# Glauber-gluon effects and B→$\pi$ $\pi$, $K$ $\pi$ puzzles

XIN LIU(刘 新)

Department of Physics, Jiangsu Normal University

Collaborated with Prof. H.-n. Li and Prof. Z.-j. Xiao

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# Outline

- ☞ Motivation
- ☞ Factorization formulas
- ☞ Numerical results and discussions
- ☞ Summary

# Motivation

- Experimentally, the current data on the BR of $B^0 \to \pi^0\pi^0$

$$
\begin{cases}
(1.83 \pm 0.21 \pm 0.13) \times 10^{-6} & \text{(BaBar)}, \\
\boxed{(0.90 \pm 0.12 \pm 0.10) \times 10^{-6} \quad \text{(Belle)},} \\
(1.17 \pm 0.13) \times 10^{-6} & \text{(HFAG)},
\end{cases}
$$

M. Petric@ICHEP2014

arXiv: 1412.7515[hep-ex]

Hierarchy,

$Br\,(B^+ \to \pi^+\pi^0)$ >(~) $Br\,(B^0 \to \pi^+\pi^-)$ > $Br\,(B^0 \to \pi^0\pi^0)$

and on the $\triangle A_{K\pi} \equiv A_{CP}^{\rm dir}(K^\pm\pi^0) - A_{CP}^{\rm dir}(K^\pm\pi^\mp)$

$$\Delta A_{K\pi} = 0.119 \pm 0.022$$

arXiv: 1412.7515[hep-ex]

$A_{CP}^{\rm dir}(B^\pm \to K^\pm\pi^0) = +0.037 \pm 0.021$, $A_{CP}^{\rm dir}(B^0 \to K^\pm\pi^\mp) = -0.082 \pm 0.006$,

- Theoretically, e.g., in the NLO pQCD formalism,

$$Br\,(B^0\to\pi^+\pi^-) \;>\; Br\,(B^+\to\pi^+\pi^0) \;>>\; Br\,(B^0\to\pi^0\pi^0)$$

Phys.Rev.D 73, 114014(2006), Li and Mishima
Phys.Rev.D 90, 014029(2014), Zhang *et al.*

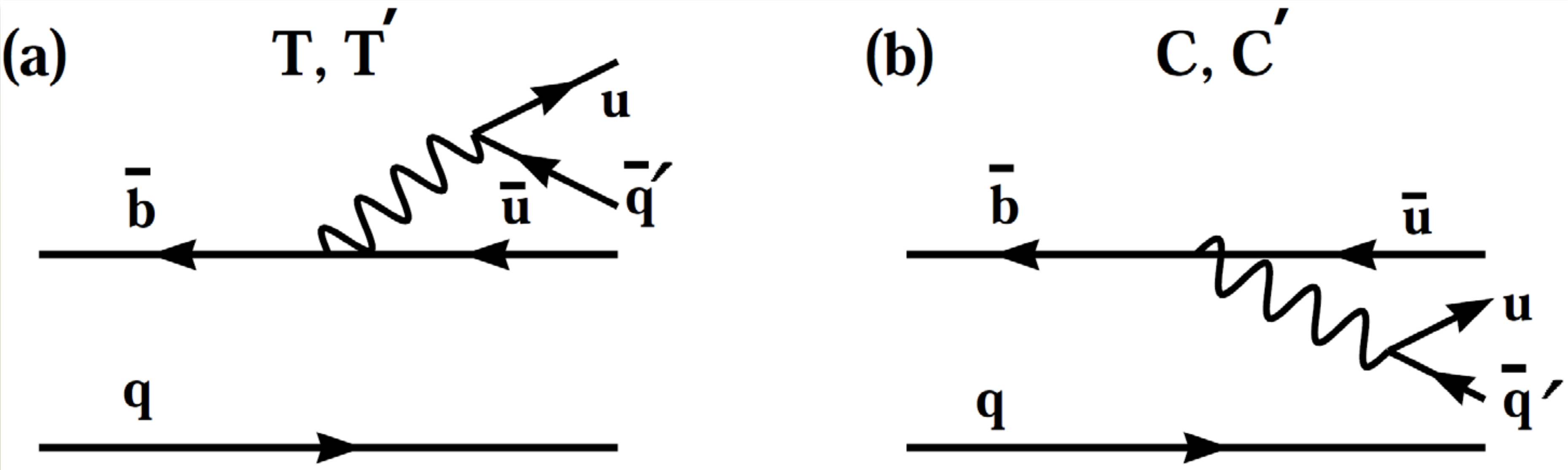
In particular, in the factorization theorems,

$$Br\,(B^0\to\pi^0\pi^0)\sim(0.2-0.3)\times 10^{-6}$$

For $B\to K\pi$ decays,

$$A_{\rm CP}^{\rm dir}(B^0\to K^\pm\pi^\mp) \;\sim\; A_{\rm CP}^{\rm dir}(B^\pm\to K^\pm\pi^0)$$

- The above contradictions between theory and experiment for the $B\to\pi\pi$ decay rates and the differences of the $B\to K\pi$ direct CP asymmetries have been known as long-standing puzzles.




