technische universität dortmund

Fakultät Physik

Experimental particle physics

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29.11.2023

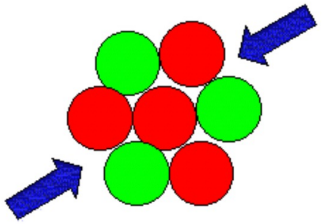
Many references to B. Mitreska and Q. Führing, Lamarr meeting 8.11.23

Modern particle physics

We know of four fundamental forces of nature

Strong force (QCD)

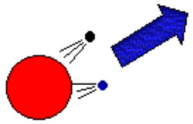
Color



Strong force binds quarks to nucleons / hadrons

Weak force

Flavor



Weak force in radioactive decay

Strong and weak force need to be studied jointly

Electrodynamics

Electromagnetic force binds atoms

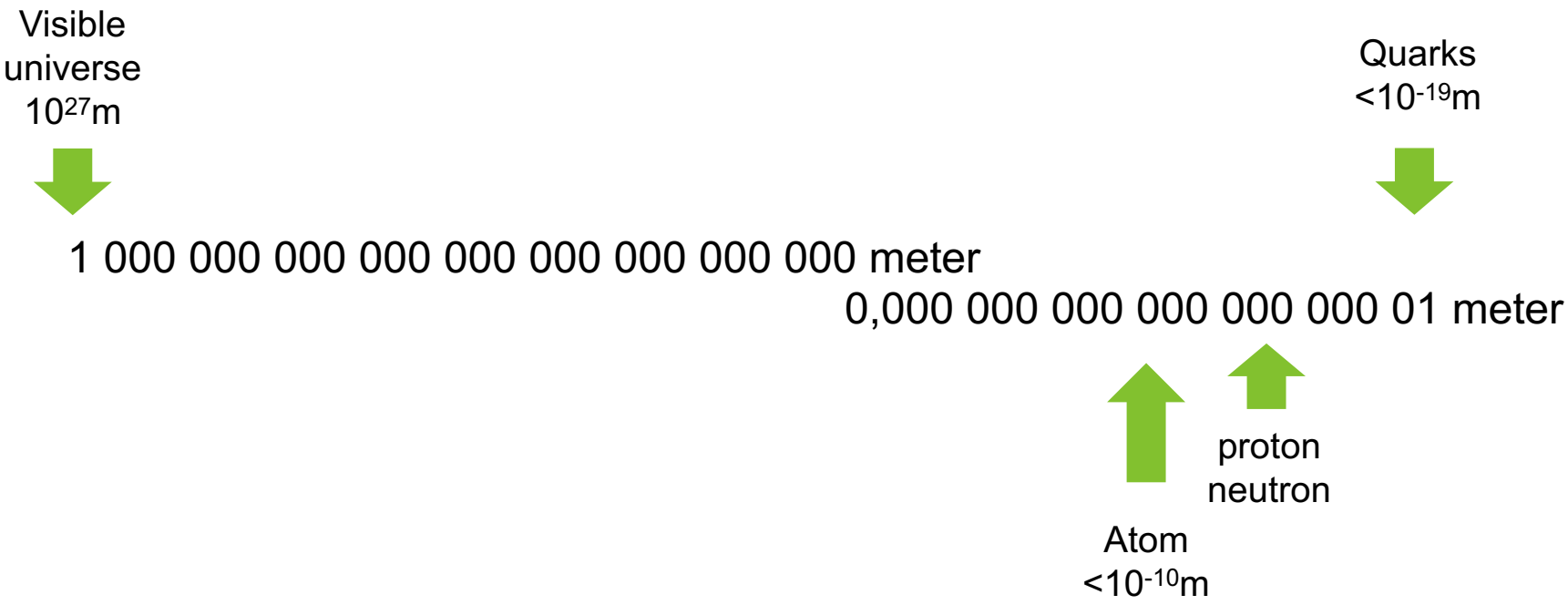
Well understood

Gravity

Gravitational force binds the solar system

Can only be studied on large scales (Astro- [particle] physics, Gravitational waves)

