PhD studentship on LHCb

Beauty mesons as a probe of New Physics

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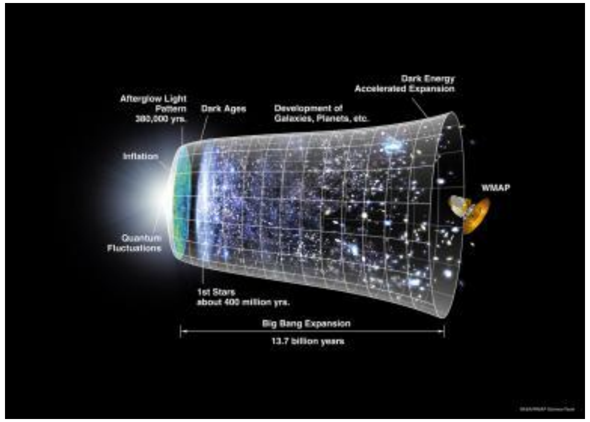
Science and Technology Facilities Council

LHCb

THE UNIVERSITY OF EDINBURGH

The need for New Physics

The Standard Model of Particle Physics works very well up to energy scale of a few hundred GeV
However there are compelling reasons to state its incompleteness. To mention just a few examples:



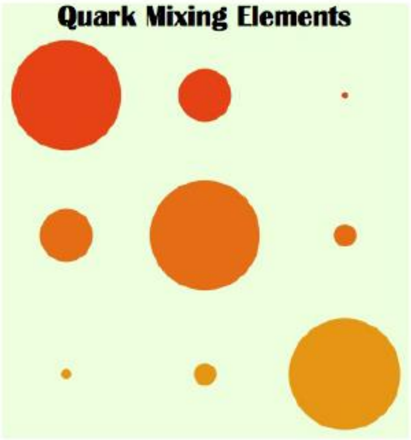
Cosmology

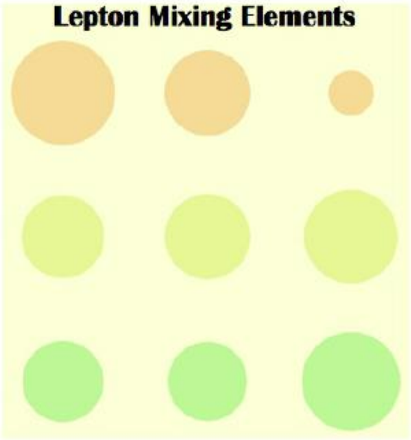
- New sources of CPV required by baryogenesis.
- Missing Dark matter candidate

Standard Model flavour puzzle:

- why 3 generations quarks and leptons?
- what is the origin of the hierarchy observed in the fermion masses and quark mixing parameters

  (and why so different from lepton mixing anarchy?)

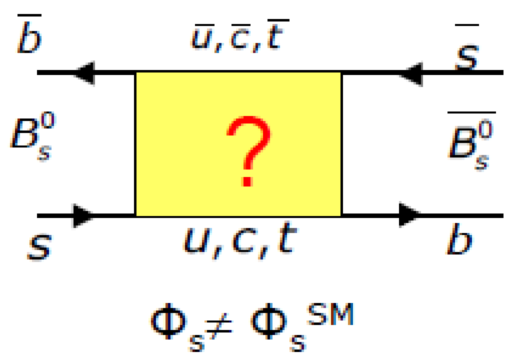


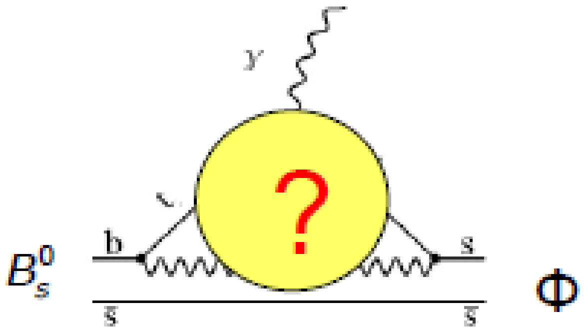


Indirect New Physics search at LHCb

Discovery potential far beyond the energy frontier via studies of forbidden or SM suppressed processes, e.g. loop processes where new virtual particles may contribute

Complementary to direct searches at ATLAS and CMS, where new particles may be directly produced and observed

