IMAPP Thesis projects LHCb Group
TU Dortmund

technische universität dortmund

LHCb

FSP LHCb
Erforschung von Universum und Materie

Bundesministerium für Bildung und Forschung

color meets flavor

EXZELLENZ STRATEGIE des Bundes & der Länder

Emmy Noether-Programm DFG

Heisenberg-Programm DFG

Alexander von HUMBOLDT STIFTUNG

SMARTHEP
REAL-TIME ANALYSIS FOR SCIENCE AND INDUSTRY

SFB1491

LAMARR
INSTITUTE FOR MACHINE LEARNING AND ARTIFICIAL INTELLIGENCE

PUNCH 4NFDI

UA RUHR

Group leaders

Johannes Albrecht <johannes.albrecht@tu-dortmund.de>

Dominik Mitzel <dominik.mitzel@tu-dortmund.de>

Research focus:

- **Physics analysis:** CP violation and rare decays in beauty and charm, Semileptonics, Soft QCD
- **Detector operation + R&D:** SciFi, Beam Condition Monitor (BCM), Luminosity, Future Upgrades: MightyTracker, BCM, LumiTracker, Future experiments (FCCee)
- **Real-Time Analysis (RTA):** Tracking, Triggers, Detector alignment
- **Analysis tools:** Flavour tagging, Luminosity, Machine Learning & statistics tools

Former IMAPP students (now PhD)

Lorenzo Nisi <lorenzo.nisi@tu-dortmund.de>

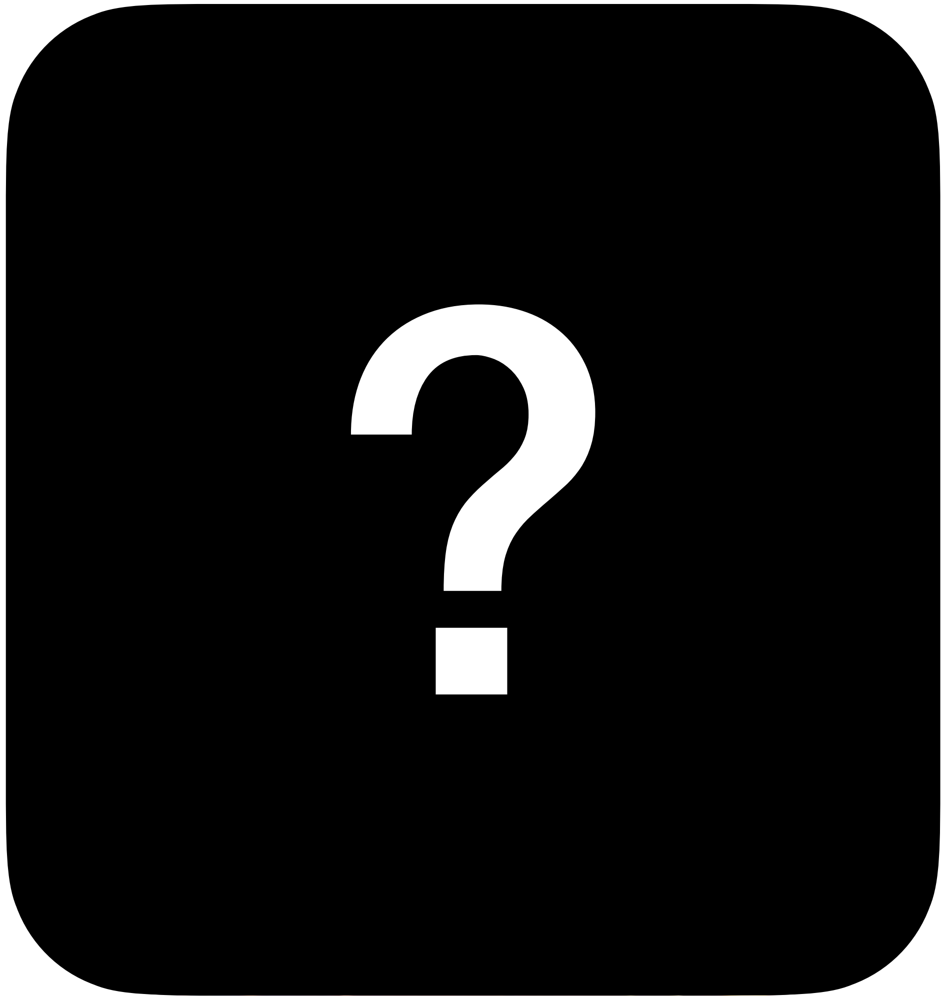
Marco Colonna <marco.colonna@cern.ch>

Luca Balzani <luca.balzani@tu-dortmund.de>

Theodor Zies <theodor.zies@tu-dortmund.de>

Please reach out if you have questions!

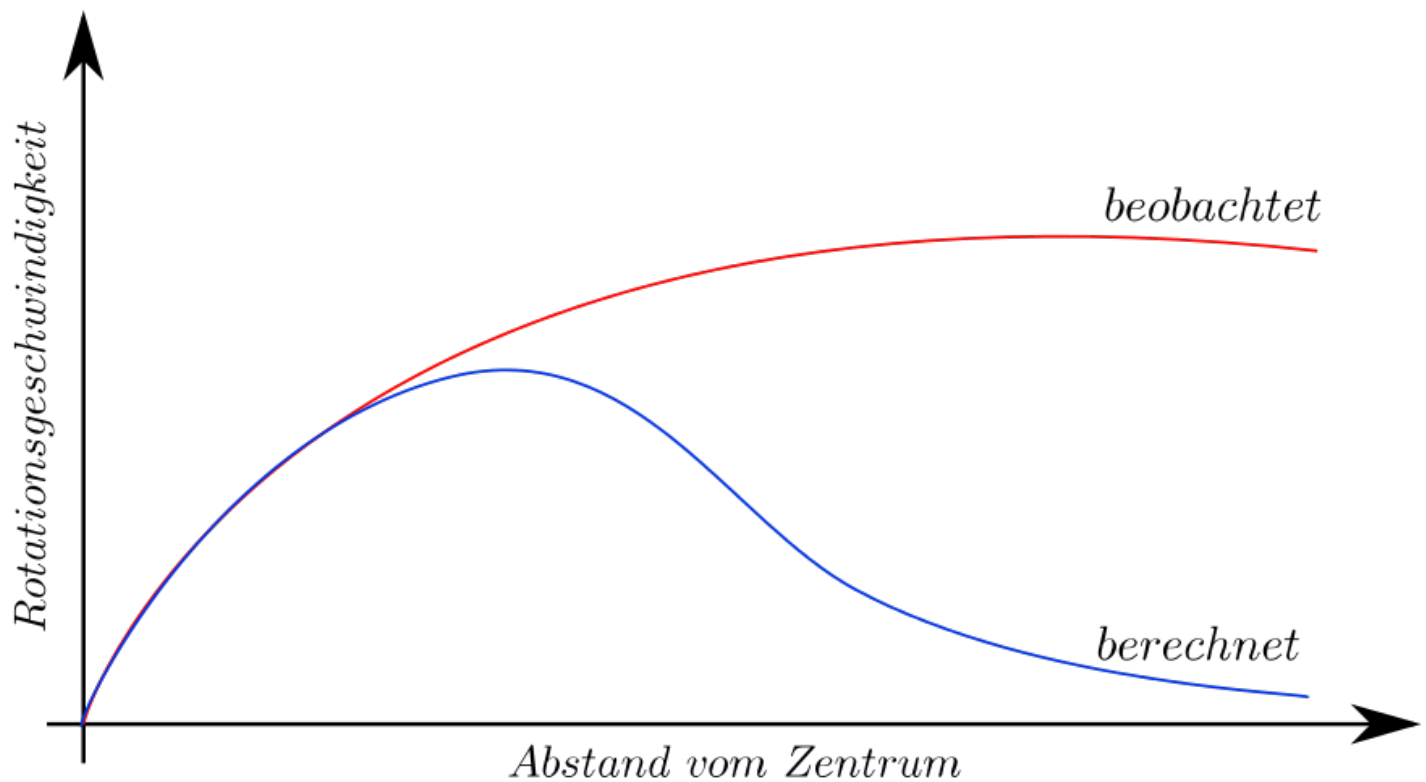
Open Questions Of the Standard Model?



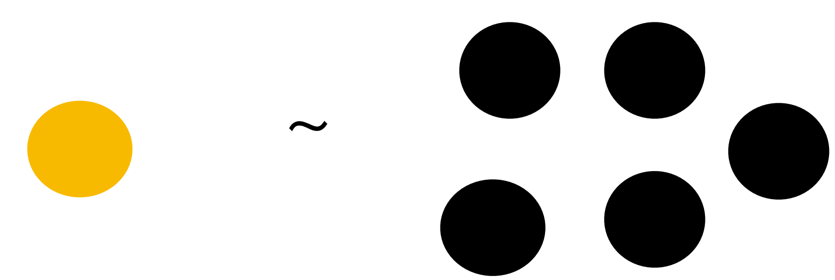
Open questions of the SM

What is dark matter?

https://de.wikipedia.org/wiki/Dunkle_Materie#/media/Datei:Dark_matter_diagram.svg



Matter : Dark Matter



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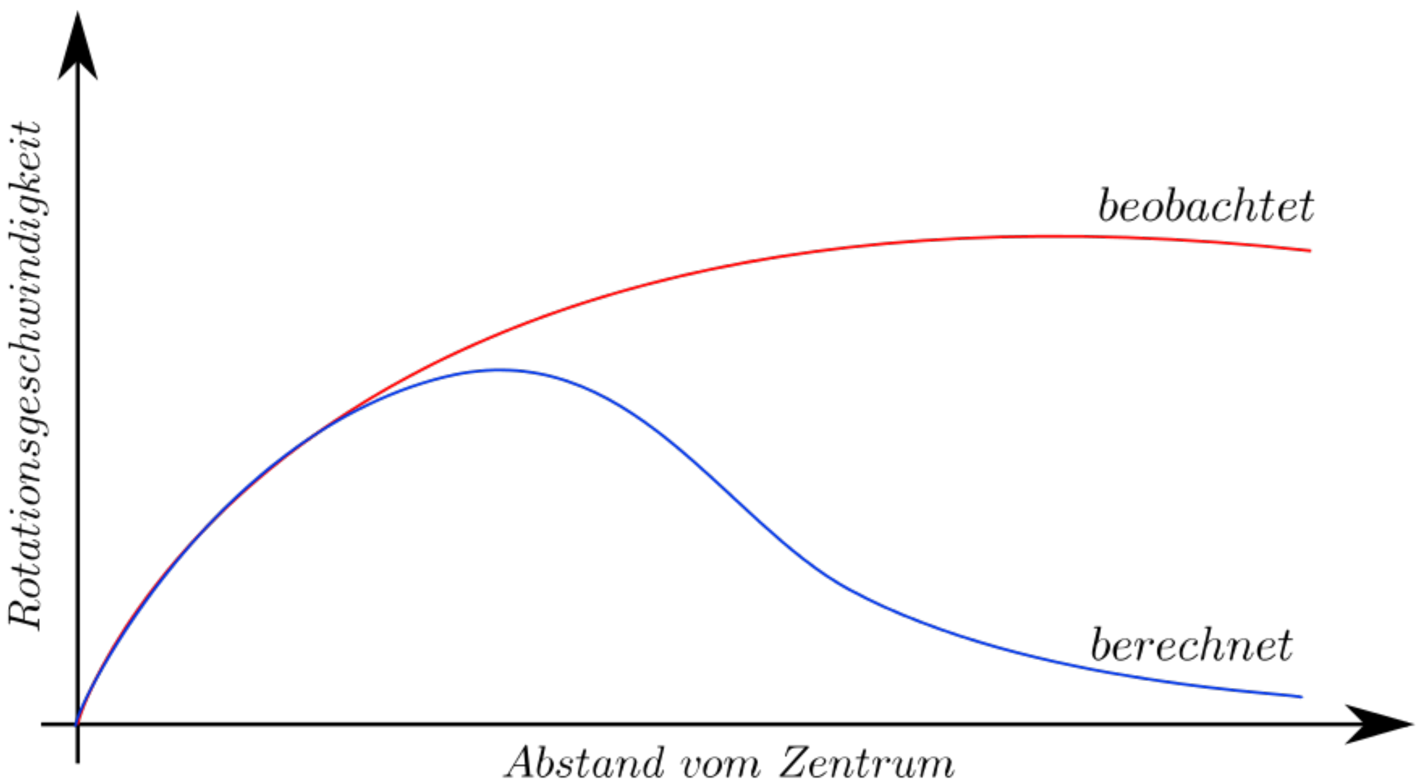
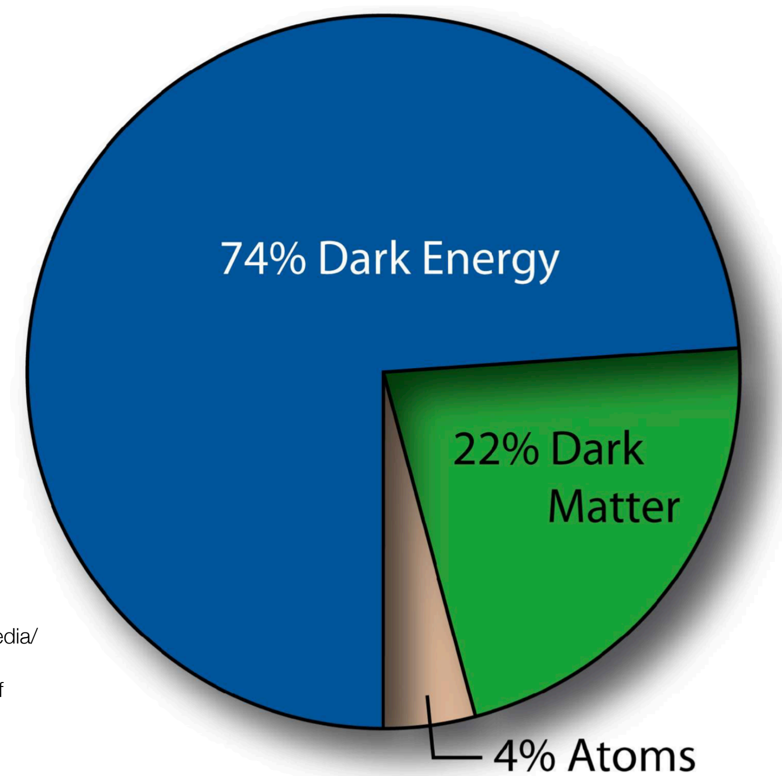
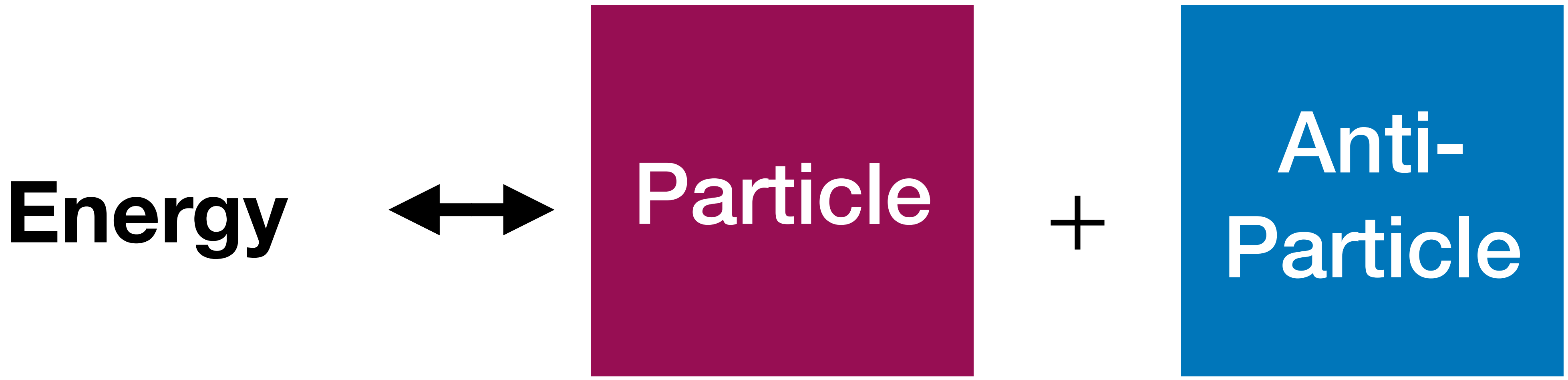


https://www.teilchenphysik.de/multimedia/e73816/e74077/e74079/infoboxContent74091/MNUVortrag.pdf



Open questions of the SM

What's the origin of the baryon asymmetry?



