F_+(D->4Pi) from KsPiPi vs 4Pi and KlPiPi vs 4Pi

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Claire Prouve, Chris Thomas, Guy Wilkinson, Sneha Malde

What is F_+(D->4Pi) ?

F_+ is the CP-even fraction of the D->4Pi decay:

$F_+(D \to K^+K^-) = 1$ CP even

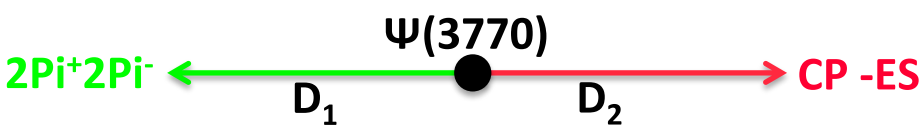
$F_+(D \to K_S\, Pi^0) = 0$ CP odd

$F_+(D \to 2Pi^+2Pi^-) = [0,1]$ CP mixture

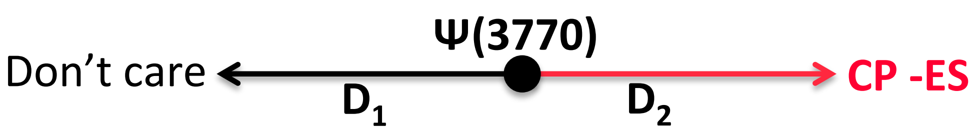
Measure F+ using the quantum correlated D^0/D^0 decays at CLEO:

CLEO-c reminder: ee -> Psi(3770) -> D^0D^0 / D^-D^+

- Straight forward measurement of F_+:
  1. count 4Pi vs. CP even/ CP odd eigenstates ==> M^+ / M^-



  2. count the total number of CP even/ CP odd decays in sample ==> S^+ / S^-



  3. $N^+ = M^+ / S^+$ ==> $$F_+ \equiv \frac{N^+}{N^+ + N^-}$$

Measuring F_+ with K^0PiPi

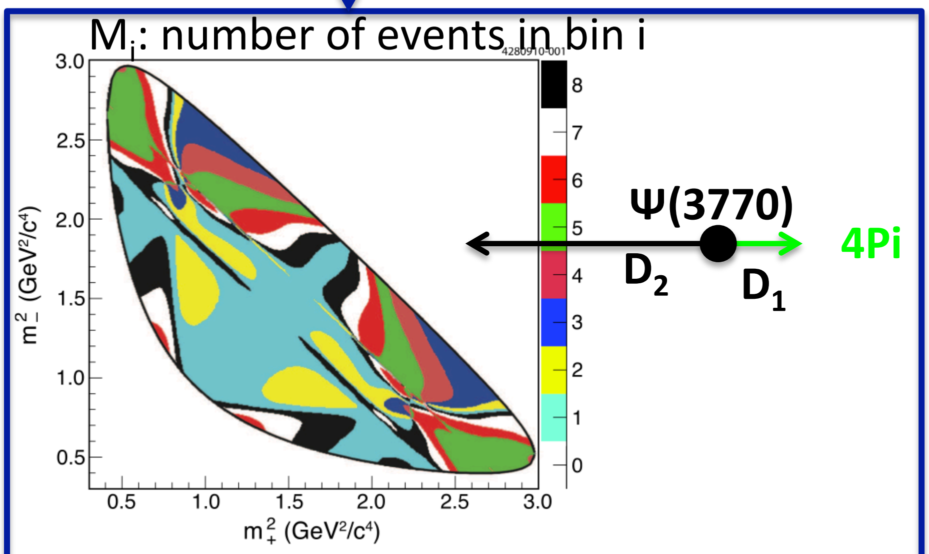
F_+ is related to the strong phase difference in the D-decay:

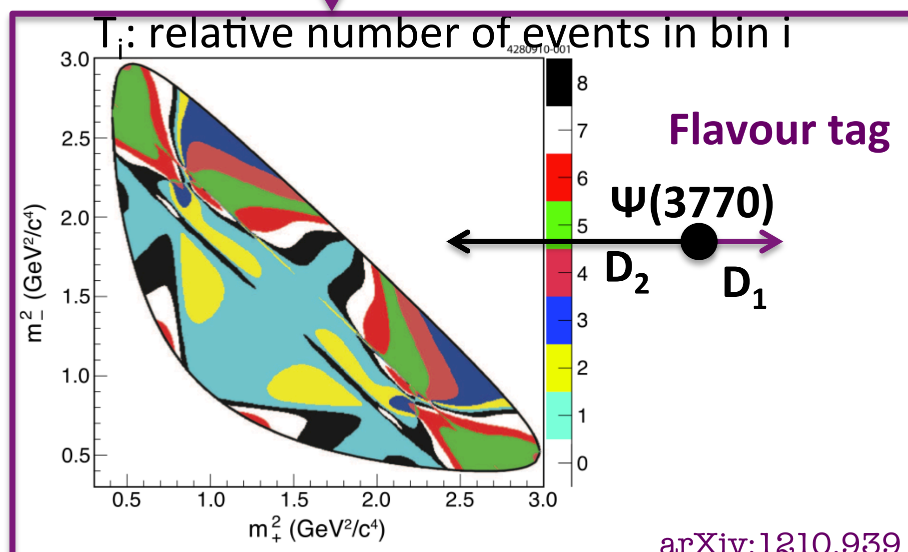
We know the **binned** strong phase difference of $D \to K_S$PIPi and $D \to K_L$PiPi! (arXiv:1010.2817)

Amplitude weighted cos of strong phase difference

Here is how to get F_+(4Pi):

$$M_i^{K_S^0\pi\pi} = h_{K_S^0\pi\pi}\left(T_i^{K_S^0\pi\pi} + T_{-i}^{K_S^0\pi\pi} - 2\,c_i\sqrt{T_i^{K_S^0\pi\pi}T_{-i}^{K_S^0\pi\pi}}\;(2F_+^{4\pi} - 1)\right)$$



