Karlsruher Institut für Technologie

Closing Talk

Ulrich Nierste
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Closing Talk

Hier vollend' ich's, die Gelegenheit ist günstig!
Here I bring it to an end, the occasion is favourable!

Friedrich Schiller, in: *Wilhelm Tell*

The Olympic Flame of
Beyond Flavour Anomalies
will soon leave Siegen…

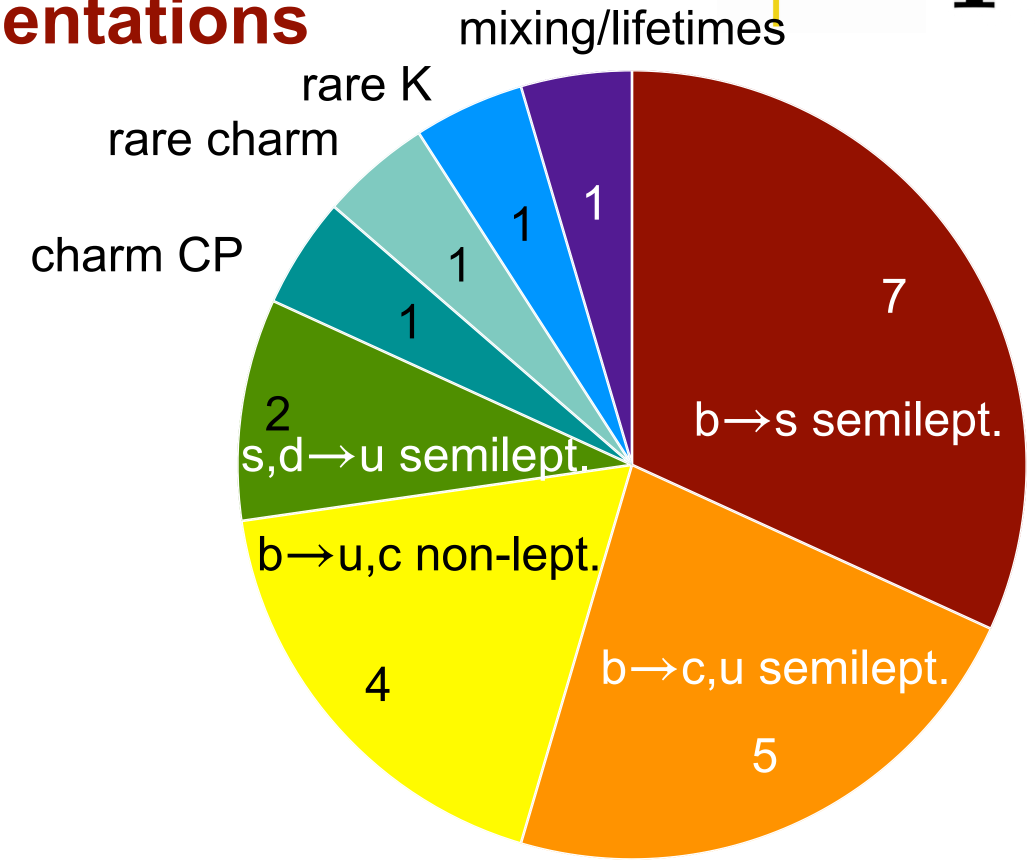
24 Presentations

- Andrea Mauri, Arianna Tinari, Mark Smith: Analysis of the $B \to K^*\mu^+\mu^-$ decays: theory and experiment
- Caspar Schmitt, Danny van Dyk: On recent measurement of $B \to K\nu\bar{\nu}$ decay by Belle II
- Jack Jenkins: Inclusive $B \to X_s\ell^+\ell^-$ semileptonic decays
- Meril Reboud: $e^+e^- \to$ open charm and the $\psi(3770)$
- Markus Prim, Patrick Owen: Status and prospects of R(D) and R(D*) measurements
- Judd Harrison, Marzia Bordone: B→D$^{(*)}$ form factors in the heavy quark expansion
- Marco Fedele: Recent theory developments in $b \to c\ell\bar{\nu}$ transitions
- Andreas Jüttner, Davide Fazzini: $B_s \to K\mu\bar{\nu}_\mu$ decays: experiment and Lattice QCD
- Meril Reboud, Diego Guadagnoli: $B \to \mu^+\mu^-\gamma$ decays
- Alexander Marshall, Javier Virto, Keri Vos: Confronting theory predictions with $B \to K\pi$ experimental data
- Martin Hoferichter, Simon Mutke: Analyticity structure of nonlocal form factors
- Florian Bernlochner: Developments in inclusive V_{cb} determinations

