Holographic History of the CME

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EXCELENCIA SEVERO OCHOA

Karl Landsteiner

Holographic Perspectives on chiral transport and spin dynamics,
ECT, Trento, 24.03.2025*

Holographic History of the CME

“The universe came into being with a BIG BANG”

“Experimental Search for the Chiral Magnetic Effect in Relativistic Heavy-Ion Collisions: A Perspective”, Feng, Voloshin, Wang, arXiv:2502.09742

1) Big Bang
2) Electroweak symmetry breaking (Baryogensis ?)
3) QGP phase with approx. chiral symmetry (CME ?)
4) Hadronization
5) …
6) Workshop at ECT*

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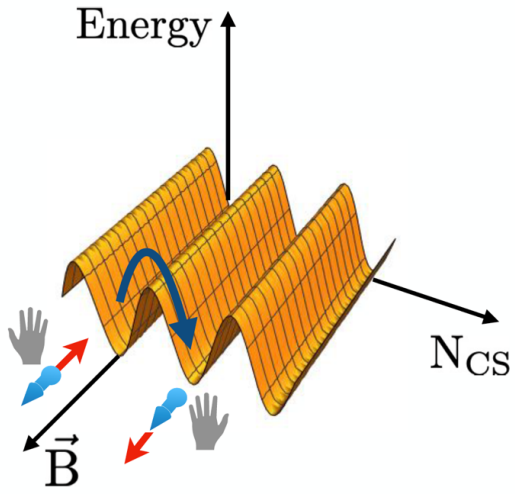
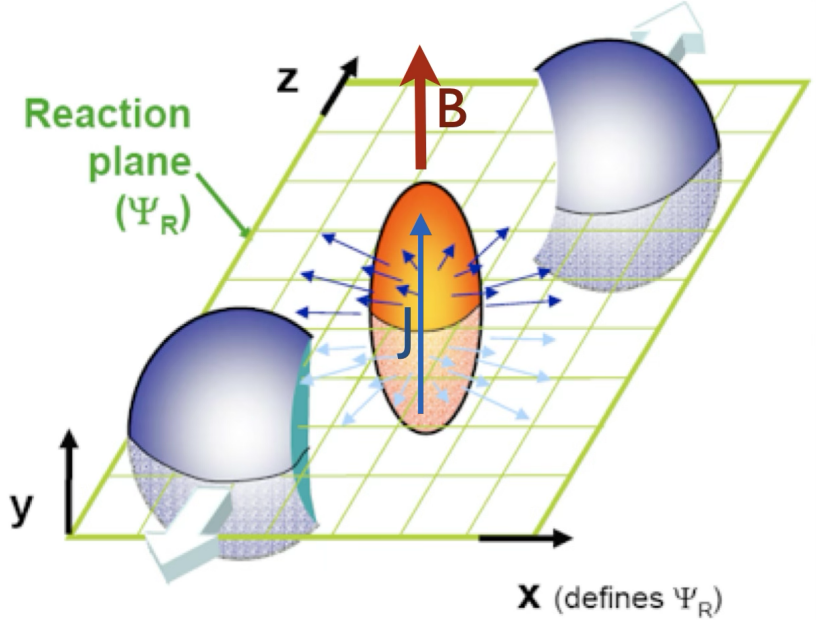


$$\partial_\mu J_5^\mu = \frac{g^2 N_f}{16\pi^2}(G_{\mu\nu}\tilde{G}^{\mu\nu})$$



$$\vec{J} = \frac{\mu_5}{2\pi^2}\vec{B}$$

McLerran, Kharazeev, Warringa] 2008
[Fukushima, Kharazeev, Warringa] 2008

- Analogy to electroweak baryogenesis!
- Sacharov conditions!

