First look at three and four-body K/π exclusive processes in Run 2

Daniel Martínez Teruel
LHCb - CERN
Universidad Nacional Autónoma de Honduras
teruel_daniel@unah.hn
Supervised by Timothy David Evans

***Abstract*—Three and four-body CEP processes have not been well studied in LHCb data from run 2 yet. CEP processes allow the studying of some QCD aspects that can't be easily measured in other processes. Expected CEP processes that result in light hadrons include $2K$, 2π, $2K2\pi$, $4K$, 4π, $2K\pi^0$ and $2\pi\pi^0$. The 2-body processes have already been studied and have been show to include rich structures, our data coincides with this. Because of this, three and four-body processes are expected to show similarly rich structures, at least in their two-body mass spectra. After applying cuts related to event identification and measurement defects, the mass spectra on these processes from 2018 data are studied to identify possible intermediate particles and particles that they could stem from.**

I. General Description

Central Exclusive Processes (CEP) are processes that can be written as
$H_1 + H_2 \longrightarrow H_1 + X + H_2$, were X is a neutral state. The H_1 and H_2 hadrons are found in the forward region. These events are usually low multiplicity, and result in an almost empty detector and a clean signal. CEP processes occur on a t-channel on an exchange of gluons, resulting in a $gg \longrightarrow X$ interaction. The, the X state decays into hadrons that are detected by the LHCb detectors. It is from these detected hadrons that we rebuild the X particle.

II. Preliminar information

There are already studies on some of the K/π states for CEP, focused primarily on two and four body same hadron processes. In order to have a reference for how the two body mass spectra in three and four-body final states looks, we'll take a look at the mass spectra in $2K$ and 2π, expecting them to be similar when logical. The states that will be studied are:

- $2K$ and 2π in $2K2\pi$
- $2K$ in $2K\pi^0$
- 2π in $2\pi\pi^0$

In the $2K$ mass histogram, we can see several possible resonances, particularly a high one at $\sim 1000MeV$, expected to be a $\varphi(1020)$, thus confirming this to be a $2K$ process. We also see peaks at $\sim 1250MeV$ and $\sim 1600MeV$.

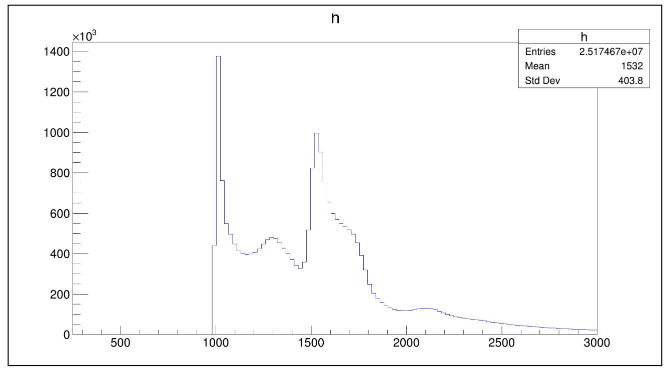

Fig. 1. Mass spectrum on $X \longrightarrow 2K$

In the 2π mass histogram, around 4 resonances with a very distinct one at $\sim 500MeV$, and others at $\sim 800MeV$, $\sim 900MeV$ and a low one at $\sim 1250MeV$.

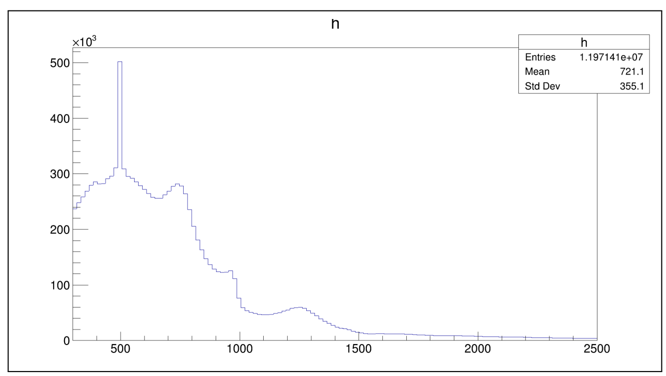

Fig. 2. Mass spectrum on $X \longrightarrow 2\pi$

III. Pre-cuts applied to every distribution

In order to prepare the data, cuts were applied to every single data set studied. Every data set has a cut on velo-track numbers and PID corresponding to the expected process.

