Test of lepton flavor universality with $D^0 \to K^- \ell^+ \nu_\ell$ at BESIII

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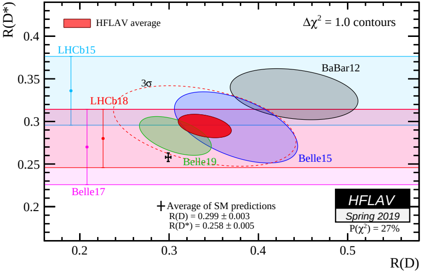
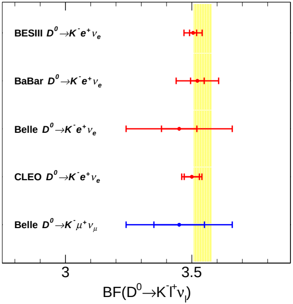
June 7, 2019

Motivation



$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau^+\nu_\tau)}{\mathcal{B}(B \to D^{(*)}\ell^+\nu_\ell)}$$

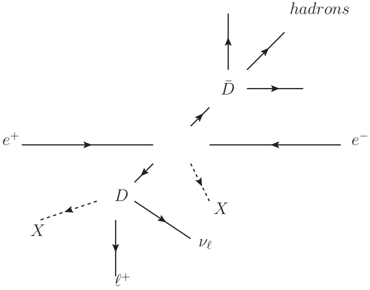


Does the non-universality really exist? Or if it exists, does it applies to the charm sector or the leptons other than τ?

Much larger statistics for $D^0 \to K^-\ell^+\nu_\ell$.

$D^0 \to K^-\mu^+\nu_\mu$ not well studied before.

Analysis method



$$N^i_{\rm ST} = 2N_{D\bar{D}}\mathcal{B}^i_{\rm ST}\epsilon^i_{\rm ST}$$

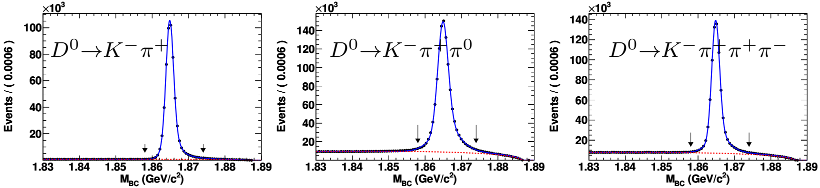
$$N^i_{\rm DT} = 2N_{D\bar{D}}\mathcal{B}^i_{\rm ST}\mathcal{B}_{\rm sig}\epsilon^i_{\rm DT}$$

The number of signal events is determined by examining the kinematic variables of the missing neutrino

$$U_{\rm miss} = E_{\rm miss} - |\vec{p}|_{\rm miss}$$

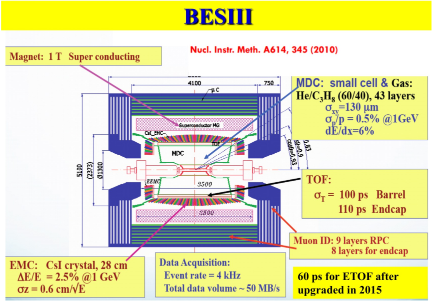
Reconstruction of the tag side D

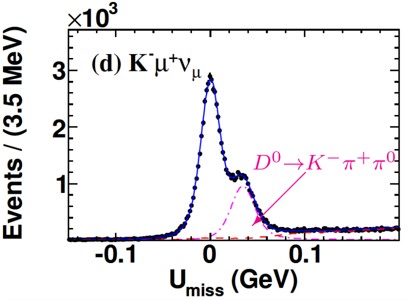
$$M_{\rm BC} = \sqrt{E_{\rm beam}^2 - p_{Kn\pi}^2}$$



In total about 2.3×10^6 D^0 mesons are reconstructed, and the background level is very low.

