Monte-Carlo generator development on the $B \to K_{res}\gamma \to K\pi\pi\gamma$ decay

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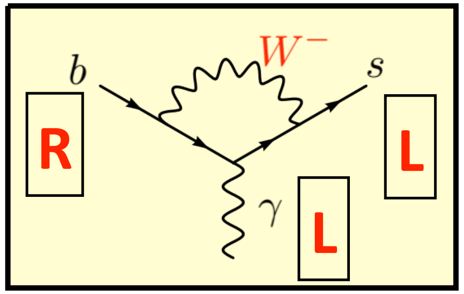
Motivation

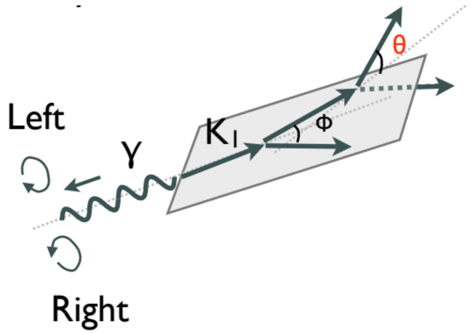
- To measure the photon polarisation in $b \to s\gamma$ process, which a good probe of BSM (Beyond Standard Model).

- The polarisation of photon is the same as the polarisation of the K_{res} . The photon is predominately left-handed, up to small corrections of the order m_s/m_b .

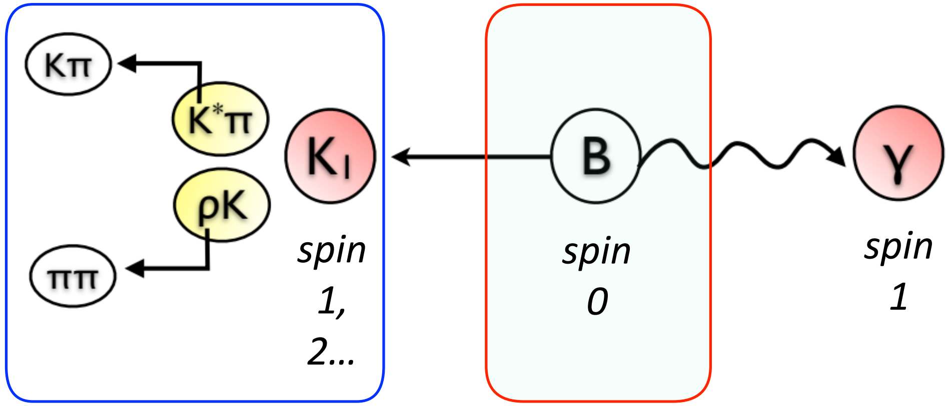
- Measuring the angular distribution from the K_{res} decay can give the polarization information.

- To have the angular information, 3-body decay is necessary. The $B \to K\pi\pi\gamma$ process gives us an opportunity to look for it.





Photon polarisation = Recoiling K_{res} polarisation
⟶ measure it from K_{res} decay angular distribution



Gronau, Grossman, Pirjol, Ryd, *Measuring the Photon Polarization in B→Kππγ*, PRL 88.051802

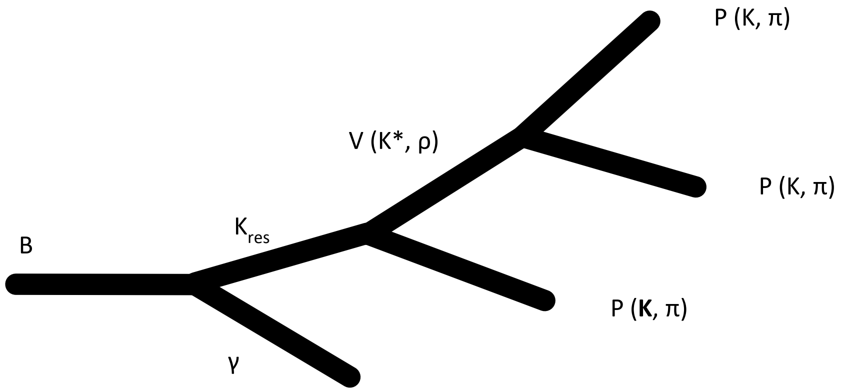
The Monte-Carlo generators

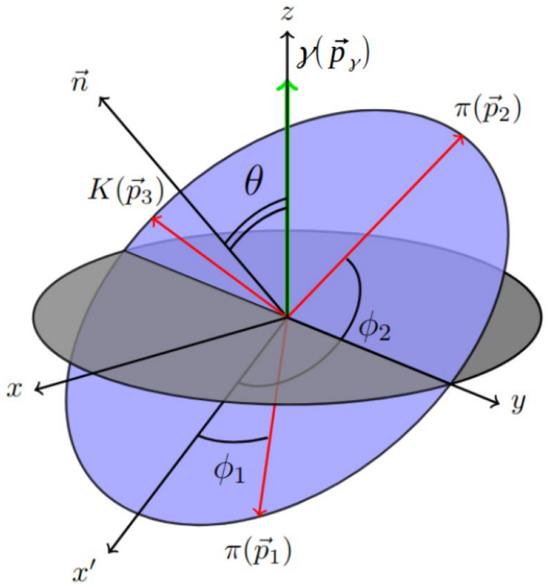
- MINT II generator:
  using "covariant-tensor" method.
  (LHCb?)

- GamPola generator:
  using "Form Factor" method, developed by B. Knysh, a former IJC Lab PhD student.

- Due to some difficulties of maintenance of Gampola, and the limited development potential of Gampola by the code structure, we are now developing a totally new Monte-Carlo generator, but with the same "Form Factor" method.

- In our generator, the events are firstly generated in the K_{res} rest frame, then boosted back to the B-meson rest frame. Then will be rotated randomly finally (the same rotational method as EvtGen).



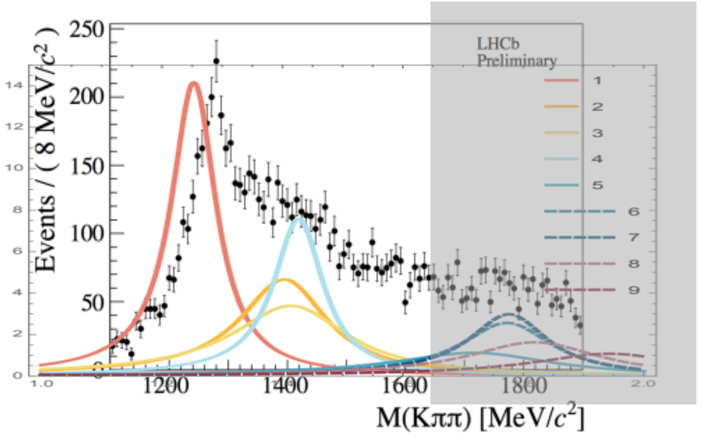


The Monte-Carlo generator

- There are a dozen of Kaonic resonances (K_{res}) identified below 2 GeV. Among them, the lightest five are well established (mass, width, decay to $K\pi\pi\gamma$…), K(1270), K(1400), K(1410), K(1430), and K(1680).

