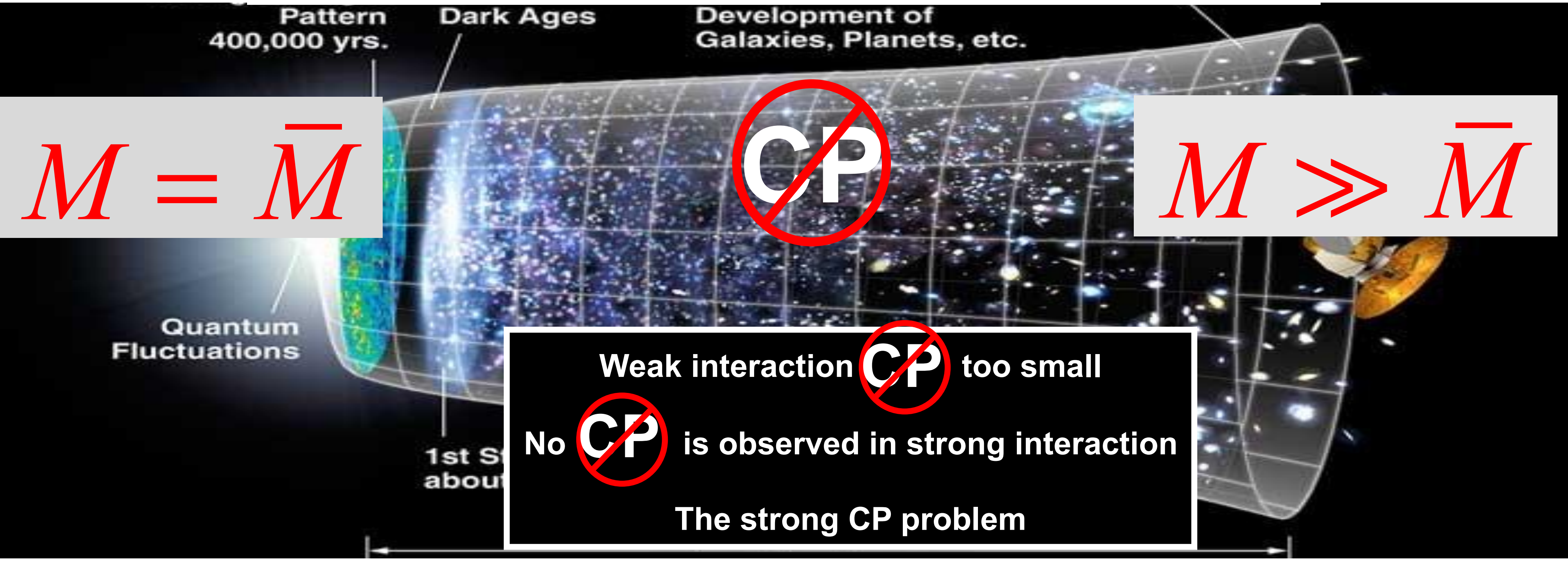
Experimental search of CME at RHIC

Jie Zhao

Jan. 13, 2024

The strong CP problem

Kharzeev, Pisarski, Tytgat, PRL 81 (1998) 512; Kharzeev, et al. NPA 803 (2008) 227



$M = \bar{M}$

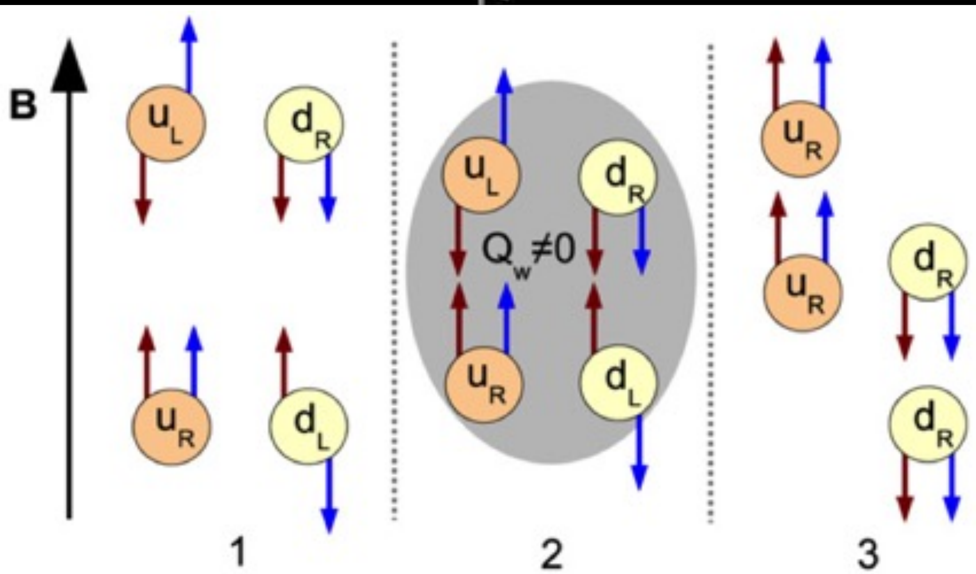
~~CP~~

$M \gg \bar{M}$

Weak interaction ~~CP~~ too small

No ~~CP~~ is observed in strong interaction

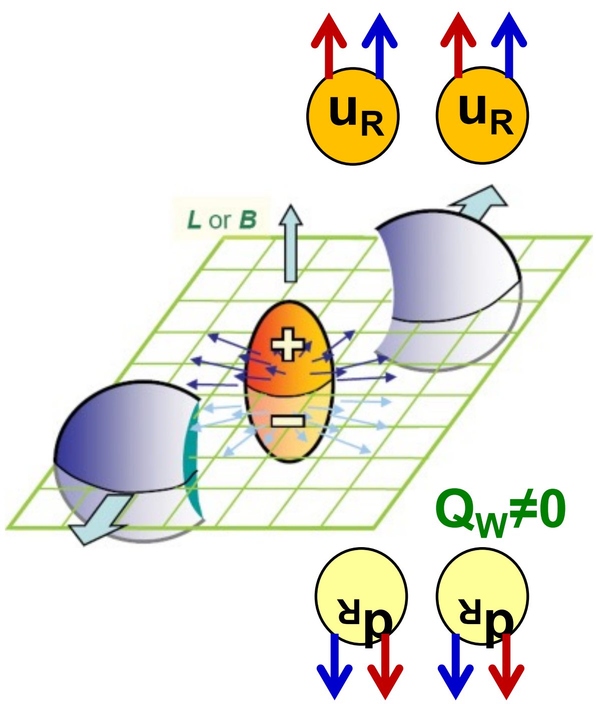
The strong CP problem

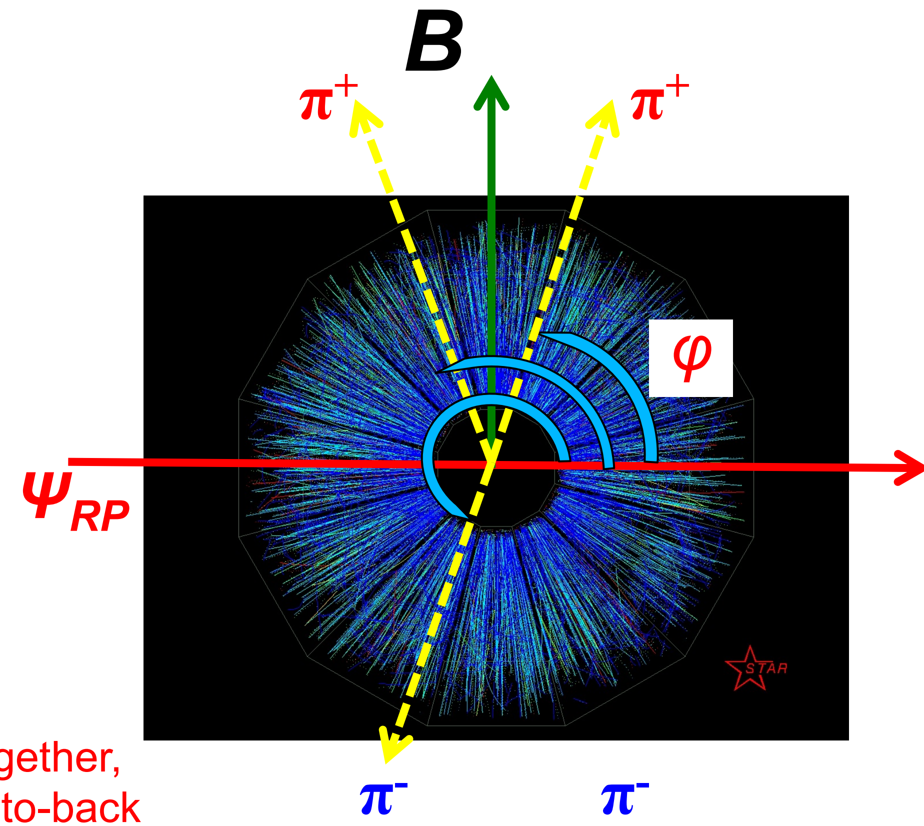


- Strong magnetic field
- Quark degree of freedom, χ-symmetry
- QCD vacuum fluctuations,
  Topological gluon field, $Q_w \neq 0$.
- Local P, CP violations

How to measure CME?

S. A. Voloshin, Phys.Rev. C 70 (2004) 057901





same-sign (++/--) pairs go together,
opps.-sign (+-/-+) pairs back-to-back

The sign of Q_w **can vary** event to event and domain to domain ➔ one has to measure correlations

$$\gamma = \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\psi_{RP}) \right\rangle$$

$$\gamma^{+-} = \cos(\pi^+ + \pi^- - 0) = \cos(360°) = +1$$

$$\gamma^{++} = \cos(\pi^+ + \pi^+ - 0) = \cos(180°) = -1$$

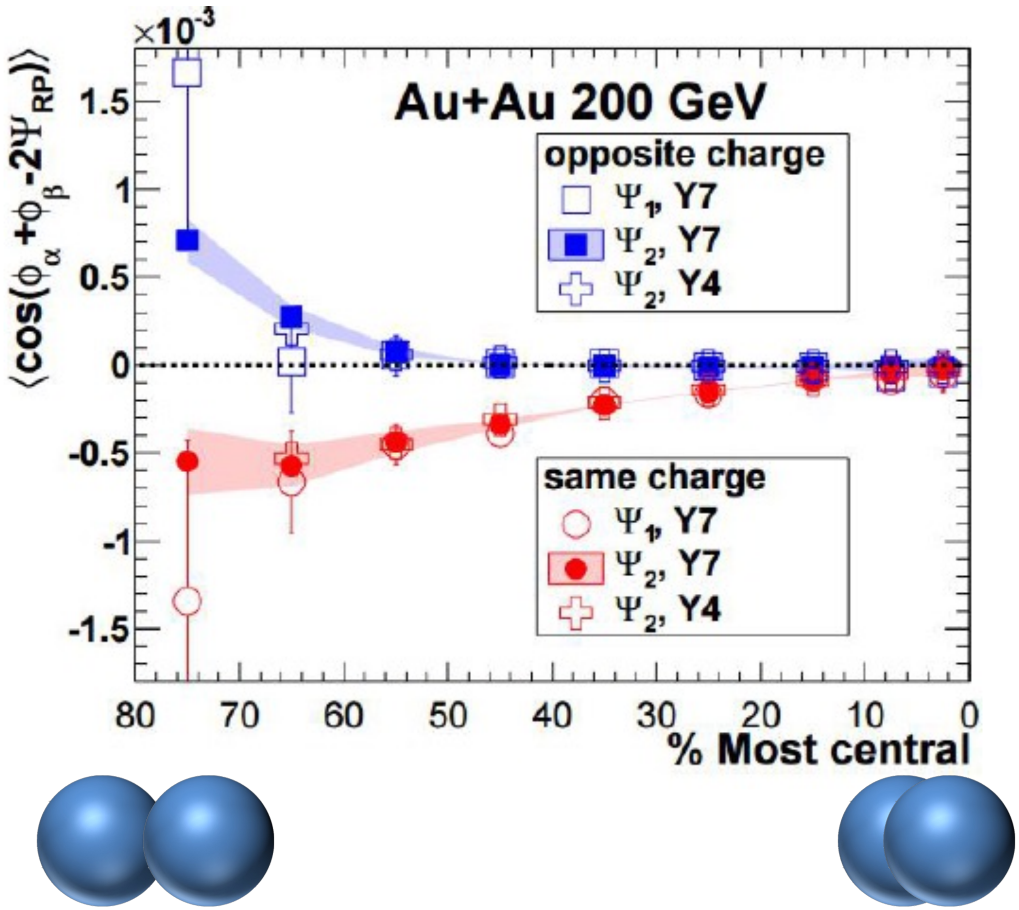
$$\Delta\gamma = \gamma^{+-} - \gamma^{++/--} = 2 > 0$$