24 Presentations

- Eleftheria Solomonidi, Serena Maccolini: ΔA_{CP}: experiment and theory
- Gudrun Hiller: Rare charm decays
- Maria Laura Piscopo, Nicole Skidmore: Non-leptonic $B_{(s)} \to D_{(s)}(\pi, K)$ decays: experiment and theory
- Benjamin Stefanek, Davide Lancierini: The links between $B \to K^* \bar{K}^*$, $R(D^{(*)})$ and $B \to K\nu\bar{\nu}$
- Mauro Valli: Behind the Flavour Anomalies: Where do we stand?
- Aritra Biswas, Gilberto Tetlalmatzi-Xolocotzi: New observables in non-leptonic B-decays
- Matthew Kirk: Cabibbo anomaly and relation to other anomalies
- Aleksey Rusov: Status of b-hadron lifetimes and of neutral B-meson mixing
- Vitalii Lisovskyi: Belle II prospects
- Titus Mombacher: LHCb prospects at Run 3
- Nazila Mahmoudi: BSM prospects for rare kaon decays
- Ulrich Nierste: Closing talk

24 Presentations



Highlights

Significant developments since *Beyond Flavour Anomalies IV* !

My favourites:

$b \to s\ell^+\ell^-$

$B \to K\nu\bar{\nu}$

$b \to c\tau\nu$

$A_{CP}(D \to \pi^+\pi^-)$

$B \to K^{(*)}\bar{K}^{(*)}$

Cabibbo anomaly

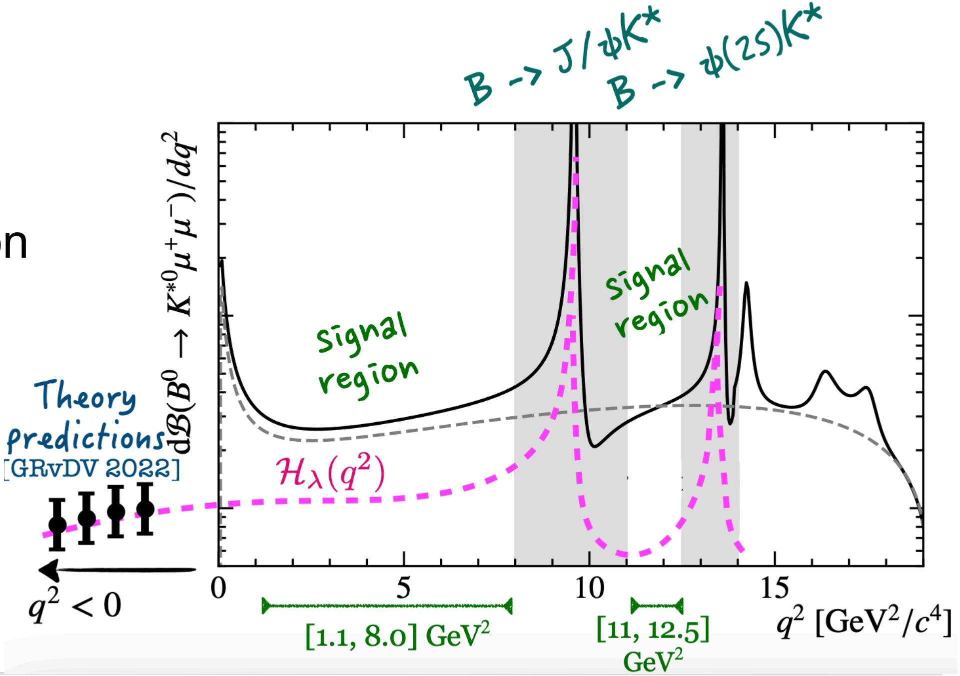
Apology: Not summarised in this talk are the presentations on rare processes which may become the flavour anomalies of the future.

$b \to s\ell^+\ell^-$

No new LHCb analysis of $B \to K^*\mu^+\mu^-$, but progress on determination of the non-local charm loop contribution $\mathscr{H}^\lambda$.

Mark Smith, Andrea Mauri, Arianna Tirani: Simultaneous fit to Wilson Coeffcients and parameters of non-local charm loops.

