

P and CP-odd fluctuations and New Thermalization Scenario in Heavy Ion Collisions (based on: arxiv- 1008.3598)

Ariel Zhitnitsky

University
of British Columbia,
Vancouver, Canada



The first heavy ion collisions at the LHC-HIC10

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1. MOTIVATION.

- THE MAIN GOAL OF THIS TALK IS TO ARGUE THAT TWO, NAIVELY UNRELATED, PHENOMENA:
- 1. LOCAL P, CP VIOLATING FLUCTUATIONS IN QCD AS OBSERVED AT RHIC
- 2. UNIVERSAL BEHAVIOUR OF MULTIHADRON PRODUCTION IN HIGH ENERGY e^+e^- , $\bar{p}p$, pp , NN COLLISIONS DESCRIBED BY A UNIVERSAL HADRONIZATION TEMPERATURE $T_H \sim 150$ MeV ARE IN FACT TIGHTLY RELATED, AS THEY DESCRIBE DIFFERENT SIDES OF THE SAME FUNDAMENTAL PHYSICS.

2. CHARGE SEPARATION EFFECT. CME.

THE $\theta \frac{\alpha_s}{8\pi} G_{\mu\nu}^a \tilde{G}^{\mu\nu a}$ TERM IS A KEY PLAYER IN STRONGLY INTERACTING QCD

$\theta \frac{\alpha_s}{8\pi} G_{\mu\nu}^a \tilde{G}^{\mu\nu a} = \theta \partial_\mu K^\mu$ IS TOTAL DERIVATIVE, DOES NOT CHANGE THE EQUATION OF MOTION. STILL, IT LEADS TO THE PHYSICALLY OBSERVABLE EFFECTS: DIPOLE MOMENT, $\eta' \rightarrow 2\pi$

$\theta < 10^{-9}$ MUST BE SMALL (NOW) AS IT VIOLATES P, CP INVARIANCE IN STRONG INTERACTIONS.

STILL, A LARGE DOMAIN WITH EFFECTIVE $\theta_{ind} \neq 0$ MAY BE INDUCED AS A RESULT OF NON-EQUILIBRIUM DYNAMICS DURING THE QCD PHASE TRANSITION. IT MAY RESULT IN LOCAL P AND CP ODD FLUCTUATIONS.

- FOR THE UNIFORM MAGNETIC FIELD THE ELECTRIC FIELD WILL BE INDUCED ALONG \mathbf{B} IN THE PRESENCE OF θ

- THE INDUCED ELECTRIC FIELD WILL LEAD TO THE INDUCED CURRENTS AND TO THE SEPARATION OF CHARGES ALONG \mathbf{B} (CME):

$$L^2 E_z^{ind} = - \left(\frac{e \theta}{2\pi} \right) l, \quad \text{where } l = \frac{e}{2\pi} \int d^2 x_{\perp} B_z^{ext}$$

$$\vec{J} = (\mu_L - \mu_R) \frac{e \vec{B}}{2\pi^2}, \quad \text{where } (\mu_L - \mu_R) = \dot{\theta}$$

- A SIMILAR PHENOMENON HAPPENS WHEN THE SYSTEM IS ROTATING (IT EFFECTIVELY REPLACES THE MAGNETIC FIELD \mathbf{B}). THEREFORE: AN UPPER HEMISPHERE CAN THUS HAVE EITHER EXCESS OF QUARKS OVER ANTI-QUARKS OR VICE-VERSA.

$$[Q(z = +L) - Q(z = -L)] \sim \left(\frac{e \theta}{2\pi} \right) l$$

- D. Kharzeev and A. Zhitnitsky, 2007; D. E. Kharzeev, L. D. McLerran, H. J. Warringa, 2007; K. Fukushima, D. E. Kharzeev and H. J. Warringa, 2008;

3. UNIVERSAL HADRONIZATION TEMPERATURE

- HADRON PRODUCTION STUDIES IN A VARIETY OF HIGH ENERGY COLLISION EXPERIMENTS HAVE SHOWN A REMARKABLY UNIVERSAL FEATURE, INDICATING A UNIVERSAL HADRONIZATION TEMPERATURE $T_H \sim (150 - 200) \text{ MeV}$
- IT IS VERY DIFFICULT TO UNDERSTAND ITS NATURE AS THE STATISTICAL THERMALIZATION IN e^+e^- ANNIHILATION AS WELL AS IN pp AND $\bar{p}p$ COULD NEVER BE REACHED IN THOSE SYSTEMS.
- WE ADOPT THE CONJECTURE THAT THIS "APPARENT THERMALIZATION" ORIGINATES FROM THE EVENT HORIZON IN AN ACCELERATING FRAME: THE INCIDENT HADRON DECELERATES IN AN EXTERNAL COLOUR FIELD, WHICH CAUSES THE EMERGENCE OF THE CAUSAL HORIZON. QUANTUM TUNNELLING THROUGH THIS EVENT HORIZON THEN PRODUCES A THERMAL FINAL STATE OF PARTONS, SIMILAR TO THERMAL CHARACTER OF UNRUH RADIATION.

■ **EARLY PAPERS ON THE SUBJECT (TREATING THE “THERMALIZATION” AS THE UNRUH EFFECT):** A. Salam and J. Strathdee, 1977; S. Barshay and W. Troost, 1978 ; A. Hosoya, 1979 ; M. Horibe (1979).

■ **THE MODERN, QCD BASED FORMULATION OF THIS IDEA HAS BEEN DEVELOPED QUITE RECENTLY:** D. Kharzeev and K. Tuchin, 2005; D. Kharzeev, E. Levin and K. Tuchin, 2007; P. Castorina, D. Kharzeev and H. Satz, 2007.