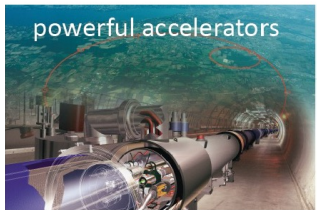
Fundamental Physics



Fundamental Physics

Visible universe 10^{27}m

Visible with eyes



Quarks $<10^{-19}$m

1 000 000 000 000 000 000 000 000 000 meter

0,000 000 000 000 000 000 01 meter

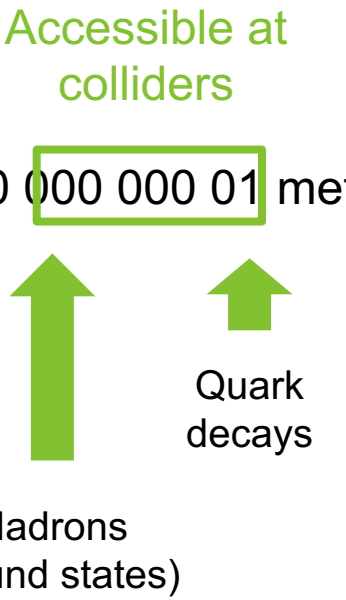
Atom $<10^{-10}$m

proton
neutron

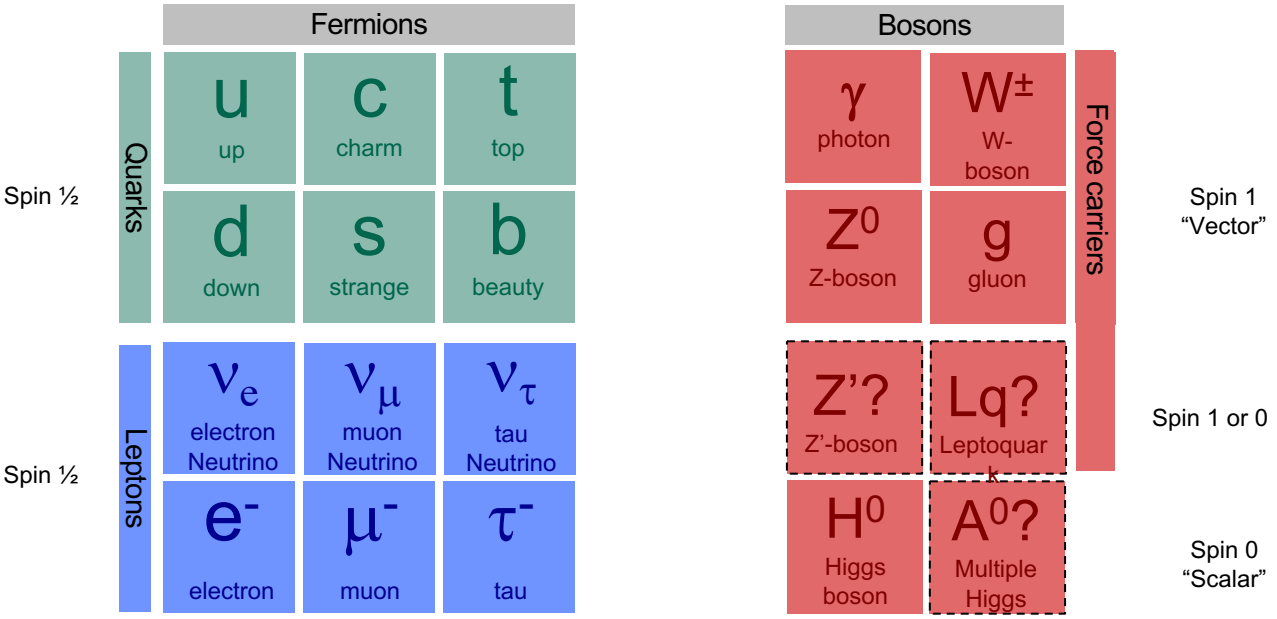
Fundamental Physics

1 000 000 000 000 000 000 000 000 000 meter

0,000 000 000 000 000 000 01 meter



The Standard Model of Particle Physics



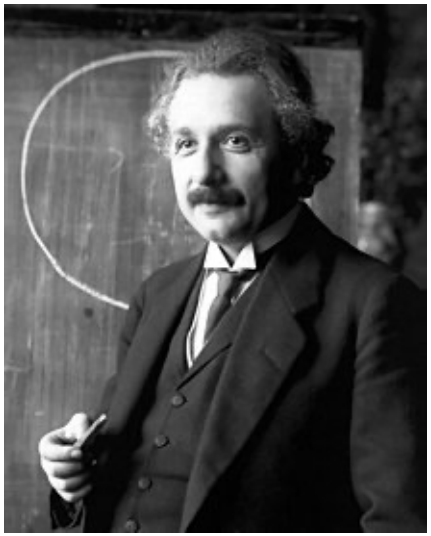
Open questions of the SM

- Cosmological observations: dark matter & matter-antimatter asymmetry
- Hierarchy of masses & couplings

Extended theories come with new heavy particles

How can we discover these extensions?

Einstein and Heisenberg



Einstein: $E = m\,c^2$

Typical collider

→ Limited by collider energy
→ LHC: O(1TeV)

→ No increase in energy until ~2050

Heisenberg: $\Delta \mathrm{E} \cdot \Delta t \geq \hbar/2$

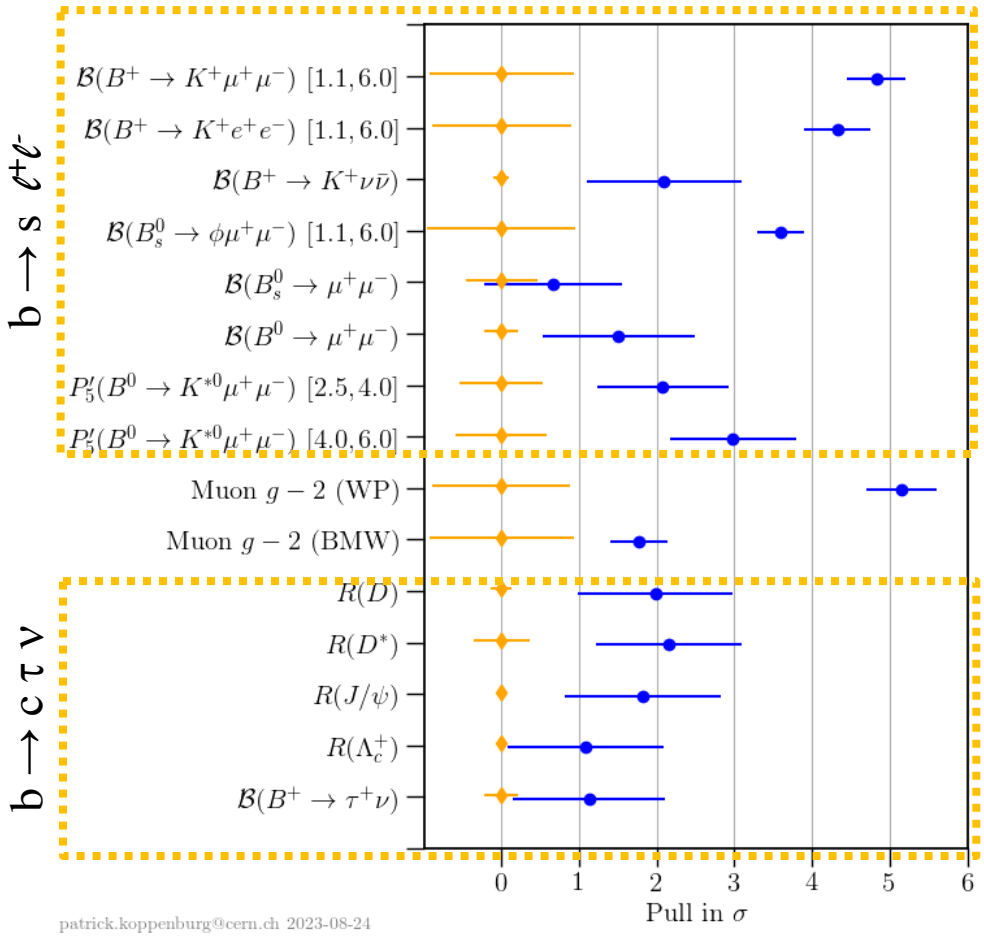
Use quantum fluctuations

→ Limited only in precision
→ Model dependent O(100)TeV

→ A lot of precision data coming
(HL-LHC, Belle 2, CERN BDF, …)