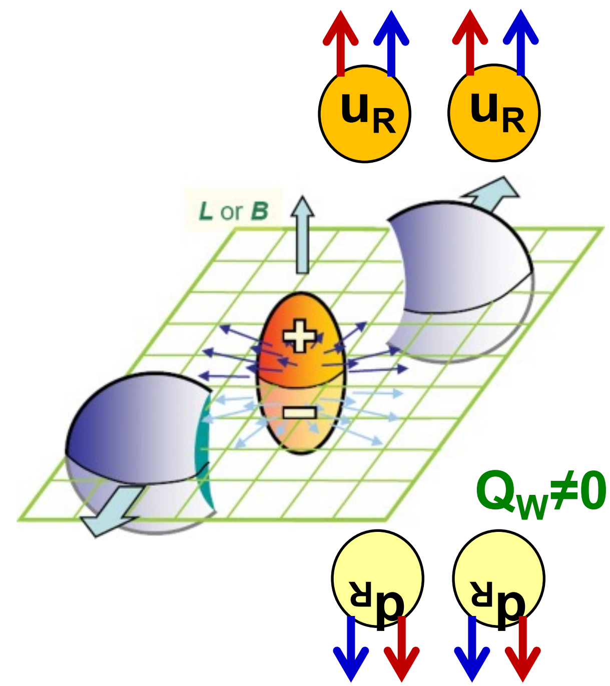
φ represents the azimuthal angle

α, β denote the charge of the particles, with combination of +-(-+), ++, --

Early measurements

STAR collaboration, PRL 103(2009)251601; PRC 81(2010)54908; PRC 88 (2013) 64911



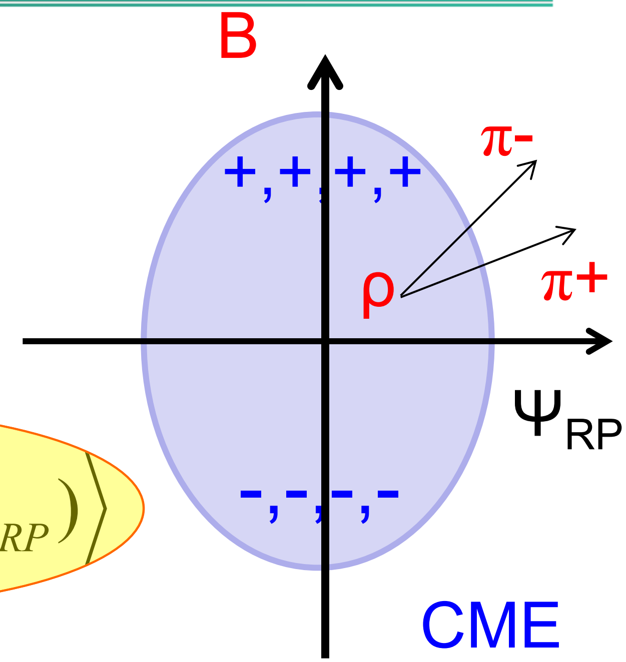


++/-- pairs go together,
+-/-+ pairs back-to-back

➢ Qualitatively consistent with CME expectations

Background?

S. A. Voloshin, PRC 70, 057901 (2004)
F. Wang, PRC 81, 064902 (2010)
A. Bzdak, V. Koch and J. Liao, PRC 83, 014905 (2011)
S. Schlichting and S. Pratt, PRC 83, 014913 (2011)
F. Wang, J. Zhao, PRC 95,051901(R) (2017)



$$\gamma = \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\psi_{RP}) \right\rangle$$

$$= \frac{N_{cluster}}{N_\alpha N_\beta} \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{cluster}) \cos(2\varphi_{cluster} - 2\psi_{RP}) \right\rangle$$

two-particle correlation

v_2

$\gamma^{+-} = \cos(\pi^+ + \pi^- - 0) = \cos(360°) = +1$
$\Delta\gamma > 0$ CME

$\approx$

$\gamma^{+-} = \cos(\pi^+ + \pi^- - 0) = \cos(0°) = +1$
$\Delta\gamma > 0$ Decay BKG.

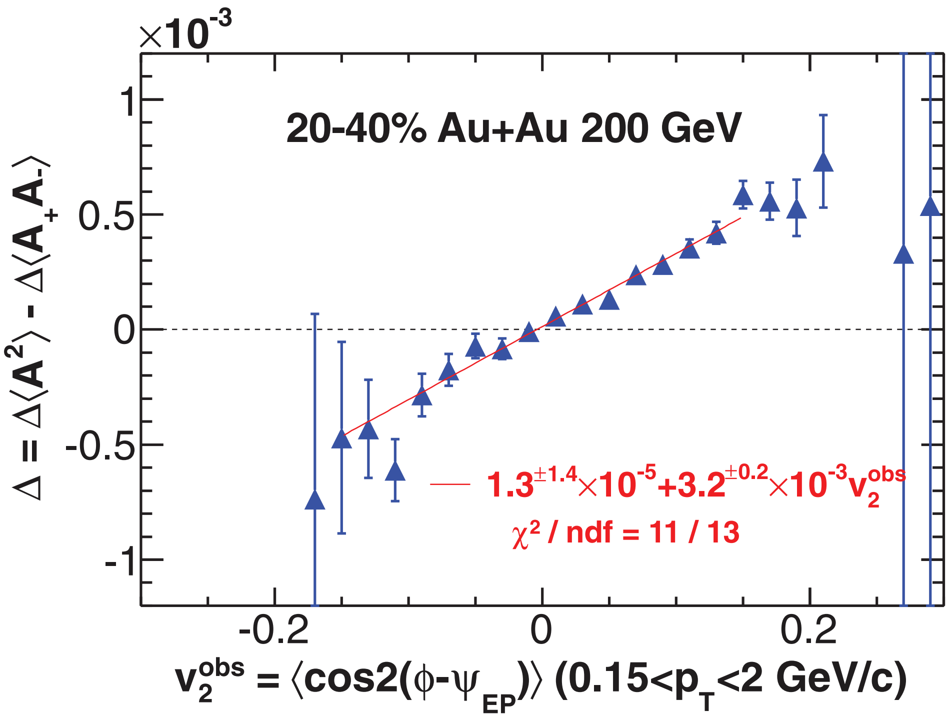
- Background from two-particle correlation coupled with v_2
- Remove background by selecting on $v_2=0$ (event shape)

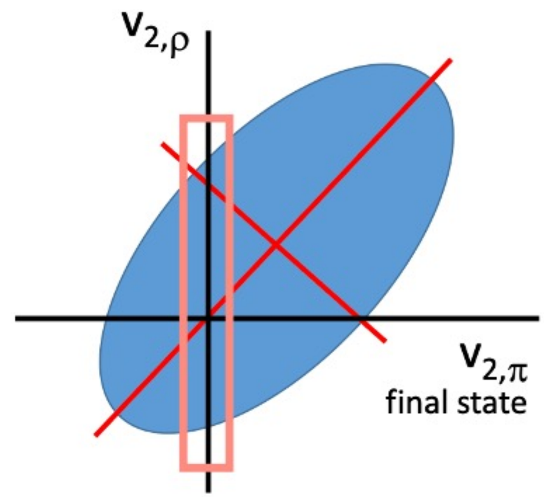
Background issue, event-by-event v_2

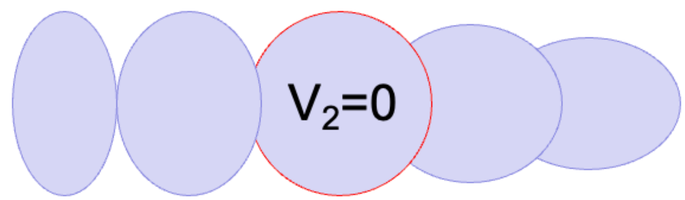
STAR, PRC 89,044908 (2014)

F. Wang, J. Zhao, PRC 95 (2017) 051901(R)

Δ similar to Δγ



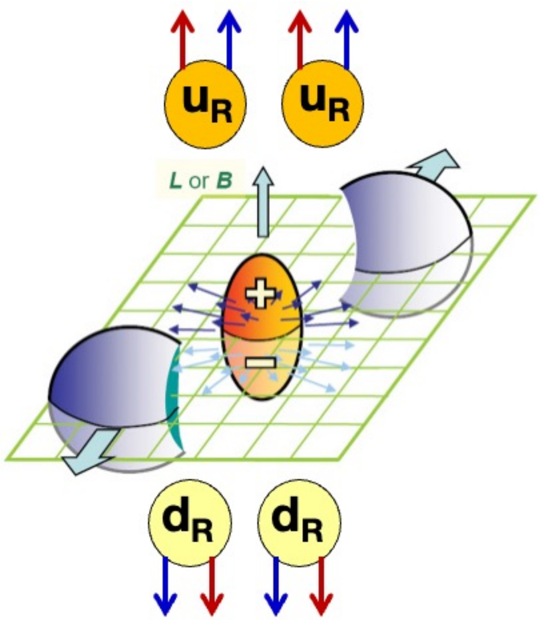




- Charge correlator linear as function of event-by-event v_2 (v_2^{obs} or $v_{2,ebye}$)
- suggests large v_2 background contributions
- By selecting the events with v_2^{obs} = 0, the correlator is largely reduced, but not totally eliminated, as background ~ $v_{2,\rho}$ not $v_{2,\pi}$

Search for the CME

S. A. Voloshin, Phys. Rev. C 70 (2004) 057901



$$\gamma = \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\psi_{RP}) \right\rangle$$

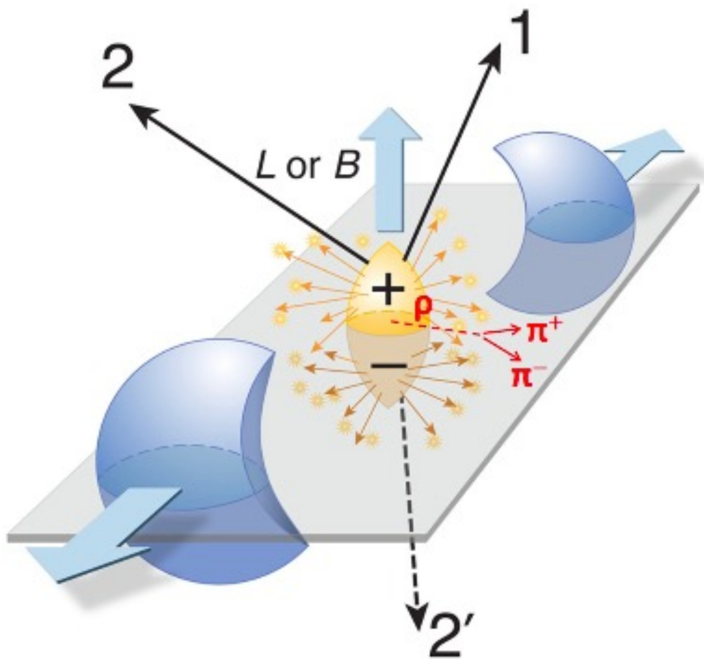
$$= \frac{N_{cluster}}{N_\alpha N_\beta} \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{cluster}) \cos(2\varphi_{cluster} - 2\psi_{RP}) \right\rangle$$

