STAR probes of fundamental QCD symmetries and novel collective phenomena in relativistic heavy ion collisions

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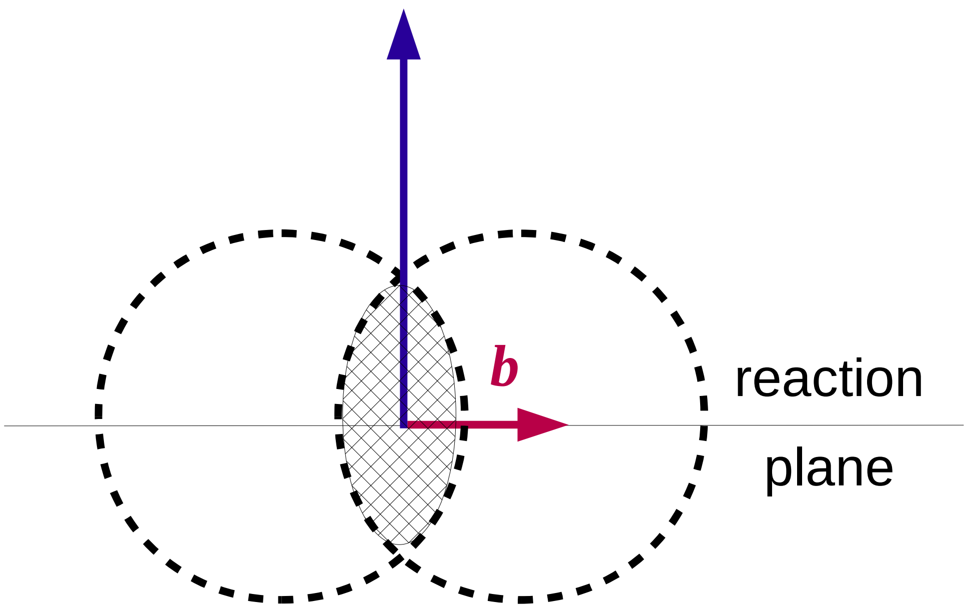
Non-central relativistic heavy ion collision (HIC)

$\mathbf{B}$ - magnetic field

$\mathbf{L}$ - orbital momentum



$\boldsymbol{b}$ – impact parameter

Colliding nuclei are moving out-of-list

- Overlapped area:
  non-uniform particle density
  and pressure gradient

- Large orbital angular momentum:

$$\mathbf{L} \sim 10^5$$

Liang, Wang, PRL94:102301 (2005)
Liang, JPG34:323 (2007)

- Strong magnetic field:

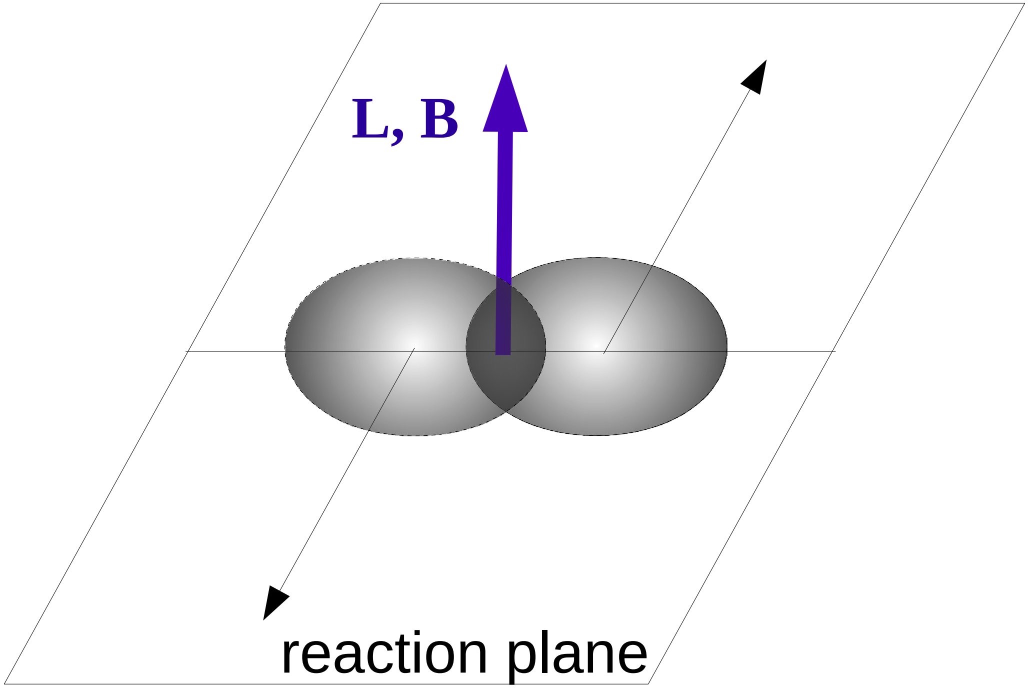
$$\mathbf{B} \sim 10^{15}\,\mathrm{T} \qquad (e\mathbf{B} \sim 10^4\,\mathrm{MeV}^2)$$

$$(\mu_{\mathrm{N}}\mathbf{B} \sim 100\,\mathrm{MeV})$$

Rafelski, Müller PRL36:517 (1976)
Kharzeev, PLB633:260 (2006)
Kharzeev, McLerran, Warringa
NPA803:227 (2008)

Particle production in HIC: asymmetries wrt. the reaction plane

L - orbital momentum
B - magnetic field



Anisotropic transverse flow

Initial space anisotropy
of the overlapped area
evolves into momentum space

Global polarization/spin alignment

Preferential orientation of
the spin of produced particles
wrt. the system orbital momentum

Local strong parity violation

Charge separation along the
magnetic field/orbital momentum

Experimental observation of these effects provide:

- Information on initial condition & evolution of the system created in HIC
- Insight on hadronization mechanism & origin of hadronic spin
- A probe of fundamental QCD symmetries

Anisotropic flow

Anisotropic transverse flow

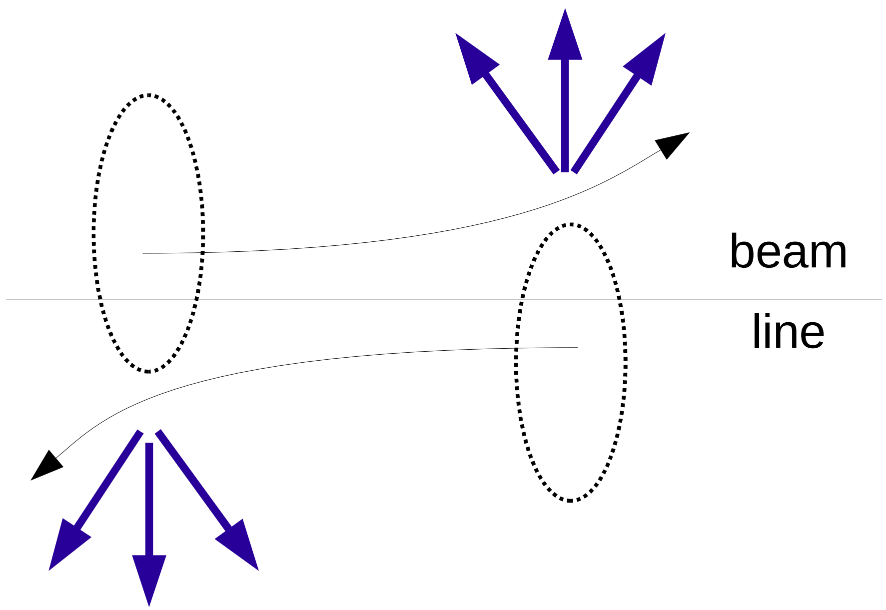
Fourier decomposition of particle azimuthal distribution wrt. the reaction plane:

$$\frac{dN}{d\phi} \sim 1+2\sum_{n=1} v_n \cos(n[\phi-\Psi_{RP}])$$

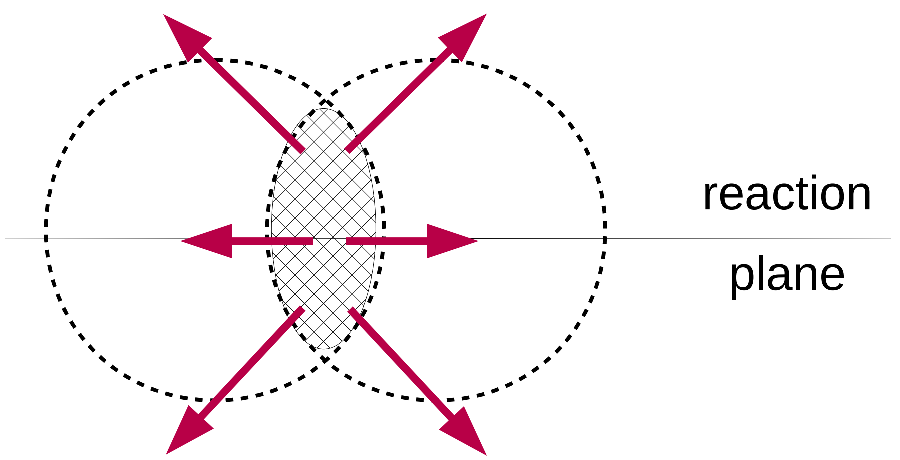
Ψ_{RP} - reaction plane (RP) angle

ϕ - particle azimuthal angle

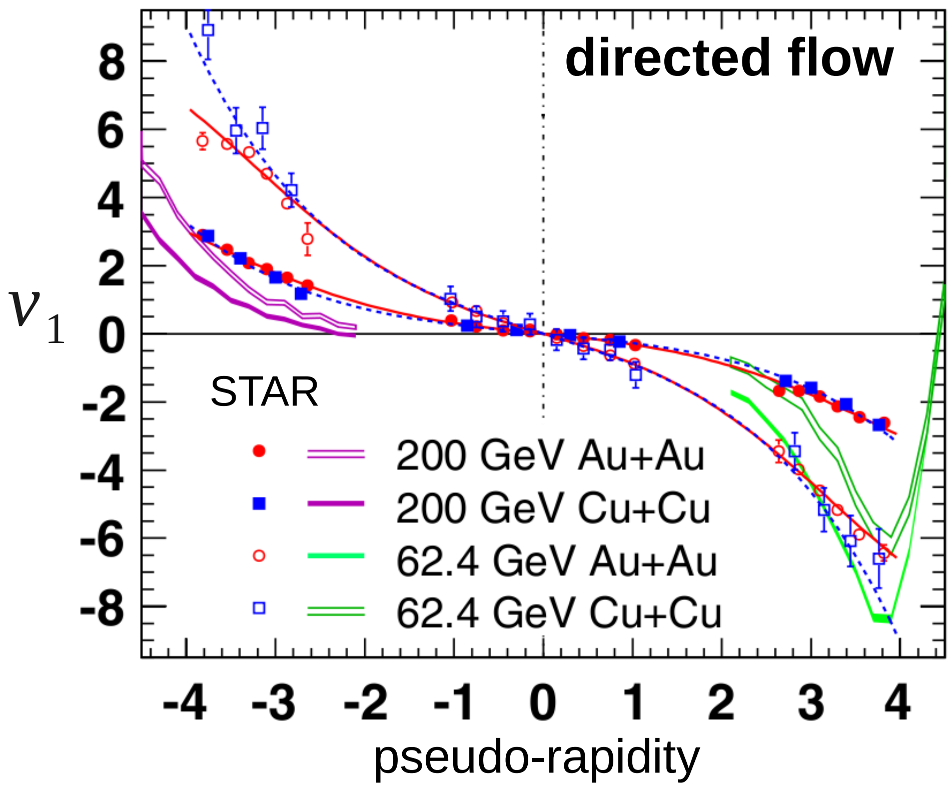
Directed flow: $v_1 = \langle \cos(\phi - \Psi_{RP}) \rangle$

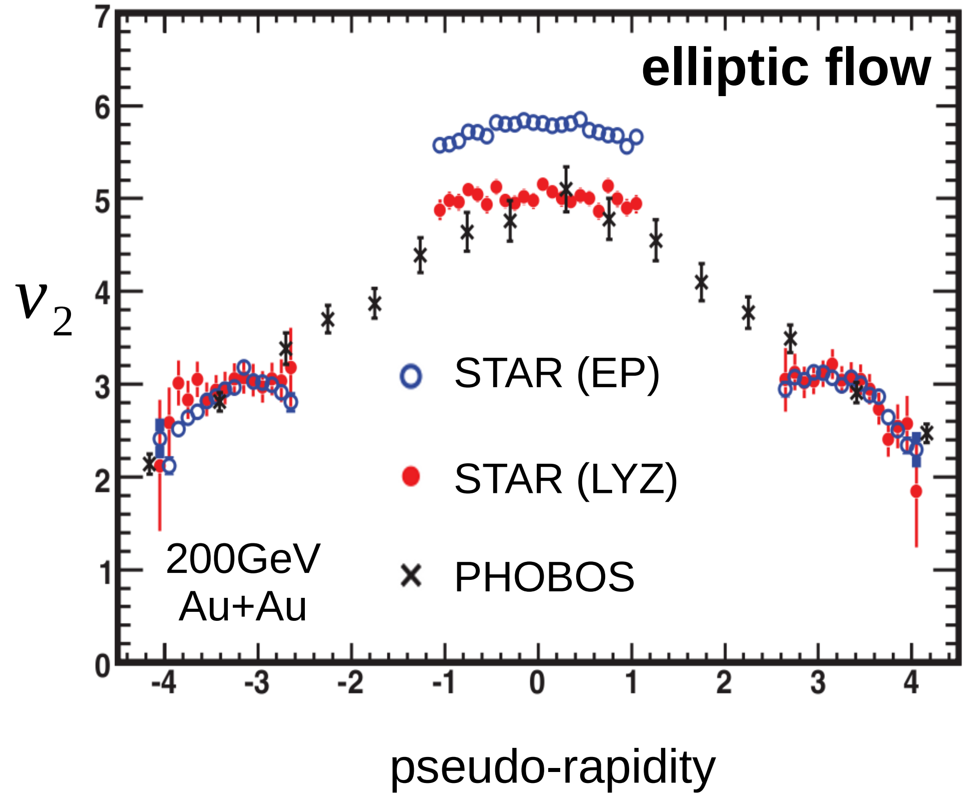


Elliptic flow: $v_2 = \langle \cos(2[\phi - \Psi_{RP}]) \rangle$



Charged particle flow at RHIC





STAR papers as principal author:

Directed flow:
PRC 73:034903 (2006)
PRL 101:252301 (2008)

Elliptic flow:
PRC 75:054906 (2007)
PRC 77:054901 (2008)
arXiv:1001.5052 (2010)

Method paper on acceptance effects:
Selyuzhenkov & Voloshin **PRC** 77:034904 (2008)

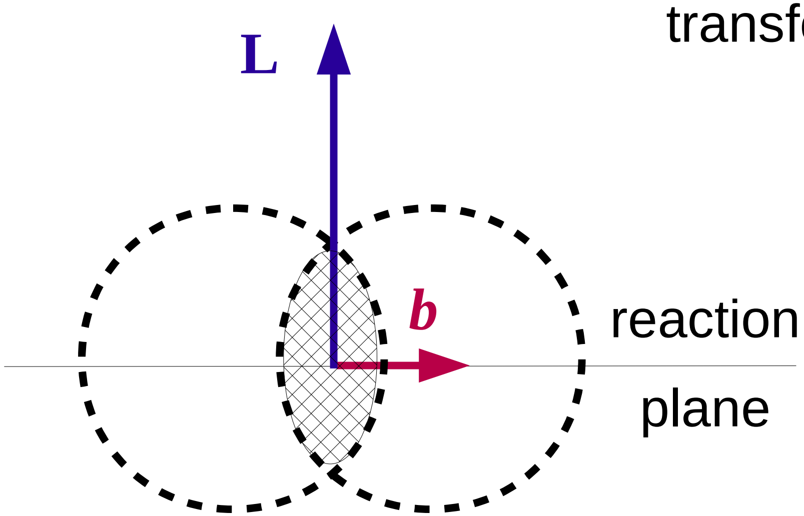
Strong collectivity at RHIC:

- Probe early stage of collision
- Test hydrodynamic predictions
- Quark Gluon Plasma signature

Global polarization

Global polarization and spin alignment in HIC

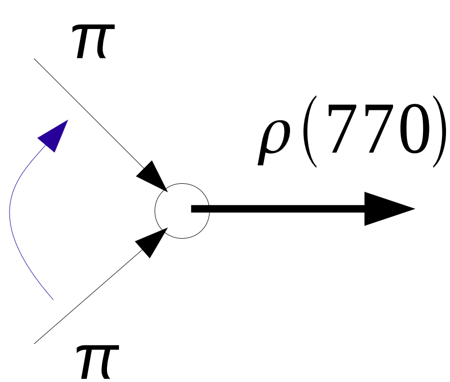
Orbital angular momentum → spin-orbital transformation → preferential orientation of the spin of produced particles along the system orbital momentum



Liang&Wang **PRL**94:102301 (2005)
Voloshin **arXiv**:nucl-th/0410089

Relative orbital momentum

$$\vec{l}_{\pi\pi} \parallel \vec{L}$$



$$\vec{l}_{\pi\pi} \longrightarrow \vec{J}_{\rho} \parallel \vec{L}$$

Theory calculations

- Exclusive parton recombination:

$$P_{\Lambda,\bar{\Lambda}} = P_q \approx 0.3$$

Liang&Wang **PRL**94:102301 (2005)
erratum: 039901 (2006)

- HTL gluon propagator:

$$-0.03 < P_q < 0.15$$

Liang **JPG**34:S323 (2007)

Sensitivity to:
- evolution of the system
- hadronization mechanism
- origin of hadronic spin

Hyperon's global polarization

$$\frac{dN}{d\cos\theta^*} \sim 1+\alpha_H P_H \cos\theta^*$$

Reconstruct hyperon spin via its weak, self-analyzing decay

P_H - hyperon global polarization

α_H - decay constant: $\alpha_{\Lambda(\bar{\Lambda})}=\pm 0.642$

θ^* - angle between the system orbital momentum and the hyperon decay baryon 3-momentum in the hyperon's rest frame

---

Observable

$$P_H=\frac{3}{\alpha_H}\langle\cos\theta^*\rangle$$

$\phi_p^*(\theta_p^*)$ - decay baryon azimuthal (polar) angle in hyperon's rest frame

Using angle relation:

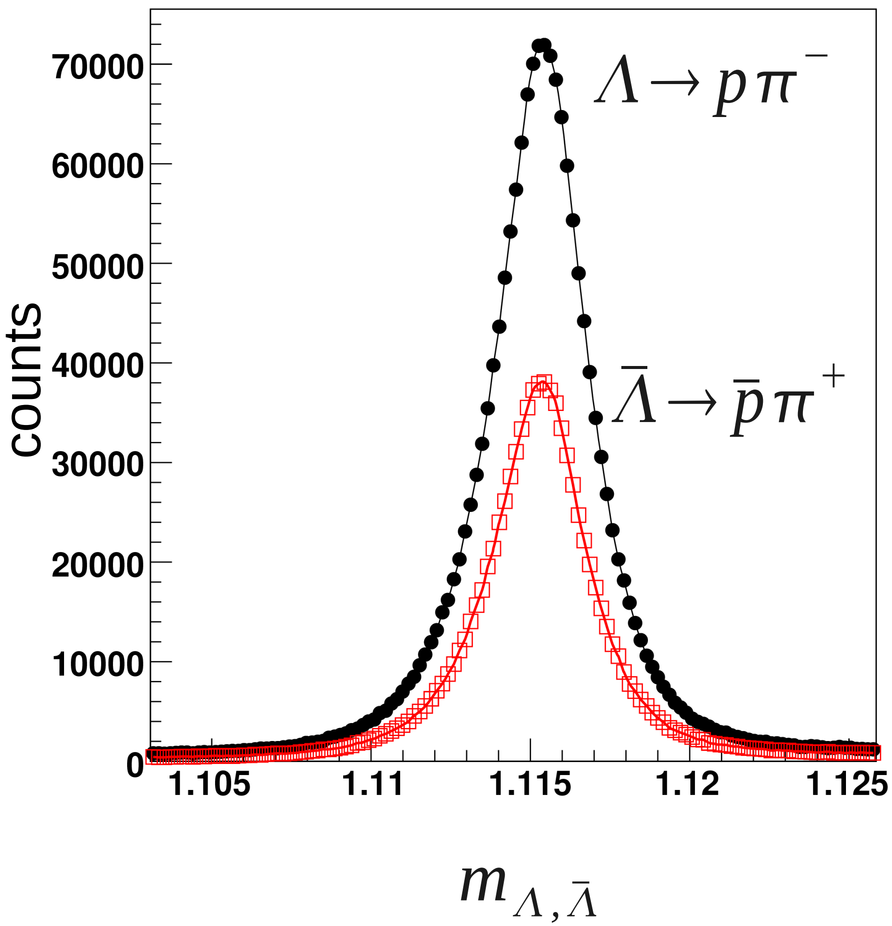
$$\cos\theta^* = \sin\theta_p^* \; \sin(\phi_p^*-\Psi_{RP})$$

$$P_H= \frac{8}{\pi\alpha_H}\langle\sin(\phi_p^*-\Psi_{RP})\rangle$$

similar to directed flow observable
→ anisotropic flow measurement technique!

Global polarization: systematics study

62 GeV Au+Au



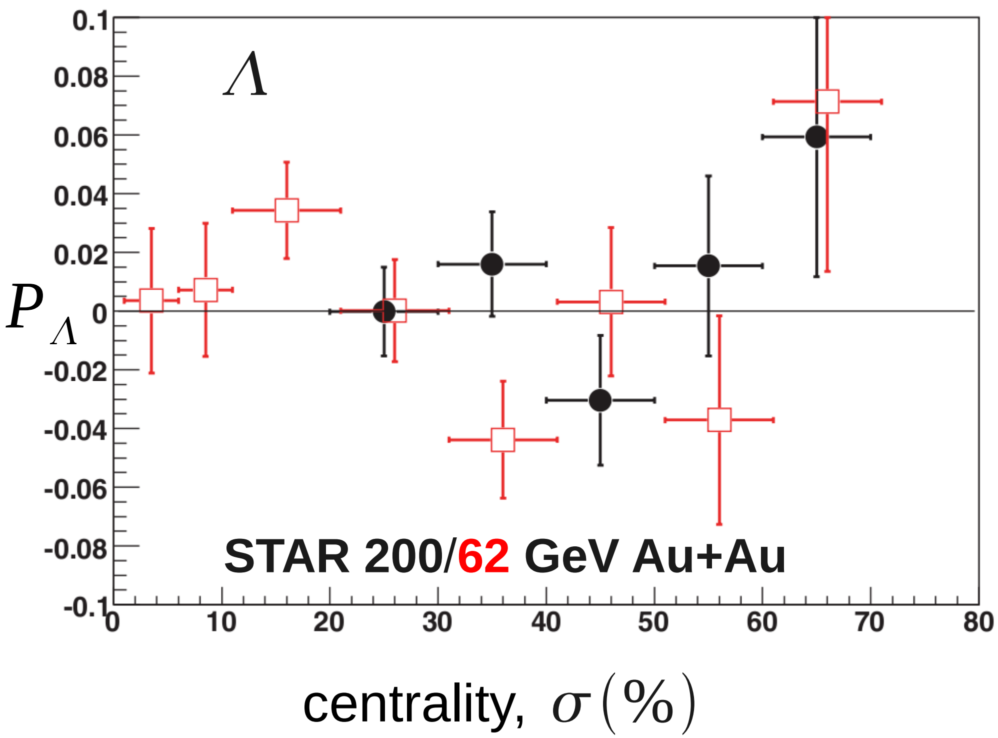
• Background, K_S^0 contamination	8%
• Non uniform detector acceptance	20%
• Higher harmonics contribution	20%
• Reaction plane reconstruction	30%
• Spin precession	0.1%
• Multi-strange feed-down	15%
• Σ^0 feed-down	30%
• Decay parameter $\alpha_{\Lambda(\bar{\Lambda})}$ error	2%
• Hyperon directed flow contribution	1%

- Comparison between $\bar{\Lambda}$ and Λ results
- Verify results with Monte-Carlo simulations

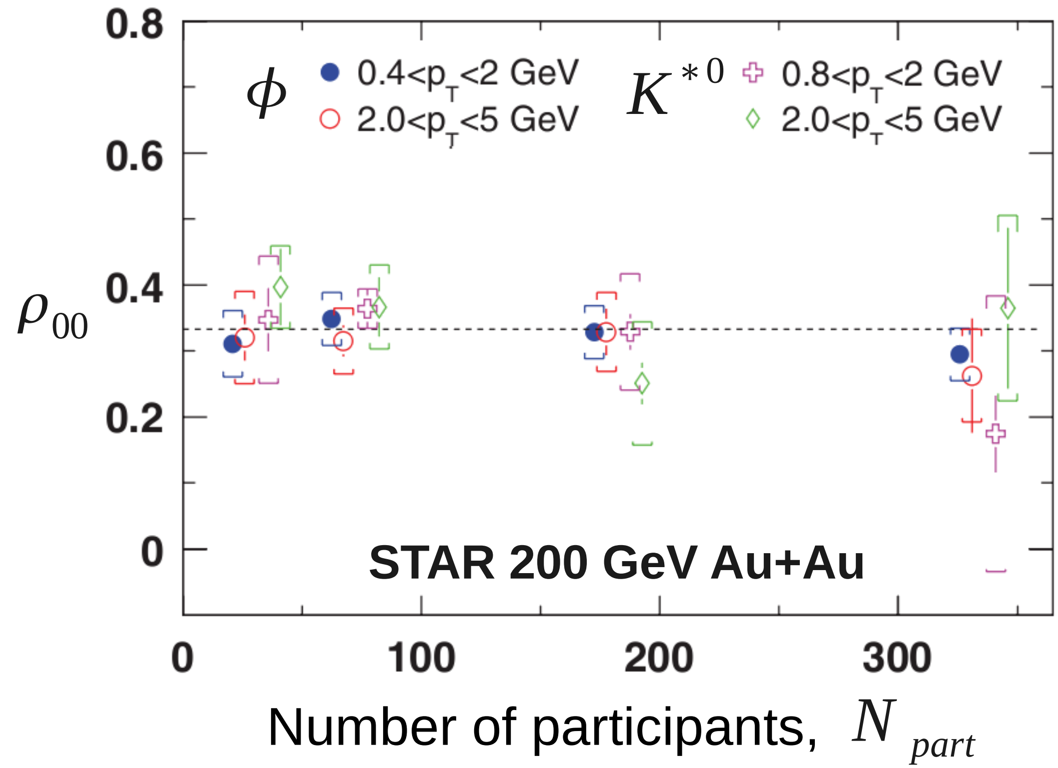
Overall (relative) systematic error: < factor of 2

