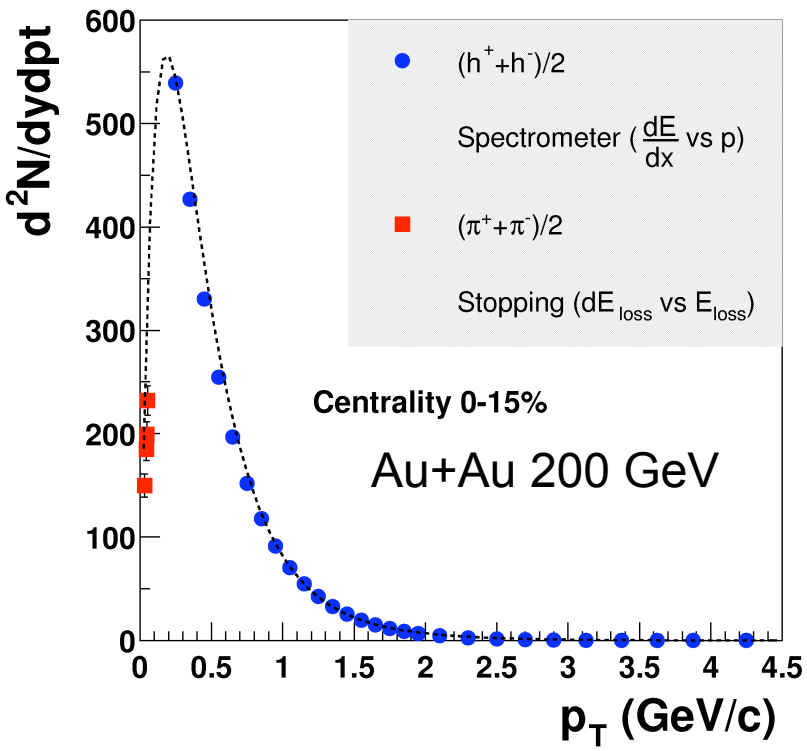
Charge Transport in High-Energy Hadron Collisions

Paul Stankus, ORNL

PANIC 05

The most interesting question at RHIC (IMHO)



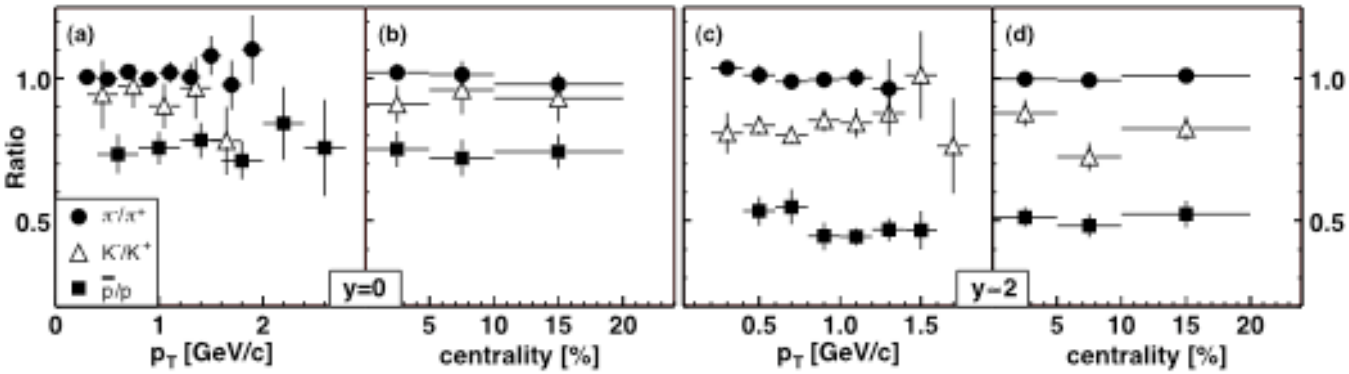
PHOBOS, Nucl. Phys. A 757, 28

Allowing that "the bulk" of hadrons produced in a RHIC A+A collision are from the decay of an extended QGP, then:

