Novel method to reliably determine the photon helicity in $b \to s\gamma$

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Outline

- Heavy Flavor Physics

- Photon polarization in $b \to s\gamma$:

$$B \to K_1(\to K\pi\pi)\gamma$$

- Model-independent extraction using

$$D \to K_1(\to K\pi\pi)e^+\nu$$

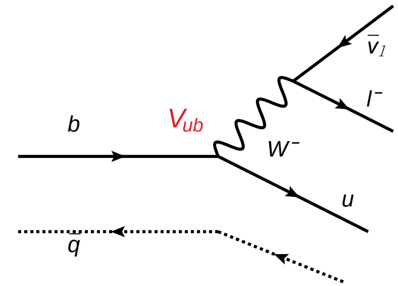
- Summary

Heavy Flavor Physics

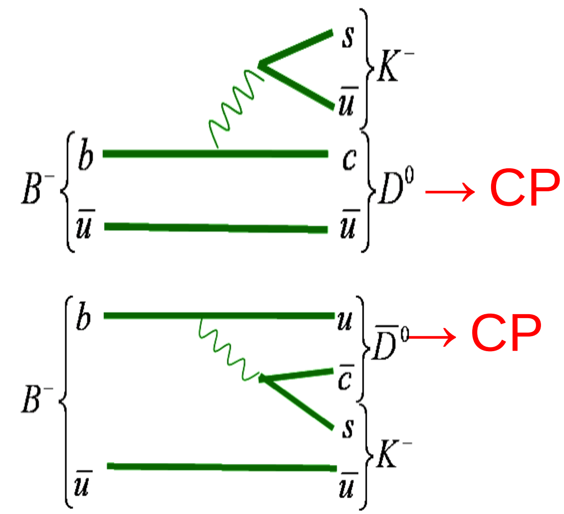
Heavy Flavor Bottom Physics

- Extract the SM parameters:

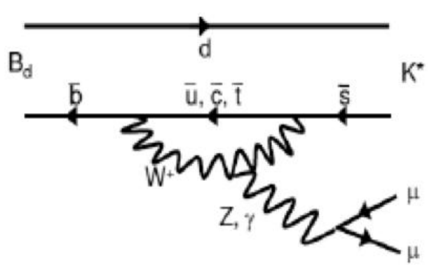
  Vub, Vcb, Weak Phases

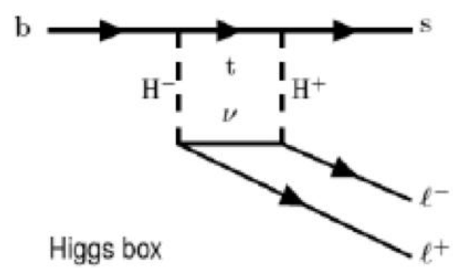


- Test SM: unitary triangle



- Hunt for NP: Rare Decays

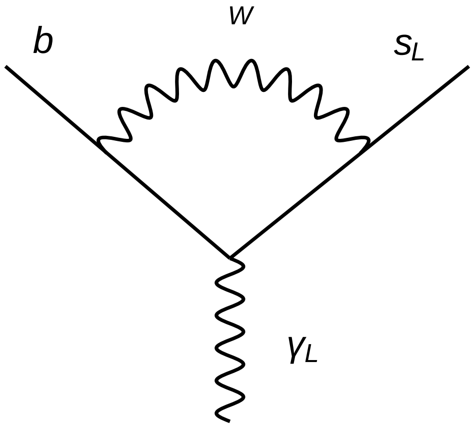




Photon polarization in $b \to s\gamma$: $B \to K_1(\to K\pi\pi)\gamma$

Photon polarization of $b \to s\gamma$

- An unique sensitivity to BSM with right-handed couplings
- Never been measured at a high precision: an important challenge for LHCb (and its upgrade) and Belle II



$$\mathcal{H}_{\rm eff}^{\rm SM} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* C_{7\gamma} O_{7\gamma}$$

$$O_{7\gamma} = \frac{e m_b}{16\pi^2} \bar{s} \sigma_{\mu\nu} \frac{1+\gamma_5}{2} b F^{\mu\nu}$$

SM

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* (C_{7L} O_{7L} + C_{7R} O_{7R})$$

$$O_{7L,R} = \frac{e m_b}{16\pi^2} \bar{s} \sigma_{\mu\nu} \frac{1 \pm \gamma_5}{2} b F^{\mu\nu}$$

New Physics

How do we measure the polarization?