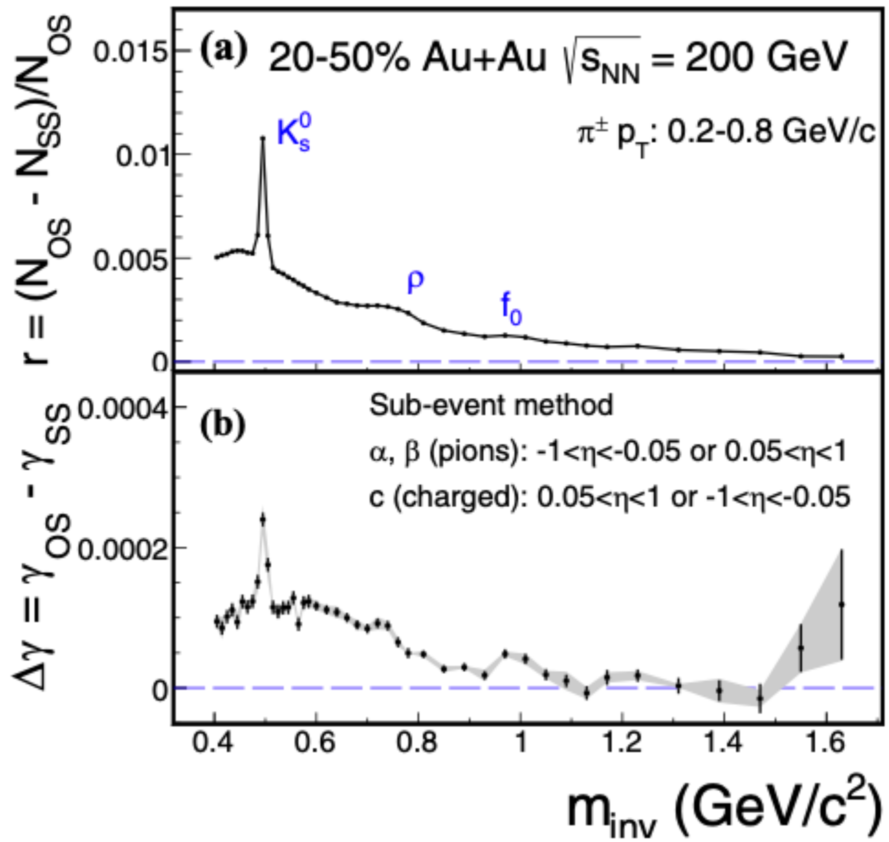
Resonance decay … v_2

- **Invariant mass method**
- **Δγ with respect to Ψ_{RP} (ZDC) and Ψ_{PP} (TPC)**
- **CME in isobar collisions**
- **Event-Shape-Engineering**

Invariant mass method

STAR, Phys. Rev. C 106 (2022) 034908
J. Zhao, H. Li, F. Wang, EPJC (2019) 79:168





$$\gamma = \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\psi_{RP}) \right\rangle$$

$$= \frac{N_{cluster}}{N_\alpha N_\beta} \left\langle \cos(\varphi_\alpha + \varphi_\beta - 2\varphi_{cluster}) \cos(2\varphi_{cluster} - 2\psi_{RP}) \right\rangle$$

Resonance decay … v_2

- Identify the background by invariant mass of α+β pairs
- Explicit demonstration of “resonance” background

Isolate the CME from background

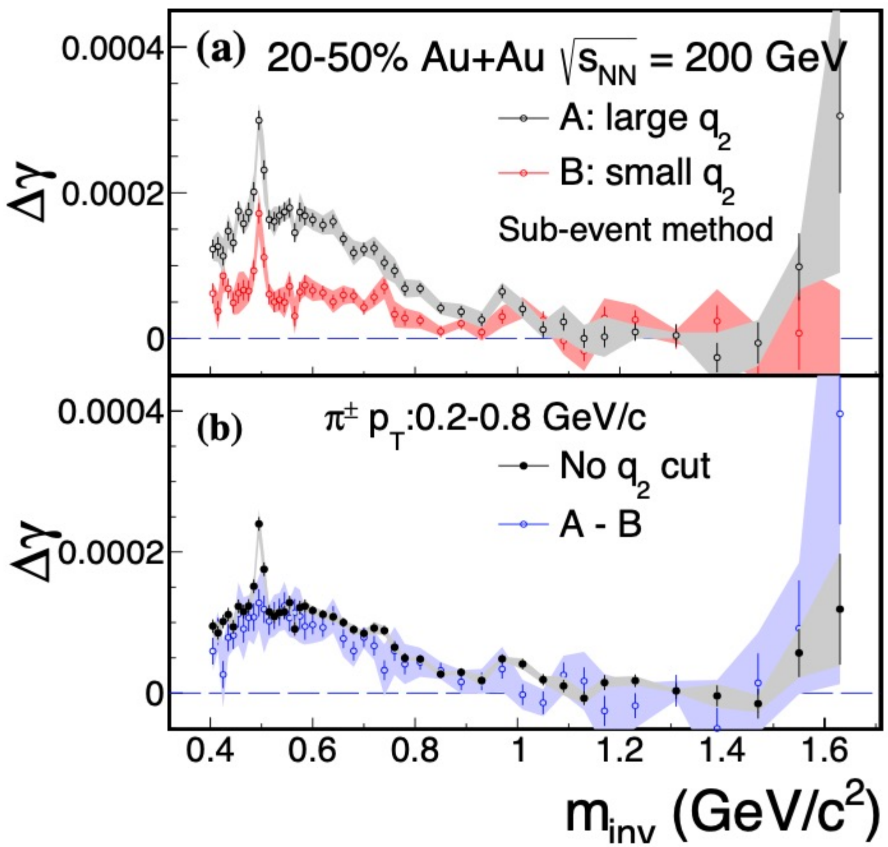
STAR, Phys. Rev. C 106 (2022) 034908

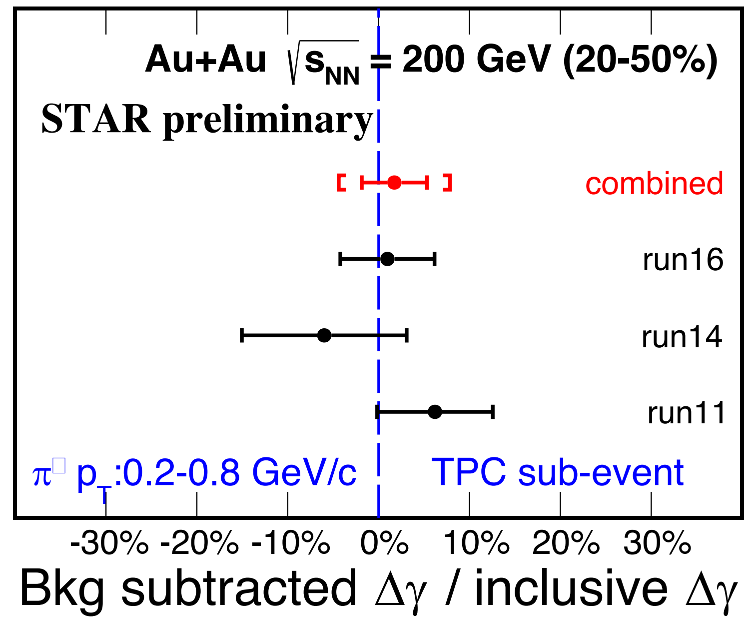
$\Delta\gamma(m) = \boxed{r(m)*\cos(\alpha+\beta-2\phi_{reso.})*v_{2,reso.}} + \text{CME}$

Background shape

Bkg. shape: $\mathbf{\Delta\gamma_A - \Delta\gamma_B}$ (A,B select by q_2)

Fit $\Delta\gamma = k*(\Delta\gamma_A - \Delta\gamma_B) + \text{CME}$





$$\frac{N_{cluster}}{N_\alpha N_\beta}\left\langle \cos(\varphi_\alpha+\varphi_\beta-2\varphi_{cluster})\cos(2\varphi_{cluster}-2\psi_{RP})\right\rangle$$

vary v_2

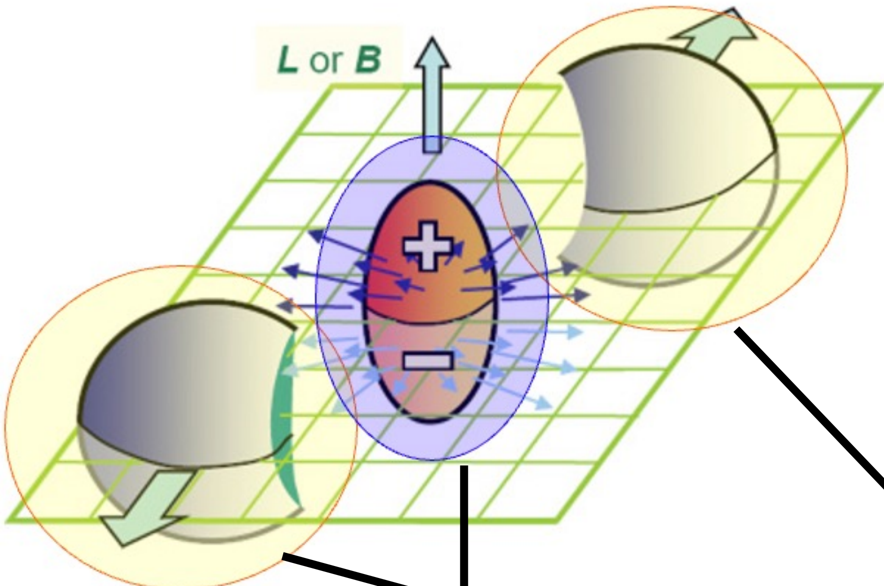
J. Zhao, H. Li, F. Wang, EPJC (2019) 79:168

> ➢ CME signal fraction is ~15% at 95% C.L.

Use Ψ_{PP} and Ψ_{RP} to solve Bkg and CME

H-J Xu, J. Zhao, X. Wang, H. Li, Z. Lin, C. Shen and F. Wang, CPC 42 (2018) 084103
H-J Xu, X. Wang, H. Li, J. Zhao, Z. Lin, C. Shen and F. Wang, PRL 121 (2018) 022301

B. Alver *et al.* (PHOBOS) , PRL **98**, 242302 (2007).

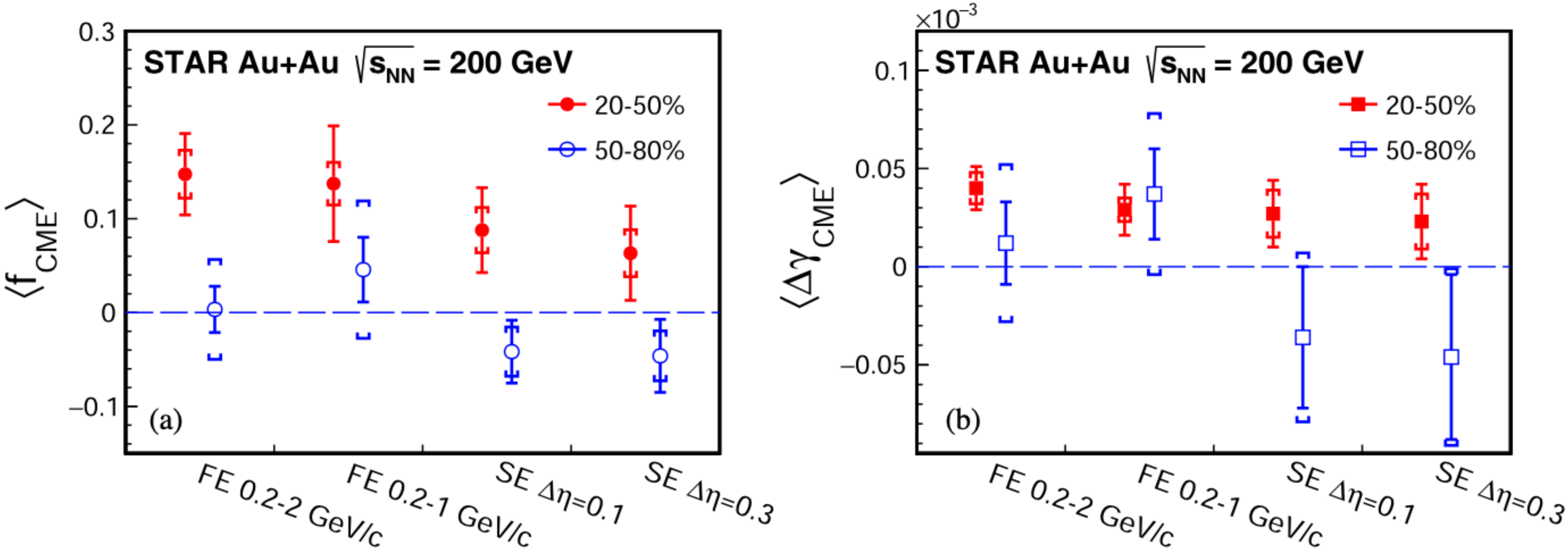


- Ψ_{PP} maximizes v_2,
  - ➔ v_2 background
- Ψ_{RP} maximizes the magnetic field (B),
  - ➔ CME signal
- Ψ_{PP} and Ψ_{RP} are correlated, but not identical due to geometry fluctuations

