Quark matter 2017 @ Chicago

Chiral magnetic effect in isobaric collisions

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Outline

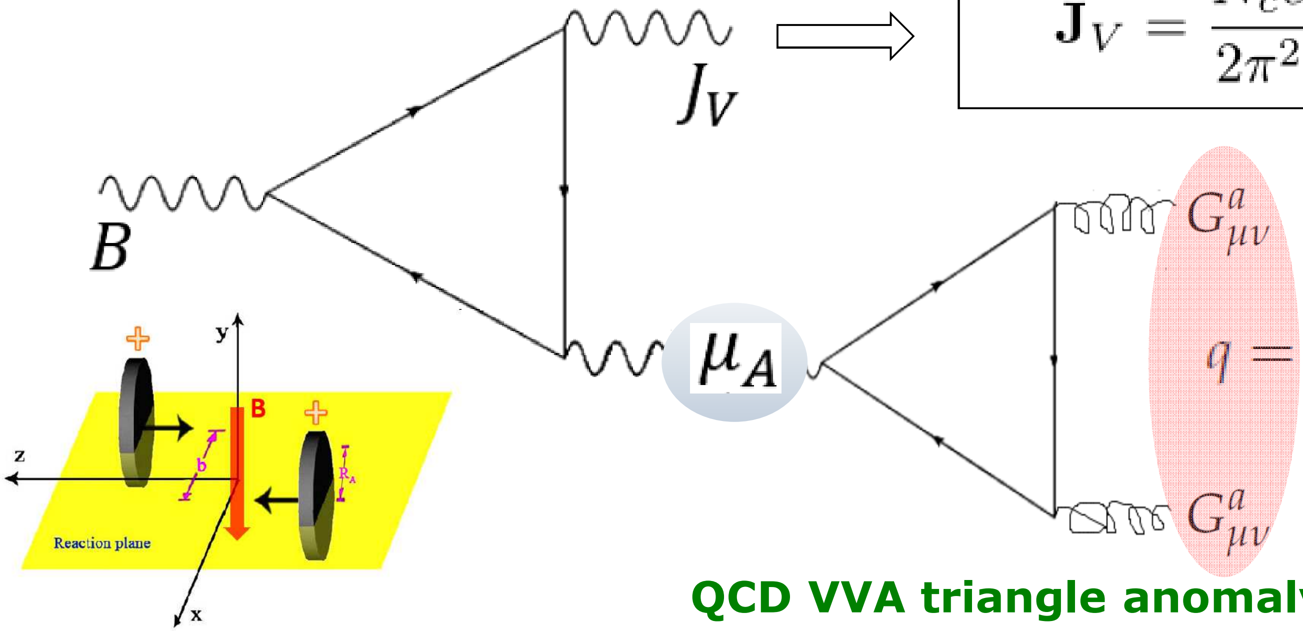
- **Introduction:** **chiral magnetic effect (CME) and its experimental observables**
- **Isobaric collisions:** **a promising way to disentangle CME and background contributions in experimental observables**
- **Summary**

Introduction

Chiral magnetic effect

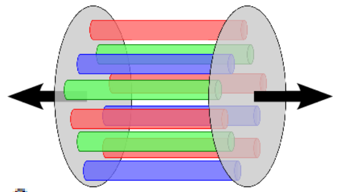
A probe of nontrivial topology of QCD using B field

QED VVA triangle anomaly

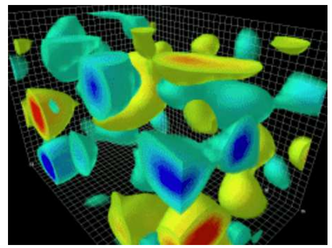


Chiral magnetic effect (CME)

$$\mathbf{J}_V = \frac{N_c e}{2\pi^2}\mu_A \mathbf{B}$$



$$q = \frac{g^2}{32\pi^2}\int d^4x G^a_{\mu\nu}\tilde{G}^{\mu\nu}_a$$



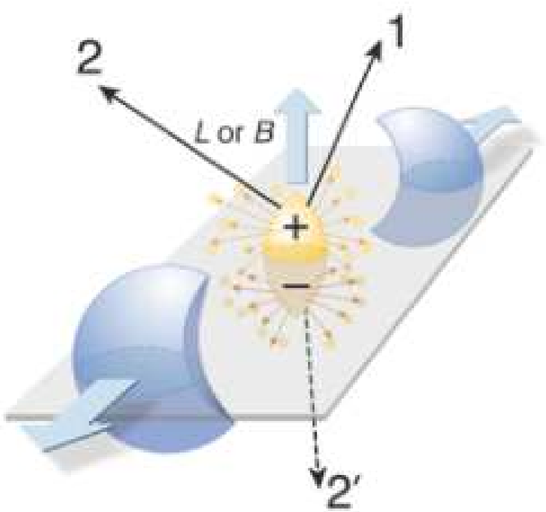
QCD VVA triangle anomaly

- **P- and CP-odd transport**
- **Time-reversal even, no dissipation**
- **Fixed by anomaly coefficient, universal**

