2025 European Edition of the International Workshop on the Circular Electron-Positron Collider (CEPC), Barcelona, Spain

Sustainability for future colliders

Samuel Calvet

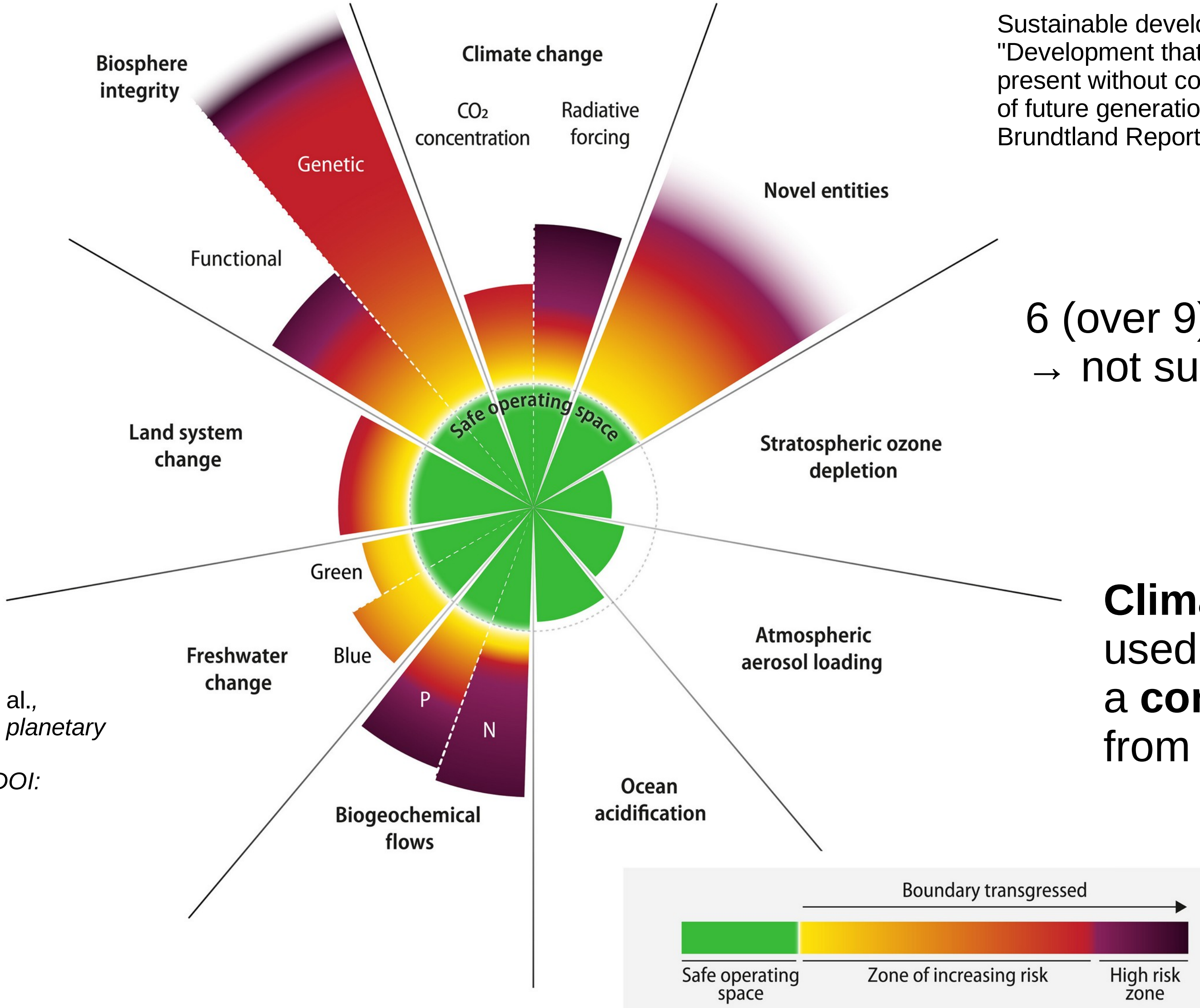
19/06/2025

NUCLÉAIRE & PARTICULES

LPC Particules pLasmas Univers applicationS
Laboratoire de Physique de Clermont

Sustainability = be within planetary boundaries

Sustainable development:
"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
Brundtland Report (1987) for UN



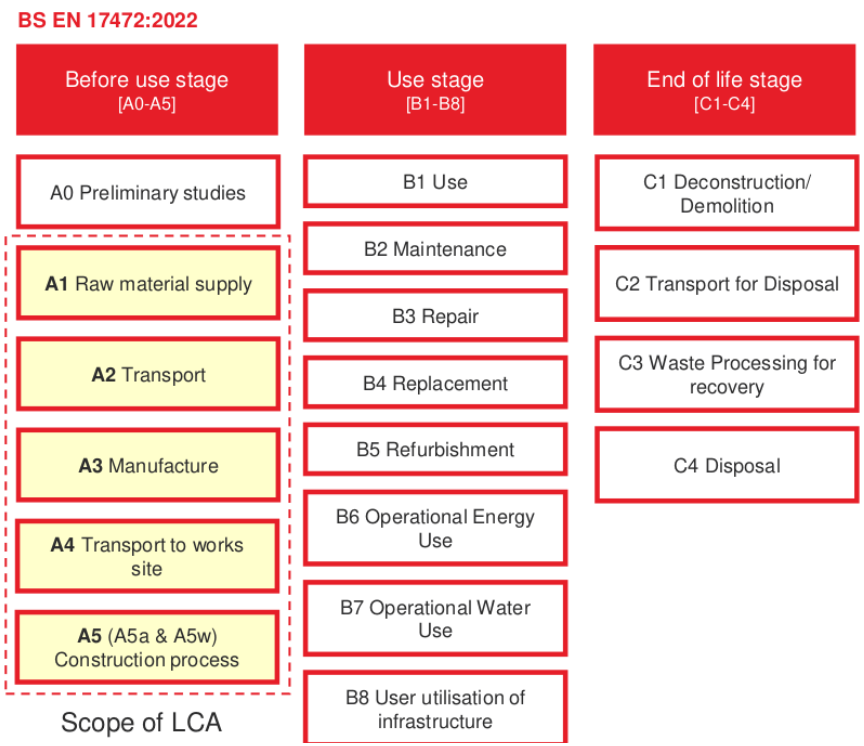
6 (over 9) limits overrun
→ not sustainable

Climate change used as a **convenient proxy** from now on...

Katherine Richardson et al., *Earth beyond six of nine planetary boundaries.Sci. Adv.9,eadh2458(2023).DOI:* 10.1126/sciadv.adh2458

Life Cycle Assessment/Analysis

- LCA very useful to reduce env. footprint of project during R&D
  - Estimate impacts in terms of C, water consumption, ozone, …
  - For the different stages of a project



Midpoint Impact Categories	Abbr.	Unit
Global warming	GWP	kg CO_2 eq
Stratospheric ozone depletion	ODP	kg CFC-11 eq
Ionizing radiation	IRP	kBq Co-60 eq
Fine particulate matter formation	PMFP	kg PM2.5 eq
Ozone formation, Human health	HOFP	kg NOx eq
Ozone formation, Terrestrial ecosystems	EOFP	kg NOx eq
Terrestrial acidification	TAP	kg SO_2 eq
Freshwater eutrophication	FEP	kg P eq
Marine eutrophication	MEP	kg N eq
Terrestrial ecotoxicity	TETP	kg 1,4-DCB
Freshwater ecotoxicity	FETP	kg 1,4-DCB
Marine ecotoxicity	METP	kg 1,4-DCB
Human carcinogenic toxicity	HTPc	kg 1,4-DCB
Human non-carcinogenic toxicity	HTPnc	kg 1,4-DCB
Land use	LOP	m^2a crop eq
Mineral resource scarcity	SOP	kg Cu eq
Fossil resource scarcity	FFP	kg oil eq
Water consumption	WCP	m^3

Life Cycle Assessment/Analysis

- Identified as a key component of future R&D
  Examples:
  - CERN course:
    https://lms.cern.ch/ekp/servlet/ekp?PX=N&TEACHREVIEW=N&CID=EKP000044552&TX=FORMAT1&LANGUAGE_TAG=en&DECORATEPAGE=N

Introduction to Environmental Life Cycle Assessment (LCA) for Engineers (e-learning)

Accéder à la session

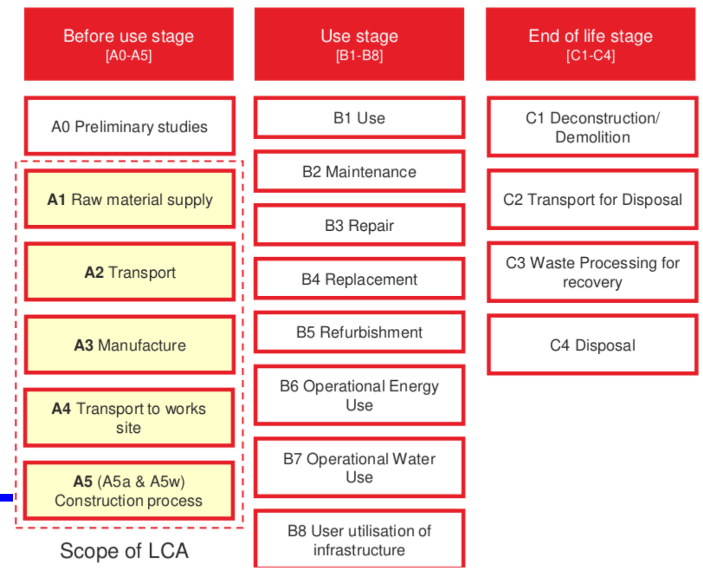
This e-learning provides an **introduction to Life Cycle Assessment (LCA)**, a detailed method for evaluating the environmental impacts of products throughout their entire life cycle, from raw material extraction to disposal. The primary objective of this course is to build your knowledge and skills in the Life Cycle Assessment, enrich the theoretical part of LCA, and understand how to use this in your work.

  - IN2P3 one-week training

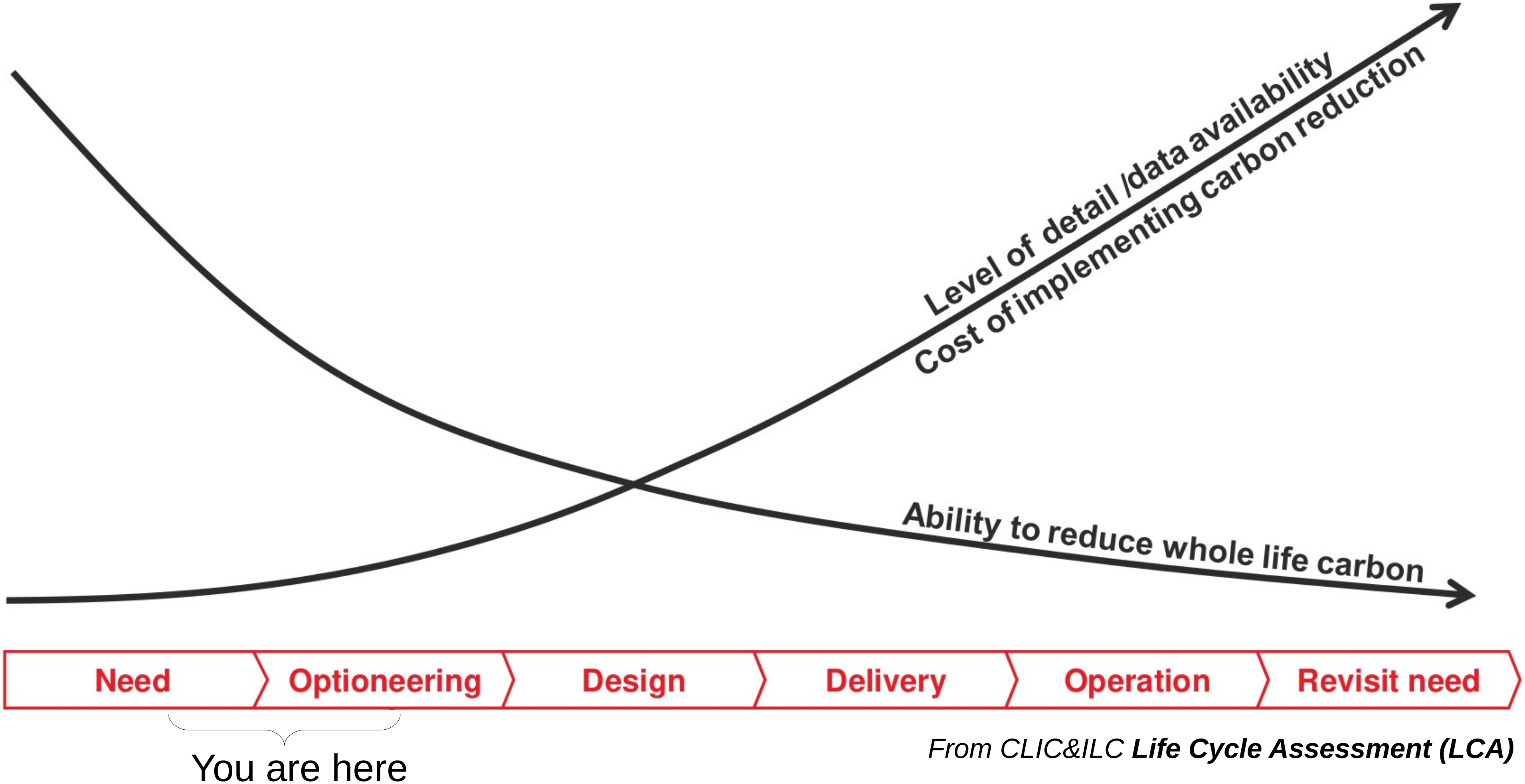
Action Nationale de Formation "Eco-conception orientée projets"

12–17 oct. 2025

Midpoint Impact Categories	Abbr.	Unit
Global warming	GWP	kg CO_2 eq
Stratospheric ozone depletion	ODP	kg CFC-11 eq
Ionizing radiation	IRP	kBq Co-60 eq
Fine particulate matter formation	PMFP	kg PM2.5 eq
Ozone formation, Human health	HOFP	kg NOx eq
Ozone formation, Terrestrial ecosystems	EOFP	kg NOx eq
Terrestrial acidification	TAP	kg SO_2 eq
Freshwater eutrophication	FEP	kg P eq
Marine eutrophication	MEP	kg N eq
Terrestrial ecotoxicity	TETP	kg 1,4-DCB
Freshwater ecotoxicity	FETP	kg 1,4-DCB
Marine ecotoxicity	METP	kg 1,4-DCB
Human carcinogenic toxicity	HTPc	kg 1,4-DCB
Human non-carcinogenic toxicity	HTPnc	kg 1,4-DCB
Land use	LOP	m^2a crop eq
Mineral resource scarcity	SOP	kg Cu eq
Fossil resource scarcity	FFP	kg oil eq
Water consumption	WCP	m^3



The key plot



From CLIC&ILC ***Life Cycle Assessment (LCA)***

What are the main ingredients for a collider ?

Environnemental footprint = tunnel
+ accelerator construction
+ accelerator operation
+ detector construction
+ detector operation
+ computing
+ collaboration life

(detector construction, detector operation, computing, collaboration life) x $N_{experiments}$

What are the main ingredients for a collider ?

Environnemental footprint = tunnel
+ accelerator construction
+ accelerator operation
+ detector construction
+ detector operation
+ computing
+ collaboration life

} x $N_{experiments}$ (applies to: detector construction, detector operation, computing, collaboration life)

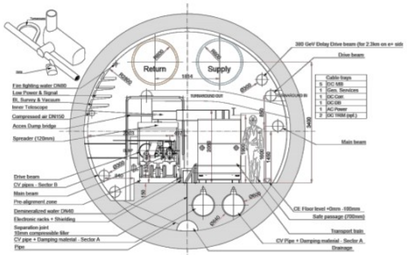
Today: 35tCO_2eq/year/LHC physicist when LHC is running
(not accounting for travels, WLCG, ...)

Tunnel (@LO)

Main parameters:

length, profile : amount of concrete and steel

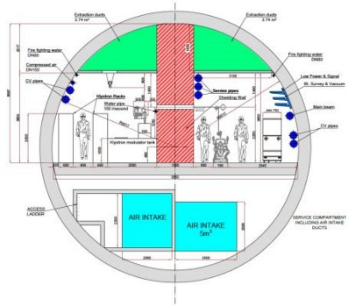
11-50km



CLIC Drive beam, 5.6m dia.

Geneva

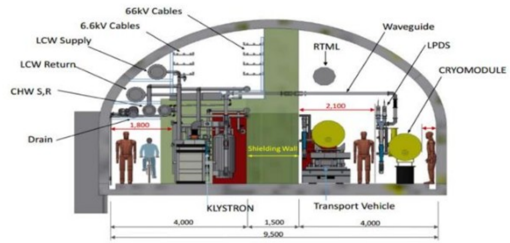
Energies: 380GeV, 1.5TeV, 3TeV.



