CHARGE-CONSERVATION-DRIVEN CORRELATIONS

A MICROSCOPIC APPROACH

2 Motivations:

1. Investigate Evolution of Charge Content (u,d,s)
2. Background for CME Signal

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RELATING CORRELATIONS

$$C_{ab}(r_1, r_2) = \langle \delta\rho_a(r_1)\delta\rho_b(r_2)\rangle$$

$$\int dr_2\ C_{ab}(r_1, r_2) = 0, \quad \text{(finite system)}$$

$$\int dr_2\ C_{ab}(r_1, r_2) = \chi_{ab}(r_1) = \frac{1}{\Omega}\langle \delta Q_a \delta Q_b\rangle, \quad \text{(equilibrium)}$$

WE MODEL C'

$$C_{ab}(r_1, r_2) \approx \chi_{ab}(r_1)\delta(r_1 - r_2) + C'_{ab}(r_1, r_2)$$

FROM C′ TO MEASUREMENT

At Hypersurface:

$$\frac{\partial N_h}{\partial q_a} = \chi_{ab}^{-1} q_{h,b}$$

If charge equilibrated amongst hadrons

$$\langle \delta\rho_h(r_1)\delta\rho_{h'}(r_2)\rangle = C'_{ab}(r_1, r_2)\frac{\partial N_h}{\partial q_a}\frac{\partial N_{h'}}{\partial q_b}$$

Defining Charge Balance Function:

$$B_{hh'}(p_2|p_1) \equiv -\frac{\langle[\delta n_h(p_1) - \delta n_{\bar{h}}(p_1)]\,[\delta n_{h'}(p_2) - \delta n_{\bar{h}'}(p_2)]\rangle}{n_h(p_1) + n_{\bar{h}}(p_2)}$$

$$B_{pK}(p_2|p_1) \equiv -\frac{\langle[\delta n_p(p_1) - \delta n_{\bar{p}}(p_1)]\,[\delta n_{K^+}(p_2) - \delta n_{K^-}(p_2)]\rangle}{n_p(p_1) + n_{\bar{p}}(p_1)}$$

p_1, p_2 refers to rapidity, azimuthal angle Q_{inv}…

FROM C′ TO MEASUREMENT

MOMENTS, e.g γ_p

$$\gamma_p = \langle \cos(\theta_1 + \theta_2) \rangle_{\text{o.s.}} - \langle \cos(\theta_1 + \theta_2) \rangle_{\text{s.s.}}$$

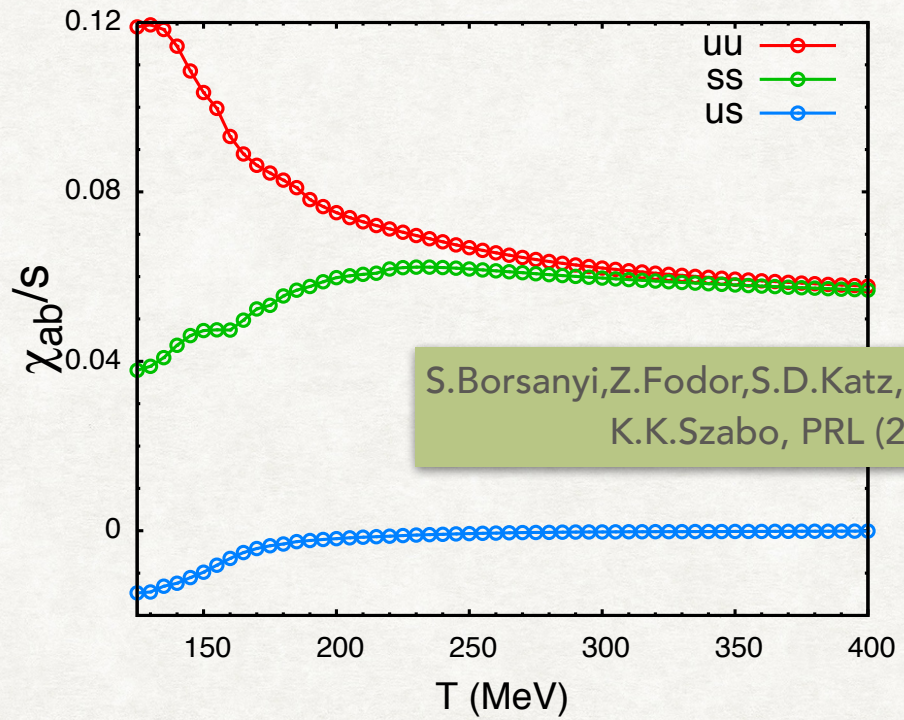
p_1, p_2 refers to rapidity, azimuthal angle Q_{inv}…

MODEL C'

1. Base C' on Hydro Evolution, OSU Hydro (boost-invariant)

2. Generate MC Pairs of charge *a* and *-b* with probability:

$$d^4x \; \partial \cdot (u\chi_{ab})$$



S.Borsanyi,Z.Fodor,S.D.Katz,S.Krieg,**C.Ratti**, K.K.Szabo, PRL (2014)

