Labnotes

Kylie Tailin Zhu

February 27, 2020

27 Jan 2020, Monday

Catch up the work done in the last term:

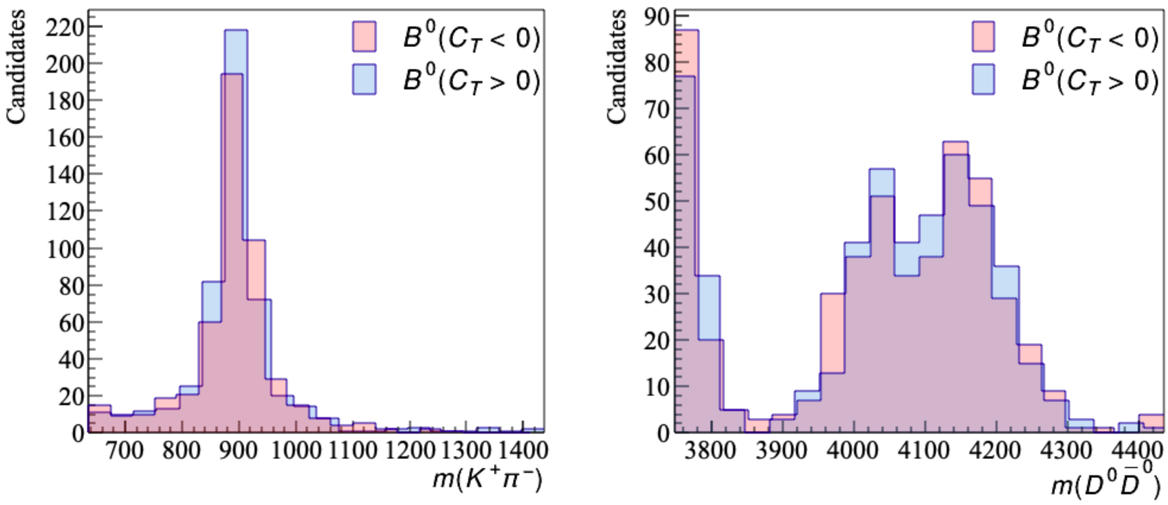


Figure 1: The binned distributions of simulated B^0 events in the variables of $m(K^+\pi^-)$ (left) and $m(D^0\bar{D}^0)$ (right) for different values of C_T.

A summary of previous work:

- Found the resonance for the Kπ and $D\bar{D}$ final states with the 1000 events for the $C_T > 0$ and $C_T < 0$ cases. The data has already been in the initial frame of B^0, so no Lorentz boost is required.

- Find the triple product asymmetry of the simulated data using
  $(N(C_T > 0) - N(C_T < 0))/(N(C_T > 0) + N(C_T < 0))$,
  which gives
  (501-499)/(501+499) = 0.002.

- calculating the invariant mass of $m(D^0\bar{D}^0K^+\pi^-)$ find that all the values equal to 5279.4 MeV/c^2, which is the mass of B^0. Since all the data are generated to give this.

Next Steps:

- Find the errors in the triple product asymmetry

- Fit the binned distributions using the Breit-Wigner distributions and Poisson distribution

- Find the distribution of other CM variables

Triple Product asymmetry:
Given a Poisson distribution, the error in $N(C_T > 0)$ is simply $\sqrt{N(C_T > 0)}$ for a large number of samples, and for $N(C_T < 0)$ is $\sqrt{N(C_T < 0)}$. Denote the asymmetry A_T as

$$A_T = \frac{N_+ - N_-}{N_+ + N_-}, \tag{1}$$

I can calculate the error in A_T as

$$\begin{aligned}\Delta A_T &= (\frac{\partial A_T}{\partial N_+}\Delta N_+)^2 + (\frac{\partial A_T}{\partial N_-}\Delta N_-)^2 \\ &= (\frac{2N_-}{(N_+ + N_-)^2})^2 N_+ + (\frac{-2N_+}{(N_+ + N_-)^2})^2 N_-.\end{aligned} \tag{2}$$

The result is $A_T = 0.002 \pm 0.0316$, using $C_T = \vec{p}_{K^+} \cdot (\vec{p}_{D^0} \times \vec{p}_{\bar{D}^0})$ This error is much larger than the result which indicates that no CP violation is in this sample.

28 Jan 2020, Tuesday

Aiming to find the distribution of the five CM variables:

- the invariant masses of daughter pairs in the rest frame of the mother particle B^0: $m(D^0\bar{D}^0)$, $m(K^+\pi^-)$
- the cosine of the helicity angles between the daughter particle and the mother-particle B^0, in the rest frame of its daughter pairs
  - $\cos(\theta_{D^0})$ between the momentum of D^0 and B^0 in the center of mass frame of $D^0\bar{D}^0$
  - $\cos(\theta_{K^+})$ between the momentum of K^+ and B^0 in the center of mass frame of $K^+\pi^-$
  - to boost the momentum to the daughter pair rest frame:
    daughter pair rest frame has four-momentum
    $$\boldsymbol{P} = (p_{1x} + p_{2x},\ p_{1y} + p_{2y},\ p_{1z} + p_{2z},\ E_1 + E_2) = \boldsymbol{p}_1 + \boldsymbol{p}_2, \tag{3}$$
    the boost vector is then
    $$\vec{V} = (p_{1x} + p_{2x},\ p_{1y} + p_{2y},\ p_{1z} + p_{2z})/(E_1 + E_2) = (\vec{p_1} + \vec{p_2})/M. \tag{4}$$
  - M is not the invariant mass of the daughter pair, but the sum of the masses of two daughters, i.e.$E_1 + E + 2$.
  - particularly check the direction of the boost, sometimes need to add a minus sign before the boost vector
  - check if the boost is correct:
    a. boost the daughter pair Lorentz vector to its rest frame gives zero in the three-momentum.
    b. the distribution of the cos(angle) should look uniform and not peak at one side of the graph.
- the angle ϕ between the planes of the daughter pairs in the rest frame of mother particle B^0. In this case, the between the plane $D^0\bar{D}^0$ and the plane $K^+\pi^-$.

The distributions were found with 100 bins:

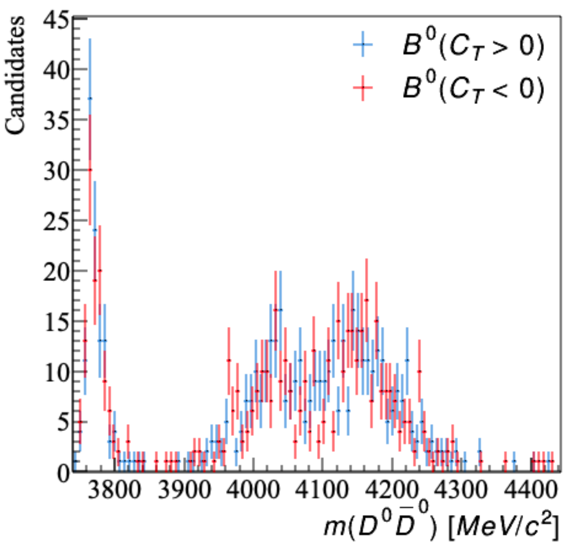


Figure 2: The binned distributions of invariant mass $m(D^0\bar{D}^0)$ for different values of C_T.

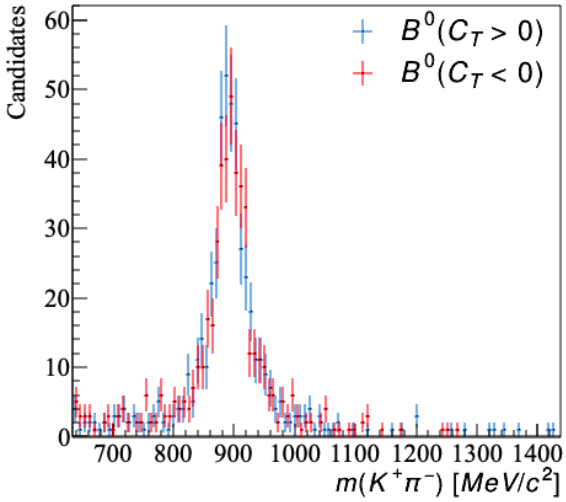


Figure 3: The binned distributions of invariant mass $m(K^+\pi^-)$ for different values of C_T.

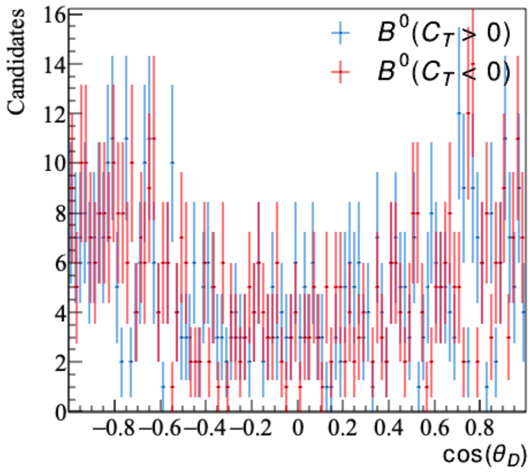


Figure 4: The binned distributions of helicity angle $\cos(\theta_{D^0})$ for different values of C_T.

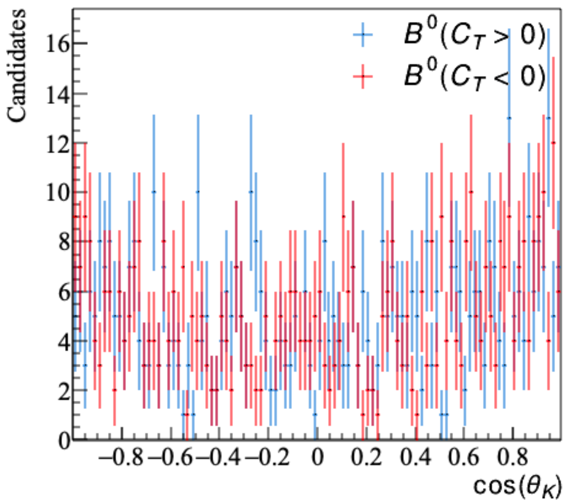


Figure 5: The binned distributions of helicity angle $\cos(\theta_{K^+})$ for different values of C_T.

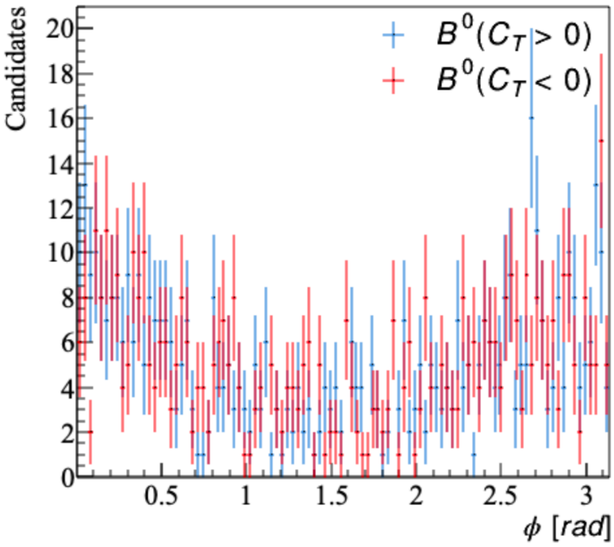


Figure 6: The binned distributions of the angle ϕ bbetween the plane $D^0\bar{D}^0$ and the plane $K^+\pi^-$ for different values of C_T.

29 Jan 2020, Wednesday

Fitting the invariant mass distributions using the relativistic Breit-Wigner distribution:

$$f(E) = \frac{k}{(E^2 - M^2)^2 + M^2\Gamma^2}, \tag{5}$$

$k = \frac{2\sqrt{2}M\Gamma\gamma}{\pi\sqrt{M^2+\gamma}}$,
$\gamma = \sqrt{M^2(M^2+\Gamma^2)}$,
E - center of mass energy that produce the resonance,
M - mass of the resonance,
Γ - resonance width.

Fit was performed using `ROOT` by defining a class for the fitting function. The left and right limit of the fit was roughly approximated from the left and right ends of the peaks in the histogram. This gives individual fitting for each peak.

The fitted results are given by:

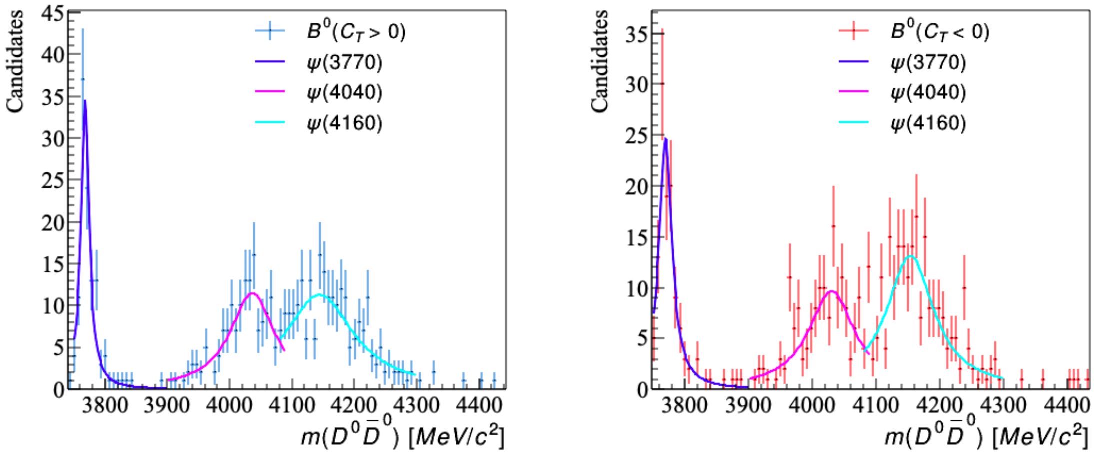


Figure 7: The binned distributions of invariant mass $m(D^0\bar{D}^0)$ for different values of C_T fitted using Eq.5

resonance	mass(M)	err_mass	width(Gamma)	err_width	Chi2	type
psi(3770)	3770	0.33	27.2	1		PDG
psi(3770)	3768.30	1.11	15.98	3.17	10.52	C_T > 0
psi(3770)	3769.36	1.62	24.52	3.96	8.95	C_T < 0
psi(4040)	4039	1	80	10		PDG
psi(4040)	4036.19	5.57	86.47	15.25	13.92	C_T > 0
psi(4040)	4030.10	5.21	88.63	17.02	29.27	C_T < 0
psi(4160)	4191	5	70	10		PDG
psi(4160)	4144.08	8.52	134.07	20.90	22.05	C_T > 0
psi(4160)	4153.57	4.17	90.23	11.73	30.86	C_T < 0

Figure 8: The fitted values from the curves in MeV

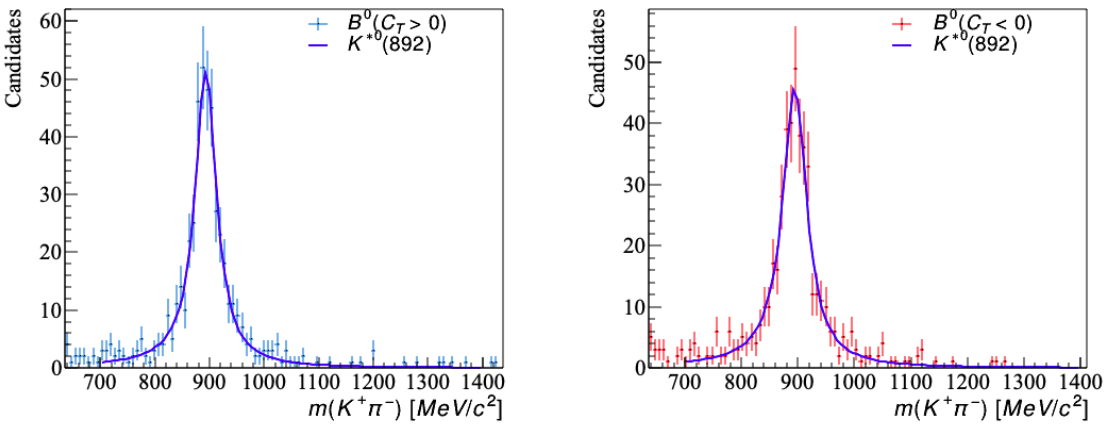


Figure 9: The binned distributions of invariant mass $m(K^+\pi^-)$ for different values of C_T fitted using Eq.5

resonance	mass(M)	err_mass	width(Gamma)	err_width	Chi2	type
K*0(892)	895.55	0.2	47.3	0.5		PDG
K*0(892)	893.52	1.53	48.07	3.55	37.29	C_T > 0
K*0(892)	894.35	1.65	52.39	3.90	34.30	C_T < 0

Figure 10: The fitted values from the curves in MeV

30 Jan 2020, Thursday

Start trying to download AmpGen:

The main problem is that the AmpGen is downloaded but not be able to compile it, with the problem

```
ignoringfile/Library/Developer/CommandLineTools/SDKs/MacOSX10.14.s
dk/usr/lib/libSystem.tbd,filewasbuiltforunsupportedfileformat(0x2D
0x2D0x2D0x200x210x740x610x700x690x2D0x740x620x640x2D0x760x33)which
isnotthearchitecturebeinglinked(x86_64):/Library/Developer/CommandL
ineTools/SDKs/MacOSX10.14.sdk/usr/lib/libSystem.tbd
Undefined symbols for architecture x86_64:
```

One method tried:

Download a different version of the sdk: MacOSX10.10.sdk.tzr.xz, which is suggested from here and here.

