PHOBOS Physics Capabilities

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$\mathcal{PHOBOS}$ is the name of a detector and of a research program to study systematically the physics of relativistic heavy-ion collisions over a large range of impact parameters and nuclear species. Collisions with a center of mass energy of 200 $A\ GeV$ at RHIC are expected to produce the highest energy densities ever accessible in the laboratory.

In this writeup, we outline the physics capabilities of the $\mathcal{PHOBOS}$ detector and describe the detector design in terms of the general philosophy behind the $\mathcal{PHOBOS}$ research program. In order to make the discussion concrete, we then focus on two specific examples of physics measurements that we plan to make at RHIC: $dN/d\eta$ for charged particles and the mass spectrum from $\phi \to K^+K^-$ decays.

1. Overview

The aim of the $\mathcal{PHOBOS}$ research program is to study the collective behavior of hadronic matter under conditions of extreme energy density. This is interesting in its own right, but the primary goal is to see if, under these conditions, there are manifestations of new physics, such as a deconfinement phase transition leading to a Quark-Gluon Plasma (QGP). In particular, we know that there are partons in the nucleus, but we would like to see some evidence of long-range collective partonic phenomena. If new physics is discovered, the aim will shift to a thorough study of the new phenomena. This should lead to a better understanding of confinement and of the structure of the vacuum in strong interactions.

The central philosophy underlying the design of the $\mathcal{PHOBOS}$ detector is that we are entering a new physics regime and that theory can only provide us with rough guidance. For this reason we must examine our collisions in as unbiased a way as possible. We plan

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to achieve this by studying the production of all hadronic particles in a detector which has essentially 4π coverage event-by-event and a high data taking rate - allowing the use of a minimum bias trigger. We can measure $d^2N/d\eta d\phi$ as well as the total charged multiplicity for every *Au-Au* collision within ± 10 cm of our nominal vertex. This should provide a rich unbiased database for the study of these collisions.

If a Quark Gluon Plasma is formed in such a collision, the color deconfinement will lead to a larger number of thermodynamic degrees of freedom — more entropy content — than would be present in the initial stages of the collision. This will be true even though the system will be thermodynamically small and even if the system doesn't fully equilibrate. In order to hadronize again without losing entropy, the system will have to undergo a large expansion, live a long time, and generate many more particles than a purely hadronic system would. If the transition is first order, we may be able to see a rapid change in some variable as a function of centrality or beam energy. If, instead, the transition is higher order, the entropy argument still holds — the system should still show expansion, long lifetime, and large particle production. Such a higher order phase transition would be more difficult to see because most variables wouldn't undergo a sharp change, but the large effects should still occur.

Therefore, we designed our detector assuming that long times, large volumes, and increased particle production will be associated with the phenomena of interest. Since large-volume collective phenomena are generally associated with lower values of p_T, we emphasized our ability to measure particles and also pairs of particles at low p_T. Another advantage of the $\mathcal{PHOBOS}$ configuration is that we will be able to make fairly subtle measurements in the mid-rapidity, low p_T region, such as the mass and width of the ϕ.

To summarize the above discussion, we want our detector to be able to handle large multiplicities, and we want it to be sensitive to low p_T particles, to large source sizes (through Bose-Einstein correlations), and to subtler effects, such as a change in the ϕ mass or width. In order to accomplish these goals, our detector consists of two parts: a multiplicity detector covering almost the entire psuedorapidity range of the produced particles and a two-arm spectrometer at mid-rapidity. Figure 1 shows the entire PHOBOS detector, including the spectrometer arms, the multiplicity and vertex array, and the lower half of the magnet. Figure 2 shows the multiplicity and vertex array alone.