- $\Delta\gamma$ w.r.t. TPC Ψ_{EP} (proxy of Ψ_{PP}) and ZDC Ψ_1 (proxy of Ψ_{RP}) contain different fractions of CME and Bkg

$\Delta\gamma$ with respect to Ψ_{PP} and Ψ_{RP}

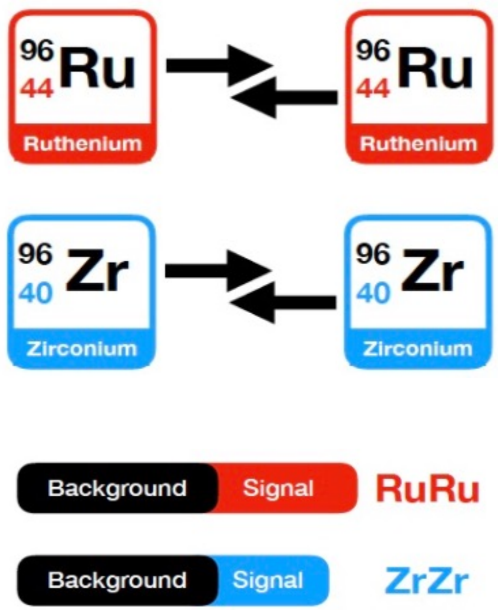
STAR collaboration, PRL. 128, 092301 (2022)

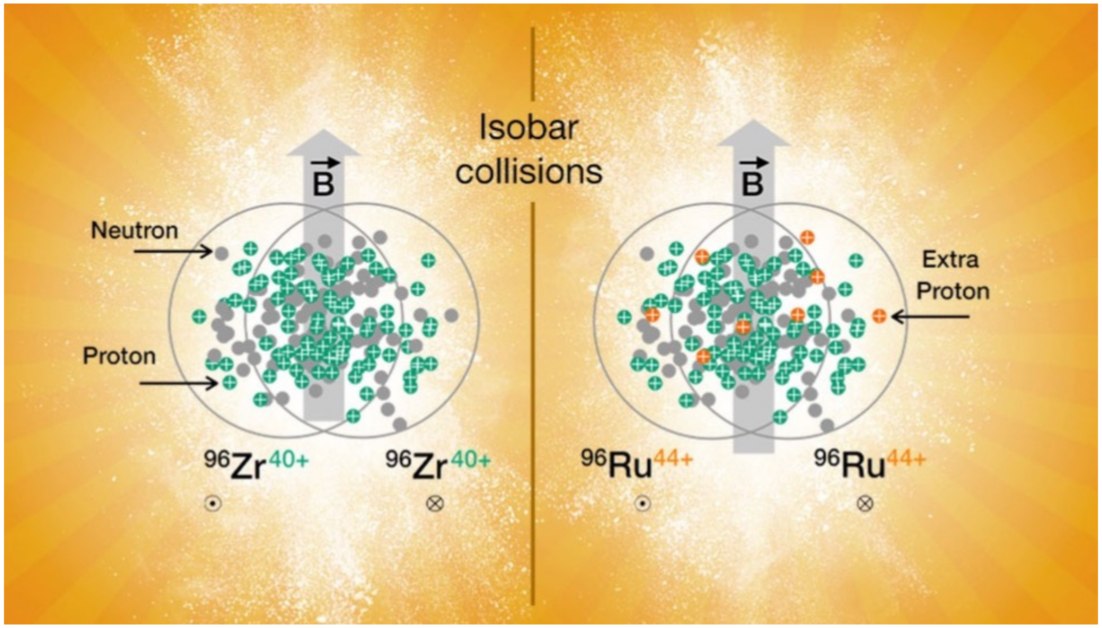


- possible CME signal is 5-10% of the early measurements, with1-3σ significance， may still have non-flow contributions
- Expect 20B from 2023+25 runs, more precise conclusion

CME in isobar collisions

STAR , Phys. Rev. C 105 (2022) 14901
S. A. Voloshin, Phys.Rev. Lett. 105, 172301 (2010)
W-T Deng, X-G Huang, G-L Ma, and G. Wang Phys. Rev. C 94, 041901(R) (2016)





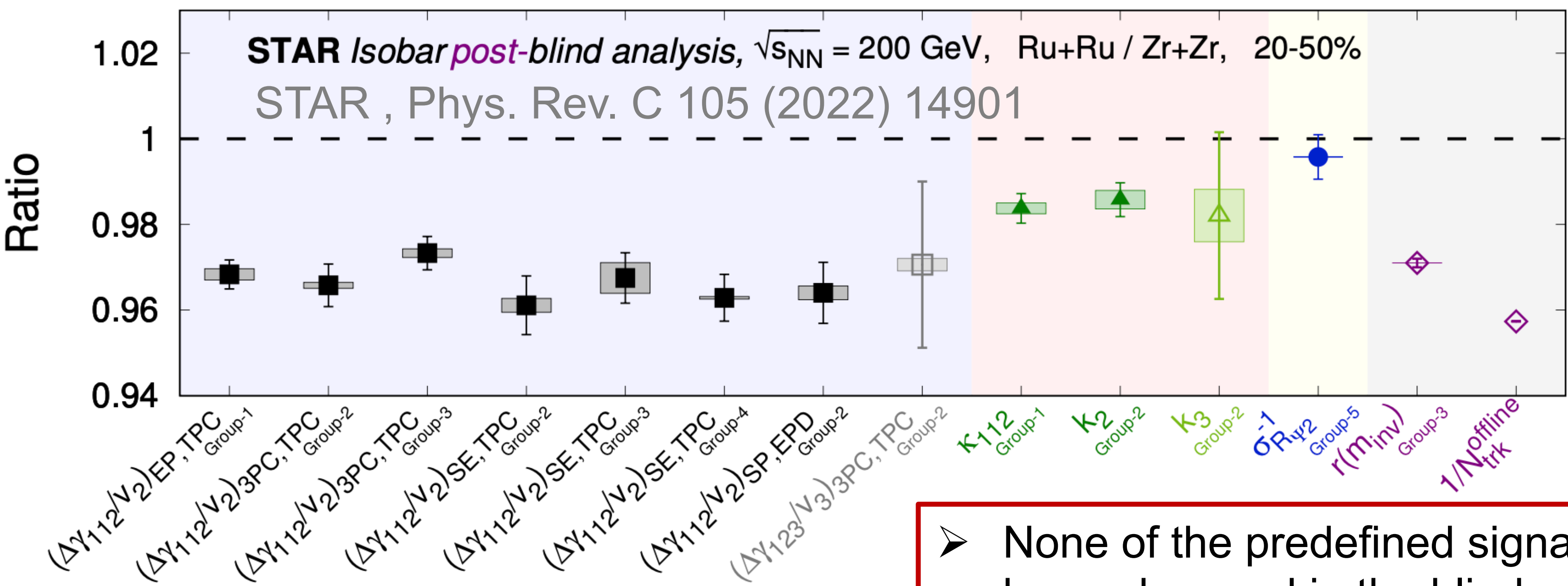
D. E. Kharzeev, J.F. Liao, Nature Rev.Phys. 3 (2021) 1, 55-63
S. Shi，H. Zhang, D. Hou, J.F. Liao, Phys. Rev. Lett. 125 (2020) 242301

Isobars idea:

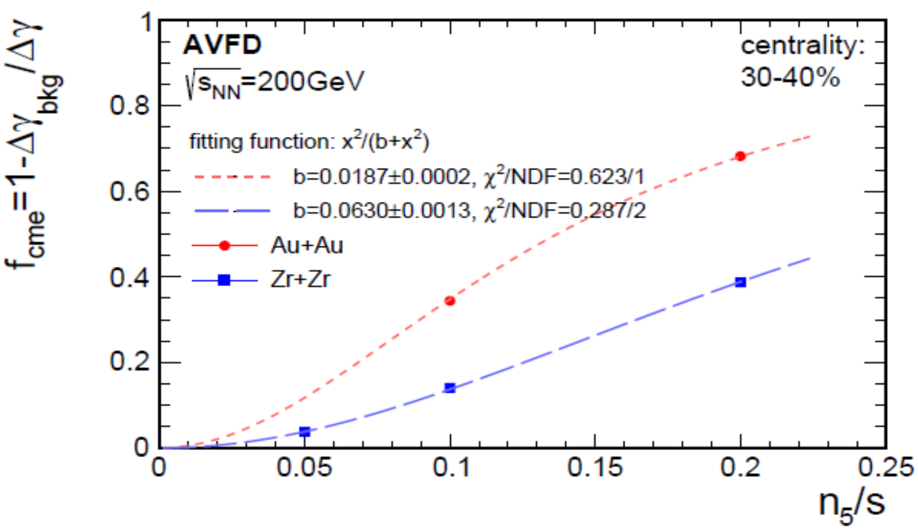
✓ **similar shape -> similar background,**

✓ **different Z -> different magnetic field -> change in CME signal**

CME in isobar collisions



- None of the predefined signatures have been observed in the blind analysis
- Blind analysis assumes background ~ v_2 only. Multiplicity, nonflow effect.

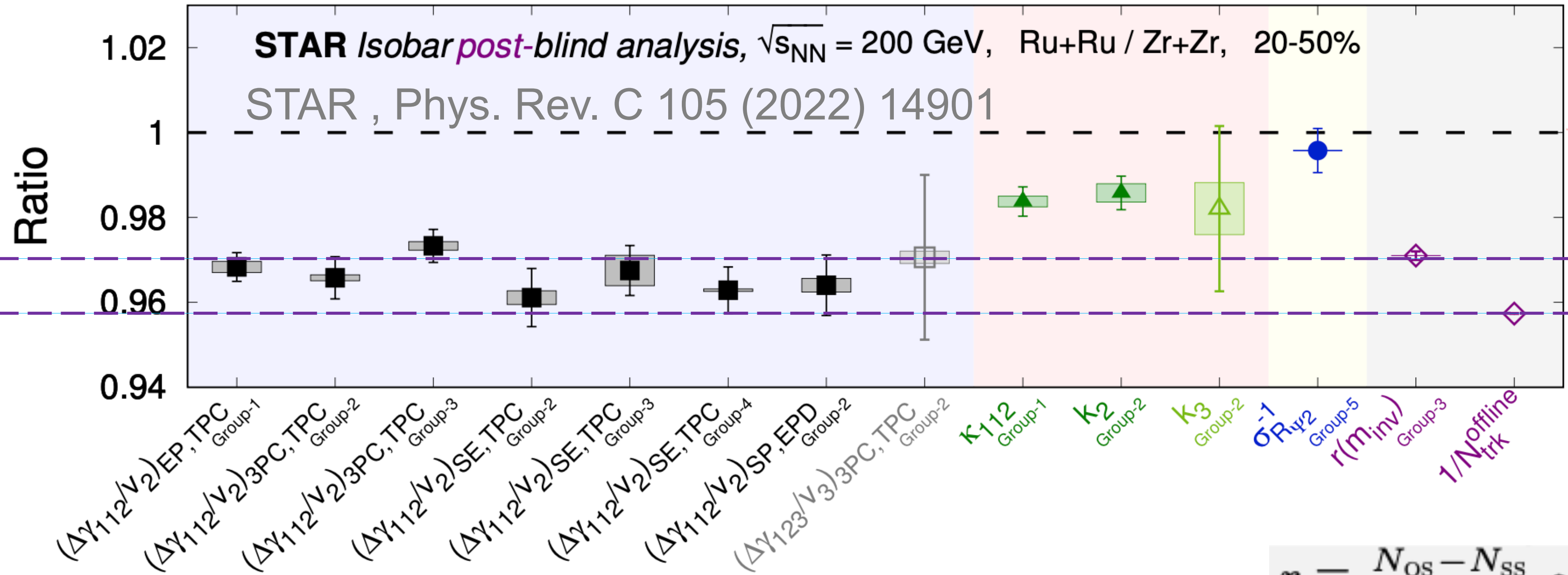


Y. Feng, F. Wang, etal., Phys. Lett. B 820, 136549 (2021)

Bkg. ~ 1/N ~ 1/A
$\Delta\gamma_{CME}$ ~ B^2 ~ $A^{2/3}$ (B. field ~ $A/A^{2/3}$ ~ $A^{1/3}$)
Background: isobar/AuAu ~ 2
Signal: AuAu/isobar ~ 1.5
f_{cme} possibly a factor of ~3 reduction

