$B_s \to K$ form factors

and their impact on CKM elements

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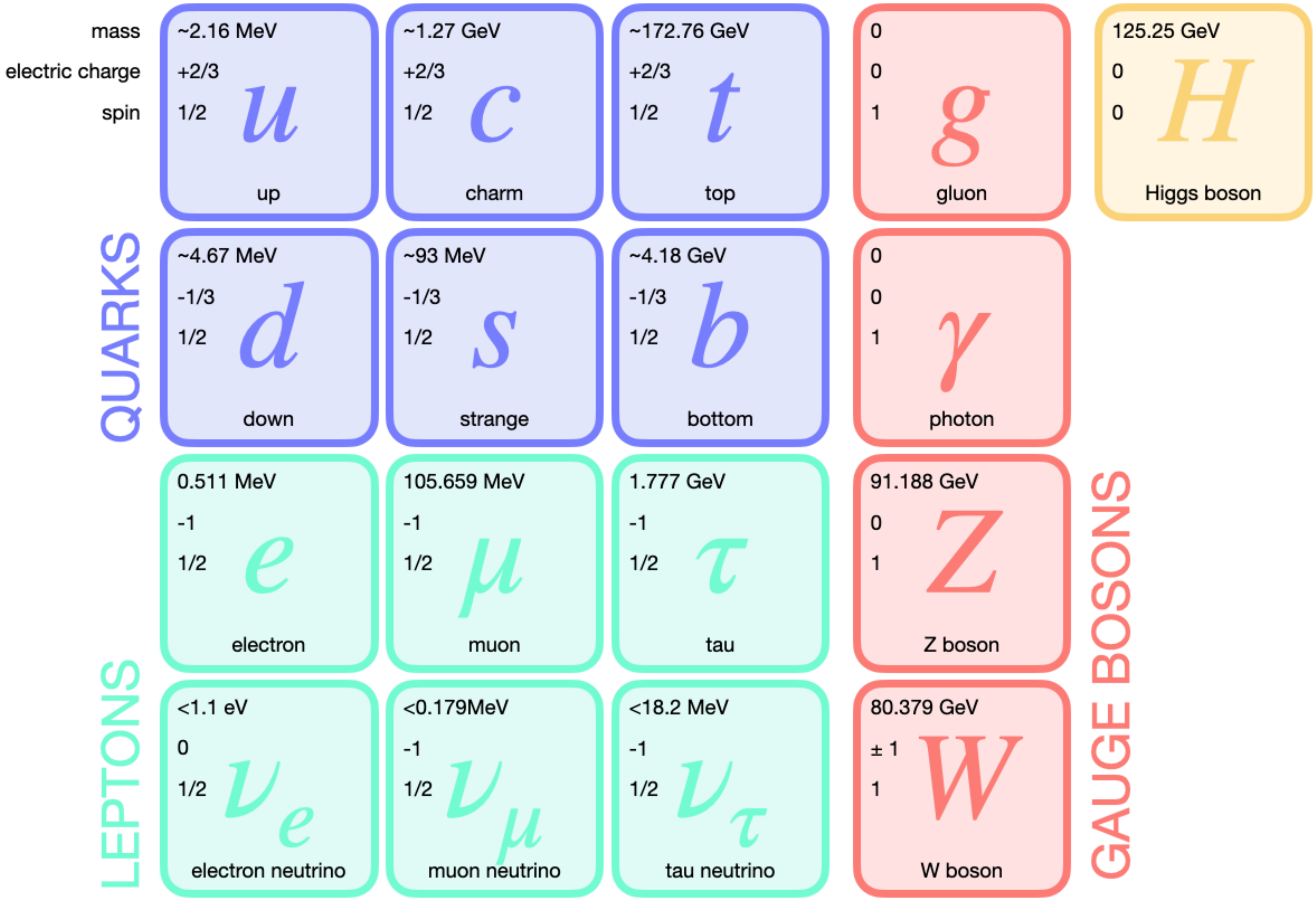
Motivation

- Standard model of particle physics is incomplete → precision tests are necessary!
- Need good understanding and measurements of all free parameters



