Compressed Baryonic Matter
GSI, 2002

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Hadronization – When and How

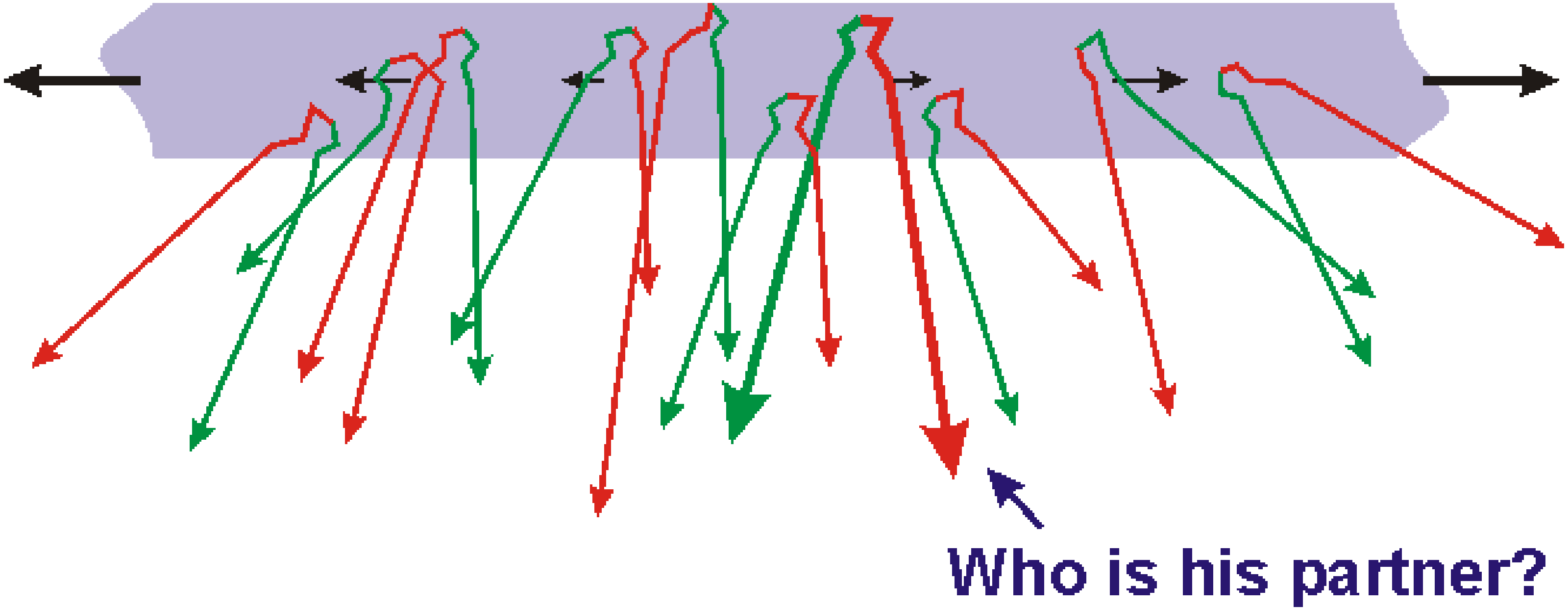
- **What are *Balance Functions*?**
- **What do STAR results say?**
- **Qualifications for large baryon number environment**

Charge is Created at Hadronization

1. Gluonic modes carry entropy, but no charge
2. Coalescence of quarks at same *T* should have: $N_{mesons} \sim N_{quarks} + N_{antiquarks}$
   → quark number ~ doubles
3. Coherent sources (chiral fields, bag energy…) can produce new charge.