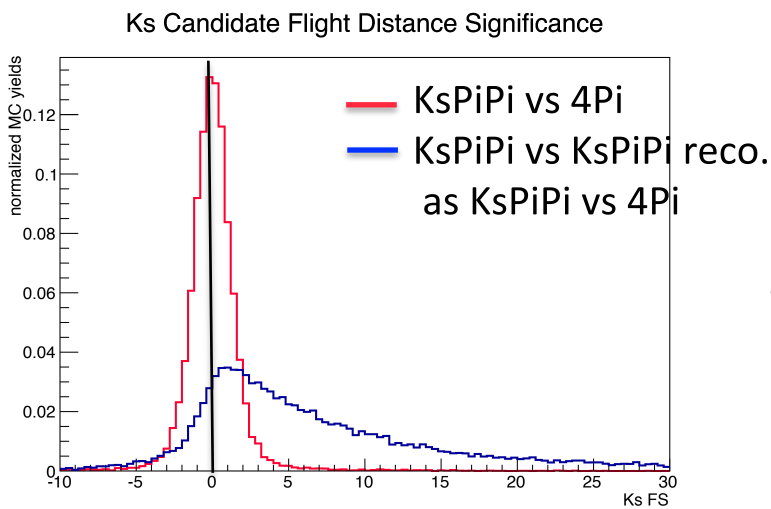


➔ **Select K^0PiPi vs 4Pi events and count how many signal events there are in each bin!**

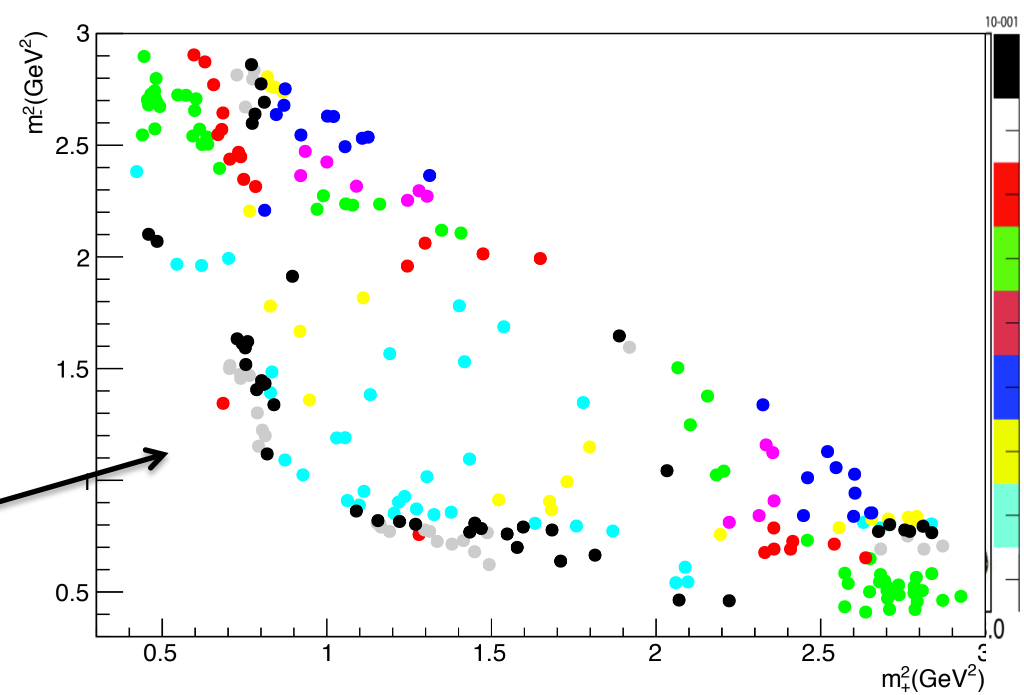
(and then fit the data with the above formula for F_+)

K_SPiPi vs 4Pi

- Fairly boring selection (CLEO is just so clean)
- Fitting the final state particles to the D Mass
- Rejecting K_SPiPi in the 4Pi side using the flight distance significance of a *possible Ks formed of two opposite sign pions*



