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Measuring the DAΦNE luminosity with large angle Bhabha scattering

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Abstract

In this memo we propose to measure the DAΦNE luminosity by using Bhabha events hitting the Barrel of the KLOE electromagnetic calorimeter. These events can be easily accepted, without introducing an eccessive load on the DAQ, by switching off the Bhabha veto in the Barrel. It's shown how this method can allow to achieve a precision on the luminosity better than 1%, at the ϕ mass.

1 Introduction

One of the topics of the physics program at DAΦNE concerns the measurement of the hadronic cross section at different energies. To perform such a measurement with the necessary accuracy, the machine luminosity must be known with a relative error better than 1% [1].

At e^+, e^- colliders the machine luminosity can be precisely determined by measuring the rate of the Bhabha scattering at small angle, which is a clean process, either from the experimental and from the theoretical side. At DAΦNE the presence of the focusing quadrupoles, close to the interaction point ($3^o < \theta < 20^o$), doesn't allow to use such a method.

To avoid the above problem, bremsstrahlung photons, emitted in the forward direction, can be used, together with dedicated detector. This method has been adopted by the DAΦNE team wich uses two luminosity monitors, [1] close to the beam intersection, in the direction followed by the positrons.

Hovewer, the background introduced by the residual gas in the pipe, put a limit on the precision of this method, which is expected to be of the order of 5% [2].

A considerably better accuracy on the luminosity can be achieved by using Bhabha events in which the positron and the electron are emitted at large angle (L.A.B.), $20^o < \theta_{e^+,e^-} < 160^o$, which, at the DAΦNE energies ($\sqrt{s} \sim 1\,\mathrm{GeV}$), are produced with a significant cross section ($\sigma_{20^o<\theta<160^o} \sim 6.86\mu barn$). In this case the KLOE detector itself can be used to detect these events.

The choice of the angular region is driven mainly by the following two conditions:

1. to collect enough statistics;
2. to achieve a good resolution on the boundaries. In particular, the precision in the determination of the boundaries of the angular region is less restrictive at large angle w.r.t. the small one, due to the $1/\theta^3$ dependence of the differential cross section.

At first, it was proposed to use events in the $20^o < \theta < 160^o$ angular range [3, 4]: while the above requirements on the statistics and on the boundary resolution can be satisfied by this choice, the Bhabha events emitted in this region can't be accepted without modifying the KLOE trigger system.

Infact, from the viewpoint of the KLOE trigger, the Bhabha events are background processes for the ϕ, which must be rejected as much as possible since they would provide an unacceptably high load to the DAQ. Therefore a dedicated veto has been implemented at the trigger level which rejects the events for which at least two deposits above a defined threshold (by default correspond to 300 MeV of deposited energy) are found. The forward ($\theta < 45^o$) and the backward ($135^o < \theta$) regions are covered by the endwalls of the electromagnetic calorimeter, whose modules are transversal to the beam direction (z direction): in these regions, the KLOE trigger [5], can't use the information on the polar angle, to discriminate between events emitted at small angle ($\theta < 20^o$), which should be vetoed, and those at larger angle, ($20^o < \theta < 45^o$), which should be accepted [2]. Therefore, for a defined sector of the

[1] The luminosity monitors, SciFi calorimeters, has been designed and built in Pisa.

[2] Clearly, when the beams energy will be shifted from the ϕ mass, the trigger strategy will be changed: indeed, in this case, the machine background and the small angle bhabha must be rejected. As we'll show, in the following, our strategy can be successfully applyied also to these energies.

endcap, Bhabha events with $\theta < 45^o$ (and $\theta > 135^o$) are rejected, independently by their polar angle.

The above difficulties lead us to consider the possibility of measuring the luminosity using Bhabha events in which the positron and the electron are emitted in the angular region covered by the **Barrel** of the electromagnetic calorimeter, $45^o < \theta < 135$, in which we select the fiducial region defined by $50^o < \theta < 130$. This requires **to switch off the Bhabha veto in the Barrel**, which otherwise, should reject about 90% of the signal. As will be shown, the two criteria on the angular region are satisfied, with an additional load, introduced by the new trigger definition, estimated to be $\sim 400Hz$ at $5 \times 10^{32} cm^{-2} sec^{-1}$, quite tolerable by the DAQ. This rate is expected to be statistically sufficient to perform the measurement, with the needed accuracy and with very low background.

To achieve the precision of 1%, at least three other ingredients are required: a detailed study of the simulation of the detector answer w.r.t. the real data, a precise knowledge of the alignment of the detector w.r.t. the beam axis, an accurate theoretica description of the processes under study. Regarding this last point, the groups of Pavia and Parma, involved in the EuroDAΦNE collaboration, are working on two generators, optimized to work at large angle, which they claim to achieve an accuracy better than 1% [6]. These points will be discussed in the final part of the memo, in which also the energy, polar angle and acollinearity resolutions will be studied for Bhabha events selected by implementing the proposed trigger. It will be shown how these contributions are expected to be negligeble w.r.t. the systematics of the detector, which will be really known only with the data taking.

2 Monte Carlo Study

2.1 L.A.B. selection criteria

A sample of 10000 elastic (with O(α^3) radiative corrections) and radiative Bhabha events has been generated [7] from Monte Carlo in the region $40^o < \theta < 140^o$ [3]. The corresponding Born cross section is $\sigma_{Born} \sim 1.29 \mu barn$. To this number we'll normalize our sample [4].

[3] In the generation, the θ angle is defined in the e^+e^- center of mass system, wich is different from the labortory system, due to the 12 MeV boost of the e^+e^- in the x direction.

[4] The error associated to this normalization is expected to be of few per cent. Such an accuracy, which is not required by the present study, will be necessary for the the measurement of the luminosity at the 1% level.

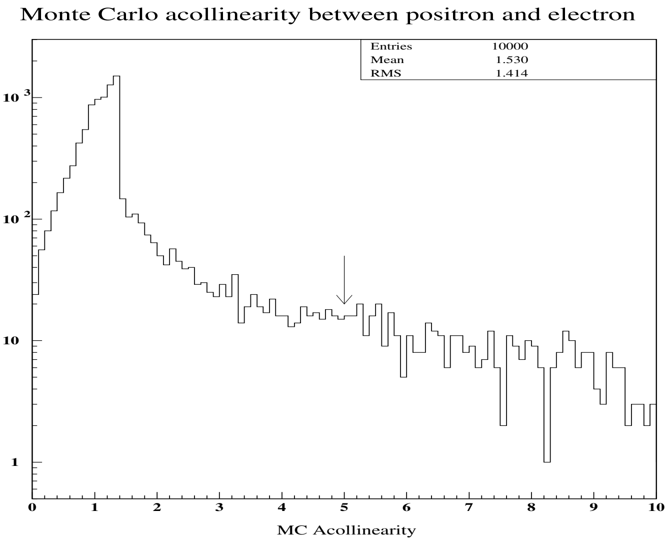

Figure 1: Acollinearity distribution from Monte Carlo.