Uncompress it to the `/opt` directory in the laptop:

```
sudo tar xf  /Downloads/MacOSX10.10.sdk.tar.xz -C /opt
```

Add the lines into the file `$HOME/.condarc`:

```
conda_build:
  config_file:~/.conda/conda_build_config.yaml
```

Here is more details of using conda_build.

Then create the file `$HOME/.conda/conda_build_config.yaml` and add:

```
CONDA_BUILD_SYSROOT:
  - /opt/MacOSX10.10.sdk # [osx]
```

- But this doesn't work.

4 Feb 2020, Tuesday

AmpGen: now find a way to work from Paras - Remove everything that has been done before and follow the instructions on the installation notes.

AmpGen has been succeeded installed - now analysis the $D \to K^+K^-\pi^+\pi^-$ decay using the previous written code and check if its working correctlyy.

6 Feb 2020, Thursday

Outputs from AmpGen generated events:

1. $D^0 \to K^+K^-\pi^+\pi^-$

run the DtoKKpipi_v2.opt file
Number of Events: 171300
$C_T = \vec{p}_{\pi^-} \cdot (\vec{p}_{K^+} \times \vec{p}_{K^-})$

TP Asymmetry $A_T = -0.0740 \pm 0.0024$

The distributions of CM variables with 100 bins:

The distributions match the distributions in the literature, which means AmgGen can give correct results.

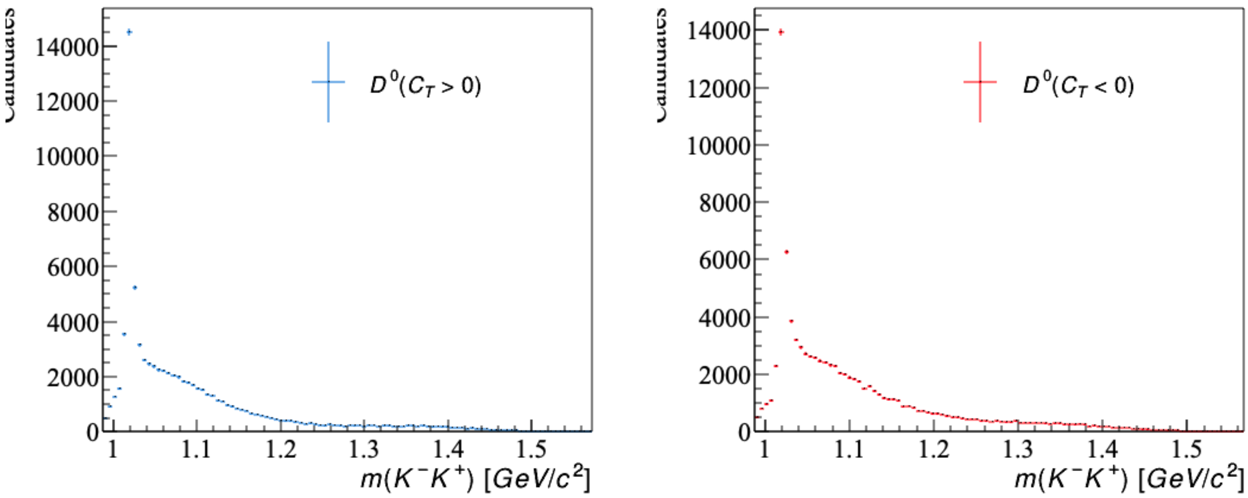


Figure 11: The binned distributions of invariant mass $m(K^-K^+)$ for different values of C_T.

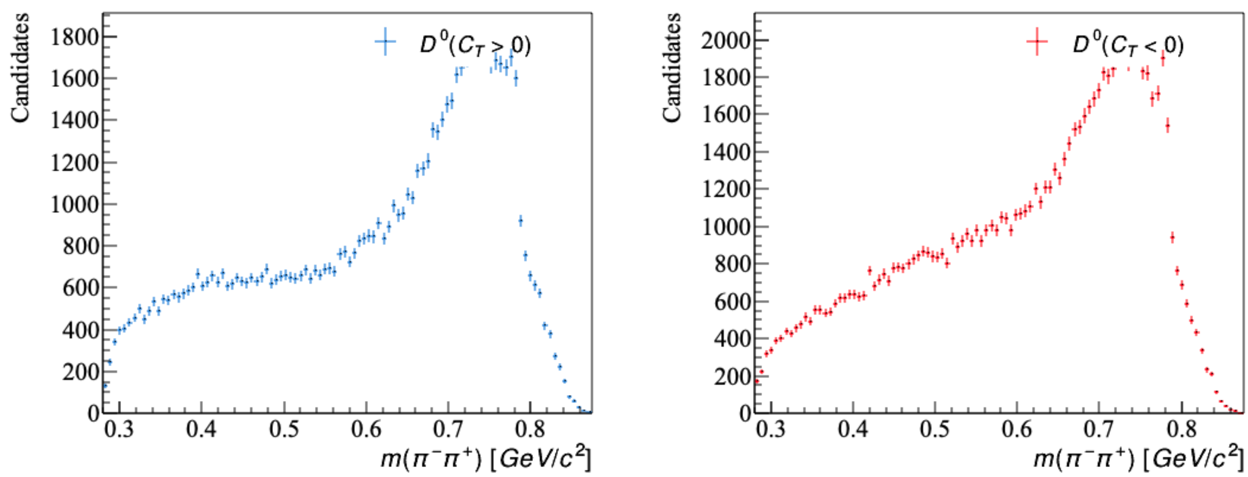


Figure 12: The binned distributions of invariant mass $m(\pi^-\pi^+)$ for different values of C_T.

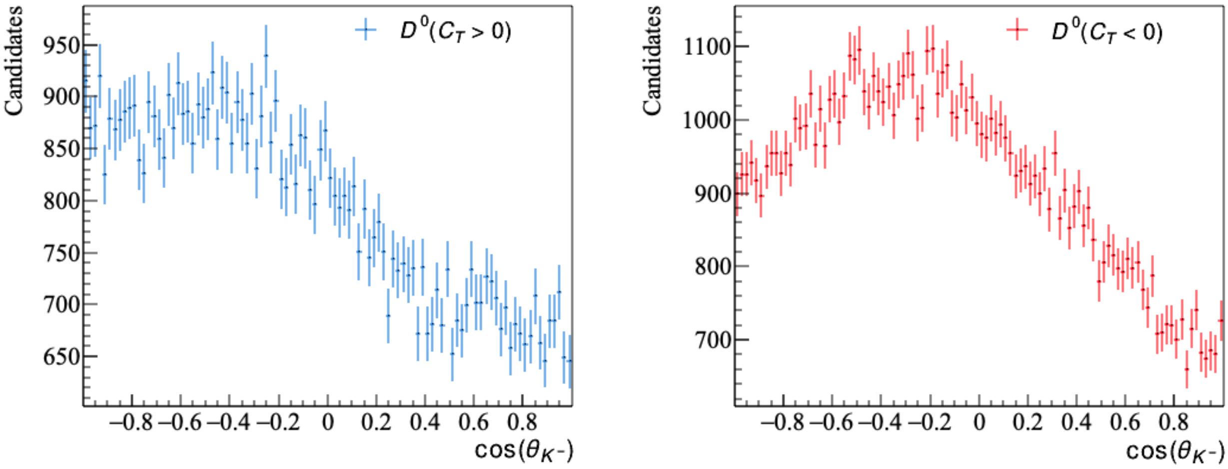


Figure 13: The binned distributions of helicity angle $\cos(\theta_{K^+})$ for different values of C_T.

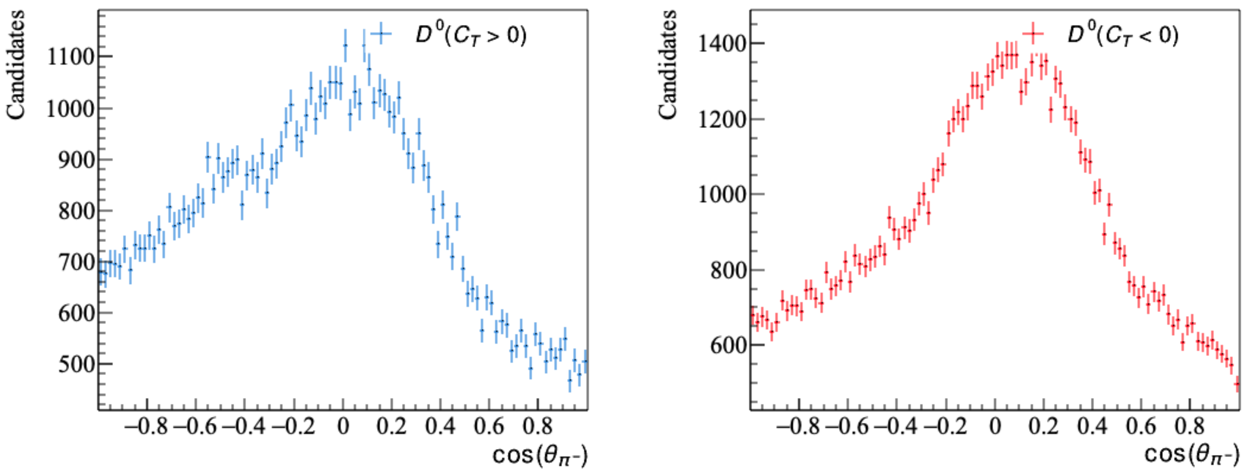


Figure 14: The binned distributions of helicity angle $\cos(\theta_{\pi^+})$ for different values of C_T.

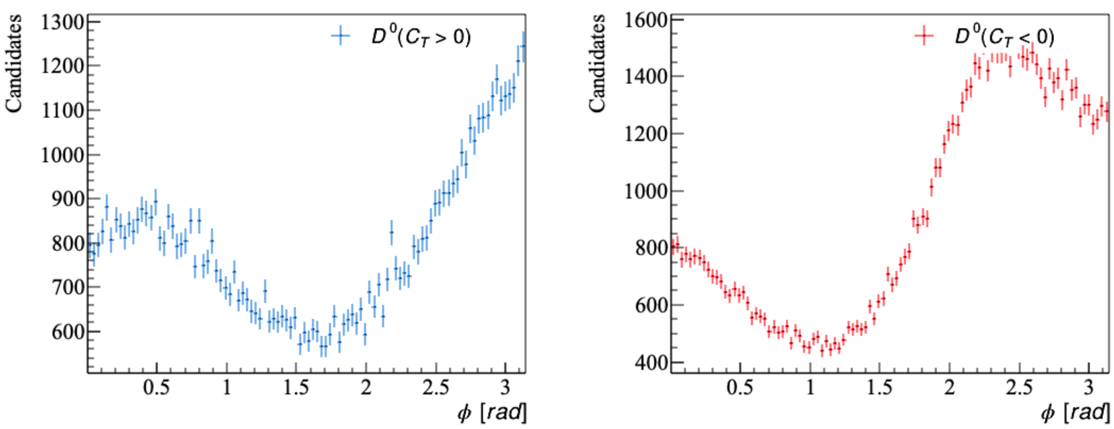


Figure 15: The binned distributions of the angle ϕ bbetween the plane K^-K^+ and the plane $\pi^-\pi^+$ for different values of C_T.

Use AmpGen to generate $B^0 \to D^0 \bar{D}^0 K^+ \pi^-$ events.

Changes made with AmpGen:

- add B0toDDbar0K+pi-.opt file to /AmpGen/build/bin/
- inside the B0toDDbar0K+pi-.opt file, use the resonances from the MINT file (4BodyModel.txt), change the format of the resonance list and numerical values to adapt AmpGen.
- inside the B0toDDbar0K+pi-.opt file, change `kappa0` to `K(0)*(800)0` - the particle name has been updated in PDG.
- inside the B0toDDbar0K+pi-.opt file, change the non resonance part

  e.g. change `D0Dbar0` to `NonResS0{D0,Dbar0}`.

  From Paras: This will improve the speed considerably when including the narrow D* resonances. It only works if all decays are done in quasi-two-body steps (i.e. B-¿psi K* as a resonance works, but B-¿ D Dbar K* doesn't)
- inside the mass_width.csv file, change line 385: J=2, P=+ for particle D(s2)(2573).

