Charged particle multiplicity dependence of the J/ψ yield in $p+p$ collisions at $\sqrt{s}$ =510 GeV using run13 data

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Although J/ψ production has been studied at RHIC and other facilities for many years, theoretically there is still large uncertainty in the production mechanisms. To provide additional information that might constrain these uncertainties we have looked at the event multiplicity associated with the J/ψ production. Specifically, we have measured the J/ψ production yield through the dimuon decay channel at forward rapidities (1.2< $|y|$ <2.2) in 510 GeV $p+p$ collisions, as a function of the number of charged tracks produced at the J/ψ vertex, and normalized to the average yield in minimum bias collisions. The vertices, as well as the number of tracks associated with each vertex are determined by the FVTX detector. The results show an increase of the number of J/ψ counts per $p+p$ collision when the charge particle multiplicity increases. This may be an indication of multiple parton interactions in $p+p$ events, so the result can set a scale for the number of binary parton-parton collision in $p+p$ events.

Contents

I. INTRODUCTION

The production of J/ψ in p+p collisions has been vastly studied in several experiments, PHENIX has a long story of experimental studies, the most recent reported in PPG104 [1]. The assumption usually made in theoretical models is that there is one hard scattering process per pp collision. The study presented here is testing this assumption by looking at

$p+p$ events which perhaps have more than one parton-parton interaction. The idea is to measure the J/ψ yield as a function of the track multiplicity at large rapidities. The track multiplicity will work as a scale for the number of binnary collisions in pp events.

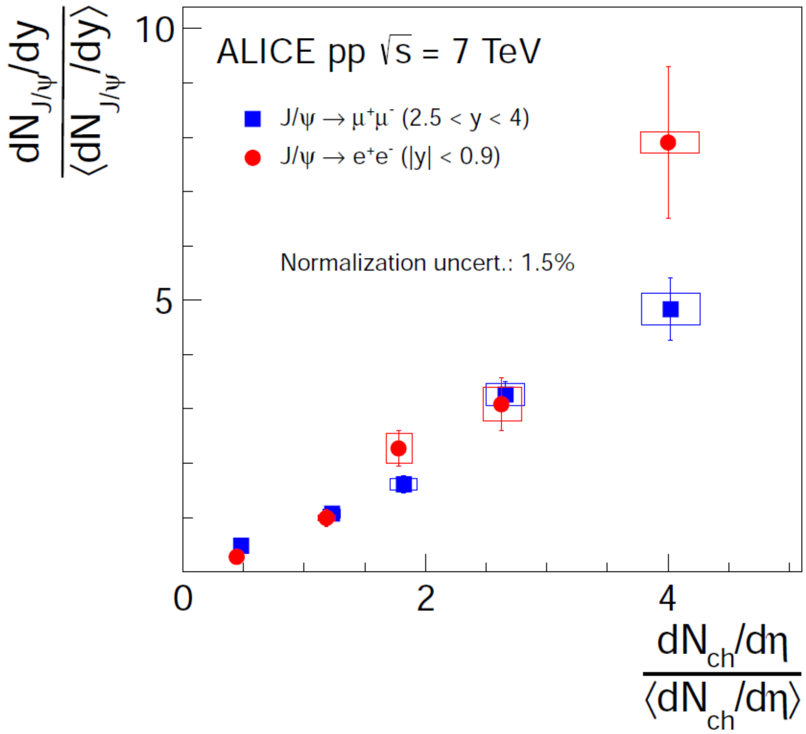


FIG. 1: Relative charged particle multiplicity dependence of the relative J/ψ yield at $\sqrt{s}$ =7 TeV measured by ALICE in the dielectron and dimuon channels [2].

Previous studies were performed in the ALICE detector at LHC using $p+p$ collisions at $\sqrt{s}$ =7 TeV [2]. They found indeed a scale of the J/ψ yield with the relative track multiplicity (Figure 1), possibly confirming the role of multi-parton interactions in LHC $p+p$ collisions. The question is how different is the distribution of parton interactions at lower energies.

II. DATA SET, QA, GENERAL CUTS

A. Data set and luminosity rate distribution.

This study used the run13 510 GeV $p+p$ run produced using pro build 97. During this run the FVTX was fully functioning and the VTX had only the pixel layers readout, but no VTX data from this run has been produced. The taxi scanned 1007 runs, containing $7.4{\cdot}10^{12}$ events, corresponding to an integrated luminosity of 228 pb-1.

The live event rate distribution for the entire run is shown in Figure 2 along with its dependence with the mean number of collisions. The scalers return negative numbers in several runs because of the limited range of the registers. The solution was to use scaler scaled number of events multiplied by the scale down, providing the number of live events without the problem of overrun. Table I quantify the fraction of events with more than one collision for different BBC rates.

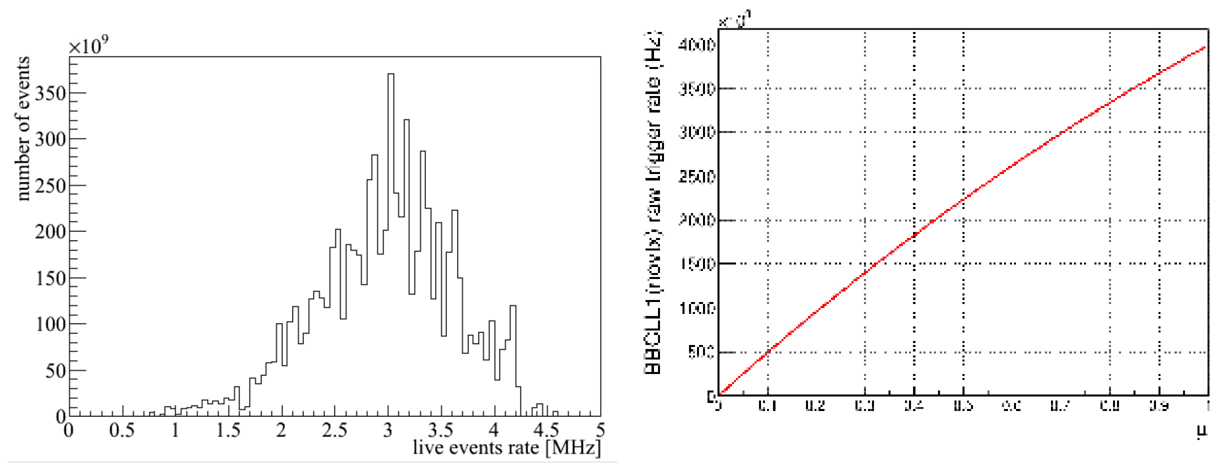


FIG. 2: (left)Live BBC event rate distribution for the entire run 13 p+p 510 GeV. (right) Dependence between raw BBC rate and mean number of collisions (μ) [AN1103].

TABLE I: Fraction of multiple collisions based on BBC rate and average number of collisions (μ) as presented in Figure 2. Fraction of multiple collisions obtained assuming Poissonian distribution.

	average BBC rate	average multiplicity μ	>1 collision per event
BBC rate = 1 MHz	1 MHz	0.2	1.7%
BBC rate <2.5MHz	2.1 MHz	0.45	7.5%
BBC rate >3.5MHz	3.8 MHz	0.85	21%
BBC rate = 4 MHz	4 MHz	1.1	29%
all run13	2.7 MHz	0.65	14%

B. Quality Assurance.

A full QA study for the run13 p+p data was performed by Aaron Key in AN1151. Given the need to have a stable track reconstruction efficiency in the FVTX, we required

- the number of FVTX coordinates per event is stable
- not more than 40 missing wedges in at least one PRDF segment
- stable average χ^2 of the standalone FVTX track.

Only 98 runs were removed by these criteria, corresponding to 9.41% of thec total number of runs. They are mostly from a week where the FVTX was not functioning because of readout issues. The dimuon reconstruction by MuTr+MuID was quite stable throughout run13 as can be seen in Figure 3. So, no run was rejected because of the MuTr, MuID reconstruction.

C. Event Selection and cuts.

The `((MUIDLL1_N2D||S2D)||(N1D&S1D))&BBCLL1(noVtx)` trigger was used in selecting the J/ψ sample. The trigger `(BBCLL1(>0tubes) novertex)` was used to obtain the minimum bias track multiplicity.

