Sustainability in HEP - What we can do!

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DESY Zeuthen

25th of January 2024
IKTP Institute Seminar

Special thanks to: Daniel Britzger, Kristin Lohwasser, Juliette Alimena, Eleanor Jones, Nils Gillwald

Introduction to global warming

- Global warming is a hot topic: Climate scientists are among the [most cited scientists](#) in the world
- [Nobel prize](#) for contributions to developing climate models in 2021 for *research on the **greenhouse gas effect** and climate analysis to **prove anthropogenic impact***

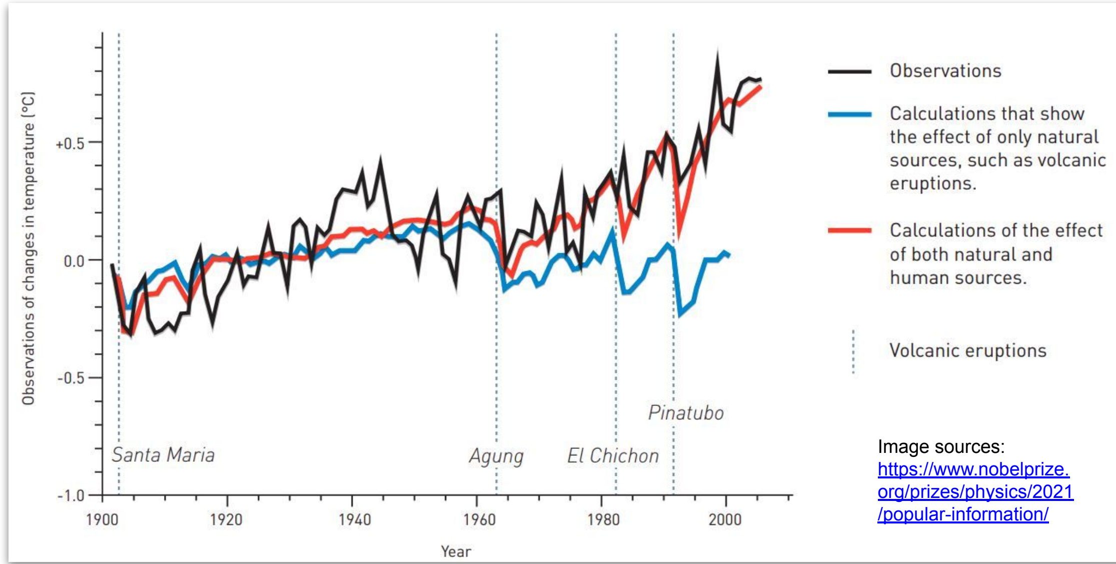

Image sources: https://www.nobelprize.org/prizes/physics/2021/popular-information/

- Warmer air can store more water vapour ([Clausius-Clapeyron relation](#))
  - → droughts, floodings
  - → destroyed crops & infrastructure
  - → need more fresh water, diseases
- Rising sea levels from melting pole ice
- Less snow → water reservoirs
- Feedback effects, e.g. less snow → less reflection → more heating

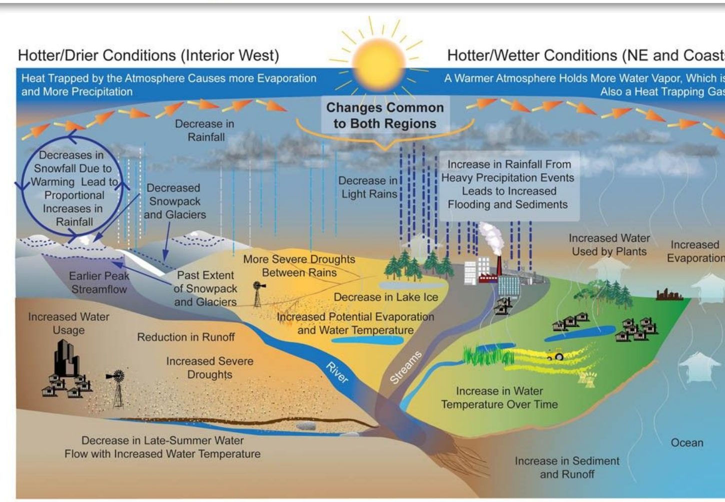

Image source: http://downloads.globalchange.gov/usimpacts/allimages/3-Water/3-Hi%20res/3-Water-pg-42_top.jpg

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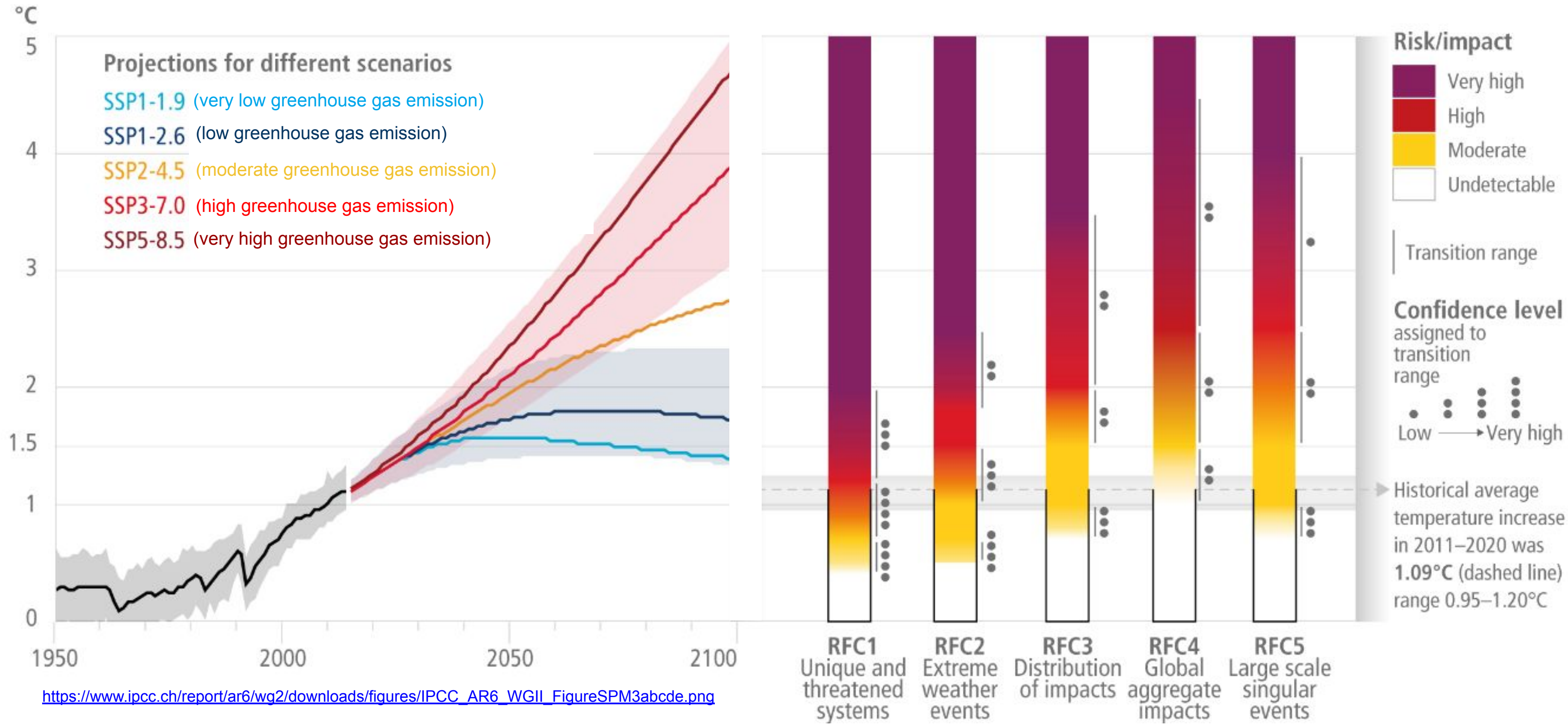
[1] USGCRP (2014). Georgakakos, A., P. Fleming, M. Dettinger, C. Peters-Lidard, Terese (T.C.) Richmond, K. Reckhow, K. White, and D. Yates. Ch. 3: Water Resources. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 69-112.
[2] IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-33, doi:10.1017/9781009325844.001.

How bad will it be?



https://www.ipcc.ch/report/ar6/wg2/downloads/figures/IPCC_AR6_WGII_FigureSPM3abcde.png

- The warmer it gets, the bigger the problem
  → reduce greenhouse gas emissions as much as possible!
- 300 Gt CO2e can be emitted to stay within 1.5°C at 83% CL
  → **1 T CO2e per person per year until 2050, currently 5-10 T pP in western countries**

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[1] IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001.

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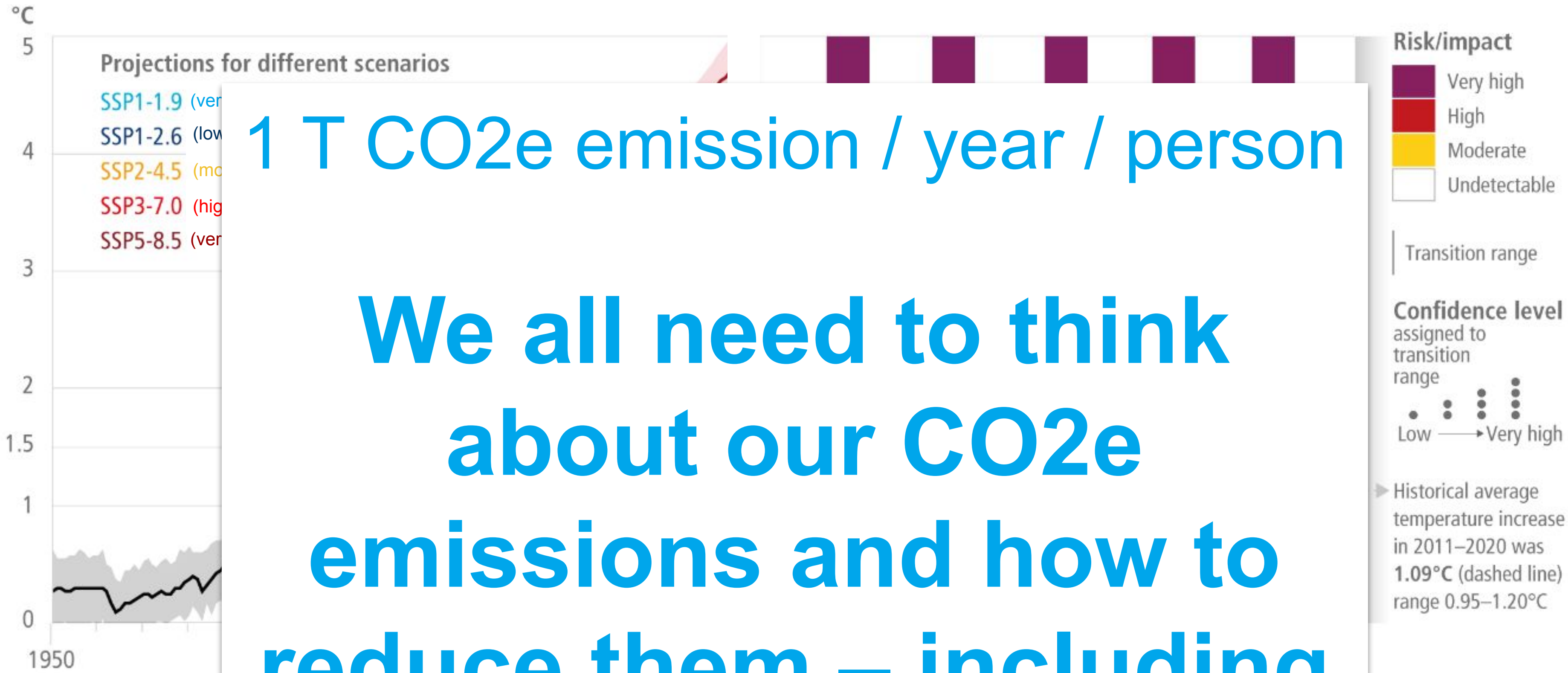

https://www.ipcc.ch/report

1 T CO2e emission / year / person

We all need to think about our CO2e emissions and how to reduce them – including HEP and all scientists!

- T
  —
- 3
  → **1 T CO2e per person per year until 2050, currently 5-10 T pP in western countries**

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[1] IPCC, 2021: Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001.

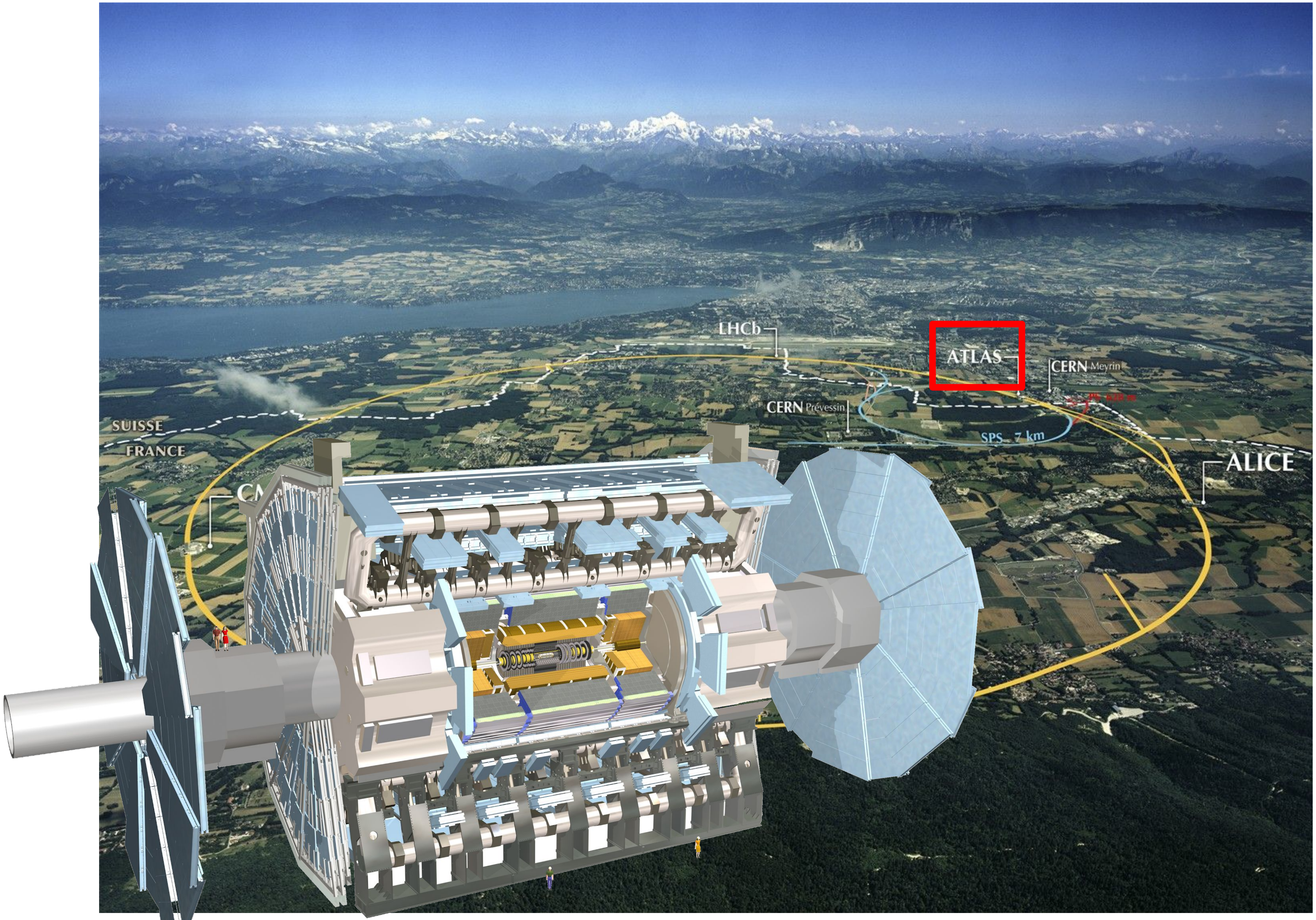
More reasons why sustainability matters

- Funding: will (likely) be tied to sustainability in the future
  - “A detailed plan for the minimisation of environmental impact and for the saving and re-use of energy should be part of the approval process for any major project.” (European Strategy for HEP 2020, Ch. 7, Paragraph A; example: LHCb phase-II upgrade TDR)
- Legal: e.g. German scientists self-committed to be CO2e neutral by 2035 & many countries demand to reach the Paris agreement
- Collaboration: several members may be interested in being more sustainable
- Outreach: we should tell the world in the future how sustainable we are and how we got there
- Society:
  - we have extraordinary many smart minds around
  - we can help pioneering ideas and be a role model for society and companies
  - **who if not scientists will start paving the way?**