The following cuts define our signal:

$$50^o < \theta_{e^+} < 130^o \quad (1)$$

$$50^o < \theta_{e^-} < 130^o \quad (2)$$

$$E_{e^+} > 400\,\text{MeV} \quad (3)$$

$$E_{e^-} > 400\,\text{MeV} \quad (4)$$

$$\zeta = \left(180^o - arccos(\frac{\vec{p_{e^+}} \cdot \vec{p_{e^-}}}{\mid \vec{p_{e^+}} \mid\mid \vec{p_{e^-}} \mid})\right) < 5^o \quad (5)$$

where E_{e^+}, E_{e^-} and $\vec{p_{e^+}}$, $\vec{p_{e^-}}$ are respectively the energies and momenta of positron and electron and ζ is the e^+e^- accollinearity. The cuts (1) and (2) select a fiducial region in which the polar angle is reconstructed with higher accuracy. However, all the eventes with the electron and the positron impinging on the Barrel ($45^o < \theta_{e^+e^-} < 135^o$) are useful to study the fiducial window. As shown in Fig. 1, the cut on the acollinearity is applied on the tail of the distribution. This cut selects *quasi-elastic* Bhabha events.

Tab. 1 shows the number of Monte Carlo events surviving to the cuts. Since the cuts can be applied either in the laboratory frame or in the center of mass system, in each column it is specified if the cuts are applied with (CMS) or without the boost correction (LAB). At $10^{32} cm^{-2} sec^{-1}$, therefore, the expected rate is:

Cuts	Events (CMS)	Events (LAB)	Events (CMS)	Events (LAB)
(1): angular cut	$45^o < \theta_{e^-,e^+} < 135^o$		$50^o < \theta_{e^-,e^+} < 130^o$	
	7232	7136	5374	5322
(2): (1) $\cap$ $E_{e^+,e^-} > 400\,\mathrm{MeV}$	6613	6512	4933	4882
(3): (2) $\cap$ $\zeta < 5^o$	6164	6037	4569	4499

Table 1: Bhabha selection criteria efficiency.

$$\underbrace{\nu}_{rate} = \underbrace{.45}_{events} \times \underbrace{1.29 \mu barn}_{\sigma^{Bhabha}_{40^o<\theta<140^o}} \times \underbrace{10^2 \mu barn^{-1} sec^{-1}}_{lumin.} \sim 60 Hz$$

and, clearly, a factor 10 better at full luminosity ($10^{33} cm^{-2} sec^{-1}$). At this rate a statistical error less than 0.3% can be obtained in 45 minutes:

$$\delta_{stat} L \sim 1/\sqrt{162000} \sim .25\%$$

Due to the $1/s$ dependence, the Bhabha cross section increases for energy lower than the ϕ mass, but this effect is compensated by a reduced value of the luminosity. Tab. 2 reports the expected rate for an energy in the center of mass below the ϕ peak, assuming a luminosity of $10^{30} cm^{-2} sec^{-1}$. The statistics obtained is sufficent to perform the measurement, but if the luminosity is less than $10^{30} cm^{-2} sec^{-1}$, or for energies above the ϕ mass, the angular region should be widened.

	Beam Energy			
	100 MeV	200 MeV	300 MeV	400 MeV
ν (Hz)	~ 15	~ 4	~ 2	~ 1

Table 2: Expected L.A.B. frequency for beam energy below the ϕ mass, assuming a luminosity of $10^{30} cm^{-2} sec^{-1}$.

2.2 Triggering on L.A.B.

Almost all the L.A.B. are rejected by the Bhabha veto in the Barrel. In particular of 10000 Bhabha generated, about 9000 (90%) are identified and rejected by the Bhabha veto, with a $\sim$ 300 MeV energy threshold. Figs. 2 show the positron and electron energies correlation, without the Bhabha veto (a), and for the events which are rejected by the veto (b). As can be noted, our method can't be applied if the veto is kept. Therefore we require to switch off the Bhabha veto in the Barrel. In the next paragraph the additional load introduced by our strategy is estimated.

In addition the proposed trigger strategy allows to solve the problems due to the rejection of the radiative ϕ decays by the Bhabha veto [8] in the Barrel.

2.2.1 Load on DAQ from the signal

Our signal is defined by the events in which **both** the electron and positron are emitted with a polar angle in the Barrel, $45^o < \theta < 135^o$. From this condition the fiducial region can selected.

With a luminosity of $5 \times 10^{32} cm^{-2} sec^{-1}$, the rate introduced, switching off the Barrel veto, with a 300 MeV threshold, is estimated to be:

$$\nu = \underbrace{.9}_{veto\ eff.} \times \underbrace{.9\ \mu b}_{\sigma^{Bhabha}_{45^o<\theta<135^o}} \times \underbrace{500\ \mu barn^{-1} sec^{-1}}_{lumin.} \sim 400 Hz,$$

Of these, $\sim$ 300 Hz will constitute the L.A.B. inside the fiducial region $50^o < \theta < 130^o$.

2.2.2 Load on DAQ from the background Bhabha processes

In addition to the signal, the new proposed trigger can be enabled by Bhabha events for which one of the positron or the electron is emitted outside the angular region covered by the Barrel ($\theta < 45^o$ or $\theta > 135^o$), but with two energy deposits in the Barrel over threshold (one of which, essentially, produced by an energetic radiative photon).

The addition load due to these Bhabha's of background, has been estimated by generating 50000 events with $20 < \theta < 160$. The corresponding cross section is $\sigma = 6.86 \mu barn$ [5]. In about 120 events of the $\sim$ 44829 vetoed by the Bhabha veto in

[5] The events emitted in the forward direction ($\theta < 20$) with two deposits over threshold in the Barrel shouldn't constitute an appreciable rate.

