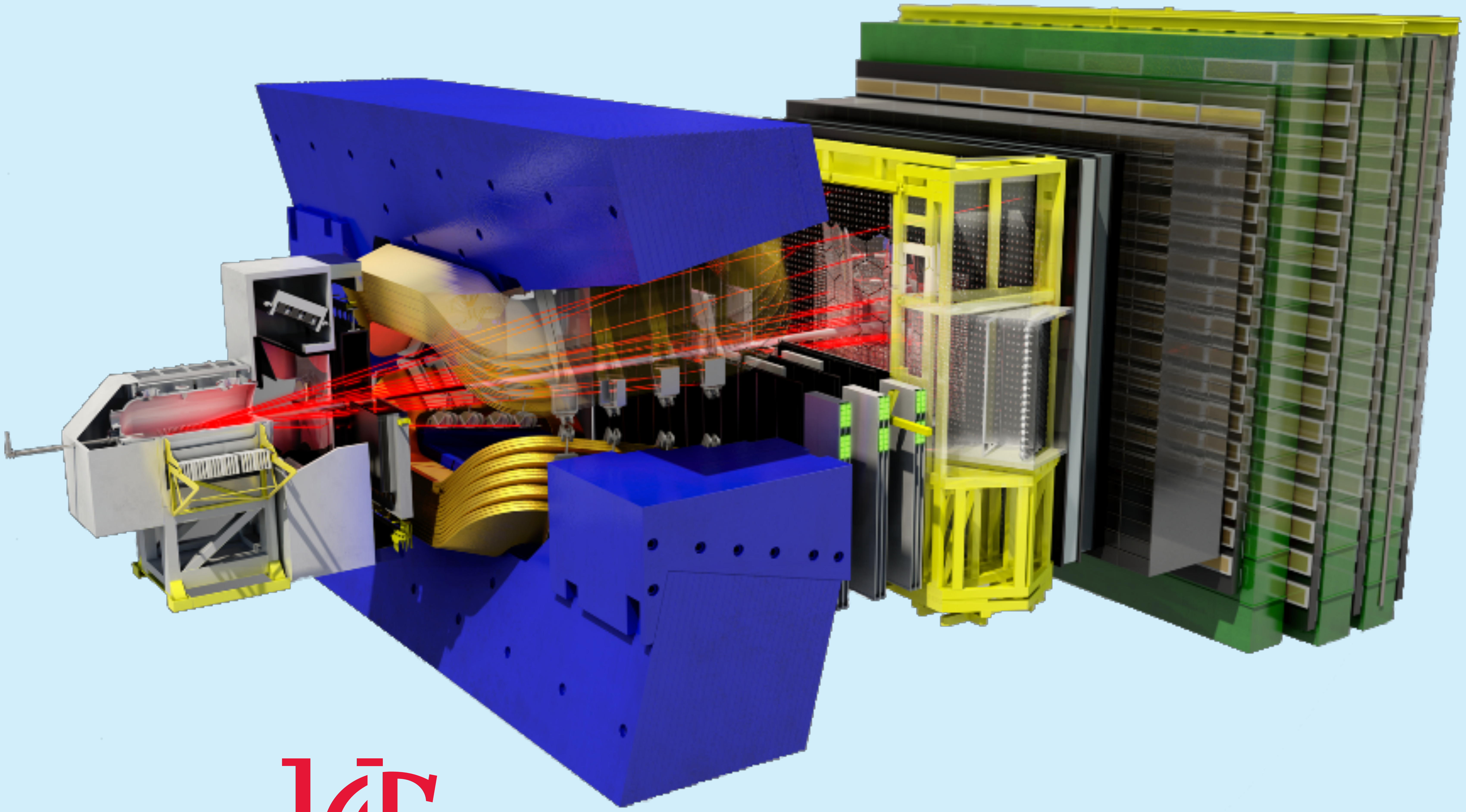
# A Flavor of the Flavor Physics at LHCb