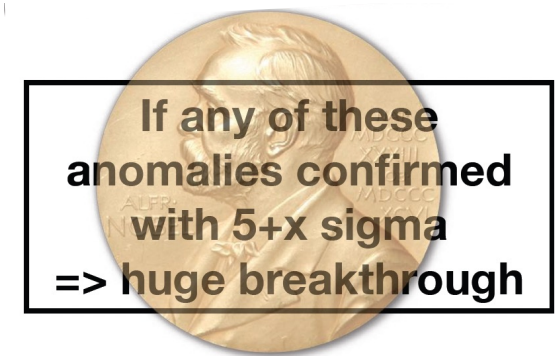
Expected and unexpected discoveries

Where are we? Anomalies

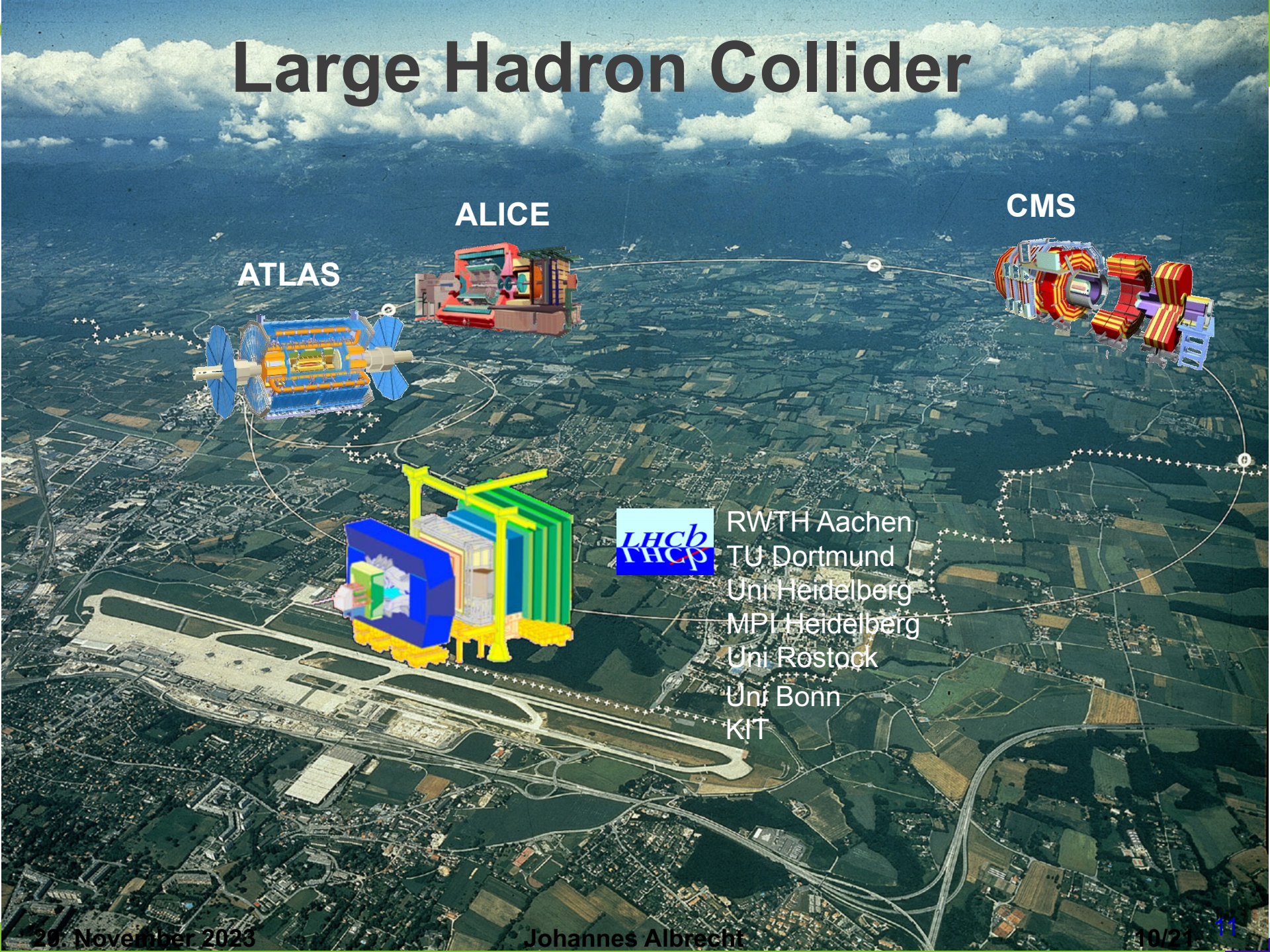


So far no clear 5σ sigma deviation

Falsifying anomalies is prime task for flavour-physicists



Large Hadron Collider



Beschleuniger, Experimente und Zeitskalen

LS2 (2019-21)

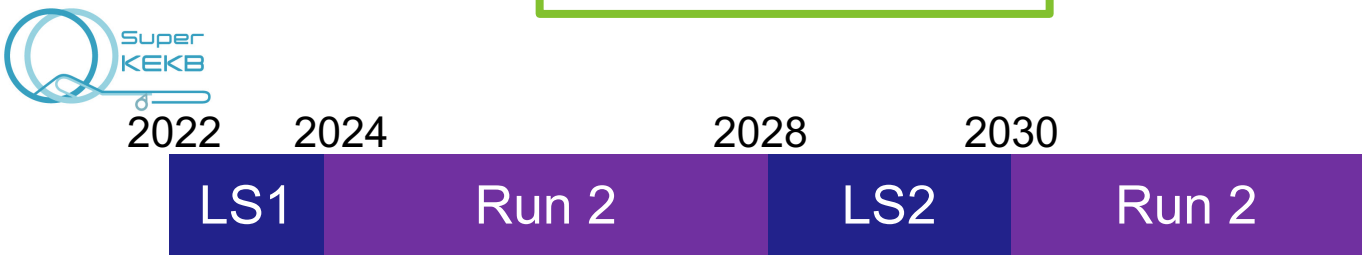
ALICE Upgrade
LHCb Upgrade 1

LS3 (2025-27)

HL-LHC
ATLAS Phase 2
CMS Phase 2

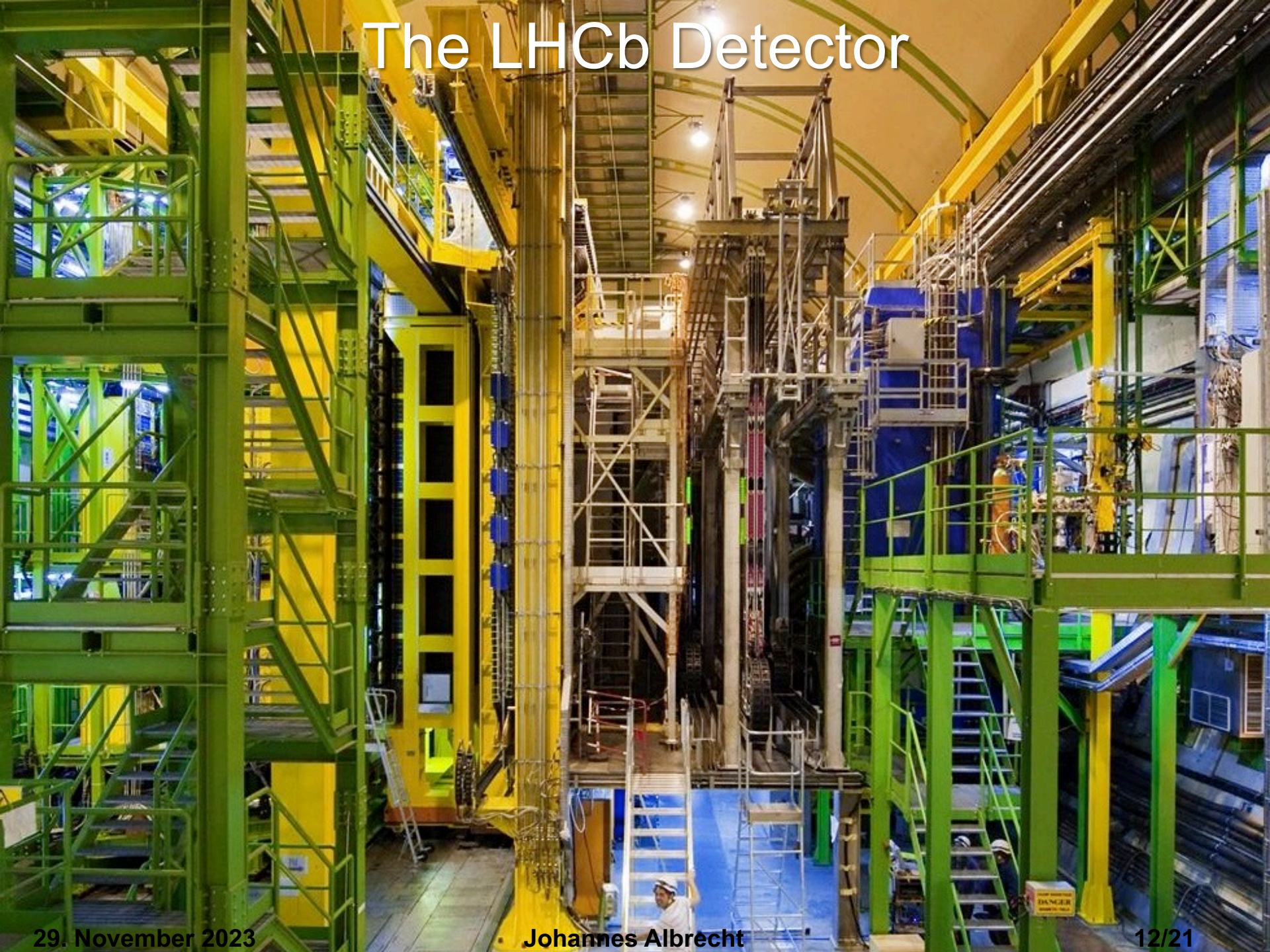
LS4 (2033-35)

