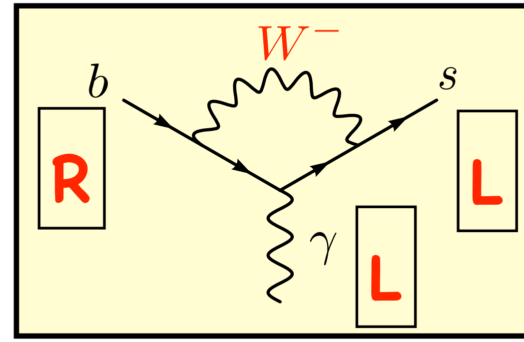
Photon polarisation determination via B→Kππγ decays

Emi Kou
(LAL-IN2P3)

CKM 2018
@ Heidelberg, 17-21 September 2018

Photon polarisation of $b \to s\gamma$

Photon polarization of b→sγ process



- The photon polarization of b →sγ process has an unique sensitivity to BSM with right-handed couplings.
- However, the photon polarization has never been measured at a hight precision so far: an important challenge for future experiments such as LHCb and Belle II.

In SM

W-boson couples only left-handed ⟺ γ of b →s γ should be circularly-polarized

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

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

Current status on the constraint on the right-handed contribution

We can write the amplitude including RH contribution as:

$$\mathcal{M}(b\to s\gamma) \simeq -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \left[\underbrace{(C_{7\gamma}^{\rm SM} + C_{7\gamma}^{\rm NP})\langle \mathcal{O}_{7\gamma}\rangle}_{\propto \mathcal{M}_L} + \underbrace{C_{7\gamma}^{\prime\rm NP}\langle \mathcal{O}_{7\gamma}^{\prime}\rangle}_{\propto \mathcal{M}_R} \right]$$

We have a constraint from inclusive branching ratio measurement:

$$Br(B\to X_S\gamma) \propto |C_{7\gamma}^{\rm SM} + C_{7\gamma}^{\rm NP}|^2 + |C_{7\gamma}^{\prime\rm NP}|^2$$

While the polarization measurement carries information on

$$\frac{\mathcal{M}_R}{\mathcal{M}_L} \simeq \frac{C_{7\gamma}^{\prime\rm NP}}{C_{7\gamma}^{\rm SM} + C_{7\gamma}^{\rm NP}}$$

Note: new physics contributions, $C_{7\gamma}^{NP}$ and/or $C'^{NP}_{7\gamma}$ can be complex numbers!

Other scenarios, see

A. Tayduganov et al. JHEP 1208

How do we measure the polarization?!

see also talks by Gershon, Sanchez Mayordomo

- **Time dependent CP asymmetry**
  - ✓ $B_d \to K_S \pi^0 \gamma$, $B_d \to \rho\gamma$ (Belle II) <—Golden channel of Belle II
  - ✓ $B_d \to K_S \pi^+ \pi^- \gamma$ (Belle II)
  - ✓ $B_d \to K_S \phi \gamma$, $K_S \eta \gamma$
  - ✓ $B_s \to K^+ K^- \gamma$ (LHCb)
- **Angular distribution (require more than 4 body final state)**
  - ✓ Transverse asymmetry in $B_d \to K^* l^+ l^-$ (called $A_T^{(2)}$, $A_T^{(im)}$) (LHCb)
  - ✓ $B \to K_{res}(\to K\pi\pi)\gamma$ (called λ_γ) (Belle II/LHCB)
  - ✓ $\Lambda_b \to \Lambda^{(*)}\gamma$ (LHCb)

see also talk by de Boer

For recent theoretical works, see
S. de Boer & G. Hiller, Eur.Phys.J. C78 (2018)
J. Gratrex, R. Zwicky arXiv:1807.01643

Why?

- ✍ The BR is large ($Br(K_1(1270)\gamma) = Br(K^*\gamma)$)
- ✍ $K_1 \to K\pi\pi$ system is not easy but solvable!

How do we measure the polarization?!

see also talks by C... ...domo

- Time dependent CP asymmetry
  - ✓ $B_d \to K_S \pi^0 \gamma$, $B_d \to \rho\gamma$ (Belle II) <—Golden ch...
  - ✓ $B_d \to K_S \pi^+ \pi^- \gamma$ (Belle II)
  - ✓ $B_d \to K_S \phi \gamma$, $K_S \eta \gamma$
  - ✓ $B_s \to K^+ K^- \gamma$ (LHCb)
- Angular distribution (require more than 4 body...
  - ✓ Transverse asymmetry in $B_d \to K^* l^+ l^-$ (called A...
  - ✓ $B \to K_{res} (\to K\pi\pi)\gamma$ (called λ_γ) (Belle II/LHCB)
  - ✓ $\Lambda_b \to \Lambda^{(*)} \gamma$ (LHCb)

Later, I'll show $B_d \to K_S \pi^+ \pi^- \gamma$ can provide two independent information.

Tremendous efforts on-going to disentangle different intermediate resonances !!

Why?

✍ The BR is large ($Br(K_1(1270)\gamma) = Br(K^*\gamma)$)

✍ $K_1 \to K\pi\pi$ system is not easy but solvable!

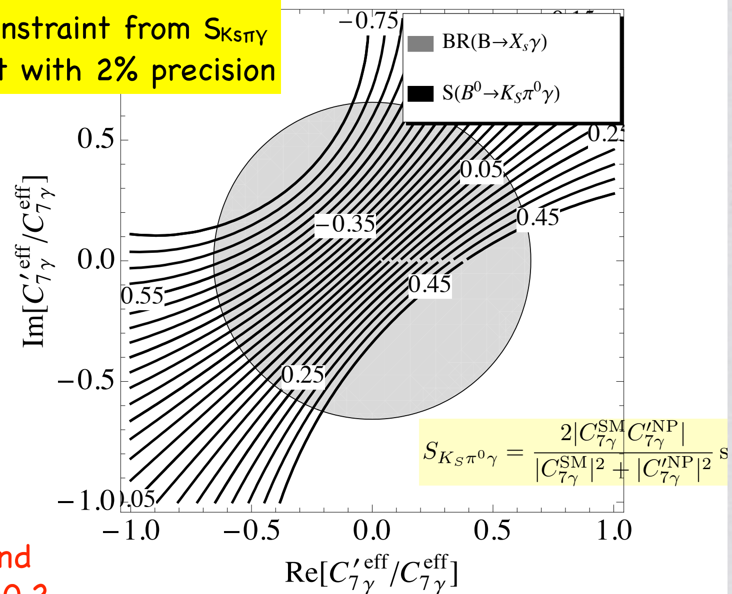
see also talk by de Boer

For recent theoretical works, see
S. de Boer & G. Hiller, Eur.Phys.J. C78 (2018)
J. Gratrex, R. Zwicky arXiv:1807.01643

Prospect...