Open questions of the SM

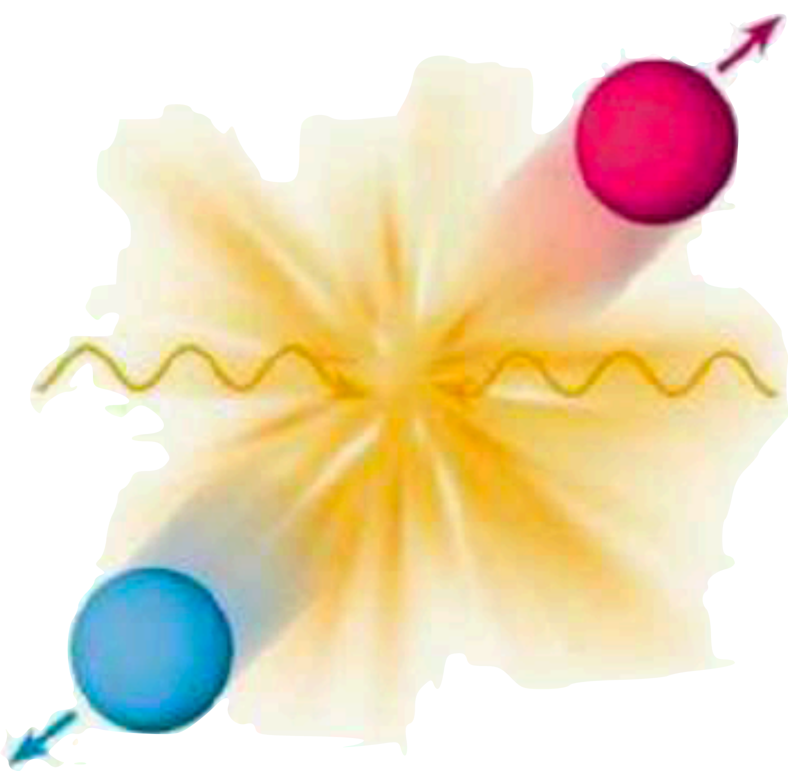
What’s the origin of the baryon asymmetry?

Energy ⟷ Particle + Anti-Particle

Big Bang ⟶ **?**

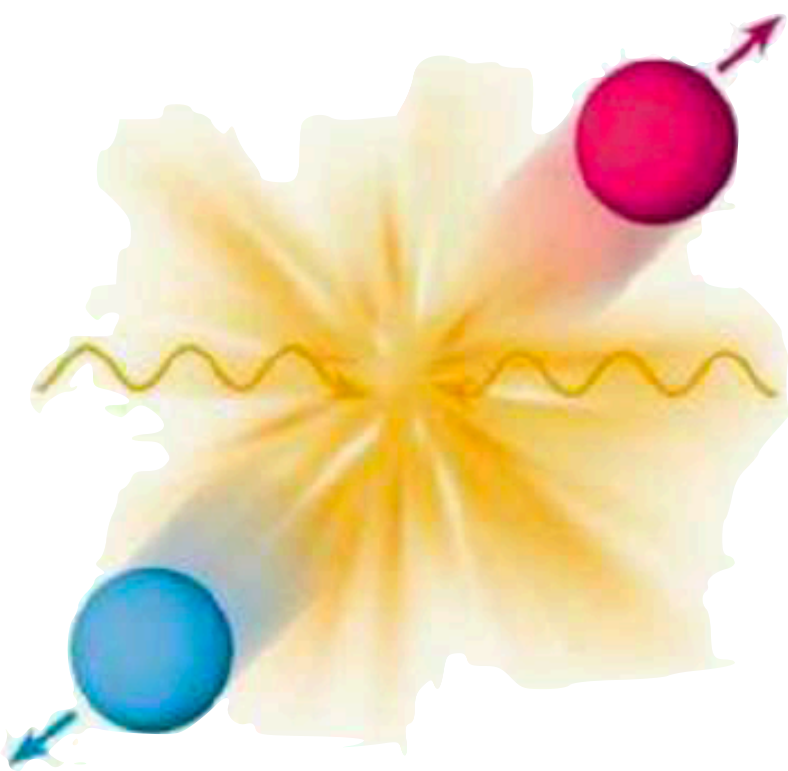
https://de.wikipedia.org/wiki/Spiralgalaxie#/media/Datei:M101_hires_STScI-PRC2006-10a.jpg