FVTX tracks are selected by requiring a $\chi^2/NDF < 4$ and a distance of closest approach from the associated vertex of 1cm. For good quality MuTr/MuID track selection and removal of non-prompt contributions the following cuts were applied to single muons and dimuon pairs:

- `Evt_vtxchi2<2`: is the χ^2 of the fitted dimuon pair with the associated vertex
- `Evt_vtxoor<1`: is the radial distance of the dimuon crossing with the associated vertex
- `DG0<15`: is the distance between the MuTr track projection and the MuID road projection at the first MuID gap
- `DGG0<10`: is the angle between the MuTr track projection and the MuID road projection at the first MuID gap

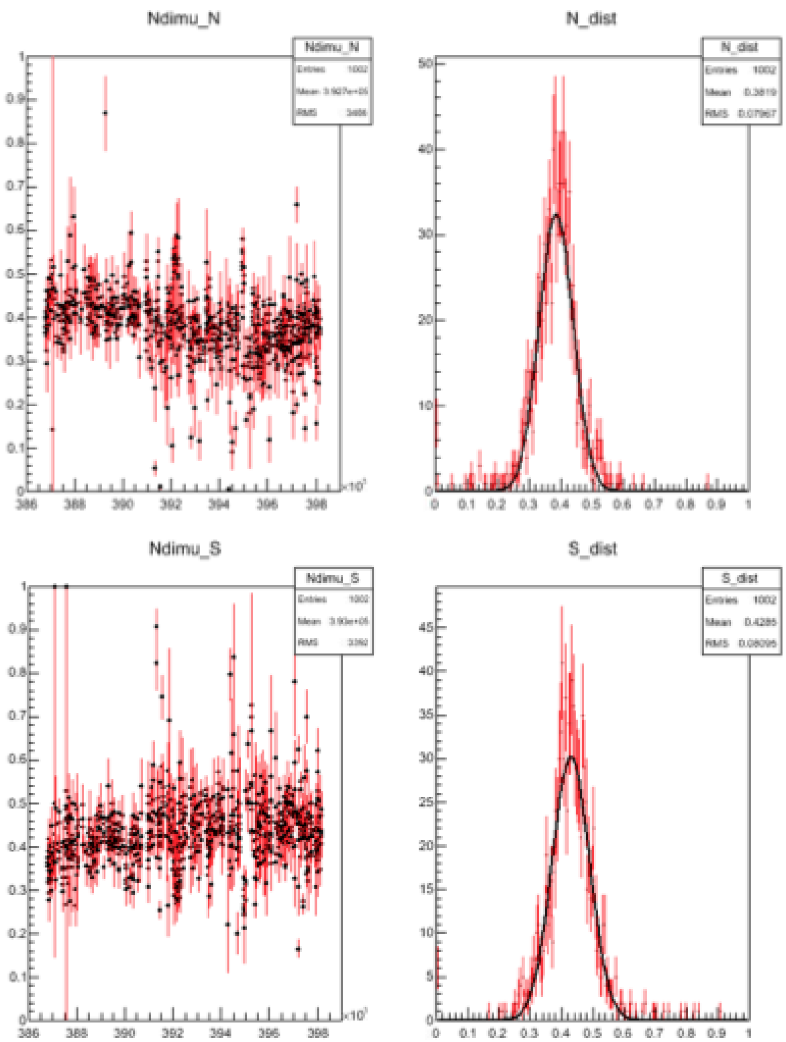


FIG. 3: Distribution of the number of dimuons, as reconstructed by MuTr/MuID, per MuIDLL1 2D event.

- `ntrhits>9`: is the number of hits in the MuTr track
- `nidhits>5`: is the number of hits in the MuID road
- `lastgap>2`: is the last gap with hits in the MuID road
- `dca_r<5`: is the radial DCA calculated by the MuTr using the assign matching vertex
- `pT<10`: is the transverse momentum of the dimuon pair
- `2<pZ<100`: is the longitudinal momentum of the dimuon pair

In the case where more than one vertex was reconstructed for an event, both dimuons need to be associated to the same vertex in order to remove fake vertex associations. The mass range used to count J/ψ decays is 2.6< $M_{\mu\mu}[GeV/c^2]$ <3.6. A total of 80K J/ψ counts (after like-sign subtraction) were used in this analysis.

III. DATA ANALYSIS

A. Analysis Procedure

In this section we describe the FVTX track and vertex reconstruction during production and the anslysis performed in an afterburner in the picoDST. In summary, we will describe

- muon and FVTX track reconstruction during production
- primary vertex determination, including multiple vertexes
- counting of the number of FVTX standalone tracks uniquely associated to each vertex in the event
- association of each muon track (MuTr+MuID) to one vertex
- dimuon reconstruction requiring the two muons belong to the same vertex
- calculation of J/ψ yield as a function of track multiplicity of the vertex

The following subsections describe the details of each step.

1. *Muon and FVTX track reconstruction*

The muon arm reconstruction code that was used for this analysis is the same code that has been used for previous muon analyses. In the pro.97 build the MuTr was still using the BBC vertex to fit MuTr tracks. However, later in the picoDST module the MuTr track is extrapolated to the best matching FVTX vertex.

The FVTX is described in details in [3]. Standalone FVTX tracks are found during data production using a Hough transform algorithm. It requires three or more FVTX coordinates (cluster of hits in one of the two planes of each FVTX station). The tracking reconstruction efficiency is 80% according to embedding studies integrated over all momenta. The efficiency goes to 99% for tracks associated to MuTr tracks (very soft particles do not make MuTr tracks). Figure 4 shows the η,Z vertex coverage map of the FVTX tracking considering different number of fired stations.

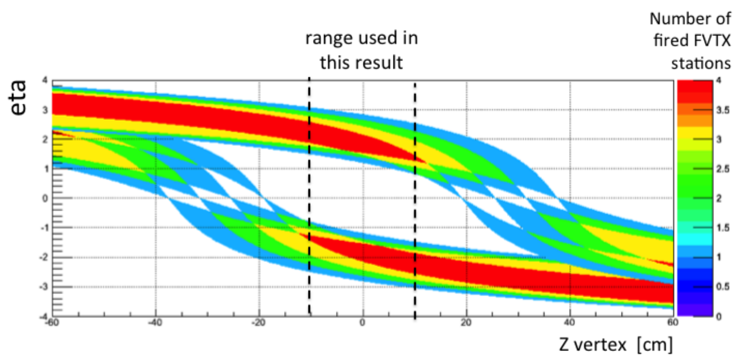


FIG. 4: FVTX pseudo-rapidity coverage as a function of Z vertex for different number of fired stations.

All FVTX tracks are used to find vertex(es) within the events. The vertex is determined by finding clusters of track crossings and them reconstructing the vertex position using these cluster of track crossings. The module responsible for the vertex reconstruction is

`offline/packages/fvtx_subsysreco/FvtxPrimVertex`

The vertex reconstruction efficiency for the FvtXPrimVertex module was studied using PYTHIA events thrown at different Z-vertex locations. The Z vertex dependence of the vertex reconstruction efficiency is shown in Figure 5. In this study, the extracted reconstructed vertex must be within 5 cm from the simulated one to be counted. Figure 6 gives some idea of the extention of the Z vertex range measured by FVTX.

Up to 4 vertexes can be reconstructed in any given event. The ability to reconstruct two vertexes correctly was extracted by mixing two simulated events (Figure 7-left). The fraction of events which have a reconstructed vertex position within 5 cm of the thrown position is 92%. The fraction of fake second vertexes is presented in Figure 7-right for different reconstruction algorithms and is smaller than 5% in the vertex region $|Zvertex|$ <10 cm used in this analysis.

