A Linear Collider Facility for CERN

LC Vision Community Event
Jan 10, 2025

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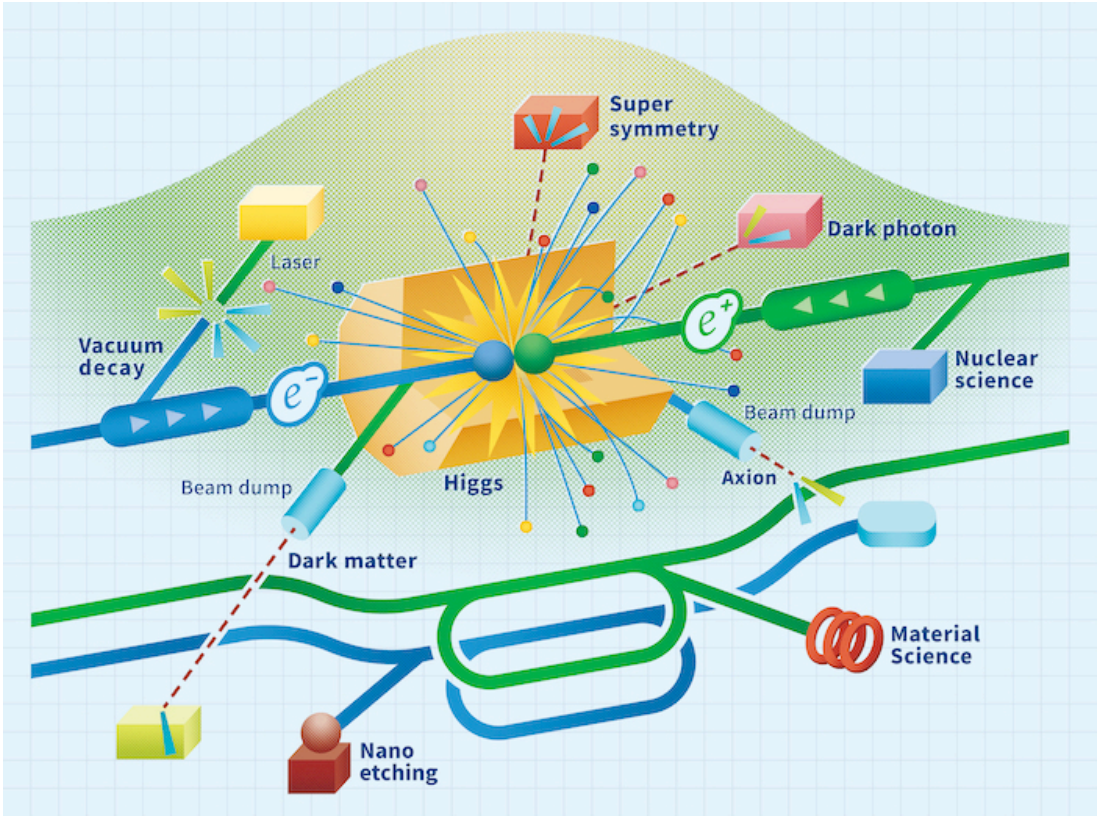

Introduction

The LCF@CERN and the EPPSU

- The remit of the EPPSU demands a preferred choice and (at least) one alternative for the next flagship project of CERN
- In particular, the alternative(s) should address the scenarios in which the preferred choice is
  - not feasible financially
  - not competitive due to developments in other regions (in particular: CEPC moves ahead)

=> Can a Linear Collider Facility fit the bill?

The Linear Collider Facility at CERN

Overview

- A linear e+e- collider spanning energies from the Z pole to 1 TeV (at least)
- 2 interaction regions
- extensions for R&D facilities, beam dump and extracted beam experiments
- a first stage aiming for
  - first Higgs measurements in e+e- as fast as possible
  - at an affordable price — minimizing the need for contributions beyond the CERN budget
- with a lot of flexibility
  - for upgrades with advanced technologies
  - which could be accelerated or become even the starting point if competition demands and sufficient external funding can be acquired

Designed to be compatible with SCRF and warm (& cool) copper RF

Why SCRF should also be considered

in addition to drive-beam technology

- a CLIC-like machine very well studied for CERN and a viable option (c.f. Steinar's talk)
- need to understand how an SCRF-based machine would look like at CERN
  - perfectly suited to cover the physics-optimized stages up to ~1 TeV
  - proven and *industrialised* technology
  - strong general interest in technology around the world
  - significant industrial production capacities in Europe (and elsewhere)
  - strong lab expertise *outside* of CERN => could take significant load off CERNs shoulders while CERN still busy with HL-LHC

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Opportunity to minimize time til next project
=> crucial for next generation of our community!

Basic Considerations

Overview

- tunnel cross-section: round 5.6 m tunnel (molasse) => talk by John
- access shafts: can be placed in a compatible way between ILC / CLIC designs => talk by John
- to be revisited (after March):
  - IR design: 2 experimental areas separated, one compatible with gamma-gamma
  - BDS design, crossing angles at IPs => talk by Angeles
- tunnel length? => initial energy & upgrade possibilities
- initial AC power? => initial luminosity
  - at least 2625 bunches / train?
  - final **power cap** at ultimate energies? ILC (1 TeV): 300 MV, CLIC (3 TeV): 600 MeV
- go over the books of all components, e.g.:
  - klystron efficiency: 65% => 80% ?
  - initial gradient & Q0: (31.5 MeV, 1E10) => (35MeV, 2E10) ?
  - update damping ring design to modern light source standards

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not yet factored in today

The Financially Optimized Scenario

Assume 20.5 km length

- today's ILC-like SCRF: 250 GeV
- advanced SCRF (c.f. Sergey's talk):
  - 5 year horizon => 50 MV/m: would reach even 380 GeV
  - longer-term: ~500 GeV
- warm / cool copper (Emilio's talk):
  - CLIC-like: ~ 1 TeV
  - C3-like: 1-2 TeV

The Intermediate Scenario

Assume 27 km length

- today's ILC-like SCRF: ~380 GeV
  - always have the option to start operation with only 250 GeV installed
- advanced SCRF (c.f. Sergey's talk):
  - 5 year horizon => 50 MV/m: ~550 GeV ?
  - longer-term: ~700 GeV ?
- warm / cool copper (Emilio's talk):
  - CLIC-like: ~ 1.5 TeV
  - C3-like: 1.5-2.5 TeV

The All-in Scenario

Assume 33.5 km length

- today's ILC-like SCRF: 550 GeV from day one, 300 MW ?
  - always have the option to start operation with only 250 GeV installed
- advanced SCRF (c.f. Sergey's talk):
  - 5 year horizon => 50 MV/m: ~700 GeV ?
  - longer-term: ~1 TeV ?
- warm / cool copper (Emilio's talk):
  - CLIC-like: 3 + x TeV ?
  - C3-like: 3 … TeV ?

General Considerations

for a Linear Collider Facility

- risk minimisation: the original ILC and CLIC designs are very well studied and carefully costed
- however, we want to be more ambitious than the minimal solutions!
- “empty tunnel” solutions could allow to reduce initial cost, and continue production of accelerator modules while taking first data => upgrade cheaper since production capacity already there
- for March, any costing will be based closely on these realistic designs
- however we have good reasons to assume that we can do better in many aspects even for the baseline => lower cost (risk) or increase performance (opportunity)
- important to understand what investment would be needed to make the higher-gradient options construction ready
  - well-known for CLIC
  - estimate for higher gradient SCRF, cool copper, …
- in any case, there is really a lot of potential in such a facility!

Outlook
on a Linear Collider Facility

- a lot of important input and discussions this week!
- still a lot to do
  - define baseline based on
    - material presented & discussions at this workshop
    - ILC & CLIC cost updates
    - prepare strategy submission
    - and the back-up documents
- much more concrete information will follow in the next talks!

European Strategy Update

Contact:
eppsu2024-strategy-secretariat@cern.ch

Guidelines for submitting input for the 2026 update of the European Strategy for Particle Physics

Cover page (1 page)
Each document submitted should carry a single cover page containing no more than the title, the contact person(s) and an abstract.

Comprehensive summary (maximum 10 pages)
The submitted document must be no more than 10 pages long (excluding the cover page) and must provide a comprehensive and self-contained summary of the input. It should address:

- scientific context,
- objectives,
- methodology,
- readiness and expected challenges,
- timeline,
- construction and operational costs (if applicable).

Back-up document
Additional information and details can be submitted in a separate back-up document, which can be consulted by the Physics Preparatory Group (PPG) if clarification on any aspects is required. But the back-up document is not a mandatory component of the submission.

Format and deadline for submission
The cover page and the comprehensive summary are to be submitted in portable document format (pdf) by 31 March 2025. The back-up document should have a cover page with the same title and contact persons and with the words "Back-up Document" added. A dedicated submission portal for both documents will be made available via the ESPPU website.

Distribution
All the documents submitted will be forwarded to the PPG and the European Strategy Group (ESG). Unless explicitly requested otherwise, they will also be made public. The option not to make a given document public will be available upon submission via the dedicated portal.

Any Questions?