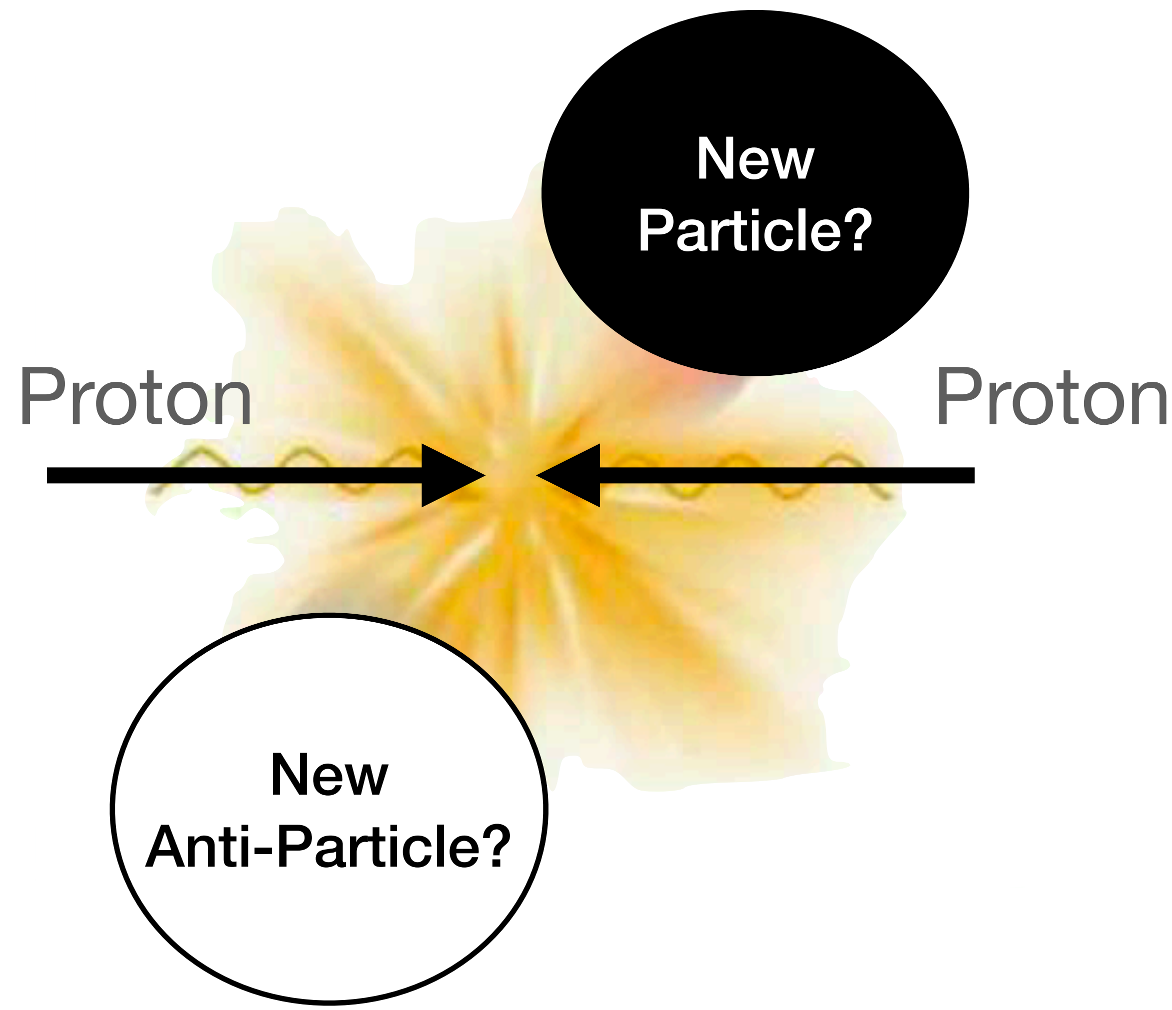
Search for new phenomena



$$E = mc^2$$

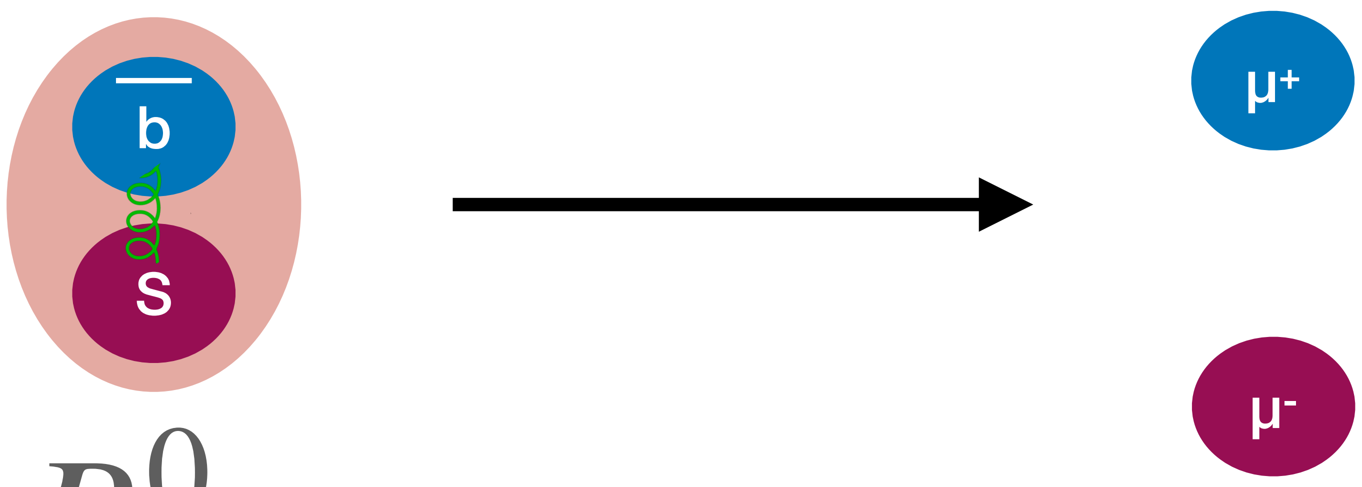
Search for new phenomena





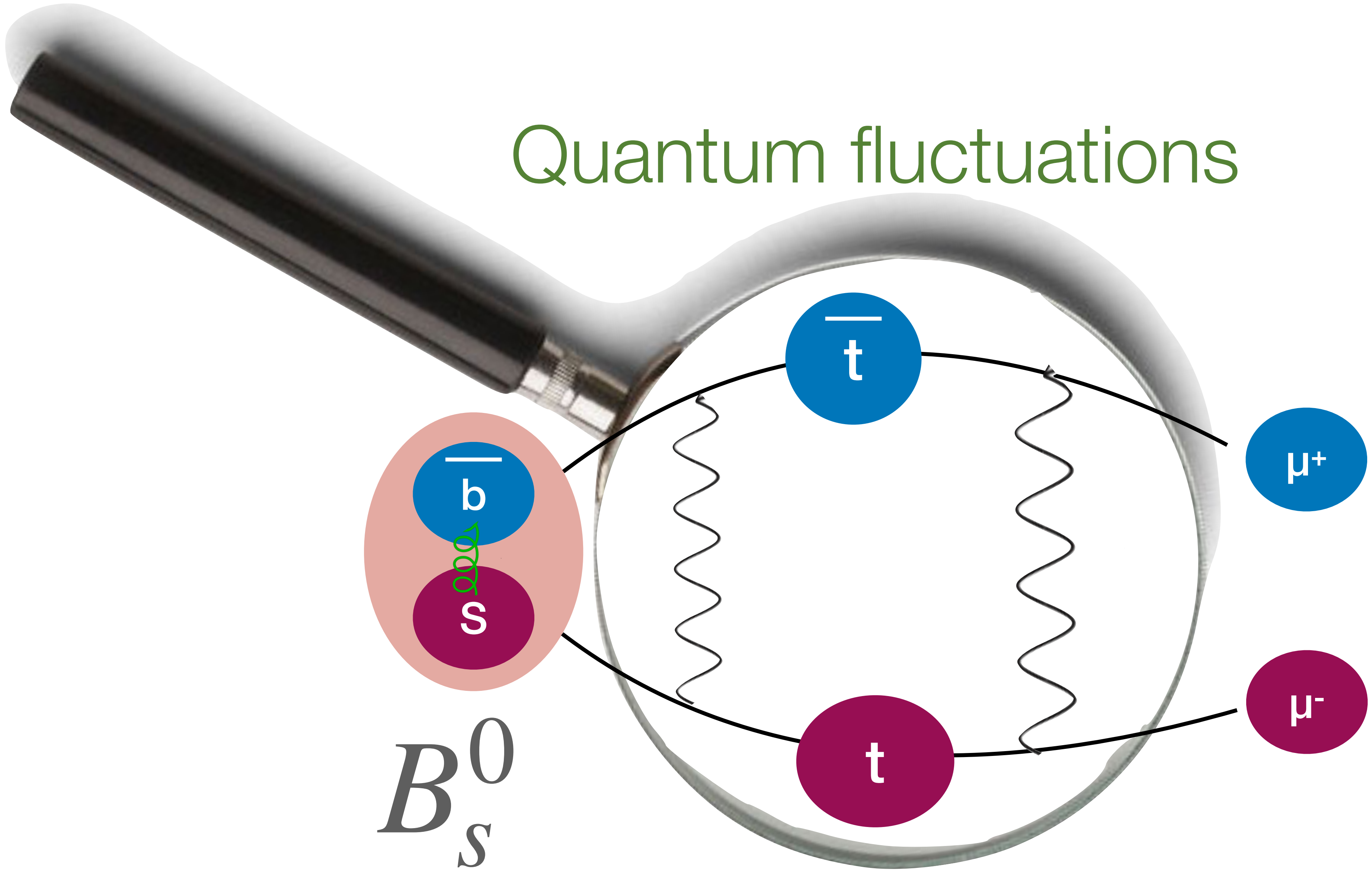
$$E = mc^2$$

Indirect searches in flavour physics



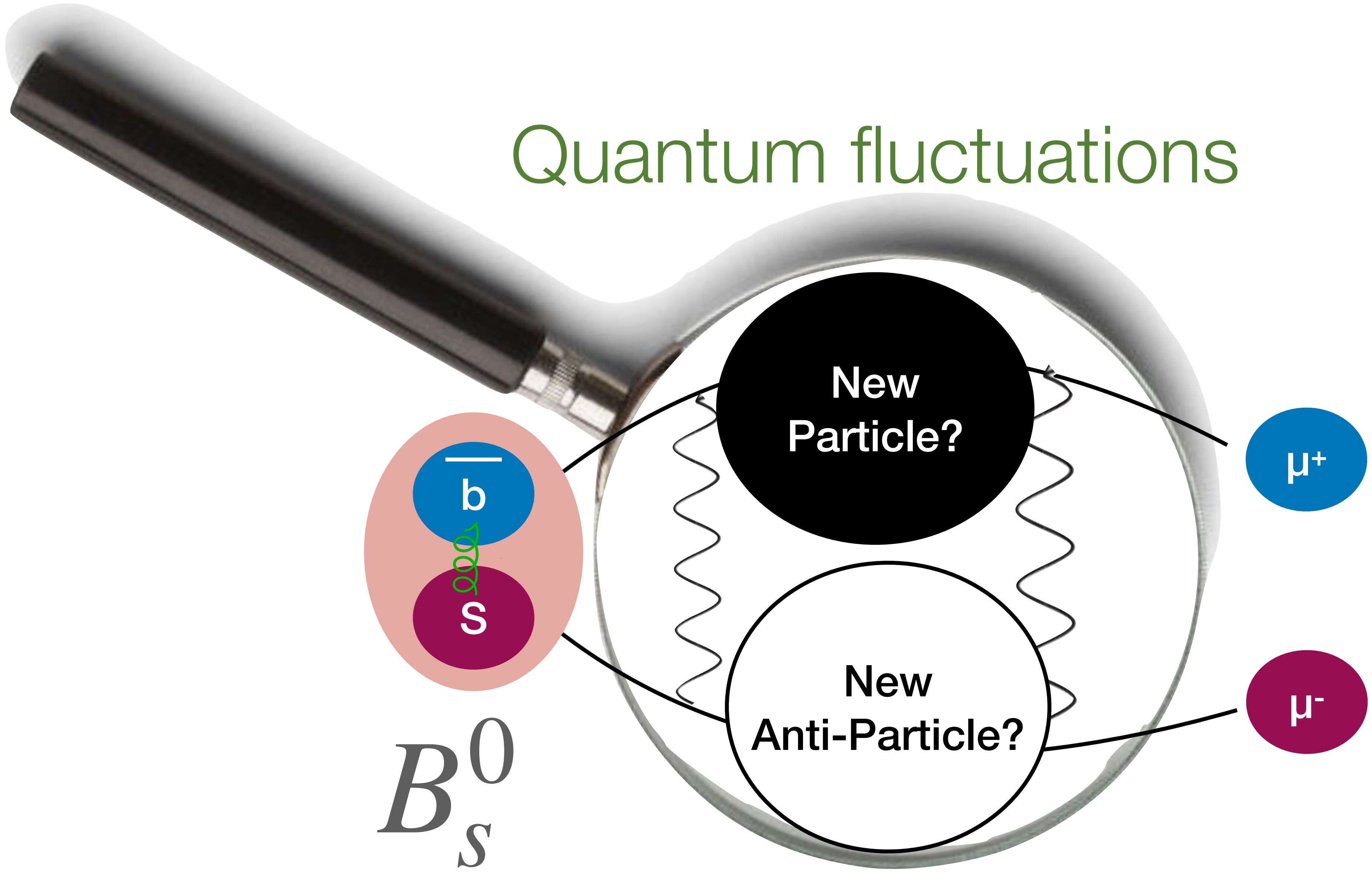
B_s^0

Indirect searches in flavour physics



$$\hbar/2 \leq \Delta t\, \Delta E$$

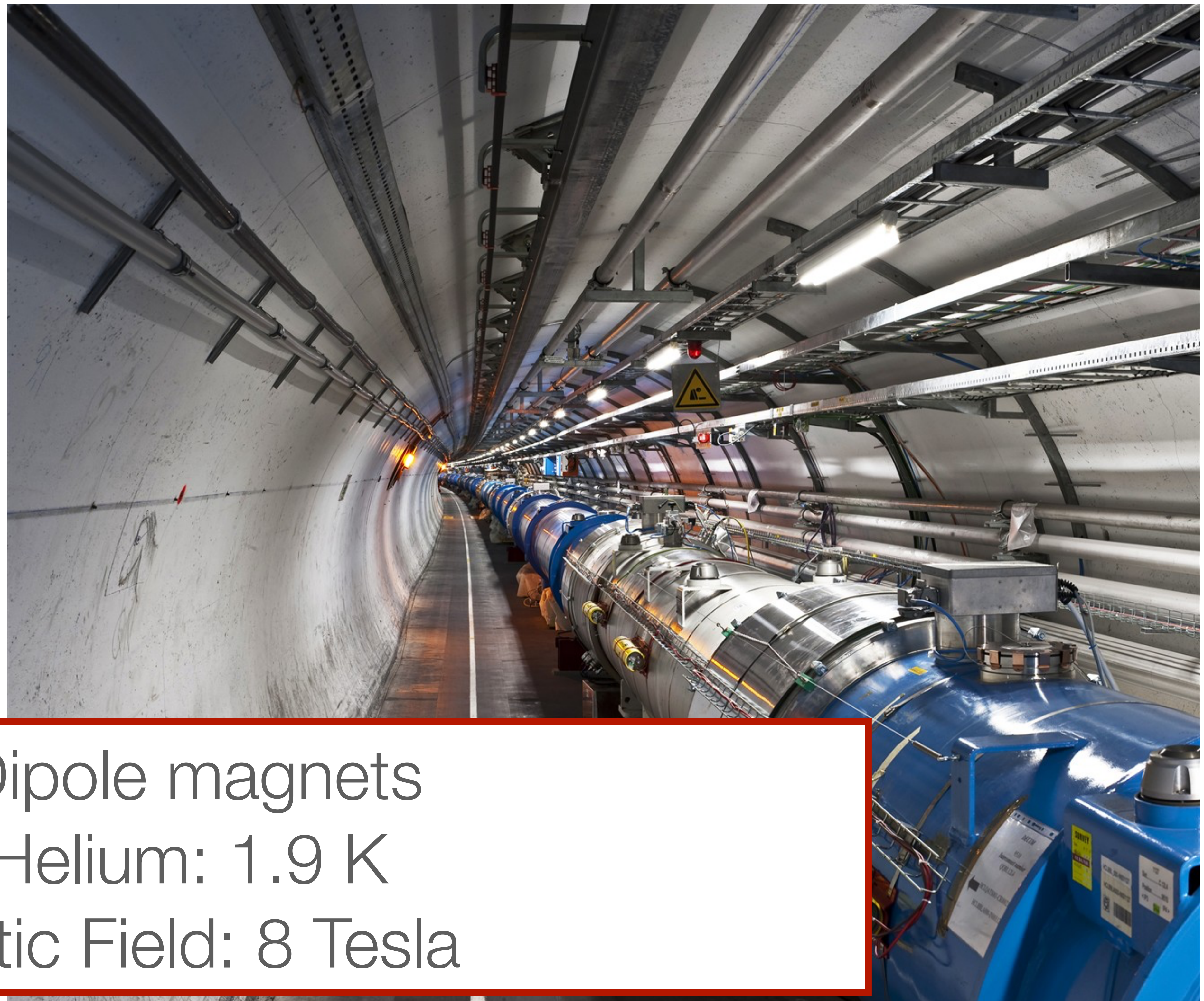
Indirect searches in flavour physics



$$\hbar/2 \leq \Delta t \, \Delta E$$

You want to help?

Large Hadron Collider (LHC)

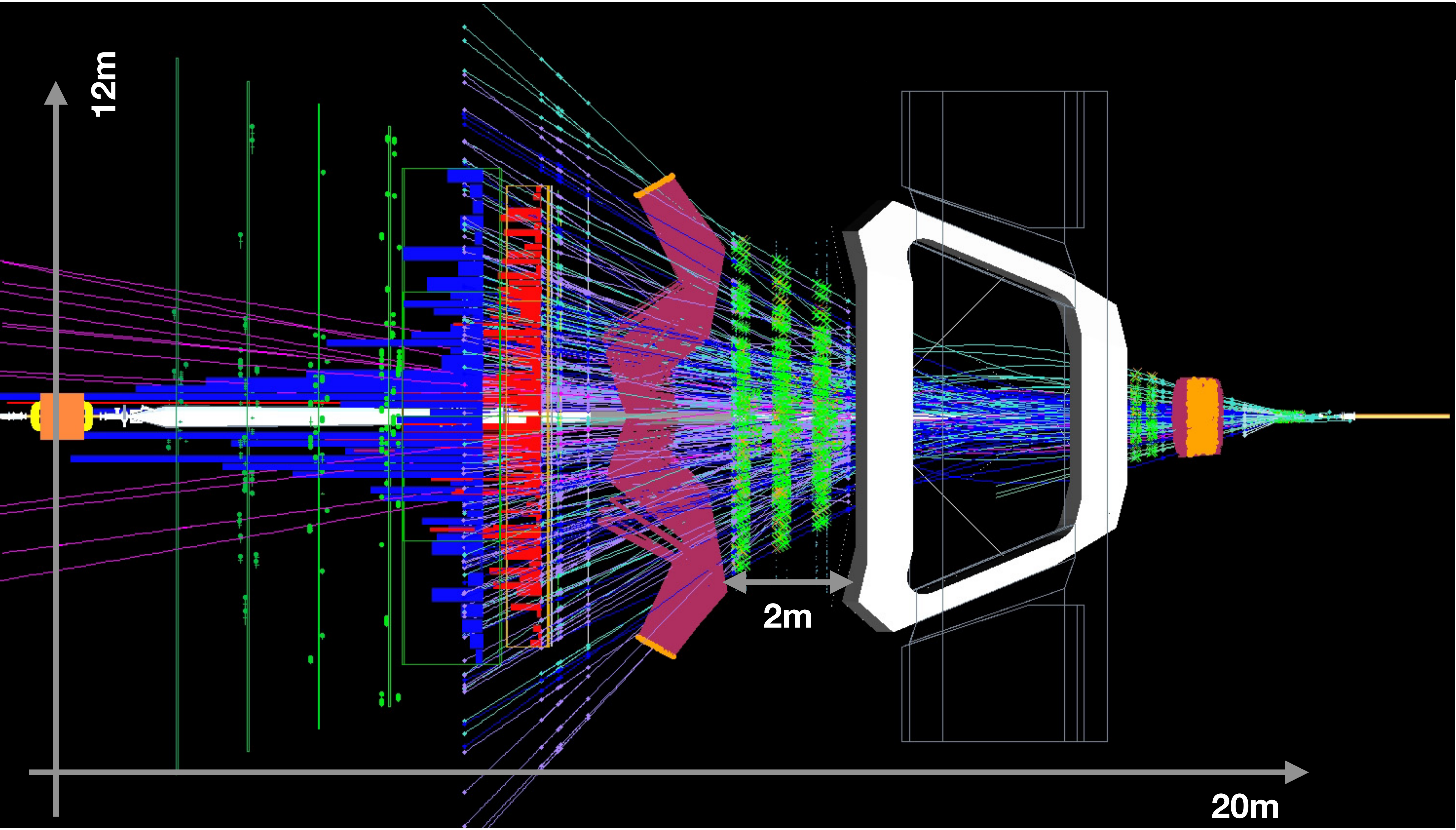


1296 Dipole magnets
Liquid Helium: 1.9 K
Magnetic Field: 8 Tesla

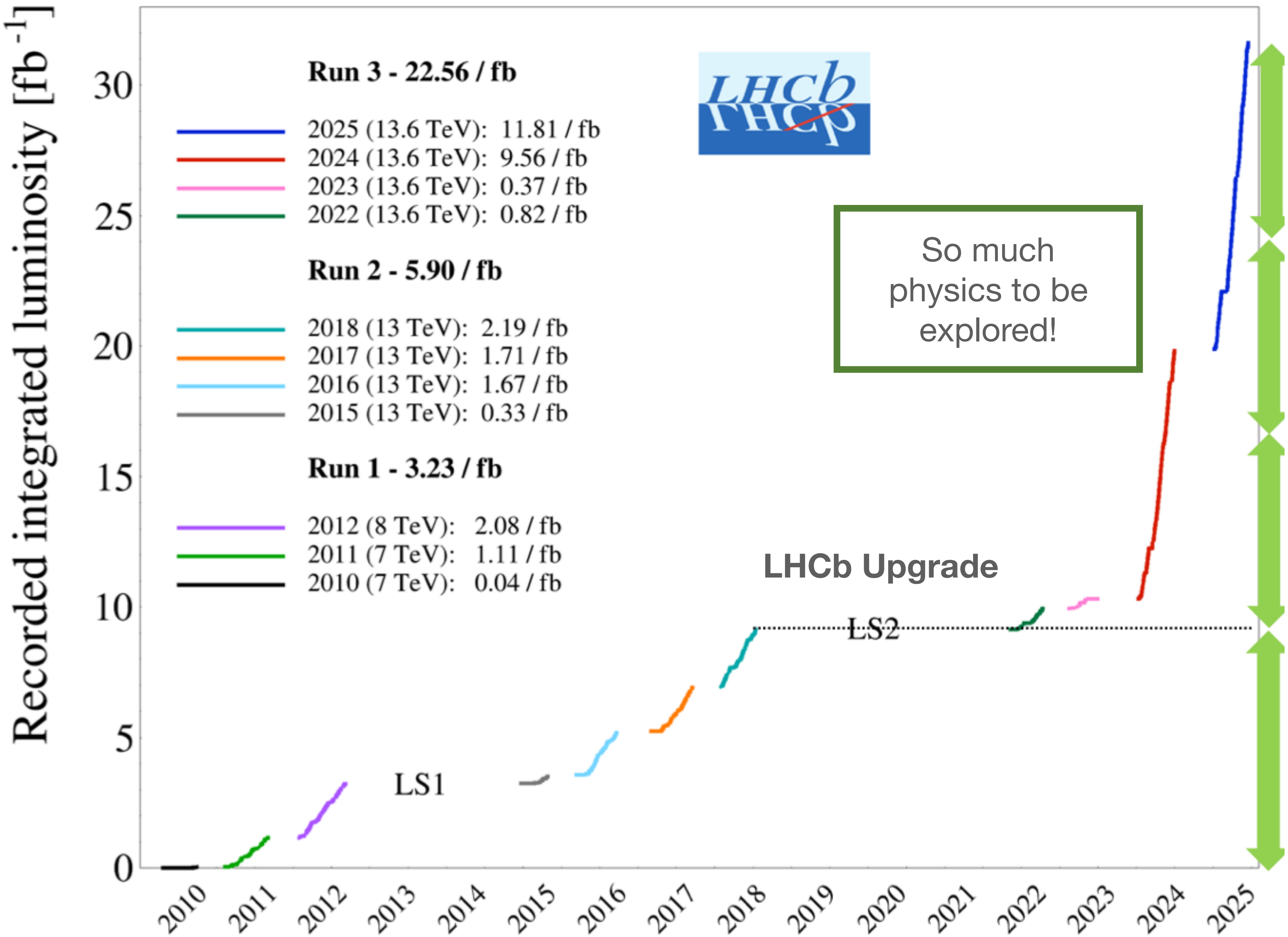
LHCb Detector

https://lhcb.web.cern.ch/lhcb/speakersbureau/html/Material_for_Presentations.html