- Time-dependent measurements:
  - ✓ $B_d \to K_s \pi^0 \gamma$
  - ✓ $B_d \to K_s \pi^+ \pi^- \gamma$
  - ✓ $B_s \to K^+ K^- \gamma$

- Angular distribution:
  - ✓ Baryonic decays: $\Lambda_b \to \Lambda\gamma$

    request to the polarization of Λ_b or Λ
  - ✓ $B \to K_{res}(\to K\pi\pi)\gamma$

Photon polarization of $B \to K_1(\to K\pi\pi)\gamma$

$$\lambda_\gamma \equiv \frac{|\mathcal{A}(\bar{B} \to \bar{K}_{1R}\gamma_R)|^2 - |\mathcal{A}(\bar{B} \to \bar{K}_{1L}\gamma_L)|^2}{|\mathcal{A}(\bar{B} \to \bar{K}_{1R}\gamma_R)|^2 + |\mathcal{A}(\bar{B} \to \bar{K}_{1L}\gamma_L)|^2}$$

$$\simeq \frac{|C_{7R,NP}|^2 - |C_{7L,SM}|^2}{|C_{7R,NP}|^2 + |C_{7L,SM}|^2}$$

In the SM, $\lambda_\gamma \simeq -1$

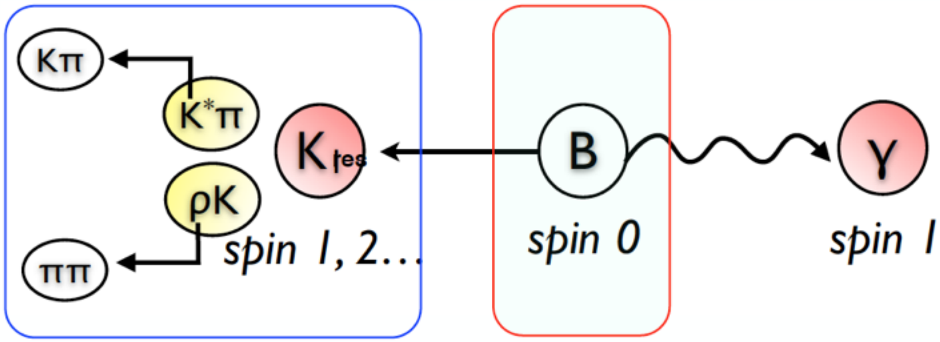
Angular distribution method

Gronau,Grossman, Pirjol, Ryd PRL88('01)

- Photon polarization

= Recoiling K_1 polarization

=> measure it from K_1 decay angular distribution



$K_1(1270)$

$I(J^P) = \frac{1}{2}(1^+)$

Mass $m = 1272 \pm 7$ MeV [l]
Full width $\Gamma = 90 \pm 20$ MeV [l]

$K_1(1270)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\rho$	(42 ± 6) %	46
$K_0^*(1430)\pi$	(28 ± 4) %	†
$K^*(892)\pi$	(16 ± 5) %	302
$K\omega$	(11.0 ± 2.0) %	†
$K f_0(1370)$	(3.0 ± 2.0) %	†
γK^0	seen	539

Up-down asymmetry for K_1

Angular distribution:

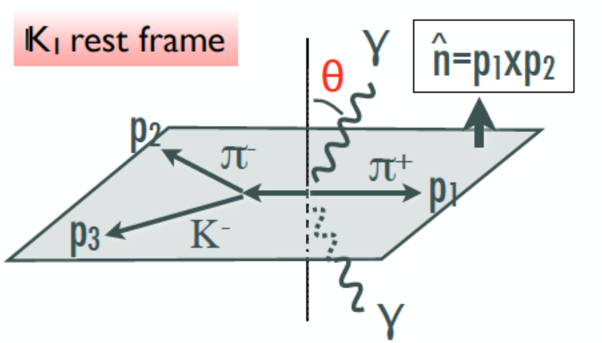
Gronau,Grossman, Pirjol, Ryd PRL88('01)

$$\frac{d\Gamma_{K_1\gamma}}{d\cos\theta_K} = \frac{|A|^2|\vec{J}|^2}{4} \times \left[1 + \cos^2\theta_K + 2\lambda_\gamma \cos\theta_K \frac{\mathrm{Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{|\vec{J}|^2}\right].$$