3. Also create initial pairs at τ_0 with probability

$$d^3r \; \chi_{ab}$$

Initial pairs already separated,
gaussian parameter in spatial rapidity: σ_0

MODEL C'

4. Model diffusion of charges, free stream + collisions

$$\Gamma_{\text{coll.}} = \frac{1}{6D}$$

D comes from lattice: Aarts et al, [hep-lat]1412.6411v2

CONVERT C' BALANCE FUNCTION

4. For each charge q_a that passes through hyper surface

$$d^4x \; \partial \cdot (u\chi_{ab})$$

Probability of creating hadron of type *h* is:

$$\delta N_h = \langle N_h \rangle q_{h,a} \chi_{ab} q_b,$$

$$\langle N_h \rangle = \frac{\Omega^\mu}{(2\pi)^3} \int \frac{d^3p}{E_p} p^\mu f(\mathbf{p})$$

5. Only correlate particles (and their daughters) with those from corresponding pair

6. Model denominator of BF with usual Cooper-Frye, add contributions from to numerator

7. Convolute with STAR acceptance filter (provided by G.Westfall)

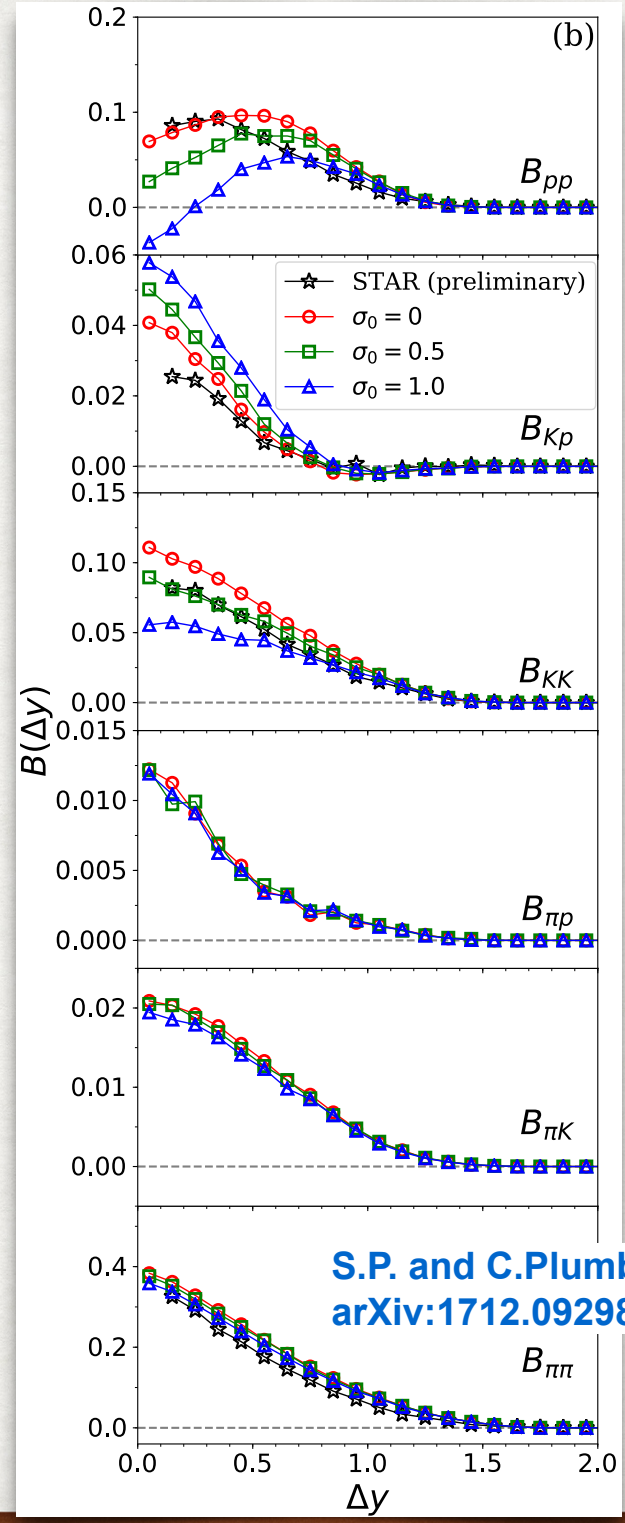
NUMERICAL COST

Little noise, because you track correlated pairs

- One hydro event
- sample ~ 10^6 charge pairs, ~10^7 hadron pairs
- ~ 5 minutes on laptop (not counting hydro)