■ **THE KEY INGREDIENT OF THIS APPROACH IS AS FOLLOWS: AN OBSERVER MOVING WITH AN ACCELERATION “A” EXPERIENCES THE INFLUENCE OF A THERMAL BATH WITH AN EFFECTIVE TEMPERATURE EXPRESSED IN TERMS OF THE STRING TENSION:**

$$T = \frac{a}{2\pi}, \quad a \simeq \sqrt{2\pi\sigma}, \quad a \sim 1 \text{ GeV}$$

■ **IT EXPLAINS A NUMBER OF PUZZLES, E.G. THE UNIVERSALITY OF THE TEMPERATURE, AS IT DOES NOT DEPEND ON THE PROCESSES, NOR ON THE ENERGY OF COLLIDING PARTICLES.**

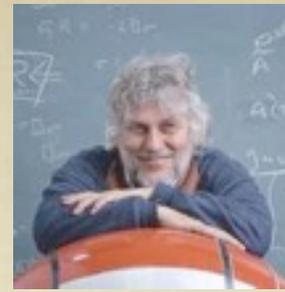
■ **OUR VIEW: THE REASON FOR THE UNIVERSALITY IS THE COMPLETE RECONSTRUCTION OF THE QCD VACUUM STATE IN ACCELERATING FRAME. THIS IS ONLY A TECHNICAL ELEMENT IN COMPARISON WITH KHARZEEV & CO APPROACH. HOWEVER, IT WILL PLAY A CRUCIAL ROLE IN ANALYSIS OF P, CP-ODD FLUCTUATIONS WHEN NO CLASSICAL TRAJECTORIES OF REAL PROPAGATING PARTICLES EXIST.**

■ **ONE CAN EXPLICITLY COMPUTE THE BOGOLUBOV'S COEFFICIENTS AND DEMONSTRATE THAT ALL THE EXCITATIONS HAVE THE THERMAL SPECTRUM.**

■ **THIS RESULT WILL BE OUR BASIC EXPLANATION FOR THE THERMAL SPECTRUM OBSERVED IN ALL HIGH ENERGY COLLISIONS WHEN THE STATISTICAL THERMALIZATION (DUE TO THE CONVENTIONAL COLLISIONS) CAN NOT BE EVER REACHED IN THOSE SYSTEMS. IN ADDITION: THE P, CP-ODD FLUCTUATIONS WILL BE PART OF THIS GENERIC PICTURE.**

4. ACCELERATING SYSTEM.

THE UNRUH EFFECT, $T \neq 0$



- THE MINKOWSKI SEPARATION (OF POSITIVE FREQUENCY MODES FROM NEGATIVE ONES) IS MAINTAINED THROUGHOUT THE WHOLE SPACE AS A CONSEQUENCE OF POINCARÉ INVARIANCE.
- A TRANSITION FROM A COMPLETE ORTHONORMAL SET OF MODES TO DIFFERENT ONE (THE SO-CALLED BOGOLUBOV'S TRANSFORMATIONS) IN ACCELERATING SYSTEM WILL ALWAYS MIX POSITIVE FREQUENCY MODES WITH NEGATIVE FREQUENCY ONES.
- AS A RESULT OF THIS MIXTURE, THE VACUUM STATE DEFINED BY A PARTICULAR CHOICE OF THE ANNIHILATION OPERATORS WILL BE FILLED WITH PARTICLES IN A DIFFERENT SYSTEM (THE UNRUH EFFECT).

THE RINDLER METRIC DESCRIBES A CONSTANTLY ACCELERATING SYSTEM WHEN L(R)-OBSERVERS DO NOT EVER HAVE ACCESS TO THE ENTIRE SPACE-TIME

$$ds^2 = e^{2a\xi}(d\eta^2 - d\xi^2), \quad t = \frac{e^{a\xi^R}}{a} \sinh a\eta^R, \quad x = \frac{e^{a\xi^R}}{a} \cosh a\eta^R$$

BOGOLUBOV'S COEFFICIENTS ARE KNOWN EXACTLY FOR THIS CASE (MIXING THE POSITIVE AND NEGATIVE MODES), WHICH ALLOWS TO REPRESENT THE MINKOWSKI VACUUM AS A NONTRIVIAL "SQUEEZED STATE"

$$|0_M\rangle = \prod_k \frac{1}{\sqrt{(1 - e^{-2\pi\omega/a})}} \exp \left[e^{-\pi\omega/a} b_k^{R\dagger} b_{-k}^{L\dagger} \right] |0^R\rangle \otimes |0^L\rangle,$$

