Charge balancing and correlations in relativistic heavy-ion collisions

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Initial State Fluctuations and Final State Correlations in Heavy-Ion Collisions, ECT*-EMMI Workshop, Trento, 2-6 Jul 2012

(based on PRC 85 (2012) 044910, PRC 83 (2011) 034911, arXiv:1204.3580)

Initial fluctuations

Correlations carry rich info on the physics of the heavy-ion collision
Our approach: initial → hydro → statistical hadronization

- **Initial phase** - "geometric fluctuations" from the distribution of nuclei [Miller & Snellings 2003, PHOBOS 2006, Andrade et al. 2006]
- **Hydrodynamics** - here deterministic
- **Statistical hadronization** - fluctuations from a finite number of hadrons

flow/non-flow? jets?

[Takahashi et al. 2009, Alver et al. 2010, Staig & Shuryak 2010, Moscy & Sorensen 2010, Luzum 2011, Schenke et al. 2011, Qiu et al. 2012, Kapusta, Mueller & Stephanov 2012, ... **(all audience)** ... , Trainor]

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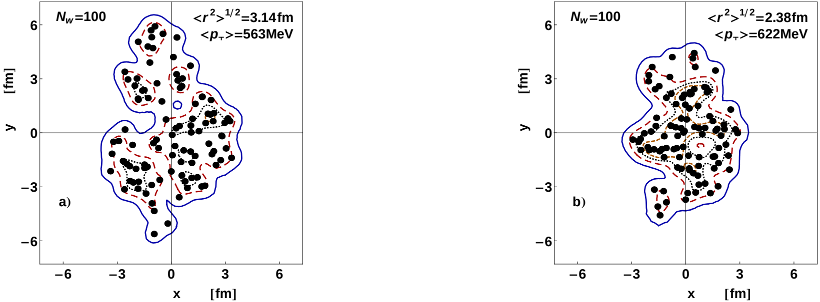
Local charge conservation (balancing) very important for 2-particle correlations → explanation of the data

Initial fluctuations in the Glauber approach

[concerning issues discussed on Monday see WB, PB, M. Rybczynski, PRC76 (2007) 054905 **(odd harmonics, r^k weighting, superimposed distributions)**, WB, MR, PRC81 (2010) 064909, PRC84 (2011) 064913 **(NN correlations and realistic wounding profile)** $\rightarrow$ GLISSANDO]



Two typical configuration of wounded nucleons in the transverse plane generated with GLISSANDO, isentropes at $s = 0.05$, 0.2, and 0.4 GeV^{-3}

No need to talk about hotspots

Hydrodynamics

3+1D viscous event-by-event hydrodynamics, tuned to reproduce the one-body **RHIC** data [Bożek 2012]

standard set of parameters:

$\tau_{\rm init} = 0.6$ fm/c, $\eta/s = 0.08$ (**shear**), $\zeta/s = 0.04$ (**bulk**), $T_f = 140$ MeV

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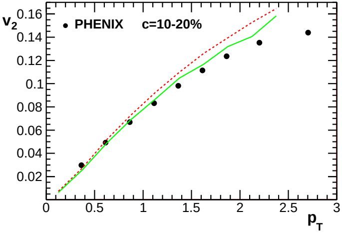
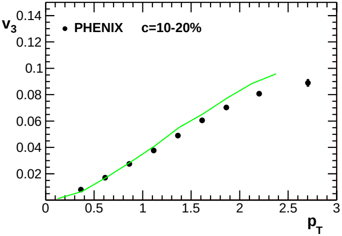
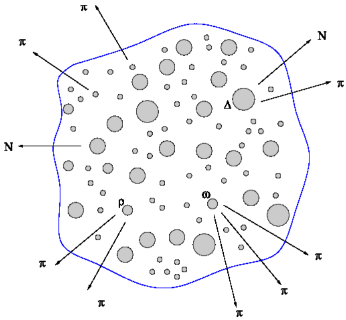
sample results (see Piotr Bozek's talk)





solid: e-by-e, dashed: averaged initial condition

Final fluctuations

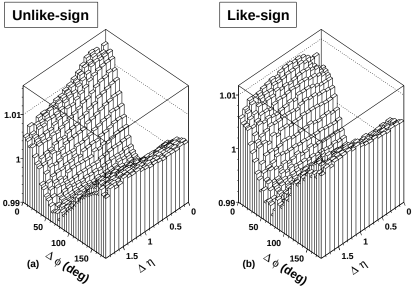


Statistical hadronization via Frye-Cooper formula + resonance decays (THERMINATOR)

