Search for baryon junction in isobar collisions at RHIC

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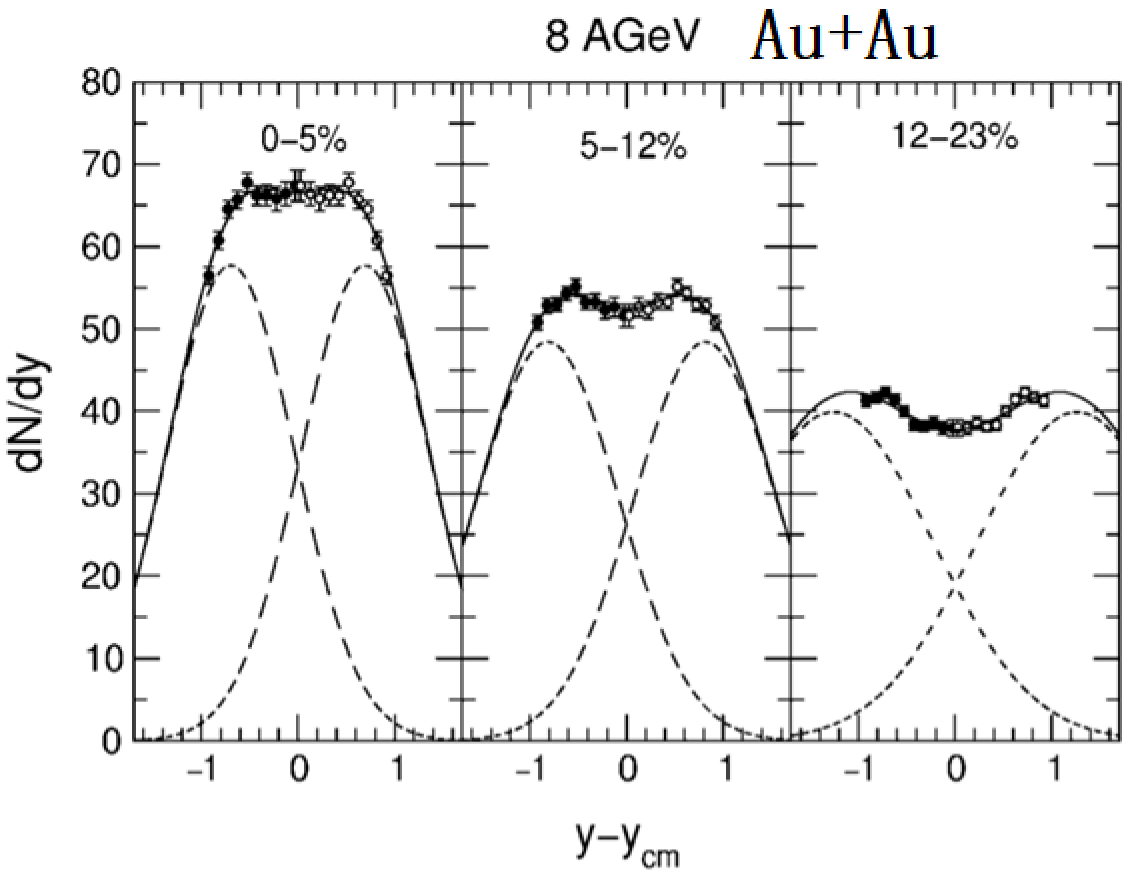
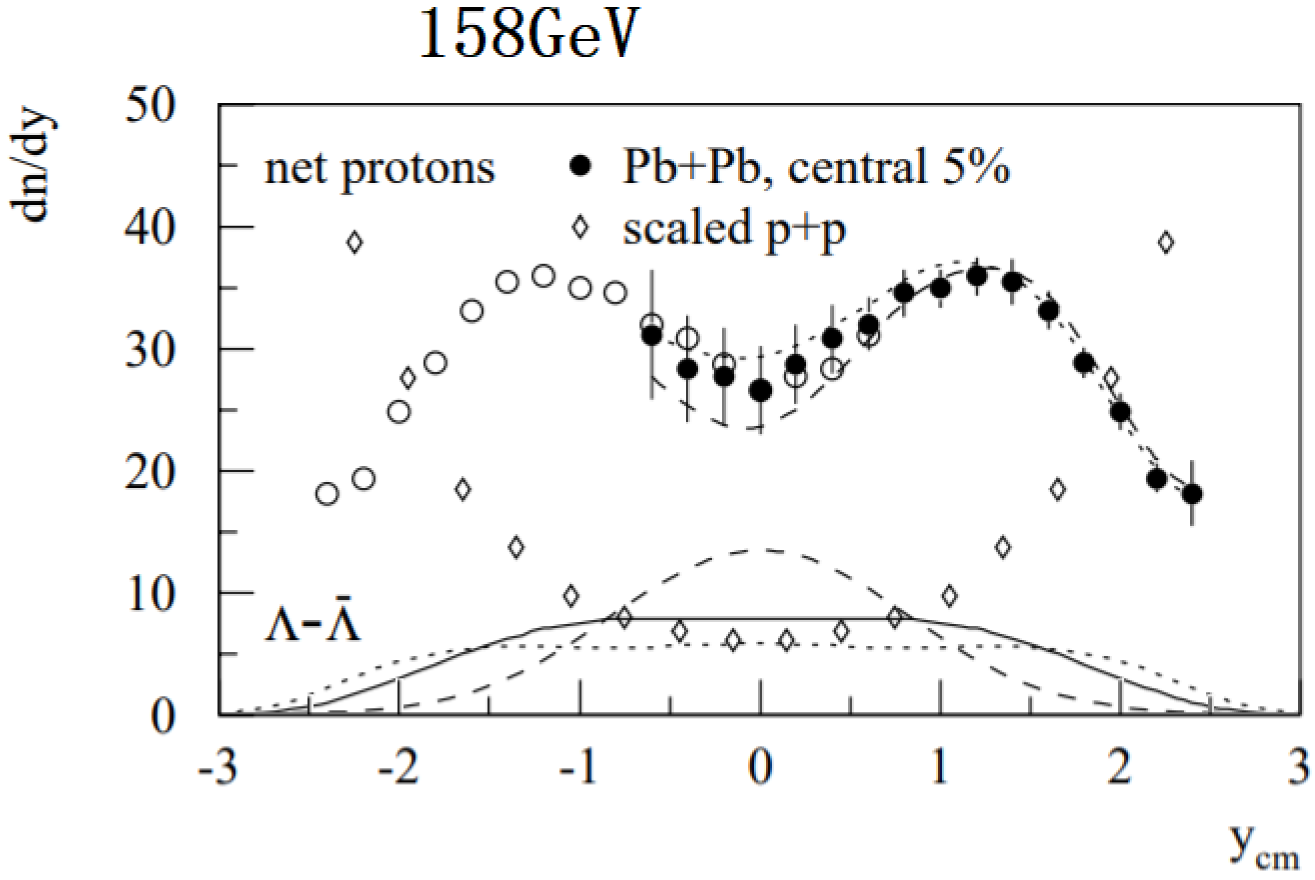
Substantial baryon excess in the midrapidity region