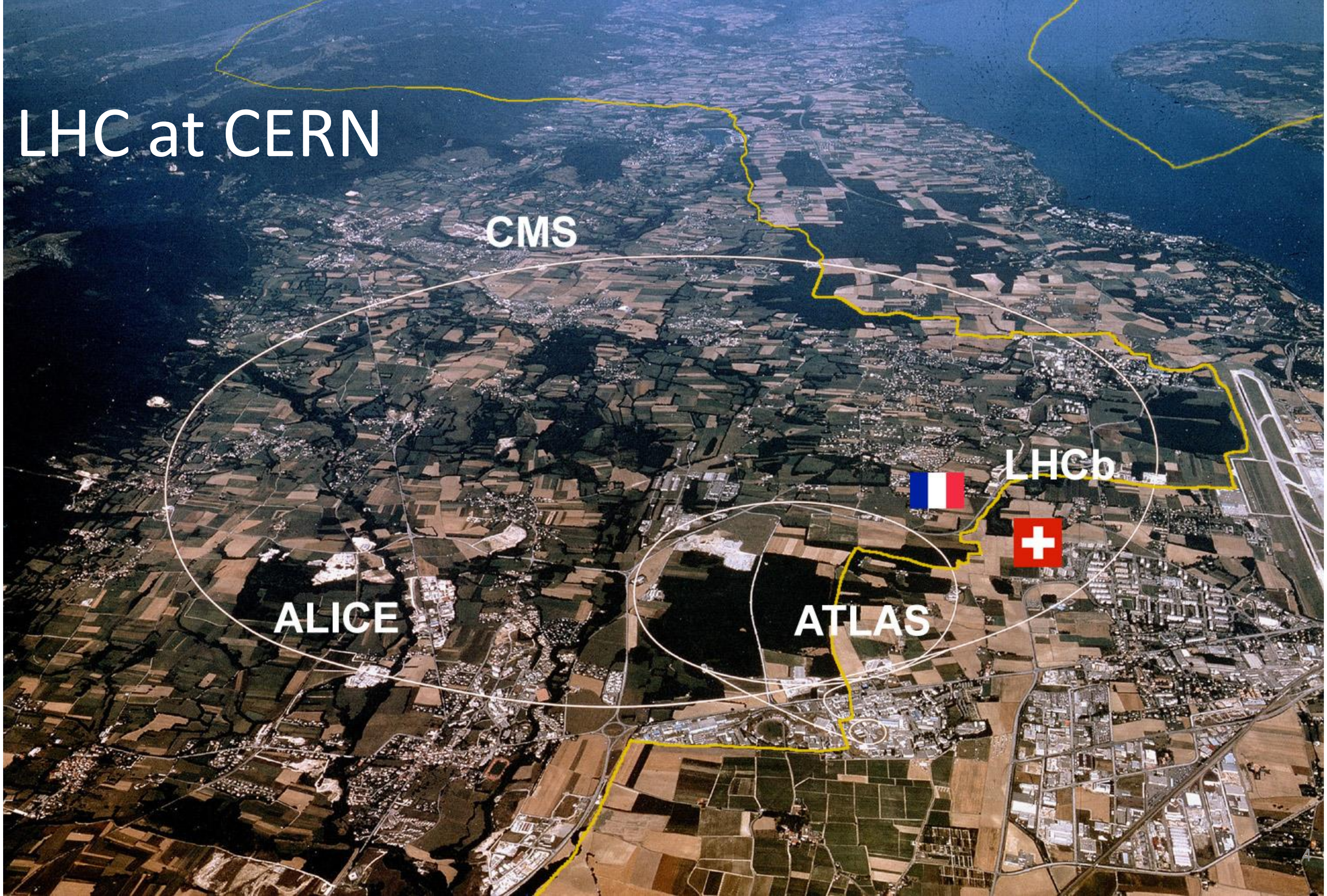




New particles can be virtually produced ⇒ sensitivity limited by precision, not by collision energy. Sensitivity to new particles up to ~100 TeV can be reached at LHCb

[A. Buras et al. JHEP1411(2014)121]

LHC at CERN



LHCb Collaboration

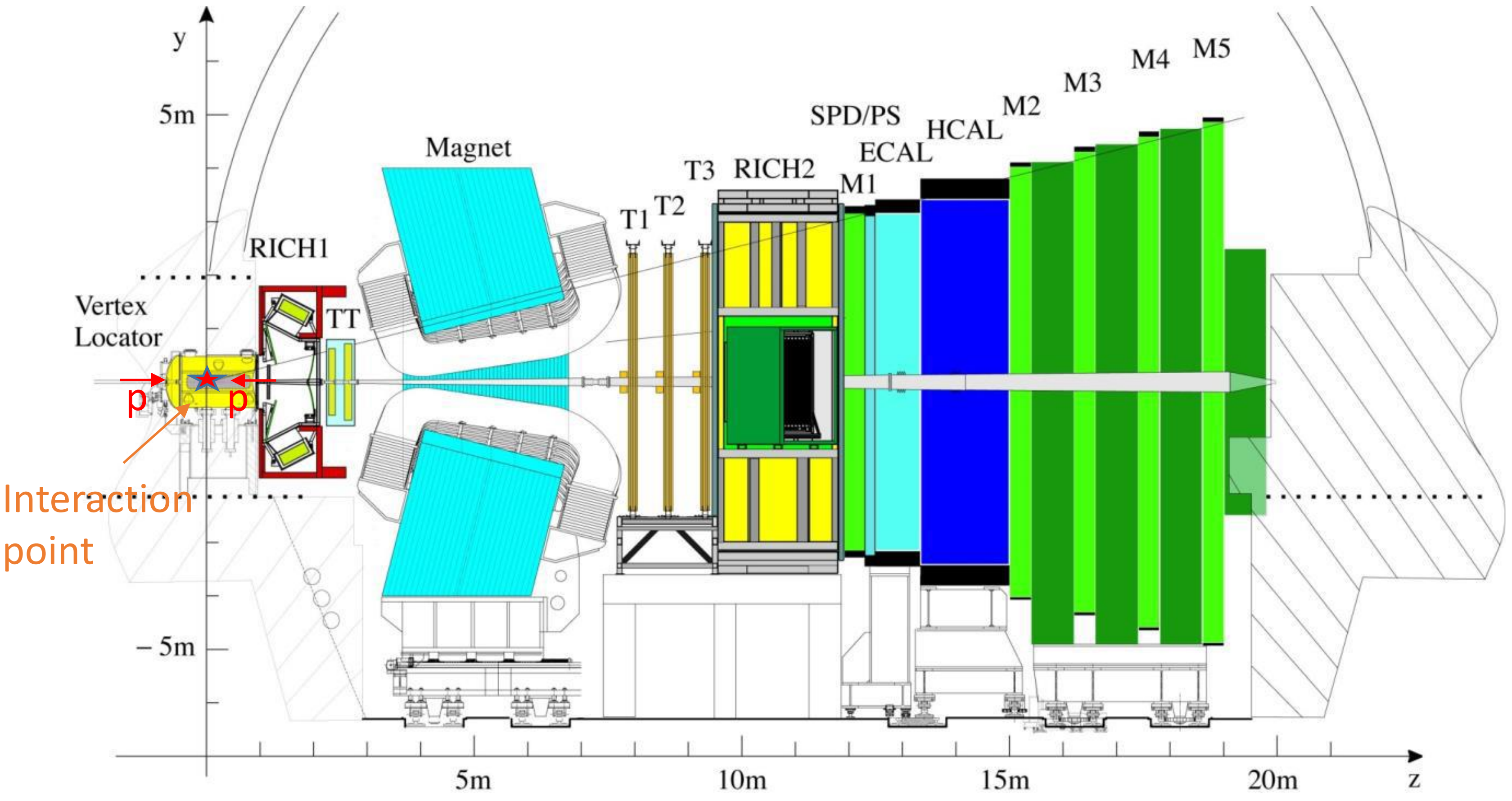
~1000 authors and >40 nationalities
87 institutes from 18 countries

Edinburgh group:
P. Clarke, F. Muheim, M.Needham, M. Williams, R. Currie, S. Eisenhardt, S. Gambetta, F.Oliva +
PhD students: K.Gizdov, S.Mitchell, R.O'Neil, S.Petrucci, G. Robertson
+ MPhys and Msc students and dedicated engineers

RAL group: S. Easo, R. Nandakumar, A.Papanestis, S. Ricciardi, F. Wilson +
PhD students: Z. Aliouche, D. Foulds-Holt + Msc students
RAL TD

LHCb : a forward single-arm spectrometer

At the LHC: $\frac{m_b}{\sqrt{s}} \sim 10^{-3}$. Highly boosted b-hadrons are produced => forward spectrometer