- 5 resonances are planned to be included in our generator, which allows us to use the energy range of 1.1-1.6 GeV.

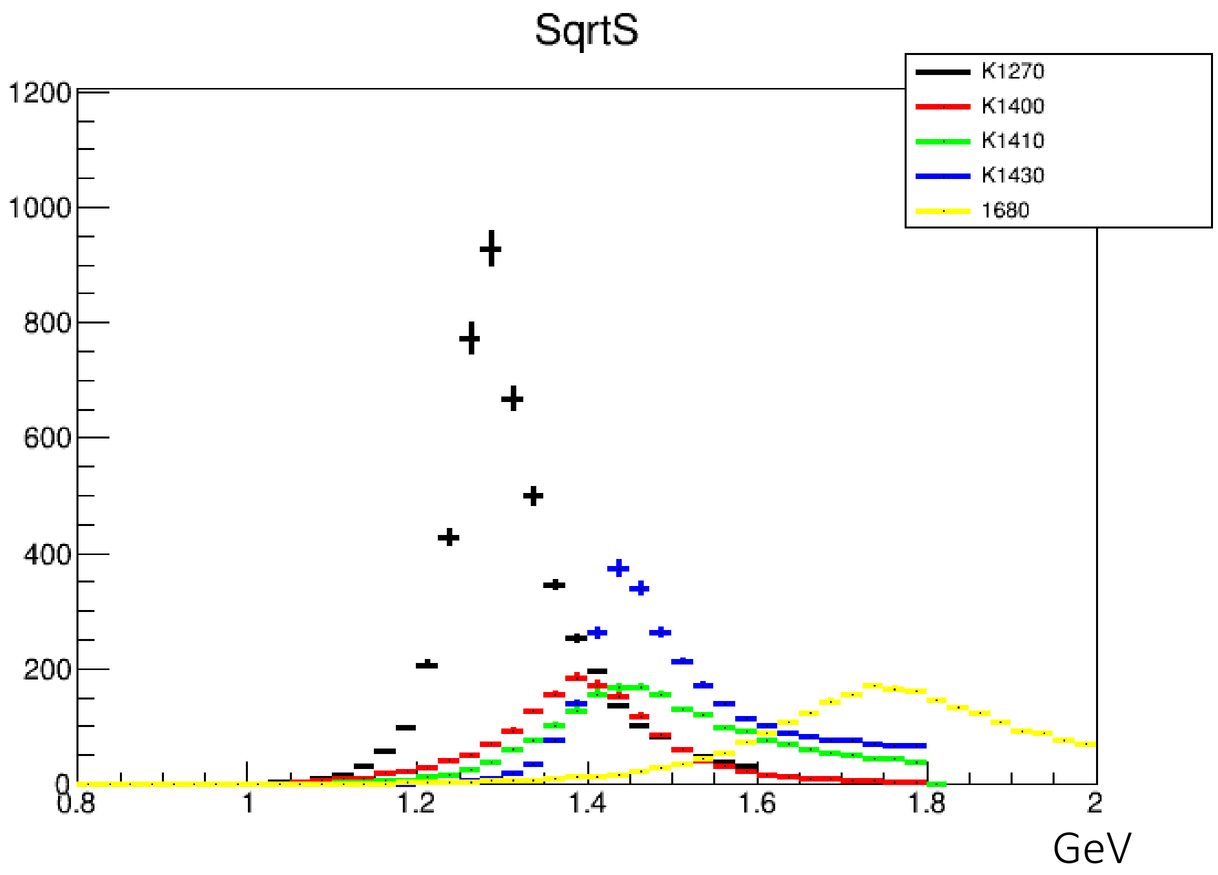
- In our generator, few mixing effects are included:
  1. The hadronic form factor of K(1270) and K(1400).
  2. Interference between difference K_{res} .
  3. Interference between the isobar decays.



One should aware that this plot is NOT on scale, but just an illustration.

	Name	J^P	mass	width	Br(ρK)%	Br(πK*)%	others
1	K(1270)	1^+	1253±7	90±20	42±6	16±5	28±4% ($K_{1430}\pi$) 11±2 (Kω)
2	K(1400)	1^+	1403±7	174±13	3±3	94±6	
3	K(1410)	1^-	1414±15	232±21	<7	>40	6.6±1.3% (Kπ)
4	K(1430)	2^+	1427.3±1.5	100.0±2.1	8.7±0.8	24.7±1.5	49.9±1.2% (Kπ)
5	K(1680)	1^-	1718±18	322±110	$31.4^{+0.5}_{-2.1}$		38.7±2.5% (Kπ) 13.4±2.2 (K*ππ)
6	K(1770)	2^-	1773±8	186±14			Kππ seen
7	K(1780)	3^-	1776±7	159±21			Kππ seen
8	K(1820)	2^-	1819±12	264±34			Kππ seen
9	K(1980)	2^+	1943±50	307^{+50}_{-31}			Kππ seen

