上海交通大学物理与天文系
粒子物理和核物理研究所

Semi-Leptonic Bs/Ds decays into $\pi^+\pi^-$

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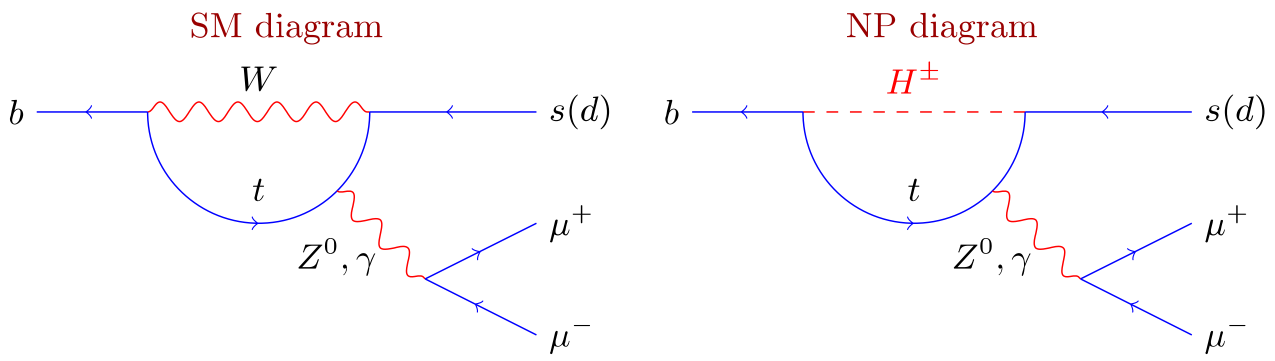
第十三届重味物理与CP破坏会议

Outline

- Semi-Leptonic B decays into a vector
  B->K*l+l-
- S-wave contributions
- Results for scalar form factor
- Bs/Ds decays into $\pi^+\pi^-$
- Summary and Outlook

Indirect Search for NP

- ❑Flavor Changing Neutral Currents (FCNC) is forbiddend at tree level in SM, but can proceed via the loop diagrams.
- ❑New particles may change the amplitudes

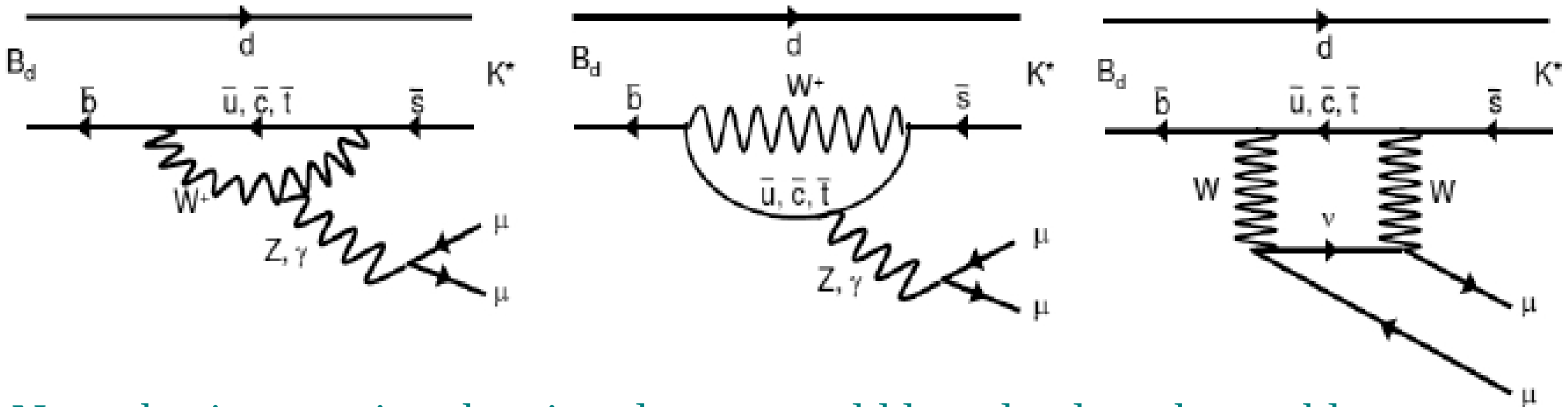


- ❑Rare decays FCNC can probe NP virtual particles

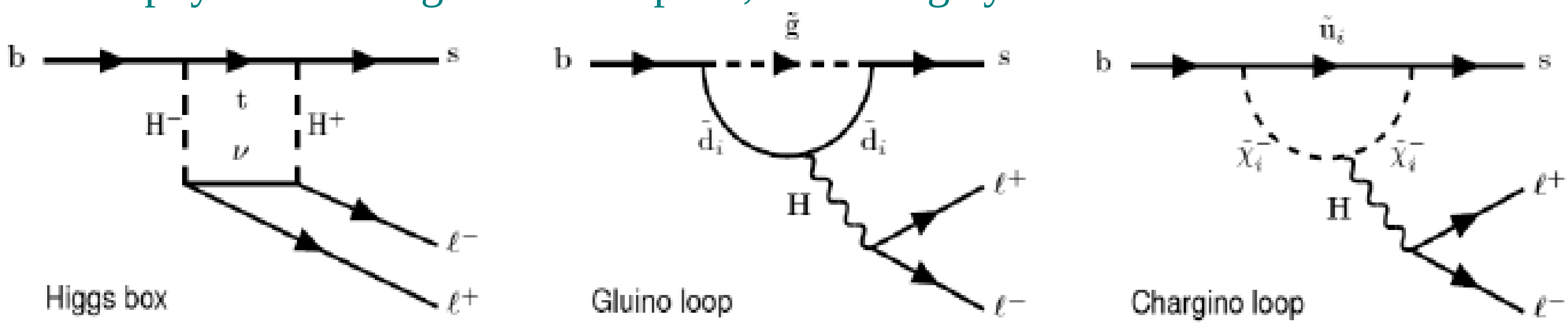
  - **NP phases**
  - **Masses, Couplings**
  - **Helicity structure**

$B \rightarrow K^* l^+ l^-$

- Within the SM, these processes proceed via loop diagrams like



- New physics entering the virtual parts, could largely alter observables



- Effective Hamiltonian: $\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} \left(C_i^{SM} + \Delta C_i^{NP} \right) \mathcal{O}_i$

Wilson coeffs. (short-dist. interactions)

Operators (long-dist. interactions)

S-wave contributions

Due to limited life-time, vector mesons are reconstructed from two-pseudo-scalar mesons: K* (50 MeV): Kπ

B→K*l+l- is a four-body process.