- ***For B=0 QGP, >1/2 of charge is created at hadronization***
- ***For CBM, ????***

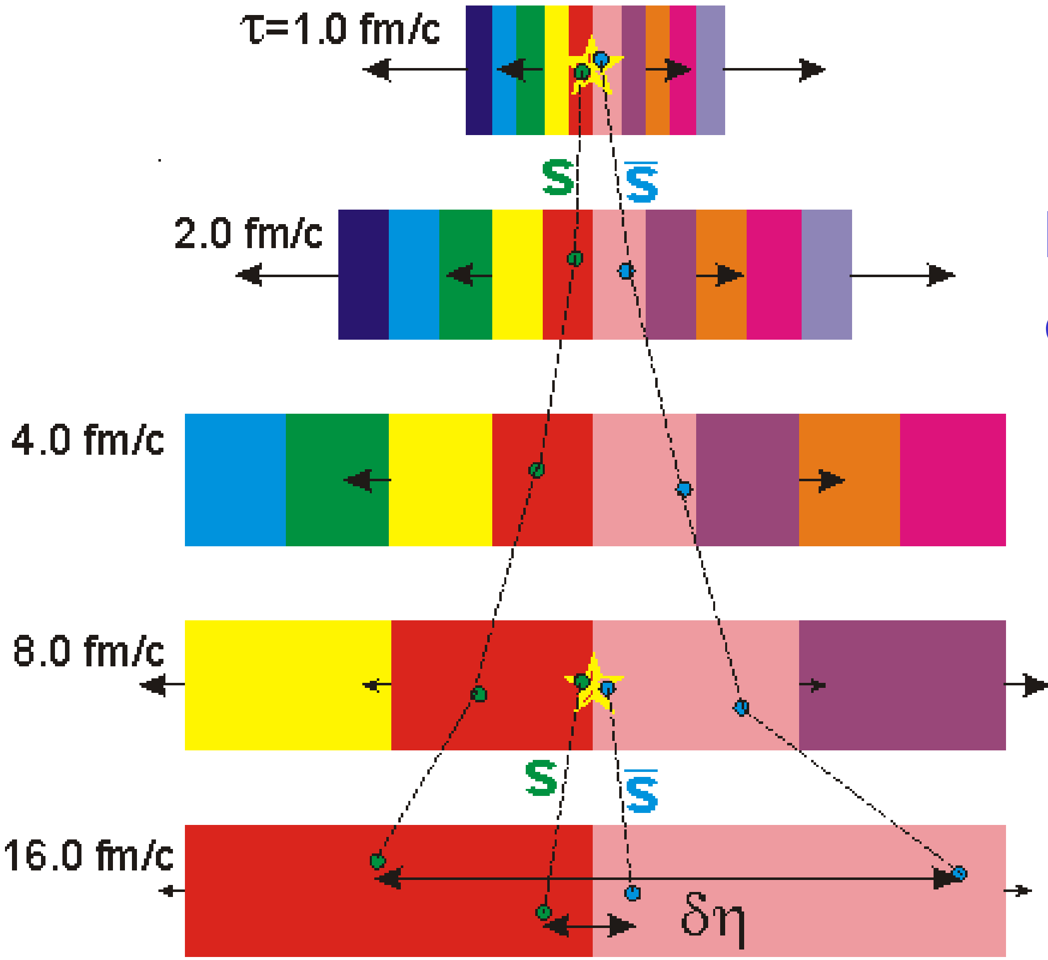
Balance Functions: How They Work



For each charge +*Q*, there is one extra balancing charge –*Q*.

$$B(\Delta y)=\frac{1}{2}\left\{\frac{N_{+-}(\Delta y)-N_{++}(\Delta y)}{N_{+}}+\frac{N_{-+}(\Delta y)-N_{--}(\Delta y)}{N_{-}}\right\}$$

Charges: electric, strangeness, baryon number



If one knows breakup *T*, one can determine $\sigma_{\delta\eta}$

Difficulty:
Identifying balancing partners

$$\sigma^2_{\delta y} = \sigma^2_{\delta\eta} + \sigma^2_{\text{therm}}$$

experiment

diffusive

determined by breakup temp.