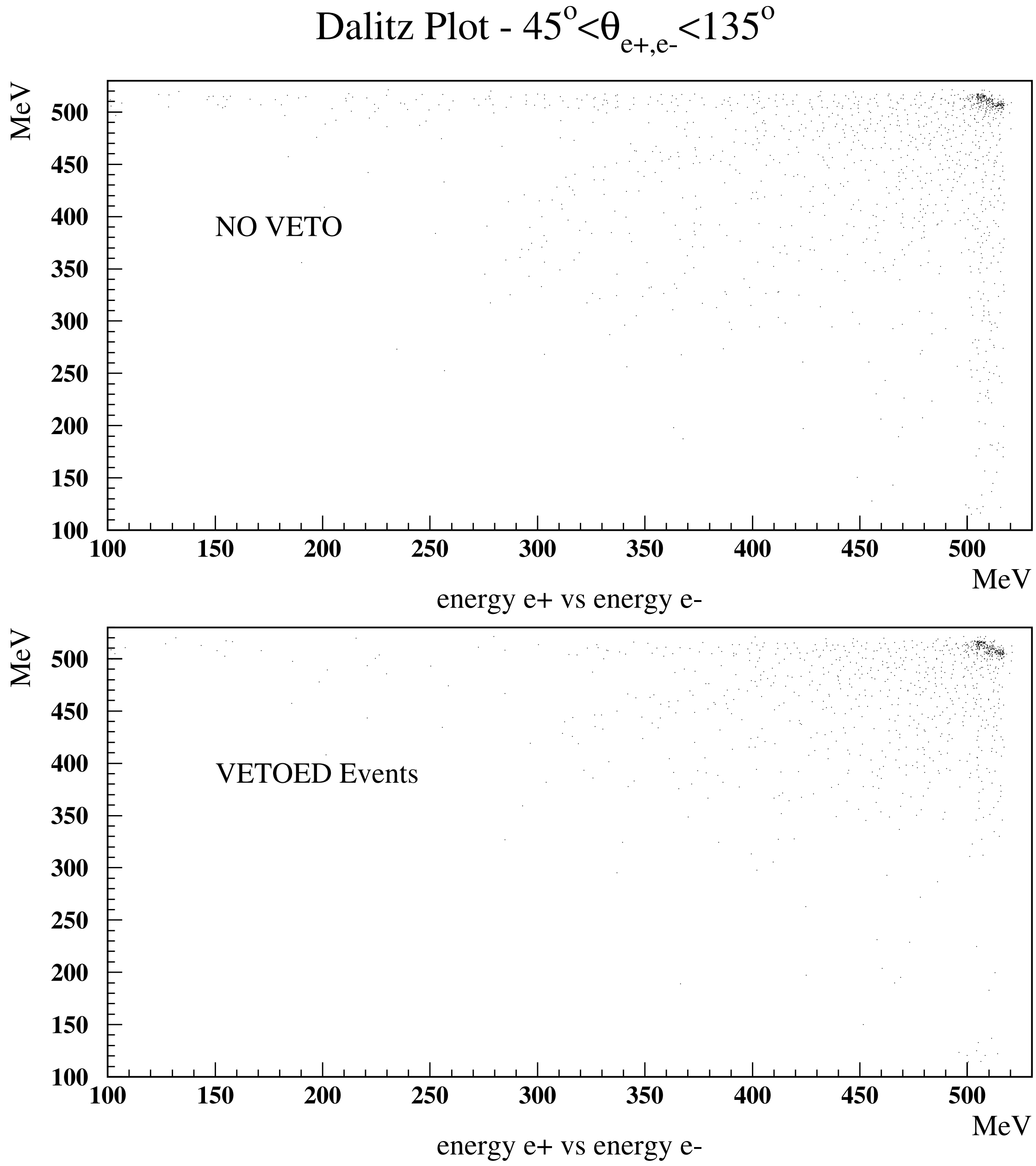

Figure 2: Positron and electron energies correlation, without the veto bhabha (a), and for the vetoed events (b). The events in (b), are rejected by the veto: we notice that an event can be rejected even if the electron (positron) has an energy below 300 MeV, because of the hard bremsstrahlung γ, witch releases in the EMC an energy amount above the veto threshold.

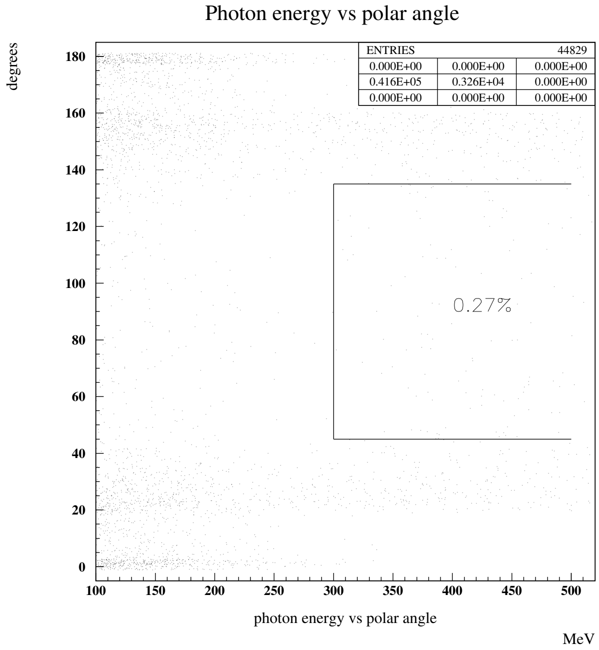

Figure 3: Energy distribution as a function of the polar angle for photon emitted between 20^o and 160^o. It is shown the region in which the Bhabha veto in the Barrel can be selected.

the Barrel or in the endcap, an photon is emitted inside the angular region covered by the Barrel, as shown in Fig. 3. By requiring for these events two deposits over threshold in the Barrel the residual rate is reduced to ~ 15 events, less than $\leq 5\%$ of the signal rate.

3 Dependence of the measured cross section from a shift on the boundaries of the selected phase space

3.1 Required accuracy on the angular region.

The expected precision on the measurement imposes selective requirements, expecially on the knowledge of the values of the selection cuts. This is particular true for the geometrical acceptance, for which a shift on the boundaries value traslates in a systematic error on the selected events. The $1/\theta^3$ dependence of the Bhabha differential cross section by the polar angle, makes negligible the error on the $\theta = 130^o$ boundary, w.r.t the low θ one, $\theta = 50^o$. The error on the evaluation of the measured cross section depends on the uncertainty in the determination of low θ boundary, by the following relation:

$$\frac{\Delta\sigma_0}{\sigma_0} \sim \frac{\frac{\Delta\sigma_0}{\Delta C_{max}}\Delta C_{max}}{\sigma_0} = \frac{(3+C_{max}^2)^2(1-C_{max}^2)^2}{16(1-C_{max})^2}\frac{\delta R}{R}$$

where $C_{max} = \cos(50^o) = 0.643$ and $R = 200\,\text{cm}$ is the transversal distance of the Barrel to the beam axis. In particular requiring an error on $\frac{\Delta\sigma_0}{\sigma_0} = 0.005$ imposes the angular region to be known with the following accuracy:

$$\delta R \sim 5\text{mm} \quad \delta Z \sim 4\text{mm} \quad \delta\theta = 3\text{mrad}$$

this is the required accuracy on the central value of the measurement: otherwise the effect of the finite resolution on θ is less relevant, and can be easily introduced in the MC simulation for the Bhabha process.

3.2 Required accuracy on the Acollinearity and Energy cuts

Figs. 4(a) and 4(b) respectively show the dependence of the relative error on the measured cross section from a shift in the values of the acollinearity and energy cuts.

It can be noted that:

- a shift of 2% on the energy of the electron (or positron) produces a relative error on the mesured cross section of 0.3%;
- a shift of 3 mrad on the acollinearity translates in a relative error of 0.3%;

To achieve an error on the luminosity of .5%, the systematic shift on energy and acollinearity cuts must be known with an accuracy of the order of the above values.

