Decay Constants and SU(3) Symmetry Breaking in *B*-mesons with Quenched Relativistic *b*-quarks

Sophie Hollitt

Ross Young and James Zanotti

INPC 2016, Tuesday 13th September

Australian Government
Australian Research Council

Special Research Centre for the Subatomic Structure of Matter

The University of Adelaide

CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

Why B-mesons?

- B-meson decays provide access to multiple CKM matrix elements
- The CKM matrix governs quark mixing and CP violations
- Deviations from unitarity indicate BSM physics.
- Evaluate CKM matrix elements by combining experimental results with lattice calculations.

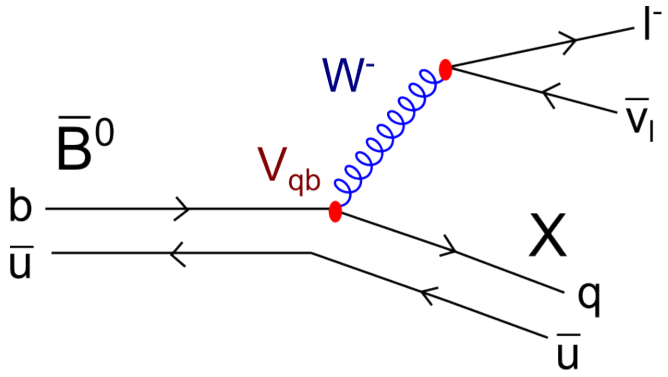
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

From semileptonic B decays

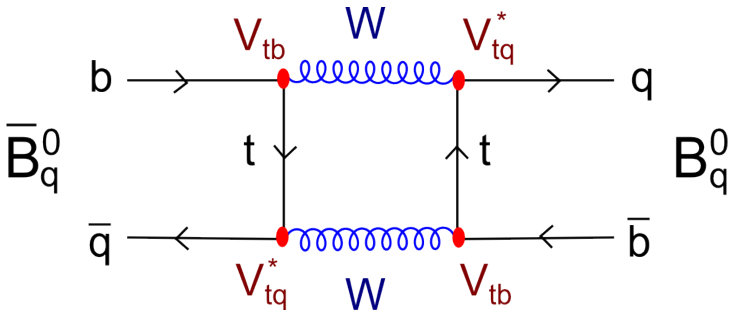
From B^0-$\overline{B}^0$ oscillations

Why B-mesons?

- Semi-leptonic decays of B-mesons are used to calculate elements $|V_{qb}|$.
- Discrepancy between $|V_{ub}|$ calculated from inclusive and exclusive decay channels, greater understanding of SM QCD flavour-changing processes required to reduce error size or search for new physics.



Why B-mesons?



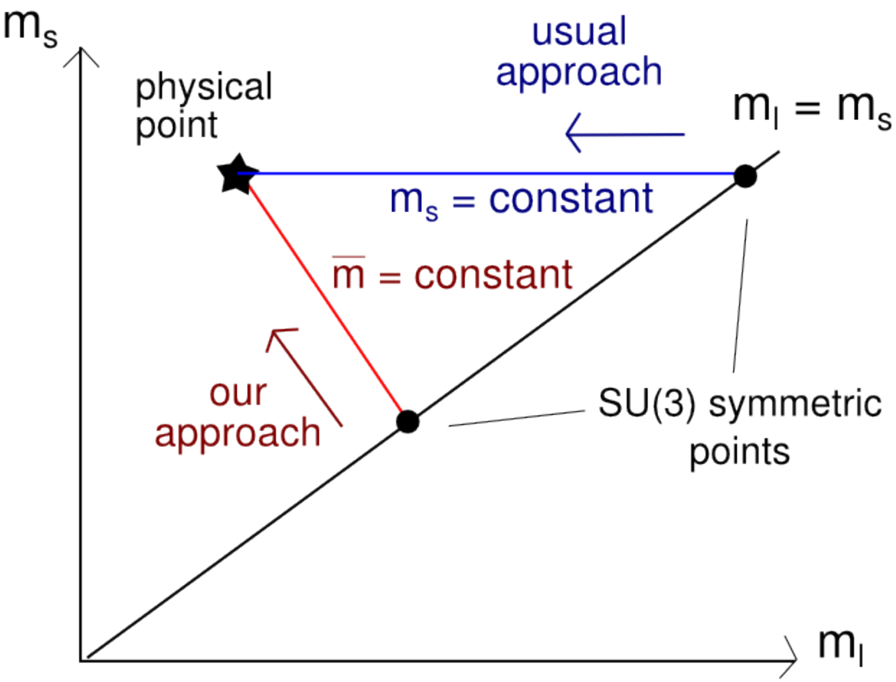
- Oscillations between B^0 and $\overline{B^0}$ used to calculate elements $|V_{tq}|$
- Calculation requires input from experiment and from lattice QCD.

$$\Delta M_q = \frac{G_F^2 m_w^2}{6\pi^2} \eta_B S_0 M_{B_q} f_{B_q}^2 B_{B_q} |V^*_{tq} V_{tb}|^2$$