LHCb: two analyses (z expansion, dispersion relation)

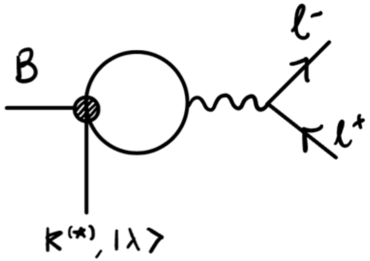


Take home message #1

- **Very compatible results between the 2 analyses**
- alternative/complementary q^2 model
- shift in C_9 of order -0.7

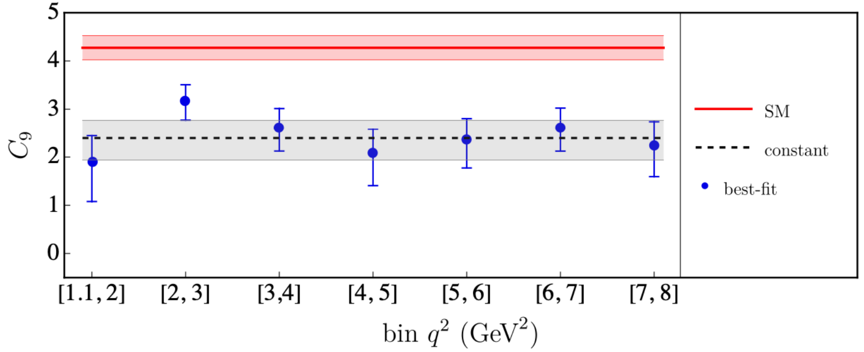
$b \to s\ell^+\ell^-$

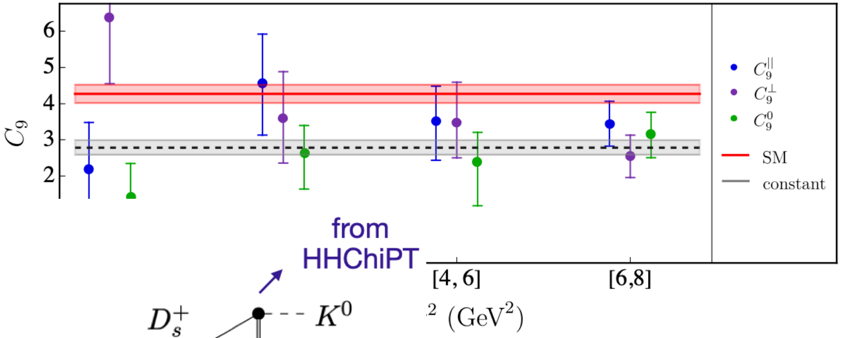
Mark Smith, Andrea Mauri, Arianna Tirani:
Zurich group:

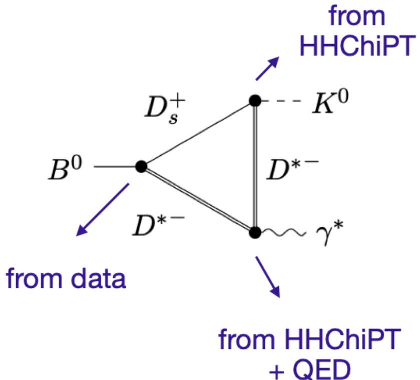


Compatible with LHCb analysis!