STAR measurements of global polarization

Strange hyperon ($\Lambda/\bar{\Lambda}$) polarization



Vector meson (ϕ/K^{*0}) spin alignment



$$|P_{\Lambda/\bar{\Lambda}}| < 0.02$$

$$|\rho_{00} - 1/3|_{\phi/K^{*0}} = 0.010 \pm (0.036/0.098)$$

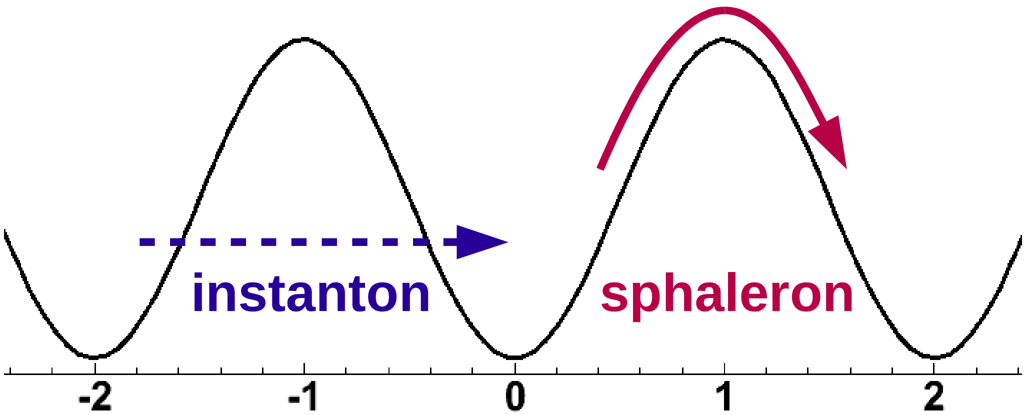
STAR papers as principal author:
Polarization: **PRC** 76:024915 (2007)
Alignment: **PRC** 77:061902 (2008)

Consistent with no/small polarization:
→ No transformation of global orbital momentum into particle's spin?

Local strong parity violation

Chiral symmetry breaking and P-violation

QCD vacuum (gluonic field energy) is periodic vs. Chern-Simons number, N_{CS}:



N_{CS} (generalized coordinate)

Localized in space & time solutions.
Transitions between different vacua via **tunneling**/**go-over-barrier**

Quark interaction changes chirality, which is a P and T odd transition

P/CP invariance are (globally) preserved in strong interactions.

Evidence from neutron EDM (electric dipole moment) experiments:

Pospelov, Ritz, PRL83:2526 (1999)
Baker *et al.*, PRL97:131801 (2006)

$$\theta < 10^{-10}$$

If $\theta \neq 0$, then QCD vacuum breaks P and CP symmetry.

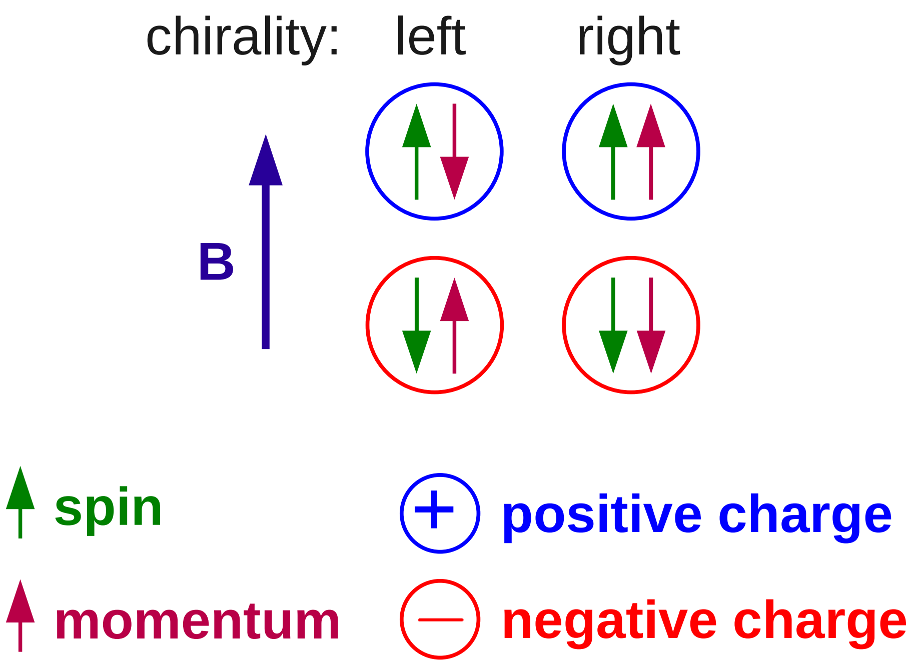
but:

In HIC formation of (local) metastable P-odd domains is not forbidden.

T.D. Lee, PRD8:1226 (1973)
Morley, Schmidt, Z.Phys.C26:627 (1985)
Kharzeev, Pisarski, Tytgat, PRL81:512 (1998)
Kharzeev, Pisarski, PRD61:111901 (2000)
Voloshin, PRC62:044901 (2000)
Kharzeev, Krasnitz, Venugopalan, PLB545:298 (2002)
Finch, Chikanian, Longacre,
Sandweiss, Thomas, PRC65:014908(2002)

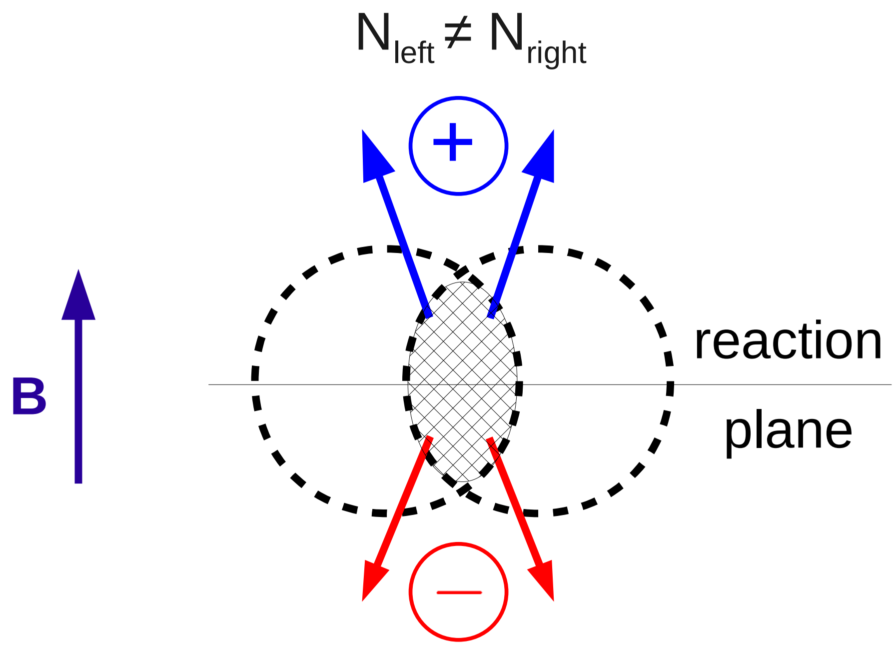
Charge separation in HIC

Magnetic field aligns quark spins along or opposite to its direction



Right-handed quark momentum is opposite to the left-handed one

Vacuum transitions produce local excess of left/right handed quarks:



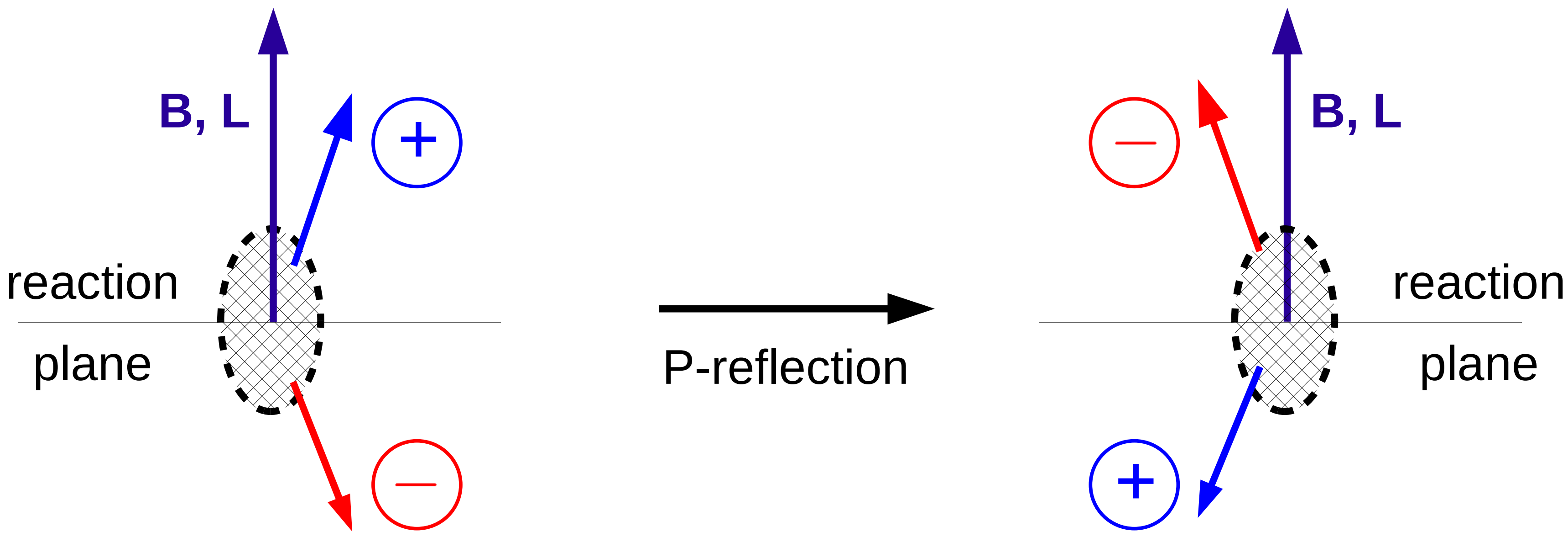
Induced electric field (parallel to B):

$$E \sim \theta \cdot B$$

Positive and negative charges moving opposite to each other
→ charge separation in a finite volume

Kharzeev, PLB633:260 (2006)
Kharzeev, Zhitnitsky, NPA797:67 (2007)
Kharzeev, McLerran, Warringa, NPA803:227 (2008)
Fukushima, Kharzeev, Waringa, PRD 78:074033 (2008)

Why charge asymmetry wrt. the reaction plane is P-violation?



Coordinate/momentum (vectors):

$$\vec{r} \to -\vec{r} \qquad \vec{p} \to -\vec{p}$$

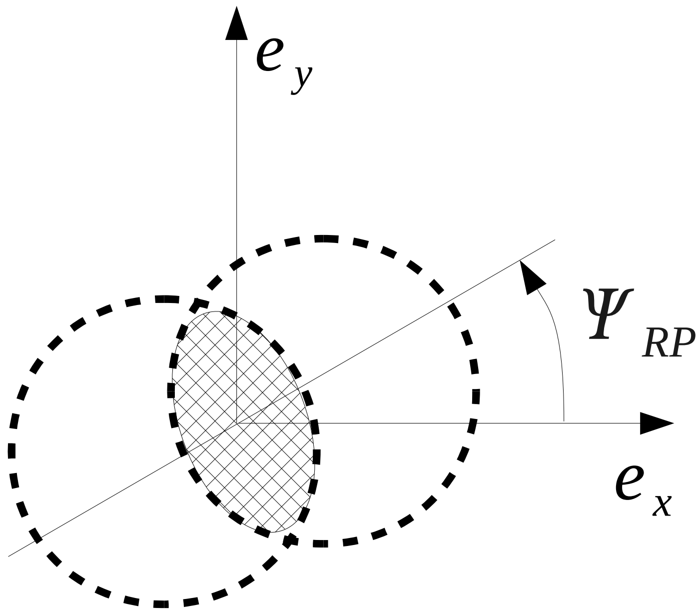
Orbital momentum/magnetic field (pseudo-vectors):

$$\vec{L} \to \vec{L} \qquad \vec{B} \to \vec{B}$$

Experimental observable

Azimuthal distribution in case of P-violation

$$\frac{dN_{\pm}}{d\phi} \sim 1+2\sum_{i=1} v_n \cos(n\Delta\phi) + 2a_{1,\pm}\sin\Delta\phi + \ldots$$



