Rap-up of the session

heavy flavours

but mainly with b,

for t, c and s, see talks by T. J. Kim, CP. Shen and K. Vos

Precision theory for precise measurements at LHC and future colliders

Quy-Nhon, Vietnam, 25 September-1 October 2016

T. Nakada

EPFL-IPHYS-LPHE

Lausanne, Switzerland

I was told

"We are organising the Heavy Flavour session, and would like to ask you to wrap up the session. This would involve showing a few slides to stimulate discussion, which you should then lead."

"Speakers are instructed to upload their talks well in advance."

But…

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- What is the origins of flavours?
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Most probably an interesting discussion but a little outside of the scope of this conference...

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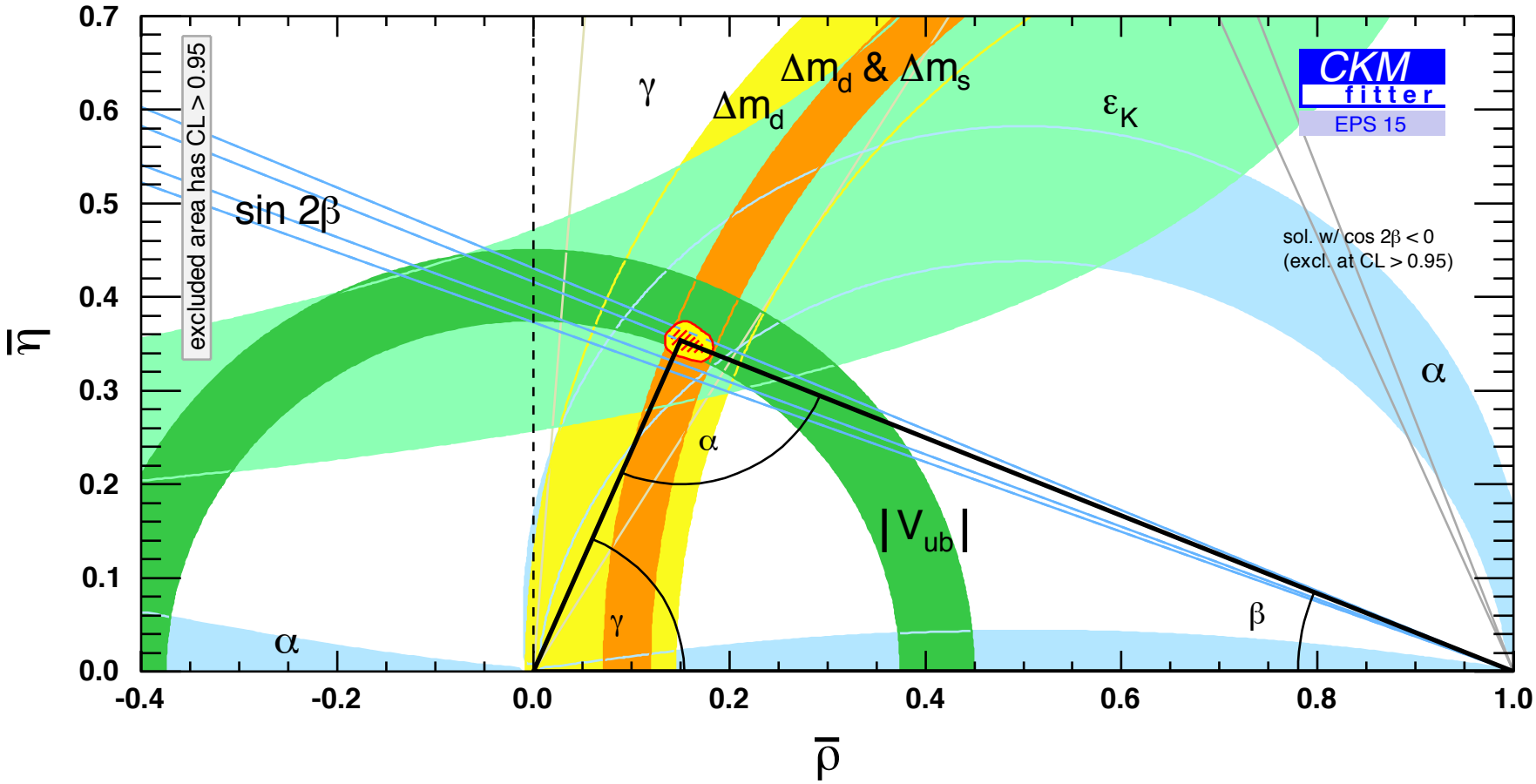
- Search for deviations from the Standard Model predictions
- Some predictions are very "accurate", i.e. forbidden in the Standard Model:
  - Neutrino masses, lepton flavour violating decays, charge non-conserving decays, …
- Others are with a different degrees of theoretical uncertainties
  - Known as Golden channel or silver channel, (Golden channel: CPV in $B_d \to J/\psi K_S$, $B_s \to J/\psi\phi$, ...)
  - Kown to suffer from hadronic uncertainties, (CPV in the decay amplitudes, ...)

