An Amplitude Analysis of D^0->4pi at CLEO-C

I.O.P.

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University of BRISTOL

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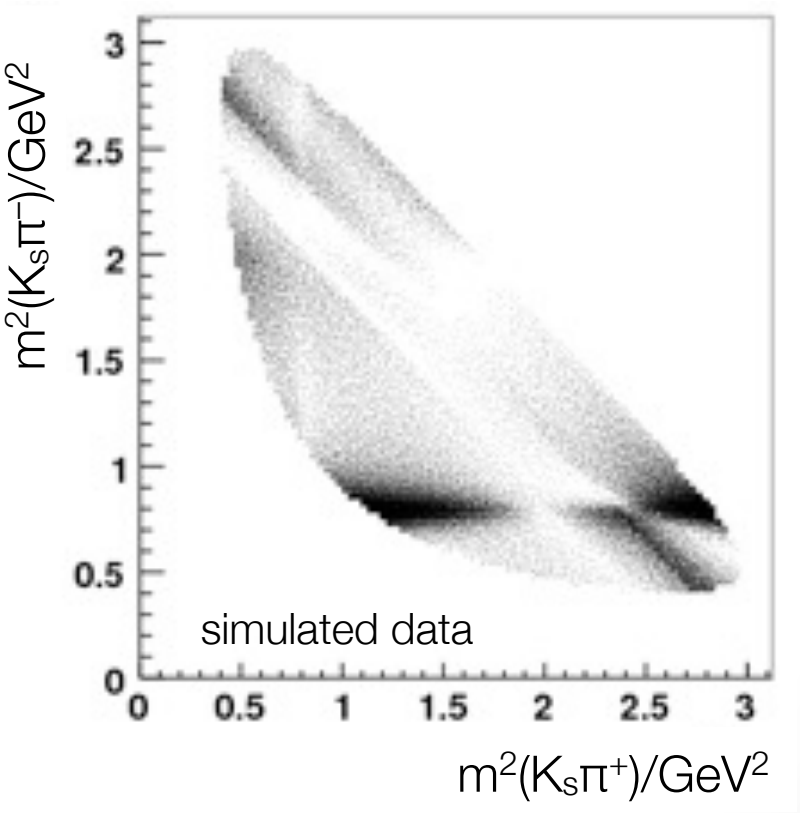
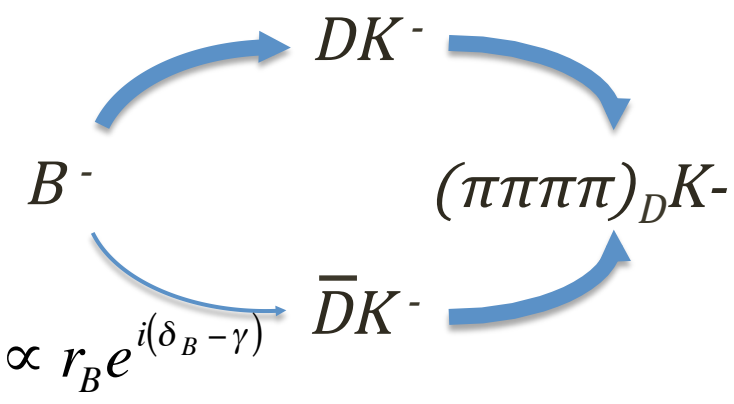
What is an Amplitude Analysis?

- A decay can have many possible paths and intermediate resonances which effect the kinematic properties of the final state particles.
- If you want to observe fine details of a decay process, such as spin properties and relative phases, you need an amplitude analysis.
- Typically this involves building a model of known resonances and fitting a Dalitz plot, like for $D^0 \rightarrow K_s\pi^+\pi^-$ to the right.



Our Motivation

- At Bristol, we have a research group dedicated to measuring the CP violating phase gamma.
- One strategy is to use the decay of B to D^0/D^0bar mesons where gamma is introduced as a relative phase.
- Before extracting gamma a thorough amplitude analysis of the D decay is required, in this case D^0 to four charged pions.



- The Focus Collaboration published a model for this channel in 2007.
- Try to obtain a more accurate model with CLEO-c's increased dataset.

Constructing A $D^0 \rightarrow \pi^-\pi^+\pi^+\pi^-$ Model

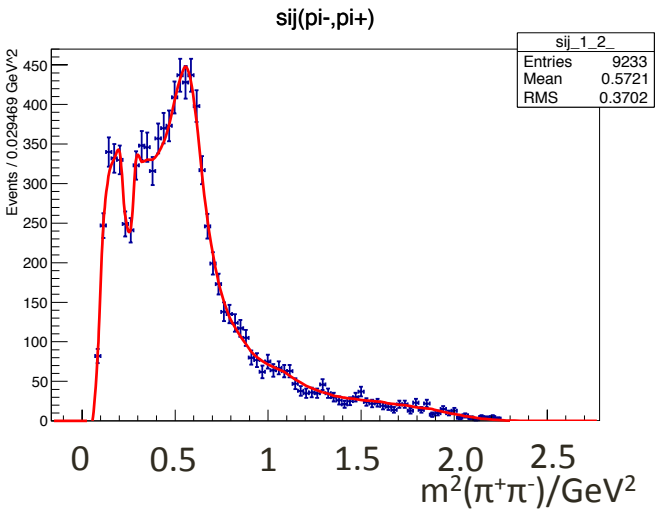
- As $D^0 \rightarrow \pi^-\pi^+\pi^+\pi^-$ is a four body decay mode, our Dalitz plot is 5-dimensional instead of 2.
- Conceptually difficult, but same computational process.
- We build a Model out of a list of possible intermediate resonances, such as:

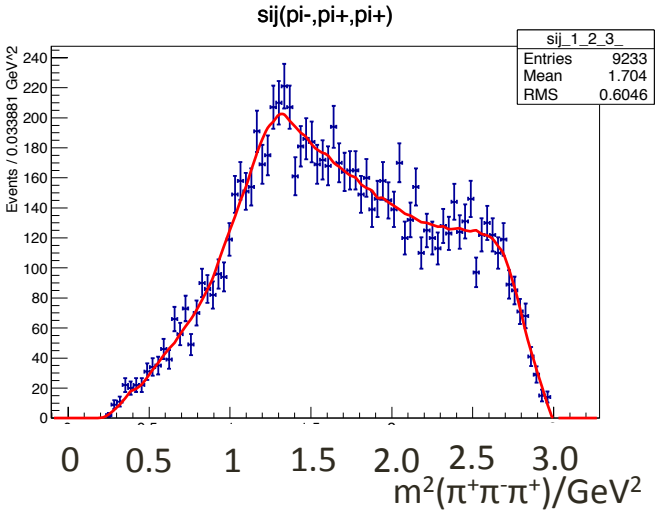
$$D^0 \rightarrow \rho(770)\, \pi^+ \pi^- \rightarrow \{ \pi^+ \pi^- \}_\rho \pi^+ \pi^-$$