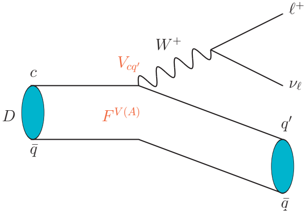
Reconstruction of $D^0 \to K^- \mu^+ \nu_\mu$





Hard for low momentum muon to hit the muon identifier, which leads to high background from pion misidentification.

Decay rate of $D^0 \to K^- \mu^+ \nu_\mu$ in the SM



$$\mathcal{M} \propto |V_{cs(d)}| H^\mu L_\mu$$

$$< P(p_2)|V^\mu|D(p_1) >$$

$$= f_+(q^2)(p_D + p_P)^\mu + f_-(q^2) q^\mu$$

$$q^\mu L_\mu \to 0 \text{ when } m_\ell \to 0$$

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{cs}|^2}{8\pi^3 m_D} |\vec{p}_K| |f_+^K(q^2)|^2 (\frac{W_0 - E_K}{F_0})^2$$
$$\times [\frac{1}{3} m_D |\vec{p}_K|^2 + \frac{m_\ell^2}{8m_D}(m_D^2 + m_K^2 + 2m_D E_K)$$
$$+ \frac{1}{3} m_\ell^2 \frac{|\vec{p}_K|^2}{F_0} + \frac{1}{4} m_\ell^2 \frac{m_D^2 - m_K^2}{m_D} \mathrm{Re}(\frac{f_-^K(q^2)}{f_+^K(q^2)})$$
$$+ \frac{1}{4} m_\ell^2 F_0 |\frac{f_-^K(q^2)}{f_+^K(q^2)}|^2],$$

Taken from FOCUS (Phys.Lett.B607(2005)233)

$$W_0 = \frac{m_D^2 + m_K^2 - m_\mu^2}{2m_D}$$

$$F_0 = \frac{q^2}{2m_D}$$

Form factor parametrizations

Single Pole form

$f_{+}(q^2)=\frac{f_{+}(0)}{1-\frac{q^2}{M^2_{\rm pole}}}$

ISGW2

$f_{+}(q^2)=f_{+}(q^2_{\rm max})(1+\frac{r^2_{\rm ISGW2}}{12}(q^2_{\rm max}-q^2))^{-2}$

Modified pole

$f_{+}(q^2)=\frac{f_{+}(0)}{(1-\frac{q^2}{M^2_{\rm pole}})(1-\alpha\frac{q^2}{M^2_{\rm pole}})}$

Series expansion

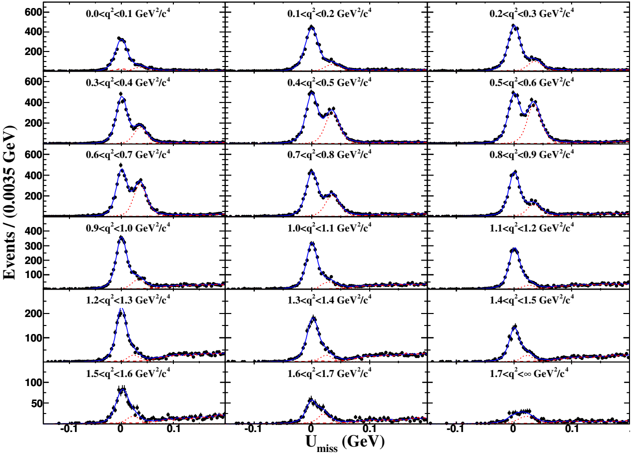
$f_{+}(t)=$
$\frac{1}{P(t)\Phi(t,t_0)}a_0(t_0)(1+\sum_{k=1}^{\infty}r_k(t_0)[z(t,t0)]^k)$

