



Selection of prompt J/ψ events using decay time

Santorinaiou Nefeli- Domniki, Aristotle University of Thessaloniki, Greece

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Abstract

The aim of this project is to find a way to select prompt J/ψ events in a mixture of prompt and non-prompt components of J/ψ decays, using the decay time information. After selecting J/ψ events by reconstructing the invariant mass, we implemented the calculation of the decay length with respect to the primary vertex of the event and performed a validation with Monte Carlo information. A good correlation was observed between the reconstructed decay length and decay time when compared to the Monte Carlo truth information. The reconstructed decay time was then used to select the prompt component of J/ψ , to get a pure sample of it and reject the non-prompt component as much as we can achieve. To accomplish this, we first measure and plot efficiency for the two components. We then plot decay time and compare them with data. Finally, we measure the fraction of prompt J/ψ (purity) in data by applying some cuts on decay time and found that this fraction increases by using tighter cuts on the decay time. With a cut of $-1 < \tau < 1$ ps, a fraction of 67% can be obtained.

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1 Motivation

Generally, $Z \rightarrow ee$ and $J/\psi \rightarrow ee$ events are used to measure electron identification and trigger efficiencies. In previous studies, it was shown that $J/\psi \rightarrow ee$ process contains prompt and non-prompt components and that the efficiency is different in those two cases. As a result, a way to separate those components and estimate the relative fractions is needed. For this purpose, we investigate the possibility of using the decay time information. For the J/ψ that is produced promptly at the interaction point, the J/ψ decay vertex is expected to be at the primary vertex while J/ψ produced from the decay of B hadron, it is expected to be found a few $100 \mu m$ away from the primary vertex due to the long lifetime of B hadrons.

We use the track parameters of the decay electrons and identify the decay vertex position as the intersection of the two tracks. In the vicinity of the interaction point tracks are approximated as straight lines, therefore an analytical solution of the vertex position is obtained.

After the implementation of the decay vertex calculation, we show that the decay line distribution of data is described well by Monte Carlo using two components (prompt and non-prompt). Estimation of the prompt fraction and a way to increase this fraction is presented.

2 LHC, ATLAS

2.1 Large Hadron Collider

The Large Hadron Collider is a circular particle accelerator located in CERN, built in the same underground tunnel as LEP, its predecessor. The LHC ring, which has a total circumference of 26.7 km, will be offering collisions antiparallel proton beams at a center-of-mass energy of 14 TeV in its full operation. Protons are accelerated in 2800 bunches per beam colliding every 25 ns in specific places of the ring, the detectors:

- ATLAS and CMS: they are the two general-purpose detectors, which are designed to detect any particles produced from pp collisions
- ALICE: it is specialized in heavy-ion physics while studying the quarkgluon plasma
- LHCb: it is focusing on b-quark physics and CP- violation.

2.2 A Toroidal Lhc ApparatuS

ATLAS is one of the four big experiments of LHC accelerator. It has a cylindrical shape, weighs about 7000 tones and has 25m height and 44m length. It contains 4 main subsystems: The inner detector, the calorimeters, the muon spectrometer and the magnet system.