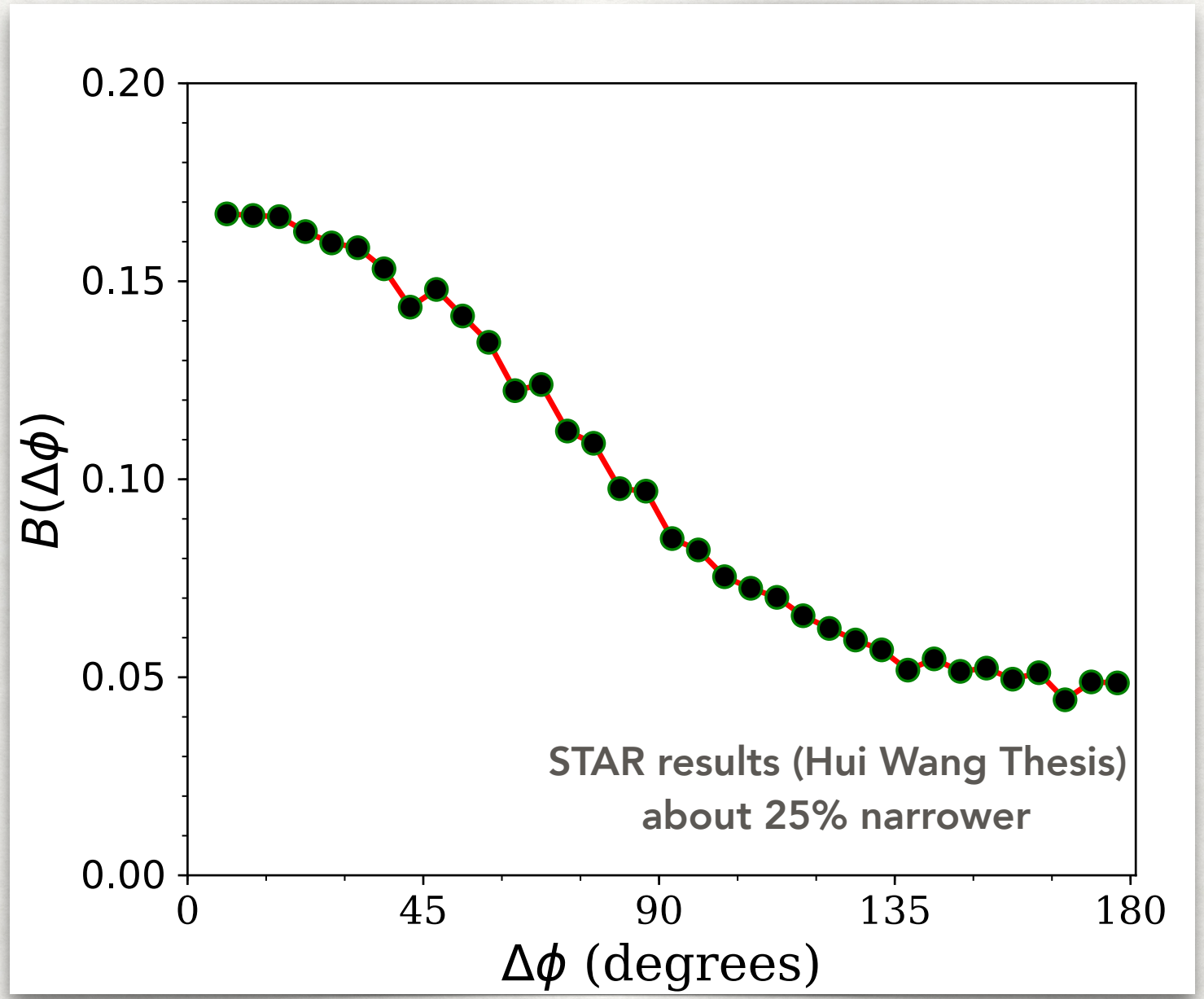
RESULTS (BINNED BY RAPIDITY)