Henry Schreiner

University of Cincinnati
Princeton University

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**Provo, Utah**
**USA**

UNIVERSITY OF Cincinnati

LHCb

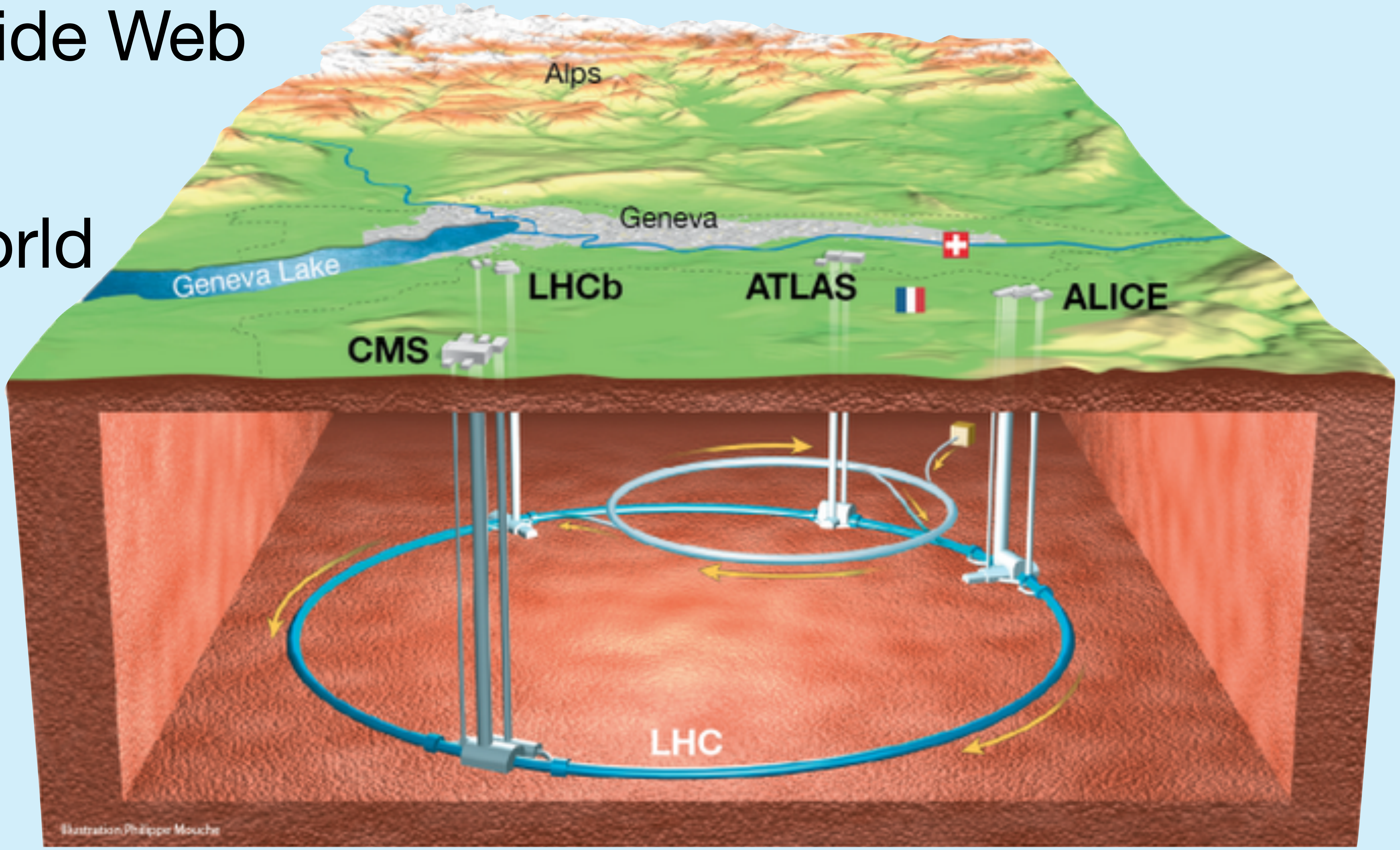
# CERN and the LHC



- Birthplace of the World Wide Web

**The Large Hadron Collider**

- Largest machine in the world
- Cost over $4 billion
- Proton - Proton collisions at 14 TeV
- 4 main experiments and several smaller ones



# LHC by the numbers

LHC

- 150 million sensors in the detectors
- 300 million collisions per second
- 50,000 TB a year (50 PB) produced
- Power: 230 MW (130 MW for LHC alone)
- Operating costs: $21M per year
- Protons travel at 0.999999991c (7 TeV)
- 6,000+ superconducting magnets

**One day at the LHC would fill 137 1TB hard drives!**

**Most of the LHC power goes to the supercooled magnets!**

**The energy stored in the magnets is 30x larger than the energy stored in the beam!**

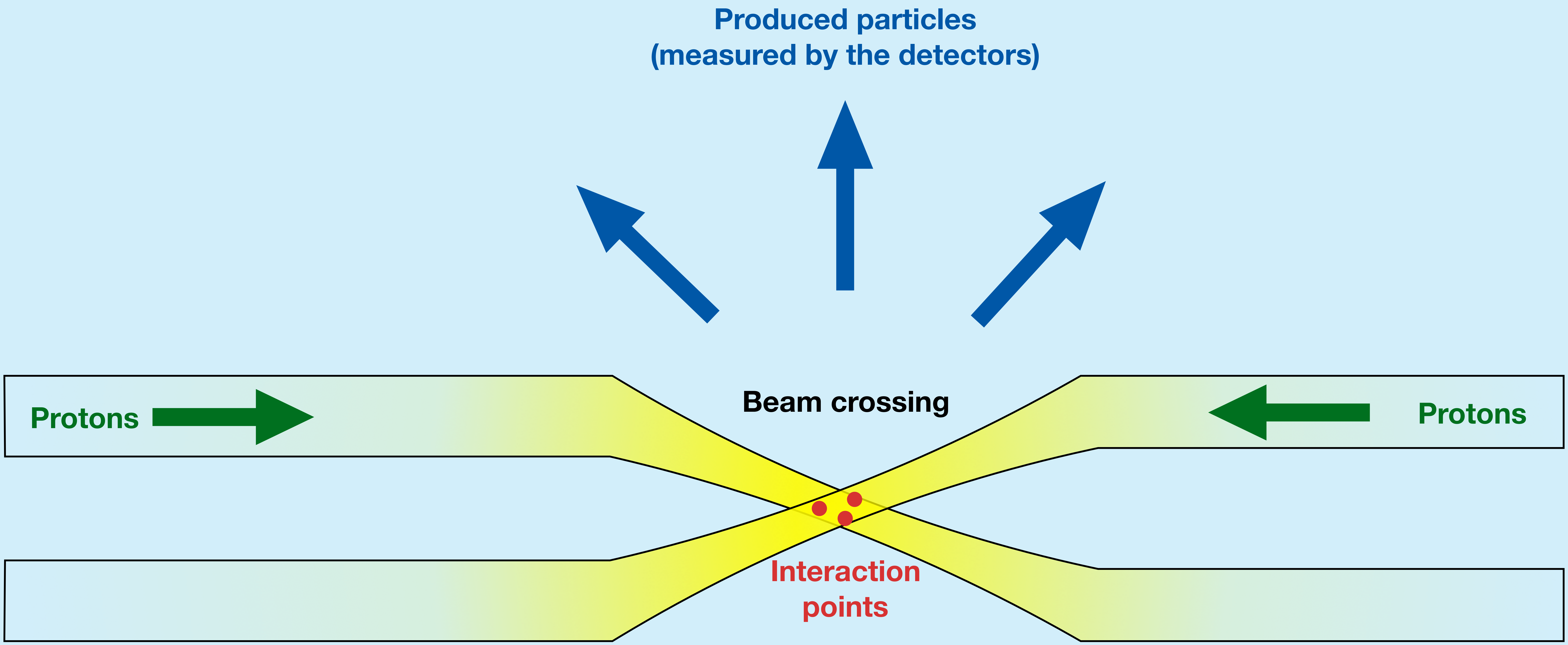
**Protons travel the 27km ring 11,000 times per second!**

**If you unravel all the filaments in the magnets, it would stretch to the sun and back 6 times, plus 150 trips to the moon**

**There is more iron in the CMS magnet system then in the Eiffel tower!**

# The Beam

LHC



Produced particles
(measured by the detectors)
Beam crossing
Protons
Protons
Interaction
points