2. $B^0 \to D^0 \bar{D}^0 K^+ \pi^-$

Fit the results for different events...
This still uses Eq.5 to fit but using a different approach - by summing over the Breit-Wigner functions for each peak. In this case, the events are not enough to make a clear fit for the left figure in Fig.17, the right figure in Fig.18, and the left figure in Fig.19. The fitting outcomes for resonance peaks are shown in Fig.16. For the successfully fitted peaks, it gives the expected results.

a. old results from MINT - 1000 events: $A_T = 0.002 \pm 0.0316$

bin=40 A1=45 A2=40 A3=50

resonance	mass(M)	err M	width	err w	Chi2	type	
psi(3770)	3770	0.33	27.2	1		PDG	
psi(3770)	3771.31	0.67	18.29	1.91	127.20	combined	
psi(3770)	3771.37	1.26	20.61	3.80	44.53	C_T > 0	
psi(3770)	3767.06	1.29	16.95	5.06	24.09	C_T < 0	
psi(4040)	4039	1	80	10		PDG	D0Dbar0
psi(4040)	4117.43	3.80	192.86	12.04	127.20	combined	
psi(4040)	4106.79	5.85	220.99	22.96	44.53	C_T > 0	
psi(4040)	4155.43	4.53	84.13	11.20	24.09	C_T < 0	
psi(4160)	4191	5	70	10		PDG	
psi(4160)	760.09	276.88	1.06E6	1.32E4	127.20	combined	
psi(4160)	-0.09	0.50	9.92E6	2.899E7	44.53	C_T > 0	
psi(4160)	4027.25	5.10	61.49	11.41	24.09	C_T < 0	
K*0(892)	895.55	0.2	47.3	0.5		PDG	K+pi-
K*0(892)	893.33	1.15	54.14	2.74	45.24	combined	
K*0(892)	892.69	1.55	51.55	3.90	17.84	C_T > 0	
K*0(892)	897.09	311.89	0.30	311.88	367.96	C_T < 0	

Figure 16: The fitted values from the curves in Fig.17,18,19(MeV)

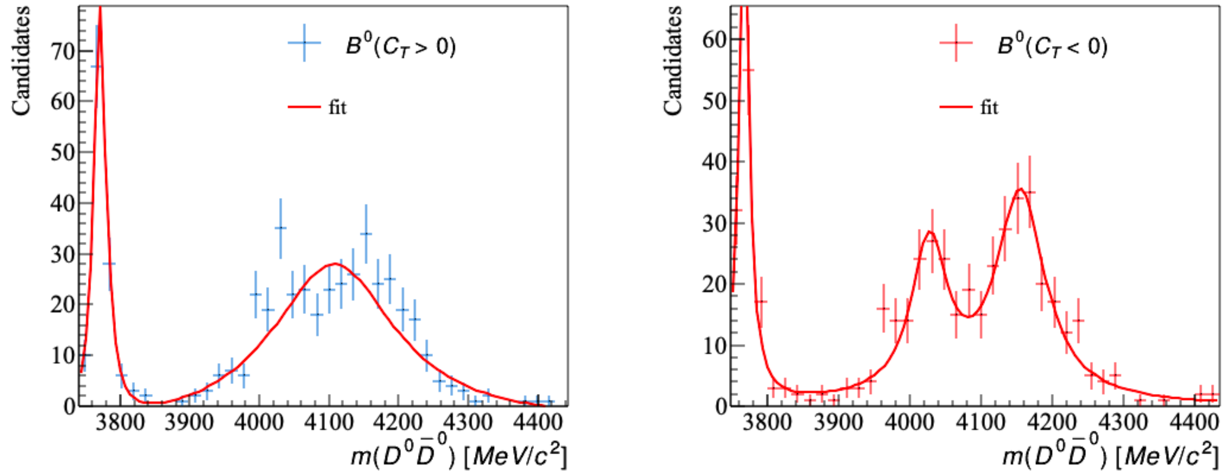


Figure 17: The binned distributions of invariant mass $m(D^0\bar{D}^0)$ for different values of C_T.

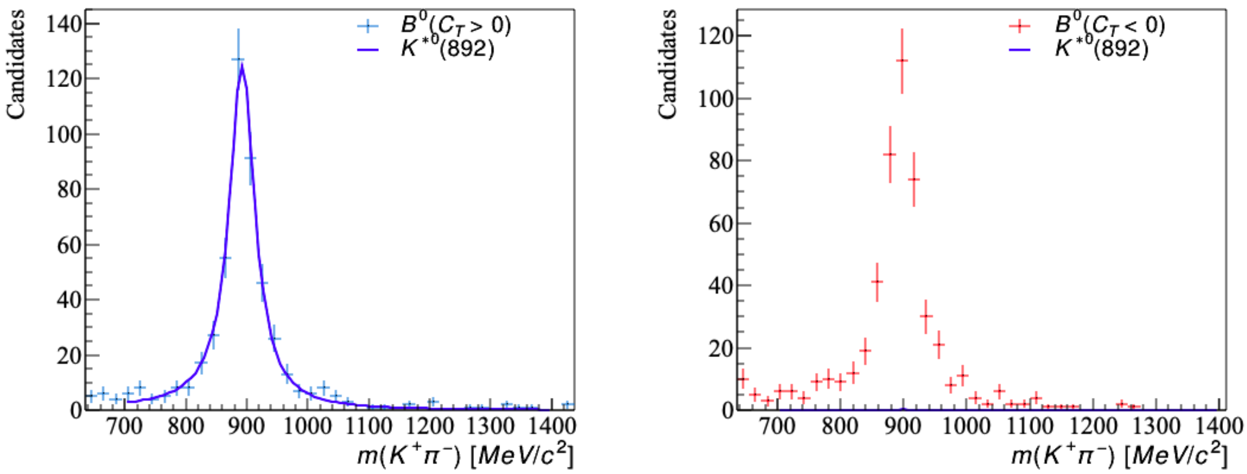


Figure 18: The binned distributions of invariant mass $m(K^+\pi^-)$ for different values of C_T.

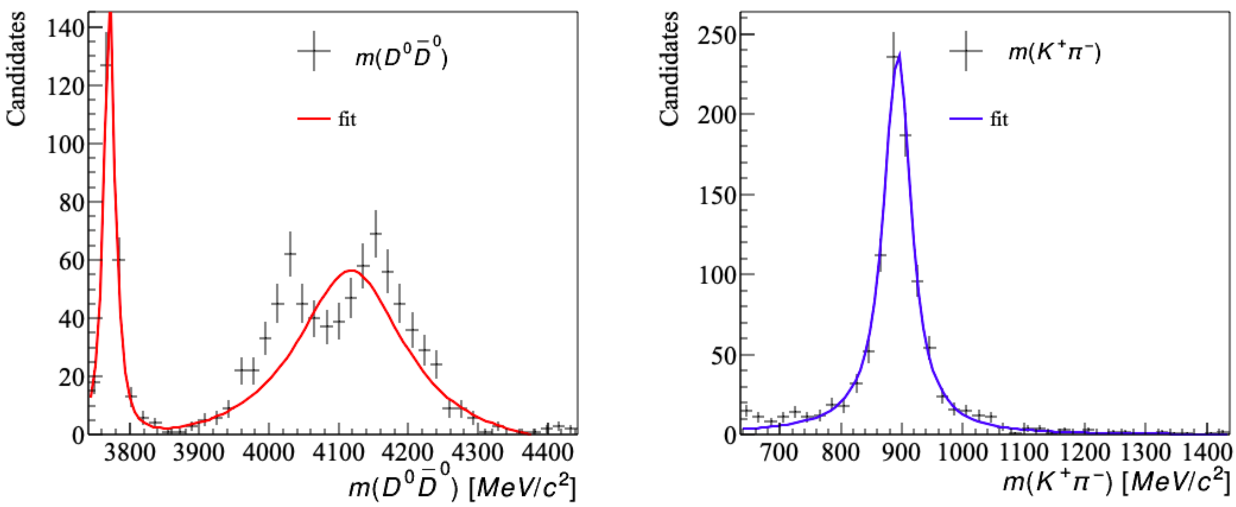


Figure 19: The binned distributions of invariant mass $m(D^0\bar{D}^0)$ with combining data from $C_T < 0$ and $C_T > 0$.

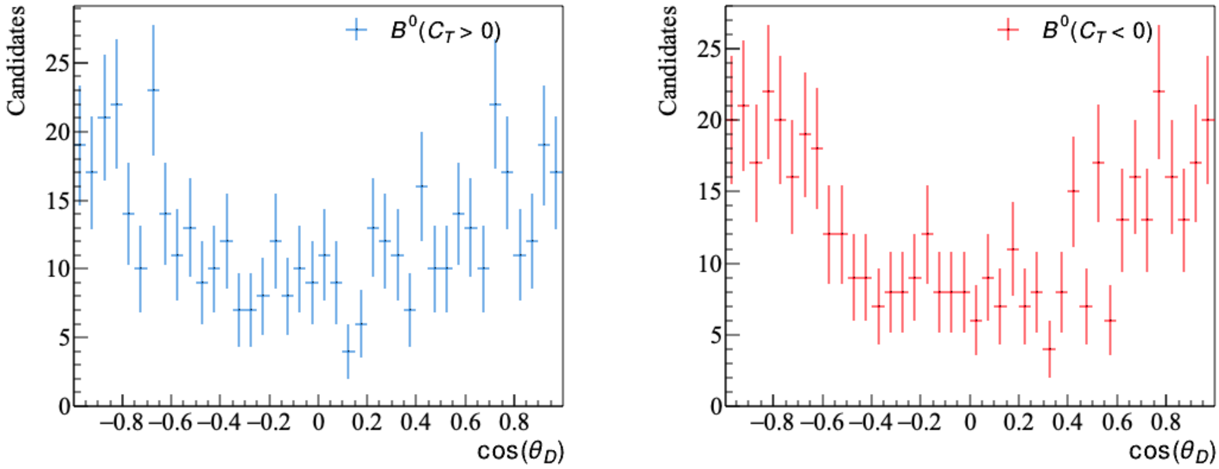


Figure 20: The binned distributions of helicity angle $\cos(\theta_{D^0})$ for different values of C_T.

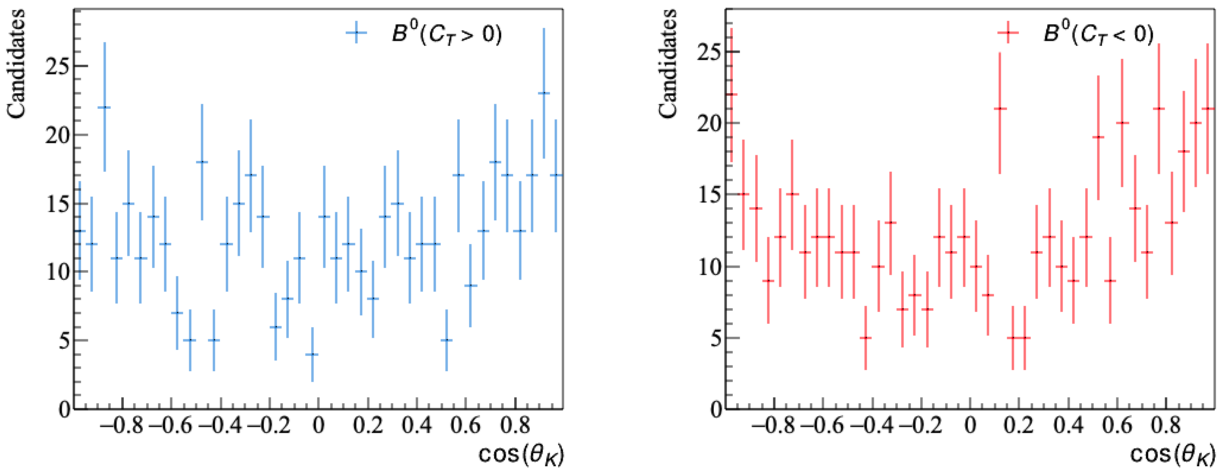


Figure 21: The binned distributions of helicity angle $\cos(\theta_{K^+})$ for different values of C_T.

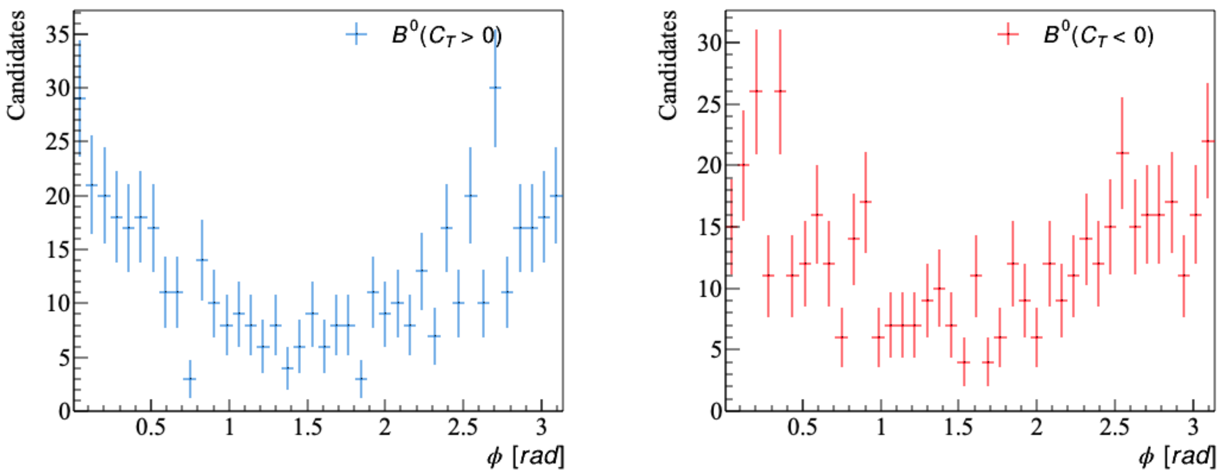


Figure 22: The binned distributions of the angle ϕ bbetween the plane $D^0\bar{D}^0$ and the plane $K^+\pi^-$ for different values of C_T.

In order to have better fittings, more events were generated.

b. AmpGen - 10000 events: $A_T = 0.0156 \pm 0.0099987$

This fit the data properly with an increasing confident level and errors 10^2 smaller in the fitted parameters. An investigation in the confidence level of A_T, the errors in the parameters vs the number of events can be carried out.

For Fig.27, Fig.28, Fig.29, it was asked why the peaks are downwards rather than upwards in the LHCb seminar (8th Feb). It is also expected to be more flat for the helicity angles?

bin=100 A1=10 A2=10 A3=10

resonance	mass(M)	err_M	width	err_w	Chi2	type	
psi(3770)	3.770	0.00033	0.0272	0.001		PDG	
psi(3770)	3.7726	0.0005	0.0236	0.0010	578.2912	combined	
psi(3770)	3.7718	0.0006	0.0215	0.0014	217.7001	C_T > 0	
psi(3770)	3.7729	0.0007	0.0236	0.0014	243.6756	C_T < 0	
psi(4040)	4.039	0.001	0.08	0.01		PDG	
psi(4040)	4.0209	0.0020	0.1206	0.0049	578.2912	combined	D0Dbar0
psi(4040)	4.0203	0.0029	0.1305	0.0086	217.7001	C_T > 0	
psi(4040)	4.0225	0.0031	0.1276	0.0083	243.6756	C_T < 0	
psi(4160)	4.191	0.005	0.07	0.01		PDG	
psi(4160)	4.1599	0.0014	0.0878	0.0028	578.2912	combined	
psi(4160)	4.1612	0.0020	0.0944	0.0047	217.7001	C_T > 0	
psi(4160)	4.1589	0.0022	0.0968	0.0045	243.6756	C_T < 0	
K*0(892)	0.89555	0.0002	0.0473	0.0005		PDG	
K*0(892)	0.8941	0.0003	0.0495	0.0008	123.0759	combined	
K*0(892)	0.8943	0.0005	0.0498	0.0011	112.0466	C_T > 0	K+pi-
K*0(892)	0.8939	0.0005	0.0478	0.0010	94.4253	C_T < 0	

Figure 23: The fitted values from the curves in Fig.24,25,26(MeV)

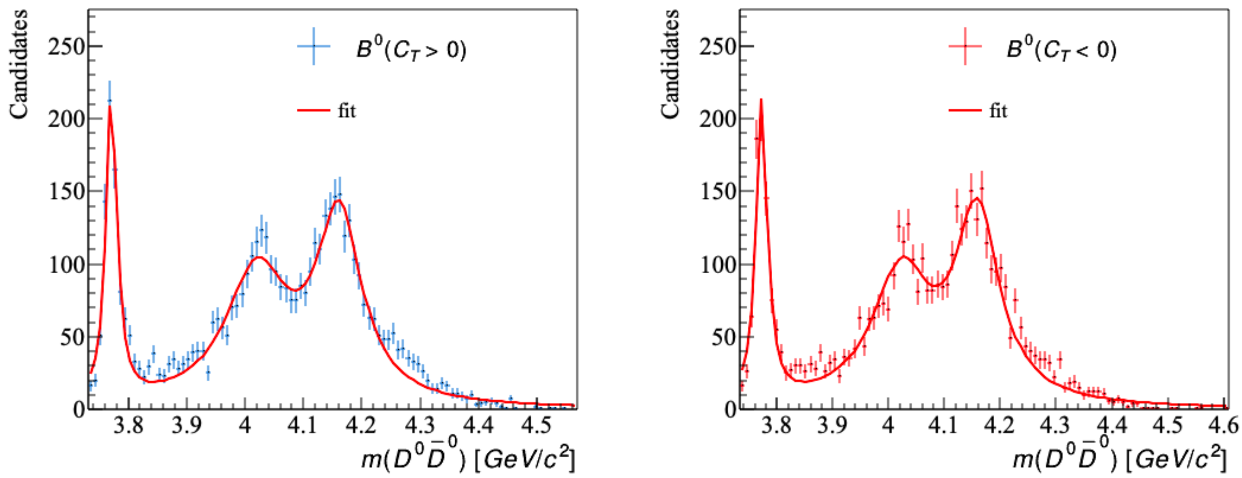


Figure 24: The binned distributions of invariant mass $m(D^0\bar{D}^0)$ for different values of C_T.