Up-down asymmetry for K1

$$\mathcal{A}_{\mathrm{UD}} \equiv \frac{\left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_K \frac{d\Gamma(B\to K_1\gamma)}{d\cos\theta_K}}{\left[\int_0^1 + \int_{-1}^0\right] d\cos\theta_K \frac{d\Gamma(B\to K_1\gamma)}{d\cos\theta_K}}$$

$$= \lambda_\gamma \frac{3}{4} \boxed{\frac{\mathrm{Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{|\vec{J}|^2}}$$



To measure λ_γ, we need to know ***the decay factor***

LHCb result on up-down asymmetry

LHCb PRL ('14)

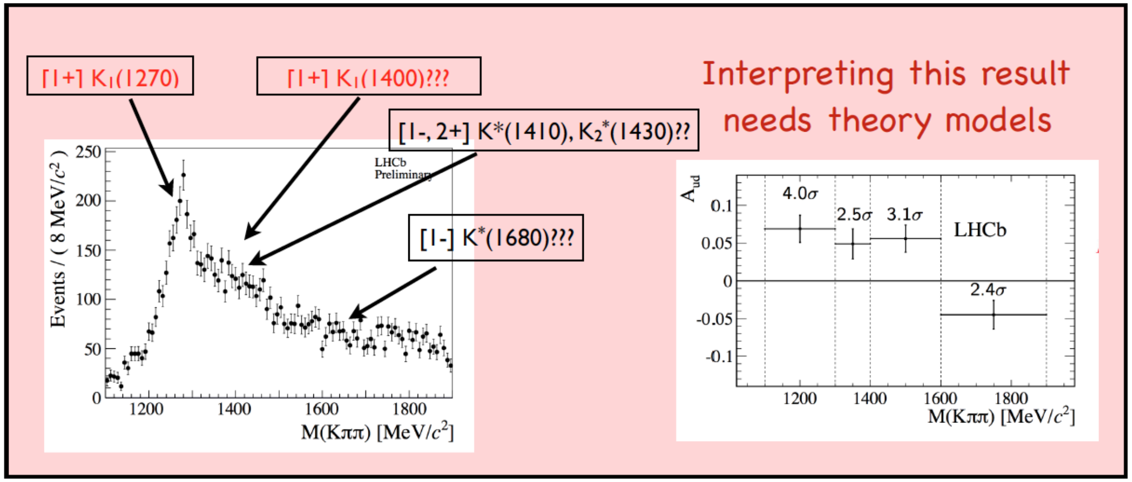
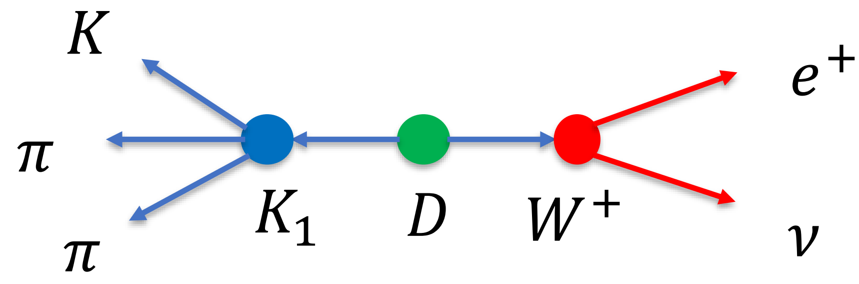