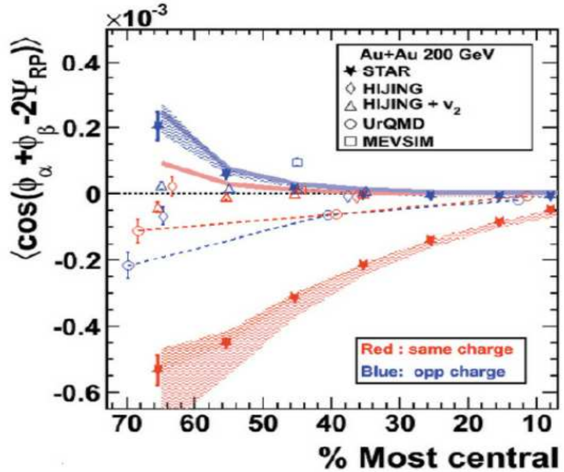
Kharzeev 2004, Kharzeev, Warringa, McLarren, Fukushima 2008 … …

Chiral magnetic effect

Event-by-event charge separation wrt. reaction plane

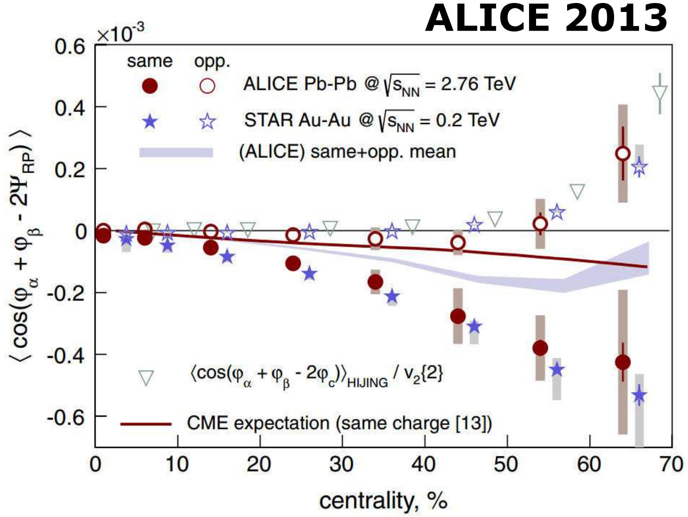


The observable:
The gamma correlator (Voloshin 2004)