Definition and Star data, 2007

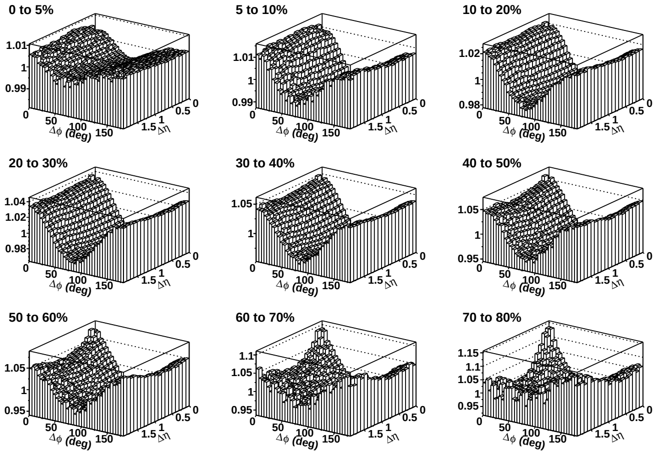
$$R_2(\Delta\eta, \Delta\phi) = \frac{N^{\text{pairs}}_{\text{phys}}(\Delta\eta,\Delta\phi)}{N^{\text{pairs}}_{\text{mixed}}(\Delta\eta)}$$

$(0.8 < p_T < 4$ GeV - "unbiased", no high-p_T trigger)



STAR data, 2008

like sign ($0.8 < p_T < 4$ GeV - "unbiased")



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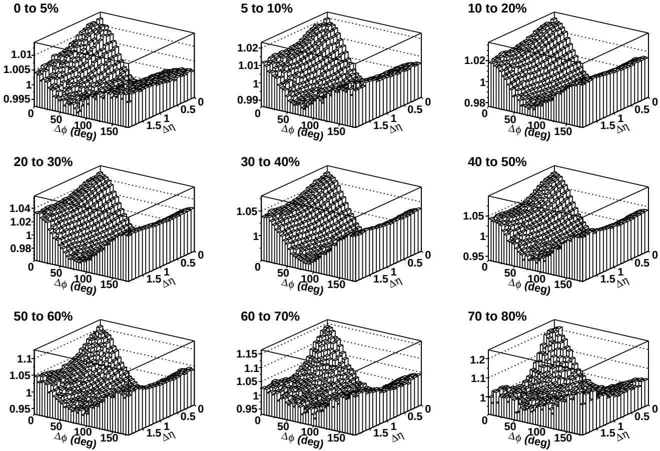
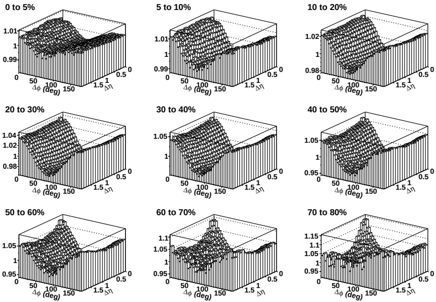
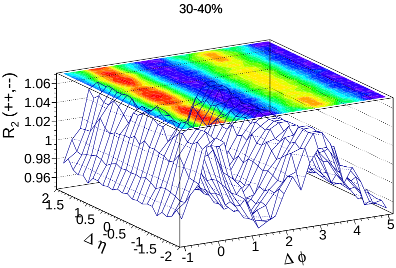


STAR vs. model

(like sign, $0.8 < p_T < 4$ GeV, unbalanced)