Balance Function: Definition

B is a conditional distribution, e.g., P_1 is anywhere in the detector and P_2 is relative rapidity.

$$B(P_2|P_1) = \frac{N(+,P_1;-P_2) - N(+,P_1;+,P_2)}{2N(+,P_1)} + \frac{N(-,P_1;-P_2) - N(-,P_1;+,P_2)}{2N(-,P_1)}$$

If matter is neutral,

$$B(P_2|P_1) = \frac{\langle (N_+(P_1) - N_-(P_1))(N_+(P_2) - N_-(P_2))\rangle'}{\langle N_+(P_1) + N_-(P_1)\rangle}$$

Charge fluctuations are given by $B(P_1|P_1)$. (S.Jeon & S.P., PRC 2002)

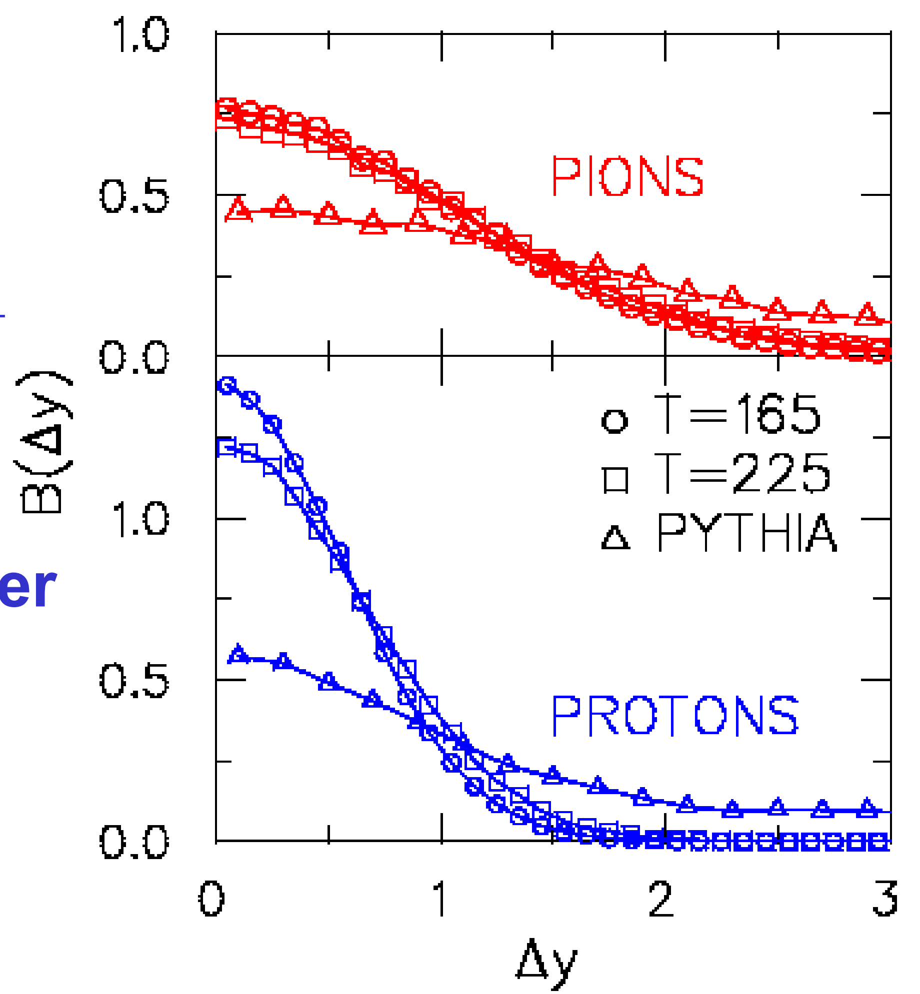
If $\langle N_+\rangle \neq \langle N_-\rangle$, one may wish to define

$$\begin{aligned}\tilde{B}(P_2|P_1) \;=\; & \frac{\langle (N_+(P_1) - N_-(P_1))(N_+(P_2) - N_-(P_2))'\rangle}{\langle N_+(P_1) + N_-(P_1)\rangle} \\ & - \frac{\langle (N_+(P_1) - N_-(P_1))(N_+(P_2) - N_-(P_2))\rangle_{\rm mixed}}{\langle N_+(P_1) + N_-(P_1)\rangle}\end{aligned}$$

to eliminate contribution for uncorrelated excess charge.