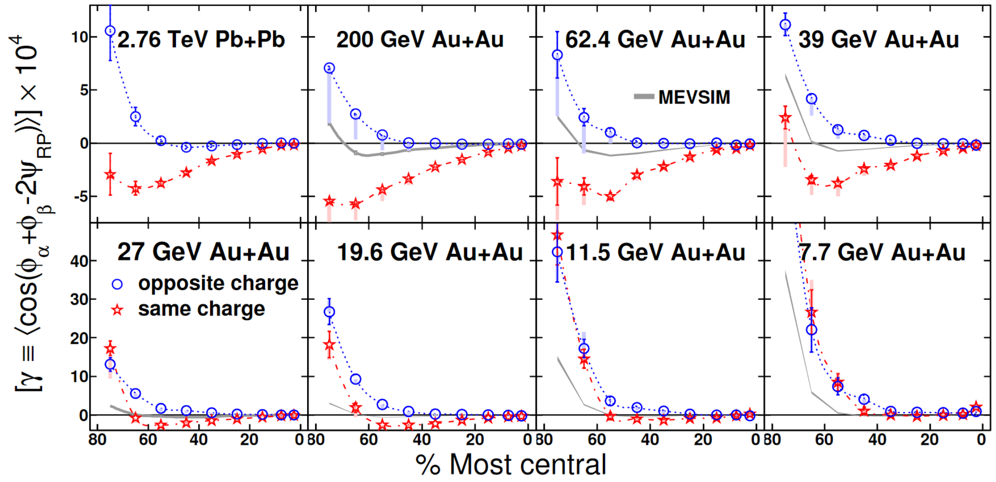


STAR 2009

ALICE 2013



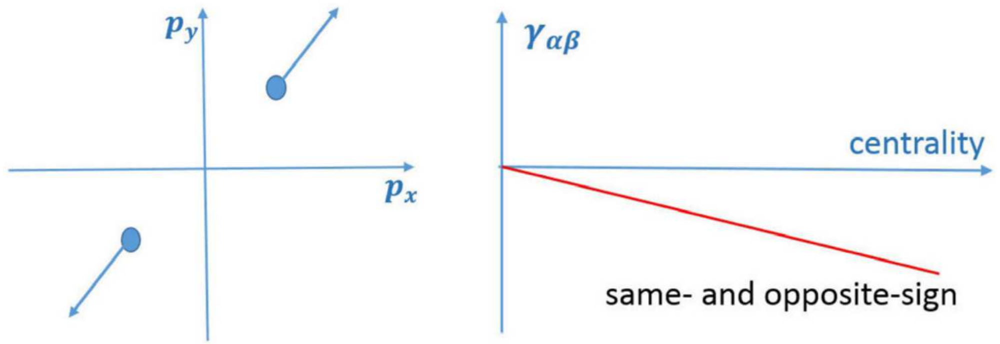
STAR 2014



Chiral magnetic effect

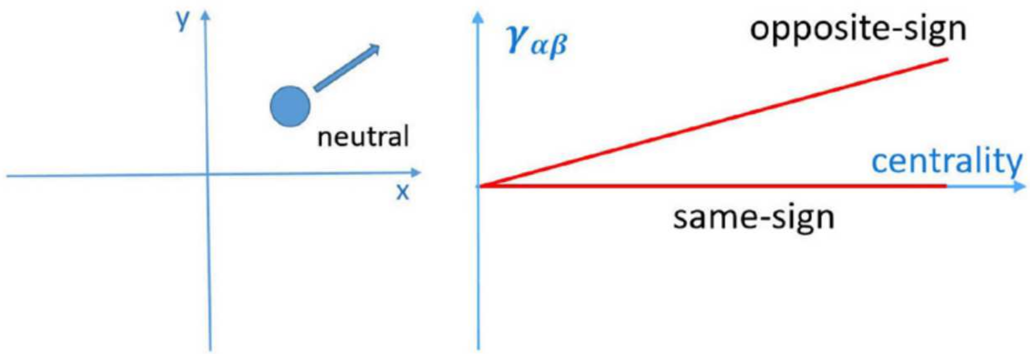
Back-ground contributions to gamma correlator

Transverse momentum conservation **(Pratt 2010; Liao, Bzdak,Koch 2011):**



- **Charge blind**
- $\gamma \propto -v_2/N$
- **Can be subtracted in** $\Delta\gamma = \gamma_{\rm OS} - \gamma_{\rm SS}$

Local charge conservation **(Pratt, Schlichting 2011)** **or neutral resonance decay** **(Wang 2010) :**



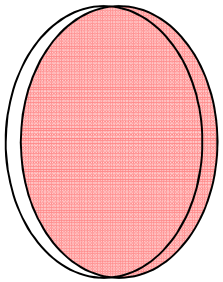
- **Charge sensitive**
- $\gamma_{\rm OS} \propto v_2/N, \gamma_{\rm SS} \sim 0$
- **Cannot be subtracted in** $\Delta\gamma = \gamma_{\rm OS} - \gamma_{\rm SS}$

Main challenge: how to separate the background effects?

Chiral magnetic effect

Recall the challenge: How to separate the CME signal from the elliptic flow induced backgrounds?

Way 1: Fix the magnetic field, but vary the flow: central U + U collisions (Tribedy, last talk) or event shape engineering (Dobrin, last talk)

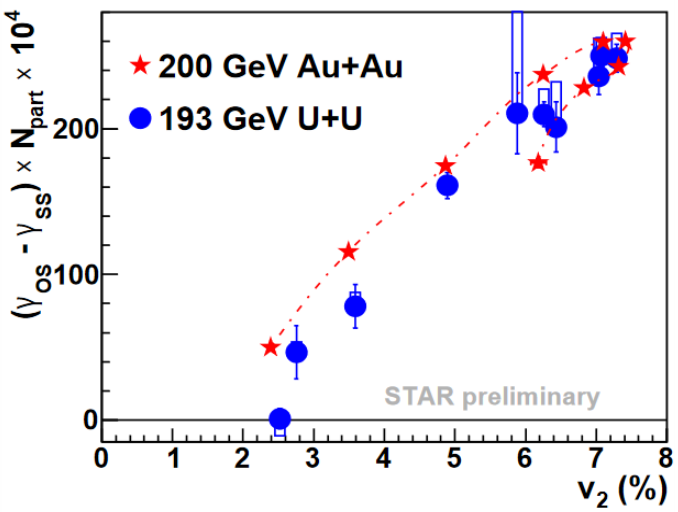


U nucleus is deformed,

Very cental body-body:

B=0 while $v_2 \neq 0$

Voloshin 2010

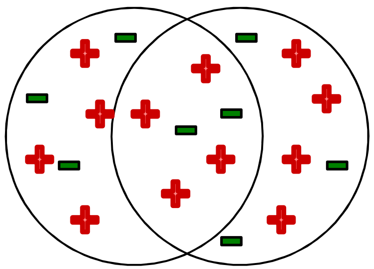


Wang 2012

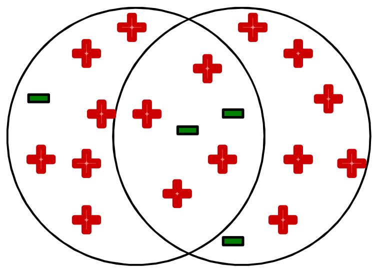
Chiral magnetic effect

Recall the challenge: How to separate the CME signal from the elliptic flow induced backgrounds?

