SUSTAINABLE HIGH-ENERGY PHYSICS 2026

# Life Cycle Assessment of the LHCb data centres

Overall impacts & preliminary results for Upgrade II

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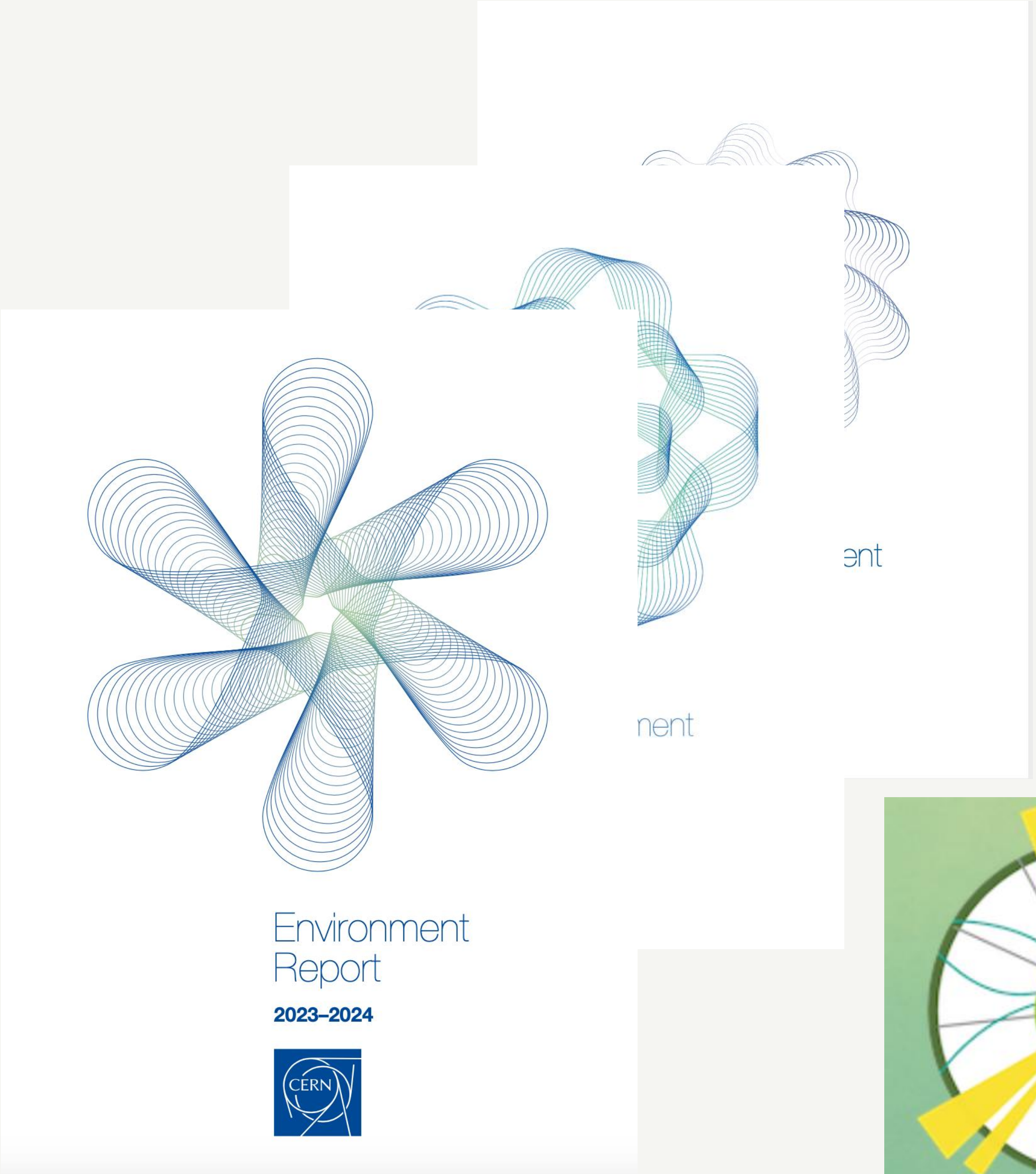
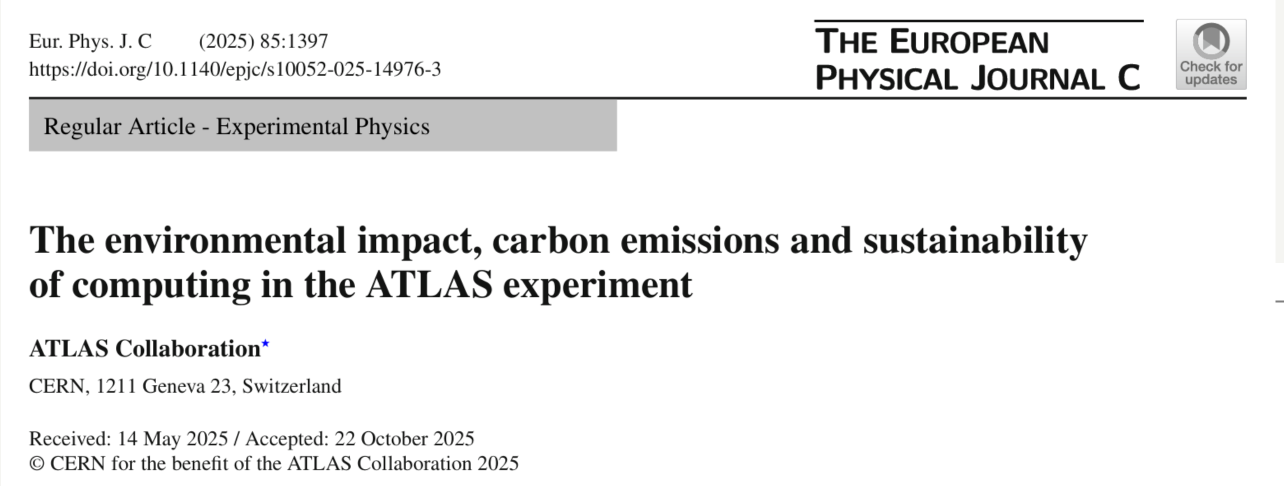
10 July 2026