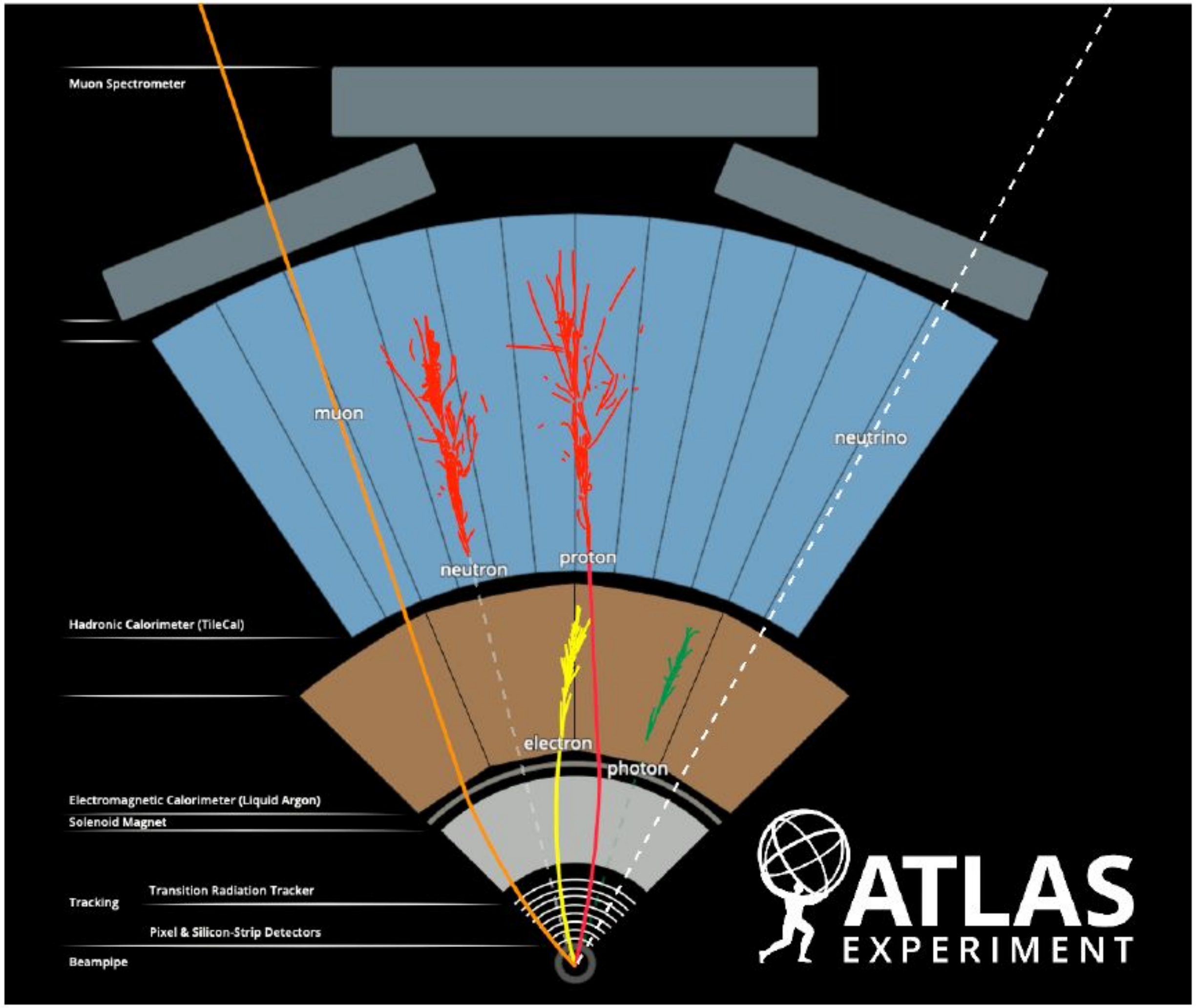
ATLAS at the LHC

ATLAS at the LHC

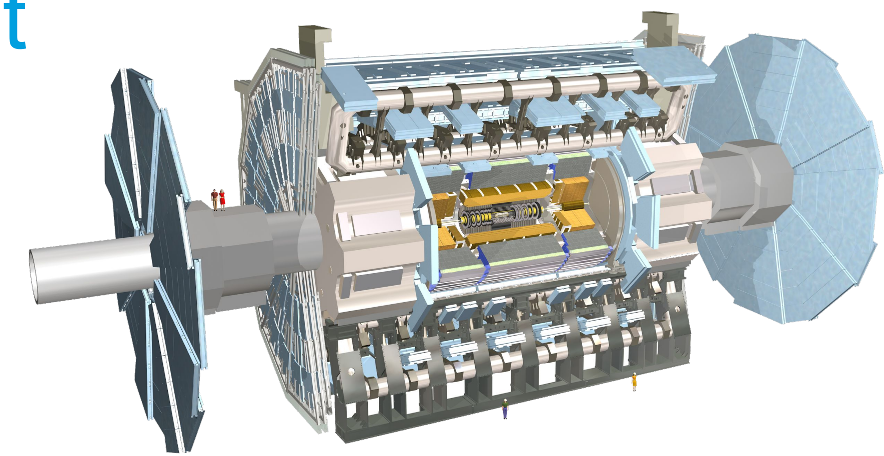
ATLAS at the LHC

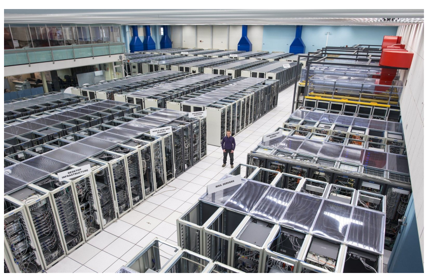


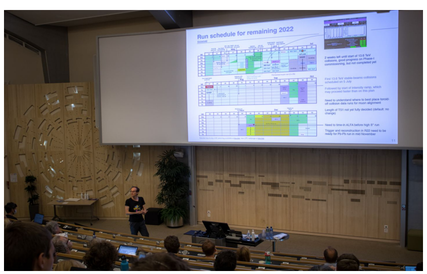
ATLAS at the LHC



Environmental impacts of an LHC experiment



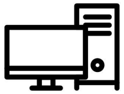




Build the cavern & detector

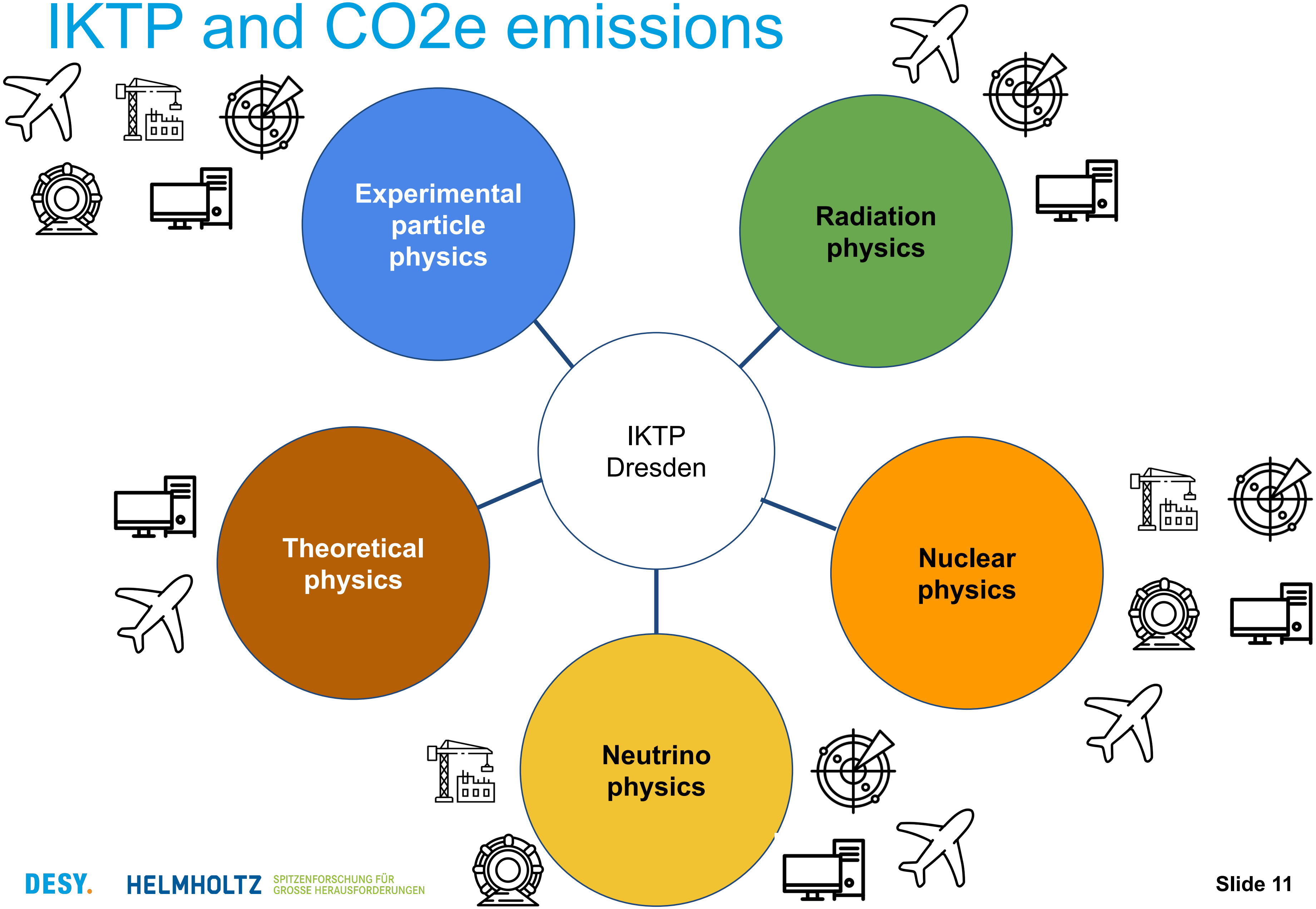
Take the data: LHC & detector operation

Analyse the data



Present your results

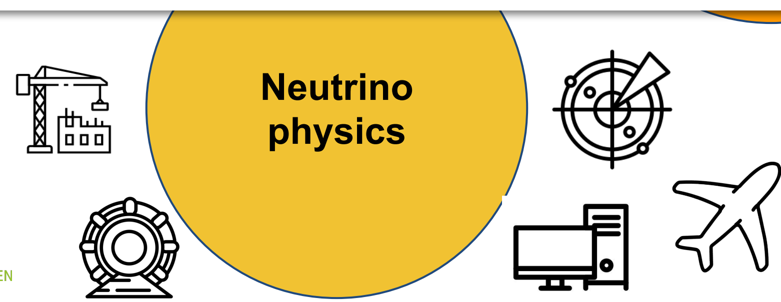
IKTP and CO2e emissions



IKTP and CO2e emissions

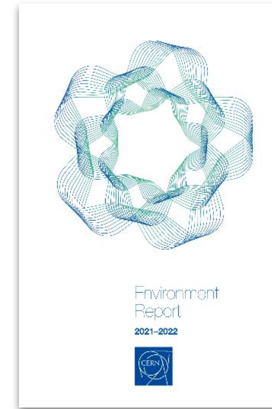
Disclaimer

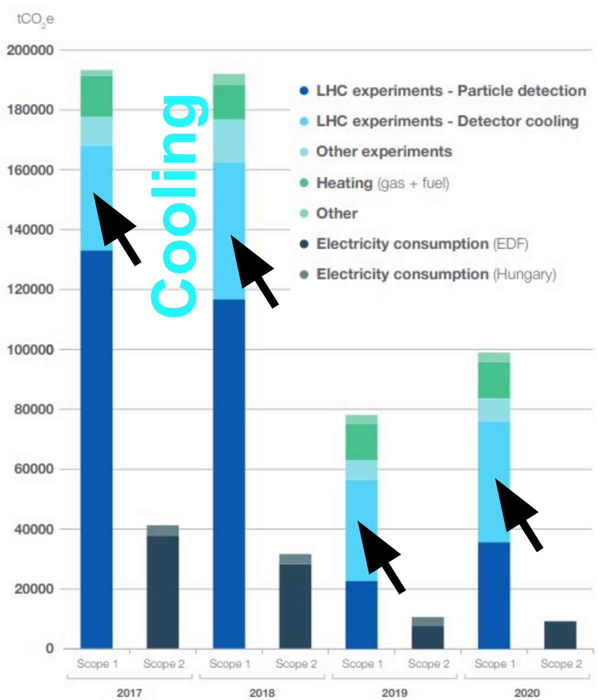
Will focus on CO2e emissions from ATLAS / LHC experiments in the following.



