APH N.S., Heavy Ion Physics 4 (1996) 139-148

HEAVY ION PHYSICS
©Akadémiai Kiadó

Charm in PHENIX—a signal or a background?

M. J. Tannenbaum

Brookhaven National Laboratory
Upton, NY 11973-5000 USA

Received 26 June 1996

Abstract. Charm, as well as Strangeness, plays an important role in searches for the Quark Gluon Plasma. J/Ψ Suppression and Strangeness Enhancement are two of the earliest proposed QGP signatures. Recent theoretical work on charm in Relativistic Heavy Ion collisions has focussed on dilepton production. However, even before the discovery of the J/Ψ, evidence of open charm was seen in hadron collisions via the observation of prompt **single** leptons "resulting from the semi-leptonic decays of charm particles."[1] The 'copious' yield of direct (i.e. not from Dalitz decays) single electrons and muons—at a level $e/\pi \sim 10^{-4}$ for $p_T \geq 1.3$ GeV/c—observed in the early 1970's was explained by Hinchliffe and Llewellyn-Smith and Bourquin and Gaillard as evidence of open-charm production. It is likely that e/π at RHIC is large and is a good measure of charm production. Thus, a measurement of single electrons with moderate $p_T > 1.5$ GeV/c at RHIC should give a clean charm signal in heavy ion collisions, **with no combinatoric background**.

1. Introduction

Both Charm and Strangeness play important roles in the search for the Quark Gluon Plasma. J/Ψ Suppression[2] and Strangeness Enhancement[3] are two of the earliest proposed QGP signatures. Recent theoretical work on Charm in Relativistic Heavy Ion collisions has focussed exclusively on charm-pair production with emphasis on the large background it provides for Drell-Yan and thermal di-leptons[4] and as a method to measure the gluon structure function[5]. This has led to some interesting new ideas[6].

2. Being too early may be worse than being too late

A recurring theme in some of the recent work on charm is typically[4] "*At RHIC $e\mu$ coincidence measurements could prove useful. Charm was first measured by this method at the CERN Intersecting Storage Rings (ISR)[7]...*" Interestingly, this statement ignores a real triumph of experimental physicists in the early 1970's—

0231-4428/95/ $ 5.00

even before the discovery of the J/Ψ, evidence of open charm was seen in hadron collisions[8]. The 'copious' yield of direct (i.e. not from Dalitz decays) single electrons and muons, at a level $e/\pi \sim 10^{-4}$ for $p_T \geq 1.3$ (see Fig. 1), was eventually explained by Hinchliffe and Llewellyn-Smith[10] and Bourquin and Gaillard[11] as evidence of open-charm production. A glance at these papers from the early 1970's reveals much uncertainty about[11] "the conjectured charmed meson" whose discovery was published only in August 1976[12]. Part of the problem with the early

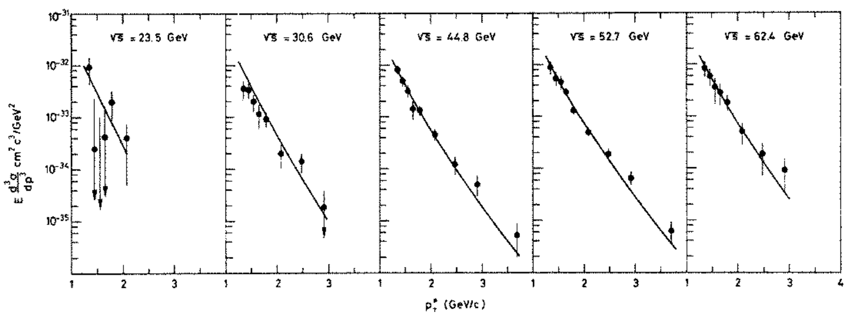

Fig.1. The charge-averaged invariant cross section for electron production from the ISR[15] for 5 values of c.m. energy $\sqrt{s}$. The solid curves represent fits to corresponding $(\pi^+ + \pi^-)/2$ data, multiplied by 10^{-4}.

direct lepton measurements and their interpretation as the result of semi-leptonic decays of charm was that there were several spurious results[13] from experiments that claimed to have measured direct leptons, but had not properly rejected or removed the background from the known sources of π^0 and η Dalitz decays. In fact, I said at the time that "all those who try to measure direct leptons become the world's experts on η Dalitz decay." (A proof of this is even in the literature[14].) A further confusion stemmed from the possibility that the ISR results[15], even with strong rejection of conversions, Dalitz and other low mass e^+e^- pairs, could possibly have been explained by a continuum, $d\sigma/dm \sim 1/m$, resulting from internal conversion of a direct photon signal[16] at the level of $\gamma/\pi^0 \simeq 5\%$ for $p_T \geq 1.3$ GeV/c. This wasn't the case[17], but the suggestion by Farrar and Frautschi[16], among others, initiated the study of direct photons in hadron collisions well before the advent of QCD and the "Inverse QCD Compton effect"[18].

