CHARGE-CONSERVATION-DRIVEN CORRELATIONS

A MICROSCOPIC APPROACH

Motivations:

1. Investigate Evolution of Charge Content (u,d,s)
   Extract/confirm $\chi_{ab}(\tau)$
2. Diffusion Constant for Light Quarks
3. Background for CME Signal

SCOTT PRATT — MICHIGAN STATE UNIVERSITY
CHRIS PLUMBERG — UNIVERSITY OF MINNESOTA

CORRELATIONS & SUSCEPTIBILITIES

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

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

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

GASES

$$\chi_{ab}^{\text{hadron}} = \sum_h n_h q_{ha} q_{hb}$$

$$\chi_{ab}^{\text{QGP}} = (n_a + n_{\bar{a}})\delta_{ab}$$

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

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}…

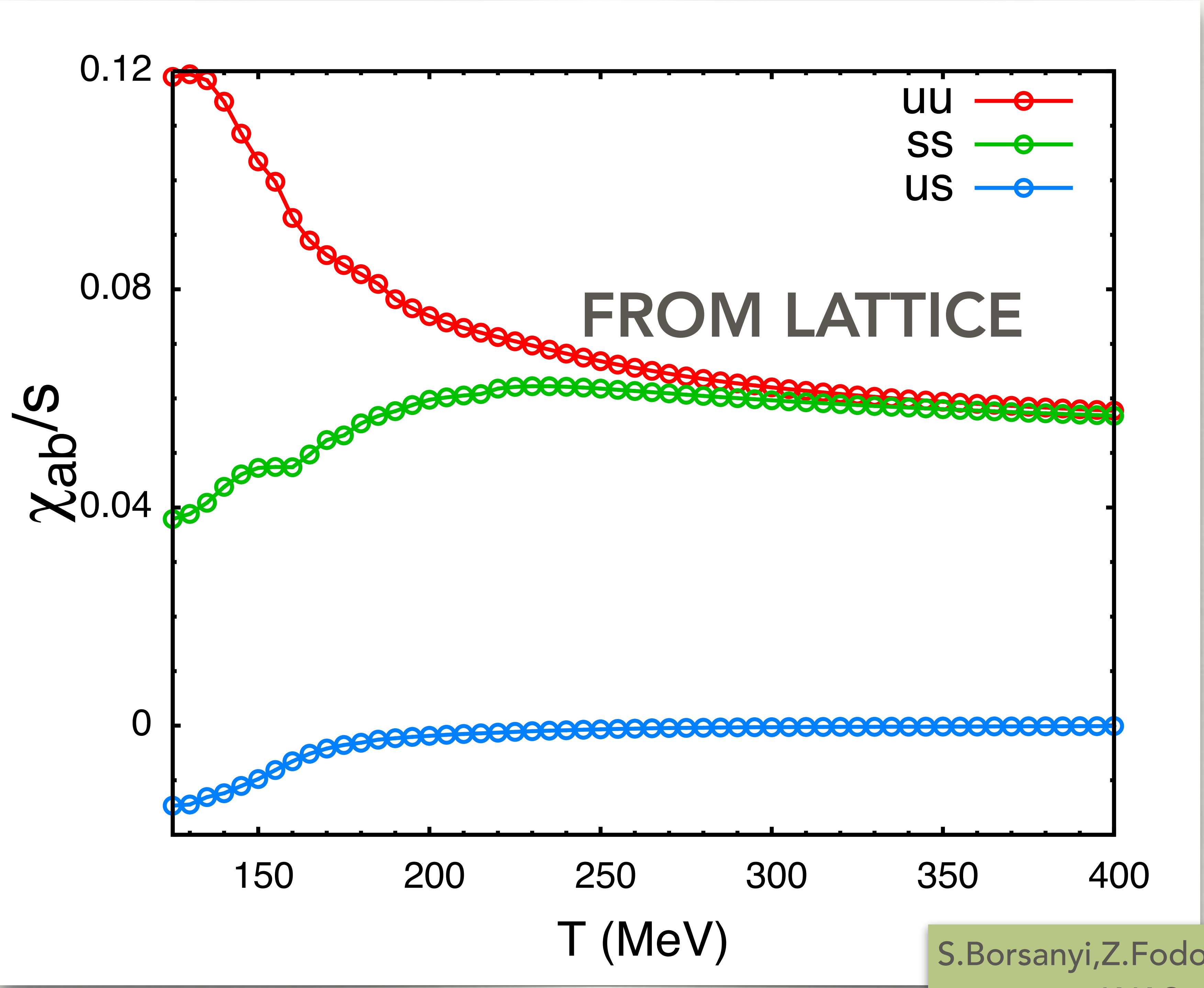
FROM C' TO MEASUREMENT CME "SIGNAL"

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

FROM TWO-SURGE BLAST-WAVE MODEL

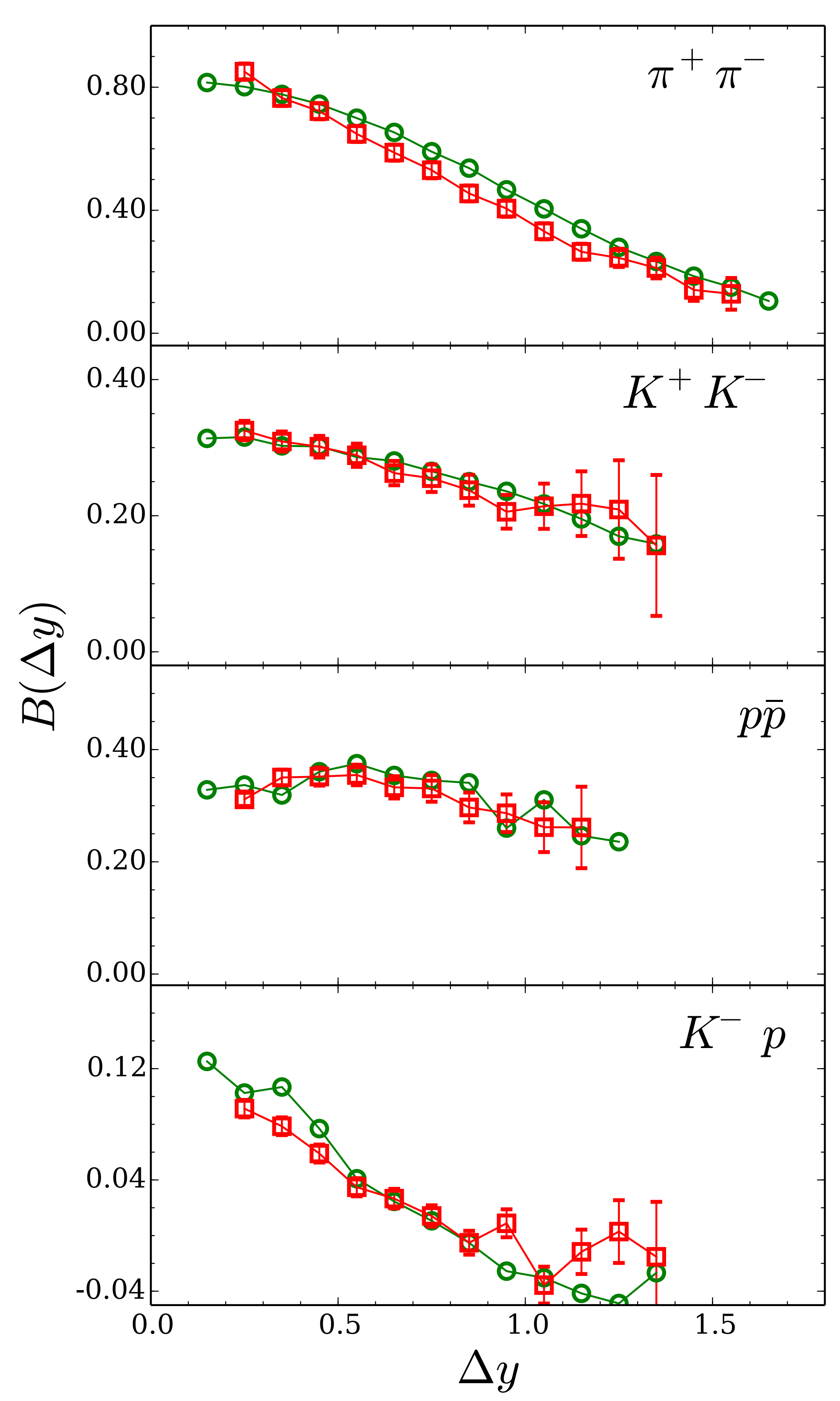
Adjust Initial-State Chemistry (First Surge)