Low q^2



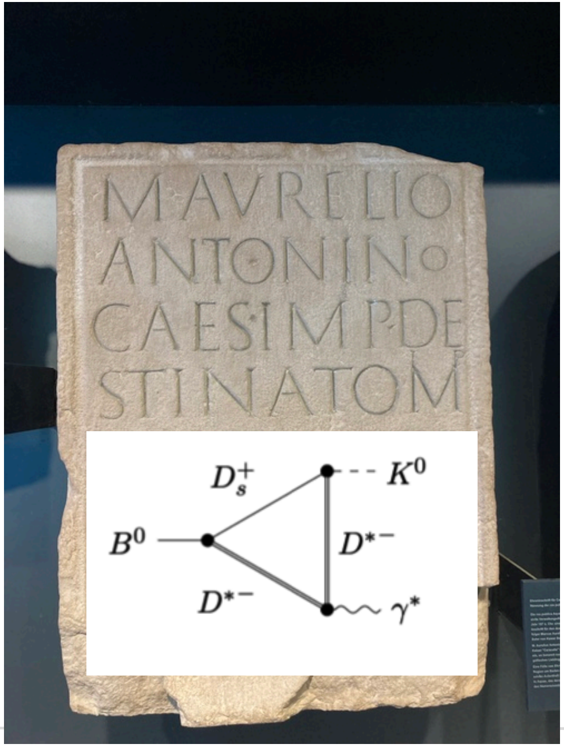


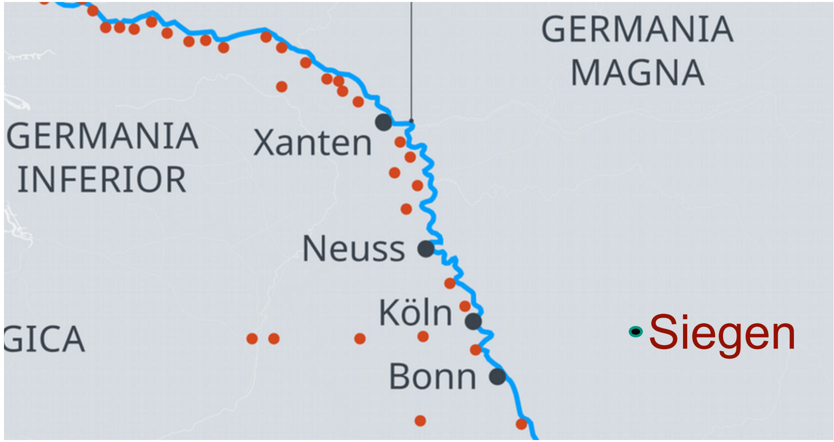


No evidence of q^2-dependence. Hard to imagine large constant contribution.

$b \to s\ell^+\ell^-$

Rome had spoken:





Roman Empire

limes

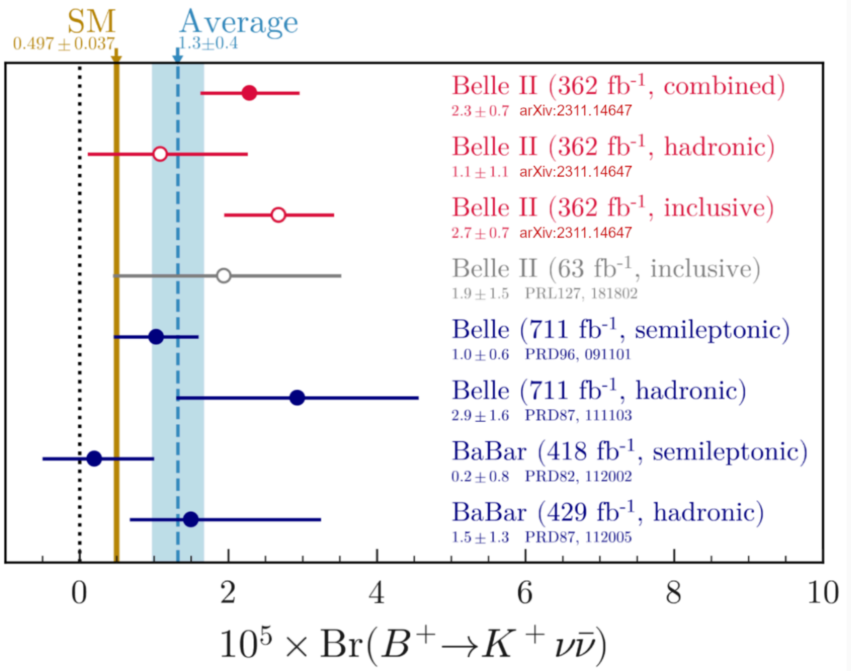
wild barbarians

My view:

No calculation supports an explanation of $b \to s\ell^+\ell^-$ data in terms of a large SM charm contribution.

$B \to K\nu\bar{\nu}$

Caspar Schmitt, Danny van Dyk: Evidence for $B^- \to K^-\nu\bar{\nu}$ by Belle II (arXiv:2311.14647)



Combined result is compatible with SM at 2.7 σ.

ν_ℓ and ℓ form an SU(2) doublet $L = \begin{pmatrix} \nu_\ell \\ \ell \end{pmatrix}$.

$\Rightarrow$ Connection to $b \to s\ell^+\ell^-$.