CO2e emissions of an LHC experiment

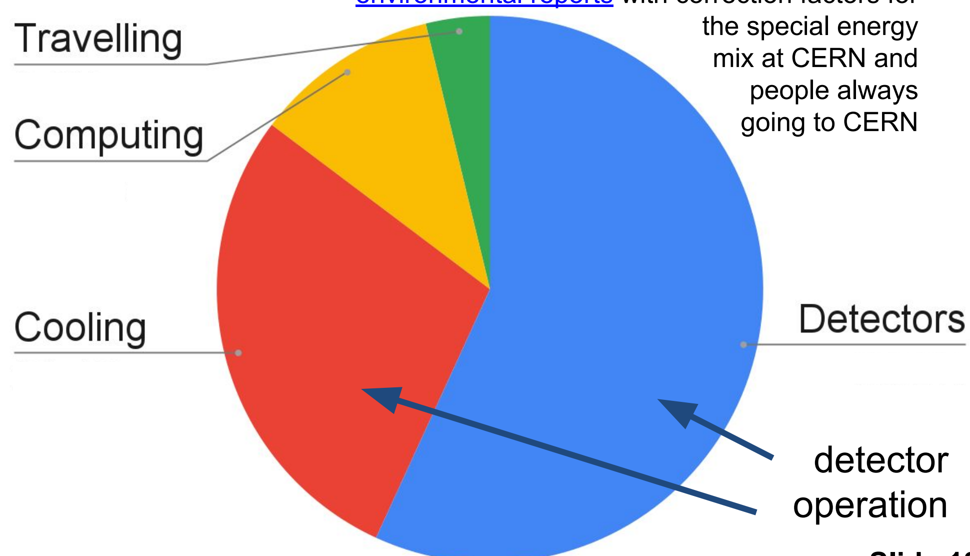
- Numbers estimated w/ CERN's latest [report]
- Main drivers: gaseous detectors, cooling emitting highly potent greenhouse gases (e.g. $C_2H_2F_4$)
- Computing: apply correction factor to CERN's numbers, as world-distributed and electricity more CO_2 intense in most countries
- Similar for travelling, CERN numbers based on CERN's staff, but many physicists regularly travel to CERN





https://doi.org/10.25325/CERN-Environment-2021-002

Preliminary & self-estimated! Contributions Based on [CERN's environmental reports] with correction factors for the special energy mix at CERN and people always going to CERN

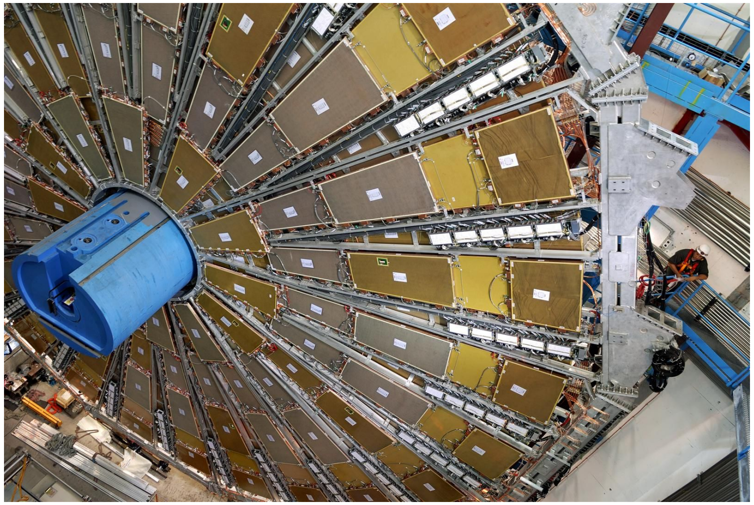


Particle detectors

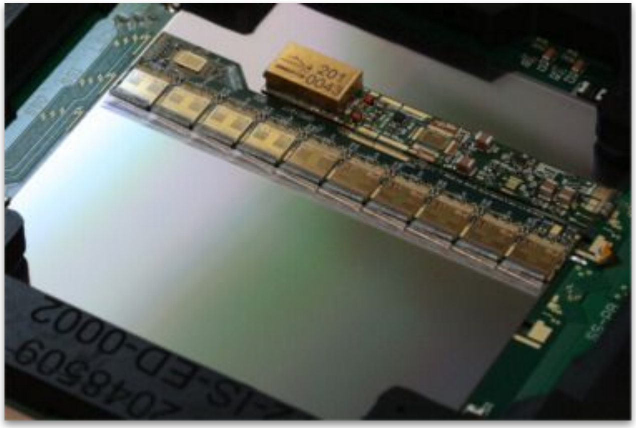
Overview of detector technologies used

- Typically have a deposition layer and a detection layer
  - Deposition layer can be gaseous, liquid or solid
- Detection layer often produces electrical signal
- Different systems used for particle tracking, particle identification, energy measurements, etc.

- Footprint very device dependent
- Different contributions from construction / operation



https://cds.cern.ch/images/CERN-EX-0609016-02/file?size=large

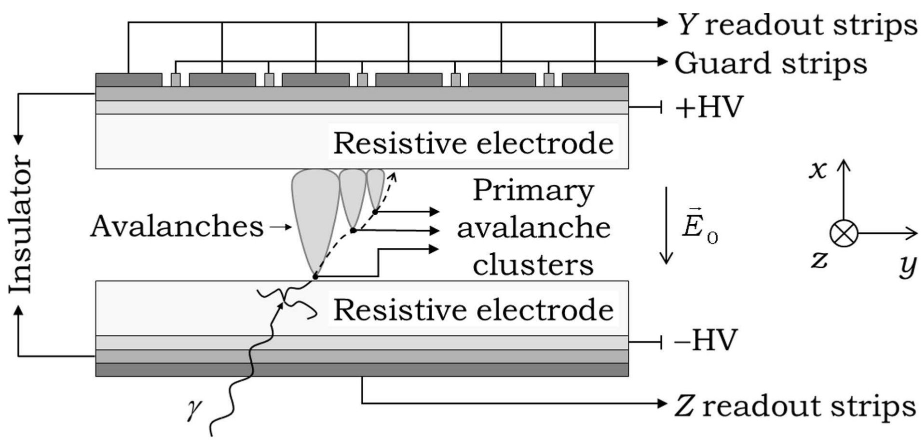


L. Gonella, NIM A, 1045/167597, 2023, doi: 10.1016/j.nima.2022.167597

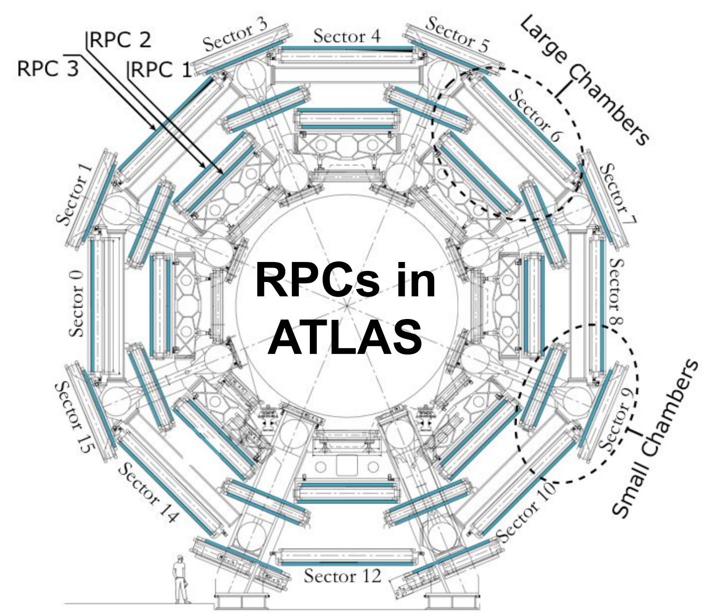
Resistive Plate Chambers (RPCs)

- Electrode-covered resistive plates enclose gas
- Signal-collection by metallic readout strips on the electrodes
- Features: high resolution in time & space, high readout rates & signal

- **RPCs widely used, e.g. ATLAS, CMS, ALICE e.g. for triggering on muon signals**



http://przyrbwn.icm.edu.pl/APP/PDF/127/a127z5p04.pdf



G. Ciapetti et al, 12th Workshop on Electronics for LHC and Future Experiments (LECC 2006), 323-327, http://cds.cern.ch/record/1035895

RPCs in ATLAS

- Gas mixture in ATLAS (similar in ALICE & CMS):

  $C_2H_2F_4$ (94.7 %) + Iso-C_4H_{10} (5 %) + SF_6 (0.3 %)

  many charges/particle — remove photons — prevent discharge & ensure localised avalanche

  Wermes, Kolanoski - Teilchendetektoren, p. 210, Springer, 2016;
  ATLAS Collaboration, JINST 3 (2008), S08003,
  doi: 10.1088/1748-0221/3/08/S08003

- **$C_2H_2F_4$ (R134A), SF_6 have high global warming potential!**
  - GWP = how much tons of CO_2 would heat the atmosphere like 1 T of the gas would?

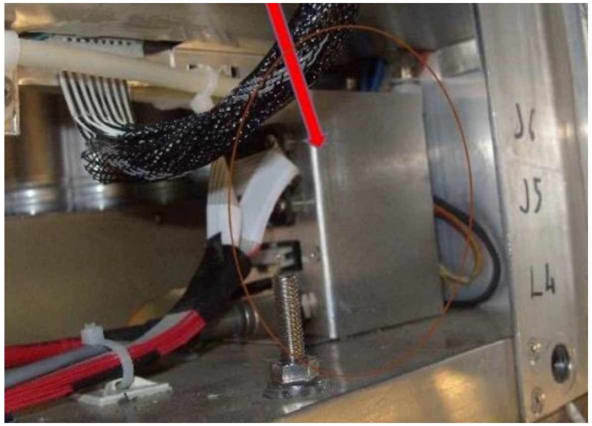
- GWP of ATLAS gas is ~1400

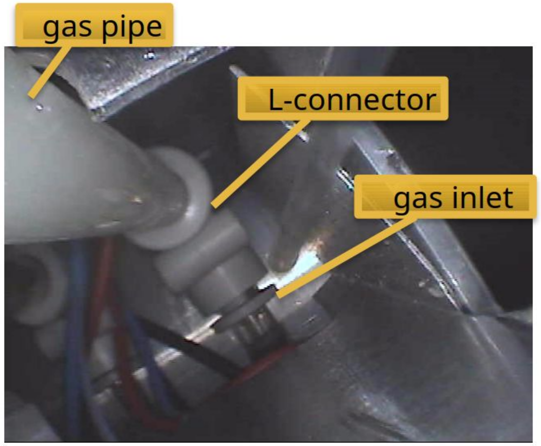
  D. Boscherini, NIM A (2023), 1056, 168479, doi: 10.1016/j.nima.2023.168479

Gas	GWP
CO_2	1
$C_2H_2F_4$	**1430**
SF_6	**22800**
C_3F_8	8830
C_6F_{14}	9300

Unfortunately :(…

D. Boscherini,
https://indico.cern.ch/event/1123140/contributions/4994339/attachments/2515656/4324912/boscherini-RPC2022.pdf





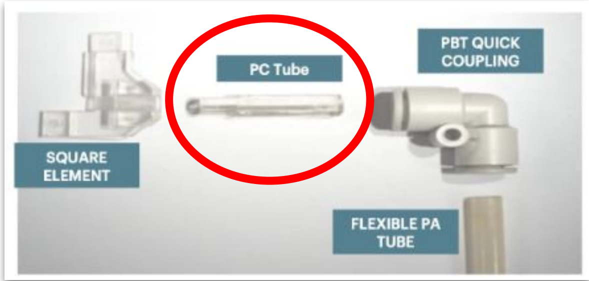
incomplete crack

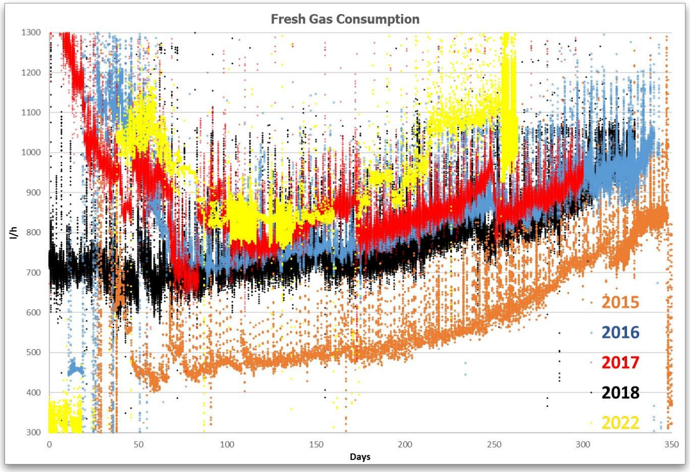
complete crack

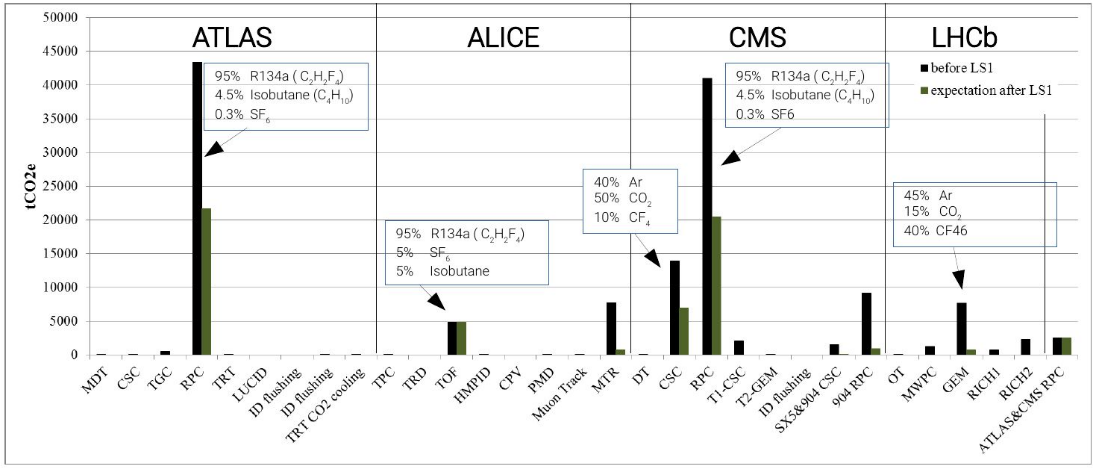
- Cracks due to chemical / mechanical stress, vibrations and pressure spikes

RPCs: gas emerging

- ~1000 l/h gas escaping ATLAS
  → high green-house gas emissions
- Similar for other experiments, e.g. CMS
- Leaks in gaseous detectors in ATLAS, CMS, ALICE lead to ~80 % of the direct GHG emissions ("scope 1") of CERN







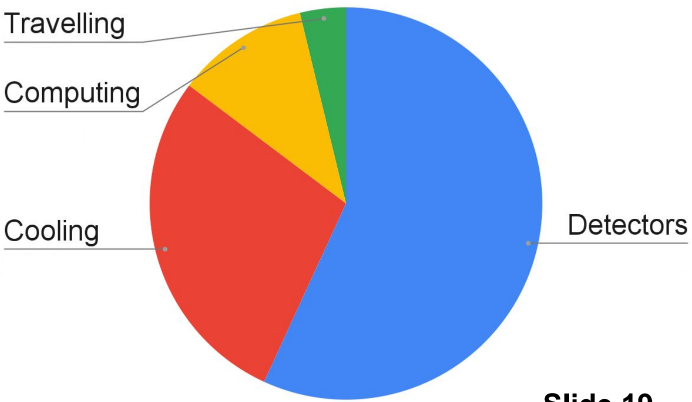
R. Guida, M. Capeans, F. Hahn, S. Haider, B. Mandelli, 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (2013), pp. 1-7, doi: 10.1109/NSSMIC.2013.6829415;

Lohwasser, Britzger, https://indico.desy.de/event/34904/

D. Boscherini, NIM A (2023), 1056, 168479, doi: 10.1016/j.nima.2023.168479, https://indico.cern.ch/event/1123140/contributions/4994339/attachments/2515656/4324912/boscherini-RPC2022.pdf

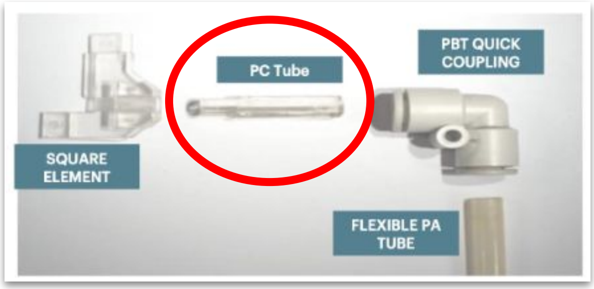
for more on CMS, see G. Pugliese, https://indico.cern.ch/event/1022051/contributions/4325945/attachments/2231022/3780366/CMS_ATLAS_talk_22_4_21.pdf

Preliminary & self-estimated!



