Sorry for all of us not being in A Toxa

Wishful thinking #1: There will be a future conference in A Toxa
Outline of the non-summary talk:

- Flavour physics within Fundamental Physics
- Motivation for Flavour Physics
- Future of Flavour Physics
- Selected lessons I learnt from Quark Flavour Physics = QFP
- Conclusion

4 predictions from looking into my crystal ball with serious impact on flavour physics
Many, many excellent talks

I will not repeat that...

March 2020 update of 1903.09578

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<th>All</th>
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<td>(C_{NP}^{+}, C_{NP}^{-})</td>
<td>(-0.98,+0.19) 6.2 39.8% (-0.31,+0.44) 3.2 70.0%</td>
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<td>(C_{NP}^{+}, C_{T})</td>
<td>(-1.04,+0.01) 6.0 36.5% (-0.92,-0.04) 3.0 57.4%</td>
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<td>(-1.14,+0.55) 6.5 47.4% (-1.86,+1.20) 3.5 81.2%</td>
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<td>(C_{NP}^{+}, C_{W})</td>
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Anomalies will of course always have a dominant role...
Status of (Quark) Flavour

A less well known 4 sigma anomaly...

Anomalies will of course always have a dominant role...
Status of Quark Flavour within Collider

To date, more than 2700 peer-reviewed physics papers have been published by the seven running LHC experiments (ALICE, ATLAS, CMS, LHCb, LHCf, MoEDAL and TOTEM). Approximately 10% of these are related to the Higgs boson, and 30% to searches for BSM phenomena. The remaining 1600 or so report measurements of SM particles and interactions, enriching our knowledge of the proton structure and of the dynamics of strong interactions, of electroweak (EW) interactions, of flavour properties, and

ATLAS and CMS are joining in

CMS publications

969 papers on collider data published or submitted to a journal.
994 papers overall

We have now had several CMS papers accepted in Machine Learning journals

Michelangelo Mangano
LHC at 10 - CERN Courier
2003.05976
10% Higgs = 270 paper

No number for quark flavour

LHCb @ Inspire

May be, we have to work harder on our reputation! (Ask Sven for help)
Wishful thinking #2: Flavour Physics will even be more important in the future.
Status of Flavour Physics within fundamental physics

Currently there is a huge interest from students and funding agencies in e.g.

• Gravitational Waves
• Quantum Computing
• Machine Learning
• Quantum Sensors
• Atoms Interferometry
• ...

see. e.g. RECONNECT 2020

May be, we have to top up our game!
## Motivation for Flavour Physics

<table>
<thead>
<tr>
<th></th>
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<th>Charm</th>
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<th>Spectroscopy</th>
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<tr>
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### Sorry for not covering all aspects

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- **Top, Higgs, nEDM...**
## Motivation for Flavour Physics

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- **Top, Higgs, nEDM...**

**Note:**
- Red marks indicate areas that are not applicable or not yet covered.
- Green checks mark areas that are covered or applicable.

**Legend:**
- ✔️: Covered
- ❌: Not applicable
- _-_: Not yet covered
**Motivation for Flavour Physics**

**Astrophysics to top up our game**

Quark flavour experiments as DM detectors

Neutrino experiments as telescopes

---

**Summary**

**Baryogenesis and Dark Matter from B-mesons:**
- Which actually relates the CP violation in the $B^0$ system to Baryogenesis
- Baryon number is conserved and hence Dark Matter is anti-Baryonic

**Distinctive experimental signatures:**
- Positive semileptonic asymmetry in $B^0$ meson decays $A_{}\ell\ell > 10^{-5}$
- Neutral and charged $B$ mesons decay into a baryon and missing energy: $\text{Br}(B \rightarrow \psi + \text{Baryon} + X) > 2 \times 10^{-3}$