LC Vision Overview

organisation

Chairs: J. List, S. Stapnes

Coordination Group

Halina Abrahmovic, Erik Adli, Ties Behnke, Ivanka Bosovic, Phil Burrows, Marcel Demarteau, Yuanning Gao, Carsten Hensel, Mark Hogan, Masaya Ishino, Daniel Jeans, Imad Laktineh, Andy Lankford, Benno List, Kajari Mazumar, Shin Michizono, Emmanuela Musumeci, Tatsuya Nakada, Mihoko Nojiri, Dimitris Ntounis, Jens Osterhoff, Ritchie Patterson, Aidan Robson, Daniel Schulte, Taikan Suehara, Geoffrey Taylor, Caterina Vernieri, Marcel Vos, Georg Weiglein, Filip Zarnecki, Jinlong Zhang, Patrick Koppenburg, Hitoshi Murayma, Laura Monaco, Jochen Schieck

Expert Team 1

"Physics-driven run plan and EPPSU documents"
Roman Poeschl, Michael Peskin

Expert Team 3

"SCRF upgrades"
Sergey Belomestnykh, Hiroshi Sakai, Marc Wenskat

Expert Team 5

"ERL upgrades"
Walid Kaabi, Vladimir Litvinenko, Kaoru Yokoya

Expert Team 7

"Beyond Collider"
Yasuhito Sakaki, Ivo Schulthess

Expert Team 2

"LCF@CERN"
Steinar Stapnes, Thomas Schörner

Expert Team 4

"C3/CLIC upgrades"
Angeles Faus-Golfe, Enrico Nanni

Expert Team 6

"Plasma upgrades"
Brian Foster, Spencer Gessner

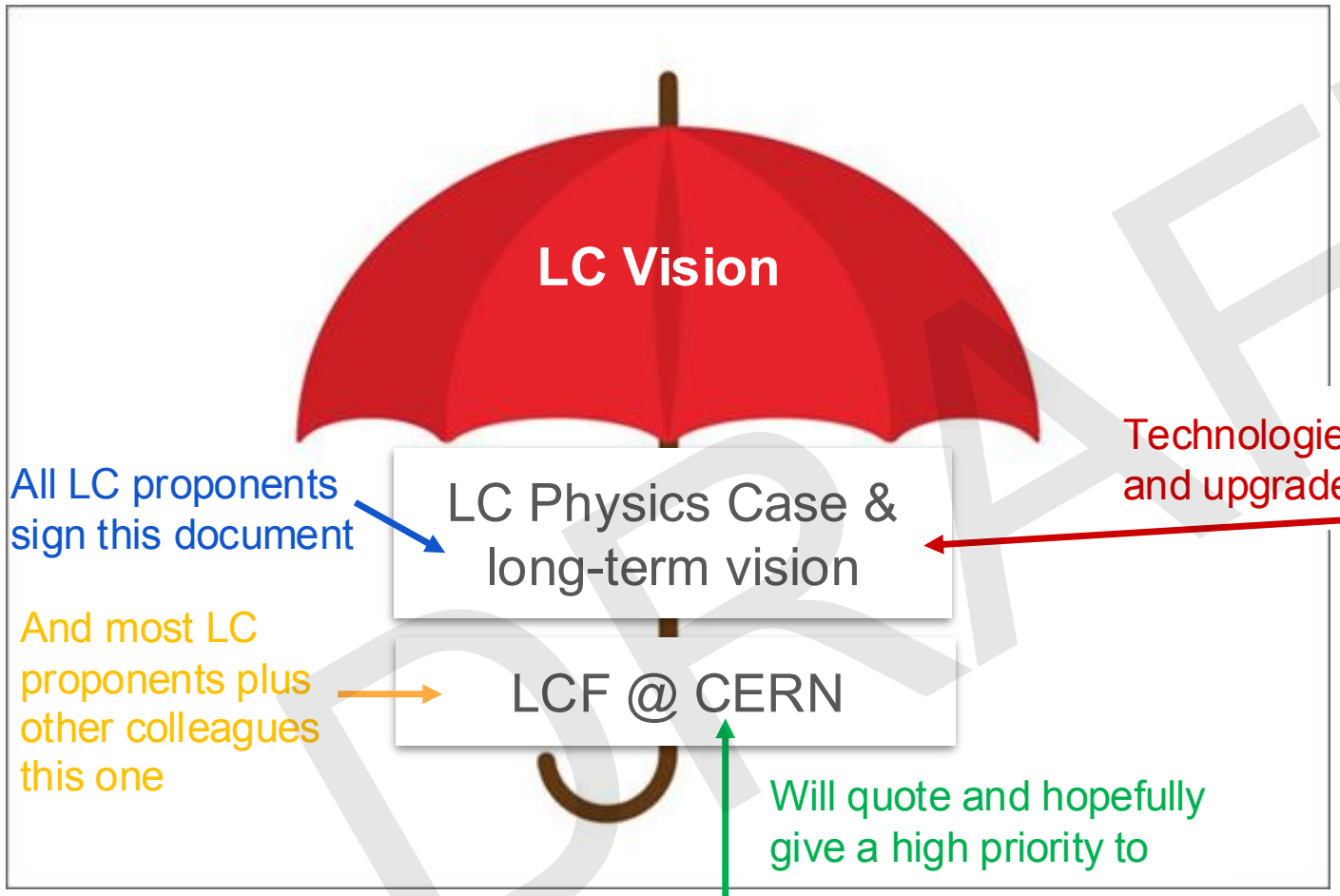
Expert Team 8

"Alternative Collider Modes"
Tim Barklow, Gudi Moortgat-Pick

LC Vision Documents

and their relations to other EPPSU inputs

idea: S. Gessner



- ILC in Japan (IDT)
- CLIC at CERN
- Advanced SCRF
- C^3
- ERLs
- HALHF
- 10 TeV Wakefield
- $\gamma\gamma$ / eγ collider
- Beyond Collider

Scenarios for Expert Teams

to get started

- **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 — minimal cost)
  - **b) ~30 km** (e.g. 550 GeV SCRF — CEPC complementarity from day-one)
- **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)?**

Documents to be written

Overview - not listed: executive summaries as actual EPPSU inputs (10-pages) needed…

A. main, generic LC Vision document, "site agnostic" (100+ pages)

- **Linear Collider Physics Case**
  - capabilities at low energies (90-380GeV)
  - unique added-value at high energies (500GeV - 1 TeV, 3 TeV, x TeV)
- **Long-term upgrade / add-on opportunities**
  - physics motivation, community size
  - requirements on initial facility
  - required R&D, milestones for decision, timeline, cost

B. LinearColliderFacility @ CERN (~30 pages)

- concrete proposal for CERN => cite specific
- carefully understand scope, likely distinguish
  - "FCCee too expensive"
  - CEPC goes ahead
- crisp summary of physics opportunities
- 1-2 baseline configurations + portfolio of add-ons / upgrades

=> realistically, final cost <-> performance optimisation part of strategy process?

Food for thought — Luminosity & Power Consumption of Linear Colliders

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

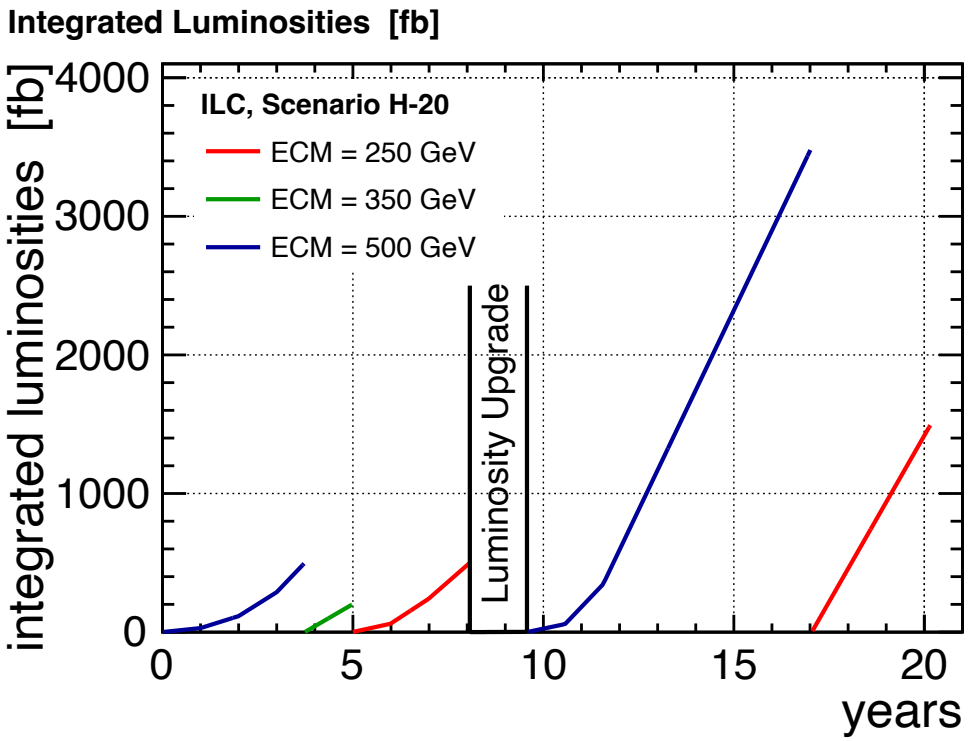
T. Barklow, J. Brau, K. Fujii, J. Gao, J. List, N. Walker, K. Yokoya

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.