2.2.1 The Inner Detector

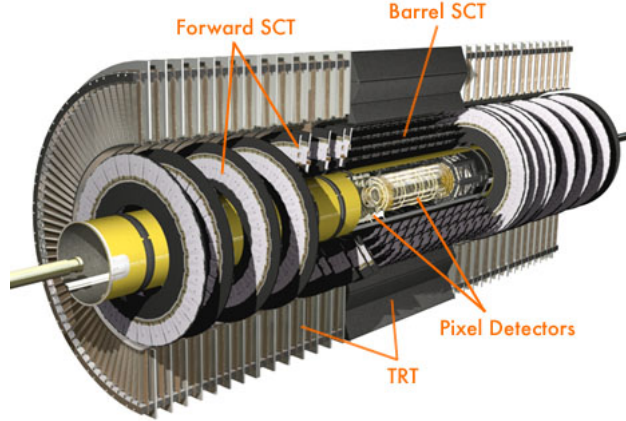


Figure 1: The ATLAS Inner Detector

It is located in the inner part of the ATLAS detector and constructed for measuring the tracks of charged particles that are produced at the collision point. It is divided into 3 parts: the Pixel Detector, the Semiconductor Tracker and the Transition Radiation Tracker, in order of radial distance from the collision point. In order to measure the track in events with high particle multiplicity, silicon trackers have a very high granularity readout which provides a position resolution of a few $10\mu m$. The beams produce great levels of radiation and as a result, radiation resistance is a top priority of the ID's materials and electronics. Additionally, ID's material must be minimised so as not to disturb particles' tracks that are supposed to go through its main body.

2.2.2 The Calorimeters

The ATLAS calorimeter system consists of electromagnetic, hadronic and forward calorimeter parts. They are the subdetectors which surround the inner detector and measure the energies of the particles produced in the collisions. The electromagnetic covers the range $|\eta| \leq 3.2$ and the hadronic, including the forward calorimeter, extends up to $|\eta| \leq 4.9$. Another Calorimeters' major contribution is the isolation information they provide, which is essential for signal selection and background suppression.

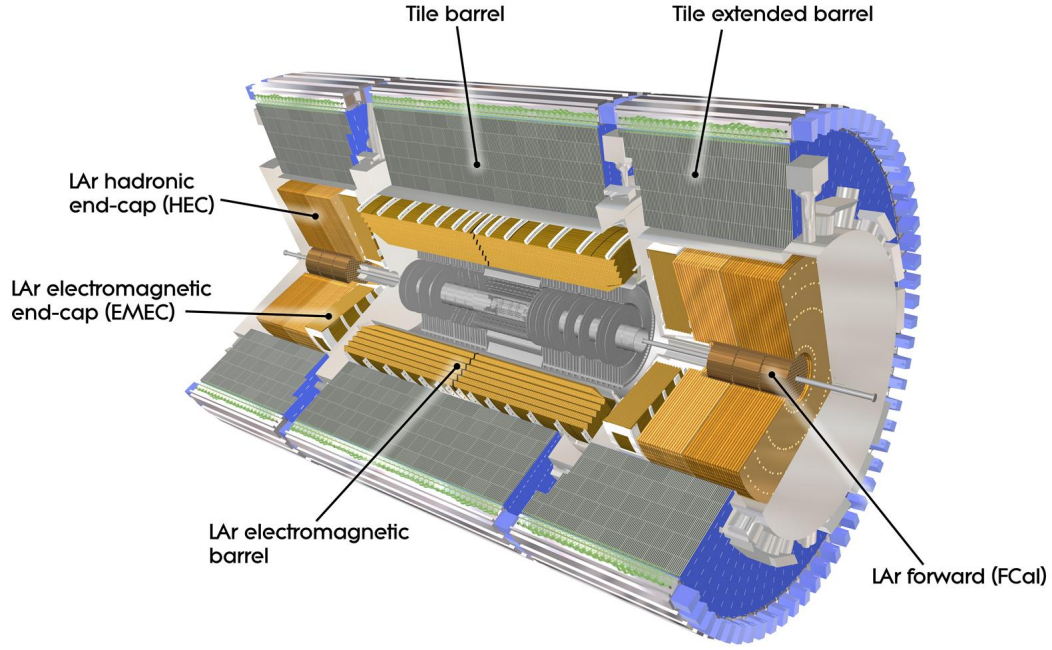


Figure 2: The ATLAS Calorimeters

3 Some Definitions

3.1 Decay Length

Measurement of the fraction of J/ψ yield coming from decays relies on discrimination of the J/ψ produced away from the pp collision vertex determined by the distance between the dielectron vertex and the Primary Vertex. In other words, decay length is the vector from the Primary Vertex to the J/ψ decay vertex, as we can also see in figure 3.