Adjust 2 Widths of C′(Δη)



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

FROM TWO-SURGE BLAST-WAVE MODEL



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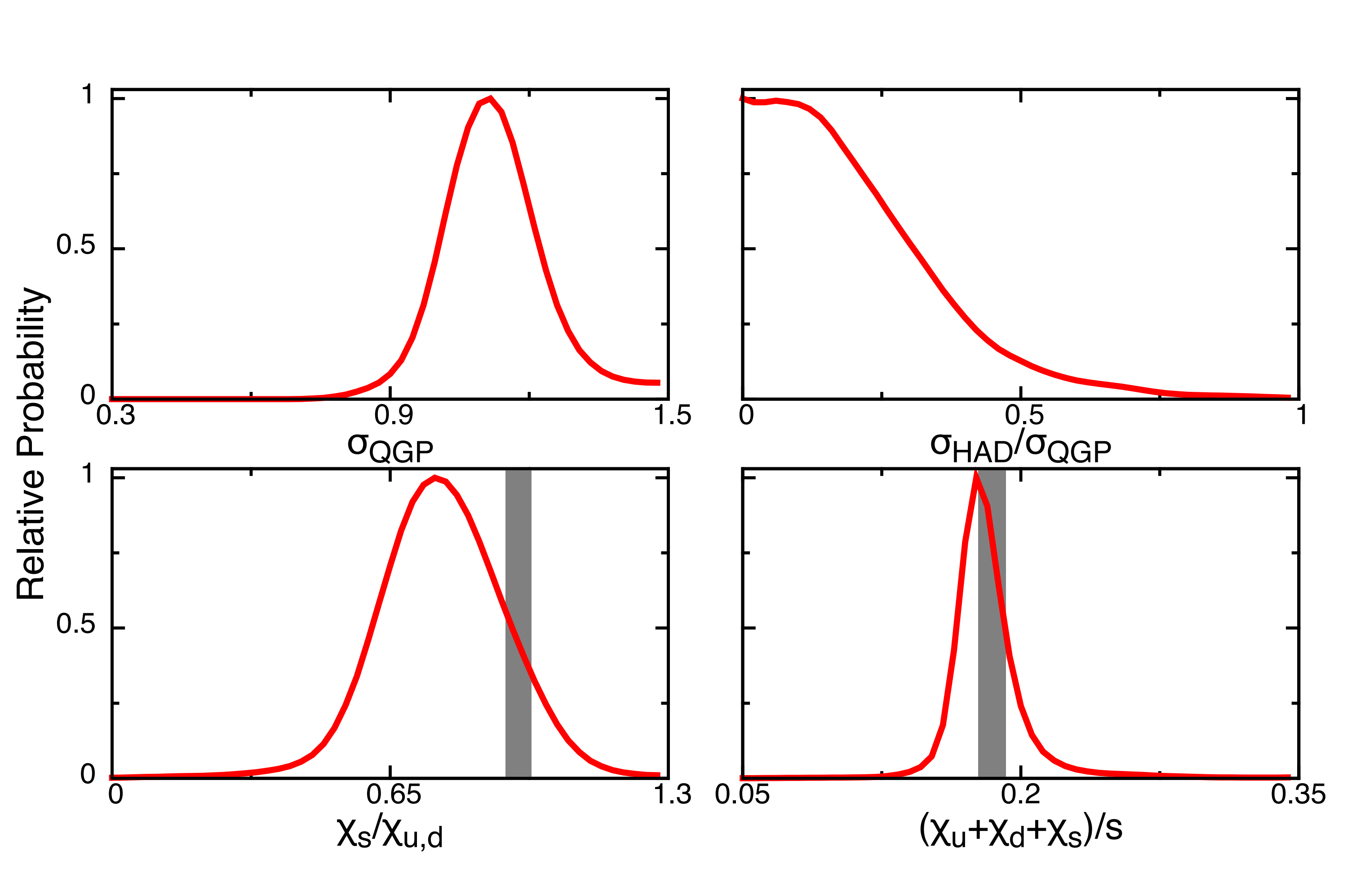