CLIC Klystron, 10m dia.

Geneva

Energies: 380GeV



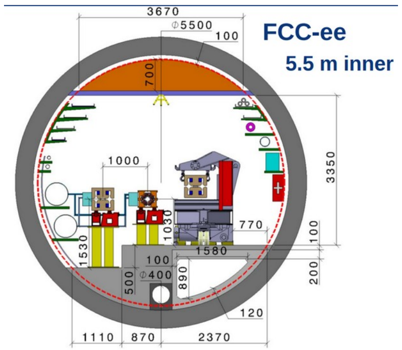
ILC, 9.5m span

Tohoku Region, Japan

Energies: 250GeV

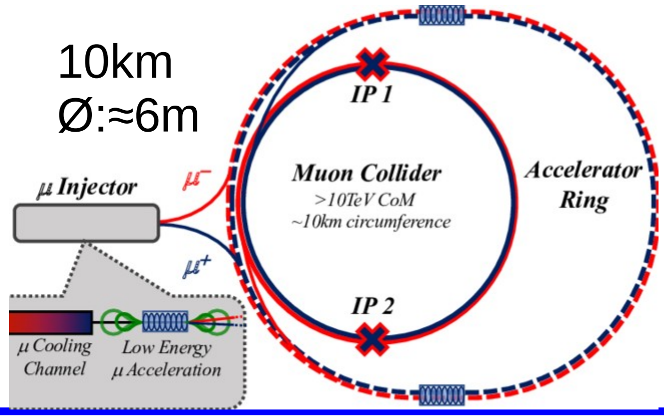
33km

90km



10km

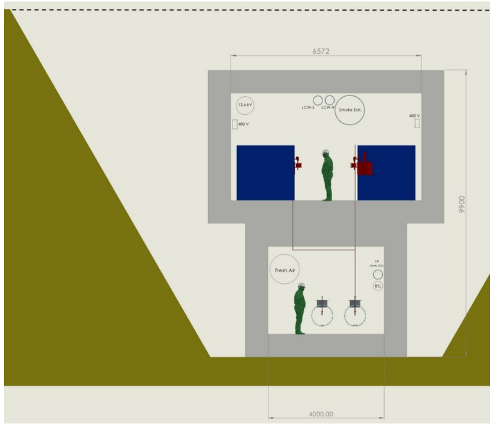
Ø:≈6m



CCC

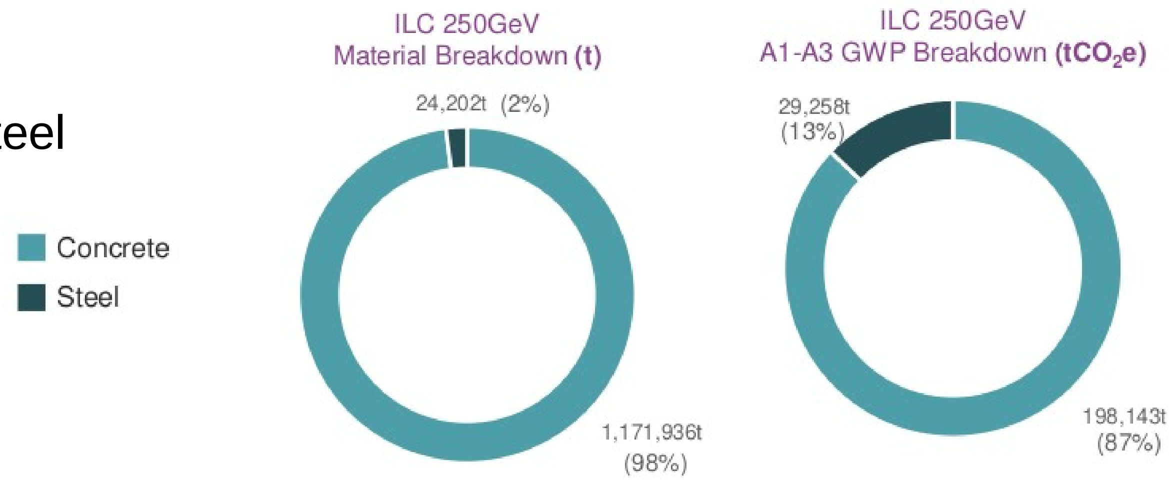
8km

T=80K



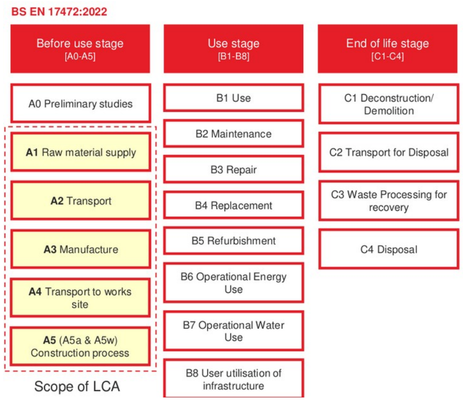
Tunnel (LO) + everything related to it (NLO)

Ex: ILC
- CEMI concrete
- 80% recycled steel



Project	Main tunnel length (km)	GWP (kton CO_2e) Main tunnel	+ other structures	+ A4-A5	
FCC	90.6	578	751	939	+60%
CEPC	100	638	829	1040	
ILC	13.3	97.6	227	266	+170%
CLIC	11.5	73.4	98	127	+70%
C^3	8.0	133	133	146	+10%

A4-A5: transport + construction process



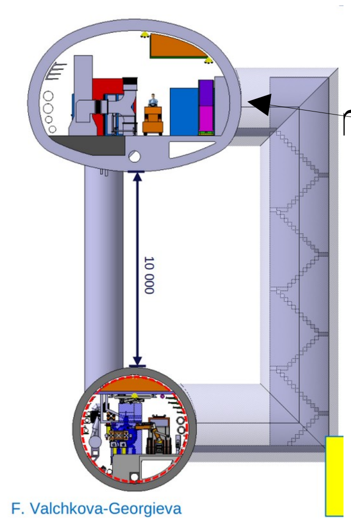
From https://arxiv.org/abs/2307.04084
FCC&CEPC: rough estimates from CLIC LCA!

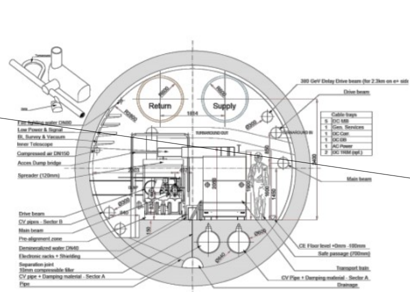
Tunnel @NLO

Main parameters:

length, profile : amount of concrete and steel, technology

Klystron isolation, number of shafts, caverns

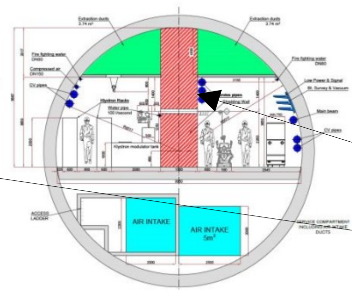




CLIC Drive beam, 5.6m dia.

Geneva

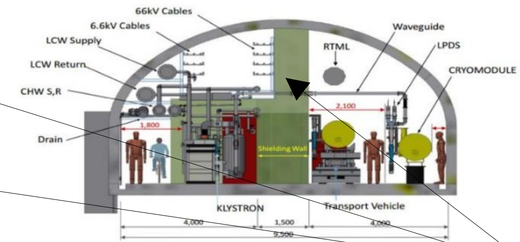
Energies: 380GeV, 1.5TeV, 3TeV.



CLIC Klystron, 10m dia.

Geneva

Energies: 380GeV

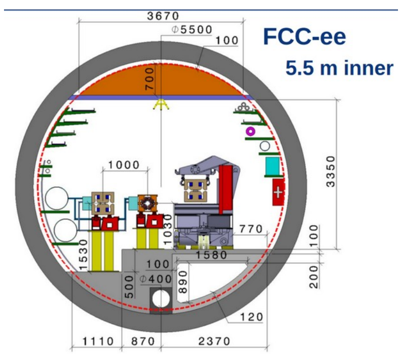


ILC, 9.5m span

Tohoku Region, Japan

Energies: 250GeV

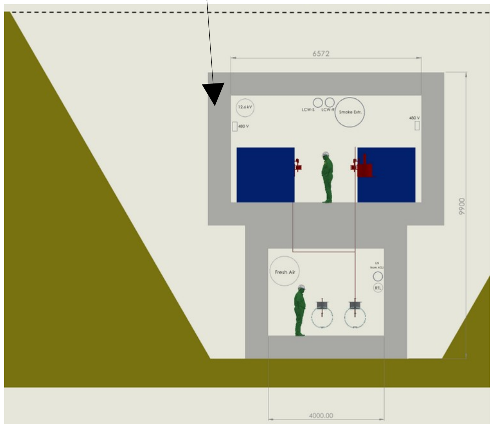
Isolate the beams from klystron's heat and electromagnetic noise



CCC

8km

T=80K

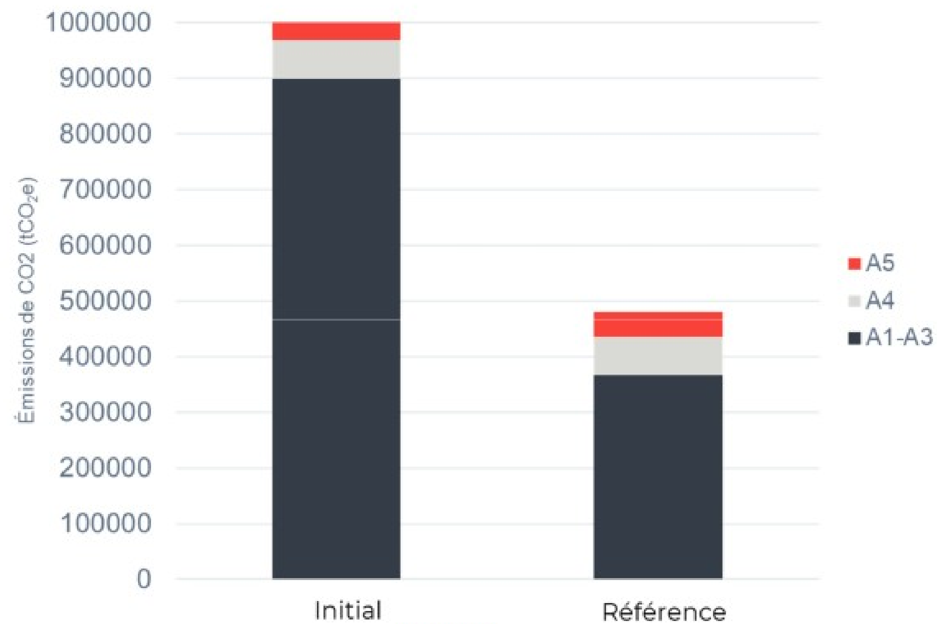


Tunnel @NLO

- FCC LifeCycleAnalysis:
  ”improving” concrete and steel types:

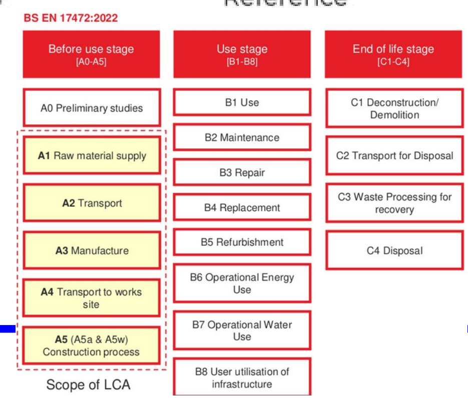
Calcul initial	Scénario de référence
999 780 tCO_2(eq)	**477 390 tCO_2(eq)**
Réduction	**52%**

Matériaux de référence dans l'outil OneClickLCA	Émission CO_2	Fournisseurs locaux avec une proposition équivalente	Réduction par rapport au matériau initial
Steel sheets, generic, 100% recycled content, S235, S275 and S355	0.87 $kgCO_2e/kg$	Sottas Morand	77%
Steel fibre for concrete reinforcement, 100% recycled content	0.51 $kgCO_2e/kg$	Sottas	75%
Reinforcement steel (rebar), generic, 100% recycled content, A615	0.42 $kgCO_2e/kg$	Stahl Sottas	70%
Ready-mix concrete, normal strength, generic, C35/45 (5000/6500 PSI) with CEM III/A (340 kg/m^3)	170.36 $kgCO_2e/m^3$	Probéton Vigier Holcim	48%
Ready-mix concrete, low-strength, generic, C12/15 (1700/2200 PSI) (220 kg/m^3)	149.41 $kgCO_2e/m^3$	Probéton Vigier Holcim	31%
Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI) with CEM III/B,	173.00 $kgCO_2e/m^3$	Probéton Vigier Holcim	39%



Possible k-factor of 0.5

But need to check ...
- the scaling up with industry
- the cost
- the timescale



Toward a 0-net CO_2 emission tunnel ?

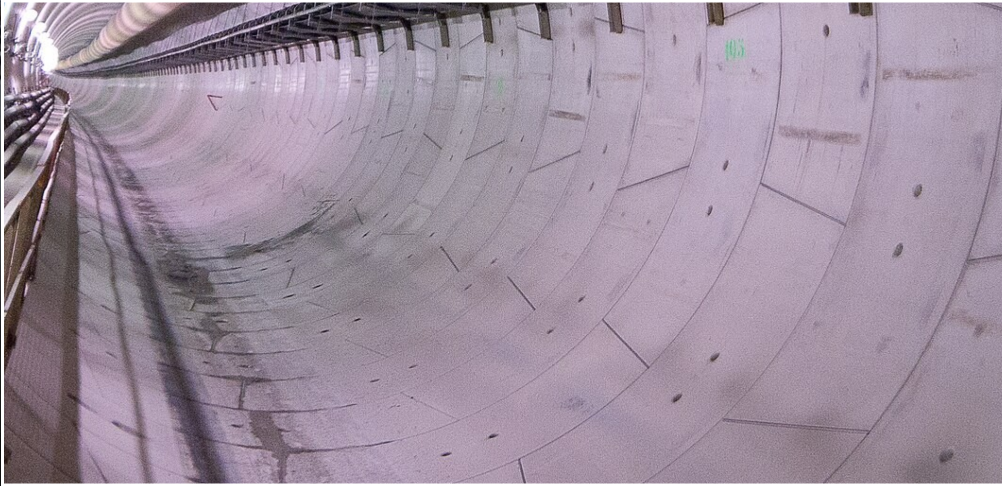
Industry is elaborating cement free concrete

https://carbicrete.com/specify-carbicrete/

- Cement fully replaced by steel slag
- CO_2 captured from a plant
- CO_2 injected into the slag+gravel to produce concrete

→ **negative CO_2eq concrete** ! (but only prefab)

Needs to certify the concrete
for tunnel usage
Usual scaling-up issue,
but would help the civil society



Idea submitted to CERN

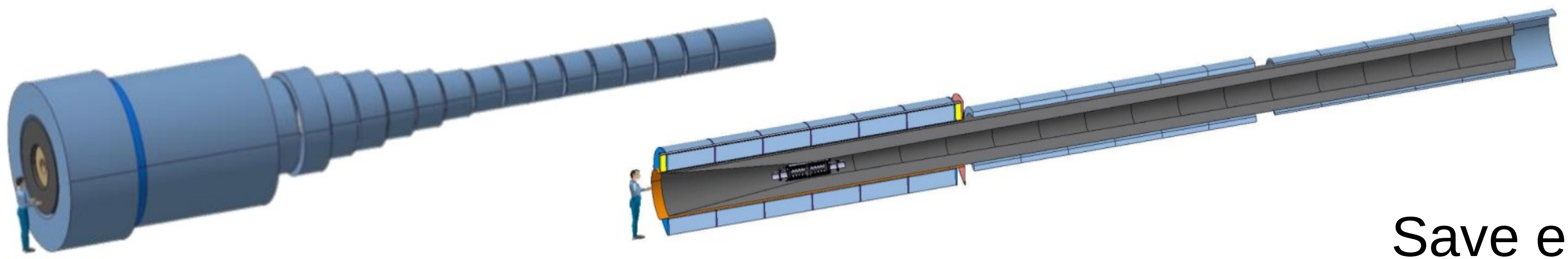
Accelerator construction

- Interesting one: muon collider

Future accelerator technologies?
High Temperature Superconductors

International MUON Collider Collaboration

Target & Capture Solenoids for the Muon Collider



Save energy & materials

US-MAP Proposal (<2016)