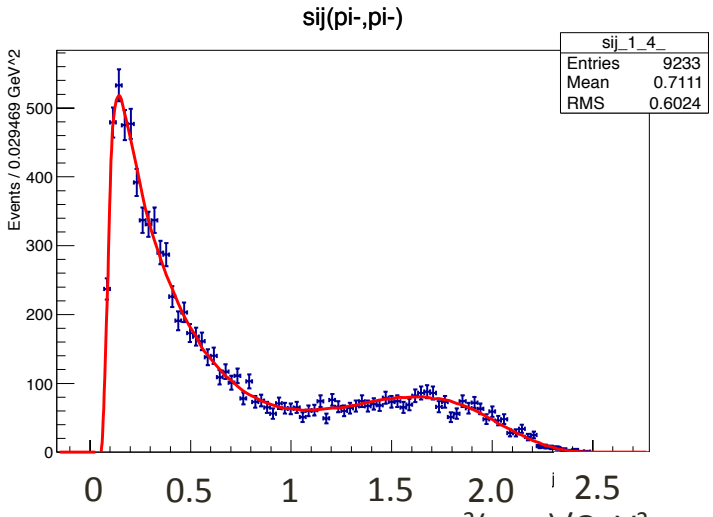
or

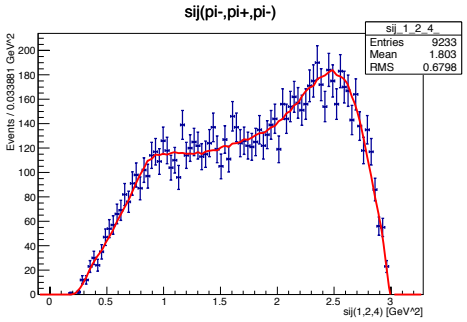
$$D^0 \rightarrow a_1(1260)^+ \pi^- \rightarrow \{ \rho(770)\, \pi^+ \}_{a1} \pi^- \rightarrow \{\pi^+ \pi^-\}_\rho \pi^+ \pi^-$$

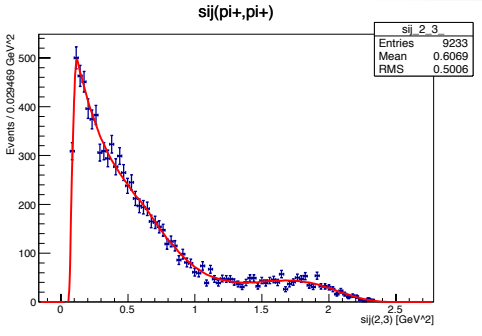
5-D Dalitz Fitting Example







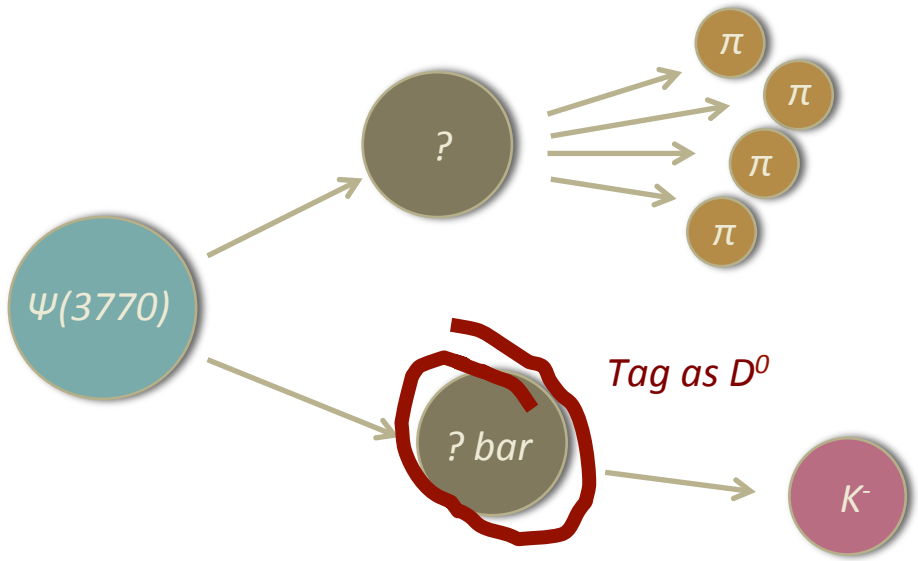




The CLEO-c Dataset

- CLEO-c ran at the Ψ(3770) resonance and so we expect D^0/D^0bar pair production.

- We require the standard selection criteria for four pions and an 'other side' kaon for D-tagging.



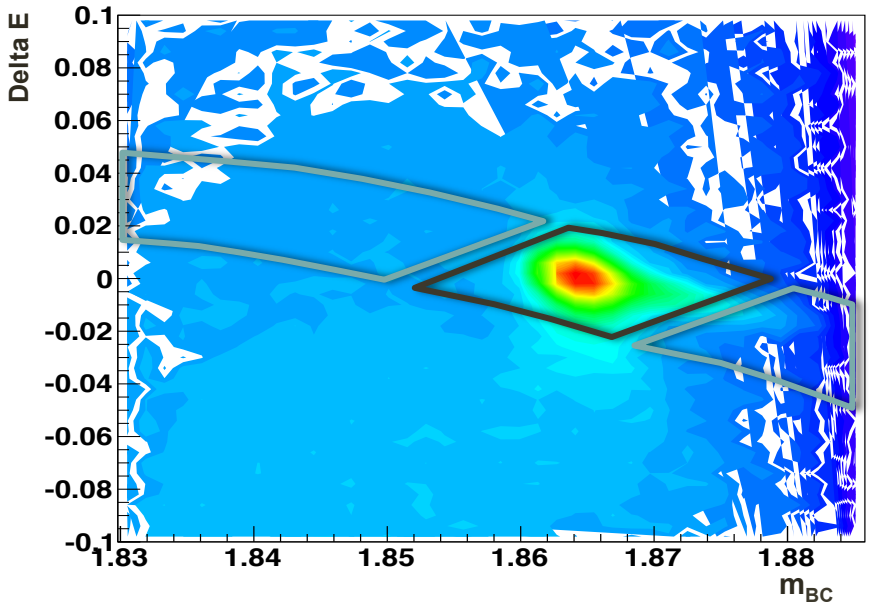
The CLEO-c Dataset

- The data is cut in variables of delta E and beam constrained mass, but square cuts in these variables are not suitable.

$$\Delta E \equiv E_D - \sqrt{s}/2 \qquad m_{bc} \equiv \sqrt{s/(4c^4) - \mathbf{p}_D^2/c^2}$$