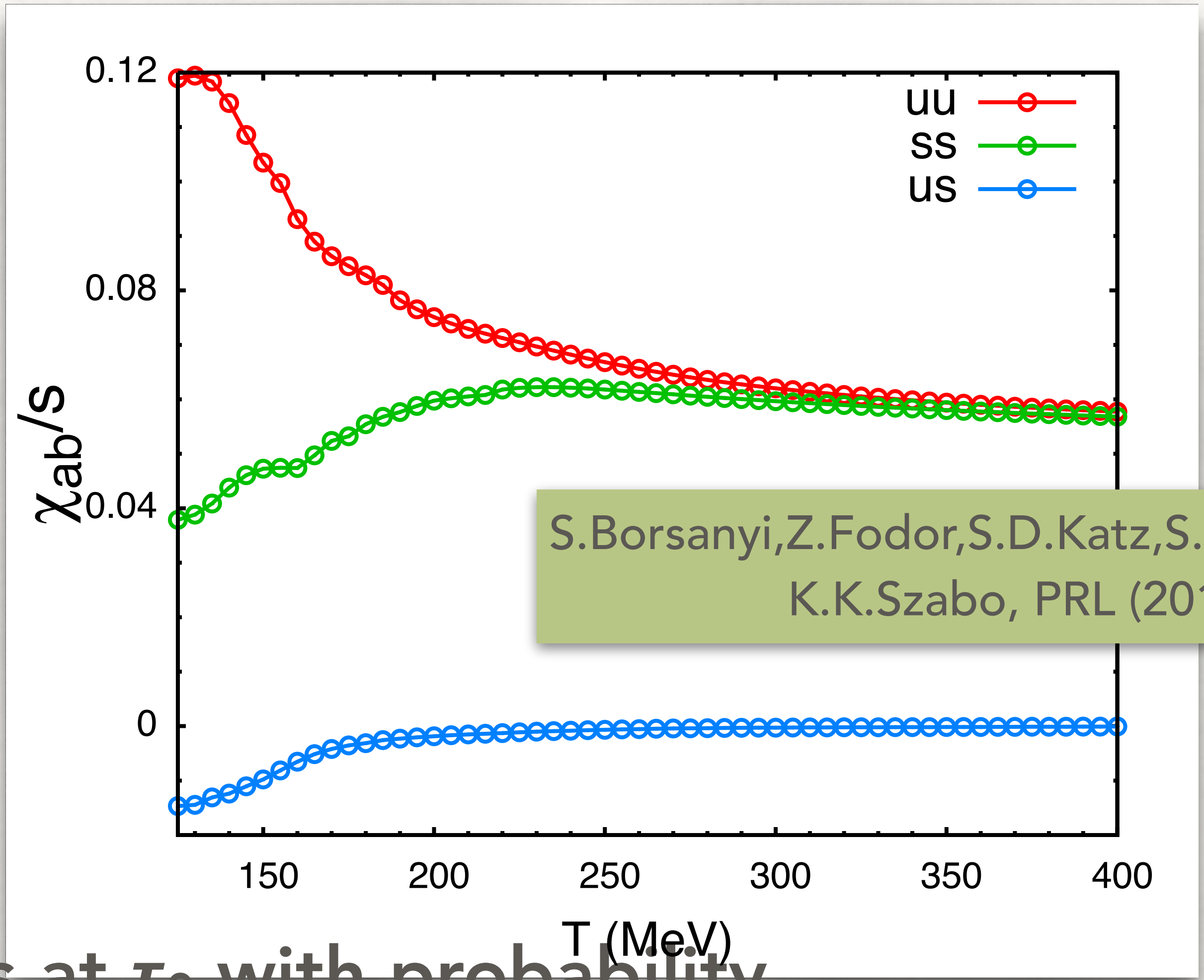
S.P., W.McCormack and C.Ratti, PRC 2015

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' THROUGH HYDRO

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

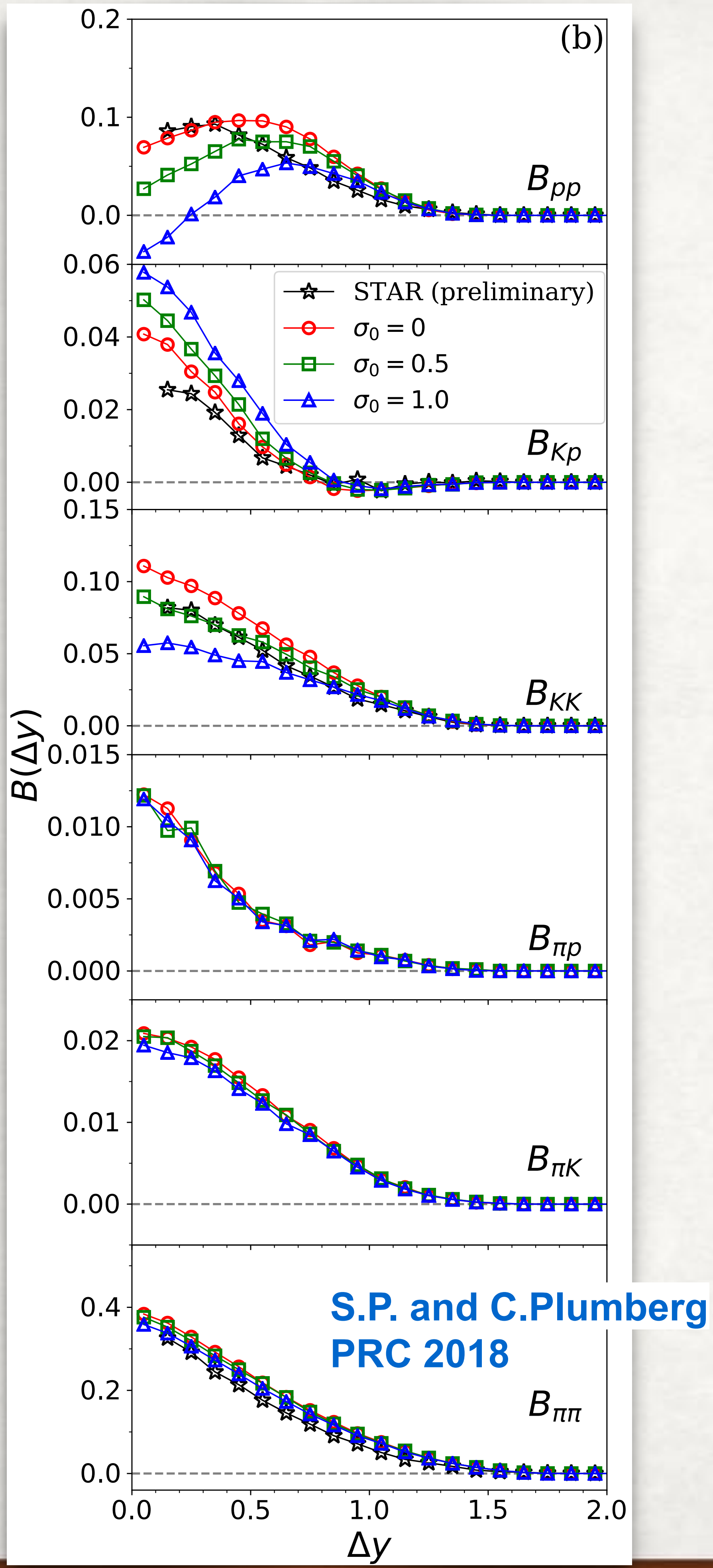
Little noise, because you track correlated pairs

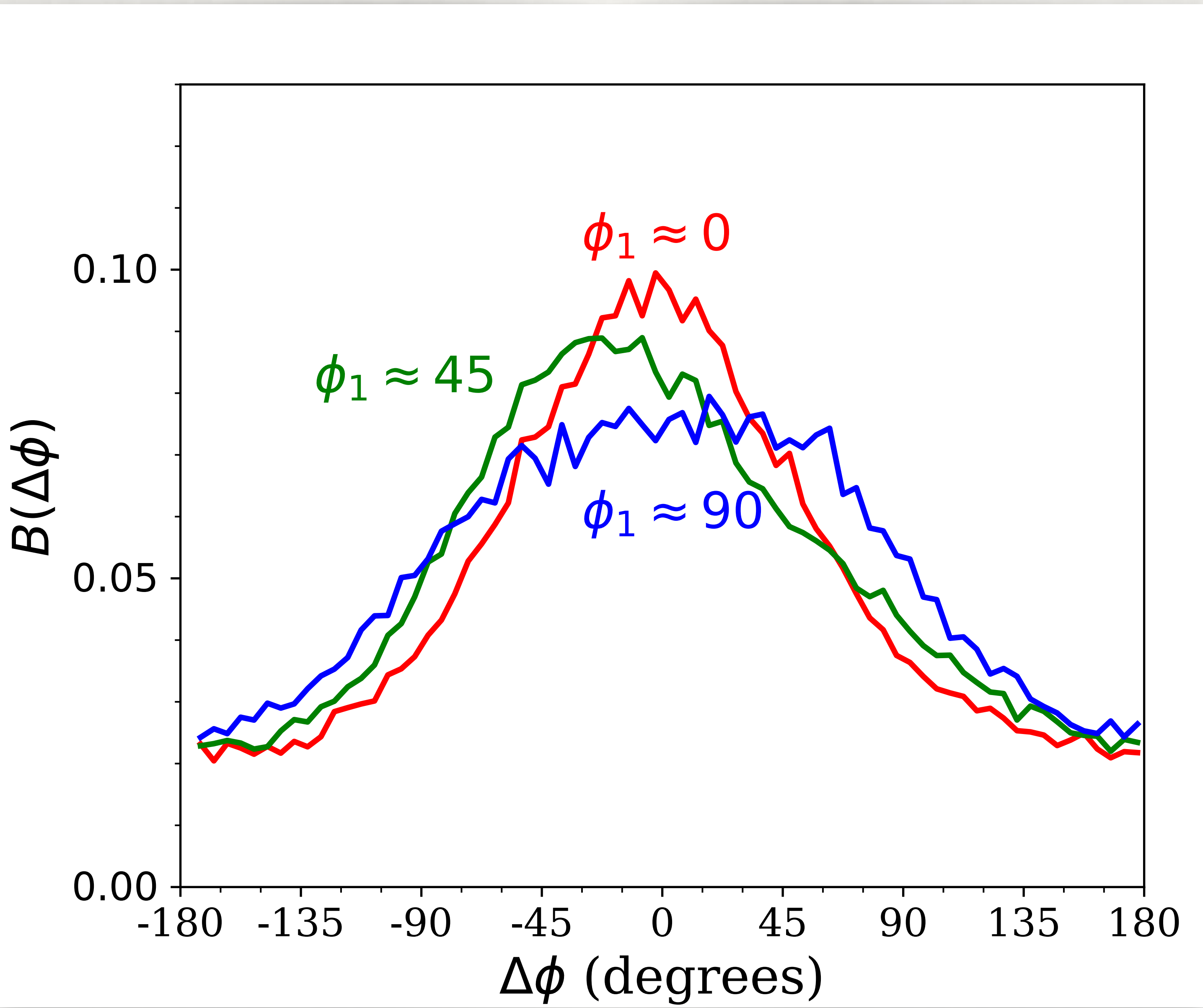
- One hydro event
- sample ~ 10^6 charge pairs, ~10^7 hadron pairs
- ~ 5 minutes on laptop (not counting hydro)
- BUT, much more computing when cascade added