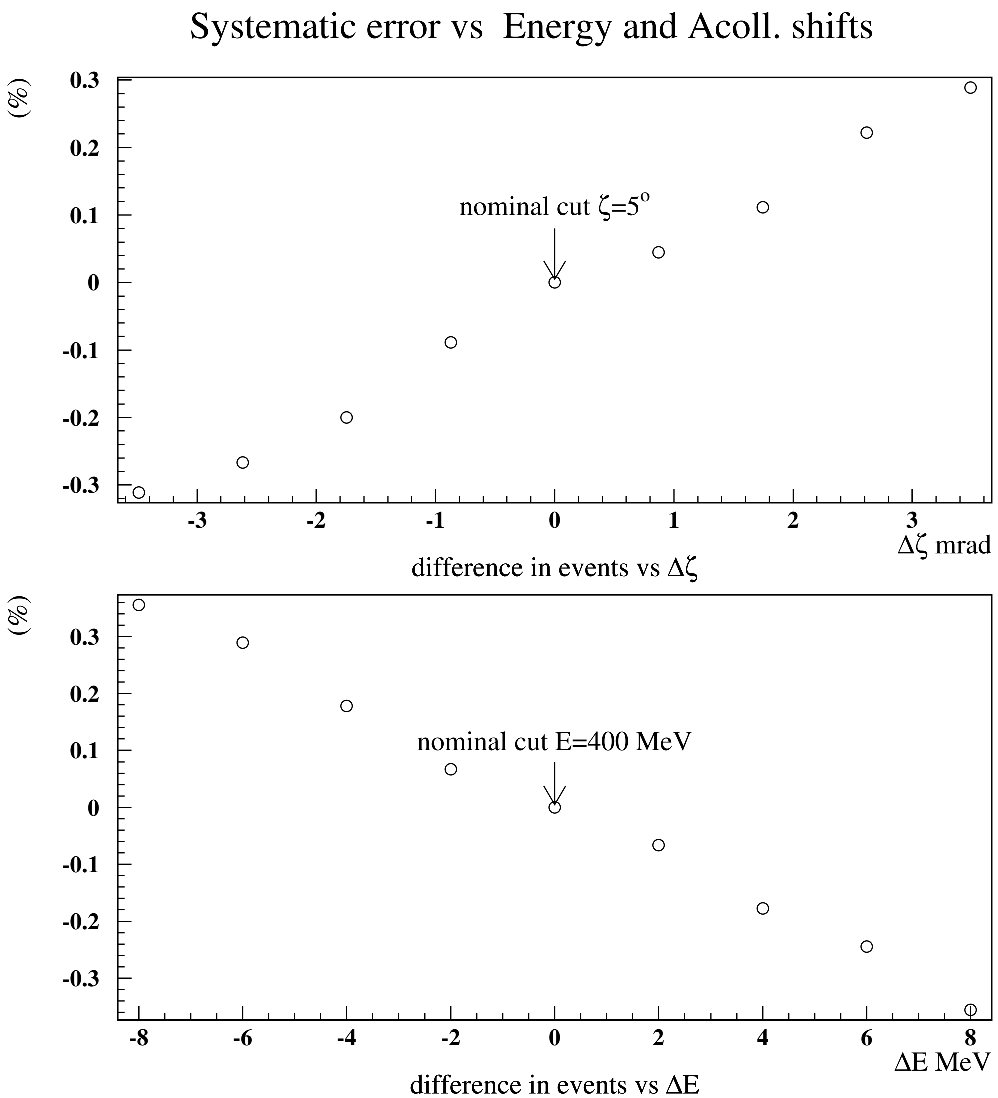

Figure 4: (a) Dependence of the cross section from a shift in acollinearity; (b) dependence of the cross section from a shift in energy.

4 General remarks on the measurement

The following conditions are necessary to reach the required accuracy on the luminosity:

1. Alignment of the oder of few mrad of the detector w.r.t. the beam axis;
2. Determination of absolute energy scale;
3. Creation of a very precise generator of Bhabha events with radiative corrections, whose effect are expecially relevant at large angle;
4. Calibration of the simulation of the detector response with real data.

All the above criteria can be verified with the data taking; however, the following cosiderations persuade us to be optimistics to achieve these goals:

1. The detector beam alignment is very important also to gain the full luminosity;
2. The standard methods used to measure the beam energy in e^+e^- machine (for example at LEP) can be applied in a natural way also to DAΦNE;
3. A group is forming in the EuroDAΦNE collaboration to study in particular the radiative correction and hadronic cross sections. A first version of Bhabha generator which uses the so called *parton shower* method has been presented by the Pavia group and it is ready to be tested with our Monte Carlo. The expected accuracy is of .5%. Also another generator of Bhabha events is under test by the Parma group. It uses a quite different approach and should achieve the same precision of .5%.
4. The calibration of the Monte Carlo with the "real" data is a preliminary step for all the precision measurement for KLOE, as, for example, $\mathrm{Re}\,(\epsilon'/\epsilon)$.

5 Reconstruction study of L.A.B. events

5.1 Implementing the new trigger strategy

In section 2 we estimated indirectly the additional rate introduced by changing the Bhabha veto. To check this result the simulation of the trigger has been modified to switch off the Bhabha veto in the Barrel. The fraction of filtered Bhabha events with $40^o < \theta_{e^+e^-} < 140^o$, is 68% (see Tab. 3) for a corresponding rate of $440Hz$ at $5 \times 10^{32} cm^{-2} sec^{-1}$:

$$\nu = \underbrace{.68}_{trg\ eff.} \times \underbrace{1.3\ \mu b}_{\sigma^{Bhabha}_{40^o<\theta<140^o}} \times \underbrace{500\ \mu barn^{-1} sec^{-1}}_{lumin.} \sim 440Hz,$$

which is good agreement with the value obtained in par. 2.2.1 ($\sim 400Hz$).

5.2 Large Angle Bhabha selection algorithm

A selection algorithm has been implemented to identify L.A.B.. The algorithm is divided into two steps:

1. a *filtering* phase which uses only the calorimeter informations, by requiring at least two clusters inside the angular region $45^o < \theta_{clust} < 135^o$, each one with energy $> 300\,MeV$ and with $180^o - (\theta_{clust}(1) + \theta_{clust}(2)) < 10^o$. The θ_{clust} is defined by the position of each cluster centroid;

2. a *selection* phase in which the selection criteria are applied to *filtered* events, by using the information coming from the drfit chamber. A charged vertex with two tracks satisfying the following criteria is required:

$$\begin{aligned} 50^o &< \theta_+ < 130^o & (6)\\ 50^o &< \theta_- < 130^o & (7)\\ E_+ &> 400\,\mathrm{MeV} & (8)\\ E_- &> 400\,\mathrm{MeV} & (9)\\ \zeta &= \Big(180^o - arccos(\frac{\vec{p_+} \cdot \vec{p_-}}{\mid \vec{p_+} \mid\mid \vec{p_-} \mid})\Big) < 5^o & (10) \end{aligned}$$

   where the $\theta_{+,-}$ and $p_{+,-}$ are the polar angle and momentum of the positive and negative charged track, respectively.