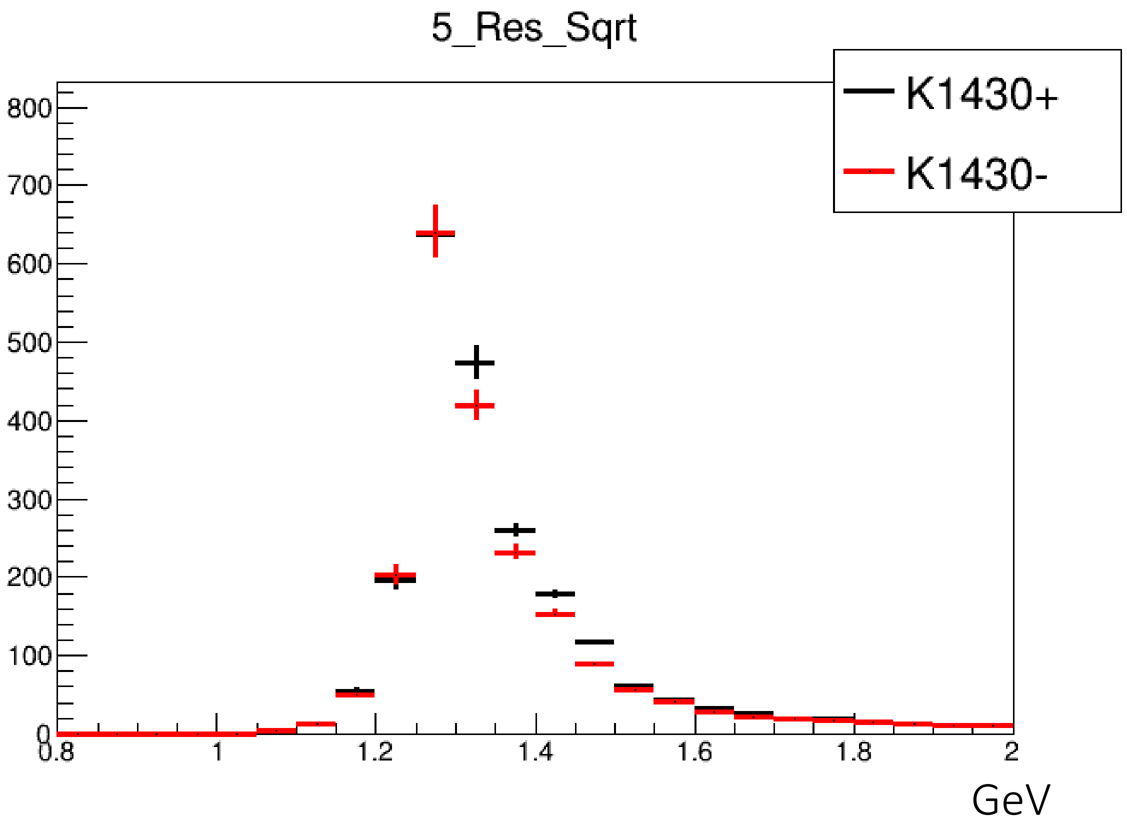
The Kaonic resonances K_{res}



K_{res}	Signal strength c_i
K(1270)	1.
K(1400)	1.
K(1410)	1.
K(1430)	1.
K(1680)	1.

- The 5 histograms are generated separately, each with signal strength equals to one.

The Kaonic resonances K_{res}



Currently we confine ourselves in only using real numbers.

- $P_{NoInt} \sim \sum_i c_i^2 \left|A_{res}^i\right|^2$
- $P_{WithInt} \sim \left|\sum_i c_i A_{res}^i\right|^2$
- If you generate the sample without accounting the interference effect, the 2 histograms should be the same.
- Now since our generator takes the interference into account, we can see the 2 histograms have different behaviours.

K_{res}	Signal strength c_i
K(1270)	1.366
K(1400)	-0.366
K(1410)	0.1
K(1430)	0.3
K(1680)	0.1

K_{res}	Signal strength c_i
K(1270)	1.366
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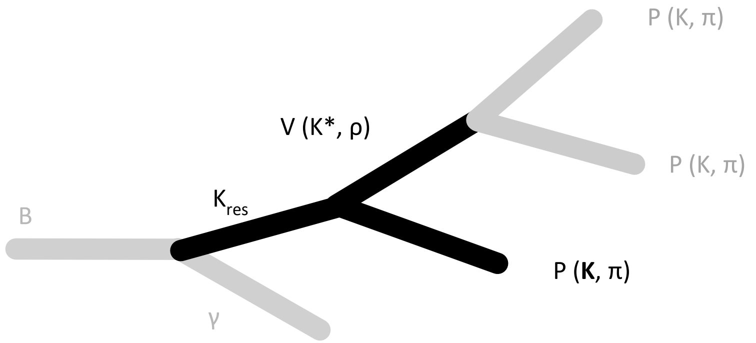
K(1680)	0.1

The K_{res} decay

- For the K_{res} we planned to include, they are either 1^+, 1^-, or 2^+.
- The form factors of K(1270) and K(1400) are related by the mixing angle (theoretically).
- In our new MC generator, the strength of K(1270) and K(1400) can be set separately.
- The strength of K(1410), K(1430), and K(1680) could be set manually also.
- The isobar decays detail are included.



1^+ $$\langle V(p_V,\epsilon_V)P_k(p_k)|\Delta\mathcal{H}|K_1(p_{K_1},\epsilon_{K_1})\rangle = \epsilon^{\mu}_{K_1} T_{\mu\nu}\epsilon^{\nu *}_V$$

$$T_{\mu\nu} = f^V g_{\mu\nu} + h^V p_{V\mu} p_{K_1\nu}$$

1^- $$\langle V(p_V,\epsilon_V)P_k(p_k)|\Delta\mathcal{H}|K^*(p_{K^*},\epsilon_{K^*})\rangle = i g_{K^* V P_k}\epsilon_{\mu\nu\rho\sigma} p^{\mu}_{K^*} p^{\nu}_V \epsilon^{\rho}_{K^*}\epsilon^{\sigma *}_V$$

2^+ $$\langle V(p_V,\epsilon_V)P_k(p_k)|\Delta\mathcal{H}|K_2^*(p_{K_2^*},\epsilon_{K_2^*})\rangle = i g_{K_2^* V P_k}\epsilon^{\mu\nu\rho\sigma}\epsilon^*_{V\alpha} p_{K_2^*\beta}\epsilon^{\gamma\rho}_{K_2^*} p_{k\rho} p_{k\delta}$$

$$(\epsilon^{\gamma\rho}_{K_2^*})_{\pm} = \pm\frac{1}{\sqrt{2}}[(\epsilon^{\gamma})_{\pm}(\epsilon^{\rho})_0 + (\epsilon^{\gamma})_0(\epsilon^{\rho})_{\pm}]$$

$$\mathcal{M}_I(K_1^+ \to \pi^0(p_1)\pi^+(p_2)K^0(p_3)) = \frac{\sqrt{2}}{3}\mathcal{M}^{K^{*0}}_{(P_1P_3)P_2} - \frac{\sqrt{2}}{3}\mathcal{M}^{K^{*+}}_{(P_2P_3)P_1} + \frac{1}{\sqrt{3}}\mathcal{M}^{\rho^+}_{(P_1P_2)P_3} \quad (2.29a)$$

$$\mathcal{M}_{II}(K_1^+ \to \pi^-(p_1)\pi^+(p_2)K^+(p_3)) = -\frac{2}{3}\mathcal{M}^{K^{*0}}_{(P_1P_3)P_2} - \frac{1}{\sqrt{6}}\mathcal{M}^{\rho^0}_{(P_1P_2)P_3} \quad (2.29b)$$