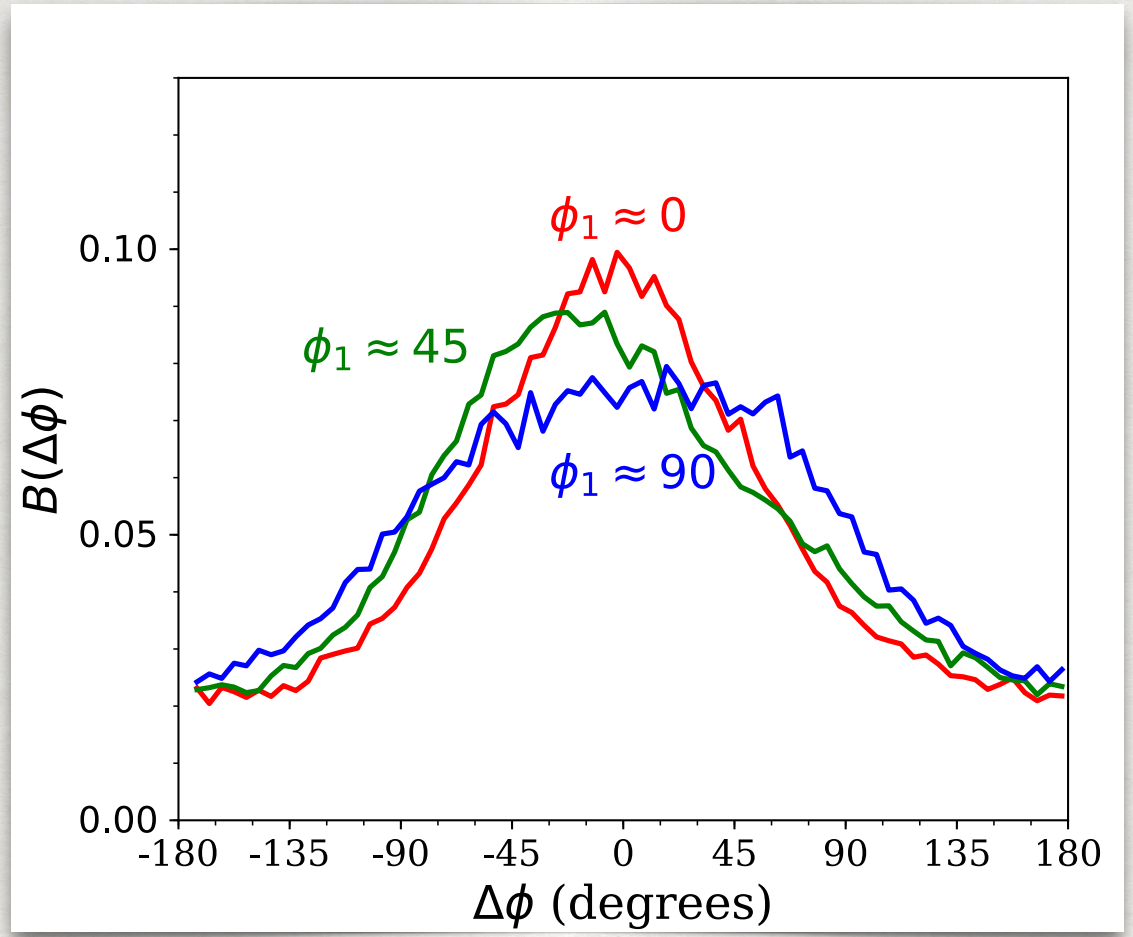
Results depend on σ_0, T_f, D



S.P. and C.Plumberg
arXiv:1712.09298 [nucl-th]

RESULTS BINNED BY ΔΦ





RESULTS BINNED BY Φ_1 AND $\Delta\Phi$

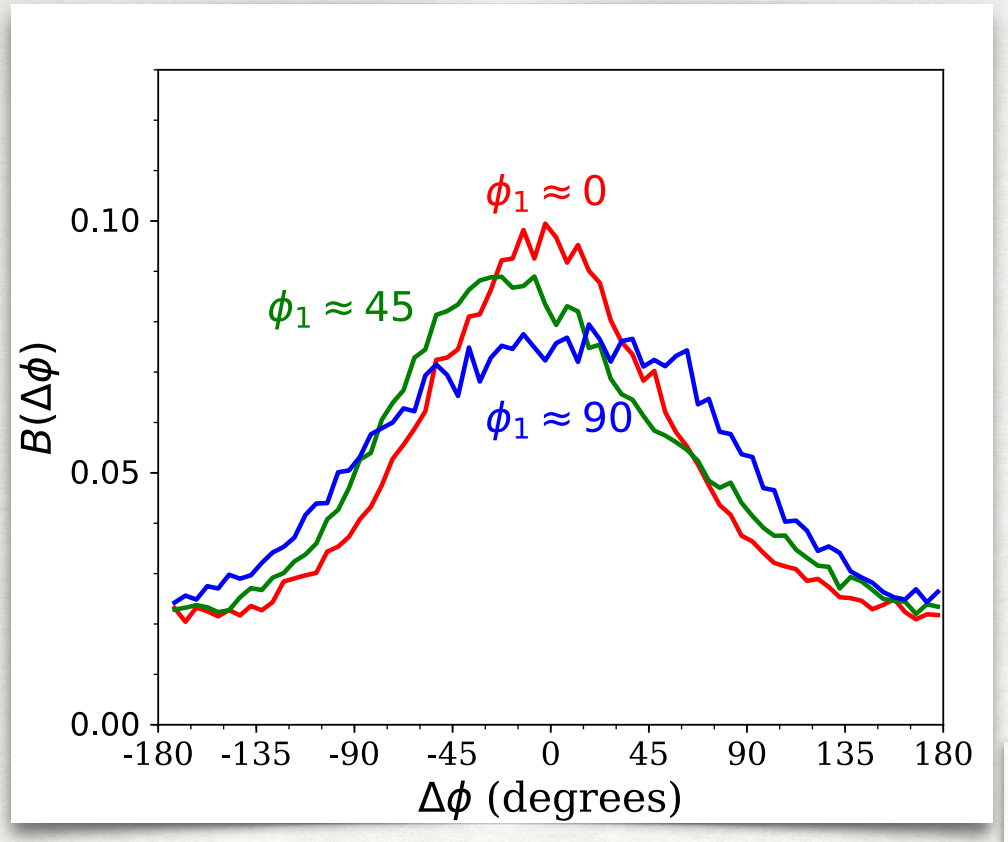
More flow in-plane ➜ narrower BF
More particles in-plane ➜ $\langle\Delta\varphi\rangle\neq 0$
STAR preliminary results qualitatively similar

$$\langle\cos(\phi_1+\phi_2)\rangle_{os} - \langle\cdots\rangle_{ss}$$

$$= \boldsymbol{\gamma_p} = \langle\cos\phi_1\rangle\langle\cos\Delta\phi\rangle_{os}$$