# Sustainability as a first-class metric in HEP

hecap.eco Sustainable HECAP+





Eur. Phys. J. C (2025) 85:1397
https://doi.org/10.1140/epjc/s10052-025-14976-3

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

**The environmental impact, carbon emissions and sustainability of computing in the ATLAS experiment**

**ATLAS Collaboration***

CERN, 1211 Geneva 23, Switzerland

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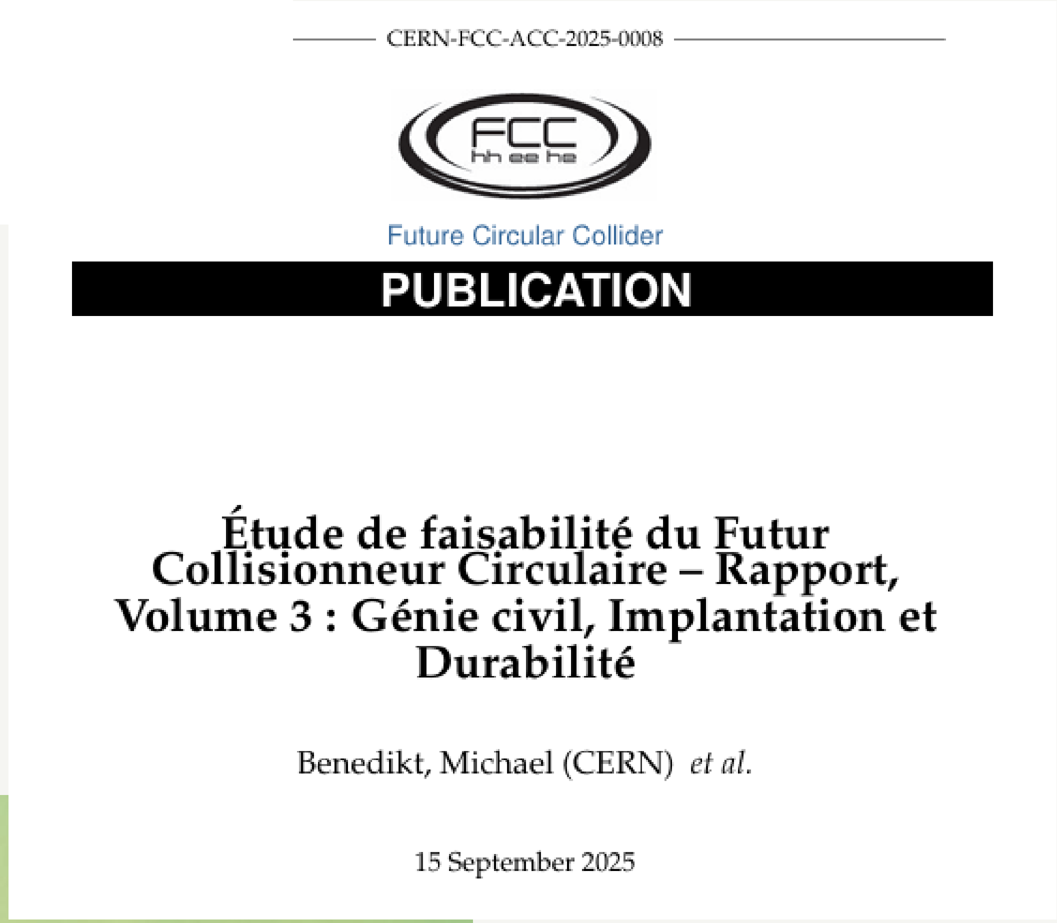



PART I · LHCb data centers

# Life Cycle Assessment of the LHCb data centers

From data-centre operations to the embodied carbon of the hardware itself.

What is it about ?

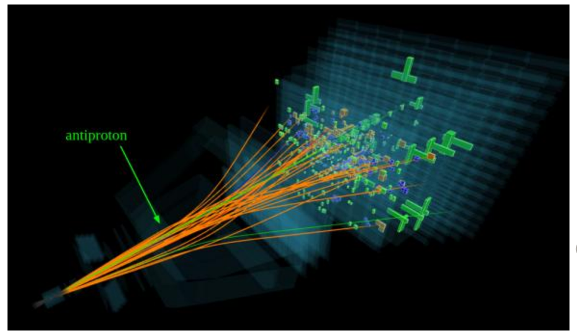
# Goal & Scope - Methodology

Important to bear in mind: In this presentation, results are analysed focusing on Climate change impact. However, this is only one category among many others

## Details

| | |
|---|---|
| Reference flow | Treatment and analysis of LHCb data during one year |
| System boundary | Cradle-to-grave |
| Grid intensity | Country-level, annual, lifecycle approach |
| Allocation | Mass & energy based |
| Software | openLCA 2.6.1 |
| LCIA method | Environmental Footprint 3.1 |
| System model | APOS |
| Data sources | Internal CERN documents, Ecoinvent 3.12, Literature, ResilioDB 2026.6, Electricitymaps, EPD, Grafana |

## LHCb data flow




Detector collecting data from the collisions

Online computing (on LHCb site) : Event building, High Level Triggering 1 & 2, local storage

WLCG
Worldwide LHC Computing Grid

Offline computing (WLCG/Grid) : CERN, National centers, Universities, LHCb collaboration (users)

# Some challenges in my work

## Methodology

Challenge

There is no standardized functional unit widely accepted for data center LCA. (ISO 30134 presents KPIs, no Functional Unit)

Approach

Restraining the scope of comparison and normalize the experiment's environmental impacts by the experiment output: the integrated luminosity delivered ($fb^{-1}$), linking impact directly to physics output.

## Data

Challenge

Reliable IT-hardware datasets are rare. Ecoinvent 3.12 covers a broad range of sectors but lacks granularity and representativeness for recent IT hardware.

Approach

Use of ResilioDB 2026.6 for finer modelling, then comparison against ecoinvent 3.12 on equivalent models to quantify inter-database uncertainty.

## Offline/Grid

Challenge

Assessing globally distributed hardware and infrastructure under a single homogeneous method is complex.

Approach

Electricity consumptions are modeled from grid activity. Embodied hardware is excluded from the offline scope

If interested :

A service assessment approach has been brought by [EPFL EcoCloud team]