RESULTS (BINNED BY RAPIDITY)

Results depend on

σ_0, T_f, D





RESULTS BINNED BY Φ₁ AND ΔΦ

More flow in-plane ➜ narrower BF

More particles in-plane ➜ ⟨Δφ⟩≠0

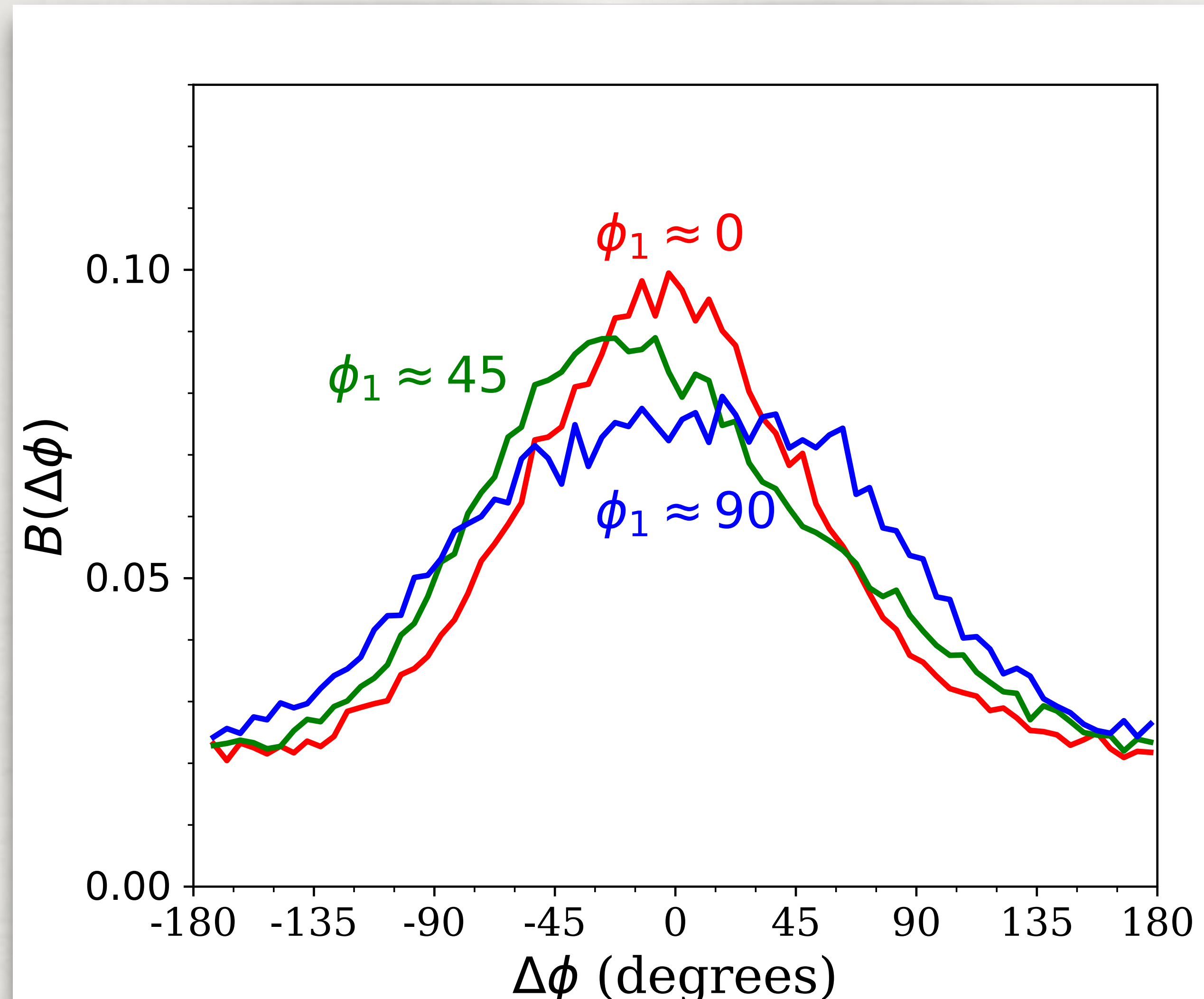
STAR preliminary results qualitatively similar

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

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

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

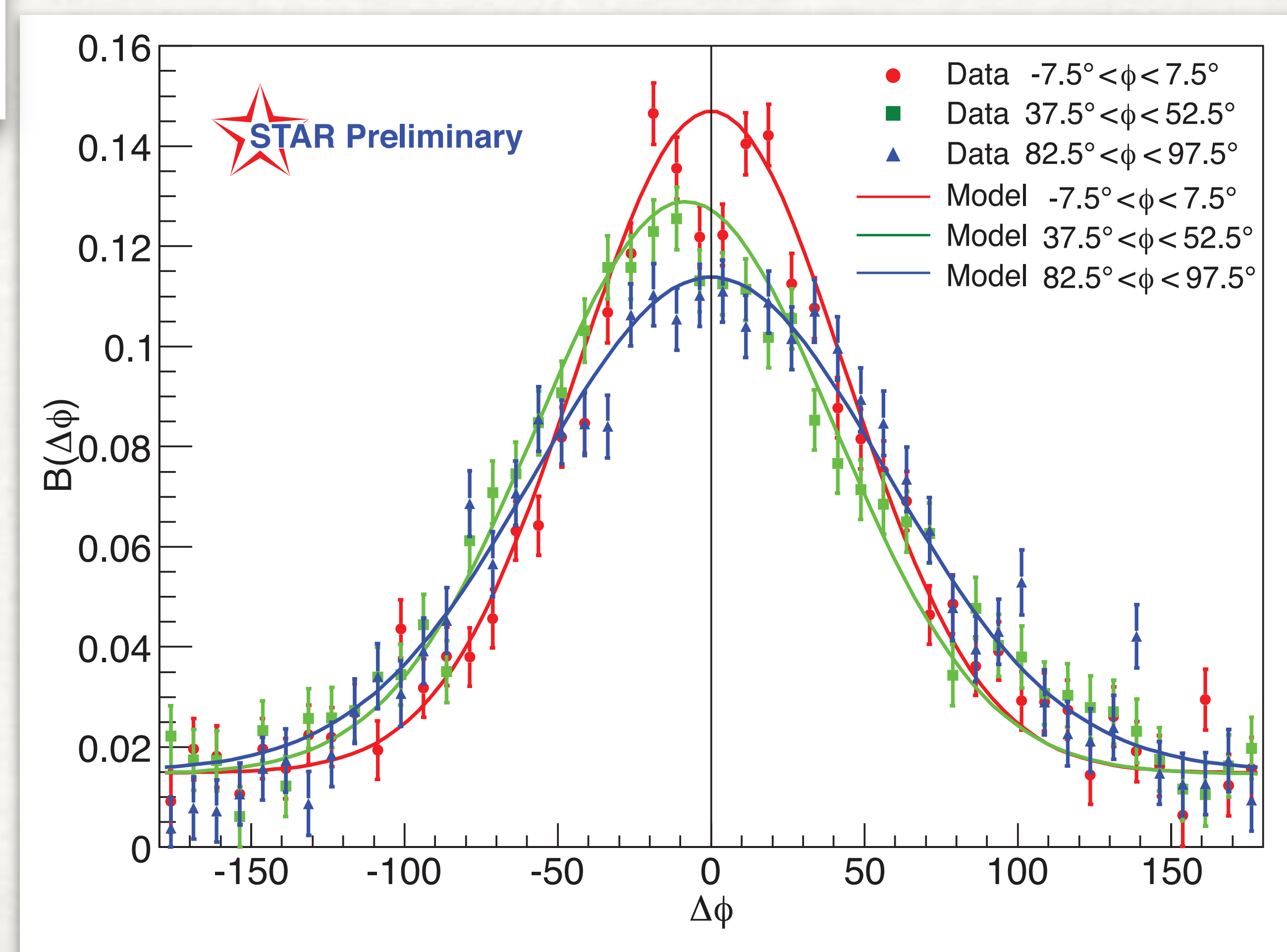
$$- \langle\sin\phi_1 \ \sin\Delta\phi\rangle_{os} - \langle\cdots\rangle_{ss}$$