Experimental cuts by LHCb: *LHCb-CONF-2015-002*

$$m_{K^*} - \delta_m < m_{K\pi} < m_{K^*} + \delta_m \qquad \delta_m = 100\mathrm{MeV}$$

$$\int_{(m_{K^*}-\delta_m)^2}^{(m_{K^*}+\delta_m)^2} dm^2_{K\pi} |L_{K^*}(m^2_{K\pi})|^2 = 0.56$$

L denotes the distribution function of Kπ system from K*

Narrow width limit (theoretical results):

$$\int dm^2_{K\pi} |L_{K^*}(m^2_{K\pi})|^2 = \mathcal{B}(K^{*+} \to K^0\pi^+) = \frac{2}{3}$$

S-wave contributions

Experimental cuts by LHCb:

$$m_{K^*} - \delta_m < m_{K\pi} < m_{K^*} + \delta_m \quad \delta_m = 100\mathrm{MeV}$$

We expect the S-wave:

Doring, Meissner, WW, 1307.0947

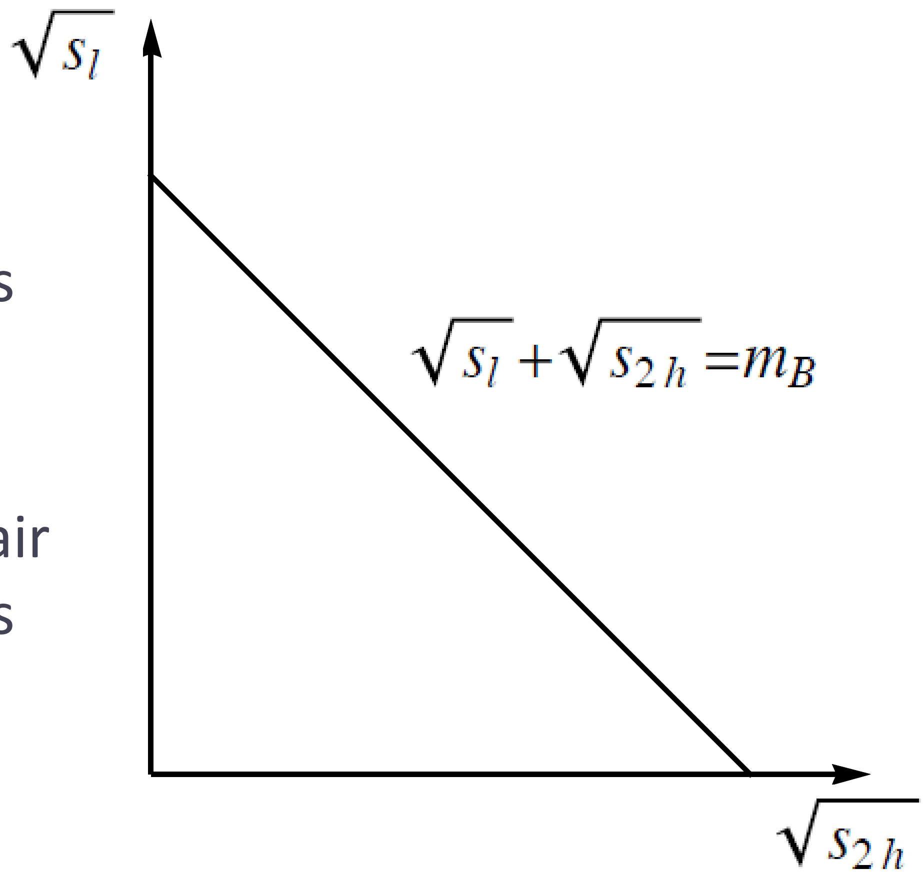
$$\int_{(m_{K^*}-\delta_m)^2}^{(m_{K^*}+\delta_m)^2} dm_{K\pi}^2 |L_S(m_{K\pi}^2)|^2 = 0.17$$

It is mandatory to make further studies on the S-wave.