The multiplicity detector covers the range $-5.4 < \eta < +5.4$, measuring total charged multiplicity, $dN/d\eta$, and even $d^2N/d\eta d\phi$ over almost the entire phase space. The focus of the spectrometer is on detailed measurements for central rapidity and low p_T. It covers about 0.4 radians in azimuth and one unit of pseudorapidity in the range $0 < \eta < 2$, depending on the interaction vertex, allowing us to measure the momenta and species of particles with p_T down to 40 MeV/c. Both detectors are read out together and are easily capable of handling the 600 Hz minimum bias rate expected for all collisions (within 10 cm of the nominal interaction point) at the nominal luminosity. More details can be found in the $\mathcal{PHOBOS}$ Conceptual Design Report [1].

The following sections discuss the $\mathcal{PHOBOS}$ detector capabilities in the context of two
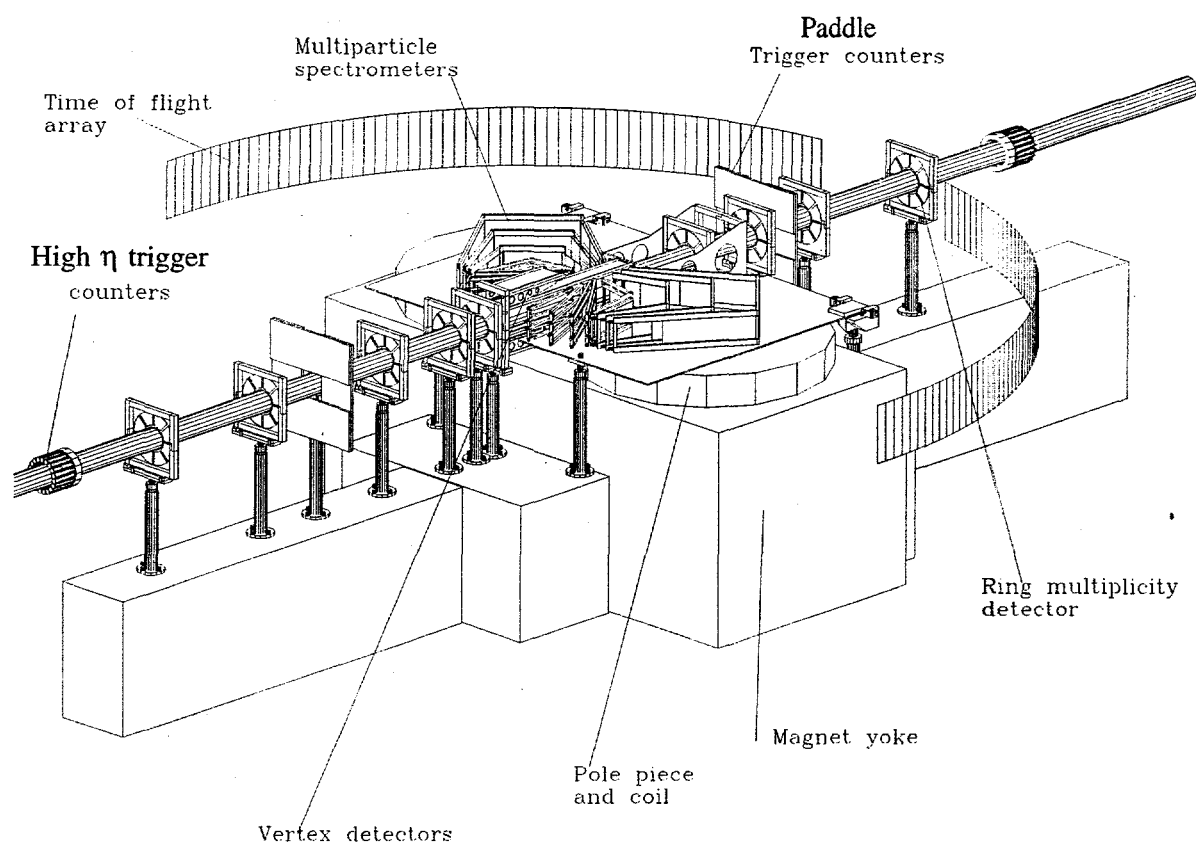
Figure 1. The PHOBOS detector.
The PHOBOS beam pipe, multiplicity and vertex detectors, spectrometer arms, lower half of the magnet, and a schematic TOF detector.
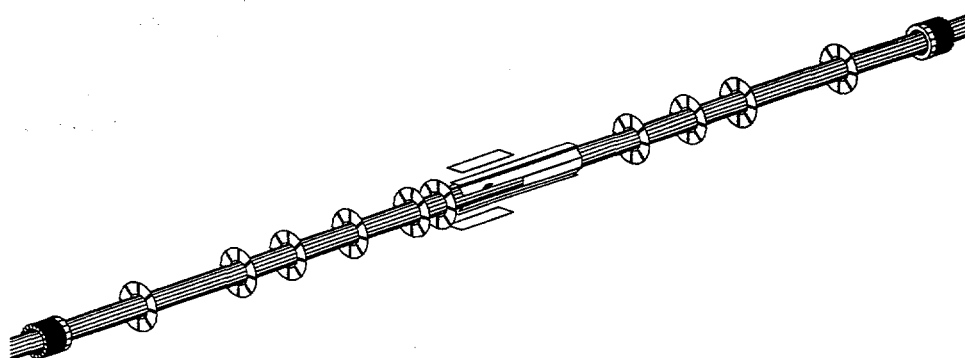