Method I

Expected constraint from $S_{K_S\pi\gamma}$ measurement with 2% precision



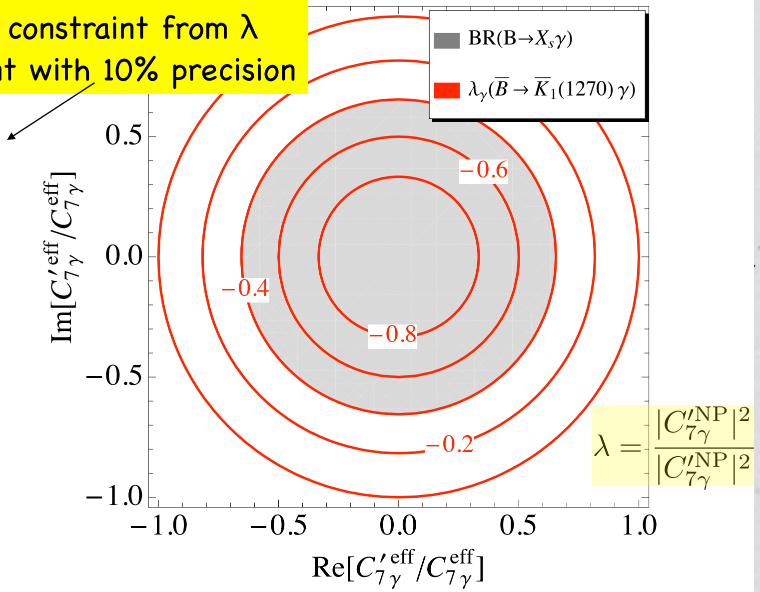
Current bound

$S_{K_S\pi^0\gamma}$ = -0.15±0.2

Method III

Expected constraint from λ measurement with 10% precision

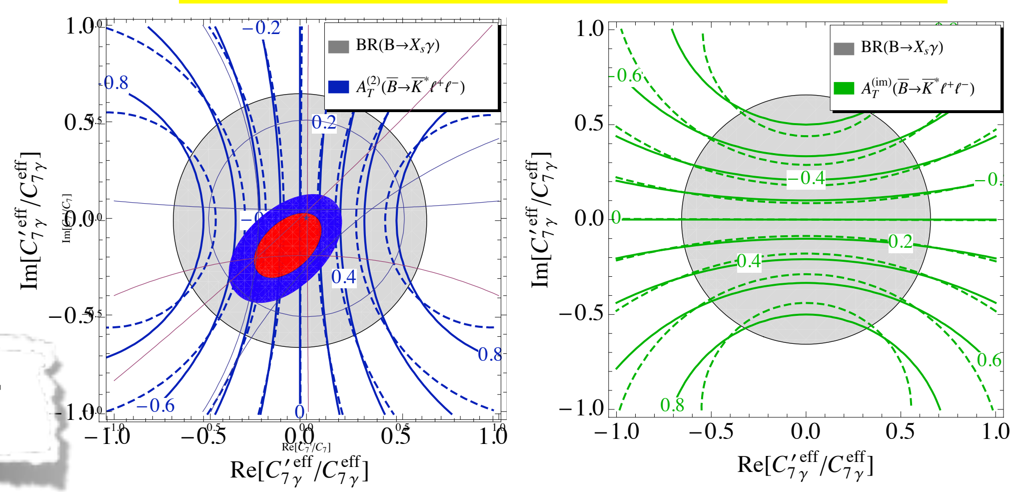
3%



more in the talk by Sanchez Mayordomo

Method II

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



LHCb measurement JHEP '15

It turned out that Method I with $B_s\to K^+K^-\gamma$ gives similar constraints.

$C'^{NP}_{7\gamma}\neq 0$, $C^{NP}_{7\gamma}=0$

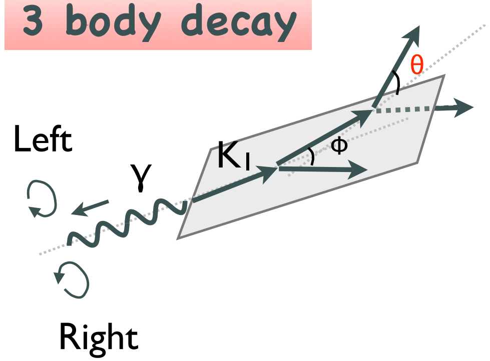
Becirevic, EK, Le Yaouanc, Tayduganov JHEP 1208

Angular analysis of $B \rightarrow K_{res}\gamma \rightarrow (K\pi\pi)\gamma$

Angular distribution method

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

3 body decay



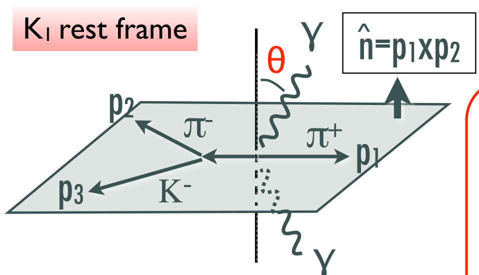
$$\mathcal{A} = \frac{\int_0^1 \cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 \cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 \cos\theta \frac{d\Gamma}{d\cos\theta}}$$

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

A= - 0.085
±0.019(stat)
±0.003(syst)

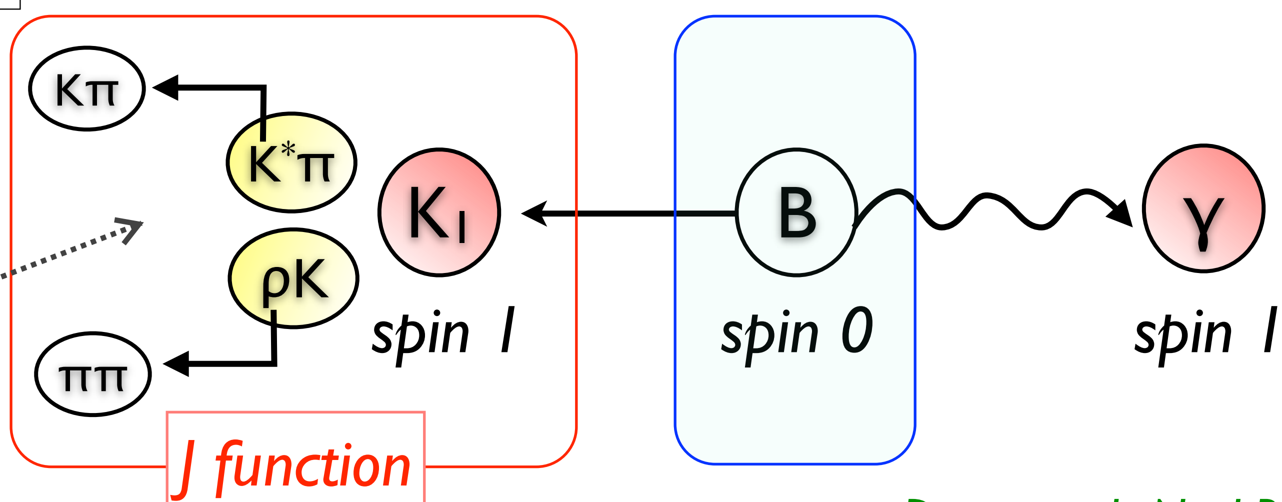
LHCb - PRL 112 (2014)

K_1 rest frame



$\vec{J}$: Helicity amplitude of $K_1(1^+)$➔Kππ

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



Source of imaginary part : overlap of two Breite-Wigner

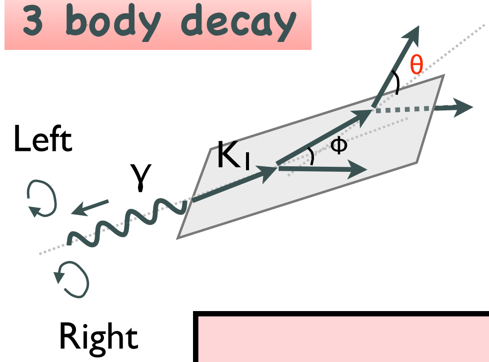
Daum et al, Nucl Phys, B187 ('81)
Thesis of S.Akar (Babar)

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

Angular distribution method

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

3 body decay



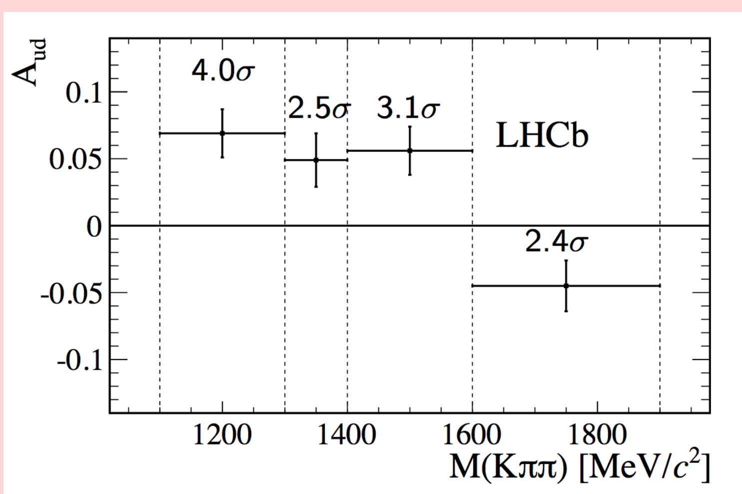
$$\mathcal{A} = \frac{\int_0^1 \cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 \cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 \cos\theta \frac{d\Gamma}{d\cos\theta}}$$