On top of this, cuts on cloned particles had to be applied. This "cloned particles" are particles, either with equal or opposite charge, that are detected with a very small angle between them ($\sim 0rad$) and, thus, cannot be part of the same event.

These particles usually contribute to a very, very small part of the background, but it is a possibility for them to form a sort of fake signal. In the $2K2\pi$ process, an apparent resonance of a weird shape can be seen to the left of the entire spectra, when zooming in it looks like this:

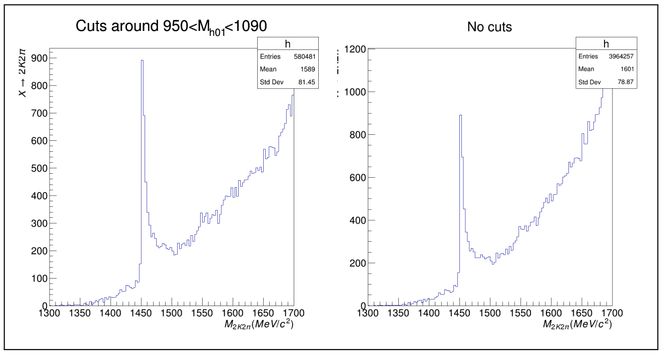

Fig. 3. Zoom on an abnormal peak formed from clones.

However, this peaks turn out to be made of cloned particles. This clone particles, when checking the angle in equally charged hadrons, look like this:

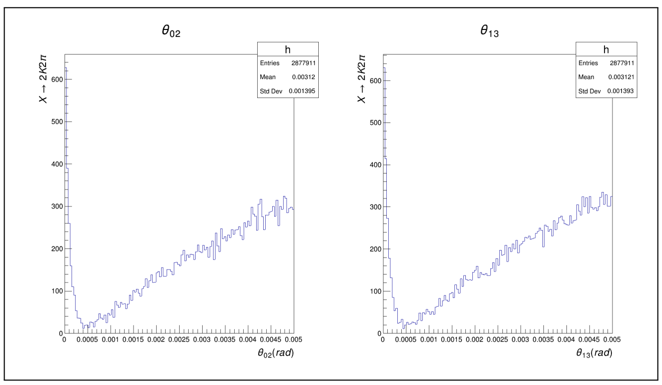

Fig. 4. Angle between same signed hadrons in $X \longrightarrow 2K2\pi$.

The peak at around $0rad$ is evidently abnormal, and thus must not be considered. As it will be seen later, getting rid of these data results in the peak seen on Fig. 3 disappearing completely.

Every angle distribution in every process had a similar shape, so corresponding cuts are applied to all of them.

IV. Analysis on $2K2\pi$

Once we get rid of the clones, sadly, the invariant mass for $2K2\pi$ is rather featureless.

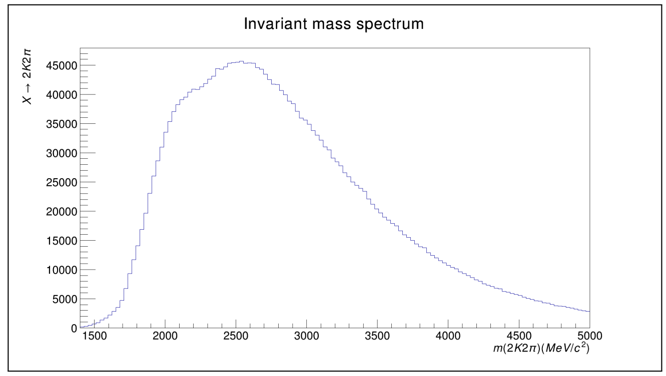

Fig. 5. $X \longrightarrow 2K2\pi$ invariant mass spectrum. Applied cuts are PID and clones for same sign and opposite sign particles.

Since nothing can be seen, we check the two body masses for KK, $\pi\pi$ and $K\pi$ combinations.