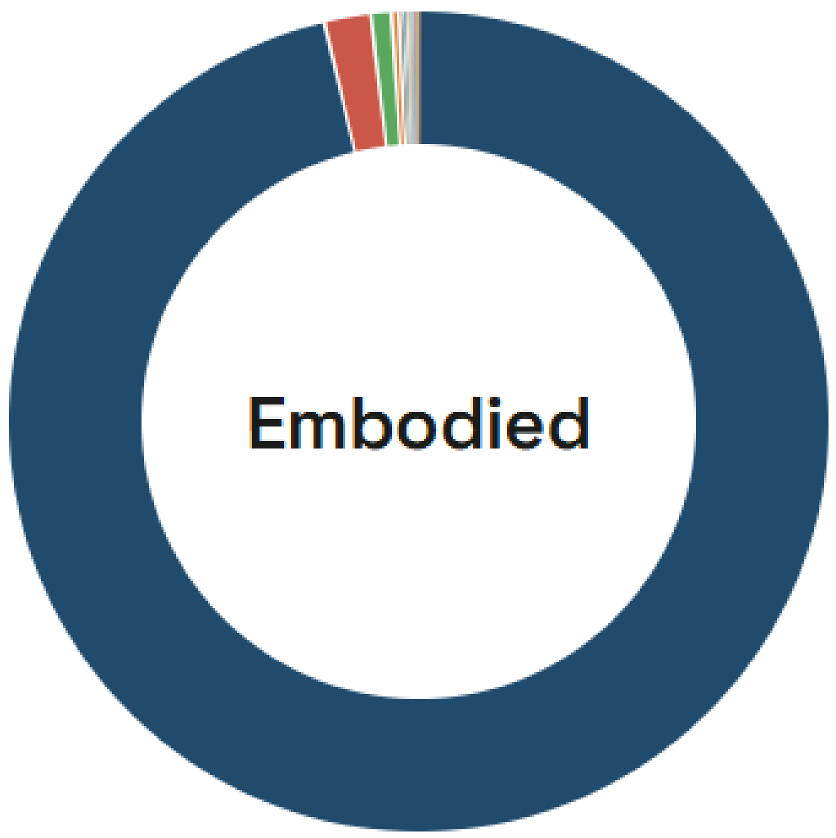
Outside of this work, undergoing [work] for development of standardized monitoring and benchmarking for the WLCG

# Online data centers – Climate Change impact [kg $CO_2$eq] – Embodied – 2025 configuration

## MAKING COMPONENTS COMPARABLE

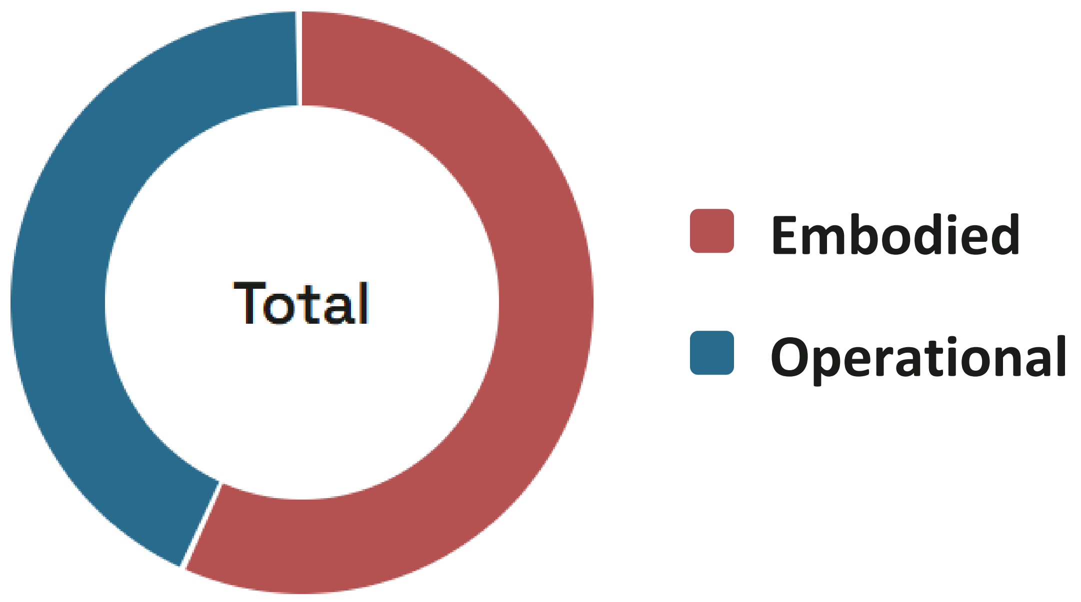
Components have very different lifetimes. We take each one's full cradle-to-grave impact and divide by its assumed lifespan — an equivalent impact per year.

```
Annual impact = Total LCA impact ÷ Lifespan
```




| COMPONENT | LIFESPAN (YEAR) |
|---|---|
| Servers | 10 |
| Containers | 50 |
| Cores (AHU) | 20 |
| Routers | 10 |
| Hard disk drive | 5 |
| Foundations | 50 |
| Inverters | 20 |
| Water pumps | 20 |
| Transformers | 50 |
| Racks | 50 |
| Air filters (AHU) | 0.5 |
| RO pumps | 20 |
| Cables | 50 |

# Online data centers – Climate Change impact [kg $CO_2$eq] – Global – 2025 configuration




## WHY THE EMBODIED SHARE IS SO LARGE ?

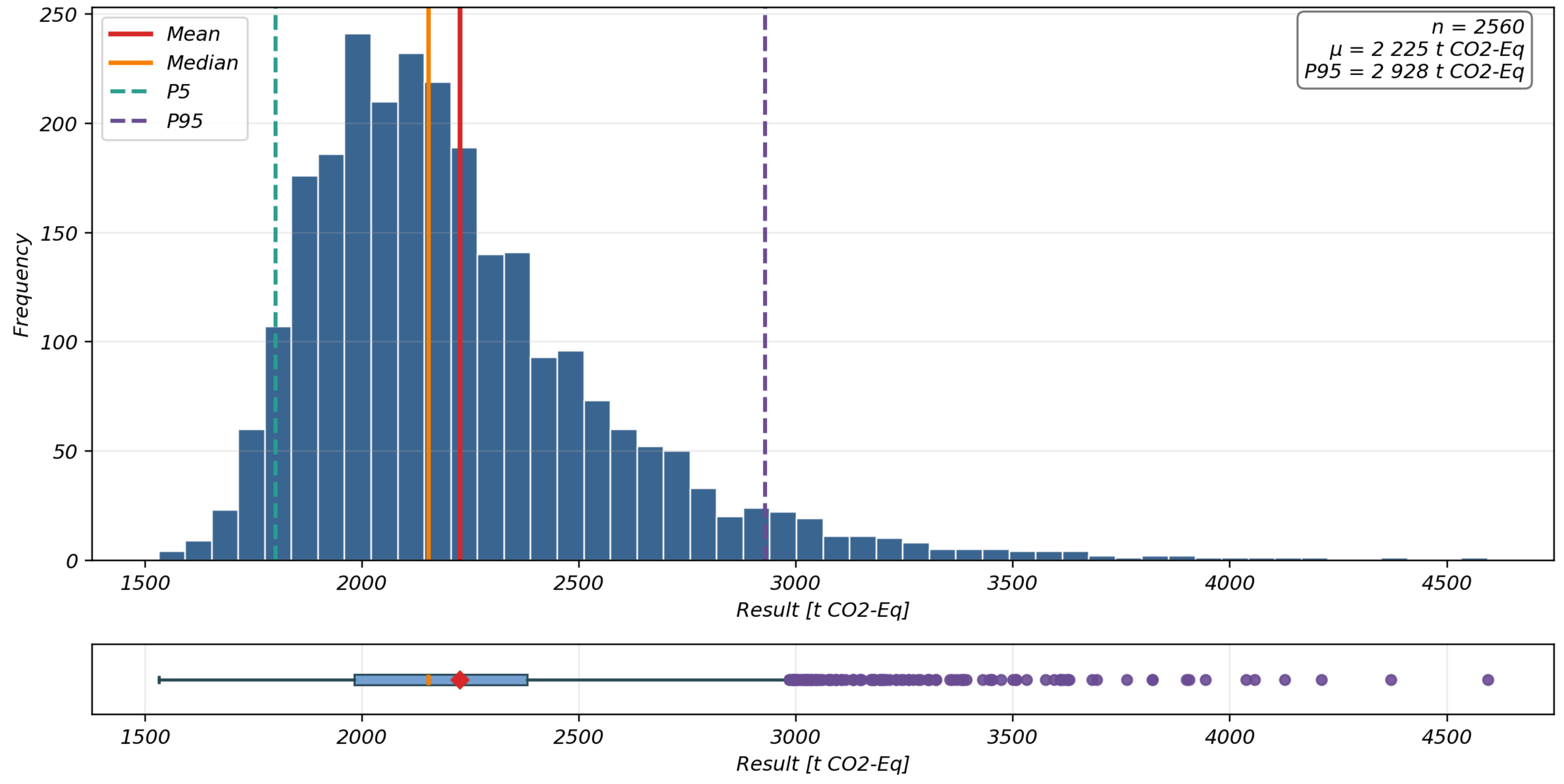
**01** **Low-carbon French electricity mix**

