Sustainability issues

13/11/24

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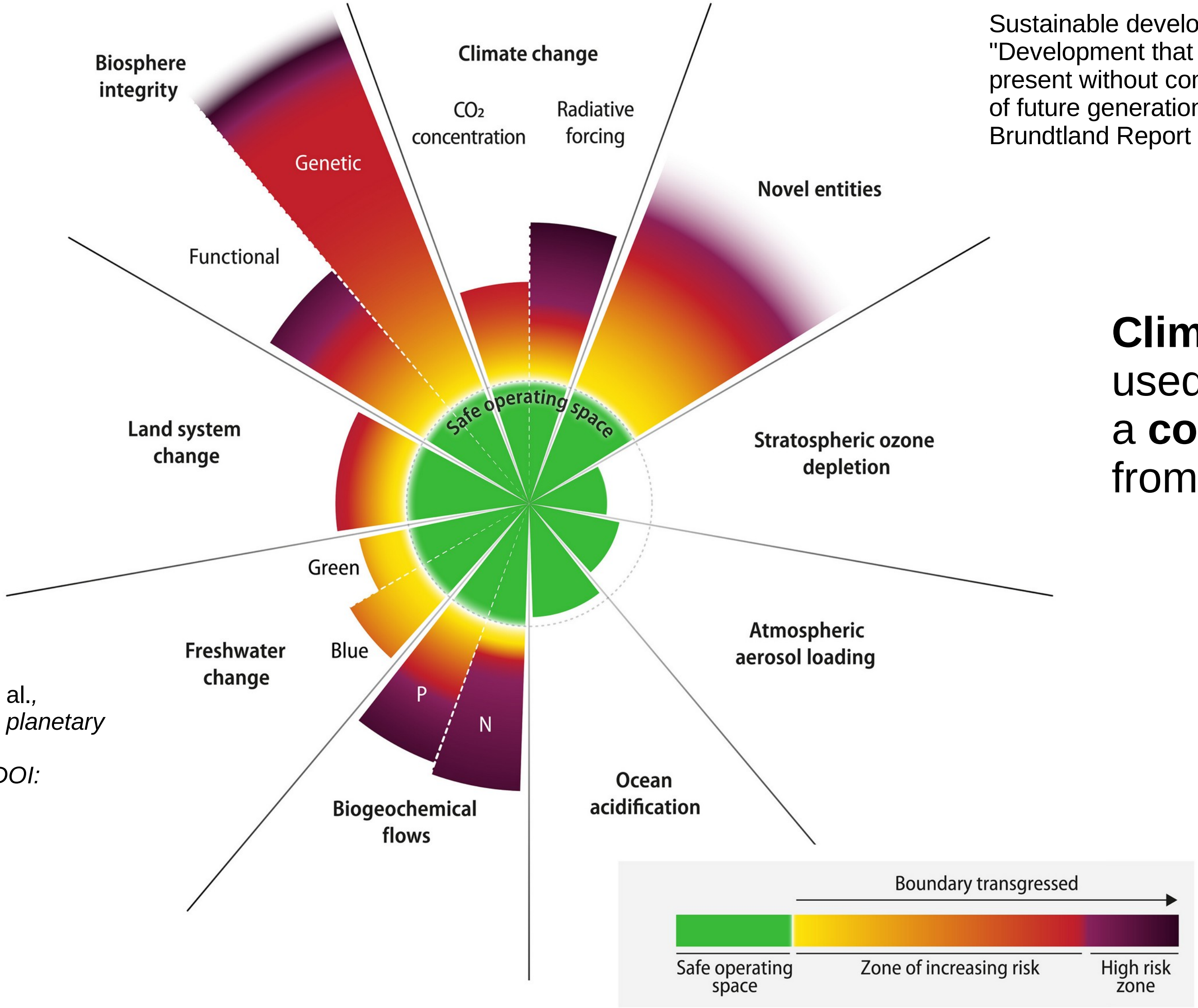
Sustainability = be within planetary boundaries

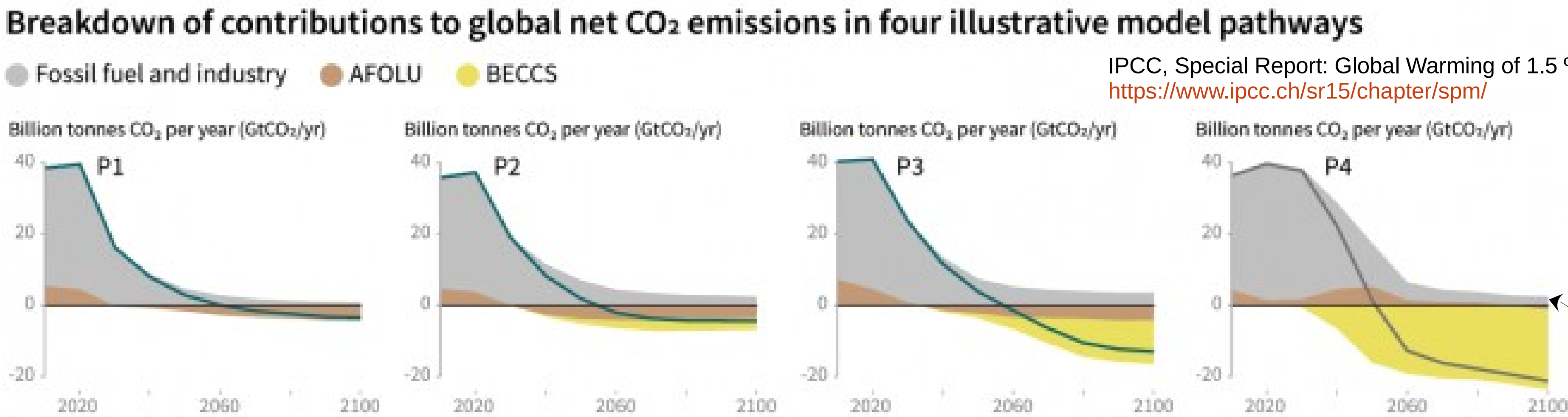


Sustainable development:
"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
Brundtland Report (1987) for UN

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*

Climate change & society – in 1 slide



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

=2t/pers

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

- Neutrality needed by ~2050

- CC techs are not yet ready

- Carbon budget (to stay <2°C, with 50% chance) : 200GtCO_2eq (starting from early 2023)
Forster et al., 2024, Earth System Science Data

This talk...

- I am not an accelerator/detector expert !

- Going to do a short bibliography review
  - Using a critical sustainability perspective
  - Trying to answer some questions:

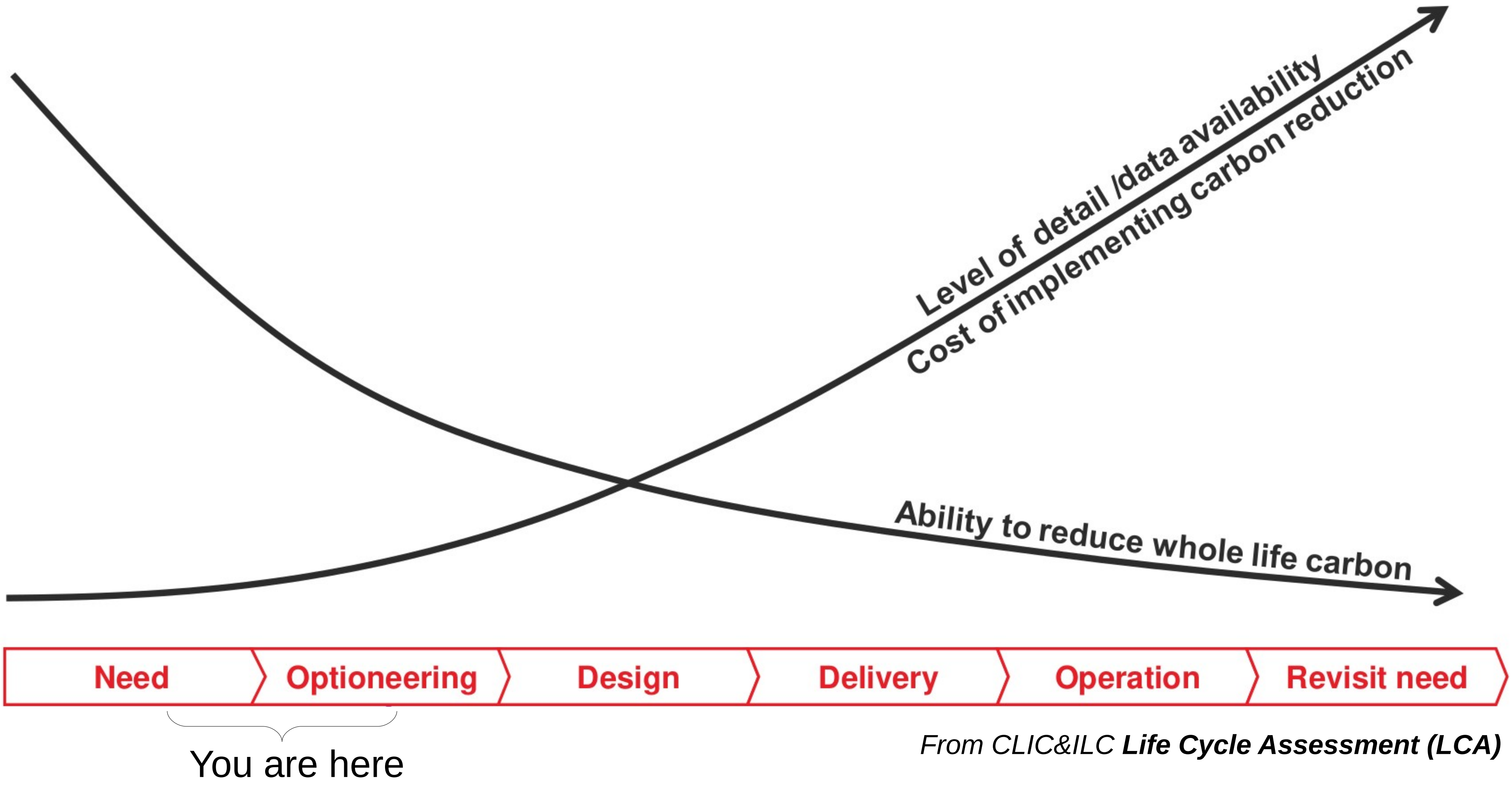
- How could we minimize our emissions ? (carbon budget!)
and environmental footprint ?

- How could our big projects help humanity to meet its challenges ?

- What kind of projects can live in 2050 ?

Assuming: a zero net emission world, stable enough to perform big science

The key plot



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

What are the main ingredients ?

Environnemental footprint = tunnel
+ accelerator construction
+ accelerator operation
+ detector construction
+ detector operation x Nexperiments
+ collaboration life

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Environnemental footprint = tunnel
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$\left.\begin{array}{l}\text{+ detector construction}\\\text{+ detector operation}\\\text{+ collaboration life}\end{array}\right\}$ x Nexperiments

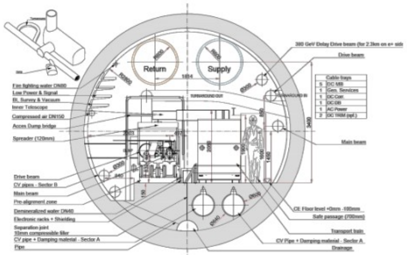
Today: 35tCO_2eq/year/LHC physicist when LHC is running
(not accounting for travels, WLCG, ...)

Tunnel (@LO)

Main parameters:

length, profile : amount of concrete and steel

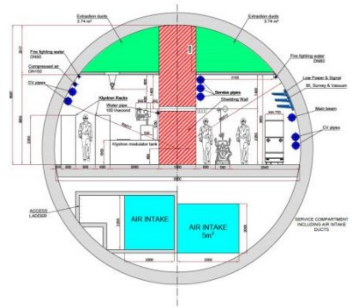
11-50km



CLIC Drive beam, 5.6m dia.

Geneva

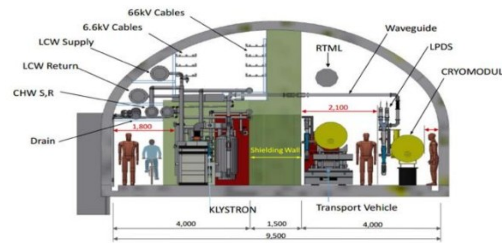
Energies: 380GeV, 1.5TeV, 3TeV.



CLIC Klystron, 10m dia.

Geneva

Energies: 380GeV



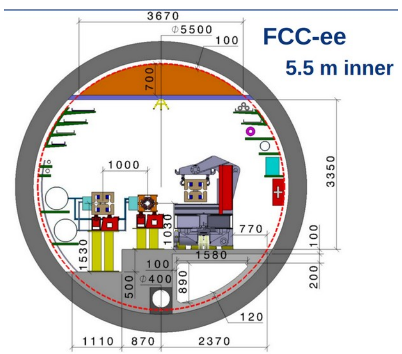
ILC, 9.5m span

Tohoku Region, Japan

Energies: 250GeV

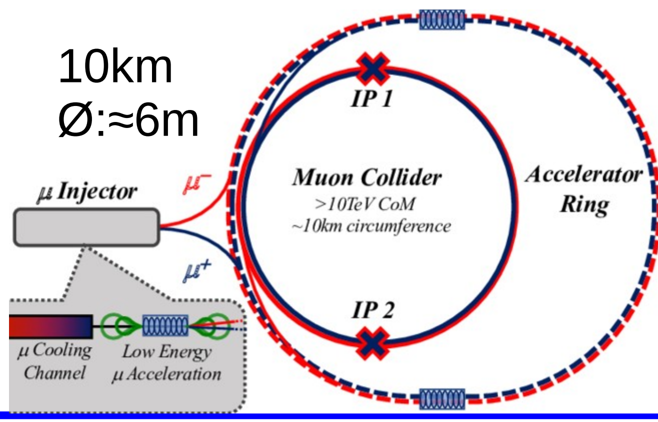
33km

90km



10km

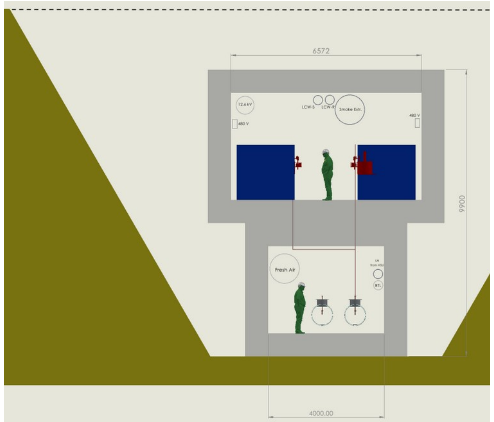
Ø:≈6m



CCC

8km

T=80K

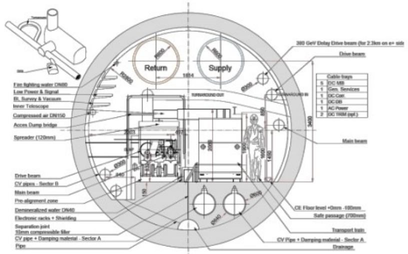


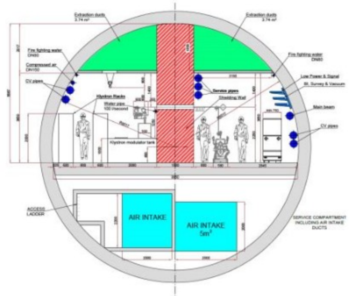
Tunnel (@NLO)

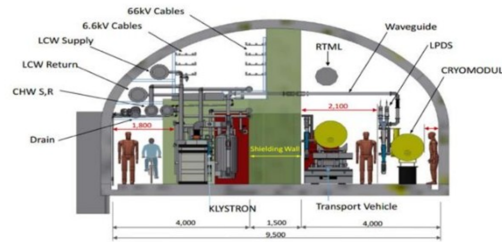
Main parameters:

