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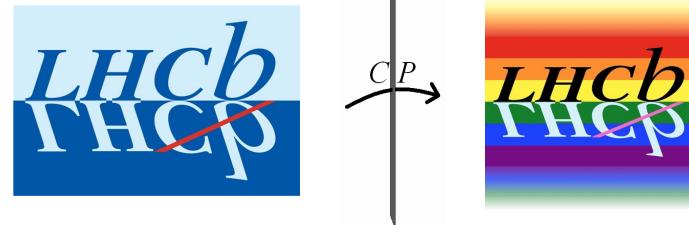
LHCb

Plans for Run-4 and the Phase IIb Upgrade

Johannes Albrecht (TU Dortmund)

KET Strategieworkshop

22.11.2025



Motivation: ESPPU Physics Briefing Book



"It is only through the **combined exploration of flavour, Higgs and electroweak domains** that the **structure of physics beyond the SM** can be uncovered.."

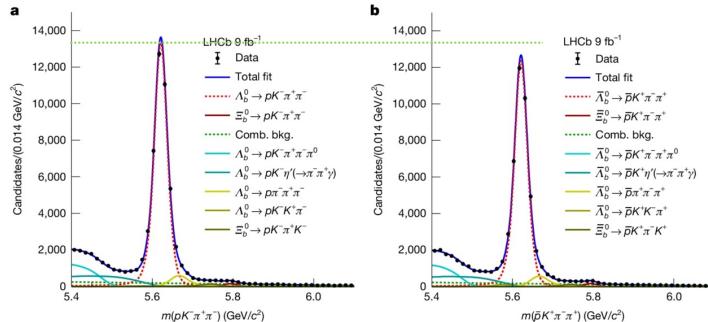
"[In flavour] major progress is anticipated through the full exploitation of existing experimental facilities up to the 2040s, **particularly of LHCb Upgrade II and Belle II** ... this is one of the areas of particle physics where the largest gain ... is expected in the next 20 years."

- Joint flavor study by all experiments
 - **LHCb UP2 will give best precision to broad range of key observables**
 - Belle II unique capabilities for specific neutral/invisible modes
 - ATLAS & CMS competitive for modes with multiple muons
- Reminder: LHCb program also includes hadron spectroscopy, heavy ions, fixed target physics, EW precision, dark sector searches, ..

arXiv:2503.24346

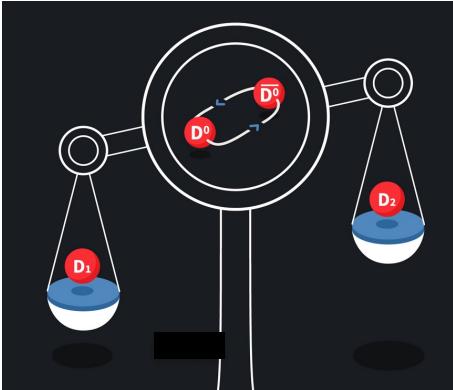
LHCb: a continuing success story

2025: CPV in baryons discovered



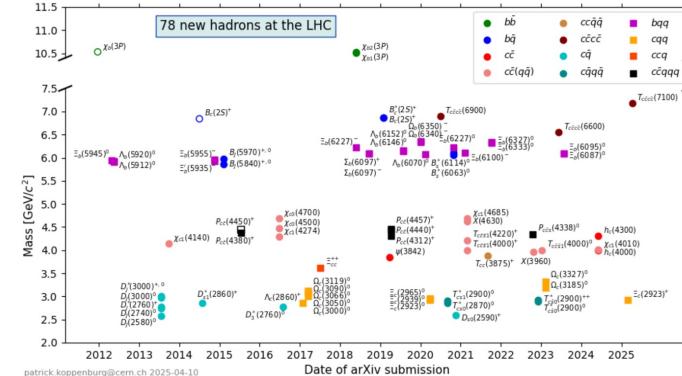
nature

CPV and mixing in charm discovered



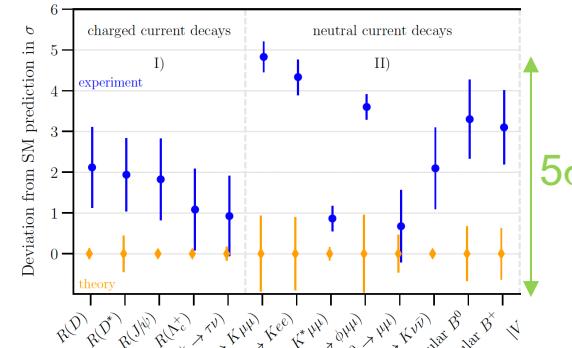
Discovery from 2019, still not clear if SM or not ?