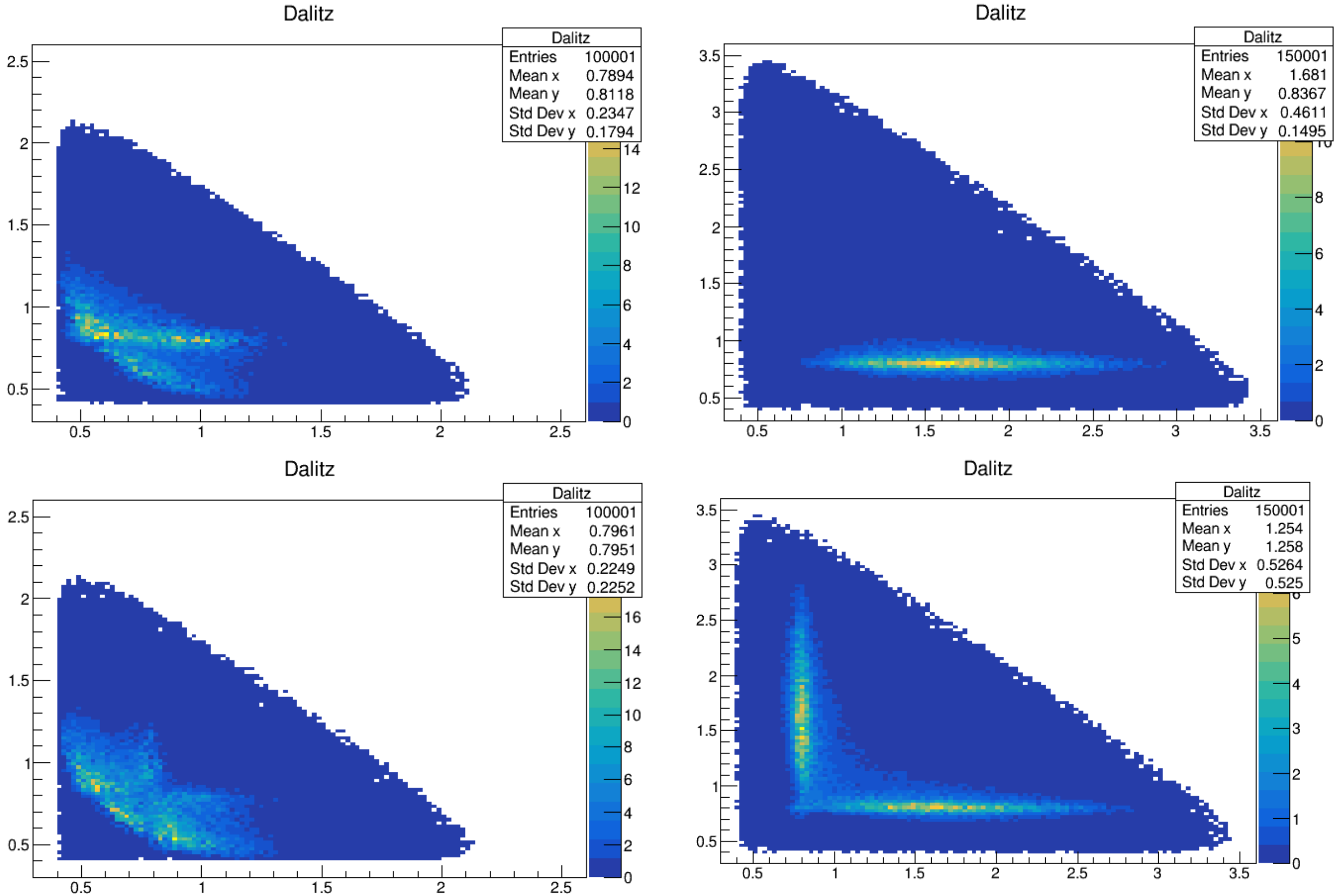
$$\mathcal{M}_{III}(K_1^0 \to \pi^0(p_1)\pi^-(p_2)K^+(p_3)) = \frac{\sqrt{2}}{3}\mathcal{M}^{K^{*+}}_{(P_1P_3)P_2} - \frac{\sqrt{2}}{3}\mathcal{M}^{K^{*0}}_{(P_2P_3)P_1} + \frac{1}{\sqrt{3}}\mathcal{M}^{\rho^-}_{(P_1P_2)P_3} \quad (2.29c)$$

$$\mathcal{M}_{IV}(K_1^0 \to \pi^+(p_1)\pi^-(p_2)K^0(p_3)) = -\frac{2}{3}\mathcal{M}^{K^{*+}}_{(P_1P_3)P_2} - \frac{1}{\sqrt{6}}\mathcal{M}^{\rho^0}_{(P_1P_2)P_3} \quad (2.29d)$$

Dalitz plots

K^+

K^0



K1270, $\sqrt{s} < 1.6$ GeV

K1680, $\sqrt{s} < 2.0$ GeV

- In the left hand-side, they are Dalitz plots with x-axes are s_{13} [GeV^2] and y-axes are s_{23} [GeV^2].

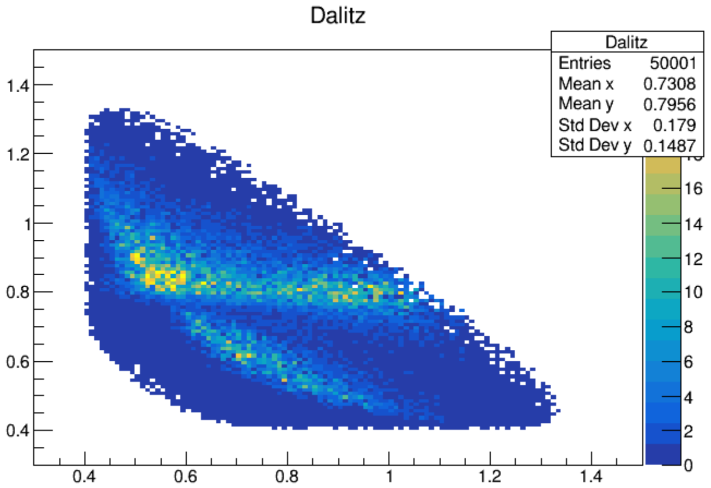
$$K^+_{\text{res}} \to \begin{Bmatrix} K^{*+}\pi^0 \\ K^{*0}\pi^+ \\ \rho^+ K^0 \end{Bmatrix} \to K^0\pi^+\pi^0$$

$$\begin{Bmatrix} K^{*0}\pi^+ \\ \rho^0 K^+ \end{Bmatrix} \to K^+\pi^+\pi^-$$

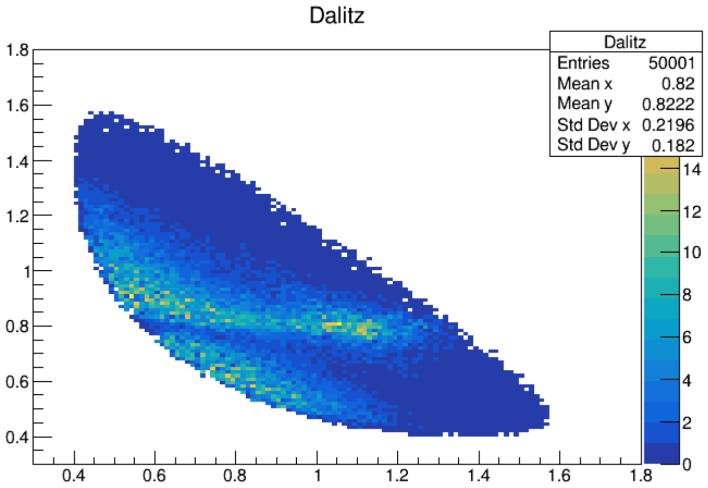
- The charged kaon K^+ doesn't have the s_{13} line, which is expected.