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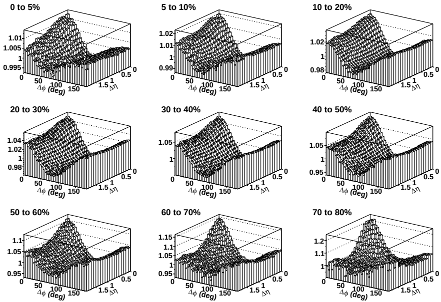
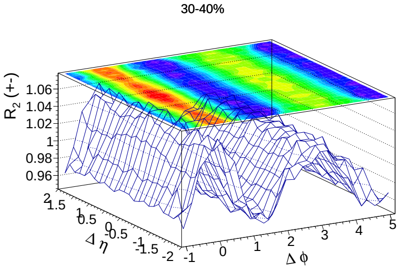
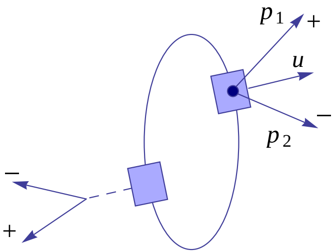




Charge balancing (from resonance decays and “direct”)

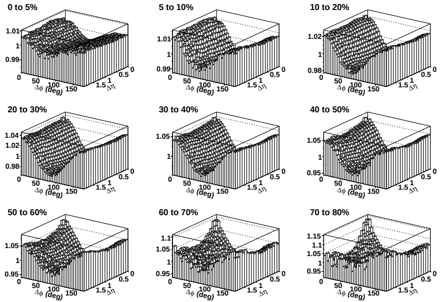
transverse-plane view of the expanding system at freeze-out

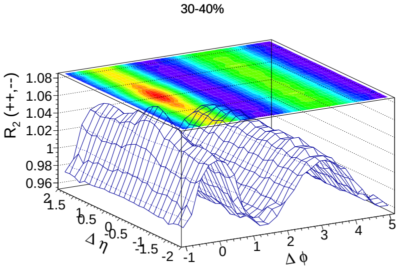


direct balancing: pair emitted from the neutral hydro medium from the same space-time point
resonances also contribute
special kind of clusters

STAR vs. model

(like sign, $0.8 < p_T < 4$ GeV, balanced)





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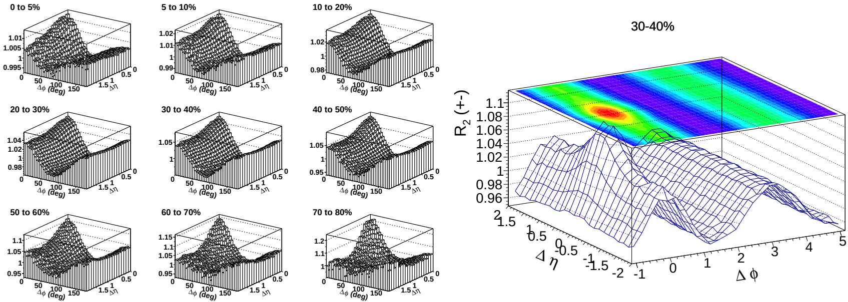
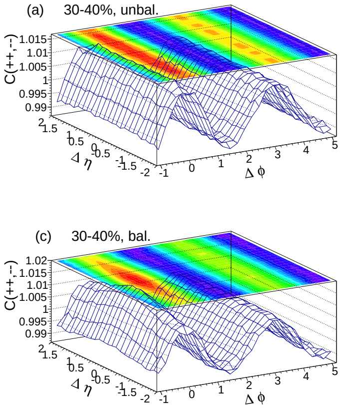