Figure 2. The PHOBOS multiplicity detector.
The PHOBOS beam pipe, multiplicity ring and barrel detectors, and vertex detector.
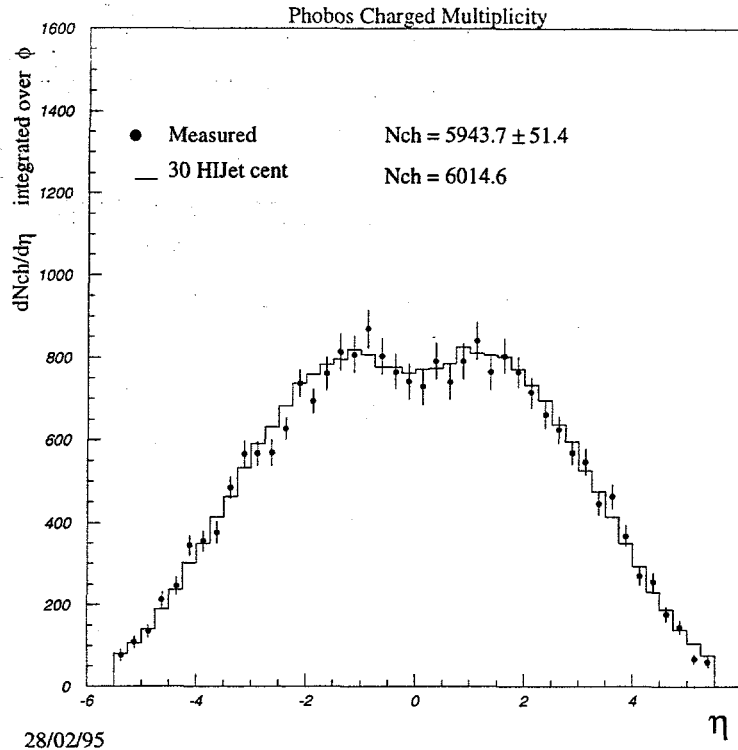
4

Figure 3. PHOBOS Single Event Multiplicity Measurement.
This plot illustrates our ability to measure $dN/d\eta$ on an event-by-event basis. The points show the results for a single central event using a full HIJET + GEANT simulation and multiplicity detector analysis. The histogram shows the average of 30 central HIJET events as generated.

specific examples of measurement topics: event-by-event $dN/d\eta$ and the mass and width of the ϕ meson. For a related discussion of the Bose-Einstein correlation measurement capabilities of $\mathcal{PHOBOS}$, see Günther Roland's contribution to these proceedings [2].