length, profile : amount of concrete and steel, technology

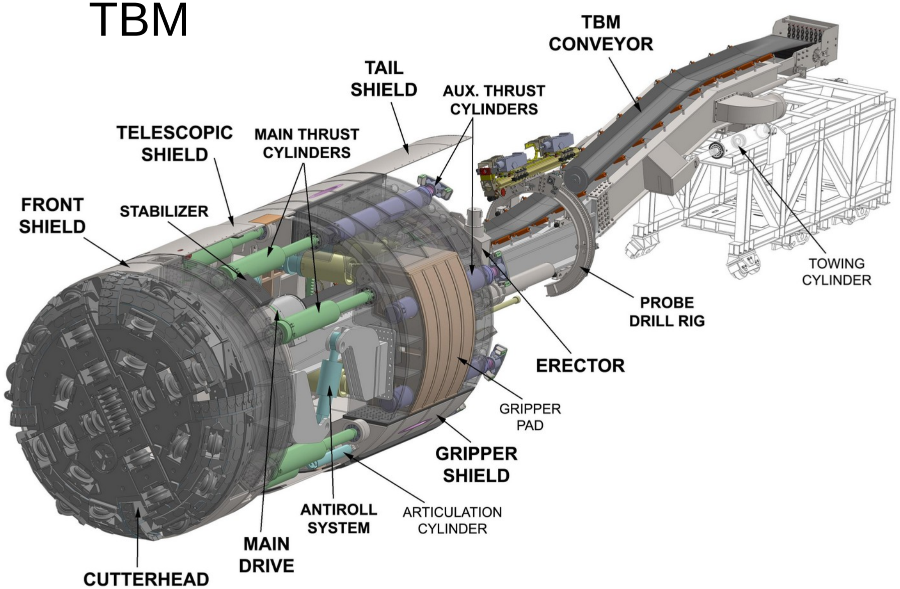
11-50km



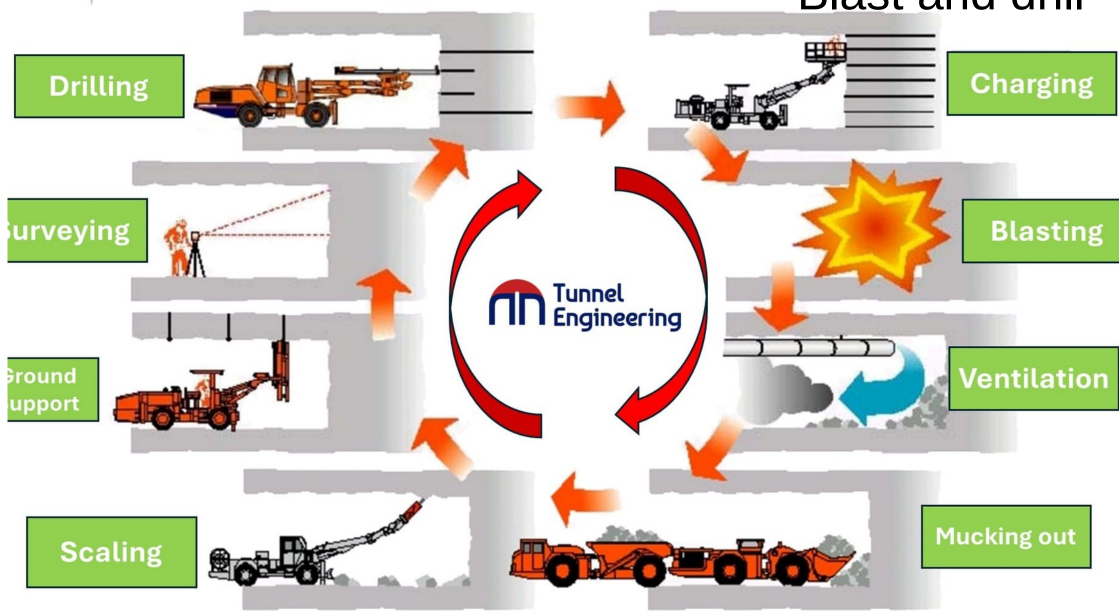




TBM



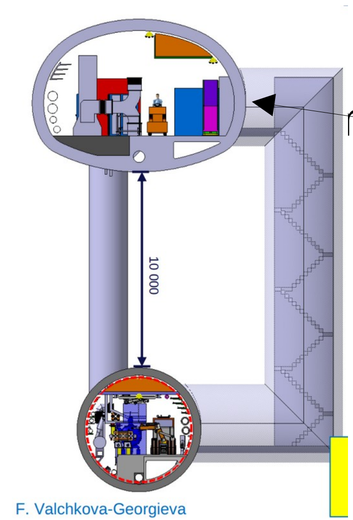
Blast and drill

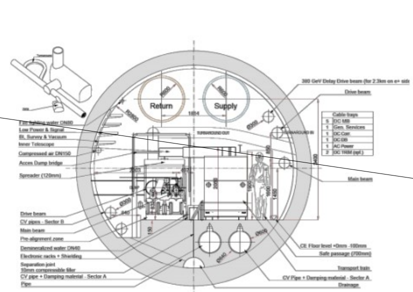


Tunnel (@NLO)

Main parameters:

- length, profile : amount of concrete and steel
- klystron isolation, number of shafts, caverns





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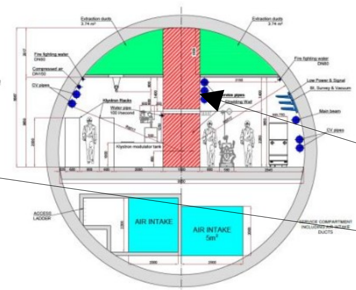
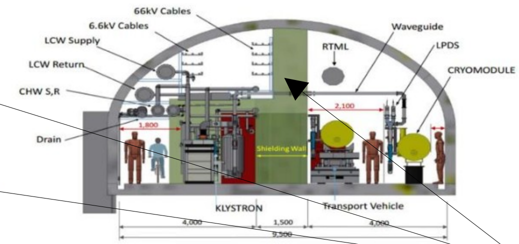
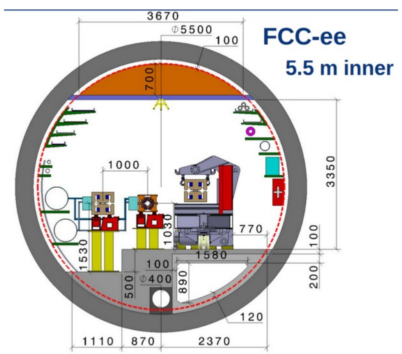


CLIC Klystron, 10m dia.
Geneva
Energies: 380GeV

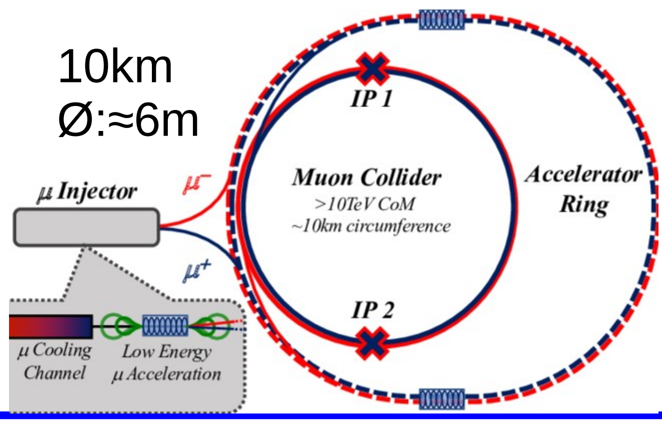


ILC, 9.5m span
Tohoku Region, Japan
Energies: 250GeV

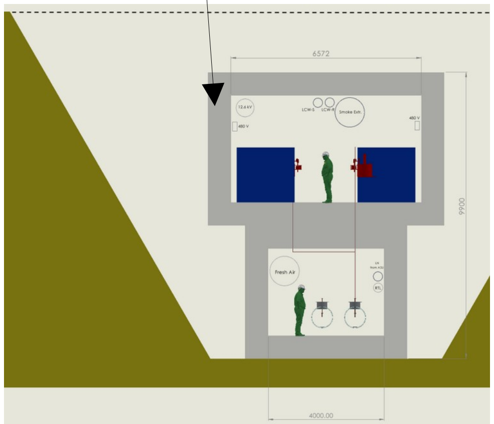
Isolate the beams from klystron's heat and electromagnetic noise