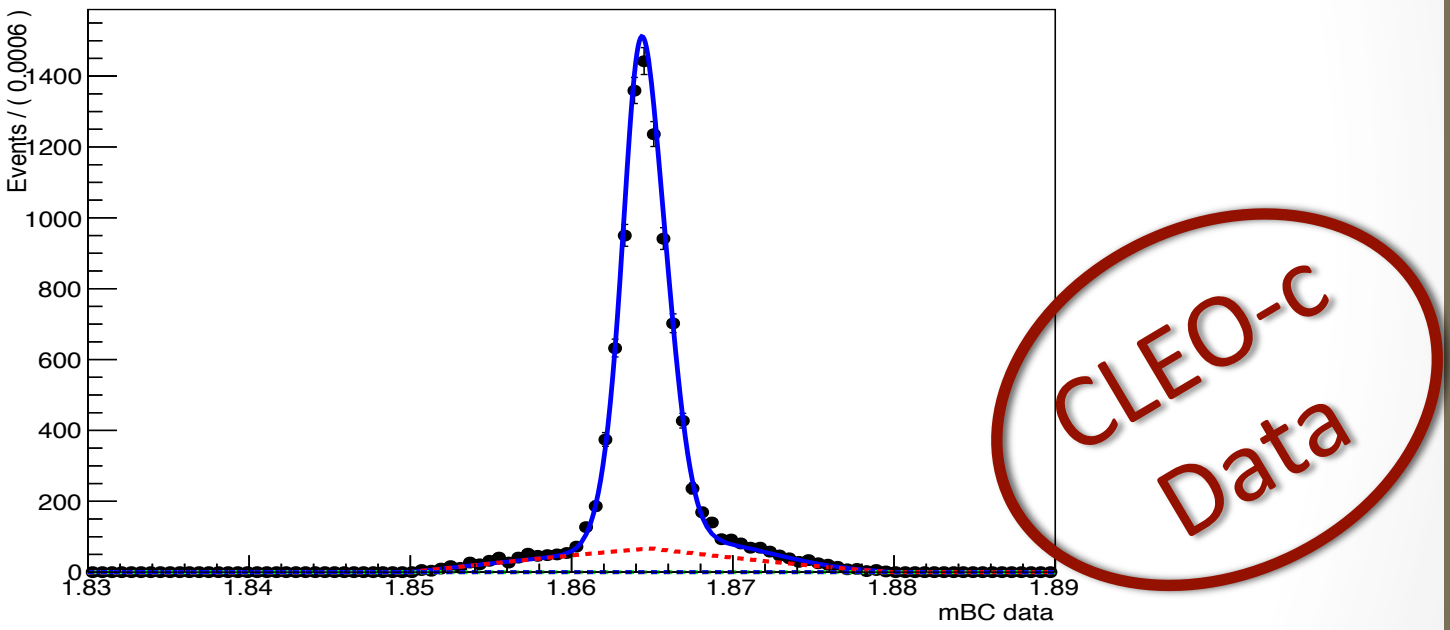
- To define signal and background regions with uniform phase space, cuts were made along lines of constant invariant mass.

- Results in 'contour' cuts, demonstrated below.



Background Fraction

- The background fraction within the signal region has been estimated from two dimensional pdf fits in RooFit. The distributions were determined from sideband samples.



- Determine 18.5% of events in signal region are combinatoric BG.

Model Selection

- To generate and test models in a systematic way, a fitting algorithm has been developed.
- Adopt the use of an genetic algorithm to ‘breed’ the most successful combination of resonances and decay descriptors.
- Models are fitted to the data and ranked using their Chi square per degree of freedom.

Daughter Generation

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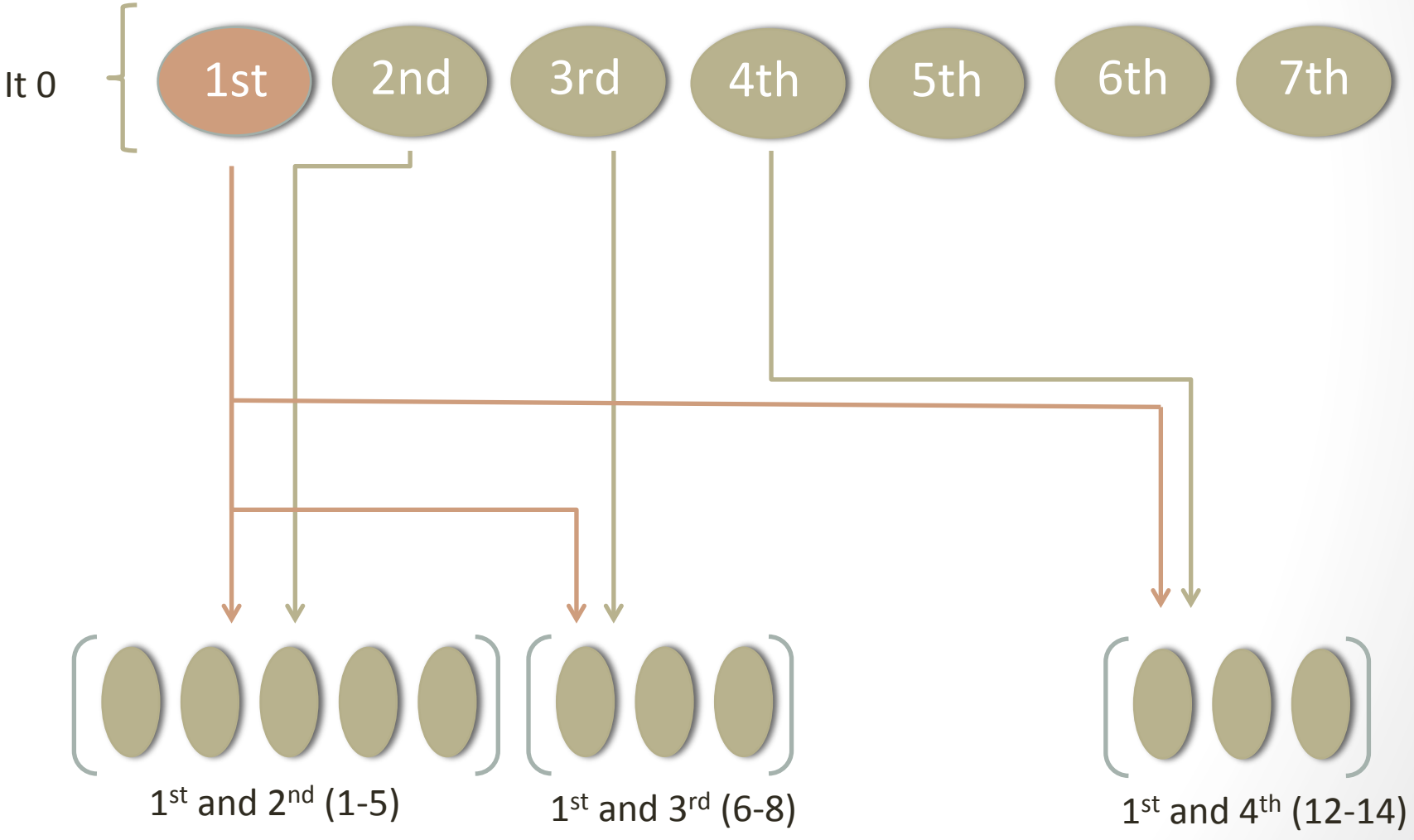