- The K1680 also doesn't show the s_{12} ρ decay line because of our setting, which is calculated from the particle data group.

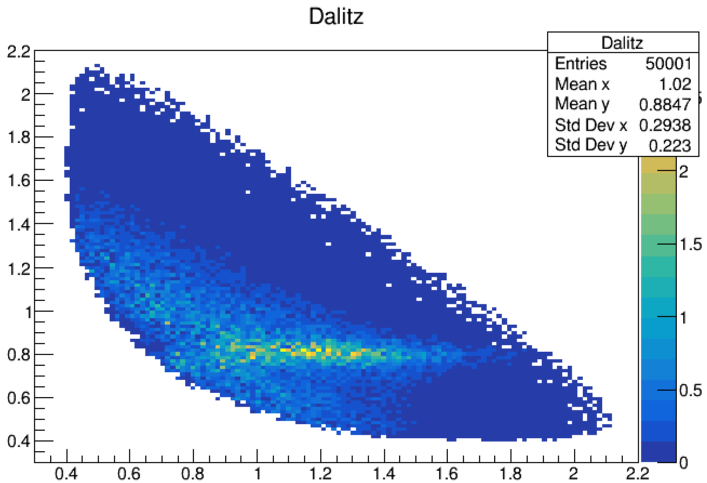
Dalitz plots



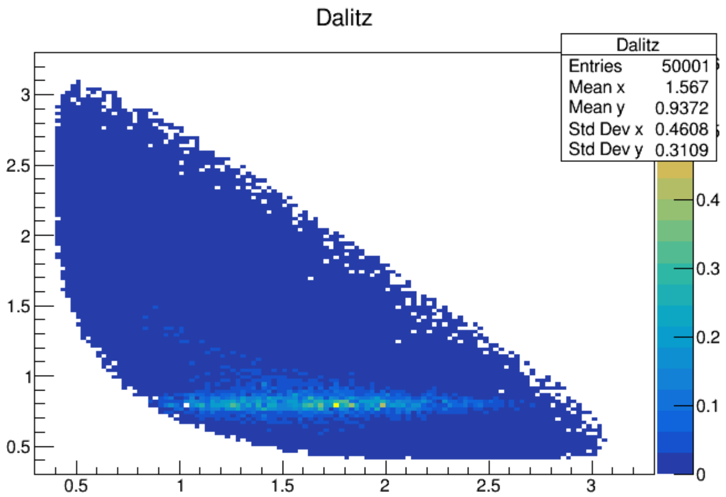
$1.0 < \sqrt{s} < 1.3$ GeV



$1.3 < \sqrt{s} < 1.4$ GeV



$1.4 < \sqrt{s} < 1.6$ GeV

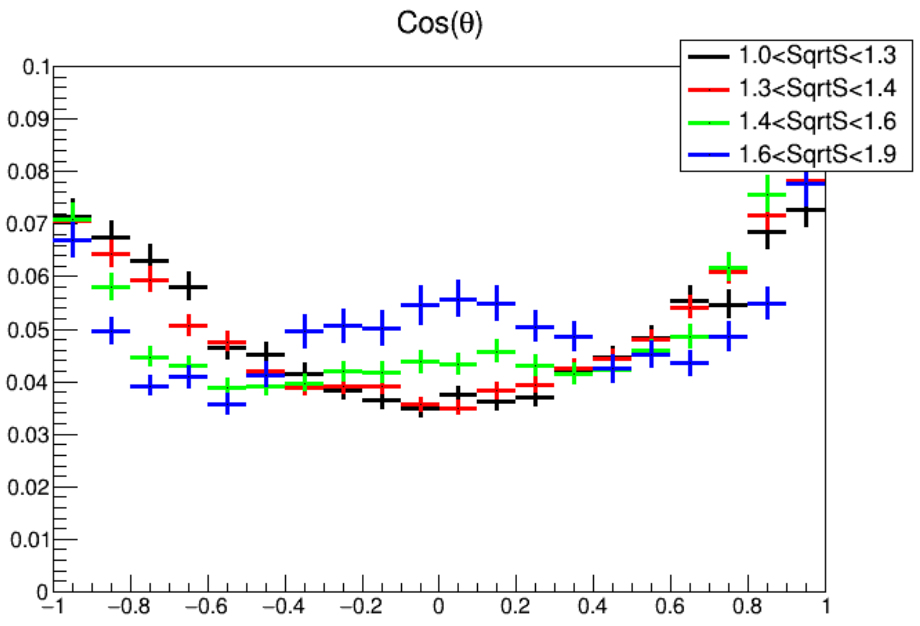


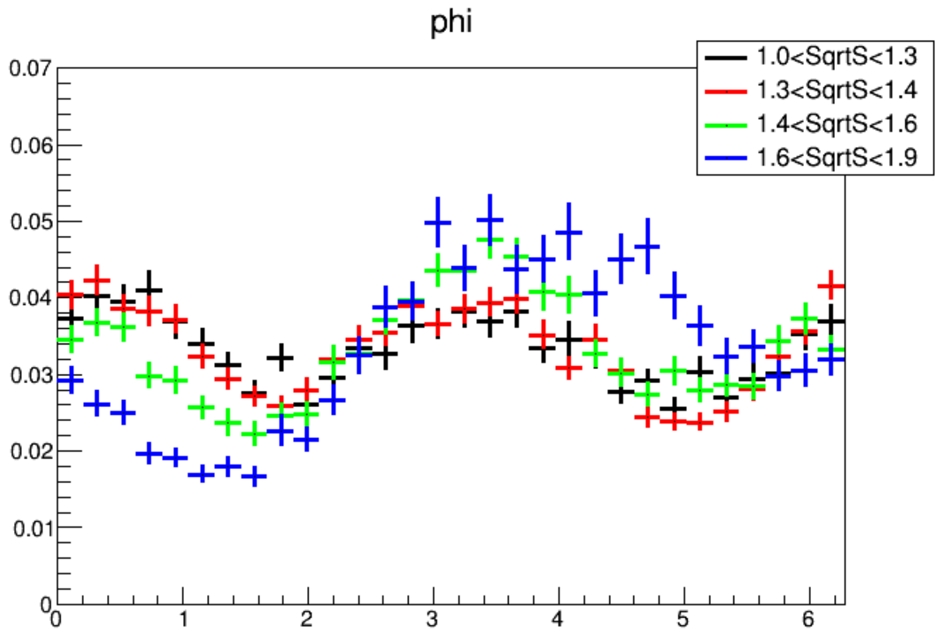
$1.6 < \sqrt{s} < 1.9$ GeV

- In the left hand-side, they are Dalitz plots with 5 kaonic resonances.
- Only charged kaon K^+.
- Generated separately in different center-of-mass $\sqrt{s}$ range.
- The signal strength of the 5 K_{res} is shown in the following table.