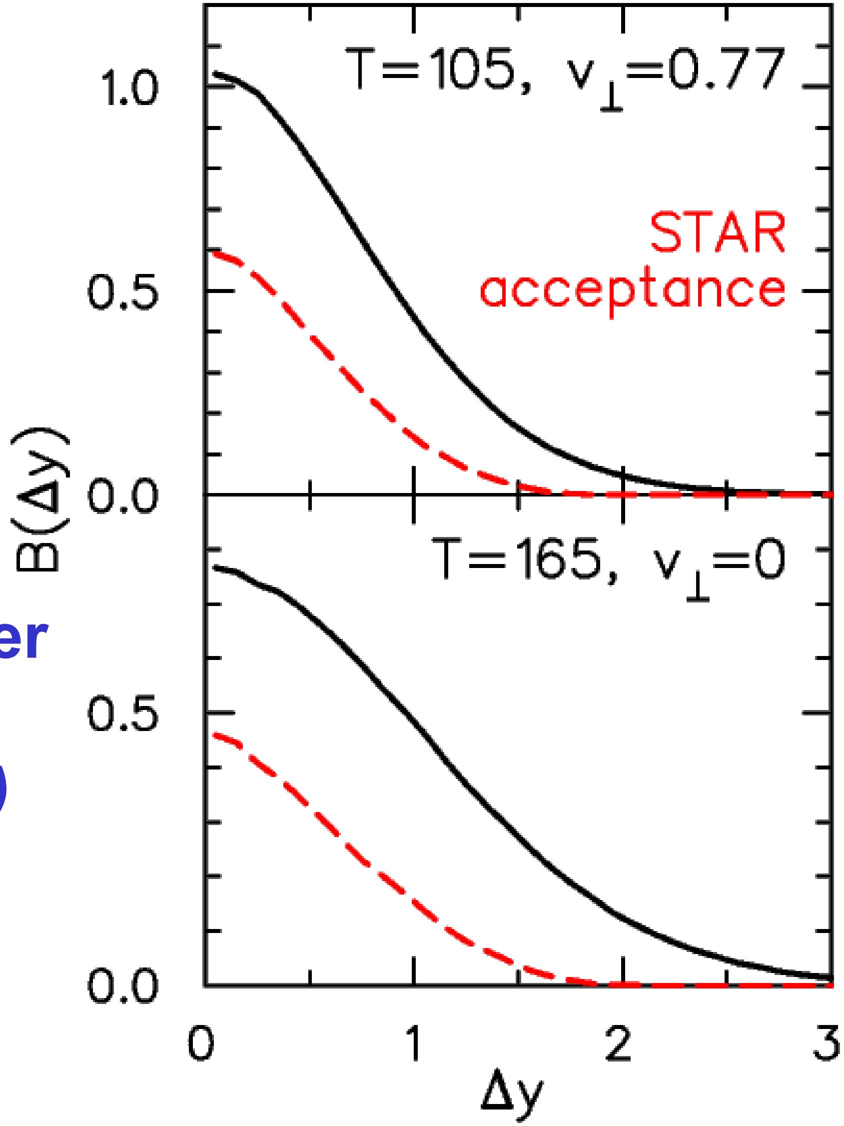
Bjorken Thermal Blast Wave Model

- Assume $\bar{Q}$ & Q produced at same point.
- B⟨Δ*y*⟩ determined only by *T*, $v_\perp$ and *m*.
- Proton balance function narrower that pion's.
- Thermal model always narrower than string model.

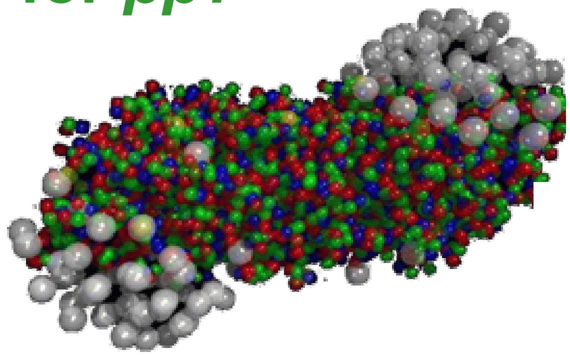


Bjorken Thermal Blast Wave Model

- Assume $\bar{Q}$ & Q produced at same point.
- $B\langle \Delta y \rangle$ determined only by T, $v_{\perp}$ and m.
- Proton balance function narrower that pion's.
- Thermal model always narrower than string model.
- Transverse flow narrows $B(\Delta y)$



