

MSc projects in LHCb

Exciting states of D_s mesons

Suzanne Klaver

25 April 2021



Who am I?



- BSc from UCR, Middelburg
 - MSc at UvA/Nikhef
 - PhD in Manchester
 - PostDoc in Frascati
 - PostDoc at VU/Nikhef (Veni)
 - I had no clue about any of the following projects as MSc student ;-)
- mainly LHCb data analysis
- mainly software development (so far, to change)

Where am I?

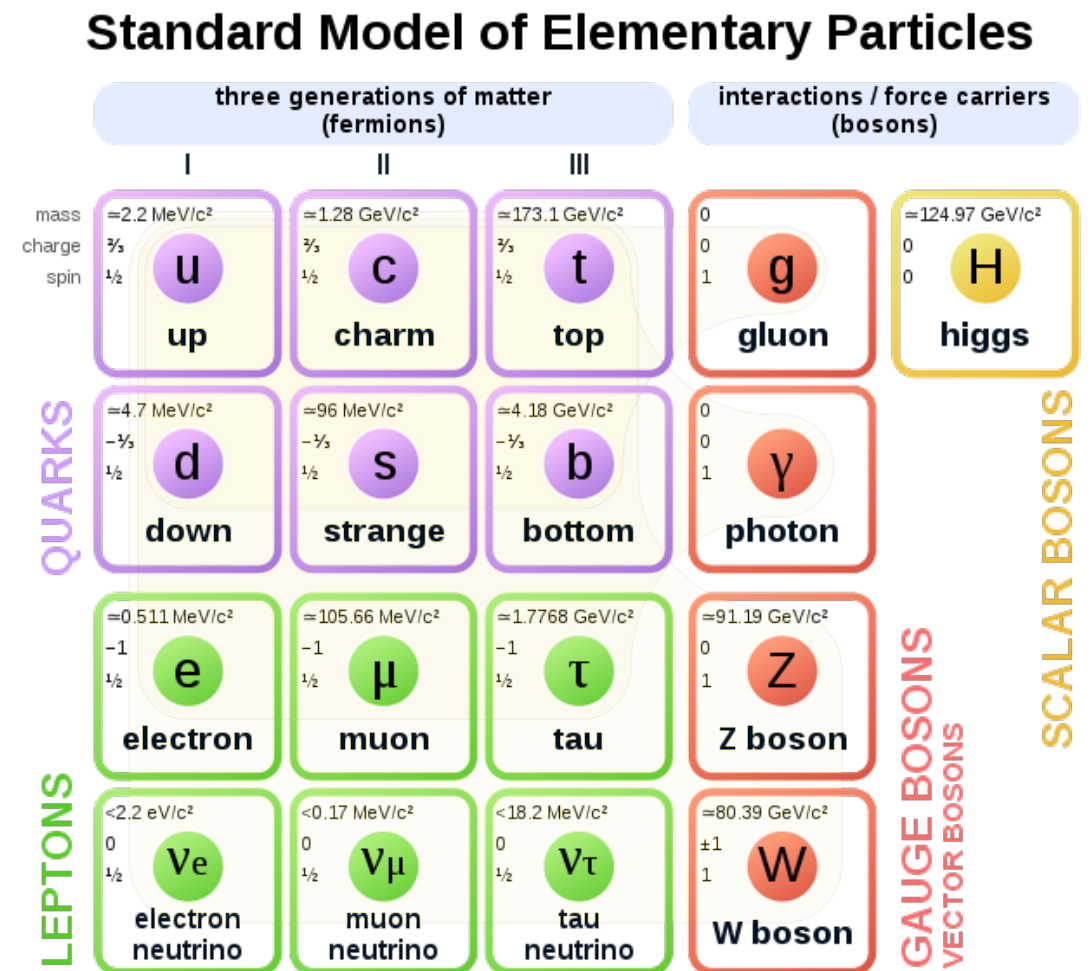
.....



Lepton flavour universality

In the SM there are three families of fermions:

- same gauge charge assignments
→ same coupling (**universality**)
- only difference from the Yukawa couplings with the Higgs field, resulting in **CKM** and **PMNS** matrices and **different masses**
- measure lepton universality in **ratios**: CKM elements cancel, and only difference is in **lepton mass**