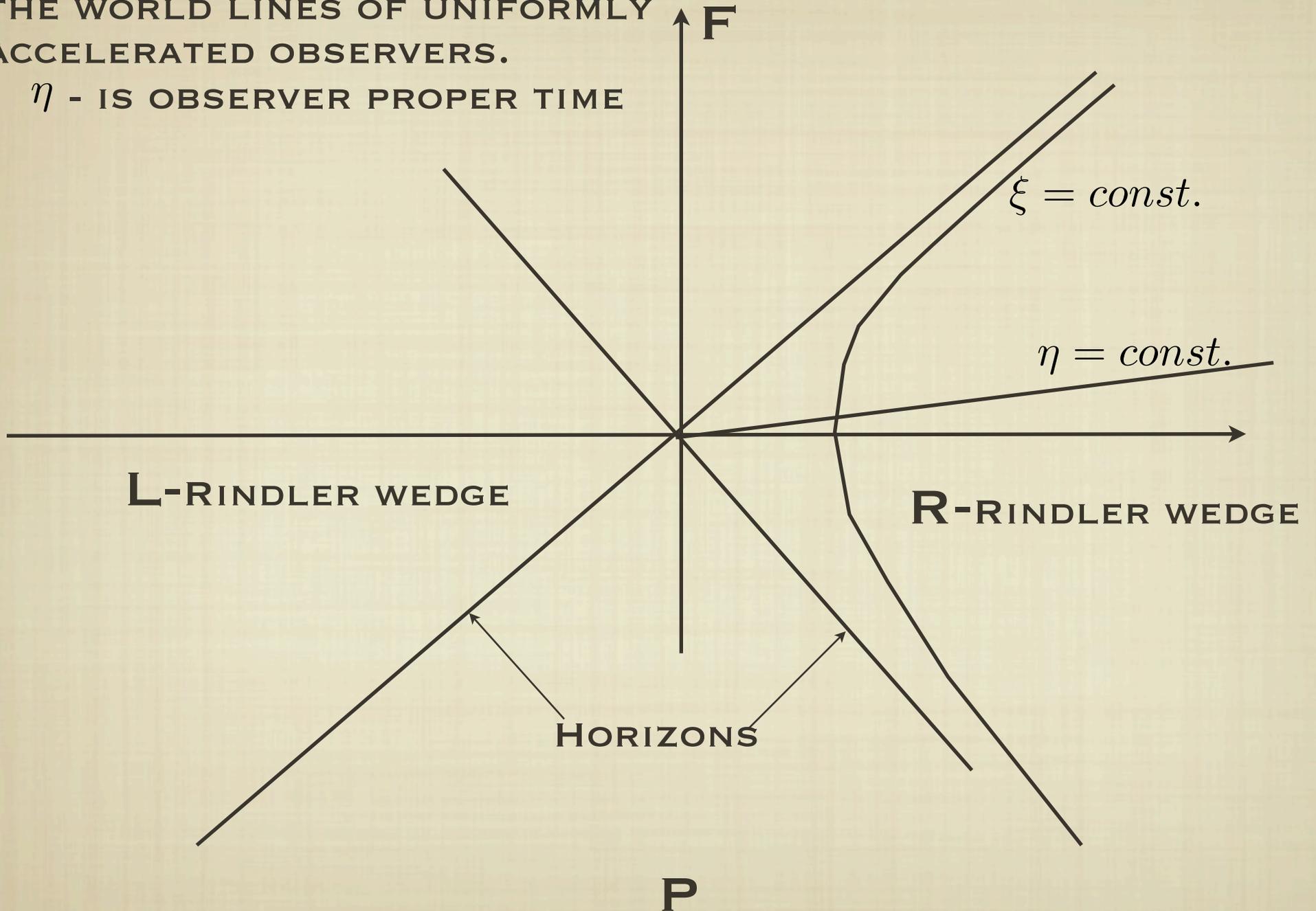
NUMBER OF PARTICLES IN MODE "K" IS DETERMINED BY THE BOGOLUBOV'S COEFFICIENTS

$$\langle 0_M | N^R | 0_M \rangle = \frac{1}{(e^{2\pi\omega/a} - 1)},$$

THE PLANCK SPECTRUM OBSERVED IN HIGH ENERGY COLLISIONS IS INTERPRETED AS A RESULT OF PREPARATION OF THE GROUND STATE $|0_M\rangle$. IT EXPLAINS THE PUZZLE WITH RAPID "THERMALIZATION" OBSERVED IN ALL SYSTEMS

$\xi = const.$ CORRESPONDS TO
THE WORLD LINES OF UNIFORMLY
ACCELERATED OBSERVERS.

η - IS OBSERVER PROPER TIME



5. ANOTHER θ -RELATED CONNECTION...

- THE θ DEPENDENCE IN QCD DETERMINES THE η' MASS (WITTEN, VENEZIANO, 1979)

$$L = \frac{1}{2} \partial_\mu \eta' \partial^\mu \eta' - \frac{1}{\chi} Q^2 - \left(\theta - \frac{\eta'}{f_{\eta'}} \right) Q + N_f m_q | \langle \bar{q}q \rangle | \cos \left[\frac{\eta'}{f_{\eta'}} \right]$$

$$Q \equiv \frac{\alpha_s}{8\pi} G_{\mu\nu}^a \tilde{G}^{\mu\nu a}, \quad \chi = -\frac{\partial^2 \epsilon_{vac}(\theta)}{\partial \theta^2} = i \int d^4x \langle T\{Q(x), Q(0)\} \rangle$$

- THE TOPOLOGICAL SUSCEPTIBILITY $\chi \neq 0$ DOES NOT VANISH IN SPITE OF THE FACT THAT OPERATOR Q IS TOTAL DERIVATIVE
- SIGN OF $\chi < 0$ IS NEGATIVE (IT IS OPPOSITE TO WHAT ONE SHOULD EXPECT FROM A PHYSICAL DEGREE OF FREEDOM)-- SO THE TERM “THE VENEZIANO GHOST”
- INTEGRATING OUT Q FIELD PRODUCES η' MASS WITH NO ANY TRACES OF MASSLESS (UNPHYSICAL) GHOSTS.

Technical reason for ghost to emerge in the system:

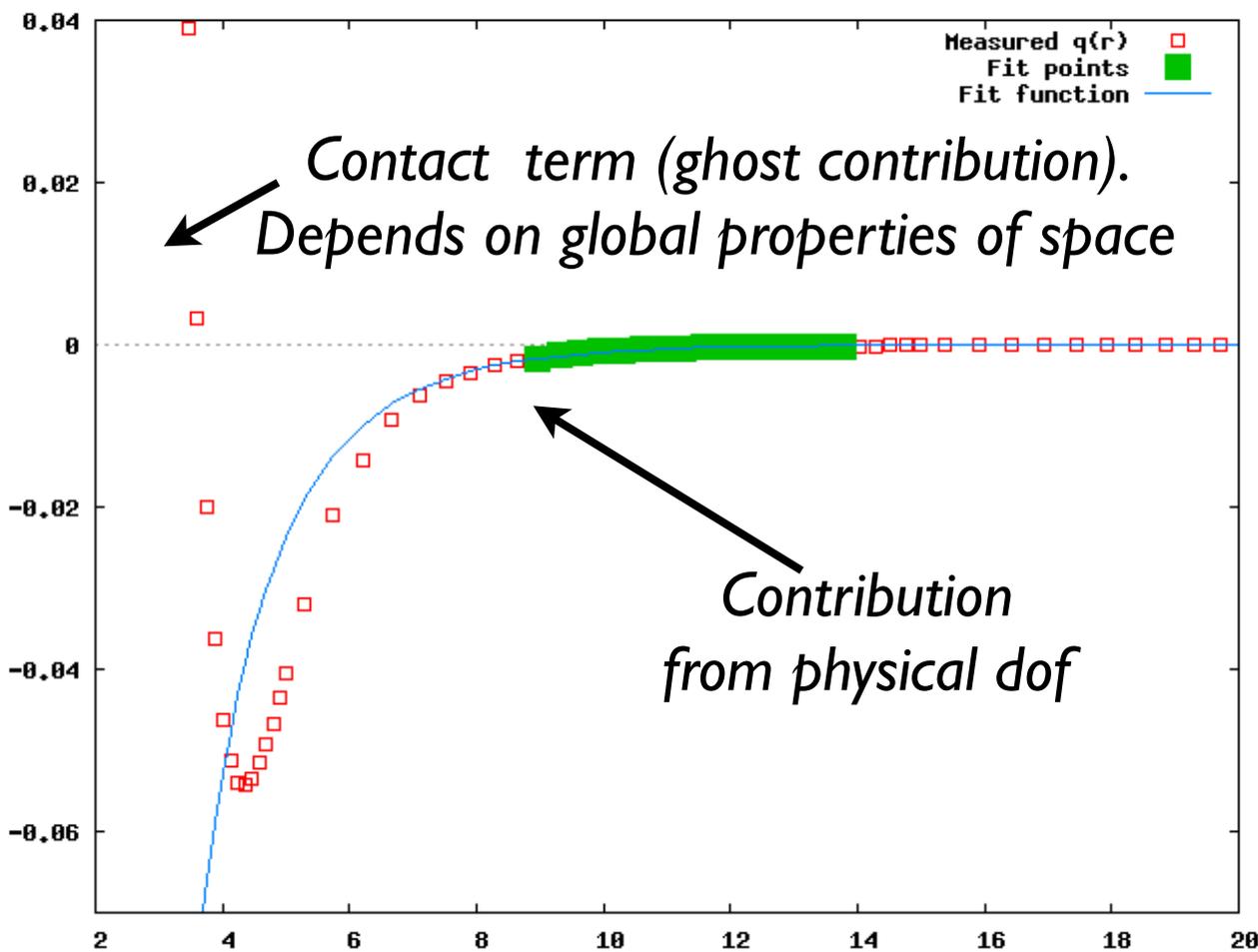
■ THE LONGITUDINAL PART OF THE TOPOLOGICAL DENSITY OPERATOR SATURATES THE TOPOLOGICAL SUSCEPTIBILITY

