Precision predictions for B $\to \rho\tau\nu$ and B $\to \omega\tau\nu$ in the SM and beyond

EPS 2019 - Flavour Physics and CP Violation

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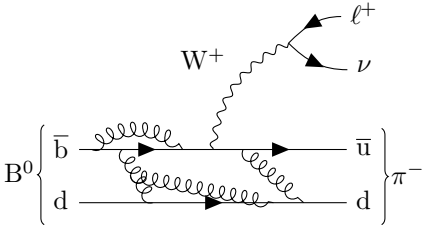
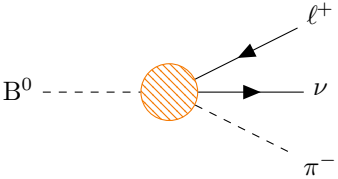
INSTITUT FÜR EXPERIMENTELLE TEILCHENPHYSIK (ETP)

Form Factors

- Form factors encode the structure of matrix elements in terms of representations.



$$\propto \langle M(p_M)|u\gamma^\mu P_L b|B(p_B)\rangle$$



$$\propto \sum T_i^\mu F_i(q^2)$$

Form Factors - BCL Parametrization

The Bourrely-Caprini-Lellouch (BCL) parametrization is a model-independent ansatz for the form factors based on a fast converging series expansion of:

$$z(q^2, t_0) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$

$$\text{with} \quad t_+ = (m_\mathrm{B} + m_M)^2$$

$$t_0 = (m_\mathrm{B} + m_M)(\sqrt{m_\mathrm{B}} - \sqrt{m_M})^2$$

The form factors are expanded as:

$$F_i(q^2) = P_i(q^2) \sum_k \alpha_k^i \left(z(q^2) - z(0) \right)^k$$

$$\text{with} \quad P_i(q^2) = (1 - q^2/m_R^2)^{-1} \quad m_R : \text{Mass of first resonance in spectrum}$$

Form Factors - B $\to V\ell\nu$ with $V = \rho, \omega$

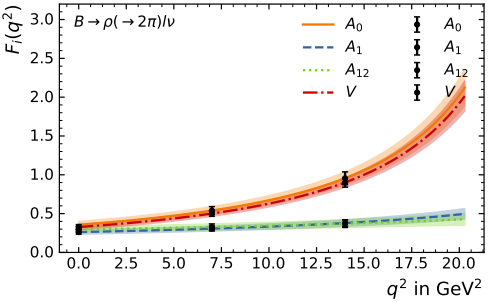
- In total exist 8 independent form factors: A_P, V, A_0, A_1, A_{12}, T_1, T_2, T_{23}.
- The pseudoscalar form factor can be removed under the equations of motion:

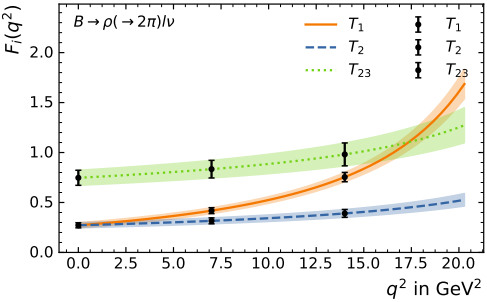
$$A_P = -2\frac{m_M}{m_\mathrm{b} + m_\mathrm{u}} A_0 \,.$$

- 4 form factors contribute to the SM process: V, A_0, A_1, A_{12}.
- 3 form factors can contribute to BSM processes: T_1, T_2, T_{23}.

Form Factors - B $\to V\ell\nu$ with $V = \rho, \omega$ from Theory

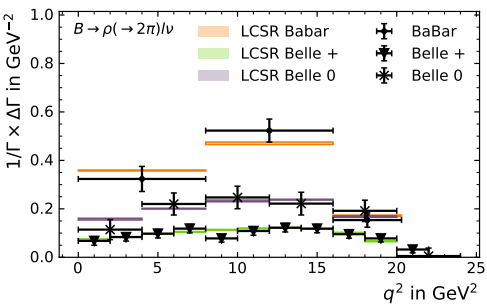
- Theory predictions available from LCSR calculations:
  - JHEP 1608 (2016) 098
- Only valid up to $q^2 \approx 14\,\mathrm{GeV}^2$.
- For $q^2 > 14\,\mathrm{GeV}^2$ solely extrapolation available (no LQCD).