# Why was the LHC built?

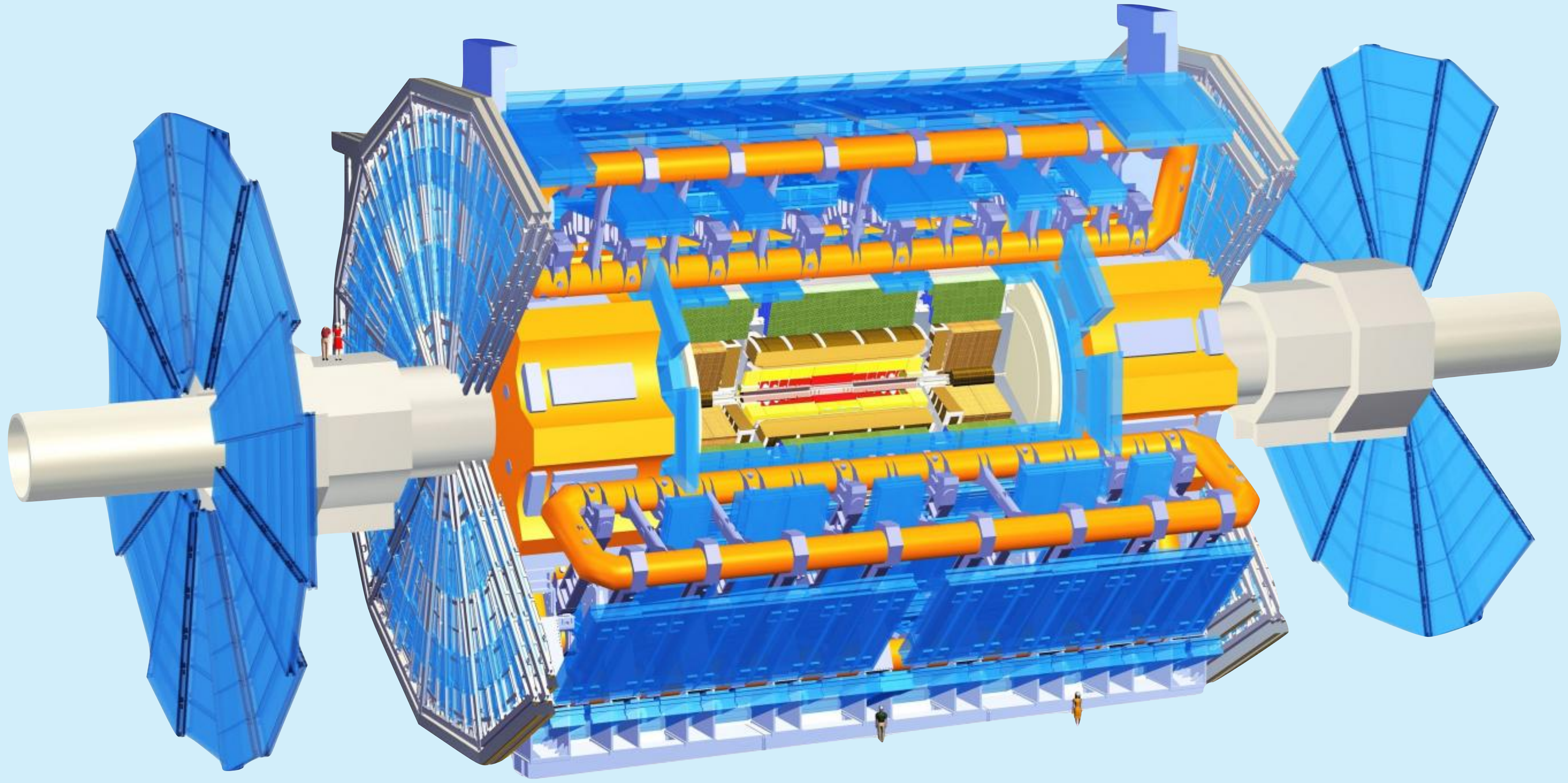


- Higgs Boson discovery (2012) (ATLAS, CMS)
- Look for evidence for supersymmetry or other unifying theories
- Look for dark matter
- Study matter / antimatter asymmetry
- Quark Gluon plasma (ALICE)

