Extended Summary

One of the way to form a Quark-Gluon Plasma (QGP) is by colliding heavy nuclei at ultra-relativistic energy. When the QGP is created, the quarks and gluons are liberated and they are free to move on their own. The system cools down afterward and the quarks and gluons recombine into particles which can be detected by the experiments.

Studying J/Ψ, which is a ground state of $c\overline{c}$, is one of the way to probe the characteristics of the QGP. In that case, the measurement of inclusive J/Ψ yield gives information on the QGP created after the collision.

The double J/Ψ is part of inclusive J/Ψ. The production of double J/Ψ is expected in A-A collision (A is a heavy nucleus). In the A-A collision the double nucleon scattering (two different nucleons within one nucleus scatter with two different nucleons within the second nucleus) is expected the main process which produces double J/Ψ. This process has been observed in p-p [1][4][5] and pion-A [2] collisions, but double J/Ψ production in A-A collision has not yet been discovered.

Double J/Ψ in A-A collision can contribute to better understanding the single J/Ψ production and the Pb-Pb collision initial-state. In the ALICE experiment, J/Ψ can be measured through their dimuon decay channel.

The related detectors in muons detection are Silicon Pixel Detectors which are used to reconstruct the primary vertex, V0 Detectors which are used to give a minimum-bias trigger and Zero Degree Calorimeters which are used to reject electromagnetic Pb-Pb interactions.

The muon spectrometer, it composed of a front absorber 0.9m from the interaction point to filter the hadrons. Next, the tracking system contains five tracking stations which help to reconstruct the trajectory of the tracks. In the tracking system, the first two tracking stations are put right behind the front absorber. And another tracking station is inside of a magnetic dipole which tracks deflected muons. Third, there are again two tracking stations behind the dipole to track the muons. The last, after a 1.2m iron wall, which also helps to stop the hadrons, are two trigger stations which are handling the trigger of the interesting events.

The internship started with the basic training of the ROOT which is as the description on the ROOT website: "a modular scientific software framework. It provides all the functionalities needed to deal with big data processing, statistical analysis, visualization and storage. It is mainly written in C++."

After I received the account of the ALICE group, I completed a template program which select the opposite sign muons in the data recorded by the ALICE experiment. Only unlike-sign low-pt dimuon triggers were selected. After some adjustments of the program, the program was able to get muons to reconstruct the dimuon invariant mass and to extract the number of J/Ψ by fitting the invariant mass distribution. The total number of J/Ψ was compared to the published paper [3].

In order to fit the distribution of the invariant mass of dimuons 12 tests were applied with different options in the fitting procedure: 2 fitting ranges, 2 background functions and 3 extended Crystal Ball function (CB2) tail sets. Figure 1 gives an example of the fit; the total number of J/Ψ is obtained from the integral of the signal function (CB2) and the tail of CB2 was fixed to simulated tails so there are 10 free parameters to be fit; despite the large number of free parameters, the χ^2/ndf = 0.95 shows that the fit is pretty good. Figure 2 shows the extracted number of J/Ψ and its statistical uncertainties from the 12 fits. The number of the J/Ψ is the mean of the 12 fits. The uncertainty on the number of J/Ψ are from two main sources, one is the statistical uncertainty from the average of errors of the 12 fits. And the systematic one is obtained from the R.M.S of the 12 fits.

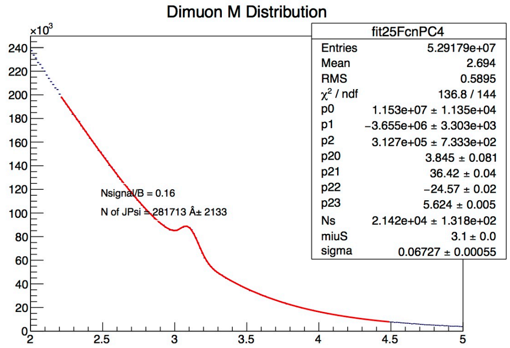

Figure 1: One of the fitting graph of the muons detected by the ALICE

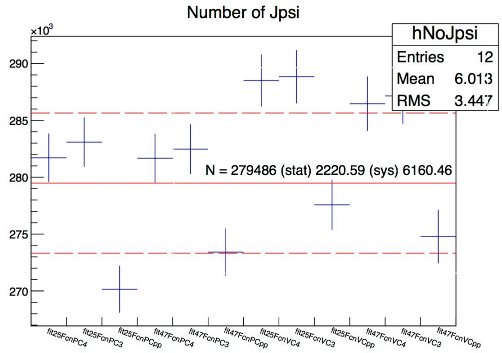

Figure 2: The number of inclusive J/Ψ acquired from the integral of CB2 function

I'm now developing the code for analyzing events with at least 4 muons in order to extract double J/Ψ. The expected value of double J/Ψ is determined by the equation:

$$N = \sigma \cdot A\varepsilon \cdot L \cdot BR^2$$

(N = number of events, L = luminosity, σ = cross section, $A\varepsilon$ = acceptance x efficiency, BR: branching ratio of muon)

the cross section is retrieved from the previous work of LHCb in pp collision at a center of mass energy of 7 TeV [4] And 13 TeV [5]. After proper scaling of atomic number [6], energy and rapidity, the cross section of double J/Ψ production in Pb-Pb collision is expected to be 13.9 mb. The $A\varepsilon$ of double J/Ψ is simply assumed to be the value of single J/Ψ squared. We get the expected number of double J/Ψ of 236 (without nuclear correction).

The following works can be separated into 4 main parts: going through more theoretical and experimental papers and articles about double J/Ψ production; the data analysis of the ALICE 2015 Pb-Pb collision; the analysis of simulated data to compute the acceptance and efficiency of the detector for double J/Ψ; if the result is complete enough, presenting the result to the IPN group and the CERN J/Ψ analysis group.

Reference:

[1] The CMS collaboration, Khachatryan, V., Sirunyan, A.M. et al. J. High Energ. Phys. (2014) 2014: 94. doi:10.1007/JHEP09(2014)094

[2] J. Badier et al. [NA3 Collaboration], Phys. Lett. B114, 457 (1982).

[3] ALICE Collaboration (Jaroslav Adam (Prague, Tech. U.) et al.), Phys.Lett. B766 (2017) 212-224

[4] Aaij, R., et al. "Observation of J/ψ-pair production in pp collisions at." *Physics Letters B* 707.1 (2012): 52-59.

[5] LHCb collaboration, R. Aaij et al., Measurement of forward J/ϕ production cross- sections in pp collisions at $\sqrt{s}$ = 13 TeV, JHEP 10 (2015) 172, arXiv:1509.00771.

[6] David d'Enterria (CERN), Alexander M. Snigirev (SINP, Moscow), Phys.Lett. B727 (2013) 157-162