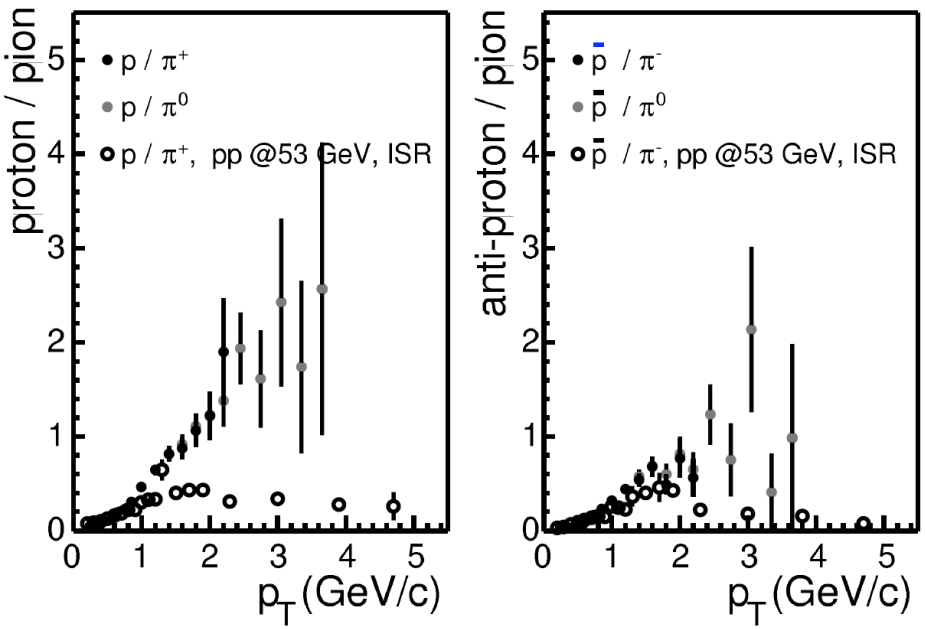
How does "the bulk" form?

- Initial transport?
- Initial thermalization?

Transport of conserved quantities



BRAHMS, Phys Rev Lett 90, 102301 (2003)



PHENIX, Phys. Rev. C 69, 024904 (2004)

Example: Baryon number

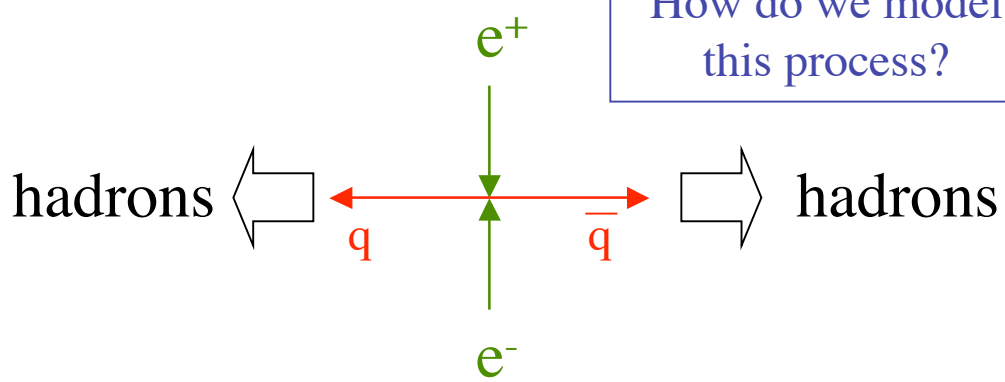
How does it get to mid-rapidity?

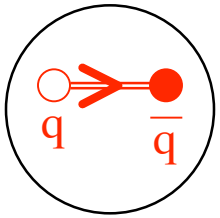
How does it get to high p_T?

Cannot be treated easily in pQCD!