✿ Color-suppressed tree amplitude ***C*** is an important but least-understood quantity in *B* decays;

Phys.Rev.D 83, 034023 (2011), Li and Mishima

$$\mathcal{B}(B^0 \to \rho^0\rho^0) = \begin{cases} (0.92 \pm 0.32 \pm 0.14) \times 10^{-6} & (\mathrm{BaBar})\,, \\ (1.02 \pm 0.30 \pm 0.15) \times 10^{-6} & (\mathrm{Belle})\,, \\ (0.97 \pm 0.24) \times 10^{-6} & (\mathrm{HFAG})\,; \end{cases}$$

arXiv: 1412.7515[hep-ex]

➢ Can $C$ be larger? How to reach? Sub-leading corrections or new QCD mechanism?

❀ The $B \to \rho\rho$ data seriously constrained the possibility of resolving the $B \to \pi\pi$ puzzle. Phys.Rev.D 73, 114014 (2006), Li and Mishima

➢ Many efforts have been made on this puzzle. But, no satisfactory resolution can be achieved yet. (Naively enhancing the hard spectator amplitudes(HSA) to ***C*** !)

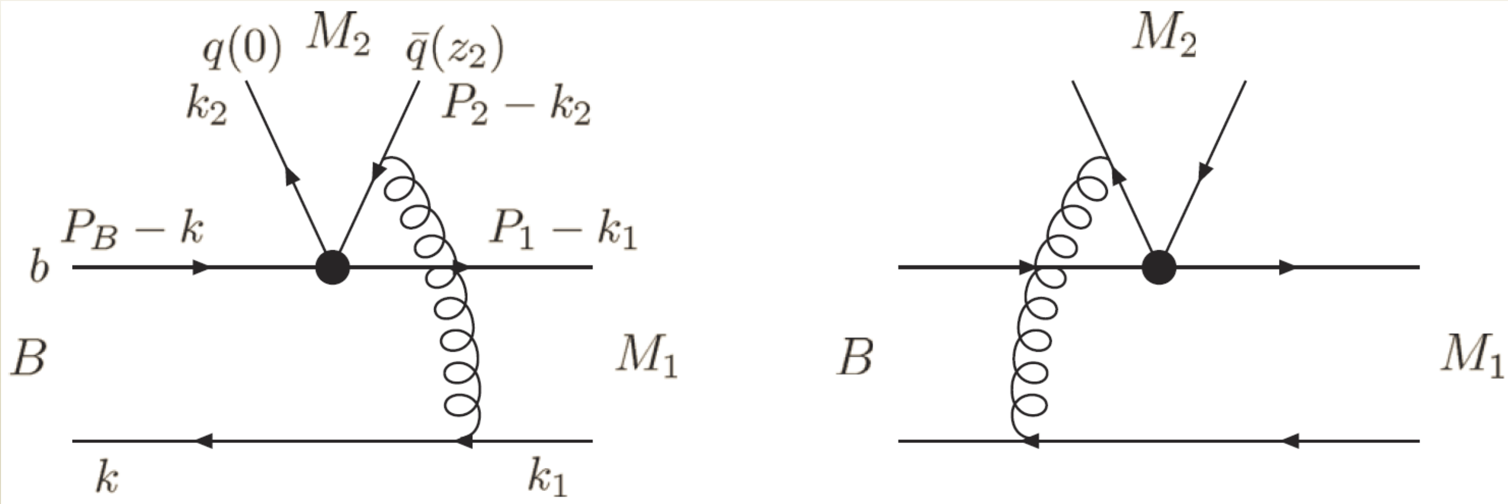
➢ To our best knowledge, all the strategies in the literature adopted to resolve this puzzle either evaded the $B^0 \to \rho^0 \rho^0$ constraint or did not survive the constraint in the SM.

A new mechanism is demanded!

Mechanism must differentiate pion from $\rho$ meson!

# Have checked the $k_T$ factorization of the spectator nonfactorizable diagrams

Phys. Rev. D 83, 034023 (2011); *ibid.* 90, 074018 (2014), Li and Mishima




Considered the factorization of $M_2$ meson wave function

Observed the existence of Glauber gluons

Leading IR regions $l \sim (l^+, l^-, l_T)$

$$\begin{cases} l^+(Q) \gg l_T(\Lambda_{QCD}) \gg l^-(\Lambda^2_{QCD}/Q) & \text{Collinear} \\ l^+(\Lambda_{QCD}) \sim l_T(\Lambda_{QCD}) \sim l^-(\Lambda_{QCD}) & \text{Soft} \\ l^+(\Lambda^2_{QCD}/Q) \sim l^-(\Lambda^2_{QCD}/Q) \ll l_T(\Lambda_{QCD}) & \text{Glauber} \end{cases}$$

- Li and Mishima observed the glauber divergences with the NLO spectator amplitudes in the $k_{\mathrm{T}}$ factorization theorem, then gave universal phase factors by all-order summation.

Phys. Rev. D 83, 034023 (2011); *ibid.* 90, 074018 (2014), Li and Mishima

- the phase factors associated with the emitted meson will turn the destructive interference between the LO spectator diagrams into a constructive one, then modify ***C***;

$$I_a \approx \exp(iS_e)\mathcal{M}_a^{(0)}, \qquad I_b \approx \exp(-iS_e)\mathcal{M}_b^{(0)},$$

- like $1-1 \Rightarrow e^{iS_e} - e^{-iS_e}$ , large imaginary C

- the phase factors associated with the recoiled meson will rotate the enhanced ***C*** then modify the interference between ***C*** and ***T***.