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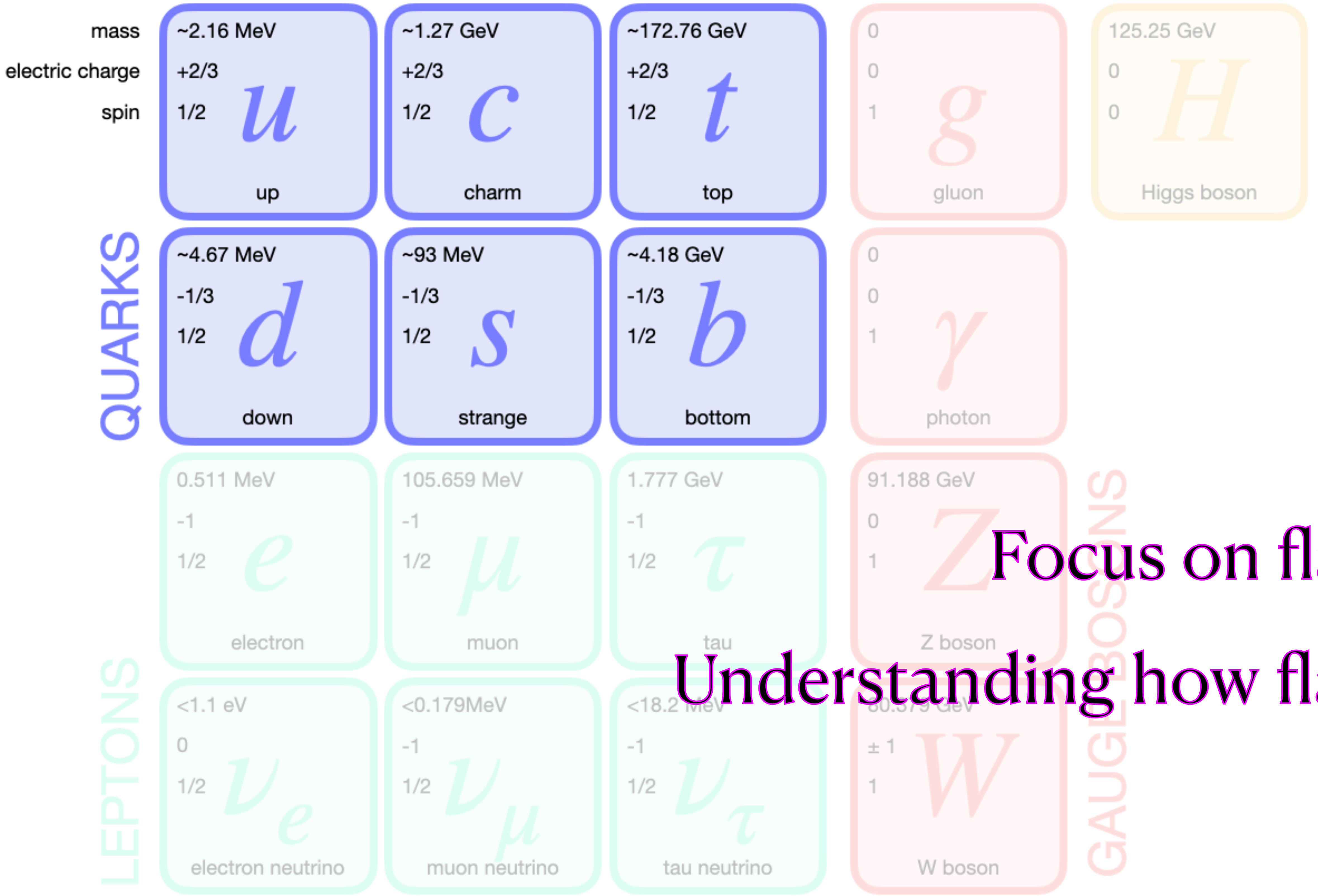
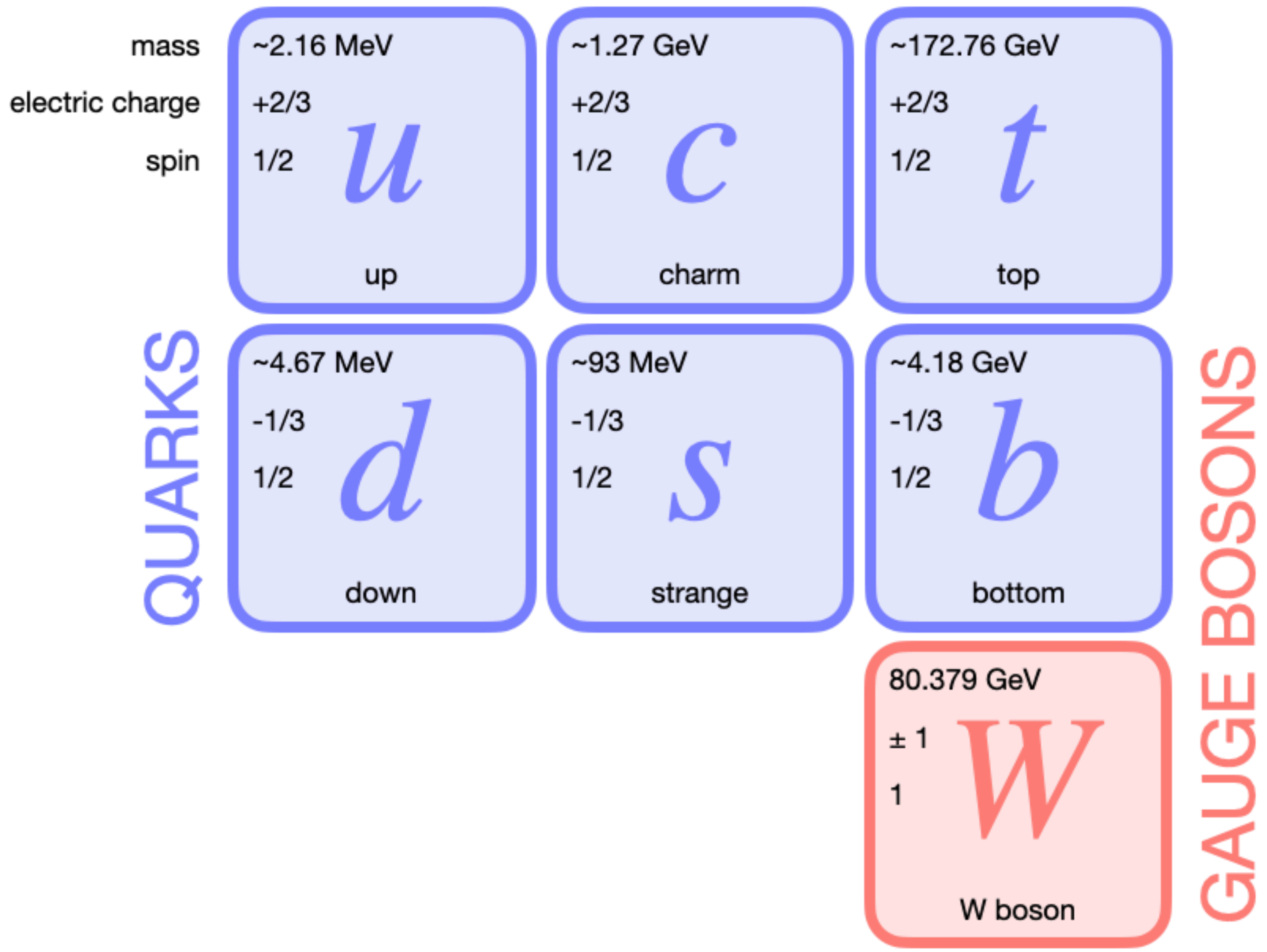


Focus on flavour physics

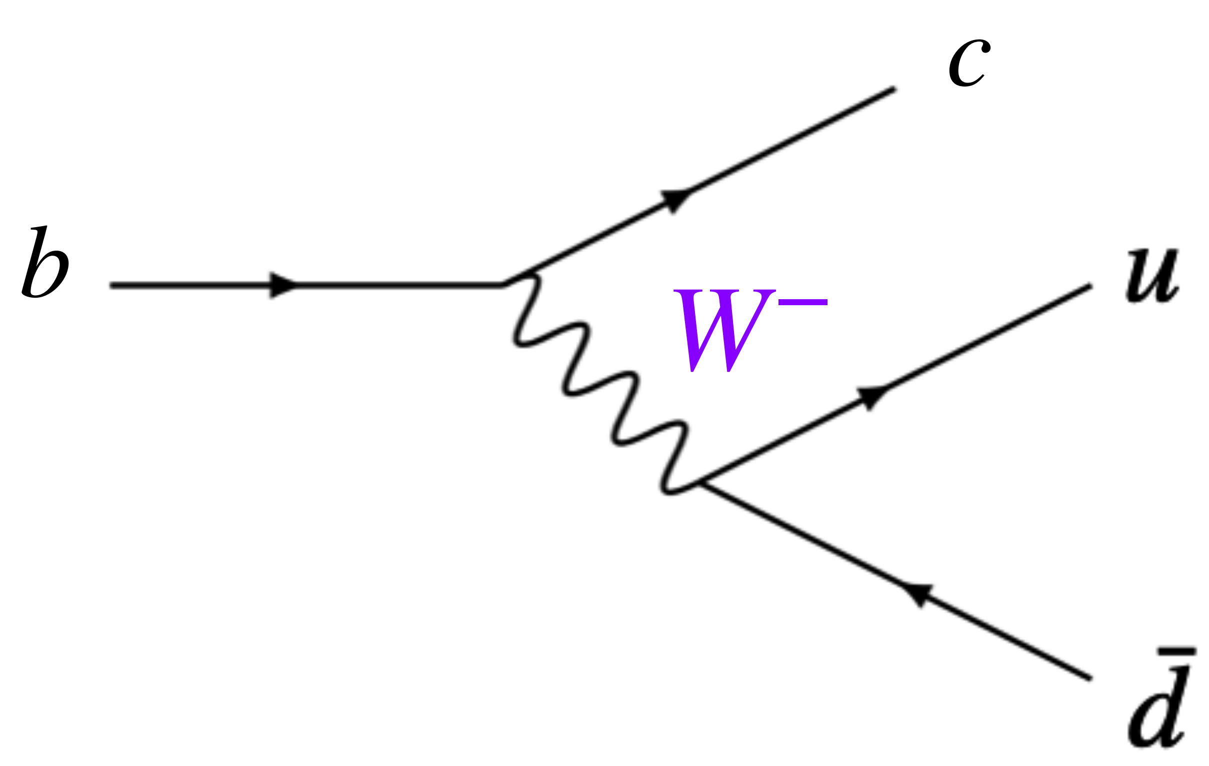
Understanding how flavours of quarks change