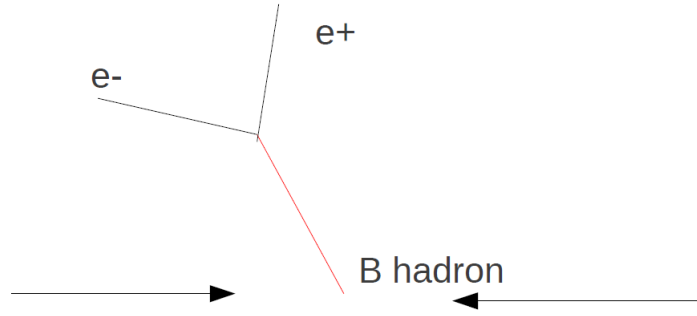


Figure 3: The red line indicates the decay length, the vector that joins the secondary with the primary vertex

3.2 Transverse Decay Length

The projection of J/ψ flight distance onto its P_t (shown in figure 4) is constructed according to this formula:

$$L' = \vec{L} \cdot \vec{P}_t / P_t$$

It can also take negative values at small decay lengths because J/ψ momentum vector and the one joining the primary and secondary vertices can be mismeasured in opposite directions in the transverse plane.

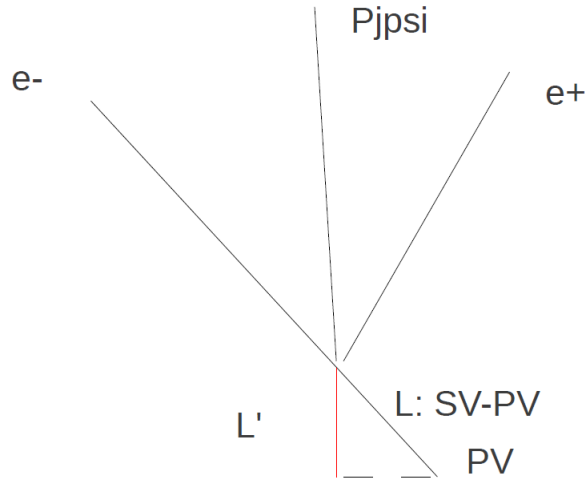


Figure 4: The red line indicates the transverse decay length, the projection of L on Jpsi momentum vector

3.3 Decay Time

In a particle decay, we have an exponential distribution of the probability of the particle to stay 'alive', as is shown in figure 5.

The pseudo proper time of J/ψ is given by this formula:

$$\tau = \frac{L * mc^2}{(pc) * c}$$

where m is the J/ψ mass: 3.1 GeV.

We can also define τ' , using L' instead of decay length:

$$\tau' = \frac{L' * mc^2}{(pc) * c}$$

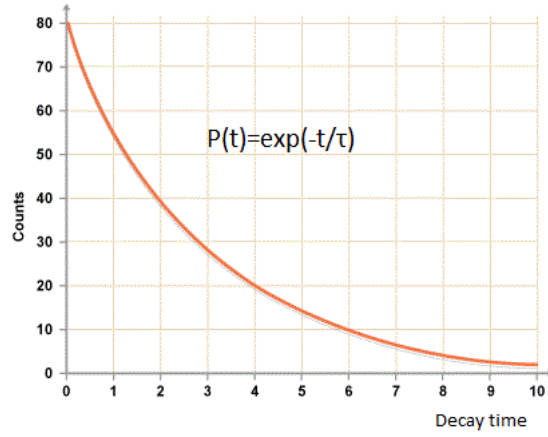


Figure 5: Exponential distribution of the probability of the particle to stay 'alive'

4 Calculation of Decay Length and validation with truth information

4.1 J/ψ invariant mass reconstruction

The first step of the analysis is to reconstruct the J/ψ mass: It starts by searching for two good electrons, which satisfy some criteria. Events with at least two electron candidates passing the tight identification criteria are selected. Then, we calculate their Lorentz vectors and we get the reconstructed invariant mass peak. Below, in Table 1 we can see the cuts that have been used for the two electrons. In figure 6, 3 peaks are depicted, the first one of J/ψ , at 3.1 GeV, the one of Υ at 9.5 GeV and the one of the Z boson, at 91 GeV. In figure 7 we can see the J/ψ reconstructed peak more clearly.