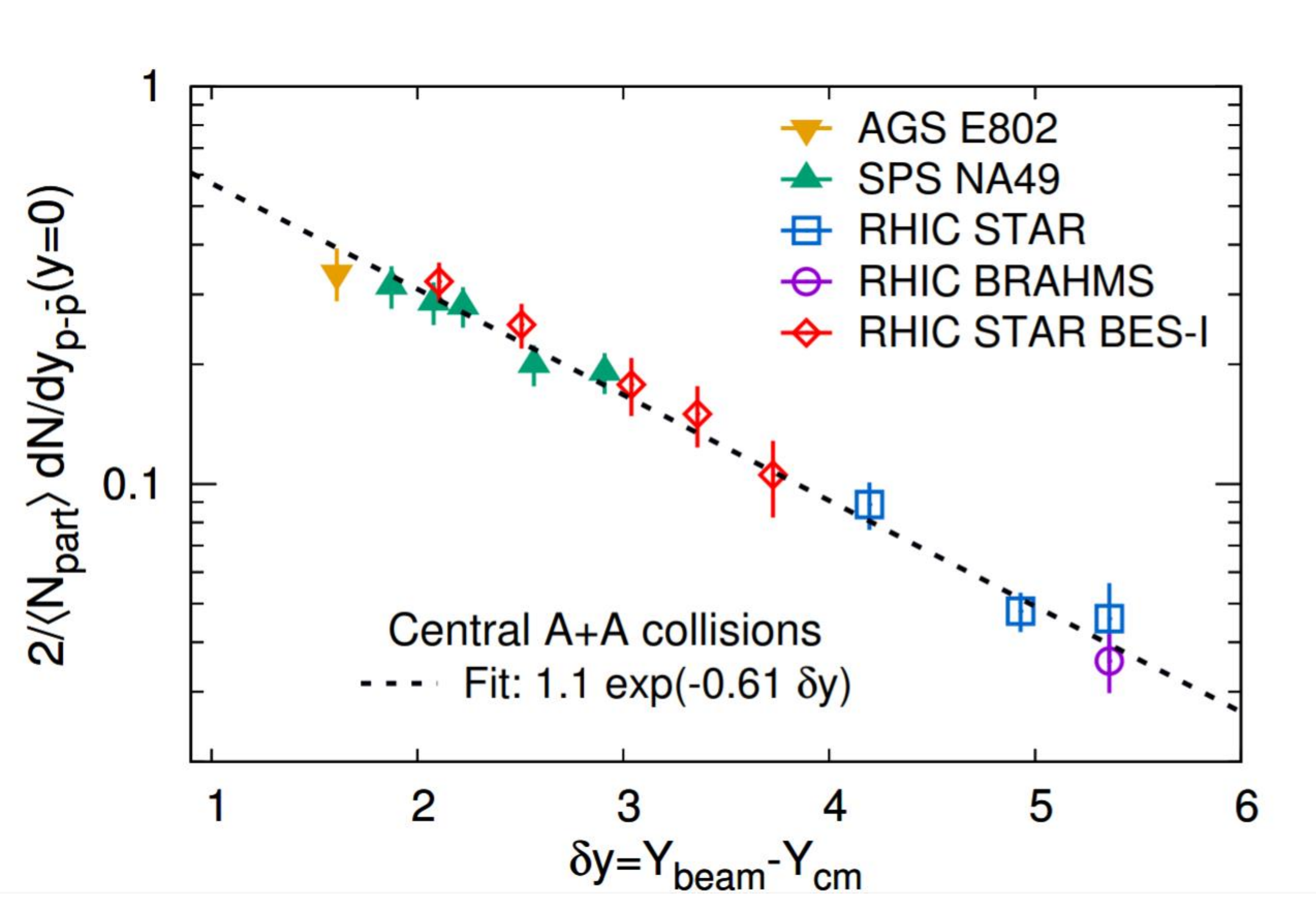




Net-proton as a function of rapidity in heavy ion collisions at several different energies.

Yield of net-proton per nucleon of one nuclear at mid-rapidity is about 70/197/2 ≈0.17 and 25/207/2 ≈0.06 at 8GeV (Beam rapidity is 2.14) and 158GeV (Beam rapidity is 5.13) respectively.

Substantial baryon excess in the midrapidity region



The right plot is the yield of net-proton per nucleon at mid-rapidity as a function of beam rapidity.