Globally speaking…

- CKM picture looks fine, no room for large BSM any more…



But looking closer (I)

- Long standing problem with $|V_{ub}|, |V_{cb}|$ Chunhua LI Soumitra Nandi
  Discrepancies between inclusive and exclusive SL-decays: $\sigma_{\text{experiment}} \lessapprox \sigma_{\text{theory}}$

exclusive		FHAG
$(38.94\pm0.49\pm0.58)\times10^{-3}$	(D)	
$(39.45\pm1.42\pm0.88)\times10^{-3}$	(D*)	$(3.23\pm0.29)\times10^{-3}$
$(42.46\pm0.88)\times10^{-3}$		$(4.45\pm0.16\pm0.22)\times10^{-3}$
$\|V_{cb}\|$	inclusive	$\|V_{ub}\|$

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$|V_{cb}|$ inclusive $|V_{ub}|$

Annoying…

A, ρ and η are vital parameters for the SM predictions!!!

NB: Baryonic decay, $\Lambda_b \to pK\ell\nu$ agrees with exclusive result LHCb2015

To me this appears as a QCD problem…

But looking closer (II)

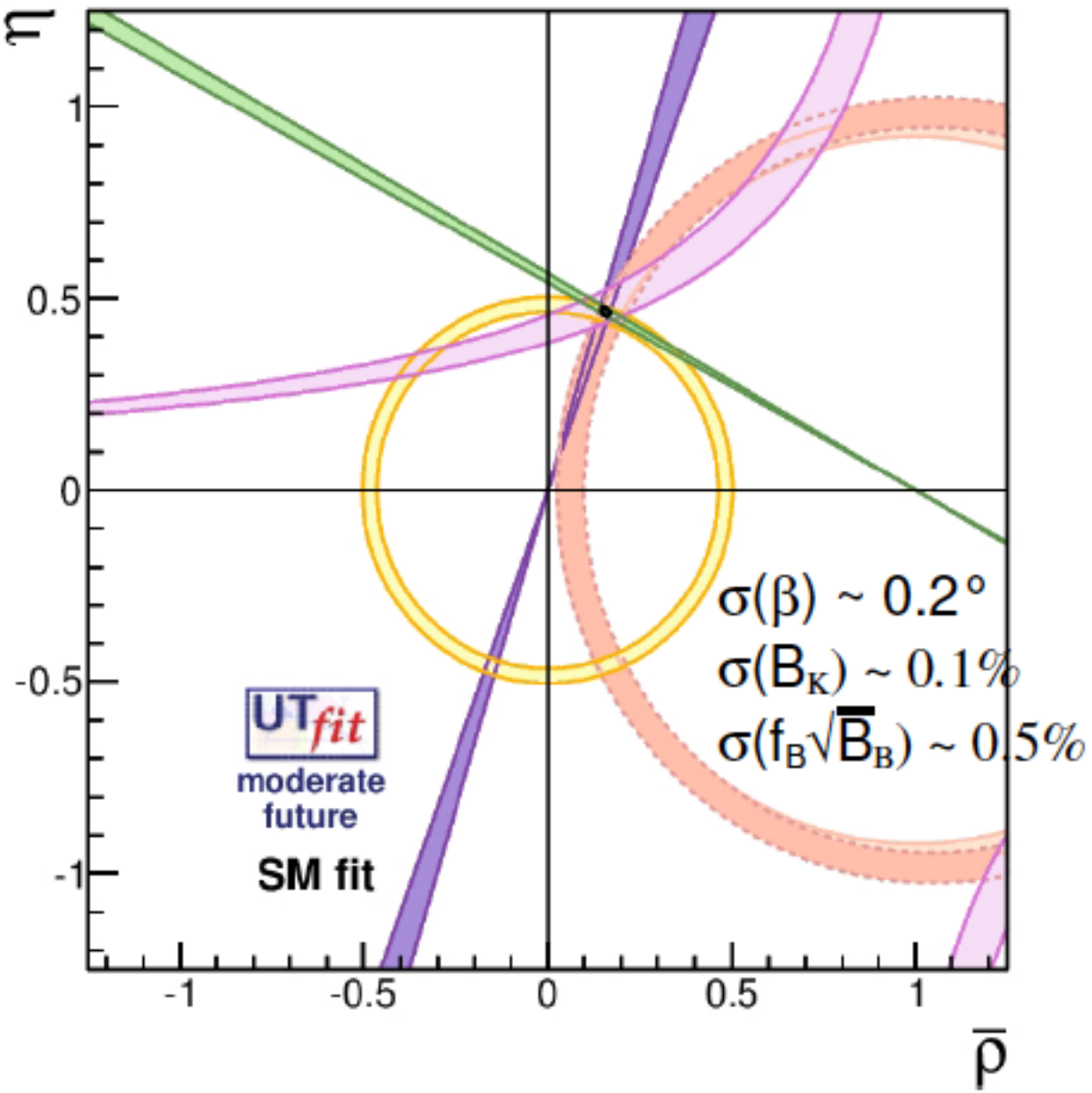
- CKM predictions need accurate tree level $|V_{cb}|$, $|V_{ub}|$ and γ measurements (A, ρ and η)
- Some of the relevant parameters have been measured very well…
  - $|\varepsilon_K|$ to 5×10^{-3}
  - Δm_d to 6×10^{-3}
- σ for β and γ are statistically limited
- We have some flavour "anomalies" now…
- NB:
  LHCb Run-2 era (~2020), experimental σ's ~1/2
  Belle II, LHCb upgrade era (~2025), up to <1/5