Table 1: Cuts that have been used on the 2 electrons for the J/ψ mass reconstruction

Tag	Probe
Author 1 or 3	Author 1 or 3
$ \eta < 2.47$	$ \eta < 2.47$
$Pt > 5GeV$	$Pt > 4GeV$
Pass the tight++ electron criteria	Pass the tight++ electron criteria
	$\Delta R > 0.1$

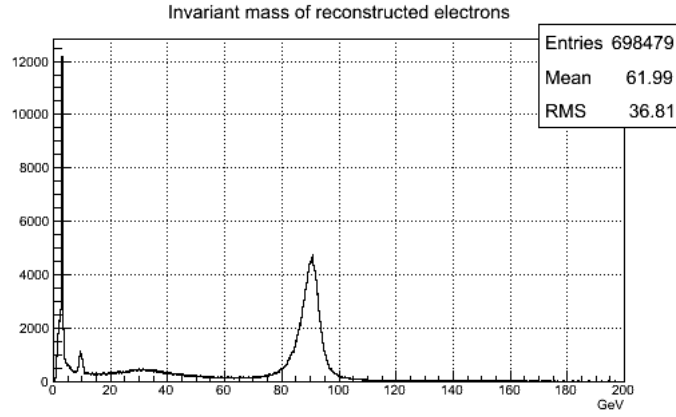


Figure 6: 3 reconstructed invariant mass peaks for J/ψ , Υ and Z boson

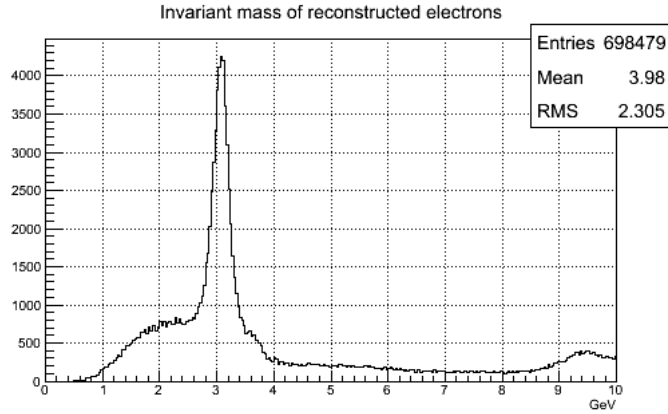


Figure 7: J/ψ mass reconstruction

4.2 Decay vertex and L' correlation

As we can see in figures 8, 9, 10, the reconstructed vertex position matches quite well with the true decay vertex position in most cases. The same thing happens for the L' , where there is also a nice correlation between reconstruction and Monte Carlo (figure 11).

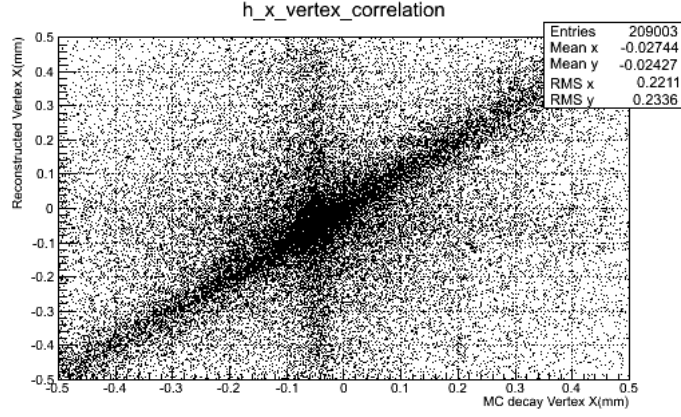


Figure 8: Correlation between reconstructed vertex position for x axis with respect to the MC truth information