Outline

- Measuring B-mesons on the lattice:
  - Selecting light quarks
  - Simulating *b*-quarks and tuning B mesons
- Symmetry breaking of the decay constant f_B
- Upcoming work

Selecting light quarks



- QCDSF collaboration 2+1 flavour formalism
- Focus on symmetry breaking with constant average mass $\overline{m} = m_u + m_d + m_s$
- Select $\overline{m}$ to match the physical value of $\overline{m}$

b-quarks on the lattice

- *b*-quarks are heavy and "fall through" the lattice without modification.
- Use an anisotropic, clover-improved action and then tune free parameters to physical quantities

$$S_{lat} = a^4 \sum_{x,x'} \overline{\psi}(x') \left(\underline{m_0} + \gamma_0 D_0 + \underline{\zeta} \vec{\gamma} \cdot \vec{D} - \frac{a}{2}(D^0)^2 - \frac{a}{2}\underline{\zeta}(\vec{D})^2 + \sum_{\mu,\nu} \frac{ia}{4} \underline{c_P} \sigma_{\mu\nu} F_{\mu\nu} \right)_{x,x'} \psi(x)$$ [1]

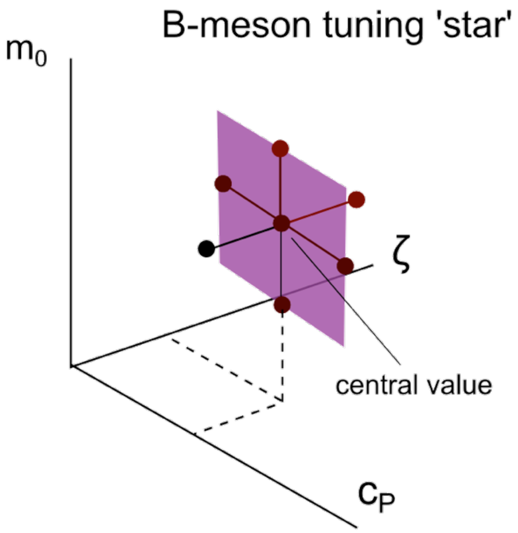
bare mass → spin-averaged meson mass

anisotropy → dispersion relation

clover coefficient → hyperfine splitting between B* and B

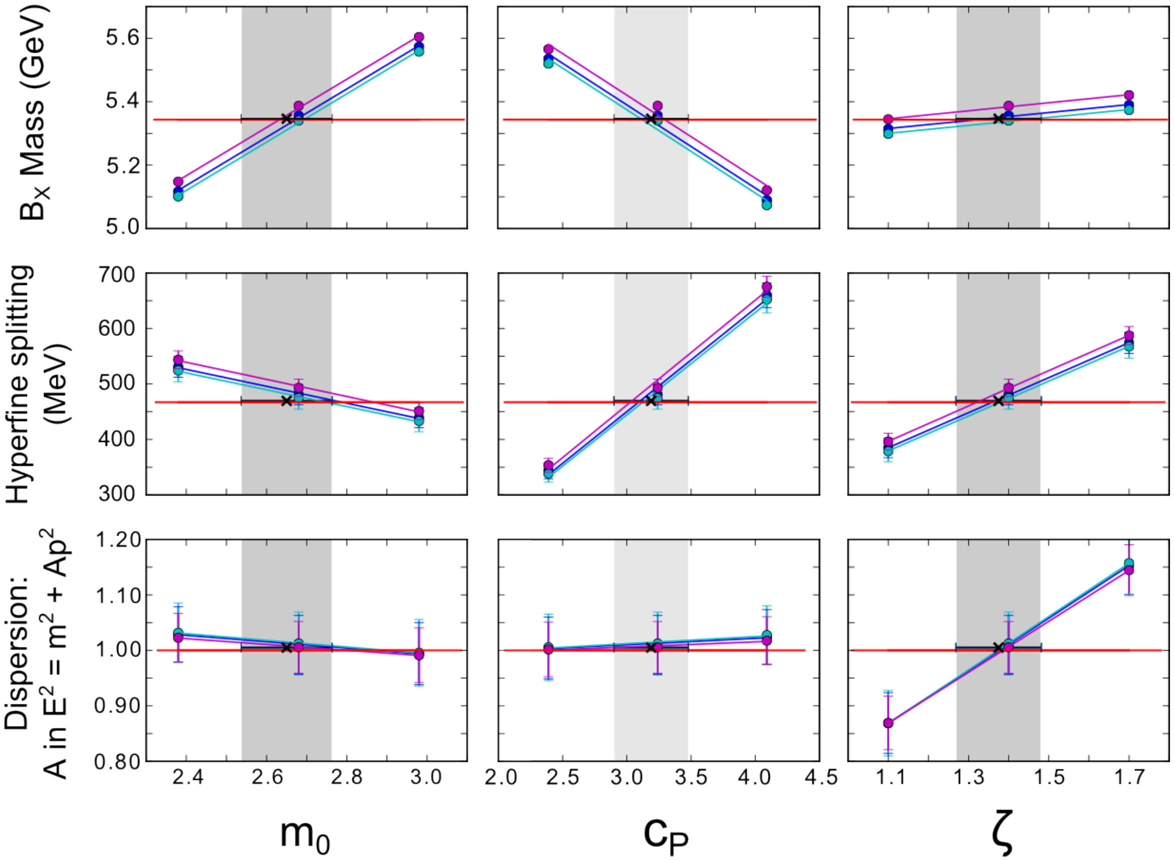
1 Aoki, Y et al (2012). "Nonperturbative tuning of an improved relativistic heavy-quark action with application to bottom spectroscopy." *Physical Review D*, *86*(11), 116003. doi:10.1103/PhysRevD.86.116003