What if Balance functions are narrower for *AA* than they are for *pp?*



RQMD-type descriptions are qualitatively wrong

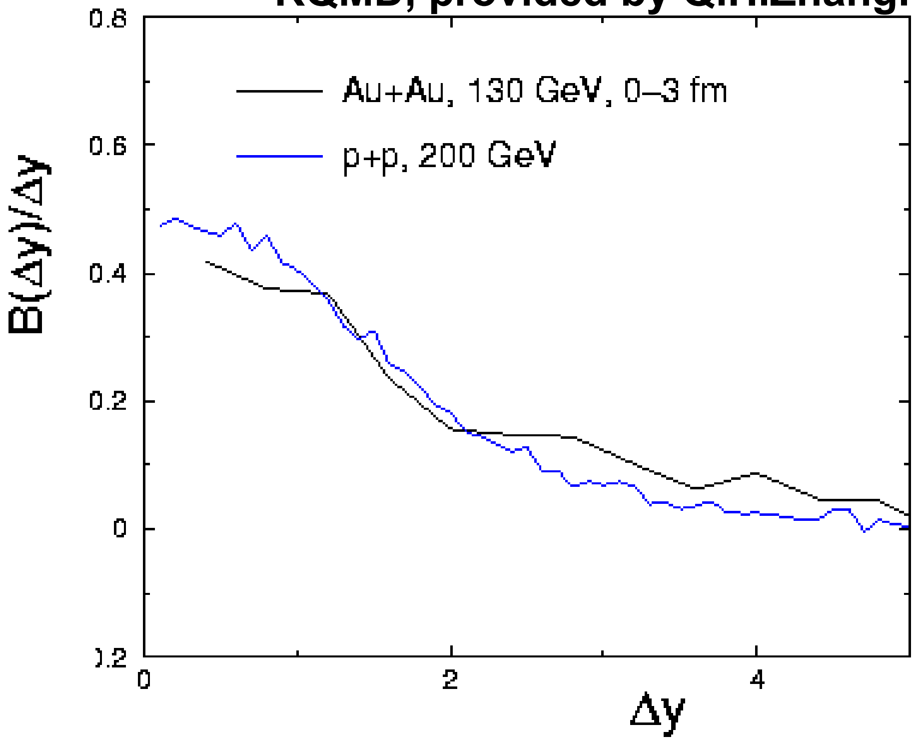
AND EITHER

1. Delayed production of charge
   - Change in degrees of freedom
   - QGP least exotic explanation

OR

2. Anomalously short mean free paths
   - would be contrary to common wisdom

What if *AA* balance functions are NOT narrower?