10km
Ø:≈6m

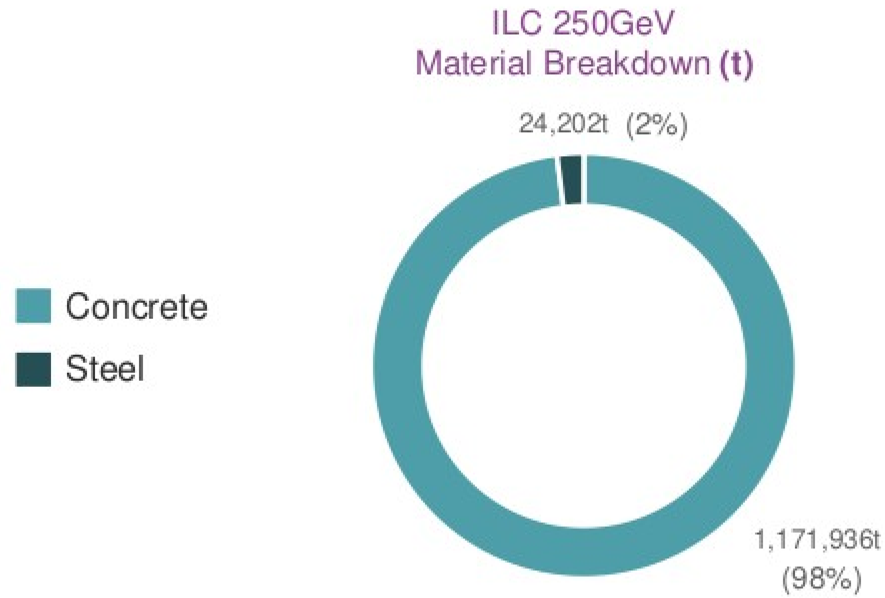


CCC
8km
T=80K

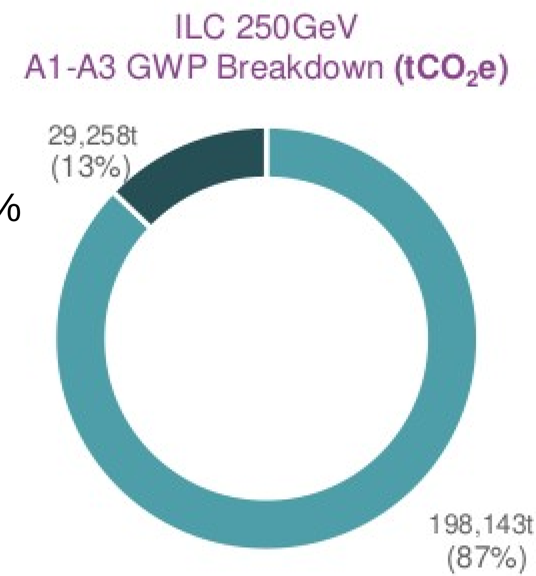


Tunnel + everything related to it

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%



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

Tunnels @NLO

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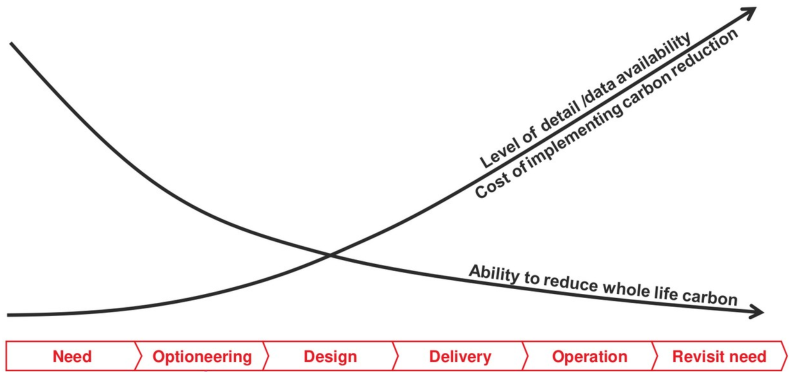
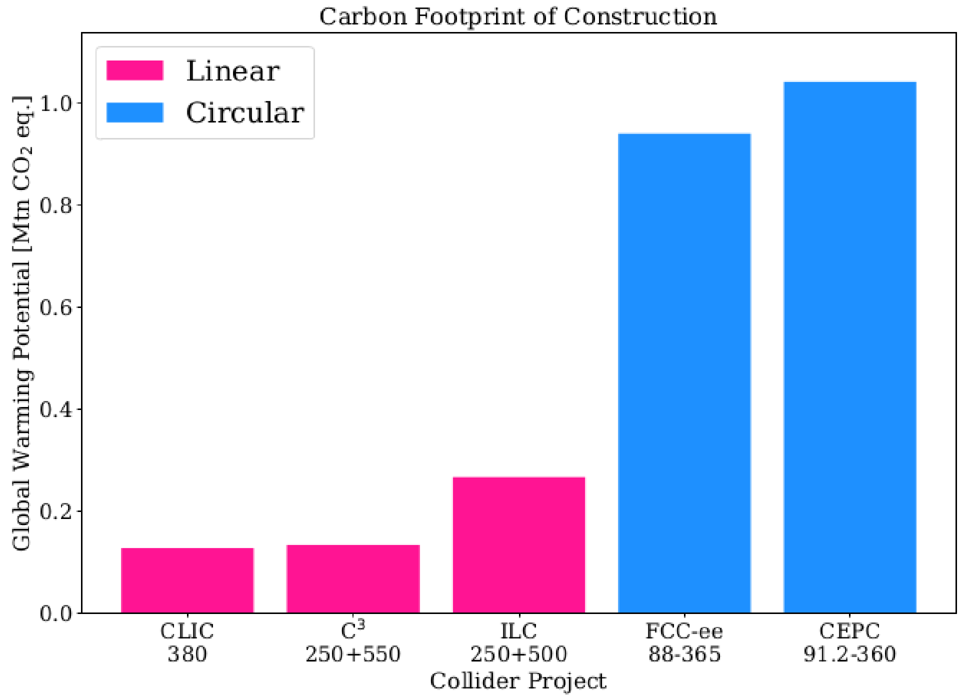
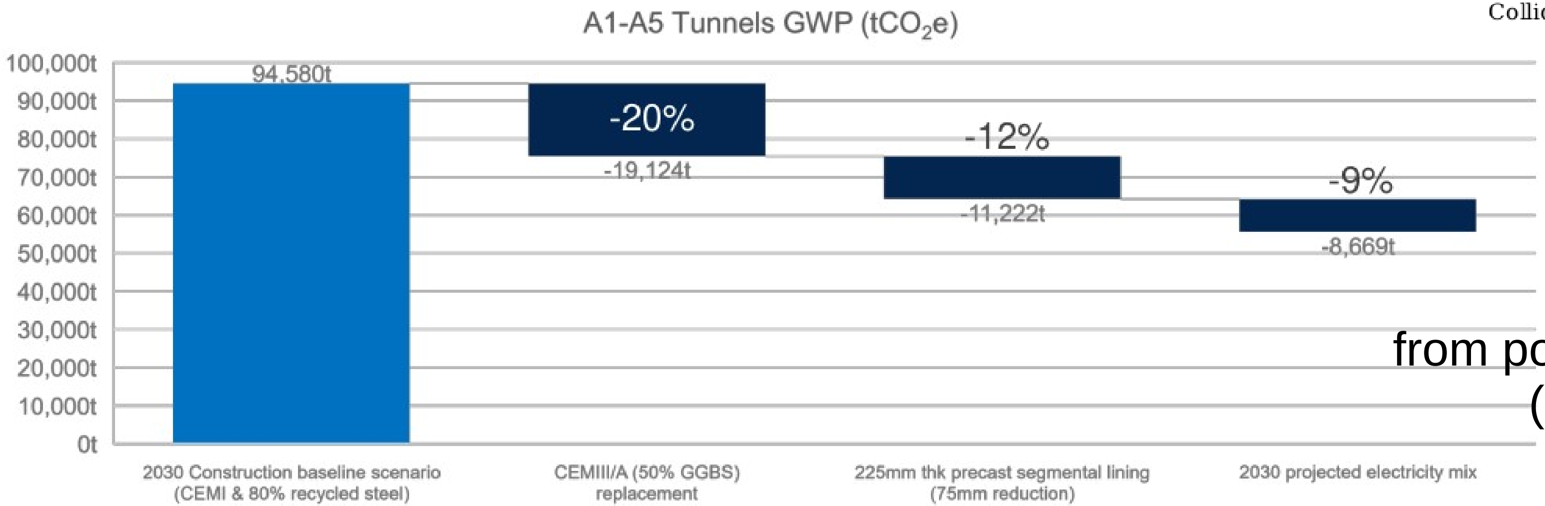