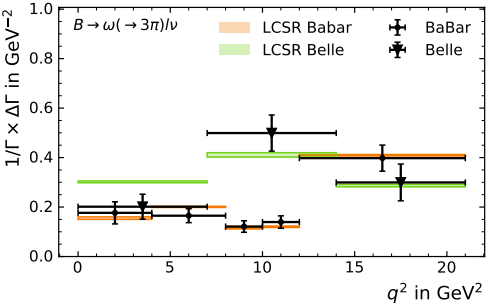




Differential Rate - Help from Experiment

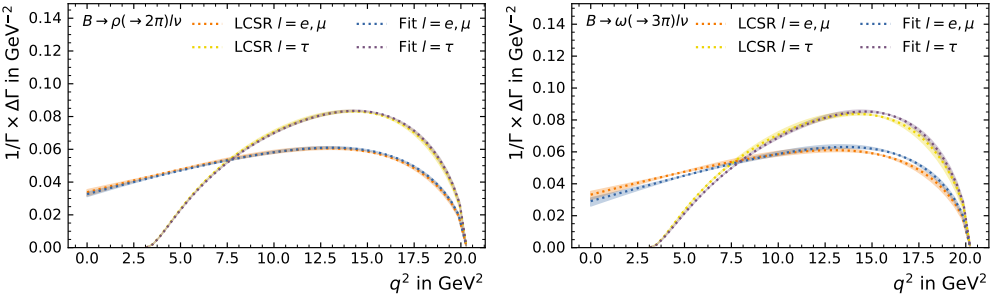
- Fit form factor coefficients with theory and experimental input:
  - Phys.Rev. D88 (2013) no.3, 032005
  - Phys.Rev. D83 (2011) 032007
  - Phys.Rev. D87 (2013) no.3, 032004
- Use normalized spectra to take V_{ub} out of the equation.





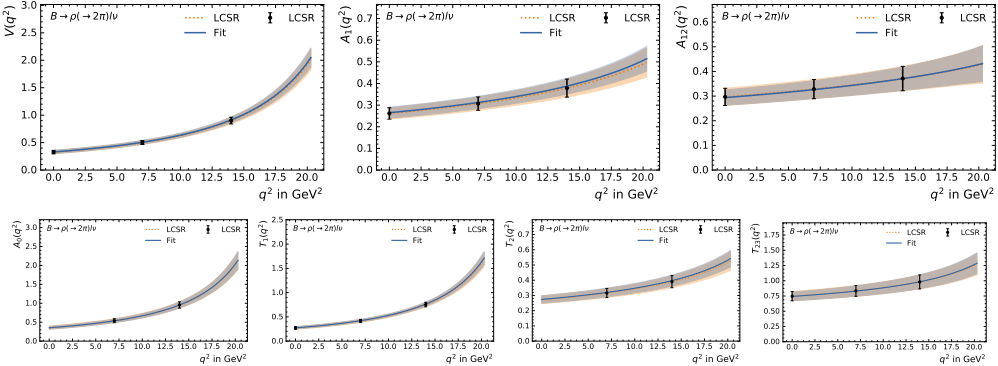
Differential Rate - Fit Result

$$\chi^2(\vec{a}) = \chi^2_{\text{LCSR}}(\vec{a}) + \sum_{\text{Exp}} \chi^2_{\text{Exp}}(\vec{a})$$



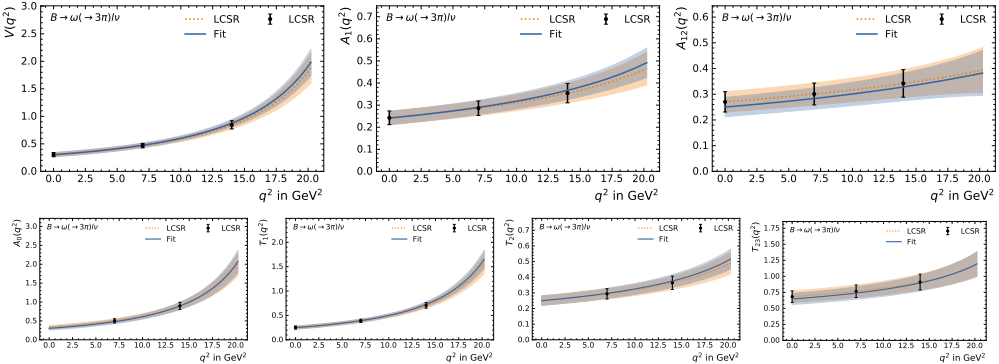
Differential rate corrections are extracted from experimental data.

