Flavour Physics: A Taster

CERN Summer Student Lecture Programme 2020

Student Q&A Session, and some resources

3 Aug 2020

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Questions from students:

If the CP violation doesn't exist, could our universe and us form as today?
(Erdene Bulgan)

Short answer: probably not!

Without CP Violation, the matter-antimatter asymmetry of our universe could not be generated **dynamically** during the earliest stages after the big bang.

There is a loophole – if the big bang itself were asymmetric, and produced more matter than antimatter, we would no longer need CP violation.
⇒ This brings its own problems – why an asymmetric BB?

Questions from students:

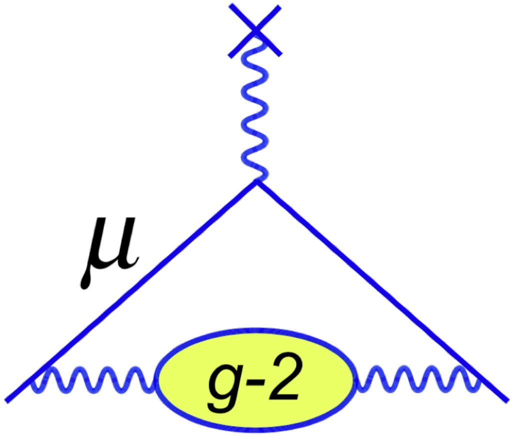
For the experimental deviations such as muon anomaly g-2, can a new particle (e.g. leptoquark) explain that?
(Erdene Bulgan)

Short answer: Yes (good question!)

Any quantity which has contributions from 'quantum loop' diagrams, i.e. new virtual particles being created and annihilated, will in general be influenced by new particles.

This includes the muon g-2 parameter, and the new particles can indeed include leptoquarks
e.g. the recent paper https://arxiv.org/abs/1910.03877
https://arxiv.org/abs/1612.06858

The challenge is to develop a theory which fits all the experimental observables **simultaneously**, while addressing the other big questions (matter-antimatter asymmetry, dark matter, etc)



Questions from students:

Is Lorentz invariance a gauge symmetry of gravity?
(Kandekar Jaydeep)

Short answer: No

Lorentz invariance is a principle governing the universe even without gravity

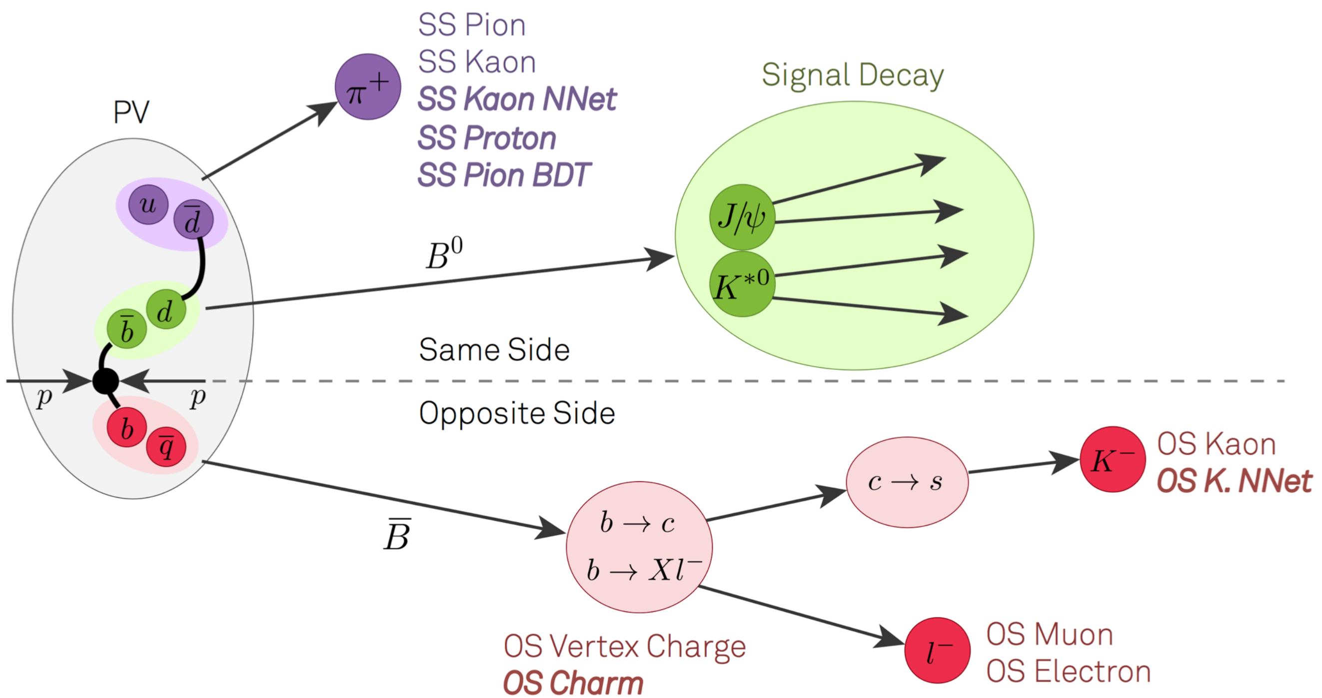
The best description of gravity is given by general relativity, which is **not** a gauge theory (but which does satisfy Lorentz invariance)