Phase-space for $B \to M_1 M_2 ll(\nu)$

s_l: lepton pair invariant mass square

s_{2h}: 2-hadron pair invariant mass square



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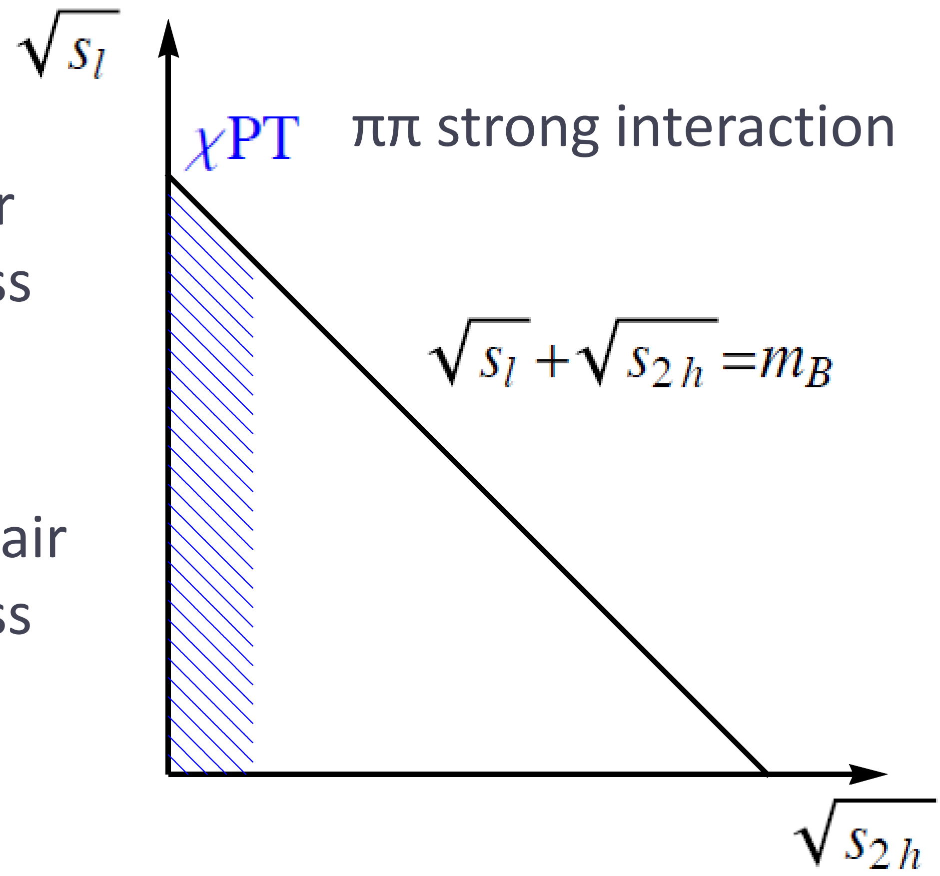

Phase-space for B →$M_1M_2ll(\nu)$

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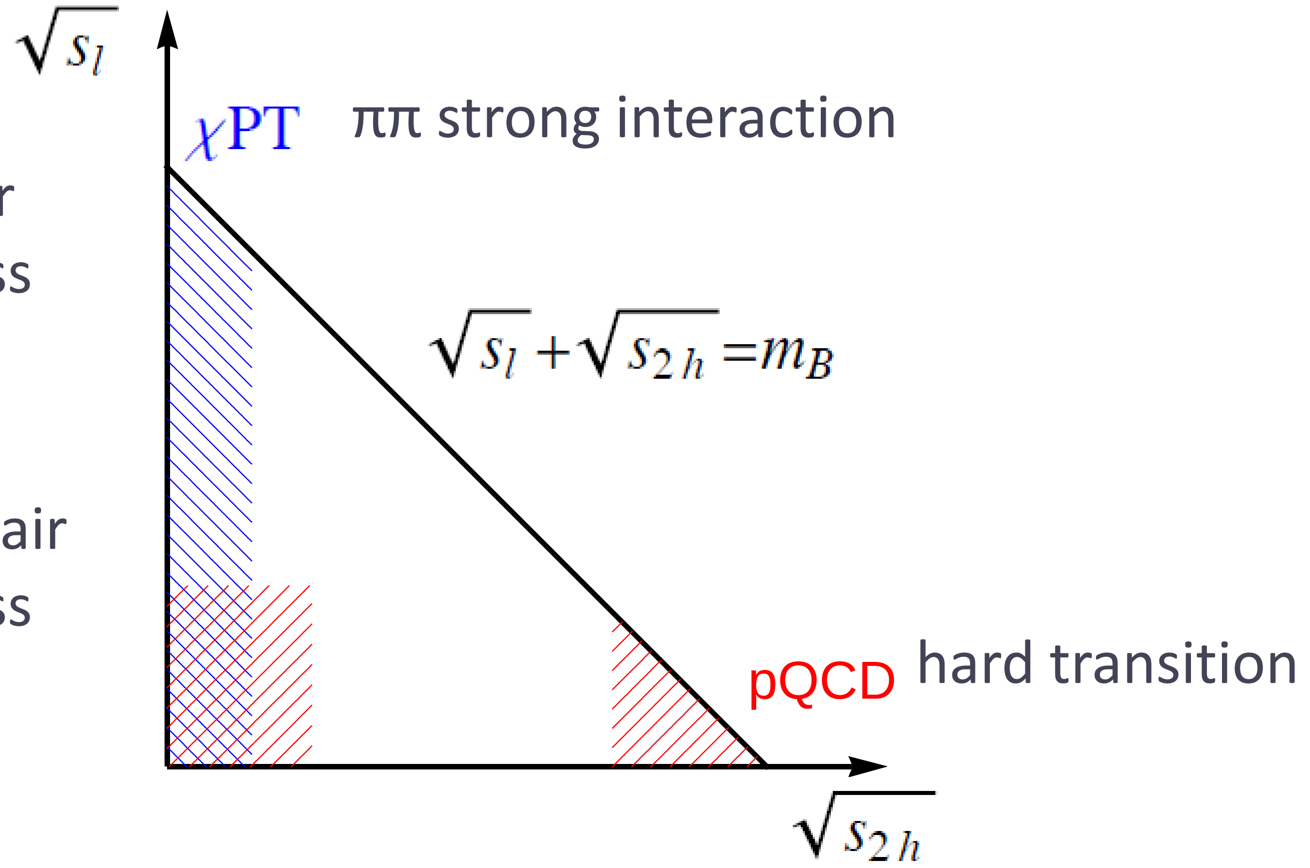
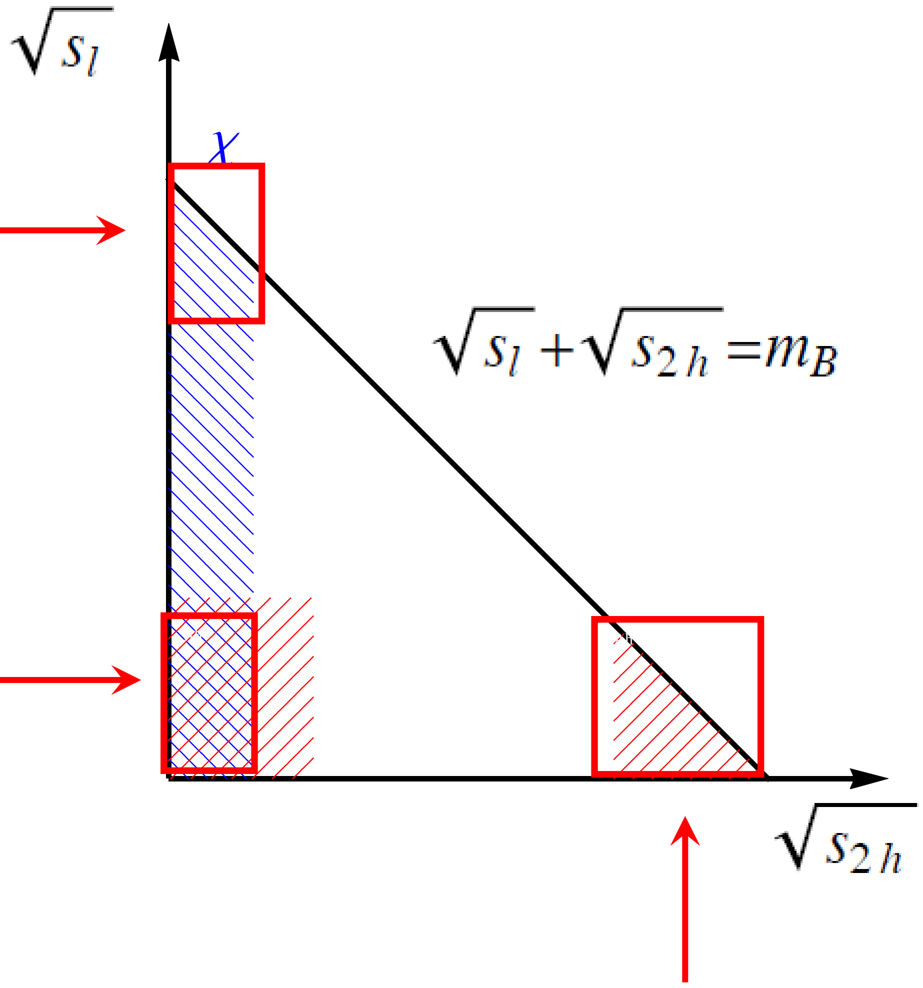