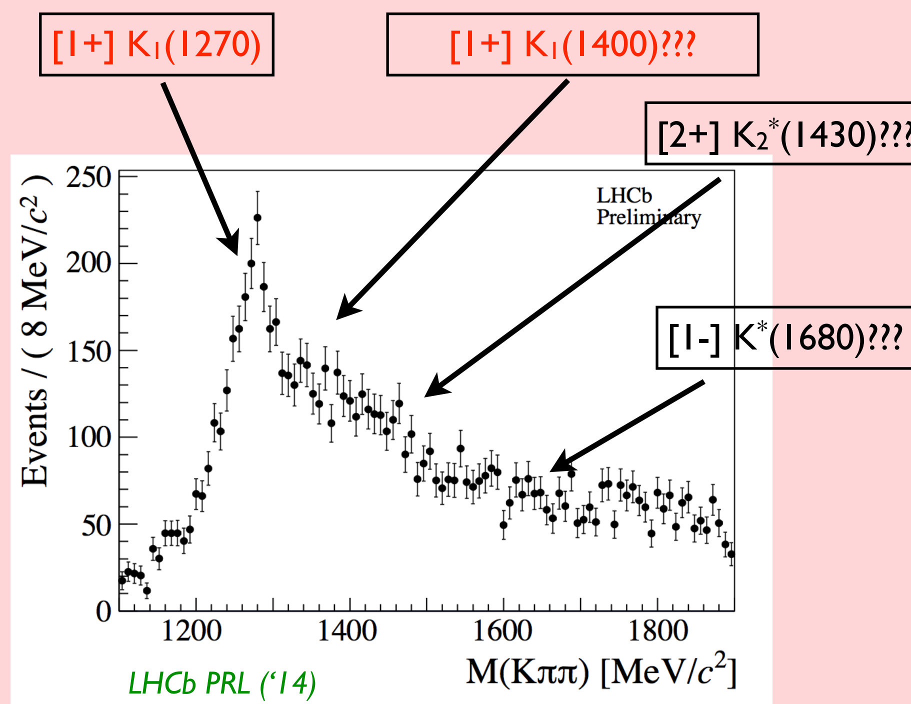
$$= \frac{3}{4} \frac{\langle Im(\hat{n}\cdot(\vec{J}\times\vec{J}^*))\rangle}{\langle|\vec{J}|^2\rangle} \frac{|c_R|^2 - |c_L|^2}{|c_R|^2 + |c_L|^2}$$

A= - 0.085
±0.019(stat)
±0.003(syst)

LHCb - PRL 112 (2014)

We need J function to interpret the LHCb result.





LHCb PRL ('14)

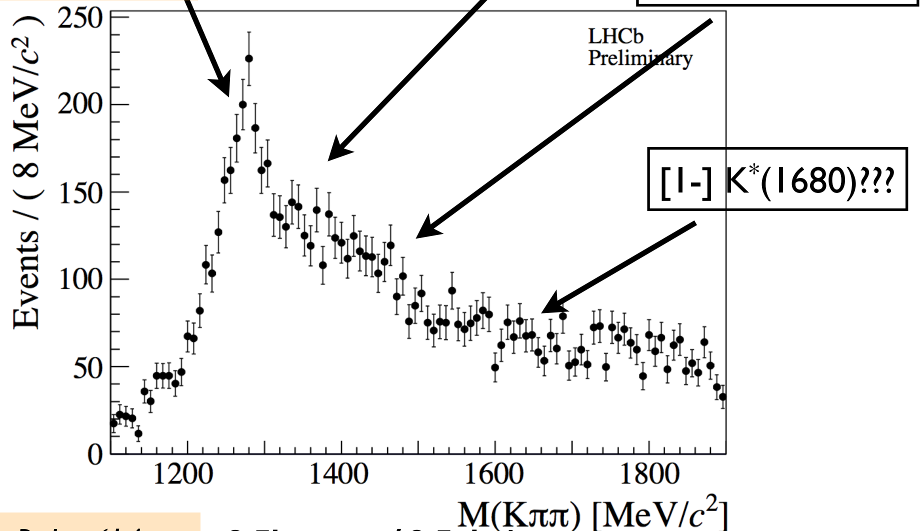
Sourc
overlap

1)

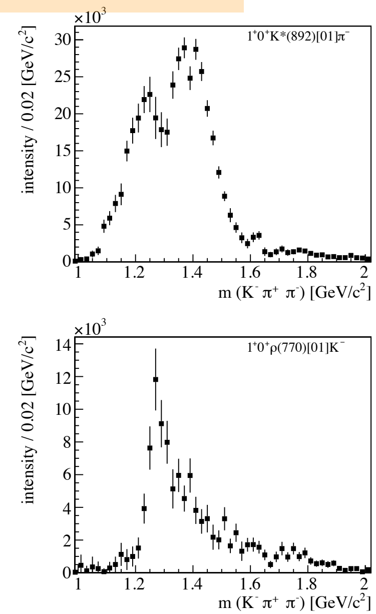
, too.

Disentangling resonances

LHCb '14 **14k event / 3fb-1**

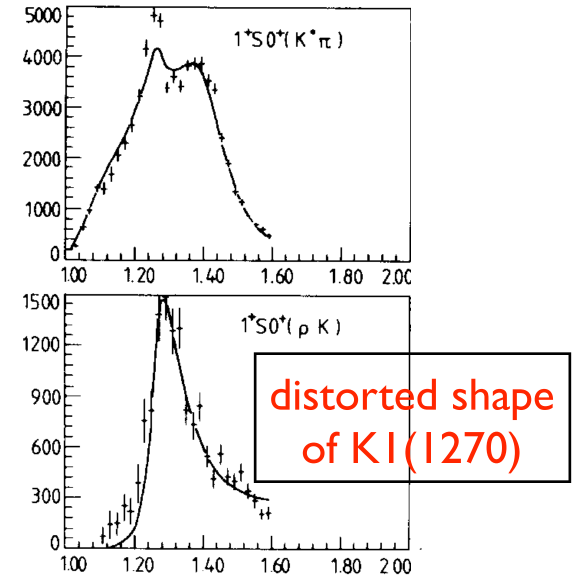


COMPASS '12 **270k event**

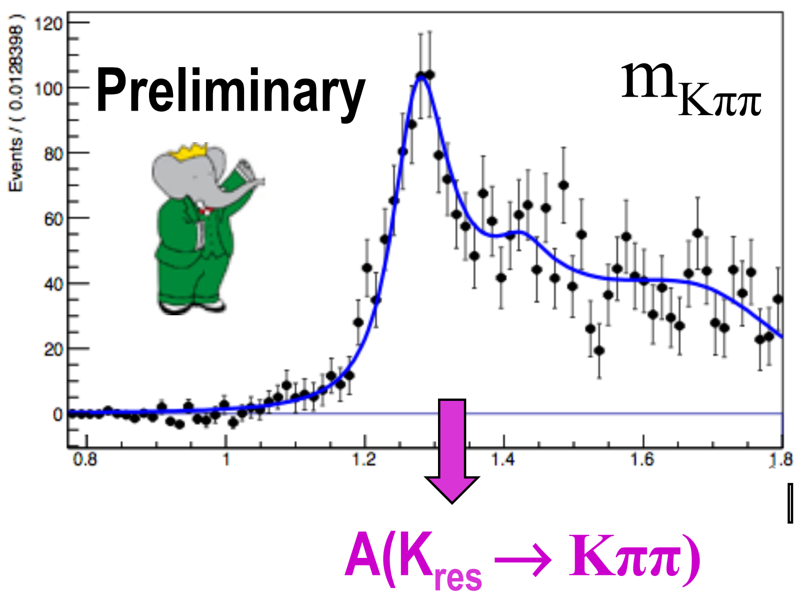


thesis P-K. Jasinski

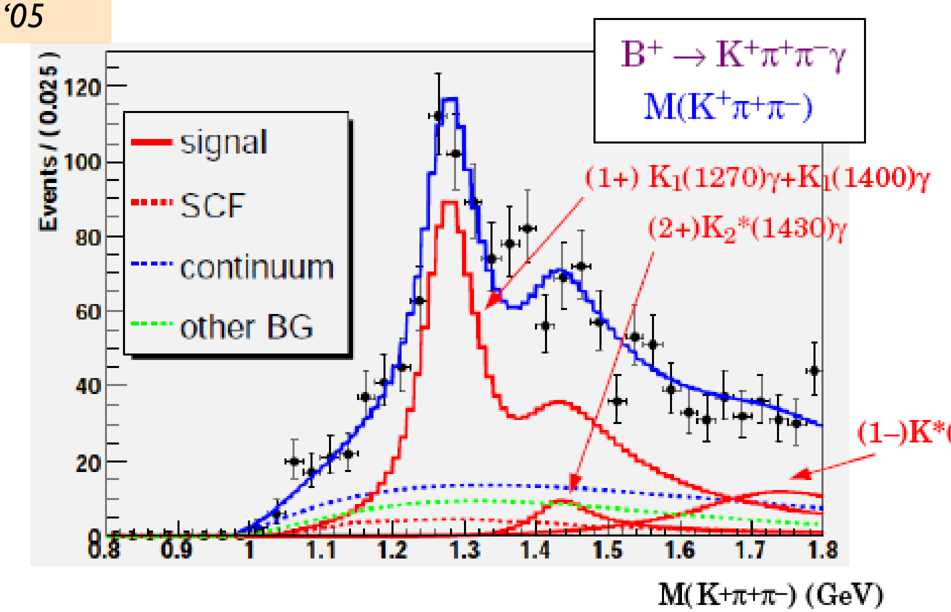
ACMMOR '81



Babar '14 **2.5k event / 0.5ab-1**



Belle '05



Generator for K_{res}→Kππ decays…

see also M. Gronau, D. Pirjol, Phys.Rev. D96 (2017)

1. $K1_{1270}$(1+) & $K1_{1400}$(1+) decays based on quark model

A.Tayduganov, EK, Le Yaouanc PRD '13

Assume K_1→Kππ comes from quasi-two-body decay, e.g. K_1→K*π, K_1→ρK, then, J function can be written in terms of:

- 4 form factors (S,D partial wave amplitudes)

2. $K^*_{1410,\ 1680}$(1-) and $K2_{1430}$ (2+)

A. Kotenko, B. Knysh talk at Lausanne WS '17

Lesser parameters

- Known to decay mainly K_{res}→K*π, ρK
- Only 1 form factor for each resonance

On total 10 complex couplings needed (20 real number)!