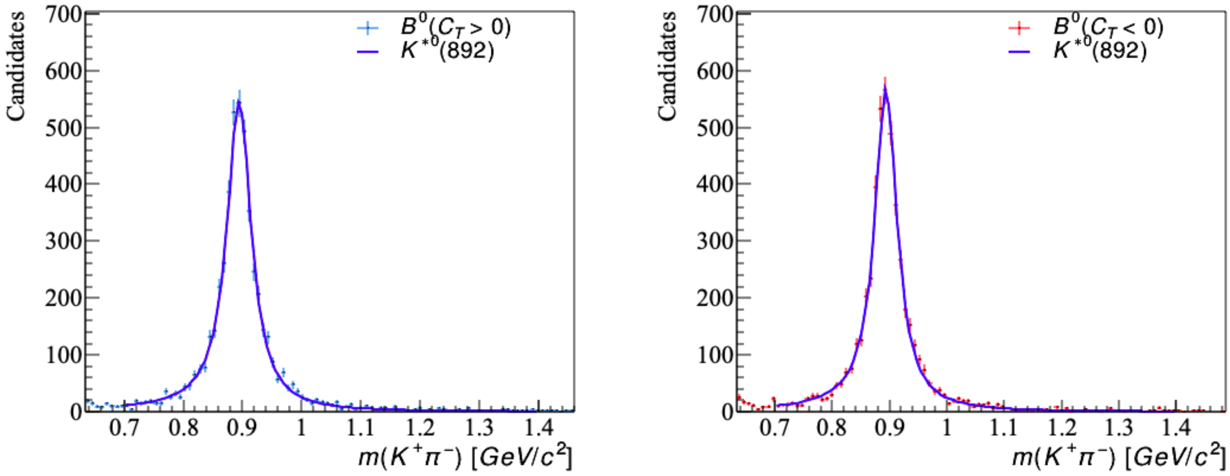


Figure 25: The binned distributions of invariant mass $m(K^+\pi^-)$ for different values of C_T.

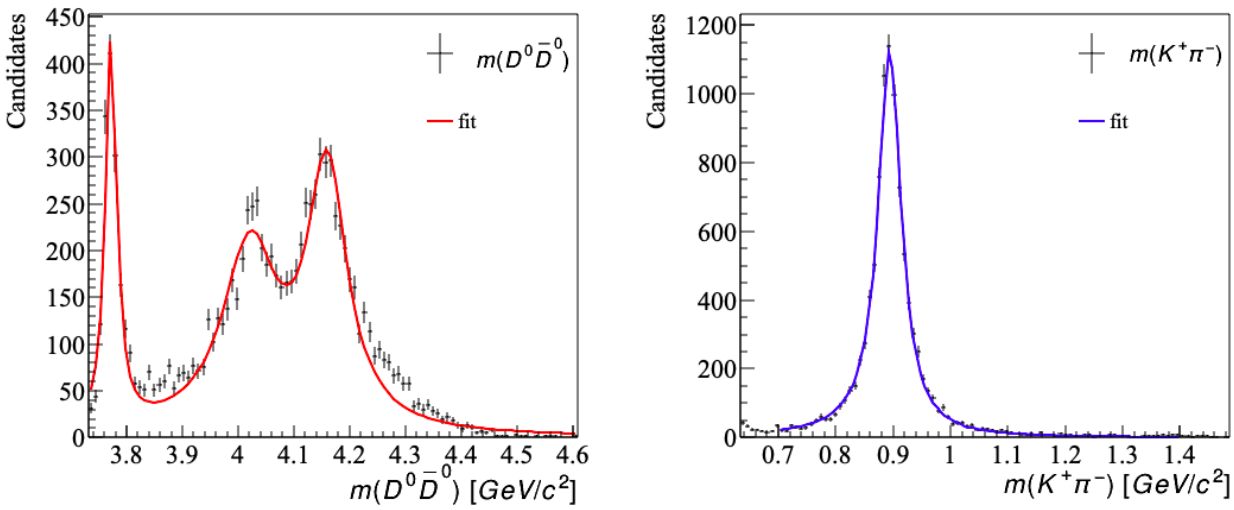


Figure 26: The binned distributions of invariant mass $m(D^0\bar{D}^0)$ for different values of C_T.

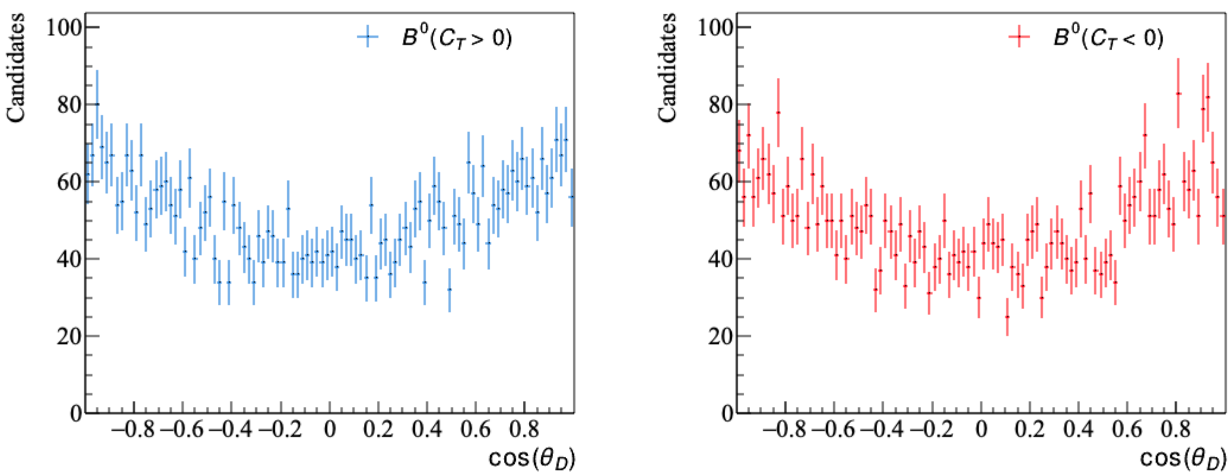


Figure 27: The binned distributions of helicity angle $\cos(\theta_{D^0})$ for different values of C_T.

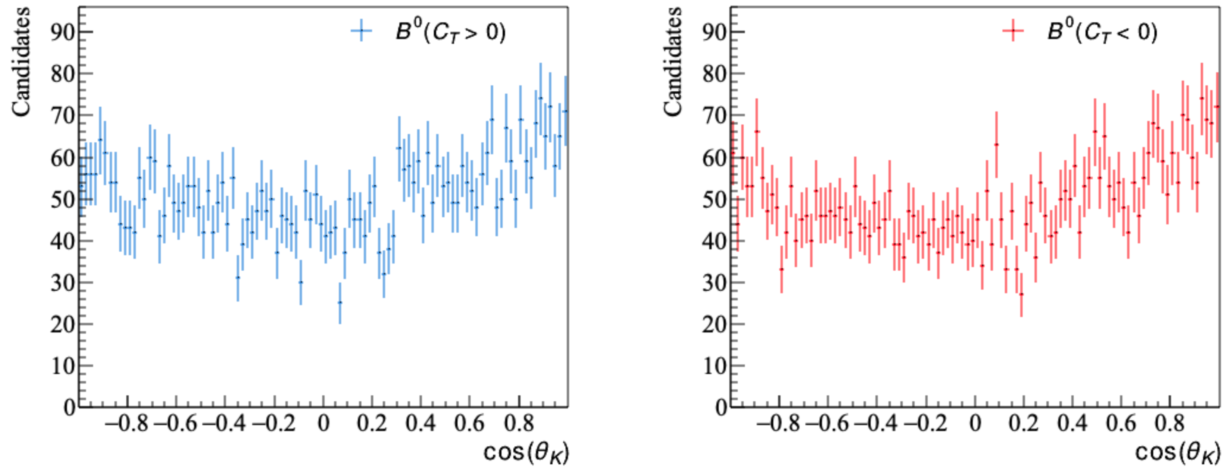


Figure 28: The binned distributions of helicity angle $\cos(\theta_{K^+})$ for different values of C_T.

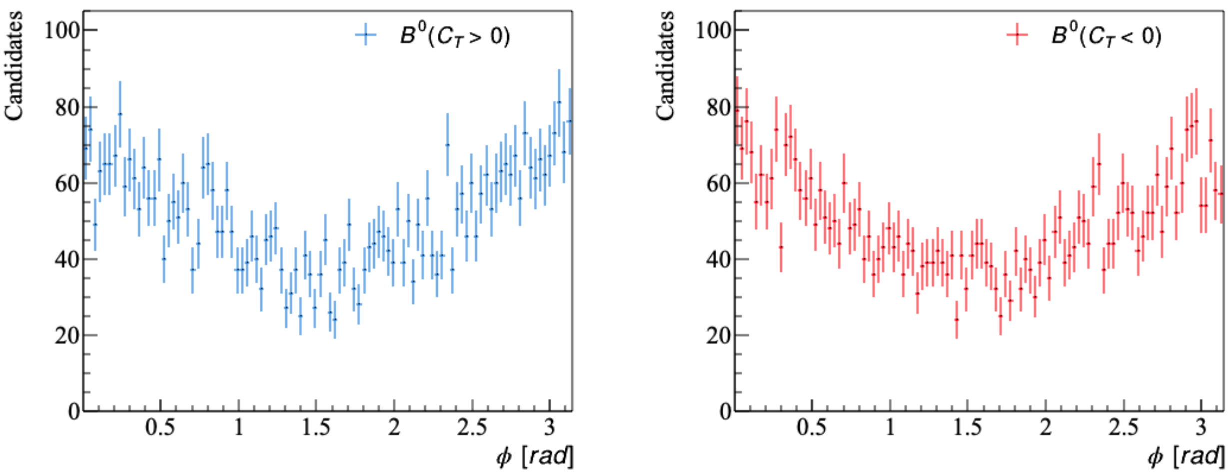


Figure 29: The binned distributions of the angle ϕ between the plane $D^0\bar{D}^0$ and the plane $K^+\pi^-$ for different values of C_T.

7 Feb 2020, Friday

To do list:

- CP violation for D0 and for B0 decay.
- split spins, 1/3 amplitude and make the phase equal
- check the amount of CP violation vs number of events
- check p violation in several decay modes
- check K∼, pi# meaning in the root file (try flipping the sign of the momentum for _3_K∼ and _4_pi#) ⇒ have got the same results for CM variables

The charge conjugate decays can be generated using a different Seed in AmpGen (e.g. add a line in the .opt file: Seed 6) and filpping the sign in the three momentum and adding a minus sign before $\bar{C}_T$.

a. Find the CP violation in $\boldsymbol{D^0 \to K^+K^-\pi^+\pi^-}$ decay:

Re-run the DtoKKpipi_v2.opt file using Seed 5, gives

$\bar{A}_T = -0.072563 \pm 0.0024$, and together with
$A_T = -0.073987 \pm 0.0024$ (previous results),
gives $\mathcal{A}_{\mathcal{CP}} = 0.5(A_T - \bar{A}_T) = -0.000712 \pm 0.0017$.

This is over a half smaller than the literature.

b. Find the CP violation in $\boldsymbol{B^0 \to D^0\bar{D}^0K^+\pi^-}$ decay:

Re-run the B0toDDbar0K+pi-.opt file twice after adding `NonResS0`, with 10000 events, using Seed 5 and 7, gives

$A_T = 0.012 \pm 0.00999927$,
$\bar{A}_T = 0.0102 \pm 0.00999947$,
and, hence $\mathcal{A}_{\mathcal{CP}} = 0.5(A_T - \bar{A}_T) = 0.0008999999999999998 \pm 0.007070622334946903$.

For 100000 events, with the B0 decay, no seed specified (seed 0), gives

$A_T = 0.0014978601997146933 \pm 0.003447862046481769$,

conjugate process using Seed 8 gives,

$\bar{A}_T = -0.00148 \pm 0.0031622741968399893$,

find $\mathcal{A}_{\mathcal{CP}} = 0.001488930099857346 \pm 0.002339216256974195$.

This value of $\mathcal{A}_{CP}$ was investigated further for a range of event numbers:

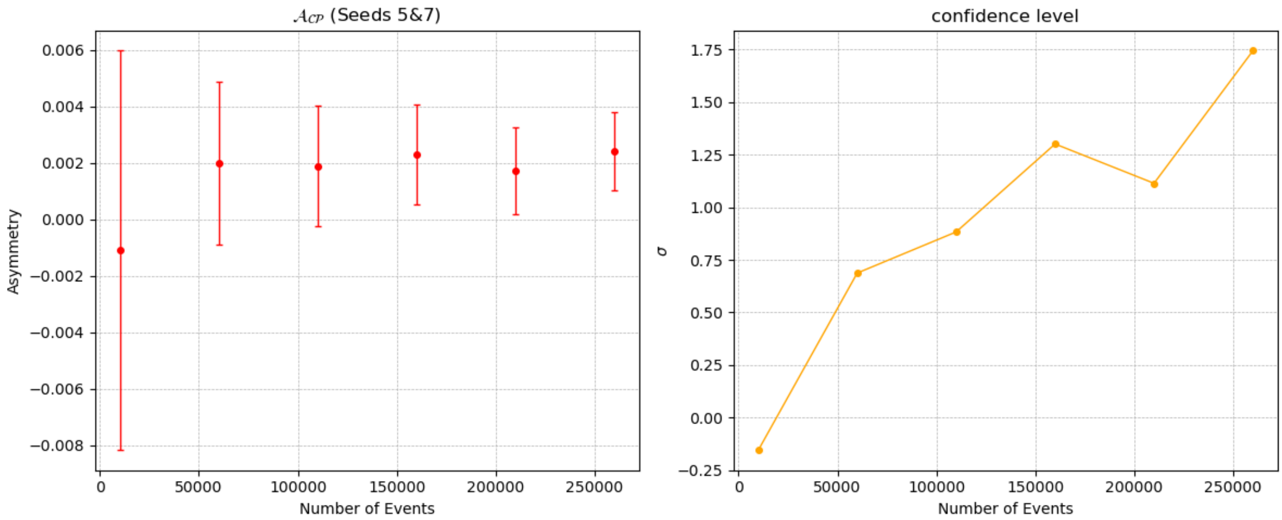


Figure 30: The asymmetries calculated for different number of events.