K_{res}	Signal strength c_i
K(1270)	1.366
K(1400)	-0.366
K(1410)	0.1
K(1430)	-0.3
K(1680)	0.1

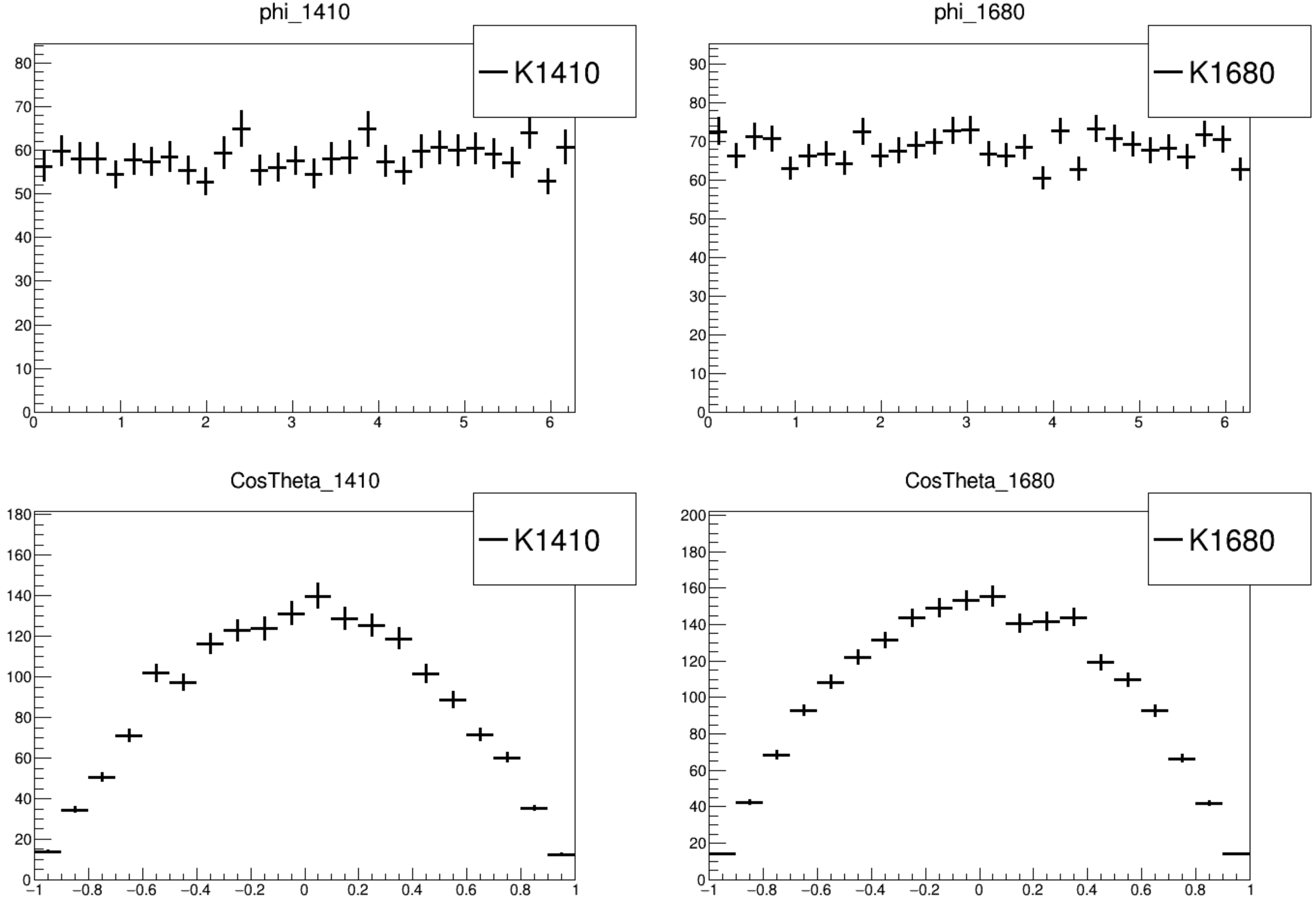
Angular plots





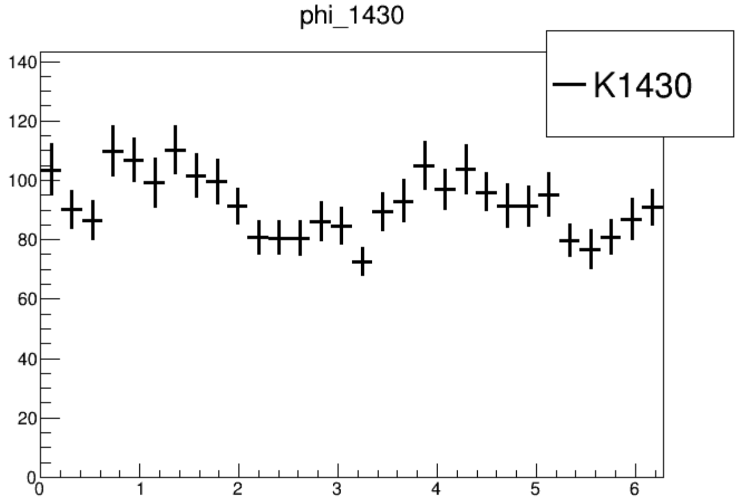
- The above angular plots are 5 kaonic resonances.
- Only charged kaon K^+.
- Generated separately in different center-of-mass $\sqrt{s}$ range.

