# Searching a signal beyond the SM by studying the photon polarization in $\mathrm{b} \rightarrow \mathrm{s} \gamma$ 


in collaboration with Cai-Dian LU (IHEP), Fu-Sheng Yu (Lanzou U.)

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## Flavour Physics beyond SM

- The indirect search of new physics through quantum loop effect: very powerful tool to search for new physics signal!

- Despite of our expectations, a significant deviation from SM has not been observed so far. $\Rightarrow$ A proposition of new observable is called for!
- The $b \rightarrow s \gamma$ process is a good probe of fundamental properties of SM as well as of beyond SM.
- However, the polarization of $b \rightarrow s \gamma$ has never been confirmed at a high precision $\Rightarrow$ important challenges for LHCb/Belle II!
- Direct CP violation in $b \rightarrow s \gamma$ is an important null test of BSM. $\Rightarrow$ new challenges for LHCb/Belle II!


## The photon polarization of $b \rightarrow s \gamma$

The $b \rightarrow s \gamma$ process is produced by magnetic operator with "a particular Dirac structure" in SM:


$$
\begin{aligned}
& b \rightarrow s \gamma_{L} \text { (left-handed polarization) } \\
& \bar{b} \rightarrow \bar{s} \gamma_{R} \text { (right-handed polarization) }
\end{aligned}
$$

* However, this left-handedness has never been confirmed experimentally at a high precision !
* Possible large new physics effect due to "chiral enhancement" !!


## Example: Left-Right Symmetric Model

Extended gauge group
EK, C.-D. Lu and F.-S. Yu (JHEP 2013)
Thesis of F.-S. Yu (China-France co-supervision)

$$
S U(2)_{L} \times S U(2)_{R} \times U(1)_{\tilde{Y}} \rightarrow S U(2)_{L} \times U(1)_{Y} \rightarrow U(1)_{\mathrm{EM}} .
$$

[Pati,Salam, 1974;Mohapatra,Pati, 1975;Mohapatra,Sejanovic, 1975]
Two step Symmetry breakings
$\langle\Phi\rangle=\left(\begin{array}{cc}\kappa & 0 \\ 0 & \kappa^{\prime} e^{i \omega}\end{array}\right), \quad\left\langle\Delta_{L}\right\rangle=\left(\begin{array}{cc}0 & 0 \\ v_{L} e^{i \theta_{L}} & 0\end{array}\right), \quad\left\langle\Delta_{R}\right\rangle=\left(\begin{array}{cc}0 & 0 \\ v_{R} & 0\end{array}\right)$

$$
\kappa, \kappa^{\prime}, v_{L} \ll v_{R} \quad \text { Right handed mass very large }
$$

W boson with left- and right-handed couplings ( $W_{L}$ \& $W_{R}$ )

$$
\begin{aligned}
& \binom{W_{L}^{-}}{W_{R}^{-}}=\left(\begin{array}{cc}
\cos \zeta & -\sin \zeta e^{i w} \\
\sin \zeta e^{-i w} & \cos \zeta
\end{array}\right)\binom{W_{1}^{-}}{W_{2}^{-}} \\
& \sin \zeta \approx \frac{g_{L}}{g_{R}} \frac{|\kappa|\left|\kappa^{\prime}\right|}{v_{R}^{2}}=\frac{g_{L}}{g_{R}} \frac{1}{2} \epsilon^{2} \sin 2 \beta \approx \frac{M_{W_{1}}^{2}}{M_{W_{2}}^{2}} \frac{g_{R}}{g_{L}} \sin 2 \beta .
\end{aligned}
$$

Mass eigenstates $W_{1} \& W_{2}$ are a mixture of left and right $W^{\prime} s$

## Example: Left-Right Symmetric Model

Right handed-photon contribution

$$
C_{7 \gamma}^{\prime}\left(\mu_{R}\right)=\frac{1}{2}\left[\frac{g_{R}^{2}}{g_{L}^{2}} \frac{V_{t s}^{R *} V_{t b}^{R}}{V_{t s}^{L *} V_{t b}^{L}}\left(\sin ^{2} \zeta A_{\mathrm{SM}}\left(x_{t}\right)+\cos ^{2} \zeta \frac{M_{1}^{2}}{M_{2}^{2}} A_{\mathrm{SM}}\left(\tilde{x}_{t}\right)\right)\right.
$$



Chiral enhancement term

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$$
\frac{C_{7 \gamma}^{\prime}(\mu \mathrm{C})}{C_{7 \gamma}(\mu \square} \sim-1180 \frac{g^{2}}{g^{2}} \frac{M^{2}}{M_{2}^{2}} \sin 2 \beta V_{\text {唃 }}^{*} e^{- \text {回 }}
$$



Model parameters; $g_{R} / g_{L}=I$, tan beta $=10$

## How do we measure the polarization?!

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proposed methods
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- Method I:Time dependent CP asymmetry in $B_{d} \rightarrow K_{s} \pi^{0} \gamma B_{s} \rightarrow K^{+} K^{-\gamma}$ (called $\left.S_{K s \pi 0 \gamma}, S_{K+K-\gamma}\right)$
$\rightarrow$ Method II:Transverse asymmetry in $\mathrm{B}_{\mathrm{d}} \rightarrow \mathrm{K}^{*} \mathrm{I}^{+}{ }^{-}$ (called $\mathrm{AT}^{\left({ }^{(2)},\right.} \mathrm{A}_{\left.T^{(i m)}\right)}$
- Method III: $B \rightarrow K_{1}\left(\rightarrow\right.$ KTTT) $\gamma$ (called $\left.\lambda_{Y}\right)$
- Method IV: $\Lambda_{b} \rightarrow \Lambda^{(*)} \gamma, \Xi_{b} \rightarrow \Xi^{*} \gamma \ldots$