RPC cracks – What is done in ATLAS?

- Avoid new leaks → changes to gas distribution system undertaken



<u>Fixing leaks</u>

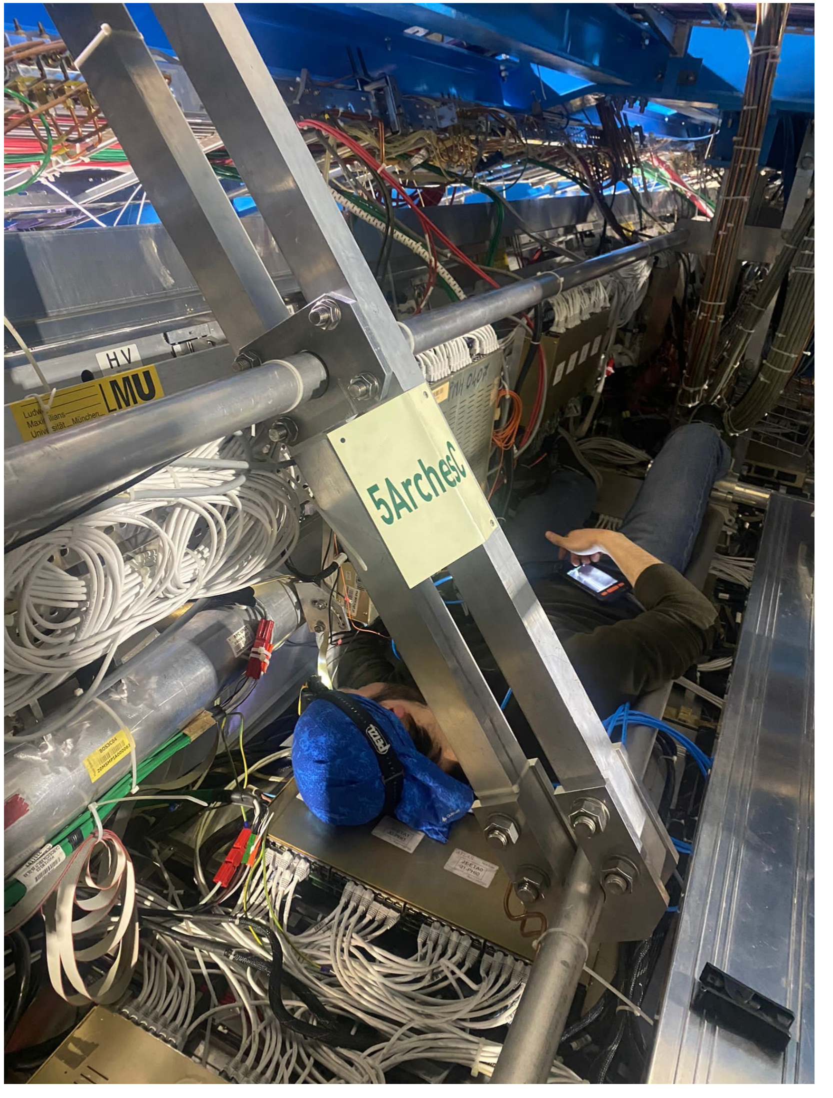
- Difficult to access
- Seal cracks with glue
  → need to be very precise
  → cracks may reappear
- Leaks form fast, hard to keep up with repairs
- New technique w/ special expansive foam
  → faster & easier
  → appears to seal crack for good
  → large scale application started

D. Boscherini, NIM A (2023), 1056, 168479, doi: 10.1016/j.nima.2023.168479,
https://indico.cern.ch/event/1123140/contributions/4994339/attachments/2515656/4324912/boscherini-RPC2022.pdf

ATLAS collaboration, arXiv:2305.16623

Dresden involvement in fixing leakages!!!

Thank you Orcun!!
(& Frank!!)



RPCs: other mitigation techniques

Recirculation

- don’t let gas escape detector, but reuse it
- requires return pipes, purification
- have gas exhaust in purification step

Recuperation

- elaborate “cleaning” of gas returned from detectors
- only makes sense if little leaks in detectors

https://indico.desy.de/event/36020/

Replacement

- use gases w/ less climate impact
- difficult to find gas which is safe and good for detection
- may need physical detector adaption

Removal

- eliminate emitted greenhouse gases
- very expensive

RPCs: other mitigation techniques

R. Guida, https://indico.cern.ch/event/1123140/contributions/4994277/attachments/2517501/4328439/RPC2022_GHG_recuperation_RGuida_v0.pdf
M. Bruno, Master's thesis, Torino, 2023, https://webthesis.biblio.polito.it/secure/28358/1/tesi.pdf

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https://indico.desy.de/event/36020/

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- Recuperation system for $C_2H_2F_4$ under investigation
  → first results promising
  → already in use in CMS now saving 10% of fresh gas

- Replacement of $C_2H_2F_4$ / SF_6? → Testing e.g. $C_3H_2F_4$, $C_3H_2ClF_3$
  - difficult to find gas that keeps read-out efficiency high and sparking probability/ageing low

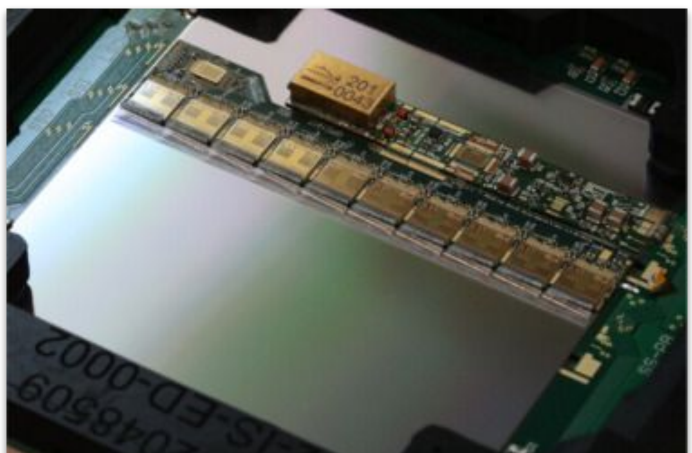
- **Short-term: dilute gas mixture with 30% CO_2, increase SF_6 to 0.5-1%?**
  - **1% SF_6 very promising, reduces CO2e by ~14% on 20y scale**, for 500y larger GWP
  - studying if can reduce SF_6 to 0.5% → overall reduced GWP

G. Proto, https://indico.cern.ch/event/1123140/contributions/5000800/attachments/2517497/4328395/RPC_2022_3.pdf

G. Rigoletti, https://indico.cern.ch/event/1123140/contributions/5000807/attachments/2517531/4328462/RPC%202022%20-%20Gianluca%20Rigoletti%20(1).pdf

Other detector systems at the LHC

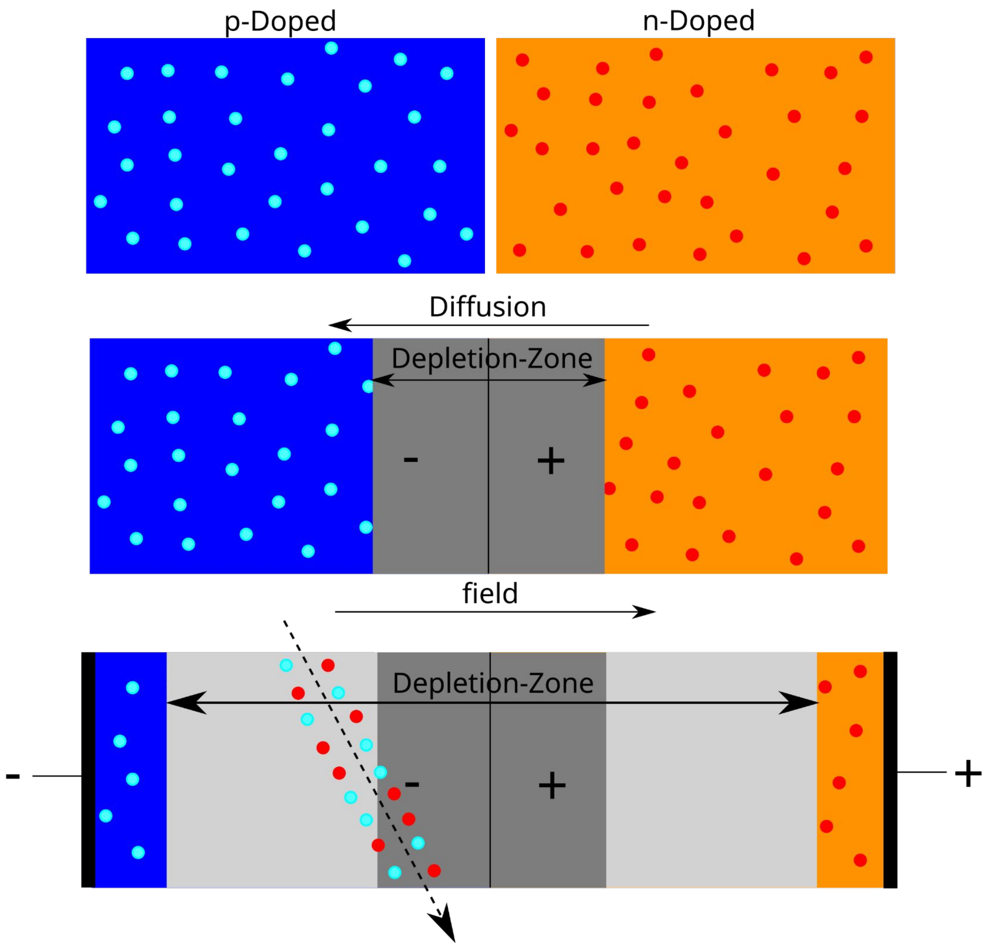
- Also use other detector systems apart from gaseous detectors at the LHC
- Among them: semiconductor detectors
  - Embedded emissions from producing the wafer & read-out chips
  - But by far not the largest emissions…



