Energy consumption & carbon footprint of proposed Higgs factories

J. Gonski, on behalf of US FCC

More information in arxiv:2208.10466, submitted to Snowmass'21 proceedings

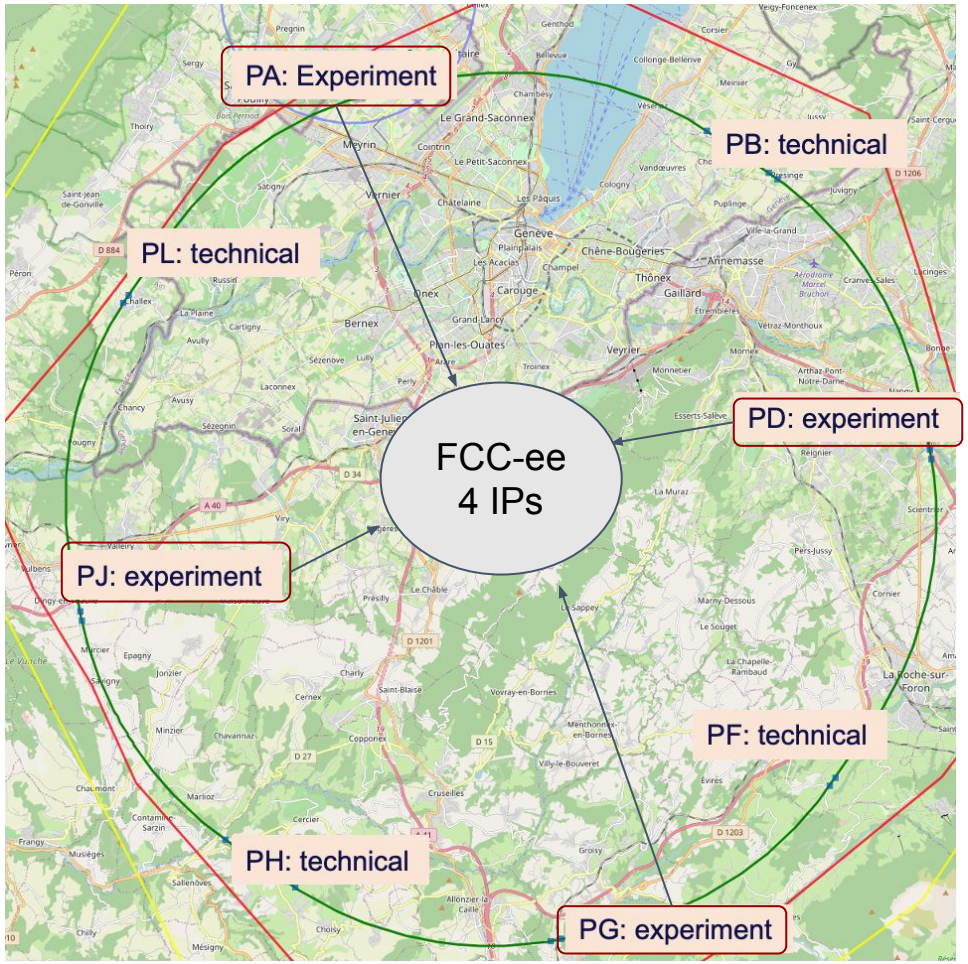
- It is important to send the message that scientists are sensitive to global warming & environmental health in our collider choice, design, & optimization.
- **We aim to do the most science with the least energy consumption & minimum environmental impact.**

