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Continuous Monitoring of STAR's Main Time Projection Chamber

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Abstract

STAR refers to the Solenoidal Tracking instrument At RHIC (the Relativistic Heavy Ion Collider). For momenta above 500 MeV/c charged kaons are not separated from pions within STAR's Main TPC (Time Projection Chamber) by track density alone and they are poorly separated below 500 MeV/ c, even when using information from other sources like the vertex tracker. Within the TPC large numbers of kaons and pions decay into muons (and undetected neutrinos). Earlier work has shown parent pions and kaons whose decays are detected within a TPC may be distinguished uniquely from each other in a two-dimensional plot of muon-emission angle versus momentum difference (between each parent meson and its decay muon). Since pions and kaons have zero spin, each muon decay-product emerges isotropically in its parent meson's rest frame. Identification of particle type provides the parent meson's rest mass and, thus, its total energy. This means the measurement of each decay event is kinematically complete. Thus, Lorentz Transformations may be used to transform each component of the decaying muon's laboratory four-momentum into the "rest frame" of its parent meson, where the muon decay is isotropic. An aggregated plot of muon directions from many "parent rest frames" will be isotropic in each (selected) sub-volume of the TPC unless there is a problem within the TPC or in its tracking algorithms. Continuous monitoring of a TPC is possible using this subset of detected charged particles.

Introduction

Previous work using muon decays of pions and kaons (Braithwaite and Braithwaite, 1997b) has shown that by using relativistic kinematics alone (Braithwaite, 1972) parent pions and kaons whose decays are detected within a TPC (Time Projection Chamber) may be distinguished uniquely from each other. This separation is accomplished using a 2-D plot of observables within the TPC: muon-emission angle versus momentum difference (between parent meson and muon). This previous work was predicated on even earlier work (Climer et al., 1996) where mapping STAR's TPC for acceptance and efficiency was suggested using parent kaons. What was missing from this earlier work was a feasibility study of the expected quality of the separation of kaons from the much more prevalent pions using the relativistic kinematics of muon decays.

Uniquely identifying kaons and counting them measures the amount of strangeness production occurring in each central collision between two ultrarelativistic nuclei; kaon production is a direct measure of strangeness production as kaons are singly strange. This method for measuring strangeness production using charged kaon decay complements measurements of neutral kaon decay within a microTPC designed to be the component detector located closest to the collider vertex for ultra-relativistic nucleus-nucleus collisions (Braithwaite and Braithwaite, 1997a).

Despite the importance of measuring strangeness production as one signature of the onset of the Quark Gluon Plasma (Harris and Müller, 1996), the present work concentrates on a new approach to mapping STAR's Main TPC (Sauli, 1987) for acceptance and efficiency as a function of position within the TPC, using both kaons and pions. For each parent meson, the spin = 0 description of the quantum ground state requires the direction of each muon decay to be isotropic in its parent meson's rest frame. As outlined below, this feature of isotropic decay, due to the decaying pions and kaons being spin = 0 mesons, provides a new dimension in the monitoring of STAR's Main TPC.