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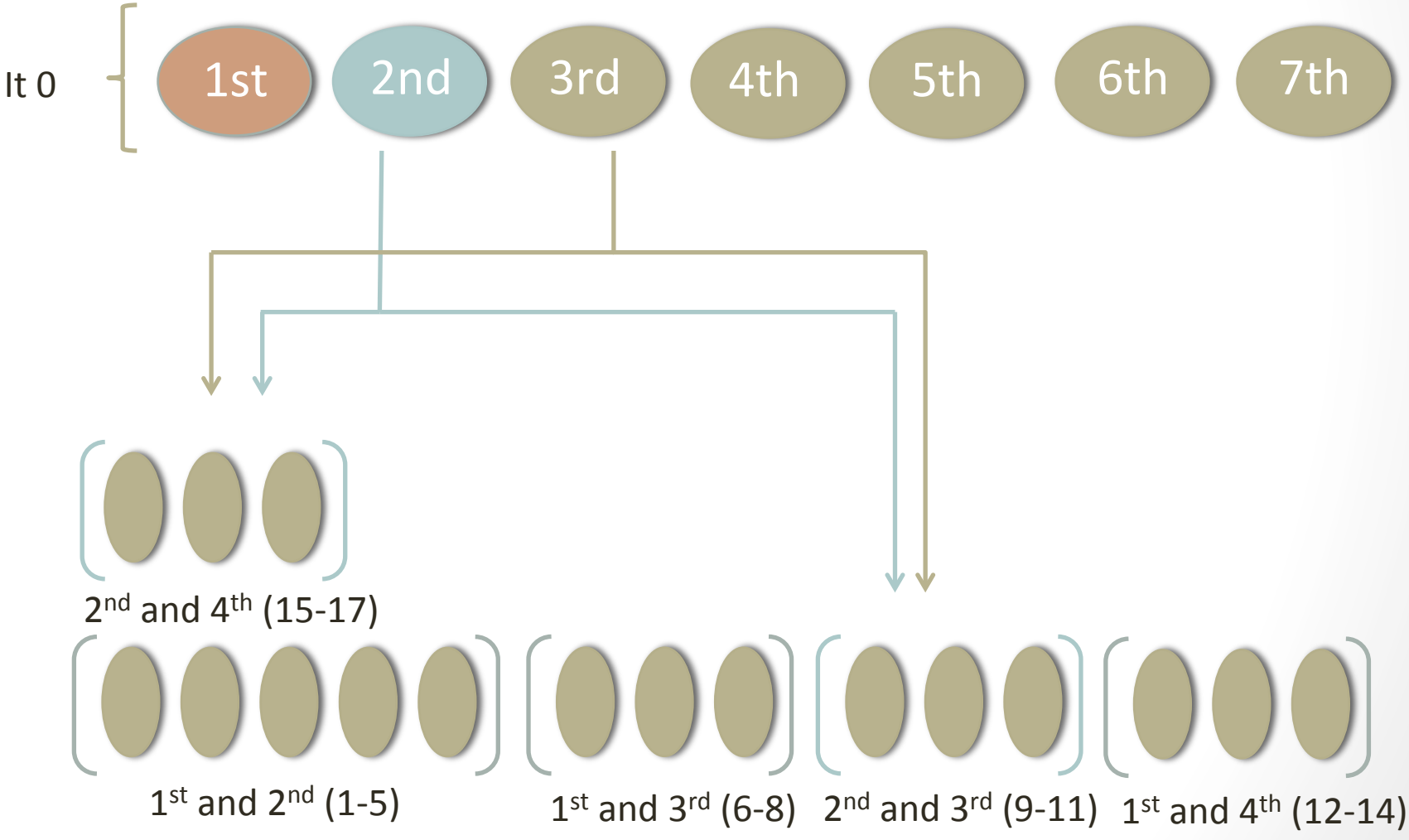

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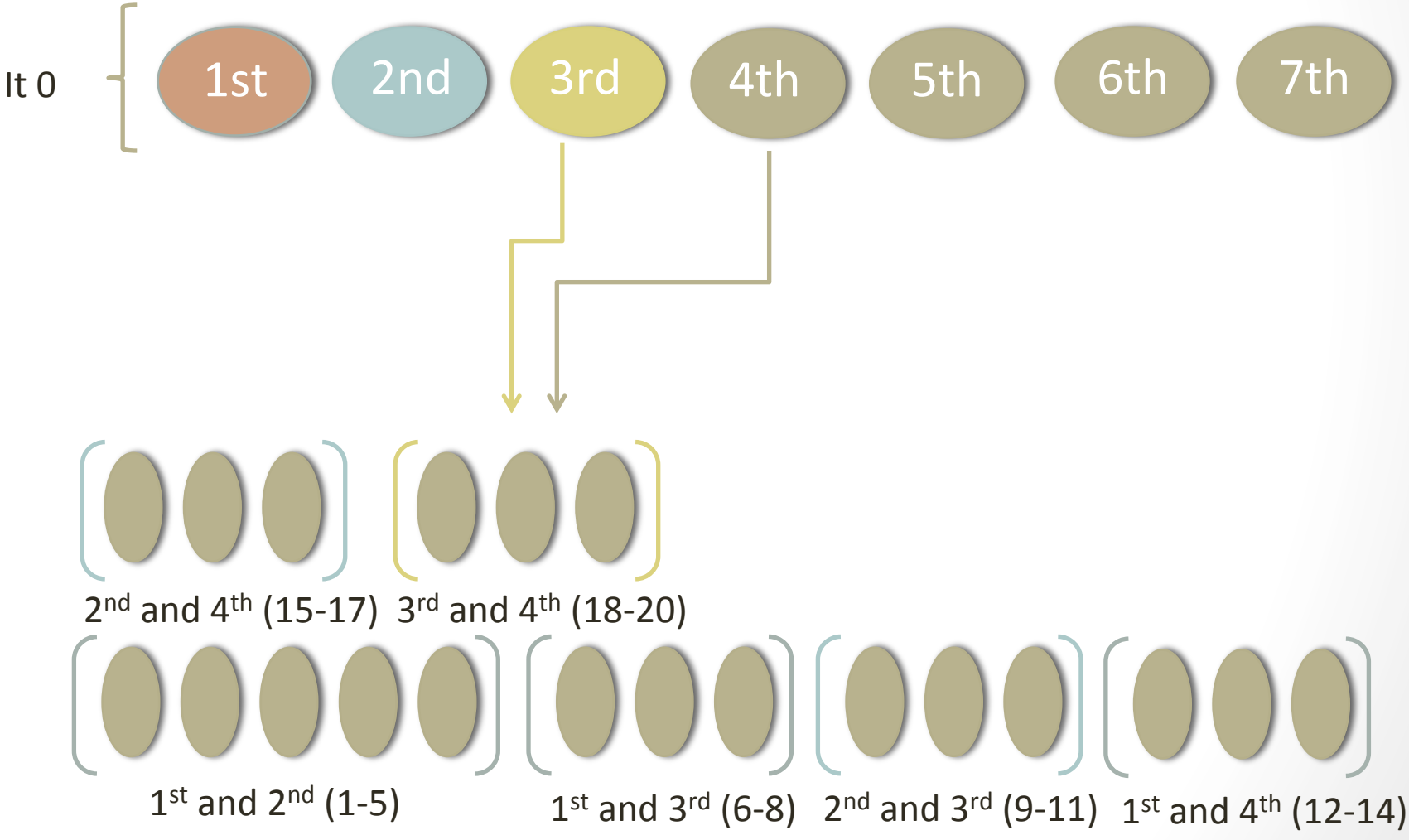