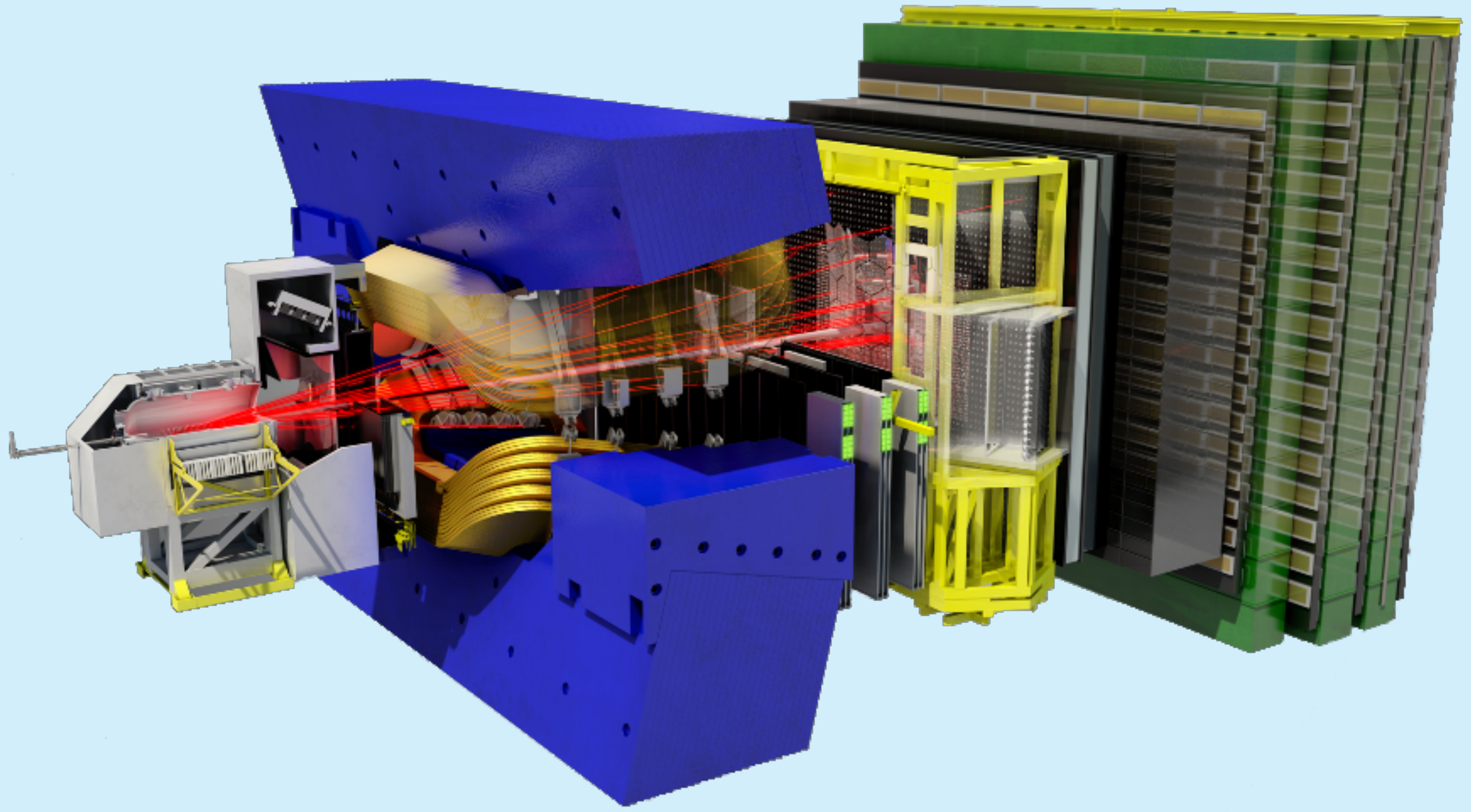
# The detectors at the LHC



ATLAS/CMS surround the collision



LHCb is a forward spectrometer

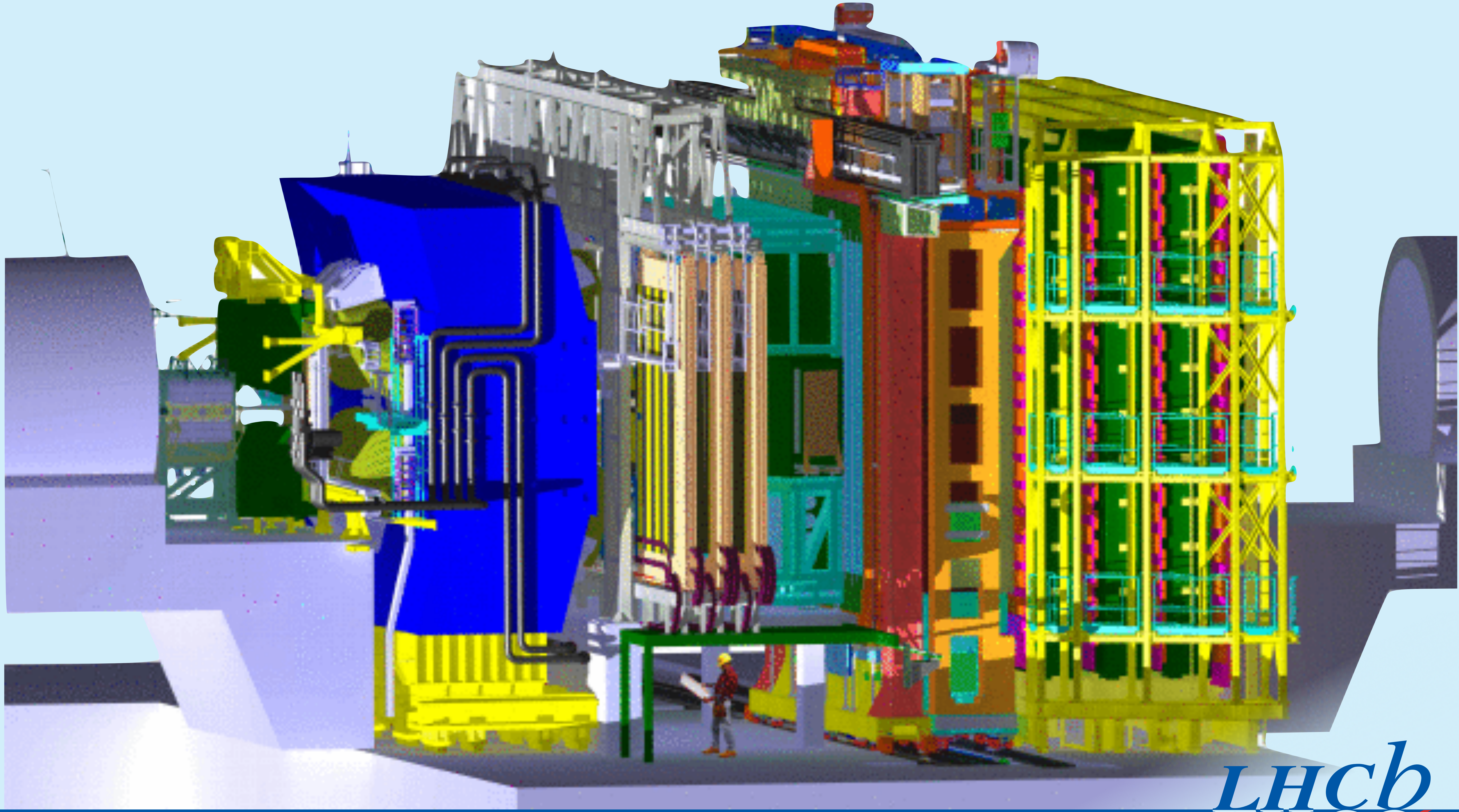


B mesons stay close to the beam pipe
(and other light particles, too)

# The LHCb Detector



- 21 meters in length
- 10 meters high
- 13 meters wide
- 100 m underground
- Weighs 6,000+ tons
- Construction cost over $75M
- 850 collaborators in 18 countries

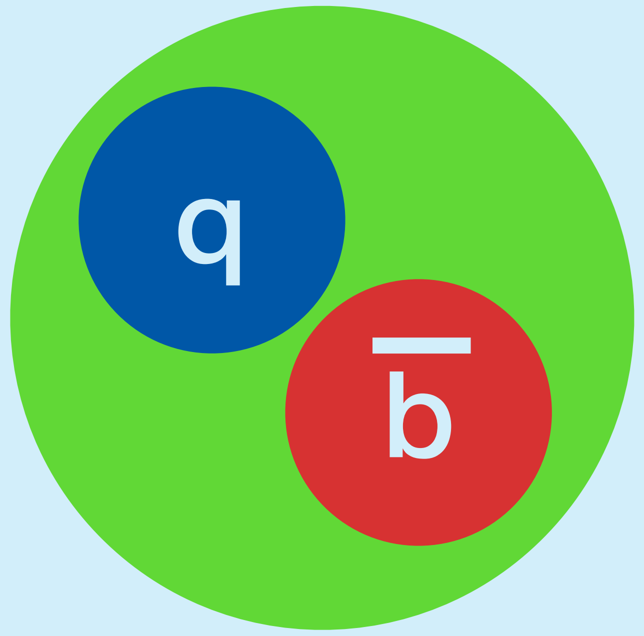


# The Standard Model

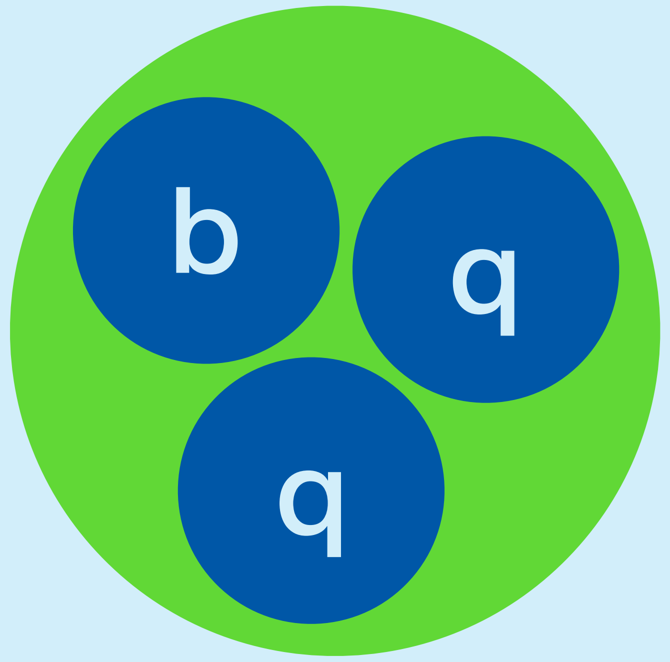


Particles made of quarks: Hadrons

- Two quarks: meson
  - Pions, Kaons, and many more
- Three quarks: baryon
  - Protons, neutrons, and many more




B meson




B baryon

Quarks

| | | |
|---|---|---|
| u<br>.002<br>up | c<br>1.3<br>charm | t<br>173<br>top |
| d<br>.005<br>down | s<br>.098<br>strange | b<br>4.2<br>bottom |

Masses in GeV/$c^2$



Note: Neutrinos and bosons not shown

# New Physics



Direct search (ATLAS, CMS)

- Looking for new particles

Indirect Search (LHCb)

- Looking for enhancements of rare processes

Precision measurements enable:

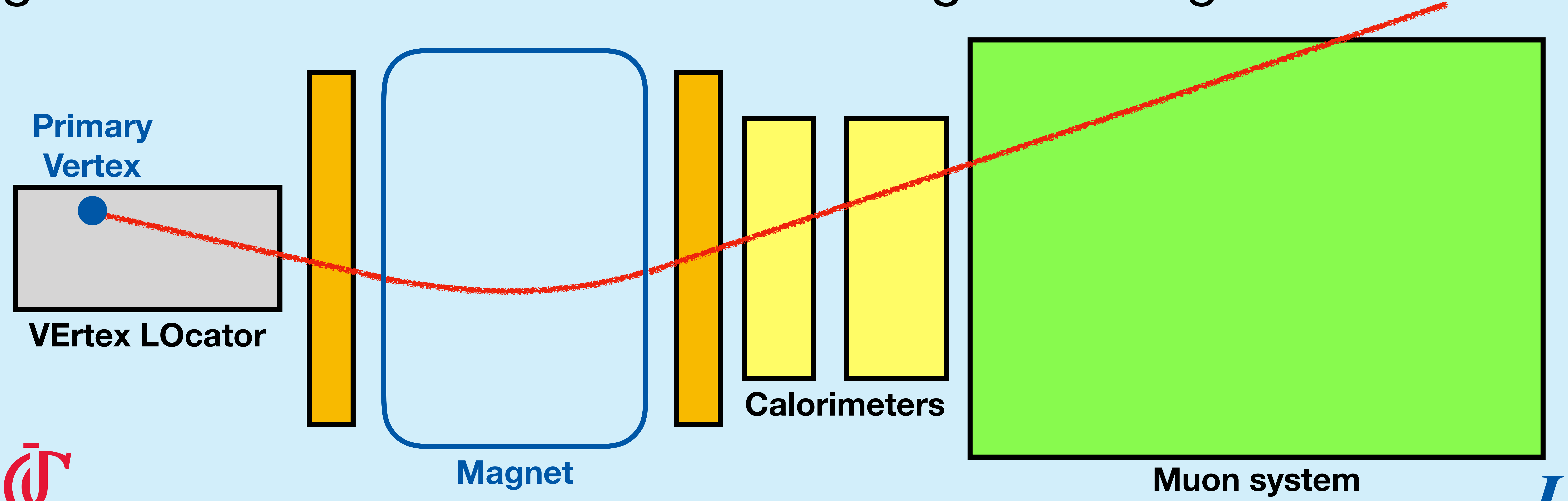
- CP violation in beauty and charm decays
- Rare decays
- New exotic states

**Matter/Antimatter asymmetry:**
**CP violation**

# Experimental detection

**Detector**

- Long lived particles are tracked in the detector
- Electronic calorimeters measure energy of charged particles
- Hadronic calorimeters measure energy of hadrons
- Magnetic fields allow momentum and sign of charge measurement