Tuning B-mesons

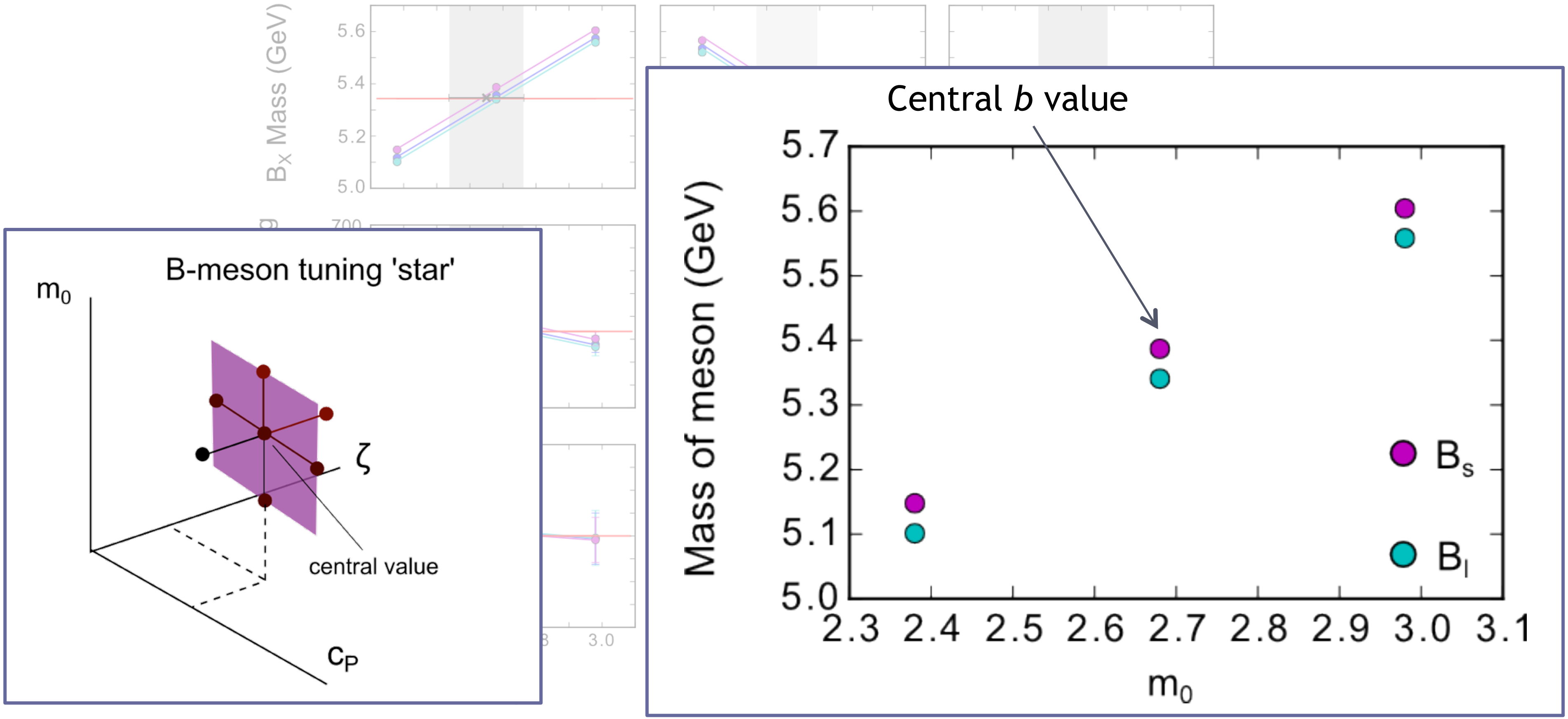


1. For every light quark, generate one “central” *b*-quark and six other *b*-quarks by varying our three free parameters.
2. Calculate a “flavour singlet” B meson, $B_X = (2/3)\ B_l + (1/3)\ B_s$ for each of our seven *b*-quarks.
3. Compare the calculated B_X mesons to the physical B_X meson to tune the free parameters.