Ψ_{RP} reaction plane (RP) angle

$\Delta\phi = \phi - \Psi_{RP}$ particle azimuth relative to RP

v_n *n*-harmonic anisotropic transverse flow.
n=1 – directed flow, *n*=2 - elliptic flow

$a_{\pm}$ asymmetry in charged particle production
(consider only first harmonic)

e_z beam direction (out of sheet)

$e_x e_y e_z$ laboratory frame axes

Predicted asymmetry is about 1%
for mid-central collisions

→ within an experimental reach

Kharzeev, PLB633:260 (2006)

Observable

- Charge asymmetry is too small to be observed in a single event
- Asymmetry fluctuates event by event. P-odd observable yields zero: $\langle a_{\pm} \rangle = \langle \sin(\phi_{\pm} - \Psi_{RP}) \rangle = 0$
- Study P-even correlations: $\langle a_\alpha a_\beta \rangle$ $(\alpha, \beta = \pm)$
  Measure the difference between **in-plane** and **out-of-plane** correlations:

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle = \langle \cos\Delta\phi_\alpha \cos\Delta\phi_\beta \rangle - \langle \sin\Delta\phi_\alpha \sin\Delta\phi_\beta \rangle =$$

Voloshin PRC70:057901 (2004)

$$= [\langle v_{1,\alpha} v_{1,\beta} \rangle + Bg^{(in)}] - [\langle a_\alpha a_\beta \rangle + Bg^{(out)}]$$

$$\Delta\phi_{\alpha,\beta} = \phi_{\alpha,\beta} - \Psi_{RP}$$

- Large RP-independent background correlations cancel out in $Bg^{(in)}$ - $Bg^{(out)}$

  $Bg^{(in)}$ ($Bg^{(out)}$) denotes in- (out-of) plane background correlations

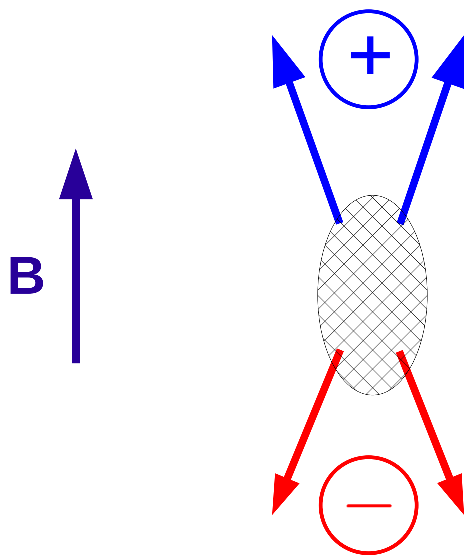
- RP-dependent (P-even) backgrounds contribute:
  → $Bg^{(in)}$ - $Bg^{(out)}$ term
  → $\langle v_{1,\alpha} v_{1,\beta} \rangle$: directed flow (zero in symmetric rapidity range) + flow fluctuations

Medium effects on charge correlations

P-odd domain formation

(no medium)

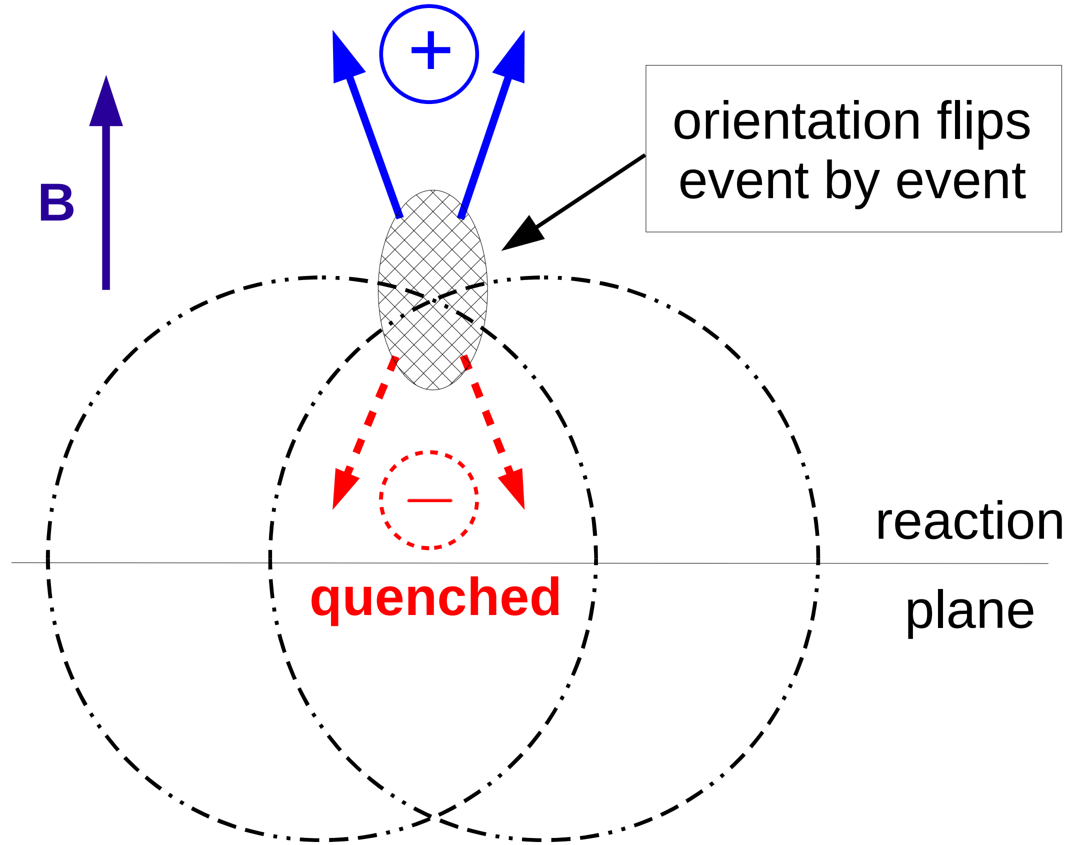
$$a_+ = -a_-$$



$$\langle a_+^2 \rangle = \langle a_-^2 \rangle > 0$$

$$\langle a_+ a_- \rangle = -\langle a_+^2 \rangle$$

Quenching in medium



$$\langle a_+^2 \rangle = \langle a_-^2 \rangle > 0$$

$$\langle a_+ a_- \rangle \ll -\langle a_+^2 \rangle$$

D. Kharzeev, PLB633:260 (2006)

Kharzeev, McLerran, Warringa, NPA803:227 (2008)

Expectations for charge correlations

- Magnitude: $a_{\pm} = \pm \frac{4}{\pi} \frac{Q}{N_{\pm}}$

  $Q = N_R - N_L$ - topological charge ($Q = \pm 1, \pm 2, ...$)

  $N_{\pm}$ - charged particle multiplicity $\langle Q \rangle \sim \sqrt{N_{\pm}}$

  For midcentral Au+Au collisions (1 P-odd domain/collision):
  $N_{\pm} \sim 100$ per unit of rapidity $\rightarrow a_{\pm} \sim 1\%$

  $$\langle a_{\alpha} a_{\beta} \rangle \sim 10^{-4}$$

- Correlation width in rapidity: about one unit
- Localized at $p_t < 1$ GeV/c (non-perturbative effect)
- Proportional to the magnetic field: $a_{\pm} \sim B$
- Stronger opposite-sign signal
  for a smaller colliding system (atomic number)

Kharzeev, PLB633:260 (2006)
Kharzeev, Zhitnitsky, NPA797:67 (2007)
Kharzeev, McLerran, Warringa, NPA803:227 (2008)
Fukushima, Kharzeev, Waringa, PRD78:074033 (2008)

Measurement technique

- Goal: 2-particle correlations wrt. the reaction plane (RP):

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$$

- In experiment RP is unknown
  → estimated from azimuthal distribution of produced particles:

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle / v_{2,c}$$

$v_{2,c}$ - elliptic flow of c-particle

Implies: c and (α, β) particles are correlated only via RP
→ validity needs to be tested experimentally

- Measuring (mixed harmonics) **3-particle azimuthal correlations:**

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle = -\langle a_\alpha a_\beta \rangle v_{2,c} + \text{[non-parity correlations]}$$

STAR probes of P-violation

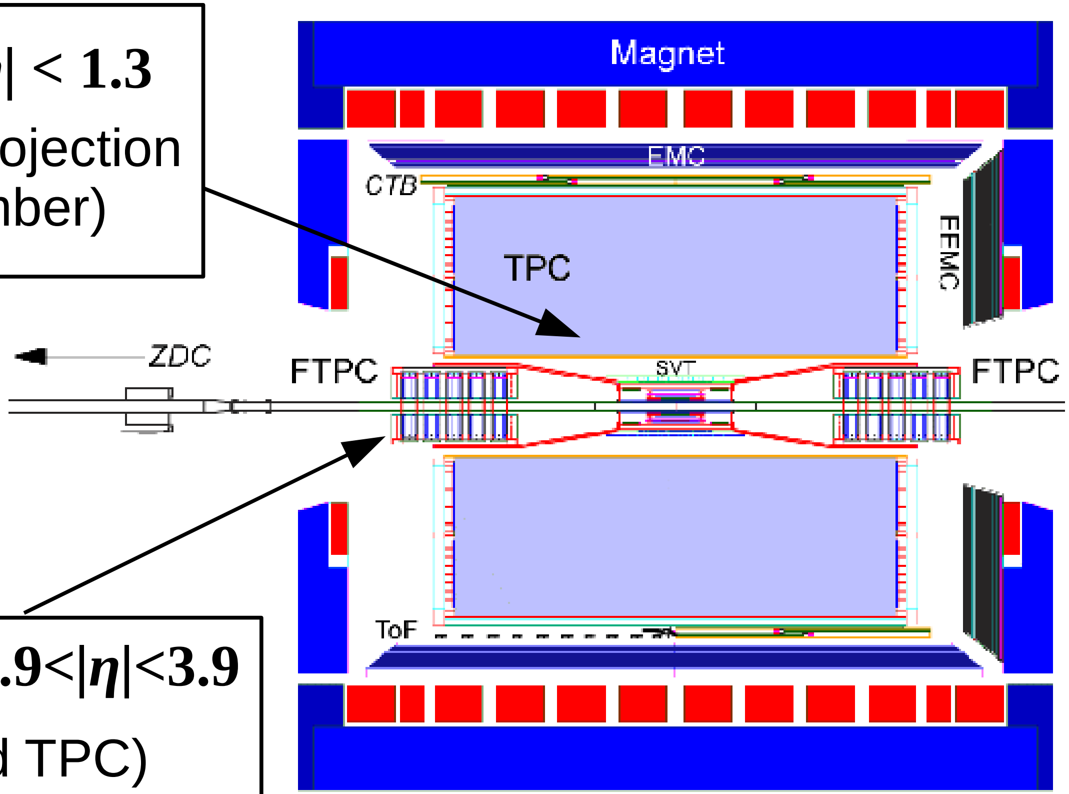
The STAR experiment

TPC: $|\eta| < 1.3$

(Time Projection Chamber)

FTPCs: $2.9<|\eta|<3.9$

(Forward TPC)



Charged particle cuts:

Pseudo-rapidity

$|\eta| < 1$

Transverse momentum

$0.15 < p_t < 2$ GeV/c

RP reconstruction with TPC, FTPCs and ZDC SMDs

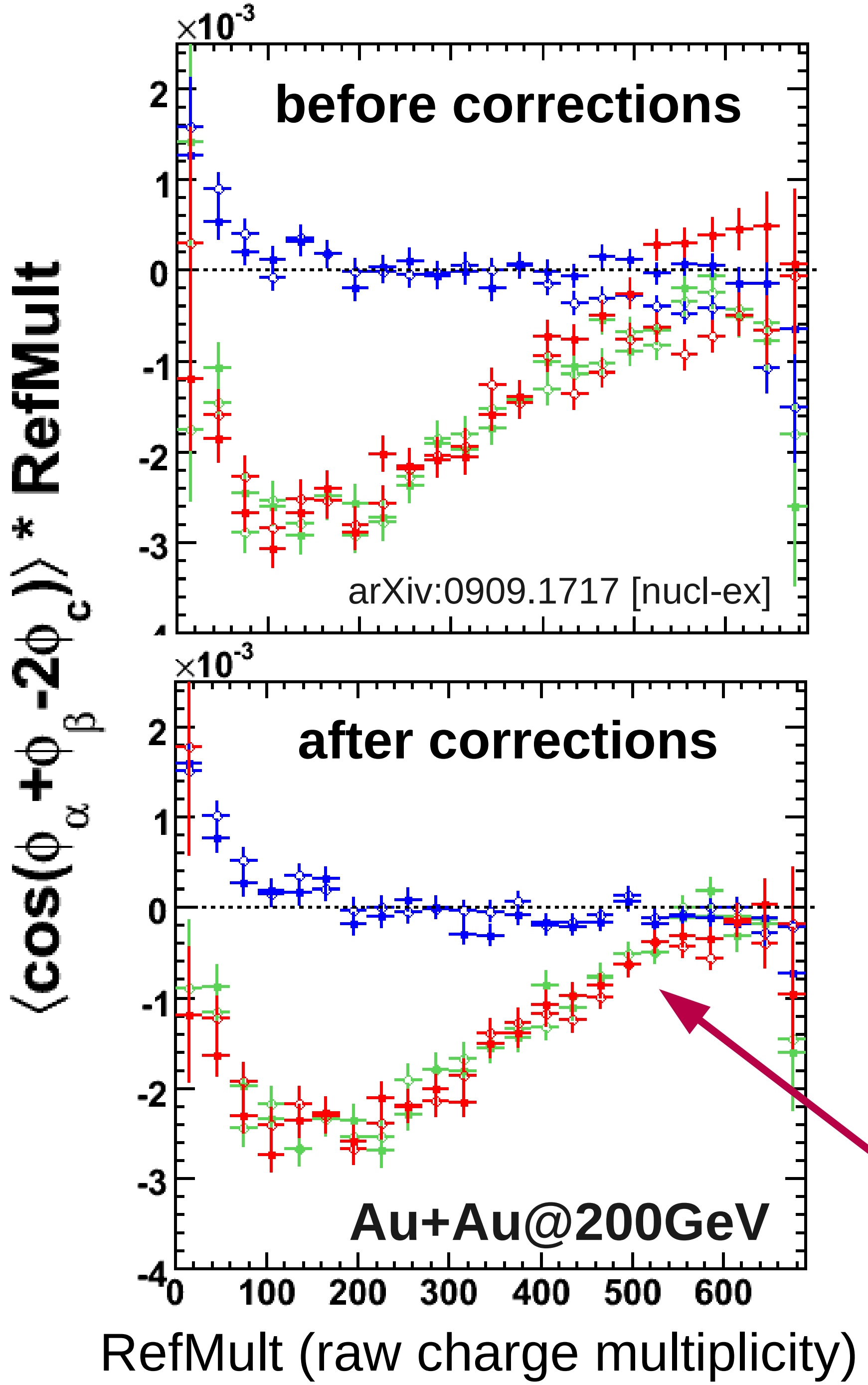
ZDC SMDs:
recoil neutrons at **beam rapidity**