➢ After treating the glauber phases as free real parameters $-\frac{\pi}{2}$ in the $B \to \pi\pi$ decays, the BR was

Phys. Rev. D 90, 074018 (2014), Li and Mishima

$$Br\,(B^0 \to \pi^0\pi^0) \sim 1.2 \times 10^{-6}$$

☞ the postulation on vanishing of glauber phases in the $B \to \rho\rho$ decays was made.

☞ But, the question should be answered:

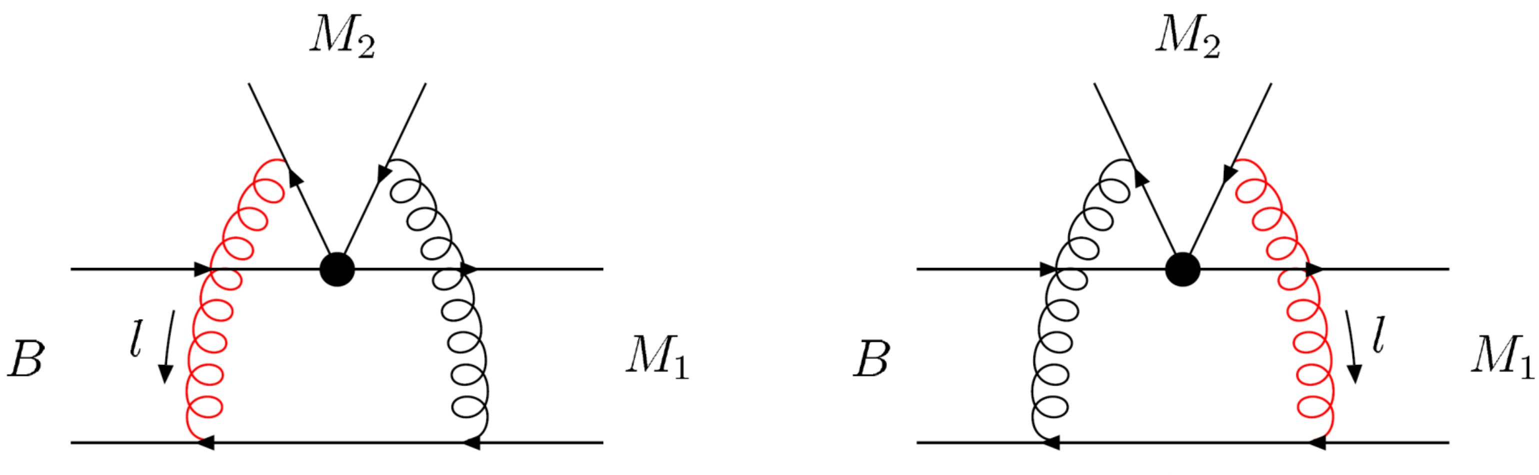
Why the color-suppressed tree amplitudes are so different in the $B \to \pi\pi$ and $B \to \rho\rho$ decays?

➢ We attempt to answer this question by quantitatively estimating different glauber effects through convolution in the $B \to \pi\pi$ and $B \to \rho\rho$ decays.

# Factorization formulas

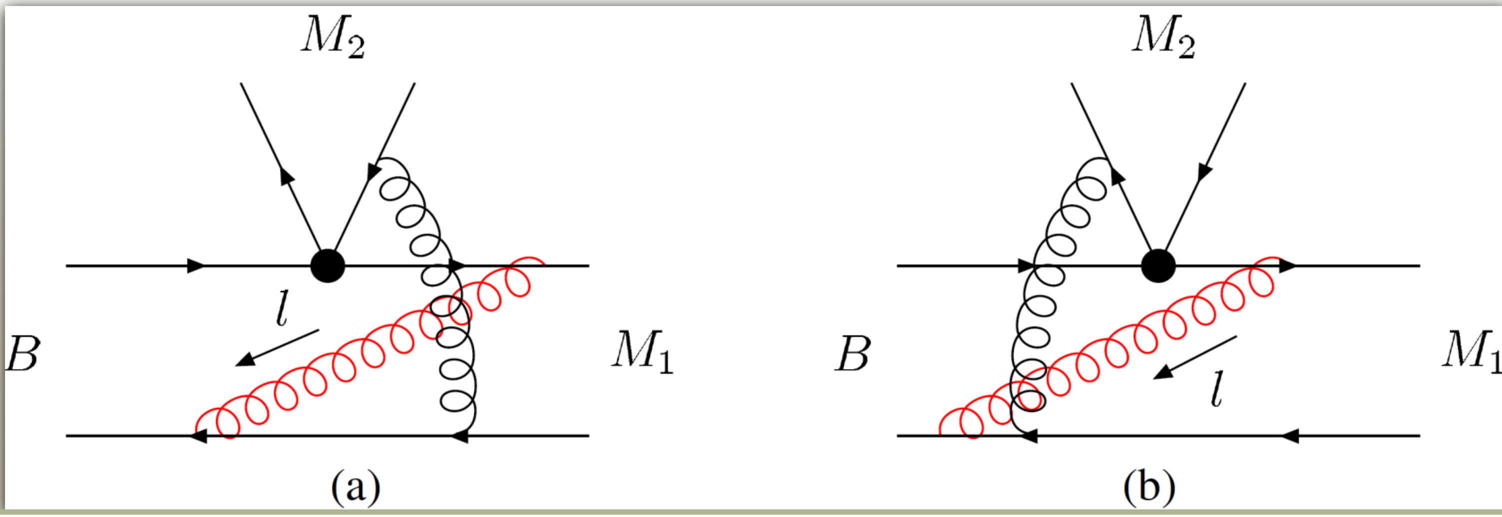
➢ Glauber gluons have been identified from the higher order corrections to the spectator diagrams in $B \to M_1\, M_2$ decays.