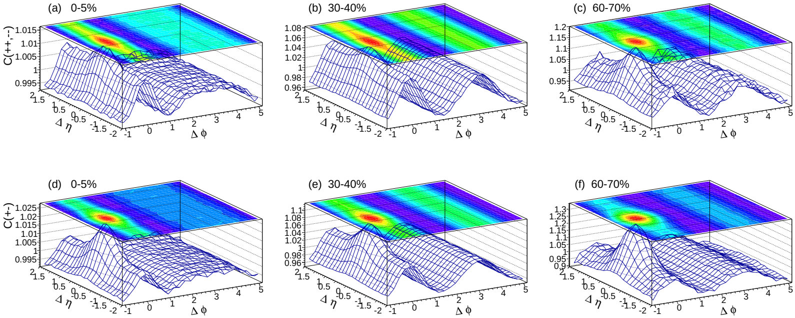
Role of balancing

$(0.2 < p_T < 2 \text{ GeV}, C = R_2)$

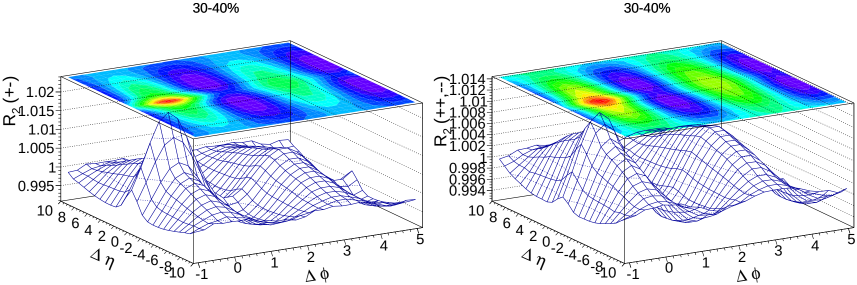


3 centralities

$(0.8 < p_T < 4$ GeV)

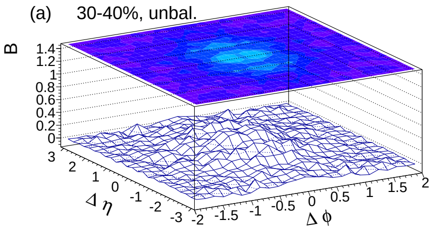


Large η coverage



2D balance functions

$$B(\Delta\eta, \Delta\phi) = \frac{\langle\ N_{+-} - N_{++}\rangle}{\langle N_+\rangle} + \frac{\langle N_{-+} - N_{--}\rangle}{\langle N_-\rangle}$$



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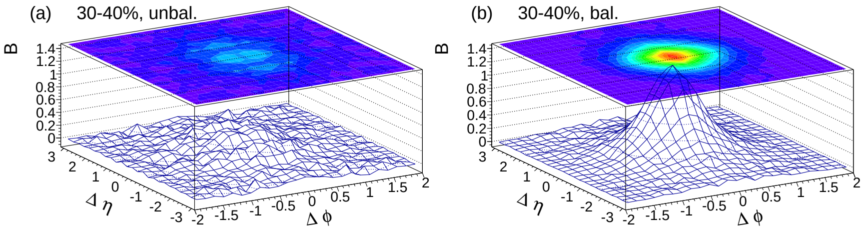


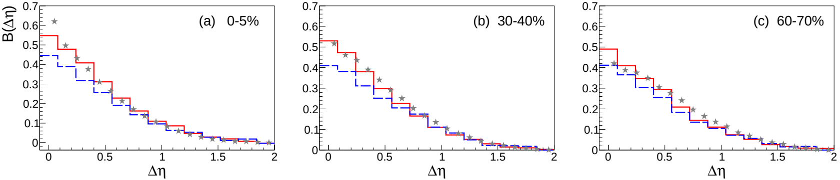
small (resonance decays only) big (direct balancing)

balancing $\rightarrow$ collimation
important non-flow effect, a way to look at the data

Balance functions in relative rapidity

[Jeon & Pratt 2002, Bass et al. 2010, Bożek et al. 2005]