Coupling Precision from a global EFT fit

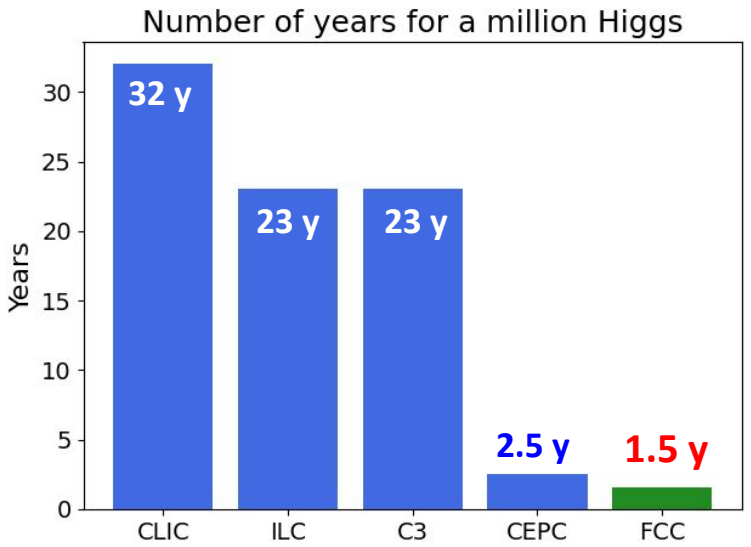
Higgs Coupling	ZZ/WW	bb	cc	gg	$\tau\tau$
Without long. polarization (%)	0.41	0.72	1.2	1.1	0.81
With long. polarization (%)	0.36	0.71	1.3	1.2	0.79

Numbers extrapolated from Table XIX of arXiv:1903.01629

→ **The physics outcome of an e^+e^- Higgs factory depends on the number of H events produced** *(left: coupling precision* ***with 10^6 ZH*** *events)*



- Once the desired physics outcome is agreed upon by scientific committees, the **FCC-ee**, with its **4 experiments** and its **larger luminosity** at each interaction point, can deliver **more Higgs events** faster than other Higgs factory proposals



Impact on energy consumption during operation

Higgs factory	CLIC	ILC	C^3	CEPC	FCC-ee
$\sqrt{s}$ (GeV)	380	250	250	240	240
Instantaneous power P (MW)	110	140	150	340	290
Annual collision time T (10^7 s)	1.20	1.60	1.60	1.30	1.08
Operational efficiency ϵ (%)	75	75	75	60	75
Annual energy consumption E (TWh)	0.4	0.7	0.8	1.6	1.0

(see also FACT2022-FRXAS0101)

The Snowmass'21 Implementation Task Force collected the power (in MW) of each Higgs factory (arXiv:2208.06030) …

… from which the annual energy consumption during operation as a Higgs factory can be inferred consistently (arXiv:2208.10466)

Impact on energy consumption during operation

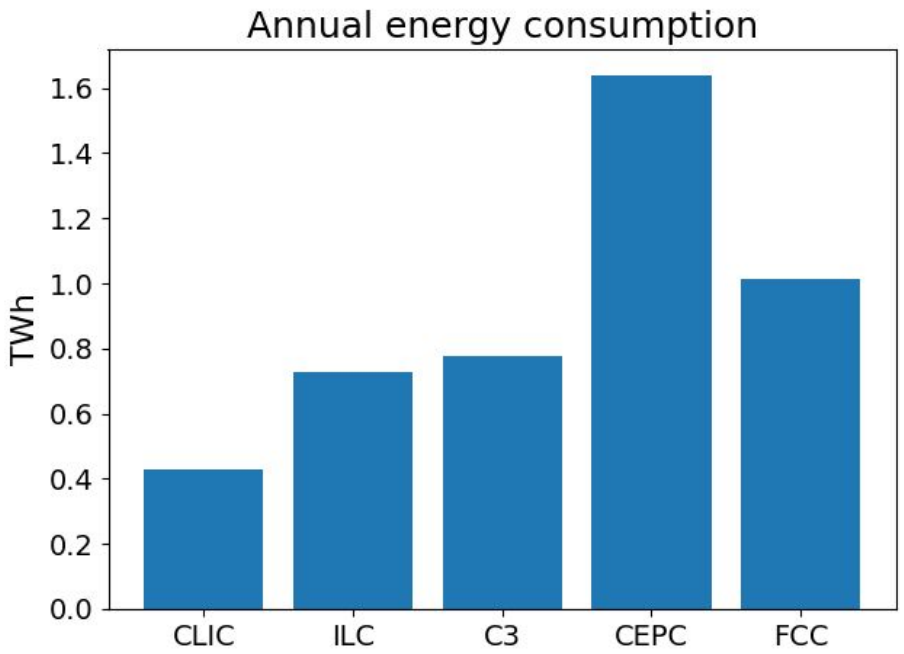
Higgs factory	CLIC	ILC	C^3	CEPC	FCC-ee
$\sqrt{s}$ (GeV)	380	250	250	240	240
Instantaneous power P (MW)	110	140	150	340	290
Annual collision time T (10^7 s)	1.20	1.60	1.60	1.30	1.08
Operational efficiency ϵ (%)	75	75	75	60	75
Annual energy consumption E (TWh)	0.4	0.7	0.8	1.6	1.0