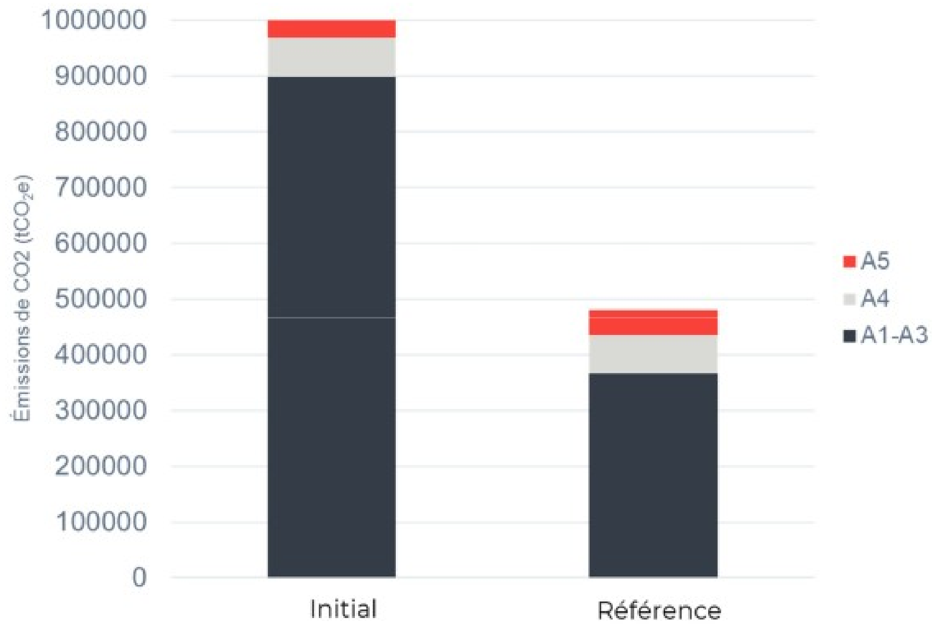
NLO corrections…
from possible improvements
(ex CLIC Drive beam):

Tunnels @NLO

- Recent FCC LCA: big impact of

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

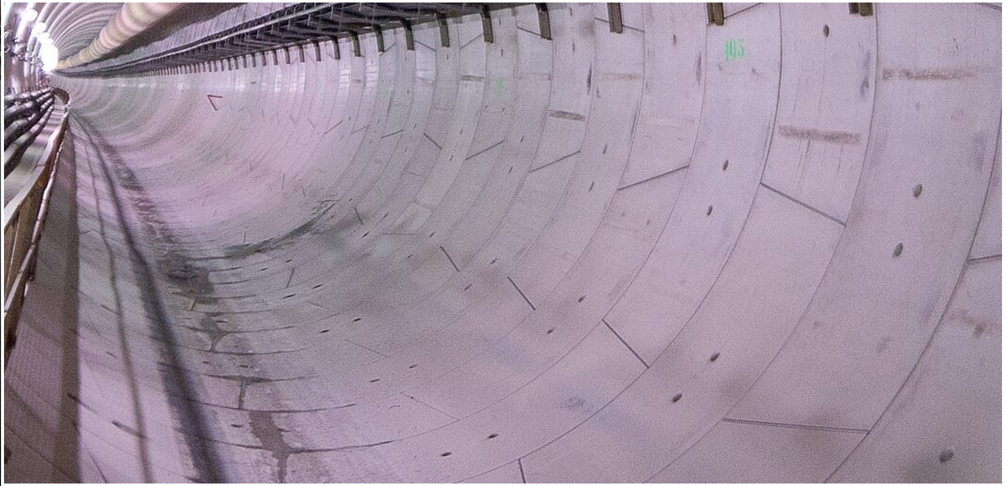
Toward a 0-net CO_2 emission tunnel ?

Industry is elaborating cement free concrete
- cement fully replaced by steel slag
- $C0_2$ captured from a plant
- CO_2 injected into the slag+gravel to produce concrete

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

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

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



Idea submitted to CERN last week

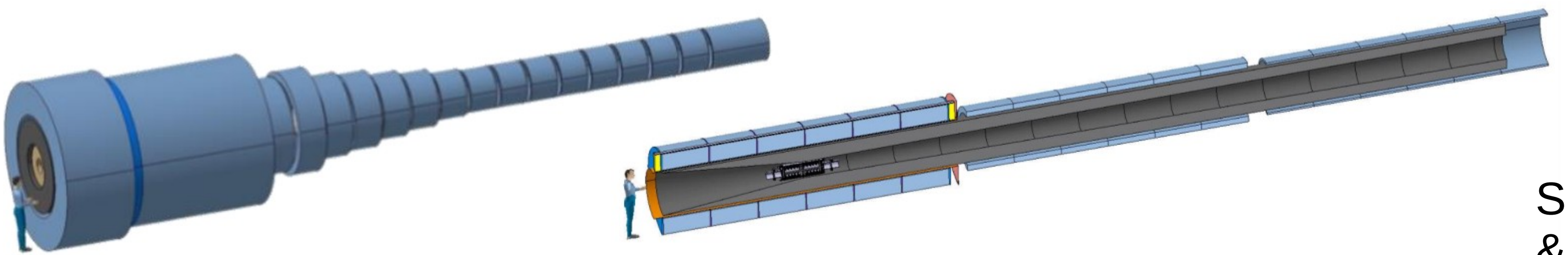
Accelerator construction

- Could not not find a lot of evaluations...
- 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)

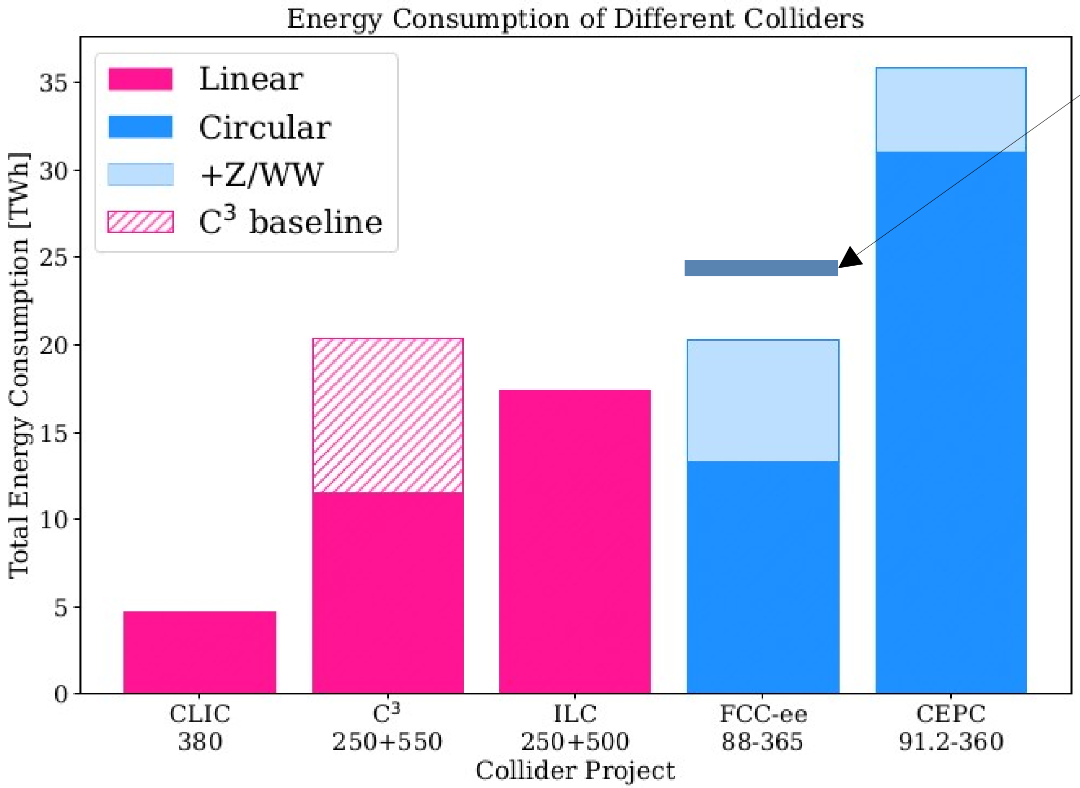
E_M = 2.9 GJ
T_{op} = 4.2 K
M_{coils} = 200 tons
M_{shield} = 300 tons
P = 12 MW

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

IMCC Proposal (2023)

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

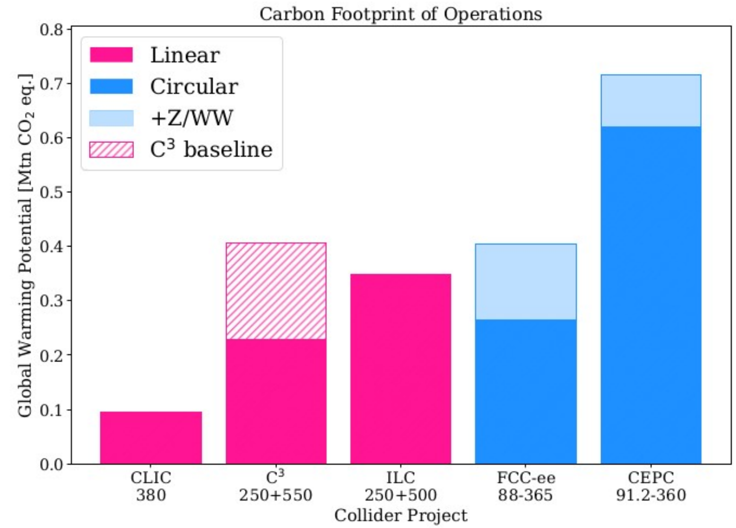
Accelerator operations



From J.P Burnet (sept 2024)