AVFD simulation: indicates smaller signal in isobar than Au+Au

Post-blind isobar results



$$r \equiv \frac{N_{OS}-N_{SS}}{N_{OS}} \sim \frac{N_{cluster}}{N^2}$$

relative pair multiplicity

Y. Feng QM23

- isobar collisions differ in N, v_2, due to nuclear structure.
- ratio higher than multiplicity scaling, lower than pair multiplicity scaling

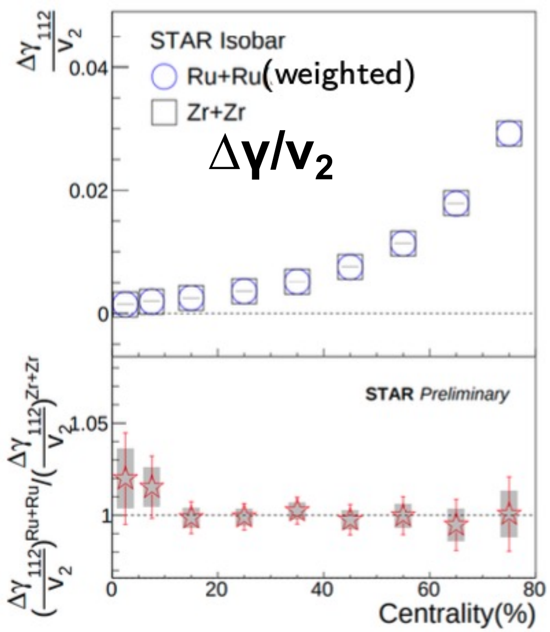
Forced match method
- Re-weight events according to N, V_2, EP resolution
- Mitigate isobar differences

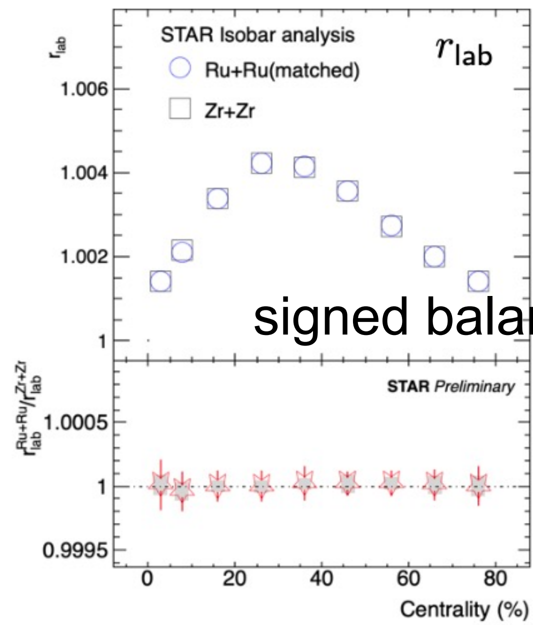
Background baseline study
- Estimate nonflow backgrounds
- Set upper limit on CME fraction

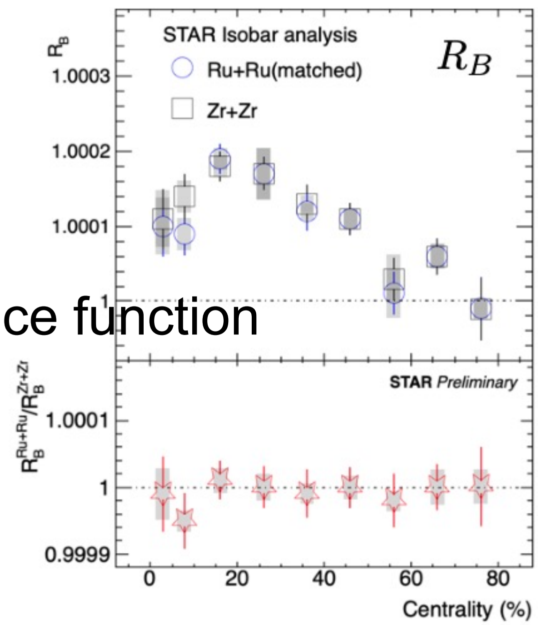
Results from the forced match method

YuFu Lin, QPT23

Tang, Chin. Phys. C 44, 054101 (2020)







signed balance function

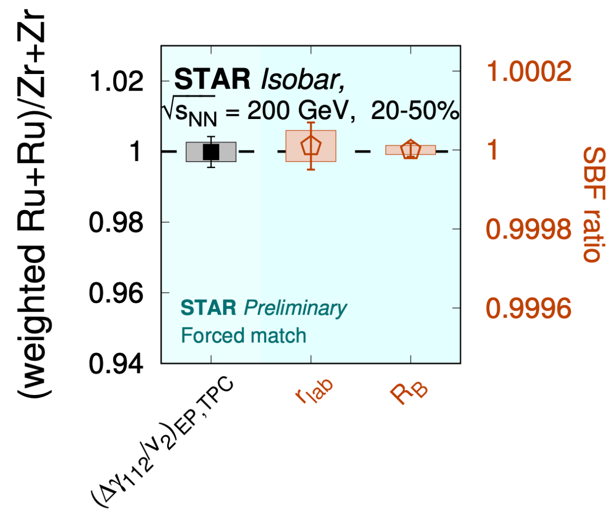
look for enhanced e-by-e fluctuation of net ordering in y direction

$$f_{W,\text{bin}} = N_{\text{bin(Zr)}} / N_{\text{bin(Ru)}}$$

$$S_O = \sum_{\text{bin}} O_{\text{bin(Ru)}} N_{\text{bin(Ru)}} f_{W,\text{bin}}$$

$$S_W = \sum_{\text{bin}} N_{\text{bin(Ru)}} f_{W,\text{bin}} \qquad O_{\text{matched(Ru)}} = S_O / S_W$$

With forced match, isobar ratios in Δγ/v_2, SBF consistent with unity.



Isobar background baseline

Y. Feng QM23

STAR, arXiv:2308.16846

$\Delta\gamma$ measurement using 3p correlation

$$C_{3,\alpha\beta} = \langle\cos(\phi_\alpha + \phi_\beta - 2\phi_c)\rangle, \quad \Delta\gamma = (C_{3,\text{os}} - C_{3,\text{ss}})/v_2^* = C_3/v_2^*.$$

- background decomposition [Feng et al., PRC105(2022)024913] :

$$\frac{\Delta\gamma_{\text{bkgd}}}{v_2^*} = \frac{C_3}{v_2^{*2}} = C_{2\text{p}}\frac{v_2^2}{Nv_2^{*2}} + \frac{C_{3p}}{N^2v_2^{*2}} = \frac{C_{2\text{p}}v_2^2}{Nv_2^{*2}}\left(1 + \frac{C_{3\text{p}}/C_{2\text{p}}}{Nv_2^2}\right)$$

- over the correlated pairs $C_{2\text{p}} = \langle\cos(\phi_\alpha + \phi_\beta - 2\phi_{2\text{p}})\rangle_{2\text{p}}$
- over the correlated triplets $C_{3\text{p}} = \langle\cos(\phi_\alpha + \phi_\beta - 2\phi_c)\rangle_{3\text{p}}$

$$Y_{\text{bkgd}} \equiv \frac{\left(\Delta\gamma_{\text{bkgd}}/v_2^*\right)^{\text{Ru}}}{\left(\Delta\gamma_{\text{bkgd}}/v_2^*\right)^{\text{Zr}}} \approx 1 + \frac{\delta(C_{2\text{p}}/N)}{C_{2\text{p}}/N} - \frac{\delta\epsilon_{\text{nf}}}{1+\epsilon_{\text{nf}}} + \frac{1}{1 + \frac{Nv_2^2}{C_{3\text{p}}/C_{2\text{p}}}}\left(\frac{\delta C_{3\text{p}}}{C_{3\text{p}}} - \frac{\delta C_{2\text{p}}}{C_{2\text{p}}} - \frac{\delta N}{N} - \frac{\delta v_2^2}{v_2^2}\right)$$

$\delta X = X^{\text{Ru}} - X^{\text{Zr}}$

X w/o label is for Zr

flow-induced background:
correlated pairs coupled with flow (e.g., resonance decay …)
- Resonance/cluster multiplicity not strictly proportional to N

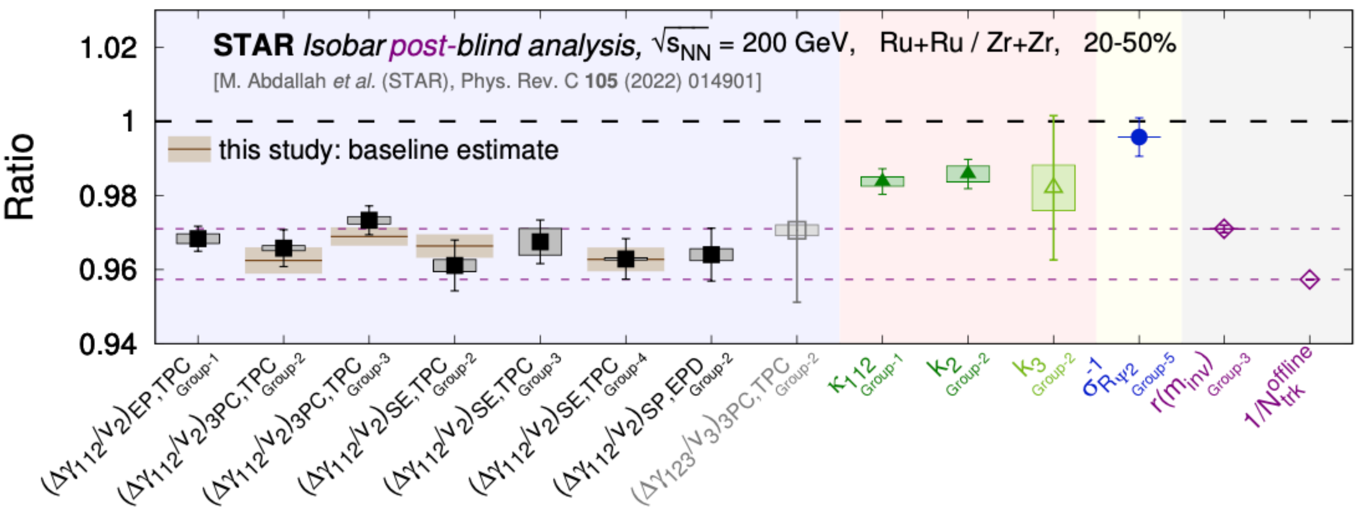
nonflow in v_2^*: $\epsilon_{\text{nf}} = v_2^{*2}/v_2^2 - 1$
- 2p-cumulant $v_2^{*2} = \langle\cos 2(\phi_\alpha - \phi_\beta)\rangle$ contains flow and nonflow $v_2^{*2} = v_2^2 + v_{2,\text{nf}}^2$
- 2D fit on $(\Delta\eta, \Delta\phi)$ distribution

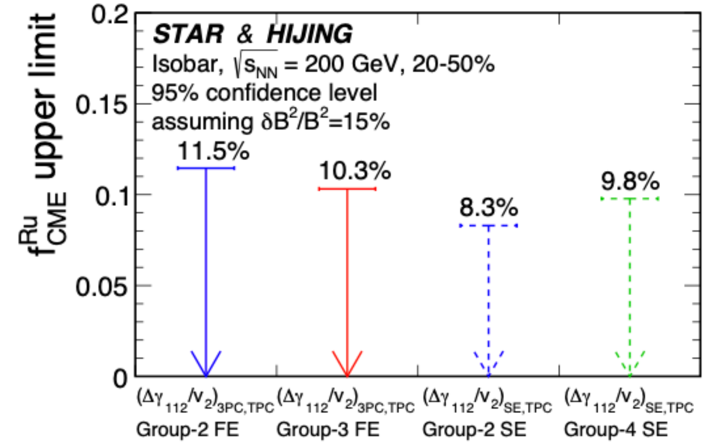
3p nonflow: correlated triplets (e.g., jets, di-jets …)
- HIJING simulations

