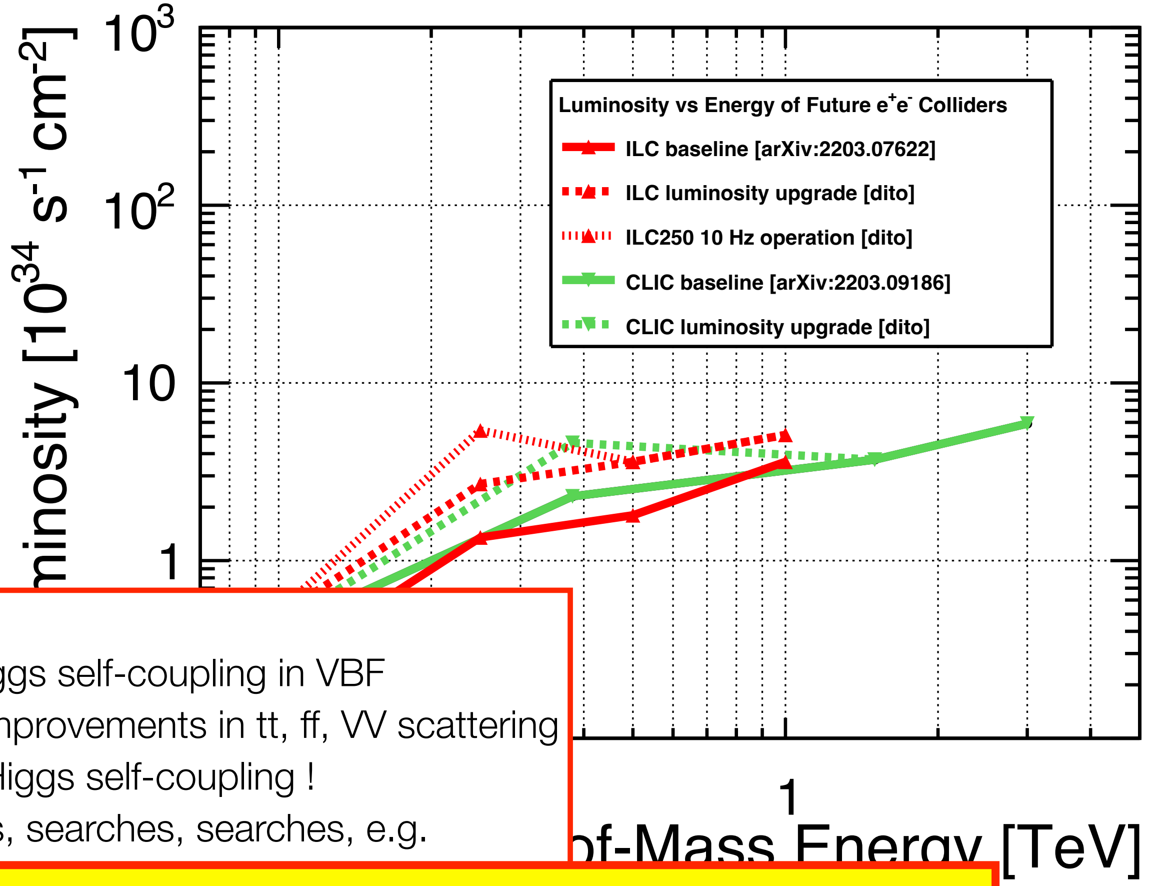

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New results from HL-LHC might change the priorities anytime => flexibility is key!

Notes from Physics Sessions

On overall presentation aspects

- present energy-ordered improvements for each measurement (rather than group all physics which can be done at one energy stage)
- indicate the potential improvements with more luminosity, higher polarisations
- type of projections: provide “prospects” (from full study / mild extrapolations) and “targets” (in reach with more work) — c.f. Marcel Vos’ talk
- include LHC results / HL-LHC projections in comparison plots wherever possible
  => can those of you who are on ATLAS/CMS help with this?
- provide up to date set of *inputs* for global fits to PPG and other interested colleagues
- don’t forget about CP properties of the various Higgs, top and gauge boson couplings

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=> important input for physics writing teams, need to see what can be done in the next few weeks…

Other Aspects

beyond L, E, P

- **Strong community wish to re-instantiate a *2nd interaction region*:**
  - will not double the luminosity
  - but add a lot of flexibility and complementarity to the facility (alternative collider modes, technology R&D for future upgrades, ….)
  - designs exist for ILC and CLIC
  - need updates and revision, but no fundamental show stopper (was simply eliminated to reduce cost…)
- **Plan extra facilities from beginning:**
  - Beam-dump experiments
  - Extracted beam experiments (e.g. LUXE/ ELBEX @ Eu.XFEL)
  - R&D facilities for detector and accelerator technology — also for later upgrades of the collider itself!
- **Foresee upgrades from beginning:**
  - Today we do not know yet which long-term R&D approach will turn out to be most suitable
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Will hear more details about all these ideas during today's program!

Initial Scenarios given to Expert Teams

as a basis for discussion

- **let's assume we start with a Linear Facility, with 2 Beam Delivery Systems (2 IRs), length**

  a) **~20 km** (e.g. 250 GeV SCRF or ~800 GeV copper)

  b) **~30 km** (e.g. 550 GeV SCRF or ~1.5 TeV copper)

- **what could "your" technology offer as**

  i. **decision-ready in < 5 years (e.g. 2-3 year targeted engineering effort after EPPSU adoption in early 2026)?**
  - ILC-like SCRF, CLIC-like drive-beam
  - alternative collider modes, beyond-collider facilities?
  - anything else?

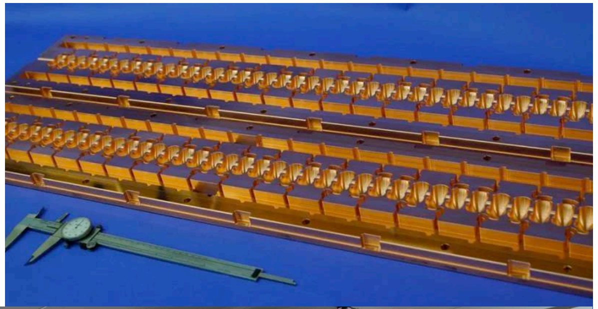
  ii. **as upgrade, decision-ready after the first years of data-taking of initial facility (e.g. 2045-2050)?**
  - requirements on initial facility to make upgrade viable?
  - required R&D and ressources until decision-readiness?

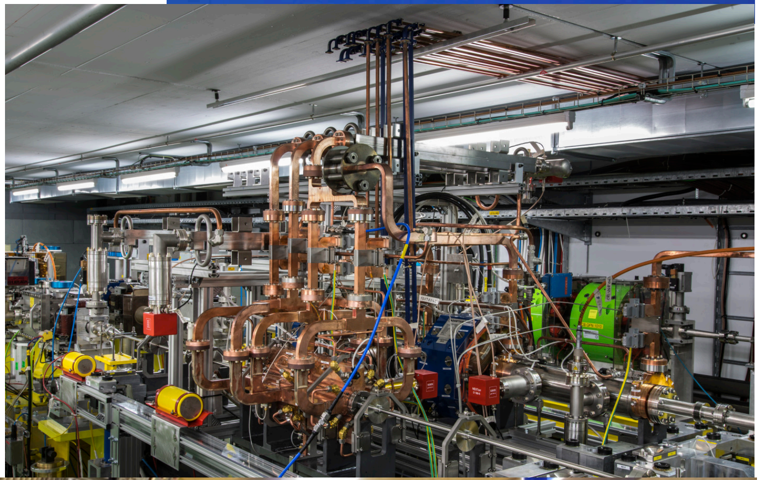
The Linear Collider Facility — Generically

What could be the initial technology?

- **For now, the LCF footprint is designed to be compatible with both SCRF and warm (or cool) copper cavities**
- **The key aspect of LCVision is the need for a Linear Collider at all, able to probe e+e- collisions with polarised beams and beyond the ttbar threshold**
- Technology should be chosen — at the point in time when the decision is required — according to
  - physics priorities
  - industrial readiness
  - industrial / societal interest in contributing regions
  - cost, risk, sustainability, …
- Due to
  - the industrialisation advantage and the many running XFELs
  - the strong expertise in many regions of the world
  - and the number of well-defined physics targets up to 1 TeV

LCVision for now assumes SCRF as baseline for fastest readiness





Now take a look at the range of energy, power and luminosity options — and the resulting running scenarios — taking ILC as example

A bit of History

ILC Parameters Joint Working Group

- group of accelerator and particle physics experts
- charged to develop running scenarios for the ILC
- integrated luminosities kept fixed ever since!

	integrated luminosity with $\mathrm{sgn}(P(e^-),P(e^+)) =$			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[fb^{-1}]	[fb^{-1}]	[fb^{-1}]	[fb^{-1}]
250 GeV	1350	450	100	100
350 GeV	135	45	10	10
500 GeV	1600	1600	400	400

	integrated luminosity with $\mathrm{sgn}(P(e^-),P(e^+)) =$			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	[fb^{-1}]	[fb^{-1}]	[fb^{-1}]	[fb^{-1}]
1 TeV	3200	3200	800	800
90 GeV	40	40	10	10
160 GeV	340	110	25	25

ILC-NOTE-2015-068
DESY 15-102
IHEP-AC-2015-002
KEK Preprint 2015-17
SLAC-PUB-16309
June 25, 2015

