Photon polarization in $b \to s\gamma$ decays

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In collaborations with A. Tayduganov and A. Le Yaouanc

Implications of LHCb measurements and future prospects @ CERN (14-16 October)

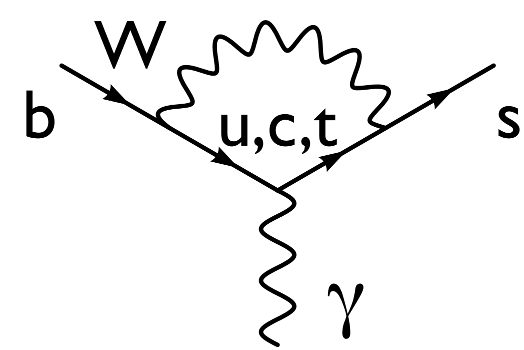
Why Photon Polarization of $b \to s\gamma$?

- The $b \to s\gamma$ process is a good probe of fundamental properties of SM as well as BSM (top mass, new particle mass/coupling etc...).
- The left-handed nature of the W-boson coupling of SM predicts:

W-boson couples only left-handed ⇔ γ of $b \to s\,\gamma$ should be circularly-polarized*

✍ $b \to s\,\gamma_L$ (left-handed polarization)

✍ $\bar{b} \to \bar{s}\,\gamma_R$ (right-handed polarization)



** There is small fraction (ms/mb) of admixture*

How do we measure it?

- However, the polarization of $b \to s\,\gamma$ has never been confirmed at a high precision yet ⇨ challenges for LHCb/Belle II !

proposed methods

- Method I: Time dependent CP asymmetry in $B_d \to K_S\pi^0\gamma$ $B_s \to K^+K^-\gamma$ (called $S_{K_S\pi^0\gamma}$, $S_{K^+K^-\gamma}$)
  Atwood et.al. PRL79, Muheim PLB '08
- Method II: Transverse asymmetry in $B_d \to K^* l^+ l^-$ (called $A_T^{(2)}$, $A_T^{(im)}$)
  Kruger, Matias PRD71, Becirevic, Schneider, NPB854
- Method III: $B \to K_{res}(\to K\pi\pi)\gamma$ (called λ_γ)
  Gronau et al PRL88, E.K. Le Yaouanc, Tayduganov PRD83
- Method IV: $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi^*\gamma$ ...
  Gremm et al.'95, Mannel et al '97, Hiller et al '01, '07, Legger et al '07, Oliver et al '10
- Method V: Angular distribution, CP observables in $B \to PV\gamma$ ($\Phi K\gamma$, $\rho K\gamma$...)
  Atwood et.al. '07

These are complementary, and none is more important than the others!

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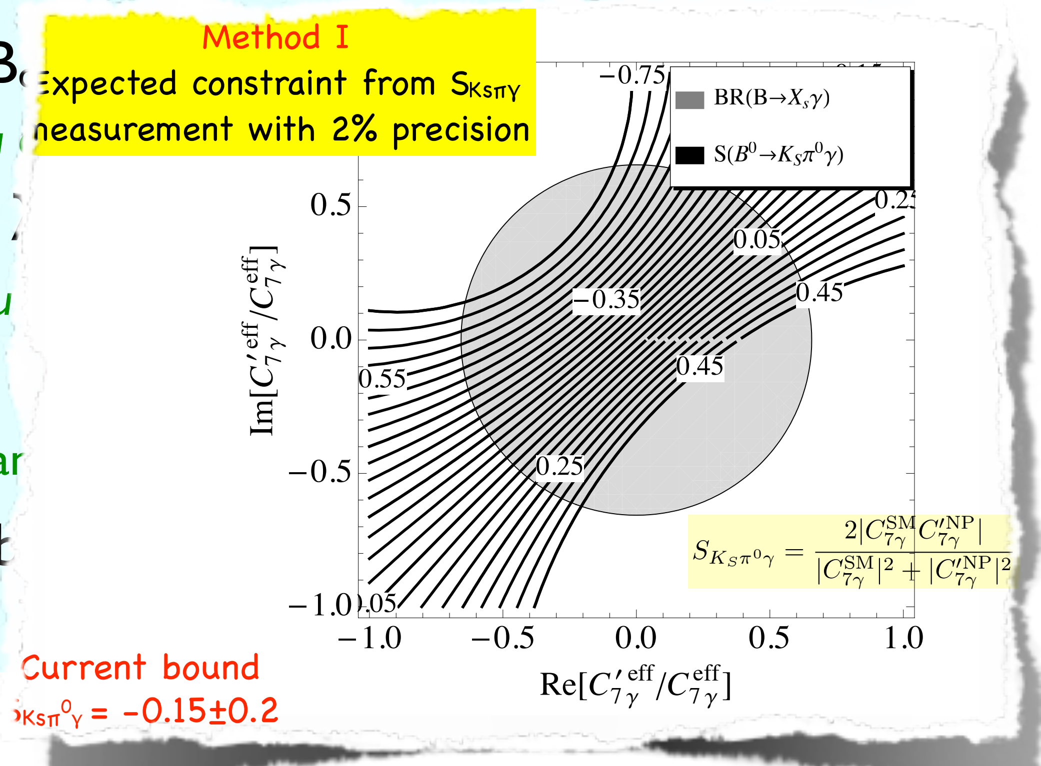
- Method II: Transverse asymmetry in B_d ... *Gronau ...*
- Method III: B➔K_{res}(➔Kππ)γ (called ... *Gronau ...*
- Method IV: Λ_b➔$\Lambda^{(*)}\gamma$, Ξ_b➔$\Xi^*\gamma$ ... *Gremm et al.'95, Mar...*
- Method V: Angular distribution, CP ob...