Way 2: Fix the flow, but vary the magnetic field: isobar collisions



Vs



$^{96}_{40}Zr + ^{96}_{40}Zr$

$^{96}_{44}Ru + ^{96}_{44}Ru$

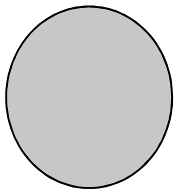
At same energy, same centrality, they would have equal elliptic flow but 10% difference in magnetic field.

Let us go into numerical detail to see whether it works.

Isobaric collisions

Isobaric collisions

Nucleus shape, Wood-Saxon distribution



$$\rho(r,\theta) = \frac{\rho_0}{1+\exp\left[(r-R_0-\beta_2 R_0 Y_2^0(\theta))/a\right]}$$

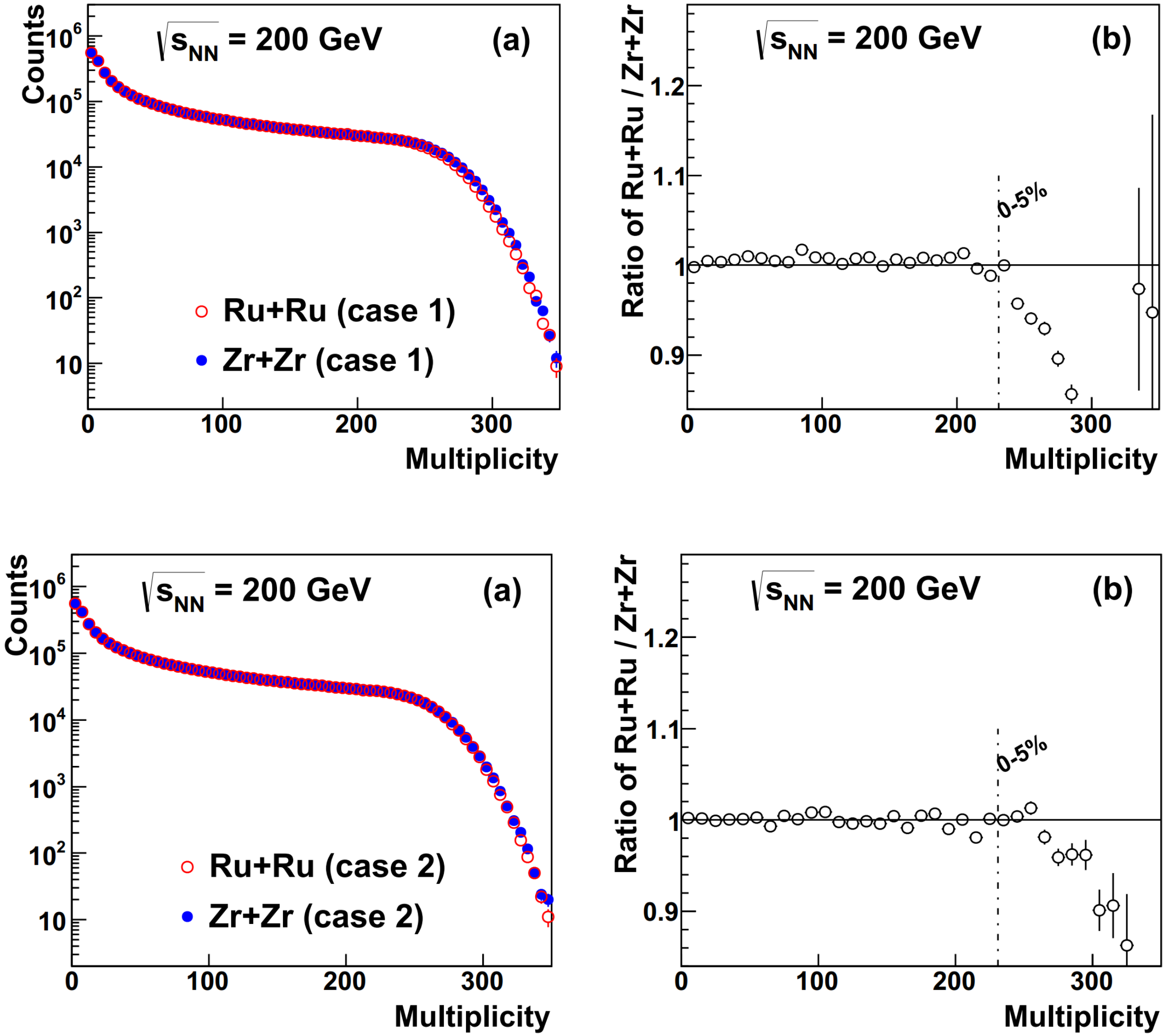
Current experimental data for the parameters:

Case 1: e-A scattering experiments **(nucl. Data tab. 2001)**
Case 2: comprehensive model deductions **(nucl. Data tab. 2001)**

		R_0(fm)	a(fm)	β_2
Case 1	Ru	5.085	0.46	0.158
	Zr	5.02	0.46	0.08
Case 2	Ru	5.085	0.46	0.053
	Zr	5.02	0.46	0.217

Isobaric collisions

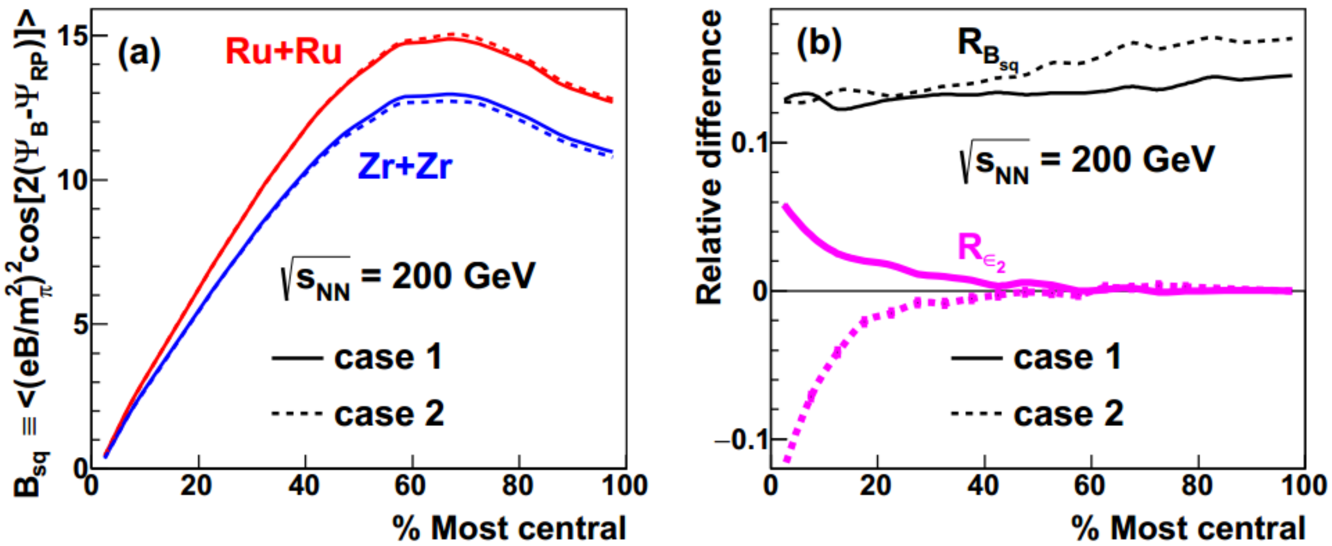
Multiplicity from Monte Carlo Glauber simulation



The ratio consistent with 1 for both cases except for very central events

Isobaric collisions

Initial magnetic field and initial eccentricity



Deng, XGH, Ma, and Wang, 2016

B_{sq} quantifies magnetic-field fluctuation (Blozynski, XGH, Zhang, and Liao, 2013)
R is the relative difference: 2(RuRu-ZrZr)/(RuRu+ZrZr)

Centrality 20-60%: sizable difference in B ($R_{B_{sq}} \sim 10-20\%$) but small difference in eccentricity ($R_{\varepsilon_2} < 2\%$)

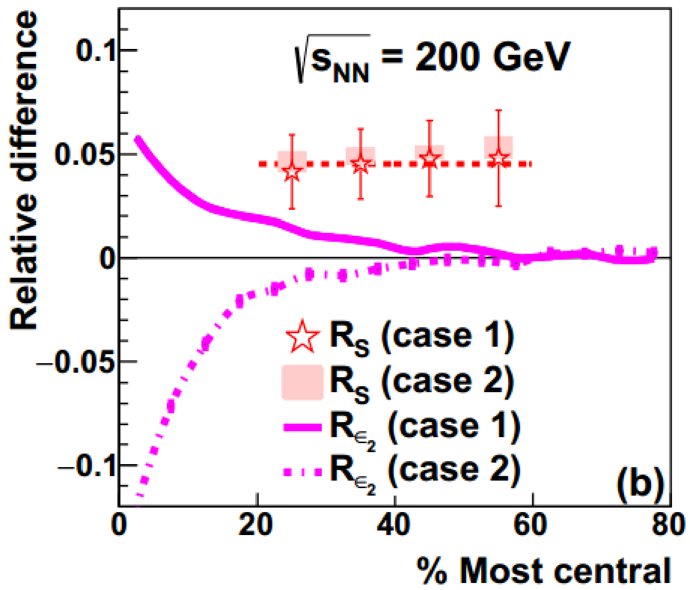
Isobaric collisions

Gamma correlator $S \equiv N_{\text{part}}\Delta\gamma$, here N_{part} compensates dilution effect, as both CME and v2 background $\propto 1/N_{\text{part}}$