Phys. Rev. D 83, 034023 (2011); *ibid.* 90, 074018 (2014), Li and Mishima




(a) (b)

NLO spectator diagrams contain the glauber divergences associated with the $M_2$ meson for $B \to M_1 M_2$ decay. Other NLO diagrams with the glauber divergences are referred to Phys.Rev.D 83, 034023(2011).




NLO spectator diagrams contain the glauber divergences associated with the $M_1$ meson for $B \to M_1 M_2$ decay. Other NLO diagrams with the glauber divergences are referred to Phys.Rev.D 90, 074018 (2014).

$$\int d^2\mathbf{b}_1 d^2\mathbf{b}_2 \int d^2\mathbf{b}_{s1} d^2\mathbf{b}_{s2} \bar{\phi}_B(\mathbf{b}_1)\bar{\phi}_1(\mathbf{b}_{s1}+\mathbf{b}_1,\mathbf{b}_{s1})$$

$$\times\bar{\phi}_2(\mathbf{b}_{s2},\mathbf{b}_{s2}+\mathbf{b}_2)\exp\left[-iS(\mathbf{b}_{s1}-\mathbf{b}_2)+iS(\mathbf{b}_{s2}-\mathbf{b}_1)\right]H_a(\mathbf{b}_1,\mathbf{b}_2)$$

$$\int d^2\mathbf{b}_1 d^2\mathbf{b}_2 \int d^2\mathbf{b}_{s1} d^2\mathbf{b}_{s2} \bar{\phi}_B(\mathbf{b}_1)\bar{\phi}_1(\mathbf{b}_{s1}+\mathbf{b}_1,\mathbf{b}_{s1})$$
$$\times\bar{\phi}_2(\mathbf{b}_{s2}+\mathbf{b}_2,\mathbf{b}_{s2})\exp\left[-iS(\mathbf{b}_{s1}-\mathbf{b}_2)-iS(\mathbf{b}_{s2}-\mathbf{b}_1)\right]H_b(\mathbf{b}_1,\mathbf{b}_2)$$

Comments:

- the universal glauber factor associated with $M_1$, same for both amplitudes
- the universal glauber factor associated with $M_2$, "(-)+" denotes the glauber gluons radiated from valence (anti-)quark

- Though the glauber factor is universal, the glauber effect appears different through the convolution with the TMD wave functions $\bar{\phi}_1(\mathbf{b}_{s1}+\mathbf{b}_1,\mathbf{b}_{s1})$ and $\bar{\phi}_2(\mathbf{b}_{s2}+\mathbf{b}_2,\mathbf{b}_{s2})$ which contains different intrinsic ***b*** dependences for pion, kaon, and $\rho$ meson.

# Numerical analysis and discussions

☞ Two important elements:

① TMD meson wave function(different intrinsic $k_T$)

② parameterization of glauber phase factor

➢ TMD meson wave function with the intrinsic $k_T$ part in the Gaussian form

SLAC-PUB-2540, Brodsky *et al.*, AIP Conf. Proc. 68,1000(1981), Huang J.Phys.G 34, 1845 (2007), Yu *et al.*

$$\phi_M(x, \mathbf{k}_T) = \frac{\pi}{2\beta_M^2} \exp\left(-\frac{\mathcal{M}^2}{8\beta_M^2}\right) \frac{\phi_M(x)}{x(1-x)},$$

For pion: $$\mathcal{M}^2 = \frac{k_T^2 + m^2}{x} + \frac{k_T^2 + m^2}{1-x},$$

For kaon: $$\mathcal{M}^2 = \frac{k_T^2 + m_q^2}{x} + \frac{k_T^2 + m_s^2}{1-x}$$

☞ Then the modified wave function is expressed as,

$$\bar{\phi}_M(x,\mathbf{b}',\mathbf{b}) \equiv \boxed{\bar{\phi}_M(\mathbf{b}',\mathbf{b})}\,\phi_M(x) = \boxed{\frac{2\beta_M^2}{\pi}\exp\left[-2\beta_M^2 x b'^2 - 2\beta_M^2(1-x)b^2\right]}\,\phi_M(x)$$

$$\bar{\phi}_K(x,\mathbf{b}',\mathbf{b}) = \frac{2\beta_K^2}{\pi}\boxed{\exp\left[-\frac{1}{8\beta_K^2}\left(\frac{m_q^2}{x}+\frac{m_s^2}{1-x}\right)\right]}$$
$$\times \exp\left[-2\beta_K^2 x b'^2 - 2\beta_K^2(1-x)b^2\right]\phi_K(x)$$

☞ We simply parameterize the glauber phase $S(\boldsymbol{b})$ by a sinusoidal function,

$$S(\boldsymbol{b}) = r\,\pi\,\sin(p\,\boldsymbol{b})$$

☞ another important procedure— determination of the shape parameters of pion, kaon and $\rho$ meson

J.Phys.G 34, 1845 (2007), Yu *et al.*

① widely adopted $\beta_\pi \sim 0.4$ GeV for pion in the literature

② $\beta_\rho \sim 1/3\ \beta_\pi$ fixed through the $B \to \rho$ form factor

③ $\beta_K \sim 0.25$ GeV fixed through the $B \to K$ form factor

☞ Important implication:

➢ pion($\rho$ -meson) WF with a weak(strong) falloff in parton TM $k_T$ , and kaon WF reveals a stronger(weaker) falloff in $k_T$ compared to the pion($\rho$ -meson) one, which means pion requires a tighter spatial distribution of its leading Fock state relative to higher Fock states.