Generator for K_{res}→Kππ decays...

see also M. Gronau, D. Pirjol, Phys.Rev. D96 (2017)

1. $K1_{1270}$(1+) & $K1_{1400}$(1+) decays based on quark model

A.Tayduganov, EK, Le Yaouanc PRD '13

Assume K_1→Kππ comes from quasi-two-body decay, e.g. K_1→K*π, K_1→ρK, then, J function can be written in terms of:

- 4 form factors (S,D partial wave amplitudes)

2. $K^*_{1410,\ 1680}$(1-) and $K2_{1430}$ (2+)

A. Kotenko, B. Knysh talk at Lausanne WS '17

Lesser parameters

- Known to deca
- Only 1 form f

Another implementation on-going with MINT II program

V. Belle, P. Pais talk at Lausanne WS '17

On total 10 complex couplings needed (20 real number)!

Generator for K_{res}→Kππ decays…

see also M. Gronau, D. Pirjol, Phys.Rev. D96 (2017)

1. $K1_{1270}(1+)$ & $K1_{1400}(1+)$ decays based on quark model

A.Tayduganov, EK, Le Yaouanc PRD '13

Assume K_1→K … body
deca… n be
w…

Full angular and Dalitz variable fits are essential for successful resonance study!

2. K^*_{1410}, 16…

…sanne WS '17

Lesser para…

- Known to decay mainly K_{res}→K*π, ρK
- Only 1 form factor for each resonance

On total 10 complex couplings needed (20 real number)!

CKM2020

Full angular/Dalitz analysis!

STAY TUNED!

$$\mathcal{W}^{K_1}(s,s_{13},s_{23},\theta,\phi) = -A_1^{K_1}(1+\cos^2\theta)+\lambda_\gamma B^{K_1}\cos\theta + \left(A_2^{K_1}\cos 2\phi + A_3^{K_1}\sin 2\phi\right)\sin^2\theta$$

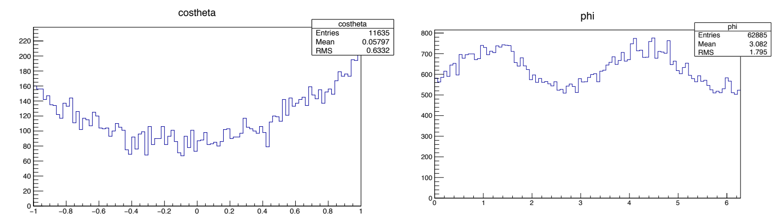
$$\mathcal{W}^{K^*}(s,s_{13},s_{23},\theta,\phi) = A^{K^*}\sin^2\theta$$

$$\mathcal{W}^{K_2}(s,s_{13},s_{23},\theta,\phi) = A^{K_2}+\lambda_\gamma B^{K_2}\cos\theta + C_1^{K_2}\sin^2\theta + D_1^{K_2}\sin^4\theta + \lambda_\gamma E^{K_2}\sin^2\theta\cos\theta + \left(C_2^{K_2}\sin^2\theta + D_2^{K_2}\sin^4\theta\right)\cos 2\phi$$

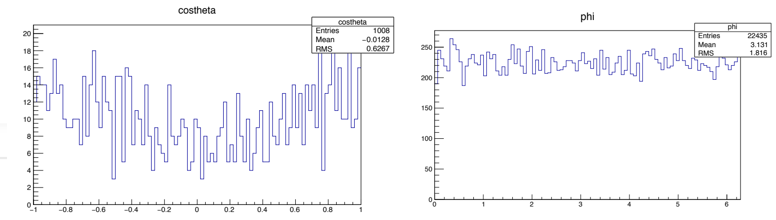
$$\mathcal{W}^{K_1K^*}(s,s_{13},s_{23},\theta,\phi) = A^{K_1K^*}+\lambda_\gamma E^{K_1K^*}\cos\theta + D_1^{K_1K^*}\sin^2\theta + \left(B_1^{K_1K^*}\sin\phi + B_2^{K_1K^*}\cos\phi\right)\sin\theta + \lambda_\gamma\left(C_1^{K_1K^*}\sin\phi + C_2^{K_1K^*}\cos\phi\right)\sin\theta\cos\theta + \left(D_2^{K_1K^*}\cos 2\phi + D_3^{K_1K^*}\sin 2\phi\right)\sin^2\theta$$

$$\mathcal{W}^{K_1K_2}(s,s_{13},s_{23},\theta,\phi) = A_1^{K_1K_2}+\lambda_\gamma A_2^{K_1K_2}\cos\theta + B_1^{K_1K_2}\sin^2\theta + \lambda_\gamma C_1^{K_1K_2}\sin^2\theta\cos\theta + D_1^{K_1K_2}\sin^4\theta + \left(B_2^{K_1K_2}\cos 2\phi + B_3^{K_1K_2}\sin 2\phi\right)\sin^2\theta + \lambda_\gamma\left(C_2^{K_1K_2}\sin\phi + \dots\right) + D_2^{K_1K_2}\cos 2\phi\sin^4\dots$$

$$\mathcal{W}^{K_2K^*}(s_{13},s_{23},\theta,\phi) = A_1^{K_2K^*}+\lambda_\gamma A_2^{K_2K^*}\cos\theta + B_1^{K_2K^*}\sin^2\theta + C_1^{K_2K^*}\sin^4\theta + \lambda_\gamma D^{K_2K^*}\sin^2\theta\cos\theta + \left(B_2^{K_2K^*}\sin^2\theta + C_2^{K_2K^*}\sin^4\theta\right)\cos 2\phi + \lambda_\gamma\left(E_1^{K_2K^*}\sin\phi + E_2^{K_2K^*}\cos\phi\right)\sin\theta\cos\theta + \left(F_1^{K_2K^*}\sin\phi + F_2^{K_2K^*}\cos\phi\right)\cos 2\theta\sin\theta$$

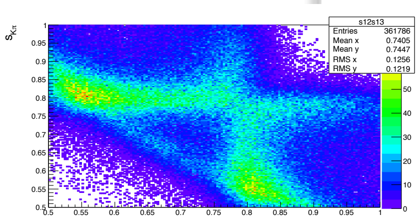


$1.3<\sqrt{s}<1.4$ $K_1^{1270}: A_1\cdot sin(2\phi)+B_1\cdot cos(2\phi)$

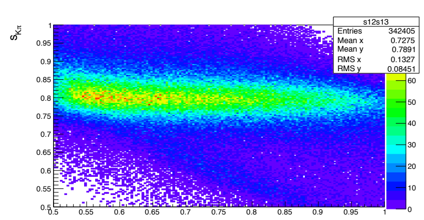


$1.6<\sqrt{s}<1.9$ $K^{*1410}: A_3$

Kotenko, B. Knysh talk at Lausanne WS '17 Multivariable fit by "Gampola" B. Knish