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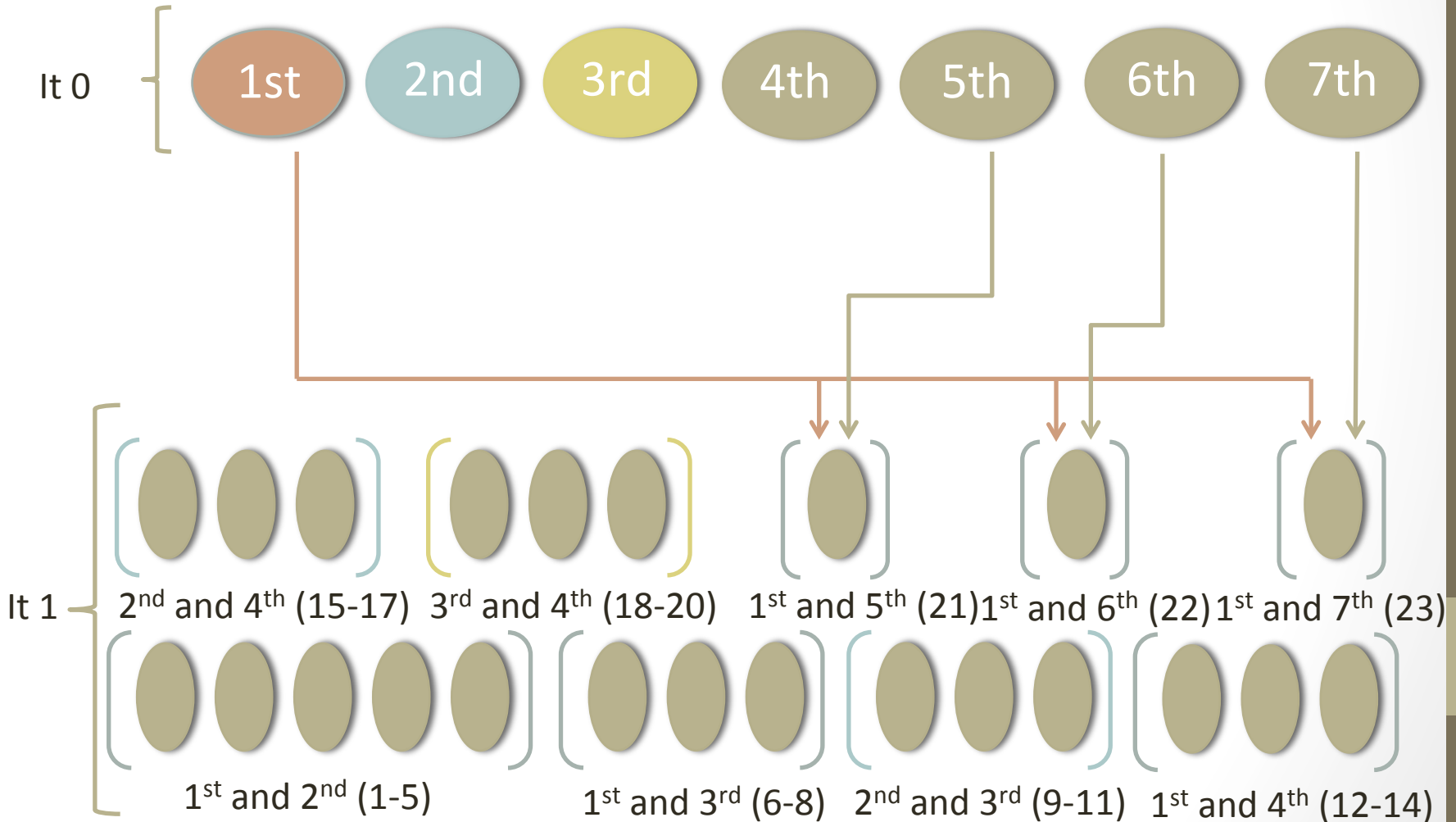
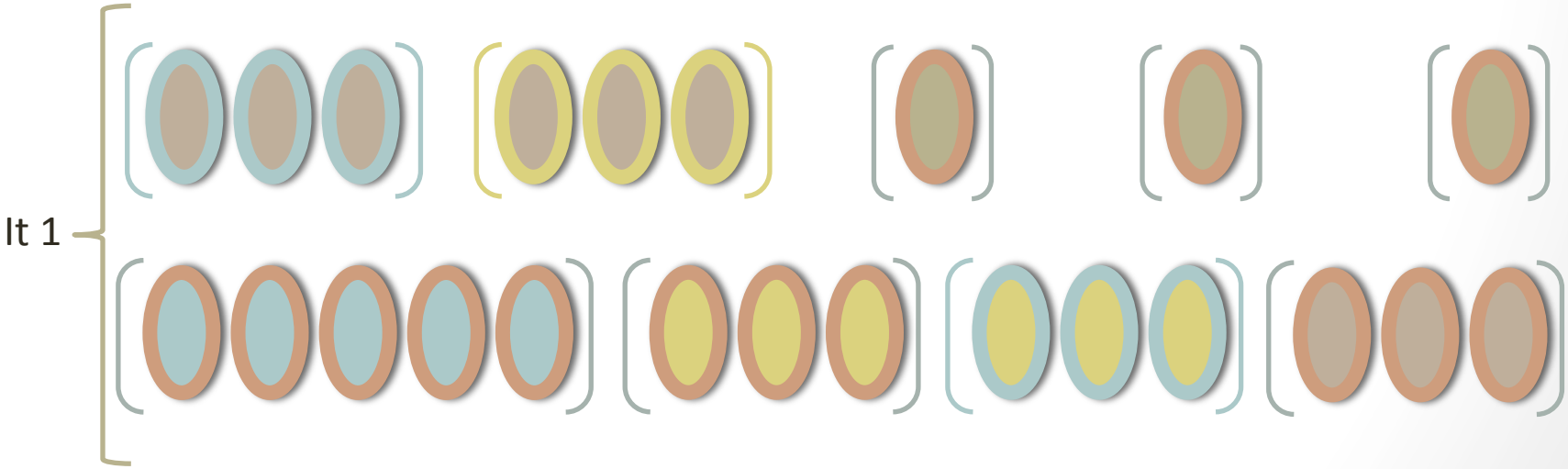


Daughter Generation

- To produce the 1st iteration, the random models are 'bred' together in the following manner:

- Get 23 New Models in total, where only the 'fittest' 7 from the last iteration are used. This procedure is repeated every iteration. This is a somewhat arbitrary choice of system.



Conclusions

- Currently have ~9000 candidate $D^0 \rightarrow 4pi$ events at CLEO-c. The events are experimentally clean and with a well known acceptance.
- We have developed the necessary tools to perform an amplitude analysis on this data and have tested our fitter thoroughly.
- Now in the process of testing our selection algorithm and expect to apply it to data soon.
- Once ready, plan to use the final model in an analysis of the complete decay mode $B \rightarrow DK$ at LHCb. We expect a competitive measurement of gamma (similar to $K_s\pi\pi$).
- Can expand our analysis at Cleo to use CP-tagged data samples.

Back Up - Background Model

- To account for the background component in the data, an amplitude model was fitted to a sideband sample.

- The components of this model are not expected to be resonant and are therefore not very physically significant. A background model is useful then to increase fitting accuracy of the remaining signal structure.