As $\mathrm{R}_{\mathrm{B_{sq}}}$ and $\mathrm{R}_{\varepsilon_2}$ are small, we do perturbative expansion:

$R_S = (1 - bg)R_{B_{sq}} + bg \cdot R_{\epsilon_2}$ **with bg the background level**

Deng, XGH, Ma, and Wang, 2016



bg=2/3

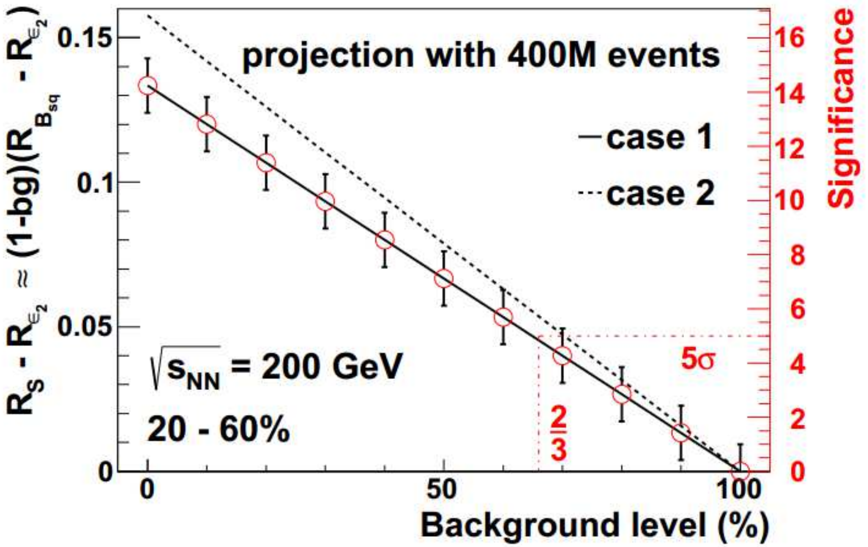
400M events

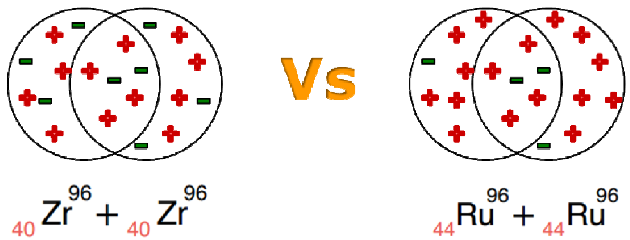
5σ signal

Centrality 20-60%: clear difference between CME=1/3 and CME=0.
Very promising to disentangle CME from v2 backgrounds

Isobaric collisions

May also determine the background level





First run: 2018 @ RHIC
STAR BUR for 7 weeks

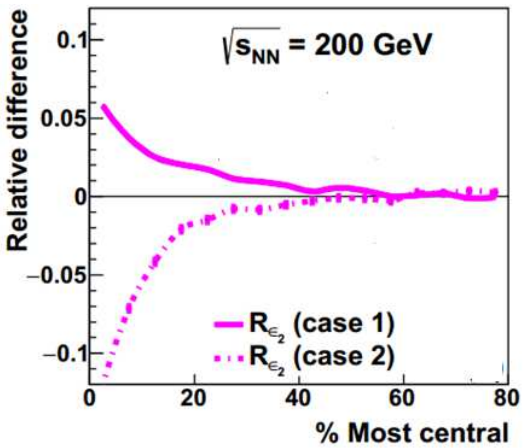
Other anomalous transports:

Observable	$^{96}_{44}$Ru + $^{96}_{44}$Ru vs. $^{96}_{40}$Zr + $^{96}_{40}$Zr
flow	$\approx$
CME	$>$
CMW	$>$
CVE	$\approx$

Isobaric collisions

By product 1: which nucleus is more deformed, Zr or Ru?