$K^0\pi^+\pi^0$ and $K^+\pi^-\pi^0$

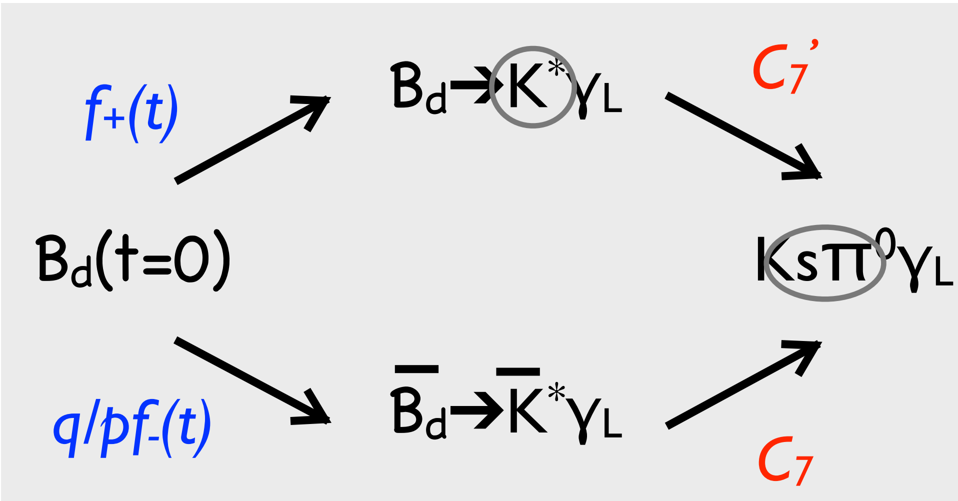


$K^+\pi^+\pi^-$ and $K^0\pi^-\pi^+$

The functions, $A_i^{K_res}$, $B_i^{K_res}$, $C_i^{K_res}\cdots$, are the functions of the Dalitz variables

Time dependent analysis of $B \rightarrow K_{res}\gamma \rightarrow (K\pi\pi)\gamma$

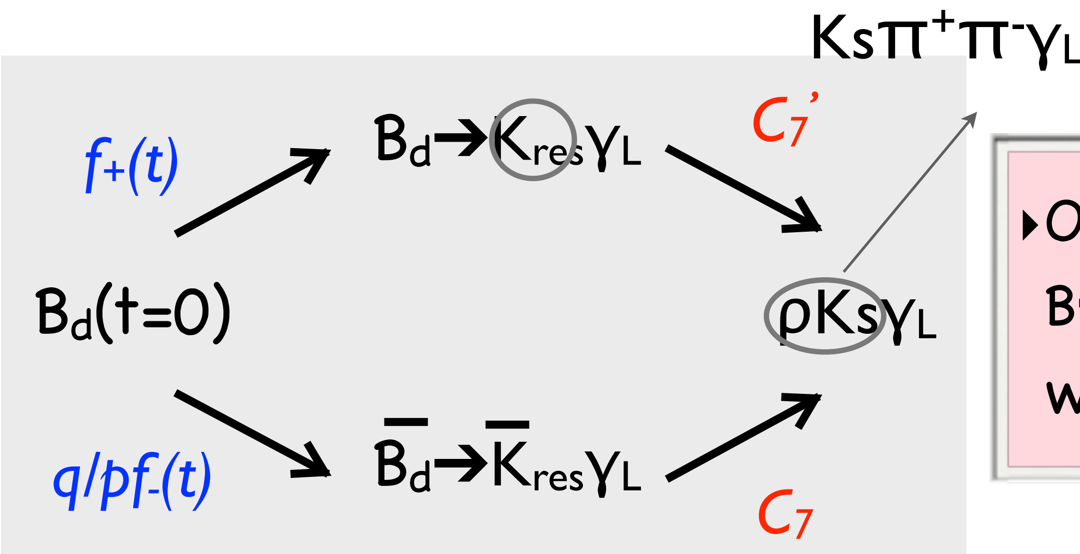
Time dependent CPV method



Atwood, Gronau, Soni, PRL 79 (1997)
Atwood, Gershon, Hazumi, Soni, PRD71 (2005)

- In SM C_7' is negligibly small, so the interference does not occur (no CPV).
- Thus, observation of CPV is a signal beyond the SM.

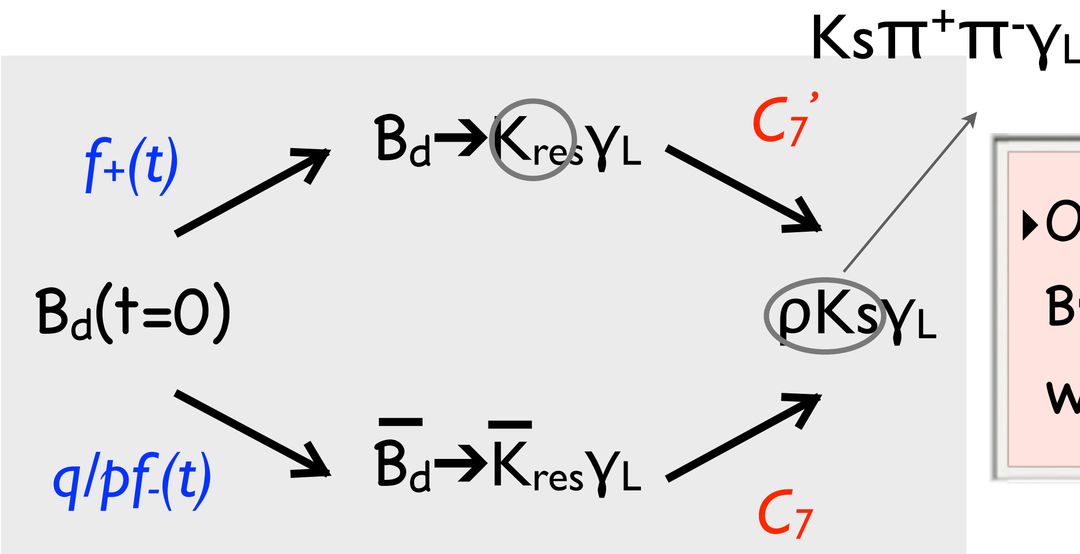
Time dependent CPV method



Atwood, Gronau, Soni, PRL 79 (1997)
Atwood, Gershon, Hazumi, Soni, PRD71 (2005)

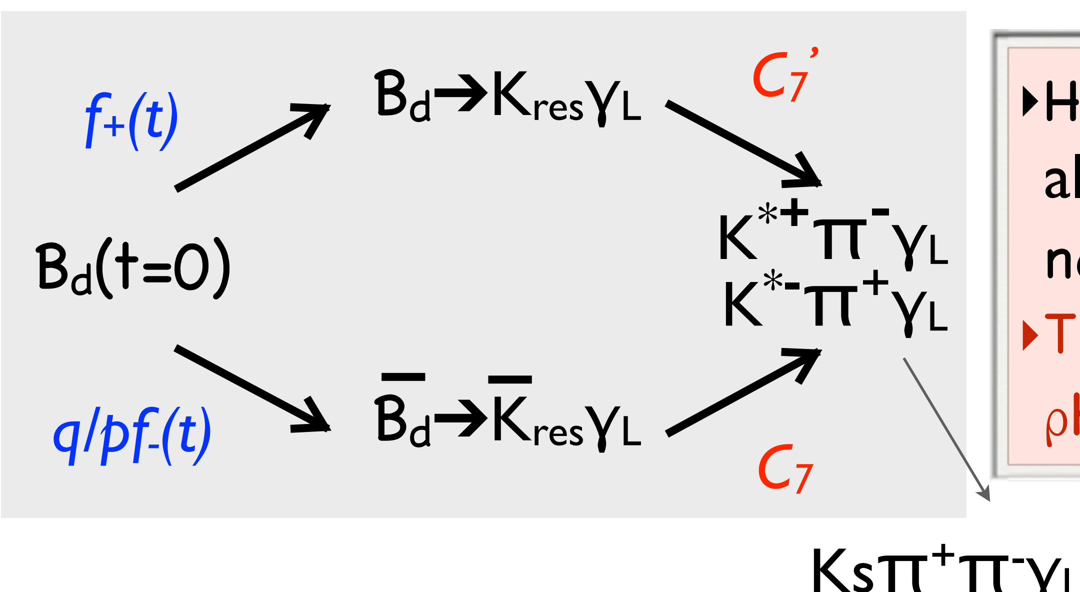
- One can do the same study using $B \to \rho K_S \gamma_L$ channel (CP eigenstate) with final state $K_S \pi^+ \pi^- \gamma_L$.

Time dependent CPV method



Atwood, Gronau, Soni, PRL 79 (1997)
Atwood, Gershon, Hazumi, Soni, PRD71 (2005)

- One can do the same study using $B \to \rho K_S \gamma_L$ channel (CP eigenstate) with final state $K_S\pi^+\pi^-\gamma_L$.



- However, $K_S\pi^+\pi^-\gamma_L$ final state can also come from $K^*\pi$ channel, which is not CP eigenstate.
- This can "dilute" the CP violation from $\rho K_S \gamma_L$ channel.