Very successful spectroscopy program

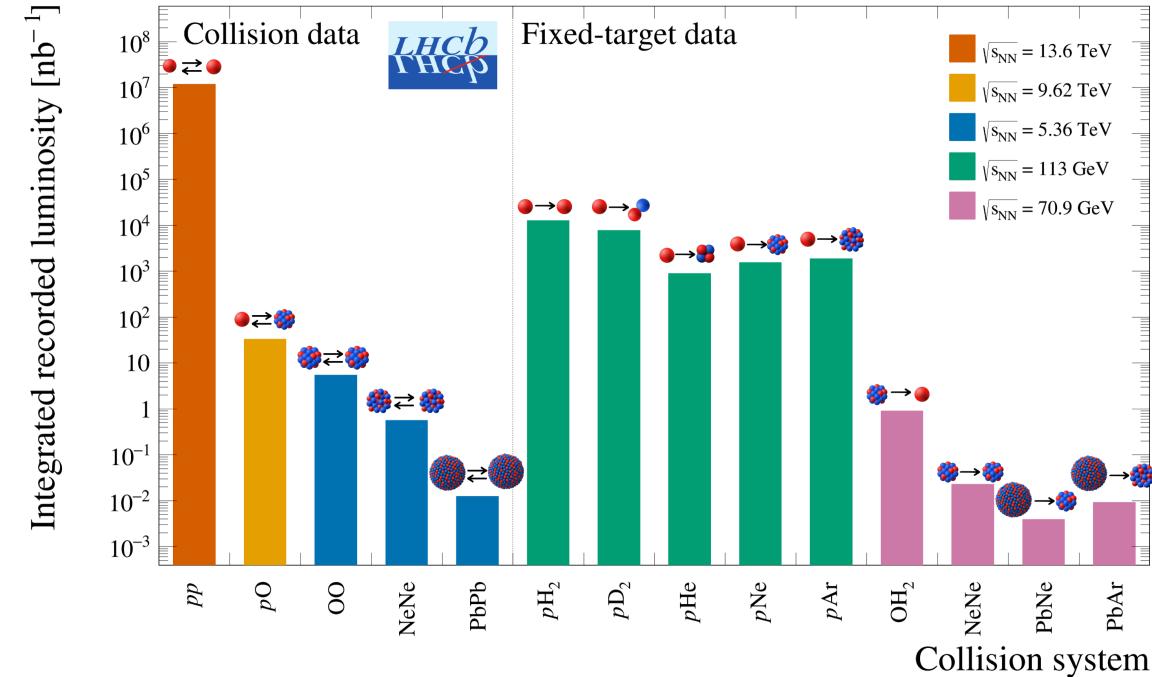


24 new exotic hadrons measured

Flavor anomalies: TH issues or BSM?



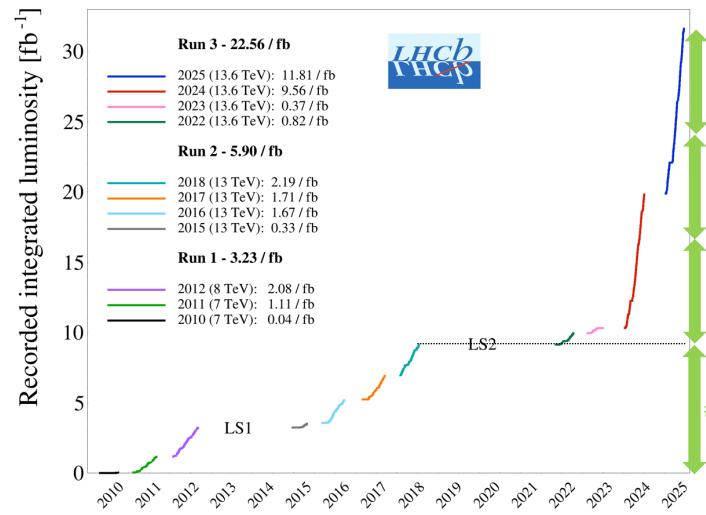
New measurements from CMS and LHCb seem to confirm anomaly

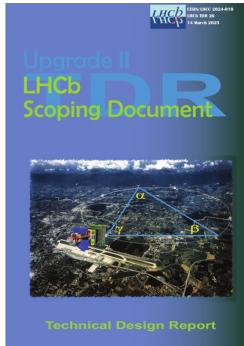


- Very successful Run 3 data taking, recorded #B increased by factor 4

- SMOG2 system allows parallel data taking in collider and fixed target mode

Zoom in to proton collisions





- **Detailed study on different scenarios below “baseline”**
 - LHCC recommended: “Middle Scenario”
- Globally, LHCb is advancing well in discussions with funding agencies to secure the overall funding of the project
Estimated likely support > 85% of total funds already now