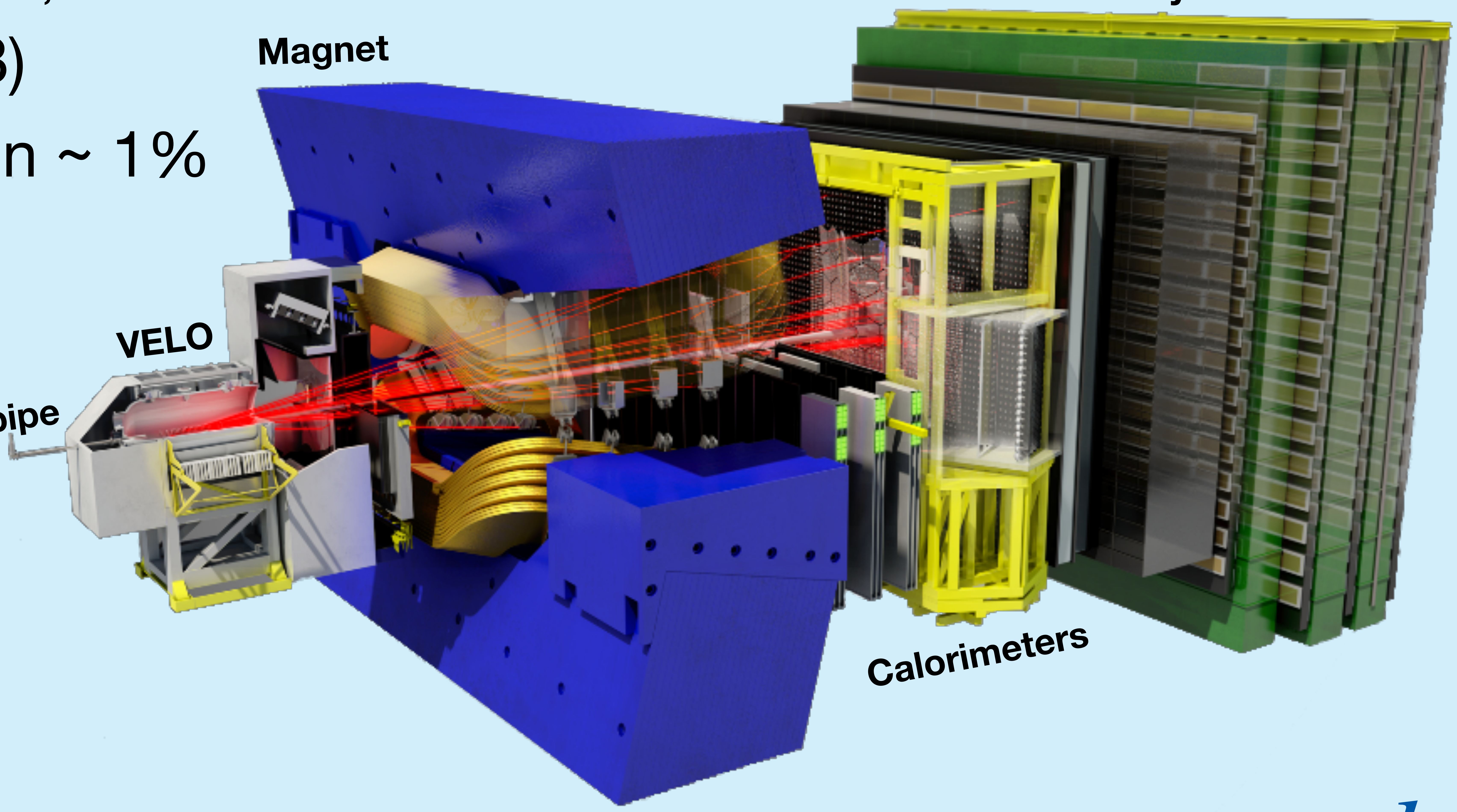


# The LHCb Detector specs



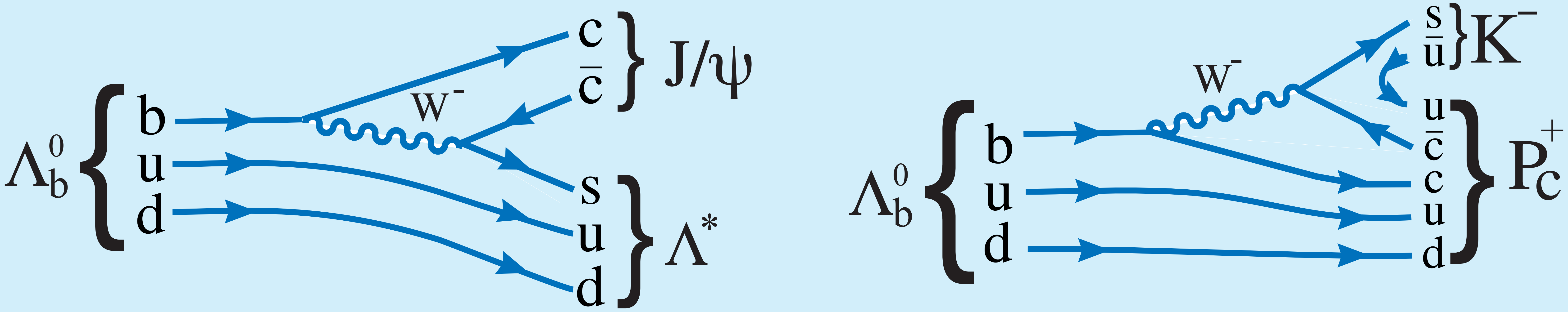
- Mass resolution: 24 MeV/$c^2$ (2-body B)
- Momentum resolution ~ 1%
- Magnetic field measured to 0.03% precision
- About 24 tracks per event