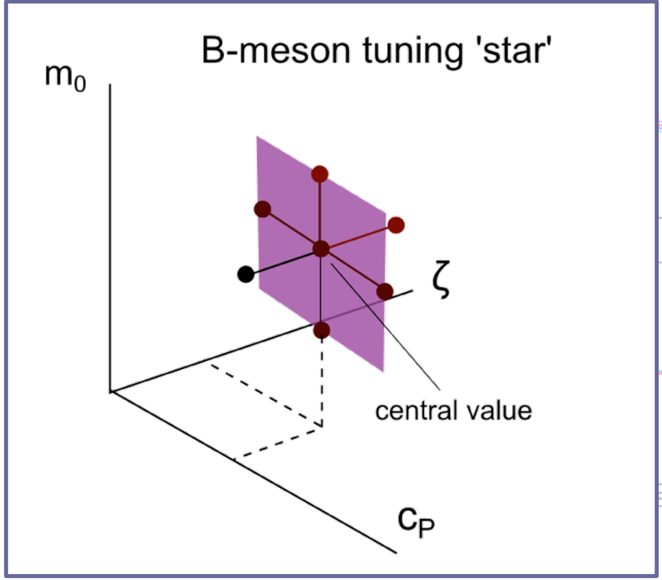
Tuning B-mesons

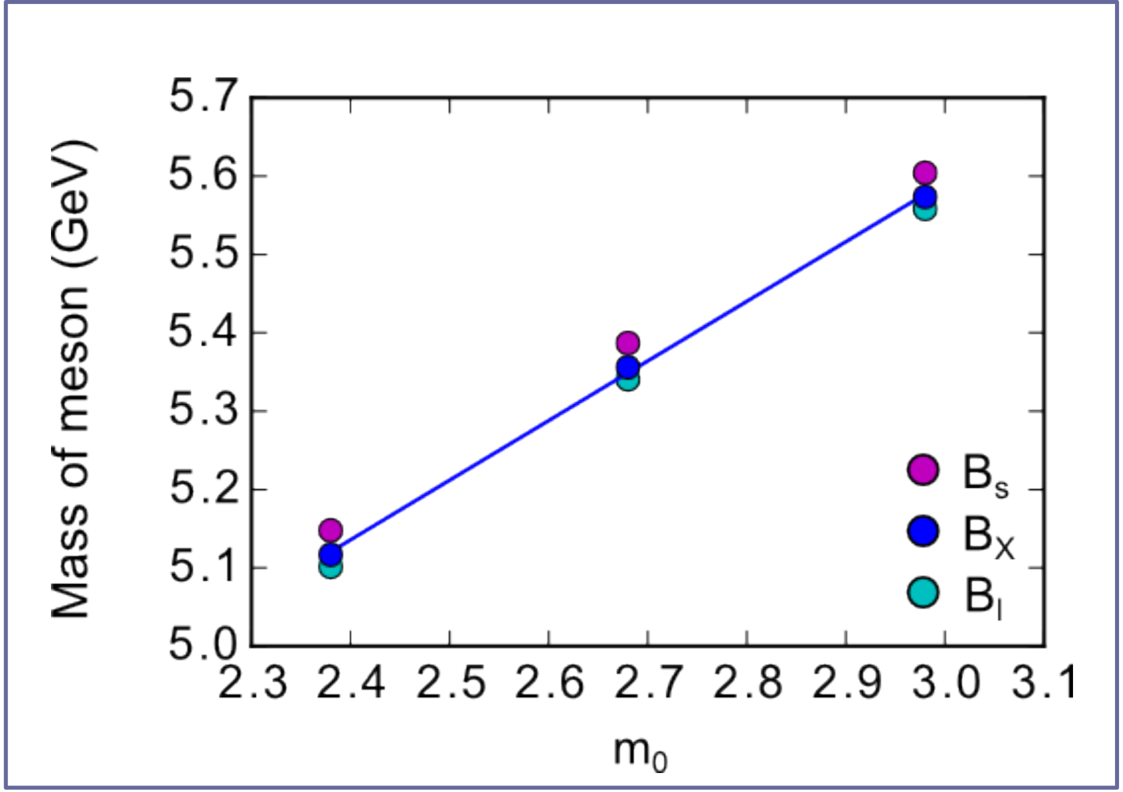


Tuning B-mesons

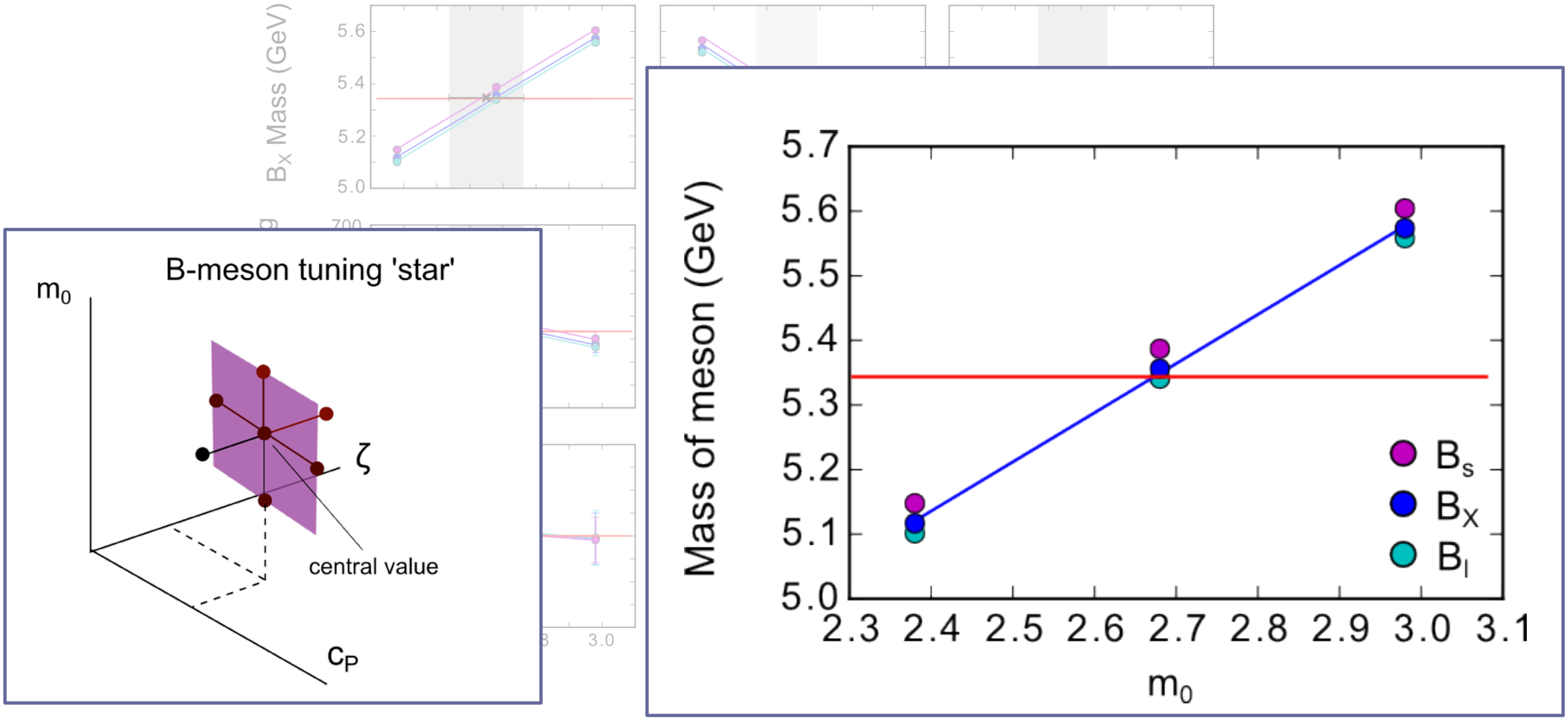


Tuning B-mesons