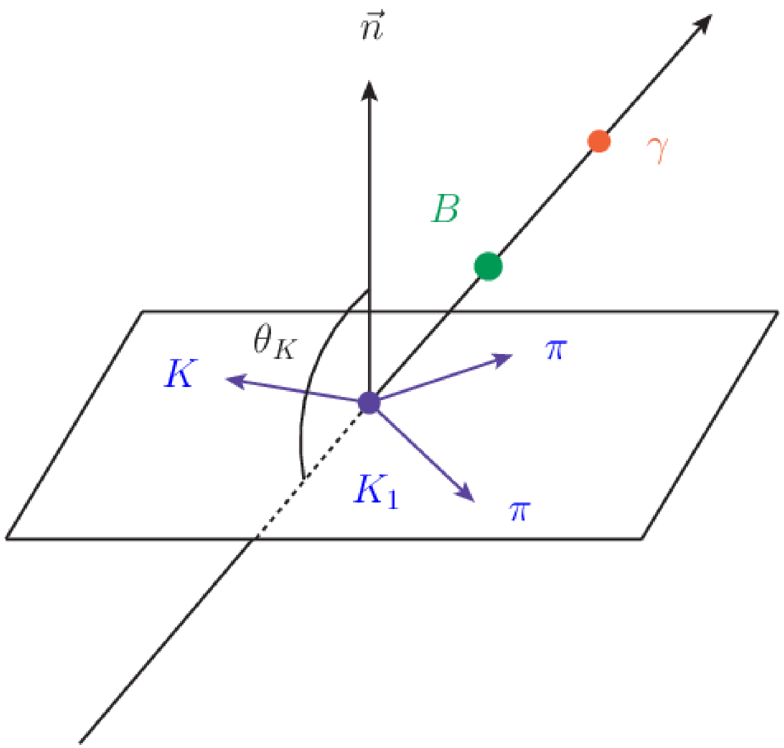
TABLE I. Legendre coefficients obtained from fits to the normalized background-subtracted $\cos\hat{\theta}$ distribution in the four $K^+\pi^-\pi^+$ mass intervals of interest. The up-down asymmetries are obtained from Eq. (4). The quoted uncertainties contain statistical and systematic contributions. The $K^+\pi^-\pi^+$ mass ranges are indicated in GeV/c^2 and all the parameters are expressed in units of 10^{-2}. The covariance matrices are given in Ref. [22].

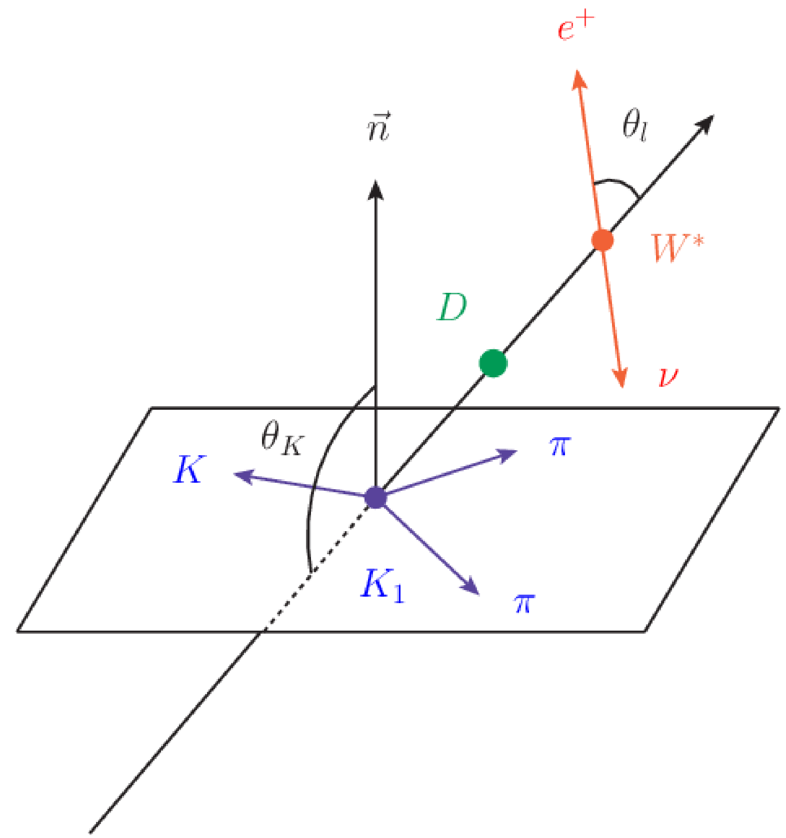
	[1.1,1.3]	[1.3,1.4]	[1.4,1.6]	[1.6,1.9]
c_1	6.3 ± 1.7	5.4 ± 2.0	4.3 ± 1.9	-4.6 ± 1.8
c_2	31.6 ± 2.2	27.0 ± 2.6	43.1 ± 2.3	28.0 ± 2.3
c_3	-2.1 ± 2.6	2.0 ± 3.1	-5.2 ± 2.8	-0.6 ± 2.7
c_4	3.0 ± 3.0	6.8 ± 3.6	8.1 ± 3.1	-6.2 ± 3.2
$\mathcal{A}_{ud}$	6.9 ± 1.7	4.9 ± 2.0	5.6 ± 1.8	-4.5 ± 1.9