2. Multiplicity and $dN/d\eta$

Figure 3 illustrates our ability to measure $dN/d\eta$ as well as total N on an event-by-event basis. The curve represents the average of 30 central HIJET events as generated while the data points represent the measured value for $dN/d\eta$ for a single event resulting from a full GEANT simulation of the detector followed by a complete analysis, including corrections. The measurement is high precision (1% in total N) and covers almost the full acceptance. Because of our high rate capability, we can take 600 Hz of minimum bias data, or 60 Hz of central (10%). Figure 3 therefore represents 16 ms of beam time. We also have segmentation in ϕ, allowing a measurement of $dN/d\eta d\phi$ in bins of size $\Delta\phi = \pi/8, \Delta\eta = 0.25$ with errors bars 4 times larger than the corresponding ones in figure 3.

If there is a QGP, it is likely that the most striking signature will be a large tail of high multiplicity events in the total multiplicity distribution. This signature can then be correlated with other measurements to enhance other signals. Another, more subtle, signature of a phase transition would be fluctuations in the multiplicity distribution. In order to examine our sensitivity to such fluctuations, we added an anomaly to the single event and then compared it to 30 "normal" events from the Monte Carlo. In practice, such a comparison would be made with the average of hundreds or thousands of events with a similar multiplicity.

We chose to examine anomalies that contain more than 170 charged particles produced isotropically in some frame. For definiteness, we used Sean Gavin's model for the pion emission from disordered chiral condensates (*DCCs*) [3]. In this model, pions are emitted isotropically from a source in the central rapidity region. We chose the case where the *DCC* emits only charged pions. Since the largest *DCC* considered by Gavin (4 fm) yields very few particles ($\sim$ 85) compared to the several thousands that are created in the conventional hadronic fireball, we considered instead artificially enhanced signals. The first artifically enhanced signal consisted of simply doubling the number of particles to 170. In the model this corresponds to doubling the energy density in the *DCC* from $60 \ MeV/fm^3$ to $120 \ MeV/fm^3$. The second artificially enhanced signal was generated by assuming an even larger radius of 6 fm, yielding $\sim$ 280 particles.

Figures 4 and 5 show the measured distribution resulting from anomalous signals containing more than 170 particles with an isotropic distribution. Clearly if the particles were more focussed in either η or ϕ, we could pick out an even smaller signal on an event-by-event basis. Also, by measuring rapidity and phi correlations, we may be able to pick out smaller signals on a statistical basis.

3. ϕ Mass and Width

An interesting effect that has been predicted, but not yet seen, is the changing of resonance masses and widths in hot hadronic matter. Observing such a change would teach us something about high temperature QCD. These effects can be quite large. For instance, Lissauer and Shuryak [4] predict an increase in the ϕ width of a factor of 2–3 in the mid-rapidity region for central collisions at RHIC. The effect is dominated by low p_T ϕs in the midrapidity region, where $\mathcal{PHOBOS}$ excels.