Optimised for b physics
The "b" in LHCb name stands for "beauty"

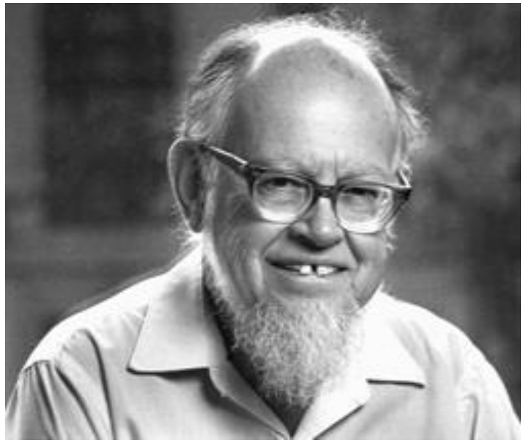
Excellent vertexing, tracking and particle identification (RICH system, unique at LHC)

b-hadrons have emerged as an optimal laboratory to look for NP in rare decays and study CP violation

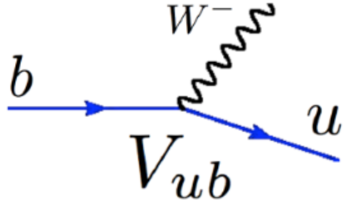
CPV and CKM: a reminder

$$V_{CKM}=\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Wolfenstein parameterisation

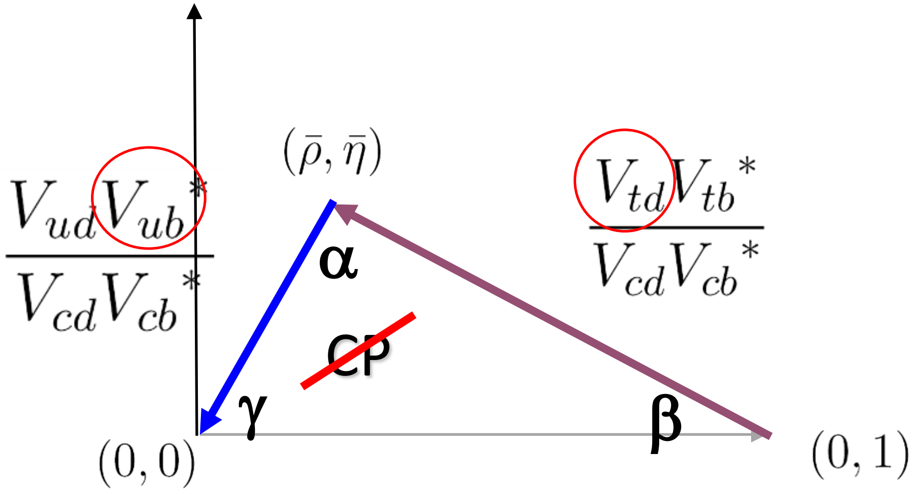


$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



$VV^\dagger = 1$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

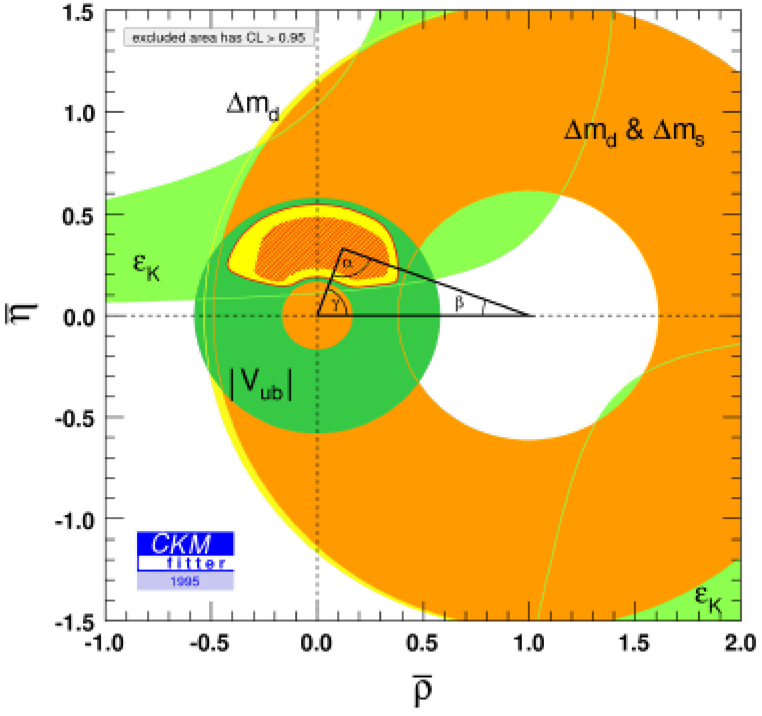


Unitarity Triangle apex can be overconstrained by doing several independent measurements

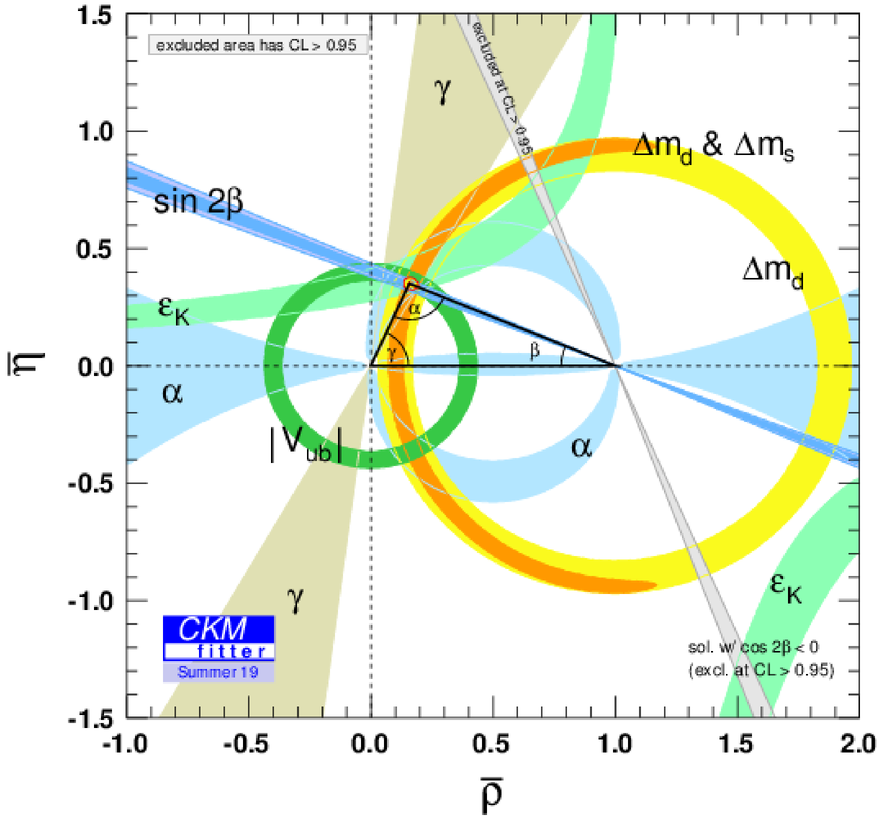
Testing the consistency of the Unitarity Triangle is one of the main goals of flavour physics!