The new trigger and the selection algorithm have been tested by using the sample of 10000 events with $40^o < \theta < 140^o$. In particular the efficiencies have been studied w.r.t. the *signal* (4333 events), which is defined by the fraction of the events surviving to the selection cuts, without applying any filter or trigger selection.

Tab. 3 shows both the new trigger and *filtering* phase efficiencies.

An selection efficiency for L.A.B. of 99% is therefore expected.

Efficiency	Signal	Background	Total
NO filt	4333	5667	10000
Trigger ϵ_{trg}	4297/4333 99.2%	2492/5667 44%	6789/10000 67.9%
Filter ϵ_{fil}	4296/4297 99.9%	1671/2492 69%	5967/6789 87.9%
Total $(trg \cdot filt)$ ϵ_{tot}	4296/4333 99.2%	1671/10000 17%	5967/10000 59.7%

Table 3: Selection efficiencies for trigger and *filtering* phase of the algorithm. The signal is defined by the events which satisfied the selection cuts, without applying any filter or trigger selection.

No relevant backgrounds are expected from processes different from the Bhabha: infact the major background, which is due to $\pi^+\pi^-\gamma$ events, is expected to be small; however, it can be easly removed by applying a constraint on the invariant mass of the two tracks.

5.3 Study of energy, angular and acollinearity resolution

By assuming our Monte Carlo to satisfy the requirements discussed in the previous section, we have studied the resolution of the reconstructed quantities which are used to select the required phase space. Figs.(5,..., 11) plot the distribution of angular, momentum resolution and acollinearity of positron and electron tracks, as we get from the track reconstruction of the drif chamber. These distributions show a very good resolution on the angular and momentum of the tracks, allowing to select a good reconstructed phase space. The systematic error due to these resolutions ($\sim \sigma/\sqrt{N}$) is quite negligible w.r.t. to the foreseen systematic contributions coming from the detector.

6 Conclusion

A method which uses radiative Bhabha events on the Barrel of the KLOE Electromagnetic Calorimeter, is proposed to measure the DAΦNE luminosity. It requires to switch off the Bhabha veto in the Barrel. We have shown how this method can allow to achieve a statistical error, as well as the systematic one, better than 1%,

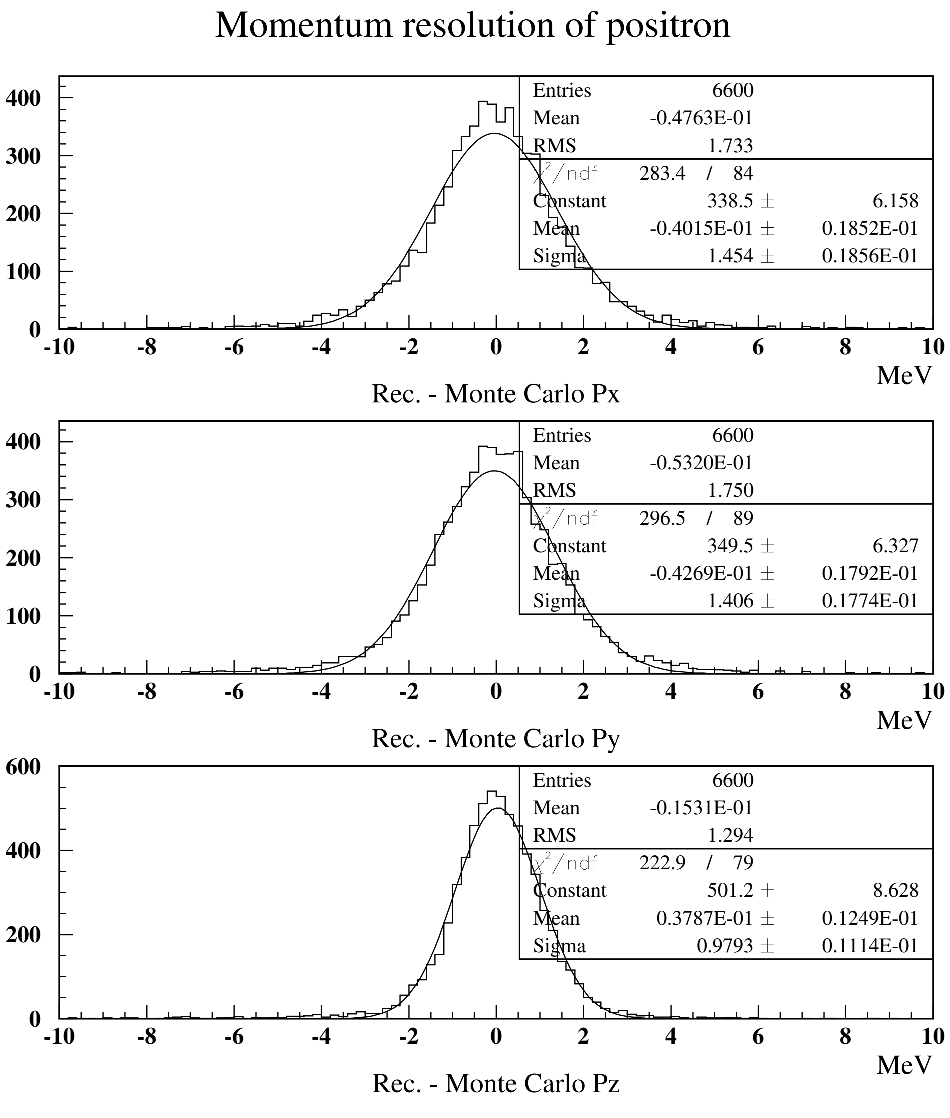

Figure 5: Momentum resolution of positron obtained by the tracks reconstruction in the drift chamber.