Decay (D0's are incoherent and Spin zero)	Fit Fraction
D0->NonResV0(->pi+,pi-),f(0)(980)0(->pi+,pi-)	0.057 +/- 0.011
D0->NonResVbar0(->pi+,pi-),f(0)(980)0(->pi+,pi-)	$(4.6 +/- 1.1) \times 10^{-5}$
D0->rho(770)0(->pi+,pi-),rho(770)0(->pi+,pi-)	0.055 +/- 0.012
D0->sigma10(->pi+,pi-),pi+,pi-	0.888 +/- 0.021
D0[P]->rho(770)0(->pi+,pi-),rho(770)0(->pi+,pi-)	$(2.8 +/- 2.6) \times 10^{-9}$

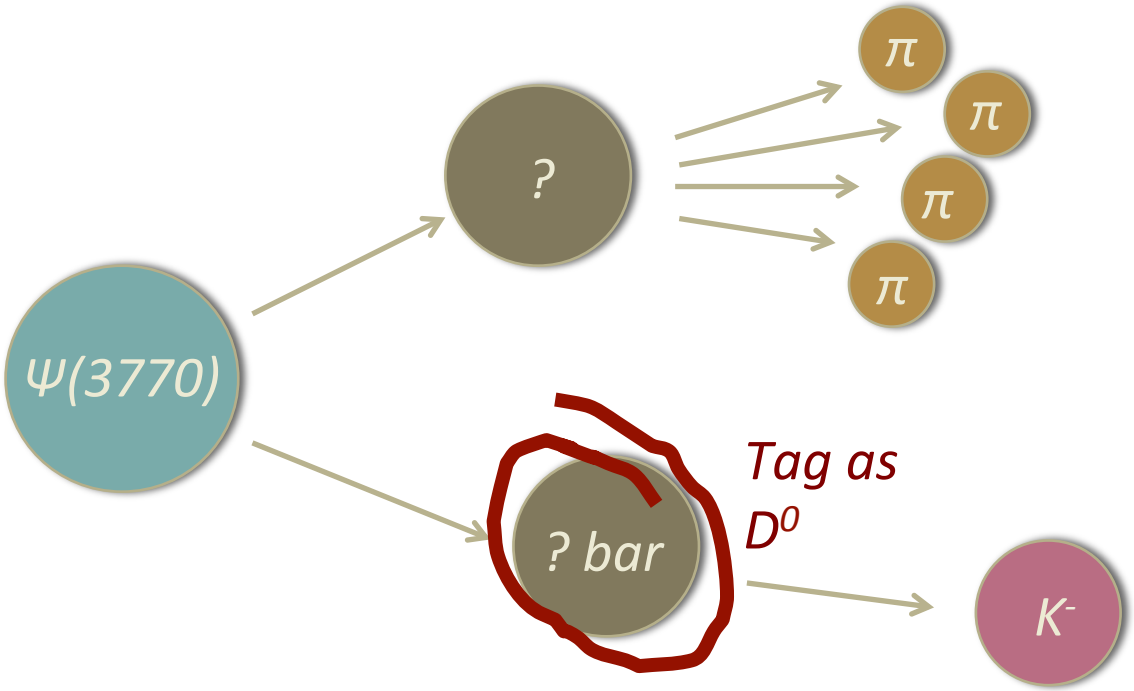
- A first pass at a background model is shown above. The parameters are fixed and added to subsequent data fits with a fraction of 18.5%.

Back Up – Kaon Tagging

- We separate D0 and D0bar by kaon tagging.

- From Psi(3770) have D^0 and D^0bar pair production
  - $P(D^0 \rightarrow K^- X) = 54.7\%$
  - $P(D^0 \rightarrow K^+ X) = 3.4\%$

  So if we tag all other sign D's with Kaons, we have a ~5% mis-ID rate



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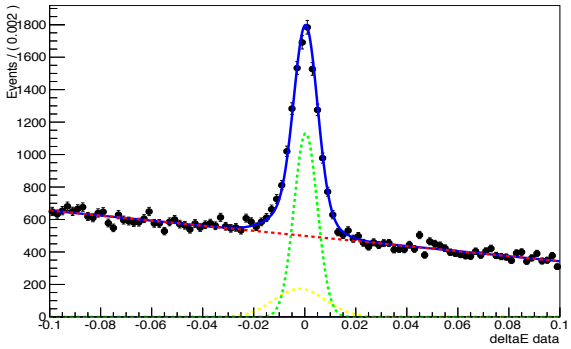

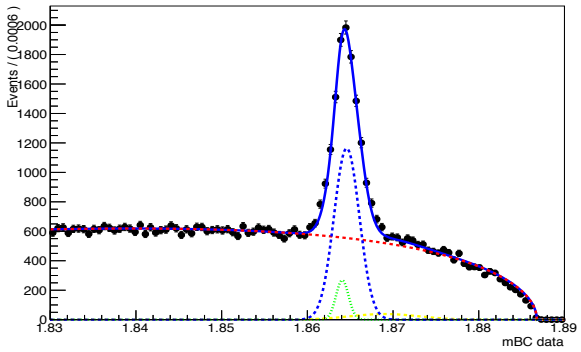

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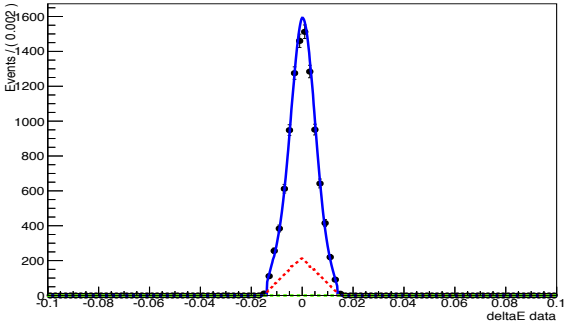
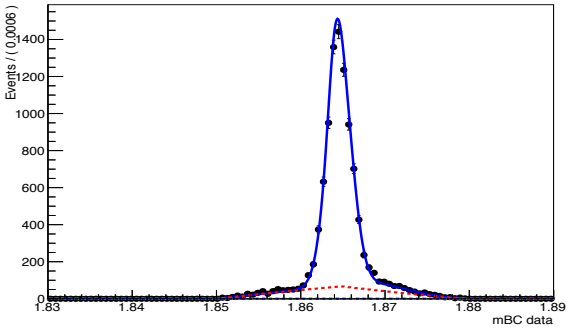




Model Selection

- To generate and test models in a systematic way, a fitting algorithm has been developed.
- Adopt the use of an genetic algorithm to ‘breed’ the most successful combination of resonances and decay descriptors.
- Models are fitted to the data and ranked using their Chi square per degree of freedom.
- Depending on the rank of the model, they are paired and ‘bred’ together. In this process the components of each model have a 50% chance of succeeding to the daughter model.
- Additionally, there is a 50% chance of mutation, via the inclusion of a new component. These are selected at random from a list of possible resonances.

Model Selection

- Iteration 0 is the starting point of the algorithm and is not determined from previous fits.

- The original models are generated randomly, from these rules:

  -All models must contain a random rho(770) resonance.
  -All models must contain a random a_1(1260) resonance.
  -An additional element is added at random which contains neither a rho or a1(1260) resonance.

- For all iterations, the models are checked to make sure individual components are not repeated within the same model and no two models are generated twice.

- Finally, when an element is added to the model, any existing charge conjugate description is added with it.