Becirevic, EK, Le Yaouanc, Tayduganov JHEP08 ('12)

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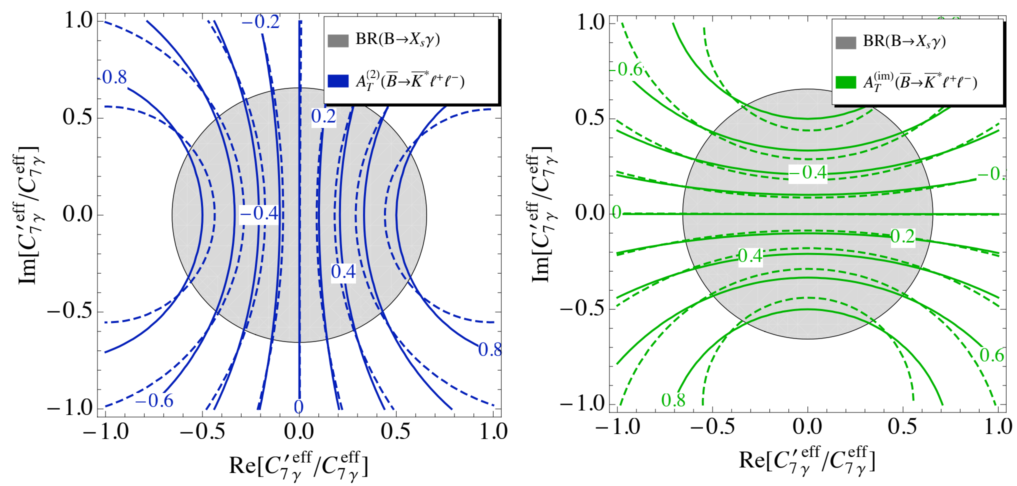
- Method II: Transverse asymm
- Method III: $B \to K_{res}(\to K\pi\pi)\gamma$
- Method IV: $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi$ Gremm
- Method V: Angular distributi

Method II

Expected constraint from $A_T^{(2)}$, $A_T^{(im)}$ measurement with 10% precision



Assumption for γ*/Z penguin (C_9,C_{10} contributions) necessary!

Becirevic, EK, Le Yaouanc, Tayduganov JHEP08 ('12)

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  Gremm et al.'95, Manne
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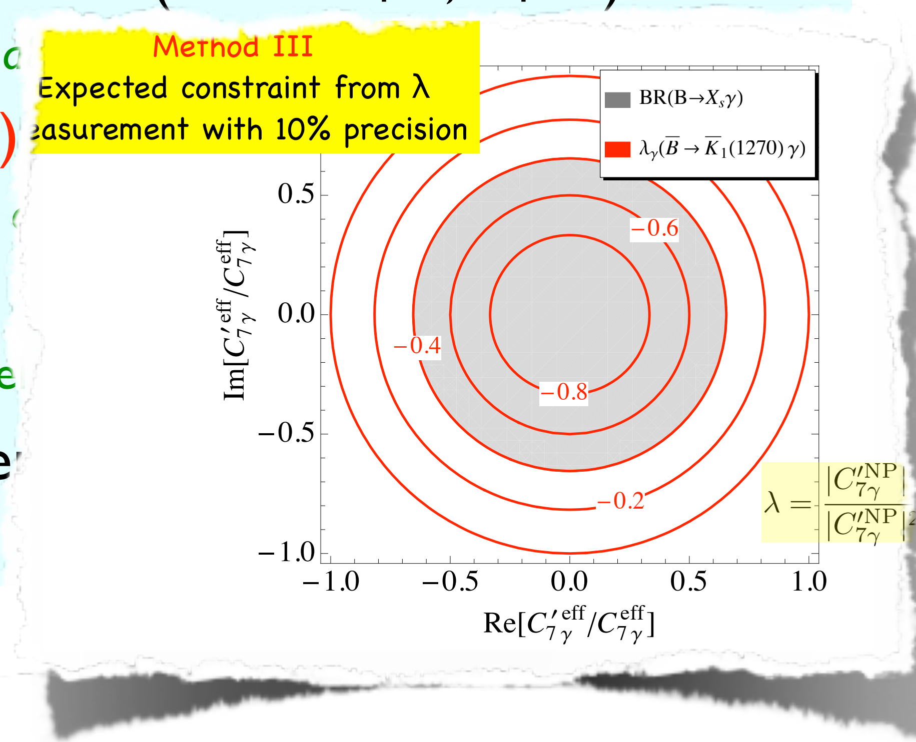
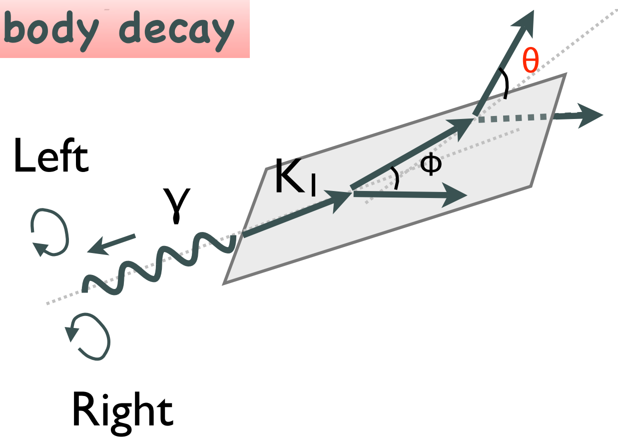


Becirevic, EK, Le Yaouanc, Tayduganov JHEP08 ('12)

Up-Down Asymmetry of $B \to K_{res}\,\gamma \to (K\pi\pi)\gamma$

Gronau, Grossman, Pirjol, Ryd PRL88('01)
Gronau, Pirjol PRD66('02)

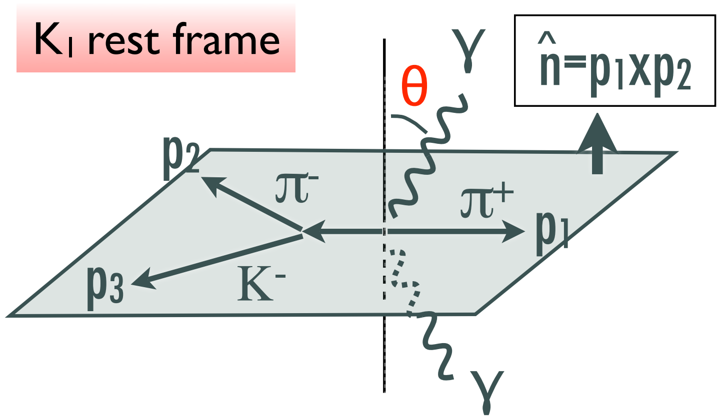
3 body decay



Circular polarization measurement of γ ⟺ Angular distribution of K_{res} decay

Up-Down Asymmetry : Count the number of events with photon above/below the K_{res} decay plane and subtract them.