ALICE 3 upgrade
LHCb Upgrade II

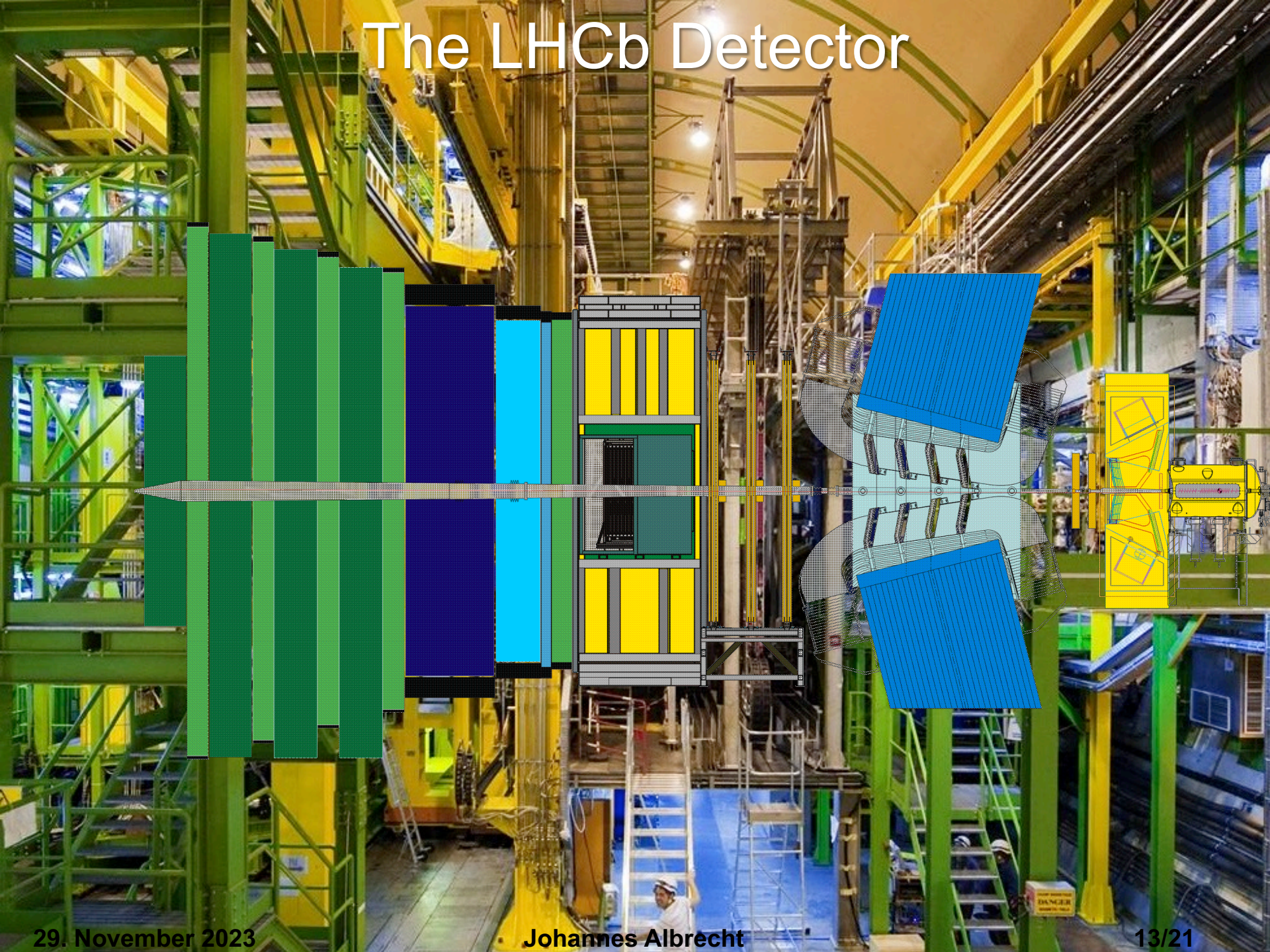


Disclaimer: SuperKEKB Zeitplan nicht offiziell

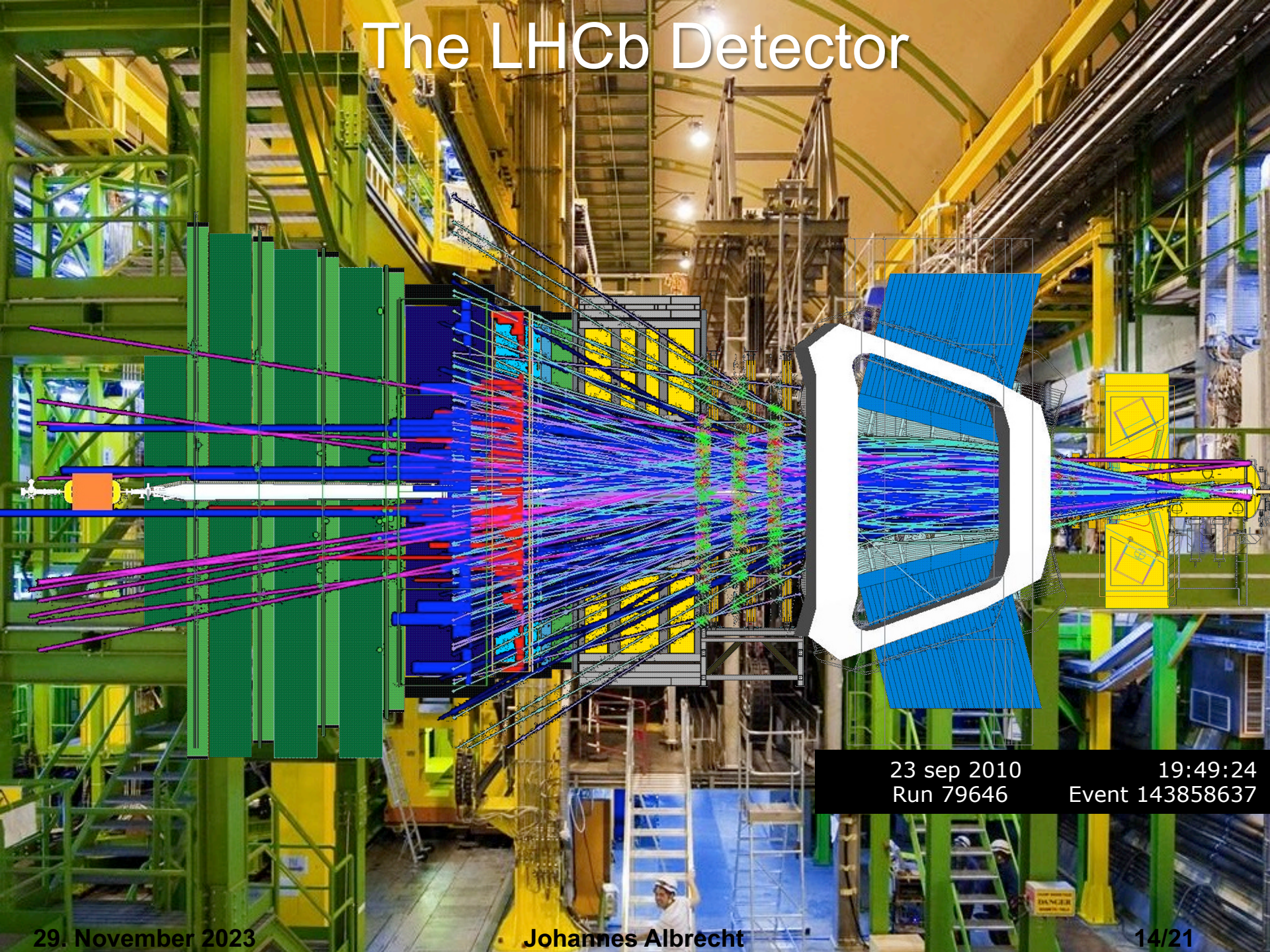
The LHCb Detector



The LHCb Detector

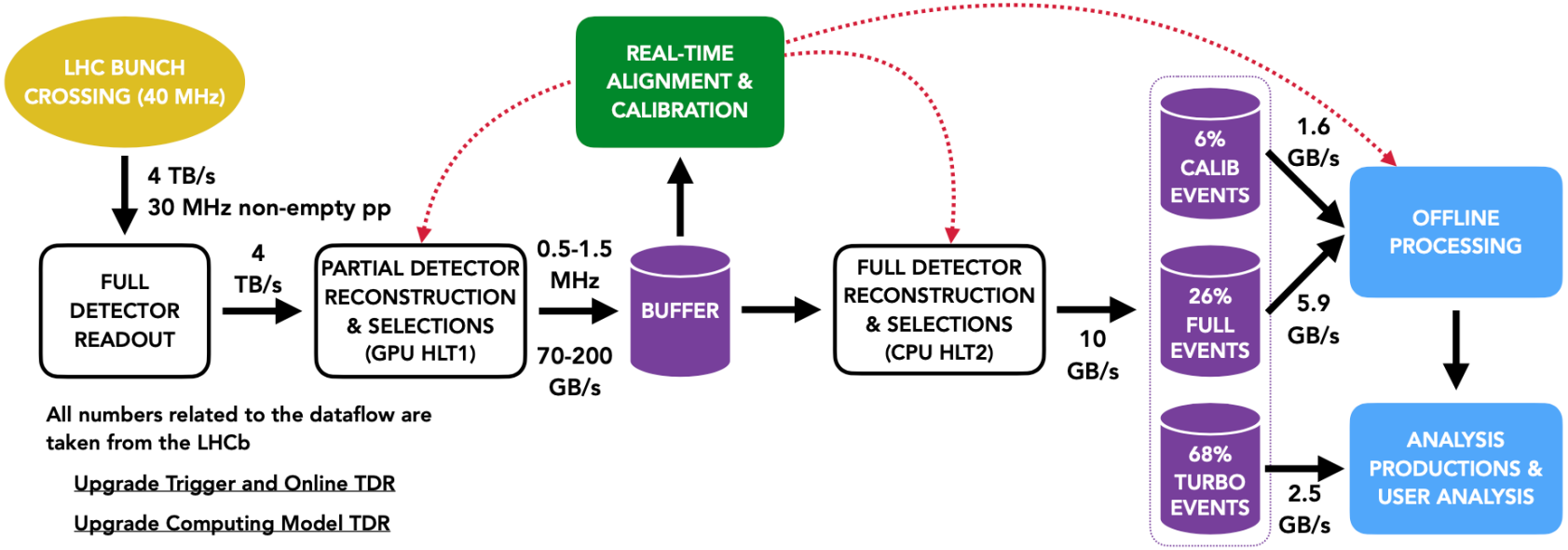


The LHCb Detector



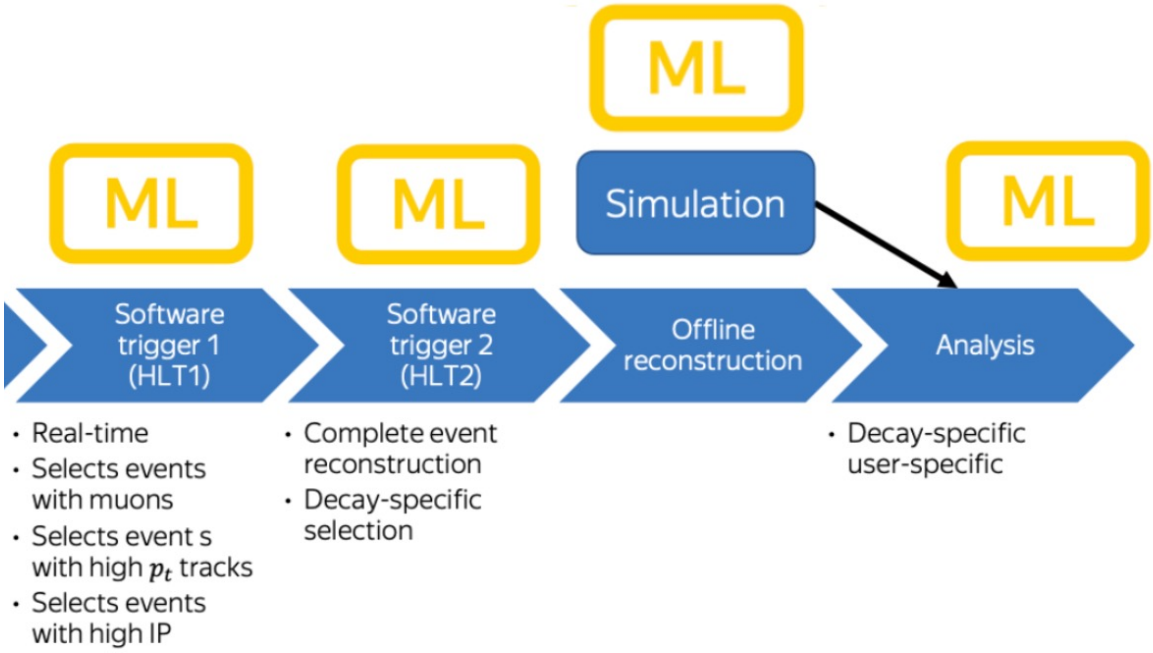
Data collection: „real time“ filtering

LHCb gets 4TB/s to process, for ~10^7s year, for ~30 years