$$Q = \frac{g^2}{64\pi^2} \epsilon_{\mu\nu\rho\sigma} G^{a\mu\nu} G^{a\rho\sigma} = \partial_\mu K^\mu = \square\Phi, \quad K_\mu \equiv \partial_\mu \Phi$$

■ THE INDUCED (VENEZIANO) TERM IN THE LAGRANGIAN IS A 4-DERIVATIVE OPERATOR $Q^2 \sim (\square\Phi)^2$. IT PLAYS A KEY ROLE IN THE RESOLUTION OF THE $U(1)_A$ PROBLEM.

■ THE INDUCED 4-DERIVATIVE OPERATOR SIGNALS THAT THE GHOST (VENEZIANO GHOST) MUST BE IN THE SYSTEM:

$$\frac{m_{\eta'}^2}{\square\square + m_{\eta'}^2\square} = \left(\frac{1}{-\square - m_{\eta'}^2} - \frac{1}{-\square} \right).$$



The topological susceptibility $\chi(r)$ as a function of r . Wrong sign for $\chi(r \rightarrow 0) \sim \delta(r)$ is well established phenomenon; it has been tested on the lattice (plot above is from C. Bernard et al, LATTICE 2007). This contribution is not related to any physical degrees of freedom, and can be interpreted as a contact term (Witten, 79) or as the ghost contribution (Veneziano, 79). It is related to necessity to sum over different k -topological sectors of the theory.

■ THIS IS THE OLD AND WELL-KNOWN STORY WHEN THE THEORY IS FORMULATED IN INFINITE MINKOWSKI SPACE.

■ WHAT WOULD HAPPEN TO THE VENEZIANO GHOST IF THE SYSTEM IS ACCELERATING WITH RATE “A” ?

■ THE VENEZIANO GHOST IS TOPOLOGICALLY PROTECTED AND SENSITIVE TO THE BOUNDARY, HORIZON AND OTHER GLOBAL CHARACTERISTICS OF THE SYSTEM. THEREFORE: WE SHOULD BE VERY CAREFUL WITH “INTEGRATING OUT” PROCEDURE WHICH HAS BEEN USED IN MINKOWSKI SPACE.

■ WE WILL FIND AN EXTRA CONTRIBUTION IN ACCELERATING FRAME. THIS EXTRA ENERGY IS ORIGINATED FROM THE (P-ODD) Q-FIELD SENSITIVE TO THE GLOBAL PROPERTIES OF SPACE. THESE P-ODD FLUCTUATIONS MAY HAVE LARGE SIZE. THE LARGE P-ODD DOMAINS WILL PLAY A KEY ROLE IN ANALYSIS OF P-ODD CORRELATIONS FOUND AT RHIC.

6. THE VENEZIANO GHOST IN 4D. T=0

CAREFUL ANALYSIS: NO INTEGRATING OUT.

ONE CAN EXPLICITLY DEMONSTRATE THAT THE LOW ENERGY LAGRANGIAN FOR U(1)_A DEGREES OF FREEDOM IN 4D QCD IS IDENTICAL TO THE 2D QED, INCLUDING θ TERM AND KS GHOST (KOGUT- SUSSKIND, 1975) .

$$\begin{aligned}
 \mathcal{L} = & \frac{1}{2} \partial_\mu \eta' \partial^\mu \eta' + \frac{1}{2} \overset{\text{Veneziano ghost's partner}}{\partial_\mu \phi_2 \partial^\mu \phi_2} - \frac{1}{2} \partial_\mu \phi_1 \overset{\text{Veneziano ghost}}{\partial^\mu \phi_1} \\
 & - \frac{1}{2} m_{\eta'}^2 \eta'^2 + m_q | \langle \bar{q} q \rangle | \cos \left[\theta + \frac{\eta' + \phi_2 - \phi_1}{f_{\eta'}} \right]
 \end{aligned}$$

THE VENEZIANO GHOST IS INTRODUCED TO ACCOUNT FOR THE “WRONG” SIGN IN χ . IT GIVES THE SAME PHYSICS AS THE WITTEN’S CONTACT TERM AND PROVIDES THE η' MASS.