(see also FACT2022-FRXAS0101)

The Snowmass'21 Implementation Task Force collected the power (in MW) of each Higgs factory (arXiv:2208.06030) …

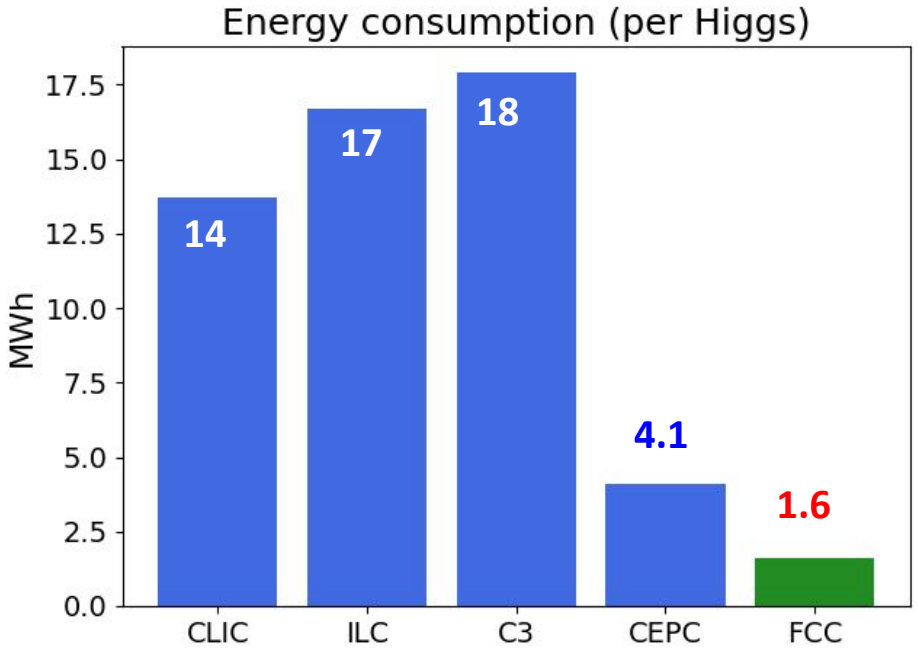
… from which the annual energy consumption during operation as a Higgs factory can be inferred consistently (arXiv:2208.10466)

→ Normalizing the energy consumption by the # Higgs produced shows the circular colliders are lowest



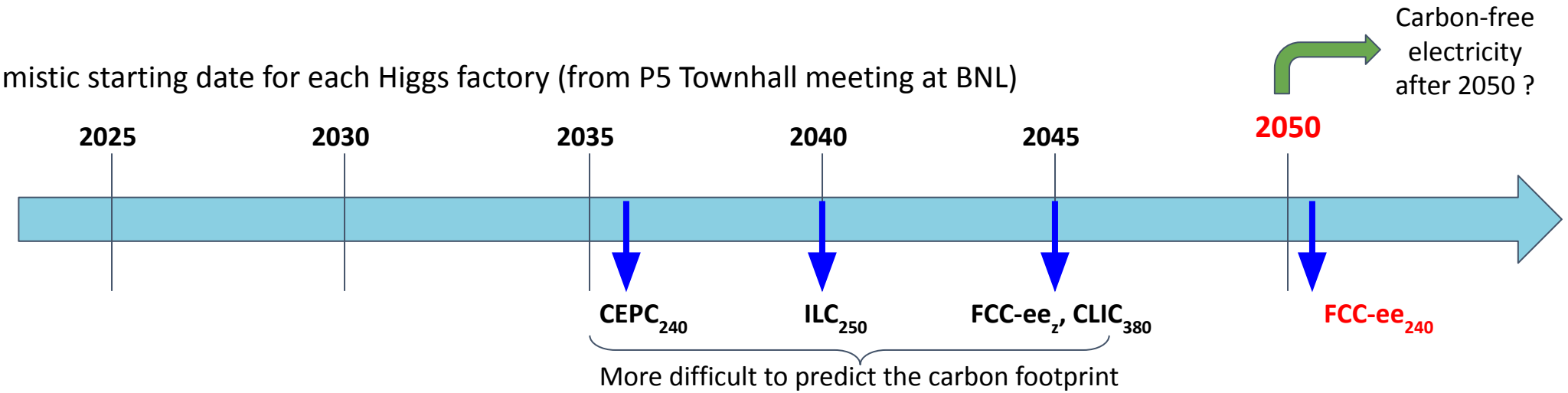
x (number of years to 10^6 Higgs bosons)