Can theoretical errors keep up with this?

- CKM pre… …l, $|V_{ub}|$ and γ mea…
- Some of … measured
  - $|\varepsilon_K|$ to 5
  - Δm_d to …
- σ for β a…
- We have …
- NB: …1/2 LHCb Ru… Belle II, … …/5 Can t…

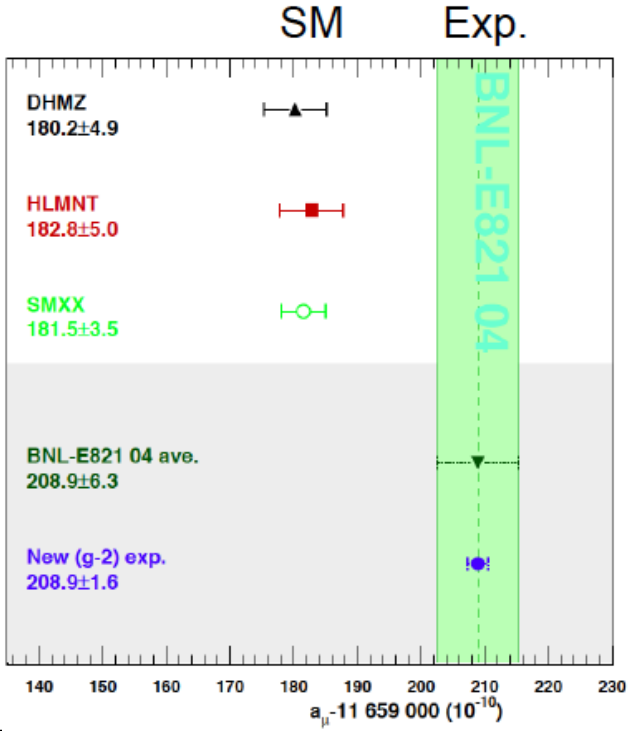
errors predicted from Belle II + LHCb upgrade

Bona@ICHEP2016



Flavour anomalies (lepton)

- Neutrino oscillations
  - Well established, beyond the basic Standard Model
- muon (g−2)
  QCD, statistics or BSM?



P. Mackenzie

Contribution	Result ($\times 10^{11}$)	Error
QED (leptons)	$116\ 584\ 718 \pm 0.14 \pm 0.04_\alpha$	0.00 ppm
HVP(lo) [1]	$6\ 923 \pm 42$	0.36 ppm
HVP(ho)	$-98 \pm 0.9_{\rm exp} \pm 0.3_{\rm rad}$	0.01 ppm
HLbL [2]	105 ± 26	0.22 ppm
EW	$154 \pm 2 \pm 1$	0.02 ppm
Total SM	$116\ 591\ 802 \pm 49$	0.42 ppm

Note that the strong interaction contribution is only 6×10^{-5}!!