(Zero Degree Calorimeter - Shower Maximum Detector)

Data from RHIC running in year 2004/2005

System	Energy, $\sqrt{s_{NN}}$	Events
Au+Au	200 / 62 GeV	10.6 / 7 M
Cu+Cu	200 / 62 GeV	30 / 19 M

Detector effects



Acceptance corrections (re-centering):

$$\sin n\phi \;\rightarrow\; \sin n\phi \;-\; \langle \sin n\phi \rangle$$

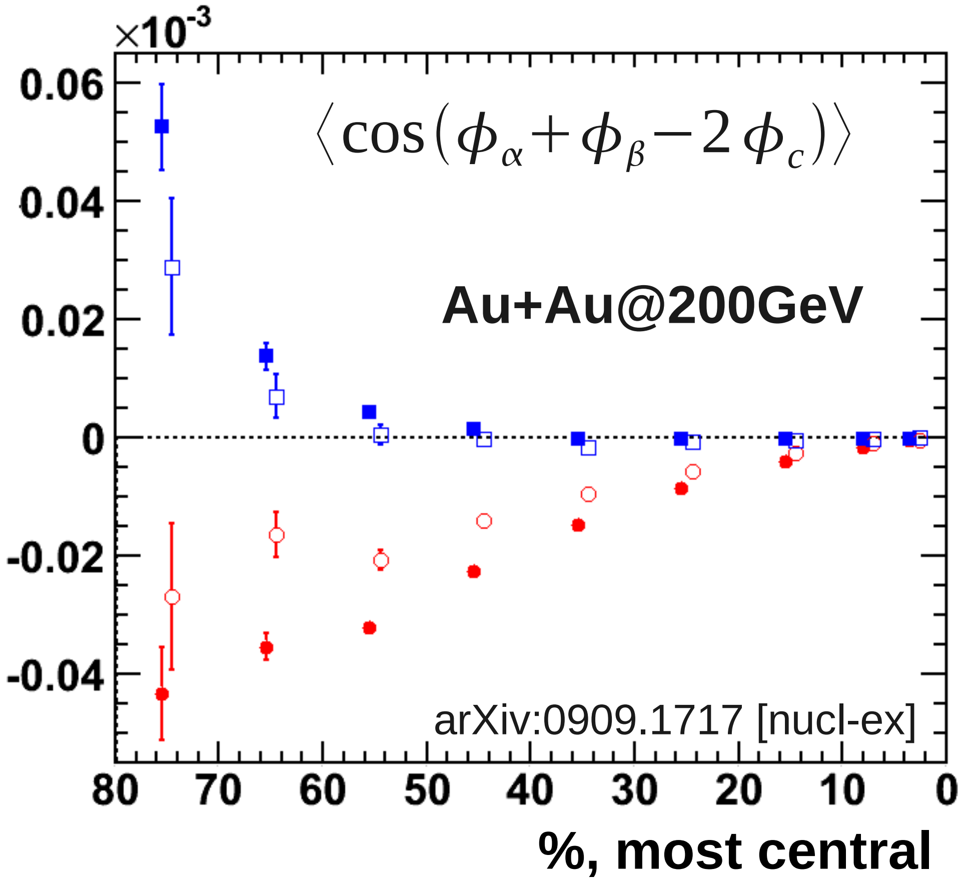
$$\cos n\phi \;\rightarrow\; \cos n\phi \;-\; \langle \cos n\phi \rangle$$

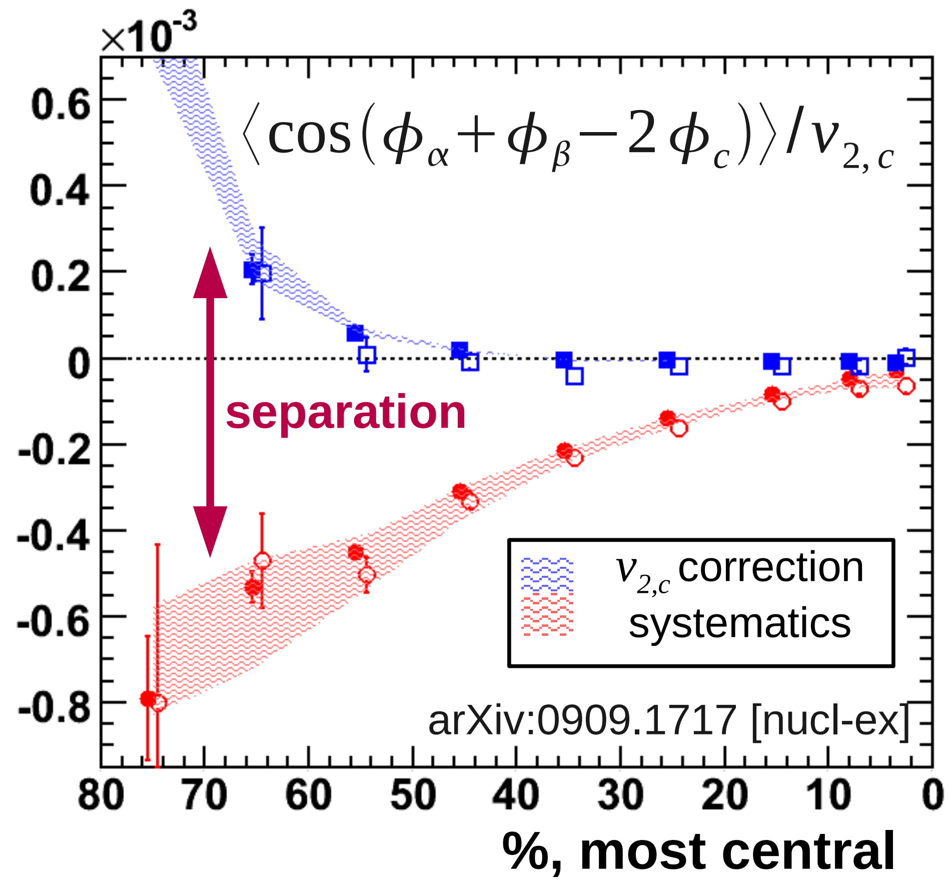
Poskanzer, Voloshin, PRC58:1671 (1998)
Borghini, Dinh, Ollitrault, PRC66:014905 (2002)
Selyuzhenkov, Voloshin, PRC77:034904 (2008)

symbol	*(α, β)* charges	*c*-particle
	opposite sign, + -	positive
	same sign, ++	
	same sign, - -	
	opposite sign, + -	negative
	same sign, ++	
	same sign, - -	

- After corrections: consistent results for all charge combinations
- Conclude from a number of tests:
  → detector effects are not responsible for observed correlations.

Testing sensitivity to 2-particle correlations wrt. RP





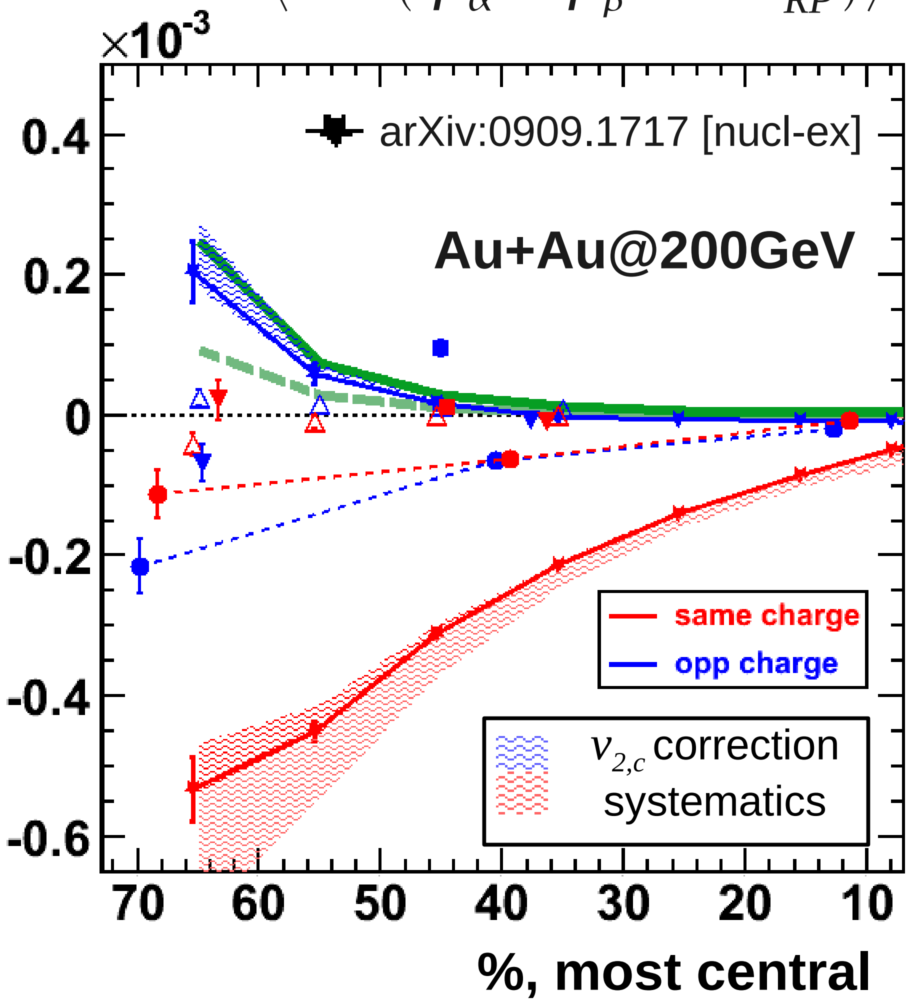
symbol	(α, β) charges	c-particle
● ■	same sign opposite sign	|η|<1.0 (TPC)
○ □	same sign opposite sign	2.9<|η|< 3.9 (FTPCs)

- $v_{2,c}$ correction gives consistent result with TPC/FTPC *c*-particle (similarly ZDC-SMD)

  → Probing 2-particle correlations wrt. RP
- Same- and opposite-sign correlations consistent with P-violation

Modeling physics backgrounds

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle = \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle / v_{2,c}$$



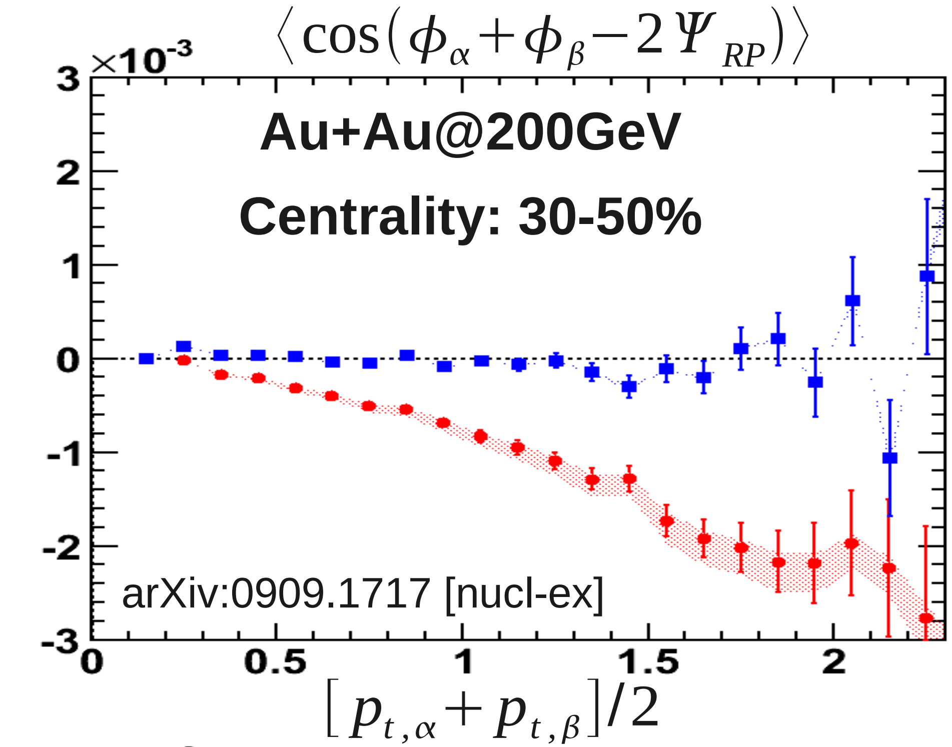
symbol	model	c-particle
▼ △ ● ■	**HIJING** **HIJING + v_2** **UrQMD** **MEVSIM**	true reaction plane
opposite (solid green line) same (dashed light-green line)	**HIJING 3-particle correlations**	$\|\eta\|<1.0$