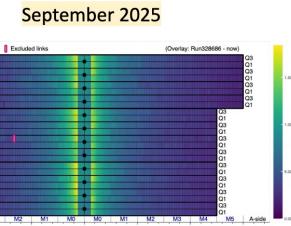
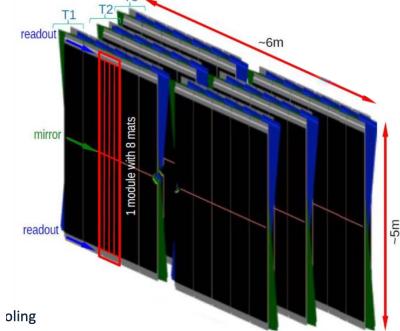
Costs per subsystem from Scoping Document
<https://cds.cern.ch/record/2903094>

$\mathcal{L}_{\text{peak}}$ ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$)	Baseline (kCHF)	Middle (kCHF)	Low (kCHF)
VELO	16672	15906	13753
UP	8077	7719	6887
Magnet Stations	2592	2234	0
Mighty-SciFi	21767	21273	17388
Mighty-Pixel	15994	11641	11061
RICH	21450	18415	14794
TORCH	12508	8756	0
PicoCal	27607	27607	21584
Muon	9785	8266	8266
RTA	18800	11700	9500
Online	11800	9467	8993
Infrastructure	14463	13284	12430
Total	181515	156268	124656

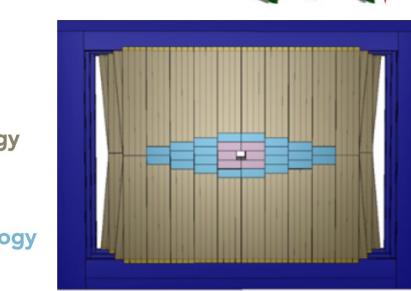


Main tracker of LHCb

Upgrade I

German lead during installation
& commissioning (HD)Real Time Analysis (RTA)30MHz readout
& full sw trigger

Upgrade II

MT-Pixel
HVMaps technology

German lead from 2027 (HD)



Leading German contributions to key technologies:
SciFi modules & KIT HV-CMOS sensors

Successful first implementation of
heterogenous (GPU/CPU) triggerSignificant Run 4 project:
Evolve this novel system

Germany project lead at proposal (DO) and running stage (HD)

Other duties:Beam Conditions Monitor, data
preservation, open data, gridKA

Accelerator, timescales and German projects

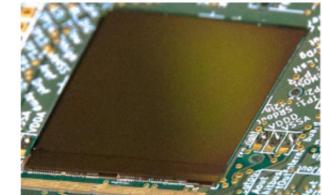
Run 3
2026
LS3
2030
Run 4
2033
LS4
2036
Run 5&6
2041

BMFTR 24-27	Commissioning & operation of SciFi RTA: proof of principle running at 30MHz readout Additional duties: Beam Monitor, open data, GridKA LHCb-Upgrade 2 Mighty Tracker R&D → preparation of TDR
BMFTR 27-30	Tooling, QA, (Pre-)production Mighty Tracker (LHCb-UP2) RTA: developments for optimal running (all GPU trigger) SciFi consolidation (VTRx problems, cooling plant), operation, data processing Additional duties: Beam Monitor, open data, GridKA
BMFTR 30-33	Construction of Mighty Tracker, preparation of infrastructure develop trigger strategy, additional duties
BMFTR 33-36	Installation & commissioning Mighty Tracker Implement new trigger, additional duties
BMFTR 36-39	Running Mighty Tracker and LHCb UP2 Physics exploitation

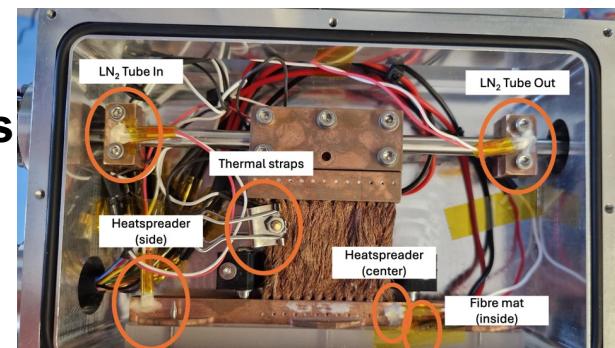
3rd generation main tracker: Mighty Tracker (MT)

- MT-pixel: HV-CMOS ~8m² pixel (BN, DO, FR, HD, KIT)
 - About 60:40 split UK/Germany
 - R&D and test of MightyPix chip (German development)
 - Contributions to electronics and detector control
 - Production and QA of sensor chips, preparation and production of staves
- MT-SciFi: large scale ~300m² detector (AC, BO, DO, FR, HD)
 - Dominantly pushed forward by Germany & EPFL + Spain, Poland, BR
 - **Cryo cooling of SiPMs to suppress dark counts**
 - Fibers (QA, fibre mat production starting)
 - Module production