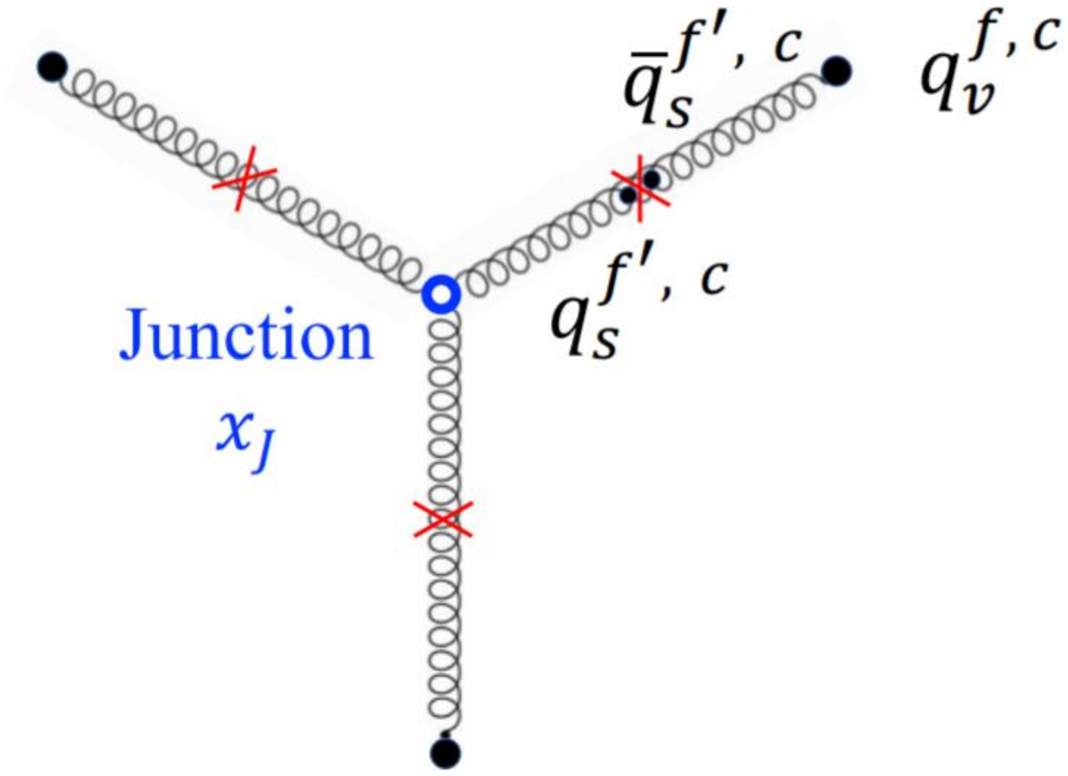
These points can be fitted by a exponential function $1.1e^{(-0.61\delta y)}$.

In a conventional picture, the valence quarks carry baryon quantum number in both the target and projectile.

At sufficiently high energies these valence quarks pass through each other and end up far from mid-rapidity in the fragmentation regions.

What caused the non-zero net-proton at mid-rapidity?

Conjecture about baryon junction



This is a non-perturbative Y-shaped structure in gluon fields.

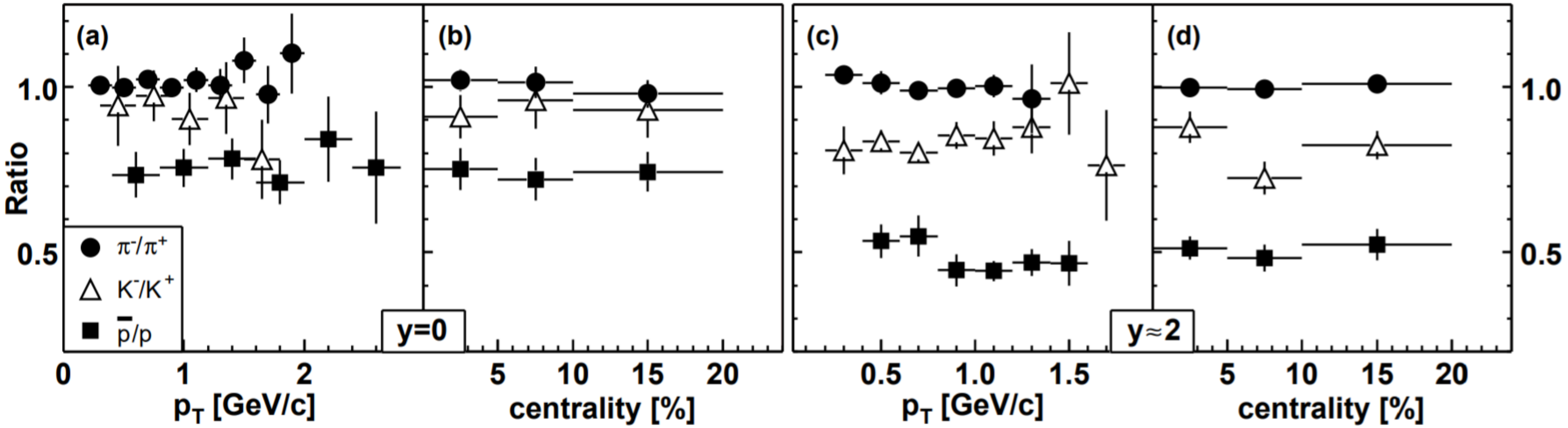
The fraction of momentum carried by the baryon junction is far smaller than it carried by valence quarks.

In heavy ion collisions, baryon junction have enough time to interact and stop at mid-rapidity.

The valance quarks carry charge. So the question is whether they also carry the baryon quantum number.

One of the most straightforward investigations of whether valence quarks carry baryon number is to study the correlations of charge and baryon stopping in heavy ion collisions.

Test of baryon junction hypothesis with isobar collisions



$$Au + Au, \sqrt{s_{NN}} = 200GeV$$

The detector acceptance and efficiency will give difficulty in measuring the net-charge.

$$Q = \left(N_{\pi^+} + N_{K^+} + N_p\right) - \left(N_{\pi^-} + N_{K^-} + N_{\bar{p}}\right)$$

And at the same time, numbers of pions and baryons also cause tiny charge difference.

$\frac{\pi^+}{\pi^-} < 1, \frac{p}{\bar{p}} > 1$ in heavy ion collisions because of the detail balance of isospin from neutron excess. Such as $n + X \leftrightarrow p + \pi^- + X$.

The charge excesses in pions and baryons have opposite sign in A+A collisions and they would cancel to the first order.

Test of baryon junction hypothesis with isobar collisions

However, if we consider the isobar collisions

$$^{96}_{44}Ru + {}^{96}_{44}Ru \text{ and } {}^{96}_{40}Zr + {}^{96}_{40}Zr$$

at $\sqrt{s_{NN}} = 200GeV$.

The detector acceptance and efficiency all cancel out between these two systems and allow us to detect very small differences in the charge stopping.