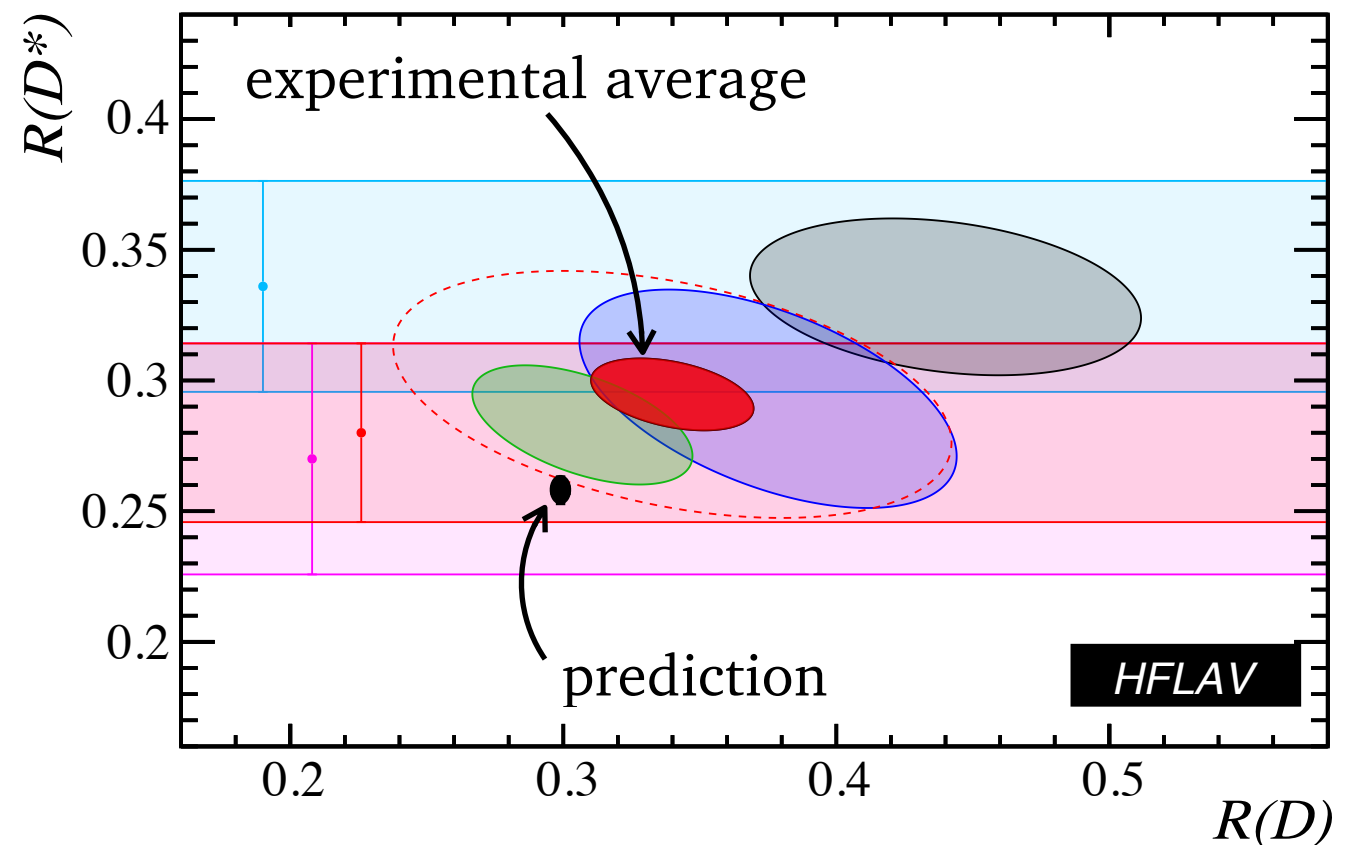
Overview $R(D)$

$$\mathcal{R}(D^*) = \frac{\overline{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau}{\overline{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu}$$

$$R(D) = N \left(\begin{array}{c} \tau \\ \nu_\tau \end{array} \right) / N \left(\begin{array}{c} \mu \\ \nu_\mu \end{array} \right)$$

The diagram shows two Feynman diagrams for the decay of a $\overline{B}^0$ meson. The left diagram represents the decay into $D^{*+} \tau^- \bar{\nu}_\tau$, where the τ and ν_τ are enclosed in a red dashed circle. The right diagram represents the decay into $D^{*+} \mu^- \bar{\nu}_\mu$, where the μ and ν_μ are enclosed in a blue dashed circle. Both diagrams show a b quark and a d quark line, with a W boson exchange between them, and a c quark line.