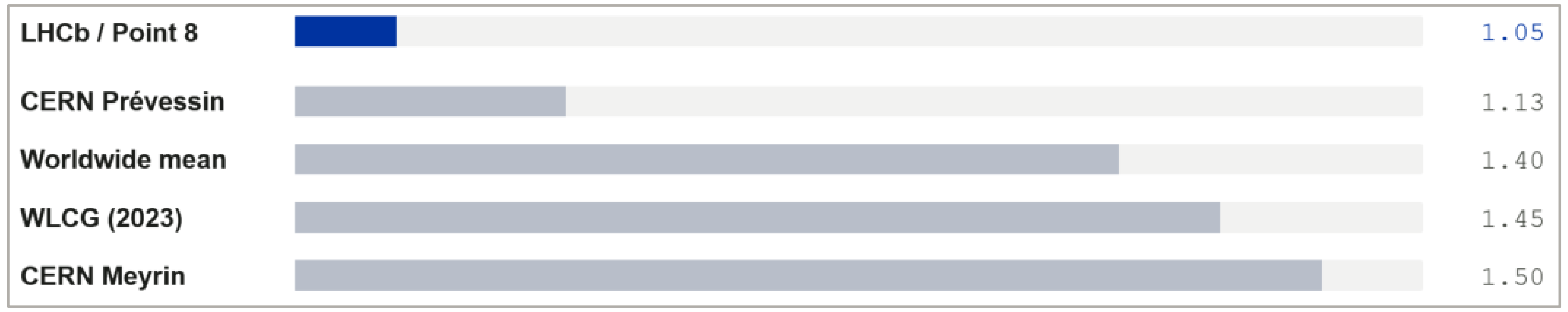
A largely nuclear grid keeps operational $CO_2$ small.

**02** **Excellent PUE ≈ 1.05**

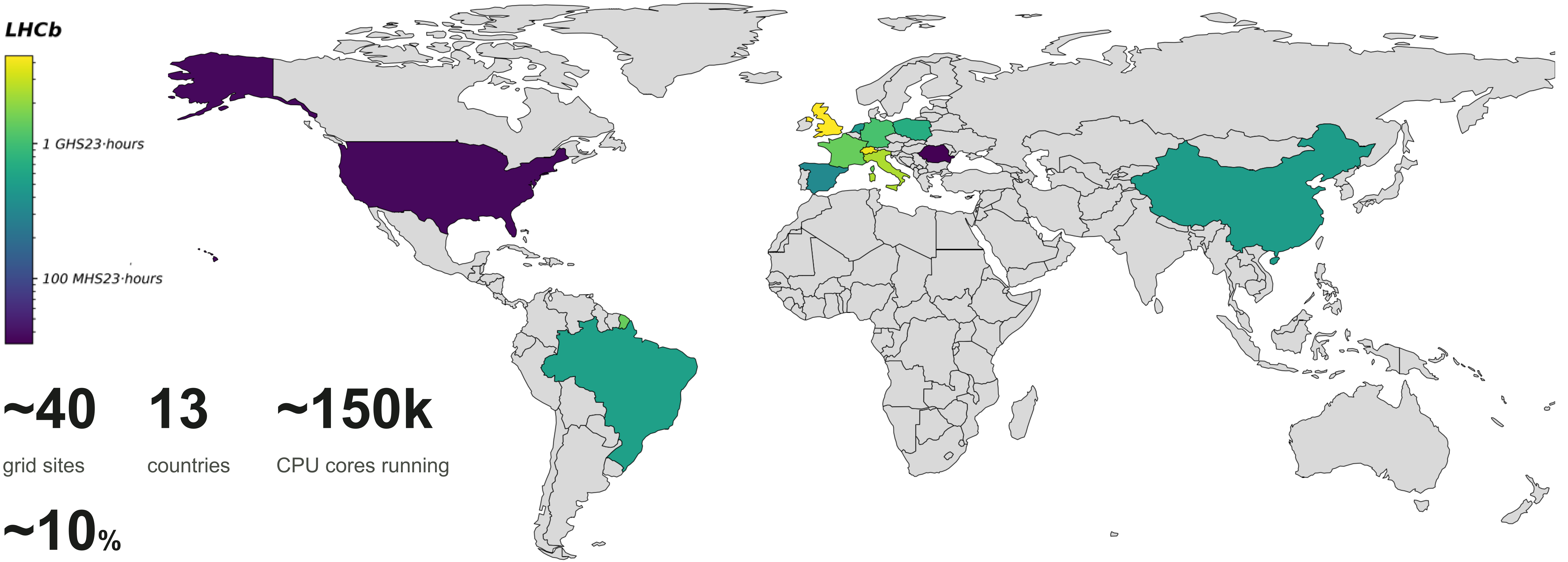
Free-air cooling wastes almost no energy on overhead.