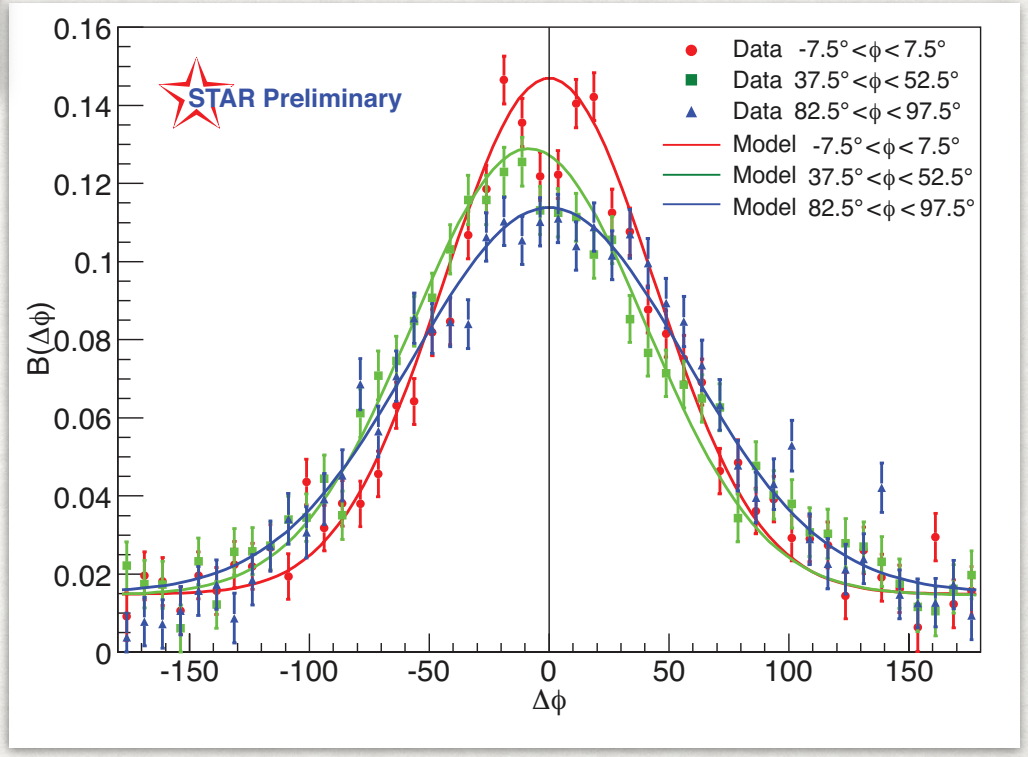
$$+ \langle\cos\phi_1 \ \cos\Delta\phi\rangle_{os} - \langle\cos\phi_1\rangle\langle\cos\Delta\phi\rangle_{os}$$

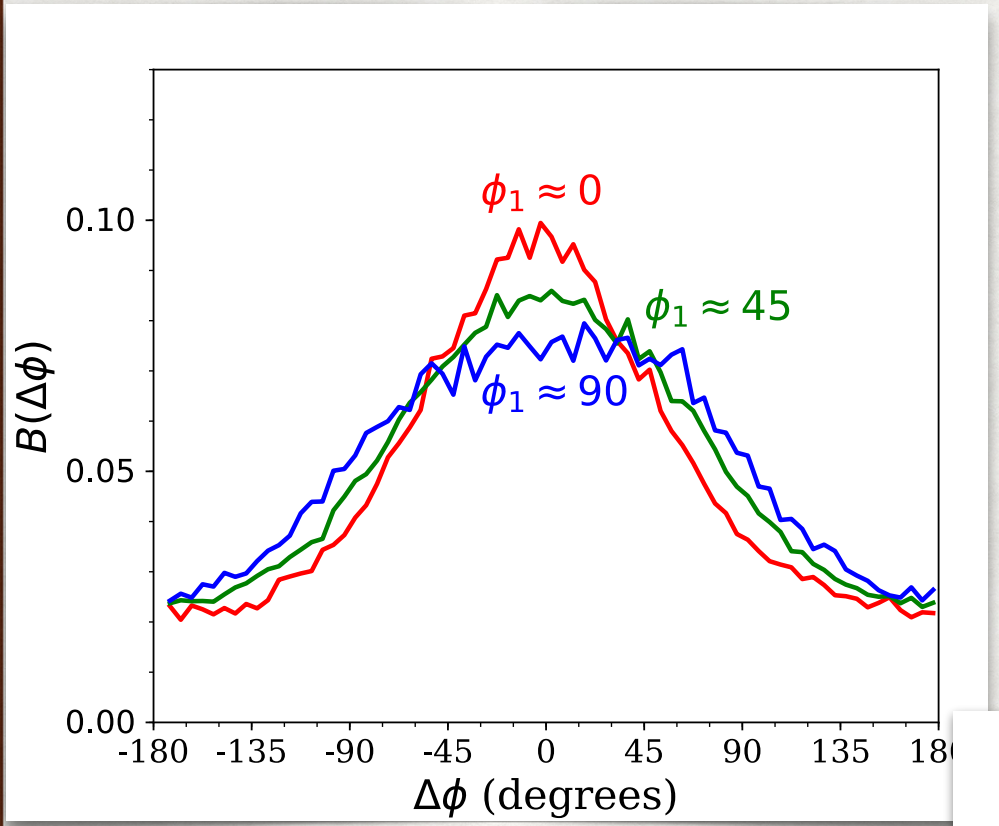
$$- \langle\sin\phi_1 \ \sin\Delta\phi\rangle_{os} - \langle\cdots\rangle_{ss}$$