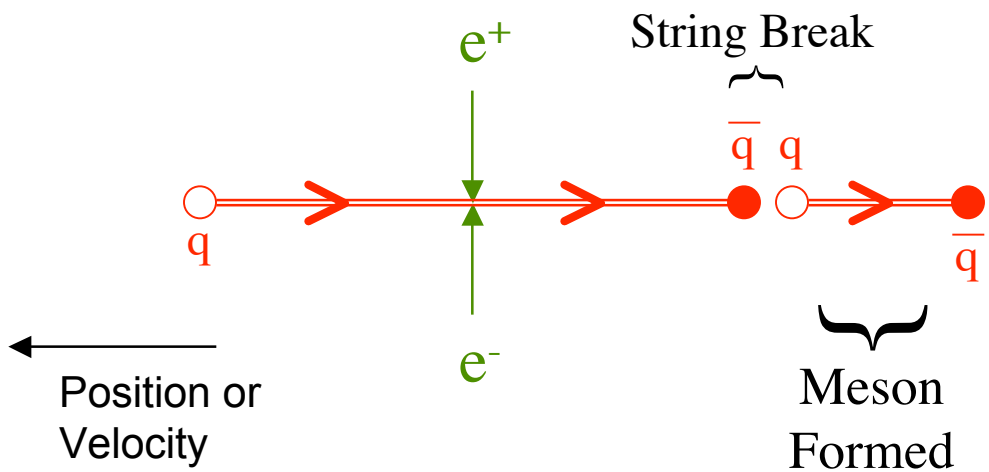
Low-brow review of color strings

How do we model this process?





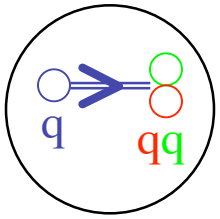
Model of a meson



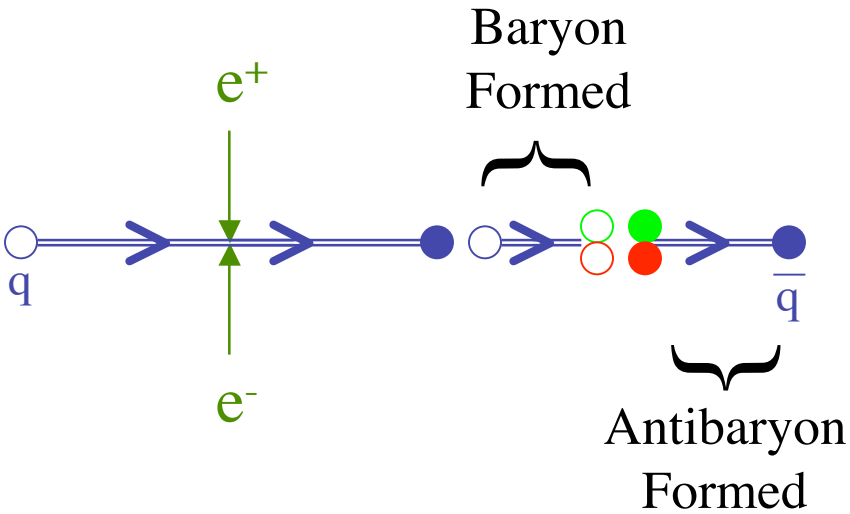
Extension to baryons

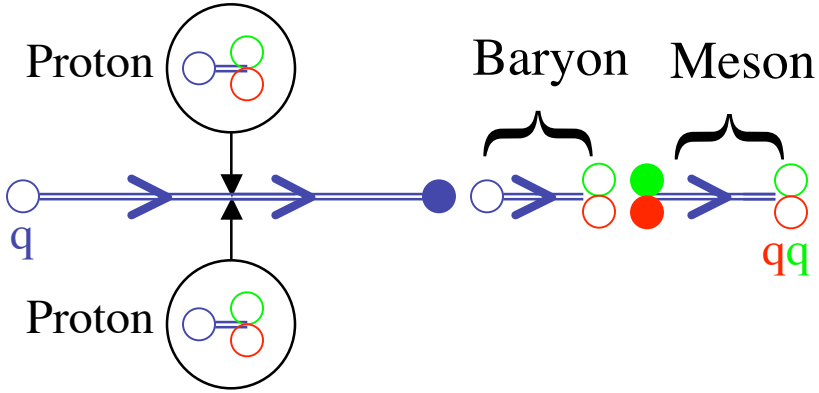
Enter the Diquark, an anti-colored object