ILC Operating Scenarios

ILC Parameters Joint Working Group

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

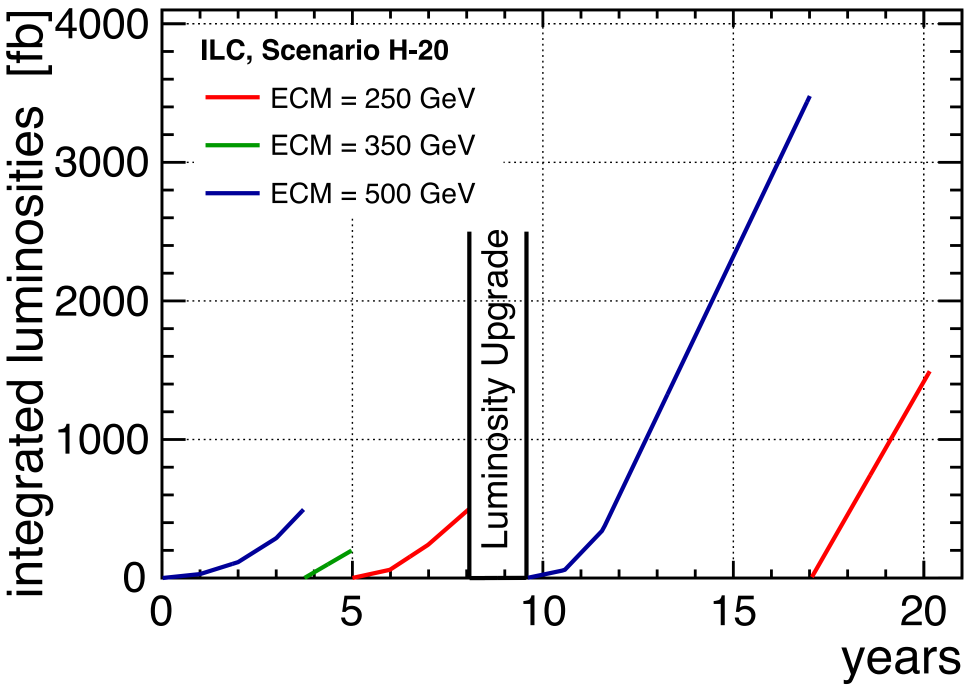
Abstract

The ILC Technical Design Report documents the design for the construction of a linear collider which can be operated at energies up to 500 GeV. This report summarizes the outcome of a study of possible running scenarios, including a realistic estimate of the real time accumulation of integrated luminosity based on ramp-up and upgrade processes. The evolution of the physics outcomes is emphasized, including running initially at 500 GeV, then at 350 GeV and 250 GeV. The running scenarios have been chosen to optimize the Higgs precision measurements and top physics while searching for evidence for signals beyond the standard model, including dark matter. In addition to the certain precision physics on the Higgs and top that is the main focus of this study, there are scientific motivations that indicate the possibility for discoveries of new particles in the upcoming operations of the LHC or the early operation of the ILC. Follow-up studies of such discoveries could alter the plan for the centre-of-mass collision energy of the ILC and expand the scientific impact of the ILC physics program. It is envisioned that a decision on a possible energy upgrade would be taken near the end of the twenty year period considered in this report.

Running Scenario in 2015

ILC started still at 500 GeV, but initial luminosity had already been halved ("low power" option)

Integrated Luminosities [fb]



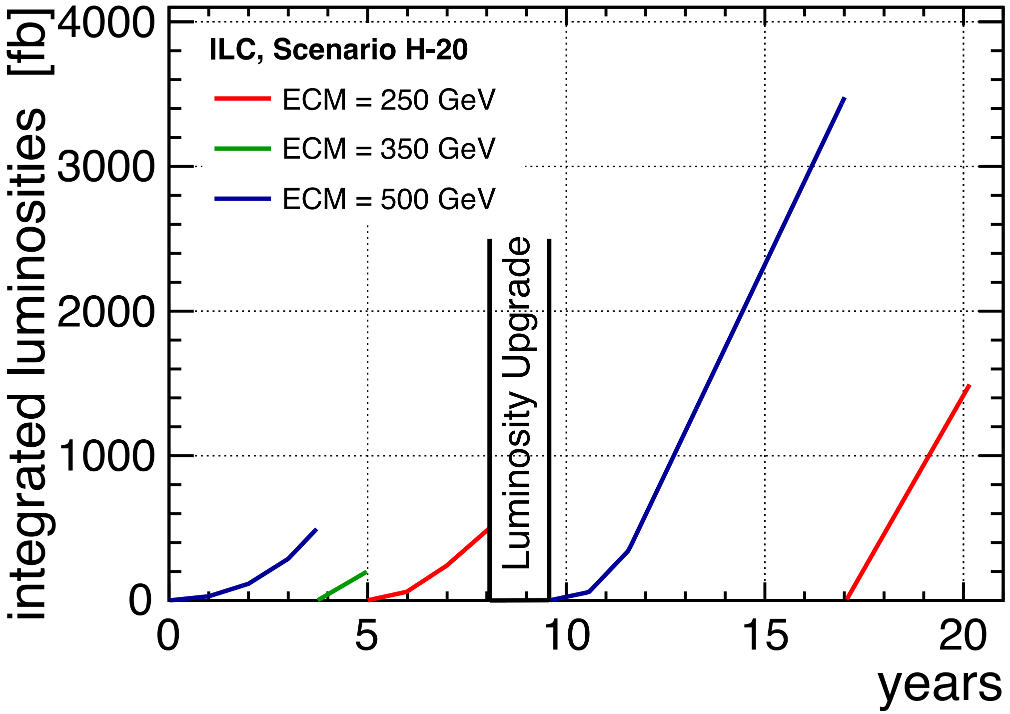
- **operation 1.6E7 s / year** (more than std CERN assumption)
- **start at 500 GeV**
  - initial peak lumi = 1.8E34 / s / cm2 (= 1315 bunches / train)
  - luminosity upgrade 3.6E34 / s / cm2 (= 2625 bunches / train)
- at lower energies
  - linac is operated at lower gradient
  - **use spare RF & cryogenic power to increase train repetition rate to 10 (7) Hz at 250 (350) GeV**
- **assume slow ramp-up to peak luminosity**
  - 0.1, 0.3, 0.6, 1.0 in years 1-4
  - 0.25, 0.75, 1.0 after first change to 10 Hz
  - 0.1, 0.5, 1.0 after lumi upgrade

Staged machine 2017

Start at 250 GeV: half the linac length, and also reduced RF & Cryo power

- **no 10 Hz operation possible in initial configuration**
- initial peak lumi 1.35E34 /s /cm2

Integrated Luminosities [fb]