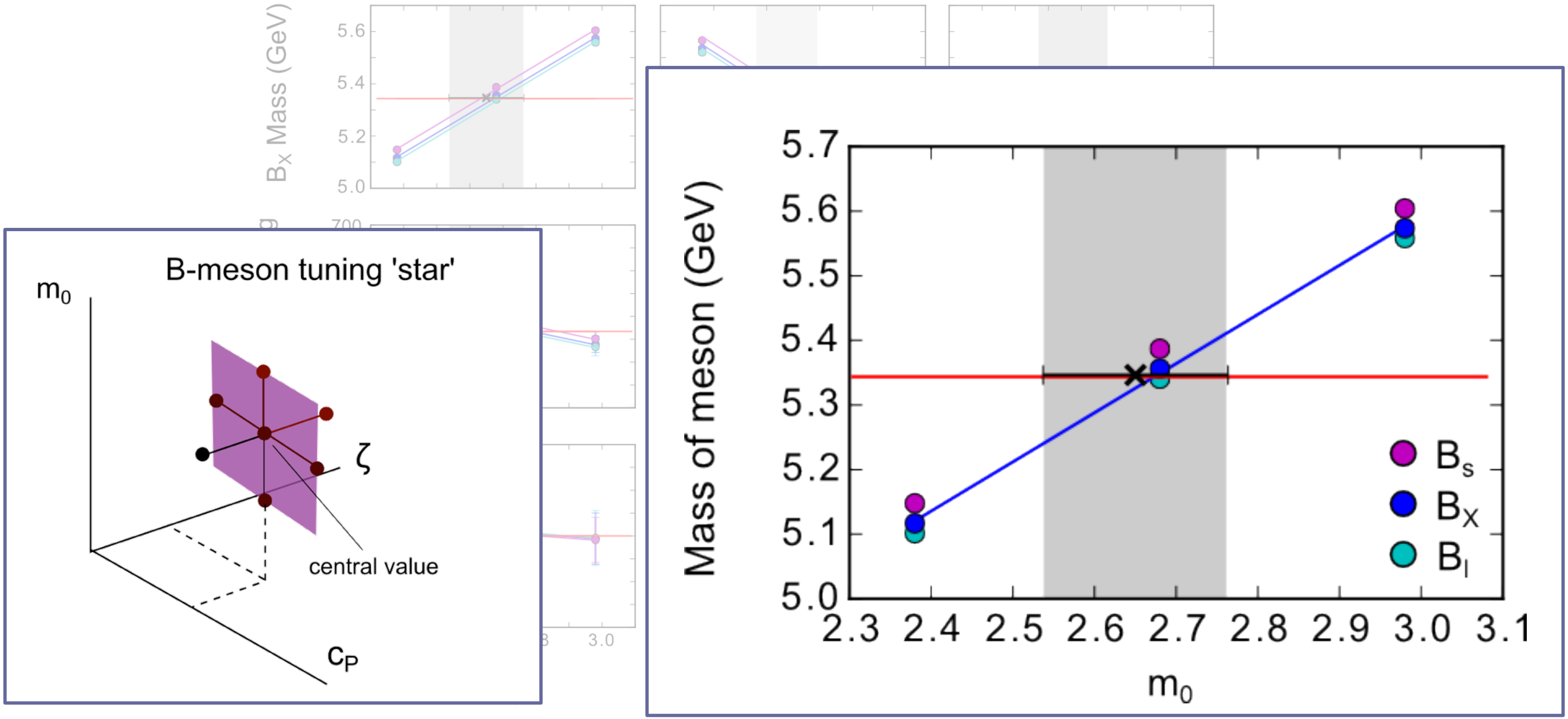




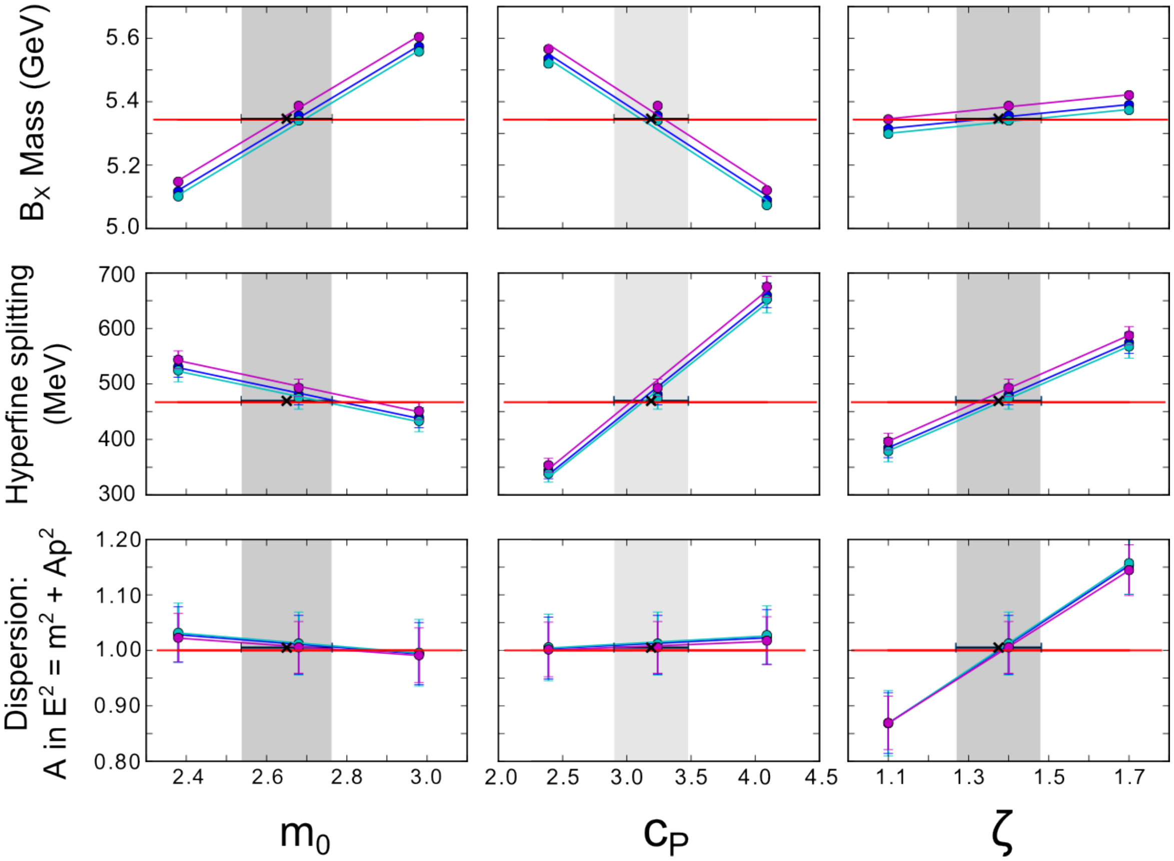
Tuning B-mesons



Tuning B-mesons

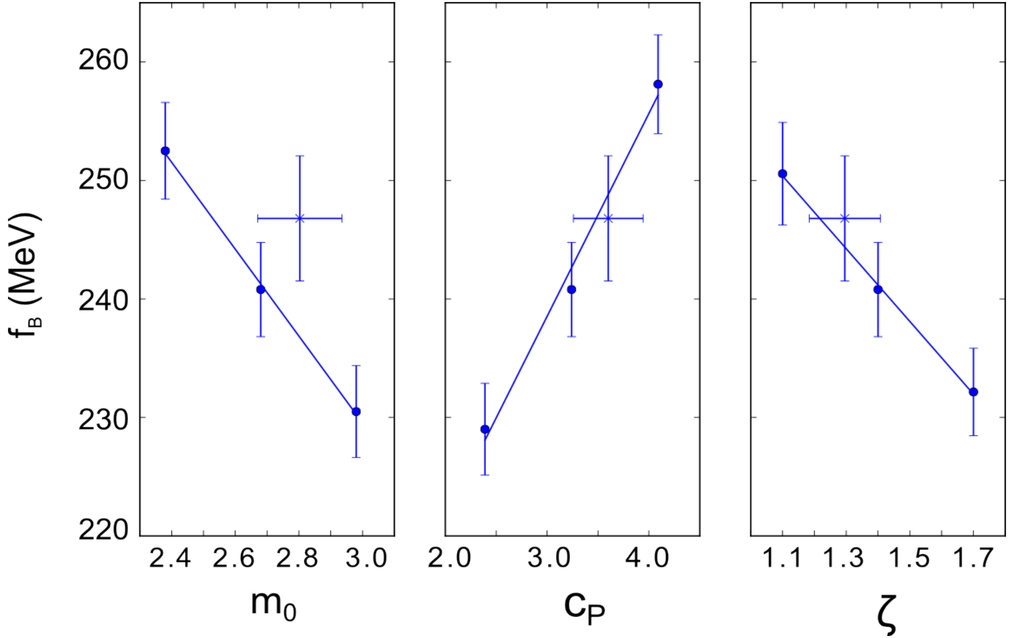


Tuning B-mesons



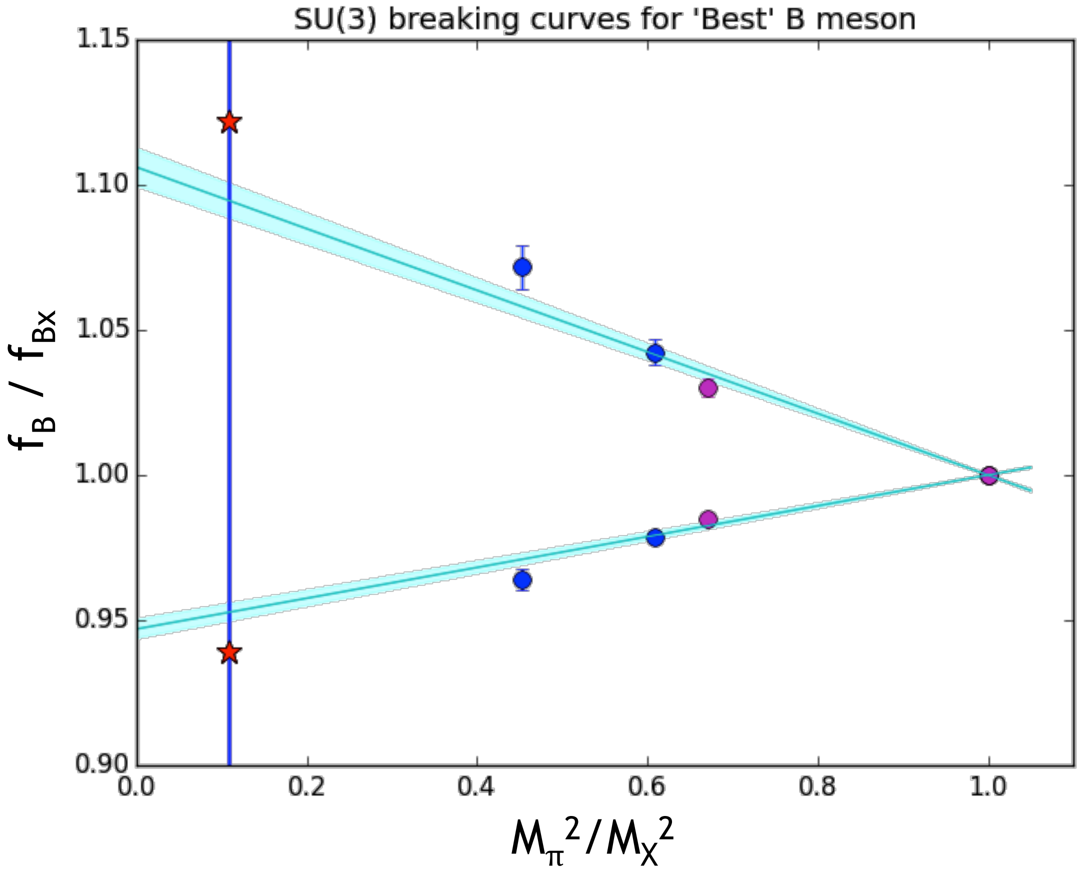
Decay constant f_{Bq}

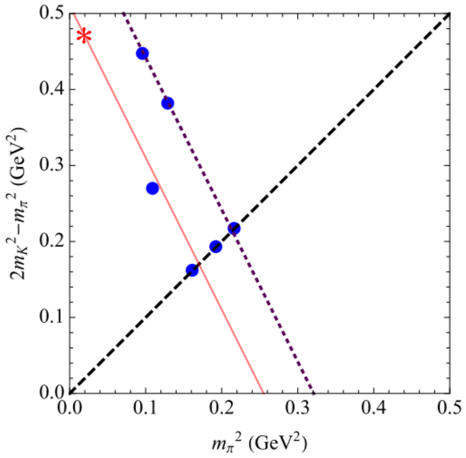
$$\Delta M_q = \frac{G_F^2 m_w^2}{6\pi^2}\eta_B S_0 M_{B_q} f_{B_q}^2 B_{B_q} |V_{tq}^* V_{tb}|^2$$



- Calculate f_B for each B meson, and use the tuning to interpolate the "best" B-meson and thus "best" f_B

Decay constant f_{Bq}: SU(3) breaking





- Compare f_{Bl} and f_{Bs} to f_{Bx} to cancel out some sources of error.