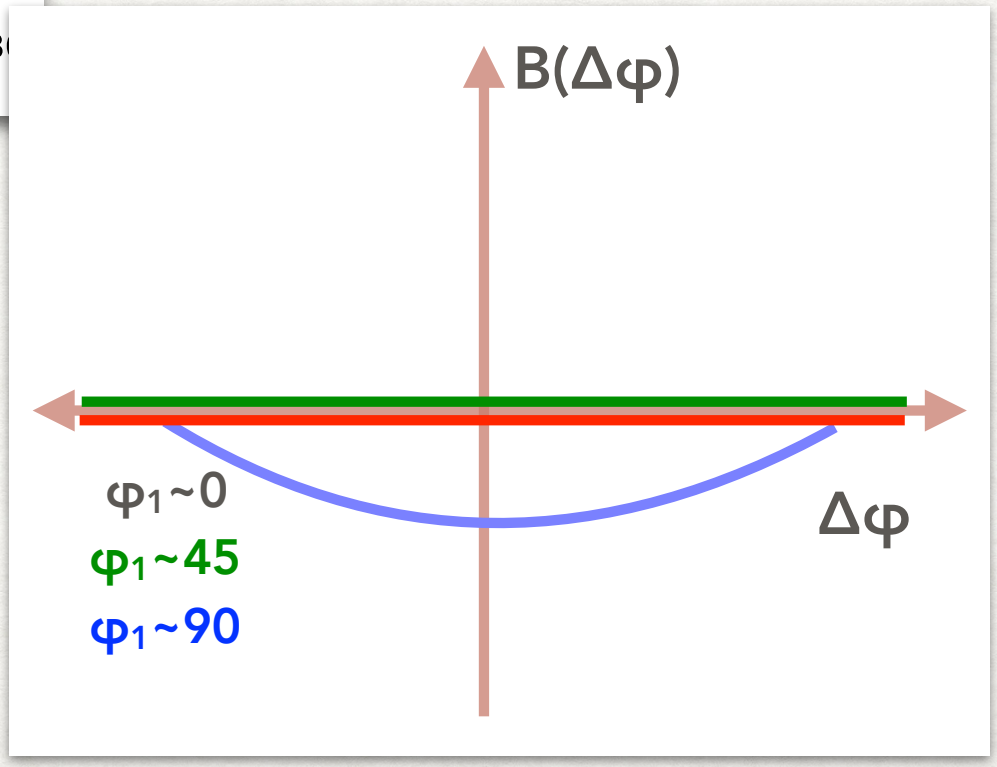
COMPARE TO STAR

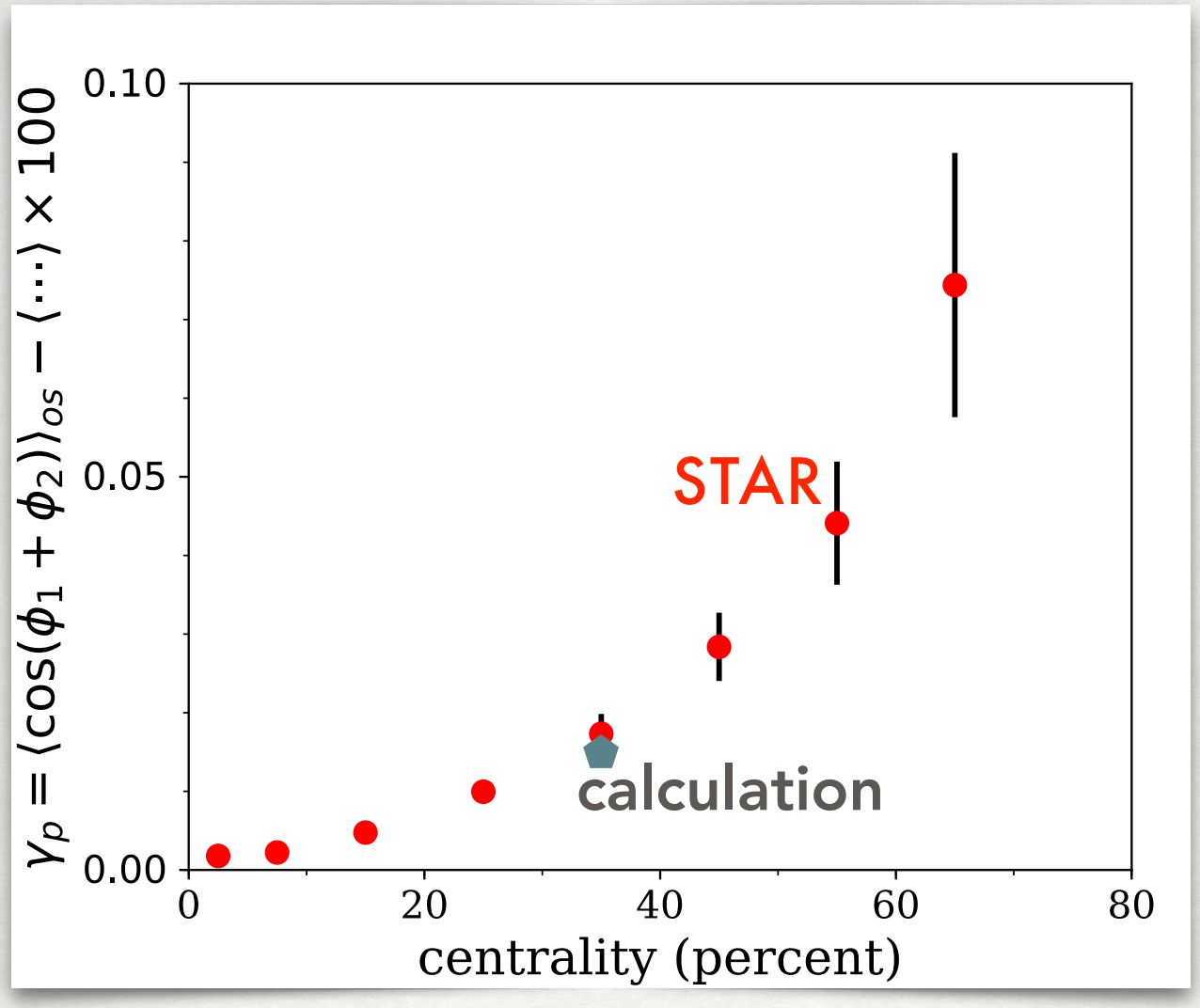
- Qualitatively similar
- BUT!
  STAR results ~25% narrower for all φ_1