/ (10^6 Higgs bosons)

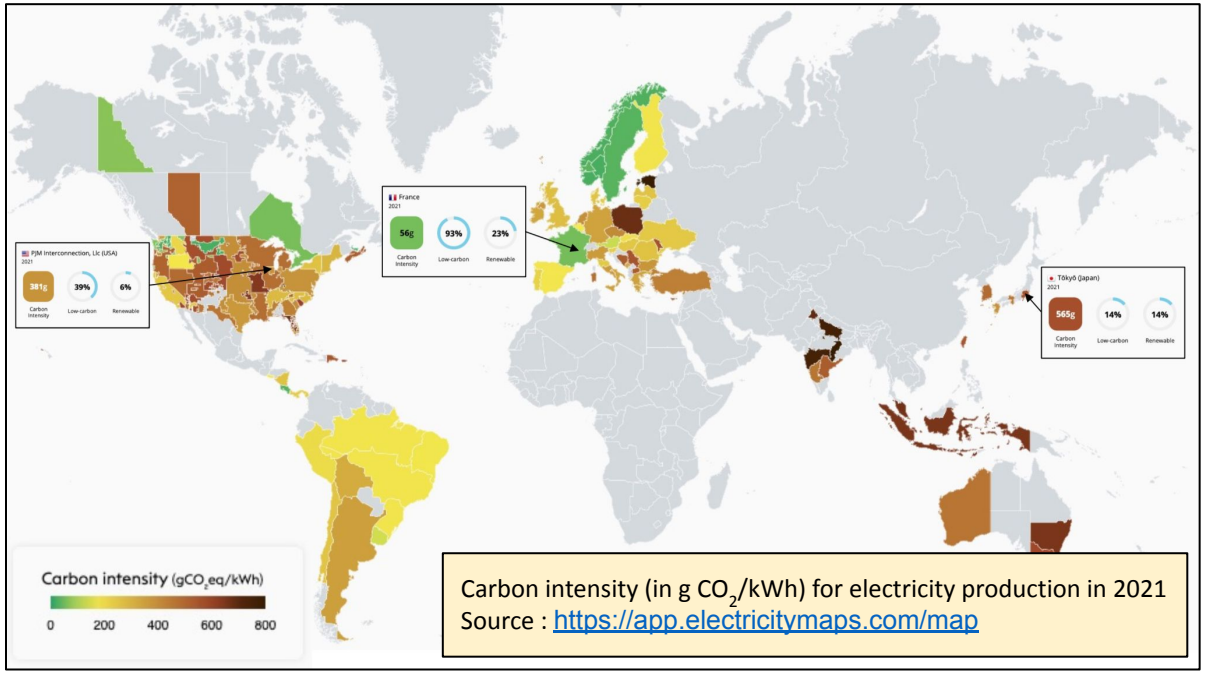


Impact on carbon footprint during operation

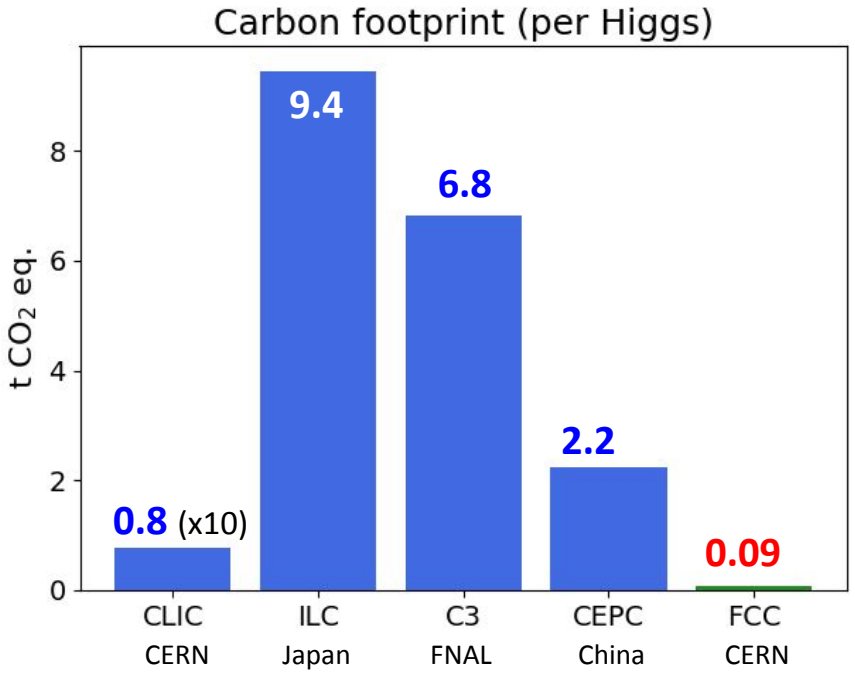
Most optimistic starting date for each Higgs factory (from P5 Townhall meeting at BNL)



If all Higgs factories were to start **TODAY**, CERN (CLIC, FCC-ee) would benefit already from an almost carbon-free electricity



Carbon intensity (in g CO_2/kWh) for electricity production in 2021
Source : https://app.electricitymaps.com/map



Conclusions

➔ A Higgs factory is an attractive option for the next collider, and many strong proposals exist (linear & circular)

- FCCee, with 4 interaction points and high luminosity, delivers **more Higgs events faster** than other options
  - Linear colliders have **lower annual power consumption**, but FCCee has the **lowest power per Higgs**
  - *How could we incorporate a harmonized physics outcome into energy considerations?*
- Hosting FCCee at CERN benefits from **cleaner/lower carbon** sources of power (if started today)
  - *How can we best predict carbon neutrality of power and comprehensively account for all sources?*

➔ **Accounting for the physics output of the collider & carbon intensity reveals there are multiple ways to evaluate the "best" candidate from an energy perspective: we all benefit from a harmonized & comprehensive view across communities!**

Additional remarks

- The FCC-ee realistic annual running time is about six months, to be compared to the optimistic nine months for ILC

- Less physics days every year also give additional flexibility
  - To operate the collider only when electricity is available (priority always given to the population)
  - To operate the collider only when electricity is carbon-free

- The dissipated heat and the geothermal energy in the tunnel can be used for domestic uses. For the latter, the longer and deeper the tunnel, the better!

- Today, the construction of the FCC tunnel has a carbon footprint that corresponds to three years of running
  - Similarly to solar panels or electric vehicles, the investment pays off after three years in terms of CO_2 footprint
  - The FCC tunnel is also fully recyclable, as it may be used again by FCC-hh for several decades, and maybe used again for other options later on (muon collider?)
  - Today, the tunnel carbon footprint is dominated by concrete production: cleaner production methods are being developed as we speak, and could be available by the time of construction
  - A complete estimate of the FCC carbon footprint will be available at the end of the feasibility study

- CERN (and other candidate hosts) will do a lot in the direction of reducing energy consumption and carbon footprint
  - For example: Improve the lattice towards larger specific luminosity; Develop energy-efficient technologies (RF power sources, etc.); Generalise dissipated heat and geothermal energy recovery; Maximise synergies with carbon-free energy production; Develop new ideas that transcend the limits of silicon for data storage and analysis; …
  - All these efforts are highly incentive of innovative developments
  - These developments will serve the society at large