Time-development in 2015

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

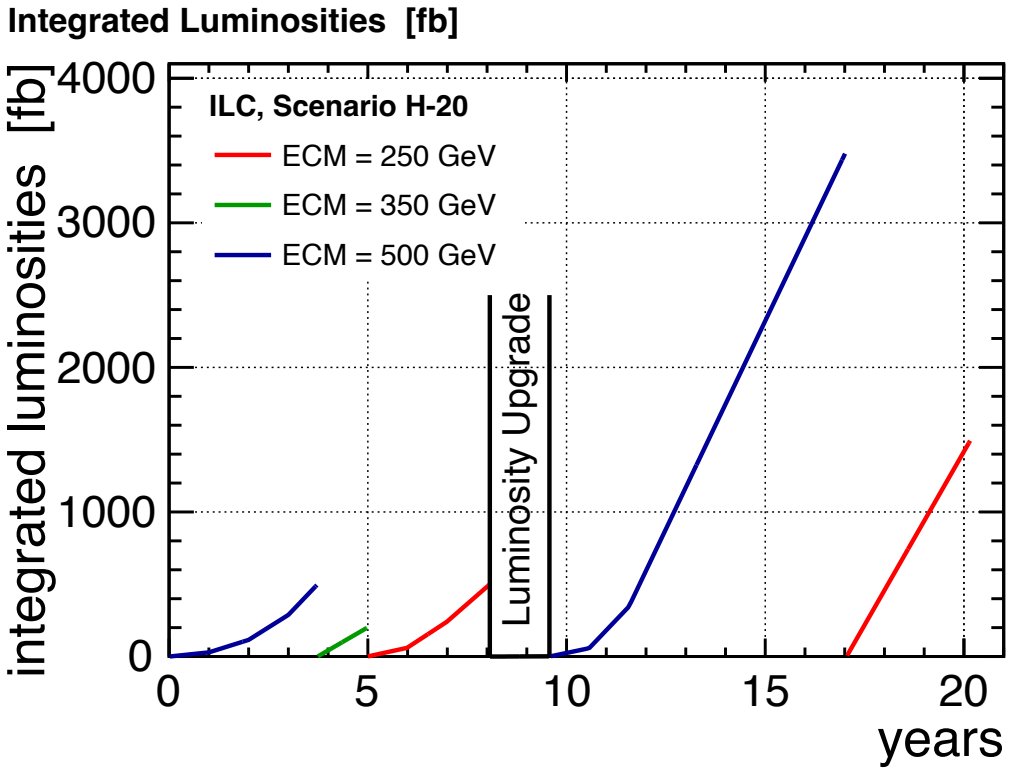


- **operation 1.6E7 s / year** (more than std CERN assumption)
- **start at 500 GeV**
  - initial peak lumi = 1.8E34 / s / cm2 (= 1315 bunches / train)
  - luminosity upgrade 3.6E34 / s / cm2 (= 2625 bunches / train)
- at lower energies
  - linac is operated at lower gradient
  - **use spare RF & cryogenic 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



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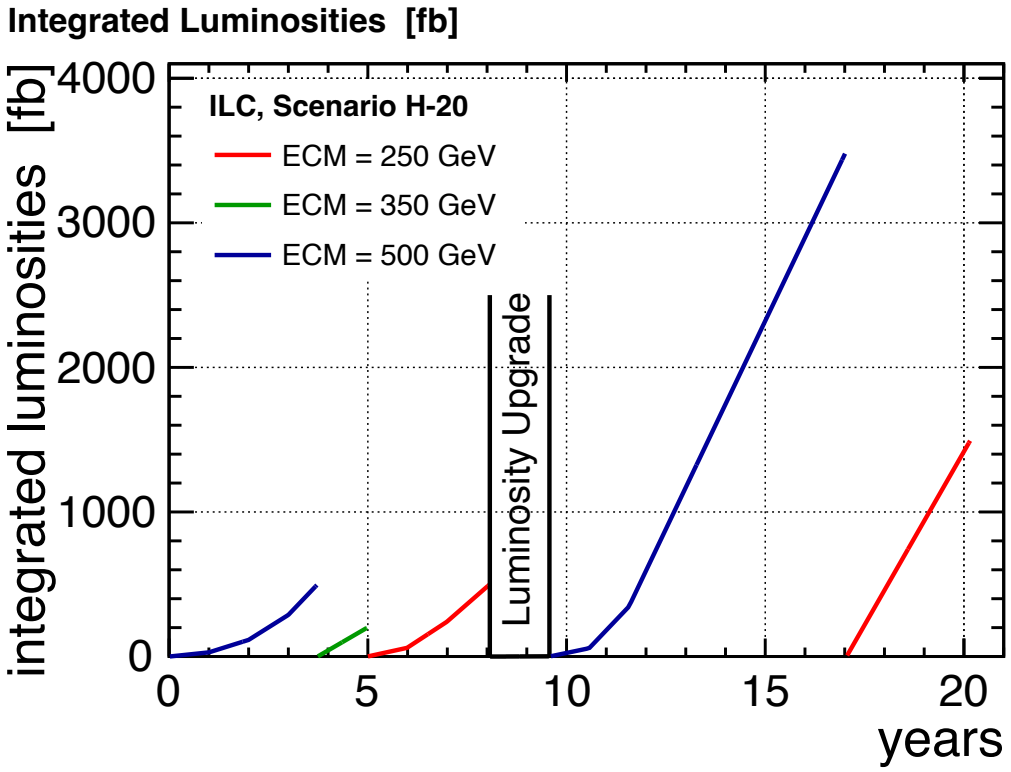
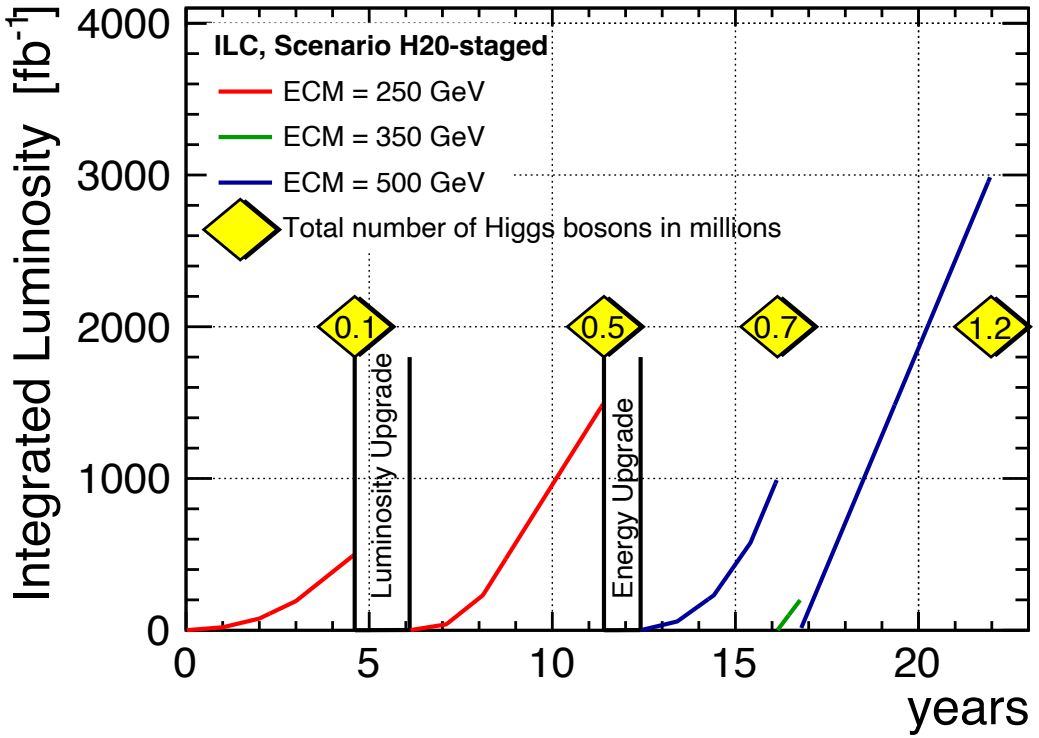
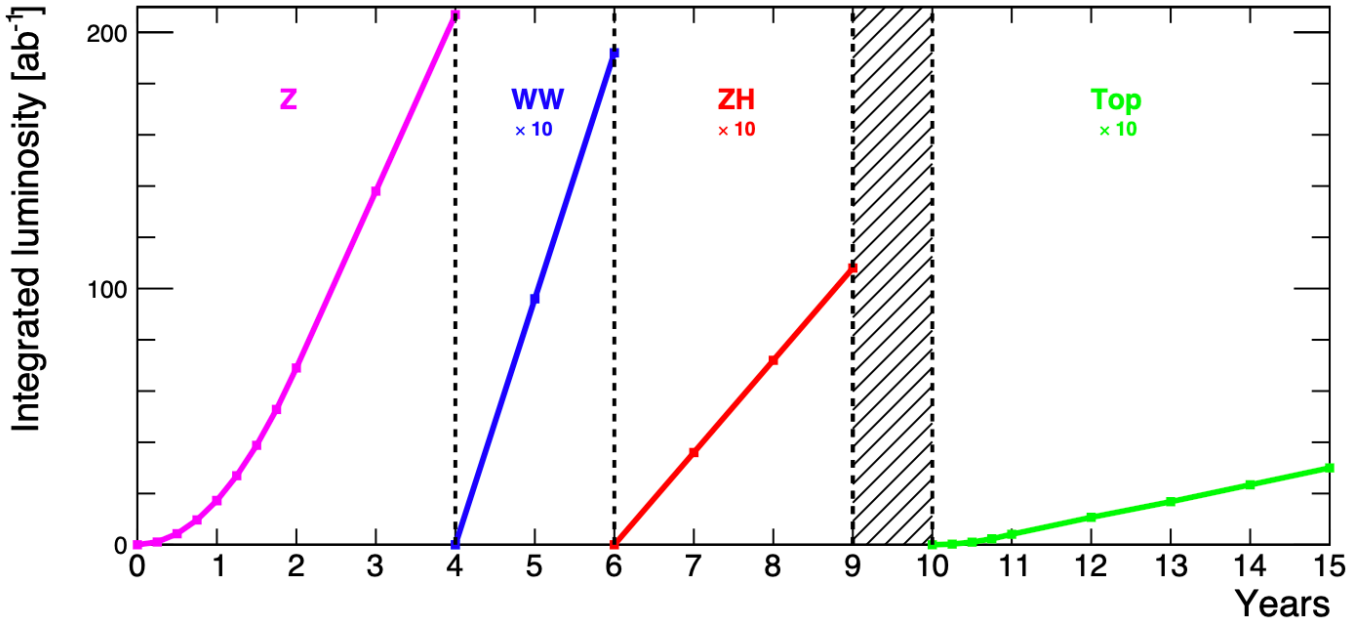