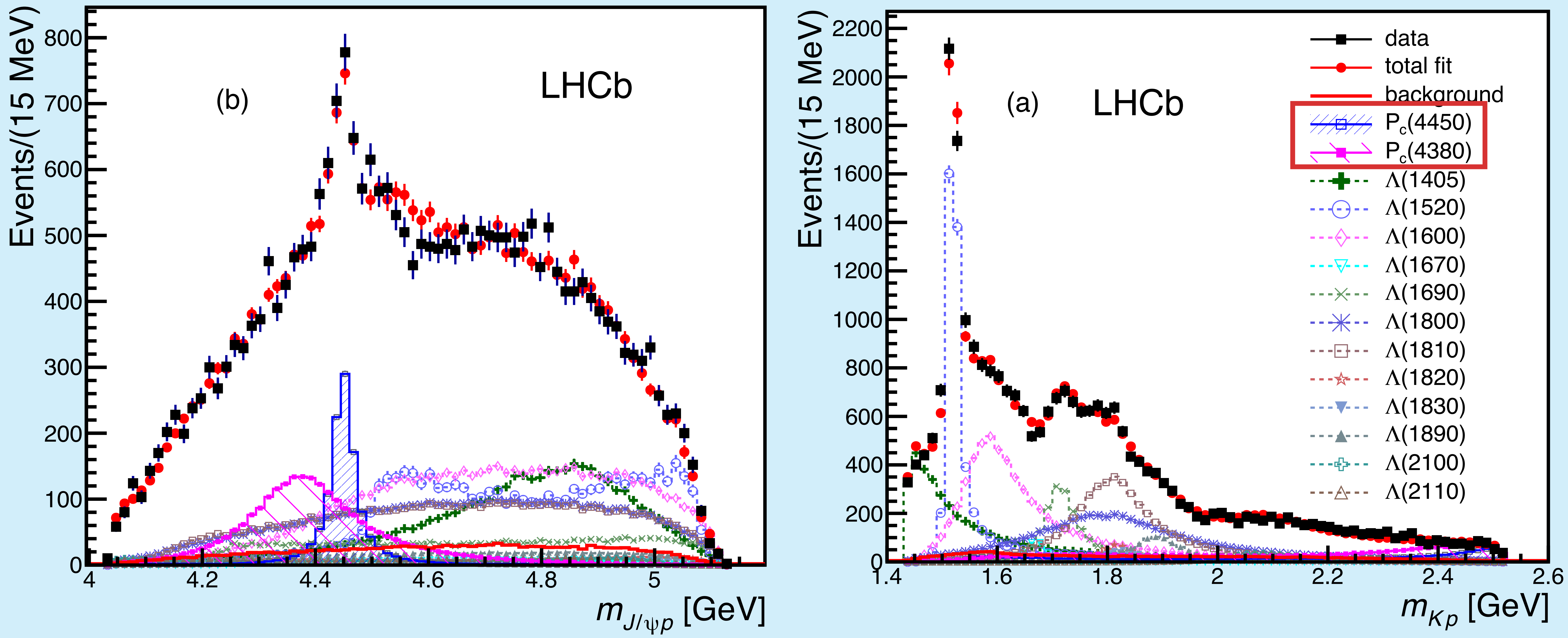
b mass: 4,200 MeV



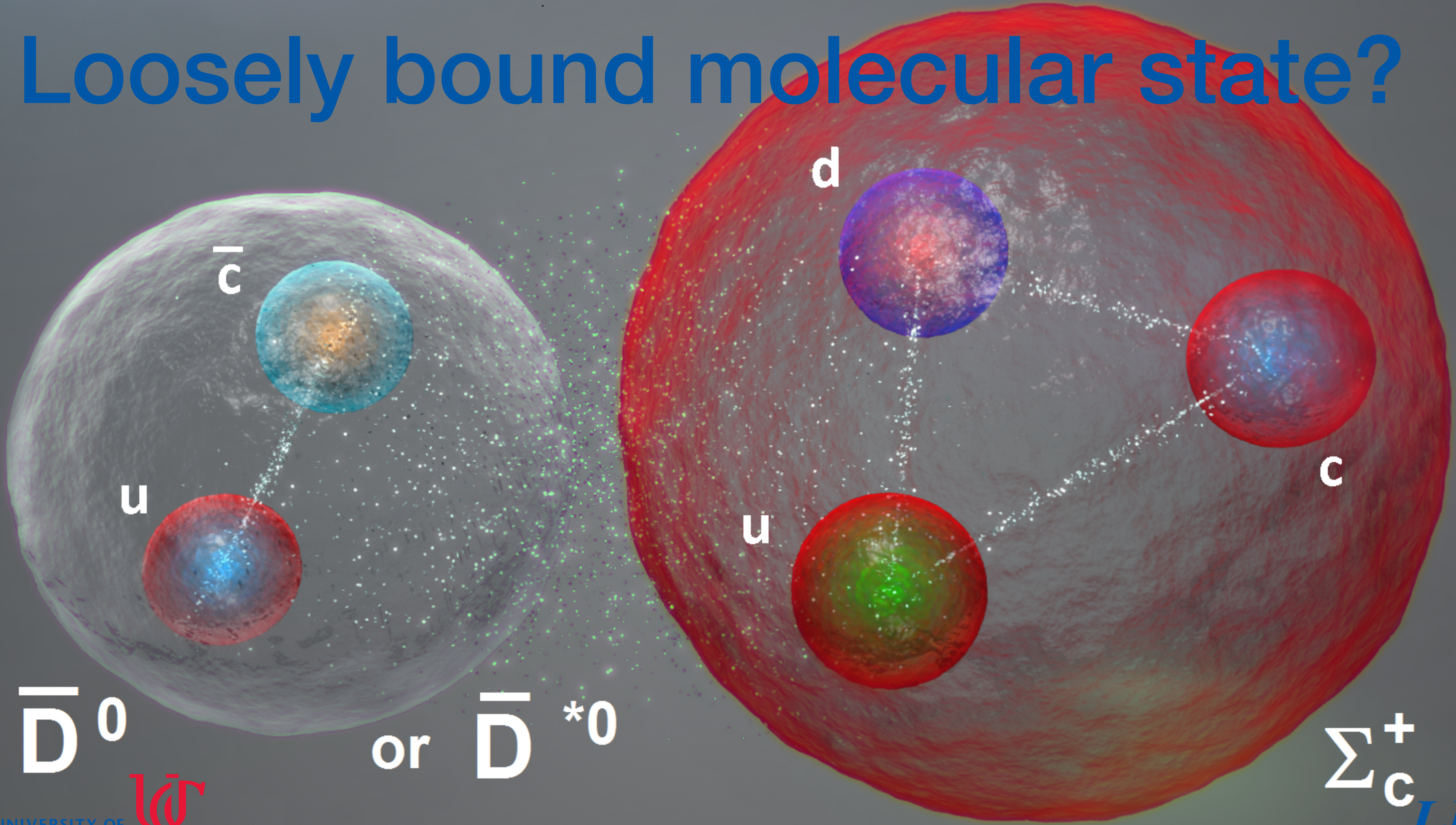
# Pentaquark

- $\Lambda_b^0 \rightarrow J/\psi p K^-$
- 2015: Observed
  - Now looks like 2 structures
- 2019: Second pentaquark observed