Model-independent extraction using $D \to K_1(\to K\pi\pi)e^+\nu$



$B \to K_1(K\pi\pi)\gamma$ vs $D \to K_1(K\pi\pi)e^+\nu$





Polarization of γ: +, -

Polarization of W: +, -, 0, t

t: timelike, $\epsilon^\mu(t) \sim p_W^\mu$

Angular Distribution of $D \to K_1(\to K\pi\pi)e^+\nu$

$$\frac{d\Gamma_{K_1 e\nu_e}}{d\cos\theta_K d\cos\theta_l} = d_1[1+\cos^2\theta_K\cos^2\theta_l] + d_2[1+\cos^2\theta_K]\cos\theta_l + d_3\cos\theta_K[1+\cos^2\theta_l] + d_4\cos\theta_K\cos\theta_l + d_5[\cos^2\theta_K+\cos^2\theta_l].$$

The angular coefficients are given as:

$$d_1 = \frac{1}{2}|\vec{J}|^2(4c_0^2+c_-^2+c_+^2), d_2 = -|\vec{J}|^2(c_-^2-c_+^2),$$
$$d_3 = -\mathrm{Im}\,[\vec{n}\cdot(\vec{J}\times\vec{J}^*)](c_-^2-c_+^2),$$
$$d_4 = 2\mathrm{Im}\,[\vec{n}\cdot(\vec{J}\times\vec{J}^*)](c_-^2+c_+^2),$$
$$d_5 = -\frac{1}{2}|\vec{J}|^2(4c_0^2-c_-^2-c_+^2).$$

Up-down asymmetries

$D \to K_1(\to K\pi\pi)e^+\nu$

$$\mathcal{A}'_{\rm UD} \equiv \frac{\left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_K \frac{d\Gamma_{K_1 e\nu_e}}{d\cos\theta_K}}{\left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_l \frac{d\Gamma_{K_1 e\nu_e}}{d\cos\theta_l}}$$