3. Hadroproduction of Charm—Direct Single Leptons

Of course, the theorists are not to be blamed for this slight to experimentalists of the early 1970's, since the the origin of the quote implying that hadroproduction of open-charm at the CERN-ISR was first measured using $e\mu$ coincidences is from two RHIC experimental documents[19, 20], including (gulp) the PHENIX Conceptual Design Report[20]: "the first measurement of the charm cross section in hadronic interactions was performed at the CERN-ISR using two electron specrometers with a dimuon spectrometer at 90° between them [7]." However, a quote which more accurately refelects the history and possibilities for charm hadroproduction appears in an earlier RHIC Letter of Intent[21]: "The charm signal in hadron collisions (without a vertex detector) has been seen in the single electron channel (Dalitz conversions rejected) at a level $e/\pi \sim 10^{-4}$ for $p_T \sim 1.3$ to 1.5 GeV/c. At the ISR the e/π ratio varied systematically by a factor of ~ 1.8 from $\sqrt{s} = 30$ to 60 GeV, and by a fit to this data would be predicted to be 2.6×10^{-4} at $\sqrt{s} = 600$ GeV [15]" (see Fig. 2). Recent measurements at CERN give larger values with large errors [22]. In more modern language, NLO-QCD predicts[4] a factor of 4.5 ± 1.1 increase of the $c - \bar{c}$ cross section from $\sqrt{s} = 63$ to 200 GeV in $p - p$ collisions, roughly 2.5 times the increase in the average number of pions. Thus, it is likely that e/π at RHIC is large and is a good measure of charm production.

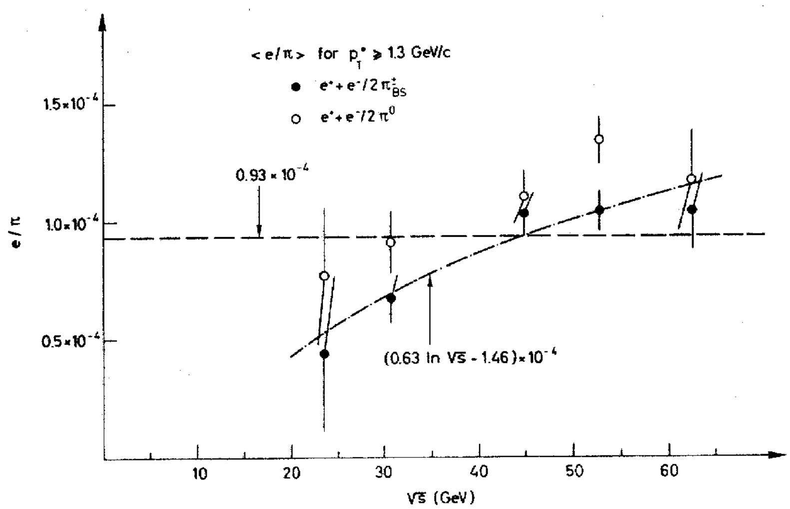

Fig.2. The ratio[15] e/π for $p_T \geq 1.3$ GeV/c as a function of c.m. energy $\sqrt{s}$. The dot-dash curve is the fit mentioned in the text.

3.1. Experimental Issues

To quote Appel[1], again, "Among the difficulties" (of open-charm hadroproduction in $p-p$ collisions) "are (a) the small fractional charm production cross section (one $c\bar{c}$ pair event per 10^3 interactions, typically), (b) the high multiplicity of particles in the charm events, and (c) the small branching ratios to specific final states (typically 1–10%)." These problems can be solved by picking a final state with a lepton, and using a selective leptonic trigger[9]. Alternatively, micro-vertex detectors have been used, more recently, with great success[1].