➢ consistent with the dual role of pion as a massless NGB and as a $q\underline{q}$ bound state simultaneously.

☞ two sets of parameters $r$ and $p$ corresponding to largest BR of $B^0 \to \pi^0 \pi^0$ decay

| ✖ $r \sim 0.47,\ p \sim -0.632$ GeV | ✓ $r \sim 0.60,\ p \sim 0.544$ GeV |
|---|---|
| $Br(B^0 \to \pi^+\pi^-) = 5.90 \times 10^{-6}$ | $Br(B^0 \to \pi^+\pi^-) = 5.39 \times 10^{-6}$ |
| $Br(B^+ \to \pi^+\pi^0) = 3.88 \times 10^{-6}$ | $Br(B^+ \to \pi^+\pi^0) = 4.45 \times 10^{-6}$ |
| $Br(B^0 \to \pi^0\pi^0) = 0.62 \times 10^{-6}$ | $Br(B^0 \to \pi^0\pi^0) = 0.61 \times 10^{-6}$ |
| $Br(B^0 \to \rho^0\rho^0) = 1.07 \times 10^{-6}$ | $Br(B^0 \to \rho^0\rho^0) = 0.89 \times 10^{-6}$ |

| Modes | Data [1, 2] | NLO | NLOG |
|---|---|---|---|
| $B^0 \to \pi^+\pi^-$ | $5.10 \pm 0.19$ | $6.19^{+2.09}_{-1.48}(\omega_B)^{+0.38}_{-0.34}(a_2^\pi)$ | $5.39^{+1.86}_{-1.31}(\omega_B)^{+0.28}_{-0.25}(a_2^\pi)$ |
| $B^+ \to \pi^+\pi^0$ | $5.48^{+0.35}_{-0.34}$ | $3.35^{+1.08}_{-0.77}(\omega_B)^{+0.23}_{-0.22}(a_2^\pi)$ | $4.45^{+1.38}_{-0.99}(\omega_B)^{+0.39}_{-0.36}(a_2^\pi)$ |
| $B^0 \to \pi^0\pi^0$ | $0.90 \pm 0.16$ | $0.29^{+0.11}_{-0.07}(\omega_B)^{+0.03}_{-0.02}(a_2^\pi)$ | $0.61^{+0.16}_{-0.12}(\omega_B)^{+0.14}_{-0.12}(a_2^\pi)$ |
| $B^0 \to \rho^0\rho^0$ | $0.97 \pm 0.24$ | $1.06^{+0.29}_{-0.21}(\omega_B)^{+0.19}_{-0.16}(a_2^\rho)$ | $0.89^{+0.26}_{-0.18}(\omega_B)^{+0.13}_{-0.10}(a_2^\rho)$ |

Phys.Rev.D 91, 114019(2015), Liu, Li, and Xiao

❀ The results obtained with second set of parameters show the preferred pattern: *$B^0 \to \pi^+\pi^-$ and $B^0 \to \rho^0\rho^0$ BRs decrease 13% and 16%, respectively, while $B^+ \to \pi^+\pi^0$ and $B^0 \to \pi^0\pi^0$ ones increase by 33% and a factor of 2.1, respectively.*

❀ The agreement between the theoretical predictions and the data for all the $B \to \pi\pi$ and $B^0 \to \rho^0\rho^0$ BRs is improved simultaneously.

❀ The ratio of enhancement factor of $B^0 \to \pi^0\pi^0$ over reduction factor of $B^0 \to \rho^0\rho^0$ is about 2.5, close to 3 observed in Phys.Rev.D 90, 074018 (2014).

❀ To clarify the glauber effect, the results(in units of $10^{-2}$ GeV$^3$) of the nonfactorizable spectator amplitudes from operator $O_2$ without and with glauber phase are

$$\mathcal{A}_{a,b}(B^0 \to \pi^0\pi^0) = \begin{cases} 11.86 - i9.04, & -7.13 + i6.18, \quad (\mathrm{NLO}), \\ 10.80 - i7.25, & 7.67 - i3.42, \quad (\mathrm{NLOG}), \end{cases}$$

$$\boxed{5.53e^{-i0.54}} \longrightarrow \boxed{21.33e^{-i0.52}}$$

$$\mathcal{A}_{a,b}(B^0 \to \rho^0\rho^0) = \begin{cases} -42.44 + i24.42, & 28.88 - i18.07, \quad (\mathrm{NLO}), \\ -5.78 + i4.32, & -3.61 - i3.23, \quad (\mathrm{NLOG}), \end{cases}$$

It is possible to resolve the *B*→ππ puzzle!