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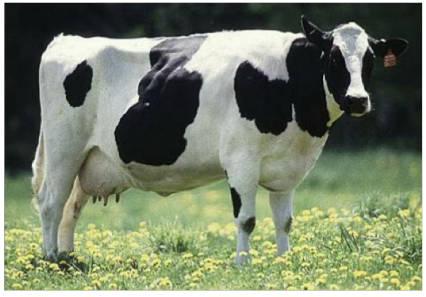
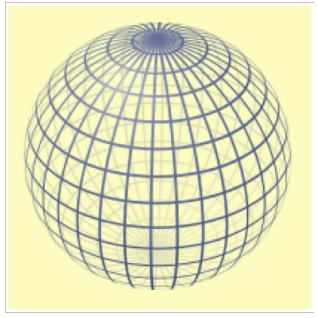
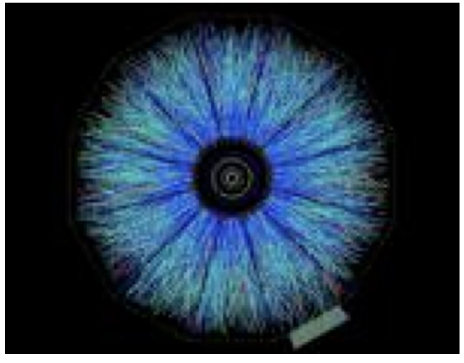
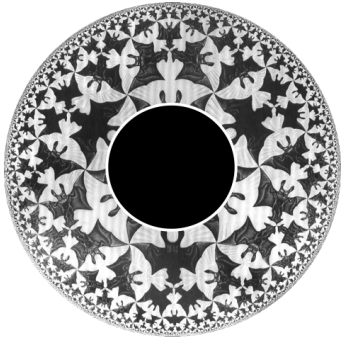
Great! But what is Holography good for in this story?









"AdS is the hyperbolic cow of sQGP"

$$\frac{\eta}{s} = \frac{1}{4\pi}$$

Son, Starinets, Policastro , Kovtun ...

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Anomalies are better than that:

$$\vec{J} = \frac{\mu\mu_5}{2\pi^2}\vec{\Omega}$$ [Erdmenger, Haack, Kaminski,Yarom] [Benerjee,Bhattacharya^2,Dutta,Loga,Surowka]

- Fluid-gravity correspondence
- Experts on hydro: impossible because not in Landau-Lifschytz

$$\vec{J} = \frac{\mu_5 - A_5^0}{2\pi^2}\vec{B}$$ [Rebhan, Schmitt, Stricker] [Gynther, K.L., Pena-Benitez, Rebhan]

- Strict equilibrium: $H - \mu_5 Q_5$

$$A_5^0 = \mu_5 \qquad \vec{J} = 0$$

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- Chiral Magnetic and Vortical effects

$$\vec{J}_A = d_{ABC}\frac{\mu_B}{4\pi^2}\vec{B}_C + \left(d_{ABC}\frac{\mu_B\mu_C}{4\pi^2} + b_A\frac{T^2}{12}\right)\vec{\Omega}$$

$$\vec{J}_\epsilon = \left(d_{ABC}\frac{\mu_B\mu_C}{8\pi^2} + b_A\frac{T^2}{24}\right)\vec{B}_A + \left(d_{ABC}\frac{\mu_A\mu_B\mu_C}{6\pi^2} + b_A\frac{\mu_A T^2}{6}\right)\vec{\Omega}$$

Anomalies: $$\nabla_\mu J^\mu_a = \frac{d_{abc}}{16\pi^2}F^a_{\mu\nu}\tilde{F}^{\mu\nu}_a + \frac{b_a}{348\pi^2}R^{ab}_{\mu\nu}\tilde{R}^{\mu\nu}_{ab}$$

Hydrodynamics: [Son, Surowka], [Neiman,Oz]

Holography: [K.L., Megias, Melgar, Pena-Benitez]

Geometry: [Jensen, Loga, Yarom], [Kim, Stone]

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Pre-History:

- [Vilenkin ‘79, ‘80] killed by Nobel prize winner
- [Alekseev, Chaianov, Fröhlich] cond-mat
- [Giovannini, Shaposhnikov] astro-particle physics
- [Son, Zhitnitsky],[Metlitski, Zhitnitsky],[Kharzeev, Zhitnitsky] CVE
- [Newman] first holographic paper on CME

Worth some PhD in the sociology of science?