E_M = 2.9 GJ
T_{op} = 4.2 K
M_{coils} = 200 tons
M_{shield} = 300 tons
P = 12 MW

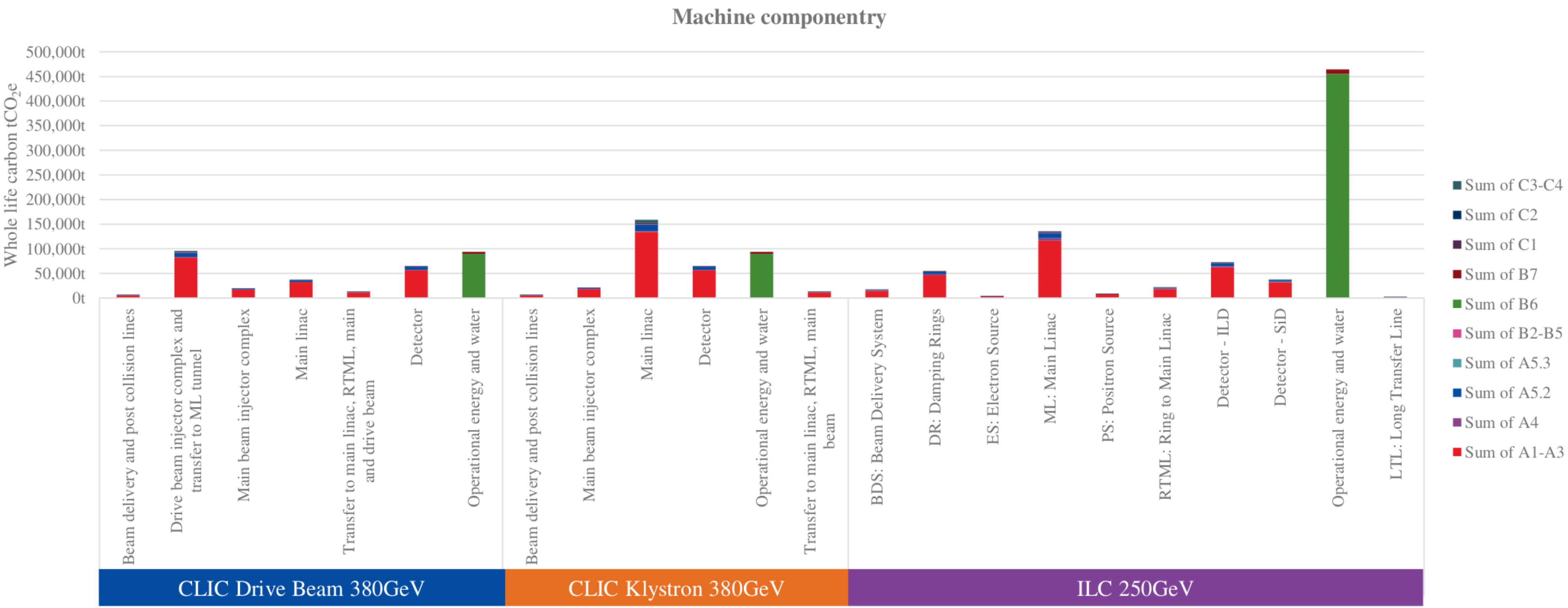
EM = 1 GJ
Top = 10…20 K
Mcoils = 110 tons
Mshield = 196 tons
P = 1 MW

IMCC Proposal (2023)

CERN 8 November 2024 R. Losito, CERN and the Environment Town Hall Event 1

Accelerator construction

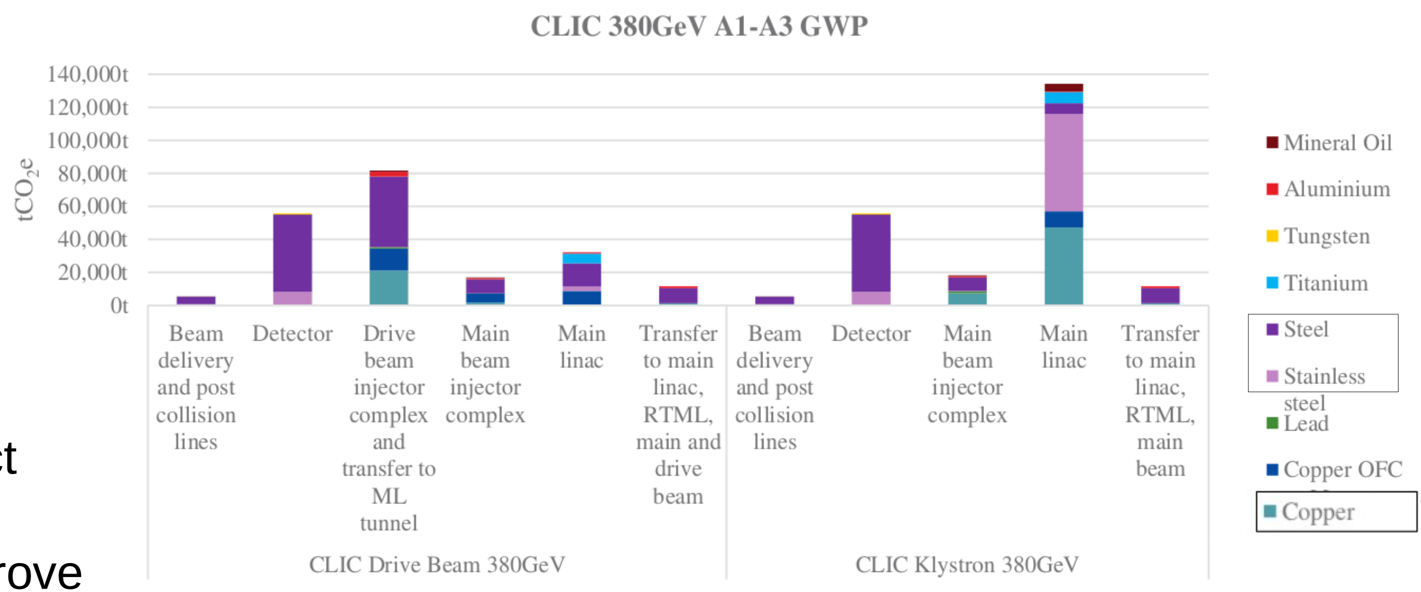
- Construction of accelerator can have impact as large as the operations

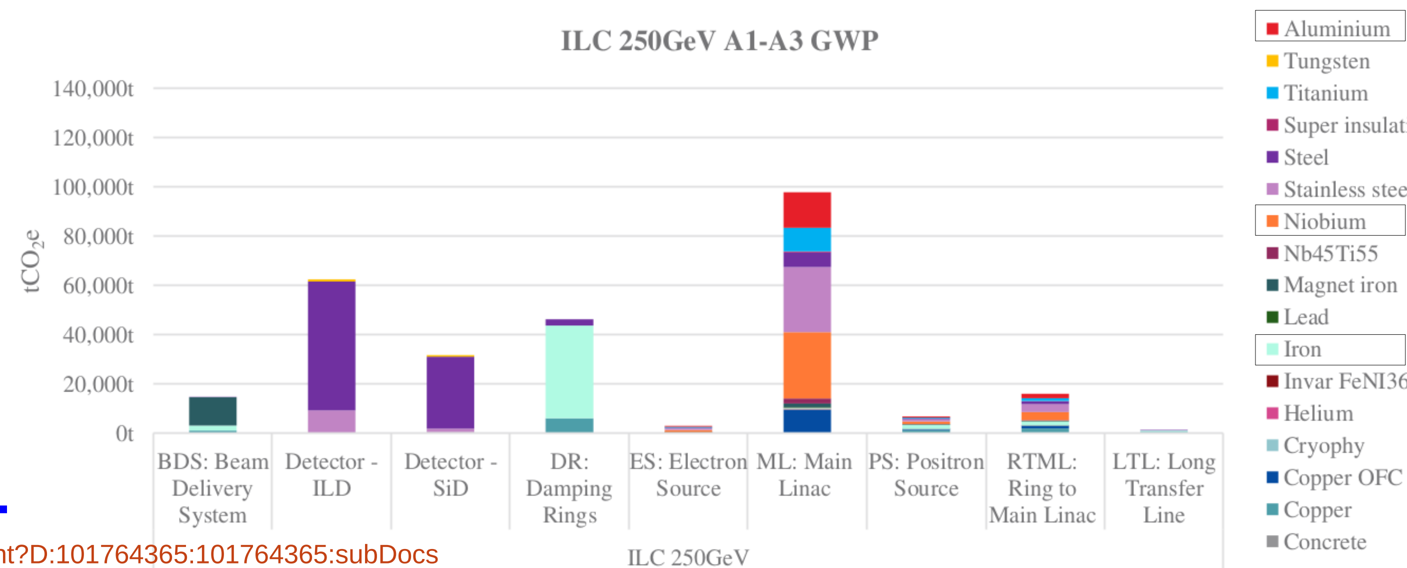


https://edms.cern.ch/ui/#!master/navigator/document?D:101764365:101764365:subDocs

Accelerator construction

- Identifying the key contributors allows to :
  - Work on the design to reduce their impact
  - Initiate discussions with suppliers to improve their processes

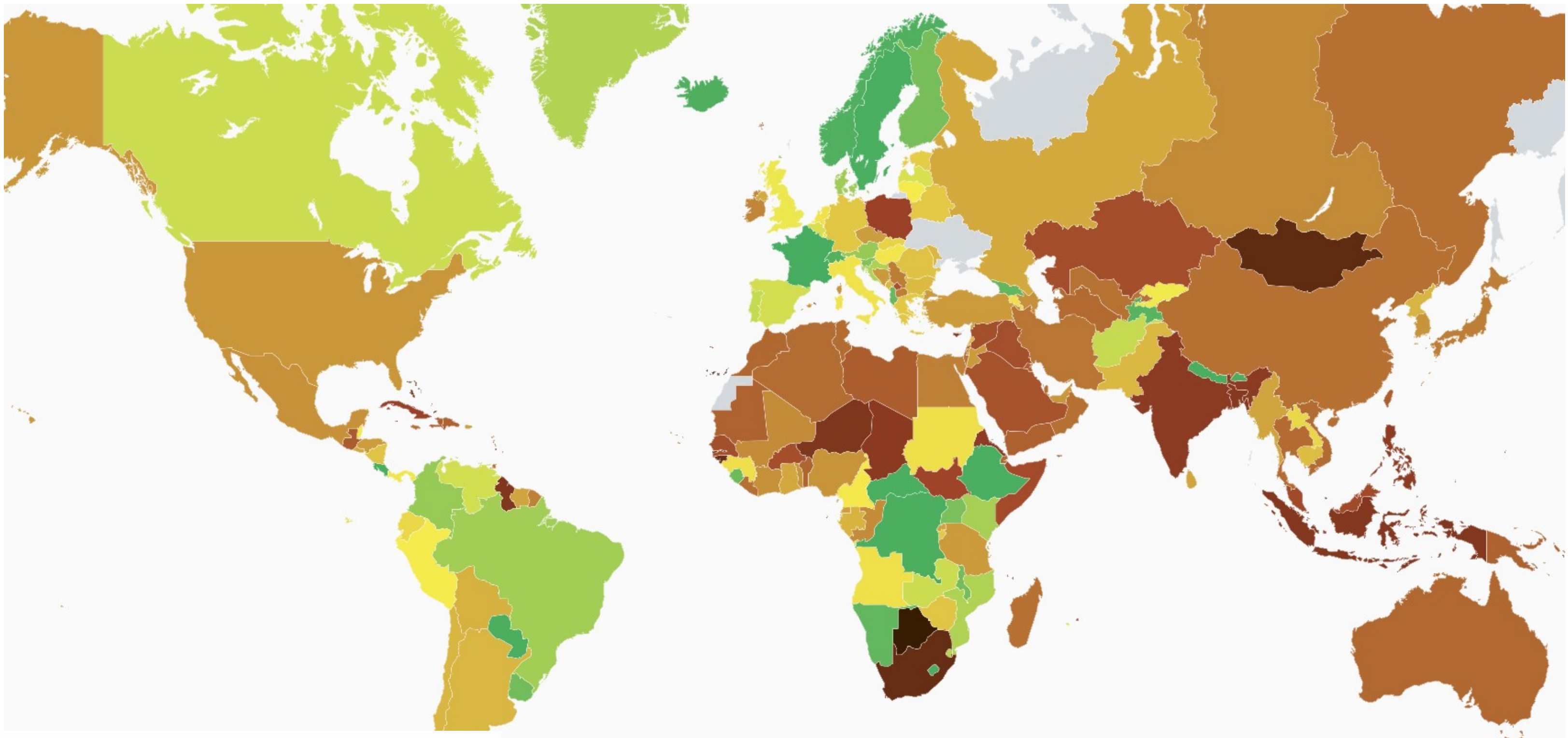


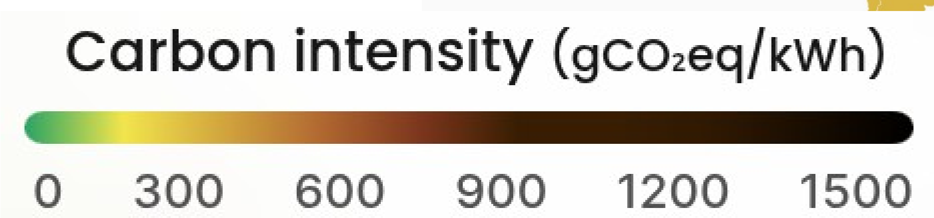


https://edms.cern.ch/ui/#!master/navigator/document?D:101764365:101764365:subDocs

Accelerator operations @LO

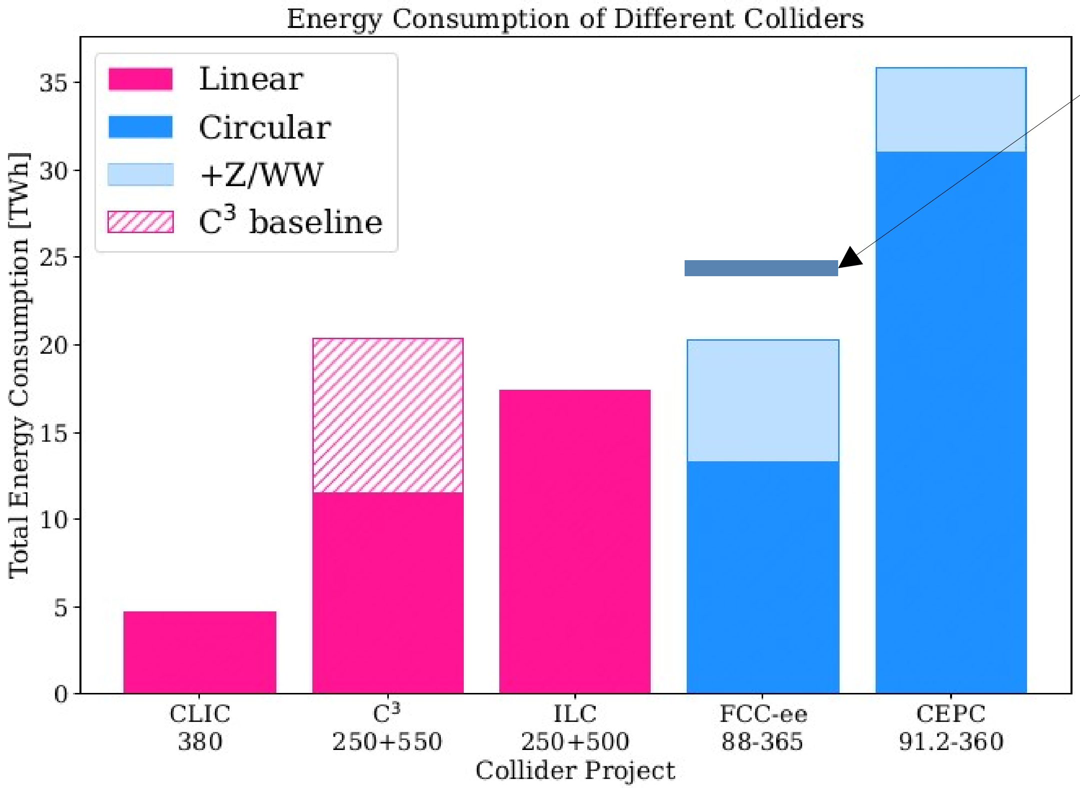
- Will depend accelerator energy/luminosity AND on the **electricity mix**
  (at the time of running the accelerator)
- Presently, very country dependent:





https://app.electricitymaps.com/map/12mo/monthly

Accelerator operations

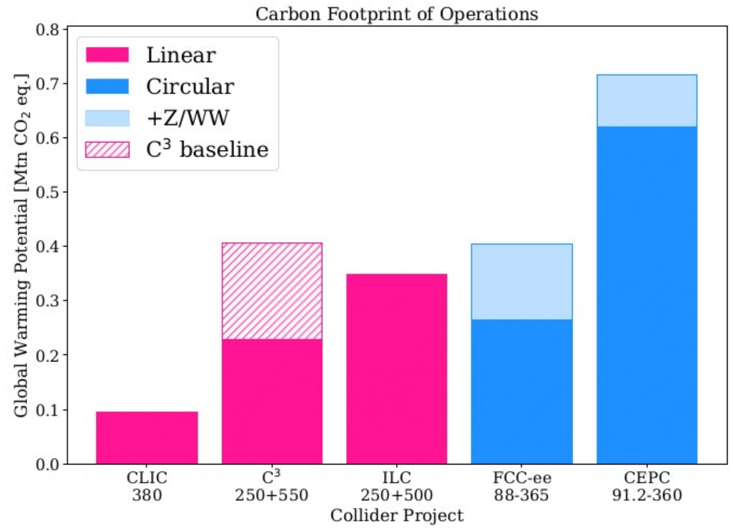


From J.P Burnet (sept 2024)

https://agenda.ciemat.es/event/4431/timetable/#20240926.detailed

To compare with 1.2TWh/year of present total CERN consumption

From https://arxiv.org/abs/2307.04084



Higgs factory	CLIC [40]	ILC [12]		C^3 [11]		CEPC [53], [54]				FCC [20], [55], [56]					
$\sqrt{s}$ (GeV)	380	250	500	250	550	91.2	160	240	360	88,91,94	157,163	240	340-350	365	
P (MW)	110	111	173	150 (87)	175 (96)	283	300	340	430	222	247	273	357		
$T_{\text{collisions}}$ (10^7 s/year)	1.20	1.60		1.60		1.30				1.08					
T_{run} (years)	8	11	9	10	10	2	1	10	5	2	2	2	3	1	4
$\mathcal{L}_{\text{inst}}$/IP ($\cdot 10^{34}$ cm^{-2} s^{-1})	2.3	1.35	1.8	1.3	2.4	191.7	26.6	8.3	0.83	115	230	28	8.5	0.95	1.55
$\mathcal{L}_{\text{int}}$ (ab^{-1})	1.5	2	4	2	4	100	6	20	1	50	100	10	5	0.2	1.5