Broadly speaking, there are two complementary ways to pursue these effects: if the ϕ mass or width changes, it should be visible in either the leptonic or hadronic decays. The leptonic channel has the advantage that the produced leptons interact very little with the hadronic medium, providing the most direct measure of what happens to ϕs that decay early in the collision process. The hadronic channel, $\phi \rightarrow K^+K^-$, has three main advantages: high branching ratio, low q value of the decay (making the kaon momenta very sensitive to changes in the ϕ mass), and the fact that kaons are easy to detect and identify. The main disadvantage of the kaon channel lies in the fact that the outgoing kaons will also be affected by the hadronic medium: they may undergo collisions and they
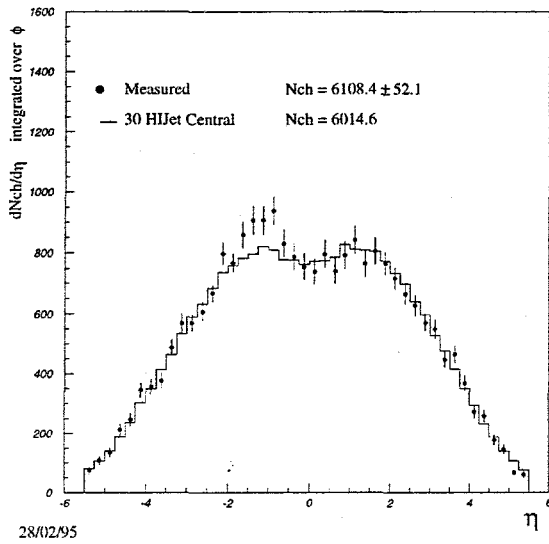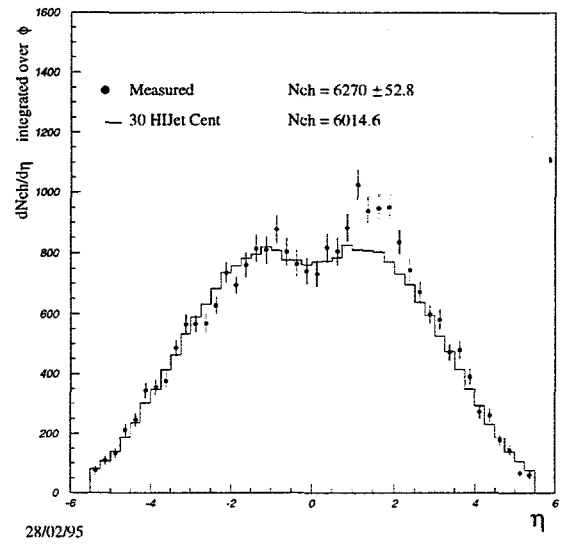
Figure 4. Single PHOBOS central event with 170 particle anomaly.

The points show the results for a single HIJET event with a 170-particle anomaly (4 fm DCC with $\varepsilon = 120 MeV/fm^3$) centered at a rapidity of -1. The histogram shows the average of 30 central HIJET events as generated, without an anomaly.

Figure 5. Single PHOBOS central event with 280 particle anomaly.

The points show the results for a single HIJET event with a 280-particle anomaly (6 fm DCC with "normal" $\varepsilon = 60 MeV/fm^3$) centered at a rapidity of +1. The histogram shows the average of 30 central HIJET events as generated, without an anomaly.

may interact with the medium in order to go on mass-shell as they leave it.

The $\mathcal{PHOBOS}$ collaboration will study the $\phi \rightarrow K^+K^-$ channel for midrapidity, low p_T ϕs. Our strategy will be to examine the width, mass, and number of ϕ particles found in this channel as a function of centrality and p_T. The medium effects should show up as a change in the width, mass, or number of ϕs for the most central collisions. This effect should be a decreasing function of p_T.

Figure 6 shows the total distribution of identified K^+K^- pairs accepted into the spectrometer from 19 hours of good running at the nominal beam luminosity, including those from ϕ decays as well as the continuum background. Figure 7 shows the distribution of ϕ particles accepted into the spectrometer (requiring 2 fully identified kaons) as a function of the ϕ invariant mass for 19 hours of running. The acceptance is not uniform as a function of M, leading to an increase in the tail on the low mass side. This effect is purely geometrical and can be corrected for. In the analysis that follows, we will ignore the effect and just exclude the low-energy tail from the fit. In a more complete analysis, we would, of course, just correct for the effect. Figure 8 shows the background-subtracted distribution of ϕs.

Figure 9a shows the event-by-event invariant mass resolution of the detector. A Breit-Wigner fit to this δM distribution yields a centroid of zero ($-8 \pm 5 keV$) and a width Γ_{res} of 2.03 MeV, corresponding roughly to a σ of about 1 MeV (given equivalent FWHM). Figure 9b shows the background-subtracted ϕ distribution fit to a Breit-Wigner. This yields $M = 1019 \pm 0.2 MeV$ and $\Gamma_{raw} = 6.57 \pm 0.48 MeV$. Deconvoluting the resolution function yields $\Gamma_{meas.} = \Gamma_{raw} - \Gamma_{res.} = 4.5 \pm 0.5 MeV$.