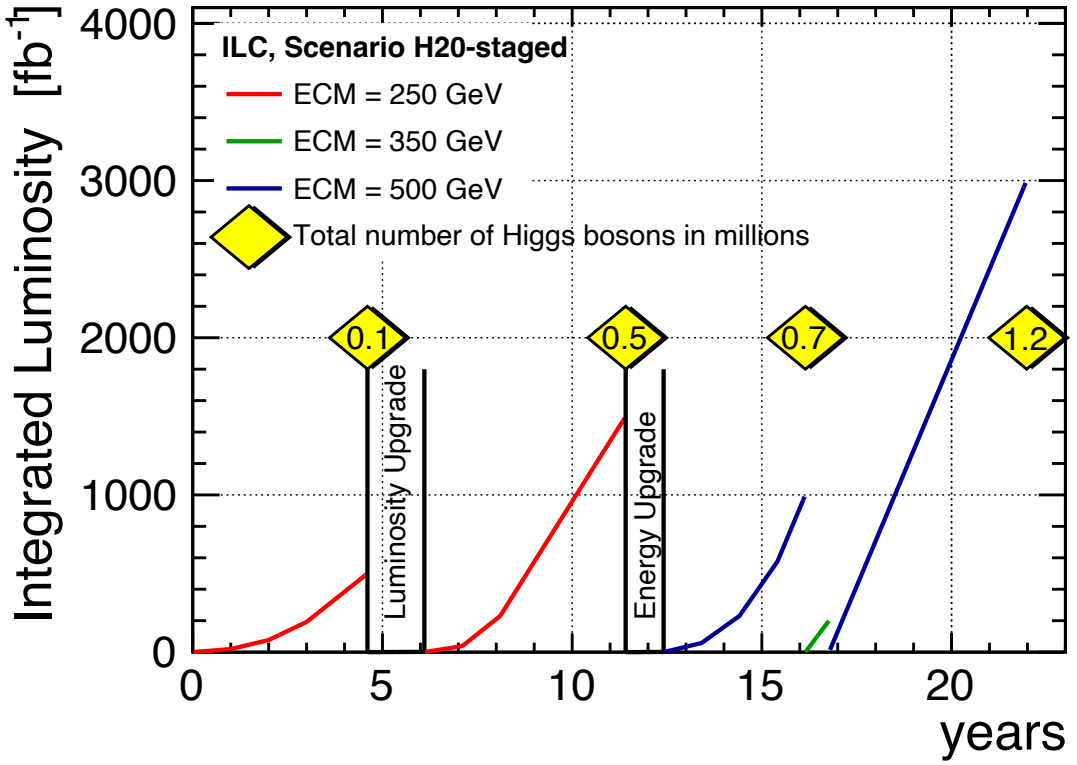
Running Scenarios

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



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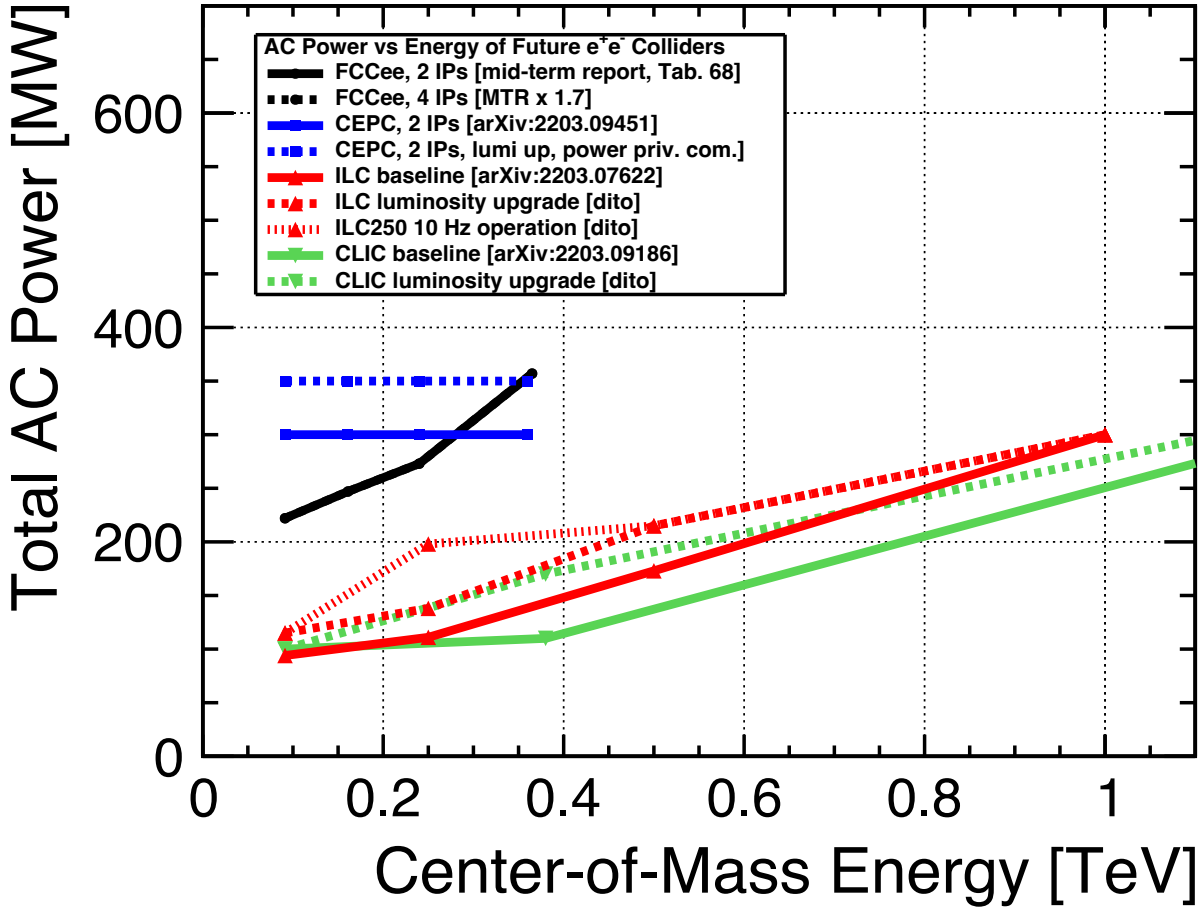
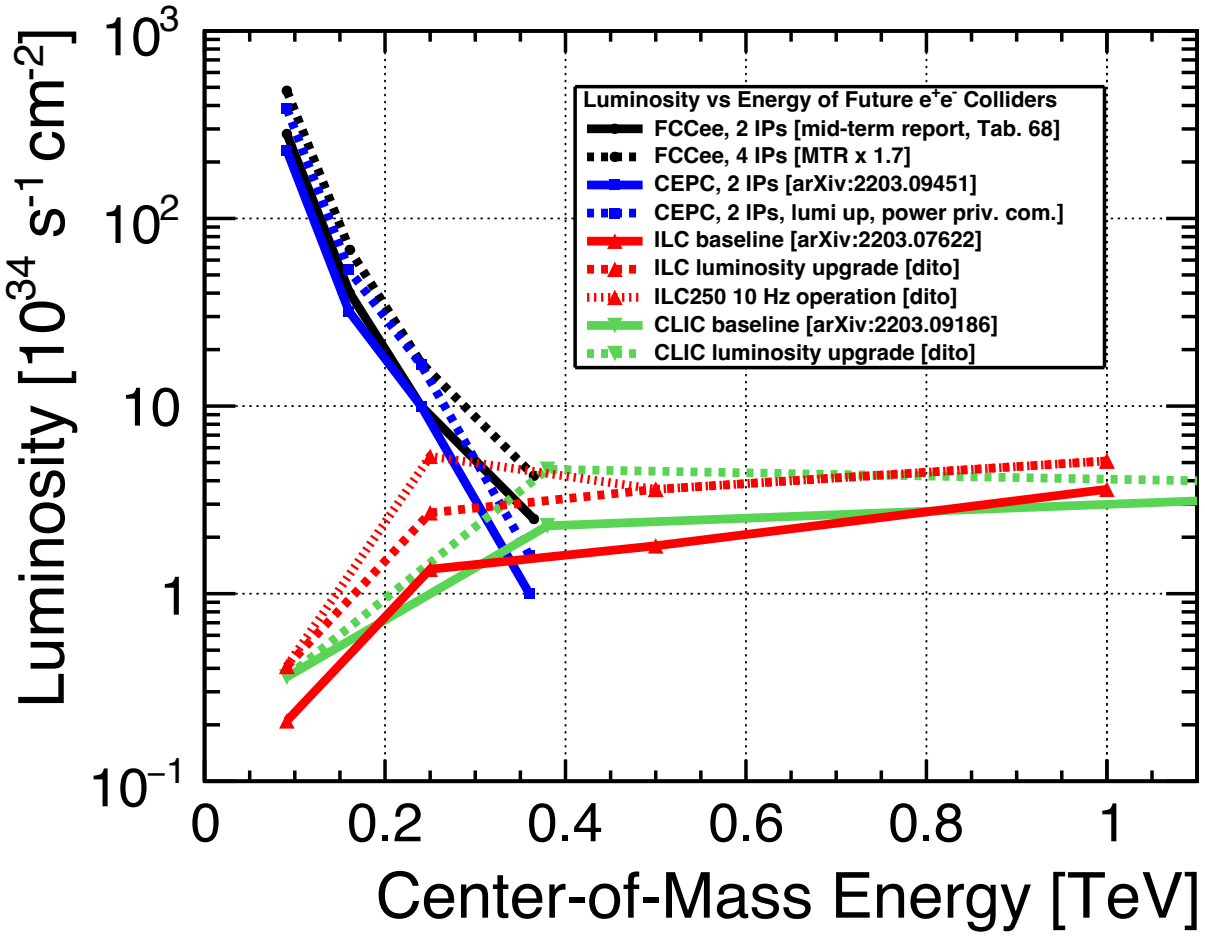
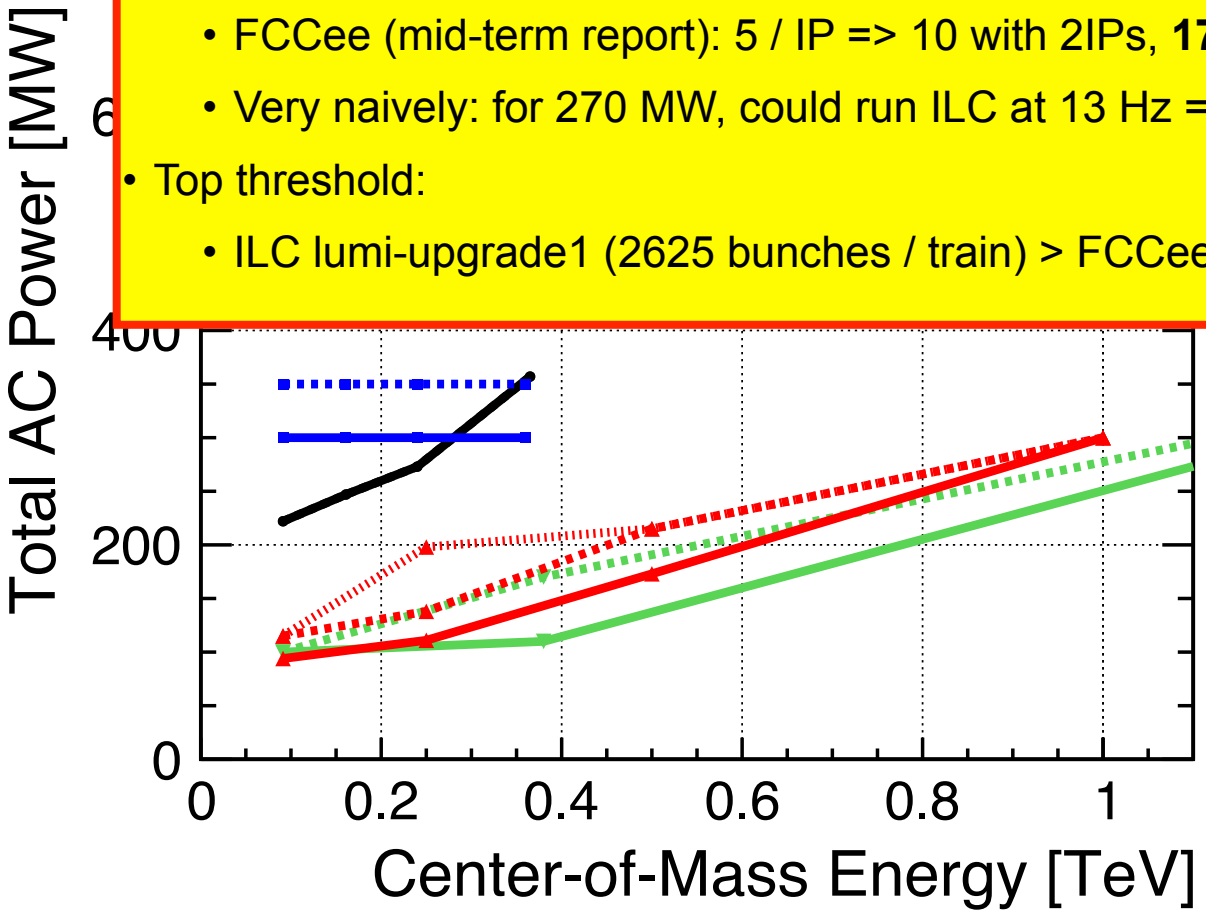