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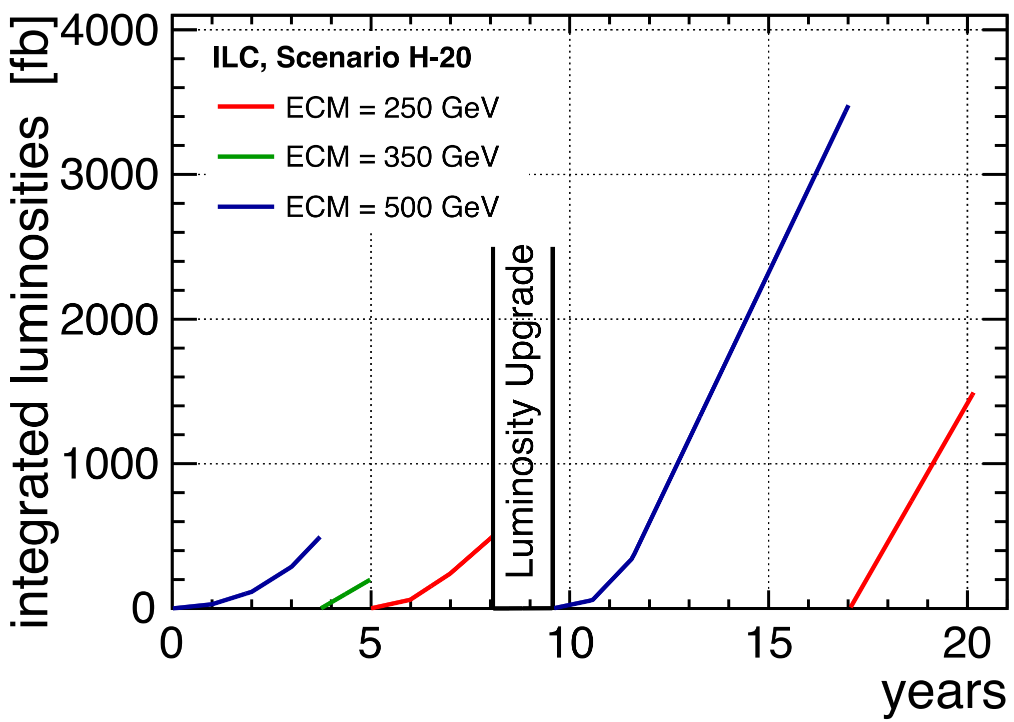
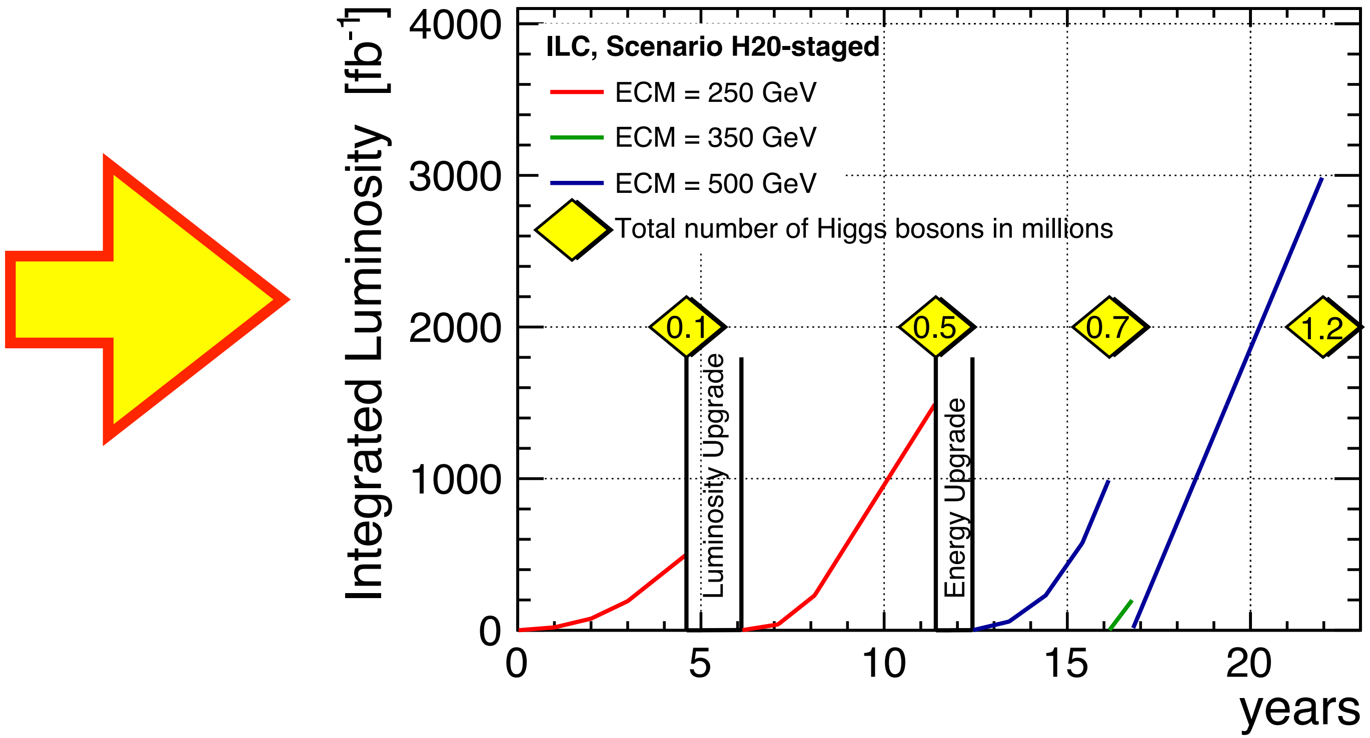
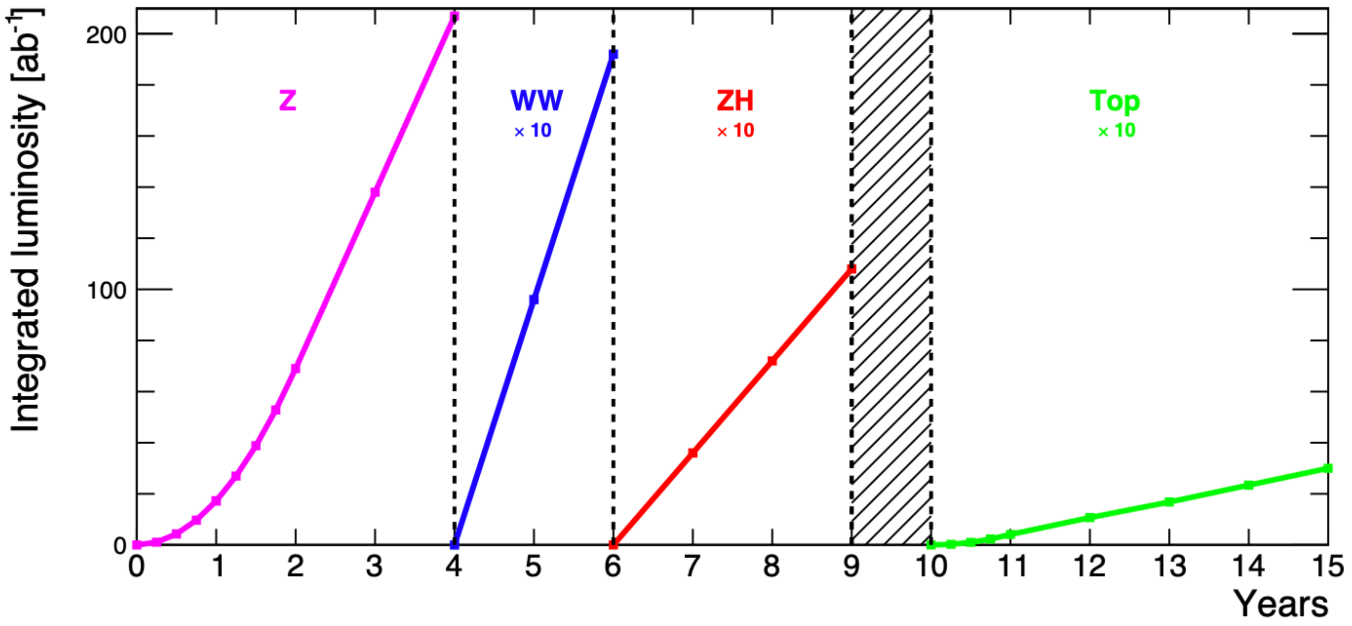


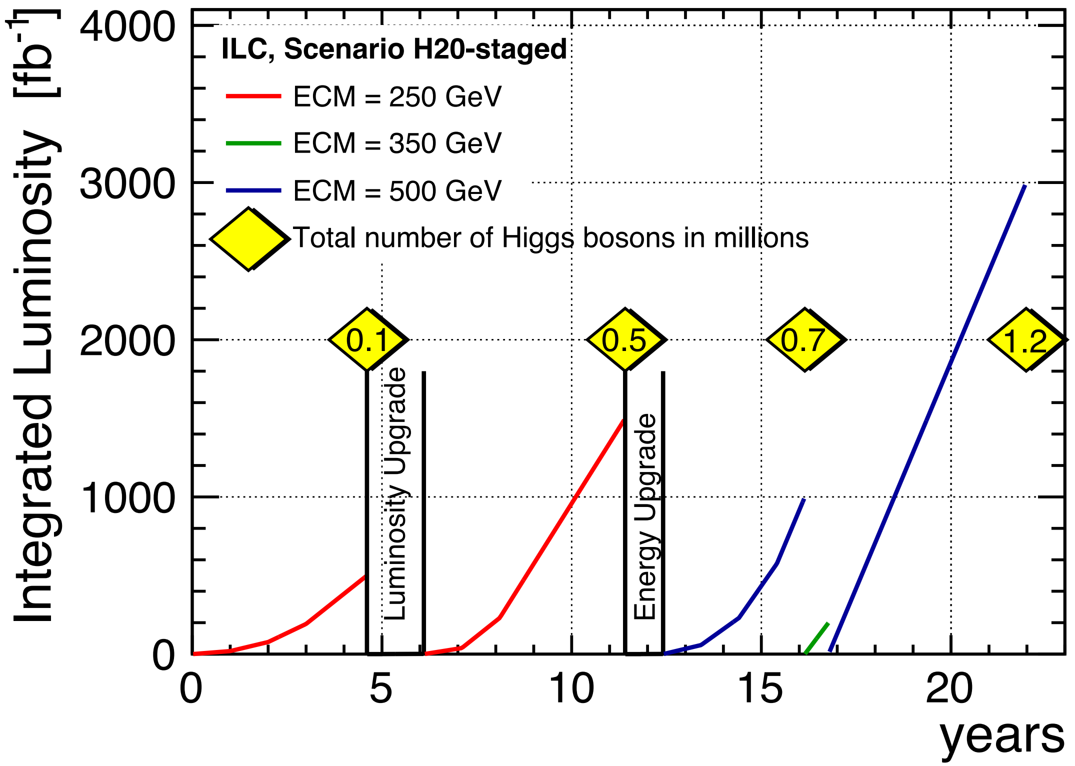


Running Scenarios

Luminosity, Power Consumption and all that

- typical criticism: "low luminosity of LCs requires much more time to do the Higgs program"
  - indeed, in std ILC250 run plan, **ZH run takes ~11 years, vs 3 years** in FCCee plan
  - **however: ILC250 starts with minimal power => let's take a look!**