THE NEGATIVE SIGN IN THE LAGRANGIAN DOES NOT LEAD TO ANY PROBLEMS (UNITARITY, CAUSALITY...) WHEN AUXILIARY (SIMILAR TO GUPTA-BLEULER IN QED) CONDITIONS ON THE PHYSICAL HILBERT SPACE ARE IMPOSED:

$$(Gubta - Bleuler \text{ in } QED) : \quad (\partial_\mu A^\mu)^+ |\mathcal{H}_{\text{phys}}\rangle = 0;$$

$$(\phi_2 - \phi_1)^{(+)} |\mathcal{H}_{\text{phys}}\rangle = 0. \quad \underline{\text{positive frequency part enters this condition!}}$$

THE HAMILTONIAN HAS SIGN MINUS FOR THE GHOST. HOWEVER, THE EXPECTATION VALUE FOR ANY PHYSICAL STATE VANISHES AS A RESULT OF GB CONDITION,

$$H = \sum_k \omega_k (b_k^\dagger b_k - a_k^\dagger a_k). \quad \langle \mathcal{H}_{\text{phys}} | H | \mathcal{H}_{\text{phys}} \rangle = 0.$$

IT IS SIMILAR TO WHAT HAPPENS IN QED WHEN TWO UNPHYSICAL PHOTON'S POLARIZATIONS CANCEL EACH OTHER AS A RESULT OF GUPTA-BLEULER CONDITIONS.

I USE THE VENEZIANO (RATHER THAN THE WITTEN'S) APPROACH AS IT CAN BE EASILY GENERALIZED FOR A TIME DEPENDENT, CURVED BACKGROUND (FINITE MANIFOLD).

7. VENEZIANO GHOST IN RINDLER SPACE $T \neq 0$

■ WE TREAT ACCELERATION “A” AS A FREE PARAMETER IN ORDER TO SEPARATE TOPOLOGICAL FLUCTUATIONS OF SIZE $\sim 1/A$ FROM CONVENTIONAL QCD FLUCTUATIONS \sim FM.

$$1 \text{ GeV} \gg a \gg m_q$$

■ IN THIS LIMIT THE PROBLEM IS REDUCED TO THE PREVIOUSLY STUDIED CASE WHEN THE BOGOLUBOV’S COEFFICIENTS ARE EXACTLY KNOWN.

■ THE CANCELLATION BETWEEN THE VENEZIANO GHOST AND ITS PARTNER DOES NOT HOLD FOR THE ACCELERATING RINDLER OBSERVER (IN CONTRAST WITH MINKOWSKI).

$$\langle 0 | \omega_k \left(b_k^{(R,L)\dagger} b_k^{(R,L)} - a_k^{(R,L)\dagger} a_k^{(R,L)} \right) | 0 \rangle = \frac{2\omega}{(e^{2\pi\omega/a} - 1)}.$$

Technical reason for non-cancellation:

■ THE GROUND STATE FOR MINKOWSKI OBSERVER IS DEFINED AS USUAL

$$a_k |0\rangle = 0, \quad b_k |0\rangle = 0, \quad \forall k.$$

■ THE VACUUM FOR R-RINDLER OBSERVER IS DEFINED AS

$$a_k^L |0_R\rangle = 0, \quad a_k^R |0_R\rangle = 0, \quad b_k^L |0_R\rangle = 0, \quad b_k^R |0_R\rangle = 0, \quad \forall k.$$

■ THE BOGOLUBOV'S COEFFICIENTS ARE KNOWN TO MIX POSITIVE AND NEGATIVE FREQUENCY MODES:

$$a_k^L = \frac{e^{-\pi\omega/2a} a_{-k}^{1\dagger} + e^{\pi\omega/2a} a_k^2}{\sqrt{e^{\pi\omega/a} - e^{-\pi\omega/a}}}$$

$$b_k^L = \frac{e^{-\pi\omega/2a} b_{-k}^{1\dagger} + e^{\pi\omega/2a} b_k^2}{\sqrt{e^{\pi\omega/a} - e^{-\pi\omega/a}}}$$

$$a_k^R = \frac{e^{-\pi\omega/2a} a_{-k}^{2\dagger} + e^{\pi\omega/2a} a_k^1}{\sqrt{e^{\pi\omega/a} - e^{-\pi\omega/a}}}$$

$$b_k^R = \frac{e^{-\pi\omega/2a} b_{-k}^{2\dagger} + e^{\pi\omega/2a} b_k^1}{\sqrt{e^{\pi\omega/a} - e^{-\pi\omega/a}}}.$$

8. VENEZIANO GHOST IN ACCELERATING SYSTEM. INTERPRETATION, $T \neq 0$

- NO CANCELLATION BETWEEN THE VENEZIANO GHOST AND ITS PARTNER COULD OCCUR AS A RESULT OF OPPOSITE SIGN (-) IN COMMUTATION RELATIONS AND NEGATIVE SIGN (-) IN HAMILTONIAN.
- THE CANCELLATION FAIL TO HOLD FOR THE ACCELERATING RINDLER OBSERVER BECAUSE THE PROPERTIES OF THE OPERATOR WHICH SELECTS THE POSITIVE FREQUENCY MODES WITH RESPECT TO η MINKOWSKI TIME t AND OBSERVER'S PROPER TIME ARE NOT EQUIVALENT.
- VENEZIANO GHOST DOES FLUCTUATE, BUT IT DOES NOT PROPAGATE TO INFINITY. IT IS NOT AN ASYMPTOTIC STATE

■ WE INTERPRET THE EXTRA CONTRIBUTION TO THE ENERGY OBSERVED BY AN ACCELERATING OBSERVER AS A RESULT OF FORMATION OF THE SQUEEZED STATE WHICH CAN BE COINED AS THE “GHOST CONDENSATE” SIZE $2\pi/a$ (WILL BE IDENTIFIED WITH P-ODD DOMAINS) RATHER THAN A PRESENCE OF “FREE PARTICLES” AT $T = a/2\pi$ PREPARED IN A SPECIFIC MIXED, RATHER THAN PURE QUANTUM STATE,

$$|0\rangle = \prod_k \frac{1}{\sqrt{(1 - e^{-2\pi\omega/a})}} \exp \left[e^{-\pi\omega/a} \left(b_k^{R\dagger} b_{-k}^{L\dagger} - a_{-k}^{R\dagger} a_k^{L\dagger} \right) \right] |0^R\rangle \otimes |0^L\rangle$$

■ WE INTERPRET THE GHOST CONTRIBUTION TO THE ENERGY AS A CONVENIENT WAY TO ACCOUNT FOR TOPOLOGICALLY NONTRIVIAL SECTORS OF THE THEORY IN ACCELERATING FRAME.

■ IT IS POSSIBLE THAT THE SAME PHYSICS, IN PRINCIPLE, CAN BE DESCRIBED WITHOUT THE GHOSTS (SUCH A DESCRIPTION IS NOT PRESENTLY KNOWN, AND LIKELY WILL BE MUCH MORE TECHNICALLY COMPLICATED).