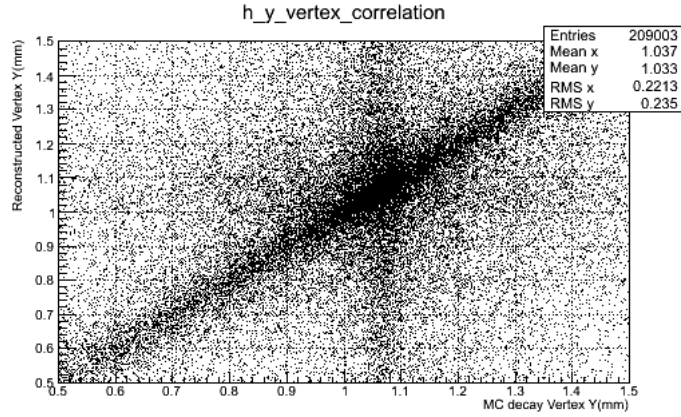


Figure 9: Correlation between reconstructed vertex position for y axis with respect to the MC truth information

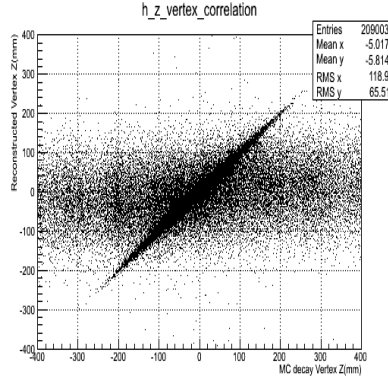


Figure 10: Correlation between reconstructed vertex position for z axis with respect to the MC truth information

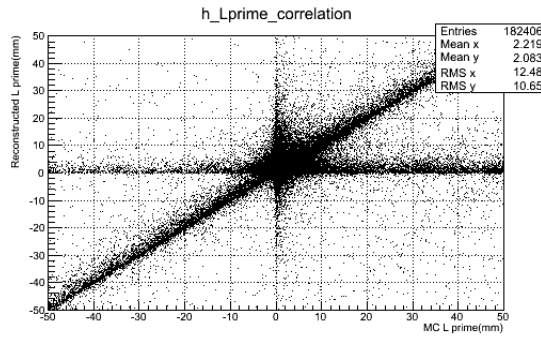


Figure 11: L prime correlation

4.3 Comparison of L'

Distributions of L' for prompt and non-prompt J/ψ Monte Carlo samples are shown in figure 12 and 13. In the prompt component, L' distribution is distributed symmetrically around zero, but the distribution for the non-prompt component has a large fraction of events on the positive side, due to the B-hadron decay.

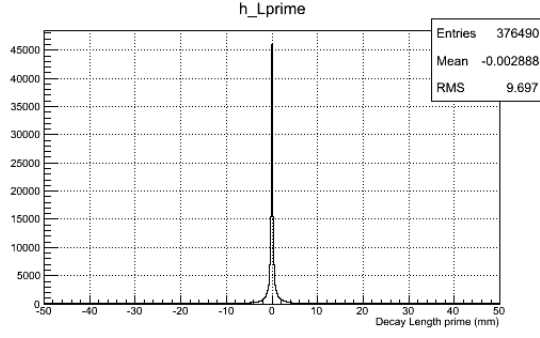


Figure 12: L' distribution for pp component with MC sample

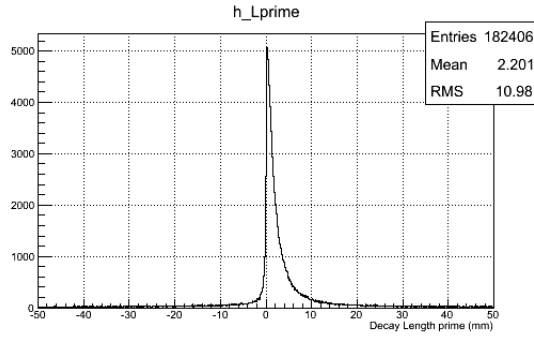


Figure 13: L' distribution for bb component with MC sample

4.4 $\Delta\Phi(\vec{P}, \vec{L})$

In figure 14, we have the $\Delta\Phi$ distribution between J/ψ momentum and decay length. We can derive from it being around zero, that J/ψ momentum vector and the vector that joins the secondary with the primary vertex (decay length, L) are parallel. There is also a small peak at $\Delta\Phi(\vec{P}, \vec{L}) \sim \pi$, which occurs when the secondary vertex is reconstructed in the opposite direction to the J/ψ momentum, due to finite resolution. These events give entries in $L' < 0$ and $\tau' < 0$.