$b \to c\tau\nu$

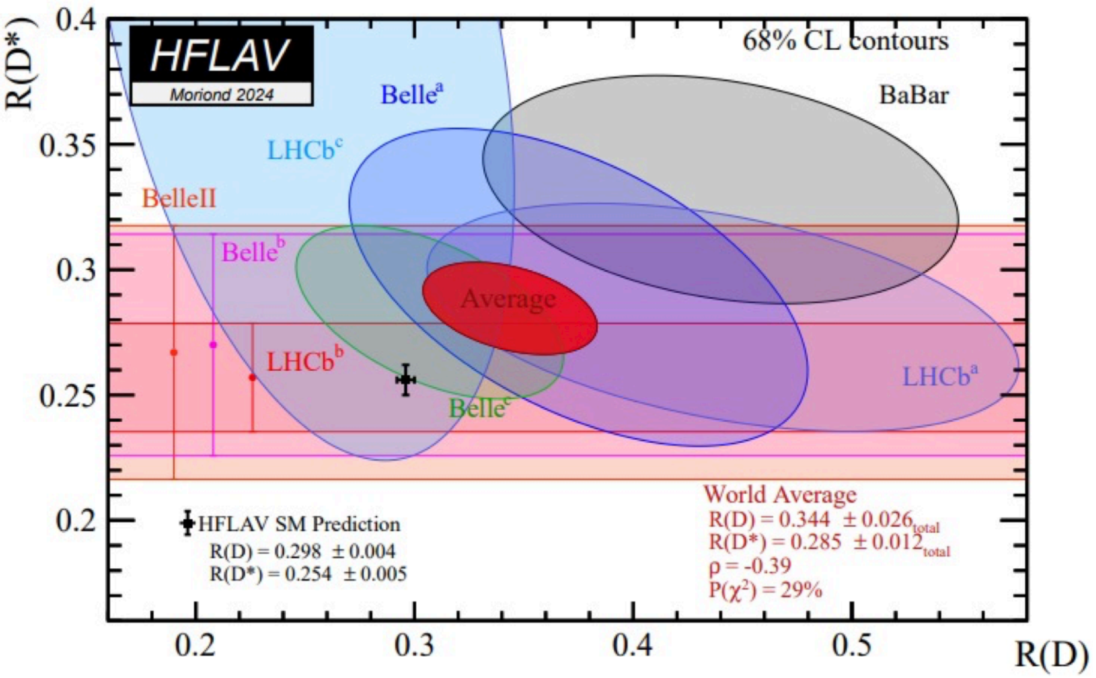
Patrick Owen, Markus Prim:

$$R(H_c) \equiv \frac{B(H_b \to H_c\tau\nu)}{B(H_b \to H_c\ell\nu)}$$

New LHCb $R(D^+)$ measurement:
Significance of deviation from SM down:

3.3σ → 3.1.σ

After $R(D^+)$



$b \to c\tau\nu$

SM predictions:

HFLAV: $R(D) = 0.298 \pm 0.004,\qquad R(D^*) = 0.254 \pm 0.005$

Judd Harrison, Marzia Bordone:

$$R(D) = 0.301 \pm 0.004,\qquad R(D^*) = 0.257 \pm 0.004$$

Patrick Owen, Markus Prim:

New LHCb $R(D^+)$ measurement:

$$R(D)^{\rm exp} = 0.357 \pm 0.029 \longrightarrow R(D)^{\rm exp} = 0.344 \pm 0.026$$

$$R(D^*)^{\rm exp} = 0.284 \pm 0.012 \longrightarrow R(D^*)^{\rm exp} = 0.285 \pm 0.012$$

New LHCb measurement: $F_L^{D^*} = 0.43 \pm 0.06 \pm 0.03$ SM-like,

unlike earlier Belle result $F_L^{D^*} = 0.60 \pm 0.08 \pm 0.04$

} reduces case for charged-Higgs explanation, but leptoquark explanation ok

$A_{\rm CP}(D^0 \to \pi^+\pi^-)$

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$\Delta A_{CP} = A_{CP}(D^0 \to K^-K^+) - A_{CP}(D^0 \to \pi^-\pi^+)$

$= (-15.4 \pm 2.9) \times 10^{-4}$

Eleftheria Solomonidi, Serena Maccolini:

LHCb measurements:

$$a^d_{K^-K^+} = (\ 7.7 \pm 5.7) \times 10^{-4}$$
$$a^d_{\pi^-\pi^+} = (23.2 \pm 6.1) \times 10^{-4}$$

Theory explanation challenging:

- SU(3) (or U-spin) symmetry predicts $a^d_{\rm CP}(D^0 \to \pi^+\pi^-) = -\, a^d_{\rm CP}(D^0 \to K^+K^-)$
- Dynamical calculations find $a^d_{\rm CP}$ with much smaller magnitude.

  SM interpretation requires large "penguin over tree" ratio >1 and large strong phase .