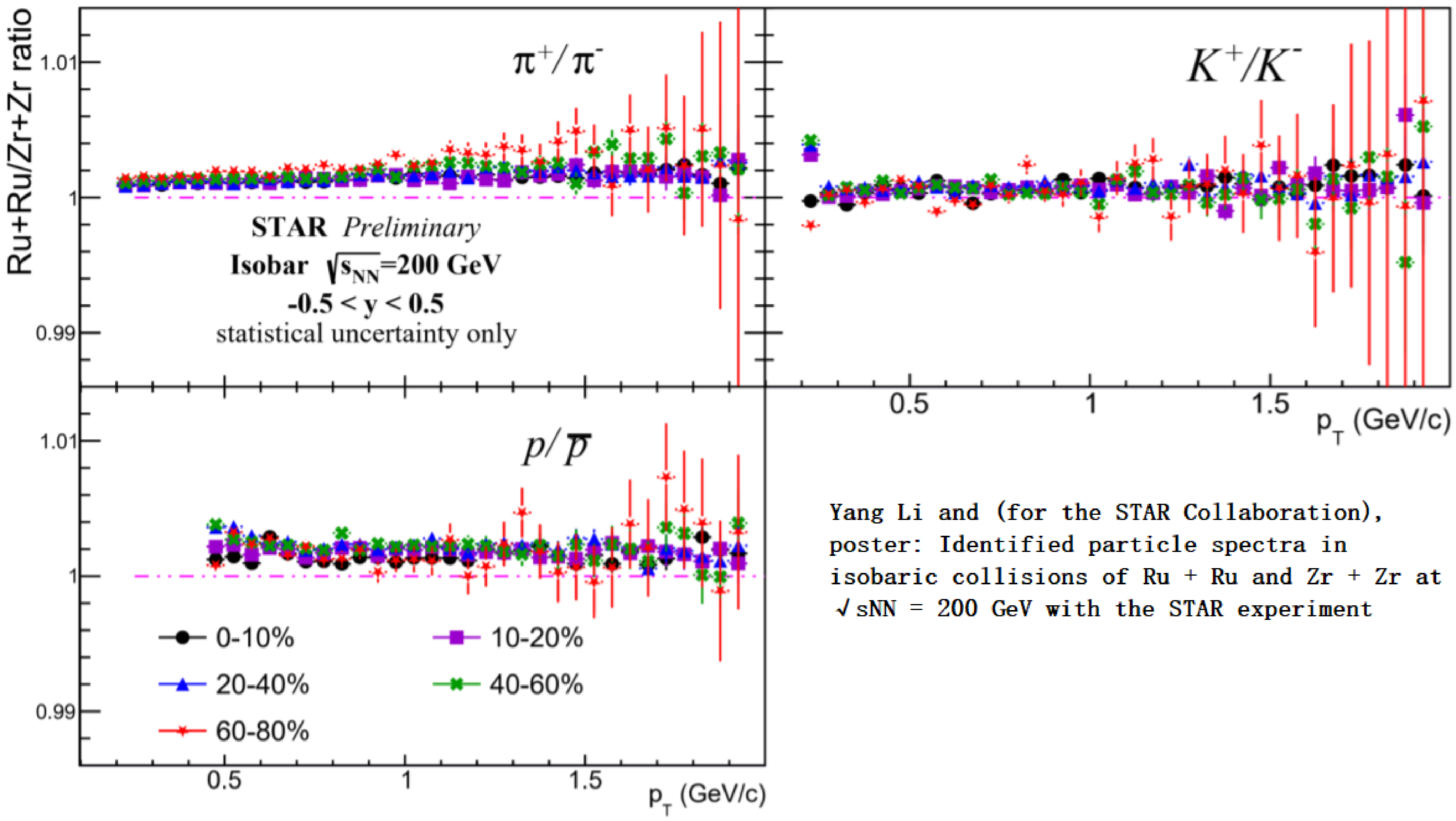
And we can calculate the difference of net-charge between these systems by this method.

$$\Delta Q \approx N_\pi \left[(R2_\pi - 1) + \frac{N_K}{N_\pi}(R2_K - 1) + \frac{N_p}{N_\pi}\left(R2_p - 1\right) \right],$$

$$R2 = \frac{N_+^{Ru}/N_-^{Ru}}{N_+^{Zr}/N_-^{Zr}} \approx 1 + \frac{N_+^{Ru}}{N_+^{Zr}} - \frac{N_-^{Ru}}{N_-^{Zr}}$$

This approximation we assume that $|R2\text{-}1| << 1$.

Test of baryon junction hypothesis with isobar collisions

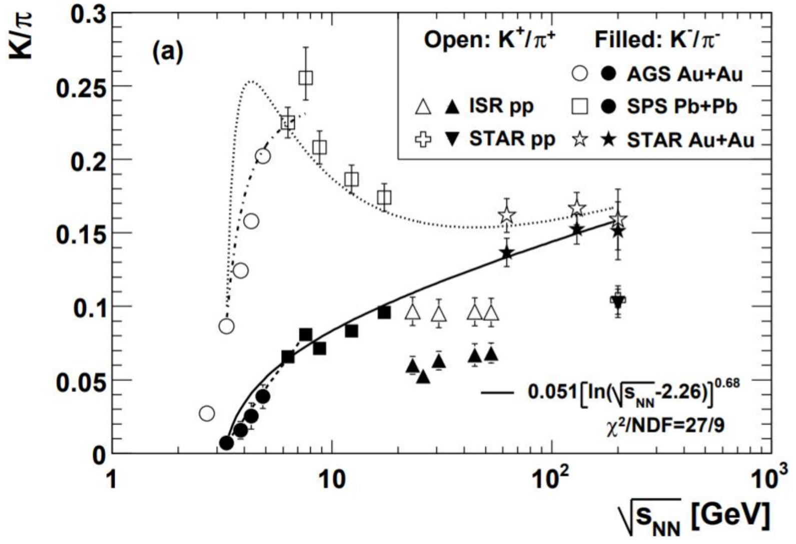


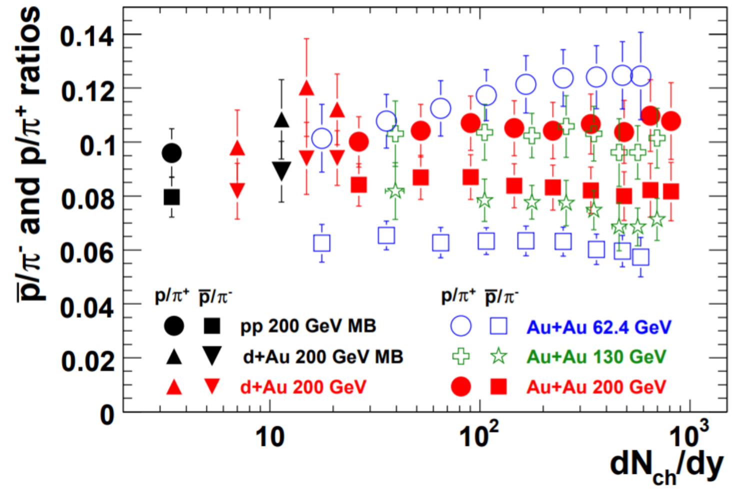
Yang Li and (for the STAR Collaboration), poster: Identified particle spectra in isobaric collisions of Ru + Ru and Zr + Zr at √sNN = 200 GeV with the STAR experiment

According to the preliminary data presented by STAR Collaboration.