## ➢ CP-averaged branching ratios of $B \to K\pi$ decays,

| Modes | Data [13,14] | NLO | NLOG |
|---|---|---|---|
| $B^0 \to K^\pm \pi^\mp$ | $1.96 \pm 0.05$ | $2.33^{+0.74}_{-0.52}(\omega_B)^{+0.12}_{-0.11}(a^K)^{+0.21}_{-0.20}(a^\pi)$ | $2.17^{+0.71}_{-0.49}(\omega_B)^{+0.11}_{-0.10}(a^K)^{+0.17}_{-0.16}(a^\pi)$ |
| $B^\pm \to K^\pm \pi^0$ | $1.29 \pm 0.05$ | $1.53^{+0.50}_{-0.35}(\omega_B)^{+0.08}_{-0.07}(a^K)^{+0.12}_{-0.12}(a^\pi)$ | $1.40^{+0.46}_{-0.33}(\omega_B)^{+0.06}_{-0.06}(a^K)^{+0.10}_{-0.10}(a^\pi)$ |
| $B^\pm \to \pi^\pm K^0$ | $2.37 \pm 0.08$ | $2.72^{+0.88}_{-0.61}(\omega_B)^{+0.15}_{-0.13}(a^K)^{+0.25}_{-0.24}(a^\pi)$ | $2.41^{+0.80}_{-0.56}(\omega_B)^{+0.11}_{-0.11}(a^K)^{+0.17}_{-0.17}(a^\pi)$ |
| $B^0 \to K^0 \pi^0$ | $0.99 \pm 0.05$ | $1.02^{+0.32}_{-0.22}(\omega_B)^{+0.05}_{-0.05}(a^K)^{+0.11}_{-0.10}(a^\pi)$ | $0.93^{+0.30}_{-0.21}(\omega_B)^{+0.06}_{-0.05}(a^K)^{+0.08}_{-0.07}(a^\pi)$ |

**Glauber-gluon effects modify the branching ratios moderately with around 10% reduction;**

**Dominance of the penguin contributions make the values be insensitive to amplitude $C$.**

Phys.Rev.D 93, 014024(2016), Liu, Li, and Xiao

## ➢ Direct CP asymmetries of $B \to K\pi$ decays,

| Modes | Data [13,14] | NLO | NLOG |
|---|---|---|---|
| $B^0 \to K^\pm \pi^\mp$ | $-0.082 \pm 0.006$ | $-0.076^{+0.008}_{-0.009}(\omega_B)^{+0.013}_{-0.013}(a^K)^{+0.007}_{-0.007}(a^\pi)$ | $-0.081^{+0.009}_{-0.009}(\omega_B)^{+0.011}_{-0.011}(a^K)^{+0.010}_{-0.009}(a^\pi)$ |
| $B^\pm \to K^\pm \pi^0$ | $+0.037 \pm 0.021$ | $-0.008^{+0.008}_{-0.009}(\omega_B)^{+0.009}_{-0.009}(a^K)^{+0.006}_{-0.006}(a^\pi)$ | $+0.021^{+0.008}_{-0.008}(\omega_B)^{+0.003}_{-0.004}(a^K)^{+0.014}_{-0.013}(a^\pi)$ |
| $B^\pm \to \pi^\pm K^0_S$ | $-0.017 \pm 0.016$ | $+0.003^{+0.001}_{-0.000}(\omega_B)^{+0.001}_{-0.001}(a^K)^{+0.000}_{-0.000}(a^\pi)$ | $+0.004^{+0.000}_{-0.001}(\omega_B)^{+0.001}_{-0.002}(a^K)^{+0.000}_{-0.000}(a^\pi)$ |
| $B^0 \to K^0_S \pi^0$ | $0.00 \pm 0.13$ | $-0.056^{+0.001}_{-0.001}(\omega_B)^{+0.004}_{-0.004}(a^K)^{+0.000}_{-0.001}(a^\pi)$ | $-0.089^{+0.001}_{-0.000}(\omega_B)^{+0.013}_{-0.009}(a^K)^{+0.005}_{-0.005}(a^\pi)$ |

**Glauber-gluon effects modified the DCP of $B^+ \to K^+\pi$ mode significantly with sign flipping attributed to its sensitivity to amplitude $C$**

## ➤ CP-averaged branching ratios of $B \to K\underline{K}$ decays,

| Modes | Data [13,14,23] | NLO | NLOG |
|---|---|---|---|
| $B^{\pm} \to K^{\pm}\bar{K}^0$ | $1.52 \pm 0.22$[a] | $2.45^{+0.83}_{-0.58}(\omega_B)^{+0.17}_{-0.17}(a^K)$ | $2.27^{+0.79}_{-0.54}(\omega_B)^{+0.17}_{-0.14}(a^K)$ |
| $B^0 \to K^0\bar{K}^0$ | $1.21 \pm 0.16$ | $2.19^{+0.77}_{-0.54}(\omega_B)^{+0.09}_{-0.09}(a^K)$ | $2.02^{+0.72}_{-0.50}(\omega_B)^{+0.08}_{-0.08}(a^K)$ |

[a]This is the very recent measurement reported by the LHCb Collaboration [23], which is comparable with $1.64 \pm 0.45$ by the *BABAR* Collaboration [24] and a bit larger than $1.11 \pm 0.20$ by the Belle Collaboration [25].