cut of KS_FS<0:
Signal efficiency: 85.1%
bkg efficiency: 9.6%



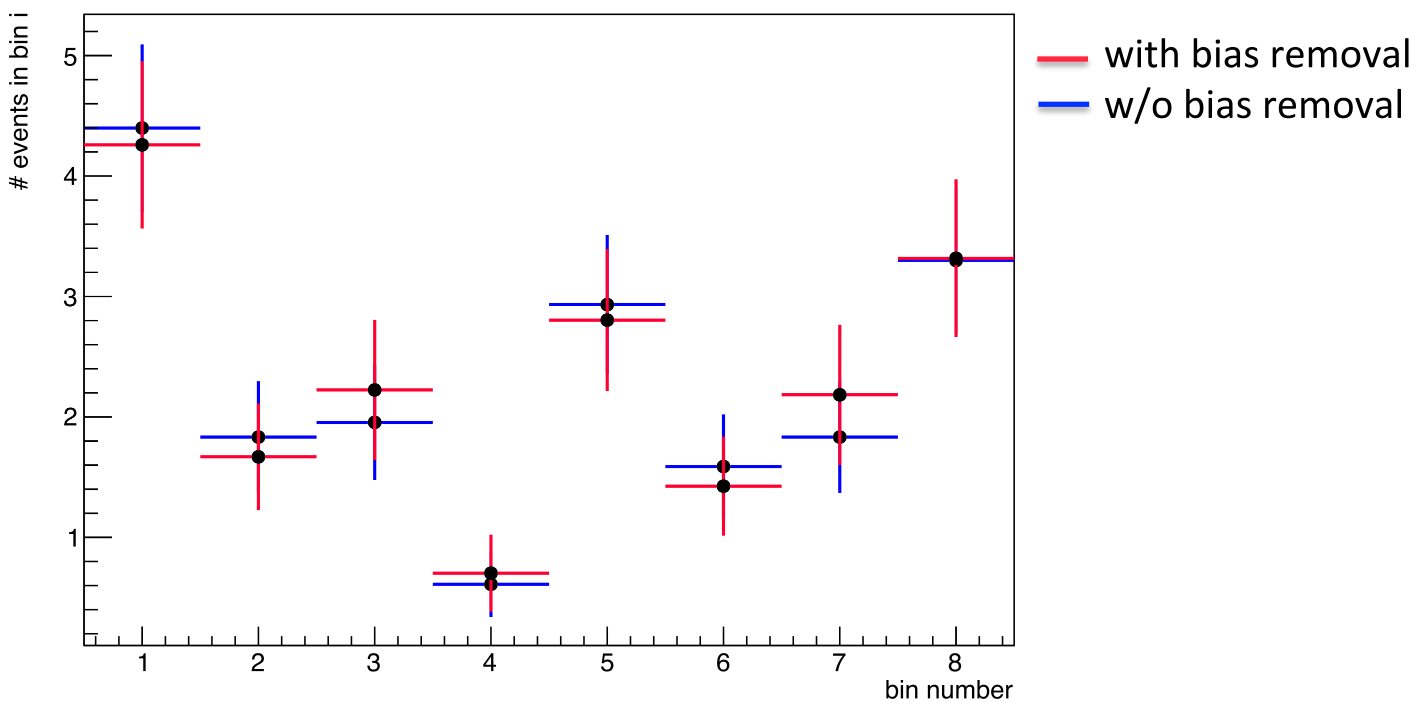
<u>Getting the signal yield:</u>

Signal yield = raw event yield
– peaking bkg yield
– flat bkg yield

K_SPiPi vs 4Pi – peaking bkg

Peaking bkg: K_SPiPi vs K_SPiPi $B_i^{peak} = B_{tot}^{peak} \cdot a_i^{peak}$

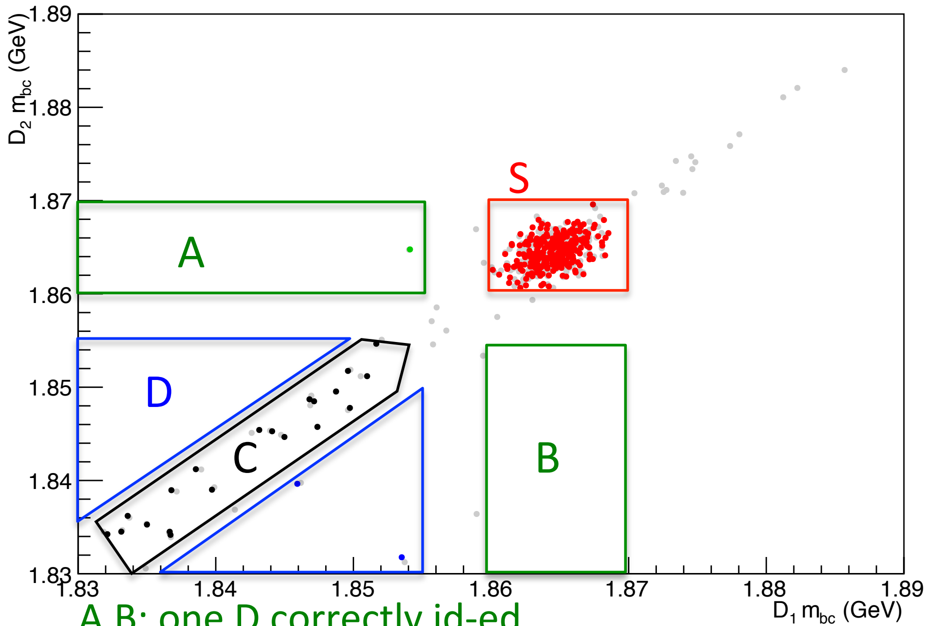
- total number of peaking bkg events from *generic MC*: 18.45 ± 1.13
- distribution of peaking bkg events over bins from data:
  apply K_SPiPi-*Selection* cut on 4Pi side to get a K_SPiPi vs K_SPiPi data sample
- Remove bias due to K_S-Selection instead of K_S-Veto with K_SPiPi vs K_SPiPi Signal MC



K_SPiPi vs 4Pi – flat bkg

Total number of bkg events determined extrapolating from the sidebands in data:

$$B_{tot}^{flat} = \frac{a_S}{a_D} N_D + \sum_{j=A,B,C} \frac{a_S}{a_j}\left(N_j - \frac{a_j}{a_D} N_D\right)$$