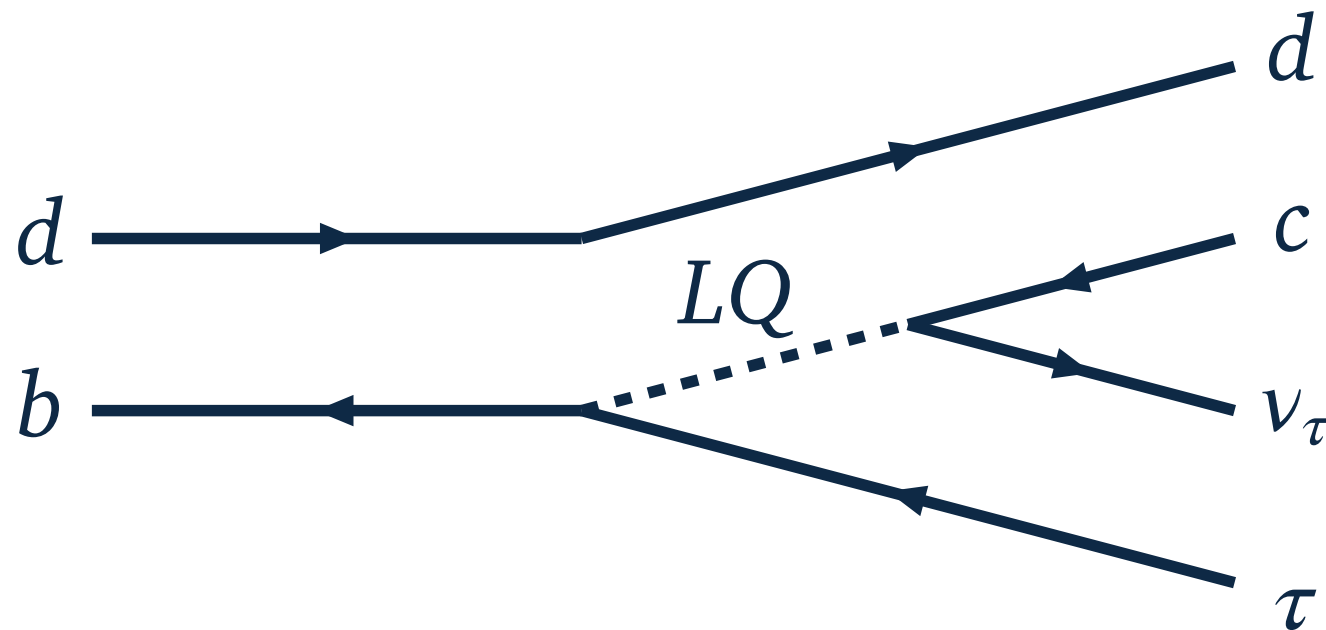
- $R(D) \neq 1$,
because $m_\tau \neq m_\mu$
- Tree-level processes are sensitive to new physics.
- Predictions are theoretically clean.
- 3-4 σ tension with the SM for $R(D)$ - $R(D^*)$.



<https://hflav-eos.web.cern.ch/hflav-eos/semi/spring19/html/RDsDsstar/RDRDs.html>

Where does tension come from?

- Could there be **new physics**?
- What could this be? Z' ? Leptoquarks?