(in this case, red+green = anti-blue)



Model of a Baryon

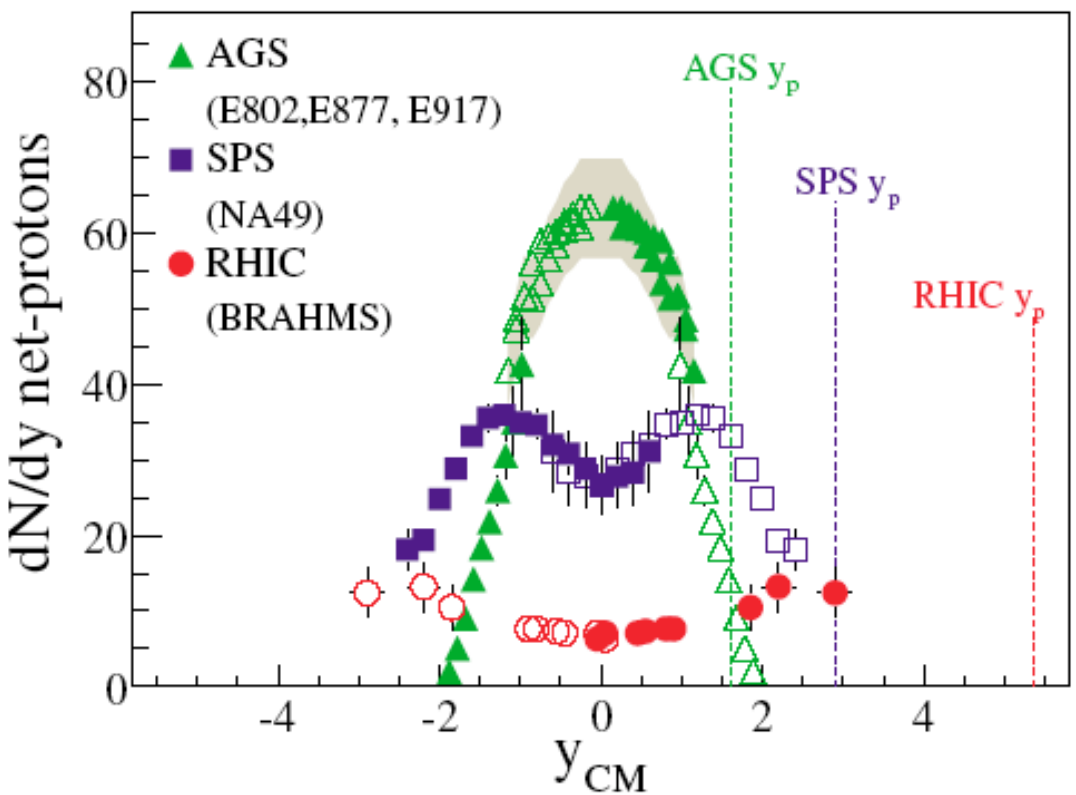


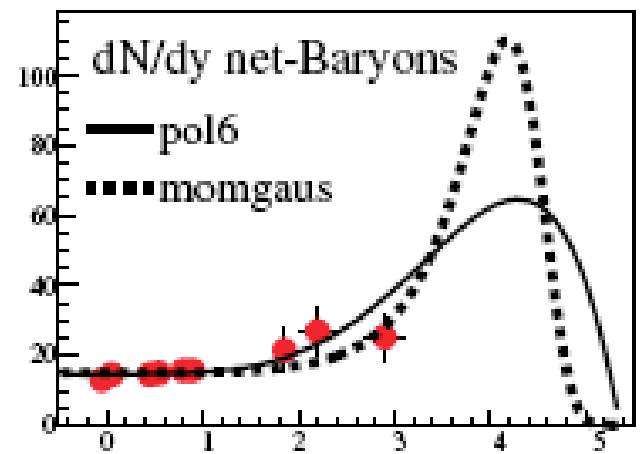


(Second string not shown)

Baryon transport combinatoric!