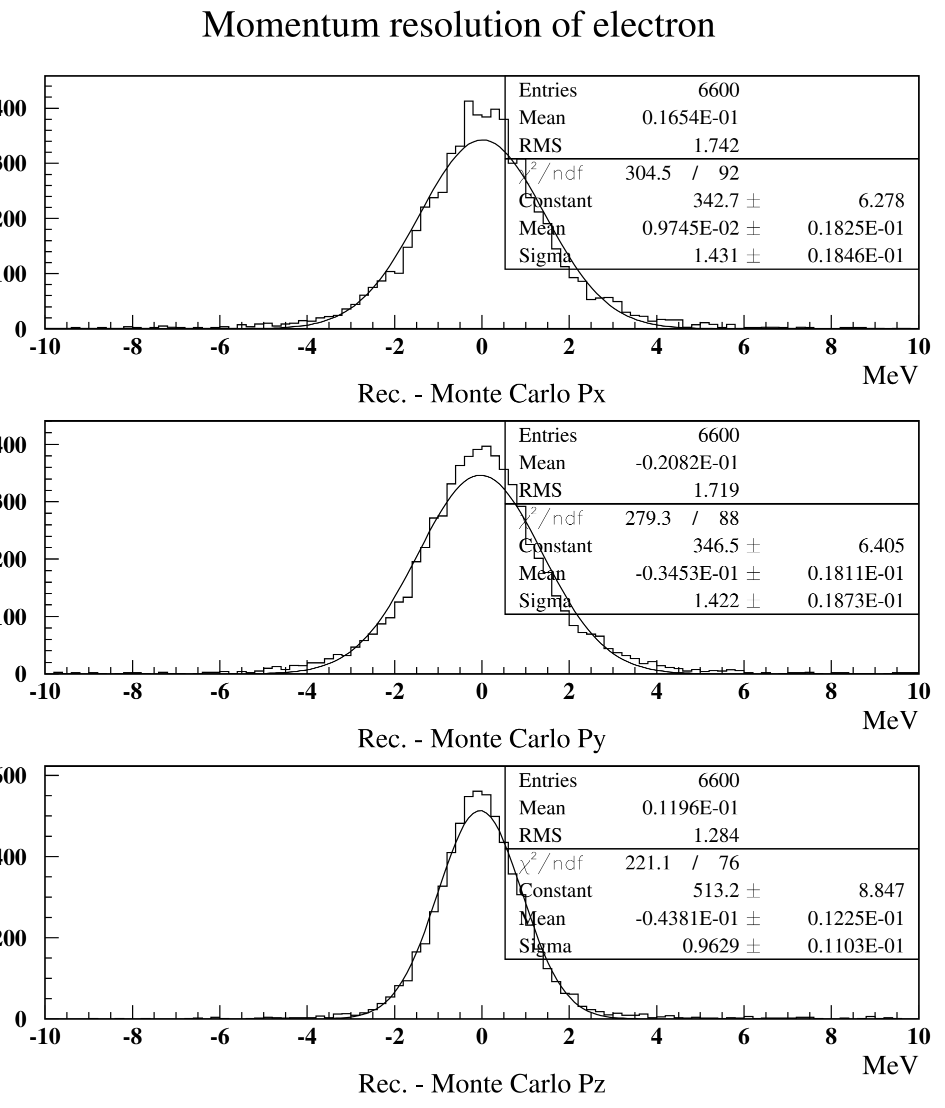

Figure 6: Momentum resolution of electron obtained by the tracks reconstruction in the drift chamber.

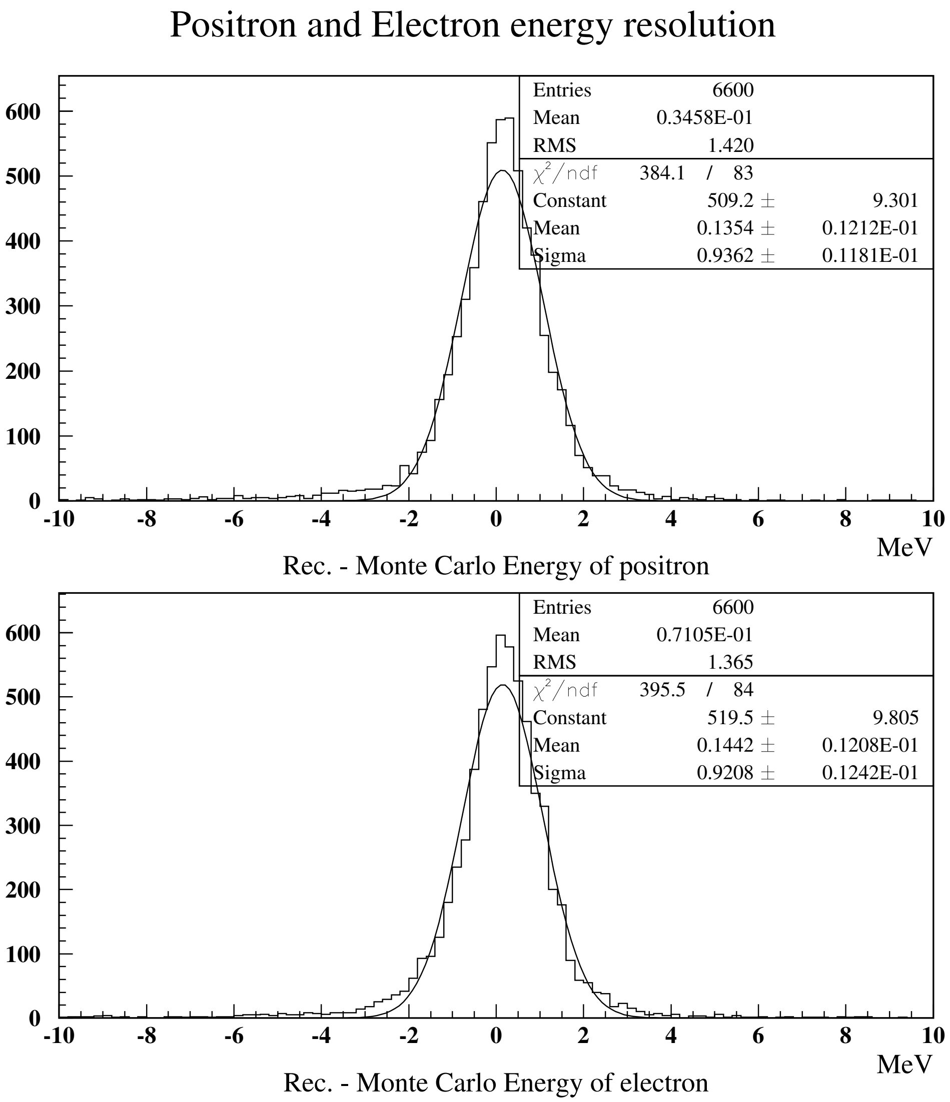

Figure 7: Energy resolution of positron and electron obtained by the tracks reconstruction in the drift chamber.