In nucleus-nucleus collisions, the problems are somewhat different. Charm is more plentiful—predictions range from 2 to 8 $c-\bar{c}$ pairs per central Au+Au collision at RHIC[4]. However, triggering is much harder because the multiplicity is so high for a central Au+Au collision that there are many real electrons from conventional sources. The main experimental problem for charm detection via direct electrons[23] is the fierce background from internal (Dalitz) and external conversions of photons from the decays $\pi^0 \rightarrow \gamma+\gamma$, $\eta \rightarrow \gamma+\gamma$, $\omega^0 \rightarrow \pi^0+\gamma$. For instance, for $dn(\pi^0)/dy = 400$ expected at RHIC, there are 800 photons and 4.8 π^0-Dalitz pairs, on the average, per unit of rapidity. It is nearly impossible to calculate this background correctly to the accuracy required. Thus, the conversion and Dalitz pairs must be rejected as strongly as possible and any remaining background must be **measured** in order for experiments to obtain reliable results.

The classical method to determine the conversion and Dalitz background from two-photon decays of π^0 and η is to artificially increase the external converter (typically a very thin vacuum pipe) by adding material of a few % of a radiation length (X_o). The yield, Y, per photon, of electrons or e^+e^- pairs from two-photon decays is proportional to t/X_o, the total external converter thickness in radiation lengths

$$Y \propto \frac{\delta_2}{2} + \frac{t}{\frac{9}{7}X_o} \propto \frac{9}{14}\delta_2 + \frac{t}{X_o} \qquad , \tag{1}$$

where $\delta_2/2$ is the Dalitz branching ratio per photon, and the factor 9/7 comes from the ratio of conversion length to radiation length. For π^0 and η decays, the yield extrapolates to zero at the "Dalitz point" $-\frac{9}{14}\delta_2 \sim -1\%$—actually -0.8% for π^0 and -1.0% for η—so the method has the added advantage that it depends very little on the η/π^0 ratio. In Fig. 3, the extrapolation for the signal[15], curve (a) where Dalitz and conversions are rejected, shows only a small decrease from the normal thickness used for data-collecting ($t/X_o = 1.6\%$) to the Dalitz point, while curve (b) where conversions are selected (instead of being rejected) extrapolates nicely to the Dalitz point, indicating a photonic source.

4. Prospects for Charm at RHIC by Direct Single Electrons

The main point of this presentation is that a measurement of single electrons with moderate $p_T > 1.5$ GeV/c at RHIC should give a clean charm signal in heavy ion

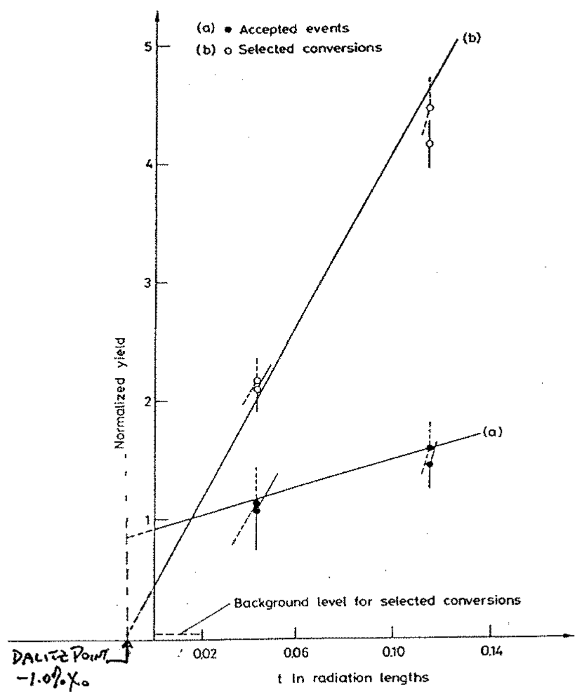

Fig.3. The yield[15] of accepted events (a) and selected conversions (b) as a function of the total thickness of material (in radiation lengths) in front of the first counter. The yields are both normalized to unity at $t/X_o = 0.016$, the normal thickness for data collection.

collisions, **with no combinatoric background**. In addition, production of multiple same-side moderate p_T (> 1.5 GeV/c) electrons may be important—and could serve as a charm signal, as well as an estimator of the combinatoric background due to charm in the opposide-side e^+e^- spectrum. Correlated charm background (di-leptons from the same $c - \bar{c}$ pair) can be measured by $e^{\pm} - \mu^{\mp}$ coincidences.