## BUT KEEP IN MIND that…



# Offline - Worldwide distribution of LHCb offline computing for the year 2025




**~40**
grid sites

**13**
countries

**~150k**
CPU cores running

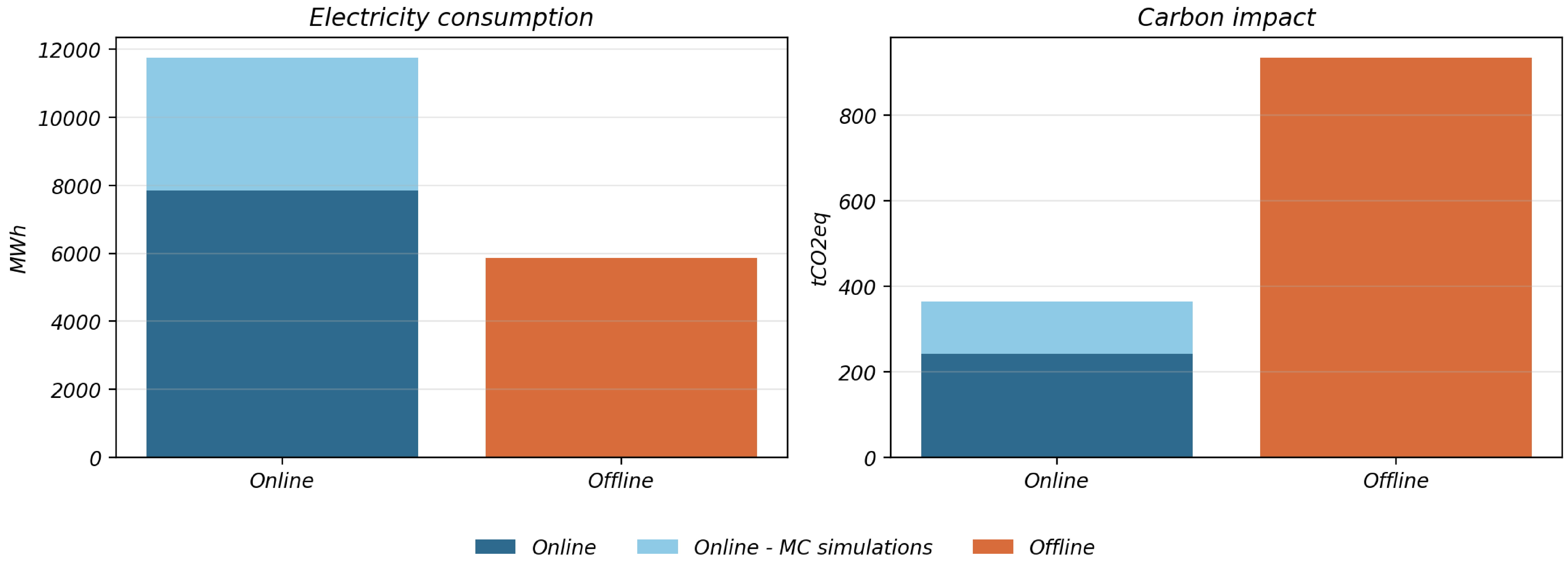
**~10%**
used for CERN treatment

[2306.08118] HEPScore: A new CPU benchmark for the WLCG

ACAT 2024 (11-15 mars 2024): HEP Benchmark Suite: Enhancing Efficiency and Sustainability in Worldwide LHC Computing Infrastructures · Indico

# LHCb Online vs Offline - 2025

For this Long Shutdown 3, Online will RUN MC simulations for 3 years, this will help relieve the grid computing




ESTIMATION MODEL

emissions = Σ (cores·hours) × W/core × PUE × carbon intensity

**3.8** W/core

Median TDP/core, 2015–2024 — replaces the earlier ~10 W placeholder.

**1.45**

WLCG PUE applied to grid sites.

**Loc.**

Location-based intensity — except CERN Tier-0 (market-based).

PART II · UPGRADE II

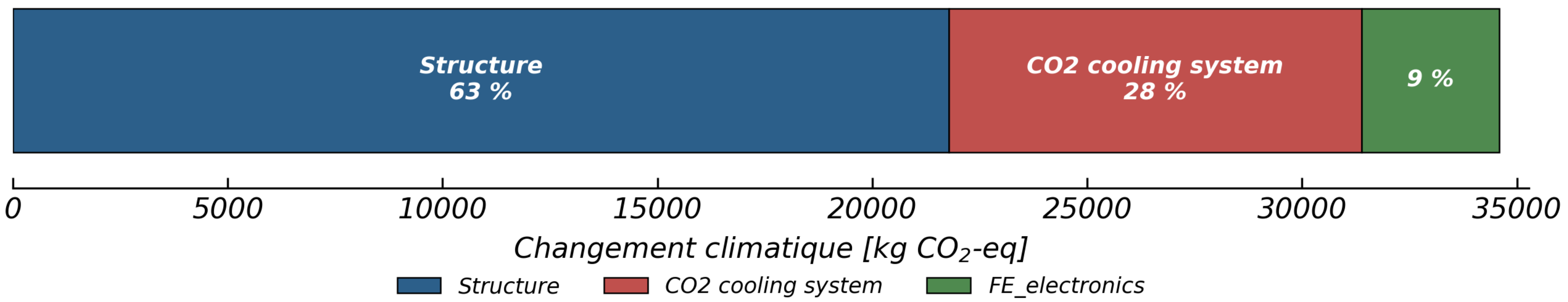
# Upgrade II calls for a full life-cycle view of the detector