(no longer) Flavour anomalies

- ~~$A_{SL}(B_S)$: sign of large CP violation in B_s-$\bar{B}_s$ oscillation~~
- ~~Δ_{CP}: large CP violation in D decay amplitudes~~

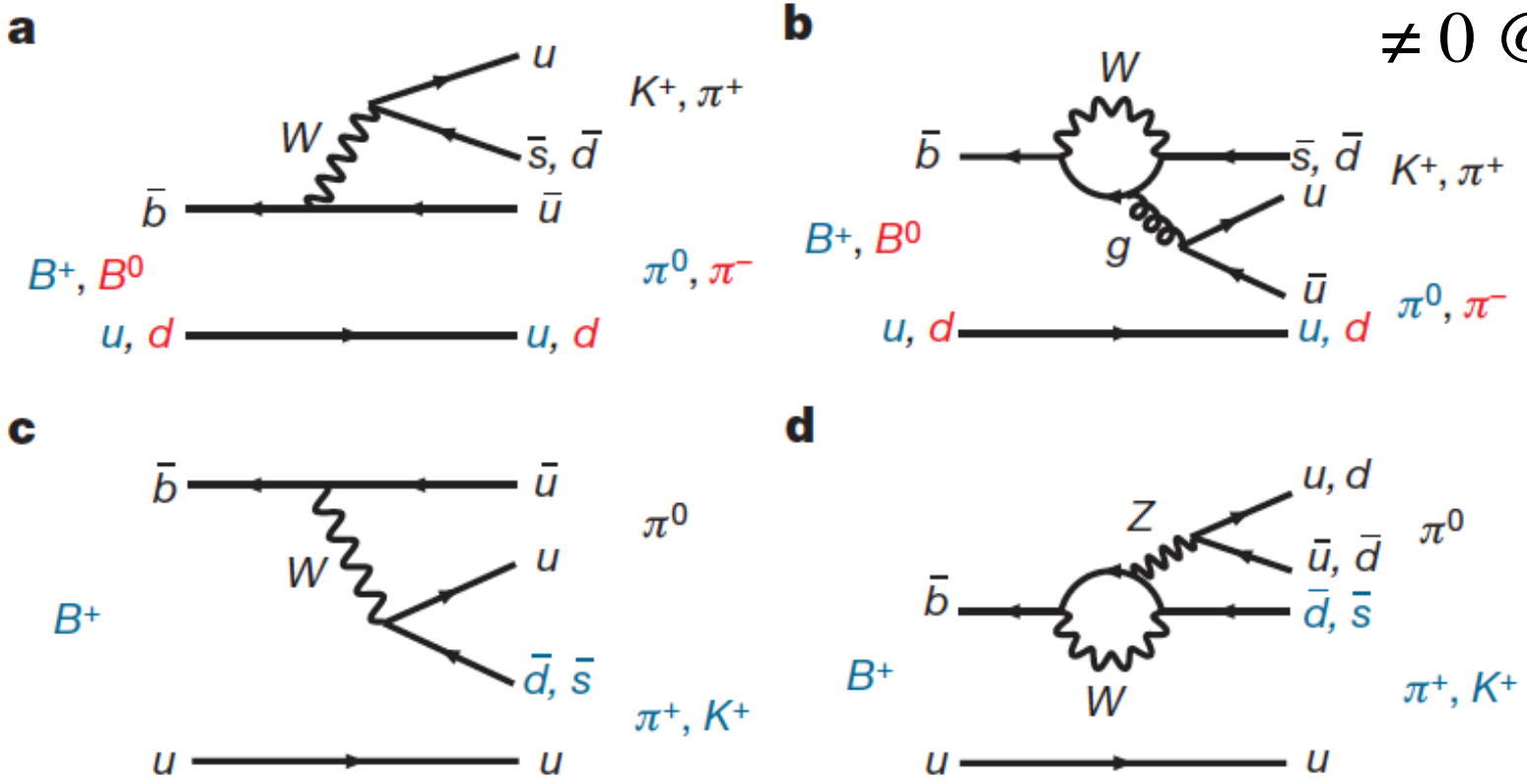
Flavour anomalies

- $A_{CP}(K\pi)$: anomalous CP violation in $B \to K\pi$