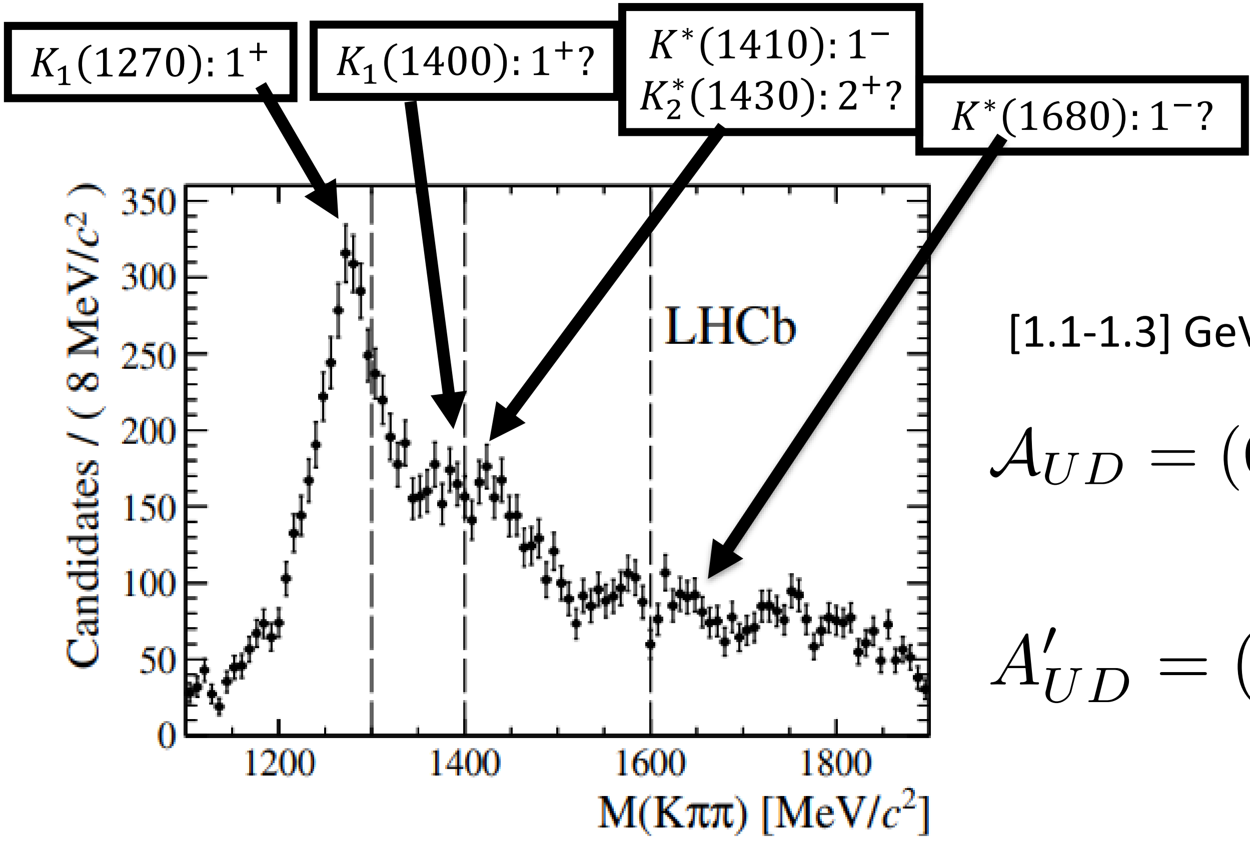
$$\mathcal{A}'_{\rm UD} = \frac{{\rm Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{|\vec{J}|^2}$$

$B \to K_1(\to K\pi\pi)\gamma$

$$\mathcal{A}_{UD} \equiv \frac{\left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_K \frac{d\hat{\Gamma}_{K_1\gamma}}{d\cos\theta_K}}{\left[\int_0^1 + \int_{-1}^0\right] d\cos\theta_K \frac{d\hat{\Gamma}_{K_1\gamma}}{d\cos\theta_K}} = \lambda_\gamma \frac{3}{4} \frac{{\rm Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{|\vec{J}|^2}$$

Prospect at BESIII & BelleII

LHCb: PRL112.161801(2014)



[1.1-1.3] GeV:

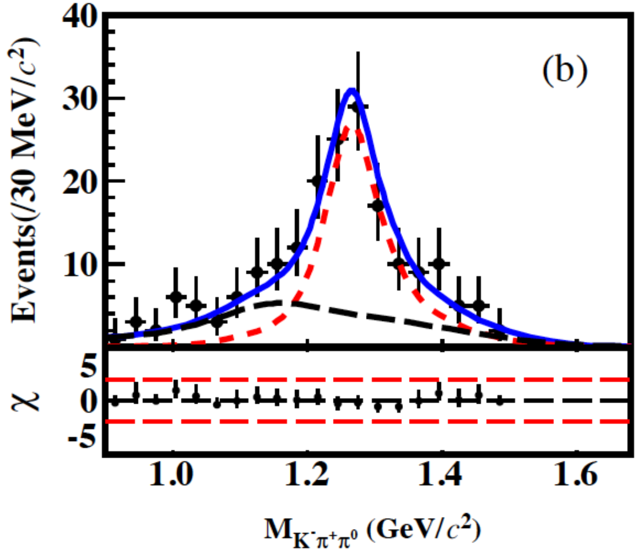
$$\mathcal{A}_{UD} = (6.9 \pm 1.7) \times 10^{-2}$$

$$\mathcal{A}'_{UD} = (9.2 \pm 2.3) \times 10^{-2}$$

A significant deviation from the above value would be a clear signal for new physics beyond SM.