Too many baryons?



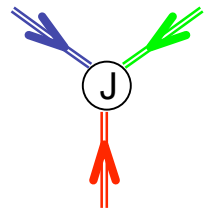


Exponential transport *not* observed!

BRAHMS Phys Rev Lett 93 102301 (2004)

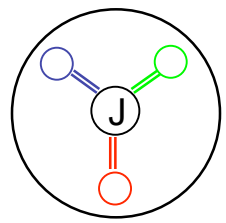
Enter the Junction

Montanet, Rossi, Veneziano, *Phys Rept.* 63 (1980)
Kharzeev, *Phys Lett* B378 (1996)

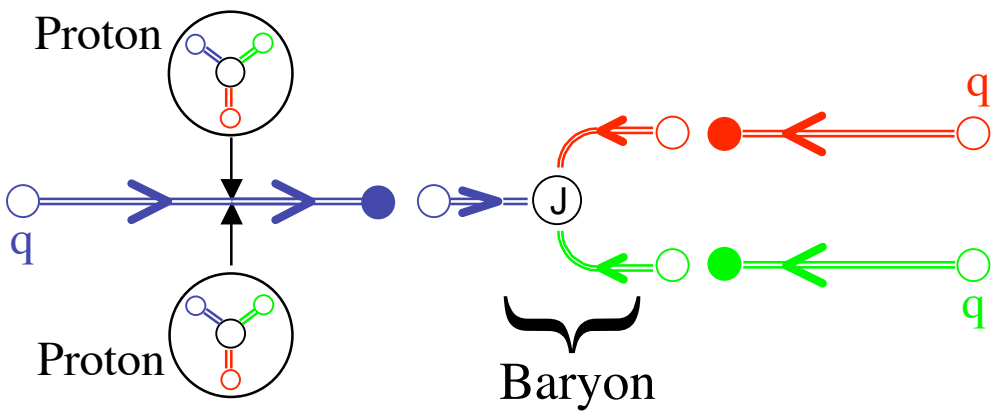


The **Junction:**

A legal QCD object
Gluon fields
Electrically neutral



New Model of a Baryon



Baryon number transported *separately* from quarks

What's the big idea?

We can measure baryon transport and charge transport *independently* and distinguish between different mechanisms:

$$\text{If} \quad \frac{dN^{B}}{dY} - \frac{dN^{\bar{B}}}{dY} = \begin{matrix}\text{Net}\\ \text{Baryons}\end{matrix} \neq 0 \quad \text{then test :}$$

$$\begin{matrix}\text{Net}\\ \text{Charge}\end{matrix} \quad \frac{dN^{(+)}}{dY} - \frac{dN^{(-)}}{dY} = 0$$

Pure junction stopping

$$\begin{matrix}\text{Net}\\ \text{Charge}\end{matrix} \quad \frac{dN^{(+)}}{dY} - \frac{dN^{(-)}}{dY} = \frac{Z_{\text{Beam}}}{A_{\text{Beam}}}\left[\frac{dN^{B}}{dY} - \frac{dN^{\bar{B}}}{dY}\right]$$

Pure quark stopping

A simple plan

Assume: All charge in $\pi^{\pm}$, $K^{\pm}$, $\boldsymbol{p}$, $\boldsymbol{p}$bar

All baryon number in $\boldsymbol{p}$, $\boldsymbol{n}$, Λ

Notation: "π^{+}" = $dN^{\pi^{+}}/dY$

"π^{Net}" = $\pi^{+} - \pi^{-} = dN^{\pi^{+}}/dY - dN^{\pi^{-}}/dY$

Strategy: Examine RHIC A+A, d+A, p+p, ISR data

In *theory* look at $N^{+}-N^{-} = \pi^{Net} + K^{Net} + \boldsymbol{p}^{Net}$

In *practice* look at $(\pi^{Net}+K^{Net})/\boldsymbol{p}^{Net}$

$$\frac{\pi^{\mathrm{Net}} + K^{\mathrm{Net}}}{p^{\mathrm{Net}}} = 1.00$$

Junction stopping

Quark stopping

$$\frac{\pi^{\mathrm{Net}} + K^{\mathrm{Net}}}{p^{\mathrm{Net}}} = \frac{Z}{A}\left(\frac{n^{\mathrm{Net}}}{p^{\mathrm{Net}}} + \frac{\pi^{\mathrm{Net}}}{p^{\mathrm{Net}}}\right) + \left(1 - \frac{Z}{A}\right)$$