**Ongoing search for $B \rightarrow \text{Baryon} + \text{ME}$ at BaBar&Belle-II!**

B-factories should test this scenario given the constraints on other missing energy channels: $\text{Br}(B^+ \rightarrow K^+\nu\bar{\nu}) < 10^{-5}$

**Sharpening experimental signatures in 2006.XXXX**

with: Gonzalo Alonso-Álvarez, Gilly Eior & David McKeen
Instead of predicting the future - try to identify some lessons that might be useful to shape the future
Future of Flavour

Poll done among theorists, concerning

The most interesting future topics in CPV in b- and c-decays

Instead of predicting the future - try to identify some lessons that might be useful to shape the future

We have to get more control over theory

Serious prediction #1: If CPV in charm mixing is measured, there will be paper claiming SM and BSM
Lesson a) learnt in QFP

Anomalies are great and should be fully exploited, but do not forget…

\[
\frac{\tau(B_s)}{\tau(B_d)} \approx 1, \quad \frac{\tau(B^+)}{\tau(B_d)} \approx 1.1, \quad \frac{\tau(\Lambda_b)}{\tau(B_d)} \approx 0.96
\]

See also: History of $\epsilon'/\epsilon$

<table>
<thead>
<tr>
<th>Year</th>
<th>Collaboration</th>
<th>Decay Mode</th>
<th>Average $\tau(\Lambda_b)$ (ps)</th>
<th>Average $\tau(B_d)$ (ps)</th>
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<td>2003</td>
<td>HFAG</td>
<td>$\Lambda_c l$</td>
<td>$1.212 \pm 0.052$</td>
<td>$0.798 \pm 0.034$</td>
</tr>
<tr>
<td>1998</td>
<td>OPAL</td>
<td>$\Lambda_c l$</td>
<td>$1.29 \pm 0.25$</td>
<td>$0.85 \pm 0.16*$</td>
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<tr>
<td>1998</td>
<td>ALEPH</td>
<td>$\Lambda_c l$</td>
<td>$1.21 \pm 0.11$</td>
<td>$0.80 \pm 0.07*$</td>
</tr>
<tr>
<td>1995</td>
<td>ALEPH</td>
<td>$\Lambda_c l$</td>
<td>$1.02 \pm 0.24$</td>
<td>$0.67 \pm 0.16*$</td>
</tr>
<tr>
<td>1992</td>
<td>ALEPH</td>
<td>$\Lambda_c l$</td>
<td>$1.12 \pm 0.37$</td>
<td>$0.74 \pm 0.24*$</td>
</tr>
</tbody>
</table>
Lesson a) learnt in QFP

Anomalies are great and should be fully exploited, but be careful....

Status in 2019

\[
\frac{\tau(A_b)}{\tau(B_d)}^{\text{HQE 2014}} = 0.935 \pm 0.054
\]

\[
A_b = 1.471 \pm 0.009 \text{ ps} \quad \frac{A_b}{B^0} = 0.969 \pm 0.006
\]

4.9 sigma above 2003 average!!!
keep this in mind when discussing experimental anomalies

See also:
History of \( \epsilon'/\epsilon \)

Platitude #1: Experimental numbers can change and we need control experiments


**Lesson b) learnt in QFP**

Theory predictions for extremely precisely measured B mixing

**Experiment:** HFLAV 2019

\[
\Delta m_s = 17.757 \pm 0.021 \text{ ps}^{-1} \quad | \quad \Delta m_d = 0.5064 \pm 0.0019 \text{ ps}^{-1}
\]

**Macroscopic Quantum Effect**

- Pure loop effect => sensitive to BSM
- Very precisely measured
- Sensitive to badly know CKM elements \( V_{tx} \)

**Theory precision** dominated by non-perturbative input

**See also:** History of \( \epsilon'/\epsilon \)

**In the SM one operator:**

\[
Q = \bar{s}^\alpha \gamma_\mu (1 - \gamma_5) b^\alpha \times \bar{s}^\beta \gamma^\nu (1 - \gamma_5) b^\beta
\]

\[
\langle Q \rangle \equiv \langle B_s^0 | Q | \bar{B}_s^0 \rangle = \frac{8}{3} M_{B_s} f_{B_s} B(\mu)
\]