In summary, our resolution on the M and Γ of a sample, given 19 hours of running, is 0.2 MeV and 0.5 MeV respectively. For a full year's run, we should be able to plot the measured M and Γ of the ϕ in the hadronic decay channel as a function of other observables such as centrality and p_T. The key feature of PHOBOS that allows us to achieve such good statistical precision on the ϕ measurement, even with small acceptance, is our high data-taking rate.

4. Conclusions

The $\mathcal{PHOBOS}$ detector is a high-rate detector with good acceptance for charged particle detection, and with good particle identification and momentum measurement at low p_T in the mid-rapidity region. These features make it well-designed for studying collective phenomena at RHIC and complementary to other detectors planned for RHIC.

Two specific measurements were considered as examples: $dN/d\eta$ for charged particles and the mass spectrum from $\phi \rightarrow K^+K^-$ decays. It was shown that we have a resolution of about 1% on the total multiplicity event-by-event and can easily see anomalies of ~ 170 or more charged particles superimposed on a central event. It was also shown that 19 hours of beam time provides us with a measurement of the ϕ mass with an error of 0.2 MeV and
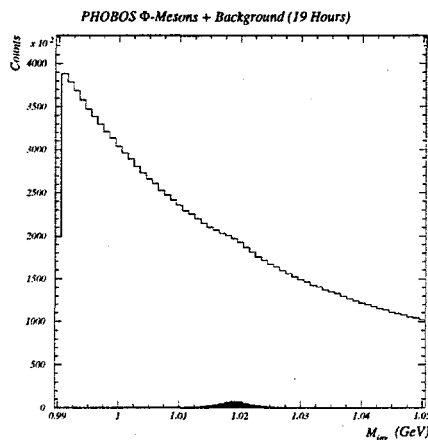
8

PHOBOS Φ-Mesons + Background (19 Hours)

Figure 6. PHOBOS ϕ mesons + background in 19 hours.
The open histogram shows the invariant mass distribution of all fully identified K^+K^- pairs in the spectrometer, including both the ϕs and the background (19 hours - 10% central). The filled histogram shows only the accepted ϕs.
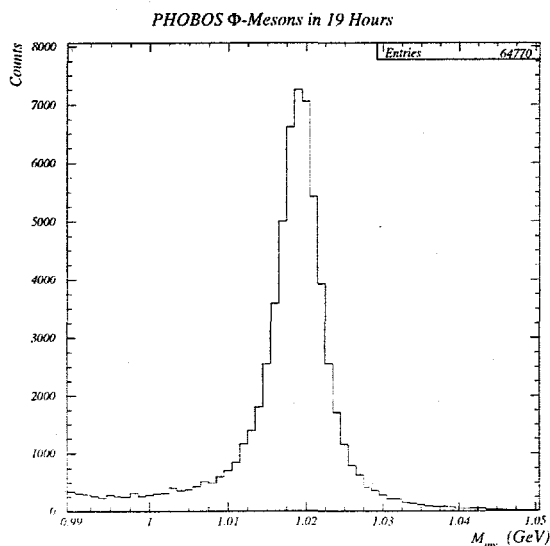