L. Gonella, NIM A, 1045/167597, 2023, doi: 10.1016/j.nima.2022.167597

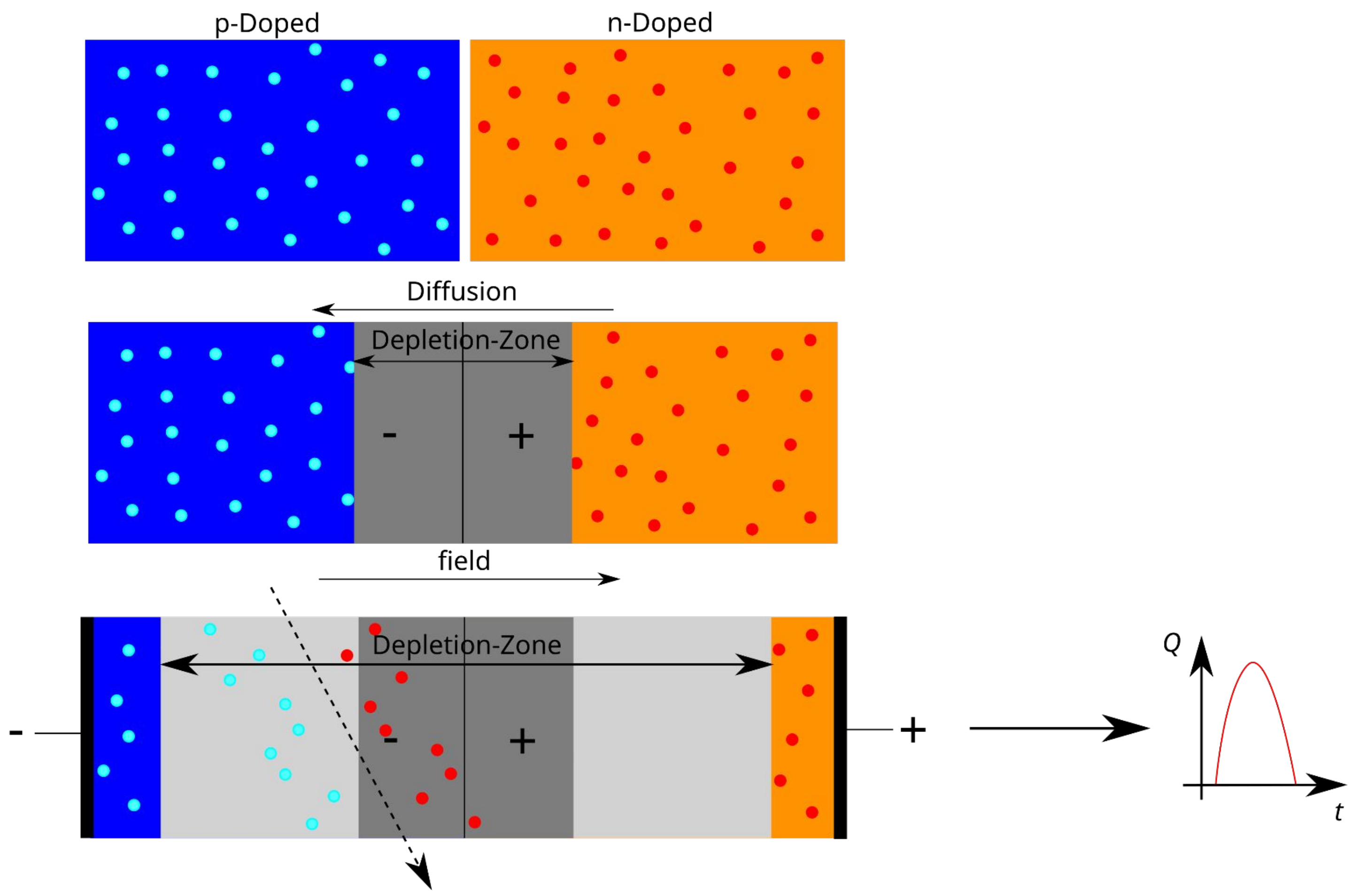
Other detector systems at the LHC

- Penetrating particles deposit charges in semiconductor detector



Other detector systems at the LHC

- Penetrating particles deposit charges in semiconductor detector → drift signal



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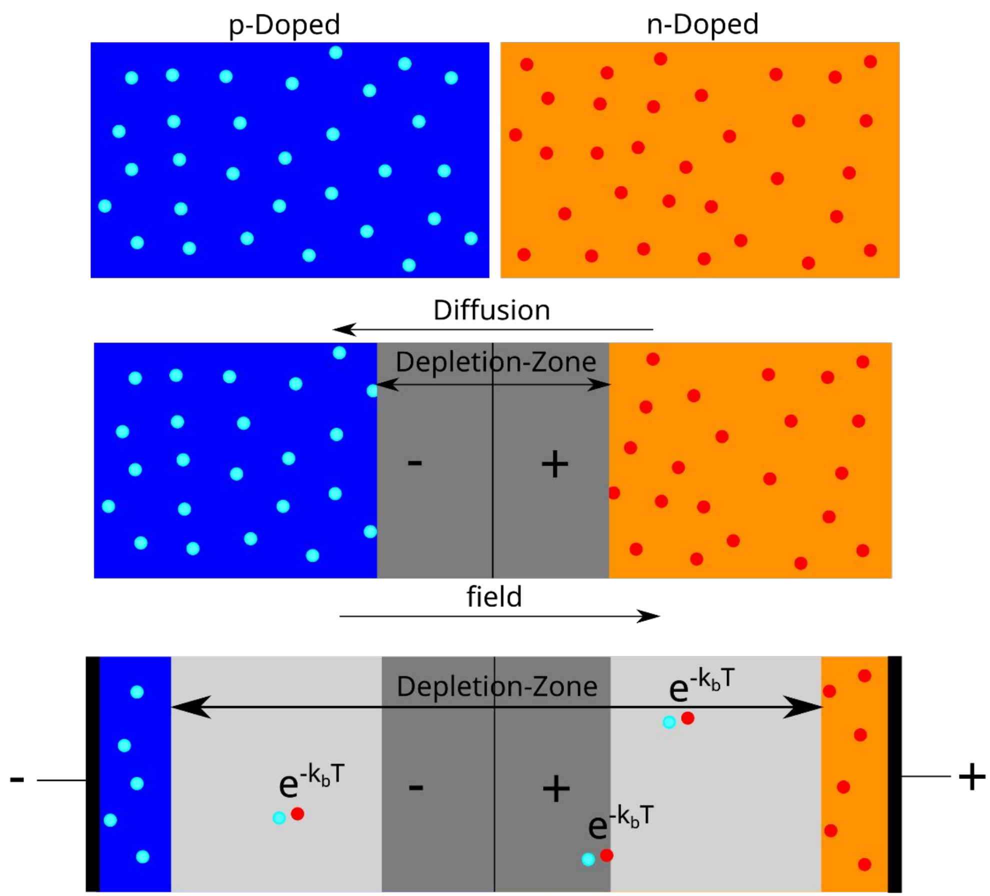
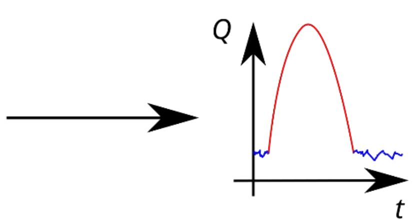


- Leakage current from thermally produced electron-hole pairs



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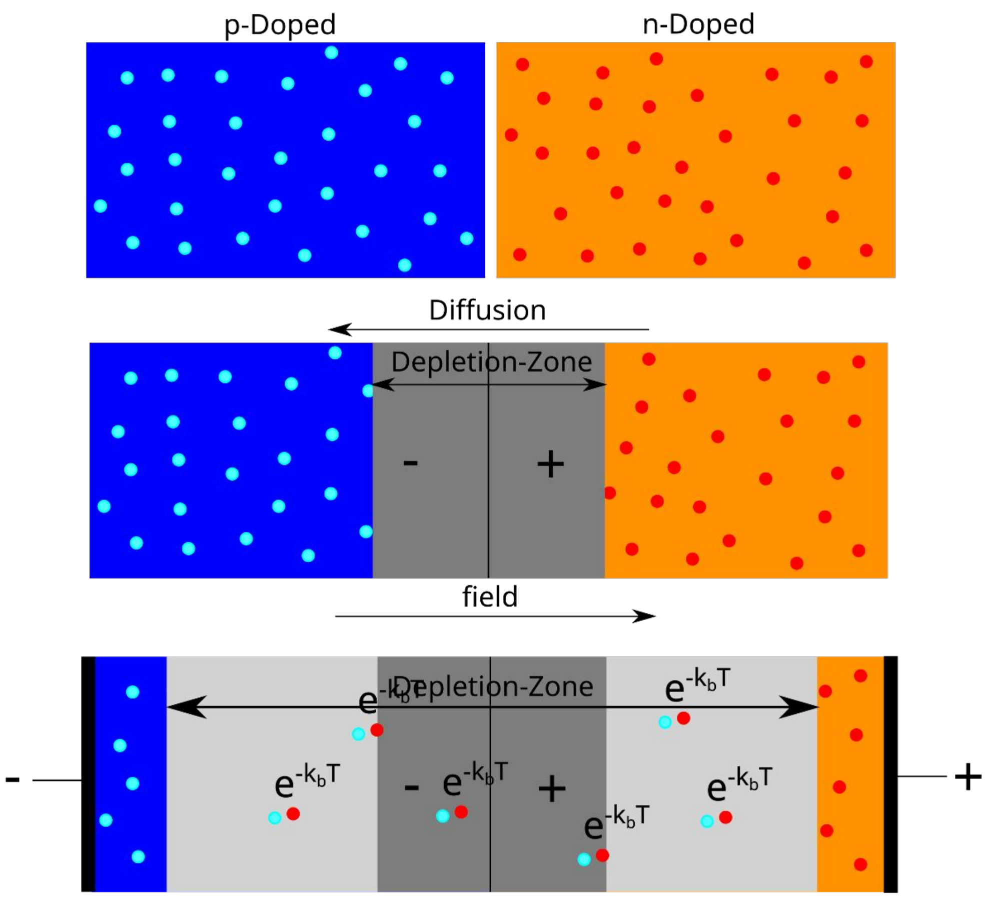
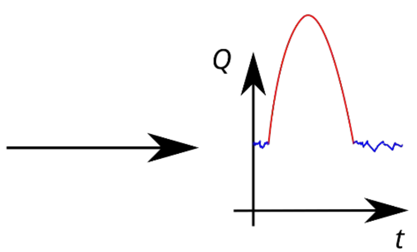


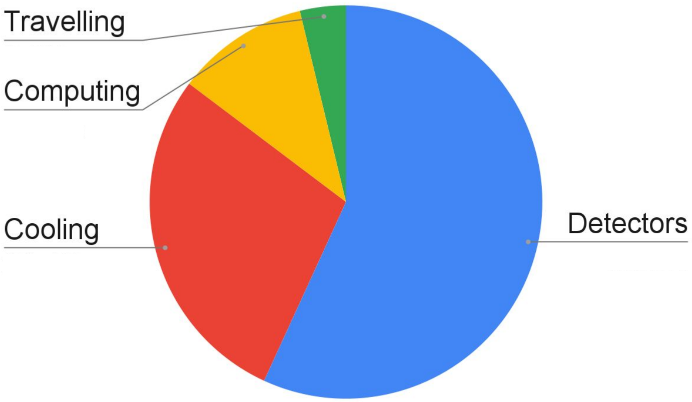
- Leakage current from thermally produced electron-hole pairs
- High leakage current (e.g. from radiation damage) → heat → more leakage current → more heat
- **Need to cool detector to prevent thermal runaway!**



Cooling contributions to CO2e

- **In ATLAS and CMS, cooling systems of silicon detectors use high GWP gases C_3F_8 / C_6F_{14}**
- **C_6F_{14} also used in many other places**
  - ATLAS cooling cables and TRT
  - ALICE PHOS crystals
  - CMS ECAL
  - LHCb RICH cooling
- **Unfortunately, have leaks**
- Work on-going to reduce them
  → use CO2-cooling
  → switching off detectors
  → refurbishments in longer maintenance periods

Preliminary & self-estimated!



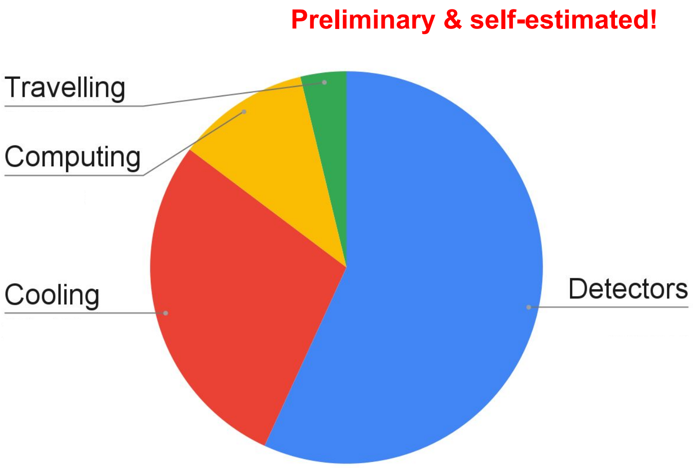
GROUP	GASES	tCO_2e 2021	tCO_2e 2022
Perfluorocarbons (PFCs)	CF_4, C_2F_6, C_3F_8, C_4F_{10}, C_6F_{14}	55 921	68 989
Hydrochlorofluorocarbons (HFCs)	HFC-23 (CHF_3) HFC-32 (CH_2F_2) HFC-134a ($C_2H_2F_4$) HFC-404a HFC-407c HFC-410a HFC-507	36 557	86 211
Other F-gases	SF_6, NF_3	16 838	18 355
Hydrofluoroolefins (HFO)/HFCs	R-449 R1234ze NOVEC 649	86	199
	CO_2	13 771	10 419
Total Scope 1		123 174	184 173

CERN Environment Report, Vol. 3, 2023, doi: 10.25325/CERN-Environment-2023-003

Gas	GWP
CO_2	1
R134A	1430
SF_6	22800
C_3F_8	**8830**
C_6F_{14}	**9300**

Lohwasser, Britzger, https://indico.desy.de/event/34904/

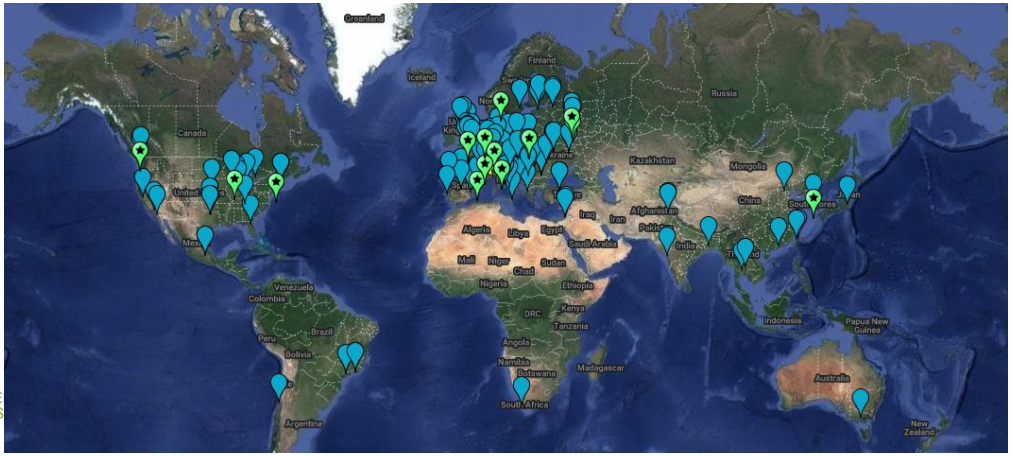
L. Zwalinski, HighRR Lecture Week - April 2016, https://indico.cern.ch/event/524795/contributions/2236586/attachments/1347371/2032209/20161004_ECFA_det_cool_final.pdf


Preliminary & self-estimated!
Travelling
Computing
Cooling
Detectors

Computing

What do we use computers in HEP for?

- This presentation ;)
- Data processing
  - Filtering data, applying calibrations, calculating new variables, reducing information, compressing data, …
- Simulation
  - E.g. Monte-Carlo simulations of LHC collision events
    → theoretical calculation + detector simulation
- Use distributed computing systems such as the WLCG



https://wlcg.web.cern.ch/using-wlcg/monitoring-visualisation

Emissions from computing

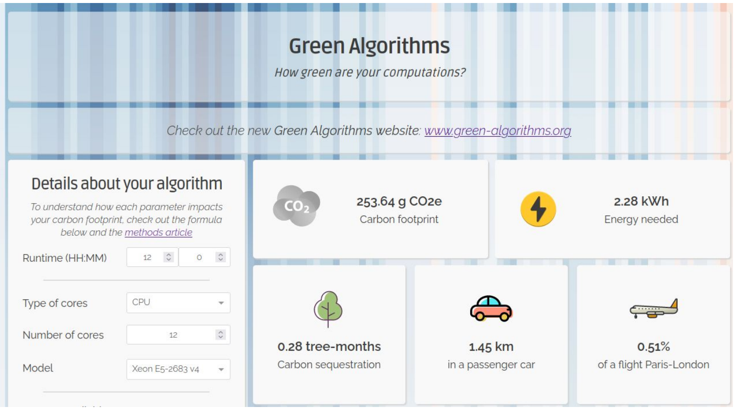
- *Example*: Ben's PhD time
  → **Write efficient code and test it!**
- Watch out! CO_2e/CPU hour largely varies, depending on what you include/assume!

Preliminary!