K_1 rest frame



$$\mathcal{A} = \frac{\int_0^1 \cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 \cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 \cos\theta \frac{d\Gamma}{d\cos\theta}}$$

First measurement of Up-Down Asymmetry at LHCb!

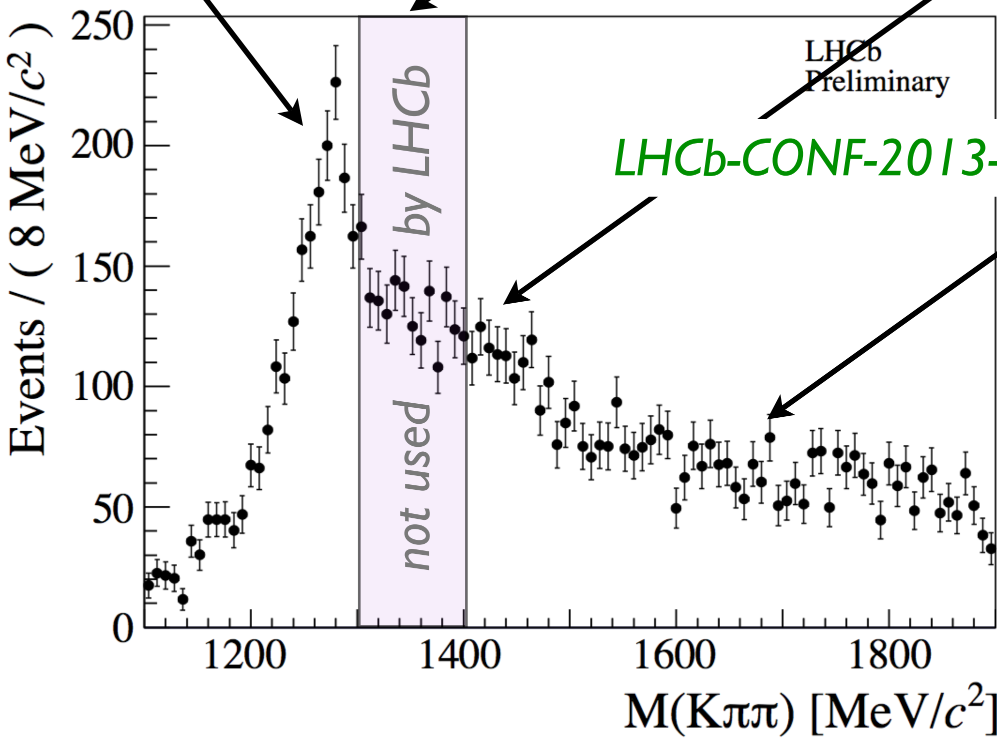
[1+] $K_1(1270)$

The suppression of [1+] $K_1(1400)$ confirmed

[2+] $K_2^*(1430)$???

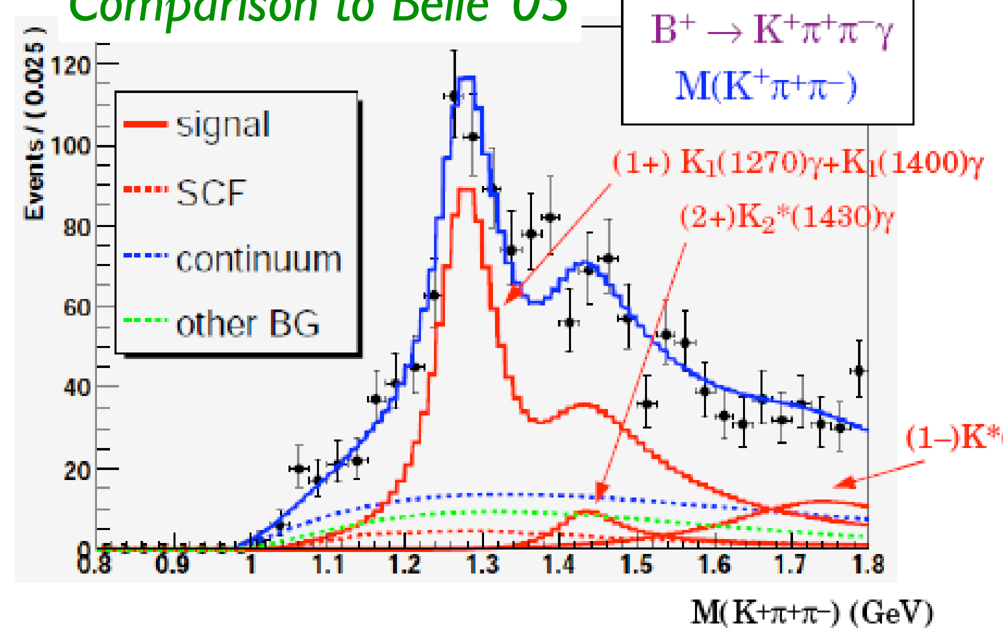
[1-] $K^*(1680)$???

No resonance study done by LHCb so far. But results look similar to the Belle result.