All of the $R2$ meet $|R2-1| \sim 10^{-3} << 1$.

Test of baryon junction hypothesis with isobar collisions



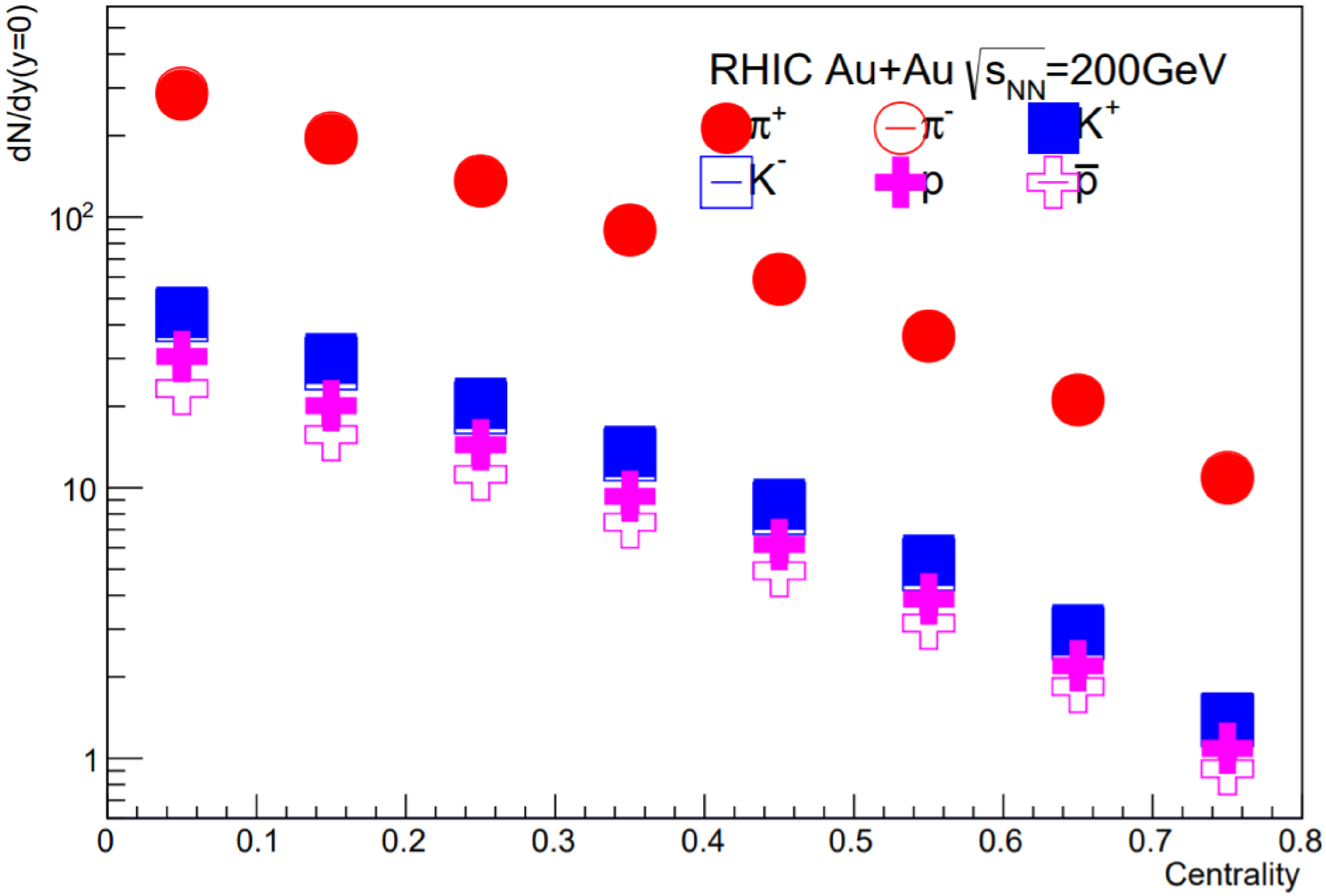


System	Centrality	π^-	π^+	K^-	K^+	$\overline{p}$	p	$p-\overline{p}$
	70-80%	10.9 ± 0.8	10.8 ± 0.8	1.38 ± 0.13	1.41 ± 0.13	0.915 ± 0.081	1.09 ± 0.10	0.170 ± 0.030
	60-70%	21.1 ± 1.6	21.1 ± 1.6	2.89 ± 0.26	2.98 ± 0.27	1.84 ± 0.16	2.20 ± 0.20	0.361 ± 0.061
	50-60%	36.3 ± 2.8	36.2 ± 2.7	5.19 ± 0.47	5.40 ± 0.49	3.16 ± 0.29	3.88 ± 0.35	0.72 ± 0.11
Au+Au	40-50%	58.9 ± 4.5	58.7 ± 4.5	8.37 ± 0.78	8.69 ± 0.81	4.93 ± 0.46	6.17 ± 0.57	1.24 ± 0.18
	30-40%	89.6 ± 6.8	89.2 ± 6.8	13.2 ± 1.3	13.6 ± 1.3	7.46 ± 0.72	9.30 ± 0.89	1.85 ± 0.30
200 GeV	20-30%	136 ± 10	135 ± 10	19.7 ± 2.0	20.5 ± 2.0	11.2 ± 1.1	14.4 ± 1.4	3.22 ± 0.51
	10-20%	196 ± 15	194 ± 15	28.7 ± 3.1	30.0 ± 3.2	15.7 ± 1.7	20.1 ± 2.2	4.42 ± 0.77
	5-10%	261 ± 20	257 ± 20	39.8 ± 4.6	40.8 ± 4.7	21.4 ± 2.5	28.2 ± 3.3	6.8 ± 1.3
	0- 5%	327 ± 25	322 ± 25	49.5 ± 6.2	51.3 ± 6.5	26.7 ± 3.4	34.7 ± 4.4	8.0 ± 1.8