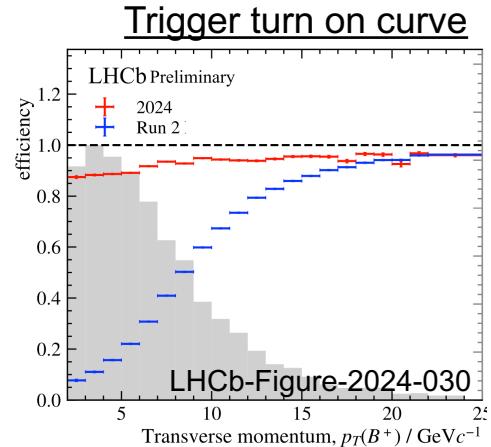
MightyPix 2:
Full size prototype submitted



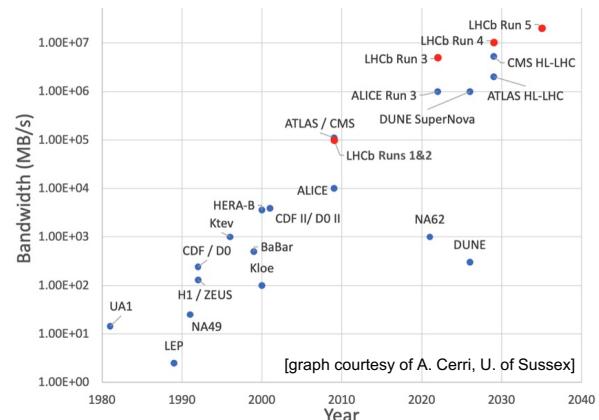
SciFi Cold box demonstrator

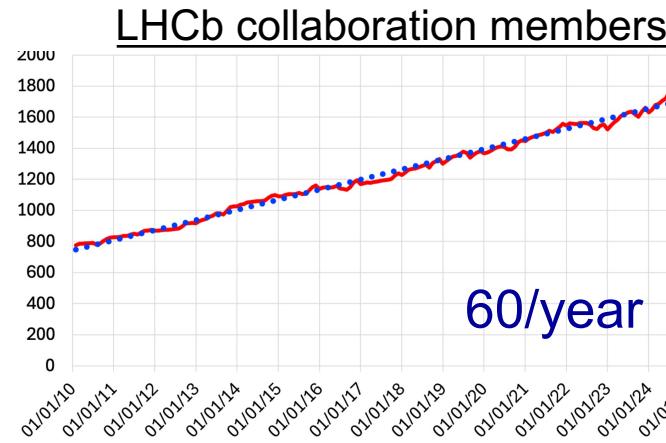


- Run 3: full software trigger proof of concept
 - Main hadronic B signatures: **gain factor 2-4**
 - Tricky signatures not yet fully implemented
- Main goal for Run 4: **full exploitation of system**
 - optimal use of resources
(eg. full GPU trigger, FPGA assisted tracking, ..)
 - Full RICH reco in GPU early in trigger
 - Tracking of displaced tracks and low PT signatures
 - Analysis tools: development from basic work
(alignment) to precision tools (flavor tagging)
- U2: unprecedented challenge in data processing
 - Requires continued innovations in both online and offline computing



Evolution of readout bandwidth



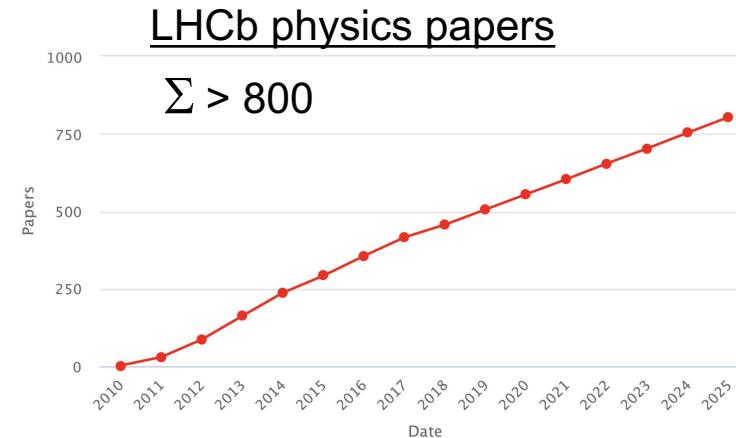


New group in **Bochum**: **Mikhasenko**
Nf. Uli Wiedner (PANDA)