Phase-space for $B \to M_1 M_2 ll(\nu)$

Heavy Meson χPT

χPT+pQCD



Chiral perturbation theory

χPT effective field theory based on the two assumptions

- π's are the Goldstone boson of $SU(3)_L \otimes SU(3)_R \rightarrow SU(3)_V$
- *(chiral) power counting* i.e. the theory has a small expansion parameter: $p^2/\Lambda^2_{\chi SB}$: $\Lambda_{\chi SB} \sim 4\pi F_\pi \sim 1.2$ GeV

$$\mathcal{L}_{\Delta S=0} = \mathcal{L}^2_{\Delta S=0} + \mathcal{L}^4_{\Delta S=0} + \cdots = \frac{F_\pi^{\ 2}}{4} \overbrace{\langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + U \chi^\dagger \rangle}^{\pi\to l\nu,\ \pi\pi\to\pi\pi,\ K\to\pi..} + \overbrace{\sum_i L_i O_i}^{K\to\pi..} + \cdots$$

Fantastic chiral prediction $A_{\pi\pi} \sim (s - m_\pi^2)/F_\pi^{\ 2}$ Weinberg, Colangelo *et al*

$$\mathcal{L}_{\Delta S=1} = \mathcal{L}^2_{\Delta S=1} + \mathcal{L}^4_{\Delta S=1} + \cdots = G_8 F^4 \underbrace{\langle \lambda_6 D_\mu U^\dagger D^\mu U \rangle}_{K\to 2\pi/3\pi} + \underbrace{G_8 F^2 \sum_i N_i W_i}_{K^+\to\pi^+\gamma\gamma,\, K\to\pi l^+ l^-} + \cdots$$

⚠ ChiPT limited to low energies

Scalar form factors in χPT

Scalar form factor : $\langle 0|\bar{s}d|K\pi\rangle = C_X B_0 F_{K\pi}(m_{K\pi}^2)$

QCD: $\mathcal{L} = \bar{q}i\not{D}q - m_q\bar{q}q$

$$\bar{q}q = -\frac{\partial\mathcal{L}}{\partial m_q}$$

Scalar form factors in χPT

Scalar form factor : $\langle 0|\bar{s}d|K\pi\rangle = C_X B_0 F_{K\pi}(m_{K\pi}^2)$

Chiral Lagrangian: $\mathcal{L} = \frac{f^2}{4}\langle U^\dagger \chi_s + \chi_s^\dagger U\rangle$

$$U = \exp\left(\frac{i\sqrt{2}}{f}\Phi\right)$$

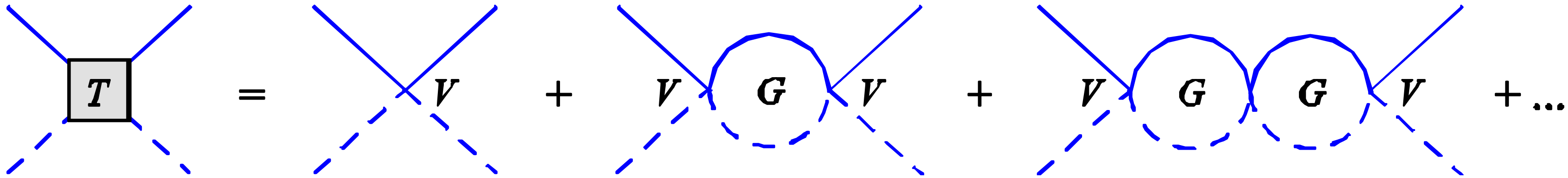
$$\chi_s = 2B_0 \begin{pmatrix} 0 & 0 & m_{\bar{u}s} \\ 0 & 0 & m_{\bar{d}s} \\ m_{\bar{s}u} & m_{\bar{s}d} & 0 \end{pmatrix}$$

$$\Phi = \begin{bmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{bmatrix}$$