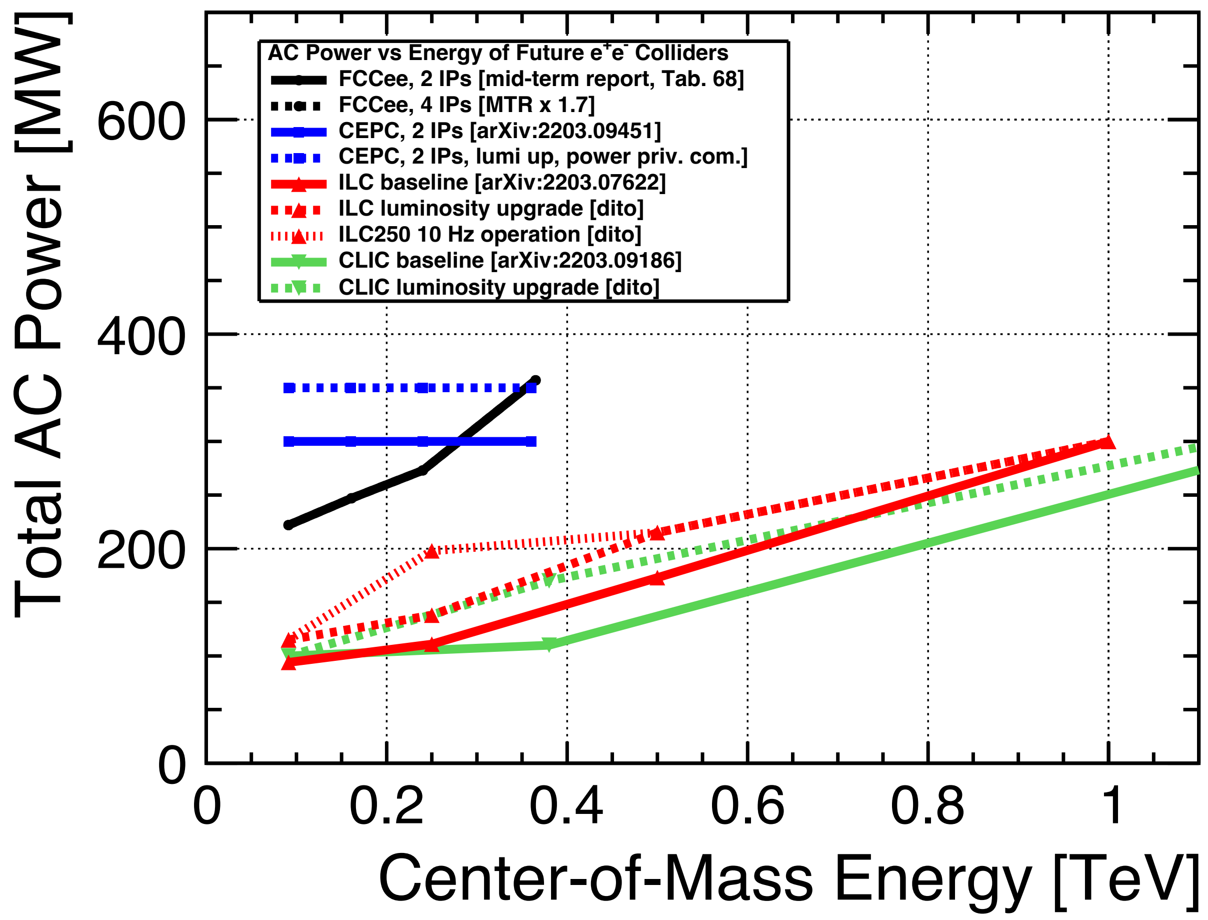


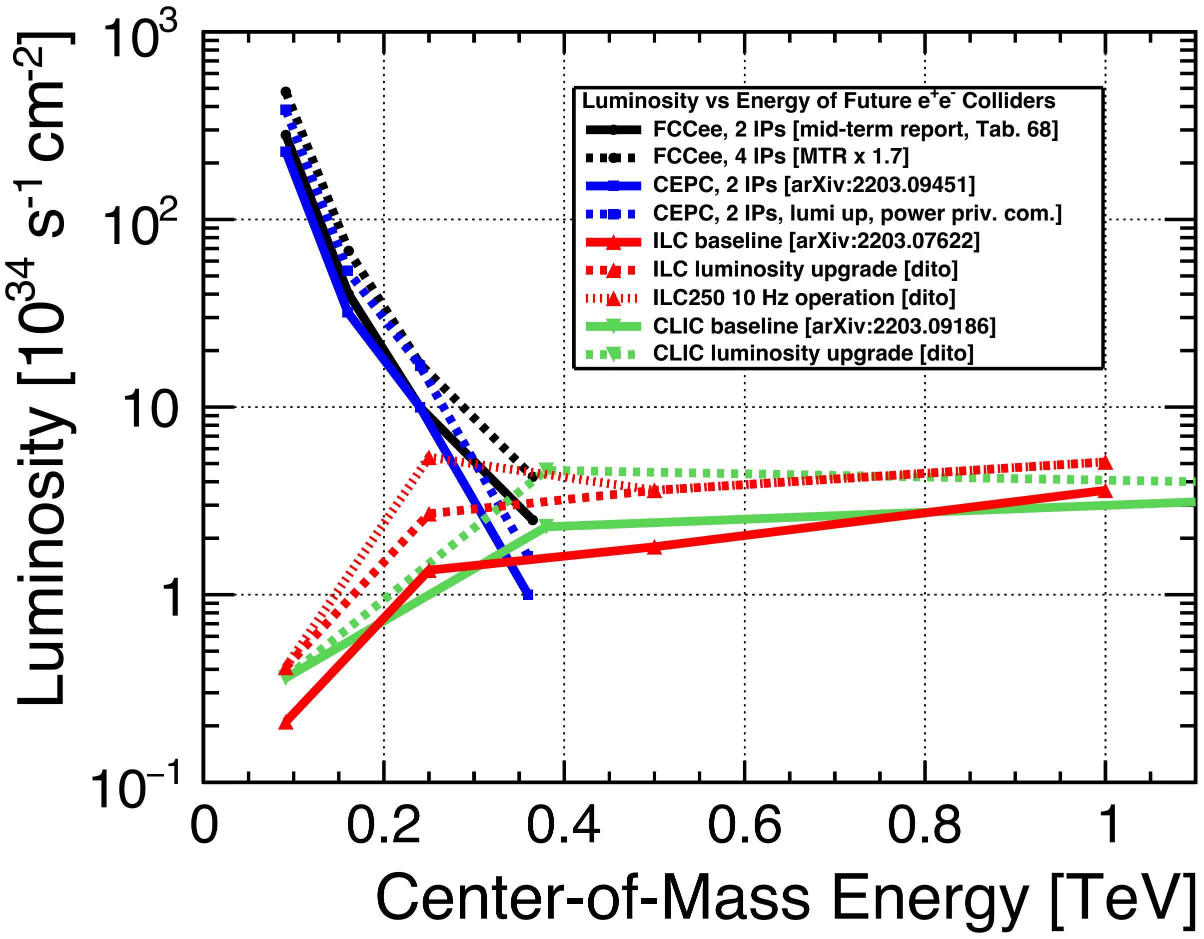


note: no lumi ramp-up assumed apart from Z pole

Power and Luminosity

as function of center-of-mass energy

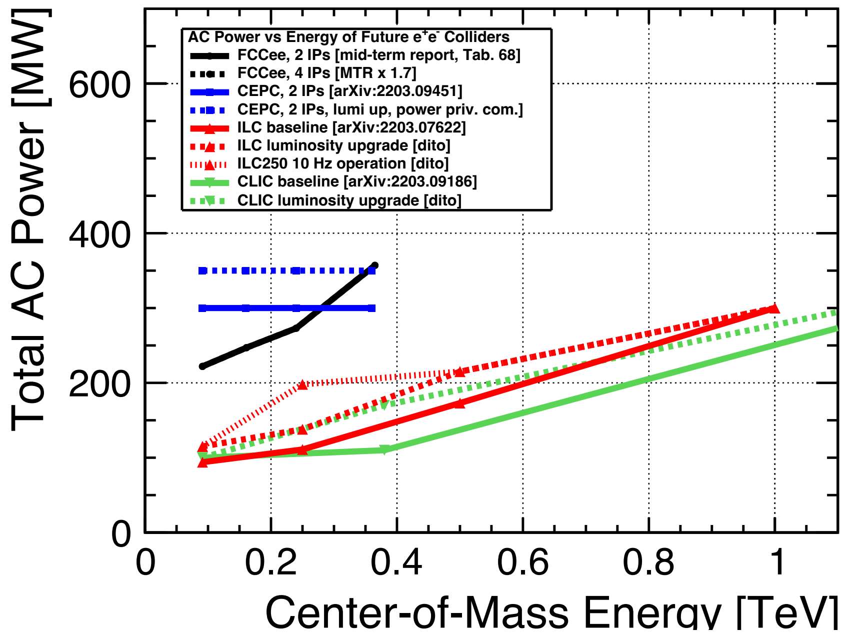


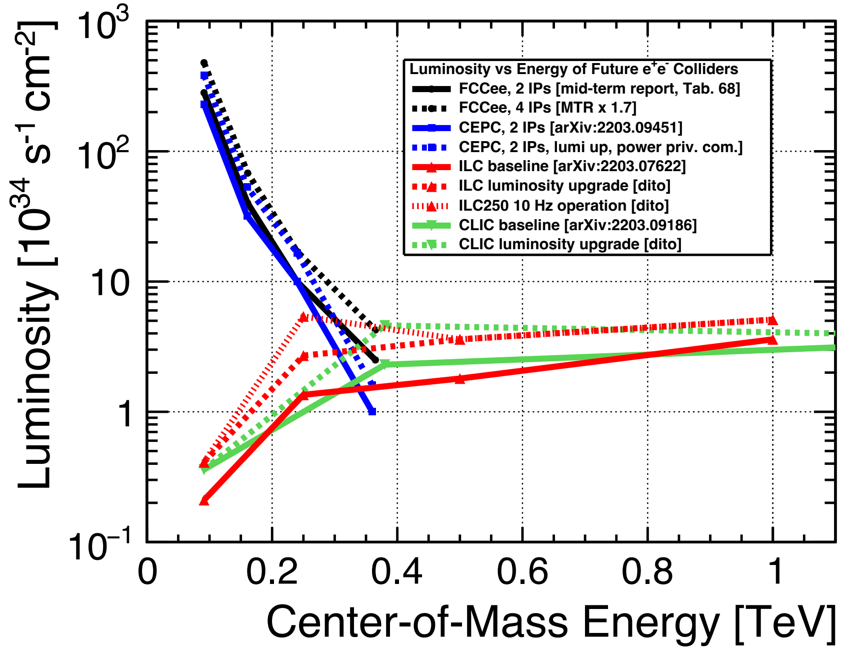


Some comparisons

based on the lumi-power relations

- **Single-Higgs program at 240/250 GeV:**
  - Linear Collider luminosity restricted by *self-assigned* power limit (all lumis in s^-1 cm^-2)
    - 250 GeV ILC lumi, polarised:
      baseline 1.35E34, 100 MW => 2.7E34 => 5.4E34, 200MW
  - FCCee (mid-term report): 5E34 / IP => 10 with 2IPs, 17E34 with 4 IPs with 273 MW
  - Very naively: for 270 MW, could run ILC at 13 Hz => 7E34 with 270 MV, polarised
    => at comparable power consumption, instantaneous lumi at ILC would be ~2.5x less than at FCC with 4 IPs
- **Top threshold:**
  - ILC lumi-upgrade 1 (2625 bunches / train): lumi larger than FCCee with 2IPs
  - 7Hz running ~= FCC 4IPs - but 200 MW vs 350 MW!