Atwood et.al. PRL79

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Kruger, Matias PRD7I
    Becirevic, Schneider,
        NPB854
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Gronau et al PRL88 E.K. Le Yaouanc, Tayduganov

PRD83
Gremm et al.'95, Mannel et al '97, Legger et al '07, Oliver et al ‘। 0

## Polarization determination with $\mathrm{B} \rightarrow \mathrm{K}_{1}(\rightarrow \mathrm{~K} \pi \pi) \gamma$



Gronau, Grossman, Pirjol, Ryd PRL88('0 I)

$$
\begin{aligned}
\mathcal{A} & =\frac{\int_{0}^{1} \cos \theta \frac{d \Gamma}{d \cos \theta}-\int_{-1}^{0} \cos \theta \frac{d \Gamma}{d \cos \theta}}{\int_{-1}^{1} \cos \theta \frac{d \Gamma}{d \cos \theta}} \\
& =\frac{3}{4} \frac{\left\langle\operatorname{Im}\left(\hat{n} \cdot\left(\vec{J} \times \overrightarrow{J^{*}}\right)\right)\right\rangle}{\left.\left.\langle | \vec{J}\right|^{2}\right\rangle} \frac{\left|c_{R}\right|^{2}-\left|c_{L}\right|^{2}}{\left|c_{R}\right|^{2}+\left|c_{L}\right|^{2}}
\end{aligned}
$$

$\vec{J}: \begin{gathered}\text { Helicity amplitude } \\ \text { of } \mathrm{K}_{1}\left(\mathrm{I}^{+}\right) \rightarrow \mathrm{K} \pi \Pi \pi\end{gathered} \quad \begin{aligned} & \text { Polarization parameter } \\ & \text { related to C7, C7' etc... }\end{aligned}$

## Polarization determination with $\mathrm{B} \rightarrow \mathrm{K}_{1}(\rightarrow \mathrm{~K} \pi \pi) \gamma$



## First measurement of up-down asymmetry at LHCb!



## Strong decay of $K_{1} \rightarrow K \pi \pi$

How to extract the hadronic information (i.e. function J)?
proposed methods

- Model dependent way : theoretical compute it 4 form factor, 2 couplings, I phase (more if there is $\left.(\mathrm{K} \pi)_{s}\right)$
-(Semi-)model independent way
$\rightarrow$ Diffractive process $\mathrm{pK} \rightarrow \mathrm{pKK}$ ।
$\rightarrow B \rightarrow J / \Psi K_{\text {I }}$
$\rightarrow$ J/ $/ \rightarrow \mathrm{K}_{1} \mathrm{~K}, \Psi^{\prime} \rightarrow \mathrm{K}_{1} \mathrm{~K}$
$\rightarrow T \rightarrow K_{1}$ V...
$\rightarrow B \rightarrow K \pi \pi \gamma$ direct CP violation

Tayduganov, EK, Le Yaouanc, PRD ‘II

## Brandenburg et al,

Phys Rev Lett, 36 (‘76)
Otter et al,
Nucl Phys, BIO6 (‘77)
Daum et al, Nucl Phys, BI87 (‘8I)
Thesis of Jasinski (COMPASS ‘l 2)
EK, Le Yaouanc in preparation
BES Phys. Lett. B '06 (?)
ALEPH, Eur. Phys. J. CI I '99
Collaboration with C.D. Lu and F.S.Yu

## Conclusions

- In the era of LHCb/Belle II, a plenty of $b \rightarrow s$ transition processes where a large new physics contribution are possible will be measured.
- The radiative decays are particularly interesting (to me) due to the chiral-enhancement factor.
- We discussed the photon polarization determination of $b \rightarrow s \gamma$ processes.
- For interpretation of the LHCb up-down asymmetry measurement of $B \rightarrow K_{1} \gamma \rightarrow(K \pi \pi) \gamma$, understanding of the hadronic information is necessary. We are now discussing how to extract this information by using different experimental data.

Backup

## Extracting J-function - Kı strong decay amplitudes-

## COMPASS‘I2




ACMMOR ‘8।



## First measurement of Up-Down asymmetry at LHCb!



Direct $C P$ violation in $b \rightarrow s \gamma$ is an important null test of BSM. It may plays a role to disentangle real and imaginary part of new physics contributions.

- Deriving the Direct CP violation formulae for $B \rightarrow K \pi \pi \gamma$.
- Removing "fake" CP violation by disentangling the different spin parity states using the angular distribution.
- Quantifying the improvement in sensitivity to the new physics.
$\Rightarrow$ Further applications: many similar cases in B/D decays


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SM-like left handed-photon contribution


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$$



Chiral enhancement term

## Kobayashi-Maskawa mechanism at work!



$$
\begin{aligned}
& \Phi_{\text {I }} \text { is measured to be }(21.7 \pm 0.64)^{\circ} \quad \text { HFAG } \\
& \text { Improvement in } \Phi_{3} \text { measurement is on-going }(B \text { factories, LHCb). } \\
& \text { Issues in } V_{\text {ub }} \text { measurements. Improvement in the branching ratio } \\
& \text { measurement of } B \rightarrow \text { TV can be done at Belle II. }
\end{aligned}
$$

## Many expectations, many 2-3 sigmas...



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