Calculated using Green-Algorithms.org	**CO_2e**
Grid (WLCG)	39 t
HTCondor	0.2 t
Other	0.12 t
Travel - Train	0.7 t
Travel - Plane	0.9 t
SUM	**41 t**

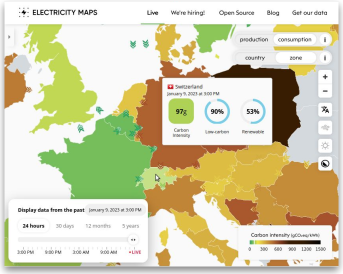
Estimate of Ben's PhD's CO_2e

- Computed CO_2e emission as in *Adv. Sci. 8 (12) p. 2100707* (available at https://www.green-algorithms.org/)



- **Automatic calculation of CO_2e on distributed computing system desirable**
  - Done for NAF at DESY
  - Now also done for ATLAS' grid

ATLAS WLCG CO2e emission tool



https://app.electricitymaps.com/map

$$n_{\text{cores}} \cdot \text{energyConsumption}_{\text{cores}} \cdot \int_{\text{startTime}}^{\text{endTime}} \text{emissionIntensity}(t)\, dt$$

Default is 10 W, sites can specify usage

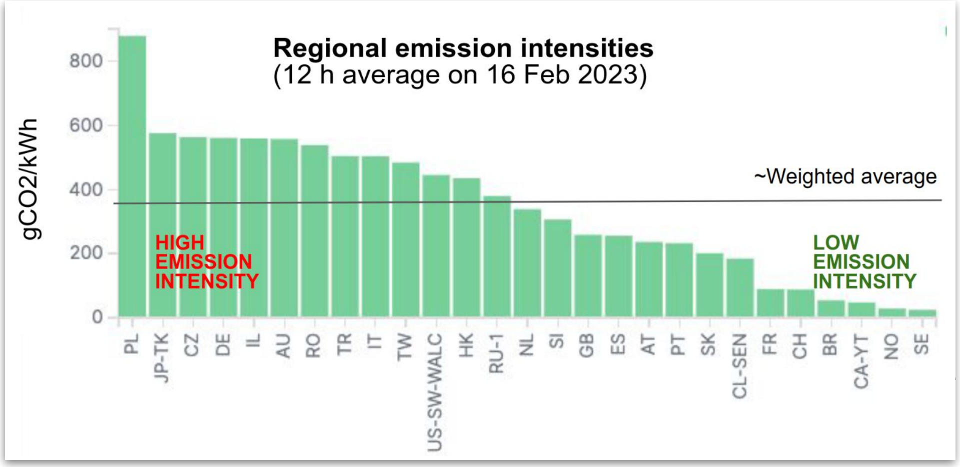
https://indico.cern.ch/event/1257299/contributions/5280612/attachments/2599027/4614292/PanDA_%20gCO2_job%20calculations%20(1).pdf

		gCO2/kWh
CH	16-FEB-23 10:30:33	93
CH	16-FEB-23 11:31:11	96
CH	16-FEB-23 12:31:01	86

E.g. a 8 core job running at CERN from 11:00 to 12:30 would emit roughly

*8 * 0.5h * 10W * 93 gCO2/kWh + 8 * 1h * 10W * 96 gCO2/kWh = 11.4 gCO2*

- Estimate CO2e of computing jobs
- Emission intensity depends on country
- Calculate average CO2e over all available sites



Towards more sustainable computing

- Reduce & reuse
- Users:
  - write efficient code
  - test & think before sending jobs
  - don’t produce samples never used
  - → show users CO2e footprint?
  - → **training programs / courses?**
  - → **virtual “budget” of emitted CO2e?**
- Computing centers:
  - buy efficient hardware
  - use efficient cooling systems
  - reuse waste heat if possible
  - **use hardware for long time, recycle**
  - **Operate when energy is “green”?**

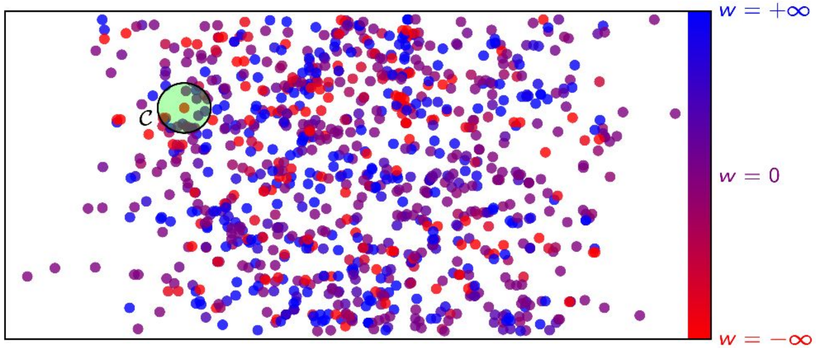
13-inch MacBook Pro life cycle carbon emissions

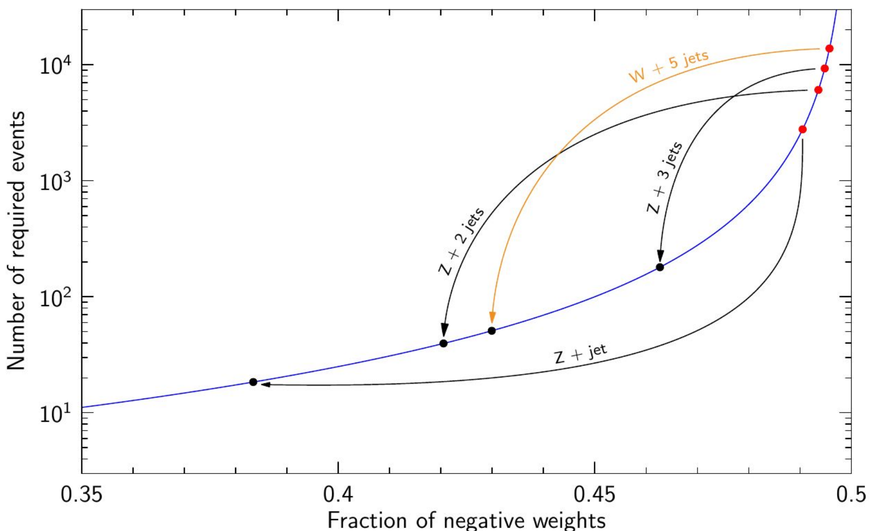
73%	Production
7%	Transport
19%	Use
<1%	End-of-life processing

https://www.apple.com/environment/pdf/products/notebooks/13-inch_MacBookPro_PER_Nov2020.pdf

Reduce footprint of Monte Carlo simulation?

- Monte Carlo simulations give us e.g. simulated LHC collision events
- Each event contains particle types, momenta, etc. **& weight w**
- Σ w = σ (total cross-section)
  Σ w^2 = stat. uncertainty
- Weight can be negative (e.g. @NLO)
  → more events for same stat. accuracy
- Idea of Andersen, Maier et al: redistribute event weights
- For an event with w < 0: can always find phase space region with Σw > 0
  - redistribute weights in this region such that all weights > 0
- Method looks promising & being tested





BlackHat + Sherpa

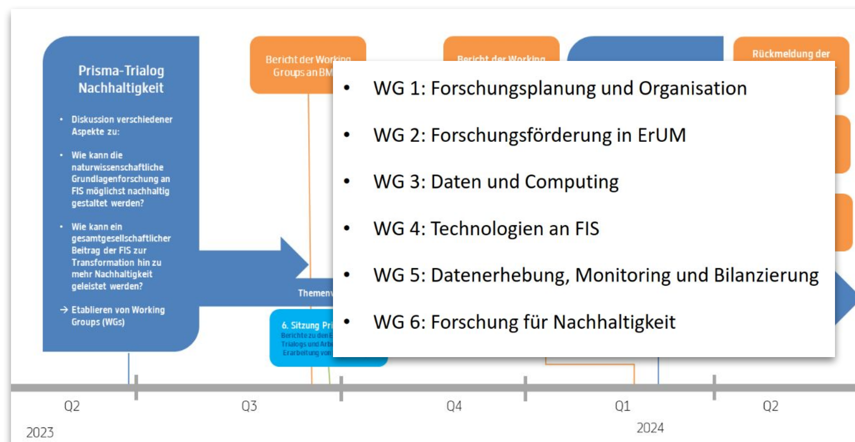
R. Andersen, C. Gütschow, A. Maier, S. Prestel, Eur. Phys. J. C 80 (2020), 1007
R. Andersen, A. Maier, Eur.Phys.J.C 82 (2022) 5, 433
J. R. Andersen, A. Maier, D. Maître arXiv:2303.15246
A. Maier, https://indico.desy.de/event/40118/

There is more on sustainable computing!

- Data preservation, e.g. FAIR principles, e.g. PUNCH 4 NFDI
  - Keep data such that it is reusable!
- Code preservation, e.g. git
- Data storage, e.g. tape vs disk

- German-wide initiative by ErUM Data Hub → workshop in May / June 2023
  - Paper arXiv: 2311.01169
  - Many interesting ideas / discussions
  - E.g. central computing center
- Input from BMBF at workshop
  - More sustainable research
  - New funding opportunities
  - Strategy currently being defined

https://erumdatahub.de/

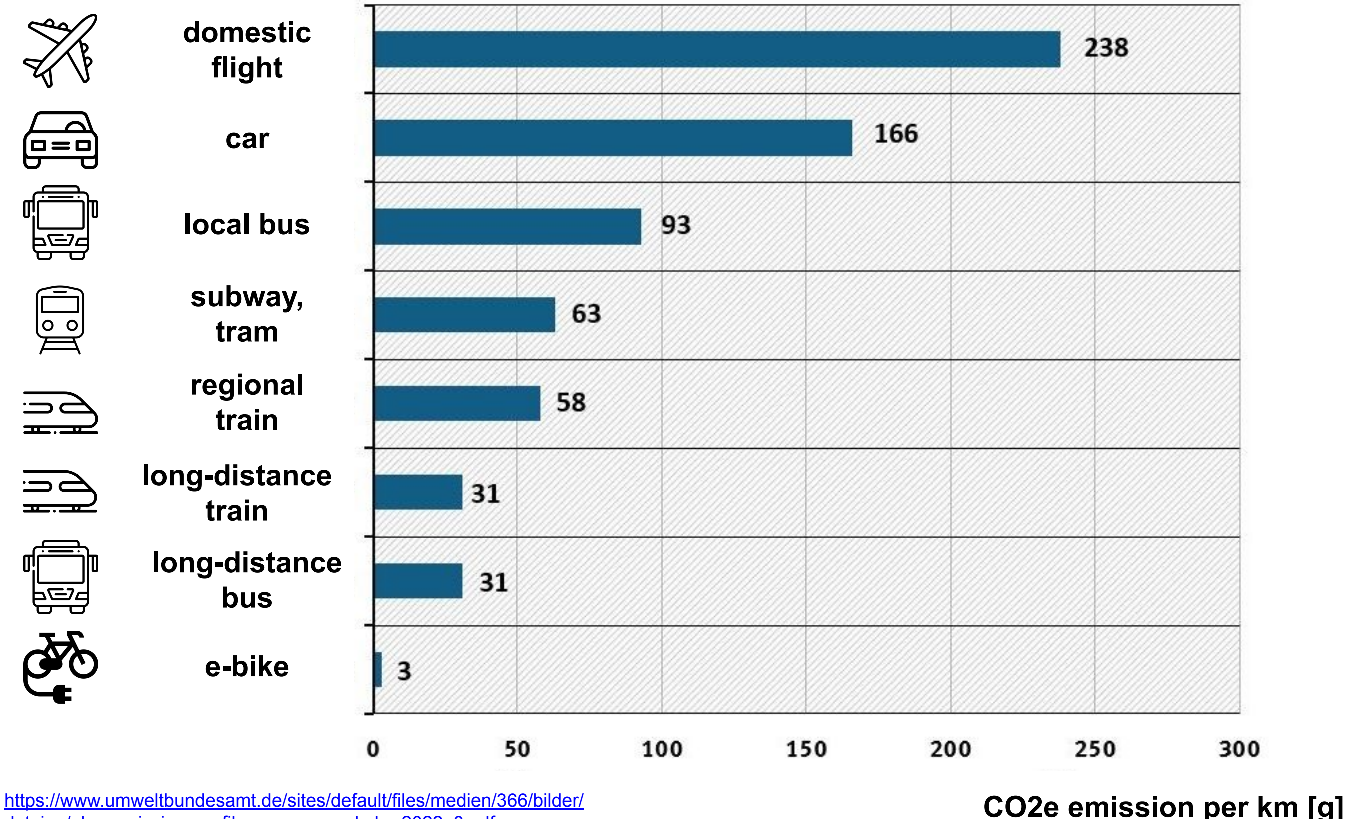


Salome Shokri-Kuehni, https://indico.desy.de/event/37480/sessions/15515/attachments/82406/108617/2023-05-31_ErUM-Data%20Workshop_Nachhaltigkeit.pdf

Travelling

Transportation is not free of emissions…

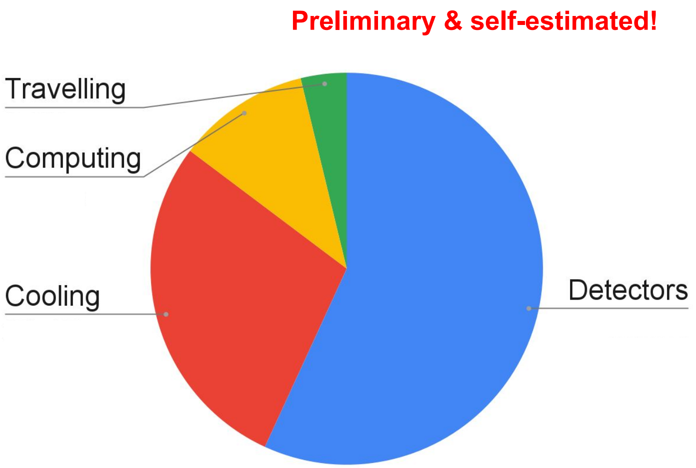
- Mobility / transportation is very important for our business
- Need to get to work, present work at conferences, discuss next steps with colleagues, collaborate internationally
- Emissions depend strongly on the form of transportation we use



https://www.umweltbundesamt.de/sites/default/files/medien/366/bilder/dateien/uba_emissionsgrafik_personenverkehr_2022_0.pdf

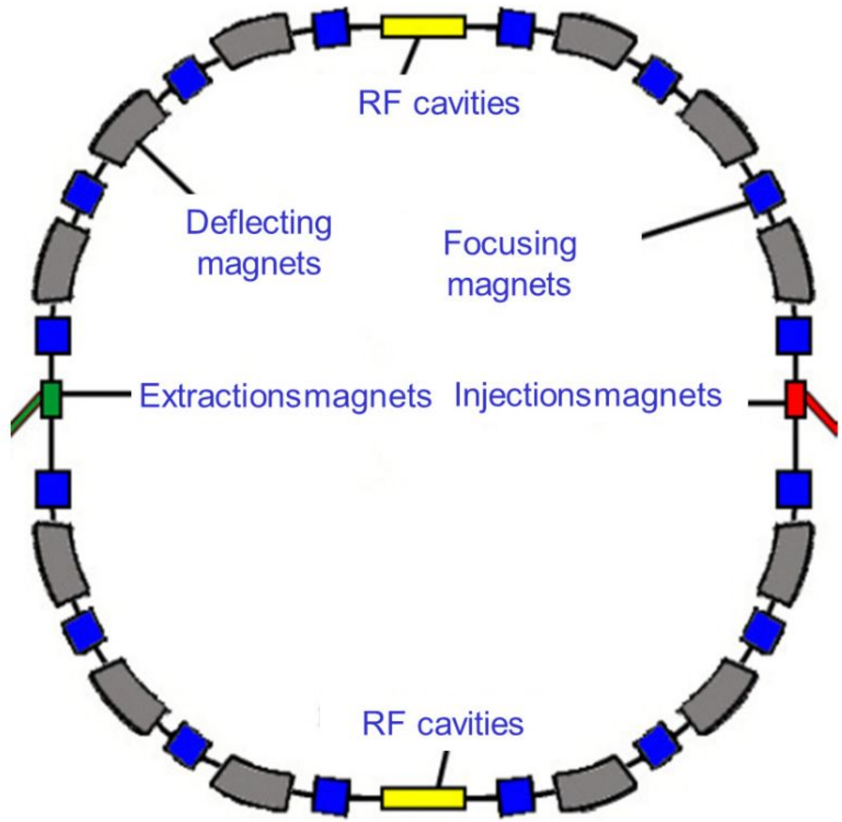
What to do regarding travelling?