A. *Two-body mass spectra*

Both same hadron combinations show similar behaviour to the $2K$ and 2π CEP processes. The $\sim 1000\text{MeV}$ peak in the $2K$ process is a $\varphi(1020)$

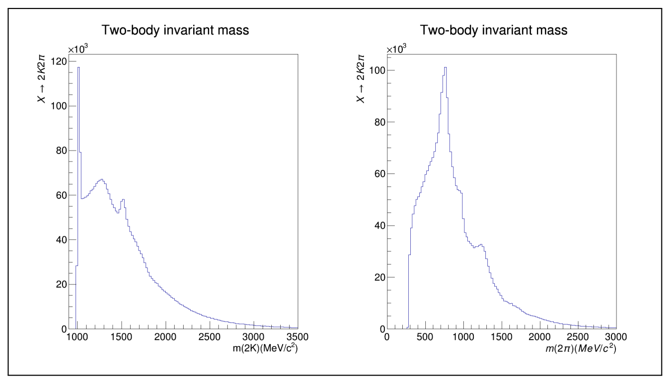

Fig. 6. Two body mass spectra for same hadron combinations

To check for any $X \longrightarrow (A \longrightarrow 2K) + (B \longrightarrow 2\pi)$ processes (or some with only A or B), cuts are made on expected peaks for A or B and then the two-body mass and four-body mass with and without the cut is plotted.

Cuts around $\varphi(1020)$ are applied to the 2π mass in order to find any A and B particles and the invariant mass for the entire process to find candidates for X.

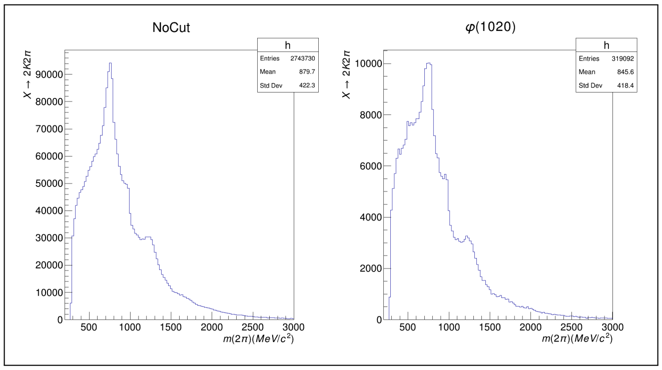

Fig. 7. Two body mass spectrum for same for 2π around $\varphi(1020)$

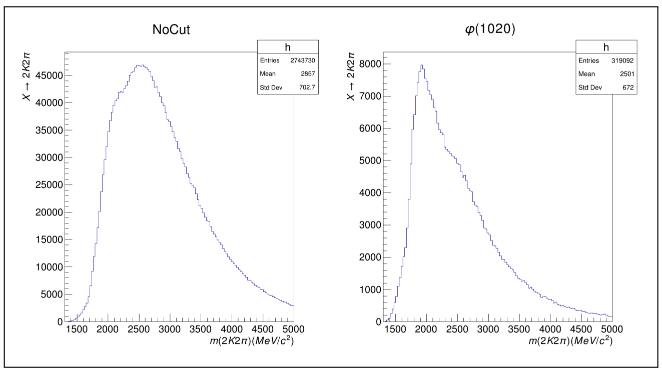

Fig. 8. Mass spectrum for same for $2K2\pi$ around $\varphi(1020)$

No interesting behaviour arose when making cuts around the other peaks.

The other possible two-body combinations are $K\pi$ spectra; both mass spectra for this combination have the same behaviour. The resonance at $\sim$ 900MeV is most likely a $K^*(892)$, which would be expected to peak highly in a $K\pi$ process.