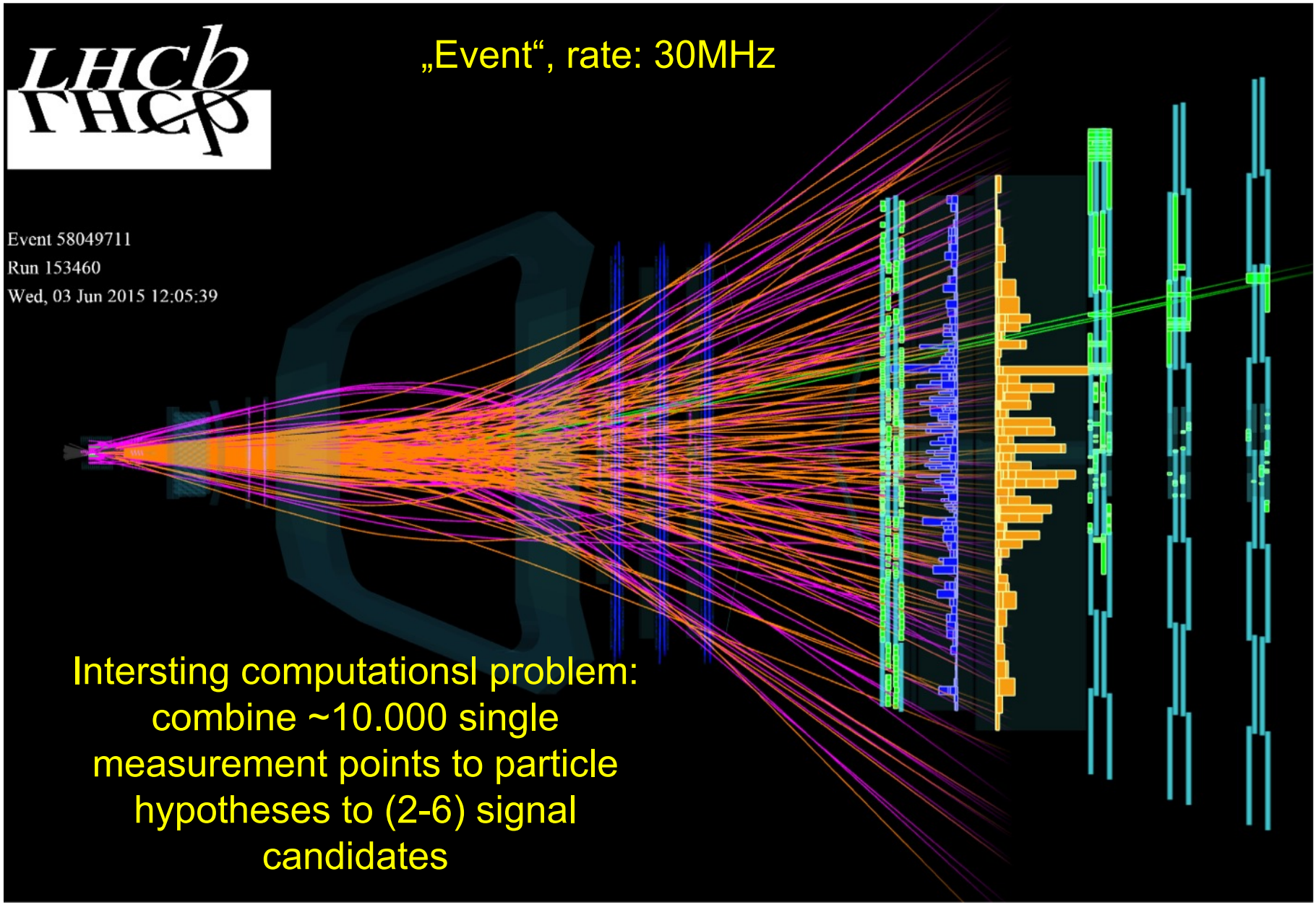
1. Collision events selected with partial reconstruction (HLT1)
2. Selected events stored in a buffer
3. Alignment and calibration are executed
4. Second software stage (HLT2) applies the full reconstruction

The physics objective: case for machine learning



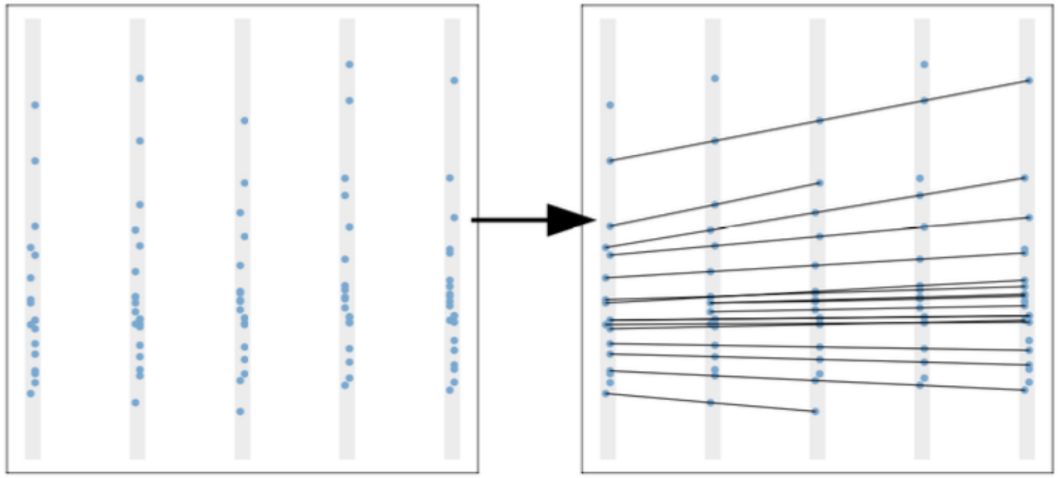
- **Track reconstruction: find matching hits and fake tracks rejection**
- **Trigger: Selects any B decay with at least 2 particles**
- PID: produce a single decision on particle type
- **Analysis: separate signal to background**
- Fast simulation at LHCb

Detector images

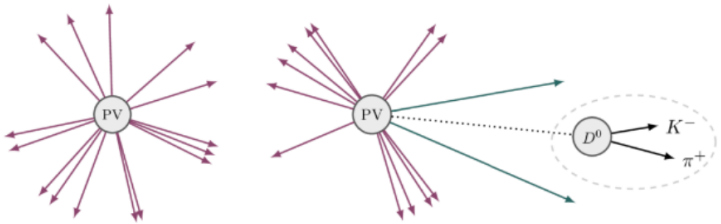


Track and vertex reconstruction

- Correctly match the hits in detector planes
- p-p colisions are busy with producing many tracks