A,B: one D correctly id-ed

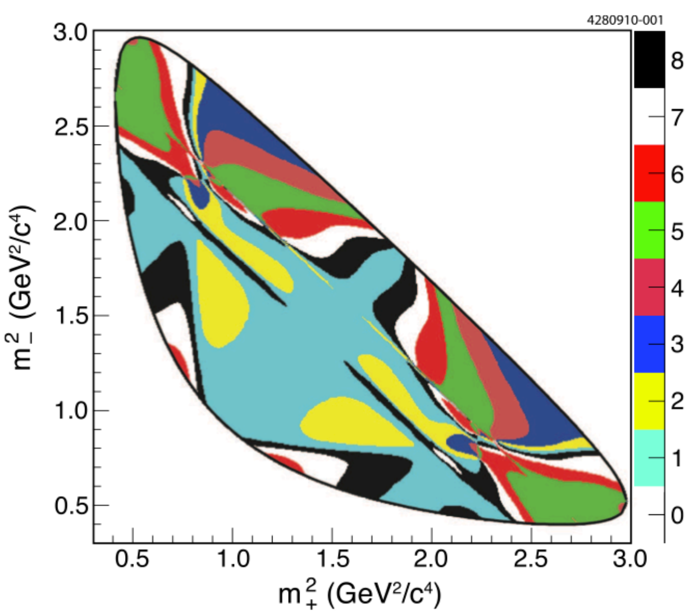
C: continuum bkg

D: pure combinatoric

⇒ 11.64 ± 2.90 flat bkg events in the signal region

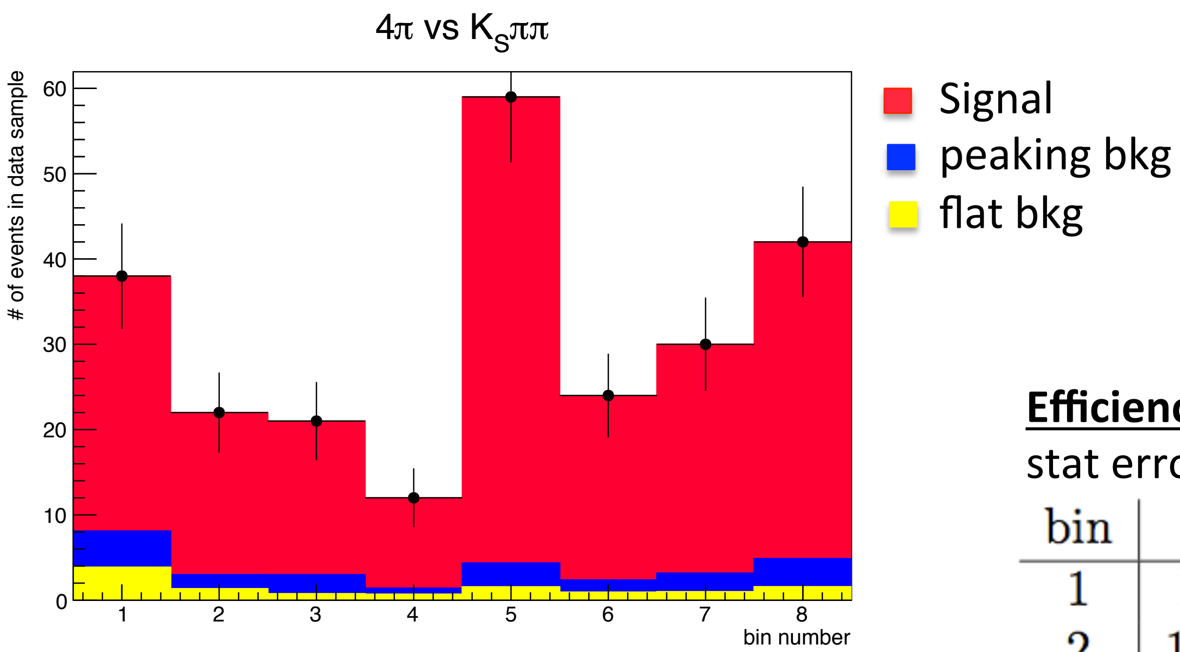
Distribute them 'flatly' across the bins

= proportional to the are of the bin



K_SPiPi vs 4Pi – signal yields

$$M_i = (N_i^{meas} - B_i^{peak} - B_i^{flat})$$



Efficiency corrected signal yields:

stat errors only, (first MC, second data)

bin	MM_i
1	$185.4 \pm 2.4058 \pm 39.054$
2	$119.24 \pm 1.8904 \pm 29.642$
3	$98.618 \pm 2.1205 \pm 25.254$
4	$61.551 \pm 1.1733 \pm 20.21$
5	$333.14 \pm 4.3184 \pm 47.018$
6	$127.08 \pm 2.1409 \pm 28.908$
7	$165.69 \pm 2.895 \pm 34.025$
8	$222.47 \pm 3.2254 \pm 39.089$

K_LPiPi vs 4Pi – peaking bkg

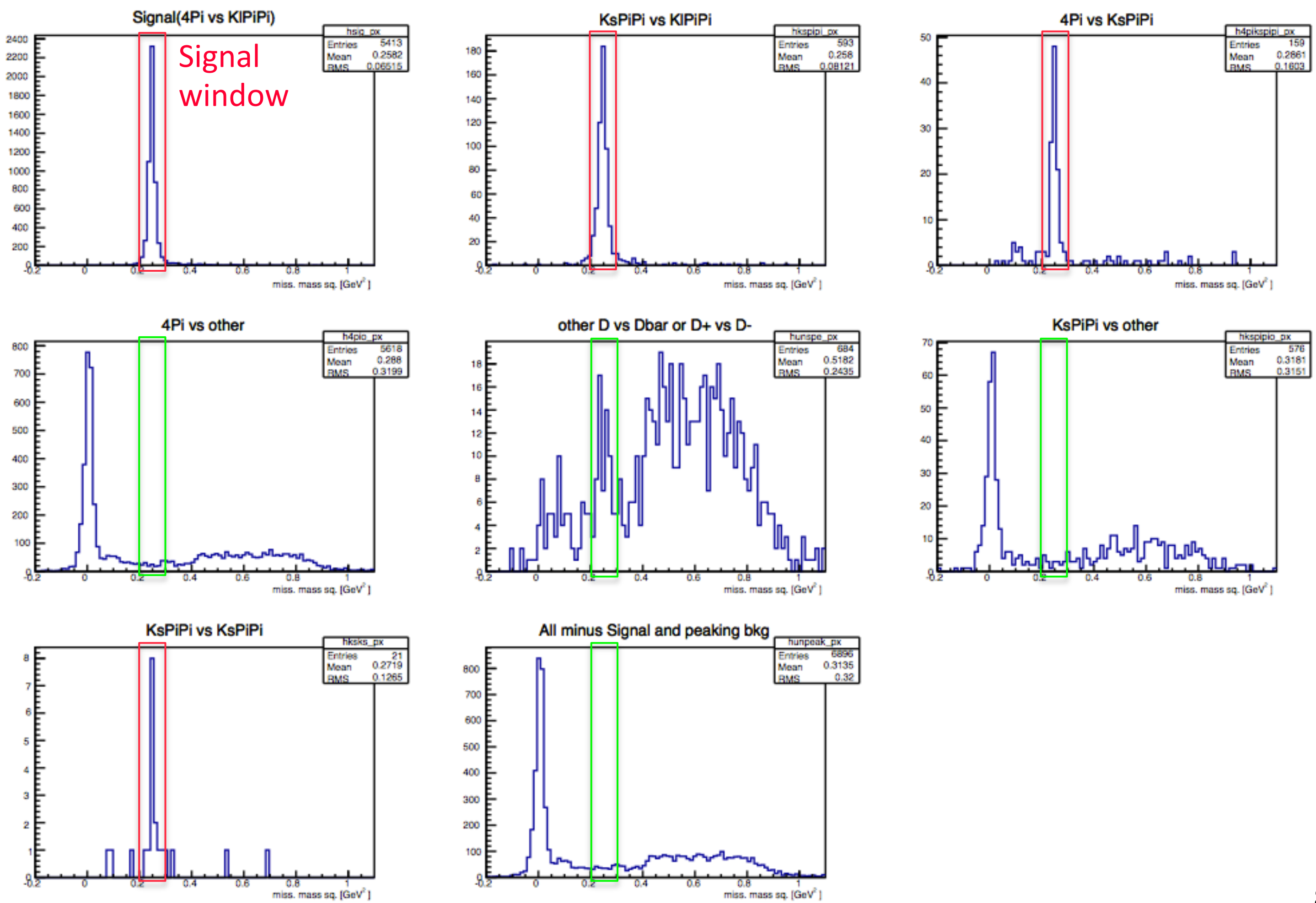
Same strategy as for K_LPiPi vs 4Pi, but more tricky due to more and different bkg.

