# *Resonances* in Central Exclusive Production

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## Introduction to Central Exclusive Production

Central exclusive production refers to the process $pp \to p+X+p$, where + denotes a gap in rapidity between outcoming protons and X (**Figure 1.**) [1], [2]. Here, *central* refers to a rapidity gap which emerges as the produced state decays as a separate system , *exclusive* to the property that the protons stay intact, and *production* to $X$'s production. The produced $X$ continues to decay, usually through short-living bound states called resonances. Such central exclusive production takes place in parameter range of high $\sqrt{s}$ (center of mass energy) and low $q^2$ (four-momentum transfer squared). Lattice Quantum Chromodynamics (lQCD) and sum rules predict the production of a glueball –a bound state made up of gluons and quark-antiquark pairs –with mass in range ~ 1000 – 1700 MeV [3]. As of now, such a region is solely described by phenomenological models, especially Regge theory. In its context the production is modelled as protons exchanging two quantum states known as Reggeons in the $t$-channel. When $\sqrt{s} >> t$ production is dominated by the exchange of two Pomerons, a quantum state with vacuum quantum numbers $C$ and $P$ and $J$ equal to 0 or 2. Regge picture's Pomerons correspond to the parton cloud surrounding protons.

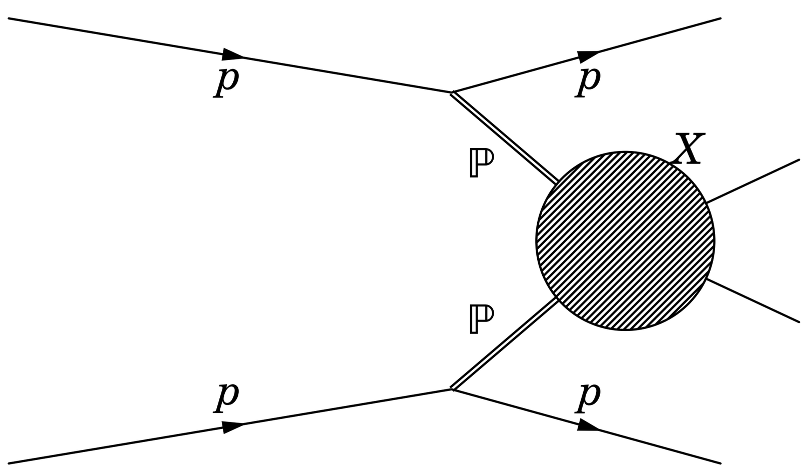


**Figure 1.** Diagrammatic representation of central exclusive production, as modelled in Regge theory.

## Quantum Numbers of X

The interesting task is to figure out the quantum numbers for possible produced states $X$, and furthermore to compare them with those of the lightest glueballs. On one hand, a Pomeron is restricted to having vacuum quantum numbers $P = C = +1$. On the other hand, the massless gluon is a vector, i.e. has $J = 1$. The most simple glueball consists of two gluons. Thus, it is restricted to have $J \neq 1$ and $C = +1$ [3]. Thus, the possible quantum numbers of this glueball are either

$$0^{++}, 2^{++}, \ldots; 0^{-+}, 2^{-+}, \ldots \text{ or } 3^{++}, 5^{++}, \ldots.$$

As such, in terms of quantum numbers there are glueball candidates in central exclusive production, namely those with

$$J^{PC} = 0^{++}, 2^{++}, \ldots.$$

The corresponding masses predicted by lQCD and sum rules of the lowest $J$ are tabulated in [3] after several authors. The general conclusion is that the bound states of lowest $J$ are found under around 2 GeV, most studies suggesting 1.4 – 1.7 GeV or 1 GeV. States with $J^{PC} = 0^{++}$, mass under 2 GeV, according to PDG, are $f_0(500)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$ .

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## Track Classification

The $X$-state is indirectly observed by observing final states with appropriate double gap in rapidity i.e. by observing a hit only in the central barrel [4]. In ALICE, the outgoing protons are not measured, but in the context of the Regge model, $pp \to p+X+p$ is dominated by double Pomeron exchange [4]. In ALICE, for $\sqrt{s} = 7$ TeV such events are selected following F. Reidt's algorithm , see [5], for finding double gap events with two, four or six tracks. For 13 TeV, similar event selection is conducted with a macro by Guillermo Contreras.
The $X$ is identified by analysing *invariant mass* and *angular distributions*. In our analysis, the following *soft particle classification scheme* is employed.