Tree Level current: $\bar{s}u = -\partial\mathcal{L}/\partial m_{\bar{s}u}.$

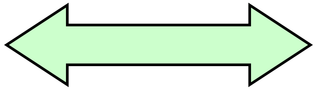
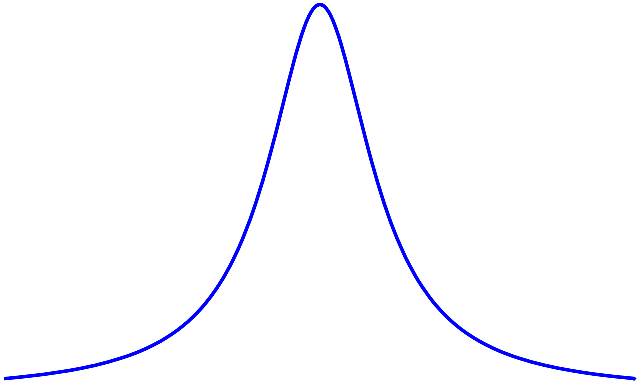
$$\begin{aligned} \bar{q}q' = \bar{u}s + \bar{d}s + \bar{s}u + \bar{s}d \;&=\; \frac{B_0}{6}\Big[6\left(\pi^- K^+ + K^-\pi^+ + \pi^+ K^0 + \pi^-\bar{K}^0\right) \\ &-\; \sqrt{2}\left(K^- + K^+\right)\left(\sqrt{3}\eta_8 - 3\pi^0\right) \\ &-\; \sqrt{2}\left(K^0 + \bar{K}^0\right)\left(\sqrt{3}\eta_8 + 3\pi^0\right)\Big] \,. \end{aligned}$$

Unitarized Approach



Summing all order contributions:

$$V + VGV + VGVGV + \ldots = \frac{V}{1 - GV}$$

1-GV＝0  

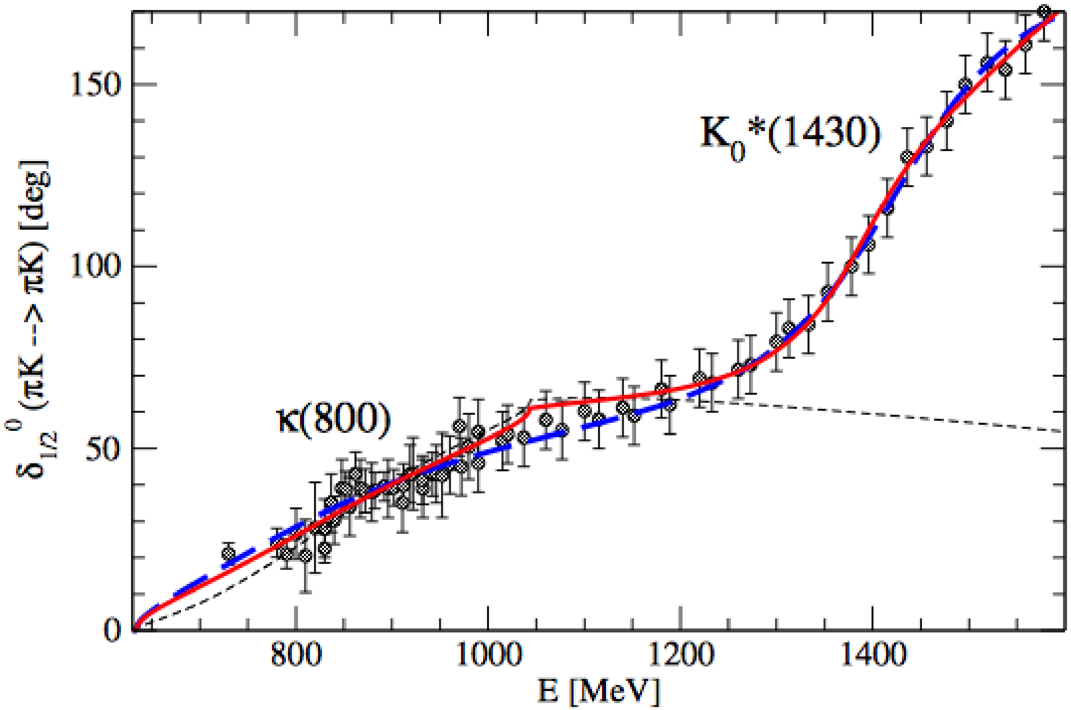
$s=s_0$

Above Threshold: pole corresponds to resonance

→ Hadron Molecule

Unitarized χPT and phase shift

M.Döring,U.-G.Meißner,WW,arXiv:1307.0947



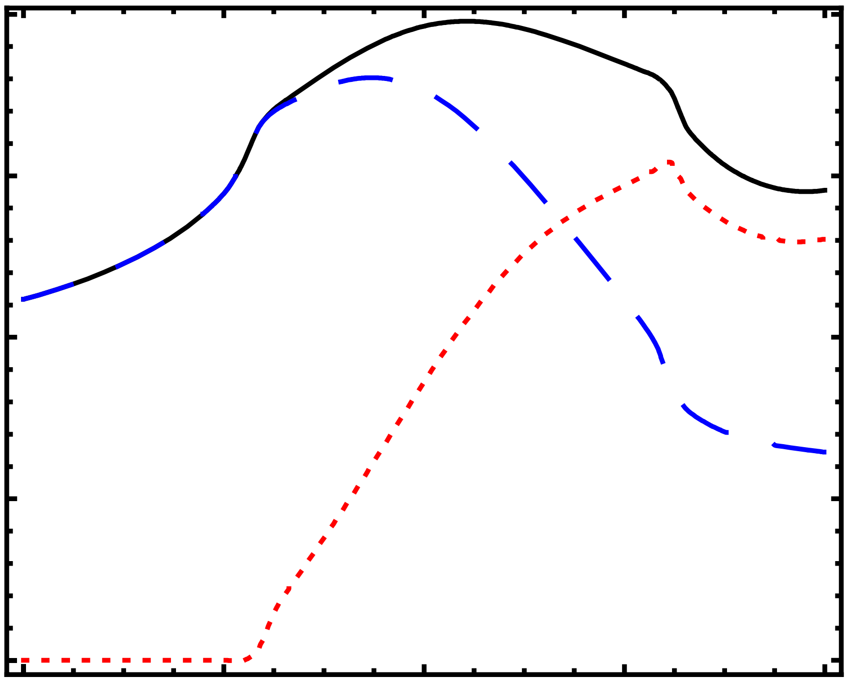
Phase Shift

Mass Pole

		z_0 [MeV]	$a_{-1}(K\eta)$ $[M_\pi]$	$a_{-1}(K\pi)$ $[M_\pi]$
$\kappa(800)$	this work (2-ch.)	$792-i\,279$		$-29-i\,57$
	this work (1-ch.)	$715-i\,283$		$-45-i\,62$
	Ref. [32] (χU)	$815-i\,226$		$-30-i\,57$
	Ref. [65] (Roy-S.)	$658-i\,279$		