Form Factor - Fit Result B $\to \rho \ell \nu$



Form factor corrections are extracted from experimental data.

Form Factor - Fit Result B $\to \omega \ell \nu$



Form factor corrections are extracted from experimental data.

Form Factor - Fit Result

- Only small improvement in the individual uncertainties of the form factors.
- But the fit allows to **constrain combinations of form factors**.
- This improves the precision on certain observables, e.g. $R(\rho)$ and $R(\omega)$.

Predicting $R(\rho)$ and $R(\omega)$ in the SM

- Use fitted coefficients to predict $R(V)$.

$$R(V) = \frac{\int_{m_\tau^2}^{q^2_{\max}} \frac{\mathrm{d}\Gamma(\mathrm{B}\to V\tau\nu)}{\mathrm{d}q^2}\,\mathrm{d}q^2}{\int_0^{q^2_{\max}} \frac{\mathrm{d}\Gamma(\mathrm{B}\to V\ell\nu)}{\mathrm{d}q^2}\,\mathrm{d}q^2} \qquad \hat{R}(V) = \frac{\int_{m_\tau^2}^{q^2_{\max}} \frac{\mathrm{d}\Gamma(\mathrm{B}\to V\tau\nu)}{\mathrm{d}q^2}\,\mathrm{d}q^2}{\int_{m_\tau^2}^{q^2_{\max}} \frac{\mathrm{d}\Gamma(\mathrm{B}\to V\ell\nu)}{\mathrm{d}q^2}\,\mathrm{d}q^2}$$

$R(V)$	LCSR	Fit	Improvement
$R(\rho)$	0.532 ± 0.011	0.535 ± 0.008	**25 %**
$R(\omega)$	0.534 ± 0.018	0.546 ± 0.015	**16 %**
$\hat{R}(\rho)$	0.605 ± 0.007	0.606 ± 0.006	**6 %**
$\hat{R}(\omega)$	0.606 ± 0.012	0.612 ± 0.011	**7 %**

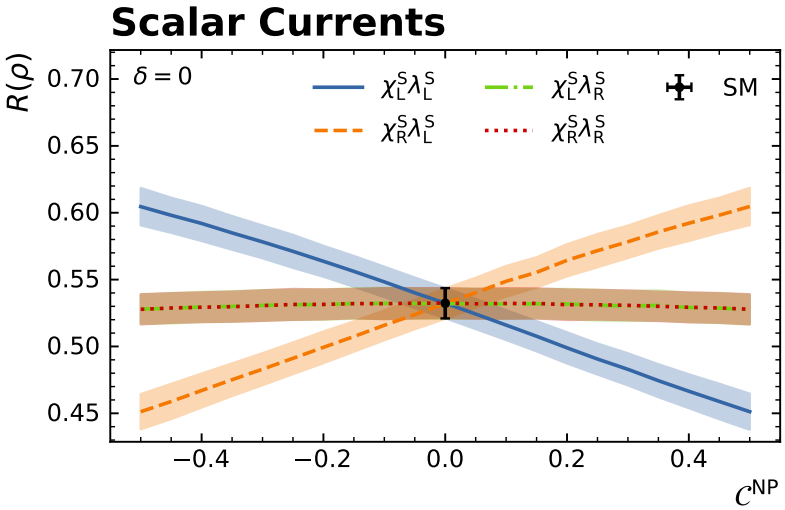
Predicting $R(\rho)$ and $R(\omega)$ beyond the SM

The complete basis of the four-Fermi operators mediating the b $\to q\ell\nu$ decay:

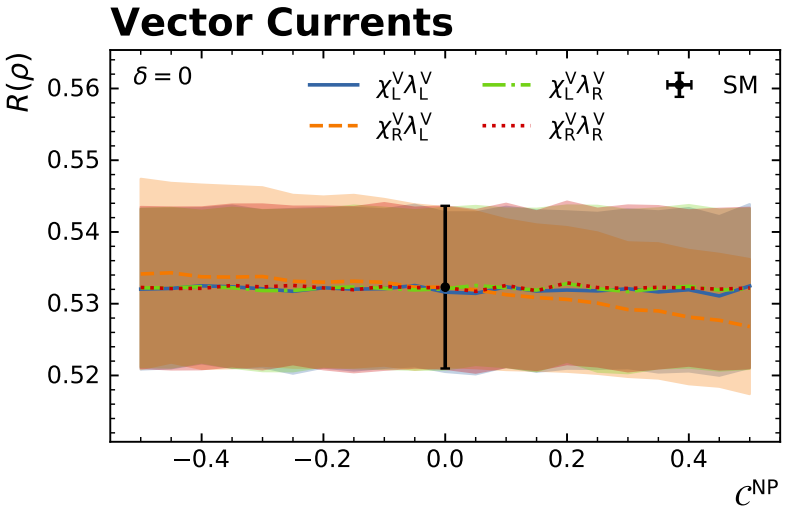
$$i2\sqrt{2}V_{\mathrm{ub}}G_{\mathrm{F}}\,[\bar{q}\chi_j^i\gamma^\mu P_j \mathrm{b}][\bar{\ell}\lambda_l^k\gamma_\mu P_l\nu]$$

- χ_j^i: NP coupling to quark current.
- λ_l^k: NP coupling to lepton current.
- $j, l =$ L, R: Helicity of b quark or ν respectively.
- $i, k =$ S, V, T: Type of current.
- NP couplings normalized to SM.
- Influence of new physics on $R(\rho)$ and $R(\omega)$ the same (both vector-like particles).

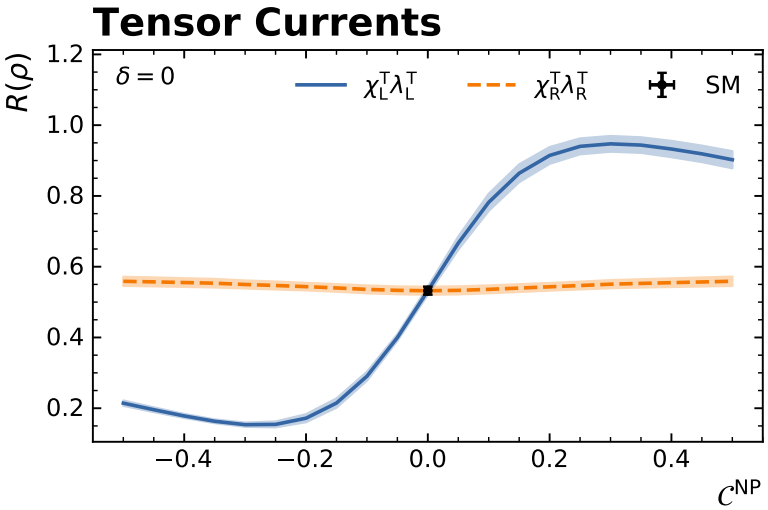
Predicting $R(\rho)$ and $R(\omega)$ beyond the SM



Predicting $R(\rho)$ and $R(\omega)$ beyond the SM



Predicting $R(\rho)$ and $R(\omega)$ beyond the SM



Summary & Outlook

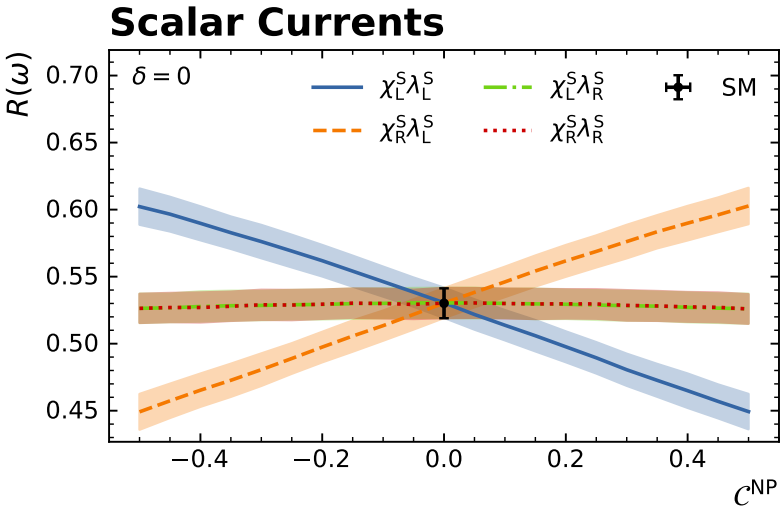
- Form factors constrained from theory and experiment over whole q^2 range.
- Improved predictions of $\mathcal{O}(20\,\%)$ for $R(\rho)$ and $R(\omega)$
- Analysis of BSM physics influence on $R(\rho)$ and $R(\omega)$.
- No measurements of $R(\rho)$ and $R(\omega)$ yet.