It can be seen that the a_{CP} is slightly deviated from zero with errorbars becoming smaller and excluding zero, but the confidence level is less than 2σ, where $\sigma = asymmetry/\Delta(asymmetry)$. Clearly, more events need to be generated to see the trend of asymmetry and error bars.

13 Feb 2020, Thursday

Generate the S, P, D waves for two spin-1 particles

From Paras:

One is that we indeed still have to specify independent couplings of differing spin configurations separately. In practical terms, for the "vector-vector" decays i.e decays to two spin-1 particles (such as B-¿psi K*) we need to specify S P and D waves, there should be examples of this in the D-¿KKpipi opt file. We should discuss at some point how to split the amplitude and phase across the components (first instinct: make each amplitude 1/3 of the current value, and make all phases the same

So in the B0toDDbar0K+pi-_v3.opt file, the two spin-1 particles are:

$\psi(3770)$ and $K*(892)0$
$\psi(4040)$ and $K*(892)0$
$\psi(4160)$ and $K*(892)0$
$\psi(4415)$ and $K*(892)0$

The changes made are e.g

For a single resonance,

```
B0{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}  2  6.28  0.05  2  0.  10.
```

This was changed by taking 1/3 of the second number column - amplitude):

```
B0[S]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}  2  2.093  0.05  2  0.  10.
B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}  2  2.093  0.05  2  0.  10.
B0[D]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}  2  2.093  0.05  2  0.  10.
```

- There are no errors generated and gives different values in the output file.

Next:

Adjust the p waves and check p-violation
test for more event numbers
use different seeds

17 Feb 2020, Monday

The events were generated with increasing event numbers and smaller intervals. It can be seen in Fig.31 that there is a fluctuation in the asymmetries at around $2 \cdot 10^5$ events and the asymmetries goes to zero at larger events numbers. This shows no CP and P violation. The errors in the asymmetries decreases asymptotically closing to zero as the event number increases.

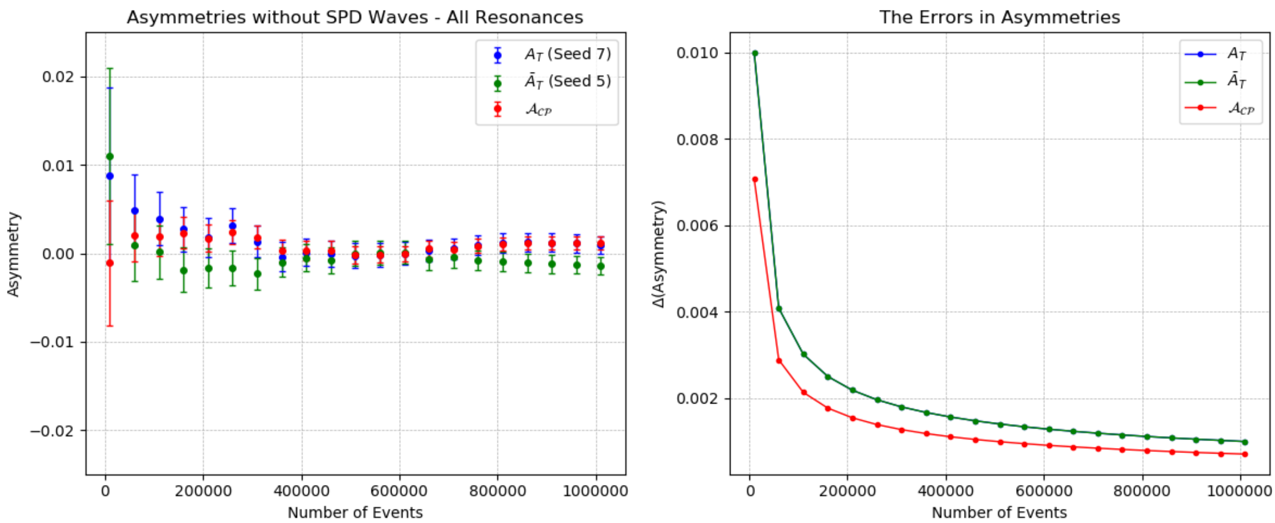


Figure 31: The asymmetries calculated for different number of events.

With the SPD waves, as shown in Fig.32, the values of A_T and $\bar{A}_T$ are no longer consistent with zero which means there are P violation induced in both decay processes.

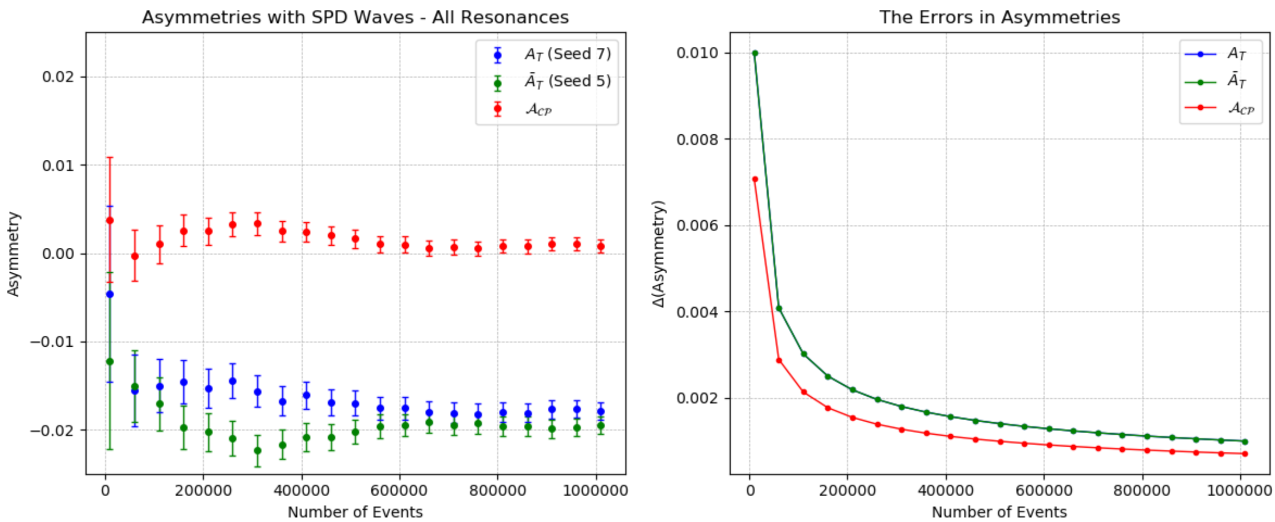


Figure 32: The asymmetries calculated for different number of events with equal SPD waves.

18 Feb 2020, Tuesday

This part starts by changing P waves in the resonance files:

A. Change all P wave amplitudes

Input files: AmpGen/build/bin/spd_waves_gen

Output files: Simulations/B02DDbarKPi/p_waves

event file (.opt) Example:

```
1  EventType B0 D0 Dbar0 K+ pi-
2
3  B0{NonResS0{D0,Dbar0},K*(892)0{K+,pi-}} 0   2.09    1.  0   0   10
4
5  B0{NonResS0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0   0.66    1.  0   0   10
6
7  B0{K(0)*(800)0{K+,pi-},NonResS0{D0,Dbar0}}  0   0.66    1.  0   0   10
8
9  B0{D(s2)(2573)+{D0,K+},Dbar0,pi-}   0       0.10   0.05 0       0.     10.
10
11 B0[S]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       2.093   0.05    2   0.  10.
12 B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.  10.
13 B0[D]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       2.093   0.05    2   0.  10.
14
15 B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.000826    0.05    0       0.  10.
16 B0[S]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.826       0.05    0       0.  10.
17 B0[D]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.826       0.05    0       0.  10.
18
19 B0[D]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       1.31    0.05    0.  0.  10.
20 B0[S]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       1.31    0.05    0.  0.  10.
21 B0[P]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.00131 0.05    0.  0.  10.
22
23 B0[P]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.00051 0.05    0.  0.  10.
24 B0[S]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.51    0.05    0.  0.  10.
25 B0[D]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.51    0.05    0.  0.  10.
26
27 B0{psi(3770)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       1.99    0.05    0.  0.  10.
28 B0{psi(4040)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       0.78    0.05    0.  0.  10.
29 B0{psi(4160)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       1.24  0.05  0.  0.  10.
30 B0{psi(4415)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       0.48  0.05  0.  0.  10.
31
32 B0{psi(3770)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       1.99  0.05  0.  0.  10.
33 B0{psi(4040)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       0.78  0.05  0.  0.  10.
34 B0{psi(4160)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       1.24  0.05  0.  0.  10.
35 B0{psi(4415)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       0.48  0.05  0.  0.  10.
36
37 #B0{Z(c)(3900)+{D*(2010)+{D0,pi+},Dbar0},K-}    2   1   0   2   0   0
```

Figure 33: An example of event file for the plot in Fig.36

Changed the second number column in line 12, 15, 21, 23.

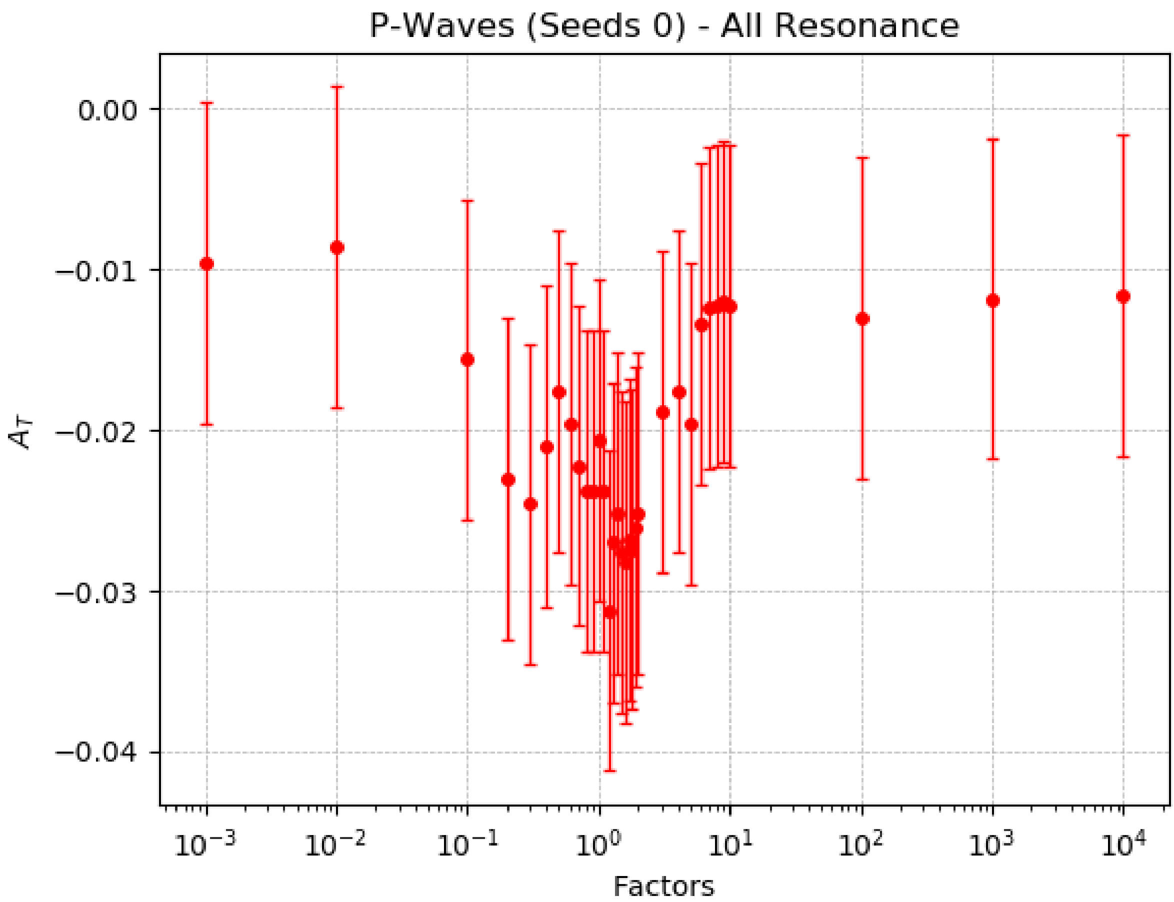


Figure 34: The change of A_T by multiplying all the P wave amplitudes with the factors in x-axis using 10^4 events.

All the events and P wave values are generated with the same seed - no seed specified (Seed 0).

B. Change all SP wave amplitudes and make them equal

Input files: AmpGen/build/bin/spd_waves_gen

Output files: Simulations/B02DDbarKPi/sp_waves

event file (.opt) Example:

```
1  EventType B0 D0 Dbar0 K+ pi-
2
3  B0{NonResS0{D0,Dbar0},K*(892)0{K+,pi-}} 0   2.09    1.  0   0   10
4
5  B0{NonResS0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0   0.66    1.  0   0   10
6
7  B0{K(0)*(800)0{K+,pi-},NonResS0{D0,Dbar0}}  0   0.66    1.  0   0   10
8
9  B0{D(s2)(2573)+{D0,K+},Dbar0,pi-}   0       0.10    0.05 0       0.      10.
10
11 B0[S]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.  10.
12 B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.  10.
13 B0[D]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       2.093   0.05    2   0.  10.
14
15 B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.000826    0.05    0       0.  10.
16 B0[S]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.000826    0.05    0       0.  10.
17 B0[D]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.826       0.05    0       0.  10.
18
19 B0[D]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       1.31    0.05    0.  0.  10.
20 B0[S]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.00131 0.05    0.  0.  10.
21 B0[P]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.00131 0.05    0.  0.  10.
22
23 B0[P]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.00051 0.05    0.  0.  10.
24 B0[S]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.00051 0.05    0.  0.  10.
25 B0[D]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.51    0.05    0.  0.  10.
26
27 B0{psi(3770)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       1.99    0.05    0.  0.  10.
28 B0{psi(4040)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       0.78    0.05    0.  0.  10.
29 B0{psi(4160)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       1.24   0.05  0.   0.  10.
30 B0{psi(4415)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       0.48   0.05  0.   0.  10.
31
32 B0{psi(3770)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       1.99  0.05  0.  0.  10.
33 B0{psi(4040)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       0.78  0.05  0.  0.  10.
34 B0{psi(4160)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       1.24  0.05  0.  0.  10.
35 B0{psi(4415)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       0.48  0.05  0.  0.  10.
36
37 #B0{Z(c)(3900)+{D*(2010)+{D0,pi+},Dbar0},K-}    2   1   0   2   0   0
```

Figure 35: An example of event file for the plot in Fig.36

Changed the second number column in line 11, 12, 15, 16, 20, 21, 23, 24.