- CO2e from business travel / commuting depends on institute
- Conference travel / collaboration meetings lead to lots of CO2e
    - e.g. LHCb collaboration weeks: ~0.5 tCO2e / participant
- Strong reduction if reduce travelling & distance
- **Don't forget:** in-person meetings very efficient → **do travel! But trade-off if worth it**



LHCb collaboration, phase-II TDR, 2022,
https://cds.cern.ch/record/2776420/files/LHCB-TDR-023.pdf

Accelerators & construction



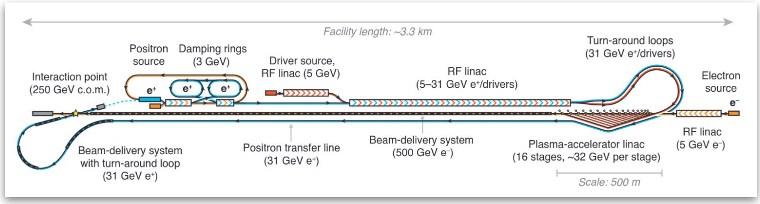
[arXiv:1608.03087](https://arxiv.org/abs/1608.03087)

Sustainability and accelerators

- Accelerators consume much more electricity than experiments
  - Cavities, magnets, cooling
  - >50 % of CERNs energy usage
- Much effort to reduce footprint of next machine
- More efficient, high(er) temperature magnets
  - Few Kelvin can make large difference!
  - Use permanent magnets, rare-earth caveat?
- More efficient klystrons being developed
- Waste heat recovery?
- Power re-use, e.g. energy recovery linacs?
  arxiv:2207.02095
- Wake field acceleration? arxiv:2303.10150

https://cms.cern/news/how-green-are-we-environmental-footprint-lhc-detector

UKRI, accessed via https://acceleratingnews.web.cern.ch/index.php/news/issue-43/ifast-ifa/rare-earths-permanent-magnets-blessing-or-curse



arxiv:2303.10150

R. Losito, https://indico.cern.ch/event/1317615/

Emissions from construction

- Construction is an essential part of our work
- Need buildings to work in, host detectors, etc.
- Many of the experiments / accelerators in HEP are underground
  → need tunnels and excavated areas
- Digging, drilling, building (in particular concrete) have a large CO2e footprint
- E.g. building 1m^2 [emits ~550 kgCO2e]

- Cannot improve emissions that already went into construction, but can take care of future constructions

- Recent study by the ARUP company: CO2e of [tunnel building] for CLIC / ILC
  - 150 ktCO2e – 300 ktCO2e
    from tunnels, shafts, caverns

K. Bloom, V. Boisvert, D. Britzger, M. Buuck, A. Eichhorn, M. Headley, K. Lohwasser, P. Merkel, https://arxiv.org/abs/2203.12389

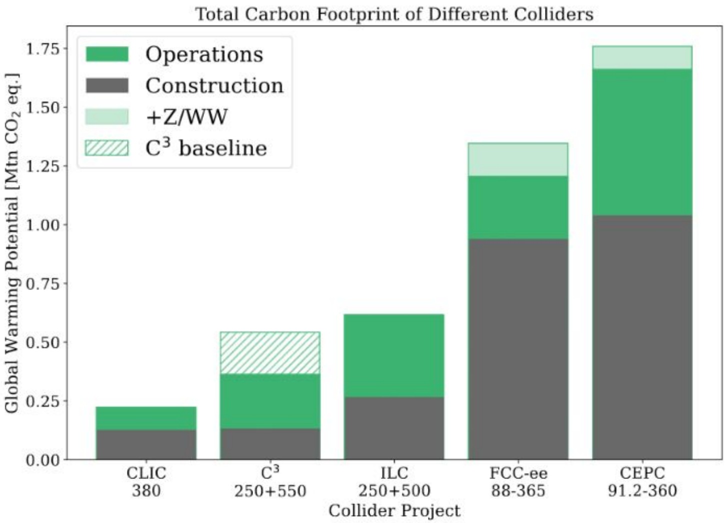
Sustainability and the future

S. Gessner et al, https://indico.cern.ch/event/1160140/contributions/5014540/attachments/2503851/4301660/CERN_sustainability_ITF_Turner_Gessner.pdf

- Sustainability important for next HEP projects
  → **it's not about stopping science/HEP, but doing it in a sustainable way**

- Life-cycle assessment
  → identify large CO2e sources
  → determine most efficient next machine
  - electricity consumption of next projects compared for Snowmass arxiv:2208.06030
  - recent paper comparing construction / operations CO2e: arxiv:2307.04084
    - Estimate absolute numbers; also try to establish a "CO2e / physics" case

- **Beware:** use established methods, inputs from reliable sources, comparisons must be fair!
  → much room for getting numbers wrong
  (e.g. arxiv:2208.10466)



arxiv:2307.04084

Other on-going, uncovered projects

- **ECOGAS collaboration (eco-friendly gas detectors)**

- Multiple computing projects:
    - Software optimisation (e.g. in the SWIFT-HEP project, HEP software foundation training and other coding trainings e.g. DESY sustainable coding workshop, Pythia merging optimisation, Avoiding negative event weights)
    - Highly efficient computing centers (e.g. Prevessin computing centre, Green IT cube Darmstadt, etc.)
    - Use waste heat of computing centers and re-use of cooling water (e.g. Prevessin, DESY, KIT, …)

- **The KITTEN project: store energy when it is "green", re-use later → aim for 100% green operation of KARA accelerator (Karlsruhe)**

- Setting up energy use assessment tools (e.g. ISO 50001 @ CERN)

- **Organising conferences with low GHG (e.g. PhD school Vienna, Women in Physics Canada)**

- Improving sustainability in commuting (e.g. Freiburg)

- And many, many more! (see e.g. Sustainability in HEP conference, HECAP)

Summary and conclusion

- There is scientific evidence for human activities increasing average temperatures on the planet
  → Will make habitated areas uninhabitable

- **HEP contributes to the CO_2e emissions, e.g. CERN emits ~360 ktCO_2e / year or ~30 tCO_2e / scientist** **(assume 12000 scientist)**
  - **Can largely be reduced by fixing gas leaks**
  - Compares to astronomer with ~20-40 tCO_2e / scientist

- Much activity on-going in HEP community to reduce footprint of current and upcoming projects

- What can I do?
  - Make efficient use of your resources
  - Think about emissions sources and how to reduce them
  - **Involve greenhouse gas emissions & their minimisation in current & the planning of future projects**
  - Raise awareness

CLIMATE CHANGE
WILL NOT WAIT
FOR US TO FINISH
OUR RESEARCH.

LET'S TAKE
ACTION NOW!

Backup slides

What can we do about global warming?

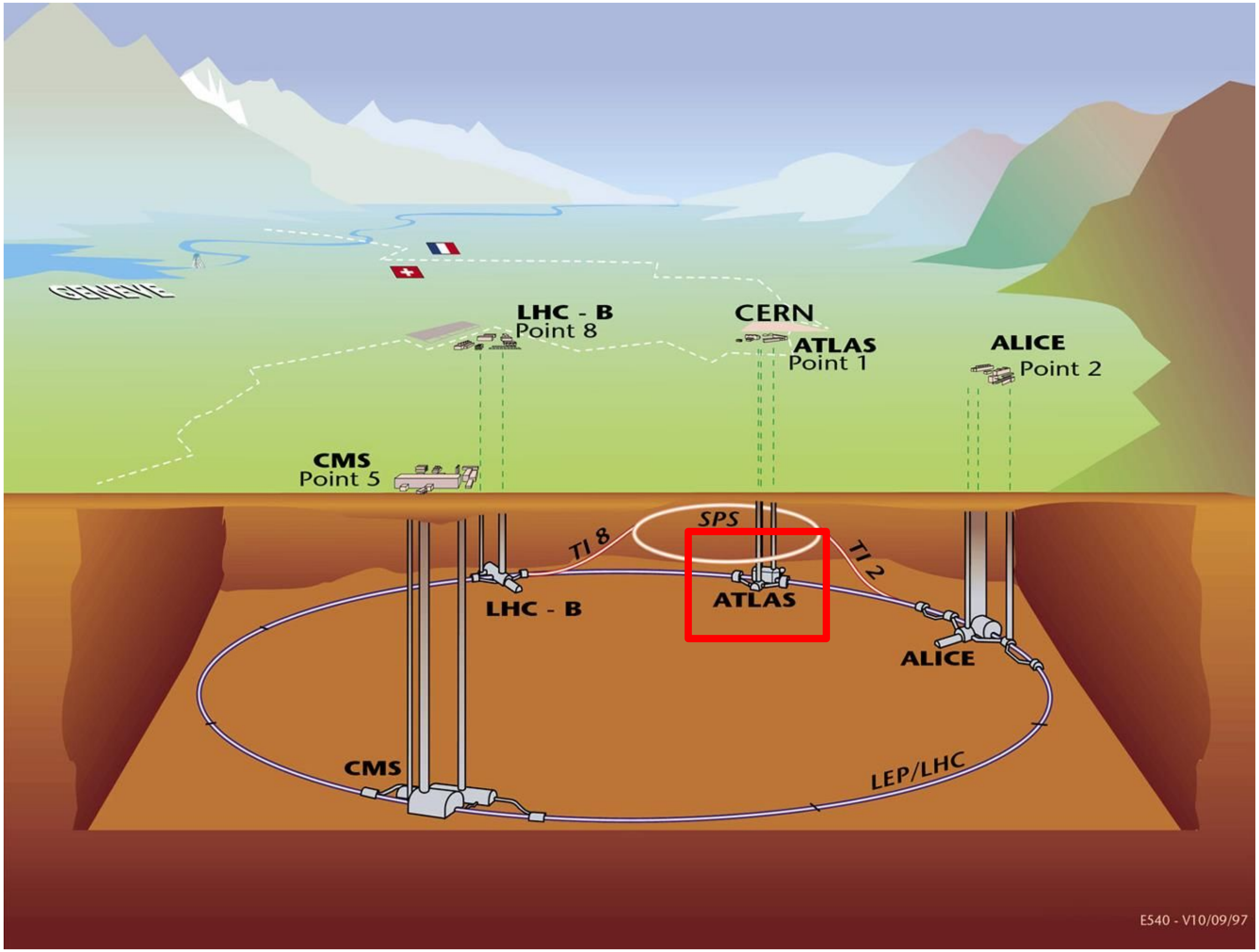
If we want to tackle global warming, we must look for solutions everywhere:

- Make carbon footprint & reusability a design parameter
- Develop more energy efficient detectors & accelerators
- Reduce travelling – or use more sustainable transportation
- Introduce climate panels
- Introduce climate / CO_2 budgets – similar to monetary budgets
- Calculate & publish CO_2 consumption of publications
- Carbon footprints for computing jobs:
  - show CO_2 monitor
  - stricter rules on usage (grid retries, ...)
  - Prefer “green” grid sites
- CO_2 friendly coding: Profiling & (compiler) optimization, …
  - faster code’s nicer anyway!
- Check physics: Less systematics? More skimming? …
- …

But most importantly:

Make sustainability and the impact on global warming part of everyday work!

ATLAS at the LHC

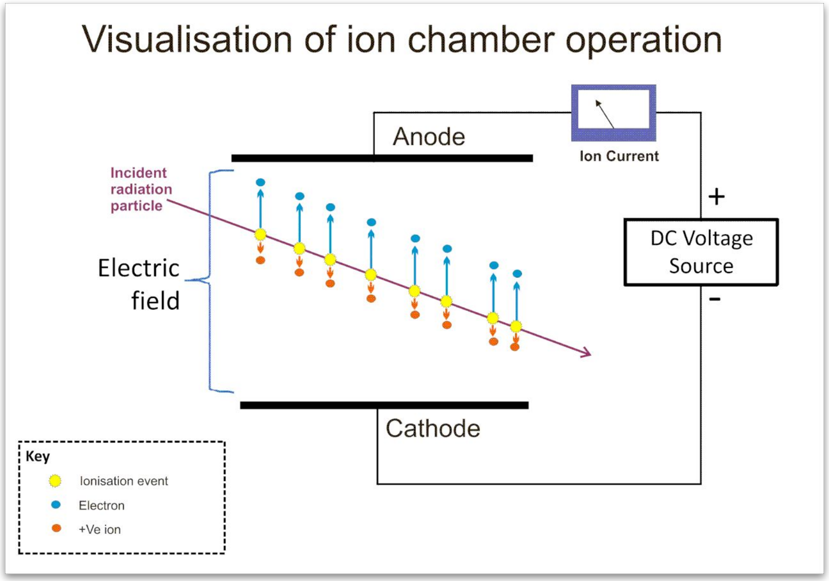


Gaseous detectors

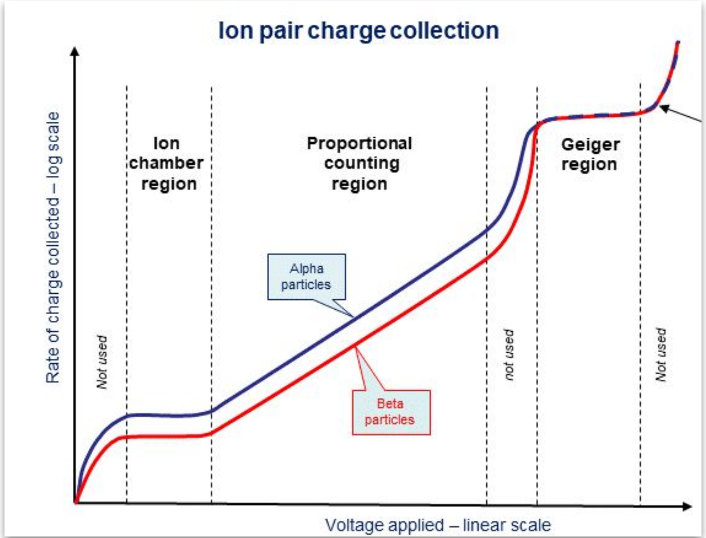
- Enclose gas in electric field
- Incoming particles ionise gas
- Electrons / holes drift to electrodes → signal

- Charge/particle depends on gas
- If field gradient large: multiplication of initial charges

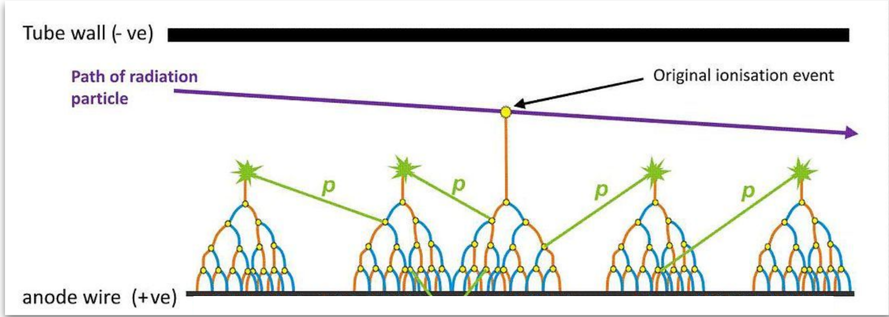
- **Multiplication side effect: photons**
  → initiate additional showers
  → modify signal, prolong dead time
  → avoid → add special gases



https://en.wikipedia.org/wiki/Gaseous_ionization_detector#/media/File:Ion_chamber_operation.gif



https://en.wikipedia.org/wiki/Gaseous_ionization_detector#/media/File:Detector_regions.gif



https://en.wikipedia.org/wiki/Gaseous_ionization_detector#/media/File:Spread_of_avalanches_in_G-M_tube.jpg

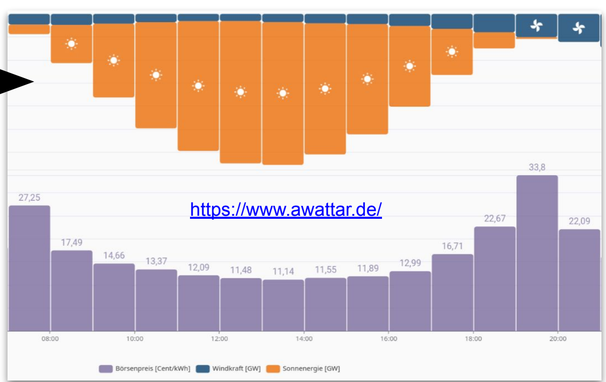
Compute when energy is “green”?