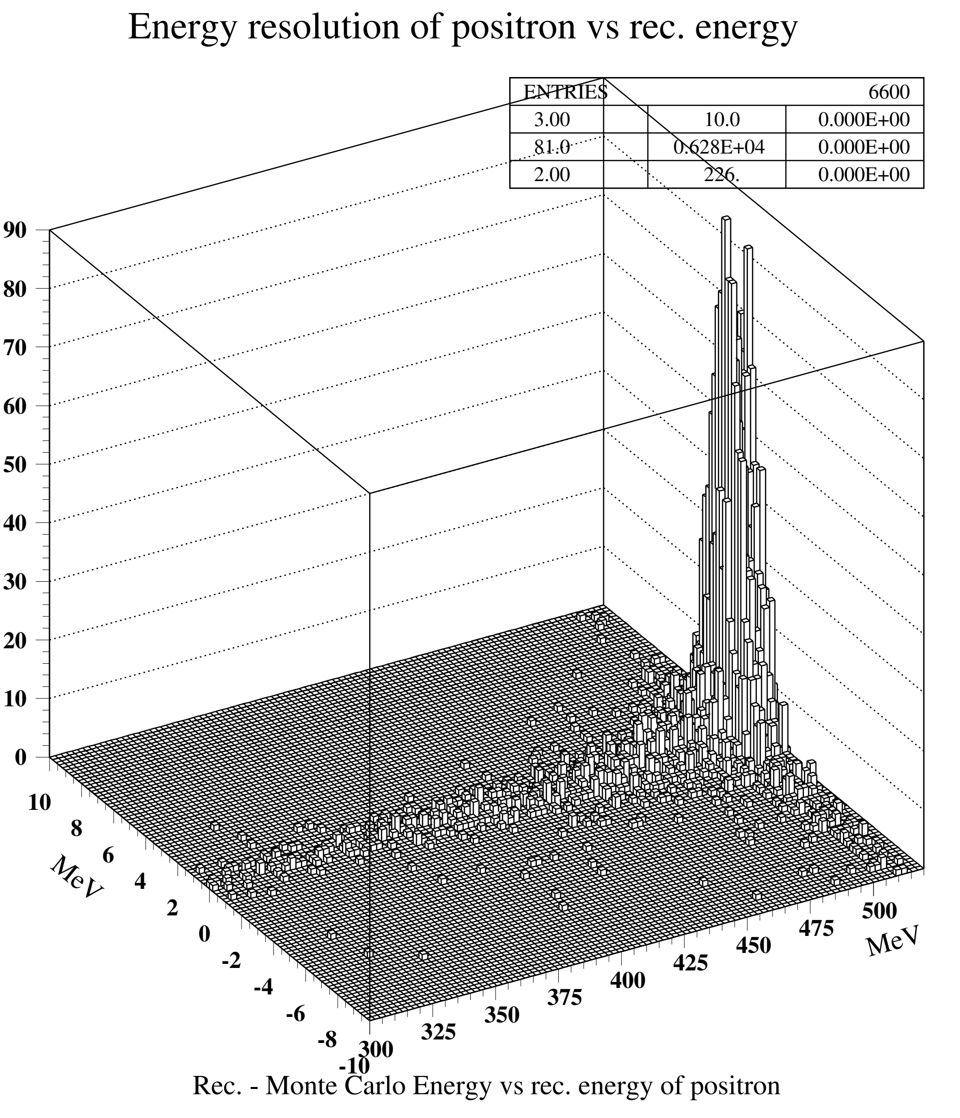

Figure 8: Energy resolution of the positron as a function of the positron reconstructed energy by the track reconstruction in the drift chamber.

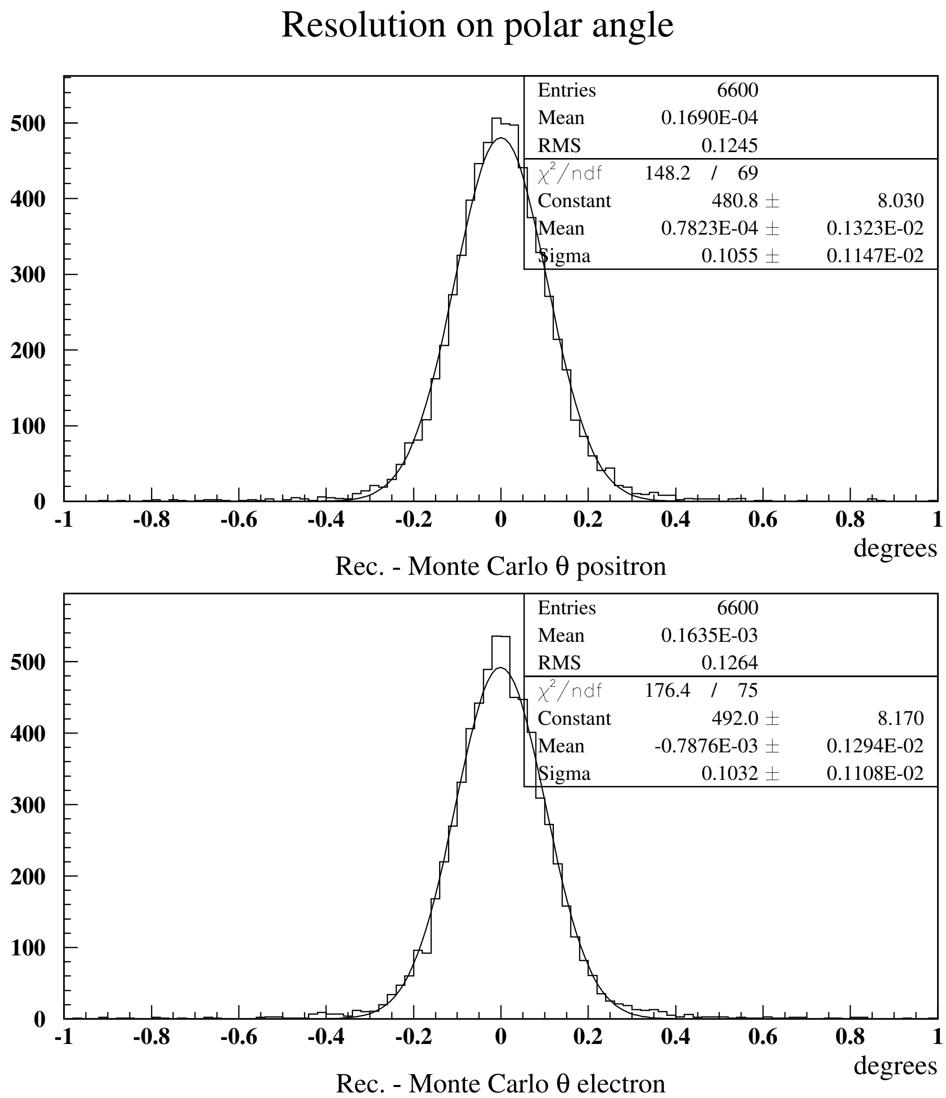

Figure 9: Resolution on polar angle for positron (a), and electron (b) with the track reconstruction in the drift chamber.