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037,$$

BELLE2008

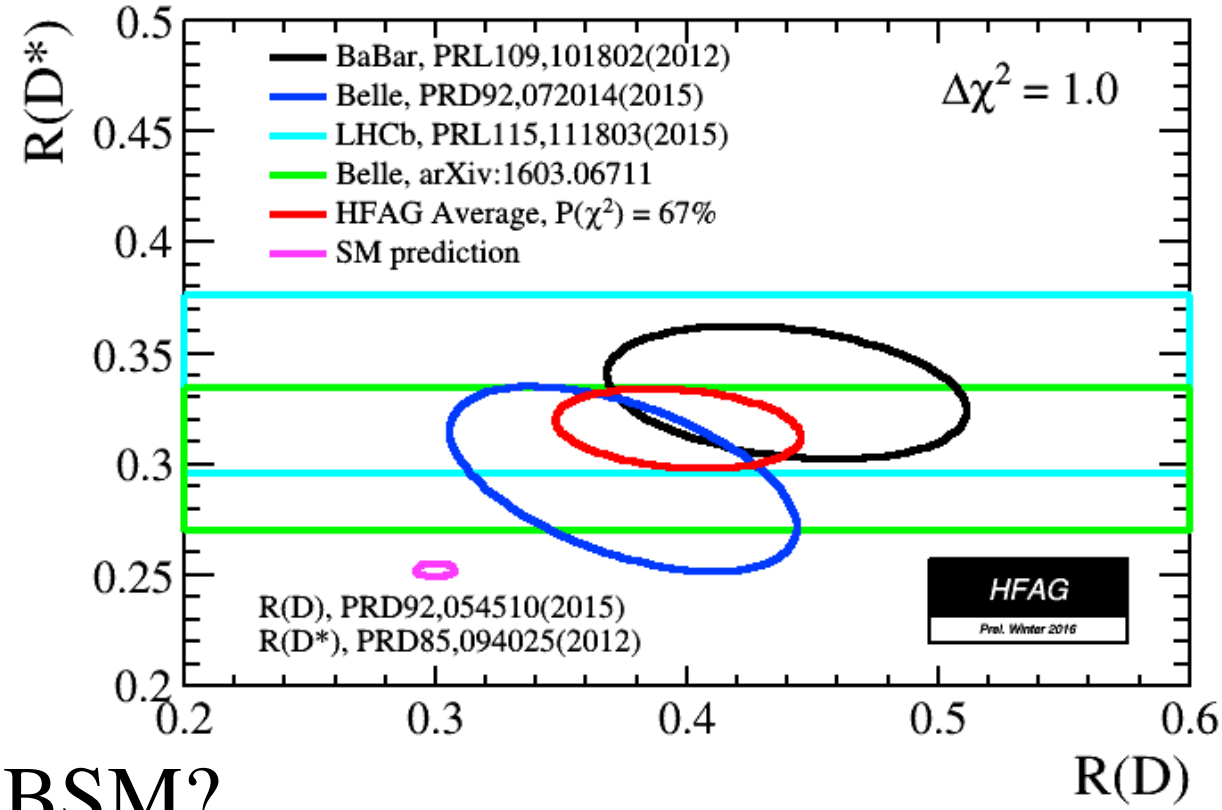
$\neq 0$ @ 4.4σ



QCD, statistics or BSM?

Flavour anomalies

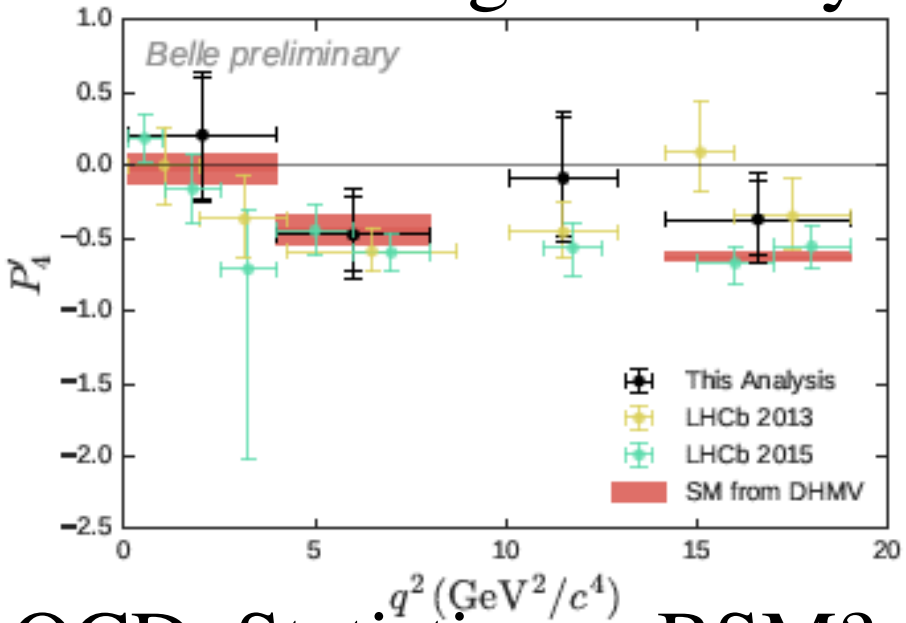
- $A_{CP}(K\pi)$: anomalous CP violation in $B \to K\pi$
- $Br(B \to D^{(*0)}\tau\nu)/Br(B \to D^{(*0)}\mu\nu)$ anomaly