What's next from here?

Symmetry breaking of f_B and f_{Bs}

- Continued investigation of f_B using multiple lattice spacings and lattice volumes to quantify systematic errors and discretisation effects.

Upcoming work: form factors

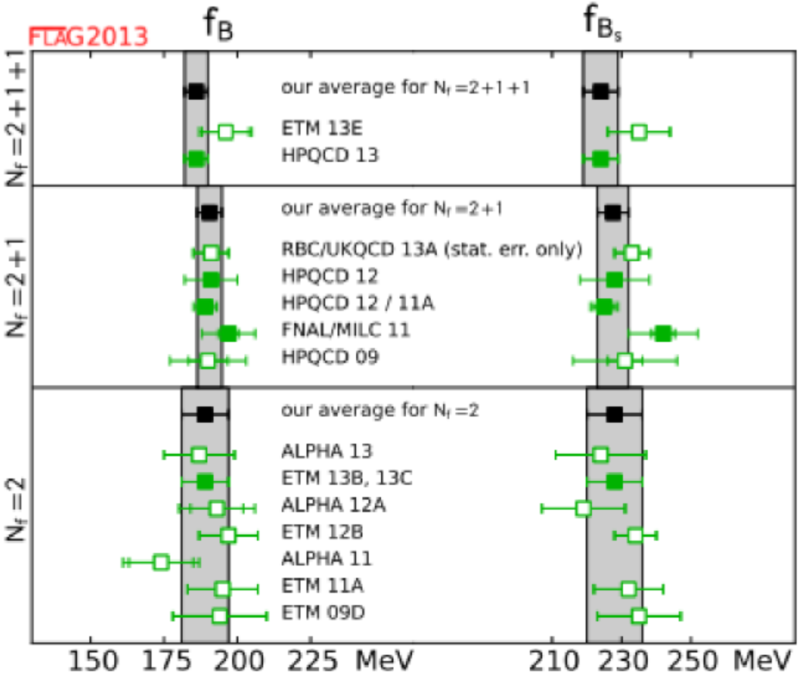
- Calculation of form factors for the B-meson
- Calculation of semi-leptonic weak decay of the B-meson to assist with $|V_{bq}|$ at Belle II.

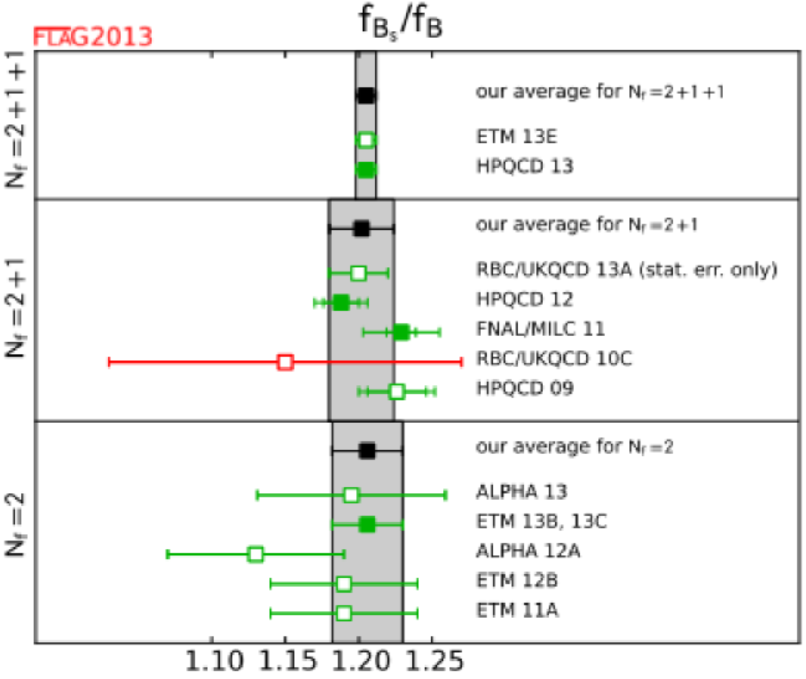
Summary

- Lattice calculations of B-meson decays lead to CKM matrix elements and possible BSM physics.
- We generate B-mesons with
  - light and strange quarks chosen to have a constant average mass matching the physical mass
  - *b*-quarks tuned to match physical B-meson properties

- We presented early results for f_B and f_{Bs}, with a full study of systematic error upcoming.

2013 World Averages for f_B





Nf = 2+1: fB = (190.5±4.2) MeV, fBs = (227.7±4.5) MeV

Nf = 2+1: fBs/fB = 1.202 ± 0.022