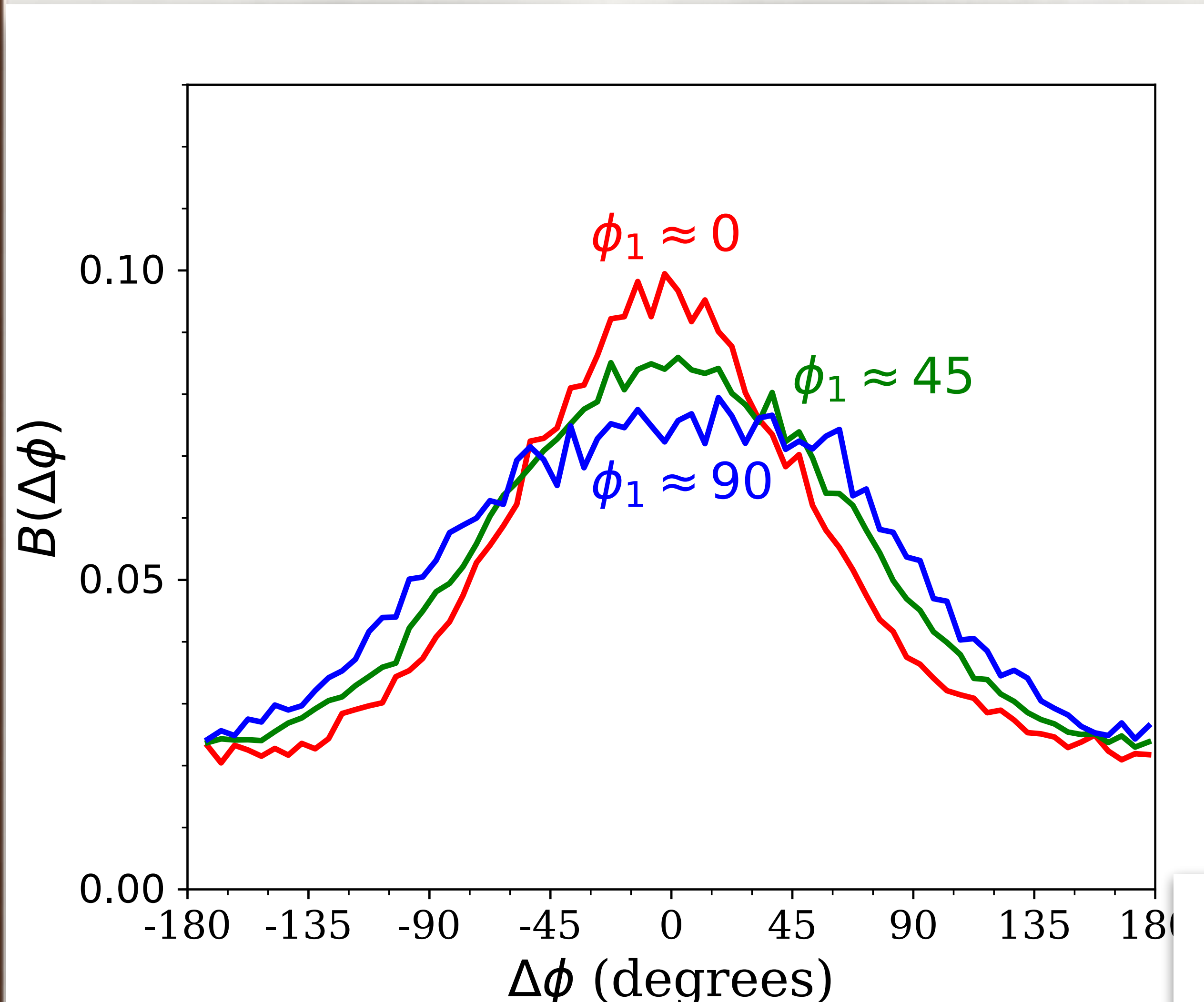


COMPARE TO STAR

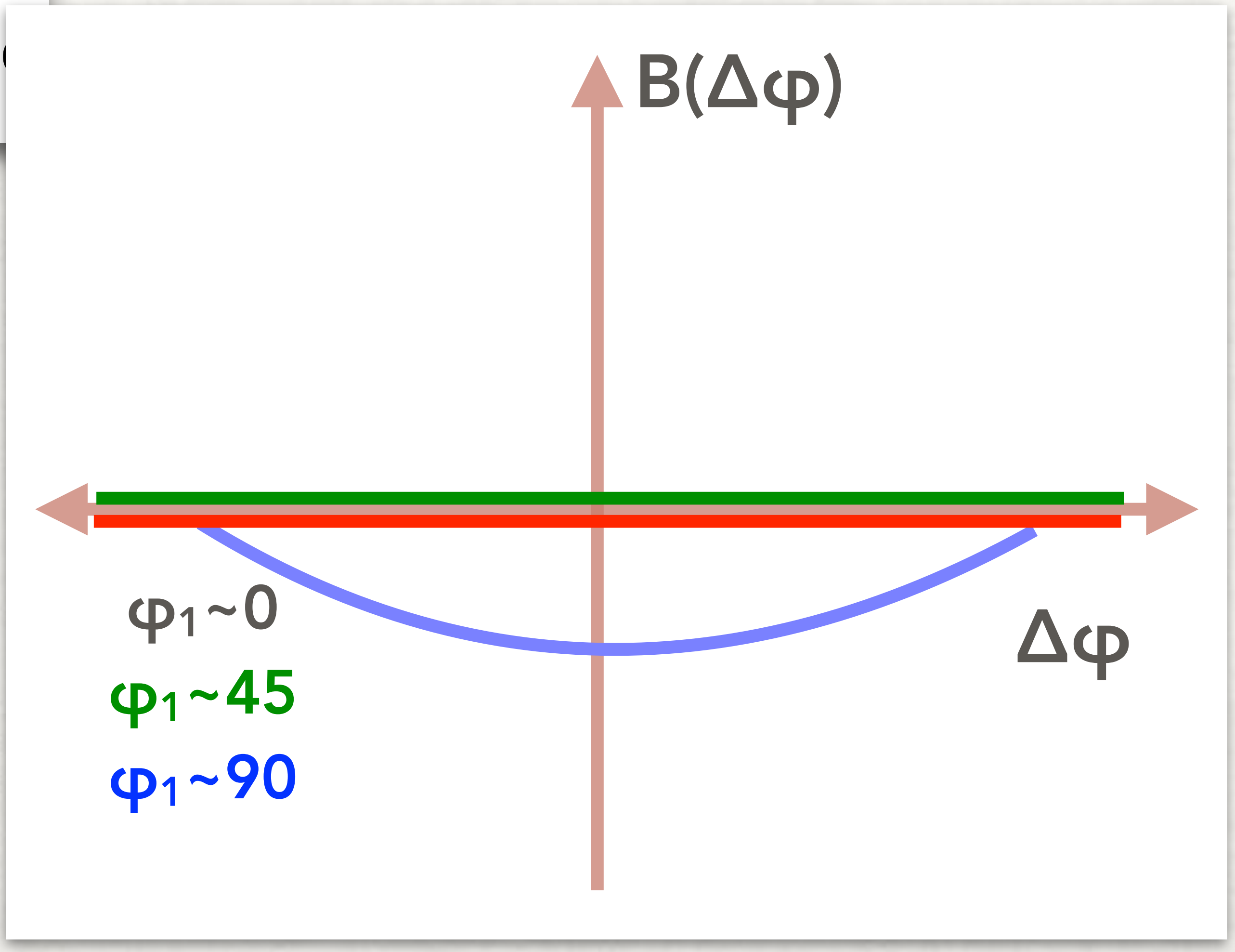
- Qualitatively similar
- BUT!

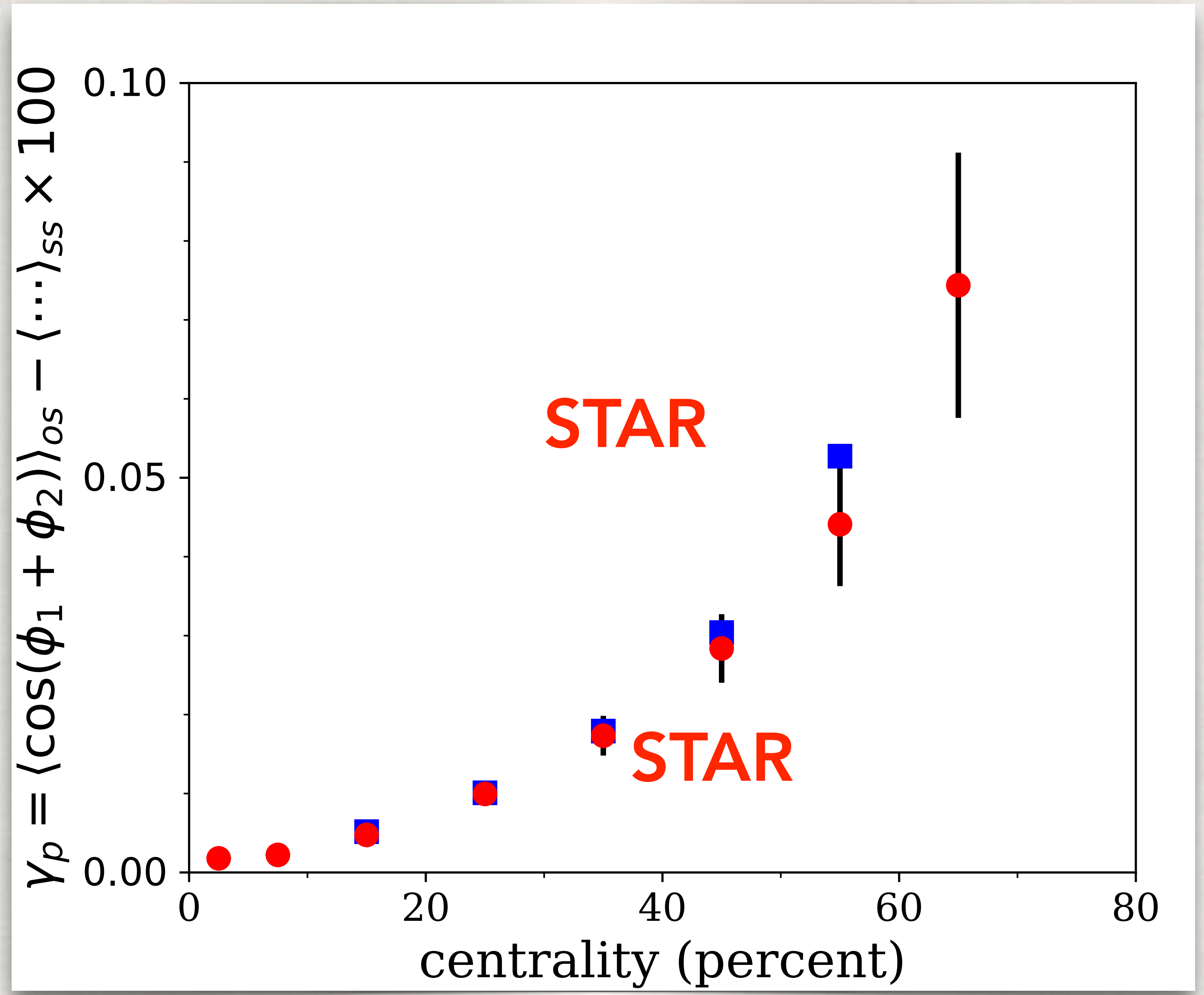
  STAR results ~25% narrower for all φ_1