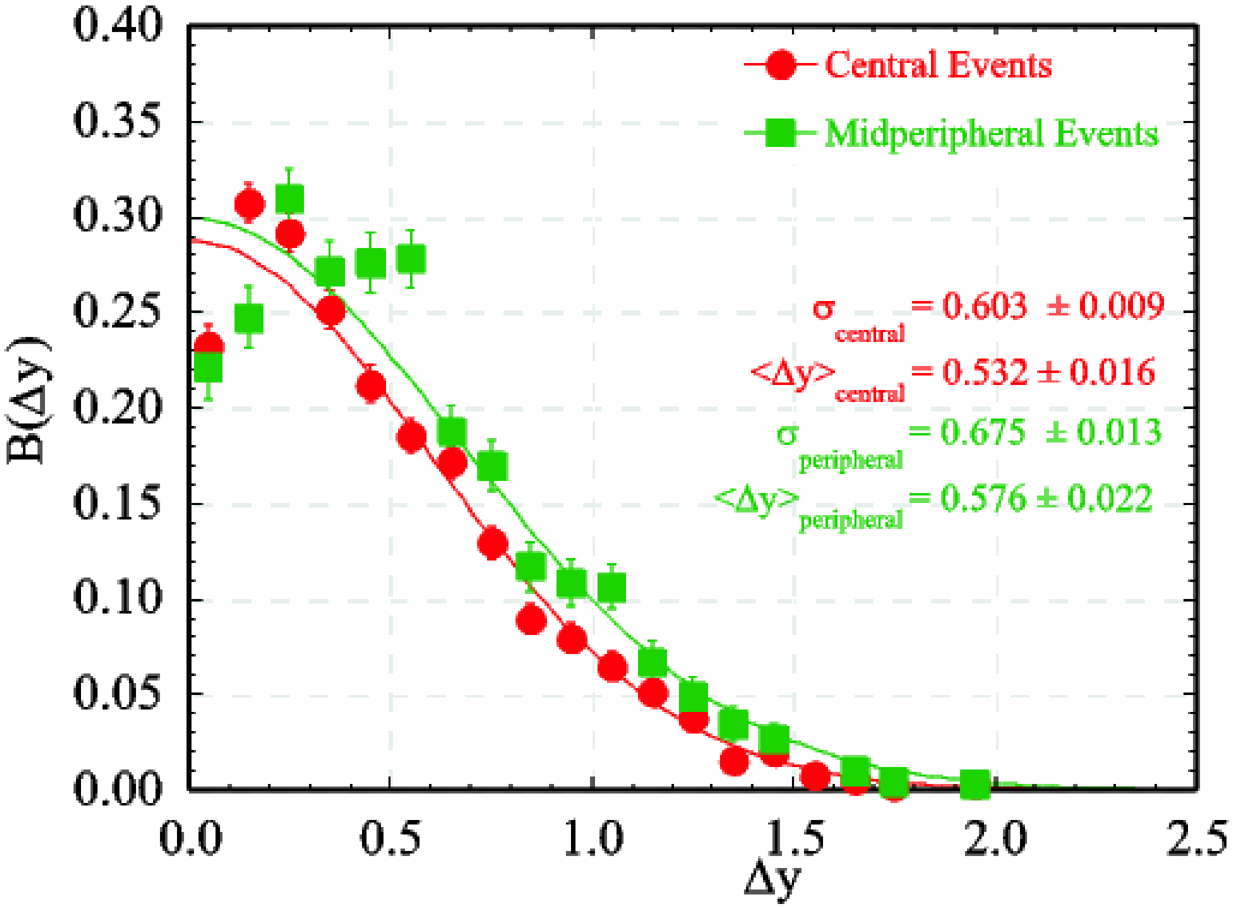


- Gluonic modes did not contribute to entropy
- No dramatic change in degrees of freedom.
- Usual strangeness enhancement arguments are wrong.
- *J*/Ψ & Jet-quenching phenomenology are misguided.