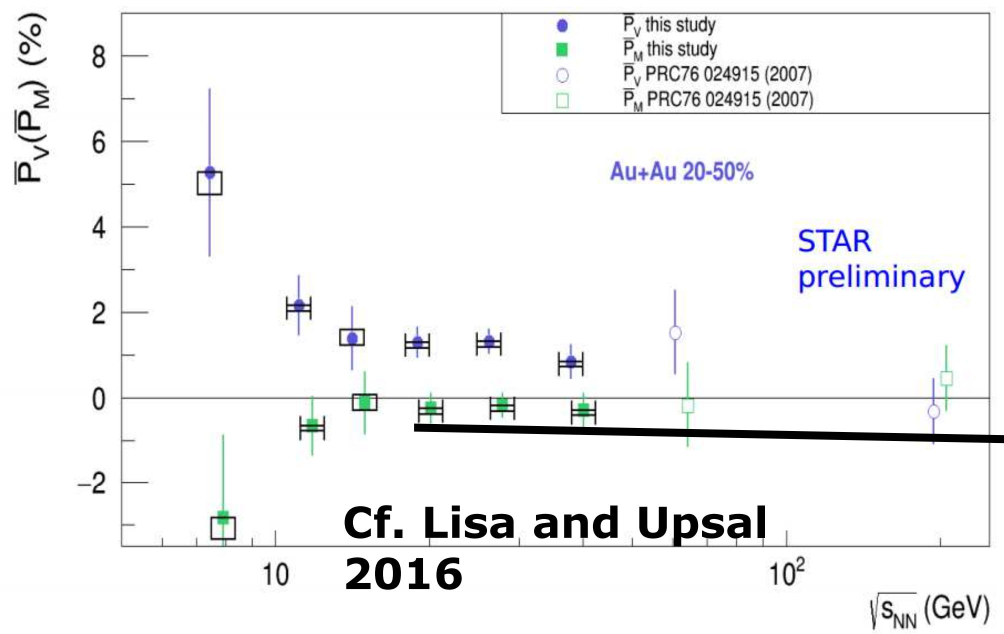
		R_0(fm)	a(fm)	β_2
Case 1	Ru	5.085	0.46	0.158
	Zr	5.02	0.46	0.08
Case 2	Ru	5.085	0.46	0.053
	Zr	5.02	0.46	0.217



Measurement of the v_2 at central collision can tell us about the deformation of the nuclei

Isobaric collisions

By product 2: difference between Lambda and anti-Lambda polarizations, Magnetic field or others?



Expect 10% difference between Zr+Zr and Ru+Ru, if it is due to magnetic field.
Need beam energy scan

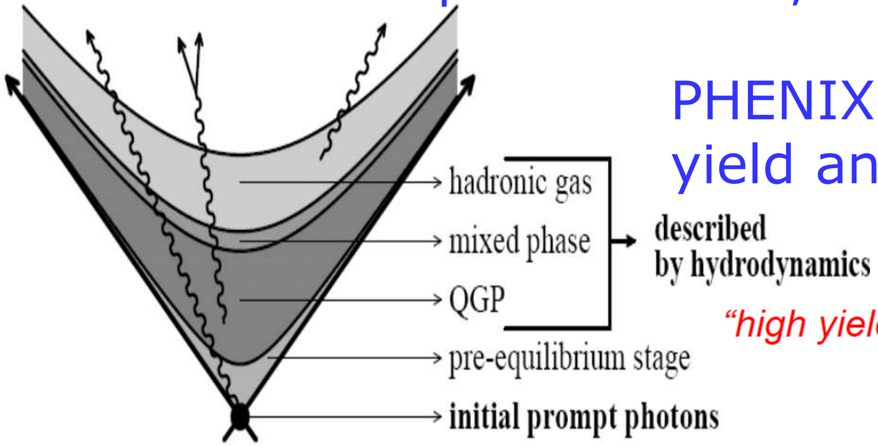
Decomposition into vortical and magnetic

$$P_{\text{Vortical}} = \frac{1}{2}\left(P_{\Lambda} + P_{\bar{\Lambda}}\right) \qquad P_{\text{Magnetic}} = \frac{1}{2}\left(P_{\Lambda} - P_{\bar{\Lambda}}\right)$$

Isobaric collisions

By product 3: is magnetic field responsible to the PHENIX direct photon puzzle?

When do direct photons emit, early stage or late stage?



PHENIX@QM2012: direct photon has high yield and large v2. This is puzzling.

"high yield -> early emission, high anisotropy -> late emission"

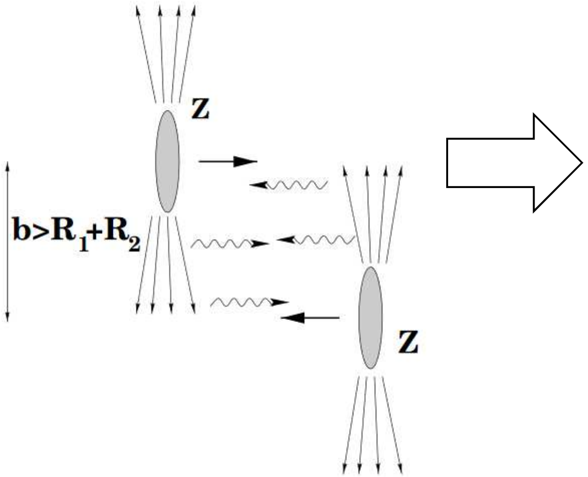
One possible solution: anisotropy in the early stage, like the magnetic field.