LHCb-CONF-2013-009

Comparison to Belle '05



A= -0.085±0.019(stat)±0.003(syst)

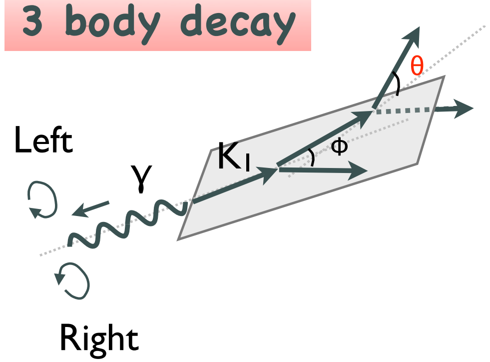
[1100-1300] & [1400-1600] added (?!)

Talk by S.Nishida at CKM2008

Interpreting Up-Down Asymmetry

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

3 body decay



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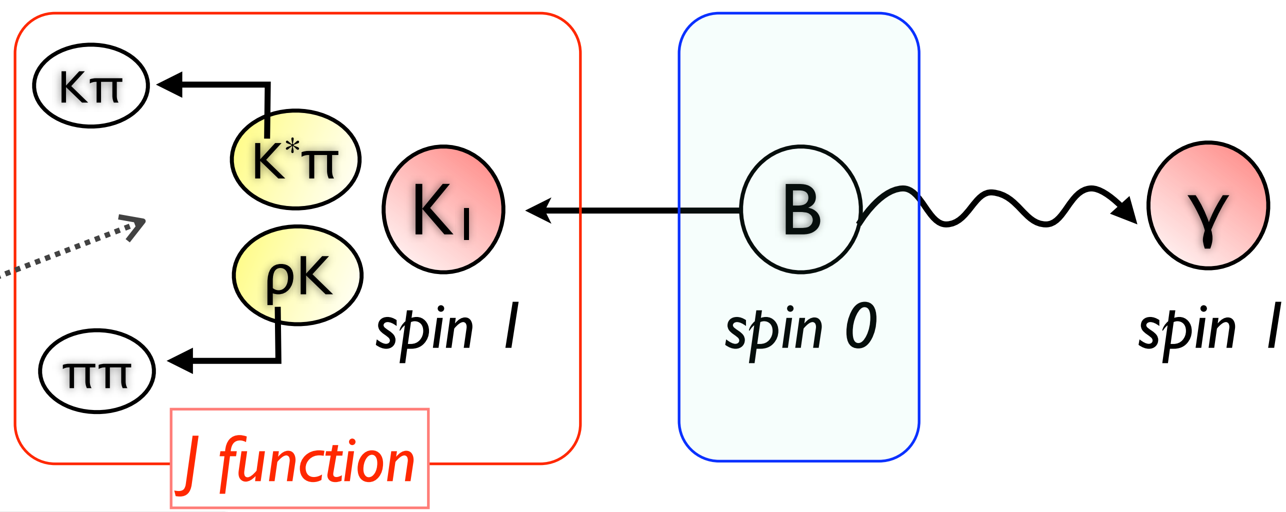
$$= \frac{3}{4} \frac{\langle Im(\hat{n}\cdot(\vec{J}\times\vec{J}^*))\rangle}{\langle|\vec{J}|^2\rangle} \frac{|c_R|^2 - |c_L|^2}{|c_R|^2 + |c_L|^2}$$

A= - 0.085
±0.019(stat)
±0.003(syst)

LHCb-CONF-2013-009

$\vec{J}$: Helicity amplitude of $K_1(1^+) \rightarrow K\pi\pi$

λ : Polarization parameter related to C7, C7' etc...



Source of imaginary part :
overlap of two Breite-Wigner

Daum et al, Nucl Phys, B187 ('81)
Thesis of S.Akar (Babar)

* *Most likely, K_1 can decays through $(K\pi)_S\pi$, too.*

Computing J function

Tayduganov, E.K. Le Yaouanc PRD85 ('12)

- Modeling J function (two resonance example):

Assume $K_1 \to K\pi\pi$ comes from quasi-two-body decay, e.g. $K_1 \to K^*\pi$, $K_1 \to \rho K$, then, J function can be written in terms of:

- 4 form factors (S,D partial wave amplitudes)
- 2 couplings ($g_{K^*K\pi}$, $g_{\rho\pi\pi}$)
- 1 relative phase between two channels

- Model parameters are extracted by fitting to data:

✓ $Br(K_{1(1270)} \to K^*\pi)/Br(K_{1(1270)} \to \rho K)=0.24\pm0.09$

✓ $Br(K_{1(1400)} \to \rho K)/Br(K_{1(1400)} \to K^*\pi)=0.01\pm0.01$

✓ $Br(K_{1(1400)} \to K^*\pi)_{D\text{-wave}}/Br(K_{1(1400)} \to K^*\pi)_{S\text{-wave}} =0.04\pm0.01$

✓ $Br(K_{1(1270)} \to K^*\pi)_{D\text{-wave}}/Br(K_{1(1270)} \to K^*\pi)_{S\text{-wave}} =2.67\pm0.95$

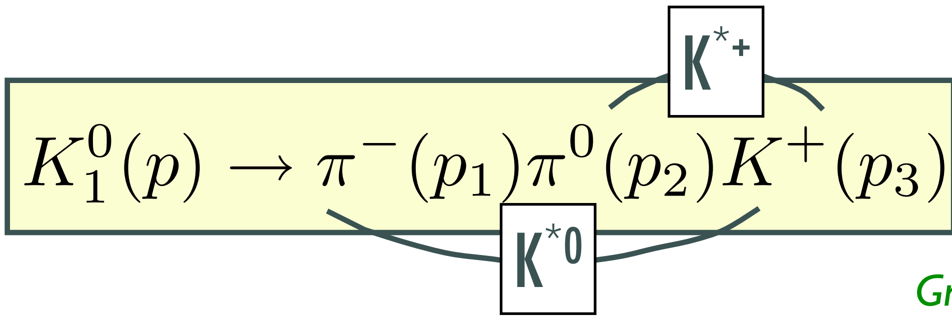
Brandenburg et al, Phys Rev Lett, 36 ('76)
Otter et al, Nucl Phys, B106 ('77)
Daum et al, Nucl Phys, B187 ('81)

Re-analysis is on-going at COMPASS (x10 more statistic)!!