Long history

1995



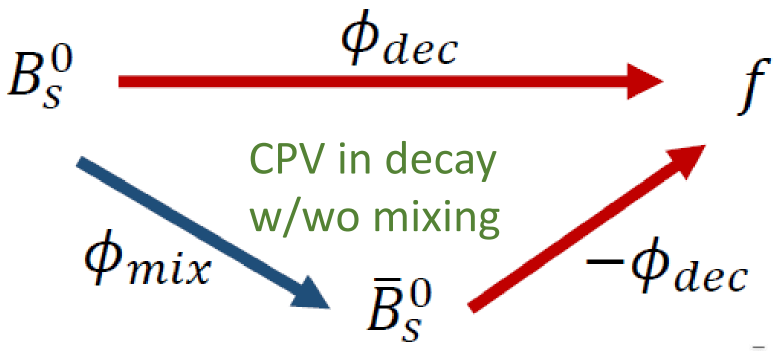
25 years of work

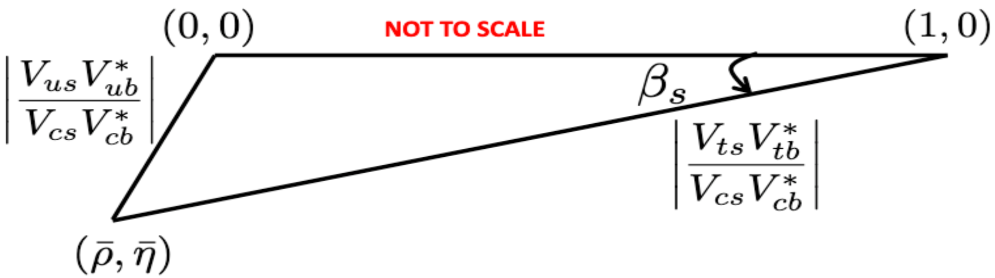


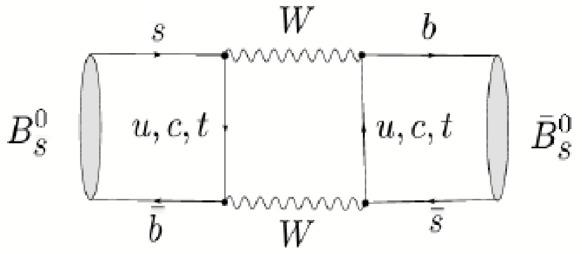
Each coloured band defines the allowed region for the apex of the UT according to a specific measurement
All bands overlap, **huge success for the SM!** Still room for NP, but more precision required