Materials and Methods

"Kinematic trajectories" for meson decays cluster into

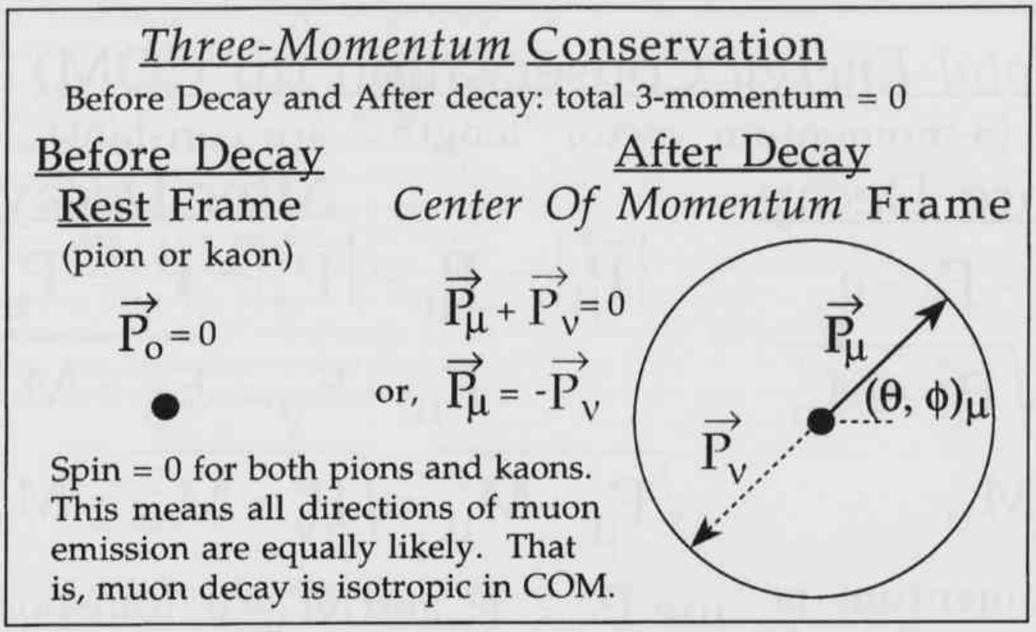

Fig. 1. Both pions and kaons decay isotropically in their respective rest frames. Each muon and unobserved neutrino has an equal but opposite 3 momentum value in the COM (center of momentum) frame, which is also the parent's rest frame.

completely separated 2-D regions of difference-momentum ⊗ muon-angle space, or $\Delta P \equiv |\vec{P}_o - \vec{P}_\mu| \cdot \mathrm{sign}(P_o - P_\mu)$ versus θ_μ, showing kinematic separation is possible between charged kaon decays and charged pion decays. The reason for this complete kinematic separation is the much larger breakup momentum, 235.5 MeV/c in the center of momentum frame, available to each of the binary decay species (muon and neutrino) in the process of $K^\pm \rightarrow \mu^\pm + \nu$ decay. In contrast, a much smaller breakup momentum of 29.8 MeV/c is available in the center of momentum frame to each of the binary decay species (muon and neutrino) in the process of $\pi^\pm \rightarrow \mu^\pm + \nu$ decay.

Identifying which meson is decaying (kaon or pion) determines its rest mass and, thus, its total energy, so each muon decay is kinematically complete. That is, the relativistic 4-momentum (3-momentum, total-energy) is known for each parent meson as well as for its associated muon. This means each muon's 4-momentum may be transformed into the rest frame of its parent (also the μ–ν center-of-momentum frame) using measured kinematic observables (to perform the relevant Lorentz-transformations).

The idea is to aggregate muon directions from rest frames for each type of parent meson for the entire TPC or selected subgroupings. The resulting plot of data points must be isotropic unless there is an acceptance or efficiency problem within the TPC or its subgroupings. This method is also sensitive to any efficiency problem associated with the TPC's tracking algorithms (Howe et al., 1995).

Results and Discussion

Laboratory distributions for isotropic emissions of muons in the COM (Center of Momentum) Frame may be calculated using a known method for assuring spherical symmetry in the COM frame (McCloskey and Braithwaite, 1995). This method uses a triplet of numbers (x, y, z), with each randomly distributed between -1 and +1. Spherical symmetry is assured for this triplet if $x^2 + y^2 + z^2 < 1$. If not, the triplet of numbers is discarded (~48% of the time). If the inequality is satisfied, the randomly oriented position vector is renormalized to 1 and then multiplied by the known length of the muon-momentum in the COM frame as provided in Fig. 2, and each COM momentum is transformed back into the laboratory for each selected value of the parent meson's laboratory 4-momentum.

Probably a better approach is to obtain the distribution for isotropic emissions of muons in the COM Frame and analyze them there rather than comparing the muons' laboratory distribution to their calculated distribution, as transformed back into the laboratory from the COM. This is because an isotropic distribution will be a simpler distribution to analyze using standard methods such as describing the muon yields in the COM using surface-harmonic yield expansions.