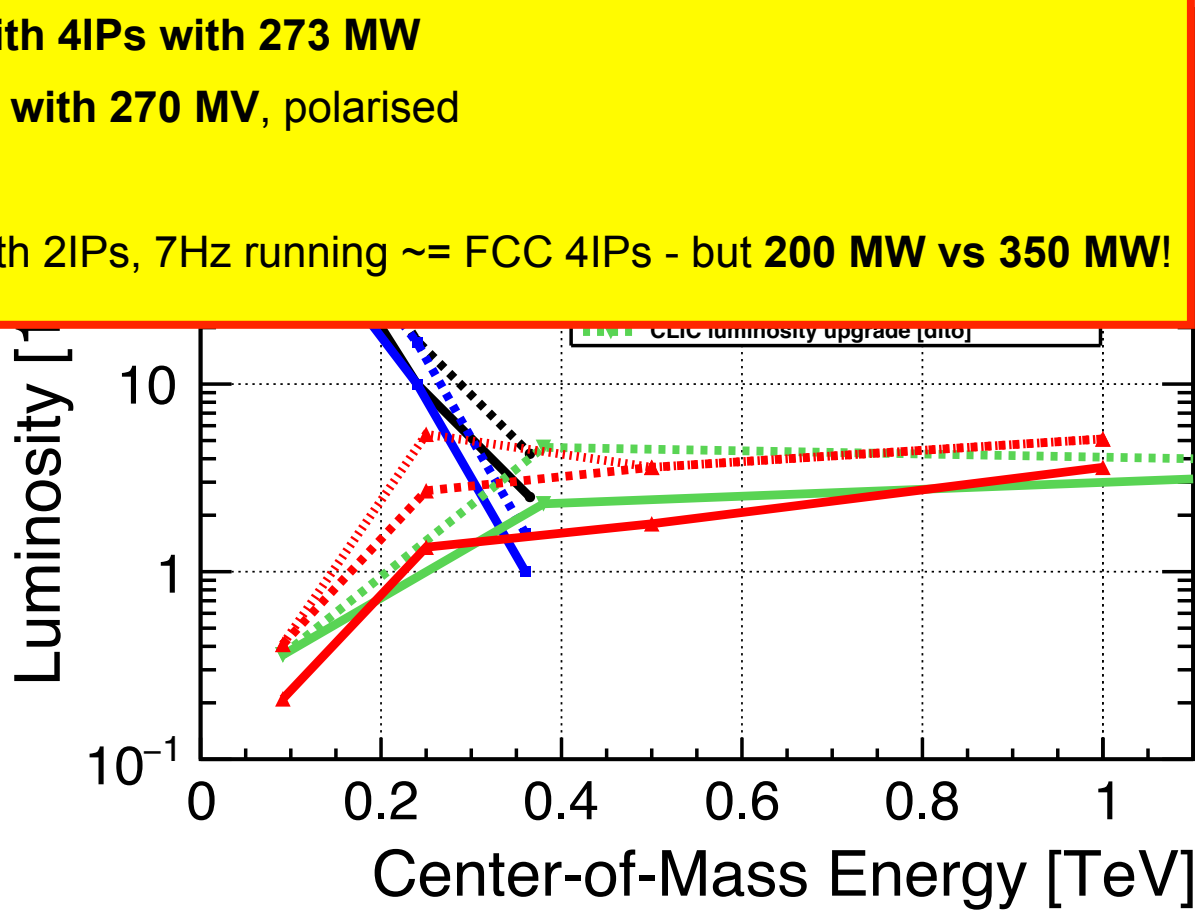


R

Lu

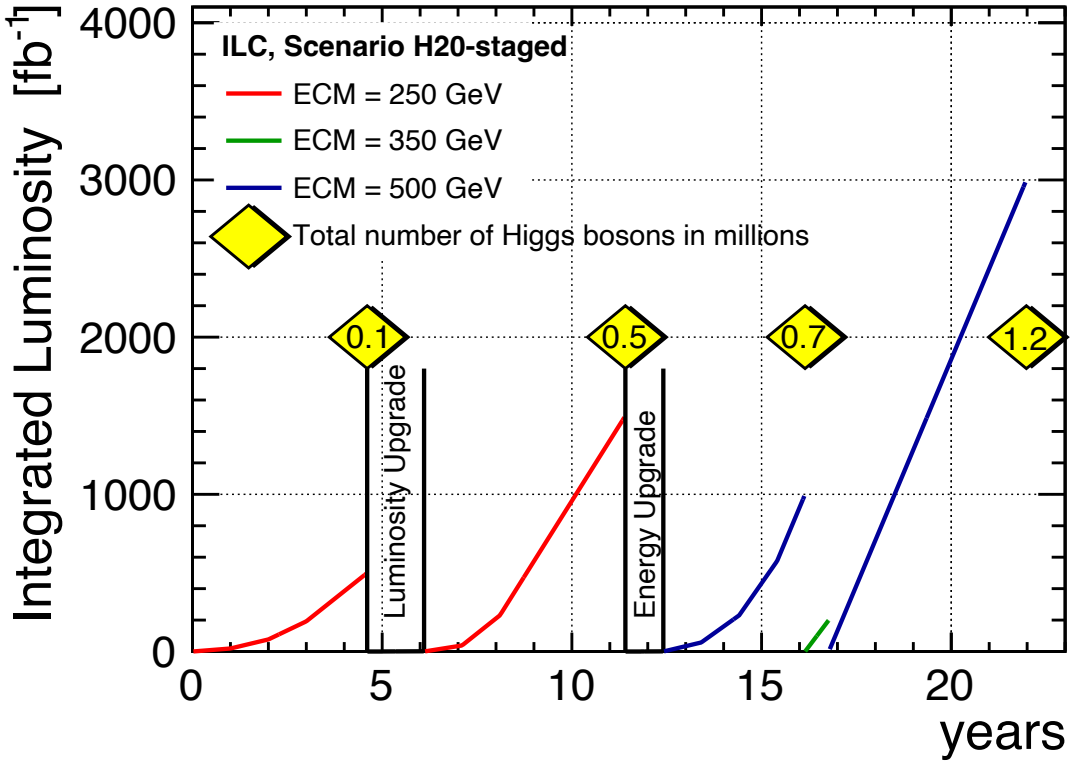
- Single-Higgs program at 240/250 GeV:
  - Linear Collider luminosity restricted by *self-assigned* power limit (all lumis in x10^34 s^-1 cm^-2)
    - 250 GeV ILC baseline lumi **1.35 => 2.7 => 5.4 with 200MW**
    - **less luminosity for *same* Higgs coupling precision due to polarised beams (2ab-1 pol ~= 5 ab-1 unpol)**
  - FCCee (mid-term report): 5 / IP => 10 with 2IPs, **17 with 4IPs with 273 MW**