Accelerator operation (details)

CEPC-TDR p. 965

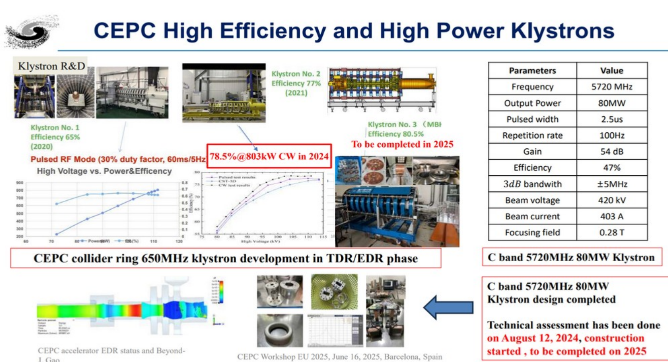
Table A3.13: Total facility power consumption in Z mode (30 MW/beam)

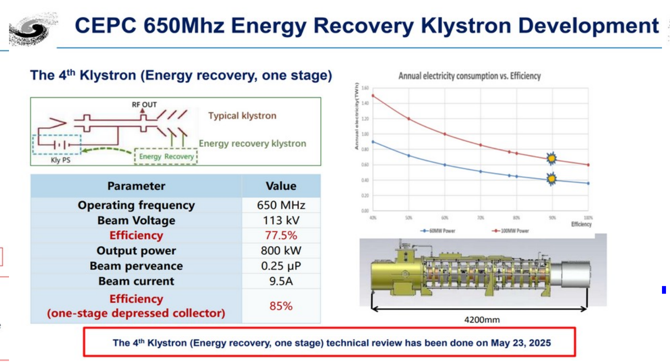
	System for W (30 MW /beam)	Location and power Requirement (MW)						Total (MW)
		Collider	Booster	Linac	BTL	IR	Surface building	
1	RF Power Source	96.90	0.15	12.26				109.31
2	Cryogenic System	3.32	0.77			0.16		4.25
3	Vacuum System	9.60	3.80	0.65				14.05
4	Magnet System	6.71	1.28	2.15	4.89	0.05		15.08
5	Instrumentation	1.30	0.70	0.20				2.20
6	Radiation Protection	0.25		0.10				0.35
7	Control System	1.00	0.60	0.20	0.005	0.005		1.81
8	Experimental Devices					4.00		4.00
9	Utilities	25.80	2.80	2.00	0.60	1.20		32.40
10	General Services	7.20		0.30	0.20	0.20	12.00	19.90
	Total	152.08	10.10	17.86	5.70	5.62	12.00	203.35

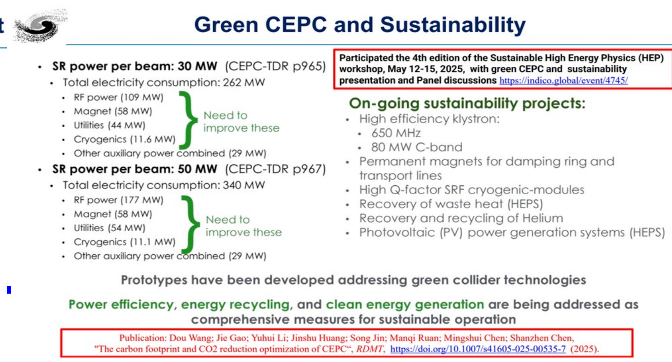
Total facility power consumption in $t\bar{t}$ mode (30 MW/beam)

	Location and power Requirement (MW)						Total (MW)
	Collider	Booster	Linac	BTL	IR	Surface building	
1	96.90	0.15	12.26				109.31
2	27.53	2.32			0.16		30.01
3	9.90	4.20	0.65				14.75
4	93.03	18.94	2.15	4.89	0.30		119.31
5	1.30	0.70	0.20				2.20
6	0.30		0.10				0.40
7	1.00	0.60	0.20				1.80
8					4.00		4.00
9	47.20	4.80	2.50	0.60	1.20		56.30
10	7.20		0.30	0.20	0.20	12.00	19.90
Total	284.36	31.71	18.36	5.69	5.86	12.00	357.98

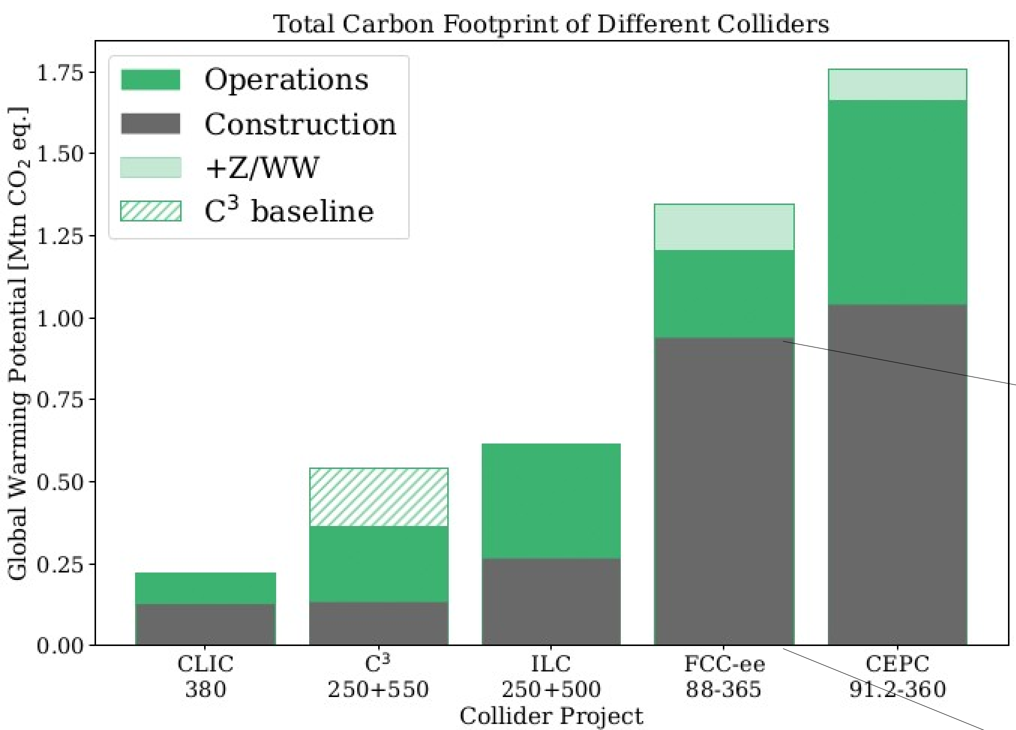
- At CEPC the main contributors are RF power and magnet
  - Nice to see the ongoing work to improve the efficiencies (see talk by Jie Gao)



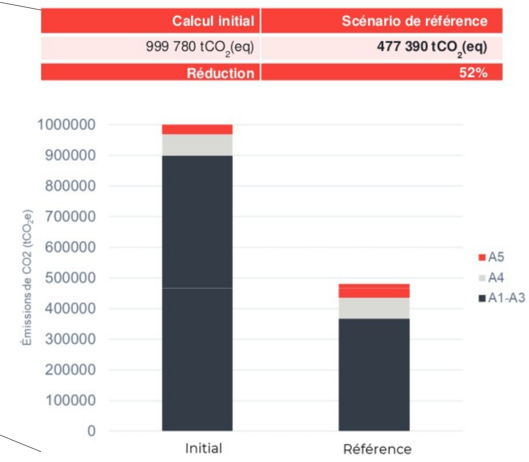




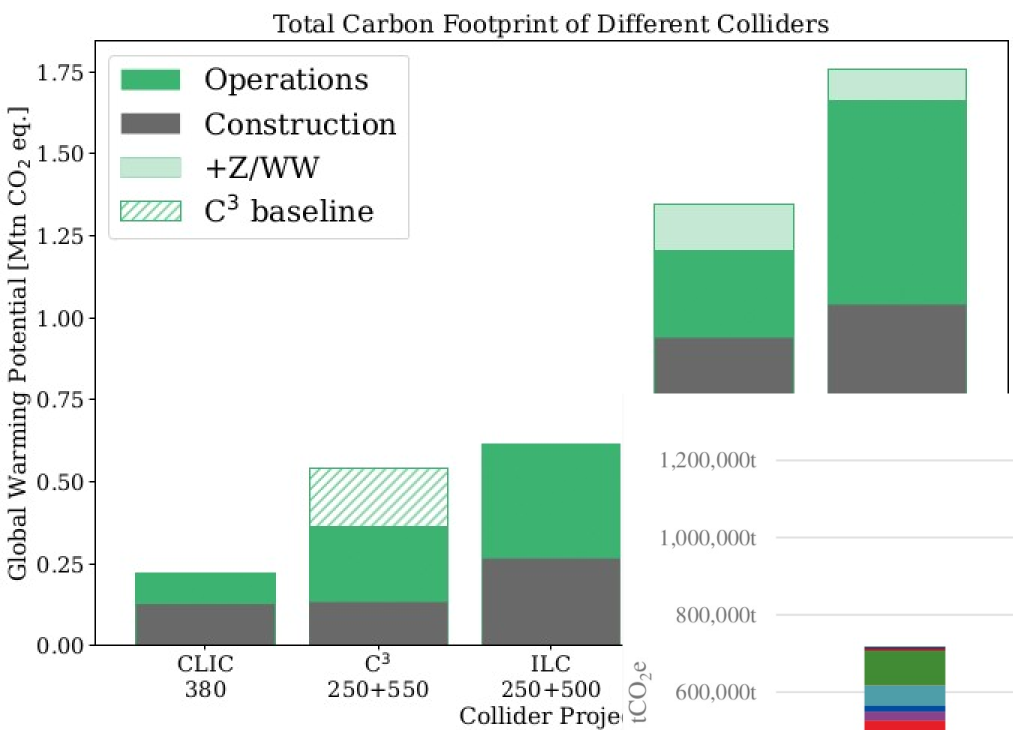
Tunnel + accelerator operation (wo/ building accelerator!)



Present estimates give similar order of magnitude between these 2 items
Sum = O(0.5-1.5)MtCo2eq

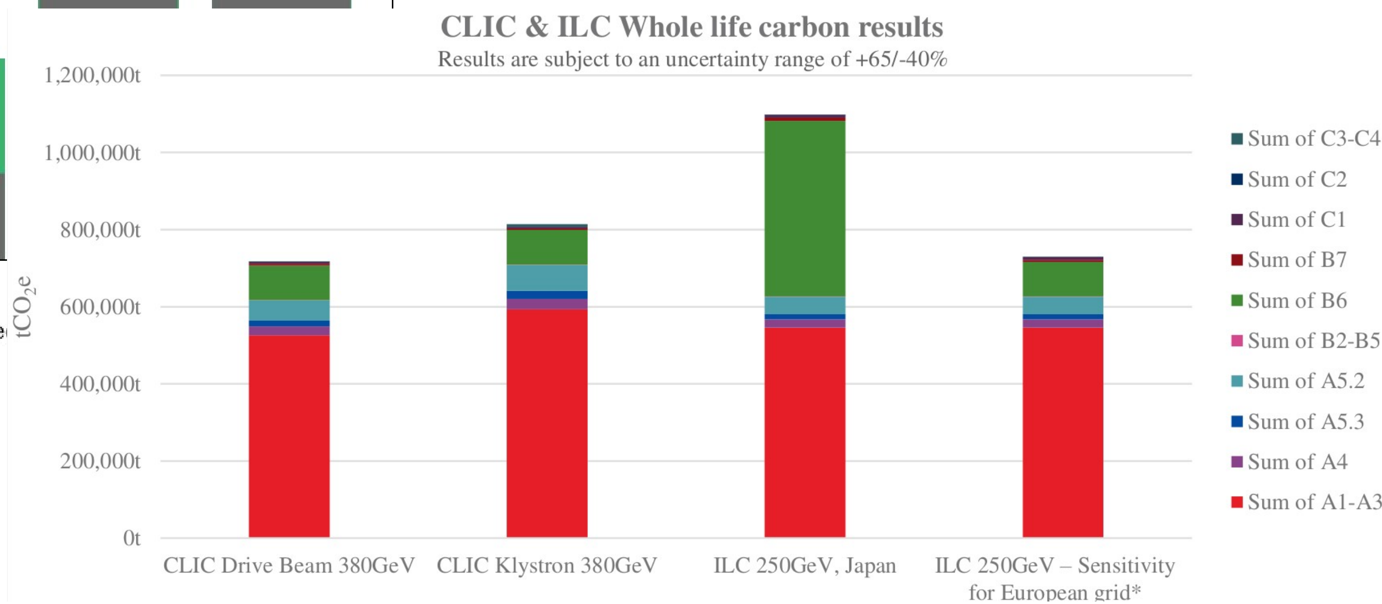


Tunnel + accelerator operation (**w/** building accelerator!)



