Anomalies in flavour physics

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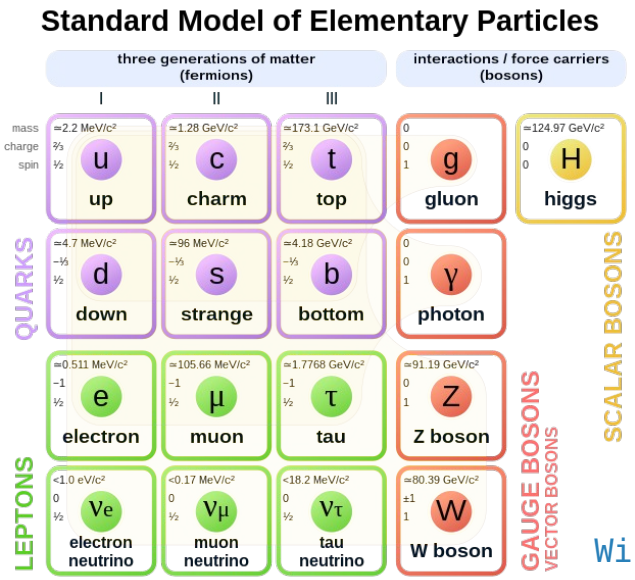
What is Flavour physics?

- 3 copies of each quark and lepton
- SM says same interactions, different masses



Wikipedia

What is Flavour physics?

- 3 copies of each quark and lepton
- SM says same interactions, different masses
- CKM and PMNS matrices have some structure

What is Flavour physics?

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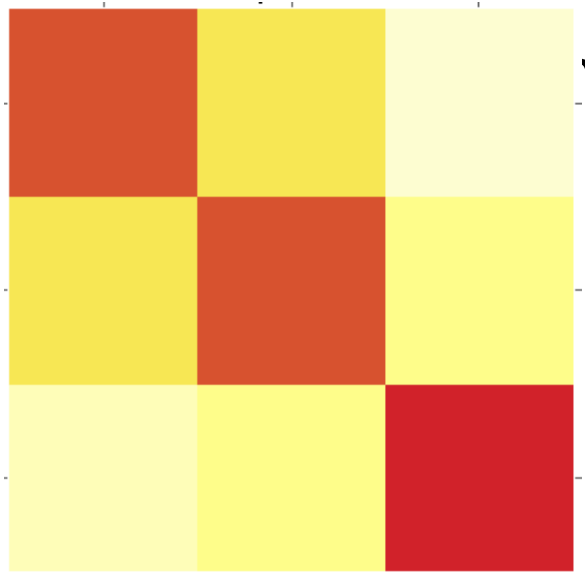
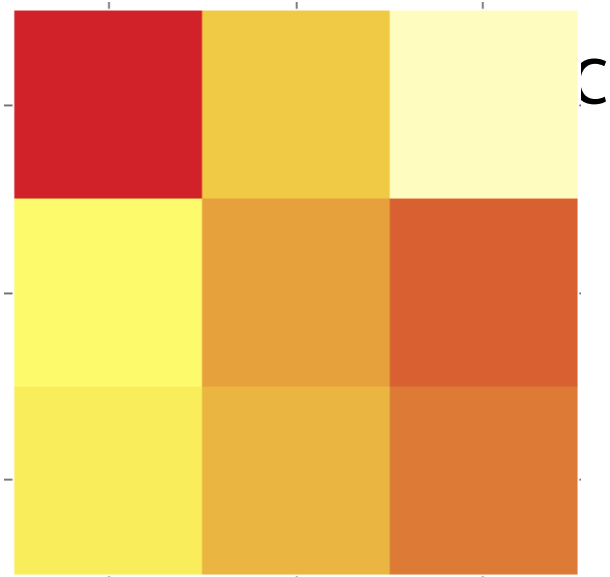
- C  natrices  cture

What is Flavour physics?

- CKM particularly – governs quarks physics
- Study of quark transitions
- Big picture – why is the CKM / flavour structure the way it is?