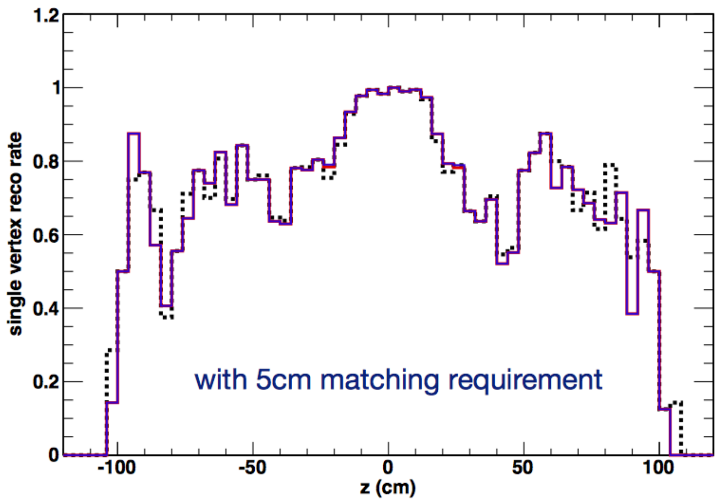


FIG. 5: Z vertex dependence of the vertex reconstruction efficiency for two algorithms used in FVTXPrimVertex module using PYTHIA simulation. The reconstructed vertex needs to be not farther than 5cm from the simulated vertex.

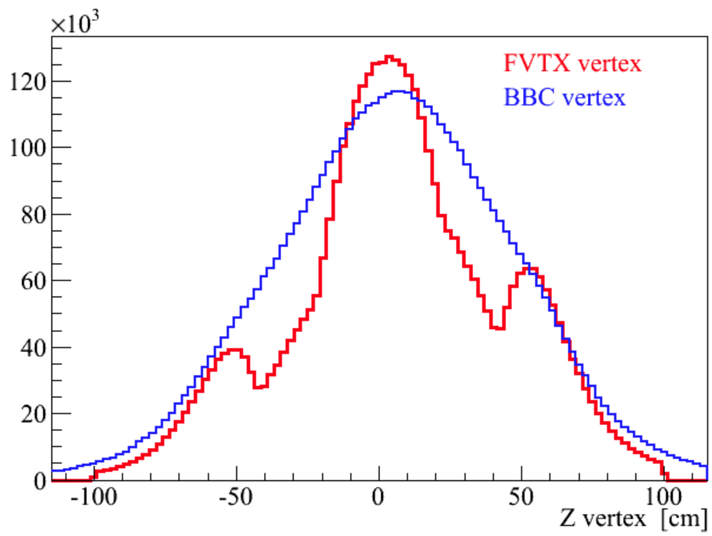


FIG. 6: Z vertex distribution in 510 GeV p+p events using FVTX and BBC.

B. Afterburner dimuon reconstruction

The analysis was performed using the picoDST framework:

```
offline/AnalysiTrain/picoDST_object/mFillSingleMuonContainer
offline/AnalysiTrain/picoDST_object/mFillDiMuonContainer
offline/AnalysiTrain/picoDST_object/mFillFvtxPrimVtxContainer
```

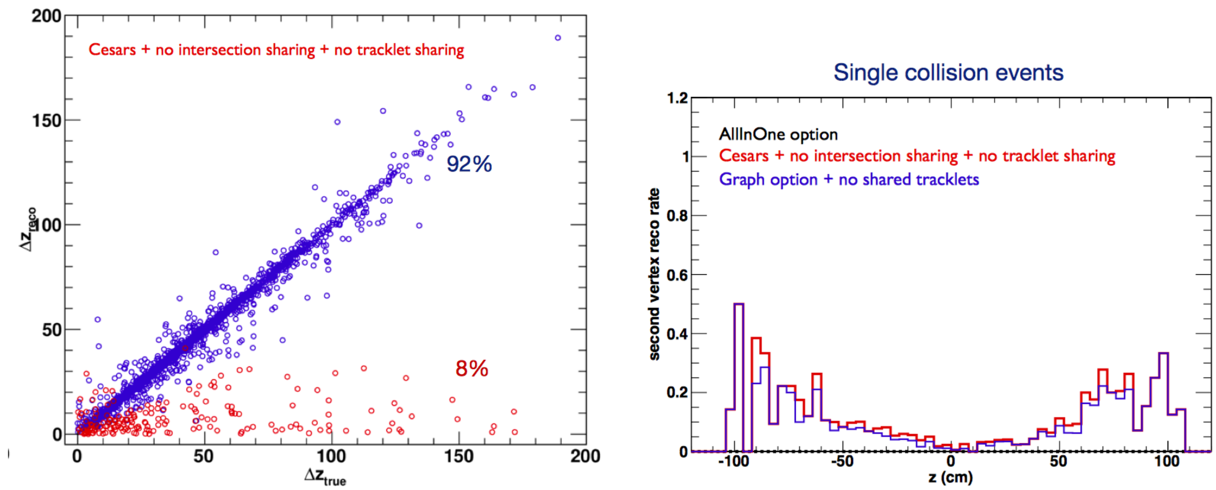


FIG. 7: Results of a Poissonian number of PYTHIA events reconstructed in one event using FvtxPrimVertex. (left) Reconstructed vs. original vertex. Two ambiguous vertexes with different number of crossings are in blue, same number of crossings are in red. (right) Fraction of fake second vertexes in single vertex events.

which loads MWG files and produce a set of Fun4All synchronized object containers of single muons, dimuons and primary vertexes. These objects are saved and synchronized along with VtxOut and PHGlobal. File outputs were produced for MuID2D and BBCLL1 triggers and are located at:

```
Muon, picoDST
/phenix/spin/phnxsp01/yuhw/taxi/Run13pp510Muon/3958

Muon, histo
/phenix/spin/phnxsp01/yuhw/taxi/Run13pp510Muon/4024

MB, histo
/phenix/spin/phnxsp01/yuhw/taxi/Run13pp510MinBias/4023
```

In the picoDST object module each standalone FVTX track is uniquely assigned to one vertex and a track multiplicity is assigned to each vertex in the event. Each MuTr track is also associated to one vertex. If there is more than one vertex in the event, the MuTr track is projected to each z vertex plane and the one that produces the smallest DCA is selected as the matching vertex.

Figure 8 shows the track multiplicity for vertexes that have been associated to a dimuon (in blue) and the total number of tracks in an event that contains a dimuon (in red). The excess tracks in the red distribution shows the effect of multiple collisions (vertexes) in one event on the track multiplicities.

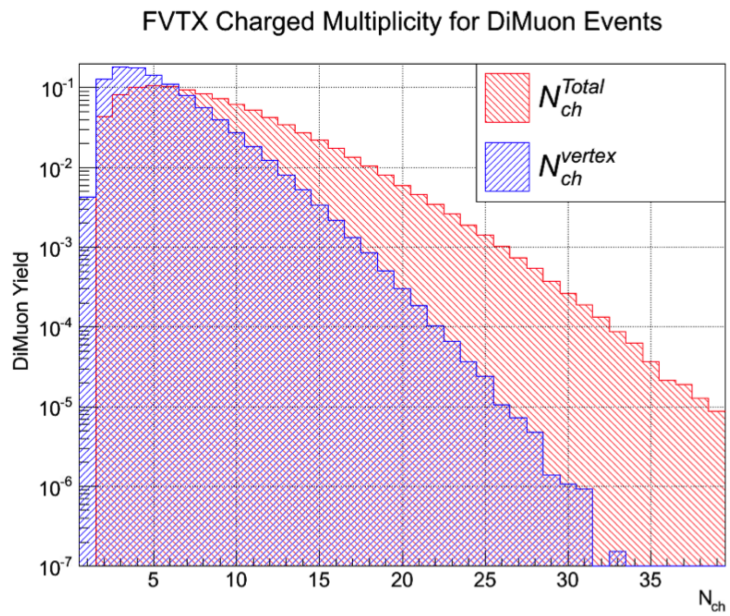


FIG. 8: Track multiplicity distribution of individual vertexes associated with a dimuon (blue) and total number of tracks in an event containing a dimuon (red).

The fraction of events with one vertex is plotted in Figure 9 along with the estimation for single collision per crossing based on Figure 2. One can see, if the estimation is correct, there is room for up to 15% fake vertex fraction, specially at lower luminosity rate. At high luminosity rate the estimation and measurement match.

Finaly, in order to veryfy the fraction of events we miss a second or third vertex within the region we count FVTX tracks (1 cm around the vertex position). Figure 10 shows the contamination of missing vertexes in our track-vertex association is less tha 1%.