LHCb Detector



LHCb Detector



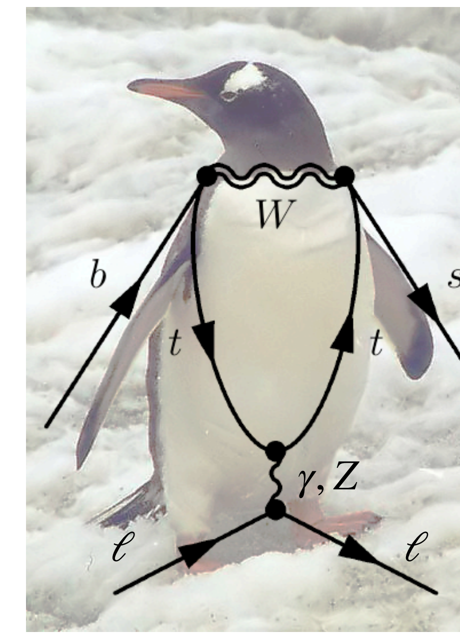
Rare decays

Mick Mulder <mick.mulder@cern.ch>

Rare decays at LHCb

Rare decays proceed through **loop diagrams (e.g. penguin diagrams),**
are **strongly suppressed in Standard Model**
and therefore **extremely sensitive to new heavy particles (e.g. Z', leptoquark)**

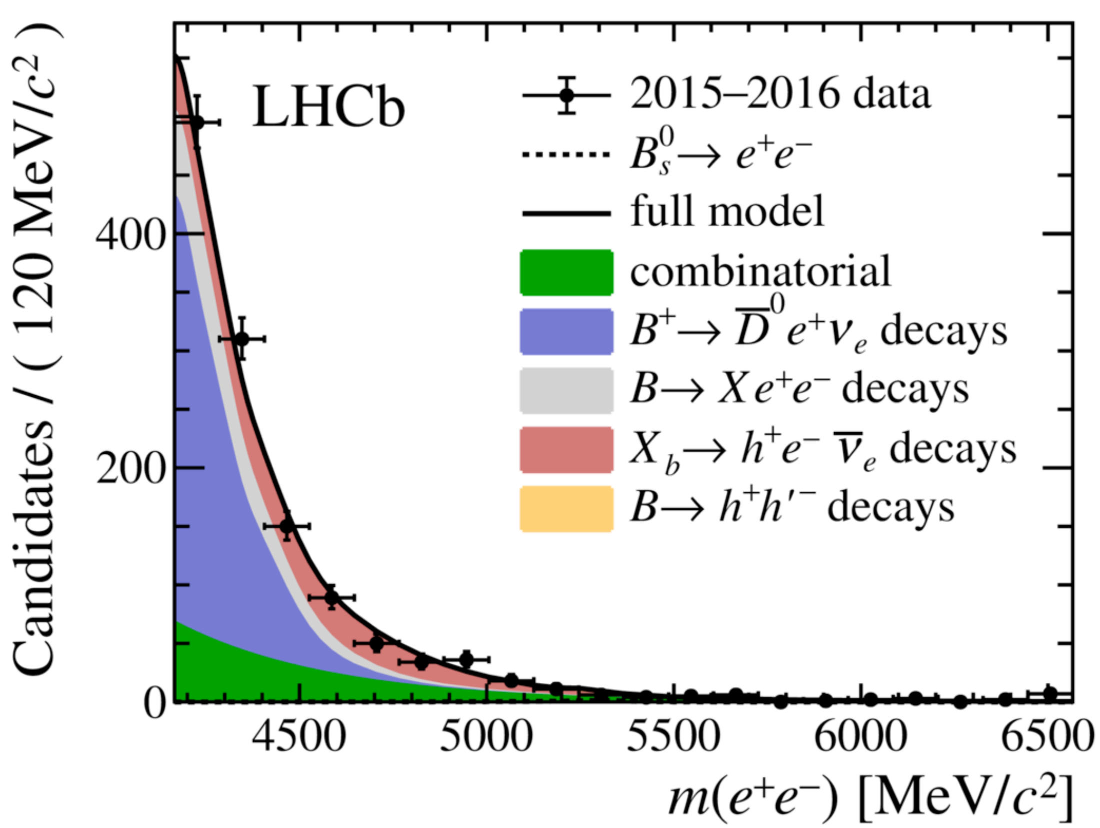
Penguin diagram



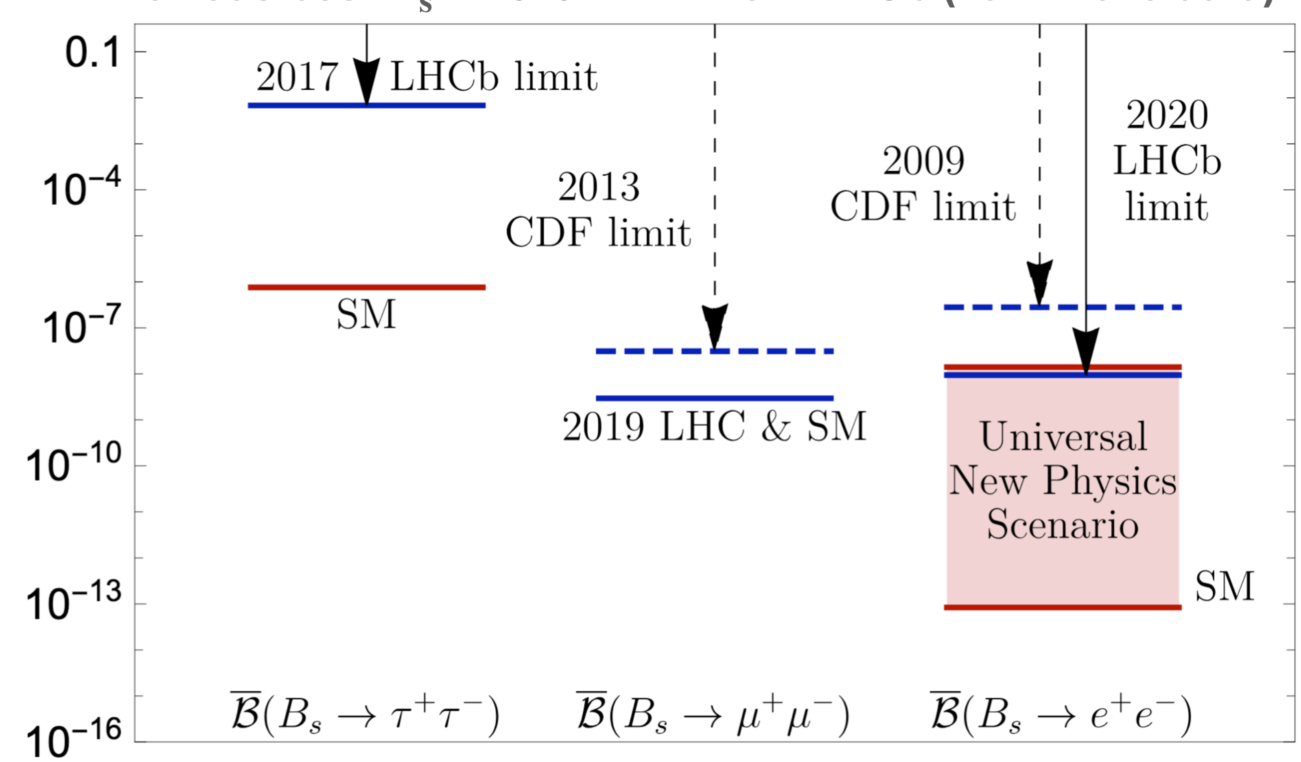
Perfect time to study **rare modes** with **LHCb Upgrade:**
- Collected **>2.5 times as much data in 2024-25** as previous full dataset (2011-18)
- **Another gain of ~2** due to **full software trigger**,
  for **electrons (e.g. $B^0_s \to e^+e^-$) and low momentum tracks (e.g. $\tau \to 3\mu$)**

$B^0_s \to e^+e^-$ **is strongly suppressed** by helicity suppression in SM
→ **any observation** with current data would be **sign of new scalar particles** (e.g. extra Higgs)

$B^0_s \to e^+e^-$ mass fit in 2015-2016 data



Previous best $B^0_s \to e^+e^-$ limit from LHCb (2011-2016 data)



(with only ~1/2 full dataset)

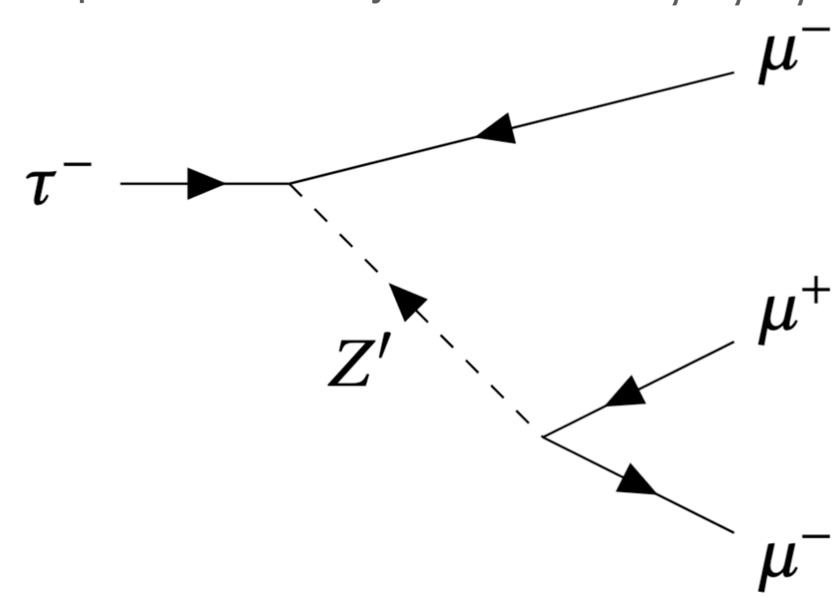
Rare decays at LHCb

Lepton Flavour Violation (LFV) is extremely rare, e.g.
BF($B^+ \to K^+ e^\mp \mu^\pm$) = $O(10^{-50})$ in Standard Model
(only occurring due to neutrino oscillations)

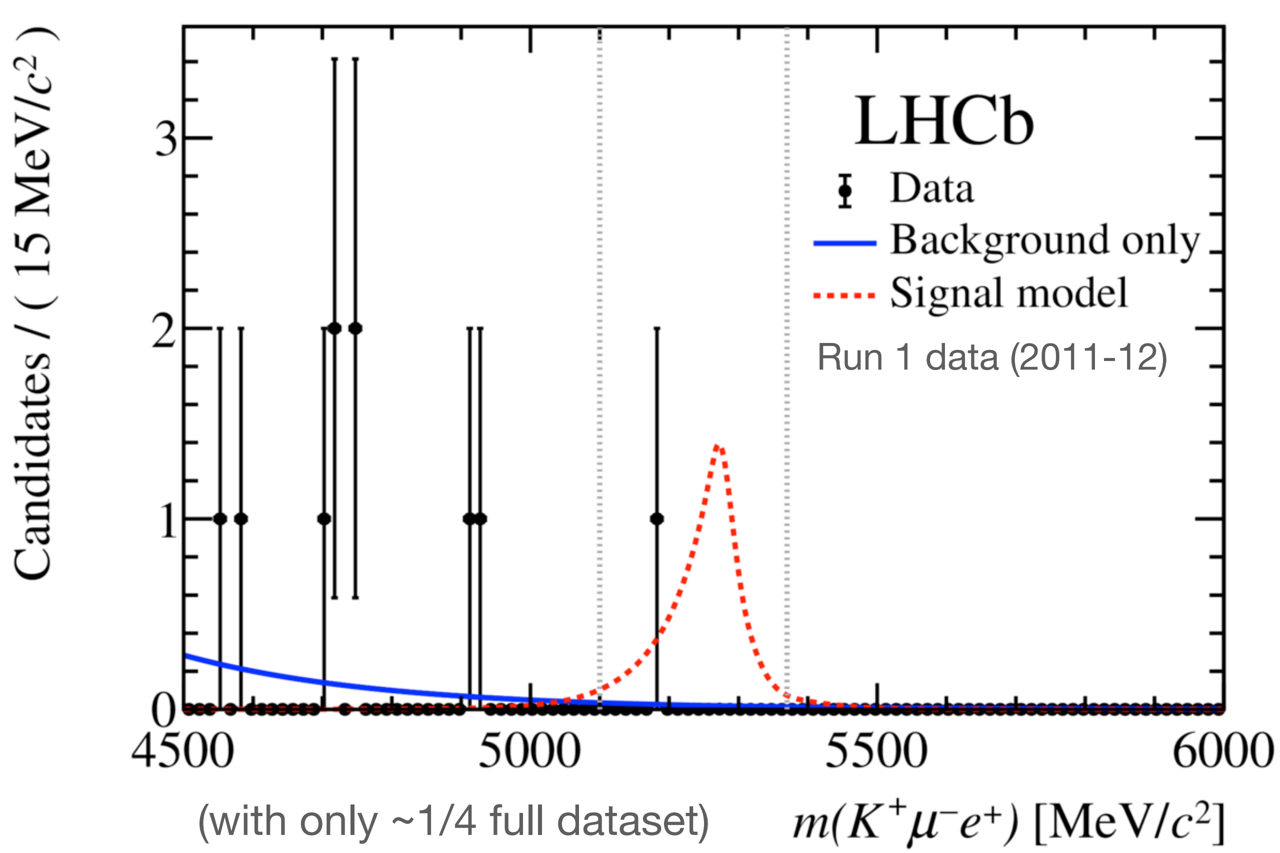
Any observation of such an LFV mode **means New Physics!**

Same profit from LHCb Upgrade as other rare decays:
more data and more sensitive triggers than before