- We need reconstructed tracks to form particles

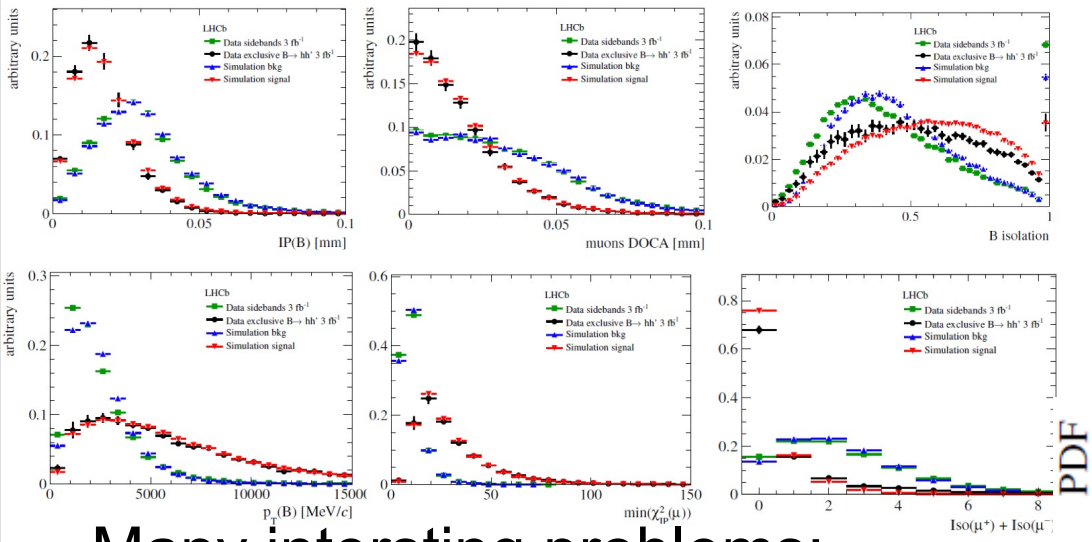


Many problems where expert knowledge might be able to help:

- Pattern recognition
- Parameter estimate
- Ring finding
- Anomaly testeing
- System architecture, hybrid optimization
  (Volume: 400 nvidia A5000 GPUs + O(70k) Intel E5-2630 equivalent physical cores, 30PB disc, 1-2M network cost)
- Fast and efficient candidate selection ~signal fraction up to $1{:}10^{10}$
- …

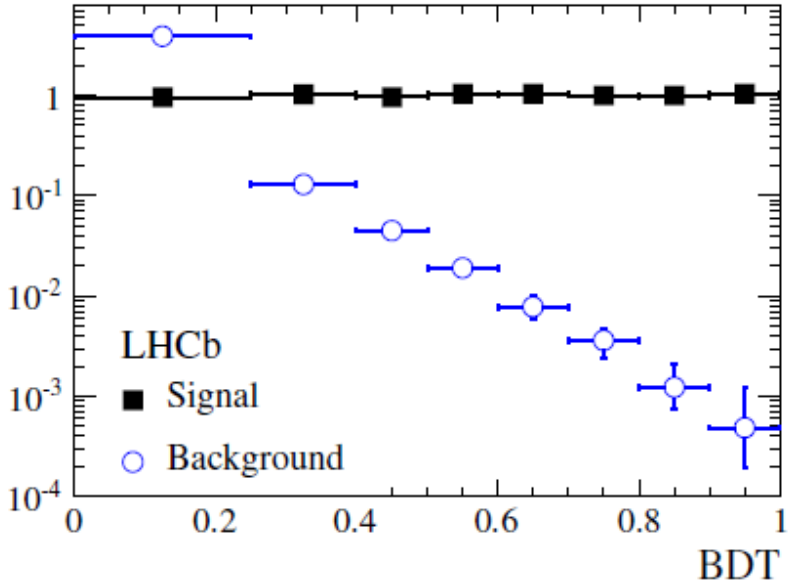
Analysis: signal separation

- Typical: many variables, all with some separation power
  - Total of 12 variables, including:

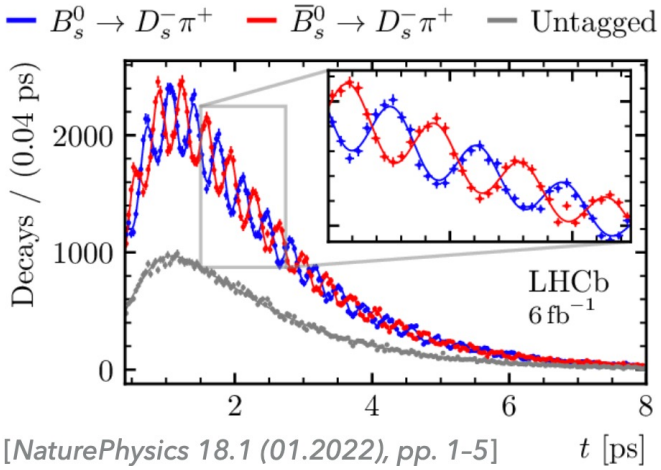


- Combine variables in clasifier (BDT, NN, ..)
- Problem: simulation & signal proxy
- Put some thought in Labelling ?

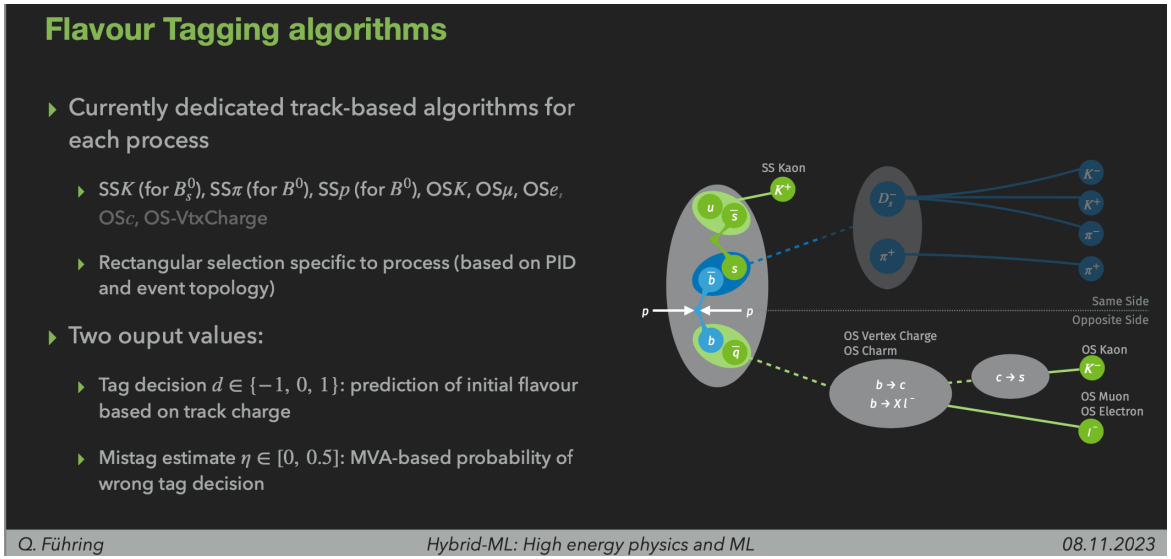
- Many intersting problems:
  - Simulation: enourmous ressources, event generation (learning possible?), detector response, etc
  - Smart use of entire event?
  - Hypothesis based analysis → learned Standard Model ?