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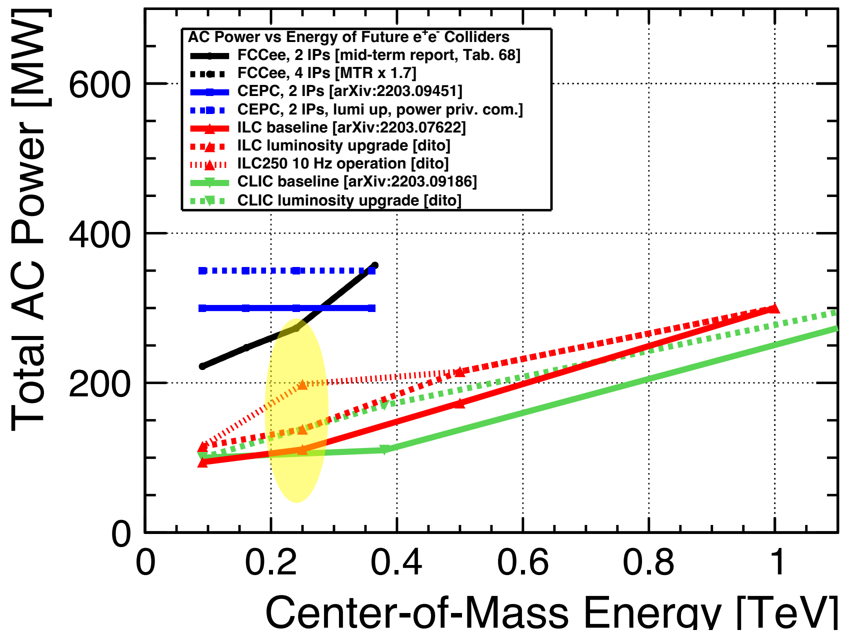

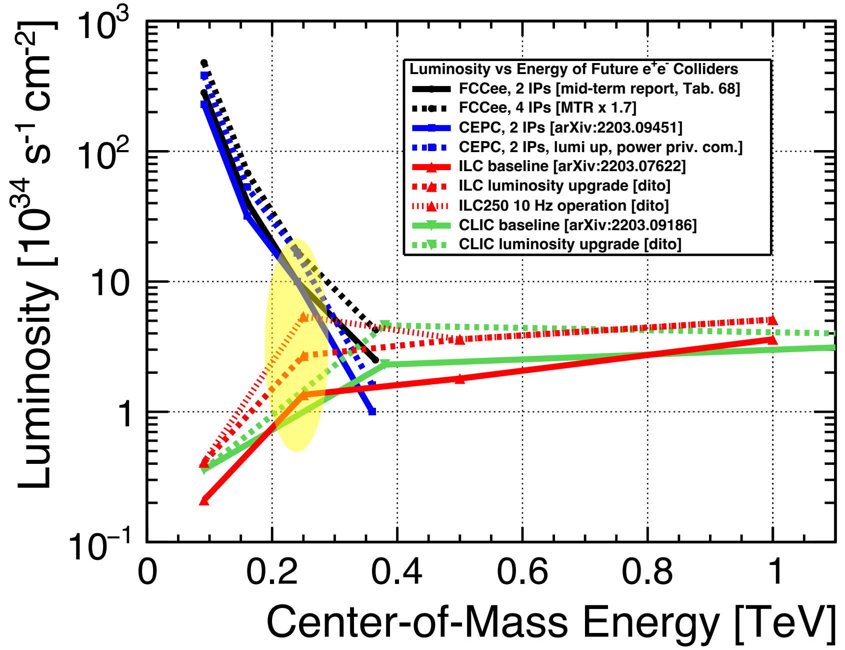

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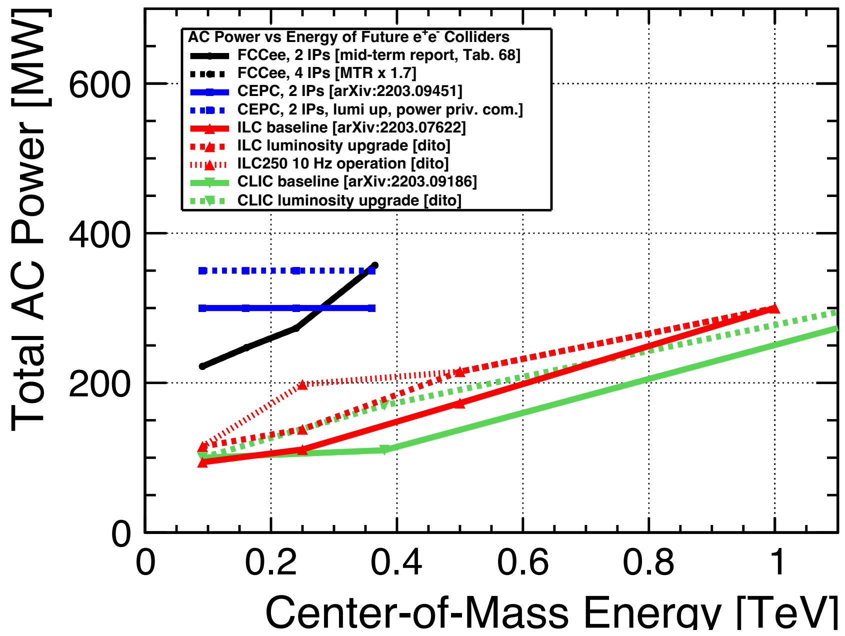