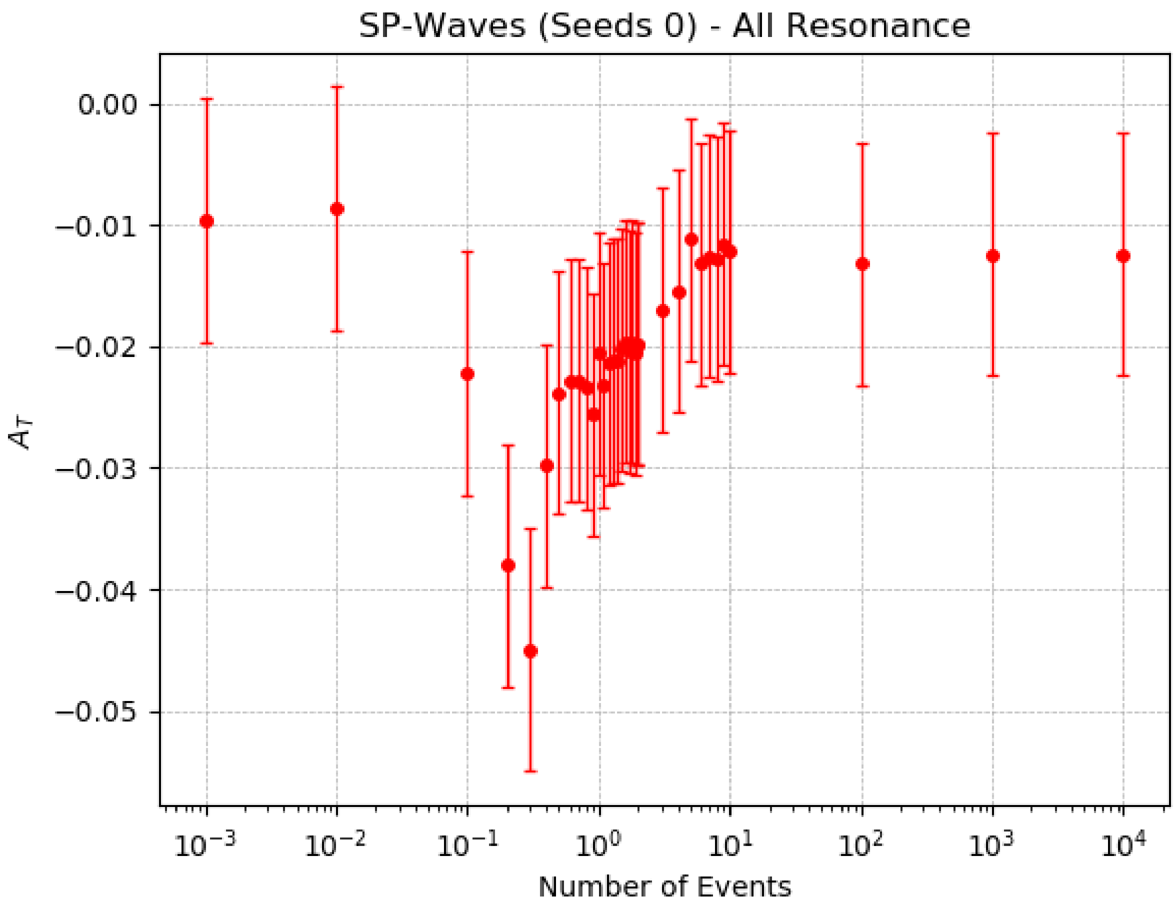


Figure 36: The change of A_T by multiplying all the S and P wave amplitudes with the factors in x-axis using 10^4 events.

19 Feb 2020, Wednesday

C. P waves and SP waves for all resonances

Input files: AmpGen/build/bin/spd_waves_gen_sr2

Output files: Simulations/B02DDbarKPi/spd_waves_sr2

event file (.opt) Example:

~/AmpGen/build/bin/spd_waves_gen_sr2/B0toDDbar0K+pi-_p1E-3.opt

```
1  EventType B0 D0 Dbar0 K+ pi-
2
3  B0{NonResS0{D0,Dbar0},K*(892)0{K+,pi-}} 0   2.09    1.  0   0   10
4
5  B0{NonResS0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0   0.66    1.  0   0   10
6
7  B0{K(0)*(800)0{K+,pi-},NonResS0{D0,Dbar0}}  0   0.66    1.  0   0   10
8
9  B0{D(s2)(2573)+{D0,K+},Dbar0,pi-}   0       0.10   0.05 0       0.     10.
10
11 B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.  10.
12
13 B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.000826    0.05    0       0.  10.
14
15 B0[P]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.00131 0.05    0.  0.  10.
16
17 B0[P]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.00051 0.05    0.  0.  10.
18
19 B0{psi(3770)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       1.99    0.05    0.  0.  10.
20
21 B0{psi(4040)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       0.78    0.05    0.  0.  10.
22
23 B0{psi(4160)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       1.24   0.05  0.  0.  10.
24
25 B0{psi(4415)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       0.48   0.05  0.  0.  10.
26
27 B0{psi(3770)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       1.99  0.05  0.  0.  10.
28
29 B0{psi(4040)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       0.78  0.05  0.  0.  10.
30
31 B0{psi(4160)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       1.24  0.05  0.  0.  10.
32
33 B0{psi(4415)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       0.48  0.05  0.  0.  10.
34
35 #B0{Z(c)(3900)+{D*(2010)+{D0,pi+},Dbar0},K-}    2   1   0   2   0   0
```

Figure 37: An example of event file for the P-wave plot in Fig.39

Changed the second number column in line 11, 13, 15, 17.
Changed the second number column in line 11, 12, 14, 15, 17, 18, 20, 21.

```
~/AmpGen/build/bin/spd_waves_gen_sr2/B0toDDbar0K+pi-_sp1E-3.opt
EventType B0 D0 Dbar0 K+ pi-

B0{NonResS0{D0,Dbar0},K*(892)0{K+,pi-}} 0   2.09    1.  0   0   10

B0{NonResS0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0   0.66    1.  0   0   10

B0{K(0)*(800)0{K+,pi-},NonResS0{D0,Dbar0}}  0   0.66    1.  0   0   10

B0{D(s2)(2573)+{D0,K+},Dbar0,pi-}   0       0.10   0.05 0       0.      10.

B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.  10.
B0[S]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.  10.

B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.000826    0.05    0       0.  10.
B0[S]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.000826    0.05    0       0.  10.

B0[P]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.00131 0.05    0.  0.  10.
B0[S]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.00131 0.05    0.  0.  10.

B0[P]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.00051 0.05    0.  0.  10.
B0[S]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}}    0   0.00051 0.05    0.  0.  10.

B0{psi(3770)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       1.99    0.05    0.  0.  10.

B0{psi(4040)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       0.78    0.05    0.  0.  10.

B0{psi(4160)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       1.24  0.05  0.  0.  10.

B0{psi(4415)0{D0,Dbar0},K(0)*(800)0{K+,pi-}}        0       0.48  0.05  0.  0.  10.

B0{psi(3770)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       1.99  0.05  0.  0.  10.

B0{psi(4040)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       0.78  0.05  0.  0.  10.

B0{psi(4160)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       1.24  0.05  0.  0.  10.

B0{psi(4415)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}}   0       0.48  0.05  0.  0.  10.

#B0{Z(c)(3900)+{D*(2010)+{D0,pi+},Dbar0},K-}    2   1   0   2   0   0
```

Figure 38: An example of event file for the SP-wave plot in Fig.39

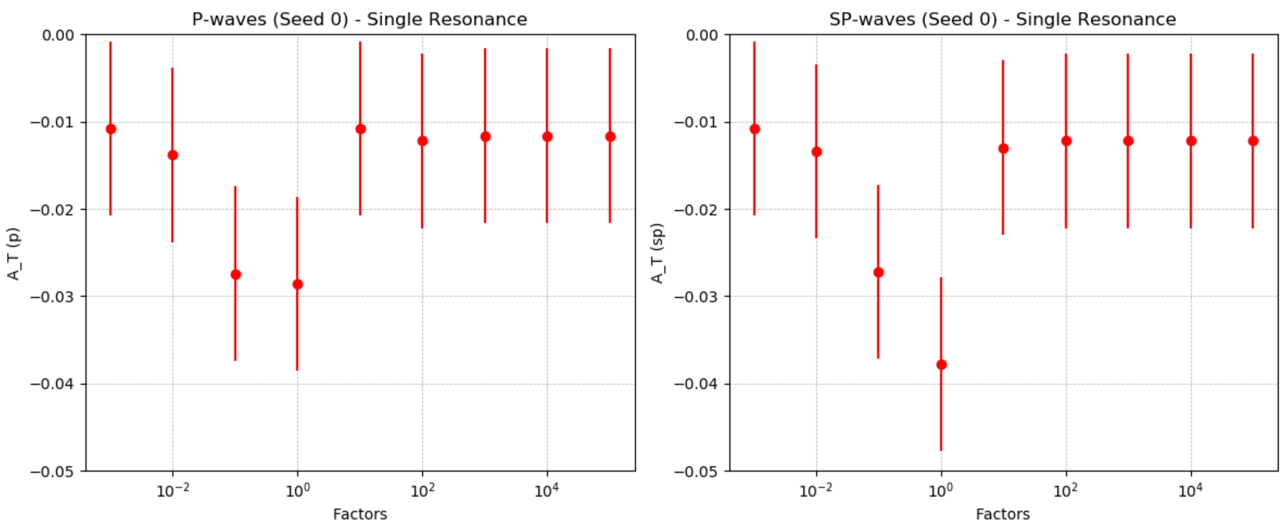


Figure 39: (left) The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using 10^4 events. (right) The change of A_T by multiplying the S and P wave amplitudes equally with the factors in x-axis using 10^4 events.

Investigation on single resonance ψ(3770)K*(892)0:

D. use only the P waves or SP waves for a single resonance

Input files: AmpGen/build/bin/spd_waves_gen_sr1

Output files: Simulations/B02DDbarKPi/spd_waves_sr1

event file (.opt) Example:

~/AmpGen/build/bin/spd_waves_gen_sr1/B0toDDbar0K+pi-_p1E-3.opt

```
1 EventType B0 D0 Dbar0 K+ pi-
2
3 B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.   10.
```

Figure 40: An example of event file for the P-wave plot in Fig.42

Changed the second number column in line 3.

~/AmpGen/build/bin/spd_waves_gen_sr1/B0toDDbar0K+pi-_sp1E-3.opt

```
1 EventType B0 D0 Dbar0 K+ pi-
2
3
4
5 B0[S]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.   10.
6 B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}}    2       0.002093    0.05    2   0.   10.
```

Figure 41: An example of event file for the SP-wave plot in Fig.42

Changed the second number column in line 5, 6. Reasons for flat?

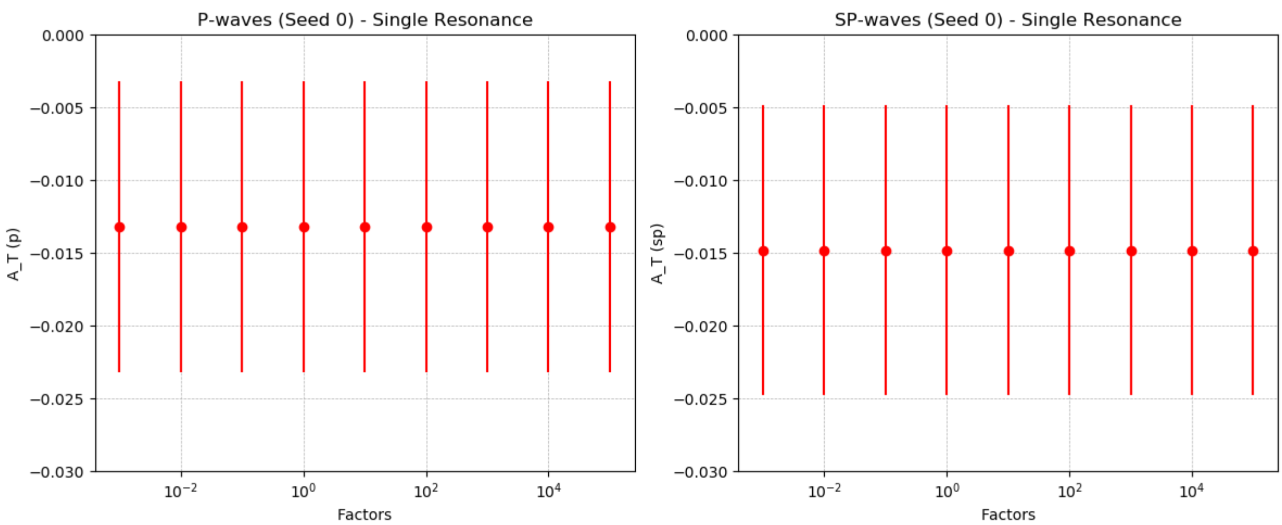


Figure 42: (left) The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using 10^4 events. (right) The change of A_T by multiplying the S and P wave amplitudes equally with the factors in x-axis using 10^4 events.

Investigation on single resonance ψ(4040)K*(892)0: **E. P waves and SP waves single resonances with interferences**

Input files: AmpGen/build/bin/spd_waves_gen_sr3
AmpGen/build/bin/B0_event_spd_sr3_4040/sr1_seed200_10000 (for smaller intervals between -1 and 1)

Output files: Simulations/B02DDbarKPi/spd_waves_sr3
Simulations/B02DDbarKPi/spd_waves_sr_4040

event file (.opt) Example:

```
~/AmpGen/build/bin/spd_waves_gen_sr3/B0toDDbar0K+pi-_p1E-3.opt
1  EventType B0 D0 Dbar0 K+ pi-
2
3  B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0      0.000826     0.05    0        0.  10.
4  B0[S]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0      0.826        0.05    0        0.  10.
5
```

Figure 43: An example of event file for the P-wave plot in Fig.45

Changed the second number column in line 3.

```
~/AmpGen/build/bin/spd_waves_gen_sr3/B0toDDbar0K+pi-_sp1E-3.opt
1  EventType B0 D0 Dbar0 K+ pi-
2
3  B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0      0.000826     0.05    0        0.  10.
4  B0[S]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0      0.000826     0.05    0        0.  10.
5  B0[D]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0      0.826   0.05    0       0.  10.
```

Figure 44: An example of event file for the SP-wave plot in Fig.45

Changed the second number column in line 3, 4.