- Spectroscopy of conventional and exotic hadrons
- Significant detector labs (Wiedner/PANDA) for MightyTracker (SciFi)



Misha Mikhasenko



New group in **Freiburg**: **Gersabeck**
Nf. G. Herten (ATLAS)

- CP violation in beauty and charm
- BSM searches with semileptonics
- Real Time Analysis
- Significant detector labs (Herten/ATLAS) for Mighty Tracker (Fibre and Pixel)



Marco Gersabeck

Coming soon: New LHCb group in Dortmund (Color meets Flavor)

- Total cost (invest): LHCb middle scenario **156MCHF**
 - Assume current fair share: German contribution about **9.5MCHF** invest for LHCb
 - Additionally: Personnel for upgrade, operation, maintenance, consolidation
- Funding period 2027-30:
SciFi maintenance, RTA development, U2 R&D, start of (pre-) production
 - **Two significant groups joined**, more coming (Gersabeck/Nf. Herten (Freiburg) from ATLAS and Mikhasenko/Nf. Wiedner (Bochum) from PANDA)
 - changes the German impact significantly
 - needs to be reflected in funding

Total cost of running & upgrade: 2027 - 30

BMFTR 2027-30	MEUR
LHCb Upgrade 1 (Consolidation, data-processing, analysis)	2.4
LHCb Upgrade 2 (R&D + Invest)	4.53
LHCb Upgrade 2 (personel & travel)	5.65
M&O	1.02
Total	13.6
Total + PP	16.3

- Financial risks for upgrade
 - Delay in schedule
 - Variations in invest cost (currency), estimated to be 20% of total invest cost
 - Inflation

2022

2026

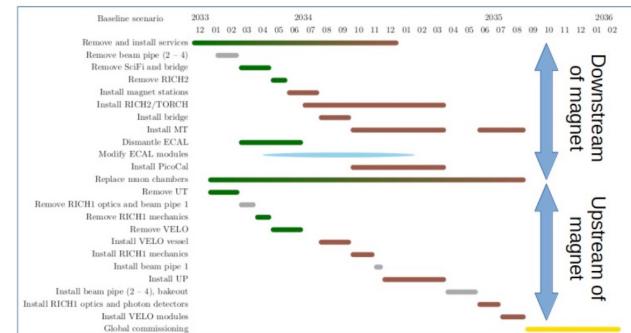
2029

2033

2035

Run 3**LS3****Run 4****LS4****Run 5&6**

- Development of new ASICs can be a source of delay
 - Expert review with detailed questionnaires ongoing / converging
- LS3 will be a very long shutdown (currently planned 4 years)
 - Wake up current detector after such a long sleep might impose risks
- Only 2 years for installation, but benefitting from open geometry
 - Expert review addressed this point
- Unknown production delays



- ESPP recommendation “**full exploitation of flavor**”
→ LHCb Upgrade 2 for Run 5
- Germany is playing a leading role in the experiment (main tracker, RTA)
→ R&D now needed to maintain this for LHCb-Upgrade 2
→ Schedule requires TDR until end 2026
- German groups want to define the projects in R&D phase
 - Key technologies with leading developments from German groups:
large scale SciFi tracker & KIT HV-CMOS Sensor
 - Other countries (e.g. UK) are investing massively,
if we want to shape the experiment, we need to do it now
- Our detectors and methods are highly relevant for the Hightech Agenda

Transfer

Technology and Knowledge Transfer



Central office

News



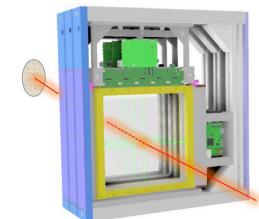
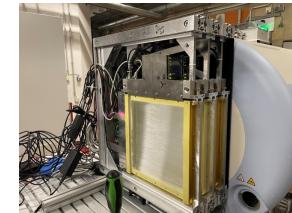
July 03, 2025
LHC-ErUM FSPs at the ISC High Performance 2025 in Hamburg



February 12, 2025
Transfer Workshop: ErUM Science meets Industry



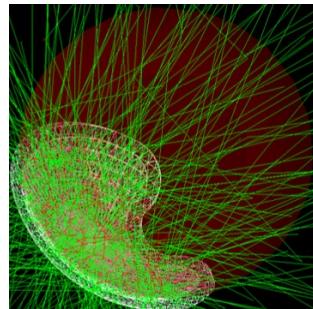
HIT radiation monitor



HIT therapy center installs “SciFi tracker” for 10kHz beam position measurement



Brachytherapy



Eye cancer therapy improved with HEP methods

Also supported by: DFG455163177 and DFG528648187

Industry collaborations or joint studentships

“Transfer” of highly educated students to HighTech

point8
data matters.