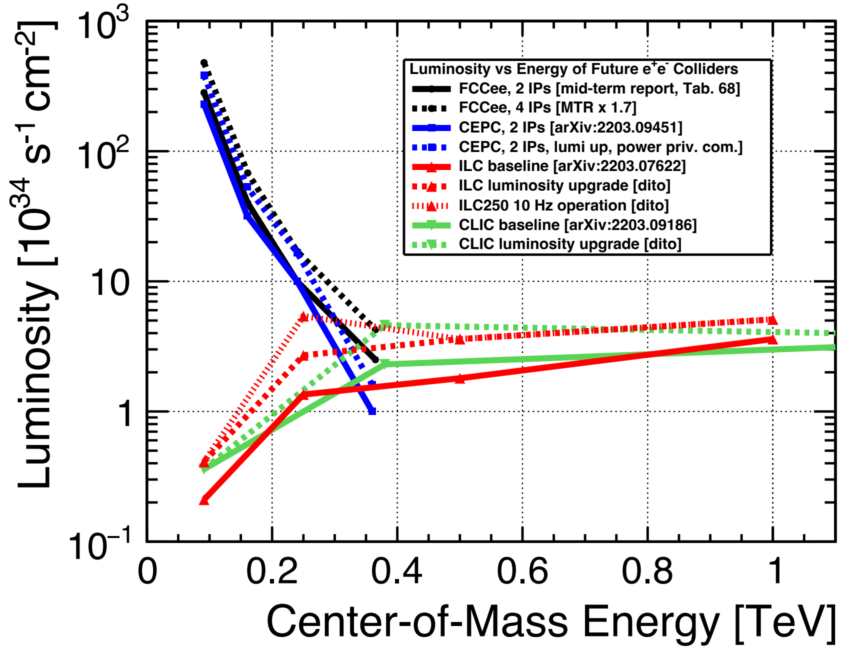

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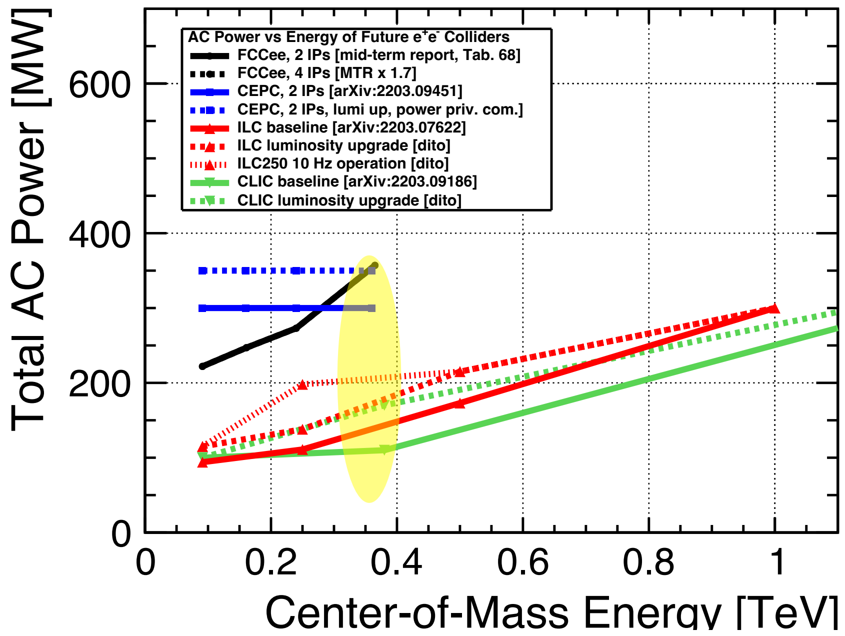
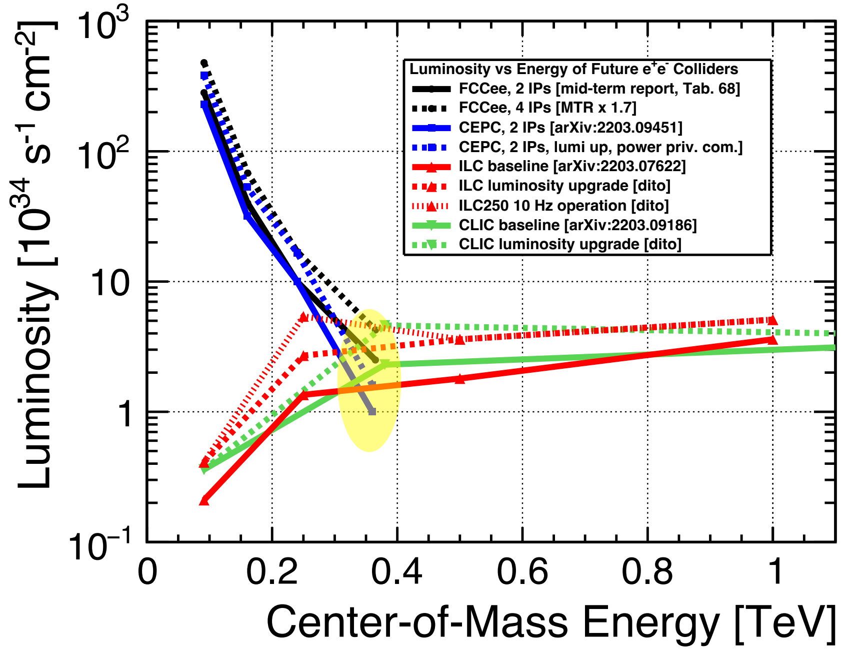
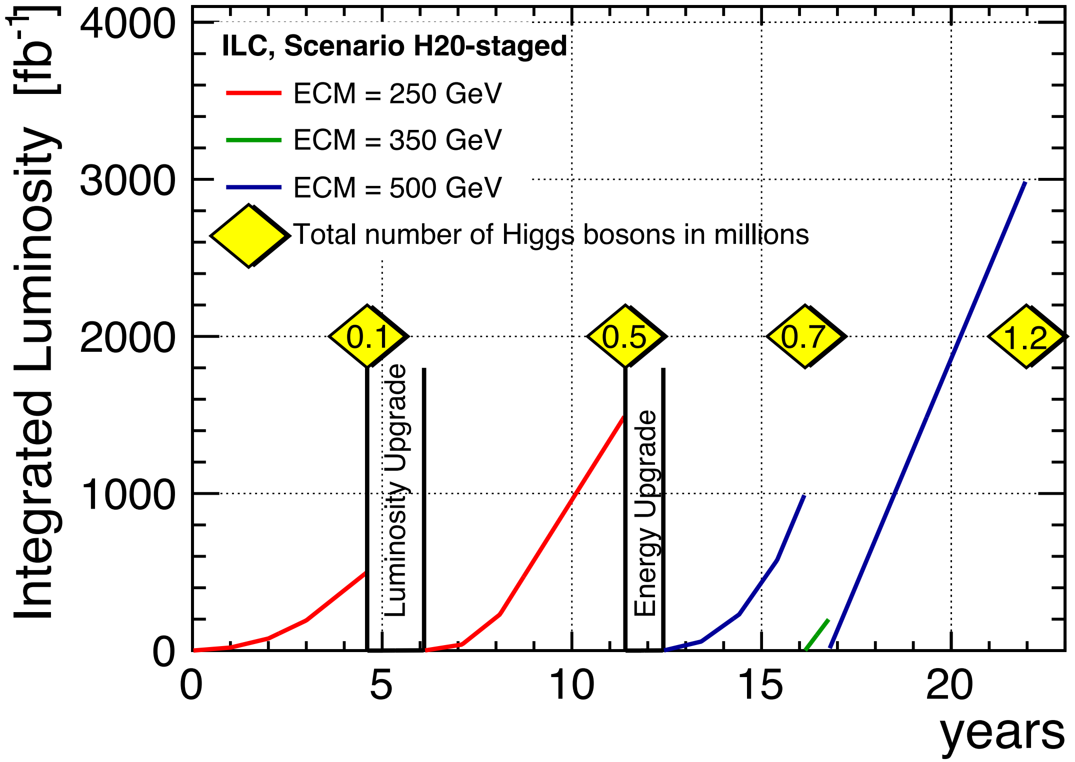




Cranking up ILC power

Full number of bunches per train from day-one "lumi upgrade" on previous page



Higgs run down to 6-7 years

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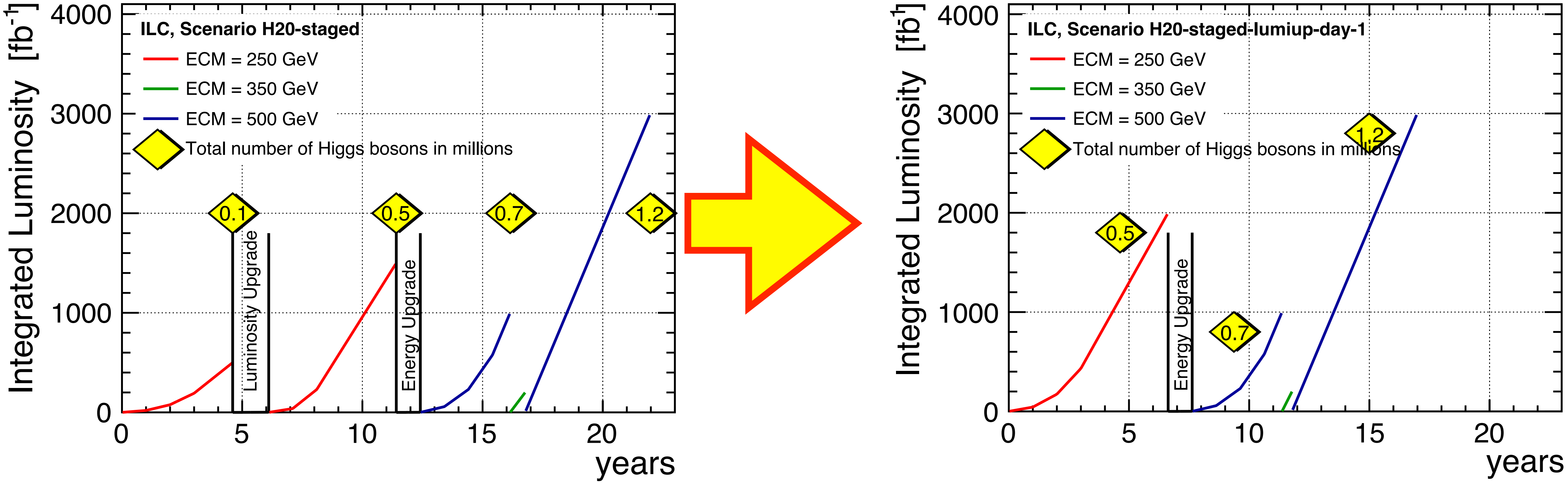
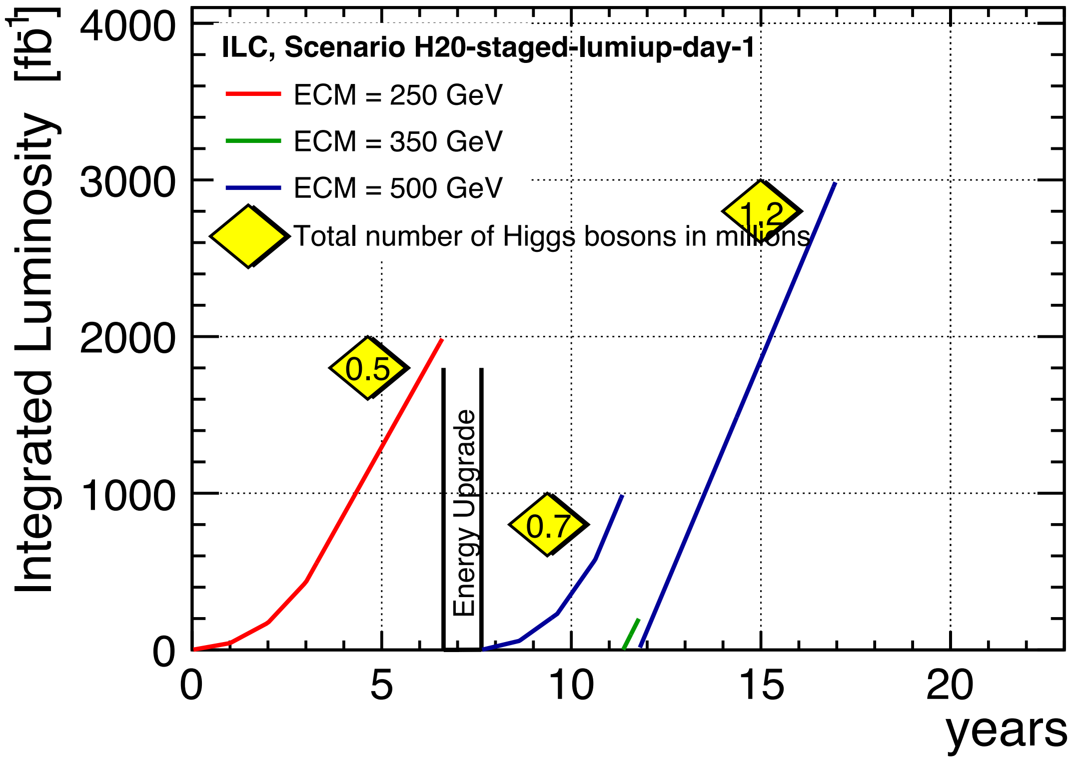