An example of New Physics in $\tau^+ \to \mu^+\mu^+\mu^-$

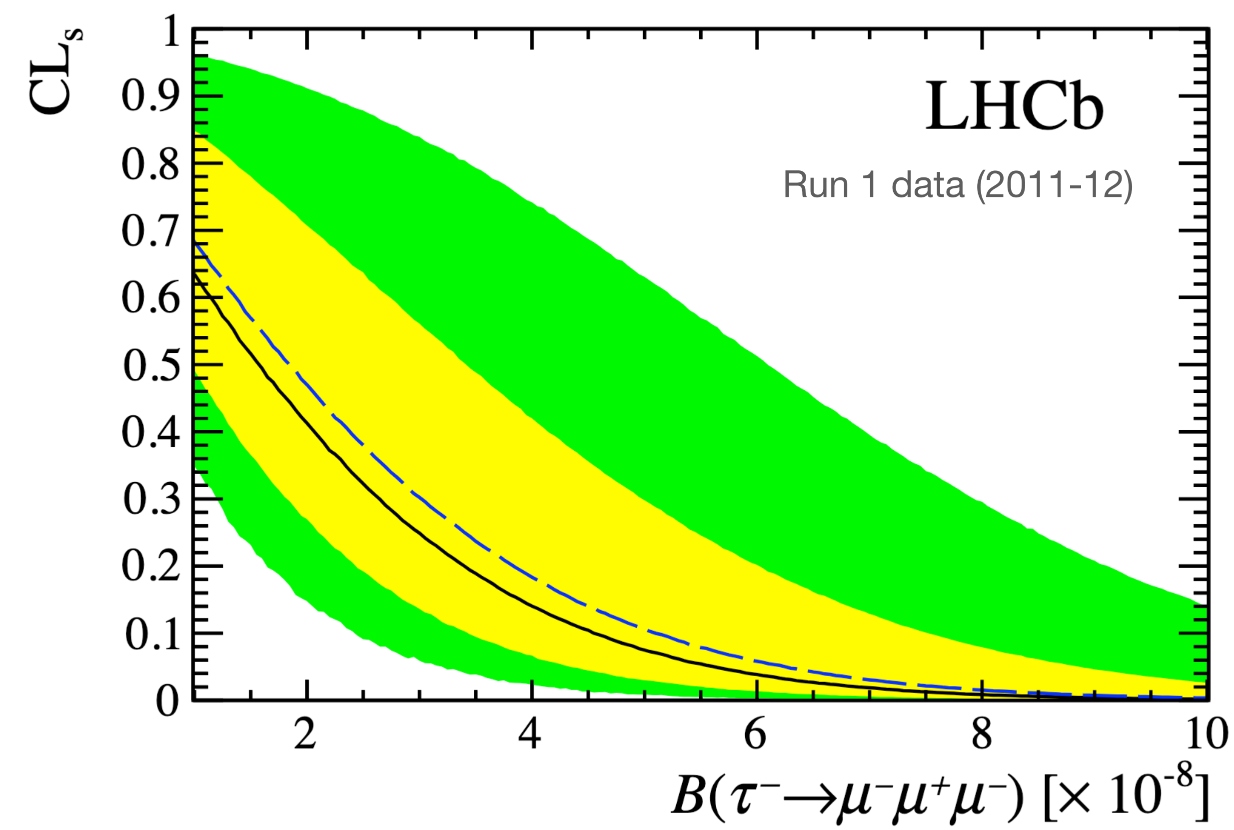


BF($B^+ \to K^+ e^\mp \mu^\pm$) $< 6.4 \cdot 10^{-8}$ at 90% CL



(with only ~1/4 full dataset)

BF($\tau^+ \to \mu^+\mu^+\mu^-$) $< 4.6 \cdot 10^{-8}$ at 90% CL



Rare decays at LHCb

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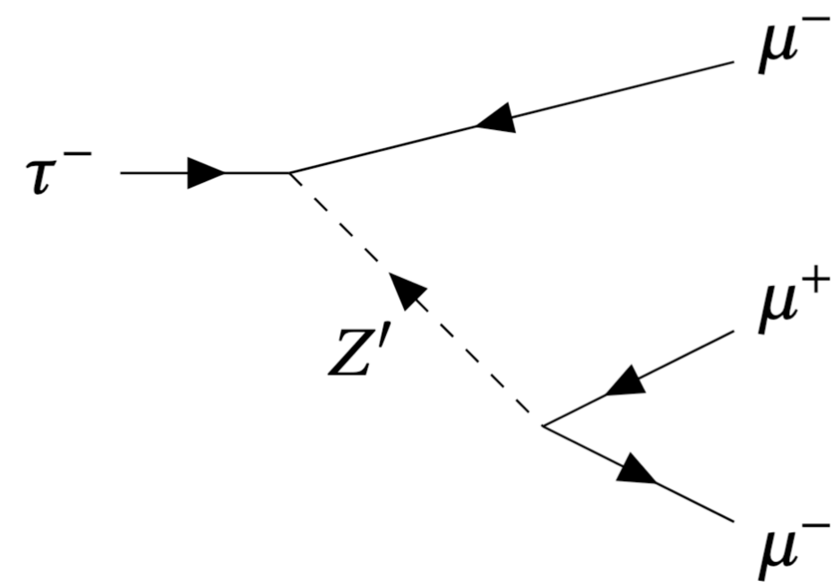

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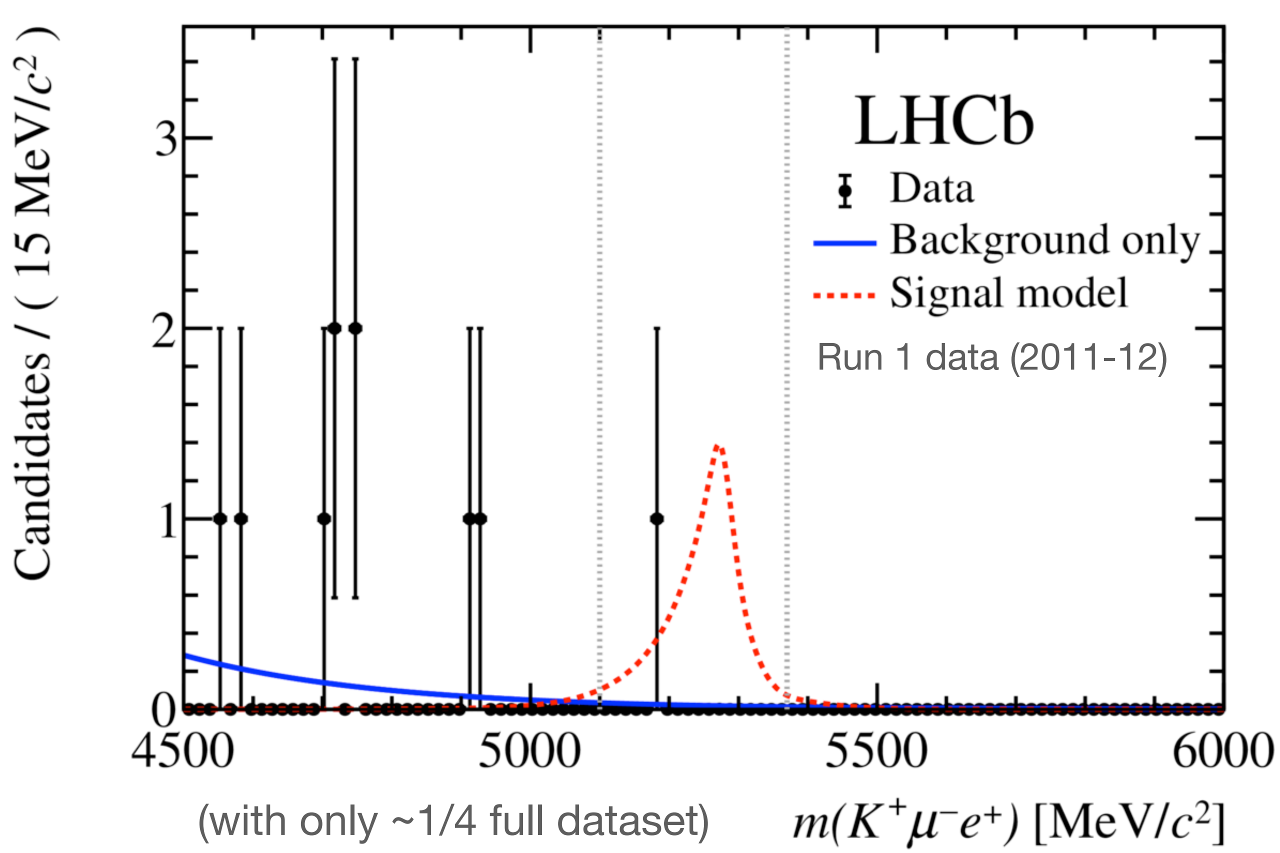


(with only ~1/4 full dataset)

Internships:

- Project 1: Hunting for $\mathbf{B_s^0 \to e^+e^-}$
- Project 2: Search for $\mathbf{B^+ \to K^+e^\mp\mu^\pm}$
- Project 3: Analysis of $\tau^+ \to \mu^+\mu^+\mu^-$

All with Run3 Data!

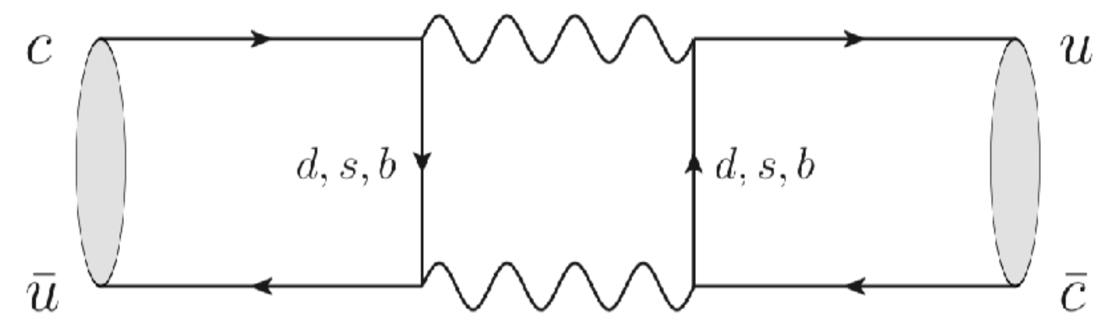
Charm Physics

Dominik Mitzel <dominik.mitzel@tu-dortmund.de>

Charm Physics

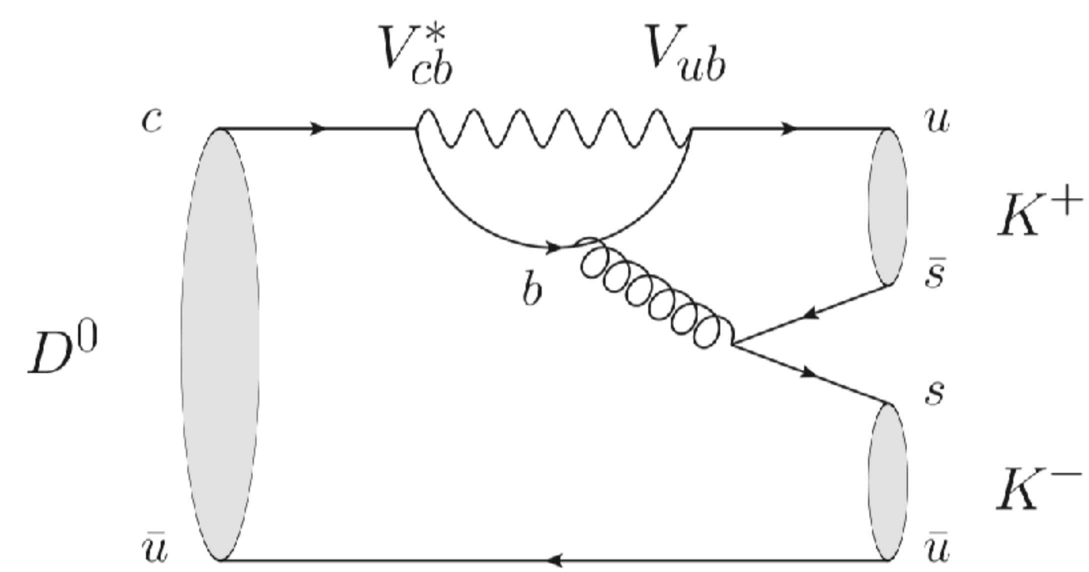
Unique:

- Only bound HF system made of up-type quarks, complementary sensitivity to BSM couplings wrt to K and $B_{(s)}$ decays
- $m_c \sim 1.3$ GeV/c^2 makes theoretical predictions hard, but allows for insights into QCD from a unique perspective



Discovery tool:

- All processes involving quantum-loops are highly suppressed in the SM (CKM + GIM)
    - Charm meson oscillation probability very low ($x, y \sim \mathcal{O}(10^{-3})$)
    - CP violating effects tiny ($\lesssim \mathcal{O}(10^{-3})$)
    - Rare decays extremely rare ($\lesssim \mathcal{O}(10^{-9})$)



Room for new physics to show up!

Charm Physics

- CPV in the charm system has only been observed few years ago in the difference of asymmetries of two decays

Run1+Run2

PRL 122 (2019) 211803

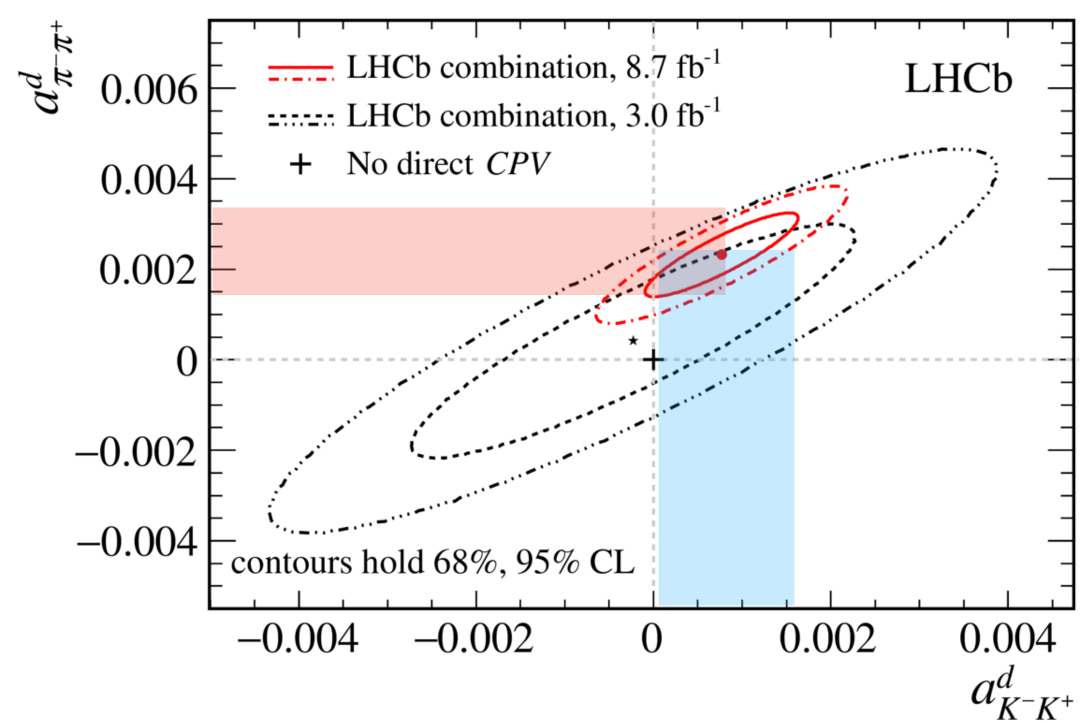
$$a^d_{CP}(K^+K^-) = [7.7 \pm 5.7] \times 10^{-4}$$

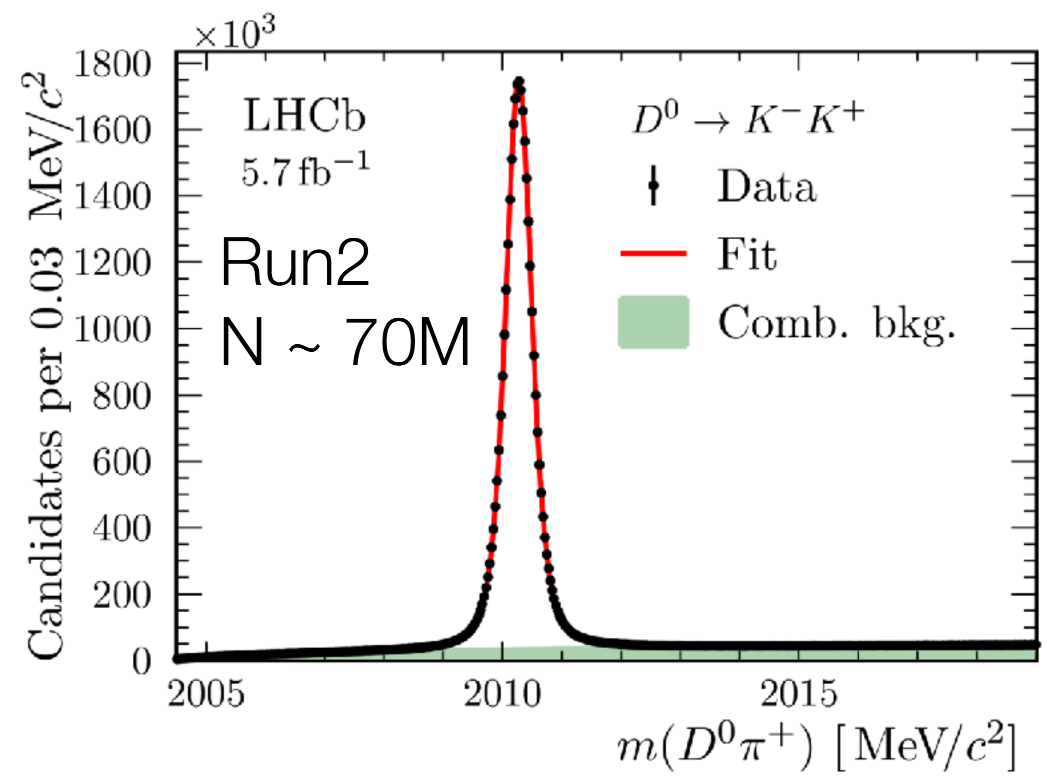
$$a^d_{CP}(\pi^+\pi^-) = [23.2 \pm 6.1] \times 10^{-4}$$

- First evidence (3.8σ) of CPV in $D^0 \to \pi^+\pi^-$! Is this compatible with the SM? Highly debated! We need to understand better!