1. Vertex association efficiency.

The association between J/ψ decays and the reconstructed vertex can be affected by wrong reconstructed vertex, especially if a vertex is split by the primary vertex algorithm or when two collisions happen very close to each other in the same event record. The J/ψ -

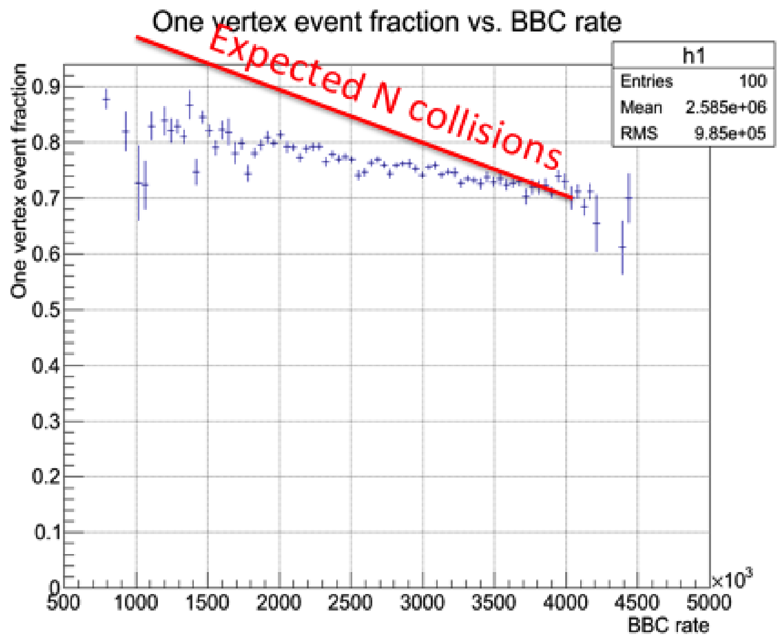


FIG. 9: Fraction of events with one reconstructed vertex as a function of the live BBC rate. Red line is the estimated number of single collisions based on Figure 2.

vertex DCA using MuTr tracks is in average 7cm because of the multiple scattering in the absorbers, if multiple vertexes are too close each other the J/ψ is also wrongly associated. In order to study the fraction of J/ψs with a wrong vertex association, and hence wrong track multiplicity, J/ψs generated by PYTHIA were embedded in real data.

The embedding steps are as follows:

- Real 510 GeV p+p events are run through the full reconstruction chain and the reconstructed vertex for each event is stored along with the output DST which holds all of the FVTX and Muon hit information. The vertex object (VtxOut) is also stored including all vertexes reconstructed by FVTX and BBC. No trigger selection is applied in this reconstruction. The run number used in this embedding was 397401 which had one of the largest BBC rates (3.9 MHz live BBC rate).

- J/ψ events are generated using the PYTHIA event generator (see Apendix VI A for the pythia configuration used in this generator), and with the same vertex position the real data vertex (FVTX label in VtxOut.)

- The generated J/ψ events are run through PISA, where the vertex position is smeared

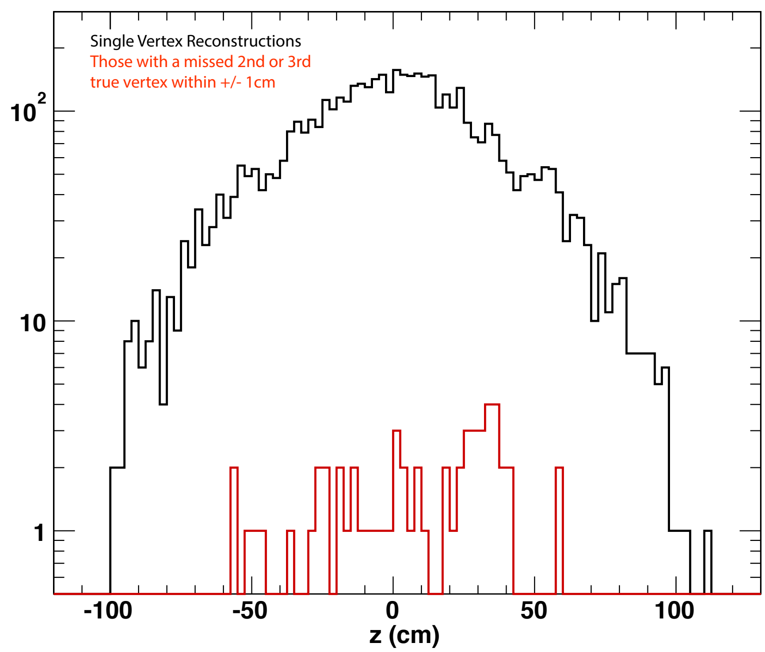


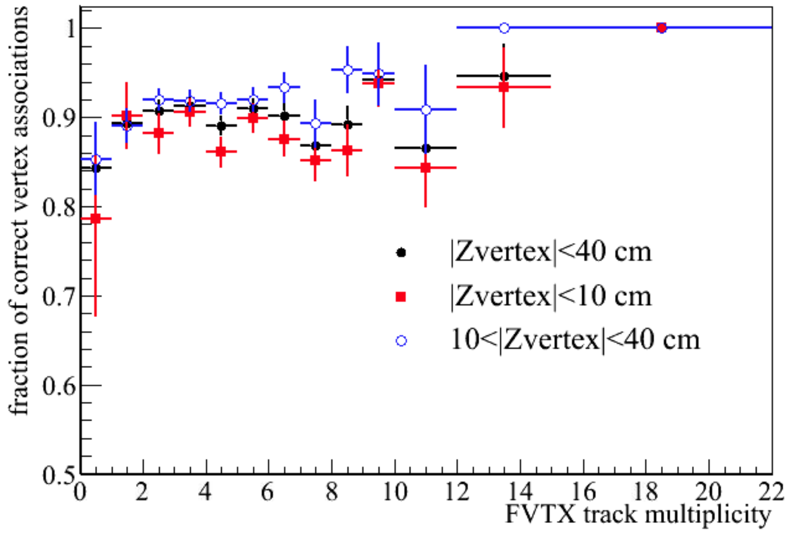
FIG. 10: Expected rate of contamination in the single reconstructed vertex sample of a 2nd or 3rd truth vertex within $\pm$ 1 cm (the hadron association requirement) that was not reconstructed separately.

by 200 μm in X and Y coordinates and 500 μm in the Z coordinate to reflect the measurement accuracy of the FVTX detector

- PISA hits are ran through the first stage of event reconstruction so that a DST file with FVTX and Muon hits can be generated.
- The real data DST file and the Monte Carlo generated J/ψ file are read in to an unpacker which adds the hits from the real data file to the J/ψ hits and these combined hits are then run through the full reconstruction chain.
- picoDST files are produced as in real data.

The ability to associate the J/ψ events with the correct reconstructed vertex is measured using this embedding simulation. Figure 11 shows the resulting track multiplicity and Z vertex range dependence of the fraction of J/ψs correctly associated with the original vertex after embedding. Overall 90% of the J/ψs are associated with the correct vertex. In events with more than one vertex 70% of the J/ψs are associated with the correct vertex. No Z

vertex or track multiplicity dependence is observed, hence no correction is done regards this check.



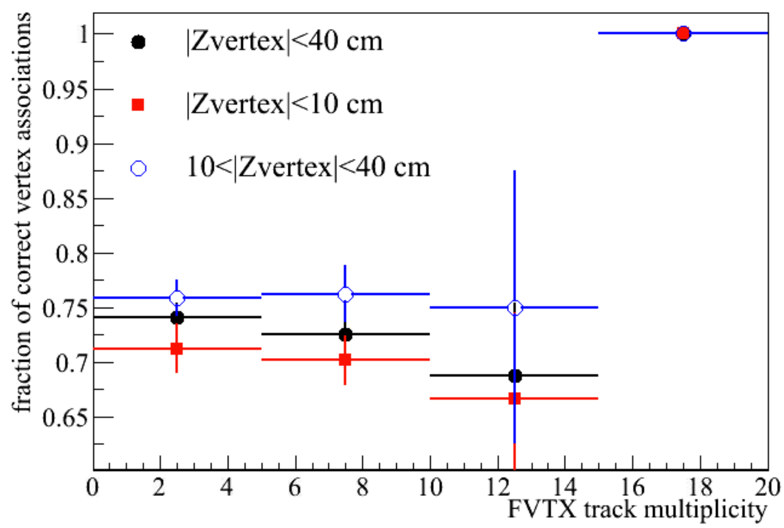


FIG. 11: Track multiplicity dependence of the fraction of simulated J/ψs associated with the correct vertex for different Z vertexes ranges. (top) All events, (bottom) events with more than one vertex reconstructed.