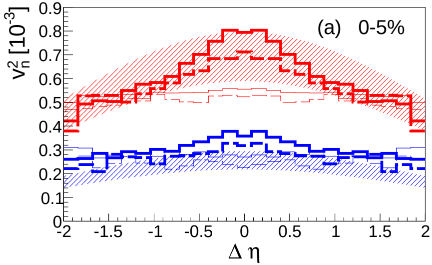
Marginal distribution of the above 2D function: the charge balance function in $\Delta\eta$



comparison to the STAR data
solid: $T_f = 140$ MeV, dashed: $T_f = 150$ MeV

$v_n^2(\Delta\eta)$

$$v_n^2(\Delta\eta) = \int d\Delta\phi/(2\pi)\ \cos(n\Delta\phi) R_2(\Delta\eta, \Delta\phi)$$



comparison to extracted STAR data, v_2^2, v_3^2

fat: with balancing, thin: no balancing - completely **flat**

solid: $T_f = 140$ MeV, dashed: $T_f = 150$ MeV

balancing → explanation of the fall-off of the same-side ridge in $\Delta\eta$

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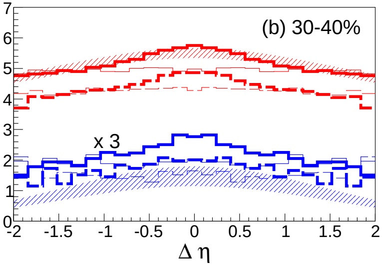

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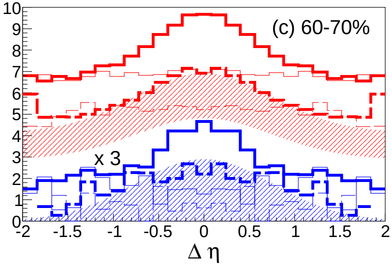

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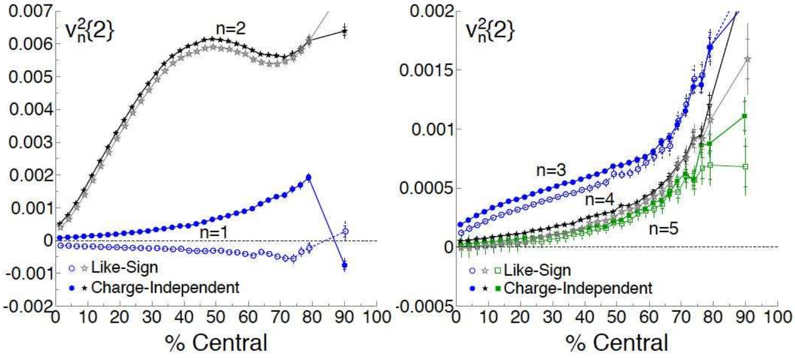
STAR 2011

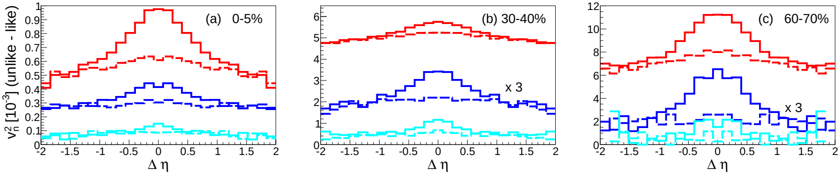
Paul Sorensen at QM2011, STAR preliminary



[Art Poskanzer on Friday]

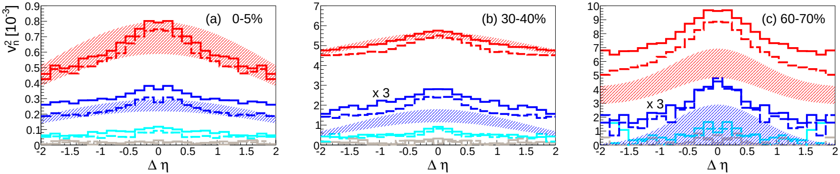
Charge-dependence of $v_n^2(\Delta\eta)$

$(0.15 < p_T < 2$ GeV$)$



solid: unlike, dashed: like

Dependence on viscosity



solid: $\eta/s = 0.08$, dashed: $\eta/s = 0.16$

$v_n^2\{2\}$

$(0.15 < p_T < 2$ GeV)