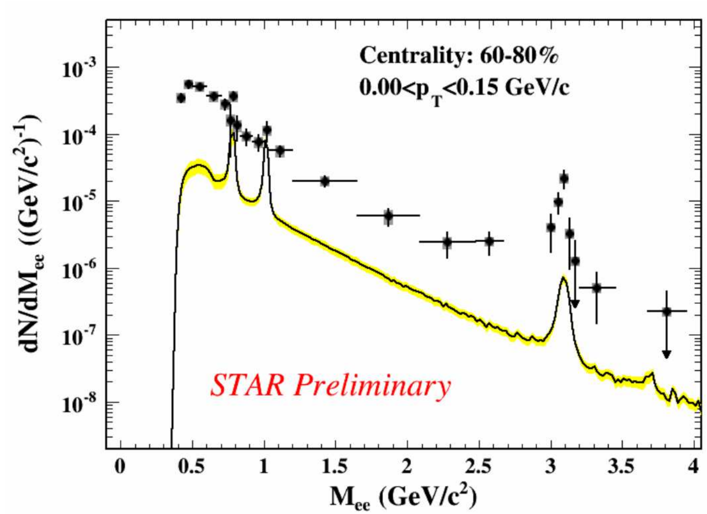
(Basar, Skokov, Kharzeev 2012, Tuchin 2012, Muller, Wang, Yang 2013, Yee 2013, ...)

Anisotropy is proportional to B^2, thus can be tested in isobar collisions

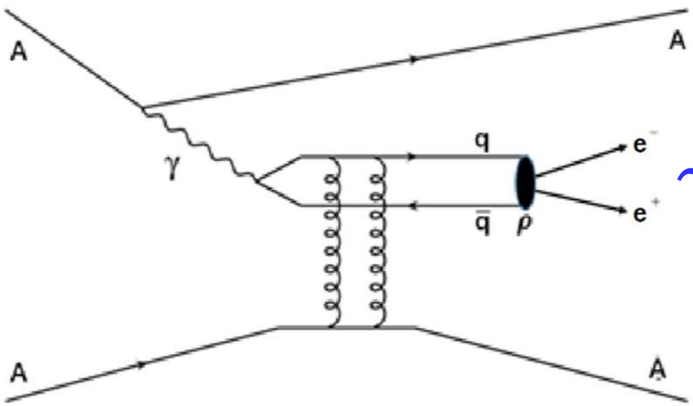
Isobaric collisions

By product 4: enhanced dilepton production in very peripheral collisions?



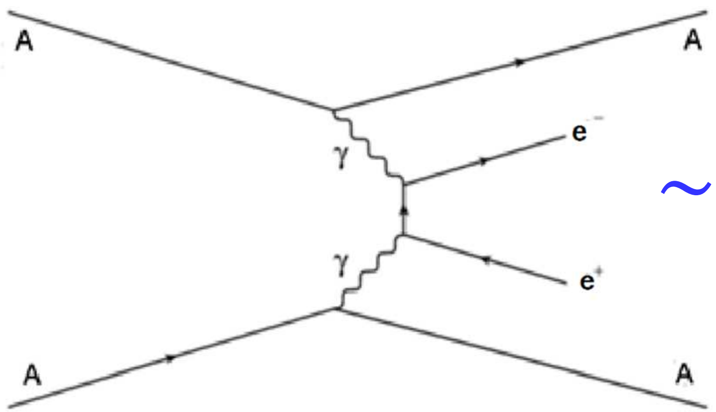


Scenario 1: photonuclear interaction



$\sim Z^2$

Scenario 2: two-photon process



$\sim Z^4$

Summary

- **The signal of chiral magnetic effect in heavy ion collisions suffers from strong elliptic-flow driven backgrounds**
- **Isobar collision provides a promising way to disentangle CME signal from flow backgrounds**
- **Isobar collision also provides play ground for other phenomena**

Thank you!

Table of Anomalous transports

	E	B	ω
J_V	σ Ohm's law	$\frac{N_C e}{2\pi^2}\mu_A$ Chiral magnetic effect	$\frac{N_C}{\pi^2}\mu_V\mu_A$ Vector chiral vortical effect
J_A	$\propto \frac{\mu_V\mu_A}{T^2}\sigma$ Chiral electric separation effect	$\frac{N_C e}{2\pi^2}\mu_V$ Chiral separation effect	$N_C\left(\frac{T^2}{6}+\frac{\mu_V^2+\mu_A^2}{2\pi^2}\right)$ Axial chiral vortical effect

And the collective waves arising from them

Constitute a set of "soft probes" of topological sector of QCD