2. Track Multiplicity of J/ψ and minimum bias events.

A histogram `htrackmulti_jpsi` is filled with the track multiplicity from vertexes associated to unlike-sign dimuons identified as J/ψ candidates according to the criteria defined in section II C. Like-sign dimuons obeying the same criteria are also counted and used to subtract out combinatorial background from the unlike-sign count.

We use the minimum bias triggered data to obtain the unbiased track multiplicity from p+p which is used to normalize the J/ψ counts made in the previous section. A histogram `htrackmulti_MB` is filled up with the track multiplicty of each vertex from `BBCLL1(>0 tubes) novertex` using the scale down as weighting for each entry. The distributions are shown in Figure 12. On average 4.5 FVTX tracks per event are found in minimum bias events and 6.1 tracks per event are found for J/ψ events.

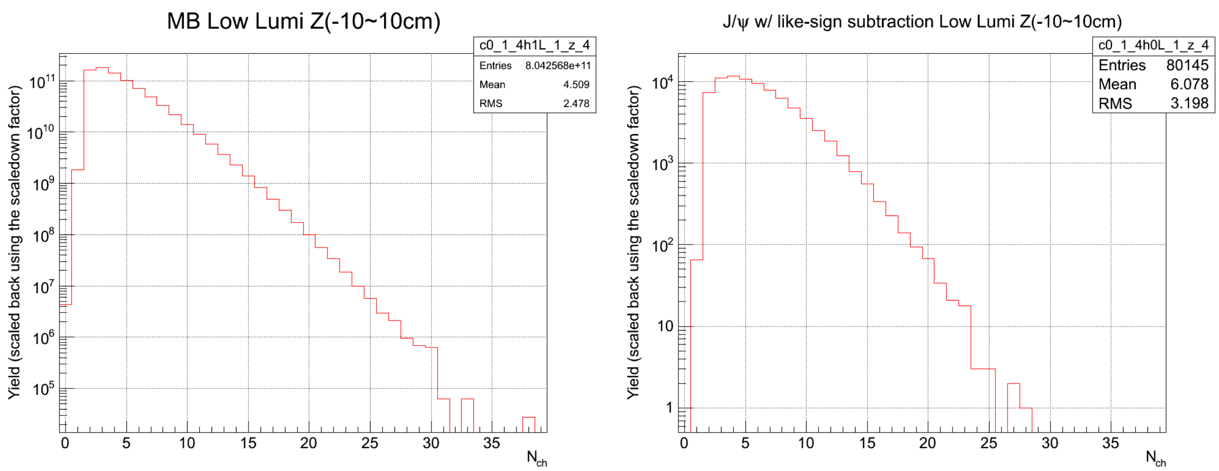


FIG. 12: FVTX track multiplicity per vertex distribution in MB events (left) and J/ψ events(right).

3. Track multiplicity dependence of the J/ψ yield.

The number of reconstructed J/ψ decays per collision is determined by dividing the histograms `htrackmulti_jpsi/htrackmulti_MB`. The result is shown in Figure 13. The result shows an increasing of the J/ψ yield with the FVTX track multiplicity.

IV. CORRECTIONS AND SYSTEMATIC UNCERTAINTIES

A. Corrections and Systematic Uncertainties

In order to convert the plot presented in Figure 13 in a physics plot the track multiplicity needs to be corrected by the FVTX tracking acceptance and efficiency, the J/ψ yield needs

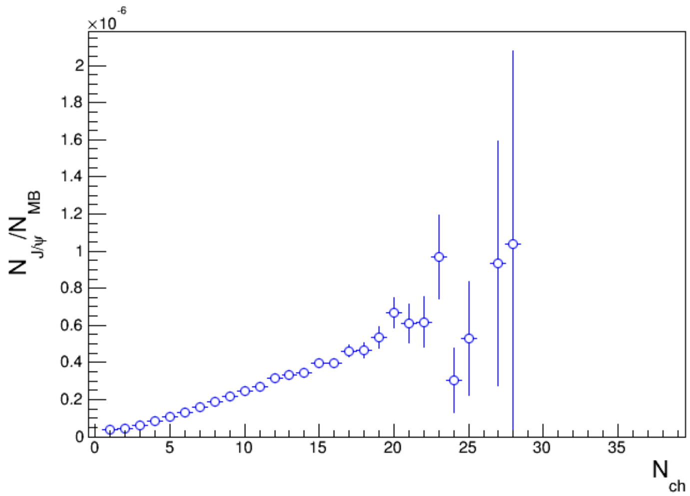


FIG. 13: FVTX track multiplicity dependence of the number of reconstructed J/ψ counts per minimum bias event.

also acceptance and efficiency corrections which are not going to be addressed at this preliminary request. A easy way to make a plot which can be compared with other experiments and simulations is present the relative J/ψ yield and track multiplicity relative to their corresponding averages. The plot presented this way will show how different the J/ψ yield is when the charge particle deviates from its average behavior.

The average J/ψ yield and the average track multiplicity in minimum bias events in different Z vertex ranges is listed in Table II.

TABLE II: Average J/ψ yield and track multiplicity used to normalize the track multiplicity dependence of the J/ψ yield plots.

	$\|Z\|$, 10 cm	$\|Z\| < 5$ cm	$5 < \|Z\| < 10$
$\left\langle N_{ch}^{MB} \right\rangle$	$(6.194 \pm 0.022) \cdot 10^{-6}$	$(6.314 \pm 0.031) \cdot 10^{-6}$	$(6.058 \pm 0.032) \cdot 10^{-6}$
$\left\langle N_{ch}^{MB} \right\rangle$	3.58783 ± 0.00002	3.64752 ± 0.00003	3.51964 ± 0.00003

The relative track multiplicity dependence of the relative J/ψ yield is shown in Figure 14.

The ratios eliminate the detector response effect in the Y and X axis if there is no multiplicity dependence on the detector performance. We used the simulated J/ψ embed in real data for this verification. We found the track multiplicity seems to not affect the reconstruction efficiency of J/ψs (Fig. 15). A polynomial was fit to the data points (dashed line)

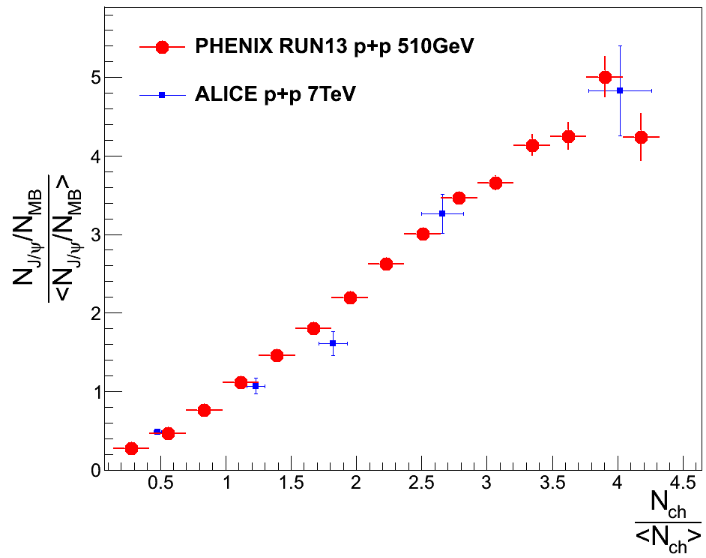


FIG. 14: Relative J/ψ yield as a function of the relative track multiplicity.

indicating a 2% uncertainty for the average reconstruction efficiency. To be conservative, we assume 5% relative uncertainty for the flatness of the reconstruction efficiency.

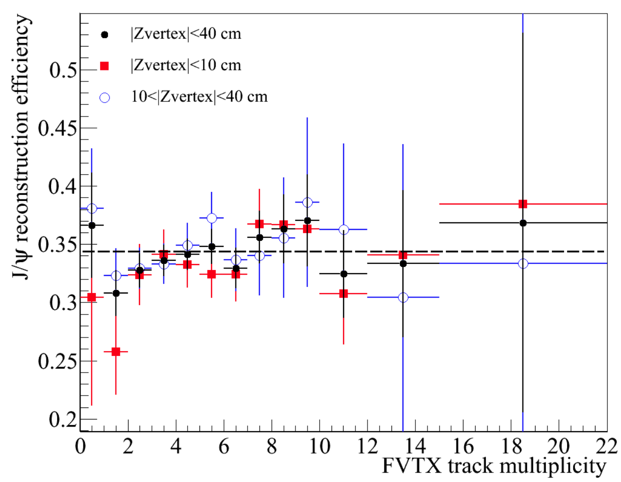


FIG. 15: FVTX track multiplicity dependence of the J/ψ reconstruction efficiency for three Z vertex ranges. Dashed line is a polynomial fit to the points $|Zvertex| < 40$ cm.