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

To compare with 1.2TWh/year (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 operations

- Lots of developments on going. For example, a French one:

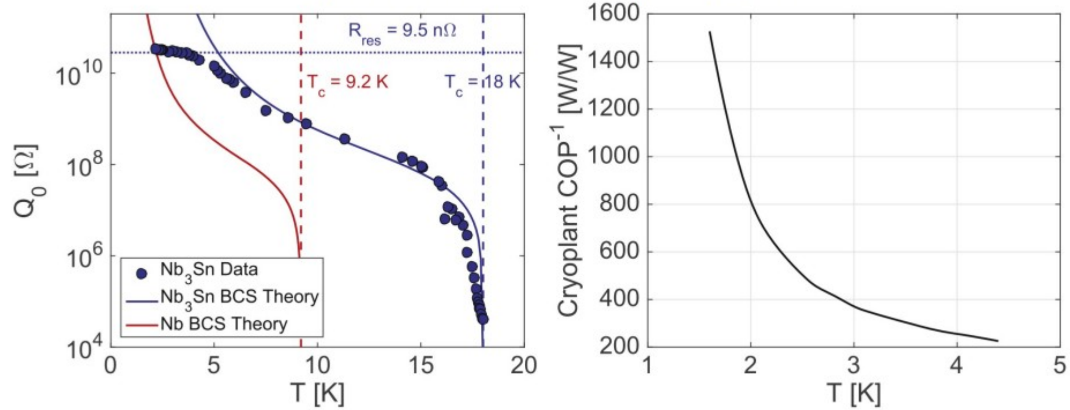
iSAS develops, prototypes & validates SRF energy-saving technologies

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).

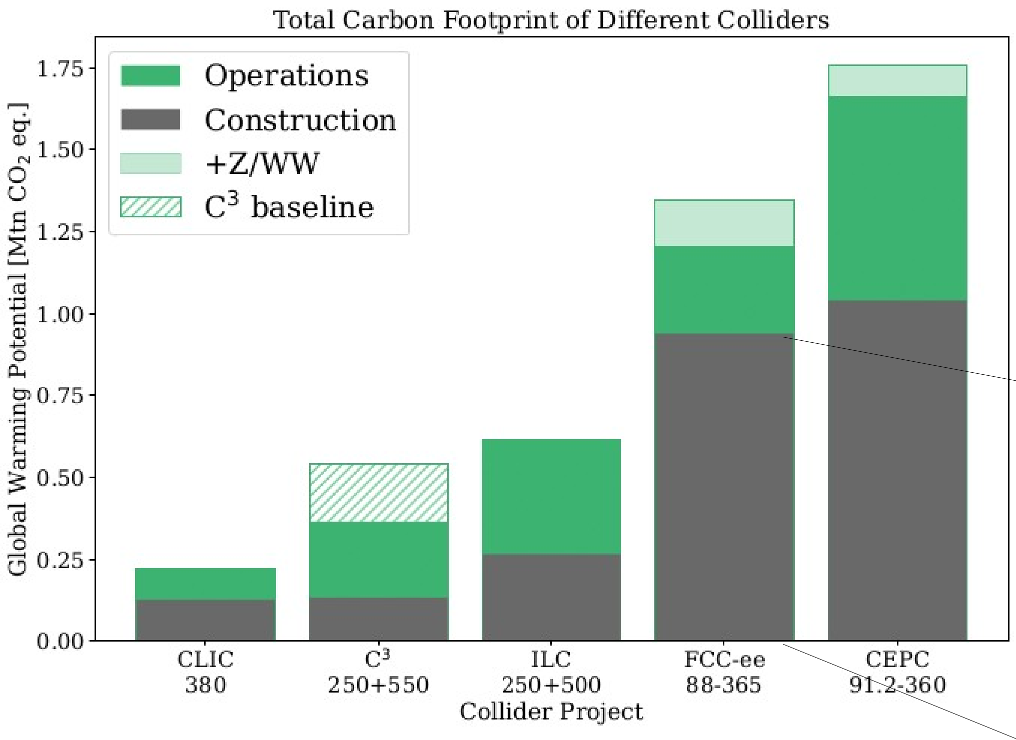
Supercond. Sci. Technol. 30 (2017) 033004



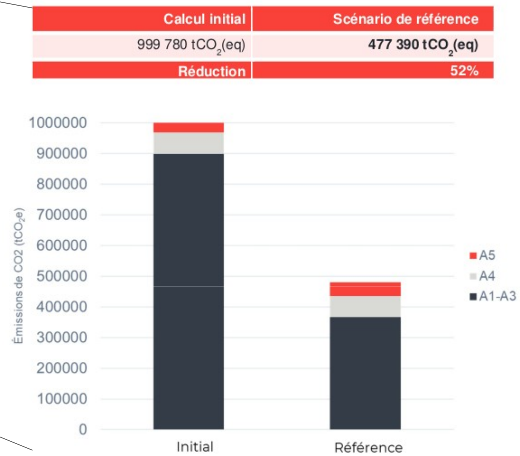
The higher critical temperature (T_c) of Nb_3Sn allows for the maximum value of quality factor Q_0 for 1.3 GHz cavities to be achieved at operating temperatures of about 4 K compared to 2 K for Nb (left figure). The graph on the right shows the efficiency of a cryogenic plant (COP) as a function of temperature 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/

Tunnel + accelerator operation (wo/ building accelerator!)