Peaking Bkg:

Generic MC:
Reconstruct K_LPiPi vs 4Pi and see what we get ➔

Peaking in SW:

- $K_L^0\pi\pi$ vs $K_S^0\pi\pi$: 8% o
- $K_S^0\pi\pi$ vs 4π: 1.9% of
- ~~$K_S^0\pi\pi$ vs $K_S^0\pi\pi$: 0.3%~~



K_LPiPi vs 4Pi – peaking bkg

1. Scale the total number of peaking bkg events from generic MC:

$$B_{tot}^{peak}(K_L^0\pi\pi\ vs\ K_S^0\pi\pi) = 31.24 \pm 1.46$$

$$B_{tot}^{peak}(K_S^0\pi\pi\ vs\ 4\pi) = 18.45 \pm 0.62$$

2. Get K_LPiPi vs K_SPiPi distribution over bin using data with K_S-Selection on the 4Pi side:

generic MC tells us that the data sample with K_S-Selection contains:

- $K_L^0\pi\pi$ vs $K_S^0\pi\pi$: 92%
- flat events: 5%
- ~~$K_L^0\pi\pi$ vs 4π: 1.5%~~
- ~~$K_S^0\pi\pi$ vs $K_S^0\pi\pi$: 1.5%~~

Put a systematic on it later

➔ Subtract the flat distribution from the data to get the peaking bkg

➔ Remove the bias introduced by the K_S-Selection

3. Get K_SPiPi vs 4Pi distribution over bin using data from KsPiPi vs 4Pi analysis :

➔ Take results from K_SPiPi vs 4Pi and reweight according to the bin-dependent efficiency in K_LPiPi vs 4Pi

The efficiency for reconstructing and selecting K_SPiPi vs 4Pi events as K_LPiPi vs 4Pi events is taken to be the same as that for genuine K_LPiPi vs 4Pi events - under the assumption the K_S is 'lost' which should result in the same kinematics of the two decays.

K_LPiPi vs 4Pi – flat+cont bkg

Since for K_LPiPi vs 4Pi only 4 pions are reconstructed, the amount of continuum bkg is considerable.

<u>Use the *Powell method* to determine the total number of flat and cont. bkg event</u>

- Divide the MissMassSq region into lower sideband, signal region, upper sideband
- Assume that the ratio of events between these regions is correctly modeled by MC:
  for example $N_{sig}^{KLPiPivs4Pi} = MC_{sig}^{KLPiPivs4Pi} / MC_{LU}^{KLPiPivs4Pi} N_{LU}^{KLPiPvs4Pi}$
- 3 equations with 3 unknowns: $D_i = T_{Si} + T_{Pi} + T_{Ci} + T_{Fi}$

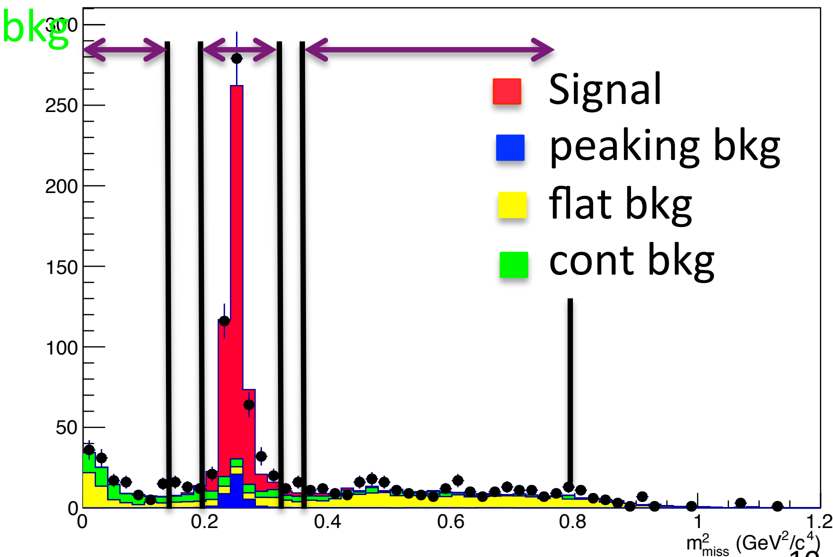
Continuum bkg

Flat bkg

Raw data yields

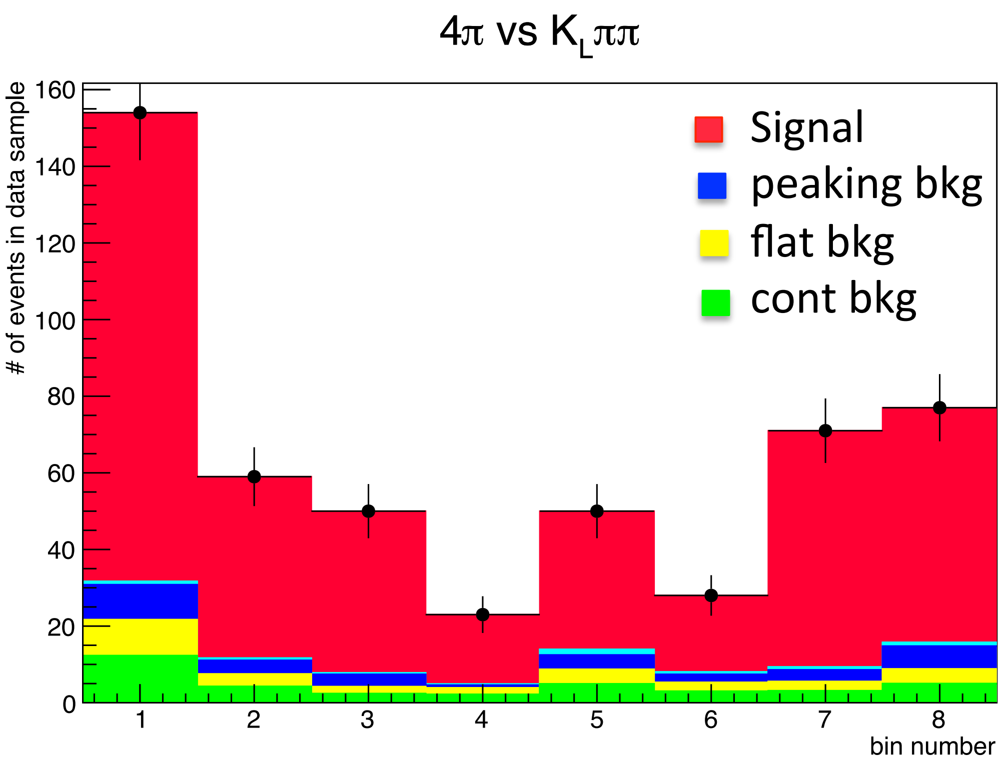
Signal yields

Peaking bkg



- Solve and get:
  B^{flat} = 28.42 ± 10.80 ± 6.80
  B^{cont} = 37.15 ± 10.85 ± 9.45
- Distribute 'flatly' over bins, i.e. according to bin area.