Higgs run down to 6-7 years

Being honest: adjusting to CERN operation year = 1.2x10^7s

Old ILC assumption used to be 1.6x10^7 s / year



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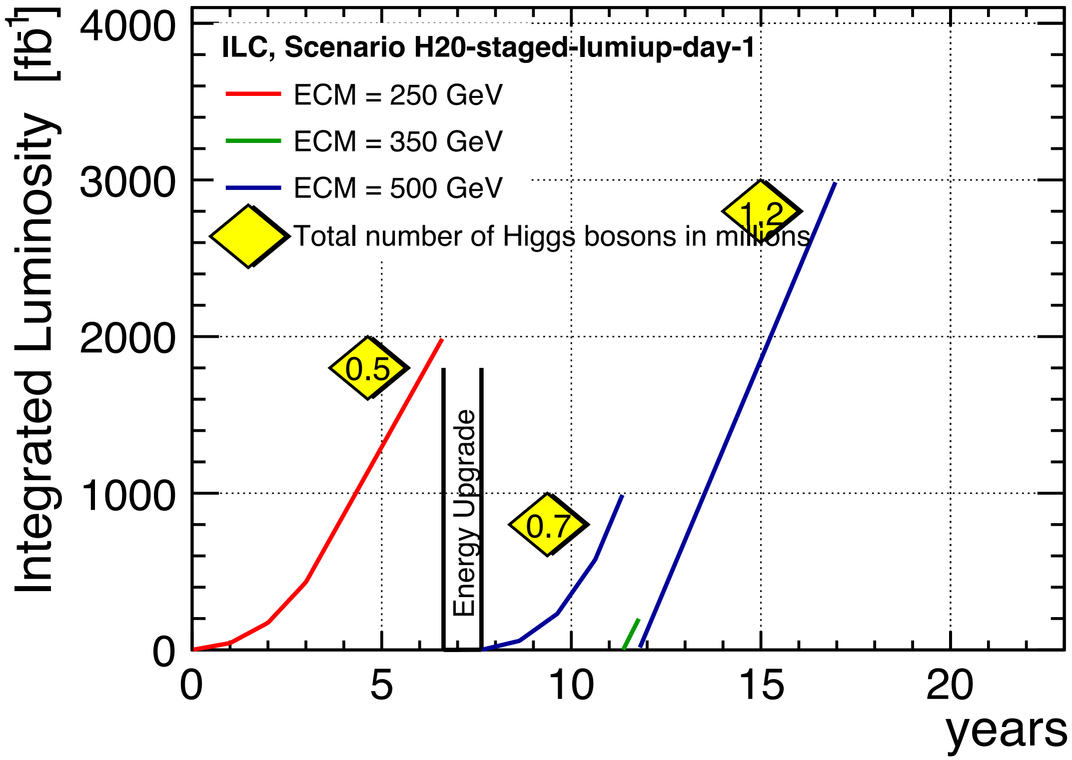
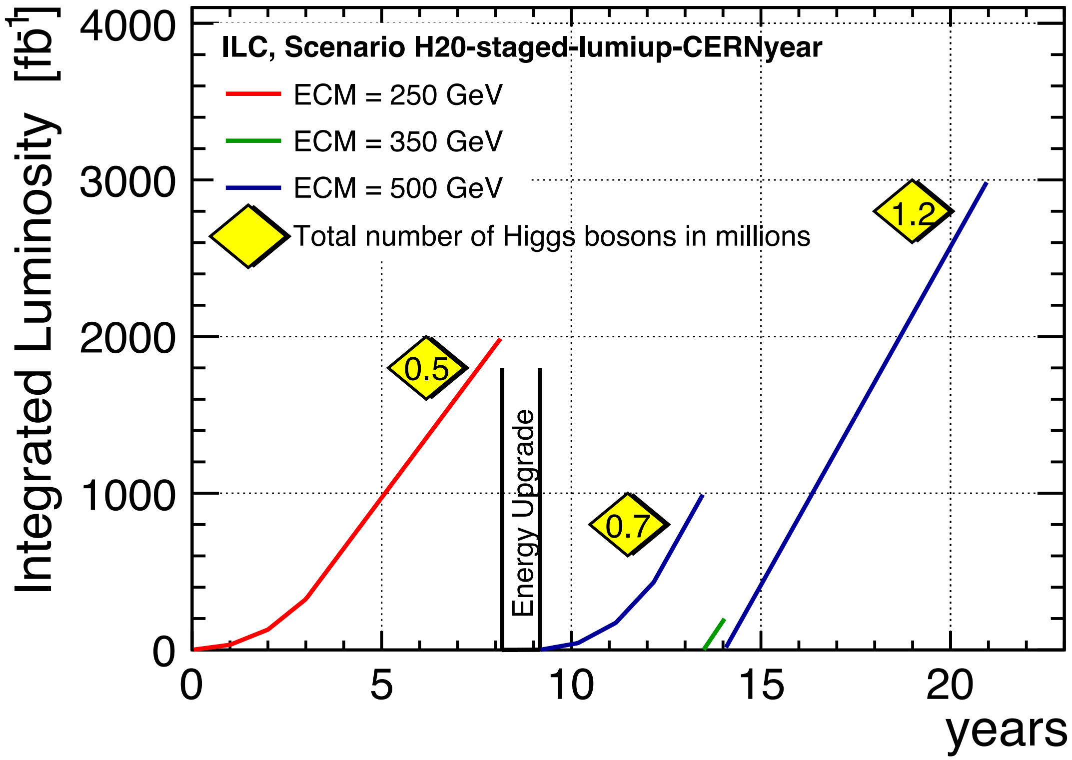
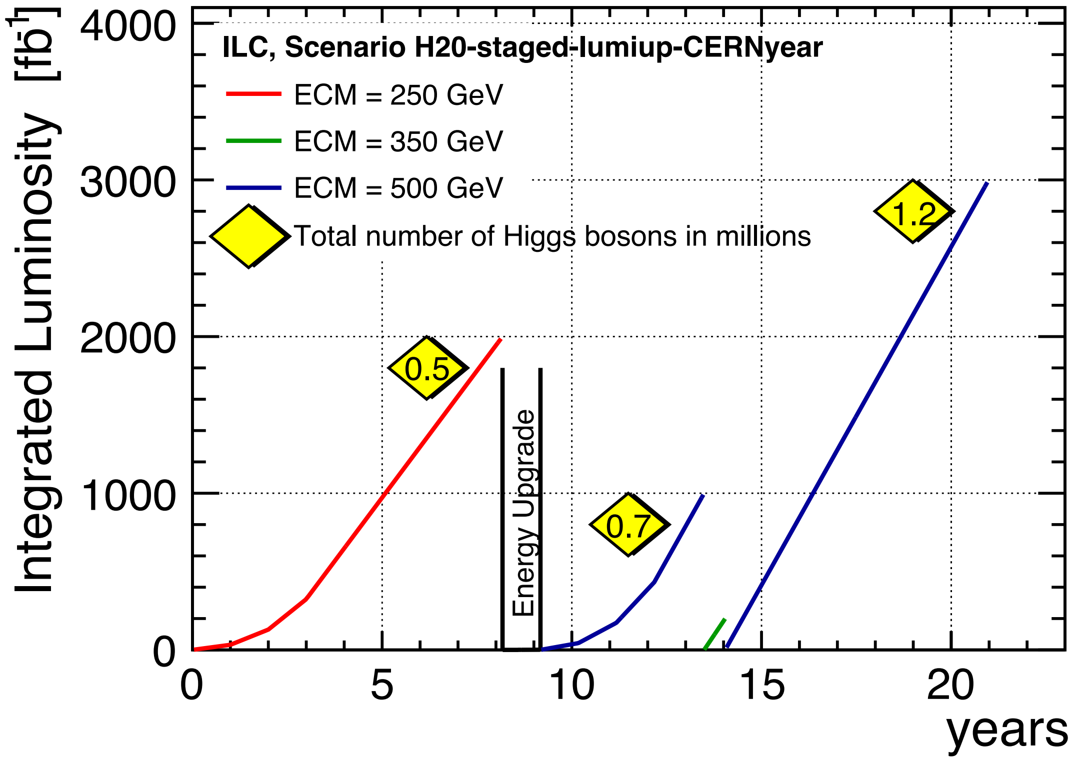