However – there are attempts to describe gravity as a gauge theory, like the other interaction ("Gauge gravitation theory" - https://en.wikipedia.org/wiki/Gauge_gravitation_theory)

Questions from students:

Could you explain some more on B tagging, please? It could be less than 30% accurate or even ~5% at LHCb. How is it possible to make precise measurements (e.g. CKM phases) without exact knowledge of the initial state?
(Arthem Uskov)

Short answer: Yes, I can explain some more 😀



Questions from students:

What other systematic uncertainties do you encounter at LHCb and most importantly, how do you mitigate them?
(Arthem Uskov)

Short answer: It depends on what we are trying to measure

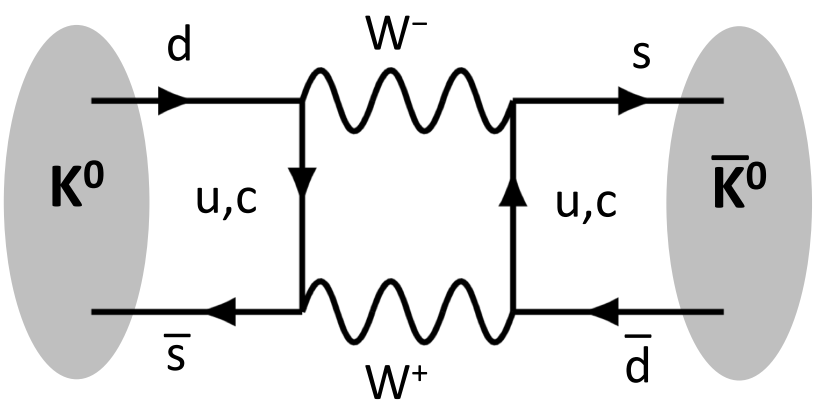
- Cross-section measurements
- Lifetime or mass measurements
- Searching for new particles or rare processes
- Charge asymmetries & CPV
- Lepton non-universality

What assumptions / inputs go into the measurements, and how much do we trust them?

Questions from students:

Is there any reason why the D^0 meson oscillates so much slower? Or is it just an experimental fact (by measuring Δm)?
(Carolina Bolognani)

Short answer: Yes! There are good reasons coming from symmetries of nature



$$\Delta m_k = \frac{G_F^2}{4\pi} m_K f_K^2 m_c^2 \left| V_{cs} V_{cd} \right|^2$$

Questions from students:

Could you explain where the strong phase comes from? Is it well determined for different decay processes or can we only see its effect through a combined parameter with the weak, CP violating, phase?
(Carolina Bolognani)

Short answer: Yes, I can try to explain

Quantum mechanical processes have complex amplitudes, which can be described by magnitude and phase. For strong (QCD) interactions these are invariant under a CP transformation – they are what we call strong phases.

They cannot be predicted reliably, due to the complexity of QCD processes (where many different diagrams can contribute)

But… they can be measured with a sample of ‘quantum entangled’ decays

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(Carolina Bolognani)

Examples of strong phase measurements:

https://arxiv.org/abs/1210.0939 (CLEO $D^0 \to K^{\pm}\pi^{\mp}$)

https://arxiv.org/abs/2007.07959 (BES-III $D^0 \to K_S^0 K^+K^-$)

Principle:
(1) Operate e^+e^- collider at an energy which produces $\psi(2S)$ mesons, which decay immediately into a $D^0\overline{D}^0$ pair (and nothing else)

(2) The two charm mesons are correlated in their initial states, which allows the strong phase to be determined by inspecting both D^0 and $\overline{D}^0$ decays

Questions from students:

Why is the Strong CP Problem a problem? I would expect that the quarks breaking CP in weak interactions wouldn't interfere with the quarks breaking CP or not in strong interactions, as the CP violation comes from the interaction and not from the type of fermion that it is interacting.
(Beatriz de Errico)

Short answer: CPV is allowed in the standard model of strong interactions, so why does it happen to be identically zero? It just seems unlikely without some underlying cause.

$\Rightarrow$ Related to the broader issue of 'naturalness'

Questions from students:

If the neutrinos are indeed majorana particles, than how could you explain the complex phase in the PMNS matrix? That is, how could there be CP violation for neutrinos if they are their own antiparticle, would the PMNS need alteration?
(Beatriz de Errico)

Short answer: Good question – it is complicated!

The PMNS matrix is indeed in general different for 'Dirac' and 'Majorana' neutrino hypotheses
The usual phase δ_{CP} is often called the 'Dirac Phase'
For Majorana neutrinos there are two additional phases.