$A_{\rm CP}(D^0 \to \pi^+\pi^-)$

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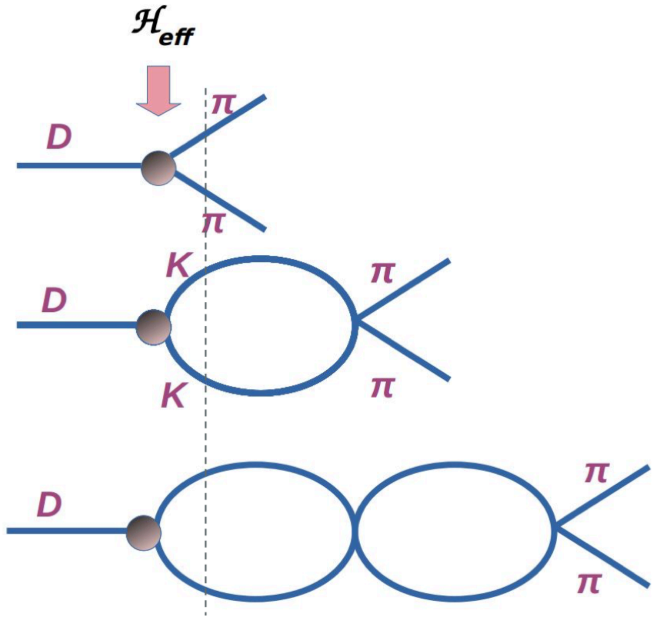
New theory calculation:
Approximate penguin amplitude
($d\bar d, s\bar s \leftrightarrow d\bar d, s\bar s$ rescattering) by two-body
$\pi\pi \leftrightarrow K, K$ rescattering, Omnès formalism:

We find $\Delta a^{dir}_{CP} \approx -5 \cdot 10^{-4}$ ~⅓ of the measured value!

while $a^{dir}_{CP}(\pi^+\pi^-) \approx 3 \cdot 10^{-4}$ $a^{dir}_{CP}(K^+K^-) \approx -2 \cdot 10^{-4}$



Sign of $\Delta A_{\rm CP}$ comes out as measured! Input from $\pi\pi$ scattering data.

$B \to K^{(*)}\bar{K}^{(*)}$

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Aritra Biswas, Gilberto Tetlalmatzi-Xolocotzi:

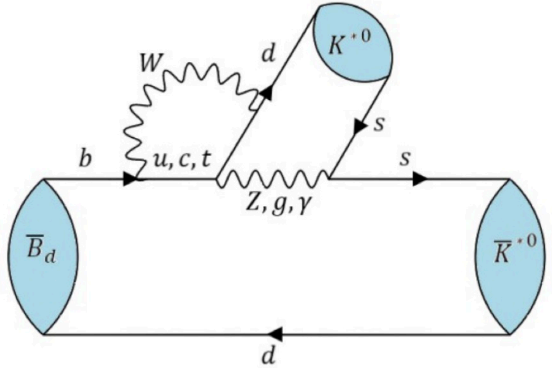
Optimised observables:

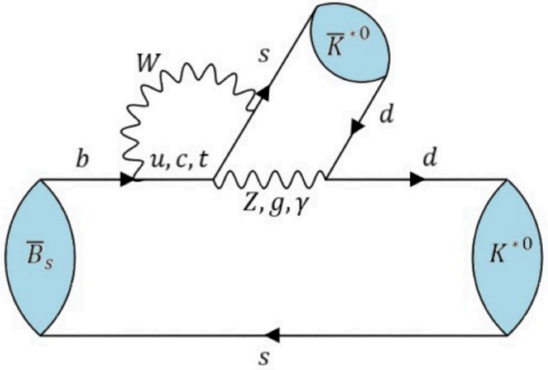
$$L_{K\bar{K}} = \rho(m_{K^0}, m_{K^0}) \frac{\mathcal{B}(\bar{B}_s \to K^0 \bar{K}^0)}{\mathcal{B}(\bar{B}_d \to K^0 \bar{K}^0)} = \frac{|A^s|^2 + |\bar{A}^s|^2}{|A^d|^2 + |\bar{A}^d|^2}$$

$$L_{K^*\bar{K}^*} = \rho(m_{K^{*0}}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \to K^{*0} \bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \to K^{*0} \bar{K}^{*0})} \frac{f_L^{B_s}}{f_L^{B_d}} = \frac{|A_0^s|^2 + |\bar{A}_0^s|^2}{|A_0^d|^2 + |\bar{A}_0^d|^2}$$