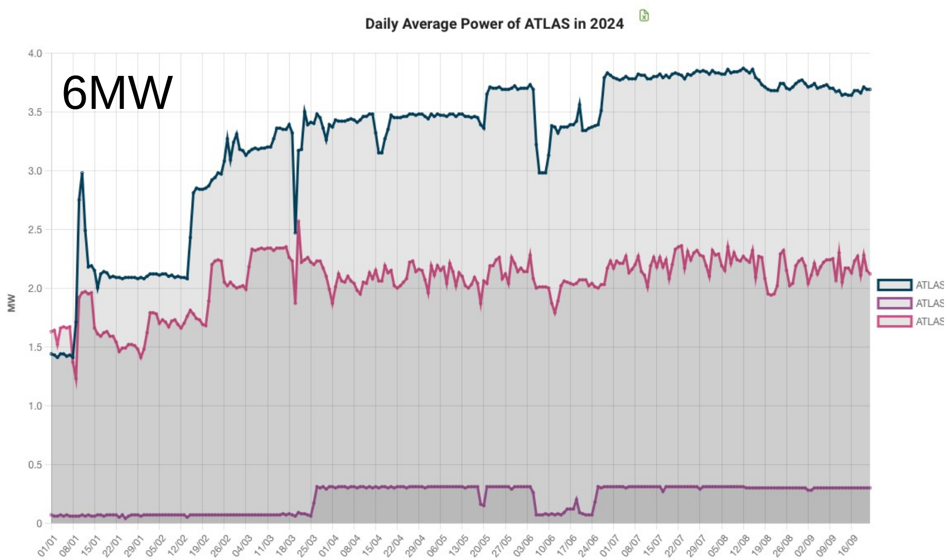


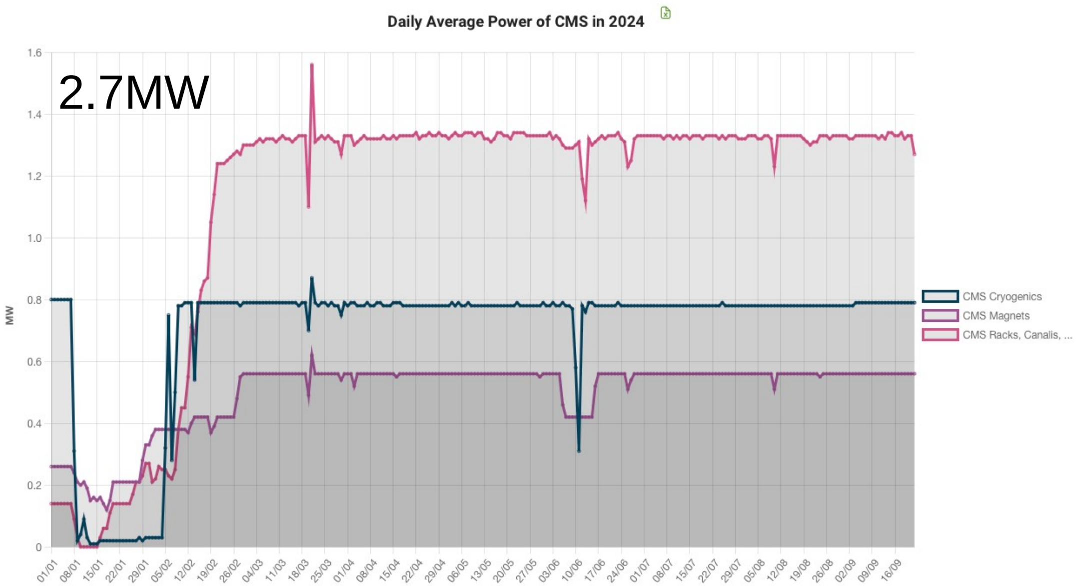
Present estimates give similar order of magnitude between these 2 items
Sum = O(0.5-1)MtCo2eq



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 FCCee
    - **Cryogeny is the key**





ATLAS

CMS

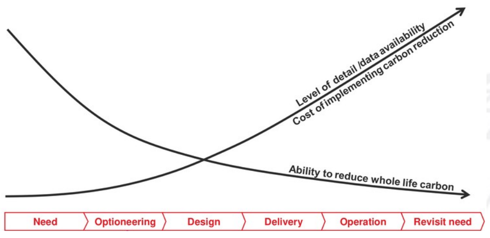
Detectors: Direct emissions

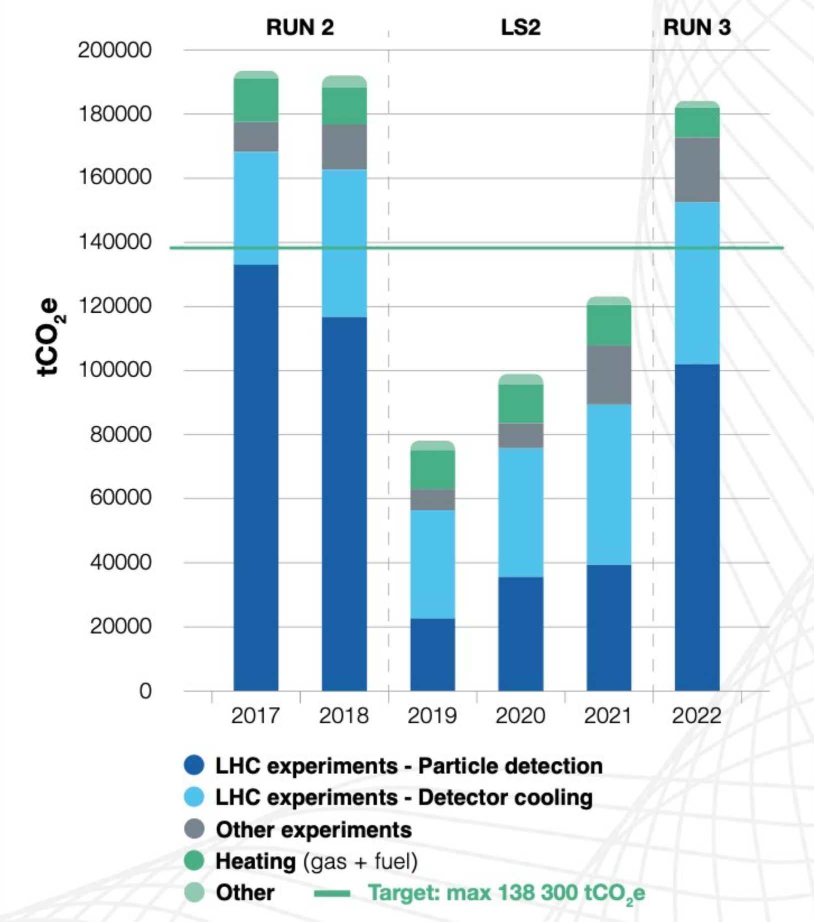
- Presently, the **main contributor** of CERN GHG
  - Cooling, RPC, RICH
  - HFCs, PFCs and SF_6
  - **O(0.2)MtCO2eq/year**

  - **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 to my knowledge
  - 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.

Collaboration structure/life

- Still assuming a world that has achieved its transition in 2050…

- 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 2050…?):
    organizing the 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

  Paris-NY

Life Cycle Assessment

- LCA very useful to reduce env. footprint of project during R&D
  - Extremely important for your future detector R&D !

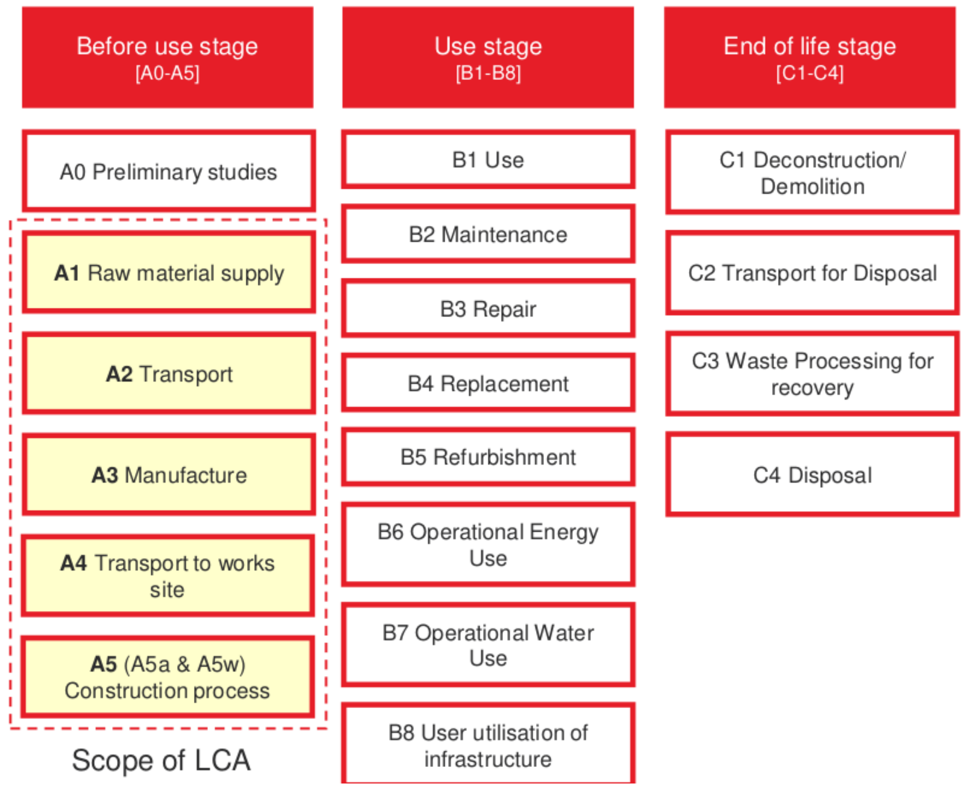
- New CERN course:
  https://lms.cern.ch/ekp/servlet/ekp?PX=N&TEACHREVIEW=N&CID=EKP000044552&TX=FORMAT1&LANGUAGE_TAG=en&DECORATEPAGE=N

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.