$D \to K_1(\to K\pi\pi)e^+\nu$ from BESIII

BESIII: 1907.11370



$$\mathcal{B}(D^+ \to \overline{K}_1^0 e^+\nu) = (2.3 \pm 0.26 \pm 0.18 \pm 0.25) \times 10^{-3}.$$

BESIII, BelleII, LHCb, Super Tau-Charm, CEPC in future?

Summary

- Heavy Flavor Physics: indirect search for NP
- Photon polarization in $b \to s\gamma$: unique to probe right-handed couplings
- Model-independent extraction using $D \to K_1(\to K\pi\pi)e^+\nu$
  - ✓ Hadron inputs
  - ✓ Photon polarization in a model-independent way: NP?
  - ✓ BESIII, BelleII, LHCb, Super Tau-Charm, CEPC in future?

Thank you very much!

Backup

Including more K_J resonances

The angular distribution for $D \rightarrow K_{res}(\rightarrow K\pi\pi)e^{+}\nu$

$$\frac{d\hat{\Gamma}}{d\cos\theta_K d\cos\theta_l} = \sum_{K_J=K_1,K_1^*,K_2,K_{12}^I} \frac{d\hat{\Gamma}_{K_J l\nu}}{d\cos\theta_K d\cos\theta_l}$$

- For $K^*(1410)$

$$\frac{d\hat{\Gamma}_{K_1^* l\nu}}{d\cos\theta_K d\cos\theta_l} = (|c''_+|^2 + |c''_-|^2)\sin^2\theta_K(1+\cos^2\theta_l)$$
$$+2(|c''_+|^2 - |c''_-|^2)\sin^2\theta_K\cos\theta_l + 4|c''_0|^2\cos^2\theta_K\sin^2\theta_l$$

Including more K_J resonances

- For $K_2^*(1430)$

$$\frac{d\hat{\Gamma}_{K_2 l\nu}}{d\cos\theta_K d\cos\theta_l} = |c_0'|^2 \frac{3}{2}\sin^2(2\theta_K)\sin^2\theta_l |\vec{K}|^2$$
$$+2|c_1'|^2 \cos^4\frac{\theta_l}{2}\{|\vec{K}|^2(\cos^2\theta_K + \cos^2 2\theta_K)$$
$$+2\cos\theta_K\cos 2\theta_K \mathrm{Im}[\vec{n}\cdot(\vec{K}\times\vec{K}^*)]\}$$
$$+2|c_{-1}'|^2 \sin^4\frac{\theta_l}{2}\{|\vec{K}|^2(\cos^2\theta_K + \cos^2 2\theta_K)$$
$$-2\cos\theta_K\cos 2\theta_K \mathrm{Im}[\vec{n}\cdot(\vec{K}\times\vec{K}^*)]\}$$

- $K_1 - K_2$ interference

$$\frac{d\hat{\Gamma}_{K_{12}^I l\nu}}{d\cos\theta_K d\cos\theta_l}$$
$$= -4\sqrt{3}\sin^2(\theta_K)\cos\theta_K\sin^2\theta_l \mathrm{Re}[c_0(c_0')^*\vec{J}\cdot\vec{K}^*]$$
$$-8\cos^4\frac{\theta_l}{2}\{\frac{1}{2}(3\cos^2\theta_K - 1)\mathrm{Im}[c_+(c_+')^*\vec{n}\cdot(\vec{J}\times\vec{K}^*)]$$
$$+\cos^3\theta_K \mathrm{Re}[c_1(c_1')^* * (\vec{J}\cdot\vec{K}^*)]\}$$
$$-8\sin^4\frac{\theta_l}{2}\{\frac{1}{2}(1 - 3\cos^2\theta_K)\mathrm{Im}[c_-(c_-')^*\vec{n}\cdot(\vec{J}\times\vec{K}^*)]$$
$$+\cos^3\theta_K \mathrm{Re}[c_{-1}(c_{-1}')^*(\vec{J}\cdot\vec{K}^*)]\}.$$