CONTRAST TO CME



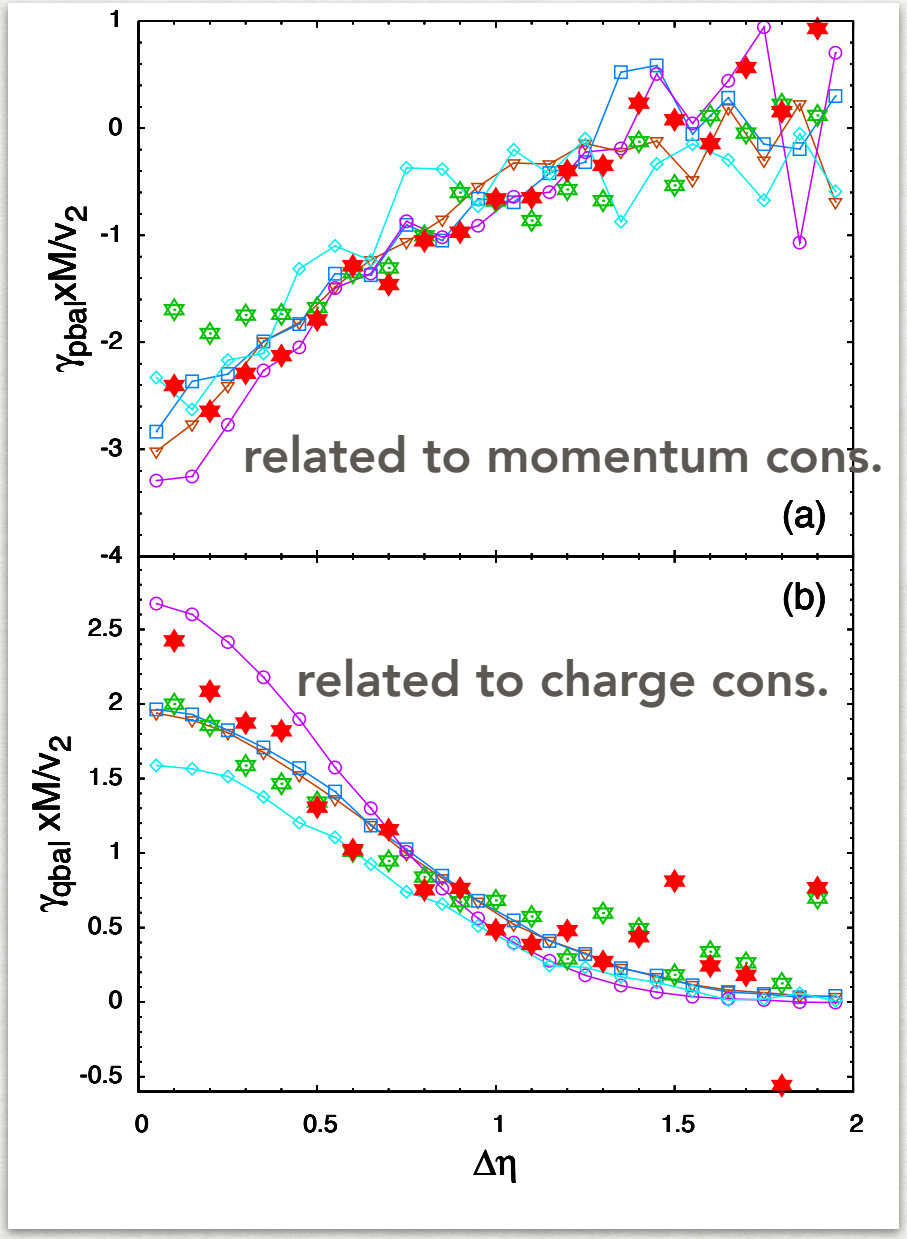


COMPARE TO STAR

Calculation:

- only one centrality, so far
- ~ 15% below STAR
- must first explain B(Δφ) width

S.P., S.Schlichting and S.Gavin
PRC 2011



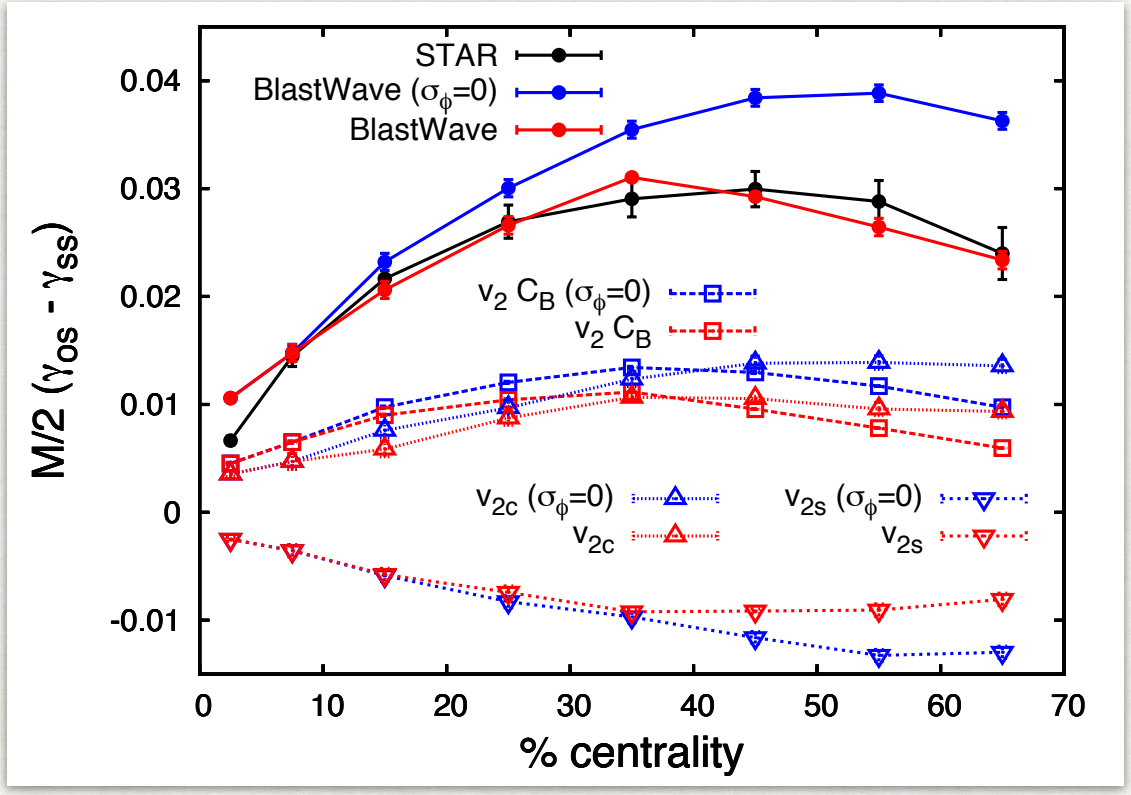
OTHER CALCULATIONS VS. STAR

PION CASCADE:

- initial local charge conservation
- vary spatial anisotropy
- vary cross section
- similar to STAR
- includes momentum conservation (~explains both same/opposite sign

S.Schlichting and S.P.
PRC 2011

OTHER CALCULATIONS VS. STAR



BLAST WAVE:

- parameters:
  widths of B(Δφ) & B(Δy)
  Use Retiere/Lisa BW parameters

GOING FORWARD

- Reproduces ~85% of γ_p
- Fix overall width of $B(\Delta\varphi)$
  - perhaps q-production comes after flow?
- Evolve correlations past hydro (cascade)
  - — numerical challenges
  - — also needed to understand chemical evolution and light quark diffusion

One man's background is another man's treasure