Missing information (phase, amplitudes etc.) are complemented by the $^3P_0$ pair creation model

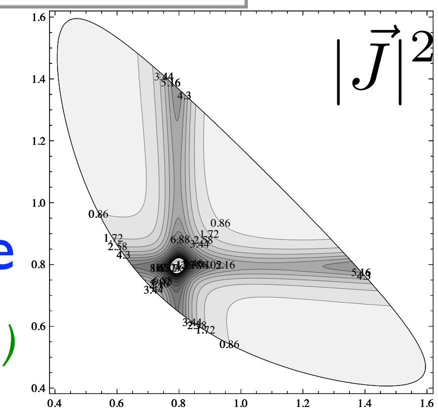
$B^0 \to K_1^0(1400)\gamma \to (K^+\pi^-\pi^0)\gamma$

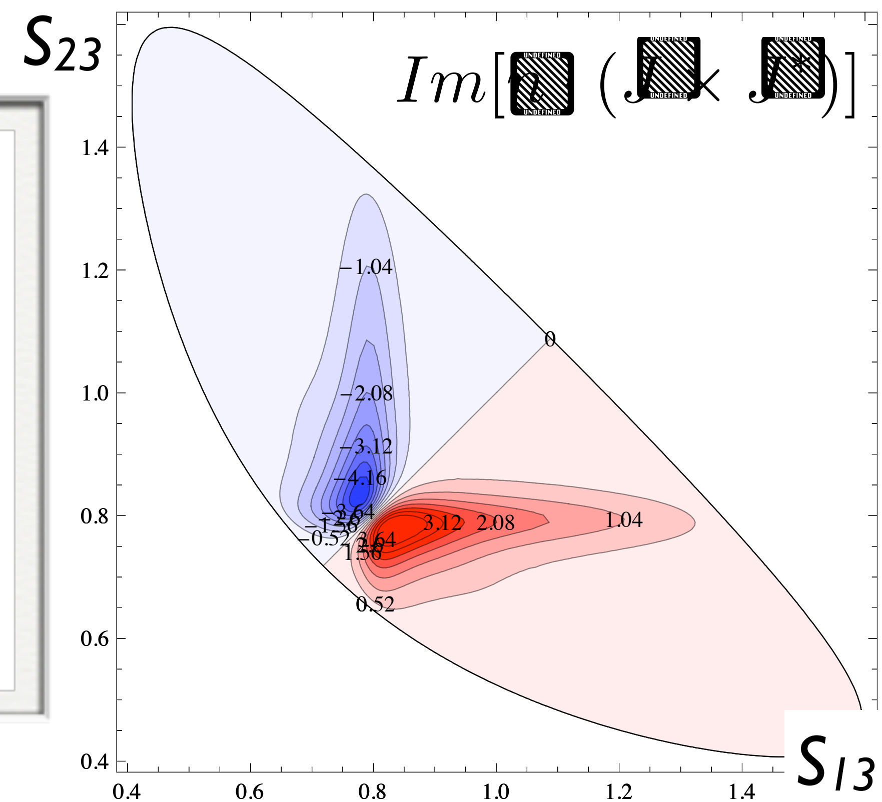
$$\frac{d\Gamma}{ds_{13}ds_{23}d\cos\theta} \propto \frac{1}{4}|\vec{J}|^2(1+\cos^2\theta) + \lambda\frac{1}{2}Im\left[\vec{n}\cdot(\vec{J}\times\vec{J}^*)\right]\cos\theta$$



- K* dominance
- K*+-K*0 interference

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





- A sign function sign(s_{13}-s_{23}) has to be introduced to avoid the cancelation of the asymmetry.
- After taking into account the sign function, we find : A~=(0.21~0.26) λ_γ
- However, the Belle has shown that the decay rate for this channel is quite suppressed (c.f. mixing angle).

$B^0 \to K_1^0(1400)\gamma \to (K^+\pi^-\pi^0)\gamma$

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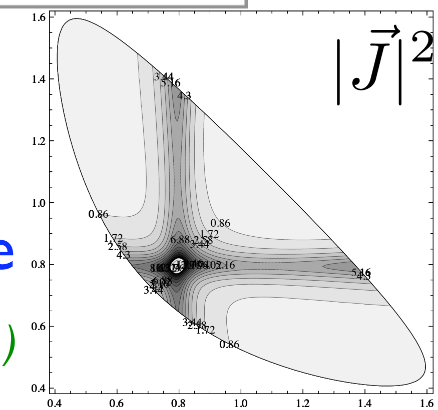
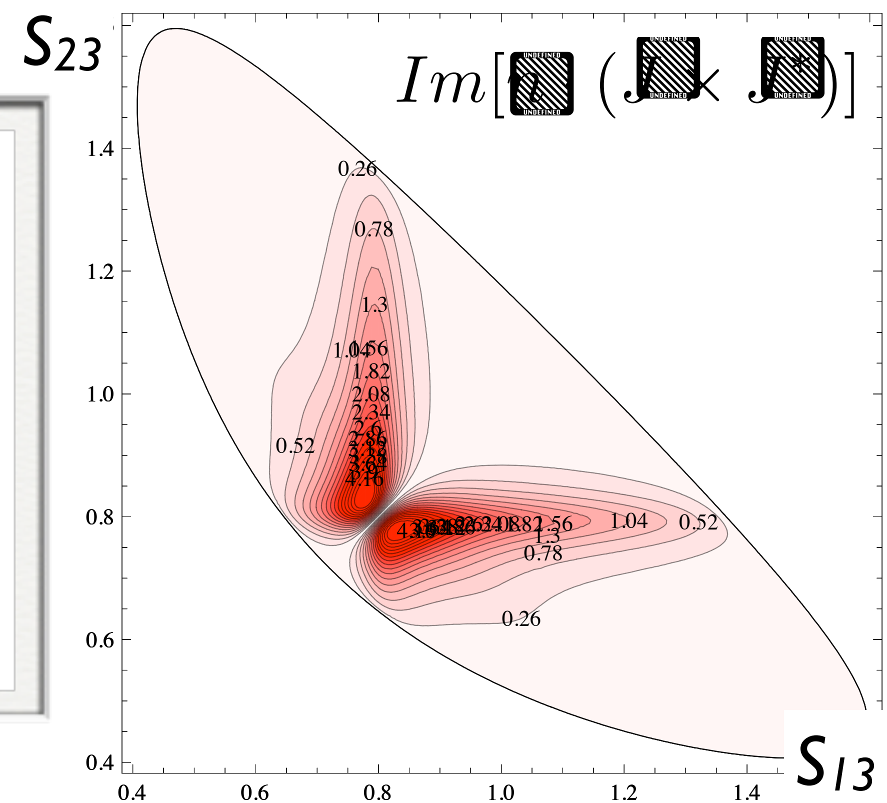
$$K_1^0(p) \to \pi^-(p_1)\pi^0(p_2)K^+(p_3)$$