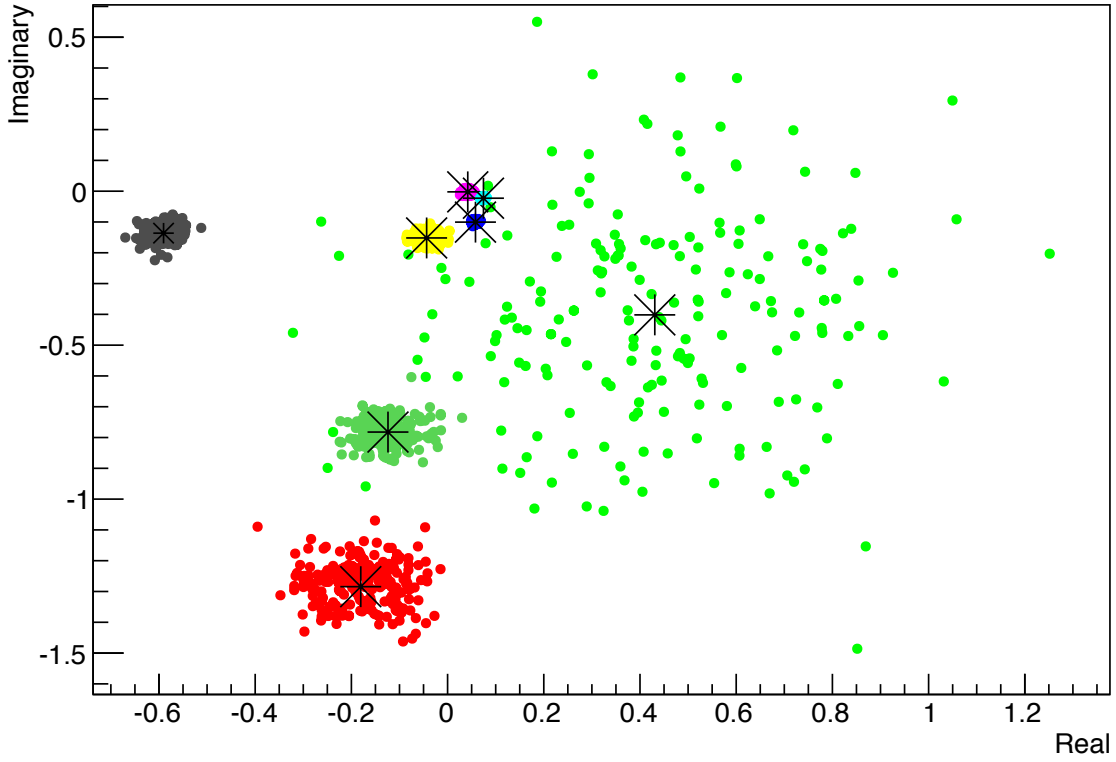
Dalitz Fit Tests

- Minuit INTerface (MINT) is a program developed by Jonas Rademacker, designed to fit input amplitude models in multi-dimensional phase space. It uses the Isobar formulism, describing resonant structure with a summation of Breit-Wigner function.

- MINT uses Monte Carlo integration to normalize the fit likelihood function. By using MC which has been subjected to the same cuts and detector effects at CLEO-c, the varying efficiencies across phase space can be accounted for.

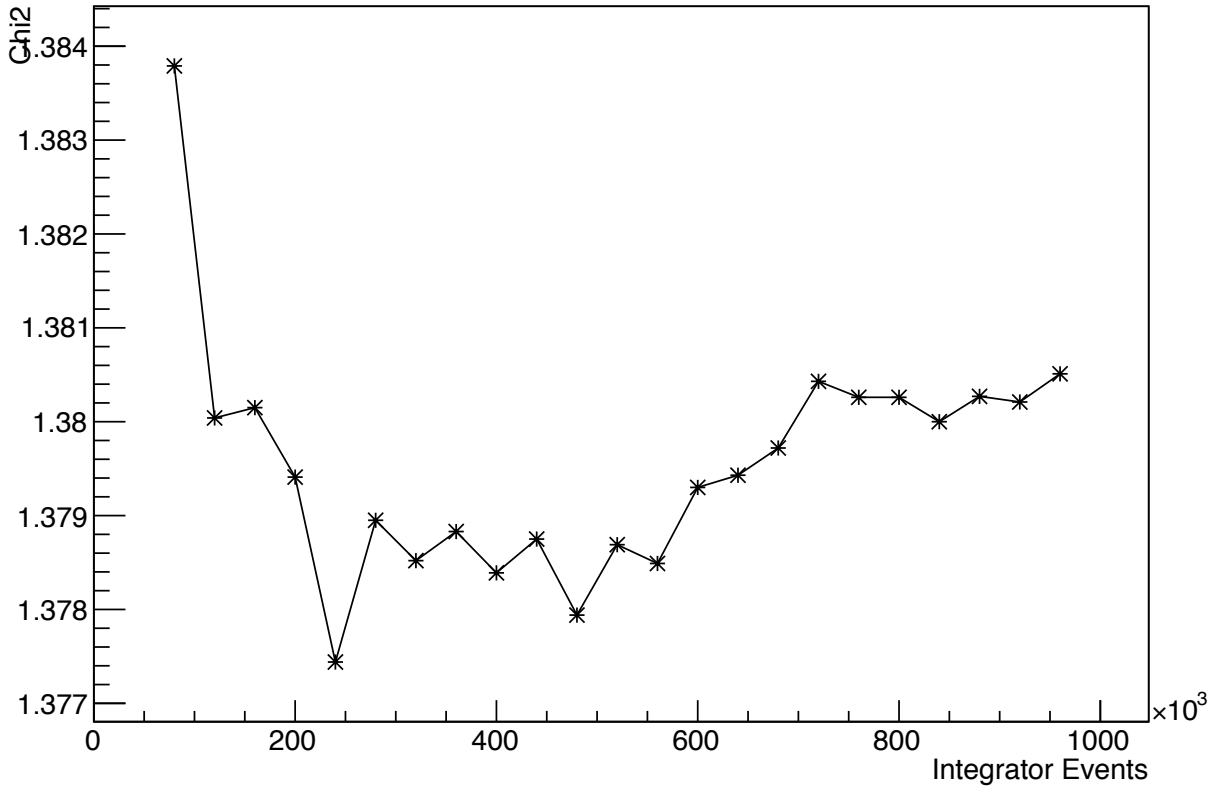
Pull Study of MINT fit Values

- A pull study was conducted to test the handling of efficiencies. The Focus Model was used to generate MC that was passed through the full CLEO-c detector simulation. 10000 event samples were fitted using the same model while a remaining MC was used for integration.



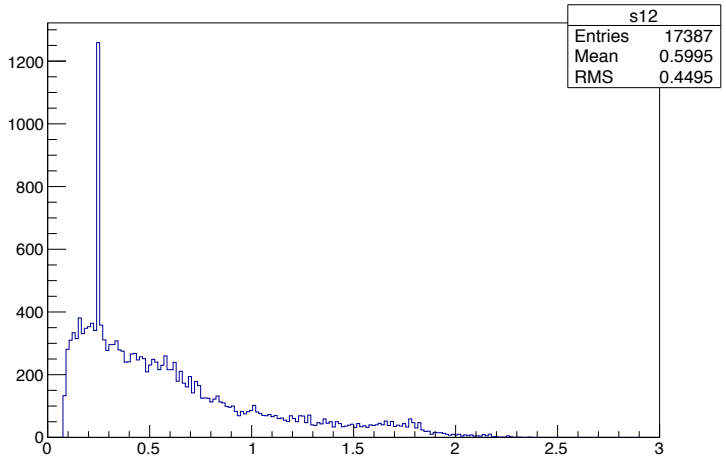
Pull Study of MINT fit Values

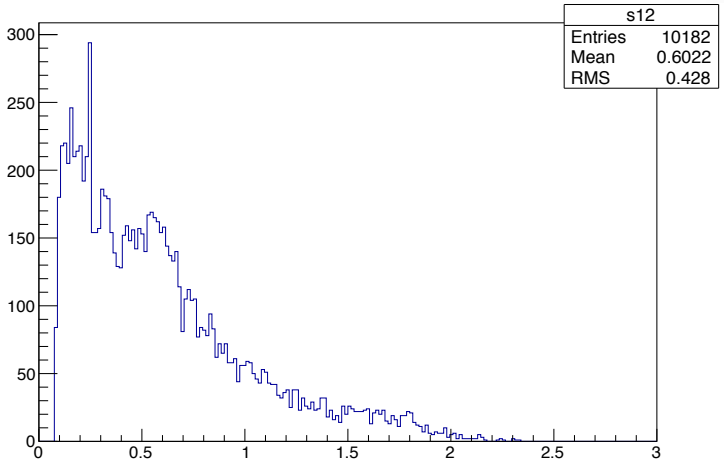
- The number of efficiency integration events required to achieve reasonable and stable fits was also studied. Here the number of events used is plotted against the Chi square per degree of freedom of the fit.