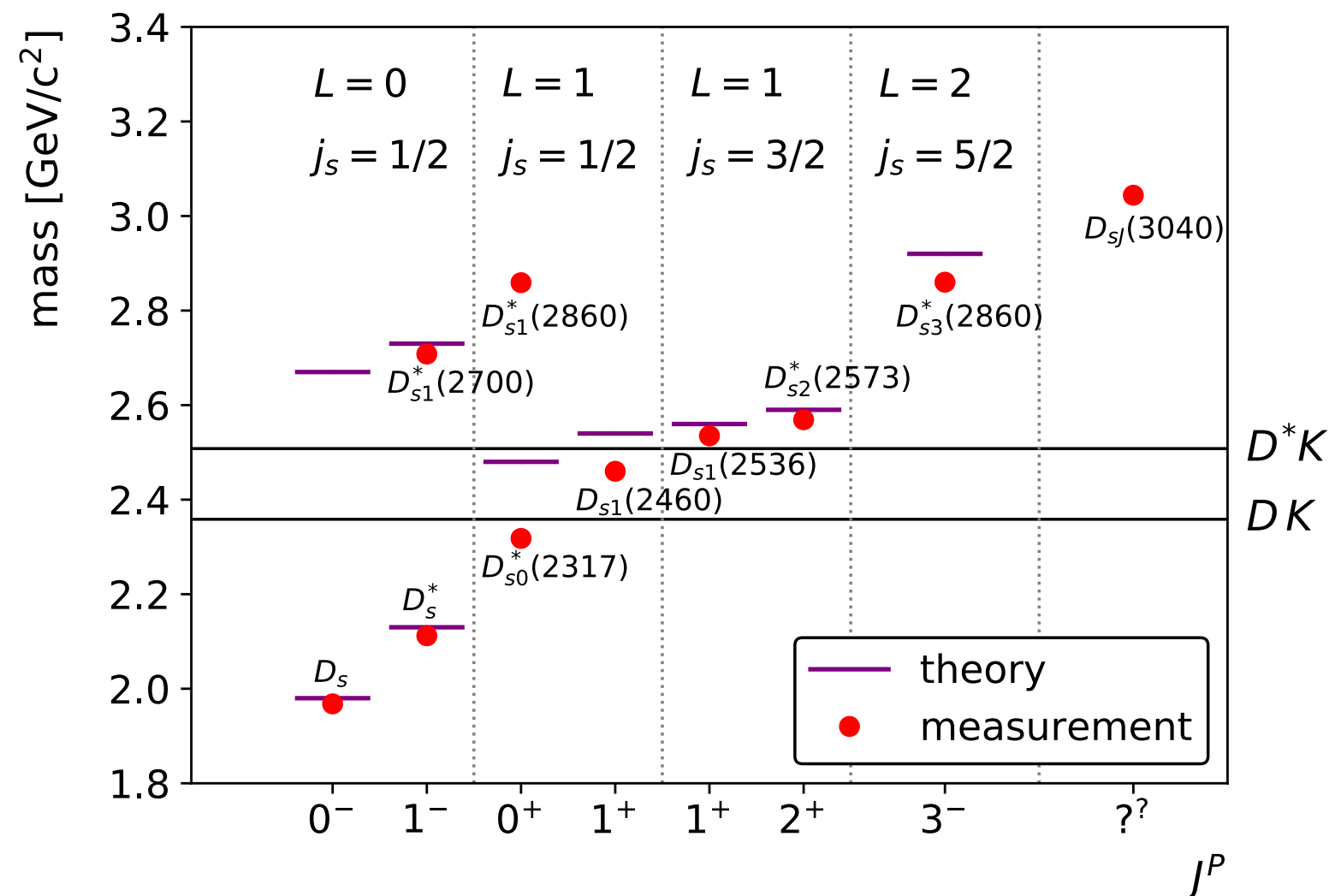


- More measurements needed! :)
 - other ratios: use B_s decays instead of B
 - different quantities, different types of particles

MSc project ideas

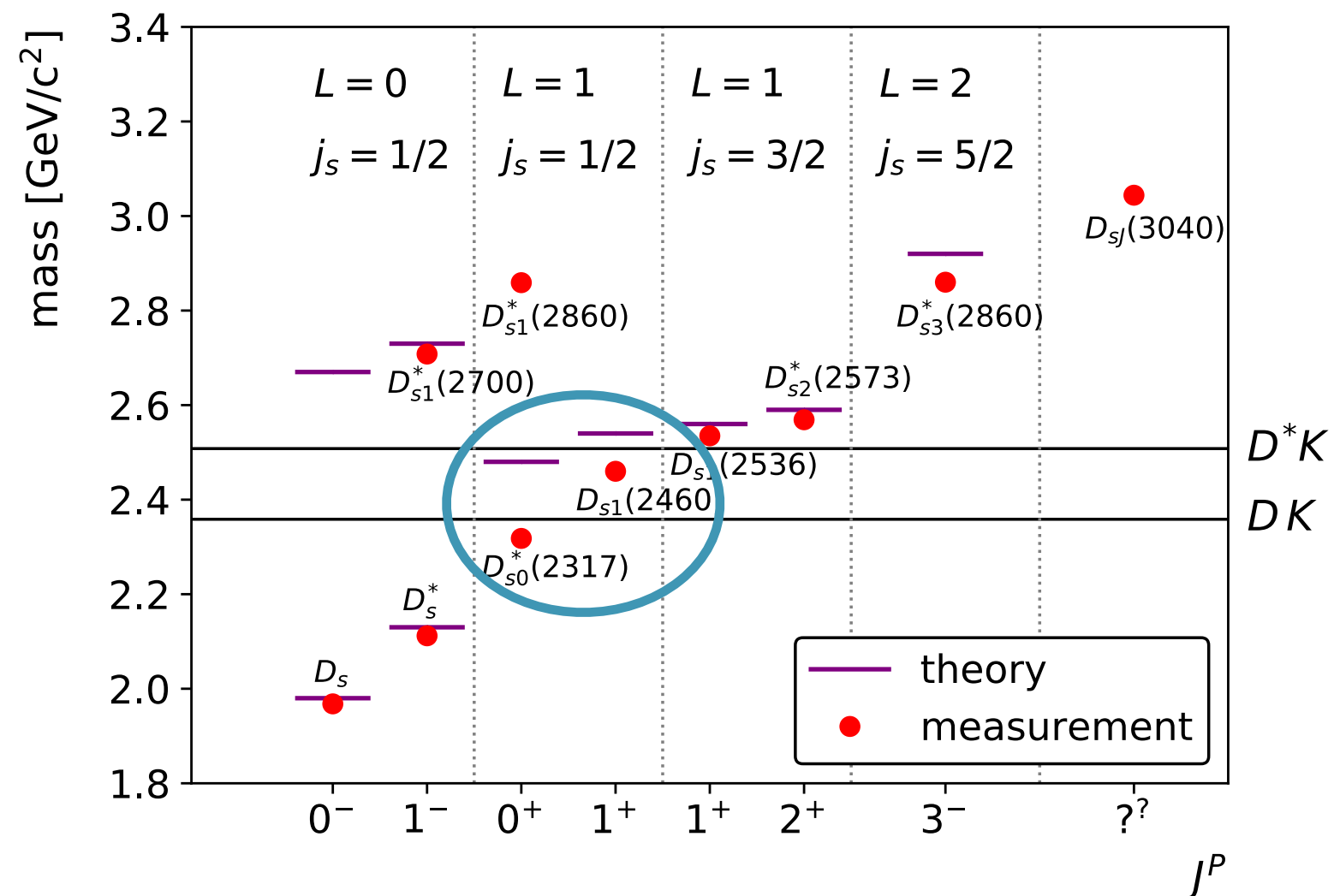
Excited states of D_s mesons

- Analogous to hydrogen atom, mesons can have radial and orbital excited states



Excited states of D_s mesons

- Some have a mass that's very different from the predicted mass, but it's not clear why.
- D_s excited states are very different from the D because they're very narrow, rather than very broad.