Present estimates give similar order of magnitude between these 2 items
Sum = O(0.5-1.5)$MtCO_{2eq}$

Recent update on linear colliders (incl. Building acc.): O(1)$MtCO_{2eq}$



Detector construction

Radiotelescop array in China

- **No data yet !**

- Nice example of LCA :

Life Cycle Analysis of the GRAND Experiment

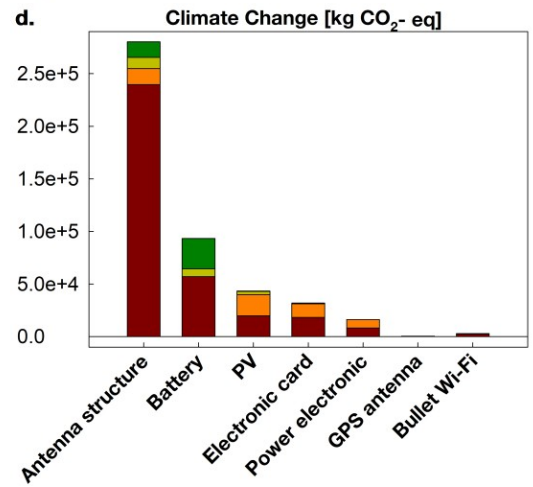
Leidy T. Vargas-Ibáñez[a,b], Kumiko Kotera[c,d], Odile Blanchard[e], Peggy Zwolinski[a], Alexis Cheffer[f], Mathieu Collilieux[f], Paul Lambert[f], Quentin Lefèbvre[f], Thomas Protois[f]

https://arxiv.org/abs/2309.12282

Antenna structure	Raw material production (extraction)	Total/net (including all components and processes)	AAPD* (%)
Climate Change [kg CO2eq]			
Base case X5CrNiMo18 (316)	239649.43	282015.80	
Alloy 1 X5CrNi18 (304)	229170.75	268695.30	4.72
Alloy 2 X20Cr13 (420)	146834.08	186358.63	33.92
Stainless Steel (secondary)	56667.74	91552.11	67.54
Ressource use, fossils [MJ]			
Base case X5CrNiMo18 (316)	3290049.95	3678502.85	
Alloy 1 X5CrNi18 (304)	3146177.23	3493535.40	5.03
Alloy 2 X20Cr13 (420)	1999582.65	2346940.82	36.20
Stainless Steel (secondary)	908311.97	1385277.37	62.34
Ressource use, minerals and metals [kg Sb eq]			
Base case X5CrNiMo18 (316)	11.60	11.60	
Alloy 1 X5CrNi18 (304)	1.94	1.94	83.30
Alloy 2 X20Cr13 (420)	3.98	3.97	65.78
Stainless Steel (secondary)	0.01	0.01	99.91
Acidification [mol H+ eq]			
Base case X5CrNiMo18 (316)	841.15	936.53	
Alloy 1 X5CrNi18 (304)	675.27	763.35	18.49
Alloy 2 X20Cr13 (420)	642.97	731.05	21.94
Stainless Steel (secondary)	98.85	210.65	77.51
Ionizing radiation, human health [kBq U235 eq]			
Base case X5CrNiMo18 (316)	106.47	4019.62	
Alloy 1 X5CrNi18 (304)	109.43	4013.06	0.16
Alloy 2 X20Cr13 (420)	156.69	4060.33	-1.01
Stainless Steel (secondary)	156.73	3111.96	22.58

Optimize the alloy of antenna, battery/Photovoltaic panel/PCB

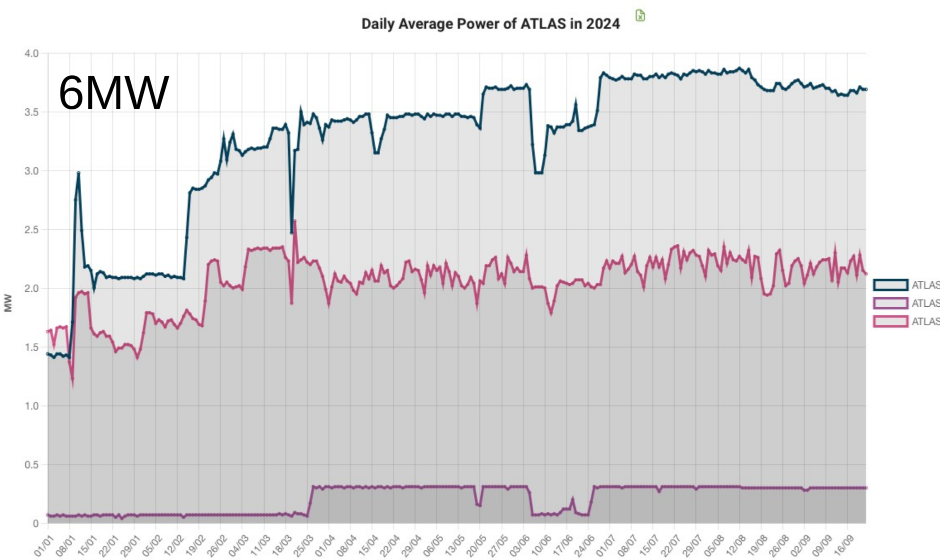
No impact on physics !



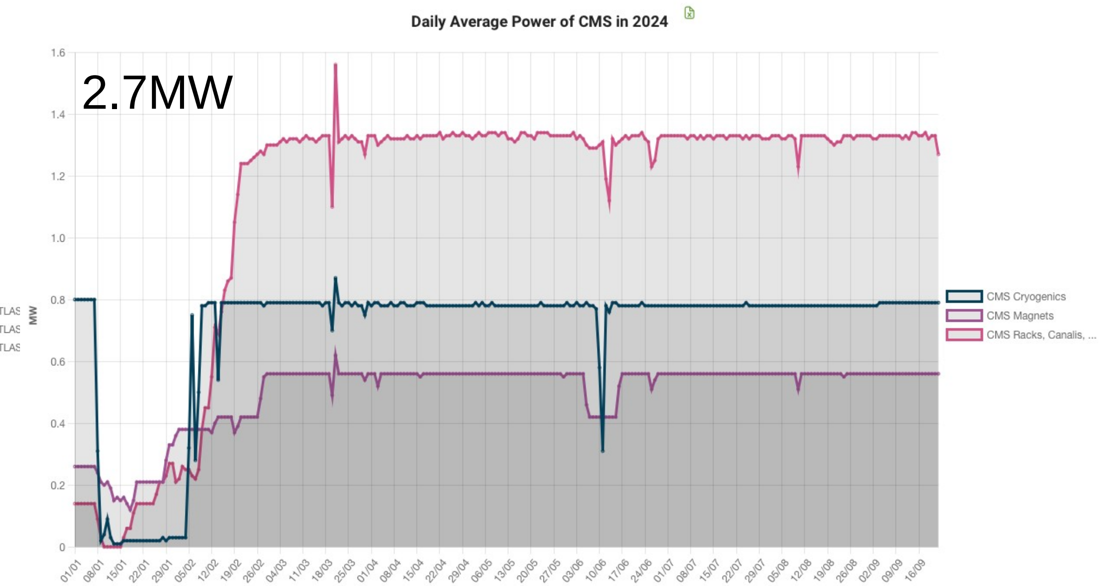
Impact categories	Base case	Battery weight -10% mass	AAPD (%)	PV size -10% size	AAPD (%)	Printed circuit board weight -10% mass	AAPD (%)
Climate Change [kg CO2eq]	471460	461999	2,01	467383	0,86	468860	0,55
Ressource use, fossils [MJ]	6220747	6099235	1,95	6171177	0,80	6176872	0,71
Ressource use, minerals and metals [kg Sb eq]	28	27	3,48	28	0,52	28	1,20
Acidification [mol H+ eq]	1709	1682	1,55	1687	1,29	1697	0,68
Ionizing radiation, human health [kBq U235 eq]	15565	15512	0,34	15343	1,43	15074	3,16

Detectors: Power consumption

- W. Riegler (sept 2024) https://agenda.ciemat.es/event/4431/contributions/5081/
  - For the LHC, ~5% of the PC is from the experiments
  - **O(5MW)/experiment**, but depend a lot of the deseign !
  - Same consomption is expected for future accelerators
    - **Cryogenics is the key !**



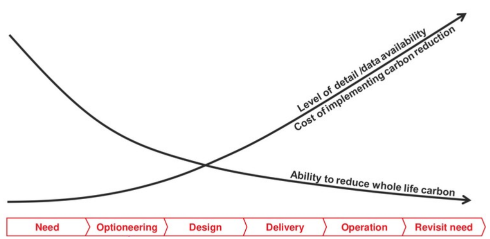
ATLAS

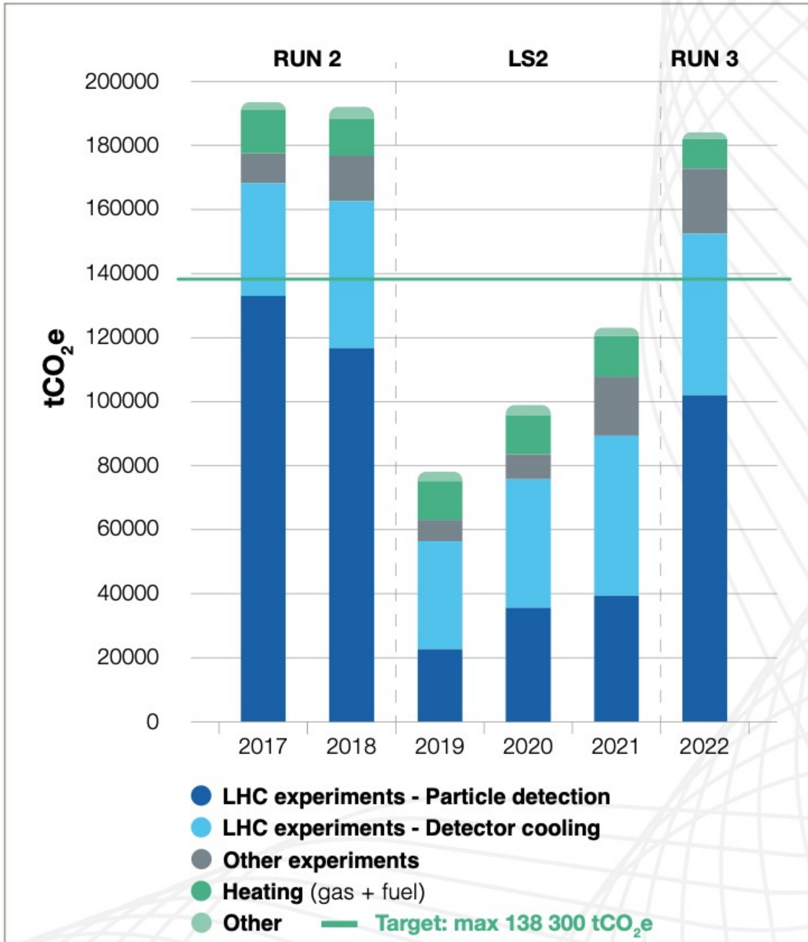


CMS

Detectors: Direct emissions

- Presently, the **main contributor** of CERN GHG
  - Cooling, RPC, RICH
  - HFCs, PFCs and SF_6
  - **O(0.2)MtCO2eq/year**
  - **Future detectors are expected to drastically reduce such usages**
- **Warning**: detector complexity may have strong impact on the cpu/gpu needed for **simulation/reconstruction** !
- No LCA yet
  - The sooner the better





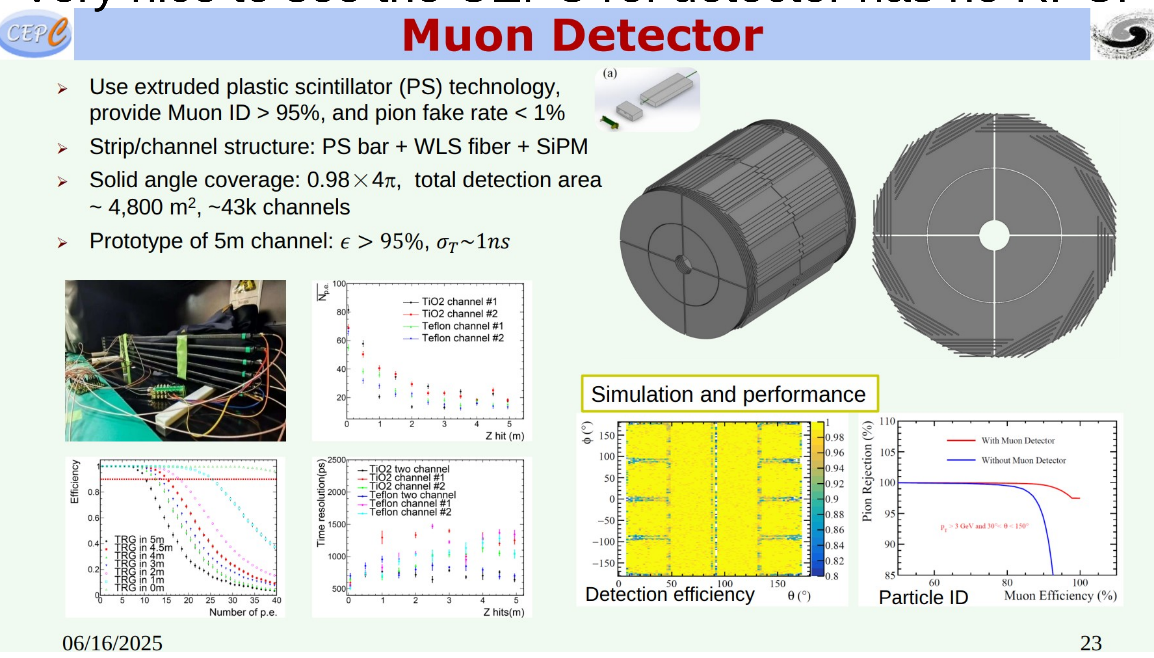
CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY
"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.

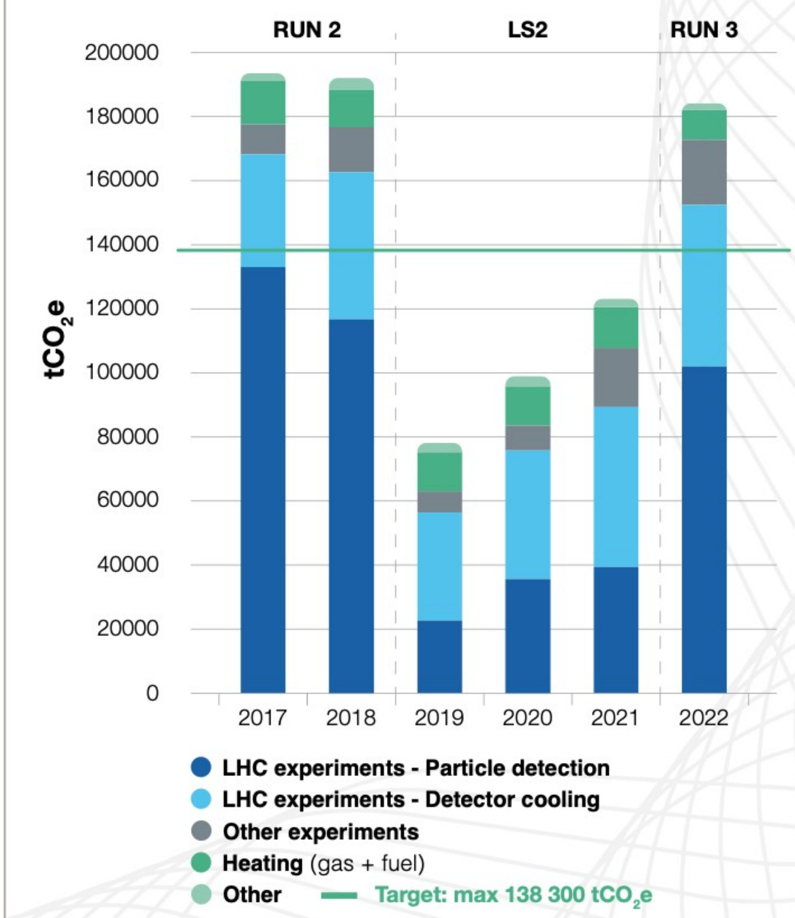
Detectors: Direct emissions

- Presently, the **main contributor** of CERN GHG
  - Cooling, RPC, RICH
  - HFCs, PFCs and SF_6
  - **O(0.2)MtCO2eq/year**

  - **Future detectors are expected to drastically reduce such usages**

Very nice to see the CEPC ref detector has no RPC!





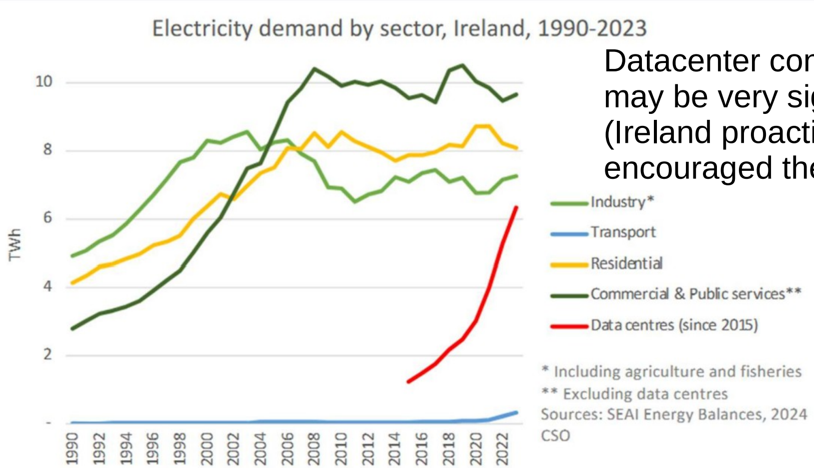
CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY
"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.