RHIC heavy ion collisions data

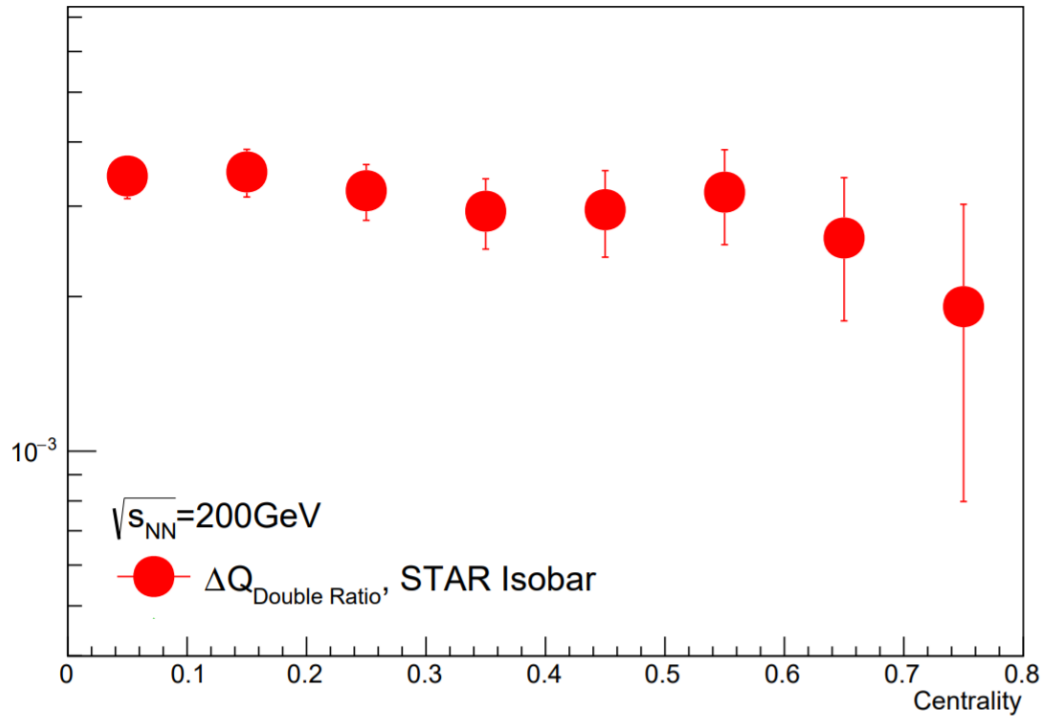
$$Au + Au, \sqrt{s_{NN}} = 200GeV$$

Test of baryon junction hypothesis with isobar collisions



Charged hadron spectrum in RHIC heavy ion collisions
$Au + Au, \sqrt{s_{NN}} = 200GeV$

Test of baryon junction hypothesis with isobar collisions



Now we can estimate the difference of net-charge between two collisions systems.

$$\Delta Q = N_\pi \left[(R2_\pi - 1) + \frac{N_K}{N_\pi}(R2_K - 1) + \frac{N_p}{N_\pi}(R2_p - 1) \right]$$

$$\sigma\left(\frac{\Delta Q}{N_\pi}\right) = \sqrt{\sigma^2_{(R2_\pi-1)} + \sigma^2_{(R2_K-1)}\left(\frac{N_K}{N_\pi}\right)^2 + \sigma^2_{(R2_p-1)}\left(\frac{N_p}{N_\pi}\right)^2 + (R2_K - 1)^2 \sigma^2_{\left(\frac{N_K}{N_\pi}\right)} + \left(R2_p - 1\right)^2 \sigma^2_{\left(\frac{N_p}{N_\pi}\right)}}$$

Test of baryon junction hypothesis with isobar collisions

dN/dy

$^{96}_{44}Ru + ^{96}_{44}Ru$, $\sqrt{s_{NN}} = 200GeV$

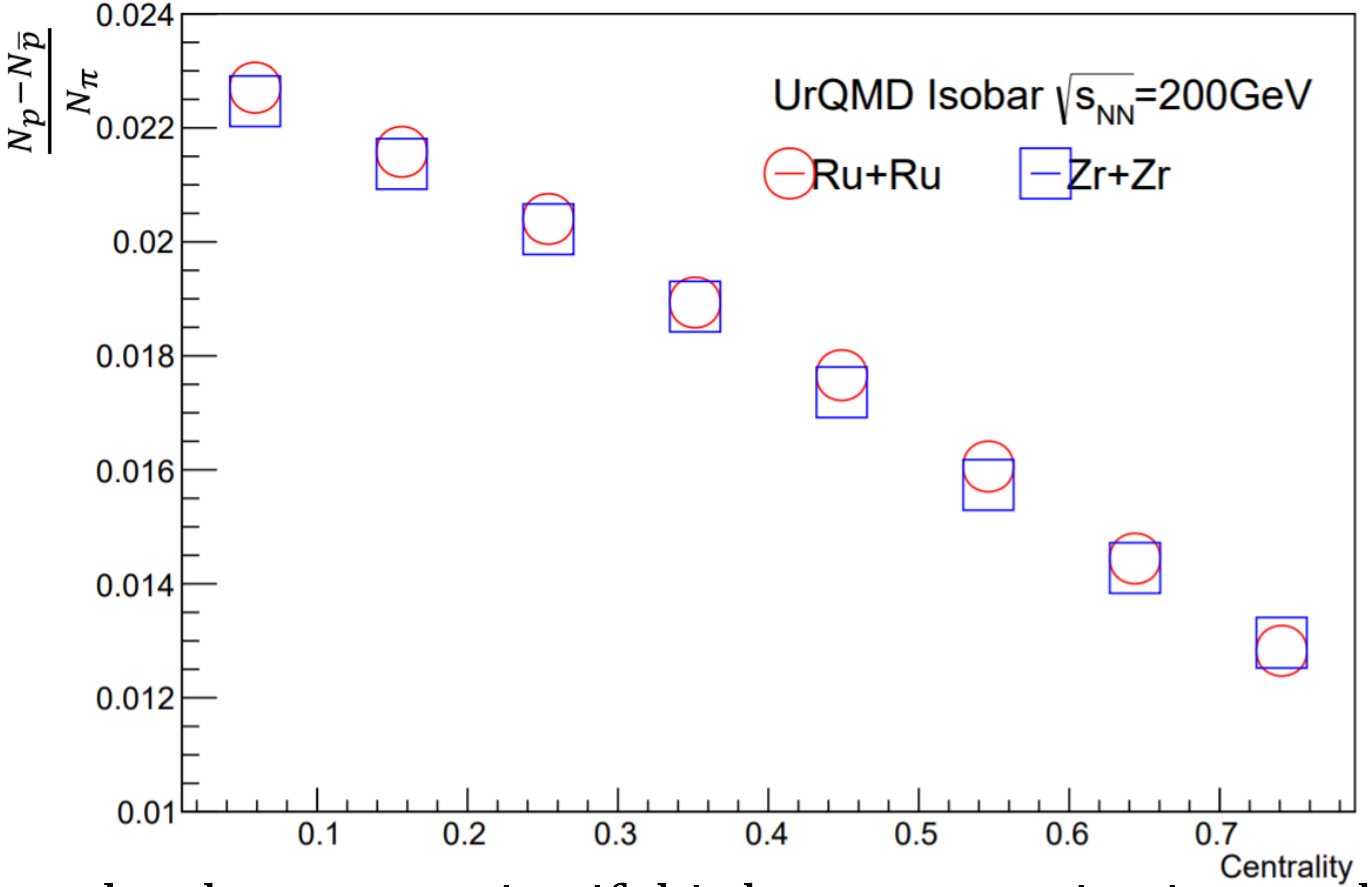
	π^-	π^+	K^-	K^+	$\bar{p}$	p
0%~10%	146.411 +- 0.008	146.034 +- 0.008	16.228 +- 0.003	17.849 +- 0.003	4.943 +- 0.002	8.263 +- 0.002
10%~20%	98.552 +- 0.007	98.333 +- 0.007	10.905 +- 0.002	11.952 +- 0.002	3.540 +- 0.001	5.665 +- 0.002
20%~30%	66.743 +- 0.006	66.584 +- 0.006	7.398 +- 0.002	8.075 +- 0.002	2.548 +- 0.001	3.908 +- 0.001
30%~40%	43.885 +- 0.005	43.792 +- 0.005	4.882 +- 0.002	5.319 +- 0.002	1.790 +- 0.001	2.620 +- 0.001
40%~50%	28.598 +- 0.004	28.537 +- 0.004	3.199 +- 0.001	3.473 +- 0.001	1.241 +- 0.001	1.745 +- 0.001
50%~60%	17.983 +- 0.003	17.947 +- 0.003	2.025 +- 0.001	2.193 +- 0.001	0.833 +- 0.001	1.121 +- 0.001
60%~70%	10.340 +- 0.002	10.325 +- 0.002	1.175 +- 0.001	1.270 +- 0.001	0.511 +- 0.000	0.660 +- 0.001
70%~80%	5.854 +- 0.002	5.842 +- 0.002	0.671 +- 0.001	0.725 +- 0.001	0.307 +- 0.000	0.382 +- 0.000