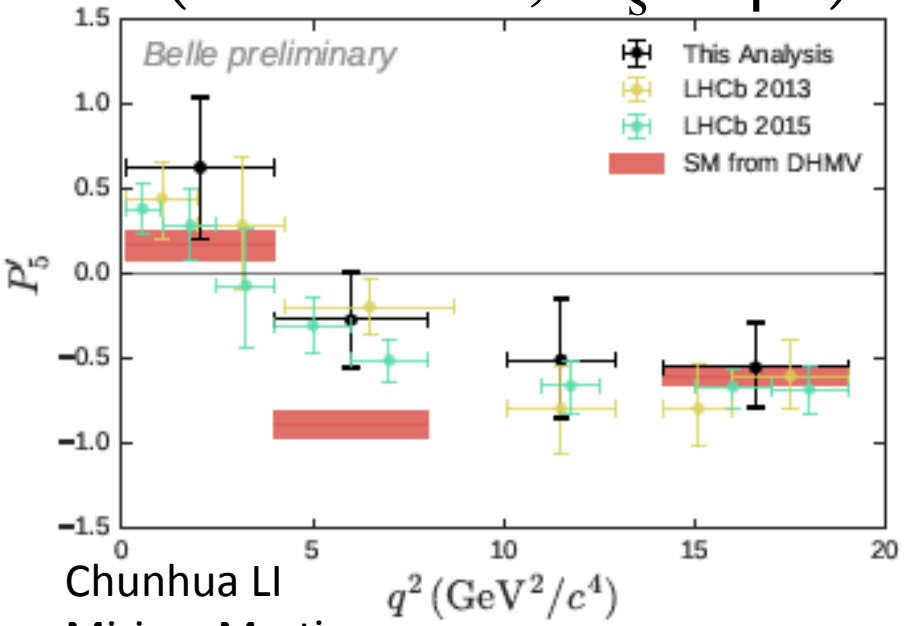


Statistics, QCD or BSM?

Flavour anomalies

- $A_{CP}(K\pi)$: anomalous CP violation in $B \to K\pi$
- $Br(B \to D^{(*0)}\tau\nu)/Br(B \to D^{(*0)}\mu\nu)$ anomaly
- P5´: anomaly in the angular distribution of the decay final states generate by $b \to s l^+ l^-$ ($B^0 \to K^{*0} ll$, $B_s \to \phi ll$)





Chunhua LI
Miriam Martinez

QCD, Statistics or BSM?

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- R_K: anomalous lepton universality

$$R_K = \frac{\int_{q^2_{\min}}^{q^2_{\max}} \frac{d\Gamma[B^+ \to K^+ \mu^+ \mu^-]}{dq^2} dq^2}{\int_{q^2_{\min}}^{q^2_{\max}} \frac{d\Gamma[B^+ \to K^+ e^+ e^-]}{dq^2} dq^2} = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

LHCb2014

BSM or statistics.