Project 1: Can we use new strategies to measure CPV in charm decays with Run 3?

PRL 131 (2023) 091802





Charm Physics

- FCC-ee: Proposed new large-scale (~90km) accelerator @CERN

Attribute	$\Upsilon(4S)$	pp	Z
All hadron species		✓	✓
High boost		✓	✓
Enormous production cross-section	✓	✓	
Negligible trigger losses	✓		✓
High geometrical acceptance	✓	✓	✓
Low backgrounds	✓		✓
Flavour-tagging power	✓		✓
Initial-energy constraint	✓		(✓)
Production of polarised baryons		(✓)	✓

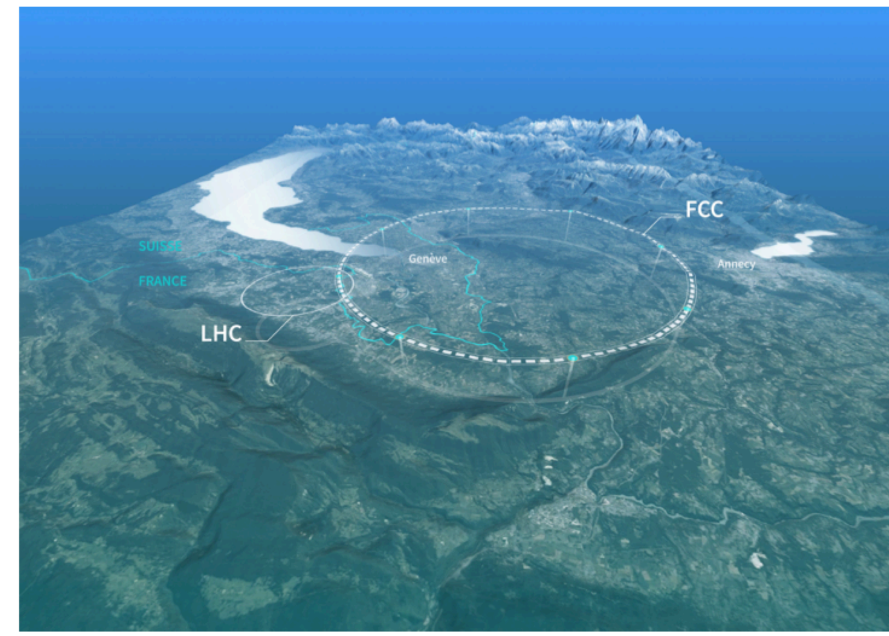
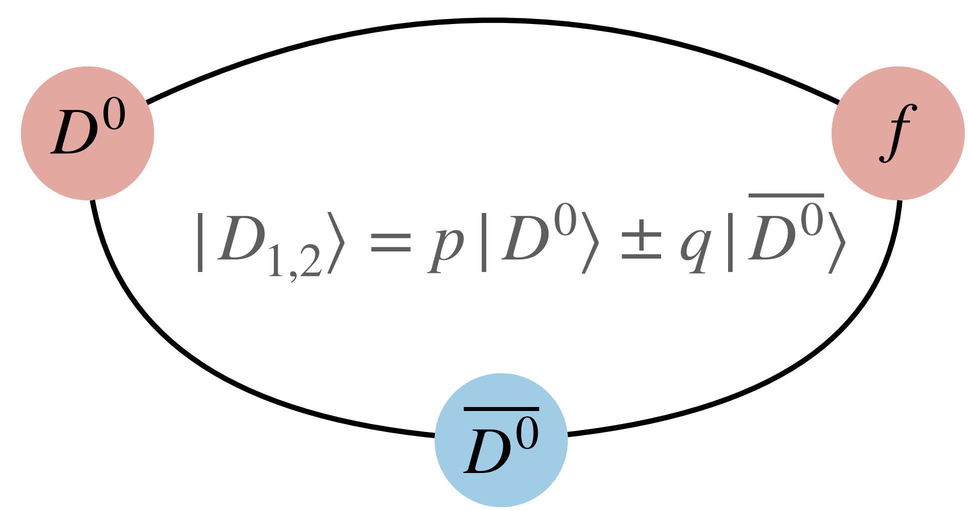


Image: CERN

- Great prospects to make flavour physics at FCC-ee, many opportunities yet unexplored

Project 2: How well can charm mixing be measured at FCC-ee? Collaboration with CERN



LHCb QCD & astro particle physics

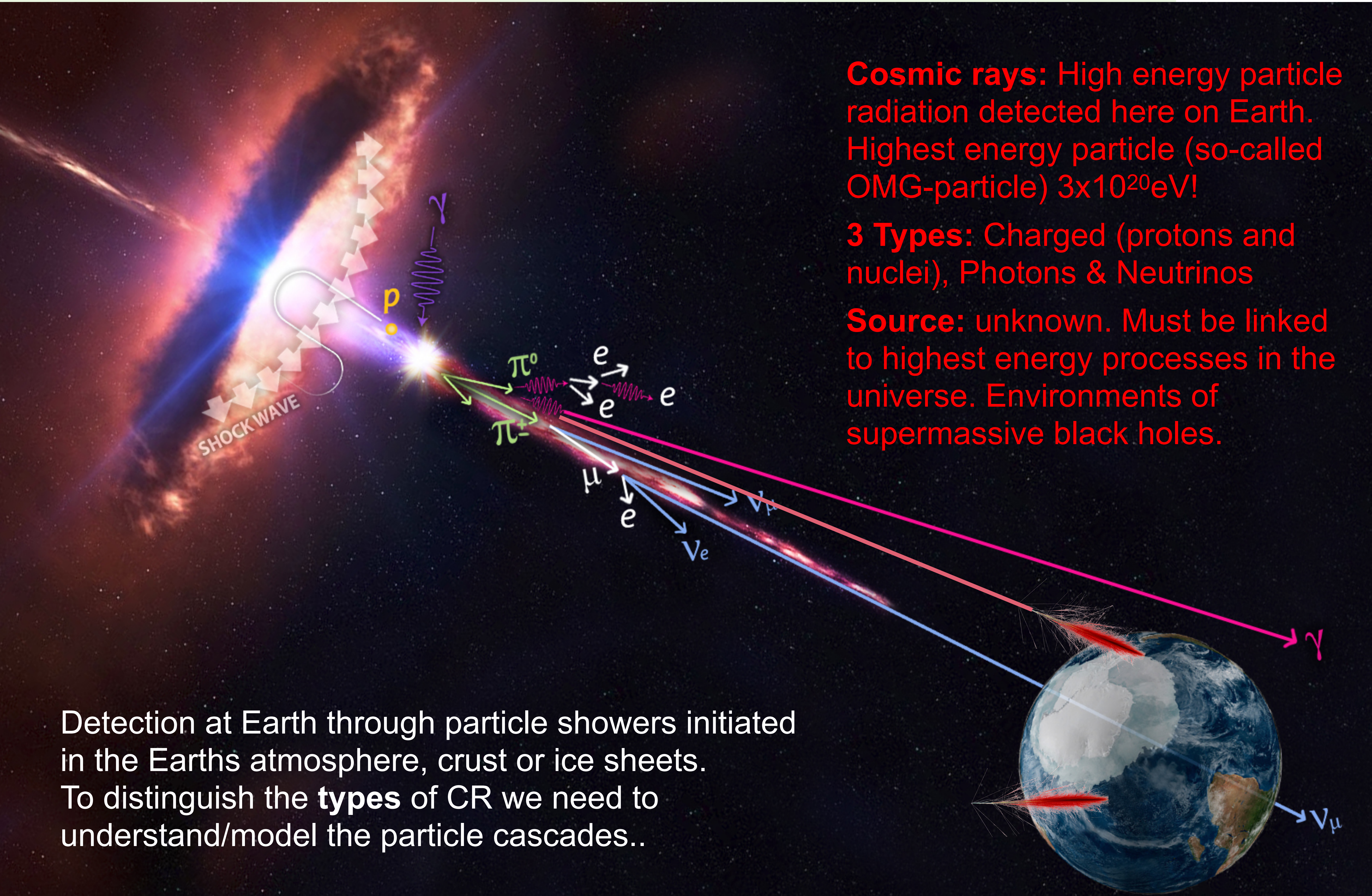
Felix Riehn <felix.riehn@tu-dortmund.de>

The universe at ultra-high energy

Cosmic rays: High energy particle radiation detected here on Earth. Highest energy particle (so-called OMG-particle) $3x10^{20}$eV!

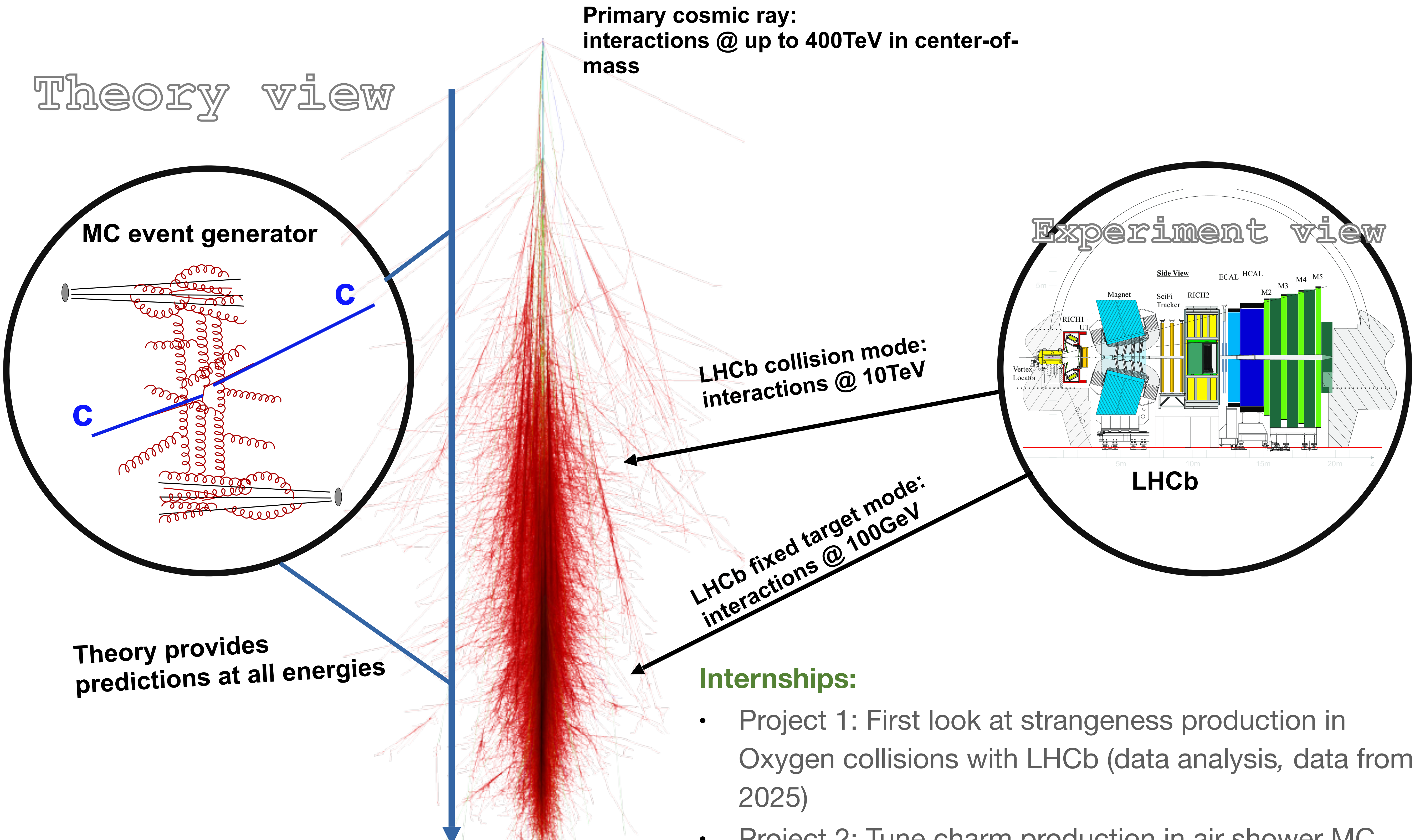
3 Types: Charged (protons and nuclei), Photons & Neutrinos

Source: unknown. Must be linked to highest energy processes in the universe. Environments of supermassive black holes.



Detection at Earth through particle showers initiated in the Earths atmosphere, crust or ice sheets.
To distinguish the **types** of CR we need to understand/model the particle cascades..

Probing interactions in air showers



Internships:

- Project 1: First look at strangeness production in Oxygen collisions with LHCb (data analysis, data from 2025)
- Project 2: Tune charm production in air shower MC event generators to LHCb data (phenomenology)

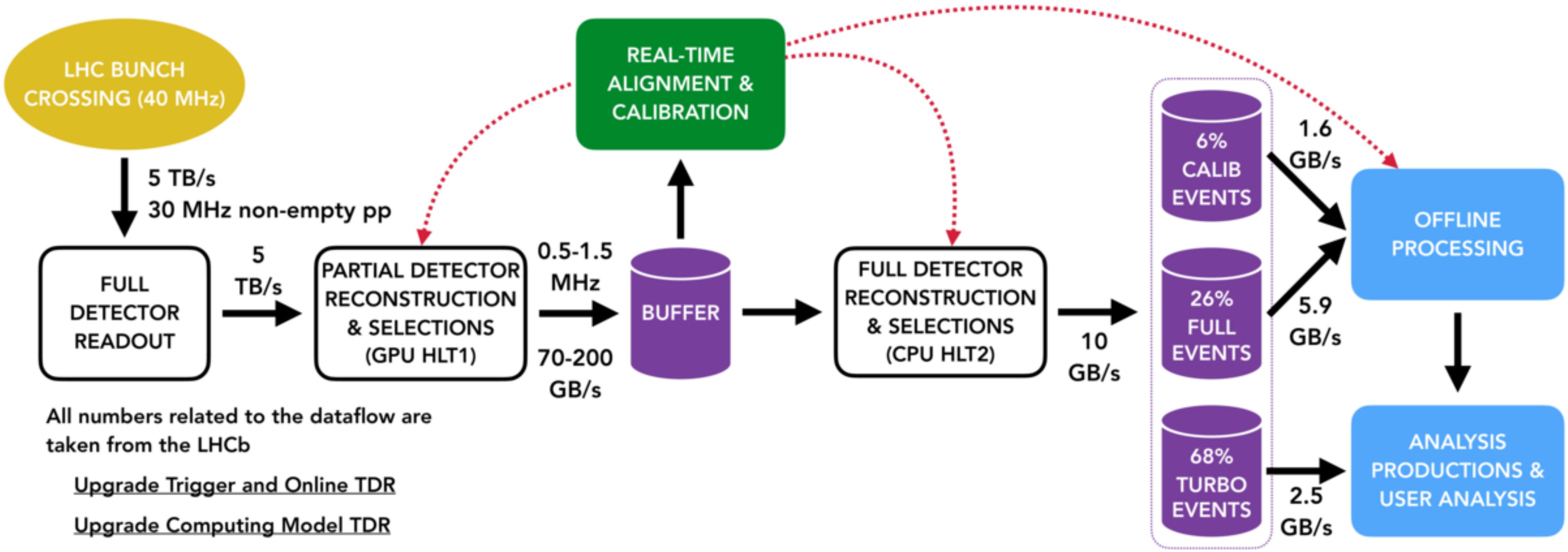
Real Time Analysis (RTA)

Alessandro Scarabotto <alessandro.scarabotto@cern.ch>

Real Time Analysis (RTA)

30 million proton-proton collisions per second at LHCb → 5 TB/s of data

Select events via the trigger with a Real Time Analysis!