$^{96}_{40}Zr + ^{96}_{40}Zr$, $\sqrt{s_{NN}} = 200GeV$

	π^-	π^+	K^-	K^+	$\bar{p}$	p
0%~10%	146.674 +- 0.008	145.863 +- 0.008	16.239 +- 0.003	17.845 +- 0.003	4.948 +- 0.002	8.235 +- 0.002
10%~20%	98.696 +- 0.007	98.191 +- 0.007	10.911 +- 0.002	11.943 +- 0.002	3.545 +- 0.001	5.649 +- 0.002
20%~30%	66.840 +- 0.006	66.489 +- 0.006	7.400 +- 0.002	8.079 +- 0.002	2.550 +- 0.001	3.898 +- 0.001
30%~40%	43.989 +- 0.005	43.776 +- 0.005	4.887 +- 0.002	5.321 +- 0.002	1.792 +- 0.001	2.620 +- 0.001
40%~50%	28.621 +- 0.004	28.494 +- 0.004	3.198 +- 0.001	3.472 +- 0.001	1.242 +- 0.001	1.738 +- 0.001
50%~60%	18.007 +- 0.003	17.920 +- 0.003	2.024 +- 0.001	2.192 +- 0.001	0.833 +- 0.001	1.116 +- 0.001
60%~70%	10.356 +- 0.002	10.315 +- 0.002	1.174 +- 0.001	1.269 +- 0.001	0.511 +- 0.000	0.659 +- 0.001
70%~80%	5.850 +- 0.002	5.826 +- 0.002	0.669 +- 0.001	0.721 +- 0.001	0.305 +- 0.000	0.381 +- 0.000

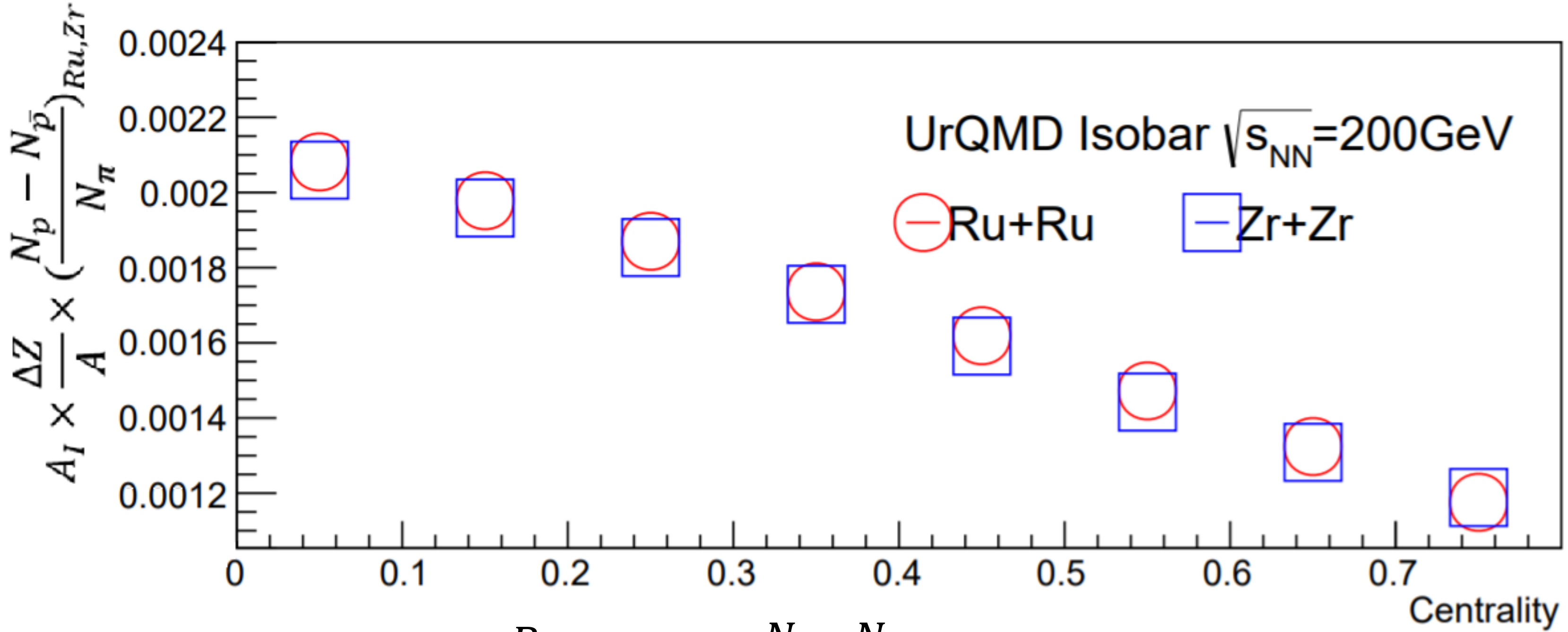
Isobar collisions data from UrQMD.