Higgs run ~8 years

200 MW (aka 10 Hz scheme) from day 1

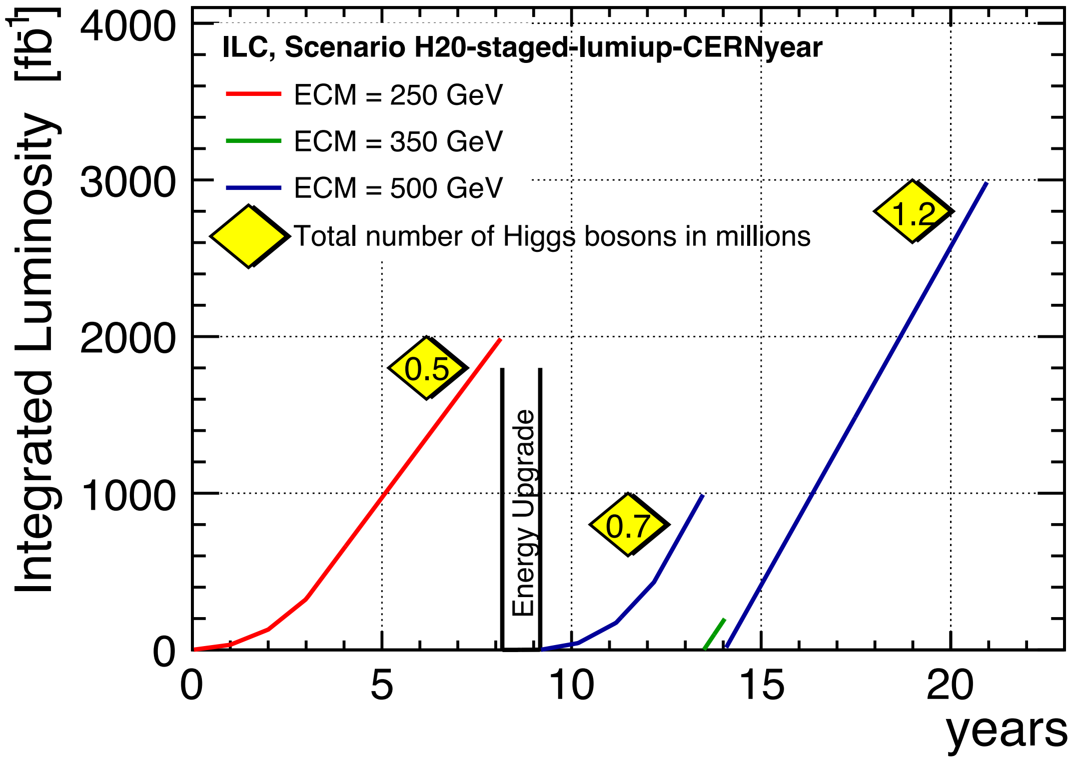
Remember: FCCee uses 270-350 MW

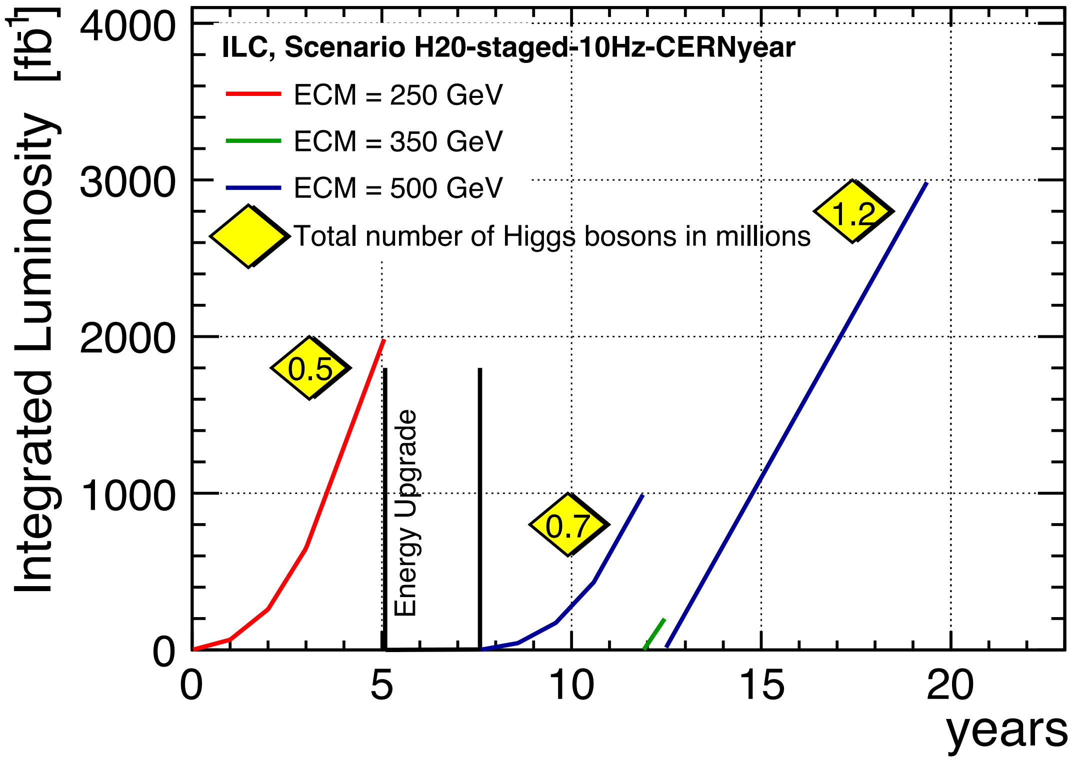


Higgs run 5 years

200 MW (aka 10 Hz scheme) from day 1

Remember: FCCee uses 270-350 MW

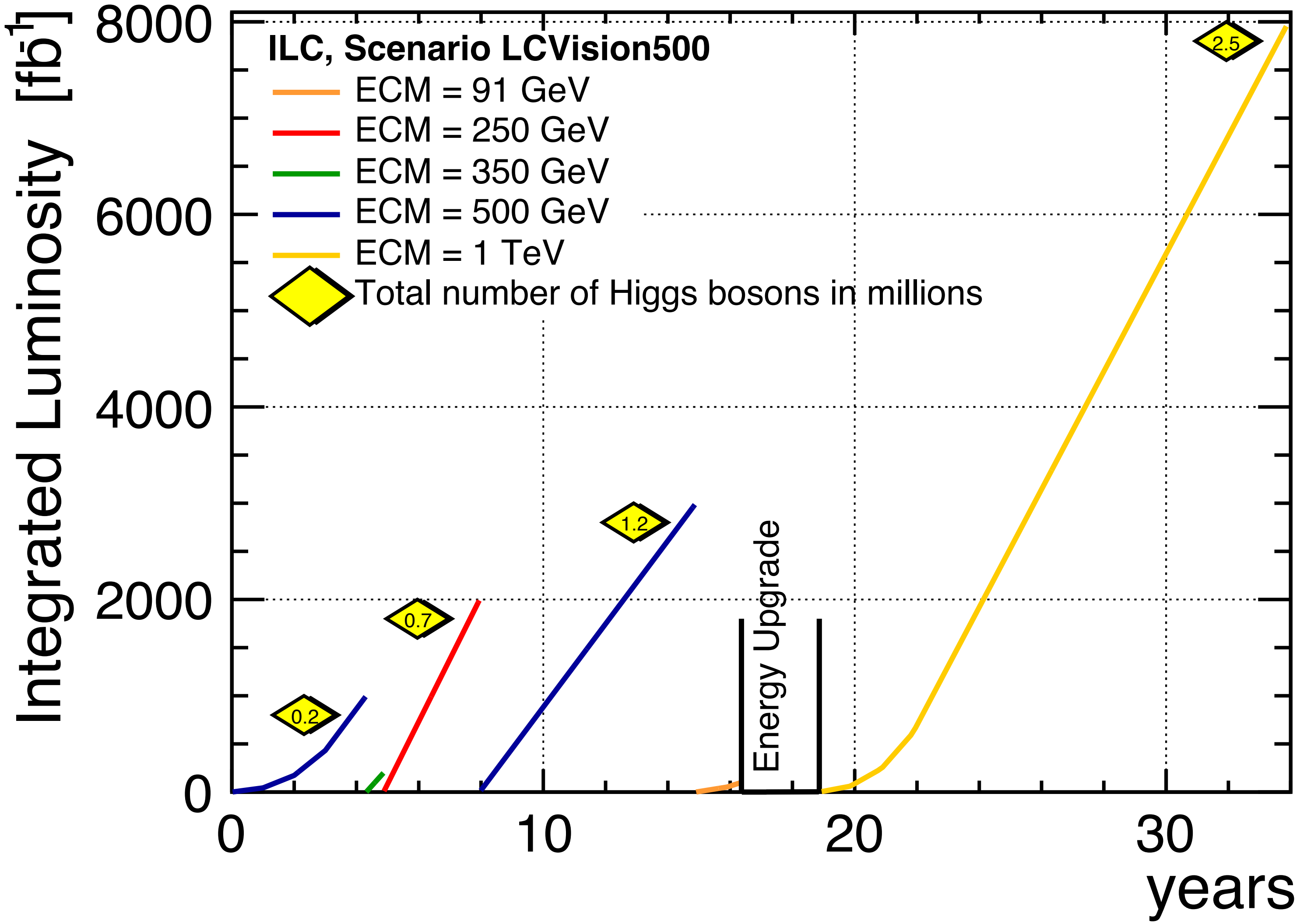




Higgs run 5 years

Dream a little dream…

Starting at 550 GeV



without lumi ramp-up (i.e. like FCCee assumption): Higgs run < 2 years

Conclusions on Running Scenarios

Some take-away messages

- for physics results, the combination of energy, integrated luminosity and beam polarisation counts
- for construction and operation costs, the total AC power counts
- power and instantaneous luminosity are strongly correlated
- Integrated luminosity depends on peak instantaneous luminosity and assumed operating efficiencies, learning curves etc pp
- the 11years the minimal ILC250 needs to collect the 250 GeV sample is driven by all the cost reductions applied to the orginal design
- **If we could build a 550 GeV “2625 bunch” machine right away (still 25% less AC power than FCCee), and use the same operation assumptions as for FCC-ee, the canonic ILC250 data set could be taken in < 2 years**
- **Would be awesome if we could find a way to pay for this!!! :)**

On the way to a baseline definition

some food for thought & discussion

- 2 IPs => detailed design of BDSes and IRs needs to be revisited and updated
- Tunnel laser straight
  => favoured for many technologies, not needed but can be done for SCRF
- length of facility (and AC power ~lumi) needs to be balanced against initial cost
- e.g. for ILC-type SCRF:
  - 21 km: 250 GeV
  - 27 km: ~380 GeV — or install initially only 250 GeV
  - 33 km: 550 GeV — or install initially only 380 or even 250 GeV
- different approaches:
  - What's the cheapest machine to study the Higgs? the top ?
  - What can we get for ~<= 10 Billion ILCU / CHF / …?
  - What could we get for the cost of FCC-ee ?
- intellectually all valid and interesting questions which we'll try to answer as ingredients to the discussion

Any Questions?