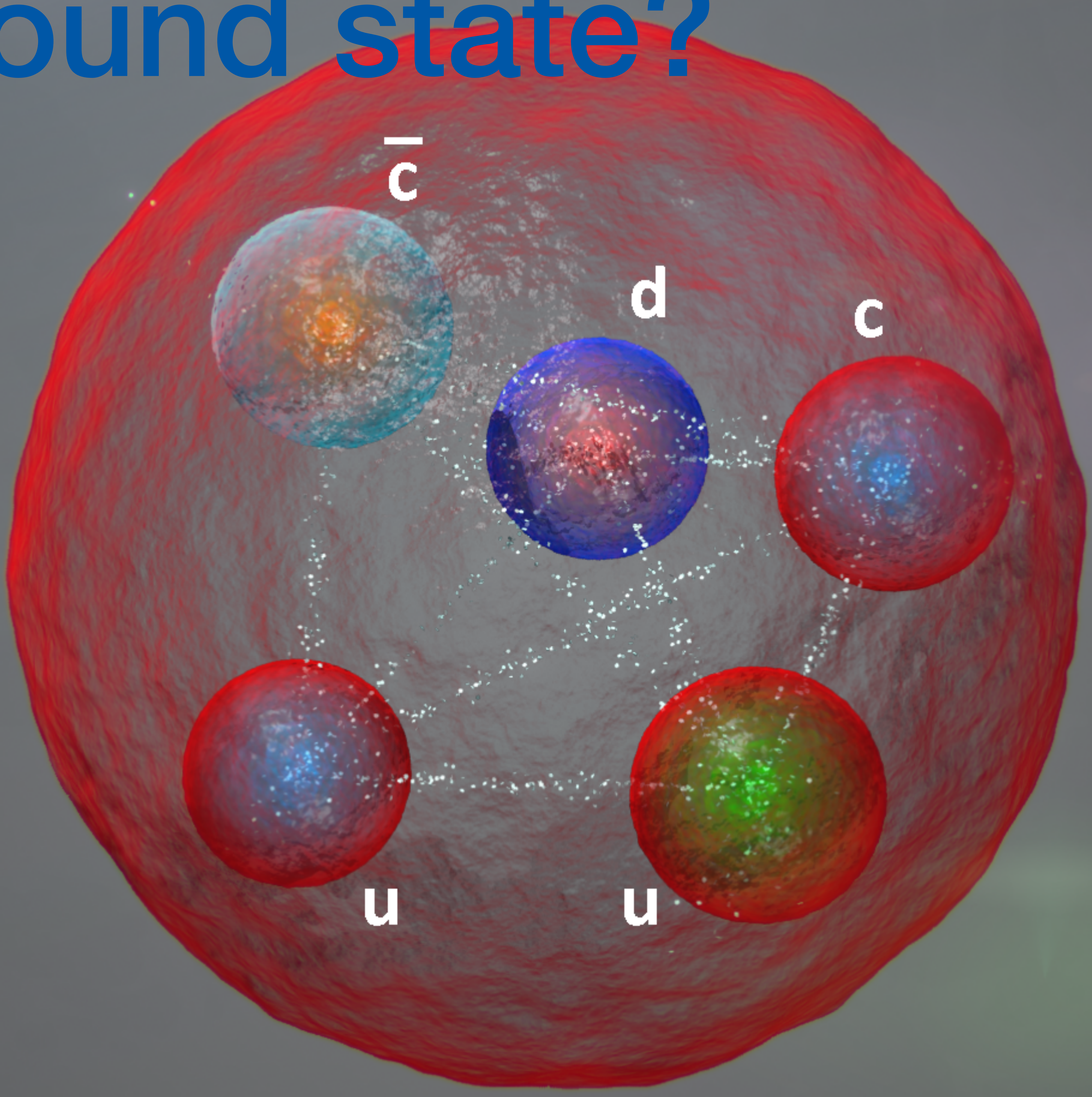


# Loosely bound molecular state?



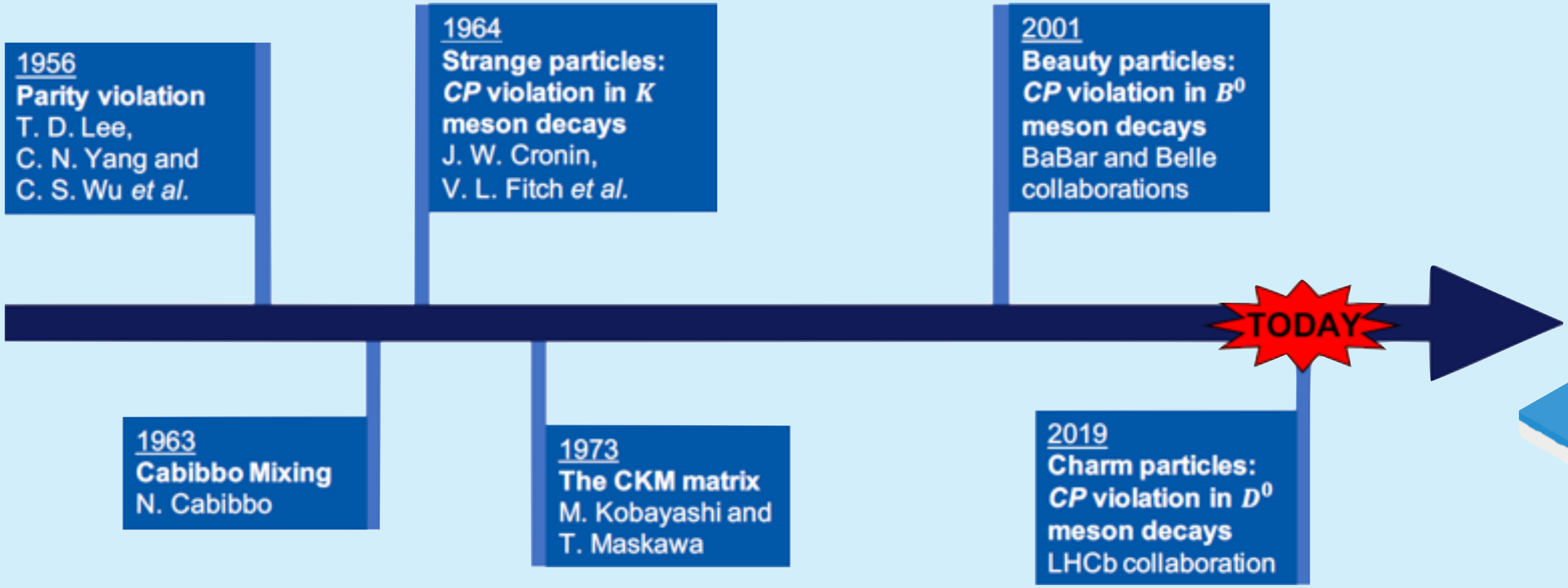
# Tightly bound state?

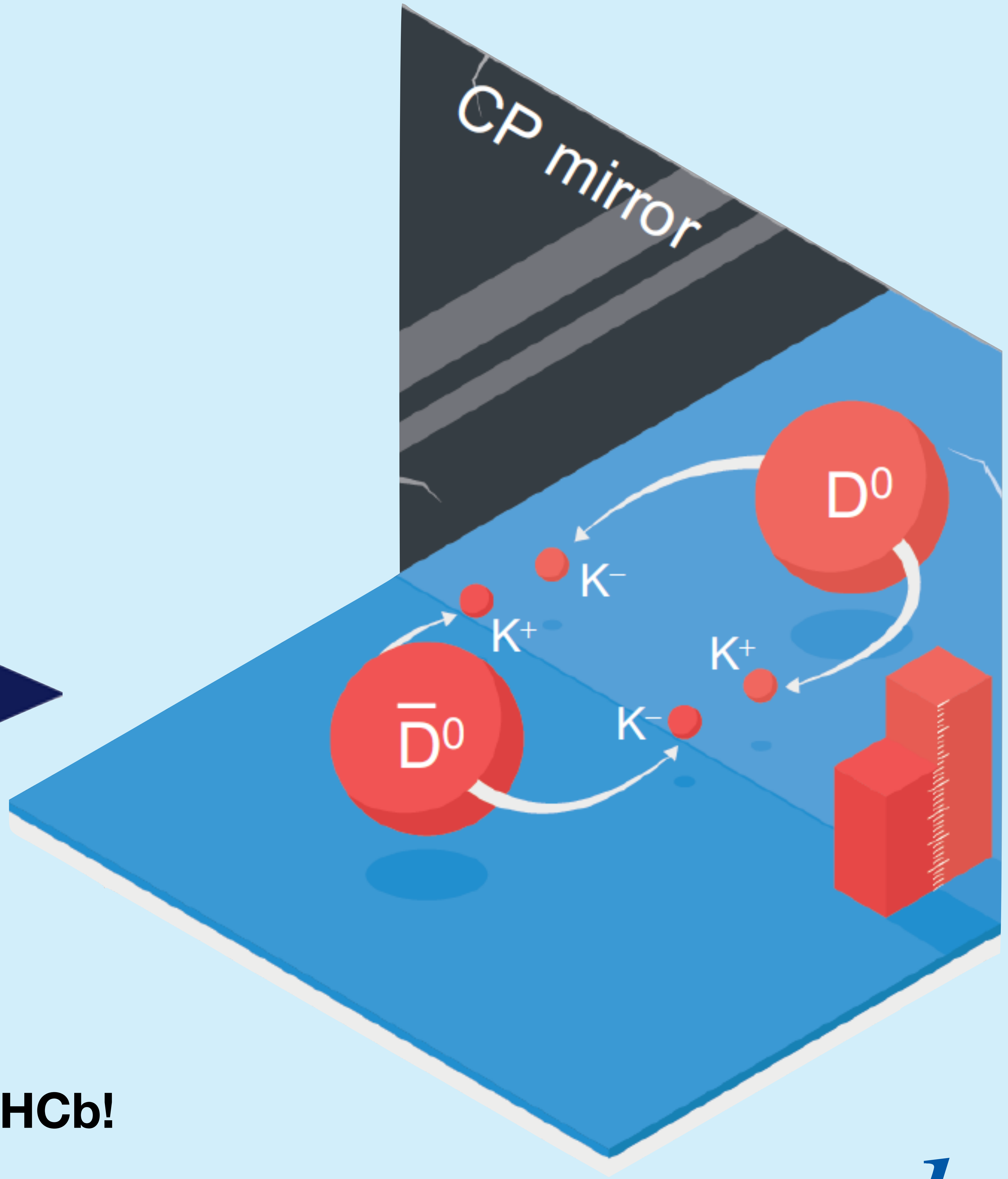


# Charm CP violation

**Results**

- 53 million $D^0 \to K^- K^+$ decays
- 17 million $D^0 \to \pi^- \pi^+$ decays




**CP violation observed in charm decays at LHCb!**

# The Upgrade



- We are now in the upgrade era (run 3, CMS/ATLAS change in run 4)
  - We are looking for new physics and trying to take high precision measurements
- Software L0 trigger
- More PP collisions per event
- Opportunity for charm physics and dark matter candidate searches!

# Challenges

Upgrade

- 1MHz to 40 MHz readout
- Factor of five luminosity increase
  - More interactions per crossing
- Computers have been getting more transistors but not faster
- Storage will also be a huge issue

Looking into GPUs, FPGAs, machine learning algorithms, and more

# Conclusions

- The LHC is an exciting place to do physics
- LHCb is uniquely positioned to capture interesting physics
- Ground breaking results are have been and will be achieved!
- LHCb in the lead facing challenges for the LHC upgrade

# References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- Overview of LHCb, H. Terrier, arXiv:hep-ex/0506047
- https://home.cern/sites/home.web.cern.ch/files/2018-07/CERN-Brochure-2017-002-Eng_0.pdf
- https://arxiv.org/pdf/1507.03414.pdf
- http://lhcb-public.web.cern.ch/lhcb-public/

# Resources

- http://lhcb-public.web.cern.ch/lhcb-public/en/Detector/Detector-en.html
- https://www.eurekalert.org/multimedia/pub/88092.php?from=290875
- https://lhcb.web.cern.ch/lhcb/speakersbureau/html/Material_for_Presentations.html
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