Test of baryon junction hypothesis with isobar collisions



Then we calculate the charge stopping if this baryon stopping is completely due to valence quark stopping. From the table, we can get $\frac{N_p - N_{\bar{p}}}{N_\pi}$ of each centrality.

Test of baryon junction hypothesis with isobar collisions



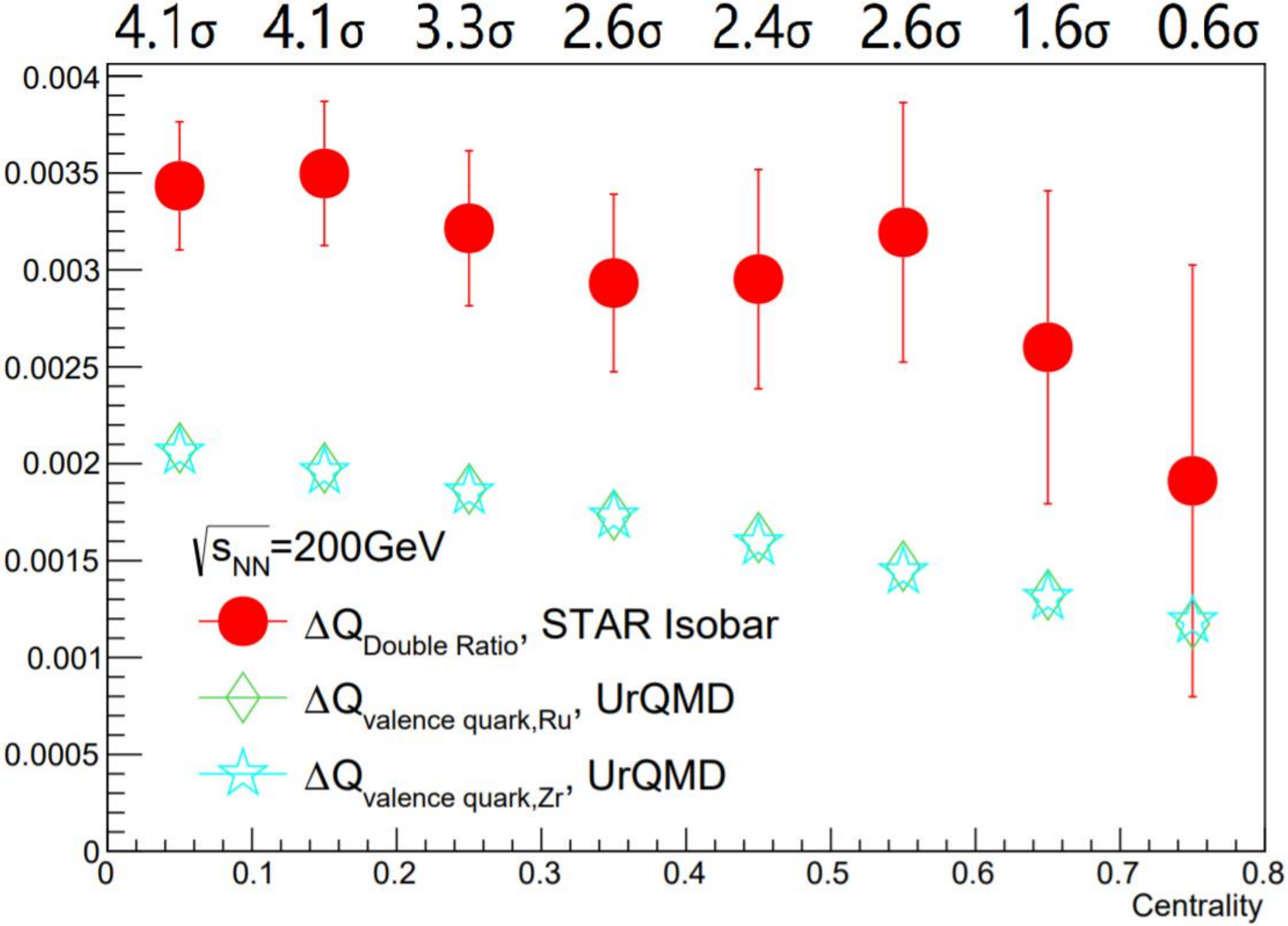
And the baryon-to-pion ratio is $\frac{B}{N_\pi} = A_I \times \frac{N_p - N_{\bar{p}}}{N_\pi}$, A_I is isospin factor with an imbalance between protons and neutrons.

If baryon stopping is completely due to valence quark stopping, charge stopping is expected to be

$$\Delta Q_{valence\ quark} = Q_{valence\ quark,Ru} - Q_{valence\ quark,Zr} = B \times \frac{\Delta Z}{A}$$

$$\frac{\Delta Q_{valence\ quark}}{N_\pi} = A_I \times \frac{\Delta Z}{A} \times \frac{N_p - N_{\bar{p}}}{N_\pi}$$

Test of baryon junction hypothesis with isobar collisions



$$(\chi^2/ndf)_{Ru} = 66.61/8$$
$$(\chi^2/ndf)_{Zr} = 68.44/8$$

Summary

Baryon number is one of the most strictly conserved physics quantities in the Universe. We presented a possible observable which may shed light into what carries this quantum number: is it quarks or a gluonic topological junction? All evidence points to the possibility of a baryon junction playing a significant role in the baryon stopping experimentally observed in rapidity distributions. Future data analyses and experiments with the proposed observables would provide conclusive answers to this fundamental question.

Test of baryon junction hypothesis with isobar collisions