- Tracks are identified using particle identification (PID) data from the detectors (TPC, ITS, TOF and HMPID in ALICE). This particle species classification is soft: tracks are weighted by probability of being each considered possibility (currently, $\pi$,$K$ or $p$), and each possibility is considered separately. See poster by Marc Härkönen for details.
- Both particles in a track-pair with charges $(+,-)$ are assumed to be of same species. With four tracks there are several permutations i.e. ways to form pairs out of the positively and negatively charged track. This is taken into account either by plotting all possible permutations or choosing the most likely one.
- Finally, the invariant mass and angular distributions for each possible final state may be plotted. From invariant mass distribution, the masses of resonances may be observed as peaks. From angular distributions, the most likely $J$ may be deduced with partial wave analysis.
- When tracing back a cascade decay, say $X \to aa$ followed by $a \to bc$, one may concentrate to said cascade by weighting final state's invariant mass by $a$'s Breit-Wigner distribution. Thus, this weighting has the same goal as performing cuts.

This weighting is applied to all appropriate distributions.

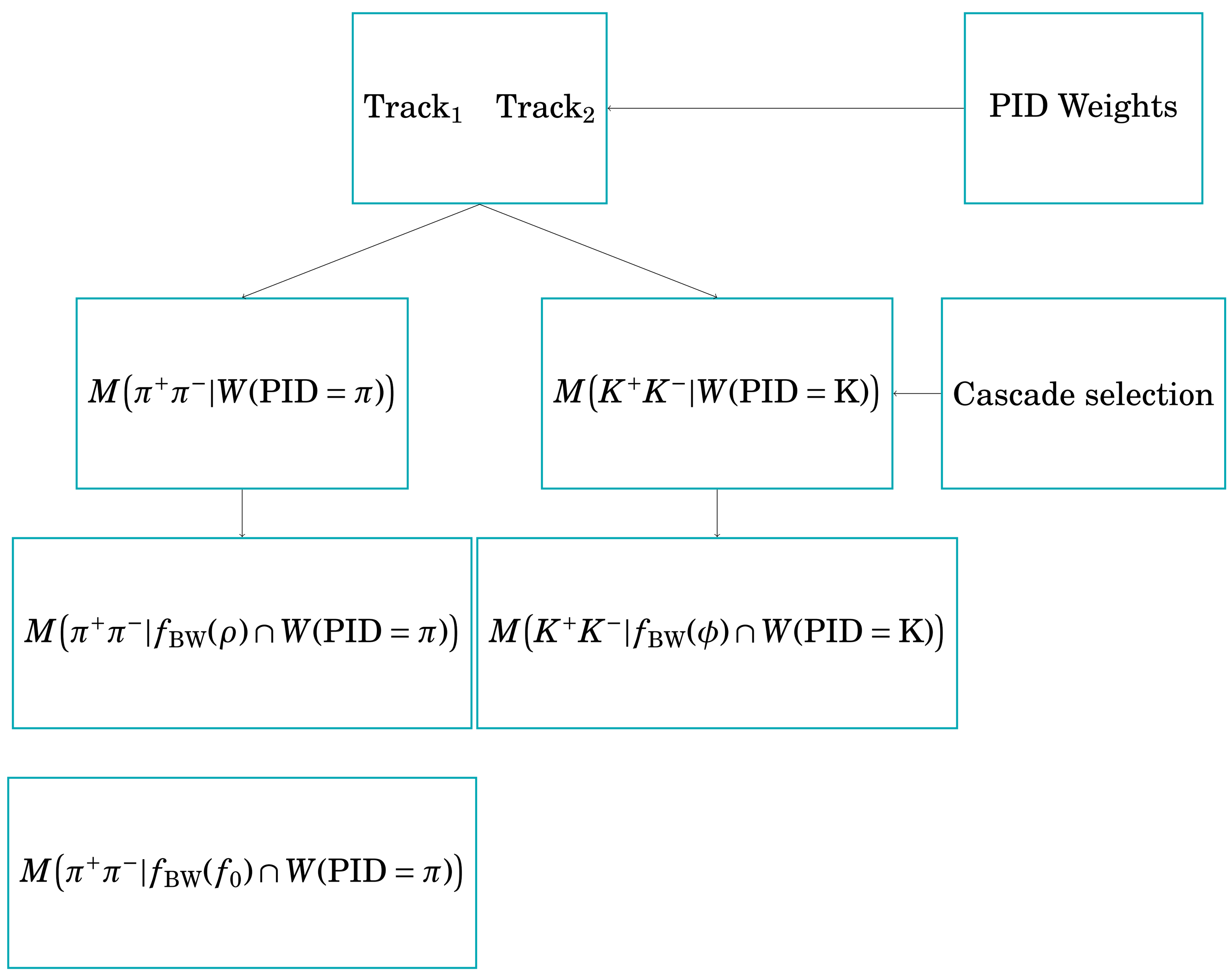


**Figure 2.** Example of the track classification.

## References

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