$$= \frac{Z}{A}\frac{n}{p}\left(1 + \frac{\bar{p}/p - \bar{n}/n}{1 - \bar{p}/p}\right) + \frac{Z}{A}\left(1 + \frac{\bar{p}/p - \bar{\pi}/\pi}{1 - \bar{p}/p}\right) + \left(1 - \frac{Z}{A}\right)$$

$$= 0.0 - 0.2 \quad \text{for RHIC Au + Au}$$

Know $\bar{\pi}/\pi \approx \bar{p}/p$ Presume $\bar{n}/n \approx \bar{p}/p$

Know $\pi/p \approx 0.5$ Presume $n/p = [1 - (A - Z)/Z = 1.5]$

$$\frac{\pi^{\mathrm{Net}} + K^{\mathrm{Net}}}{p^{\mathrm{Net}}} = \frac{\pi^{+}(1 - \pi^{-}/\pi^{+}) + K^{+}(1 - K^{-}/K^{+})}{p(1 - \bar{p}/p)}$$

Examine RHIC central Au+Au, Y~0, 200 GeV

$\pi^{+} = 290 \quad K^{+} = 47 \quad p = 26$ BRAHMS

PRL 93 102301 (2004)
PRL 94 162301 (2004)

$\bar{p}/p = 0.74 \pm 0.03$ various

$K^{-}/K^{+} = 0.95 \pm 0.05$ BRAHMS

$= 0.95 \pm 0.042$ PHOBOS

$= 0.95 \pm 0.032$ combined

PHOBOS PRC 67 021901 (2003)

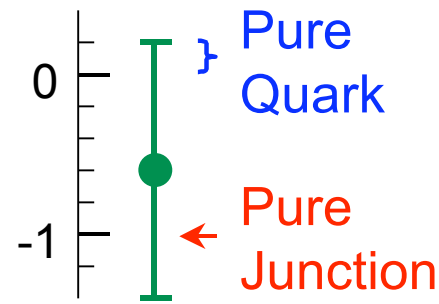
BRAHMS PRL 90 102301 (2003)

$\pi^{-}/\pi^{+} = 1.01 \pm 0.04$ BRAHMS

$= 1.025 \pm 0.019$ PHOBOS

$= 1.022 \pm 0.017$ combined

Dominant!



$$\frac{\pi^{\mathrm{Net}} + K^{\mathrm{Net}}}{p^{\mathrm{Net}}} = \frac{290(-0.022 \pm 0.017) + 47(0.05 \pm 0.032)}{26(0.26 \pm 0.03)}$$

$$= \frac{(-6.38 \pm 4.93) + (2.35 \pm 1.50)}{6.76 \pm 0.78} = -0.60 \pm 0.82$$

Similar conclusion for RHIC p+p and d+Au data.

Conclusions

Inconclusive! at least, with current data

pbar/***p*** measures baryon stopping; ±5% precision needed

π^-/π^+ measures charge stopping; ±0.5% precision needed

Current RHIC experiments can probably achieve this….

…but how would you design a *new* precision low-p_T experiment?

Next: Fix up this calculation (include $\pi^\pm$, ISR data, π_Q, etc.)

Charge transport vs p_T or Y_T

Control input charges: *p*+A vs *n*+A, or

$^{96}_{40}\mathrm{Zr}+^{96}_{40}\mathrm{Zr}$

$^{96}_{44}\mathrm{Ru}+^{96}_{44}\mathrm{Ru}$