9. APPLICATIONS TO P ODD FLUCTUATIONS OBSERVED AT RHIC. BASIC PICTURE.

■ THE CONVENTIONAL QUARK AND GLUON FLUCTUATIONS WITH FM-SCALE ARE PROPAGATING IN THE ENVIRONMENT OF VERY SLOW TOPOLOGICAL FLUCTUATIONS WITH WAVELENGTHS $2\pi/a$, $a \ll 1 \text{ GeV}$.

■ THESE SLOW TOPOLOGICAL FLUCTUATIONS CARRY 0^{-+} QUANTUM NUMBERS AND CAN BE THOUGHT AS LARGE P-ODD DOMAINS FOR CONVENTIONAL FAST FLUCTUATIONS (ANALOGOUS TO $\dot{\theta}_{ind} \sim a$ DISCUSSED PREVIOUSLY).

■ FAST FLUCTUATIONS PROVIDE THE EXPECTED PLANCK SPECTRUM WITH TEMPERATURE "T". THE ONLY NEW ELEMENT OF THIS WORK: THE FAST FLUCTUATIONS ARE FORMED IN THE P-ODD ENVIRONMENT EFFECTIVELY DESCRIBED BY SLOW FLUCTUATING "GHOST CONDENSATE" WITH 0^{-+} QUANTUM NUMBERS.

10. DIRECT CONSEQUENCES OF THIS BASIC PICTURE. THE UNIVERSALITY.

■ 1. P AND CP ODD FLUCTUATIONS ARE PRESENT IN ANY ACCELERATING SYSTEM WHEN THE THERMAL ASPECTS HAVE BEEN ALREADY OBSERVED (INCLUDING e^+e^- , pp , $p\bar{p}$)

■ HOWEVER, “ a ” FOR POINT-LIKE PARTICLES IS LARGE \sim GEV
---> P-ODD EFFECTS ARE SUPPRESSED.

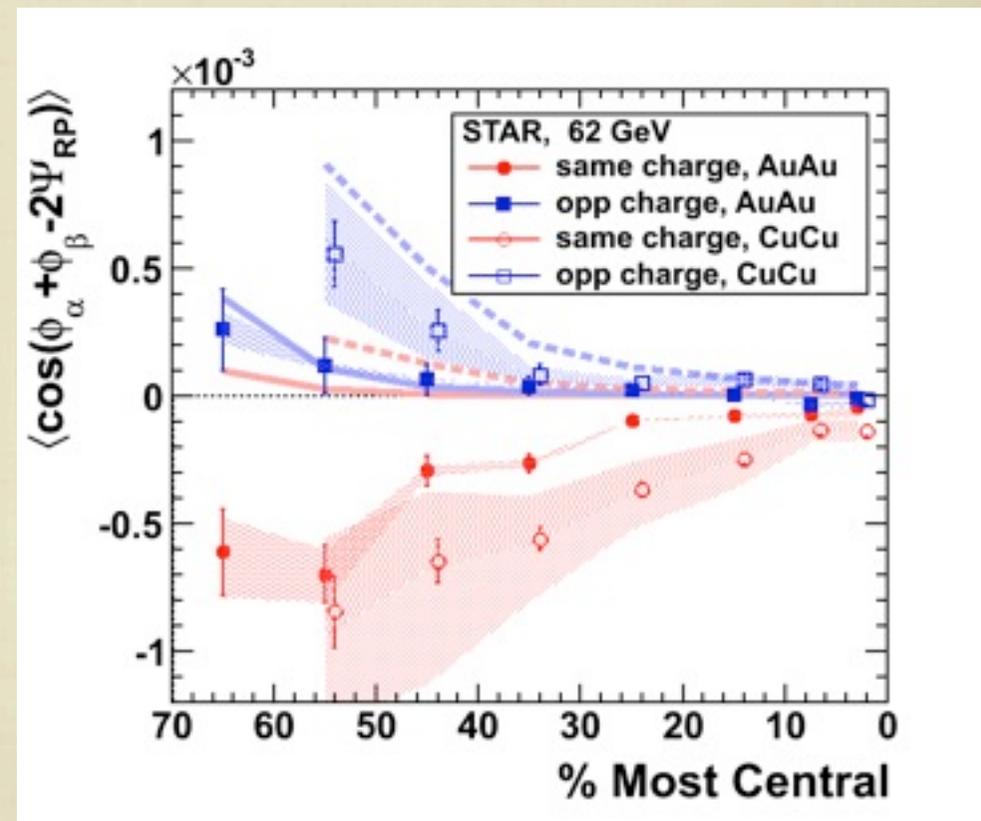
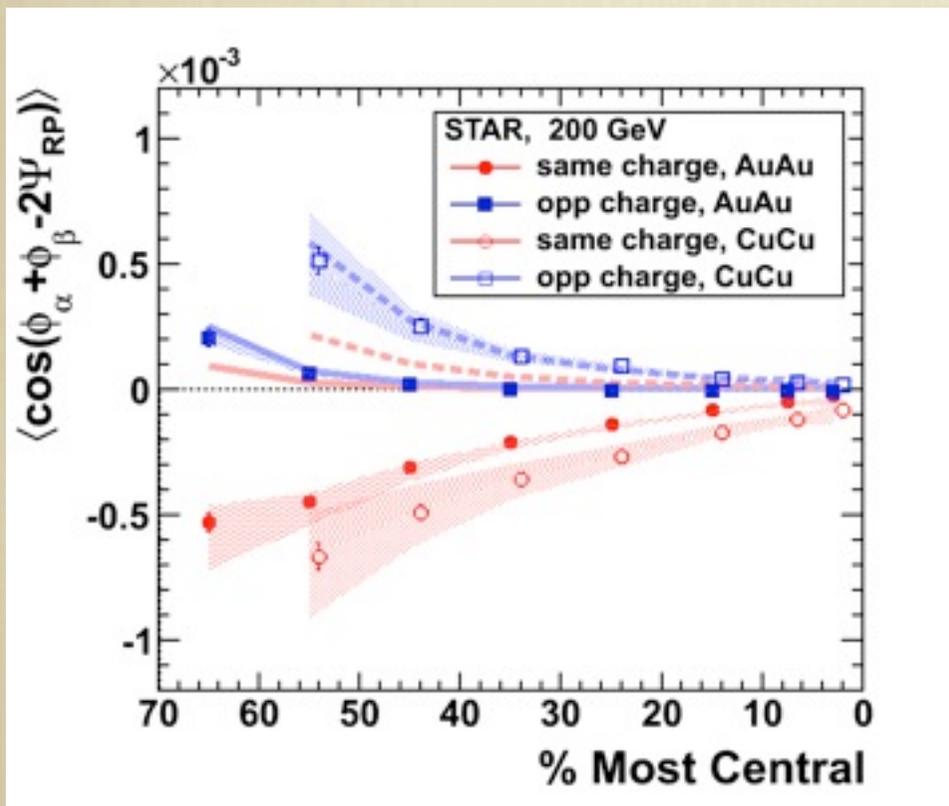
IF “ a ” BECOMES SMALL ---> P-ODD EFFECTS BECOME LARGE