Methodology and preliminary results

Preliminary Results

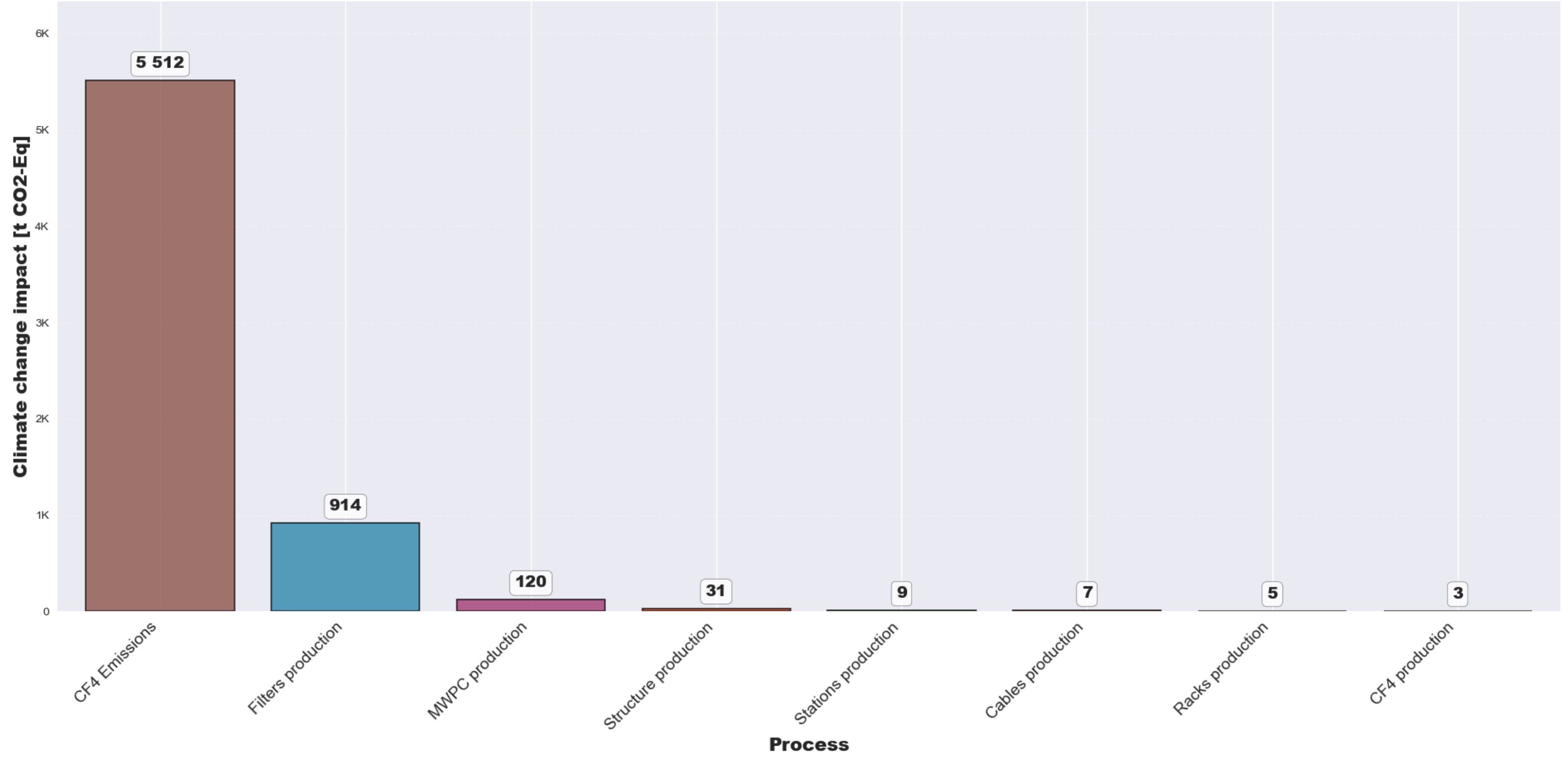
# Vertex Locator (VELO) & MUON

## VELO 34.6 t $CO_2$-eq · Embodied




Those results should be refined by bringing a higher level of details in the LCA models.

## MUON Global (Embodied + Operational)




Dominated by **$CF_4$ emissions** (high GWP) — eclipsing filter production (914), MWPC (120), structure (31). **Impact is operational** (F-gas)

Two detectors, two opposite hotspots — **structure (VELO) vs gas (MUON)** . Eco-design must be targeted per sub-detector, and gas choice is a major lever.

Important to bear in mind: In this presentation, results are analysed focusing on Climate change impact. Which is only one of several envrionmental impact categories.

Be aware that the results of the MUON are per functional unit

Methodology

# Assessing the changes

STEP 1

### Baseline LCA

Cradle-to-grave inventory of every current sub-detector (VELO, UT, SciFi, RICH, Calorimeters, Muon + magnet, beampipe), normalized per functional unit.

STEP 2

### Delta analysis

Identify which components are removed, replaced or added for Upgrade II — the parts that change, in materials and in operation.

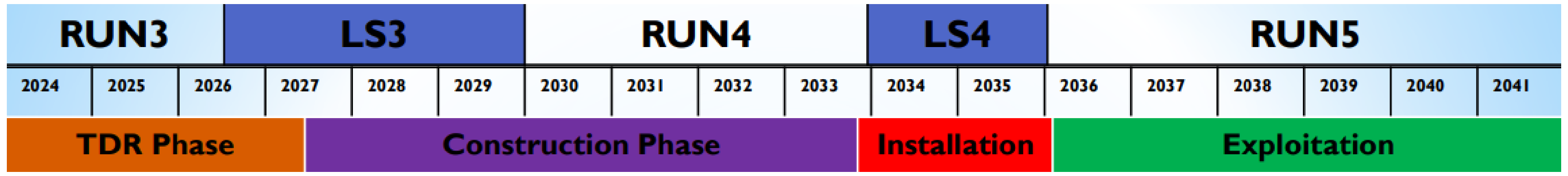
STEP 3

### Component LCA

LCA using a detailed breakdown of the components that changes, down to materials, electronics and assembly.

# LHCb & Upgrade II

LHCb Upgrade II is the next major upgrade of the experiment. It will be installed during LS4 (2034–35) and start data-taking in Run 5 (2036).