  - Very naively: for 270 MW, could run ILC at 13 Hz => **7 with 270 MV**, polarised
- Top threshold:
  - ILC lumi-upgrade1 (2625 bunches / train) > FCCee with 2IPs, 7Hz running ~= FCC 4IPs - but **200 MW vs 350 MW**!





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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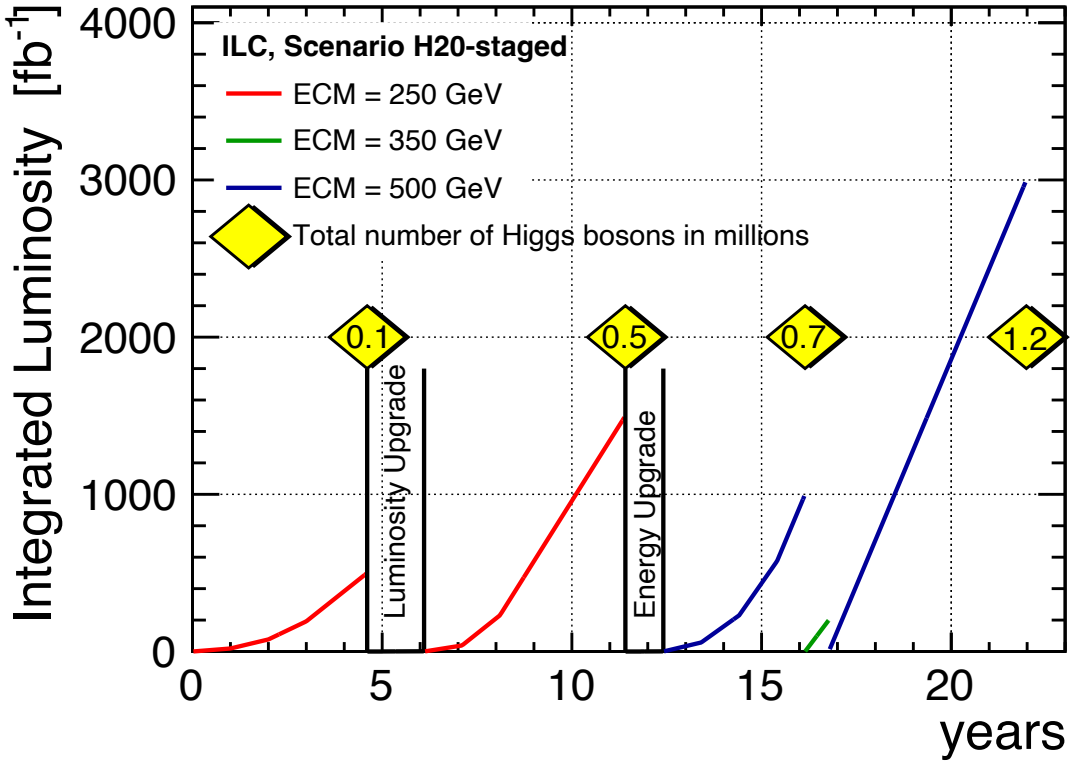
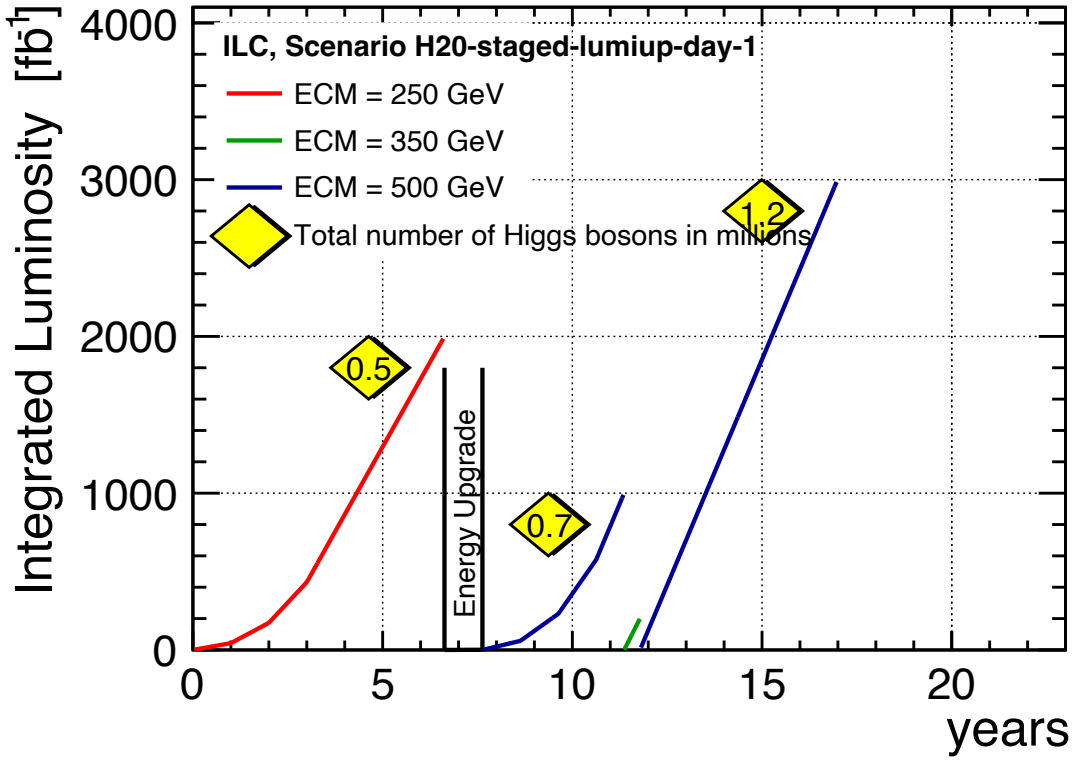
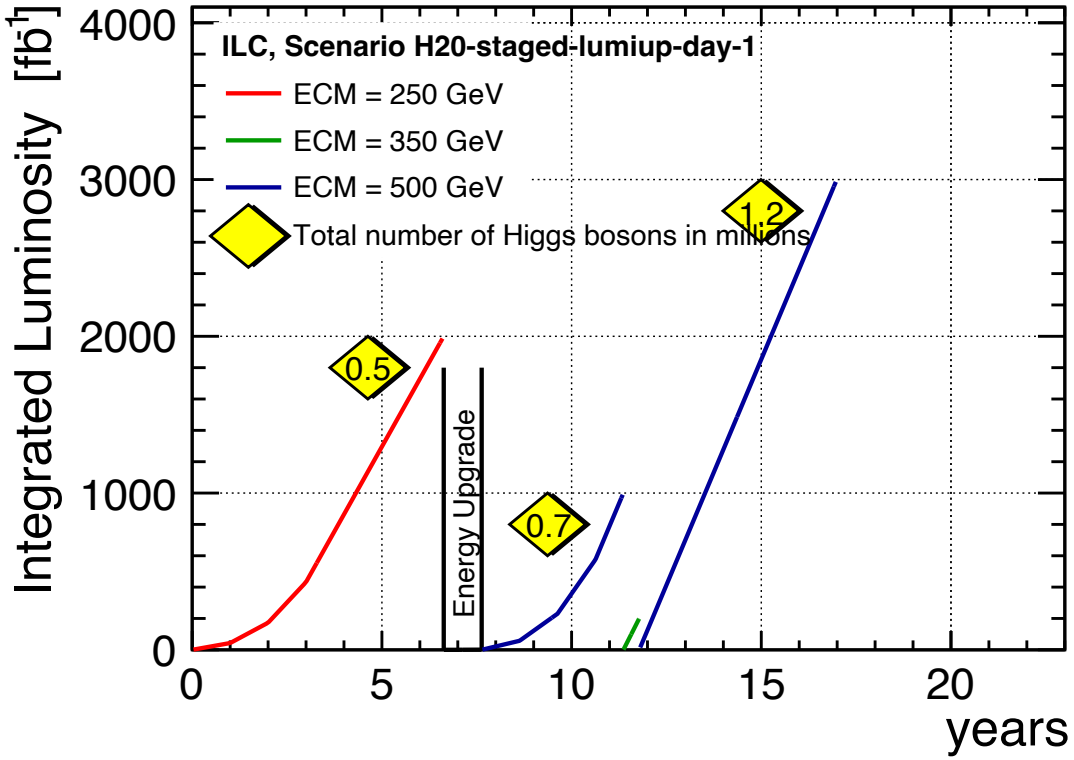