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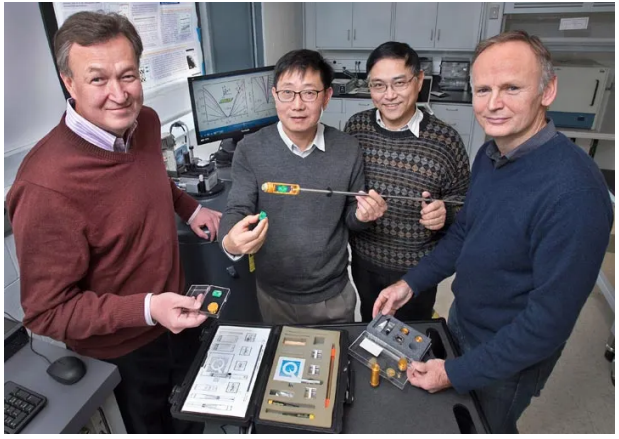
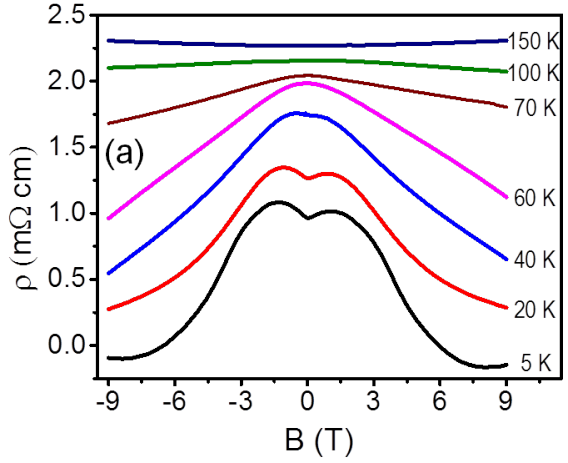
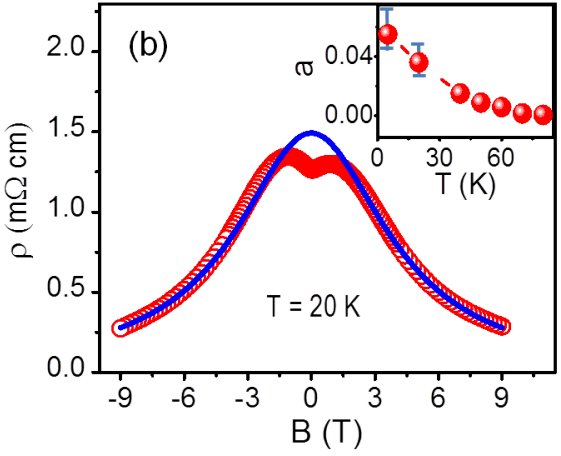
So far for theory, but what about the real world?

Weyl (Dirac) semi-metals:







[Q. Li, D. Kharzeev et al.]

Difficulty: “Current jetting”

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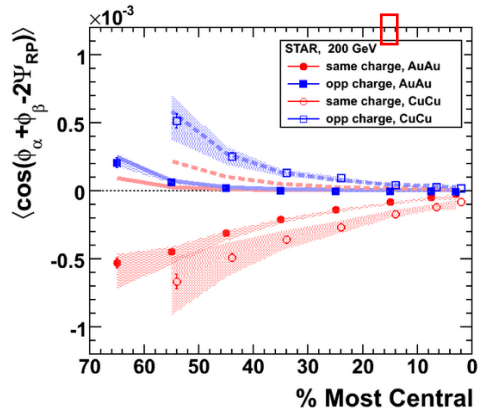
So far for theory, but what about the real world?