A nice collection of work on charm in heavy ion collisions can be found on the PHENIX WWW site: `http: //rsgi01.rhic.bnl.gov/ ~sorensen /thinc /topics /charm.html`. Of particular note for the single lepton method is Asher Shor's original work of 1987[24], where he compares his Monte Carlo simulation to the ISR data[15] of Fig 1. The latest results for the electron channel are are Yasuyuki Akiba's calculations for PHENIX[25, 26] with further work available in the "electronic proceedings" on the PHENIX home page. Akiba presents charm cross section predictions in $p-p$ collisions which he checks by comparison to the measured data, including the inclusive direct single $e^{\pm}$ measurements[15] at $\sqrt{s} = 53$ GeV from Figs. 1,2 (see Fig. 4).

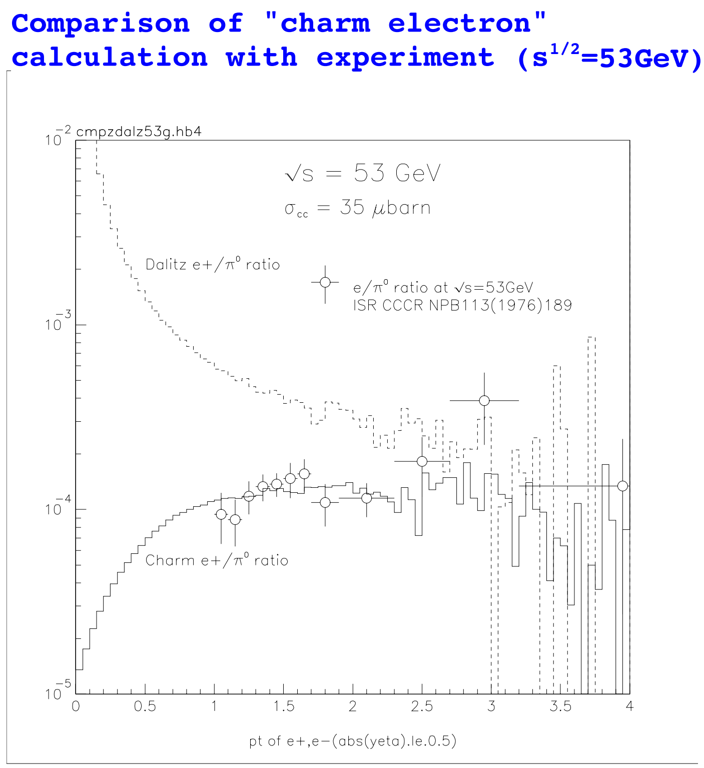

Fig.4. Y. Akiba's calculation[25] of $e/\pi = e^{+}/\pi^{0}$ for ISR data[15] at $\sqrt{s} = 53$ GeV. Note that a rejection of more than an order of magnitude against Dalitz and conversions was achieved for this data.

The charm cross section possibilities at RHIC for $\sqrt{s} = 200 \cdot A$ GeV Au+Au central collisions are then discussed, leading to a plot of the sources of electrons in PHENIX at RHIC (see Fig. 5), where $dn(\pi^0)/dy = 400$ is assumed. The yield of charm pairs, is considerable, 2.4–4.8 per central Au+Au event depending on the 'shadowing'. Other authors[4] predict as many as 8.6 $c-\bar{c}$ pairs per central Au+Au collision. The charm direct single electron yield is very large, in the range $e^{+}/\pi^{0} \simeq 0.5 - 1.0 \times 10^{-3}$, and for $p_T \geq 1.0$ to 1.5 GeV/c (depending on the shadowing)