Phase space factor

related by U-spin





$B \to K^{(*)}\bar{K}^{(*)}$

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$$L_{K\bar{K}} = \rho(m_{K^0}, m_{K^0}) \frac{\mathcal{B}(\bar{B}_s \to K^0\bar{K}^0)}{\mathcal{B}(\bar{B}_d \to K^0\bar{K}^0)} = \frac{|A^s|^2 + |\bar{A}^s|^2}{|A^d|^2 + |\bar{A}^d|^2}$$

Aritra Biswas,
Gilberto Tetlalmatzi-Xolocotzi:

$$L_{K^*\bar{K}^*} = \rho(m_{K^{*0}}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \to K^{*0}\bar{K}^{*0})} \frac{f_L^{B_s}}{f_L^{B_d}} = \frac{|A_0^s|^2 + |\bar{A}_0^s|^2}{|A_0^d|^2 + |\bar{A}_0^d|^2}$$

Observable	SM (QCDF)	Experiment	Deviation
$L_{K^*\bar{K}^*}$	$19.53^{+9.14}_{-6.64}$	4.43 ± 0.92	2.6σ
$L_{K\bar{K}}$	$26.00^{+3.88}_{-3.59}$	14.58 ± 3.37	2.4σ
$L_{K^*\phi}$	$22.04^{+7.06}_{-4.88}$	$8.80^{+6.07}_{-2.97}$	1.5σ

$$Q_{4f} = (\bar{f}_i b_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V-A}$$

$$Q_{6f} = (\bar{f}_i b_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V+A}$$

$$Q_{8gf} = \frac{-g_s}{8\pi^2} m_b \bar{f} \sigma_{\mu\nu}(1+\gamma_5) G^{\mu\nu} b$$

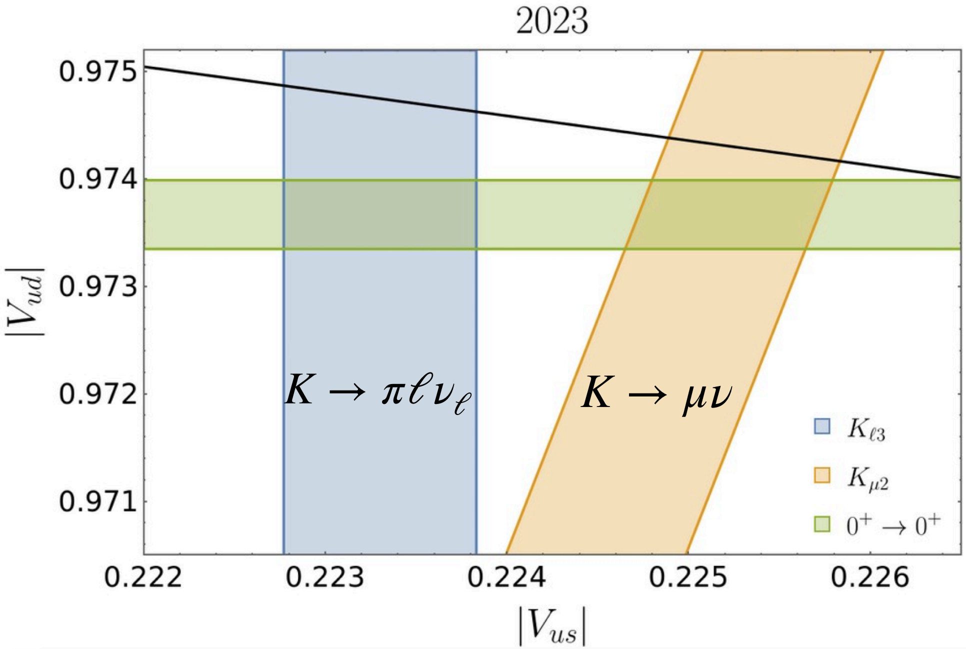
Simultaneous new-physics explanation possible in

2 operator scenarios

$Q_{4f} - Q_{6f}$ and $Q_{6f} - Q_{8gf}$

Cabibbo anomaly

Matthew Kirk: Test $|V_{ud}|^2 + |V_{us}|^2 = 1$, ($|V_{ub}|$ negligible)



CKM "first-row" unitarity

nuclear physics

Best fit for $|V_{ud}|^2 + |V_{us}|^2$ below $|V_{ud}|^2 + |V_{us}|^2 = 1$ by 3σ.