The CKM matrix

Quark flavour transitions



- Charged weak interactions allow for flavour changes in the Standard Model



The CKM matrix

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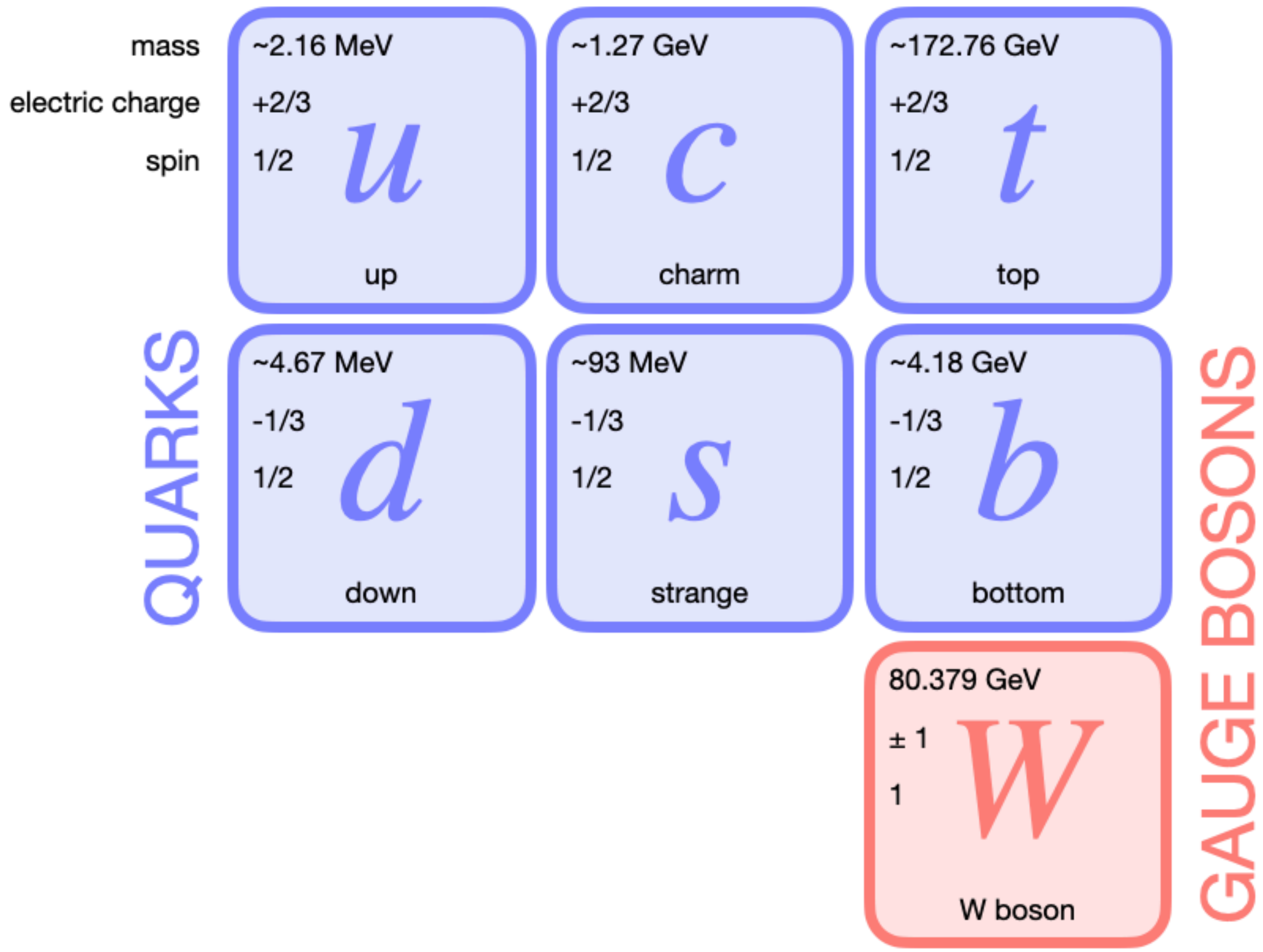
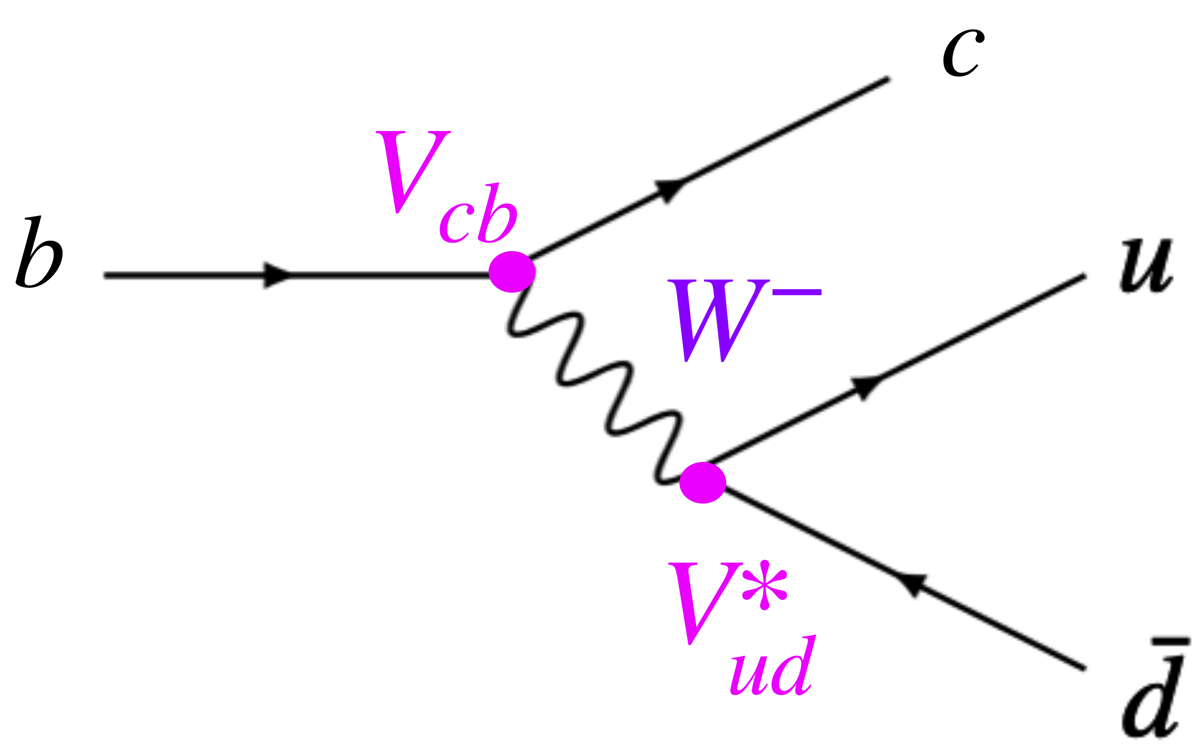