K_LPiPi vs 4Pi – signal yield



Preliminary: we are still fiddling around with some yields here…

Efficiency corrected signal yields:

stat errors only, (first MC, second data)

bin	MM_i
1	$512.33 \pm 24.16 \pm 54.52$
2	$204.17 \pm 10.19 \pm 33.69$
3	$202.33 \pm 10.02 \pm 34.23$
4	$78.20 \pm 4.89 \pm 20.92$
5	$164.73 \pm 11.46 \pm 33.18$
6	$82.38 \pm 6.30 \pm 22.26$
7	$268.10 \pm 10.49 \pm 36.93$
8	$277.09 \pm 13.55 \pm 40.47$

F_+ - from K_SPiPi vs 4Pi

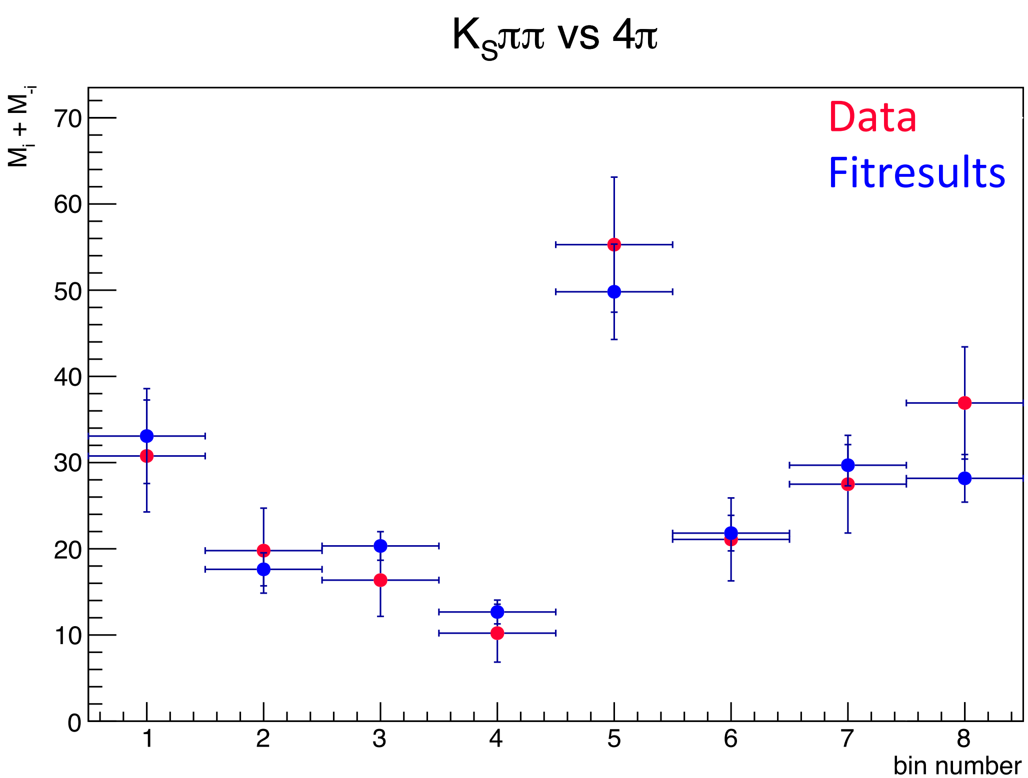
Reminder: $$M_i^{K_S^0\pi\pi} = h_{K_S^0\pi\pi}(T_i^{K_S^0\pi\pi} + T_{-i}^{K_S^0\pi\pi} - 2\, c_i \sqrt{T_i^{K_S^0\pi\pi} T_{-i}^{K_S^0\pi\pi}}\, (2F_+^{4\pi} - 1))$$

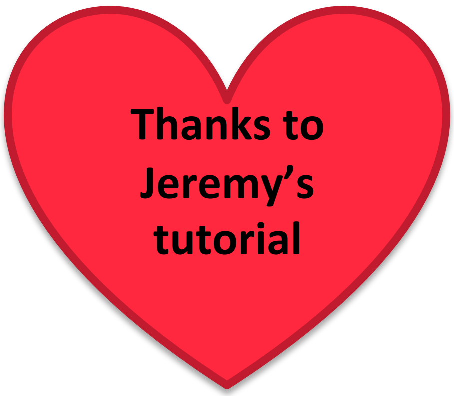
Just measured

External input

Want this

In the Fit: Gaussian constrain all input parameters, take into account correlation between c_i, fit for F_+ and h