$c = 0-5\%$

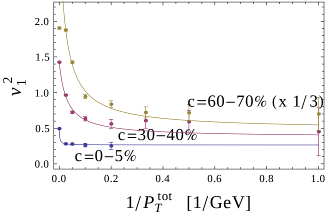
$v_n^2\{2\}$ $[10^{-3}]$	no balancing			with balancing		
	CI	$(++,--)$	$(+-)$	CI	$(++,--)$	$(+-)$
2	0.54(1)	0.53(1)	0.55(1)	0.66(1)	0.58(1)	0.74(1)
3	0.27(1)	0.26(1)	0.27(1)	0.32(1)	0.28(1)	0.34(1)
4	0.074(3)	0.071(4)	0.077(4)	0.081(3)	0.075(4)	0.088(4)

$c = 30-40\%$

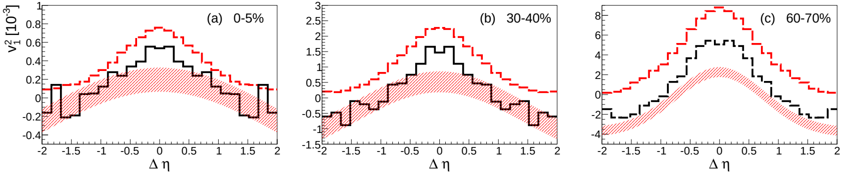
$v_n^2\{2\}$ $[10^{-3}]$	no balancing			with balancing		
	CI	$(++,--)$	$(+-)$	CI	$(++,--)$	$(+-)$
2	4.76(3)	4.75(3)	4.78(3)	5.14(2)	4.98(2)	5.39(2)
3	0.63(2)	0.64(2)	0.62(2)	0.78(1)	0.69(1)	0.88(1)
4	0.16(1)	0.16(2)	0.16(2)	0.19(1)	0.15(1)	0.23(1)

balancing $\rightarrow$ splitting, overall increase by a few %

Transverse momentum conservation

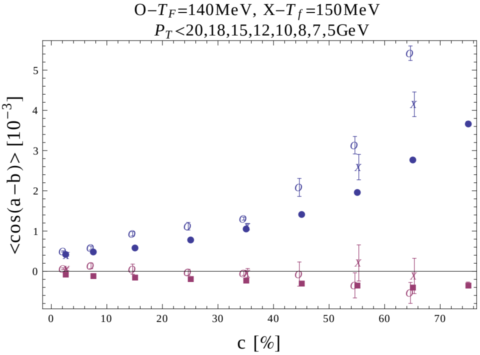


transverse-momentum conservation lowers
$v_1^2(\Delta\eta) \equiv \langle \cos(\phi_1 - \phi_2) \rangle$



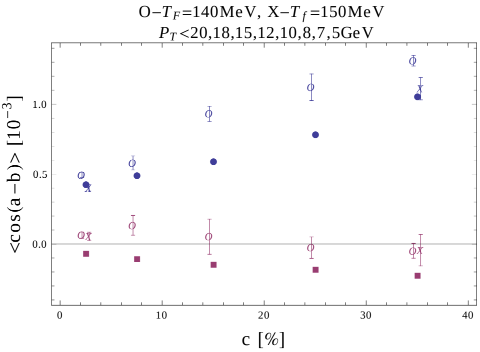
comparison to the STAR data

"Local-parity-violation" plots



blue: $(+-)$, violet: $(++, --)$

"Local-parity-violation" plots



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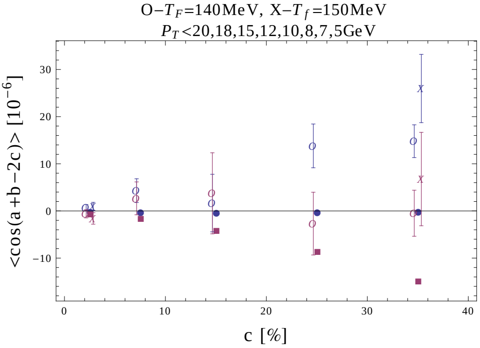