Higgs run down to 6-7 years

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

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



Higgs run ~8 years

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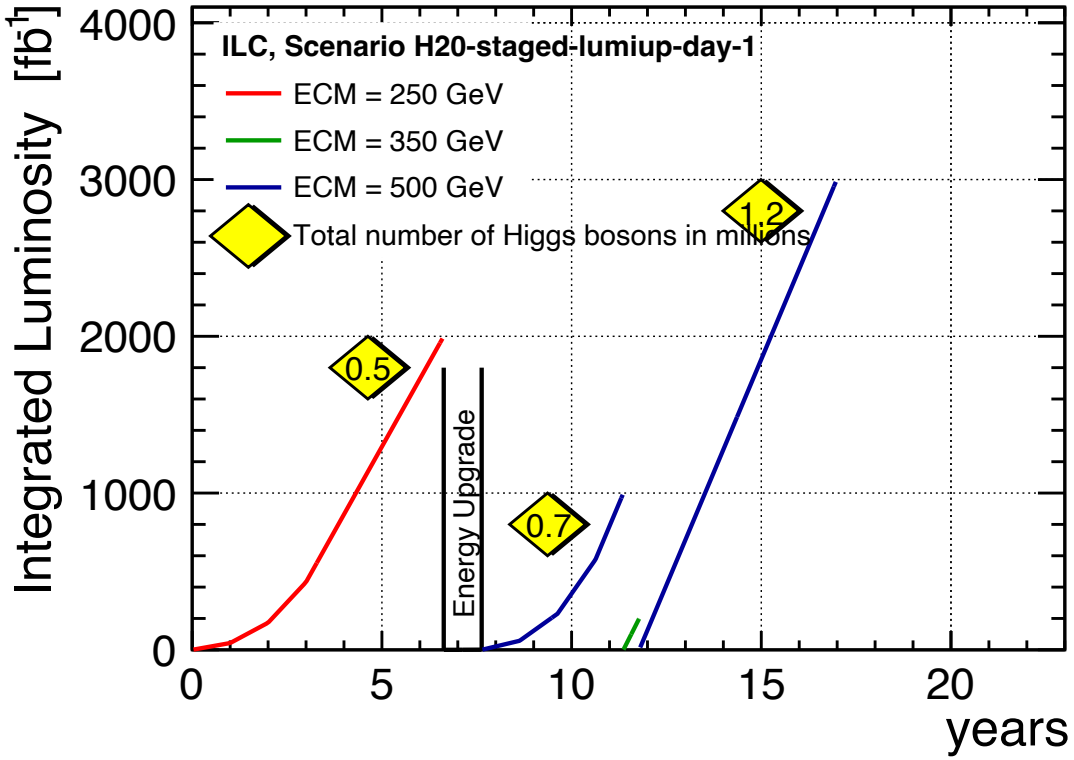
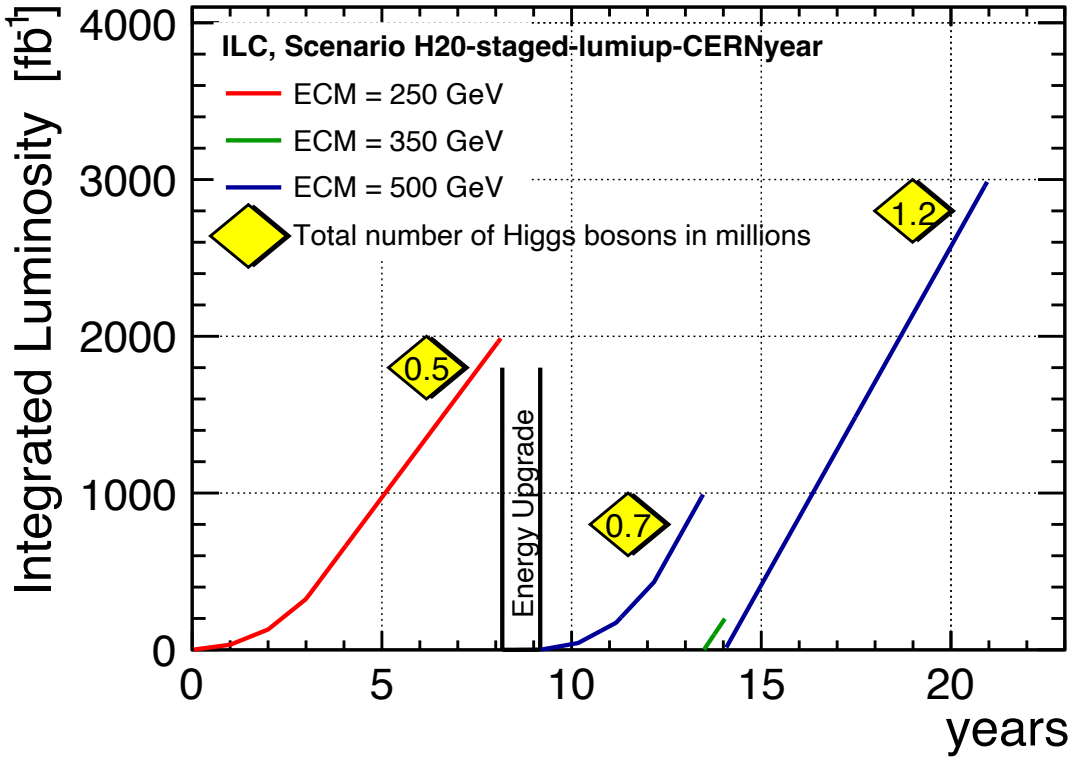
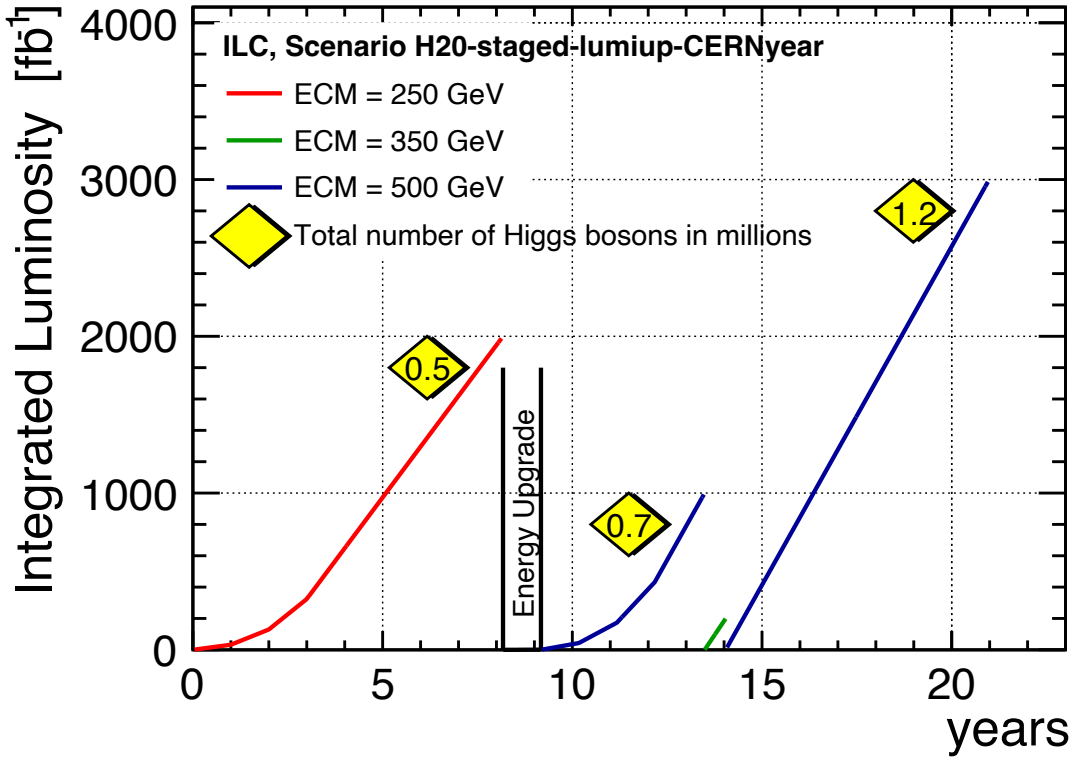