Isobar background baseline

Y. Feng QM23

STAR, arXiv:2308.16846





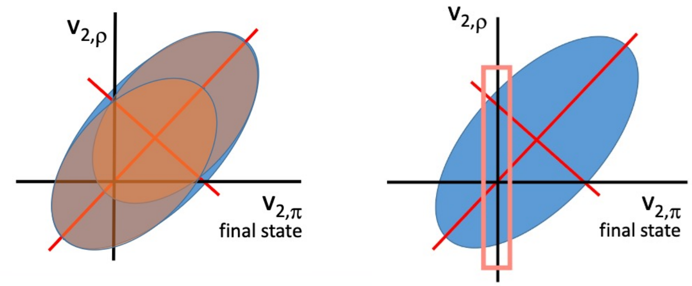
- Data are consistent with estimated baseline.
- CME fraction upper limit ~ 10% at 95% CL

Rough estimate:
Data + baseline uncertainty ~ 0.7%
Assuming B_2 difference 15%
f_{cme} uncertainty ~ 0.7%/15% ~ 5% →
2σ upper limit ~ 10%

$$Y_{\text{bkgd}} \equiv \frac{\left(\Delta\gamma_{\text{bkgd}}/v_2^*\right)^{\text{Ru}}}{\left(\Delta\gamma_{\text{bkgd}}/v_2^*\right)^{\text{Zr}}} \approx 1 + \frac{\delta(C_{2\text{p}}/N)}{C_{2\text{p}}/N} - \frac{\delta\epsilon_{\text{nf}}}{1+\epsilon_{\text{nf}}} + \frac{1}{1+\frac{Nv_2^2}{C_{3\text{p}}/C_{2\text{p}}}}\left(\frac{\delta C_{3\text{p}}}{C_{3\text{p}}} - \frac{\delta C_{2\text{p}}}{C_{2\text{p}}} - \frac{\delta N}{N} - \frac{\delta v_2^2}{v_2^2}\right)$$

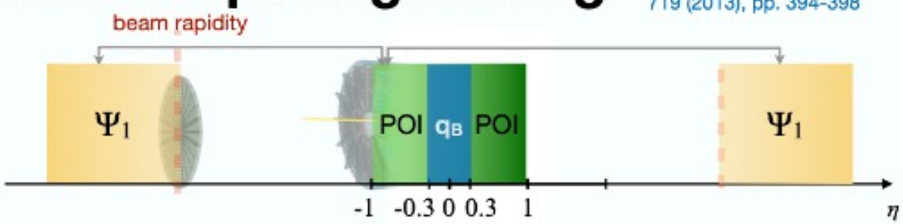
Event-Shape-Engineering

Zhiwan Xu, QM2023



Event Shape Engineering

J. Schukraft et al, Phys. Lett. B, 719 (2013), pp. 394-398



Event shape variable **Elliptic flow variable**

q_B (no POI) —— **v_2 (POI)**

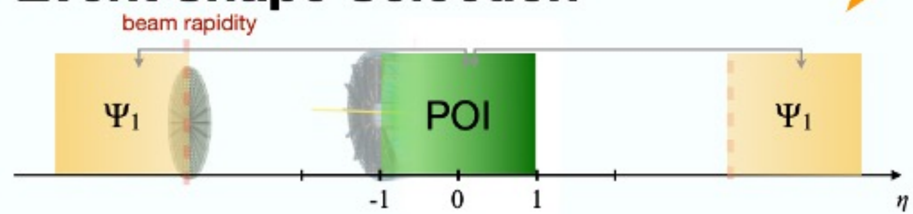
$$q_B = \sqrt{\frac{\left(\sum_{i=1}^{N} \sin 2\varphi_i\right)^2 + \left(\sum_{i=1}^{N} \cos 2\varphi_i\right)^2}{N}}$$

q_b excludes POI

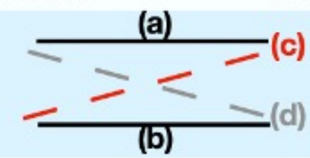
Event Shape Selection

Z. Xu et al, arXiv:2307.14997

new



Event shape variable **Elliptic flow variable**



$$q_2^2 = \frac{\left(\sum_{i=1}^{N} \sin 2\varphi_i\right)^2 + \left(\sum_{i=1}^{N} \cos 2\varphi_i\right)^2}{N(1 + N\langle v_2 \rangle)}$$

Pair from adding momenta of two POI particles.

Rely on long η range correlation from initial shape

Rely on emission pattern and geometry shape

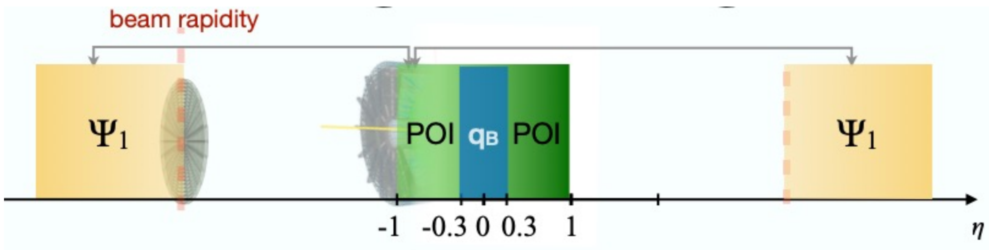
Event Shape method **Spectator Ψ_1**

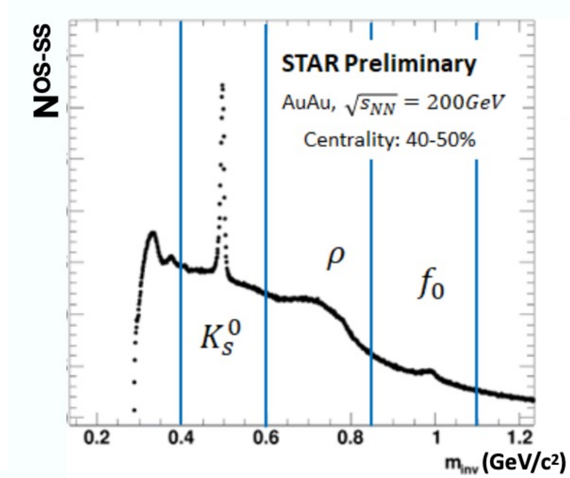
$$\Delta\gamma^{112} = \Delta\gamma^{\mathrm{CME/CVE}} + \cancel{k\frac{v_2}{N}} + \cancel{\Delta\gamma^{\mathrm{non-flow}}}$$

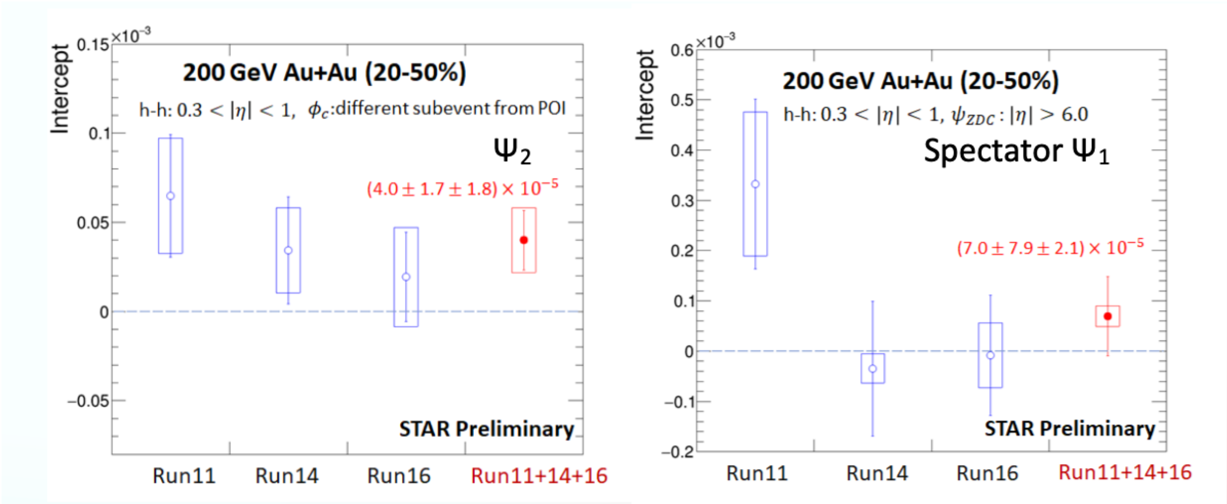
Measured **Signal** **Backgrounds**

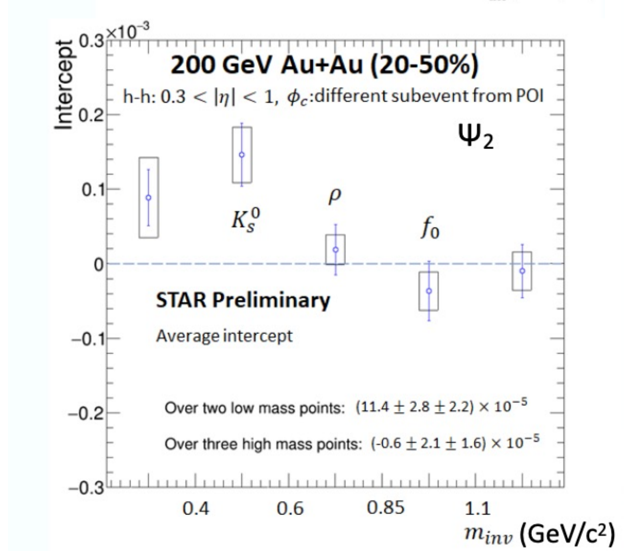
Event-Shape-Engineering

Han-Sheng Li, QM2023









Results with Ψ_2 yield 1.5σ, nonflow effects

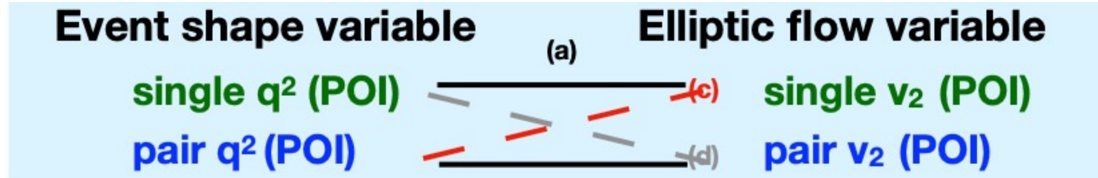
Results using $\Psi_{1,ZDC}$ is less than 1σ significance