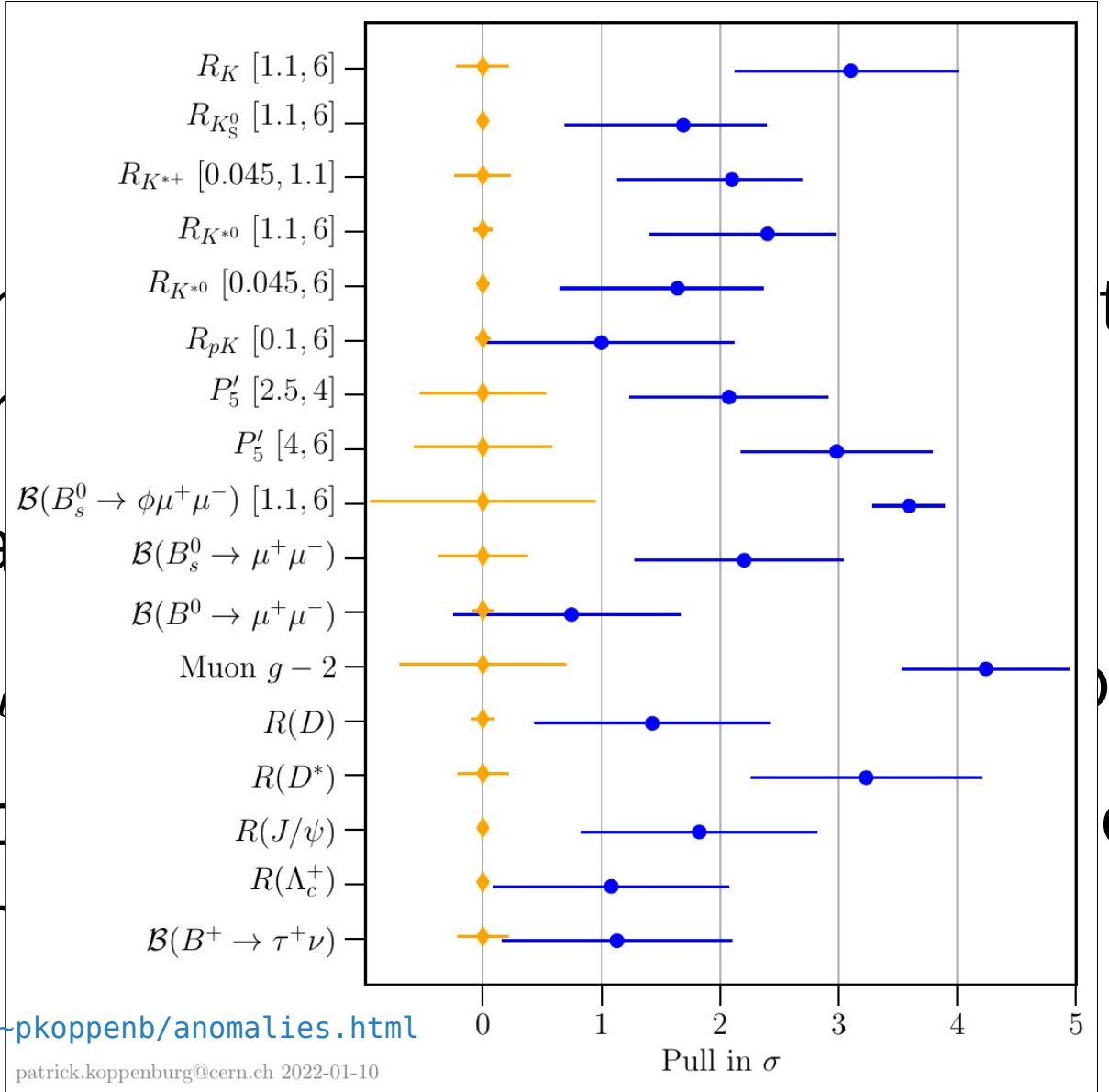
What are anomalies?

- Word with multiple meanings, even within jargon of quantum field theory
- Gauge anomalies – classical symmetries, violated at quantum / loop level
- Here, measurements that doesn't agree with predictions

Flavour anomalies

- R_K : generally what people mean by just "flavour anomalies"
- $R(D)$: also often included
- $(g-2)_\mu$: very different physics, but also muons
- Cabibbo anomaly: new theory driven anomaly, first generation quarks

- R_K : ger … t "flavour …
- $R(D)$: a …
- $(g-2)_\mu$ … muons
- Cabibbo … omaly, first ger …



https://www.nikhef.nl/~pkoppenb/anomalies.html

R_K

- $B \to K\mu^+\mu^- / B \to Ke^+e^-$
- By taking the ratio, many parts of the calculation cancel
- Also experimentally many things cancel
- $b \to s\ell^+\ell^-$

$R(D)$

- $B \to D\tau\nu / B \to D\ell\nu$
- Similar to R_K , ratio is easier (but not as easy)
- $b \to c\ell\nu$
- So also $R(\Lambda_c) = \Lambda_b \to \Lambda_c^+ \tau^- \nu / \Lambda_b \to \Lambda_c^+ \ell^- \nu$

$(g-2)_\mu$

- Muon is spin ½ particle, electrically charged
- Has g factor, approx 2

Caibbo Angle Anomaly

- SM says CKM must be unitary
- Measurements of values using first generation quarks disagrees
- BUT: driven entirely by new theory calculations

Why are people excited (or not)?