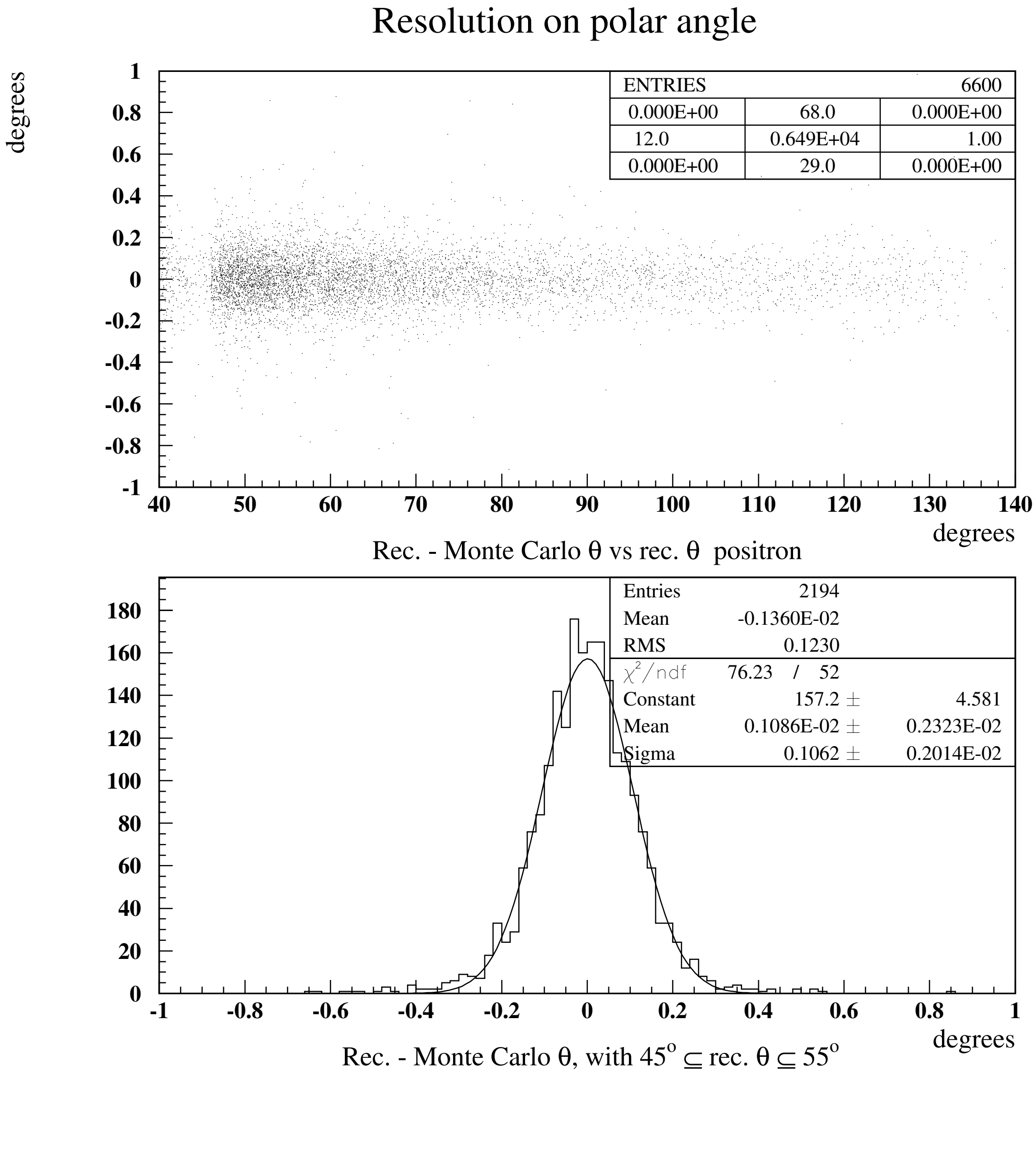

Figure 10: Up: resolution of polar angle for positron as a function of the reconstructed one. Down: Polar angle resolution in the boundary $45^o < \theta < 55^o$.

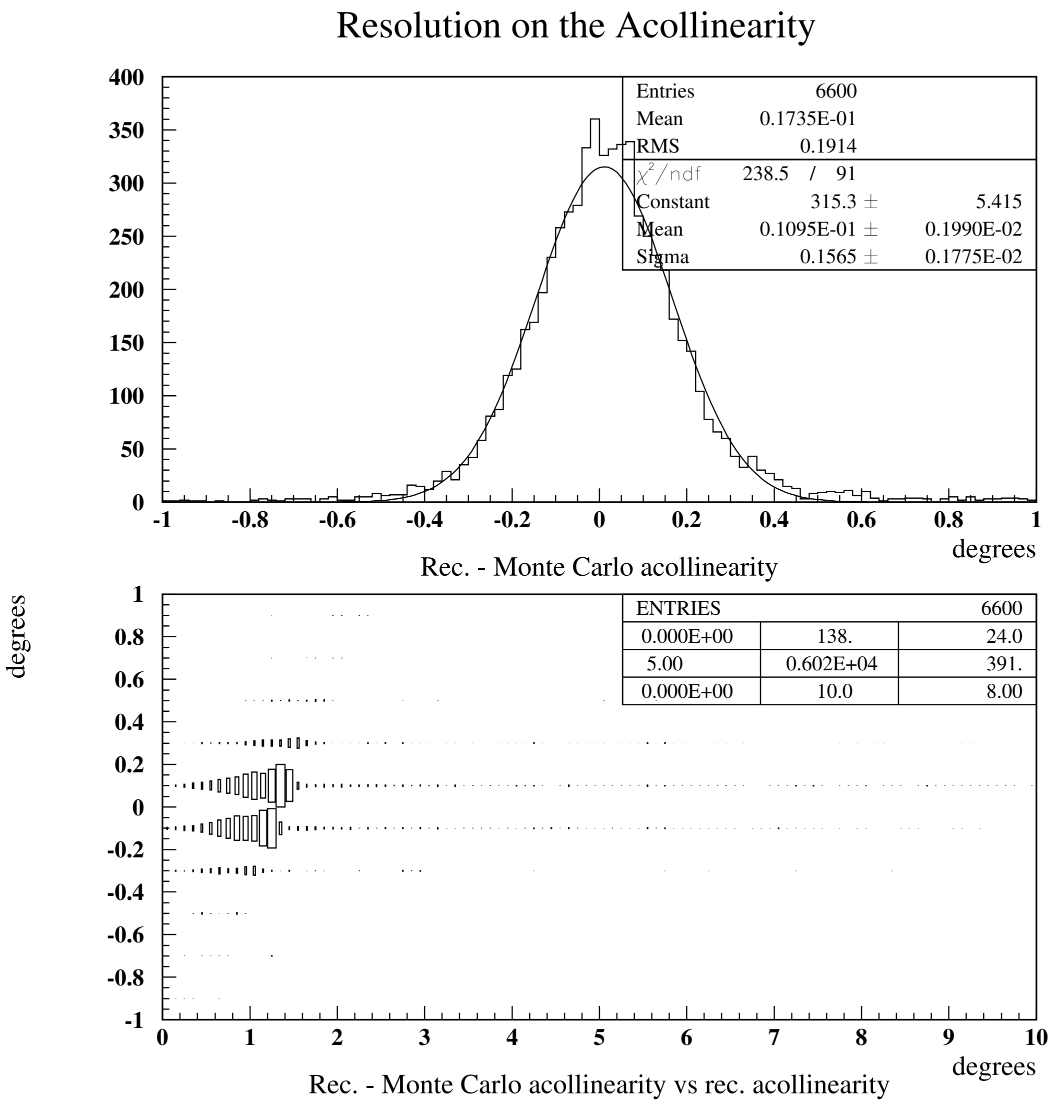

Figure 11: Up: resolution on the recontructed acollinearity with the the track reconstruction in the drift chamber. Down: Acollinearity resolution as a function of the reconstructed one.

if both the theoretical value of the Bhabha cross section, and the position of the detector are known with (or even better) the same precision.

Acknowledgements

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