- Charged weak interactions allow for flavour changes in the Standard Model
- Quark transition probabilities related to Cabibbo-Kobayashi-Maskawa matrix



$$V_{CKM} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

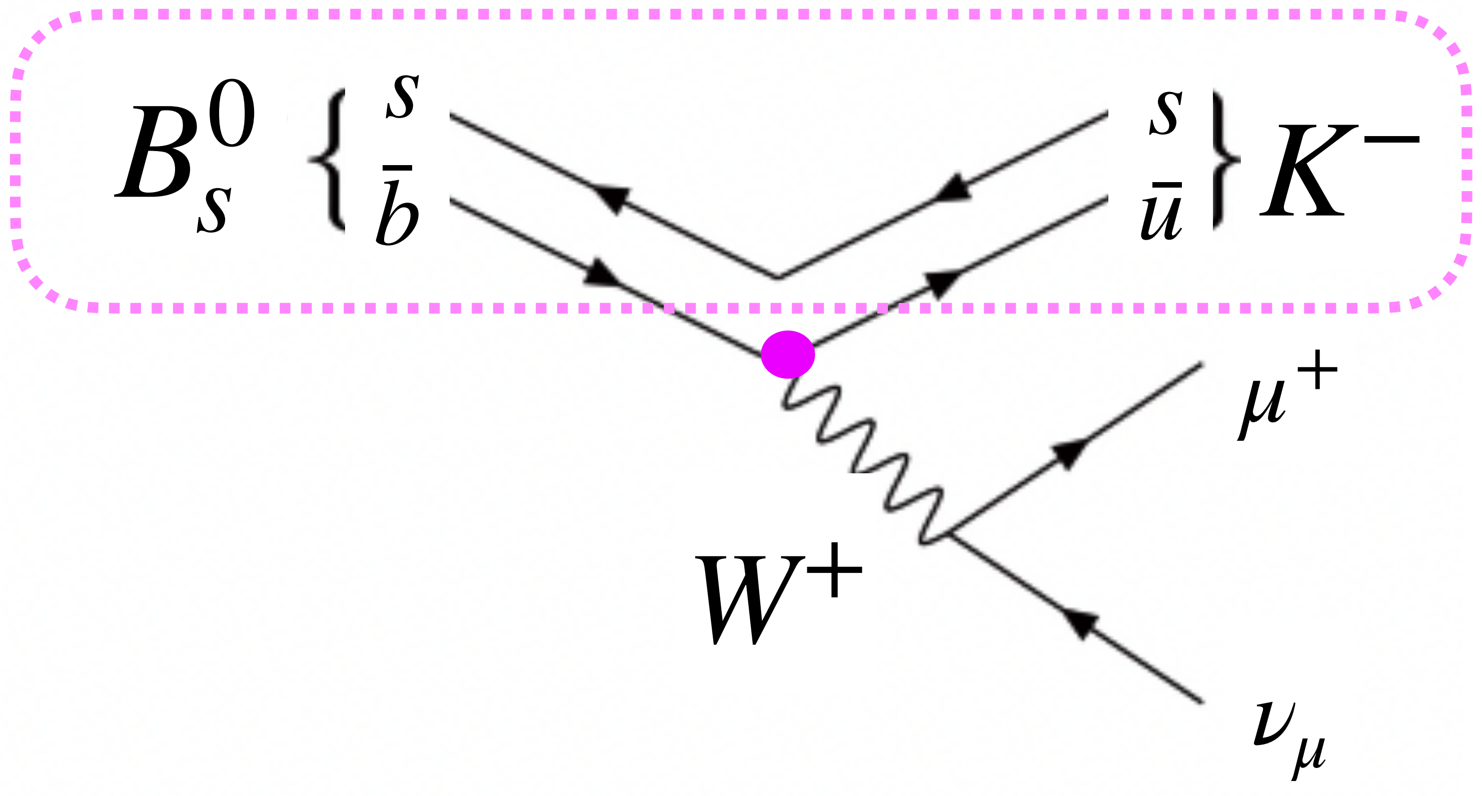
Kobayashi, M., Maskawa, T., Prog. Theor. Phys., 49:652–657, 1973

Need to be measured! Used as inputs for predictions!

The CKM matrix

Measuring the matrix elements

- Mostly extracted from data analysis of semi-leptonic decays
  - ➡ More data than leptonic decays
  - ➡ Only one hadron in the final state → cleaner theory predictions about decays
- e.g.: V_{ub} from $B_s^0 \to K^- \mu^+ \nu_\mu \Rightarrow$ compare branching ratio to theory expression



Quarks decay but hadrons are observed

↓

QCD problems reduced to form factors

This talk = how to approach FF!

The CKM matrix

The $V_{ub} - V_{cb}$ puzzle

- Inconsistency found when extracting V_{ub} or V_{cb} from exclusive or inclusive decays

$b \to ul\nu$ $b \to cl\nu$

Final state is fully known

Hadronic part : specific form factors

Form factor calculations are not straight-forward : depend on momentum of lepton pair

Final state is sum of all possible states

Hadronic part : data

Experimentally more complicated to obtain data for comparison to theory

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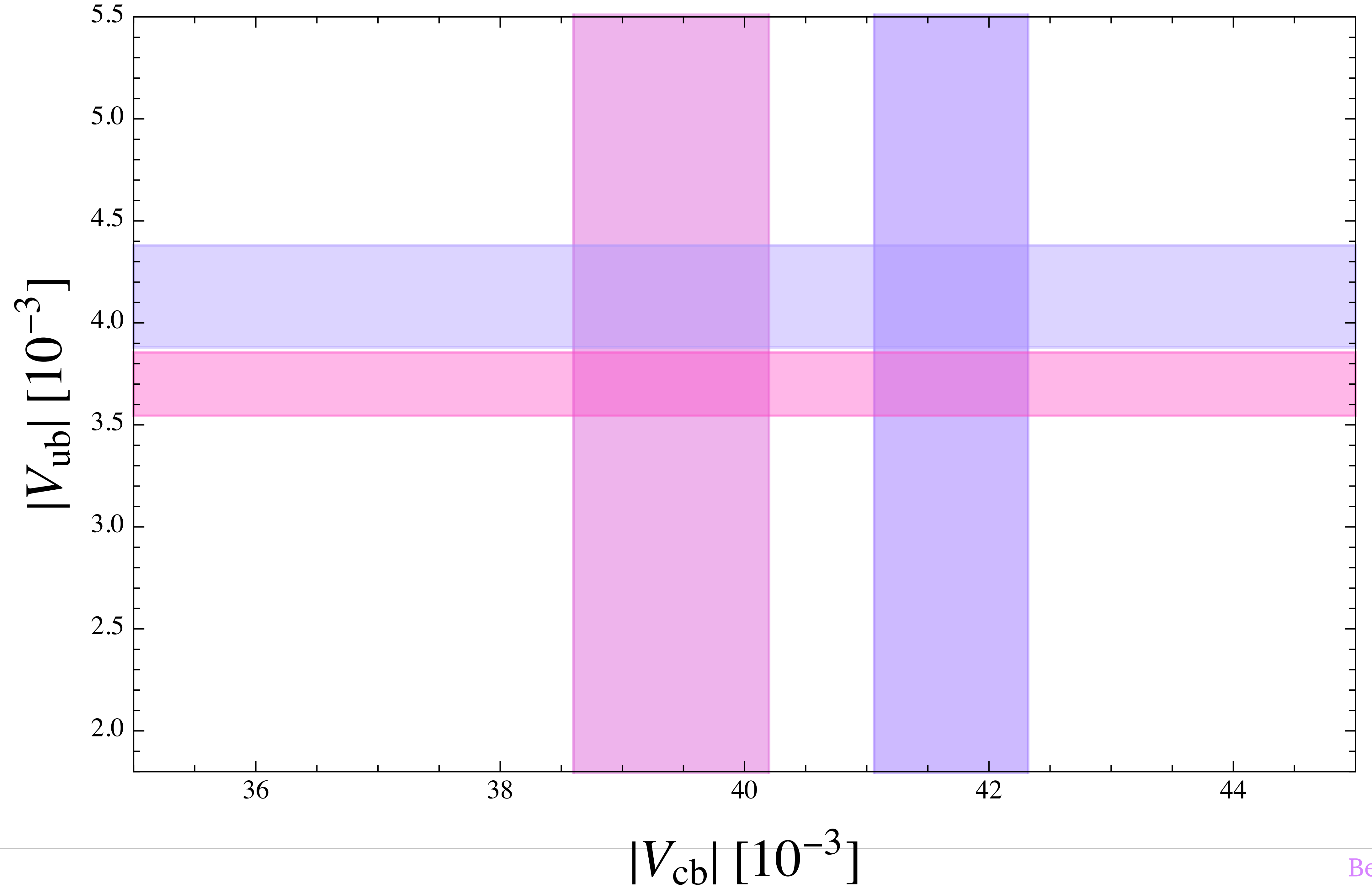