- Results also available via HAMMER:
  - http://hammer.physics.lbl.gov/
  - HAMMER: a tool for new physics searches in semileptonic decays at Belle II and LHCb by Stephan Duell (12 Jul 2019, 11:45)

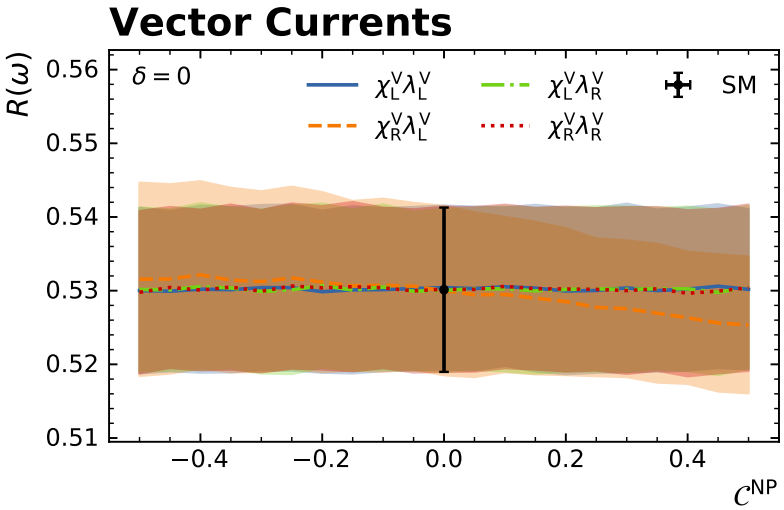
- Measurement of the full differential decay rate allows data driven extraction of form factors in the future.

Backup

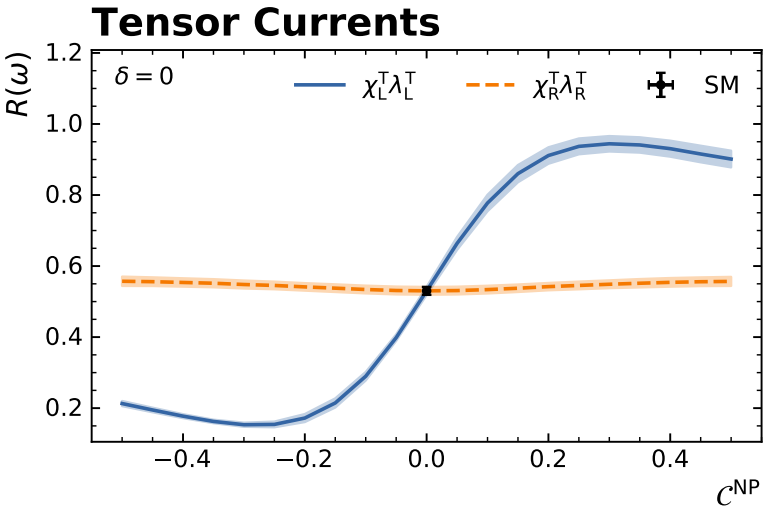
Predicting $R(\rho)$ and $R(\omega)$ beyond the SM