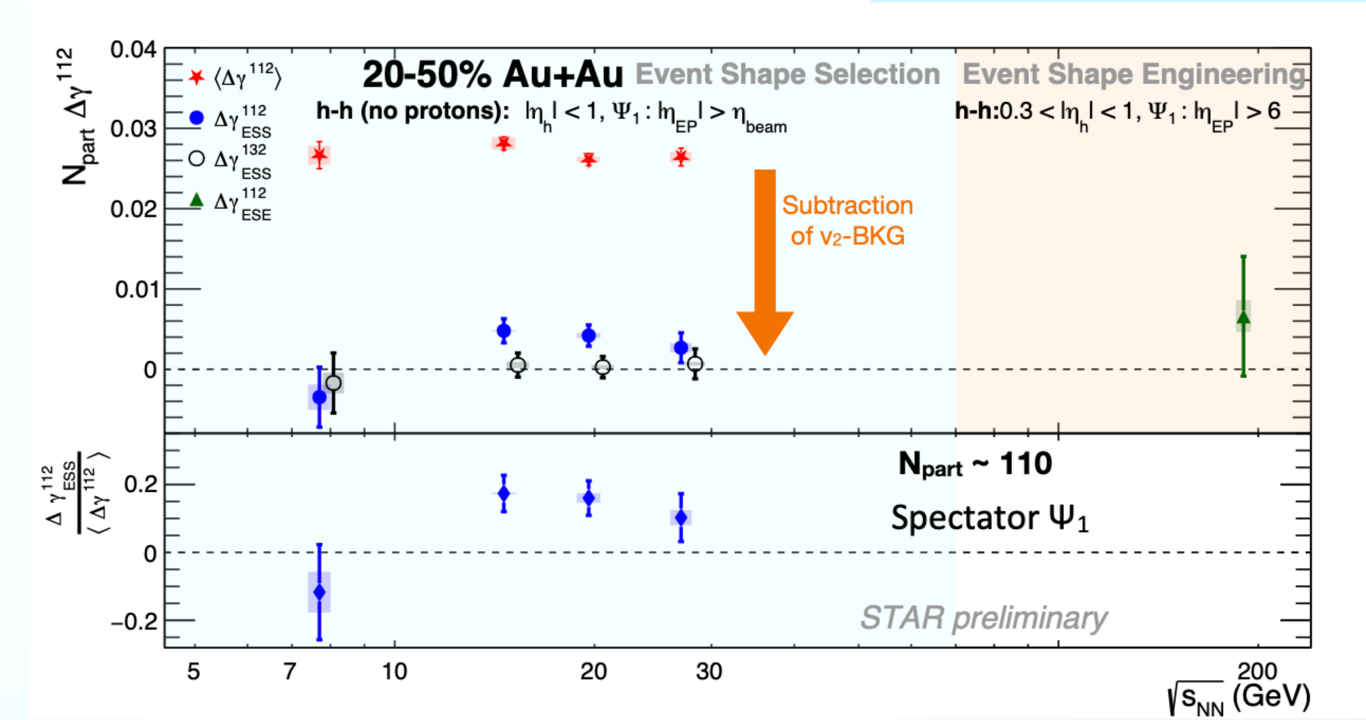
LM have a larger charge separation(3σ) than HM (consistent with zero).

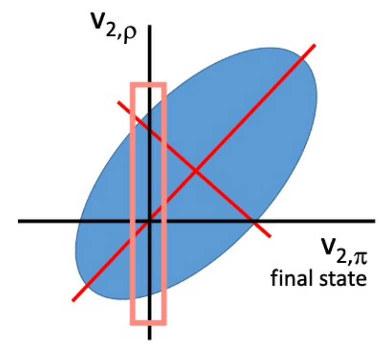
Measurement relative to Ψ_2, nonflow effects

Event-Shape-Selection

Zhiwan Xu, QM2023





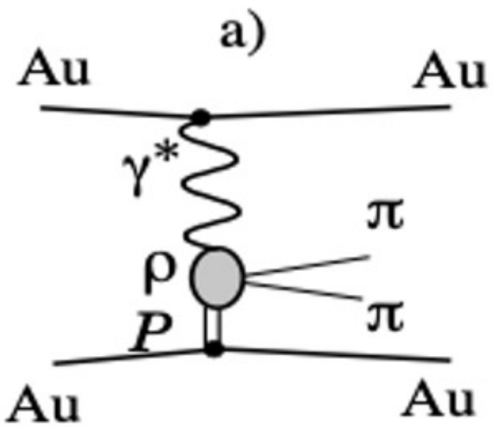


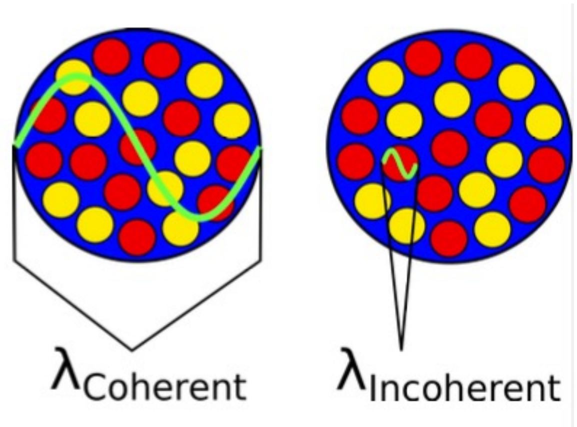
- After v_2-BKG subtraction with Event Shape variables, and nonflow suppression with Ψ_1
- The data interpretation requires further assessment on the new ESS methodology
- More BES-II data analyses for 11.5 GeV and 9.2 GeV are on the way

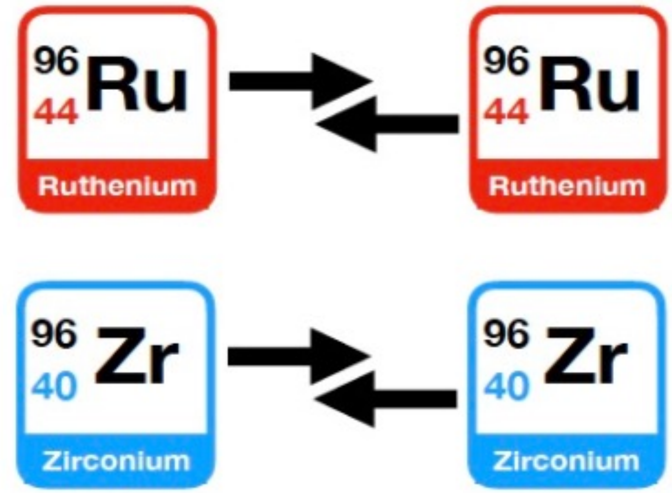
Prof. Wang raise a question

B-filed related background ?

γ-A interaction in A-A hardonic collisions



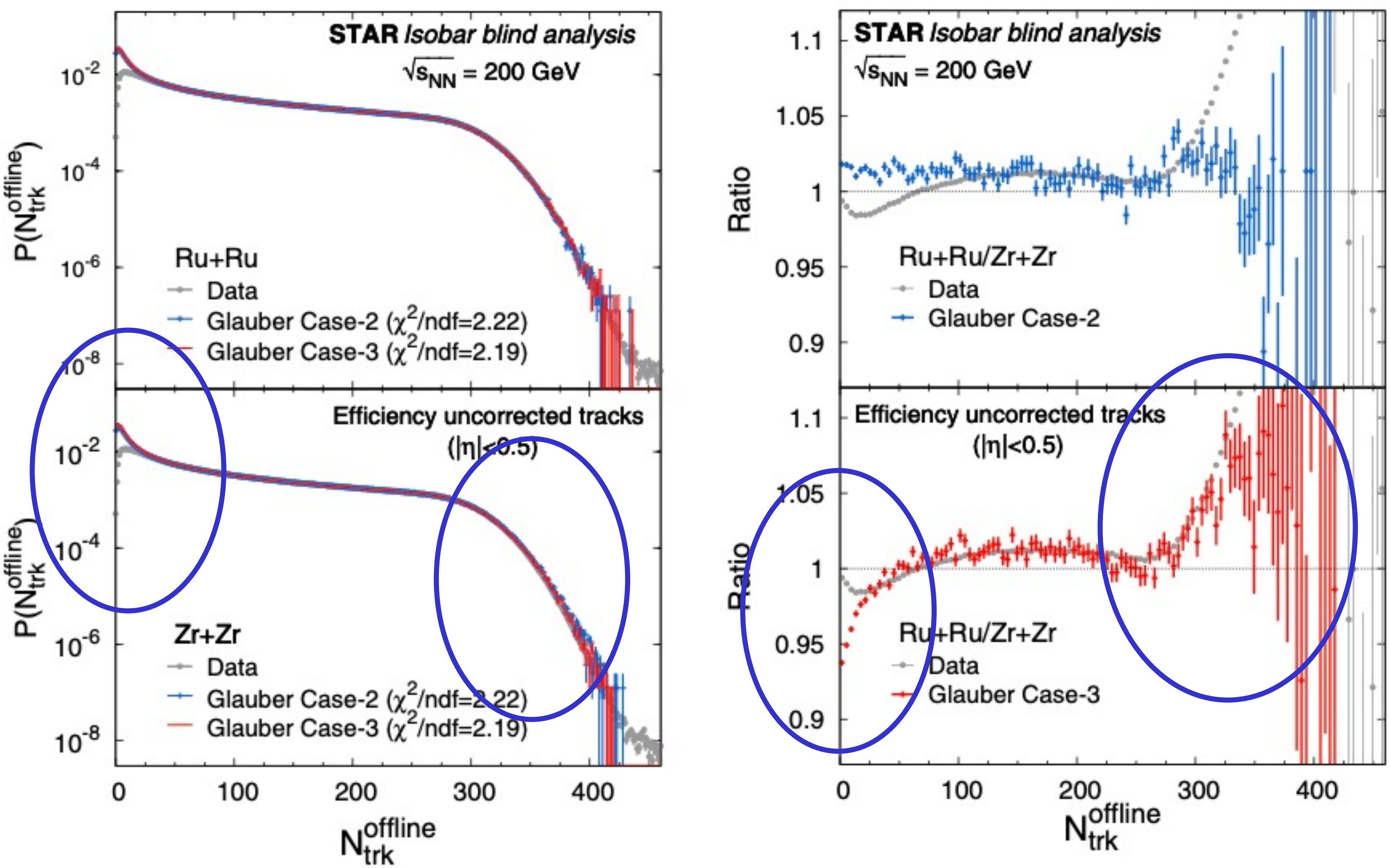




γ-A scale with charge number Z^2 (Z, in-coherent) -> $|B|^2$ ($|B|$)

1. Multiplicity different due to γ-A interaction
2. Z charge (B) dependent $\Delta\gamma$ background from (γ-A -> ρ) decay, where the vector ρ is almost aligned with E ($\perp$B) as the photon is polarized (so, this background is similar as CME signal)

Multiplicity difference due to γ-A interaction



Multiplicity difference due to γ-A interaction in the rapid change region

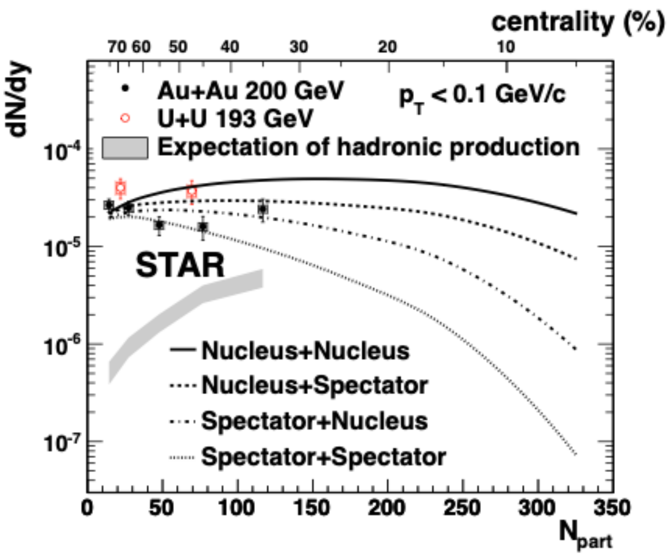
Rough estimation

	hardonic interaction (A-A)		UPC	
γ-A -> ρ	coherent	In-coherent	coherent	In-coherent
Exp.	No	No	Yes	Yes
Model cal.	No	No	Yes	Yes
γ-A -> J/psi	coherent	In-coherent	coherent	In-coherent
Exp.	Yes	No	Yes	Yes
Model cal.	Yes	No	Yes	Yes

$$\rho^{coh.}\,(A\text{-}A) = Jpsi^{coh.}\,(A\text{-}A)*\rho^{coh.}\,(UPC)/\,Jpsi^{coh.}\,(UPC)$$

$$\rho^{inc.}\,(A\text{-}A) = \rho^{coh.}\,(A\text{-}A) * \rho^{inc.}\,(UPC)/\,\rho^{coh.}\,(UPC)$$

Rough estimation



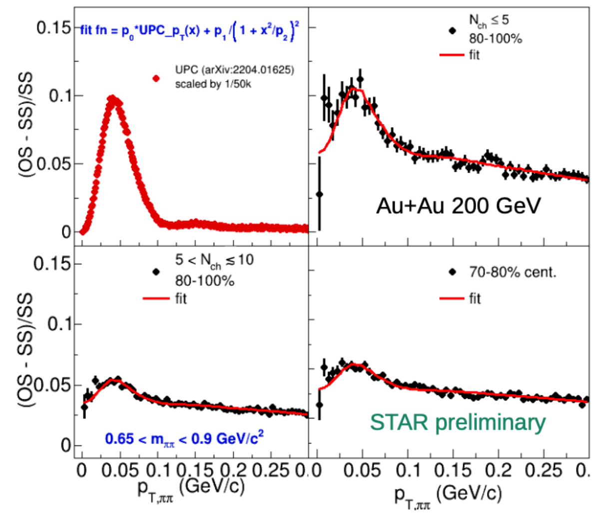
TABLES

TABLE I. Cross sections and median impact parameters b_m, for production of vector mesons.