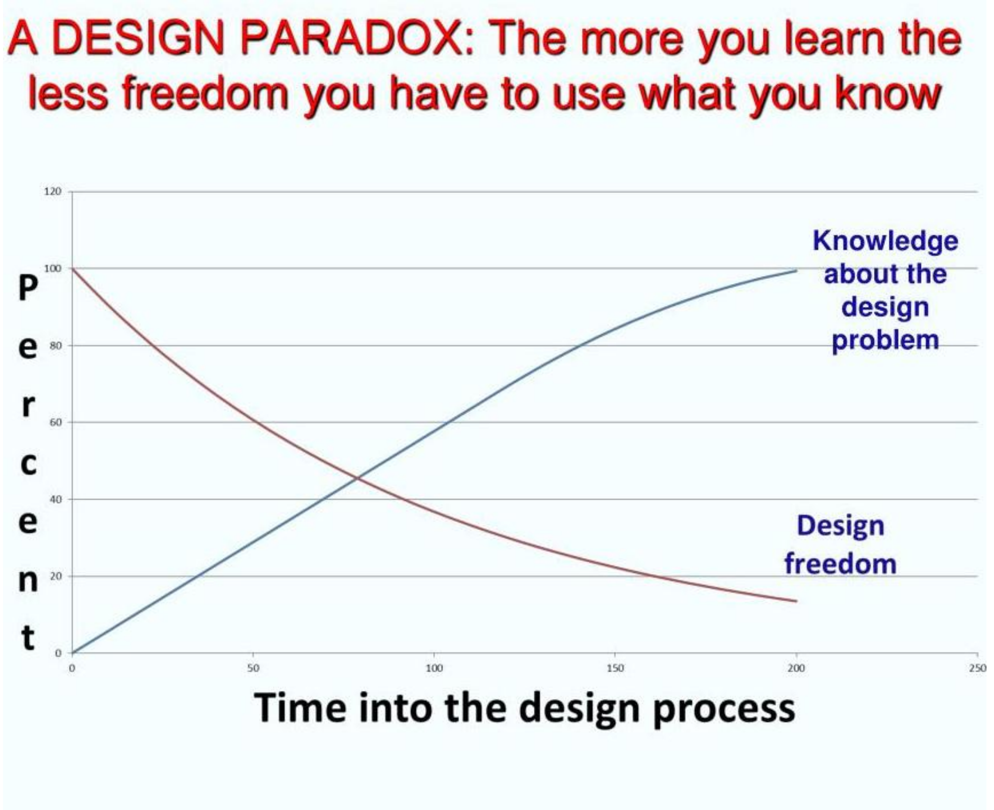


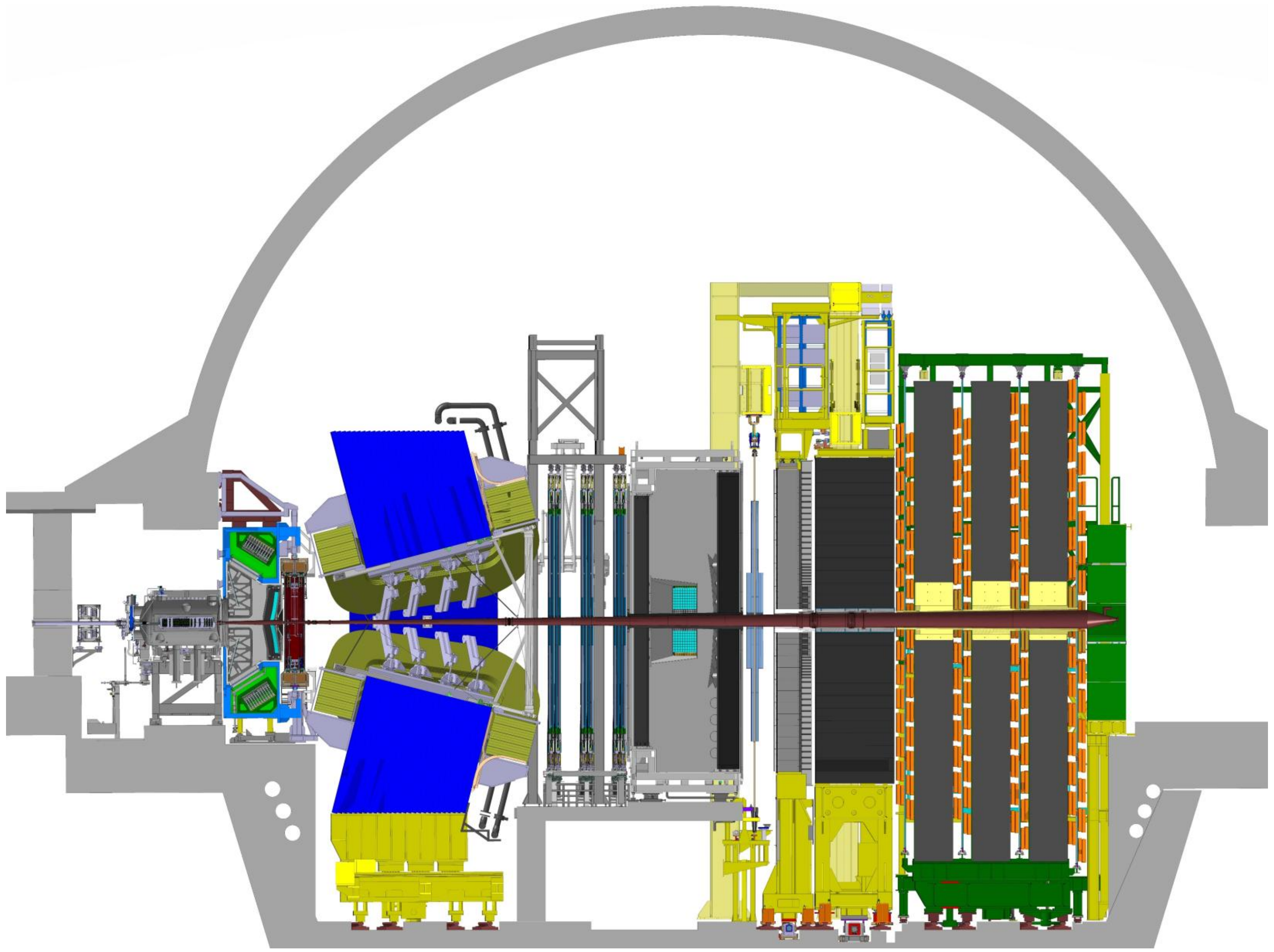

WHAT CHANGES

To exploit the HL-LHC, the detector must run at an instantaneous luminosity of up to 1.5 × $10^{34}$ $cm^{-2}$ $s^{-1}$ (~7.5× Upgrade I) and integrate ~300 $fb^{-1}$ (vs ~50 $fb^{-1}$ today) — while keeping performance at a pile-up of ~40 interactions per bunch crossing.

WHY IT MATTERS HERE

Building this much material – especially with usual low tolerance requirements-- is a large embodied-carbon event . Assessing it now brings life-cycle thinking into detector design early — while choices can still be influenced.



HOW · A NEAR-COMPLETE REBUILD

| | |
|---|---|
| **VELO** | Timing / 4D tracking, ~20 ps |
| **MightyTracker** | Silicon + SciFi |
| **PicoCal** | SpaCal + Shashlik, with timing |
| **RICH** | Upgraded optics & photodetectors |
| **Muon** | Upgraded system |