■ HEAVY ION COLLISIONS ARE UNIQUE AS “ a ” DEPENDS ON CENTRALITY, DIMA&Co, 2007. WE CAN VARY “ a ” !

$$a(J) \simeq a_{J=0} (1 - cJ^2), \quad c > 0,$$

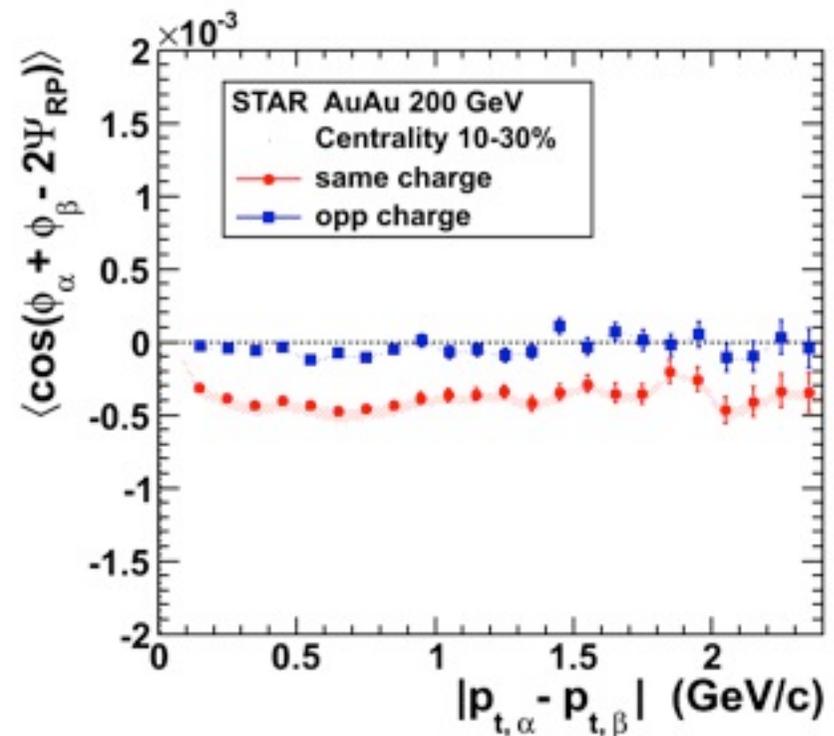
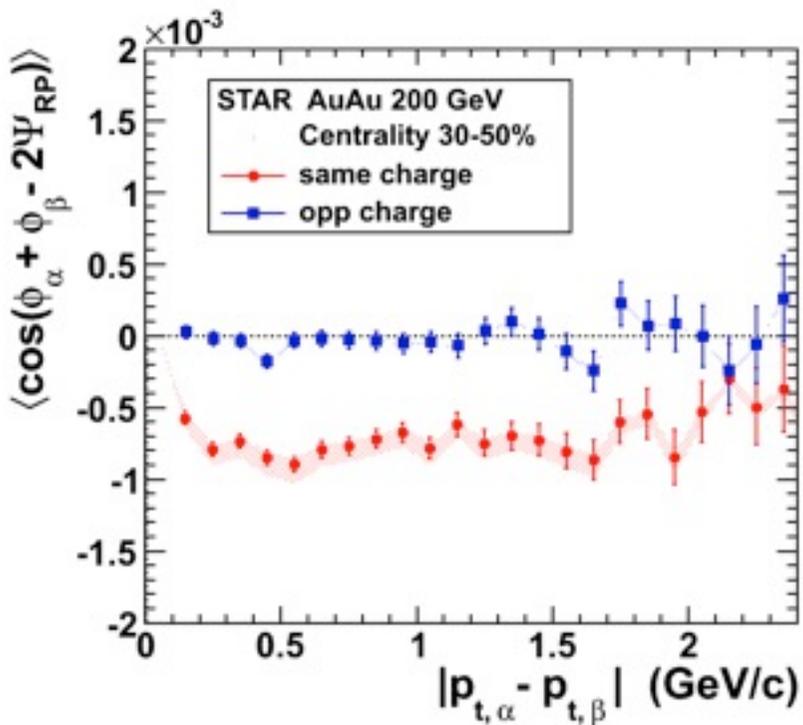
■ SENSITIVITY ON “ a ” IS EXPONENTIAL: SLIGHT REDUCTION OF “ a ” MAY PRODUCE DRASTIC CHANGES IN CORRELATIONS.

THE CORRELATIONS SHOULD DEMONSTRATE THE UNIVERSAL BEHAVIOUR SIMILAR TO THE UNIVERSALITY OBSERVED IN ALL HIGH ENERGY COLLISIONS. IN PARTICULAR, THE CORRELATIONS SHOULD NOT DEPEND ON ENERGY OF COLLIDING IONS IN IDEAL WORLD (WHEN $a \ll 1$ AND THE P-ODD DOMAINS ARE VERY LARGE IN SIZE).



THE PLOTS INDEED DEMONSTRATE THE UNIVERSALITY IN BEHAVIOUR FOR AU+AU, CU+CU FOR 200 AND 62 GEV.

THE ARGUMENTS ON UNIVERSALITY OF THE CORRELATION STRENGTH DO NOT DEPEND ON TRANSVERSE MOMENTA EVEN FOR LARGE $k_{\perp} > 1$ GeV. THIS PREDICTION OF THE UNIVERSALITY SHOULD BE CONTRASTED WITH “NAIVE” ARGUMENTS SUGGESTING SOME PREFERENCES FOR SMALL k_{\perp} . THE UNIVERSALITY ARGUMENTS ARE ALSO CONSISTENT WITH OBSERVATIONS.