Flavor Tagging: a whole playground



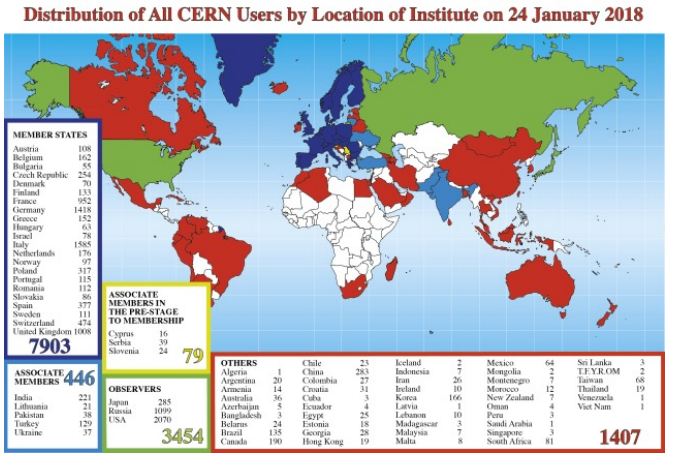
[NaturePhysics 18.1 (01.2022), pp. 1–5]



- Limits performance of analysis, currently, we loose factor 20
- Complex, hypothesis based analysis → can we do better?
- Inclusive tagger in development (since many years …)
- Differences: simulation-data known, but complex
  - Often recovered by multivariate reweighting
  - Alternative approaches to be studied (e.g. Domain Adaptation)
- Work in progress (Führing, Bunse, Pfahler)

Summary

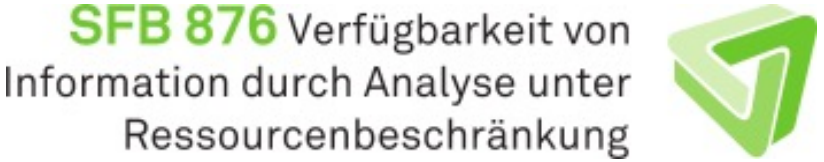
- Particle Physics: Experimental situation very interesting
  - Entire community joined forces at one accelerator center at a time
    → extremely focussed field
  - We have 10 years of LHC data and will collect another 20
    → huge dataset to exploit optimally



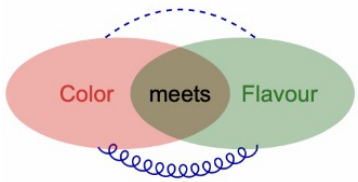
- Modern Particle Physics is (in a part) data science
  - Process 4TB/s of data in „real time“
  - Many hypothesis based approaches, often optimal, sometimes not?
  - Better access to data in any way has large potential

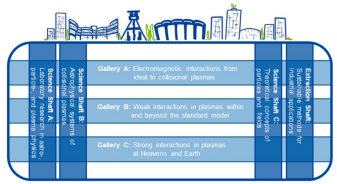
- Particle physicsts are not (entirely) naive
  - No quick solutions, joint projects needed and started within Lamarr, more collaborations welcome

Stamp Collection / Danksagung and Fördergeber

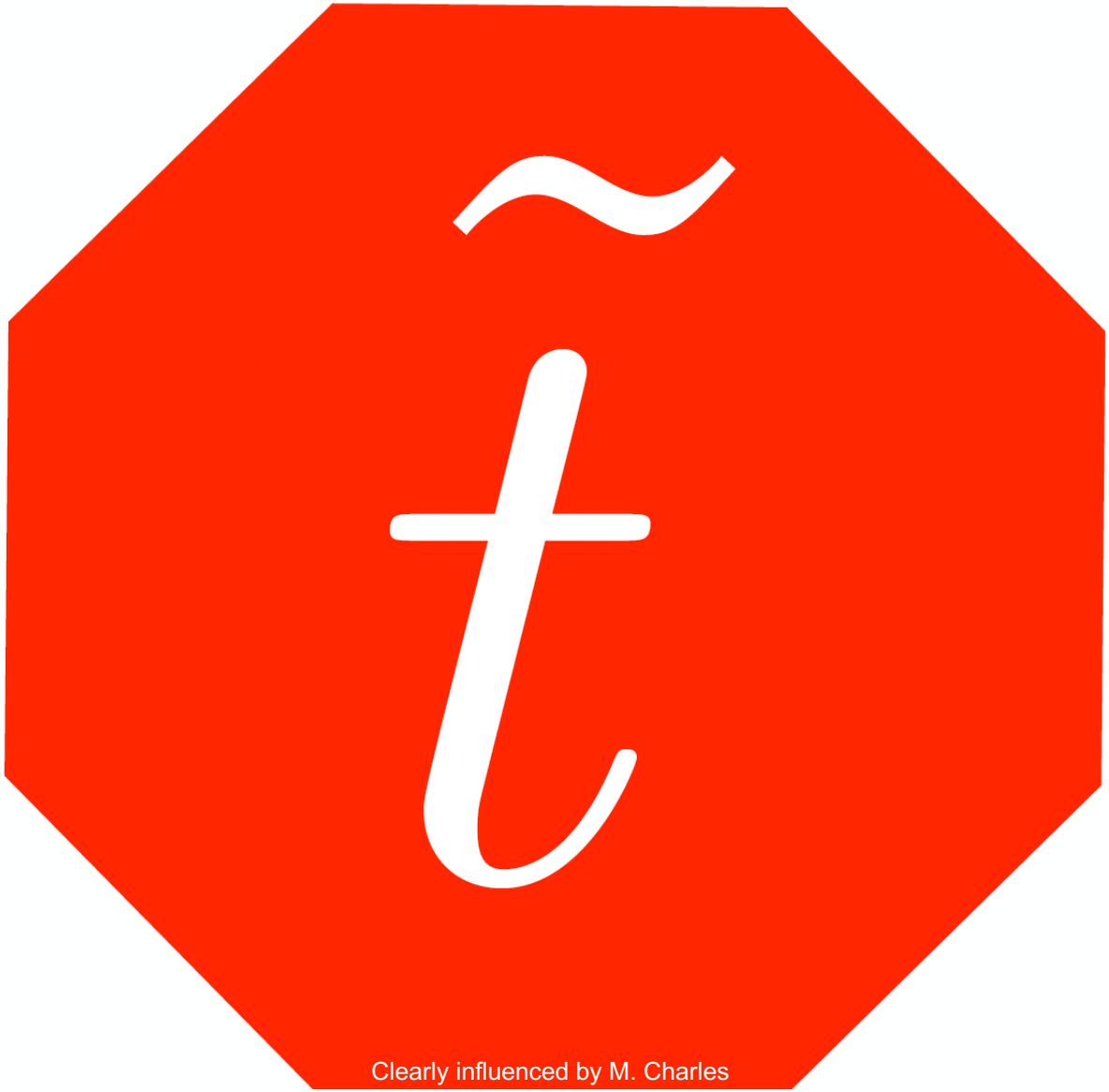


There is still some space left…





Many thanks to my group!



Clearly influenced by M. Charles