Computing

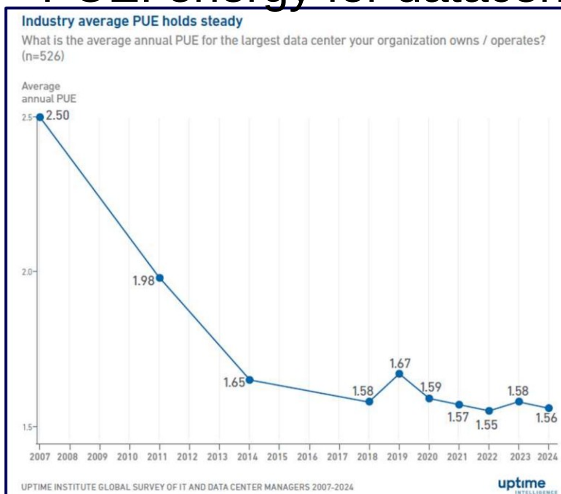
- Usually done on World wide grid → strongly depends on the electricity mix
  - So will assume a lower C-intensity for electricity production in the future…
    → Likely more intermittent
- Some ways to save energy:
  - Use the heat from datacenter for heating other buildings
  - Use different chips, with lower consumption (ARM)
  - Vary the cpu frequency
    - Decrease/increase the frequency when little/a lot of low-C electricity is produced

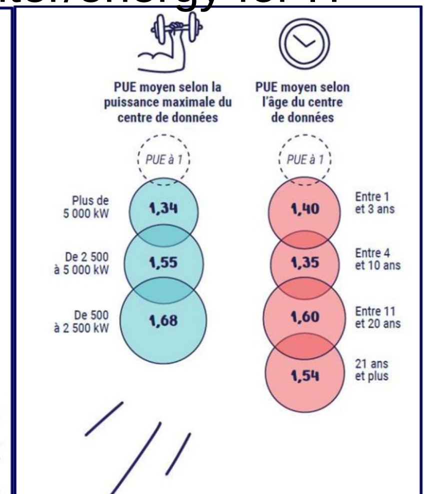
But most of the gains have already be made

PUE: energy for datacenter/energy for IT



Datacenter consumption may be very significant (Ireland proactively encouraged them)





https://theshiftproject.org/wp-content/uploads/2025/03/Rapport-intermedaire-IA-VF.pdf

Collaboration structure/life

- Assuming a world that is on track for its transition…

- Amount of fly should have been drastically reduced
  - Producing enough C-free fuel is challenging (O(25%) of today electricity to replace kerosene with e-fuel)
  - How can we organize ourself to reduce the distance and the number of flies ?

    Example (crazy idea nowadays, but in future…?):
    organizing the detector-collaborations by continent

  - How many collaborations/detectors do we really need ?

- It would be interesting to have an estimate of this item ? Bigger than acc.?

  Back to the envelop calculation:
  9k physicists x 14years x 2t/fly x 2 flies/year = 0.5MtCO2

  Geneva-NY Geneva-Beijin: 2.5t

Summary

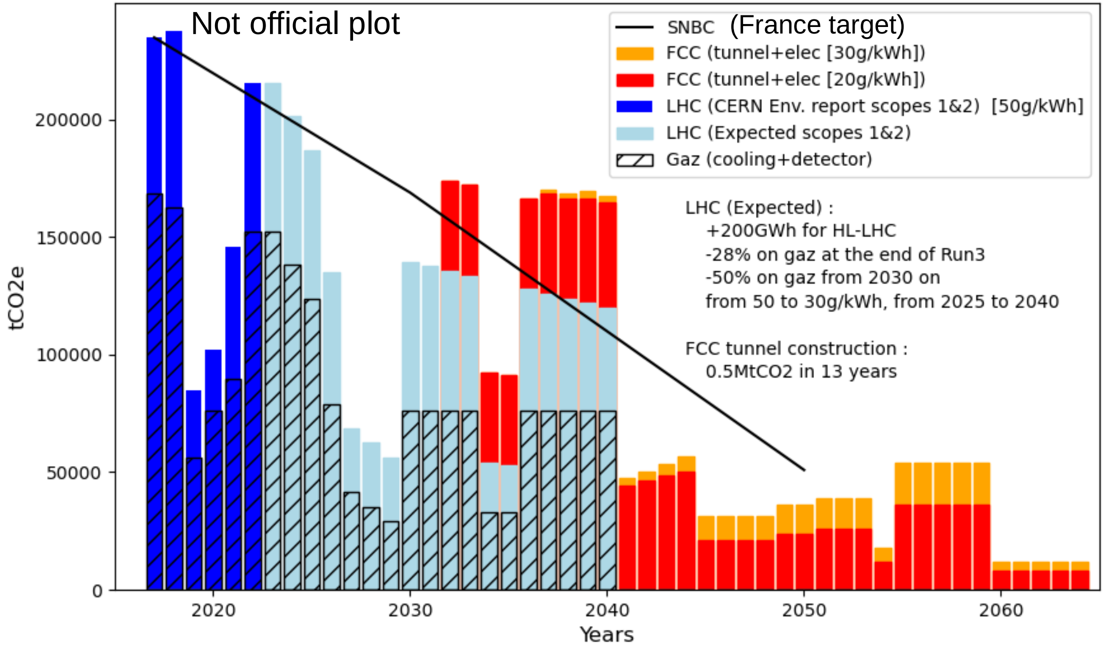
O(0.5-1.5)MtCo2eq

CO2eq footprint = tunnel ✓
+ accelerator construction
+ accelerator operation ✓
+ detector construction
+ detector operation
+ computing ??
+ collaboration life O(0.5)Mt ?

0.25-0.5Mt for linear
Likely more for circular

?? Need LCA !

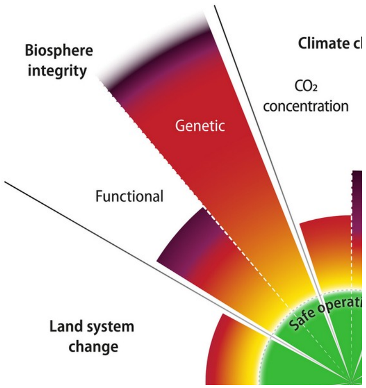
Gaz ? Cryogenics ?
Electricity source ?



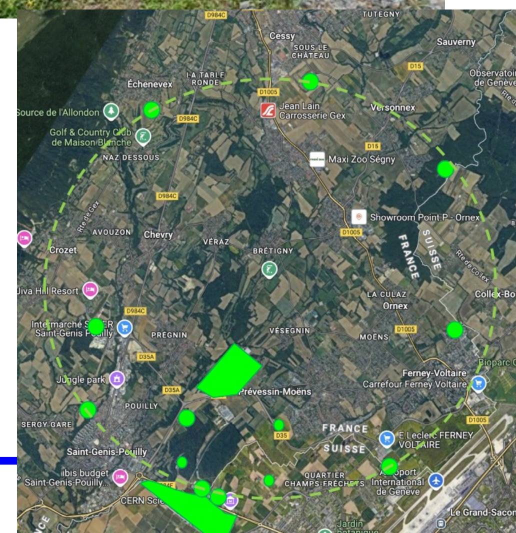
No detector included for FCCee

Biodiversity

- Reduce the impact during construction
  example at GANIL in France, *with Semi-permeable barriers around the site*:



- Plan constructions that are biodiversity friendly
  - Isolated areas for technical building can be biodiversity refuges
  - Avoid barrier, create corridors btw/ sites
  - Can be implemented without large extra-costs



©J. Faivre

National communities inputs for ESPPU

(Apologies if I missed one!)

German:

5.3 Sustainability

As scientists and as part of our society, the German HEP community is committed to building a sustainable future. Our research activities and research infrastructure must aim to minimize resource consumption and negative impacts on the environment, while exploring how research and development through our international collaborations can further contribute to the UN Sustainable Development Goals. (...)

French:

3.4 Sustainability

Sustainability considerations in HEP are pivotal, to respect the planetary boundaries, to comply with the rapidly evolving regulation, and to align with the global effort demanded on society. The HEP community should lead by example by addressing these issues from the earliest stages of future projects, thereby increasing their acceptance by civil society and strengthening the staff's engagement. (...)

Serbian:

With respect to sustainability, we reserve the right to adapt the text once additional reports are made public. Based on current information, the Linear Collider appears to have the most developed strategy. However, we expect that any future project will prioritize this issue in the long run.

Polish:

be carried out in a coordinated manner and in line with the adopted strategy. The communication narrative should not be limited to research alone, but cover a wide range of topics including societal benefits, environmental impact and demonstrating that international scientific cooperation drives progress and peace, etc. In order to achieve these goals, more effort and resources need to be put into

new GDs, such as RPCs, Micromegas, and GEMs. Environmentally friendly development is a key element of the R&D process, especially in the area of gas mixture studies, where not only detector performance is crucial but also the negative impact on the environment is minimised.

Spanish:

8. Early career researchers

The Spanish HEP ECRs stress the importance of an early decision on the next collider at CERN, as well as of their involvement in the associated R&D developments. This engagement will not only enhance their skills but also ensure their insights and ideas are integrated into the planning process. They are particularly attentive to the economic, environmental, and societal impact of HEP. Concerns about career prospects and job security are widespread among ECRs, significantly influencing their motivation to remain in academia.

Ukrainian:

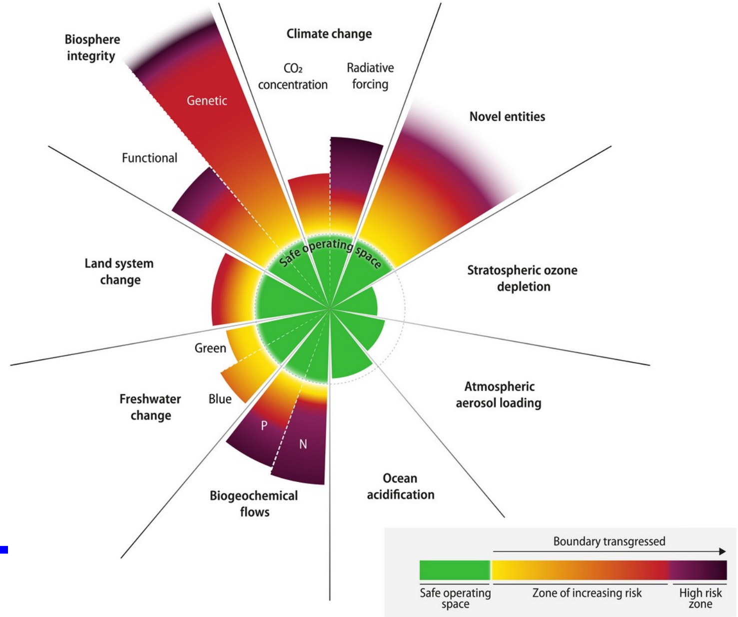
feasibility study. Ensuring that FCC is constructed in the most environmentally-friendly way requires environmental analysis and sustainability studies and, in particular, Life-Cycle Assessment of engineering infrastructure and accelerator components, studies of soil reconstitution, development of renaturalization projects and new construction techniques, as well as knowledge of landscape integrated architecture. All these topics are of immense interest for Ukraine at the moment and collaboration with CERN on them would be extremely beneficial.

Conclusions

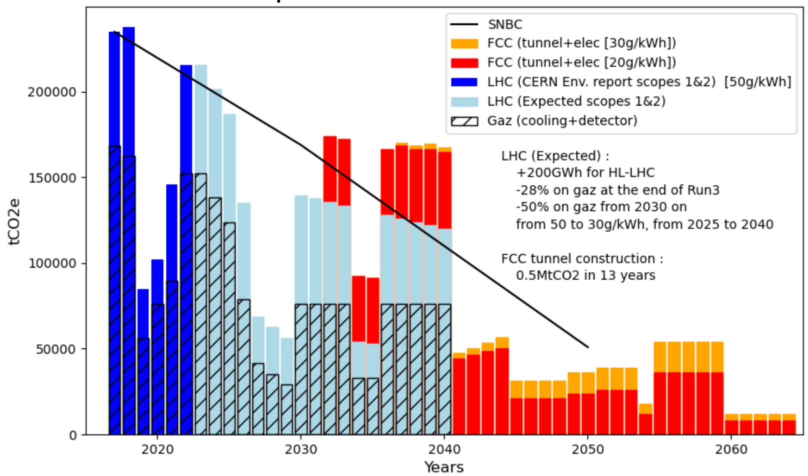
- Humanity is facing huge challenges
  - Most of European communities wants the HEP to be exemplary.

- How could HEP be part of the solution ?
  - innovations (tech, but also social ?)
  - biodiversity harvest ?

- LCA is a crucial tool, to evaluate & to plan how to reduce the impacts
  - Research field on its own



Not official plot

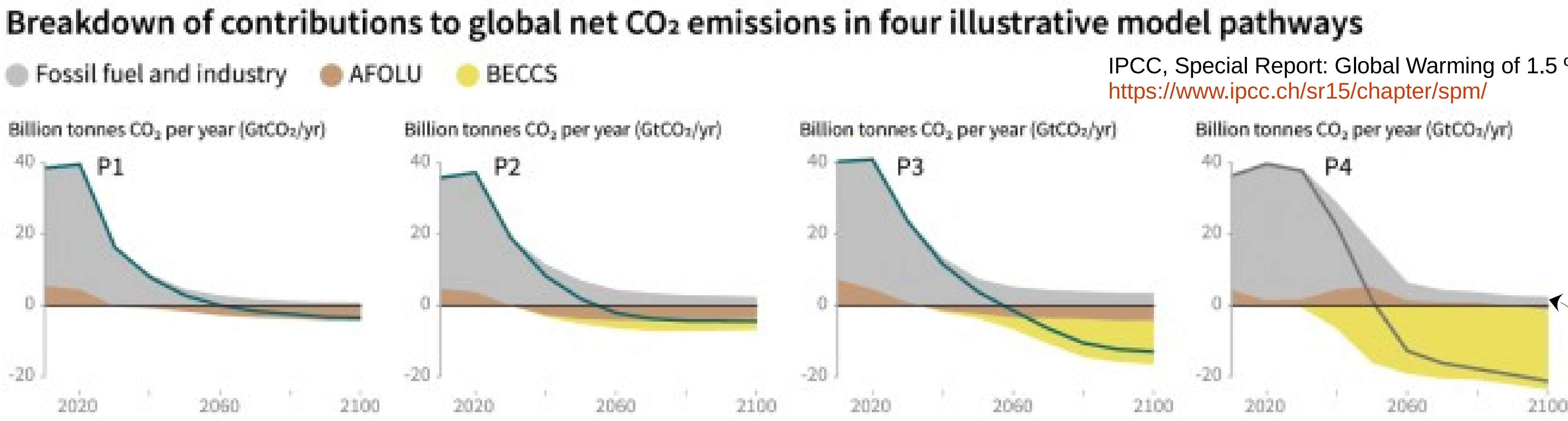


Backup

Bibliography

- CERN and the Environment (Nov 2024): https://indico.cern.ch/event/1456577/
- FCC LCA (oct 2024) https://zenodo.org/records/13899160
- Energy for Sust. Sc. At Research Infra (sept 2024) https://agenda.ciemat.es/event/4431/
- Interim report for the International Muon Collider Collaboration (IMCC) (July 2024) https://arxiv.org/abs/2407.12450
- Know your footprint (for HEP physicists) (mar 2024) https://arxiv.org/abs/2403.03308
- Sustainability Strategy for the Cool Copper Collider (nov 2023) https://arxiv.org/abs/2307.04084
- LCA of CLIC&ILC (July 2023) https://edms.cern.ch/ui/#!master/navigator/document?D:101320218:101320218:subDocs
- The carbon footprint of proposed e+e− Higgs factories (sept 2022) https://arxiv.org/abs/2208.10466

Climate change & society – in 1 slide



IPCC, Special Report: Global Warming of 1.5 ºC, 2018
https://www.ipcc.ch/sr15/chapter/spm/

- The longer we wait to reduce our CO2 emissions,
the more carbon capture (CC) technology will be needed

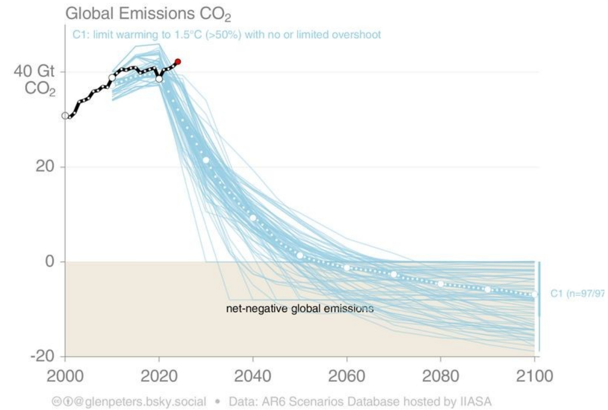
=2t/person

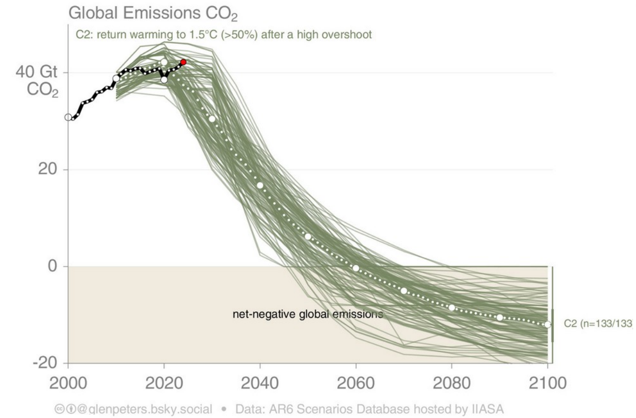
- Neutrality needed by ~2050

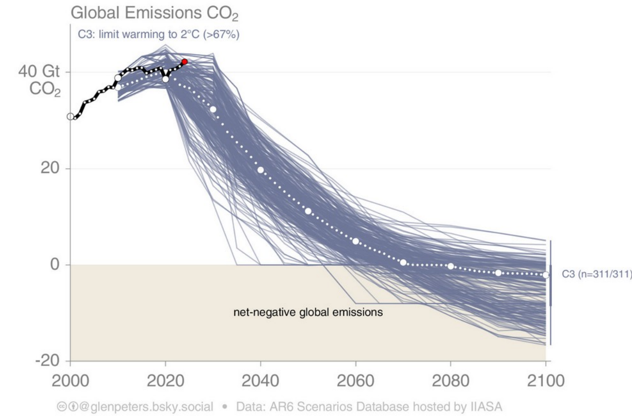
- CC techs are not yet ready or are expensive