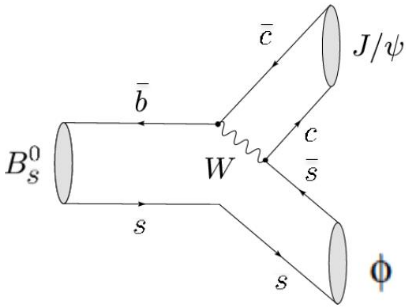
The CP-violating phase ϕ_s

It can be studied with Bs decays proceeding via $b \to c\bar{c}s$ transition









$\phi_s = \phi_{mix} - 2\phi_{decay}$

$\phi_s^{SM} = -2\beta_s = -0.03686^{+0.00096}_{-0.00068}\ rad$

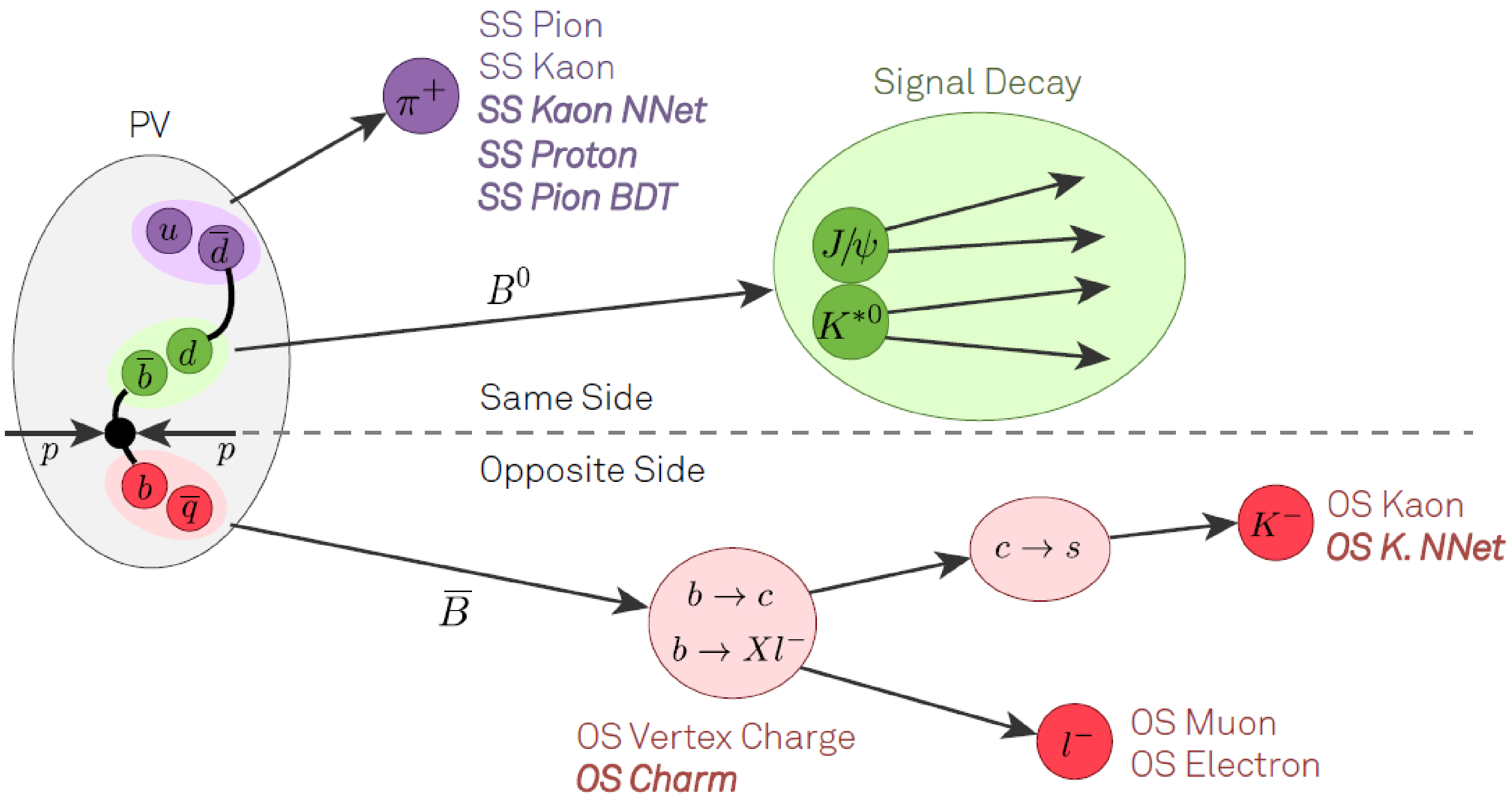
Time-dependent CP asymmetry

$$A_{CP}(t) = \frac{\Gamma(\bar{B}_S^0(t)\to f) - \Gamma(B_S^0(t)\to f)}{\Gamma(\bar{B}_S^0(t)\to f) + \Gamma(B_S^0(t)\to f)} = \eta_f \sin\phi_s \sin(\Delta m_s t)$$

- Very well known in the Standard Model
- Very small in the SM
- Very sensitive probe of New Physics

Flavour tagging: a crucial analysis ingredient

- Flavour tagging determines whether a b or a bbar was produced
- Statistical process: the tag is not always right
- Not all B candidates in an analysis can be tagged

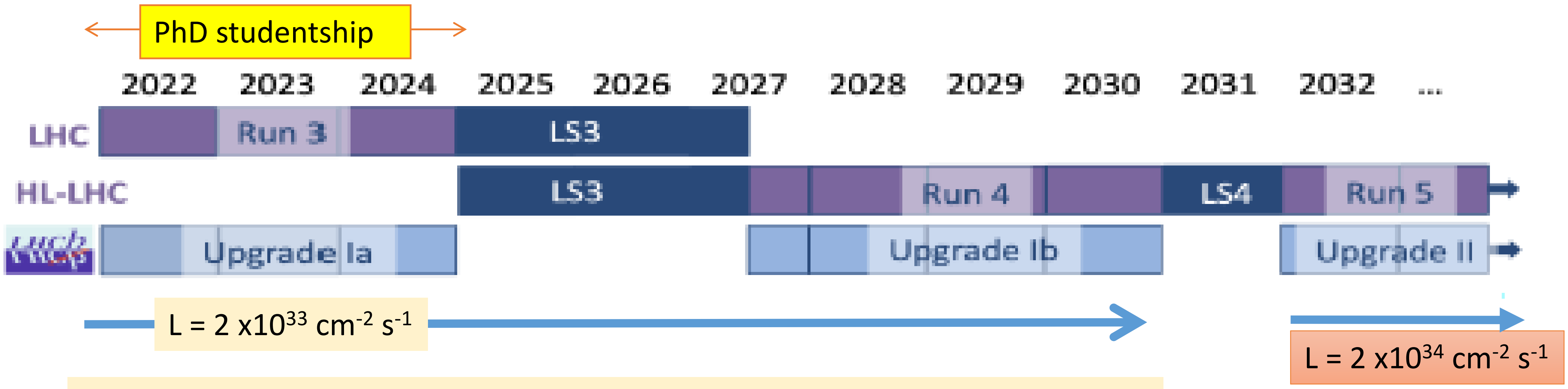


New Total Event tagger: an opportunity for this PhD thesis

Two kinds of tagger:

- Opposite side (OS) taggers: kaon, lepton, charm, vertex charge
- Same Side (SS) taggers: pion, kaon, proton

Upgrades timeline



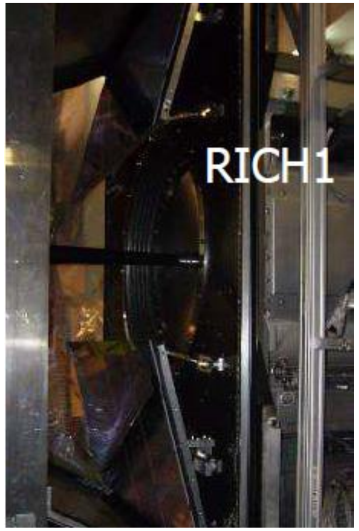
Upgrade I in construction – full software trigger

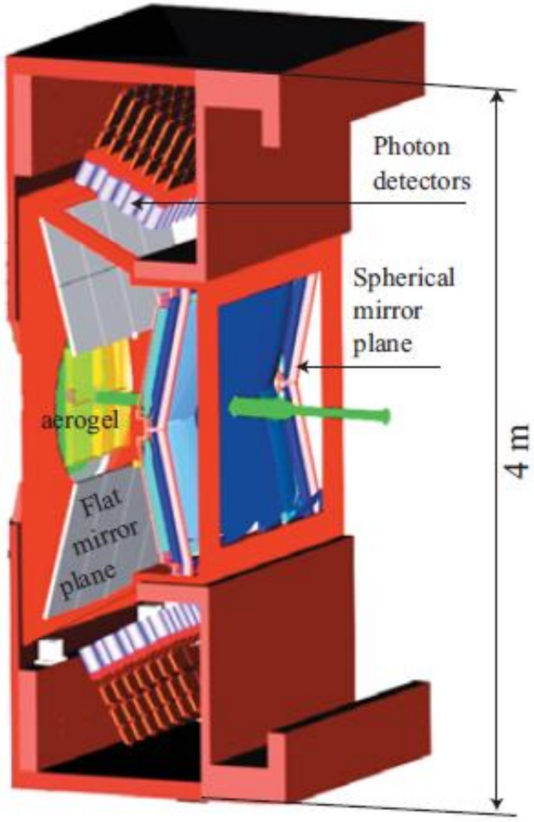
- will allow to run at 5 x pre-upgrade instant luminosity
- aim to collect 50 fb^{-1} by LS4
- detector consolidation and enhancement foreseen in LS3 (start of HL-LHC)