- LQCD: require huge amount of computational resource, currently precision not as good as the experimental measurements.
- Measurements:

$$\chi^2=\sum_{i,j=1}^{N_{\rm intervals}}(\Delta\Gamma^i_{\rm msr}-\Delta\Gamma^i_{\rm exp})C^{-1}_{ij}(\Delta\Gamma^j_{\rm msr}-\Delta\Gamma^j_{\rm exp}),$$

$$f_+^{D\to K}(0)|V_{cs}|\to|V_{cs}|\text{ input from global fit }\to f_+^{D\to K}(0)$$

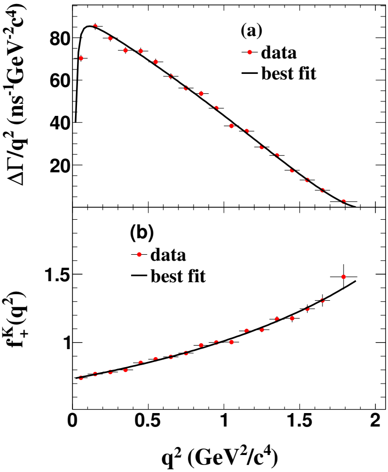
Measured decay rates in each q^2 interval

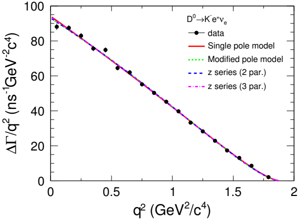


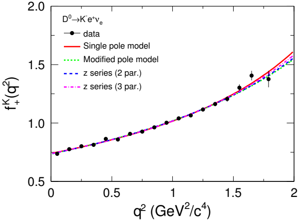
$$N^i_{\rm pro} = \sum_j^{N_{\rm intervals}} (\varepsilon^{-1})_{ij} N^j_{\rm obs},$$

$$\Delta\Gamma^i_{\rm msr} \equiv \int_i (d\Gamma/dq^2) dq^2 = N^i_{\rm pro}/(\tau_{D^0} \times N^{\rm tot}_{\rm ST})$$

Fit to partial decay rates



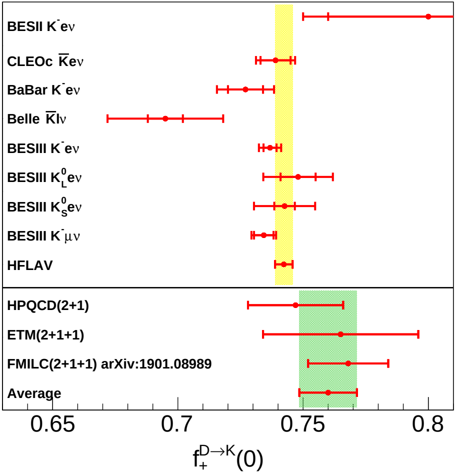




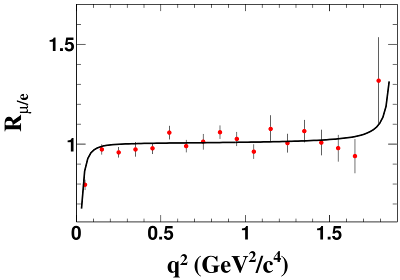
$f_+(0)\|V_{cs}\|$	r_1	f_-/f_+	$\chi^2/d.o.f.$
0.7133±0.0038±0.0030	−1.90±0.21±0.07	−0.6±0.8±0.2	15.0/15

Status of $f_+^{D\to K}(0)$

With $|V_{cs}| = 0.97359^{+0.00010}_{-0.00011}$



Test of lepton universality



For total decay rate:

$$R_{\mu/e} = \frac{\Gamma(D^0 \to K^- \mu^+ \nu_\mu)}{\Gamma(D^0 \to K^- e^+ \nu_e)} = 0.974 \pm 0.007 \pm 0.012$$

$R_{\mu/e}^{\text{expected}} = 0.975 \pm 0.001$ according to LQCD from ETM (PRD96(2017)054517).

Thanks for your attention!