Time dependent CPV formula

Time dependent CPV (measurable)

$$S_{K_S\pi^+\pi^-} = \frac{2Im\left[\frac{q}{p}\left(\frac{c}{c'^*}\right)\right]}{(1+|\frac{c}{c'}|^2)}$$

Photon polarization

$$\times \frac{\sum_{\lambda=L,R}\left\{-|A_\lambda^{\rho K_S}|^2 + \mathrm{Re}\left[A_\lambda^{*K^{*-}\pi^+} A_\lambda^{K^{*+}\pi^-}\right] + \mathrm{Re}\left[A_\lambda^{*\kappa^-\pi^+} A_\lambda^{\kappa^+\pi^-}\right] - 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{K^{*+}\pi^-}] - 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{\kappa^+\pi^-}]\right\}}{\sum_{\lambda=L,R}\left\{|A_\lambda^{\rho K_S}|^2 + |A_\lambda^{*K^{*+}\pi^-}|^2 + |A_\lambda^{*\kappa^+\pi^-}|^2 + 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{K^{*+}\pi^-}] + 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{\kappa^+\pi^-}]\right\}}$$

=D dilution factor

Dilution factor to be extracted from the resonance study (angular analysis)

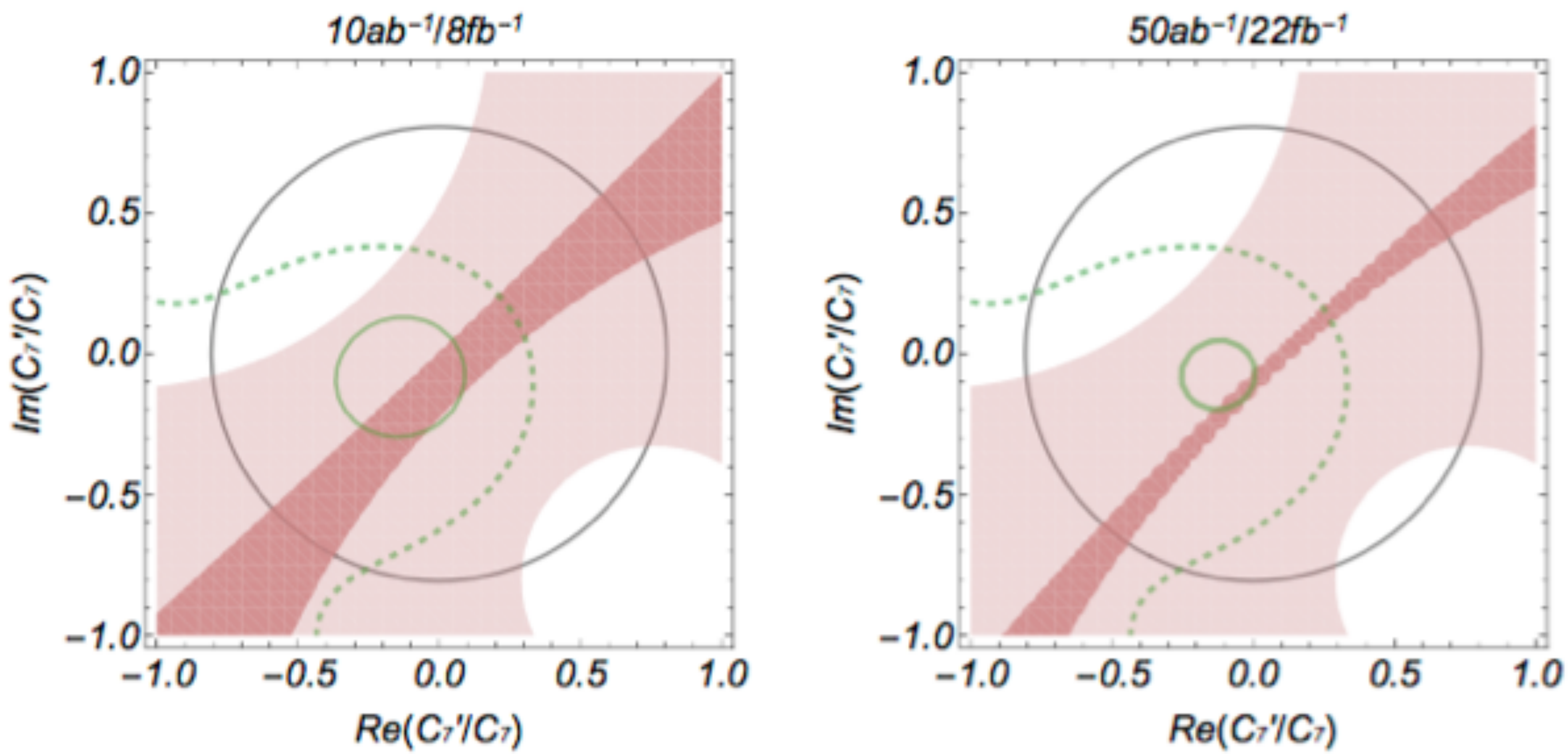
Belle: Phys.Rev.Lett. 101 (2008), Babar: Phys.Rev. D93 (2016)

- Note: a null-test can be performed without dilution factor (i.e. $S_{K_S\pi^+\pi^-\gamma} \neq 0$ is immediately a discovery of new physics!)

Time dependent analysis

$B_d \rightarrow K_S \pi^0 \gamma$ vs $B_d \rightarrow K_S \pi^+ \pi^- \gamma$

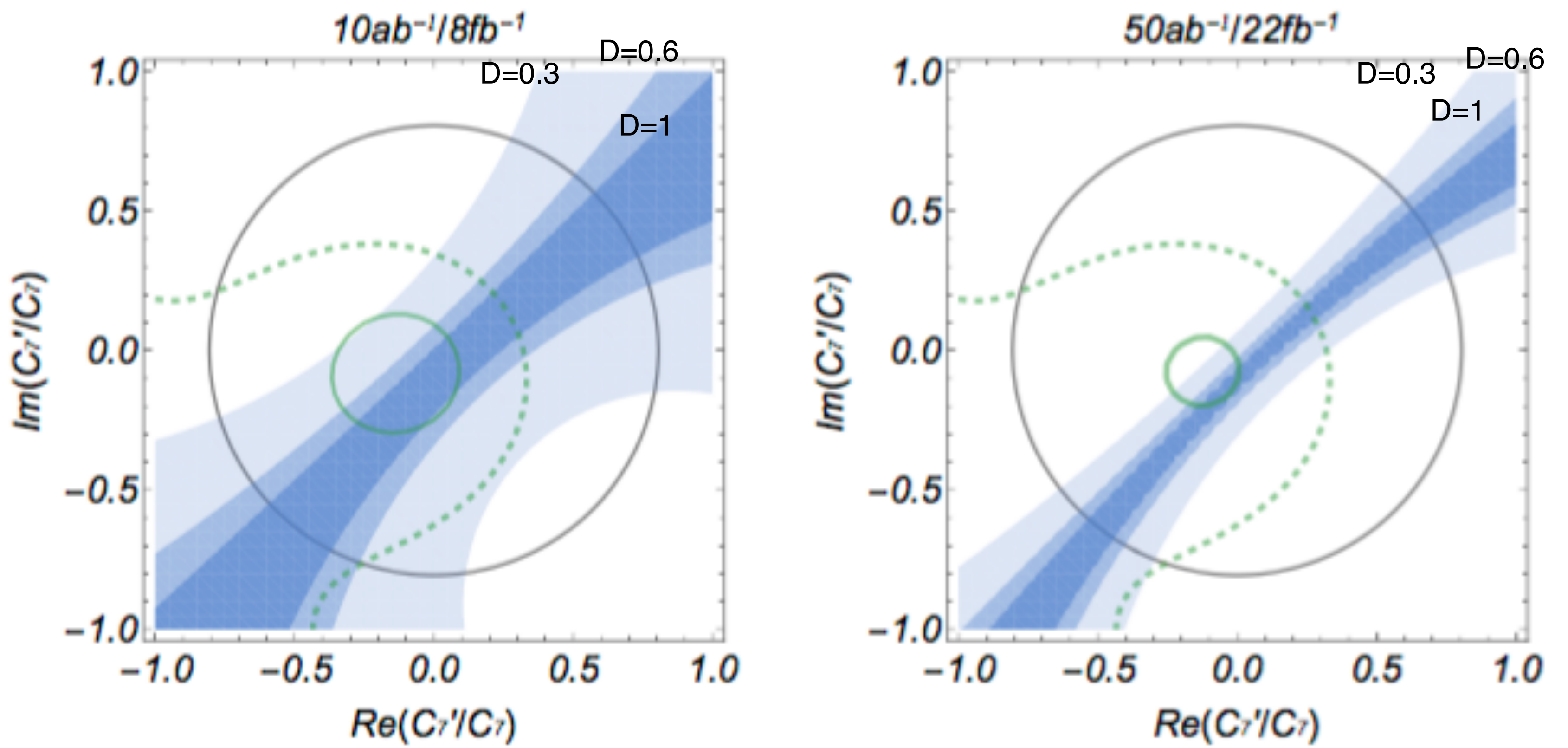
S. Akar, E. Ben-Haim, J. Hebinger, E.K. F.Yu
arXiv:1802.09433