Scalar form factors in χPT

M.Döring,U.-G.Meißner,WW,arXiv:1307.0947



$m^2_{K\pi}$ (GeV^2)

$$\langle 0|\bar{s}d|K\pi\rangle = C_X B_0 F_{K\pi}(m^2_{K\pi})$$

twice-subtracted Omnes solution matched onto χPT

Imaginary part
Real part
Magnitude

S-wave contributions

- To be more specific, consider the generalized transition form factors:

$$\langle (K\pi)_0(p_{K\pi})|\bar{s}\gamma_\mu\gamma_5 b|\overline{B}(p_B)\rangle = -i\frac{1}{m_{K\pi}}\left\{\left[P_\mu - \frac{m_B^2 - m_{K\pi}^2}{q^2}q_\mu\right]\mathcal{F}_1^{B\to K\pi}(m_{K\pi}^2, q^2) + \frac{m_B^2 - m_{K\pi}^2}{q^2}q_\mu\mathcal{F}_0^{B\to K\pi}(m_{K\pi}^2, q^2)\right\},$$

$$\langle (K\pi)_0(p_{K\pi})|\bar{s}\sigma_{\mu\nu}q^\nu\gamma_5 b|\overline{B}(p_B)\rangle = -\frac{\mathcal{F}_T^{B\to K\pi}(m_{K\pi}^2, q^2)}{m_{K\pi}(m_B + m_{K\pi})}\left[q^2 P_\mu - (m_B^2 - m_{K\pi}^2)q_\mu\right],$$

Generalized Form factors in LCSR

$$\langle (K\pi)_0(p_{K\pi})|\bar{s}\gamma_\mu\gamma_5 b|\overline{B}(p_B)\rangle = -i\frac{1}{m_{K\pi}}\left\{\left[P_\mu - \frac{m_B^2 - m_{K\pi}^2}{q^2}q_\mu\right]\mathcal{F}_1^{B\to K\pi}(m_{K\pi}^2, q^2) + \frac{m_B^2 - m_{K\pi}^2}{q^2}q_\mu \mathcal{F}_0^{B\to K\pi}(m_{K\pi}^2, q^2)\right\},$$

$$\langle (K\pi)_0(p_{K\pi})|\bar{s}\sigma_{\mu\nu}q^\nu\gamma_5 b|\overline{B}(p_B)\rangle = -\frac{\mathcal{F}_T^{B\to K\pi}(m_{K\pi}^2, q^2)}{m_{K\pi}(m_B + m_{K\pi})}\left[q^2 P_\mu - (m_B^2 - m_{K\pi}^2)q_\mu\right],$$

Consider a generic correlation function

$$\Pi(p_{K\pi}, q) = i\int d^4x\, e^{iq\cdot x}\langle (K\pi)_0(p_{K\pi})|\mathrm{T}\{j_{\Gamma_1}(x), j_{\Gamma_2}(0)\}|0\rangle$$

Hadron level:

$$\frac{\langle (K\pi)_0(p_{K\pi})|j_{\Gamma_1}|\overline{B}(p_{K\pi}+q)\rangle\langle \overline{B}(p_{K\pi}+q)|j_{\Gamma_2}|0\rangle}{m_B^2 - (p_{K\pi}+q)^2} + \int_{s_0}^{\infty} ds \frac{\rho^h(s, q^2)}{s - (p_{K\pi}+q)^2},$$

Quark Hadron Duality

Quark level: Light cone OPE

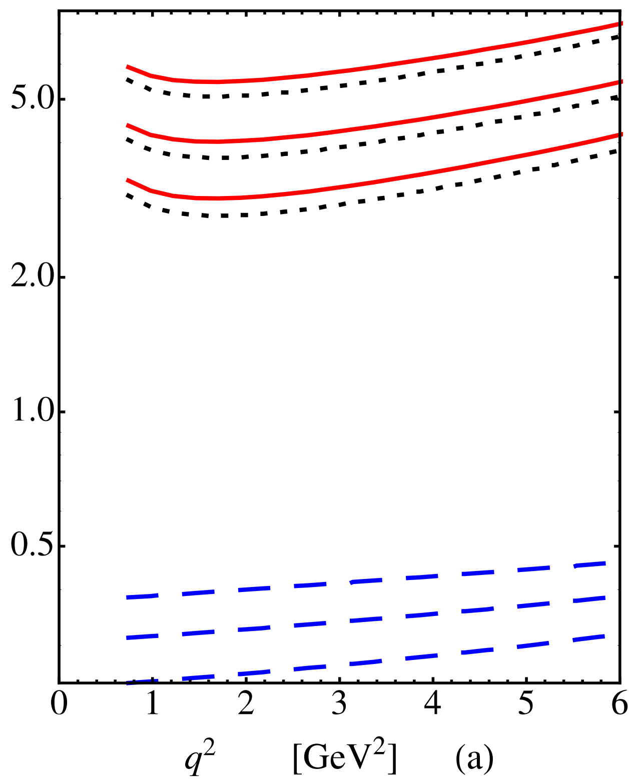
$$\langle (K\pi)_0|\bar{s}(x)\gamma_\mu d(0)|0\rangle$$