BS EN 17472:2022



- ANF “eco-conception” (CNRS)
  - IN2P3/INSIS
  - 12-17/10/2025
  - For engineers/physicists

Conclusions

- Humanity is facing huge challenges

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

- LCA is a crucial tool, to evaluate & to help reducing the impacts

- Present estimates:

O(0.5-1)MtCo2eq

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

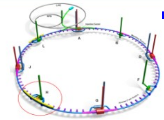
Backup

Still time to endorse contributions listed in:
https://docs.google.com/document/d/1oowNS_QzsNbuNkVplvOzo_pq5Fn2qpFhmOhDBZnoCkI/edit?tab=t.0

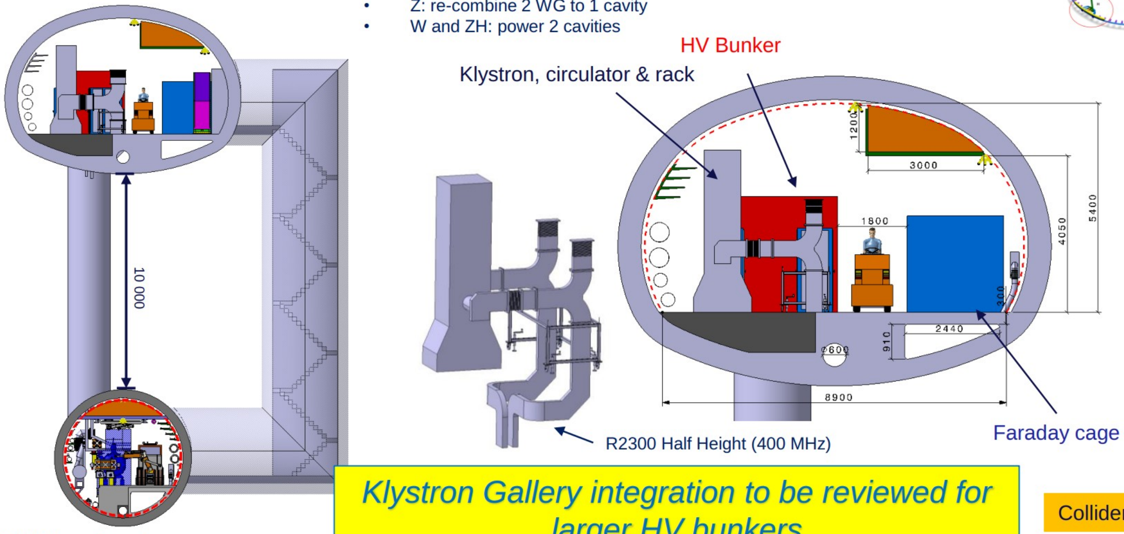
Bibliography

- 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

FCC-ee RF Machine tunnel & Klystron Gallery cross section (ttbar machine)

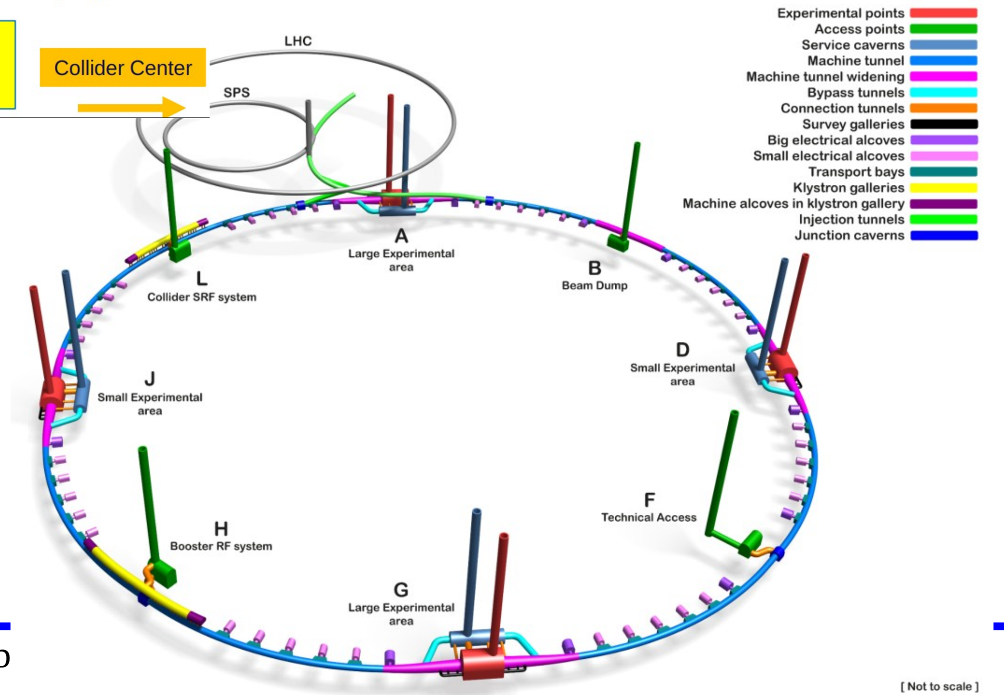


1 MW 400 MHz klystrons can be used for:
- Z: re-combine 2 WG to 1 cavity
- W and ZH: power 2 cavities



Klystron Gallery integration to be reviewed for larger HV bunkers

F. Valchkova-Georgieva

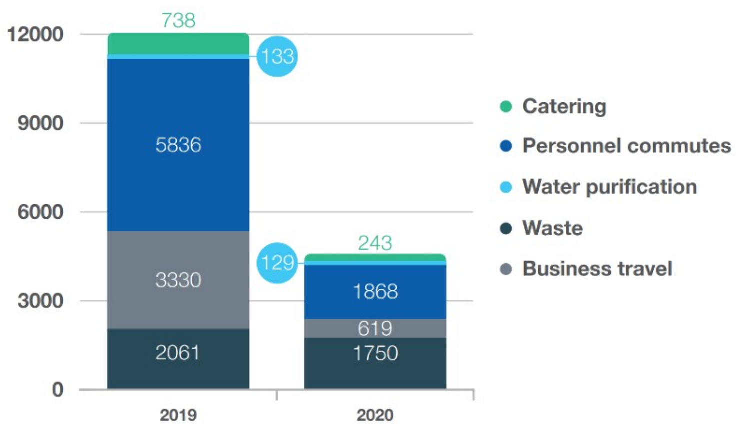


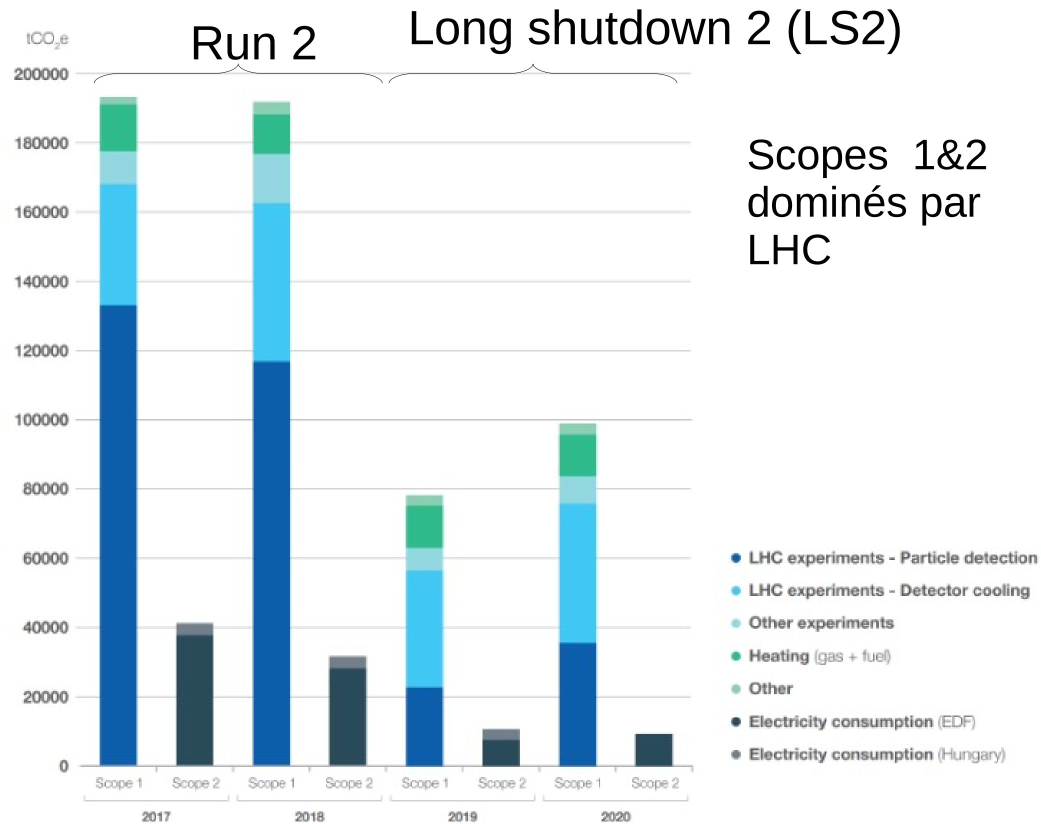
Sustainab

Inputs

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

Scope 3





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

Pas pris en compte

- Déplacements
  - Pour prises de données (shift, maintenance, …)
  - Pour workshops, conferences

- Computing hors Tier0

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