Flavour anomalies

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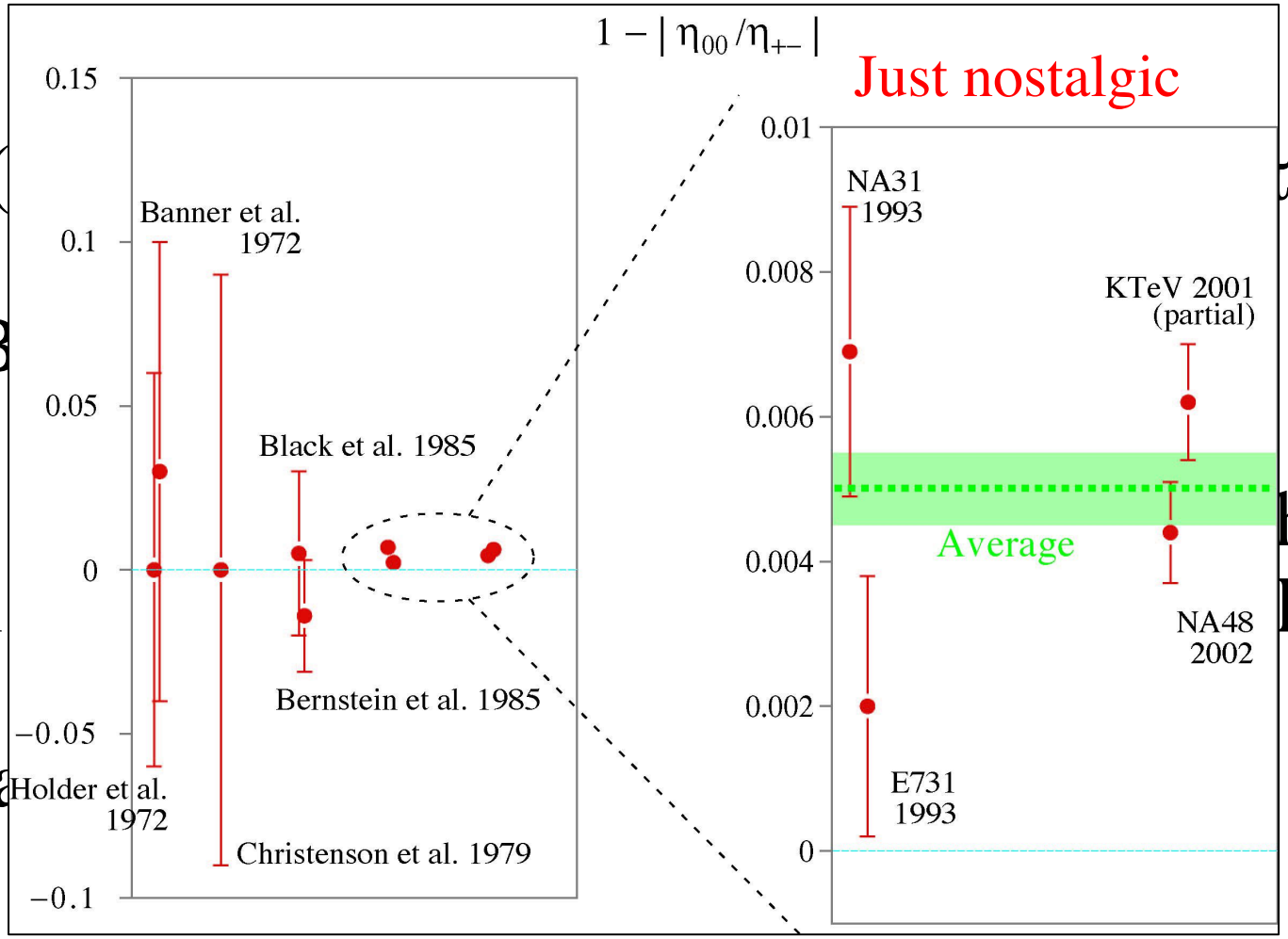
- Br(B
- P5´: he decay final $B_s \to \phi ll$)
- R_K: a