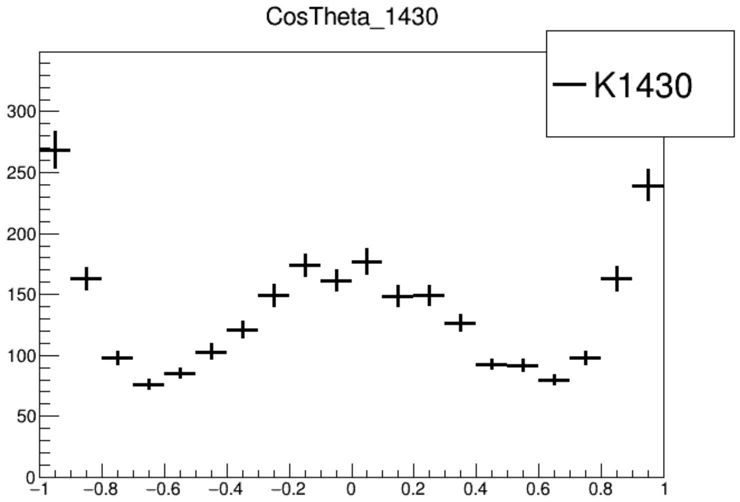
Angular Plots (The P-Wave)



- For P-wave decay, we have K(1410) and K(1680).
- constant ϕ is expected
- $-x^2$ shape is expected for $\cos(\theta)$
- The generation range of K(1410) is $\sqrt{s} < 1.8$ GeV.
- For K(1680), it is $\sqrt{s} < 2.0$ GeV.

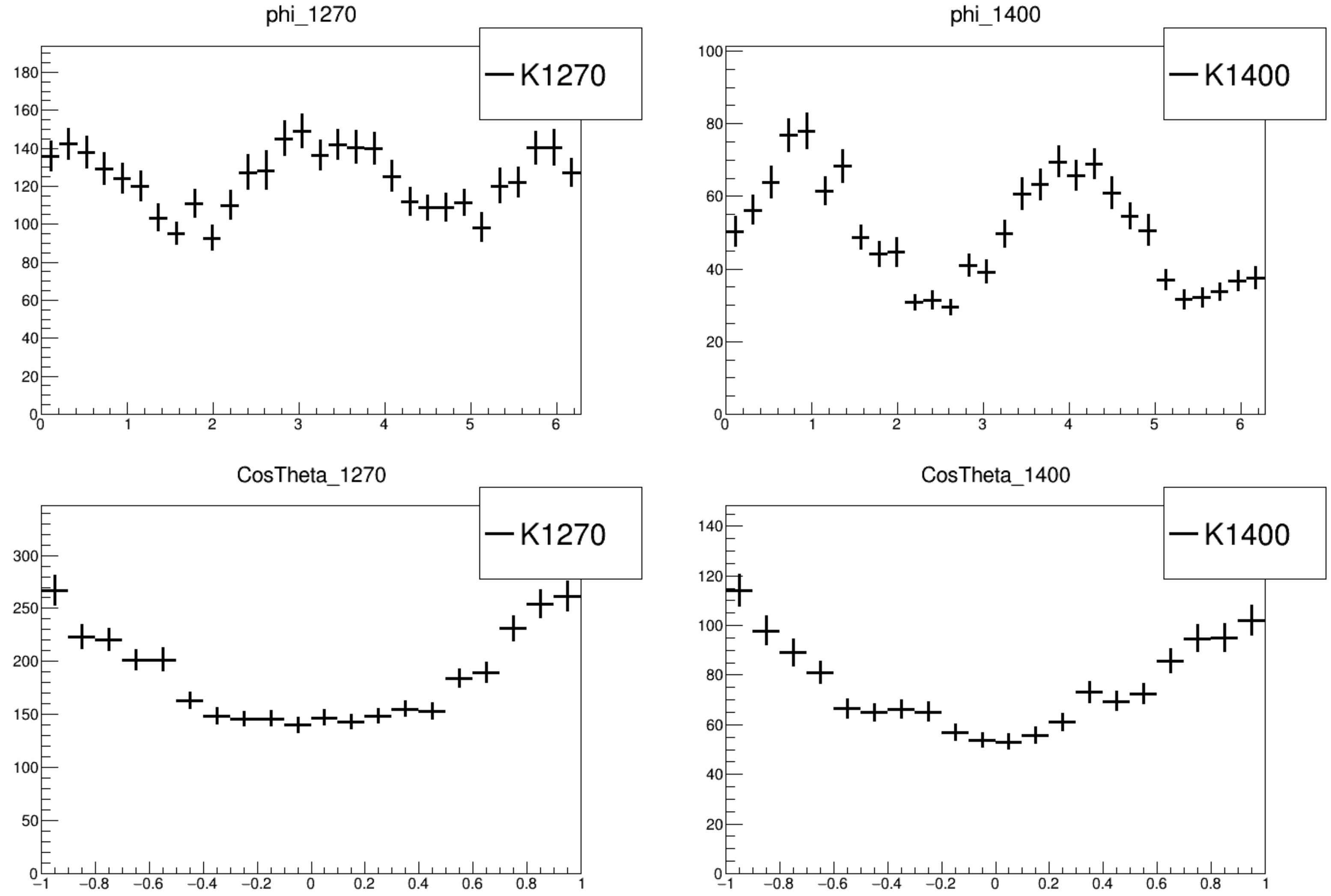
Angular Plots (The D-Wave)





- For D-wave decay, we have K(1430)
- Both the shape of $\cos(\theta)$ and ϕ is not trivial before numerical computation.
- The generation range of K(1430) is $\sqrt{s} < 1.8$ GeV.

Angular Plots (The mixing Kaons)



- K(1270) and K(1400) are mixed.
- In the mixing, both s-wave and d-wave are included.
- The shape of $\cos(\theta)$ is expected to be $+x^2$ liked.
- While the shape of ϕ is not trivial before numerical computation, highly depends on the mixing setting.
- The generation range of K(1400) is $\sqrt{s} < 1.8$ GeV, while K(1270) is $\sqrt{s} < 1.6$ GeV.

Current Status of the generator

- Five K_{res} are included, which are K(1270), K(1400), K(1410), K(1430), and K(1680).
- Both neutral mode Kaon and charged mode Kaon are included.
- Next step : to implement the generator to EvtGen.
- Once our generator is implemented, the $B \rightarrow K\pi\pi\gamma$ event in EvtGen (below 1.6 GeV) has to be removed in order to avoid double counting.
- For the right-handed and left-handed polarisation, it is already in the generator, but we want to further checking the details carefully.
- The Lorentz boosted and randomly rotation are also implemented.

Conclusion

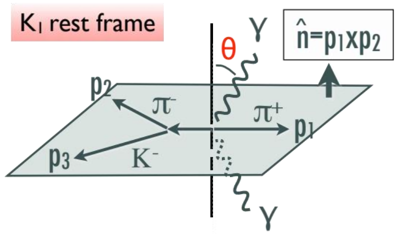
- The study of $B \rightarrow K\pi\pi\gamma$ decay give us an opportunity to probe into BSM via photon polarization.
- Different K_{res} are involved in this channel. And they interfere with each other.
- We are developing a new Monte-Carlo generator such that the interferences between different K_{res} can be included.
- Our target is to finish this generator in a few months, and to implement it in EvtGen.