Red: Belle II golden channel $B_d \rightarrow K_S \pi^0 \gamma$
Green: LHCb B->K*ee angular analysis

Time dependent analysis
$B_d \to K_S\pi^0\gamma$ vs $B_d \to K_S\pi^+\pi^-\gamma$

S. Akar, E. Ben-Haim, J. Hebinger, E.K. F.Yu
arXiv:1802.09433



Blue: Belle II $B_d \to K_S\pi^+\pi^-\gamma$ (without Dalitz information)
Green: LHCb B->K*ee angular analysis

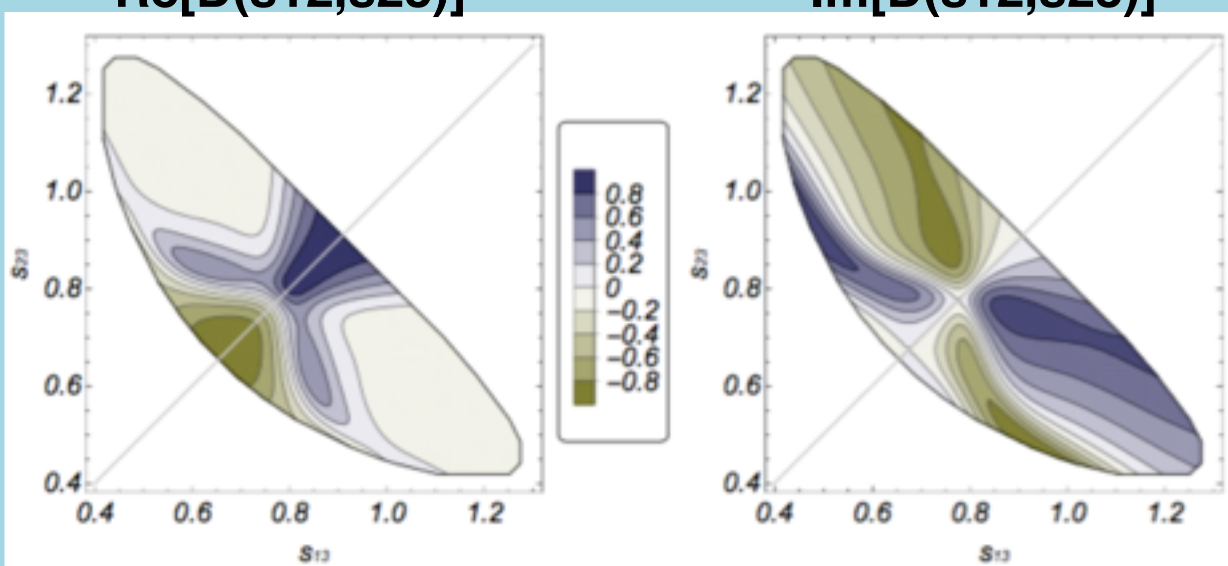
$B_d \to K_S \pi^+ \pi^- \gamma$: new observable!

S. Akar, E. Ben-Haim, J. Hebinger, E.K. F.Yu
arXiv:1802.09433

$$S_{K_S\pi^+\pi^-} = \frac{2Im\left[\frac{q}{p}\left(\frac{c}{c'^*}\right)\right]}{(1+|\frac{c}{c'}|^2)} \times \frac{\sum_{\lambda=L,R}\left\{-|A_\lambda^{\rho K_S}|^2 + \mathrm{Re}\left[A_\lambda^{*K^{*-}\pi^+} A_\lambda^{K^{*+}\pi^-}\right] + \mathrm{Re}\left[A_\lambda^{*\kappa^-\pi^+} A_\lambda^{\kappa^+\pi^-}\right] - 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{K^{*+}\pi^-}] - 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{\kappa^+\pi^-}]\right\}}{\sum_{\lambda=L,R}\left\{|A_\lambda^{\rho K_S}|^2 + |A_\lambda^{*K^{*+}\pi^-}|^2 + |A_\lambda^{*\kappa^+\pi^-}|^2 + 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{K^{*+}\pi^-}] + 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{\kappa^+\pi^-}]\right\}}$$

=D: dilution factor

Re[D(s12,s23)] **Im[D(s12,s23)]**



Im[D] is symmetric so it becomes zero when integrating over the Dalitz space

In previous studies, Dilution factor was Dalitz integrated. Without integration, we have two observables (Re and Im of Dilution factor). Using these information, we can resolve the ambiguity and constrain both real and imaginary part of C7/C7'.

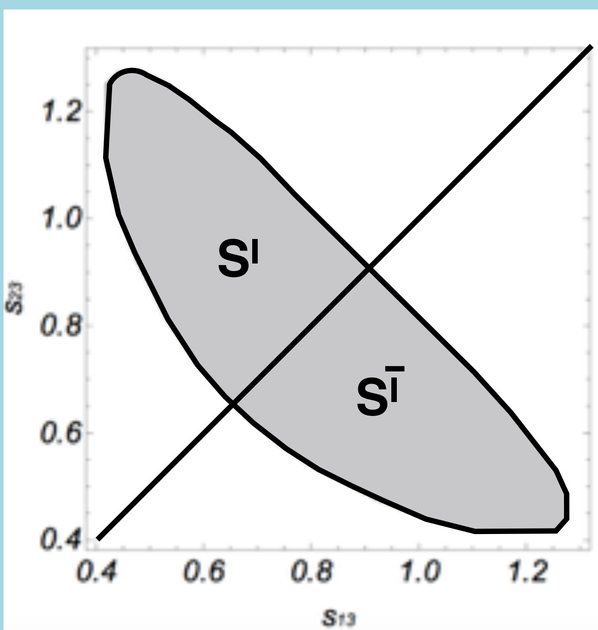
$B_d \to K_S \pi^+ \pi^- \gamma$: new observable!

S. Akar, E. Ben-Haim, J. Hebinger, E.K. F.Yu
arXiv:1802.09433

$$S_{K_S\pi^+\pi^-} = \frac{2Im\left[\frac{q}{p}\left(\frac{c}{c'^*}\right)\right]}{(1+|\frac{c}{c'}|^2)} \times \frac{\sum_{\lambda=L,R}\left\{-|A_\lambda^{\rho K_S}|^2 + \mathrm{Re}\left[A_\lambda^{*K^{*-}\pi^+} A_\lambda^{K^{*+}\pi^-}\right] + \mathrm{Re}\left[A_\lambda^{*\kappa^-\pi^+} A_\lambda^{\kappa^+\pi^-}\right] - 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{K^{*+}\pi^-}] - 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{\kappa^+\pi^-}]\right\}}{\sum_{\lambda=L,R}\left\{|A_\lambda^{\rho K_S}|^2 + |A_\lambda^{*K^{*+}\pi^-}|^2 + |A_\lambda^{*\kappa^+\pi^-}|^2 + 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{K^{*+}\pi^-}] + 2\mathrm{Re}[A_\lambda^{*\rho K_S} A_\lambda^{\kappa^+\pi^-}]\right\}}$$

=D: dilution factor

$S_{K_S\pi^+\pi^-\gamma}$



For example,

- measure the CPV parameter $S_{K_S\pi^+\pi^-\gamma}$ for upper (S^I) and lower ($S^{\bar{I}}$) part of Dalitz plane separately.
- then, we can compose two observables:

$$S^+ \equiv S^I_{\pi^+\pi^-K^0_S\gamma} + S^{\bar{I}}_{\pi^+\pi^-K^0_S\gamma}$$

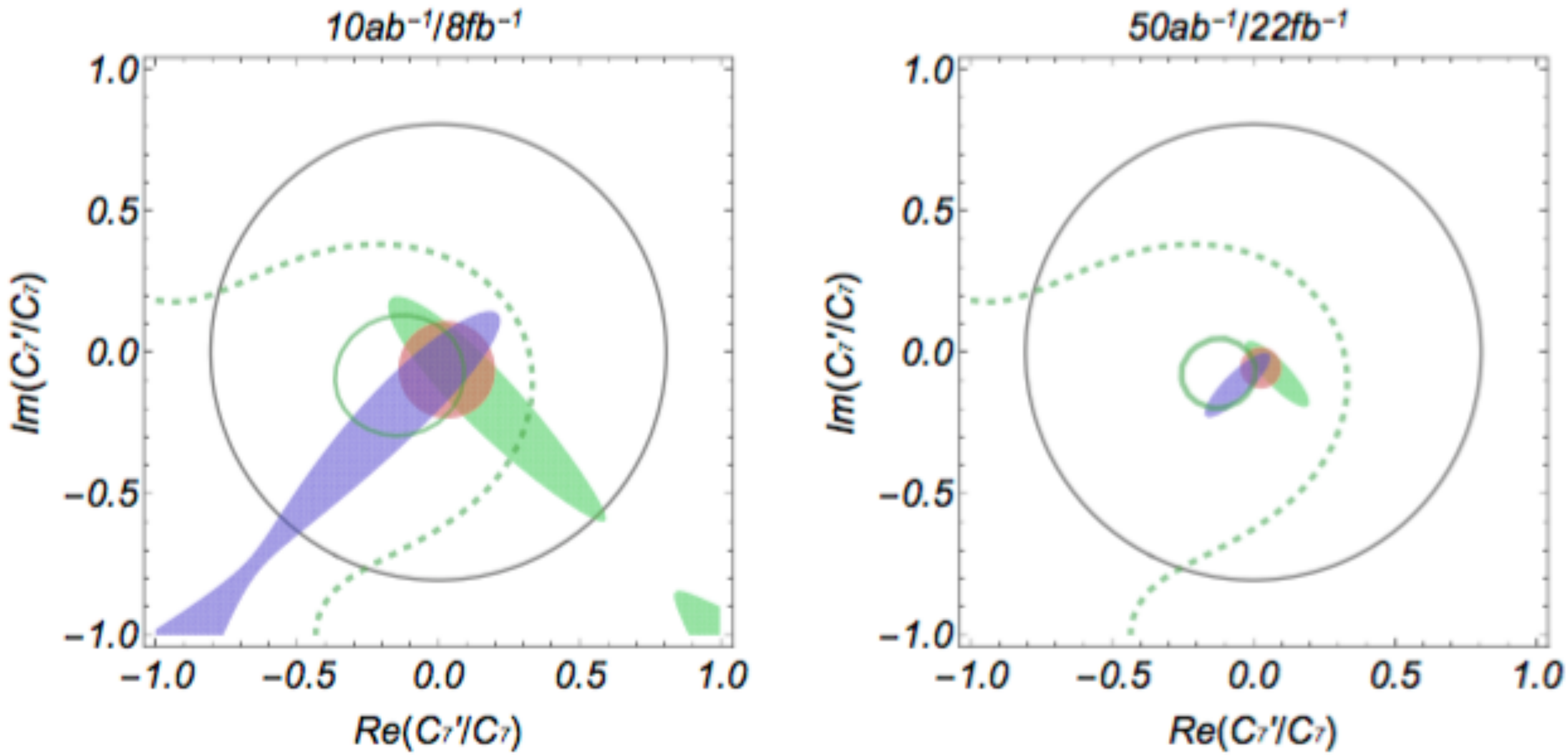
$$S^- \equiv S^I_{\pi^+\pi^-K^0_S\gamma} - S^{\bar{I}}_{\pi^+\pi^-K^0_S\gamma}$$

Similar to the GGSZ method, PRD68 (2003)

For model independent analysis, see Le Yaouanc, A.Tayduganov, EK, PLB '16

$B_d \to K_S \pi^+ \pi^- \gamma$: new observable!

S. Akar, E. Ben-Haim, J. Hebinger, E.K. F.Yu
arXiv:1802.09433



Purple : in case Re[D] > Im[D]
Green: in case Re[D] < Im[D]
Red: in case Re[D] = Im[D]

CKM2020

Conclusions

- There have been many progresses in photon polarisation determination of the $b \rightarrow s\gamma$ process.
- $B \rightarrow K\pi\pi\gamma$ channel is motivated by its large data sample. Also $B \rightarrow K\pi\pi\gamma$ is the simplest possible channel for angular analysis.
- The angular analysis method determines the photon polarisation by measuring the Kaonic resonance polarization. Thus, the challenge is to understand the $K_{res} \rightarrow K\pi\pi$ decays very precisely.
- Simultaneous fit of angles and Dalitz variables is crucial and a lot of efforts are put in such works by LHCb/Belle/BelleII.

- For the time dependent analysis, $B_d \rightarrow K_S \pi^+ \pi^- \gamma$ channel requires an extraction of the dilution factor D, which is the challenges for this channel (it can be obtained as a byproduct of the angular analysis).

- Today, we showed that $B_d \rightarrow K_S \pi^+ \pi^- \gamma$ has an advantage compared to $B_d \rightarrow K_S \pi^0 \gamma$ (golden-)channel as the Dalitz distribution can provide extra information, which provides more information, such as both the real/imaginary parts of the C7'/C7.

Backup

Model independent analysis

Use of B->J/psi Kππ channel *Le Yaouanc, A.Tayduganov, EK, PLB '16*

$$\mathcal{W}^V(s_{13}, s_{23}, \cos\theta, \phi)_s \equiv a^V + (a_1^V + a_2^V \cos 2\phi + a_3^V \sin 2\phi)\sin^2\theta + b^V \cos\theta$$

$$V = J/\psi, \gamma$$

$$\mathcal{W}^V(s_{13}, s_{23}, \cos\theta, \phi)_s = \frac{\sum_{s_z} |\mathcal{A}^V_{s_z}(s)|^2 \left|\vec{\epsilon}_{K_{1 s_z}} \cdot \vec{\mathcal{J}}_{K_1}(s_{13}, s_{23})_s\right|^2}{\int ds_{13} \int ds_{23} \int d(\cos\theta) \int d\phi \sum_{s_z} |\mathcal{A}^V_{s_z}(s)|^2 \left|\vec{\epsilon}_{K_{1 s_z}} \cdot \vec{\mathcal{J}}_{K_1}(s_{13}, s_{23})_s\right|^2}$$

$$\begin{aligned}
a^V(s, s_{13}, s_{23}) &= N_s^V \xi_a^V \left[|c_1|^2 + |c_2|^2 - 2\mathrm{Re}(c_1 c_2^*)\cos\delta\right] , \\
a_1^V(s, s_{13}, s_{23}) &= N_s^V \xi_{a_i}^V \left[|c_1|^2 + |c_2|^2 - 2\mathrm{Re}(c_1 c_2^*)\cos\delta\right] , \\
a_2^V(s, s_{13}, s_{23}) &= N_s^V \xi_{a_i}^V \left[(|c_1|^2 + |c_2|^2)\cos\delta - 2\mathrm{Re}(c_1 c_2^*)\right] \\
a_3^V(s, s_{13}, s_{23}) &= N_s^V \xi_{a_i}^V \left[(|c_1|^2 - |c_2|^2)\sin\delta\right] , \\
b^V(s, s_{13}, s_{23}) &= -N_s^V \xi_b^V \left[2\mathrm{Im}(c_1 c_2^*)\sin\delta\right] ,
\end{aligned}$$

$$\begin{aligned}
\xi_a^V(s) &\equiv \frac{|\mathcal{A}_+^V(s)|^2 + |\mathcal{A}_-^V(s)|^2}{2} , \\
\xi_{a_i}^V(s) &\equiv \frac{-(|\mathcal{A}_+^V(s)|^2 + |\mathcal{A}_-^V(s)|^2) + 2|\mathcal{A}_0^V(s)|^2}{4} \\
\xi_b^V(s) &\equiv \frac{|\mathcal{A}_+^V(s)|^2 - |\mathcal{A}_-^V(s)|^2}{2} .
\end{aligned}$$

Preliminary result on the simultaneous fit

EK & F. Le Diberder B2TiP workshop 2015

- Photon polarization is sensitive to the imaginary part of the K1 decay amplitudes

$$b^{\gamma} \propto \langle \mathrm{Im}(\hat{n} \cdot (\vec{\mathcal{J}} \times \vec{\mathcal{J}}^{*})) \rangle \left[|C_7'|^2 - |C_7|^2 \right]$$

- The imaginary part comes from interference of different resonances (either initial or intermediate states).
- These are very difficult to predict theoretically and the simultaneous fit is the most powerful!

The error matrix for simultaneous fit

$$E = \begin{pmatrix} 0.034 & -0.133 & -0.021 & -0.067 & 0.007 \\ & 0.040 & 0.260 & 0.630 & -0.320 \\ & & 0.019 & 0.395 & -0.470 \\ & & & 0.680 & -0.405 \\ & & & & 0.180 \end{pmatrix}$$

- ← Photon polarization
- ← K1(1270)/K1(1270) separation
- ← $(K\pi)_{s\text{-wave}}$ contributions
- ← K1 mixing angle c.f. (60±10)°
- ← Damping factor c.f. (4±0.5)

Preliminary result!

At ~3% level sensitivity to all 5 parameters (5k events)!