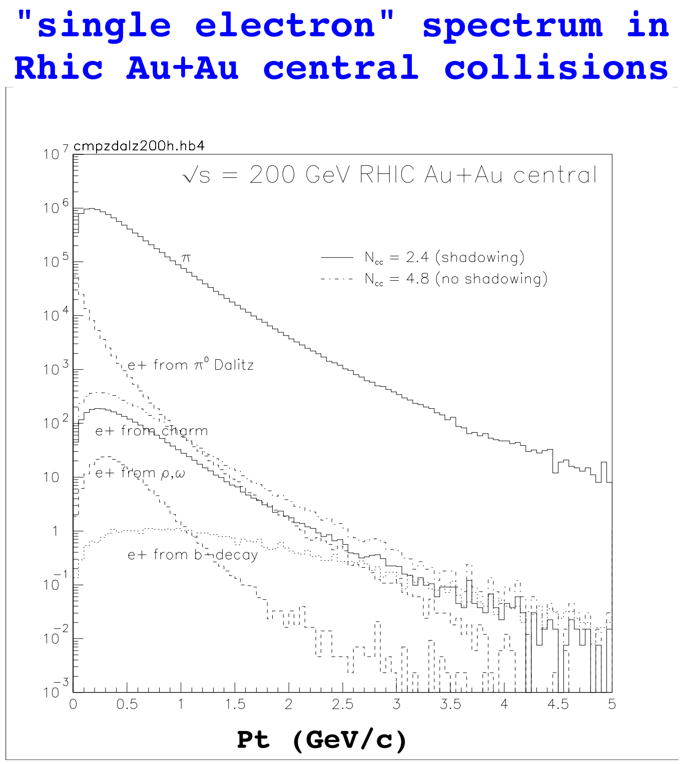

Fig.5. Y. Akiba's calculation[25, 26] of sources of electrons in PHENIX for Au+Au central collisions at RHIC. Inclusive electrons from decays of J/Ψ and Υ have not been included.

dominates all other sources of electrons including π^0 Dalitz decay (see Fig 6). The large increase in e/π from the ISR is explained both by the increase in the $c-\bar{c}$ cross section and the different nuclear A^α dependences, $\alpha_{c\bar{c}} \sim 1.0$, $\alpha_\pi \sim 0.75$[26]. The charm pair background to di-electrons is also discussed, including the effect of correlated and uncorrelated charm pairs. In agreement with other authors[4], Akiba finds that correlated charm (a di-electron pair from a the same $c-\bar{c}$ pair) dominates the e^+e^- spectrum for masses greater than the J/Ψ, dominating both Drell-Yan pairs and most predictions for thermal dileptons.

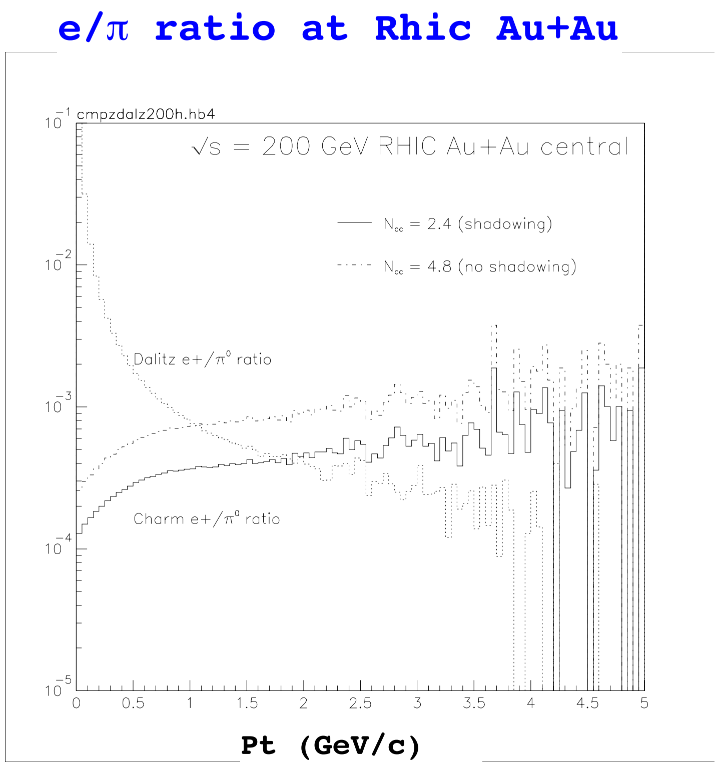

Fig.6. Y. Akiba's calculation[25, 26] of $e/\pi = e^+/\pi^0$ from Charm and π^0-Dalitz decays in PHENIX for Au+Au central collisions at RHIC.

5. Conclusions

It is possible that charm may dominate all other sources of di-leptons at RHIC. The $c - \bar{c}$ production cross section is the key to understanding this background—how well is it known and how can it be measured? Are there new effects[6] in nuclei?

$e^\pm - \mu^\mp$ coincidences are useful for estimates of correlated charm background to di-lepton production since such coincidences can not be produced by real or virtual photons. However, the cleanest charm signal signal in heavy ion collisions at RHIC, **with no combinatoric background**, should be obtained by a measurement of single electrons with moderate $p_T > 1.5$ GeV/c. Much can be learned by utilizing both of these tools.