Preliminary STAR Results

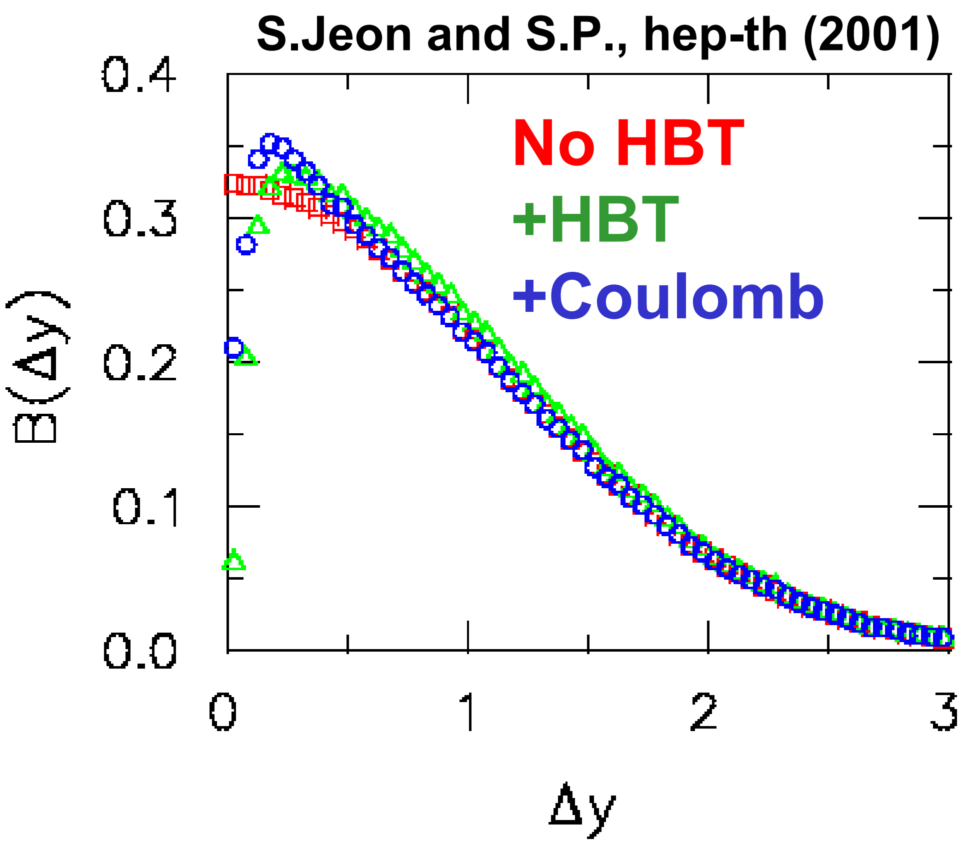
M. Tonjes, ParkCity, 2001

Identified Pions



More Central Collisions → Narrower Balance Functions !!!

The HBT Hole



HBT Weight:

- Use parameters to get weight: T=190 MeV, λ=.7, R_{inv}=7 fm
- Dip at small Δ*y*
- Applied to non-partners
- Proportional to *dn/dy*
- Does not change norm.
- No significant change in ⟨Δ*y*⟩
- Dip similar to that seen by STAR