CONTRAST WITH CME



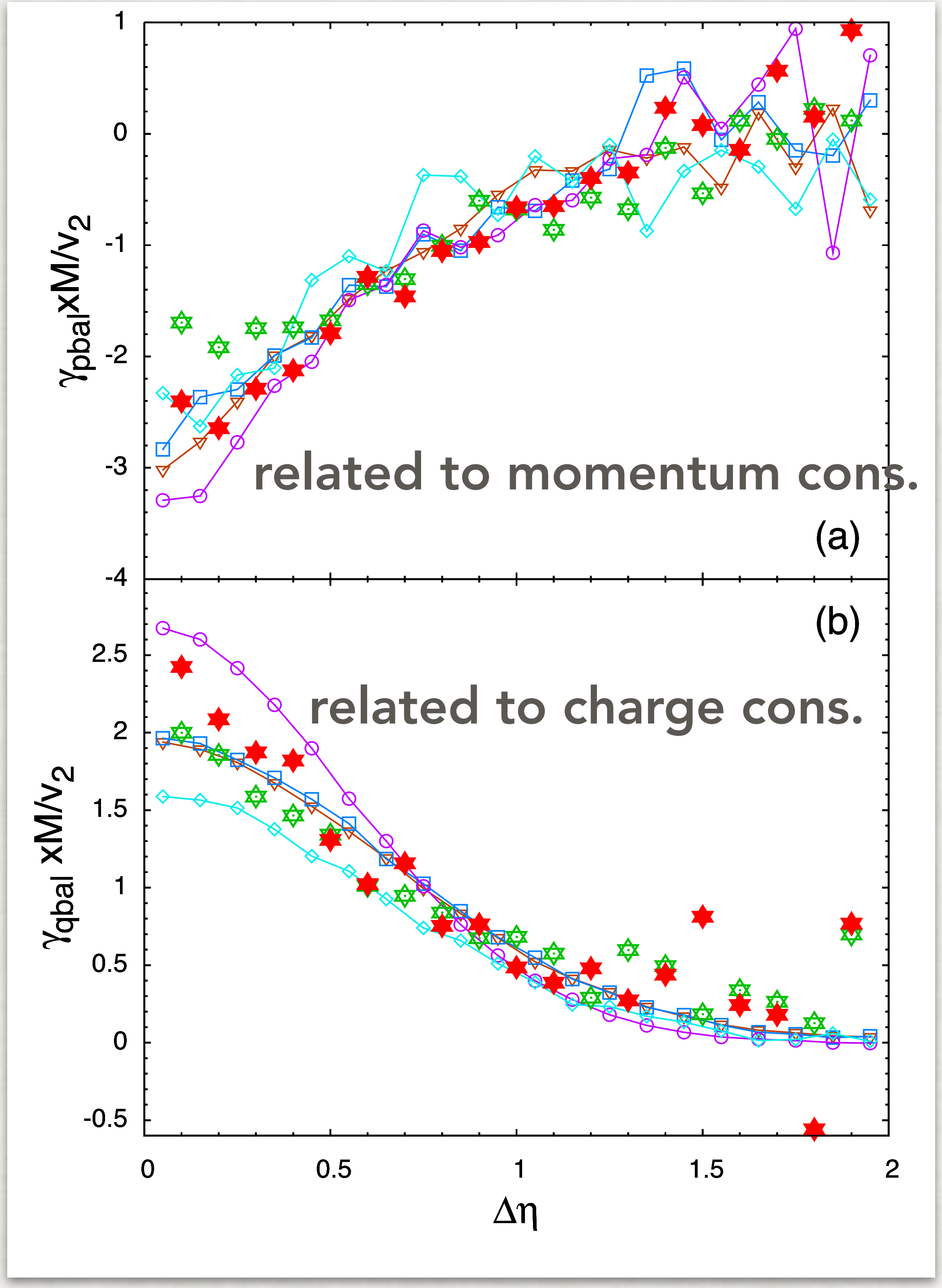


COMPARE TO STAR

Calculation:

- only one centrality, so far
- ~ 10% above STAR

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



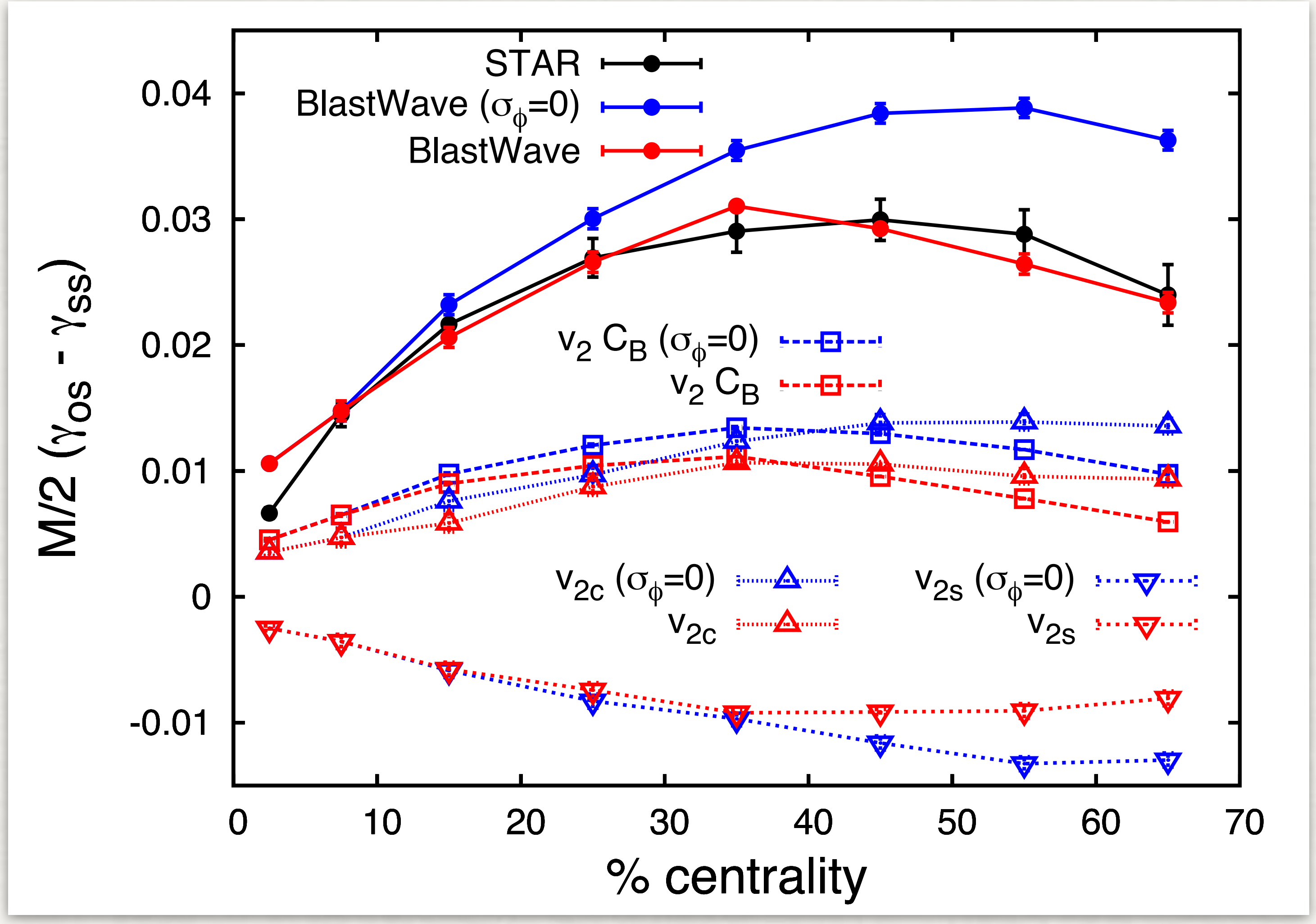
OTHER CALCULATIONS VS. STAR

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

ADD CASCADE

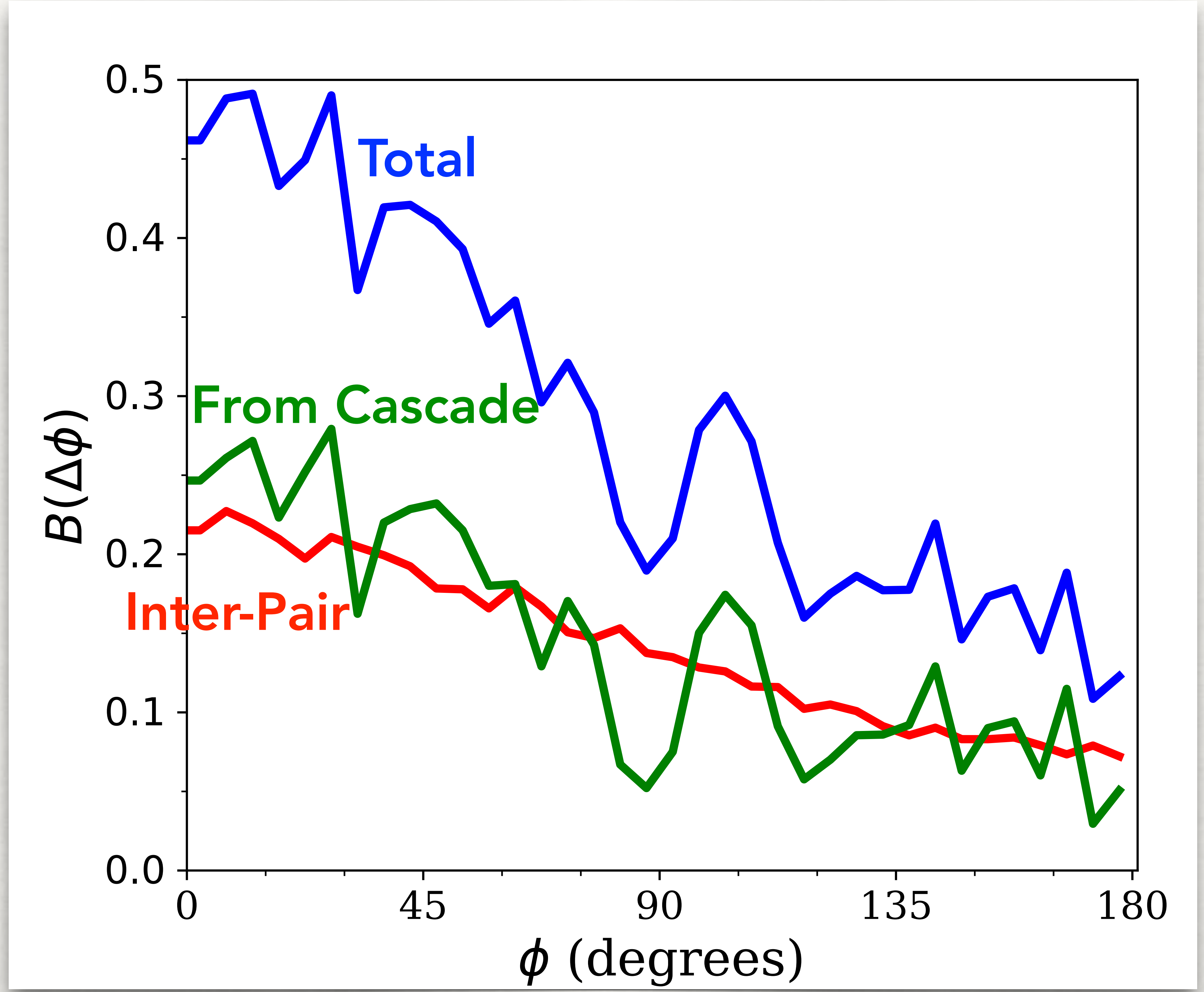
Can no longer isolate correlated particles ➜ NOISY

Divide C′ into 2 parts:

1. Inter-pair correlations (exist at hyper-surface)
   scatter particles (s-wave scattering), keep track of partners
2. Correlations that build in cascade: generate uncorrelated particles, then collide, decay, calculate correlations between all particles

(2) is NOISY!!

ADD CASCADE (PROGRESS REPORT)