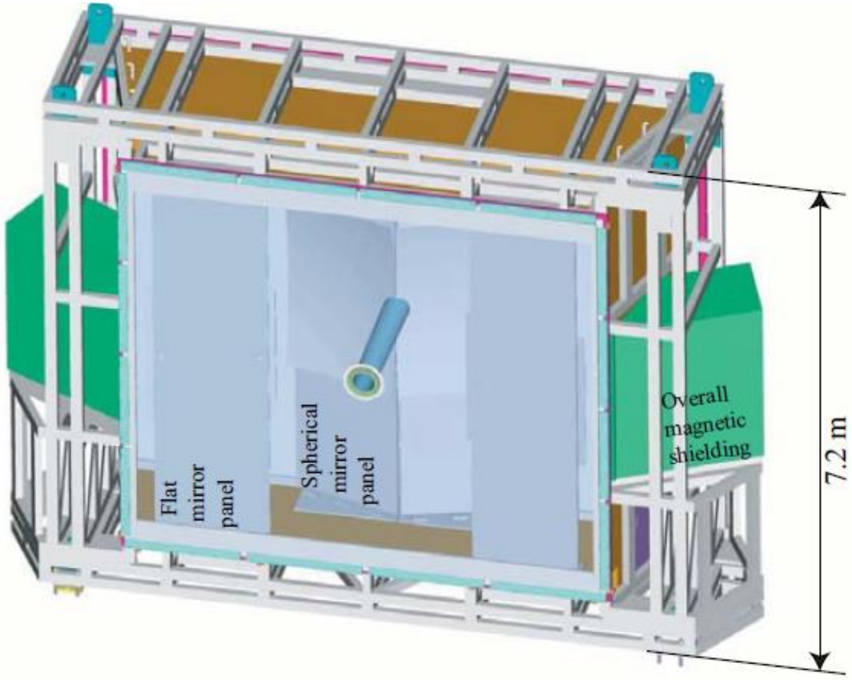
Upgrade II -

- Major detector upgrade in LS4 (2030) – R&D starting now
- Aim to run at 10 x Upgrade I luminosity and collect 300 fb^{-1}
  - Challenging conditions for flavour physics (number of visible interactions/bunch crossing ~50)
- Improved sub-detectors time-resolution

RICH System and upgrades



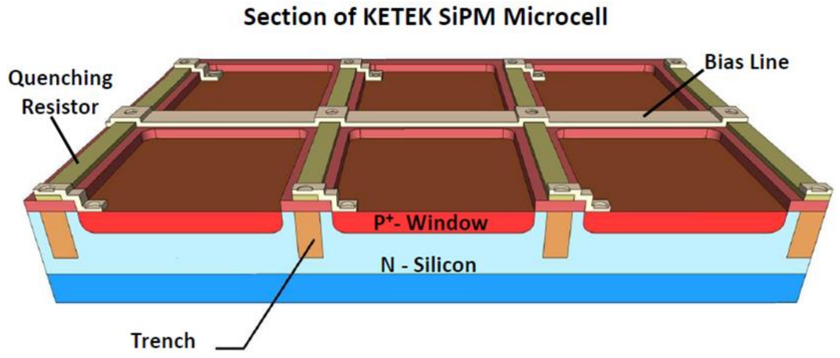




Schematic and photos of the dismantled RCH system
Upgraded detectors same structure, but different optics and different photodetectors:
Upgrade I: MAPMT   Upgrade II: SiPM (baseline choice)

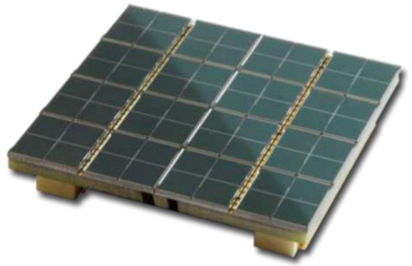
SiPM

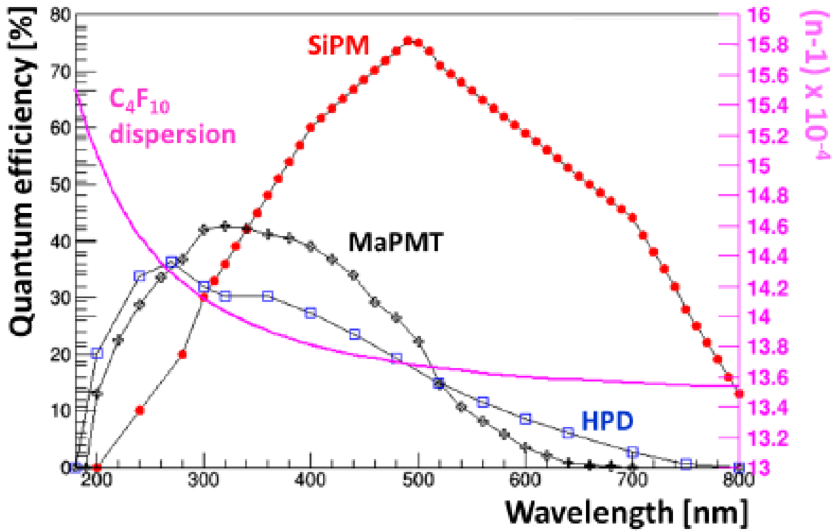
A SiPM is a matrix of APD (avalanche photodiodes) operating in Geiger mode. Each cell fires independently, so the output is proportional to the number of fired cells.



Desirable features:
- High gain (~10^6)
- Good granularity (1mm^2)
- Good timing capabilities (<=200ps)
- Large Quantum Efficiency in the green
- Excellent single photon separation
- Low bias voltage (~50V)
- Cheap and easy to produce
- Insensitive to magnetic fields

A few drawbacks:
- High dark count rate
  (->operate at low temperature -40°C)
- Sensitive to radiation damage





Characterization of SiPM is an important part of this PhD thesis

Beam tests at CERN

Detector prototypes will be operated at the CERN beam facilities.