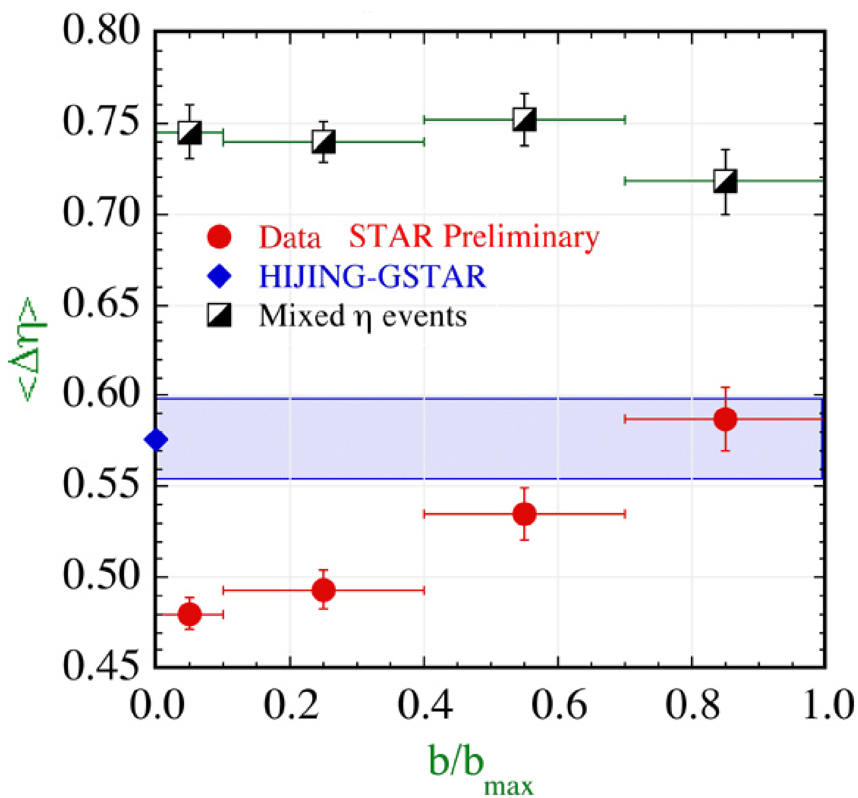
STAR Summary

	Central Data	Midperipheral Data	HIJING GSTAR Central
Charged pairs	σ=0.564±0.005 $\langle\Delta\eta\rangle$=0.555±0.011	σ=0.654±0.009 $\langle\Delta\eta\rangle$=0.612±0.017	σ=0.726±0.015 $\langle\Delta\eta\rangle$=0.659±0.026
Pion pairs	σ=0.603±0.009 $\langle\Delta y\rangle$=0.532±0.016	σ=0.675±0.013 $\langle\Delta y\rangle$=0.576±0.022	σ=0.706±0.011 $\langle\Delta y\rangle$=0.602±0.035
Kaon pairs	σ=0.350±0.031 $\langle\Delta y\rangle$=0.435±0.075	σ=0.391±0.047 $\langle\Delta y\rangle$=0.423±0.115	σ=0.743±0.096 $\langle\Delta y\rangle$=0.500±0.189

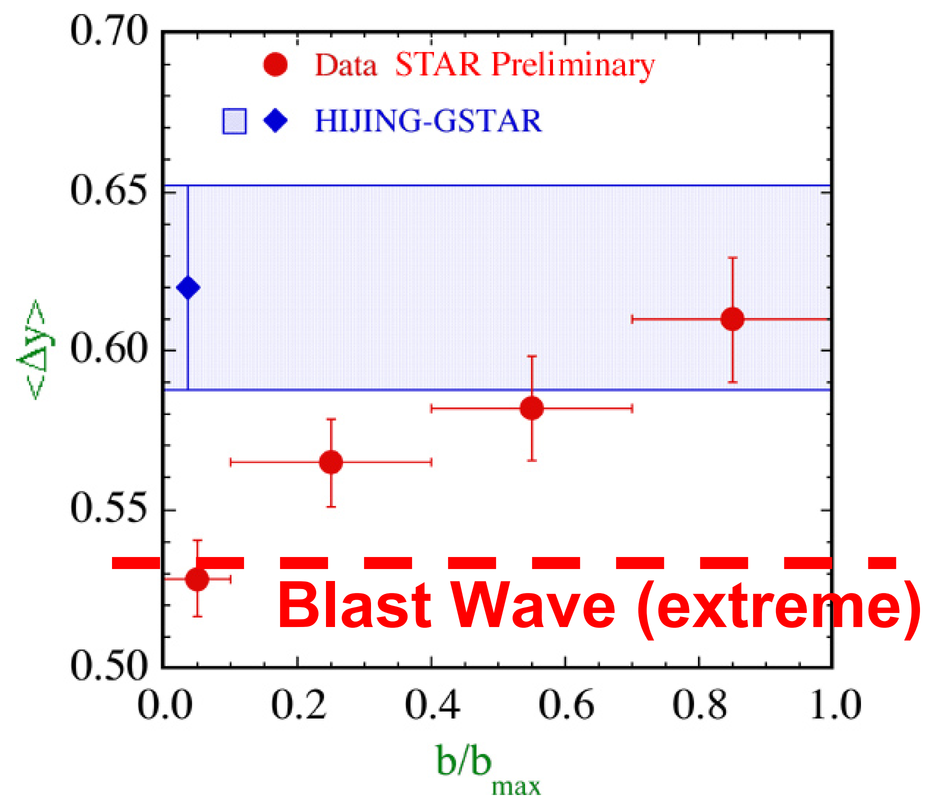
VERY PRELIMINARY

STAR, width vs. centrality

All Charges



Identified Pions



As $b \rightarrow 0$, data are consistent with ~100% delayed production with T ~ 110 MeV, $v_\perp$ ~ 0.75

Can We Convict the QGP?

1. Analyze *pp* collisions.
2. Analyze K^+K^- and *p-pbar* balance functions.
3. Decipher p_t dependence.
4. Study as functions of Q_{beam}, Q_{out}, Q_{side}, Q_{inv}.
5. Quantitatively understand normalization. (Loss of partners to other channels, e.g., π^+ balancing partner could be K^-.)

- *Much can be accomplished with STAR's 200 GeV data*
- PHENIX may be able to measure *p-pbar balance function*

Detector Requirements?

1. Large coverage, $\Delta y > 1.5$
2. Good Particle ID over large range.
3. Equal Acceptance for + and –, e.g. STAR
4. Millions of Events