Particle Data Group, 2022

Bernlochner, Welsch, Fael, Olschewsky, Persson, van Tonder, Vos, JHEP 10 (2022) 068

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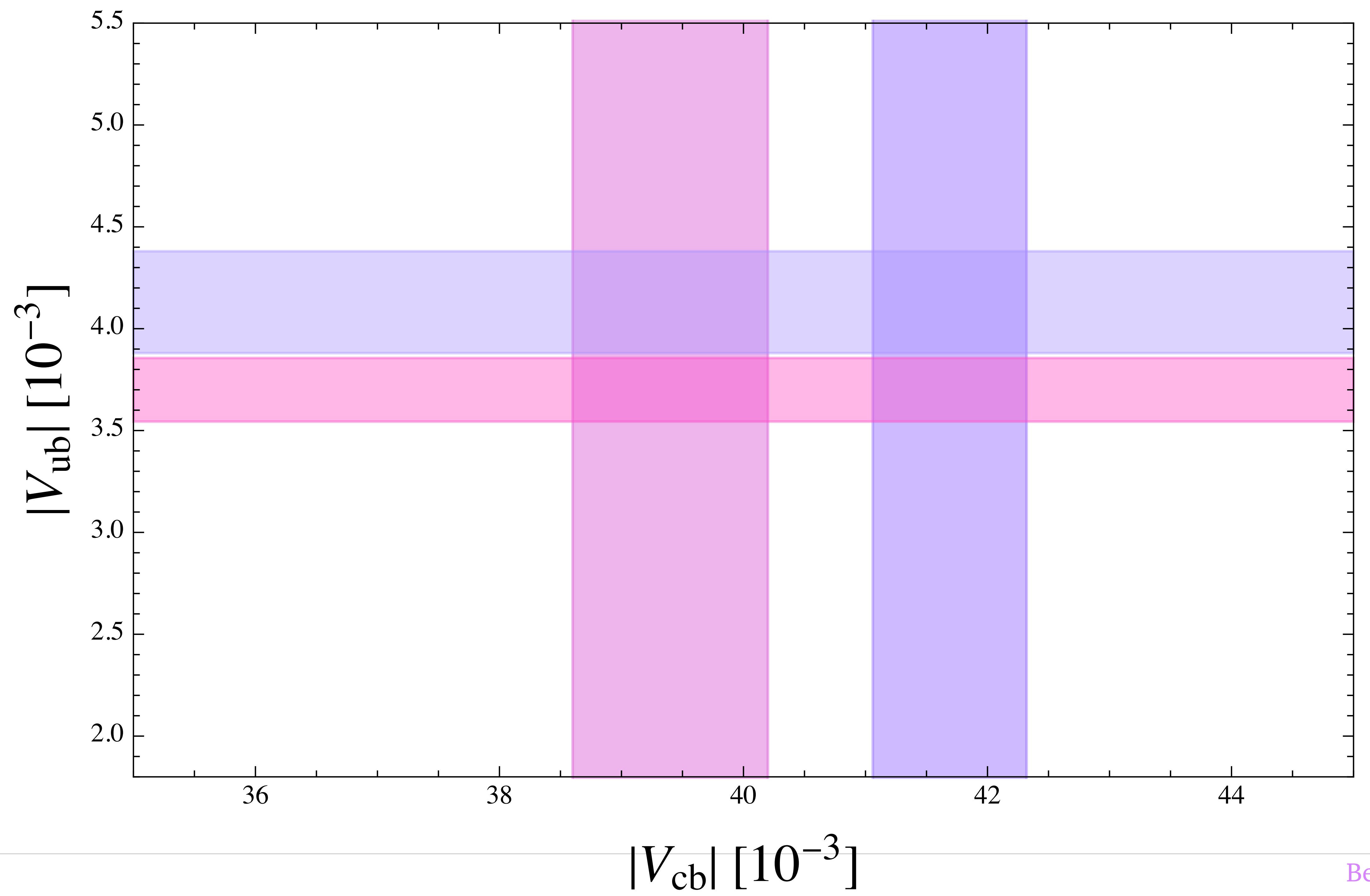
$b \to u l \nu$ $\quad$ $b \to c l \nu$



Also possible to determine ratios experimentally!

Particle Data Group, 2022

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Extracting $|V_{ub}/V_{cb}|$ from $B_s^0 \to K^- \mu^+ \nu_\mu$

2012 data LHCb analysis – Method

- First observation of decay and determination of branching ratio
- Normalised to $B_s^0 \to D_s^- \mu^+ \nu_\mu$: reduce experimental systematic uncertainty

$$\frac{\mathscr{B}\left(B_s^0 \to K^- \mu^+ \nu_\mu\right)}{\mathscr{B}\left(B_s^0 \to D_s^- \mu^+ \nu_\mu\right)} = \frac{|V_{ub}|^2}{|V_{cb}|^2} \boxed{\frac{\mathrm{FF}_K}{\mathrm{FF}_{D_s}}}$$

Form factors are important theory input!

- FF_{D_s} well determined for full range of lepton pair momentum, FF_K has two completely different determinations for different ranges!