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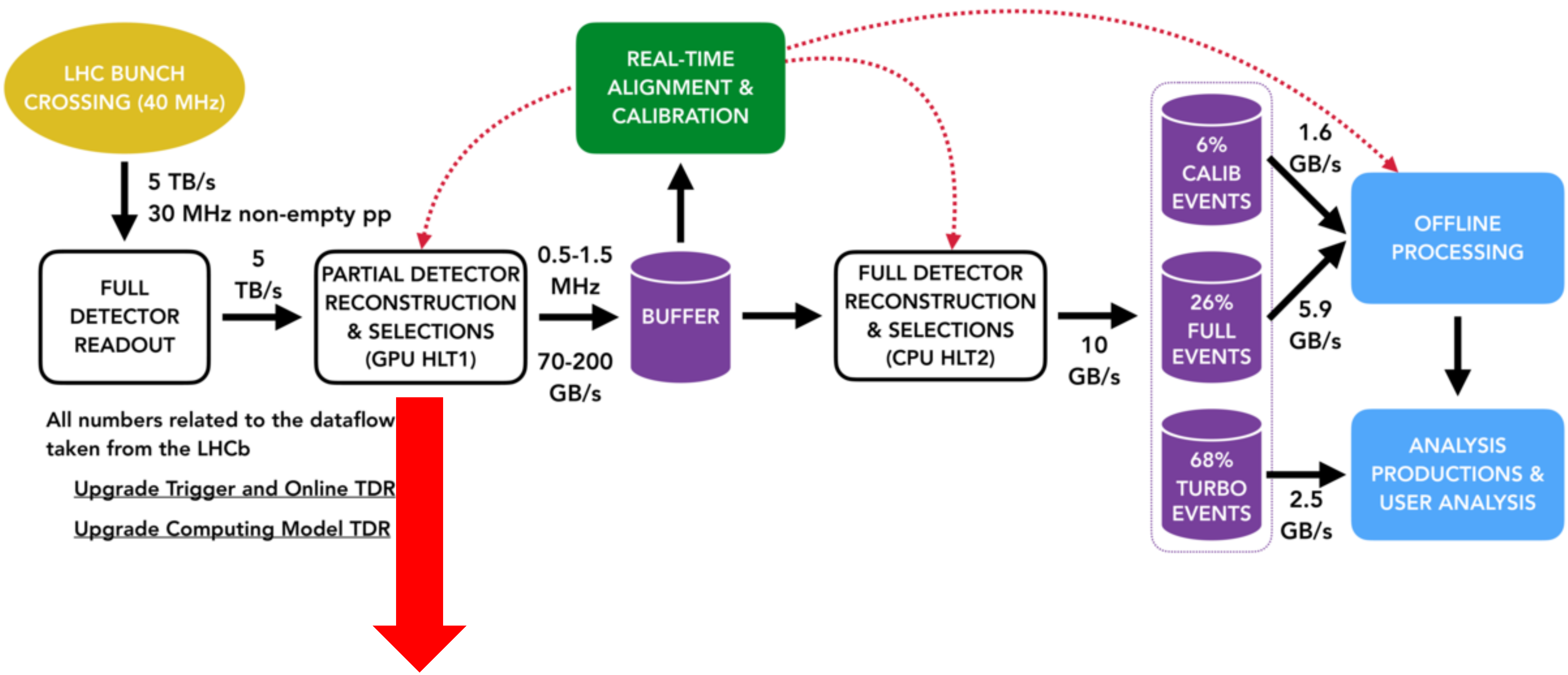

First level trigger (HLT1) developed on GPUs with a fast partial reconstruction and selection

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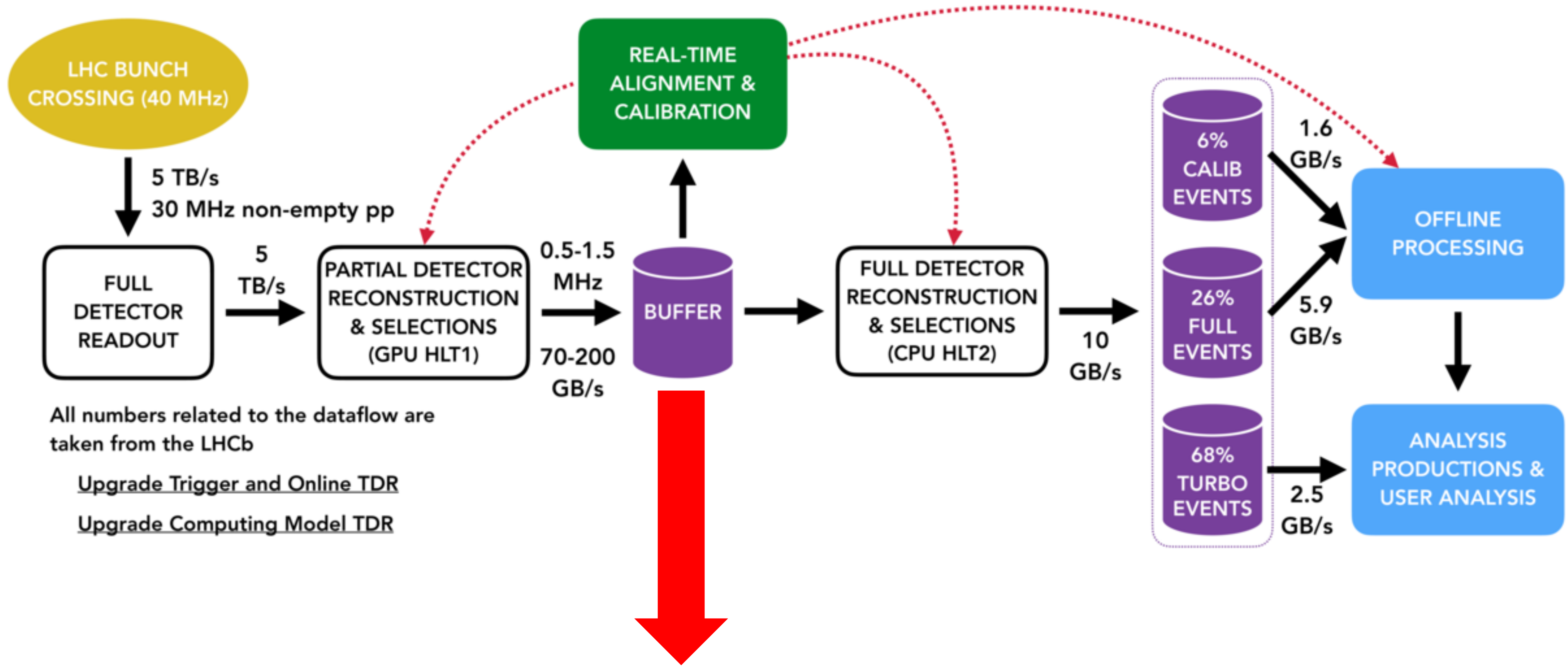

Real time alignement and calibration of the detector

Real Time Analysis (RTA)

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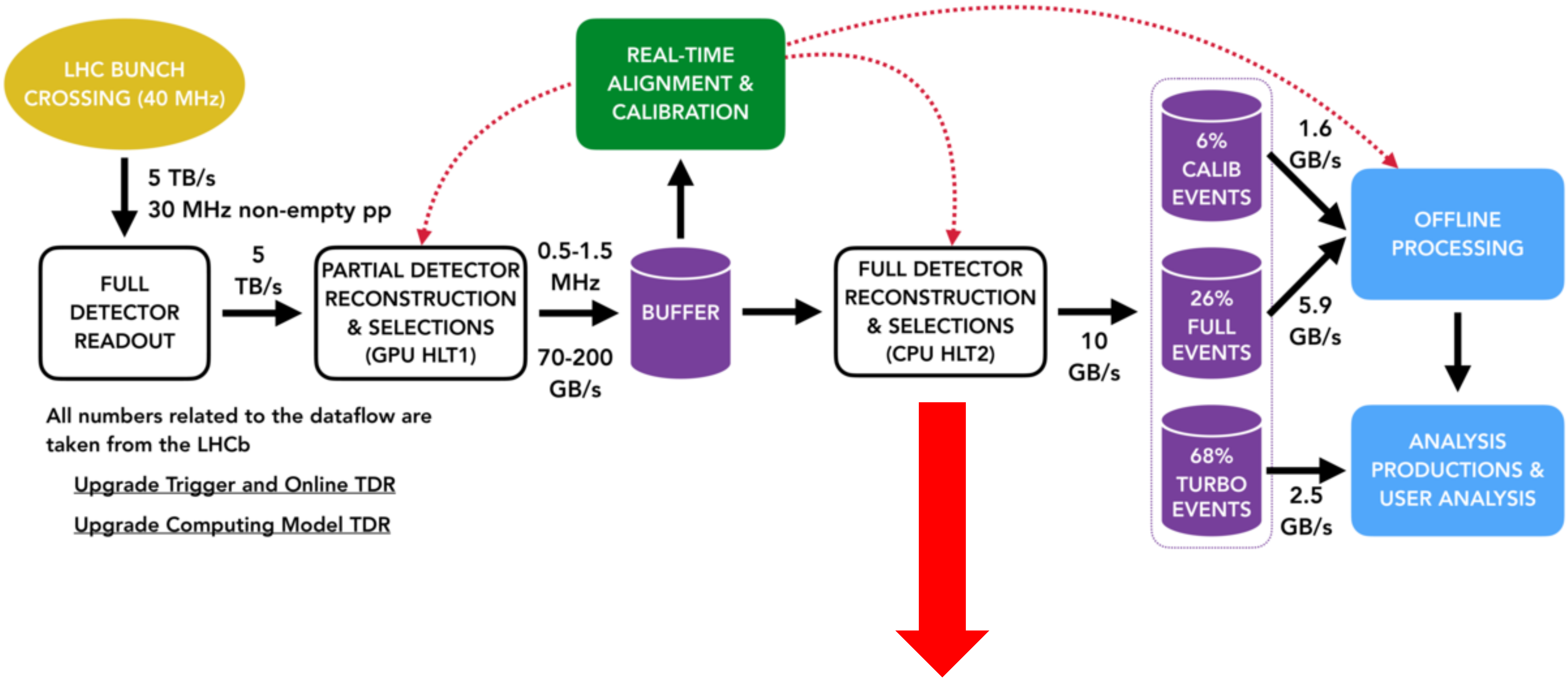

Final selection with best possible reconstruction developed on CPU (HLT2)

Real Time Analysis (RTA)

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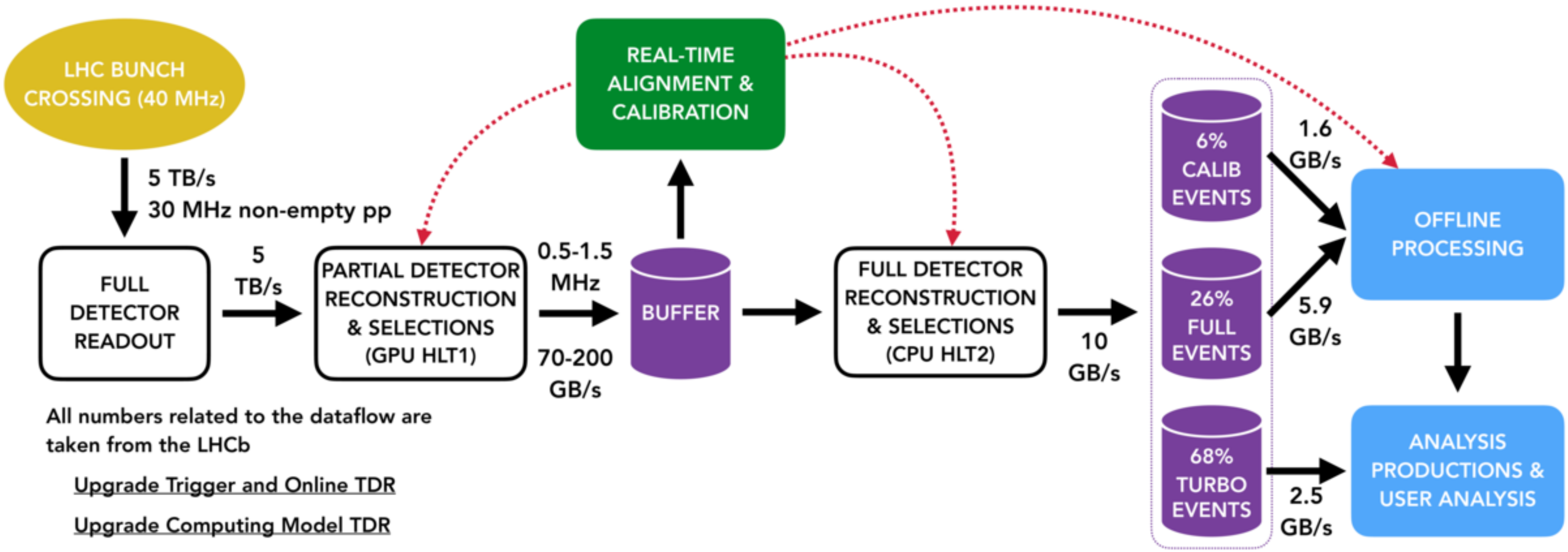
Select events via the trigger with a Real Time Analysis!



The LHCb TU Dortmund group is involved in all 3 aspects of the trigger!