1 1. P ODD EFFECTS:

RHIC vs CMB

THERE IS A DEEP RELATION BETWEEN P ODD EFFECTS AT RHIC AT $a^{-1} \sim \text{fm}$ AND P -ODD PHENOMENA STUDIED IN COSMIC MICROWAVE BACKGROUND (CMB) AT $H^{-1} \sim \text{Gpc}$

THE CRUCIAL ELEMENT RELATING THESE TWO DRASTICALLY DIFFERENT SCALES IS THE UNIQUE FEATURE OF THE VENEZIANO GHOST WHICH IS PROTECTED BY TOPOLOGY: THE VENEZIANO GHOST IS REPRESENTED BY A SPECIFIC COHERENT COLOUR- SINGLET CONFIGURATION OF GLUON FIELD SENSITIVE TO THE HORIZON/BOUNDARY.

ALL LOCAL P VIOLATION EFFECTS ARE: $\theta_{ind} \sim H/\Lambda_{QCD} \sim 10^{-41}$ (VERY SMALL). HOWEVER, IF THE PROCESS TAKES A LONG TIME $\sim 1/H$ (AS IN CASE OF CMB), THE EFFECT COULD BE ORDER OF ONE.

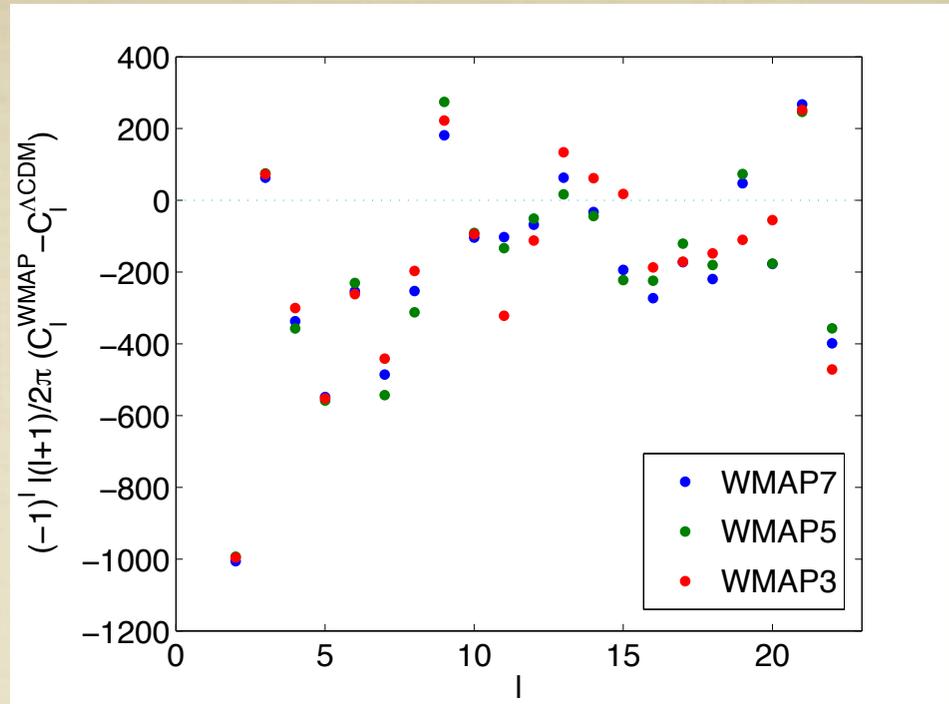
P PARITY ASYMMETRY OF WMAP POWER SPECTRUM:

$$\vec{x}' = -\vec{x},$$

$$\vec{x}' = \vec{x} - 2\vec{n}(\vec{x} \cdot \vec{n})$$

REFLECTION SYMMETRY

MIRROR SYMMETRY



PLOT INDICATES: THERE EXISTS POWER DEFICIT (EXCESS) AT MOST EVEN (ODD) MULTIPOLES AS IT IS WEIGHTED WITH $(-1)^l l(l+1)$. IT SHOULD BE CONSISTENT WITH “O” IF THE UNIVERSE IS P EVEN.

100+ PAPERS ON ASYMMETRY WITH TYPICAL TITLES: “ IS THE UNIVERSE ODD?”, “ ANOMALOUS PARITY ASYMMETRY...” ETC (THE PLOT IS FROM PAPER BY NASELSKY ET AL, 2010)

■ THE UNIVERSE CORRESPONDS TO A SINGLE LARGE P ODD DOMAIN PRODUCED IN HEAVY ION COLLISIONS AT THE SMALLEST POSSIBLE CENTRALITIES WHEN A TYPICAL SIZE OF THE DOMAIN $2\pi/a$ GREATLY EXCEEDS ALL TYPICAL SCALES OF CONVENTIONAL QCD FLUCTUATIONS \sim FM.

■ IN EXPANDING UNIVERSE THERE IS NO LUXURY (AVAILABLE TO RHIC) TO AVERAGE OVER MANY EVENTS, AS WE CAN ONLY STUDY A SINGLE EVENT OF CREATION.

■ THE CORRESPONDING STUDY FOR P VIOLATION IN CMB HAS BEEN PERFORMED FOR A NUMBER OF YEARS IN A NUMBER OF PAPERS, SEE PLOT AS AN ILLUSTRATION

1 1. FUTURE DIRECTIONS

- CONNECTION BETWEEN THE ACCELERATION “ a ” AND FAMILIAR PARAMETERS (CENTRALITY, ENERGY, ETC). IT WOULD ALLOW US TO TEST THE UNIVERSALITY.
- P-ODD CORRELATIONS IN OTHER HIGH ENERGY COLLISIONS. WHAT WOULD BE APPROPRIATE OBSERVABLE?
- TESTING THE VENEZIANO GHOST ON THE LATTICE. CASIMIR LIKE EFFECTS ARE PREDICTED FOR 4D QCD: $1/L$ instead e^{-L} . PRELIMINARY POSITIVE CONFIRMATION (M. POLIKARPOV)
- PROFOUND CONSEQUENCES FOR THE EXPANDING UNIVERSE