LHCb Collaboration, Phys.Rev.Lett. 126 (2021) 8

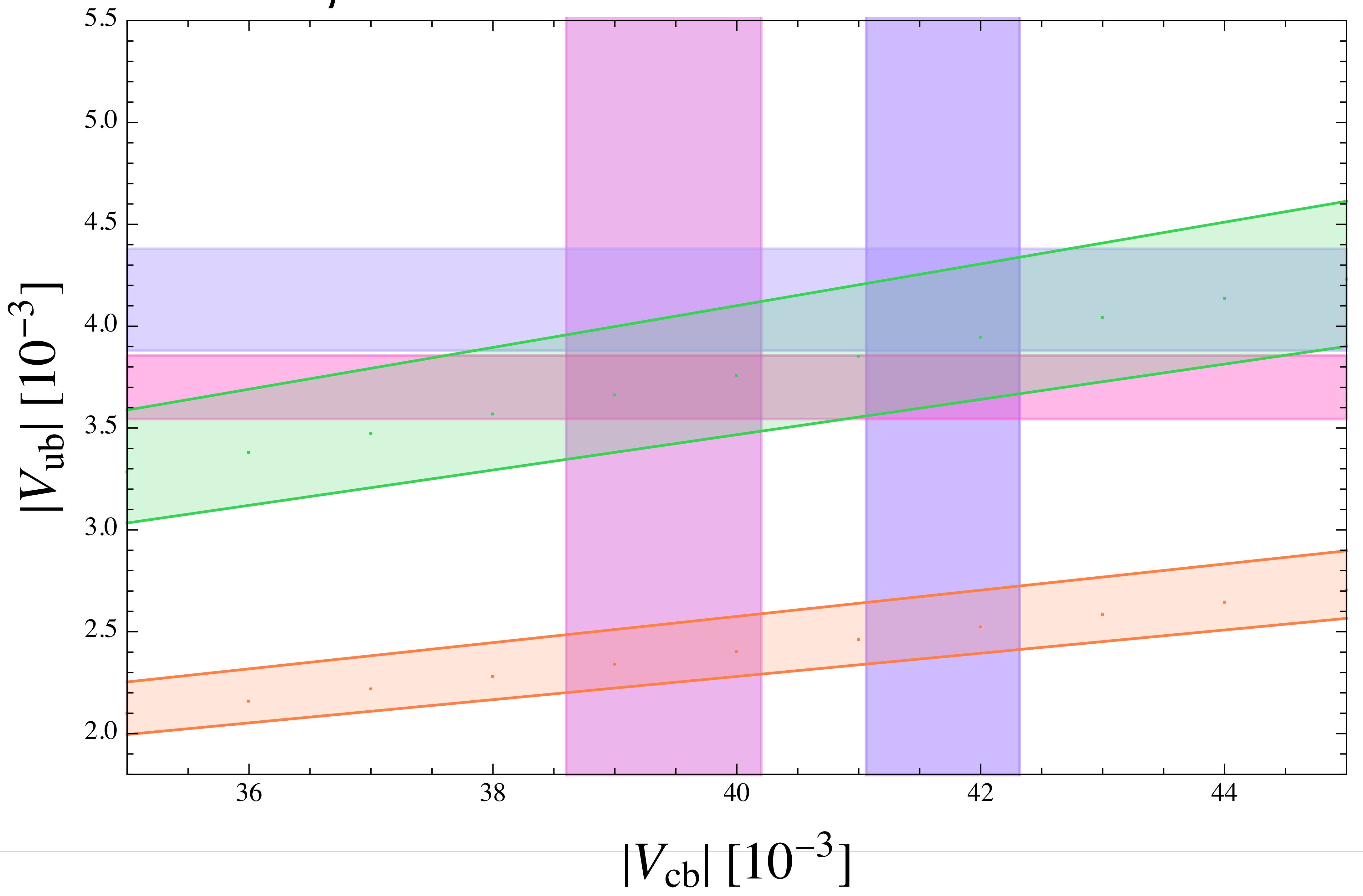
Extracting $|V_{ub}/V_{cb}|$ from $B_s^0 \to K^- \mu^+ \nu_\mu$

2012 data LHCb analysis – Results

- First observation of decay and determination of branching ratio
- Normalised to $B_s^0 \to D_s^- \mu^+ \nu_\mu$: two different q^2 ranges for $B_s \to K$ form factors!

Low q^2

FF determined with Light-Cone Sum Rules



High q^2

FF determined with Lattice QCD

LHCb Collaboration, Phys.Rev.Lett. 126 (2021) 8

Determining form factors

LCSR x LQCD

low q^2

Light-Cone Sum Rules (LCSR)

Write the hadrons in terms of currents

Expand these currents near the light-cone

Factorise out the non-perturbative part

Re-interpret in terms of sum of hadron states

➡ Some approximations are needed in the calculations

high q^2

Lattice QCD (LQCD)

Discretise spacetime and calculate: grid introduces natural regularisation of lengths and momenta

➡ Computationally intensive : large grids and small spacing

EPJ Web Conf. 245 (2020) 09008

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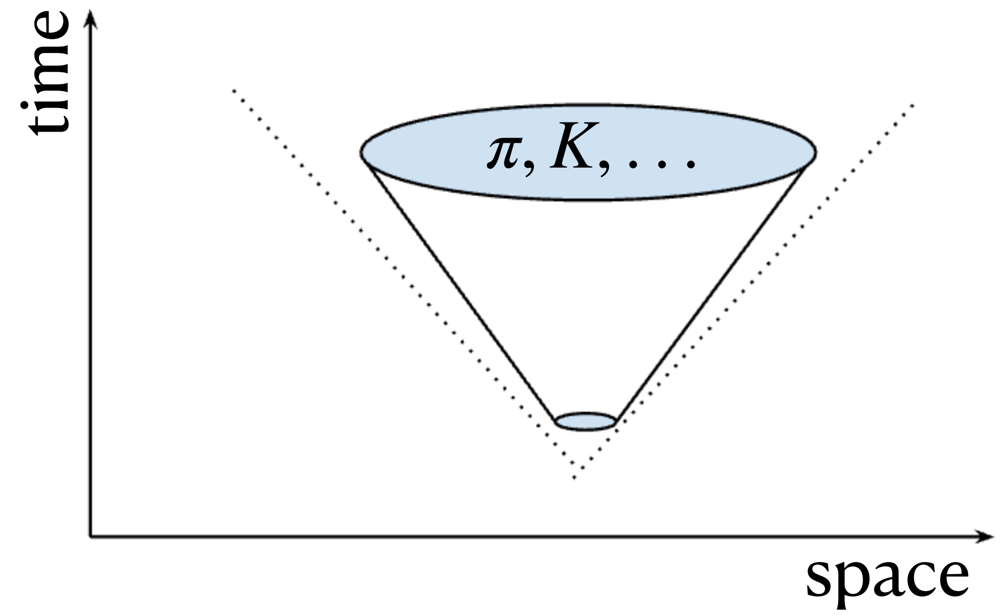