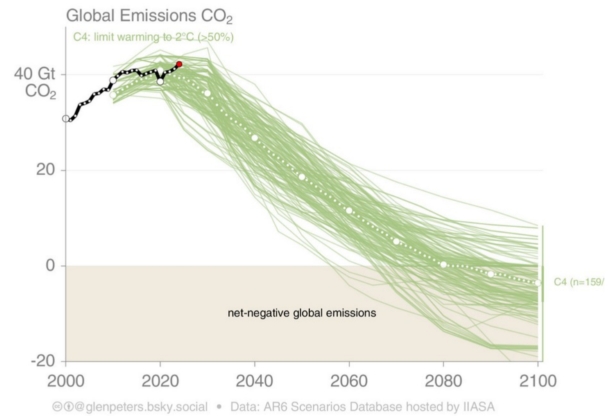
- Carbon budget (to stay <2°C, with 50% chance) : 200GtCO_2eq (starting from early 2023)

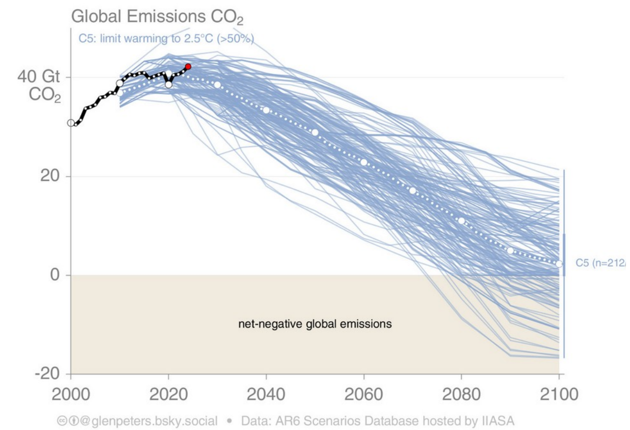
Forster et al., 2024, Earth System Science Data

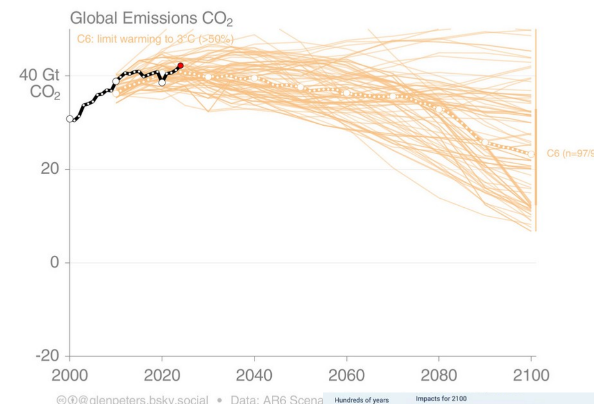


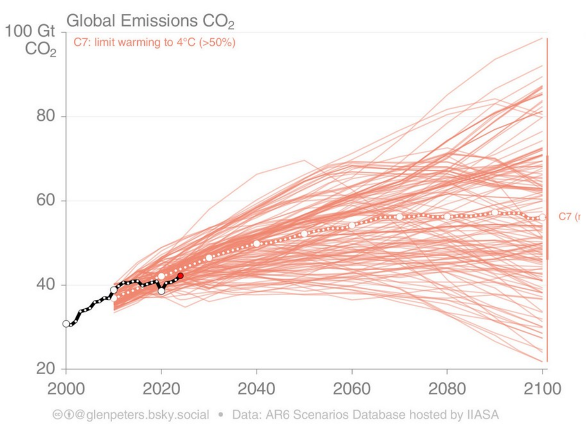


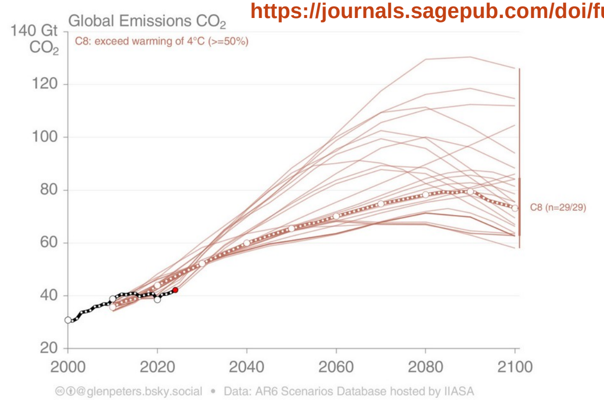




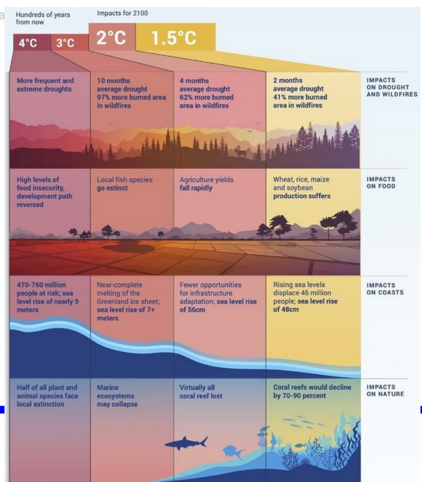


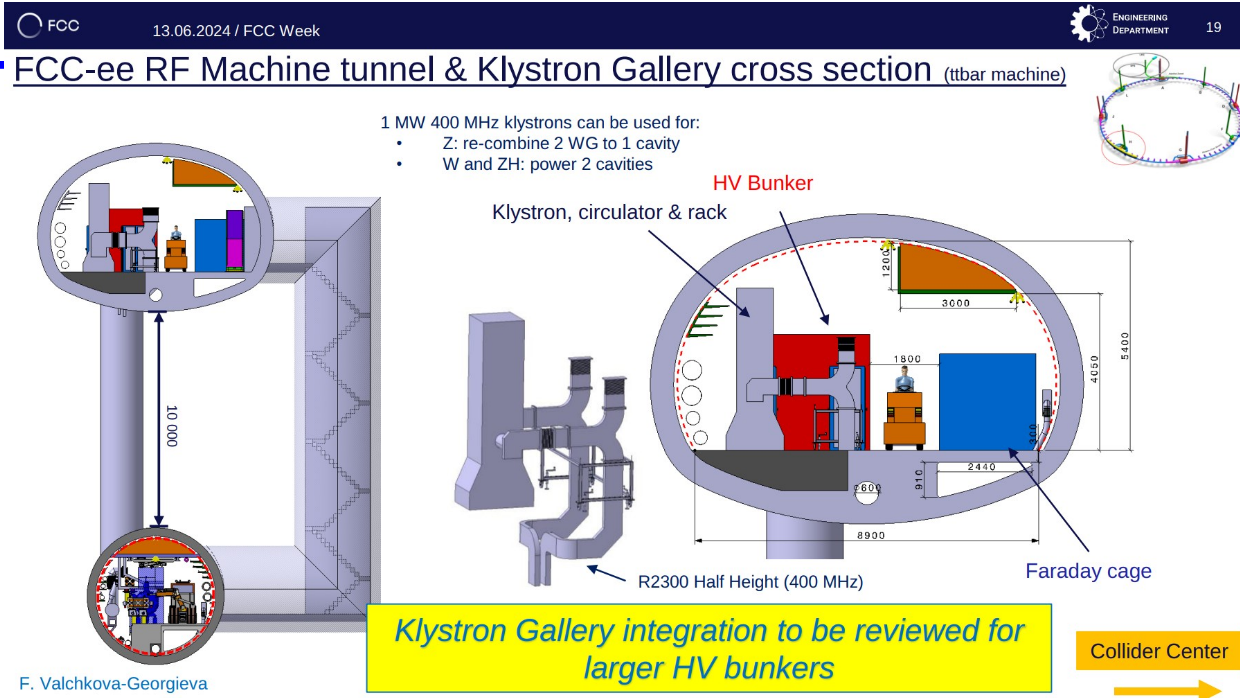


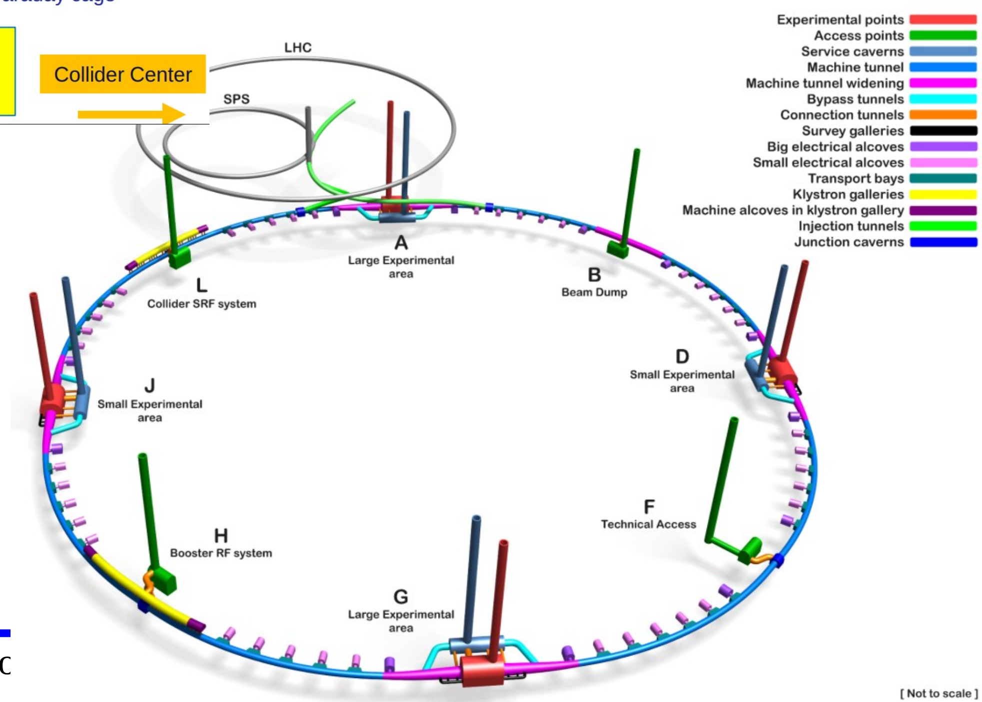




Is limiting the temperature increase to 1.5°C still possible?, G. Peters
https://journals.sagepub.com/doi/full/10.1177/29768659241293218



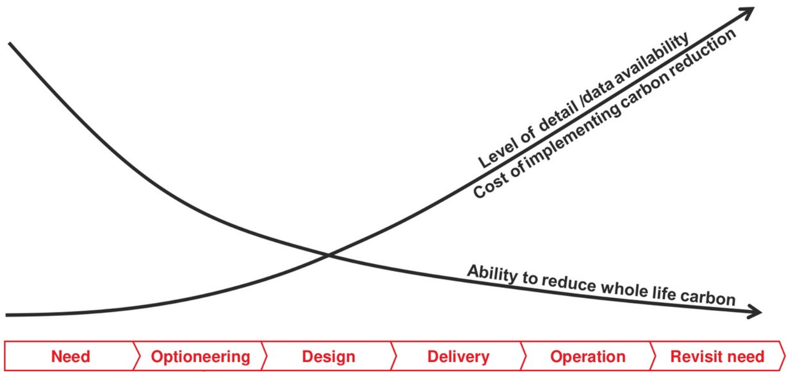


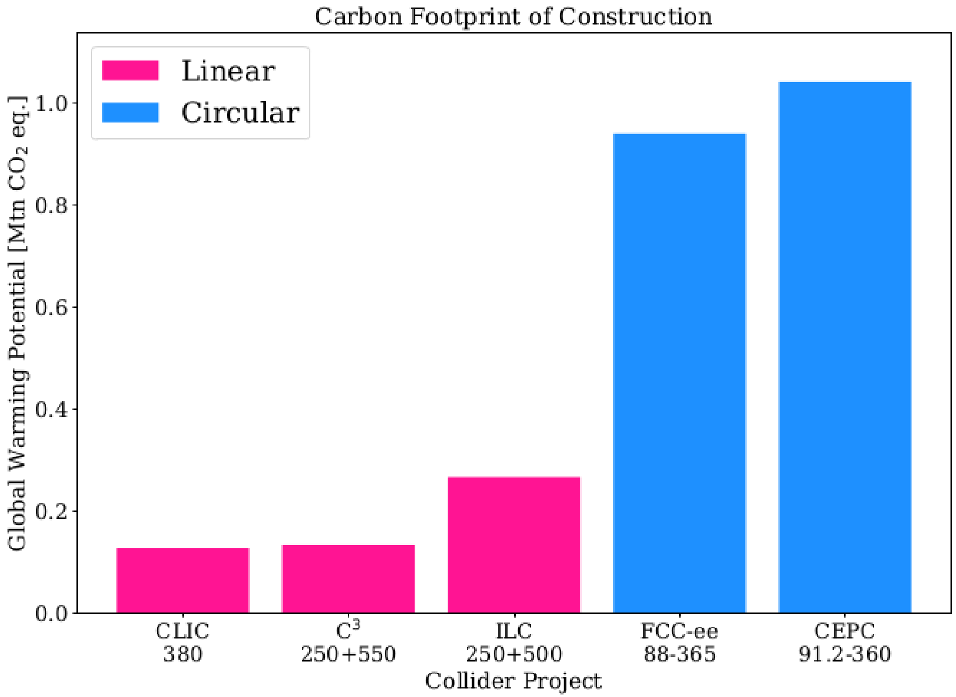


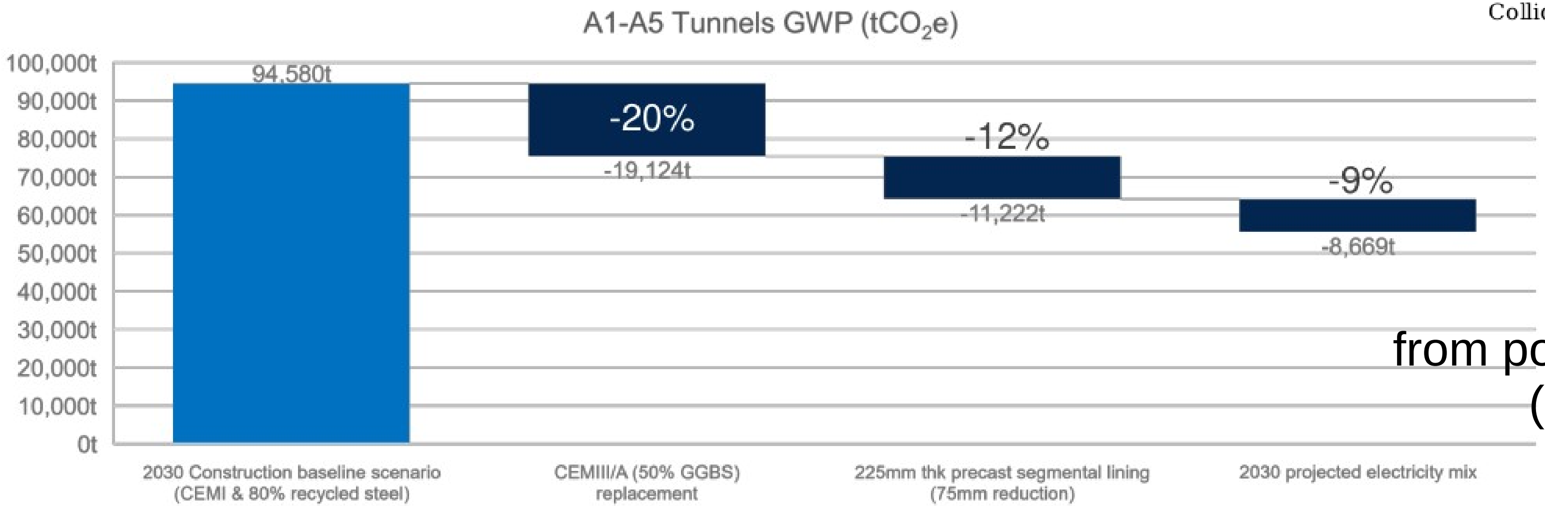
Sustainability fc

Tunnel @NLO

From https://arxiv.org/abs/2307.04084
FCC&CEPC: rough estimates
from CLIC LCA!