Acknowledgement

This work is supported by the U. S. DoE under contract DE-AC02-76CH00016. Thanks are due to many collaborators on PHENIX, especially Yasuyuki Akiba who kindly supplied the figures of his calculations.

References

1. e.g., see J. A. Appel, *Annu. Rev. Nucl. Part. Sci.* **42** (1992) 367.
2. T. Matsui and H. Satz, *Phys. Lett.* **B178** (1986) 416.
3. J. Rafelski and B. Mueller, *Phys. Rev. Letters* **48** (1982) 1066.
4. R. Vogt, *et al., Phys. Rev.* **D49** (1994) 3345. See also LBL-37981, hep-ph/9604369.
5. Z. Lin and M. Gyulassy, *Nuclear Gluon Shadowing via Continuum Lepton Pairs in* $p+A$ *at* $\sqrt{s} = 200A \cdot GeV$, nucl-th/9510041.
6. E. Shuryak, *Can dileptons be observed in heavy ion collisions at RHIC ?*, nucl-th/9605011, and references therein.
7. A. Chilingarov, *et al., Phys. Lett.* **83B** (1979) 136, and references therein.
8. *Proceedings of the XVII International Conference on High Energy Physics*, Ed: J. R. Smith, London, July 1974, The Science Research Council, Rutherford Laboratory, UK, section V, pp V-41–V-55.
9. e.g., see Leon M. Lederman, *Physics Reports* **26** (1976) 149, for a timely review.
10. I. Hinchliffe and C. H. Llewellyn Smith, *Phys. Lett.* **61B** (1976) 472; *Nucl. Phys.* **B114** (1976) 45.
11. M. Bourquin and J.-M. Gaillard, *Nucl. Phys.* **B114** (1976) 334.
12. G. Goldhaber, *et al., Phys. Rev. Letters* **37** (1976) 255. A good measure of the confusion on this subject is that this letter was submitted for publication more than a year before its publication in the same issue of PRL in which a second charmed meson was reported, I. Peruzzi, *et al., ibid.* 569.
13. See reference [11] for a good discussion.
14. e.g., see M. R. Jane, *et al.*, Erratum, *Phys. Lett.* **73B** (1978) 503.
15. F. W. Büsser, *et al., Nucl. Phys.* **B113** (1976) 189.
16. G. R. Farrar and S. C. Frautschi, *Phys. Rev. Letters* **36** (1976) 1017. See also, C. O. Escobar, *Nucl. Phys.* **B89** (1975) 174; and E. L. Feinberg, *Nuovo Cimento* **34A** (1976) 391.
17. J. H. Cobb, *et al., Phys. Lett.* **78B** (1978) 519.
18. H. Fritzsch and P. Minkowski, *Phys. Lett.* **69B** (1977) 316.
19. *A Lepton/Photon Spectrometer for RHIC Measurements of Lepton Pairs, Vestor Mesons and Photons*, RLOI-11, G. R. Young, spokesman, Brookhaven National Laboratory, July 17, 1991.

20. *PHENIX Conceptual Design Report*, S. Nagamiya, spokesman, Brookhaven National Laboratory, 29 January 1993. Also see the PHENIX web site `http://www.rhic.bnl.gov/ ~phenix/ physics.html`
21. *Two-Arm, Electron/Photon/Hadron Spectrometer*, RLOI-2, TALES Collaboration, R. S. Hayano, spokesman, Brookhaven National Laboratory, September 27, 1990.
22. O. Botner, *et al., Phys. Lett.* **B236** (1990) 488.
23. Direct muon experiments have similar problems from semi-leptonic decays in flight of $\pi^{\pm}$ and $K^{\pm}$ mesons. e.g., see P. A. Piroue *et al.* in reference [8].
24. Asher Shor, *Proceedings of the Second Workshop on Experiments and Detectors for a Relativistic Heavy Ion Collider*, Berkeley, May 1987, Eds: H.-G. Ritter and A. Shor, LBL-24604, pp 256-278.
25. Y. Akiba, *PHENIX Collaboration Meeting and Theory Workshop*, August 29–September 1, 1994, PHENIX Note PN-137, Brookhaven National Laboratory, Upton, NY (unpublished), 137-Vol.I, last article.
26. Y. Akiba, *Physics with the Collider Detectors at RHIC and the LHC, Proceedings of the Pre-Conference Workshop*, Quark Matter '95, Monterey, CA, Eds: Jim Thomas and Tim Hallman, UCRL-ID-121571, pp 131-142.