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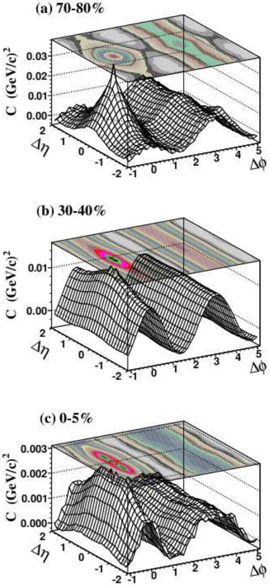
Definition

Similar to R_2, but weighting with p_T:

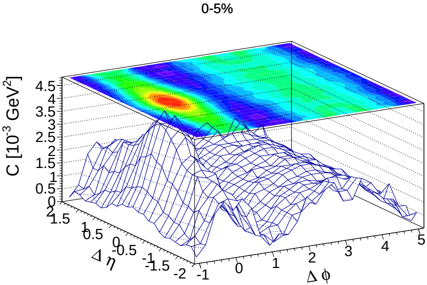
$$C(\Delta\eta, \Delta\phi) = \frac{\left\langle \sum_{i=1}^{n_1} \sum_{i \neq j=1}^{n_2} p_{Ti} p_{Tj} \right\rangle - \left\langle \sum_{i=1}^{n_1} p_{Ti} \right\rangle \left\langle \sum_{j=1}^{n_2} p_{Tj} \right\rangle}{\left\langle \sum_{i=1}^{n_1} 1_i \right\rangle \left\langle \sum_{j=1}^{n_2} 1_j \right\rangle}$$

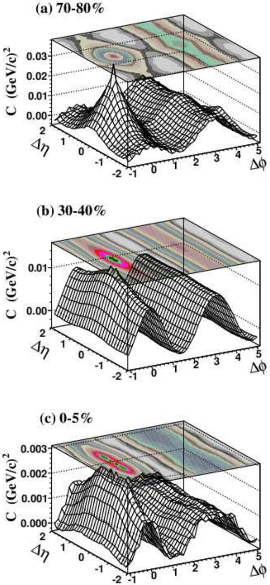


$(0.2 < p_T < 2$ GeV)

$\leftarrow$ STAR

With charge balancing and p_T conservation





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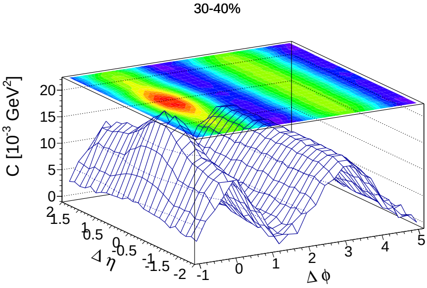

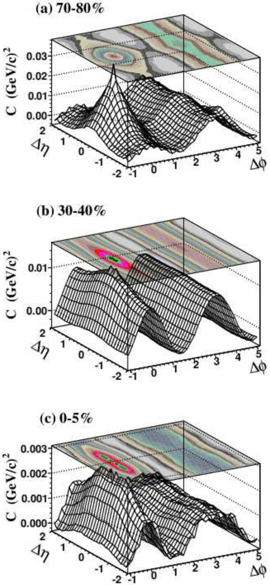

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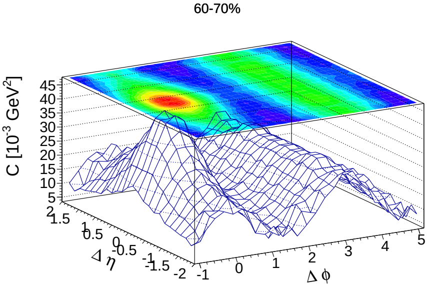

Conclusions

- E-by-e hydro with charge balancing in semi-quantitative agreement with the (soft) data for 2-particle 2D correlations from RHIC, dependence on the relative charge of the pair appears in a natural way
- **Charge balancing** explains the shape of the same-side ridge - major **non-flow** effect
- Dependence of the flow coefficients on $\Delta\eta$ reproduced
- Charge balancing increases $v_n^2\{2\}$ by a few % and splits the like-sign and unlike-sign case
- Transverse-momentum conservation important for v_1^2, semi-quantitative agreement
- Differential transverse-momentum conservation also reproduced
- Need to improve the model for peripheral collisions