**Non-perturbative theory input:**

1) Lattice: ETM, FNAL-MILC, RBC-UKQCD, HPQCD
2) Sum rules: Siegen, Durham

**B-mixing:**

- Macroscopic Quantum Effect
- Pure loop effect => sensitive to BSM
- Very precisely measured
- Sensitive to badly know CKM elements \( V_{tx} \)
Lesson b) learnt in QFP

Theory predictions for extremely precisely measured B mixing

State-of-the-art values for $f_{Bs}^2 B$ from FNAL-MILC 1602.03560 (dominated the FLAG average) gives:

$$\Delta M_s^{SM, 2017} = (20.01 \pm 1.25) \text{ ps}^{-1}.$$  

Which is around 2 standard deviations (another anomaly :-) ) larger than experiment:

$$\Delta M_s^{Exp} = (17.757 \pm 0.021) \text{ ps}^{-1}.$$  

This can have severe consequences for BSM models explaining the flavour anomalies.
Lesson b) learnt in QFP

Flavour anomalies could e.g. be explained by $Z'$ models

See e.g. Allanach, Davighi, Gripaios, Lohitsiri, Madigan, Meville, You,..

Such a models also modifies the mass difference of neutral mesons

Many times the BSM contribution to $\Delta M_q$ is positive

Using the large FNAL-MILC value:

One constraint to kill them all! Di Luzio, Kirk, AL

Independent determination of $B_s$ mixing inputs desirable

Drastic consequences of FNAL result!

See also:
History of $\epsilon'/\epsilon$
Lesson b) learnt in QFP

Independent determinations of non-perturbative $B$ mixing parameter:

Platitude #2: Theory numbers can change and we need independent calculations for a check
Lesson c) learnt in QFP

Bread and butter physics: determination of SM parameter

\[ |V_{cb}| = (38.76 \pm 0.42_{\text{exp}} \pm 0.55_{\text{th}}) \times 10^{-3} , \]

\[ |V_{cb}| = (39.58 \pm 0.94_{\text{exp}} \pm 0.37_{\text{th}}) \times 10^{-3} \]

\[ |V_{cb}| = (42.19 \pm 0.78) \times 10^{-3} \]

\[ \gamma = (72.1^{+4.1}_{-4.5})^\circ \]

Numbers from HFLAV, similar problem for V_{ub}
Lesson c) learnt in QFP

Due to the improved precision, B-mixing can be used to determine $V_{tx}$ precisely.

Within the SM this can be transformed into bounds on $V_{cb}$, $V_{ub}$ and gamma.

Within the SM we get

$\gamma = (63.4 \pm 0.9)^\circ$

$|V_{cb}| = (41.6 \pm 0.7) \cdot 10^{-3}$
Platitude #3: Bread and butter physics is crucial and can be a smoking gun for BSM!

Lesson c) learnt in QFP

\( V_{cb} \) plays an important role in UT
\[
\epsilon_K \approx x |V_{cb}|^4 + \ldots \]
and in the prediction of FCNC:
\[
\propto |V_{tb}V_{ts}|^2 \approx |V_{cb}|^2 \left[ 1 + O(\lambda^2) \right]
\]

\( V_{cb} \) inclusive is wrong: NP in B-mixing

NP in K-mixing

\( V_{cb} \) exclusive is wrong: NP in exclusive decays?