Phys.Rev.D 93, 014024(2016), Liu, Li, and Xiao

## ➤ Direct CP asymmetries of $B \to K\underline{K}$ decays,

| Modes | Data [13,14,23] | NLO | NLOG |
|---|---|---|---|
| $B^{\pm} \to K^{\pm}\bar{K}^0_S$ | $-0.21 \pm 0.14$ | $-0.03^{+0.01}_{-0.01}(\omega_B)^{+0.02}_{-0.02}(a^K)$ | $-0.03^{+0.01}_{-0.01}(\omega_B)^{+0.02}_{-0.02}(a^K)$ |
| $B^0 \to K^0_S\bar{K}^0_S$ | $0.0 \pm 0.4$ | $-0.09^{+0.00}_{-0.00}(\omega_B)^{+0.01}_{-0.01}(a^K)$ | $-0.09^{+0.00}_{-0.00}(\omega_B)^{+0.00}_{-0.00}(a^K)$ |

No amplitude $C$; only the spectator amplitudes induced by penguin operators ;

Glauber-gluon effects decrease the branching ratios by only a few percent; the DCP remains unchanged.

- for pion emission from the weak vertex with operator $O_2$,

$$\mathcal{A}_{a,b}(B^\pm \to \pi^0 K^\pm) = \begin{cases} -16.71 + i13.71, & 10.85 - i9.96, \quad (\mathrm{NLO}), \\ -12.57 + i10.80, & -9.96 + i5.85, \quad (\mathrm{NLOG}), \end{cases}$$

- for kaon emission from the weak vertex with operator $O_1$,

$$\mathcal{A}_{a,b}(B^\pm \to K^\pm \pi^0) = \begin{cases} 4.55 - i3.98, & -3.37 + i2.25, \quad (\mathrm{NLO}), \\ 3.59 - i3.23, & 3.14 - i0.90, \quad (\mathrm{NLOG}), \end{cases}$$

$$6.96e^{i2.57} \quad (2.09e^{-i0.97}) \times 10^{-2}\ \mathrm{GeV}^3$$

$$\rightarrow \quad 28.01e^{i2.51} \quad (7.90e^{-i0.55}) \times 10^{-2}\ \mathrm{GeV}^3$$

➢ to examine the similarity between pion and kaon from Glauber gluons

$$R_\pi \equiv \frac{|\mathcal{A}_a(\pi^0 K^\pm) + \mathcal{A}_b(\pi^0 K^\pm)|_{\mathrm{NLOG}-S_{e2}}}{|\mathcal{A}_a(\pi^0 K^\pm) + \mathcal{A}_b(\pi^0 K^\pm)|_{\mathrm{NLO}}} \approx 4.69,$$

$$R_K \equiv \frac{|\mathcal{A}_a(K^\pm \pi^0) + \mathcal{A}_b(K^\pm \pi^0)|_{\mathrm{NLOG}-S_{e2}}}{|\mathcal{A}_a(K^\pm \pi^0) + \mathcal{A}_b(K^\pm \pi^0)|_{\mathrm{NLO}}} \approx 3.90,$$

➢ both pion and kaon are pseudo-NGBs, but the latter one with non-negligible SU(3) symmetry breaking effect, which resulting in the weaker Glauber-gluon effects than the pion through the convolution with the TMD WF.

❀ A plausible explanation to the dynamical origin of glauber phase:

> the overlap between the $k_T$ distributions of the leading Fock state in a meson and the glauber gluons in a decay process

❀ It is stressed that the $B \to \pi\pi$, $K\pi$ puzzles must be resolved by resorting to a mechanism and that the glauber gluons should be one of the most crucial mechanisms.

# Conclusions and Summary

- The model estimate of the glauber effect has been performed and the convoluted factorization formulas have been obtained.

- A weak falloff in $k_T$ of pion WF is consistent with the dual role of the pion as a massless NGB and as a $q\underline{q}$ bound state.

- The universal glauber factors make distinct impacts on the $B^0 \to \pi^0\pi^0$ and $B^0 \to \rho^0\rho^0$ BRs through convolution with TMD WF and reasonable parameterization of glauber phase.