Quark Gluon Plasma: $$\frac{dN_\pm}{d\phi} \propto 1 + 2v_1\cos(\phi-\psi_{\rm RP}) + 2v_2\cos 2(\phi-\psi_{\rm RP}) + \cdots$$
$$+ 2a_{1\pm}\sin(\phi_\pm-\psi_{\rm RP}) + \cdots .$$

Parity odd parts: $\langle a_{1,\pm}\rangle = 0$ $\langle a_{1,+}a_{1,+}\rangle = -\langle a_{1,+}a_{1,-}\rangle$

γ-correlator: $\Delta\gamma = \gamma_{OS} - \gamma_{SS}$



Abelev et al.]

Problem: mixes with parity even background

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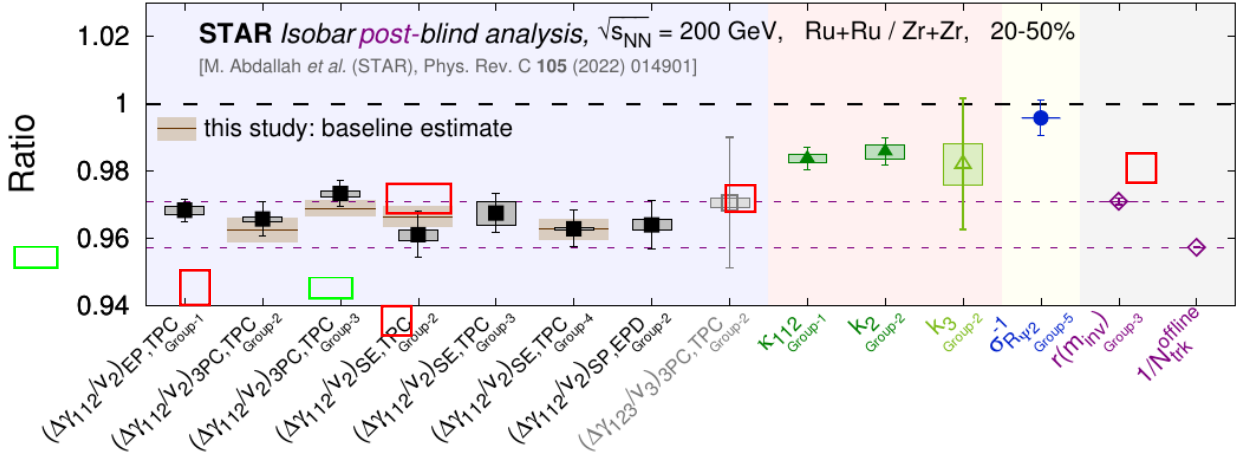
Remove background: Isobar run $^{96}_{44}\mathrm{Ru}+^{96}_{44}\mathrm{Ru}$ and $^{96}_{40}\mathrm{Zr}+^{96}_{40}\mathrm{Zr}$