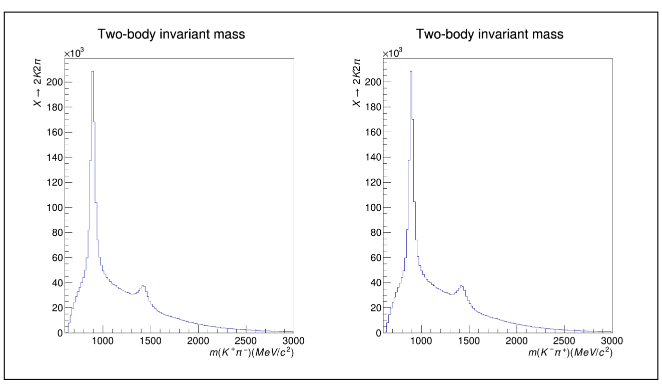

Fig. 9. Two body mass spectra for $K\pi$ combinations

Cutting on $K^*(892)$ for one two-body invariant mass doesn't result in improved resonances in the other or in the total mass spectra. Thus, we don't expect any process with an intermediate $K^*(892)$.

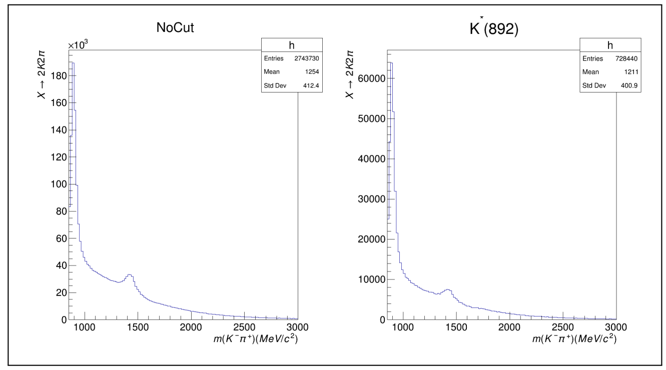

Fig. 10. Two body mass spectra for $K\pi$ combinations

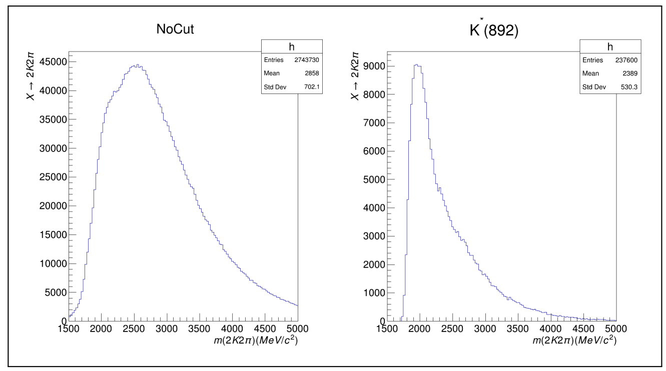

Fig. 11. Mass spectrum for X with $X \longrightarrow 2K^*(892)$

V. Analysis for $X \longrightarrow 2K\pi^0$

The invariant mass on this process is quiet rich. Resonances can be seen in the lower mass region of the spectrum, zooming in reveals there's one (which could be the sum of two) in the $\sim$ 1480MeV region, and a smaller in $\sim$ 1280MeV. This region is clean enough to make a fit and predict which particles these resonances could be.

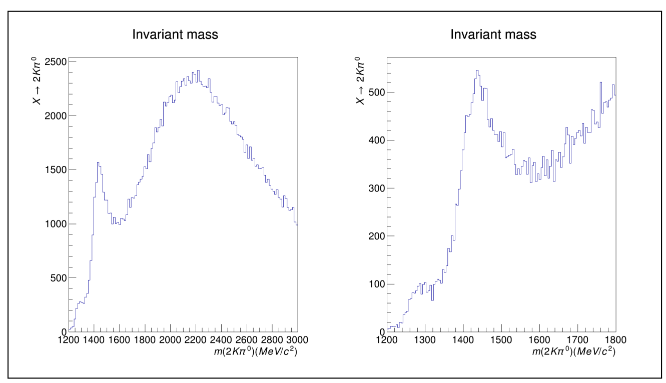

Fig. 12. Mass spectrum for $X \longrightarrow 2K\pi^0$

This signal is quiet dirty. To identify the π^0 in these events, its mass is measured and a cut is selected around the expected mass for the neutral pion. In order to clean up the signal, we can substitute the measured mass for the pion and substitute it for its known mass: $m(X) - m(\pi^0) + m_{\pi^0}$, where $m(\pi^0)$

is the measured mass used in the experiment to identify the π^0 and m_{π^0}. This results in a much cleaner histogram:

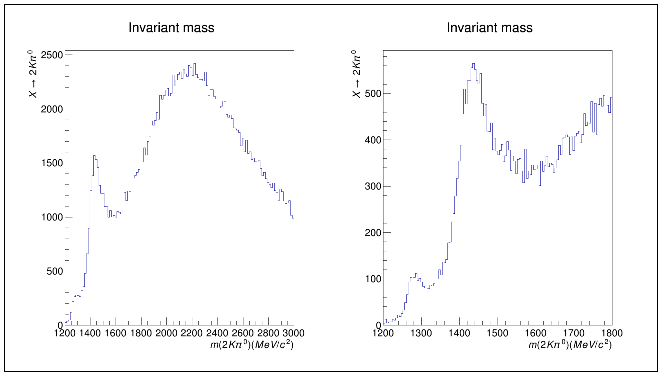

Fig. 13. Mass spectrum for $X \longrightarrow 2K\pi^0$ with the exact π^0 mass.

Now, we can easily fit to these curves and find out which particles these could be.

A. *Fit Model*

The fit considers four PDF's: one background and three signals. These are:

- A third-degree exponential polynomial as a background.
- Two Voigtian peaks with adjustable widths and a common resolution for the peaks around 1400MeV.
- A Gaussian for the peak around 1280 MeV.

When leaving all parameters free with just one common resolution amongst all signals, the masses imply these are: $f_1(1285)$, $f_2(1430)$ and $f_1(1510)$.

The current version of the fit fixes the masses for the lowest peaks, and lets the $f_1(1510)$ vary with a common resolution amongst them. Resolution is expected to be in the order of $\sim$ 10MeV.

Using the model that was described before, we get:

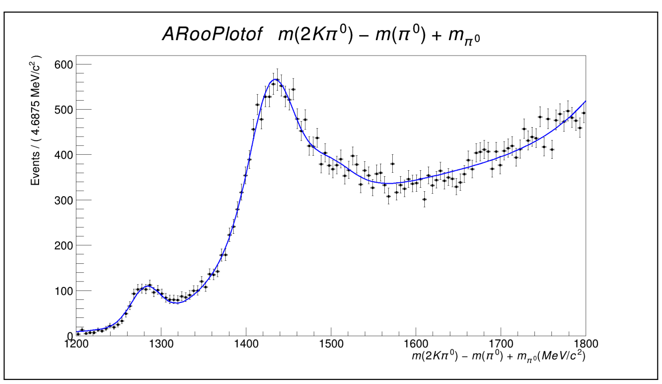

Fig. 14. Fit results, with fixed masses on $f_1(1285)$ and $f_2(1430)$.

The free parameters on this fit result in:

$m_X(f_2(1430)) =$	1497 ± 5
$\Gamma(f_2(1430) =$	47.4 ± 4.5
$\Gamma(f_1(1510) =$	65 ± 13
$\sigma =$	17.4 ± 1.1

TABLE I

FIT RESULTS. EVERY QUANTITY IS IN $\mathrm{MeV/c^2}$. HERE, σ REPRESENTS THE RESOLUTION OF THE DETECTOR.

B. *Dalitz plots*

In order to confirm that the $f's$ are addequate candidates, Dalitz Plots were used. Dalitz plots for spin-0 particles show two distinct and separate blob-like areas. These Dalitz plots seem to show that the X candidate is indeed a spin-1 particle, given the shape of the plot or, at the very least, not a spin-0 particle.