# Thank you for listening

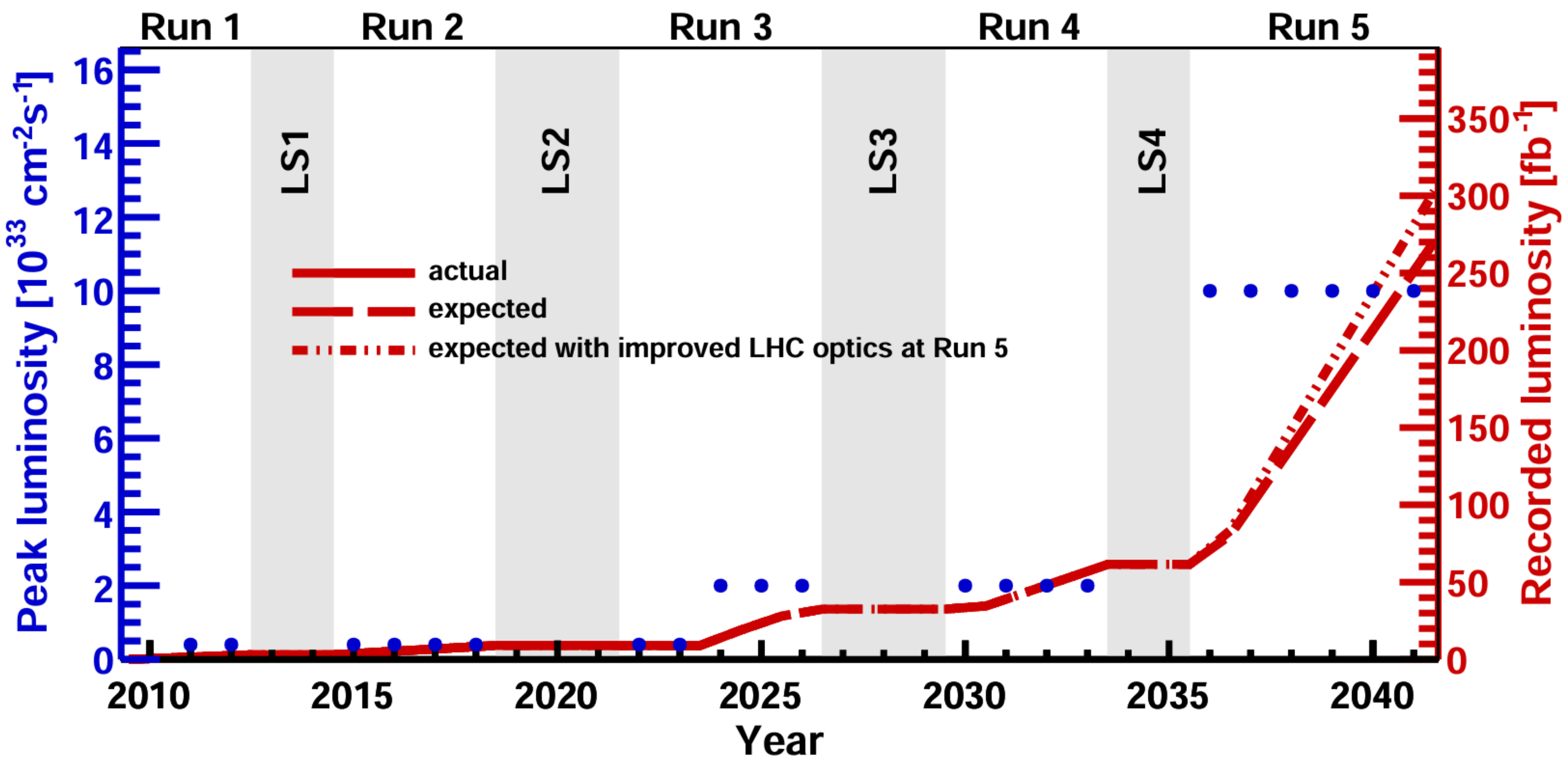
Thank you to all the persons who somehow contributed to this work

THE STAKES

# LHCb's data rate will quadruple by Run 5

**4** TB/s → **16** TB/s

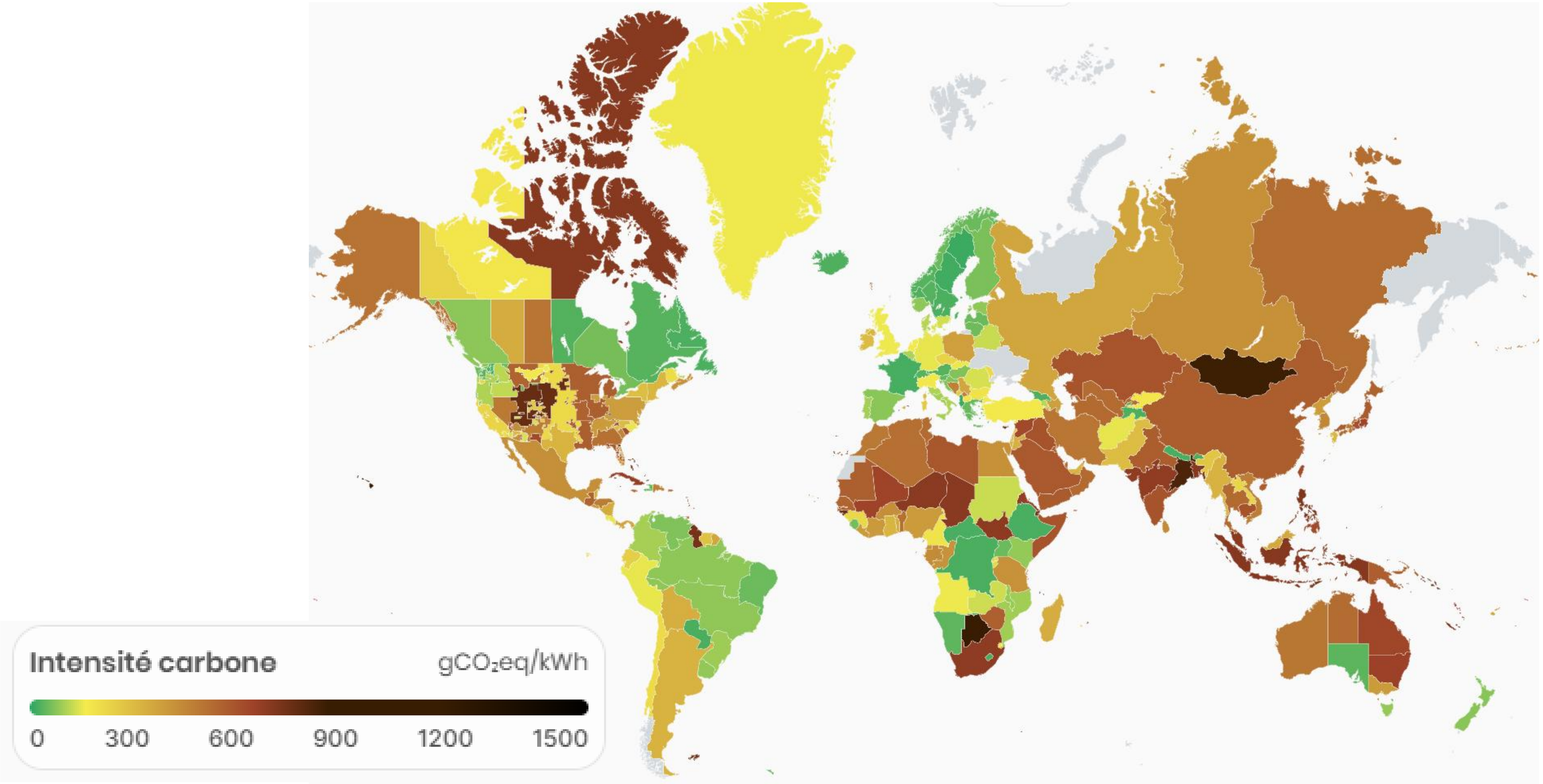
Run 3 · In Run 5 · Upgrade II




Higher luminosity means more collisions, more data to process.

1. LHCb data centers — LCA of the data flow on site (+ Grid estimation)
2. Current & Upcoming situation — LCA of the current detector and the Upgrade II

Back-up slides




[Carte | Electricity Maps]