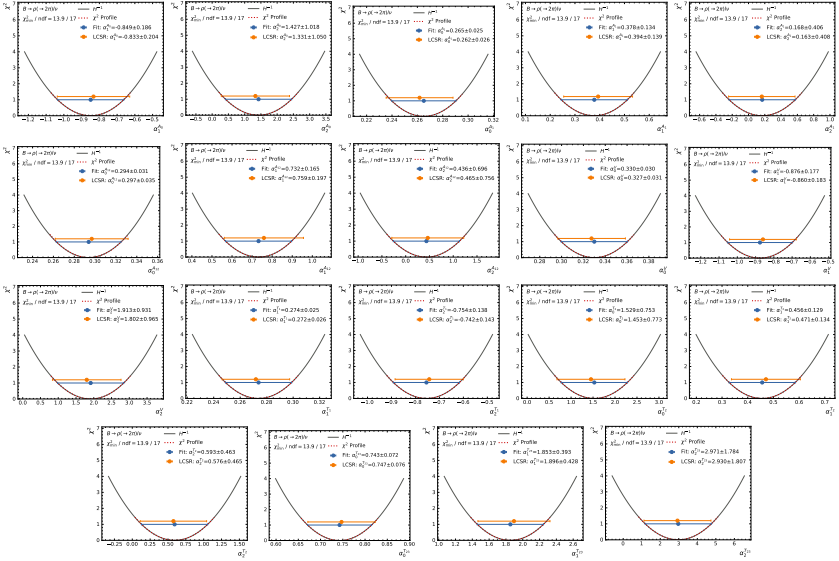
Predicting $R(\rho)$ and $R(\omega)$ beyond the SM



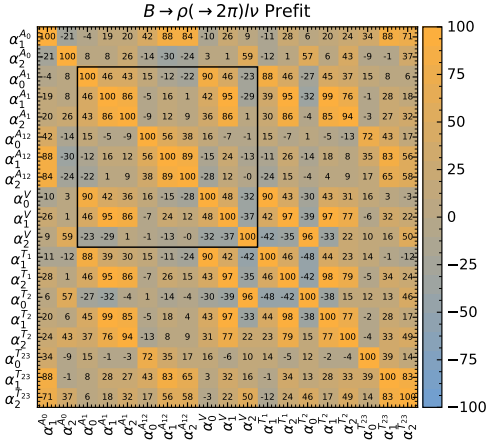
Predicting $R(\rho)$ and $R(\omega)$ beyond the SM

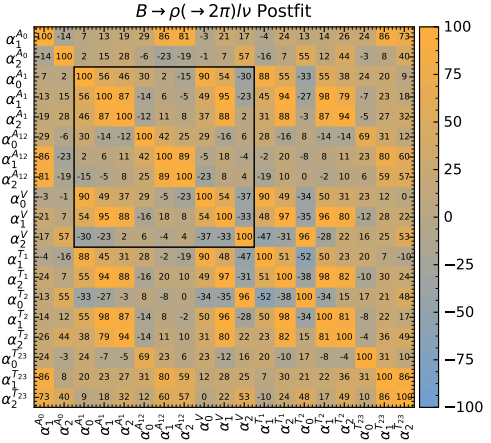


χ^2-Profiles of B $\to \rho \ell \nu$ Fit

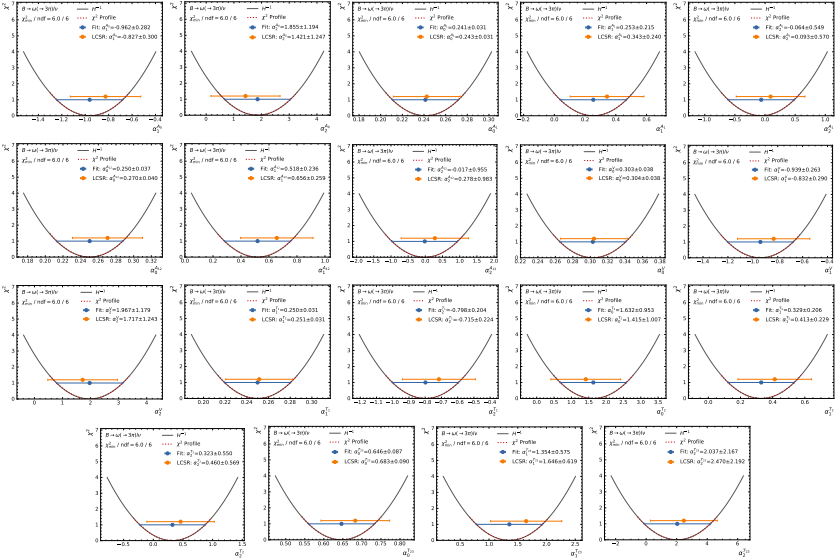


Correlations of B $\to \rho \ell \nu$





χ^2-Profiles of B $\to \omega \ell \nu$ Fit



Correlations of B $\to \omega \ell \nu$