Appendix

- With the information in hand, we may use a measurable called “up-down asymmetry” to get the K_{res} information.
- “up-down asymmetry” is to count the number of events with photon above/below the K_{res} decay plane and subtract them.
- And this provides a very first step for us to test on polarisation.

“up-down asymmetry” :

$$\mathcal{A}_{UD} \equiv \frac{\int_0^1 \mathcal{W}(s, s_{13}, s_{23}, \cos\theta) d\cos\theta - \int_{-1}^0 \mathcal{W}(s, s_{13}, s_{23}, \cos\theta) d\cos\theta}{\int_{-1}^1 \mathcal{W}(s, s_{13}, s_{23}, \cos\theta) d\cos\theta} = \lambda_\gamma \frac{3}{8} \frac{b(s, s_{13}, s_{23})}{a(s, s_{13}, s_{23})}$$

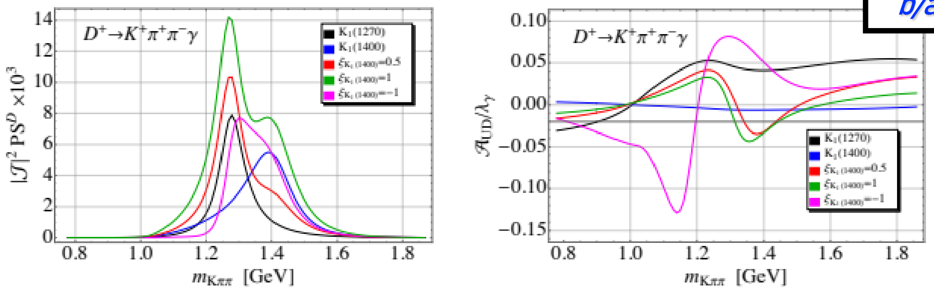


Angular distributions:

$$\mathcal{W}(s, s_{13}, s_{23}, \cos\theta) \propto a(s, s_{13}, s_{23})(1 + \cos^2\theta) + \lambda_\gamma b(s, s_{13}, s_{23}) \cos\theta$$

$K_1^+{}_{(1270,1400)} \to K\pi\pi$ is studied in detail at ACMMOR experiment. By performing amplitude analysis, the a& b functions are obtained. The result has been shown for D decay (but it is the same for B decay).

b/a



N. Adolph, G. Hiller, A. Tayduganov, *Testing the standard model with D(s)→K1(→Kππ)γ decays*, 1812.04679

Appendix : more about angular distributions

It is worth notifying that:

- K(1270) and K(1400) affects only c_1 and c_2.
- K(1430) affects all c_1, c_2, and c_3.
- K(1410) and K(1680) only affects c_3.

The different amplitudes with various spin-parity can be expressed as

$$\mathcal{M}^V_{(P_iP_j)P_k} = [c_1\vec{p}_1 - c_2\vec{p}_2 + c_3(\vec{p}_1 \times \vec{p}_2)] \cdot \vec{\epsilon}_{K_{res}}, \quad (1)$$

where $c_1(s, s_{13}, s_{23})$, $c_2(s, s_{13}, s_{23})$, and $c_3(s, s_{13}, s_{23})$ are the functions containing the Kaon information.

In the rest frame of kaonic resonance, $\vec{p}_1 + \vec{p}_2 + \vec{p}_3 = 0$, we find

$$\vec{p}_{1,2} = |\vec{p}_{1,2}|\,(\cos\theta\cos\phi_{1,2},\ \sin\phi_{1,2},\ -\sin\theta\cos\phi_{1,2}), \quad (2)$$

and

$$\vec{\epsilon}_{K_{res}} = \frac{1}{\sqrt{2}}(1,\ \lambda i,\ 0), \quad (3)$$

where $\lambda = \pm 1$ for right-handed and left-handed polarisation.

$$\begin{aligned}|\mathcal{M}^V_{(P_iP_j)P_k}|^2(\lambda) = {}& \frac{1}{4}\Big(2a - (a + a_2\cos 2\phi + a_3\sin 2\phi)\sin^2\theta + \lambda b\cos\theta\Big) \\ &+ \frac{1}{2}a_4\sin^2\theta \\ &+ (\tilde{a}_1\cos\phi + \tilde{a}_2\sin\phi)\sin\theta\cos\theta + \lambda(\tilde{b}_1\cos\phi + \tilde{b}_2\sin\phi)\sin\theta,\end{aligned} \quad (15)$$

where

$$a = |c_1|^2|\vec{p}_1|^2 + |c_2|^2||\vec{p}_2|^2 - 2\mathfrak{Re}(c_1c_2^*)|\vec{p}_1||\vec{p}_2|\cos\delta, \quad (16)$$

$$a_2 = (|c_1|^2|\vec{p}_1|^2 + |c_2|^2||\vec{p}_2|^2)\cos\delta - 2\mathfrak{Re}(c_1c_2^*)|\vec{p}_1||\vec{p}_2|, \quad (17)$$

$$a_3 = (|c_1|^2|\vec{p}_1|^2 - |c_2|^2||\vec{p}_2|^2)\sin\delta, \quad (18)$$

$$b = -4\mathfrak{Im}(c_1c_2^*)|\vec{p}_1||\vec{p}_2|\sin\delta, \quad (19)$$

$$a_4 = |c_3|^2||\vec{p}_1|^2|\vec{p}_2|^2\sin^2\delta, \quad (20)$$

$$\tilde{a}_1 = (\mathfrak{Re}(c_1c_3^*)|\vec{p}_1|^2|\vec{p}_2| - \mathfrak{Re}(c_2c_3^*)|\vec{p}_1||\vec{p}_2|^2)\cos(\delta/2)\sin\delta, \quad (21)$$

$$\tilde{a}_2 = (\mathfrak{Re}(c_1c_3^*)|\vec{p}_1|^2|\vec{p}_2| + \mathfrak{Re}(c_2c_3^*)|\vec{p}_1||\vec{p}_2|^2)\sin(\delta/2)\sin\delta, \quad (22)$$

$$\tilde{b}_1 = -(\mathfrak{Im}(c_1c_3^*)|\vec{p}_1|^2|\vec{p}_2| - \mathfrak{Im}(c_2c_3^*)|\vec{p}_1||\vec{p}_2|^2)\cos(\delta/2)\sin\delta, \quad (23)$$

$$\tilde{b}_2 = -(\mathfrak{Im}(c_1c_3^*)|\vec{p}_1|^2|\vec{p}_2| + \mathfrak{Im}(c_2c_3^*)|\vec{p}_1||\vec{p}_2|^2)\sin(\delta/2)\sin\delta. \quad (24)$$