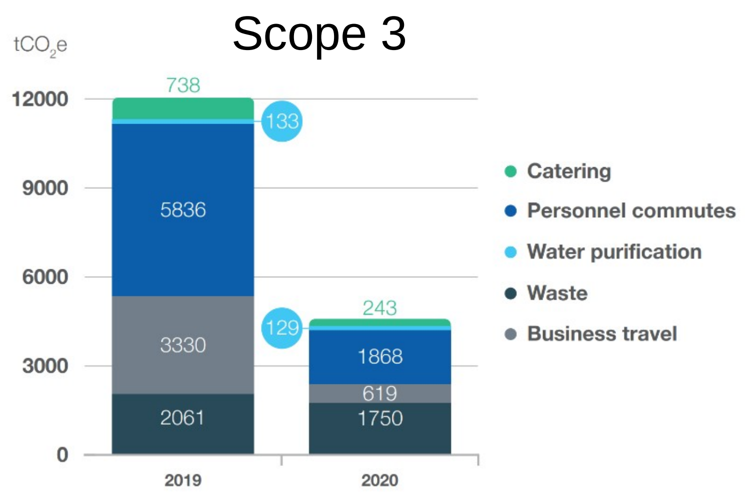


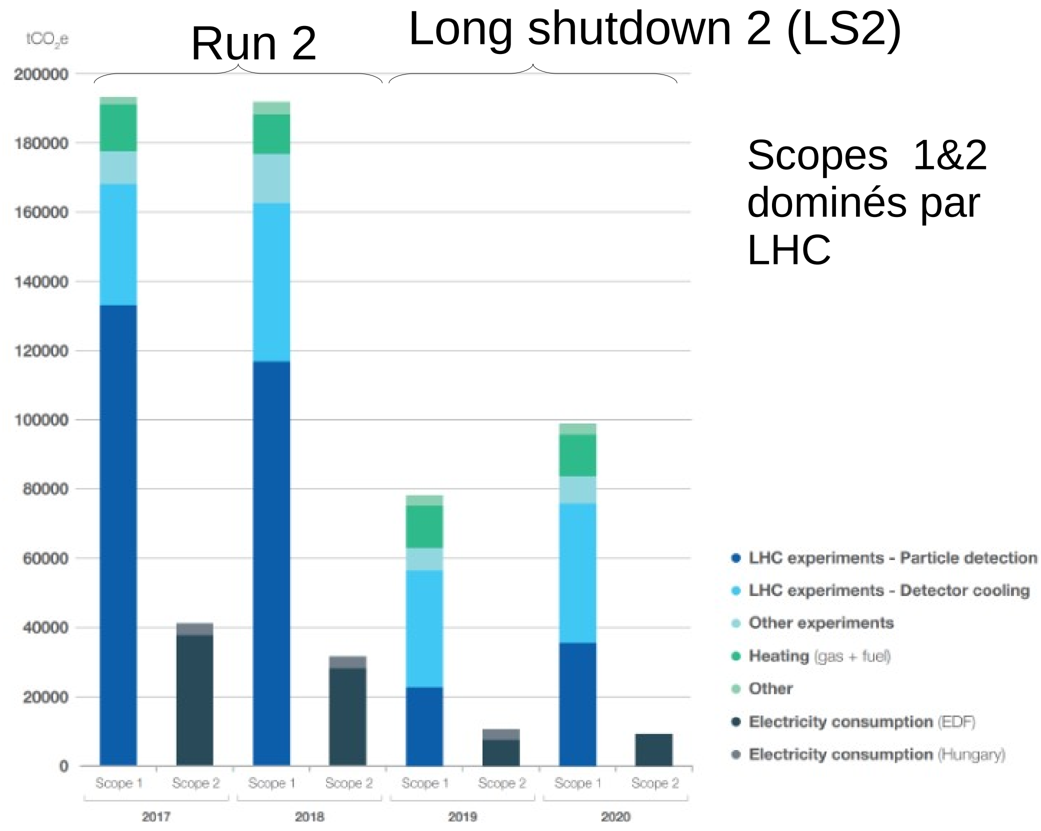


NLO corrections…
from possible improvements
(ex CLIC Drive beam):

Inputs

- CERN environment report 2019-2020
  https://hse.cern/environment-report-2019-2020





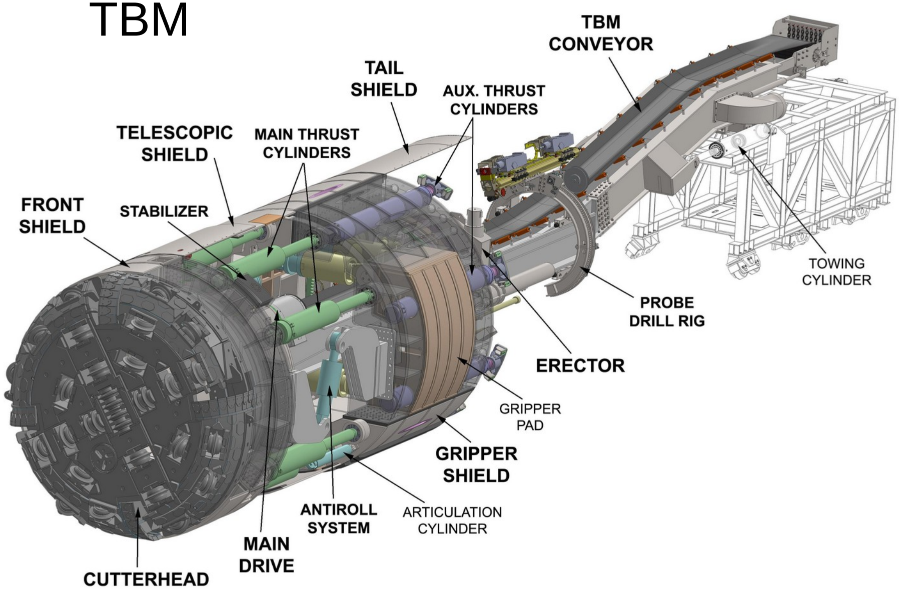
- CERN Annual Personnel Statistics
  https://cds.cern.ch/collection/CERN%20Annual%20Personnel%20Statistics

Tunnel @NLO

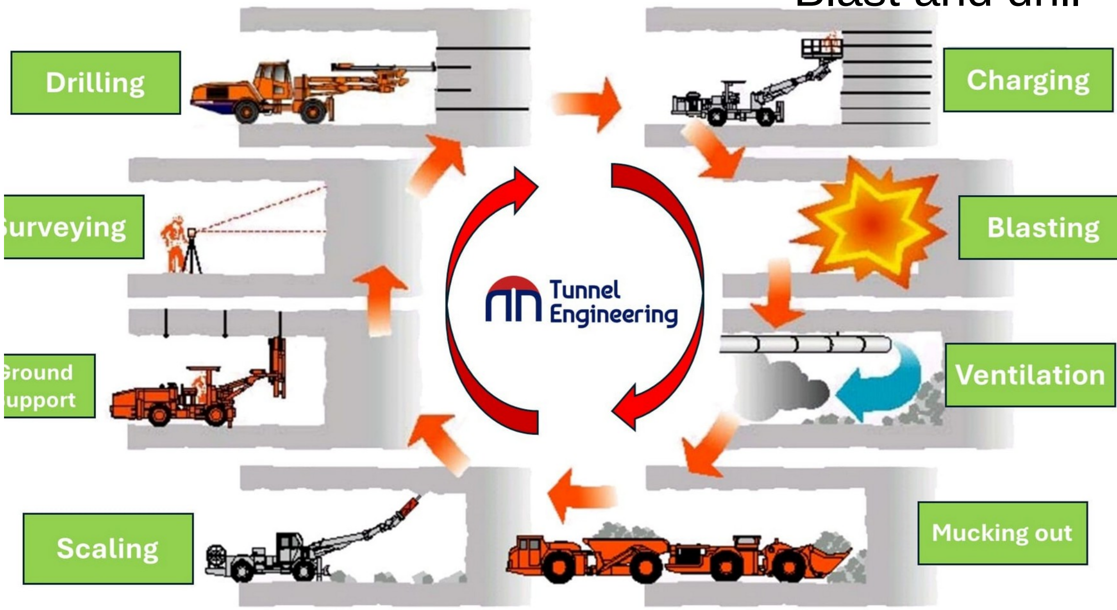
Main parameters:

length, profile : amount of concrete and steel, **technology**

TBM



Blast and drill



Accelerator operations

- Example of other developments on going, likely for after CEPC/FCCee:

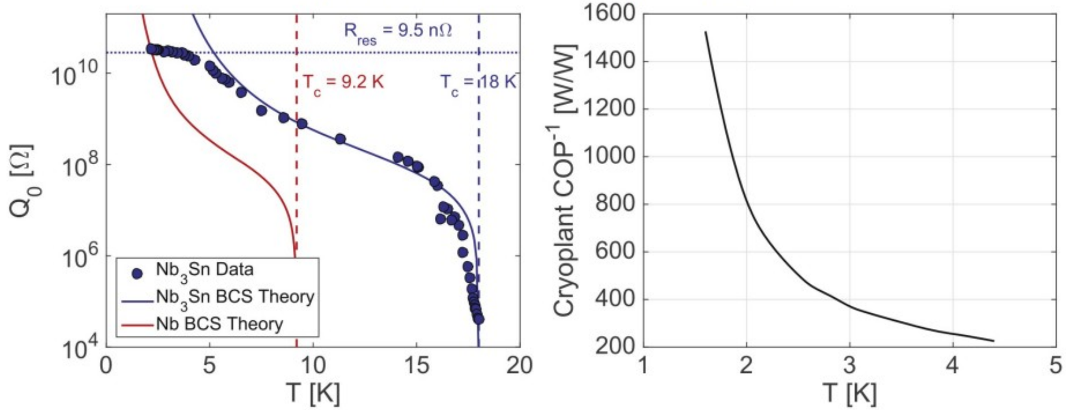
iSAS develops, prototypes & validates SRF energy-saving technologies

TA#2: energy-savings from cryogenics

The objective is focused on the development of thin-film cavities and aims to transform conventional superconducting radio-frequency technology based on off-shelf bulk niobium operating at 2 K, into a technology operating at 4.2 K using a highly functionalized material, where individual functions are addressed by different layers.

iSAS will optimize the coating recipe for Nb_3Sn on copper to optimize tunability and flux trapping of thin-film superconducting cavities and to validate a prototype beyond the achievements of the ongoing Horizon Europe I.FAST project, and the various US-based achievements (e.g., GARD).

Supercond. Sci. Technol. 30 (2017) 033004

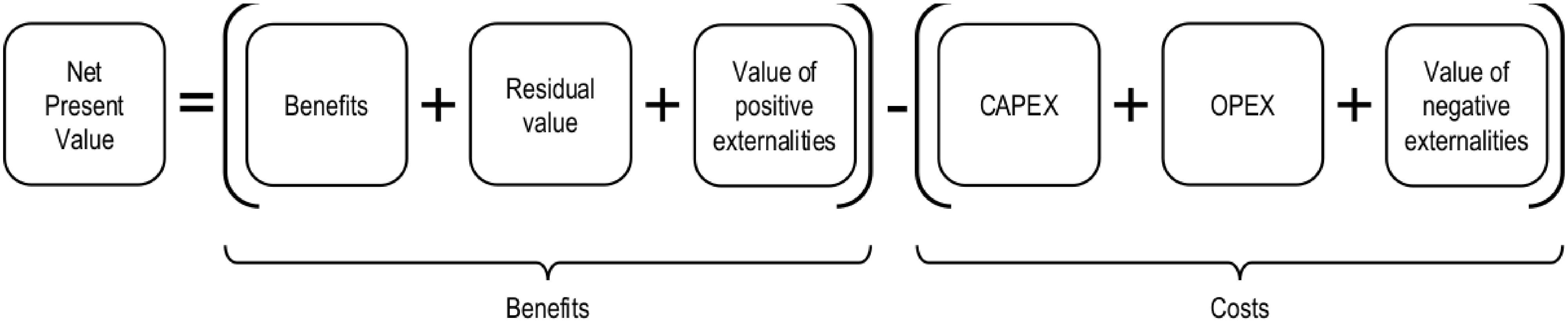


The higher critical temperature (T_c) of Nb_3Sn allows for the maximum value of quality factor Q_0 for 1.3 GHz cavities to be achieved at operating temperatures of about 4 K compared to 2 K for Nb (left figure). The graph on the right shows the efficiency of a cryogenic plant (COP) as a function of temperature achieving about 3 times higher COP efficiency when operating at a temperature of 4.2 K than at 2 K. This suggests that operating a cryogenic plant at 4.2 K with Nb_3Sn SRF cavities, can lead to significant better performances and energy savings.

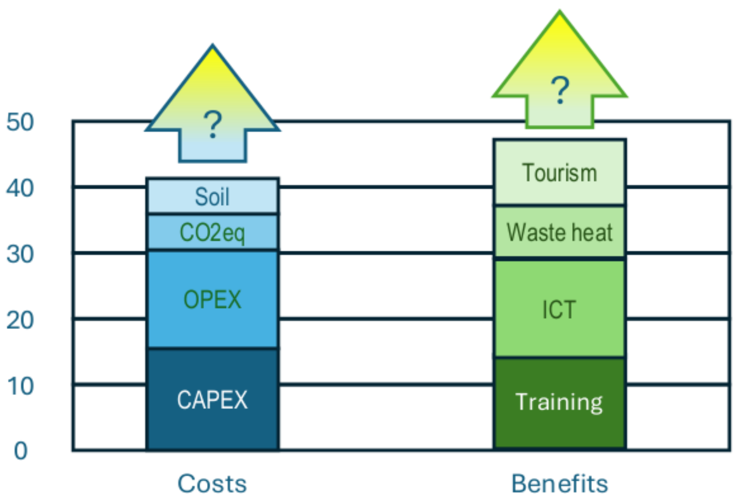
https://agenda.ciemat.es/event/4431/contributions/5058/

How do we decide whether a collider is “sustainable” ?

FCC Feasibility Study Report Vol 3 : Civil Engineering, Implementation and Sustainability
https://cds.cern.ch/record/2928194



Estimations with best estimates and unknowns...



Economic formula to actualize the benefits/costs:

$$\text{Present\_Value} = \frac{\text{Future\_Value}}{(1+\text{SDR})^{\text{year}-\text{base\_year}}}$$

SDR: Social Discount Rate

- debate on the right value:
  (0 means future generations are equally important as present one)
- set it to 2.8%

Institution	SDR for Carbon
US EPA (old)	3%
US EPA (new)	2%
Stern Review	1.4%
EIB	~1–2%

How do we decide whether a collider is "sustainable" ?

→ : Effect of SDR

Cost/Benefit	Undiscounted	Discounted
(A) Costs		**19 666 MCHF**
Investment costs (for 4 experiments, injector and $t\bar{t}$ stage)	16 215 MCHF	10 171 MCHF
Personnel costs	16 802 MCHF	7544 MCHF
Operation costs (materials, consumables, services)	4410 MCHF	1879 MCHF
Dismantling costs	228 MCHF	72 MCHF
(B) Negative externalities		**354 MCHF**
Shadow cost of carbon	634 MCHF	342 MCHF
Loss of agricultural income, biodiversity & habitat	7.6 MCHF	4.1 MCHF
Social cost of project-related, induced noise	0.02 MCHF	0.02 MCHF
Social cost of project-related, traffic-induced air pollution	0.9 MCHF	0.6 MCHF
Social cost of project-related, traffic-induced GHG externalities	9.8 MCHF	7 MCHF
Social cost of ionising radiation	1.3 MCHF	0.6 MCHF
(C) Core benefits		**23 974 MCHF**
Scientific production	6507 MCHF	2813 MCHF
Early career researcher training	20 687 MCHF	4986 MCHF
Industrial benefits for suppliers	17 577 MCHF	9569 MCHF
Onsite visitors	4538 MCHF	2129 MCHF
Online and social media	229 MCHF	102 MCHF
Open software (experiments and detectors)	7428 MCHF	4375 MCHF
Total costs including negative externalities	**(A + B)**	**20 020 MCHF**
Total core benefits	**(C)**	**23 974 MCHF**
Reference net present value (NPV)	**(C) - (A + B)**	**3954 MCHF**
Reference Benefit Cost Ratio (BCR)		**1.20**

Cost due to C-emission for tunnel construction and operations w/ 4 interaction points *(no detector, nor computing, nor collaboration life)*

>0 :FCC feasibility study concludes it is worth to make it

Construction du LHC

- Pas clair comment amortir
  - Tunnel déjà existant (accélérateur LEP)
  - Temps d'amortissement ?
  - Prise en compte des upgrades ?

- Ordre de grandeur

	A	B	C	D	E	F
1	cout:	4,50E+09	euros	LHC+4 experiences (CHF=euros)		
2	annees:	2008	2040	32	ans	
3				1,41E+08	euros/an	
4	FE:	0,3	kg/euros			
5	Co2eq:	4,22E+04	tonnes			
6	physiciens:	8600				
7		4,91	t/phys			

→ Pas pris en compte