Meson	overall		XnXn		1n1n	
	σ [mb]	b_m [fm]	σ [mb]	b_m [fm]	σ [mb]	b_m [fm]
Gold beams at RHIC ($\gamma_{cm} = 108$)						
ρ^0	590	46	39	18	3.5	19
ω	59	46	3.9	18	0.34	19
ϕ	39	38	3.1	18	0.27	19
J/ψ	0.29	23	0.044	17	0.0036	18
Lead beams at LHC ($\gamma_{cm} = 2940$)						
ρ^0	5200	280	210	19	12	22
ω	490	290	19	19	1.1	22
ϕ	460	220	20	19	1.1	22
J/ψ	32	68	2.5	19	0.14	21

TABLE VII. The coherent and incoherent cross sections for ρ^0 photoproduction within $|y| < 1$ with $XnXn$ and $1n1n$ mutual excitation, and their ratios.

Parameter	$XnXn$	$1n1n$
$\sigma_{coh.}$	6.49 ± 0.01 (stat.) ± 1.18 (syst.) mb	0.770 ± 0.004 (stat.) ± 0.140 (syst.) mb
$\sigma_{incoh.}$	2.89 ± 0.02 (stat.) ± 0.54 (syst.) mb	0.162 ± 0.010 (stat.) ± 0.029 (syst.) mb
$\sigma_{incoh.}/\sigma_{coh.}$	0.445 ± 0.015 (stat.) ± 0.005 (syst.)	0.233 ± 0.007 (stat.) ± 0.007 (syst.)



Isaac Upsal, DNP2022

STAR, Phys. Rev. Lett. 123 (2019) 132302， Phys. Rev. C 96, 054904 (2017)

- γ-A -> ρ in A-A hardonic interaction is not measured yet due to large combinatorial background (some hit of signal)
- γ-A -> J/psi in A-A had some data and calculation
- Use the ρ/(J/psi) ratio in UPC for a rough estimation (590/0.29~2000)

Rough estimation

$\rho^{coh.}$ (Au+Au) = 2.5*10^{-5}* 2000 = 0.05

$\rho^{inc.}$ (Au+Au) = 0.05*(0.2+0.4)/2=0.015

$\rho^{coh.}$ (Isobar) = 0.05*96/197 = 0.025

$\rho^{inc.}$ (Isobar) = 0.015*96/197 = 0.0075

γ-A scale with charge number Z^2 (Z, in-coherent) -> $|B|^2$ (|B|)

$\rho^{coh.}$ (Ru+Ru) = 0.025*(1+(44^2-40^2)/ (44^2+40^2)) = 2.74e-2

$\rho^{inc.}$ (Ru+Ru) = 0.075*(1+(44-40)/ (44+40)) = 7.85e-3

$\rho^{coh.}$ (Zr+Zr) = 0.025*(1-(44^2-40^2)/ (44^2+40^2)) = 2.26e-2

$\rho^{inc.}$ (Zr+Zr) = 0.075*(1-(44-40)/ (44+40)) = 7.14e-3

Rough estimation

TABLE I. Simulation inputs: primordial $\pi^\pm$ rapidity densities $dN_{\pi^\pm}/dy$ (obtained from inclusive pion dN/dy minus resonance contributions, and assumed $\pi^+ = \pi^-$), and p_T spectra $dN_{\pi^\pm}/dm_T^2 \propto (e^{m_T/T_{BE}} - 1)^{-1}$, where $m_T = \sqrt{p_T^2 + m_\pi^2}$ (m_π is the $\pi^\pm$ rest mass); dN/dy ratios of resonances to inclusive pion ($\pi_{\rm inc} \equiv \pi^+_{\rm inc} + \pi^-_{\rm inc}$), assumed centrality independent, and ρ p_T spectrum (obtained from fit to 200 GeV Au+Au data of the 40–80% centrality [19]) used for all resonances (ρ,η,ω) in all centralities; and $v_2/n = a/(1+e^{-[(m_T-m_0)/n-b]/c}) - d$, where $n = 2$ is the number of constituent quarks (NCQ) and m_0 is the particle rest mass for π,ρ,η,ω, respectively. The T_{BE} and $\pi_{\rm inc}$ dN/dy are from Bose-Einstein fit to the measured inclusive pion spectra [20,21], and the a,b,c,d parameters are from fit to the measured inclusive pion v_2 [22,23] by the NCQ-inspired function [24].

Centrality	$dN_{\pi^\pm}/dy$	T_{BE} (GeV)	a	b (GeV)	c (GeV)	d	Resonances ρ,η,ω
70–80%	7.8	0.171	0.118	0.180	0.155	0.024	
60–70%	16.7	0.179	0.140	0.116	0.173	0.046	dN/dy ratios:
50–60%	31.9	0.185	0.123	0.157	0.155	0.029	$2\rho/\pi_{\rm inc} = 0.169$ [19],
40–50%	53.9	0.190	0.136	0.145	0.175	0.039	$\eta/\rho = 0.47$, $\omega/\rho = 0.59$ [25]
30–40%	85.7	0.195	0.125	0.170	0.177	0.031	p_T spectra:
20–30%	129	0.198	0.125	0.147	0.210	0.039	$\frac{d^2N_{\rm res}}{m_T dm_T dy} = \frac{dN_{\rm res}/dy}{T(m_0+T)} e^{-(m_T-m_0)/T}$
10–20%	186	0.219	0.096	0.155	0.212	0.030	$T = 0.317$ GeV [19]
0–10%	262	0.219	0.041	0.214	0.145	0.006	

Isobar (20-50%) ρ $^{\text{hardonic}}$ = 70*0.169*96/197 ~ 5

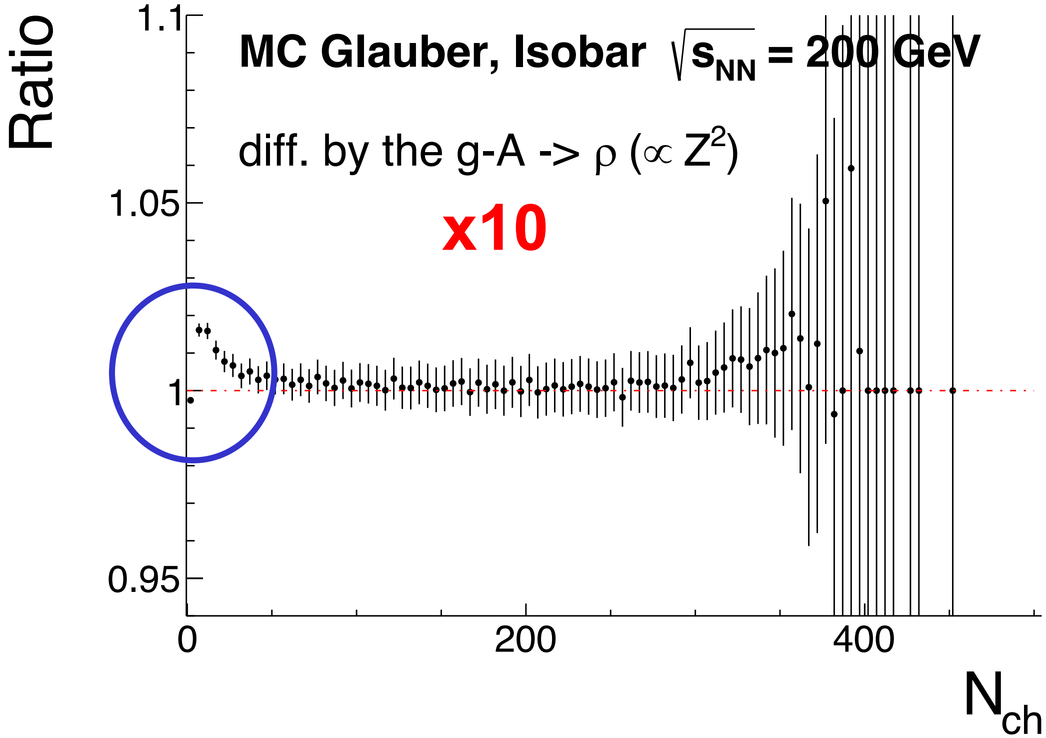
$\rho^{\text{coh.}}$ (Isobar) = 0.025

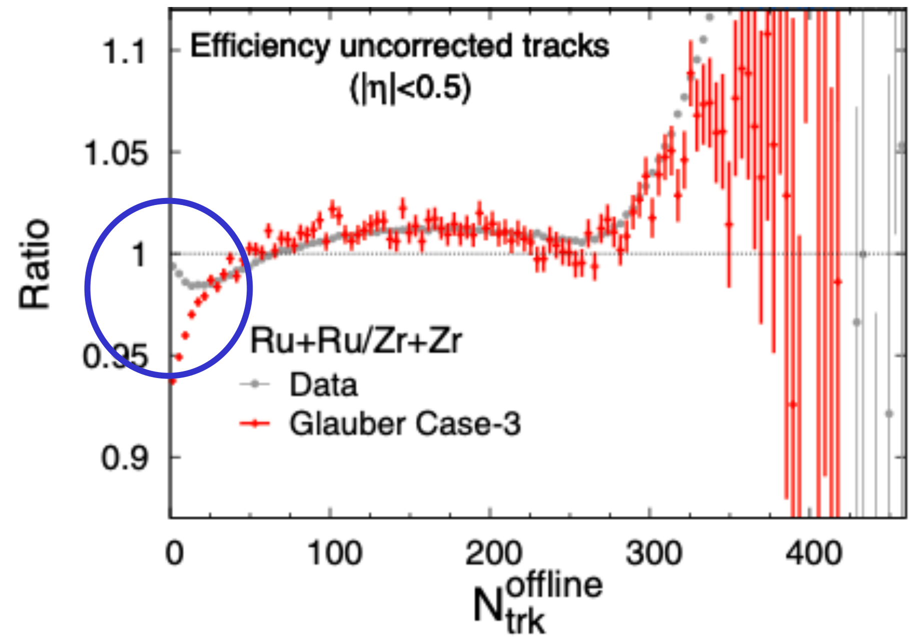
$\rho^{\text{inc.}}$ (Isobar) = 0.0075

$N_{ch}(|\eta|<1)$ shift by ~ 0.025*2*2=0.1
diff. by ~0.1*15%=0.015

- ρ photo-production is 1/200 small than hardonic production, in 20-50%
  assume 5 times large v_2 for the ρ from photo-production,
  and only 1/3 background from ρ decay
  difference for the in-coherent is 44-40/(44+40)=9.5%
  difference for the coherent is 19% (average above ~15%)
  the isobar difference due to the γ-A -> ρ bkg. ~ 1/200*5/3*15% ~ **1/1000**
  using pair pT>0.1 could reduce the coherent contribution, -> ~ 1/4000

Glauber Model Test





Isobar (20-50%) $\rho^{\text{ hardonic}}$ = 70*0.169*96/197 ~ 5

$\rho^{coh.}$ (Isobar) = 0.025

$\rho^{inc.}$ (Isobar) = 0.0075

$N_{ch}(|\eta|<1)$ shift by ~ 0.025*2*2=0.1
diff. by ~0.1*15%=0.015

γ-A scale with charge number Z^2 (Z, in-coherent) -> $|B|^2$ (|B|)

Summary

- The Chiral Magnetic Effect (CME) is extremely important in QCD
- The possible CME signal ~5-10% of the early measurements, with 1-3σ significance, nonflow may be present. RHIC 2023-2025, ~x10 more Au+Au data
- No signatures have been observed in the isobar
- Progresses on the ESE. Theoretical inputs