Higgs run ~8 years

200 MW (aka 10 Hz scheme) from day 1

Remember: FCCee uses 270-350 MW



Higgs run 5 years

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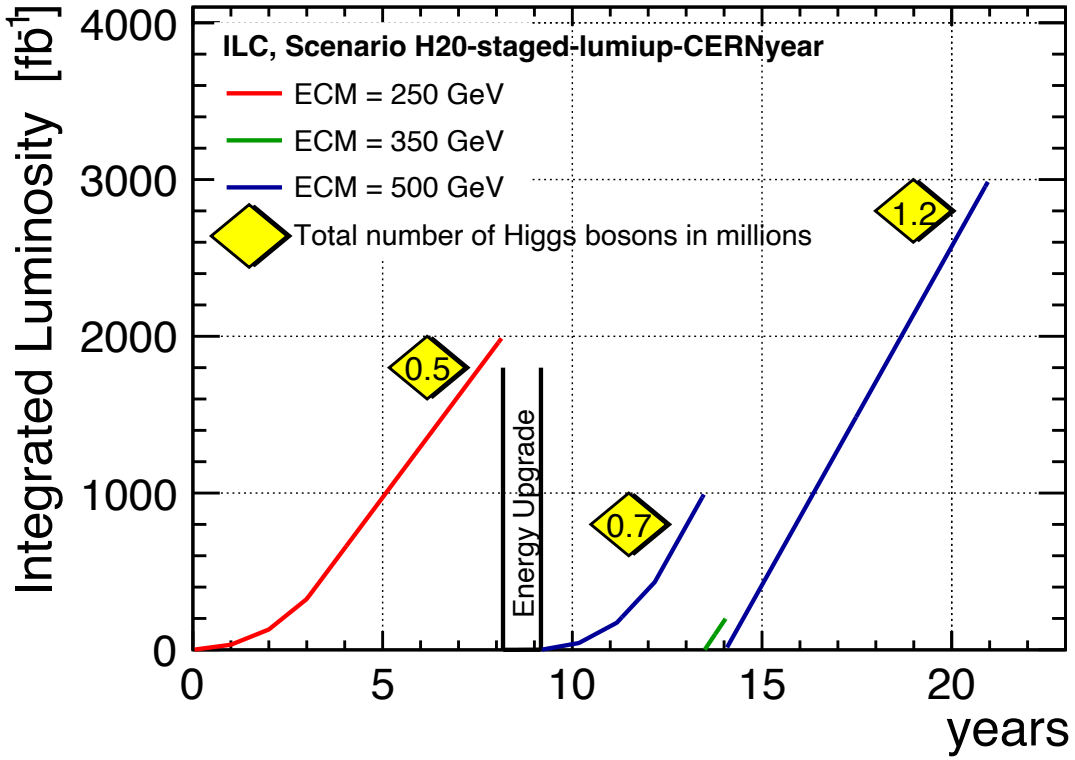
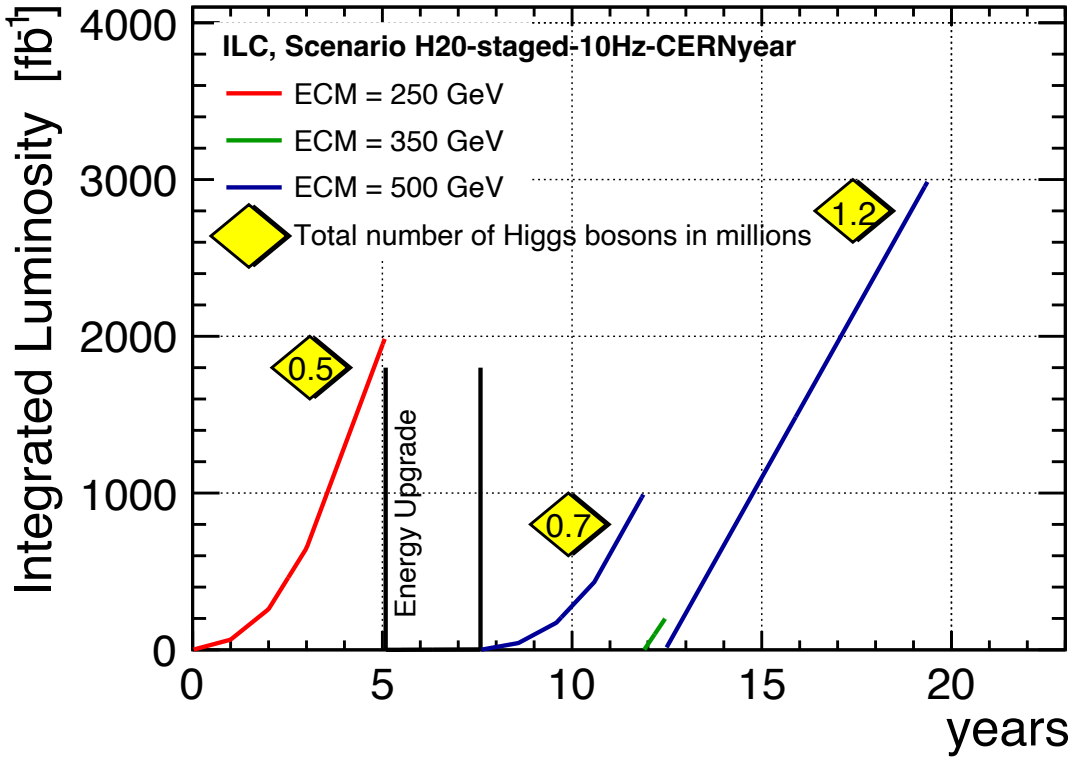
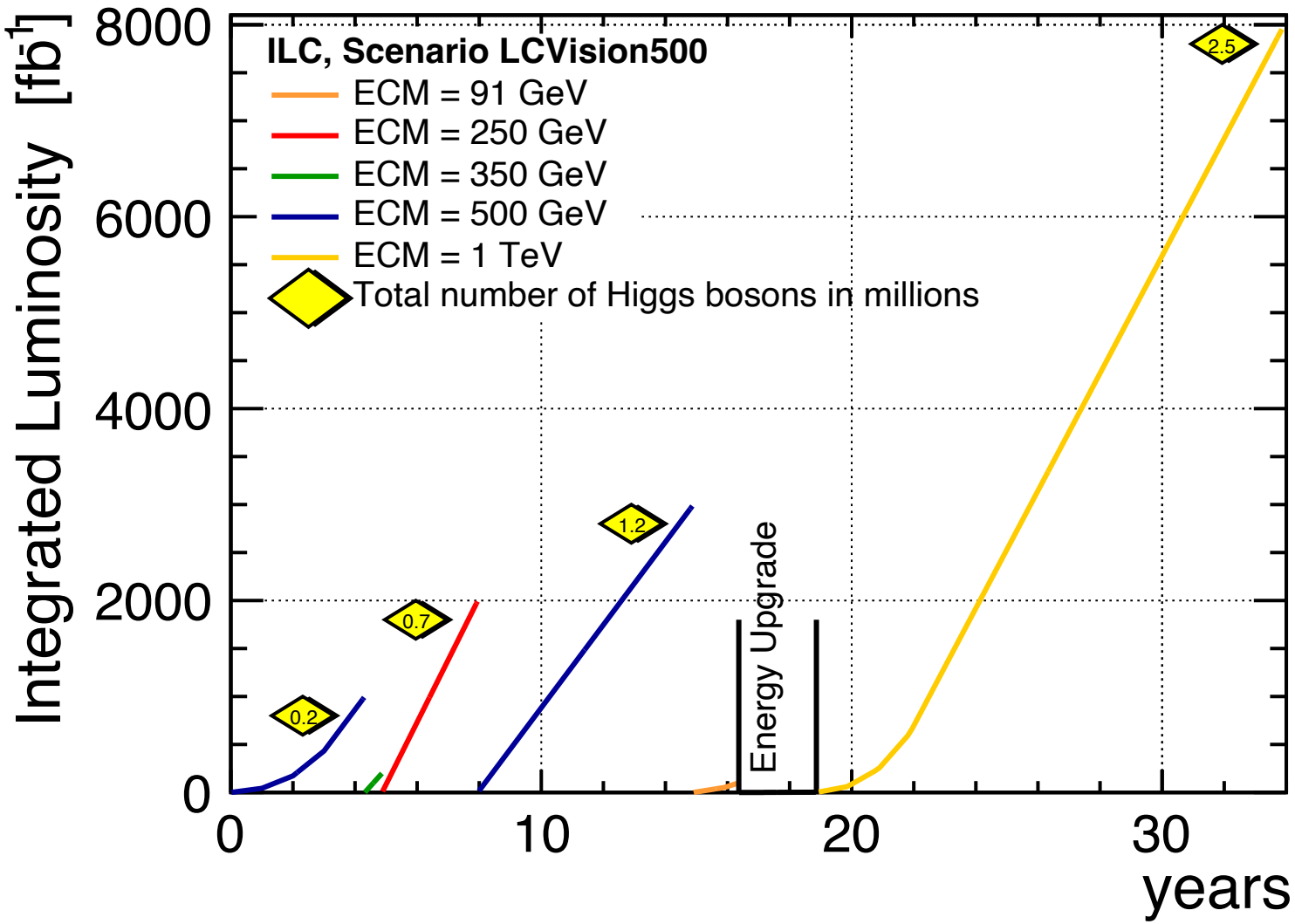




Higgs run 5 years

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 machine right away, and the same AC power and the same operation assumptions as for FCC-ee, the same data set could be taken in < 2 years**
- **Would be awesome if we could find a way to pay for this!!! :)**

LCVision Community Event

status of agenda

- https://indico.cern.ch/e/lcvision2025

- registration closed on Sunday
  - ~150 registrants
  - **~60 thereof in person**
  - if you still want to register for zoom, let me know…

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Happy Linear Collider Holidays!