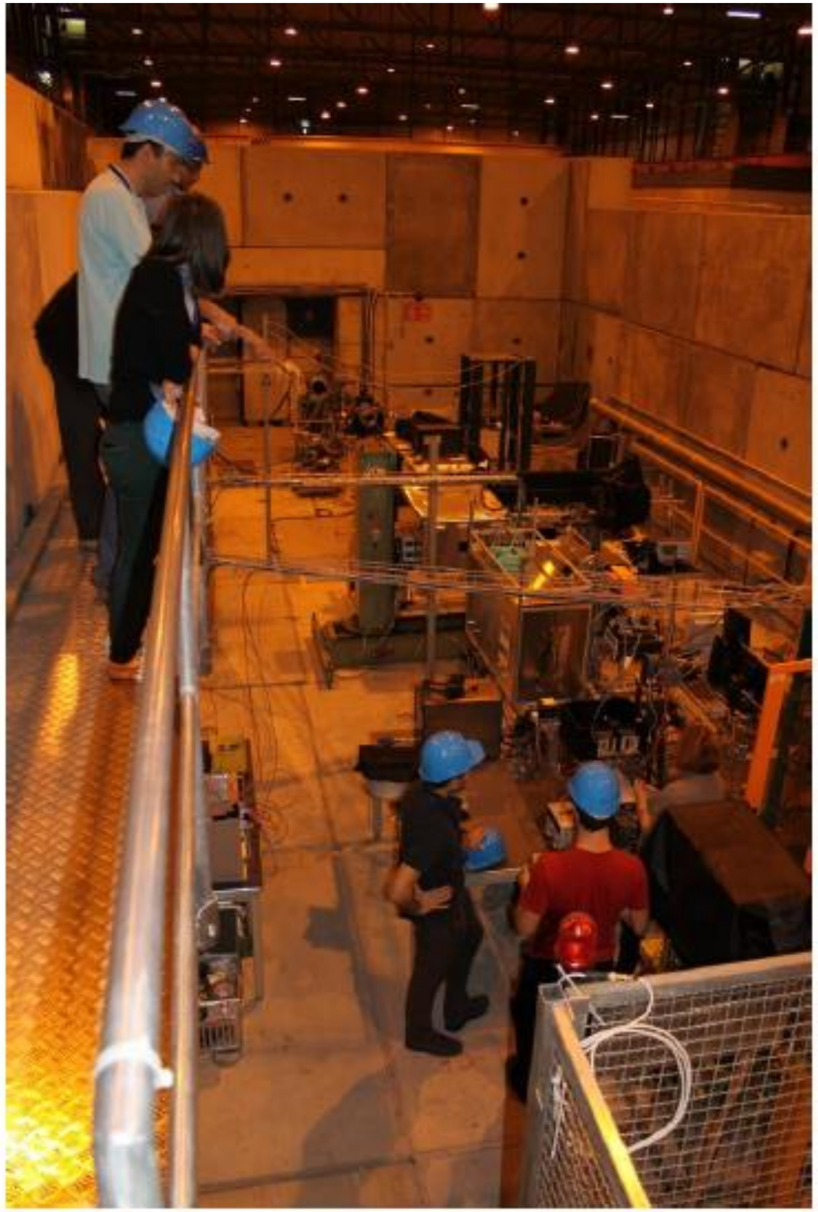
Photon sensors and readout electronics for LHCb RICH future upgrades will be tested there.

Presents exciting opportunities for PhD student to take a central role.

Work in a small team of talented and (mainly) young experts.

Develop unrivalled experience and expert insight into the detector performance under real life conditions.

Hard work but fun too…



Courtesy :Sajan Easo

Opportunities for the student

Software:
use a large fraction of the Run 3 dataset to significantly improve the measurement of one of the most sensitive observables to New Physics

- Develop data analysis tools
- Gain expertise in C++ and Python software development and Machine Learning techniques
- Become an expert in data-intensive science

Hardware:
Characterise photon detectors, such as SiPMs

- Gain experience in cutting-edge technology;

Communication:
presentations, writing, public engagement

Travel:
Several opportunities, including a placement at CERN
(extra funding to cover the costs with living abroad)

Collaborate with people from all over the world: **soft skills**!

Highly-sought set of skills for a career in particle physics, but also transferable to work in other fields

Example of projects and timeline

- **Year 1: in Edinburgh – PhD lectures**;
  - Develop flavour tagging using Run 2 data
  - Validation of early Run 3 data
- **Year 2: at CERN**
  - Perform a time-dependent data-analysis using Run 3 data
  - Contribute to the design, installation and operation of RICH prototypes in the CERN test beam facilities
  - Contribute to the LHCb data-taking as RICH expert on call
- **Year 3: at RAL**
  - Evaluate the performance of novel photon detectors such as silicon photomultipliers
  - Complete the data-analysis

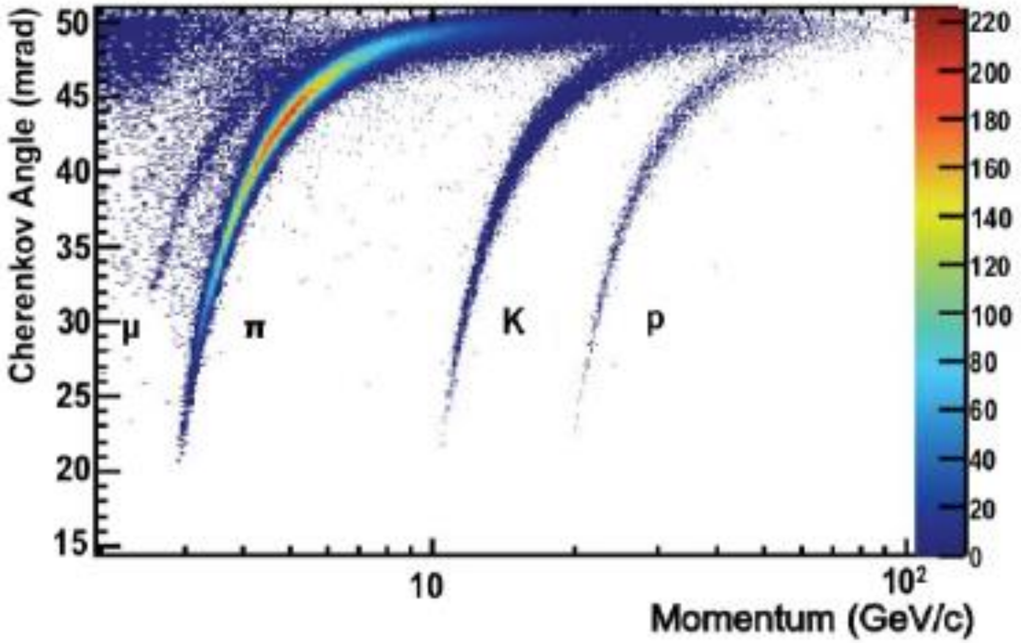
Conclusion

This project offers a combination of crucial detector development activities, and an analysis programme which could lead to several high impact publications