Figure 7. PHOBOS ϕ mesons in 19 hours.
This plot shows the invariant mass distribution of ϕ particles reconstructed from fully-identified K^+K^- pairs in 19 hours of good running (considering only the 10% central sample).
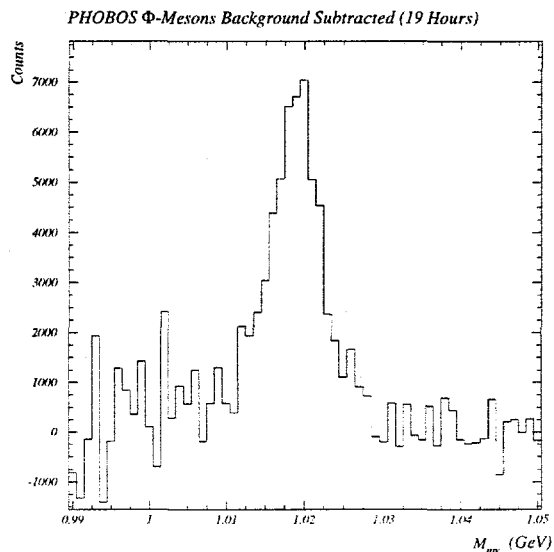
Figure 8. PHOBOS Background-subtracted ϕ mesons in 19 hours.
This histogram shows the invariant mass distribution of K^+K^- pairs after background-subtraction. This would be our ϕ signal for 19 hours of data assuming that only the most central 10% of the data contained ϕs.
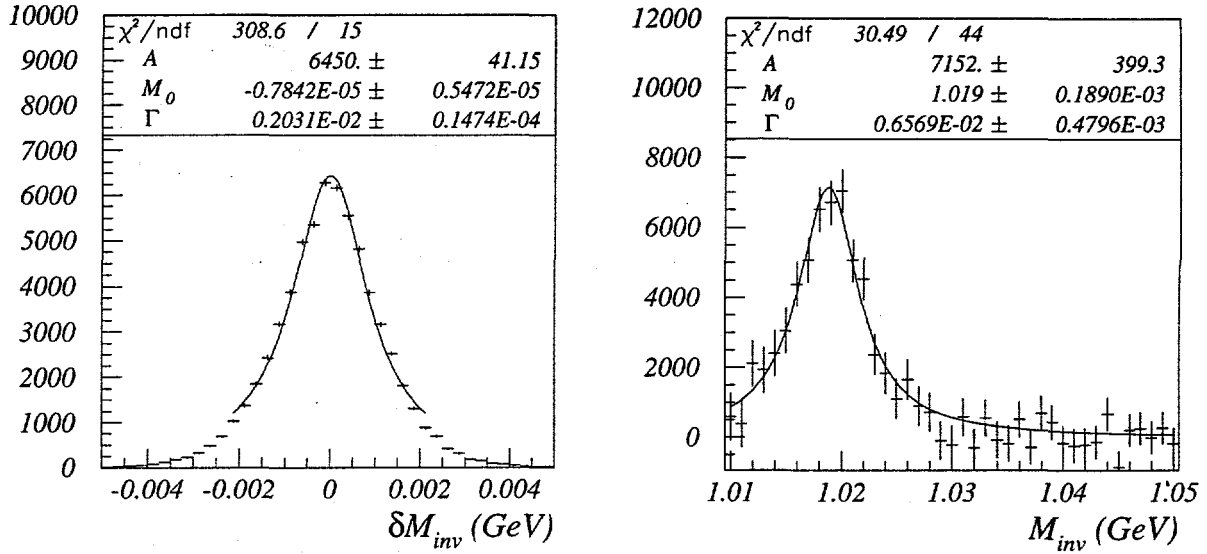
PHOBOS Φ-Mesons in 19 Hours

Figure 9. PHOBOS ϕ Mass and Width fits.
This shows a) the event-by-event mass resolution and b) the Breit-Wigner fit to the background-subtracted result after 19 hours (10% central). The final measured result corresponds to $M = 1019 \pm 0.2 MeV$ and $\Gamma_{meas.} = 4.54 \pm 0.5 MeV$ (see text).

of the width with an error of about 0.5 MeV. The multiplicity measurement covered the complete phase space and the phi measurements covered the mid-rapidity, low p_T region that should be the most important part of the phase space. This work was supported by the U.S. Department of Energy, Nuclear Physics Division, under contract W-31-109-ENG-38.

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