Other detector effect on the track multiplicity dependent relative J/ψ yield is the different BBC bias as a function of track multiplicity which may be different between minimum bias events and events containing a J/ψ . In order to account for the BBC bias, PYTHIA events in hard scattering mode and PYTHIA events containing J/ψ events were generated and reconstructed through PISA. In hard scattering mode, 85% of the events fired the BBC. In real data p+p events at $\sqrt{s}$ =510 GeV, (66 ± 6)% of the minimum bias events fire the BBC. However, in events containing high p_T π^0 (hard scattering cut) the BBC has a bias of (0.796 ± 0.036), hence BBC is fired in 0.66/0.79=(84 ± 9)% of the events, indicating a good agreement with PYTHIA simulation. Figure 16-left shows that the BBC bias indeed depend on the track multiplicity. Note that, as long one vertex is reconstructed by the FVTX, the BBC efficiency is 90% and increases with multiplicity up to 100%. In J/ψ events the minimum efficiency is higher and reach 100% faster the minimum bias events (Figure 16-right). The BBC efficiency bias ratio between J/ψ events and minimum bias events is used to correct the relative ratios in Figure 14. We fit a Fermi function to the data points and use it to correct the dependence in Figure 14. The question now is why J/ψ events produce a different BBC bias compared to simulated and real data hard scattering events. At this point we assign a systematic uncertainty which covers the possibility of no relative bias of the J/ψ . This uncertainty is up to 8% at the lowest track multiplicity.

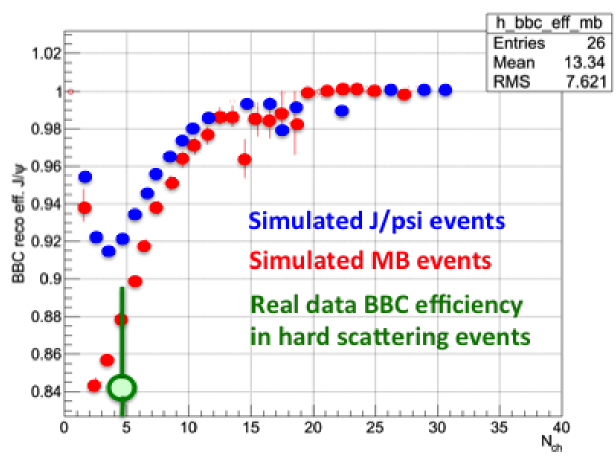


FIG. 16: BBC trigger efficiency determined from PYTHIA simulation in PISA for minimum bias events (MSEL=1) and J/ψ events. The real data BBC efficiency is determined from Vernier scan and hard scattering bias from π^0 events.

In order to test if the multiple collisions are affecting our results we repeated the analysis using low luminosity rate (BBC live rate < 2.5 MHz) and high luminosity rate (BBC live rate > 3.5 MHz) runs. The change to have multiple collisions in one event rises from 9% to 21% using these samples according to Table I. Figure 18 shows how is the result when using only low luminosity rate runs and only high luminosity rate runs. A difference of up to 6% is observed and assigned as a systematic uncertainty. The J/ψ yield is expected to be modified with the BBC rate because of the changes in the MuID efficiency, however when we divide the yield by the average yield these modificationa are cancel out. In trying to understand the change of the relative yield at chraged particle multiplicty we looked at the average FVTX track multiplicty as a function of the BBC rate. Figure 17 shows a 10% decrease of the average multiplicity when going from the lowest to the highest BBC rate in events with one vertex reconstructed (the majority of the events). The average is unmodified when the events have more than one vertex reconstructed. In order to account for this effect in our systematic uncertainties we also checked how the result can change if we analyze only events with one vertex reconstructed. Figure 19 shows the maximum difference is of 4% at the lowest track multiplicity bin.

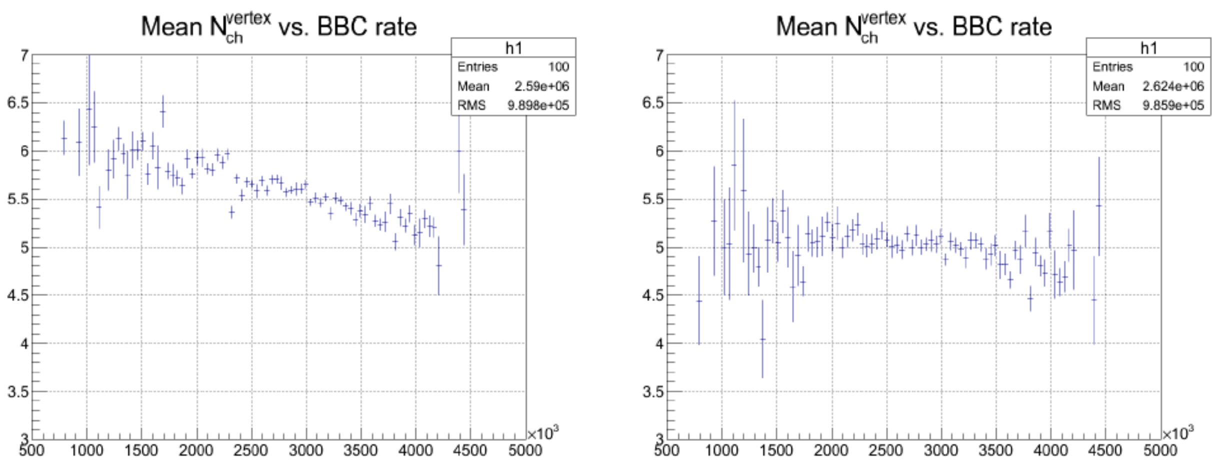


FIG. 17: BBC rate dependence of the FVTX track multiplicity in events with one vertex reconstructed (left) and more than one vertex in the event (right). Only vertexes within $|Z| <10$ cm are considered.

Variations of the track or J/ψ acceptances and fake tracks at large Z vertex can introduce bias in the relative yields and multiplicities. Figure 20 shows the relative J/ψ yield versus relative track multiplicity in different Z ranges up to 10 cm. The results using $|Z| <5$ and $5 < |Z| < 10$cm shows a difference of up to 5% for most of track multiplicity points. The first point with very small number of tracks in the vertex indicates a 15% difference which could be an additional contribution from fake vertexes. Figure 21 shows the same for an extended Z vertex range. In $|Z| > 10$cm the J/ψ acceptance ($1.2< |y| <2.2$) and FVTX

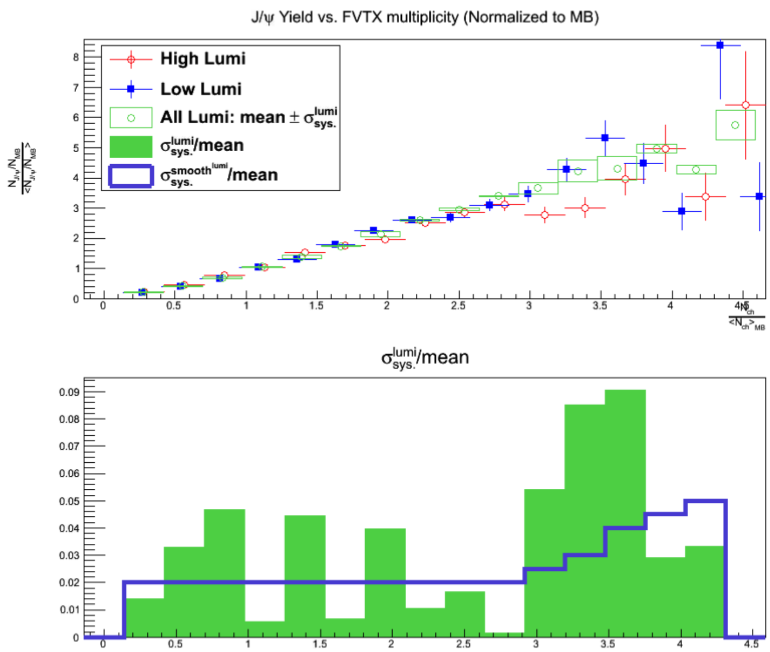


FIG. 18: Track multiplicity dependence of the J/ψ yield from low (live BBC <2.5 MHz) and high (live BBC >3.5 MHz) luminosity rate runs. Bottom panel shows the relative difference between the two options and the systematic error assigned to it as a blue line.

tracks (Figure 4) start to be different making the J/ψ yield ratio different when compared to $|Z|$ <10 cm. These differences are going to be studied in more details for the final results.