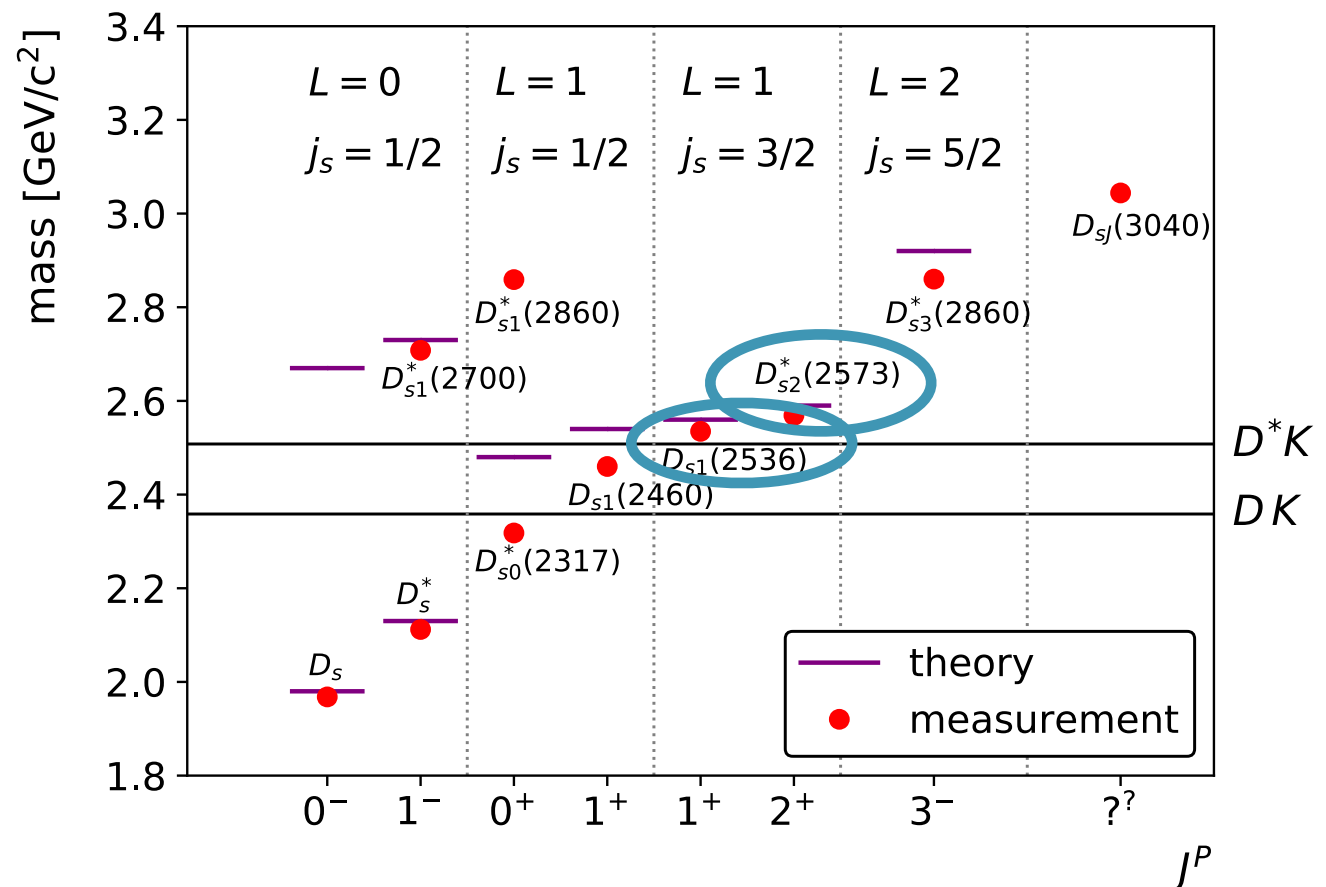


Measure the $D_s(2317)$

- The decay $B_s \rightarrow D_s(2317)\mu\nu$ never been measured before, but should be there!
 - a lot lighter than predicted, but why?
 - test its nature: molecular state/tetraquark?
[PhysRevD.92.014031](#)
 - also important to understand for future $R(D_s)$ measurements
 - measurement as a function of q^2 if possible
 - could be finished within a year