F_+ = 0.830 ± 0.071

Chi2/ndof = 0.7

F_+ - from K_LPiPi vs 4Pi

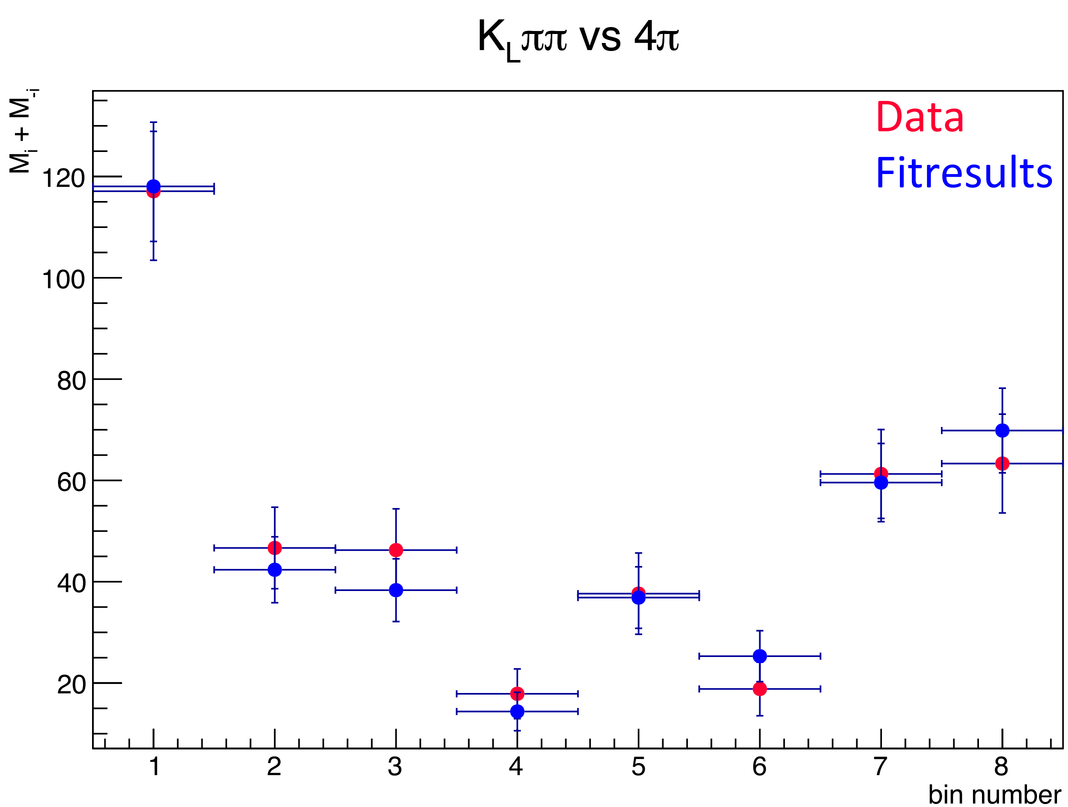
Reminder: $$M_i^{K^0_L\pi\pi} = h_{K^0_L\pi\pi}(T_i^{K^0_L\pi\pi} + T_{-i}^{K^0_L\pi\pi} + 2\,c_i'\sqrt{T_i^{K^0_L\pi\pi}T_{-i}^{K^0_L\pi\pi}}\,(2F_+^{4\pi} - 1))$$

Just measured

External input

Want this

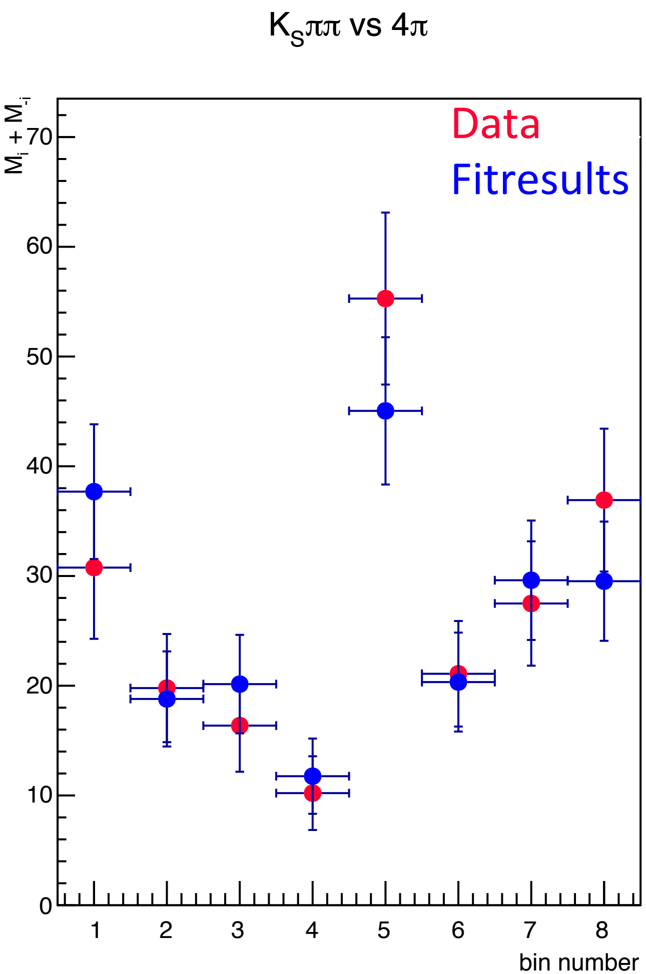
In the Fit: Gaussian constrain all input parameters, take into account correlation between c_i, fit for F_+ and h