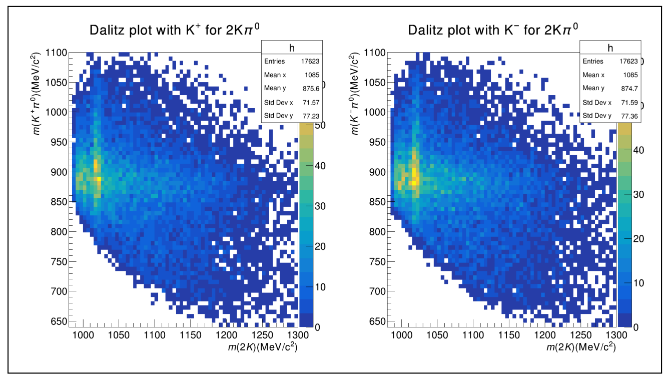

Fig. 15. Dalitz plots for $X \longrightarrow 2K\pi^0$

VI. $X \longrightarrow 2\pi\pi^0$

This process also shows quiet a lot of promise. Resonances can be seen in the lower mass region of the spectrum, zooming in reveals there's one in the ~ 550MeV region, and a smaller in $\sim$ 800MeV. This region is clean enough to make a fit and predict which particles these resonances could be.

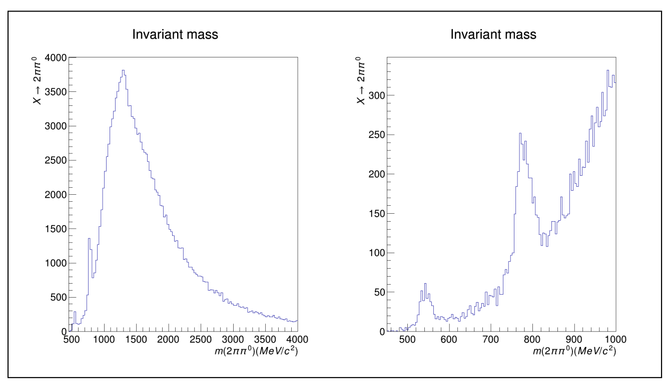

Fig. 16. Mass spectrum for $X \longrightarrow 2\pi\pi^0$

The same process that was followed with $2K\pi^0$ will be applied using the known mass for π^0. That will be the histogram used for the fit.

A. *Fit Results*

The fit considers three distributions: one background and two signals. These are:

- A second-degree exponential polynomial as a background.
- One Voigtian peak with fixed width for the higher peak.
- A Gaussian for the peak around 500MeV.

This model results in this fit:

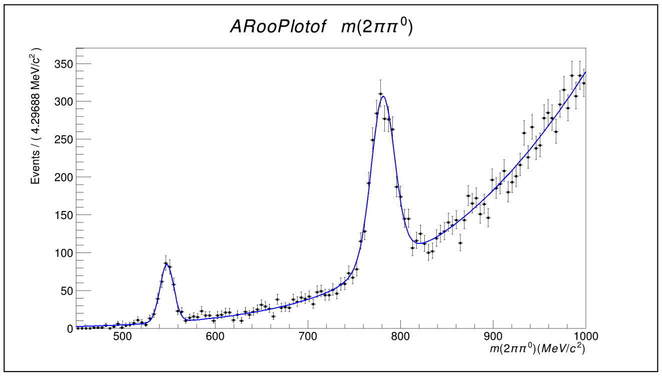

Fig. 17. Mass spectrum for $X \longrightarrow 2\pi^0\pi^0$ with the exact π^0 mass.

The free parameters are fit to:

$m_X(\eta) =$	547.8 ± 0.5
$m_X(\omega(782)) =$	780.9 ± 0.5
$\sigma(\eta) =$	7.4 ± 0.5
$\sigma(\omega(782)) =$	11.0 ± 0.5

TABLE II
FIT RESULTS. EVERY QUANTITY IS IN $\mathrm{MeV/c^2}$

Here, σ represents the resolution of the detector at the mass ranges for each particle. They're both in an expected range and similar enough for it to make sense.

VII. FUTURE WORK

This analysis is not yet complete, nor can it be said any of this is final. Pending work for this analysis is:

- Getting simulation data as a reference, we currently have no simulation data to know exactly what to expect.
- Repeating the analysis with more data (eg. Run3). Studying some variables around the peaks of interest, leaves you with too little data and barely anything to be found.
- Cleaning up the current data more to improve fits.
- Studying the Dalitz Plots in areas of interest to know what kind of particle we expect for X