Each meson is characterized by zero spin. That is, for each meson, the Quantum Mechanical description is invariant under all rotatations thus assuring each meson decay is

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Total-Energy Conservation (in COM)

(3-momentum vector "lengths" are constant)

Before Decay

$$|\vec{P}_o| = P_o = 0$$

$$E_o = \sqrt{P_o^2 + M_o^2}$$

$$= M_o$$

After Decay

$$|\vec{P}_\mu| = P_\mu = |\vec{P}_\nu| = P_\nu = P_\mu$$

$$E_\mu + E_\nu = E_o = M_o$$

$$\sqrt{P_\mu^2 + M_\mu^2} + \sqrt{P_\nu^2 + M_\nu^2} = M_o$$

μ-momentum is constant "length"

use $P_\nu = P_\mu$ and $M_\nu = 0$, transpose:

$$\sqrt{P_\mu^2 + M_\mu^2} = M_o - P_\mu$$

square both sides:

$$P_\mu = \frac{M_o^2 - M_\mu^2}{2M_o} \Leftarrow \cancel{P_\mu^2} + M_\mu^2 = M_o^2 + \cancel{P_\mu^2} - 2M_oP_\mu$$

Fig. 2. Conservation of total-energy in the COM Frame predicts a constant "length" for the muon's 3-momentum. This 3-momentum vector points with equal probability in all (θ, φ) directions in the COM Frame.

spherically symmetric. Thus each muon decay is isotropic in the rest frame of its parent. Since there is sufficient kinematic information to transform each muon's 4-momentum into its COM frame, the known isotropy of the muon decay may be used to provide additional monitoring information for the TPC, unavailable from any other monitoring method.

Figure 1 shows three-momentum conservation in the COM (Center of Momentum) Frame, which is also the parent meson's rest frame (whether pion or kaon).

Each meson that decays into muons and neutrinos (with neutrinos undetected) does so isotropically in the parent meson's rest frame. This symmetry allows these muon decays to be used for continuous monitoring of acceptance and efficiency of STAR's Main TPC for either or both types of parent mesons (pions and/or kaons).

Since all data are finite and have systematic errors, the impact of these difficulties was examined in the COM using numerically-obtained orthogonality in surface-harmonic yield expansions. Muon yields were aggregated on a symmetric spherical shell surrounding each meson rest frame. Low multipolarity expansion terms were found to be sensitive to forward-backward asymmetries. In contrast, high multipolarity expansion terms show sensitivity to the granular samplings of the spherical harmonics.

Other methods are being explored for measuring and parametrizing any variation from the required isotropy of muon decays (from these spin = 0 mesons). Continuous monitoring of acceptance and efficiency for STAR's Main TPC is possible using this subset of detected charged particles. This feature of isotropic decay, due to the decaying pions and kaons being spin = 0 mesons, makes the present method unique by providing a new dimension in the monitoring of STAR's Main TPC, not available in any other monitoring method.

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Literature Cited

Braithwaite, E.S. and **W.J. Braithwaite.** 1997a. Coplanarity Test for Selecting a Pair of Charged-Particle Tracks Resulting from a Single Neutral-Particle Decay. J. Arkansas Acad. Sci. 51: 32-35.

Braithwaite, W. J. and **E.S. Braithwaite.** 1997b. Separating $K^{\pm}$ from $\pi^{\pm}$ using In-Flight Decays to $\mu^{\pm} + \nu$. J. Arkansas Acad. Sci. 51: 36-40.

Braithwaite, W. J. 1972. Relativistic Kinematics for Two-Body Final States, J. Comp. Phys. Comm. 4: 227-232.

Climer, A.D., I.M. Sakrejda and **W.J. Braithwaite.** 1996. An Acceptance and Efficiency Study for Detection of K^+ and K^- within the Time Projection Chamber of the Solenoidal Tracking Instrument, for Use at the Relativistic Heavy Ion Collider. Abstracts Arkansas Acad. Sci. (80th Annual Meeting): 9.

Harris, J.W. and **B. Muller.** 1996. The Search for the Quark Gluon Plasma. Ann. Rev. Nuclear and Particle Sci. 46: 71-107.

Howe, W.H., C.A. Byrd, A.D. Climer and **W.J. Braithwaite.** 1995. Optimizing Tracking Software for a Time Projection Chamber. Proc. Arkansas Acad. Sci. 49: 75-79.

McCloskey, S.E. and **W.J. Braithwaite.** 1995. An Introduction to Monte Carlo Methods. Proc. Arkansas Acad. Sci. 49: 109-114.

Sauli, F. 1987. The Time Projection Chamber for Heavy-Ion Collisions: Trends and Perspectives. Reprint CERN-EP/87-233 (Invited talk: International Conf. on Ultrarelativistic Nucleus-Nucleus Collisions, Nordkirchen, 24-28 August 1987).