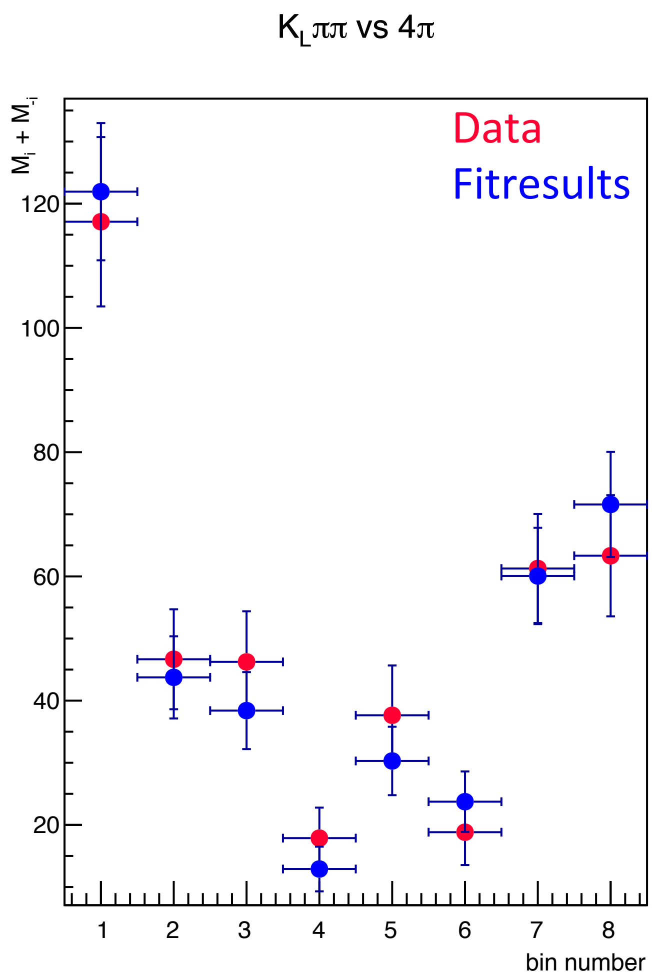


$F_+ = 0.678 \pm 0.069$

Chi2/ndof = 0.62

F_+ from simultaneous fit





F_+ = 0.753 ± 0.052
Chi2/ndof = 0.77

K_SPiPi vs 4Pi:
F_+ = 0.830 ± 0.071
Chi2/ndof = 0.7

K_LPiPi vs 4Pi:
F_+ = 0.678 ± 0.069
Chi2/ndof = 0.62

As I said: more fiddeling has to be done on the K_LPiPi part…

Question 1

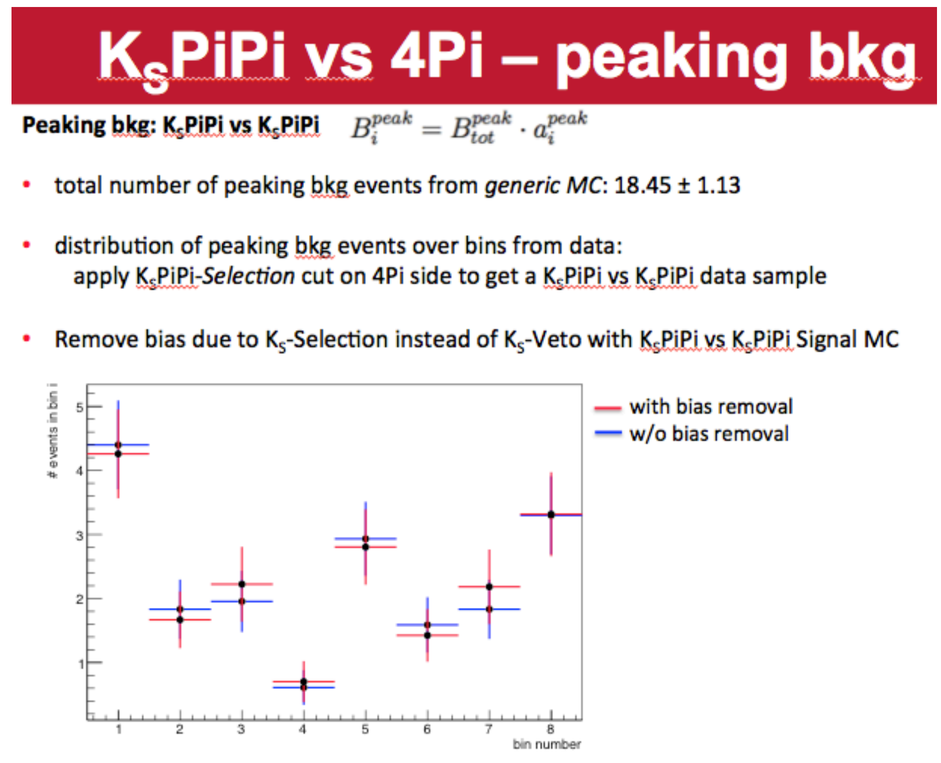
<u>When distributing the total number of flat bkg events over the bins</u>
no error on the area of the bin is assumed.
➔ The error on the bkg yield per bin is smaller than sqrt(N_i)
Is that a problem? How to fix it?

<u>For the distribution of peaking bkg</u> I only take the error from

distribution in data (multinomial error)

rescaling from MC (ratio of two efficiencies)

➔ Does that not introduce the same problem as above?



Question 2

K_LPiPi vs 4Pi – error on signal yields

Done using a toy study:

1. in the Powell method Poisson/Gauss vary all inputs (MC and data independently)

$$\boxed{D_1} - \boxed{T_{P1}} = \frac{\boxed{m_{S1}}}{\boxed{m_{S2}}} T_{S2} + T_{C1} + \frac{\boxed{m_{F1}}}{\boxed{m_{F3}}} T_{F3}$$

$$\boxed{D_2} - \boxed{T_{P2}} = T_{S2} + \frac{\boxed{m_{C2}}}{\boxed{m_{C1}}} T_{C1} + \frac{\boxed{m_{F2}}}{\boxed{m_{F3}}} T_{F3}$$

$$\boxed{D_3} - \boxed{T_{P3}} = \frac{\boxed{m_{S1}}}{\boxed{m_{S3}}} T_{S2} + \frac{\boxed{m_{C3}}}{\boxed{m_{C1}}} T_{C1} + T_{F3}$$

2. Still from within the toy study calculate the flat bkg, cont bkg yields per bin
3. Subtract from data yield per bin to get signal yields per bin

The data yield is needed twice: in step 1 and in step 2:
I generate the data yields for each bin (which I am going to use in step 2), and use the sum as input for step 1. ➔ I am using the same data yield in the entire toy. Is that correct?

Summary

- Calculated the K_SPiPi vs 4Pi signal yield per bin
- Almost finished calculating the K_LPiPi vs 4Pi signal yield per bin
- Fitter is fully setup and functional

Still to do:

- Some kinks to iron out in the K_LPiPI vs 4Pi part
- Generate more K_LPiPi vs 4Pi signal MC for the efficiency correction
- Calculate ALL the systematics

Backup

Binned strong phase difference

$$c_i \equiv \frac{1}{\sqrt{T_i T_{-i}}} \int_{\mathcal{D}_i} a_{xy} a_{yx} \cos(\delta_{xy} - \delta_{yx})\, \mathrm{d}x\, \mathrm{d}y,$$

Amplitude of D going to point x,y in the Dalitz Plot

Backup

Powell method:

$$D_1 - T_{P1} = \frac{m_{S1}}{m_{S2}} T_{S2} + T_{C1} + \frac{m_{F1}}{m_{F3}} T_{F3}$$

$$D_2 - T_{P2} = T_{S2} + \frac{m_{C2}}{m_{C1}} T_{C1} + \frac{m_{F2}}{m_{F3}} T_{F3}$$

$$D_3 - T_{P3} = \frac{m_{S1}}{m_{S3}} T_{S2} + \frac{m_{C3}}{m_{C1}} T_{C1} + T_{F3}$$