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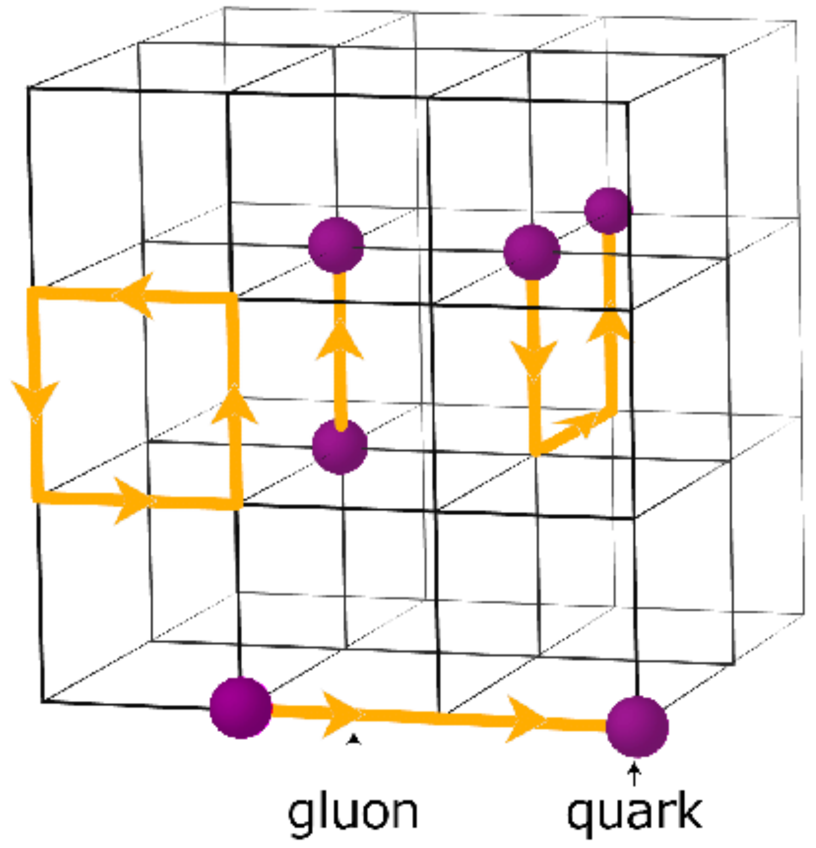


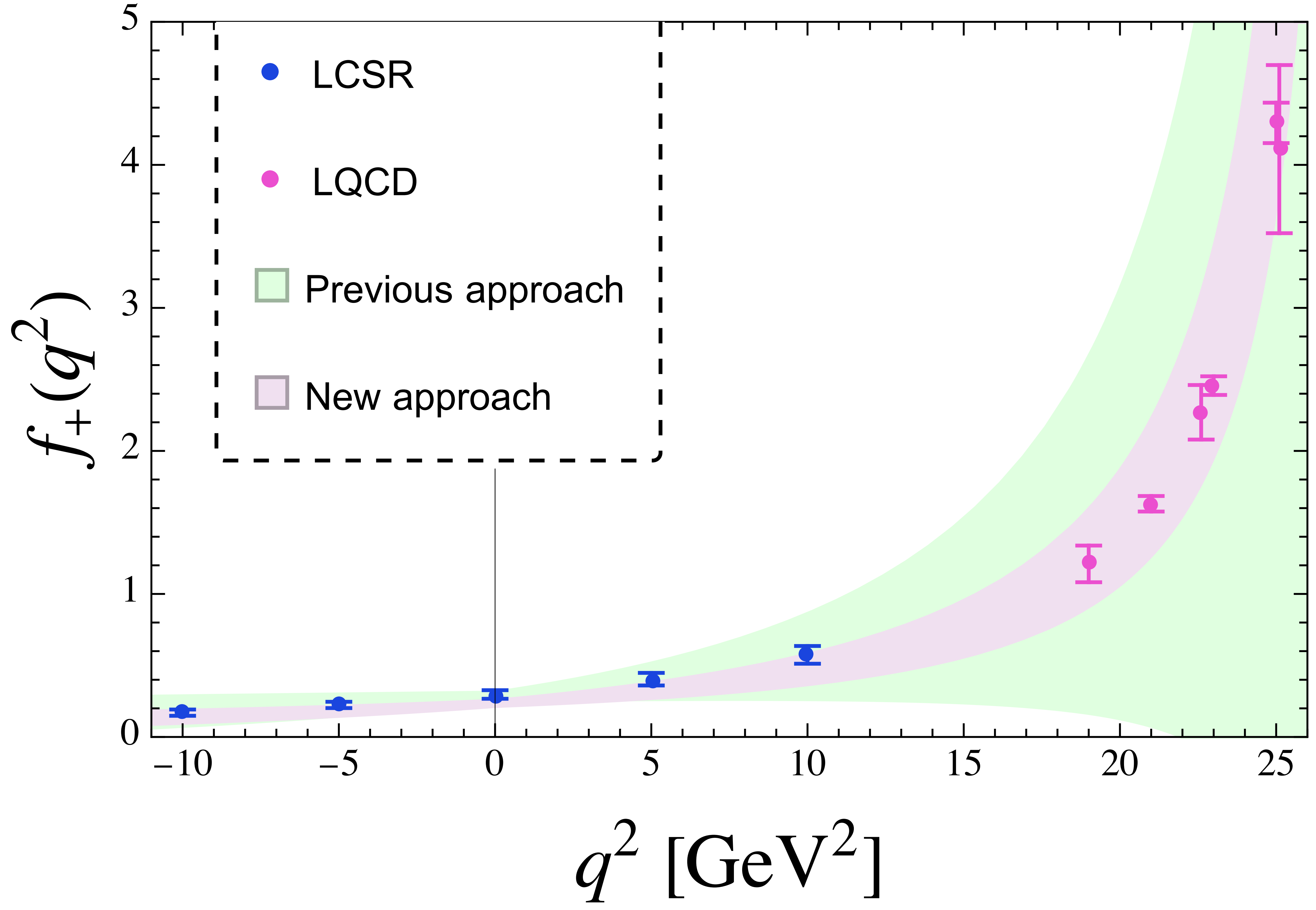
EPJ Web Conf. 245 (2020) 09008

Improving form factor determination

Extrapolating LCSR to LQCD : $B \to \pi$ example

- Calculate form factors with LCSR and extrapolate to high q^2

- Fit LCSR points and LQCD points together with new parametrisation



Leljak, Melic, Dyk, JHEP 07 (2021) 036

New approach to $B_s \to K$

Ongoing project

With Danny van Dyk and Keri Vos

New determination of the form factors: how will it impact the CKM elements?