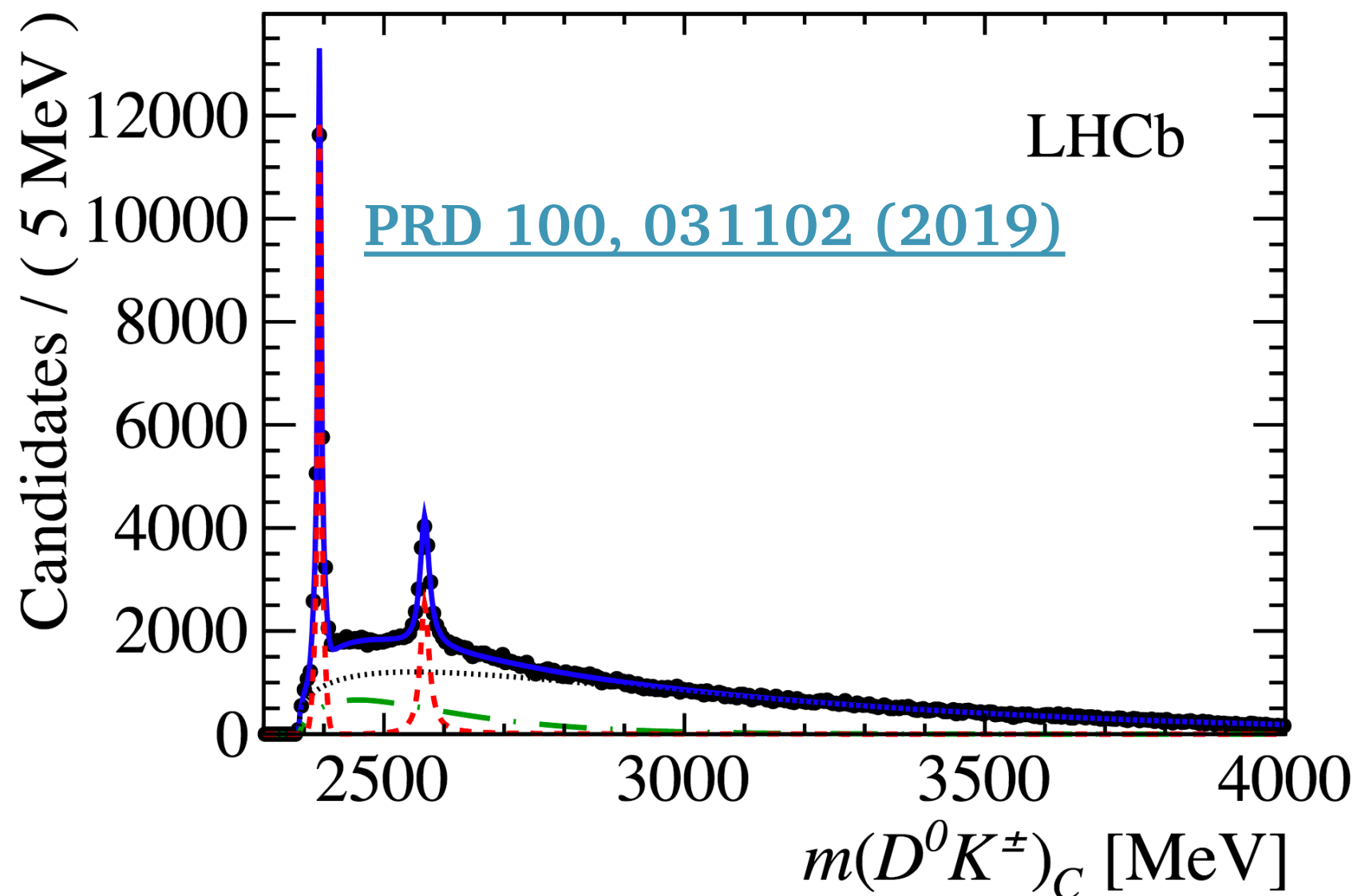
$R(D_s^{**})$

- Excited (radially and/or orbitally) states have access to different new physics couplings [PhysRevD.95.014022](#)
- Best place to look for it is in B_s decays
 - sharp, narrow peaks
- Ratio with $B_s \rightarrow D_{s1}(2536)\tau\nu$ and $B_s \rightarrow D_{s2}^*(2573)\tau\nu$
- New type of measurement
- Feasibility study



$R(D_s^{**})$

- Decay to $D^0 K$ final state: easy to reconstruct and beautifully narrow peaks.



Skills you can learn

- Prerequisites:
 - Particle physics courses, some programming
- To learn:
 - Many!
 - Data analysis
 - Physics
 - Programming: python/C++
 - Machine learning
 - Presenting to experts