K^{*+} ($\pi^0 K^+$), K^{*0} ($\pi^- K^+$)

- K^* dominance
- K^{*+}-K^{*0} interference

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





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$B^+ \to K_1^+(1270)\,\gamma \to (K^+\pi^-\pi^+)\gamma$

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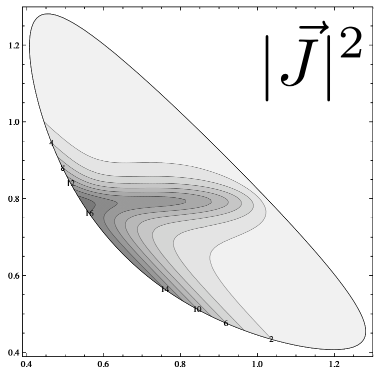
$$K_1^+(p) \to \pi^+(p_1)\pi^-(p_2)K^+(p_3)$$

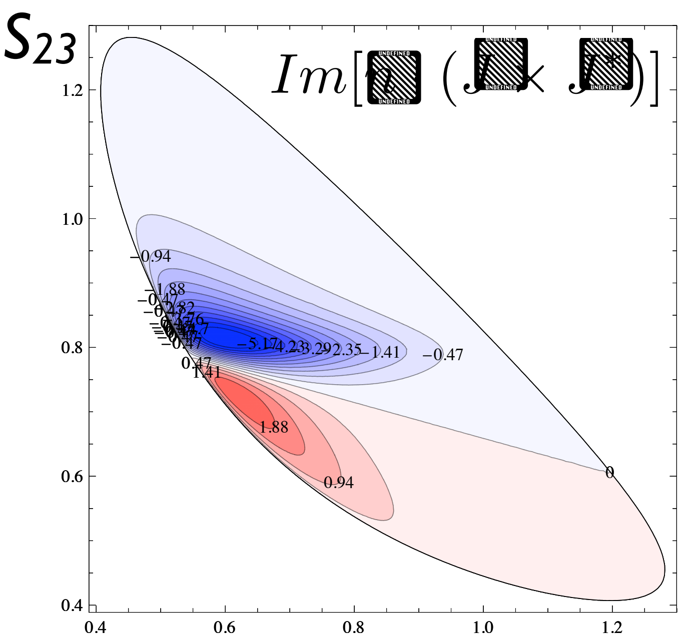
K^{*0}

ρ^0

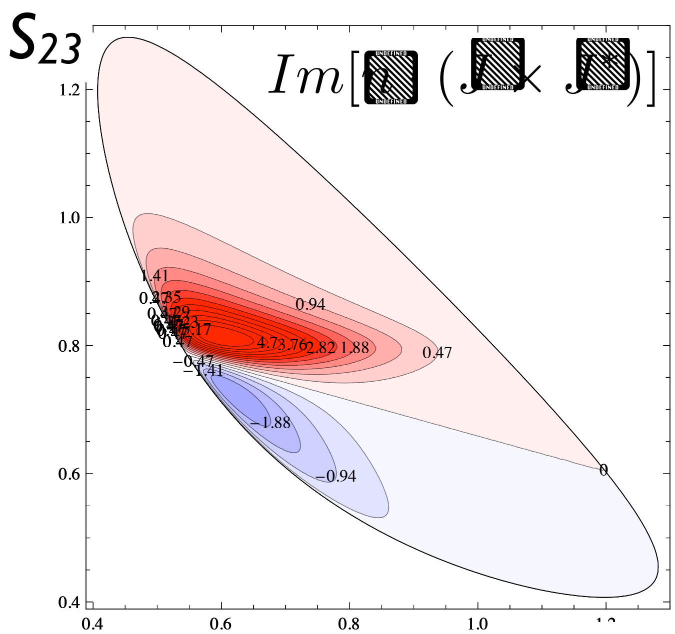
- ρ^0 dominance
- $\rho^0 K$-$K^*\pi$ interference