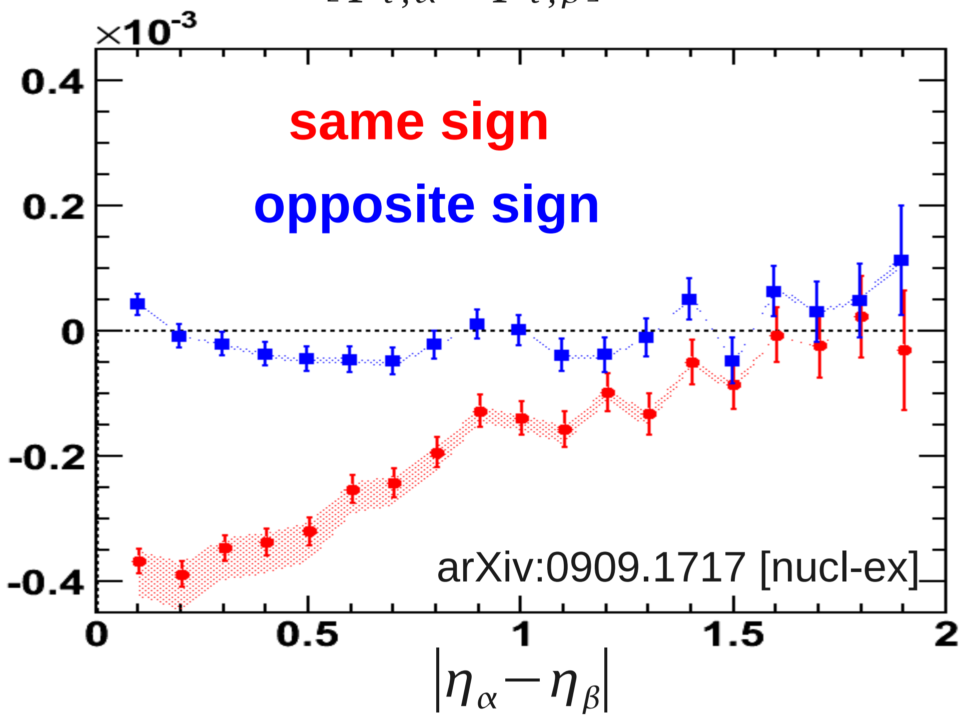
HIJING + v_2: added flow "afterburner"
MEVSIM: resonances with realistic flow

- Non-zero background correlations, but different from observed signal
- HIJING produce data-like opposite-sign 3-particle correlations:
  → opposite-sign signal can be diluted by effects not related to RP orientation

Note: cluster production is not well modeled by event generators

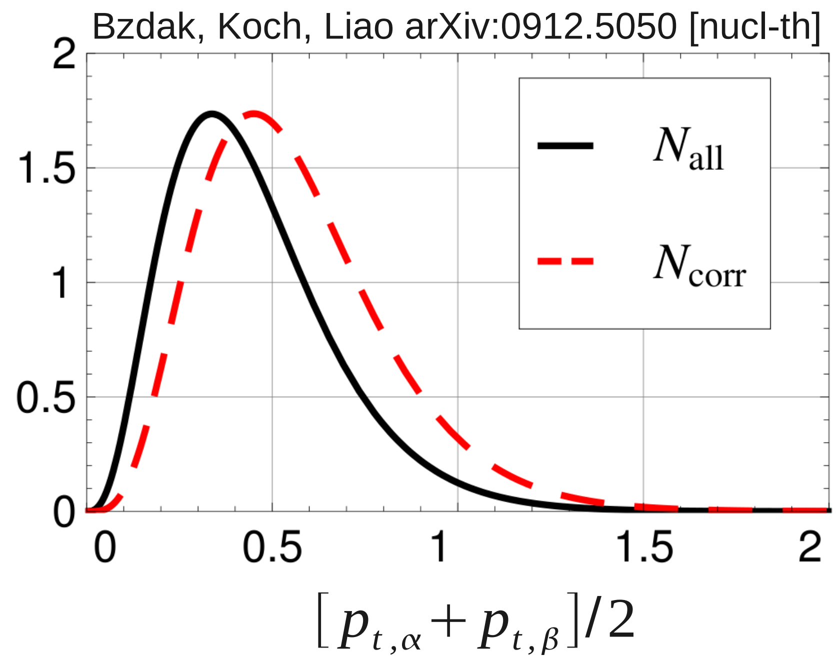
Pseudo-rapidity and transverse momentum dependence





Transverse momenta dependence:
→ the signal extends to higher pt?

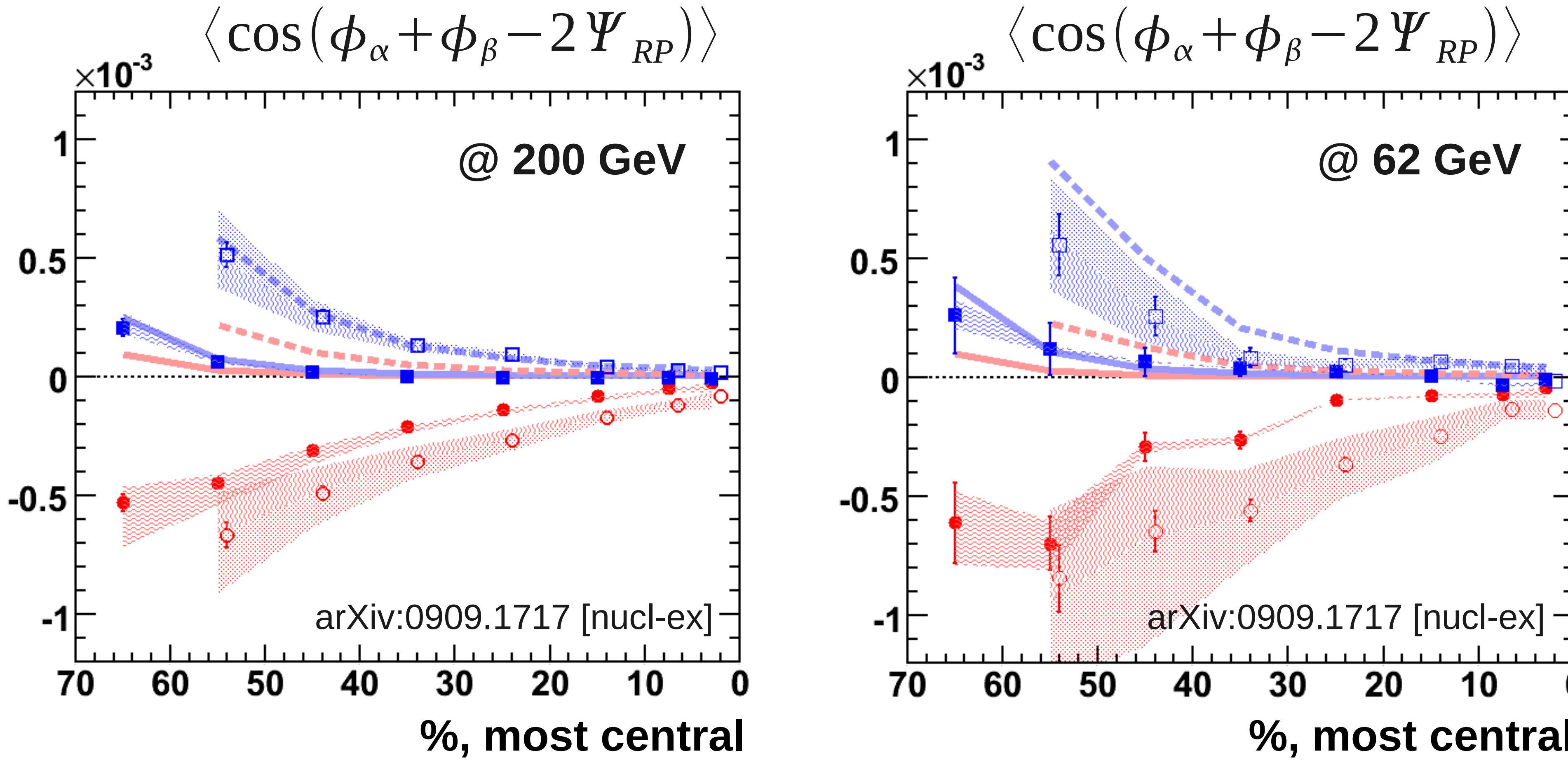
$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle = N_{corr} / N_{all}$$



Pseudo-rapidity dependence:
→ typical “hadronic” width

pt and eta dependence consistent with P-violation

Energy and system size dependence



Au+Au	Cu+Cu	α and β charges
		same sign **opposite sign**
		3-particle HIJING

$v_{2,c}$ correction systematics

Opposite sign correlations:

Stronger for a smaller (Cu+Cu) system.
In agreement with P-violation,
but large uncertainties due to possible
RP-independent correlations

Summary
(from STAR@RHIC to ALICE@LHC)

- **Collectivity at RHIC**: strong elliptic/directed flow as QGP evidence
  → study QGP properties in greater details at LHC

- **Orbital momentum in non-central collisions**: STAR sees no polarization, < 2%
  Still a question how this momentum is re-distributed among produced particles:
  → better statistics, different regime at LHC

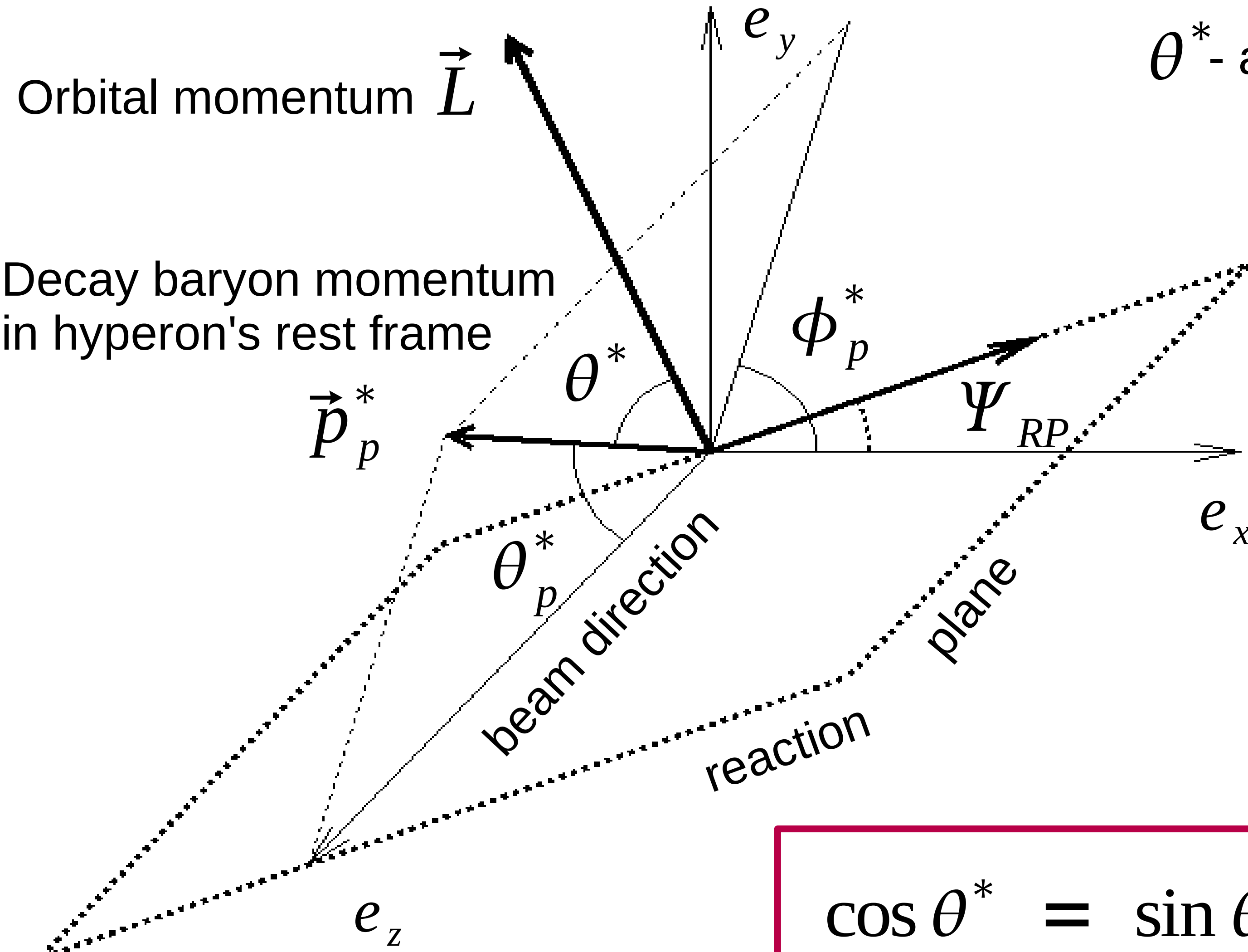
- **Local P-violation** predicted to lead to charge separation wrt. the reaction plane
  → STAR measurements with P-even observable reveal non-zero signal:
  - Can not be described with existing background models
  - Qualitatively agrees with predictions for local P-violation