BACKUP

LHCb experiment

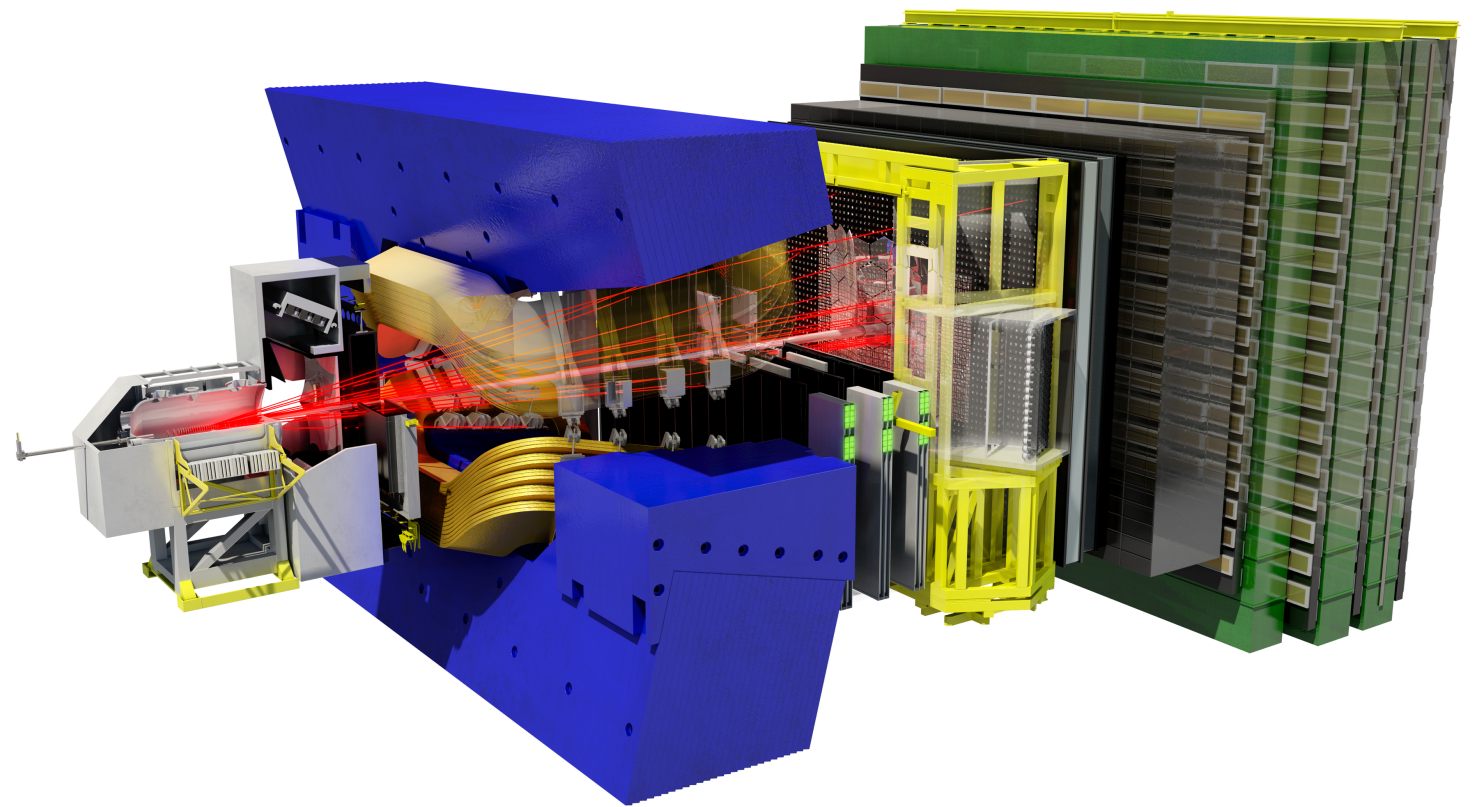
JINST 3 (2008) S08005

- pp collisions @ LHC
- b quarks produced by gluon fusion $\rightarrow$ forward direction
- boosted CM energy helps to reconstruct vertices
- many more b 's, but a lot more background
- all b -hadron species are produced: B^+ , B^0 , B_s , B_c , Λ_b

Run 1: 2011–2012: 3 fb⁻¹ @ 7-8 TeV

Run 2: 2015–2018: 6 fb⁻¹ @ 13 TeV

Run 3 starting next year!



Something completely different

Data quality monitoring (DAQ)