However, there can still be CP violation for Majorana particles
$\Rightarrow$ antiparticle $\neq$ CP-conjugate!

https://pdfs.semanticscholar.org/bec6/e0a640ba8a5177d56bbda0a2c8fdcf93955a.pdf

https://cds.cern.ch/record/492408

Questions from students:

Since the lectures last year, have any of the remaining 12 baryons been discovered?
(Dauke Zuchanke)

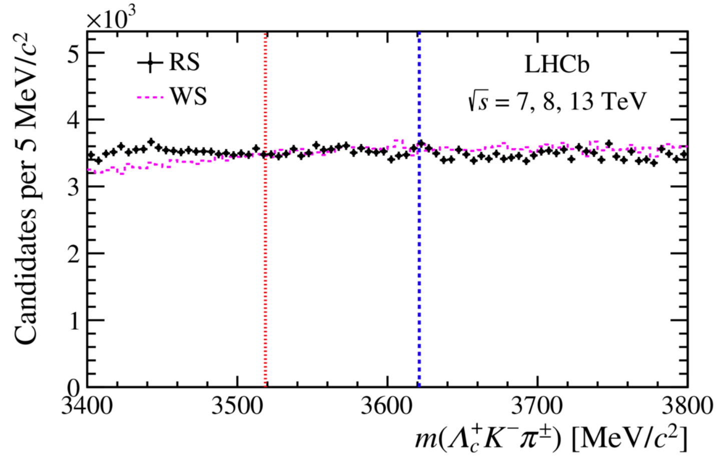
Short answer: No, but we're still looking

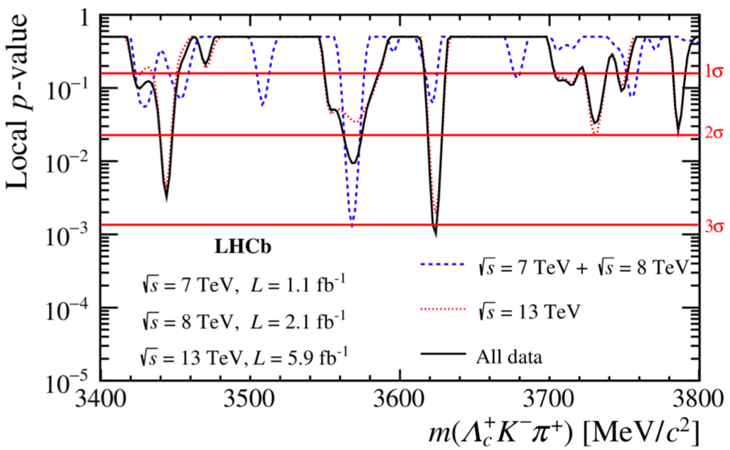
LHCb published a search for the Ξ_{cc}^{+} baryon (ccd)
$\Rightarrow$ Isospin partner of the Ξ_{cc}^{++} (ccu)

No significant signal seen, but a slight excess at the expected mass (blue line)

We have other ongoing analyses which are still 'blinded', but we might need to wait for Run 3 to discover the next baryons

https://arxiv.org/abs/1909.12273





Questions from students:

Do we have any idea what caused the extra CPV observed in cosmological models?
(Dauke Zuchanke)

Short answer: Lots of ideas, but no experimental evidence yet

We know that CPV exists in the standard model , but any impact on cosmological matter-antimatter asymmetry is highly suppressed by the low quark mass (difference), compared to the energy scale in the early universe.

For CPV to propagate into a significant baryon asymmetry in the universe, it must be associated with larger mass scales

$\Rightarrow$ We expect new physics to occur, and for this new physics to include CPV.

Questions from students:

When we will be able to visit cern?
(Nour kemicha)

Short answer: I don’t know, but hopefully soon!

What's new?

- In the lectures from 2019, I discuss many recent results (mainly in lecture 2)
  ⇒ Clearly these are no longer the 'latest & greatest' results.

- To give you an idea of what has changed since then, here is a selection of papers published since the start of 2019:

  Dedicated (quark) flavor physics experiments:

  - LHCb (41 papers submitted since 2019 lectures)
    http://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/Summary_all.html

  - BES-III Charm factory (28 papers submitted)
    https://inspirehep.net/literature?sort=mostrecent&size=25&page=1&q=find%20cn%20BESIII%20&earliest_date=2019--2020&doc_type=published&ui-citation-summary=true

  - Belle-II B-Factory (just starting to publish)
    https://confluence.desy.de/display/BI/Journal+Publications
    https://confluence.desy.de/display/BI/Conference+Papers

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  Other LHC experiments

  - Atlas flavour physics
    https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults

  - CMS flavor physics
    http://cms-results.web.cern.ch/cms-results/public-results/publications/BPH/

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  Kaon and charged lepton Physics

  - KOTO (neutral kaon)
    http://osksn2.hep.sci.osaka-u.ac.jp/~taku/koto/pub/koto_pubs.html

  - NA62 (charged kaon)
    http://na48.web.cern.ch/NA48/Welcome/papers/Overview.html

  - g-2 experiment (not yet published the flagship update!)
    https://muon-g-2.fnal.gov/publications.html