**LANL-SWME Collaboration**

We present updated results for \( \epsilon_K \) determined directly from the standard model (SM) with lattice QCD inputs such as \( \bar{B}_K, |V_{cb}|, |V_{ub}|, \xi_0, \xi_2, \xi_{LD}, f_K \), and \( m_c \). We find that the standard model with exclusive \( |V_{cb}| \) and other lattice QCD inputs describes only 65\% of the experimental value of \( |\epsilon_K| \) and does not explain its remaining 35\%, which leads to a strong tension in \( |\epsilon_K| \) at the 4.6\( \sigma \) ~ 4.2\( \sigma \) level between the SM theory and experiment. We also find that this tension disappears when we use the inclusive value of \( |V_{cb}| \) obtained using the heavy quark expansion based on QCD sum rules.

**arXiv:1912.03024 (hep-lat)**
Lesson d) learnt in QFP

prejudice

/'prɛdʒudɪs/

noun
plural noun: prejudices

1. preconceived opinion that is not based on reason or actual experience. "English prejudice against foreigners"
Lesson d) learnt in QFP

**prejudice**

/ˈprɛdʒɪdɪs/

*noun*

plural noun: *prejudices*

1. preconceived opinion that is not based on reason or actual experience.
   "English *prejudice against* foreigners"

- The “B-physics anomalies” provide a concrete demonstration of the high discovery potential of flavor physics. Even if they will go away, they have been very beneficial in shaking some prejudices in model building and in (re-)opening new interesting directions.
Lesson d) learnt in QFP

Scientific prejudices partly based on reason and experience - probably ok, as long as we are aware of it:

d1) Modelbuilding: for a long time SUSY was almost the only game in town and things like lepto-quarks were unacceptable/disgusting — now it seems that lepto-quarks and Z’-bosons are the only game in town and SUSY is unacceptable/disgusting...

I am aware that Sven, Dominik,… will not agree with the statement about SUSY!

d2) No new physics is present in hadronic tree-level decays

d3) Darwin term is unimportant for hadron lifetimes

d4) gamma extractions from B_d, B^+ and B_s have to be the same? Any ideas?

d5)… probably endless list

---

G. Isidori – bsll decays: what we learned & what we still hope to learn

III. The return of the Leptoquark

Leptoquarks suffered of an (undeserved) “bad reputation” for two main reasons:
Lesson d2) learnt in QFP

d2) do a systematic study of potential BSM effects in hadronic tree-level decays

\[ C_1(M_W) := C_1^{SM}(M_W) + \Delta C_1(M_W), \]
\[ C_2(M_W) := C_2^{SM}(M_W) + \Delta C_2(M_W), \]

Allowed size of BSM effects in tree-level decays
Lesson d2) learnt in QFP

d2) Consequences of BSM effects in hadronic tree-level decays

A deviation of the direct determination of gamma from B-mixing results could points towards:

A) BSM effects in B-mixing

B) BSM effects in tree-level decays

For a better quantitative understanding hadronic matrix elements needed

BSM effects in non-leptonic decays are not excluded by experiment

Their potential size could have dramatic effects
Lesson d3) learnt in QFP

d3) Darwin term is unimportant for Hadron lifetimes

Textbook knowledge

\[ \Gamma(B) = \Gamma_0 + \Gamma_2 \frac{\langle O_6 \rangle}{m_b^2} + \Gamma_3 \frac{\langle O_6 \rangle}{m_b^3} + \ldots + 16\pi^2 \left[ \tilde{\Gamma}_3 \frac{\langle \tilde{O}_6 \rangle}{m_b^3} + \tilde{\Gamma}_4 \frac{\langle \tilde{O}_6 \rangle}{m_b^4} + \ldots \right] \]

Spectator effects in inclusive decays of beauty hadrons


AL: "It is not worth calculating the Darwin term" - Aleksey Rusov: “Why not, it is important in sl decays”
Lesson d3) learnt in QFP

d3) Darwin term is unimportant for Hadron lifetimes?