Would you like to join us?
Please sign up for a chat with Franz and me tomorrow

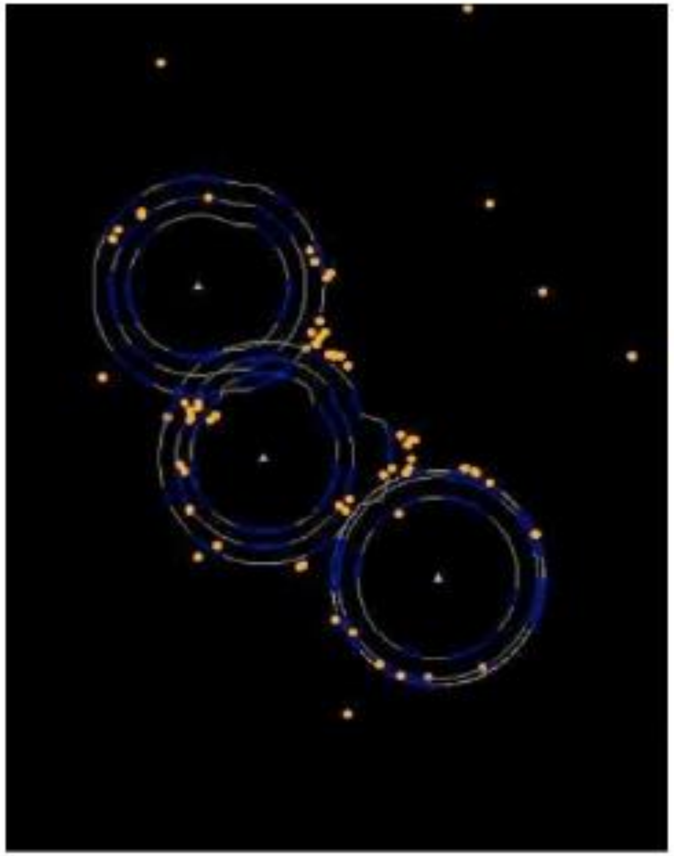
Backup

RICH system



The RICH detectors use the properties of Cherenkov radiation to separate the particles

$$\cos\theta_C = \frac{1}{n\beta} = \frac{1}{n}\sqrt{1+\left(\frac{m}{p}\right)^2}$$

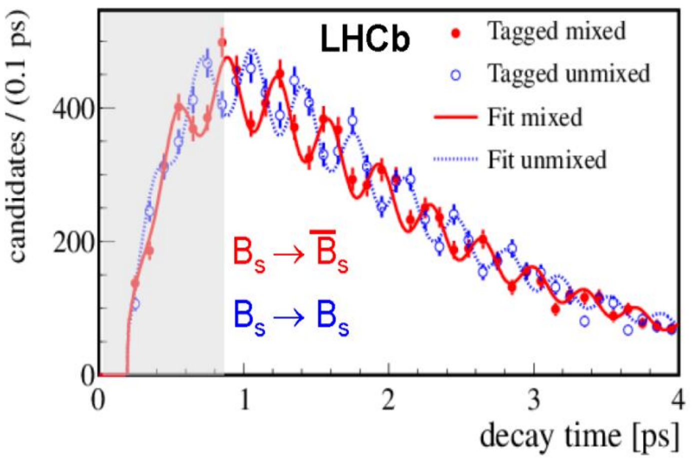


some of the first reconstructed RICH rings

Hadron PID in 2-100 GeV range, using Ring Imaging Cherenkov (RICH) detector is a unique feature of LHCb and it is used for most of the physics results of LHCb

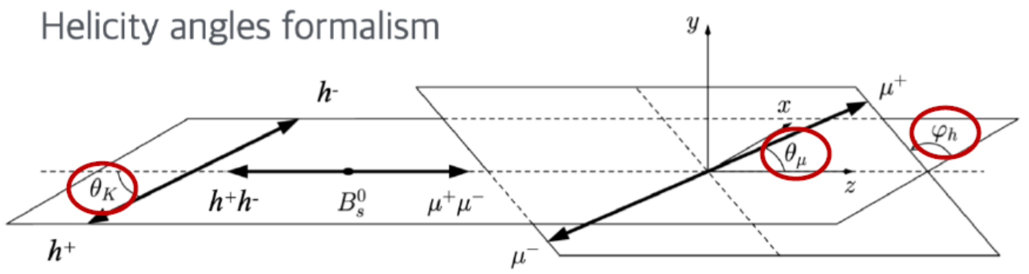
Measuring ϕ_s

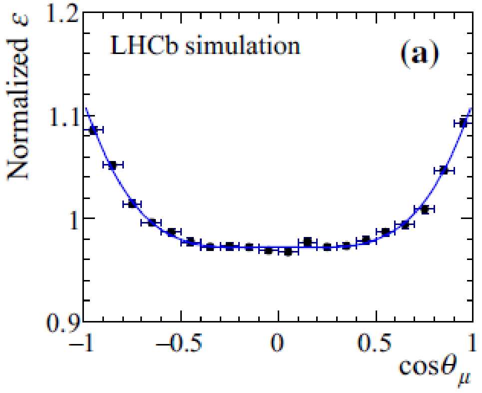
$$A_{CP}(t) = \frac{\Gamma(\bar{B}_s^0(t)\rightarrow f) - \Gamma(B_s^0(t)\rightarrow f)}{\Gamma(\bar{B}_s^0(t)\rightarrow f) + \Gamma(B_s^0(t)\rightarrow f)} = \eta_f \sin\phi_s \sin(\Delta m_s\, t)$$



Requirements:

- Knowledge of the CP eigenvalue of the final state η_f
- Fast Bs oscillation $\rightarrow$ excellent time resolution
- Model decay-time and angular efficiencies
- Knowledge of the B flavour at production $\rightarrow$flavour tagging





Current measurement of ϕ_s

- ϕ_s = -41 ± 25 mrad
- Well compatible with SM at the present level of precision
- Precision mostly driven by LHCb, Atlas, CMS
- Starting to approach the sensitivity to observe a non-zero SM value
- Tensions between the various measurements of Γ_s and $\Delta\Gamma_s$ call for a clarification of the experimental picture