GOING FORWARD

- Finish Implementation of Cascade
- Add effects of baryon annihilation
- Evaluate many species and kinematics
- Imaging:

$$B_{hh'}(\Delta\vec{p}) \rightarrow C_{ab}(\Delta\vec{r})$$

- Experiment

  — STAR and ALICE:

  Calculate BFs for multiple species,
  bin by Δφ, Δ*y*, Q_{inv} and by
  momentum/direction of first particle

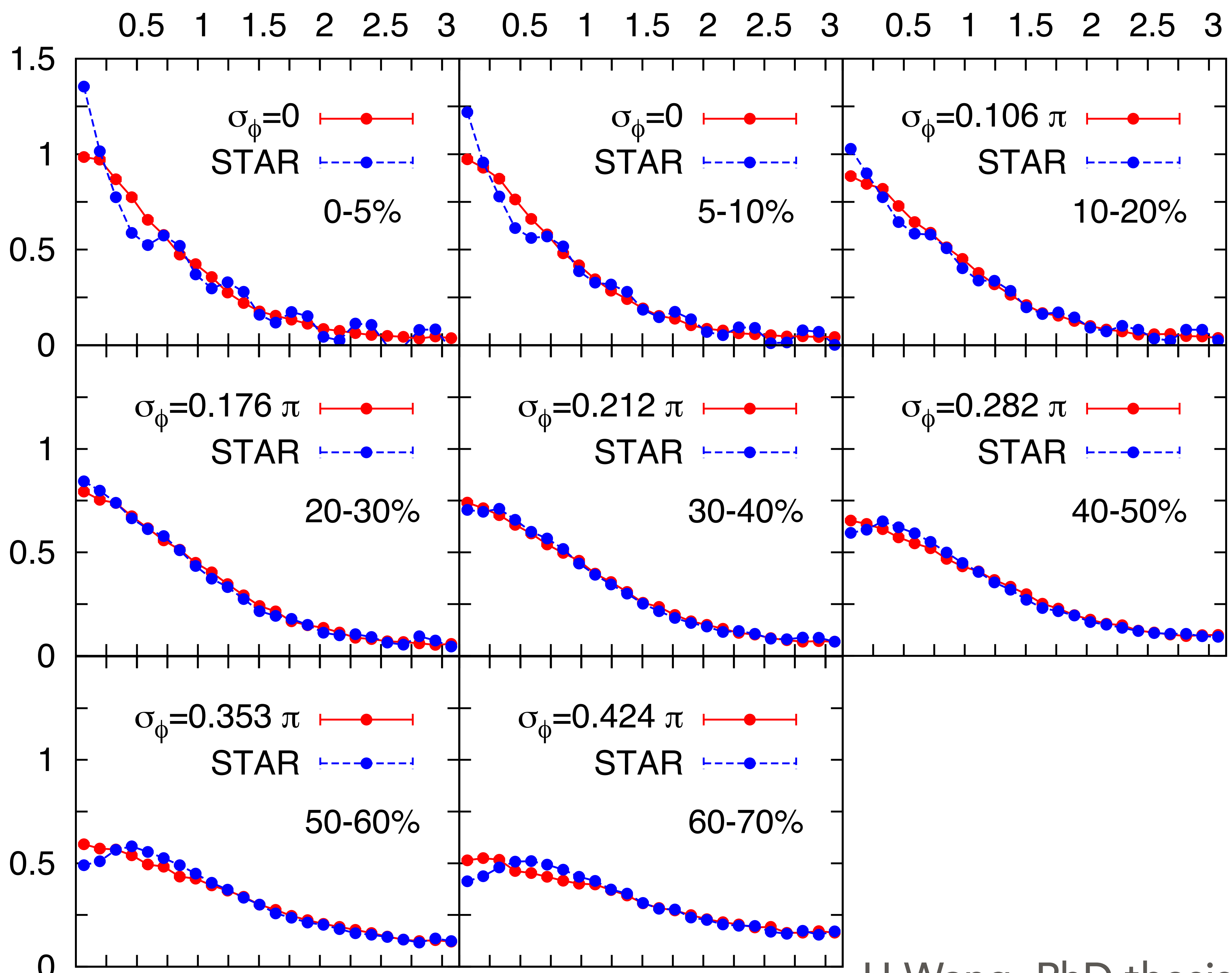
  — CMS/ALICE:

  Use wide rapidity acceptance, investigate
  spread of charges produced early
  Correlate ⟨Δφ⟩ vs ⟨Δ*y*⟩, determine *D*!!

  — Small Systems:

  Are quarks produced early?
  or at hadronization?

STAR, AZIMUTHAL BFS



H.Wang, PhD thesis