$$\langle (K\pi)_0|\bar{s}(x) d(0)|0\rangle$$

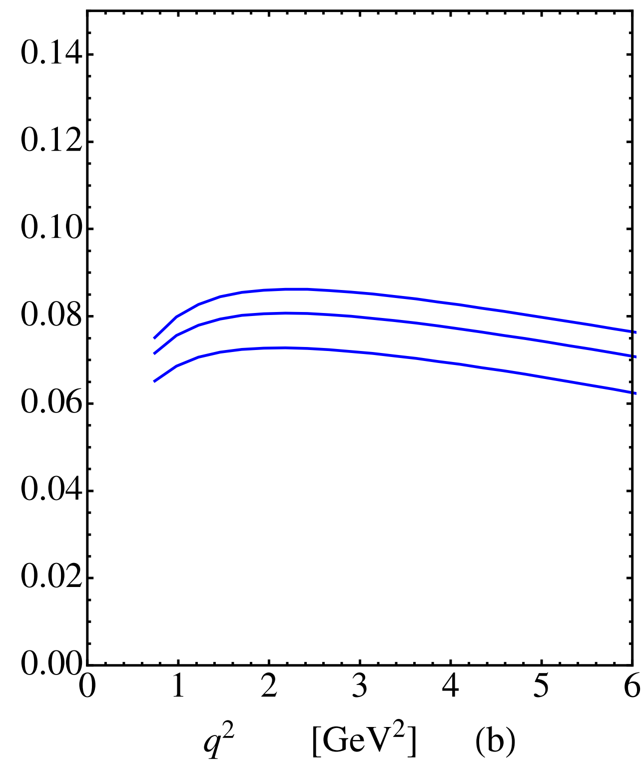
$$\langle (K\pi)_0|\bar{s}(x)\sigma_{\mu\nu} d(0)|0\rangle$$