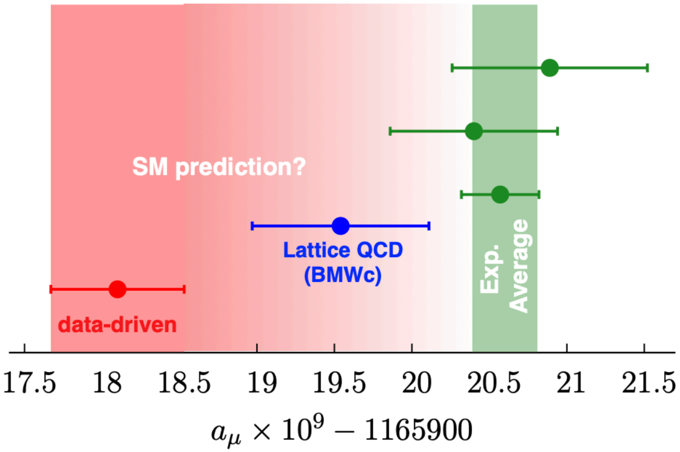
Tension in $|V_{us}|$ irrespective of $|V_{ud}|$.

Good new-physics solution: Vector-like SU(2) doublet quark.

$(g-2)_\mu$

Not discussed at this conference: Muon anomalous magnetic moment.
Talk by Hartmut Wittig at 2024 LHCb workshop in Meinerzhagen (based on arXiv:2306.04165, arXiv:2206.06582, arXiv:2401.11895):

Situation by last summer:



Data-driven: Measure R ratio at $e^+ - e^-$ colliders; newest result CMD-3 inconsistent with CMD-2.

New: Calculation of "window observables" of the vacuum polarisation contribution by four lattice groups (RBC/UKQCD 23, ETMC 22, Mainz/CLS 22, BMW 20).

$(g-2)_\mu$

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Talk by Hartmut Wittig at 2024 LHCb workshop in Meinerzhagen (based on arXiv:2306.04165, arXiv:2206.06582, arXiv:2401.11895):

without CMD-3

Tension of 3.8σ in the window observable evaluated from e^+e^- data* and four lattice calculations

$$a_\mu^{\mathrm{win}}\Big|_{\langle\mathrm{lat}\rangle} - a_\mu^{\mathrm{win}}\Big|_{e^+e^-} = (6.8 \pm 1.8)\cdot 10^{-10} \quad [3.8\,\sigma]$$

Subtract R-ratio result $a_\mu^{\mathrm{win}}\big|_{e^+e^-}$ from WP estimate and replace by lattice average $a_\mu^{\mathrm{win}}\big|_{\langle\mathrm{lat}\rangle}$:

$$a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}}\Big|^{\mathrm{win}}_{e^+e^-\to\langle\mathrm{lat}\rangle} = (18.1 \pm 4.8)\cdot 10^{-10} \quad [3.8\,\sigma]$$

would be 5.1σ with data-driven input

3.8σ are interesting, but could to shrink with more $e^+e^- \to \pi^+\pi^-$ coverage.
Need more full lattice calculations as the one by BMW.

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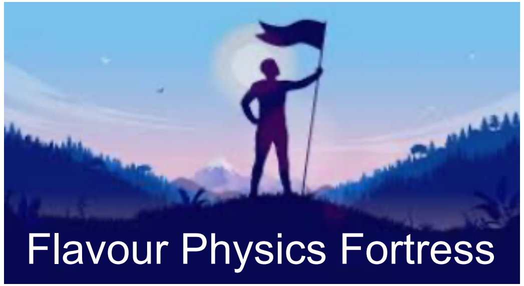
Siegen nightwatchman

Serena Jack

Neck violin: punishment for quarreling marketers.
Here: Fight over whether $A_{\mathrm{CP}}(D^0 \to \pi^+\pi^-)$ or $B \to X\mu^+\mu^-$ is more interesting.

Flavour Anomalies



“The flavour anomalies have gone away!”

$b \to s\ell^+\ell^-$: low-q^2 deficit corroborated

$B \to K\nu\bar{\nu}$: 2.7σ off

$b \to c\tau\nu$: 3.1σ discrepancy in R($D^{(*)}$)

$A_{CP}(D \to \pi^+\pi^-)$: too large

$B \to K^{(*)}\bar{K}^{(*)}$: 2.6σ and 2.4σ off.

Cabibbo anomaly: 3σ off, $|V_{us}|$ inconsistent

$(g-2)_\mu$: back with new lattice data?

Beyond Flavour Anomalies

We experienced a spectacular event in a neighbouring discipline….

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Beyond Flavour Anomalies

We experienced a spectacular event in a neighbouring discipline….
…namely climate research:

Sunshine in Siegen!

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Beyond Flavour Anomalies

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Has climate change gone out of control?