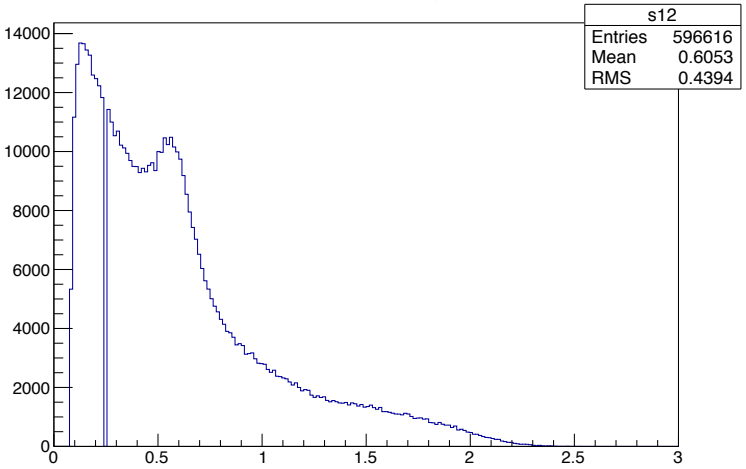


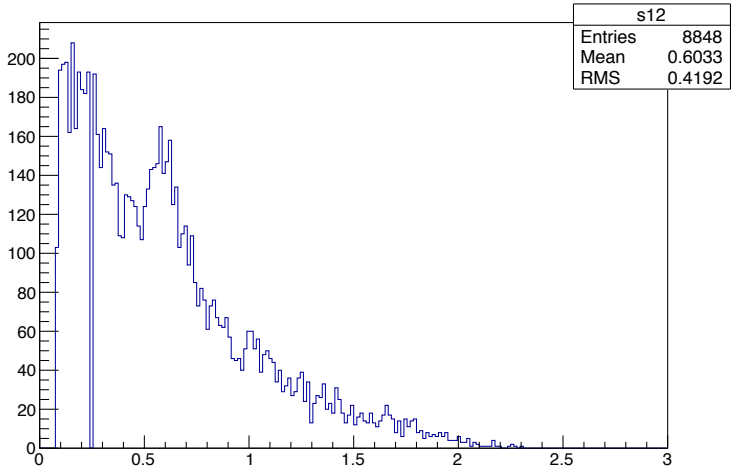
Back Up – K_s Veto

- K_sVeto in data and MC



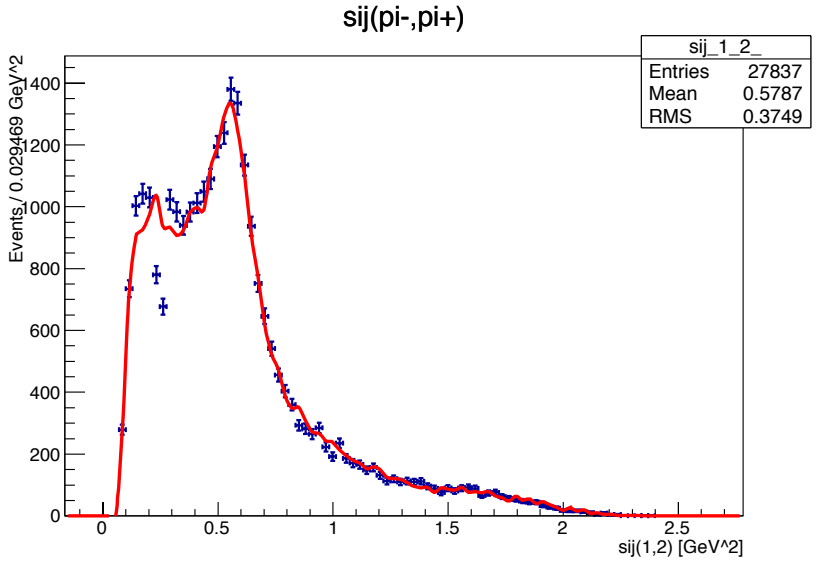


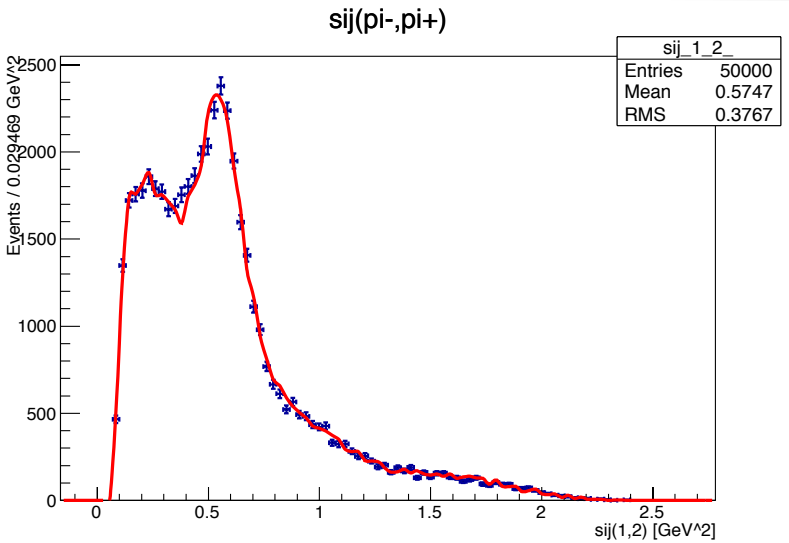




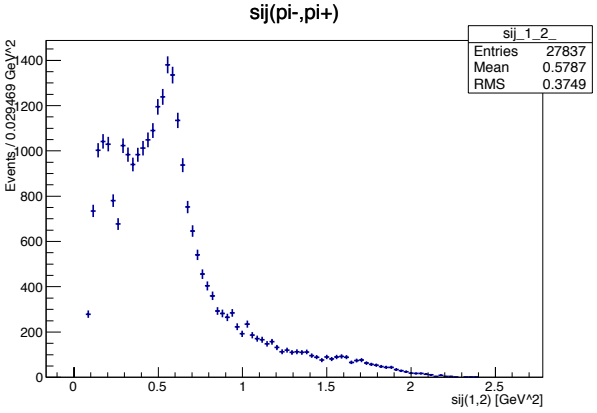
Back Up

- Example KsVeto fit projection





With



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