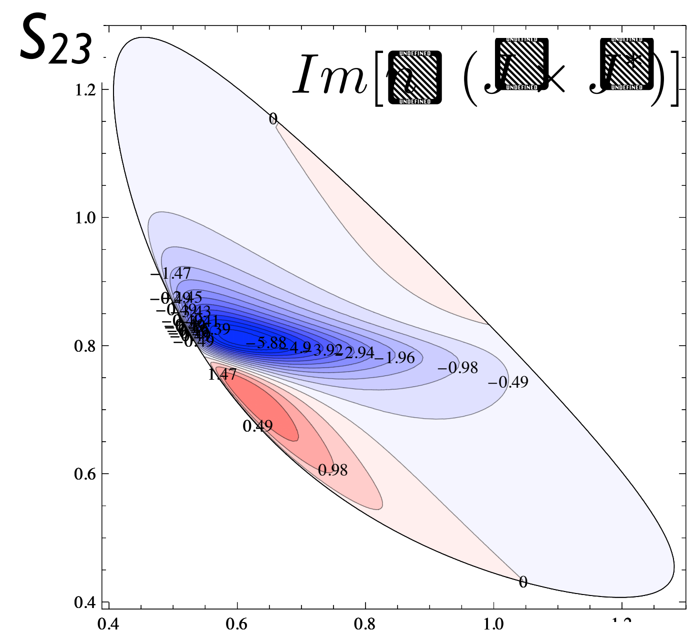
Tayduganov, E.K. Le Yaouanc PRD85 ('12)



$K^*\pi/\rho K$ with plus relative sign



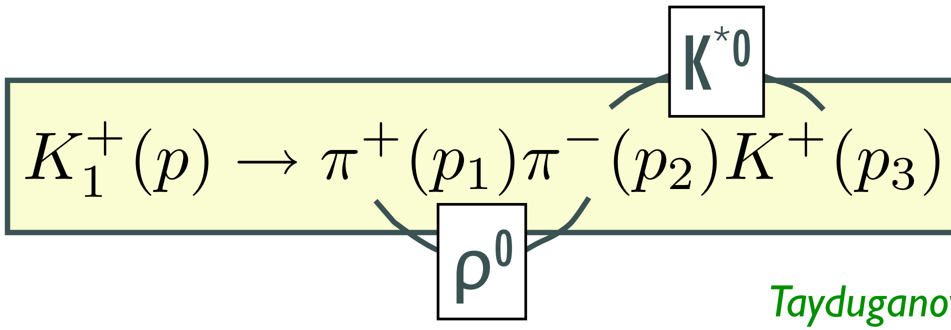
$K^*\pi/\rho K$ with minus relative sign



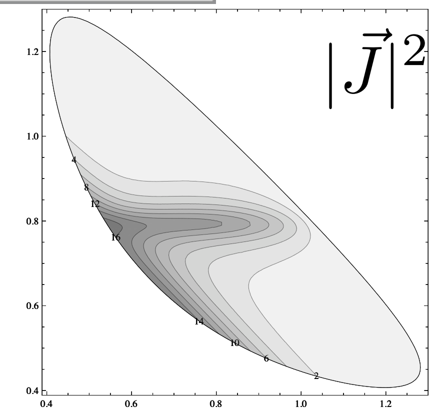
$K^*\pi/\rho K/(K\pi)_S\pi$ with sign predicted by our model

$B^+ \to K_1^+(1270)\gamma \to (K^+\pi^-\pi^+)\gamma$

$$\frac{d\Gamma}{ds_{13}ds_{23}d\cos\theta} \propto \frac{1}{4}|\vec{J}|^2(1+\cos^2\theta) + \lambda\frac{1}{2}Im\left[\vec{n}\cdot(\vec{J}\times\vec{J}^*)\right]\cos\theta$$



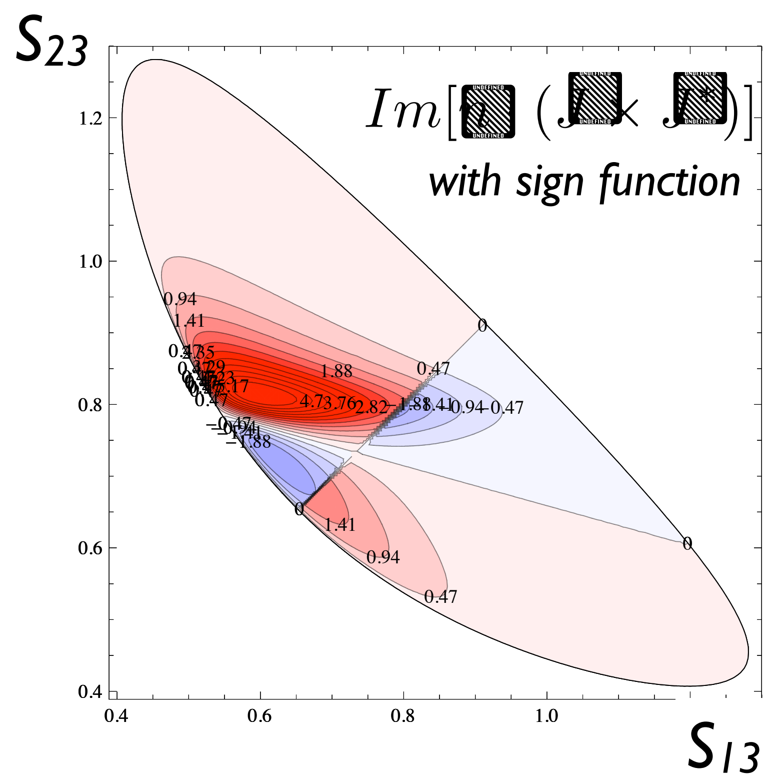
- ρ^0 dominance
- ρ^0-K^*0 interference



Tayduganov, E.K. Le Yaouanc PRD85 ('12)

- After taking into account the sign function (although it is, a priori, not necessary), we find : $A \sim= (0.07 \sim 0.12)\ \lambda_\gamma$
- Further verification of the phases between different channels and size of $(K\pi)_S\pi$ is important.
- Sensitivity can be improved up to a factor of two by knowing the Dalitz information.