Why are people not excited?

- CAA: New theory corrections started the anomaly
- Lots of reevaulations going on
- Not a clear picture

Why would people be excited?

- Some measurement that disagrees with SM, but does agree with some previously known new theory
- No previous new theory known, but easy to write something down
- No previous new theory known, but hard to write something down

Why would people be excited?

- Some measurement that disagrees with SM, but does agree with some previously known new theory
  - Suggests new theory is on the right track
  - Hopefully new theory tells us something more too

Why would people be excited?

- No previous new theory known, but easy to write something down
  - Lots of work to do, lots of papers to publish
  - Opportunities for all

Why would people be excited?

- No previous new theory known, but hard to write something down
  - Easy to falsify, not much tweaking allowed
  - Tighly defined structure hopefully tells you something
  - And big reward for those who can

Why are people excited (or not)?

- R_K : easy to write down theories
- $R(D)$: easy to write down theories
- $R_K + R(D)$: hard to write down theories without other effects

Why are people excited (or not)?

- R_K : simple add on to SM
- $R(D)$: simple add on to SM
- $R_K + R(D)$: something that requires detailed framework

What are the explanations?

- Z′: suggests new gauge symmetry, with flavour component
- Scalar LQ: easy to add on, suggest quark lepton unification
- Vector LQ: needs serious structure to explain mass

The future

It is not a mass peak. Now what?

~6σ being said. What would convince us as a community?

* Provocative questions to launch the discussion

https://indico.cern.ch/event/1055778/contributions/4561385

The future

b→sll Discussion: Building Consensus

How can we – HEP Community - convince ourselves (& the world..) ?

1) how conservative does one need to be?

2) how to quantify the significance?

3) how to proceed from here?

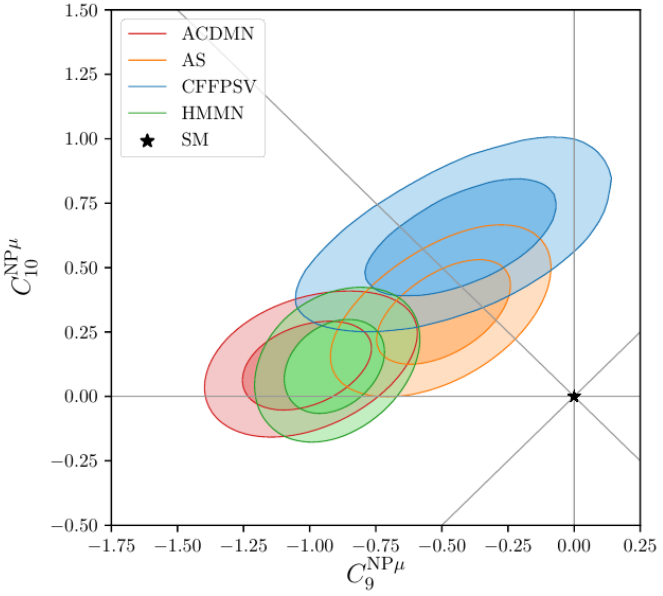
https://indico.cern.ch/event/1055778/contributions/4561385

Thanks!