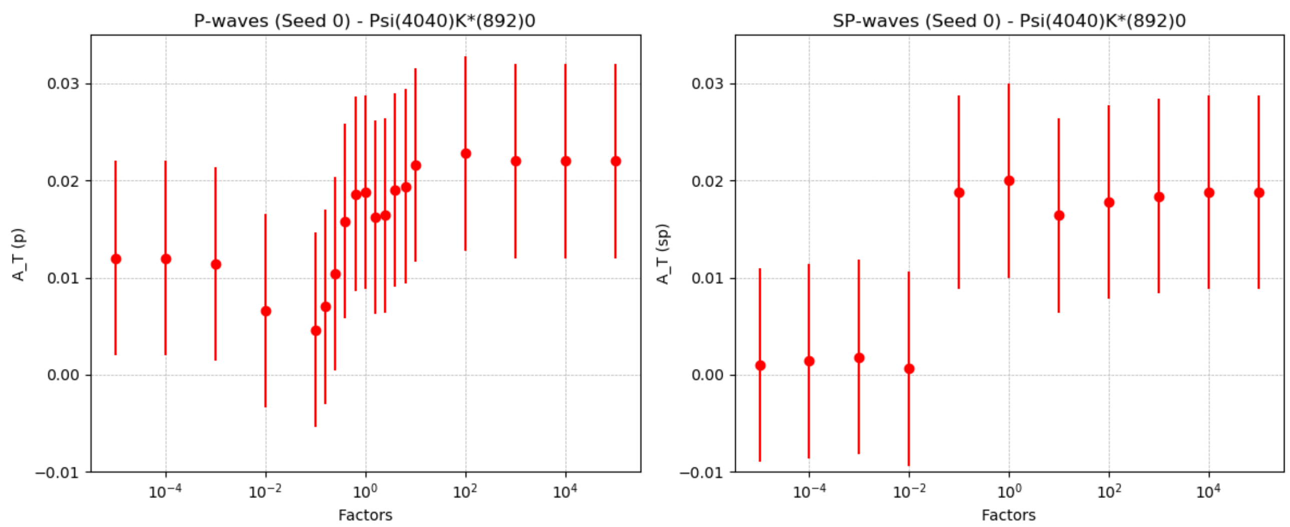


Figure 45: (left) The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using 10^4 events. (right) The change of A_T by multiplying the S and P wave amplitudes equally with the factors in x-axis using 10^4 events.

21 Feb 2020, Friday

F. Split the events into ten files generated with a set of 10 seeds

(1) Same set of seed for each p wave amplitude:
Seed 0,10,20,30,40,50,60,70,80,90 — range (0,100,10)

Input files: AmpGen/build/bin/spd_waves_gen_sr3_seed
AmpGen/build/bin/B0_event_spd_sr3_4040/sr2_seed200_1000 (for smaller intervals between -1 and 1)

Output files: Simulations/B02DDbarKPi/spd_waves_combine_1E4_4040
Simulations/B02DDbarKPi/spd_waves_sr_4040

event file (.opt) Example:

```
~/AmpGen/build/bin/spd_waves_gen_sr3_seed/B0toDDbar0K+pi-_p1E-1_s20.opt
1  EventType B0 D0 Dbar0 K+ pi-
2
3  B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0    0.0826  0.05    0    0.  10.
4  B0[S]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0    0.826   0.05    0    0.  10.
5
6  Seed 20
```

Figure 46: An example of event file for the P-wave plot in Fig.47

Changed the second number column in line 3, 6.

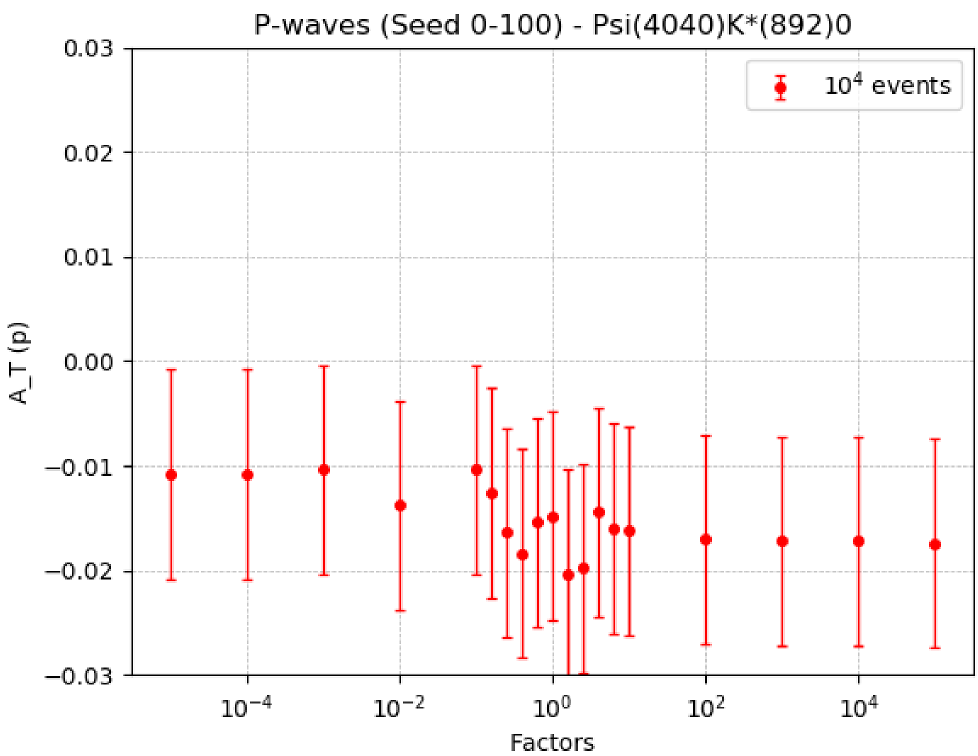


Figure 47: The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using 10^4 events.

(2) Different sets of seed for each p wave amplitude:

e.g - Seed 0,20,40,60,80,100,120,140,160,180 — range (0,200,10) for $factor = 10^{-5}$
Seed 1,21,41,61,81,101,121,141,161,181 for $factor = 10^{-4}$
, etc...

Input files: AmpGen/build/bin/spd_waves_gen_sr3_seed2
AmpGen/build/bin/B0_event_spd_sr3_4040/sr3_seed200_1000 + sr3_seed200_10000 (for smaller intervals between -1 and 1)

Output files: Simulations/B02DDbarKPi/spd_waves_combined2_1E4_4040 + spd_waves_combined 2_1E5_4040
Simulations/B02DDbarKPi/spd_waves_sr_4040

event file (.opt) Example:

~/AmpGen/build/bin/spd_waves_gen_sr3_seed2/output_opt_1E4/B0toDDbar0K+pi-_p1E-1_s64.opt

```
1  EventType B0 D0 Dbar0 K+ pi-
2
3  B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.0826  0.05    0       0.  10.
4  B0[S]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}}    0       0.826   0.05    0       0.  10.
5
6  Seed 64
```

Figure 48: An example of event file for the P-wave plot in Fig.??

Changed the second number column in line 3, 6.

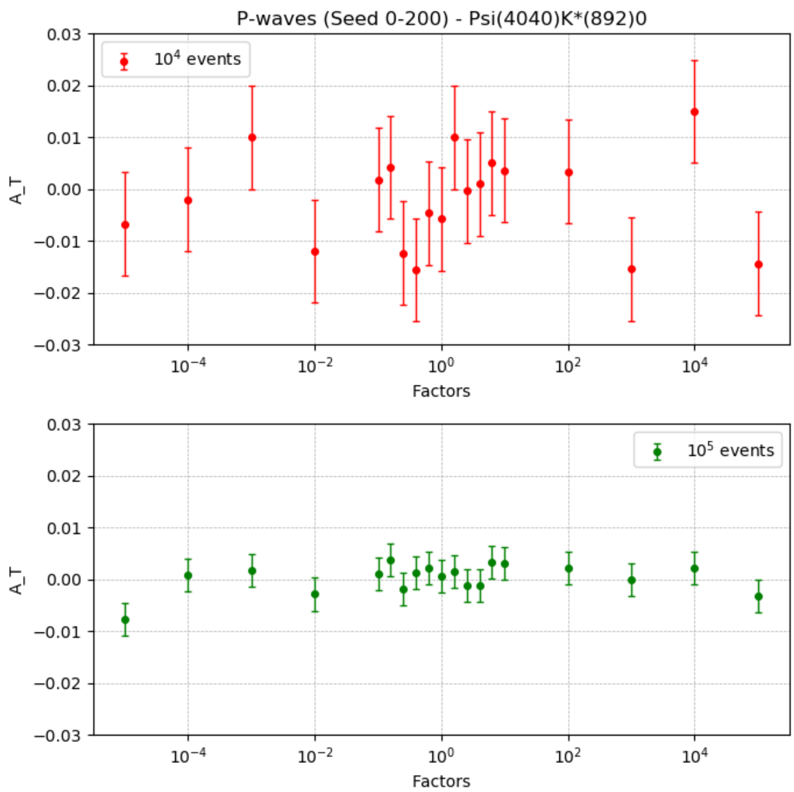


Figure 49: The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using 10^4 and 10^5 events.

Put the results for $\psi(4040)K^*(892)0$ together with more events for the **E** and **F**(1) methods, this gives

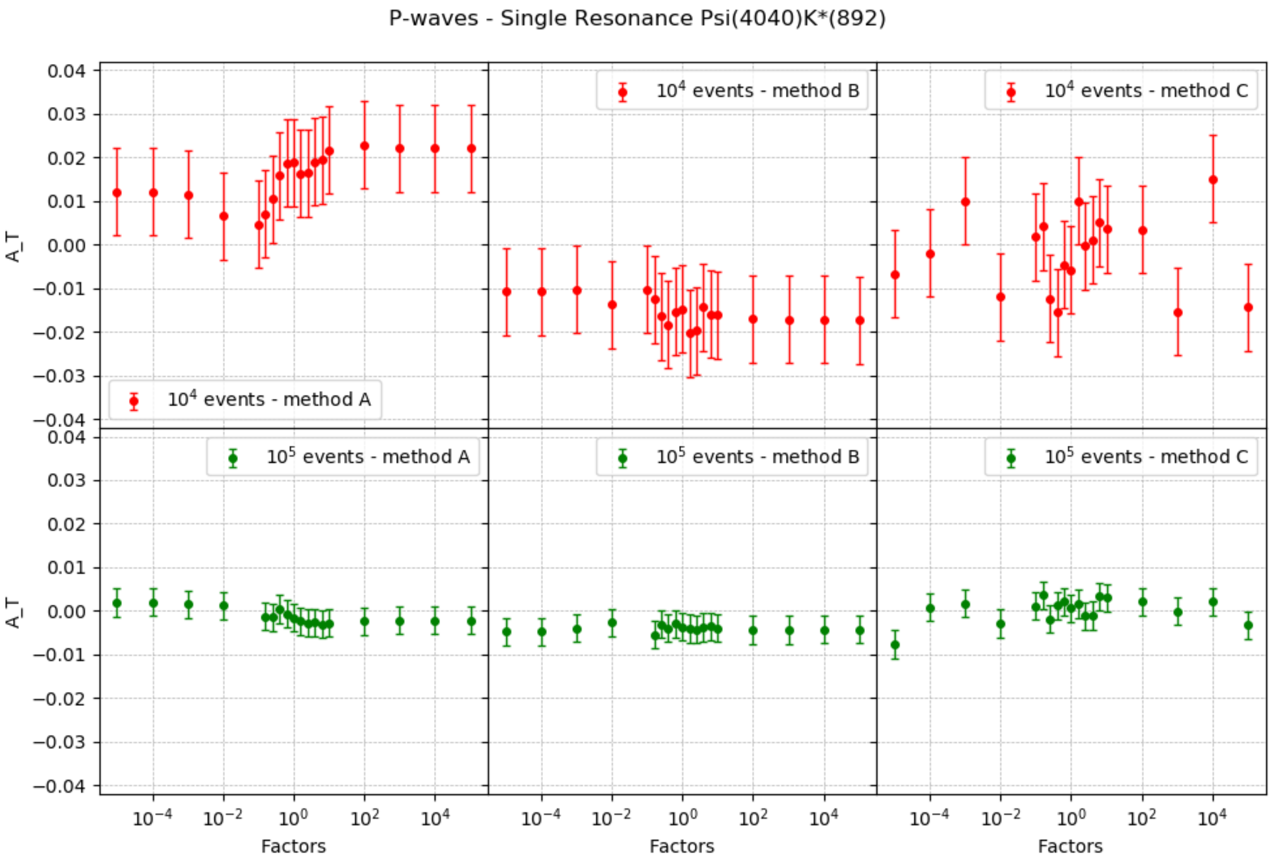


Figure 50: The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using 10^4 and 10^5 events by generating events using three different methods.

More investigation on single resonance $\psi(3770)$K*(892)0 using the methods stated in **E**, **F**(1) and **F**(2).

Input files: AmpGen/build/bin/B0_event_spd_sr3_3770

Output files: Simulations/B02DDbarKPi/spd_waves_sr_3770

event file (.opt) Example:

(It was found we didn't specify the coordinate system in the event files. However, this doesn't effect the previous results since all the results were generated from real numbers - no phases)
We should also tell the units for the phase - I use radian.

~/AmpGen/build/bin/B0_event_spd_sr3_3770/B0toDDbar0K+pi-_sr1_p_10000.opt

```
EventType B0 D0 Dbar0 K+ pi-

CouplingConstant::Coordinates polar

CouplingConstant::AngularUnits rad

B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}} 2 209300.000000000000000 0.050000000000000 2 0.000000000000000 10.000000000000000
B0[S]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}} 2 2.093000000000000 0.050000000000000 2 0.000000000000000 10.000000000000000
```

Figure 51: An example of event file for the P-wave plot in Fig.52

Changed the second number column in line 7.

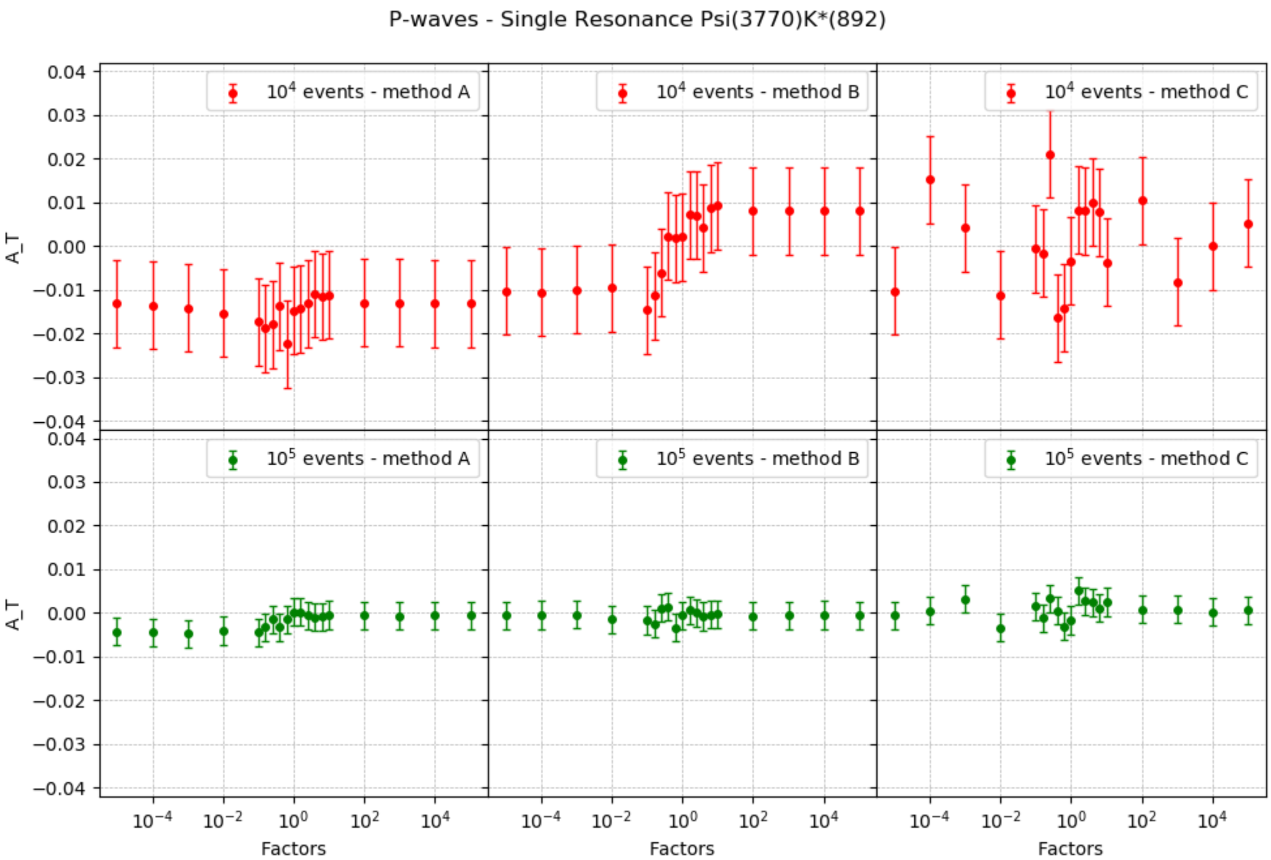


Figure 52: The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using 10^4 and 10^5 events by generating events using three different methods.