Calculation of Darwin term (independently obtained by two groups) yields, however,

\[
\Gamma_{NL}(B) = \Gamma_0 \left[ 1 - \frac{0.0112}{\mu_\pi^2} - \frac{0.0071}{\mu_G^2} - \frac{0.0415}{\rho_D^3} - \frac{0.0029}{\tau_i^{(q)}} - \frac{0.1033}{B_i^{(q)}} (B^+) + \frac{0.0148}{B_i^{(q)}} (B_d) \right]
\]

To determine effect on lifetime ratios, the matrix elements of the Darwin operator for different mesons have to be determined!

**Determination could maybe be done on a 5s run at Belle**
Lesson e) learnt in QFP

Synergies in flavour physics

• Kaon physics: Chiral perturbation theory - Lattice

  Best strategy: $\chi^\text{PT}$ (amplitudes) + Lattice (LECs)

• Semi-leptonic decays: inclusive approach on the lattice

• HQE vs. Spectroscopy - treatment of Darwin term...

• ....
Future of Flavour

• Future can be bright (many experiments), but we have quite some competition
  Provide input for future studies, e.g. SNOWMASS 21,…

• Selected lessons learnt:
  ○ Experimental numbers can change - **experimental cross checks needed:**
    Belle II, B@CMS, B@ATLAS? - Neutrino experiments….
  ○ Theory numbers can change - **independent cross-checks needed**
  - a “second” higher order or lattice calculation has to be also highly rated!
  ○ Bread and butter physics can contain some surprises
  ○ Prejudices offer a chance to write some interesting papers
  ○ …

• Control over QCD will be crucial for our future

• Synergies: looking over the fences surrounding our subfields might be very helpful
Serious prediction #2: QCD will be even more important.

Disclaimer: the sun deck is important as well, but I think it needs less advertisement.
Looking into my crystal ball
Future of Flavour

Further things that will happen for sure:

1. There will be a future flavour group where lattice and sum rules will happily work together (names are available offline)
Future of Flavour

Further things that will happen for sure:

1. There will be a future flavour group where lattice and sum rules will happily work together.

2. Yuval is wrong about the origin of direct CPV in charm, but right about the future of charm.
   - It is hard to argue that the LHCb result requires BSM.
   - Yet, BSM can still be present.

A Short History of CP Violation

This is just the beginning for charm.
Future of Flavour

Further things that will happen for sure:

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2. Yuval Grossman is wrong about the origin of direct CPV in charm, but right about the future of charm
   - It is hard to argue that the LHCb result requires BSM
   - Yet, BSM can still be present

3. Andrzej Buras will find BSM in Kaon physics


Another SMEFT Story: $Z'$ Facing New Results on $\epsilon'/\epsilon$, $\Delta M_K$ and $K \to \pi\nu\bar{\nu}$

Jason Aebischer, Andrzej J. Buras, Jacky Kumar
Comments: 35 pages, 12 figures
Subjects: High Energy Physics - Phenomenology (hep-ph); High Energy Physics -
Future of Flavour

Further things that will happen for sure:

1. There will be a future flavour group where lattice and sum rules will happily work together.

2. Yuval Grossman is wrong about the origin of direct CPV in charm, but right about the future of charm.
   - It is hard to argue that the LHCb result requires BSM.
   - Yet, BSM can still be present.

3. Andrzej Buras will still manage to find BSM in Kaon physics.

4. Prejudice will not die out in our field - see e.g. the last slide of the last talk of FPCP2020.


Another SMEFT Story: $Z'$ Facing New Results on $e^+e^-$, $\Delta M_K$ and $K \rightarrow \pi\nu\bar{\nu}$

Jason Aebischer, Andrzej J. Buras, Jacky Kumar

Comments: 35 pages, 12 figures

Thanks a lot to the organisers of FPCP 2020 for a great job.
Future of (Flavour) Conferences

Sorry for all of us not being in A Toxa

Wishful thinking #1: There will be a future conference in A Toxa.

How many live/virtual conferences do we really need?

Attendance level: virtual vs. real?

How many real new results are presented at a typical conference?

When do we need the next edition in a conference series?