  Detailed calculations for P-violating signal and backgrounds are needed:
  → New results from LHC will put more constrains on theory predictions
  for both possible signal and background correlations

- **ALICE is ideal detector for correlation studies** wrt. to the reaction plane:
  → Due to similarity between ALICE and STAR experiments
  the existing measurement techniques and wide experience
  acquired at RHIC are easily adoptable at LHC

Backup slides

Global polarization. Angles: definition and notations



θ^*- angle between $\vec{p}_p^{\,*}$ and $\vec{L}$

$\phi_p^*(\theta_p^*)$ decay baryon azimuthal (polar) angles

Ψ_{RP} reaction plane angle

$$\cos\theta^* = \sin\theta_p^* \sin(\phi_p^* - \Psi_{RP})$$

Observable for the global polarization

$$P_H(\vec{L}, \vec{p}_H) = P_H(\phi_H - \Psi_{RP}, \eta^H, p_t^H)$$

$$= \sum_{n=0}^{\infty} P_H^{(n)} \cos[2n(\phi_H - \Psi_{RP})]$$

$$P_H \equiv P_H^{(0)} = \frac{8}{\pi \alpha_H} \langle \sin(\phi_p^* - \Psi_{RP}) \rangle$$

ϕ_p^* decay baryon azimuthal angle in hyperon's rest frame

$\langle ... \rangle$ - averaging over all reaction plane orientations and decay baryon 3-momentum directions in the hyperon's rest frame

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measurement technique: two particle correlations

Need to know direction of the orbital momentum
Given by the 1-st order EP, which is defined by directed flow
Event plane from particles measured with the Forward TPCs

$$P_H = \frac{8}{\pi \alpha_H} \frac{\langle \sin(\phi_p^* - \Psi_{EP}^{(1)}) \rangle}{R_{EP}^{(1)}}$$

$\Psi_{EP}^{(1)}$ 1st order event plane angle

$R_{EP}^{(1)}$ 1st order event plane resolution

ϕ_p^* decay baryon azimuthal angle in the hyperon's rest frame

Detector acceptance effects

Acceptance effects can bias the global polarization signal

Due to detector acceptance higher harmonics ($P_H^{(n)}, n>0$) can contribute

$$\frac{8}{\alpha_H \pi} \langle \sin(\phi_p^* - \Psi_{RP}) \rangle = \frac{4}{\pi} \overline{\sin\theta_p^*} P_H^{(0)} - \frac{2}{\pi} \overline{\sin\theta_p^* \cos[2(\phi_H - \phi_p^*)]} P_H^{(2)}$$

Overall scale correction

Perfect acceptance $A_0 = 1$

$$A_0 = \frac{2}{\pi} \overline{\sin\theta_p^*} = \frac{4}{\pi} \int \frac{d\Omega_p^*}{4\pi} \frac{d\phi_H}{2\pi} A(\vec{p}_H, \vec{p}^*) \sin\theta_p^*$$

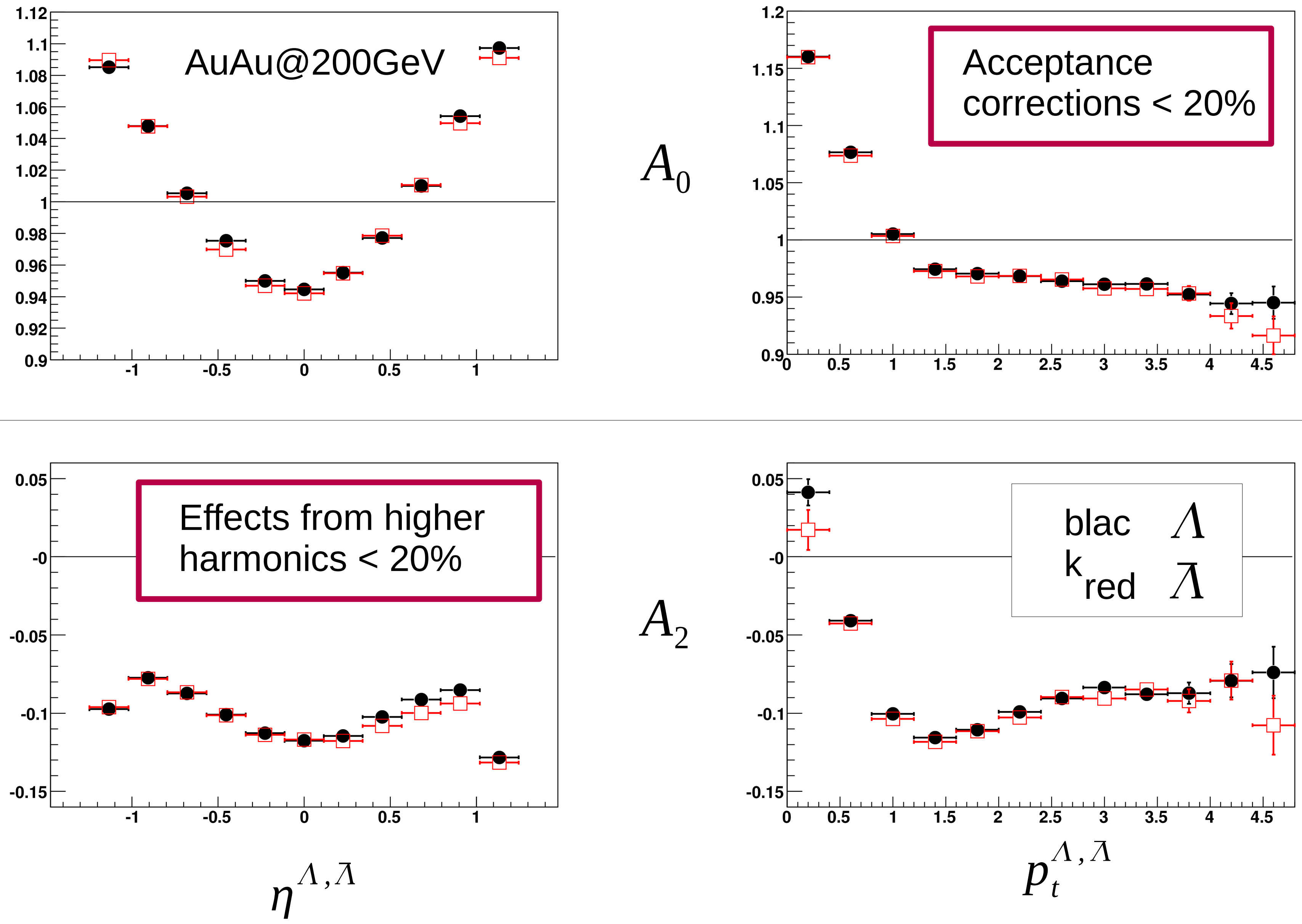
Higher harmonics (n=2) admixture

Perfect acceptance $A_2 = 0$

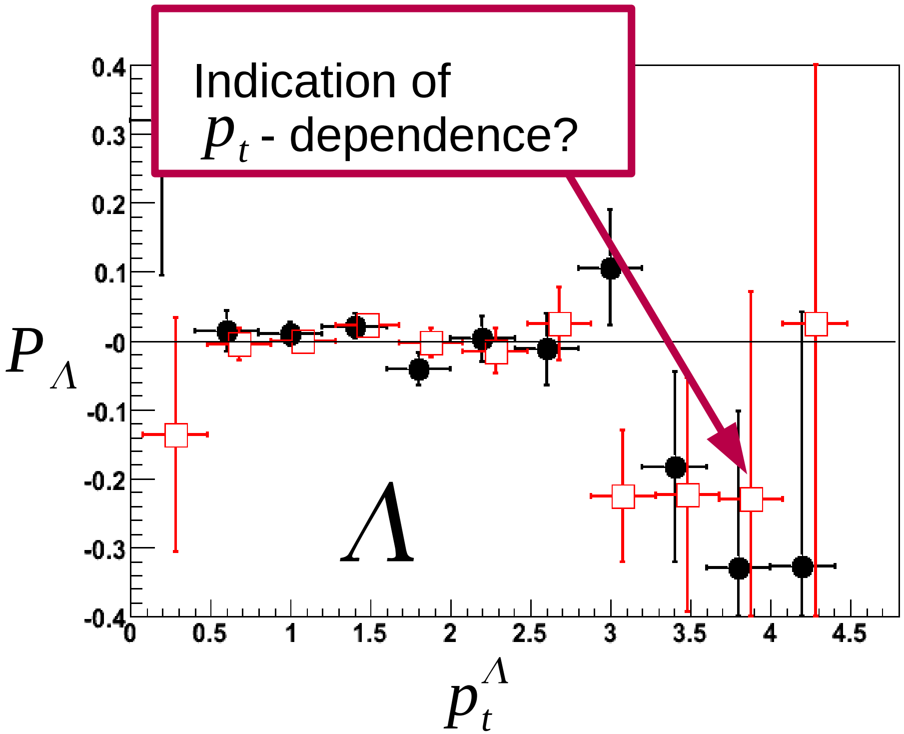
$$A_2 = \frac{2}{\pi} \overline{\sin\theta_p^* \cos[2(\phi_H - \phi_p^*)]}$$

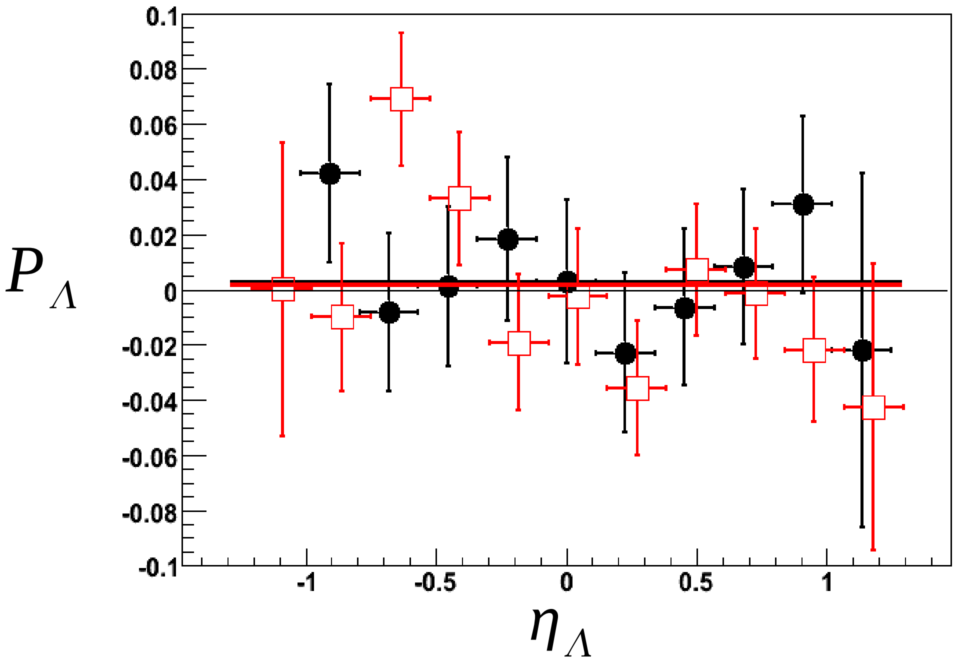
$A_{0,} A_2$ can be calculated directly from the data

Acceptance corrections (A_0) and contribution from higher harmonics (A_2)