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Flavour anomalies

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  final state
- R_K: anoma
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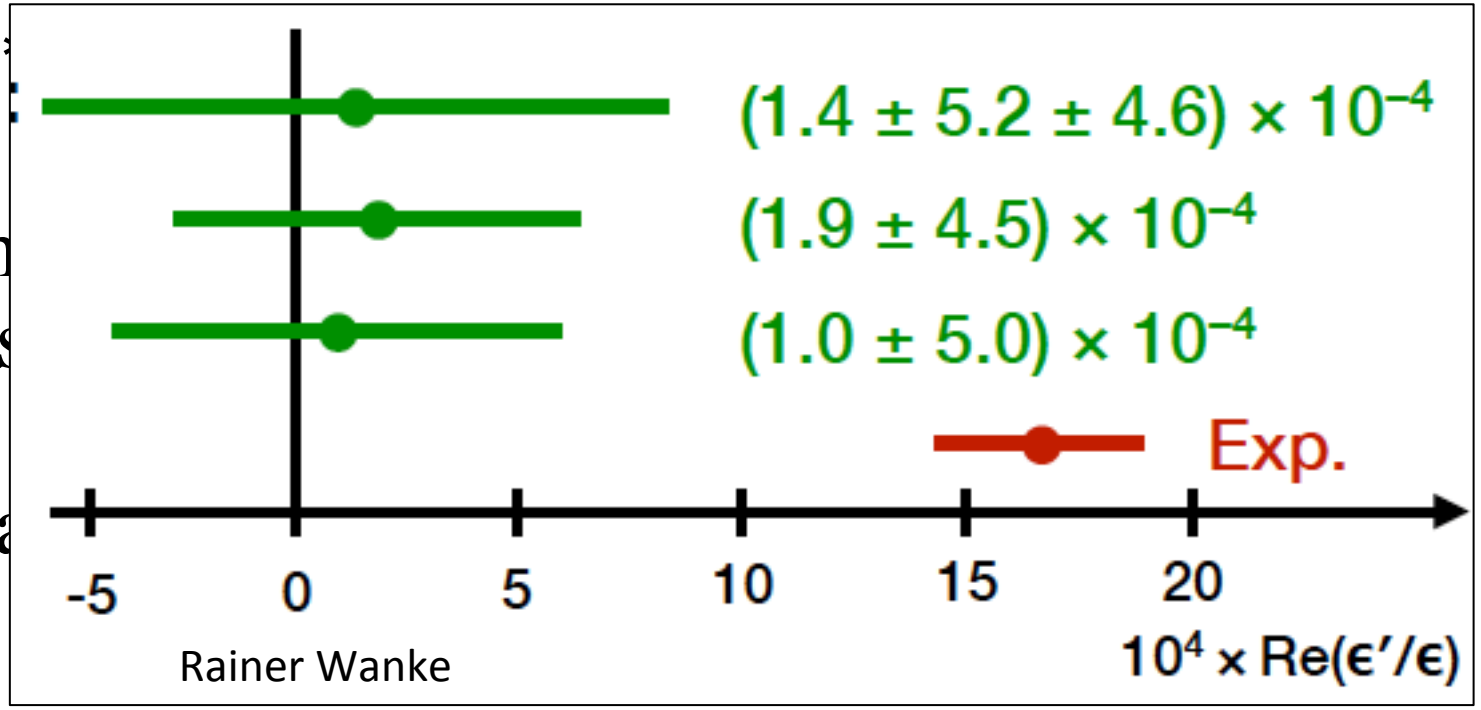

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- R_K: anomalous lepton universality
- $Re(\varepsilon'/\varepsilon)$: experimental value is too high compared with the recent QCD calculations. Shouldn't theory be able to calculate the $\Delta I=1/2$ enhancement?

Future improvement?

- $A_{CP}(K\pi)$: anomalous CP violation in $B \rightarrow K\pi$
  - Experimentally relatively easy, theoretically?

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- P5´: anomaly in the angular distribution of the decay final states generate by $b \rightarrow s l^+ l^-$ ($B^0 \rightarrow K^{*0} ll$, $B_s \rightarrow \phi ll$)
  - Unique feature to access the Lorentz structure rather than $|A|$ and arg A. Particularly interesting for "minimal flavour violation" scenario? Can QCD calculate the spin structure and polarisation of the hadronic state (resonant, non-resonant)?

- R_K: anomaly in the lepton universality
  - Experimentally not too difficult, particularly for Belle II

Question to theoreticians?

- Is $A(M \to F) = \left\langle F \left| H_{\text{effective}}^{\text{weak decay}} \right| M \right\rangle = \frac{G_F}{\sqrt{2}} \sum_i \xi_{CKM}^i C_i(\mu) \langle F | Q_i(\mu) | M \rangle$ framework sacred?
  Long range initial- and/or final- state interactions?
- What will be the progress in calculating $<F|Q_i(\mu)|M>$? HQET, QCD sum rule, PQCD, etc.
  Any hadronic component in virtual photon?
- Will the lattice QCD be the ultimate? How can one confirm the size of the systematic errors?
- Any clever way to use experimental input to get around hadronic uncertainties? (Keri Vos)
- So far neglected terms, which may not be so small?
- How experiments can help, e.g. for $|V_{ub}|$?