Ru 10% more charge , more CME, nuclear physics the same



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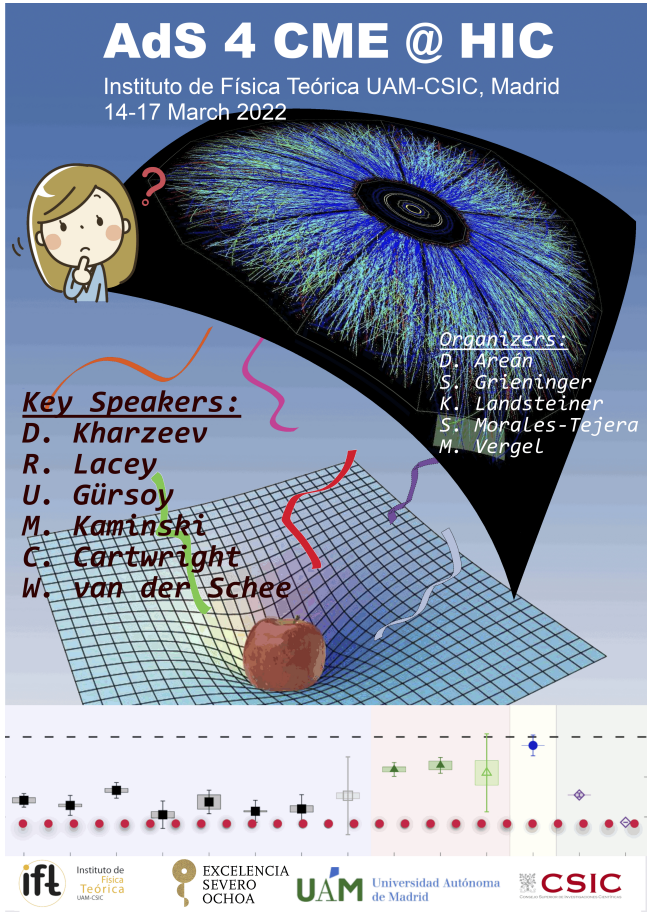
AdS4CME initiative:

https://ads4cme.wixsite.com/ads4cme

Poster of Kickoff meeting at IFT



Holographic History of the CME

Nuclear Theory

[Submitted on 2 Aug 2016 (v1), last revised 12 Aug 2016 (this version, v2)]

Chiral Magnetic Effect Task Force Report

Vladimir Skokov, Paul Sorensen, Volker Koch, Soeren Schlichting, Jim Thomas, Sergei Voloshin, Gang Wang, Ho-Ung Yee

II. THEORY UNCERTAINTIES

A) the initial distribution of axial charges,

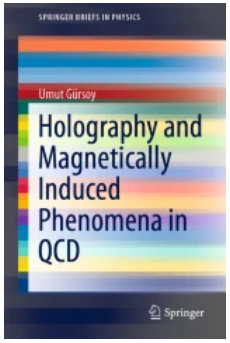
B) the evolution of the magnetic field,

C) the dynamics of the CME during the pre-equilibrium stage,

D) the uncertainties in the hadronic phase and the freeze-out.

Tasks for Holography?

Holographic History of the CME



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Hydrodynamic magneto-transport in holographic charge density wave states

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THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Theoretical Physics

Vortical waves in a quantum fluid with vector, axial, and helical charges. I. Non-dissipative transport

Sergio Morales-Tejera[1,a], Victor E. Ambruș[1,b], Maxim N. Chernodub[1,2,c]
[1] Department of Physics, West University of Timișoara, Bd. Vasile Pârvan 4, 300223 Timișoara, Romania
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8 out of 61 authors invited
All accepted
4 had to cancel because of lack of funding

Precarious situation for fundamental science?

PROCEEDINGS OF SCIENCE
Volume 438 - 11th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions (HardProbes2023) - Early time dynamics and nuclear PDFs

Early time dynamics far from equilibrium via holography

M. Kaminski*, C. Cartwright, M. Knipfer, M.F. Wondrak, B. Schenke and M. Bleicher

Full text: pdf
Published on: February 16, 2024

Abstract
We investigate the early time dynamics of heavy ion collisions studying the time evolution of the energy-momentum tensor as well as energy-momentum correlations within a uniformly thermalizing holographic

PHYSICAL REVIEW D **108,** 126004 (2023)

Spacetime dynamics of chiral magnetic currents in a hot non-Abelian plasma

Sebastian Grieninger[1,*] and Dmitri E. Kharzeev[1,2,†]
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[2] *Department of Physics, Brookhaven National Laboratory Upton, New York 11973-5000, USA*