1. Summary of systematic uncertainties

Table III summarizes the systematic uncertainties involved in the final plot. Most of uncertainties varies with the charged particle multiplicities, Figure 22 shows how each source depends with the multiplicity.

V. RESULTS

Figure 23 shows the final result with all systematic uncertainties included. The data points and uncertainties are listed in Table IV.

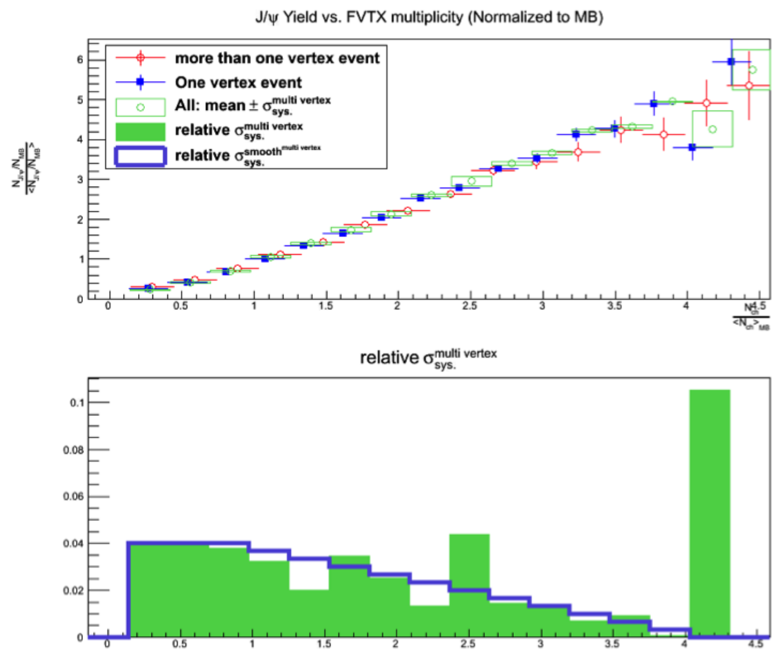


FIG. 19: Track multiplicity dependence of the J/ψ yield in events with only one vertex reconstructed and all events. Bottom panel shows the relative difference between the two options and the systematic error associated to it as a blue line.

TABLE III: List of systematic uncertainties in this analysis.

systematic uncertainty	magnitude
flatness of the J/ψ reconstruction efficiency	5%
BBC bias	0-8%
Z vertex dependence	<14%
Luminosity rate dependence	<6%
Number of vertexes in the event dependences	<4%

A. Discussion, comparison to theory

The data here presented confirms the observations from ALICE and surprisingly shows the same trend as observed in a much higher collision energy. One of the possible reasons for the increasing of the J/ψ yield with the charge particle multiplicity is the occurrence of multi-parton interactions in a fraction of $p+p$ events. This hypothesis can be tested using PYTHIA. PYTHIA has the option MSTP(81)=ON which allows multiple parton interac-

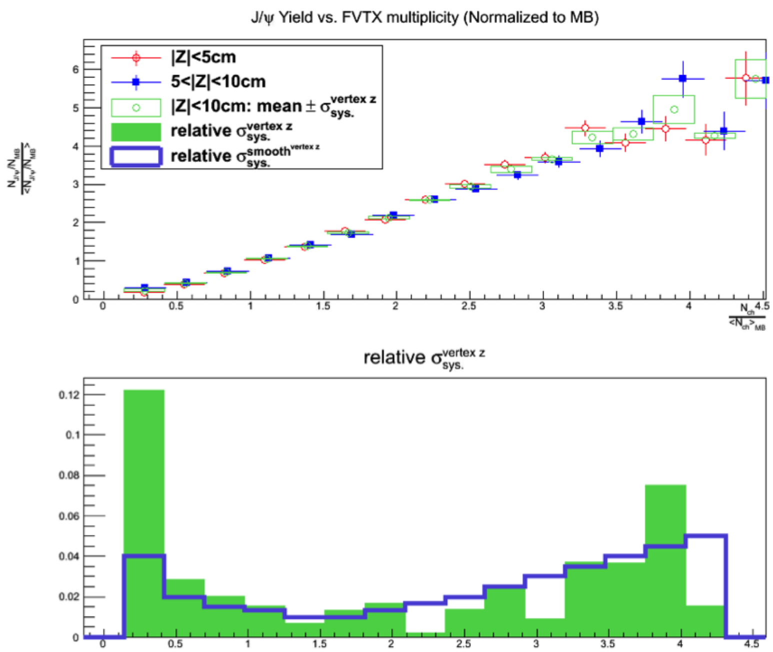


FIG. 20: Track multiplicity dependence of the J/ψ yield from different Z vertex ranges and bin-by-bin deviations and the systematic error associated to it as a blue line.

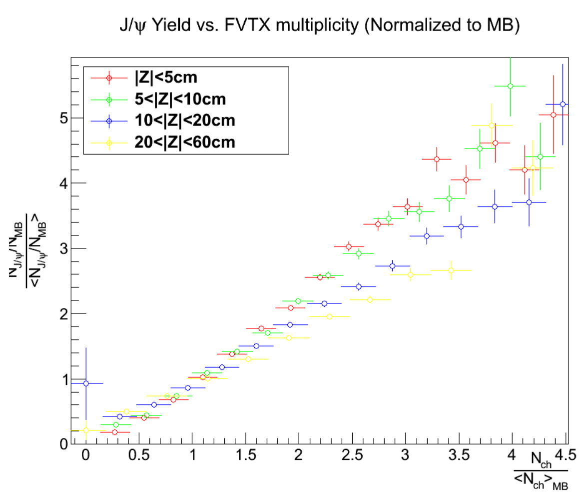


FIG. 21: Track multiplicity dependence of the J/ψ yield from different Z vertex ranges in a broad vertex range.

tions. The following steps were performed:

- We ran J/ψ events (MCJPSI) and hard scattering mode events (MCMB) in PYTHIA with and without the multi parton option.

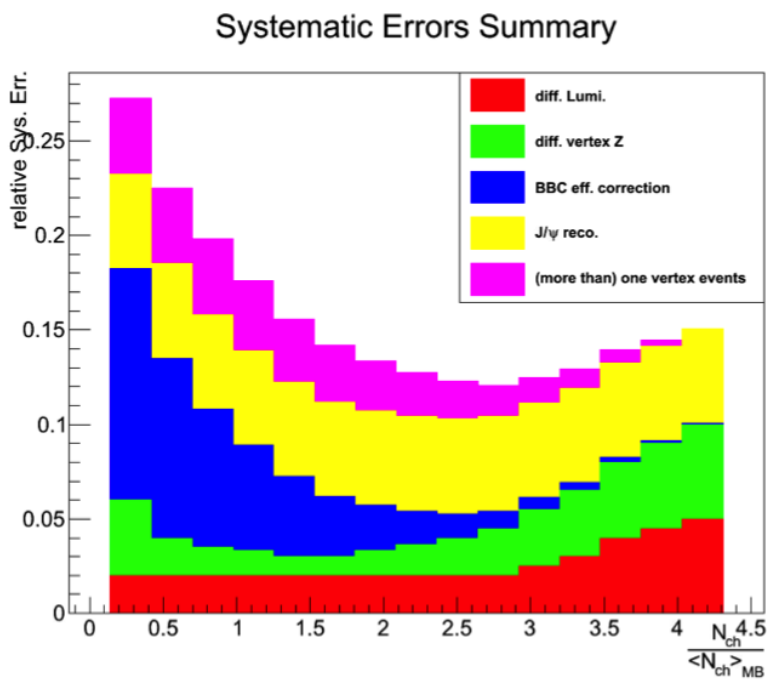


FIG. 22: Charge particle multiplicity dependence of each one of the systematic uncertainties sources. Sum does not corresponds to the total uncertainties. The total systematic uncertainty is the quadratic sum of the components.