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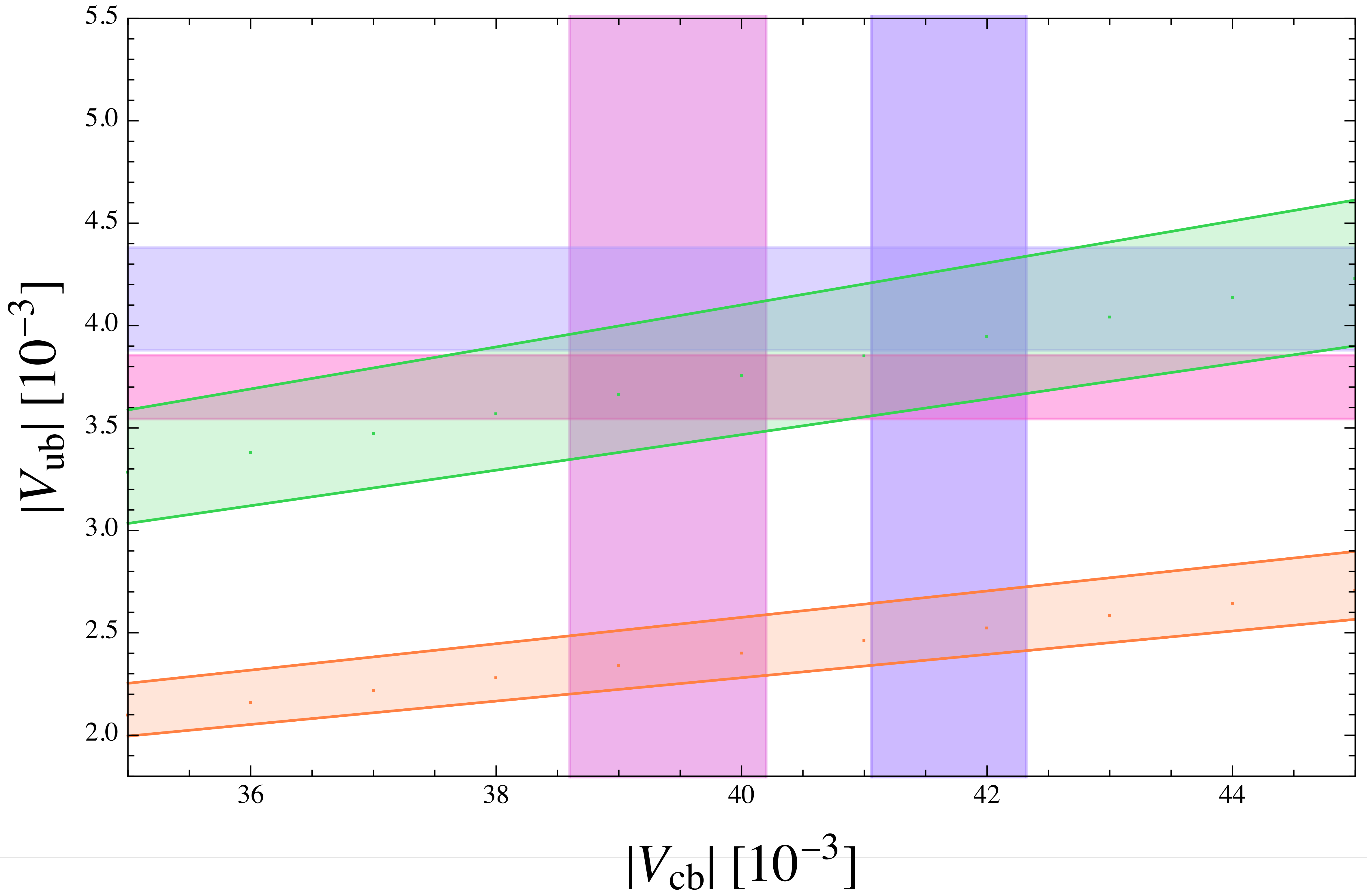
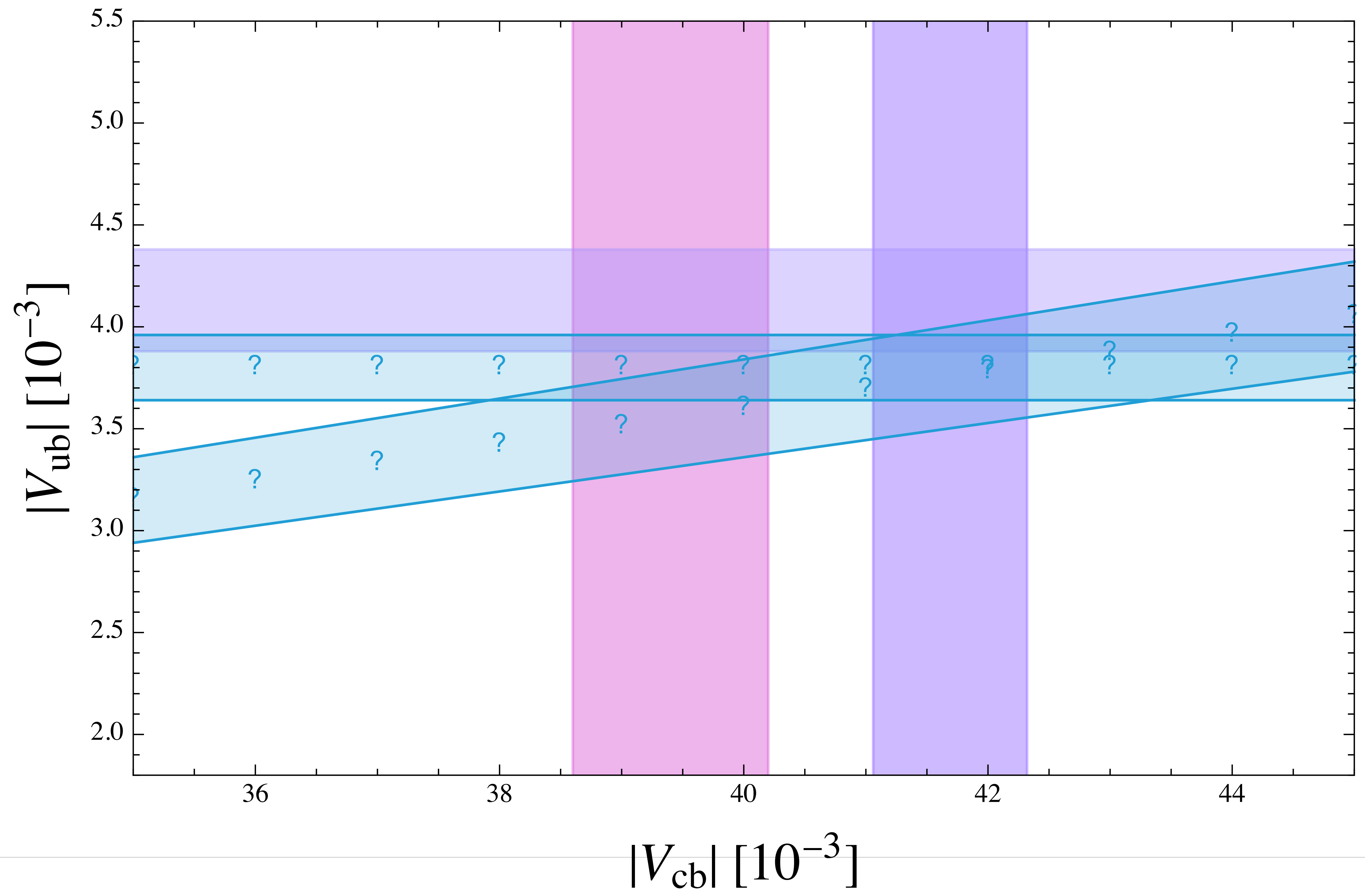


New approach to $B_s \to K$

Prospective

With Danny van Dyk and Keri Vos

New determination of the form factors: how will it impact the CKM elements?



Improve V_{ub} exclusive?

Resolve $|V_{ub} / V_{cb}|$ ratio!

Conclusion

- CKM elements are important input parameters in the Standard Model
  - ★ Currently there are inconsistencies between exclusive and inclusive determinations
- Improving theoretical form factor calculations may help resolve these inconsistencies
- A new approach appears! Work in progress with $B_s \to K$ form factors
  - ★ Unify low and high q^2 determinations in one go!
- Will the new CKM element and ratio increase or reduce the puzzle?

Thank you!

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