Chiral Magnetic Effect enhancement at lower collision energies

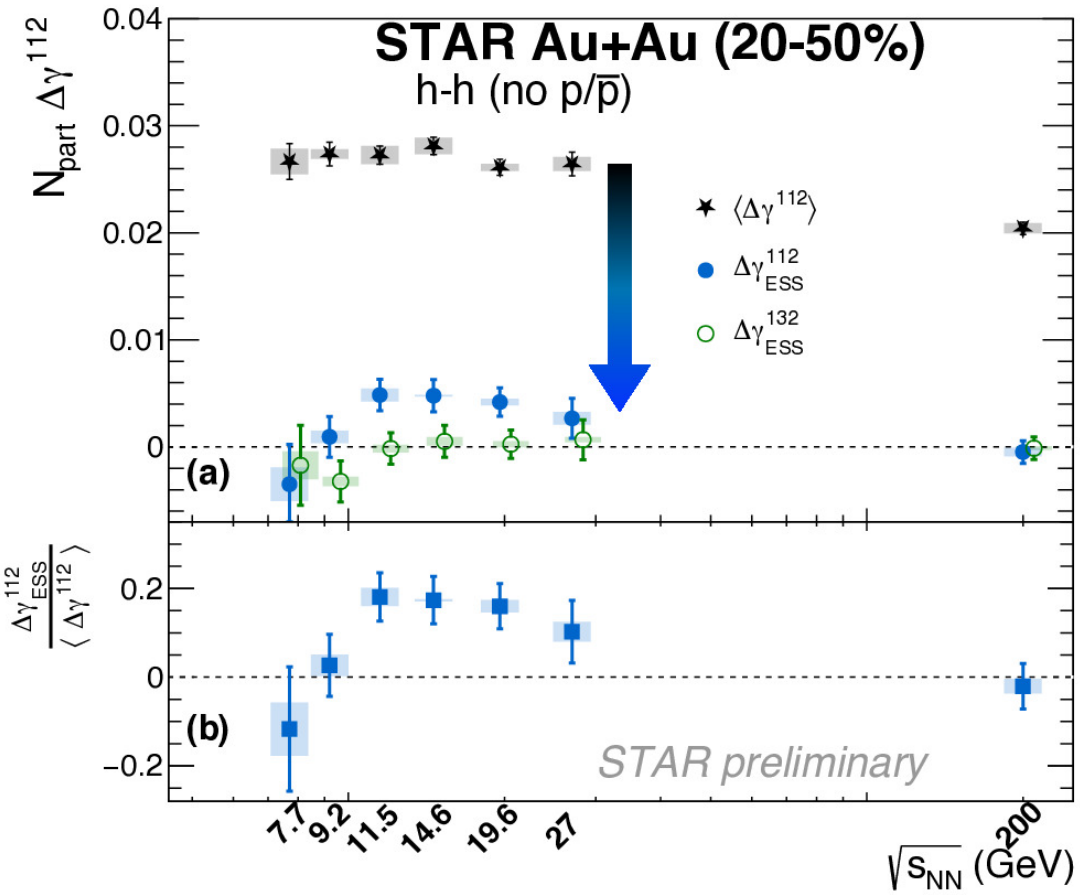
Sebastian Grieninger,[1,*] Sergio Morales-Tejera,[2,†] and Pau G. Romeu[3,4,‡]

Nuclear Theory
[Submitted on 21 Dec 2024]