U.G. Meiβner, WW, arXiv:1312.3087

S-wave contributions in B→Kπl⁺l⁻



Decay widths:
Red: total
Black: P-wave
Blue:S-wave

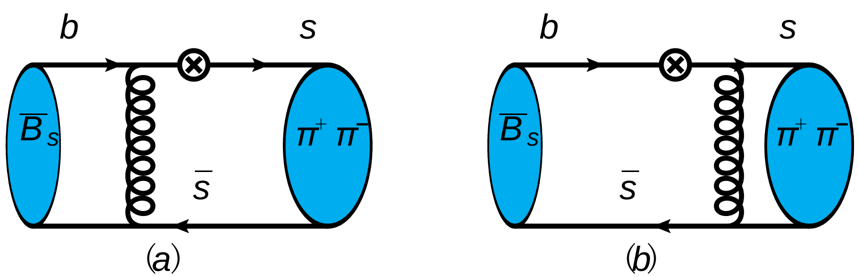


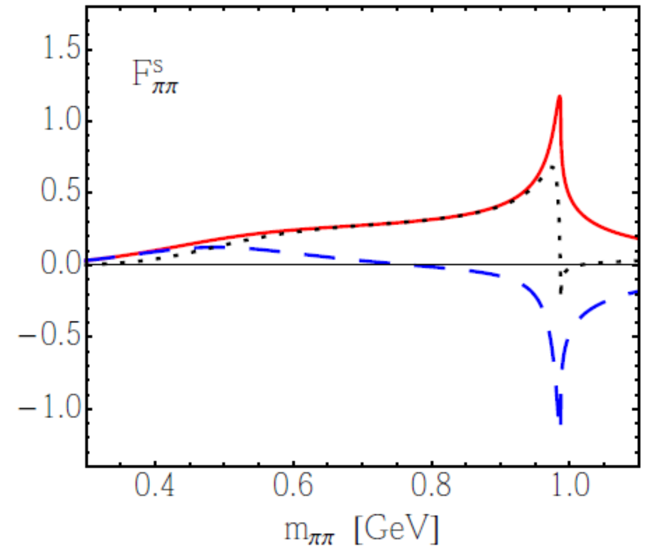
S-wave fraction

LHCb : F_S=0. 04±0. 04

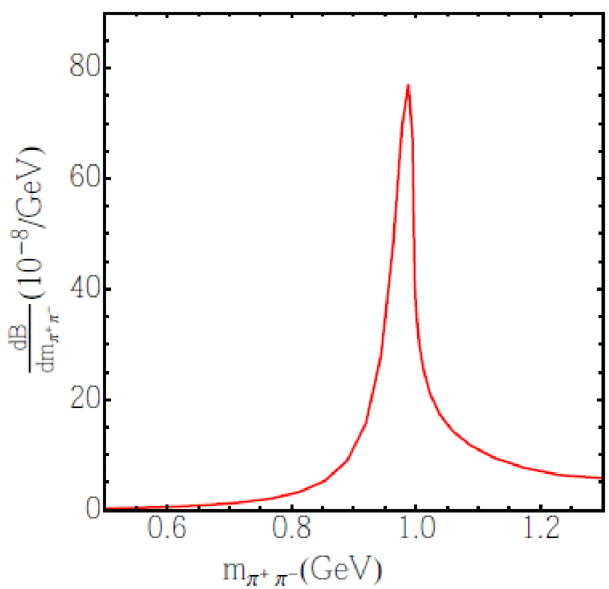
1304. 6325

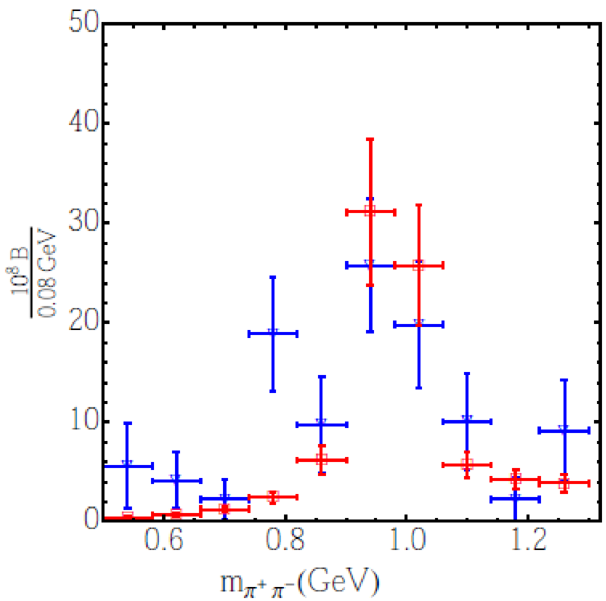
$B_s \to \pi^+\pi^-\mu^+\mu^-$





$$\sqrt{2}B_0\,F^s_{\pi\pi}(s) = \langle 0|\bar{s}s|\pi\pi\rangle_{I=0}$$

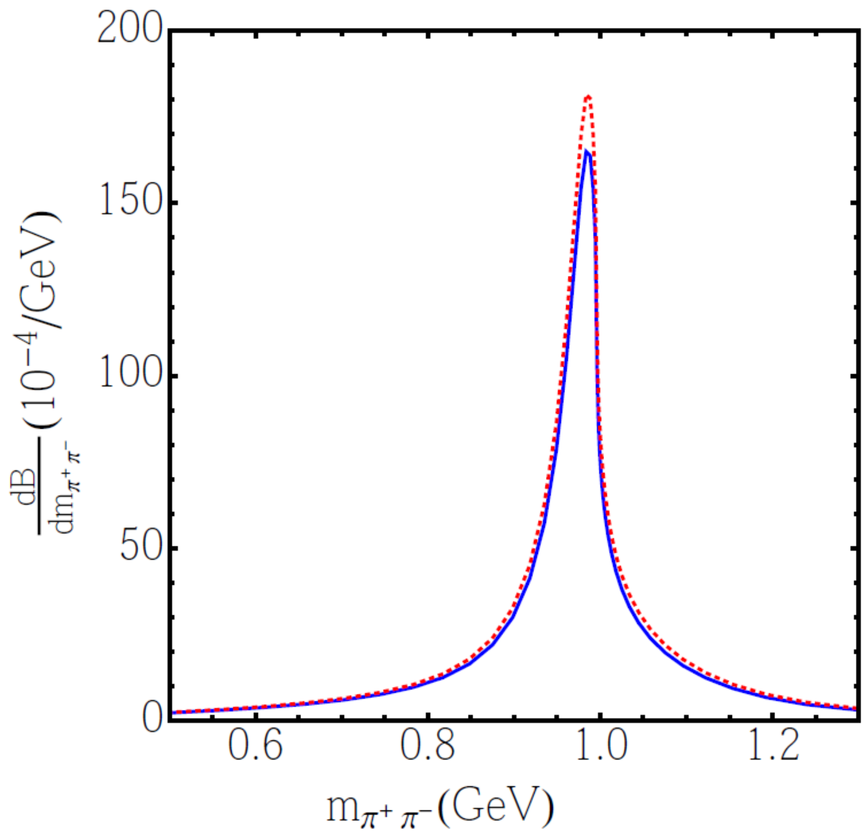


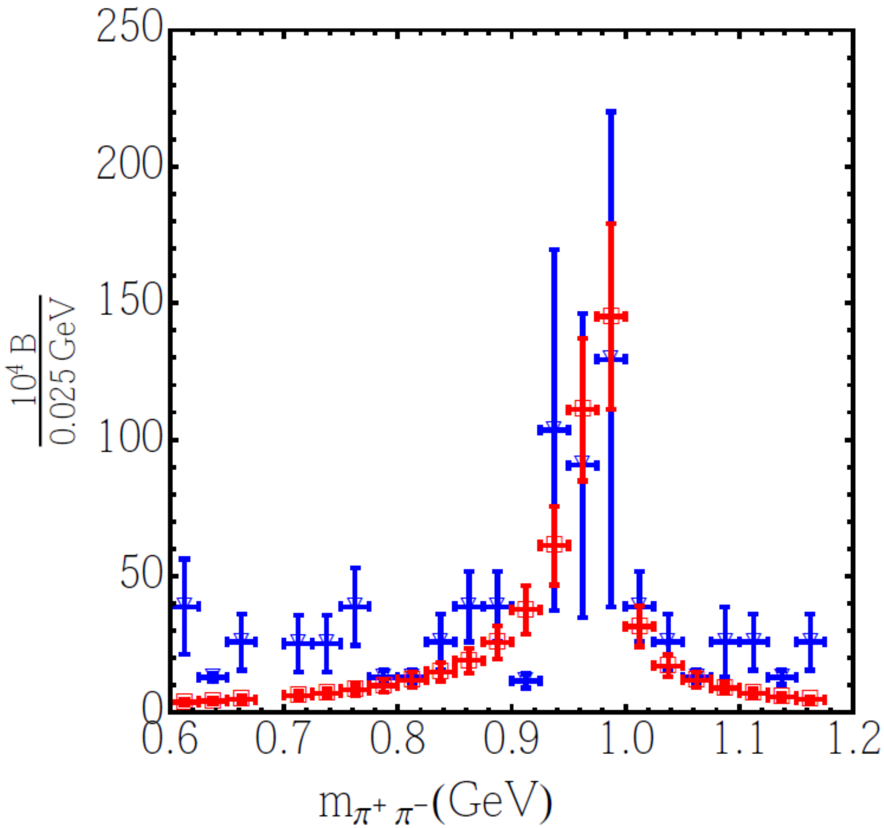


YJS, Wang, to appear

LHCb: 1412.6433

$D_s \to \pi^+\pi^- l\nu$





$D_s \to \pi^+\pi^- \mu\nu$

$D_s \to \pi^+\pi^- e\nu$

YJS, Wang, to appear

LHCb: 1412.6433

Summary

- $B \to K^* l^+ l^-$ are valuable
- S-wave contributions
- In large recoil &small invariant mass region:
  χPT & pQCD
- Application to Bs/Ds decays into $\pi^+\pi^-$

Thank you