ximantis



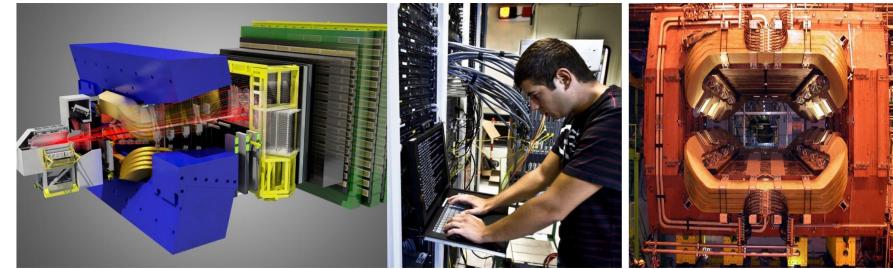
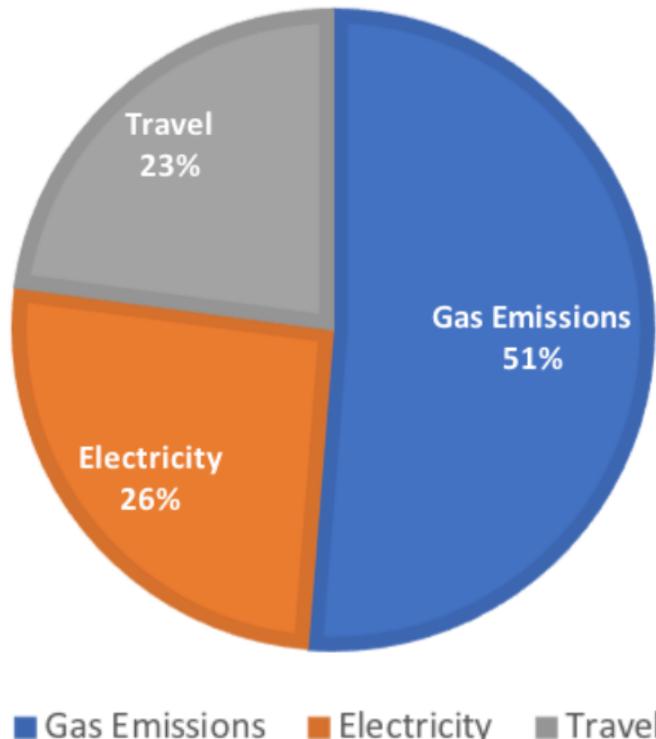
ErUM Data DEEP

INCREASING DATA EFFICIENCY IN EMBEDDED PROCESSORS THROUGH
ARTIFICIAL INTELLIGENCE

IBM

SMARTHEP
REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY



CO₂ equivalent emissions (LHCb Run 3)

LHCb detector < **0.3 MW**
(excluding the magnet)

LHCb DAQ + High
Level Trigger
1.4 MW

LHCb Magnet
4.4 MW



Recovered heat
from LHC cooling
towers at point 8
supplies heating to
Ferney-Voltaire
(~8000 households)

- Unique science case as emphasised in ESPP deliberations
 - Excellent justification for the investment
- LHCb Upgrade 2 planning is progressing
 - Estimates of likely support obtained from many funding agencies
→ Already more than 85% covered (formally not yet committed)
 - German groups focus on two projects: Mighty Tracker and Trigger (RTA)
→ continued BMFTR support will allow leading contributions to Upgrade 2
 - R&D and production (preparation) needs to start in next funding cycle

KET would like to invite you to give a presentation on “LHCb – Plans for Run-4 and the Phase IIb Upgrade” at the ErUM-Pro Strategy Workshop which will take place right after the KET annual meeting on 21./22.11. at the Physikzentrum Bad Honnef. The draft agenda can be found here: <https://indico.desy.de/event/50011/timetable/> The purpose of this workshop is to prepare the “Strategiegespräch” with the BMFTR which we expect to happen around February 2026. In this “Strategiegespräch” our community will have the opportunity to present projects which we consider important for the funding period 2027-2030. It is our opportunity to give advice to the ministry and to influence the call for applications.