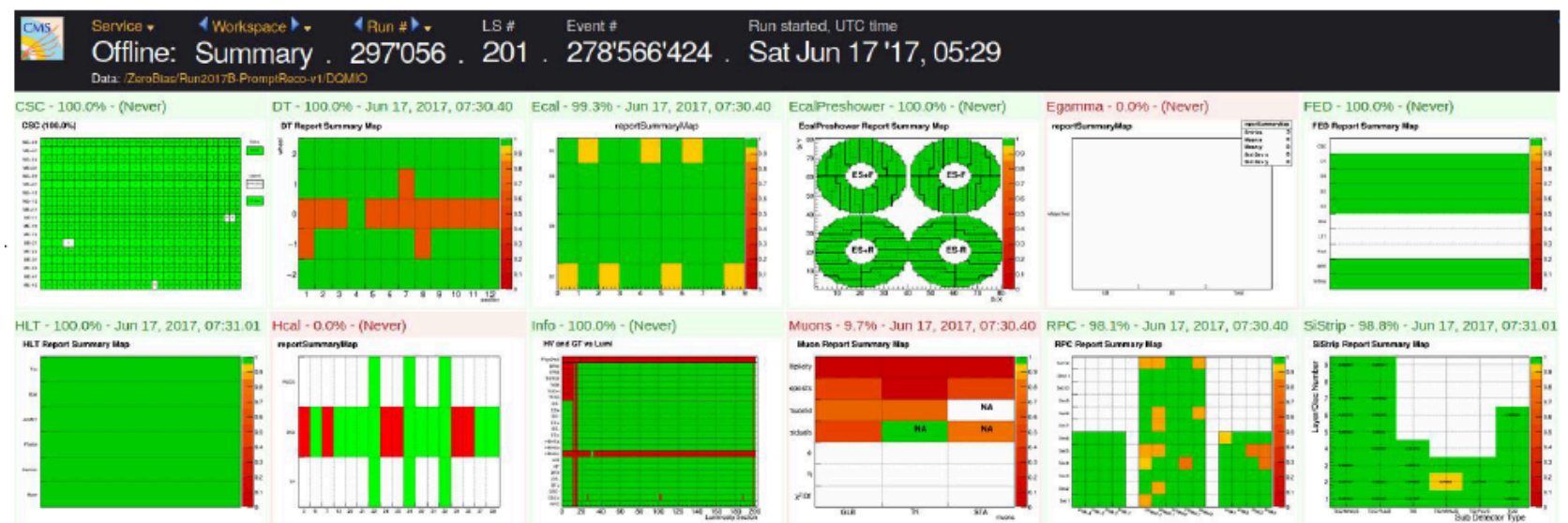
Monitoring

- LHCb is installing completely new detector, with completely new software
- Start data taking in 2023
- Good data come from a well-monitored detector!
- Can we improve the data quality monitoring?

General strategy DQ monitoring

- Many subsystems with their own type of histograms and issues
- Afterwards combined to a single flag from all subsystems as **GOOD/BAD**

example from CMS:



pixel



strip



ECAL



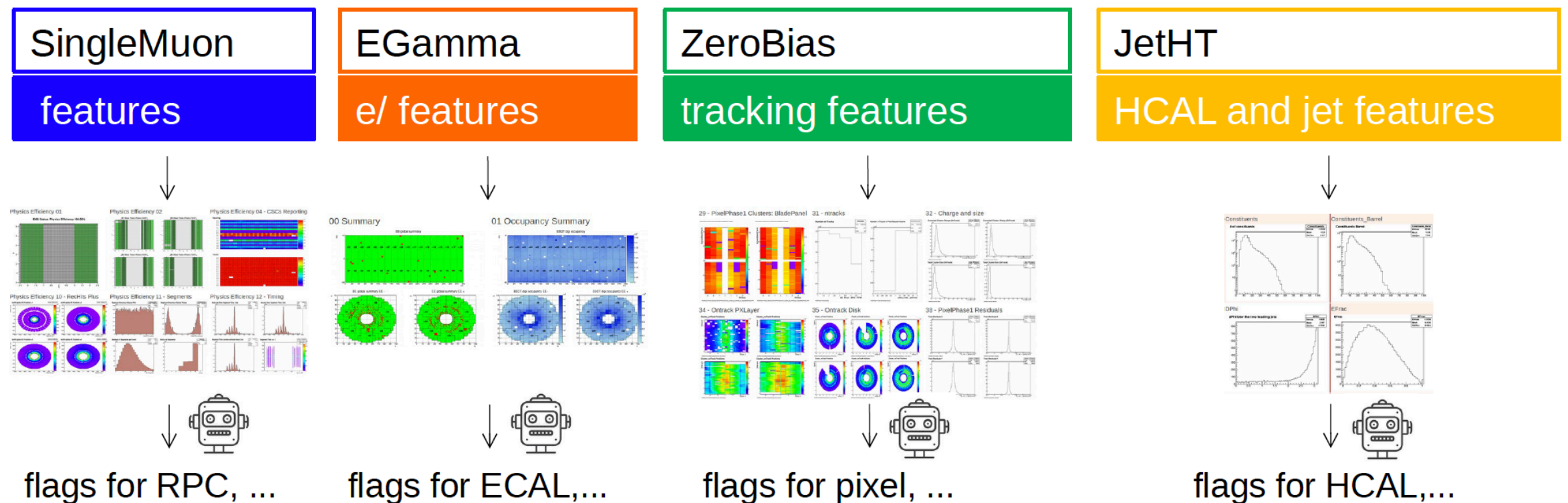
HCAL

...

Run Number	btag	castor	cms	csc	ctpps	lowlumi	dt	ecal	es	egamma	hcal	hlt
297046	GOOD	EXCLUDED	GOOD	GOOD	BAD	BAD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
297047	GOOD	EXCLUDED	GOOD	GOOD	BAD	BAD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
297048	GOOD	EXCLUDED	BAD	GOOD	BAD	BAD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
297049	GOOD	EXCLUDED	BAD	GOOD	BAD	BAD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
297050	GOOD	EXCLUDED	GOOD	GOOD	BAD	BAD	GOOD	GOOD	GOOD	GOOD	GOOD	B G
297056	GOOD	EXCLUDED	GOOD	GOOD	BAD	BAD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
297057	GOOD	EXCLUDED	GOOD	GOOD	BAD	BAD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD

ML strategy DQ monitoring

- Many subsystems with their own type of histograms and issues
- Each subsystem finds their own optimal ML method to use



- Afterwards combined to a single flag from all subsystems as **GOOD/BAD** (similar to human-based approach)
- Many successful approaches from different experiments

Monitoring

- LHCb is installing completely new detector, with completely new software
- Start data taking in 2023
- Good data come from a well-monitored detector!
- Can we improve the data quality monitoring?
- Advantages ML:
 - less people needed,
 - so less prone typical human errors (e.g. fatigue, lack of focus, dependence on clear visualisation, ...).