Real Time Analysis (RTA)

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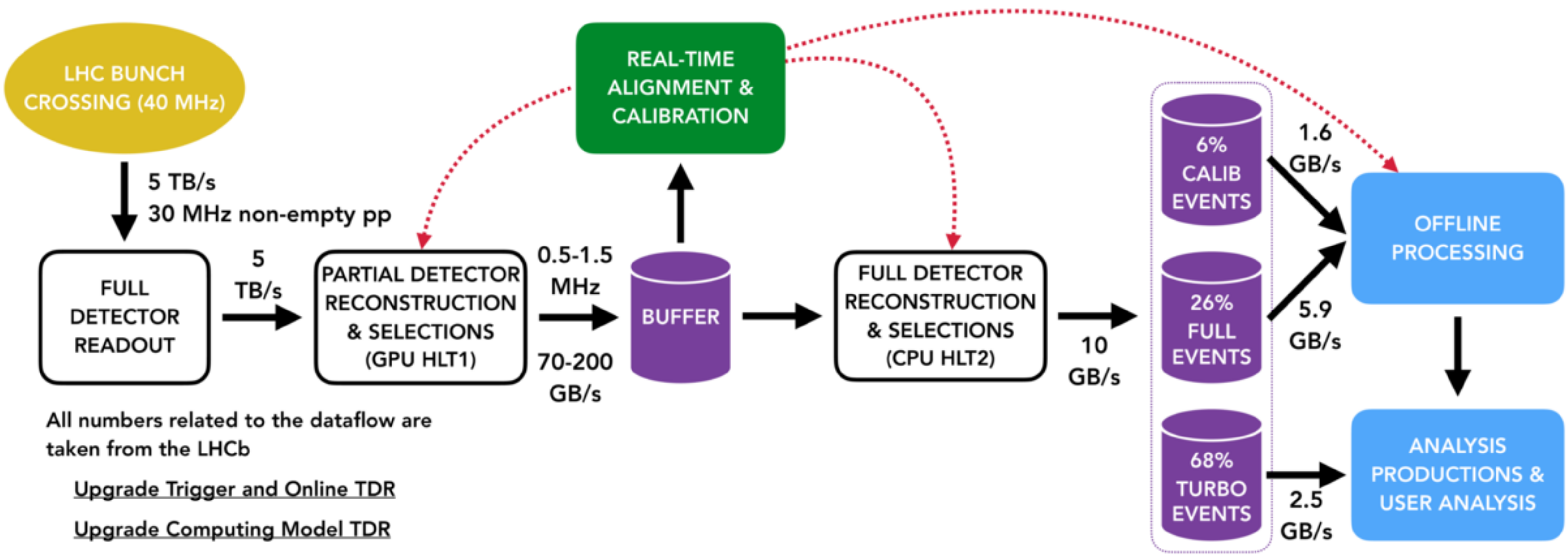


Our main questions:

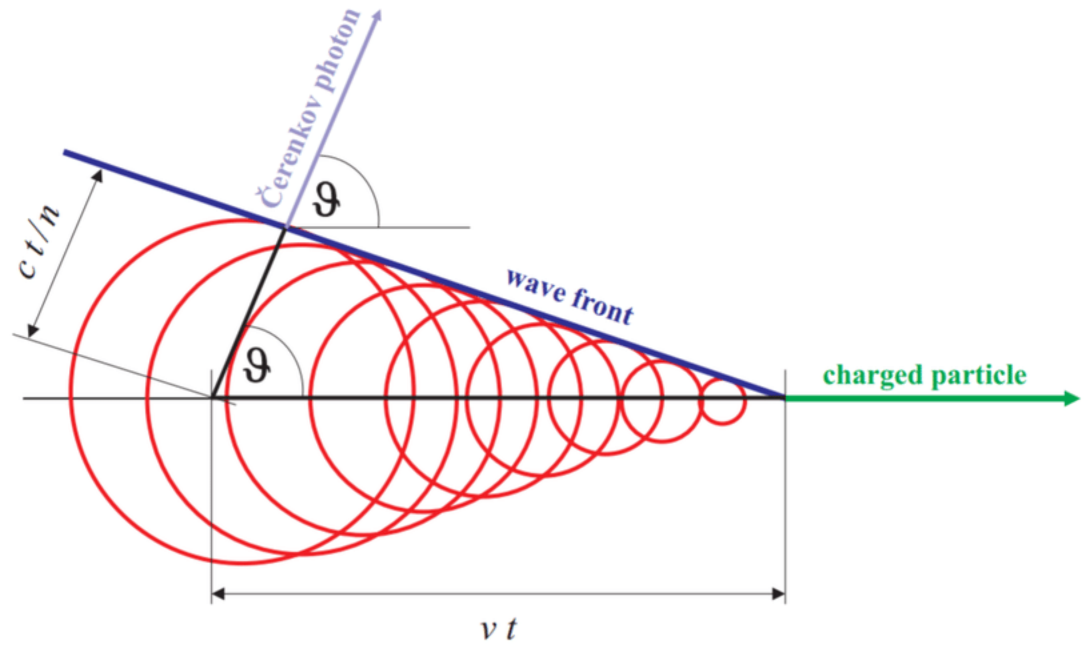
- Can we improve further the reconstruction and selection of heavy flavour decays?
- How does this scale with the next LHCb upgrade which will increase the luminosity by almost a factor 10?

Real Time Analysis (RTA)

Can we improve the HLT1-level trigger to perform as close as possible as HLT2?

Project 1: **RICH reconstruction at HLT1-level optimised on GPUs**
In collaboration with Sergio Arguedas Cuendis (at CERN)

- Ring Imaging Cherenkov (RICH) detectors used for particle identification
- Reconstruction too slow to be used at HLT1
- Work is ongoing to optmise a set of algorithms on GPUs and physics perfomance needs to be evaluated



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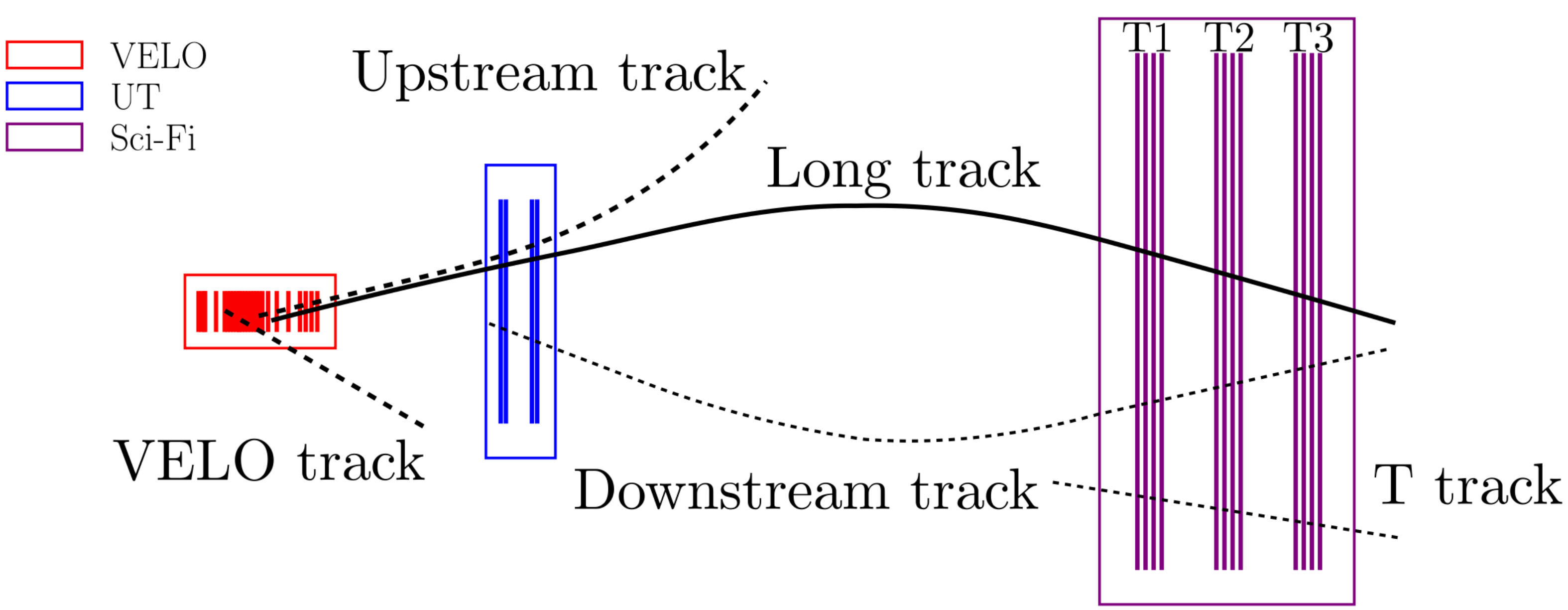
Project 2: **Development of GPU-optimised algorithms for tracking in real time**

- HLT1 tracking algorithms, due to time limitation, reconstruct 10% less particles compared to the HLT2 reconstruction
- Can we exploit the latest most performant GPUs to recover this gap? What is the impact on the physics perfomance of heavy flavour decays?
- How does this scale with the High-Luminosity next upgrade?



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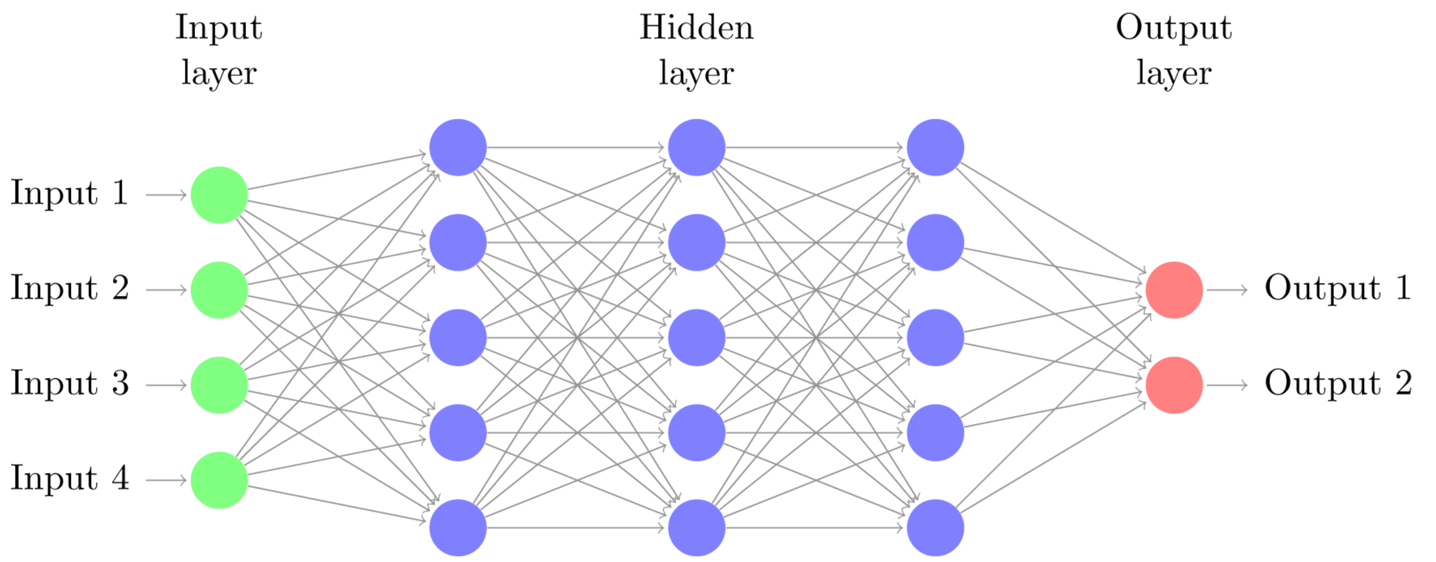
Can we exploit novel machine learning techniques to improve our heavy flavour decay selections?

Project 3: **Optimisation of HLT2 selection algorithms via novel ML techniques**

- Optimisation of trigger selections algorithms using Neural Networks (NN) and Machine Learning (ML) techniques



Detector R&D

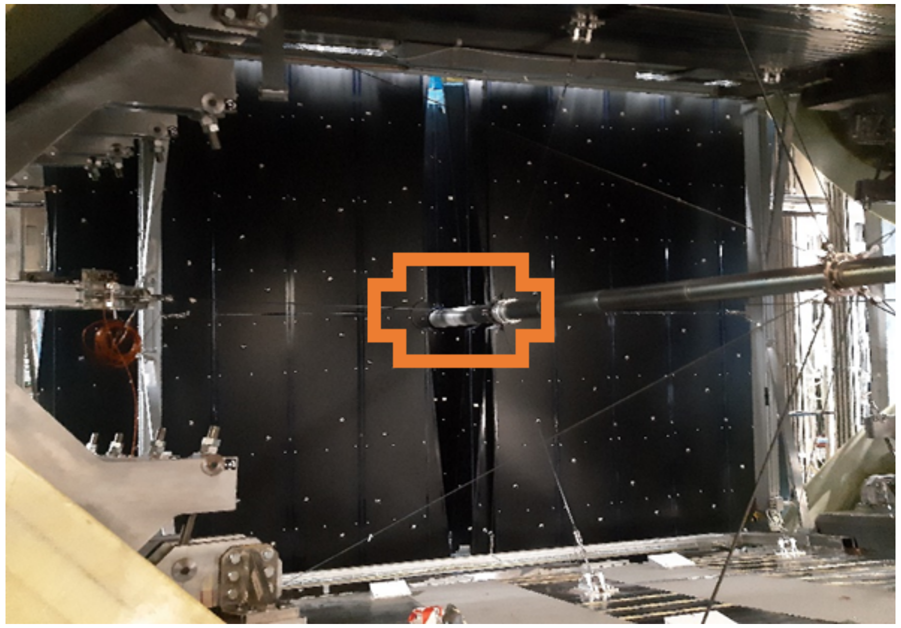
Dirk Wiedner <Dirk.Wiedner@cern.ch>
Lukas Witola <lukas.witola@tu-dortmund.de>

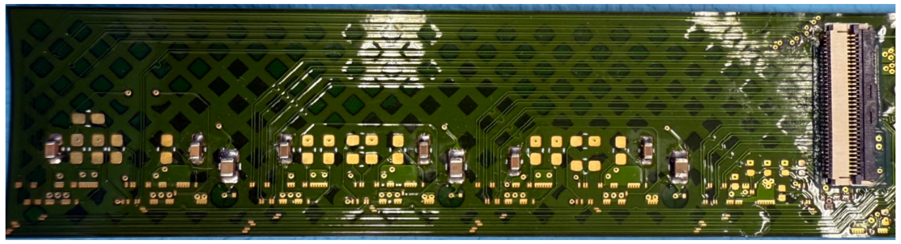
Detector R&D

Project 1: Development of the pixel module for LHCb U2

- Module must be
  - Extremely light-weight
  - Provide high speed readout
  - Carry five monolithic active pixel sensors

- You will
  - Help to develop prototypes of these modules
  - Develop a testbench
  - Be involved in testing and validation





Detector R&D

Project 2: Diamond detectors for clinical applications

- Diamond detectors are carbon based
  - Mimicking closely the physiological composition
  - Unique possibility to integrate it into the phantom of a head
  - They are already used at CERN for beam monitoring

- You will
  - Design, build and test a new diamond detector for proton therapy
  - Integrate the newest readout electronics for the diamond detector at CERN for proton therapy

Summary

Work Environment and Resources

- Your own workspace, including monitors and, if needed, a Mac Mini
- Computing cluster with roughly 1000 CPU cores and multiple GPUs for scientific computing
- Internal group seminar with talks by PhD students and postdocs for bachelor & master students

Teamwork and Communication

- Integration into a small team led by postdocs
- Professional tools and group chats for fast communication
- The working group's Q&A forum for problem-solving
- Various documentation options (Git, HackMD, Wiki, …)

Summary

Integration and Support

- Direct supervision by at least one PhD student or postdoc
- Integration into the whole group through many social activities
- Weekly meetings of the team and the entire working group
- Plenty of support from all members of the group
- Assistance with writing and revising the thesis

Travel funding available

If you are worried about funding your internship with us, please contact us

We're looking forward working with you!

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