Lambda global polarization vs transverse momentum & eta





Global polarization is zero for small Lambda p_t

No theory predictions for p_t dependence at the moment

AuAu@200GeV (20-70%)

$$P_\Lambda = (2.6 \pm 9.5) \times 10^{-3}$$

AuAu@62GeV (0-80%)

$$P_\Lambda = (1.9 \pm 8.0) \times 10^{-3}$$

$\bar{\Lambda}$ results are in agreement with those for Λ hyperon

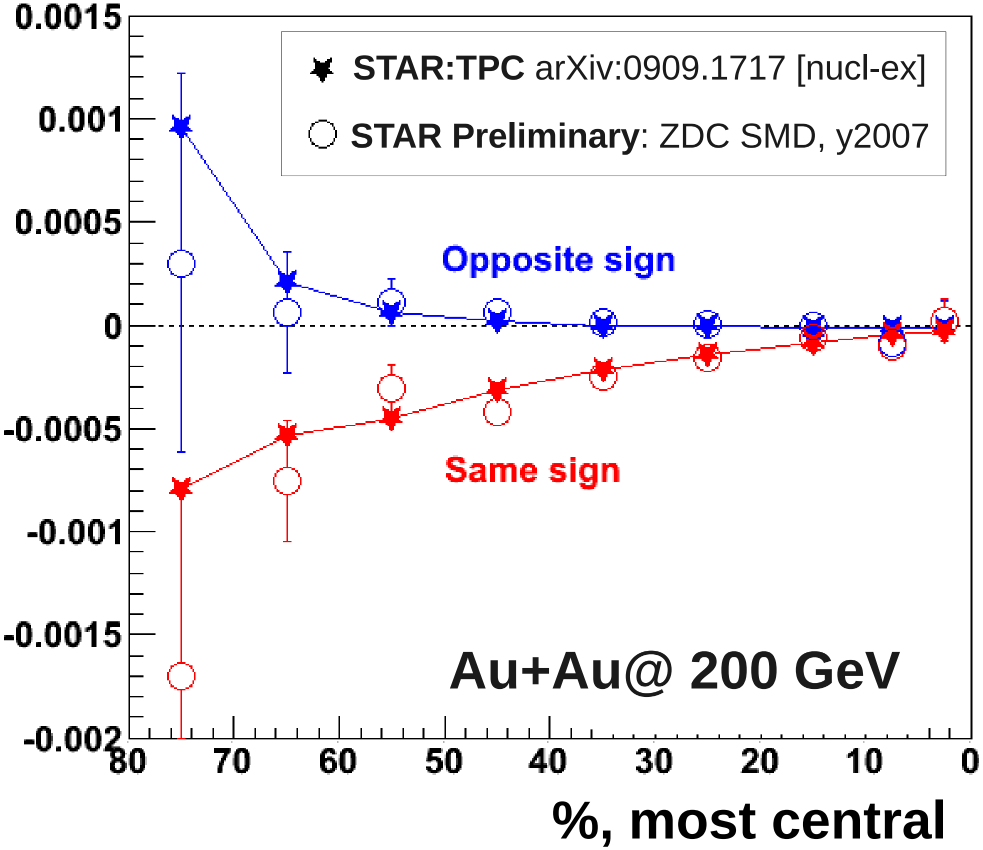
Backup slides:
parity

Publications as principal author:

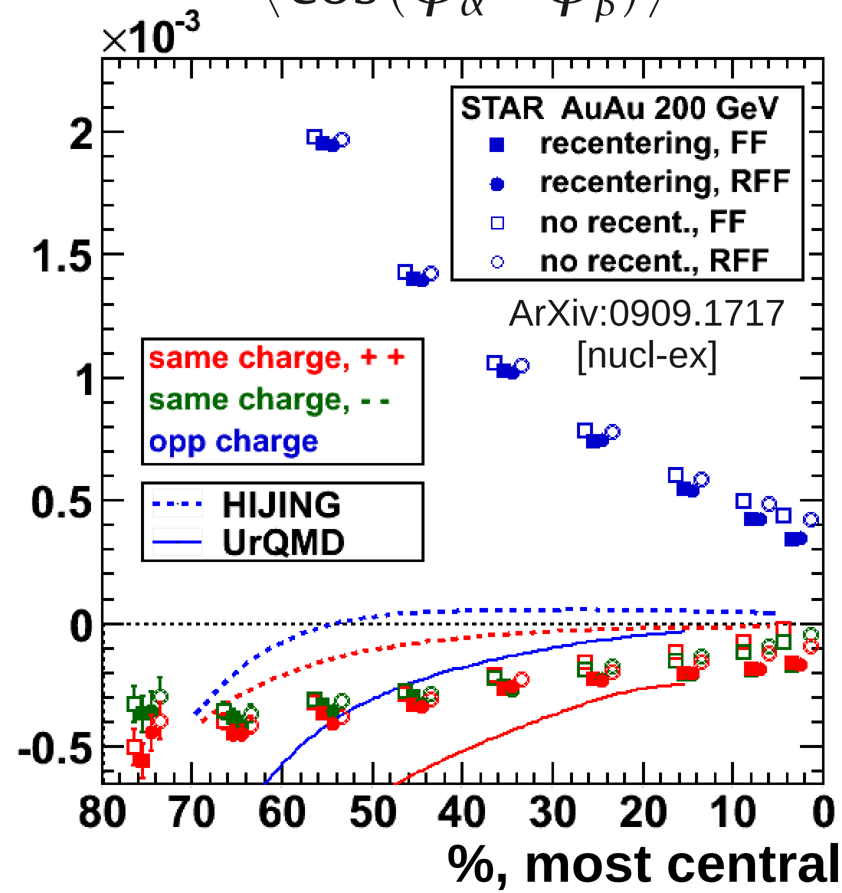
I.S. for STAR: **RRP** 58:049 (2006)
I.S. for STAR: **arXiv**:0910.0464 (2009)
STAR: **PRL** 103:251601 (2009)
STAR: **arXiv**:0909.1717 (2009) to **PRC**

Results with ZDC SMD and two particle correlations

$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$



$\langle \cos(\phi_\alpha - \phi_\beta) \rangle$



Correlations with (first harmonic) ZDC-SMD event plane from recent 2007 data yield similar result to TPC/FTPC

$$\langle \cos(\phi_\alpha - \phi_\beta) \rangle =$$

$$= \langle \cos\Delta\phi_\alpha \cos\Delta\phi_\beta \rangle + \langle \sin\Delta\phi_\alpha \sin\Delta\phi_\beta \rangle$$

$$\Delta\phi_{\alpha,\beta} = \phi_{\alpha,\beta} - \Psi_{RP}$$

Physics backgrounds

Reaction plane (RP) dependent:

- Directed flow (vanishes in symmetric eta-range), flow fluctuations:

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\phi_c) \rangle_{flow} = \langle v_{1,\alpha} v_{1,\beta} \rangle v_{2,c}$$

- Global polarization (zero from measurement)

- RP dependent fragmentation (“flowing clusters”):

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle_{clust} = A_{clust} \langle \cos(\phi_\alpha + \phi_\beta - 2\phi_{clust}) \rangle_{clust} v_{2,clust}$$

RP independent 3-particle correlations:

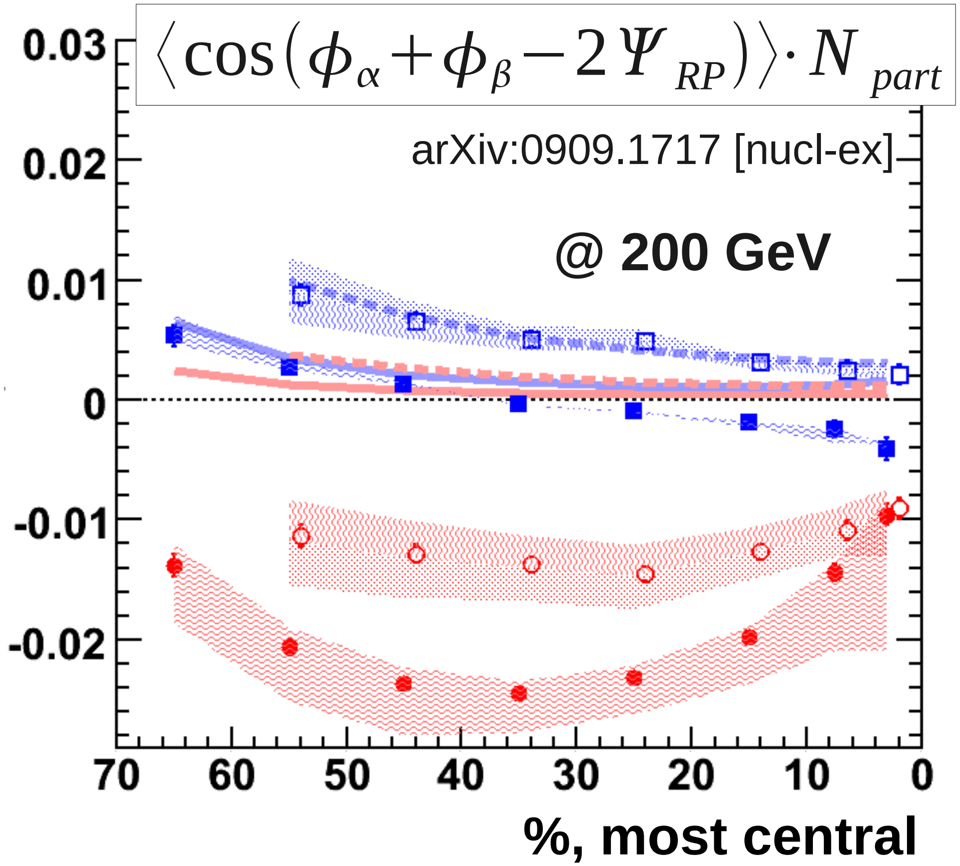
Can be removed by better RP determination
Different multiplicity scaling ($1/N_{ch}^2$) compared to P-violation

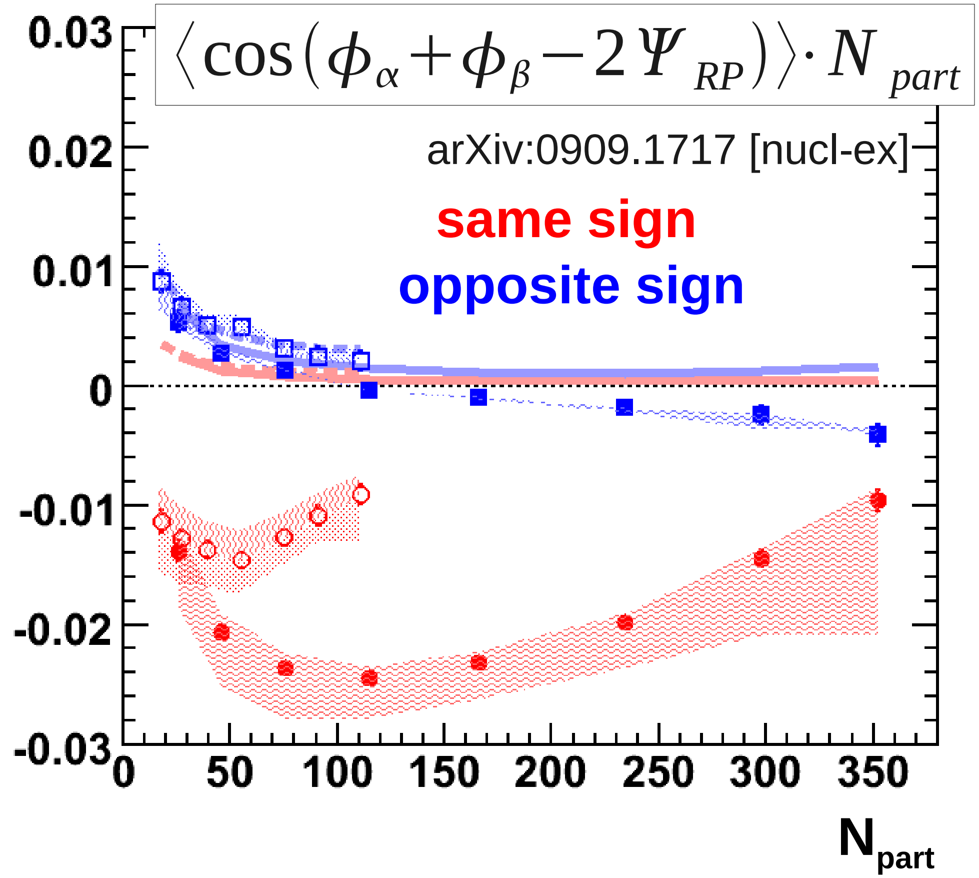
- Jet fragmentation, resonances, multi-particle clusters
- HBT, Coulomb effects, etc.

Detector effects study

- Track momenta distortions due to the charge buildup in the TPC at high accelerator luminosity
  → *Results for low/high luminosity runs are consistent*
- Dependence on reconstructed position of the collision vertex
  → *No vertex dependence found*
- Displacement of track hits when it passes the TPC central membrane
  → *Results from different half-barrels of the TPC are consistent*
- Feed-down effects from non-primary tracks (i.e. resonance decay daughters)
  → *Results for dca < 1 cm and dca < 3 cm are consistent*
- Electron contribution checked via dE/dx cut
  → *Effect is negligible*
- Studied a correlator similar to parity observable
  → *but with the reaction plane angle rotated by pi/4*
- Variation depending on the charge of the third particle used to reconstruct the reaction plane and changes of the STAR magnetic field polarity
  → *Variations does not change the observed signal*

Charge correlations and N_{part} scaling @200GeV





Correlations multiplied by N_{part} to
remove dilution in more central collisions

Au+Au	Cu+Cu	α and β charges
		same sign opposite sign
		3-particle HIJING

Opp-sign correlations scale with N_{part}

Same sign signal is suggestive
of correlations with the reaction plane

Stronger opposite charge correlations
In Cu+Cu at the same N_{part}