Strongly interacting matter in extreme magnetic fields

Prabal Adhikari, Martin Ammon, Sidney S. Avancini, Alejandro Ayala, Aritra Bandyopadhyay, David Blaschke, Fabio L. Braghin, Pavel Buividovich, Rafael P. Cardoso, Casey Cartwright, Jorge David Castaño-Yepes, Maxim Chernodub, M. Coppola, Mayusree Das, Mariana Dutra, Gergely Endrődi, Jianjun Fang, Ricardo L. S. Farias, Eduardo S. Fraga, Arthur Frazon, Kenji Fukushima, Juan D. García-Muñoz, Eduardo Garnacho-Velasco, D. Gomez Dumm, Sebastian Grieninger, Francesca Gulminelli, Juan Hernandez, Chowdhury Aminul Islam, Matthias Kaminski, Andrey Kotov, Gastão Krein, Jing Li, Pok Man Lo, Marcelo Loewe, Odilon Lourenço, Gergely Markó, Kau D. Marquez, Ana Mizher, Banibrata Mukhopadhyay, Enrique Muñoz, S. Noguera, Rodrigo M. Nunes, Helena Pais, Letícia F. Palhares, Constança Providência, Alfredo Raya, Tulio Restrepo, Juan Cristóbal Rojas, N.N. Scoccola, Luigi Scurto, Armen Sedrakian, Dominik Smith, William Rafael Tavares, Maria E. Tejeda-Yeomans, Varese S. Timóteo, Laura Tolos, Cristian Villavicencio, Fridolin Weber, Shigehiro Yasui, Renato Zamora, Zenia Zuraiq

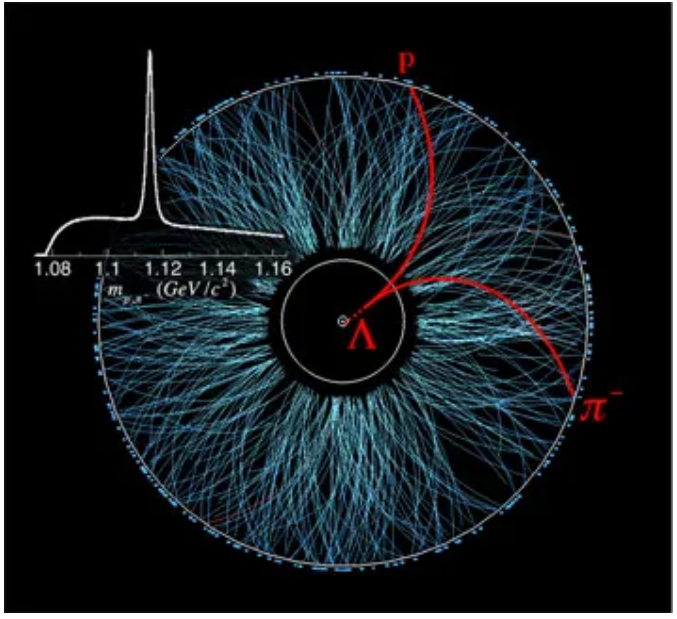
Beam Energy Dependence of CME observable



- BKG-indicator $\Delta\gamma^{132}_{ESS}$ consistent with zero
- At least 80% of $\langle\Delta\gamma^{112}\rangle$ is from the background.
- At 200 GeV, ratio is (-2 ± 5.1 ± 1.6)%
  - upper limit of fCME~10% in Au+Au
  - upper limit of fCME~ 5% in isobars using participant planes: 0.7% difference, too small to detect
- Combine three points at 19.6, 14.6 and 11.5 GeV, the literal average of the ESS results reaches an over 5σ significance (assuming similar physics conditions between 10 and 20 GeV).
- The ESS results approach zero around 9.2 and 7.7 GeV.

Holographic History of the CME

sQGP is also the most vortical liquid: spin polarization!



My personal take: theory is scary!

- Spin (relativistic?)
- Spincurrent
- Spin connection
- Torsion (is “trivial”)
- Pseudo gauge transformatoins
- Role of CVE? $J_5^\mu = \epsilon^{\mu\nu\rho\lambda} J^{\rm Spin}_{\nu\rho\lambda}$

Holographic History of the CME

This years workshop:

Spin Polarization

Anomalies

Driven Systems

Vorticity

Holographic QCD

Hydrodynamics

Chiral Magnetic Effect

Kinetic Theory

Magnetic Fields

Fluctuations

Quasinormal Modes

Holographic Transport

Looking forward to a great workshop!