This is a special presentation, and we ask you to please consider the following points:

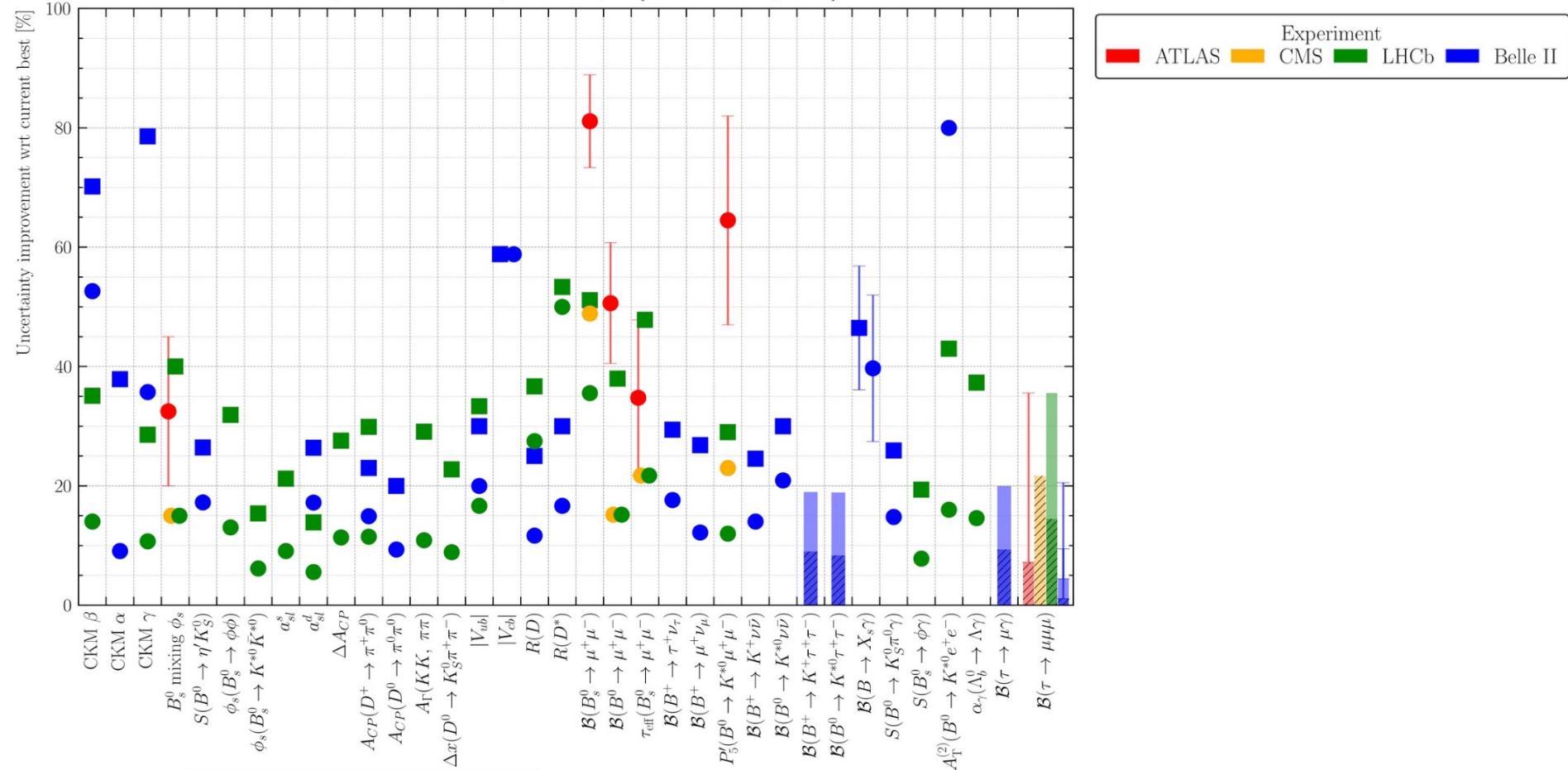
- focus on what is planned for the funding period 7/2027-6/2030
- explain how this is embedded in the full project, including a timeline for the full project
- summarize which German groups are behind this project and how this relates to the international collaboration (German impact)
- highlight news or changes in projects, structures, boundary conditions, participating groups, schedule, required resources
- highlight critical aspects
- explain why this project must be performed in that funding period (“Dringlichkeit”) and why the BMFTR should fund it (“Bundesinteresse”, “Forschung an Großgeräten”)
- give an estimate of the German funding required in the funding period, and for the required German and total funding for the full project
- comment on sustainability and on prospects for technology transfer

Please discuss and agree the content of your presentation within the community of your project or research topic.

The time allocated for your talk is only 15 minutes, plus 5 minutes for questions. There will be more time for discussions at the end of each session. Given the tight schedule you should keep the introduction to your project as short as possible.