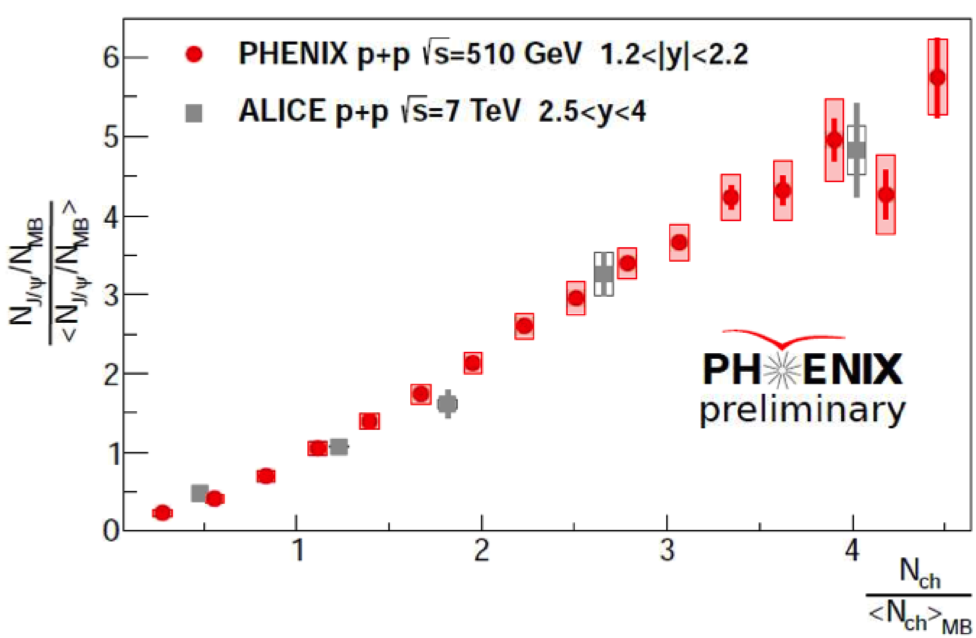


FIG. 23: Relative charged particle multiplicity dependence of the relative J/ψ yield along the same study from ALICE at forward rapidity.

TABLE IV: Numerical results of the charged particle multiplicity dependence of the J/ψ yield as ploted in Figure 23. Uncertainties are printed as statistical and systematic respectively.

$N_{ch}/\langle N_{ch}\rangle_{MB}$	$\frac{N_{J/\psi}/N_{MB}}{\left\langle N_{J/\psi}/N_{MB}\right\rangle}$
0.28	$0.239 \pm 0.013 \pm 0.034$
0.55	$0.421 \pm 0.004 \pm 0.026$
0.83	$0.705 \pm 0.007 \pm 0.043$
1.11	$1.052 \pm 0.011 \pm 0.057$
1.39	$1.398 \pm 0.014 \pm 0.074$
1.67	$1.741 \pm 0.019 \pm 0.091$
1.95	$2.137 \pm 0.027 \pm 0.113$
2.23	$2.571 \pm 0.038 \pm 0.143$
2.51	$2.987 \pm 0.052 \pm 0.156$
2.79	$3.414 \pm 0.072 \pm 0.176$
3.07	$3.613 \pm 0.096 \pm 0.207$
3.34	$4.124 \pm 0.135 \pm 0.293$
3.62	$4.242 \pm 0.177 \pm 0.367$
3.90	$4.923 \pm 0.254 \pm 0.422$
4.18	$4.294 \pm 0.303 \pm 0.273$
4.46	$5.446 \pm 0.477 \pm 0.416$

- The simulation was passed to PISA and reconstructed in order to produce the FVTX track multiplicity from MCJPSI and MCMB.
- the track multiplicity dependence of the J/ψ yield is obtained by dividing the histogram from MCJPSI by the histogram from MCMB.
- the Y and X axis are normalized by the average simulated J/ψ yield and average MCMB track multiplicity.

Figure 24 shows how our result looks like if multi-parton interactions is enabled or not according to PYTHIA.

Other explanation for the increase of the J/ψ yield with track multiplicity is reported in [4]. The article says: "Hadron multiplicities larger than the mean value in p+p collisions

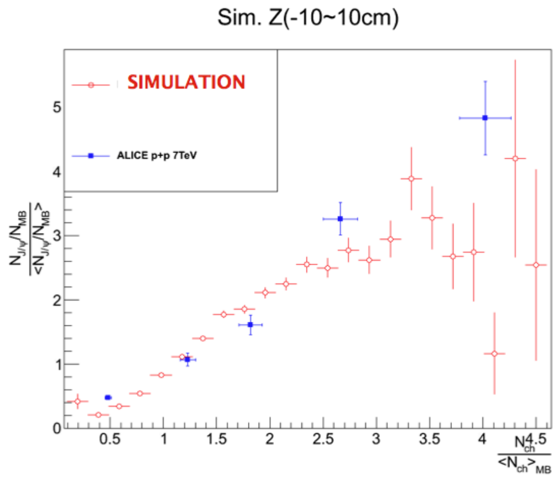


FIG. 24: Relative charged particle multiplicity dependence of the relative J/ψ yield obtained from J/ψ and minimum bias PYTHIA simulation with (left)right multiple parton interaction (enabled)disabled.

can be reached due to the contribution of higher FOCK states in the proton, containing an increased number of gluons. Correspondingly, the relative rate of J/ψ production will be enhanced, because heavy flavors are produced more abundantly in such gluon rich collisions.“. The article also says this enhancement should be energy independent. The prediction is shown in Figure 25.

VI. APPENDIX

A. PYTHIA configuration for J/ψ

```
roots   200
proj    p
targ    p
frame   cms

msel    61  // cc with CS and CO modes
parp    141 1.16  // Ojpsi[3S1^1]
parp    142 0.0119  // Ojpsi[3S1^8]
parp    143 0.01   // Ojpsi[1S0^8]
```

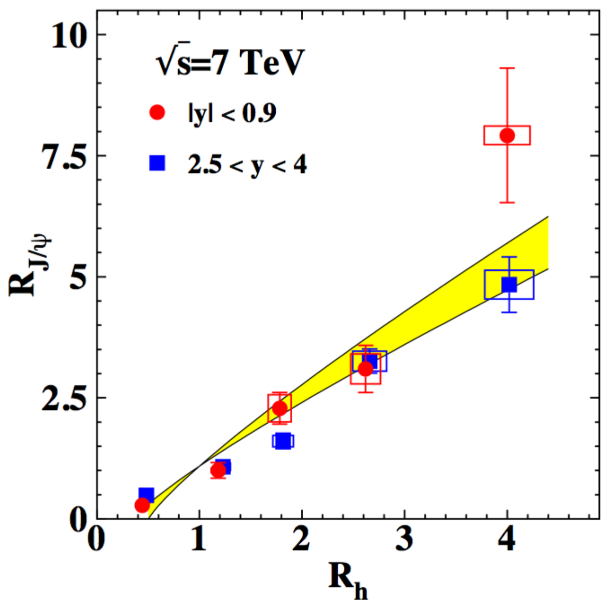


FIG. 25: Prediction for the charged particle multiplicity dependence of the J/ψ yield according to a prediction of higher Fock components in a single nucleon [4].

```
parp    144 0.01   // Ojpsi[3P0^8]
parp    145 0.05   // Ochic0[3P0^8]

mdme 858 1 0  // j/psi -> ee turned off
mdme 859 1 1  // j/psi -> mumu turned on
mdme 860 1 0  // j/psi -> random turned off

mstp    52 2   // use LHAPDF
mstp    54 2
mstp    56 2
mstp    51 10041 // CTEQ6LL
```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[3] C. Aidala et al. (PHENIX Collaboration) (2014), 1311.3594v2.

[4] B. Kopeliovich, H. Pirner, I. Potashnikova, K. Reygers, and I. Schmidt, Phys.Rev. **D88**, 116002 (2013), 1308.3638.