[arXiv: 2311.01169](https://arxiv.org/abs/2311.01169)

- “Green” electricity production varies: weather, day/night, …
- Operate computing centers when energy is green → **lower footprint!**
- “Green” electricity price is cheaper! (caveat: only w/ spot market prices)
- Needs reliable forecasting
- Requires flexible reaction of computing centers
- Kill jobs? → waste invested CPU
- Turn computers off? → lifetime :(

Renewables in energy mix

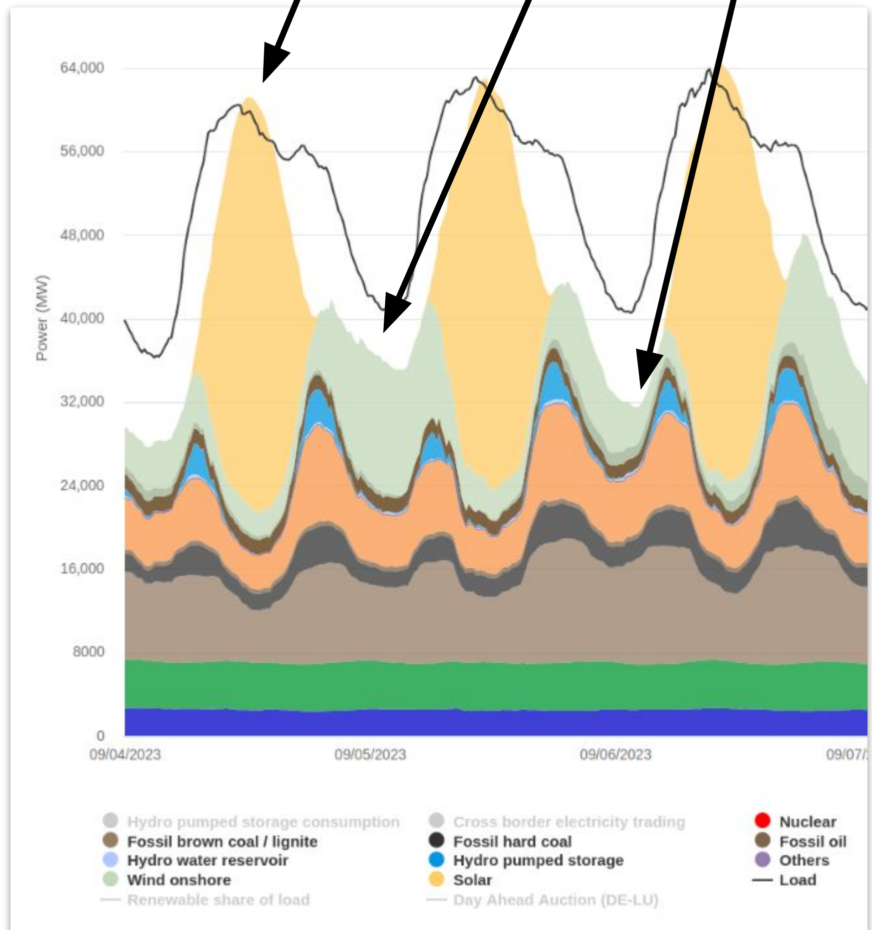
Price



much solar

much wind

mainly fossil



Rodney Walker: https://indico.desy.de/event/37480/contributions/140510/attachments/82246/108365/Meinerzhagern_compOps(2).pdf arXiv: 2311.01169

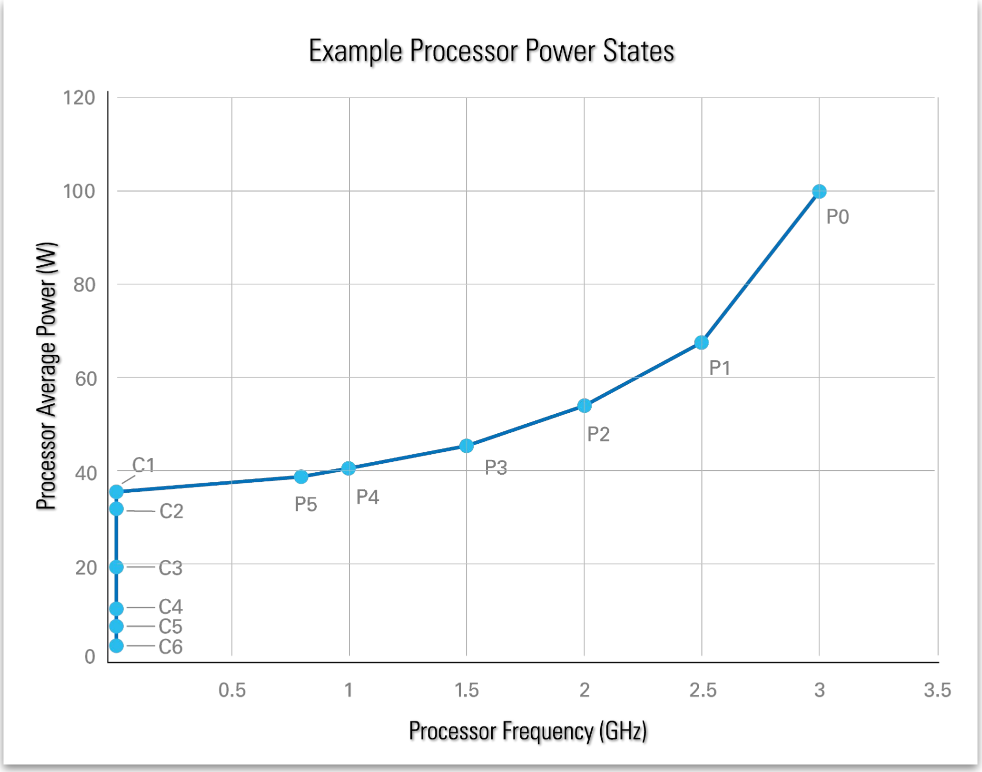
How to adjust computing consumption?

- Reduce CPU clock frequency!
- Used e.g. to save battery
- Non-linear increase of power with CPU frequency + baseline offset from periphery
  → can increase efficiency?

- Frequency reduction tested
  → no performance degradation
  → but jobs take longer
- Longer jobs not a problem if running O(days) anyway

Frequency [GHz]	Power [W]	Calculations / W [HS06]	Calculations / nominal
1.5	286	3.79	98%
2.15	330	4.32	111%
2.85	524	3.88	100%

T2 AMD, Thomas Hartmann, DESY

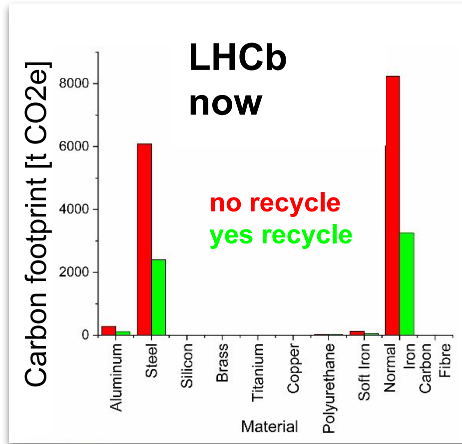


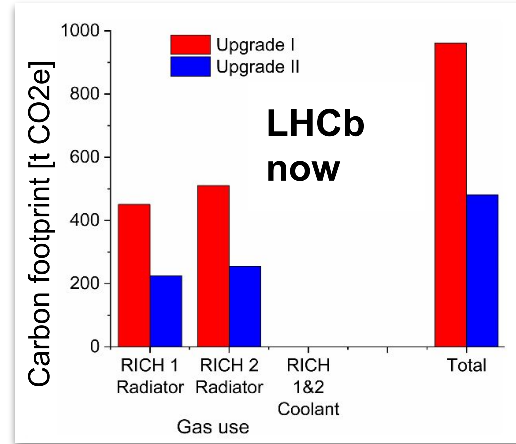
Rodney Walker: https://indico.desy.de/event/37480/contributions/140510/attachments/82246/108365/Meinerzhagern_compOps(2).pdf

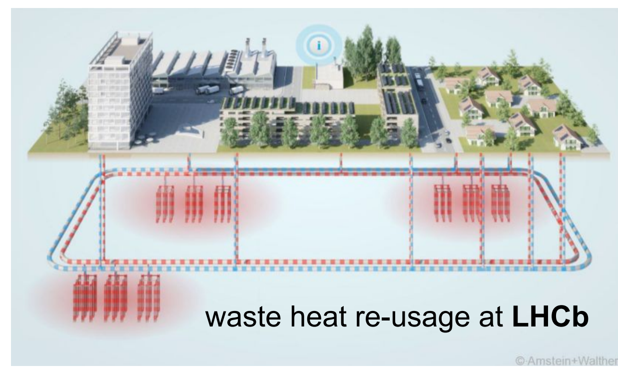
Sustainability in other HEP experiments

- CO2e emissions of **LHCb** in run-3 discussed in phase-2 TDR
- Estimates of gaseous detectors, power consumption, computing, travelling + mitigation ideas
- Initiative from management
- Waste heat used to heat houses
- Estimating post-upgrade CO2e

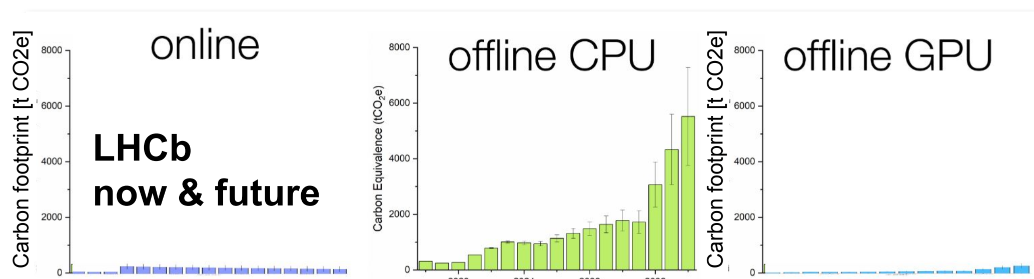
- Entire community getting interested, e.g. **Belle-II, ALPS-II**
- **CMS, ALICE** have numbers, but no report (AFAIK; ATLAS, too)







https://indico.desy.de/event/40852/

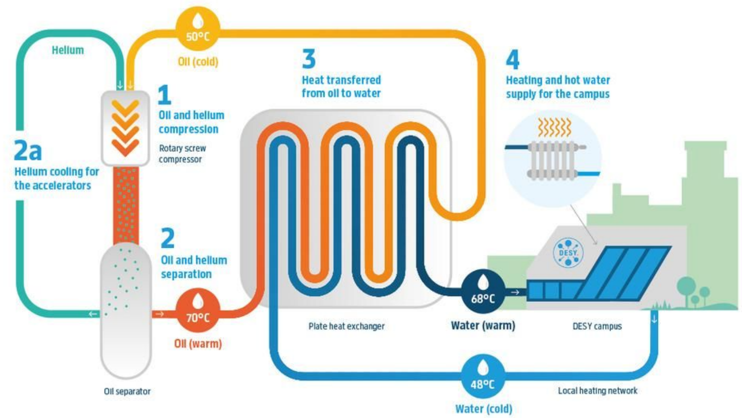


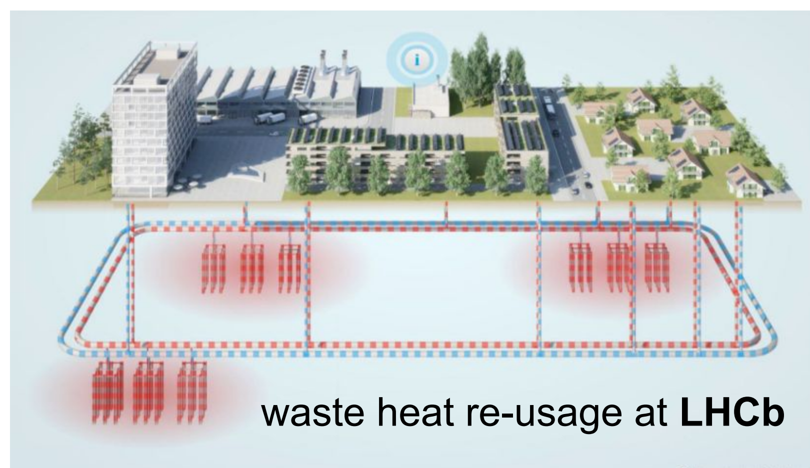
Heat recovery

- DESY hosts multiple accelerators, e.g. PETRA, FLASH, XFEL
- FLASH, XFEL use liquid helium for cooling of superconductors
- Recover heat from helium cooling & heat ~⅓ of the campus
- Heat recovery being extended to cooling of “normal” conducting magnets from PETRA

- Similarly at LHCb: use waste heat of computing center to heat private houses

https://mbb.desy.de/sites/sites_desygroups/sites_extern/site_mbb/content/e203714/Bildschirmfoto2021-06-22um09_57_57_medium_medium.jpg





https://www.desy.de/news/news_search/index_eng.html?openDirectAnchor=2769&two_columns=0

LHCb collaboration, phase-II TDR, 2022, https://cds.cern.ch/record/2776420/files/LHCB-TDR-023.pdf