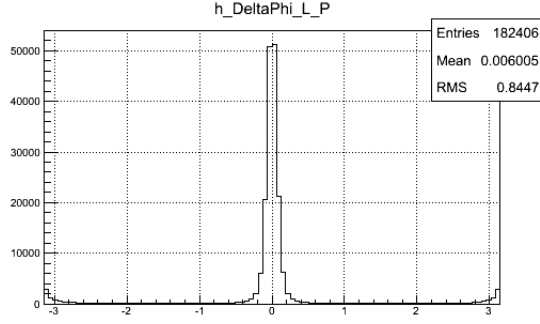


Figure 14: Delta Phi distribution between J/psi momentum and decay length

5 Selection of prompt component

5.1 Comparison of τ' and efficiency measurement

In figure 15 we can see the different distributions of the two components, due to the B-hadron decay. We can also notice that τ' can take negative values as well, since L' takes also negatives values. From this figure, we apply some cuts on decay time and we calculate efficiency for every interval that we make. Efficiency is calculated from this formula:

$$Efficiency = \frac{\text{reconstructed } J/\psi \text{ that pass the } \tau' \text{ cut}}{\text{all reconstructed } J/\psi \text{ events}}$$

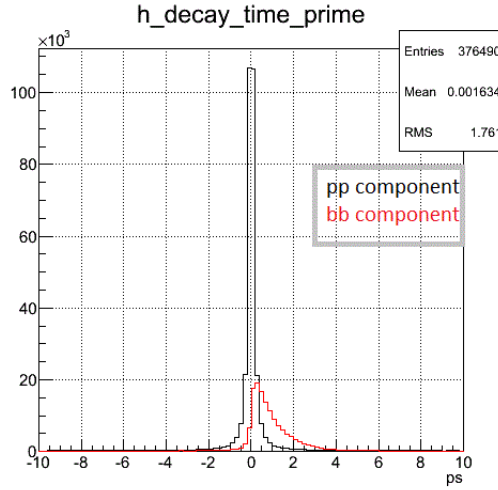


Figure 15: Decay time prime comparison between the two components

After calculating efficiency, we make a plot for the two components(figures 16 and 17). One can notice that even below 0.5 ps, where bb rejection is very big, prompt efficiency is still quite high.

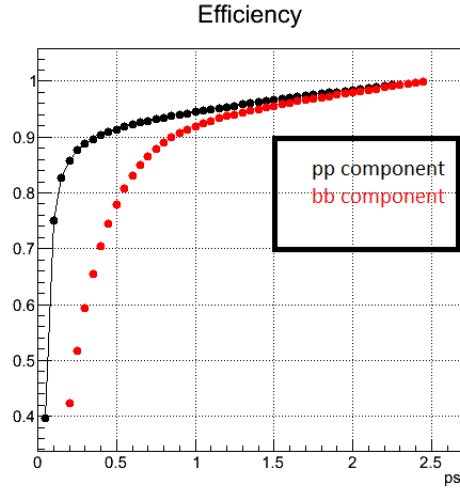


Figure 16: Efficiencies of the two components with different cut values on $|\tau'|$