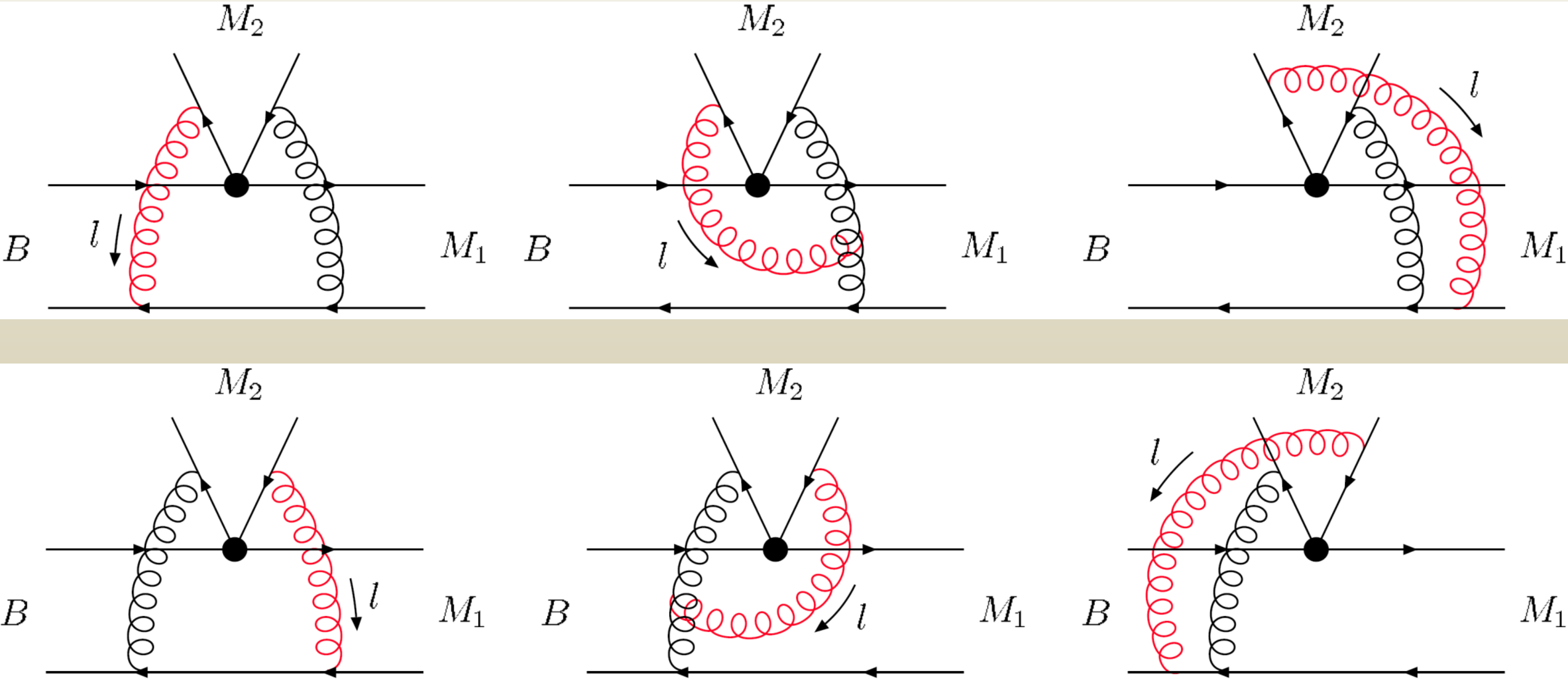
- The more significant glauber effect from pion was observed and the consistency between th. and ex. for all the modes was improved simultaneously.

- The glauber gluons should be one of the most crucial mechanisms to resolve the long-standing $B \to \pi\pi$, $K\pi$ puzzles.

谢谢！

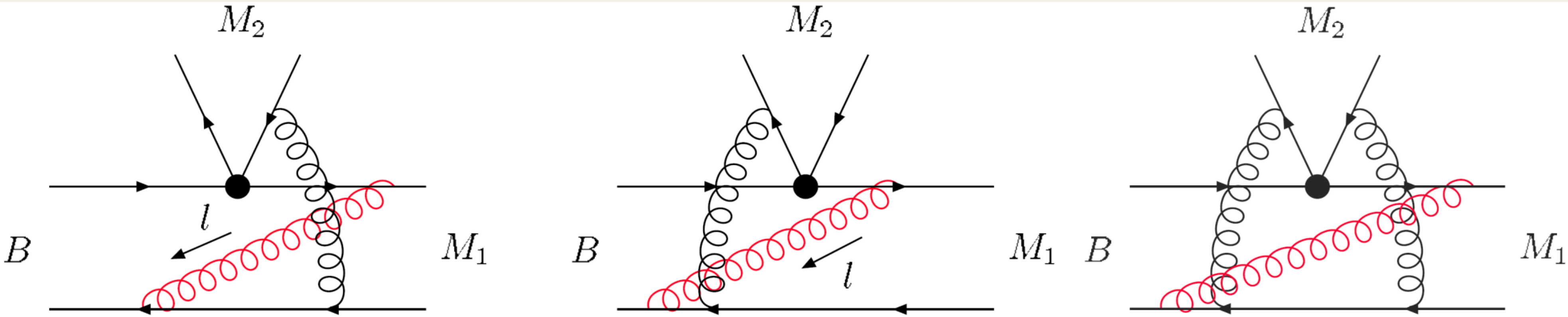
# BACKUP SLIDES

# Contributing to glauber phase $S_2$




Phys. Rev. D 90, 074018 (2014), Li and Mishima

# Contributing to glauber phase $S_1$




Phys. Rev. D 90, 074018 (2014), Li and Mishima

boson [30]: the valence quark and antiquark of the pion are separated by a short distance, like those of the $\rho$ meson, in order to reduce the confinement potential energy. The multiparton states of the pion spread over a huge space-time in order to meet the role of a massless NG boson, which result in a strong Glauber effect.

Phys. Rev. D 83, 034023 (2011), Li and Mishima

# Nambu-Goldstone boson

- Pion as a $q\bar{q}$ bound state and as a massless Nambu-Goldstone boson?
- Massless boson => huge spacetime => large separation between $q\bar{q}$ => high mass under confinement => contradiction!
- Reconciliation: leading $q\bar{q}$ state is tight, higher Fock state gives soft cloud (Lepage, Brodsky 79; Nussinov, Shrock 08; Duraisamy, Kagan 08)
  Pion is unique.
- Glauber factor for pion corresponds to this soft cloud: 3 partons in $k_T$ space

$$\int_0^{\Lambda} d^2 l_T \exp(-i\mathbf{l}_T \cdot \mathbf{b})/(l_T^2 + m_g^2)$$

Loop momentum cutoff: $\Lambda \sim 0.5$ GeV, collecting soft contributions, roughly yielding the period *p* of the oscillatory parameterization;

Gluon mass: $m_g$, together with the coefficient in the associated loop corrections such as strong coupling, controlling the magnitude *r* of the oscillation;

$b \to 0$ limit, corresponding to the integration over the transverse momentum in the collinear factorization theorem;