Tayduganov, E.K. Le Yaouanc PRD83 ('11)



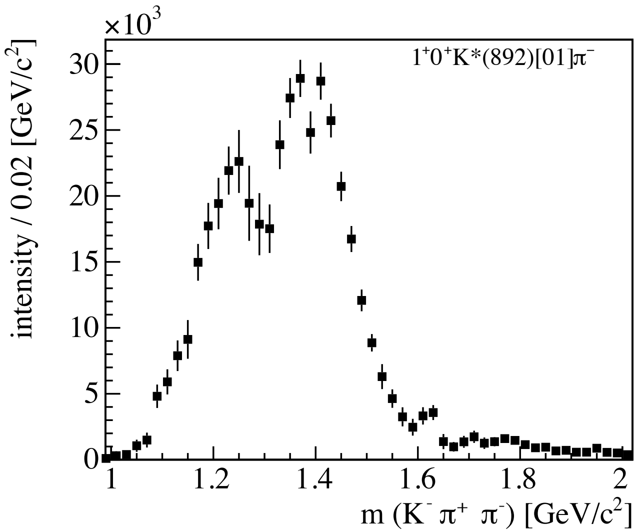
Conclusions

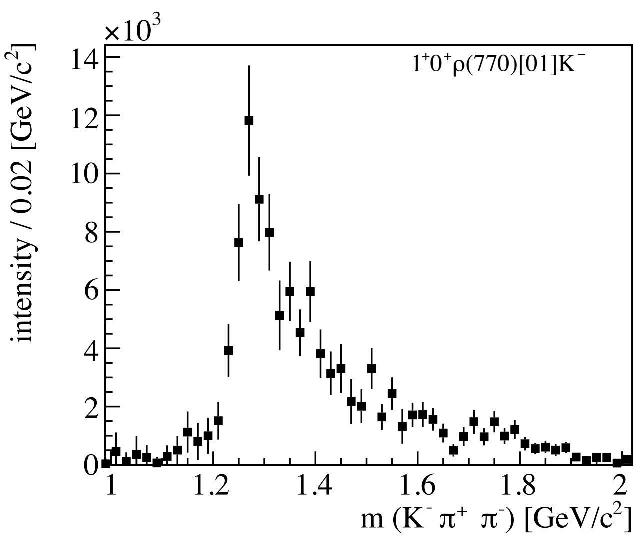
- The polarization of $b \to s\,\gamma$ has never been confirmed at a high precision yet ⇨ challenges for LHCb/Belle II !
- LHCb has shown the first result on the Up-Down Asymmetry in charged $B^{\pm} \to K\pi\pi\gamma$ channel.
- Interpretation of this result requires further resonance study as well as detailed information on the K-resonance decay.
- We have obtained the *J* function (for the case of $[1^{+}]K_1$) using ACMMOR data complemented by $^3P_0$ model. Our result can be improved further once the new COMPASS data is interpreted. A full angular analysis of $B^{\pm} \to K_1 J/\psi$ is very useful to obtain a more model independent result.
- Hope we can discuss further during the workshop!

Backup slides

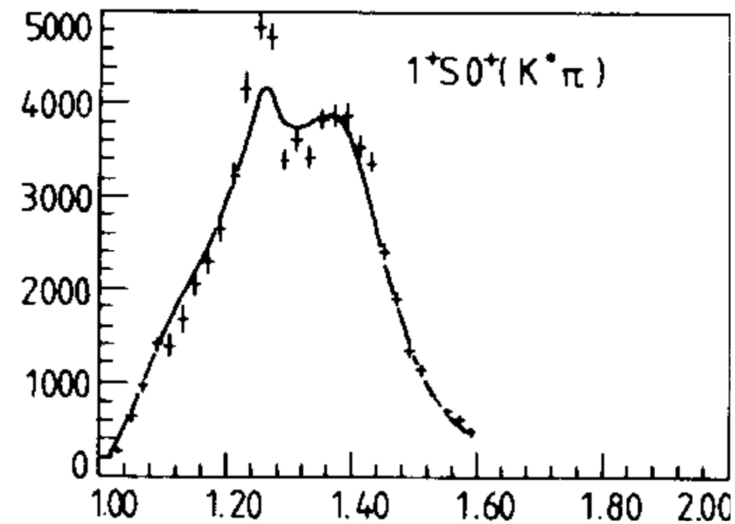
New COMPASS data!

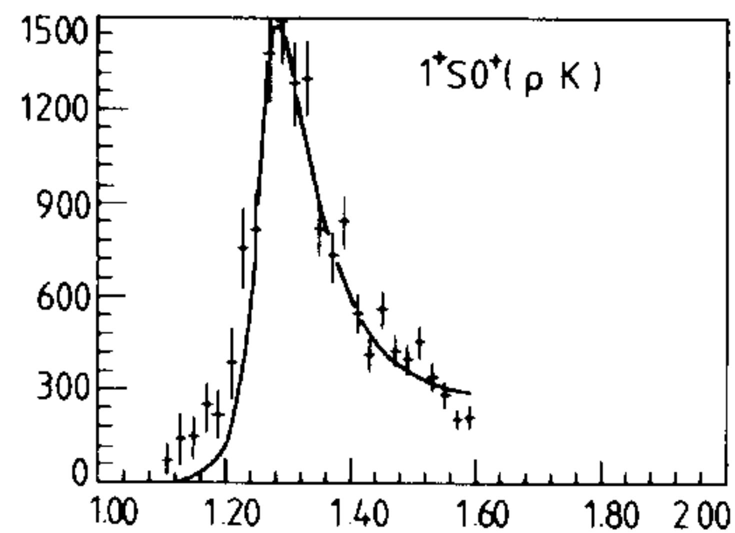
COMPASS '12





ACMMOR '81





Difference between $K_{1(1270)}$ & $K_{1(1400)}$

- In PDG:
  - $K_{1(1270)}$: $J^P=1^+$, M=1.27 MeV, $\Gamma=(90\pm20)$ MeV

$$Br(\rho K) : Br(K^{*0}\pi) : Br(K^{*0}(1430)\pi) = (42\pm6) : (16\pm5) : (28\pm4)\%$$

  - $K_{1(1400)}$: $J^P=1^+$, M=1.40 MeV, $\Gamma=(174\pm13)$ MeV

$$Br(K^{*0}\pi) : Br(\rho K) = (94\pm6) : (3\pm3)\%$$