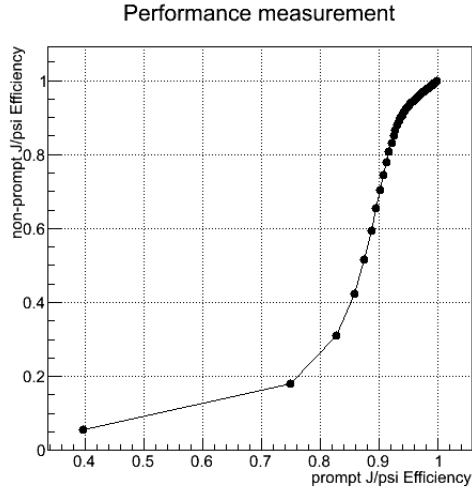


Figure 17: Performance measurement of the prompt and non-prompt components

5.2 Comparison of τ' with data and purity measurement

In figure 18, we compare the τ' distribution of pp component (red line) with bb component (blue line), we get their normalized total (black line) and compare it with data (points). Normalization of Monte Carlo samples are fit to data and there is a quite good agreement between Monte Carlo and data, at least in a region between -2 and 6 ps.

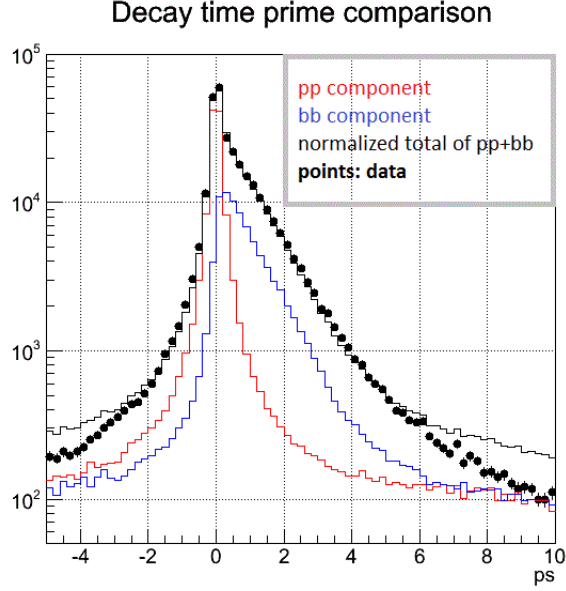


Figure 18: Decay time comparison with data

From this plot, we determine some cuts on τ' of about 50 symmetric intervals (e.g. [-1,1] ps) and calculate the prompt J/ψ fraction in each one of them, which is called purity. Purity is given by this formula:

$$Fraction = \frac{N(prompt)}{N(prompt) + N(non - prompt)}$$

Plotting purity for every one time interval produces figure 19.

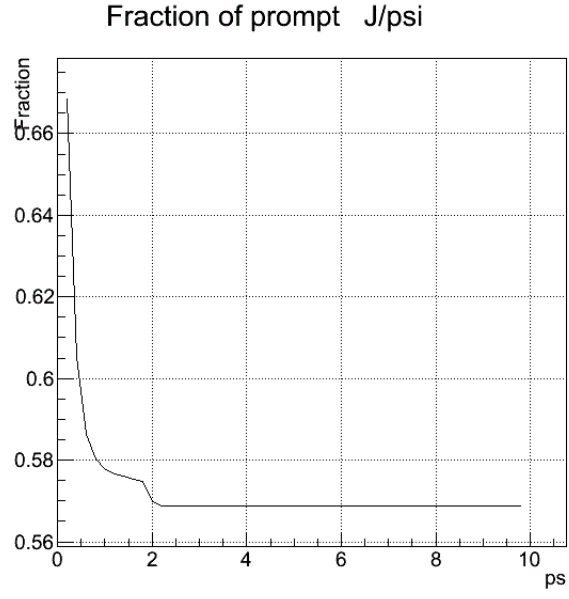


Figure 19: Fraction of prompt J/psi (Purity)

We can notice that without any time cut, the fraction is about 57%. By applying a tighter cut, $-0.2 < \tau' < 0.2$ for example, the prompt fraction can be increased up to 67%.

References

- [1] Electron performance measurements with the ATLAS detector using the 2010 LHC proton-proton collision data *The ATLAS collaboration*
- [2] <http://root.cern.ch/>
- [3] <http://pdg.lbl.gov/>