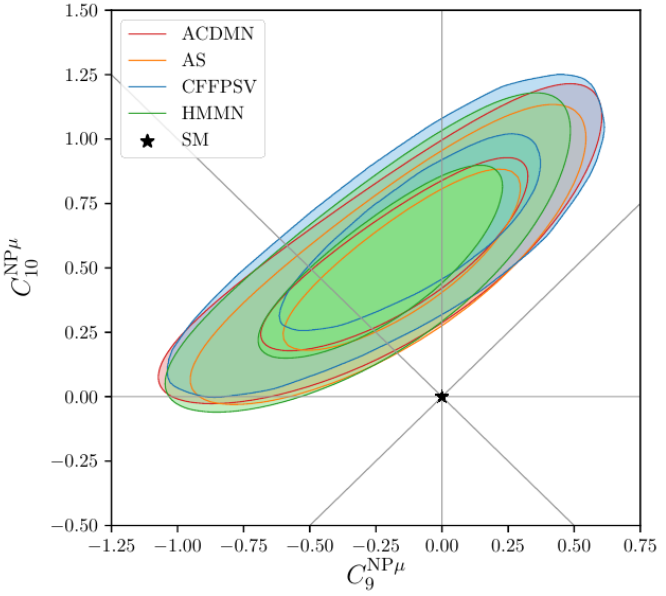
BACKUP

“Consensus talk” : important outcome yesterday

- Extremely interesting collaborative work:



global fit

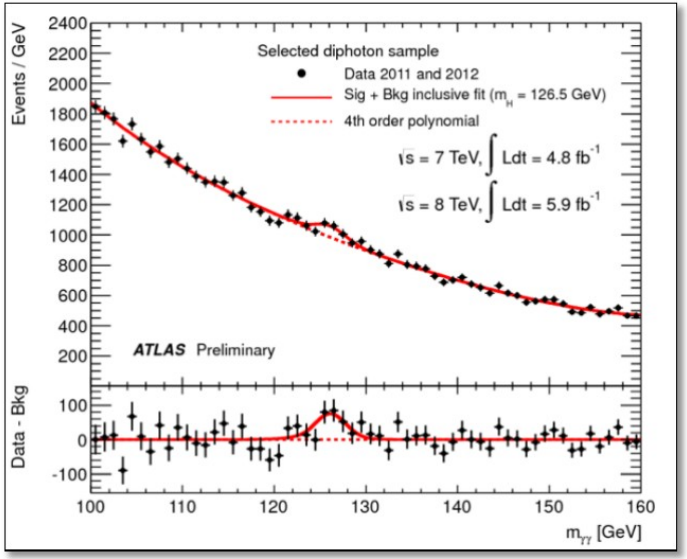


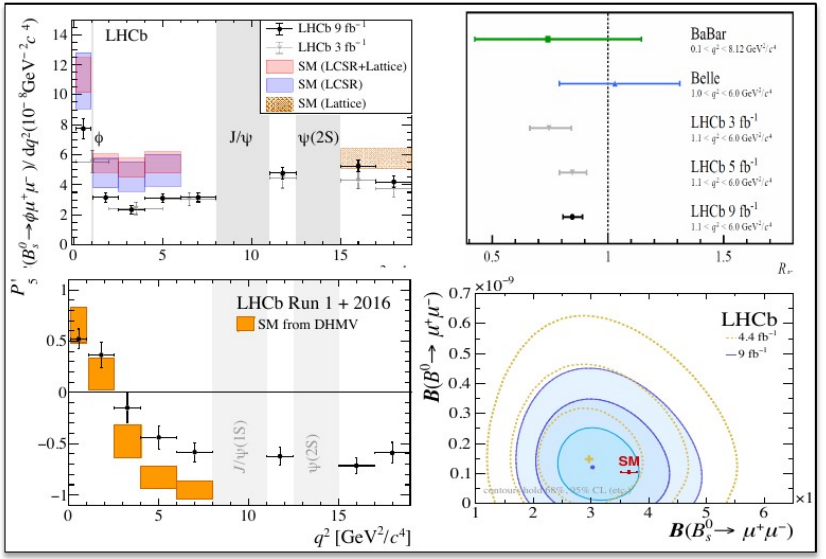
fit to LFU observables + $B_s \to \mu\mu$

- Comparison when using same input?

2) Quantifying significance ?

Higgs vs $b \to s l^+ l^-$





p-value of SM hypothesis?

$\Delta\chi^2$ wrt discovery hypothesis *(coherent pattern)* ?

Look-elsewhere effect ?

CKM matrix (V)

- 3x3 unitary matrix by construction
- We can talk about "unitary conditions", which are SM predictions like any other
- One prediction is "first row unitarity"
  - $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

- As recently as 2018 (1807.01146)
  - $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9994 \pm 0.0005$
- Good agreement with SM prediction

Beta decay

- 2018 value of V_{ud} uses Δ_R^V from 2006 (hep-ph/0510099)
- At end of 2018, new value of Δ_R^V (1807.10197)
- Gives $V_{ud} = 0.97370 \pm 0.00014$
- $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9985 \pm 0.0005$
  - Using 2020 PDG for V_{us}