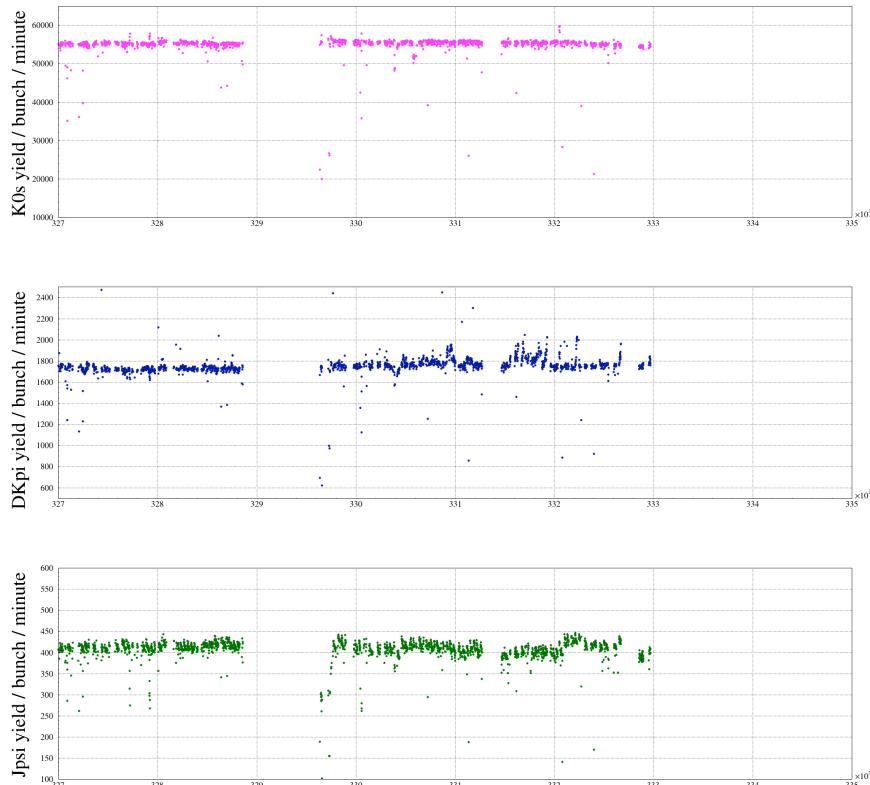
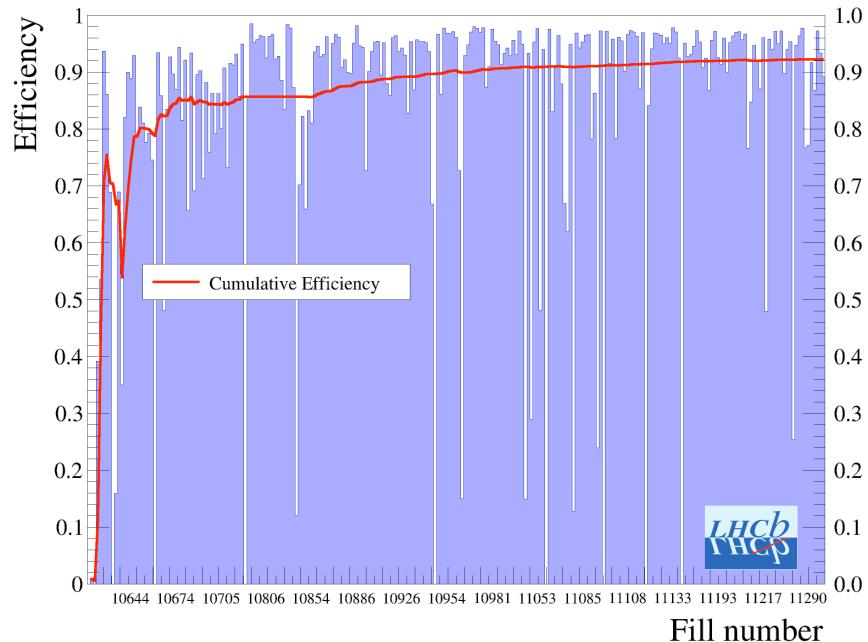
At the workshop we will try to reach agreement in the community on priorities for the next funding period. The outcome of this workshop will be the basis for the presentations at the “Strategiegespräch” with BMFTR. KET will write a summary of the workshop which will be provided to the speakers at the “Strategiegespräch” and BMFTR/PT. If time allows, we will iterate this summary with you as speaker at the workshop.

Projection for key measurements (2503.24346)



Run 3 data quality

Efficiency vs Fill number



- Neuerungen:
 - **Triggerlose 40MHz Auslese**
 - **Reiner Software-Trigger** (GPU/CPU)
 - Echtzeit-Kalibration und Analyse
 - Erfordert:
 - Neubau der Elektronik
 - Erhöhte instantane Luminosität

- Anpassungen zum Detektorsystem: Tracking
 - VELO Pixel-Detektor, 3mm vom LHC Strahl
 - Neues Tracking-System: Upstream-Tracker (Si)
 - **SciFi-Tracker** mit 11.000km Szintillierender Fasern
- Anpassungen: PID
 - RICH-Cherenkov-Detektoren und Elektronik für Myon und Kalorimeter