Method A = **E**
Method B = **F**(1)
Method C = **F**(2)

More investigation on all resonance using the methods stated in **F**(2).

Input files: AmpGen/build/bin/B0_event_spd_nophase

Output files: Simulations/B02DDbarKPi/spd_waves_combine3_1E4 + spd_waves_combine3_1E5 + spd_waves_combine3_1E6

event file (.opt) Example:

~/AmpGen/build/bin/B0_event_spd_nophase/B0toDDbar0K+pi-_p.opt

```
1  EventType B0 D0 Dbar0 K+ pi-
2
3  CouplingConstant::Coordinates polar
4
5  CouplingConstant::AngularUnits rad
6
7  B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}} 2 13.205937219970446 0.050000000000000 2.000000000000000 0.000000000000000 10.000000000000000
8  B0[P]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 5.211707665406396 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
9  B0[P]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 8.265541212690533 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
10 B0[P]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 3.217882456848986 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
11
12 B0[S]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}} 2 2.093000000000000 0.050000000000000 2.000000000000000 0.000000000000000 10.000000000000000
13 B0[D]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}} 2 2.093000000000000 0.050000000000000 2.000000000000000 0.000000000000000 10.000000000000000
14 B0[S]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 0.826000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
15 B0[D]{psi(4040)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 0.826000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
16 B0[S]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 1.310000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
17 B0[D]{psi(4160)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 1.310000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
18 B0[S]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 0.510000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
19 B0[D]{psi(4415)0{D0,Dbar0},K*(892)0{K+,pi-}} 0 0.510000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
20
21 B0{NonResS0{D0,Dbar0},K*(892)0{K+,pi-}} 0 2.090000000000000 1.000000000000000 0.000000000000000 0.000000000000000 10.000000000000000
22 B0{NonResS0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0 0.660000000000000 1.000000000000000 0.000000000000000 0.000000000000000 10.000000000000000
23 B0{K(0)*(800)0{K+,pi-},NonResS0{D0,Dbar0}} 0 0.660000000000000 1.000000000000000 0.000000000000000 0.000000000000000 10.000000000000000
24 B0{D(s2)(2573)+{D0,K+},Dbar0,pi-} 0 0.100000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
25
26 B0{psi(3770)0{D0,Dbar0},K(0)*(800)0{K+,pi-}} 0 1.990000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
27 B0{psi(4040)0{D0,Dbar0},K(0)*(800)0{K+,pi-}} 0 0.780000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
28 B0{psi(4160)0{D0,Dbar0},K(0)*(800)0{K+,pi-}} 0 1.240000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
29 B0{psi(4415)0{D0,Dbar0},K(0)*(800)0{K+,pi-}} 0 0.480000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
30
31 B0{psi(3770)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0 1.990000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
32 B0{psi(4040)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0 0.780000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
33 B0{psi(4160)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0 1.240000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
34 B0{psi(4415)0{D0,Dbar0},K(0)*(1430)0{K+,pi-}} 0 0.480000000000000 0.050000000000000 0.000000000000000 0.000000000000000 10.000000000000000
35
36 #B0{Z(c)(3900)+{D*(2010)+{D0,pi+},Dbar0},K-} 2 1.000000000000000 0.000000000000000 2.000000000000000 0.000000000000000 0.000000000000000
```

Figure 53: An example of event file for the P-wave plot in Fig.54

Changed the second number column in line 7, 8, 9, 10.

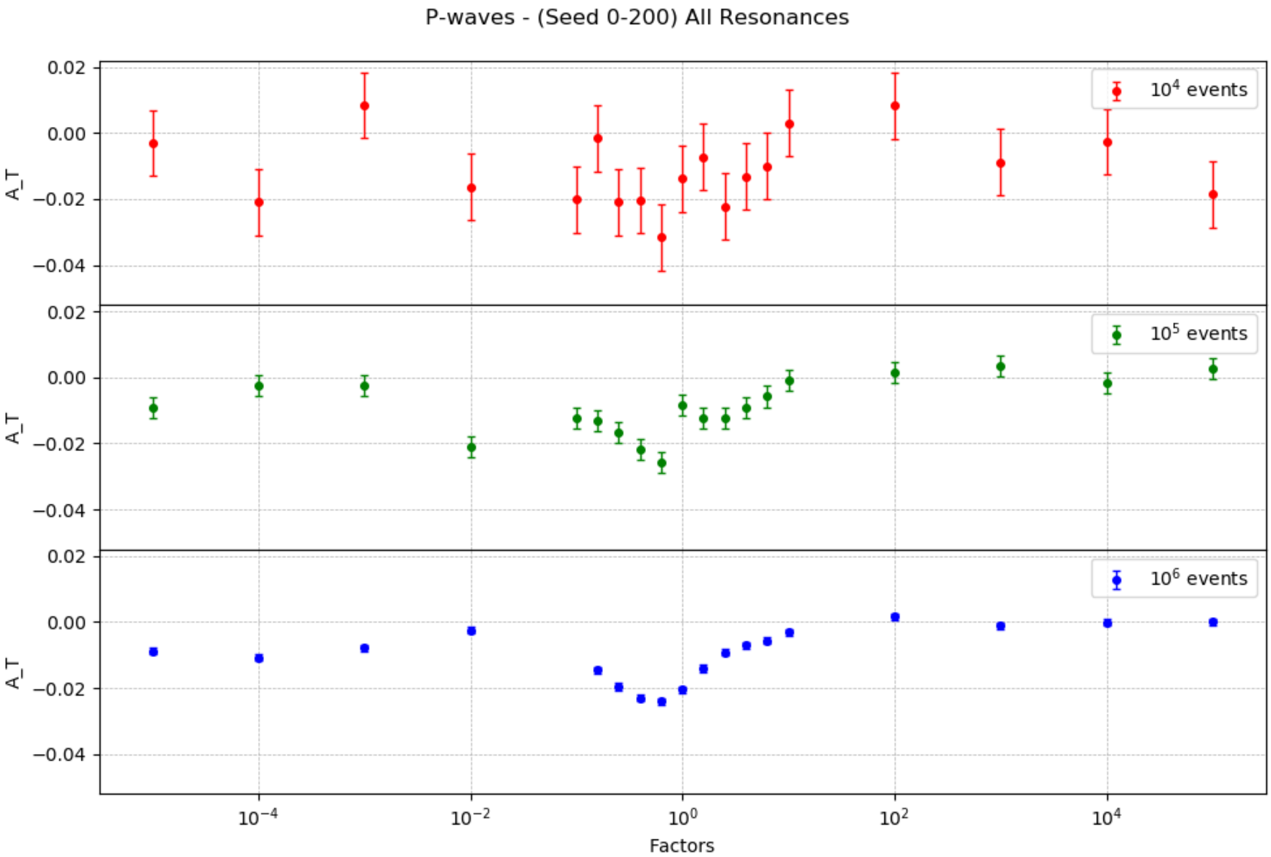


Figure 54: The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using 10^4, 10^5 and 10^6 events.

24 Feb 2020, Monday

Start varying the phase of the resonance. The phase are chosen to be from -1.5pi to 1.75 pi with intervals of 0.25pi

For the single resonance - ψ(3770)K*(892)0,

Input files: AmpGen/build/bin/B0_event_sr1_p_phase_1E5

Output files: Simulations/B02DDbarKPi/spd_waves_combine_phase_1E5

event file (.opt) Example:

```
~/AmpGen/build/bin/B0_event_sr1_p_phase_1E5/B0toDDbar0K+pi-_p.opt
1 EventType B0 D0 Dbar0 K+ pi-
2
3 CouplingConstant::Coordinates polar
4
5 CouplingConstant::AngularUnits rad
6
7 B0[P]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}} 2 209300.000000000000000 0.050000000000000 2 5.497787143782139 10.000000000000000
8 B0[S]{psi(3770)0{D0,Dbar0},K*(892)0{K+,pi-}} 2 2.093000000000000 0.050000000000000 2 0.000000000000000 10.000000000000000
```

Figure 55: An example of event file for the P-wave plot in Fig.56

Changed the second and the fifth number column in line 7.

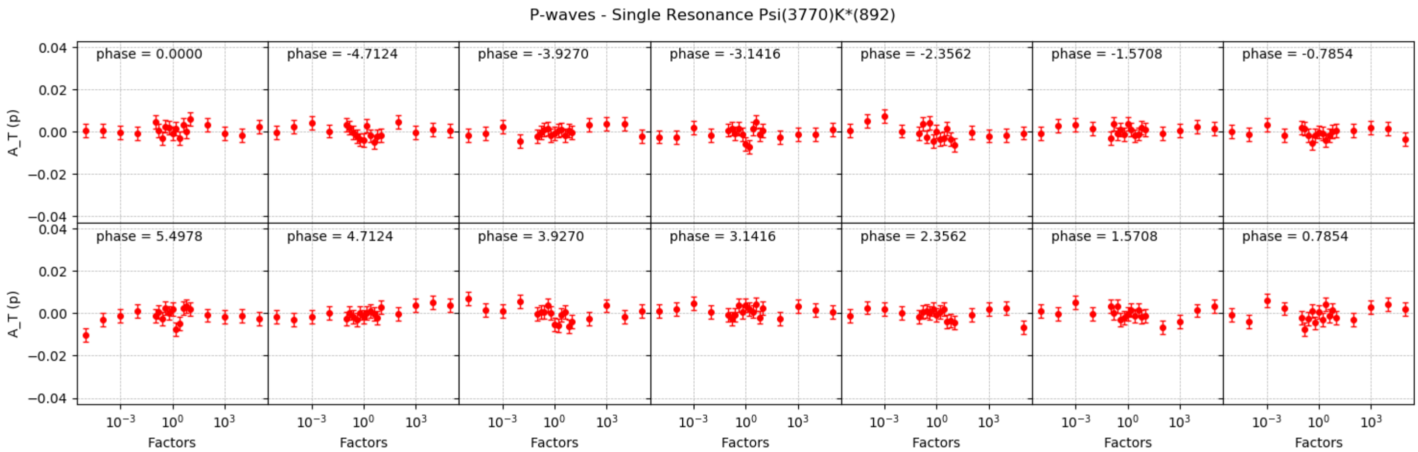
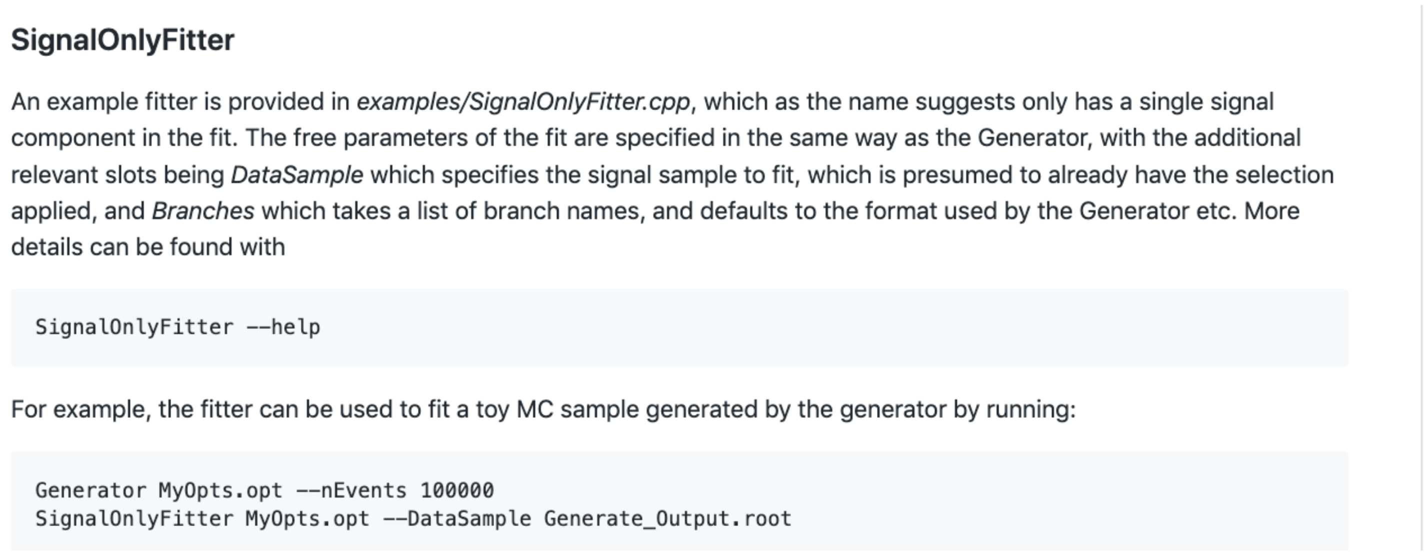


Figure 56: The change of A_T by multiplying the P wave amplitudes with the factors in x-axis using and changing the phase with 10^5 events.

- No obvious parity violation in this single resonance?
The whole process takes 22+7 hours. Would need some optimization in the codes for calculating A_T.

25 Feb 2020, Tuesday

Have looked at the fitter in AmpGen by first generate 1000 events using AmpGen and fit the results with `SignalOnlyFitter`:



SignalOnlyFitter

An example fitter is provided in *examples/SignalOnlyFitter.cpp*, which as the name suggests only has a single signal component in the fit. The free parameters of the fit are specified in the same way as the Generator, with the additional relevant slots being *DataSample* which specifies the signal sample to fit, which is presumed to already have the selection applied, and *Branches* which takes a list of branch names, and defaults to the format used by the Generator etc. More details can be found with

```
SignalOnlyFitter --help
```

For example, the fitter can be used to fit a toy MC sample generated by the generator by running:

```
Generator MyOpts.opt --nEvents 100000
SignalOnlyFitter MyOpts.opt --DataSample Generate_Output.root
```

Figure 57: Instruction of using SignalOnlyFitter

The was done by unfixing (fix=0) the amplitudes and phases of the resonance in the spd event file and leaving only one resonance fixed. Here fixing ψ(3770)K*(892)0[S] (set to be fix=2) for both amplitude and phase.

The fitting returns back the real and imaginary part of the amplitude in the resonances of the decay and percentage/probability for the each resonance to occur, based on the four momentum data. This also generates a plot.root file containing the phase space plots. It takes about 5 mins to finish the fitting for 1000 events.

Next steps:

- test the validity of the fitter using different number of events with the some seed
- induce CP violation by change the number of C_T by several percent
- binned analysis for the CM variables
- real data from LHCb

27 Feb 2020, Thursday

First look of LHCb data: